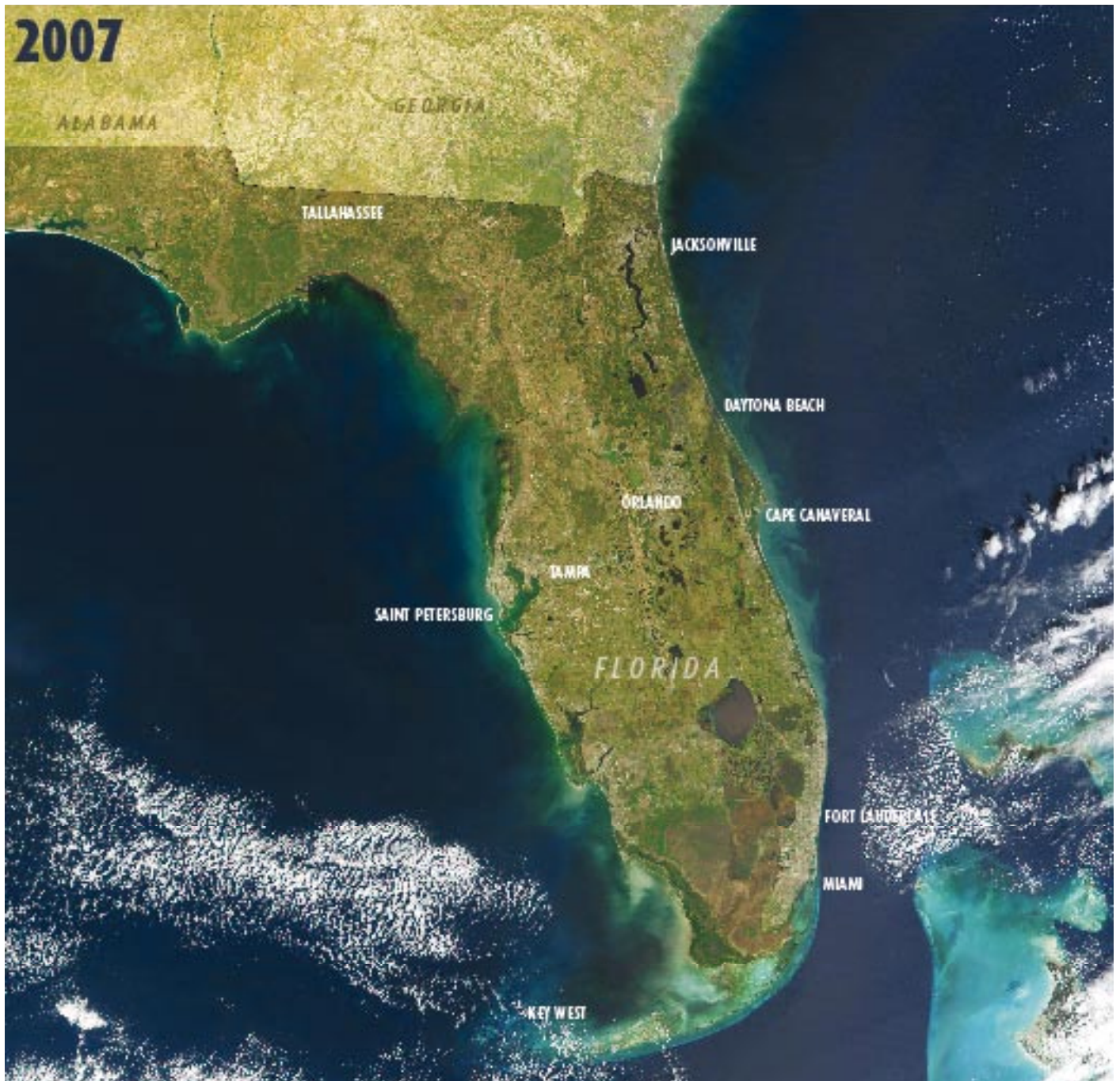


# Climate catastrophe

NASA physicist **James Hansen** explains why he thinks a sea level rise of several metres will be a near certainty if greenhouse gas emissions keep increasing unchecked – and why other scientists are reluctant to speak out



I FIND it almost inconceivable that “business as usual” climate change will not result in a rise in sea level measured in metres within a century. Am I the only scientist who thinks so?

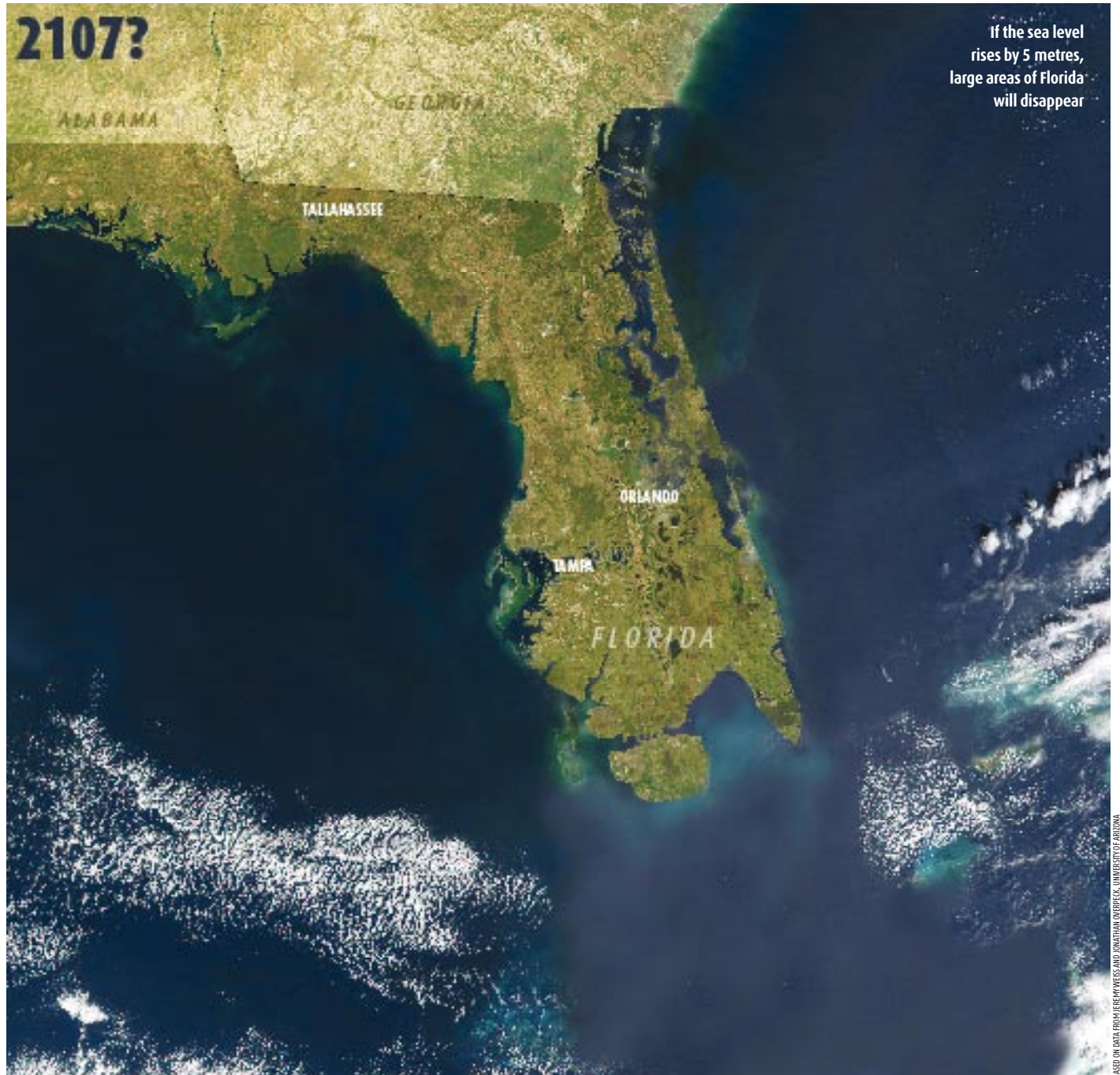
Last year I testified in a case brought by car manufacturers to challenge California’s new laws on vehicle emissions. Under questioning from the lawyer, I conceded that I was not a glaciologist. The lawyer then asked me to identify glaciologists who agreed publicly with my assertion that sea level is likely to rise more than a metre this century if greenhouse gas emissions continue to grow: “Name one!”

I could not, at that moment. I was dismayed, because in conversations and email exchanges with relevant scientists I sensed a deep concern about the stability of ice sheets in the face of “business as usual” global warming scenarios, which assume that emissions of greenhouse gases will continue to increase. Why might scientists be reticent to express concerns about something so important?

I suspect it is because of what I call the “John Mercer effect”. In 1978, when global warming was beginning to get attention from government agencies, Mercer suggested that

global warming could lead to disastrous disintegration of the West Antarctic ice sheet. Although it was not obvious who was right on the science, I noticed that researchers who suggested that his paper was alarmist were regarded as more authoritative.

It seems to me that scientists downplaying the dangers of climate change fare better when it comes to getting funding. Drawing attention to the dangers of global warming may or may not have helped increase funding for the relevant scientific areas, but it surely did not help individuals like Mercer who stuck their heads out. ▶





I can vouch for that from my own experience. After I published a paper in 1981 that described the likely effects of fossil fuel use, the US Department of Energy reversed a decision to fund my group's research, specifically criticising aspects of that paper. I believe there is pressure on scientists to be conservative. Caveats are essential to science. They are born in scepticism, and scepticism is at the heart of the scientific method and discovery. However, in a case such as ice sheet instability and sea level rise, excessive caution also holds dangers. "Scientific reticence" can hinder communication with the public about the dangers of global warming. We may rue reticence if it means no action is taken until it is too late to prevent future disasters.

So why do I think a sea level rise of metres would be a near certainty if greenhouse gas emissions keep increasing? Because while the growth of great ice sheets takes millennia, the disintegration of ice sheets is a wet process that can proceed rapidly.

Sea level is already rising at a moderate rate. In the past decade, it increased by 3 centimetres, about double the average rate during the preceding century. The rate of sea level rise over the 20th century was itself probably greater than the rate in the prior millennium, and this is due at least in part to human activity. About half of the increase is accounted for by thermal expansion of ocean water as a result of global warming. Melting mountain glaciers worldwide are responsible for several centimetres of the increase.

Greenland and Antarctica are also contributing to the rise in recent years. Gravity measurements by the GRACE satellites have recently shown that the ice sheets of Greenland and West Antarctica are each losing about 150 cubic kilometres of ice per year. Spread over the oceans, this is close to 1 millimetre a year, or 10 centimetres per century.

## Runaway collapse

The current rate of sea level change is not without consequences. However, the primary issue is whether global warming will reach a level such that ice sheets begin to disintegrate in a rapid, non-linear fashion on West Antarctica, Greenland or both. Once well under way, such a collapse might be impossible to stop, because there are multiple positive feedbacks. In that event, a sea level rise of several metres at least would be expected.

As an example, let us say that ice sheet melting adds 1 centimetre to sea level for the decade 2005 to 2015, and that this doubles each decade until the West Antarctic ice sheet is largely depleted. This would yield a rise in sea level of more than 5 metres by 2095.

Of course, I cannot prove that my choice of a 10-year doubling time is accurate but I'd bet \$1000 to a doughnut that it provides a far better estimate of the ice sheet's contribution to sea level rise than a linear response. In my opinion, if the world warms by 2 °C to 3 °C, such massive sea level rise is inevitable, and a substantial fraction of the rise would occur within a century. Business-as-usual global warming would almost surely send the planet beyond a tipping point, guaranteeing a disastrous degree of sea level rise.

Although some ice sheet experts believe that the ice sheets are more stable,

I believe that their view is partly based on the faulty assumption that the Earth has been as much as 2 °C warmer in previous interglacial periods, when the sea level was at most a few metres higher than at present. There is strong evidence that the Earth now is within 1 °C of its highest temperature in the past million years. Oxygen isotopes in the deep-ocean fossil plankton known as foraminifera reveal that the Earth was last 2 °C to 3 °C warmer around 3 million years ago, with carbon dioxide levels of perhaps 350 to 450 parts per million. It was a dramatically different planet then, with no Arctic sea ice in the warm seasons and sea level about 25 metres higher, give or take 10 metres.

There is not a sufficiently widespread appreciation of the implications of putting back into the air a large fraction of the carbon stored in the ground over epochs of geologic time. The climate forcing caused by these greenhouse gases would dwarf the climate forcing for any time in the past several hundred thousand years – the period for which accurate records of atmospheric composition are available from ice cores.

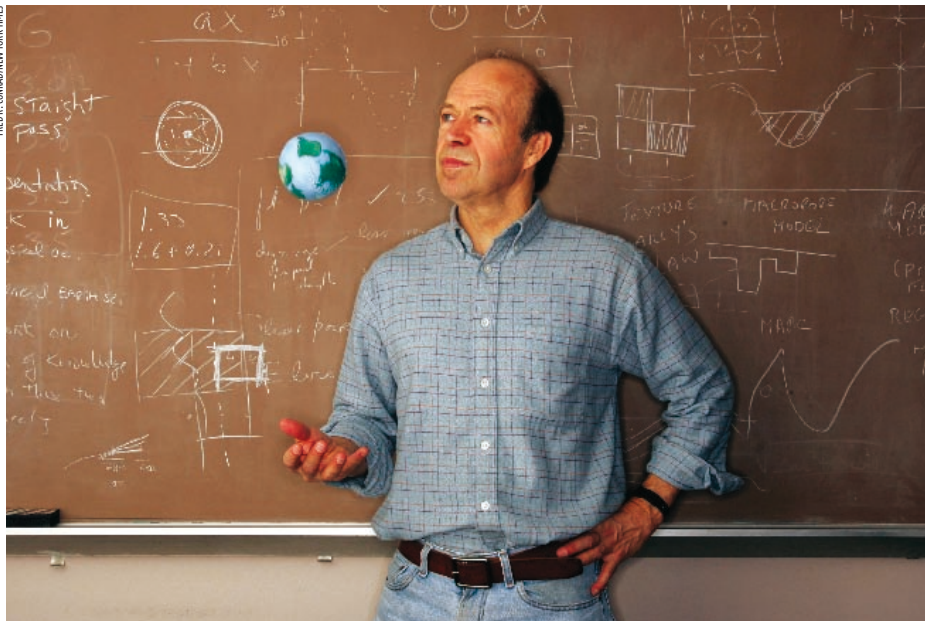
Models based on the business-as-usual scenarios of the Intergovernmental Panel on Climate Change (IPCC) predict a global warming of at least 3 °C by the end of this century. What many people do not realise is that these models generally include only fast feedback processes: changes in sea ice, clouds, water vapour and aerosols. Actual global warming would be greater as slow feedbacks come into play: increased vegetation at high latitudes, ice sheet shrinkage and further greenhouse gas emissions from the land and sea in response to global warming.

The IPCC's latest projection for sea level rise this century is 18 to 59 centimetres. Though it explicitly notes that it was unable to include possible dynamical responses of the ice sheets in its calculations, the provision of such specific numbers encourages a predictable public belief that the projected sea level change is moderate, and indeed smaller than in the previous IPCC report. There have been numerous media reports of "reduced" predictions of sea level rise, and commentators have denigrated suggestions that business-as-usual emissions may cause a sea level rise measured in metres. However, if these IPCC numbers are taken as predictions of actual sea level rise, as they have been by the public, they imply that the ice sheets can miraculously survive a business-as-usual climate forcing assault for a millennium or longer.

There are glaciologists who anticipate such long response times, because their ice sheet models have been designed to match past climate changes. However, work by my group shows that the typical 6000-year timescale



**“Business-as-usual global warming will almost surely send the planet beyond a tipping point, guaranteeing a disastrous degree of sea level rise”**



James Hansen heads NASA's Goddard Institute for Space Studies in New York. A physicist and astronomer by training, he began his career studying the clouds on Venus. Since the late 1970s he has been studying and modelling the human impact on Earth's climate, and has published more than 100 papers. He entered the public spotlight in the 1980s with his outspoken testimony to congressional committees on climate change. Last year he made headlines when he spoke out against attempts by the US administration to gag climate scientists.

for ice sheet disintegration in the past reflects the gradual changes in Earth's orbit that drove climate changes at the time, rather than any inherent limit for how long it takes ice sheets to disintegrate.

Indeed, the palaeoclimate record contains numerous examples of ice sheets yielding sea level rises of several metres per century when forcings were smaller than that of the business-as-usual scenario. For example, about 14,000 years ago, sea level rose approximately 20 metres in 400 years, or about 1 metre every 20 years.

There is growing evidence that the global warming already under way could bring a comparably rapid rise in sea level. The process begins with human-made greenhouse gases, which cause the atmosphere to be more opaque to infrared radiation, thus decreasing radiation of heat to space. As a result, the Earth is gaining more heat than it is losing: currently 0.5 to 1 watts per square metre. This planetary energy imbalance is sufficient to melt ice corresponding to 1 metre of sea level rise per decade, if the extra energy were used entirely for that purpose – and the energy imbalance could double if emissions keep growing.

So where is the extra energy going? A small part of it is warming the atmosphere and thus contributing to one key feedback on the ice sheets: the "albedo flip" that occurs when snow and ice begin to melt. Snow-covered ice reflects back to space most of the sunlight striking it, but as warming air causes melting on the surface, the darker ice absorbs much more solar energy. This increases the planetary energy imbalance and can lead to more melting. Most of the resulting meltwater burrows through the ice sheet, lubricating its base and speeding up

the discharge of icebergs to the ocean.

The area with summer melt on Greenland has increased from around 450,000 square kilometres when satellite observations began in 1979 to more than 600,000 square kilometres in 2002. Seismometers around the world have detected an increasing number of earthquakes on Greenland near the outlets of major ice streams. The earthquakes are an indication that large pieces of the ice sheet lurch forward and then grind to a halt because of friction with the ground. The number of these "ice quakes" doubled between 1993 and the late 1990s, and it has since doubled again. It is not yet clear whether the quake number is proportional to ice loss, but the rapid increase is cause for concern about the long-term stability of the ice sheet.

Additional global warming of 2 °C to 3 °C is expected to cause local warming of about 5 °C over Greenland. This would spread summer melt over practically the entire ice sheet and considerably lengthen the melt season. In my opinion it is inconceivable that the ice sheet

could withstand such increased meltwater for long before starting to disintegrate rapidly, but it is very difficult to predict when such a period of large, rapid change would begin.

Summer melt on West Antarctica has received less attention than on Greenland, but it is more important. The West Antarctic ice sheet, which rests on bedrock far below sea level, is more vulnerable as it is being attacked from below by warming ocean water, as well as from above by a warming atmosphere. Satellite observations reveal increasing areas of summer melt on the West Antarctic ice sheet, and also a longer melt season.

## Warmer oceans

The warming atmosphere and increased absorption of sunlight are not the only factors that will increase surface melt. If there is a significant loss of ice, the surfaces of the ice sheets will be at lower altitudes, where the air is warmer, causing additional melt: another positive feedback.

Most of the excess energy due to the planetary imbalance is going into the ocean rather than the atmosphere, because it takes about 1000 times as much energy to heat the oceans by 1 °C as it does to heat the atmosphere as much. The acceleration of ice sheet disintegration depends on how much of the extra ocean heat is transferred to the ice. ▶

## If sea level rises by 5 metres...

**Viewed from space, Earth will not look that different: there will be surprisingly little loss of land. The trouble is, there are an awful lot of people on the land that will go.**

**While a mere 2 per cent of the world's land is less than 10 metres above the mid-tide sea level, it is home to 10 per cent of the world's population – 630 million and counting – and much valuable property and vital infrastructure.**

**Without mega-engineering projects to protect them, a 5-metre rise would inundate large parts of many cities – including New York, London, Sydney, Vancouver, Mumbai and Tokyo – and leave surrounding areas vulnerable to storm surges. In Florida, Louisiana, the Netherlands, Bangladesh and elsewhere, whole regions and cities may vanish. China's economic powerhouse, Shanghai, has an**

**average elevation of just 4 metres.**

**The Stern report prepared for the UK government last year warned that climate change could bring about economic and social disruption on the scale of the 1930s depression and the world wars, with up to a fifth of global wealth lost. A 5-metre rise in sea level would make the impact far greater. Worst of all, the sea may keep rising. Michael Le Page**





## “While the growth of great ice sheets takes millennia, they can disintegrate rapidly”

This transfer can occur in two main ways: by the speeding up of glaciers resulting in more ice being discharged into the oceans, and by direct transfer of heat from the water underneath and against fringing ice shelves. Since fringing ice shelves float on water, their melting does not raise sea level directly. However, ice shelves hold back the ice sheets resting on land or on the seabed, so as the ice shelves melt or break up, the ice streams draining the ice sheets accelerate, providing another positive feedback effect.

An example was recently seen on the Antarctic Peninsula. The combined effect of surface melt and ice shelf thinning from below led to the sudden collapse of the Larsen B ice shelf, which was followed by the acceleration of glacial tributaries far inland.

Positive feedback from loss of buttressing ice shelves will influence some Greenland ice streams, but the West Antarctic ice sheet will be affected much more. The local warming and melt that preceded the Larsen B collapse was only a fraction of the expected warming in the West Antarctic under business-as-usual scenarios. In fact, observations show the ocean around West Antarctica is already warming, ice shelves are thinning by several metres per year, and glaciers are discharging more icebergs.

There are also some negative feedbacks,

in the short term at least. As the discharge of ice increases, regional cooling by the icebergs will be significant. This cooling can lead to increased sea ice and cloud cover, and thus increased reflection of sunlight. However, cooling of the ocean surface by melting ice also reduces heat radiation from the water surface. This increases the planetary energy imbalance, thus supplying additional energy for ice melt. Models confirm that the cooling effect of melting ice is temporary and that there will be a net increase in ocean heat uptake around West Antarctica and Greenland as greenhouse gases increase.

Another negative feedback is increasing snowfall on ice sheet interiors, because of the higher moisture content of the warming atmosphere. Some models predict that ice sheets will grow overall with global warming, but those models do not include realistic processes of ice sheet disintegration. Palaeoclimate data confirms the common-sense expectation that the net effect is for ice sheets to shrink as the world warms, as the GRACE satellites show is happening already.

The findings in the Antarctic are the most disconcerting. Warming there has been limited in recent decades, in part due to the effects of ozone depletion. The fact that West Antarctica is losing mass at a significant rate suggests that the thinning ice shelves are already beginning to affect ice discharge rates.

So far, warming of the ocean surface around Antarctica has been small compared with the rest of the world, as models predict, but that limited warming is expected to increase. The detection of recent, increasing summer surface melt on West Antarctica

### Greenland's summer melt is growing more extensive and lasting longer

raises the danger that feedbacks among these processes could lead to non-linear growth of ice discharge from Antarctica.

This problem is urgent. The non-linear response could easily run out of control, both because of the positive feedbacks and because of inertias in the system.

Ocean warming and thus melting of ice shelves will continue even if CO<sub>2</sub> levels are stabilised, because the ocean response time is long and the temperature at depth is far from equilibrium for current forcing. Ice sheets also have inertia and are far from equilibrium. There is also inertia in human systems: even if it is decided that changes must be made, it may take decades to replace infrastructure.

The threat of large sea level change is a principal element in my argument that the global community must aim to restrict any further global warming to less than 1 °C above the temperature in 2000. This implies a CO<sub>2</sub> limit of about 450 parts per million or less. Such scenarios require almost immediate changes to get energy and greenhouse gas emissions onto a fundamentally different path.

Is my perspective on this problem really so different than that of other relevant members of the scientific community? Based on interactions with others, I conclude that there is not such a great gap. The apparent differences may arise partly from a natural reluctance to speak out.

Reticence is fine for the IPCC. Individual scientists also can choose to stay within a comfort zone, and not worry that they may say something that proves to be slightly wrong. But perhaps we should consider our legacy from a broader perspective. Do we not know enough to say more? Using the fact that a glacier on Greenland slowed after speeding up as “proof” that reticence is appropriate is little different from the common misconception that a cold weather snap disproves global warming.

The broader picture strongly indicates that ice sheets will respond in a non-linear fashion to global warming – and are already beginning to do so. There is enough information now, in my opinion, to make it a near certainty that business-as-usual scenarios will lead to disastrous multi-metre sea level rise on the century time scale. ●

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