Sunspot-Weather Link Holding Up

Last year's suggestion that the solar cycle modulates the weather has passed the first barrage of statistical tests; lingering doubts will require more observations

THE LATEST PROPOSED CORRELATION between the 11-year cycle of varying solar activity and the weather on Earth is hardly behaving true to form. By now it should have faded away to insignificance, as most other such correlations have during the centuries-long search for a sun-weather connection. Some meteorologists still think that this apparent connection will disappear soon enough.

But, so far, the current sun-weather connection has passed several stringent statistical tests with flying colors. The strength of the link is so impressive that it will even be consulted to help make the official Weather Service winter forecast.

This most promising of sun-weather studies got its start in a 1987 paper in which Karin Labitzke of the Free University in Berlin pointed out that a clear-cut effect of the 11-year sunspot cycle on the atmosphere had been masked by its interaction with an internally generated modulator of the atmosphere, the Quasi-Biennial-Oscillation or QBO (*Science*, 23 October 1987, p. 479). The QBO is a less than perfect periodic reversal of stratospheric winds over the equator every 13 months or so. Its effects reverberate through the stratosphere and down into the troposphere where weather occurs, but the magnitude of its effect outside the tropics is modulated by the solar cycle, Labitzke showed. It had been known since 1980 that the north polar stratosphere during winter tended to be colder during the QBO's west phase than its east phase, but Labitzke pointed out that at solar maximum its behavior was just the opposite of that general trend.

In a subsequent paper Labitzke and Harry van Loon of the National Center for Atmospheric Research in Boulder showed how sorting out east-phase from west-phase winters transformed a complete muddle, in which the opposing effects of the solar cycle in opposite phases wiped out any correlation, into dramatic correlations. Correlations of the solar cycle with temperature could be traced from the north pole stratosphere, into the troposphere, and to the surface, at least in large regions over the hemisphere. Labitzke and van Loon tested the significance of the correlations at the center of these regions using both a Monte Carlo technique and the bootstrap technique, methods intended for this kind of data. The correlations were significant at the 95% confidence level or better.

That did not convince most meteorologists. Too many sun-weather correlations had come and gone before. Anthony Barnston and Robert Livezey of the National Weather Service's Climate Analysis Center in Camp Springs, Maryland, had discredited their share of such correlations. "We've always had a reputation here as being pretty hard critics," says Livezey, "in particular of solar-weather statistics. But this was the first time that I *wanted* to give something a second look."

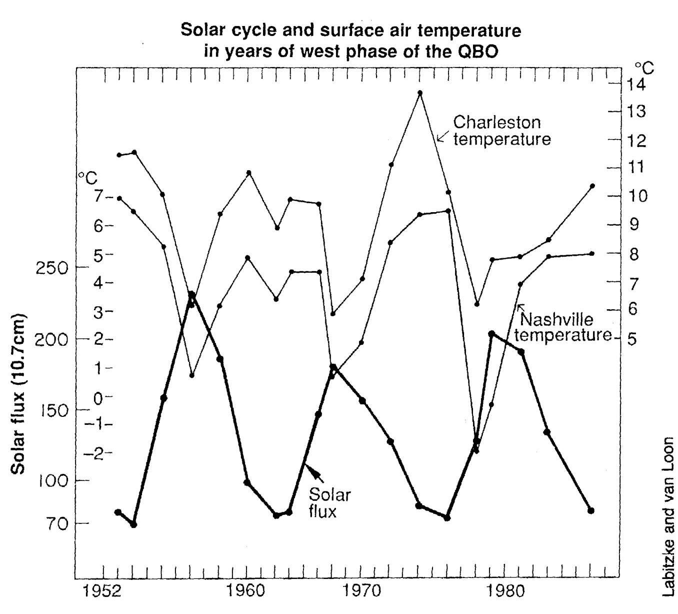
Like Labitzke and van Loon, they used the Monte Carlo technique to see how often the same correlation might occur by chance. They too made an allowance for the extent to which one year's temperature is related to the temperature of the year before, which is called autocorrelation. But they determined the significance of the hemispheric map of varying correlation as a whole rather than at a few points of highest correlation.

"We threw everything at it," says Livezey, "and it held up. I would characterize these correlations as highly significant statistically." The observed correlation between the solar cycle and the temperature at an altitude of about 3.3 kilometers in the west phase was exceeded by randomly generated correlations only two times out of a thousand tries.

Was he surprised at the outcome? "Yes, but that's the way it is. I don't understand it, of course, which means that we still have to be a little nervous about it; the climate could still show us a different face, but the correlation is awfully strong. We think there is a strong basis for accepting the signal as physically meaningful and we will take it into account in making our forecasts, we hope for this winter. I think we'd be derelict if we didn't include it."

That will be an ironic development. In little more than a year, sun-weather relations would be going from neglect and disrepute to their use, albeit in an entirely new form, by the country's leading long-range forecasters.

There have been other tests. Kirby Hanson of the Environmental Research Laboratory in Boulder and Glenn Brier, a retired meteorological statistician living in Arlington, Virginia, did a Monte Carlo test in which only the QBO record was randomized and then only within some constraints imposed by the observed QBO. This was to counter complaints that the autocorrelation



A sun-weather correlation. *Labitzke and van Loon found that the southeastern United States tends to be colder than normal during maximum solar activity (solar flux) if stratospheric winds are blowing from the west. At Charleston, all but one of the eight west-phase, low solar activity years had above normal temperatures.*

problem had not been dealt with properly. "As far as statistics are concerned," says Brier, "I think it's clearly significant. I don't think any test would be more appropriate than the one we used."

While the basic claim is being scrutinized, Labitzke and van Loon have been extending their initial correlations. "Everything should hang together if it makes physical sense," says van Loon. "And everything we have touched has turned out right. We have found no contradictions to the original conclusions." The solar cycle correlates with sea level atmospheric pressure and surface air temperature during the Northern Hemisphere summer as well as during winter, but primarily over the oceans. The separation of the record into east- and west-phase years reveals correlations in the Southern Hemisphere too, but the correlations are especially marked in the east phase there rather than the west phase. The strength of the east-phase correlation is particularly evident in the Antarctic stratospheric temperature, which is a crucial factor in the formation of the Antarctic ozone hole (*Science*, 28 October, p. 515).

Much on the minds of those who take these correlations seriously is the question of reliability. The apparent solar effects found in the record since 1952, when the record becomes good enough to identify the QBO, might have been a fluke coincidence, despite the statistically strong correlations. Many researchers would take the whole thing much more seriously if a solar connection could be found in the earlier record too.

There are some promising signs that the sun-weather connection will be traced over more than three and a half solar cycles. In 1979 G. M. Brown and J. I. John found that winter storms in the North Atlantic tracked 2.5° farther south during solar maximum than during solar minimum. In light of the subtlety of the effect, researchers simply ignored Brown and John's paper.

After Labitzke pointed out how sorting according to the QBO phase could help, Brian Tinsley of the University of Texas at Dallas reworked the Brown and John storm track analysis. The deviation between solar maximum and minimum increased from 2.5° in unsorted data to 6° in the west phase during winter. Labitzke and van Loon note that "As Brown and John's signal extends back through three solar cycles before 1952, their work suggests that our results may also be applicable to the period before 1952." Tim P. Barnett of Scripps Institution of Oceanography has also reported that he finds signs of a solar-QBO interaction in long records of tropical sea surface temperature and sea level pressure without stratifying the data according to QBO phase.

Even if the correlations hold up, there would remain the question of mechanism. How could the feeble variations in solar output over a cycle be amplified to give the apparent changes in the weather, a required amplification of over a million? No one has any answers. One encouraging sign, however, is the way geographical patterns of sun-weather correlations resemble the patterns of behavior often taken up by the atmosphere. Thus the sun-weather correlations appear to make some physical sense.

As discussed by Tinsley, solar forcing could conceivably be amplified through multistep processes, several of which he gives for illustrative purposes. Galactic cosmic rays, which are modulated by the solar cycle, might produce chemical reactions in the upper atmosphere that lead to changes in ozone or cirrus cloud particles, both of which affect the amount of atmospheric heating. The resulting changes in heating could lead to temperature changes, changes in winds, perturbation of unstable circulations, and ultimately changes in the weather.

All this is getting much too far ahead of the facts for many meteorologists. "Given the fact that there is no physical basis for expecting these relationships," says John Wallace of the University of Washington, "I would need really strong statistical evidence." That evidence may still be compromised, he says, by the need to group the data by both the QBO and solar cycle. "I have a feeling that this procedure raises deeper statistical issues that haven't been addressed." The more the data are stratified, he notes, the more data are needed to demonstrate significance. The way the patterns of atmospheric behavior make physical sense does not by itself prove a correlation with solar variabilities, he notes.

"I've seen so much time wasted on such things that went away," says Wallace. "I wouldn't say there's nothing there, but I would be very surprised if it does hold up in the long term. This feels like one of the flukes that will go away." Perhaps it will. But by passing its first tests, this sun-weather connection has caught the attention of the scientific community, the essential first step to vindication or outright repudiation.

■ Richard A. Kerr

ADDITIONAL READING

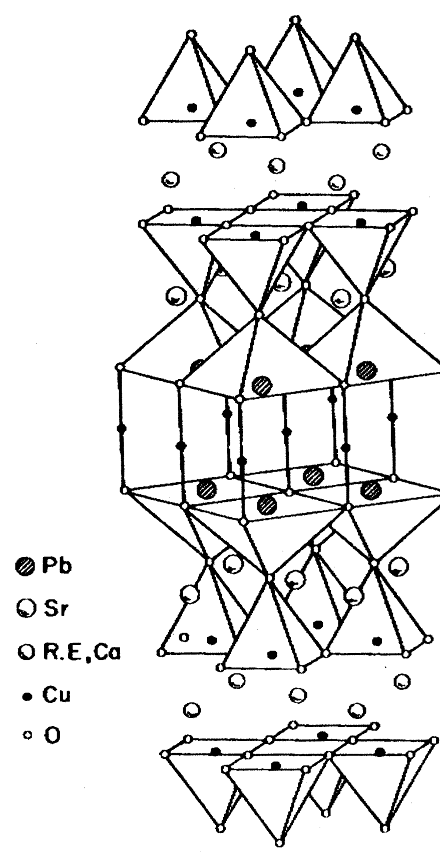
H. van Loon and K. Labitzke, "Association between the 11-year solar cycle, the QBO, and the atmosphere. Part II: surface and 700 mb on the Northern Hemisphere in winter," *J. Climate* **1**, 905 (1988).

B. Tinsley, "The solar cycle and the QBO influences on the latitude of storm tracks in the North Atlantic," *Geophys. Res. Lett.* **15**, 409 (1988).

One More Family of Superconductors

Researchers at AT&T Bell Labs have discovered yet another family of high-temperature superconductors. In the 17 November *Nature*, Robert Cava, Bertram Batlogg, and co-workers describe a group of copper-oxide compounds that become superconducting (lose resistance to electric currents) at temperatures as high as 68 K and whose crystalline structures are similar to previously known high-temperature superconductors. Although the critical temperatures of the materials—the temperatures at which they become superconducting—do not set any records, the Bell Labs researchers say the compounds give new insight into high-temperature superconductivity.

The discovery, Batlogg said, offers more evidence for what superconductivity researchers already believed—that double pyramidal layers of copper and oxygen atoms such as those found in the new materials play a crucial role in high-temperature superconductivity. So far, all of the materials discovered with critical temperatures over 50 K have these same double Cu-O layers, Batlogg noted. "This is apparently the main



AT&T Bell Labs

Double pyramidal layers *of Cu-O sandwich a Pb-O/Cu-O/Pb-O triple layer.*