A New Dawn for Sun-Climate Links?

The long-dismissed idea that the sun could be a major driver of climate change is gaining new adherents as researchers detect the pulse of the sun in the ocean, on land, and in glacial ice

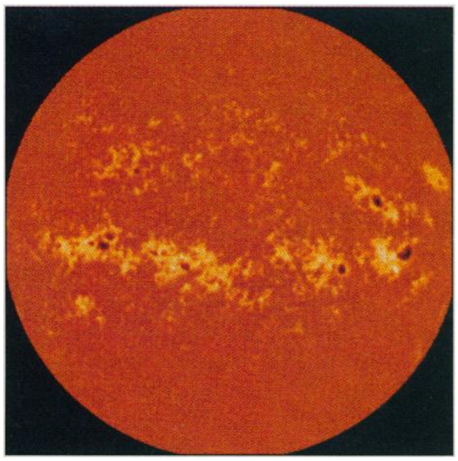
For decades, claims that the waxing and waning of the sun might drive climate change have drawn little but snubs from most climate researchers. The idea was seductive, but it always fell apart on closer scrutiny. Until the early 1980s, after all, there was no sign that the sun was anything but rock-steady. Even when satellite measurements showed that it does dim and brighten over the 11-year sunspot cycle, those variations—about 0.1%—seemed far too small to drive temperature change on Earth. But a brace of new findings is enticing many climate researchers to look again at the sun-climate connection.

"In the past I've been skeptical" of such claims, says climatologist Daniel Cayan of the Scripps Institution of Oceanography. But since Cayan and colleague Warren White stumbled on evidence that the world's oceans have been warming and cooling in time with the sunspot cycle, they have had to reconsider. "I wouldn't want to come off as a zealot," says Cayan. "It's certainly only one part of an explanation of interdecadal climate variability, but if [our finding] is just happenstance, it's terribly fortuitous."

And while most sun-climate links in the past have been isolated, unconfirmed sightings (*Science*, 1 November 1991, p. 652), this time the sun's fingerprints are showing up all over the climate records. The 11- and 22-year sunspot cycles have turned up in other analyses of ocean temperature and in ice cores, and an effort to reconstruct changes in the sun's brightness over the last 400 years has yielded an intriguing match with the global temperature record. The correlation implies that the sun could have been responsible for as much as half of the warming of the past century. If so, the role of greenhouse gases in the warming would dwindle—as would estimates of how much they will warm climate in the future as they continue to build up.

"It's absolutely astonishing," says Lonnie Thompson of Ohio State University about the apparent sun-climate connection he has seen in an ice-core record. But he notes that these connections only underscore the question that has plagued sun-climate claims from the beginning: "Why are they so strong" when the sun's variations are so subtle? To skeptics—and there are still plenty of them—the need for some unknown amplifying mechanism limits the sun to a minor role in past and future climate. Even that may change, however: White and Cayan, for example, see signs that the tropical ocean and atmosphere conspire to amplify small changes in solar radiation into a palpable climate signal.

White and Cayan didn't start out looking for solar signals. But after compiling North Pacific sea surface temperatures of the past 50 years, they noticed some long-period fluctuations that bore a striking resemblance to the satellite record of solar irradiance, which they happened to see in the weekly geophysics newspaper *Eos*.



Sum of the sun. Dark sunspots and bright patches called faculae compete to determine the sun's overall brightness.

The resemblance was suggestive, but the satellite record goes back only 17 years. To explore a possible correlation between the sun and the ocean temperature record, White and Cayan needed a longer solar record. So they contacted aeronomist Judith Lean of the Naval Research Laboratory in Washington, D.C., who with solar physicist Peter Foukal of Cambridge Research and Instrumentation Inc. in Massachusetts had extrapolated solar irradiance back before the satellite records began. Reasoning that the overall brightness of the sun reflects a balance between sun spots, which tend to lower solar output, and bright patches called faculae, which boost it, Lean and Foukal had parlayed records of both features into a 120-year record of the 11-year irradiance cycle.

When White and Cayan compared that record with their 50-year record of ocean temperature, they got a shock. "They just nailed each other," says White. "You could not tell them apart." Expanding their sun-climate comparisons beyond the North Pacific, they found that the tropical and subtropical portions of all three ocean basins were warming and cooling about 0.1°C in time with the 11-year solar variations. And a comparison of surface and subsurface temperatures in all three ocean basins pointed to the sun as the driver: The 11-year cycle gradually faded with increasing depth, disappearing within the ocean's uppermost, sun-warmed layer.

Here comes the sun

White and Cayan aren't the only researchers who have experienced this shock of recognition lately. In ice cores that Thompson and his colleagues recovered from glaciers in the high Andes, five climate-related signals such as the abundance of dust particles wafted in by winds varied with an 11-year cycle. "I was amazed how strongly this signal came out," says Thompson, who usually focuses on long-term climate change of the past 10,000 years. Lean and Foukal's extrapolation of the sun's behavior prompted another newcomer to sun-climate research, Vikram Mehta of the Goddard Space Flight Center in Greenbelt, Maryland, to examine records of global ocean temperatures for solar signals. He too found a sizable 11-year pulse that was in synch with the sun.

Still, even climate researchers who accept some solar influence on climate are skeptical about its size. The cycle White and Cayan are reporting is just too big, these skeptics say. Meteorologists Gerald North and Mark Stevens of Texas A&M University, for example, recently reported detecting both 11- and 22-year surface temperature cycles in 100-year records around the globe, but "the signal is very, very faint," says North. It is only 0.02°C, a fifth of White and Cayan's.

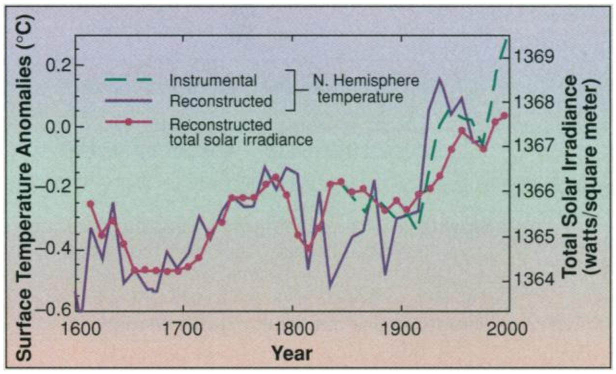
"We may be seeing the same thing they are seeing," says North, "but they are seeing a larger amplitude than I would have expected" based on the present understanding of how climate responds to the sun. The only explanation for an effect that large—one that North says "doesn't seem very likely to me"—is that the ocean and atmosphere are interacting in some way that amplifies the solar signal. An amplified signal would probably elude his signal detection scheme, he notes.

White and Cayan think that's exactly what is happening. They found that the warming and cooling cycle in the tropical ocean is strongest in the easternmost parts of each ocean basin, and that higher latitudes cool instead of warm as the sun brightens. Says White, "These patterns look a heck of a lot like the patterns for El Niño," a periodic interaction of the equatorial ocean and atmosphere that heats the eastern tropical Pacific and alters climate worldwide. That suggests to him that "the same physics that accelerates the El Niño on time scales of 4 to 7 years seems to operate here to intensify the solar signal on the decadal scale."

Another such amplifier may help the sun shape climate over the longer term as well. At least that's an implication of recent comparisons between the sun's inferred behavior over the past 400 years and long-term temperature records. Estimating long-term solar brightness changes is even harder than reconstructing 11-year cycles, as Lean and Foukal did in their study, because the satellite records give no hint of century-scale variations. So Lean and her colleagues Juerg Beer of the Swiss Federal Institute for Environmental Science and Technology and Raymond Bradley of the University of Massachusetts sought clues in the behavior of other, sunlike stars.

Astronomer Sallie L. Baliunas of the Harvard-Smithsonian Center for Astrophysics in Cambridge, Massachusetts, had identified two classes of sunlike stars: those that, based on brightness variations at two near-ultraviolet wavelengths, seem to have sunspot cycles like the present-day sun's, and those that do not (*Science*, 26 November 1993, p. 1372). The noncyclers, Baliunas proposed, resemble the sun 300 years ago, during the so-called Maunder minimum, when sunspots disappeared from the face of the sun for decades and Earth was locked in a prolonged cold period. And because those ultraviolet wavelengths are also a measure of faculae in the present-day sun, Lean and her colleagues were able to estimate the abundance of faculae on noncycling stars. From that figure, they inferred that the sun was 0.25% dimmer in its own quiescent period 300 years ago.

The group then relied on sunspot records to reconstruct the sun's irregular brightening in the following centuries. Comparing the reconstruction with a long Northern Hemisphere temperature record, Lean's group found a strong correlation between the shape of the two records. Between 1610 and 1800, before industrial emissions of greenhouse gases could have affected climate, the records track each other so closely that fully three-quarters of the warming after the Little Ice Age of the late 1600s could have been driven by the brightening sun, according to the group. Later, the sun could have driven about half the 0.55°C warming seen since 1860 but only about one third of the warming since 1970, with the remainder possibly being greenhouse warming. Paleoclimatologist Thomas Crowley and Kwang-Yul Kim of Texas A&M recently compared two long temperature records and two irradiance reconstructions, including the pair used by Lean, and reached similar conclusions.



J. LEAN, J. BEER, A. BRADLEY/GRL

Eerie likeness. Global temperature records closely trace a reconstruction of the sun's brightness over the past 400 years.

Lean notes that her reconstruction of the sun's long-term behavior has plenty of uncertainties. But if the sun did indeed play a large role in recent climate warming, the greenhouse gases that have been pouring into the atmosphere in the same period must have had a smaller influence than most climate modelers have thought. And that would imply that future greenhouse-gas increases may heat the climate less than predicted—perhaps 20% less, Crowley guesses.

Climatologist T.M.L. Wigley of the National Center for Atmospheric Research in Boulder, Colorado, isn't ready to amend the greenhouse models, however. Wigley, who has traced solar influences on climate himself, says Lean's "qualitative conclusions, I think, are right." But he wouldn't give the sun as big a role in the warming of the last century. "I think it's probably somewhere between 10% and 30% of the past warming." For the sun's slight brightening to rival the influence of burgeoning greenhouse gases, Wigley says, Earth's climate would have to have "a big difference in [climate] sensitivity according to the character of the forcing"—something even the most sophisticated computer models don't show.

Others, however, are prepared for the sun to surprise them again. "In this business, observations drive theory," says climate modeler David Rind of the Goddard Institute for Space Studies in New York City. "So if it turns out that somehow the climate system has within itself the capability of amplifying [solar] forcings, maybe the theoreticians and modelers, myself included, will be the last ones to find that out."

–Richard A. Kerr

Additional Reading

T. J. Crowley and K.-Y. Kim, "Comparison of proxy records of climate change and solar forcing," *Geophysical Res. Lett.* **23**, 359 (1996).

PHYSICS

Oil-Drop Trap Is Set for a Lone Quark

Throughout 1995, there was a steady drip in the corner of a graduate student office at the Stanford Linear Accelerator Center (SLAC). No one called the plumbers, however, because physicists hoped the leak would reveal a hole in their current ideas about matter. So far, their theories have remained watertight, but the Stanford University group is still hoping that it might find some gaps when the drip starts up again later this year.

The drip consists of tiny droplets of silicone oil, about 7 micrometers in diameter, falling languidly between two electrically charged plates while a charge-coupled device video camera records their movements. The rate at which each drop falls through the varying electric field indicates the charge it carries. It's the same principle that Robert Millikan applied 85 years ago in his classic measurement of the charge of a single electron. This time, however, investigators led by Martin Perl, co-recipient of the 1995 Nobel Prize in physics, are hoping to find a droplet bearing a still smaller morsel of charge—the amount that a quark, one of the fundamental particles that make up protons and neutrons, would carry on its own.

No free quarks were spotted in the first round of this experiment, which concluded late last year after examining a milligram of silicone oil. The results were not surprising. Indeed, they're precisely what quantum chromodynamics (QCD), the theory of the strong force that binds quarks, predicts: It holds that these particles can only exist in groups, like the trios that form protons and neutrons. But far from being discouraged, Perl and his Stanford colleagues—Nancy Mar, Eric Lee, and Edward Garwin—are now rebuilding the apparatus for a faster and more extensive search.

The effort is a "very long shot," concedes Perl, but the case against free quarks is "mainly a reflection of the experimental data." Conceivably, he says, there are still some lone quarks, born in the early universe, that withstood peer pressure to join a quark triplet or quark-antiquark pair. "A positive finding would overturn 30 years of our thinking about strong interactions," Perl adds. "Present QCD would be like Newtonian mechanics—accurate for just about everything we see, but breaking down in certain cases."

It's worth the trouble to look, agrees Los