PONTIFICIAE ACADEMIAE SCIENTIARVM SCRIPTA VARIA

58

STUDY WEEK

ON:

THE IMPACT OF SPACE EXPLORATION ON MANKIND

October 1-5, 1984

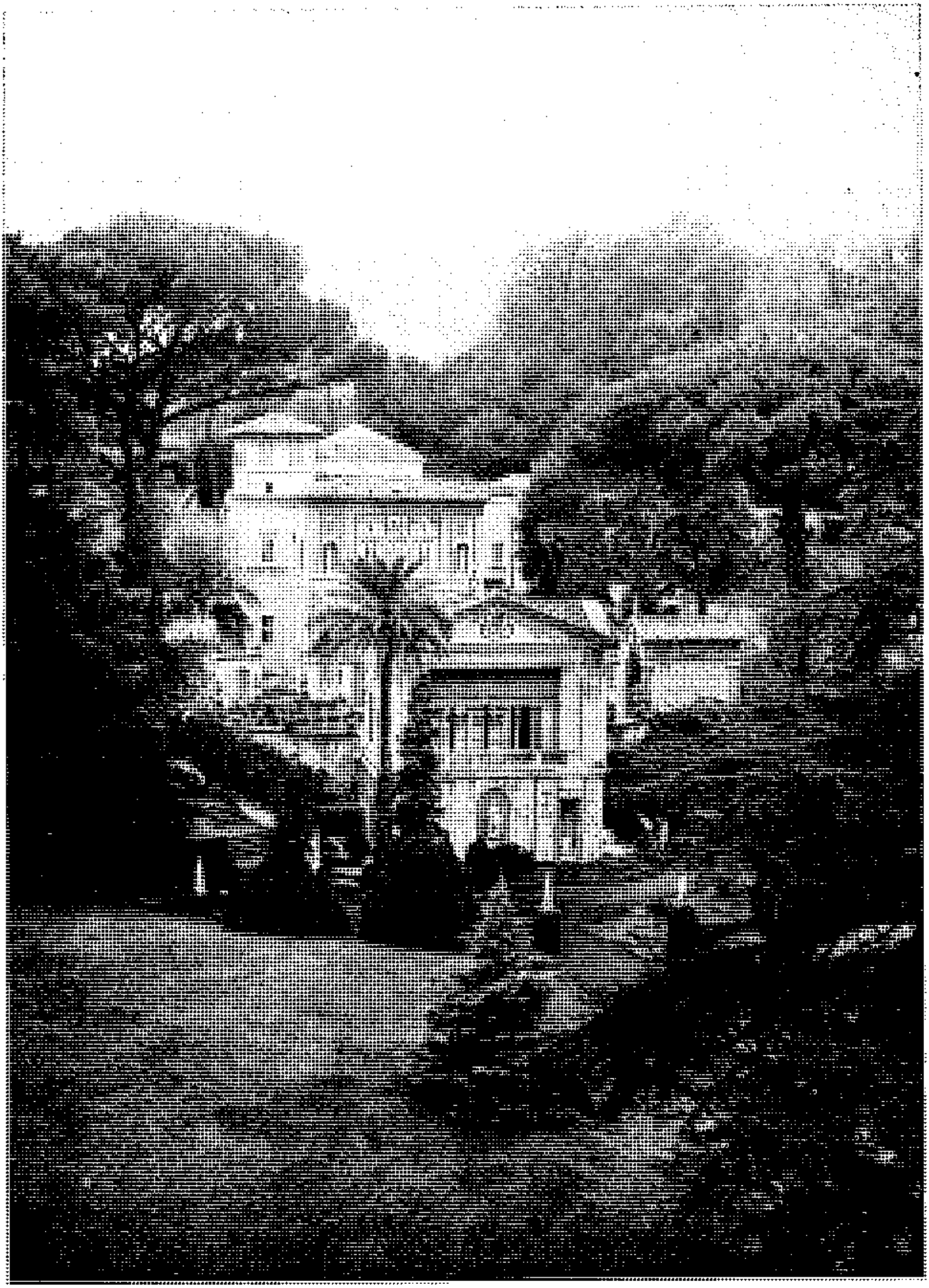
EDITED BY

CARLOS CHAGAS and VITTORIO CANUTO

PONTIFICIA
ACADEMIA
SCIENTIARVM

EX AEDIBVS ACADEMICIS IN CIVITATE VATICANA

MCMLXXXVI



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REMOTE SENSING

FOREWORD

The Study Week on "The Impact of Space Exploration on Mankind", held at the Pontifical Academy of Sciences on October 1-5, 1984, surpassed my best expectations, by the warmth of its debates, the quality of the papers presented, and the general consensus arrived at by its participants coming from all parts of the world. Space exploration marks the last part of this century and opens new perspectives for humankind's entry into the third millennium of the Christian civilization. It is, however, a challenging perspective, and humanity has to approach it with the serenity and fearlessness that only wisdom can bring.

Space exploration is a formidable lever for the improvement of the human condition all over the world. But as His Holiness John Paul II pointed out, it may bring joy and happiness to humankind, but in unscrupulous hands it may increase bondage to wealth and poverty, and even generate war. It is the duty of all women and men of good will — those who believe that our life can be useful only when devoted to our neighbour — to foresee and promote the actions which may benefit humankind and to prevent the misuse of such an extraordinary field of human knowledge and endeavour.

The Pontifical Academy of Sciences will undertake all efforts in order to persevere in the desire to help that space exploration be used only to improve living conditions on the earth.

This Study Week is the result of the strenuous work done by Professor Vittorio Canuto. His vast knowledge of the field and the vigour with which he embraces his responsibilities were the elements which have secured the success of our meeting. It is my honour to thank Professor Canuto for the help he has given to the work of the Academy.

I wish also to emphasize the interest shown by H. Exc. Rev. Monsignor Giovanni Cheli, the Permanent Observer of the Vatican to the United Nations, in following the development of the program of the

Study Week. Monsignor Cheli was responsible for the introduction of its "Conclusions" as an official document of the XL General Assembly of the United Nations, an initiative taken by the governments of Argentina, Cuba, India, Italy and Nigeria.

Every Study Week has the support of the small but diligent group of co-workers who help me here in Rome. It is a pleasure to thank Father Enrico di Rovasenda, Madame Michelle Porcelli, Mrs. Gilda Massa and Silvio Devoto for what they bring to my task.

CARLOS CHAGAS
President of the Pontifical Academy of Sciences

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PONTIFICAL AUDIENCE

On October 2, 1984, His Holiness John Paul II granted an Audience in the Apostolic Palace to the Participants in the Study Week organized by the Pontifical Academy of Sciences on "The Impact of Space Exploration on Mankind".

His Excellency Professor Carlos Chagas, President of the Academy, and Reverend Father Enrico di Rovasenda, Chancellor, introduced the Group.

The President pronounced the following address:

Holy Father,

In bringing to Your attention the various aspects of "The Impact of Space Exploration on Humankind" the Pontifical Academy of Sciences follows, once more, one of its objectives, that of studying the scientific aspects of global interest whose knowledge is of great significance to the whole world.

To study how science and technology can be used for the benefit of living children, women and men, and to improve the quality of their life is a theme very dear to Your heart and soul, one to which You have devoted many of Your prayers.

Your Holiness, the second part of this century is marked greatly by the conquest of space by man. One of the most important aspects of the achievements attained in the scientific and technological field is that of the use of artificial satellites. What satellites can do for humankind is of such significance that it would be very difficult to describe in a few moments all the advantages they may bring to social development.

We are now used to the speed with which information — be it words or images — is sent from one place in the world to another very *remote one, but we are quite unaware, as yet, that the communication system which the satellites offer has shrunk the dimensions of the world. However, we can, from anywhere, at any time, observe what is happening, for better or for worse, in any other part of the world as if our antipodes were in our fingertips. By their capacity of remote sensing, satellites can inform us of the riches of natural resources and shorten to a few hours an analysis which would take months or years to be completed. They can bring basic education, music, poetry, to the most recondite areas of the world. They may also give to all people in the world the images of the misdemeanor caused by the disarray which pervades people in so many parts of the world. They can also be an important weapon to fight the misuse of power and military strength. Most unhappily, however, they may — alas! — serve also war purposes.*

But, Holiness, let me say some words of how the net of information brought by satellites is particularly important for the Third World. It is not only by their information capacity or sensing capacity, able to discover the ore deposits, the prevailing geological and pedological conditions, which will allow for a more productive agriculture, that the use of satellites becomes important for developing countries. It is also not only for its significance for the development of basic education or for fighting poverty that we hail this system. It is because as a whole, satellite connection may bring to each country the knowledge of its anthropological culture, thus establishing the unity of thought and feelings which are indispensable for the establishment of a country's image and strength.

That is why I plead for a national system of satellite information, because the unique world of which we dream can only be built up from a mosaic of independent nations between which a solid system of co-operation is established, and this can be done only by satellites.

Thus it is important for the benefit of humans and of the less powerful countries that the satellite system should not be a privilege of large nations with big economic and military strength, or developed for the benefit of big corporations which may forget that their shareholders are but a small part of a very large human flock, which needs social and *economic justice. A neocolonialism based on the information brought by satellites is a danger the developing countries must face, and avoid.*

The space around the earth cannot be the property of a single nation, but it can be the place where a real understanding and cooperation of all nations can be established.

Let us pray that abusive governments we have found so many times in many nations do not use this wonderful instrument for their own profit but do their best to increase the capability of less developed countries. Thus it is indispensable that the powers who have resources and are at present far advanced in satellite technology should leave orbital space in the future for the use of satellites produced, borrowed, bought or rented by the developing countries.

Holy Father, in thanking You for Your extraordinary generosity in giving Your attention to our group — whose participants have come from near and distant countries to help the Academy in its work — let me express a wish which is in the hearts of all of us. We pray that You, with the strength of Your voice, heard all over the world, Your sacred position, which places You above all political and national considerations, make an appeal for measures to be taken by all nations in order that space exploration be used in observation of the rules which defend freedom of communication and human dignity, and used in such a way that social development of all nations of the world may be assured.

The Holy Father answered with the following Discourse:

Dear Friends,

1. *I am very grateful to the Pontifical Academy of Sciences and to its President, Professor Carlos Chagas, for having arranged this interesting Study Week on the subject of "The Impact of Space Exploration on Mankind" being held in the Casina of Pius IV.*

For me it is a source of great satisfaction to meet you, the members of the Pontifical Academy and scientists from all over the world. The present assembly gives me an opportunity to express my admiration at the exceptional developments which have taken place in space technology. At the same time it enables me to expound the guidelines of a moral, social and spiritual order which belong to the mission entrusted to the Successor of Peter by Christ.

2. *Centuries have passed since Galileo's telescope penetrated the heavens and gave mankind a new vision of the universe. In his brief but fundamental work entitled* Sidereus Nuncius, *published in Venice in 1610, he spoke of the discoveries made by means of his telescope, but he added, being both a scientist and a believer, that he had made them* divina prius illuminante gratia, *preceded by the enlightenment of divine grace.*

Other great scientists such as Kepler and Newton likewise searched the heavens with the spirit of believers. Poets and philosophers such as Pascal contemplated with awe the mysterious silence of outer space.

3. *Today, your gaze is directed at the heavens not only in order to study and contemplate the stars created by God, as was done by the great figures I have just mentioned, but in order to speak of the space probes, space stations and satellites made by man. I am with you in your work, for I regard the presence in space of man and of his machines with the same admiration as that of Paul VI at the time of the Apollo 13 undertaking when he invited those taking part in the Study Week on "The Nuclei of the Galaxies" to "pay homage to those who, by their study, action and authority have once more shown the world the unlimited powers of the sciences and of modern technology. With us also you will raise an ardent hymn of gratitude to God, the Creator of the universe and Father of humanity, who in these ways also wishes to be sought and found by man, adored and loved by him".*

4. *Today, years after those first events, we can see the immense path covered by man's intelligence in knowing the universe, and we rejoice in this by reason of our very faith, for the perfection of man is the glory of God. The researches of science on the nature of our universe have progressed and will progress still more, with the use of highly sophisticated systems such as those perfected by the late member of the Pontifical Academy, Professor Giuseppe Colombo. Instruments are capable of going into space and avoiding the disturbances connected with the earth's surface and the lower layers of the atmosphere. Space probes, a new challenge by man to the distances of space and a symbol of his ever restless desire for knowledge, are coming ever closer to the heavenly bodies, in order to reveal their inmost secrets. Permanent space stations will in their turn be centres of observation making possible experiments never before attempted and the study of new techniques. All these new*

space instruments have been achieved thanks to the great progress of fundamental scientific research in mathematics, physics and chemistry, and through the development of the telecommunications techniques discovered by a great member of the Academy, Guglielmo Marconi.

5. *These various modes of man's presence in space lead us to ask a question: to whom does space belong? While space was something merely observed and studied by the human eye, though with the aid of powerful astronomical instruments, this question was not yet asked. But now that space is visited by man and his machines, the question is unavoidable: to whom does space belong? I do not hesitate to answer that space belongs to the whole of humanity, that it is something for the benefit of all. Just as the earth is for the benefit of all, and private property must be distributed in such a way that every human being is given a proper share in the goods of the earth, in the same way the occupation of space by satellites and other instruments must be regulated by just agreements and international pacts that will enable the whole human family to enjoy and use it. Just as earthly goods are not merely for private use but must also be employed for the good of neighbour, so space must never be for the exclusive benefit of one nation or social group. The questions of the proper use of space must be studied by jurists and given a correct solution by governments.*

The presence of man in space with his satellites and other instruments also involves other matters of a cultural, moral and political nature which I would bring to your attention.

6. *One of the biggest tasks that can be carried out by the use of satellites is the elimination of illiteracy. About one billion people are still illiterate. Again, satellites can be*

used for a wider spreading of culture in all the countries of the world, not only in those where illiteracy has already been eliminated but also in those where many can still not yet read or write, for culture can be spread with the use of pictures alone. I hope that the scientific and technological progress which you are now discussing will cooperate in the spreading of a culture that will truly promote the all-round development of man.

But the transmission of culture must not be identified with the imposition of the cultures of the technologically advanced countries on those still developing. Peoples with ancient cultures, though sometimes still partly illiterate but endowed with an oral and symbolic tradition capable of passing on and preserving their own cultures, must not fall victim to a cultural or ideological colonialism that will destroy those traditions. The rich countries must not attempt, through the use of the instruments at their disposal, and in particular modern space technology, to impose their own culture on poorer nations.

7. Satellites will carry out a beneficial task when instead of imposing the culture of the rich countries they favour a dialogue between cultures, which means a dialogue between the nations, essential for the peace of the world. Nations have cultural frontiers that are more deeply rooted than geographical and political ones: it must be possible to cross these latter, for every human being is a citizen of the world, a member of the human family. These barriers must not, however, be altered in a violent way. Similarly, cultural frontiers must not impede a fruitful dialogue between cultures, nor must they be violated by forms of cultural or ideological dictatorship. Modern space technology must not be used by any form of cultural imperialism, to the detriment of the authentic culture of human beings in the legitimate *differences that have developed in the history of the individual peoples.*

8. Modern space technology properly understood also provides observations useful for the cultivation of the earth, far beyond anything that can be done by any system working on the earth's surface. Through the use of satellites it is possible to obtain exact data regarding the condition of tracts of land, the flow of water and weather conditions. These data can be used for the purpose of improving agriculture, checking the state of woodlands and forests, evaluating the condition of individual zones or of the whole earth, thus making it possible to draw up particular or global programmes in order to meet concrete situations.

This so-called "remote sensing" is of fundamental importance in the fight against hunger, provided that the economic and political powers that possess these special means of observing the world situation help the poorer countries to draw up programmes of economic development and help them in a practical way to carry out these programmes.

9. With your knowledge and practice of modern space technology, you are well aware of how it would be possible to work out adequate programmes for helping the world to overcome the imbalance of agricultural practices, the advance of deserts, ecological disasters caused by human rapacity against the earth, in the waters and in the atmosphere, with the ever more alarming destruction of animal and plant life, and with grave and mortal illnesses affecting human life itself.

Order and justice must be re-established, harmony between man and nature must be restored. We must strive for a technology that will free the poor peoples and relieve oppressed nature, that will promote projects and agreements.

Space technology can make a highly effective contribution to this cause.

10. *Ladies and Gentlemen, true peace is born from the heart of those who are open to the gift of God, that God who at the coming of Christ promised peace to people of good will. In your scientific researches and technological inventions I invite you to seek the God of peace, the Invisible One who is the source of everything that is visible. I exhort you to seek Him by listening to the silence of space. Heaven and earth proclaim that they are only creatures, and they urge you to rise into the supreme heaven of transcendence, in order to open your minds and hearts to the love that moves the sun and the other stars. Thus you will be the creators not only of ever more perfect instruments but also of that civilization which is the only one desired by God and by men and women of good will: the civilization of truth and love, so necessary to guarantee peace between the nations of the world.*

SCIENTIFIC PAPERS

THE STRUCTURE AND EVOLUTION OF THE UNIVERSE

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There is little doubt that truly scientific (i.e. observationally testable) conjectures about the structure of the Universe bave been formulated only in the last sixty years in spite of having been the primary concern to scientists and philosophers for thousands of years. The early flat model of the Universe was challenged by the Greeks, who realized that the world is round. In turn, their elaborate model of concentric spheres lasted until the 17th century, when it was dismantled by Galileo, who further showed that the so-called "fixed stars" (the ones pinned to the last concentric sphere), had to he located at very great distances since they did not show any apparent movement as the earth revolved around the sun.

This led naturally to the postulate that those stars were objects like our Sun, wandering perhaps in an infinite Universe. This called for (a) the study of those stars as objects per se (astrophysics) and (b) the study of the space in which they move (cosmology). Let us look first at cosmology, dealing with the structure of the Universe, in which we suppose there is an infinitely large number of stars. An elementary application of Newton's law of universal attraction implies that a static Universe is impossible, since the stars would simply fall toward the center. This is however not the case. Why? It turns out that the only way to have an infinite static Universe is by postulating that the force of gravity becomes repulsive at great distances, a tampering of Newton's law for which there is no evidence. In spite of the lack of an acceptable

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solution, the problem remained unsettled for more than two centuries, until the advent of Einstein's theory of general relativity in 1915, which predicted either an expanding or a contracting Universe, but not a static one. Basing his entire line of reasoning on few general principles, Einstein was able to derive a set of mathematical equations that predicted that a static Universe, as conceived for three thousand years, could not be stable.

This circumstance will be regarded by future historians of science as perhaps the greatest missed opportunity in theoretical physics. Had Einstein had more faith in his equations, he could have predicted theoretically that the Universe must be either expanding or contracting, undoubtedly the greatest prediction ever to be made by man. Victim perhaps of the philosophical trappings of the past, Einstein invented an *ad hoc* correction to his famous equations so as to permit a static Universe, an exercise he is reported to have greatly regretted.

It was in the United States a few years later that astronomers Vesto Slipher and Edwin Hubble began a systematic study of the properties of the light received from far away galaxies. It is known that the wavelength of sound perceived by a receiver depends on the state of motion of the emitter (the Doppler effect). The same phenomenon applies to light: a fast receding source appears to become redder while a fastly approaching one will become bluer.

After several years of careful compilation of observational data, E. Hubble in 1929 was able to announce his famous law: all the galaxies he had observed showed a distinct displacement toward the red, indicating that they were moving away from us at a speed directly proportional to their distance. E. Hubble had therefore proved that the Universe is not static but expanding.

It was the Russian mathematician Alexander Friedman who in 1922 constructed the first detailed model of an expanding Universe using Einstein equations. Three possibilities arose: in the first model, galaxies move sufficiently slowly for gravity to be able to stop and then reverse the expansion. In this scenario, the size of the Universe will reach a maximum size followed by a collapse into what goes under the name of the "Big Crunch".

In the second model, galaxies move so fast that gravity will never be able to stop them. The Universe will expand forever.

Finally, there is the possibility that galaxies are now cruising along at *just* the critical speed to avoid collapse.

The first and the third models are referred to as "open Universes", while the second is called a "closed Universe". In all three models, the expansion starts from a state of infinite density and temperature called the Big-Bang. The age of the Universe, computed from that moment, is estimated, by different methods, to be approximately (15-20) billion years. (As a reference, the age of the earth is 4.5 billion years).

Do we have a "direct" proof that a Big-Bang really occurred? We do as of 1965, as I'll explain later. It is therefore no surprise that the idea of the Big-Bang, or more generally that of a "beginning", was not accepted by everyone before 1965. Some people disliked it so much as to propose a hybrid model, i.e., one that while retaining the concept of expansion (since it is almost a fact), craftily avoided the "age problem". This model was put forward by H. Bond, T. Gold and F. Hoyle in 1948 and is known under the name of Steady State. As galaxies move apart from one another, in accordance with Hubble's law, "new" galaxies form between them (i.e. matter is continuously being created), so that the Universe looks the same at all times, just like a river appears steady simply because the amount of water flowing away from any given section is exactly compensated by an equal amout of water flowing in. The model is indeed very ingenious in that it accommodates dynamics and steadiness. The price to pay is that of having matter being continuously created, which of course demanded an alteration of Einstein's original equations.

Continuous creation of matter may not have a great aesthetic appeal but it cannot be ruled out. After all, in the Big-Bang model creation of matter occurred all once at $t = 0$, whereas in the steady state it is spread thinly over time. In this picture, the age of the Universe is infinite, no beginning and no end. The Universe would look the same at any place and any time, the density being always the same.

The strong philosophical appeal of this model had soon to face the ugly reality of a first set of astronomical data collected by M. Ryle and his collaborators. Using the radio telescope of Cambridge (England), they showed in the 50s' and early 60s', that the number of radio-galaxies must have been greater in the past, implying a dynamical Universe.

To many people this was the death knell of the Steady State Theory, which was then largely abandoned. However, not everybody was convinced, primarily because of the intrinsic difficulties in analyzing radio astronomical data. A dispute arose that was not quenched until 1965 with the discovery made at Bell Telephone Laboratories in the United States. To fully appreciate the importance of this great discovery, it is useful to back track and consider the implications of the Big-Bang scenario.

If indeed there had been a state of very high temperature and density and if the Universe had indeed expanded from this hot state, one should he able even today, 20 billion years later, to find some relics of that explosion. If the Universe was very hot, the corresponding very short wavelengths would have been stretched by the expansion. One should therefore be able to find this long wavelength radiation permeating the whole Universe as a background radiation, isotropic, homogeneous and without an apparent source. Theory tells us that when the Universe was 1 second old, the radiation was at a temperature of 10 billion degrees. After 20 billion years, the radiation has cooled down to about 3°K above absolute zero. If one could verify its existence, one would acquire a great deal of confidence in the Big-Bang picture. This proposal was put forward by the school of cosmology created by G. Gamow in the late 40s'. Faithful to the tradition whereby great scientific proposals have to hibernate for a long time before they are resurrected or independently rediscovered, Gamow's idea did not receive the attention it deserved, not ultimately because in the 50's cosmology had not yet acquired the respectability it now enjoys and also because the technology was not advanced enough to measure 3°K above absolute zero. It is like measuring nothing very accurately!

Be that as it may, the fact remains that it was only in 1965 when A. Penzias and R. Wilson announced in the pages of the Astrophysical Journal Letters that during experiments at Bell Labs they had detected an isotropic, unpolarized and season-free radiation field corresponding to 3.5°K. As Purcell is credited to have said "it just may be the most important thing anybody has ever seen".

Indeed it may go down in history as the most fascinating archeological find of all times: the very relics of an event that took place some 20 billion years ago. Together with Huhhle's discovery of the late twenties, the 1965 discovery of the 3°K background radiation, as it came to be known, has put the Big-Bang scenario of an expanding Universe on solid, verifiable grounds, thus disposing of the Steady State Theory in which it is almost impossible to account for this radiation field.

Since 1965, cosmology is a different science. More precisely, it is a science in its own right, if admittedly a difficult one because of the scarcity of data and the uniqueness of the object under observation, the Universe. With this in mind, let us go hack to the time when the Universe was only a few seconds old, and its temperature and density were exceedingly high. What kind of environment can one envisage under those circumstances?

The enormous temperature and density clearly preclude the existence of the structures we are used to think in terms of, namely molecules, atoms or even nuclei. The Universe was a soup of protons, neutrons, electrons, neutrinos, etc., a structureless plasma of particles and anti-particles. This simple picture creates an immediate problem which only recently seems to have found a plausible solution. If anti-matter was as abundant as matter, how can we be here? The Universe should be made of radiation only. In fact, collision of matter with anti-matter wields radiation, which in turn can resplit into matter and anti-matter, the swing going back and forth. However, since the Universe is expanding and the radiation is cooling off (faster than matter), a moment was reached when the radiation generated by matter anti-matter collision could no longer recreate the original partners. Thus, the only final product would have been radiation and today's temperature would be much higher than 3°K. Obviously, this did not happen since we (and everything around us) are made of matter that must have survived the annihilation process. Somehow the destruction was not complete, some matter was left over. The delicate balance between matter and anti-matter must have been broken by some force that violates the otherwise expected symmetry, thus favoring matter at the rate of one proton every 100 million pairs of proton-anti-protons, since in fact today we observe 10^8 photons for every proton. This favoritism occurred at a time estimated to be 10^{-38} second after the Big-Bang, an embarrassing extrapolation back in time of the laws of physics and one to be aware of.

Now that 1 out of 100 million particles of matter survived annihilation, we have to think of how to put them together to form what we see today, nuclei, atoms, molecules, crystals, planets, stars, galaxies, etc.

If the Universe had remained at the temperature it had when it was 1 second old, i.e. 10 billion degrees, nothing of morphological interest would ever have happend. We would have a featureless plasma. Fortunately, the Universe expanded, its temperature cooled off, thus presenting an opportunity for elementary particles to get together and stay that way without being sizzled back into their constituents by the hot radiation of the environment.

Not counting the hydrogen nucleus (which is a simple proton), the first nucleus to form was helium. Conditions were ripe for only a short period of time that was over when the Universe was about 3 minutes old. After that, it became impossible for neutrons and protons to find one another since the density had become too low (prior to that the temperature was too high and helium too fragile an element to survive).

Use of straightforward physical laws yields a remarkable result: the amount of helium formed at the end of this "grace period" is predicted to be around 25% (by mass) of the total budget. One quarter of the entire mass of the Universe must be in the form of helium. This simple and almost parameter-free prediction is an additional bonus for the Big-Bang scenario. In fact, the measurements of the helium abundance in stars, galaxies and planets do indeed confirm that the helium abundance is around 25%. Stars themselves make "some" helium, but the "some" is nowhere near the observed abundance. On second reflection, this is to be expected since the physical conditions inside a star meet only half of the needed requirements to form helium. The temperature may be in the right range but stars do not expand, i.e. they do not cool off (fortunately for us) and so the helium that forms gets largely destroyed. And yet, we observe that stars do have ~ 25% helium content. The Big-Bang explanation of helium, being primordial, is just too simple and too quantitatively correct not to be taken very seriously.

We have therefore succeeded in building up the second most abundant element in the Universe. How about the remaining 90 or so elements? It was an early hope of G. Gamow and his collaborators to be able to synthetize *all* the elements during the first stages of the Big-Bang. All the elements would therefore have been primordial. However, Nature did not comply with Gamow's expectation. For some reason there are no stable elements in Nature with mass 5 (or 8). In order to jump over this gap, one can resort to the concerted action not of two but of three helium atoms. This can be done only if the density is appropriate, i.e. if the three partners come sufficiently close together, an ecounter hard to come by in an expanding Universe where the density is rapidly decreasing. For a dense, not expanding environment to reappear in the cosmic scene, we have to wait till stars get formed, quite some time ahead of us.

As we said, while the Universe was expanding, the overall temperature and density were decreasing. When the Universe was 1 million years old, the temperature had dropped to ~ 10,000 °K, thereby allowing the first atom ever, the hydrogen atom, to form as a permanent structure. It was an extremely important moment in the evolution of the Universe. In fact, from that moment on, radiation could no longer damage matter, the latter having become neutral, i.e. refractory to radiation. The long interplay between matter and radiation that had lasted one million years was finally over. Matter and radiation decoupled, each following its own path. Having lost its grip on matter, radiation kept on cooling rather uneventfully. Twenty billion years later, we observe it today as cold 3°K background radiation.

Quite on the contrary, matter began its period of major activity after decoupling. All the action was still to come, an action that led to galaxies, stars, planets and life, a morphologically most diversified sequence of events.

It is reasonable to expect that at the moment of decoupling from radiation, matter was homogeneously distributed, its previous interactions with radiation having smoothed out any incipient clumpiness. Probably galaxies formed first, the gas in them successfully clumping into stars under the action of gravity. Regrettably, we know very little about the details of galaxy formation, this being in fact one of the outstanding unresolved problems in modern astrophysics. An early suggestion that galaxies should be viewed as the frozen eddies of an early turbulent medium, while appealing at the morphological level, was unable to propose a lasting source of energy, without which any turbulent medium would naturally revert to laminarity. The difficulty in forming galaxies is actually due to the expansion of the Universe, the first instance in which expansion creates a severe difficulty. It can be seen in the following way. Any accidental congregation of particles would grow in size at a geometrical rate (Jeans instability) were it not for the fact that the expansion of the Universe pulls space apart, thereby making the process a slow one. In fact, it is so slow that 20 billion years may be insufficient to bring a primordial fluctuation to the presently observed clumpy structure. The situation is rather embarrassing if we consider that galaxies are the most striking large scale structure of the Universe.

Recently, great hopes have been attached to the possibility that neutrinos may have a finite rest mass. Neutrinos were invented so to speak by W. Pauli (back in the thirties) to explain an apparent violation of energy conservation in weak interactions. Since then, they bave played a fundamental role in physics and astrophysics. They have, however, always been thought to be massless particles, traveling at the speed of light. Two years ago, a Russian team reported evidence of a tiny non-null rest mass. By tiny we mean of the order of one ten thousandth of the mass of the electron. How could such a tiny particle be of cosmological interest?

The reason is that there are plenty of them, almost (but not quite) as many as photons, of the order of 150 for every cubic centimeter, which is enough to be important. While radiation decoupled from matter only at the 1 million year mark, neutrinos, which are weakly interacting particles, decoupled much earlier at around 300 years after the Big-Bang. By the time ordinary matter decoupled, neutrinos had already had ample time to collapse into clumps or "neutrino clouds" (10^{15} solar masses), as they have come to be known. This would have been very helpful. Matter could have taken advantage of "neutrino pits" and just slide in, thus favoring the formation of subsequent structures like galaxies. It may well be that this tiny, almost massless neutrino will turn out to play a most significant role in the overall cosmological scenario. We'll have to wait until the original report from Russia is confirmed by other groups.

In slightly better shape is the description of star formation. Galaxies contain both gas and stars. It is widely believed that the gas will ultimately collapse into fragments destined to become stars. It is the same type of gravitational instability that operated in galaxies with the important difference that since we are dealing with much smaller scales, the expansion of the Universe is no longer important. From studies of our own galaxy, it has become clear that large clouds (of density typically 10^{9}-10^{13} particles per cm^3 and masses up to a million solar masses), are the sites of star formation. Why and exactly how an original cloud begins to collapse and then fragments, has not been fully understood as yet although some push from a nearby supernova explosion cannot be excluded. After the original cloud has broken up into fragments, each of them will follow the same pattern. The collapse of an individual fragment (a protostar) will terminate only when the temperature inside the fragment (which is increasing during the collapse), will reach the point when nuclear reactions get ignited, thus creating sufficient heat to stop the collapse. At that moment, a star is legally born as an entity in delicate but stable balance between the centripetal gravity and the nuclear engine at the center that opposes it. A star is just a "gravitationally confined fusion reactor", which has to be big because gravity is so weak as to require a lot of mass to deliver a sizeable force. That explains why there are no stars much less massive than the Sun.

Stars are born, live and die. Much of the details of their evolution has been charted in detail and rather successfully compared with observational data. It is no exaggeration that stellar evolution is one of the most successful chapters of astrophysics. Stars are cosmic chemical factories endowed with the specific duty of cooking the original stock of H and He into all the remaining elements from beryllium to uranium.

Our Sun, an average star by every measurable standard, has lived 4.5 billion years burning hydrogen, and has still quite a way to go before that process is completed. The life-span of a star is dictated by the mass it was born with. Massive stars burn their fuel faster and die young. However, the entire labor of cooking the elements would be of little cosmic importance if at the end of their life stars did not do something spectacular and generous. They explode and disperse the fruits of their labor to the surrounding gas, which in turn may be on its way to collapse to form a new star. Since our own sun contains heavy elements that it certainly had no time to make on its own, it must have been born in a "polluted" environment. We conclude that the elements we are made of, C, N, Mg, Ca, . . . were therefore cooked in a by-now-gone exploded star. The detailed steps of a supernova explosion are rather complex and only a few gifted astrophysicists can comprehend it all. In any case, the phenomenon is a real one, it has been observed in our and other galaxies and can be considered the farewell of a star.

The left-overs of the supernova explosion have in recent years become a subject of much interest and for good reasons. They are of two kinds: *neutron stars* (pulsars) and/or *black holes.* The existence of the former was foreseen by Landau and Oppenheimer more than 40 years ago but the first candidate was discovered only in 1968 and in serendipitous manner. Neutron stars are objects with a mass roughly equal to that of the sun but packed so tightly (their size is about 20 km) that a lump of neutron star matter may weigh as much as the entire population of the earth. Neutron stars are solid, hot objects with no internal source of energy and therefore destined to cool off irretrievably. The original supernova explosion leaves behind neutron stars that spin on their axis at fantastic rates, several times per millisecond. For example, the Crab nebula pulsar has a rotation period of 36 milliseconds. Since centrifugal forces will tear any object asunder if its period is less than say 1 millisecond (for $\rho \approx 10^{14}$ gr/cm^3), we conclude that pulsars are the fastest rotating objects presently known and due to the regularity of their radio emission, they further constitute a most perfect natural clock. Pulsars possess another property of great interest, namely magnetic fields with strengths up to a thousand billion gauss. Since the behavior of matter is strongly affected by such huge fields, it is to be expected that the surface properties of neutron stars might be considerably different from those of other solid bodies. A new chapter of physics may be opening up.

The second and perhaps more widely known category of by-products of a supernova explosion is black-holes, fantastic objects that were imagined since the time of Laplace. These are objects whose gravitational pull is so strong as not to allow even light to escape, thus cutting off the only communication channel. They therefore look black to us and only with an indirect method, the gravitational forces they might exert on a companion, can we hope to detect them. Several good candidates exist today thanks to recent advances in x-ray astronomy.

Let us now go back to our initial topic, the structure of the Universe. Having inferred that the Universe was born, has expanded, and is still expanding today, it is only natural to ask the next question: what is its future? Mindful of Bohr's famous remark that it is difficult to predict, especially the future, we had better be very cautious.

While it is true that the Universe is expanding, it is also true that if there were enough mass in it, (of whatever form and shape), its concerted gravitational pull might well be sufficient to stop the expansion and eventually reverse it into a contraction. The question of the future of the Universe can therefore be formulated in terms of the amount of mass available: is there enough of it? It is easy to estimate what is known as the critical density, i.e. the minimum necessary to halt the expansion. It works out to be about 5 atoms per cubic meter, by far smaller than the best vacuum produced in laboratory. Let us look first at galaxies, the largest visible structure in the Universe. There is an average of one galaxy every 10^{21} cubic light years. Every galaxy contains some 100 billion suns. Spreading this mass over that volume yields a density 30 times smaller than the critical value. The whole ensemble of luminous galaxies is barely a few percent of the critical density.

Can it be that galaxies are indeed all there is in the Universe and that the Universe is therefore open, i.e. forever expanding? There are at least two reasons why this is probably not the case.

First of all, in clusters of galaxies, visible matter turns out to he ten times less than what we measure (indirectly) via its gravitational action reflected in the velocities of the galaxies.

Secondly, there is the so-called flatness problem. The intriguing fact is that today's mean density of the Universe ρ_{av} is very close to the critical density ρ_{cr} separating two radically different long-range forecasts. The important thing however is that this *almost equality* of ρ_{AV} with ρ_{cr} is a function of time and it becomes even more surprisingly equal as we go back in time. For example, at the so-called Planck time, $t \sim 10^{-43}$ sec, we have

$$\left| \frac{\rho_{av} - \rho_{cr}}{\rho_{cr}} \right| \leqslant 10^{-59}$$

This means that if at that time ρ_{av} was only slightly larger than ρ_{cr}, say

$$\frac{\rho_{av}}{\rho_{cr}} \gtrsim 1 + 10^{-55}$$

the Universe would have collapsed onto itself long ago. On the contrary,

$$\frac{\rho_{av}}{\rho_{cr}} \lesssim 1 + 10^{-55}$$

the Universe would be open and its present density negligibly small. Neither case happens, showing the Universe to be fantastically fine tuned.

No explanation to this unnatural accuracy was available until the so-called "inflationary scenario" was proposed by A. Guth in 1981. Because of the passage through a phase change during the first instants of its expansion, the post-inflationary Universe is predicted to be expanding at a rate of about one part in a million of the critical density. The fantastic accuracy is therefore no longer so miraculous, since a physical process has been found that can account for it.

These two arguments have convinced most people that the so-called "missing mass" is a reality, i.e. that beyond standard matter, i.e. protons and ordinary atoms, there must exist a smoothly distrihuted kind of "cosmic matter" (the so-called missing matter) that is optically invisible and yet dynamically all-important. The reason why this "missing matter" cannot he made of ordinary baryons is because the abundances of He and D (that depend on the *baryonic* density) allow an uncertainty between 5 and 10% of the critical density. This leaves about 90% of the critical mass unaccounted for!

What can this matter be? Its form is completely unknown. It could be anything from massive neutrinos (10^{-32} grams) to objects of $10^{6}\,M_\odot$ (10^{39} grams), i.e. 70 decades of mass speculation as M. Rees has noted.

We have already mentioned the possibility that massive neutrinos, on account of their abundance, may close the Universe. However, recent detailed computer simulations of the distribution of galaxies in a neutrino dominated Universe do not compare very favorably with the observed distribution. In view of this difficulty, cosmologists have begun to explore alternative possibilities.

Recently, elementary particle physicists have scored an impressive success in the description of the ultimate constituents of matter. A zoo of new elementary particles by the strange names of photinos, gluons, axions, etc. have been discussed, although none of them has yet been discovered in the laboratory.

Cosmologists have been quick in realizing their potential significance and have performed extensive computer simulations of the distribution of galaxies in a Universe dominated for example by axions. The results are very encouraging in that they reproduce the observed distribution of luminous matter rather well, certainly better than models using massive neutrinos. The overall situation cannot yet be fully assessed since much of the work is still being carried out.

For the first time in history, cosmology has joined forces as an equal partner with elementary particle physics. The global structure of the Universe can teach us a great deal about the ultimate components of matter, thus establishing an important link between macro and microphysics. Moreover, since the study of elementary particles requires increasingly higher energies (that translate into costlier accelerators), a moment of saturation may come when we rather switch to cosmology and use the Big-Bang with its arbitrarily high energy, as the natural laboratory.

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SPACE STATION: THE POTENTIAL TO SERVE HUMANITY THROUGH SCIENCE, EXPLORATION AND UTILIZATION

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Introduction

The United States has recently embarked upon the design and development of a Space Station as the focus of its civil space program for the next decade. As directed by President Reagan, the Space Station will provide, within a decade, a permanent U.S. manned presence in space serving broad international, commercial, scientific and technological communities. It is NASA's intent to have the core Space Station components orbited and operating by the early 1990's with additional capability evolving throughout the 90's.

The Space Station program is being approached in a manner quite different from the precursor manned programs of Mercury, Gemini, Apollo, Skylab and Shuttle. Those programs had rather narrow, highly focussed objectives which made it relatively easy to establish specific designs and operating procedures. The Space Station, alternatively, builds upon experience gained from all of those programs as well as from the hundreds of automated satellite missions of the first 25 years of space exploration and is thought of as providing a multi-use capability which will evolve with time.

The stated goals of the Space Station are to:

1. Assure free world leadership in space during the 1990's.
2. Stimulate advanced technology.

3. Promote international cooperation.
4. Enhance capabilities for space science and applications.
5. Develop further the commercial potential of space.
6. Contribute to national pride and prestige.
7. Stimulate interest in science and engineering education.

These broad goals, along with the experience base, lead to the concept of a multi-function capability which provides laboratories, observatories, transportation, factories, on-orbit assembly, and servicing of satellites and platforms. As such, the Space Station program is more a way of conducting space activity than it is a "thing" *per se*. A consequence is that while there will be significant new hardware in the Space Station program, many other elements of space activity, such as satellites and experiments, not a formal part of the Station, must be designed to take advantage of the new capability.

Historical Aspects

Consideration of putting people and large structures in earth orbit goes back well beyond the formal space age initiated in 1957 with the orbiting of the Soviet Sputnik. One can find the elements of fantasy, dream, and future reality in Edward Hale's 1869 article "The Brick Moon" in the *Atlantic Monthly*. Hale even wrote about one of today's functional uses of satellites—navigation. In the 1920's and 30's two of the pioneers of rocket technology, Tsiolovsky and Oberth, both envisioned multi-purpose manned orbiting facilities with functions now being discussed for Space Station.

Since the creation of NASA, a Space Station has been uppermost in the minds of the engineers of the Agency. In the very early 1960's it was a competitor with the lunar mission for a national commitment but lost out to Apollo. During the 60's NASA and industry conducted many studies on Space Station configurations and objectives, none of which came to fruition due to a combination of budget pressures and unconvincing arguments as to demonstrable benefits of a Space Station. NASA again tried to sell a Space Station along with the Shuttle in the early 1970's, with the Shuttle clearly touted as the mode of lower cost (relative to expendable launch vehicles) re-usable transportation to and from low-earth orbit, including to a Space Station locale. Once more the Space Station fell out but NASA did get the go-ahead to develop the Shuttle.

In the 1970's two endeavors were undertaken to partially make up for the lack of a Space Station. One was the one-shot Skylab mission in 1973-74 in which a Saturn stage was outfitted as an orbital workshop and which accommodated three separate three-man crew visits to conduct scientific research and biomedical studies on the effects of long-duration space flights. Second was the decision to enhance the Shuttle payload capability with a research laboratory, later known as Spacelab, contributed by the European Space Agency.

Skylab demonstrated the ability of astronauts to perform useful long-term scientific and technological experiments and to use their dexterity and innovativeness to repair broken equipment. Of great significance was the physiological finding that for periods of up to three months (extended to over six months on Soviet Salyut flights) there was no major impediment to human habitation in space although several findings, especially that of bone calcium loss, indicate that flights of several years may not be feasible without either artificial gravity or some other method of ameliorating body function degradation.

Shuttle and Spacelab experiences to date, although limited, provide a number of lessons which bear on the approach to structuring a Space Station program.

1. Most of the experiments researchers want to do in space need time significantly exceeding the Shuttle seven to 10 day capability.

2. Sending the non-pilot astronaut experts into space to conduct their own experiments is profitable.

3. International cooperation can be extremely productive but it is essential that the conditions for cooperation be thoroughly understood from the beginning.

4. Users of space services must be involved early with the developers in order to assure optimum accommodation in terms of cost and ease of use.

5. Users need to dedicate themselves to the new opportunities at an early stage of development but at the same time need to be convinced of the benefits of the opportunity.

Functions and Architecture of the Space Station

The utilization of a Space Station is dependent upon the permanent presence of a crew of six to eight in space. Thus the core capability must provide the basic elements of habitability—living quarters, food, hygiene, recreation opportunity, routine and emergency medical treatment and repair capability. It is likely that an entire module will be dedicated to habitation and another module to the utilities and resources.

Laboratory modules are expected to form the core research facilities. It is in these modules that research in materials processing, technology and life sciences will occur. They may be used as a locale for conducting earth-observing or astronomy experiments via airlocks, or as a control center for remote operation of those experiments. Because of the need for extremely quiet conditions, accurate pointing and freedom from core station induced contamination, many experiments, especially those involving astronomical observing or terrestrial remote sensing, will require locations exterior to the laboratories.

The use of the term "module" is significant: each of the core Space Station elements is to be carried to orbit in the Space Shuttle payload bay and the Station will be assembled on-orbit in a modular fashion, flight by flight. Depending on the outcome of the definition phase studies for Space Station (the next two years), the modules may be functionally identifiable (e.g. logistics, habitability, life sciences, materials research, repair) but will depend upon the core resources for power, attitude and thermal control, and data handling.

Space Station scientific experiments which must be exterior to lab modules will be accommodated either as payloads attached to exterior Space Station structures, or will be placed on remote space platforms. The determination of whether a given experiment will be attached or on a platform will depend upon its requirements for servicing and crew interaction as well as consideration of contamination. For example, visible light solar telescopes, relatively insensitive to contamination, using film as a detector would work best as attached payloads with the inherent ease of access by astronauts for film changeout (this was essentially the mode of the solar Apollo telescope mount on the Skylab mission). Infrared telescopes, however, are extremely sensitive to contamination, use electronic detectors and can be located well away from the core Station.

Experiments located away from the core Station will be accommodated in two significantly different ways: on independent "free flyers" much like today's satellites and on space platforms. A platform is defined as a long-life experiments carrier, plus its associated experiments. It is planned that the carrier, providing basic resources such as power, attitude control, and command and data handling, will be derived from core Space

Station subsystems thereby providing commonality and reduced costs. Experiments would be attached to carriers via instrument modules. The entire platform will be serviceable, allowing for experiment addition, exchange or upgrade and for repair/maintenance of the carrier.

The concept of servicing and repair of platforms and satellites was just that a year ago. It has now been demonstrated to be viable with the recent Shuttle mission which repaired and up-graded the solar maximum mission satellite. Solar Max is back at work after a serious failure half a year after launch in 1979.

NASA is now, in fact, designing all of its major satellites which go into low earth orbit, to be repairable and maintained on-orbit. These include the space telescope, gamma ray observatory, upper atmospheric research satellite and Landsats 4 and 5.

The Space Station will enable a significant extension of the repair capability over that now existing using the Shuttle. The short Shuttle stay-time on orbit (maximum of 10 days) dictates that repairs be done quickly and in a precisely pre-planned manner, using Astronaut Extravehicular Activity (EVA). On the Space Station it will be possible to deal with complex repairs, possibly at the level of individual circuit boards. Studies will be done in the definition phase to examine the merits and techniques of repair within a module in the shirt-sleeve environment — the goal is to create the equivalent of the lab bench on earth.

Two platform locations are planned: co-orbiting with the core Station at 28.5° inclination and polar or near-polar sun-synchronous. The former would contain primarily astronomical type experiments while the latter would serve earth-observing experiments which require global coverage. The polar platform may well turn out to be multiple small platforms: the individual experiments have sufficiently different basic viewing requirements (sun angle, time-of-day) that no single orbit satisfies the scientific objectives.

The whole platform scenario is in a state of definition for the next two years. Studies must be made of the relative scientific merits of the different experiments and of their requirements.

The latter is especially critical for polar earth-observing platforms because the low-inclination Space Station will not be able to service polar locations directly. Polar platforms will be dependent upon the basic Shuttle for launch and servicing for the foreseeable future (the restricted Shuttle polar payload capability is another argument in favor of a number of small platforms rather than one large monolithic platform).

So far, we have been discussing basic core Space Station hardware (modules and platforms) and have touched on some of the functional aspects, mostly servicing of platforms and satellites and research inside laboratory modules. "Ancillary" hardware is needed also, including equipment for repairing and servicing and an orbital maneuvering vehicle which can retrieve satellites or platforms from non-space station orbits, and bring them to the Station for work, and then place them back in their original orbits.

Evolution of Space Station

The entire Space Station program is based on a new philosophy: the Initial Operating Configuration (IOC) planned for 1992 will be but a start. The Space Station program is defined as extending at least to the end of the century — i.e., it is to constitute a "permanent presence in space". A number of factors then demand that the Space Station be evolutionary:

1. As a research facility, it is inevitable that experience in its use will dictate new ways to operate and we must be able to accommodate them.

2. Technology will evolve allowing one to upgrade component systems or subsystems.

3. There is not sufficient budget being planned for the initial operating configuration to allow one to do all the things one can now justify. For example, an orbital transfer vehicle to take satellites to geosynchronous orbits and return is a post-1992 requirement.

Transition to Space Station

A characteristic of previous NASA manned programs has been the dead-ended aspect in which, although the experience was passed on, the hardware was obsolete. Not so with Shuttle and Space Station. Besides providing the basic transportation of Space Station elements to orbit, the Shuttle will continue to provide the routine up and back operational transportation. Shuttle-based programs will also provide much of the initial experiment complement and functional capability. For example, the space telescope can have its experiments changed on a Shuttle flight although repair of an experiment can be done now only on a return-to-earth basis. In the Space Station it may be possible to repair that same experiment on-orbit.

Throughout the rest of the 1980's and early 1990's there will be a large number of Shuttle spacelab experiments, many of which will be relocated on the Space Station to take advantage of its long duration capability (recall that the spacelab is in a sense a gap-filler in the absence of a Space Station).

Another transition factor is one of practicality: the spacelab experiments are now coming into the pipeline and more are included in the budgeting for the next several years. Further, there is little apparent "budget opportunity" for the building of experiments designed specifically to take advantage of Space Station unique capability. Moreover, given the budget planning cycle and at least a five year development time for large space experiments, experiments not already planned and budgeted now could not possibly be ready by 1992. This is not an excuse to dawdle, however. To the contrary, it is important to get started and come up with several major experiments to force Space Station designers to work with and accommodate real payloads rather than paper designs. Spacelab experience shows that the latter simply would not establish firm design requirements for the Station — in fact what would likely happen is that experiment design and cost would later be driven by cumbersome, complex Space Station interfaces.

Space Station benefits

Perusal of the multiple Space Station goals (see Introduction) convinces one that the top level decision to build a Space Station was largely political, for it would be close to impossible to prove on any economic basis that it must be built. Indeed, there was a presidential directive for NASA to proceed. Let us now accept, at face value, the goals of stimulating development of advanced technology and developing the commercial potential of space as being economically desirable and worthy goals which deserve emphasis and which will come about. Those goals alone, however, might not justify the building of a Space Station.

The desire to be a leader in space and the promotion of international cooperation are two linked goals which are unquantifiable. In today's world, space activity is still viewed in many quarters as a very visible sign of technologic prowess and overall capability. In the 1960's and early 1970's the U.S. and Soviets dominated space. That situation is now much changed because of the increasing capability of other nations or groups (European Space Agency, individual European Countries, Japan, China and India). This new "talent" plus the increasing cost of space operations suggests that Space Station cooperation can be mutually beneficial — lower cost to the U.S. which still accomplishes its goal of leadership, and provision of a relatively low-cost opportunity to other countries to participate visibly in a major space endeavor.

Thus far, the opportunity to participate in Space Station is being actively explored by the European Space Agency, France, Germany, Italy, Japan, and Canada. The final result — participation or not — will be a strong function of perceived relative roles and benefits, mutual access, commercial opportunities, pricing policies, and long-term continuity. Of concern to some of the potential partners is the question of involvement of the Department of Defense. To date, the Space Station program is a NASA civil program with no current support or interest from the Department of Defense.

Turning to the goal of enhancing opportunities for space science and applications, we come to an area where there truly is the potential to make a major contribution to humanity. There are opportunities, for example, to conduct new types of astronomical observations by constructing large telescopes in orbit, thus adding to our basic knowledge of the universe. The benefit of this is not measurable or easy to convey — one can simply pose a belief that humans are endowed with an intellectual capability which allows us to know and to want to know about ourselves and nature. To do this is to be awed and respectful of the universe, its raw power and beauty, its complexity and simplicity, its interconnections. To be knowledgeable of the universe can but diminish our ego, leading us as individuals to some painful questions: what is it that we can do to enable others to share this wonderment? Can we not spend our world resources in more productive and beneficial ways than armaments? Is it not desirable to work towards providing the world's population with the basic requirements of life so that they too can fulfil the human potential?

One might argue that satisfying the intellectual cravings of the world's elite (or at least well-to-do) is hardly a compelling reason to explore space. Are there applications which might be of more direct benefit to the masses? Yes, there are. We are coming into an era in which there is a confluence of man's increasing awareness of and concern for the fragility of his environment with his scientific and technological ability to understand it. From such understanding might arise a greater political and social wisdom in the stewardship of earth.

The increasing awareness of our place on earth is well addressed by Thomas Lewis [1]: "This world... looks like the biggest organism I, ve ever heard of, and at the same time the most delicate and fragile..." He is also convinced that by viewing and understanding earth as a complex system of which we are an integral part, we... "are more likely to take pains not to do damage to the other vital parts..." around us.

Before one can propose actions relative to the impact of man's actions on his environment, one must understand and describe the environment sufficiently well to be able to predict future courses. To do so requires knowledge of global aspects of the atmosphere, hydrosphere, land masses, ice sheets and life itself. To do so requires that we study tbese major systems and their interactions over long periods of time, building up data sets and computational models. We are in possession of the technologies to do this: powerful computers and global observing satellites. Are we doing it? Not very well as of now.

A prime missing ingredient in our attempt to make headway on studying the earth as a system is the long-term, dedicated multi-satellite observing facilities. Several countries own individual satellites and there is some international cooperation in weather satellite development and operations. Now needed is the multi-disciplinary dedicated facility continually observing the whole earth with a variety of instruments. Outfitting and operating such a facility is an expensive but worthwhile venture. By now the reader may have guessed my view (wisb, hope, plea?) that internationally developed Space Station polar platforms may be a solution. Opportunity knocks. The recent discussions of an International Geophysical Biophysical Program are a start.

The last goal, the stimulation of interest in science and engineering education, has been proposed mostly in consideration of future economic benefits derived from a scientifically/technologically trained work-force. And there is no doubt that space exploration does stimulate many of our youth towards careers in science and engineering. Such a work-force might well aid in obtaining progress towards supplying the basic needs of a significant portion of the world's population. What then? How much more material goods do we need or want?

Cleveland and Wilson [2] pose an interesting possibility: "The achievement of leisure... is no longer... a valid reason for a life of hard but boring labor. Economic security becomes the launching pad for adventure. And people in "advanced" societies will have to find adventure mostly in their working time". Dare we suggest that some of us are now finding their adventure on the launching pad of Space Station?

Adventure, yes. Maybe a reason for humans in space. Most certainly automated satellites could do many of the proposed Space Station activities and NASA will be looking at a mix of man and machine. But also maybe there is more than just adventure. Hannah Arendt in an essay on "The Conquest of Space and the Stature of Man" [3] touches on it... "and yet, an actual change of the human world, the conquest of space or whatever we wish to call it, is achieved only when manned space carriers are shot into the universe, so that man himself can go where up to now only human imagination and its power of abstraction, or human ingenuity and its power of fabrication, could reach". Written in 1963, her thoughts remain valid and have special meaning if we admit that development of a Space Station is not totally an end in itself but also a step towards yet further human reaching. Perhaps to Mars in the next century; some day, I known not when, beyond the solar system.

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SATELLITE COMMUNICATIONS

SPACE COMMUNICATIONS AND THE GLOBAL FAMILY

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The late Herman Kahn used to be fond of the phrase "surprise-free futures". But for better or worse, the future is seldom surprise-free. In the realms of scientific discovery, politics and human affairs, the prophets are almost always wrong.

One might expect them to do a better job in the limited and more manageable field of technology; I attempted it myself, a quarter of a century ago, in *Profiles of the Future.* Nevertheless, the record of technological prediction is dismal, even for experts — I am tempted to say, *especially* for experts. There seems no way of inoculating society against Future Shock: the best vaccine yet discovered is science-fiction — and even that is highly unreliable...

So I am courageously attempting the impossible by trying to predict the future of satellite communications, despite its record of continuous surprises. In 1945, I certainly never dreamed that the global COMSAT and INTELSAT organisations would be only twenty years ahead. In 1965, who could have imagined that there would be a million earth stations by 1985 — some with dishes *less than a metre across*? So, what about 2005?

As a preliminary exercise in mind-stretching, let me tell you a story from the dawn of the Telephone Age — still little more than a century ago. When he heard about this wonderful new invention, one far-sighted American mayor was wildly enthusiastic. Despite the hysterical laughter of his friends, he made this brave prediction: "I can foresee the time when *every city* will have one".

Remember that mayor, before you start laughing at me. I'm trying to reverse Diagaliev's famous order to Jean Cocteau. I want to *prevent* you from being "astonished".

So first, let's look at a few recent technological astonishments and see what we can learn from them. They all stem from what is probably the most important invention since the wheel — one, indeed, that will do a good deal to uninvent the wheel, and none too soon. I refer of course to the microchip — using that term in the very widest sense to cover the whole range of solid-state electronics.

No-one would ever have dreamed that one day there would be more radios than people on the planet earth. (If we've not already reached that stage, we soon will.) Yet the transistor revolution is still just beginning, for one key element was missing until recently. In remote parts of the world, radios can be out of commission for weeks, because batteries aren't available — or are too expensive. The advent of cheap solar cells is about to change that situation, as has already happened with pocket calculators. Before long the world will be flooded with inexpensive radios — and other low-powered electronic devices — that will cost nothing to run and will last virtually forever. They will be scrapped only because of technological obsolescence — not because they wear out.

The economic and sociopolitical consequences of this will be profound. Even an expensive piece of equipment, if it costs little to run, lasts many years, and fills some overwhelming demand, will eventually reach the average man and woman, in every country. The bicycle and the sewing machine are classic examples from the Pre-electronic Age. The transistor radio, the Sony Walkman, and now the videocassette recorder are their successors. And please understand tbat I'm not talking merely about "developing" countries. In this context, there's no other kind.

Now I want to consider a very simple little 4 × 4 matrix which, it seems to me, maps out virtually the entire universe of communications, not only for the man-in-the-street, but also for the man-in-the-jungle.

STATION		SERVICE
1. Person	(1) *	1. Text messages (300 h) **
2. Vehicle	(10)	2. Data (300 - 3000 h)
3. Home	(100)	3. Speech, music (3 - 15 kh)
4. Village	(1000)	4. Video (5 - 10 Mh)

* Cost (arbitrary units - say a week's wages?).
** Bandwidth, hertz.

I have ignored towns and cities on this listing, for two reasons. Obviously, anything that the village can afford will be available many times over in larger human settlements. They will have access to cables and earth stations of enormous capacity: I am focussing here on the requirements of the smallest possible groups, down to individual human beings, and asking this question: "What are the services which *only* communications satellites can provide?".

The simplest and most basic service — though far from the cheapest in terms of power and bandwidth — is of course telephony. So let us start with our old science-fiction friend, the wrist-watch telephone.

Frankly, I don't believe in it. I'm not going to stand like an idiot holding my arm in front of my face. The telephone of the future will be a waistbelt box — just like the Walkman and its successors — with a very light earpiece and throat microphone, working through an optical or electromagnetic link so that one doesn't get continually entangled in tiny wires.

The main unit can hardly be smaller than today's pocket calculators, because it will require at least a one-line visual display *and* a full alphanumeric keyboard. People who talk about wrist-watch telephones seldom mention that small but essential extra — the wrist-watch telephone *directory* — in this case, a global one, with several billion entries. Although the most used numbers would have to be loaded into memory, keyboarding would often be necessary to access Directory Enquiries.

Something like this facility will soon be available in many areas, through the ground-based "cellular" networks now being established. But I am talking about the whole planet — three-quarters of which, please remember, is ocean. Only satellites can provide universal, global coverage. And it doesn't really matter whether those satellites are in the high stationary orbit or, as Dr. Yash Pal has advocated, in low orbits with periods of an exact number of hours. I'm sure we'll need both.

The fact that close satellites will be moving swiftly across the sky is no longer a handicap, at least in this application. The personal telephone — shall I call it a Talkman? — need have no more directionality than the ordinary transistor radio or cordless telephone. As long as there is an appropriate satellite above the horizon, that will be sufficient.

At some cost in complexity, however, the system *could* be made directional, thus reducing satellite power levels by factors of tens or even hundreds. Antennas have already been installed in the roofs of cars which automatically lock on to the source, despite any movement of the vehicle

— or, for that matter, the satellite. The Rutherford Appleton Laboratory in the UK is working on such a system, using satellites in the high-inclination, 12 hour orbit suggested many years ago by Dr. William Hilton and pioneered by the Soviet "Molynias". It is not difficult to imagine simpler man-rated versions for personal use.

If you don't believe this, would you accept the attaché-case or Executive model? The flat antenna is built into the lid, which has merely to be tilted in the approximately correct direction, and the phasing elements automatically take care of the rest. Its facilities would, of course, include printer and full visual display. In fact it would be very much like the portable word-processors which are now changing journalists' lives, as they sit in front of the TV and gather the news. But instead of a modem connected to the local phone system, there would be a microwave beam pointing up at the sky.

For tbe first time in history, businessmen, reporters, tourists, travellers on the high seas, would have full, real-time communications with anyone they wished, wherever they might be. The tedious polemics about the free flow of information, and cross-horder data transfer, are going to be decided by the engineers, not the politicians.

The implications of this in huuan affairs will be at least as great as that of the telephone itself; I will address only a few particular issues.

The most obvious one is this: how will today's sovereign states view this instrumentality, which so blithely ignores all national frontiers? Even countries which consider themselves open will be concerned by possible loss of telecommunications revenue, as well as such problems as security and copyright. But once a technology arrives which fills an irresistible need, there is no way of holding it back — though it can be delayed.

I have two cautionary stories to demonstrate this point. When I first described the "attaché-case" earth station, in my address at the United Nations on World Telecommunications Day (17 May 1983), I used these words:

"You may think this a naive prediction, because many countries wouldn't let such subversive machines across their borders. But they would have no choice; the alternative would be economic suicide, because very soon they would get no tourists and no businessmen offering foreign currency. They'd get only spies, who would have no trouble at all concealing the powerful new tools of their ancient trade".

Well, just a few months later, a gentleman from a country I won't mention was found in another which I shall likewise refrain from naming, carrying exactly this kind of equipment. (For a small consideration, I'll give you the address of the manufacturer.) The transmit-receive unit looked like a pocket calculator, the antenna like an ordinary umbrella. For all I know they were just that; but they were also a good deal more...

My second tale is even more instructive, and begins almost two centuries ago. It shows how a nation of notoriously intelligent people can bring ruin upon itself by trying to restrict — censor, if you like — a new communications technology.

France was the first nation in the world to have a telegraph system — installed, *incredibile dictu*, in 1793. Of course, it was not electric, but purely optical, depending on chains of semaphores observed through telescopes. In this way, the central government was able to communicate with the provinces — *and control them.* No-one else was allowed to use the system; indeed, a law was passed imposing jail sentences of up to a year on anyone — I quote — "transmitting unauthorised signals from one place to another by the telegraph machine or any other means".

When Samuel Morse's invention rhreatened this system — as satellites now threaten the monopoly of terrestrial systems — the visual telegraph had its fanatical defenders. Significantly, they argued that "supervision would be impossible" with wired networks. Listen to this *cri de coeur* from one of the bureaucrats who knew what was best for the people:

"No, the electric telegraph is not a sound invention. It will always be at the mercy of the slightest disruption, wild youths, drunkards, etc... The visual telegraph on the contrary has its towers, its high walls, its gates well guarded from the inside by strong armed men... substitution of the electric telegraph for the visual one is a dreadful measure, a truly idiotic act...".

So much for the free flow of information, in mid-nineteenth century France. Yet ten years later, despite violent opposition, this "idiotic act" had been carried out, and the electric telegrapb began to spread across the country. Nevertheless, the legacy of state control over internal communications lingered on for another century, with the disastrous result that until very recently the French telephone system was the laughing-stock of the world. Though this story has now a happy ending, who can estimate the trillions of francs that the Republic lost through decades of state mismanagement? Those who are now considering their countries' involvement in the next generation of comsats would do well to compare the fortunes of the French and American telephone systems, between 1880 and 1970.

Returning to my little 4×4 matrix, after "person" the next entry is "vehicle". Although these divisions are arbitrary — and indeed overlapping — I am thinking specifically of bicycles, cars and boats, which might justify more expensive installations. And in this context I was delighted to see a photograph in a recent issue of TIME Magazine showing a gentleman sitting beside his bicycle somewhere in the wilderness, typing away on a solar-powered Hewlett/Packard portable. This is exactly the sort of thing I had in mind; and I'm not ruling out bullock carts, either.

Item 3 — the Home — is included for completeness, but I will bypass it because it will be a very long time before most of the world's homes contain any form of permanently installed telecommunications device. Let us go straight to Number 4 — the Village — because that is still the fundamental unit in society for most of the planet, as it has been ever since the invention of agriculture.

The importance of providing good communications to *all* human settlements for economic and cultural reasons, as well as for dealing with medical and natural emergencies, is so overwhelming that there should be no need to stress it. Unfortunately, it is not yet obvious to everyone; telephones are not as glamorous as factories or steel mills, and don't provide as much political mileage.

For the majority of the human race that is not yet urbanised — and with any luck never will be — only satellite technology can provide good, real-time communications. And when the economy-sized solar-powered earth-station comes to the village in the jungle, history, you may be surprised to learn, will be repeating itself. Something very similar happened in Europe and America a century and a half ago. The telegraph sounder in the local railway station or post-office brought, for the first time, instant news of the outside world to communities whose isolation we can no longer easily imagine.

And I can see the rise of a new profession, as universal and as essential as that of the village blacksmith in earlier times. Someone will have to learn the modest skills needed to run the community's ground-station, and to access the global data banks and information networks. Not everyone need acquire electronic literacy — but any intelligent and properly motivated person can do so in a surprisingly short time. Within another generation, every community of more than a few hundred people will need a member of this newest trade.

I will do no more than glance at the other four elements of the little matrix — text, data, speech, video — arranged in increasing (but often overlapping) bandwidth. A great deal can be done with very narrow bandwidths, and hence low powers; the so-called "electronic blackboard" is an obvious example. But for all except very specialised applications a speech capability is essential; for people who cannot read or write, there is no substitute for the human voice, at least where two-way communication is required.

At this point I can't resist the temptation of passing on a hundred-year-old piece of Bell System folklore. After the linesman had installed the first telephone seen in the New Jersey countryside, the farmer came up to him and said anxiously: "I forgot to ask — can I talk Italian over it?".

The engineer shook his head. "You should have told me that before", he remonstrated. "Now I'll have to put in an extra wire — and it will cost you another fifty dollars".

That's more than just a joke. It probably sums up rather well the reactions *we* would have, to the communications systems that will exist when the telephone celebrates its second Centennial, in 2076.

* * *

I am well aware that this paper has not even mentioned scores of fascinating problems raised by the advent of individualised, global communications. I will list a few, in the hope that others at this conference may care to take them up.

How is this system going to be paid for? Telephone billing has always been a mystery to me, and keeping track of a billion mobile stations would be an accounting nightmare. Perhaps the equipment will be rented, and there will be no charge for individual calls — which makes sense, in a world where "long-distance" has ceased to have any meaning.

What about language problems, and standardised protocols? The global air control systems and the computer manufacturers can teach us many lessons here. I suspect that the language of the communications satellites will be that of international physics — broken English. It's a pity about Latin, but we're five centuries too late.

Finally — what about the socio-political implications, which will be the most important of all?

During the last decade, something new has come into the world. Two-dimensional networks are replacing vertical chains of command, in which orders moved downwards and only acknowledgements went upwards. We are witnessing the rise of the Global Family — or Tribe, if you like. Its electronically-linked members will be scattered across the face of the planet, and its loyalties and interests will transcend all the ancient frontiers. Those frontiers which are so conspicuously absent in the photographs from space: those frontiers which to call "sacred" in the age of thermonuclear weapons is no longer patriotism — but blasphemy.

It has been wisely said that the State has now become too big for men — but too small for Mankind. Is the present proliferation of nations — about 160 at the moment! — a planetary cancer, or an evolution towards a healthier world, in which political structures will be built on a more human scale?

And to continue the analogy from evolution, let us remember something that happened on this planet once before. There was a time when it was dominated by monsters who tried to protect themselves by ever more cumbersome armour, until they were walking fortresses. They never noticed, as they blundered through forest and swamp, the little creatures that skipped out of their way: the first mammals — our ancestors.

Intelligence, not armour, was to inherit the Earth. May it do so once again.

Note. — Many of the above concepts are also discussed in « Beyond the Global Village » (World Telecommunications Day, UN Headquarters, N.Y. May 1983) and « New Communications and the Developing World » (UNESCO IPDC Conference, Paris, June 1981). Both will be found in *1984: SPRING* - A Choice of Futures (Dey Rey, NY; Granada, UK).

SATELLITE COMMUNICATIONS: REGULATORY FRAMEWORK AND APPLICATIONS FOR DEVELOPMENT

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It is a rather special honour for the Secretary-General of the International Telecommunication Union to be invited to speak to you today on what is a key element in the whole of space exploration and use, namely the international regulatory regime for the technical and operational aspects of communications between men and objects in space and the rest of us on Earth — and how this relates to development.

The starting position can be stated quite simply; telecommunications provide the only link between space and earth and whatever happens in space or whatever use is made of space, telecommunications are required to make it possible.

Without a legal framework, observed by all nations of the world, reliable communications between space and the earth would not be possible and it would not be feasible to envisage projects and investments of the magnitude which we have already seen in the as yet rather brief period of man's exploration and use of space.

It is only because those who plan these projects know for certain that the international community, as a whole, will uphold and apply the texts of the International Telecommunication Union — which serve to ensure the reliability and trustworthiness of earth-space communications — that projects which require many years of advanced planning can be envisaged.

An important aspect of the ITU's working methods should be explained at the outset. The ITU is in practical terms a cooperative of knowledge, an organization in which member countries come together bringing with them their experience and the research concepts they have explored, so as to develop a common position based on the best possible consensus. In this way the ITU comes to conclusions which the whole of the membership and the world can recognize as sound and workable.

The inherent strength of the ITU's legislation is that it concerns the physically possible, rather than what might be seen as standards of conduct. The ITU deals primarily with what is appropriate in a technical or operational sense and while man may be able to make better use of the laws of nature through advanced technology or better understanding he cannot modify the laws themselves.

This is then the general context in which I shall be speaking to you today. May I just add that the ITU was founded in 1865 and that we plan to celebrate our 120th anniversary next year.

In order to explain to you what the ITU has achieved so far and in which direction it plans to go, I should start by saying something about the principal instruments through which the ITU works. In so doing I have chosen to emphasize the strictly practical side of the matter rather than the more formal legal divisions of ITU texts as I believe this to be the best way to explain what I wish to say.

Telecommunications with objects and people in space have of necessity to rely on radio. There can be no physical connection in the sense of a cable between the earth and space.

An absolutely fundamental aspect of the use of radio is that the stations at each end of a radio circuit must be tuned to the same frequency or frequencies, otherwise they cannot receive each other.

The frequency, the specific characteristic which enables users of radio to separate different transmissions, is therefore a fundamental element of radiocommunications. It is, therefore, a matter which needs to be regulated and its use agreed between all potential users.

One can distinguish three broad levels in the way in which the use of frequencies is structured at both the national and international level.

The first covers the sharing of the radio spectrum between different categories of users, figuratively speaking rather like cutting it into slices reserved for particular uses. This is a very long established practice ever since the early days of radio when a distinction was first made between maritime radiocommunications and communications between stations on land.

Today, there are many kinds of so-called « radio services » including the broadcasting satellite service or the aeronautical radionavigation service, to name but two. There are in fact some 35 definitions for specific terrestrial and space radio communications service in the Radio Regulations, the official ITU texts. The reason for dividing spectrum up into such slices, correctly termed allocations, is that propagation conditions vary depending upon the part of the radiofrequency spectrum one is considering. Similarly, different kinds of users can make better use of one part of the spectrum than another either due to the type of radiocommunications which they need or the kind of equipment they may use.

At the same time it is true that a more efficient use can be made of the radio frequency spectrum if stations of the same service share the same frequency band.

As this kind of distribution of the radio spectrum is a very fundamental act and could potentially affect the quasi totality of radiocommunications users, it is something which is done rather rarely. The last occasion when this was done was the World Administrative Radio Conference of 1979, the occasion previous to that having been twenty years earlier, in 1959.

One has also to keep in mind that as the use of the radiospectrum increases it becomes progressively more difficult to make changes to the frequency allocation table.

This leads me to the second level in the structuring of the use of the radio frequency spectrum, namely the use of detailed planning in an international context for the frequencies and other characteristics of specific stations so that these can share the frequency space in an optimal way.

Not all radio services are planned like this, but a substantial part of the broadcasting and the mobile (aeronautical and maritime) services has for many years now been planned in this fashion.

Sound broadcasting in Europe was first planned by an ITU conference as far back as 1933, by a conference held in Lucerne to be precise. In passing, it should be noted that such internationally agreed frequency assignment plans can comprise hybrid arrangements under which some kinds of stations are the subject of detailed planning while others operate subject to administrative provisions.

With the advent of space communications this kind of planning was extended, in 1977, to the use of the geostationary-satellite orbit for direct satellite broadcasting to Africa, Asia and Europe; and more recently, in 1983, this was also done for the Western Hemisphere taking account of the particular needs of the region. The ITU is now preparing for a comprehensive exercise on the use of the geostationary orbit which will culminate in the second part of a two session world administrative conference "on the use of the geostationary-satellite orbit and the planning of space services utilizing it", due to be held in 1988.

The first conference or session due to be held in 1985 will deal with an overall review of the relevant issues. The conference will, among other things, determine which radio services should be planned in detail and which can be handled through national planning and case-by-case international co-ordination. I believe that at the first session the real focus will be on how to approach the different fixed satellite service requirements for global, regional, sub-regional and domestic uses and on how the specific features of each of these uses affect planning.

The extraordinary success of the international use of satellite communications and the reductions in transmission cost which this technique has brought about have opened up the possibility of using satellite communications for national purposes including for quite small user needs.

This leads us to the real importance of the 1985 and 1988 conferences. These conferences will have to find the solutions which will "guarantee in practice for all countries equitable access to the geostationary orbit and the frequency bands allocated to space services", to quote the precise terms of the resolution asking for the conferences to be convened.

In this regard, may I underline the fact that in the use of the geostationary-satellite orbit the limiting factor at present appears to be the need to keep satellites far enough apart to avoid interfering with one another in the radio sense. The problem of collisions seems to be more easy to handle. As a matter of fact, in the 1983 Plan for satellite broadcasting for the Americas, it was considered feasible to work a cluster of two or more satellites at the same nominal orbital position.

Finally, I would like to say something about the third level of sharing the use of the radio spectrum between users. Very obviously, radiocommunications needs reflect human activity and wherever there is human activity there may also be a need to adjust to short and medium term requirements.

The same applies to the use of the radio frequency spectrum. There are procedures for handling new or modified frequency usage between planning conferences or for those services for which no plans exist. These procedures are either contained in the Radio Regulations or set out in the agreements which accompany frequency plans. The ITU has a special body, the International Frequency Registration Board, which looks after this side of the matter in ensuring that only those frequency assignments of countries (and where applicable the associated geostationary-satellite orbital position) which are in accordance with the Radio Regulations are registered for international recognition.

I have spoken at length about the most fundamental aspect of the ITU's involvement in space telecommunications, the use of the frequency spectrum and the geostationary-satellite orbit.

There is, however, another vast field of activity, which is less easy to summarise. This ranges from the determination of the basics of the Rational Use of the Radio Frequency Spectrum and of the Geostationary Satellite Orbit or the Right of the Public to Use the International Telecommunication Service, etc., to the vast range of technical and operational criteria which have to be met with in order to interconnect a telephone, telex machine or telecopier in one country to a similar device in another.

Many of these texts are of a general nature and apply independently of whether communications are via satellite or not, but a substantial part deals with matters specific to space communications.

The subject matter can be very detailed and ranges from recommendations on the intensities of transmissions from satellites to the kind of steps which have to he taken in order to ensure that telephone calls made via satellites are possible without the echo of one's own voice interfering with one's speech after the signal has travelled up to the satellite down to the distant subscriber and all the way back again.

I should add that a large part of this detailed work is carried out by organs of the Union which bring together telecommunication operating agencies, industrial and scientific organizations and specialized international organizations. These organs are the International Radio Consultative Committee (abbreviated by the French initials CCIR) and the International Telegraph and Telephone Consultative Committee, CCITT for short.

Although these bodies are referred to as consultative committees, this is their original name dating from the twenties; they are really a network of study groups and working parties overseen by plenary assemblies which meet every three and a half years. The aggregate number of delegates participating in the work of a CCI may exceed 10,000 between two plenaries and as the conclusions represent the best available consensus of knowledge and experience, the relevant texts are very likely to be applied even though they are not mandatory.

I have spoken at length about the mechanism and before going on to talk about the future, I wish to say something about the practical consequences of all this.

Here I have to come back to a very fundamental aspect of telecommunications and that is that telecommunications are really used in two ways, (i) the most obvious, by the "end user", you and me when we use the telephone or even when a telex message is sent on our behalf and then (ii) there are the other uses of telecommunications where the end user is not really aware of the role telecommunications are playing in what he or she is doing. Perhaps the most obvious is travel by air where air to ground communications, radio navigation and radar all ensure a safe flight.

The same is true of space telecommunications and we are aware of it to varying degrees. When we make a telephone call via satellite we are sometimes conscious of the slight delay in our correspondent answering our questions; as we watch a direct television re-broadcasting of some distant event, we are told it is coming to us via satellite and we perhaps still associate this with space; when we look at the satellite weather map shown to us on television we probably no longer ask ourselves how the picture got down to us on earth, and when we come to even more sophisticated applications such as earth resource satellites, only the experts know the frequency bands — in as far as these are within the allocated radio frequency spectrum — to which the sensitive satellite-borne radiometers respond.

The international legislation concerning space telecommunications assures not only the daily use of space applications, but it also allows long term planning and long term uses. One need only consider the space probes sent to explore other planets, and especially the outer planets, to realize the importance of ensuring frequency usage over long periods of time.

Similarly, at the day-to-day level we do not have the weather forecast announcer on television saying that he is not able to show the satellite cloud cover picture because some other station has interfered with tbe radio frequency usage of the meteorological satellite concerned.

These are all cases where the success of the technological achievement, which we must never underestimate, rests in the final analysis upon something in essence much more fragile, human agreement between nations.

Perhaps it is the fact tbat radio waves simply do not observe national frontiers which has really made this possible. Perhaps it is also the fact that any form of interconnection requires a minimum of understanding and agreement between those at both ends of the circuit which has led to this degree of achievement inside the ITU.

Whatever it is, however, the ITU must look forward to new challenges — to the challenges of a developing world and the complexities of introducing on a large scale, and this even in the most remote parts of the world, a basic public telecommunication service.

It is in this perspective — the challenge before us — that I would like to present my view of the future.

Basically, we have to ask ourselves the question inherent in the title of your symposium "What has space activity brought to mankind?". One can then follow this question through to its simplest or most logical conclusion.

When we deal with manufacturing processes in space, the property we are looking for is perhaps quite remarkable — weightlessness, but the property we are seeking for most other applications is probably not so well recognized because it is just a new vantage point, a new place from where to see or act.

I venture to suggest that many of the uses of telecommunications involving space applications are really concerned with putting a station some place from where one can at any instant see — and therefore direct to, or receive from, radio waves, for all kinds of applications, be they telephony, broadcasting, meteorology, earth-resources survey or whatever, — a part of the Earth far greater than one can from a terrestrial vantage point, and by the time one gets to higher orbits, such as the geostationary satellite orbit, one can see almost a whole hemisphere.

There comes, from this property of having such a high vantage point, a very special advantage — obstacles which on the surface of the earth would constitute a very serious impediment to the establishment of facilities, like a cable or microwave link for example, are no longer a determinant factor.

On top of this there are further advantages — the cost of linking a point "a" with a point "b" is independent of the distance on earth between these points provided that both can be seen from the same satellite. This is very important in the case of the most isolated areas of developing countries as it means that once the basic space communication infrastructure is established, outlying or difficult to get to places can be linked to a central point at similar costs to those incurred for terrestrially easier and shorter routes.

The whole question of delaying the development and expansion of difficult and remote routes to later — and the consequences which such decisions may have on economic and social development in an age when telecommunications are fast becoming an essential medium even in the least developed countries — takes on a different form when one has space communications.

Communities no longer need to be isolated or poorly connected because they are difficult to get to. The provision of basic telecommunications — by this I mean simply the telephone and such other telecommunication services which can be easily carried over a telephone circuit — has already become mainly a question of political will, the expression of the priorities which governments determine within the available national resources.

Obviously, many countries do not possess the means to install extensive telecommunication networks and one has also to say that some governments have perhaps not adequately emphasized overall communication needs, possibly due to other pressures.

Yet here too, within certain limits, satellite communications offer an advantage over other communication systems. I have mentioned that the cost of satellite communication systems are largely independent of the distance one has to cover on the face of the earth. Another property of satellite communication systems is that, once again within limits and in contrast to the terrestrial network, new destinations can be added without increasing the cost to the already existing network.

This is a very important property of satellite systems when it comes to using them in the development context: its ability to accommodate with ease any new station that falls within its coverage area. It is this that has made satellites so very useful not only for point-to-point services but also for other types of services like broadcasting and earth resources survey, both of which have significant implications for development.

Other speakers addressing the Symposium will be talking to you about specific practical applications of satellite communication systems and I shall therefore confine myself to a brief outline of the different approaches which have been adopted by developing countries as far as the use of such systems for national or regional purposes is concerned.

The point I wish to make is that it is not so much the technical aspects of the systems which are determinant, but the way the organizational and operational factors have influenced the choice of solutions adopted in each case.

India was one of the first to realize the importance of space communications for developing countries. This resulted in policy decisions and the establishment of a strong national programme as far back as the late sixties. The aim of the programme was to develop indigenous capacity and expertise. The ITU participated actively in telecommunication elements in this task. The practical application of space technology started with the use of an experimental satellite belonging to the United States.

These initial efforts have, over the years, advanced to a point where India now has an independent launch capacity and the facilities successfully to build its own satellites even if it continues for the moment to procure commercial service type communication satellites from external suppliers.

Algeria is an example of a country which chose satellite communications to access its more remote centres of population. The approach was different from India in that Algeria chose to use a transponder on an Intelsat satellite for this purpose, in this way bypassing satellite ownership, launching and operation issues. Satellite communications provide a large part of Algeria with a quality of communications which it would have taken a long time and a very considerable cost to attain by terrestrial means. Algeria now operates earth stations in the international facilities of Intelsat and Intersputnik.

Indonesia, with its terrestrially almost intractable communication problem of linking up a large country consisting of many islands, has chosen to use dedicated national satellites, the PALAPA satellites. What is particularly interesting in this development is that it has now become possible to provide certain telecommunication services to and from other countries in the subregion with the help of these satellites. This illustrates the flexible nature of satellite communication systems and the way in which other countries may, given the required international co-operation, benefit from co-operation in the use of such systems.

Another different approach is that of some of the South Pacific island states, themselves widely separated islands and furthermore not in a position to finance their own satellite. They started off by using a satellite which had been constructed by the United States for experimental purposes. It has operated since the mid 1960's and while its scope of application was limited it provided very useful services in times of natural disasters, for health care and for the educational programmes of the University of the South Pacific. It was in fact the only available means for doing what it did. So much so that the Heads of State in the South Pacific Forum concluded that the future inter-island national telecommunications would have to depend upon an appropriate satellite system. As the original satellite will eventually come to the end of its service life, Australia (which is a member of the Forum) has offered the use of a transponder on its national telecommunication satellite to these countries when this second generation satellite is launched in a few years' time.

In the meantime, ITU and bilateral studies are proceeding through the South Pacific Bureau for Economic Co-operation with a view to establishing general plans for the evolution of the national networks concerned.

Yet another approach to the organization of satellite communications for developing countries is that being adopted for Africa. Here the ITU, as the lead agency, is working in close association with African regional organizations and UNESCO with a view first to identifying the telecommunication needs, and then to advise on the resulting system options which would enable the various countries concerned to integrate space communication facilities into their national networks and to service regional development as a whole.

Here then we have five different ways in which space communications can be used in order to provide telecommunications for developing countries. Their diversity illustrates particularly well both the range of solutions which exists and the need to adapt the possibilities offered by technology to the practical requirements and available resources of the countries or regions concerned. A particular aspect to consider is the potential for low cost services if users can share certain terrestrial and satellite facilities.

I have spoken extensively on how the ITU bas, through its legislative and developmental functions, contributed to space exploration and use and how this has been and will in the future be reflected in day-to-day space activities.

The title of your seminar, the "Impact of space exploration on mankind", could be put in other terms to read "the Path from the Idea to Practical Reality"; and I would therefore like briefly to sum up the contribution which adequate international telecommunication regulation with its associated standardization and developmental actions has made to this field.

There are three aspects which should be considered:

— the institutional
— the practical or material
— the psychological.

I have already spoken at length about the institutional aspect, and there is just one point I should make about this in my conclusions.

The achievements of the ITU are not to be seen as an attribute of an organization; they should instead be considered as the realization by all the Member countries of the Union of a need to find workable solutions and the will of these countries to come together and do just that.

I have also already mentioned some of the practical consequences of the ITU's work and I do not wish to enlarge on these as you will be hearing from other speakers detailed and extensive presentations on this. The work of the ITU is also closely inter-related with that of the United Nations on the Peaceful Uses of Outer Space and the UN's co-ordination role, as well as the UN's own field of more general space legislation.

Finally, what I would like to emphasize is the psychological consequences of the ITU's work. I have, during the development of my theme, repeatedly pointed out that from a practical point of view ITU legislation and association work has provided security for planning and day-to-day operation.

This has made possible direct real time public viewing — I would almost say participation — of life on board space stations as well as walks in space and, let us not forget, on the moon. While this may, to some extent, have made space look easy, perhaps even commonplace, it has helped familiarize an area of human activity which, by virtue of its great potential for future development, is vital to mankind.

TELECOMMUNICATIONS WITH SATELLITES: THE STATE OF THE ART

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1 - *Foreword*

The importance of satellite communication systems in the general framework of world telecommunications continues to increase: in fact traffic carried by satellites, which is presently of the order of several hundred thousand telephone channels (or the equivalent), will increase by an order of magnitude before the end of the century, reaching millions of telephone channels, and possibly more if video-conference services develop as foreseen by recent studies.

In the present paper, after some historical remarks meant to present organically general system concepts, problems and solutions will be reviewed as they arise in the development of present and future systems, along the trend of greatly increasing the capacity in orbit while decreasing the cost per communication unit, in order to offer large and more diffused possibility of communication to humanity.

2 - *Historical remarks and system concepts*

In the following, consideration will he given only to geostationary satellites, which, after initial doubts and debates, proved to be by far the preferable solution as originally foreseen by A.C. Clarke [1].

Practical satellite communication systems started with a conceptually simple solution, whose evolution (from Intelsat I to Intelsat III) consisted mainly in pointing to earth a directional on-board antenna, capable of covering only the earth surface as seen by the satellite, thus avoiding waste of power in space. The system so obtained can be generalized, for what concerns antenna coverage, as shown in figure 1, which will be referred to as *basic* in the present paper. This solution has a remarkable system simplicity, especially in regard to the space segment which consists in effect of a "transparent" transponder (i.e. an amplifier including a frequency conversion), associated to a "full coverage" antenna, covering the full territory to be served.

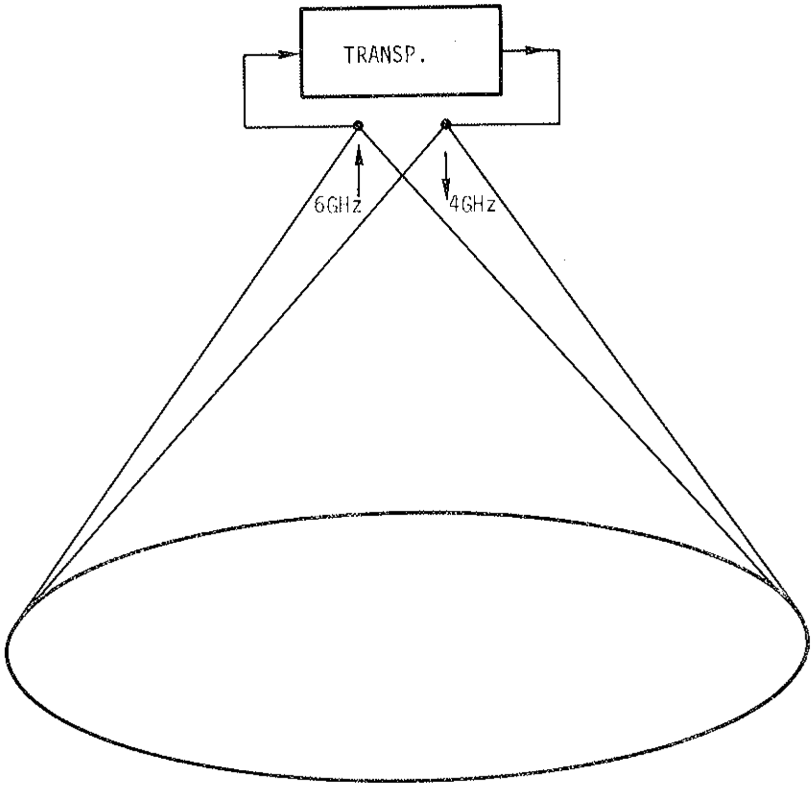

Fig. 1.

— Transparent on-board equipment } Flexibility
— Full coverage antenna }
— Ideal propagation
— Dominant path: Down-path

SUBSEQUENT REQUIREMENTS

— Efficient utilization of — Power
— Frequency spectrum
— Orbit
— Use of new frequencies

As the satellite-antenna power gain is inversely proportional to the projected service area [1], the power to be transmitted, from satellite and from earth, for a given earth antenna, is proportional to this area, as it is the earth-antenna area, for the same transmitted powers.

As indicated in figure 1, the basic solution possesses to a high degree the system flexibility, whose various aspects are described in table 1 and which represent an important characteristic of satellite communications.

Flexibility A), in transmission methods, allows, for a given satellite, to follow changes due to technical evolution or different needs; flexibility B), in rapid system construction, allows the satellite to rapidly face new communication needs and to anticipate new services (this is particularly important for developing countries); C), in system growth, has been for example essential in the development of the Intelsat network up to its present level [2] allowing widely dispersed countries to be connected rapidly with the developed world in a global communication system; flexibility D), in capacity distribution, allows to face sudden traffic changes, in particular traffic increases in certain locations due to the movement of people for various reasons or to emergency situations arising from natural disasters or failures of terrestrial communications. The latter point is fundamental, as it will be emphasized later in regard to the reliability of an integrated network of satellites and terrestrial facilities.

The flexibility of satellite systems has been further enhanced, from a certain point of view, by including in the space segment in lieu of a single transponder (fig. 1), a number of transponders in parallel, each covering a portion of the available band (Intelsat IV satellite). In this

TABLE 1 — *Satellite System Flexibility.*

A)	In Transmission Methods (Modulation, Access, etc).
B)	In Rapid System Construction (A complete communication network can be set up in a short time).
C)	In System Growth (New stations may be set up any time wherever needed in the covered region).
D)	In Communication Capacity Distribution among the stations.

(1) Service area projected over a sphere centered at the satellite.

case, for example, different modulation or access methods may be used simultaneously in different transponders; or different transponders may be assigned to different systems. For instance transponders have been leased to specific countries allowing them to set up their own internal communication networks. In figure 1 it is also shown that in the basic system, operating at 4-6 GHz, electromagnetic wave propagation from earth to space and vice versa occurs ideally, as in free space. This constitutes indeed the unique case of radio communications enjoying free-space propagation and assuring a practically constant received power, almost at the maximum level which can be realized in a radio system. This power level can be calculated with accuracies of the order of 1 dB and allowed to set up the basic original systems with reasonable and available amounts of satellite power. Moreover it was possible to fully appreciate advantages of the order of a few decibels obtained through the use of new modulation and demodulation methods and of low-noise amplification. The latter was in effect facilitated by the fact that in the 4 GHz band the noise received by the earth antenna is at a minimum (fig. 2).

A last remark with respect to figure 1 concerns the fact that in the basic original system the down-link was dominant, in the sense that the allowable system noise was to a large extent assigned to the down-link on account of the high cost of satellite power. Large amounts of power were instead used at the earth stations, together with very large antennas of 30 meter diameter. This solution was acceptable in that stations were installed to carry intercontinental traffic with only one or at most two or three stations per country.

Finally, figure 1 recalls the main subsequent technical requirements which followed and follow the basic original solution in order to fulfil the new needs arising not only from the large traffic increase on the intercontinental routes, but also from the application of satellites at the continental and national levels, which implies very large capacities and small cost per communication unit (e.g. per telephone channel). These requirements will be at first examined with reference to fixed point-to-point communications. The efficient utilization of power (reference will be made at first to satellite power) is a key factor for reducing, for a given capacity, size and cost of the satellite. A first approach to this problem led to a comparison between the two main methods of multiple access to the satellite (Table 2). The first is the originally used frequency-division multiple-access (FDMA) based on well established techniques and characterized by the transmission from the earth stations of radio carriers at

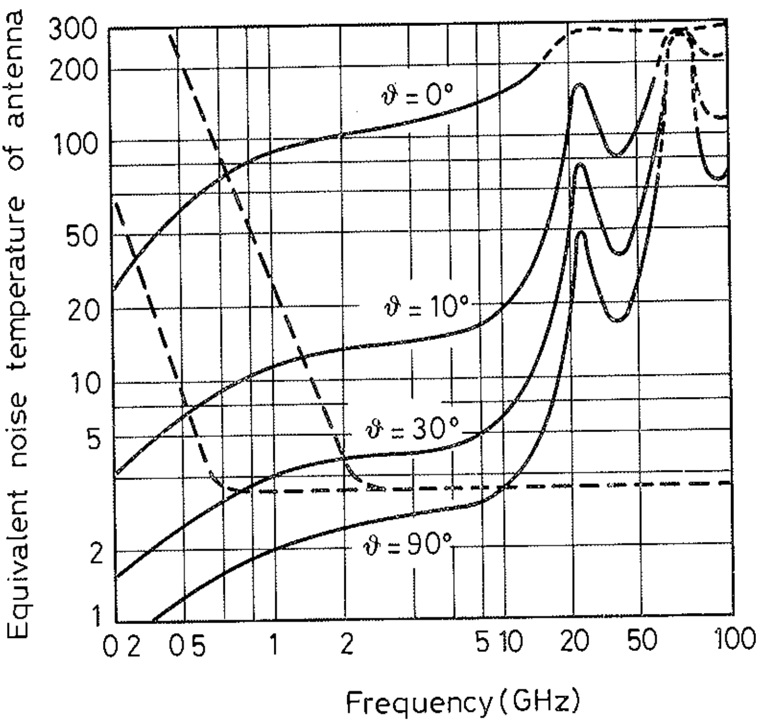

FIG. 2. Cosmic noise (dotted line); atmospheric noise (solid line); ϑ elevation angle.

TABLE 2 — *Access to Satellite.*

	DOWN-LINK	UP-LINK
Frequency division	Power loss due to linearity problems	If a single carrier is transmitted from earth the earth power is used efficiently
Time division	Efficient use of the satellite power	Power loss due to burst-operation of the earth transmitter

different frequencies (one or a few carriers per station) modulated by the outgoing signals. Each station receives and demodulates the carriers and uses the signals destinated to it. The other method is the time-division multiple-access (TDMA), which is characterized by the transmission from the earth stations of digital signals in different time slots (fig. 3). Each receiving earth station extracts from each time slot the signals destined to it. With reference to the first column of table 2, a well known drawback of a multiplicity of carriers passing through the same amplifier is that the amplifier non-linearity produces intermodulation among the carriers and therefore additional noise, which in turn requires, if it is maintained within reasonable limits, that the total emitted power, in this case at the satellite final travelling wave amplifier output, be reduced to several decibels below the saturation level. This decrease in power utilization is practically overcome by TDMA due to the fact that only one signal is handled by the satellite at any given time (fig. 4).

It is to be noted that the previous comparison refers actually to the *signal distribution* from satellite to earth (either by frequency- or time-division) and that it is transferred to a comparison between *access methods* only because a transparent transponder was assumed.

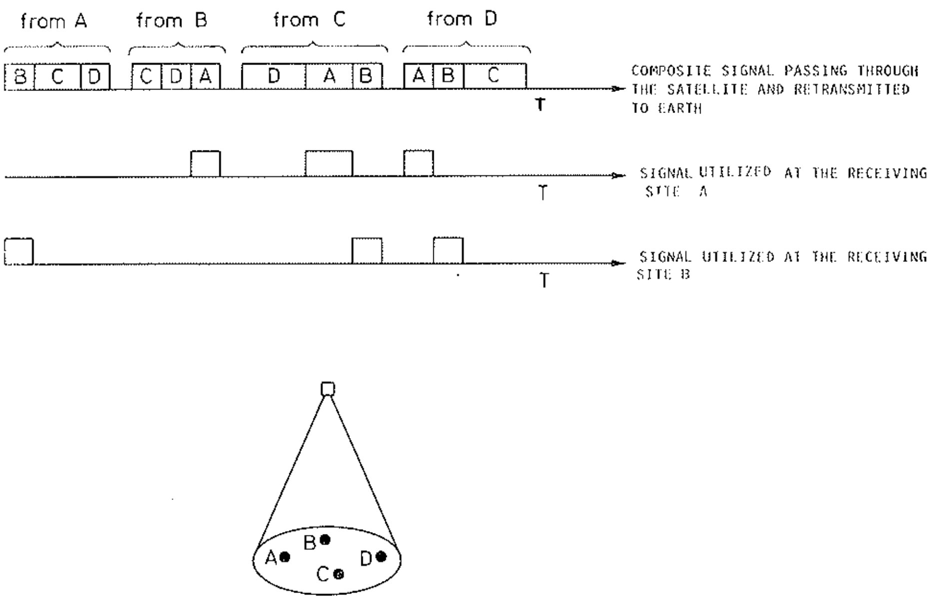

FIG. 3. Time-division multiple-access.

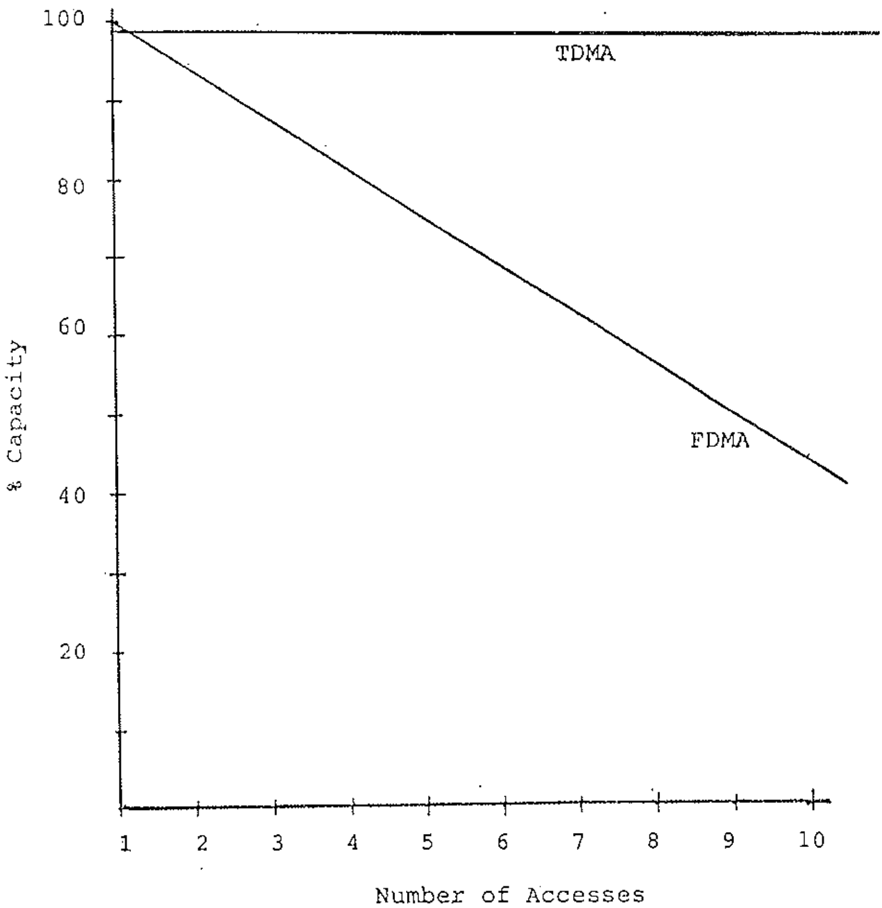

FIG. 4. Transponder capacity as a function of the number of accesses.

As a matter of fact, the access method has a direct influence on the power efficiency on the up-link (second column of table 2), i.e. on the efficient use of the earth-station power which acquires increasing importance in addition to the efficient use of the satellite power, in the recent developments. In effect there has been an increasing interest in spread systems with many earth stations installed at peripheral points of the national communication networks and even at the user premises. In this case the balance between satellite cost and cost of a single earth station changes in the sense of increasing their ratio: small and low cost stations are essential to make such systems acceptable. Consequently the importance of up-link increases until it becomes at times the critical path, in contrast to what happened in the basic original solution. In this respect TDMA, which was found advantageous on the down-link, is characterized by a loss in power efficiency on the up-link, because of the discontinuous transmission from the earth stations. Since the output amplifiers are in practice peak-power limited, the transmitted power from earth is reduced according to the factor 1/s if s is the number of stations in the system, assuming identical stations for simplicity's sake ([2]).

In addition to an efficient use of the power (in space and on earth) an efficient use of the frequency spectrum (and of the orbit) is required, in order to provide the large capacities needed. Under such circumstances there is not too much to maneuver with modulation methods which, as it is well known, at least in an interference-free environment, are capable to trade off power at the expense of band width and vice versa, i.e. they are efficient in power when inefficient in spectrum utilization and vice versa. In practice, when satellites are angularly closer along the orbit to improve orbit efficiency, an interference-limited environment arises, with a resulting optimum band width expansion by the modulation process. A fully different perspective, which will be considered in the next paragraph, is offered by special highly-directional antennas, which make it possible to increase simultaneously power *and* spectrum efficiency.

In spite of the efforts pursued to improve an efficient utilization of the spectrum, the frequencies used in the basic solution are inadequate to accommodate the new capacity requirements. Consequently new frequency bands must be used, which will be discussed later on in this paper.

3 - *Multibeam on-board antennas as a means to jointly increase power and spectrum utilization*

Figure 5 shows a general state-of-the-art solution in which a satellite antenna of greater directivity than that shown in figure 1 is used. The antenna footprints are drawn in the figure. Two possible solutions may be considered: a) a steering-beam solution [3, 5] using TDMA, in which a single transmitting beam and a single receiving beam are moved from

([2]) It would be of importance to develop amplifiers (or methods to use them) having a cost dependent on the average power instead of on the peak power.

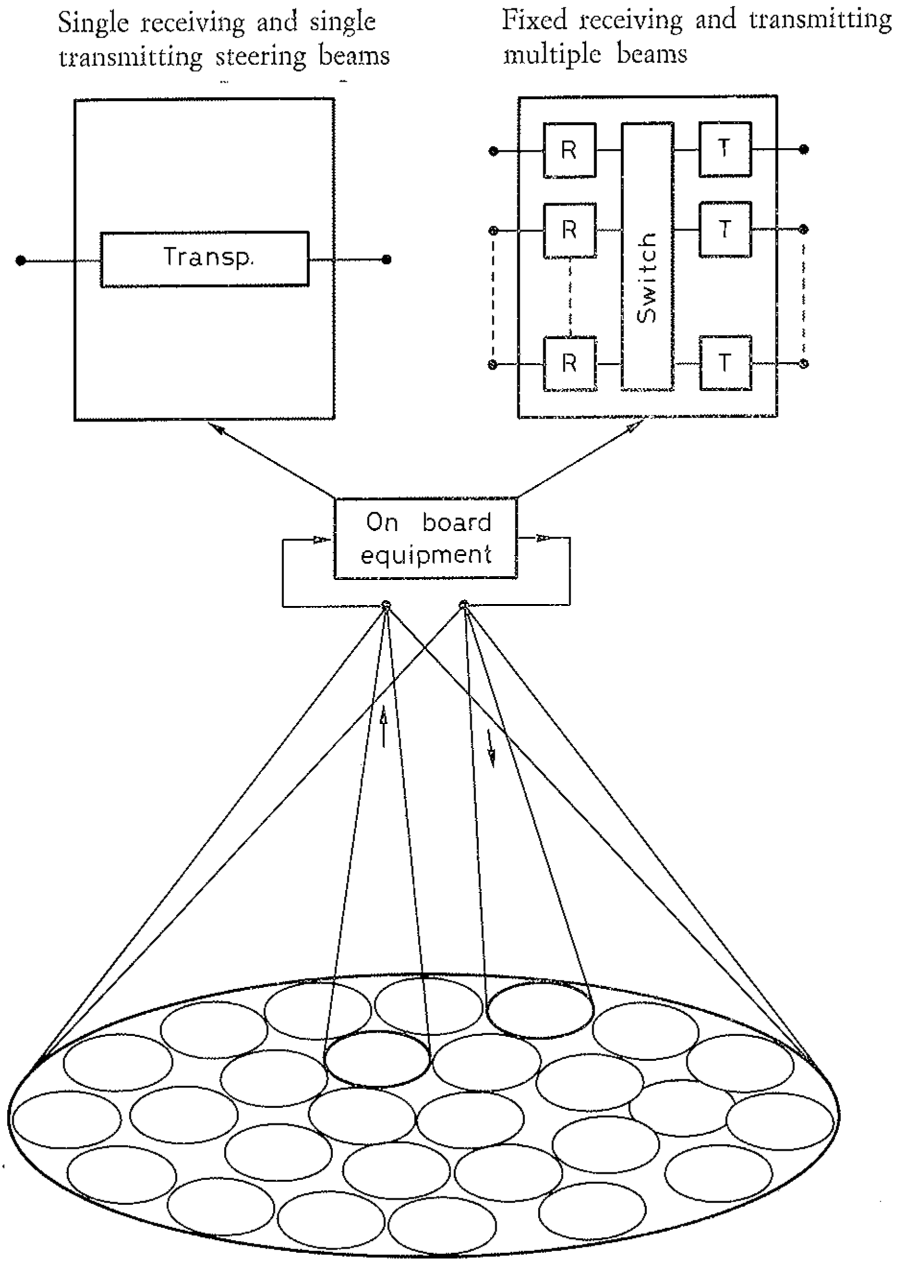

FIG. 5. Use of highly directive on-board antenna.

s stations; s_1 stations/beam; n beams: $s = s_1/n$

one position to another according to the time-division operation: for instance the receiving beam is pointed at any time in the direction from which signals arrive at the satellite; b) a fixed multiple-beam solution [4, 5, 16] in which all beams are simultaneously active; obviously in this case at least a receiver and a transmitter are permanently associated to each beam and switching equipment is needed to interconnect the various beams.

If s is again the total number of identical stations in the region to be served, s_1 the number of stations per beam and n the number of beams, then $s = s_1 n$. The antenna gain with respect to the solution of figure 1, is clearly n.

Consider at first the steering-beam system (table 3), which, as pointed out, can be only set up with time-division access and distribution; on the down-link the antenna gain represents a net power gain with respect to the satellite available power because the latter is fully exploited. On the contrary, in the up-link, the achieved antenna gain n tends only to compensate the power loss due to the burst-operation of the earth transmitter. Taking into account this loss, the net power gain is $n \cdot 1/s = 1/s_1$ which means that, with respect to figure 1 with continuous emission from earth, a power loss is again encountered when $s_1 > 1$, as it generally happens.

In the case of multiple fixed beams (table 4) the first consideration to be made is that its application is general, i.e. it is not constrained to time-division access or distribution, although the satellite switching matrix may be better realized using time-division techniques, and thus it favors time-division access and distribution in the absence of on-board memories.

The net power gain on the down-link is n in case of time-division distribution; on the up-link the net gain is also n in the case of continuous emission from earth and decreases to n/s_1 in the case of time-division access.

TABLE 3 — *Steering Beam.*

DOWN-LINK :	Power gain n
UP-LINK :	Gain or partial loss recovery? Power gain in respect to TDMA: n Power gain in respect to continuous transmission from earth (as in FDMA): $n \cdot 1/s = 1/s_1$

TABLE 4 — *Multibeam.*

DOWN-LINK :	Net power gain n in case of time-division distribution;
UP-LINK :	Net power gain n in case of continuous emission from earth; n/s_1 in case of time division access
Efficient use of spectrum	
Efficient use of orbit	

In addition to an efficient use of power, as indicated, the multibeam solution has a highly efficient spectrum utilization, because the same frequencies may be re-used in non-adjacent beams, i.e. may be re-used approximately $n/4$ times. As a result, the multibeam solution makes it possible to concentrate a very high capacity in a single orbit position and thus to increase very noticeably the orbit utilization. Of course the orbit utilization depends also on how far apart on the orbit satellites serving the same region must be located. Angular separation depends strongly on the directivity of earth and satellites antennas, especially with regard to their sidelobes.

Spectrum and orbit utilization will also take advantage from the possibility of discriminating, with proper antennas, isofrequency signals having orthogonal polarizations: this possibility makes it possible to further increase the frequency re-use by using isofrequency orthogonally-polarized signals in the same beam, or in adjacent beams, or in adjacent satellites.

In conclusion antennas are and will be key components of future satellite systems. In particular the steering-beam solution keeps the single on-board transparent transponder of the basic solution, gaining n times in power on both links when a TDMA system is used. There is however the mentioned power loss in respect to continuous emission due to burst operation, which may suggest to use the steering beam only in the down-link and to adopt on the up-link a different better arrangement whose consideration is however outside the scope of the present paper. This solution gives no improvement in spectrum efficiency and is of interest for regions with comparatively low traffic requirements but strong requirements in power efficiency like in the case of spread systems in developing or low-density inhabited countries. The multi-beam solution gains n times in power on both links for any transmission method; it gains also noticeably in spectrum efficiency and is a very useful solution for regions with high traffic requirements.

4 - *Configurations of future systems and technologies*

Communication technology is developing toward a continuously increasing and extensive adoption of digital transmission and switching techniques. Satellite systems will also follow this trend, which makes it possible on one hand to realize more sophisticated and efficient solutions with modern electronic technologies, while permitting, on the other hand, the direct interconnection and integration of satellites with terrestrial networks. Indeed, as pointed out in paragraph 2, satellite systems will make it possible, in many circumstances, to anticipate the terrestrial integrated-service digital network (ISDN), thus becoming a test bench for new techniques and new services.

Reasons for more sophisticated on-board equipment have been already mentioned in the previous paragraph: for example a steering-beam solution, realized with a phased array antenna (whose principles are illustrated in figure 6), requires large antennas using a number of components based on microwave solid-state technology and, whenever possible, on integrated solid-state technology. In the case of a multibeam solution, capable of increasing power and spectrum utilization, the production of narrow well-decoupled beams requires again a large antenna with a very well designed and built primary source whose stringent requirements are further constrained when cross-polarization decoupling and side-lobe level-reduction are considered. Also a sophisticated on-board equipment is required in case of large-capacity multibeam satellites, as indicated in figure 5; in effect a large number of receivers and transmitters must be connected through a switching equipment, which, if working at base-band, which is desirable in the case of a large number of beams, implies on-board regeneration of the signals.

The sophistication of the on-board equipment will further greatly increase if different transmission methods are adopted for the up- and down-links, and still more if different transmission methods are adopted for different up- and down-links. For instance it has been already pointed out that time-division, while power-efficient on the down-link, has lower power-efficiency on the up-link due to the non-continuous operation of the earth transmitters. Power efficiency could be high on both paths by using frequency-division access on the up-link and time-division distribution on the down-link. In this case signal memories must be added on-board; in addition, the problem of demodulating on-board a large number of carriers, possibly with a single equipment (as done in time-division systems) is presently under study.

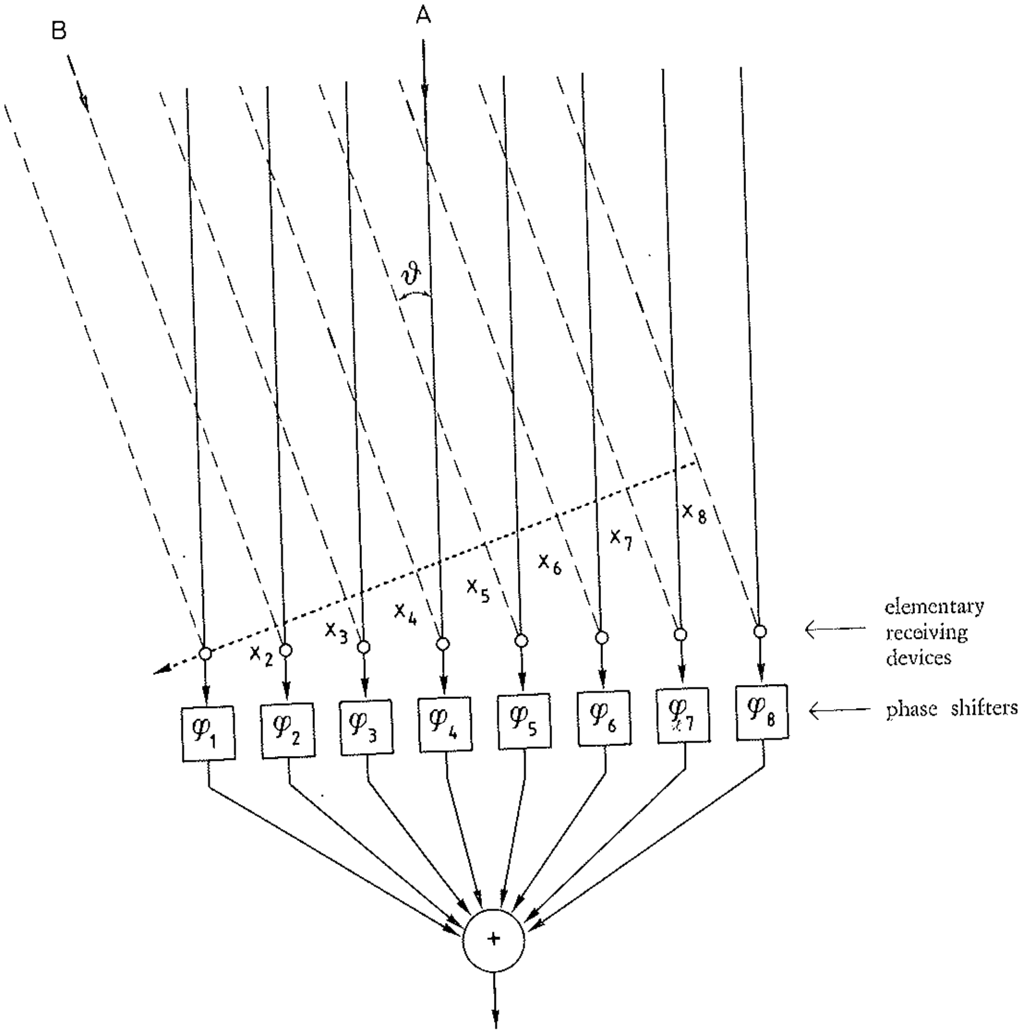

FIG. 6. Phased array antenna.

A) Phase shifters in zero phase positions:
- A wave from A produces elementary signals having the same phase; thus adding coherently the adder-output signal is n times the elementary signal.
- A wave from B produces elementary signals with different phases due to path-length differences x_i; they produce at the adder output a signal of reduced amplitude (this phenomenon identifies itself with antenna directivity).

B) Phase shifters arranged to compensate the relative phases of the elementary signals produced by wave B:
- A wave arriving from B produces the maximum output signal.
- A wave arriving from A produces a signal of reduced amplitude.
- In total the antenna beam is pointed in direction B.

The same operation may be performed in transmission using elementary transmitting devices instead of receiving devices.

The need for on-board memories is emphasized if different digital rates are adopted in the various directions of communication, in relation with different traffic capacities of the various stations.

5 - Frequencies above 10 GHz

With respect to the classical frequencies of 4-6 GHz used in the basic system, frequencies above 10 GHz, toward which an inexorable push is exerted by the saturation of the lower frequencies, present advantages and disadvantages [6] which will now be briefly illustrated (Table 5). Among the advantages, mention has to be made, first of all, of the higher directivity offered by an antenna of given size, the beam-aperture angle being in effect directly proportional to the ratio between wavelength and the linear dimension of the antenna. This increased directivity makes the new frequencies particularly suited for setting up systems with narrow beams as described in paragraph 3: in this connection it is to be remembered that a 4 meter on-board antenna radiates at 20 GHz a beamwidth of 0.25 degrees corresponding to a footprint of 150 km diameter on the earth. If, in addition to the above, one takes into account the fact that the new frequencies offer very wide bands (fig. 7) it is easy to conclude that frequencies above 10 GHz can offer the answer to the need of setting up large communication capacities in the sky. Another important advantage which must be mentioned concerns the interferences which may arise to and from terrestrial radio relay systems. The classical frequencies of 4-6 GHz used in the basic system are the same largely employed, since the fifties, in long distance radio relays: to avoid unacceptable interferences, the earth stations of the basic original satellite system had to be installed in locations particularly well protected: for instance the first Italian earth station was built by Telespazio at Fucino, which is a flat country, actually a dried lake, surrounded by mountains which act as a very effective electromagnetic screen. This

TABLE 5 — *Frequencies above 10 GHz.*

ADVANTAGES	:	Easy concentration of energy in narrow beams Availability of wide frequency bands Reduced interference problems with terrestrial radio relay systems
DISADVANTAGES	:	Propagation through atmosphere affected by precipitations, especially by rain

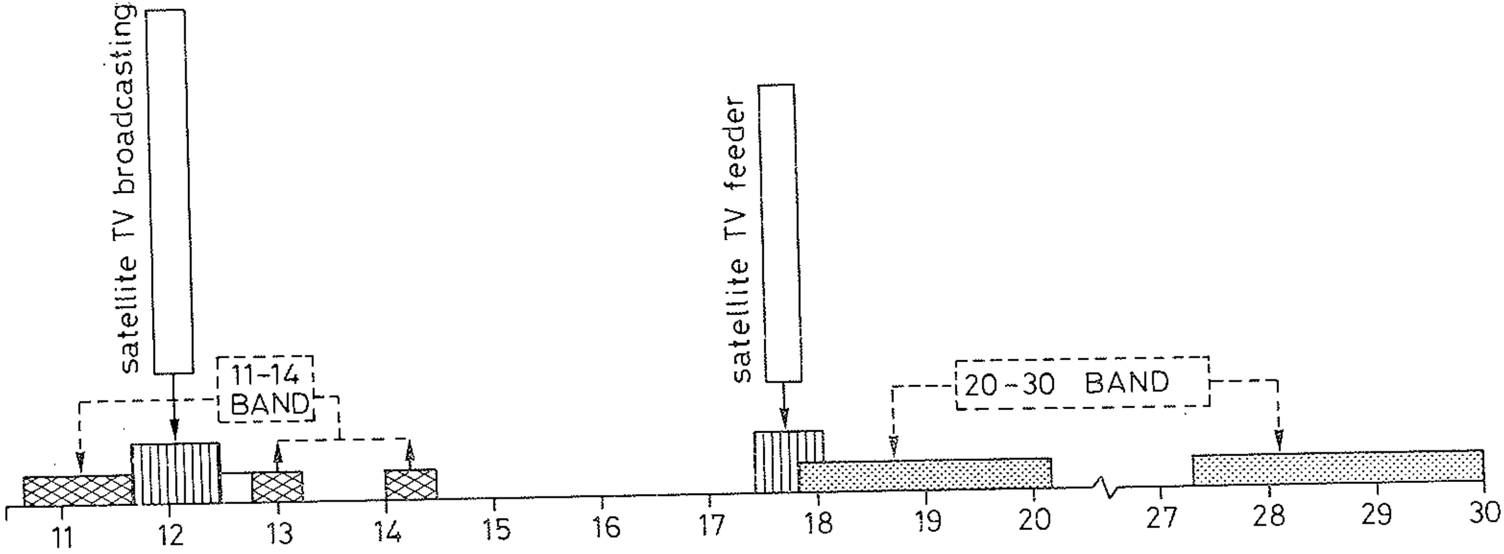

Fig. 7. Frequency assignments to satellite systems between 10 and 30 GHz (Region 1).

need of placing the earth stations, at least in the developed countries, in special locations is generally tolerable in intercontinental communications because the terrestrial tail, required to connect, within a country, the earth station to the international node of the terrestrial communication network, is only a small part of the total communication link and represents therefore an acceptable penalty. On the contrary, in national satellite systems, especially in the case of many earth stations serving the peripheral nodes of the terrestrial network or even directly the subscribers, the stations must be set up where they serve. Frequencies above 10 GHz are capable of fulfilling this need because the problem of interferences with terrestrial radio relays either does not exist, due to the availability of frequency bands exclusively assigned to satellite systems, or it is much less serious (at least at frequencies above about 15 GHz) because radiation at these frequencies can be better controlled; moreover, as radio relays grow simultaneously with satellite systems, a coordination between the two is more easily attainable.

Figure 7 shows the frequency assignement (between 10 and 30 GHz) to fixed satellite systems (and to satellite TV broadcasting) in Region 1 (Europe, USSR, Africa), according to the World Administrative Radio Conference of 1978. In the figure the telecommunication band 11-14 GHz should be first focused upon; outside this band, an interval of 250 MHz between 12,5 and 12,75 GHz is exclusively devoted to satellite systems and can be very advantageously used in the down-link of national systems, in association with a similar band around 14 GHz for the up-link (3). In the same figure, the band around 12 GHz devoted to direct television broadcasting is also shown together with a corresponding band, at 17-18 GHz, for feeding from earth the broadcasting satellites: satellite broadcasting will be dealt with later on in this paper. Finally the 20-30 GHz band, having the remarkable width of 2500 MHz, of which 500 devoted exclusively to satellites, is indicated in the figure: this band will be fundamental for the national systems of the nineties.

The substantial disadvantage of frequencies above 10 GHz is that their propagation through the atmosphere is adversely affected by precipitations and in particular by rain. Heavy rainstorms produce large attenuation on the signals: for instance figure 8 reports a recording of

(3) A microwave beam covering a frequency interval of 250 MHz can transmit in digital form, without coding, about 5000 telephone channels.

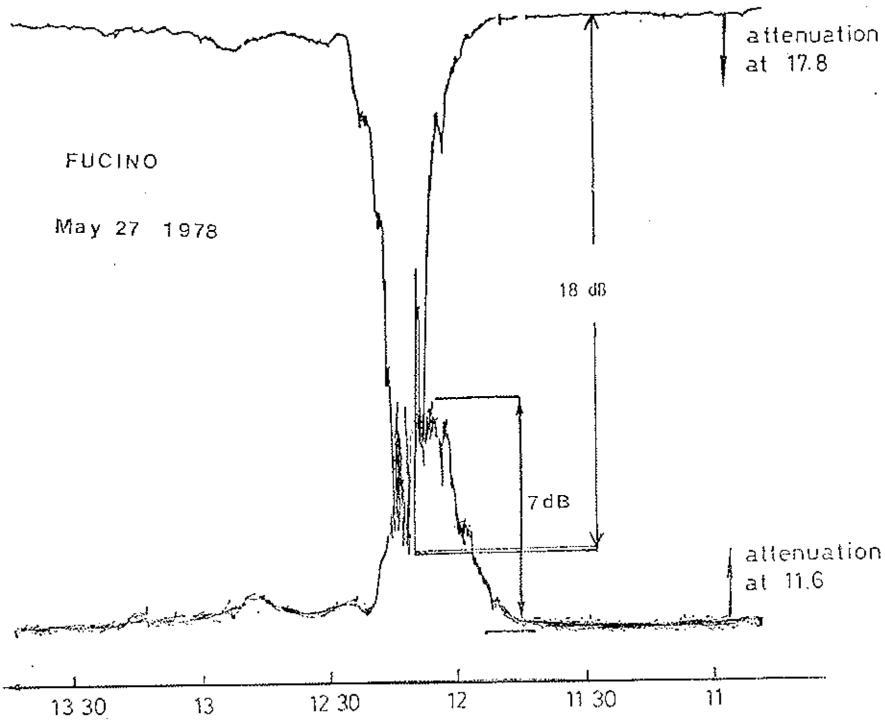

FIG. 8. Attenuation recording in the SIRIO experiment.

the signal level during a rainstorm, taken from the SIRIO experiment data [7].

SIRIO is an Italian satellite, which has been largely devoted to investigate the mentioned effects of precipitations and to provide data for the design of satellite systems at the new frequencies: its operational bands (11-12 GHz and 17-18 GHz) make it possible also to study the variation of the mentioned phenomena with frequency. SIRIO data, acquired in Europe and on the east coast of the United States, add to other important data acquired in Europe, North-America and Japan. A characteristic of the SIRIO experiment has been the long life of the satellite, which has made available 5 years of collected data, i.e. a very significant and consistent statistical sample.

In addition to attenuation (fig. 8), precipitations produce other phenomena: for instance the non-sphericity of raindrops influences the wave polarization and can destroy the orthogonality between the polarizations of two waves. This phenomenon can thus produce a reduction in the reusability of frequency: methods have been devised, however, to compensate the interferences due to this phenomenon and other causes.

Coming back to signal attenuation, which is by far the most important phenomenon, figure 8 shows clearly that this attenuation can be very large at times: in this particular case it reached the value of about 7 dB at 11.6 GHz and of about 18 dB at 17.8 GHz. These attenuations would produce link outages, unless a correspondingly higher power is used to counteract the attenuation effects.

The problem becomes increasingly difficult as the frequency increases on account of the higher attenuation (fig. 8 and table 6). The power must be increased as far as needed by the availability requirements of the communication system, i.e. by the outage fractional time which may be tolerated. To establish the power increase requirements, the statistical distribution of attenuation is needed. Figure 9 reports for example the attenuation distributions at 11.6 GHz obtained over the five years of the SIRIO experiments in the three Italian stations (fig. 10): these distributions report along the ordinate axis the fraction of time for which the attenuation has been larger than the value indicated on the abscissae; from a system engineering point of view, the same curves give on the abscissae the power margin to be introduced in the link (with respect to free space propagation) to maintain the outage time within the limit indicated along the ordinates. It is easily seen how different the situation is with respect to the ideal propagation of the classical frequencies of the basic system, especially in locations subjected to heavy rainstorms like Lario and Spino. In Italy as well as in other parts of the world there are locations having still worse meteorological behaviour.

For the Lario station, figure 11 reports the attenuation distributions extrapolated to the frequencies of the 12-14 GHz band and of the 20-30 GHz band. These distributions show that the required power margin

TABLE 6 — *Rain Attenuation.*

- Rain attenuation rapidly increasing with frequency
- Attenuation distribution almost log-normal
- Availability problems
- Interest for adaptive methods

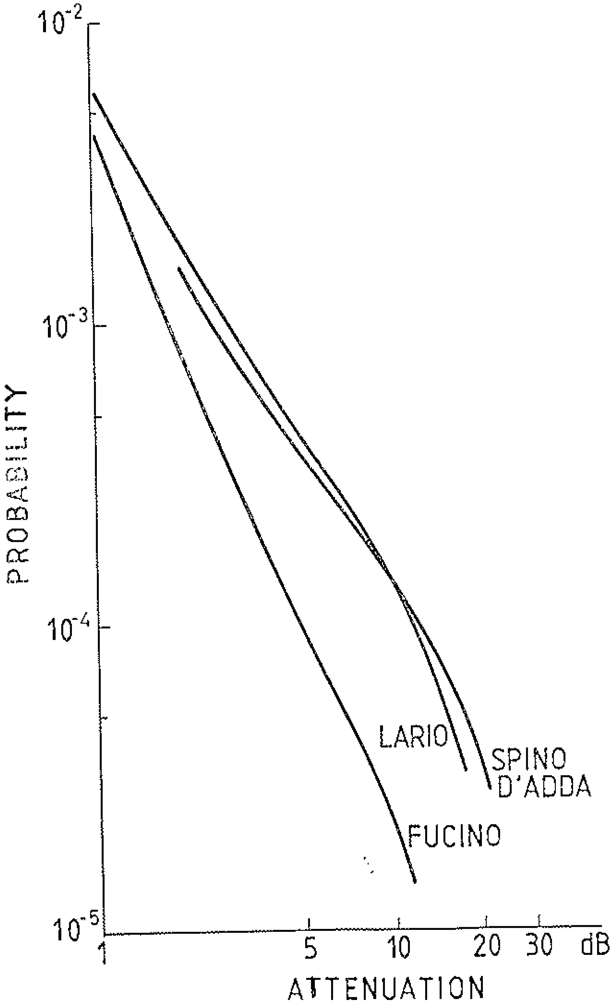

FIG. 9. Attenuation distributions at 11.6 GHz.

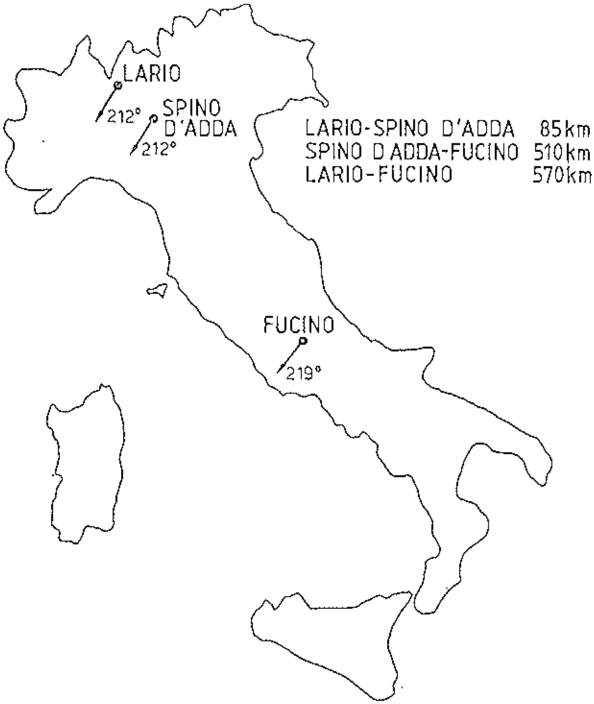

FIG. 10. Italian stations used in the SIRIO experiment.

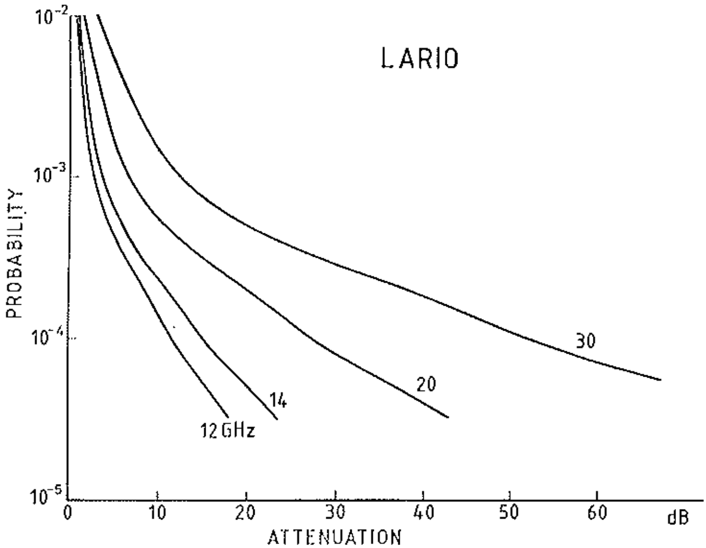

FIG. 11. Attenuation distributions at 12-14 and 20-30 GHz.

is relatively small when a high outage time (10^{-2} or more) is tolerated (as it may happen when satellite services are given directly to the users and/or when no other communication media exist); but it increases very rapidly, especially at the highest frequencies, when the outage time is reduced down to $10^{-3} \div 10^{-4}$ as presently considered in public networks. It is likely that the latter constrains move toward the smallest values as far as communication systems will become more and more a vital structure of society. In this case the large power margins which must be introduced in the link appear clearly from the figure and represent a heavy power penalty, which constrasts with the technical efforts to increase the power efficiency and thus decrease the systems costs, which have been mentioned in the previous paragraphs.

For instance, considering a Lario-like station, if the link outage time is to be maintained within 10^{-4}, the power at 30 GHz has to be increased by about 50 dB (i.e. 10^5 times) with respect to free space propagation! It is thus clear that the "brute-force" method of increasing the transmitter power as much as needed to overcome rain attenuation does not represent a correct way to follow in case of stringent outage-time requirements and frequencies considerably above 10 GHz. Adaptive methods (table 7), able to take advantage of the limited extent of heavy rainstorms, and their statistics, are much more interesting. The most elementary form of adaptive method is site-diversity (fig. 12), which applies to any earth station of a satellite system and uses actually two stations, separated by 10-15 km, to take advantage of the very low probability that heavy rainstorms be simultaneously present at both sites.

The penalty of this method is represented mainly by the double site set up and by the terrestrial link needed to connect the two stations, whilst the provision of two different earth equipment for the two stations is only a minor penalty because usually a second equipment set is needed also in the case of single station for back-up purposes.

TABLE 7 — *Adaptive Methods.*

— Site diversity
— Power control
— Burst-length control
— Frequency diversity

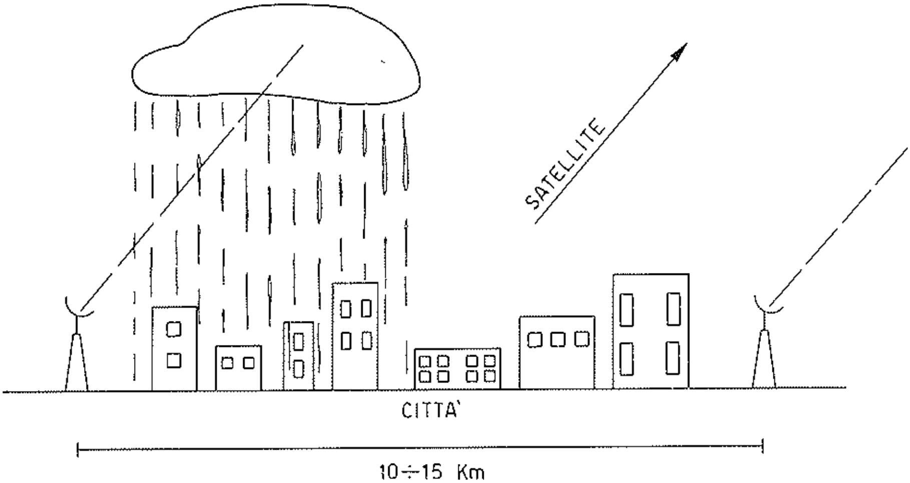

FIG. 12. Site diversity.

The other three adaptive methods mentioned in table 7 are different in concept with respect to site diversity inasmuch as they share among the stations a common resource from which a proper help can be obtained by any station in difficulty due to heavy rain [8]. For simplicity's sake only one of them will be illustrated in this paper, namely frequency diversity, which appears quite promising and has been deeply studied, with other methods, at the Politecnico di Milano. The method simply consists in the use, in an integrated way, of two different frequency bands in the same satellite system, for instance the 12-14 GHz band and the 20-30 GHz band: this makes it possible to combine the advantages of the large communication capacity of the higher frequency band and the low rain attenuation of the lower frequency band. Each station (and the satellite) are equipped for both frequency bands, the lower of which is dynamically assigned, when needed, to the stations under heavy rain. To evaluate the advantages obtainable by the method, the joint attenuation distribution among the stations of the system is needed; some first investigation on the subject has been carried out with SIRIO and some first evaluation of the advantages of adaptive methods has been derived therefrom. For instance table 8 shows these advantages (very remarkable) in the case of a system comprising 100 Lario-like stations (of which, at any given time, 90 working at 20-30 GHz and 10 at 12 GHz) with an outage time below 10^{-4}. The penalty in the earth stations for obtaining the mentioned

TABLE 8 — *Advantages of Frequency Diversity (Integrated Use of 12-14 GHz and 20-30 GHz Bands).*

	12-14 GHz 10 stations at a time		20-30 GHz 90 stations at a time	
	12	14	20	30
Power margin (dB) without diversity (two independent systems)	18	18	43	62
Power margin (dB) with diversity (integrated use of the two bands)	18.5	18.5	3.1	5.7

large advantages is represented by the double equipment for the two frequency bands: this means actually to provide a back-up equipment in a different frequency band.

Adaptive methods using a shared resource like frequency-diversity require a further sophistication of the on-board equipment: in the case of frequency diversity, for instance, there is the need to provide not only a double band in the on-board equipment, but all the switching and switching control necessary to assign from time to time the proper band to each station. As already remarked, however, such types of sophistication are well within the possibility of future integrated electronics.

6 - *Signal processing*

It has been already mentioned that some form of signal processing will be introduced in future satellites to regenerate, memorize, switch and possibly code and decode signals.

Sophisticated signal processings will be used at the earth stations in order to increase the efficiency of the communication systems. Such processing procedures concern in particular digital speech interpolation and signal redundancy reduction. These forms of signal processing are indeed of interest to all communication systems, but they are often promoted by satellite systems insofar as they act as precursors in anticipation of new communication techniques. Digital speech interpolation, which has received already several applications, consists in transmitting over a certain number of telephone channels (say 30) a larger number of telephone signals (say 60) by taking advantage of the fact that speech in a telephone conversation is not continuous but presents pauses, during which other information can be sent. Redundancy reduction takes advantage of the fact that most signals to be transmitted are originally redundant. This is certainly the case, for instance, of television signals, because: a) in each frame, all the points of the image are transmitted so that the signal is capable of representing a picture in which every point is different from the adjacent ones; this is not the case in practice, because wide uniform areas exist in a normal picture (spatial redundancy); b) from frame to frame, all points are retransmitted, and the signal is therefore capable of representing a moving image in which from frame to frame everything changes. Again this is not the case in practice, because there are fixed parts of the image which do not change from one frame to the next (time redundancy). Methods have been devised to at least partially reduce such redundancies: today, equipment is available which, for videoconference applications, can reduce the needed bit rate from a value around 80 Mbit/s down to 2 Mbit/s [9, 10, 11]. For speech the original value of 64 kbit/s can be reduced without loss of quality to 16 kbit/s and even less. All these forms of signal processing make it possible evidently to increase the communication capacity of systems, at the expense of a somewhat complicated terminal equipment, which again can be realized today reliably, economically, within small volume and with small power absorption thanks to modern electronic technology.

7 - *Television broadcasting via satellite*

Direct television broadcasting to users via satellite is receiving at present considerable attention and many application programs are under development.

Figure 13 shows the coverages foreseen for Italy and adjacent European countries by the plan approved by the 1977 World Administrative Radio Conference, which assigned to each country in Region 1 and 3 (Europe, Africa, Asia) an orbital position with 5 television channels per country in Region 1 (800 MHz bandwidth) and 4 television channels per country in Region 3 (500 MHz bandwidth). For broadcasting, when the same signal has to be sent to all users, the basic solution (fig. 1) remains the best one, although it is fundamental to use higher frequencies (fig. 7). However, it is seen in figure 13 that the intended national coverages spill beyond national boundaries, so that also several foreign programs

FIG. 13. Coverages of the television broadcasting satellites for Italy, Switzerland, Germany and Austria.

can be received in the various countries. Indeed, satellites are intrinsically able, using a proper large coverage, to establish a real international or global television system. But human society is still subdivided into nations and countries, jealous of their independence and worried about the possibility that the new communication media can menace that independence. The result is that, according to present agreements, television broadcasting should be designed as a national service. When this requirement must be interpreted in the more strict sense and/or the maximum number of national channels has to be provided, technical efforts must be directed towards shaping the antenna beam to cover as exactly as possible only the country of interest.

A plan recently approved (1983) for region 2 (Americas) has been able to reach a higher efficiency in terms of available channels, thanks also to better antenna characteristics, which will be further improved in the future, using shaped coverages. (See for instance figure 14 which shows the coverage which will be adopted in USA by the Satellite Television Corporation [12].

International or global systems may be in any case obtained by interconnecting national systems in the sky.

The receivers for television broadcasting will be very simple and will use a small antenna with a diameter down to 1 m or less.

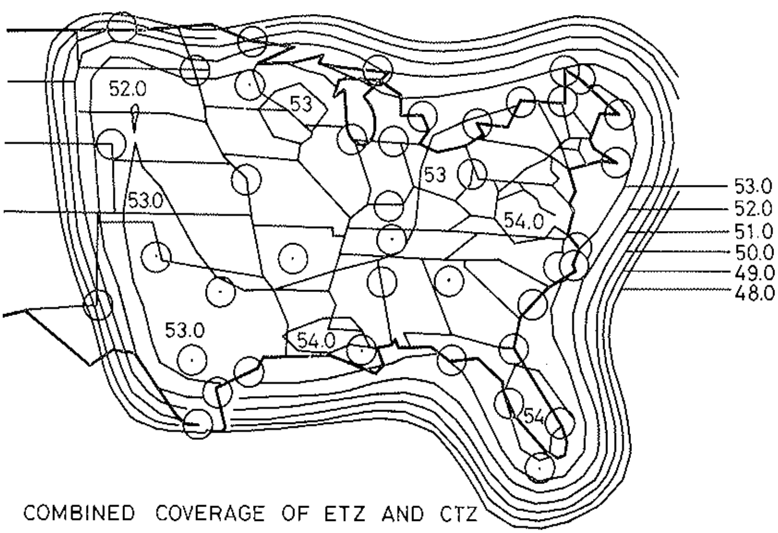

FIG. 14. Contours of specified power density for a shaped-beam antenna.

There is still under discussion the possible adoption for satellite broadcasting of some enhanced television standard able to improve noticeably the picture quality also througb the use of new signal processing techniques in the domestic receiver. This quality improvement may be an important opportunity offered hy the satellite. For instance in Europe the so-called MAC and in particular the MAC-C/packet transmission standard [13] is considered, which is able to carry, on a time-division basis, the luminance and colour information together with digital data, the latter being able to represent not only sound, but also graphics, still picture, etc. for all new possible types of data broadcasting services.

This standard permits us to use in a better way the same number of lines of present standards.

High-definition television with large-screen presentation [14] is an ultimate goal, to be possibly exploited in association with redundancy reduction techniques.

On the other hand, considerations have been advanced [15] on the fact that, also with the present standard, large improvements in picture quality can be obtained by introducing only signal processing techniques in the receiver.

It is thus uncertain at present which path will be followed; the choice will also depend on how much money people will be prepared to spend in order to have a better quality on their large or small screen.

8 - *Mobile systems*

Communications by radio have no substitute for mobile services. Satellites have been able to offer an excellent solution in tbe case of maritime communications, because the previous systems using short-waves were unable to provide an acceptable service due to lack of channels and to poor quality. The international organization INMARSAT is devoted to such purpose. The first system has been set up using: satellites specifically dedicated to this service (Marisat satellite built in USA and Marecs satellite built in Europe); multipurpose satellites associating in the same spacecraft a payload for maritime communication with a payload for fixed communication services (Intelsat V satellite).

Also in the case of mobile services, steering beam and multibeam antennas will give in the future substantial advantages in terms of communication capacity and reduction of earth station dimensions.

Applications to aeronautical mobile and land mobile are also considered although under less pressure. In fact aircrafts cannot use the normal VHF or UHF line-of-sight communications only during a comparatively small fraction of intercontinental flights. Aeronautical services may be introduced in the existing INMARSAT system. For land mobile services, the satellite is not able, at least with the presently foreseeable techniques, to offer the large capacities of modern cellular earth systems: however it may well complement the earth systems, covering the applications for user-low-density areas and/or long-distance travels: experiments are in program and will help for a better understanding of the problems involved.

9 - *Space platforms and satellite clusters*

The concentration of very high communication capacities in a single orbital position requires the installation in that position of a large quantity of communication equipment. Also if technologies permit the efficient use of powers, volumes and weights, large structures — using this word in a broad sense — have to be provided. A considered possibility for the future is the launch of large space platforms (fig. 15) able to sustain very large antennas and many equipment, so to concentrate in the platform a large number of communication systems [17]. Modularity can allow astronauts or robots to substitute obsolete or out-of-order parts.

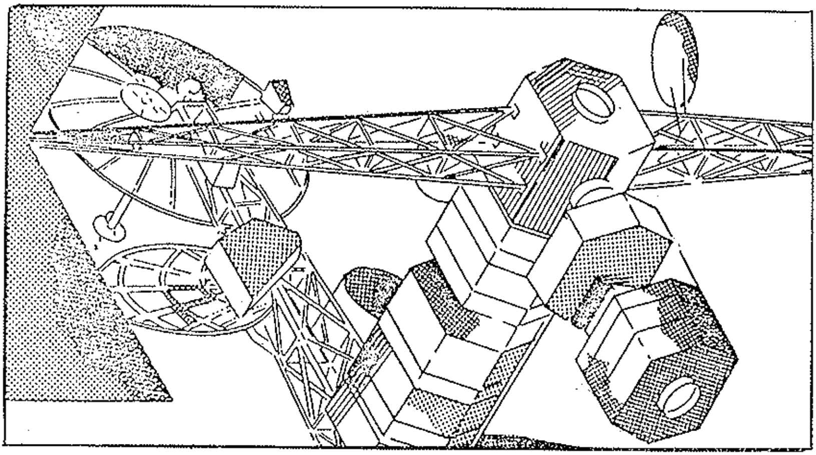

FIG. 15. Space platform (partial view).

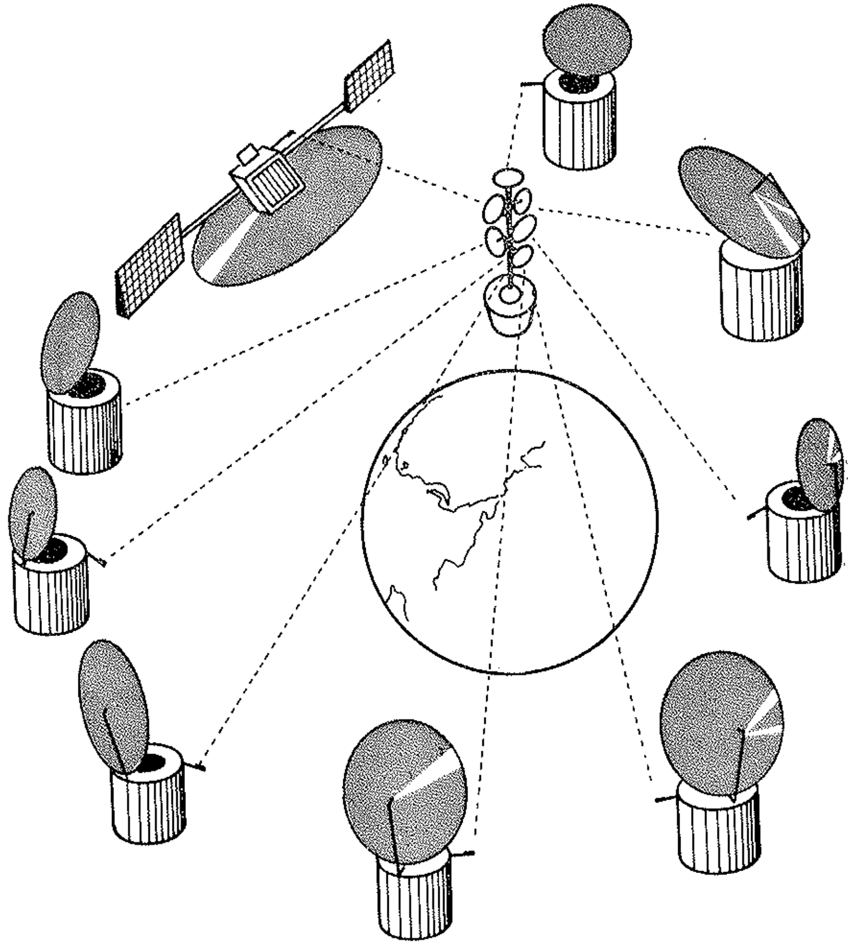

FIG. 16. Satellite cluster.

Special advantages of the platform are a common power supply and a common attitude and position stabilisation for all the systems, which, in addition, can be directly interconnected in the platform.

An alternative to the platforms, having a better flexibility and the possibility of being realized with presently available techniques, is the satellite cluster (fig. 16) in which many satellites are linked electromagnetically together and controlled in their relative positions [18]. Both space platforms and satellite clusters require, to be exploited, a well defined international cooperation.

10 - *Conclusions*

Satellite communication technology and techniques are still in a phase of continued development, which will make it possible to increase the efficiency and thus decrease the costs per communication unit, offering at the same time very large communication capacities and/or the possibility of using smaller stations on earth.

In this development, especially in advanced countries, proper account has to be taken of the simultaneous important developments in the terrestrial communication network, toward an integrated service digital network (ISDN) which, in its second generation will be also broadband, using to a large extent optical fibers also in the user plant. Integration of satellite systems in the terrestrial network, also at this advanced stage, will offer a number of advantages in flexibility, availability and capability of reaching any remote user.

Flexibility, as a typical important satellite characteristic, has been emphasized at the beginning of this paper. However, the modern developments which have been subsequently illustrated show a tendency to reduce this flexibility, producing solutions tailored for each situation in particular, with rigid distribution of traffic in each beam of a multibeam system. It is thus important to examine carefully this aspect, and to make efforts to introduce in the system some kind of reconfigurability, because satellites without flexibility would lose one of their most appealing properties.

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THE INDONESIAN DOMESTIC SATELLITE COMMUNICATION SYSTEM AND ITS IMPACT ON THE NATIONAL DEVELOPMENT

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Background

It was in the middle of Indonesia's Second Five-Year Plan of National Development when the crucial decision was taken to acquire and operate a domestic communication satellite. It has not been an easy decision nor was it devoid of criticism from inside as well as outside the country. Indonesia still suffered from the after-effects of centuries of colonial exploitation, years of wartime occupation and revolutionary struggle followed by costly and debilitating internal strife. The nation had only begun to overcome some of its basic problems, like the production of enough food for its then 140 million people and the restoration of social order and political stability. But assessing a decade of arduous work and the huge task still to be done to achieve the nation's development goal, the government arrived at the conclusion that communication was a major factor in almost every problem that hampered the nation's progress. One reason is the geographical and physical features of the country, which is the world's largest archipelago consisting of more than 13 thousand islands spread along the Equator 1800 kilometers wide and 5000 kilometers long, and inhabited unevenly now by 160 million people with diverse customs and traditions.

While never oblivious of the many direct needs of the people clamoring for fulfillment, the national leadership very early recognized the potential and crucial importance of the emerging space communication technology in providing overall and lasting solutions to the nation's major problems.

The Pre Palapa Situation

Until the introduction of the first Indonesian domestic communication satellite, the Palapa A1, in 1976, inter city communication was substandard and inter island telecommunication service limited and unreliable, making administration of the country and control of its apparatus an extremely difficult task. Hence affinity between the central government and the outlying regions and between regions was stretched thin, seriously affecting national cohesion. Commerce was centered in the main islands and slow in developing and was stagnant in the more remote parts. Development efforts while conscientiously designed to embrace the whole nation met endless delays in the outer islands. I have no intention or reason to belittle the gallant efforts of the telecommunication department to establish a nationwide telecom network conventionally prior to the advent of Palapa, but obstacles were just too many and too intractable on account of the countless bodies of water and high mountains that literally fracture the achipelago. Telecommunication cables have been laid and microwave links set up but to extend them to interconnect all parts of the country would have taken many more decades of herculean efforts at forbidding costs.

The Palapa System

Since its inauguration on August 16, 1976 the Palapa SDCS has provided smooth communication services throughout the archipelago, channeled audio-visual programs via television rebroadcast networks and multiplied radio broadcast services.

In its limited service life of seven years the two first generation Palapa A satellites have launched the country into the space age. The achieved success and the promise of more have prompted the purchase of their successors, the Palapa B series with two-fold capacity.

The estimated requirement until 1990 for domestic use is 12 transponders and for the Asian countries another 9 transponders, totalling 21 transponders, hence the Palapa B1 satellite launched in June 1983 has been designed to carry 24 transponders, powerful enough to serve the region with ample spare capacity.

Orbital positions in the geostationary Orbit (GSO) assigned by IFRB or International Frequency Registration Board are 108° EL for Palapa B1 and 113° EL for Palapa B2. The latter, which was to function as Palapa Bl's back-up, unfortunately failed to reach its position and was declared lost. But as long as Palapa B1 functions flawlessly, as it does now, regular and routine services need not be interrupted. To replace Palapa B2 and A2, the second first generation satellite which is still operating exceeding its service life time, Palapa B3 or sometimes named Palapa B2' is on order and planned to be launched in August 1986 to its position in the GSO at 118° EL.

The technical specifications of the Palapa Satellites are as follows:

	Palapa A	*Palapa B*
— Satellite	12 transponders	24 transponders
— Number of TWT	12	30 (6 spares)
— Orbital location	77°E, 83°E	108°E, 113°E, and 118°E
— Power of transponder output	5 watt	10 watt
— Total power capacity satellite (beginning of life)	300 watt DC	1100 watt DC
— Frequency bandwidth	30 MHz of 40 MHz	36 MHz of 40 MHz
— Life time	7 years	8 years
— Weight	574 kg	1194 kg
— Service area (Coverage)	All six Asian countries (Indonesia, Thailand, Malaysia, Philippines, Singapore and Brunai).	All Asian + Papua New Guinea

The Nation's Progress Attributable to Palapa

There has been a dramatic change in the rate of Indonesia's development progress in many areas and in many ways since the operation of Palapa DSCS. In the field of communication itself the statistics are eloquent. In 1969 only one out of 625 inhabitants had a telephone, and the increase per annum was 6% amounting to 233.000 telephone lines by 1974, in a span of 5 years. In 1979, after 3 years of Palapa operation that number was more than doubled, reaching 550.000 lines with an annual increase of 20%. In 1984 the nation's telephone network had a capacity for 612.700 lines, and long distance direct dialing facilities were available at 89 centres, and these numbers have been growing continuously. The coverage of television services has also expanded as more relay stations are constructed.

The impact on the nation's economy is obvious. The nation's economic growth rate of 7% for several years in the late 70's can be attributed to some extent to the easier and more reliable communications within the country. People from overpopulated Java are easier to move to the fertile but thinly populated outer islands because they feel that they will now be able to maintain contact with their relatives. This has boosted the government's transmigration program with multiple results: easing population pressure on Java, opening up new productive land and stimulating business in hitherto dormant regions, just to name a few. Better and reliable communications also expand business operations and facilitate commercial transactions, as contacts are easily made and information quickly exchanged.

The sharp increase of the telecommunication network and television coverage effected by the Palapa system set off a boom in the electronics business that in turn caused the electronic industry to flourish, and in its wake other associated industries as well, contributing significantly to the national GNP. Another sector that has benefited from better communication services and increased information traffic is the tourist industry, bringing in increased foreign earnings.

The growth of these industries has a multiplying effect that can be observed in various sectors of the economy.

Another field of development that benefits greatly from the Palapa network is education. Centuries of colonial rule followed by decades of revolutionary struggle and social upheavals have left the state of Indonesia's education a shambles. Very aptly the government is giving high priority to education in its development policy. Now with Palapa's expanding capabilities the government major drive to combat illiteracy, the program of extending all levels of education to all parts of the country, the intensifying of informal education to penetrate rural areas and the major program of nationwide family planning have acquired a powerful tool. But the rapid proliferation of schools has created new problems, namely the scarcity of qualified teachers in the remote regions and especially at academic levels. In quest of a solution nine universities in the eastern part of the country have embarked on a unique cooperation with the aim to share professors, lecturers and other scarce resources with the aid of Palapa. In this project each university is provided with a special classroom equipped with TV monitors, electronic blackboard, microphones and facsimile, where students can follow lectures delivered at any one of nine universities, hundreds or thousands of kilometers away, can conduct teleconferencing with peers and tutors and can have tuition and library material transcribed instantly from and to each location. If this project, now in its first year of implementation, will actually prove that satellite-aided distant teaching is practicable and sustainable, other applications are certain to follow, now already under consideration, like in the field of health, agriculture and rural development.

One can easily surmise that all these activities have an overall positive impact on the national development, which is firmly directed to the establishment of a strong and united nation where social justice and prosperity of body and mind are equitably enjoyed by all the people. In all the described activities which are all important components of the national effort toward the realization of the ultimate goal, one can find common aspects such as the vastness of scope, the equitability of opportunity and existence and maintenance of two-way contact over wide distances, which are all concurrent to Palapa's features.

All the while the government and the people of Indonesia are fully aware that for a developing nation that less than 4 decades ago was still subjected to colonial domination and has been for years ravaged by wars, the achievement of that goal requires many more decades of hard and diligent effort. Many challenges and difficulties lie ahead, some may not be easily overcome, but Palapa and its proven capability to accelerate progress in many areas have strengthened the people's confidence that its ideals are indeed achievable.

Conclusion

Summarizing I would restate my opinion that the Indonesian Domestic Satellite Communication System has not only favourably affected the national development but has also become an essential and indispensable element in the development system itself. The size and morphology of the country, the diversity of the people and the complexity of the overall development effort require an effective and powerful management tool of a scope that only space technology can provide.

That the epoch-making decision taken boldly 10 years ago amid misgivings and criticism was a wise and farsighted one has been substantiated by another decision taken 7 years later to replace the first satellites with a second generation of doubled capacity.

For sure, there are the negative sides of the picture; in the first place there was the purchase price of the satellites and the investments to be made on infrastructure and the cost of building hundreds of groundstations, which are high enough to deter many developing countries. Then there is the adverse effect of the advanced communication technology bringing an avalanche of information to simple and unprepared rural communities, the damaging impact on the valued traditional culture, and the contamination of social values.

The costs have been more than offset by the benefits, tangible and intangible, quantifiable and inquantifiable, as discussed before. We are concerned and very watchful as to the negative impact of ill-designed radio and television programs on the socio-cultural development. But vis-a-vis every undesired effect there are advantages that by far outweigh the harm. And anyway, as there is always a price to be paid for progress, we are prepared to pay our way to the ultimate national goal: an equitably prosperous, united, harmonious and humane nation, a secure society based on the Pancasila philosophy.

TOWARDS A NEW CONNECTIVITY THROUGH SPACE

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India is a large country with a population of 730 million and per-capita income of the order of Rs. 2000 per year. We have about 400 million people who cannot read and write and according to current plans there should be nearly 160 million children going to school by the year 1990. Our farmers need to adopt new practices in agriculture and animal husbandry. Our craftsmen, mechanics and doctors need continuous retraining and our universities need access to expensive equipment, computers and other such facilities. A great deal yet remains to be done towards providing clean drinking water to all habitations, expansion of the electricity grid, in the areas of housing, health and wiping out of infectious diseases. In terms of normal communication infrastructure, we have less than 3 million telephones. Though we have a large number of Post and Telegraph Offices, the increasing load on the system makes it difficult to maintain the highest quality of service, particularly in regard to telegraph and telex.

This scenario is often used as an argument that a country like India has no business playing around with a modern technology like Space; that the resources spent for the purpose could be used better for digging wells and improving health services and doing a whole lot of other things. On the other hand, many of us have tended to argue that for doing precisely these very things, it is necessary to transfer the initiative and action to the people themselves and that the only way of doing this is to connect them with each other and with the resources of information, knowledge and infrastructure. To the extent the space way of establishing these connections is recognised as one of the quickest and most efficient means available, we need to use space technology even more than the developed countries, because our needs are so very basic and urgent. Space for us is a part of a major socio-economic mission.

It is this argument that provides a specific character to the Indian Space Programme and has, by and large, provided the basic motivation to both the doers and the supporters of this programme. It is clear, therefore, that while we learn to build payloads, satellites, rockets and ground stations, we have also to learn to configure the whole system in ways appropriate to our mission and, indeed, sometimes to get involved with a whole lot of other things which are normally not considered to lie within the functions and responsibilities of a space venture. Since technology, even space technology, is largely international in character, it normally wishes to follow the fashions of the metropolitan countries. Therefore, a sociologically motivated bending of this technology will continue to require significant efforts.

In this presentation I would like to give you some glimpses of the process we have gone through, where we stand at the moment and what are our hopes for the future. The process has involved wide-ranging discussions, attempts to identify the most appropriate configurations and systems, and a fairly large space programme tuned to work towards its socially defined mission. It has also involved many friendly skirmishes, some life-size experiments and a continuing atmosphere of doing, questioning and internally instigated dissatisfaction with what we have achieved in developmental terms. It appears that such exercises would continue and, indeed, the searching and the arguments would increase as the technological achievements mount, because the software and organisation aspects of the effort, and induction of related support systems, always tend to trail behind. In spite of numerous visible successes in social areas, we have yet to give substance to our vision that the use of space technology for information transfer would abolish distance and eliminate discrimination against those who do not live close to the centres of existing infrastructure. Since the normal establishment of any facilities, even space facilities, tends to give more to those who have more, the concern, the restlessness and the arguments will stay with us. A policy of positive discrimination in favour of the under-priviliged can remain just an empty statement unless the new technological capabilities are also accompanied by a transformation, and reorientation, of the earlier systems of information generation and transmission, and the newly developed connectivity is also invested with significant content.

Let me go back a little, and trace the basic features of the Indian space adventure. In the late sixties, Vikram Sarabhai realised that space-based television broadcasting might be one way of quickly reaching the distant parts of the country with audio-visual messages related to developmental education. While technical studies and discussions in regard to a possible space-based system were conducted in collaboration with NASA, General Electric etc., there was a simultaneous concern to gain experience in generation of relevant messages and evaluating their impact through a pilot experiment in a hundred odd villages around Delhi, which had the only TV transmitter of the country. It is significant that the initiative for this was taken by an Indian space enthusiast who dreamed of a future where all villages in this vast land would be connected via satellite. This programme, the so-called Krishi Darshan, has since become a permanent feature of all our television broadcasting. I do believe that some of our most useful programmes are broadcast in this segment, in spite of the dissatisfaction of some of our urban elite.

Creative collaboration between NASA and the Department of Atomic Energy, which was then responsible for space affairs in India, led to the Satellite Instructional Television Experiment (SITE).

In its magnitude and intent, as also in the range of organisations and disciplines involved, the SITE was a rather unique effort.

It covered a few thousand secluded villages, with direct reception television sets. Many of these villages had never seen a moving picture before.

Besides using film crews and portable TV cameras, five studios were specially set up for the programme — this at a time when the country had only three metropolitan TV stations. There was massive involvement of social scientists for providing inputs to the programmes, a continuous feed-back and extensive process — and impact — evaluation of the experiment.

The space organisations, NASA and ISRO, along with other Indian participating agencies, were engaged in a rare, creative, cooperative venture where the designers and builders of hardware like the ATS-6 spacecraft, the ground segment, including direct-reception sets and earth stations, came to be passionately concerned about the quality and depth of the social goals. The programme makers and social scientists began to talk of PERT charts, while appreciating the power and limitations of the brand new technology. While the United States moved its 200 M dollar ATS-6 satellite over Lake Victoria and maintained it there for a year, India spent the equivalent of $ 20 million, including several thousand man-years of qualified manpower.

For fifteen hundred odd people directly engaged in the experiment, the SITE was a deep human experience. It generated new capabilities, demystified space technology and helped to nucleate a large island of self-confidence. But, of a far greater significance was the generation of a new kinship between technologists and the grass-root problems of the country, a common concern for the ultimate social and human goals, a sort of awakening to a situation where technical capability and intimate personal drives began to merge with social action. No wonder that Arthur Clarke called SITE the greatest communication experiment in history.

It took almost six years after the end of SITE for India to have an operational satellite, a satellite which combines telecommunication, direct television broadcasting and meteorological functions. This satellite, Insat I-B, has been working for over a year. It was built by Ford Aerospace, to our specifications and design, and launched by NASA. The fact that practically all of the ground segment, including thirty-odd ground stations, along with some transportable ones, the master control facility, thousands of S-band direct reception sets, one hundred and eighty TVRO and VHF broadcast stations, the data collection platforms, the disaster warning system, and a hundred odd radio networking stations, were designed and built in the country, is largely due to the fact that we had people who were earlier engaged in the SITE experiment, and later, in experimental work with the Symphony satellite of France and Germany and over home-built Apple satellite, launched gratis on the third Ariane flight.

Let us first see what the induction of this operational satellite has done to television in the country. During the last one year the total number of the T.V. transmitters has increased from around forty to about one hundred and seventy, and with the inauguration of one or two new transmitters every day, the number should go up to 180 in another month or so. All these transmitters are linked to Delhi or the location of a possible mobile uplink through an S-band Insat transponder. So we have a national networking of a large fraction of Delhi originated programmes, or others that are piped to Delhi via microwave links from other metropolitan cities. With all these 180 transmitters, 70 percent of the population in the country would have a VHF TV signal, though by using direct reception sets — somewhat more expensive — the same signal has been available over the whole of Indian land mass from the day Insat became operational.

Perhaps no large country in the world has seen such a steep function increase in linking its inhabitants in so short a time. But what has become of the developmental goals of television in the midst of this tremendous new capability for distributing Hindi movies, coverage of cricket and hockey matches, Lucy, Star Trek, Yes Minister, Odd Couple, etc., along with Zubin Mehta concerts, Los Angeles Olympics, classical dances and music and a lot of Hindi soap opera, to a virgin new audience, never exposed to television before (remember that 70% of 730 million is nearly twice the population of the United States)? Much of this programming can be financed through the increasing revenues from advertising, but is this developmental programming? Well, as I said in the beginning, there is power in the initiating rhetoric, and therefore, quite a bit is going on to change the menu, and much more is likely to follow. Soon about 2000 direct reception community sets would have been installed at government cost in as many villages. There would be many more V.H.F. community sets around transmitters fed by the satellite. They receive many specially produced programmes, for children during the day, and for mixed audiences in the evening. Since 3 language groups are covered, each of them gets about a third of the time. Children's programmes are produced jointly by Doordarshan and the Central Institute for Educational Technology, and the adult programmes by the "SITE continuity" studios, which have never stopped working after SITE. Recently, the University Grants Commission has begun a university hour on the S-band of Insat, with retransmission by VHF transmitters, the programmes being produced by special facilities in the universities, and some selections from outside. Many of us feel that this might be the beginning of a countrywide classroom, which might expand to occupy a central role in the national educational activity — particularly that related to continuing education — because other modes of delivering education are becoming somewhat inadequate. The growing consensus to delink degrees from jobs would enhance the role of such distance learning by leaving the chore of certification and testing to employers or individuals themselves.

But while the representation of everything desirable exists in the menu, as also in the organisation setup, there are continuous fears that our television system might have a tendency to become just like another T.V. system, similar to the T.V. networks of the industrialised West.

Some might welcome it. In my view it would be a disaster. We have higher expectations — and needs.

There are real challenges to be met. The satellite mode of linking up gives you a country-wide reach. It was all right for the State to put in 2500 direct reception sets during the SITE experiment, but who will pay if all 500,000 villages are to be covered? It does not look like much, after all the other efforts, particularly because the social behaviour of Indians does allow the proved possibility of serving an average population of one thousand per village through a single community receiver. But the organisation and management problems still befuddle a country which has already built, launched and maintained in orbit eight satellites of its own and is moving towards its indigenous, home-built remote sensing, meteorology and communication satellites, and its own launch vehicles to boost them into orbit.

It will be done, I am sure, because it must be done; but the simple things required to complete the chain take ever so long. Many of us are convinced that we have to follow the community reception approach, at least in the beginning, or else the access would be limited and tbe system would end up working for the powerful and the affluent, and be used primarily for diversion and titillation.

Of course we have an additional challenge — how do you creatively use the long reach of the satellite in a country which has such diversity of languages and custom? Yes, an English-speaking tourist can get by in touristic India, with a little bit of English; but English speaking and writing is confined to no more than a few — certainly less than ten per-cent — of our population. One has only to look at an Indian currency note to be reminded of the fact that we have fifteen officially recognised languages, each of them spoken by tens of millions. Therefore, while the satellite link-up is fine, and everywhere there are lots of people who would understand a programme in any language, there is no doubt that hundreds of low power transmitters now coming on stream cannot be fed only through the satellite. It has been accepted that we must have local programmes using new organisational patterns and inexpensive mobile production equipment, if we want to address the intimate developmental concerns of the mass of our people. But the satellite link is essential for bringing in the fresh breezes, the national and international scene, without which the local channels would become parochial and fossilized. I must again confess that the movement toward this near-far combination is painfully slow.

Before I stop talking of television and broadcasting, it may be worth mentioning that a large fraction of the people who are, with some success, pushing for appropriate rural and developmental programming have been, at some time or other, part of our space venture. Indeed one of the major training facilities for rural programming staff has emerged in a unit within a space centre, and is recognised as such, both nationally and internationally. I can easily persuade myself that a "space ethos" has generated this feeling of care and belonging with people far away in geographic terms, because they are perceived to be close neighbours in communication terms.

Information transfer through broadcasting is, of course, not a true interaction... too many are exposed to too few. Therefore telecommunication is basically a better medium for social transactions and development. Yes, we are also planning to spend a lot of effort on increasing the number of telephones, developing and installing digital exchanges, more radio links, also some fibre-optic links. And we also talk of Integrated Systems Digital Networks. But many of us feel that we must give priority to a basic needs programme in telecommunication. One basic need, in my view, would imply that within a few years every habitation in the country must be connected with every other habitation through a message network; that every habitation should have an access to the relevant resources information — computer or people based — to seek developmental information, about weather, seeds, fertilizers, advice on crop-management or whatever. We should have a number of data networks, to serve important sectors like power, irrigation, industry, banking, airlines, railways, bus companies. Preferably, much of this should by-pass the existing bottlenecks in the system. And all this could be done by using a few C-Band transponders on the Insat system. My friends have worked out several schemes which are in the process of evaluation and discussion. One of the schemes for a rural telegraph network, for example, would use half a transponder, and support a few hundred times the traffic in telegrams that is booked these days and often delivered by mail because they get stuck en route at one of the retransmission nodes. Similarly a satellite-based packet switching data network to meet the needs of many of the potential users would again need half a transponder, and awaits decision and implementation.

My friend Arthur Clarke would say, why not telephones? Yes, telephones also, but for the same amount of information transfer, the telephone needs 1000 times the channel capacity! The average cost of providing one new telephone, with all that it implies in terms of exchanges, links etc., varies between two to three thousand dollars. It will be much more expensive if I go to the thin routes, primarily because the terminal plant and route cost is shared by so few. This being 10 to 15 times the average yearly income of an Indian, a home telephone will not be a mass facility for a long time to come, in many parts of the world. But the information is needed and interaction is required. So let us change the order in the so-called normal development of communication facilities. Start with packet switching, and messaging systems made possible by present technology of satellites and computers, and come to universal telephones somewhat later. This possibility has come too late for the industrialized countries. Here we have a chance to be more modern than they are.

Remote Sensing

Man's living encompasses, and demands, another category of communication — that between things happening and people. In this respect India has some special needs (I suppose this is true of every country), because of its size and its dependence on one of the major atmospheric events of each year, namely its monsoon. It was natural therefore that our attention should turn to the advantages of developing a remote sensing component to our space programme. By now, optical, infrared, microwave and radar sensors have been developed and used widely — some in satellites, many of the others in aircraft. Three rudimentary remote sensing satellites have been built and launched. A Landsat receiving station has been operational for a number of years but even more important is the work done on the ground, to handle the down-to-earth problems through remote sensing. The number of people engaged in this field must be well over a thousand. The emphasis has been to get involved in a number of end-to-end missions. Through this, one has come to separate the sensational from the relevant.

In some sense our attitude towards remote sensing technology development has been somewhat similar to that for satellite communication development; remote sensing utilisation has been given an important place right from the beginning. User participation in projects is considered almost mandatory. Many joint experiments have been conducted, not only for learning and disseminating technologies, but also to identify the parameters of the sensors to be incorporated in the IRS-1, the Indian Remote Sensing Satellite to be launched in 1986. This satellite will have two sets of linear imaging cameras with 4 bands each and resolutions of 75 and 35 metres respectively; it will be launched by a Russian rocket.

Satellite remote sensing for weather is now routinely done through the VHRR on board the Insat satellite. Over a year's experience so far has ensured that geostationary weather observation and monitoring will from now on be a permanent feature of the Indian scene. The weather forecasts have demonstrably improved, and cyclones do not descend on us unannounced. Leaving many of the practical benefits aside, a dynamically changing picture of India abutting the Asian land mass in the north and the vast ocean below — seen every night by millions on their TV screens — has an important cultural effect.

Already the time lapse imagery of the forest cover has provided important impetus to the afforestation programmes. Drainage pattern analysis has led to the development of believable tools to locate ground water in hard rock areas. The monitoring of snow cover on the Himalayas begins to give useful estimates of the expected snow-melt contribution in reservoirs and rivers a few months later. Waterlogging in canal basins and intensity of salinity problems are better understood and, perhaps more important, more easily communicated to the sectors where decision-making and action reside.

Thus there is emerging a new connectivity between people — the public, the decision makers, the analysts and the doers — features, happenings and events — and their relational aspects — in the country at large. This might become increasingly important in years to come.

Let me very briefly indicate the Indian space plan for the next five years. By 1990:

— We would have designed and built our own remote sensing satellites, which would provide 4 channel data with a resolution of 35 metres and 75 metres. The first one would be launched by a Russian rocket.

— We would have developed the advanced version of SLV, namely ASLV, capable of launching 150 kg. payloads into low earth orbit.

— A number of small Science and Technology satellites would have been designed, built and launched with our own rockets.

— Towards the end of the decade, we would have developed the PSLV launcher capable of putting a 1000 kg. payload in a 1000 kg. polar orbit.

— A couple of years later we might be able to have our own geosynchronous launch vehicle.

— Insat 1-C would come in 1986; at that time we would also have another Indian in space, this time on the U.S. Shuttle.

— Proto-Insat, a forerunner of the Insat-II series, would have been designed and built in the country and launched. This satellite would be an advanced version of an operational satellite in the nature of, but going beyond the capability of, the Insat-I series.

Thus by the end of the decade one would have a substantial self-reliance and capability in building the payloads, the satellites, the launchers, and the ground segment to meet the country's operational needs in communication, TV broadcasting, weather services, and remote sensing.

The specificity of the Indian programme lies in proceeding in directions which are well oriented with our socio-economic goals; it also lies in the fact that indigenous development and collaborations have been made to work in a synergistic manner. The urge has been to seek a new connectivity for all the people living in our land. There is yet a long way to go.

EUROPE IN SPACE COMMUNICATION

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I shall begin my presentation by quoting from the Apostolic Brief issued by Pope Pius XII on 12 January 1951 proclaiming the Archangel Gabriel Heavenly Patron of Telecommunication: "To the wisdom of God, our tribute of admiration is due for those many inventions of modern science which make it possible for men to use electricity to communicate witb one another at a distance. Admirable is the Divine wisdom which empowers them to telegraph their messages to those at a distance; to converse by long distance telephone; to broadcast their information over the ether waves; to transmit by television and make present what is actually happening far away. Technical instruments of this kind, it is true, can do a great deal of harm if they are not put to correct use. But they can equally render precious service in many ways when properly employed. They may greatly promote the brotherhood of man and human culture. They may contribute to the spread throughout the world of the liberal arts of scientific research".

In 1951, of course, satellite telecommunication — as indeed any other peaceful use of outer space — was not yet available to mankind. Nonetheless Pope Pius XII's words are still fully appropriate for any telecommunications technology of today and tomorrow. Of this there is no doubt and it is with pride that we, the Western Europeans, are in a position to state that we never departed from Pope Pius XII's recommendations about the correct and peaceful use of new techniques, in particular in the field of public communication.

Let us pause for a while on the road we have been following in Europe for the past twenty years. Let us look back from our vantage point and take full stock of the work that we Europeans have accomplished in the field of space communication. Twenty years ... or, as they say, a generation ...

If what they say is true, then we belong to a generation of people that has achieved great things indeed in fundamental science and in advanced technology for the development and well-being of this immense community of men and women that make up Europe, and this in full observance of Pope Pius XII's encouragement.

Space-age Europe. ... *This* is the Europe that took up the resounding technological challenge issued twenty years ago by the two giants of space communication operation and research. To achieve this, there were men who had the courage to propose the idea of unity so that this age-old continent of ours could take part in this new era of civilization represented by the conquest and utilization of space for telecommunication. But these men who planned for the future were joined during these past two decades by others, who contributed their knowledge, their enthusiasm and their patience to the numerous and spectacular studies and achievements that we know today.

No-one doubts either that the creation of common European bodies, and, most particularly, the establishment of the European Space Agency and of EUTELSAT, played a large part in focusing and wisely distributing the efforts that were demanded.

In the end it was thanks to ESA that space-age Europe came to pass, and to such an extent in fact that the European Space Agency has become one of the symbols — if not *the* symbol — of modern Europe and of its firm intention of using space only and exclusively for peaceful purposes, for the good of mankind. ESA has not only conquered space but has conquered too, the opinion of the terrestrial scientific environment — if I may express myself in this way.

As Secretary General of the European Telecommunications Satellite Organization, EUTELSAT, I can bring to bear my own testimony of the remarkable success of the ESA programmes in the field of telecommunications. These programmes were designed to provide Europe with a telecommunications satellite system which would make full use of the most recent technology and put on offer a wide range of top quality, highly reliable services. Before the ECS satellites were developed, EUTELSAT's operation of the experimental OTS satellite was of great value in enabling the European telecommunications Administrations to develop and, subsequently, to obtain full knowledge of the most recent techniques of space transmission.

The European telecommunications entities have, therefore, benefited from the results of the ESA programmes with which they have been associated. Research is one of the Agency's missions: the application of that research is, of necessity, a task for a specific body. It is precisely for this reason that EUTELSAT was created: Europe today has an international organization responsible for establishing, operating and developing a space segment for its members — i.e. the telecommunications Administrations or telecommunications entities. The establishment of this satellite system began almost a year ago when using its Ariane launcher, ESA launched the first EUTELSAT satellite and continued with the second launch of a EUTELSAT satellite two months ago, on August 4th, 1984. As the operator of the system, I would like to give public expression to my total satisfaction with the quality of what I shall call the "product" which has been provided to me by the European Space Agency and which has, moreover, been built by European industry — industry that has benefited greatly from the results of the research and coordination activities of ESA.

In my own area of space communications, the European Space Agency, under the auspices of the European governments, has and must continue to play in Europe the role played by NASA in the United States of America. ESA is, in particular, able to make it possible to choose high-budget research programmes and, at the same time, enable national industries in Europe to take giant steps forward. Equally, we feel that this leadership that the Agency provides would be perfectly suited to communications satellites.

Such satellites are earmarked for widespread development and must be given the advantage of the very latest technological applications that require large technical and financial means. These technical and financial means can only be provided through a joint common effort of the European governments participating in the European Space Agency.

A similar situation applies, *mutatis mutandis*, to organizations such as INTELSAT, EUTELSAT, INMARSAT etc., which are responsible for the implementation and operation of such large, costly and technologically sophisticated satellite systems. The advantages of sharing these large responsibilities for establishing international ventures for the provision of telecommunication services via satellites, as opposed to national or even private initiatives, are clear to the point of being obvious.

Those who, like me, were already in the satellite business in the sixties may remember that the cooperative formula of INTELSAT was invented by the United States of America, through the Department of State and COMSAT, who jointly succeeded in selling it first to a group of developed countries and subsequently to practically the whole of the rest of the world. The United States, the only country capable at that time of making and launching communication satellites, could easily have selected a different type of formula, whereby the rest of the world would, for example, have participated as users and not as shareholders in a United States satellite system. Why did the United States prefer the first arrangement?

The fact of the matter was and still is that the United States had, in 1962, already foreseen the important advantages of an initiative shared at government level by many countries in the form of a cooperative as opposed to a typical "unilateral" enterprise — even though the latter was indeed economically promising.

The same philosophy was later followed when establishing other international cooperative institutions whose objectives are not competition and profit, but merely the provision of good services at low cost to the general public, via the PTT Administrations.

Recognizing this trend, seventeen Administrations or recognized telecommunication entities, under the aegis of the CEPT, established Interim EUTELSAT in 1977 as the provisional European Organization for operating commercial satellite telecommunications systems. At present Interim EUTELSAT has 20 member countries. The definitive status of EUTELSAT was adopted in May 1982 by an intergovernmental conference held in Paris and attended by representatives of 24 European Governments. The Convention creating EUTELSAT's definitive status is expected to enter into force at the beginning of 1985.

EUTELSAT has been made responsible for the design, development, construction, establishment, operation and maintenance of the space segment of European telecommunication satellite systems. Its prime objective is the provision of the space segment required for international public telecommunications services in Europe, fixed or mobile, which can be provided by satellite and which are available to the public.

As telecommunication services become more and more an integral part of modern life, information assumes, in addition to the role of social integration, the role of economic booster. Fulfillment of this role is the objective of EUTELSAT, for the good of the four hundred million users of the Western European telecommunication network.

In conclusion there are two points that I would like to stress before this eminent audience for possible inclusion in the final recommendations of this Study Week on the Impact of Space Activities on Mankind:

First, space activities directed to the provision of services of vital and social importance, such as public telecommunication services, should never be put in the hands of private initiatives, where profit is the main and only objective. Governments which might show such a tendency, should be reminded that the control of all activities in this field is of their direct responsibility.

The second conclusion is that the improvement of telecommunication services — an infrastructure of fundamental importance for the developing countries — can only be achieved as a result of the common effort of all countries together. This is shown by the brilliant results obtained by the international, intergovernmental organizations operating in the field of public telecommunication services by satellite. Individual countries working in isolation will, with the exception of the few industrialized countries or certain very large countries, never be able to finance and manage extremely costly projects like satellite projects for public telecommunications. Furthermore, the problem of the scarcity of orbital locations that has been repeatedly mentioned in previous interventions here and whicb represents a real obstacle facing us, can more easily be overcome if satellite projects are implemented by groups of countries, using, whereever possible, common facilities, for example, multipurpose satellites able to provide high density communications to bighly populated areas and, at tbe same time, rural telecommunications to the developing areas referred to by Professor Pal yesterday.

I am sure that Mr. Colino, the Director General of INTELSAT, will tell you much more about this.

INTELSAT: THE GLOBAL COMMON DENOMINATOR

RICHARD R. COLINO
Director General INTELSAT

INTRODUCTION

The world has changed dramatically in modern times. Population has increased from some 500-million to nearly 4.5-billion people in the last three centuries. We have seen a pattern of rapid urbanization that has accompanied a pattern of industrial revolution and automation.

We have, over the same time period, seen a dramatic change in the industrial world in the nature of work. We have seen agricultural and mining activities decrease dramatically, so that they account for an ever-shrinking percentage of total employment, the figure is now less than 5 percent in the United States, for example. On the other hand, there has been an equally dramatic increase in the numbers of people employed in the "service" industries, of which communications and computer processing have become such a vital part. In the last decade in particular, employment growth in information and communications-related activities has boomed. Japan and the United States have been referred to as "Information Societies", where approximately 50 percent of the entire labor force is involved in the collection, analysis, organization, distribution and storage of information. On a parallel basis, we have seen exciting breakthroughs in medicine and in health services, that have extended longevity. In broad terms, we have begun to think of our shrinking world in the imagery of a global village.

Such concepts have become more vivid and real as Man has gone into space and we have been able to see our small planet for what it really is — namely, a six sextillion-ton mass of land and water, separated from any other living creatures (if there are other living things in the universe) by millions of kilometers of empty space. We have come to recognize that all of mankind travels through space on a large spaceship called Planet Earth.

The Past 20 Years

If we look at more recent times (say the last two decades) we find that the pace of change has quickened still further. During that period of time, the population of the earth has roughly doubled, from 2.2 billion to nearly 4.5 billion, and we have seen some of Man's most startling and remarkable achievements: ever smaller electronic computers, robotics, artificial parts for the human body, manned space exploration to the moon, and space probes beyond the solar system. The horizons of what man can accomplish have increased dramatically in these last 20 years. Yet, at the same time, there is a paradox in all of this with the reality that more than 2.5 billion people live in rural or isolated communities and have little or no access to the benefits of high technology.

We at INTELSAT view our role in linking together all parts of the globe during these last 20 years with great pride and satisfaction. This year, INTELSAT is celebrating its 20-year anniversary and we feel we have become one of the world's best examples of international cooperation and commitment to shared goals by all mankind. Over these 20 years, INTELSAT has dramatically changed the nature and concept of global communications. We have gone from a very modest satellite, Early Bird, or INTELSAT I (which we launched in 1965), to spacecraft such as the INTELSAT VI, which dwarfs our diminutive operational prototype with an amazing 170 times greater capacity. That's a difference comparable to that between the height of a toolshed and the Empire State Building.

I am, of course, tempted to explain to you in great detail the dramatic new technologies that INTELSAT has been developing that have allowed this tremendous increase in the capacity of our satellites to occur. Equally so, I might share with you the exciting new services we now offer, such as the INTELSAT Business Service (IBS), which allows businesses to plug directly into the global telecommunications network, often called a "telenet". Or, we could talk about dramatic improvements in the earth segment, such as Time-Division-Multiple-Access (TDMA) techniques, which triple the capacity of our satellites; or about

INTELNET, a service where 75-meter antennas (or "microterminals") receive thousands of bits of data per second. INTELNET data speeds are indeed high enough to remotely print a newspaper. However, I will not go into detail on any of these because of one of the most poignant lessons we have learned over the last 20 years, namely that it is ultimately utility, and not technology, which is of true importance. The critical question is: How can the remarkable new electronic communications technologies be put to constructive use for the world's social, economic and political development? That is what I want to talk about today.

In particular, I would just like to spend some time explaining three fundamental changes that the INTELSAT System has effected in its short 20 years of existence. During this period, INTELSAT has, first and foremost, redefined what is meant by "international" communications. Secondly, the INTELSAT System has brought about a fundamental shift in patterns of "domestic" telecommunications in developing countries. Thirdly, let's discuss the role that INTELSAT plays in addressing one of the world's most difficult problems — that of bringing reliable communications to the most rural and remote parts of the world, where close to half the world's population still lives. Here, INTELSAT is hard at work, developing and implementing new solutions.

INTELSAT AND GLOBAL COMMUNICATIONS

When INTELSAT launched Early Bird in 1965, there were only a few submarine cables spanning the Atlantic and Pacific Oceans, and none in the Indian Ocean Region. The few hundred circuits that these submarine cables could carry, plus highly unreliable HF microwave communications, represented all the resources available to tie our fragile world together. International communications — particularly overseas communications — were very expensive and highly unreliable. Even if telephone facilities were available at each end, establishing a connection was often difficult or impossible. In addition, the patterns of interconnection reflected the historical results of several hundred years of colonial links between developed and developing countries. For one to call from Lagos, Nigeria, to Accra, Ghana, the call had to be routed through London, England; a call between Abidjan, Ivory Coast, and Dakar, Senegal, was routed through Paris, France; and a call from Santiago, Chile, to Caracas, Venezuela, would go by way of New York City. Today, direct access connections among all countries of the world — developed and developing, planned economies and market economies, as well as large, medium and small countries — can always be provided through the INTELSAT Global System.

INTELSAT today has 109 member countries and links together 170 different countries and territories around the world. Some 1,500 earth-station-to-earth-station pathways exist, with many of these routes carrying a very modest amount of traffic. Indeed, close to half of those links represent under 10 percent of INTELSAT's revenues. But of course INTELSAT was charged with a responsibility, in its original charter, to provide global interconnectivity. The ability to establish links of all sizes, among and between all countries, has been one of the guiding principles of INTELSAT's development. Today, overseas telecommunications are more than 99.9 percent reliable. The cost of the service has decreased dramatically, as INTELSAT's rates have been decreased on 12 different occasions. Indeed, when one adjusts for inflation, the cost of INTELSAT's telephone service today is almost 20 times less than when we began service in 1965.

Today, citizens in all countries of the world expect, almost as a matter of routine, to be able to see global events, like the World Cup Soccer Matches and the Olympic Games. Among its many accomplishments in the last decade, INTELSAT has been proud to televise a number of Papal visits (to Africa, to South America, to North America, and to Asia), so that literally millions and millions of people have been able to share this experience via television. The recently concluded Olympic Games were witnessed by almost 2-billion people, or close to half the world's population.

Of course, these global links have done more than simply tie a world together in order to share common social and cultural goals. They have also important economic impacts. In the South Pacific, the island nation of Tonga installed an INTELSAT international earth station a few years ago. After this earth station went into operation the citizens of Tonga began to to experience some rather major economic changes as a result of having reliable and low-cost communications available to them. First, they found that the cost of their imports (for which they in the past had to pay premium prices), fell by up to 30 percent. Equally important, they found that their export prices, which they were now able to negotiate by telephone rather than relying upon the first ship to come into harbor, rose by as much as 30 percent.

These experiences have been duplicated time and time again, in countries which previously had been isolated in their communications, but which now are linked together into a global network via INTELSAT. It is estimated on a global scale that close to $ 7-trillion in electronic funds transfer travel through the INTELSAT System each year. Also, it has been estimated by a large international airline carrier that each minute their global reservation computer network is out of operation they lose some $ 30,000 in revenues. Although one could continue to cite examples and statistics, it is clear that the world of global communications is today radically different from what it was two decades ago and that, in many instances, this change can be directly attributed to the growth and development of the INTELSAT System.

Making Fundamental Shifts in Domestic Telecommunications in Developing Countries a Reality

Satellite technology has, of course, been utilized for more than a decade to increase domestic links in both developed and developing countries. A large number of developed countries are operating, or will soon operate, their own satellite systems to meet their domestic telecommunication needs. Indeed, some developing countries (such as Mexico, Brazil, Indonesia and India) are or soon will be launching their own domestic satellite systems. For most developing countries, however, a separate domestic satellite system is far too expensive and operationally difficult to consider building and launching on one's own.

In 1973, Algeria became the first developing country to come to INTELSAT and ask whether it could perhaps lease spare capacity on the INTELSAT System for domestic communications. This service began in 1974 and dozens of other third-world countries soon followed suit. Today, 27 countries lease capacity from INTELSAT for domestic services, while another 8 lease capacity for a combination of domestic and international video links. Alphabetically, these countries range from Algeria to Zaire. Based on projections for the future, some 50 countries (predominantly developing) expect to be leasing capacity from INTELSAT within the next decade. These countries, which can lease capacity from INTELSAT for rates as low as $ 200,000 per annum (with the most typical price being $ 800,000 per annum for both television and long-distance telephone and telex services), have found that very attractive services and charges are available by leasing spare capacity from

INTELSAT. These leases have allowed many developing countries to achieve effective integration of all of their large cities and regional capitals into one long-distance telephone network. They have, at the same time, also served as a means of establishing an effective national TV system. In many instances, these countries make even more effective use of their leased capacity, by time-sharing it between television and telephone during the evening and day, respectively.

When Algeria introduced this service, it quickly found that there were social implications that resulted from this technological innovation. For centuries the bazaars in the regional desert cities had tended to open at sunrise and close at sunset but, within a matter of weeks, the bazaars started to close just before 5:00 p.m., because that was when the television system began transmitting the news.

The ability to create national networks has, of course, had dramatic impacts on the economic development of many of these countries, where suddenly it became possible to support manufacturing, mining, and oil drilling operations in remote parts of the country without large and permanent investments in communication facilities. This growth in domestic communication systems in developing countries, in terms of integrating all of the major regional cities into a single domestic network, has been a major impetus in the economic development of these third-world countries over the last 20 years.

Finding Solutions for the World's Most Rural and Remote-Area Communications

There are, today, more telephones in Japan than there are in the remaining developing countries of Asia, South America and Africa combined. As dramatic as this statistic is, it masks the fact that in the developing countries themselves 90 percent of the telephones are typically concentrated in the capital city and in regional capitals which are the urban centers of those countries. Thus, the people who live in rural towns and villages, where between 60 and 80 percent of the population of these countries is concentrated, have limited or no access to telecommunications at all.

One of the key objectives of the Decade of Communications and Transportation Development in Africa is to bring a telephone within 5 kilometers of every inhabitant of the sub-Sahara and Africa. This ambitious goal, unfortunately, is not likely to be reached — perhaps not in the next 20 years. This is because not only is an investment in the billions of dollars required, but the industrial capability to manufacture all of the telecommunications equipment, as well as the training of human resources for maintenance of these systems, are not readily available.

Nevertheless, new technology in the space communications field is giving rise to new hopes for rural communications development. Just last year, INTELSAT introduced what we call "VISTA" communications service. VISTA is a basic thin-route telephony service, which was designed to promote full-time service for only a small number of telephone channels at a particular earth station operated in rural and remote areas. These stations would serve as the huh for the surrounding area, perhaps providing a "party" line link for 10 to 20 phones, serving perhaps up to several hundred people. The key to VISTA service is an innovative and inexpensive tariffing plan, that allows charging for individual channels but on a hasis similar to that for bulk capacity. The other key is the authorization of small earth stations of innovative yet standard design that currently may cost in the range of $ 50,000 (U.S.) per unit, but which we hope will eventually drop in volume production.

Beyond VISTA, however, INTELSAT is beginning to explore the possibility of very small microterminals — perhaps as small as 1.2 meters in size — that could transmit data communications from remote locations at speeds such that digitally encoded voice service, albeit of a perhaps limited quality, could go to the most remote regions of the world. The cost of such installed terminals perhaps might be as low as $ 5,000 to $ 10,000 per unit.

Of course the key to rural communications involves more than technological innovation in spacecraft and ground terminal technologies. There remain also the issues of technical assistance, training of skilled human resources and financing of such systems. INTELSAT introduced, several years ago, the INTELSAT Assistance and Development Program (IADP), which provides such assistance to our developing-country members. In addition, in conjunction with the Independent Commission on Worldwide Telecommunications Development (commonly known as the Maitland Commission), established hy the ITU in Nairobi in 1982, INTELSAT is endeavoring to develop a means to assist countries to locate funding for communications development in rural and remote areas and would allow the integrated planning of space and terrestrial facilities for communications development in Africa, Asia, South America or other regions seeking assistance. Such a mechanism would, of course, have to be consistent with the INTELSAT Agreements and the commercial operating characteristics of INTELSAT.

There is yet another new initiative of which INTELSAT is particularly proud, which we have introduced as part of our 20th anniversary program. We call it "Project SHARE" (Satellites for Health and Rural Education). We will, over the 16-month period from January 1985 through April 1986, make satellite capacity available free of charge for tests and demonstrations by qualified educational and health service organizations around the world. This, we believe, will allow a real blossoming of tele-education and tele-health projects in developing countries. We hope these projects will eventually give rise to operational programs which have the potential to benefit many millions of people.

We can see then, that over the last 20 years INTELSAT, as the world's global satellite system, has fulfilled its commitments to the developed and developing countries and has benefited the world enormously. We particularly pride ourselves in assuming the role of the global common telecommunications denominator that assists countries at all levels and stages of economic, social and political development. The innovations that we have introduced — in terms of international overseas telecommunications; in terms of domestic leases, particularly to developing countries; and now, increasingly, in the area of rural communications — we believe are truly helping to shape a future world which is better educated, has better access to health services, and where all nations of the world feel more closely tied together. We can assure you that INTELSAT will not lose sight of these goals during our next 20 years.

The INTELSAT Agreements have, over the years, demonstrated a *formula* for success. The best of many diverse elements have been combined in its charter (i.e., global cooperation; international competitive procurement of spacecraft; continuing emphasis on development of new technology; integration of global traffic; "global averaging" in INTELSAT's pricing structure, in order to benefit equally small, medium and large countries; international recruitment of staff on the basis of competency; decision making on the basis of technical, operational and financial factors, rather than political factors; commercial operating procedures; and a carefully balanced and orchestrated decision-making structure that typically results in consensus).

This success is shown in the growth of the system, the twenty-fold reduction in charges, and the explosive growth in satellite technology in the INTELSAT System while improving reliability. It is also shown by the use of INTELSAT as a model for international cooperation. The INTELSAT Agreements have served in a parallel role for INMARSAT, EUTELSAT and ARABSAT and are often cited as an "optimum structure" for approaching space-based manufacturing, operation of international space stations, or even for earth-based new high-technology ventures requiring international cooperation.

The ability of INTELSAT to span — and span effectively — the gaps between developed and developing economies and between countries with very low and very high volumes of traffic is a rare and special quality of which the founders of INTELSAT can be justly proud.

There is danger, of course, in any organization looking to the past and resting on the laurels of previous accomplishments. In terms of technical innovation and new operational techniques, we have little doubt about the future. Nevertheless, key challenges, affecting basic policy choices, confront INTELSAT as it enters its twenties. I would like to conclude by briefly addressing two issues which I believe are most critical.

1. *Heavy Route Trunking, Vs. Global Thin-Route Networking, or Vs. a new Dynamic, and Integrated Approach to Global Communication Services: INTELSAT's Course for the Future*

INTELSAT must choose its best course for the future, in light of a wide range of factors. We must consider, for instance, competition from fiber optics, new types of "trunking satellite" concepts and completely new types of satellite architectures. We must also consider orbital congestion of the Clarke orbit, dramatic new digital circuit multiplication techniques, and the need for greatly expanded rural communication services. Further, we must consider new market-place and customer demands, particularly the demand to use small and low-cost earth station antennas.

In light of these factors and others that characterize today's complex international communications environment, there have been questions, in recent months, about whether INTELSAT can continue to be an effective global common denominator. Questions about whether INTELSAT can respond well to the needs of large and geographically diverse networks with small pathways, and still also serve heavy streams of traffic. The answer is, emphatically, "yes". There have been others that have said that, even if this were technically and operationally feasible for INTELSAT, the concept of "global averaging" cannot be sustained in the future. I am confident that ways will be found, regardless of changing future circumstances, to continue to derive these benefits for the developing world.

INTELSAT, through the future application of new technologies, such as on-hoard processing and advanced satellite and earth station antenna designs, can continue its traditional role and yet further diversify its service offerings (already over one-hundred in number). There are continuing economies of scale and economies of scope which can only be achieved in a diversified global system and which uniquely allow INTELSAT to be more responsive to a globally competitive communication services market. We are already pursuing a balanced strategy which allows the strengths of new video services, INTELSAT Business Services, VISTA, INTELNET and domestic services, to reinforce one another, as well as conventional international telecommunication services, underscoring the fact that INTELSAT does deliver the benefits of competition — innovation, low rates, diversity of services, and operational efficiency — primarily because it is a global common denominator.

2. *INTELSAT as an Instrument of Communications Development and Global Cooperation*

There are those who have stated in a critical way that INTELSAT has a "schizoidal personality". On one hand, they note that INTELSAT was created on a "commercial basis", that its prime owners are the most prosperous countries and its biggest users are multinational enterprises. On the other, they note that INTELSAT is a not-for-profit cooperative, and that two-thirds of its members and some 80 percent of its communications pathways are to and from developing countries. They also note INTELSAT's commitment to universal access to all countries, the INTELSAT Assistance and Development Program; Project Share; VISTA rural telephone service; serious plans for an INTELSAT Development Fund; and INTELSAT's special service to the United Nations for peacekeeping and emergency relief. They question "how" and "whether" INTELSAT can serve such diverse constituencies and do so well and cost effectively.

We answer by saying we can do so because we have already proven it is possible for two decades. But more importantly, we must. In short, we believe we must because we believe there should be one world — not two, or three, or four or more; we believe in unifying the world, not splintering it. Likewise, we believe that INTELSAT should be closing the gaps between countries and cultures — not opening them. We believe that INTELSAT truly represents the kind of symbiosis between developing and developed societies that represents mankind's best hope.

I feel that the world's leaders who are concerned with world peace and economic development for third-world countries should consider these questions:

— Who better than INTELSAT has brought affordable satellite communications to developing countries for both international and domestic services?

— What other telecommunications operator has the range and scope of activities and services aimed at benefiting third-world countries more?

— Finally, who believes that INTELSAT's outstanding developmental programs have seriously undercut our ability to offer low-cost, affordable and responsive services to the world's most sophisticated users? Frankly, I believe INTELSAT's record over the last 20 years provides convincing answers to all these questions.

Now, it is fashionable, and certainly good manners, not to speak too much about your own organization's accomplishments. And in this respect, I would certainly also want to salute the efforts of others who have worked long and hard in the area of global communications development. Certainly, we should recognize the valuable contributions of the International Telecommunication Union (ITU); the UN Development Programme (UNDP); the International Bank for Reconstruction and Development (IBRD; the Inter-American Development Bank; the United Nations Educational Scientific and Cultural Organization (UNESCO); the International Programme for Development of Communications; the International Bureau of Informatics; the Organization of American States' Inter-American Telecommunication Committee (CIETL); the African Union of Post and Telecommunications; a large number of private foundations; and many, many national and regional aid agencies (like AID, DMZ, JICA, CIDA, etc.). The list, of course, could be much, much longer.

There is a special reason why I today take such liberty in stating so emphatically what INTELSAT, along with others, has done for world peace. There is today, it would seem, a need to reaffirm to our world political leaders the importance of linking our fragile world together, and closing the gaps between the information-rich and the information-poor.

It, unfortunately, is true that the basic principles of global sharing which INTELSAT exemplifies have come under scrutiny and indeed, in some quarters, under attack. These attackers would try to deny the symbiosis of global sharing from which INTELSAT has drawn its life-blood. They would, in the pursuit of the creation of private satellite networks, apparently sacrifice global connectivity, erode the economies of scale that allow third-world satellite communication service to be affordable, and endanger the principle of universal access that the INTELSAT System has represented for two decades.

In closing, I would like to recall the hopeful words that Arthur C. Clarke, the father of the communications satellite, spoke on the occasion of the signing of the INTELSAT Agreements:

> "... today, gentlemen, whether you intend it or not, whether you *wish* it or not — you have signed far more than yet another inter-governmental agreement.
>
> "You have just signed the first draft of Articles of Federation of the United States of Earth".

LEGAL ASPECTS OF SPACE ACTIVITIES

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Introduction

Through the relevant incorporation of the concept of the "Common Heritage of Mankind", the Law of Outer Space has come to represent a veritable revolution in the Juridical Sciences. It has established the need for pinpointing its scope and content, taking into account the influence which this branch of the Law might exercise in the evolution of a new international standard.

The first historic mention by the United Nations of the peaceful use of outer space was in Resolution 1348 adopted by the General Assembly on 13 December 1948. Resolutions 1721, 1962 and 1963 which stressed the same idea were also important.

With reference to the treaties which constitute the Law of Outer Space, the most vital is undoubtedly the "Treaty of the principles governing the activities of the States in the exploration and utilization of outer space, including the Moon and other celestial bodies".

Although the aforesaid legal antecedents do not contain an explicit mention of the Common Heritage of Mankind, this can be inferred from their norms and the doctrine they embody. The Moon Agreement of 1979 refers clearly and definitively to such a concept (article XI of the Moon Agreement).

Political-Juridical Context

Beginning with the United Nations Charter, International Law has undergone profound changes. Likewise, discussion of a "Universal" law or a General International Law began. No state can disregard the norms of this law on the grounds they were unforeseen, in view of the fact that the international peace, justice and security of all of the world's States, regardless of their membership in the United Nations, is called into play. One of its most far-reaching legislative manifestations is Resolution 2625 (XXV) of 1970, entitled "Declaration on the principles of International Law regarding friendly relations and cooperation of the States in conformity with the United Nations Charter". It identifies the seven fundamental principles of the Charter, including prohibition of the use of force, autodetermination and non-intervention.

This amplification of classical International Law resulted in the appearance of an "International Law of Cooperation". Its fundamental premises are based on the right of a people to be accorded the minimum levels of well-being and development. It is worth noting in this regard that the Member States of the United Nations, meeting in 1974 at the Sixth Period of Special Sessions, proclaimed their intention to work for the establishment of a New International Economic Order. Among other concepts emphasized in that declaration were the complete and permanent sovereignty of each State over its natural resources and all of its economic activities. Also relevant is Resolution 3281 which led to the Charter on the Economic Rights and obligations of the States (adopted by 120 votes in favor, 6 against and 10 abstentions), reaffirming the above mentioned principles.

In this regard, Mohamed Bedjaoui, member of the International Court of Justice, points out (Toward a new International Economic Order. Unesco. Holmer-Meier Publishers, New York, 1979): "Participation with notable economic reach and elements of solidarity and co-operation is an international right, which should make the correction of imbalances, rather than the pursuit of total equality, its primary aim".

With respect to the role of Customary Law, it should be noted that the principles of the Charter were drafted for the purpose of applying them in the context of the contemporary process for formulation of International Law. Extensive use of the General Assembly and Security Council's Resolutions, and the confidence expressed therein, was sought in order to produce legislative results. There are also certain principles of Space Law which, because of the *jus cogens* character, are not susceptible to any change whatsoever. Any change would be null and void because it would contradict an absolutely unrepealable pre-existent principle.

Thus, for example, there would be opposition to the creation and consolidation of a customary norm which permits militarization of the cosmos, since the validity of the primary norm and *jus cogens* of International Law prohibiting the threat or use of force, cannot be questioned.

The impact of technology on Space Law

The expanding armament race, the dispersion of real military economic power in the world, the development of regional powers or hegemonies, the existing inequalities among nations and within them, the conflict of ideologies, the concern over the supply of energy from trustworthy sources, the growing number of displaced persons, the steadily growing size of the world population, constitute, among many other factors, events which characterize an area of instability and conflict in the international arena. (A.E. Gottbield, Impact of Technology on Contemporary International Law. Recueil des Cours. Académie Internationale de la Haye, 1981, vol. 1. Martins Nijholf, Publishers, The Hague).

The technological differences are particularly illustrative in the case of outer space, including the exploration and exploitation of celestial bodies and their resources, the military use of the cosmos, the utilization of remote sensing through satellites, the development of telecommunications, the applications of special techniques for meteorology, solar energy, control of ecology, etc...

Technology has resulted in a close relationship between the different actors in the international community. The impact this exercises on the progressive evolution of the Law, characterized by the political, economic and technical aspects which underlie the negotiations of new legal formulas, produces a high degree of uncertainty and a growing recognition of unpredictability. This certainly does not imply disregard, in the case of Space Law, of the constituting doctrine (the benefit to humanity and international cooperation — its two basic pillars). The absence of clear models of recognizable action in the actions of the States makes an urgent normative development in the new areas of International Law imperative, consistent with the legitimate expectations of all the countries and the sharing of natural resources, on an objective basis of fairness and justice. As a result of the strong and ever-growing interests at hand, technology has significantly reduced the interval during which the actions of the States are converted into International Law.

General Outline of Space Law

Characteristics

1) *Previsibility*: This branch of Law implies the need to anticipate technical advances. 2) *Internationality*: Product of the fact that the legislative process has been carried out in the field of the United Nations. 3) *Universality*: Its norms have general application, even for those States which are not parties to, or are not members of, the United Nations, since they emanate from the consensus expressed unanimously by the international community. 4) *Integrality*: Brings together the concepts of Public Law and Private Law.

Principles

1) International Law and the Charter of the United Nations are applied to outer space. 2) Freedom of exploration and utilization of outer space and other celestial bodies (articles 1 and 2 of the Space Treaty) implies the right of free access to the space regions and the right to free exploration and use of the cosmos. This principle would be violated if a State had recourse to technical procedures or means which seriously impeded or obstructed the right to free exploration and use by third parties.

The illicit exercise of space freedom is subject to a truly firm condition: that exploration and use of the cosmos be carried out for the benefit and interest of all countries. For this to happen, freedom must be based (primarily) on the sovereign equality of the States, in conformity with the provisions of International Law. 3) Non appropriation: this stems from article 2 of the Space Treaty and provides the basis for maintaining that outer space is a *res communis humanitatis*. 4) Principle of pacifism: A comprehensive review of the norms of International Law and the doctrine governing Space Law permits the conclusion that outer space, the moon and other celestial bodies must be explored and used for peaceful purposes exclusively. Unfortunately article 4 of the Space Treaty is not consistent with the aforesaid doctrine since it only considers partial demilitarization. 5) Principle of jurisdiction and control: States party to the Treaty with a registered object launched into space will retain jurisdiction and control over such object, as well as over all personnel traveling in it while it is in outer space or on a celestial body (article VIII, Space Treaty). 6) Humanitarian Principle. Space agreements, and more specifically the Agreement on Rescue and Return of Astronauts and Return of

Objects Launched into Outer Space, are based on this principle. In addition, for reasons of a general nature, this principle is based on the fact that the cosmonaut is considered a special envoy from Mankind. 7) Responsibility of the States. By virtue of this, the States are responsible for the national activities of their governmental and non-governmental organizations in the same manner as international organizations (article VI, Space Treaty). In the case of damage caused by space objects to third parties on the surface, an extensive, absolute and limitless system is applied in accordance with the Agreement on Responsibility of 1972 (objective responsibility, without guilt). 8) International Cooperation. Its explicit mention in diverse norms of the special Agreements is related to the basic doctrine emanating from the Right to Development and Cooperation. It should be added that since it deals with Space Law, it assumed great importance because its motivating idea, the concept of the Common Heritage of Mankind, would represent a mere aspiration if space activity were not sealed by cooperation.

Range of the Concept of the Common Heritage of Mankind

The concept of the Common Heritage of Mankind embodies its maximum expression, the notion of the "Common good", a reflection of the high principles of justice and fairness. It is a political, juridical response to the unequal distribution of natural resources in the world as well as of human capabilities. The word "mankind" appears in the space treaties as an entity distinct from that of "international community". It speaks of "peoples", and article I of the Space Treaty refers to "countries", instead of "States". It deals with a rejuvenated idea of International Law which, in accordance with the idea of the "common welfare", expands its sphere of application to all human groups, States or not.

The 1967 Space Treaty, which has been given constitutional status, does not contain an explicit reference to the Common Heritage of Mankind. However, this can be concluded from its articles I and II. Article I, clause I, states: "Exploration and utilization of outer space must be done for the benefit and interest of all countries, without regard to their level of economic and scientific development, and is incumbent on all humanity". Article II establishes: "Outer Space, including the Moon and other celestial bodies, cannot be the objective of national expropriation for recovering sovereignty, use or occupation, or for any other reason".

Both articles demonstrate the pre-eminence of Space Law over other forms of Law, singularized among other reasons by the exclusions of the traditional modalities in the acquisition of property.

Meanwhile article XI, number 1 of the 1979 Moon Agreement makes explicit reference to the aforementioned concept when it provides that: "The Moon and its natural resources are the Common Heritage of Mankind". The 1967 Space Treaty does not contain any reference to natural resources.

The basic elements of the notion of the Common Heritage of Mankind are: a) that no one can claim for himself title to any property in outer space, on the moon and other celestial bodies. The only legal authority that can exercise Sovereignty in this area is "humanity", and an adequate institutional mechanism will have to be constructed for that purpose. b) Space activity will only be legal if the copulative condition is effected for exclusively peaceful purposes and for the benefit and the interest of all peoples, "no matter what their degree of scientific and technological development" (article 1, clause 2, Space Treaty). c) Freedom of exploration.

The Jus Cogens and its relation to the Common Heritage of Mankind

The so-called *jus cogens*, which finds its legislative expression in the Convention of Vienna on the Law of Treaties is a group of higber status norms "at the top of the hierarchical scale" with a close relationship to Natural Law which cannot be derogated. (Antonio Gomez Robledo. El *jus cogens* internacional. Académie de Droit International, Recueil de Cours, vol. III, 1981, Martins Nijhoff Publisbers, The Hague, p. 24). It is reckoned that these rules are derived from the principles which the juridical conscience of mankind considers absolutely indispensable for the survival and development of the international community. Universal character can be attributed to the Charter of the United Nations. From it rise many norms *juris cogentis*, such as the exclusive sovereignty of States over their natural resources, the free determination of peoples and the prohibition of the use or threat of use of force. In that sense the Charter has only codified the most fundamental postulates of international juridical order.

In accordance with the provisions of articles 53 and and 54 of the Convention of Vienna, sanctions in treaties whose dispositions are contrary to *jus cogens* can be of two classes: the nullification and the termination of the treaties.

One of the outstanding principles of *jus cogens* is its prohibition of the use of force. Article 52 of the Convention of Vienna refers to it broadly as "coercion upon a State through the threat or the use of force". Not only would "armed force" he included but also any type of duress which destroys peace. This article is the only one in the Convention which categorically identifies one of the fundamental principles of *jus cogens*, thus attributing exceptional importance to it. With regard to the Resolutions of the General Assembly, the authors establish that the following would be of *jus cogens*: 1) Resolution 1514 on decolonization; 2) Resolution 1803 regarding permanent sovereignty over natural resources; 3) Resolution 2131 on the inadmissibility of intervention in the internal affairs of the States and protection of their independence and sovereignty; 4) Resolution 2625 which identifies the seven most important principles of the United Nations Charter; 5) Resolution 3314 which defines aggression, and 6) Resolution 2749 on sea and oceanic bottoms.

The Universal Declaration of Human Rights and those related to the peaceful uses of outer space should be added. With regard to the violation of their norms, the Commission of International Law of the United Nations has said that this would imply an "international crime" (Recueil des Cours 1981, p. 183).

The juridical nature of these and other rights is indispensable for civilized co-existence, permitting the limitation and regulation of the exercise of conventional freedom by the States. The theory of *jus cogens* is the legislative expression of the limitation of exclusive state sovereignty when certain values affecting all mankind are concerned.

The Space Law has developed concepts that can be catalogued as of *jus cogens*. The Common Heritage of Mankind is the most relevant. It implies the irrepealable obligations to undertake space activity for the benefit of man. The fact, for example, that no nation can claim sovereignty or any other form of dominion over outer space is one of the consequences of a measure to ensure the benefit of all mankind.

In summary, the elements of the Common Heritage of Mankind which would permit it to be given the character of *jus cogens*, are: a) Categorization of outer space as *res communis humanitatis*. This implies exploration and exploitation of space for the benefit of mankind. b) Protection of the atmosphere against unnecessary degradation. c) Conservation and increase of the natural resources of the universe for present and future generations. e) Equitable distribution of resources with particular attention to the needs of developing countries.

However, formation of an international regime will be required to put into practice the Common Heritage of Mankind.

Sovereignty, jurisdiction and space freedom

One of the most evident limitations on sovereignty in International Law can be found in article II of the Space Treaty. This norm prohibits States from exercising any form of acquisition of domain in outer space, the moon and other celestial bodies. This ban is a logical corollary to the condition of *res communis humanitatis* of outer space. It is compatible with space freedom prescribed by article I of the same Treaty. It is the product of an agreement among the States by virtue of which they renounce full and exclusive sovereignty. The principle of space freedom implies: a) the right of free access, on an equal basis, to different regions of the cosmos; b) the right to free exploration, and c) the right to free utilization.

The legal exercise of space freedom is subject, as has been seen, to a resolute condition that action be taken for the "benefit and interest of all countries". On the other hand, the States retain jurisdiction over the "space object and the persons and property aboard same". Jurisdictional competence also requires there be security zones around the space stations which facilitate their operation and control on celestial bodies. The possibility of extending state authority to areas adjacent to a station guarantees exercise by the registered State but does not in any way imply that it has acquired any property right.

Given the nature of *terra firma* of celestial bodies, construction or establishment of space stations might result in establishment of a form of effective control by the State owning the space ship or certain adjacent areas. This phenomenon must be understood in the context of assuring and stimulating free scientific and technological research "incumbent on all mankind". It is necessary to clarify the fact that in accordance with existing legal dispositions, only the State of registry (equivalent in this case to the nationality) retains exclusive jurisdiction over its vehicles.

Militarization of Outer Space

As noted earlier, the most relevant principle of the United Nations Charter is undoubtedly the ban on the threat or use of force. A comprehensive reading of the Charter, as well as of its guiding principles, leads to the conclusion that any coercion that breaks the peace would be considered as exercise of "force". This could also be concluded from the Convention of Vienna on the Law of Treaties. Regardless of the characteristics of the "force" employed, armed or not, it would be offensive to the supreme ideals of the United Nations: the maintenance of peace and international security and cooperation between nations. It has the character of *jus cogens*, that is to say, it is absolutely irrevocable. The only possibility for using force is a legitimate defense. The norm contained in article 2, number 4 of the Charter is, therefore, universally obligatory and has generated customary law.

Exploration and use of space, in order to be legitimate, must be in conformity with the provisions of the article 1, number 1 of the Space Treaty that it be for the "benefit and interests" of humanity. That mandate represents an innovation of Space Law which implies that the legality of a space activity must be in compliance with article 1, number 1 of the Space Treaty. Unfortunately article 4 of the same legal instrument which refers to the militarization problem is not in conformity with the general doctrine of International and Space Law. The prohibition which emerges from that article is certainly partial since in accordance with it only "the Moon and other celestial bodies should be explored for exclusively peaceful purposes". In addition, the norm alludes to "objects carrying nuclear arms" and another type of arms for "mass destruction", without including, for example, conventional arms. Article 3 of the Moon Agreement is more complete although it does not apply to outer space. It offers the positive element of condemning "other hostile acts or the threat of such acts on the Moon".

In any case, the central point of the analysis remains in the interpretation of the term "peaceful uses" which the Agreements use. The concept of "peaceful uses" should be examined within the context of the progressive evolution of International Law and of the principles of the Space Law. In accordance with this situation, solely those activities which do not have a "non-peaceful" character would be permissible in outer space, on the Moon and other celestial bodies. Those who defend the "aggressive" thesis believe that it is difficult or impossible to juridically separate the "military" category from the "non-military", and for that reason only armed force or its attempts should be prohibited. However, preambular paragraph 9 of the Space Treaty condemns propaganda designed to provoke a "breakdown of peace". The fact that an activity is not precisely aggressive does not modify, therefore, its intrinsically illicit nature. The criterion of legality must be sought in the rule of article 1, n. 1 of said juridical instrument. In accord with the general principles, legitimate defense is also acceptable in outer space and must be exercised by the State of Registry. In qualified cases, collective defense would also fit in. However, there are certain military uses which, from a doctrinary standpoint, are permissible since they do not fall into the general concept of "uses of force". These would be: 1) Vigilance in compliance with disarmament agreements, 2) Vigilance in critical situations. These are applicable for a) early attack alert, without this implying recognition of the status of "legitimate anticipated defense", which could not be accepted. Legitimate anticipated defense is a very dangerous recourse which in action becomes transformed into a preventive attack; b) evidence of violation of boundaries; c) vigilance of a cease fire; d) assistance to United Nations observers for the maintenance of peace; e) strengthening of the measures of confidence and observation of the prohibition of the use or the threat of the use of force.

Satellites are able to fulfil important functions in the protection of national and international security. This would require a casuistic examination and the attribution of corresponding international responsibility when called for. Within this framework, even space objects which carry out intelligence missions would be valid, as long as their objective was to preserve peace, and was not contrary to the principle of autodetermination of peoples.

The most significant is, in any case, adaptation to the norm of article 1, number 1 of the Space Treaty in the sense that all hostile actions in space or from and towards space, should be absolutely prohibited.

The Cosmonaut: Special envoy of mankind

Ordinarily International Law does not grant special treatment of any kind to individuals. However, article V of the Space Treaty, as a logical corollary to the fact that space is the "Common Heritage of Mankind", attributes to the cosmonaut the category of "Special Envoy of Mankind".

Legislation of Space does not contain a definition of the term "cosmonaut". It has been maintained with reason that all persons aboard a spacecraft should share the common status of astronauts, no matter what function they may carry out.

However, this will require further clarification when special vehicles begin to carry passengers. The purpose of this idea was to assure international immunity. That privilege originates in the importance of the duty of the cosmonaut, that is his search for the benefit of mankind.

Consequently, transnational immunity would be lost when he does not carry out the activities of exploration and utilization in fulfilment of that ethical imperative. Military activities, for example, do not offer immunity of any type to those who undertake them.

Space objects and celestial bodies

Both concepts must be charged to the account of notable omissions in space legislation. With regard to celestial bodies, these in the fullest sense would be all those areas that have a solid surface ("land areas"), and their juridical situation would be similar to that of outer space. (The Law of Outer Space, p. 71, 1972. Manfred Lachs).

As for space objects, each of the agreements refers to them in an indistinct form. The conclusion has been reached that the most satisfactory approach would be to consider them as those in which the hand of man intervened for their construction and they can he launched into outer space; that is to say, they have an artificial character.

International responsibility

The idea of responsibility is in the nature of any standard system. Every illicit act attributable to a State involves the origin of international responsibility. It is composed of two elements, one subjective, equivalent to imputability, that is to say, the relationship between the illicit act and its author; and the other objective, a State's violation of a certain obligation. In addition to these two elements, the question of whether it is also necessary to add damages has been brought up. The Commission of International Law does not establish damages as an additional requisite for responsibility; not for being considered irrelevant but because under International Law any violation of an obligation injures a subjective right of a State. This constitutes harm or at least moral damage to that State. The harm would be implicit. This despite the fact that the harm could effectively constitute a key aspect in the determination of the amount of reparations (Agreement on Space Responsibility, 1972). In any case, the practice is uniform in the sense that the State which exercises the action of responsibility always does so by invoking damage. It should be noted that in regard thereto a new typically criminal item has appeared: "international crimes". They refer to the violation of certain obligations which are essential to safeguarding the fundamental interests of the international community.

The subjects of Space Law are the States (article VI, Space Treaty) and International Organizations. With regard to the latter, article VI is applied only to inter-governmental organisms, that is, they are the product of an international agreement or law (article XIII, clause 1, of the Treaty). With reference to the problem of damages, space legislation contemplates them particularly: a) in general mention in article 7, Space Treaty, and b) in the Agreement on Space Responsibility, when there are damages to third parties on the surface. Both agreements establish the objective responsibility. This is based on the so-called theory of risk and implies that he who creates a risk, and through its employment benefits from it, must take the consequences, while the person who might be hurt thereby accordingly merits special protection from the law. However, the Agreement on Responsibility also considers subjective responsibility for certain and specific cases.

Peaceful settlement of disputes

The Space Treaty does not include any disposition or even obligatory procedures for settlement of disputes. The Agreement on Space Responsibility, like the Convention of Vienna on the Law of Treaties, establishes the method of conciliation, in the event that the diplomatic approach fails (article XIV). It provides for the formation of a Commission and the respective procedure, in a manner similar to those used for setting up arbitration tribunals.

The basis and the form of the decision are thus comparable to an arbitral award. The decision must be based "on international law and on the principles of justice and fairness". The Convention of the ESA includes an obligatory arbitration procedure as well as an Intelsat Agreement. It is regrettable that space legislation does not provide a compulsory procedure for the settlement of disputes.

International cooperation in outer space

The Space Treaty establishes the general doctrine in this sense: space activity must be aimed at obtaining benefits for all peoples, "no matter their degree of economic, scientific or technical development". As seen earlier, the legislator felt that to favor cooperation it was necessary to have the broadest space freedom, which would only be legal if it did not lead to acts of "appropriation". In this regard, a distinction must be made between appropriation of regions of outer space and celestial bodies, which is expressly forbidden, and that of natural resources. The law does not pronounce itself on the latter. It has been proposed that a distinction be made between inexhaustible resources which might be the objectives of domain and the exhaustible which obviously would not be the objects of acts of domain. On the other hand, it is important that the States exploiting space should have the right to compensation for services to mankind.

With reference to the so-called "transportable" or "separable" goods, these also could be placed within the legal framework described.

Another interesting approach to be considered is the difference between "shared" and "non-shared" goods but greater deliberation on the subject will be necessary. What is clear and permissible is the existence of freedom of scientific research (article XI, Space Treaty).

Items of the Copuos Agenda

a) *Remote Sensing*: Two elements are brought together here: space freedom and the object of that activity, namely the sovereign territories of States. If it is true that remote sensing is developed from outer space, where sovereignty does not exist and there is no juridical possibility of claiming it, the information on natural resources is gathered for the purpose of use on Earth, where sovereignty does exist. As a legal mark of reference one must keep in mind article III of the Space Treaty (space activities must be effected with respect for International Law) and Resolution 2625 which identifies the seven most relevant principles of the United Nations Charter. These include sovereign access to natural resources and autodetermination (the *jus cogens* status of both is duly recognized). A combination of those principles should juridically establish that the countries being observed have prior access to the data on their territory and subsequent international responsibility for abusive uses of the information obtained by remote sensing.

b) *Direct Broadcast Satellites*: There is an apparent contradiction here between two fundamental questions: the free flow of information and respect for state sovereignty. As with remote sensing, the Space Treaty and Resolution 2625 recognize the basic juridical context. The regulation should view all that does not go against the sovereignty rights of peoples for autodetermination as legitimate. Consequently, as provided by preambular paragraph 8 of the Space Treaty, there should be room for international responsibility. This "condemns propaganda destined to provoke or encourage, or susceptible of provoking any threat to peace, break of peace, or act of aggression".

c) *Nuclear Power Sources*: This field urgently requires a standard that is in harmony with the 1972 Agreement on Space Responsibility — objective responsibility for all types of damages, including direct and delayed. There should also be legislation on the obligation of States launching nuclear space objects to adopt appropriate security measures. Finally, it is important that there should be dispositions relative to assistance and rescue in case of accident, consistent with the basic norms of International Law. A good legislative basis could be the 1938 Brussels Agreement on "Unification of certain rules relative to Assistance and Rescue of Airships or by Airships".

d) *Delimitation of Space and the geostationary orbit*: Space Law is apparently the only field of a juridical branch which does not have a defined physical area of application. Since the evolution of the technology makes it impossible to establish a clear boundary, a conventional delimitation becomes necessary. The delimitation is juridically and politically of great interest because aerial space is ruled by state sovereignty (1944 Chicago Agreement) while outer space is the Common Heritage of Mankind and should be explored and exploited for exclusively peaceful purposes. Some even believe that Space Law has given rise to a new subject of International Law: humankind. Obviously delimitation prevents the determination of where and how far the distinct legal systems in dispute can be applied. With reference to the Geostationary Orbit, its *sui generis* status and the fact that it is a limited exhaustible natural resource in danger of saturation, make its technical planning and regulation imperative, taking into account particularly the rights of the developing countries as well as those which are in a geographic space situation in relation to it.

Need to establish a World Authority

In order to transform international cooperation in outer space into something viable, it should be channeled through a method which makes it really feasible for the benefit of mankind. Thus it is necessary to think of an organism which expresses equitably the expectations of the different nations; that is to say, a supranational organization.

Modalities have been debated with regard to its structure. Some have talked of the creation of a Spatial Agency of the United Nations Organization while others favor the idea of a gradual extension of the United Nations' jurisdiction and its specialized agencies which might lead to the establishment of an autonomous or semi-autonomous organism. Its model could be the OIEA. The Moon Agreement expressly refers to this problem in article 11, n. 5, when it advocates the adoption of "appropriate procedures" for the exploitation of the Moon's natural resources.

The Space Shuttle: new juridical phenomenon

Considering the fact that the Space Shuttle is designed for space activities, it should be considered a space object, for all juridical effects. Section 308 of the NASA Act leaves no doubt that the Space Shuttle and its component parts belong in the category of "space object". The fact that it must pass through the air space of a country affects, in theory, the latter's sovereign rights. This also lends importance to the idea of delimiting space. It also is important to legislate on the right of "innocent passage", which would require a specific treaty. (Space freedom would be illusory if it did not carry with it free transit and innocent passage when called for).

Since it is a space object, all the Space Agreements are applicable to the Space Shuttle and its mission must be realized in conformity with their dispositions. For example, it should be registered in conformity with the stipulations of the Agreement on Registration and be subject to the system of objective responsibility for damage to third parties on the surface. Nor can sovereignty of any type be claimed in outer space. As regards jurisdiction, it is important to note that he who retains jurisdictional competence in the case of the space shuttle possesses a laboratory which might be the property of a different owner.

It would be desirable for practical as well as juridical reasons if the State in whose name the shuttle is registered was made primarily responsible to the State launching the shuttle. It would be worthwhile adopting the same doctrine for shuttle commanders with regard to responsibility for and command of the crew. That is to say that the attribution of authority as well as the pertinent functions to a civilian official would devolve upon the shuttle commander. When circumstances require, the agreements of Tokyo, The Hague and Montreal should be used as a model for preparation of a legislative approach in the future.

THE EUROPEAN SPACE AGENCY

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I would like first to express the regrets of the Director General of ESA who was unable to be among us during this week. As you probably know, Prof. Lüst has taken up his duties in ESA on September 1st and it was very difficult for him to be free in his early days in the Agency. He has asked me to convey to you his best wishes for the success of this Study Week.

My presentation is limited to the Telecommunications and Remote Sensing programmes of ESA and a written paper is specifically devoted to these programmes and the main problems encountered in their implementation. But I would like to make some more general points about the Agency, first because other speakers have already presented programmes developed by ESA and because a broader presentation will give me the opportunity to comment on issues raised by other speakers and thus to give an overall perspective and better situate the programmes already carried out.

The Agency was created in 1975 as a result of a merger of two organisations that were created in 1964, ESRO and ELDO.

Hence the European concerted effort in space is 20 years old, and last May we celebrated this event in our main technical establishment in Holland in the presence of the Queen of the Netherlands.

Since the beginninig of the Space Age, the Europeans, whether scientists, technicians or politicians have seen:

1) that space would become a major issue by the end of this century;

2) that the European countries — individually — were unable to face the space challenge and that their only hope to be present in the space venture was to unite their efforts and to have an integrated European approach.

As with every effort to create Europe, the setting up of a European space organisation was difficult and sometimes erratic, but when one looks at the outcome after 20 years, the positive results are there: Ariane, the European satellite launcher is operational, a European telecommunications satellite network is operating in Europe, and a European operational meteorological satellite system has been decided and is in the course of implementation.

More than 15 scientific satellites have been successfully launched and operated. The Europeans have cooperated with the U.S. in the Space Transportation System and last year saw the first launch on the shuttle of Spacelab, a manned laboratory built in Europe.

We may therefore conclude that the efforts of the Europeans in space have been fruitful.

Of course, it is not enough for a dynamic organisation to have a successful past, we need also a challenging future.

The Director General has recently presented a long-term programme to our Member States which is now being studied by them. Early in 1985 our Council will meet at Ministerial level to chart the broad course of future space activities in Europe and to take the first steps for implementing the programme. Without giving you a full account of that programme, I would like to mention a few issues in order to show that even within the constraints of a very modest budget, the Europeans aim to be present in all the areas of space activity.

The basic aim of the European space effort is to improve our autonomy in the field of space techniques and thus enable Europe to enter into international cooperation on an equal footing with other space powers.

To achieve this aim, Europe will pursue its launcher activities and will produce a new launcher generation: Ariane V. This will comply with the needs of Europe and foreign users to place heavier satellites in orbit in 1995. This launcher will be manrated and will therefore closely complement the cooperation Europe is now thinking of undertaking with the U.S. in the Space Station programme.

After the decision by the U.S. Government to undertake the Space Station Programme and President Reagan's invitation to the Europeans to participate in its implementation and utilisation, ESA is now studying the Space Station elements which could be developed in Europe and will start very soon in-depth negotiations with the U.S. It is expected that the European participation in that programme could represent around 20% of the U.S. participation.

As well as these spectacular programmes, Europe will increase the amount of money devoted to the scientific satellite programme, will enhance the capabilities of European industry in satellite communications technology and develop Earth observation programmes both in the fields of Meteorology and Remote Sensing.

Last, but not least, a significant microgravity programme will help the Europeans to make use of the Space Station when this facility becomes available.

Finally, it is the intention of the Europeans to increase by 50% their space expenditure in the coming years. The ESA Budget, which is actually around 1 Billion of Account Units (ECU), would increase to 1.5 Billion of Account Units (ECU).

Speaking of ESA and Europe, it may be worthwhile mentioning that ESA has currently 11 Member States: Belgium, Denmark, Germany, France, Ireland, Italy, Netherlands, Spain, Sweden, Switzerland, United Kingdom.

We are expecting 2 more countries: Norway and Austria.

Furthermore, Canada is linked to the Agency by a cooperative agreement and is actually participating in several of our programmes.

ESA — as mentioned in its Convention — is also open to more extended forms of international cooperation.

* * *

I now come to the Telecommunications and Remote Sensing Programmes of the Agency.

With regard to telecommunications, Dr. Caruso has already explained how the European telecommunications satellite network was created on the initiative of the Agency and is now managed by Eutelsat. The Agency has also developed the Maritime satellites system (MARECS), which has been leased to INMARSAT. The second MARECS satellite will be put into orbit next November by Ariane. The interest of the Agency in mobile satellites led to the development of the PROSAT programme, which will allow us to make experiments with various types of Mobiles equipped with very small and simple antennas.

I also want to mention the OLYMPUS satellite that will be launched in 1987 and will provide many services including a direct TV broadcasting service for the RAI and several experiments for the European Broadcasting Union. In particular, the performances of Olympus could provide the opportunity for creating a European TV programme. I would also mention the experiments at 20-30 GHz to which Professor Carassa has referred.

ESA is responsible for research into and development of new technologies and for the demonstration of satellite systems, but ESA is not in charge of operational systems. For that reason, there is perfect complementarity between ESA and EUTELSAT and we certainly want to enlarge the cooperation between the two organisations.

In the field of Earth observation, the Agency is developing 2 types of activities:

— the meteorological satellites and the remote sensing activities.

In the field of Geostationary Meteorological Satellites: ESA has developed the METEOSAT family. Two satellites have been launched and you can see pictures of the Earth from that satellite on your TV screen during weather forecasts everywhere in Europe.

A few remarks about the Meteorological satellite which are in line with the object of the present Study Week.

15 European countries have decided to create a new organisation, EUMETSAT, to manage a Geostationary Meteorological Satellite system which will be operational at least until 1995. Furthermore, ESA, according to its mandate, is already studying the next generation for the end of the century.

The coverage zone of such satellites is not limited to Europe but extends to the Middle East and the whole of Africa. All the countries of the coverage zone have therefore the possibility of using that satellite system on the sole condition that they have the very cheap and simple appropriate ground equipment. The benefits from using such satellites are of course primarily in the field of weather forecasting but already many non-meteorological uses of that satellite are going on. In the fields of hydrology, agro-meteorology and earthquake prediction, Meteosat may provide useful service. Meteosat data may also usefully complement data derived from remote sensing satellites.

Access to this satellite is practically free. No intellectual property problems make the operators of the satellite reluctant to share the data with other users. The cost of the necessary equipment and the training of the appropriate technicians constitute a very limited problem.

Nevertheless Meteosat has so far been poorly used by the developing countries. This means that an effort of information and explanation is necessary to indicate to the potential users the benefit they could get from that satellite. This is a very clear example of a case where suitable international cooperation could usefully, and at no great cost, help the economic progress of many developing countries far away from any political constraints.

For the time being some sort of international coordination exists and works well in very limited fields. The Meteosat system is surrounded by other satellites of the same type which cover the rest of the world. (1 Japanese and 2 American satellites). A Committee on geostationary meteorological satellites has been meeting for 12 years and has helped very efficiently to solve many problems of technical compatibility.

Such coordination could go further and lead to the setting up of a real worldwide system.

This question was touched on at Unispace '82 and several paragraphs of the final report are devoted to it. It does not seem that basic objections have been or could be raised against an increased and efficient international cooperation. Nevertheless no real willingness to go ahead has appeared and perhaps this very concrete example could be mentioned in the report of the Study Week as a field in which some emphasis on the usefulness of international cooperation could be developed.

In the field of Remote Sensing: Europe is acquiring the Landsat data from 3 stations: Kiruna, Fucino and Maspalomas.

Of course, we have some concern for the future and the trend to commercialisation in the U.S. is not an indication that the international cooperation built up will be improved in the future.

We consider nevertheless that the experience gained in using Landsat both by developed and developing countries should not be abandoned.

In Europe, we are developing our own satellite system, ERS-1.

This satellite is designed to exploit the coastal, ocean and ice applications of remote sensing data.

Its practical interest is mainly related to offshore activities and fisheries and also to the acquisition of global data for meteorology.

The particular interest of the satellite is the Synthetic Aperture Radar which will be on board and which allow acquisition of worldwide data independently of the weather conditions.

Although the satellite is optimised for oceans, the SAR will also image the Earth and will complement the optical data from satellites like LANDSAT and SPOT.

This already shows that the 2 remote sensing satellites presently developed in Europe: SPOT by France, which will be presented later this week, and ERS-1 are complementary. ERS-1 is the first satellite of a family of remote sensing satellites. An advanced Land Observation Satellite is also being studied.

Efforts are made on both sides of the Atlantic to ensure optimum compatibility and complementarity between the various projects under development, but we must recognise that a better global result would be achieved if there were more unity in the planning of such systems and that, from the point of view of the users, it would be more encouraging and bring down costs if satellite operators were better coordinated.

I will not enter into further details on the Earth observation programme of the Agency but I would like to conclude with a few remarks which tie in with the general concerns of the participants in this week.

Firstly I would like to mention another example of possible cooperation with developing countries.

Everybody recognises that telecommunications in Africa are very poor and that their improvement would make an invaluable contribution to the economic and social development of that Continent.

In view of the lack of infrastructure and the size of these countries, satellites provide the only opportunity for them to develop a national and international telecommunication network.

Nevertheless, it is proving very difficult to start in-depth studies on this question, mainly for institutional reasons and due to many conflicts of competence between various organisations and administrations.

ESA efforts in this field are limited and we could do more than offer the European technical expertise which we have. But I would like to point out that over the last 4 years we have received 10 African engineers per year for 3 months in our technical establishment in order to familiarise them with the various aspects of satellite systems (this is one of our training schemes).

* * *

Finally, Mr. Chairman, I would like to say that when one is involved in space activities, it is rather easy to see the number of opportunities for improving the quality of life of the citizens of the developed and of the developing countries.

We are happy to celebrate a few real successes, such as for instance the setting up and the good health of an organisation like EUTELSAT.

But you also have the feeling that more could be done if we were more sensitive to the needs of mankind.

I hope that the present Study Week will increase such sensitivity and will lead to guidelines being determined that will help our work in this aspect.

REMOTE SENSING

INTERNATIONAL COOPERATION: THE CORNERSTONE OF REMOTE SENSING FROM SPACE

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Introduction

The launch of TIROS-1 on April 1, 1960, marked a breakthrough in gaining a comprehensive understanding of the dynamics of the Earth's atmosphere. From this point on, mankind would have access to the vantage point of space to make global measurements for studying atmospheric, oceanic, and land mass phenomena. This dramatic scientific and engineering accomplishment also ushered in a new era in international cooperation. To make this technology truly useful would require the global reception and dissemination of data from the meteorological satellites and validation of these data by scientists around the world. To this end, data from TIROS-1 and its successors were transmitted directly to receiving stations located globally. Today, over 1,000 stations in more than 120 countries receive data from no less than eleven meteorological satellites operated by not only the United States (GOES, NOAA), but also the European Space Agency (METEOSAT), India (INSAT), Japan (GMS) and the USSR (METEOR-2). These data are vital to forecasting and monitoring severe weather phenomena such as hurricanes, typhoons, flooding, and tornadoes.

Through the good offices of the World Meteorological Organization (WMO), nations of the world have worked closely in defining the necessary conditions for optimum use of meteorological satellite systems. These efforts include applications, research and training, the development of identical transmission characteristics and operating procedures for data collection, and standard procedures for data processing and dissemination. This work has been undertaken to mitigate the difficulties and minimize the cost for users wishing to exploit space-derived data. Additionally, satellite data have been exchanged internationally along with conventional observations through the WMO's Global Telecommunications System (GTS). The regular operation of weather satellites and the global acquisition and dissemination of data are sterling examples of what extensive international cooperation can do.

Programs in the 1960's-1970's demonstrated the utility of studying the Earth's land masses and oceans using imagery from space. The U.S. Gemini, Apollo, and Skylab missions and the Soyuz-Salyut programs of the U.S.S.R. yielded excellent results in panchromatic, color, and multispectral photography from space. The success of these efforts stimulated interest in flying sensors on long-duration satellite missions. In the early '70's and into the 1980's, land and ocean remote sensing satellites were launched by India (Bhaskara-SEO series), the U.S.S.R. (METEOR series) and the United States (LANDSAT series, SEASAT, NIMBUS). Extensive international cooperation was the hallmark of many of these programs. For example, there were well over 100 U.S. and foreign participants in NASA's Landsat 1-3 Principal Investigator Programs. This effort was intended to solicit support in validating LANDSAT data and its applications from scientists and engineers worldwide. As well, today there are 16 nations (developed and developing) operating or building stations for the direct reception of LANDSAT data. Users in over 100 countries have purchased LANDSAT data products from the United States or one of the ten currently operating foreign ground stations.

In an effort to standardize satellite operations and maximize the utility of data, current and future operators of land and ocean remote sensing satellites have been meeting since 1980 to explore mechanisms for enhancing the compatibility of those systems. Within the United Nations, the Committee on the Peaceful Uses of Outer Space (COPUOS) has provided a forum for exchange of technical information which has fostered efforts by satellite operators to make the various systems compatible and complementary. Through these efforts, users worldwide will be able to use the same receiving, processing, and analysis hardware and software for data from different national systems. International coordination of this type makes land and ocean remote sensing a more practical and affordable venture for providers and users of data alike.

Geostationary meteorological satellites provide images for monitoring the development and movement of storm systems at least every one-half hour. Regular cloud observations greatly improve forecasting capabilities. In turn, the loss of life and property due to severe storms has been reduced. The polar-orbiting meteorological satellites have similar capabilities but offer less frequent coverage. In a lower earth orbit, the polar-orbiters have higher resolution sensors with several spectral channels that can be used for meteorological, ocean and land (particularly agricultural monitoring) applications. The global coverage of these spacecraft enhances our ability to conduct worldwide environmental programs.

Land and ocean satellites have a whole other set of practical uses that have an impact on daily life. Land remote sensing missions are utilized for monitoring agricultural production, mineral exploration, disaster assessment, managing water resources, land use planning, monitoring forestry resources, and coastal zone management. Ocean satellites contribute to our understanding of ocean dynamics and interactions (important for climate studies).

Regional wave development and intensity are important for ship construction and routing as well as for identifying sites for offshore oil drilling platforms. The formation and movement of sea ice are particularly critical to monitor for shipping in the Arctic region. As such, meteorological, land, and ocean remote sensing satellite data are and will be instrumental in saving human lives, protecting property, and managing the Earth's renewable and non-renewable resources.

This paper will discuss briefly the current and planned land, ocean, and meteorological satellite programs. It will also describe the numerous bilateral and multilateral cooperative activities being undertaken. The accomplishments in satellite remote sensing over the past 25 years are outstanding technological advances enabling us to study and perhaps eventually to understand the Earth and its environment. Equally important has been the participation of the world community in these programs. As such, international cooperation has assured that the benefits of remote sensing from space are shared by the world community. As envisaged by the Outer Space Treaty, continued global collaboration remains an integral part of conducting these activities "for the benefit of all mankind".

Meteorological Remote Sensing

In the late 1950's, with the launch of Sputnik and Explorer I, the potential for meteorological monitoring using satellites was recognized.

At the Third Meteorological Congress of the WMO in 1959, Member States requested that the Executive Committee keep abreast of developments in the potential use of satellites for weather remote sensing. With the success of TIROS-1, the WMO took further steps to coordinate the role of satellites in its atmospheric studies and weather forecasting programs. Foremost was the integration of satellite data into the World Weather Watch (WWW) Program. This initiative, proposed in 1961, established World Centers and Regional Centers. These facilities would collect satellite data and conventional observations. These forecasts from these data would be disseminated to the various Member States (1).

The WMO also established the Executive Council Panel of Experts on Satellites in 1959. Members on the panel are chosen from Member States with and without a satellite program. Over the years, the "EC Panel" has assumed responsibility for coordinating training seminars on satellite data applications, identifying requirements for weather satellite data, reviewing meteorological satellite developments, coordinating WMO activities with other international programs including meteorological satellites and reviewing the satellite component of the WWW (2). The "EC Panel" and the WWW offer the opportunity for non-satellite operators to influence the development and operation of national systems to meet their data requirements.

In the 1960's, the WMO and the International Council of Scientific Unions (ICSU) began to develop a joint program for atmospheric research called the Global Atmospheric Research Program (GARP). GARP represented large-scale environmental data collection projects requiring extensive international cooperation. In particular, significant quantities of meteorological satellite data were required, especially over oceans, polar regions, and other remote areas where conventional data were lacking.

The primary project under GARP was the First GARP Global Experiment (FGGE), conducted in 1978-1979. Close coordination among nations was undertaken to implement FGGE successfully. Much attention was given to developing the required weather satellite coverage.

During this period, India, Japan, the U.S.S.R., the United States, and the European Space Agency (ESA) were developing and launching

(1) World Meteorological Organization, *Satellite Systems In Support of WMO Programmes and Joint Programmes with Other International Organizations,* Submission to UNISPACE '82, January 1982, A/CONF. 101/BP/IGO/12.

(2) WMO Executive Council *Resolution 9* (*EC-XXXI*) and *Resolution 9* (*EC-XXXV*) *Regarding EC Panel of Experts on Satellites.*

geostationary and polar-orbiting meteorological satellites. The successes of the TIROS polar-orbiting series and the early U.S. geostationary satellites (Synchronous Meteorological Satellite [SMS]) encouraged other nations with space programs to follow suit. The constellation of current and planned national programs can be summarized as follows:

Meteorological Satellite Programs

— *Indian National Satellite System (INSAT)*: The operational system will consist of two spacecraft located in geostationary orbit at 74°E and 99°E longitude. The satellite combines telecommunications capabilities with weather monitoring. The primary meteorological instrument is a high resolution radiometer which senses in the visible and infrared channels. INSAT has a Data Collection System (DCS). Though the first three spacecraft of this series will be built by U.S. contractors, the second generation (INSAT-II) will be designed and built by India. INSAT-1A was launched in April 1982. A premature failure necessitated launch of INSAT-1B in August 1983. INSAT-1C is scheduled for flight in 1986 ([3]).

— *Japanese Geostationary Meteorological Satellite (GMS)*: The GMS satellites carry a radiometer for visible and infrared scanning, a Data Collection System and a WEFAX (Weather Facsimile) service for the regular transmission of processed images. The operational GMS satellite is located at 140°E longitude. GMS-1 was launched in July 1977, GMS-2 in August 1981, and GMS-3 in August 1984. Japan is now considering plans for development of GMS-4.

— *European Space Agency METEOSAT*: The first spacecraft of the METEOSAT series was launched in November 1977; METEOSAT-2 was launched in 1981. These satellites carry a visible and infrared scanning radiometer, a DCS and a WEFAX service. METEOSAT-2 will be launched when required to provide coverage until the next generation of spacecraft is ready in 1987.

— *U.S.S.R. Geostationary Operational Meteorological Satellite (GOMS)*: The planned GOMS satellite will be located in geostationary

([3]) INSAT Coordination Committee, *INSAT, The Indian National Satellite System*, January 1984.

orbit at 70°E longitude. The scanning radiometer will sense in the visible range at 2-4 km resolution and in the infrared channel at 12 km resolution. Images will be transmitted every 30 minutes. GOMS will include also a DCS and WEFAX capability. Launch of the first GOMS is expected in 1985.

— *United States Geostationary Operational Environmental Satellite (GOES)*: The GOES system is comprised of two spacecraft in geostationary orbit located at 135°W and 75°W longitude. The principal sensing instrument on the GOES satellite is the Visible Infrared Spin-Scan Radiometer (VISSR) Atmospheric Sounder (VAS). Major communications capabilities include the DCS and WEFAX service. The first prototype of the GOES satellite, the Synchronous Meteorological Satellite (SMS-1), was launched in May 1974. Six satellites have subsequently been launched. The next launch is planned for 1986.

— *U.S. NOAA/Advanced TIROS-N Satellites*: The operational NOAA system consists of two satellites in sun-synchronous orbit at an altitude of 870 km. Equator crossing times are 1330 local solar time and 0730 local solar time. The major observation systems on the polar orbiting satellites are: the Advanced Very High Resolution Radiometer (AVHRR), the TIROS Operational Vertical Sounder (TOVS), the Space Environment Monitor (SEM), and the ARGOS Data Collection System (DCS). Major data transmission systems include: three S-Band transmitters at three frequencies, two VHF beacon transmitters at two frequencies and a search and rescue communication system (SARSAT). The U.S. has been operating polar-orbiting weather satellites since 1960.

— *U.S.S.R. METEOR-2*: The METEOR-2 operational program consists of two or three satellites in a polar-orbit at an altitude of 900 km. Equator crossing times for the satellites are 0300 and 1500 local time, respectively. The major instruments flown on this series are infrared and visible scanning radiometers and a vertical sounder.

Meteorological Satellite Cooperation

Through the coordination efforts of the WMO and the satellite operators, data from all these spacecraft are available directly free-of-charge. Users in the Western Hemisphere receive regularly data from GOES; centers in Europe and Africa utilize METEOSAT; and data from GMS are transmitted directly through Asia and the Pacific Basin. Using

VHF and S-band receivers, stations globally take advantage of data acquired by the NOAA and METEOR-2 satellites. In all, it is estimated that 1,000 facilities in over 120 countries utilize these spacecraft.

As mentioned previously, FGGE represented a major international effort in understanding the global atmosphere. FGGE also stimulated one of the most successful examples of satellite system coordination. To maximize support for FGGE, representatives from Japan, the United States and the European Space Research Organization (ESRO) (now ESA) met in 1972 to form what is now known as the Coordination on Geostationary Meteorological Satellites (CGMS). In subsequent meetings in the 1970's, India, the U.S.S.R., and the WMO joined the discussions.

The CGMS coordinates the technical characteristics and operational procedures of current and planned geostationary weather satellites. This was particularly important in the early years prior to FGGE because platforms were being developed which would be able to receive data and information from all geostationary spacecraft. In support of FGGE, geostationary slots were selected that would assure continuous global coverage. (See Figure 1).

CGMS has continued since the early 1970's as an informal technical

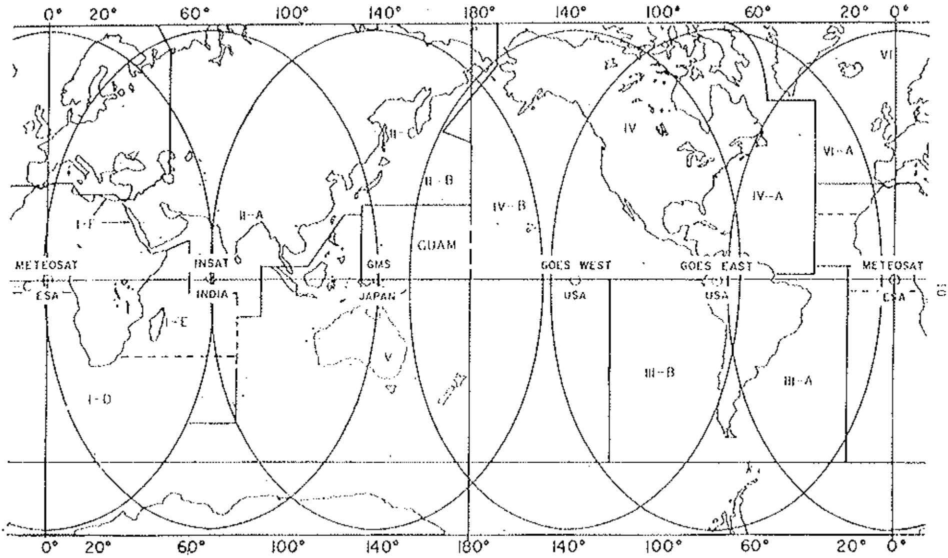

FIG. 1.

coordination group. As a result, while the current and planned systems remain independently designed and developed, they meet common mission objectives and produce compatible data products. Matters such as compatible data formats, standard transmission frequencies, compatible data collection platform standards and complementary orbits are regularly examined by CGMS. In a recent development, the System Engineering Working Group of CGMS has studied a proposal to develop a back-up satellite which could be used to replace, in the event of an unexpected failure, any one of the spacecraft in the geostationary constellation. Cost-sharing mechanisms and technical parameters are now being examined. Such an international effort would limit disruption of weather satellite services.

Bilateral cooperation continues to be an important element in meteorological satellite programs. For example, under an agreement between France's Centre National d'Etudes Spatiales (CNES) and the U.S. National Oceanic and Atmospheric Administration (NOAA), France provides at no cost to the United States the ARGOS Data Collection and Platform Location System instrument. The ARGOS instrument is flown on the NOAA polar-orbiters and is used to locate and collect environmental data from moving or fixed platforms. This cooperative venture was initiated in the mid 1970's and will continue into the decade of the 1990's.

The Meteorological Office of the United Kingdom, since the 1970's, has provided at no cost to NOAA, the Stratospheric Sounding Unit (SSU). This instrument, flown on the NOAA polar-orbiters, provides global temperature information in the stratosphere. A follow-up system, the Advanced Microwave Sounding Unit (AMSU), will be developed jointly by the United Kingdom and NOAA for the next generation of NOAA spacecraft. The ARGOS and SSU/AMSU cooperative efforts have involved significant cost-sharing and provide vital data which might otherwise not be available to users around the world.

As satellite data are becoming more and more a part of operational weather monitoring and forecasting, concern has increased as to the reliability and continued operation of national meteorological satellite systems. Constrained national budgets have cast a shadow over the future of some national programs that provide important data to users worldwide. It is apparent that individual nations are not willing to shoulder alone the burden of maintaining global satellite observation systems. Recognizing this eventually, two international efforts have been undertaken to pool resources to assure continuity of satellite data.

In the United States, the rapidly escalating costs of satellites have caused the Administration to propose reducing the current NOAA polar-orbiting satellite system from two satellites to one. This reduced system would meet the core of U.S. weather forecasting requirements with added risk of loss of data continuity, but it reduces significantly support to other countries and to the global monitoring activities of the United States. For this reason, the United States proposed to representatives at the 1983 and 1984 Summits of Industrialized Nations (Canada, France, the Federal Republic of Germany, Italy, Japan, the United Kingdom, and the European Community) that they join in the study of an internationally-sponsored polar-orbiting weather satellite to complement the existing system. The Summit Nations supported this concept and established the International Polar-Orbiting Meteorological Satellite (IPOMS) group. IPOMS will examine mechanisms for international contributions (direct funding or in-kind) to supplement the U.S. polar-orbiting satellite program. Contributing Members in IPOMS are those countries that have secured national approval for contributions to a polar-orbiting satellite. Observer Member status is extended to those countries that intend to pursue national approval for funding or in-kind contributions. IPOMS will examine data requirements, instrument capabilities, spacecraft parameters, and alternative space platforms (such as a man-tended polar-orbiting platform of a space station) for meteorological sensors. The first meeting was held in November 1984.

In May 1983, twelve European nations (Belgium, France, the Federal Republic of Germany, Italy, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, and the United Kingdom) signed a convention establishing the ratification process for the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT). EUMETSAT will manage Europe's meteorological satellites and provide data continuity using the current and next generation METEOSAT satellites. It is expected that the Convention will be fully ratified by mid-1985.

EUMETSAT represents the first international, albeit regional, organization established solely for owning and operating a meteorological satellite program. Through cost-sharing, the European nations will meet their long-range data requirements. It should be noted that arrangements made under IPOMS and EUMETSAT will honor the traditional free international exchange of, and direct access to, meteorological satellite data.

In addition to these concrete steps toward international arrangements, addressing a polar system and a geostationary system, several studies have been conducted regarding a truly global meteorological satellite program to assure data continuity. In a NOAA report entitled "International Meteorological Satellite Systems: Issues and Options", institutional models were examined that could be adapted to support an international system of polar-orbiting and geostationary satellites (4). Mechanisms for an International Meteorological Satellite System (IMSS) ranged from informal technical arrangements to the creation of a formal international organization. Each model was evaluated in light of technical, financial, and policy considerations. The study concluded that in the near-term the most feasible course of action was to strengthen existing cooperation with a view toward more formal and extensive international collaboration in the long-term.

The Second United Nations Conference on the Exploration and Peaceful Uses of Outer Space (UNISPACE '82) noted the important issue of continued access to meteorological satellite data. The Conference recommended that the WMO conduct a study on establishing an international structure for this purpose. The WMO prepared a document entitled "Considerations for Future International Cooperation in a Global Meteorological Satellite System". This study examined issues such as data compatibility, cost-sharing, national system coordination, and technological growth in developed and developing countries (5).

Brief mention should be made of another important program that, though not remote sensing *per se*, utilizes the NOAA polar-orbiting weather satellites. That program is COSPAS-SARSAT. Since the mid 1970's, Canada, France, the United States, and the U.S.S.R. have cooperated in using satellites equipped with receivers to detect and locate emergency transmissions from aircraft and ships in distress. Timely warning and location significantly increase the survival rate of people in emergency situations.

Under the SARSAT (Search and Rescue Satellite-Aided Tracking) agreement, Canada and France provide, at no cost to the United States, spacecraft instruments for receiving and relaying transmissions from emergency beacons in aircraft or ships. These instruments are flown on

(4) National Environmental Satellite, Data, and Information Service, National Oceanic and Atmospheric Administration, *International Meteorological Satellite System: Issues and Options*, November 1983.

(5) World Meteorological Organization, *Considerations for Future International Cooperation in a Global Meteorological Satellite System*, CGMS-XII WMO-WPI, April 1983.

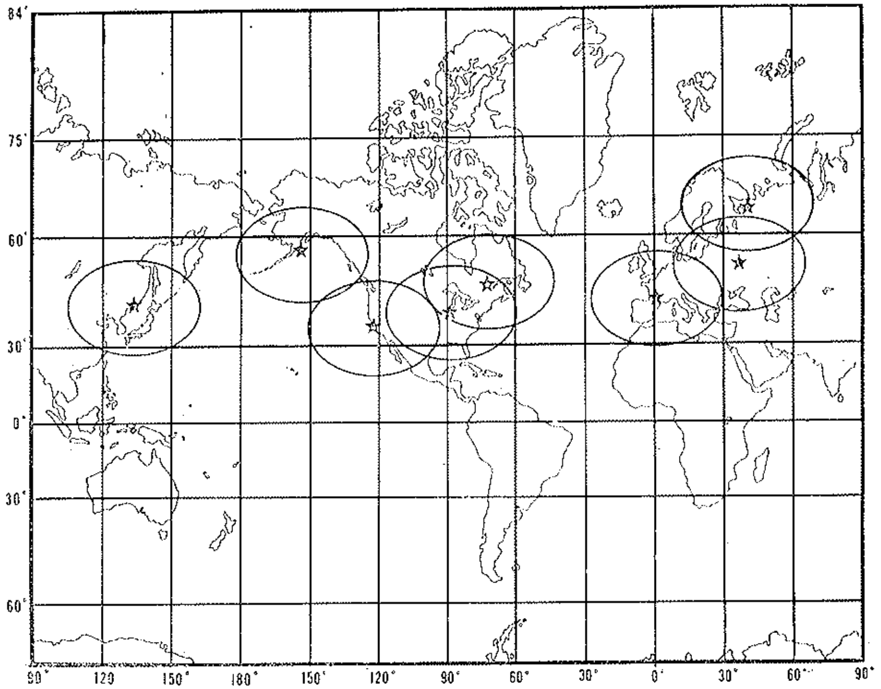

FIG. 2. Search and Rescue Ground Stations.

the NOAA weather satellites. The U.S.S.R. has equipped its COSPAS satellites with instruments that are interoperable with the SARSAT system. Since 1982, over 400 lives have been saved as a direct result of early detection and location using the COSPAS-SARSAT system. Figure 2 shows the existing network of COSPAS-SARSAT receiving stations. Australia, Brazil, Bulgaria, Finland, Norway, and the United Kingdom have joined or are considering joining the COSPAS-SARSAT program. Canada, France, the United States, and the U.S.S.R. are collaborating to provide this humanitarian service through the 1990's. Consideration has been given to establishing permanent international arrangements to assure the long-term continuity of satellite-aided search and rescue (6).

(6) LEVESQUE D., HODGKINS K. and DROVER P., *The Development of an Institutional Structure for the Future Global Satellite System for Search and Rescue,* International Symposium on Satellite Aided Search and Rescue, April 9-13, 1984, Toulouse, France.

Land and Ocean Remote Sensing

The success of the U.S. and U.S.S.R. manned space programs in panchromatic and multispectral photography of the Earth stimulated the development by many countries of satellites for land and ocean remote sensing. In 1972, the United States launched ERTS-1 (LANDSAT). Carrying a Multi-Spectral Scanner (MSS) and a Return Beam Vidicon Instrument (RBV), this satellite provided global data for renewable and nonrenewable resources management. LANDSAT-5, the fifth and last satellite in this series, launched in March 1984, has an MSS instrument and an advanced instrument with higher resolution and thermal infrared sensing capabilities called the Thematic Mapper (TM).

The first U.S. satellite dedicated to oceanography was SEASAT launched in 1978. This satellite had sensors for determining ocean topography, significant wave height, surface wind speed and direction, sea surface temperature, and wave and current patterns. In both programs, scientists and engineers from around the world participated in validating that data, and using it for specific applications. Through this experience with land and ocean satellite data, many countries are now developing their own spacecraft to meet specific requirements. As in the case of meteorological satellites, significant benefits have been and will be realized through cooperation and system coordination.

Before addressing these international activities, a brief review of some of the current and planned land and ocean missions is in order.

Land and Ocean Satellite Programs

— *Canada RADARSAT Satellite*: This satellite is planned for launch in 1990 and will carry a Synthetic Aperture Radar (SAR) optimized for sea ice monitoring. Candidates for additional sensors include a microwave scatterometer and an altimeter. Discussions are under way with the United Kingdom and the United States for cooperation in spacecraft development and construction.

— *European Space Agency ERS-1 Satellite*: ERS-1 instrumentation will consist of a SAR, radar altimeter, wind scatterometer, and scanning radiometer. The projected launch date is 1989. ESA will depend on a network of national receiving stations for providing global coverage.

— *France SPOT Satellite*: The SPOT satellite will carry two high resolution instruments for land resources monitoring. The sensors are pointable to maximize the satellite's repeat coverage and provide stereo pairs. The first in a series of four spacecraft will be launched in late 1985. Negotiations are proceeding with numerous countries for the direct reception and distribution of SPOT data. SPOT data will be marketed by a commercial firm, SPOT-Image.

— *India IRS-1 Satellite*: In 1986, IRS-1, built by India, will be launched. The IRS-1 payload will consist of two medium resolution multispectral sensors for land and water resources applications. The launch of three satellites in this series is envisaged.

— *Japan MOS-1 Satellite*: The MOS-1 spacecraft will carry sensors optimized for ocean observation. The instruments include a visible and near infrared radiometer and a microwave radiometer. The launch of the first of three planned satellites will be in 1986.

— *Japan JERS-1 Satellite*: JERS-1, a satellite for land observing, will carry a SAR and optical sensors. Three satellites are planned for launch, with the first ready in the late 1980's.

— *United States LANDSAT*: LANDSAT-1, launched in 1972, and two subsequent satellites carried two sensors for multi-spectral and panchromatic imaging. LANDSAT-4, launched in 1982, and LANDSAT-5, launched in 1984, have a multi-spectral scanner similar to that flown on the earlier satellites as well as an advanced sensor for thermal infrared imaging. Data are received by 14 stations located around the world and used for renewable and nonrenewable resources monitoring. The United States Government is in the process of transferring civil land remote sensing satellite responsibilities to the private sector. Data from the current and future systems will be available on a public, nondiscriminatory basis.

— *United States N-ROSS Satellite*: This satellite, scheduled for launch in 1989, will acquire data on ocean and sea ice dynamics. The payload complement will consist of a wind scatterometer, an altimeter, a microwave imager, and a microwave radiometer.

In addition to these missions, Brazil, the People's Republic of China, and Indonesia (in cooperation with the Netherlands) are planning land remote sensing satellite programs ([7]). In the case of Indonesia, for example,

([7]) VOUTE C., *The Potential Role of Satellite Remote Sensing in Socio-Economic Development: A Perspective at the Threshold of the Twenty-First Century*, International Institute for Aerial Survey and Earth Sciences, 1982.

a Tropical Earth Resources System (TERS) spacecraft is in the planning stages. This satellite will fly in a low-earth equatorial orbit with optical sensors optimized for coverage of the tropical regions ([8]).

Land and Ocean Satellite Cooperation

The preceding discussion has served to illustrate that there is indeed a significant international effort to provide land and ocean observations from space. Cooperation in this area takes two forms — collaboration among nations participating in the same program, and coordination among satellite operators. For example, in the former case the United States and 16 other nations (see Figure 3) operate or are planning stations for the reception and distribution of LANDSAT data. Countries with stations sign agreements with the U.S. NOAA and pay an annual fee of $ 600,000 for direct access to LANDSAT. To achieve technical compatibility among different data centers within the same satellite program, the Landsat Ground Station Operations Working Group (LGSOWG) was organized. The LGSOWG is designed to serve as a forum for the exchange of information among station operators on the acquisition, processing, archiving, and dissemination of data from LANDSAT.

Since its inception, the LGSOWG has worked to standardize many land remote sensing data products and services offered by the various distribution centers. For example, the group has developed and adopted for all digital products a set of standards and guidelines for computer compatible tape formats. As a result, all currently operating facilities offer digital tapes in formats meeting these standards. Customers are able to utilize similar processing and analysis programs for LANDSAT data purchased at different stations. This standard tape format developed by the LGSOWG is being considered by France for use in producing tapes derived from SPOT data as well. Japan is exploring the possibility of utilizing this format concept for data from its planned MOS-1 program, as well as Canada for its RADARSAT system.

In an effort to achieve similar coordination, the French SPOT program will include also a technical group to be known as the Groupe des Opérateurs de Stations SPOT (GOSS). The GOSS will work to

([8]) Hoeke A. and Irsyam M., *Tropical Earth Resources Satellite (TERS)*, AIAA, 1983.

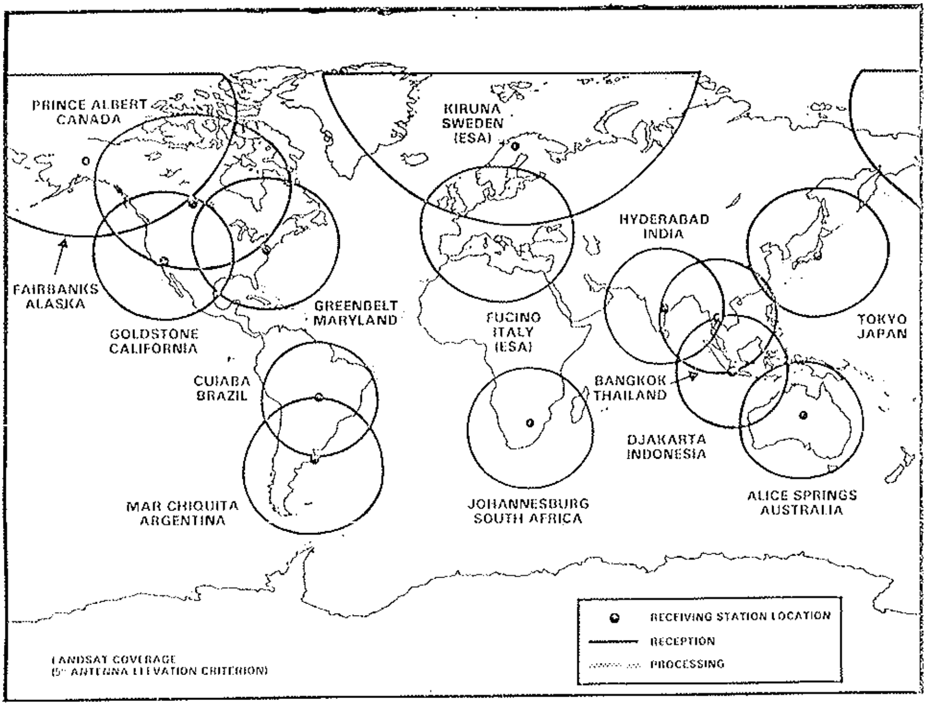

FIG. 3. Distribution by Foreign Ground Stations.

LANDSAT GROUND STATIONS

Operating	*Planned*
ARGENTINA	BANGLADESH
AUSTRALIA	ECUADOR
BRAZIL	PAKISTAN
CANADA	PEOPLE'S REPUBLIC OF CHINA
EUROPEAN SPACE AGENCY	SAUDI ARABIA
— ITALY	
— SWEDEN	
INDIA	
INDONESIA	
JAPAN	
SOUTH AFRICA	
THAILAND	
UNITED STATES	

standardize procedures among the station operators within the SPOT program. As a means of maximizing users' access, remote terminals will be located worldwide which will give individuals immediate information concerning all SPOT data archived and available for sale.

As remote sensing data have become increasingly useful in many operational programs, users have expressed serious concern over the development of national satellite systems and the rapid emergence of new and diverse technologies which require frequent capital investment in system-specific analysis and processing components. This issue is of particular concern for users in developing countries. For satellite remote sensing to be cost-effective, users must be able to maximize the utility of expensive processing and analysis hardware by having the capability to integrate data sets from different satellite systems. Remote sensing from space will not be a viable option for a majority of the user community if hardware must be purchased for each national system.

Taking the example of the CGMS, current and potential operators of land and ocean satellites (Canada, France, India, Japan, the United States and ESA) met in 1980 for the first of two multilateral meetings (Ottawa 1980 and Paris 1982) on long-term planning for remote sensing satellites. It was agreed that such technical consultations could improve the benefits of these systems for operators and users. Regular meetings could serve as a basis for identifying areas of cooperation and implementing system modifications to enhance program compatibility and complementarity. Two groups were formed for coordination of satellites planned for operation by the end of the 1980's — the Coordination on Land Observing Satellites (CLOS) and the Coordination on Ocean Remote Sensing Satellites (CORSS). Both groups were charged with considering coordination of such topics as missions, orbits, sensor parameters, downlink characteristics, and user products [9]. As with CGMS, these groups would exchange technical mission information and make nonbinding recommendations on areas of collaboration.

(9) *Reports of the Multilateral Meeting on Long-Term Planning for Remote Sensing Satellites*, Ottawa 1980 and Paris 1982. *Report of the Coordination on Land Observing Satellites*, Paris 1982. *Report of the Coordination on Ocean Remote Sensing Satellites*, Paris 1982.

Multiple Program Cooperation

Perhaps one of the more dominant trends in satellite remote sensing has been the erosion of a clear distinction between land, ocean, and environmental satellite missions. Data from meteorological/environmental satellites are being used for agricultural monitoring. LANDSAT data are useful for coastal zone monitoring. It is evident that many areas of study require data sets not only from different national programs, but also from different missions.

Recognizing that program distinctions based on applications are no longer valid, the functions of the multilateral group on long-term planning, the CLOS, and CORSS have been combined into one group. The Committee on Earth Observation Satellites (CEOS) was established to examine the need to provide efficient and cost-effective services to meet a broader user community. Of particular concern is the achievement of a broader consensus on data standards, products, and archiving methods. In short, current and potential operators will collaborate with a view to making their systems more "user friendly" for a wide range of applications.

The first meeting took place in September 1984. Members of CEOS are those countries that have secured government approval to proceed with the design phase (Phase-B) of their remote sensing satellite programs. In attendance at the first meeting were representatives from Brazil, Canada, France, India, Japan, the United States, and ESA.

Conclusion

This paper has only touched on one aspect of international cooperation in remote sensing, i.e., the space segment. For end users of data from meteorological, land, and ocean systems there exist extensive international arrangements. Regional remote sensing facilities are located throughout Africa, Latin America, and Asia assisting countries in incorporating this technology into their development plans. Organizations such as the WMO, the Food and Agriculture Organization (FAO), the U.N. Environment Program (UNEP), and the United Nations Office of the Disaster Relief Coordinator (UNDRO) also make extensive use of satellite remote sensing. International scientific programs such as NASA's Global Habitability, the International Satellite Cloud Climatology Program (ISCCP), and the International Geosphere-Biosphere Program (IGBP) will rely heavily on observations from space for worldwide monitoring. Cooperation among satellite operators will ensure that data for these activities will continue to be available in an efficient and cost-effective manner.

The impact of remote sensing from space on mankind has been tremendous. Thousands of lives have been saved through disaster (hurricanes, typhoons, drought, flooding) early warning, and there has been more efficient use of financial and human capital in utilizing the Earth's resources. Cooperation in remote sensing has magnified these benefits. As well, such collaboration has forged important bilateral and multilateral relations (where some might not exist). Mutually beneficial ties in this area of science and technology serve national and bilateral as well as global interests. Cost-sharing, the joint development of new technology, enhancement of commercial opportunities (data and hardware sales) and access to otherwise unavailable data and information are important elements in this greater interdependence.

What is the future for international cooperation in remote sensing from space? We can expect new and innovative approaches to exploiting this technology. A polar platform component of the planned U.S. space station offers numerous opportunities for cooperative flights of Earth observing instruments ([10]). As well, there is interest in establishing international arrangements/organizations for meteorological satellites, remote sensing satellites for resource monitoring, and satellites for international crisis surveillance ([11]). System coordination and international/regional programs for data reception and dissemination will continue in order to take advantage of the planned satellite missions.

The benefits to mankind of remote sensing from space have been demonstrated over the past 25 years. Through international cooperation these benefits will continue to be available to all nations.

([10]) McElroy J., *Preliminary Thoughts on the Utilization of the Space Station to Operational Earth Observations*, National Environmental Satellite, Data, and Information Service, National Oceanic and Atmospheric Administration, May 1984.

([11]) Voute C., "Agreement and Disagreement on An International Satellite Monitoring Agency", *International Journal of Remote Sensing*, March/April 1984.

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REMOTE SENSING AND POVERTY: AN ECCLESIASTICAL PRECEPT

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Abstract

Remote sensing technology is used in developing countries for appropriate economic purposes. Information derived from the data acquired by satellites is used to address management issues of natural resources and discovery of badly-needed water. The technology transfer process works two ways — equipment and image analysis know-how flows from North to South, but scientific understanding of tropical conditions necessary to corroborate information gleaned from remote sensors flows from South to North. Intentions lacking in charity can introduce technology into the Third World whicb can prove to be of no use or worse can rob poorer nations of opportunities to investigate other technologies. Remote sensing, a neutral and unobtrusive science, suddenly finds itself embroiled in issues of natural resources and poverty, as well as the equitable distribution of wealth derived from these resources. Effective use of remote sensing requires open sharing of information and an appeal to the charitable nature of science. The history of the Catholic Church bears strongly on the integration of scientific and theological thought into the whole man in introducing high technology to poverty and peace.

"Remote sensing is generally defined as sensing an object or phenomenon without having the sensor in direct contact with the object being sensed". [1]

"The eye is not satisfied with seeing, nor the ear with hearing. Strive,

(1) ROBERT K. HOLZ, *The Surveillant Science* (Boston: Houghton Mifflin Co., 1973), p.v.

therefore, to turn away thy heart from the love of the things that are seen, and to set it upon the things that are not seen". (2)

Background

The science and technology of remote sensing rest in capable hands in a comfortable setting in the developing world. The evolution of the technology in the North stems from a military background. As the technology became open, it was tacked onto foreign assistance programs of donor nations to carry out development goals in the Third World. In the early 1970's, with the advent of satellite remote sensing, the use of space sensors to monitor trends in land use change over large and remote areas was rapidly adopted by developing countries. The need to know about this technology and to learn how to use it was based on the importance of natural resources to development and the acquisition of information necessary to intelligently negotiate concessions with multinational firms. The threat to tropical forests and ensuing loss of biological diversity, the finding of new groundwater supplies in drought-stricken countries, and the dependence of good rangeland management practice on the economies of many Third World countries generated the requirements which led to successful absorption of remote sensing technology in almost one-half of all the developing nations on earth.

The technology flow has been from North to South, but the resulting understanding of global resources results from a two-way flow, the South providing the knowledge of local conditions which serves as "ground-truth" in analyzing satellite imagery. The successful applications in satellite sensing of tropical forests — for example, mapping of mangrove in all coastal regions of the tropics, the identification of aguaje palm in the eastern rainforests of Peru, and the locating of teak in Northeast Thailand — have all depended as much on the difficult ground reconnaissance by the knowledgeable Third World scientific partners as on the image processing technology provided from the North. To better understand our planet and the interrelationship between ecology and natural resources, we are all learning that collaboration between North and South is required.

This collaboration is further manifested by a level of maturity in

(2) THOMAS à KEMPIS, *The Imitation of Christ.* « Harvard Classics », Vol. 7, ed. Charles W. Eliot (New York: P.F. Collier & Son Co., 1909), p. 214.

the South, which is rejecting extraneous technology and focusing attention on appropriate space platforms and processing techniques to address its needs.

The Church, Science and Poverty

This brief description of the mature use of remote sensing technology in developing countries, as well as descriptions which could be made for other sciences, illustrates the fit of science into the economic development of the poorer nations of this planet. The question posed by many development planners and charity organizations is whether the "poor", the economically disadvantaged, also benefit in the economic progress of these countries. A brief inspection of refugee camps and many rural areas reveals that the poor are not always pulled along on the development tracks. If science doesn't directly address the needs of the poorer segments of society (and it will take some intellectual effort to relate space science to poverty), then theology (the winning of souls) and politics (the winning of minds) will continue the fight to overcome poverty without the contribution of science (the winning of knowledge and, with its application, bread).

The roles of Church and State in addressing the needs of the poor have clashed in many regions of the Third World, and have given rise to the radical "liberation theology" manifested most strongly in Latin America. This radicalization of a segment of the Church is claimed to have started with Pope Paul VI's *Populorum Progressio* in March of 1967. (3) Quade interprets this proclamation to mean that the Church claims for itself all knowledge of equitable development, and that the Church does not acknowledge that people of equal virtue have different ideas in politics and economics. Quade further attempts to portray the Church as seemingly all-knowing when he quotes Pope Paul VI during the dedication at the creation of the Pontifical Commission on Justice and Peace: (4) "to bring to the whole of God's people the full knowledge of the part expected of them at the present time, so as to further the progress of poorer peoples, encourage social justice among nations, and offer to less developed countries the means whereby they can further their own progress".

To further substantiate his claim of a Church which sees its role as

(3) QUENTIN L. QUADE, « Introduction », *The Pope and Revolution*, ed. Quentin L. Quade (Wash., D.C.: Ethics and Public Policy Center, 1982), pp. 6-8.
(4) *Ibid.*, p. 7.

the only adequate one, Quade refers to speeches of the late Ms. Barbara Ward in which he claims that she implies that the Pope places the blame of Third World poverty on greed and ostentation in the North and on the North's lack of a systematic analysis of development problems. (5)

It is not at all clear that Pope Paul VI's *Populorum Progressio* was intended to represent a unique solution to underdevelopment and poverty, or that it was intended to radicalize the Church in any way on this issue. It certainly was not intended to justify present "liberation theology", as substantiated again and again by Pope John Paul II.

Pope John Paul II's attack on Third World poverty is based on the Church dealing with the whole person, and the development of man depends upon the integration of his religious, political and economic makeups. Pope John Paul II reminds us: (6) "... in the last analysis He (Christ) will identify himself with the disinherited — the imprisoned, the hungry, and the abandoned — to whom we have offered a helping hand". John Paul reaches for all dimensions of development, including science, and realizes that evangelization and human promotion are tied by an anthropological, theological, and charitable nature. John Paul quotes Paul VI's Apostolic Exhortation *Evangelii Nuntiandi* 29: "evangelization would not be complete if it did not take into account the mutual interaction that takes hold in the course of time between the Gospel and the concrete personal and social life of the human being".

Again, emphasizing the whole person in equitable development, John Paul quotes *Gaudium et Spes* (Pastoral Constitution on the Church in the Modern World): (7) "... an indispensable condition for a just economic system is that it foster the growth and spread of public education and culture. The juster an economy is, the deeper will be its cultural awareness". He goes on to say that in order to achieve a worthy life: "one cannot limit oneself to having more, one must strive to be more".

Thus the Church deals with the whole person, and would include the scientific man into the process of development and alleviation of poverty. History has not treated the relationship between Church and science kindly. Nevertheless, the link between Church and especially the

(5) *Ibid.*, p. 8.

(6) Pope John Paul II, « Opening Address at Puebla, Third General Conference of Latin American Bishops », Puebla de Los Angeles, Mexico, January 28, 1979, *The Pope and Revolution*, ed. Quentin L. Quade (Wash., D.C.: Ethics and Public Policy Center, 1982), p. 63.

(7) *Ibid.*, p. 65.

space sciences is strong. The history of this relationship begins with Church thought in astronomy and cosmology.

Although many aspects of this relationship will remain irreconcilable, religion and science can remain in their separate dimensions of thought and yet still participate in the alleviation of suffering and the development of human diginity.

The roads to spiritual faith and scientific understanding both lead to wisdom and compassion. Although there will always be controversy whether the two ever emerge to an Ultimate Truth, it seems that the wisdom and compassion shared along the way give promise to the Church's application of space science to help the poor and unfortunate.

A scientific experiment (how else could one describe it), as related to St. Augustine by Firmimus, is a case in point. (8) Firmimus convinced St. Augustine that the belief in astrology was false. During the birth of Firmimus, it was noted that one of his family's maid-servants began labor at roughly the same time as Firmimus' mother. Messengers were sent from the home of Firmimus and that of the maid-servant at the birth of each child. Both messengers met at roughly equal distances from the homes and thus surmised that the births occurred simultaneously under the same arrangement of the constellations. Yet Firmimus grew up rich and with honor, while the maid-servant's child remained a slave. This loss of faith in astrology spurred St. Augustine's rejection of the heretical Manichaeans with whom he had been associated for so long and hegan St. Augustine's drift to the service of God.

More recently the Church has interested itself in cosmology and quantum physics, and has looked at space sciences to reconcile some of the basic disagreements between the Church and science. One of the fundamental questions space scientists have not been able to resolve is the paradox of the Second Law of Thermodynamics (entropy) and the fact that the universe is not already at a steady state of maximum disorder. The acceptance of the "Big Bang" theory for the creation of the universe and thus for a finite age would support the observation of an ordered universe in which entropy has not had sufficient time to reduce every thing to chaos. In 1951, before the Pontifical Academy of Sciences, Pope Pius XII attempted to incorporate the "Big Bang" theory with

(8) AURELIUS AUGUSTINUS, *The Confessions of St. Augustine.* « The Harvard Classics », Vol. 7, ed. Charles W. Eliot (New York: P.F. Collier & Son Co., 1909), pp. 108-110.

Genesis. (9) Although many laymen take comfort that space science observations can be reconciled with Genesis, Ernan McMullin of Notre Dame emphasizes that cosmology and theology are not mutually supportive.

Church thought for one and one-half millennia has dealt with the origin of the universe and its relation to time. The causal argument for the creation of the universe consists of tracing backwards in time reasons for things to demonstrate that the universe must have a cause, and that cause is God, the prime mover. This cosmological argument was enunciated by both Plato and Aristotle, developed by Thomas Aquinas, and reached its most developed thought with von Leibniz and Samuel Clarke. (10) Skepticism of this causal argument by David Hume, Immanuel Kant, and Bertrand Russell eventually paved the way for contingency explanations of the universe. However, the causal argument connotes the existence of time (before-after), and thus if time is removed from the argument (or put another way, if it is created simultaneously with the universe), then there need be no cause-effect explanation for the universe. It was created by God, who remains outside the coverage of time.

This argument, which fits remarkably well with modern scientific cosmology, was postulated by St. Augustine in the 4th Century when he stated in *The City of God*: (11) "The world was made, not in time, but simultaneously with time". (12)

Thus the concept of the Church addressing fundamental issues of space science in its quest for understanding of the universe is not novel. This quest can extend to the moral use of science for peace and to the alleviation of suffering. Science does have a good side, and it must be used carefully and with charitable motives. In the words of Thomas à Kempis: (13) "For no worldly good whatever, and for the love of no man, must anything be done which is evil, but for the help of the suffering a good work must be postponed, or be changed for a better; for herein a good work is not destroyed, but improved". Dante introduced one of the

(9) PAUL DAVIES, *God and the New Physics* (New York: Simon and Schuster, 1983), p. 20.

(10) *Ibid.*, p. 33.

(11) *Ibid.*, p. 38.

(12) The Church later challenged St. Augustine's postulation when the Church came under the influence of the Ancient Greek tradition in the 13th Century. The Fourth Lateran Council in A.D. 1215 refuted Aristotle's theory of the infinite age of the universe and stated that the universe had a finite age.

(13) THOMAS à KEMPIS, *The Imitation of Christ*. «Harvard Classics», Vol. 7, ed. Charles W. Eliot (New York: P.F. Collier & Son Co., 1909), p. 227.

skills of remote sensing (geometry) with the World-Will of the Creator as the driving force of the universe. He claimed that circular motion symbolizes faultless activity.

"But like to a wheel whose circling nothing jars
Already on my desire and will prevailed
The Love that moves the sun and other stars". (14)

Space Remote Sensing and Poverty

Remote sensing from space has the capability to assist the Church and other organizations in alleviating the plight of the poor and homeless. Because remote sensing is multidisciplinary in nature and provides information of use in agriculture, health, nutrition, population, energy, and education, it has the promise of playing a pivotal role between the use of natural resources and the poverty of peoples who must sustain themselves with these resources. Generally speaking, the Third World is rich in natural resources.

Any exploitation of these resources by the industrialized North cannot be blamed as a cause for Third World poverty. Michael Novak speaks of "the missing measurements" of this so-called exploitation when he criticizes Marxist supporters of liberation theology. (15) In countering liberation theologists such as Bishop Helder Camara, who lays the blame for natural resource exploitation on the North, Novak points out that, although a small fraction of mankind enjoys a large fraction of the earth's resources, this small fraction produces most of the wealth.

Natural resources have no value until they're discovered. The sharing of remote sensing technology and training with scientists in developing countries and applying it for the needs of the lower income groups will help improve the equitable distribution of wealth generated by the conversion of the resources into usable products. The Church has a role — in the Third General Conference Statement (*Church Collaboration with the Builders of a Pluralistic Society*) of the Latin American Bishops in Puebla, Mexico, in 1979, Part Four, Chapter Three has a proposal to

(14) Dante Alighieri, *Paradiso*, Canto XXXIII, « World Masterpieces Revised », Vol. I (New York: W.W. Norton & Co., 1965), p. 1022.

(15) Michael Novak, *Liberation Theology and the Pope*. « The Pope and Revolution », ed. Quentin L. Quade (Wash., D.C.: Ethics and Public Policy Center, 1982), p. 83.

"preserve the natural resources created by God for all human beings, in order to hand them down as an enriching heritage to future generations".

The Church has developed a charitable basis for the application of remote sensing technology for the benefit of the poor. The Third General Conference Statement asks scientists and technologists to research methods to create goods to rescue humanity from underdevelopment. The Church urges us to seek answers to the riddles of the universe and to gain dominion over the earth. We are to love truth and seek to avoid the negative effects of a hedonistic society and temptation of technocracy. Wisdom and love must accompany science in development, and the Statement quotes *Gaudium et Spes*: "The future of the world stands in peril unless wiser men are forthcoming". An interdisciplinary dialogue is needed among theology, philosophy, and the sciences. Pope John Paul II urged scientists and technicians to help the poor during his speech in Toronto on September 15, 1984. ([16])

To be applied in the war on poverty, information about natural resources must be open to society and shared with all. Francis Bacon, quoting whom he called the Divine Philosopher, stated: ([17]) "it is the glory of God to conceal a thing, but it is the glory of the King to find a thing out". He continues: "Lastly, I would address one general admonition to all; that they would consider what are the true ends of knowledge, and that they seek it not either for pleasure of the mind, or for contention, or for superiority to others, or for profit or fame, or power, or any of these inferior things; hut for the benefit and use of life; and that they perfect and govern it for charity".

Only through the openness of remotely sensed data and the sharing of this technology with the poor can information about food grains be used to augment or decrease international grain sales to balance them against locally grown crops by poor farmers. The war on illicit drugs must be fought by convincing small farmers to substitute other crops for illegal ones. The monitoring of illegal and substituted crops involves remote sensing now — its use in a compassionate sense for the benefits of the farmer may fall to the role of the Church. The study of village distributions and their people's access to potable water and fuelwood can be gleaned from

([16]) MARJORIE HYER, *Pope urges Harnessing Technology*. « Washington Post », 16 Sept. 1984, p. A 16, col. 1.

([17]) FRANCIS BACON, *Procemium, Epistle, Dedicatory, Preface, and Plan of the Instauratio Magna*, etc. « Harvard Classics », Vol. 39, ed. Charles W. Eliot (New York: P.F. Collier & Son Co., 1909), p. 135.

remote sensing and could be used to ease the toil of women who must carry water and fuelwood many miles. Associations of village communities with insect habitats have health implications. It is hard to imagine foreign assistance donors relating new experimental space sensors with the needs of the poor — the Church may have a role to play. Religious private volunteer organizations are attempting to argue for improved information sharing among multinational firms and developing countries to improve negotiations for the production of resources.

Conclusion

Because natural resources and ecology transcend political boundaries, nations are sharing talent in their investigations at regional remote sensing centers, thus promoting the cause of world peace. This may be satellite remote sensing's greatest potential contribution to the alleviation of poverty — that by inducing people of differing ideologies to look at their physical resources in an open, communicative environment, people may begin to think of ways to utilize their resources for the betterment of the disadvantaged. Again, quoting Pope John Paul II: ([18]) "Those in charge of the public life of states and nations will have to realize that internal and international peace will be assured only when a social and economic system based on justice takes effect".

Science has contributed to peace in the past. Space science, and particularly space remote sensing with the guiding hand of the Church, can in the future.

"So drink at these authentic fonts, brothers. Speak in the idiom of Vatican II, John XXIII, and Paul VI. For that is the idiom that embodies the experience, the suffering, and the hope of contemporary humanity". ([19])

([18]) Pope John Paul II, « Opening Address at Puebla, Third General Conference of Latin American Bishops », Puebla de Los Angeles, Mexico, January 28, 1979, *The Pope and Revolution*, ed. Quentin L. Quade (Wash., D.C.: Ethics and Public Policy Center, 1982), p. 65.

([19]) *Ibid.*

THE RELEVANCE OF REMOTE SENSING TO BRAZIL

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Abstract

Satellite Remote Sensing has proved to be of great importance to both developing and developed countries. It helps forecasting crops, weather and climate; monitoring environmental changes and natural disasters, and gaining knowledge about renewable and non-renewable resources, among many other applications. But, so that mankind may deeply profit from all this technology, it must be made accessible worldwide at an affordable cost. This paper presents the Brazilian state-of-art in Satellite Remote Sensing, including the Brazilian Remote Sensing Experiment on board of NASA's Space Shuttle, calling attention to the necessity of cooperation among nations with or without such technology, and concluding with the Brazilian offer to share its knowledge in this space application technology in benefit of mankind.

1. *Introduction*

The aim of this paper is to discuss the relevance of the utilization of satellite remote sensing to Brazil, the major results that have been obtained and the most important problems that the program has been facing during its more than one decade of existence.

In order to better understand why satellite remote sensing is play-

* The proofs have not been corrected by the Author.

ing such a spectacular role in Brazil it is necessary to understand a little more about the conditions that are met in our region.

First of all, Brazil is a developing country which does not have an efficient conventional data collection system to provide the basic information necessary for planning, decision-making and for the efficient utilization of its natural resources. It presents a very large territory, with vast areas of difficult access, and the population distribution is not uniform, mainly concentrated on the Atlantic Ocean border.

Also Brazil is not yet an industrialized nation and, for that reason, its economy is strongly based on its natural renewable and non-renewable resources. Consequently, the survey and monitoring of these resources become a crucial and indispensable activity, providing a useful and important tool for establishing procedures for policy and decision making in the area.

On the other hand, natural and man-made modifications that are taking place in the Brazilian environment have to be monitored and well understood, in order to prevent, whenever possible, or at least mitigate their undesirable consequences.

Geological, geographical and climatic conditions in the country are such that a large number of natural disasters occur every year, producing major social and economic impacts. Drought, flood and frost are some examples of such events. Also desertification is a process that starts to become very important lately in some areas of the country.

Another point that should be mentioned here is the importance that the oceans have in this part of the globe, due to their large influence on the weather and climate and on food production (agriculture and seafood production). If gathering direct information on land is difficult, the situation in the oceans is even worse.

Brazil, like the other Latin American countries, besides not knowing well its natural resources, is also poorly mapped. Consequently, efficient and modern tools have to be used in order to expedite the solution of the problem.

So, territory integration and the necessity of obtaining real-time low-cost reliable and periodic information about it and about the neighboring oceans were the key factors responsible for the large utilization of data collected and/or transmitted by the so-called application satellites. Consequently, earth observation satellites which allow the almost real-time periodic survey of large areas very rapidly and at relatively low cost became an effective tool for Brazil to increase the knowledge about its renewable and non-renewable resources, its weather and climate, and to monitor the modifications that take place in its environment.

The Brazilian remote sensing activities started in 1968. However, it was during 1970 that two important studies were done at the Instituto de Pesquisas Espaciais - INPE (Institute for Space Research). The first one was related to the installation of a Landsat receiving and processing station in Brazil and the second was dedicated to the survey of mineral resources of part of the Amazon region (about 44,000 km^2), using a side-looking radar as the main source of information. These initial studies gave birth to the two major existing remote sensing programs in Brazil: the Satellite Remote Sensing Program and the Radar (Radambrasil) Program. The Satellite Remote Sensing Program has as its main objectives the reception, processing and dissemination of remote sensing data and the development and utilization of methodologies for the application of these data in a large number of areas. This Program will be discussed later on.

Brazil has been participating in international satellite telecommunication programs since the early beginning. With rented transponders of foreign satellites utilized both for international and domestic communications, the major effort was concentrated on research and development in the area of design and fabrication of ground stations and on propagation studies. However, the constant increase in the utilization of the rented satellites for domestic communications and the cost of their use have made the Brazilian Ministry of Communications propose to and get the approval from the Brazilian government to buy two geostationary telecommunication satellites (24 transponders each, operating in the 4-6 GHz range) which will cover the whole national territory. The first satellite will be launched in February 1985 and the second six months later. It is expected that for the next generation of national telecommunication satellites, a reasonable participation of Brazilian organizations and industries in the conception, design, manufacturing and testing of the space segment will occur. The satellites will be used for telephonic, telex, TV programs and data transmissions. No direct broadcasting capabilities will be available, but it is expected that both private and governmental educational TV programs on a broad range of applications (primary and secondary schools, health and medical care, nutrition, land utilization, agricultural processes and technology, etc.) will be transmitted, covering an increasing number of communities, families and individuals.

In the following sections, a general description about satellite remote sensing activities in Brazil will be presented. It will cover the fields of data reception, processing, distribution and utilization, satellite and Shuttle experiments, image processing systems and training programs. In the presentation not only the remote sensing satellites will be included, but also the meteorological satellites. At the end, the most important results obtained and problems encountered will be discussed.

2. *Data Reception, Processing and Dissemination*

It is worthwhile mentioning that Brazil was the third country in the world where a Landsat receiving and processing station was installed.

The Brazilian Landsat receiving station was established in 1972 in Cuiabá, MT (15°33′S; 56°14′W), covering Brazil and a great part of neighboring countries; the processing station is located at Cachoeira Paulista, SP (Figure 1).

Data distribution centers are strategically located at different cities in the country in such a way that any user can very easily obtain information about the quality and characteristics of the satellite data available (Figure 2). The Brazilian satellite remote sensing program, as mentioned before, is under the responsibility of INPE. Today both MSS and TM data from Landsat 4 and 5 are routinely received and processed in INPE's facilities. Modifications on the stations to receive and process SPOT data have been programmed to occur in a very near future. According to the Memorandum of Understanding signed between the US National Oceanic and Atmospheric Administration — NOAA — and the Comissão Brasileira de Atividades Espaciais — COBAE (*) (Brazilian Commission on Space Activities) — data received and processed by INPE's Landsat ground stations are distributed to national and foreign users on a non-discriminatory basis.

Since the beginning of the Brazilian satellite remote sensing program the number of images produced and the number of users have grown steadily. In terms of image production and utilization, Brazil was, some years ago, the second in the world, thus reflecting the importance that this type of data has for the country.

The strategy established in the program was, in a first stage, to buy the stations and progressively gain experience and know-how on their operation and maintenance, besides obtaining knowledge of the techniques

(*) COBAE is the governmental agency responsible for space activities in Brazil.

FIG. 1. Brazilian Landsat Ground station location and coverage.

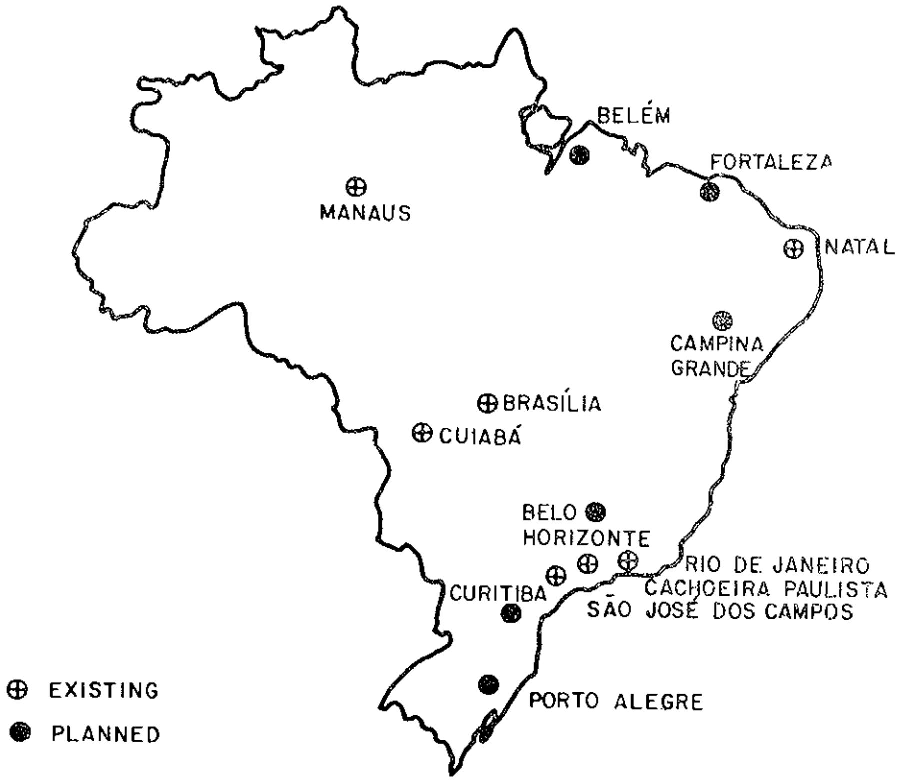

FIG. 2. Brazilian Data Distribution Centers.

and technologies involved in the processes. In a subsequent phase, an increasing participation of Brazilian teams in the modification of the stations took place. The basic design and the establishment of the complete specifications of the new Brazilian Landsat 4-5 MSS and TM receiving and processing stations, for example, were all performed by INPE's staff, and the development of almost 50% of the processing software was developed by INPE's engineers. Today, Brazil is helping other developing countries in their effort to upgrade or to establish satellite remote sensing receiving and processing ground stations.

As far as the meteorological satellites are concerned, INPE operates in Cachoeira Paulista, SP, complete receiving and processing ground stations for both NOAA's polar orbiting (Advanced TIROS-N) and geostationary (GOES) satellites. The data received at the station — that was projected, built and integrated by INPE — include GOES/VISSR-

VAS visible and infrared images (also water vapor content) and TIROS-N/AVHRR-TOVS images and soundings. The images are distributed to the users both in film/paper format or in almost real-time digital form through telephone lines. In this last case, the users (in general operational organizations) possess digital image storage and processing systems which were also developed by INPE. The Brazilian Diretoria de Hidrografia e Navegação da Marinha - DHN (Navy Hydrography and Navigation Directorate) recently installed a GOES receiving and processing station manufactured by the Brazilian industry, where digital visible and infrared data are received, processed and analysed for almost real-time utilization. TIROS-N/APT and GOES/WEFAX transmissions are received in Brazil by a large number of users. Data Collection Platforms (DCP) are also used in order to obtain environmental data (basically meteorological and hydrological information) through the utilization of both polar orbiting (ARGOS system) and geostationary (GOES) satellites. INPE operates receiving, processing and distribution ground stations for both systems.

3. *Data Utilization*

A large number of meteorological and remote sensing data utilization methodologies have been developed in Brazil by an increasing group of institutions and persons in a wide range of applications, which include, among others, the survey and monitoring of natural resources (mineral, agronomical, forest, hydrological, oceanographic), observation of the environment, monitoring of land use, conventional and thematic cartography, regional and urban planning, pollution, disaster forecast and monitoring.

Probably more than 200 different satellite remote sensing methodologies have been derived after Landsat data of the region started to become available. One should also add to this figure a reasonable number of case studies and proof-of-content analyses which were performed in order to show the importance and to demonstrate the potentialities of the new technology. However, only its effective utilization in operational applications produces benefits and conclusively contributes to the solution of existing problems.

Most of the elements of the multidisciplinary groups that were established, at the beginning of the program, in order to develop the application methodologies were trained at foreign research centers and universities and started progressively to gain know-how and experience on the utilization of satellite remote sensing data. As a consequence, specific short term and on-the-job training courses started to be offered, besides graduate courses (MSc and PhD levels), multiplying, very rapidly, the number of professionals working on the area. Today more than 1,500 Brazilian institutions are using Landsat data and this number has a clear tendency to increase due to the new products offered by Landsat/TM and, in a near future, by SPOT satellites.

Besides the development of satellite remote sensing data application methodologies done by the multidisciplinary groups of professionals at INPE and other research and development centers, and their effective utilization by operational organizations, the national program includes grants which are given to individuals or groups of individuals to support remote sensing research and development in both governmental and private institutions.

More recently, Regional Remote Sensing Research Centers, equipped with all the necessary software and hardware, including low-cost image processing systems developed by INPE and manufactured by Brazilian industries, are being established, preferably at Universities. These Centers, which are run by INPE, have as their main task the development of data utilization methodologies for regional application.

Significant results have been obtained with the use of remote sensing techniques in a wide range of applications. Monitoring and evaluation of reforestation and deforestation, natural vegetation mapping, crop identification and area estimation, crop forecasting, soil mapping, survey of potential areas for agricultural expansion, survey and control of potential mineral and oil deposits, cartographic applications, control of sedimentation in water reservoirs, obtention of fishing charts, survey and control of pollution, land use, and survey of potential areas for water obtention in semi-arid regions are important examples which have reached an operational stage in the country.

One of the characteristics of the Brazilian program — probably the key factor responsible for its great success — is the mandatory engagement of the user organization in the development phase of the application methodology. Consequently, training, absorption and technology transfer and the operational utilization of the data, basic objectives of the program, occur at the same time. Most of the operational methodologies which are today producing important results were established with such a strategy. Additionally, the know-how gained by the user organization is sufficient for the development of new methodologies, thus multiplying, very fast, the utilization of satellite remote sensing data.

Another important point that should be mentioned here is that a large number of applications of remote sensing satellite data which are today operational in Brazil cannot be performed by standard methods, thus making them unique and consequently with a very low cost/benefit ratio.

One example is the continuous monitoring done by Brazilian institutions of the deforestation in the Amazon region and of the consequent establishment of cattle raising farms and urban centers in some of the deforested areas and the occurrence of desertification processes in others. It is important to mention that the problem of deforestation in the Amazon forest has raised considerable national and international interest and that since a long time ago, the Brazilian government has been worried about the occupation of the Amazon region and its economic integration with the rest of the country. As the Amazon is the only still existing tropical forest not drastically altered by man and because of its importance for the energy and particle exchange among different layers of the atmosphere, thus contributing to the world weather and climate, the occupation strategy to be adopted for the region should definitely include the preservation of the environment.

The situation became a little more complicated after 1969 as a consequence of a federal program on which fiscal incentives were offered for enterprises to be established in the Amazon region. The choice of most of these enterprises was the cattle raising activity, which greatly increased, thus making it difficult for the federal government to control them efficiently. With the construction of a great number of highways crossing the Amazon region (for example, Belém/Brasília, Transamazônica, Cuiabá/Santarém, Cuiabá/Porto Velho highways), individuals and private companies were attracted to the region, either using federal economic incentives or their own resources. As a consequence of the implantation of the cattle raising and pasture projects, a large number of problems appeared. Among them one can mention the exact localization of the project, amount of deforested area, lease-holder, land regulation, incorrect limits, area occupied by the pasture and its quality, and so on.

Pilot projects were performed for some critical areas and showed that Landsat imagery could effectively be used as basic data for operational deforestation vigilance programs for the Amazon region. Consequently, in 1978 a decision was made by the Brazilian government to determine the deforested area in the whole Amazon region. Two periods were chosen for the study (1973/1975 and 1976/1978) in order to gain also information on the deforestation rate and the critical regions. Although the deforestation percentage could be considered low (1.55%), the deforestation increment rate could not (almost 170% in the last three years of the study). Also, it was concentrated in some critical areas.

Due to these important results obtained, the Brazilian government decided to establish an operational program to determine, on a yearly basis, the deforestation in the Amazon region, with special emphasis on the monitoring of the critical areas. The relevance of this program is related not only with the importance of the information it generates, but also with the fact that it has stopped the great number of speculations about those subjects that were raised by both the national and the international communities.

On the other hand, applications producing information which is of direct interest for the country's economic planning, evaluation and development are those that major impacts create on government opinion and, as a consequence, better justify the investment made.

In general, importing and exporting countries manage a delicate balance between supply and demand, anticipating the determining factors of transactions as early as possible. In such situations, timely information relevant to anticipate resupply of new harvests is crucial. Without timely and reliable crop demand and supply information, an exporting nation may impose a costly and unnecessary moratorium on its grain sales; importing countries with limited storage capabilities must have early forecasts of their own supply positions to make effective purchasing decisions. Distribution and transportation arrangements within and between exporting and importing nations benefit greatly when accurate crop forecast and food supply information is available.

Thus, in a country like Brazil, where Agriculture and Energy are national priorities, Crop Survey and Forecasting become a crucial and basic information for the government, from the economic, social, strategical and security points of view. However, the large Brazilian territory, with regions presenting different characteristics, like soil, topography, climate, etc., and where adverse meteorological phenomena such as drought, frost and flood commonly occur, makes the National Crop Forecasting a difficult task to accomplish. For those reasons, earth observation or environmental satellite data became a very important source of information. Although designed to complement the existing conventional system, the satellite crop forecasting system presents some advantages, as: reduction of the necessary ground truth data, applicability to the whole territory and high monitoring capacity.

Feasibility studies for area estimation were successfully performed for a large number of crops, especially those which are important for the country's economy: sugar-cane, soy beans, corn, wheat and rice. Today a national sugar-cane crop forecasting program conducted by INPE with the participation of other federal and state organizations is under way. Started in 1978, this program is now operational for the region responsible for 80% of the national production and is expected to be fully operational for the whole country by 1987. The information generated by the program is important not only for the sugar production itself but also for the planning, monitoring and evaluation of the Brazilian alcohol production. One should recall that nearly 40% of the Brazilian cars run with alcohol engines and that in 1984 the total alcohol production in Brazil is expected to be almost nine billion liters. Regional crop forecasting programs for soy beans, wheat, corn and rice are also under way and are expected to include the most productive areas in such a way that, in a very near future, almost-national forecasts will be available for those crops.

One outstanding result of these programs is the possibility to determine, farm by farm, the area prepared for plantation — and also the crop estimation —, information of great value for federal, state and private banks that lend money to farmers for the implementation of agricultural projects. A pilot project was successfully performed by INPE for Banco do Brasil (Federal Brazilian Bank) in an important area of the State of São Paulo. Today the project is being enlarged in order to cover other critical areas and it has been decided that this will be the standard procedure to be adopted by the Bank to treat the problem.

Another important application of satellite remote sensing data in Brazil is the survey and monitoring of reforested areas. Besides the standard utilization of commercial forests for wood and paper production, countries like Brazil, where there is an oil deficit, have also developed programs to utilize forest trees for charcoal and alcohol production, in order to reduce the dependence on imported oil, thus relieving the country's energy crisis. Consequently, several fiscal incentives have been offered by the government to encourage the private sector to be involved in the enterprise. Additionally, the existence of vast parts of the territory which were not used for any economic or agricultural purpose (thus making the price of the land very low) was another positive factor for the quick implementation of the program. Also, the use of artificial reforestation as an alternative energy source has several advantages, as reforested trees need a short period of time to reach the cutting age, are renewable, cause fewer problems to the environment, and may solve social problems by increasing employment. Therefore, monitoring, control and production estimation of those large reforested areas became important goals to be achieved.

Reforestation studies using remote sensing techniques in Brazil started in 1976 and today they are routinely utilized for pinus and eucalyptus area mapping and estimation and age classification with a very high accuracy. Both Federal and state governments and the private sector are using them on an operational basis.

The discovery and mapping of mineral and oil deposits in Brazil are another example of great economic impact. With a few Landsat scenes and some hours of image processing it is sometimes possible to identify prospective areas of production which, after ground-based observations and analysis, may become economically exploitable.

Brazilian application of remote sensing in mineral exploration started in the early 70's. With the advent of the Landsat program, research was then aimed at the determination of the potentiality of its products in providing information on the lithologic and structural controls of well-known ore deposits. Later, studies were directed towards smaller areas of interest.

During the last decade, satellite remote sensing has been applied to studies dealing, among others, with deposits of bauxite, lead, zinc, tin, marble, iron, clay, copper, titanium and radioactive materials, located in different geological environments of Brazil. Because of the energy crisis, applications to hydrocarbon prospection and radioactive minerals (uranium) became of relevant importance. A very large number of Brazilian governmental and private organizations are today using satellite remote sensing data for geological mapping and for the definition of potential mineral and hydrocarbon (oil and gas) deposits.

Since pre-historic times, fishing constitutes a dominant activity of mankind, because of the need of obtaining food. Consequently, the establishment of an increasing effort in the search for a better, rational and economic utilization of fishing resources has been the preoccupation of many countries. For Brazil, it represents a mandatory activity, since the country possesses a very large coast and the population is highly concentrated in the ocean border.

Remote sensors opened a new field of applications in the subject, because they allow an assessment of the potential marine resources in large areas and in almost real-time. So, methodologies for the application of satellite remote sensing and meteorology data to the inventory, monitoring and prediction of fish catches have been derived. Today, simple fishing chart models utilizing oceanographic, fishing and remote sensing data for the detection of the best fishing areas for various fish species are being routinely used.

Also, the routine utilization in Brazil of Landsat data as planimetric basis for both new and upgraded 1:250,000 cartographic maps has generated enormous impacts. Both topographic maps and aeronautical charts are being produced in the program.

The above applications were here described just to give an idea to the reader about the relevance of the utilization of remote sensing data in Brazil and not to present a detailed discussion about all the methodologies which have been derived, which would be out of the scope of this paper.

Finalizing this section, it is worthwhile mentioning that Brazil presents a large and successful experience on the utilization of combined microwave and optical/infrared remote sensing data. For that reason, efforts are being made for the country to participate in both optical/infrared and microwave space-borne foreign programs. The participation could vary from the utilization of data obtained over selected areas of the Brazilian territory (e.g. data from SIR-A, SIR-B and MOMS experiments on board of Space Shuttle), to the reception and processing of the data acquired by remote sensing satellite or even in the development of the space segment itself.

4. *Brazilian Satellite and Shuttle Experiments*

Due to the importance that environmental satellite (meteorological and remote sensing) data has for the country and the degree of development attained by its earth observation satellite application programs, the Brazilian government accepted in 1979 the challenge to carry out a small but ambitious space mission, tuned to the country's modest means, but in keeping with its unbending desire to close the gap that exists between it and the most advanced nations in the world. Proposed by

COBAE, the Brazilian Complete Space Mission (MECB), as it became known, calls for the design,, manufacturing, launching and operation of four satellites; and is to be completed in the early nineties. The first and second satellites of this Mission will relay information transmitted by environmental data collection platforms (DCP), while the third and fourth satellites will be devoted to Remote Sensing. INPE (with the participation of Brazilian industries) is responsible for the satellites and respective ground segment, and the Brazilian Air Force for the launching vehicle and the launching facilities. The relevant unfrozen characteristics of the Brazilian remote sensing satellites are presented in Table 1; the first of the two satellites is scheduled to be launched in 1991. It has been designed with characteristics optimized for applications of national interest, which include tropical climate agriculture and vegetation, geology, geomorphology, soils, land use, and special problems of hydrology and coastal zones.

The success of the US Space Transportation System and the opportunity offered by the President of the United States to the President of Brazil to participate in a cooperative experiment with NASA have introduced a significant new factor in the preparation of the Brazilian MECB. The possibility of flying an early version of the CCD Multispectral Camera on the US Shuttle greatly motivates INPE's team of development engineers, much increases their confidence of ultimate success, and enhances the capabilities of accurately determining optimal specifications for the hardware that will have to reach the goals of the Mission.

TABLE 1 — *Relevant Unfrozen Characteristics of the Brazilian Remote Sensing Satellites.*

Orbit	Circular, heliosynchronous, 98° inclination; 650 km altitude; Equator crossing time = 12 hrs; repetition cycle = 35 days (4 days with off-nadir pointing)
Dimension	Prism (octagonal basis; 100 cm diam. × 90 cm high; two deployable solar panels
Mass, Power	170 kg; 140 watts
Orbit and Attitude Control	Three axis stabilization; excentricity $\leqq 10^{-3}$; pointing accuracy $\leqq 0.5°$ in all axes
RS Camera	Derived form BRESEX (see Table 2); resolution $\leqq$ 59 m at 650 km
Lifetime	Greater than 2 years

TABLE 2 — *BRESEX Characteristics.*

Orbit	Circular orbit; 28.5° inclination; 300 km maximum altitude
Mass; Volume and Power	Not more than 30 kg × 30 dm^3 × 30 watts
Characteristics	Push-broom multispectral imager (CCD array technology); resolution = 20 m at 300 km altitude; radiometric sensitivity ≦ 1%; ± 15° side pointing flat mirror for cross-track imaging; along-track imaging; 40 km swath at 300 km altitude; encoding = 8 bits/pixel
Spectral bands	Band 1: 0.47 - 0.53 μm Band 2: 0.63 - 0.68 μm Band 3: 0.83 - 0.91 μm

The basic objectives of the Brazilian Remote Sensing Experiment (BRESEX) which should fly on the US Shuttle probably in mid 1987 are, thus, to develop a prototype of the instrument that will, four years later, fly in the Brazilian Remote Sensing satellites; to use this instrument on board of the US Shuttle to obtain data over Brazil in the greatest possible variety of conditions (time of day and off-nadir especially); and to help freeze specifications on the final satellite instrument. The important technical specifications for BRESEX are listed in Table 2.

5. *Image Processing Systems and Training Programs*

The importance that automatic digital image processing systems have in operational utilization of satellite remote sensing and meteorological data both for application methodologies and for geo-coded data banks, has forced their development in Brazil. Today, complete systems developed by INPE (system design; application software development; integration and testing) and based on Brazilian hardware (mini and micro-computers) are available for purchase. All the Regional Remote Sensing Centers will be equipped with such systems and many user institutions are ordering them from the Brazilian industries.

Consequently, a great impulse was given to the pattern recognition area, and application software for medical imagery analysis and industrial processes image control was also developed.

As Brazil possesses a national remote sensing agency (INPE), training programs are regularly offered or coordinated by such organization, because one of its goals is the dissemination of information and the establishment of national competence in the area of remote sensing science, technology and applications. Those programs are generally offered by a multidisciplinary group of professionals and are specially designed to meet the country's needs and to create the necessary know-how and manpower.

While in Brazil some universities offer the possibility for undergraduate and graduate remote sensing studies in their traditional courses, most of the specialized and on-the-job satellite meteorology and remote sensing training programs that exist in the country are organized and delivered by INPE's staff at its training facilities or at user organization. With the establishment of INPE's Regional Remote Sensing Centers, regular and specially-designed courses will also be offered there. Regular tuition-free graduate programs at Master and Ph.D. degree levels on Meteorology and on Remote Sensing can be attended by Brazilians and foreigners at INPE's facilities in São José dos Campos. A new National Remote Sensing Training Center at INPE's installations in Cachoeira Paulista, SP, is under construction. Specialized full-time courses on basic and application remote sensing technology will be regularly offered there to the user's community in Portuguese and other foreign languages. International short-term courses on meteorological satellite data applications for weather and climate forecasting and other utilizations, and on satellite remote sensing have been regularly offered by INPE. Also, a one-year remote sensing course dedicated to Latin American professionals will be held at INPE's headquarters in 1985.

6. *Conclusions*

Research and technological development on Remote Sensing have been carried out in Brazil for more than one decade. The experience acquired during that period has confirmed that the benefits provided by this new technology are enormous, helping the governmental and private sectors of the society to establish efficient planning and procedures for policy and decision making.

Due to the characteristics of the country, satellite remote sensing and meteorology are the appropriate techniques to be used in order to obtain periodic almost real-time data and information about the whole territory and to utilize them in a wide variety of applications. Most of those applications which have an intrinsic strategic, economic and social content cannot be developed by conventional non-satellite methods.

Consequently, Brazil has indigenously developed national capabilities to deal with earth observation satellite applications and technology. A complete satellite remote sensing program which includes indigenously developed space and ground segments, application methodologies and low-cost image processing systems is under way.

Some individuals or even government officials have argued that the usefulness of the data collected and/or transmitted by the application satellites in areas where there is an effective conventional ground data collection and/or transmission system is very limited. Though this is probably true for countries with small developed areas, the experience gained in Brazil has shown that it does not apply even for the most developed regions of the country. The information obtained and/or transmitted by the satellite is of great importance for updating and improving on a very low cost basis the existing systems or even for use as a back-up system.

Most of the problems related with the effective utilization of satellite remote sensing data by developing countries have been discussed during UNISPACE-82 and they are presented in the Conference's report. However, there are some important points which should be here stressed.

The first problem is related to the present situation and future trends in the commercialization of the international meteorological and remote sensing satellite programs. While the meteorological satellite programs present a certain degree of operationality and continuity, with the data being offered (at least until the end of this decade) free-of-charge to all countries, the same does not occur with the remote sensing satellite programs. Following the experimental phase of the Landsat program, where symbolic access fees to the satellite data were charged to the ground station operators, a pre-operational phase is now underway with significantly higher access and distribution fees. The US Congress has already approved the transfer of the program to the private sector, which definitively will operate it on a commercial basis. The French SPOT program was basically conceived within this commercial framework, and the same will occur with the future remote sensing satellites.

The proliferation of such commercial systems very soon will make it more difficult for developing countries to continue to receive, process and distribute data transmitted by the different remote sensing satellites or even to acquire and utilize the enormous number of products that will certainly be available in the market.

For countries which are large satellite data users (like Brazil) and can afford it, the tendency is to establish national programs with their own space segments and with data products more appropriate to their needs. For others, the trend will probably be in the direction of buying the desirable analysed information and not the basic satellite data, a solution that is of great interest to the satellite owners and associate companies, because the great profit is not connected with the selling of the data but with the information extracted from them. The degree of dependence of the user will increase, precluding him from developing his own capability to derive other important and strategical applications. Also, an increase of knowledge of one country — the one that acquires the data — about other countries will be a natural consequence of the process. This is particularly important in the relationship between developed countries — which in general possess data about developing countries — and the developing countries themselves, because the process will definitively increase the gap that exists between them.

Two action items could be adopted in order to minimize the consequences of such situation.

The first action is related to the necessary steps needed to obtain compatibility and complementarity between the existing systems and the ones that will be implemented in the future, in order to both decrease the number of products offered to the user and make those products as much as possible "transparent" from the source that has generated them. Although a reasonable success has been achieved within the Landsat program (due to the Landsat Ground Station Operators Working Group - LGSOWG actions) and discussions are under way among the agencies that today operate remote sensing satellite systems or will operate them in a near future (example of this action is the Committee on Earth Observation Satellite - CEOS), a much greater effort has to be undertaken. If not, the utilization of the data by developing countries will be seriously jeopardized.

The second action will consist in establishing the important characteristics and specifications of an optimal, noncommercial worldwide coverage and distributing satellite remote sensing system and its implementation, which will allow all nations the opportunity of obtaining periodical remote sensing satellite data about their own territory on a low-cost and almost real-time basis.

On the other hand, the increasing number of different satellite sensor systems with continuously increasing resolutions will produce an amount of data impossible to be handled in the way it is being done nowadays.

The combination of the digital satellite data to generate digital geographic or even more general information systems should be a constant preoccupation for those countries like Brazil that intend to generate useful and up-to-date information, in the forthcoming years.

Also, because developing countries — despite their widely ranging levels of economic, scientific, technological and industrial development — recognize the similarity of their problems and the complementarity of their needs and resources, it can be assumed that the cooperation among them will be the most effective tool to solve the problems faced and to allow them to profit from space science, applications and technology.

Developing countries with greater experience in a particular space application or with greater scientific and technological capability in a given field, can help other developing nations which may now be entering these areas. Brazil, due to the experience gained in its satellite remote sensing and meteorology application programs, is ready to help other developing countries that need assistance in the subject. Multi or bilateral programs in both training and development of application methodologies are desirable and Brazil is firmly committed to participate in those activities.

Finally, the problem of militarization of space should also be discussed in conjunction with satellite remote sensing applications. First of all, one should recall that the utilization of space-borne data for military applications is not related to the quality of the data itself, but to the degree of development presented by a given user country. While developed nations do present spy satellites, with improved sophisticated data collecting sensor systems — thus compelling other developed nations to design and construct special weapons to destroy them and, consequently, generating more tension and enmity and aggravating the already unstable relationship among world leading countries — less developed countries can use the available civil satellite remote sensing data to get useful strategical information about other countries and consequently use them for military applications. And this situation is becoming worse, as the accuracy of the available satellite remote sensing data is becoming greater.

There is no doubt that satellite remote sensing will continue to play an important role in the next decade. However, international regulation and effective coordination should be implemented in such a way that all nations could profit from the pacific use of outer space, once the achievements of scientific and technological progress should be put at man's service independently of his geographical, political, economic or social conditions, and not for one group to increase the control and subjugation of another group, thus contributing to enlarge the social and economic differences between them. With this strong belief in mind, Brazil is prepared to transfer its experience and know-how to any other country, so that the benefits of this space application technology can be shared by mankind.

REMOTE SENSING AND FOOD PRODUCTION FOR A GROWING WORLD POPULATION

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1. Introduction

The production of food provides probably the livelihood of at least half of the world's population and is intimately associated with the problems of rural poverty and malnutrition (FAO, 1979). In fact, agriculture in providing food, with associated activities in forestry and fisheries, can be viewed as the most important factor of the world economy.

A perusal of technical applications will indicate that recent advances in remote sensing technology have outstripped its practical application to man's needs. It may be surprising to learn that leadership in applying remote sensing to the earth's natural resources rests not with agriculture, but principally with cartography, forestry and geology. However, with the increasing capability of satellite remote sensing to support monitoring of extensive regions of the earth (albeit at low resolution and often with a cloud-cover limitation), agricultural leadership may be favoured in the future.

The reasons for the lag in agricultural leadership are complicated and appear in general terms to be political, economic and educational, but this problem must be overcome if human society is to benefit from remote sensing applications in combating the emerging worldwide traumas associated with food production. It should be appreciated that many countries are restrictive on access to airborne sensed data and that opinion is sharply divided on the unrestricted access internationally to satellite acquired data with a ground resolution exceeding about 50 m, although the resolution of imagery from military satellites may be several times finer.

Further, there is the problem of cost. Most developing countries cannot afford to install remote sensing ground stations for acquiring real time, high resolution imagery from satellites and many developing countries cannot afford to purchase the more sophisticated remote sensing equipment for digital imagery analysis manufactured in industrialized countries. However, in the future, education and training in remote sensing technology applied to agriculture in developing countries may prove to be the most important constraint, since few graduates in agriculture, as compared with forestry and geology, have received formal university courses in remote sensing. For example, in Australia and Canada, two of the largest agriculturally advanced countries, there are no undergraduate or postgraduate university courses in remote sensing applied to agriculture.

2. The Impact of World Population Growth

Trends in food production have led to a situation which, despite notable achievements, is fundamentally unsatisfactory with 450 million people already seriously undernourished. A continuation of current food consumption trends and income distribution would raise this figure to some 650 million people seriously under-nourished by the year 2000 (FAO, 1981). In addition, the movement of food from surplus to deficit areas is hampered by balance of payment problems and often difficult communications (Dudal, 1982).

By the end of this century, the world population will surpass 6 billion and probably reach 10.5 billion by 2110 (Sala, 1981) against less than 3 billion 20 years ago and 4.8 billion today (New Scientist, 1984). Eighty seven percent (cf. 72% in 1972) will live in developing countries. Also the population density may become acute in some areas (e.g. an estimated 140 million in Java).

Almost 50 percent more food will have to be grown in the year 2000, if only to meet present inadequate intake levels (Dudal, 1982). Additional food supplies will be needed by the end of the century, to conquer famine and malnutrition and to accommodate the requirements for improved nutrition as well as the demands arising from higher incomes. At the same time, it must always be remembered that agriculture, as the chief user of land, carries most of the responsibility for safeguarding its heritage.

Resulting primarily from the population explosion, probably more serious than the future threats of pollution, will be major changes in patterns of land use and the accelerating threats to agriculture caused by deforestation, soil erosion, declining soil fertility including salinity etc. and in some regions increased desertification. In North Africa alone, the loss of land to desert encroachment has been estimated as exceeding 100,000 ha a year (Le Houerou, 1970). Also, preliminary land degradation assessments indicate that unless conservation measures are introduced on all cultivable land, 544 million hectares of potentially productive rainfed cropland could be lost to agriculture by the year 2000 (Higgins *et al.*, 1982).

Such are the challenges posed to a sector where output is determined by the naturally built-in limits to biological growth and where many decisions taken today can affect production only in the first half of the nineties (FAO, 1981). Major land development schemes may require 20 years from the time they are decided on, before they are in full production. Moreover, agriculture is not only technical, it is the core around which socially complex human cultures have evolved: for peoples to change their cultures, so as to permit the full modernization of their farming, is a task of decades.

Finally, the question may be asked whether there is enough land to feed the population of the future and this has been summarized as follows (Dudal, 1982): "if the people of the world were to live in harmony, if resources were shared, if all cultivable land were used in an optimal way, and if there were unrestricted movement of produce, there would be food for all for many years to come".

3. State-of-the-Art of Remote Sensing

As we will be aware from other papers presented in this Study Week, remote sensing or teledetection is concerned primarily with the capture of data at a distance and the analysis of the collected data. When viewed as being confined to studies of the earth's surface at a distance, remote sensing may be considered as a branch of geography. The collected data, after processing to provide information, will be found most frequently to be synoptic, of very low cost per unit area of land, timely as compared with rural surveys relying entirely on data collected on the ground and sometimes unique in character.

Black-and-white aerial photography and the interpretation of the processed imagery (i.e. photographs) provides the traditional approach to the applications of aircraft remote sensing, which began 73 years ago with aerial photography in north Africa; but this has been eclipsed in recent years by the spectacular advances in satellite remote sensing. In the last 30 years there have also been major advances in conventional aerial photography due to the much improved resolution of camera lens and choice of film filter combination (e.g. colour infrared, panchromatic colour). Light high-wing aircraft are also now used much more widely for aerial reconnaissance and for point and strip aerial photography, using miniature cameras (35 mm, 70 mm). In contrast, high altitude jet aircraft equipped with modern survey cameras can provide complete photographic coverage in stereo of 10 000 km^2 to 20 000 km^2 a day with a resolution of ground objects on the colour infrared photographs as small as 1-2 m.

Two other major airborne sensors are also available today to support planning and management in agriculture. Side-looking airborne radar (SLAR) with its cloud penetrating capability, has been used for over 25 years to provide small-scale planimetric maps (e.g. 1:100 000, 1:250 000) and for providing information about the ground surface beneath dense forest. Secondly, multispectral scanning (MSS), including thermal sensing, has been used for about 20 years to provide imagery beyond the aerial photographic spectrum (0.38 to 0.95 microns). However, with the exception of the thermal sensing of forest fires and water temperatures associated with pollution, scanning has remained mainly experimental since its operational cost is two to three times greater than aerial photography.

On the other hand, most frequently satellite sensed data is collected by scanner systems (e.g. Landsat), since data transmission between satellite and the ground station is easier. At the present time, satellite remote sensing technology is very much at the applied research level of development as compared with aerial photography, but its operational uses are increasingly being identified. Satellite sensing is much more cost effective for repetitive coverage of the same ground areas than airborne sensing. In comparison, aerial photography of the same ground area can seldom be justified financially more often than every 5-10 years. Complete ground coverage of an area by satellite imagery may be a thousand times cheaper than aerial photography, SLAR or optical mechanical scanning; but the resolution of ground objects by aerial photography may be five to fifty times finer than by satellite remote sensing. Thus the airborne and satellite systems are complementary and recognition of this fact is now favouring multistage sampling techniques using both aerial photographs and satellite imagery in combination with field collected data.

The family of satellites currently used in agricultural studies ranges from the geostationary (e.g. Meteosat, GOES, GMS) and polar-orbiting environmental satellites (e.g. NOAA, Nimbus) to the earth resources polar-orbiting satellites (e.g. Landsat) and manned spacecraft (Space Shuttle, Salyut/Soyuz). The geostationary satellites provide the lowest spatial resolution (i.e. 1-5 km), but the highest temporal resolution (e.g. every 30 minutes for GOES). Data from polar orbiting environmental satellites with higher temporal resolution (e.g. NOAA AVHRR: 1 km^2, 16 km^2) are receiving increased attention for providing regional information for agriculture.

The earth resources polar-orbiting satellites, Landsat-5, and the planned SPOT and ERS-1, are expected to provide global coverage, albeit at higher cost for imagery, until the early 1990s. These experimental satellites, particularly the defunct Landsats 1-4, have demonstrated the increasing spectrum of uses to which data, collected mainly by scanner systems, can be adapted, although often restricted by problems of cloud cover and their relatively low temporal coverage (e.g. Landsats 1-3, every 18 days). Landsat-5 launched in March 1984, provides coverage every 16 days with a resolution of approximately 80 m (MSS) and 30 m (Thematic Mapper). Satellite photography was used with Gemini in 1965, Skylab in 1977, the Metric Camera and OMS on the US Space shuttle in 1984 and continues with the USSR Salyut/Soyuz. Synthetic aperture radar (SAR) was recorded for two weeks in the aborted Seasat programme in 1979 and provided considerable coverage of coastal areas in North America, Europe and the Mediterranean; but the imagery has not been analysed for agricultural purposes. SAR is planned to be used on the European ERS-1 in 1989 and will provide useful land resources data, particularly of cloud prone areas.

4. Application of remote sensing technology in agriculture

The application of remote sensing to agriculture calls for the matching of the needs of the growing world population (section 2) with advances in appropriate technology (section 3) and the skills of experienced imagery analysts using analogue and digital techniques.

Whilst the skill of the aerial photo-interpreter demands the extraction of information from a mass of data contained in aerial photographs, satellite analysis requires the maximum use to be made of very limited data contained in the satellite imagery and which is often of a general nature. The overall approach to photo-interpretation and satellite imagery analysis is to proceed from the general to the specific using deductive reasoning, whilst most other scientific work, including the use of the theory of statistics, proceeds usually from the specific to the general, using inductive reasoning.

The application of remote sensing to food production implies using the technology to provide data and information extracted from the remotely sensed imagery which is useful directly or indirectly to the planning and management of agriculture. Remotely sensed inputs may take the form of estimating the agricultural crop areas, assessing crop and rangeland conditions, obtaining information on environmental factors influencing crop growth and crop yield, including agro-meteorological data, and providing information useful to decision-making in agriculture and for assessing agriculture productivity in the short, medium and long term. The latter include derived remote sensing information on loss of forest cover, soil degradation and desertification.

4.1 *Direct applications of remote sensing to agricultural production*

For many years, large-scale aerial photography has been demonstrated as useful to identifying a wide range of agricultural crops, including cereals (e.g. Brunnschweiler, 1957; Bomberger *et al.*, 1960; Anuta and Mac Donald, 1971), and for assessing their areas and the crop condition, including incidence of disease (e.g. Colwell, 1956; Brenchley and Dodd, 1962; Howard and Price, 1972). Unfortunately the regular monitoring of agricultural crops has not proved cost-effective, and airborne monitoring is confined therefore to emergency situations. However, new impetus to monitoring and the timely acquisition of data is provided by the environmental satellites and the earth resources satellite, Landsat; and considerable progress has been made on evaluating satellite remote sensing systems for monitoring rangelands and for assessing crop areas and crop yields, which when combined provide estimates of crop production.

We know now that the coarse ground resolution of satellite imagery, the problem of cloud cover in the crop growing season, and often the delivery time between data capture and processing and the supply of the imagery to the agricultural user, are major constraints to the direct use of earth resource satellites for monitoring agricultural crop production. Whilst Landsat continuously covers the same area of the earth's surface every 16 days (previously 18 days), relatively cloud free imagery may be obtained only once or twice or possibly thrice in the crop growing season. It seems that, even if there were major advances in satellite remote sensing technology, the economic and effective monitoring of extensive areas of some cereal crops would still not be possible. For example, for rice in the Far East, the field sizes are often very small (e.g. 0.1 ha), the rice crop in the same locality may be at several stages of growth (e.g. in Java 5 stages of growth in 1 km^2) and multiple cropping may be common practice (e.g. beans and maize).

The NASA Large Area Crop Inventory Experiment was completed in the late 1970s and this has been followed by the Agristars Programme and the parallel adoption by some developing countries of methods of estimating crop production using the area sampling frame, which was developed by the USDA Crop Reporting Service. The latter uses satellite imagery or topographic maps primarily to establish field sampling strata and in this respect, work at the FAORSC in the mid-1970s showed that Landsat imagery could be applied in place of maps to define homogeneous land-systems as the basis of the strata of the area sampling frame.

The LACIE programme was conducted in the USA between 1974 and 1978. Its objective was to demonstrate that Landsat could be applied to forecasting wheat production. The programme was later extended to other cereals and combined the assessment of crop area with historical wheat yield statistics and climatic and weather data. Provided the field sizes were large and the cropping patterns simple, an accuracy acceptable to many developing countries (e.g. 85% to 90%) was achieved; but this is still well below the operational standard of the USDA Crop Reporting Service, using the area sampling frame. Using Landsat imagery under ideal conditions in North Dakota, the area under small grain was inventoried with an accuracy of 96.5%. The study of weather data as part of the programme stimulated interest in the development of yield models in which environmental satellite data was introduced as a variable.

This was followed in 1980 by the "Agriculture and Resources Inventory Survey through Aerospace Remote Sensing" (AGRISTARS). The overall goal of AGRISTARS is to determine the feasibility of integrating aerospace remote sensing technology with USDA acquisition systems. The usefulness of timely and inexpensive meteorological data acquired by the NOAA polar-orbiting and geostationary operational environmental satellites (GOES) was recognized and integrated into the crop yield models.

Another aspect of remote sensing in which remote sensing can be applied directly is for rangeland planning and management. Currently there is the possibility of obtaining estimates of forage production of large areas through the use of remote sensing techniques even if only a low precision is possible and for over twenty years the usefulness of light aircraft reconnaissance in counting livestock has been demonstrated to be efficient and often as accurate as ground counts.

Sampling procedures are adopted which are commensurate with the rangeland characteristic measurements taken in the field. Many characteristics of rangeland, such as herbage production and livestock production, vary greatly even over short periods of time, whilst shrubs and trees and human densities change much slower. Generalization of localized information on the vegetation, which forms the backbone of rangeland surveys, to more extensive areas is achieved by classifying the rangeland by types and then sampling in each type.

The application of remote sensing to rangeland studies favours firstly the interpretation of the vegetation on aerial photographs and photomosaics and then the use of the differential reflectivity of red and near infrared radiation by green vegetation and other surfaces, as recorded by scanners on the satellite. Various ratios have heen constructed by the combination of the recorded reflectivity data of the red and near-IR spectral bands which are referred to as vegetation greenness indices. A more complex index (i.e. normalized difference vegetation index) is frequently used in the analysis of NOAA AVHRR data which is combined with vegetation data (i.e. plant cover, green biomass) using training sites on the ground. Once an acceptable mathematical correlation is achieved between the satellite recorded spectral reflectivity and the data collected at the field sites, the relationships are extended to the overall area as recorded on the satellite imagery.

Recently in Botswana, through the FAO rangeland project, high correlations were estahlished between the vegetation index and ground samples for green herb cover and bare ground cover (Prince, 1984). NOAA AVHRR imagery derived from using the normalized vegetation index techniques was observed also to correlate well with the ground samples and Landsat data (Astle, 1984).

In Senegal (Van Praet, 1984), false colour imagery of the NOAA satellite's AVHRR data have been used to monitor the growth of the standing crop through the rainy season and to assess the green standing crop at the end of the rainy season. Measurements collected at the same time as the satellite's passage, by clipping grass in the field, have allowed the project to compare the false colours shown on the imagery with the true primary production, and thus to produce maps (scale 1:500 000) of the standing crop biomass. These maps are of particular use in the comparison of carrying capacity with stocking rate, and in the determination of spatial distribution of forage. Two obvious applications are in the provision of early warning of future movements of livestock (which depend in large measure on the availability of pasture) and in indicating areas of potential fire hazard.

Turning now to coastal and inland fisheries, the rapid changes which can take place in lakes, on riverine flood plains or in coastal lagoons and estuaries may not be reflected in available maps. Aerial photography may be used to detect these, such as changes in flooded areas, as has SLAR in one FAO project on the Magdalena River in Colombia (FAO, 1982).

Considerable use has also been made of visual observation and miniature camera photography from light aircraft to monitor fixed fishery installations, such as the brush parks in coastal lagoons in Benin, for the enumeration of temporary fishing camps and the number of boats or fishery units in use. When combined with ground sampling, economic production and productivity data can then be derived (FAO, 1982).

Remote sensing using satellite imagery and aerial photographs is assisting in the mapping of coastal features and shallow-water bottom topography, including reefs. Satellite imagery, particularly Landsat and SPOT MSS simulation, give a valuable synoptic view. In Bangladesh, for example, Landsat was used to determine what flood-plain lakes retained flood water throughout the dry season. With marine fisheries, however, dynamic phenomena take place against a dynamic background in which it is difficult to provide a fixed frame of reference for remotely sensed data.

4.2 *Applications of remote sensing to study factors associated with agricultural production*

As mentioned, remote sensing can be applied indirectly to the study of environmental factors associated with agricultural production. These studies include estimates of precipitation which are then related to cereal crop production taking into consideration the distribution of the rainfall in the crop growing season and rainfall in previous years as related to crop production. If necessary, this type of study can be extended to estimates of ambient temperature near ground level (e.g. US/Mexico screw-worm study in 1973/75 using NOAA imagery).

The following examples, drawn mainly from FAO, which has the UN mandate covering food and agriculture, including forestry, fisheries and conservation of natural resources, extend from monitoring forest cover, which, when degraded, may adversely affect agriculture through micro-climatic changes, increased surface run-off, erratic stream flow and soil erosion, to the mapping and estimating the area of land units (e.g., land systems) or ecozones suited to specific crops and the surveillance of desert areas for the breeding of the migratory locust. FAO has assisted in the use of satellite data in over 40 countries and the FAO Remote Sensing Centre has contributed to short-course training to more than 750 persons from 82 countries.

4.2.1 *Soils*

Aerial photographs have been used for many years in soil surveys namely to serve as a field map, to help locate the position on the ground of sample strips and sample points and to extrapolate the soil information obtained from these points or strips to the overall area.

FAO has conducted studies to evaluate the application of satellite imagery to small-scale soil surveys, and to develop efficient methods of interpretative analysis. Work has indicated that small-scale soil mapping can be achieved by using Landsat imagery coupled with minimal, but carefully organized, ground truth collection of quantitative data. The technique involves: (1) the delineation of the landscape depicted on the imagery into relatively homogeneous units; (2) the point-by-point classification of the area within each unit on the basis of land inventory approach; (3) a sampling procedure for the collection of ground data for the adjustment and verification of the soil mapping units. For example, Landsat imagery was used to produce small-scale or exploratory soil maps of six provinces of Central Sudan covering an area of about 570 000 square kms (Pacheco and Howard, 1977). The primary purpose was the regional inventory of the soil resources to enable a broad assessment of land potential to be made. These surveys were based on visual image analysis supported by low intensity field observations. In China recently a soil survey at a scale of 1:250 000 has been completed of the Beijing area using a combination of Landsat imagery and aerial photographs (Morain, 1984).

4.2.2 *Land Resources*

In land resource investigations, FAO has combined Landsat imagery analysis with the land unit approach, which was first proposed by Bourne in 1927 and later developed by the Australian CSIRO Division of Land Research (1946) and others in Australia, Canada, South Africa and U.K. (Howard and Mitchell, 1980). Methods depend upon the interpretation of aerial photographs and satellite imagery supported by ground truth, the identification and delineation of land units, each of which is characterized by a particular combination of physiographic and natural vegetation characteristics. These land units of varying magnitude identified by remote sensing imagery, may then be aggregated according to soil types, current land use and land potential. For example, Landsat-1 imagery was used to carry out a land unit classification in four months of the Kingdom of Jordan. Land systems were defined and mapped at 1:250 000 scale on the basis of phytogeomorphic subdivisions, recognizable on the imagery by changes in tone, colour, texture and drainage patterns.

A similar basic approach was applied to the soil and land use mapping of the central region of the Yemen Arab Republic (Pacheco, 1978). This project had the objective of demonstrating the unique characteristics of Landsat imagery as an aid to extracting basic information relating to agricultural and other renewable resources, providing basic data for planning the development of soil resources and land use within the region and recommending to the Governments what follow-ups might be carried out. Terrain units were defined and delineated, and the soil associations corresponding to these were identified as were the main categories of land use.

As a contribution to combating soil degradation, FAO has prepared a soil degradation map at a scale of 1:5 000 000. A methodology was developed for use with Landsat and a legend was evolved as the first stage input by mapping representative areas in Africa and the Near East, which provided transects from the humid tropics, to arid and semi-arid areas. The final world legend was tested by applying it to the mapping of Iran. Landsat imagery was shown to be capable of providing accurate boundaries to geomorphological, hydrological and biotic features, notably snow lines, drainage networks, slope lengths, rock types, saline areas, wind action, vegetation density and land use types.

FAO, on behalf of the UN, has also used remote sensing imagery to provide a preliminary assessment of potential land suitability of Namibia as a basis for future development planning. Since the circumstances in the country preclude any direct access to field data, it has been necessary to rely entirely on satellite imagery analysis supplemented by published sources of information. Visual interpretation was undertaken of Landsat prints at 1:1 000 000 scale. The land potential map at 1:4 000 000 combined with a Landsat mosaic of the entire country of 1:1 million is expected to be published in 1985.

In Ethiopia, the new land use and land cover map at a scale of 1:1 000 000 results from a combination of manual interpretation of Landsat imagery, field surveys and existing information. Landsat provided the backbone of data generation, using the imagery elements of colour, tone, texture and pattern. Imagery of both wet and dry seasons was used. The map has a total of 31 mapping units derived from 12 major classes. The legend was built up in an iterative manner from field observations and existing documentation. It gives information on the following: major land classes (e.g. cultivated land); cadastral units (e.g. state farm); main land use activity (e.g. rainfed crop cultivation); main crops (e.g. cereals and pulses); unit distribution (i.e. area extent); soil use distribution where relevant (i.e. what percentage of the unit is given over to different component land uses) (Henricksen, 1984).

4.2.3 *Water Resources*

The application of satellite remote sensing to water resources problems is still at an early stage. Investigations include assessing annual precipitation related to the introduction and management of agricultural crops, identifying areas where there is likely to be a reserve of ground water, and assessing the area of irrigated lands (FAO, 1982).

Precipitation is the largest contribution factor to grain yield. The importance of environmental satellite acquired data in providing precipitation estimates has been recognized for over eight years (e.g. Follansbee, 1976; Schofield *et al.*, 1977; Barrett, 1977), and is receiving increased attention. For example, the Canadian Wheat Board now monitors global precipitation within wheat growing areas on a daily basis, and is using

NOAA AVHRR imagery morning and evening to identify convective clouds with a high precipitation potential. Accuracies above 75% are obtained when the information is combined with other data including pressure classes, 3-5 days weather forecasts of the region and past weather conditions (Glick and Benci, 1984).

In Oman an investigation was undertaken of the extent to which satellite data and rainfall gauge observations could be integrated to provide improved information on annual precipitation. Existing sparsely distributed stations, for which dependable rainfall data could be expected, were identified and used to calibrate cloud data from environmental satellites. Rainfall maps were prepared, using gauge data only and a combination of gauge and calibrated cloud data. The total rainfall received during the year studies in terms of depth/area, was calculated to be 30% lower than the figure calculated from gauge readings alone, which is significant for agricultural development.

The exploitation of groundwater resources is an essential component for any scheme for development. In Upper Volta the greater part of the country is underlain by cristalline rocks of the West African Precambrian shield. Rainfall is highly seasonal and there are few perennial streams or rivers. The only substantial unexploited source of water is to be sought therefore in fractures in the crystalline basement, but not all fractures contain exploitable supplies. An analysis was made of linear features on Landsat imagery, from which maps of the fracture pattern were prepared. Deductions were made as to the directions of tension, which could be expected to have opened those fractures along the strike, for water penetration and thus to provide potential locations for boreholes. Similar techniques were used in a recent pilot study in the People's Democratic Republic of the Yemen (Travaglia and Mitchell, 1982) where it was observed that the distribution of vegetation in this arid area could not always be related to present day surface drainage following infrequent falls of rain.

4.2.4 *Forestry*

For many years aerial photographs have been used to assist forest inventory and forest management. More recently a matter of world-wide concern has been the rapid rate of destruction of forest cover in tropical countries, the need for this to be monitored at world and country levels and its future impact on agriculture. FAO is testing methods and techniques to assess the present trends in tropical forest cover. For example, maps of forest and other vegetation cover were prepared for the whole of Benin and Togo at 1:500 000 and of the southern two-thirds of Cameroon at 1:1 000 000 using a multistage procedure by which keys, derived from ground survey, reconnaissance flights and aerial photo-interpretation over limited areas, were extrapolated to the interpretation of Landsat cover of the entire area (Baltaxe, 1980).

Recently in Burma 1:1 million Landsat imagery has been used for forest-type mapping and is being followed up with maps at 1:50 000 using recently acquired aerial photographs. On Landsat imagery broad-leaved forest was broken down into closed forest, closed forest with slight cultivation, degraded forest, degraded forest with slight cultivation and non-forest. The results indicate that the loss of forest cover is more rapid than previously assumed. Aerial photographs enable much more detailed forest typing to be made which follows closely the Burmese standard forest types and provides approximately 20 classes and sub-division of the forest by height and crown density classes (Allen, 1984).

4.2.5 *Marine fisheries*

As a highly mobile resource is being exploited for fisheries production, information gathered must be passed on very rapidly if any practical benefits are to be obtained. This therefore is a major constraint to the use of satellite imagery. In marine fisheries, FAO has been heavily involved througb the use of hydro-acoustic equipment for the assessment of fish populations and the direct location of fish concentrations. Fishermen also benefit from the contribution of space and airborne remote sensing to the monitoring and forecasting of the weather and of ice conditions and to general science of the sea, particularly biological and physical oceanography.

Satellite remote sensing has been used to detect experimentally chlorophyll in phytoplankton concentrations. Thermal sensing (e.g. Nimbus Coastal Zone Color Scanner) has been used to map ocean upwellings and cool/warm water interfaces, which are well known as centres of fish productivity.

4.2.6 *Rural Disasters: Monitoring and Anticipation*

Rural disasters can be categorized into those with short-term sudden effects, sucb as floods, earthquakes, storms, forest fires, and the explosive growth in numbers, or mass movements of migratory pests, with short term cumulative effects such as flooding from prolonged rainfall, droughts, and insect infestation and/or disease, and those with long term effects such as climatic changes, soil degradation and desertification (Howard, Barrett and Hielkema, 1979).

FAO's first involvement using Landsat imagery to the monitoring of catastrophic floods was when heavy rain in July/August 1976 produced extensive flooding of the Indus River in Pakistan. Working in cooperation with Pakistan and the US Geological Survey, FAO used Landsat multitemporal imagery to identify and map the areas affected which included extensive agricultural crop land (FAO, 1982). Another project was undertaken in the Sudan at very short notice. This was an assessment of the flooding of the extensive Gezira/Managil irrigated agricultural area, following heavy rains in July/August 1978. Special arrangements were made with NASA to activate Landsat-3 over the flooded area; and maps were prepared to estimate the flood area precisely, and for use of the FAO mission, which was to evaluate damage.

A further distinction of the first category of short term sudden effects is represented by the need to anticipate and control desert locust breeding: the desert locust potentially threatens crops and rangeland resources over some 30 000 000 km^2 in 60 countries in Africa, the Near East and South West Asia, impinging upon the livelihood of a fifth of the world's poorest population. Successful breeding, triggered by widespread rainfall and subsequent vegetation development in the insect's natural habitat, can lead to large scale upsurges of activity and invasion of agricultural production areas by highly mobile and devastating swarms (Hielkema and Howard, 1976; Hielkema, 1980).

Timely and accurate information concerning the location, extent and intensity of rainfall and vegetation development in the locust recession area is a major requirement of the programme carrying out the strategy for the prevention of desert locust plagues. Through the use of Meteosat, NOAA and Landsat MSS data, a comprehensive picture can be obtained of the ecological conditions. Techniques are now used to detect and monitor rainfall in the recession area, allowing for selection of specific areas for ground surveys and aerial spraying. Information on vegetation cover is extracted from multitemporal Landsat data, allowing for precise location of the actual breeding/development habits and thus greatly facilitating field operations (Hielkema, 1980, 1984).

In conclusion, it can be stated that FAO is in the forefront in developing satellite-based techniques for drought monitoring over large areas of Africa. It is becoming apparent that no technique can be singled out as superior to others. The most efficient system of drought monitoring in Africa will integrate the precipitation monitoring by METEOSAT, the vegetation greenness monitoring by NOAA AVHRR and ground meteorological data.

The advantage of satellites is that they permit regular and frequent observations of large areas over a long period of time and transmit the recorded imagery to processing and distribution centres with minimal delay. The satellite observations system functions even when the ground-based reporting is disrupted. Thus satellite-derived information on precipitation patterns provides early warning of drought before data from other sources are available and supplements conventional data, particularly in areas from which the reporting is inadequate.

5. Conclusions

The increasing interest in remote sensing or teledetection, as a new technology, is seen at least in part as a response to assist in solving the many problems associated with the rapidly expanding world population, although the technology has not been fully tested and occasionally has been assumed incorrectly to be panacea. Remote sensing is also not new, but, depending on how it is defined, can be said to date back many centuries (e.g. water divining). Impetus to its development was given by the introduction of the camera in the 19th century, aircraft in the early 20th century, the availability since the 1960's of sensors other than the aerial camera, the advent of satellite imagery on a regular basis since the 1970's and recently the availability of lower cost, computer assisted analysis.

As indicated earlier, the operational use of airborne and satellite sensing applied to agriculture is seen as delayed due more to the lack of application "know-how" than the availability of the technology. This offers in the next few years a major challenge to agriculturists in research and development, which can probably best be approached through training, through close interdisciplinary and international cooperation and through very careful testing of methods and techniques. The cooperation of the UN and FAO in providing international short-course training for the benefit of developing countries in a wide spectrum of remote sensing applications associated with food production is helping in the technology transfer.

Concerning remote sensing technological advances, new equipment and new techniques can be expected to become available in the next few years. For example, it is likely that the use of optical-mechanical scanners on satellites (e.g. Landsat) will decline and be replaced by solid state array devices (e.g. on SPOT), which will have a reduced signal to noise ratio and can be expected to provide improved spatial resolution (e.g. SPOT 20 m); but it is not clear, however, whether this will provide more useable information for agriculture despite the higher spatial resolution, since the within-pixel noise may be increased. There will also be problems associated with the processing of much larger volumes of data and the effect of higher costs for tapes and imagery.

In the future, remote sensing applications could help much more in agricultural decision making, management and planning, than in the past, since the multistage techniques provide a monitoring capacity in addition to providing timely, cost-effective and sometimes unique information, which can be readily adapted to geographical information systems. The improved resolution of satellite imagery will enable thematic maps to be prepared at larger scales (e.g. 1:100 000; 1:50 000), which will facilitate uniform national coverage depicting data useful to improving agricultural production.

The impact of satellite remote sensing on factors associated with food production was examined and illustrated in section 4 and also helps to demonstrate the impact of the technology of space exploration. It is likely that remote sensing in the future will continue to emphasize its indirect role (section 4.2) and not mainly the direct observation of crops (section 4.1). The role of remote sensing applied to food production can be expected to diversify and expand in the next few years, particularly in providing early warnings of adverse factors influencing agriculture and forage crop production over extensive areas. This will require a willingness on the part of the user to adapt his requirements to new types of satellite-derived information with which he is either not familiar or which was not recognized as important.

The expansion of satellite remote sensing in the future in providing information on large areas can be expected to encourage further bilateral and multilateral cooperation and may lead to new regional and eventually global monitoring programmes, which has been technologically conceivable for several years. Whether these programmes, directed towards improving food production and strengthening food security, should be built up on a country-by-country basis or initially should transcend national boundaries, will require very careful assessment. Decisions will need to consider the willingness of countries to share field collected data as inputs to regional satellite observations and the type of information being produced and its accuracy.

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SPACE ACTIVITIES IN CUBA

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Introduction

The twentieth anniversary of the Space Age, inaugurated by the successful launching of the first *sputnik*, was commemorated at the Cuban Academy of Sciences with a special meeting held on October 4, 1977. In retrospect, it is clear that the most remarkable fact about the gathering itself was the presence among the attending public of the initially selected group of Cuban pilots who had volunteered to be trained as future cosmonauts. Almost three years later, one of them actually flew to outer space and performed there some twenty experiments prepared by our scientists and engineers, thanks to the highly valuable international co-operation contributed by the Intercosmos Programme.

As it happened, some of the activities which had to be started under the pressing conditions connected with the above mentioned flight proved to be instrumental in stimulating our country's subsequent engagement in certain areas of space research, such as space medicine and materials science, which in all probability would have taken a much longer time to develop under ordinary conditions.

Generally speaking, for the time being space studies cannot be rated as a top priority in Cuban research and development plans, since at present the available financial and human resources must go mainly to applied research which is closely linked to the solution of important problems — derived from the country's specific conditions — in agriculture, industrial production, energy supply, public health, and so on. However, this circumstance should not be interpreted to mean that we underestimate the potential for development implicit in space investigations, particularly in some areas such as space meteorology and remote sensing; it is just a question of priorities. On the other hand, we feel that we should participate in selected subjects of space research which are fundamental in character, not only because of their inherent intellectual value, but also because it cannot be ignored that the world as a whole is already living in the Space Age, a situation which is continuously exerting its influence, in one way or the other, on the scientific, technological, industrial and cultural progress of all countries, large or small, developed or underdeveloped.

The space achievements of the world's leading scientific and industrial powers are well known and often spectacular. Those of a few large developing countries are also noteworthy. But since the participation in space activities of the smaller developing countries is generally not so well known, I believe it would be useful to examine a few pertinent case histories while dealing with the impact of space exploration on mankind. This I would like to take as a justification for the subject matter of my paper.

I will endeavour to give here a brief description of how Cuba, a small developing country, is modestly participating in the investigation and peaceful use of outer space, pointing out at the same time the national context in which these activities have taken place and the outstanding role played by international cooperation in their encouragement and accomplishment [1-5].

First space activities

As far as our country is concerned, the earliest steps deliberately taken in connection with space studies can be traced back to the year 1964, when the first optical observations of artificial Earth satellites were performed at the Cuban Academy of Sciences. A few years later, measurements were made of the Doppler effect affecting radio signals from satellites, with the purpose of using the data thus obtained for ionospheric research. In 1969, the reception of meteorologic satellite images of the atmosphere above the Island of Cuba and other regions was initiated for use in weather forecasting. Continuous measurements of the rotation of the polarization plane of radio waves, emitted by geostationary satellites and transmitted through the ionosphere, began in 1974. All these activities were under the auspices of institutes belonging to the Cuban Academy of Sciences (founded in 1962) in collaboration with the corresponding institutes of the Soviet Union and the German Democratic Republic.

Nevertheless, the strongest incentive for the progress of the country's space activities in the late 1960's and early 1970's actually came from the field of radio communications, in the rather special way which I will now try to explain.

Soon after the triumph of the revolutionary forces in 1959, the new Cuban Government realized that it was in the country's interest to establish its own reliable international point-to-point communications and short-wave radio broadcasting, since at that time such services either did not exist at all, or were controlled by transnational companies. Following a two year period of intensive work at the Ministry of Communications, our short-wave services began to operate on a regular basis, using high power and independent-sideband transmitters, complemented by the required receiving facilities. Quite naturally, the country's new interest in the development of radio communications gave rise in the 1960's to a programme of ionospheric research set ut at the Institute of Geophysics and Astronomy of the Cuban Academy of Sciences, which has been going on ever since. After some time this was extended to include magnetospheric research, itself a genuine outcome of the Space Age.

After a decade of operation and progressive expansion of our short-wave radio services, it became clear that additional measures would have to be taken to meet the growing traffic demands. This, added to the prospect of getting rid of the vagaries of the ionosphere as a transmitting medium, incapable of accommodating wideband channels, made the possibility of setting up in Cuba a ground station for international communications via satellite an attractive idea. By the end of 1974, the "Caribe" station, located not far from Havana, began regular service as part of the Intersputnik communications system, using the "Molniya" highly elliptic orbit satellites first, and geostationary satellites later. After some time, the station was linked to the Intelsat system too.

When a national agency for the coordination of the research and peaceful utilization of outer space was instituted in 1966, according to the Cuban Government's agreement to participate in the Intercosmos international cooperation project originally proposed by the USSR in 1965, the new agency was put under the patronage of the Ministry of Communications. In 1974, it was transferred to the Academy of Sciences as the Cuban National Commission for the Exploration and Peaceful Use of Outer Space, also known as the Intercosmos Commission.

The fact that our country had the opportunity to participate in the Intercosmos Programme since its inception gave us the possibility of a somewhat early acquaintance with a variety of space research activities in spite of the very serious limitations then imposed by the discouraging scarcity of local scientific manpower and equipment, and also by the lack of a sufficiently high-level scientific and technological tradition. To a large extent this was a result of decades of neocolonial conditioning which not only hindered the development of a reasonably sound national economy but quite effectively contributed to the stagnation of science in Cuba. Only gradually did the national scientific potential start to build up after the required corrective measures were taken in the early 1960's. Apart from the general updating of curricula and the setting up of many new university courses and careers, those measures included a thorough re-orientation of higher education, the founding of various research institutions, the sustained encouragement of post-graduate training and the establishment of a vast system of full scholarships for high school and university students, many of whom were sent abroad to continue their studies at a higher level.

Coming back to our initial approach to space research, which, understandably enough, was largely tentative, it may be pointed out that as an outgrowth of the country's early involvement with the Intercosmos Programme, two scientific stations were built in Cuba: a telemetric one in Havana, in operation since 1976, and a laser radar station in Santiago de Cuba, inaugurated in 1977, whose equipment was developed by the GDR, Poland, Czechoslovakia, the USSR and Cuba. The first station was to receive the standardized telemetric signals sent by the Intercosmos satellites and could decode and record them for later processing, thus providing a valuable source of data which has been used by our scientists in their research work on solar-terrestrial physics. The laser radar installation was set up for the performance of high precision range-measurements suitable for different applications, geodetic and otherwise, such as those required for the East-West Long Arc Project, coordinated by the Intercosmos Working Group on Space Physics, and the accurate determination of the position of research satellites. In connection with their work at these stations, some of our scientific and technical workers received specialized training abroad, in Czechoslovakia and the GDR, on certain subjects such as electronic signal processing and laser radar design and operation.

Spurred by the needs of our incipient space research involvement, in the 1970's some Cuban scientists and engineers working at our Academy's Institute for Fundamental Technological Research engaged in the design and construction of certain types of electronic equipment, such as compact, very stable and precise secondary frequency and time standards for use in laser radar applications, compact spectrometers for use in remote sensing field work, and electronic equipment applicable to the digital processing of images. One of the results of this activity was a substantial contribution to the initial development of time and frequency research in our country.

Remote sensing

The participation of Cuba in the Intercosmos Working Group for Remote Sensing, established in 1975, aroused our interest in the potential applications of remote sensing methods and data to the systematic study of the country's largely unexplored natural resources and to the protection of the environment from the impact of accelerated social and economic development. Accordingly, the necessary first steps were taken to organize remote sensing research in Cuba as soon as possible, counting on the possibilities of international cooperation offered by the Intercosmos Programme.

To begin with, a small group of Cuban scientific workers was trained in remote sensing techniques at various laboratories belonging to the academies of sciences of Bulgaria, the German Democratic Republic and the Soviet Union. Experts from these countries also visited us to collaborate in the planning, actual performance and interpretation of aerial multispectral surveys of certain key areas of our territory whose geologic, geographic, vegetational, agricultural and other characteristics had been thoroughly studied at ground level.

The Institute for Space Research of the Soviet Academy of Sciences provided a strong support for the performance of the remote sensing experiments called "Trópico I" (1977-1978), "Trópico II" (1979) and "Trópico III" (1980). From the first two experiments suitable series of simultaneous aerial photographs were obtained in five spectral windows (four in the visible band of the electromagnetic spectrum and one in the near infrared) to be used mainly as the raw material for establishing a substantial part of the methodological basis required for later scientific and operative remote sensing applications. Experiment "Trópico III" was performed by simultaneously taking multispectral photographs with two identical six-channel cameras, one of them on board the "Salyut 6" orbital station and the other one on board an airplane.

Notwithstanding tbe fact that up to now remote sensing activities in Cuba have been directed basically toward the performance of methodological work, the acquisition of expertise and the creation of the minimum required infrastructure, certain results were obtained that have been already of practical use in some applications. For instance: the discovery of seismogenerating zones and other important geologic structures and features, the drawing of preliminary soil erosion maps of large parts of the country, the study of agricultural soils affected by salinity, the determination of the displacement of polluting effluents from the port of Havana, and the location of better fishing zones are some cases of applications which already benefited from the information furnished by remote sensing imagery.

Remote sensing has proved to be very helpful for the study of the country's complicated geology and for the integral evaluation of certain intricate regions such as the Sierra Maestra Great National Park. It is also expected to be of considerable assistance to our very important sugar-cane agriculture, and to the integral study of the Cuban submarine shelf, whose area amounts to more than 60% of that of the territory above sea level.

First experiments in orbit

Cuba's most noteworthy achievements to date in the field of space research are closely connected with the USSR-Cuba Intercosmos space flight that took place on September 18-26, 1980, thus culminating a period of nearly three years of intensive work devoted to the design and implementation of the research programme carried out during the flight which made our countryman, Arnaldo Tamayo, the first Latin American cosmonaut.

The preparation of the individual scientific projects represented both a unique opportunity for Cuban scientific workers and a major challenge to their capacity for working creatively in an unfamiliar field. Some two hundred Cuban scientists and engineers and six hundred auxiliary workers helped to prepare the research programme to be fulfilled during our cosmonaut's visit to outer space.

The over twenty experiments proposed by Cuban scientists can be grouped in four classes: biomedical, such as the ones named "Cortex", "Support", "Anthropometry", "Balance", "Hatuey" and others; psychological, such as those called "Coordination", "Perception" and "Stress"; physical-technological, such as those identified as "Sugar", "Zone" and "Caribe"; and some others, such as "Trópico III", devoted to the exploration of the Earth from outer space.

Cuba's modest contribution to the deepening of our knowledge of man's behaviour in space basically concentrated on biomedical and psychological experiments.

Scientific workers from the University of Havana and the Cuban Sugar Research Institute prepared some physical-technological experiments aimed at obtaining greater knowledge about certain inorganic and organic materials (semiconductors and sucrose, respectively) considering not only the intrinsic scientific value of the experiments themselves, but also the country's long-range interests in the electronic and sugar industries. "Hologram" — another experiment in the physical-technological class originally prepared for the USSR-Cuba space flight — was carried out by the crew of the USSR-Mongolia Intercosmos flight which followed ours. A product of the close collaboration established between Cuban scientists and their colleagues from the Ioffe Physical-Technological Institute in Leningrad, it included the transmission to ground of holographic images through standard communications channels, and the use of especially designed on-board laser equipment.

As far as the remote sensing of the Earth is concerned, the opportunity offered by Tamayo's space trip was used to take multispectral photos and obtain other relevant data of our territory, its surrounding seas and the submarine shelf, and also to simultaneously perform some complementary work by the use of appropriate means. In particular, sets of multispectral images corresponding to the areas surveyed from the "Salyut 6" orbital station were taken from an airplane equipped with an "MKF-6M" multispectral camera supplied upon the occasion by the German Democratic Republic. Additional data were obtained from the Bulgarian-made "Spectrum 15" spectrometer aboard the orbital station.

Most of the equipment used for the scientific work associated with this space flight was designed and built by Cuban personnel, but some of it had to be constructed in the USSR because it could not be completed locally within such a short time as was required. Needless to say, our scientific workers benefited greatly from other kinds of assistance provided by their Soviet colleagues, such as highly qualified overall scientific collaboration and the supply of certain hard-to-get components required for our work. In this connection, it is fitting to acknowledge the multifarious collaboration offered to Cuba by the Institute for Biomedical Problems and the Institute for Space Research, both of the USSR. The assistance contributed by the GDR, Bulgaria and other participants in the Intercosmos collaboration was also of considerable value in preparing certain important experiments.

As far as the training of our cosmonaut is concerned, it must be said that he and his alternate were given very effective and friendly support by their fellow cosmonauts at the "Yuri Gagarin" training centre near Moscow, and by the scientists, doctors and others who had to do with the "Soyuz 38" spacecraft flight which carried Arnaldo Tamayo and Yuri Romanenko to outer space for later coupling with the "Salyut 6 - Soyuz 37" orbital complex. The experiments prepared for this flight were performed in orbit with the additional collaboration of Valeri Riumin and Leonid Popov, who at the time of Tamayo and Romanenko's arrival had already been in space for about five and a half months.

The USSR-Cuba joint space flight gave our scientists, for the first time, the opportunity to extend their work so as to cover very special conditions formerly well beyond their reach. This, of course, stirred their imagination, but, on the other hand, care was taken to avoid as much as possible reducing the proposed experiments to mere exercises in the handling of exciting new techniques. Accordingly, every effort was made to include matters which appeared to be important for our country's future development, side by side with other matters of significance for science and technology in general and cosmonautics in particular. As a matter of fact, it was not too difficult to integrate the scientific and technological task force required for the design of an adequate experimental programme and the construction of most of the equipment used, with the result that many young scientific workers were temporarily teamed up together and could convincingly demonstrate their ability to assimilate in a very short time various quite sophisticated techniques completely new to them.

Further participation in space activities

The experience gained in dealing with the scientific task force especially set up for the preparation of our first space experiments in orbit made it clear that it was not only convenient, but also feasible, to create in our country two new research groups which previously were practically non-existent: one group dedicated to materials science research in microgravity, and another one devoted to space biomedicine.

The present immediate aims of the group for materials science in space have to do mainly with the further study of some of the results yielded by our experiments aboard "Salyut 6" named "Sugar" and "Zone", the first of which dealt with the growth process of sucrose monocrystals, while the second one was devoted to the study of the kinetics of sucrose crystallization under microgravity conditions through the technique of zonal fusion with temperature gradient. Accordingly, new equipment for the continuation of these experiments is now being designed and constructed at the Cuban Sugar Research Institute.

Regarding space medicine, we may note here that in the course of Tamayo's space trip some interesting experiments were carried out which led our scientists to engage in new investigations aimed at evaluating the effects of microgravity and reduced muscular activity on the physiology and general state of health of tropical man. For example, some of the relevant characteristics were simulated on earth for the experiment named "Hypokinesia and Antiorthostasis", which yielded some rather unexpected results suggesting possible practical applications to the management of bed-ridden patients. Work has continued to be done on improved versions for later use in orbit of biomedical equipment originally developed for our cosmonaut's space flight. A few new pieces of equipment for space research purposes, biomedical and otherwise, have also begun to be designed and constructed by Cuban scientific and technical workers.

Two space-related research areas considered to be important for the development of our country are aerospace remote sensing and weather forecasting aided by information from meteorological satellites.

Remote sensing techniques and data are now currently employed in Cuba by scientists working in quite different specialties. Some of them have studied the optical-meteorological factors affecting the choice of optimal periods for aerospace surveys, while some others have been busy at applying multispectral images to the updating of thematic maps and charts. Geologists are processing remote sensing imagery so as to put it into a form suitable for tectonic studies and mineral prospecting. Geographers have begun to accurately study our country's coastal morphology through the use of remote sensing images, which have also proved to be useful for the botanists to complete some preliminary evaluations of the vegetation covering different regions.

In the domain of meteorology, a long series of images obtained from weather satellites has been studied to establish statistical correlations between certain North Atlantic cloud patterns and some important characteristics of hurricanes which are typical of the Caribbean region. On this basis, a new criterion has been recently proposed by our meteorologists for the genesis of tropical cyclones, and a method has been developed for estimating their maximum wind velocity. Satellite imagery of cloud patterns over the Gulf of Mexico has also been correlated to the cold fronts moving over our country every year from November to April.

I have chosen the above examples hoping that they may serve as some indication of the main research areas in which Cuban scientific workers are now engaged. A further indication of the overall situation may be derived from the fact that when the First National Symposium on Space Research was held in Havana, in 1983, there were over two hundred participants and some eighty papers were discussed on topics which covered space physics, materials science in microgravity, space communications, aerospace remote sensing, space meteorology and space law.

Modest as it still is, Cuba's activity level in the realm of space research is now considerably higher than it was before our scientific workers engaged in the preparation of the experimental programme associated with the USSR-Cuba joint space flight. Actually, this event had a catalytic action in many ways; for example, it considerably increased the public prestige of space science in our country, and was able to strongly motivate a sizable group of young scientists. It was also instrumental in acquiring the basic specialized skills required for space work, and proved that the real threshold for our country to join space research could be quite reasonable. Additionally, our participation in this space flight showed that, from a scientific point of view, it could be mutually beneficial for all the parties involved.

After 1980, it became quite clear that the time had come to strengthen our country's participation in space-related international meetings within the bounds imposed by the local availability of human and financial resources. Accordingly, Cuba's participation in the Intercosmos specialized sections increased, as did its presence in the United Nations Committee on the Peaceful Uses of Outer Space and a few other international gatherings, both global and regional, dealing with space activities.

Conclusions

Space activities require highly qualified experts, advanced technological skills and means, and important financial resources which are generally unavailable to small developing countries, so that these must rely heavily on international cooperation if they want to start to actively participate in the Space Age as soon as possible. However, even the best forms of international cooperation will yield only superficial results if the developing countries involved in this effort fail to consistently support space research and create the basic local conditions necessary to bring forth a critical mass of duly qualified scientific and technical manpower.

The rather sketchy description given in this paper of Cuba's approach to space activities illustrates the particular way in which a small developing country is trying to meet the challenge of the Space Age in the presence of other competing priorities which are essential for the country's development. This approach is based, on the one hand, upon the favourable conditions for the progress of science and technology brought about in Cuba since the 1960's, and on the other hand, upon international cooperation in the context of the Intercosmos Programme, which, according to our experience, can be taken as an outstanding example of international cooperation that is both effective and respectful of all participant countries' interests and sovereignty. One of its results was the remarkable stimulation and support to national space research obtained in connection with the space flight of a Cuban cosmonaut in 1980.

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THE USE OF REMOTE SENSING AND ITS IMPACT ON THE ECONOMY AND AGRICULTURE

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I - Introduction

1.1 *Description of Remote Sensing Techniques*

1. The term Remote Sensing is generally considered to mean the acquisition of information and data concerning our environment by various devices not in direct physical contact with the objects or phenomena being sensed, (i.e. non-contact sensing). In broad terms this definition includes sensors and capabilities as old as man himself, as the human eye is one of the most sophisticated remote sensors known. However, in a more restricted and specific sense, this term is normally used to mean acquisition of images and data with various auxiliary devices man has designed to extend his natural sensory capabilities. Aircraft and satellites are the common platforms from which remote sensing observations are made.

Throughout the discussions in this paper, however, the term remote sensing is restricted to techniques employing electromagnetic energy as the means of detecting and measuring target characteristics. Electromagnetic energy includes light, heat and radio waves. This definition excludes most methods falling under the heading of "airborne geophysics", such as electrical, magnetic and gravity surveys that measure force field, rather than electromagnetic radiation. For present purposes, we may confine our discussions to electromagnetic energy sensors that are currently being operated from airborne and spaceborne platforms to assist in inventorying, mapping and monitoring the earth resources and environment.

Although, in theory, imaging systems for environmental monitoring can utilize radiation of any wavelength or waveband in the electromagnetic

* The proofs have not been corrected by the Author.

spectrum that passes through the atmosphere, the limitations of sensor sensitivity and background radiation (noise) have obviously limited the development of remote sensing systems to only those which operate in wavelengths that are most strongly emitted or reflected from various targets. Gamma rays, for example, have low level of emission from non-radioactive targets, and also are highly attenuated by the atmosphere over short distances. Therefore, no imaging gamma ray systems have been developed.

1.2. *Principles and Elements of Remote Sensing*

There are three major sectors in the electromagnetic spectrum that are used for remote sensing of the environment. These are:

(i) The ultra-violet to near infra-red (0.3 to 1.1 μm)

(ii) The thermal infra-red (1.5 to 14 μm)

(iii) The microwave (1 mm to 30 cm - "300 to 1 GHz).

Sensor systems operating in various bands of these sectors may be either active or passive. Passive systems record radiation from targets which is either self-emitted or reflected from another source — usually the sun. The photographic camera is an example of this type of passive system. Active systems, on the other hand, generate their own illumination of the ground and form the image from returning signals reflected by various targets. The radar is an example of the use of this principle.

Figure 1 schematically illustrates the generalized principles and

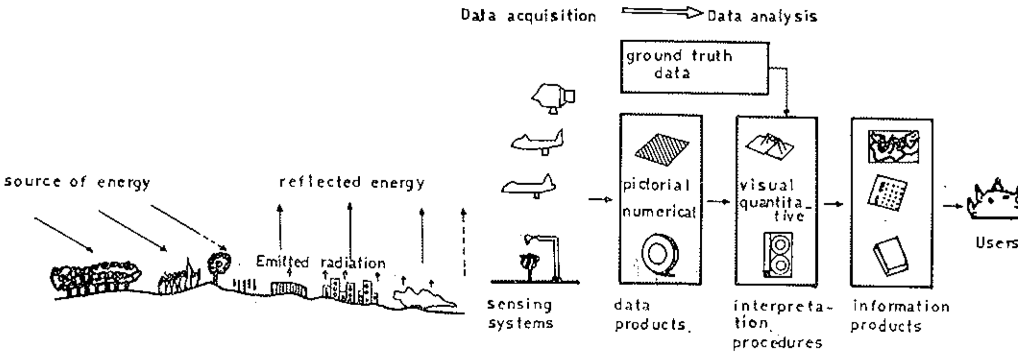

FIG. 1. Elements of the remote sensing of the environment.

elements involved in electromagnetic remote sensing of environment. The two basic processes involved are: data acquisition and data analysis.

Data acquisition involves the following elements: source of energy, propagation of energy through the atmosphere, energy interaction with various targets, aircraft or satellite sensor and generated data in pictorial or digital form. In short, various types of remote sensors are used to record variations in the way environmental phenomena or targets reflect and emit electromagnetic energy.

Data analysis process involves the examination of generated pictorial data using various interpretation and viewing techniques, and computers to analyze digital sensor data.

If available, ground-truth and reference data about the phenomena being monitored are used to assist in data analysis. With the aid of such reference data, the analyst extracts various information about tbe environmental phenomena being investigated.

Resulting information is presented in form of maps, tables, and or technical reports, for example land use, soils and vegetation maps, sources of water pollution... etc.

The information is then presented to users who apply it to their decision-making process.

II - Remote Sensing Application in Resources Monitoring and Management

2.1 In the first views of the earth from space in the early sixties, scientists found that there are much more than the ampleness and sphericity praised by the poets. The wealth of potential information that could be derived from such space photographs and images was evident, but it took man nearly a decade to appreciate the amount of information available and to learn how to use it.

2.2 It was during the seventies that great technical advances were accomplished in the area of earth observation satellites and the great potential uses of their data for the benefit of mankind. It was not perhaps coincidental, that during the same decade, people all over the world became highly aware and concerned that the natural resources of their earth are not limitless. It also became evident that if even the basic needs of the people of the earth were to be met on a continuing basis, the earth's natural resources would have to be managed and developed with care and wisdom. Food production and distribution systems need to be improved, clean water supplies must be extended, clean air must be assured and raw materials and energy must be developed (*).

2.3 In the past, when man did not have the power to exhaust the resources of nature, and when most production and consumption were local activities, man's intuitive understanding of his immediate environment seemed sufficient to sustain him. Now, with man's power over the environment increasing and with production and consumption based on international exchange, the traditional knowledge that shaped man's attitude toward his planet may no longer be adequate.

2.4 Therefore, if man is to acquire a new understanding of his planet, he needs new tools. If the understanding is to be dynamic and global, the tools must be capable of dynamic and global application. Remote Sensing from space is inherently dynamic and global with its synoptic view, repetitive coverage and multispectral scanning capabilities.

2.5 The full benefits of earth observation satellite technology could be realized if the earth's resources were managed on a global and dynamic basis. Traditionally, however, man's activities are planned and co-ordinated on a local or national basis and the information on the state of local or national resources is periodically updated.

Therefore, the effective use of satellite data requires new approaches to both international and national resource management activities. Most of the uses of earth observation satellites have been so far in national programs and for static mapping applications. The more and more technology becomes operational, international and dynamic application for the general benefit of mankind on earth will gain more grounds.

If we take, for example, the field of meteorology, in which operational satellite systems have existed since 1966, co-operative international programs have been in existence for some time, first for exchange of data (The World Weather Watch) — and subsequently for international programs such as the Global Atmospheric Research Programme (GARP).

In remote sensing, however, which is still in the preoperational phase, international networks and procedures for distribution of data are still

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(*) Second UN Conference on Outer Space - Document No. A/Conf. 101/BP/3, 28 April, 1981.

not established, and use of satellite data for dynamic monitoring is still largely limited to national projects.

The development of earth observation satellite systems and their applications will therefore depend on the decisions that are made as to how the earth's resources are to be managed and what will be the extent of international co-operation.

If careful and foresighted management in a context of international co-operation is a priority, then the use of satellites for earth observation should develop rapidly and should make an important contribution to human beings' benefits and well-being.

2.6 This paper cites the experience of Egypt, as a developing country, in the utilization of earth observation satellites and other aircraft remote sensing techniques in some proven applications in an effort to give a feeling for the types of applications and benefits derived from them, as well as the types of facilities, equipment and expertise available.

III - Equipment and Facilities Available at the Remote Sensing Center in Egypt

The Remote Sensing Center in Cairo has accumulated a large inventory of Satellites; computer compatible tapes (CCTs) from Landsat 1, 2, 3 and the T.M. of Landsat 4, covering all of Egypt and some surrounding countries in the Middle East and Africa.

Among the major facilities and equipment available now in Egypt are:

(a) *Aircraft Data Acquisition Equipment*

1. Beechcraft King Air-200, twin engine pressurized and specially modified aircraft for remote sensing operations.
2. Two RC-8 Wild aerial cameras.
3. One four-lens multispectral aerial camera.
4. Thermal (IR) scanner (Bendix LN-3 System) with interchangeable modules.
5. An 11 band (M^2S) digital airborne scanner with HDDT output.

(b) *Satellite and Aircraft Digital Data Processing Laboratory*

This is an upgraded and modified M-DAS system that has the following basic hardware and software features:

Hardware

— PDP-11/44 COMPUTER WITH 512 KB OF MAIN MEMORY
— TWO 121 MB DISK DRIVES
— TWO 10.4 MB DISK DRIVES
— MOVING COLOR WINDOW DISPLAY
— MULTIVARIATE CATEGORICAL PROCESSOR
— HIGH DENSITY DIGITAL TAPE UNIT
— THREE 800/1600 BPI - 9 TRACK MAGNETIC TAPE UNITS
— B & W FILM RECORDER/SCANNER
— TWO ALPHANUMERIC CRT TERMINALS & ONE CRT GRAPHIC DISPLAY
— COORDINATE DIGITIZER TABLE
— DIGITAL PLOTTER

Software

— SOFTWARE TO GENERATE AND ACCESS LANDSAT AND OTHER IMAGE DATA STORED ON LARGE SCENE DISKS
— REFORMATING SOFTWARE FOR EROS OR TELESPAZIO TAPES TO PRODUCE DISK IMAGE FILES, ALSO TM DATA
— SOFTWARE TO AUTOMATICALLY OR INTERACTIVELY REPLACE DROPPED SCAN LINES
— SOFTWARE TO PRODUCE AREA TABULATION FROM DISK IMAGES BASED ON DIGITIZED BOUNDARIES
— SOFTWARE TO ENHANCE DISK IMAGES (FILTERING; HISTOGRAMMING; STRETCHING; RATIOING...) ALSO, TM DATA
— SOFTWARE TO CLASSIFY DIGITAL DATA BASED ON GROUND TRUTH DATA
— SOFTWARE TO CORRECT LANDSAT IMAGES GEOMETRICALLY AND RADIOMETRICALLY
— SOFTWARE TO MOSAIC DIFFERENT LANDSAT SCENES
— ALL STANDARD MDAS SOFTWARE WILL BE MODIFIED TO RUN UNDER THE RSX-11M MULTI-USER/MULTI-TASKING OPERATING SYSTEM

(c) *Advanced Photographic Development and Production Laboratory*

This laboratory is well equipped with highly advanced automatic processors, developers, enlargers, and various photographic quality control measurement equipment.

(d) *Other Laboratory and Field Equipment*

Which include: Portable IR Thermovision cameras (AGA - both black and white and color monitors); automatic reflectance spectro-radiometers; field radiometers, etc.

IV - Significant Applications of Remote Sensing for the Benefit of Mankind in Egypt

4.1 The Egyptian Remote Sensing Center has been one of the few centers in the World which applied Landsat imagery interpretation, both visual and digital, as early as 1971, with the launching of the first U.S. Landsat-1 program. The experience of the Center in this respect is unique and may well serve as a conspicuous example for the developing countries of the world at large, and for arid and semi-arid regions in particular.

4.2 It is not possible in this report to examine all of the applications and projects which have been accomplished in Egypt using satellite and aircraft remote sensing data, combined with other ground truth and field observations. Citations of the most significant projects are listed at the end of this paper in an effort to give a feeling for various types of applications developed.

Many of these projects will fall under one or more of the following categories:

4.3 *Landuse Mapping*:

(1) The Land Surface of Egypt (1,000,000 km^2) consists of about 94% desert, and only 6% of its total area is the traditional agricultural land of the Nile Delta and Nile Valley. Therefore there is severe pressure and demand, dictated by the growing population, on this limited area of agricultural land. The demand of this growing population for housing, utilities, services and infrastructure has been steadily eating away valuable areas of land from this limited agricultural area. A loss estimated to be at the rate of about 30,000 acres per year, makes this problem a very serious one if left uncontrolled. Therefore, land use patterns are constantly changing, commonly with agricultural land being converted to urban use.

If land in Egypt, both in this traditional agricultural area and in the other desert-type areas, is to be allocated to its most appropriate use, planners must have two types of information: information on current land use patterns; and information on potential land capability.

In the first case satellite data, with the aid of computer categorization and classification and supplemented by ground truth data, proved to be a valuable tool in providing up-to-date information on regional land use patterns. Also, repetitive satellite coverage proved to be very helpful in monitoring changes. In the second case, satellite data, with aircraft and field observations, provided valuable information on soil types, potential groundwater resources, mineral resources, and other parameters which can be used, in conjunction with information from other sources, to determine suitability of other non-agricultural areas establishing new communities away from the limited valuable agricultural area.

Landsat images in various forms of digital processing, in scales of 1:1,000,000 and 1:250,000 were successfully used for such studies and for producing Landuse maps for most of Egypt.

A study of the use of satellite data for monitoring urban expansion and encroachment on agriculture was carried out for many cities and villages of Egypt with Landsat data. To obtain the high resolution required for urban studies, various enhancement and computer analysis was used to classify the data.

Comparison of the results of the study with a map of urbanization in several Governorates of Egypt derived from aerial photography and ground survey indicated that satellite data provided accurate information more rapidly and economically than aerial photography, on a regional scale and for repetitive coverages.

(2) Also, a Landsat map atlas of Egypt to a scale of 1:250,000 is being produced. This atlas will include about 70 sheets compiled on UTM universal system of cartographic maps of Egypt, and each is made of several parts of Landsat scenes. Mosaicing of these scenes is executed on computer discs in the Remote Sensing Digital Processing Laboratory, with radiometric and geometric corrections, as well as enhancement by special software applications.

When completed this Atlas will serve as a valuable basis for updating and completing the 1:250,000 cartographic and Landuse maps of Egypt. It will also serve as a valuable basis for future development of a geographic information system for the country.

Planning for many other economic development projects in Egypt will be able to benefit significantly from this Landsat atlas project.

4.4 *Agricultural Applications*:

1. The accurate identification and classification of crop types and vegetation conditions require, in general, extensive and time-consuming ground survey and observation. Therefore, when large areas are to be surveyed, classical ground observations and survey become prohibitively time-consuming and expensive.

The use of satellite and aircraft remote sensing surveys in conjunction with limited ground truth sampling can provide accurate, economical and timely information.

Some information, such as the extent and area estimate of cultivated areas, can in many cases be interpreted accurately from Satellite images, especially with the use of supervised or unsupervised digital categorization techniques from Landsat CCT tapes, and with little need for ground data.

However, in other cases, such as crop yield prediction and estimation, extensive data from other sources may be required to ensure accuracy.

2. In Egypt several estimates for cropped areas were made in different seasons, using Landsat digital data with limited ground through information input.

Continuous monitoring by this technique proved to be able to provide needed information for agricultural planners in Egypt, on a timely and cost-effective basis.

Valuable information was also produced on cycle of planting, growth and harvesting.

It also helped to monitor the effect of increased urban encroachment on agricultural land and the changes in cultivated areas.

It was difficult, however, to conduct accurate crop identification because of the inherent limitations of ground resolution of Landsat data with the small sizes of field areas in Egypt and their varied types of crops within small areas.

It is hoped that with the improved ground resolution of future Landsat and Spot satellites, this problem will be solved.

3. Infestations by fungus and nematcde disease, as well as by plant parasites, cause large losses of crops and orchard areas every year in Egypt.

If these infestations can be predicted at an early stage, counter measures can be taken effectively and economically.

Such prediction of infestations requires knowledge of the life-cycle of these diseases, observation of weather, environmental parameters and stage of plant or crop growth which affect the extent of damage.

In Egypt several pilot projects in greenhouses and in the field were conducted using remote sensing techniques, especially from aircraft, to improve and supplement existing methods for detection of fungus, nematode and other parasitic diseases in some important economic crops and fruit trees. In many cases these methods proved to be highly successful, particularly when conducted at the proper stage of plant growth and under favourable field and environmental conditions.

4. Soil moisture distribution, salinity, alkalinity, water logging and degradation of agricultural land (for example due to desertification processes) whether in irrigated areas or in desert-reclamation projects, can be detected, and studies of these factors can be greatly enhanced with the use of satellite and aircraft remote sensing data.

Several studies in Egypt along these lines were conducted, in which remote sensing techniques from satellites and aircraft with adequate field observations, were successfully used. Accurate and economical data were produced in a timely manner compatible with the need to use this information in the management of these agricultural areas and reclamation projects.

4.5 *Water Resources*

1. In Egypt, satellite data have been used to monitor the surface area, siltation patterns and aquatic vegetation distribution for the reservoir created by the Aswan High Dam. On Landsat images from four different dates, the surface area of water was measured and was correlated with water level data from the ground. Between the lowest water level, on the image of 13 June 1973, and the highest, on the image of 17 September 1977, the water level rose by 15.3 m and the surface area increased from 2717 sq km to 5681 sq km. As the water level and the surface area change, the patterns of deposition of silt by the annual flood also change. The movement of the flood front as indicated by turbidity can be clearly monitored on the images. When water levels are high and flood volume is low, silt deposition is limited to the southernmost portion of the reservoir; as water levels decrease and as the flood volume increases, silt deposition extends northward. In general, however, both satellite imagery and hydrographic surveys indicate that siltation occurs primarily in the region from 280 km to 400 km upstream of the dam.

2. About ninety-seven percent of the land of Egypt is covered by deserts lying in one of the major arid zones of the world. These deserts include the Western Desert, the Eastern Desert and the Peninsula of Sinai. Groundwater represents an important problem to be tackled for the development of these deserts and their utilization.

The interpretation of Landsat satellite images for large areas in the deserts of Egypt has been going on for more than ten years, and its comparison with the pertinent information on groundwater aquifers in these areas deciphered a considerable number of questions regarding the conditions, source and potential of the groundwater.

Various features are interpreted which have strong bearing on groundwater in the arid environment. These include the nature of geological and lithologic units, structural lineaments, present and old drainage systems, distribution and form of water pools, geomorphologic units, weathering surfaces and other weathering phenomena, desert soils, sand dunes and dune accumulations, growths of natural vegetation and agriculture, and salt crusts and other expressions of salinization. The same features could be utilized in the regional exploration and management of groundwater aquifers in the arid zones.

There are many impressive examples which illustrate the significance of satellite image interpretation on the regional conditions of groundwater which could be traced and interconnected over several tens or even several hundreds of kilometers. This is especially true in the northern Western Desert of Egypt, where groundwater issuing from deep strata comes to the surface along ENE-WSW and ESE-WNW fault lines and fracture systems. Fresh to brackish and saline springs, and water pools in the depressions of this part of the Western Desert owe their origin to this striking phenomenon. These include Siwa Oasis Depression, Qattara Depression and El Bahariya Depression. In fact, the livelihood of the population of Siwa Oasis depends on such springs and pools.

Another striking example is illustrated hy the occurrence of fresh to brackish groundwater on the Mediterranean Sea Coastal Zone of the Western Desert where the groundwater is found in the form of lenses floating on the saline sea water. This phenomenon is caused by the presence of certain highly porous and permeahle detrital limestones which belong to a geological unit, extending along the coast, called Alexandria Formation. This latter unit has been delineated, along a distance on the coast of some five hundred kilometers, accurately and in a short time by the interpretation of Landsat satellite imagery.

4.6 *Earthquake Tectonic Studies*

Earthquakes occurred in the environs of the City of Aswan, Upper Egypt, on 14 November 1981 and 2 January 1982 with intervening seismic shocks which are continuing to the present. These earthquakes have been accompanied with conspicuous sound. They caused rock movements, fractures in the earth surface as well as fracturing and small scale collapsing of buildings and installations in Aswan environs.

The main environmental change in the sixties, seventies and eighties in Aswan environs has been the development of Aswan High Dam Reservoir on the course of the River Nile by storing Nile waters starting from 1964. The morphology and some other characteristics of the reservoir have been followed through the interpretation of Landsat imagery. The latter delineates the changing surface of the water in the reservoir, which is in turn dependent on the level of water in it, as well as the progressive collapse of some soft material on its embankments.

It has been illustrated that the water in the reservoir extends normally far beyond the preexisting river channel. Wide tracks of land have been submerged under water alongside the river channel, while in the meantime the reservoir develops arms at the expense of the dry drainage systems which have been submerged under water.

Landsat imagery interpretation has also contributed effectively to the construction of basic maps of Aswan environs leading to greater understanding of its geological-structural setting, an essential element in judging the causes of the seismic activity and assessing its potential in the future. The setting is resolved into the elucidation of old plate boundary in the area of study, lithologic boundaries between the geological units, fractures including faults and folds and circular features.

4.7 *Geological Mapping and Mineral Explorations*

1. One of the most valuable applications of remote sensing and satellite images is that they provide an overview of regional geological structure and features, as well as geomorphology and surface configuration. Most of these features are important in exploration and survey of potential mineral deposits. The combination of satellite, aircraft (especially IR thermal) and field investigation provides powerful approach for mineral exploration.

2. In Egypt, several major projects for geological mapping and mineral explorations were successfully conducted using remote sensing techniques (both satellite and aircraft data) with field studies. These included the preparation of 1:1,000,000 geological, structural and surface drainage maps for the whole territory of Egypt.

Exploration for metallic and non-metallic mineral resources were also conducted on regional and detailed levels, including iron ore and copper deposits, marble, phosphates, natural gas and oil.

V - LIST OF SOME SPECIFIC PROJECTS CONDUCTED IN EGYPT USING REMOTE SENSING TECHNIQUES TO SERVE ECONOMIC DEVELOPMENT PROJECTS

These projects include:

1. (a) *Natural Resources Survey Projects conducted by the Remote Sensing Center in Cairo*

1. Geological Interpretation of ERTS-1 Satellite Images of East Aswan Area (1972).
2. Geological Interpretation of ERTS-1 Satellite Images of West Aswan Area (1973).
3. Geology of Sinai Peninsula from ERTS-1 Satellite Images (1974).
4. Geological Interpretation of Infrared Thermal Images in East Qatrani Area, Western Desert (1974).
5. Geological and Geophysical Investigations of the Suez Canal Zone (1975).
6. Geological and Groundwater Potential Studies of El-Ismailiya Master Plan Study Area (1975).
7. Geologic Interpretation of Landsat Satellite Images for West Nile Delta Area (1975).
8. Hydrogeological and Hydrological Investigations of the Site of Proposed Tunnel at Kantara, Suez Canal Area (1975).
9. Geological and Groundwater Studies at El Dikheila, West Alexandria (1976).
10. Geological Investigation of Gebel Mokattam Area (1976).
11. Geology and Groundwater Potential of Kharga-Dakhla Oases Area, Western Desert, from Landsat-1 Satellite Images (1976).
12. Regional Prospecting for Iron Ores in Bahariya Oasis - El Fayoum Area, Western Desert, Using Landsat Satellite Images (1976).
13. Geology and Groundwater Conditions of Tushka Basin Area (1977).
14. Regional Geological and Soil Investigations of Farafra Oasis - Nile Valley Area, Western Desert (1977).
15. Geological Interpretation of Landsat Satellite Images for Qattara Depression Area, Western Desert (1976).
16. Regional Geological and Soil Investigations of Bahariya Oasis - Siwa Oasis Area, Western Desert (1977).

17. Subsurface Geology and Geochemistry of Pliocene-Quaternary Aquifers in Northwest Nile Delta Area (1978).
18. Prospecting for Iron Ores in North East Bahariya Oasis and Gebel - El Qalamun Area, Western Desert (1978).
19. Local Geological and Groundwater Investigations of Sidi Kreir Nuclear Power Plant Site (1978).
20. Regional Geological and Hydrogeological Investigations of Sidi Kreir Nuclear Power Plant Site (1979).
21. Regional Geology and Tectonics of Sidi Kreir Nuclear Power Plant Site, Mediterranean Sea (1979).
22. Geological and Structural Investigations of the site of Water Storage Tanks in Sector F, El Mokattam City (1979).
23. Delineation of Sand Dunes in Asyut Area, using Landsat Imagery Interpretation (1979).
24. Delineation of Sand Dunes in El Bahariya Oasis Area, using Landsat Imagery Interpretation (1979).
25. Geology, Landforms and Drainage of El Ismailiya Canal Environs (1979).
26. Sinai Peninsula: Landsat Imagery Interpretation Maps, Scale 1: 250,000 (1980).
27. Geologic, Structural Lineation and Drainage Maps of Egypt Scale 1:1,000,000, from the Interpretation of Landsat Satellite Images (1980).
28. Natural Resources Investigation in West Kharga Oasis Plain, Western Desert, Egypt, Using Landsat Imagery Interpretation (1982).
29. Faults and Block Boundaries Interpreted in the Western Side of the Red Sea Between Safaga and Um Gheig, Egypt and their significance (1982).
30. Regional Geological Investigation of Wadi El Allaqi Area, Southern Egypt, from the Interpretation of Landsat Imagery (1983).
31. Groundwater Investigation in Wadi Araba Area Eastern Desert of Egypt, Using Landsat Imagery (1983).
32. Atlas of Sinai Peninsula, from Landsat Images (1980).
33. Earthquake Studies in Aswan Environs, Egypt, Applying space-borne imagery interpretation and other techniques (1984).

34. Space-borne Imagery Interpretation earthquake studies in Aswan (1984).

2. (b) *Agricultural, Soils and Ecological Survey Projects in Egypt*

1. Spectral Reflectance and Photographic Studies on Some Healthy and Nematode - Infected Cotton and Corn Plants in Egypt (1974).
2. Spectral Reflectance and Photographic Studies on Some Healthy and Fungus - Infected Cotton and Corn Plants in Egypt (1974).
3. Spectral Reflectance Studies on Mineral Deficiency in Corn Plants in Egypt (1974).
4. Soil Characteristics in Seven Pilot Areas of South Port Said and Salhiya Plain Area, El Ismailiya Master Plan Region (1975).
5. The validity of Remote Sensing Techniques for an Early Detection of Nitrogen Deficiency in Cotton Plants in Egypt (1976).
6. The use of Photography and Reflectance Data for Detecting Phosphorous - Deficiency in Broad Bean Plants (1976).
7. Soil Investigations at Bahariya Oasis - South Siwa Oasis Area, Western Desert (1977).
8. The Assessment of Surface Area, Siltation and Chlorophyl Distribution in Lake Nasser (Aswan Dam Reservoir) using Landsat Digital Imagery (1978).
9. Monitoring of Desertification Elements in Egypt by Remote Sensing Techniques (1979).
10. Detection of Illegal Narcotic Plantations in Upper Egypt by Remote Sensing Techniques (1980).
11. Land Use/Land Cover Mapping of El Fayoum Depression, from the Digital Processing of Landsat MSS Data (1980).
12. Inventory and Area Calculation of Cultivated Land in Egypt (1980).
13. Monitoring Urban Development of Greater Cairo Area from Sequential Landsat Imagery (1980 and 1982).
14. Classification of Lake Qarun by Digital Processing of Landsat MSS Data (1980).
15. Agriculture and Crop-Area Estimates in Egypt Using Digital Landsat Data (1982).
16. Automatic Classification of Lake Qarun Water by Digital Processing of Landsat MSS Data (1982).

17. Application of Multispectral Aerial Photography in Land Use and Land Cover Mapping of a Part of El Fayoum Depression Northern Egypt (1982).
18. Remote Sensing Investigations on Some Fruit Orchards in El Fayoum Depression Governorate, Egypt (1982).
19. Landsat Digital Data Processing for Estimation of Agricultural Land in Egypt (1983).

3. (c) *Regional and International Projects:*

1. Feasibility Study, Transnational project: The Management of the Major Regional Aquifers in Northeast Africa and the Arabian Peninsula (1977).
2. Feasibility Study on the Use of Remote Sensing and Satellite Imagery Interpretation for the Development of a Crop Information System for Near Eastern Countries (1977).
3. Satellite Mapping - Regional Geology, Geomorphology, Structure, Drainage and Hydrology of Bahr El Jebel Area (Jonglei Canal Project Area), Southern Sudan (1978).
4. Soil Resources and Potential for Agriculture Development in Bahr El Jebel Area (Jonglei Canal Project Area), Southern Sudan (1978).
5. Remote Sensing for Monitoring Resources for Development and Conservation of Desert and Semi-Desert Areas (1979).
6. Land Use/Land Cover and Drainage Mapping of River Sobat Area, Southeastern Sudan, from the Interpretation of Landsat Images (1979).
7. Land Use/Land Cover and Drainage Mapping of Bahr El Ghazal Area, Southwestern Sudan, from the Interpretation of Landsat Images (1980).
8. Classification of Shallow Water Surrounding Qatar Peninsula from the Digital Processing of Landsat MSS Data (1980).
9. Contribution to the Landsat Atlas of Qatar (1983).

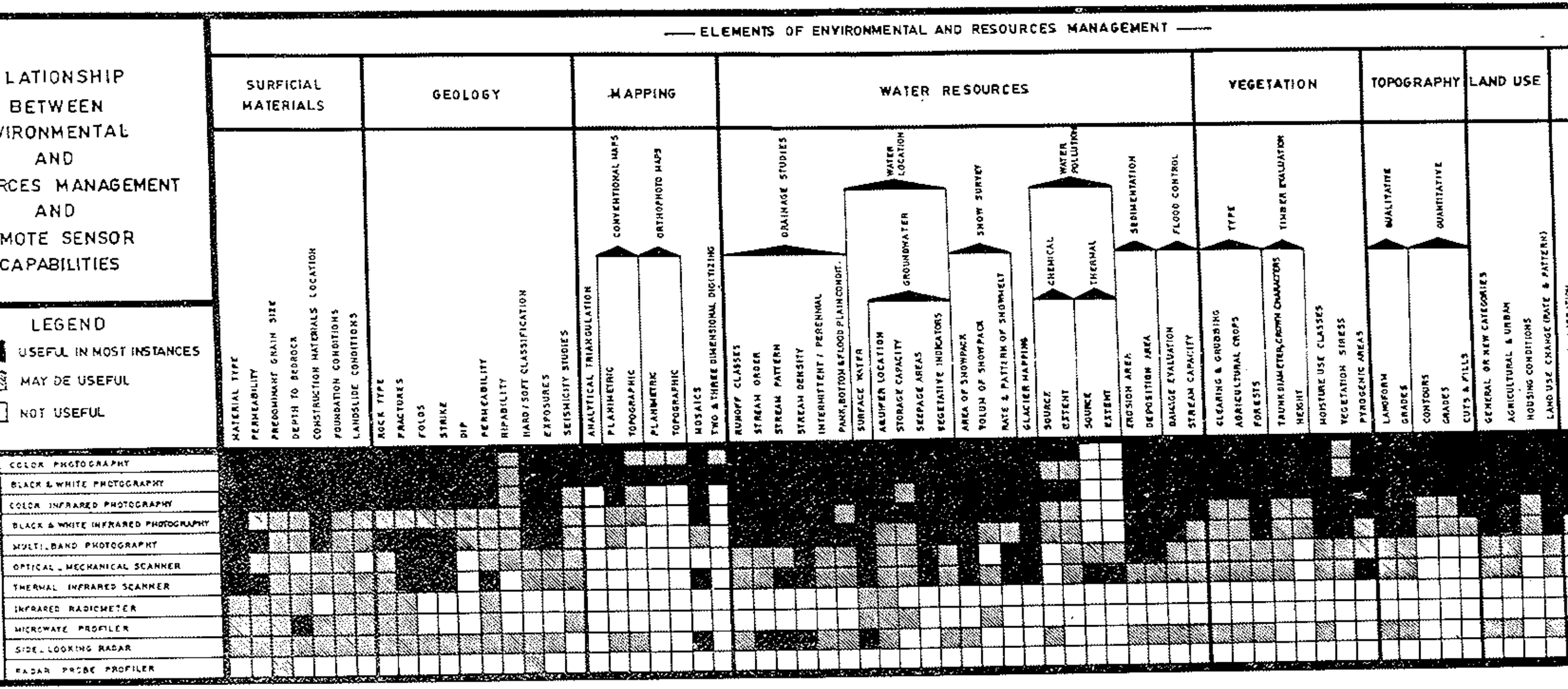

FIG. 2. General uses and limitations of remote sensing in selective spectral and modes in environmental and resources monitoring (Courtesy Raython Company).

VI - Evaluation of the Effectiveness of Use of Different Remote Sensing Techniques in Various Applications

The degree of success in the use of various remote sensing techniques in the survey and management of natural resources depends in general on many factors, some of which are related to waveband, type of sensor, and environmental conditions.

A study for evaluating the effectiveness of these remote sensing techniques in various applications was conducted, and is summarized in Figure 2. This can serve as a guideline for planning by resource specialists in the selection of the most effective method of remote sensing in a specific application project.

SPACE SCIENCE, WEATHER, AND MAN IN TROPICAL AFRICA

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INTRODUCTION

Since the first weather satellite was launched in April 1960, observation from space of the earth's atmosphere and the weather systems embedded in it has developed rapidly in quality and quantity. Today every part of the globe can be viewed at frequent intervals from both orbiting and geostationary satellites. An advantage of geostationary satellite observation is the vast spatial domain served from the vantage point of outer space. There has never been an observational platform with a resolution to coverage ratio of $1:10^8$ as in the case of geostationary satellites. Five of these satellites can provide data on an almost global basis every half an hour. With the visual and infrared sensors on the satellites it is possible to provide coverage on an almost continuous day and night basis. A geostationary satellite is a satellite, the circular orbit of which lies in the plane of the earth's equator and which turns about the polar axis of the earth in the same direction and with the same period as those of the earth's rotation. The period of a geostationary satellite is about 1436.0683 minutes. Its norminal orbit is about 35,778.6657 km. An orbiting satellite on the other hand can have its orbit as near polar as possible. This is determined by the inclination angle necessary to induce a precession of one rotation of an orbital plane in the course of a year. This ensures that the satellite passes over the equator at a fixed solar time rather than a fixed sidereal time, every day. A perfectly polar orbit satellite will not precess. An orbiting satellite can be so placed such that a minimum possible period is only ninety minutes. An orbiting satellite provides full coverage of the earth twice a day from altitudes low enough to permit good ground resolution.

Remote sensing of the earth's atmosphere from space is particularly advantageous in the tropics which is 40% oceanic and whose land area is relatively sparsely populated. Large data lacunae and even conceptual gaps had imposed a fundamental limitation on research efforts into tropical weather systems. Hence the weather systems of the tropics are not as well understood as those of the extratropical areas. The use of satellite data in conjunction with the few ground based observations, has provided new perspectives for looking at the weather systems of the tropics. The prospects of new sources of data and the desire to understand the role of the tropics in the general circulation of the atmosphere had motivated special observational experiments over the tropical oceans in the last two decades. In the late sixties localized experiments in the tropics were mounted. Such experiments included the Line Island Experiment (LIE, 1967) located in the tropical Pacific Ocean, the Barbados Meteorological Experiment (BOMEX, 1969), the Venezuelan International Meteorological and Hydrological Experiment (VIMHEX, 1979) and TROPEX, a tropical field experiment organized by the Russians in 1972. The success of such experiments only underscored the need for more elaborate experiments. The Global Atmospheric Research Program was an international research endeavour which made, as one of its main objectives, the filling of tropical weather data gaps in order to provide means of estimating the effects of smaller scale tropical weather systems on the earth's large scale circulation and to facilitate numerical modelling and prediction by developing better models of tropical weather systems. More relevant to the present discussion is the GARP sub-programme called GATE, that is, GARP Atlantic Tropical Experiment executed during the Summer of 1974. During the experiment, data were collected from about one third of the earth's tropical belt between latitude 20 N and latitude 20 S. The experiment located over the East Atlantic Ocean Area involved seventy-two nations which provided 40 ships, 13 air crafts, a Synchronous Meteorological satellite and several U.S. and USSR orbiting satellites. The GATE experiment greatly stimulated tropical weather research. Since GATE, FGGE, (First GARP Global Experiment), MONEX, (Monsoon Experiment of the Indian Ocean), WAMEX, (West African monsoon Experiment) have also been executed.

It is not possible and perhaps even not appropriate to review the results of all these experiments in this paper. This paper discusses the role played by satellite-derived data in making it possible to observe some prominent features of the weather systems and climate over tropical Africa during the execution of some of these experiments and at other times.

Figure 1 shows the essential ingredients of the weather over Tropical Africa. The Sub-tropical High Pressure systems, the Tropical Easterly Jets (TEJ), the African Easterly Jets (AEJ), the African Easterly waves, the Monsoon systems, the Intertropical Discontinuity, the desert and ocean influences all contribute in varying ways to the weather and climate over the region. The extent to which observation from space-based platforms has helped to define the structure of these atmospheric systems and influences and the promise that satellite-derived data holds for the future in the understanding of the weather and climate of Tropical Africa are the focus of this input to the study week.

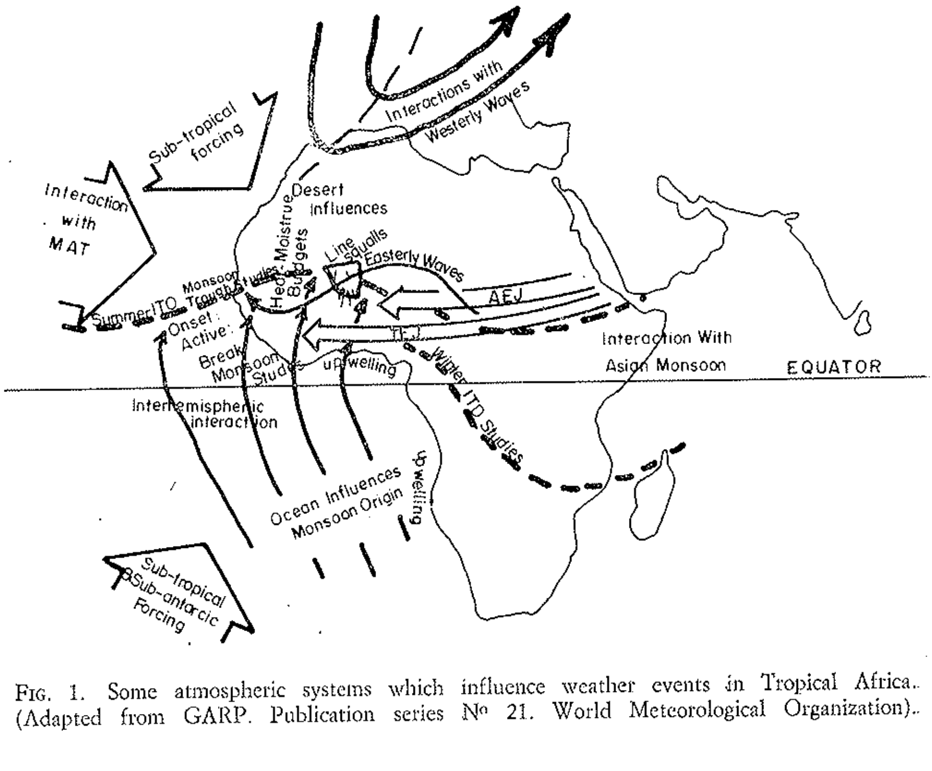


FIG. 1. Some atmospheric systems which influence weather events in Tropical Africa. (Adapted from GARP. Publication series Nº 21. World Meteorological Organization).

Meteorological Parameters Measurable from Space

The number of meteorological parameters measurable from space is only limited by the capability of the instrument that can be mounted on a satellite. Some of the weather and climate parameters that are derivable directly or indirectly from satellite-borne instruments are: cloud cover, atmospheric profiles of water vapour and temperature, surface albedo, rain areas and rain amounts, cloud drift winds, sea surface temperatures, estimates of other atmospheric constituents like ozone, dust etc., earth radiation budget and some other weather related information. The process of retrieving the various parameters can not be adequately covered in this paper. In subsequent sections summaries of the importance of these parameters in weather and climate analyses and the importance of the parameters to the understanding of the weather and climate of tropical Africa will be discussed.

Both active and passive systems aboard satellites are used in the measurement of weather parameters. Active systems, for example radar, send out signals which react with a target and after reaction are observed and measured qualitatively and quantitatively by the system. Satellite-borne active systems now feature prominently in the estimation of rainfall. Radars which perform as scatterometers and altimeters are also active sensors which image the oceans and land surfaces. Passive systems on the other hand observe and measure the natural emanations from the gas and aerosol constituents of the atmosphere or the scattered and reflected solar radiation from the earth and the atmosphere. Much of the early use of the satellite observation has been in the form of the visible and infrared imagery which were registered by passive instruments on satellites. Passive sensors can also detect radiation in the near infrared.

Most of the illustrations in the paper have been obtained from the synchronous meteorological satellite (SMS) which was available over the GATE area, the METEOSAT (the geostationary satellite of the European Space Agency), and from several orbiting satellites belonging to the United States of America and other countries. Special mention needs to be made of the METEOSAT because of its unique view of the African continent (from an altitude of 36000 km) with most of the continent being within 30° of the subpoint of the satellite and because most of the data presented in this paper was derived from its observations.

The principal pay load of the satellite was a multispectral radiometer which had two identical adjacent visible channels in the 0.4-1.1 μm spectral band, a thermal infrared channel in the 10.5-12.5 μm band and an infrared water vapour channel in the 5.7-7.1 μm band. The water vapour band is normally operated in place of one of the visible channels and because of that, two possible sets of images are available in any thirty-minute period: images with 2.5 km resolution in the visible channel and images with 5 km resolution in the infrared channels, or images with 5 km resolution in the visible channel and a 5 km resolution in the infrared channels. The latter set of images was used in the results presented in this paper. METEOSAT-I was also part of the global network of five geostationary meteorological satellites placed around the equator at intervals of approximately 70° longitude to generate cloud images during the First GARP Global Experiment (FGGE). Of interest in the preparation of this paper were observations from two of the other five satellites GOES-I and GOES-E in orbit over the Indian and the Atlantic oceans respectively. GOES-E was a replacement for the SMS.

Cloud Cover Over Tropical Africa

A striking feature of any satellite imagery of the Earth in the visible or infrared band is the presence of clouds. Satellite observed cloud cover of weather systems provided the first clues to the three-dimensional structure of the atmosphere. Clouds indicate weather processes. Configurations of cloud patterns often reflect the motion of air that carried them. Repeated occurrence of certain types of clouds often indicates the frequency of a specific set of atmospheric conditions that are responsible for the clouds. Apart from indicating weather processes, clouds also make impact on global weather in two important ways, through the albedo effect and the greenhouse effect. Because clouds are efficient scatterers of solar radiation (80% can be effectively reflected by clouds a few hundred meters thick) increased cloud cover means increased amount of the total solar radiation scattered and less energy to be absorbed by the earth's surface. This is the albedo effect. At thermal infrared wavelengths clouds are efficient absorbers and so infrared radiation from the earth surface is absorbed and reradiated downwards by the clouds so that the temperature of air near the earth surface increases. This is the greenhouse effect. There is a complex interplay between these two effects but recent investigations indicate that the cloud albedo effect is dominant.

Starting with observations from the early generation of satellites

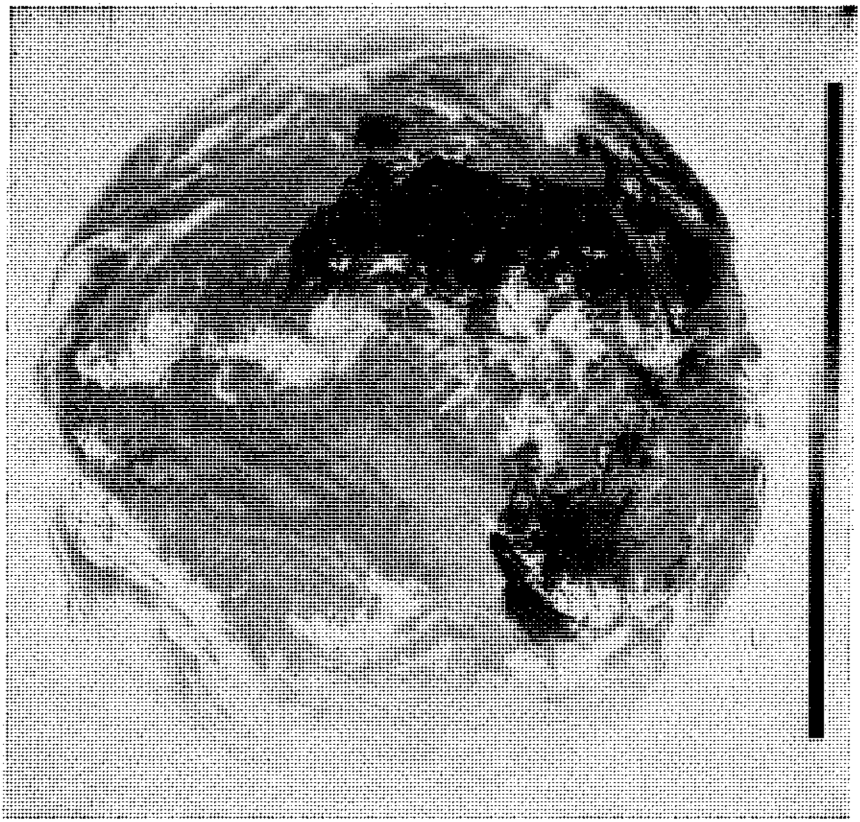


FIG. 2.

(e.g. TIROS series 1960-1966, ESSA series 1966-1969) researchers attempted to compute average cloud cover over the earth surface (Sadler, 1968; Taylor and Winston, 1970). With subsequent generation of satellites, it was possible to study the behaviour of large-scale disturbances in Tropical cloudiness (Balogun, 1972, 1975; Zangvil, 1975; Chang, 1970; Reynolds and Vander Haar, 1977; Yanai and Murakami, 1970; Wallace, 1971, Wallace and Chang, 1972; Martin and Schreiner, 1981 and others). Despite the unremitting research effort the nature of the large scale cloud fields over the tropics and its relationship with the large scale wave disturbances have not yet been clearly understood. Even spectral analysis of the cloud fields only succeeded in giving approximate estimates of the space and time scales of these disturbances.

Figure 2 shows an infrared imagery of cloud organization over Africa from METEOSAT I. The band of cloudiness over tropical Africa is made up of cloud systems in different scales of organization. In the following subsections, a further discussion of the various scales of cloud organization over tropical Africa will be presented.

Mean Cloud Cover

The mean cloudiness map prepared by Sadler (1975) shows similar features to the map shown in figure 3 even though with less details, especially as it concerned the land area of West Africa. The mean cloud cover shown in the figure was for only 32 days at the peak of the monsoon rains over West Africa. The source of data is the METEOSAT and the method of estimating the cloud cover was that developed by the author (Balogun, 1977). The significant feature of the map is that there is a zone of maximum cloud cover some 500 km south of the surface position of the Intertropical Discontinuity (ITD). The surface of transition be-

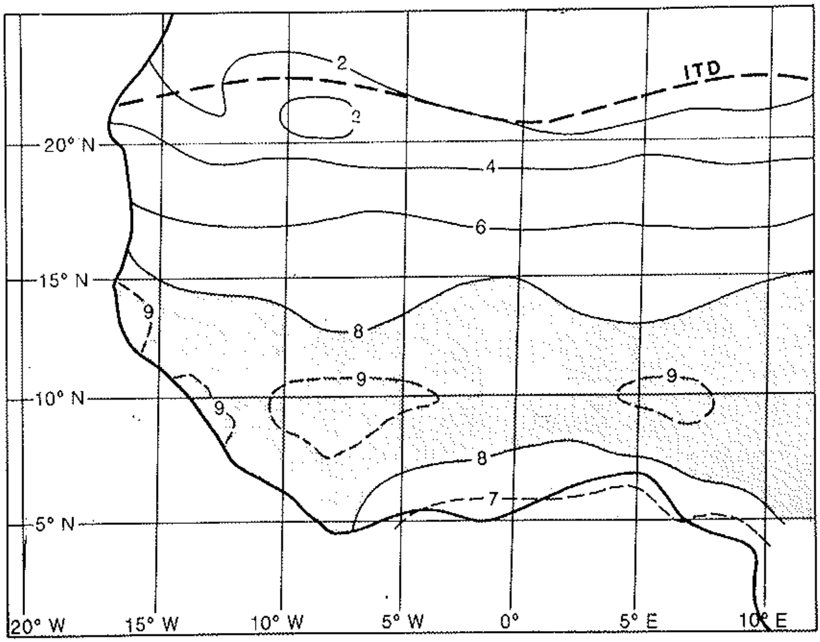


FIG. 3. Mean cloud cover in tenths for the period July 15th to August 15th, 1979, using infrared imageries from the Meteosat.

tween the moist monsoon air stream and the dry air mass from the Sahara is known as the ITD surface. The intersection of this surface with the ground has a migrating position between Lat. 4°-6° N (in January) and Lat. 22°-25° N (in August). The northernmost position of the ITD is therefore observed around the middle of August and at that time, the slope of the ITD surface is about one in five hundred.

That the zone of maximum cloudiness is not closer to the surface position of the ITD than it is as revealed by the satellite is not difficult to explain. Near the ground position of the ITD, the depth of the moist layer is small and vertical development of clouds is inhibited by the dry Saharan air aloft. However, that the zone of cloudiness did not extend further south than it is, given the fact that the moisture layer is deeper to the south, cannot be easily explained. That this zone of cloudiness marches north and south is indicated schematically in Figure 4. Zone C in the figure corresponds to the zone of maximum cloudiness in Figure 3. Figure 4 was composed by the author from conventional data sources, (other earlier authors, notably Hamilton and Archibold, 1945; Walker, 1958; Adejokun, 1966, have identified similar zones), and it illustrates how the zone of maximum cloudiness shifts in the meridional direction during the course of the year over parts of West Africa.

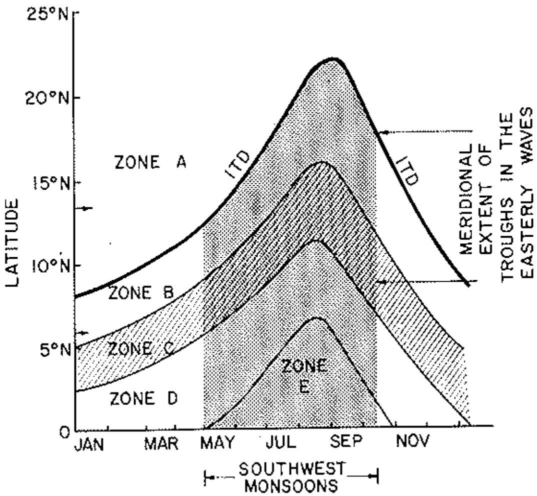


Fig. 4. Meridional variation of the ITD position at about longitude 7°E and the weather zones over Nigeria.

Cloud Clusters

The mean cloud cover over an area does not give an indication of the various cloud organizations that constitute it. Figure 5 shows the satellite imagery from the Defence Meteorological Satellite (DMS, United States Government). The picture shows various clouds assemble over East Africa. (Picture taken June 1, 1977). A cloud cluster is defined as a distinct persisting cloud mass (essentially of convective origin) containing very deep convection during some parts of its life. The average life time of these clusters has been found to be about 24 hours (Martin and Schreiner, 1981). With the help of satellite data it has been possible to study some characteristics of the cloud cluster. Their tracks, time of occurrence, their sizes have been studied and classified. To some extent their thermodynamic structure is known. What is still a mystery about these systems is the atmospheric mechanisms that trigger them off, and the mechanism for their dissipation. It is still not clear why some of these clusters move rather slowly and some, like the West African squall lines, move fast. Because of the importance of the West African squall lines as major rain-bearing systems over West Africa, they will be given special attention in a subsequent subsection.

Figure 6 shows the DMS picture of the same areas in Figure 5 for June 3, 1977. By that time the cloud clusters shown in Figure 5 had cleared with some new ones just developing. The figure also shows very clearly the East African lake systems. Figure 7 shows the frequency and the time of occurrence for cloud clusters as estimated from satellite (SMS-1) during GATE. More clusters are observed in the late afternoon than at any other time of the day over the West African land areas while a bimodal distribution is observed over the East Atlantic Ocean and at the coastal areas. Figure 8 shows a schematic diagram of the distribution of various types of clusters at 113000 on July 27, 1979, over West Africa. That convection can be organized on different scales and with different structures within the same air stream is a feature of the West African atmosphere that is still being investigated.

Figure 9 shows the vertical extent of the tops of samples of cloud clusters of different size categories over the West African region during July 14 to August 15, 1979. The diagram shows that the larger the cloud cluster, the more probable it is to find very tall cloud elements within it. The cloud heights and cloud areas were estimated from the METEOSAT observations with the aid of a computer.

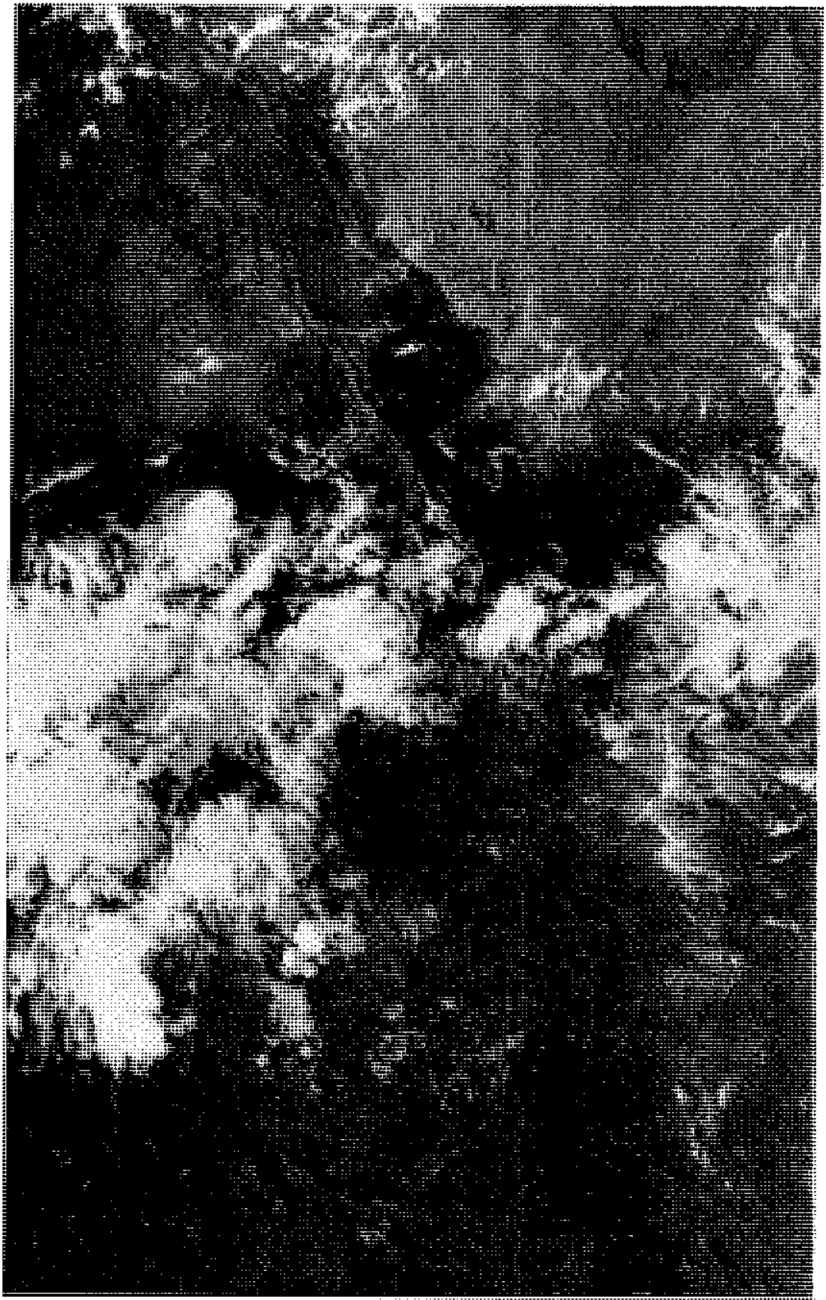


FIG. 5. East Africa.

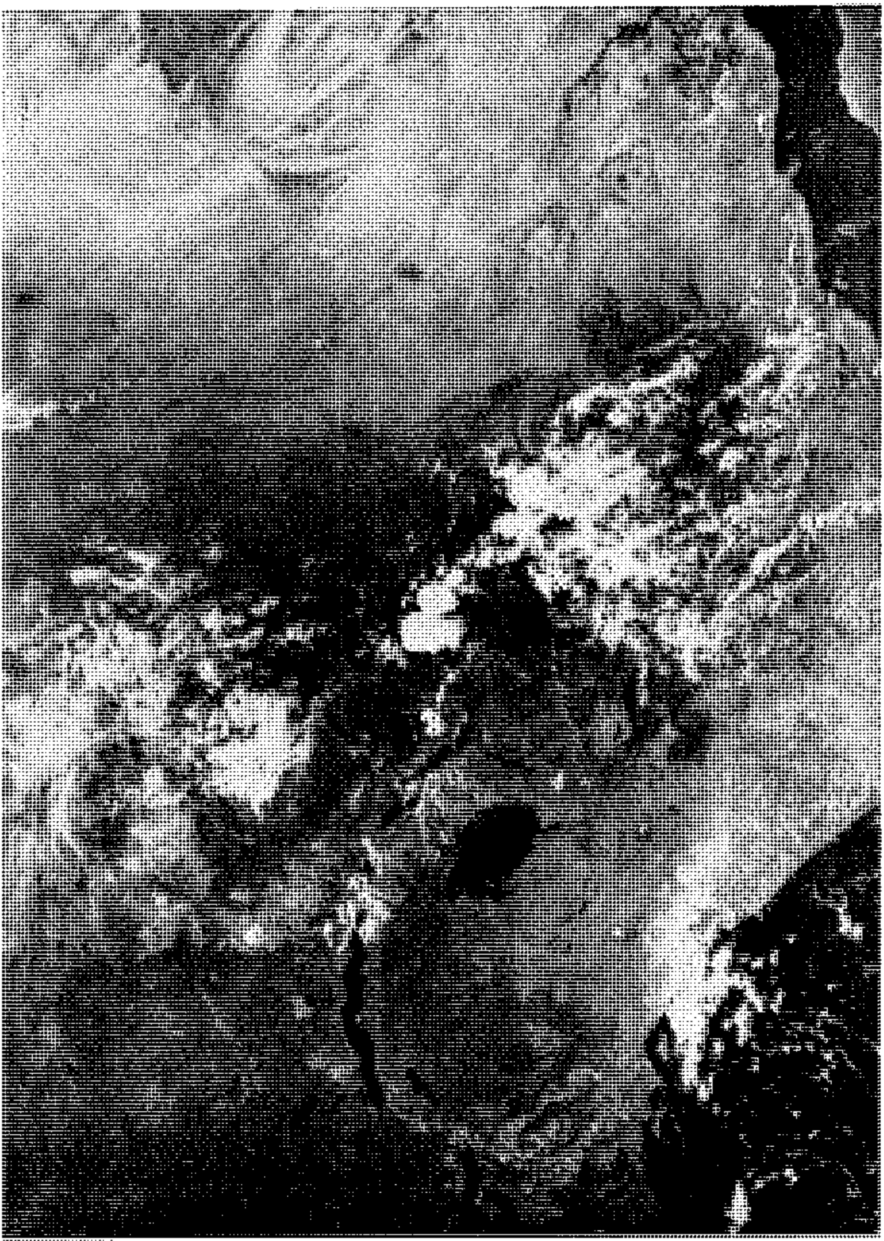


Fig. 6.

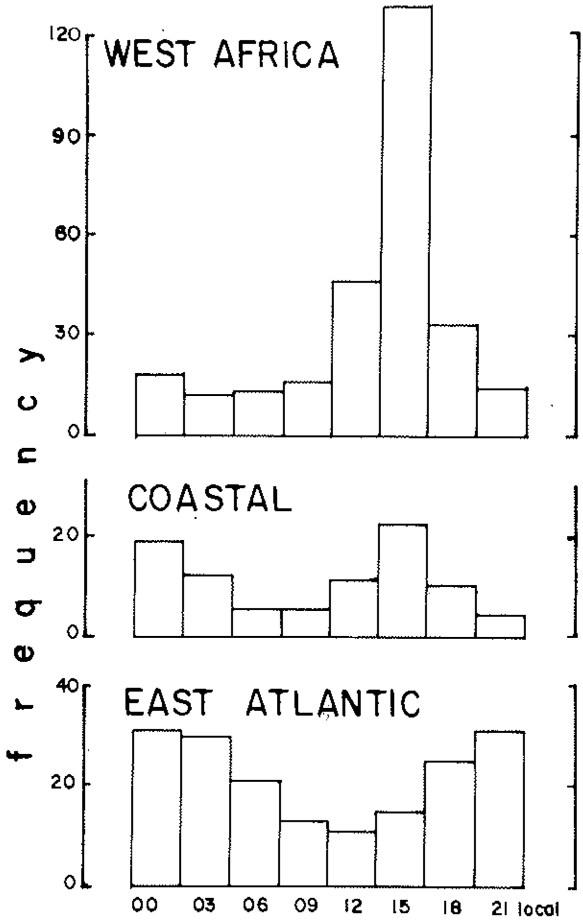


FIG. 7. Time of cloud cluster appearance and frequency (After Martin and Schreiner, 1981).

West African Squall Line

The squall line is an important rain-bearing system over West Africa. The system accounts for more than two-thirds of the rainfall over the Sahel and contributes substantially to the rainfall in other areas of West Africa. The importance of these systems to Agriculture and Water resources management over the region can not be over emphasized. Squall lines are different from other cloud clusters only in their propagation speeds and their vertical wind shears.

The West African Squall line system has been reported upon by merchants and by scholars centuries ago. Hubert (1926), Brooks (1932), and Regula (1936) have provided some information about these weather systems. The quest for the origin of the disturbances that eventually develop into hurricane and the revelations of satellite imageries motivated several publications on the disturbance over West Africa during the middle and late nineteen sixties. Publications by Arnold (1966, 1967), Carlson (1969, 1971), Frank (1963) and others focussed attention on the variety of systems over the land areas of West Africa and the adjacent oceans. More recent investigation by Olori-Togbe (1981), Balogun (1981), Burpee (1976, Dhonneur (1974), Tschirhart (1958), La Roux (1976), Latrasse (1972), Obasi (1974), Payne and McGarry (1977), Okulaja (1970), Aspliden *et al.* (1976), Houze (1977), Fortune (1980), Frank (1978), Tourre (1979), Bolton (1981) have produced a wealth of ideas about the squall line system over West Africa. Reports from special experiments like the Operation Niger ASECNA have also provided some information. Most

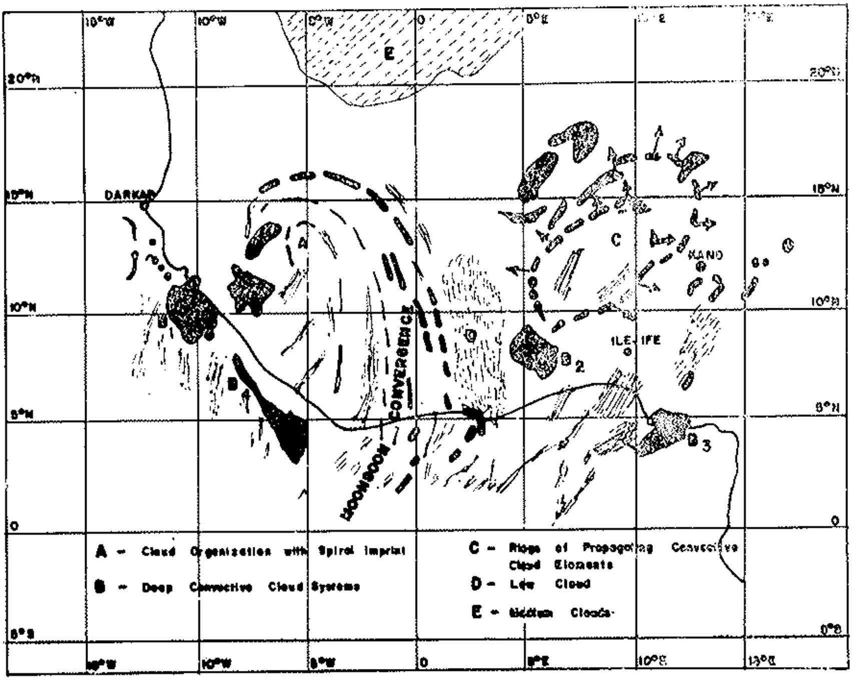


FIG 8. Approximate schematic representation of cloud organization at 113000Z, July 27th, 1979 (day 208).

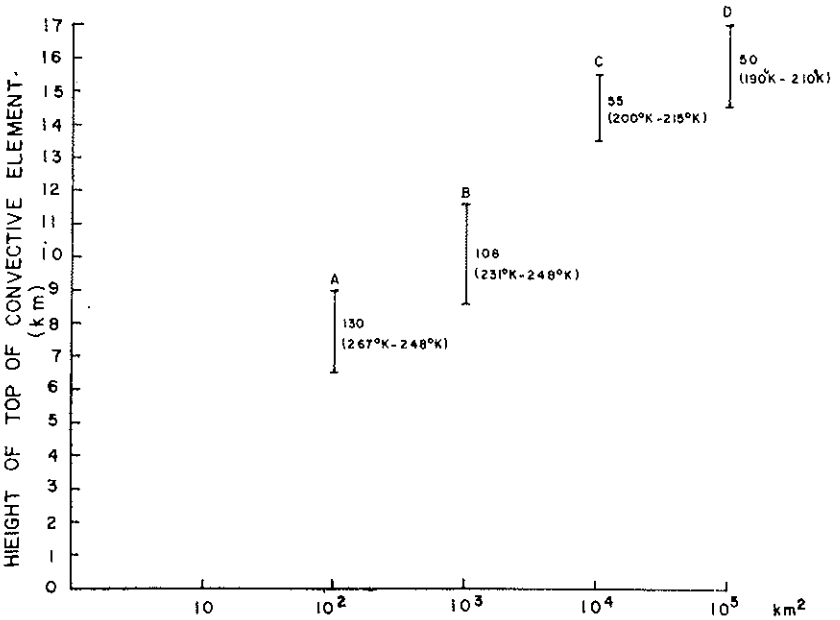


FIG. 9. Order of magnitude of cloud organization.

of the research efforts used satellite data in varying degrees. The following characteristics of the squall line have been established or confirmed by satellite data:

(a) They are identified in both infrared and visible images as distinct cloud masses characterized by explosive growth, and high brightness.

(b) They propagate generally from East to West. Most squalls move directly westwards rather than towards the Northwest or Southwest. The speed of propagation is between 15 ms^{-1} and 18 ms^{-1}.

(c) Their leading edges are usually arc shaped while their edges are generally rather indistinct and fibrous. Roll clouds are sometimes visible along the leading edge and sometimes detached from the main cloud system.

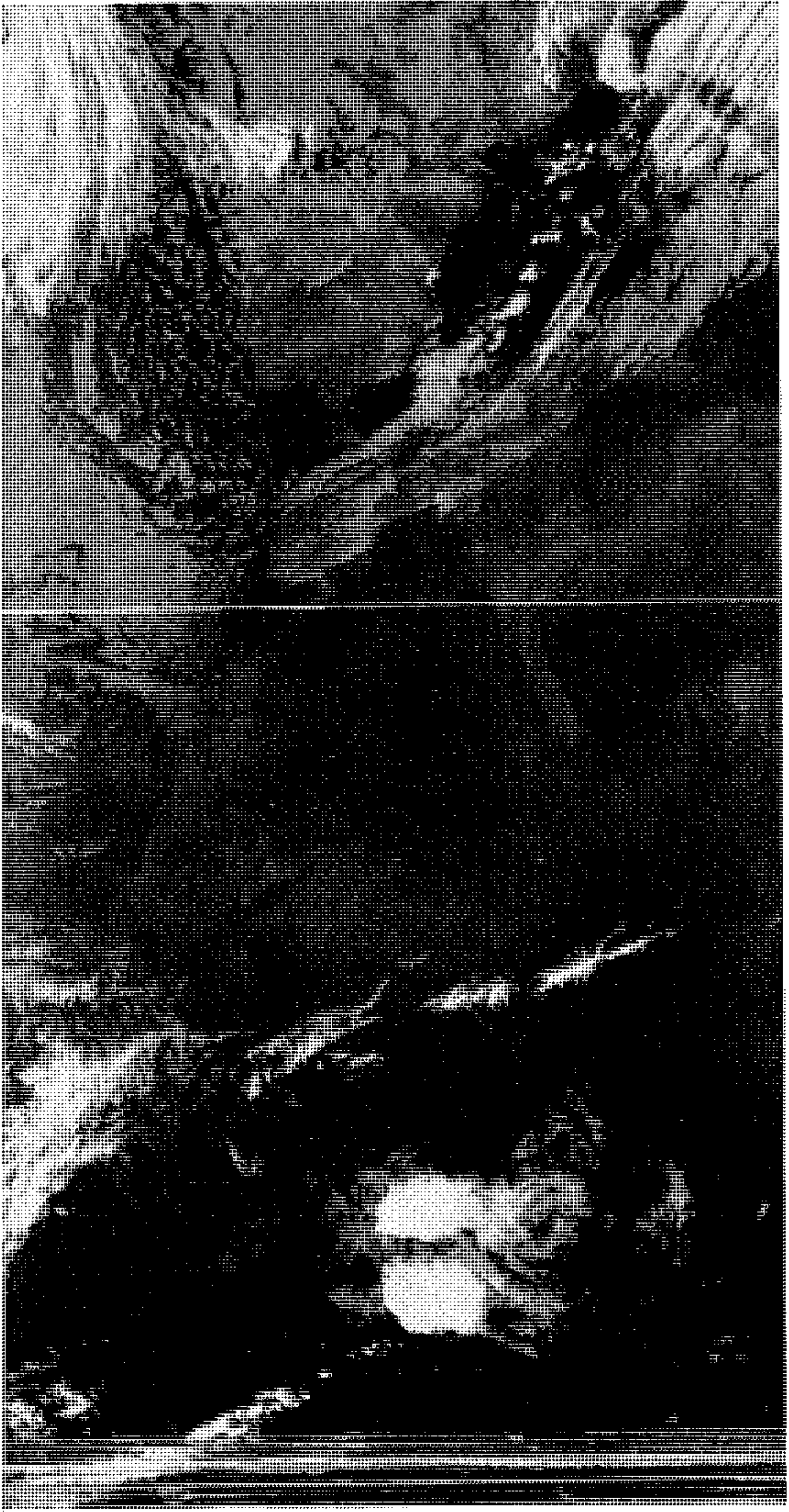
(d) Their cloud masses achieve areas about 1° square and have lifetimes of at least six hours. Cloud masses could achieve a length about 300-1000 km long and lying roughly North-South over the West African region.

(e) Squall lines forming over the West African land mass often dissipate on arriving at the coast. Squall lines forming over the oceans often differ in their orientation and direction of motion from squall lines forming over land.

(f) Tops of cloud element within the squall line may grow up to 17 km.

Several classifications of squall lines as seen by satellites have been made by some authors. Latrasse (1972) classified squall lines into two main types depending on whether they are made up of one or two arcs. Gurka (1976) using both visible and enhanced infra-red images identified four types depending on the relationship of the arc front to the main cloud mass. Balogun (1984) using data from DMS and the METEOSAT concluded that only three independent types of squall line cloud structure could be isolated. Type one is gibbous-like in structure with a well-defined convex leading edge and fibrous at the rear. Figure 10 is representative of this type. Roll clouds may or may not be discernible in front of the convex leading edge. Sometimes the gibbous-like structure may exist as a doublet as shown in Figure 11. Type two is usually made up of a long line of cumulonimbus ensemble oriented mainly in the north-south direction. The leading edges are not so well-defined as in type one and roll clouds ahead of the leading edge may or may not be seen. The impression is given of a "beaded" well developed cumulonimbus cloud. Fibrous exudants are also visible to the rear of the system. Figure 12 shows a representative of this type of squall line. The third type often appears as a semicircular ring of cumulonimbus clouds in which clouds are not as well developed as in type two and in which the clouds are not strictly of north-south orientation as in type two. Near the left edge of figures 12 and 13 are rings of propagating convective clouds which belong to this class of squall line systems. It should be noted that convection is not of the same intensity around the rings. Figure 12 has been enhanced to show the convective cores of the cloud systems.

In spite of these research efforts, there are still many unanswered questions about the West African squall lines. The important factors which if present in the right order of magnitude and at the right time within the basic flow could trigger off the chain of convection in a squall line are not known. Although there have been good suggestions as to the relationship between squall lines and low level vortices, waves and the two jet systems (AEJ and TEJ), the precise relationships are still not yet known. The prediction and detection of potential areas of initiation



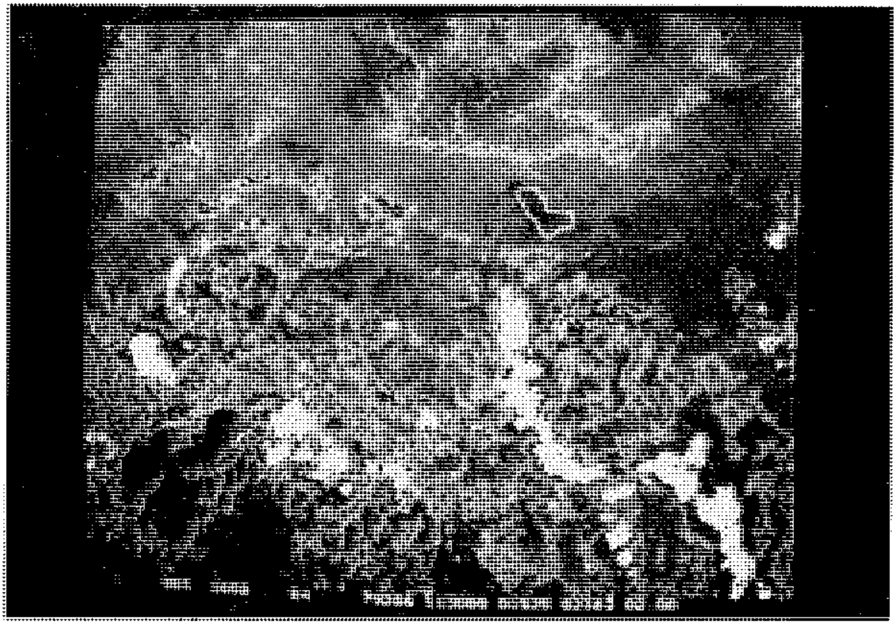


FIG. 12.

FIG. 13. Cloud rings on left-hand side.

and formation of squall lines are still difficult. Satellite data can still play a significant role in solving these problems. Rapid scan observation of the squall line system can be used effectively to detect the characteristics of the system during its formation stages. Use of such rapid scan products have so far not been reported in the study of West African squall line systems.

Satellite-Derived Cloud Drift Winds over Tropical Africa

Reports of wind measurement from conventional sources (radio sonde, pilot balloons etc.) are usually not of sufficient quantity or quality to carry out reliable wind analysis for weather forecasting purposes over tropical Africa at any given time. Weather forecasts can not be based on climatological wind maps which have been composed over long periods and from various sources (ships of opportunity, aircrafts etc.). That wind directions and strength remain the same for long periods over the tropics is a general statement that is not totally supported by recent experiments in the tropics. The great potential of satellite-derived windfields in the tropics and elsewhere lies in the improvement over conventional data sources in both temporal and spatial resolution. Even where radiosonde observations are abundant, such observations are normally available at 12 hour intervals which is too infrequent to describe the development in any meteorological phenomena particularly those occurring at subsynoptic scales. With an image frequency of one per half-hour from geostationary satellites it is possible to estimate wind flow reliably from a sequence of three images. It is now even possible to obtain an image frequency of one image in every 6 minutes from some of the existing satellites. Such rapid scan images permit computation of subsynoptic scale motions which characterize severe local weather events.

The philosophy behind estimating winds from cloud displacements from a sequence of images from geosynchronous satellites is predicated on the assumption that if cloud tracers are properly chosen and tracked their motion will reflect the speed of the air in which they are imbedded. Several metbods have been developed to estimate cloud motion from satellite imagery. Tbese range from manual to fully automatic methods. The important steps in all procedures are: a properly aligned sequence of imageries, objective criteria for cloud selections, calculation of cloud displacement and altitude assignments of the displacements. The various methods, the assumptions usually made, and the problems associated with

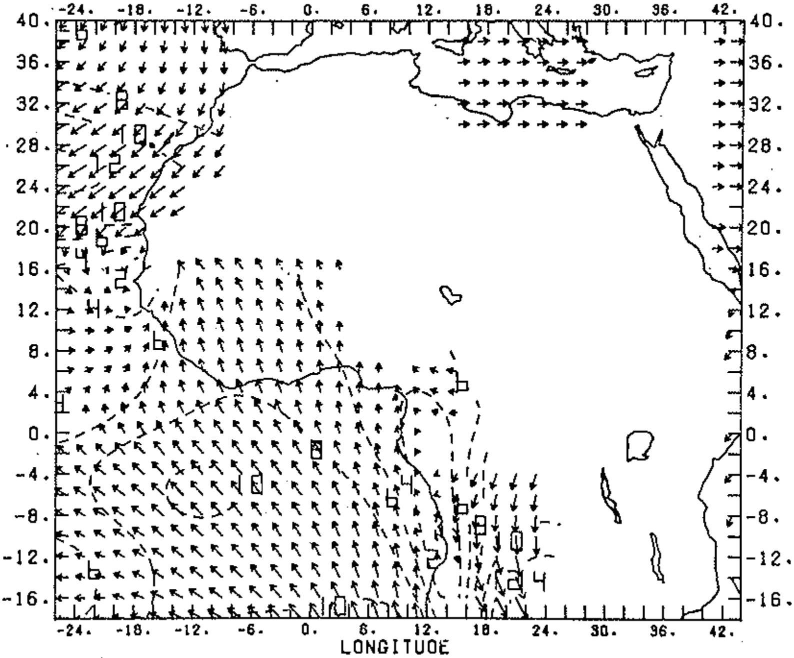


FIG. 14. Satellite-derived low level winds for 1200Z, July 18, 1979.

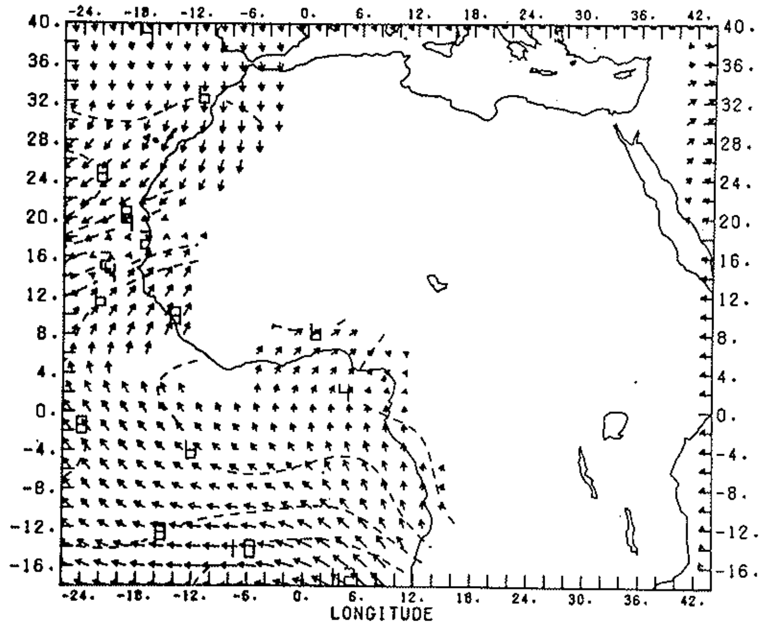


FIG. 15. Satellite-derived low level winds for 1200Z, July 20, 1979.

each step have been discussed by various researchers, among whom are Izawa and Fujita (1968), Hubert and Whitney (1971), Hasler and Smith (1976), Fujita *et al.* (1975), Bauer (1976), Suchman and Martin (1976), Hubert (1979) and Balogun (1982). In spite of the enthusiasm for satellite-derived cloud drift wind, it was also soon realized that the data set was a meteorologically biased set, that is, such data could only be obtained in cloudy areas. Attempts were therefore also made to estimate water vapour drift winds from satellite measurements. These attempts, (Mosher, 1977; Johnson, 1979; Kaestner *et al.*, 1980; Balogun, 1982 and several others) have been largely successful and have provided useful air motion data in cloud free areas.

Attempts at computing cloud drift winds over tropical Africa from METEOSAT data are shown in Figures 14-19. Figures 14 and 15 represent flow at the low levels of the troposphere (900-850 mb). Figures 16 and 17 represent flow at the mid-troposphere (650-450 mb) and Figures 18 and 19 represent atmospheric flow at the upper levels of the troposphere (200 mb). In each case, motion fields were computed from a sequence of three half-hourly photographs from the METEOSAT. Motion at the low levels was obtained by tracking low level cumulus cloud organization. Vectors in Figures 14 and 15 represent the direction of low level monsoon flow and the isotacs represent the strength of the flow. It is observed that winds were stronger on the 18th of July at the Gulf of Guinea than on the 20th of July, 1979. Such wind fields, and the noticeable changes in wind direction and strength which they can exhibit within forty eight hours could not have been obtained from conventional wind data. Tbe significance of such wind changes in the Gulf of Guinea and the southern Atlantic to weather events in West Africa is still under study by the author and his colleagues at the University of Ife, Nigeria.

Figures 16 and 17 represent mid-tropospheric flow. The important thing about these windfields is that they were obtained by tracking water vapour fields. Carefully tracked imageries of moisture in the water vapour bands (5.7-6.3 μm) are thus capable of revealing atmospheric motion between 650 mb and 450 mb level in the atmosphere. The subtropical high pressure system is very prominent in the northwestern portion of Africa in both figures. Figure 16 contains more water vapour wind vectors and apart from showing the subtropical high pressure system also shows a wind maximum (maximum of 12 ms^{-1}) around Latitude 12° N. This wind maximum can be associated with the African Easterly Jet (AEJ) whose core is known to be situated at about 700 mb level. Water vapour

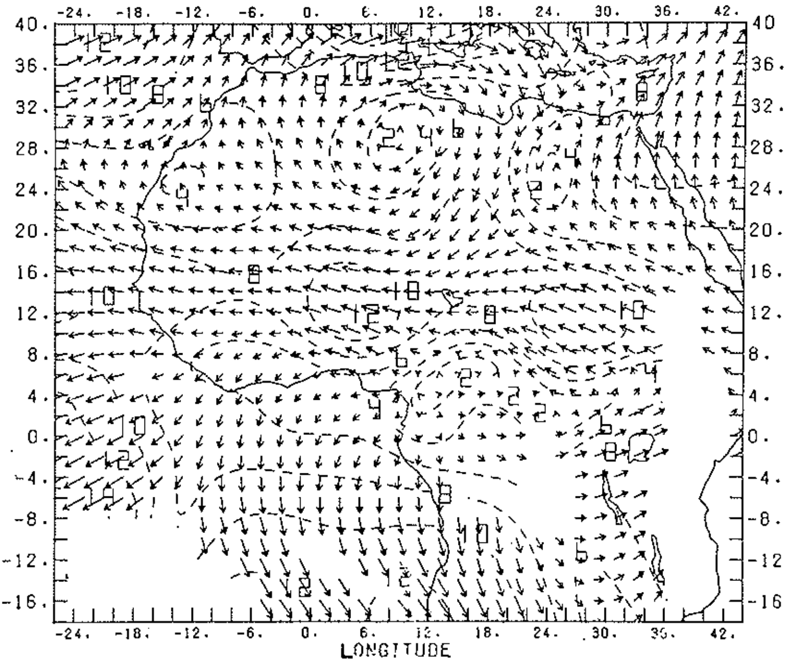


FIG. 16. Satellite-derived middle level winds for 1200Z, July 23, 1979.

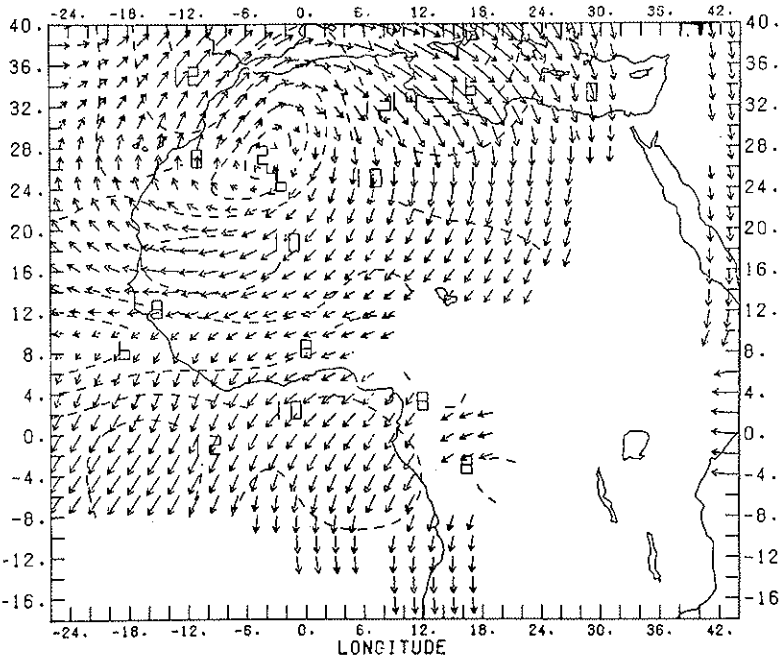


FIG. 17. Satellite-derived middle level winds for 1200Z, July 15, 1979.

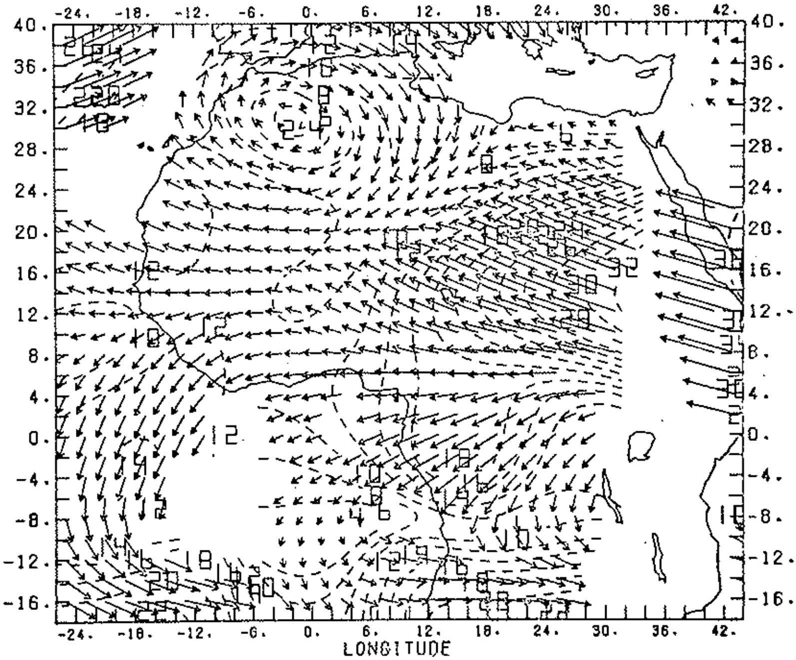


FIG. 18. Satellite-derived upper level winds at 1200Z, July 25, 1979.

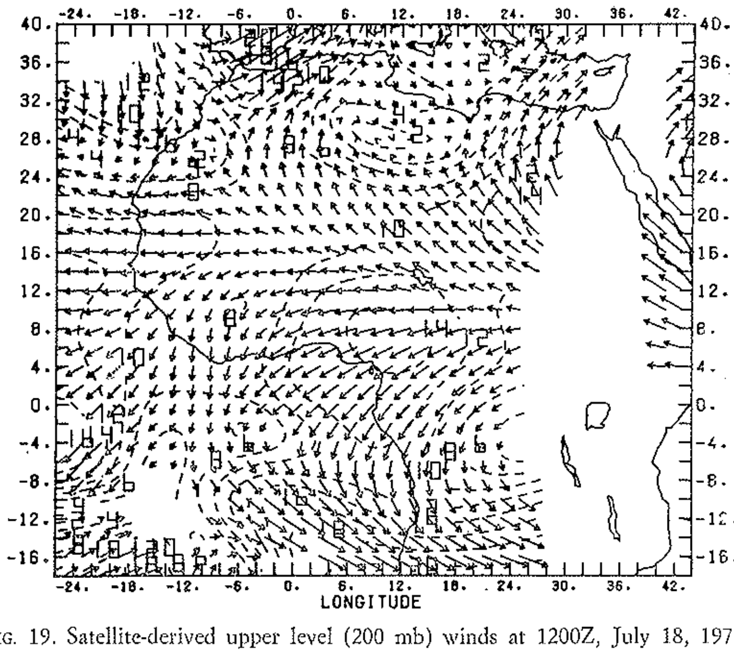


FIG. 19. Satellite-derived upper level (200 mb) winds at 1200Z, July 18, 1979.

drift winds therefore provide a means of studying the characteristics of this jet and its impact on the weather systems of Tropical Africa.

Figures 18 and 19 are samples of the upper level wind field obtained by tracking cirrus clouds. The subtropical high pressure systems in the two hemispheres and the Tropical Easterly Jets (TEJ) are indicated in the two diagrams. These systems are more prominent on July 25, 1979 than on July 18, 1979. These windfields have been computed from METEOSAT data.

At this juncture some relevant questions may be asked. How accurately can the cloud displacements represent the wind? How accurately can different cloud trackers reproduce the same set of winds? How internally consistent are these drift winds? These questions have been addressed by some researchers referenced earlier and the conclusion is that flow fields obtained by tracking cumulus and cirrus clouds approximate the flow at tbe low levels (900-850 mb) and at the upper levels (200 mb) to within the accuracy of currently available ground truth data (that is data from raw-wind system). The error characteristics of water vapour drift winds are still being determined but the initial results of computations are very encouraging.

Estimates of Rainfall from Satellite Data

Publications by Martin and Scherer (1973), Barret and Martin (1981), Atlas and Thiele (1981) have reviewed the different stages in the development of precipitation measurement from space. The problems and prospects of monitoring rainfall from space were fully discussed in those publications. Attempts are often directed towards achieving two goals, namely: to delineate accurately rain areas from satellite imagery and to make quantitative estimates of rainfall from satellite radiance measurements. The success in attaining the first goal is impressive but in spite of some encouraging results, there are still major obstacles in the way of achieving the second goal. This is because most of the results obtained so far rest on uncertain assumptions. Satellite-derived rainfall estimates however hold promise in providing data for rainfall inventories, droughts and floods, water resources management, crop growth and production etc.

Barret (1980) has developed a cloud-indexing method to monitor rainfall from satellite imagery over some North African countries. This method establishes cloud indices for all significant cloud cells observed in satellite images and related conventional observations. These methods have been used operationally with some success in some countries. Results of the applications of this method for rainfall estimation over the Sahel and south of Sahel is not available to the author and therefore its success or failure over such areas can not be discussed in this paper.

Barret (1970), Woodley and Sancho (1971), Kilonsky and Ramage (1976), Scoffield and Oliver (1977), Stout *et al.* (1979), Barret (1980) have discussed in detail such techniques as brightness technique, cloud system life history technique, highly reflective cloud technique, threshholding technique, cloud indexing technique, parameterization technique etc. Some of these can only be applied with confidence over the ocean areas and some have been tested only in the temperate regions without consideration for the special circumstance of the tropical land areas. Difficulties in organizing rainfall data from conventional sources and almost complete absence of useable radar data needed has retarded the process of developing a scheme for estimating rainfall from satellite radiances over the countries around the Guinea coast. Preliminary investigation by tbe author (see Figures 20 and 21) using rainfall figures from rain gauges and cloud cover estimates from ESSA satellites over Nigeria for the coastal stations (coast to Latitude 10° N) and the inland stations (Latitude 10° N to 14° N) indicate that while an association between monthly mean rainfall and cloudiness may be obtained for inland stations, there may be considerable difficulties in drawing such conclusion between rainfall and cloudiness for the coastal regions. Most of the precipitation inland is from convective cloud. Precipitation along the coastal areas is from both convective and non-convective clouds and variations in cloudiness do not necessarily follow the variations in mean rainfall amount. Current efforts are being made to establish some relationship between cloudiness and rainfall using data from the METEOSAT for the West African land areas. Of interest at the University of Ife also is the establishment of rainfall inventory for the West African Squall line system using data from the same satellite. Progress on these projects depends on availability of funds. Such investigations should prove useful to agricultural and water resources management over the region.

Satellite Studies of the African Easterly Waves

African Easterly Waves or simply African Waves are the wave-like disturbances which propagate westward across West Africa and the Atlantic Ocean. Early observational studies of these waves by Arnold

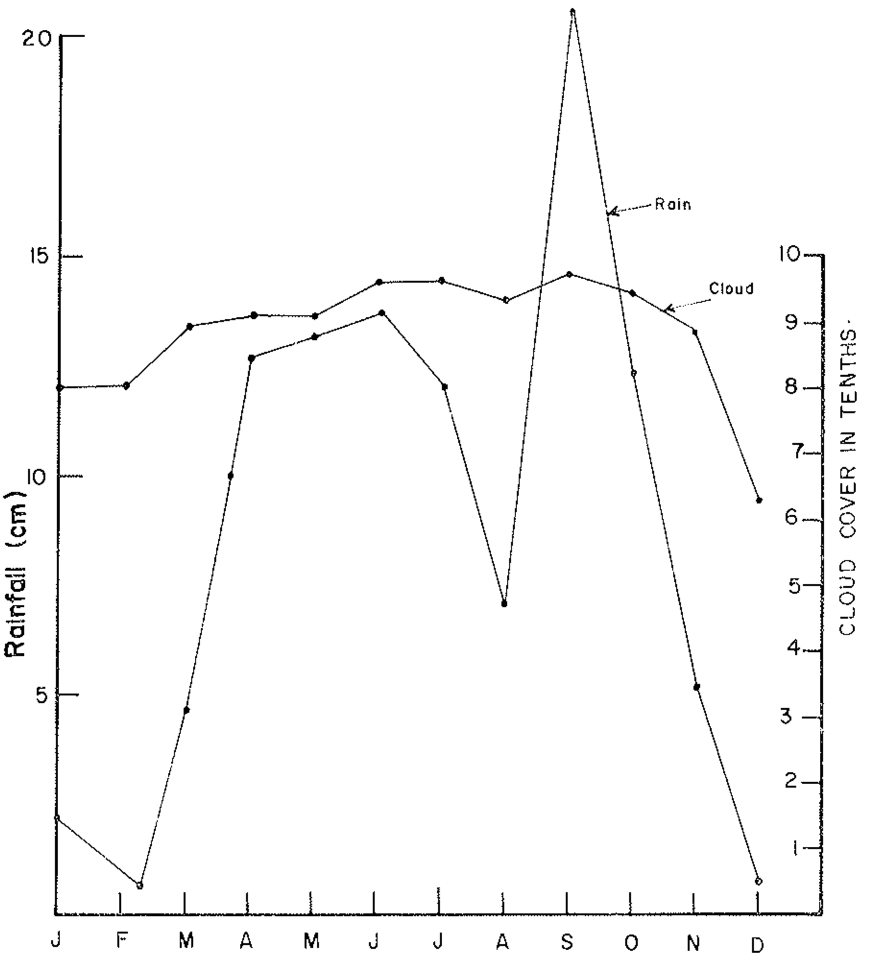


FIG. 20. Monthly mean cloud amount and monthly mean rainfall between the coast and Lat. 10°N over Nigeria.

(1966), Carlson (1969), Frank (1970), Burpee (1972), emphasized the importance of the wave system to the development of tropical cyclones in the Atlantic Ocean. Frank (1970) has shown that as many as half of all Atlantic Tropical cyclones develop from the African waves. More recent studies by Burpee and Dugdale (1975), Balogun and Tecson (1975), Rennick (1976), Reed *et al.* (1977), Thompson *et al.* (1979), Albignat and Reed (1980), Spencer (1981) focus attention on the origin, structure, and energy transformations of the wave system as it moves across the tropical African region and the Atlantic Ocean. In most of these studies satellite photographs have been used in conjunction with conventional data. Burpee (1972) suggested that the waves originate at 700 mb level near Longitude 30-35° E and that the waves are most intense at about Latitude 12° N. Later studies show that the waves amplify mainly between longitude 0°-10° E and that the waves do not have the same structure in their course. The waves are known to derive their energy from the baroclinic and barotropic

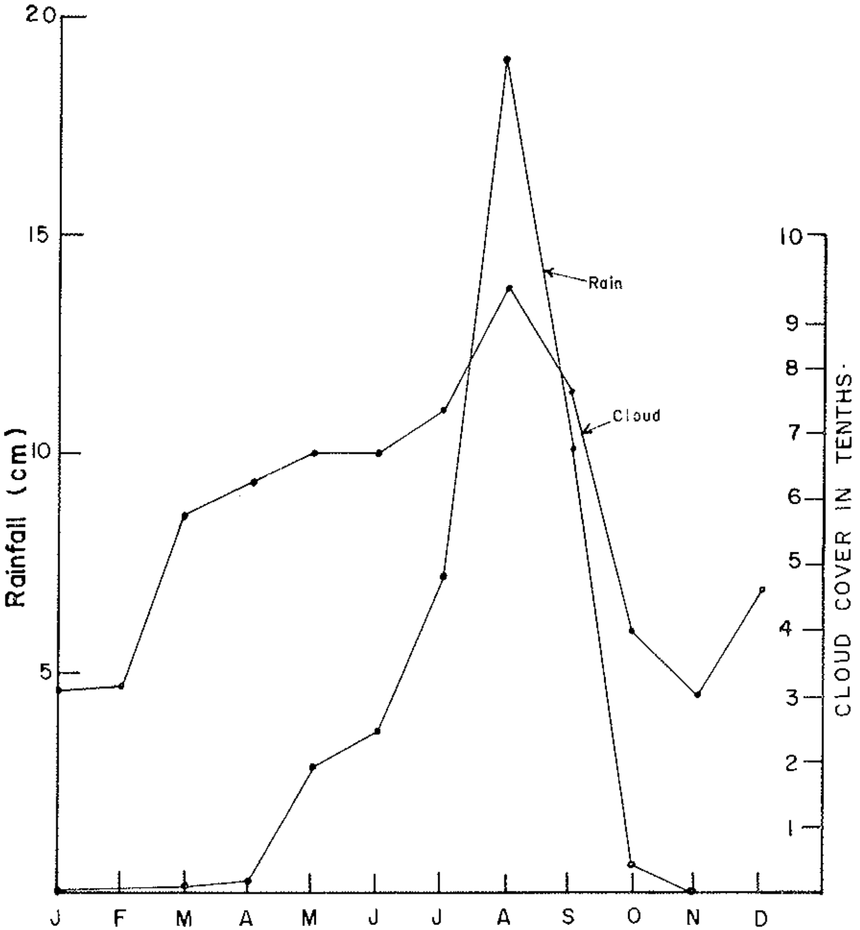


FIG. 21. Monthly mean cloud amount and monthly mean rainfall between Lat. 10°N and Lat. 14°N over Nigeria.

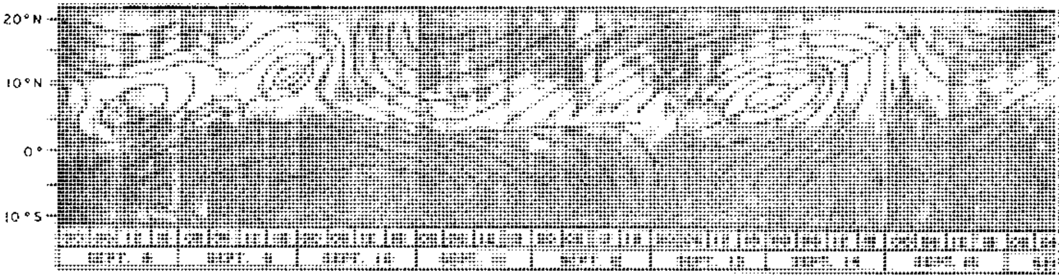


FIG. 22. (See text). After Balogun and Tecson 1975.

instabilities of the mean flow. The formation of these waves is tied to the presence of the AEJ. Waves form in the zone of cyclonic windshear on the south side of the jet axis which itself is located north of Lat 12° N. Waves intensify as they propagate across West Africa with a period of 3-5 days a mean wavelength of 2,500 km and a westward phase speed of 7-9 ms^{-1}. The importance of these wave systems to Tropical Africa is that they modify weather events over the region. Convergence and precipitation feature prominently ahead of the trough line of the wave system and squalls are known to develop in that section of the trough.

Composited satellite data have been very helpful in understanding the wave structure. Figure 22 is a time latitude section of SMS infrared pictures at six-hour intervals from September 8 to September 16, 1974. This mosaic is composed of longitudinal rectangular strips five degrees wide and centered at 23.5° W near 10° N and extending from 10° S to 20° N. Superimposed on this mosaic is the 700 mb wind analysis of observations from ships along 23.5° W. The heavy solid line indicates the trade wind confluence zone, and the trough axis appears as a heavy dashed line. Figure 22 is an illustration of how satellite imagery could be used to elucidate an atmospheric event.

SURFACE ALBEDO MEASUREMENTS FROM SATELLITE DATA OVER WEST AFRICA

The recent or more properly the on-going drought conditions over the tropical African region (Sahel, parts of Sudan, Ethiopia, Somalia, etc.) have engendered considerable interest in the climate of desert and semi-desert regions of the world among various scientists in recent times. The social, political and environmental consequences of the drought have been discussed by Glantz (1977 a,b)) and many others. An important aspect of the discussions on the drought condition is the role played by man in bringing about such conditions. It is believed by some scientists: Charney (1975), Berkofsky (1976), Otterman (1977), and some others, that the drought situation over the desert regions of the world may have been a result of increased surface albedo over those regions and that the increased albedo could be traced to man's activity in the regions. The reasoning goes as follows. As a result of overgrazing and other poor land management practices, these semidesert regions are further deprived of the little vegetation they have. The reduced vegetation leads to increased albedo. The high albedo means that more of the solar radiation that impinges on the earth surface is reflected back to space. This leads to a net radiative loss over the regions relative to its surroundings. The atmosphere near the ground cools and sinks. Sinking motion in the atmosphere is not conducive to the growth of clouds and because of the reduction in cloud formation, there is also a reduction in precipitation. There are a few scientists who hold contrary views but the weight of the opinion is in favour of such a theory or a slight modification of it.

The Sahara desert is currently the world's largest desert. It extends from the Atlantic Ocean to the Red Sea. The Sahelian region extends from west to east and lies at the southern periphery of the Sahara desert. It receives a long term average annual rainfall of between 200-600 mm. As it is a marginal climatic zone it is subject to a wide variation of precipitation in both time and space.

The Sahelian region encompasses six countries: Senegal, Mauritania, Mali, Niger, Bourkina-Fasso and Chad. The satellite therefore becomes a useful tool in monitoring atmospheric events over the region. In particular, computations of albedo variations over the region between 1967-1974 from satellite data have been carried out (Norton *et al.*, 1979) using SMS-1 imageries. The unexpected finding from that investigation which has been confirmed by observations from Landsat is that overgrazing from arid and semiarid regions has a tremendous impact on increasing surface albedo. Figures 23-25 from Norton *et al.* were computed from SMS imageries and confirm that satellite data could be used to monitor albedo changes over a large territory.

It should be noted at this juncture that apart from using satellite data for estimating albedo changes, satellite data is also becoming very useful in documenting incident and net solar radiation for agricultural, weather and climate monitoring. The existing ground-based pyranometer network produces very limited information on net solar radiation estimates.

Temperature and Moisture Profiles from Satellite Soundings over Tropical Africa

Even in the parts of the world where radiosonde facilities to measure temperature and moisture profiles in the atmosphere are relatively abundant, observations are made, probably for economic reasons, once in twelve hours. Radiosonde facilities over Tropical Africa are few and far between. Observations are usually made once a day at most of the radiosonde stations if at all. Maps showing temperature and moisture fields over tropical Africa for weather forecasting purposes are therefore difficult to prepare. Climatological maps have limited use in weather forecasting. Some examples of estimates of moisture content and temperature profiles over parts of West Africa computed from satellite data are presented in

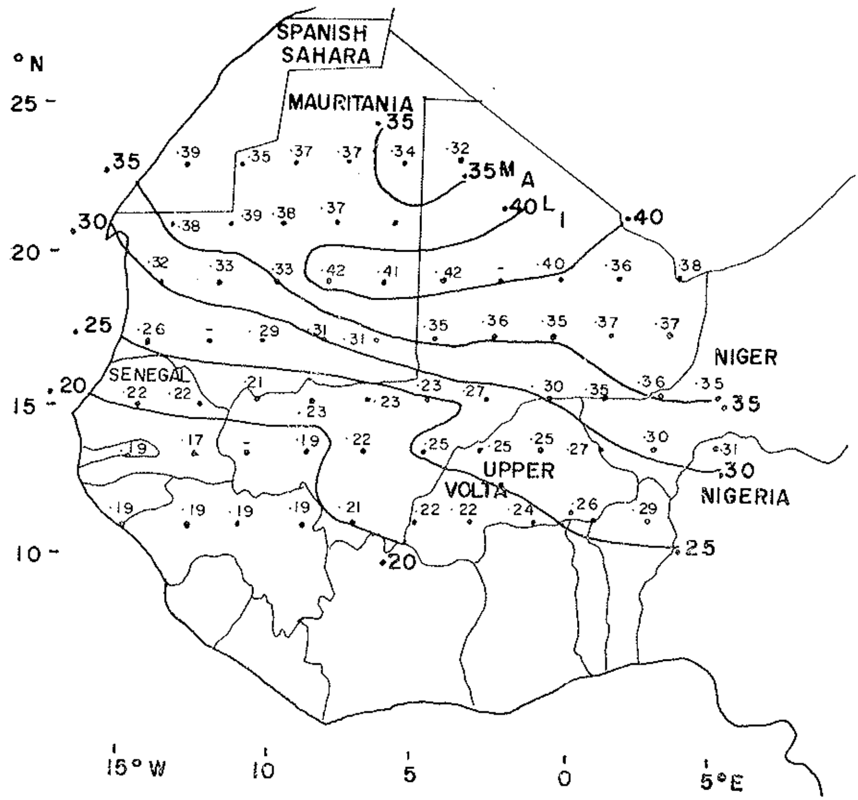


Fig. 23. Surface albedo over the Saharan Region for 19 November 1967 (1223Z) by Norton *et al.*, 1979.

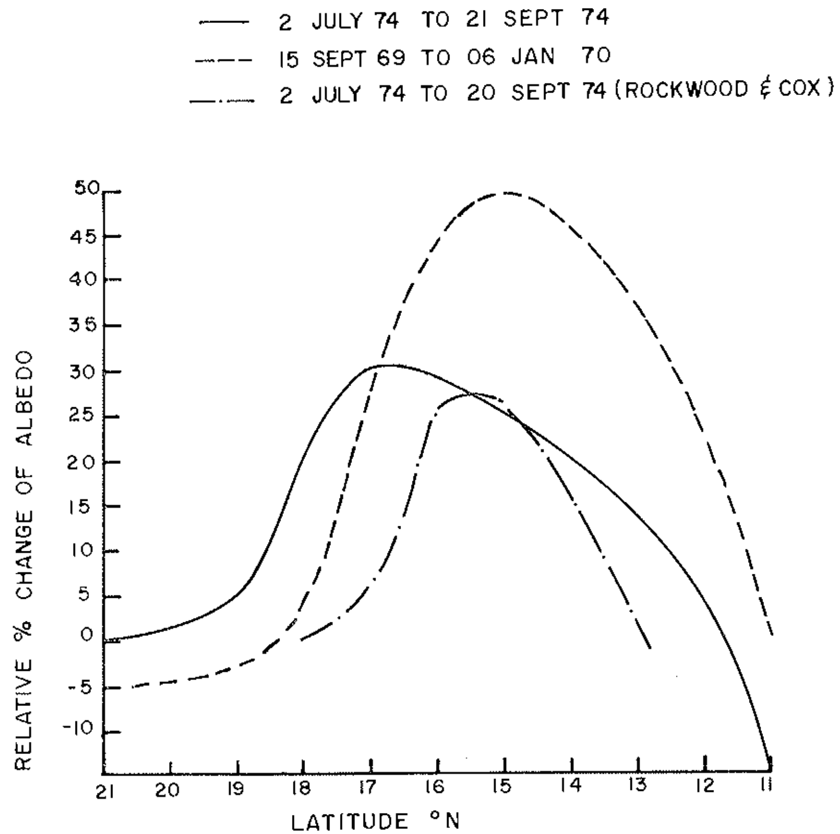


FIG. 24. Seasonal surface albedo change over the Sahel (after Norton *et al.*, 1979).

this paper to illustrate the fact that satellites can provide such information on an operational basis if the facilities and the manpower are available.

Literature now abounds on the theories relating satellite radiance measurements to the temperature and moisture distributions in the atmosphere. Details of the various methods used and the different stages in the development of the methods can be obtained from Kaplan (1959), Wark and Fleming (1966), Malkevich *et al.* (1969), and in more recent publications by Smith and Howell (1971), Smith *et al.* (1979), Lauriston *et al.* (1979), Hayden *et al.* (1981).

The concept of determining the vertical profile of an atmospheric parameter, be it temperature, water vapour or ozone from spectral radiance measurements, is based on the fact that atmospheric absorption and transmittance are highly dependent upon the wave length of the radiation and the amount of the absorbing gas. At frequencies close to the centre of absorbing gas, a small amount of gas results in considerable attenuation in the transmission of radiances and therefore most of the outgoing radiation arises from the upper levels of the atmosphere. On the other hand at frequencies which are far from the centre of the band, a relatively large amount of absorbing gas is required to attenuate transmission, therefore at those frequencies most of the outgoing radiation arises from the lower layers of the atmosphere.

For the determination of temperature, the appropriate absorption bands are those of carbon dioxide at short wave and long wave infrared, that is at 4.3 μm and 15 μm respectively, and that of oxygen at microwave lengths, that is, at wavelengths of 0.5 cm. The profiling of moisture is accomplished by utilizing the absorption bands of water vapour in the infrared at the wavelengths of 6.3 μm and 18 μm and in the microwave at 0.8 cm and 1.35 cm. The satellite radiance measurement in these spectral intervals depends both on the concentration and the temperature of the absorbing component. The concentration of CO_2 in the atmosphere is uniform. That of water vapour is not. The problems of temperature retrieval are therefore more tractable than those of moisture retrievals.

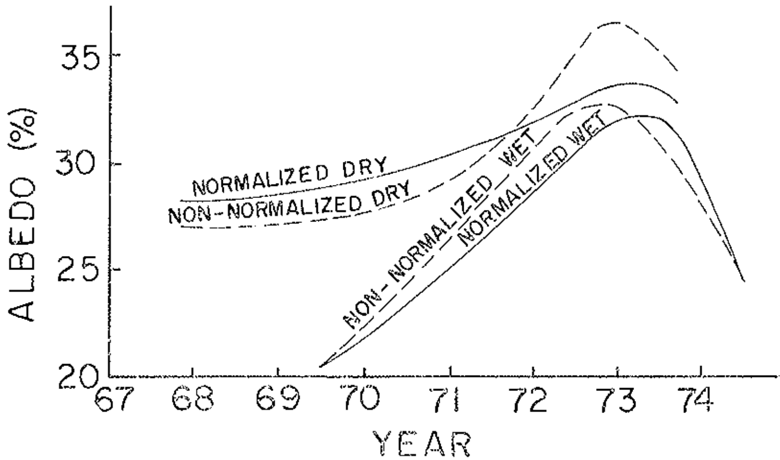


FIG. 25. Quasi-annual variation of the Saharan mean albedo (12°N to 18°N) for wet and dry season (after Norton *et al.*, 1979).

The radiative transfer equation can be written as,

$$R_{(\nu)} = B[\nu, T_{(x_0)}]\,\tau[\nu, x_0] - \int_0^{P_s} B[\nu, T_{(x)}]\, d\tau/dx\,[\nu, x]\, dx$$

The spectral radiance is given by $R_{(\nu)}$. The planck radiance at frequency ν and temperature T is denoted by $B(\nu, T)$. The independent variable x can be any single value function of pressure and $\tau(\nu, x)$ is the fractional transmittance of the atmosphere above the level x for radiation at frequency ν. The subscript 0 refers to the surface. The first term is the boundary term and represents the component of the outgoing radiation that arises from the surface and is attenuated by the atmosphere. The other term originates in the atmosphere itself and is weighted by the function $d\tau/dx$. Figure 26 shows the weighting function for eight channels of a sounding spectral interval.

The equation shown above requires special treatment in that the solution is non-unique. Several algorithms for solving the equation are described in the literature.

The estimation of moisture profile in the atmosphere is not as straightforward as the estimation of temperature profile. It is in fact more meaningful to estimate total precipitable water (i.e. the total atmospheric water vapour content in a vertical column of unit cross-sectional area extending between the earth's surface and the "top" of the atmosphere. Over ninety-five per cent of the vapour is between the surface and 300 mb however), than to estimate the vertical profile of water vapour. Detailed accounts of the systematic approach to retrieving water vapour interactively are now available at a few research centres in Europe and the United States of America. An illustration of the results of precipitable water retrieval over some locations in West Africa presented in this paper has been accomplished by the author using the facilities of the National Earth Satellite Service (NESS) laboratory at Madison, U.S.A. A summary of the problems and the assumptions that are involved in estimating moisture content from satellite-measured radiances have been given by Hayden (1981). The main elements of the philosophy behind the moisture retrieval at NESS is as follows. Three channels on the High Resolution Infrared Radiometer Sounders (HIRS) on both TIROS-N and NOAA-6 satellites are used. These channels are spectrally located at 8.3, 7.3 and 6.7 μm and covered the atmospheric regions between the ground surface to about 300 mb level. Temperature and moisture profiles are obtained mainly from atmospheric components of the radiance measurements rather than

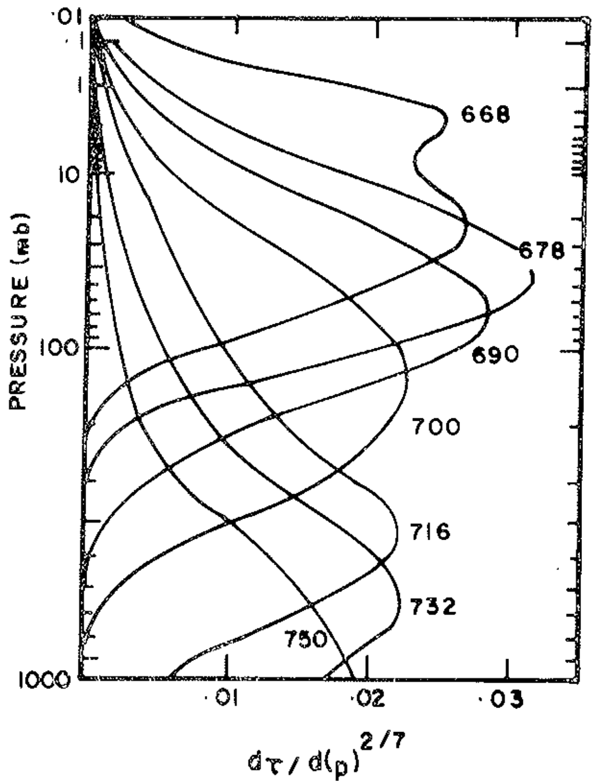


FIG. 26. Transmittance weighting functions in the 15 μm CO_2 band. Shown beside the peaks of the curves are the wave numbers (cm^{-1}).

the total radiance measurement, using multiple regression. The regression coefficients are obtained from an independent sample of current radiosonde measurements regressed against brightness temperature calculated from same radiosonde measurements. Surface contributions to radiance measurements are correctly identified and removed. In the case of retrieval over West Africa, the regression was done against climatological data as current radiosonde data was not available.

Figures 27, 28 and 29 show temperature profiles at three locations over West Africa on October 21st 1981. Figure 30 shows the temperature distribution on the 700 mb surface. Although vertical temperature profiles do not show inversions characteristic of the atmosphere over the region, the differences between the profiles and the distribution of temperatures

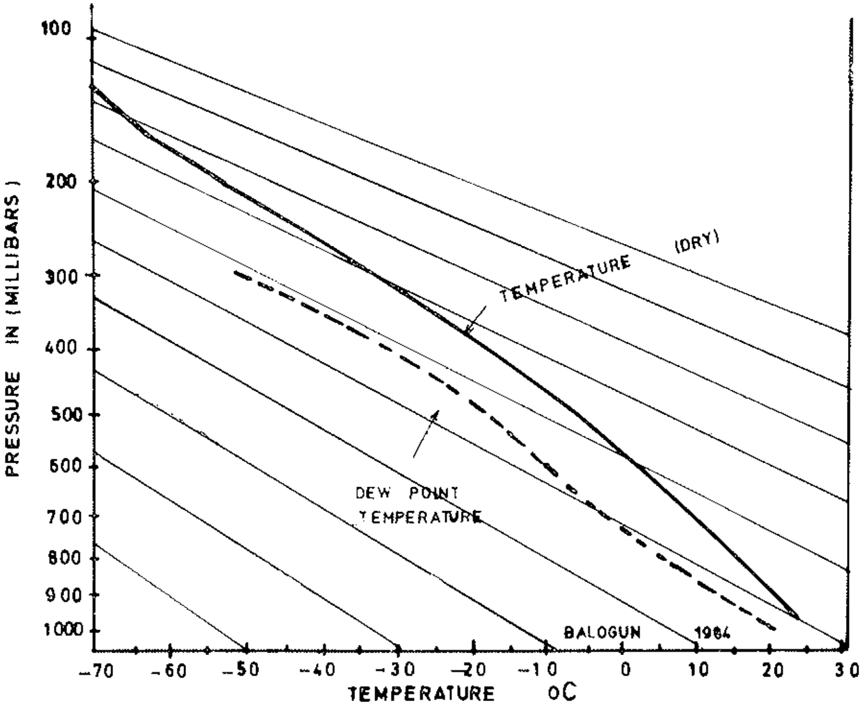


FIG. 27. Vertical distribution of temperature at lat. 12.45N, long 8.43E from NOAA-6 satellite measurements, 21 October 1981.

on the 700 mb surface confirm that satellite-derived temperature fields can at least indicate useful temperature gradients over areas of interest.

Figures 31 and 32 show the distribution of precipitable water over parts of the Gulf of Guinea and some parts of the Sahel respectively. The values of precipitable water obtained compare very well with those obtained from radiosonde measurements. More studies of temperature and moisture profiling in the tropical African areas need to be carried out so that the reliability and the errors characteristic of such data sources can be established.

One also needs to mention at this point the possibility of estimating the skin temperature of earth's land and sea surfaces. The need to estimate surface energy budgets has prompted research in those areas. The retrieval goal for sea surface temperature (SST) of a root-mean-square accuracy of 1.0°C has largely been achieved and SST maps for many ocean areas have been produced. The potential use of such maps in the study of upwelling processes along the Guinea Coast of West Africa and the characteristics of ocean surfaces along the coast of East Africa is immense.

There are also on-going experiments to map soil surface temperature over the Sahel with the ultimate goal of developing the ability to monitor soil moisture over the region. The TAMSAT (Tropical Agricultural Meteorology using satellite and other data) programme of the University of Reading, England, has for some time now been looking into the potential use of satellite and other data to aid agriculture in the Sahel region. This programme, which is sponsored by the United Kingdom Overseas Development Administration, looks into the possibility of inferring soil moisture from surface temperature derived from thermal infrared channel of METEOSAT. The TAMSAT programme also operates in collaboration with the Agrihymet Centre, Niamey, Republic of Niger.

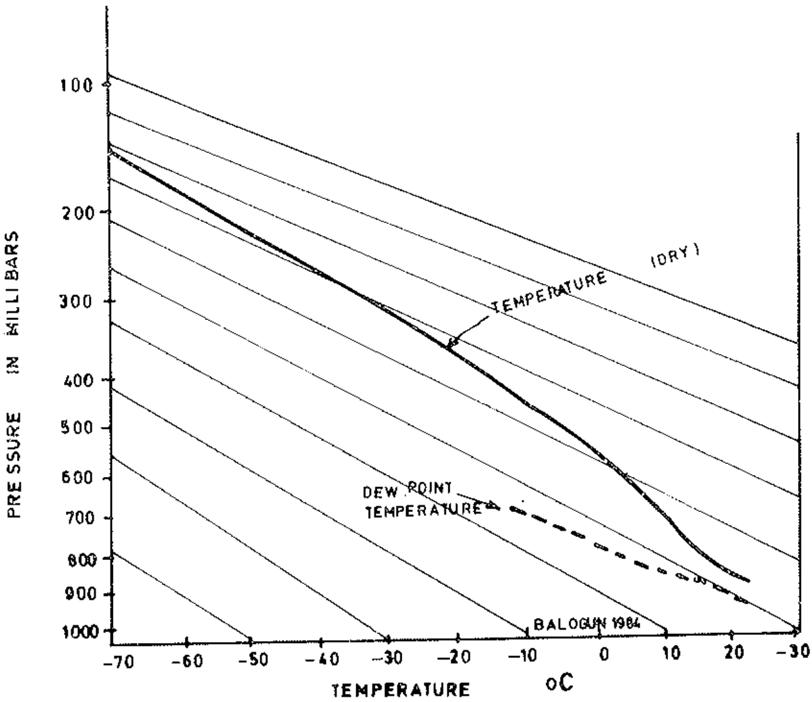


Fig. 28. Vertical distribution of temperature at lat. 12.45N, long. 8.43E from NOAA-6 satellite measurements, 21 October 1981.

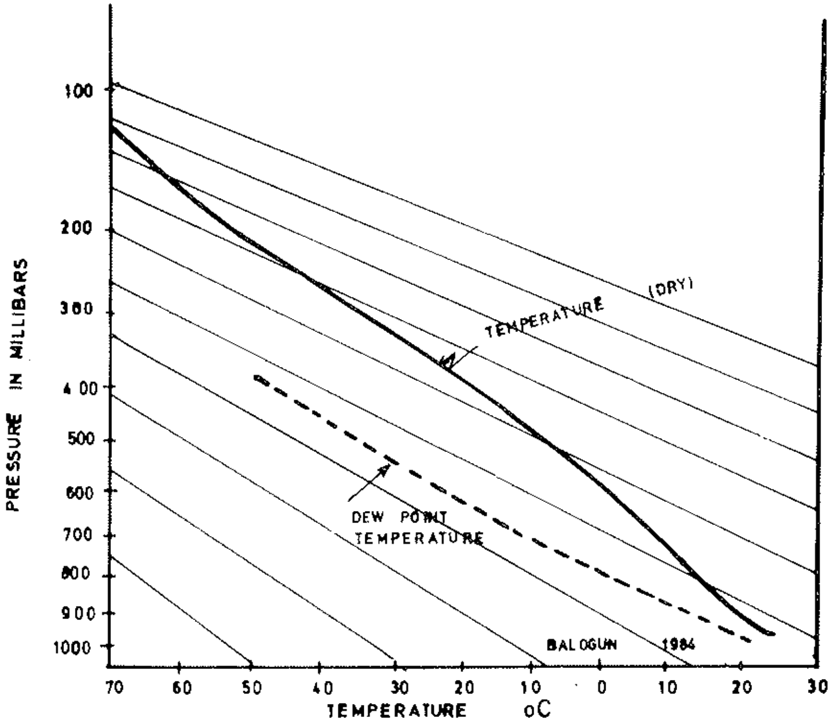


FIG. 29. Vertical distribution of temperature at lat. 15.9N, long 15.53E from NOAA-6 satellite measurements.

The basic assumption in retrieving surface temperature from satellite observed radiances is that the emissivity of the earth's sea and land surfaces is near unity and that in the absence of cloud and atmospheric attenuation the brightness temperature observed with space-borne window radiometer is equal to the surface skin temperature. Cloud and water vapour absorption usually prohibit direct interpretation of the window channel data. Algorithms have been developed in various research centres and applied to satellite measured radiances to alleviate the influences of clouds and water vapour absorption.

Conclusion

An attempt has been made in this paper to discuss in a limited way the potential uses of satellite-observed data in the understanding of the weather and climate over Tropical Africa. Satellite observation in conjunction with conventional observation can provide useful information on rainfall climatology, water resources, crop survey and forecasting, locust control and drought assessment. With the combination of such data sources it should be possible to carry out precipitation impact assessment on agricultural production and to estimate soil moisture budget over a large area.

There are some pertinent questions that may be posed at this point. Is it really necessary for African nations to use satellite data for weather monitoring purposes when the few conventional facilities now available to them have not been fully utilized? The truth is that the satellite observations have made it possible to maximise the use of the sparse data since the data are by themselves of very limited use. Can African nations afford satellite data? No African nation is planning to launch a weather satellite or any satellite in the near feature that the author is aware of. African

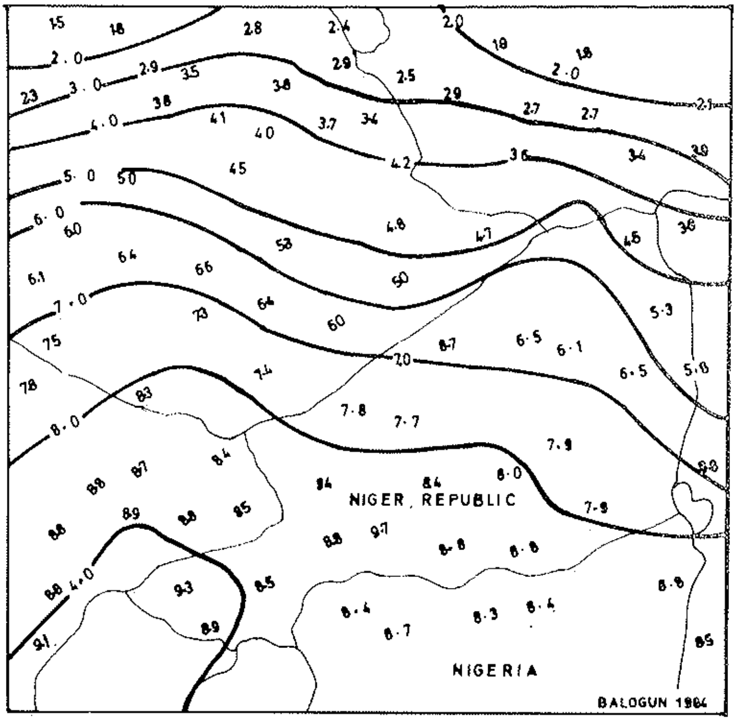


FIG. 30. Temperature distribution (in degrees centigrade) at 700mb over the Sahara from NOAA-6 satellite measurements, 21 October 1981.

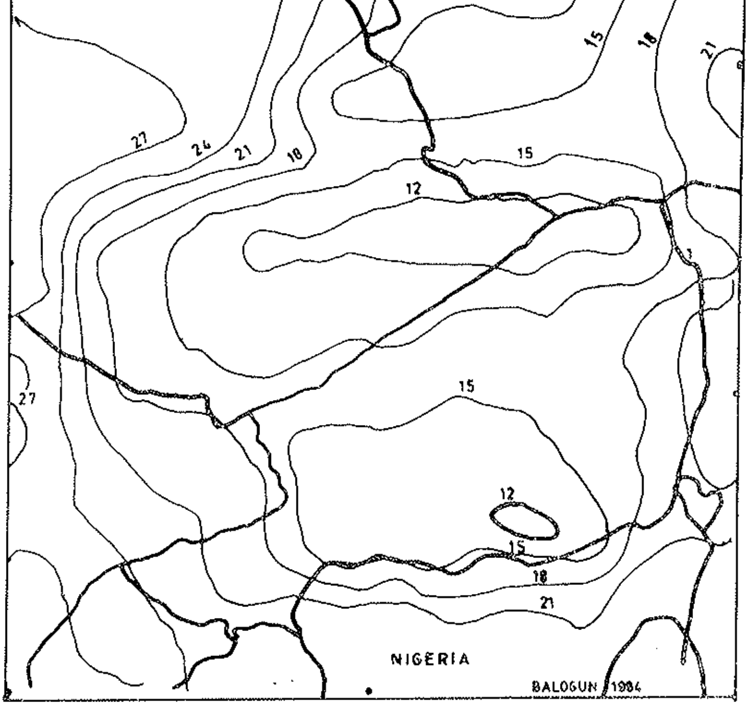
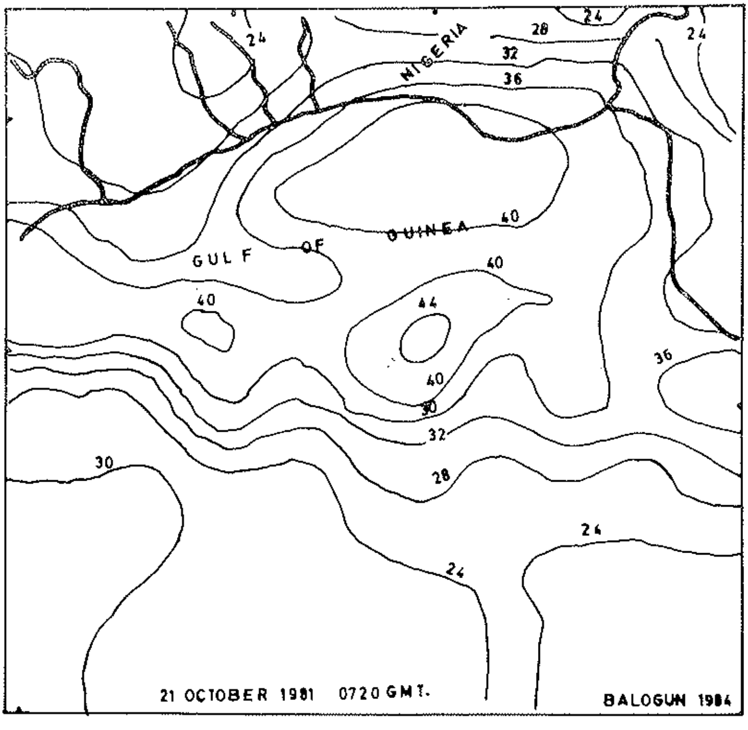


Fig. 31. Precipitable water (in mm) over the Sahara desert from NOAA-6 satellite measurements, 21 October 1981, 0720 GMT.



nations will rely, at least for some time to come, on observations made by satellites launched by other nations. African nations can use data from existing satellites either by an agreement with countries that own those satellites or by acquiring the wherewithal to receive and interpret data from those satellites. At this time it is at least possible to do the latter without too many formalities.

It is therefore important for the African countries to develop the know-how to receive and interpret satellite data. In the case of the weather, it is obvious from the points raised in this paper that weather systems over the tropics differ remarkably from those of the temperate regions. Techniques applicable in the temperate regions are sometimes different from those that may be useful in tropical areas.

Observation from space provides an important means of monitoring weather systems on a large scale. If Africa should know at least what other countries who now own these satellites know about her, then her scientists need to develop the skill for interpreting the data from these satellites. The need is even greater if they hope to develop satellite facilities of their own in the future.

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INTERNATIONAL COOPERATION: ENSURING THAT FUTURE SPACE PROGRAMS HAVE THEIR MAXIMUM IMPACT ON HUMANITY

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Assessing the impact of space exploration on humanity is a difficult task even when only past programs are considered, not to mention those which are still to come. While communications satellites have brought the peoples of Earth closer together, and meteorological satellites have saved many thousands of lives by advance warning of destructive storms, poverty and civil strife are still rampant. While the ability of humans to leave this planet, travel to the Moon, and return home again has had an enormous psychological, perhaps even spiritual, effect, the general condition of the world seems unchanged by it. Thus, it must be sadly concluded that despite the wonderful successes of the world's space programs in the last 27 years, they have not yet had a truly significant impact on humanity.

This is not to say that space exploration and its exploitation do not have the *potential* for an enormous impact, however. When communications satellites are used to provide at least an elementary level of education to everyone, regardless of their nationality or economic status, that will be an impact on humanity. When new drugs are developed in the weightlessness of space that can eradicate widespread illnesses, that will

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be an impact on humanity. When representatives of many nations, large and small, developed and developing, can work together in a space station or on a space voyage, creating a cohesive bond among their countrymen back on the planet, that will be an impact on humanity. Clearly these events cannot occur because of space activities alone (new drugs will only be able to save lives if a distribution system exists for getting them to the people in need), but space does have a role to play.

One extremely important factor which may determine whether space programs live up to this potential is the extent to which they are international in character.

Competition and Cooperation

The United States and the Soviet Union are and have been the world leaders in space activities, a situation that will probably hold true for the indefinite future. They have been the pacesetters in space exploration, serving both as role models for and stimulators to other countries. Today, virtually every nation in the world uses space (primarily for communications and weather forecasting), and three countries (China, India and Japan) plus one group of eleven countries (the European Space Agency) also have the ability to launch satellites into space. Virtually all have benefited extensively from cooperation with the United States and/or Soviet Union. The two major space powers themselves have had important cooperative space activities between themselves, although more often their programs have been conducted competitively.

The traditional rivalry in space between these two countries is well known. The early days of space flight were filled with each country trying to surpass the other, and even today that competitive spirit continues, particularly in the field of manned space activities.

Competition is good, whether in space or on the Earth, motivating individuals and nations to perform at their peak levels of ability, but cooperation is also beneficial, and can lead to innovative solutions to problems and the ability to accomplish more with less cost to a single participant. Thus, all types of space programs should be encouraged, whether they are national, international, or regional in character.

There are certain areas, however, which seem particularly suited for international cooperation. In many areas, this cooperation has already developed significantly, such as communications. In others, such as manned space flight and planetary/interplanetary exploration, cooperation has been on a much smaller scale, with only a few countries participating. These areas could become the focus for expanded international space cooperation.

The International Geophysical Year

The idea that space activities should be international is hardly a new concept. In fact, the space program had its origin in an international scientific effort, the International Geophysical Year (IGY), which ran from July 1, 1957 to December 31, 1958. Planning for the IGY began in 1954, and at that time prominent scientists concluded that the effort could benefit from observations from space. The Comité Spécial de l'Année Géophysique Internationale (CSAGI), which organized the IGY, passed a resolution in October 1954 stating that:

> In view of the great importance of observations during extended periods of time of extraterrestrial radiations and geophysical phenomena in the upper atmosphere and in view of the advanced state of present rocket tecbniques, the CSAGI recommends that thought be given to the launching of small satellite vehicles, to their scientific instrumentation, and to the new problems associated with satellite experiments, such as power supply, telemetering, and orientation of the vehicle ([1]).

The United States and the Soviet Union responded affirmatively to the challenge, and both countries' first satellites were launched during the IGY (Sputnik 1 on October 4, 1957 and Explorer 1 on January 31, 1958). Since then, the two countries have had different approaches to cooperative space programs.

Selected Examples of International Cooperation in Space

United States

The U.S. space program has had heavy international involvement since that time. In fact, one of tbe major reasons that President Eisen-

([1]) Annals of the International Geophysical Year, vol. IIa.

hower wanted to establish an agency whose single purpose was conduct of civilian space programs was to encourage other countries to cooperate with the United States in exploring space. Thus, the 1958 National Aeronautics and Space Act (the NAS Act) established the National Aeronautics and Space Administration (NASA) to conduct U.S. civilian space activities, while the Department of Defense retained jurisdiction over those programs which have primarily military applications.

During consideration of President Eisenhower's proposal to establish NASA, the U.S. Congress ensured that international cooperation would play a major role in NASA's activities by stating in Section 205 of the NAS Act:

> The Administration, under the foreign policy guidance of the President, may engage in a program of international cooperation in work done pursuant to this Act, and in the peaceful application of the results thereof, pursuant to agreements made by the President with the advice and consent of the Senate.

NASA estimates that it has engaged in over 1,000 activities with more than 100 countries for international space projects ranging from the development of the Automatic Picture Transmission (APT) stations which allow receipt of data from U.S. weather satellites by any country wishing to purchase an APT receiver, to analysis of samples returned from the Moon by the Apollo crews. Other cooperative activities have included the joint development of free-flying satellites, development of the Spacelab module which flies inside the cargo bay of the space shuttle, and the inclusion of people from other countries on U.S. manned spaceflights (a West German, representing the European Space Agency, was launched on a shuttle mission in November 1983 and at least one other ESA representative, from the Netherlands, will fly in the future; a Canadian will fly on the next shuttle flight in October 1984; and France, West Germany, the Netherlands, Japan, Australia, Britain, and Saudi Arabia have plans to fly crew members on the shuttle). Other countries, including the Peoples Republic of China, also have indicated an interest in doing so.

In addition to NASA's activities, the National Oceanic and Atmospheric Administration (NOAA) of the Department of Commerce, and the Agency for International Development work with other countries in acquisition and use of land remote sensing data.

A discussion of NASA's international activities alone would fill many volumes, so only a few examples will have to suffice for this report. In the hope of choosing some that will not be covered by other papers at this symposium, it would seem appropriate to focus on SITE, KOSPAS/SARSAT, and ASTP.

The SITE Project

The Satellite Instructional Television Experiment (SITE) project is still heralded as one of the most successful of NASA's international endeavors. From August 1, 1975 to July 31, 1976, the United States loaned its ATS-6 satellite to India for four hours each day to broadcast television programs directly to 2,400 Indian villages. Another 2-3,000 villages received the programs by redistribution through VHF transmitters. Programs on health, family planning, education, and agriculture were developed by the Indian Government and broadcast in eight different languages: Hindi, Kashmiri, Bengali, Oriya, Marathi, Gujarati, Tamil, and English. The program was so successful that there was considerable pressure to continue it after the one year agreement elapsed, but the satellite was needed back in the United States where it was used for a variety of programs in sparsely populated regions such as Appalachia and the Rocky Mountain area. Subsequently, India developed its own satellites, called INSAT, which have a television broadcast capability in addition to meteorological and general communications functions.

The impact of the SITE program was summarized in a report to the U.N. Committee on the Peaceful Uses of Outer Space:

> SITE can be considered a pace-setter and forerunner of satellite television systems particularly of those meant for development. It is an example of technological and psychological emancipation of the developing world. Its most important element was the commitment and dedication of all people and organizations involved to the one overriding goal of rural development in India. From this follows the crucial role of motivation and cooperation for the success of complex and challenging tasks. ([2])

The ATS-6 satellite was used for additional demonstration in 27 countries as the satellite was being moved back into position over the

([2]) "Report on the SITE Winter School". United Nations Committee on the Peaceful Uses of Outer Space. U.N. Document No. A/AC.105/177, December 2, 1976, p. 13.

United States. The countries which participated in the program, called AIDSAT, were: Thailand, Bangladesh, Pakistan, United Arab Emirates, Oman, Jordan, Yemen, Kenya, Libya, Sudan, Morocco, Mali, Cameroon, Central African Republic, Ivory Coast, Upper Volta, Mano River Union (Sierra Leone and Liberia), Peru, Argentina, Bolivia, Uruguay, Ecuador, Surinam, Costa Rica, Jamaica, and Haiti. NASA technicians would set up one transmitter-receiver in the nation's capital and up to four receivers elsewhere in the country. Programming included both live and pre-recorded broadcasts concerning communications satellite and remote sensing satellite technology.

KOSPAS/SARSAT

Another international program is for satellite-aided search and rescue. Called KOSPAS/SARSAT, the program involves satellites launched by the Soviet Union and the United States, and control centers and ground stations in those countries plus Canada, France, Norway, and Britain for receiving messages from aircraft and ships in distress. The SARSAT equipment on the U.S. satellites is developed jointly by the United States, Canada, and France; the KOSPAS equipment was designed by the Soviets. Finland, Bulgaria, and Sweden also participate in the program.

An agreement was signed between the United States and Soviet Union in 1979 for the conduct of the demonstration phase of the program, and an operational agreement will be signed in October 1984. Since June 1982, when the first KOSPAS satellite was launched, 278 lives have been saved because of the system. The first rescue took place on September 10, 1982, when three Canadians whose plane had crashed in British Columbia were located. Of the 278 rescues, 138 were marine, 130 were air, and 10 were pedestrian (hikers, for example), and took place in the United States, Canada, or Western Europe. The Soviet Union does not have many distress transmitters on its ships and aircraft, so they have not benefited extensively from the system yet, although they apparently are considering installation of the transmitters on ships and aircraft in the future.

Currently, three KOSPAS satellites are in orbit. One SARSAT transponder was launched on the U.S. NOAA-8 weather satellite in 1983, but the satellite suffered a malfunction in 1984 and is no longer working. Another SARSAT-equipped weather satellite is scheduled for launch in November 1984.

The Apollo-Soyuz Test Project

In 1972, the United States and Soviet Union signed a five-year agreement for cooperation, which led to the conduct of a joint manned mission in 1975. Called the Apollo-Soyuz Test Project (ASTP), it involved the docking of an American Apollo spacecraft carrying three astronauts and a Soviet Soyuz spacecraft carrying two cosmonauts.

Perhaps the most interesting part of ASTP was not the mission itself, but the preparatory activities which allowed astronauts and cosmonauts and associated personnel to spend time with each other and learn more about the other's country and culture. The Soviet cosmonauts and their colleagues visited the United States five times; the astronauts visited the Soviet Union three times. These crew exchanges resulted in friendships which seem to have withstood the test of time.

The mission was an outstanding achievement, too. Not only were worthwhile experiments conducted by both crews, but the demonstration that these two rivals could cooperate in a manned space flight, whose noble mission was development of a universal docking adapter which would allow one country to rescue the other country's space crews, was heartwarming (although since this was the last flight of the U.S. Apollo hardware, the adapter was obsolete as soon as the mission was completed). The image of astronauts and cosmonauts shaking hands in space illustrated more clearly than words ever could what détente truly meant.

From a Western perspective, the experience was also extremely valuable in terms of learning more about the Soviet space program. For whatever reasons, the Soviets have been reluctant to show their launch facilities to foreigners, or discuss mission failures or plans for the future. With ASTP, Americans were allowed to visit the Tyuratam launch facility for the first time, and details were made available by the Soviets about a mission failure in 1971 which resulted in the death of the three-man crew. Since ASTP, the Soviet Union has appeared increasingly willing to provide information about their space program, albeit in tiny increments. In 1983, for example, articles were published in Soviet newspapers on two of the Soviet launch sites (Plesetsk and Kapustin Yar) which had rarely, if ever, been discussed in the Soviet media before. Details were published on several manned space failures which had occurred in previous years, and excerpts from a diary written by a member of a long duration space station crew were printed. While these may seem like small steps, one can hope that they are indicative of a general opening of the Soviet program so that all nations can share in both their triumphs and tribulations. Perhaps such openness will eventually lead to expanded international involvement in the Soviet program.

Soviet Union

While Soviet space activities already have an international component to which the Soviets can point with pride, it has not been nearly as extensive as that of the United States. There was no international aspect to the Soviet space program at all until ten years after it had begun. Then, in 1967, the Interkosmos organization was established to facilitate cooperation between the Soviet Union and its allies. The original membership was Bulgaria, Cuba, Czechoslovakia, East Germany, Hungary, Mongolia, Poland, Romania, and the Soviet Union. In 1979, Vietnam became the tenth member. In addition to the cooperation with the Interkosmos members, the Soviets have had cooperative space projects with France, India, Sweden, Austria, and, as already mentioned, the United States.

The projects on which other countries work with the Soviets include data analysis and providing hardware for earth-orbiting scientific spacecraft and planetary probes. In a few cases, non-Soviet experiments have been flown on the Soviet space stations Salyut 6 (in orbit from 1977 to 1982) and Salyut 7 (1982 to present). These usually have been in conjunction with the launch of a representative of another country to one of the stations. The Soviet Union became the first country to place a non-Soviet, non-American in space in 1978 with the launch of the Soyuz 28 crew, which included Vladimir Remek of Czechoslovakia. Since then, ten more non-Soviet individuals have travelled to Soviet space stations (from the other Interkosmos countries plus France and India), although one could not dock because of an engine malfunction (the Soyuz 33 crew, which included a Bulgarian).

Of the western countries, France has had the most extensive cooperation with the Soviet Union. French scientists have provided experiments not only for the Salyut 7 space station (which are still used even though the French "spationaut" was on board for only one week in 1982), but also for satellites such as the Astron space observatory, launched in 1983, and several of the Venera and Mars interplanetary probes. In December 1984, the Soviets will launch two spacecraft, called Vega, for rendez-vous first with Venus and then with Halley's Comet.

While at Venus, the spacecraft will drop off French-designed balloons which will float down through the Venusian atmosphere for *in situ* measurements of its constituents. The spacecraft buses, which also carry French equipment, will then continue on to intercept Halley's Comet (ESA and Japan are also launching Halley's Comet probes, and there is an international agreement, to which the Soviets are a party, for sharing data from the spacecraft as well as Earth-based observations).

India has also had substantial cooperation with the Soviet Union. The Soviets have launched three Indian satellites: the first, a scientific satellite called Aryabhata, was launched in 1975; the other two, launched in 1978 and 1981 respectively, were remote sensing satellites called Bhaskara 1 and 2. The two countries have an agreement whereby the Soviets will launch another Indian remote sensing satellite in 1986 under a "commercial" launch agreement, the first of its kind in the Soviet program. The details of the agreement have not been released, but the Soviets have offered to launch satellites for INMARSAT (the International Maritime Satellite Organization) on a commercial basis as well. These activities may act to further open the Soviet program to the world.

The Soviets have also had cooperative projects with the United States, primarily in the area of the data exchange from planetary probes and biomedical findings from manned space flights. There have been a few exceptions in which more extensive cooperation has occurred, including the KOSPAS/SARSAT and ASTP programs already described, and four biosatellites on which the Soviets invited the United States to include experiments. These were launched in 1975, 1977, 1979 and 1983 respectively. The most recent of these involved the launch of two Macaque monkeys (plus several rats and fish) for studies of the central nervous system and various sensory systems and how they relate to adaptation to weightlessness. The United States sponsored three experiments on the mission; France and several of the Interkosmos countries also participated.

ESA, Japan, China and India

The other countries which currently have a launch capability are those which are members of the European Space Agency, Japan, China, and India.

The European Space Agency (ESA)

ESA is itself an example of international cooperation in space. Formed in 1975 as the merger of the European Launcher Development Organization (ELDO) and the European Scientific Research Organization (ESRO), its founding members were Belgium, Denmark, France, West Germany, Italy, the Netherlands, Spain, Sweden, Switzerland, and the United Kingdom. Ireland became a member later that year. Austria and Norway are currently associate members, and ESA has a technical agreement of cooperation with Canada.

As an organization which was created because of a desire by the member nations for international cooperation, ESA's mere existence is a testimony to the virtues of international space activities. Every project on which ESA has worked is, *de facto*, a cooperative endeavor, and in addition ESA has had substantial cooperative projects with outside partners, primarily the United States. As with NASA, a complete review of ESA activities is outside the scope of this report, so only one project will be mentioned. This is the development of Spacelab, a module which flies in the cargo bay of the U.S. space shuttle.

ESA developed Spacelab at its own cost and provided one module free to NASA, with additional copies available on a reimbursable basis. The first Spacelab made its maiden flight in November 1983. With a project of this scale, problems could be expected, and were encountered, particularly in terms of changing specifications over the lifetime of its development (1974-1983). Nevertheless, it seems unlikely that there is anyone who would not categorize this program as a great success. Spacelab paved the way for the current discussions concerning ESA participation in the new U.S. space station initiative, and while it is well known that ESA wants to ensure a larger role for itself in any new endeavor of this scale, the interest is there, fueled at least in part by the Spacelab experience.

Japan

Japan's space program has been cooperative since its earliest days. In 1969, Japan signed an agreement with the United States for manufacture of the "N" rocket based on the U.S. Delta rocket design. Japan also drew heavily upon U.S. companies for satellite construction in the early years of its program, as well as upper stages, and still does to some extent.

While Japan appears to be shifting to a more national program in which it designs and constructs its own satellites for communications, remote sensing, meteorology, and science, it has not forsaken international cooperation. For example, Japan is party to an agreement to share data on Halley's Comet with ESA, the Soviet Union, and the United States; its own Halley's Comet probes, Planet A and MS-T5, are scheduled for launch in 1985. Furthermore, Japan plans to launch an astronaut on the U.S. space shuttle, and is interested in cooperating in the U.S. space station program.

China

For the most part, China has pursued its space program alone, although recently it has begun to show interest in cooperation with other countries. For example, China recently proposed to launch an astronaut on the U.S. space shuttle, and reportedly has signed a contract with ESA for the launch of two television broadcast satellites on Ariane in 1987 and 1988. In addition, during 1984 China signed two protocols for cooperation in space, with West Germany (for development and implementation of a communications satellite system) and Italy (for general cooperation in space technology).

On a broader scale, at the 1982 U.N. Conference on the Peaceful Exploration and Uses of Space (UNISPACE '82), China announced that once it had the capability to launch satellites into geostationary orbit, it would offer to do so for other developing countries. China succeeded in placing its first geostationary communications satellite into orbit in April 1984.

India

India is also developing an independent launch capability, but its initial involvement in space was through international cooperation with other countries. The U.S./Indian SITE experiment has already been described, as have the launches of three Indian satellites by the Soviet Union and the launch of an Indian as part of a Soviet space crew in 1984. Both the United States and ESA have also launched Indian satellites. In 1980, however, India began placing its own satellites in orbit with the launch of Rohini 1. While the Indian space program is still in the early stages of development, it can be hoped that India will remain interested in cooperation with other countries.

The Future of International Cooperation in Space

This brief review of international cooperation, which necessarily omits a large number of important cooperative efforts, demonstrates clearly the benefits of international cooperation and its impact on humanity. Because of the KOSPAS/SARSAT search and rescue satellite system alone, 278 people are alive who might not have been otherwise. Thanks to the SITE program, India was able to assess the value of satellite television broadcasting for educating its people. Due to opportunities presented by the Soviet Union and the United States, individuals from twelve other countries have already had an opportunity to journey into space and view the world as "spaceship Earth", and many more are scheduled to follow.

The majority of cooperative programs that have taken place so far have been exactly that, cooperative. Perhaps in the future, a closer relationship can be developed where countries work together from the very beginning of planning for new space activities, a relationship that might be described as collaboration.

One possible area of collaboration which is receiving increasing discussion in the United States is the possibility of an international mission to Mars. In September 1984, hearings were held before the Senate Foreign Relations Committee of the U.S. Congress on the potential of increasing U.S./Soviet cooperation. Four noted scientists, including Carl Sagan, supported the concept of an international manned Mars mission. While the hearings focused on U.S./Soviet cooperation, there is no reason that other countries could not be included in such a project.

While the crux of this paper is the suggestion that international cooperation in space should receive increased attention, it is recognized that such cooperation is not always an easy task. There are legitimate concerns on the part of countries about factors such as technology transfer, and one partner shouldering an unfair amount of the costs. In addition, there are usually broader political considerations that must be taken into account. It had been hoped, for example, that ASTP would open new horizons of cooperation between the United States and the Soviet Union, and indeed a new five-year space cooperation agreement was signed in 1977. Political considerations intervened, however, and now the climate between the two countries does not appear conducive to major new space agreements. Nevertheless, President Reagan recently offered to initiate discussions for a space rescue agreement that could develop a capability, once again, for each side to be able to rescue the other's space crews and would involve the rendez-vous of the U.S. space shuttle with the Soviet Salyut space station. Although the Soviets have not yet responded to this offer, it can be hoped that they will do so in the near future.

The Possible Impact of Military Space Activities

There is growing concern about the "militarization" of space, and since these activities could affect the conduct of international space endeavors, it seems appropriate to mention this issue, although other papers to be presented at this conference will deal with it in more detail.

There has been a considerable amount of rhetoric in the past several years about the "militarization" of outer space and who is responsible for destroying the "sanctuary" of outer space. While the military uses of space have received attention only in the past two to three years, they have occurred since the earliest days of the space program. Neither the United States nor the Soviet Union can be fairly charged with single-handedly "militarizing" space, since these activities have been part of the many uses to which satellites have been put throughout the history of the space program by both countries.

The arguments concerning the "militarization" of space have become very emotional, with charges and countercharges flying across oceans. One problem may be semantics. In these discussions, the term "military" is often considered "bad" and compared with "peaceful", which is "good". It may be more helpful to think in terms of "aggressive" and "non-aggressive" space activities, however, for many "military" space systems serve a positive role. Reconnaissance satellites are used for treaty verification, and navigation, weather, and communications satellites serve non-hostile functions (although they can act as force multipliers in times of crisis). These systems can be considered "non-aggressive" and "good", even though they are "military". In fact, it could be argued tbat reconnaissance satellites have had the greatest impact on humanity of any space activity through their contrihution to keeping the peace. It is becoming more common to define "peaceful" activities as "non-aggressive", and comparing them with "aggressive" activities, such as space weapons.

Both the United States and the Soviet Union have non-aggressive military satellites for reconnaissance, navigation, communications, weather, and geodesy and mapping. Britain and NATO have communications satellites for their military forces, and Japan recently allowed its Self Defense Forces to use the Sakura 2A communications satellite. China has launched several satellites with characteristics which suggest that it is developing reconnaissance satellites, and Japan and France may also develop such a capability. India's development of remote sensing satellites may presage reconnaissance satellites as well. Thus, not only are they not new, but military space activities are not unique to the United States and Soviet Union.

In reality, it is the debate over space weapons that has generated most concern about the "militarization" of space, and therefore it can more correctly be described as a concern over the "weaponization" of space. As with military space activities in general, space weapons are not new, but only the debate over them. The United States launched its first satellite interceptor in 1959 (this particular program was not pursued for very long, however), and it is thought that the Soviets had an antisatellite (ASAT) capability as early as 1962. Today, only the Soviet Union has what can be termed an "operational" ASAT capability using a ground-launched co-orbital satellite interceptor, and that characterization is disputed by some because of the 20 tests conducted since 1968, only 9 have been successful. (3) The United States is currently developing its own ASAT capability using an air-launched missile, which is scheduled to be operational in 1987. Also of great interest to the world at large is President Reagan's Strategic Defense Initiative (SDI) which, if pursued, could result in a ballistic missile defense (BMD) system including space-based components.

The many and varied political issues involved in the ASAT and SDI debates are not an appropriate topic for discussion here, but the potential impact on humanity of space weapons programs cannot be ignored. Whether that impact will be positive, as President Reagan hopes, or negative, as his critics fear, remains to be seen. The important point to stress now is that no decision has been made by the United States to proceed with the development, testing, or deployment of an SDI-type system. At this point, SDI is research only, and violates no treaties.

In terms of international space activities, military uses of space will become an important factor only if they start to impinge on civilian/international space activities either because of budgetary restrictions or because the space weapons are actually used against another State or its property. Clearly, this is an eventuality that everyone hopes would never

(3) JOHNSON NICHOLAS, *Soviet Year in Space, 1983*. Colorado Springs, Colorado, Teledyne Brown Engineering, 1984, p. 39.

happen, and if it did, there will be more immediate concerns than the welfare of the world's space programs.

It must be pointed out, however, that military space activities have co-existed with international activities for the past 27 years, and there is no reason to expect that they cannot continue to do so. Military space programs have not precluded international involvement in space exploration, just as international space programs have not prevented the use of space for military purposes, including weapons.

Conclusion

The history of the space program has been filled with examples of the success of international cooperative endeavors, resulting in benefits to all of those who participated. At a time when the countries of the world are facing economic difficulties, it seems quite apparent that many valuable space activities will not be able to be pursued by individual countries. Thus, international cooperation and perhaps an even closer relationship that could be termed collaboration may offer an answer to ensuring that space is used to its full potential for benefiting humanity.

CAN SPACE END THE TYRANNY OF DISTANCE?

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Introduction

The period between Sputnik I's first orbit of the Earth and Pioneer 10's escape from the solar system has been one of outstanding technological development and scientific progress. The spectacular achievements of space exploration have excited our imagination while space research has enriched our knowledge of the universe through scientific advances in astronomy, solar physics, planetology and the earth sciences. Viewed from the platform of space we have been able to see our planet Earth as one world which we all share. Space applications have improved communication, meteorology, navigation, land management, mineral exploration and search and rescue. Almost all countries now make some practical use of space technology, primarily to assist with their meteorological and communications services. The United Nations Committee on the Peaceful Uses of Outer Space recognizes the importance of ensuring that the benefits of space applications are widely shared by peoples in all countries, both developed and developing.

For many countries the major practical benefit to come from space has been the provision of better global, and in some cases, national communication. Communications satellites have proved to be the first commercially successful ventures in space. They have reduced costs and extended a range of reliable, improved and new services which in remote areas have done much to moderate the penalty of distance. The experience of "live by satellite" television of major international events has diminished many people's sense of isolation and reduced their perceived distance scale.

Rather than attempt the enormous task of reviewing space communications in general I shall take as a particular case the Australian experience, hoping that this may have some interest, and possibly some lessons, for others. Since Australian participation in space communications has been heavily dependent on international developments I shall be able, in this way, to trace some of the history of these developments from the viewpoint of their impact on our own telecommunications.

Space communication is a spectacular, modern example of technological innovation. In order to appreciate its significance I shall recall one earlier technological innovation, the Overland Telegraph Line, which supplied Australia's first telecommunication link with the rest of the world and began the conquest of distance. Both the old and the new examples provide fascinating illustrations of the interplay between science and technology.

No country has had such a preoccupation with the problems of distance and isolation as has Australia. In his book "The Tyranny of Distance" Geoffrey Blainey describes how distance has shaped Australia's history. "Distance", says Blainey, "is as characteristic of Australia as mountains are of Switzerland". We have a sparse population inhabiting an area about equal to that of the continental United States (excluding Alaska) and surrounded on the east, south and west by vast expanses of ocean. Distance and isolation are recurring themes in Australian literature. The sense of remoteness has only slowly abated as new technologies have offered improved means of transport and communication.

Until well into the 19th century the problems of communication were the same as those of transport. Communication was no quicker than the vehicle that conveyed it. From the time of the first European settlers in Australia, communication and transport over long distances have presented extreme problems. The First Fleet bound for Botany Bay left Portsmouth Harbour on Sunday morning 13 May 1787, and travelling via Teneriffe, Rio de Janeiro and the Cape of Good Hope, took over eight months to arrive on 20 January 1788. Travel times were slow to improve. The first regular mail service between Britain and Australia was started in 1852 but letters often took more than three months to be delivered. A century later ships still carried the vast majority of passengers and typical journeys lasted five weeks. Not until the introduction of jet aircraft in the 1960's did air travel become the most popular means of overseas transport with travel times between Australia and Europe now taking just under one day.

The Overland Telegraph Line

Telecommunications, as distinct from the physical transport of letters, began in Australia in 1854 and by 1858 Sydney, Melbourne and Adelaide were linked by telegraph line. International telecommunications became possible on 22 August 1872 with the completion of the 3000 km Overland Telegraph Line between Adelaide and Darwin. At Darwin the telegraph line messages were transferred to a submarine cable from Java and then linked through India by overland cable to London. With the completion of the Overland Telegraph Line, Australia, for the first time, had rapid communication with the rest of the world, albeit at only a few words of Morse per minute. Messages could now be exchanged between England and Australia in a matter of hours whereas it took months for mail sent by ship to make the journey.

The chief architect of the Overland Telegraph Line was Charles Tood, who in 1855 had been appointed Superintendent of Telegraphs and Astronomer for South Australia. Todd had worked at Greenwich and his appointment to South Australia had been recommended by Sir George Airy, the Astronomer Royal. As another personal aside on the interaction between science and technology in the construction of the Overland Telegraph Line it is interesting to note that one of Todd's assistant engineers was Benjamin Babbage, son of the mathematician Charles Babbage, famous for his proposal of the modern digital computer.

Todd's Overland Telegraph Line played a vital role in Australia's national and international communications systems for the next 70 years despite the destruction of its original wooden poles by white ants and the predilection of exhausted travellers to cut the wires so that they would be found by the linesmen. The final episode in the history of the Overland Telegraph Line was truly heroic. In 1942 news of the Japanese air raid on Darwin reached Adelaide via the Overland Telegraph Line when Harry Hawke, the Divisional Engineer, connected a pocket Morse relay key to the end of the line in the main street of Darwin, the telegraph office having then been completely destroyed.

Charles Todd made remarkable contributions to what we would now call technological innovation. He used his telegraphic repeater stations to establish a network of meteorological observations in remote areas to begin a service that now benefits from the much more complete coverage provided by the meteorological satellites. Todd and his son-in-law William H. Bragg, then Professor of Physics at Adelaide University, made the first practical application of wireless telegraphy in Australia in 1899 when they established two-way Morse code communication between Adelaide and Henley Beach. Radio science in Australia had begun.

The need to improve national and international telecommunications led to a fostering of radio research in Australia with the establishment in 1926 of the Radio Research Board and the development of strong research groups in the CSIRO and the universities. Radio provided Australia's only speech communication to the rest of the world until 1963, when the COMPAC cable was completed across the Pacific, linking Sydney-Auckland-Suva-Hawaii-Vancouver and then connecting across Canada with the CANTAT Atlantic cable to Britain.

Radio and the COMPAC and CANTAT cable systems carried Australia's international telecommunications until satellite services became available through INTELSAT.

The Beginnings of Satellite Communications

The October 1945 issue of Wireless World contained an article on "Extra-Terrestrial Relays" in which Arthur C. Clark described the general principles of global communications using a system of three satellites in geostationary orbits. The system included intersatellite links, a concept which is only now being brought to reality. With their global coverage Clark's relays in space promised an end to the tyranny of distance.

A few quotations from the 1945 article will serve to describe the system and indicate the breadth and accuracy of Clark's vision.

> "One orbit, with a radius of 42,000 km, has a period of exactly 24 hours. A body in such an orbit, if its plane coincided with that of the earth's equator, would revolve with the earth and would thus be stationary above the same spot... [A satellite] in this orbit could be provided with receiving and transmitting equipment and could act as a repeater to relay transmissions between any two points on the hemisphere beneath... A transmission received from any point on the hemisphere could be broadcast to the whole visible face of the globe".

Clark pointed out that three satellites would be required for a world-wide cover "though more could be readily utilized". After noting the problems of providing electric power and speculating that developments in photoelectricity might make it possible to use the solar energy directly, Clark went on to discuss the problems of eclipses.

> "The total period of darkness would be about two days per year, and as the longest period of eclipse would be little more than an hour there should be no difficulty in storing enough power for an uninterrupted service".

Radio engineers were quick to exploit space technology for communications purposes. The first communications experiments used satellites in low earth orbit. The US SCORE satellite, launched in 1958 just a year after Sputnik I, carried the first satellite repeater which was used to relay messages between Arizona, Georgia and Texas. In 1960 ECHO I, a large metal coated balloon, demonstrated the use, in space, of a passive reflector for communication purposes. TELSTAR, a low orbit active repeater satellite launched in July 1962, provided the first transatlantic colour television transmission.

The potential benefits of space communications were demonstrated by these pioneering experiments but the low orbit satellites used required complex ground stations and provided limited geographical coverage. These problems could be overcome by operating in the geosynchronous orbit, which simplified the tracking required at the earth stations and provided nearly hemispheric visibility. The first successful synchronous orbit satellite, SYNCOM II, was brought into operation in July 1963. SYNCOM II and the later SYNCOM III had two transponders operating in the 8/2 GHz bands. SYNCOM became the prototype for commercial communications satellites.

The experience gained with SYNCOM provided the basis for the development of space systems to serve both international and national communications needs. In Australia's case the relevant systems are INTELSAT, the global telecommunications network that came into being in 1964, and AUSSAT, the Australian National Satellite system, that will begin service in 1985.

INTELSAT

INTELSAT was formed in 1964 with eleven members including Australia. Over a hundred countries are now members of INTELSAT and many others use its services. The original "Early Bird" satellite

(INTELSAT I) launched in 1965, was a commercial development of the SYNCOM satellite. Early Bird provided the first operational satellite services from the geosynchronous orbit. Although there were eleven members of INTELSAT in 1965 there were only five earth stations, four in Europe and one in the United States. Following the success of Early Bird the service was rapidly expanded. The first of the enlarged and improved INTELSAT II satellites was launched in 1966. By 1969 a complete global coverage was provided by three INTELSAT III satellites and a worldwide audience of 500 million people were able to watch "live" as Neil Armstrong landed on the moon.

Major technical improvements have been made with each generation of INTELSAT satellites. Early Bird weighed 38 kg and had a capacity of about 240 two-way telephone circuits. INTELSAT V (first launched December 1980) weighs 967 kg and can carry 12,000 telephone circuits plus two television channels. The new INTELSAT VI satellite planned for 1986 will have 33,000 telephone circuits plus four television channels. It will weigh about 1,800 kg and generate 2 kW of electric power.

INTELSAT's technological achievements have been accompanied by an equally remarkable reduction in real unit costs. The initial Early Bird cost was $ 64,000 per year for a complete 8 kHz telephone circuit. By 1983 the cost of an INTELSAT circuit had fallen to $ 9,360 per year. If allowance is made for inflation, the true cost reduction for the service is about a factor of 18.

Australia is the fourth largest shareholder in INTELSAT. INTELSAT satellites over the Indian and Pacific Oceans carry about two-thirds of the 11 million international telephone calls Australians make each year. All international television relays entering Australia come via INTELSAT.

Improved services, greater reliability and reduced costs have been provided by the satellite service. International direct-dial telephone calls are now commonplace. Marshall McLuhan's global village appears to be becoming a reality through live television relays of major international events such as the Moscow and Los Angeles Olympic Games with possible total audiences of up to two billion people. Data transfer and computer communications are expanding services. Video conferencing, still in its infancy, could, in some cases, offer an alternative to travel and has great potential for growth. Satisfaction of the growing demand for international telecommunications will require substantially increased services. A combination of larger satellites plus transoceanic cables using advanced optical fibres is the most likely way of meeting the demand and ensuring a desirable diversity of communication links. It is interesting to compare the projected rates of data transmission ($\sim 10^{11}$ bits/sec in the year 2000) with the few words of Morse per minute signalled along Charles Todd's Overland Telegraph Line.

Domestic Services - AUSSAT

Geography has meant that Australians are well aware of the benefits of telecommunications and have been willing to bear the large costs involved in establishing the necessary infrastructure. The Australian investment in telecommunications accumulated over a period of years now totals 10% of GDP. Despite the existing investment in telephony and broadcasting services there are additional needs, particularly in remote areas, that can best be met by the introduction of a domestic satellite system.

The existing broadcasting arrangements are a unique blend of goverment and commercial services. The Government-funded Australian Broadcasting Corporation (ABC), which carries no advertising, operates a national broadcasting service using 251 colour television transmitters, 95 AM radio stations and 25 FM radio stations. A Remote Area Television Service operated by the ABC leases transponders from INTELSAT to provide programs to 52 community transmitters in remote parts of Australia. This service has already demonstrated some of the benefits of satellite broadcasting in remote areas. The Special Broadcasting Service (SBS), also a Government authority, broadcasts in some 50 different languages to serve Australia's growing multicultural society. A multicultural television service, with English sub-titles, is transmitted at UHF via an increasing network of stations. There are also commercial (i.e. advertiser-supported) radio broadcasting stations and 50 commercial colour television stations providing services throughout Australia. In addition about 30 public radio stations provide community services funded by subscription.

Despite these extensive broadcasting facilities there are still many Australians who have no access to radio or television services. It is estimated that about 300,000 people are affected. Space technology offers the best way of providing television services throughout Australia's remote areas, which, although sparsely settled, contribute much to the nation's pastoral and mineral wealth. Operation of a domestic satellite system will, of course, affect all aspects of Australia's telecommunications system, not just those relating to services in remote areas. The decision to acquire a domestic satellite system has therefore been a matter of great importance to the established Australian telecommunications industry and to the people that it serves. As a consequence there has been extensive public debate not only about the satellite system's technical properties and economic potential, but also about its social implications.

The Australian National Communications Satellite system, AUSSAT, will initially comprise two satellites in geostationary orbit at longitudes (156° E and 164° E) just east of Australia. A third spare satellite will be available on the ground and is expected to be launched in about 1987 to meet the anticipated high demand. The first two satellites in the system are scheduled for launch in July and October 1985 using the NASA Space Shuttle. Once the satellites are in orbit they will be controlled and monitored by stations in Sydney and Perth.

Each satellite will have a capacity of 15 transponders operating at 14.0-14.5 GHz uplink and 12.25-12.75 GHz downlink. The satellite will be capable of receiving signals from anywhere within Australia and will provide downlink transmission in a national beam and in four more localised beams with footprints generally covering the Australian states. There is a fifth switchable spot beam available for use by Papua New Guinea for its internal communications.

Major earth stations are being constructed in each of the eight capital cities of Australia to provide public access communication gateways to and from the satellite. Other users of the system will be able to establish their own private earth stations but they will not act as common carriers of third party traffic.

The domestic satellite system will link Australian centres at costs which are independent of the surface distance between them. It will offer a cost-effective means for the assembly, distribution and relay of television programs throughout Australia, which will be more flexible than a terrestrial system. It will provide a great improvement in outback broadcasting services. Some communities will receive their first services through AUSSAT; others in remote under-serviced places will have the services available to them greatly improved.

The ABC with its national service and the commercial and public broadcasting operators are expected to be major users of the satellite, providing a diversity of television and radio programs throughout the country. The Australian business community, airlines, banks, building societies, credit unions and other organisations with operations covering several states will be able to make extensive use of AUSSAT. The improved communications available to remote areas including the off-shore North West Shelf will be particularly valuable to mining and exploration companies. AUSSAT should allow a major expansion in business services, providing in an economical and reliable fashion access to data, facsimile, videotext and teleconferencing across the whole continent.

For people living in remote areas of Australia the most urgent communications need is a reliable, continuous telephone service. In many cases the present outback service is provided by HF radio. To improve the service AUSSAT will offer a Remote Telephony Satellite Service (RTSS) using antennae of about 3 metre diameter at earth stations providing a single telephone circuit for individual homesteads or up to 12 telephone circuits for small isolated communities. Transportable earth stations with up to 12 telephone circuits will also be available for rapid restoration of services in emergencies.

The education of children in the Australian outback has been helped for many years by the School of the Air, which has been a pioneer in distance education. This service at present uses an HF radio network operating from 12 base stations which provide two-way communications with a large number of outstations in individual homesteads. AUSSAT will be able to provide improved communications for the School of the Air either through stand-alone earth stations or add-on facilities to remote telephony earth stations. In order to evaluate the potential of the system the Queensland Education Department will conduct satellite tests for the Mt Isa School of the Air in January 1986.

Direct broadcasting from AUSSAT will offer a new range of entertainment and news services to outback Australia. A Homestead and Community Broadcasting Satellite Service (HACBSS) is designed to broadcast radio and television programs to remote communities and individual homesteads that are outside the range of existing terrestrial transmitters or are in regions of marginal reception. The Homestead service will be received using small antennae of 1.2 to 1.8 metre diameter.

AUSSAT will be able to offer more effective aeronautical and maritime transport communications, thus contributing to air safety and safety of life at sea. Applications to Air Traffic Control are particularly interesting. Voice and data communication links will be provided to aircraft using both manned traffic control centres and unmanned VHF repeater stations. These aeronautical services will use earth stations with 3-5 metre diameter antennae at some 240 locations throughout Australia. In order to achieve high reliability the service will be duplicated at each location to operate simultaneously through both satellites in orbit.

The powerful and flexible technology provided by the satellite system opens up a range of new opportunities for better communications throughout Australia, virtually without regard to distance. Introducing these new services will have social implications, some of which have been critically discussed within Australia during the debate leading to the establishment of AUSSAT. Some of the new satellite services have the potential to disturb the existing communications order within the country. The satellite will be able, for example, to provide for the first time telecommunications in competition with the terrestrial telephone network. Satellite broadcasting, in particular national networking, could significantly alter the existing broadcasting arrangements which have emphasized regional needs and limited the concentration of station ownership. Direct satellite broadcasting of subscription television services would also alter the status quo. These issues continue to be matters of vigorous argument to ensure that the greatest benefit is obtained from the technological opportunities provided by the domestic satellite system.

Conclusion

Charles Todd's Overland Telegraph Line revolutionized Australian communications when it was completed in 1872 and "instantaneous" links were first established with the rest of the world. The original data rates of a few words of Morse per minute have now been improved by over 8 orders of magnitude as cable, radio and satellite communications provide extensive, flexible and economical services both nationally and internationally. Global and regional satellite communication services are now available at costs which are essentially distance free. While the tyranny of distance may never be completely vanquished, space communications offer the technical and economic means to make that tyranny much less oppressive.

In this paper I have drawn my examples from Australian experience solely because I know that experience best. Many other countries share in the benefits obtained from investments in space communications. In our own region of the world Indonesia has been the leader in introducing a domestic satellite service. The PALAPA system has been able to supply national telecommunications throughout the many islands that comprise Indonesia. These services would be extremely expensive to provide by any means other than space technology. The scattered island countries of the South Pacific offer another prime example of a region where satellites can satisfy the urgent need for better communication. Use of the ATS I satellite has already demonstrated the potential for improved service by satellite in the South Pacific. The Low-Density Telephony Service proposed by INTELSAT could be of great benefit to island nations using the space segment on a shared basis. It may also be possible to take account of the needs of the South Pacific countries when planning a second generation AUSSAT system.

Space technology has the capacity to provide adaptable cheap telecommunications services throughout the entire globe with great benefits to the world's people. While that potential is widely recognised and the improvement in services continues to be spectacular, the hard fact remains that telecommunications are still very unevenly spread amongst nations. Unfortunately the technological gap does not appear to be narrowing. Thus although space has the potential to end the tyranny of distance, the challenge remains to make that potential a reality for all.

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SPACE WEAPONS: POLICY IMPLICATIONS

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Weapons

In an imperfect world individuals look for security to *nations* (their own or another) and to alliances. The world has come to a wide recognition of the inherent rights of the individual and also of the state as a means of self-government, although many states fall short of ideal and a few use universally condemned means of intimidation, torture, and murder in support of the state or even of the group in power.

In such a world, states have long depended on weapons to preserve their citizens against depredations by outlaws or other nations. Such weapons have at times served to destroy offensive weapons in combat, or those who wield these weapons, or those who supply the weapons. With the introduction of the fission bomb it became possible to destroy within hours the structure and substance of the state, and the advent of the thermonuclear weapon (hydrogen bomb) made it possible to build megaton or multi-megaton class weapons deliverable by ballistic missiles of modest size.

Civilization could be destroyed in minutes. It would take much longer to rebuild.

We cannot change the past, but we can and must choose the future. We should welcome, encourage, and support those changes which are clearly in the common interest; attempt to prevent, inhibit, and reverse those which benefit no one; and think carefully about those whose consequences may be very negative, even though there can be some benefits perceived. To cross the threshold of powerful space weaponry mistakenly or inadvertently would be a tragedy for all, even for the first across that threshold.

While it is widely held that the existence of nuclear weapons is a powerful inhibition to war between the largest nuclear powers, the vast number of nuclear weapons and their delivery means are universally condemned. The decision to go to war is deterred by the capability and promise of nuclear retaliation — a sad and unsatisfactory state of affairs, until it is compared with the available alternative. Still, nuclear armories grow, their increase in numbers justified by political necessity, either domestic or international, or by potential use against vast numbers of military targets on the other side. The Soviet Union and the United States now each possess some 25,000 nuclear warheads.

Stability

If nuclear weapons are to serve only for deterrence of attack by tbe other side, they must survive in numbers sufficient to destroy, but it is fundamental that they must not be used except in response to attack. To this end, satellites have long provided effective early warning of massive attack by ballistic missiles. More precisely, these satellites under normal circumstances provide constant reassurance that no attack is on the way.

Since the 1972 ABM Treaty between the U.S. and USSR, tbe satellites have also been accepted as playing a vital and legitimate role in *verification* of compliance with treaty obligations, by their ability to detect significant violations of a treaty which has been appropriately drafted. Thus, the national (even weapons-related) use of space is generally acknowledged to have contributed mightily to world security.

Military Support Use of Space

In recent years communications satellites have been used for military purposes; weather and navigation satellites have proliferated; and it is clear that the effectiveness of military forces in conducting conventional and even nuclear war has benefited from space support. A mucb-noted example is the Soviet radar ocean-reconnaissance satellite (RORSAT), which can detect ships on the ocean for purposes of surveillance or targeting. The growth of such military support capability in space has led to the development of technologies and systems to counter these satellites, as detailed in the article by Garwin, Gottfried, and Hafner in the June, 1984 *Scientific American*.

Space-based Ballistic Missile Defense

The advance of space technology has led to the claim that strategic ballistic missiles might eventually be destroyed as they were being launched (boost phase) or as the warheads were falling through space toward their targets (mid course). These proposals are discussed in the article by Bethe, Garwin, Gottfried, and Kendall in the *Scientific American* of October, 1984. It is my judgement, shared by the Director of the Strategic Defense Initiative Program Office, General James Abrahamson, and by essentially all other technical individuals in or out of the U.S. Government, that there is no prospect for preserving society against nuclear attack by an adversary armed with large numbers of thermonuclear warheads and committed to destruction or retaliation; the effectiveness of a nuclear warhead in destroying a city is just too great, and the use of technology as a *countermeasure* to a defensive system is too promising. So a space-hased system does not offer tbe promise of a secure and perfect defense to replace "deterrence by threat of retaliation".

Interactions

Unless checked by national leaders and an international commitment to stability and security, national efforts to counter opposing military capability will lead to the perfection of antisatellite systems which could produce near-instant destruction of those satellite systems which contribute to stability. The search for space-based defense against ballistic missiles will lead not to such a defense of society but to a potent threat to these same satellites, and the ASAT capabilities in turn will be stimulated to provide the capability for instant destruction of space-deployed elements of the defensive system.

The dream of security under a defensive system so powerful that one could ignore tens of thousands of nuclear warheads would be replaced by a reality far more frightening than the present system of deterrence — by a confrontation of modernized and strengthened strategic offensive forces, by defenses confronting one another and clearly more effective in countering a retaliatory strike than in nullifying a first strike by the other side. No more severe instability could be imagined than a system in which the side that goes first could destroy and disorganize much of the defense, thereby preserving its own quite capable defense to defend against the diminished retaliatory strike on the other side. Absolute instability is the result of a confrontation in which one side logically decides that it is essential to survival to initiate nuclear war.

Remedies

Unlike many serious problems facing the world today, this most serious problem of indefinitely delaying nuclear war is not insoluble. It has no permanent solution, because the problem continues to change, but one remedy is to reduce the rate at which change gets out of hand. My own judgement is that it is feasible, desirable, and urgent to

— Ban tests of antisatellite weapons, of space weapons, and of weapons from ground to space.

— Immediately adopt a moratorium on tests of ASAT or space weapons.

— Use the mechanism of the Standing Consultative Commission of the ABM treaty to reinforce the prohibition of that treaty against defense of the national territory.

— Begin a process of temporarily taking nuclear weapons out of service, while inviting the other side to do likewise, initiating a process which has as its goal the reduction of numbers of nuclear warheads in each of the largest national armories to 1000 instead of the current 25,000.

— Adopt a comprehensive ban on nuclear explosions (comprehensive test ban — CTB) in order to strengthen the international consensus against proliferation of nuclear weapons.

These modest achievements would allow us to pass to our children the problem of living with or abolishing nuclear weapons.

THE UNITED NATIONS OUTER SPACE PROGRAMME

VLADIMIR KOPAL (*)

Introduction

The progress of space science and technology opened far-reaching prospects for human knowledge, experience and know-how. First of all, it enabled us to learn much more about the Universe, our solar system as a whole and particularly about our own planet. The condition of a high value of life has become one of the most important news that has come to us by up-to-date space accomplishments.

Recent years of space activities have gained us further experience. It has become evident that man can not only survive but also stay and work in outer space without any substantial harm to his organism. Step-by-step, a permanent presence of humankind in space is becoming a reality.

Progress in space science and technology has been accompanied by endeavours to use its results for practical aims. Thus new industries have been developing, based on the use of satellites for telecommunications, meteorology, geodesy, and navigation. Moreover, the advent of direct broadcasting satellites is imminent.

Systematical observation of the earth from space has also clearly proved its utility and remote sensing satellite systems are now passing from an experimental to an operational stage of their performance.

Some of the new technologies, e.g. in the field of electronics, originated from urgent space requirements. However, their economic, technical and

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cultural impact has become broader. Many specialized instruments and techniques that have made our life more comfortable would not have been invented at all, or at least so soon, without an impetus from space ventures.

The ever-growing need for resources, which is one of the consequences of the world's economic growth, will inevitably lead to the exploration and exploitation of space resources, including the great potential of energy from outer space.

Nevertheless, the latest period of space activities has been mostly characterized by an emphasis on applications of space science and technology. The question of what practical benefits may he derived from space activities occupies most of the interests of governments when they consider different projects of space exploration.

In the developing world, space science and technology is regarded as a tool which could be helpful in narrowing the gap between industrially advanced and less developed countries. However, this requires to build up, both nationally and internationally, mechanisms and create adequate financial bases for enabling all States to benefit from space, bearing in mind their various economic and technological levels.

Such a development will lead to increasing the number of nations participating in space activities and augmenting the degree of their involvement in different space programmes.

In the light of these brief characteristics of the development and role of space science and technology I will now concentrate on the emergence of principles of international co-operation in space activities in the institutional framework of the United Nations.

Organizational framework of outer space co-operation in the United Nations

By resolution 1472 A (XIV) of 12 December 1959, the United Nations General Assembly established a permanent body, the Committee on the Peaceful Uses of Outer Space (COPUOS). Its original membership was 24 States, but it was later expanded several times: to 28 members in 1961, to 37 members in 1973, to 47 members in 1977 and to 53 memhers in 1980.

In resolution 1721 (XVI) of 20 December 1961, a comprehensive programme for multilateral co-operation of Member States of the world organization was unanimously adopted by the General Assembly. In this document COPUOS was invited to study and report on the legal problems which might arise from the exploration and use of outer space. In other parts of this resolution, guidelines were provided for the development of international co-operation in several fields which were considered at that time as feasible. They included a request for prompt information by States launching objects into orbit or beyond for the registration of launchings and maintaining a public registry of the information furnished by the Secretary-General. COPUOS was requested to provide, in co-operation with the Secretary-General, for exchange of information supplied by governments on a voluntary basis, as well as assist in the study of measures for the promotion of international co-operation in outer space activities. Still other parts of resolution 1721 (XVI) dealt with international co-operation in two specific areas: that relating to improvement of meteorology in the light of developments in outer space and that concerning communications by means of satellites that should be available to the nations of the world on a global and non-discriminatory basis.

At the same time the organizational structure for international co-operation in space activities crystallized. COPUOS has become the focal point for all space-related co-operative programmes furthered by the United Nations. Two Sub-Committees, one legal, the other scientific and technical, each composed of the same Member States as the parent body, held their first sessions in the spring of 1962. Since that time both Sub-Committees have met regularly each year. Later on, in successive stages of its deliberations, COPUOS also established four working groups of the whole, on navigational satellites, broadcasting satellites, remote sensing satellites and the use of nuclear power sources. One of these groups, that on nuclear power sources, has resumed its work this year.

Within the United Nations Secretariat, an Outer Space Affairs Division was set up in the Department of Political and Security Council Affairs, in order to assist COPUOS, and its Sub-Committees and working groups, in their activities. It has been fulfilling this task for a quarter of a century.

As the universal organization of a general character, the United Nations can rely on the co-operation with various organizations and bodies having responsibilities in special fields of interest. From among the specialized agencies the Food and Agriculture Organization of the United Nations (FAO), the World Meteorological Organization (WMO), the International Telecommunication Union (ITU), the United Nations

Educational, Scientific and Cultural Organization (UNESCO) and the International Bank for Reconstruction and Development (World Bank) have been particularly involved in space matters, some of them having special operational groups for space affairs of their particular concern. Other organizations and bodies within the United Nations system, such as the International Civil Aviation Organization (ICAO), the International Maritime Organization (IMO), the International Atomic Energy Agency (IAEA), the Natural Resources and Energy Division (NRED), the Office of the United Nations Disaster Relief Co-ordinator (UNDRO), the United Nations Development Programme (UNDP) and the United Nations Environment Programme (UNEP) have also had interests in space affairs in accordance with their respective terms of reference. Therefore, it is the United Nations system as a whole that has heen stimulating international co-operation in space exploration and promoting a wide utilization of achievements reached in this vast field of human activities [1].

The First United Nations Conference on the Exploration and Peaceful Uses of Outer Space was held in Vienna in 1968. Its main objective was an examination of the practical benefits to be derived from space exploration and the extent to which non-space Powers, especially the developing countries might enjoy these benefits, particularly in terms of education and development. The Conference had also to examine the opportunities to non-space Powers for international co-operation in space activities, taking into account the extent to which the United Nations might play a role.

Following the Conference, a United Nations Programme of Space Applications was initiated by COPUOS and established in 1971. Between 1972 and 1983, the Programme focused on helping the developing countries to establish space application programmes which would allow them to participate in the benefits inherent in the technology. The initial activities of the Programme were centred on panel meetings designed to inform the political and technical authorities of these countries of the wide scope of practical application of space technology. Other activities included short-term missions, in co-operation with other organizations and bodies of the United Nations system, to requesting countries, to evaluate the various technologies available to these countries in order to help the competent decision-makers appreciate the potential impact of space applications on their social and economic development. Programmes on training of technical personnel and on dissemination of technical personnel and on dissemination of technical information were later introduced. Under these activities, provisions were made for specialists to participate in meetings and short duration training courses on a regional basis. Fellowships have also been provided for training of selected candidates in appropriate institutions in developed and developing countries. Other United Nations organizations and bodies have adopted the recommendations of COPUOS and have established space-applications-related programmes in their own field of activities.

In accordance with one of its purposes as spelled out in Art. 1 of the Charter, the United Nations has thus become a centre for harmonizing the actions of nations in the attainment of their common ends in outer space.

International co-operation in establishing the legal basis for space activities

In resolution 1721 (XVI) of 20 December 1961, the first basis for developing a legal order for space activities was laid down. It was emphasized in this document that the law of outer space should be growing from valid norms of international law, particularly those inserted in the United Nations Charter. At the same time, the leading principles of the new legal régime for outer space were declared — those of freedom of exploration and use of outer space and celestial bodies in conformity with international law, and non-appropriation of any part thereof by States.

On 13 December 1963, the General Assembly unanimously adopted resolution 1962 (XVIII), entitled "Declaration of Legal Principles Governing the Activities of States in the Exploration and Use of Outer Space". This document, being a General Assembly resolution, did not yet have the binding force of an international treaty. Nevertheless, the Declaration created the starting point of the forthcoming development of space law.

The present multilateral legal basis for the exploration and peaceful uses of outer space was established by a series of international treaties negotiated primarily by COPUOS and its Legal Sub-Committee between the years 1966 and 1979 [2].

The first and fundamental instrument is the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies, which was commended by the United Nations General Assembly in its resolution 2222 (XXI) of 19 December 1966, opened for signature on 27 January 1967 and entered into force on 10 October of the same year. Up to now, 83 States (including all five permanent members of the Security Council) have become Parties to this Treaty.

According to the leading principle of the 1967 Outer Space Treaty "the exploration and use of outer space, including the moon and other celestial bodies, shall be carried out for the benefit and in the interests of all countries, irrespective of their degree of economic or scientific development, and shall be the province of all mankind". This principle, together with other principles inserted in this Treaty, has also created the basis for the whole international space law of our times.

In Art. IV States Parties to the Treaty have undertaken "not to place in orbit around the earth any objects carrying nuclear weapons or any other kind of weapons of mass destruction, install such weapons on celestial bodies, or station such weapons in outer space in any other manner". In the second paragraph of the same article, more far-reaching limitations of military activities have been enshrined; however, tbey bave concerned only the moon and other celestial bodies and not outer space itself. According to this provision "the moon and other celestial bodies shall be used by all States Parties to the Treaty exclusively for peaceful purposes" and this general clause was accompanied by a number of specific prohibitions of different kinds of military activities.

Several principles of the 1967 Outer Space Treaty have been dedicated to furthering international co-operation and mutual assistance. A mechanism of international consultations has been provided, in order to ensure due regard to interests of all parties to the Treaty. An agreement on informing, "to the greatest extent feasible and practicable", of tbe nature, conduct, locations and results of activities in the peaceful exploration and use of outer space was reached in Art. XI, such information to be submitted to the United Nations Secretary-General as well as the public and the international scientific community.

The 1967 Outer Space Treaty was followed by further steps in space legislation which led to the conclusion of four additional treaties dealing with specific subjects. They are as follows:

Agreement on the Rescue of Astronauts, the Return of Astronauts, and the Return of Ohjects Launched into Outer Space. This Agreement was commended by the United Nations General Assembly in its resolution 2345 (XXII) of 19 December 1967 and opened for signature on 22 April

1968; it entered into force on 3 December 1968. So far, 76 States have been Parties to this Agreement; one declaration of acceptance was also made by an international organization.

Convention on International Liability for Damage Caused by Space Objects, which was commended by the United Nations General Assembly in its resolution 2777 (XXVI) of 29 November 1971 and opened for signature on 29 March 1972; it entered into force on 1 September 1972. So far, 63 States have become Parties to this Convention. Also one declaration of acceptance was made by an international organization.

Convention on Registration of Objects Launched into Outer Space, which was commended by the United Nations General Assembly in its resolution 3235 (XXIX) of 12 November 1974, opened for signature on 14 January 1975 and entered into force on 15 September 1976. However, a relatively lower number of States (32) have adhered to this Convention so far; also with one declaration of acceptance.

The Agreement Governing the Activities of States on the Moon and Other Celestial Bodies, which was commended by the United Nations General Assembly in its resolution 34/68 of 5 December 1979 and opened for signature on 18 December 1979. So far, this instrument has assembled but 11 signatures and 5 ratifications; it entered into force quite recently, on 11 July 1984 [3].

The Moon Agreement includes some new elements, particularly a principle declaring the moon and its natural resources as "common heritage of mankind". According to Art. 11, States shall have the right of exploration and use of the moon without discrimination of any kind, on the basis of equality and in accordance with international law and the provisions of the Agreement. As to the exploitation of the natural resources of the moon, however, States Parties to the Agreement "undertake to establish an international régime, including appropriate procedures, to govern the exploitation of the natural resources of the moon as such exploitation is about to become feasible".

Due to the fact that the total number of contracting parties of all space law treaties, particularly of the two latter instruments, remains limited, the United Nations General Assembly recalled on several occasions its concern about further development of the rule of law in the exploration and use of outer space. In resolution 38/80 adopted on 15 December 1983, this principal organ once again invited States that have not yet become parties to the international treaties governing the use of outer space to give consideration to ratifying or acceding to those treaties. Without any doubt, an increase of the number of States adhering to all space law instruments would not only enlarge the effect of the up-to-date space legislation, but it would also stimulate the law-making process which has now been passing a rather difficult period. Nevertheless, this process should continue by applying the procedure used by COPUOS and its Legal Sub-Committee, i.e. by formulating additional treaties based on the principles of the 1967 Outer Space Treaty which would regulate new outstanding problems of space activities.

For almost a decade, the topic of legal regulation of direct television broadcasting was on the agenda of COPUOS. Initiated by the USSR, which submitted in 1972 a proposal of a Convention on Principles Governing the Use by States of Artificial Earth Satellites for Direct Television Broadcasting, this item was under discussion of the Legal Sub-Committee, which agreed on drafting of most of the principles involved. Still, some important issues, especially those relating to the principle of "State responsibility" and "Consultation and agreement between States", remained unsettled, largely due to divergent philosophies underlying the positions of different groups of States. This disagreement reflected the gap between the views of those emphasizing the need for ensuring the free flow of ideas and information, and those whose overall priority was the respect for sovereign rights and an adequate protection of cultural identity of all nations.

When several attempts to reach a compromise in COPUOS had failed, the United Nations General Assembly adopted resolution 37/92 of 10 December 1982 including, in its Annex, Principles Governing the Use by States of Artificial Earth Satellites for International Direct Television Broadcasting. The draft of this resolution was sponsored by a group of developing countries and the resolution was endorsed by a large majority of Member States [4].

For several years, another item of similar magnitude has been under consideration in COPUOS and its Legal Sub-Committee: that concerning legal implications of remote sensing of the earth from space, with the aim of formulating draft principles. The Legal Sub-Committee started consideration of this subject in 1972. In the following years a substantial progress has been reached and a number of principles have been drafted without major difficulties. However, differences in some points still persist.

In particular, different positions have been maintained with regard to the dissemination of data or information on the natural resources of sensed States to third parties. As expressed at different stages of the discussion, some delegations, particularly the Western industrially advanced countries, feel that a system of unrestricted dissemination would be in the best interest of all States and that prohibitions on dissemination would be impractical. Other delegations, however, mostly representing developing nations, are of the view that making the dissemination of certain data and information subject to the approval of the State whose territory is affected by the remote sensing activities is necessary, since this is a corollary to the principle of the sovereignty of States. So far, no compromise solution for this complex issue could be found, though several attempts at approaching it from a new standpoint were made.

The present agenda of the Legal Sub-Committee also includes two other items, one of them involving an issue which has been known in the doctrine of space law for years, the other of a relatively recent origin.

The former is called "Matters relating to the definition and delimitation of outer space, bearing in mind, *inter alia,* questions relating to the geostationary orbit". In specific terms, a delimitation between the scope of the principle of sovereignty of States, on which the legal régime of air space is based, and the scope of the freedom of outer space, which has been one of the fundamental principles of space law, is under consideration. This could be achieved by establishing a boundary between two different spaces by an international agreement. The drawing of such a boundary should be supplemented by the recognition of the right of passage for space objects through air space of another State for the purpose of reaching orbit or returning to earth. This position, however, is opposed by some States which maintain the view that the establishing of a boundary at a particular altitude would be arbitrary and premature. Still another trend favours what is called a "functional approach", seeking to reach agreement on defining and regulating "space activities" rather than delimiting outer space.

In recent years the problem of definition and delimitation of outer space has been widened by additional aspects, particularly those concerning the legal status of the geostationary orbit (GSO). The discussion on these aspects was initiated mainly by a group of equatorial countries which feel special responsibilities for preserving appropriate utilization of the segments of the GSO that are superjacent to their territories. This view, however, is not shared by other groups of States. Some of them emphasize that the part of outer space, in which the orbits of geostationary satellites are placed, is inseparable from outer space as a whole. It should be used effectively and economically so as to ensure equitable access of all States to this valuable orbit in accordance with their needs and capabilities.

Another new item, which is under discussion of the Legal Sub-Committee, is entitled "Consideration of the possibility of supplementing the norms of international law relevant to the use of nuclear power sources in outer space". The main issue concentrates on the question of whether the present international law already contains satisfactory norms relating to the use of nuclear power sources (NPS) in outer space, or not. At the last session of the Legal Sub-Committee, a group of delegations made suggestions to work out, in particular, precautionary measures and actions to be taken before and after the reentry of a malfunctioning space object carrying NPS [5].

It should be recalled in this connection that a Working Group established by COPUOS was considering the use of NPS in outer space during three sessions of the Scientific and Technical Sub-Committee held during the period from 1979 to 1981. It reached the conclusion that NPS could be used safely in outer space, provided that all necessary safety requirements were met. The same group formulated a number of recommendations, including those concerning the format of notification for re-entering space vehicles containing NPS which may give rise to radiological hazards. These recommendations also served as a basis for further deliberations of the Legal Sub-Committee. The General Assembly noted in its resolution 38/80 with satisfaction "the successful efforts of the Legal Sub-Committee of COPUOS in elaborating an agreed text concerning the format and the procedure for notification in case of a malfunction of a spacecraft carrying a nuclear power source on board".

During the last session of the Scientific and Technical Sub-Committee held in 1984, the Working Group on NPS was reconvened and according to the recommendation made by COPUOS it should continue in its work.

PROGRAMME OF INTERNATIONAL CO-OPERATION IN THE SCIENTIFIC AND TECHNICAL FIELD

As evident from the foregoing example, tbe Scientific and Technical Sub-Committee, too, has been considering some of the problems studied by the Legal Sub-Committee, concentrating, however, on the scientific and technical aspects of the respective points. Besides the use of NPS in outer space, questions relating to remote sensing of the earth by satellites and examination of the physical nature and technical attributes of the geostationary orbit have belonged to such topics. Moreover, this Sub-Committee has examined some topics of its own, such as questions relating to space transportation systems and their implications for future activities in space.

In recent years, however, the main concern of the Scientific and Technical Sub-Committee has been related to the preparation — and now the implementation of the results — of the Second United Nations Conference on the Exploration and Peaceful Uses of Outer Space held in Vienna in 1982 (UNISPACE 82). This Conference dealt with three major agenda items: (a) State of space science and technology, (b) Applications of space science and technology and (c) International co-operation and the role of the United Nations. The discussions at the Conference focused on matters of a global nature and the utilization of space technology with respect to all participating countries. Furthermore, the Conference made an impetus towards an orderly growth of space activities favourable to socio-economic advancement of mankind and, in particular, of the peoples of the developing countries through creation and reinforcement of their national capacities.

The Conference adopted by consensus a comprehensive report to the General Assembly on its work [6], which included its recommendations pertaining to international co-operation in the exploration and peaceful uses of outer space. The General Assembly endorsed these recommendations in its resolution 37/90 adopted also by consensus on 10 December 1982. In resolution 38/80 adopted on 15 December 1983, the General Assembly emphasized the urgency and importance to implement fully the recommendations of UNISPACE 82 as early as possible. All organs, organizations and bodies of the United Nations system and other intergovernmental organizations working in the field of outer space or on space-related matters have been requested to co-operate to this end. In this way, the basis for the present programme of the United Nations in the field of space science and technology was laid down. It is being implemented in several areas, the present state of which will now be briefly summarized [7].

1. *Study projects*

In resolution 38/80, the General Assembly endorsed the recommendation of COPUOS that, of the study projects proposed by UNISPACE 82, the following three studies be carried out on a priority basis:

(a) Assistance to countries in studying their remote sensing needs and assessing appropriate systems for meeting such needs;

(b) The feasibility of using direct broadcasting satellites for educational purposes and of internationally or regionally owned space segments;

(c) The feasibility of obtaining closer spacing of satellites in the geostationary orbit and their satisfactory coexistence, including a closer examination of techno-economic implications, particularly for developing countries, in order to ensure the most effective utilization of this orbit in the interest of all countries.

In accordance with the procedures approved by the General Assembly, a Group of Experts was organized for each of the studies. Representatives from interested specialized agencies also participated in the groups. The three groups met in 1984, that on Remote Sensing during the session of the Scientific and Technical Sub-Committee in New York, that on the Geostationary Orbit during the session of the Legal Sub-Committee in Geneva and that on Direct Broadcasting Satellites for Education during the COPUOS session in Vienna. The final draft studies as approved by the Groups of Experts will be submitted to the Scientific and Technical Sub-Committee at its next session to be held in 1985 for consideration and evaluation, and through it to COPUOS for recommendations for appropriate action.

2. *Space Applications Programme*

In its resolution 37/90, the General Assembly endorsed the recommendations of UNISPACE 82, that the United Nations Space Applications Programme be directed towards the following seven specific objectives:

(a) Promotion of greater exchange of actual experiences with specific applications;

(b) Promotion of greater co-operation in space science and technology between developed and developing countries as well as among developing countries;

(c) Development of a fellowship programme for in-depth training of space technologists and applications specialists, with the help of Member States and relevant international organizations;

(d) Organization of regular seminars on advanced space applications and new system developments for managers and leaders of space application and technology development activities as well as seminars for users in specific applications;

(e) Stimulation of the growth of indigenous nuclei and an autonomous base in space technology in developing countries;

(f) Dissemination, through panel meetings and seminars, of information on new and advanced technology and applications, with emphasis on their relevance and implications for developing countries;

(g) Arrangements for provision of technical advisory services on space applications projects, upon request by Member States or any of the specialized agencies.

Under the scope of this newly mandated and expanded Space Applications Programme, the United Nations organized in 1984 the following actions:

Two short-term training courses on remote sensing applications. The first, on forestry, was organized in collaboration with the Government of the USSR; the second, on Aquaculture, was organized in collaboration with the Government of Italy and FAO. Two workshops were also conducted in collaboration with the Committee on Space Research (COSPAR) on (i) remote sensing of interest to developing countries and (ii) promotion of space research in the developing countries.

In promoting the development of indigenous capability, the Programme implemented fourteen long-range fellowships in 1984 for in-depth training of participants from developing countries, in the areas of telecommunications, satellite meteorology and remote sensing. It is anticipated that these fellowships will be renewed and further extended in 1985.

Other approaches to the development of indigenous capability at the local level will be extensively explored during a series of the United Nations international workshops on space technology applications within the framework of educational systems. The first of these workshops is being organized in co-operation with the Government of India for the benefit of Member States in the ESCAP region in 1985.

With reference to the mandate on technical advisory services, the United Nations requested Member States to provide information on their needs and requests in specific areas of space applications. On the basis of these enquiries, a series of meetings of experts on space science and technology and its applications has been convened under the Space Applications Programme in different regions. These meetings are focusing on appropriate space applications projects at regional levels, including the assignment of priorities to these projects.

3. *International Space Information Service*

In its resolution 37/90, the General Assembly also decided to establish an International Space Information Service, initially consisting of a directory of sources of information and data services to provide direction, upon request, to accessible data banks and information sources. In implementing this mandate, the United Nations organized a United Nations Meeting of Experts on Remote Sensing Information Systems in 1984, which was hosted and co-sponsored by the Government of the Federal Republic of Germany.

4. *Regional mechanism of co-operation*

In resolution 37/90, the General Assembly approved the recommendations of UNISPACE 82 regarding the establishment and strengthening of regional mechanisms of co-operation and their promotion and creation through the United Nations system. In pursuance of this decision, the Secretariat continued to seek to strengthen the regional mechanisms of co-operation in carrying out various activities under the Space Applications Programme. For example, the United Nations organized in 1984 a regional meeting of experts on Space Science and Technology and its Applications in Jakarta, Indonesia, for the benefit of Member States of the ESCAP region, and a similar meeting of experts in the ECLA region is to be hosted by the Government of Argentina in 1985.

5. *Voluntary contributions*

One of the most difficult problems, causing substantial constraints on the implementation of the recommendations of UNISPACE 82, is the financing of these activities. In resolution 37/90, the General Assembly decided that all new or expanded activities are to be funded mainly through voluntary contributions of States in money or in kind, as well as through the rearrangement of priorities within the next regular budget of the United Nations. In 1983, the Secretary-General of the United

Nations brought the appeal for voluntary contributions, particularly with respect to the newly mandated and expanded activities of the Space Applications Programme, to the attention of Member States. This appeal was reiterated in broader terms in 1984. However, the number of governments and international organizations which have positively responded to these appeals to date have been limited and much still remains to be achieved in order to improve the financial basis for these activities.

PREVENTION OF ARMS RACE AS AN ESSENTIAL CONDITION FOR INTERNATIONAL CO-OPERATION IN OUTER SPACE

The picture of the United Nations activities relating to outer space would not be complete without mentioning a topic that has become one of the most serious issues of our times.

At recent sessions of COPUOS, during the discussions at the sessions of the General Assembly in the last three years and also at UNISPACE 82, delegations of many Member States repeatedly expressed their deep concern over the growing dangers of the military use of outer space, stressing the need for the early consideration by the international community of measures to prevent an arms race in outer space. Besides other negative effects, the introducing of weapons into this environment and establishing of new weapon systems might have a serious impact on the development of international co-operation for the exploration and peaceful uses of outer space. Therefore, already at the 1981 session of COPUOS, it was proposed by some delegations to include in the agenda of the Committee a new item entitled "Ensuring the use of outer space exclusively for peaceful purposes" [8]. The discussions on it could lead to a further elaboration of the principle of non-militarization of outer space, the first basis of which was already enshrined in Art. IV of the 1967 Outer Space Treaty.

Though the problem of the growing militarization of outer space was not on the UNISPACE 82 agenda, discussion of this subject was among the most vigorous of the Conference deliberations. Ultimately, the Conference succeeded in finding a compromise conclusion which was inserted in the report of UNISPACE 82. In this document, which was adopted by consensus, the extension of an arms race into outer space was qualified as "a matter of grave concern to the international community" and as "detrimental to humanity as a whole". Furthermore, it was emphasized that "the prevention of an arms race and hostilities in outer space is an essential condition for the promotion and continuation of international co-operation in the exploration and use of outer space for peaceful purposes" [9].

In the meantime, in the agenda of the thirty-sixth session of the General Assembly held in 1981, an item called "Conclusion of a treaty on the prohibition of stationing of weapons of any kind in outer space" was included. It was done so upon the initiative of the USSR, which also provided the text of a draft treaty on this subject to be negotiated as a separate instrument in addition to the existing space agreements [10].

At its thirty-seventh session, the General Assembly succeeded in adopting a single resolution 37/83 of 9 December 1982, requesting the Geneva Committee on Disarmament to consider the question of preventing an arms race in outer space as a matter of priority. However, in the course of its session in 1983, this Committee was not able to reach any progress and did not even establish a working group on outer space due to disagreement on a mandate for it [11].

A new basis for the deliberations on this subject was created by the Draft Treaty on the Prohibition of the Use of Force in Outer Space and from Space against the Earth, submitted by the USSR [12] and by the discussion that developed during the consideration of the point "Prevention of an arms race in outer space" at the thirty-eighth session of the General Assembly. In its resolution 38/70 of 15 December 1983, the General Assembly *inter alia*, emphasized that further effective measures to prevent an arms race in outer space should be adopted by the international community and reiterated that the Conference on Disarmament (as the Geneva Committee on Disarmament was to be known from the date of commencement of the annual session in 1984) had a primary role in the negotiation of an agreement or agreements on the prevention of an arms race in all its aspects in outer space.

On the same day the United Nations General Assembly also adopted by a majority vote a resolution concerning International Co-operation in the Peaceful Uses of Outer Space (Resolution 38/80 of 15 December 1983). In this document, the General Assembly called upon all States, in particular those with major space capabilities, "to undertake prompt negotiations under the auspices of the United Nations with a view to reaching agreement or agreements designed to halt the militarization of outer space and to prevent an arms race in outer space, thus contributing to the achievement of the internationally accepted goal of ensuring the use of outer space exclusively for peaceful purposes". At the same time, the General Assembly requested COPUOS to consider, as a matter of priority, the questions relating to the militarization of outer space, taking into account the need to co-ordinate the efforts of COPUOS and the Conference on Disarmament.

In accordance with the decision of the General Assembly, COPUOS considered the questions relating to the militarization of outer space at its last session held in Vienna in 1984. Notwithstanding all efforts, it was not possible to reach a compromise as to how to approach this issue that would be acceptable for all Members of the Committee. Under these circumstances, the full scale of divergent views and suggestions regarding this subject has been reflected in the report from this session which has been submitted to the thirty-ninth session of the General Assembly [13].

In this connection it should also be recalled that at the first special session of the General Assembly devoted to disarmament, which was held in 1978, the delegation of France proposed the establishment of an international satellite monitoring agency (ISMA) by means of which the use of observation satellites within the framework of disarmament would be placed at the service of the international community. In the final document from its special session, the General Assembly requested the Secretary-General to undertake, with the assistance of qualified governmental experts, a study on the technical, legal and financial implications of establishing an ISMA.

In the study, which resulted from the considerations of the said group of experts and was published in 1981 [14], the contribution which monitoring by satellites could make to the verification of compliance with certain arms control and disarmament agreements was generally recognized. Moreover, the role that satellite monitoring could play in preventing or settling international crises and thus contribute to confidence building among nations was emphasized. It was also made clear that from the legal point of view there was no provision in international law, including space law, that would entail a prohibition for an international governmental organization such as ISMA to carry out monitoring activities by satellites.

When reviewing the results of its first special session on disarmament at its thirty-seventh session, the General Assembly, in resolution 37/78 K adopted by a majority vote on 9 December 1982, took note of the conclusions of the study and requested the Secretary-General to report to the General Assembly on the practical modalities for implementing those conclusions with respect to the institutional aspects of the draft. In his report submitted to the thirty-eighth session of the General Assembly in 1983, the Secretary-General noted that the General Assembly would have to decide upon a process and a legal framework which could result in the establishment of an ISMA and that most of the institutional aspects of ISMA would have to be settled by negotiations between the participating States [15].

Conclusion

During the twenty-five years of its operation, the United Nations outer space programme, as developed by COPUOS and its sub-committees, has embraced a variety of activities, both in the legal, and the scientific and technical fields. In particular, the United Nations has succeeded in establishing the multilateral legal basis for space activities and is continuing its efforts further to develop the present legal régime of outer space. Two United Nations Conferences on the exploration and peaceful uses of outer space became landmarks in the co-operative efforts of nations relating to space science and technology. A viable Space Applications Programme was designed and expanded, step-by-step, in the period between these Conferences and particularly after UNISPACE 82.

Fruitful working relations have been set up between the United Nations and other organizations of the United Nations system dealing with space matters in order to reach a productive co-ordination in their actions and to avoid duplication. Moreover, this institutional basis has been enlarged by regular contacts and co-operation with other international organizations having consultative status with COPUOS.

All these efforts have had one common denominator: To use tbe increasing human knowledge and know-how as a new effective tool for the benefit of all countries, notwithstanding the differences in the degree of their economic or scientific development. The United Nations outer space programme has been conceived in the belief that such co-operation will contribute to the development of mutual understanding and to the strengthening of friendly relations between all nations. This belief is spelled out in one of the preambular paragraphs of the 1967 Outer Space Treaty and remains to be valid.

However, the ways and means that have been available for attaining these aims by and through the United Nations have been limited and it is hardly possible to expect that they will be substantially increased under present international conditions. Much depends on the Member States, particularly those having major space capabilities, on their political will to find solutions for problems relating to outer space and other issues. Today, the most impending space-related problem is to ensure that outer space be reserved for peaceful uses, serving the needs and interests of mankind. A substantive progress on this path would open new prospects and stimulate the growth of international co-operation concerning outer space. It would also create a prosperous climate for undertaking new, and perhaps more ambitious, co-operative projects under the scope of the United Nations space programme.

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[2] For the English texts of all these instruments *see* in The United Nations Treaties on Outer Space, United Nations, New York, 1984 (UN publication Sales No. E.84.1.10, 00200). Similar publications in other official languages of the United Nations will follow.

[3] The present state of Parties to all these instruments was established on the basis of the informal document Present Status of Outer Space Treaties, distributed at the Twenty-third session of the Legal Sub-Committee held in Geneva, 1984, and completed by additional announcement.

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[5] For more detailed information on the present state of negotiations on all these issues *see* Report of the Legal Sub-Committee on the Work of its Twenty-third Session (19 March - 6 April 1984), UN doc. A/AC.105/337 of 12 April 1984.

[6] *See* Report of the Second United Nations Conference on the Exploration and Peaceful Uses of Outer Space, Vienna, 9-21 August 1982, UN doc. A/CONF.101/10, 31 August 1982, and Corr. 1 and 2.

[7] The following part of this paper is based on the text of the report of United Nations Secretary-General on Implementation of the recommendations of the Second United Nations Conference on the Exploration and Peaceful Uses of Outer Space, prepared for the Thirty-ninth session of the General Assembly (UN doc. A/39/515).

[8] *See* Report of the Committee on the Peaceful Uses of Outer Space, GAOR: Thirty-sixth session, Suppl. No. 20 (A/36/20), para. 68 on p. 13.

[9] *See* Report of UNISPACE 82, UN doc. A/CONF.101/10, 31 August 1982, and Corr. 1 and 2, paras. 13 and 14 on p. 5.

[10] *See* UN Doc. A/36/192 of 20 August 1981, Annex.

[11] *See* Report of the Committee on Disarmament, GAOR: Thirty-eighth session, Suppl. No. 27 (A/38/27)), pp. 167-169.

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STATUS AND PROSPECTS FOR MILITARY USE OF SPACE

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1.0 Introduction

I am a member of a private, non-profit organization and represent only myself here.

Today it is of no practical use to debate whether or not space should be kept free of military operations. There are now, and have been for over twenty years, important military uses for and activities in space. They are already subject to some international control agreements. The practical question is how such control agreements ought to evolve from now on.

The principal international control agreements that affect the military use of space include:

1. The 1963 Partial Test Ban Treaty that bans nuclear weapons tests except underground ones. (The Threshold Test Ban Treaty, which is not yet ratified, further limits underground tests to 150 kilotons).

2. The 1967 Outer Space Treaty that bans placing "weapons of mass destruction" or nuclear weapons into earth orbit or to stationing such weapons anywhere in outer space. Also, Article II states that "outer space, including the moon and other celestial bodies, is not subject to national appropriation by claim of sovereignty, by means of use or occupation or by any other means". (In December 1983, the Peoples Republic of China became a party to this treaty, thereby further strengthening its international acceptance).

3. The 1972 Anti-Ballistic Missile (ABM) Treaty signed by the US and USSR — which entered into force as part of Strategic Arms Limitation Treaty (SALT I) agreements. Among other things the ABM Treaty

bans, for an unlimited duration, the testing and deployment of ballistic missile defense (BMD) systems. Also, Article XII specifies that "For the purpose of providing assurance of compliance... each party shall use national technical means (NTM) of verification at its disposal in a manner consistent with international law, and that each party undertakes not to interfere with the national technical means of the other party...".

There is a general consensus today that the actual language of these treaties effectively minimizes the scope for differing legalistic interpretations. For example, there is general agreement that Article V of the ABM Treaty and the accompanying documents prohibit the use of non-nuclear exotic ABM systems (such as lasers and particle beams) and that such components of an ABM system could be developed and tested only in connection with fixed, ground-based ABM systems and at fixed ABM sites. The current absence of an Anti-Satellite (ASAT) or a space-based-BMD treaty, then, should not be construed as permitting the open-ended testing and deployment of such weapons.

2.0 Current Military Use of Space

2.1 *Satellites*

Outer space today is an area of vital military interest to the US, and also to the USSR as reported in reliable, unclassified Western literature [1-7]. For over twenty-five years both nations have steadily expanded their military use of space to the extent that satellites now support a wide range of important military missions. These space assets serve desirable and stabilizing functions, the most important of which is the collection of reconnaissance data for verification of arms control treaties and for ensuring that an adversary is not mobilizing for an attack. The multipurpose array of reconnaissance and surveillance satellites deployed by both nations is the backbone of each nation's means of verification. The fact that each nation uses such means to monitor the military activities of the other was discussed publicly at the time of the SALT I negotiations in the late 1960's and the use of photo-reconnaissance satellites was officially declassified in 1978.

As also reported in the unclassified Western literature mentioned earlier [1-7], the satellite systems have other types of sensors than imaging, including infrared and radiation sensors, nuclear-weapon-detonation sensors, radar, and electronic listening devices for collecting signals from surface-based radar and communications sources. These capabilities constitute the major portion of each nation's NTM. They provide early warning of ballistic-missile attack, monitoring of treaty provisions limiting strategic arms, strategic target data, and data on nuclear explosions in the atmosphere. Thus, NTM guard against surprise attack and help to promote arms control and stability of international relationships.

Satellites are also used today in other ways to support and amplify the effectiveness of terrestrial military forces. These uses include communications, navigation, weather-data collection, geodesy and mapping, and ocean reconnaissance.

As also reported in the unclassified Western literature [1-7], both the US and USSR have extensive networks of communications satellites for military command and control functions; navigation satellites to furnish signals to military platforms to calculate their positions accurately; and weather and geodetic satellites to collect, respectively, weather and mapping data for military operations. The USSR, for example, also uses Radar and Electronic Ocean Reconnaissance Satellites (RORSAT and EORSAT) for surveillance and location of naval vessels.

The dependence of each nation on its space assets for essential military functions probably varies. The US, for example, depends on satellites for NTM, early warning, strategic target data, and worldwide communications for command and control of forces. It would be very difficult to carry out these functions reliably with terrestrially-based systems.

The USSR depends on satellites for a similar set of functions and for ocean surveillance as well, as noted above. These ocean reconnaissance satellites illustrate how difficult it can be to learn the purpose (or purposes) of a specific satellite. The RORSAT seems fairly easy to recognize because it emits recognizable radar pulses; other satellites may not be so easy to recognize because they do not emit recognizable signals. Further, satellites can no longer be identified with a single function; for example, the RORSAT may provide intermittent fixes on Soviet naval vessels as well as provide surveillance of US vessels.

Today, there are hundreds of such satellites actively used by the USSR and US and now by other nations, as noted by M. Smith of the US Congressional Research Service in her remarks today. In general, the use of satellites for communications, reconnaissance and surveillance, navigation, early warning, detection of nuclear-weapon detonations, weather and geodesy should continue in the foreseeable future. They provide essential functions reliably, especially in peacetime and during crises, and hence promote stability of international relations. They do not constitute weapon threats in and of themselves, although they also can support and amplify the effectiveness of terrestrially-based forces. In the latter case, they can supply real-time navigation and surveillance information, for example, to forces engaged in tactical fighting. It is in this area that the most legitimate motivation is to be found for developing anti-satellite (ASAT) systems. However, it may still be in the best security interest of a nation to forego ASAT weapons, given the reasons outlined above with respect to the needs for NTM and early warning of attack. I will return later to satellite vulnerability to hostile actions and to future prospects for ASAT control.

2.2 *Manned Space Program*

Both the US and USSR have carried out extensive man-in-space programs the past twenty-three years in support of space exploration and the peaceful uses of space. No official statements of operational military use of manned space stations have been made by either nation. The US space shuttle, in addition to its use by NASA, is to be used as a space-transport vehicle by the Department of Defense to launch military satellites of the kind noted above. With respect to the USSR, there have been a number of reports in the Western literature (see, for example, "*Soviet Military Programs and the New High Ground*", Professor Stephen Meyer of MIT, Survival Journal, September/October 1983, International Institute for Strategic Studies, London) that the USSR Salyut space station has been outfitted and tasked in two distinct versions, one for civilian purposes, one for military. Meyer reports that reconnaissance and command and control tasks and experiments have been performed by Soviet cosmonauts during their extended stays in space. These examples illustrate that the field of multifunction platforms will grow as space stations proliferate.

2.3 *Satellite Vulnerability to Anti-Satellite (ASAT) Weapons and Potential ASAT Treaty Implications*

The *US Administration's Report to the Congress on US Policy on ASAT Arms Control*, 31 March 1984, states:

"The current Soviet ASAT capabilities include an operational orbital interceptor system, ground-based test lasers with probable ASAT capabilities, and possibly, the nuclear-armed GALOSH ABM interceptors, and the technological capability to conduct electronic warfare against space systems" . . .

"Continuing, or possible future, Soviet efforts that could produce ASAT systems include developments in directed energy weapons. We have indications that the Soviets are continuing developments of ground-based lasers for ASAT applications. In addition, we believe the Soviets are conducting research and development in the area of space-based laser systems. We have, as yet, no evidence of Soviet programs to develop ASAT weapons based on particle beam technology" . . .

"The US ASAT system presently under development consists of a miniature vehicle (MV) warhead mounted on a two-stage SRAM/Altair booster. This is carried aloft and launched from a specially modified F-15 aircraft. The MV will be capable of attacking satellites in low altitude orbits. The system is currently undergoing testing. It is to be deployed at one Air Force base on each coast of the United States.

"The US has no plans to extend the altitude capability of the MV ASAT system to place high altitude satellites at risk. We are, however, continuing to review ways in which US ASAT capability could be improved. The US ASAT program is being conducted in a manner fully consistent with all US obligations including the ABM and Outer Space Treaties. Directed energy weapons technologies, including high energy lasers have the potential for ASAT use. These technologies are in the research and development phase".

In addition to the US and USSR ASAT capabilities noted above, others include:

— Boosters and spacecraft (manned or unmanned) with the ability to maneuver in space and then firing a weapon. (The US Homing Overlay Experiment using a Minuteman I (1) booster illustrates this capability. The booster payload intercepted a target in space that was fired from thousands of miles away).

— Satellites placed in orbit near a quarry and then exploded by command from the ground (space mines).

I should note at this point that any treaty that bans the testing and use of ASAT systems in space such as the USSR co-orbital system and

(1) Retired ICBMs now in storage.

the US F-15 MV system cannot eliminate the capability for use, at any time of an attacker's choosing, of so-called residual threats (2) such as direct-ascent interceptors consisting of ICBMs, ABM interceptors (3), electronic countermeasures, and ground-based lasers. However, such a treaty could limit specialized threats to satellites and constrain future threats to such key satellites as those high-orbit satellites for early warning. Such limitations, together with satellite survivability measures such as spares and hardening, could help to preserve the international stability these satellites engender.

An ASAT treaty could also raise the political threshold for attacks against satellites and help preserve satellites in peacetime and in non-strategic wars. It could also help to eliminate the instability of space "armed to the teeth" with ASATs and counter-ASATs. Finally, an ASAT treaty could meet some international concerns regarding the use of space for military purposes. To be negotiated successfully, a treaty must provide for effective verification procedures and clear definitions of which specific prohibitions would be included under testing limitations.

3.0 Future Prospects

3.1 *ASAT Treaty*

The *US Administration Report* of 31 March 1984 referenced earlier states, "... ASAT arms control appears to span a greater breadth of subjects than any other area of arms control". This breadth derives, in part, from the dichotomies noted above that are inherent in the purpose and use of current space assets. An ASAT treaty that provides to such assets, including those which directly support terrestrial military forces, a special sanctuary status is of concern to those people who would not like to have assets in sanctuaries used for military purposes. Others give the mission of NTM more priority and strongly support an ASAT treaty.

This situation is complicated further by the possible use of space weapons in a space-based ballistic missile defense (BMD) system such as that envisioned in the US Strategic Defense Initiative (SDI), for example.

(2) Where a weapon has a dual or potential ASAT capability.

(3) For example, from the one system per country permitted by the ABM Treaty or from an Anti-Tactical Ballistic Missile (ATBM) system, which is not limited by the ABM Treaty.

The interaction, then, of satellite use for space mines, ASAT systems, BMD and space law is broad and complex. BMD, including a space-based one, is strictly limited by the 1972 ABM Treaty as noted earlier. The US has stated unequivocally, in initiating its SDI research program, that it will abide by all the provisions in the treaty. One issue, then, is whether an ASAT treaty would inhibit BMD research permitted by the ABM treaty.

I should note here that the strategic relationships and the requirements of a useful ASAT system differ greatly from those for a BMD system. They have only a technical relationship that involves attacks on objects moving through space. A BMD system can perform ASAT missions easily; the reverse is not true. However, ASAT systems are prime threats to BMD assets deployed in space. Consequently as BMD deployment programs proceed, there can be motivation to develop ASAT systems and space mines.

The set of relationships and dichotomies noted above, coupled with uncertain verification requirements, have made it difficult to find enough common ground to proceed to agreement on an ASAT treaty. One of my US colleagues here, Dr. Richard Garwin, has proposed with others a specific treaty agreement which in effect bans all testing and use of ASAT systems, as well as the stationing of weapons in space. As he has noted, such a treaty would help preserve satellites in peacetime and in non-strategic wars. Although the residual threats noted earlier would continue to exist, conventional international law would be reinforced in its prohibition of any nation from interfering or destroying satellites of other nations.

Prospects for an ASAT treaty would be promising if measures specifying effective verification procedures and clear definitions of which specific prohibitions would be included under testing limitations could be negotiated. Such measures should not inhibit BMD research programs permitted by the ABM treaty.

3.2 *"Rules of the Road" Treaty*

One other prospect in addition to an ASAT Treaty is an international "Rules of the Road" Treaty with measures such as govern behavior on the high seas. Such a treaty could also help to protect satellites used for early warning and NTM during peacetime and crises if an ASAT treaty were not negotiated. The establishment of "rules of the road" in space could also ease verification requirements for ASAT and ABM treaties.

"Rules of the road" covering the use of space by all nations could involve, for example, such subjects as systems which can jam satellite signals, weapons tests which release radiation resulting in electromagnetic pulse (EMP) effects, deconfliction (i.e., removal of path interference) of orbits, frequency allocation, insurance against unplanned collisions, pre-notification of test activities in space, and procedures to be followed to obtain agreement to inspect satellites. Also, agreements could be made not to destroy, damage, or change the trajectory of satellites of other nations. Although some of these subjects may be already covered in part in other treaties and conventional law, the collection of them into a single comprehensive treaty could lend new emphasis to the need to develop explicit and clear "rules of the road" for space. Some people feel that "rules of the road" could best be used to help verify a formal ASAT treaty rather than to replace one.

Given that the ABM treaty prohibits BMD in space, an ASAT Treaty need not wait until a comprehensive weapons ban in space can be negotiated. As noted earlier, the adoption of a verifiable ASAT treaty could help to preserve stability of international relationships and deterrence of nuclear war by protecting those space assets needed for early warning and NTM of verification during crisis periods.

Military and civil space activities have coexisted for many years and there is no reason to believe that they cannot continue to do so for many more as long as military satellites are non-aggressive in nature.

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SPACE TECHNOLOGY AND THE CONQUEST OF HUNGER

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A Hungry World

At the First International Conference on Food and Agriculture convened by President Roosevelt in 1943 in Hot Springs, Virginia, United States, it was resolved "This conference, meeting in the midst of the greatest war ever waged, and in full confidence of victory, has considered the world problem of food and agriculture and declared its belief that the goal of freedom from want of food suitable and adequate for the health and strength of all people, can be achieved".

At the Second World Food Congress held 20 years later in Washington in June 1963, President J.F. Kennedy declared: "So long as freedom from hunger is only half achieved, so long as two thirds of the nations have food deficits, no nation can afford to be satisfied. We have the ability, as members of the human race, we have the means, we have the capacity to eliminate hunger from the face of the earth in our lifetime. We need only the will".

Again, at the World Food Congress held in Rome in Novemher 1974, it was resolved that the problem of hunger and malnutrition should be solved by 1985. The United Nations Assembly, in a resolution on the Third United Nations Development Decade, declared in 1980 that hunger and malnutrition should be eliminated as soon as possible and certainly by the end of the century.

At the World Food Day Colloquium held on 16th October 1982 at the FAO Headquarters in Rome, the eminent panelists drawn from different parts of the world made the following statement: "We believe that it is indeed possible to end world hunger by the year 2000. More than ever before, humanity possesses the resources, capital, technology and knowledge to promote development and to feed people and all its children can be fed and nourished". "Only a modest expenditure is needed each year — a tiny fraction of total military expenditure which amounts to about $ 650 billion a year. What is required is the political will to put first things first and to give absolute priority to freedom from hunger".

My own commitment to the study of cosmochemistry and problems related to the study of origin of life and the search for life beyond the earth may be considered far out from the point of view of down to earth scientific considerations. This very reason, however, emboldens me and gives me some comfort that the view from the distance may provide a better perspective of the prohlems before us. My current involvement in the international activities of the American Chemical Society, my participation in the UNESCO programs in South Asia, my response to requests from the government of Sri Lanka to help them in the scientific development of that island nation, and finally to CHEMRAWN to outline a blueprint for action for the conquest of hunger gives me a little more courage to address you on the question of space technology for the conquest of hunger.

In the long range, for the future well-being of the human race, food is inevitably the greatest common denominator. Life itself and all of the complexities of biological function depend on the continuing availability of those materials which provide energy and the building blocks for growth, development, and the reproduction of the species. The phenomenon is universal in the entire biosphere and the success with which each individual obtains the elements and compounds essential to an adequate diet determines ultimate survival. Food is the single most important component for survival.

The moment of deliberation on this matter is extremely timely. A sense of urgency pervades the talk of those who are knowledgeable. In a recent statement at the American Chemical Society meeting in New York, Norman Borlaug, Nobel Laureate and Father of the Green Revolution, commented, "It is my belief that expanding food production fast enough to meet the increasing needs of a large and growing population, over the next four decades, will be vital to the survival of civilization". The imminence of disaster is before us. It is closer than most people realize or are prepared to admit.

The Presidential Commission on World Hunger, which concluded its studies under the Carter administration, made its central and most important recommendation, that the United States make the elimination of hunger the primary focus of its relationship with the developing countries, beginning with the decade of the 1980's.

In the year 2000, our planet earth will be the home of 7 billion people, double today's population. It is a sobering thought that almost all the females who are going to give birth to those children in century 21 are already with us. It will not suffice to double our food production — we must at least triple it. Two-thirds of humanity are already suffering from inadequate nutritional balance, as the experts would say, or in common language, they are starving.

In the past twenty years, thanks to the Green Revolution, miracle rice, and miracle wheat, we have increased world food production by 40%. But during that period, the world population has doubled. The gap between the number of hungry people and the amount of food needed to feed them has thus widened. Hunger is spreading, unchecked by marches, fasts, public declarations, or charity. Everyone supports these noble causes in theory, but in practice there are no easy solutions to the problem. The control of the population is the obvious answer, but the numerical stabilization of the human race is not achieved in a decade, not in two, perhaps in half a century. Thus, at least for another generation, we must turn to science and technology to provide adequate food for humanity.

A closer look at this population problem shows us that at the time of the discovery of agriculture, twelve thousand years ago, the population of the earth was about 15 million by the beginning of the Christian era. Another doubling had occurred by about 1650, and yet another by 1850, bringing the world population to 1 billion. It took over 80 years, up to 1930 to bring the population to 2 billion. The latest doubling bringing world population to 4 billion was reached in 1975. If the population growth were to continue at the 2% level which prevailed in 1975, it would double to 8 billion by the year 2015.

Fortunately, there is some preliminary evidence to suggest that there is a slowing down of the population. But it is frighteningly high in the developing nations, where food is most deficient. Even with the slowing down of the population, the figure 8 billion will be reached in 60-80 years, or 2040-2060. The task of producing the basic necessities of life for all those who are going to be on the stage of the world is a horrendous prospect.

The solution to such a problem is bewildering to the layman. We have on the one hand rank pessimism, and on the other a certain utopian, scientific optimism. We have the modern echoes of Malthus: the "Population Bomb" of Paul Ehrlich, "Limits to Growth of Meadows and Meadows" and other studies of the Club of Rome which have highlighted the enormity of the problem and left many in a state of utter despair.

After the World Food Conference sponsored by the United Nations there were even some highly respected world scientists who advocated the totally unthinkable and absolutely abhorrent solution of triage: let the hungry die of starvation, they said, while the strong and well of the world conserve the food for themselves.

On the other hand, there are those who professed a certain exuberant hope that science can solve all problems.

Francis Bacon gave us his idea of utopia. The modern proponents of this concept quote the great and significant developments in science: the conquest of space, the harnessing of the atom or the decoding of DNA as examples. If we can land a man on the moon, surely then we can solve our food problem! The Apollo program was without a shadow of a doubt, a supreme triumph of science and technology, and will go down in all human history as one of man's greatest achievements, the casting off of the shackles which bound us to earth, and gave us the exhilarating freedom to explore the universe. But perhaps there is a fallacy in this reasoning. The truth may lie between the dismal pessimism on the one hand and the over-confident, exuberant, utopian optimism on the other.

The magnitude of the problem, even in this context, is still staggering. World production of all kinds of food in 1975 reached a new record of 3.3 billion metric tons. At a 2% population growth, the resulting 8 billion people in 2015 will require 6.6 billion tons of food each year, just to maintain the per capita consumption at the estimated 1975 level. This means that in the short period of 40, 60, or 80 years, depending on how the population changes, world production must again be increased by at least as much as was achieved during the entire 12,000 year period from the beginning of agriculture to the year 1975.

The complexity of the problem also relates to the question of poverty. India is a classic example where enough grain is produced to feed the people, but the main cause of hunger is not the lack of food, but the lack of the wherewithal to buy it. India reached cereal grain self-sufficiency in 1977, and in 1978 and 1979 1% of its crops were exported. India did for Vietnam what the U.S. previously did for India. The low standard of living however did not permit the poor Indian the access to the very means of sustenance.

Synthetic Food

Let us, however, in the few minutes at my disposal, devote ourselves to the discussion on how the world food supply might be improved or increased. Is it possible for man to produce some food independent of climate? The chemical synthesis of food is a tantalizing area for exploration. If we can make the material of our shirts, we can also make the substance of our breakfasts and our lunches. Carbohydrates arise from the fixing of carbon, hydrogen and oxygen. Proteins similarly result from the same three elements with nitrogen thrown into the bargain. The laboratory of nature achieves this result through the complex process of plant photosynthesis and animal metabolism. In the laboratory of modern chemistry, the shortcut from molecules to meals is perhaps within scientific reach. In my own laboratory, our studies on the origins of life have shown that an atmosphere containing carbon, nitrogen, and oxygen, whether in the form of methane, ammonia, and water; carbon monoxide, nitrogen, and water; or even carbon dioxide, nitrogen and water when energized, gives rise to amino acids. Formaldehyde is a simple molecule formed in this process, which when polymerized gives rise to sugars. Indeed at this very moment we are engaged on behalf of NASA in a program to see whether in a long range space flight the carbon dioxide which would be available in the closed space craft environment could be converted into food, into the carbohydrates necessary for sustenance. Such a process, if successful, could be translated to terrestrial needs to help in the conquest of world hunger. There is an intriguing science fiction story of an eighth floor restaurant serving gourmet meals, but the only raw material that enters the building is the coal in the basement. Such an idea may not be a mere technological fantasy. What a marvelous challenge to convert the entire Green River Shale to food on the table.

The science is there. Perhaps what is required is the technology. A major effort is necessary to come up with the technology to produce the food that is necessary. Perhaps an Apollo program-type approach — I'd rather not use the word Manhattan-project — would be required in order to produce the synthetic food in a short time. Such an effort may not be of great appeal in the United States, where we have a super abundance of plant and animal food. However, in countries like India, where self-sufficiency in grain is only tenuous, where the crops depend on the monsoon, and where there is a large pool of scientific talent, a project of this type could perhaps be initiated for the betterment of mankind. A telling slogan, "Burn your garbage and convert it into food".

Remote Sensing

Because of its importance as a staple in the diet of more than 90 percent of the people in developing countries and because of its importance in international trade, rice must be viewed in the global context. From the perspective of increasing rice production, the most important areas of the world are those where water is not a limiting factor. However, from a global economic perspective, the important areas of the world are those where production varies widely from year to year.

Rice is extremely adaptable to the environment, growing from tidal marshes to altitudes exceeding 3000 meters and from 35°S to 50°N latitude. It is adapted to wide ranges of rainfall (from 100 mm/year to more than 4500 mm/year) and temperature during the growing season (from 17°C to 33°C). As a result of this adaptation, it is a very complex crop to model in either biological or econometric terms.

It is clear that, when properly supported by existing national government infrastructure, satellite remote sensing, including both land and atmospheric remote sensing, has the potential to enable a global program to be developed to inventory and monitor rice. Major elements of the technology are in an advanced state of development but have not yet been adequately tested on rice. Many but not all elements of the science are ready to be used in any such program.

A five-year plan of research can be identified in each of five specialty areas: crops, soil, water, pests, and modelling. In a recent workshop held at the International Rice Research Institute some of the panels identified research requirements beyond the initial five-year period. The water group noted that the first five years should be spent on inventory and then begin the development of appropriate models. Although not specifically stated, the crop group likewise expressed concern about a special inventory problem: the dynamics of the area planted with rice. Similarly, the soils group called for an inventory period initially with special emphasis on problem soils. For the second five-year period they recommend a second inventory on a much larger scale.

Each of the groups has identified the gaps in basic knowledge and developed an outline for a plan of research to provide the requisite information. In addition there is either an explicit or implicit recognition that the current state of the art is sufficient to mount a major program in the remote sensing of rice production. There is much that can be done while the research proceeds, largely in the area of inventory. This inventory period is expected to involve a system of satellites, aircraft, and both national and international scientific ground survey teams.

The groups, in plenary, took special note of the requirements for international standards for measurements, including field, airborne, and satellite data. They encouraged software standards to facilitate the sharing of data and they encouraged coordinated experimental design. Finally, in recognition of the extraordinary difficulty in mounting a multinational program in which major elements of the research are the responsibility of different governments, it was proposed that a pilot program of the application of remote sensing to rice production be undertaken in India. In this way, those governments who are able to participate may do so and thus the program of research will be enhanced by their participation but not jeopardised by their failure to do so.

Remote Sensing for Water

In the southeast Asian rice-growing areas it is important to detect and monitor water because the within and between yearly distribution of rainfall is variable. Particularly in monsoon areas, the nature of the precipitation can produce vegetation gaps. The primary driving factor for rice production in this area is water variability and availability at tbe proper time. Of all field crops, rice production requires the largest amount of water; 1 m to 1.5 m is used for a 3-month crop on the average. It is noted however that the actual requirement of the plant for water is not greatly different from wheat (~ mm/day). Further, if the plant is started in a flooded environment it must be maintained in a flooded environment even though that same plant could have been grown as a dry land crop. Rice has the extraordinary ability to develop special cells which permit it to survive in a flooded environment. Rice is also a determinant crop; that is, it requires specific amounts and quality of water at critical stages, and therefore is very sensitive to drought and flooding.

A complete inventory of water-related parameters is essential. The following features need to be detected and monitored: snow, humidity, ground water, surface water, soil moisture, field water, and the intensity, amount, and duration of rainfall. Table 1 further explains the parameter characteristics, sampling interval, and spatial resolution required for each feature. Other features that need to be mapped are those related to irrigation systems such as wells, tanks, canals, and pumping stations.

Inventory of Water Resources

Water-related parameters that need to be inventoried include snow, humidity, ground water, surface water, soil moisture, field water, and rainfall. The remote sensing requirements for these parameters are shown in Table 1.

TABLE 1 — *Water-Related Parameters that Need to be Inventoried and Monitored.*

Parameter	Characteristics	Sampling interval	Spatial resolution
Snow	To obtain snow melt	Seasonal or less	1 km or less
Humidity and temperature	At ground to 3 m level	Daily	1 km or less
Ground water	Water table and amount	Weekly	1 km or less
Surface water	Duration, stage, discharge, recharge, amount, circulation	Weekly (daily) for modelling	0.25 ha or less
Soil moisture	Entire profile in root zone	Daily (rainy season) Weekly (dry season)	0.20 ha
Field water	Depth resolution from 5 cm to 3 m	Biweekly	0.25 ha or less
Rainfall	Intensity, amount, and duration	Daily/hourly	1 km or less

Water Management

In an effort to determine the extent to which the inventoried water parameters could assist in the management of water resources, the following list was compiled:

1. Design and operation of irrigation systems.

2. Monitoring of various irrigation systems (to determine where the water has gone).

3. Assist in water use and movement discussions (that is, those associated with weed infestation and siltation of canals).

4. Assist in identifying water use problem areas (associated with seepage, soils, waterlogging, and so forth).

5. Water use efficiency (as regulated by such things as soil types and conditions).

6. Delineate flood-prone and geologic flood plains.

7. Flood damage assessment.

8. Drainage basin characteristics (that is, the amount and quality of water, run-off, coefficients, and so forth).

9. Flood mapping and residence times.

10. Knowledge of phenological stages (to ascertain water needs).

11. Water quality (which involves measurements of the following parameters):

a) Temperature (0.5°C)

b) Turbidity

c) Suspended solids

d) Pollution sources

e) Salinity

f) Algae.

Water-Related Projections

Water-related forecasts or projections refer to projections both ahead of the cropping season and during the growing season. The water-related parameters that are needed to manage water resources for rice production and the desired sampling time associated with each are shown in Table 2.

TABLE 2 — *Measurements (Ground) and Remotely Sensed Data Needs for Delineating Areas of Soils in which Nutrient Deficiency and Toxicity Problems Occur.*

	Ground observations	Remotely Sensed observations
Cultivated problem soils (saline, sodic acid sulfate)	Reflectance patterns and biophysical composition of crops in ameliorated and unameliorated fields in controlled experiments.	Remotely sensed scenes of large areas in which the problems are known to occur, at critical seasonal stages (Satellite).
	Reflectance patterns and cultivar distribution data from affected and unaffected fields in areas where the problems are common.	Remotely sensed scenes of small test areas (2000 ha) at critical seasonal stages.
	Field mapping (1:25,000) of selected areas where problems occur.	
Uncultivated problem soils (saline, sodic, potentially acid sulfate, peaty)	Reflectance patterns from major natural vegetative communities in areas where problem soils are common.	Remotely sensed scenes of small test areas (2000 ha) at critical seasonal stages.
	Field mapping (1:25,000) of selected areas where problems occur.	
Deficiencies (N, P, Zn)	Reflectance patterns and biophysical composition of crops grown on soils in which the deficiency has been corrected and uncorrected, in controlled experiments.	Remotely sensed scenes of small test areas (2000 ha) at critical seasonal stages.
	Reflectance patterns and fertilizer application data from fields in areas where the deficiencies are common.	
Selected bands in visible and near middle and far infrared	Field mapping (1:25,000) of selected areas where the problems occur.	

Remote Sensing of Water Resources

From a consideration of the various aspects of rice cropping areas, the following reasons suggest the use of remote sensing:

1. Vastness and remoteness of the area.
2. Complexity and dynamic nature of the area.
3. Inadequate existing data and ground-based sampling program.
4. Need for a standardized data base, and
5. More time and cost effective (especially where rapid predictions are required).

It is my belief that remote sensing could assist greatly in optimizing water use for increased and standardized rice production. We also understand that these water resource requirements are directly related to other environmental parameters such as soil types and conditions, crops, insects, and diseases, and to the process of mathematical modelling. The state-of-the-art technology can be used to contribute substantially to the data requirements in this area. Last, it is felt that the goals of this water program will greatly assist resource managers in the optimization of the limited water resources related to rice production. Also determine temporally and spatially areas where rice cropping could either be expanded, reduced, or stopped according to water availability.

All these forecasts or projections, understandably, will require sophisticated modelling activities and will be concentrated upon during the second 5- to 10-year phase. The first 5-year phase will be consumed by the delineation of rice cropping systems, upgrading of topographic maps, and inventorying of water resources.

Remote Sensing for Crops

Remote sensing has been used for the past 20 years both for research and limited operational programs in monitoring crops and crop conditions by use of low-altitude aircraft multispectral photography. With the initial launch of the Landsat series of spacecraft in 1972, a new series of platforms for monitoring global vegetation became available. The LACIE (Large Area Crop Inventory Experiment), USA, and other research conducted using Landsat data by a large number of investigators throughout the world have shown that satellite multispectral remote sensing data could be used as an additional and potentially valuable data source in determining areas devoted to particular land covers and some vegetative characteristics. Using the AGRISTARS (Agricultural and Resources Inventory Surveys Through Aerospace Remote Sensing), USA, extensive research is being undertaken with respect to satellite data including the crops of wheat, barley, corn, and soybeans; rice, however, is receiving very little attention.

Landsat, SPOT, and meteorological satellites are, and will be, providing remotely sensed data that could be used for area and yield studies for rice. Because of the frequency of the observations, it may be possible to space sensors to provide timely information on planted areas, catastrophic events (such as drought and floods) and harvested areas. However, before this information becomes a reality, a substantial amount of research needs to be conducted to relate ground and aircraft spectral data to known crop characteristics. This research includes crop phenology and physical effects such as row spacing, fertilizer treatment, and so forth. A program to understand the spectral measurements as a function of growing time should also be undertaken. It should be noted that national experiments must be coordinated by using common definitions and procedures.

Crop Environmental Plan

1. Establish a topology of rice-based cropping systems which could be used in the framework of a global production study. The classification should include the commingled crops, their succession, and the general temporal pattern of succession.

2. Determine optimum stratification alternatives for ground and remote sensing data collection to maximize precision of crop area determination and yield potential. [An example is the work being done in the USA by Westins on the delineation of Agricultural Production Units (APU)]. This research would include soils and existing cropping practices.

Crop Production Plan

1. Preparatory investigations necessary for remote sensing studies. These studies would involve the accuracy of identifying the growth stage of the crop via spectral characteristics. The objective here is to be in a position to establish biological time scales. Special attention should be given to identifying the critical stages of the crop (such as heading and flowering) that are amenable to remote sensing measurements.

2. Determine area parameters. The relative importance of area parameters. The relative importance of area parameters should be established for each of the rice-growing areas of Asia. Clearly, the added advantages of a remote-sensing information system is directly related to the present state of the crop information system. Each region appears to have specific requirements in this respect. Efforts should also be made to conduct the following studies:

a) The dynamics of area parameters with reference to environmental constraints (mainly water availability, pondage as a possible indicator of planting).

b) The assessment of area losses in rice due to catastrophic events.

3. Determine yield parameters. More research should be done in the development of operational yield models for rice; the probability of using spectral data of the crop canopy in such an approach should be given special attention. This research should be conducted using ground or aircraft platforms. Study areas should include Leaf Area Index (LAI), biomass, stress, insects, and diseases. The relationship of yield potential to radiation, precipitation, and temperature data (in that order) as derived from environmental satellites should also be investigated.

4. Monitor crop development. The optimum frequency for monitoring rice production on a global scale should be established with specific reference to local cropping patterns and growing period. The duration of critical periods has also to be taken into account. Once such requirements have been established, remote-sensing technology should be examined to establish how well it satisfied present needs and what improvements could be made. Experimentation along the line of the AGRESTE project, France, should be revived.

Remote Sensing for Soil

In densely populated countries of Asia, where both food and arable land are scarce, there are about 100 million hectares of land which are suitable for rice cultivation lying idle largely because of soil problems. On millions of hectares of cultivated rice lands, soil toxicities and nutrient deficiencies limit rice yields. The lack of data on the extent and distribution of these lands is a serious obstacle to their efficient utilization. The dearth of data is due mainly to the limitation of past technology in mapping the vast, inaccessible areas where most of the problems occur. Remote sensing coupled with complementary ground work offers the hope that areas where the stresses occur can be delineated and measures taken to increase rice production.

The following soil toxicities were identified: salinity, alkalinity, acid sulfate soil conditions, and peaty soil problems. Deficiencies of nitrogen, phosphorus, and zinc were considered important yield-limiting factors. The main soil degradation process affecting rice lands was identified as waterlogging. Waterlogging refers to the prolonged submergence of fields which results in extreme soil reduction. Water need not be deep (<30 cm) although periods of deep water may occur where waterlogging is a problem.

Remote sensing has the following advantages over conventional ground methodology; it can cover vast, inaccessible areas synoptically and repeatedly; and it is objective, faster, and cheaper. Current technology permits mapping of association of sub-groups of soils on the scale of 1:250,000 or larger depending upon resolution. Future remotely sensed data will permit mapping on a scale of 1:100,000. Problem soils that can be recognized and mapped are salt-affected soils and waterlogged soils. Separation of sodic from saline soils is not ordinarily possible but can be achieved by using multitemporal data. Saline soils can be categorized into strongly and moderately saline soils. There is a dearth of information on coastal saline soils, acid sulfate soils, peat soils, and nutrient-deficient rice lands. Soil characteristics need correlation with spectral data. That correlation requires both ground work as well as remote sensing as summarized in Table 2. Correlation of data from aircraft and satellites with ground observations is necessary.

Recommendations

The working group recommends the following actions for the first 5 years and the next 5 to 10 years:

1. First 5-year action plan:

   Map and categorize problem rice lands;
   Identify and delineate problem rice lands by using natural vegetation as indicator;
   Correlate satellite-sensed data with ground and aircraft data by using a multidisciplinary approach;
   Monitor soil reclamation and degradation;
   Remove the effect of vegetation and moisture to enhance spectral

response of soils, and use other preprocessing techniques to increase classifier accuracy;

Incorporate texture analysis in the classifier.

2. Next 5- to 10-year action plan:

Improve resolution of future sensors to obtain a mapping scale of 1:50,000;

Incorporate stereo effects for image interpretation;

Increase frequency of availability of satellite data;

Interpret the data and provide advice to farmers on corrective measures.

Remote Sensing for Models

Model development problems that need to be addressed by remote sensing are as follows:

1. Determination of the biophysical nature of rice as affected by biological and environmental stress and cultural practices and their manifestation in spectral information;

2. Development of agrometeorological-spectral models for crop development;

3. Development of agrometeorological-spectral yield/growth model for each water culture, major soil zone, and other agrophysical regions; and

4. Development of uniform minimum data requirements and standards for addressing these problems.

Objectives of Remote Sensing Applications

The overall objectives of remote sensing applications for models are to develop agrometeorological-spectral models which provide information on crop identification, crop development, crop conditions, and yield. These models will serve to provide estimates of crop production over the primary major rice-growing areas of the world. In addition, these models can be used to assess optimal cropping regimes and assess the factors that limit crop production in these areas. Improved dynamic estimates can be made from these interactive models. In addition, it would be desirable to develop methodology for using these or other models on a real-time basis for crop management purposes.

Scientific Approach

The scientific and technical approach proposed for achieving these objectives is as follows:

1. Determine the biophysical nature of rice as affected by biological and environmental stresses and cultural practices and assess how these biophysical features are manifested in spectral information;

2. Develop agrometeorological-spectral models for crop development by

a) assessing current agrometeorological models and their limitations;
b) improving these models for crop development.

3. Develop agrometeorological-spectral yield and growth models by

a) assessing current agrometeorological models;
b) improving these models with spectral data, and
c) designing agrometeorological-spectral models.

In order to do so, the following data requirements need to be implemented:

a) Develop minimum data requirements for model use obtained from remote sensing and collateral sources;

b) Develop an international field experimental program to provide data bases for the development and testing of models; and

c) Establish functional relationships between biophysical characteristics and spectral data.

General Recommendations

1. Establish a technical working group to coordinate cooperative research activities in the use of remote sensing for rice production.

2. Establish a technical coordinating committee for field research program and model assessment and development.

3. Use the United States LACIE experience in wheat-yield modelling for developing rice models.

4. Coordinate the development of crop, weather, and soil data banks possibly through international organizations such as Food and Agriculture Organization (FAO), World Meteorological Organization (WMO), Committee on Space Research (COSPAR), and International Rice Research Institute (IRRI); and

5. Provide communication between the user groups (decision makers) and the modelling groups.

Remote Sensing for Rice Insects and Diseases

So far no systematic work on the use of remote sensing on rice insects and diseases has been done. The National Remote Sensing Agency (NRSA) has attempted to detect and identify through satellite data the large area infested with Bacterial Leaf blight in 1980 in Punjab, India. Japanese and Chinese scientists have investigated the brown plant hopper movement from tropical and subtropical areas to Japan, Northen China, and Korea. In addition, incidence of rice blast has been remotely sensed by United States scientists.

Rice Problems which Need Remote Sensing Techniques

Remote sensing techniques are needed to determine the presence of rice insects, diseases, and other causes, such as

Insects:

1. Brown Plant Hopper
2. Gall midge
3. Stem borers
4. Sporadic pests (becoming a serious problem over land areas)
   a) Rice bugs
   b) Army worms-cutworms
   c) Leaf folder

Diseases:

1. Tungro virus
2. Bacterial Leaf blight
3. Rice blast

Other causes:

1. Sheath blight
2. Ragged stunt virus

Justification of the Need for Remote Sensing Techniques

The present ground surveillance is laborious and time consuming.

Remote sensing, with proper methodology development, can be accurate, expeditious, and readily conducted over difficult terrains. Its coverage of large areas will allow timely preventive and control measures. In addition, remote sensing can make it possible to detect not only the population of pests before they reach economic injury level, but also insect migration and movement of pathogen spores. This information when supplemented with agro-meteorological data may provide a faster and more accurate method of forecasting pest build-ups than the traditional ground methods.

State of the Knowledge about Remote Sensing for Rice Insects

The methodology of studying remote sensing techniques for rice pests has not been standardized. Knowledge of the basic information on the spectral reflection of insects/pathogens and plants infested with them both individually and in combination with others, is a prerequisite to determining the quantities listed in subsections.

Remote Sensing Measurements Needed

Remote sensing techniques need to be applied to make the following surface observations and measurements and collect the following epidemiological data:

Surface Observations and Measurements Required

a) Detection of incidence and damage;

b) Measurement of crop canopy reflection change;

c) Measurement of crop canopy geometry change;

d) Detection of defoliation.

Epidemiological Data Required

a) Inventory of host plant; plant growth and measurement;

b) Determination of intensity level-insect population of inoculum build-up;

c) Monitoring of spread rate (migration) and direction; and

d) Determination of agrometeorological information to forecast pests incidence and/or damage.

Recommendations for a Plan of Action

1. Study the change in spectral reflection caused by insects and diseases individually and in combination with each other at different stages of plant growth and growing under different types of rice culture.

2. Standardize methodology for investigating insect migration and pathogen dispersion.

3. Establish correlations between intensity of spectral change caused by pests and crop damage.

Sensor and Data Management

Of the sensors required for remote sensing of rice production in the research program recommended at this workshop, those that are currently available in the existing spaceborne, aircraft-borne, and ground-based sensor systems are presented. In the future, it is possible that new sensors will be required, but they are not defined here. The sensors in space systems are those that are in the meteorological and earth-observing spacecraft systems which are currently either in operation or are in a research and development status. The specific systems listed in this section are selected to meet the observational requirements imposed by the recommendations of the five other working groups of this workshop. The data management programs discussed later are concerned with the need for uniform data acquisition, retrieval, dissemination, and communication among the participating scientists in the proposed pilot research program described next.

In order to establish the research and data management program guidelines and to evolve working relationships and practices, it has been proposed that a pilot program for the application of remote sensing to rice production be undertaken in India. An area is to be selected which contains representative landscapes and crop production practices. The planning will be undertaken for satellite, aircraft, and ground observations for the establishment of specific field and research projects, the management of data and the establishment of data standards. The participation of concerned agencies, national and international, will be established.

This pilot program will permit the early evolution of the recommended research program and the relationships among the participating agencies. In this regard, it is an essential step.

The Rice Problems that Need to be Addressed by Remote Sensing

The information required for the recommended research program includes inventories of soil, water, and biological resources for effecting rice production. These include the inventory and monitoring of the upland, lowland, and flooded areas, the detailed and frequent observations of water levels and rice crops, and the observations of the development of rice crops as well as plant stress in the field.

Importance of Remote-Sensing Techniques

It will be necessary to develop a detailed data acquisition plan including sensors, remote-sensing platforms, field instrumentation, and data processing hardware and software to meet the needs of the research program.

State of the Knowledge about Remote-Sensing Techniques in Connection with Rice Speciality

The flight schedules and sensors of operational and experimental spacecraft are listed in Table 3. The sensor characteristics and specific applications for soil, water, environment, crop, and disease and insect impact are given. A detailed data management plan must await the formulation of the experimental program for the proposed pilot research project.

Data Management

Data standards are required for all aspects of the experimental program. Such standards include the use of calibration standards issued to participants for instruments used in the field as well as aircraft and space sensors. Uniform field data formats and processing methods are to be developed in the pilot program. Although the computers to be used in the program will differ in the various installations, their software must accommodate uniform data formats. In many cases, these will require a certain amount of preprocessing of data on the part of the individual installations. However, these requirements are essential for the effective analysis of data as well as for communication of data and results among

TABLE 3 — *The Sensor Matrix.*

Platforms and Sensors	Observations
Space Platforms (Regional)	
1. Meteorological Satellites Geosynchronous	Observations at low resolution for soils, surface water, precipitation, and vegetation.
Polar Orbiting	Observations in visible and infrared bands of soils, water, environment and vegetation.
2. Earth Observation Satellite Polar Orbiting	Visible and infrared high resolution observations of soils, water, vegetation, and medium resolution. Lidar topographic observations.
Manned	Photographic coverage at annual intervals.
Aircraft (National Programs)	
1. High Altitude	High resolution photo missions as required. Lidar topographic observations.
2. Medium Altitude	Standard aerial photography.
3. Low Altitude	Photographic, spectrometric and radiometric observations of crop for 4 months. Lidar topographic observations and visual observations.
Ground-based Platforms	
1. Data Collection Platforms	Environmental parameters including water levels, rainfall, temperature, winds.
2. Spectrometers	As required for field observations.
3. Radiometers	As required for field observations.

the research groups and standard data entries into crop models developed in the program.

Additionally, experimental design will be centrally coordinated so that ground truth and remote-sensing observations can be analyzed on a continuing basis. To facilitate the implementation of this data standards program, the program coordinating committee will maintain a central data management facility in which data will be stored for distribution, and adherence to the standards program will be reviewed. The central committee will also develop the interfaces for data exchange with other international programs such as The Food and Agricultural Organization (FAO) and the International Rice Research Institute (IRRI). During the planning of the pilot program, it will be necessary to establish the data standards program as a part of the first phase of the recommended research program.

Throughout history food shortages and rising food prices have been a major cause of political instability, triggering riots and strikes, providing a unifying focus for opposition to establish political systems, and ultimately causing governments to fall. The threat of hunger has also been a frequent source of international conflict, inciting wars of territorial expansion and propelling desperate people to migrate en masse across national borders. Hunger and poverty are the main impulses in fact, behind the growing tide of migration, both legal and illegal, from Mexico and the Caribbean area to the United States. This historic movement of populations has its constructive aspects as long as it remains within the absorptive capacity of the receiving countries. But it also contains ominous implications for future conflict. In the long run, the solution may not be for the rich countries to import poverty, but for the developing countries, with appropriate help, to overcome it on their own ground.

The substantial alleviation of world hunger is indeed an attainable goal, provided that the governments in both developed and developing countries recognize its necessity and give it the long term priority it requires.

At no time in history has there been a greater need of inputs by scientists to help people of the world feed themselves. We have to build on the developments of the past 25 years. Although these are great achievements they are insignificant compared to the challenges which will face us in the future. The numbers are increasing, the soil is inferior, the cost of fertilizer has increased, there is a demand for higher quality food. All these require that major quantum jumps be made, if we must avoid a world crisis. Space technology might provide the answer for the entire world.