Launching a new field of science is always tricky, but starting up the study of hurricane behavior over the decades—in the wake of Katrina—has proved challenging indeed.

**A Tempestuous Birth for Hurricane Climatology**

**MONTEREY, CALIFORNIA**—It’s not every day one can witness the inception of a new field. Researchers attending the 27th Conference on Hurricanes and Tropical Meteorology late last month got their usual diet of potential vorticity analyses and Madden-Julian oscillations. But they also debated a newborn science created to assess whether tropical cyclones—variously called hurricanes, typhoons, or cyclones—have strengthened under global warming.

Until *Science* and *Nature* published two papers last year contending that tropical cyclones around the world had strengthened, few scientists paid much attention to long-term variations in such storms. In those papers, a couple of academic meteorologists took the long view of tropical cyclone records compiled day-by-day by weather forecasters. From those weather records, the meteorologists extracted storm climatologies, statistical histories of storm behavior that could be searched for any change over the decades. Unexpectedly, they found a surge in tropical cyclone intensity—and if it continued under global warming, they concluded, it would noticeably amplify the destruction in coming decades. In the wake of Hurricane Katrina, those analyses were enough to spark a highly public and sometimes raucous new field: hurricane climatology.

**For some, a turnaround**

In theory, tropical cyclones aren’t supposed to be noticeably stronger after a few decades of warming, which explains why no one had been searching for a trend in the ups and downs of the storm record. Then, at an October 2004 press conference, meteorologist Kevin Trenberth of the National Center for Atmospheric Research (NCAR) in Boulder, Colorado, reacted to claims that the particularly active 2004 season in the Atlantic Ocean was just part of a natural cycle that pumps up Atlantic storms every few decades. He and the others on the panel “didn’t think that was right,” says Trenberth. “We thought global warming was playing a role.” The burst of hurricane activity since 1995 just seemed too strong to be entirely natural.

Others thought Trenberth was the one getting it wrong. “We were rather skeptical” of Trenberth’s remarks, says Peter Webster, who specializes in monsoons and other tropical phenomena. “We thought Kevin was sounding his trumpet a little bit.” So Webster, a meteorologist at the Georgia Institute of Technology in Atlanta, and his colleagues looked at records of maximum wind speed of storms around the world as gauged from satellite images.

In the 16 September 2005 issue of *Science* (p. 1844), less than 3 weeks...
Rising threat? The number of Atlantic hurricanes (left) jumped in 1995, but globally the number of tropical cyclones is steady. The debate is over whether storms have been getting stronger as the world warms.

After Hurricane Katrina ravaged New Orleans, Webster and colleagues reported that in fact the abundance of tropical cyclones had not increased between 1970 and 2004. But the number of the strongest storms—those in categories 4 and 5—had jumped 57% from the first half of the period to the second. That reinforced findings by meteorologist and hurricane specialist Kerry Emanuel of the Massachusetts Institute of Technology in Cambridge. He had reported in the 4 August 2005 issue of *Nature* that the total power released during the lives of Atlantic and western North Pacific storms had risen between 40% and 50% from the first half of a 45-year record to the last half.

Both Webster and Emanuel were taken aback by their own findings. “I changed my mind in a big way” about how much the warming could be intensifying storms, says Emanuel. But it wasn’t just because of the apparent upward trend of storm intensity. When Emanuel looked at how storm power and ocean temperature had varied, “what I found startled me,” he told the conference. In the area just north of the equator in the Atlantic Ocean, where most hurricanes get their start, the power released during the lifetimes of storms is “spectacularly well correlated with sea surface temperature,” says Emanuel. Hurricane intensity had risen along with temperature over the past half-century, even matching ups and downs along the way.

The region where Atlantic hurricanes develop has in turn warmed in step with the Northern Hemisphere for the past half-century, Emanuel noted. And that warming is widely held to be driven at least in part by rising greenhouse gases. Two studies may not be enough to prove that Trenberth is right about greenhouse warming driving storm activity, but both Emanuel and Webster now believe they see a strengthening of tropical cyclones suspiciously in synchrony with global warming.

Stormier models

Newly minted hurricane climatologists at the conference got some support from climate modelers. Kazuyoshi Oouchi of the Advanced Earth Science and Technology Organization in Yokohama, Japan, and his colleagues presented results from highly detailed climate simulations run on Japan’s Earth Simulator, the world’s most powerful supercomputer devoted to earth sciences. Global climate models typically calculate climate at points 200 kilometers or more apart. The resulting pictures of climate are too fuzzy to pick up anything as small as a tropical cyclone. But the Japanese group simulated the present climate and the greenhouse-warmed climate near the end of the century at a resolution of just 20 kilometers, thanks to the Earth Simulator’s power. That was detailed enough for tropical cyclones to appear in the model, allowing the researchers to roughly gauge their intensities. In the warmer world, the total number of storms over the globe had actually decreased by 30%. But the number of the rarer category 3 and 4 storms had increased substantially, not unlike Webster’s observational results.

Additional support for intensification also came from a new, independent analysis of wind data, mentioned in passing at the conference.

Climate researchers Ryan Sriver and Matthew Huber of Purdue University in West Lafayette, Indiana, will soon report in *Geophysical Research Letters* on how they measured the power released by storms by using a compilation of the world’s weather data developed at the European Centre for Medium-Range Weather Forecasting in Reading, U.K. They found a 25% increase in storm power between the first half of the 45-year record and the second, consistent with Emanuel’s analyses.

Even stormier objections

Intensifying tropical cyclones possibly driven by the greenhouse might sound like one more chapter in the familiar global warming story—melting glaciers, rising seas, searing heat waves—but some read it differently. The U.S. National Oceanic and Atmospheric Administration (NOAA) stated last year in press releases that “long-term climate change appears to be a minor factor” in “the most devastating hurricane season the country has experienced in modern times.” The surge in Atlantic hurricane activity since 1995 is the latest upswing in a natural cycle, the releases said. As the Atlantic Ocean warms and wind patterns shift, hurricanes increase for a decade or two until a lull sets in again.

NOAA’s seemingly official pronouncements sounded moderate next to that of William Gray of Colorado State University (CSU) in Fort Collins, an elder statesman of the hurricane community. Well known for his forecasts of the coming hurricane season, Gray pushes natural cycles with a vengeance. “There’s definitely a big multidecadal cycle going on,” he said in his conference talk, not just in the Atlantic Ocean but around the world. “This isn’t global-warming induced; this is natural. We may go for a few years, and then it’s going to cool.” And with the cooling, hurricanes will calm down again, he said, just as they have before.

The warming of recent decades and the jump in hurricanes are being driven by a surging ocean current that brings warm water northward into the Atlantic Ocean, Gray insisted. Climate models in which mounting greenhouse gases drive global warming have simply got it wrong, he said; greenhouse gases are feeble agents of warming. “I’m a great believer in computer models,” he said. The audience laughed skeptically. No, he assured them, “I am—out to 10 or
12 days. But when you get to the climate scale, you get into a can of worms. Any climate person who believes in a model should have their head examined. They all stink.”

“This was highly entertaining,” observed meteorologist Gregory Holland of NCAR from the audience, “but unfortunately you obfuscate the real issue.” Holland, a graduate student of Gray’s at CSU in the early 1980s, is second author on Webster’s Science paper. He went on to staunchly defend climate models. “Right now, they’re providing a very good, rational picture of the situation,” he concluded. Supportive applause rose from the audience.

Later, during a panel discussion, Emanuel questioned even the existence of a natural cycle of Atlantic warming and cooling, at least one that influences the development of hurricanes. He believes a misstep in a classic analysis—a 2001 Science paper on which Gray was an author—tended to create a cycle where none exists. By subtracting a linear trend from a record of rising temperature that actually contained the nonlinear, upward-curved trend of global warming, the analysis created an oscillation, he said. In the end, Emanuel finds “no evidence for natural cycles in late summer tropical Atlantic sea surface on these time scales,” which for him leaves global warming as the leading candidate for a driver.

A haphazard record
Emanuel’s line of argument caught critics by surprise, and his challenge to a purely natural driver for hurricane activity went largely unanswered at the conference. NOAA scientists such as meteorologist Christopher Landsea of the National Hurricane Center in Miami, Florida—another former Gray student—claimed that NOAA public affairs staff members writing the press releases had overstated the case for a natural cycle. And the warming may well be largely human-induced, said Landsea. The question, he argued, is not what’s causing tropical warming, but how much of an impact does that warming have on hurricane intensity? Not much, he suspects. According to theory and computer modeling, by now the intensification should be only a sixth of what Webster and Emanuel have reported, he noted. Rather than a real strengthening, Landsea said, Emanuel and Webster may well be seeing a fictitious one created by a deeply flawed hurricane record.

Emanuel disagrees. “They tend to count [the anomalous strengthening] against the observations,” he says. “I count it against the theory, although I helped develop the theory.”

That moved the debate to the observational record of tropical cyclone intensity, where attempts found considerable grounds for agreement: The record is far, far from perfect. Hurricane climate researchers have the same problem as climate researchers had when they began searching for signs of global warming. Weather forecasters created the surface temperature record as they went about their business predicting the next day’s weather. They never planned to string their twice-daily measurements into a century-long record, so they had no qualms about moving their thermometers from place to place, and they paid no mind when heat-retaining cities grew up around them.

Likewise, forecasters’ observations of tropical cyclones “weren’t designed to be climate records,” notes Landsea. And to make matters even worse for hurricane climatologists, hurricanes forecasters almost never directly measure storm intensity—the maximum wind speed 10 meters above the surface averaged over 1 minute. Instead, they usually gauge maximum wind speed indirectly.

Indirect measurements of storm intensity haven’t always been done well or frequently, either. By the time Hurricane Carol hit in 1954, Landsea noted, forecasters were flying into storms—if they weren’t too strong—and judging wind speed by looking down at waves on the ocean. Sometimes they would estimate maximum winds by making their best guess of how winds would change from their aircraft’s altitude to the near-surface. Such sampling wouldn’t have caught Hurricane Wilma’s 1-day leap last fall from minimal hurricane to category 5, he said. That took eight types of measurements made 280 times over 12 days, and some of those measurements required air-dropped instrumentation and satellites. Even today, says Landsea, “there are big discrepancies about how strong a storm was.” The U.S. and Japanese typhoon warning centers for the Pacific Ocean—where no aircraft reconnaissance is done now—at times differ in their estimates by as much as two categories.

At the conference, a half-dozen speakers documented the sad state of tropical cyclone intensity measurements. Two groups—led by John Knaff of CSU and by Bruce Harper of Systems Engineering Australia Proprietary Limited in Brisbane—attempted to correct intensity records from parts of the Pacific Ocean for now-obvious errors. Both reanalyses reduced the upward trend of storm intensity. Knaff’s work, in particular, suggests that Emanuel’s and Webster’s studies “may have been premature,” says Landsea. “The database wasn’t up to it.”

On the other hand, the reanalyses did not eliminate the trend. “The data’s not very good,” agreed Webster. “However, to say it’s all artificial is an exaggeration. We would have had to have misidentified 160 to 180 category 4’s and 5’s.” He doubts they were off by that much.

The discussions at the conference, although informative, did not change many minds. “There are persuasive arguments on both sides,” says Hugh Willoughby of Florida International University in Miami and former director of NOAA’s Hurricane Research Division. “Honestly, we don’t know” who’s right, he says. “That’s the real story.” Tropical cyclones probably intensify under warmer climates, he says, but most likely not as much as Webster and Emanuel believe. “We don’t know where we are in the middle.” That’s what the new field of hurricane climatology hopes to find out.

―Richard A. Kerr

Storm central. Planes were able to penetrate Katrina’s eye wall (left) and drop probes through the storm (lower left), greatly improving storm-intensity measurements.