Weather Satellites Coming of Age

After 25 years, observations from satellites have become clearly useful in weather forecasting by computers, but only for some places at some times

Those satellite views of the weather that you see on the evening news can be quite comforting. If the forecasters know where the weather is today, then they should be able to say where things will stand tomorrow, one might reason. Unfortunately, knowing where the clouds are today, even if they are the distinctively swirled clouds of a cyclone or hurricane, aids only a little in forecasting where they will be tomorrow much less how strong the storm will be.

Potentially more useful data have been flowing down from weather satellites for 25 years, but only recently have researchers been able to show that such data improve forecasts made by computers, the backbone of modern weather forecasting. But the improvements are not as great as expected and do not show up in every forecast. For satellites to help in the Northern Hemisphere, a region must have few conventional observations, meaning it should be over the oceans, and the weather should be relatively intense. Then, to be of interest to a large number of people, the weather system should move over a continent. Researchers have now thoroughly documented such improvements in specific cases but have yet to show how often a positive effect occurs.

Forecasters and meteorologists agree that satellite observations have demonstrably improved computer forecasts only since 1979 or 1980, 20 years after the first of 5.5 million weather pictures came down from space. Undoubtedly, cloud pictures had by then begun providing short-range forecasters with at least subjective guidance, and pictures and other satellite observations had probably improved the forecasting of some kinds of violent weather over the United States (*1*). Such observations also created invaluable data files for research in meteorology and climatology. But in the 1970's a sometimes bitter controversy arose over why researchers at the National Meteorological Center in Camp Springs, Maryland, could find little statistically significant improvement in computer forecasts that employed satellite observations.

There will probably never be complete agreement on what the problem was, but one part of it may well have been the limitations of satellite data quality, limitations that are still restricting the usefulness of satellite data. The most important errors are in the determination of where between the top and bottom of the atmosphere an observation was made. The motion of individual clouds tracked from one geostationary satellite picture to the next can yield wind speeds, but those wind speeds must be assigned to rather uncertain altitudes depending on whether the clouds were fluffy cumulus, ones that appear fairly consistently around an altitude of 1 kilometer, or wispy cirrus and other cloud types that can appear over a wide range of higher altitudes.

> Satellite observations can have a positive effect on computer forecasts but at times are of no help at all.

Atmospheric temperatures sensed remotely by polar-orbiting satellites are also difficult to assign to a proper altitude. Satellite temperature sounders are radiometers that record emissions from carbon dioxide, oxygen, and water vapor at specified wavelengths. Each wavelength or channel responds most sensitively to temperature-dependent emissions at different altitudes depending on how efficiently the atmosphere absorbs energy at that wavelength. But the altitude ranges of each channel overlap and there are only four independent infrared channels in the troposphere, where weather occurs. In overcast regions, microwave channels must be used instead of infrared, reducing the tropospheric channels to only two. The resulting error is about 2°C at best for layers 2 to 4 kilometers thick. When satellite sounders were being developed, some meteorologists had been hoping for an accuracy of better than 1°C. Weather balloons have their drawbacks too, but they measure temperature continuously through the 10-kilometer-thick troposphere with an accuracy that is better than 0.5°C.

For many meteorologists, how computer forecast models used satellite observations presented a bigger problem than any errors in those observations. Before a computer model simulates future weather, an adjunct of the model, called the analysis system, tries to make an ordered picture of the present weather by blending a variety of types of observations made by a variety of instruments, each kind of observation having characteristics peculiar to it. Satellite temperature soundings, for example, present the analysis system with exceptionally fuzzy pictures of the variation of temperature with altitude that some analysis systems of the 1970's found too lacking in detail to accept. As a result, temperature soundings fed into forecast models simply disappeared in the model without affecting the model's weather. The introduction of new analysis techniques by 1980 marks for many researchers the first consistent, useful incorporation of satellite observations into operational model forecasting.

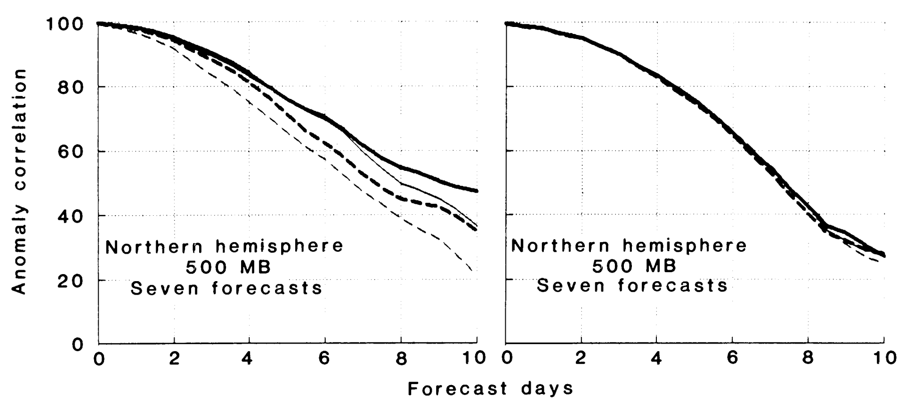
Satellite observations are now being effectively incorporated into routine forecasts and can have a positive effect on computer forecasts, but researchers are finding that satellites can at times be of no help at all. A number of computer experiments described last September at a seminar at the European Center for Medium Range Weather Forecasts, Reading, England, and in the seminar's recently published proceedings (*2*) were set up to examine what effect different observing systems had on forecasts.

All the experiments draw on observations made during the First Global GARP Experiment (FGGE) of 1979, when an intensive international effort acquired as complete a set of global observations as was ever made before or since. In each set of experiments, forecasts were made drawing on all of the observing systems available—satellite temperatures, satellite cloud-track winds, winds and temperatures from commercial aircraft, surface observations (land and ship), and balloon observations. Then new sets of forecasts drew on this maximum system with one or more observing systems deleted from it.

An ambitious observing system experiment reported at the European Center seminar was by Sakari Uppala, Anthony Hollingsworth, and Stefano Tibaldi of the European Center and Per Kållberg of the Swedish Meteorological and Hydrological Institute in Norrköping. They chose two periods, 8 to 19 November and 22 February to 7 March, from which to begin a total of 85 10-day forecasts using different combinations of observing systems. The November period had exceptionally good coverage, including two polar-orbiting satellites, and considerable weather activity over the Pacific that included an intense storm heading toward North America. In this period, either kind of satellite observations or the aircraft observations improved the forecasts over those made without any of these systems, more so in the Southern Hemisphere than in the Northern Hemisphere. Satellite temperatures alone added to a minimum observing system of conventional surface and balloon observations produced as good a forecast as one including aircraft and both kinds of satellite observations.

In contrast, in the February-March period results were mixed. Satellite observations again improved forecasts in the Southern Hemisphere. A consistent positive effect had also been seen there in earlier studies, due obviously to the sparse conventional observations in that thinly populated, predominately oceanic half of the globe. But satellite data had no measurable effect on the forecasts for the Northern Hemisphere. In fact, a minimum system lacking satellite or aircraft data did a particulary good job by itself.

The failure of satellite observations to affect forecasts during the second Northern Hemisphere period seems to have multiple causes, according to the experimenters. There was only one satellite, which led to a gap in coverage to the west of North America, an area of particularly strong activity during the period. And the weather over the land was in general more active than over the ocean, where the sparseness of conventional observations might otherwise let satellites make a real contribution. The authors conclude that "the impact of a particular observing system (for example, satellite temperatures) is dependent on the level of synoptic activity present in the areas where this particular observing system is the main source of meteorological information."



The varying effect of satellite observations

Whether an observing system increases forecasting skill seems to depend on the particular weather situation. The anomaly correlation—a measure of skill in this case of predicting broad weather patterns—depends on which special observations are added to a conventional surface-based system. On the left, during November 1979, adding aircraft observations helped (thin dashed line), but the addition of satellite winds helped more (thick dashed line), and satellite temperatures alone (thin solid line) helped almost as much as all three systems combined (heavy solid line). But in February and March (right), any one of the added systems performed about as well as the conventional system. [*From S. Uppala* et al., *in* (2), *p. 198*]

A closer look showed how this principle applied to the February-March period. K. Kashiwagi of the Japan Meteorological Agency, Tokyo, ran an experiment on that period and examined the forecasts region by region. Satellite data did improve the model's initial picture of the weather over the Pacific and thus the forecasts downwind over North America. But forecasts over the Atlantic and Europe were little improved and East Asia forecasts, which are influenced by land-based observations in the continental interior, showed no improvement whatever with satellite observations.

These and other observing system experiments focus on the frontiers of global forecasting to see how far into the future general weather patterns can be usefully predicted. In the European Center study, the maximum amount of FGGE data allowed useful forecasting out to about 7 days in the Northern Hemisphere during the November study period, which is about the limit of present operational medium-range forecasting. Satellite temperatures alone plus conventional surface-based observations did almost as well. That is almost a full day better than forecasts without satellite data, an impressive difference in the global forecasting business.

On a bit smaller scale, any one of the nonsurface-based systems—satellite winds, satellite temperatures, and aircraft observations—allowed a good forecast of the big November storm in the Pacific out to at least 4 days, although surface-based systems missed it entirely. The European Center group views the evident redundancy of the three systems in this particular case as an essential feature of a global observing system, not a sign of unnecessary coverage, in that at other times only one system may be in a position to catch such a storm.

At a range of 3 days, Eugenia Kalnay and her colleagues at the Goddard Space Flight Center, Greenbelt, Maryland, also found positive effects of satellite observations (*3*). As usual, the positive effects over Australia and South America were large and consistent. But over Europe and North America they were quite small and intermittent. Unlike the European Center's results for the entire Northern Hemisphere, the Goddard model's forecasts could actually be degraded by the addition of satellite data and other special observations. For every two useful forecasts over Europe and North America improved by satellite data, one was degraded.

On a shorter time scale, the contribution of satellites to computer forecasting 1 to 2 days ahead, perhaps the range of most interest to the public, remains more poorly defined. Several characteristics of current satellite data limit their usefulness in short-range forecasting in particular. As Andrew Gilchrist of the Meteorological Office, Bracknell, England, pointed out at the seminar, "The need for detail in the vertical structure of the atmosphere and for accurate representation of the humidity fields is much greater for short than for medium range forecasts, and this is the kind of information that is provided by conventional upper air sounding techniques, but generally lacking in space-based observations." Also, winds must often be inferred from satellite temperature distributions, which severely degrades satellite descriptions of the jet streams crucial to the genesis and steering of major weather systems.

Ongoing efforts to improve the usefulness of weather satellites in computer forecasting range from studies of a possible satellite-mounted laser wind sensor to improving the mathematical techniques for extracting measurements from the raw data to developing new ways of incorporating satellite data into forecast models. A conceptually simple experiment has been to mount a radiometer called VAS on the geostationary GOES-5 satellite rather than a polar-orbiting satellite. That increased the horizontal resolution and provided nearly continuous rather than twice daily coverage.

John Le Marshall of the Cooperative Institute for Meteorological Satellite Studies in Madison, Wisconsin, and William Smith and Geary Callan of the National Oceanic and Atmospheric Administration in Madison found that the VAS data reduced the mean position error in two 12-hour forecasts of Hurricane Debby from 139 to 50 kilometers (*4*). Analysis results from 12 storms are still encouraging, says Smith, but still do not represent strong statistical evidence of a consistent positive effect.

Such evidence of a positive effect in the Northern Hemisphere is something that all satellite observing system experiments still lack. Pre-FGGE computer experiments had indicated that the effect of satellites would be far more evident, probably because of a flaw in experiments designed to run on simulated data in the absence of real observations. In part to acquire such statistically valid evidence, an international field experiment will be conducted over the North Atlantic beginning in 1986. The observing systems tested during FGGE—including satellites, aircraft, ships, and buoys—will operate for 1 year to produce a sufficient number of cases for observing system experiments.

—**Richard A. Kerr**

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Parkinson's Disease: An Environmental Cause?

As the pace of research on drug-induced Parkinsonism increases, data are produced, and disputed, that identify pesticides as causative agents

It is little more than 2 years since researchers in several laboratories discovered that a relatively simple pyridine compound, 1-methyl-4-phenyl-1,2,3-tetrahydropyridine (MPTP), induces a parkinsonian-like state in humans and some animals (*1*). The discovery stemmed from an incident in which a "synthetic heroin" was contaminated with by-product MPTP that produced severe neuropathies in several dozen young people in southern California (*2*). As a consequence of this unfortunate episode, however, there has been a tremendous surge of research in the United States and throughout Europe on the mechanism of action of the chemical, which some consider might give insights into the etiology of the natural disease. Four separate conferences on the topic within the past several weeks attest to the intensity of research activity, especially as most of the data presented are yet to reach the printed page.

Parkinson's disease, which involves degeneration of certain dopaminergic neurons in the substantia nigra of the midbrain, typically develops late in life. Treatment with L-dopa usually relieves the neurological symptoms, which include tremor, partial or complete paralysis, and characteristic posture, but with time the condition usually deteriorates.

People who have been exposed to MPTP develop within a few days clinical symptoms that are virtually indistinguishable from those of the natural disease. On the neuropathological level, however, there are some differences. Although the neurons of the substantia nigra are affected in both conditions, some groups of cells that look pathological in the natural disease are apparently unaffected in the drug-induced state. Most significantly, characteristic inclusions derived from neurofilaments, known as Lewy bodies, are present in the natural disease but absent in the MPTP syndrome.

One argument offered to explain the differences at the cellular level is that the MPTP syndrome is an acute condition brought about by the acceleration of naturally occurring processes. The more diffuse pathology, including the Lewy bodies, of the natural disease might simply be the product of time, it is suggested.

The striking chemical similarity of MPTP and its metabolites with certain industrial chemicals, specifically the herbicide paraquat, is sufficient to persuade some observers that Parkinson's disease is environmentally caused and that the MPTP syndrome is therefore a very direct model of the natural disease. Opponents of this view say that the natural condition simply does not have the appearance of paraquat-like toxicity at the cellular level and that evidence on the involvement of environmental agents is negative. The balance of opinion at a recent meeting held at the National Institutes of Health (NIH)* supported the position that Parkinson's is not an environmental disease.

Therefore, evidence presented a few days later by Andre Barbeau and his colleagues at a subsequent meeting in New York came as something of a surprise.† Barbeau, who is at the Clinical Research Institute of Montreal, collected data on the incidence of Parkinson's disease in the nine hydrographic regions of Quebec Province and matched it with pesticide use. The Montreal team used four independent methods to track the disease incidence and came up with more than 5000 cases in all. The correlation between disease incidence and level of pesticide use was very strong—0.967.

An area southwest of Montreal, Quebec's "breadbasket," recorded the highest rural incidence, 0.89 per thousand of population compared with 0.13 per thousand in regions where pesticide use was low. In Montreal itself there was a similar disparity between the industrialized east of the island and the residential west. All comparisons were adjusted for age structure of the populations.

Barbeau and his colleagues stress that pesticides are just one class of potential environmental neurotoxin that might be important in the etiology of Parkinson's

*Symposium on MPTP, Uniformed Services University of the Health Sciences, Bethesda, Maryland, 6–7 June.

†The Eighth International Symposium on Parkinson's Disease, New York, 9–12 June.