THE SUNSPOT SYNDROME

The sun is heading toward the peak of its 11-year cycle and stirring up research—and controversy—here on Earth.

BY MARCIA BARTUSIAK

A tower of hot gas erupts from a seething sun in this ultraviolet image made in 1973 by the astronauts on *Skylab*. The shadowy images show the different features of the sun when it's examined at various wavelengths.

PHOTOGRAPH COURTESY NASA

In a narrow room at the Space Environment Laboratory in Boulder, 16 computer monitors are lined up alongside a video display of the sun. This is the forecast room, where solar researchers routinely gather to try to predict what the sun is going to do next, and how that will affect the space environment, for people who need to know—satellite users, for example. Last March 6, in the early morning hours, the sun watchers got an eyeful. First a tremendous group of dark spots appeared along the sun's eastern limb. Then, at around 7:00 A.M., the sunspots erupted.

It was the largest solar flare that anyone had seen in years—a huge burst of high-speed particles and X-rays, equivalent in energy to the explosion of hundreds of millions of hydrogen bombs. The X-rays were detected by satellites orbiting Earth, and that signal was transmitted to the computers at Boulder. Their eyes fixed to the monitors, forecasters watched the signal surge, its intensity increasing a hundred, a thousand, ten thousand times in the space of just a few minutes, until at last the satellite-borne detectors were saturated.

That was the beginning. Over the next ten days the sun threw off eight major flares and a couple of dozen minor ones. A blast on March 10 was particularly potent, and it was pointed almost directly at Earth. Several days later the particles from that flare slammed into Earth's magnetic field, squeezing it, strengthening it, and accelerating hordes of electrons toward the poles. Descending into the upper atmosphere along the magnetic field lines, those electrons collided with molecules of nitrogen and oxygen to create stunning and far-flung auroras—northern and southern lights.

By the early morning of March 13 auroras were dancing over Boulder. They were seen as far south as the Caribbean. "The sky was bluish red in the north, as if the sun were coming up in the wrong place," recalls Joseph Hirman, who had arrived at the lab early that day. The forecasters' phones rang off the hook all day long. Military and commercial satellite users were concerned for the safety of their instruments; geologists in Texas wondered why their geomagnetic surveys were going haywire; television stations were eager to alert their viewers to the nighttime fireworks; and electric companies worried about power failures. The concern was justified: the entire province of Quebec lost power that morning as the geomagnetic storm induced destructive current surges in transformers and transmission lines.

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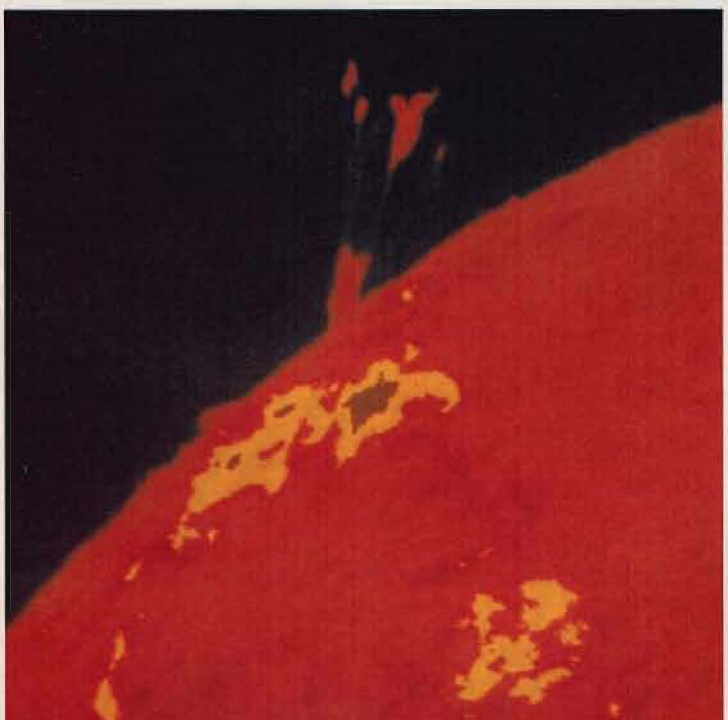
Hirman could not have predicted the scale of the sun's flare-up. But he knew something like it was coming. Solar activity follows a cycle, 11 years long on average, during which the intensity of the solar wind, the number of flares, and particularly the number of sunspots waxes and wanes. The last time the cycle reached a peak, known as the solar maximum, was in 1980. Its most recent minimum was in 1986. The cycle is now rushing toward another peak, which it will probably reach early next year. All indications are that this solar maximum will be one of the highest, if not the highest, since sun watchers started keeping records centuries ago.



An explosive flare in March heralded the coming solar maximum.

PHOTOGRAPH COURTESY U.S. AIR FORCE/NOAA/SELSIS

The flares of March were just the opening salvo. Another intense outburst was observed in August, and there will surely be more to come in the next few months. Researchers in Boulder and elsewhere will be watching for more auroras and more geomagnetic storms, for those are the inevitable and comparatively well-understood effects of a solar maximum.

But they may not be the only ones, and for many researchers they may not be the most exciting ones either. What solar scientists find exhilarating these days is the very real possibility that the effects of sunspots are felt not just in the environment of space but in the much more immediate environment of Earth. It may be that the sun's cyclical fluctuations have a significant influence on Earth's weather.

Two atmospheric scientists, one in West Germany, the other in the United States, have recently proposed that a host of climatic phenomena, from the strength of stratospheric winds over the North Pole to the severity of a winter in Nashville or Nome, fluctuate in step with the 11-year sunspot cycle. Just how that could happen, the researchers cannot say; but, they argue, a statistical analysis of solar and climatic data suggests that it does indeed happen.

The claim is controversial—particularly because it can be seen as merely the latest in a long series of proposed sun-weather connections, none of which has stood the test of time. But this one may be different. The statistics have convinced even some confirmed skeptics. And unlike some of the previous studies, which had found only local effects for the solar cycle—such as changes in the water level of a single African lake—this latest one claims an effect on wind and weather patterns throughout the Northern Hemisphere. That makes it inherently more plausible; if the solar cycle has any effect at all on weather, it is likely to be planet-wide.

In any case, the very possibility of a sun-weather connection has added an extra kick to the countdown to solar maximum. "If a good case could be made for the sun's influence on weather," says Peter Foukal, a solar physicist at Cambridge Research and Instrumentation in Massachusetts, "then that fact alone would be more important than anything else studied in solar-terrestrial physics."

No one doubts, of course, that the sun is ultimately responsible for Earth's weather; the sun supplies the energy. By heating the tropics more than it heats the poles, it sets up the temperature

Sunspots don't raise the water level in Lake Victoria . . .

imbalance that drives not only winds in the atmosphere but also currents in the ocean. Solar heat, however, comes from sunlight, not from sunspots or the solar-particle wind, and the intensity of sunlight changes little over the course of a solar cycle. It has always been hard to imagine how the fluctuating number of spots on the sun could produce fluctuations in Earth's atmosphere. But that has not stopped researchers from trying. "The question is so stimulating," says Foukal, "that people can't be restrained from going out and attempting to see connections."

Speculation about a possible link between the sun and the weather began in earnest in the early nineteenth century, when scientists noticed that solar flares were somehow connected with stunning auroras. And it was greatly strengthened in the 1840s, when Heinrich Schwabe, a German amateur astronomer, determined that the number of sunspots rose and fell in a regular cycle.

Since then we've learned a few other things about the solar cycle—that it isn't entirely regular, for one. By continuing Schwabe's observations and delving into historical records, researchers have charted the sunspot cycle through 21 repetitions, and they've found that its period varies from 9 to 13 years, with an average of 11. They also now know that sunspots are regions where intense magnetic fields, generated deep within the sun, erupt to the solar surface; the intense fields, it is generally thought, inhibit the rise of hot gas from the solar interior, making the spots relatively cool and dark. (But only relative to the rest of the sun: a sunspot is still hotter than a blast furnace and brighter than the moon.) Astronomers have also observed that at the start of a cycle sunspots occur only at high solar latitudes, and that as the cycle advances spots are generated progressively closer to the equator, until, at the cycle's end, they are huddled along it.

Yet despite more than a century of concerted sun watching, no one really understands what causes the cycle. That the sun's various latitudes rotate at different speeds—the equatorial zone completes a circuit in 25 days, while the polar zones take as long as 36 days—is surely important. So is the precise pattern in which hot streams of electrically charged gas move upward to the solar surface, while cooler gas moves inward to refuel the nuclear fire in the core. It is these turbulent currents that induce the sun's magnetic fields. And, somehow, over the course of the 11-year cycle the field lines become tangled and kinked, kinks poke through the surface to form pairs of sunspots, and then the field relaxes again as the cycle starts anew. *Somehow* is a key word here—there is no consensus on how.

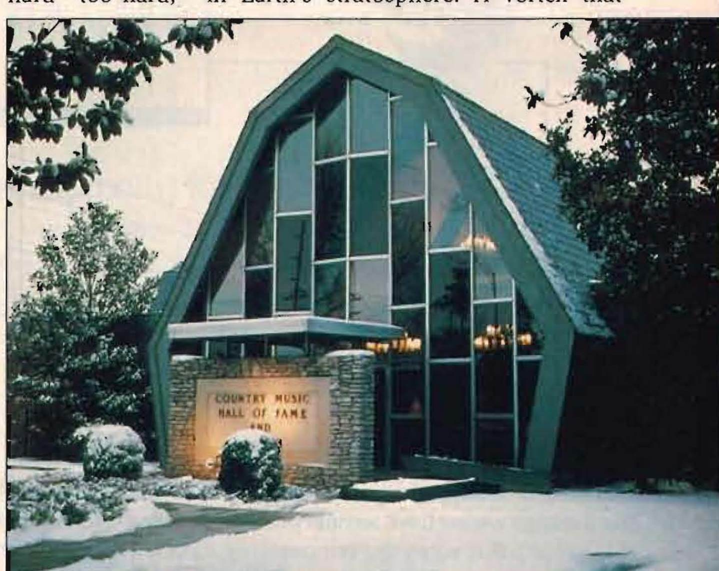
Of course, you don't need to know what causes the solar cycle to look for its effects on Earth. And ever since Schwabe's momentous discovery, researchers have looked hard—too hard, in some cases. Soil temperatures, monsoon patterns, salmon catches, influenza outbreaks, admissions to psychiatric hospitals—all have been linked to the solar cycle at one time or another, and all those links have fallen apart.

"As soon as scientists recognized that the sun followed an eleven-year cycle, it seemed logical to assume they could find a response in Earth's climate," says solar astronomer Jack Eddy. "But they were guided more by hope than by reason." An infamous example involved Africa's Lake Victoria, whose waters seemed to rise and fall in perfect synchrony with sunspot counts between 1900 and 1923; in succeeding years the match vanished, never to recur.

Just a few years ago many researchers were intrigued by a report that the thickness of sedimentary rock layers deposited on a lake bottom in southern Australia some 680 million years ago appeared to vary according to an 11-year cycle. George Williams, the Australian geologist who found the formation, suggested that the solar cycle had governed temperatures in Precambrian Australia. The thickest sediment layers, he said, could have been deposited during warm summers, when glacial meltwater rushed into the lake. But last year, after studying other layered sediments, Williams changed his mind: he now thinks that the lake was more likely part of an ocean, and that the rocky stripes record not the 11-year cycle of solar activity, but the two-week cycle of lunar tides.

So it has gone in the search for sun-weather connections, with refutations following claims as inexorably as troughs follow peaks in the solar cycle itself. But the latest claim, its enthusiasts argue, is different. It involves a discovery that Eddy describes as "the hottest breaking story in the game."

The long route to discovery began in 1980, when University of Washington meteorologists observed an interesting harmony between two separate winds in Earth's stratosphere. A vortex that



. . . but they may bring snow to Nashville.

PHOTOGRAPHS: TOP, BY KAY CHERNUSH/THE IMAGE BANK; BOTTOM, COURTESY TENNESSEE TOURIST DEVELOPMENT swirls 15 miles above the North Pole during winter, they noticed, was especially strong and cold whenever another stratospheric wind, this time over the equator, was blowing from the west. This equatorial wind is known as the quasi-biennial oscillation, because it periodically reverses direction, switching from a westerly to an easterly and back again roughly every 27 months.

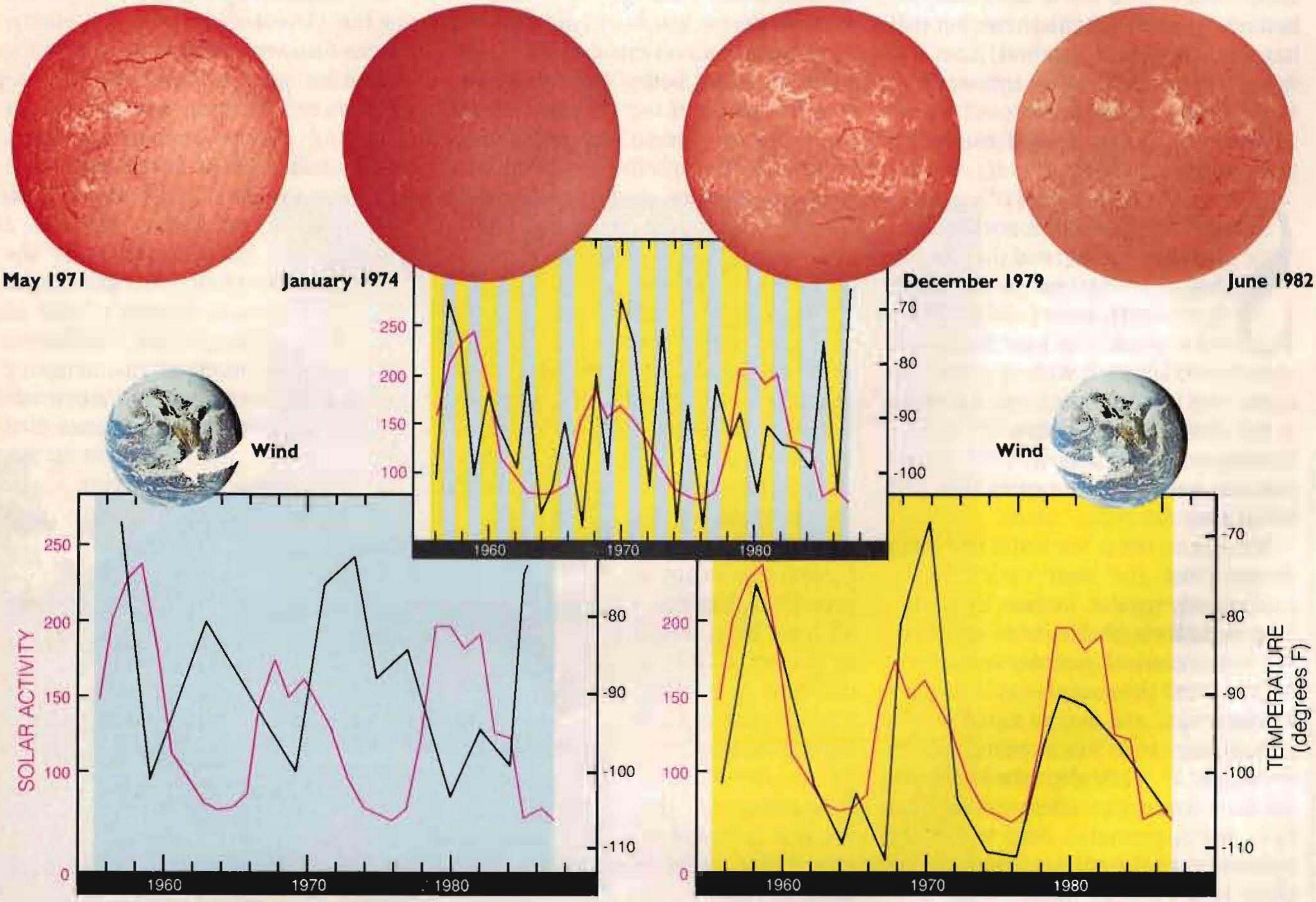
Karin Labitzke, an atmospheric scientist at the Free University of Berlin, was very interested in the Washington group's finding, for the polar vortex has a strong influence on the weather in northern Europe. She had also been encouraged by a former academic adviser to be on the lookout for sun-weather connections. ("I inherited his interest," she says, "but was cautious since the topic is so controversial.") In 1982 Labitzke reported that the polar vortex and the quasi-biennial oscillation were indeed coupled, as the Washington workers had found—but that the coupling somehow fell apart when the number of sunspots was at its maximum. When the equatorial wind was blowing from the west, the winter winds over the North Pole were supposed to be strong and cold; yet at solar maximum, Labitzke noticed, the polar vortex turned weak and allowed warm air to intrude into the Arctic stratosphere.

Left at that, the observation would have been interesting but hardly earthshaking. At solar maximum the polar winds were tamer and the temperatures were warmer, but there was no evidence that they followed the solar cycle as a whole. No evidence, that is, until early 1987, when Labitzke, whiling away some time in a Washington, D.C., hotel room after a conference, happened upon a novel way of plotting temperatures. "The idea suddenly came to me," she recalls, "to group the data." Looking at a set of wintertime temperatures in the polar stratosphere, Labitzke plotted only those temperatures measured when the equatorial oscillation was in its west phase; she left out those years when the wind was blowing from the east.

When she connected the pared-down set of dots, she immediately saw the temperature curve go up and down in near-perfect step with sunspot counts over the past three and a half decades. Temperatures were relatively high, as high as –65 degrees, when the sun was very active; they were lower, by some 40 degrees, when solar activity was low.

Traveling on to Boulder, Labitzke showed the finding to her friend Harry van Loon, a meteorologist at the National Center for Atmospheric Research. Although long a skeptic of such observations, Van Loon was quickly converted. "I had never seen a sun-weather signal that I believed in," he recalls, "but the

PHOTOGRAPHS: SUN, COURTESY NATIONAL GEOPHYSICAL DATA CENTER (4); EARTH, COURTESY NASA. GRAPHS BY KAREN WILLOUGHBY



The level of solar activity, illustrated here by four photographs of the sun, follows an 11-year cycle (red curve). At first glance, the average wintertime temperature in the stratosphere above the North Pole (black curve) doesn't follow the solar cycle at all (top graph). But when the temperature data are separated into two groups (blue and yellow), strong connections emerge. If you look only at years when certain equatorial winds are blowing from the west (bottom right), the polar temperature rises and falls with solar activity. When the winds are easterly (bottom left), the temperature does the opposite of what the sun is doing.

statistics were too strong to ignore." On a scale of zero to one (one being a perfect match), Labitzke and Van Loon figured that the correlation between the solar cycle and polar stratospheric temperatures was .76—extremely high by the standards of sun-weather research. And as it turns out, the quasi-biennial oscillation's east phase is interesting, too. Then the temperature trends reverse to some degree, and solar activity and polar stratospheric temperatures become anticorrelated: temperatures are high when sunspot counts are low, and low when sunspot counts are high.

It's not known why polar temperatures should be linked to solar activity during the phases of the quasi-biennial oscillation; it's not even known why the equatorial wind is coupled to the polar vortex, quite apart from any solar connection. For the moment, the connections are simply statistical.

The intense magnetic field of a sunspot keeps it cool and dark by preventing hot gas from rising to the solar surface. This spot is 9,100 miles across.

Since 1987 Labitzke and Van Loon have broadened their search for correlations, proceeding south from the Arctic and into the lower atmosphere, where much of our weather occurs. They've now looked at atmospheric pressures and surface temperatures over the entire Northern Hemisphere, and Van Loon's office in Boulder is wallpapered with the resulting maps and graphs.

If their findings are correct, the sun-weather connection is more than an esoteric phenomenon of interest only to stratospheric specialists and Arctic balloonists. The lower atmosphere over much of North America, for example, seems to beat to a solar rhythm. Labitzke and Van Loon have found that when the sun is at the peak of a cycle, and the quasi-biennial oscillation is blowing from the west, wintertime air pressures tend to be high in the interior of the United States and Canada. At the same time, winters tend to be colder in the southeastern United States (as evidenced by temperature records from Nashville, Cape Hatteras, and Charleston) and milder in the higher latitudes of Alaska and Canada.

Such correlation over a broad region is important in establishing the validity of any purported effect of solar activity on Earth's weather. It's also important that the observed pattern make some sort of physical sense, of course, and in this case it does. Since winds in a high-pressure system circulate clockwise, an inland high brings cold, northerly winds to the east coast of North America and warm southerly winds to Alaska and western Canada.

Labitzke and Van Loon have found similar connections in Europe and the Soviet Union. And other researchers have followed their lead. For example, Brian Tinsley of the University of Texas has shown that, at least when the quasi-biennial oscillation is in its west phase, the tracks of winter storms over the North Atlantic follow the solar cycle: the tracks move a bit south at solar maximum and a bit north at solar minimum. The latitude shift is as much as 6 degrees, or some 400 miles.

That these weather shifts span an entire hemisphere, and in a physically consistent way, explains in part why interest in them is so high. "It's a far cleaner correlation," says Space Environment Lab director Ernest Hildner, "than any other in solar-terrestrial physics, and one that, if real, could have tremendous consequence for us." If the solar cycle causes the average wintertime temperature at a given location to vary by as much as several degrees, then it makes the difference between a mild winter and a severe one. What's more, it does so in an eminently predictable way. Farmers, for one, would benefit from such knowledge: sun-weather forecasters could advise them when to plant or when not to plant.

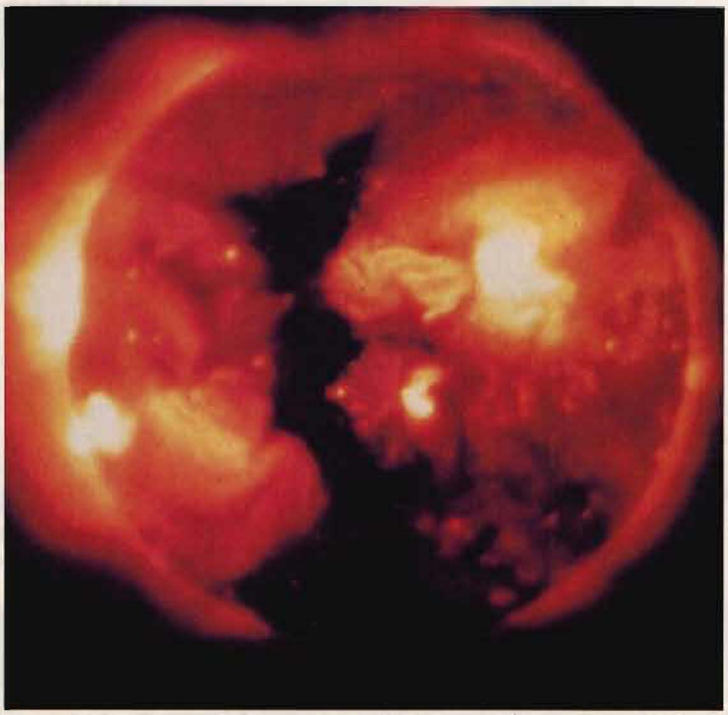
Yet as Van Loon himself is quick to note, there are two reasons to be cautious about thinking that the solar cycle will soon be the key to accurate seasonal forecasts. First, there is Lake Victoria, that infamous example of statistics that lie, which Van Loon's critics never let him forget. His and Labitzke's data go back only to 1952, when the quasi-biennial oscillation was first observed, which means they cover a mere three-and-a-half solar cycles. The data have passed rigorous tests of statistical significance, but it will still take several more solar cycles to convince critics that the apparent sun-weather connection is more than a fluke.

"Lots of terrestrial phenomena experience cycles that are totally unrelated to the sun," says Caltech solar astronomer Ken Libbrecht. The fluctuating number of Republicans in the U.S. Senate is Libbrecht's favorite example: for many years it correlated quite nicely with sunspot counts, though the Republicans lagged four years behind the sunspots.

The second reason for caution is that neither Labitzke and Van Loon nor anyone else can offer a good physical explanation for the sun-weather connection. "We must find a mechanism," says Van Loon. "It will make a hell of a difference." He draws an analogy to the theory of continental drift: although it was an attractive idea, one that explained such things as the jigsaw-puzzle-like fit of South America and Africa, it was

PHOTOGRAPH COURTESY NATIONAL SOLAR OBSERVATORY, SACRAMENTO PEAK virtually ignored until the 1960s, when geologists figured out that heat rising from Earth's interior could cause continents to slide around on the surface.

If the solar cycle influences Earth's weather, says Eddy, it must do so by changing the amount of radiant energy, primarily visible light, that reaches Earth from the sun. That quantity is called the solar constant, because for a long time it was thought to be just that. But observations by satellites during the past decade, particularly by the *Solar Maximum Mission* spacecraft, have proved otherwise. An analysis of the data collected by *Solar Max* since 1980 has shown that the sun's brightness seems to be following the 11-year cycle: it declined from 1980 to 1985, as the number of sunspots was declining, and it is now rising once again, as the cycle heads toward its next maximum.


Sunspots can grow into large dark holes in the solar corona, which is seen here in an X-ray image from *Skylab*.

That pattern is surprising: one would expect the sun to get dimmer, not brighter, as dark sunspots increase. But as the number of sunspots rises, so does the number of solar faculae, which are unusually bright regions that often surround sunspots. During times of high activity the excess radiation from the faculae apparently outweighs the decrease caused by dark sunspots. Similarly, a decline in faculae during a solar minimum diminishes the sun's brightness.

The change is small: during the last minimum the sun dimmed by only a tenth of a percent. Computer models suggest that Earth's climate isn't even budged by such fluctuations (even though the cut in the planet's power supply is equal to the output of 100,000 large power plants). On the other hand, the models are crude, and it would not be surprising if they turned out to be wrong. In fact, as Eddy has pointed out, there is some evidence that small changes in solar output can have dramatic effects on climate.

The evidence comes from a curious historical period known as the Little Ice Age, which was at its coldest from 1645 to 1715. It was a time when the Zuider Zee, the shallow body of water that nearly splits the Netherlands in half, froze completely each winter; a time when Hans Brinker raced for miles over icebound waterways on his silver skates; and a time when Londoners set up winter carnivals on the frozen Thames. It was also a time when sunspots all but vanished from the face of the sun, and auroras were rare. The sun, apparently, was mired in 70 years of quietude—in a protracted solar minimum. No one knows why; perhaps the sun's dynamo was not vigorous enough to "stir the pot" and create sunspots.

Whatever the cause, the Little Ice Age suggests that a small drop in solar activity can change Earth's climate substantially if it persists for decades. Whether the 11-year solar cycle could have a proportionate impact is more doubtful—again, the computer models say no—but researchers won't be able to answer that question until they understand how the various layers of Earth's atmosphere interact. In particular they need to figure out how energy might trickle into the lower atmosphere from the thermosphere—the region of rarefied gases, millions of times less dense than the air we breathe, that lies from 50 to 300 miles above Earth's surface.

The thermosphere is heated by the sun's ultraviolet light, and even under normal conditions the temperature there is in the hundreds of degrees. But around solar maximum, during geomagnetic storms, it jumps into the thousands as solar flares dump their energy into the thermosphere, triggering auroras along with the storms. Even as you read this, the entire thermosphere is expanding, swollen by the heat of the oncoming solar maximum. In the process—irony of ironies—it is engulfing the *Solar Maximum* satellite and dragging it toward an early doom.

Some researchers think the same forces that heat the thermosphere have a better chance of influencing Earth's weather than do tiny fluctuations in the solar constant. Geomagnetic storms, for instance, with their monstrous electrical potentials, might trigger waves of heat or pressure that filter downward through the atmosphere. If so, then the upcoming maximum may offer a chance to find out, especially since it is on a pace to break the record for solar activity set in 1958. More likely, though, the issue of a sun-weather connection will not be settled during this solar cycle; more statistics are needed to determine whether the new correlations hold up, and the sun can't be rushed. But in principle a few more cycles should do the trick.

Unfortunately, researchers may not have that much time. The tremendous injection of carbon dioxide into the atmosphere since the start of the Industrial Revolution is making it more and more difficult to unravel the solar effects on climate from the man-made effects. Greenhouse-related climate changes could well dwarf any effects from solar-output variations. It is surely not the most serious danger posed by the greenhouse effect, but it is a sad plot twist all the same. On the verge of finally tracing a fundamental connection between sun and Earth, we may obscure the answer before it can be found. ❑

Marcia Bartusiak wrote about gravity waves in the August issue.

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