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The Polar Regions

Peter Wadhams

In a time of universal deceit, telling the truth becomes a revolutionary act
George Orwell

I underestimated the risks. The planet and the atmosphere seem to be absorbing less carbon than we expected, and emissions are rising pretty strongly. Some of the effects are coming through more quickly than we thought then
Lord Stern (Observer, London, 27 Jan 2013, at 2013 World Economic Forum)

Abstract

The Arctic sea ice cover is retreating at a rate which greatly exceeds the predictions of climate models. Instead of basing further predictions on observed ice data, climate modellers still persist in using discredited models, which fail to predict the present state of change, as a basis for projecting future sea ice change in fora such as IPCC where these predictions will be used by policy makers. This is disingenuous and is directly aimed at inducing complacency. We examine the implications of sea ice retreat predictions and also the possible implications of a large-scale methane outbreak from the Arctic sea bed as a consequence of sea ice retreat. We find that the likely cost to society of such an outbreak, some 60 trillion dollars over 100 years, exceeds by several orders of magnitude the supposed economic benefits of sea ice retreat due to easier Arctic navigation and oil exploitation.

Introduction

The session in which this paper is presented is entitled "Competing demands on the cryosphere" and we have already heard about glaciers as sources of water. You will have heard about the accelerated de-icing of our planet due to global warming, and the effect that the increasing rate of mass loss from the Greenland ice sheet, the Antarctic ice sheet and subpolar glaciers is having on global sea levels. Before the end of this century many scientists are predicting a global sea level rise of 1 m or more, though IPCC takes a more conservative position. As many authors have shown (e.g. Houghton, 2004), a rise in mean sea level, serious in itself, conceals a worse effect in that if a community does not have the ability or resources to increase the height of flood defences, the *frequency* of catastrophic flood events increases disproportionately. A case in point is that of storm surges in the

Bay of Bengal, where there is no possibility of raising flood defences in the intricate waterways of coastal rural Bangla Desh. You will also have heard about how the role of glacier water in regulating water flow to low lying areas is disrupted if that glacier is subject to rapid decay. In this talk, therefore, I will focus on another set of rapid changes that are occurring in the cryosphere, and their implications for human life. I will talk about *sea ice*, in particular Arctic sea ice, and indicate what is happening to it, what the further implications of this are for global climate, and what we can do to mitigate the effects.

I am conscious of the Holy Father's serious statement that "today no one in our world feels responsible; we have lost a sense of responsibility for our brothers and sisters". As Prof. Dasgupta has shown, this extends to economists failing to acknowledge that climate change is a major factor in the economic future of the world, and as Prof. Kennel has shown, it includes a reluctance to take the steps needed to mitigate the inevitably increasing impact of climate change on the planet. With respect to sea ice, I will show that not only is Arctic sea ice retreating at an unprecedented rate which will lead to its disappearance in summer in a very short time, but that this involves a cluster of positive feedback effects which will make the impact much greater than simply a loss of ice, and will in fact make the Arctic to a great extent the driver of future change. If we are to take the Holy Father's warning seriously, then we must embrace an understanding and acceptance of the magnitude of the climate challenge, and be ready to take immediate action, treating this as the single biggest threat to Man's future.

Sea ice

The rapidly changing Arctic Ocean ice cover

From the time when I first sailed through the Northwest Passage in 1970 (Wadhams, 2009), to today, the Arctic has been transformed. A central ocean which was permanently ice-covered and where seasonal variations happened only in the subpolar seas has changed with bewildering speed into an ocean where significant summer ice retreat occurs, exposing its wide continental shelves to the power of the sun. Soon the Arctic ice cover will resemble that of the Antarctic – extensive in winter, but almost non-existent in summer. A ship entering the summer Arctic today from Bering Strait finds an ocean of open water in front of her. The top of the world now looks blue instead of white from space; a profound change. It is the summer changes which have created the potential for catastrophic feedback effects which may represent a serious threat to the planet.

Since the Industrial Revolution, the Arctic has been warming more rapidly than any other region of the globe (IPCC 2007, 2013; AMAP, 2011), with an amplification factor of 2-4 over the planet as a whole, which is increasing (Screen *et al.*, 2012). Average air temperatures at 60-90°N have risen by 2°C since 1980. The rapid warming, combined with related factors such as ice-albedo feedback (Perovich and Polashenski, 2012), and higher ocean heat flux (Shimada *et al.*, 2006), are major contributors to a reduction in summer (September) sea ice extent from 7 million km^2 in the 1970s to only 4.2 million in 2007. A brief recovery was followed by a further shrinkage in 2012 to 3.4 million km^2 with a further recovery in 2013.

This summer retreat has been accompanied by a significant decrease in sea ice extent in other seasons (Stroeve *et al.*, 2012), also by changes in ice type, especially a dramatic reduction in multi-year ice (Comiso, 2012); a decline of more than 40% in sea ice mean thickness (Rothrock *et al.*, 1999); a reduction of 73% in pressure ridge frequency between 1976 and 1996 (Wadhams and Davis, 2000); and changes in ice dynamics (Rampal *et al.* 2009). Some coupled models predict an 'ice-free' Arctic summer by 2040 (e.g. Holland *et al.*, 2006; Wang and Overland, 2009), while others (Maslowski *et al.*, 2012; Schweiger *et al*, 2012) predict an ice-free September within a very small number of years, before 2020 and possibly as early as 2015. Analysis of thickness leads to greater alarm. The PIOMAS project (Pan-Arctic Ice-Ocean Modeling and Assimilation System) at University of Washington examined sea ice volumes (making use of submarine data and interpolation rather than just ice extent), and found an "Arctic death spiral" (fig. 1) as the ice volumes at all seasons of the year spiral in towards zero (an ice-free Arctic). An empirical extrapolation from these data show the September figure reaching zero in 2015 or 2016 and neighbouring months (July, August, October, November) set to follow not long afterwards. We have to note that IPCC and many government institutions such as the UK Meteorological Office persist in ignoring these data and making use solely of models to insist, in the face of the evidence, that summer sea ice will persist for several decades. There has seldom been a more glaring disagreement between models and data – nor a more puzzling persistence in the use of discredited models (fig. 2).

The reasons behind this dramatic loss of sea ice are not fully understood, as the mechanisms involved are a complex interplay of atmospheric, sea ice and ocean processes, with strong feedbacks. Many of these processes are inadequately represented in large-scale sea ice models. The Arctic sea ice changes are associated with profound changes in the Arctic marine system, with increased periods and areas of open water, increased fresh water input, increased input of solar radiation, increased surface ocean temperatures, an enhanced underwater light climate, an altered nutrient supply into the euphotic zone and a significant, but yet to be understood, change in ecosystem dynamics (Carmack, 2007; Wassmann *et al.*, 2011). At this point we should note that Antarctic sea ice is not showing this rapid downward trend in area; in fact the area is slowly increasing. We concentrate on the Arctic because the trend is so rapid, and also because Man's direct impact on the Antarctic is limited by the Antarctic Treaty, which prohibits commercial exploitation.

Positive feedbacks – albedo

Of special concern are positive feedback loops, where a change in sea ice extent initiates another undesirable or unexpected change. In the Arctic we are already aware of at least two such loops. The albedo of open water of 0.1 compares to 0.5-0.7 for melting ice, and it has been recently estimated (Pistone *et al.*, 2014) that the loss of area of summer sea ice between the 1970s and 2012 has caused a global albedo decrease equivalent to one-quarter of the effect of all the carbon dioxide added to the atmosphere by man during that period. This is a "fast feedback" because its effect is immediate.

The sea ice-albedo feedback is enhanced by faster spring snow melt in Arctic coastal lands as sea ice recedes, probably due to warmer air masses moving over the coastal lands from the sea; already in 2012 we saw a 6 million km^2 negative area anomaly in June compared with 1980. This will itself create a feedback of similar magnitude to that discussed by Pistone *et al.*, so if we put them together the overall ice/snow-albedo feedback is adding 50% to the direct global heating effect due to CO_2 addition, showing how the Arctic can become a driver of, rather than just a responder to, global change.

The second major feedback that we consider below is the seabed methane feedback. However, before doing so we should mention that sea ice retreat has been coupled with an enhanced melt rate for the Greenland ice sheet (due to warmer air surrounding Greenland in summer), and also (Francis and Vavrus, 2012) it has been suggested that Arctic warming and sea ice retreat have been the cause of a slower speed of progression of Rossby waves in the upper atmosphere, one result being an increased probability of extreme weather events that stem from prolonged persistence of the weather system in one mode, e.g. drought, flooding, cold weather and heatwaves. The possibility is that the exceptional winter and spring weather experienced in North America and Europe during the last three years may be linked to Arctic sea ice loss. At the moment this is a plausible possibility, but not a definite conclusion.

Positive feedbacks – the methane threat

The removal of the ice cover takes away a vital air conditioning system for the Arctic. So long as some ice is present in summer, however thin, the near-surface water temperature cannot rise above 0ºC, since any warmer water would lose heat in melting ice. With the ice gone, the surface water can warm up by several degrees in summer (satellites have shown 7ºC and shipborne surveys up to 7.5°C, Bates *et al.,* 2013), and over the shallow continental shelves (50-100 m deep) this heat reaches down to the seabed. This melts offshore permafrost, frozen sediments which have lain there undisturbed since the last Ice Age. The thawing offshore permafrost triggers the release of plumes of **methane** gas from the disintegration of unstable solid methane hydrates which had been sealed into the sediment by the permafrost cap. Since the significant uncovering of the shelf seas started only in about 2005 this phenomenon is probably a new effect in the postglacial history of our planet.

Methane is a greenhouse gas 23 times as powerful as CO_2 though shorter-lived in the atmosphere. Russian-US summer expeditions since 2004 have observed extensive methane bubble plumes in the Laptev and East Siberian Seas, growing in extent in the most recent years. The atmospheric methane level globally is rising after a few years of stability, with the Arctic identified as the main source (Shakhova *et al.*, 2010ab, 2013). Atmospheric methane (CH_4) is the most important greenhouse gas after water vapour and carbon dioxide. The largest natural source is the decomposition of organic matter in swamps and other wetlands (104 Tg/yr, or 20% of total source 520 Tg/yr) and the largest man-made source is enteric fermentation from domestic animals (90 Tg/yr, or 17%). Another natural source is chemical reactions from the actions of termites, while a major methane resource lies under the oceans in the form of methane hydrates. Other man-made sources include leaks from natural gas pipelines and other aspects of coal and oil production including fracking; the cultivation of rice (because of rotting vegetation in the rice paddies); landfill sites; and waste treatment. Tropospheric chemistry dominates as a sink (448 Tg/yr, or 88% of the total sink), with oxidation of methane to CO_2 in the atmosphere being the main reaction, and the lifetime of a methane molecule in the atmosphere being estimated at 8-10 years. Global mean CH_4 concentration more than doubled after the 1850s, from a postglacial stable value of 700-800 ppb to a value of 2800 ppb by the end of the 20th century, a relatively more rapid growth rate than CO_2 which has only increased by 50%. From 2000 the methane level flattened off and stabilized until 2008, when it started to grow again. This coincides with the time when the decline of Arctic sea ice accelerated (Comiso *et al.*, 2012).

Despite its much lower concentration in the atmosphere than CO_2, methane makes a substantial addition to overall climate change because it is a much more powerful greenhouse gas. Latest IPCC estimates (2013) are that CH_4 contributes 0.97 W m^{-2} to radiative forcing while CO_2 contributes 1.68. Per unit mass, methane is 23 times as powerful as CO_2 when measured over a 100 year period; this is called its global warming potential (GWP). Since methane persists in the atmosphere for only about 8-10 years after emission, its GWP when measured over this period is much greater than 23; figures of 100-200 have been quoted. It is clear that a sudden release of a large quantity of methane would have a huge, if short-lived, impact on climate.

Is methane emission due to accelerate?

Shakhova, the leader of the Russian-US expeditions to the East Siberian Sea (ESS), estimated (2010a) that 50 Gt of methane are likely to be emitted from the East Siberian Shelf during the next few years, a conservative estimate based on her estimate that the total volume of methane trapped in the ESS sediments amounts to 720 Gt. Whiteman, Hope and Wadhams (2013) undertook to estimate what this emission would mean in terms of global warming and economic cost to the world. An emission of 50 Gt is assumed to take place over 2015-2025. The warming estimate was based on a standard model of response to methane emissions and yielded a warming which peaks at 0.6°C in 2040 (fig. 3), a large increase in projected warming levels, especially as, in response to the nature of methane, the effect is concentrated in the years immediately after emission which are years in which CO_2-induced warming is still gathering strength.

The economic analysis was based on the PAGE09 integrated assessment model which was used in the Stern (2007) review of climate change costs for the UK Government as well as for a more recent analysis conducted for the Asian Development Bank. The finding was that total costs (based on factors such as sea level rise, changes in agricultural productivity, changes in transport and industrial practices) amount to 60 trillion dollars over 100 years, an average exceeding 1 trillion dollars per year. A later analysis (presented at the AGU Fall Meeting, San Francisco, December 2013) showed that if the same amount of methane is emitted more slowly, the total costs end up being slightly higher, because the climate impact is being exerted at a time when the economic cost of climate change is greater, per unit of additional warming.
These results are of enormous importance for two reasons:

1. They show the invalidity of arguments which point to the advantages of sea ice retreat in terms of transport and oil exploration being easier.

2. They show that we are living in a fools' paradise if we imagine that future climate warming can be projected based only in a linear way on CO_2 emissions. The reality is that new feedbacks come into play at certain critical points, which accelerate warming and may end up dominating the future pattern of global change. We have pointed to two which are emerging merely from Arctic sea ice retreat – albedo feedback and methane feedback. Albedo feedback is real and definite and is increasing global warming by 50%. Methane feedback is postulated for the near future and will, in the short term, more than double the warming rate.

The most serious result, from the moral standpoint with which we approach this Workshop, is that these predictions are being ignored by the very body, IPCC, which was established to warn the world of dangerous climatic change. A benign interpretation is that IPCC in AR5 has gone a long way in issuing a more serious warning than ever before about the rate of climate change, and feels that warning about further accelerations might be invidious. But the problem is that many policy makers, planners, economists and philosophers, such as some of the distinguished people presenting papers at his meeting, base their view of forthcoming warming on IPCC predictions. If those predictions are too complacent, the conclusions may have to be changed. For instance, a common view is that, morally and economically, we must reduce our carbon emissions at a rapid rate in order to save the world from dangerous climate warming. I wish that I could agree with this view but my own conclusion, based only on unconsidered Arctic feedbacks, is that even a rapid reduction in CO_2 emissions will not work in time, so we must seriously and urgently consider emergency methods which could slow down the rate of warming and give us time to change to a new paradigm of living on this planet – that is, the use of geoengineering techniques, repugnant as these are to many people.

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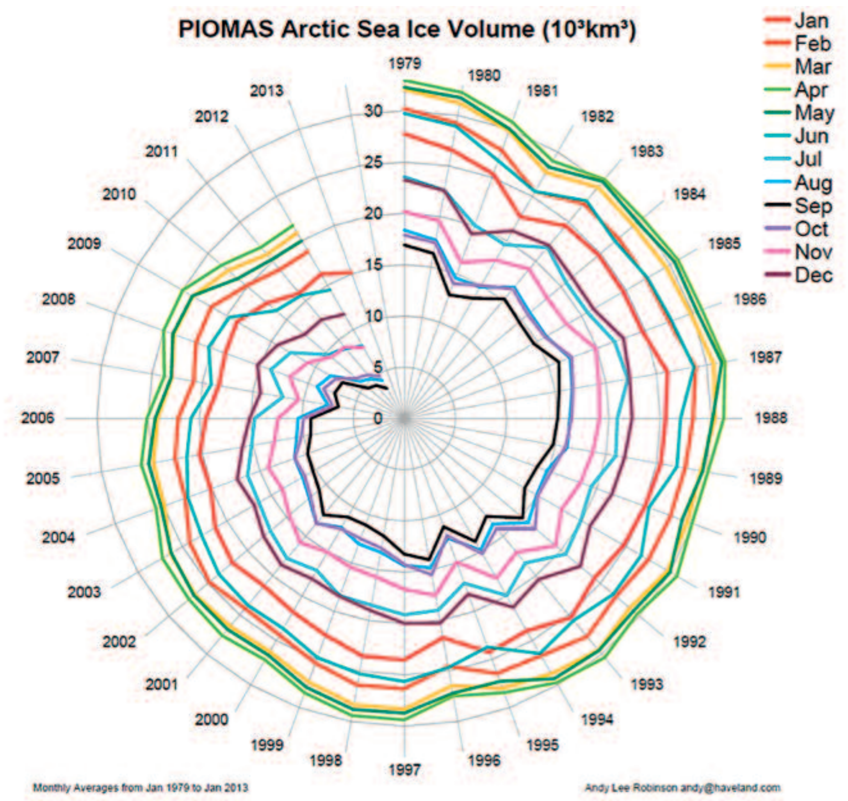

Figure 1. The "Arctic death spiral". The volume of sea ice in the Arctic Ocean in every month of the years 1979-2012, from the data-based PIOMAS model of the University of Washington (Andy Lee Robinson).

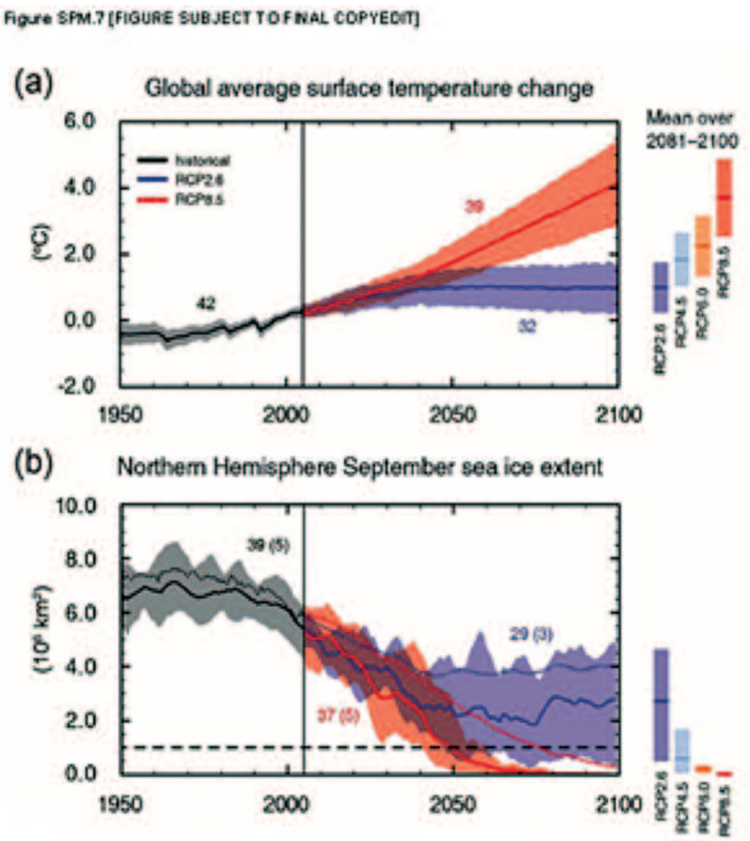

Figure 2. Figure SPM.7 from the Summary for Policymakers of the 5th Assessment Report of the Intergovernmental Panel on Climate Change. Part (b) is an example of presentation of data and model projections in a way which achieves a misleading impression. The bold black vertical bar of 2005 does not separate data on the left from model projections on the right, as one might expect, but "modelled historical evolution using historical reconstructed forcings" on left from model projections on the right. The transition in 2005 avoids showing data from 2006-2012 where very rapid declines in area occurred. The two projections are from IPCC scenarios RCP8.5 and RCP2.6. RCP, or "Representative Concentration Pathway" is approximately total anthropogenic radiative forcing in the year 2100 relative to that in 1750 before the Industrial Revolution. 8.5 watts per sq m is roughly "business as usual" and shows a decline to zero in 2050 and a decline to 3.4 million sq km in 2030 – an area already reached in 2012. 2.6 watts per sq m is generally agreed to be unattainable, since radiative forcing was already 2.29 in 2011and rising fast. Yet it is shown (in blue) as a plausible scenario in which the sea ice actually recovers some area before the end of the century. This figure is likely to be read uncritically because this is a summary for policymakers, not part of the scientific report.

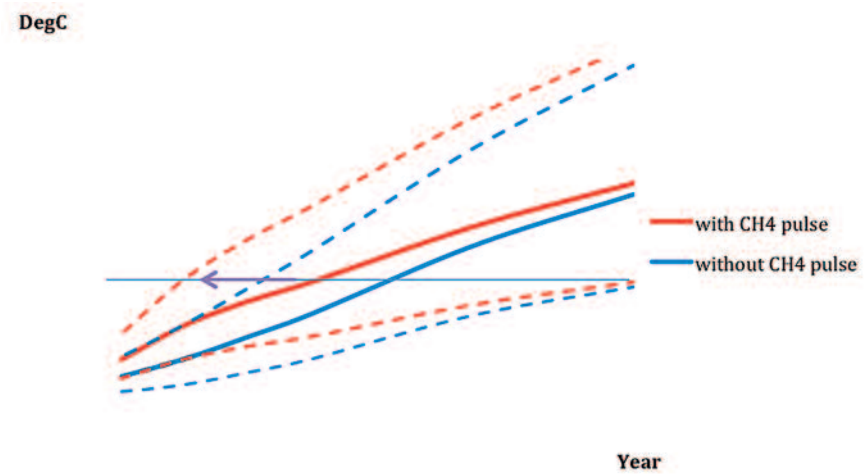

Figure 3. Projected global temperature changes up to 2100 as affected by a 50 Gt methane pulse taking place from 2015 to 2025 (after Whiteman, Hope and Wadhams, 2013). Solid line is a business-as-usual scenario, dashed lines are high and low emission scenarios.