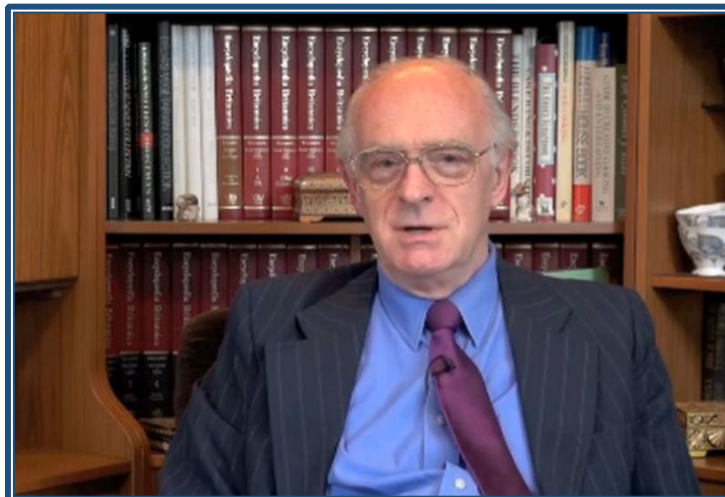


An
APOLLO-GAIA
Presentation

**Arctic
Dynamics**

A two-part video recording of this presentation on **Arctic Dynamics** is available (<http://www.apollo-gaia.org/ArcticDynamics.html>). **Part 1** deals with **Observations and Mechanisms**, while **Part 2** addresses **Consequences and Implications**.



Presented by David Wasdell

As Director of the Apollo-Gaia Project¹ I have spent the last seven years working on feedback dynamics and acceleration in the global climate system². What is going on in the Arctic area at the moment is probably the fastest moving response to global warming and climate change anywhere on the planet.

Executive Summary

Strong and interactive feedback processes are driving change in the Arctic climate faster than anywhere else on the planet.

This over-view of **Arctic Dynamics** is firmly grounded in observational data (in sharp contrast with computer models which are struggling to play catch-up). Four multi-decadal parameters are presented dealing with:

- Regional temperature change (in the context of global behaviour)
- Area of floating sea ice
- Volume (or mass) of floating sea ice
- Change in the decadal rate of mass loss of the floating sea ice.

All show strongly non-linear behaviour consistent with feedback-driven amplification of the underlying forcing from anthropogenic increase in greenhouse gas concentrations. Data-trend-analysis confirms that first occurrence of end of September ice-free conditions in the Arctic Ocean can be expected within the next three years. From that point the ice-free window will widen rapidly as the feedback dynamics increase in power.

The second part of the analysis reviews a set of implications and consequences of rapid Arctic change:

- Impact on the Tundra includes albedo feedback and release of CO₂ and methane to the atmosphere.
- Sea-bed release of methane adds to the Tundra feedback.
- Exponential change in melt-rate of the Greenland ice-cap has major implications for change in sea-level around the world.
- The accelerating disturbance of the jet-stream drives another energy feedback, disrupts weather patterns across the northern hemisphere and threatens food production from the grain belt over three continents.
- Free from global dimming, which is temporally blocking temperature change in the planetary system as a whole, the Arctic offers a foretaste of global climate dynamics of the future.

Released on the Apollo-Gaia website as a PDF with comprehensive set of hyperlinked references, **Arctic Dynamics** is accompanied by a pair of professionally-produced video presentations.

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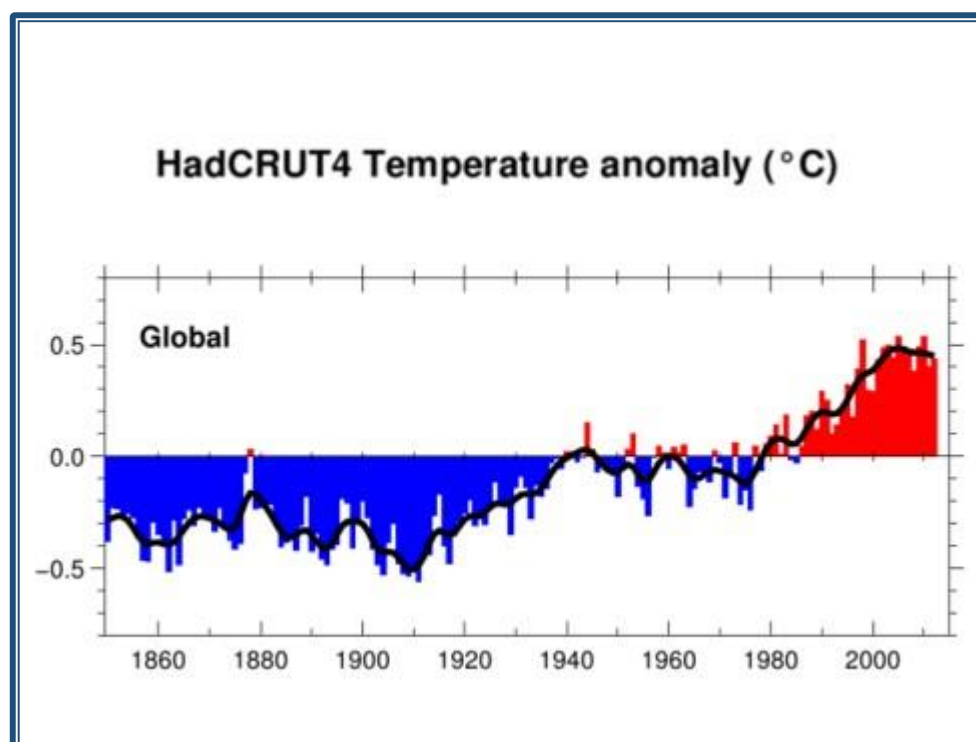
Acknowledgements

Part 1: Observations and Mechanisms

In this first part, I will look at temperature in the arctic, how it is changing and how it relates to temperature change at a global level. Then we will move on to look at the area of floating Arctic sea-ice and how that is itself responding to the changing temperature. The next section will explore the change in volume or mass of floating sea-ice. That changes in a significantly different way to the area itself. Finally we will look at the acceleration in the decadal rate of change of ice mass. As we bring these four parameters together we begin to get the whole picture of what is going on in the Arctic, to understand the complex drivers of the behaviour, and to project the most likely date for the first occurrence of an ice-free Arctic ocean.

1: Temperature Change: the Global Context

The global context for Arctic dynamics is developed in two different scales. The first looks back over some 150 years³. The second focusses on the last two decades⁴.

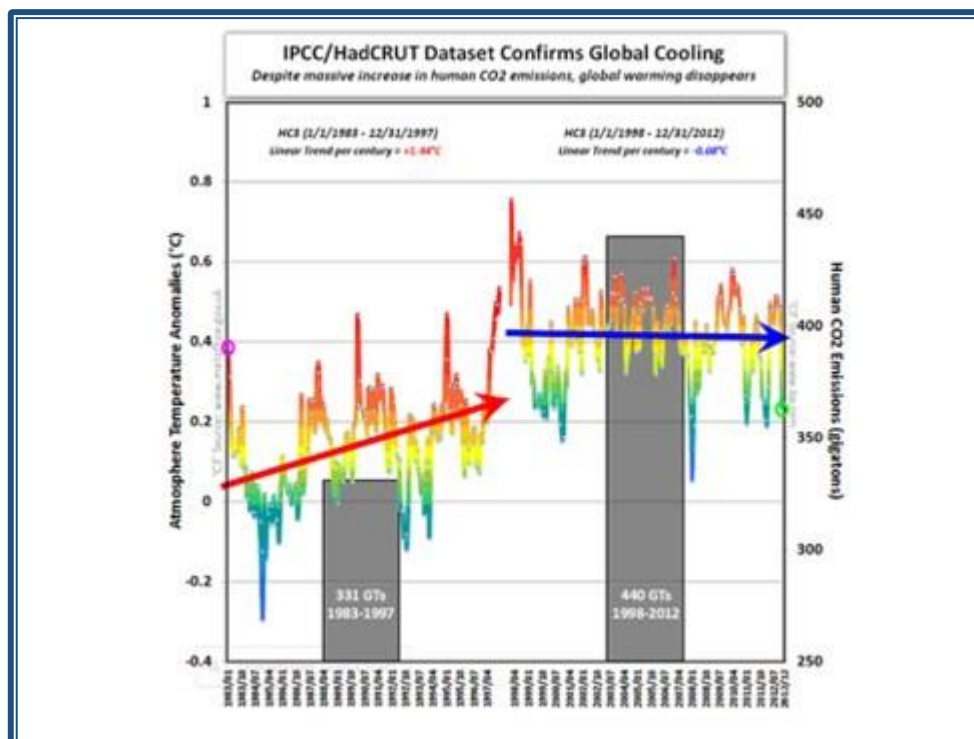


Over the last two centuries the global average surface temperature has risen from the pre-industrial benchmark. The change becomes observable from about 1910 and is sustained until the end of the Second World War. After 1945 it levelled out, in fact the temperature went down a bit until about 1975. That is a very important anomaly at a time when the concentration of atmospheric carbon dioxide was increasing.

It was probably caused by the immense amount of sulphur dioxide particulates produced from the burning of dirty coal during the hugely accelerated programme of power-production that went on across the whole western industrial economy. Remember acid rain and smog and thick

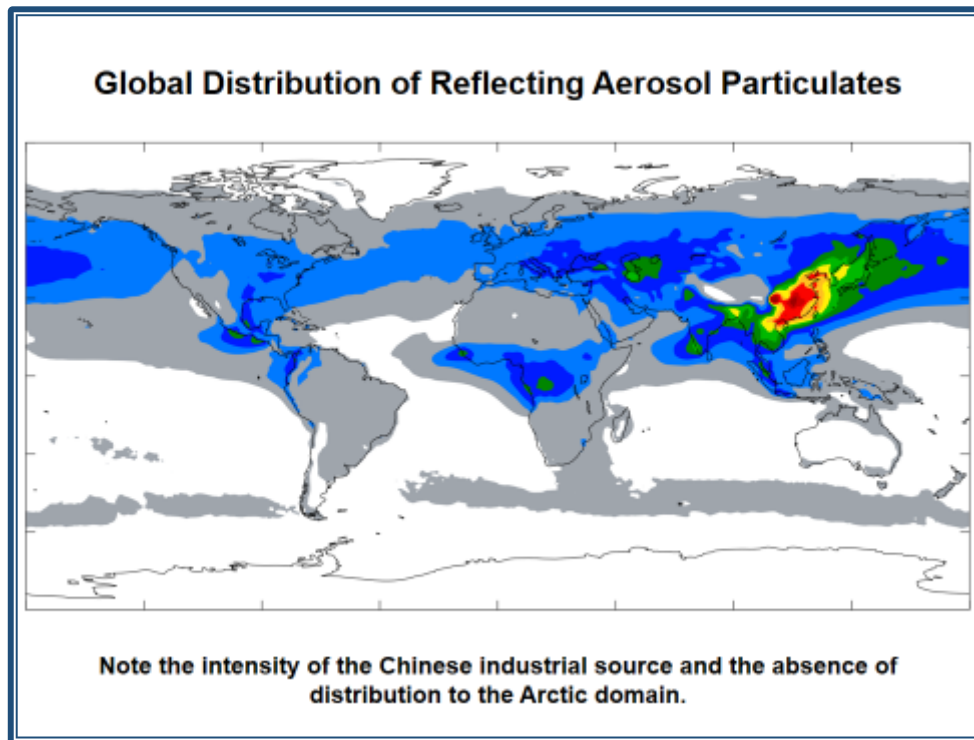
fogs and air pollution. The resulting “global dimming” blocked the greenhouse effect of increasing concentrations of carbon dioxide. Without increase in temperature the complex feedback system was brought to a halt and the expected acceleration of global warming was stopped in its tracks.

Then we began to clean our act up, to fit sulphur scrubbers to power-stations and catalytic converters to car exhausts, to ban coal burning in domestic fires and to establish smoke-free zones. As we took particulates out of the atmosphere the temperature took off again, increasing even more rapidly (and accelerated by the fast feedback mechanisms) until about 1997. Since then global temperature change has levelled off and has in fact gone down a little.



Climate-change deniers are of course crowing and saying “Although carbon dioxide concentrations have gone on increasing, and emissions are running at a higher rate than when temperature was still rising, temperature has not changed. So obviously it is independent of carbon dioxide. So we can forget all about climate change and continue to use fossil energy without any worry about contributing to global warming!” That is a complete and utter myth!

Remember what happened after the Second World War? The same thing is happening today. Today the dirty emissions are coming from Chinese power stations and the burning of very poor quality coal in an accelerating number of electricity generating stations all across the developing industrial world. Remember the pollution in Beijing and the Asian brown cloud? There has also been an increase in the smoke from multitudes of wild-fires across the drying forests of the world, together with the proliferation of smoke from many millions of hearths where biomass is burned for domestic cooking. We now have massive amounts of airborne particulates that are reflecting some of the solar energy back into space⁵.



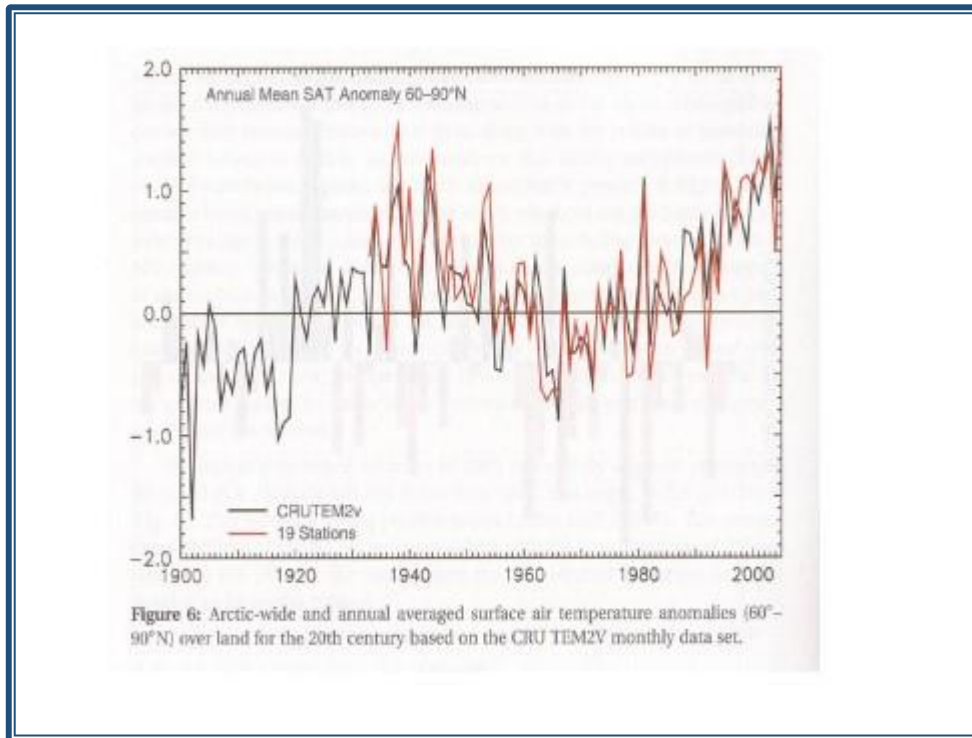
That is stopping the temperature rising as a whole in the global scene. The effects of global dimming have been enhanced during this period by the mixing of more surface heat down to deeper ocean water, by the dominance of La Nina (cooler) conditions in the Pacific, and by a prolonged period of minimal solar radiation. The absence of temperature increase has also blocked all amplification from the temperature-dependent feedback mechanisms.

2: Temperature Change: the Arctic Anomaly

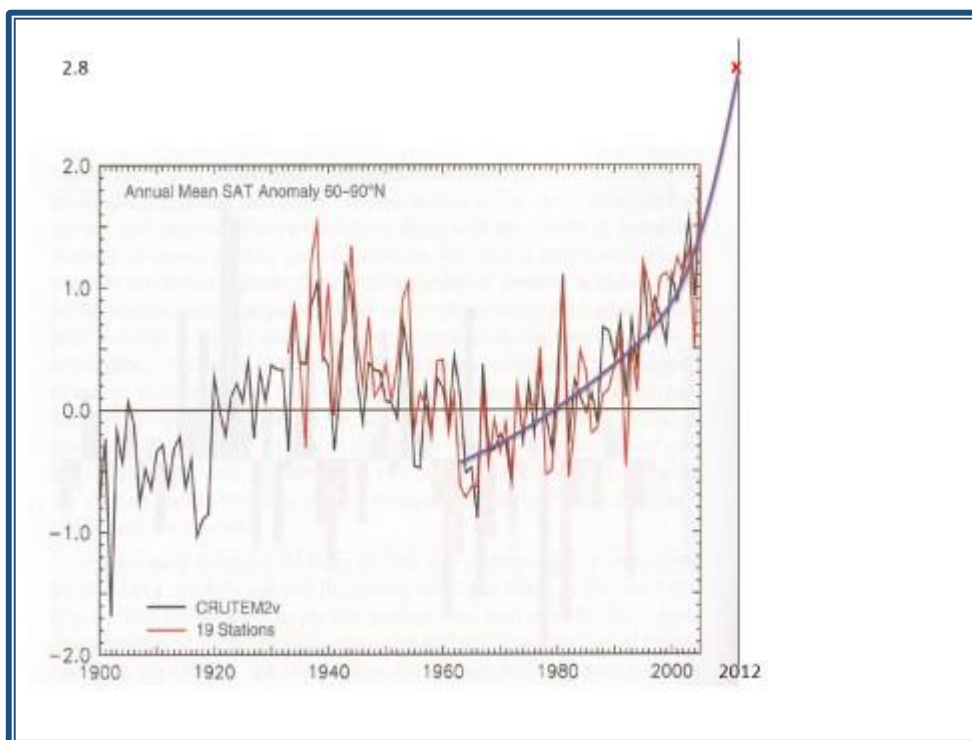
The Arctic is different. In the Arctic the air is pretty well clean, free from the effect of airborne particulates. The new industrial pollutants are not reaching the air in the Arctic in the way they did when most development was taking place in the industrial northern hemisphere. So the greenhouse effect of the increasing carbon-dioxide concentrations in the Arctic is relatively uninhibited. It started to push the local temperature up while global warming was on hold across the rest of the world.

If we now look at the temperature in the Arctic itself we see this quite clearly. Whereas the rest of the globe has cooled since 1997, temperature in the Arctic has started to increase, and to increase increasingly rapidly⁶. The hotter it gets, the faster it gets hotter.

Let us explore the reasons why this is happening. To start with the greenhouse forcing of carbon-dioxide is having an effect in the arctic while it is not happening elsewhere. As the temperature starts to rise, increased water-vapour concentration in the Arctic accelerates the heating. So as water-vapour concentration rises, as temperature accelerates, as the carbon-dioxide forcing becomes more powerful, so the floating sea ice begins to melt and the area starts to decrease. The effect is not limited to floating sea-ice, it also applies to land-based



snow cover. So the amount of brilliant white (high albedo) surface that reflects solar energy back out into space, begins decreasing year on year. That means that the sun's energy is being increasingly absorbed into the surface of the frozen wastes of the Tundra as well as into the open ocean surface where the ice had previously been. So the behaviour of the whole system is now accelerating under the influence of the complex set of feedback mechanisms. The hotter it gets, the faster it gets hotter. The faster it gets hotter the more water vapour. The more water vapour, the faster it gets hotter. The faster it gets hotter, the less ice. The less ice the less reflection and the faster it gets hotter, and so on.

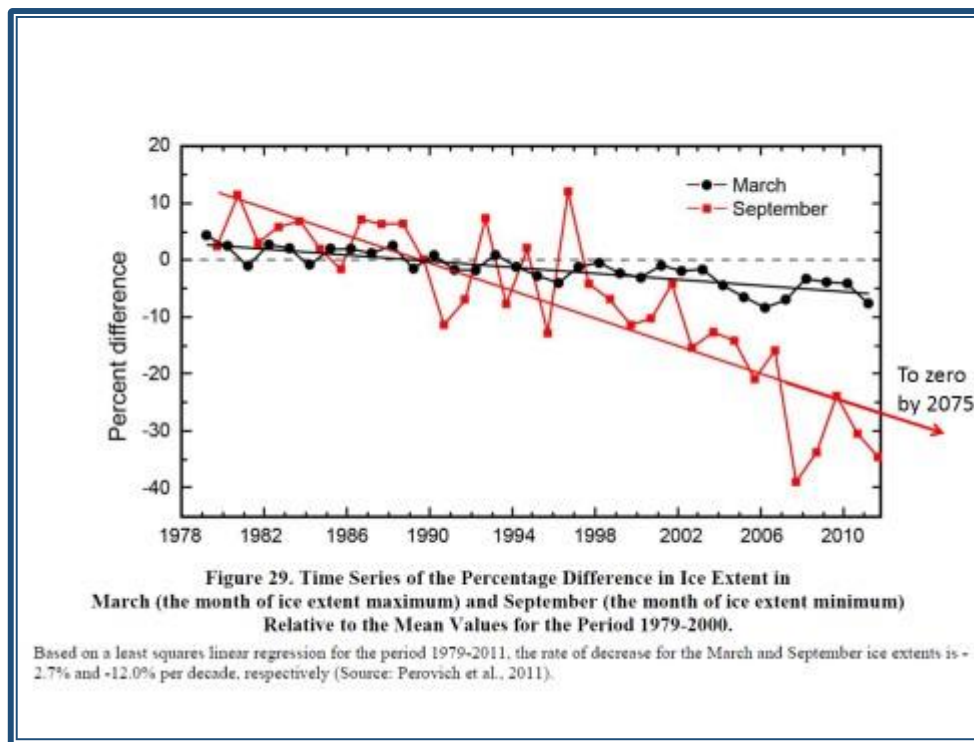


We are seeing an exponential increase of temperature in the Arctic area. The effect is clear when we add the data point for 2012 to the previous slide and then draw the best fitting curve through the data-set.

3: Change in the Area of Arctic Sea-ice

The area of Arctic sea-ice has been gradually decreasing over decades. In fact way back in the 1960's and 1970's we saw the start of a trend pattern in the area of sea-ice, particularly at its minimum in late September at the end of the summer melting season. We are going to look specifically at what has been happening to ice area at the end of September.

There is obviously a lot of noise, so the figures vary considerably from year to year. However, the trend pattern reflects what is really going on. Year by year and decade by decade that trend has taken the area of ice at the end of the summer down and down and down.

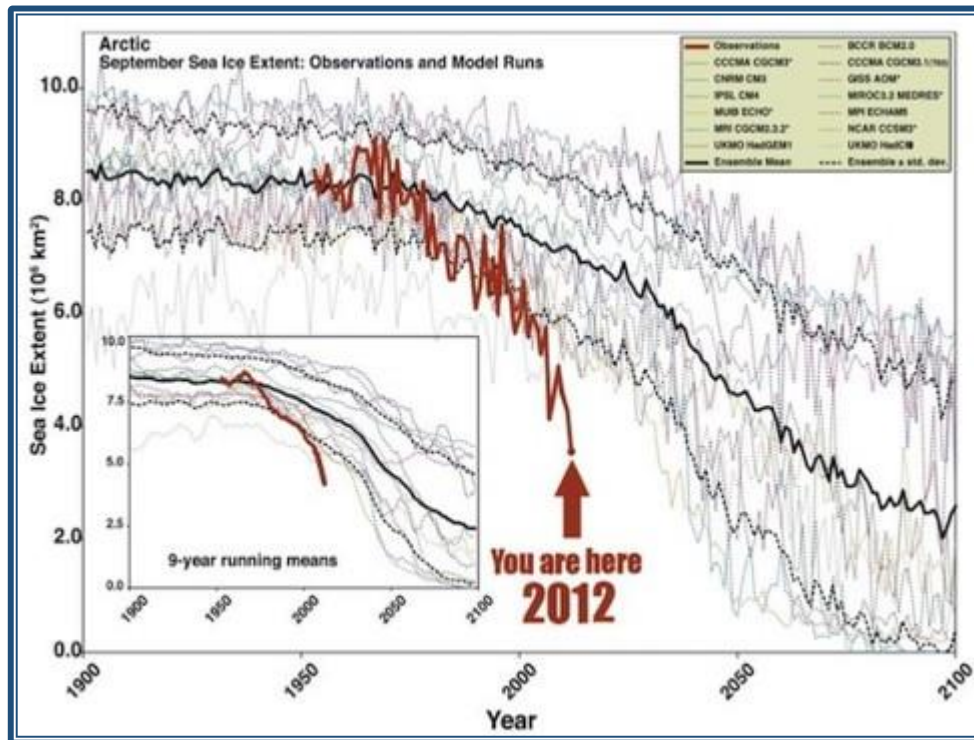


The observations have been plotted onto the graph, but there has also been an attempt to draw the best possible straight line through the data set⁷. The straight line has been generated using a least squares linear regression as a statistical method. If you follow that line down till it intersects the 100% ice-loss line, then the trend suggests that the first occurrence of zero Arctic floating sea-ice will occur in about 2075. That feels like a long way into the future.

However, if we look at the observations for the last few years, say 2007 and beyond, we find that the data points have been pulling way down below the straight line. It becomes more and more obvious that straight line representations are no longer the appropriate statistical tool for demonstrating what is going on in the Arctic. That is because there are many mutually reinforcing feedback processes going on (to which we have already referred in terms of

temperature). Where feedback sets in, straight line behaviours get bent into exponential curves. In terms of temperature we saw that the hotter it gets, the faster it gets hotter. When we look at ice area we see that the more it decreases, the faster it shrinks.

Another approach to what is going on in the Arctic is based on super-computer models using many theories, parameters and complex equations, to represent the physical processes engaged in the system. On that basis they are able to make predictions about how the system will behave in the future. This next slide shows the set of models and their varying outputs⁸.

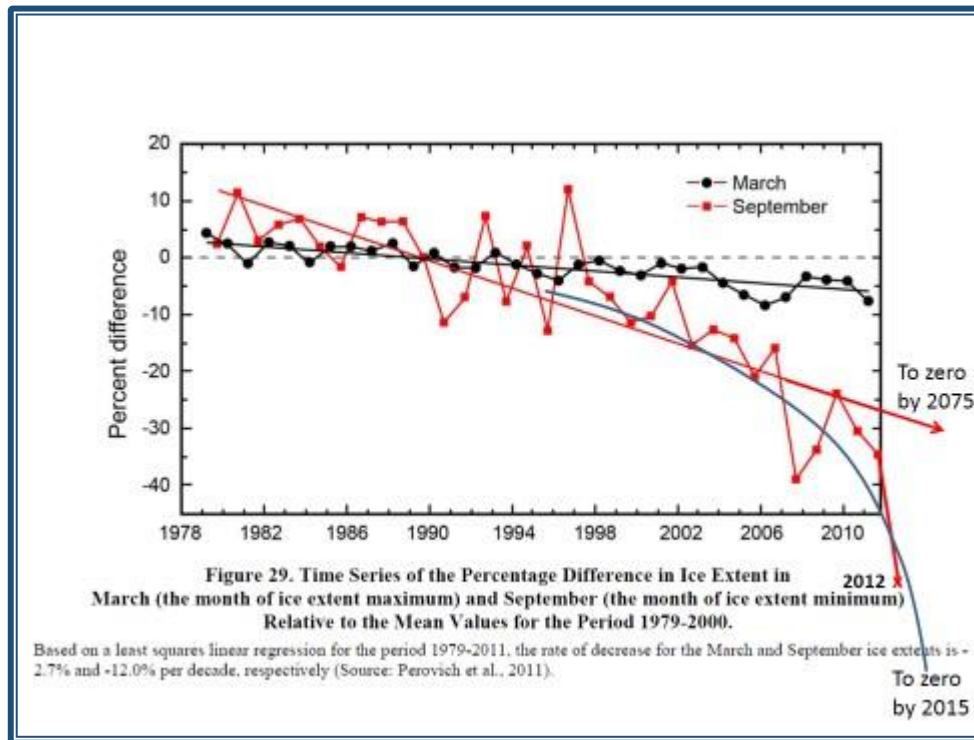


You can see that only the most extreme model predicts zero floating sea-ice around 2075. Most expect the sea-ice to continue well beyond that date. To start with, the observations, that are also plotted on this slide⁹, keep pretty well in synch with the mean of the model ensemble. Then from the 1980's onwards the observations start diverging from the model projections. By the early 2000's the observations are significantly outside the envelope of modelled expectation. 2007 was a record low in ice area that was way below the model set. Area recovered somewhat until we again saw a major new record in area loss in 2012.

It is now quite clear that the model ensemble is quite inadequate to deal with the complex feedback dynamics that are now accelerating the system behaviour in the Arctic.

If we take the data point for 2012 and insert it on the previous graph¹⁰ it becomes even clearer that we cannot maintain the straight line approach. The linear analysis has been used in many of the arguments and information that has been put forward to politicians and others as the foundation on which decisions should be based. It is no longer an appropriate basis for such decision-making.

We now need to explore the exponential curve that best portrays the descent of Arctic sea-ice area. If we follow that curve through the observational data then we see it intersects the 100% ice loss line (i.e. first occurrence of zero ice area at the end of September) in the year 2015. That is a huge difference from predictions of 2075. It is therefore really important that we use observational information as the accurate basis for our understanding of change in Arctic dynamics.

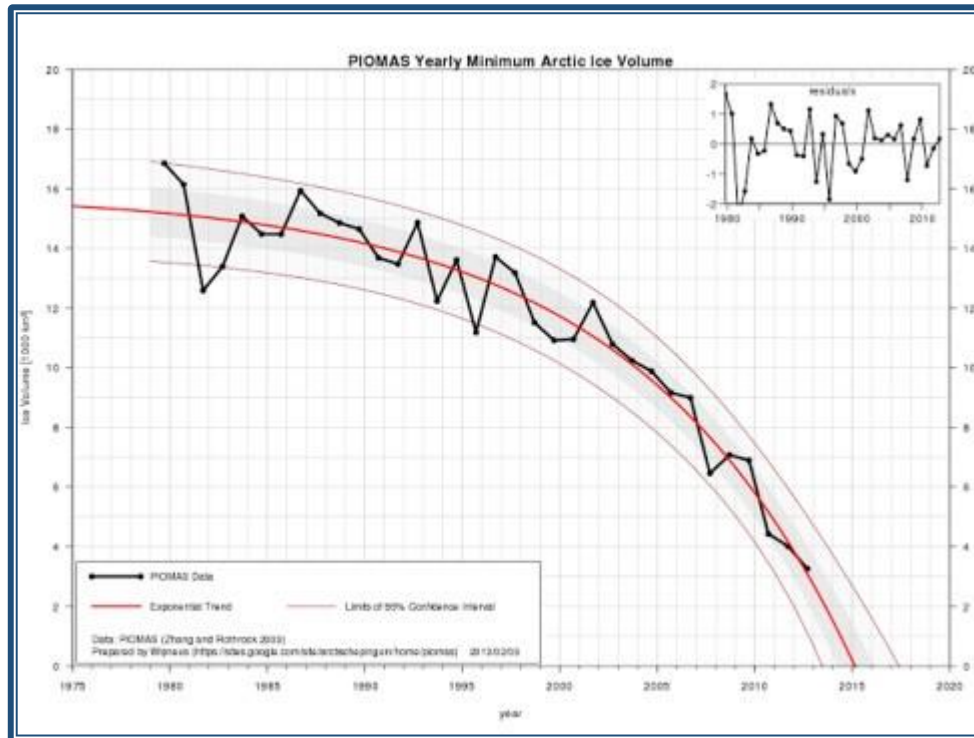


4: Change in the Volume of Arctic Sea-ice

Now we move on to examine change in the ice volume. This parameter provides an even more powerful source of information.

It depends, of course, on being able to measure the thickness of the ice right across the Arctic area. That is done using two very different approaches. The first depends on measurements of ice thickness using sonar apparatus in an under-ice submarine. That is of course limited to a particular line.

The second approach uses satellite measurements of ice thickness. It covers huge areas, but is much more difficult to quantify and calibrate. In practice it depends on the submarine data for calibration.



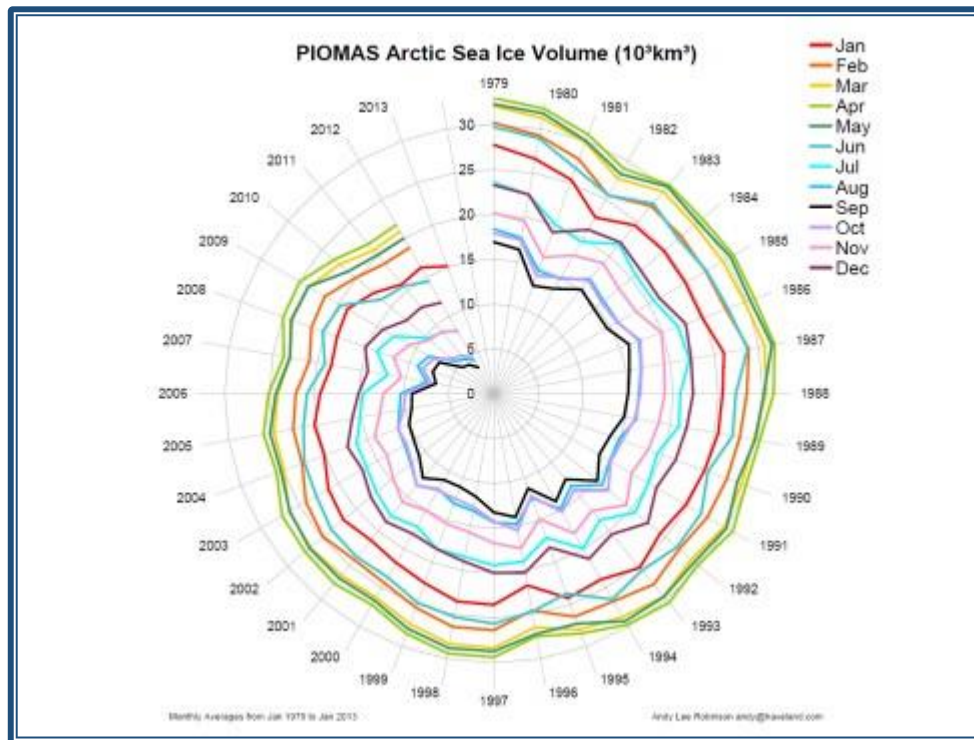
In mid-autumn 2012, the world-leading authority on submarine-based research was politically denounced as an “alarmist activist” on prime-time British television. Access to the critical data from the most recent submarine voyage was subsequently withdrawn from the Cambridge research team on the grounds that its use poses a threat to national security. The two London-based academics working on the link between submarine-based information and the satellite data have both recently died in tragic accidental circumstances. All future submarine-based data-gathering trips have been cancelled. We are therefore experiencing some difficulty in accurate calibration of satellite measurement of ice thickness.

Fortunately initial analysis had been completed and the best estimates of ice thickness are combined with the ice-area data to provide the PIOMAS graph¹¹ of yearly minimum Arctic ice volume or mass.

It is again clear that it is quite inappropriate to attempt to draw a straight line through this data set. The best fit to the data is provided by a downward curving exponential decay. If we project that line forward as is done with this particular set of equations, then it shows that ice mass floating in the Arctic Ocean tends to zero in 2015. That confirms precisely the previous work that projects that the area of floating Arctic sea-ice would tend to zero by 2015.

This next slide¹² presents the same data in a very different way:

Years are no longer arranged along the horizontal axis, but are set out around the sectors of a clock face. Starting with 1979 at the 12 o’clock position the dial moves right round to 2013. The ice mass is coded in terms of thousands of cubic kilometres ranging from 30 at the outer circumference reducing to zero at the centre of the circle. Round this grid have been entered the ice volume values for each month of each year. Each month has its own special colour code. The black inner spiral represents the least mass at the end of the summer melt in September each year.



If we take a moment to examine this slide we see that in the first decade there is very little mass loss. The volume at the end of September from 1979 to 1989 was somewhere around 15 thousand cubic kilometres. It stays roughly at that figure until the mid-1990's. Then it begins to spiral inwards. We watch its descent from 15 to 12 to 10 thousand cubic kilometres. By about 2003 it passes the 10 mark and in the next four or five years it decreases to about 7 thousand cubic kilometres. In the last three years it has plunged from 7 down past the 5 marker until in 2012 it stood at just over 3.3 thousand cubic kilometres. That is an extraordinary rate of collapse.

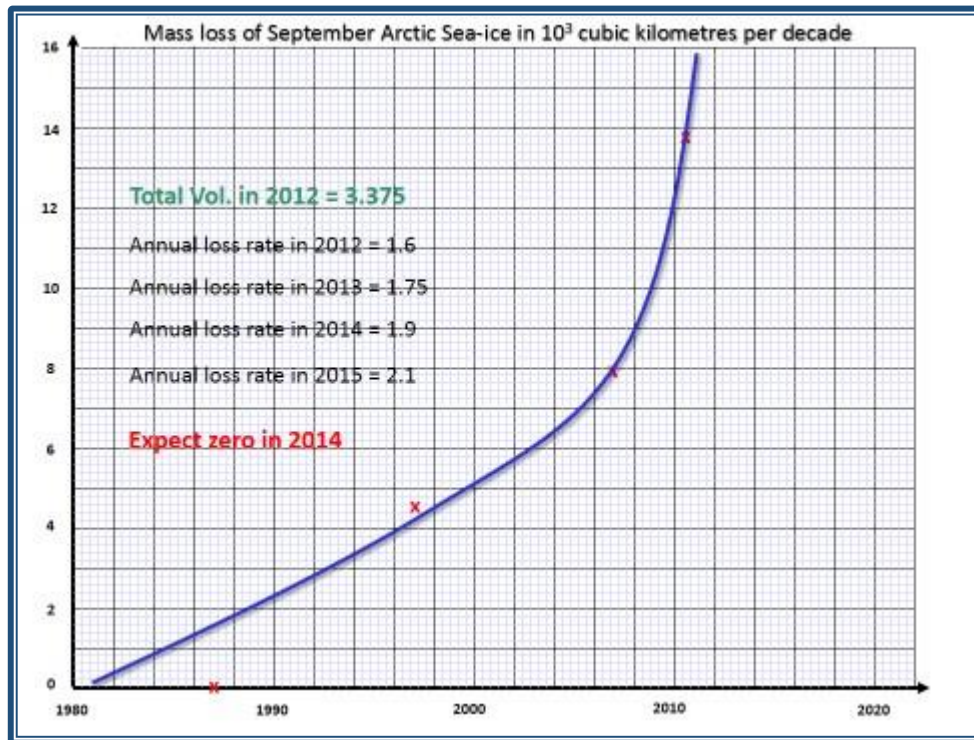
If we look at the other months, September is beginning to draw in August and October, then July starts to respond followed by a little bit of November and even June. All of those months are following the spiral down towards the zero ice point in the centre of the circle. There is no way that ice mass at the end of September can continue going round this clock-face for the next five or six decades. It is moving very rapidly towards the zero point in the centre.

5: Acceleration in the Loss of Ice Volume

So the study of ice mass and the timing of ice-mass loss help me to complete my final piece of analysis. It concerns the variation in the rate of change of ice-mass loss over the last few decades.

In the 1980's, the mass of floating Arctic sea ice at the end of September was staying roughly stable. By the 1990's it was losing about 4.5 thousand cubic kilometres per decade. In the 2000's that moved up to about 7.8 thousand cubic kilometres per decade, while in the last three years the decadal rate has surged to around 13.8 thousand cubic kilometres. So we have another of these behaviours in which the smaller the mass becomes, the faster the rate of loss. The behaviour is not linear, it is represented by an exponential curve.

If we look carefully at the amount of ice remaining at the end of September 2012, then we see some 3.3 thousand cubic kilometres. Even a very conservative projection of expected ice-mass loss for the year 2012 to 2013 would see a decrease by a further 1.6 thousand cubic kilometres. That would be followed in the year 2013 to 2014 by another 1.7 thousand cubic kilometres. Together that would wipe out the residual mass of 3.3 thousand cubic kilometres that existed at the end of 2012.



So using this form of analysis we are forced to the conclusion that we would expect zero floating sea-ice in the Arctic Ocean by September 2014. That is a little earlier than the predictions of 2015 which were noted above.

And then there is one other thing to take into account:

Ice does not just melt and thin gradually to a wafer as would be implied in these projections. When it reduces to about 45 centimetres thick it begins to break up under the impact of waves and tides and storms. The result is a lot of brash, smaller broken pieces of ice. Now broken ice of this nature melts very much faster because warmer water and warmer air and solar energy can get round to its exposed surfaces. The melt-rate increases dramatically. These curves that we have been exploring take no account of this final break-up.

So, while we would expect the first occurrence of zero ice by the end of September 2014, there is a distinct possibility that under the impact of ice break-up (of which interestingly we were already seeing signs in March 2013) the Arctic Ocean could be ice free at the end of September in 2013.

Part 2: Consequences and Implications

The review of Arctic Dynamics has shown up many of the mechanisms that are determining change in the Arctic region which is happening at an extraordinary pace. Now we want to move on and look at some of the consequences and implications of Arctic Dynamics.

1: Arctic Runaway

First of all we are going to look at the runaway behaviour which is actually happening to the Arctic system. As we reviewed the four parameters we saw the temperature change going exponential. We saw the rate of change of ice area accelerating. We saw the change in ice mass or thickness also accelerating and moving towards zero over the next two or three years. Taken all together we recognise the unmistakable footprint or signature of a system in self amplification or runaway behaviour. It is already feeding on itself, with the water-vapour feedback, the ice-albedo feedback and other factors all combining to amplify the effects of the carbon dioxide trigger which set off the dynamics in the Arctic. In a sense, the human trigger is now almost irrelevant. The feedbacks have taken over. So that is what we mean by “runaway” in the Arctic System.

2: Increasing Ice-free window

The second consequence is the increasing ice-free window. You will remember that we saw that, at the end of September, which is the minimum point for Arctic ice, we would expect there to be virtually no ice at all floating in the Arctic Ocean by 2014 or 2015. What we are talking about there is just a few days of ice-free condition before it begins to set back in again. During that period, all the sun’s energy that had been going into changing solid into liquid, melting ice into sea-water, is channelled into heating the water itself. The rate of that heat transfer was enough to melt about one thousand three hundred cubic kilometres of ice per year. In addition all the solar energy that was being reflected from the ice is also available to heat the water. So during that ice-free window, warmer water is being set in place ready for the next autumn. That means that the onset of freezing is delayed and the resulting ice is thinner. The next year, when the melt sets in again, there is thinner ice and there is less of it, so it melts earlier. The result is that once that ice-free window has formed, it expands year on year, on year.

3: Accelerating Temperature

Because all that extra energy during the ice-free window goes into temperature change, it generates a discontinuity in the upward curve of the temperature-change graph to a sharper upward trajectory at that point. This moves us naturally into Consequence 3, the consequence of the acceleration of temperature change in the Arctic region is very important indeed. As the rate of change of temperature goes on increasing, so other feedbacks are brought into play, and operate more powerfully than they had been previously. So as an example, as the temperature change increases, so the rate of water-vapour feedback also increases. The effect on the amount of solar energy that is available to the Arctic region is also a feedback, since with later formation of the ice there is less solar reflection in the early autumn, and with earlier ice-free conditions in the late summer there is less reflection in September and August, maybe

even July. So the whole process is accelerated as the ice-free window expands. Those two consequences are inextricably linked, the widening ice-free window and the accelerating rise in temperature.

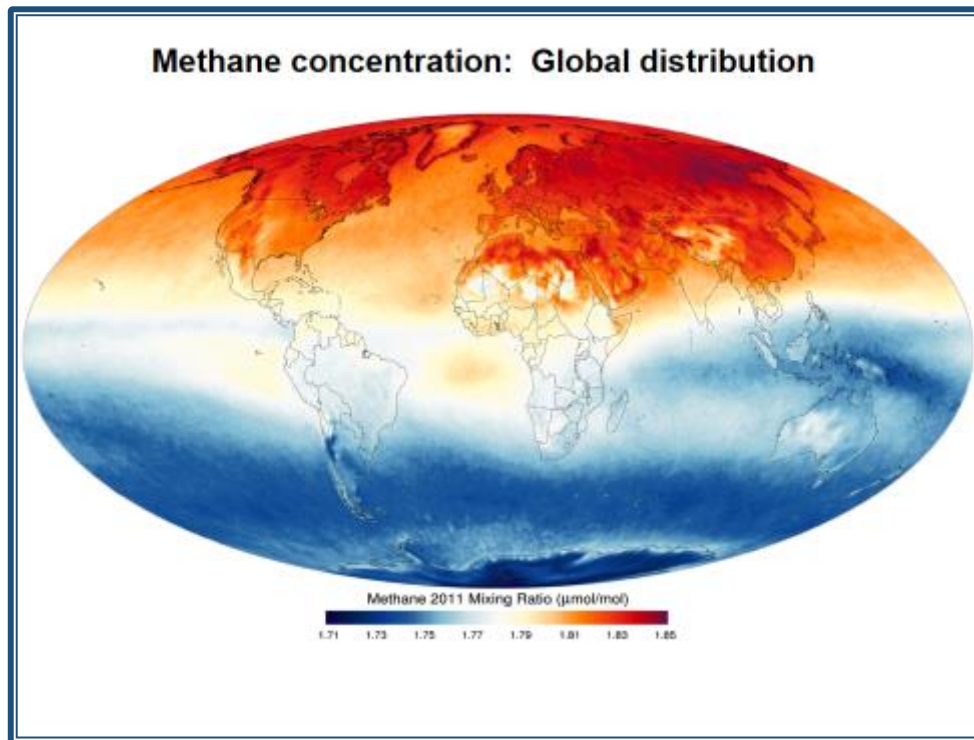
4: Tundra Impact

Let's move on now to the fourth consequence, namely the impact on the Tundra. Those land masses that border onto the Arctic Ocean now have a warmer, open and ice-free sea-coast, and warmer air is being fed back over the land-mass. What that does is increase the rate of melting of the Tundra permafrost. The depth of permafrost melt, what we call the karst, increases year on year. That also has consequences. For instance there is a lot of biological material held in the deep-freeze of the Tundra. As that melts and thaws out, so the bacteria get to work and have a field-day and out comes more carbon dioxide and methane from the rotting vegetation. That adds to the feedback loops that concern the concentration of the greenhouse gasses in the atmosphere. As the karst melt goes deeper and the surface warms more there are two other issues brought into play. One is that it takes longer to freeze in the autumn, so the snow cover is less extensive and lasts for a shorter period, so there is less solar reflection from that. Also, during the summer period itself, the warmer water from the Tundra runs northwards through the rivers and into the shallow seas across the continental shelf, so warming and desalinating the shallow surface water of the coastal areas.

5: Methane Feedback

Now I want to move on to the next consequence. The fifth implication of the Arctic Dynamics concerns the feedback of the methane release. This is probably one of the most important issues that we have to examine. With ice-free conditions and warmer waters, the surface of the ocean is open to wave energy, tidal behaviour and storm effects which, when covered in ice, did not affect it. So warm surface water is being driven down and mixed with deeper water, particularly over shallow continental shelf areas. As the water temperature at the bottom of those shallow seas increases, it begins to release methane that has been stored in what we call "clathrates", a combination of methane and ice crystals. They have been kept inert under conditions of temperature and pressure. As the temperature rises the methane begins to be released. Some of it is absorbed in the column of water, some of it begins to bubble up to the surface. The faster the temperature increases, the faster the release of the methane, and the more reaches the surface. Beneath the top layer of ocean sediment is a fossil layer of ancient ice left over from previous ice-ages. Underneath that are layers of biological rubbish and detritus as well as further clathrate deposits. What we are seeing now is that this fossil ice is beginning to rot and melt. Methane from beneath it is beginning to bubble up through it.¹³

Methane is being released into the atmosphere not only from the ocean floor, but also as we saw earlier, from the thawing of the Tundra. The more methane there is in the atmosphere, as this next slide shows¹⁴, the greater the greenhouse effect. Methane is a very powerful greenhouse gas. As the concentration goes up so the rate of heating in the Arctic goes up. And, the faster methane is released, the longer it stays in the atmosphere before it breaks down into carbon dioxide and water. There is therefore a second feedback that makes the methane feedback more powerful the faster it goes, and the faster it goes the more powerful it gets, and so on. We have another runaway feedback process able to be triggered by Arctic Dynamics.



The process has sometimes been called “the methane bomb”, but I think that is a misnomer. It takes a lot of heat and energy to melt the clathrate deposits on the sea-bed. So the rate of release is determined by the rate of heat transfer from warmer surface water to the sea-bed. That is a fairly slow process. There are some possible conditions that could lead to rapid release of large amounts of methane from the sea-bed, but overall the methane release is a fairly slow cascade feedback that can take place on the scale of decades to centuries. It does, however, have enormous consequences for the rest of the world as well as the Arctic area.

6: Greenland Ice-cap

The sixth consequence concerns what is happening to the Greenland ice-cap. It sits there as a one-and-a-half mile thick layer of ice across a land-mass. Many would say this looks immovable. However, as we move to acceleratingly increasing temperature change, as the waters all around Greenland are no longer covered with floating ice, as the waters themselves warm and as the air above the ice-cap also increases in temperature, so the ice surface begins to melt right across the dome of the ice-cap. In the summer of 2012 we saw a 97% area melt¹⁵ for a few days. That was unprecedented. We can expect that to increase and the period will start to widen.

Historically the pace of change of the Greenland ice-cap has tended to be quite slow, although we do have evidence of episodes of quite rapid melt on a decadal basis. However, in the present rate of change in the Arctic, nobody knows how fast the Greenland ice-cap will respond. We do know that the rate of melt is accelerating and that leads to several consequences. As the surface melts, it becomes lower. The lower it gets the warmer it becomes and the faster it melts. The faster it melts, the more water is being channelled down through cracks to the base of the ice. That frees it up and starts to make it move more quickly. When there is no floating ice around the Greenland coast, the glaciers moving into the ocean are free to discharge and

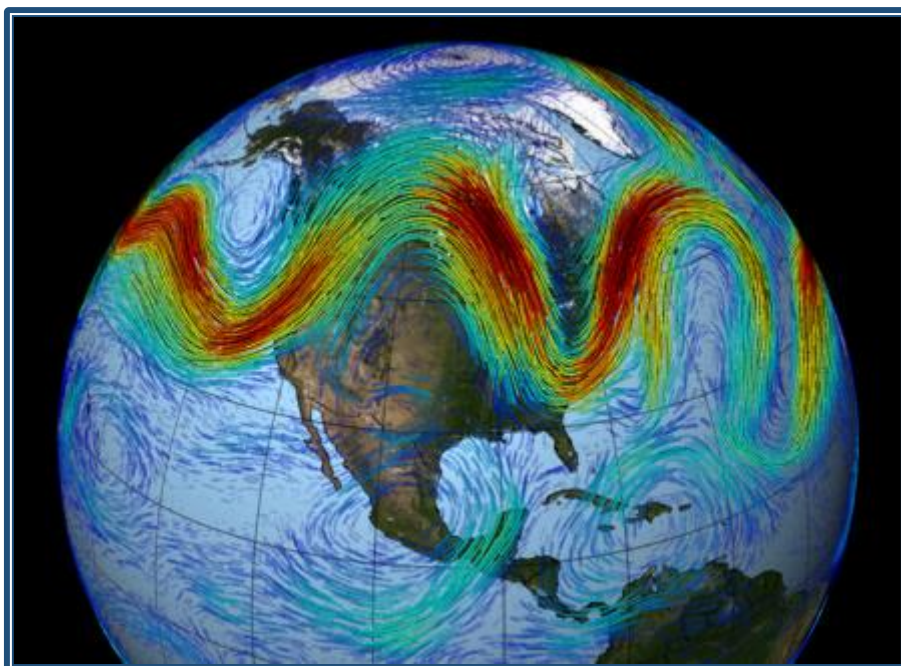
calve into icebergs more quickly. So the collapse of the ice-sheet could become exponential and could happen quite quickly. As that occurs, large quantities of cold fresh water are discharged into the North Atlantic and that can have significant effects on the drivers of the Gulf Stream, the thermohaline circulation. As that slows down (and we would expect it to under these conditions) then the heat that presently comes via ocean currents to the north-western seaboard of Europe begins to decline. In a strange anomaly, the rate of change of temperature in north-west Europe will slow down as Arctic temperatures climb.

7: Sea-level Rise

The consequences for the Greenland ice-cap are massive, and as it melts it adds fresh water to the global ocean and starts to raise sea-level. If it collapses quickly then we can expect anything up to about seven metres of sea-level change¹⁶ right across the world, possibly on a decadal basis. That would be catastrophic for civilisation many of whose urban centres would be below sea-level in the new situation. What is happening to the Greenland ice-cap must also be held in context with what is happening right at the other end of the world. We have a combination of what is happening in Greenland as a result of Arctic behaviour, and what is happening at its antipodes in the Antarctic. The West Antarctic ice field will also be subject to destabilisation and melting, though probably a little slower than what happens to Greenland. The two events combine to accelerate sea-level rise.

8: Jet-stream Behaviour

The temperature in the Arctic goes up and that decreases the gap between the cold Arctic (which is getting warmer), and the warm sub-tropical air at the lower latitudes. The difference between Arctic temperature and sub-tropical temperature is what drives the energy of the jet stream, the fast, high altitude vortex around the North Pole. As the difference between Arctic cold and sub-tropical warm decreases, the energy of the jet-stream begins to relax¹⁷.



Instead of storming around as a vortex it becomes more meandering like a river that has met the flood plain and starts to move in loops. Then the less that difference becomes, the slower those loops move around the planet. Whether you look at some of the mathematical treatment coming from the Potsdam Institute for Climate-impact Research¹⁸, or the analysis of observations and data in the work of Jennifer Francis¹⁹, the same understanding emerges.

Now we can look at some of the implications of that. Firstly the jet stream moves south, so some of the cold Arctic air moves down into the northern continental land masses. The meanders mean that in certain areas the cold air from the Arctic is being drawn southwards. Because the progression of the meanders is slowing down or even become stuck, we experience these prolonged periods with cold Arctic air being poured down into the continental areas. We have seen that happening in the last two or three winters. In other areas where the loop is the other way round, there is warm air being drawn up into the Arctic from nearer to the tropics. So we have a heat-exchanger going on. It is as if the fridge door has been left open and all the cold air is flowing out of the bottom, and the warm air is being sucked in at the top. That increases the rate of temperature change in the Arctic. That further decreases the gap between Arctic temperature and tropical temperature, which increases the effect on the jet-stream, widens the meanders and makes them move even more slowly. In turn that increases the blocking patterns of extreme drought, extreme rain, extreme cold, extreme heat, and extreme unpredictability.

And that is where the nub comes. With extreme unpredictability food production is disrupted in the bread-baskets of the northern hemisphere. We are talking about the corn and wheat producing areas of North America and Europe, of Russia and the Ukraine, and across to the wheat and rice producing areas of northern China. We have already seen major loss of food production capacity in the northern hemisphere as a result of what has already taken place. Over the next few years that will accelerate significantly. There are economic issues; there are humanitarian issues; there are political issues that all stem from that instability. We are already seeing hedge funds and pension and other investment funds buying up future food in anticipation of future shortages and high prices that all stem from this phenomenon. That means it is going to be very difficult for the poorer countries of the world to buy food on the open market to enable their populations to survive. It will be even more difficult for the Aid agencies to buy up surplus food (which is in short supply and much more expensive) for distribution in conditions of humanitarian disaster. Because of the economic spin-off there will be financial destabilisation in the wake of food shortages. That leads inevitably to political destabilisation. So we have some really important issues to deal with that all stem from the implications of the phenomena we are now understanding in the terms of Arctic Dynamics.

9: Impact on Global Dynamics

That brings me to my final section in the consequences and implications of Arctic Dynamics. What are the implications of all this for global dynamic behaviour, both for climate and indeed for humanity as a civilisation and for the biosphere of which we are a part? Well obviously, the Arctic is connected to the rest of the world. It is part of the world. What happens in the Arctic inevitably has implications and consequences and spin-off for the rest of the planet. Part of the planet is in runaway. Most of the rest of it is in stasis. In other words temperatures are held stable at the moment. Socially we know we will be starting to remove some of the aerosols, the particulates in the atmosphere that, at the moment, are reflecting some of the solar energy back into space. We also know that much energy is being taken away from surface heating by transfer to the deeper ocean layers. As the effects of carbon dioxide and other

greenhouse gasses in the global behaviour as a whole, begin to come back on stream, so global temperatures will respond much as Arctic temperatures did. CO₂ begins to increase temperature, increased temperature drives water-vapour feedback. Water-vapour feedback accelerates heating. Then we begin to get hotter conditions for some of the tropical forests. We have burn and die-back and increased release of carbon dioxide from the biomass. It is a different set of feedbacks from that operating in the high Arctic, but it is none the less potent.

As today in the Arctic, so tomorrow in the world as a whole. The implications of jet-stream behaviour and Arctic dynamics could spin off into our economics, into our food production, into abandonment of the poor, into the inability to sustain a population of 8, 9 or even 10 billion people, into our survival as a species. All this will inevitably follow unless we are able to intervene, to slow it down, to bring it to a halt and reverse it. Without that intervention, global dynamics hold a dark future for humanity and a dark future for the biosphere of which we are a part. It is time to take action, not only for the Arctic but for the whole global crisis in which we are all involved.

Notes and References

¹ For background information about the Apollo-Gaia Project visit <http://www.apollo-gaia.org/AGProjectDevelopment.pdf>

² Climate Sensitivity presentation: http://www.apollo-gaia.org/Climate_Sensitivity.htm

³ Climatic Research Unit, University of East Anglia. See: <http://www.cru.uea.ac.uk/cru/data/temperature/>

⁴ See: <http://www.c3headlines.com/2013/01/ipccs-gold-standard-temperature-dataset-authenticates-global-cooling-over-last-15-years.html>

⁵ ‘Estimates of aerosol radiative forcing from the MACC re-analysis’, N. Bellouin et al. Atmos. Chem. Phys., 13, 2045-2062, 2013. Distribution of Anthropogenic particulates. (March, April, May) p. 2049.

⁶ See: <http://www.pmel.noaa.gov/pubs/PDF/rich2952/rich2952.pdf> (fig. 6, p.6) in Richter-Menge, J., J. Overland, A. Proshutinsky, V. Romanovsky, L. Bengtsson, L. Brigham, M. Dyurgerov, J.C. Gascard, S. Gerland, R. Graverson, C. Haas, M. Karcher, P. Kuhry, J. Maslanik, H. Melling, W. Maslowski, J. Morison, D. Perovich, R. Przybylak, V. Rachold, I. Rigor, A. Shiklomanov, J. Stroeve, D. Walker, and J. Walsh (2006) State of the Arctic Report. NOAA OAR Special Report, NOAA/OAR/PMEL, Seattle, WA, 36 pp.

⁷ See: D. Perovich, et al, Arctic Report Card: Update for 2011. NOAA. At: http://www.arctic.noaa.gov/report11/sea_ice.html Cited in Climate Extremes: Recent Trends with Implications for National Security October 2012, page 63 at: http://environment.harvard.edu/sites/default/files/climate_extremes_report_2012-12-04.pdf

⁸ From 1953 to 2006, Arctic sea ice extent at the end of the melt season in September has declined sharply. All models participating in the Intergovernmental Panel on Climate Change Fourth Assessment Report (IPCC AR4) show declining Arctic ice cover over this period. However, depending on the time window for analysis, none or very few individual model simulations show trends comparable to observations. Stroeve, J., M. M. Holland, W.

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⁹ Basic image taken from: <http://climatecrocks.com/2011/09/09/graph-of-the-day-arctic-ice-melt-how-much-faster-than-predicted/> Updated to include the 2012 data point at: <http://neven1.typepad.com/blog/2012/09/models-are-improving-but-can-they-catch-up.html?cid=6a0133f03a1e37970b017c31ee85b7970b%20-%20comment-6a0133f03a1e37970b017c31ee85b7970b>

¹⁰ Updated information at: D. Perovich et al, Arctic Report Card: Update for 2012 NOAA. At: http://www.arctic.noaa.gov/reportcard/sea_ice.html

¹¹ See: <http://neven1.typepad.com/.a/6a0133f03a1e37970b015435379118970c-pi> Using data provided from Polar Science Center, see: <http://psc.apl.washington.edu/wordpress/research/projects/arctic-sea-ice-volume-anomaly/> For further discussion of issues concerning the construction of this graphical image see: <http://neven1.typepad.com/blog/2012/03/use-of-graphs.html#more>

¹² Image at: <http://haveland.com/share/arctic-death-spiral.png> With acknowledgements to Andy Lee Robinson of Haveland-Robinson Associates who generated the graphic using data from PIOMAS (see above)

¹³ See: ‘The Degradation of Submarine Permafrost and the Destruction of Hydrates on the Shelf of East Arctic Seas as a Potential Cause of the “Methane Catastrophe”’: Some Results of Integrated Studies in 2011’, I. P. Semiletov, et al, *Doklady Earth Sciences*, 2012, Vol. 446, Part 1, pp. 1132–1137. (<http://link.springer.com/article/10.1134/S1028334X12080144>)

¹⁴ AIRS 2011 annual mean upper troposphere (359Hpa) methane mixing ratio. Data source: <http://daac.gsfc.nasa.gov/giovanni/>.

¹⁵ Greenland ice-cap melt anomaly in July 2012 is shown in the Arctic Dynamics video (Part 2). It is taken from: <http://www.nasa.gov/topics/earth/features/greenland-melt.html>

¹⁶ According to the Third Assessment Report of the International Panel on Climate Change, the ice contained within Greenland Ice Sheet represents a sea-level rise equivalent of 7.2 metres (24 feet). (<https://www.ipcc.ch/ipccreports/tar/vol4/english/075.htm>)

¹⁷ Image taken from: http://svs.gsfc.nasa.gov/vis/a010000/a010900/a010902/STILL1_1024x576.jpg on 16 May 2013. With acknowledgements to NASA’s Goddard Space Flight Center. To access the animation embedded in the Arctic Dynamics Video at this point see: http://svs.gsfc.nasa.gov/vis/a010000/a010900/a010902/3843_Jet_Stream_music-540-MASTER_high.mp4

¹⁸ See: ‘Quasiresonant amplification of planetary waves and recent Northern Hemisphere weather extremes’ Vladimir Petoukhova, Stefan Rahmstorf, Stefan Petri, and Hans Joachim Schellnhuber, *PNAS*, April 2, 2013, vol. 110, no. 14. (<http://www.pnas.org/content/110/14/5336.full.pdf+html>)

¹⁹ See: ‘Evidence linking Arctic amplification to extreme weather in mid-latitudes’ Jennifer A. Francis and Stephen J. Vavrus, *GEOPHYSICAL RESEARCH LETTERS*, VOL. 39, L06801, doi:10.1029/2012GL051000, 2012 (http://marine.rutgers.edu/~francis/pres/Francis_Vavrus_2012GL051000_pub.pdf)

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