

Ever-cheaper computing is making the prediction of the most destructive weather a local affair

# Storm-in-a-Box Forecasting

The two tornadoes bearing down on Fort Worth, Texas, weren't a complete surprise: The National Weather Service (NWS) had alerted the public a few hours earlier that storms likely to spawn twisters might be on the way. But the tornadoes, rain, and baseball-size hail of 28 March 2000 still went on to kill five people. The alert helped, but more details and greater confidence could have helped more.

Part of the problem was that a half-day earlier, NWS's weather forecasting models being run back East—the basis for NWS as well as commercial forecasts across the United States—didn't give a clue that North Texas was in for any untoward weather. Globe-spanning computer models run on central supercomputers are increasingly adept at predicting the broad weather picture (see sidebar). But they often miss violent, small-scale weather such as tornadic storms developing over Texas, thunderstorms appearing on the coast of Florida, or the details of a turbulent North Pacific storm slamming into the rugged mountains of Washington state.

The answer to violent little surprises such as the storm that hit Fort Worth, an increasing number of meteorologists say, is weather forecasting models that focus on regional weather in unprecedented detail and are fine-tuned to local conditions. "Weather is local, with a lot of local influences," says meteorologist Kelvin Droegemeier

of the University of Oklahoma (OU), Norman. "Many of us feel the future of weather forecasting is regional weather models run locally." That future could soon be here.

Take the Advanced Regional Prediction System (ARPS) developed by Droegemeier and his OU colleagues. It can take in the broad picture of the weather around North Texas in the hours before the Fort Worth tornadoes, add in local details such as Doppler radar data, and then predict with striking verisimilitude the development of the intense storms that crossed Fort Worth in the following hours (see figure). And, fueled by faster, cheaper computing power, better predictions should be on the way. A new regional model—the Weather Research and Forecasting (WRF, pronounced "warf") model—that incorporates and improves on the best features of current models will be

supplanting the leading regional models later this year.

How soon local modeling will become widespread, however, remains to be seen. A few scattered local centers are already making routine storm-scale—"mesoscale"—forecasts, and NWS's National Centers for Environmental Prediction (NCEP) in Camp Springs, Maryland, will be running the WRF over various U.S. regions. But the WRF has no immediate prospects of being tuned to local conditions and run routinely at regional NWS forecast offices.

### Getting up close

Mesoscale forecasting is global modeling writ small, with an added dollop of local flavor. Because global models have only finite computing power, they must use a broad-brush approach. First they paint a picture of the current weather using observations from around the world. This snapshot is a fuzzy one, like a coarsely executed pointillist painting, because the model records the state of the weather only at widely separated points in the atmosphere. The points come at the intersections of the lines of checkerboard grids stretched across the surface and stacked up through the atmosphere. These grid points are separated by 40, 60, or more kilometers horizontally.

A global model knows the weather only at widely spaced grid points because it couldn't handle any more detail at the next step in the forecasting process. After forming its initial picture of the weather, it must calculate how the atmosphere would evolve under the laws of physics at each of thousands of grid points, minute by minute into the future, for hours and days on end. Such global forecasting at even 40-kilometer resolution takes the biggest supercomputer that a rich nation's weather service can afford. Just doubling the resolution globally to 20 kilometers

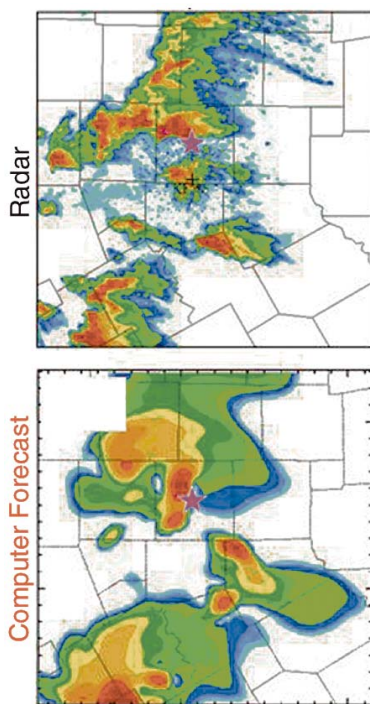


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**Bingo.** When forecasters included local weather observations in a high-resolution model that had been optimized to local conditions, they were able to forecast tornadic storms 2 hours before they hit Fort Worth, Texas (fuchsia star).

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would require eight times more computer power. Such global model forecasts—in the United States, NCEP runs them daily—form the starting point for forecasts issued by NWS forecast offices as well as for the forecast maps put out by private forecasters, from Accuweather and The Weather Channel to the local TV meteorologist.

Mesoscale modelers get beyond the fuzzy global forecast by starting with the portion of the global model's initial weather picture that covers their region, increasing model resolution there, and plugging in local weather observations. Mesoscale Model 5 (MM5), the most widely used mesoscale model among researchers, now in its fifth generation, was developed at Pennsylvania State University, University Park, and the National Center for Atmospheric Research (NCAR) in Boulder, Colorado.

Thirteen years after its debut, MM5's most ambitious operation is at the University of Washington (UW), Seattle, under the supervision of meteorologist Clifford Mass. Run within the 13-member Northwest Modeling Consortium, which includes UW and NWS, MM5 tackles forecasting over a checkerboard grid box with just 4-kilometer spacing that covers only the U.S. Pacific Northwest. MM5 forecasts are distributed to consortium members, who use them in turn to forecast regional environmental conditions such as air quality and stream flow. The MM5 forecasts are also posted on the Web.

### The mesoscale edge

Concentrating the forecasting effort in one small region has several advantages. One is that the forecaster can incorporate weather observations that never make it into a global model. In the case of the Pacific Northwest, additional observations that improve the first 6 hours of a forecast can come from the NorthwestNet—a compilation of more than two dozen regional networks of surface observations sent from ships, ferries, schools, buoys, and ground stations monitoring everything from farms to mountain avalanche areas. Regional observations can also come from commercial aircraft, NWS Doppler radar, and an upward-looking radar that profiles temperatures and winds with altitude. In the case of the Fort Worth tornado, the inclusion of Doppler radar data lets ARPS accurately forecast the tornadic storms that developed just to the north of Fort Worth; without Doppler, the model would never see them coming.

Another mesoscale-model advantage is its high resolution. MM5's 4-kilometer resolution, notes meteorologist-in-charge Christopher Hill of the NWS forecast office in Seattle, allows a more realistic simulation of storms and their winds interacting with the

mountainous terrain of the region. The more detailed the mountains in the model, for example, the more likely moisture-laden model winds will drop the right amount of rain or snow as they rise over the model mountains.

A third edge for mesoscale modeling—one not achieved in every forecasting operation—is the adaptation of the model to local conditions. “One-size-fits-all numerical weather prediction is not necessarily the best approach,” Mass has written. “What’s appropriate in one place,” he says, “may not be appropriate in another.” NWS’s mesoscale model Eta, for example, runs a large grid with 12-kilometer spacing that can be placed over the eastern, central, or western lower 48 states to sharpen forecasters’ views of approaching storms. Nothing about the model is changed between one region and



**Out of a fix.** A forecast model tailored to the Antarctic helped rescuers extract personnel from the supply ship *Magdalena Oldendorff* (left).

the next, however, leading to degraded performance in the rugged, high-standing West, Mass notes. Eta's grid in effect runs into mountains there rather than following the topography. That creates computational problems that cause unnatural features, such as too much blocked air flow.

A good example of the need for local adaptation came when researchers at NCAR and Ohio State University in Columbus wanted to run MM5 over high southern latitudes to assist air and sea operations supplying the U.S. stations in Antarctica. Because the Antarctic environment is so different from that of the central United States, where MM5 was developed, they had to adjust a half-dozen different atmospheric processes that move model heat and radiation among ice, snow, clouds, and air. Indeed, they modified it so heavily that they gave it a new name: the Polar MM5.

The heavy tuning of Polar MM5 seems to have paid off. In April 2001—early winter in Antarctica—Polar MM5 predicted a break in the blowing snow at the U.S. South Pole sta-

tion, allowing an evacuation plane to land in darkness on an unlighted runway to evacuate an ailing station staff member. And in June 2002, Polar MM5 helped guide a rescue ship around a threatening storm to reach the German supply ship *Magdalena Oldendorff* trapped in Antarctic sea ice with 28 crewmembers and 79 Russian scientists. All were safely removed, the last of them during an accurately predicted window of favorable weather on 1 July.

### Detailed but cheap

The advent of mesoscale-model forecasting—from the Pacific Northwest to Antarctica—has been a grassroots movement fueled by the plummeting cost of high-speed computing. “The world has changed,” says Mass. “Now you can have tremendous computing power locally.”

The workhorse in the Northwest is a cluster of 40 Linux 2.8-giga-hertz processors with a total of 6 terabytes of disk storage, all of which cost a total of \$80,000. “I have as much computer power as NCEP had a few years ago,” he says, power that cost NWS millions per year.

Patrick Welsh, science officer at the NWS forecast office in Jacksonville, Florida, agrees that “the revolution in computing has

been phenomenal.” With a \$25,000 Coastal Storms Initiative grant from the National Oceanic and Atmospheric Administration, parent agency of NWS, “we can build a cluster with the throughput of a super-computer of the mid-'90s,” says Welsh. The resulting WRF forecasts for the greater North Florida area captured the local sea-breeze winds better than ever before, says Welsh. That matters in North Florida because it's the sea breeze pushing inland that often sets off the region's abundant thunderstorms. With locally run mesoscale modeling, Jacksonville forecasters now often forecast afternoon thunderstorms to within a few minutes of their occurrence. Similarly cost-effective operations using MM5 have been applied to forecasting how cold it will get on a U.S. Army test range in Alaska; how much snow would fall at the 2002 Winter Olympic Games in Salt Lake City, Utah; and what combat conditions might have been like in the fall of 2001 in Afghanistan.

Although ever-cheaper computing was helping spread the local operation of

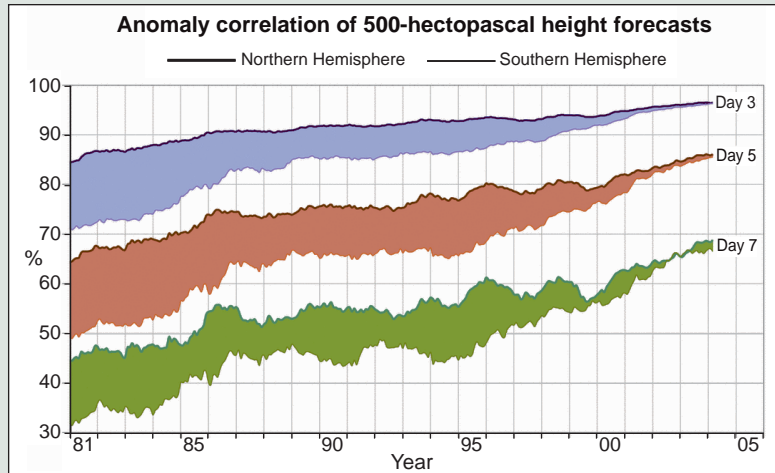
## No End Yet to Forecast Advances

While weather forecasters have been sharpening their views of tomorrow's weather in their own backyards (see main text), other researchers have been keeping up their seemingly inexorable improvement in forecasting next week's big picture of the weather. "The harder you work on each aspect of the forecast system, the

ford. The forecasts are graded on how well they predict only the general weather patterns around the world: the position and intensity of fair-weather high-pressure systems and stormy lows. Lower quality but still useful forecasts have been extended from 5.5 days to almost 8 days. "I hope we'll see useful 10-day forecasts by the end of this decade, in the winter at least," says Hollingsworth.

The most dramatic improvement of the past decade came in the Southern Hemisphere. Any computer forecast must begin with a picture of the current weather; the more accurate the initial picture, the more accurate the forecast. But the predominance of ocean over land in the Southern Hemisphere has always meant a dearth of places from which to make weather observations. In the 1990s, the advent of sophisticated weather satellites and of new ways of assimilating their observations into forecasts accelerated improvements in the south, says Hollingsworth. In the past 3 or 4 years, the gap between forecast skill in the north and south has closed. Over both hemispheres, forecasting into next week also benefited from more detailed model simulations and more realistic representations of a model's physical processes, such as cloud formation, says Hollingsworth.

All these improvements required ever-increasing computer power and new and more efficient ways to do the required numerical computations. But human forecasters are still staying ahead of their machines, says James Hoke of the National Weather Service's National Centers for Environmental Prediction in Camp Springs, Maryland. Knowing the shortcomings of the models, human forecasters are adding 10% to 15% to the skill of forecasts over that of the models alone, he says. But there's a theoretical limit to prediction—whether machine or human—somewhere around 14 days, when atmospheric chaos prevails. And as models continue to improve, Hoke says, the amount of room available for forecast improvement by humans will eventually shrink. Someday, the machines could take over. **—R.A.K.**



**Up, up, up.** Forecast accuracy out to 7 days ahead is still rising. The gap between the north and south (color) has closed while overall accuracy has increased.

better the forecasts become," says forecast model developer Anthony Hollingsworth of the European Centre for Medium-Range Weather Forecasts in Reading, England.

In its nearly 25-year history, work on medium-range forecasting by computer models has extended the length of high-quality forecasts from about 2 days to about 4 days, says Hollingsworth. That improvement required that the biggest weather forecasting models be run on the most powerful supercomputers governments could af-

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mesoscale models (mainly MM5), the mesoscale community still had a problem. Researchers (mainly in the universities) and operational forecasting modelers (mainly at NCEP and in the military) "weren't using the same models," says Mass, "so the research developments weren't going into the operational models. It was not healthy."

The solution to the community split is going to be the WRF model now in the last stages of development and testing. The product of a community collaboration involving NCAR and six government agencies including NWS, WRF builds on MM5 and Eta with new and improved versions of software, numerical calculation techniques, approximations of physical processes, and construction of an initial weather picture.

Perhaps most promising is the ability of WRF users to plug in different model components as they are developed. "That has the benefit of greatly facilitating moving advances made in the research community into the operational configuration," says Joseph Klemp of NCAR, who has coordinated the WRF project. This fall, WRF

will replace the regional version of Eta, says Geoffrey DiMego, mesoscale branch chief at NCEP. Next fall, it will replace the Eta version whose grid encompasses all of North America and in 2006 the version used to forecast hurricanes. Most MM5 users outside NWS will be transitioning to WRF as further development of MM5 ends and NCAR training support for MM5 users is eliminated.

### Local is good

Broad use of WRF will accelerate advances in mesoscale modeling, all agree, but many modelers would like to see more regional modeling being done locally. "NCEP is always going to be the center for modeling," says NWS's Welsh. "But I believe there's a place in weather forecast offices for a localized, customized model for a particular part of the country. I don't know that every part of the country needs one; I'm convinced Florida does."

Mass agrees on the need for regionally based forecasting. "Each part of the country has different needs; the way you do the

modeling is different," he says. A local mesoscale-model forecaster is also more likely to find enough local observations to feed the model, he says. And a local forecaster will be close to those who use the forecasts: a state water agency predicting river flows, a state environmental agency predicting air quality, or a U.S. Forest Service office planning controlled burns. Those connections would also make it easier to raise the \$200,000 to \$300,000 needed from diverse sources each year for operational support of a forecasting system such as the Northwest Modeling Consortium.

Such local funding will likely be vital to the continued expansion of mesoscale forecasting, at least for a few years. According to Nelson Seaman of NWS in Silver Spring, Maryland, NWS support for WRF at the regional level will consist of sequential trial runs at a half-dozen sites around the country during the next few years. So far, nothing is being promised beyond that to accelerate the devolution of forecasting power into a truly local affair.

**—RICHARD A. KERR**