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The *World* Is Warming

Consider the facts.

BY STEFAN RAHMSTORF

This April was the hottest April on record, globally, for at least 130 years, according to the worldwide temperature records maintained by NASA and the U.S. National Oceanic and Atmospheric Administration. The past twelve months was the hottest twelve-month period since measurements began.

That is what the data from weather stations and ships show. But if you prefer satellite data, the picture is similar. Satellite data have this March as the hottest March on record, with April ranking second-hottest; the surface data have it the other way round, with March the second-hottest and April the hottest.

Of course, more important, scientifically, are the long-term trends. For the past thirty years—that's how long the satellite measurements have been taken—the trend is clearly upward and similar in magnitude in all the available data sets.

Should you still have doubts that the planet is heating up, look at the shrinking mountain glaciers around the world, or the declining sea-ice cover on the Arctic Ocean, which in recent summers has been little more than half its size in the 1970s.

What is causing this climatic warming? Physics tells us that if you want to know why something is getting warmer, seek the source of the heat. (That's a consequence of the first law of thermodynamics: energy is always conserved.) We thus have to look at the heat balance of our planet to understand the reason for the warming.

That is surprisingly simple: there is only one source of heat coming in, and that is radiation from the sun (which is largely visible light, or what physicists call short-wave radiation). And there is only one form of heat leaving the planet, and that is radiative heat (which is invisible, or what physicists call long-wave radiation). They are essentially the same physical phenomenon; the difference in wavelength comes only from the sun being much hotter than Earth.

So, could changes in solar radiation explain the warming of the planet? Measurements of incoming solar radiation show that it has not increased in the past fifty years—in fact, the record even shows a small decrease. But the record's predominant feature is the recurrence of solar radiation cycles lasting about eleven years (called Schwabe cycles, after the astronomer who discovered them in 1843).

In the past few years, we've been in the deepest and longest minimum of a Schwabe cycle since satellite measurements began. That's right: while global tem-

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Whitechuck Glacier in Glacier Peak Wilderness in 1973 [left] and 2006 [right].

peratures are at a record high, the sun has been at its dimmest in decades. Changes in solar activity clearly cannot explain global warming.

But that leaves another factor affecting incoming solar radiation. How much gets reflected back into space by ice, snow, clouds, desert sand, and other bright, mirror-like surfaces? Indeed, a part of the observed warming is due to less reflection, as snow and ice cover has shrunk. This allows more solar heat to be taken up in the climate system, which is one reason why the Arctic has warmed at a faster rate than other parts of the world.

But shrinking snow and ice cover is itself a result of warming, so reduced reflection of solar rays is not the primary cause of warming. Rather, it is a feedback that amplifies warming.

Humans have altered the brightness of the Earth—as seen from space—in more direct ways. But converting forest to farmland (which is brighter than forest) and adding smog particles to the atmosphere (which reflect sunlight) have increased the reflection of solar radiation, thus tending to offset some of the global warming that would otherwise have occurred.

So we are left with the second part of the planetary heat budget: radiative heat escaping to space. That can be changed by adding heat-trapping gases to the atmosphere—the so-called greenhouse gases, which absorb long-wave radiation on its way out and send some of it back towards the surface.

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The importance of this "greenhouse effect" has been known in science since the nineteenth century, when Joseph Fourier coined the term. Perhaps nobody has described it more succinctly than the British physicist John Tyndall, who was the first to measure the effect in his laboratory in 1859 for a number of gases, including carbon dioxide. He wrote: "The atmosphere admits of the entrance of solar heat, but checks its exit; and the result is a tendency to accumulate heat at the surface of the planet."

We know from measurements that greenhouse gases are accumulating in Earth's atmosphere. Carbon dioxide levels are one-third higher now than at any time in the past million years, owing to our industrial emissions. We can calculate how much this has changed the Earth's heat balance. Voilà: just the amount to explain the observed warming. That is one of several reasons why hardly any serious climate scientist doubts that greenhouse gases are the cause of global warming.

In fact, this warming was predicted before it was observed. The rise in carbon dioxide levels has been known since 1960. In 1975 the American climatologist Wallace Broecker published a paper in the journal *Science*, entitled "Are We on the Brink of a Pronounced Global Warming?" There, he correctly predicted "that the present cooling trend will, within a decade or so, give way to a pronounced warming induced by carbon dioxide," and that "by early in the next century [carbon dioxide] will have driven the mean planetary temperature beyond the limits experienced during the last 1,000 years." He predicted an overall twentieth-century global warming of 0.8 ºC. He was right on all counts.

Many are lining up to oppose the science of global warming. But the laws of physics don't surrender to opposition: for the past thirty-five years, global warming has unfolded as predicted by science. It will most likely continue to do so until we stop it by cutting carbon dioxide emissions. ◆