A Frontal Attack on a Paradigm of Meteorology

Researchers are grappling with how to bring the 70-year-old concept of weather fronts and storms into the modern age

IT MIGHT HAVE SEEMED A SIMPLE TEST FOR some of the top meteorologists in the country. Given the latest weather observations plotted across a map of North America, they were asked to draw in the fronts—the familiar spiked lines for cold fronts, bumpy lines for warm fronts, and lines with both spikes and bumps for mergers of the two (occluded fronts). No one failed, exactly, but some of the results were disquieting. The map exercise "was terribly embarrassing," says Clifford Mass of the University of Washington, who took part in the test at a workshop on frontal analysis held last spring at the National Meteorological Center (NMC) in Camp Springs, Maryland.

Depending on the expert doing the drawing, a cold front (where a cold air mass is plowing into warmer air) was placed anywhere from the Texas coast to the Panhandle, and a warm front (where warm air is advancing over cold) was shown hovering over either Georgia or Maryland. That set Mass and some of the other participants wondering: If we don't always know a front when we see one, how useful is the very idea of traditional weather fronts? "If I had my way, there would be no fronts," says meteorologist Lance Bosart of the State University of New York at Albany. "I would just let the data speak for themselves."

That is an extreme view, but the workshop seems to have crystallized a longstanding sense that something must be done about this key concept in meteorological research and everyday forecasting. Mass sees the difficulty he and his colleagues had in defining the fronts as "a warning sign that we're doing something wrong." Just what that something might be is a matter of debate, but somehow, meteorologists agree, they need to refurbish the conceptual framework of weather forecasting—and find a new visual language to match.

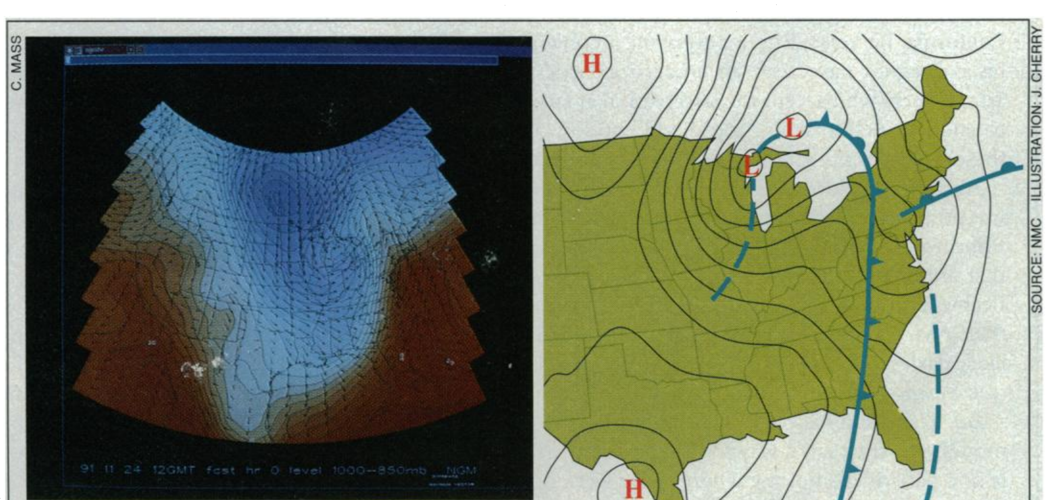
Nobody doubts that weather fronts exist; what's in question is how and where they form, and how important they are in organizing the weather. In the traditional picture, now three-quarters of a century old, warm and cold fronts are spawned in pairs along a shifting atmospheric boundary called the polar front, a line that winds across temperate latitudes, dividing polar air to the north from warmer air to the south. As Jacob Bjerknes of the Bergen School in Norway described it in his 1918 theory, warm and cold fronts are simply parts of the polar front that are mobilized during the development of cyclone—any stormy low-pressure center. According to the "Norwegian model," a cyclone begins as a gentle northward bulge of warmer air at the polar front. As the bulge grows and sharpens to a peak, its back side, now designated the cold front, sweeps toward its front side, the warm front. Eventually, the two fronts merge, starting at the peak of the bulge, where a powerful low-pressure center has formed.

This picture of a cyclone as two adjacent sections of a polar front wheeling about a low makes for nice, neat schematic diagrams in textbooks—and a convenient shorthand for describing the weather patterns of temperate latitudes. But, says Frederick Sanders, professor emeritus at the Massachusetts Institute of Technology, "We've known for a long time that the Norwegian model, however admirable in its time, doesn't really represent the state of affairs as we see it now." Sanders' deepest complaint about the model is that real warm and cold fronts can form well away from the polar front; all it takes is the atmospheric unrest generated by a cyclone. And any zone of changing temperature can be enough to create a low-pressure system and get a cyclone started.

That's not news to meteorologists, but they've only recently realized just how often cyclones—and their attendant fronts—violate the strictures of the polar-front model. Viewing the diversity of real fronts through the lens of the Norwegian model can get downright bewildering, as the workshop made clear.

Take that elusive cold front over Texas. In a just-released report summarizing the workshop, organizer Louis Uccellini and his colleagues at NMC lay out what went wrong. The cyclone that gave the analysts their first hint that a cold front should be nearby had formed not at the polar front but in the lee of the Rocky Mountains, where cold air was subsiding, creating a low. The cyclone had moved eastward and was spawning a cold front to the south. And, adding to the challenge of identifying a new front divorced from any preexisting front, other frontlike boundaries—between regions of differing winds, moisture, or pressure—were also developing nearby. Thus the analysts were faced with a whole set of contenders, none of which qualified as the one obvious cold front of the Norwegian model.

That sort of confusion may be salutary in a workshop exercise. Not so in the real world of weather forecasting, says Peter Hobbs of the University of Washington. With the luxury of leisurely hindsight, Hobbs and his colleagues found four cases of weather east of the Rockies in which the NMC plotted cold fronts that the Washington group thinks were not true fronts at all but less consequential shifts in atmospheric properties. At the same time, says Hobbs, the NMC missed key developments several hundred kilometers away: what Hobbs and



A fresh look at the weather. *The workstation picture* (left) *of the atmosphere uses color change* (blue is colder) *to highlight areas of interest traditionally marked by fronts* (right).

his colleagues call "cold fronts aloft." In the group's model, which is controversial, these fronts do not extend to the surface, where fronts are conventionally plotted, but they are still capable of triggering violent weather.

In one case, says Hobbs, the NMC missed forecasting destructive surface winds driven in part by a cold front aloft. "Perhaps because the Weather Service was viewing it in terms of the Norwegian model and tracking surface fronts," says Hobbs, "they had missed quite severe weather that tracked with the upper front."

Whether or not cold fronts aloft or any of the other half-dozen proposed variants of the Norwegian model's fronts survive to enter general use, there is a whole class of smaller weather features that researchers would like to see more often on NMC's maps. In the Norwegian model, weather develops along lines hundreds or thousands of kilometers long as the warm air on one side of a front is pushed upward by the cold air on the other side, triggering rain and snow. But Steven Koch of NASA's Goddard Space Flight Center in Greenbelt, Maryland, reminded workshop participants that smaller features—the so-called mesoscale systems that have drawn attention in recent years—can also generate interesting weather, far from any classical front. A case in point is something called a dry line, which divides moist air from dry. There's no symbol on weather maps for dry lines, but they are enough to trigger major tornado outbreaks over Oklahoma.

Still, there's no one best way to relabel the weather map, meteorologists say. Those who would prefer no fronts, especially research meteorologists who want to make up their own minds, will probably go with color-coded depictions of varying atmospheric properties—temperature for example—to help guide the eye to critical regions (see figure). Computer workstations are making that kind of display more widely available, as well as easing the analysis of the data. Traditionally, drawing weather maps has been a time-consuming matter involving paper and pencil, acetate overlays, and grease pencils.

Uccellini and his colleagues in the operations division of NMC, who must provide detailed guidance to everyone from the man-in-the-street to local Weather Service forecasters, are taking a more conservative approach. They're eagerly trading in their grease pencils for workstations but are holding off an attack on 75 years of weather map tradition. Fronts will still be labeled, and the labeling of mesoscale features will be considered on a case by case basis. Sanders can understand the cautious pace: "Because of our intimate relation to our customers, we have to take them into account even though it runs counter to our scientific inclinations." ■ RICHARD A. KERR

Now All Astronomers Need Is the Maple Syrup

Radio astronomers searching the outer reaches of the universe believe they have discovered a flapjack fit for a cosmic Paul Bunyan. Peering four-fifths of the way back to the Big Bang with the Very Large Array (VLA), the 27-antenna radio telescope on the Plains of San Agustin in New Mexico, Juan Uson, Durgadas Bagri, and Timothy Cornwell of the National Radio Astronomy Observatory have spotted a vast, flattened structure of hydrogen that, they calculate, contains as much mass as a present-day cluster of galaxies.

The mass similarity is no coincidence, the investigators think. They believe their gassy pancake is the progenitor of a cluster of galaxies. If so, the observation would be the first direct evidence to support a controversial theory proposed in the 1970s by Yakov Zel'dovich of the University of Moscow: namely that clusters and superclusters of galaxies took shape as clouds of primordial gas well before the birth of their constituent galaxies and stars.

Many astronomers are intrigued by the observation. "It's an impressive result," says theorist Joseph Silk of the University of California, Berkeley. But not everyone is convinced that Uson and his colleagues have seen an embryo galactic cluster. And even astronomers who accept the observation at face value aren't ready to endorse Zel'dovich's "top down" notion of the formation of these giant cosmic structures on the strength of a single sighting.

Although Zel'dovich's theory was warmly received soon after it was proposed, it fell from favor in the 1980s. A major reason, notes Princeton cosmologist James Peebles, is that "there are galaxies that are not in big collections—our own galaxy is an example." Peebles and many other cosmologists think these strays formed on their own in a "bottom up" process, in which smaller structures like galaxies formed first and only later migrated into larger clusters (see *Science*, 22 November, p. 1106).

But Uson and his colleagues didn't give up on the Zel'dovich model, and they saw a way to test it directly with the VLA. "This is one part of cosmology where there were no data, but we felt they might lie within our sensitivity," Uson recalls. Zel'dovich had proposed that soon after the Big Bang, the primordial gas broke up into vast clouds, which gradually collapsed along their shortest dimension into sheets—so-called Zel'dovich pancakes—before fragmenting into protogalaxies. In 1984, receivers sensitive to the radio wavelengths that should emanate from hydrogen clouds in the infant universe, at red shifts of 3.2 to 3.6, began to be retrofitted to the VLA. Uson and his colleagues saw their opportunity to mount a concerted search for Zel'dovich's postulated pancakes.

Over the past 3 years, they've aimed the VLA in 12 different directions; they detected their first candidate pancake this spring. As they describe it in this week's *Physical Review Letters*, the cloud is some 3 million light-years across, and it's probably still a pancake in the making. "As far as we can tell," says Uson, "it's collapsing mostly along the line of sight." From the flux of radio emissions, he and his colleagues estimate that this primordial cloud wields the mass of 100 trillion suns.

Those dimensions are close to what Zel'dovich predicted for his progenitor structures, but Peebles is skeptical about the match-up. "I believe the observation," he says, "but I'm still not convinced that it's a Zel'dovich pancake." Instead of a vast, smooth cloud of gas, he says, "I could imagine that they're seeing a collection of young galaxies, each of which has a lot of atomic hydrogen." In that case, the "cloud" could have taken shape in good bottom-up fashion, when galaxies that had formed on their own flocked together.

Even if the structure does turn out to be a true Zel'dovich pancake—a smooth sheet of gas that has not yet broken up into finer-scale structures—Silk says he still would not reconsider the top-down theory. The bottom-up scenario leaves room for a few very large-scale structures to form in the early universe, and Silk thinks the Uson group may simply have been lucky enough to catch one. He does grant, however, that "if the universe were swimming with these things, one might have to take another look at the top-down theory." That's a possibility that Uson and his colleagues mean to test, as they push on with their pancake search. ■ TIM APPENZELLER