The Wind and the Fury
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THE WIND AND THE FURY

Has climate change made hurricanes fiercer, or are such claims hot air?

BY NAILA MOREIRA

As Hurricane Katrina steamed forward on Thursday, Aug. 25, residents of the southeastern U.S. shore breathed sighs of relief. The storm passed Miami as a weak hurricane, rating as only a category 1 storm on a scale from 1 to 5. But within days, relief turned to alarm, amid warnings from forecasters that the worst might be yet to come. The storm sucked energy from warm Gulf of Mexico waters as it moved west, swelling into a category 5 monster and then weakening only slightly before it slammed into the Mississippi shore as a category 4 hurricane. Abundant rain and a surge of ocean water overwhelmed flood-control measures and broke levees at nearby Lake Pontchartrain, deluging New Orleans with up to 20 feet of water and plunging the city into mayhem.

GALE OF TWO CITIES — Hurricane Katrina's eye wall, in a photo taken by a hurricane-hunter pilot on Aug. 28, after the storm had left only minimal damage in Miami but before it barreled into New Orleans. The hurricane strengthened over the Gulf of Mexico. Was climate change to blame?

NOAA

Katrina's ferocity left many people asking whether the monster storm came from mere chance or from something more long lasting—global warming. Although hurricane numbers and intensities are known to vary naturally, with some years producing many violent hurricanes and others hardly any, Hurricane Katrina isn't the only exceptionally destructive event in recent memory. In 1992, Hurricane Andrew topped the charts as the most costly U.S. hurricane then on record, wreaking $25 million in damage in Florida—a record that Katrina will certainly break.

In the tropical Atlantic, moreover, hurricane numbers have been on the uptick since 1995, according to the National Oceanic and Atmospheric Administration (NOAA). In 2004, Florida suffered its worst hurricane season in 118 years, with nine hurricanes, five of which were classified as major. For 2005, NOAA's forecast predicted yet another above-average hurricane season for the region.

Scientists are divided on whether climate change, induced by industrial and automotive release of carbon dioxide and other greenhouse gases, is driving these statistics. Most climate scientists say that natural, cyclic phenomena that affect ocean currents and atmospheric temperature—such as El Niño in the Pacific Ocean and the North Atlantic Oscillation—yield decade-to-decade swings in total hurricane numbers that have nothing to do with global warming. Some researchers say that these phenomena are also responsible for all the observed changes in storm intensity.

But many other climate scientists are now pointing to global warming as the culprit for increasingly ferocious hurricanes worldwide. Both scientific theory and computer modeling predict that as human activities heat the world, warmer sea-surface temperatures will fuel hurricanes, increasing wind speeds and rainfall. Now, several new studies suggest that climate change has already made hurricanes grow stronger.

Many scientists predict that such an increase in storm violence will have consequences for coastal communities.

COOKING UP A STORM Hurricanes gain their destructive power from ocean moisture and heat. As the sea and atmosphere warm, more water evaporates from the ocean surface. When that moisture reaches the cool upper atmosphere, it condenses, releasing the energy that originally went into evaporating it. This "latent heat" powers the growing storm, says meteorologist Tom Knutson of NOAA's Geophysical Fluid Dynamics Laboratory in Princeton, N.J.

How warm the sea surface gets and how high into the atmosphere the evaporated water climbs set a speed limit on hurricane winds, says Kerry Emanuel of the Massachusetts Institute of Technology in Cambridge. In 1987, Emanuel predicted that with global warming, this speed limit would rise and that hurricanes would rev up their engines.

"If the climate warms, hurricanes have the potential to become substantially more intense," agrees Knutson. He and Robert E. Tuleya of Old Dominion University in Norfolk, Va., have used computer models to simulate how hurricanes would change in a warming world. If the atmospheric concentration of carbon dioxide, the greenhouse gas most responsible for global warming, doubles in the next 80 years, hurricanes' wind speeds will rise by about 5 percent, the researchers predicted in the Sept. 15, 2004 *Journal of Climate.*

Moreover, with the increase in atmospheric moisture that accompanies global warming, hurricane rainfall will increase by about 18 percent, Knutson and Tuleya calculate.

But in practice, changes in rainfall within a hurricane are hard to pick out. Hurricanes pour out rain in localized outbursts, but rain gauges tend to be widely dispersed and often miss the main downpour, Emanuel notes. Also, most hurricanes don't strike land, where rainfall can be tallied. "It's a hopeless measurement problem," he says.

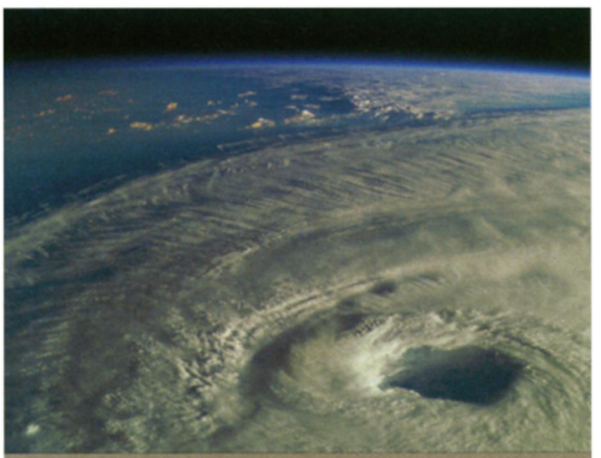
Pavel Groisman of the National Climatic Data Center in Asheville, N.C., says that his work and that of others show no measurable change in the total rain dumped by hurricanes. "When we have very strong hurricanes, we do not see changes in intensity of precipitation," he reports.

The increase of just 5 percent in hurricane intensity predicted by Knutson and Tuleya led many researchers to suggest that the variability attributable to El Niño or the North Atlantic Oscillation would dwarf any change resulting from global warming, at least for the next few decades.

"What folks in the field thought was, we weren't going to see any global warming and hurricane association for decades to come," says Christopher Landsea of NOAA's Atlantic Oceanographic and Meteorological Laboratory in Miami.

ALL AWHIRL Researchers have recently discerned, however, storm-intensity trends that correlate with global warming. In the Aug. 4 *Nature*, Emanuel reports the first evidence that today's hurricanes are more powerful than those of 30 years ago.

To gauge storm intensity, Emanuel developed a measure he calls the power-dissipation index. For each Northern Hemisphere hurricane in the tropical Atlantic and western Pacific over the past century, he used the maximum wind speed and the life span of the storm to calculate a number that estimates the energy expended by a hurricane. The measurement also relates to the total damage a hurricane can wreak on buildings and construction, Emanuel says.



SHAPE OF WRATH — Huge storms, such as Hurricane Isabel of 2003, have increased in frequency over the past 35 years, while smaller storms have become less common, scientists find. Isabel made landfall in North Carolina as only a category 2 storm.

NASA

Overall, he found that the power-dissipation index had doubled over the past 30 years in all the regions that he has studied—an increase that he says probably reflects the effect of global warming over that same period. "I was startled to see this sort of upward trend globally," he says. "It's a big trend."

Landsea contends that problems with the historical record of hurricane data render Emanuel's conclusions uncertain. Scientists have measured wind speeds in different ways over the past century, including by aircraft and satellites. To make these different measurements compatible over time, Emanuel had to apply correction factors that could introduce bias, Landsea says.

"He may think it's the smoking gun linking hurricanes and global warming, but I'm reluctant to say so at this point," says Landsea.

Emanuel concedes that wind-speed numbers are uncertain. However, he says, several factors mitigate that problem. For example, Emanuel says that his wind-speed data correlate perfectly with sea-surface temperatures over time that, in contrast to wind speeds, have been carefully measured.

"Every piece of evidence has a problem, but when you take them all together, they all point in the same direction," he says.

Oceanographer Isaac Ginis of the University of Rhode Island in Narragansett says that the measure provides a strong suggestion that hurricane intensity may already be on the upswing. "The signal is so robust, based on what I've seen in [Emanuel's] paper, that it looks fairly convincing to me," he says.

Moreover, Emanuel's finding no longer stands alone. The number of large hurricanes appears to have increased since 1970, while smaller hurricanes have become less common, report Greg Holland of the National Center for Atmospheric Research and his colleagues in the Sept. 17 *Science*. "What we've done is show that there's actually an increase in the number of intense storms," he says.

To count the hurricanes worldwide in each category of storm intensity, Holland and his colleagues used satellite data collected by scientists since about 1970. They found that the number of storms in categories 4 and 5 doubled during the past 35 years, while storms in categories 1 to 3 dropped off. Overall, he says, the larger storms now occur 20 to 35 percent more often than smaller storms do.

Peter Webster, a coauthor of the report, says, "The intensity of Katrina is consistent with the type of storms we've been finding, [which are] increasing in intensity globally."

Hurricane Katrina strengthened over anomalously deep warm waters in the Gulf of Mexico, Webster notes. If the warm patch had been shallower, the hurricane might have churned up cooler waters that would have reduced the storm's intensity. He cautions, however, that neither the warm area nor Katrina's intensity can necessarily be attributed to global warming rather than chance.

TYPHOON TALLY Hurricane intensity may be going up, but Webster and Holland find no change in the total number of hurricanes worldwide. These findings join others indicating that total hurricane numbers stay the same or even decrease as the world warms.

So far, yearly hurricane numbers have oscillated around a mean value of 90. "Since 1970, the global annual frequency of storms has been, I would say, rock steady," says Emanuel. "There's no systematic trend that you can see."

Computer simulations of the future give conflicting results for expected hurricane frequency. "Different models give different things," says Ruth McDonald of the Hadley Centre for Climate Prediction and Research in Exeter, England. "There's a large uncertainty as to whether they find fewer or more storms."

McDonald and her colleagues used a global-climate model to predict how the annual hurricane number will change as the globe warms during the next 17 years. Their model suggests that global hurricane numbers will decrease by 6 percent by 2022, a result published in an upcoming *Climate Dynamics*.

Inconsistencies among studies result from different spatial scales used by different models, says Seita Emori of the National Institute for Environmental Studies in Tsukuba, Japan. Climate simulations on a large scale, such as McDonald's, can't easily see hurricanes, which occur on a scale of only a few kilometers. Smaller-scale models don't necessarily take into account all the climate variables that come into play. Researchers also lack a clear understanding of the physical processes that control hurricane genesis, Emori says.

To better understand how climate might affect hurricane numbers, Claudia Mora of the University of Tennessee in Knoxville is looking into the past. She's examining tree rings to improve the currently spotty historical record of hurricanes.

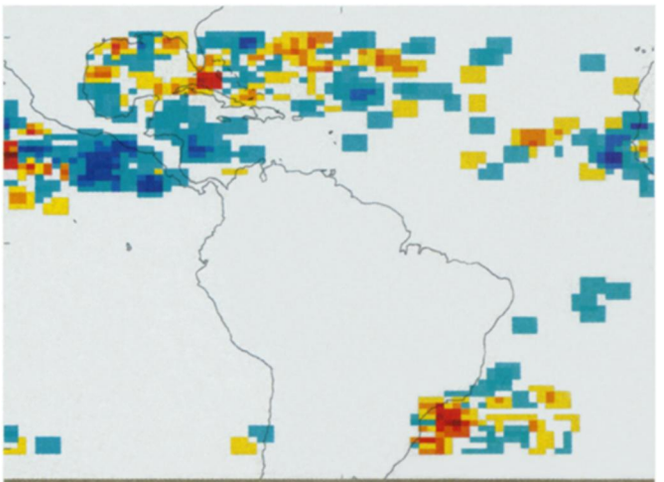
"Tree rings are a natural archive," she says. "They occur in pretty much all the coastal areas that are affected by hurricanes, and they are exactly datable."

Trees record hurricanes because the storms change the composition of rainwater. Water contains two forms of oxygen. These oxygen isotopes always have the same number of protons, but they have different numbers of neutrons. A water molecule containing an oxygen isotope with more neutrons is heavier than a molecule having an oxygen isotope with fewer neutrons.

Early on, hurricanes tend to rain out water molecules containing heavy isotopes, so later rainfall is isotopically light. When this lightweight rainfall enters the soil, it's taken up by a tree and incor-

porated into its cellulose. The scientists can then measure this signal in individual tree rings.

At the August 2005 Earth System Processes 2 conference in Calgary, Alberta, Mora and her colleagues reported that they've measured tree rings to estimate hurricane frequency from 1770 to 1997. "We're working toward development of a longer-term record," Mora says.



THE TEMPESTS — As the world warms, more hurricanes will occur in some regions (red areas), while fewer will occur in others (blue areas), according to this simulation.

COASTAL OUTLOOK Even if climate change has strengthened hurricanes, this change hasn't demonstrably affected coastal communities, says Roger Pielke of Colorado State University in Boulder. Instead of global warming, he says, coastal population growth has driven an increase in damage over the past century.

In the United States, population densities are rising more rapidly in coastal areas than elsewhere (*SN: 3/27/04, p. 197*). The coastal population climbed by 28 percent between 1980 and 2003, placing more people in hurricane-vulnerable zones, Pielke says. Florida's coastal population alone surged by 75 percent. These residents have also grown wealthier, Pielke adds, so they build larger, more-expensive houses and accumulate more goods. When damage to their properties occurs, it tends to cost more.

In the January *Population and Environment*, Pielke and his colleagues calculated that for every dollar of coastal damage produced by climate change in the future, societal factors such as these will produce $22 to $60 in additional damage.

"Societal factors are going to be the overwhelmingly dominant reason for increasing hurricane costs into the future," Pielke says.

Emanuel agrees that global warming isn't a major factor producing hurricane damage in the United States today. He says that random variability in the few storms that strike land swamp any global warming effect on hurricane-damage costs. He expects that it could take 200 years before faster hurricane winds and increased rain start to affect average yearly damage costs in the United States.

Knutson counters that although societal changes are important, the impact of rising hurricane intensity shouldn't be underplayed. "For the individual homeowners, it does matter," he says. If hurricanes grow fiercer, he says, "that means their damage potential's going up."

Meanwhile, many researchers argue that coastal communities should focus on preparing for hurricanes. Insurance regulation, building codes, and engineering improvements can all ease hurricane costs, Pielke says.

"[Katrina] should be a wake-up call for us to carefully look at our vulnerabilities," says Pielke. "Global warming is an important topic—I definitely think we should be responding to it—but we shouldn't confuse our responses to global warming with disaster mitigation." ■