The Economist

Global warming

Who pressed the pause button?

The slowdown in rising temperatures over the past 15 years goes from being unexplained to overexplained

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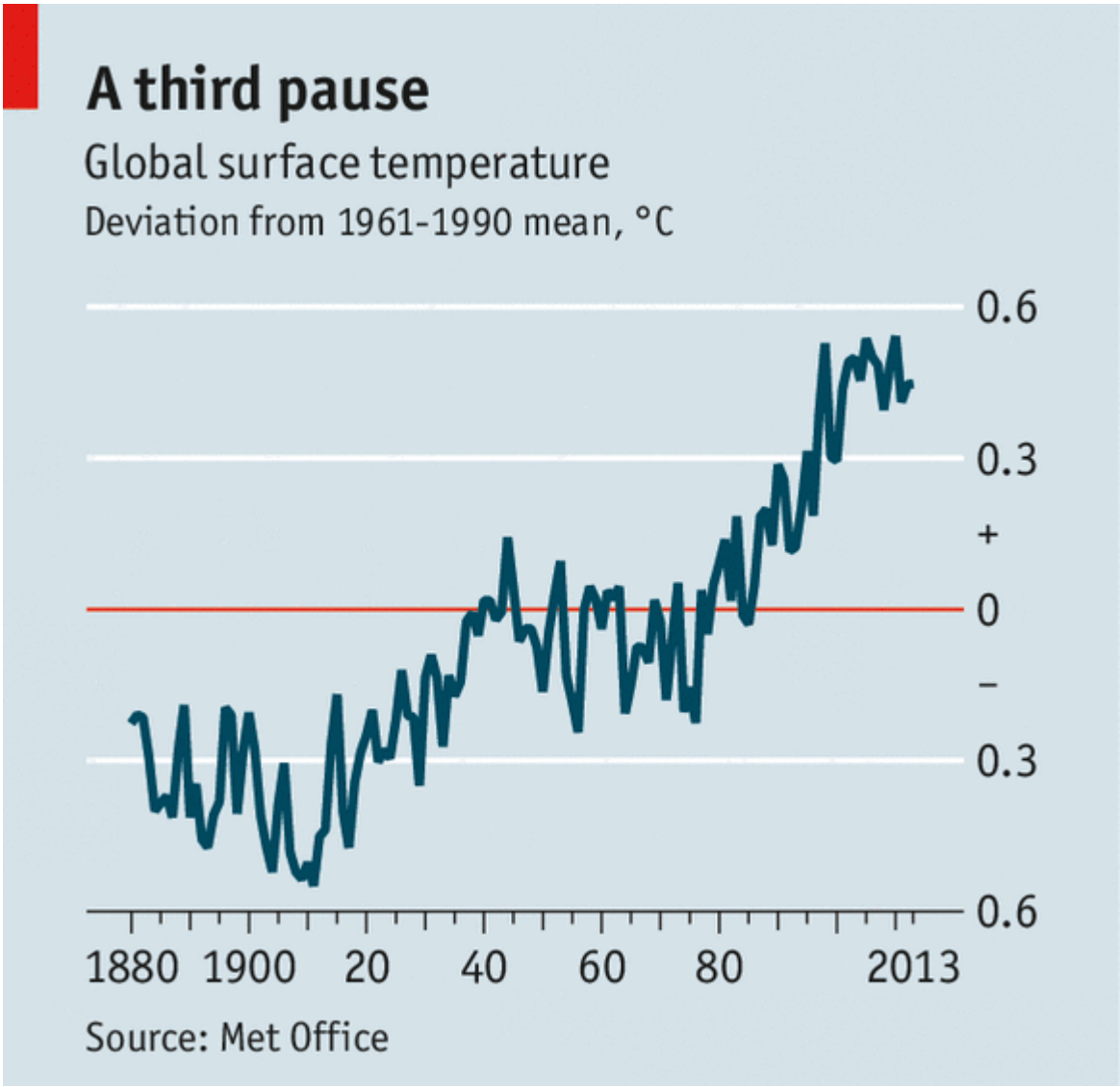
BETWEEN 1998 and 2013, the Earth's surface temperature rose at a rate of 0.04°C a decade, far slower than the 0.18°C increase in the 1990s. Meanwhile, emissions of carbon dioxide (which would be expected to push temperatures up) rose uninterruptedly. This pause in warming has raised doubts in the public mind about climate change. A few sceptics say flatly that global warming has stopped. Others argue that scientists' understanding of the climate is so flawed that their judgments about it cannot be accepted with any confidence. A convincing explanation of the pause therefore matters both to a proper understanding of the climate and to the credibility of climate science—and papers published over the past few weeks do their best to provide one. Indeed, they do almost too good a job. If all were correct, the pause would now be explained twice over.

This is the opposite of what happened at first. As evidence piled up that temperatures were not rising much, some scientists dismissed it as a blip. The temperature, they pointed out, had fallen for much longer periods twice in the past century or so, in 1880-1910 and again in 1945-75 (see chart), even though the general trend was up. Variability is part of the climate system and a 15-year hiatus, they suggested, was not worth getting excited about.

An alternative way of looking at the pause's significance was to say that there had been a slowdown but not a big one. Most records, including one of the best known (kept by Britain's Meteorological Office), do not include measurements from the Arctic, which has been warming faster than anywhere else in the world. Using satellite data to fill in the missing Arctic numbers, Kevin Cowtan of the University of York, in Britain, and Robert Way of the University of Ottawa, in Canada, put the overall rate of global warming at 0.12°C a decade



between 1998 and 2012—not far from the 1990s rate. A study by NASA puts the "Arctic effect" over the same period somewhat lower, at 0.07°C a decade, but that is still not negligible.

It is also worth remembering that average warming is not the only measure of climate change. According to a study just published by Sonia Seneviratne of the Institute for Atmospheric and Climate Science, in Zurich, the number of hot days, the number of extremely hot days and the length of warm periods all increased during the pause (1998-2012). A more stable average temperature hides wider extremes.

Still, attempts to explain away that stable average have not been convincing, partly because of the conflict between flat temperatures and rising CO_2 emissions, and partly because observed temperatures are now falling outside the range climate models predict. The models embody the state of climate knowledge. If they are wrong, the knowledge is probably faulty, too. Hence attempts to explain the pause.

Chilling news

In September 2013 the Intergovernmental Panel on Climate Change did so in terms of fluctuating solar output, atmospheric pollution and volcanoes. All three, it thought, were unusually influential.

The sun's power output fluctuates slightly over a cycle that lasts about 11 years. The current cycle seems to have gone on longer than normal and may have started from a lower base, so for the past decade less heat has been reaching Earth than usual. Pollution throws aerosols (particles such as soot, and suspended droplets of things like sulphuric acid) into the air, where they reflect sunlight back into space. The more there are, the greater their cooling effect—and pollution from Chinese coal-fired power plants, in particular, has been rising. Volcanoes do the same thing, so increased volcanic activity tends to reduce temperatures.

Gavin Schmidt and two colleagues at NASA's Goddard Institute quantify the effects of these trends in *Nature Geoscience*. They argue that climate models underplay the delayed and subdued solar cycle. They think the models do not fully account for the effects of pollution (specifically, nitrate pollution and indirect effects like interactions between aerosols and clouds). And they claim that the impact of volcanic activity since 2000 has been greater than previously thought. Adjusting for all this, they find that the difference between actual temperature readings and computer-generated ones largely disappears. The implication is that the solar cycle and aerosols explain much of the pause.

Blowing hot and cold

There is, however, another type of explanation. Much of the incoming heat is absorbed by oceans, especially the largest, the Pacific. Several new studies link the pause with changes in the Pacific and in the trade winds that influence the circulation of water within it.

Trade winds blow east-west at tropical latitudes. In so doing they push warm surface water towards Asia and draw cooler, deep water to the surface in the central and eastern Pacific, which chills the atmosphere. Water movement at the surface also speeds up a giant churn in the ocean. This pulls some warm water downwards, sequestering heat at greater depth. In a study published in *Nature* in 2013, Yu Kosaka and Shang-Ping Xie of the Scripps Institution of Oceanography, in San Diego, argued that much of the difference between climate models and actual temperatures could be accounted for by cooling in the eastern Pacific.

Every few years, as Dr Kosaka and Dr Xie observe, the trade winds slacken and the warm water in the western Pacific sloshes back to replace the cool surface layer of the central and eastern parts of the ocean. This weather pattern is called El Niño and it warms the whole atmosphere. There was an exceptionally strong Niño in 1997-98, an unusually hot year. The

opposite pattern, with cooler temperatures and stronger trade winds, is called La Niña. The 1997-98 Niño was followed by a series of Niñas, explaining part of the pause.

Switches between El Niño and La Niña are frequent. But there is also a long-term cycle called the Pacific Decadal Oscillation (PDO), which switches from a warm (or positive) phase to a cool (negative) one every 20 or 30 years. The positive phase encourages more frequent, powerful Niños. According to Kevin Trenberth and John Fasullo of America's National Centre for Atmospheric Research, the PDO was positive in 1976-98—a period of rising temperatures—and negative in 1943-76 and since 2000, producing a series of cooling Niñas.

But that is not the end of it. Laid on top of these cyclical patterns is what looks like a one-off increase in the strength of trade winds during the past 20 years. According to a study in *Nature Climate Change*, by Matthew England of the University of New South Wales and others, record trade winds have produced a sort of super-Niña. On average, sea levels have risen by about 3mm a year in the past 30 years. But those in the eastern Pacific have barely budged, whereas those near the Philippines have risen by 20cm since the late 1990s. A wall of warm water, in other words, is being held in place by powerful winds, with cool water rising behind it. According to Dr England, the effect of the trade winds explains most of the temperature pause.

If so, the pause has gone from being not explained to explained twice over—once by aerosols and the solar cycle, and again by ocean winds and currents. These two accounts are not contradictory. The processes at work are understood, but their relative contributions are not.

Nor is the answer to what is, from the human point of view, the biggest question of all, namely what these explanations imply about how long the pause might continue. On the face of it, if some heat is being sucked into the deep ocean, the process could simply carry on: the ocean has a huge capacity to absorb heat as long as the pump sending it to the bottom remains in working order. But that is not all there is to it. Gravity wants the western-Pacific water wall to slosh back; it is held in place only by exceptionally strong trade winds. If those winds slacken, temperatures will start to rise again.

The solar cycle is already turning. And aerosol cooling is likely to be reined in by China's anti-pollution laws. Most of the circumstances that have put the planet's temperature rise on "pause" look temporary. Like the Terminator, global warming will be back.

From the print edition: Science and technology