Winds of change

Hurricanes can grow more intense in a matter of hours, but exactly why remains a mystery. Mark Schrope flies into the eye of a storm to investigate.

In a spin: understanding what drives changes in the intensity of a storm means gathering data from the heart of hurricanes.

J. SCHMALTZ/MODIS/NASA GSFC

In the space of one October day, Hurricane Wilma escalated from a tropical storm to become the strongest hurricane from the Atlantic basin on record. It was a shift that no one saw coming, and Mexico's Yucatán Peninsula bore the unexpectedly strong brunt of the storm.

Over the past few decades, hurricane forecasters have dramatically improved their predictions of the paths that storms might follow. The accuracy of such 'track predictions' made 72 hours before a hurricane reaches land, for instance, have improved by more than 50% since 1970, according to the US National Oceanic and Atmospheric Administration (NOAA). But over the same period, models for hurricane intensity have remained relatively primitive. The turbulence that drives the internal dynamics of a hurricane is mind-bogglingly complex. And without understanding that turbulence, and its effects on a storm's intensity, forecasters haven't really been able to improve their overall long-range forecasts.

This year, correcting that situation became a high priority for hurricane research centres across the United States. During the most active Atlantic hurricane season on record, several new research programmes have wrestled with the question of intensity. The move may come not a moment too soon: two recent studies have suggested that hurricanes might grow more intense in the future because of climate change[1,2]. If so, the millions of people who live in vulnerable coastal areas will be at greater risk than ever, further underscoring the importance of good forecasts.

"If you have accurate track and intensity forecasts that people can rely on, it will have a huge societal benefit," says Richard Anthes, a hurricane specialist and president of the University Corporation for Atmospheric Research in Boulder, Colorado. "You would save enormous amounts of energy and protect huge numbers of lives."

One of the most extensive new programmes is a three-year, US$3-million plan to investigate how, why and when a hurricane's intensity changes. Funded by the National Science Foundation, the Hurricane Rainband and Intensity Change Experiment (RAINEX) combines a massive set of plane observations with experimental models. During August and September, RAINEX coordinated three aircraft equipped with Doppler radar to fly into the hearts of storms. All of the planes were WP-3D Orion 'hurricane hunters', more commonly known as P-3s. Two of them were run by NOAA; the third was owned by the Navy and carried ELDORA, the most advanced Doppler radar currently on hurricane duty.

Whirlwind start

Four years ago, when researchers first proposed RAINEX, they had no idea that their first year of action would bring them a nearly ideal set of storms. As coastal residents were battered by hurricane after hurricane, the RAINEX team gathered a bounty of data that may one day help protect against such devastation.

In August, Hurricane Katrina tantalized forecasters as its bands of rain organized themselves symmetrically around the storm's eye, and then failed to develop into a feature that could have weakened the storm's intensity. In September, Hurricane Ophelia spun seemingly endlessly along the US southeastern coast, allowing the team to observe how a storm maintains its intensity over relatively cold water. Later that month, Hurricane Rita suddenly blew up in strength to reach the highest, category 5, rating.

Aboard one of the P-3 flights into the heart of Rita after it had subsided to category 2, Brad Smull from the University of Washington in Seattle described the hurricane's unpredictability. "During an eight-hour flight, the storm went from category 3 to category 5," he said over the din of the plane's engines and the hurricane. "That's very exciting." Repeatedly flying through the hurricane to reach Rita's eye brought its own kind of excitement, and it was difficult for me, a first-timer on the plane, to appreciate how relatively weak the storm had become. At times I had to clutch the handrail running the length of the P-3's ceiling to steady myself as the plane bucked.

One of the hypotheses that RAINEX is testing is the idea that hurricanes grow in intensity because the bands of rain that swirl around the storm inject energy into the storm's eye. When the winds immediately around the eye —

known as the eyewall — are strengthening, rainbands tend to spiral into the eye. At other times, the outer rainbands can begin to form their own circle, or secondary eyewall, around the eye. If this happens, the secondary eyewall often starves the inner eye of energy so that it begins to fall apart. And in some cases the secondary eyewall lasts long enough to become the primary eyewall, and even begins to strengthen further.

Knowing exactly when and how this eyewall replacement happens is important for hurricane forecasts. But finding out means studying the flow of energy within a storm, which is no simple task.

Hurricanes are fuelled when evaporation transfers heat from the ocean into the atmosphere. The resulting water vapour releases energy as it rises and condenses into clouds; this process heats the surrounding air, causing it, too, to rise. All this upward movement of air causes the pressure below it to drop and winds to start blowing.

Surprisingly, estimates suggest that there is little difference between the amount of energy transferred from the ocean to a tropical storm and to a category 5 hurricane. But scientists are hard-pressed to explain why, in a hurricane, much of the transfer is concentrated in the relatively small area of the eye. These zones of energy transfer are crucial to controlling a storm's shifts in intensity, but are hard to study because they can be small and move around rapidly.

Researchers collect data (above) as they fly through Hurricane Rita onboard a P-3 plane (below).

M. SCHROPE

Flight coordinators

Getting a good picture of how the eyewall and rain bands interact requires observing both structures simultaneously. But typical hurricane reconnaissance flights can't do that because they mainly crisscross a storm's eye. The RAINEX plan uses three planes: one flying through the eye, one flying on the inside edge of the main rainband, and the other taking the outside edge of the band — something that had never been done before. "It's really fantastic that we have been able to accomplish this," says Smull.

Coordinating this aeronautical dance wasn't easy. The planes maintained a satellite connection to a computer chat room, so that scientists in the air could 'talk' to each other and to the command centre in Miami, Florida. Flight paths were constantly updated based on radar data as well as the chat-room information. "It was a very nerve-wracking process," says Shuyi Chen of the University of Miami, who with Robert Houze of the University of Washington is principal investigator for RAINEX.

Each plane uses Doppler radar to gather core data about cloud structure and winds, which reveal locations of greatest turbulence. But expanding the radar's information into a three-dimensional view of the storm requires vertical profiles of temperature and wind. The planes can't fly straight down to acquire that, nor can they fly safely at levels below 5,000 feet, so they use instruments called dropsondes. At key points the plane releases dropsondes, which radio back real-time information on temperature, pressure and wind speed until they hit the water.

But improving understanding of hurricane intensity takes more than data from planes. "Observation doesn't really give you the full picture," says Wen-Chau Lee, a RAINEX investigator at the National Center for Atmospheric Research in Boulder. "Even with eight-hour coordinated flights, we're still getting only snapshots, and we don't sample the storm for the entire 24 hours."

Whipping up a storm

Making sense out of these snapshots requires computer modelling. At the operations centre in Miami, researchers use experimental models to compare their predictions with data arriving from the hurricane flights.

If scientists could better understand why hurricanes change intensity, they might also be able to improve their predictions of a storm's path, says Lee. Large-scale environmental factors play the biggest role in influencing where a hurricane goes, but internal dynamics are also important.

"I see no fundamental reason why we shouldn't be able to predict hurricane intensity much better." — Richard Anthes

Along with RAINEX, various other projects under way this year will help hurricane researchers to answer the many questions about intensity changes. Several fall under the umbrella of the Intensity Forecasting Experiment (IFEX), which is managed by NOAA's Hurricane Research Division in Miami.

IFEX covers a variety of projects, including studies of tropical cyclones forming in their earliest stages in the eastern Pacific, as well as storms decaying in the northern Pacific. Historically, researchers have tended to study only mature storms, leading to deficiencies in understanding the complete storm cycle. Another IFEX programme has been testing unmanned aircraft for monitoring the lower levels of storms at resolutions much higher than is possible with dropsondes.

Many hurricane experts are confident that all this work will soon pay off. Anthes, for one, says that better observational and satellite data, combined with improved computers, should help to improve intensity forecasts in coming years. "I see no fundamental reason why we shouldn't be able to predict intensity much better," he says. "We just need very high-resolution models and good understanding of cloud physics and dynamics."

One such high-resolution tool is already under development at NOAA's Environmental Modeling Center in Camp Springs, Maryland. Called the Hurricane Weather Research and Forecasting model, it is scheduled to begin operation in 2007. It will incorporate the conclusions of RAINEX, IFEX and other ongoing projects, and will have nearly an order of magnitude better resolution than the main models currently in use. For coastal residents who are wary of the coming hurricane seasons, such improvements can't come soon enough. ■

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1. Emanuel, K. *Nature* 436, 686–688 (2005).
2. Webster, P. J., Holland, G. J., Curry, J. A. & Chang, H.-R. *Science* 309, 1844–1846 (2005).