match they make. The ten best matches are weighted according to the closeness of the analogy and then combined. Livezey and Barnston also included an antianalog selection in the system. Instead of assuming that what followed a similar fall in the past will follow this fall, the antianalog method assumes the opposite: a fall that was a complete opposite would have been followed by a winter that was the opposite of the winter to be forecasted. The use of antianalogs in effect doubles the size of the sample from which comparisons can be made, a distinct advantage when seasons are so variable and the usable record so short.

In its present operational form, the analog system is as skillful as human forecasters have been during the past 25 years. When applied to past data, it had an all-season skill in predicting temperature of 8%, as did human forecasters. Like them, its greatest skill came in winter forecasting, in which it scored 16% to the humans' 18%. Both, therefore, exceeded the 10% winter skill achieved by predicting that the below, above, or near-normal character of the preceding season would persist through the next season.

With the analog system in operational use, Gilman and his colleagues at CAC hope to double their long-range skills within the next few years. Presumably, forecasters will be able to increase their skills by blending the objective skill of the analog system with their independent subjective skills. Improvements in the analog system itself are under way. The skill of a forecast that a weather pattern will persist seems to be independent of analog skill and is therefore being incorporated in the system. The usefulness of adding the correlation between sunspots, the quasi-periodic shift in stratospheric winds over the equator, and the weather (*Science*, 25 November 1988, p. 1124) is being tested as well.

There is another approach to improving the usefulness of predictions that forecasters at all ranges are now taking more seriously. It involves knowing when the forecast is going to be more trustworthy than usual and when it will be less so. In the case of long-range forecasting, skill is higher in winter than any other season, in the southeast United States than in the Great Plains, and in certain phases of the El Niño cycle than in others. Utilizing such "forecasts of opportunity" at all time scales will be the subject of a subsequent story.

■ RICHARD A. KERR

ADDITIONAL READING

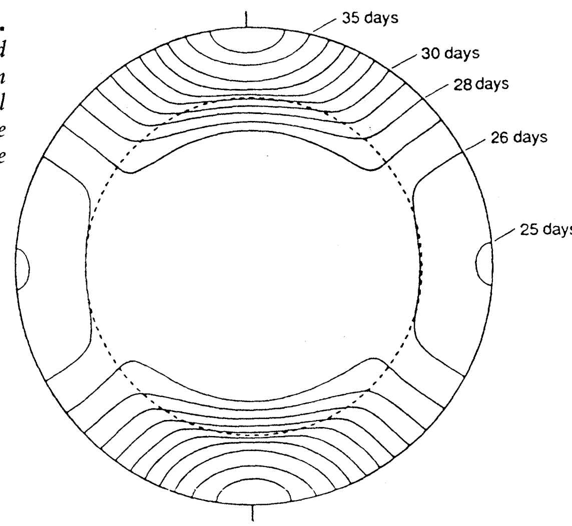
R. E. Livezey and A. G. Barnston, "An operational multifield analog/antianalog prediction system for the United States seasonal temperatures," *J. Geophys. Res.* **93**, 10,953 (1988).

Gazing into the Interior of the Sun

In much the same way that terrestrial seismologists have probed the interior of the earth by mapping the way our planet vibrates after an earthquake, astrophysicist Kenneth G. Libbrecht of the California Institute of Technology has been probing the interior of the sun by mapping how great, slow vibrations move across the face of our star like waves on a glowing sea. His latest results could provide an important clue in one of the longest standing mysteries of solar physics: the differential rotation.

The word "differential" refers in this case to the fact that the sun's rotation rate decreases steadily from the equator, where the period is 25 days, to the poles, where the period is 36 days. (The sun is not constrained to rotate as a rigid body because it is actually a ball of gas.) Presumably, says Libbrecht, this pattern is the surface manifestation of some deeper pattern, which would in turn hold the key to the mystery if we could only find out what it is.

Enter helioseismology. For more than two decades now, says Libbrecht, solar physicists have known that the seemingly chaotic rise and fall of plasma on the surface of the sun is not chaotic at all. Rather, it is the result of sound waves reverberating through the 1.4-million-kilometer sphere like the overtones in a ringing bell. The sun is now thought to harbor about 10 million such waves, each with its own unique frequency. Whatever the origin of these waves—no one knows—solar astronomers have long recognized their potential as an observational tool: the longer their wavelength, the deeper they penetrate into the solar interior. Moreover, the difference in frequency between waves moving east and waves moving west is directly related to the rotation rate. So in principle, says Libbrecht, an analysis of the surface waves could tell us most of what we want to know about the inside.



The sun in cross section. *The pattern of rotation derived from the Caltech data is shown here with contour lines of equal rotation rates. The dotted circle marks the lower boundary of the convection zone.*

In practice, that analysis has been hampered by the mountainous quantities of data required. Libbrecht and his students currently hold the record. But to win it, they spent 4 months at Caltech's Big Bear Solar Observatory taking one image of the sun every minute, for a total of 60,000 images. They then devoured at least as much Cray supercomputer time extracting the vibrational modes from the images and then converting that information into their model of the interior, which has the highest resolution yet attained.

Unfortunately, says Libbrecht, the data are not good enough to say anything about the inner 40% of the core. But what they do show very clearly is that the surface rotation rates extend 30% of the way inward, to just below the base of the sun's "convection zone." This is the region where the gaseous plasma is excited into violent, turbulent motion as it transfers heat from the hotter interior to the cooler surface. It is also the region that generates the sun's magnetic field. Below the convection zone, however, the sun seems to rotate almost rigidly, with a period of 27 days. This could be a key to the puzzle, says Libbrecht: "It confirms that the differential rotation is somehow being generated by convection." On the other hand, he says, "we don't understand convection." So thus far, it is only a clue. ■ M. MITCHELL WALDROP