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Climate downgrade: Arctic warming

Not so long ago, the Arctic Ocean was covered by thick ice several years old. Even at the end of summer, more than half of the sea surface was still shrouded in ice.

As the world has warmed in the past decades, the winter refreeze has stopped compensating for the summer melt. Heat-reflecting white ice has given way to heat-absorbing dark water; snow has melted ever earlier on surrounding lands; more heat-trapping moisture has entered the atmosphere; and bigger waves and storms have assailed weakening ice. Thanks to these feedback processes, the Arctic has begun to warm twice as fast as any other region on the planet.

By the late 1990s, the extent of sea ice had fallen to its lowest level for at least 1400 years. At the end of this summer, only a quarter of the Arctic Ocean was still covered in ice, a record low in modern times, and the total volume of ice was just a fifth of what it was three decades ago (see "Record Arctic ice loss"). What's left is a thin layer that melts easily.

It wasn't supposed to happen this quickly. In 2007, when the Intergovernmental Panel on Climate Change (IPCC) issued its most recent report on the state of the planet's climate, the consensus was that the Arctic would not be ice-free in summer until the end of the century. We might have been unlucky: natural variability might have accelerated ice loss by pushing old, thick ice out of the Arctic. But climate models clearly underestimated the pace of change, too. Older models lacked important details, such as the melt ponds on the surface of sea ice that absorb more sunlight. The latest models, which include more processes, still suggest it will be several decades before the first largely ice-free summer occurs. But if current trends are a reliable guide, such summers will happen within a decade.

However long it takes, the continued ice loss will have many knock-on effects. These could include more extreme weather in the northern hemisphere, faster melting of the Greenland ice sheet and greater releases of carbon currently locked away in permafrost.

Other, even nastier surprises might also lie in store. Paul Valdes at the University of Bristol, UK, points out that relatively small changes in Earth's state - orbital changes, shifting ocean currents, and so on - have in the past produced abrupt climate changes. Some 5500 years ago, for instance, the lush savannahs and wetlands of northern Africa turned into the Sahara desert over centuries, or perhaps just decades. Older climate models produce such dramatic change only in response to big disturbances. It is not yet clear if the newer models are any better in this respect. They may be giving us a false sense of security, says Valdes.

Climate downgrade: Extreme weather

In 2010, Russia sizzled as the temperature hit nearly 40 º C in several cities. In 2011, the "Groundhog Day blizzard" dumped astonishing amounts of snow across the eastern US and Canada. This year, too, has been one of extraordinary weather, from summer deluges in the UK to a storm knocking out power to millions in the US during a record-smashing heatwave - and of course, the devastation wrought by superstorm Sandy.

Such events fit a pattern. In a warming world, shifting rainfall and increased evaporation will lead to more droughts. A warmer atmosphere holds more water, making rainfall at times more intense.

It is difficult, though not impossible, to say how individual events are influenced by climate change. It is simpler to tell whether the overall numbers are increasing. Even at the time of the last IPCC report in 2007, the trends for extreme heat, droughts and intense rainfall were already clearly upward.

Not only are these trends continuing, but the weather is also becoming even more extreme than was predicted. For instance, a study this year of ocean-salinity data from between 1950 and 2000 by the Australian Commonwealth Scientific and Industrial Research Organisation (CSIRO) found that the global water cycle - the rate at which water evaporates and falls as rain - has increased at double the pace projected by models that aim to simulate the global climate. Work by researchers from Taiwan and China found that the increase in rainfall intensity over the past three decades has been an entire order of magnitude greater than global climate models predict. As for extraordinary heatwaves such as those in Europe in 2003 (see "Climate downgrade: Heat stress") and 2010, events so far from the norm were only projected to occur towards the end of this century.

Climate scientist Jennifer Francis of Rutgers University thinks warming in the Arctic (see "Climate downgrade: Arctic warming") could be part of the explanation. As temperature differences between the north pole and the tropics fall, the polar jet stream, which pushes weather systems around, is meandering more and slowing down. This means weather patterns are more likely to get "stuck" in place. "Following the record-shattering loss of Arctic sea ice this summer, I would expect the jet stream to dish up a smorgasbord of extreme weather events all around the northern hemisphere," says Francis. Such a blocking pattern caused Sandy's abrupt turn into the US East Coast, perhaps implicating Arctic ice loss.

Studies of past climate suggest future weather could get even wilder. Between 5 million and 3 million years ago, for instance, the world was 2ºC to 4º C warmer than today. According to a study by Kerry Emanuel of the Massachusetts Institute of Technology and his colleagues, published in 2010, rising numbers of hurricanes altered the distribution of heat in the oceans and ultimately flipped Earth's climate into a different state, with warmer tropics and far more hurricanes occurring over a much wider area than today. "I think it plausible that hurricane feedback could influence the way climate changes over the next few hundred years," says Emanuel. "I only wish we understood the problem better."

Climate downgrade: Food production hit

Earlier this year, record harvests were predicted in the US, as farmers planted more to take advantage of rising prices. Instead, yields fell because of drought and record-breaking heat. The UK had a different problem: yields fell because of too much rain. With extreme weather hitting harvests in other areas, too, global food prices are soaring yet again.

That contrasts with the 2007 IPCC report, which predicted that if global temperatures rose 1.5º C or more above pre-industrial levels, greater warmth and higher CO_2 levels would increase yields, at least in temperate regions. Only warming of more than 3.5º C was expected to lead to a big drop in production.

But it seems climate change is already having an adverse effect even though the world has warmed just 0.8º C. Last year a team at Stanford University in California looked at global production of wheat, maize, rice and soybeans - crops that provide three-quarters of humanity's calories - from 1980 to 2008. Based on what we know about how temperature, rainfall and CO_2 levels affect growth, the analysis suggests that average yields are now more than 1 per cent lower than they would have been with no warming. Without the fertilising effect of increased CO_2, they would have been 3 per cent lower. "The negative effects outweighed the positive ones," says lead author David Lobell. The analysis doesn't reflect the full effects of events such as floods, or the recent spate of extreme weather.

Wealthy countries should be able to compensate for these changes to some extent by altering what they grow and how they grow it, and by creating more heat-tolerant crop varieties. Indeed, they will have to: in 2008, the US National Bureau of Economic Research concluded that if the country's farmers kept trying to grow corn, soybeans and cotton in the same areas, yields would fall by three-quarters towards the end of the century.

Keeping up with the pace of change will not be easy, though, and with dry regions projected to get drier, irrigation water could run out in places. There is also no easy way to protect field crops from extreme heat or rainfall. With the weather projected to become more variable in some regions, and perhaps globally (see "Climate downgrade: Extreme weather"), the biggest problem for the world's farmers could be not knowing what to expect.

Climate downgrade: Sea level rise

The Summit weather station in Greenland sits more than 3000 metres up atop the country's vast ice sheet. The temperature there on a typical summer's day is a chilly -10º C. In July this year, however, the temperature rose above freezing. At one point, 97 per cent of the sheet's surface was melting, leading to floods that washed away bridges. This was not a one-off event: bright snow is being replaced by dirty ice that absorbs more heat and melts faster (see Losing its sparkle). Along the coastline, the floating tongues of glaciers are breaking up. As these "dams" disappear, the rivers of ice behind them are accelerating and thinning.

Until recently, we thought it would be centuries before Greenland lost a significant amount of ice. The Antarctic ice sheet was expected to grow, with increased snowfall compensating for melting around the edges. The 2007 IPCC report assumed that the two ice sheets would contribute just 0.3 millimetres a year to sea-level rise for the next century.

Even then, many experts disputed this, and satellite measurements have since shown the two sheets are already losing enough ice to raise sea level by 1.3 millimetres a year and climbing. Recent modelling by researchers from the Potsdam Institute for Climate Impact Research in Germany, as well as studies of past climate, suggest that the planet will soon have warmed enough to melt Greenland's ice sheet entirely - if it hasn't already become warm enough. The question is how long the melting itself will take.

Most glaciologists now think that sea level will rise by at least a metre by 2100, and possibly by as much as 2 metres. That is enough to flood many low-lying cities or render them vulnerable to storm surges. James Hansen of NASA's Goddard Institute for Space Studies in New York is even more pessimistic. He argues that as the ice starts melting, positive feedbacks will kick in, accelerating the ice loss. Satellite observations do indeed show the rate of ice loss doubling every 10 years but, as Hansen himself points out, we cannot yet be certain that this is a long-term trend rather than a short-term blip.

Then there is the possibility of the west Antarctic ice sheet collapsing, as it has on many occasions over the past few million years in response to warming. Recent discoveries about the state of the ice and the nature of the underlying topography suggest that it could be more vulnerable to warm currents in the surrounding seas than previously expected.

Whether that happens or not, we should not be deceived by the small effects we are seeing now, says oceanographer Stefan Rahmstorf of the Potsdam Institute. "Sea-level rise is slow to start, but in the longer run will turn out to be one of the gravest impacts and longest legacies of the global warming we are causing now."

Climate downgrade: Planetary feedbacks

Only half of all the CO_2 we pump into the atmosphere stays there. The rest is absorbed by the land and oceans. But as the world warms, they will be able to take up less. Eventually, they will begin to emit CO_2.

The 2007 IPCC report included projections of increasing carbon feedbacks from seas, soils and changing vegetation, but no model included the possibility that carbon locked away in permafrost and in methane hydrates in the seabed might also be released.

This is thought to have happened during past warming episodes, such as the Paleocene-Eocene Thermal Maximum 55 million years ago.

This year, researchers from the University of Victoria in British Columbia, Canada, made one of the first attempts to account for permafrost emissions and concluded that they will lead to an extra warming of around 0.25º C, and possibly 1º C, by 2100. The study assumed permafrost deeper than 3.5 metres would remain intact, and did not include erosion of coastal permafrost. It also ignored the fact that some carbon will be released in the form of the more potent greenhouse gas methane. In other words, it is likely to be an underestimate.

Surprisingly, if we emit huge amounts of CO_2, such feedbacks actually make less difference: the more CO_2 there is in the atmosphere, the less warming effect adding more has. The really worrying finding is that under certain circumstances carbon feedbacks could lead to a self-perpetuating cycle. Even if all human emissions stopped, CO_2 levels would continue to rise as permafrost melted, leading to further warming and carbon releases.

Simulations by Paul Higgins of the American Meteorological Society point to a similar conclusion. He says recent projections of carbon feedbacks may be overly optimistic about how much plant growth is boosted by increasing CO_2 levels, and how fast plants and trees colonise new areas as conditions become favourable. "Even in the lowest emissions scenario, we could end up with atmospheric CO_2 concentrations consistent with the worst-case emission scenario," says Higgins.

Climate downgrade: Human emissions

If we stopped pumping more CO_2 into the atmosphere now, we'd have a very good chance of avoiding a big hike in temperature. But there is no sign of that happening. Annual emissions fell only slightly after 2008 - the biggest financial crisis since the Great Depression - and are now climbing more rapidly than ever. So far they are near the top of the IPCC's worst-case emissions scenario. "Our emissions are not slowing," says Paul Valdes of the University of Bristol, UK. "That's the most scary aspect of our future."

The only international agreement to limit greenhouse-gas emissions, the Kyoto protocol, excluded developing countries and involved only minor cuts. The US never signed up and Canada has withdrawn. Hopes for a more effective and inclusive agreement have faded.

Meanwhile China, now the world's biggest CO_2 emitter, is investing heavily in renewable energy, but its rapid growth means its emissions will still soar. Some smaller countries have unilaterally promised big cuts, but few are investing to deliver them. On the contrary, most continue to subsidise fossil fuels and to build coal or gas-fired power stations, committing themselves to decades of continued emissions. The move away from nuclear power after the meltdowns at Fukushima has made matters worse: even Germany, which was leading the way on expansion of renewable energy, is now planning to build more coal-fired power plants. "We are going to do virtually nothing," says Kevin Anderson of the Tyndall Centre for Climate Change Research in Manchester, UK. "Every year, it looks worse than previously."

So we are on a path that the 2007 IPCC report concluded would most probably lead to a 4º C rise in temperature by 2100 – way above the 2º C level it was declared we should avoid at all costs. But this worst-case scenario was not simulated with the most advanced models when the 2007 report was being prepared, because of limited time and computing power. That has since been done, and the "best estimates" are now between 5º C and 6º C by 2100, with roughly a 10 per cent chance of a rise of 7º C. This means many of us are likely to live long enough to experience severe global warming. We are on track for 4º C by the 2070s, or the 2060s if carbon feedbacks are high. Far from being alarmist, says Anderson, most scientists have underplayed the significance of the emissions story to make their message politically more acceptable.

Climate downgrade: Heat stress

In August 2003, Europe was hit by an extraordinary heatwave. In parts of France, the temperature hit 40º C for seven days in a row. So many people died that a refrigerated warehouse near Paris was co-opted to store bodies. A study in 2008 concluded that the total death toll was around 70,000. Most of the victims were elderly or ill, but not all.

Heat has more subtle effects, too. The productivity of people who work in non-air-conditioned environments falls roughly 2 per cent for every 1º C rise above their comfort zone. If it gets too hot, people begin to suffer from exhaustion, heatstroke and kidney failure.

Recent studies suggest the effects of climate change on human health and economic output have been underestimated. "I suspect heat stress will prove the single worst aspect of climate change," says Steven Sherwood, an atmospheric scientist at the University of New South Wales in Sydney, Australia.

What matters is not so much the air temperature but the temperature of our skin: sweating cools our skin, but is less effective in humid conditions. The combined effect of heat and humidity can be gauged by the wet-bulb temperature of a "sweating" thermometer - a thermometer wrapped in a damp cloth.

Currently, the maximum wet-bulb temperatures reached anywhere on the planet do not exceed 31º C, but we do not expect that to remain so. "All our models show a strong increase in wet-bulb temperatures, and as a result higher heat stress and health impact," says Erich Fischer at the Institute for Atmospheric and Climate Science in Zurich, Switzerland.

It is very difficult to put precise numbers on the effects, because if we are healthy we don't just sit there sweating when it gets hot. We seek out cool spots, or install air conditioning, and so on. Killer heat in one country is no problem in another where people and infrastructure are adapted to it.

But there is an absolute limit. We cannot survive wet-bulb temperatures of 35º C or more for long, even standing naked in front of a fan. And a 2010 study by Sherwood and his colleague Matthew Huber concluded that if the world warms by 7º C, parts of the world will start to exceed this limit occasionally. Eventually, vast swathes of Africa, Australia, China, Brazil, India and the US will become uninhabitable for at least part of the year.

Something similar may have happened before - a mass extinction 250 million years ago is now blamed on temperatures rising too high for most animals to survive. "It looks like if we fully 'develop' all of the world's coal, tar sands, shales and other fossil fuels we run a high risk of ending up in a few generations with a largely unlivable planet," says Sherwood.