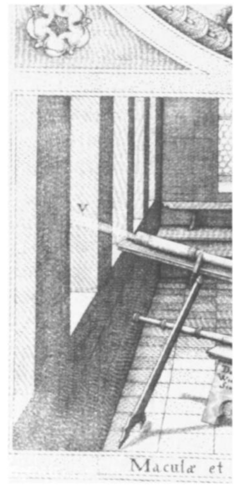
A Star in the Greenhouse



Can the sun dampen the predicted global warming?

By RICHARD MONASTERSKY

After years spent in a frustrating search, renowned astronomer Giovanni Domenico Cassini must have wondered if he would die before seeing a legendary sunspot grace the heavens again. These dark blemishes on the sun's face, so common during the days of Cassini's youth, had virtually disappeared by the time he started observing the sky in the mid-17th century. So rare were sunspots, in fact, that any reported sighting caused a celebration among European astronomers of the day. When Cassini finally spied one in 1671, the editor of the PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY OF LONDON felt obliged to describe the last recorded sighting in 1660, in case some readers had forgotten what a sunspot was during the intervening years.

Today, the idea of partying over a sunspot observation seems ridiculous. When the sun reaches its most active state, every 11 years or so, astronomers can count more than 200 in a single year. Even during the quiet part of the solar cycle, a few dark marks will march across the surface of the sun each year.

The dearth of sunspots during Cassini's time is far from just a footnote to history, for it ties into the hot '90s issue of climate change here on Earth. If the cycle of sunspots could change so dramatically since the 17th century, solar scientists wonder, could the sun's overall brightness wax or wane enough to alter Earth's climate?

Some skeptics of greenhouse warming push that idea even further, predicting that the sun will weaken significantly in the next century — an effect that would mitigate the predicted global warming caused by greenhouse gas pollution. That idea — voiced in 1989 by the Marshall Institute of Washington, D.C., a science policy organization — reportedly echoed all the way to the White House, where it fit with the President's policy of stressing the uncertainties in the climate change arena.

All these suggestions, however, inhabit the realm of speculation. Because reliable observations of the sun's brightness go back only 14 years, it remains unclear how much the sun can vary over a few decades or longer. Yet new studies are beginning to take a more serious look at whether the sun has the muscle to battle the greenhouse warming.

"The tendency has been to say that the sun doesn't have a role [in climate change] because there is no information. But there is a hint that the sun does have a role. . . . I think it's pretty important to resolve this issue," says Sallie Baliunas, an astrophysicist at the Harvard-Smithsonian Center for Astrophysics in Cambridge, Mass.

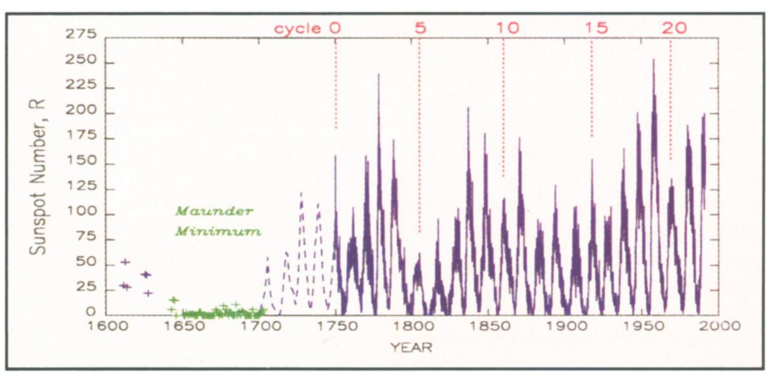
For the better part of 200 years, theories linking solar variations to conditions on Earth's surface have bounced in and out of vogue almost as often as necktie fashions. In the middle of this century, solar physicists shied away from this field of research because it still bore a stigma from the days when Charles Greeley Abbot, director of the Smithsonian Institution's Astrophysical Observatory, maintained he could predict the weather at various sites on Earth on the basis of solar variations.

"When I got into this work in the early 1970s, you could count on one hand the number of solar physicists who were willing to stand up as practitioners of the study of the sun's effect on climate," says Peter V. Foukal of Cambridge (Mass.) Research and Instrumentation, Inc.

But the black cloud over this field started to fade after solar researcher John A. Eddy published a now famous paper in SCIENCE in 1976 documenting the sunspot drought Cassini had witnessed.

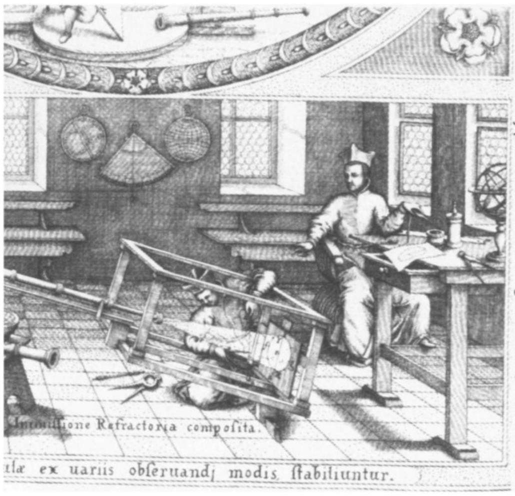
Although astronomers had long remarked on the peculiar lack of sunspot sightings in the late 17th and early 18th centuries, many researchers had written this off as a problem stemming from inadequate telescopes. Eddy presented convincing evidence that the 11-year sunspot cycle did indeed die out between 1645 and 1715 — a time he called the Maunder minimum after a 19th-century astronomer who first drew attention to the strange period. Besides sunspot sightings, Eddy also examined records of auroras, the solar corona, and carbon-14 levels stored in tree rings — all of which indicate that the magnetic activity of the sun decreased substantially during this period.

Because the sun provides the energy that determines Earth's climate, many scientists have wondered whether the solar changes in the Maunder minimum altered conditions here on our own planet. After all, this time corresponds to



Lean

Observations reaching back to the 17th century reveal that sunspots have followed a regular 11-year cycle only for the past 300 years. Very few spots appeared during the Maunder minimum.



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An illustration published in 1630 shows how astronomers of that time observed sunspots by projecting the sun onto a screen.

the coldest part of the so-called Little Ice Age, which lasted from the 16th century to the mid-19th century. With average global temperatures roughly 1°C lower than today's, the decades of the Maunder minimum were among the coldest periods Earth has seen since the end of the last true ice age 11,000 years ago.

A disappearance of sunspots would not in itself exert much effect on the overall warmth of the sun, so it shouldn't have had a major impact on Earth's climate. But the sunspot deficiency could have been symptomatic of some change in the sun's total brightness — the so-called solar constant. Eddy suggested that the frigid conditions could have developed if the sun's total radiation had dimmed by only 1 percent.

At the time of his article, Eddy did not know whether the solar constant could change at all. Although Abbot and other astronomers had tried to measure the sun's overall radiation using instruments on the ground, the measurements lacked sufficient accuracy because Earth's atmosphere obscures the minute changes that researchers seek. Only satellites could provide a definitive answer.

Two years after Eddy's paper came out, the United States launched the Nimbus 7 satellite, which carried a radiometer that could measure the sun's brightness from high above the interfering effects of Earth's atmosphere. Two years later, a second satellite, called the Solar Maximum Mission, went up carrying a radiometer specifically designed to measure total solar irradiance.

The satellite data clearly showed the term "solar constant" to be a misnomer: Over a period of a few weeks, the sun's total brightness varied by as much as 0.2 percent. Yet it took several years before scientists could detect any long-term waxing and waning of the constant. Watching from the peak of the solar cycle in 1980 to the minimum in 1986, researchers saw the sun's average brightness drop by 0.1 percent.

According to climate theory, such flickerings are too puny to cause a major warming or cooling on Earth. At most, solar variations of that order could change the planet's average temperature by about 0.2°C, says David Rind, a climate modeler at NASA's Goddard Institute for Space Studies in New York City. To explain the 1°C cooling of the Little Ice Age relative to today, the sun would have to dim by five times the amount seen during the 1980s.

To an astronomer like Baliunas, that type of cooling is not out of the question. She and Robert Jastrow of Dartmouth College in Hanover, N.H., have addressed the solar variability issue indirectly, by looking at the behavior of other stars that belong to the same class as the sun. Observations of 13 well-studied solar siblings reveal that the stars split into two distinct groups: the cyclers and the noncyclers. In about two-thirds of the sun-like stars, magnetic activity waxes and wanes over a 7- to 15-year cycle very similar to the sunspot cycle of our own sun. The rest of the stars appear to lack any cycle of magnetic activity.

Baliunas and Jastrow proposed in the Dec. 6, 1990 NATURE that an individual star could go through both phases, sometimes cycling and other times not. At present, the sun ranks among the most active of the cycling stars, but Baliunas and Jastrow suggest that in the past it may have spent time as a noncycling star with little magnetic activity. According to the researchers, this scenario might explain what happened during the Maunder minimum and other periods of minimum magnetic activity recorded in tree rings and ice cores.

If so, the cycles of more distant stars might provide a sense of how much the sun could vary over the long term. "We've seen changes of up to 0.6 percent [in visible light] over one cycle," Baliunas says. "One of the ways to understand those results is to imagine that there is some longer-term change on the sun that isn't uncovered by looking at only one cycle. The other stars can be viewed as random snapshots of some longer-term activity and, in time, the sun will also do what these stars are doing."

Judging from these other stars, Baliunas thinks the sun could brighten or dim by 0.6 percent over a period of several decades to a century. If so, the solar changes could give Earth's climate a considerable push.

In the minds of some scientists, there are hints that the sun has nudged the climate during the past century. Just as the global average temperature has risen about 0.5°C over this period, the number of sunspots has increased with each cycle. Researchers have long noted this relationship and wondered whether to consider it cause and effect or just coincidence.

Last year, two Danish researchers pushed the connection one step further when they compared the length of each sunspot cycle with the average temperature of the northern hemisphere (SN: 12/7/91, p. 380). The two curves look astoundingly alike, prompting the researchers to suggest that the global warming over the last century resulted mostly from solar variations rather than from the buildup of greenhouse gases.

While that correlation has intrigued researchers, few give it much weight because there is no evidence that solar output did indeed change dramatically over this period. "That's just another one of those mathematical correlations with no physics behind it," says James Hansen of NASA's Goddard Institute for Space Studies.

To show how farfetched correlations could be, Eddy once noted that the period of the Maunder minimum coincided almost exactly with the reign of the Sun King, Louis XIV, who ruled France between 1643 and 1715. Should one conclude from that correlation that the solar variations produced *le Roi Soleil?*

From their comparison of the sun with other stars, Baliunas and Jastrow suggest that the sun could dim enough to explain the unusually cold conditions during the peak of the Little Ice Age. Yet not all stars were created equal, and this leads many scientists to question whether the sun behaves just like these other stellar bodies.

To address the sun's potential for change, solar physicist Judith Lean of the Naval Research Laboratory in Washington, D.C., and her colleagues have looked directly at the subject in question. Like Baliunas and Jastrow, Lean's group took an approach that revolves around observations of the sun's calcium emissions, which relate to the vigor of the magnetic activity on the sun's surface.

This magnetic energy creates many of the patterns that appear on the sun. During times when magnetic disturbances grow stronger, at the peak of the solar cycle, dark sunspots and bright regions called faculae show up on the sun's surface. In the background, there is an ever-present pattern of bright lines, called the network, that also stems from magnetic activity.

When sunspots and faculae all but disappeared during the low part of the last solar cycle, total solar radiation dropped by only 0.1 percent. So Lean and her colleagues decided to explore even more dramatic solar changes. How much

Continued on p.285

Continued from p.283

further would the sun's output dim if the network, as well as sunspots and faculae, vanished?

To test this idea, the researchers used calcium emissions as a poor man's index of the sun's total brightness. Because past studies have examined variations in calcium emissions from different parts of the sun, the researchers could calculate how the emissions would dim if they hypothetically removed all the magnetic activity, including the network. In this case, calcium emissions dropped, but not enough to make the sun look like one of the noncycling stars.

If Baliunas and Jastrow are correct and the sun really did enter a noncycling mode during the Maunder minimum, then something else must have happened in the sun aside from losing the network. To get the calcium emissions down into the range of emissions from the noncycling stars, Lean and her co-workers determined that the sun's total face would have to dim substantially – enough to match the darkest one-ninth of the current solar disk. If this were to happen, total solar output would drop about 0.24 percent below its current levels, they report in the Aug. 3 GEOPHYSICAL RESEARCH LETTERS.

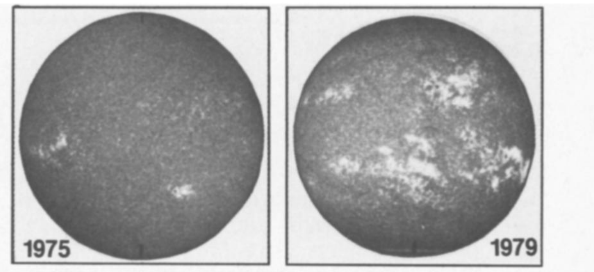
That may be enough to account for the cooling during the Little Ice Age. Calculations suggest that a dimming of 0.25 percent would chill Earth's climate by about 0.2°C to 0.6°C – roughly the amount that scientists think the temperature dropped relative to conditions before the Little Ice Age.

But today's temperatures rest about a full degree higher than those of the Little Ice Age. So despite the correlation found by the Danish workers, the work by Lean and her colleagues suggests the sun could not, on its own, explain all the warming from the Little Ice Age to the present. This finding supports the theory that rising concentrations of greenhouse gases caused much of the climate warming since the late 19th century.

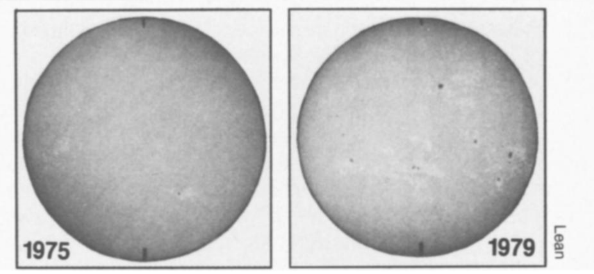
Lean's results concerning potential solar behavior also have implications for how the sun may fit in with future global warming. If the sun were to dim by 0.25 percent, it would certainly exert a cooling effect on the climate, but that effect would be a modest one. "Given our contemporary understanding, the sun is not going to ever vary enough to counter the greenhouse warming," says Lean. Energy calculations as well as sensitivity experiments with general circulation models suggest the sun would have to cool by roughly 2 percent to make up for a doubling in carbon dioxide, she says.

Lean and her colleagues readily admit that their work is speculative. "Statistically, it's very difficult because there's not much information. We put it out as a speculation, as a technique that we could apply to make some estimate of what's going on," says one of Lean's coauthors, Oran White of the National Center for Atmospheric Research in Boulder, Colo.

But despite the uncertainties in their approach, Lean thinks it offers a more informed picture than less rigorous efforts. As an example of these, she mentions the 1989 Marshall Institute report, which suggested that the sun's output could change by 0.5 percent. The report also claimed that solar activity should decrease in the 21st century and exert a major cooling force on the climate. Jastrow, who worked with Baliunas on the star comparison study, sits on the board of the Marshall Institute.



Top row: Images of the sun's chromosphere show bright blotches called faculae and a lacy network of bright lines. Few faculae appear in the image from 1975, near the low point in the solar cycle. Many more appear in the image from 1979, near the cycle's maximum. Bottom row: Images from lower down, in the sun's photosphere, show dark sunspots, which are less common in the 1975 image than in the 1979 image.



Lean sees major problems with this analysis. "They were extrapolating in a sort of hand-waving way to say that the sun could counter the greenhouse gases. You can't say that unless you do a proper analysis of the energy output of the sun, which is what prompted us to do this. What we did is put the numbers in, and until you do that, all you can do is hand wave," she says.

Of course, the best way to learn about solar variations would be to watch the sun to see if it dims or brightens. There are currently several instruments in space capable of measuring total solar output; the newest of these went up last year on the Upper Atmosphere Research Satellite. But the next equivalent instrument is not scheduled to fly until early in the next century, and researchers who study the sun worry that the current instruments will fail before a new one is in place.

To be calibrated, a new instrument must go up before the present ones die. Otherwise, no one will know how the sun changed during the time between measurements, says NASA's Hansen.

Solar scientists have long argued that measurements of the sun would be crucial in forecasting climate change – a view that earth scientists have not taken too seriously in the past, says White. But the message has recently started to catch on among a few climate researchers. Hansen, a climate modeler, has played a leading role in this movement and has lobbied NASA to launch a solar monitoring instrument on a small satellite in the next few years, in order to ensure an uninterrupted record.

Shelby Tilford, director of NASA's earth sciences division, says a French-Russian satellite scheduled for launch this year or next will carry an instrument capable of monitoring variations in solar brightness. But it is not clear how well this instrument will work or whether the satellite will last beyond a few years. Because of funding limitations, the United States has no plans for launching any such instrument in the 1990s. According to Tilford, "There is a good possibility that there will be a data gap [in solar measurements]. But that is only one of many data gaps."

Tilford stresses that many issues related to climate change are vying for funding and that most earth scientists believe several of these factors will play a greater role in climate change than will solar variations. He mentions clouds, ocean circulation, vegetation, and water vapor as some of the key areas requiring work.

Hansen, however, thinks the question of solar variations should come near the top of the priority list. "If you could make only one measurement related to long-term climate, I would say that it should measure the thing that drives the system, and that is the sun. So I think it's clear it should have a high priority," he says.

While the sun could not cancel the warming power of rising greenhouse gas concentrations, Hansen says, "you can't disprove that there could be significant variations in the sun that may be an important player in what happens during the next century." □