A New Way to Forecast Next Season's Climate

A new mathematical technique that makes 90-day climate forecasts by searching the historic record does as well as humans

MANY A SELF-TAUGHT WEATHER FORECASTER has looked up at the sky and thought, "The last time it looked like this it rained the next day. It'll probably rain tomorrow." Now long-range forecasters are following suit by using a statistical system that considers the most recent season and then searches its 40-year memory of climates of the same season to find a close match. Whatever followed that best match becomes a forecast for the coming 90-day season.

This entirely objective analog technique performs as well as human forecasters have done over the past few decades, and it will soon get better still. Researchers hope that by adding the analog technique to the tools already available, they can contribute to a doubling of forecasting skill during the next few years. Everyone from the farmer wondering whether to plant his winter wheat to the natural gas supplier wondering how much gas to have on hand should be happy about that.

An improvement in skill would certainly be welcome considering the long-range forecaster's experience so far. Over 23 years the National Weather Service's forecasters have an average skill of 8% in predicting whether the temperature during the next 90 days will be near normal, below normal, or above normal. If they had done no better than chance, their skill would have 0%, and if they had been perfect, their skill would have been 100%. The 8% skill is equivalent to being right 38 times out of 99 when chance would account for being right 33 of those times. The skill of official forecasts of precipitation has been 4%.

Until recently, the types of forecasting tools available to the Prediction Branch of the Weather Service's Climate Analysis Center (CAC) for making 90-day forecasts had remained substantially unchanged for 25 years. Branch Chief Donald Gilman has described long-range forecasting as "an empirical art" and "a kind of cook's mixture of empirical techniques." Every month, several forecasters at CAC subjectively combine the results from a number of objective methods to produce a forecast. The methods range from an informed decision that the recent climate will persist through the next 3 months to deciphering how distant events such as El Niño's warming of the tropical Pacific will affect weather in the United States. The individual forecasts are then combined to form the official forecast.

The new analog technique is now one of the tools that CAC forecasters use routinely to predict temperature, a first in seasonal forecasting. The basic analog system from which the CAC version was derived was developed by Tim P. Barnett of Scripps Institution of Oceanography and the late Rudolph Preisendorfer. They showed how to boil down the many millions of weather observations from a 90-day period into a few numerically compact variables that can say something about the coming 90 days without overwhelming a forecast system. Most of the torrent of data that goes into computer models that forecast up to 7 days ahead has nothing to do with what can be predicted about the atmosphere on the scales of 90 days and thousands of kilometers. The analog system pares the observations down to a minimum while maximizing predictability.

Robert Livezey and Anthony Barnston of CAC improved the Barnett and Preisendorfer analog system by refining the kinds of observations included. They found that the three most critical variables are a measure of atmospheric circulation over the extratropical Northern Hemisphere, a particular index of the state of the El Niño cycle and its associated atmospheric oscillation, and U.S. surface temperatures. They included sea surface temperatures from five areas in the Caribbean and Pacific and a measure of lower atmosphere temperatures because they improved skill despite their close correlation with the other three. As it turned out, all five variables contributed to winter forecast skill, but only three contributed to summer forecasts and one each to spring or fall.

Barnston and Livezey also appended some additional steps to the original system. In their version, for example, after each fall season of the past 40 years has been compared with the most recent fall in terms of the distilled climate variables, the past seasons are ranked according to how good a

The weather puzzle to be solved. *Predicting the net effect of the complex and everchanging pattern of weather systems during the next 90 days is a formidable task. Long-range forecasters have a new, completely objective technique in which past records provide a guide to the coming season's weather.*

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

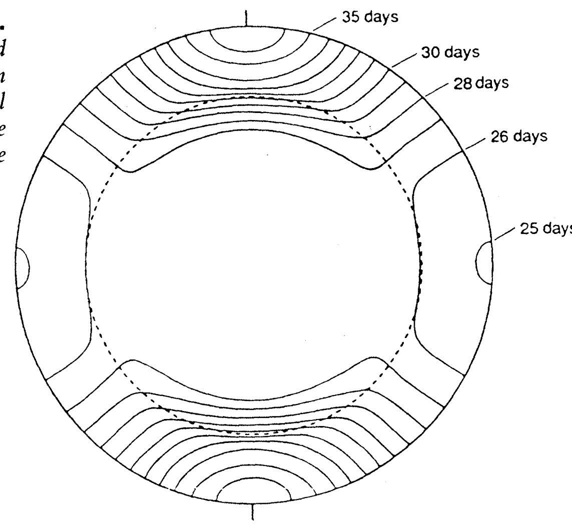
R. E. Livezey and A. G. Barnston, "An operational multifield analog/antianalog prediction system for the United States seasonal temperatures," *J. Geophys. Res.* **93**, 10,953 (1988).

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