



Forget polar bears, the rapid warming in the Arctic could be a catastrophe for us all.
Fred Pearce reports

Meltdown

I AM shocked, truly shocked," says Katey Walter, an ecologist at the University of Alaska in Fairbanks. "I was in Siberia a few weeks ago, and I am now just back in from the field in Alaska. The permafrost is melting fast all over the Arctic, lakes are forming everywhere and methane is bubbling up out of them."

Back in 2006, in a paper in *Nature*, Walter warned that as the permafrost in Siberia melted, growing methane emissions could accelerate climate change. But even she was not expecting such a rapid change. "Lakes in Siberia are five times bigger than when I measured them in 2006. It's unprecedented.

This is a global event now, and the inertia for more permafrost melt is increasing."

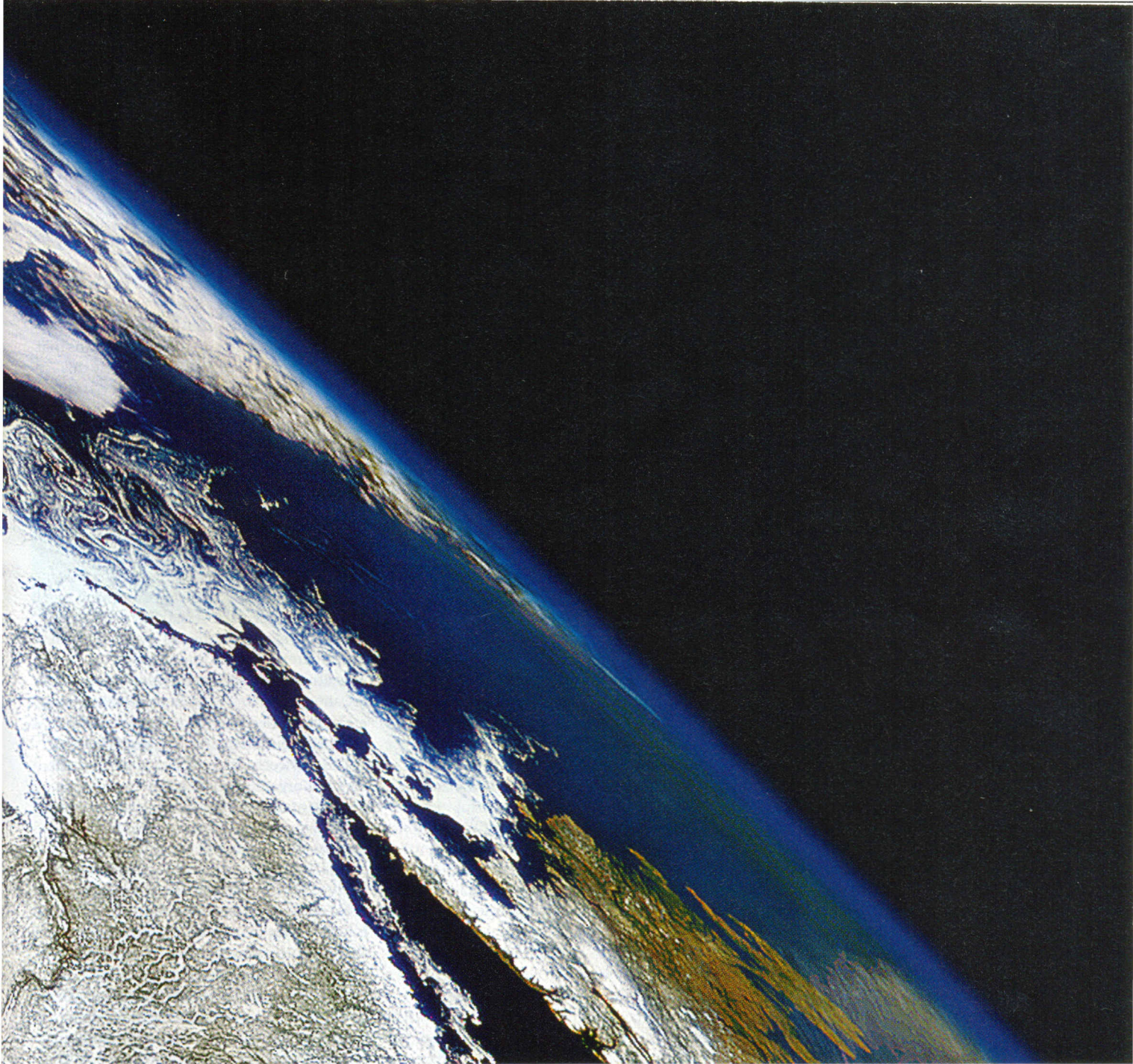
The dramatic changes in the Arctic Ocean have often been in the news in the past two years. There has been a huge increase in the amount of sea ice melting each summer, and some are now predicting that as early as 2030 there will be no summer ice in the Arctic at all.

Discussions about the consequences of the vanishing ice usually focus either on the opening up of new frontiers for shipping and mineral exploitation, or on the plight of polar bears, which rely on sea ice for hunting. The bigger picture has got much less attention: a warmer Arctic will change the entire planet,

and some of the potential consequences are nothing short of catastrophic.

Changes in ocean currents, for instance, could disrupt the Asian monsoon, and nearly two billion people rely on those rains to grow their food. As if that wasn't bad enough, it is also possible that positive feedback from the release of methane from melting permafrost could lead to runaway warming.

The danger is that if too much methane is released, the world will get hotter no matter how drastically we slash our greenhouse gas emissions. Recent studies suggest that emissions from melting permafrost could be far greater than once thought. And, although



it is too early to be sure, some suspect this scenario is already starting to unfold: after remaining static for the past decade, methane levels have begun to rise again, and the source could be Arctic permafrost.

What is certain is that the Arctic is warming faster than any other place on Earth. While the average global temperature has risen by less than 1 °C over the past three decades, there has been warming over much of the Arctic Ocean of around 3 °C. In some areas where the ice has been lost, temperatures have risen by 5 °C.

This intense warming is not confined to the Arctic Ocean. It extends south, deep into the land masses of Siberia, Alaska, Canada,

Greenland and Scandinavia, and to their snowfields, ice sheets and permafrost. In 2007, the North American Arctic was more than 2 °C warmer than the average for 1951 to 1980, and parts of Siberia over 3 °C warmer. In 2008, most of Siberia was 2 °C warmer than average (see map, page 34).

Most of this is the result of positive feedbacks (see illustration, page 35) from lost ocean ice, says David Lawrence of the National Center for Atmospheric Research in Boulder, Colorado. His modelling studies show that during periods of rapid sea-ice loss, warming extends some 1500 kilometres inland from the ice itself. "If sea-ice continues to contract

Sea ice swirls in the currents of the Labrador Sea. There is not as much as there used to be

rapidly over the next several years, Arctic land warming and permafrost thaw are likely to accelerate," he says.

Changes in wind patterns may accelerate the warming even further. "Loss of summer sea ice means more heat is absorbed in the ocean, which is given back to the atmosphere in early winter, which changes the wind patterns, which favours additional sea ice loss," says James Overland, an oceanographer at the Pacific Marine Environmental Laboratory in Seattle. "The potential big deal ►



STONE

Summer sea ice has declined dramatically across the Arctic

is that we now may be having a positive feedback between atmospheric wind patterns and continued loss of sea ice."

Incidentally, the changing winds might also be to blame for some of the cold and snowy weather in North America and China in recent winters, Overland says. Unusual poleward flows of warm air over Siberia have displaced cold air southwards on either side.

The rapid warming in the Arctic means that a global temperature rise of 3 °C, likely this century, could translate into a 10 °C warming in the far north. Permafrost hundreds of metres deep will be at risk of thawing out.

This is where things go global. The Arctic is not just a reflective mirror that is cracking up. It is also a massive store of carbon and methane, locked into the frozen soils and buried in icy structures beneath the ocean bed.

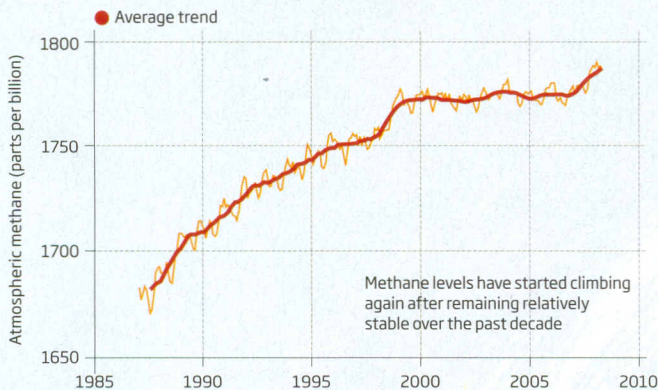
A quarter of the land surface of the northern hemisphere contains permafrost, permanently frozen soil, water and rock. In places, deep permafrost that formed during the last ice age, when the sea level was much lower, extends far out under the ocean, beneath the seabed. Large areas of permafrost are already starting to melt, resulting in rapid erosion, buckled highways and pipelines, collapsing buildings and "drunken" forests.

The real worry, though, is that permafrost contains organic carbon in the form of long-dead plants and animals. Some of it, including the odd mammoth, has remained frozen for tens of thousands of years. When the permafrost melts, much of this carbon is likely to be released into the atmosphere.

No one knows for sure how much carbon is locked away in permafrost, but it seems there is much more than we thought. An international study headed by Edward Schuur of the University of Florida last year doubled previous estimates of the carbon content of permafrost to about 1600 billion tonnes – roughly a third of all the carbon in the world's soils and twice as much as is in the atmosphere.

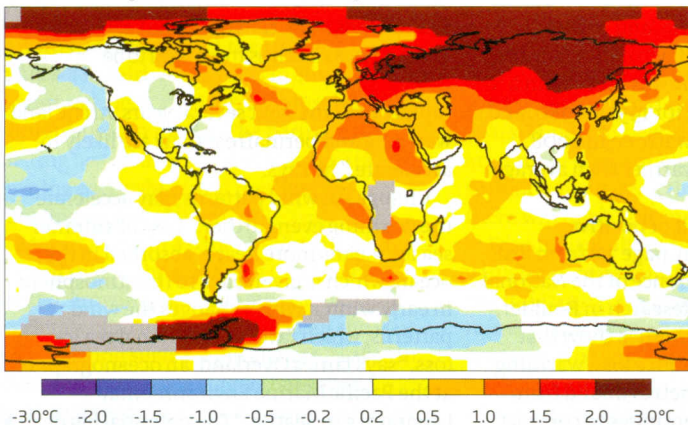
Danger signal

In 2007 and 2008, temperatures across Siberia were way above average. At the same time, atmospheric methane levels suddenly increased. Some think the rise in methane is partly due to melting permafrost



GRAPH COMPILED FOR NEW SCIENTIST BY R. PRINN, R. WANG AND THE AGAGE TEAM

In 2008, temperatures across much of the far north were more than 2 °C higher than the 1951-1980 average



SOURCE: OSTIA

Time bomb

Schuur estimates that 100 billion tonnes of this carbon could be released by thawing this century, based on standard scenarios. If that all emerged in the form of methane, it would have a warming effect equivalent to 270 years of carbon dioxide emissions at current levels. "It's a kind of slow-motion time bomb," he says.

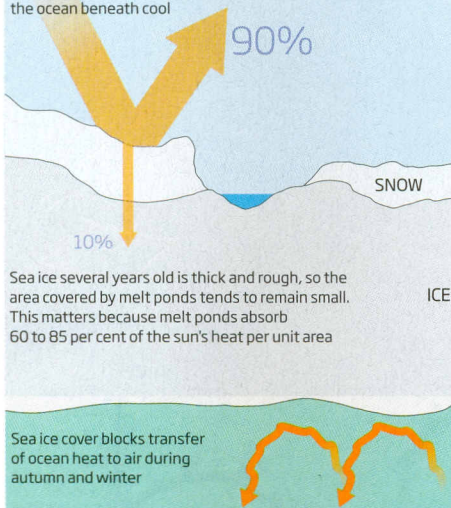
One hotspot is the 40,000-year-old east Siberian permafrost region. It alone contains 500 billion tonnes of carbon, says Philippe Ciais, co-chair of the Global Carbon Project,

The heat is on

The rapid shrinking of summer sea ice in the Arctic is not just due to the change in albedo as ice gives way to water. Recent studies suggest several positive feedback factors are involved

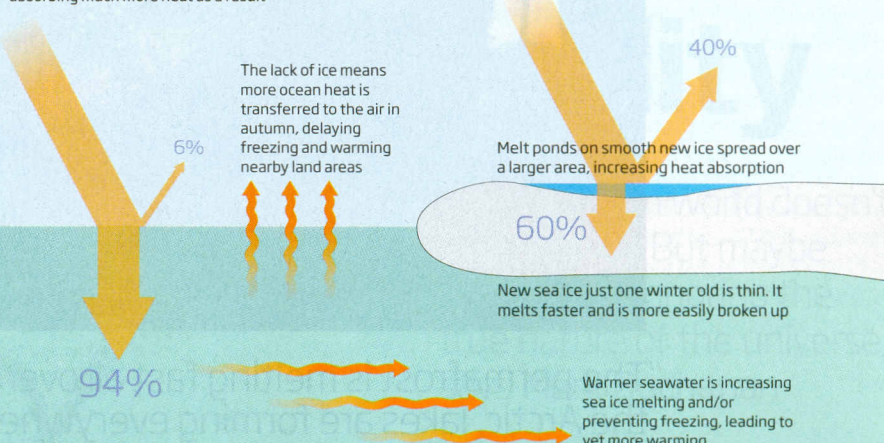
BEFORE

Snow-covered ice absorbs only about 10 per cent of the sun's energy per unit area, keeping the ocean beneath cool



NOW

Warmer air due to higher greenhouse gas levels is increasing the extent of sea ice melting. Open water absorbs around 94 per cent of the sun's energy per unit area, so the Arctic Ocean is absorbing much more heat as a result



a research network analysing the carbon cycle. East Siberia was at times 7 °C warmer than normal during the summer of 2007, he says.

Higher temperatures mean the seasonal melting of the upper layer of soil extends down deeper than normal, melting the permafrost below. Microbes can then break down any organic matter in the thawing layer, not only releasing carbon but also generating heat that leads to even deeper melting. The heat produced by decomposition is yet another positive feedback that will accelerate melting, Ciaia says.

What's more, if summer melting depth exceeds the winter refreezing level then a layer of permanently unfrozen soil known as a talik forms, sandwiched between the permafrost below and the winter-freezing surface layer. "A talik allows heat to build more quickly in the soil, hastening the long-term thaw of permafrost," says Lawrence.

The carbon in melting permafrost can enter the atmosphere either as carbon dioxide or methane, which is a far more potent greenhouse gas, molecule-for-molecule. If organic matter decomposes in the low-oxygen conditions typical of the boggy soils and lakes in these regions, more methane forms.

Researchers have been monitoring the Stordalen mire in northern Sweden for

decades. The permafrost there is melting fast and, as conditions become wetter, it is releasing ever more methane into the air, says Torben Christensen of Lund University in Sweden. This is the future for most of the northern hemisphere's permafrost, he says.

It's not just existing boggy patches that are the problem. In low-lying areas, the loss of volume as ice-rich permafrost melts leads to the collapse of the ground and the formation of thermokarst lakes from the meltwater. Satellite surveys show the number and area of these lakes is increasing and, as the work by Walter and others shows, they could be a major source of methane.

Put together, the latest research paints a disturbing picture. Since existing models do not include feedback effects such as the heat generated by decomposition, the permafrost could melt far faster than generally thought. "Instead of disappearing in 500 years, the deepest permafrost could disappear in 100 years," Ciaia says.

The permafrost is not the only source of methane in the Arctic. Shallow ocean sediments can be rich in methane hydrates, a form of ice containing trapped methane. Particularly worrying are the huge amounts of methane hydrate thought to lie beneath the Arctic Ocean. Because the waters here are

so cold, methane hydrates can be found closer to the surface than in most other parts of the world. These shallow deposits are far more vulnerable to the warming of surface waters.

Juergen Mienert at the University of Tromsø in Norway, who has analysed past eruptions of methane hydrates from the Arctic, says current conditions are disturbingly similar to those in the past when warming waters penetrated sediments, triggering the release of hydrates. "Global warming will cause more blowouts, more releases," he says.

While shrinking sea ice in 2007 may have attracted all the headlines, some researchers say what is really scaring them is a simultaneous jump in methane levels. While the level of methane in the atmosphere has more than doubled since pre-industrial times, for the past decade or so there has been little change.

Then, in 2007, several million tonnes of extra methane mysteriously entered the atmosphere. Detailed analysis from methane monitors around the world suggests that much of it came from the far north. Ciaia says it looks like the biggest source was Siberian permafrost.

This is still contentious. Matt Rigby of the Center for Global Change Science at the Massachusetts Institute of Technology, who has analysed the methane surge, says we cannot yet say whether emissions from melting permafrost contributed most to the rise. "But 2007 was unusually warm in Siberia, and we would expect emissions increases when temperature rises," he adds.

"The disruption of the monsoon would have enormous social and economic impacts in south Asia"

Methane from melting permafrost could mean warming will continue even if we cut emissions



CARY BRAASCH

"The permafrost is melting fast all over the Arctic, lakes are forming everywhere and methane is bubbling out of them"

The rise could just be a blip – or the start of something big. "Once this process starts, it could soon become unstoppable," Ciais says.

Walter agrees. Right now, she estimates, only a few tens of millions of tonnes of methane are being emitted. "But there are tens of billions of tonnes potentially available for release." And the faster the warming, the faster the emissions will rise.

Most worrying of all is the risk of a runaway greenhouse effect. The carbon stored in the far north has the potential to raise global temperatures by 10 °C or more. If global warming leads to the release of more greenhouse gases, these releases will cause yet more warming and still more carbon will escape to the atmosphere. Eventually the feedback process would continue even if we cut our greenhouse emissions to zero. At that point climate change would be out of control.

There is another concern about Arctic melting: the growing amount of fresh water flowing into the Arctic Ocean. The shrinking thickness and extent of sea ice has added a huge amount of fresh water already. Meanwhile, rivers are pouring up to 10 per cent more water into the ocean than they did half a century ago. This is partly the result of rising precipitation as the air warms – warmer air can hold more moisture – and partly the result of melting permafrost, ice and snow. Yet more fresh water is coming from the melting of the Greenland ice sheet. As the Arctic warms further, these flows of fresh water will increase.

All this extra fresh water could weaken

the pump that drives the thermohaline circulation, or ocean conveyor current. Its most famous element is the Gulf Stream in the North Atlantic, but the conveyor travels all the oceans. It has its beginnings in the far north of the Atlantic, off Greenland, where unusually dense water plunges to the ocean floor. The water becomes dense here partly because it cools and partly because the formation of sea ice increases salinity. As the water gets a bit warmer and a bit less salty, thanks to all the extra fresh water, the worry is that the pump could slow down.

Fears that the conveyor will soon shut down altogether, causing a fall in temperatures in northern Europe, have receded. Models of the climate system do not predict a shutdown any time within the next century, says oceanographer Stefan Rahmstorf of the Potsdam Institute for Climate Impact Research in Germany.

Monsoon warning

Even a slowdown in the conveyor could produce dramatic changes, though. Climate models suggest that changes in the ocean conveyor will alter rainfall patterns around the world. The models are backed by studies of how the climate has changed during past shutdowns of the ocean conveyor.

The biggest consequence, says Buwen Dong of the Walker Institute for Climate System Research at the University of Reading, UK, is likely to be a disruption, and quite probably a complete collapse, of the Asian monsoon,

causing severe droughts in south Asia. "It could have enormous social and economic impacts on these nations," he says.

You can say that again. The Asian monsoon is the main source of water for large areas of the most heavily populated continent. An estimated 2 billion – getting on for 1 in 3 citizens on the planet – rely on it to grow their food. Take away the monsoon and they would starve. All because of warming in the Arctic.

Nobody can be sure how likely all this is. Indeed, the scientists at the Intergovernmental Panel on Climate Change (IPCC) who compile its reports cannot even reach agreement on how to quantify the probabilities of such events. As a result, the "scary scenarios" were barely mentioned in the last report.

Nonetheless, the latest findings suggest we cannot afford to ignore these possibilities, especially given that everything to do with global climate is linked. The loss of Arctic sea ice could lead to the release of ever more methane from permafrost and methane hydrates. That in turn would make a dramatic reduction in the strength of the ocean conveyor sometime this century increasingly likely, which could lead to abrupt changes in the Asian monsoon.

With the summer sea ice in the Arctic Ocean already shrinking much faster than the IPCC models predicted, one thing is for sure. It is not just the polar bears who should be worrying about the warming Arctic. ■

Fred Pearce is an environment correspondent for *New Scientist*