Review of the year: Global warming

Our worst fears are exceeded by reality

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It has been a hot year. The average temperature in Britain for 2006 was higher than at any time since records began in 1659. Globally, it looks set to be the sixth hottest year on record. The signs during the past 12 months have been all around us. Little winter snow in the Alpine ski resorts, continuing droughts in Africa, mountain glaciers melting faster than at any time in the past 5,000 years, disappearing Arctic sea ice, Greenland's ice sheet sliding into the sea. Oh, and a hosepipe ban in southern England.

You could be forgiven for thinking that you've heard it all before. You may think it's time to turn the page and read something else. But you'd be wrong. 2006 will be remembered by climatologists as the year in which the potential scale of global warming came into focus. And the problem can be summarised in one word: feedback.

During the past year, scientific findings emerged that made even the most doom-laden predictions about climate change seem a little on the optimistic side. And at the heart of the issue is the idea of climate feedbacks - when the effects of global warming begin to feed into the causes of global warming. Feedbacks can either make things better, or they can make things worse. The trouble is, everywhere scientists looked in 2006, they encountered feedbacks that will make things worse - a lot worse.

Next year, the UN's Intergovernmental Panel on Climate Change (IPCC) will publish its fourth assessment on the scale of the future problems facing humanity. Its last assessment, published in 2001, had little to say on the subject of climate feedbacks, partly because, at that time, they were such an unknown quantity. This year, scientists came to learn a little more about them, and they didn't like what they learnt.

During the past two decades, the IPCC has tended to regard the Earth's climate as something that will change gradually and smoothly, as carbon dioxide and global temperatures continue their lock-step rise. But there is a growing consensus among many climate scientists that this may be giving a false sense of security. They fear that feedback reactions may begin to kick in and suddenly tip the climate beyond a critical threshold from which it cannot easily recover.

Climate feedbacks could turn the Earth into a very different planet over a dramatically short period of time. It has happened in the past, scientists say, and it could easily happen in the future given the unprecedented scale of the environmental changes caused by man.

There are two types of feedback that can play a role in the future direction of the Earth's climate. The first is a "negative" feedback, which is largely good for us, because it works against things getting

worse. The classic example of a negative feedback is the fertilising effect of carbon dioxide. As concentrations rise, then so does the amount of carbon absorbed by the higher growth rate of plants. The result is a negative feedback that tends to check rising levels of carbon dioxide.

A "positive" feedback makes things worse by adding to the existing problem. It brings about a vicious circle, in which a rise in carbon dioxide or global temperatures causes some change in the climate system which, in turn, leads to further rises in carbon dioxide or temperatures.

A classic example of a positive feedback is the melting sea ice of the Arctic. As temperatures rise, the ice floating on the Arctic sea melts, exposing dark ocean where once there was white ice that reflected sunlight, and heat, back into space. The newly revealed dark ocean absorbs more sunlight and heats up, causing more ice to melt, and so reinforcing the positive-feedback cycle.

But even this simple description belies the true complexity of life on Earth. In fact, there is a negative feedback at work as well with Arctic sea ice, which insulates the underlying ocean and keeps it warmer during the cold, dark northern winters. However, on balance, it is the positive feedback that dominates here, as it does in several other instances investigated by scientists in 2006.

"The main concern is that the more we look, the more positive feedbacks we find," says Olivier Boucher, a climate scientist at the Met Office. "That's not the case when it comes to negative feedbacks. There seems to be far fewer of them." The sentiment is echoed by Chris Rapley, the director of the British Antarctic Survey in Cambridge: "When we look at the list of all the feedbacks in the climate, the list of positive feedbacks is worryingly long - a lot longer than the negative feedbacks. To be honest, it's a wonder that the climate has remained so stable."

Let's stick with Arctic sea ice a bit longer before looking at other issues that emerged 2006. In March, NASA satellites monitored a 28-year record low for winter sea ice. Normally sea ice recovers during the long Arctic winter, but this was the second consecutive year that the ice failed to re-form fully to is previous winter extent.

This meant there was less ice at the start of the northern summer, with the result that last September saw the second monthly minimum for summer sea ice - almost hitting the record minimum set in September 2005.

During the past four or five years, there has been an acceleration in the rate at which sea ice is melting, a change that some scientists put down to a positive feedback. "Our hypothesis is that we've reached the tipping point," says Ron Lindsay of the University of Washington in Seattle. "For sea ice, the positive feedback is that increased summer melt means decreased winter growth and then even more melting the next summer, and so on."

Professor Lindsay likens the positive feedback in the Arctic to a ball that has begun to roll down a slope, gathering momentum and speed as it goes. In order to reverse the direction of movement, the ball has to be pushed back up the slope. But how? "Perhaps a cooling period could reverse the situation," he says. "But with global warming, temperatures are only bound to rise."

While we are in the northern hemisphere, take a look at another positive feedback that scientists investigated in 2006. This is connected to the frozen permafrost of Siberia and northern Canada, which lock up vast stores of carbon in the form of methane, a gas formed by the decomposition of organic matter. For more than 12,000 years, this methane - a greenhouse gas 20 times more potent than carbon

dioxide - has been safely stored under the permanently frozen ground. But now the permafrost is melting and the gas is bubbling free into the atmosphere.

Sergei Kirpotin, a botanist at Tomsk State University in Russia, has been studying the extent of the melting permafrost of Western Siberia, the site of the world's biggest frozen peat bog. During the past few years, he has watched lakes getting bigger and bigger as the solid permafrost underneath liquifies.

Normally, patches on white lichen on high Siberian ground reflect the sun's rays and help to keep the ground underneath cold. But as the dark lakes expand, more heat is absorbed and more permafrost melts. "As we predicted in the early 1990s, there's a critical barrier," says Professor Kirpotin. "Once global warming pushes the melting process past that line, it begins to perpetuate itself."

The once-frozen peat bogs of Siberia - bigger than France and Germany combined - began to "boil" furiously in the summer of 2006 as methane bubbled to the surface. Exactly how much is being released into the atmosphere is unknown, although some estimates put it as high as 100,000 tons a day - which means a warming effect greater than America's man-made emissions of carbon dioxide.

But Katey Walter of the University of Alaska believes even this could be seriously underestimated. In a study published in Nature in September, Walter and her colleagues calculated that the level of methane emissions from Siberia could be anywhere between 10 per cent and 63 per cent higher than anyone had hitherto suspected. "We have shown that the North Siberian lakes are a significantly larger source of atmospheric methane than previously recognised," she says.

So the message is clear: frozen peat bogs that turn into heat-absorbing lakes release methane, which means a stronger greenhouse effect and higher temperatures, leading to more permafrost melting. The cycle was clearly documented in 2006 but just how strong this positive feedback turns out to be has yet to be fully determined.

Another study in 2006 looked at perhaps the most important climate feedback there is. Yet it went unreported - so listen up. The Earth has been a very accommodating planet. During the past 200 years, it has absorbed more than half of all man-made emissions of carbon dioxide through natural carbon "sinks", mostly in the ocean but also on land. The rest of the emissions have been left in the air to aggravate the Earth's natural greenhouse effect, so raising global average temperatures.

But what if something were to interfere with these very useful carbon "sinks"? Can we forever rely on them to remain sinks, or could they turn into dangerous sources of atmospheric carbon? A huge international team of climatologists asked these questions in a little-known study published in the July issue of the Journal of Climate. The conclusion makes depressing reading.

The scientists investigated what would happen if they tinkered with 11 of the world's biggest computer models of the complex climate-carbon cycle. They wanted to simulate what would happen to the carbon sinks on the land and the ocean for each model as the world gets warmer. All the models agreed that as the world heated up, the ability of the land and the oceans to keep on absorbing carbon as efficiently as they have in the past 200 years gets appreciably worse.

In other words, we cannot rely on planet Earth to be so accommodating in terms of mopping up half of our carbon pollution. But could something even worse happen? Could these carbon sinks turn into carbon sources? The answer is yes. Many models suggest that the terrestrial biosphere could become a net carbon producer by the mid 21st century. Signs are that it is already happening in some parts of the

world.

Guy Kirk of the National Soil Resources Institute at Cranfield University found that the soil of Britain is releasing more carbon dioxide into the atmosphere than a quarter of a century ago because increasing temperatures are speeding up the rate of organic decay. "It's a feedback loop," says Professor Kirk. "The warmer it gets, the faster it is happening." In fact, he estimates that since 1978, Britain's soil has released on average an extra 13 million tons of carbon dioxide a year, which is more than the 12.7 million tons a year Britain saved by cleaning up its industrial emissions.

The outlook does not look any better out at sea. The important carbon sinks of the ocean are also suffering from feedback. As more carbon dioxide dissolves in seawater to form carbonic acid, the acidity of the ocean increases - the rate is 100 times faster than at any time for millions of years.

There is a physical feedback - it is just harder for more carbon dioxide to dissolve in acid water - as well as a biological feedback. Tiny organisms called coccolithophores use dissolved carbon to make their shells, but acidic seas make this more difficult. This blocks an important biological pump that pushes carbon to a long-term store on the seabed - which is what happens when billions of tiny shells sink to the depths as coccolithophores die.

Yet another ocean feedback was monitored in 2006, this time involving phytoplankton, the tiny microscopic plants of the sea that form the basis of the entire marine food chain. Nasa satellites showed earlier this month that phytoplankton - which absorb carbon dioxide - are finding it harder to live in the more stratified layers of the warmer ocean, which restrict the mixing of vital nutrients. Since 2000, when the sea surface temperatures began to rise more noticeably, the photosynthetic productivity of phytoplankton have decreased in some ocean regions by 30 per cent.

"As climate warms, phytoplankton production goes down, but this also means that carbon dioxide uptake by ocean plants will decrease," says Michael Behrenfeld of Oregon State University. "That would allow carbon dioxide to accumulate more rapidly in the atmosphere, making the problem worse." Some climate scientists believe that the risk of dangerous feedbacks tipping the Earth's climate system beyond a threshold is so great that there should be wider recognition of what they term "abrupt changes". The point is, they say, it has happened repeatedly in the past. It happened 55 million years ago when a trillion tons of methane were suddenly and mysteriously released from frozen stores on the seabed, causing global temperatures to soar 10C, and a mass extinction of species.

It happened 14,500 years ago when ice sheets catastrophically collapsed into the ocean causing sea levels to rise by 20 metres in just 400 years. And it happened 6,500 years ago when the Sahara was suddenly turned from lush vegetation to dry desert.

Scientists say that what is happening now to the planet in terms of carbon dioxide levels and global temperatures is just as abrupt as anything that has occurred in the past. "What we are doing now to the Earth is unprecedented," says Professor Rapley of the British Antarctic Survey, "so we cannot rule out the possibility that we are doing something that will create a strong positive feedback, which will push the Earth into a domain where things will happen that have never happened before."

It is a sobering thought as 2006 draws to a close, and one that must be in the minds of all the IPCC scientists preparing next year's Fourth Assessment Report on climate change.

A VISION OF THE FUTURE

The single most momentous environmental image of 2006 was a holiday snap. Of sorts. It showed typical European package tourists on a nice sandy beach in Tenerife. Until a few minutes before the picture was taken, on August 3 on Tejita beach in Granadilla, it had been a day of utter normality for these tourists. Then something very different erupted on to the scene.

From the sea came a boat. Out of it fell pitiful figures - exhausted, terrified, dehydrated, starving. They were African migrants who, out of desperation, had risked the long voyage from the African coast to the Canaries; for the Canaries are part of Europe, a place of hope and opportunity. What did the tourists do? They did the decent thing. They rushed to the aid of fellow men and women.

But will they offer such a welcome when the boat people are not just a boatload, but a whole country- or region-load? For that is coming. As climate change takes hold this century, agriculture may fail in some of the poorest and most densely populated parts of the world.

Sir Crispin Tickell, Britain's former Ambassador to the UN, who is one of the most far-sighted of environmental commentators, pointed out as long ago as 1990 that global warming is likely to create environmental refugees in the hundreds of millions. We have paid little attention to his warning.

But if you look at the picture taken on Tejita beach, you can see something even more dramatic than the fact that the ordinary European holidaymaker has a lifestyle most Africans can only dream of. You can see the future, starting to happen.