Sun, Weather, and Climate: A Connection?

A field in search of respect is finding that it can produce good science, but final answers remain elusive

"[I]n our view, none of these endeavors, nor the combined weight of all of them, has proved sufficient to establish unequivocal connections between solar variability and meteorological response." Thus a National Research Council (NRC) report* sums up a centuries-long search for a connection between known variations of the sun and the ever-changing weather and climate of Earth. The report warns that if researchers are ever going to demonstrate a convincing connection, if any actually exists, they will have to de-emphasize the blind correlations between sun and weather that are traditional in the field and bolster their efforts to understand how the atmosphere really works.

As the NRC released its report on 2 August, sun-weather researchers were convening the Second International Symposium on Solar-Terrestrial Influences on Weather and Climate† in Boulder to consider how far they had moved toward that goal. The first hurdle for the field is its own notorious history. Attempts to link solar variability to changes in weather or climate without an inkling of the intervening physical processes have been "a search guided as much by hope as by reason . . . a kind of diversion—maybe a necessary one, given the paucity of facts that have been available, but also a costly one in terms of the beleaguered credibility of the field," said keynote speaker John Eddy of the National Center for Atmospheric Research (NCAR). Eddy is chairman of the NRC study panel. The field's credibility has also been impaired by what the NRC report terms "the disturbing frequency with which errors, fallacies, and biases appear in the literature . . ."

A few studies presented at the time of the first sun-weather symposium in 1978 have avoided the pitfalls of overenthusiasm and sloppy statistical analysis, but they have since had to grapple with conflicting observations. In one study, Eddy culled from historical sources evidence of the simultaneous disappearance of sunspots, called the Maunder Minimum, and the severe cold of the Little Ice Age in Europe and North America in the 17th century. The coincidence suggested that the one could be the cause of the other.

At the second symposium in Boulder, Eddy conceded that climatologists have since questioned whether the entire globe experienced a Little Ice Age. Eddy blames the likely incompleteness of historical records outside of Europe and North America for the discrepancy. But that is not the only problem. In 1980, Minze Stuiver of the University of Washington compared ten different records of climate from around the world with the varying carbon-14 content of tree rings over the past 1000 years; carbon-14 is an indirect measure of changing solar activity. Stuiver failed to find a significant correlation between solar activity and any of the climate records. "It looked at the time as if there was a real correlation," he says. "It's no solid fact, but I still have the feeling that it is true."

Another much studied correlation suggests that Earth's passage from a sector of the solar wind having one magnetic polarity to one having the opposite polarity affects the weather. The correlation between sector-boundary crossings and a supposed measure of storminess called the vorticity area index (VAI) has held up under close scrutiny for the originally reported period of 1963 to 1973; however, it seems to hold during the winter only, and efforts to extend the correlation beyond 1973 have failed. Such efforts are doomed to failure, according to John Wilcox of Stanford University. He told the meeting that since he and his colleagues pointed out the correlation in 1974, the National Meteorological Center has introduced additional smoothing of its final data in order to decrease noise. "One person's noise is another person's signal," Wilcox noted. "They've smoothed out any possibility of saying anything about the last few years."

Perhaps the only prominent study to come out ahead since the 1978 meeting is the finding of a correlation between solar activity and drought in the western United States. At the 1978 meeting, Charles Stockton and David Meko of the University of Arizona and Murray Mitchell of the National Oceanic and Atmospheric Administration (NOAA) in Rockville, Maryland, presented evidence that drought in the American West since 1600, as recorded in the thickness of tree rings, was related to the 22-year solar cycle of changing magnetic polarity (twice the 11-year cycle of sunspot number). Since then, Stockton reported at the meeting, they have collected more tree ring samples, extending coverage eastward into the Great Plains. They also performed a Monte Carlo numerical experiment to compare the reported correlation, which was significant at the 99 percent level, with those that random processes could generate. The newly determined significance level is still an impressive 95 percent.

That the sun–western drought connection has met most challenges so far does not mean that the sun's variability dominates even this narrow aspect of the atmosphere's behavior. The connection is weak, geographically patchy, and at times unreliable. Stockton estimates that the 22-year solar cycle can account for only 10 to 15 percent of the variability of western drought; the rest of its comings and goings must be controlled by other mechanisms, or they are simply random jostles within the climate system. When drought does strike the West, its distribution is a patchwork of dry, normal, and even wet areas, so that the best correlation is made with the total area of drought. For example, drought tends to hit western Montana only during every third 22-year cycle, Stockton notes.

The major complaint against the sun-drought connection, as argued by Robert Currie, has been that western drought is not related to the 22-year solar cycle at all but rather to an 18.6-year cycle of lunar tide. Stockton conceded that Currie has a point; there is an 18.6-year lunar cycle operating during some periods. But Currie "is not being totally fair," he claimed. "He's not looking at all of the data. We still think that we're right." Although the two cycles seem to operate together over the past century or so, Stockton said, the lunar cycle is weak or

**Solar Variability, Weather, and Climate* (National Research Council, Washington, D.C., 1982). Available from National Academy Press, 2101 Constitution Avenue, NW, Washington, D.C. 20418, for $11.95 (prepaid).
†Held 2 to 6 August 1982 in Boulder, Colorado, and hosted by the National Oceanic and Atmospheric Administration.

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absent in other parts of the climate record, and is virtually undetectable in the complete 1600 to 1962 record. It does seem to come to the fore between 1860 and 1900, causing the rhythm of drought to fall out of step with the solar cycle.

Keeping in mind the obvious subtlety and unreliability of suggested sun-weather connections, Kirby Hanson of NOAA's Environmental Research Laboratories in Boulder attempted to find where and when the strongest 11-year solar signal appears in U.S. records of interannual temperature variability. He reported that between 1895 and 1980 the strongest 10- to 11-year cycle in interannual variability appeared in the records of June temperature in the north-central and Great Lakes states. But, as in the case of the 22-year, western drought cycle, there were other significant cycles of temperature variability, the four dominant periods being 2.4 to 2.8, 3 to 4, 5 to 8, and about 10 to 11 years. Likewise, the supposed solar cycle can fall apart, as it did around 1960.

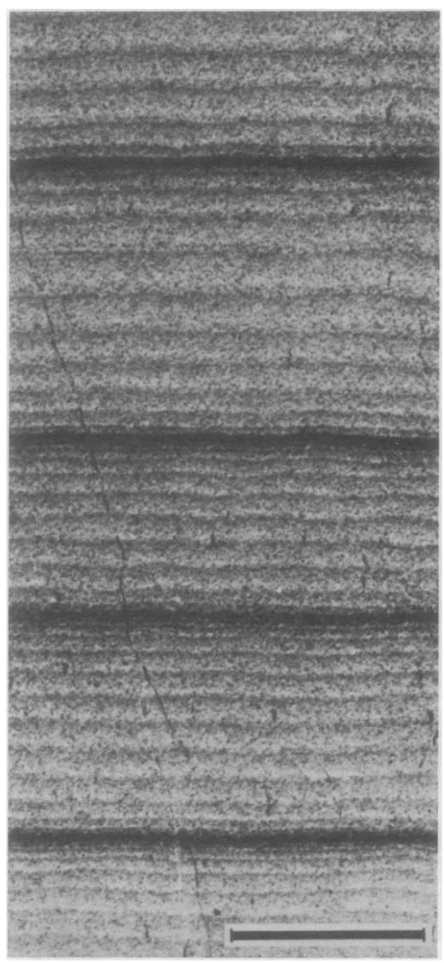
Hanson suspects that the correlation breaks down when two centers of cyclic pressure anomalies, one in the Southeast and the other in the Nebraska-Montana region, get out of synchronization. When synchronized, they alternately pump cold and then warm air into the north-central region. One center, he speculates, may be linked to the solar cycle and the other to a 7- to 8-year cycle intrinsic to the global atmospheric system.

After speakers that picked through all kinds of climate records for the slightest sign of a possible solar cycle, it was startling to see the glacial sediments collected in western Australia by George Williams of the Broken Hill Proprietary Company Limited, Victoria. Turned to rock after 680 million years, these sediments formed on the bottom of a large, glacier-fed lake when waves of sediment-heavy meltwater fanned out over the bottom. Even a casual glance reveals regular, light-colored bands set off by dark, narrow layers. Such laminations, Williams suggests, are usually interpreted as annual deposits from summertime glacial meltwater.

Although the annual nature of the laminations may be geologically debatable, no dating of the samples being available, periodic variations in the thickness of laminations are obvious to the naked eye. The variations have some familiar periods—11, 22, and 90 laminations per cycle, matching exactly the number of years in known solar cycles. Cycles of 145 and 290 laminations also resemble the cycles seen in some tree ring climate records. Plotted curves of lamination thickness and sunspot number also share similarly asymmetric peaks, sawtooth patterns of peaks, and a weakness in the "double" or 22-year cycle at overall minimums, Williams notes.

If the laminations do indeed reflect solar influences on the amount of summertime glacial meltwater, the climate was astonishingly sensitive to the sun 680 million years ago. Williams suggests that the suspected lower strength of Earth's magnetic field then might have allowed the solar wind or cosmic rays a greater influence on climate than it does today. Williams' sediments provided, if nothing else, added reason to hope that there really may be a solar signal among the morass of modern climate records.

The complexities of modern connections between solar variability and weather and climate, if the connections exist at all, would be a great deal easier to work out if researchers could identify likely physical linkages between sun and the lower atmosphere. The possibilities discussed at Boulder were bewildering. The variable solar characteristics that might be responsible include the solar constant, sunspot numbers, solar cosmic rays, galactic cosmic rays (as modulated by solar activity), sector-boundary crossings, ultraviolet emissions, geomagnetic effects, and the proportions of sunspot dimensions, among others.



Record of ancient solar variability?

Dark clay layers in lake sediments may delineate annual bands whose thickness was controlled by sun-related climate cycles. Scale bar, 1 centimeter. [G. E. Williams, Nature *(London)* ***291****, 624 (1981)]*

Variations in the solar constant, the total radiant-energy output of the sun, would produce the most straightforward effect on the lower atmosphere. The Solar Maximum Mission satellite has detected the only established variations in the solar constant, which are limited to a few tenths of percent over several days. Sunspots, being cooler than their surroundings, apparently block some solar energy as they cross the sun's face.

Eddy and Douglas Hoyt of NCAR have calculated the decreases in the solar constant over the past 108 years, assuming that only sunspot blocking was at work. The maximum calculated decrease was about 0.1 percent during the strongest sunspot maximum. Currie has detected a periodic cooling over North America during the past 80 years that seems to fit these calculated changes. That would appear to support a connection, but, as often seems to be the case in this field, it is not so simple as that. Ronald Gilliland of NCAR has confirmed Currie's North American temperature cycles but has failed to find a cycle over central Asia, where solar constant changes would be expected to have a similar effect. In addition, many of the possible sun-climate correlations reported at the meeting require the opposite response—a warming during sunspot maxima rather than a cooling.

If the effects of postulated changes in the solar constant are a bit muddled, the influence of more subtle kinds of solar variability remains a mystery. The problem is that the combined energy of the solar wind plasma, cosmic rays, and extreme ultraviolet radiation is only one-millionth of the energy in the visible radiation. Ultraviolet energy is one-tenth. Most of this energy never reaches the ground, as it is deflected or absorbed before it penetrates the upper atmosphere. Variability of these forms of solar energy does produce noticeable changes in the upper atmosphere, but this feeble, rarefied medium cannot possibly directly influence the dense, energetic lower atmosphere where weather occurs. The answer, everyone agrees, would be a mechanism that somehow gains enough leverage to trigger changes in the lower atmosphere.

Perhaps the most encouraging aspect of the meeting was the number of serious efforts to trace such trigger mechanisms from their solar origins through the upper atmosphere to an observed change in the behavior of the lower atmosphere. Bruce Springer of NOAA's Space Environment Laboratory in Boulder suggested how solar sector boundary crossings might influence Wilcox's VAI, as well as more conventional measures of the weather. Springer's mechanism involves a chain of events that converts a solar-induced infall of charged particles into changes in atmospheric motions via a huge electrical current in the auroral zone called the electrojet.

The required leverage would be gained by trapping and amplifying a normally high-ranging atmospheric wave below an altitude of 60 kilometers. This wave, called planetary wave number 1, circles the globe and can play a role in U.S. dry spells and severe cold. Springer said that the effect of sector boundary crossings on atmospheric pressure can be found during the severe cold of the winter of 1979, among other times. Changes in the VAI, he says, are minor, peripheral effects of this process. Although the electrojet segment of his mechanism did not elicit great enthusiasm among his listeners, the idea of trapping a planetary wave seemed plausible, and, contrary to many sun-weather proposals, it can be checked with reliable observations that are already in hand.

Another appealing mechanism came from George Reid and Kenneth Gage of NOAA's Aeronomy Laboratory in Boulder. They suggested that solar constant variations as small as a few tenths of a percent over an 11-year cycle can influence atmospheric convection over the tropical ocean. As dramatically visualized by towering cumulus clouds and thunderheads, tropical convection plays an important role in the global transport of heat and moisture away from the strongly heated ocean surface. Reid and Gage noted that the periodic changes in solar energy received during the year, which result from the annual variation in Sun-Earth distance, do produce noticeable changes in tropical convection. Invigorated convection pushes the tropopause, the atmospheric lid over the weather system, to greater heights when Earth is closest to the sun, they say. They also found a long-term variation in tropopause height in the western Pacific that, at least during their relatively short 20-year record, is in phase with the sunspot cycle. They have not yet compared observed sea surface temperatures and troposphere heights.

The NRC panel would probably welcome more of these studies that test specific physical models and mechanisms. It went even further in calling for a shift in emphasis "from the traditional pattern of *searching for evidence* [of a correlation] to a more directed effort at *understanding the physics* of the atmosphere and the solar-terrestrial system as a whole." Sun-weather researchers have their work cut out for them.

—RICHARD A. KERR

Computer Graphics Comes to Statistics

By looking at multidimensional data on computer screens, statisticians are finding relationships that never would have been detected with standard methods

Several groups of statisticians and computer scientists have devised computer motion graphical displays of data which allow them to see multidimensional data sets and manipulate them to search for patterns. Scientists at Stanford's Linear Accelerator Center (SLAC), and at Harvard University, for example, are seeing patterns in data that never would have been picked up with standard statistical techniques.

The aim of data analysis is to discover patterns, to find nonrandom clusters of data points. Traditionally, this is done by using mathematical formulas. But, with the advent of computer motion graphics, it has become possible to look at three-dimensional projections of the data and to make use of the uniquely human ability to recognize meaningful patterns in the data.

The new method, although powerful, is still somewhat controversial, especially among conservative statisticians. Jerome Friedman, a principal designer of the SLAC system, remarks, "The old school believes that research in statistics is research in mathematics. They believe you should only use simple statistical methods where the mathematics is well worked out." By that standard, this stuff is very far out.

Peter Huber, a Harvard statistician who also has designed a computer graphics display for data analysis, cautions that there is a danger in looking at pictures rather than using standard statistical methods. "In the orthodox view, you specify all that you will do before you look at the data," he says. "You calculate the probability that things will happen and then if you see something suspicious when you look at the data, you will be fairly sure it will be significant at the 5 or 10 percent level. If you look at data long enough you will almost always see some structure. If you are ultra-orthodox you will avoid that problem by simply not looking at the data."

Huber believes that the ultra-orthodox statisticians are veering too far in the direction of safety. With his newly developed graphical displays, he has already noticed some heretofore undetected anomalies in published data analyses. For example, Huber's colleagues David Donoho and Mathis Thoma discovered an unusual structure in data representing the fuel consumption of cars of various years. When they looked carefully at that structure, they discovered there had been a change in the definition of horsepower during the years the data were gathered. This change in definition, although present in the description of the data, was buried and had been overlooked by other analysts.

The advent of computer motion graphics in statistical analysis took place 10 years ago at SLAC when John Tukey, a Princeton statistician with a long-standing enthusiasm for looking at data to see patterns, took a sabbatical at Stanford. It was Tukey's mission to study how to use computer graphics in statistics; at SLAC he had the makings of a system—albeit an extremely expensive one. William Miller, who now is president of SRI, had put together a graphics facility whose hardware alone cost $150,000 in late 1960 dollars. The graphics facility was hooked up, by way of an expensive fast link, to a $6-million SLAC computer.

Using this system, Tukey and Mary Ann Fisherkeller of Stanford designed, in 4 months, the first graphical display of statistics data. They called their system PRIM-9, for Picturing Rotation, Isolation, and Meshing up to nine dimensions.

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