CLIMATE CHANGE: *a challenge to our* PRESENT SOCIETY

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I would like to examine climate change —as a challenge to the way we live our lives— and the fact that we are going to have to change the way in which we lead our lives. The entry point is perhaps an unusual one, which is the Arctic regions, because it is been found in recent years that these are, in fact, one of the most important drivers of climate change. The changes that are happening very rapidly there are having an impact on the entire planet. This is leading to an acceleration of warming, which means that we have to take measures that are needed to try to hold back global warming, or do away with it much more urgently than was originally thought to be the case.

"The Arctic is warming up four times as fast as the rest of the world. This is the key problem"

The planet is saying farewell to its ice cover. If we start up about the role of ice and we go back a long way in history, then the Earth has, on the whole, been a warm planet in the last several tens of millions of years. Only occasionally, for reasons not yet understood, did the Earth suddenly get cold and become something called Snowball Earth. Other than that, it was warmer, but gradually cooled off until about 2 million years ago. We started to enter a cycle of alternating cold and warm periods, which became known as the Ice Ages.

In Greenland and Antarctica, you can drill a hole right through the ice sheet and you can measure the temperatures over a period —going back up to a million years— by looking at the isotope ratio of the oxygen in the water that was deposited as snow. That isotope ratio between Oxygen-18 and Oxygen-16, tells you the temperature at which that snow fell. So we have a magical climate record going back as far as the ice sheets go back.

When we look at this, we find that these peaks that happen about once every 100 thousand years are called the interglacials. That's the warm period between ice ages, and we are in one at the moment. But scientists now think we won't get another ice age because of what we are doing to the planet.

If we look at the last Ice Age, which started 100 thousand years ago, the temperature was warm just like it is today, and gradually the temperature cooled off. The Earth slid down towards an Ice Age. Glaciers and ice sheets grew, until we were at the depths of the last Ice Age about 20 to 30 thousand years ago. Then suddenly, we came out of it and for the last 10 thousand years we've had a warm climate, which is longer than the interglacial of previous ice ages, which were very short. The Earth was no sooner out of an ice age when it started to go into another one.

But we've had a longer warm period. And the reasons for this happening are entirely natural. This is nothing to do with man's activities. This is because of, actually, astronomical effects. Very small changes in the angle of the Earth's orbit to the angle of rotation of the Earth gives you a small change in the amount of radiation reaching the northern and southern hemispheres. And this was discovered by a Serbian scientist called Milankovitch, and it led to an explanation for why the Earth goes between ice ages and warm periods. So, we are in a warm period and we are due to gradually slide down towards another ice age.

At the same time as measuring the temperature changes, it was possible with very fine instrumentation —little syringes— to take out air from the air bubbles contained in these ice sheets. That tells us how much carbon dioxide there was in the atmosphere in past periods. We see an almost exact match between carbon dioxide and temperature. When the temperature was warm, there's a high carbon dioxide level of about 280 parts per million. When the temperature's cold and during an ice age, it goes down to about 180. An amazing thing not really understood is why it goes between these two limits whichever Ice Age you look at. You can go back a million years and we are still looking at 280 parts per million in a warm period like we have now, and 180 in a cold period. Now, the difficulty is that the 280 in the warm period are not what we have at the moment because we've been adding more carbon dioxide to the atmosphere. What we have now is 406, so we've added about 50% to the natural carbon dioxide levels. And this has an effect on the climate.

When we look in detail at the temperature changes over the last 1000 years, we can see that 1000 years ago it was slightly warmer than it was 100 years ago. 1000 years ago you had the Vikings settling in Greenland. It was a relatively warm period. And then the Earth gradually cooled off over 900 years. It was heading very slowly towards the next Ice Age. Around 1850, that suddenly changed and instead of gradually cooling, the Earth started to shoot up in temperature and become much warmer. And this is an expansion of that last 100 years of warming where the Earth warmed up rapidly, then it hovered around for about 20 or 30 years, and then it continued to warm again.

Why is this enormously rapid change occurring?

People who are denying climate change say, "Oh, it is just a natural fluctuation. The Earth's climate is always changing, so this is just another natural change." But you can see that it is not. The natural fluctuations of this scale of the last 150 years are just shooting upwards. And, of course, the year 1850, when this started, corresponded to the Industrial Revolution and to a huge preponderance of steam engines everywhere burning coal and emitting carbon dioxide.

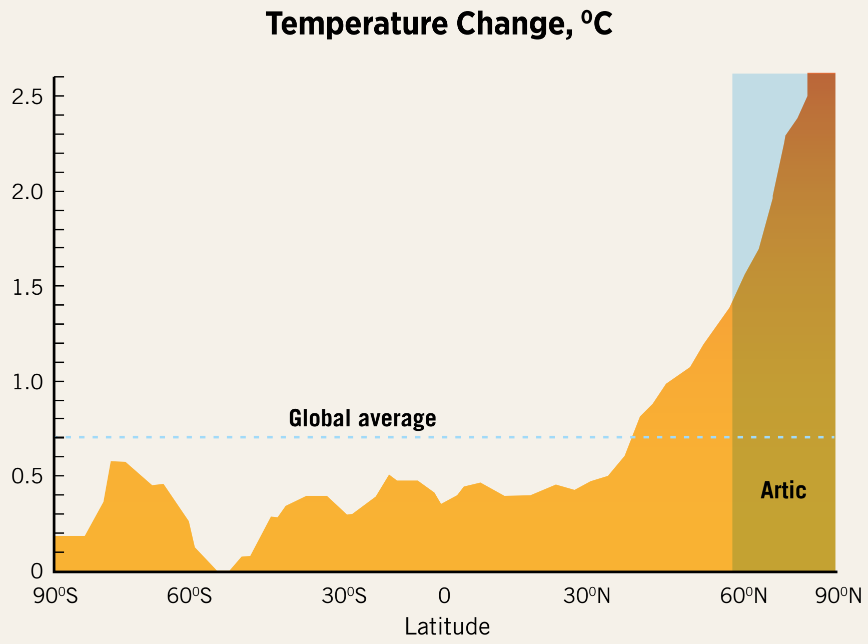
But when you look at that change, looking at the last 150 years in detail, we see the shape of this warming was in two phases. But if you only look at weather stations from the highest northern latitudes —this is north of 60 degrees— we see the same pattern, that the temperature warmed up. It held back a little bit and then it came warm again. But the difference is that the warming between the mid-19th century and now is something like 3 to 4 degrees in the Arctic, while the warming for the planet as a whole between 19th century and now is less than 1 degree. So we are getting an amplification factor in the Arctic of a factor of about three to four.

The Arctic is warming up four times as fast as the rest of the world. This is the key problem. The place that contains a lot of the remaining ice in the world is losing it at an unprecedented rate, because the Arctic's warming up so fast. This is called Arctic amplification, and there is not, again, a complete explanation for it. But we can see how the amplification factor varies with latitude, and we can see that the nearer you get to the North Pole, the more warming you get, relative to the global average. This is a really big factor.

If we look forward to the end of the century, there are various scenarios that the Intergovernmental Panel on Climate Change (IPCC) has used. One is called Business as Usual, which means that if we don't do much about climate change, this is what we'll get. So by the end of the century, we'll have a warming of about 4 degrees over most of the planet, if we are not careful. But right at the northern end, we are getting about 7 degrees. That's the Arctic, which will continue to warm faster than the rest of the world. And a warming of 7 degrees is pretty substantial. Actually, 4 degrees is substantial. That's enough to completely mess up our food production potential on the planet. But the Arctic is going to be even worse.

Before this started to become serious –which was in the 1970s and 80s, when I started working in the Arctic– there were very few Arctic scientists. Mostly we were devoted to trying to understand ice and its properties, and what a role it played, on the assumption that everything stayed the same, that the ice in the Arctic would always be there. And this is like the science of oceanography. In those days, oceanographic ships would go out, do some oceanographic stations in a place where nobody had been, put the results on a huge map, joining on the results of other ships that had been out 10, 20, 30, or 40 years earlier, on the assumption the oceans never changed. And of course that was completely wrong. We know the oceans are changing rapidly and so is the Arctic. But the view that people had from the 70s was that, in the winter, the Arctic sea ice covers the entire Arctic Ocean and lots of the seas around the Arctic –Bering Sea, Sea of Okhotsk, Baffin Bay, and part of the North Atlantic–, and it essentially glues together Eurasia and North America and makes the Northern Hemisphere into a single land mass –we have the Land Hemisphere, which is the Northern Hemisphere; and the Ocean Hemisphere, which is the Southern Hemisphere. Even in summer, in September, the ice would retreat a little away from these coastal seas, but still be there basically filling the whole Arctic Basin, joining together North America and Asia. That's what we were used to. Then, being used to that, we could do experiments where we would drift around in the Arctic through the winter, and the wind and currents moving our ships and huts around the Arctic. And in the winter as well, if you were working on the ice and you were coming into land, you'd simply come off one kind of ice and go onto another kind.

But because of this amplification factor in warming, that was not a stable situation. It looks as if the sea ice started to retreat in summer in about 1950. There was very poor evidence then because we didn't have satellites and we didn't have regular aircraft flights, just a few ships. In 1950, the area of sea ice in summer started to decrease linearly, with time. The other seasons, it didn't retreat so fast because the ice was fixed to the land. But as it retreated, there came a point where suddenly it was noticed. For a long while, nobody noticed this was happening. But once it got unglued from the coastline in summer, people started to notice it. 2005 was the first year in which there was a really large water gap between Siberia and the Arctic ice in



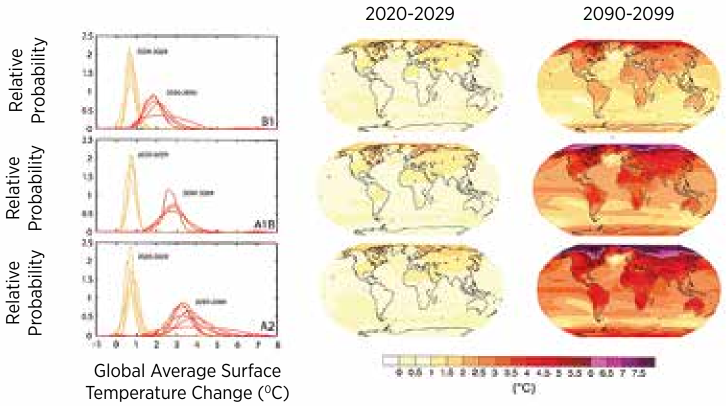
The average increase in surface temperature since the 1951-1980 reference period is greatest in the Artic.

summer, big enough that you could sail through it and have a trade route, called the Northern Sea Route. It was still close to the coast in Canada. But suddenly, people started to think, "Well, this is not a solid mass, after all, connecting these two continents. It is just a thin layer of floating ice which, in a warming climate, can disappear." So it disappeared. The first big area disappeared in 2005. Then the next big jump downwards was in 2007, when another big chunk disappeared from the part of the Arctic called the Beaufort Sea. So a huge sea suddenly appeared, which had never been there before. Then the next big jump down was in 2012, when it laid even further back. And it is hovered since then, but clearly it is shrinking back in a series of steps.

Since the 1970s, we can see how rapidly it is decreasing and that it is accelerating downwards. The Intergovernmental Panel on Climate Change has created a family of about a dozen models that are used for everything in climate —for global climate predictions, what's going to happen to Sahara, or to the Indian monsoon. And if the models are wrong in one big area, you have to fear that they might be wrong in others. So this is quite a worry, because it has been observed that climate models are completely wrong when it comes to predicting sea ice extent. We have observed that ice has been retreating much faster than any models predict. So the models are not incorporating the physics of climate change properly. And that's a very worrying thing.

One of the reasons the models are not representing retreat was that they were not taking any account of the fact that the

Projections on Surface Temperatures



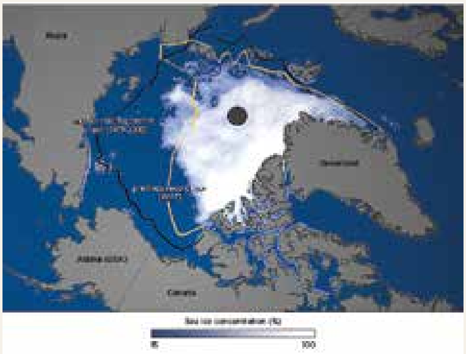
ice is getting thinner as well as shrinking. Measuring the extent of sea ice is very easy now. Having satellites, you just have to take pictures and see how much there is in area. But you can't get at the thickness from a satellite. You have to go underneath and look up from underneath the ice. So the way we've got most of the good data on thickness has come from submarines, that's British and US submarines, which means that scientists have to go in the submarine and use an upward-looking echo sounder to measure the thickness. So that's one of the things I've been doing since the 1970s. When you look at the bottom of the ice, it is not flat at all. There are flat parts, which are where the ice has just grown naturally, and then there are places where the wind has produced a crack, and then crushed the ice to produce a deep ridge, which are called pressure ridges. They can be as deep as 50 meters below the surface. So about half the ice in the Arctic is contained in these pressure ridges, and only half of it is just naturally grown.

In the most recent voyage that the Navy did, I was able to put a multi-beam sonar on the submarine, which instead of just giving you a single profile of the bottom of the ice, gives you a map. The sonar has a wide swath which generates a three-dimensional picture. So we can see really nicely what the bottom of the ice looks like.

If you are a scientist on a military submarine, you don't get a nice office. You have to sleep in the torpedo stowage rack, where the torpedoes normally are. And it is also extremely crowded on a submarine. There's no spare space. Every square inch is taken up with various instruments. You can't hang a picture on the wall, for instance. Advantages are, of course, you get the data on ice thickness which can't be obtained in any other way, and if you are lucky, they'll put you ashore on the ice, and then go and submerge, so you can measure the forces that the ice exerts on the submarine as it comes up.

The results that came out of one of these submarines were very surprising. I did the first paper on ice thinning in 1990, which was based on having the submarine go out following the same route around the Arctic in 1976 and in 1987. I found that in 1976, near Greenland, the contours of average ice thickness were 5, 6, and 7 meters. In 1987, this had gone down to 4 to 5 meters. When I went back again in 2004, it was only about 2 meters. So there was a huge drop in ice thickness. The first drop was only 15%, but it is now risen to be more than 40%. So the thickness of the ice is now about half of what it was 40 years ago. And if you take the thickness, which has gone down by 50%, and the area in summer which has gone down by 50% as it shrank, and multiply these two together, then the volume has gone down by much more than 50%. It is gone down by 75%. So the volume of ice in the Arctic now, in summer, is only a quarter of what it was at the end of the 1970s. So three-quarters of the summer ice has already disappeared. This is a huge change in the state of the planet.

September 16, 2012
(summer minimum)



The Arctic Death Spiral

You can represent it by a curve, which has been called the Arctic Death Spiral. You start off from the middle, and for each month of the year you measure the volume of ice that's there, on average, that month. We start from 1979 and come around to the present day. Now if we look at September, we can see that it is spiraling in towards the center, which means that the volume of ice in September is going down to a very low value. But the volume in other months of the year is also decreasing. If there were no change in the Arctic, you would just see a set of concentric circles. Instead, you see a spiral heading for the center, which means the ice is shrinking back every month of the year. But September is the month that will reach zero first.

This already has big impacts. The kind of ice I used to work with in the 1970s was really thick, and it is called multiyear ice. It is ice which has been growing and sitting in the Arctic for years. So it is very thick and it looks like the Grand Canyon. It is a very impressive landscape. It is hard to walk over it and even to get through it in an icebreaker.

But today, the first-year ice is very thin. It is only about a meter to a meter and a half thick, with very few pressure ridges. It is quite boring-looking. It grows during the winter and it melts again in the summer, and you have open water. Even when there is ice, it is not the same as we used to know in the 1970s, 1980s. Also, this thin ice is very dangerous because it is very easy to break up, given that it doesn't have much strength. We have satellite pictures taken in the middle

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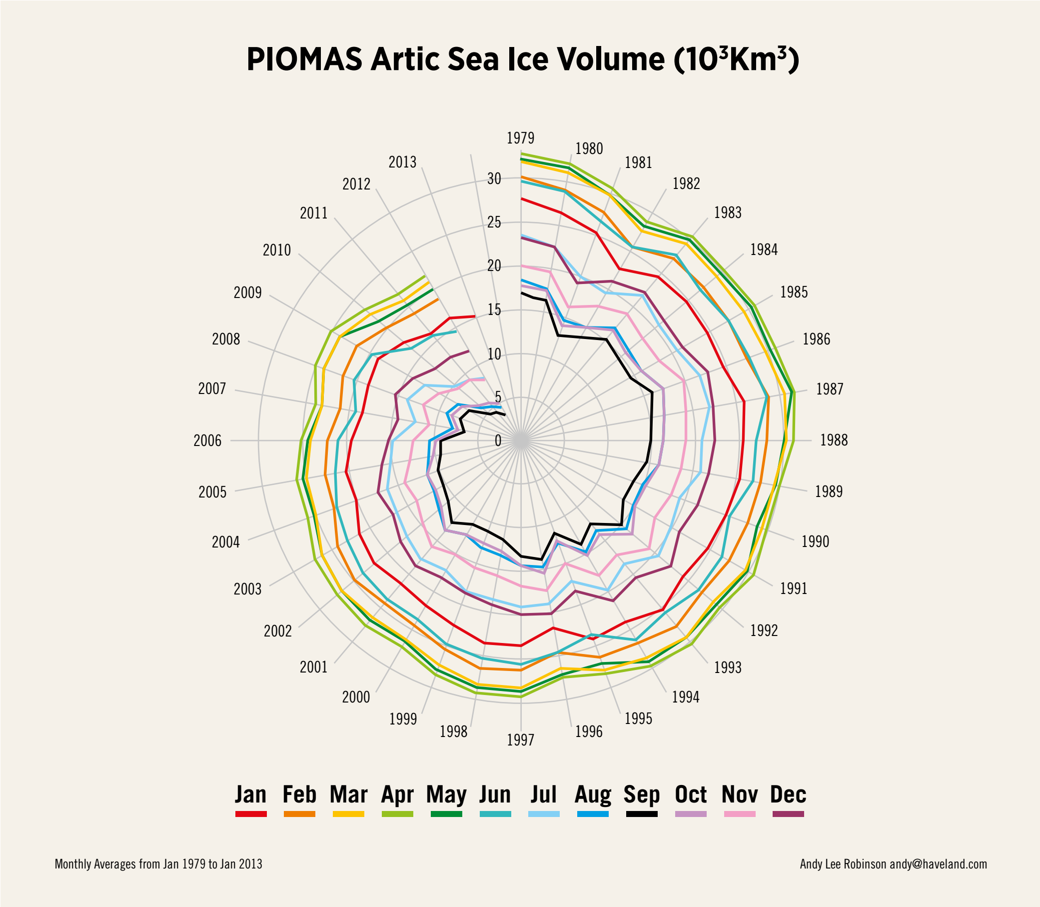
of winter that show an event where a storm came up, broke up all the ice, and created channels of open water. This means that now it is very dangerous to work on Arctic sea ice, because scientists used to use camps where you would supply them with aircraft landing on the ice. But you can't land an aircraft on this ice, because there is not a long enough stretch that's not broken up. So we had to abandon doing ice camps supplied by aircraft.

Another change is that if there's a lot of open water in the summer, it takes a long time for that to freeze up. So if we are looking in the autumn, like November, when normally the ice is completely come back and we have solid ice near the North Pole, today we don't have that solid ice in November. This shows an anomaly because instead of having ice with temperatures 10, 20, 30 below zero, we still have open water. And that gives us an anomaly of plus 20 degrees, compared to what the temperature should be north of Siberia. So we are getting very warm temperatures in the north of Siberia. That is what has happened, and what is most worrying is that has lots of feedbacks for the climate of the planet, as a whole.

The first is that as the ice retreats, you are replacing white surface by dark surface. That means you are absorbing more solar radiation. The ratio that's reflected is called the albedo. So we are reducing the albedo of the planet by reducing the amount of sea ice. Equally, the warming in the Arctic is causing snowline to retreat, and that also reduces albedo. Secondly, the warm air that's over the sea ice causes the Greenland Ice Sheet to warm more in the summer, and it is starting to melt. And melting of the Greenland Ice Sheet puts melted ice into the ocean, which causes sea level to rise. So we are seeing an acceleration of global sea level rise. Thirdly, there's a threat of a big eruption of methane from the seabed, which would cause us a very rapid climate warming. There's also a threat to food production because of the uncertainty in weather, which is also associated with sea ice retreat.

Finally, there's a change in ocean circulation. The first albedo effect is the retreat of the ice. According to their calculations, it is equivalent to adding a quarter to the amount of forcing by greenhouse gasses alone. So if we add greenhouse gasses to the atmosphere, burning fossil fuels to produce carbon dioxide, then the direct effect is increased by a quarter, due to the fact that it is causing the sea ice to retreat and replacing white surface by a dark surface. But the people who did that calculation were actually wrong. They were too optimistic, because they didn't consider the fact that snow is also retreating in the northern hemisphere. The areas that normally would be snow-covered in June are now snow-free. So as soon as the snow retreats and disappears, you have a lower albedo because you have a dark land surface. So if you add snow, the albedo changes. You can see how rapidly the area of snow in the northern hemisphere in summer has deteriorated in recent years. We have a 6-million-square-kilometer negative anomaly

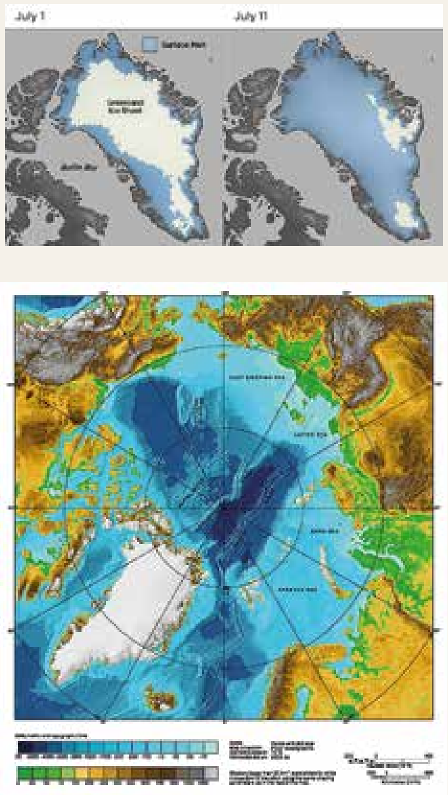


now. If you add the snow and the ice together, the equivalent is now 50%. So every molecule, every two molecules of carbon dioxide that you add to the atmosphere by driving your car around, it is equivalent to another one being added by the retreat of sea ice and the retreat of snow. We've got a feedback effect, which is a 50% acceleration of warming.

We have a map of what the different components do to climate. CO_2 is the biggest offender. Methane is still quite substantial; it has about a third as much effect as CO2. And then acting in the opposite direction, there are aerosols —that's soot in the atmosphere produced from factories— which actually acts to cool the atmosphere, because it reflects radiation back into space. But the net result is a radiative forcing that is the equivalent of the sun being increased in strength by 1 to 2 watts per square meter. Now, the sun's average strength is about 300 or 400 watts per square meter, so what man is doing with his climate change is actually equivalent to strengthening the effect of the sun by about 1%, which doesn't sound much, but this 1% change is more than enough, for instance, to have an impact on the Ice Ages fluctuations.

There are the other effects too. Firstly, the warm air in the summer now stretches over the whole Greenland Ice Sheet, causing it to melt all over its surface. Whereas in the past, you just had a little bit of melt around

2012 Greenland Surface Melt



less about sea level rise than we can about air temperature rise, so we are going to be stuck with these very large, accelerating sea level rises globally for a long time to come.

The threat from methane is that if you look at the Arctic Ocean, about a third of the area is very shallow water —less than 100 meters deep, while the middle of the Arctic is 4000 meters deep. This shallow water is now ice-free in summer. The glacier ice retreats in summer and we can see open water over these shallow shelf areas. Subsequently, open water plus shallow water plus sunlight, together mean the water warms up. And we find, for instance, in areas north of Alaska temperatures of more than 5 degrees for the water temperature in summer.

This has big effects because the seabed in the shallow water contains a huge amount of methane, which is trapped in the form of methane hydrates –a solid material. And capping it is permafrost, which frozen ground, dating from the Ice Age, holds back this methane, prevents it from coming out. That permafrost has been melting because of the warmer water, letting methane out. Plumes of methane coming out from a seabed at 70 meters have been mapped by a sonar system. It is just a huge mass of bubbles of methane. If you sail through that, you have to be really careful because it burns and it will explode. And this is an increasing effect. Each year we go up there, there's more and more methane plumes. And the fear that our Russian colleagues have is that permafrost will disappear completely, and then there'll be a huge mass of methane released very quickly. They think of about 50 billion tons.

We modeled what would happen to the global climate if that happens. If there were a sudden methane release, there'd be a sudden jump in global temperatures of 0.6 of a degree,

the edges in the summer. That extra melting is causing a big increase in the rate of global sea level rise and Greenland is now the main contributor to global sea level rise. This has caused the Intergovernmental Panel on Climate Change, which is a fairly complacent body, to change its predictions of how much sea level rise there'll be in the rest of this century.

Each time scientists study Greenland and Antarctica more, they discover new horrible things, which means each one leads to an increase in the predicted rate of sea level rise. Of course, we can't do much about. We can do which is nearly as much as the warming since the mid-19th century. It would all happen very quickly, in a year or two. That sudden impact would just cause chaos, I think. So we have to hope that that won't happen.

One of our colleagues was an economics modeler, and he used an economic model that was used by the Stern Review to look at what the costs would be to the world of having a methane burst like that. And he was getting values over 100 years of $60 trillion, which, even in terms of Trump's budget cuts, is a lot of money. This is a fear that a methane outbreak could happen. And we are already seeing the methane that's coming out now, which is affecting the global atmosphere. In the past, the methane level in the atmosphere rose to some level, which it seemed to stay at a fixed level —we don't know why. But then more recently, some German monitoring stations found it is going up again. And it is been going up faster ever since. Now we can measure it from satellites, and we find that if we look at a methane map of the global atmosphere, there's more methane in the northern hemisphere than in the south. It all suggests an extra source somewhere north. And that somewhere is thought to be the Arctic Ocean.

The fact that the permafrost on land will slowly melt as well is also involved with this. And that will cause a similar effect, but it won't be so sudden. The 0.6 of a degree will be spread out over several decades. However, the fear is that it will happen suddenly. So, that's another horror we have to try to avoid.

The weather problem has been one to do with the jet stream. We didn't have weather events like the Beast from the East in Europe until this year. It reached most of Europe, and it was basically an extremely cold period in Europe. They've been having this kind of events in the United States for about eight years now. And what happens is that the Arctic is warming faster than the rest of the world. So the temperature difference between the Arctic and the lower latitudes is decreasing. The mass of air moving east that separates these two air masses, which is called the polar jet stream, instead of going in more or less a straight line, it is slowing down because this air temperature difference is decreasing. It is reducing the strength of the wind. So the jet stream is getting to be weaker and as it gets weaker it takes up these big lobes, just like a river. A river that's flowing fast, flows in a straight line. A river that's in a flat valley meanders is slower. And these meanders allow Polar air to be moved further south than it ought to be, like air on the east coast of North America. And hot air from the Gulf of Mexico can move right up to the Canadian prairies.

So in different parts of the world, they're getting temperatures completely different from what they expect, very cold or very warm. And these weather events are clearly related to this reduction of sea ice in the Arctic and the warming of the Arctic, relative to the rest of the world. This year, in January and February, when we were having extremely cold weather in Europe, they were having extremely warm weather in the Arctic, 20 degrees warmer than normal. So, this was an extreme event, where you are getting exceptionally cold air in one place and exceptionally warm air in another place, because of the lobes of the jet stream. So, we got a lobe that gave us cold weather, and the Arctic got warm weather.

The trouble with these events —which have only been happening for the last eight or ten years, since the sea ice start retreated. Apart from the uncertainty, one of the big problems is that it is causing extremes to happen. And these extremes and these

“We are not going fast enough in carbon-emission reduction, mainly because people don't really want to change the way they live as rapidly as they should”

uncertainties are occurring in mid-latitudes of the north and those mid-latitudes —of North America, Europe, and Asia— are the places where most of the Earth's crops are grown. So, interference with crop production due to extremely hot or extremely cold conditions is quite serious. This is a serious effect on food prices. And we can already see this happening. The Food and Agricultural Organization produced a global food price index in the year 2000, which was set at 100. It rose to a peak in 2008 and 2011, which correspond to years when there was big reductions in sea ice in the Arctic. The weather extremes have occurred, reduced crop production and food prices rose to very high levels, over twice as much as they had been in the year 2000.

People in developed countries mostly can pay those prices, but if you are living in a third-world city, you can't grow your own food, and you have to pay high prices. This means a lot of unrest, especially with crowded, third world cities with a lot of young people who can't make a living. And they riot. So you have riots and changes of government. Of course, the first famous one was the Arab Spring, and the Tunisian Revolt, which happened in the 2008, coinciding with the rise in food prices. And there's been a higher one since then, in 2011. And so, one of the effects of food uncertainty due to these weather events has been really unrest in the Middle East and in many other parts of the world, where you have a lot of big cities with a lot of poor people.

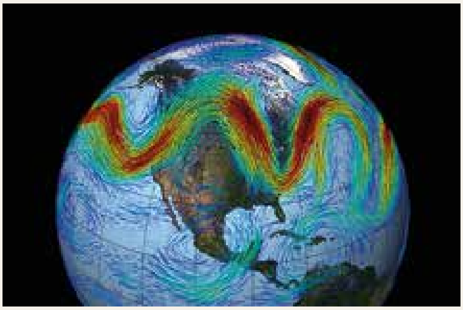
And a part from these extreme events is the very fact that the temperatures warming means that the yield of a lot of crops, the standard crops that we depend on, is going down. Up to a certain limit, the yield rises. That limit is about 1 degree, which we've now reached. But as soon as we get beyond that, the yields diminish very rapidly. This is one of the reasons why 2 degrees was selected as a temperature beyond which the planet should try not to go, because it would result in serious disruption of crops.

The ocean circulation is changing

There is lots more horrible effects, but the final one I'll mention is the fact that the ocean circulation is changing. If we think about the northern hemisphere, what keeps us warm in Europe mainly is the Gulf Stream, which is a wind-driven current. But on top of this wind-driven current, there's a very slow current driven by temperatures and salinity variations called the thermohaline circulation, or the global conveyor belt. The conveyor belt circulates around the world, and the deep currents do the return flow. You have a flow on the surface, and in places where sinking occurs, that enables the flow to continue in the deep ocean.

We've got a sinking place in the northern North Atlantic, and this sinking has stopped happening in recent years. We studied this very intensively with a European project, and the place where we used to get sinking is in the middle of the Greenland Sea. The ice is coming out of the Arctic Ocean, and there is a tongue of ice which grows out, away from the Greenland coast, because it is sitting on top

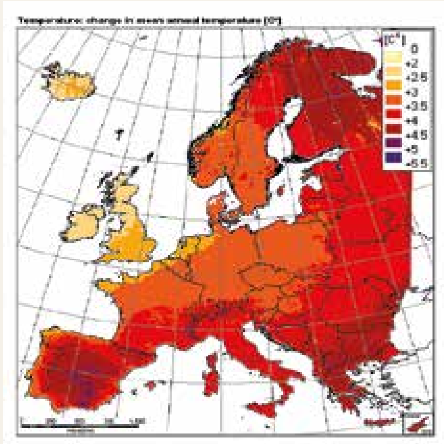
Simulation of Jet Stream (NASA)



of some cold water, that was called the Odden by the Norwegians. It was a place where they used to go and catch seals in the 19th century. The ice in that area is called pancake ice. There's a lot of wave action and the ice doesn't grow as a continuous sheet; it grows as cakes. And these cakes grow very quickly. The salt in the water goes back into the water and makes the water more dense, and the water sinks. So because of these pancake growths, the water sinks in narrow sinking columns called chimneys. It is just like the vortex you get when you take the plug out of the bath. So it is sinking, rotating columns that go right from the surface down to two-and-a-half thousand meters below the surface, all the same water. It is a very strange phenomenon. You don't get these kind of small-scale things happening in the ocean. So it is an extraordinary effect, but it allows the surface water to sink and keep this global conveyor belt circulation going.

Now the trouble is ice has stopped growing in the Odden ice tongue because of warming. We don't get these chimneys anymore, and we are getting a real weakening of the thermohaline circulation. And this will have an effect on our climate in Europe. The European Environment Agency has made a prediction of what the temperatures will be like at the end

Temperature: Change in Mean Annual Temperature (^0C)



of this century. And we see about 4 degrees of warming if we don't do anything about it, which would be catastrophic, especially for southern Europe. We see Spain here having even more than 4 degrees, because it is turning southern Europe into something approaching the Sahara. But we see that Britain, Ireland, Iceland are having much less warming, of about 2 degrees, and that's because as this thermohaline circulation weakens, there's less warm water being carried up to Europe from the starting point in the Gulf of Mexico.

In a sense, Western Europe, or extreme west of Europe, is being protected from global warming, but at the expense of the tropical Atlantic. And this means that hurricanes are going to become much more intense and frequent, because the hurricane intensity depends on the temperature of the surface water. And the surface waters in the tropical Atlantic are becoming warmer because of this weakening.

So, the whole story says things are pretty bad. What can we do? We have to do something

and we are not doing enough to be able to cope with this, because the conventional view has been, "Well, if we reduce our carbon emissions, we'll gradually get to a point where temperature or global warming will slow down and will be containable." But in fact, that's not the case. Under the Paris Agreement, they're trying to keep warming below 2 degrees. Even considering the commitments made by the different countries —forgetting the fact that the US dropped out, but even when the US was in it—, that would still result in 3.9 degrees warming by the end of the century. And that's enough to have a very serious effect on the planet, especially on food.

So, we are not going fast enough in carbon-emission reduction, mainly because people don't really want to change the way they live as rapidly as they should. I mean, people still want to drive cars, live in cities, and do all the things that can involve consumption of fossil fuels. So, in my view and in the view of a lot of scientists, the only way we can meet those climate requirements and not have a catastrophic warming is to actually do something technical to the climate, either try to mask the warming by reflecting energy back into space —now that's called geoengineering—, or actually get rid of the carbon dioxide by taking it out of the atmosphere. And that's what I think we have to do because it seems almost impossible to reduce carbon emissions. The carbon dioxide level in the atmosphere is moving almost vertically. We see huge increases in carbon emissions by China and India, more than offsetting small reductions in Europe and America. So, we are not doing very well.

The two methods that we can use are geoengineering. In one method you put powdered aerosols into the stratosphere, they spread round the atmosphere and reflect radiation, putting it back into space. I don't particularly like that method because once you've done it, you can't do anymore until it is all gone. So you have to accept whatever changes in climate happen.

However, there is a more targeted method, which was invented by a Scottish scientist called Salter. It involves injecting very finely divided seawater particles into the bottoms of clouds. It is called marine cloud brightening. So you have a mast inside a ship where you pump water up from the ocean, inject it into the bottom of the cloud, and if the particles are the right size, the cloud brightens up. There's an effect called the Twomey effect, which is that small particles, if they're small enough, will make a cloud whiter. And so this will whiten clouds. So all the gray, miserable clouds you get over Britain, for instance, will become white and happy-looking clouds. We'll need about 200 of those ships, and they're unmanned. They have a Flettner rotor, which is a form of wind-driven propulsion. And then inside, there's the pump driving up the water vapor and into the bottom of the cloud.

This is a practical method. It is being worked out how it could be done. All that's needed is the money to start doing it. What it does is reduce global warming —in fact, with enough of these, you can stop global warming—, but it doesn't do anything about carbon dioxide levels. They keep rising and that will ultimately have a very bad effect, because this will result in acidification of the oceans, which kills off marine life. So this can only be a temporary solution, a sticking plaster that will hold back global warming until we can actually get rid of carbon dioxide.

I think the only thing that will save us, in the long run, is direct air capture, where you run air through a machine which absorbs carbon dioxide into a chemical, and there's amines which will do this job. Then you get rid of the carbon dioxide by pumping it down underground, or doing some turning into something else. You would have to have this system all over the planet. There are three in existence now, which are pilot plants, one of them in Iceland, which removes carbon dioxide from the air and pumps it down into rocks, deep rocks, where it reacts with the rock to form a solid. So it works, but the cost is enormous. And when I say we need a Manhattan Project, what we need is a huge project to find ways of doing this more cheaply so that we can do it all over the world. And then, having a way to do it more cheaply, we have to actually persuade the world, the governments of the world, to pay for this. And the amazing thing about the three organizations that have come up with pilot plants is they complain that nobody's willing to pay for this development for the system. And this is the system that will save our planet, because in the end, the only way to get rid of climate change is to get rid of carbon dioxide. And yet nobody wants to pay for it. So that's a sign of something being wrong with the human race, but hopefully as the situation gets worse and education gets somewhere, we might find that we are finally willing to pay for systems that will take CO_2 out of the atmosphere and ultimately get rid of climate change for us.

Bio

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