New Technology Allows Better Extreme Weather Forecasts

New technology that increases the warning time for tornadoes and hurricanes could potentially save hundreds of lives every year

By Jane Lubchenco, Jack Hayes on May 1, 2012

After the deafening roar of a thunderstorm, an eerie silence descends. Then the blackened sky over Joplin, Mo., releases the tentacles of an enormous, screaming multiple-vortex tornado. Winds exceeding 200 miles per hour tear a devastating path three quarters of a mile wide for six miles through the town, destroying schools, a hospital, businesses and homes and claiming roughly 160 lives.

Nearly 20 minutes before the twister struck on the Sunday evening of May 22, 2011, government forecasters had issued a warning. A tornado watch had been in effect for hours and a severe weather outlook for days. The warnings had come sooner than they typically do, but apparently not soon enough. Although emergency officials were on high alert, many local residents were not.

The Joplin tornado was only one of many twister tragedies in the spring of 2011. A month earlier a record-breaking swarm of tornadoes devastated parts of the South, killing more than 300 people. April was the busiest month ever recorded, with about 750 tornadoes.

At 550 fatalities, 2011 was the fourth-deadliest tornado year in U.S. history. The stormy year was also costly. Fourteen extreme weather and climate events in 2011—from the Joplin tornado to hurricane flooding and blizzards—each caused more than $1 billion in damages. The intensity continued early in 2012; on March 2, twisters killed more than 40 people across 11 Midwestern and Southern states.

Tools for forecasting extreme weather have advanced in recent decades, but researchers and engineers at the National Oceanic and Atmospheric Administration are working to enhance radars, satellites and supercomputers to further lengthen warning times for tornadoes and thunderstorms and to better determine hurricane intensity and forecast floods. If the efforts succeed, a decade from now residents will get an hour's warning about a severe tornado, for example, giving them plenty of time to absorb the news, gather family and take shelter.

The Power of Radar

Meteorologist Doug Forsyth is heading up efforts to improve radar, which plays a role in forecasting most weather. Forsyth, who is chief of the Radar Research and Development division at NOAA's National Severe Storms Laboratory in Norman, Okla., is most concerned about improving warning times for tornadoes because deadly twisters form quickly and radar is the forecaster’s primary tool for sensing a nascent tornado.

Radar works by sending out radio waves that reflect off particles in the atmosphere, such as raindrops or ice or even insects and dust. By measuring the strength of the waves that return to the radar and how long the round-trip takes, forecasters can see the location and intensity of precipitation. The Doppler radar currently used by the National Weather Service also measures the frequency change in returning waves, which provides the direction and speed at which the precipitation is moving. This key information allows forecasters to see rotation occurring inside thunderstorms before tornadoes form.

In 1973 NOAA meteorologists Rodger Brown, Les Lemon and Don Burgess discovered this information’s predictive power as they analyzed data from a tornado that struck Union City, Okla. They noted very strong outbound velocities right next to very strong inbound velocities in the radar data. The visual appearance of those data was so extraordinary that the researchers initially did not know what it meant. After matching the data to the location of the tornado, however, they named the data “Tornadic Vortex Signature.” The TVS is now the most important and widely recognized metric indicating a high probability of either an ongoing tornado or the potential for one in the very near future. These data enabled longer lead times for tornado warnings, increasing from a national average of 3.5 minutes in 1987 to 14 minutes today.

Although Doppler radar has been transformative, it is not perfect. It leaves meteorologists like Forsyth blind to the shape of a given particle, which can distinguish, say, a rainstorm from a dust storm. Ironically, the trajectory of his career path changed when a failed eye exam led him from U.S. Air Force pilot ambitions to a career in meteorology. Since then, Forsyth has focused on radar upgrades that give forecasters a better view of the atmosphere.

One critical upgrade is called dual polarization. This technology allows forecasters to differentiate more confidently between types of precipitation and amount. Although raindrops and hailstones may sometimes have the same horizontal width—and therefore appear the same in Doppler radar images—raindrops are flatter. Knowing the difference in particle shape reduces the guesswork required by a forecaster to identify features in the radar scans. That understanding helps to produce more accurate forecasts, so residents know they should prepare for hail and not rain, for example.

Information about particle size and shape also helps to distinguish airborne bits of debris lofted by tornadoes and severe thunderstorms, so meteorologists can identify an ongoing damaging storm. Particle data are especially important when trackers are dealing with a tornado that is invisible to the human eye. If a tornado is cloaked in heavy rainfall or is occurring at night, dual polarization can still detect the airborne debris.

The National Weather Service is integrating dual-polarization technology—which is also helpful for monitoring precipitation in hurricanes and blizzards—into all 160 Doppler radars across the nation, expecting to finish by mid-2013. At the same time, NOAA personnel are training forecasters to interpret the new images. The Weather Forecast Office in Newport/Morehead City, N.C., was the first to scan a tropical cyclone using such radar when Hurricane Irene made landfall in North Carolina in 2011. During that storm, dual-polarization radars proved more accurate in detecting precipitation rates, and therefore predicting flooding, than conventional Doppler radars farther north. The improved capabilities surely saved lives in the Carolinas; farther up the coast, without this technology, Hurricane Irene was deadlier despite early warnings, claiming nearly 30 lives.

NOAA research meteorologist Pam Heinselman believes another advanced radar technology used by the U.S. Navy to detect and track enemy ships and missiles has great potential to improve weather forecasting as well. Heinselman leads a team of electrical engineers, forecasters and social scientists at the National Weather Radar Testbed in Norman, Okla., focused on a technology called phased-array radar.

Current Doppler radars scan at one elevation angle at a time, with a parabolic dish that is mechanically turned. Once the dish completes a full 360-degree slice, it tilts up to sample another small sector of the atmosphere. After sampling from lowest to highest elevation, which during severe weather equates to 14 individual slices, the radar returns to the lowest angle and begins the process all over again. Scanning the entire atmosphere during severe weather takes Doppler radar four to six minutes.

In contrast, phased-array radar sends out multiple beams simultaneously, eliminating the need to tilt the antennas, decreasing the time between scans of storms to less than a minute. The improvement will allow meteorologists to “see” rapidly evolving changes in thunderstorm circulations and, ultimately, to more quickly detect the changes that cause tornadoes. Heinsel-man and her team have demonstrated that phased-array radar can also gather storm information not currently available, such as fast changes in wind fields, which can precede rapid changes in storm intensity.

Heinselman and others believe phased-array technology alone could extend tornado warnings to more than 18 minutes, but much more research and development needs to be done. Ideally, the phased-array system would have four panels that emitted and received radio waves, to provide a 360-degree view of the atmosphere—one each for the north, south, east and west. Researchers in Norman have made only one-panel systems operable for weather surveillance, and it is likely to be at least a decade before phased arrays become the norm across the country.

Eyes in the Sky

Of course, even the best radars cannot see over mountains or out into the oceans, where hurricanes form. Forecasters rely on satellites for these situations and also rely on them to provide broader data that supplement the localized information from a given radar. NOAA's weather satellites supply more than 90 percent of the data that go into daily and long-range forecasts, and they are critical in providing alerts of severe weather potential multiple days in advance. To improve the delivery of this essential environmental intelligence, NOAA will deploy a range of new technologies in the next five years.

Without more detailed satellite observations, extending the range of accurate weather forecasts—especially for such extreme events as hurricanes—would be severely restricted. Monitoring weather requires two types of satellites: geostationary and polar-orbiting. Geostationary satellites, which stay fixed in one spot at an altitude of about 22,000 miles, transmit near-continuous views of the earth's surface. Using loops of pictures taken at 15-minute intervals, forecasters can monitor rapidly growing storms or detect changes in hurricanes (but not tornadoes).

Polar satellites, which orbit the earth from pole to pole at an altitude of approximately 515 miles, give closer, more detailed observations of the temperature and humidity of different layers of the atmosphere. A worldwide set of these low Earth orbit (LEO) satellites covers the entire globe every 12 hours.

NOAA plans to launch a new series of LEO satellites this decade, as part of the Joint Polar Satellite System, with updated hardware, fitted with more sophisticated instruments. Their data will be used in computer models to improve weather forecasts, including hurricane tracks and intensities, severe thunderstorms and floods. The suite of advanced microwave and infrared sensors will relay much improved three-dimensional information on the atmosphere's temperature, pressure and moisture, because rapid changes in temperature and moisture, combined with low pressure, signify a strong storm. Infrared sensors provide these measurements in cloud-free areas, and microwave sensors can "see through clouds" to the earth's surface.

In April 2011, five days before a powerful storm system tore through six southern states, NOAA's current polar-orbiting satellites provided data that, when fed into models, prompted the NOAA Storm Prediction Center to forecast "a potentially historic tornado outbreak." The center elevated the risk to the highest level at midnight before the event. This level of outlook is reserved for the most extreme cases, with the least uncertainty, and is only used when the possibility for extremely explosive storms is detected. The new LEO satellites should allow such predictions as much as five to seven days before a storm.

Geostationary satellites will improve, too. Advanced instruments that will image the earth every five minutes in both visible and infrared wavelengths will be onboard the GOES-R series of satellites to be launched in 2015. They will increase observations from every 15 minutes to every five minutes or less, allowing scientists to monitor the rapid intensification of severe storms. The GOES-R satellites will also provide the world's first space view of where lightning is occurring in the Western Hemi-sphere. The lightning mapper will help forecasters detect jumps in the frequency of in-cloud and cloud-to-ground lightning flashes. Research suggests that these jumps occur up to 20 minutes or more before hail, severe winds and even tornadoes.

Billions of Data

Each of the new radar technologies and satellites could improve warning times by several minutes, but incorporating the data derived from all these systems into forecasting computer models could provide even more time. Warnings for tornadoes, for example, could be issued up to an hour in advance. That is the kind of lead time that would have made a big difference in Joplin.

Forecasting models are based on physical laws governing atmospheric motion, chemical reactions and other relationships. They crunch millions of numbers that represent current weather and environmental conditions, such as temperature, pressure and wind, to predict the future state of the atmosphere. Imagine a grid that lies over the planet's surface. Imagine another one a few hundred feet above that—and another and another, in layer after layer, all the way to the top of the stratosphere some 30 miles up. Millions of lines of code are needed to translate the billions of grid points under observation.

A typical forecast model today uses grids at the surface that run about five to 30 miles square. The smaller the squares, the higher the model's resolution and the better it will be at detecting small-scale atmospheric changes that could spawn storms. Processing more data points, however, requires faster supercomputers.

Advances in modeling also require talented people who can integrate all these data and interpret them. Bill Lapenta, acting director of NOAA's Environmental Modeling Center, heads that translation effort, which churns out numerical forecasts for 12, 24, 36, 48 and 72 hours ahead and beyond. Meteorologists compare NOAA's models with others from international modeling centers to come up with the forecasts seen on the Web or the evening news.

NOAA supercomputers in Fairmont, W.Va., can process 73.1 trillion calculations a second. But Lapenta believes faster speeds are possible, which will allow the models to run at even smaller scales. For example, grids of just one mile square would enable models to simulate the small-scale conditions that catapult a routine thunderstorm or hurricane into a monster. NOAA plans to access some of the latest supercomputers at Oak Ridge National Laboratory to begin to build such models. Lapenta hopes such high-resolution models might begin to appear by 2020.

Lapenta foresees a day in the next decade when the increasing capabilities of new radars and satellites will be coupled with an evolving generation of finely detailed weather-prediction models running in real time on computers at speeds exceeding a quintillion computations a second. To make them a reality, scientists such as Lapenta are working on the mathematical, physical and biogeochemical relations that need to be encoded in a way that enables those relations to work together seamlessly.

If major NOAA investments in this “brainware” pay off, forecasters will not have to wait for a radar image to detect an actual storm before issuing a warning with 14 or 18 minutes of lead time. Instead they will be able to issue tornado, severe thunderstorm and flash-flood warnings based on highly accurate model forecasts produced well in advance, giving the public 30 to 60 minutes to take safety precautions.

Better Science, Better Decisions

With all these improvements, meteorologists such as Gary Conte in the New York City Weather Forecast Office will be able to predict more accurately, with longer lead times, weather hazards that can shut down the city, such as storms with snow and ice. Severe weather outlooks will extend beyond five days, hurricane forecasts beyond seven days, and the threat of spring floods will be known weeks in advance. This vision for a weather-ready nation is motivated by the desire to avoid the unmitigated disasters of 2011.

The goal is that by 2021 the rebuilt and thriving city of Joplin would receive a severe tornado warning more than an hour in advance. Families would have more time to gather and get to a safe room. Nursing homes and hospitals would be able to transfer residents and patients to shelter. Retailers would have time to get employees to safety and close up shop. Cell phones would thrum with multiple messages to seek shelter while local meteorologists broadcast similar warnings on television and radio. The clarion call of tornado sirens would reinforce the urgency of these warnings. As a result, even nature’s most powerful tornado would pass through town without any loss of life.

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