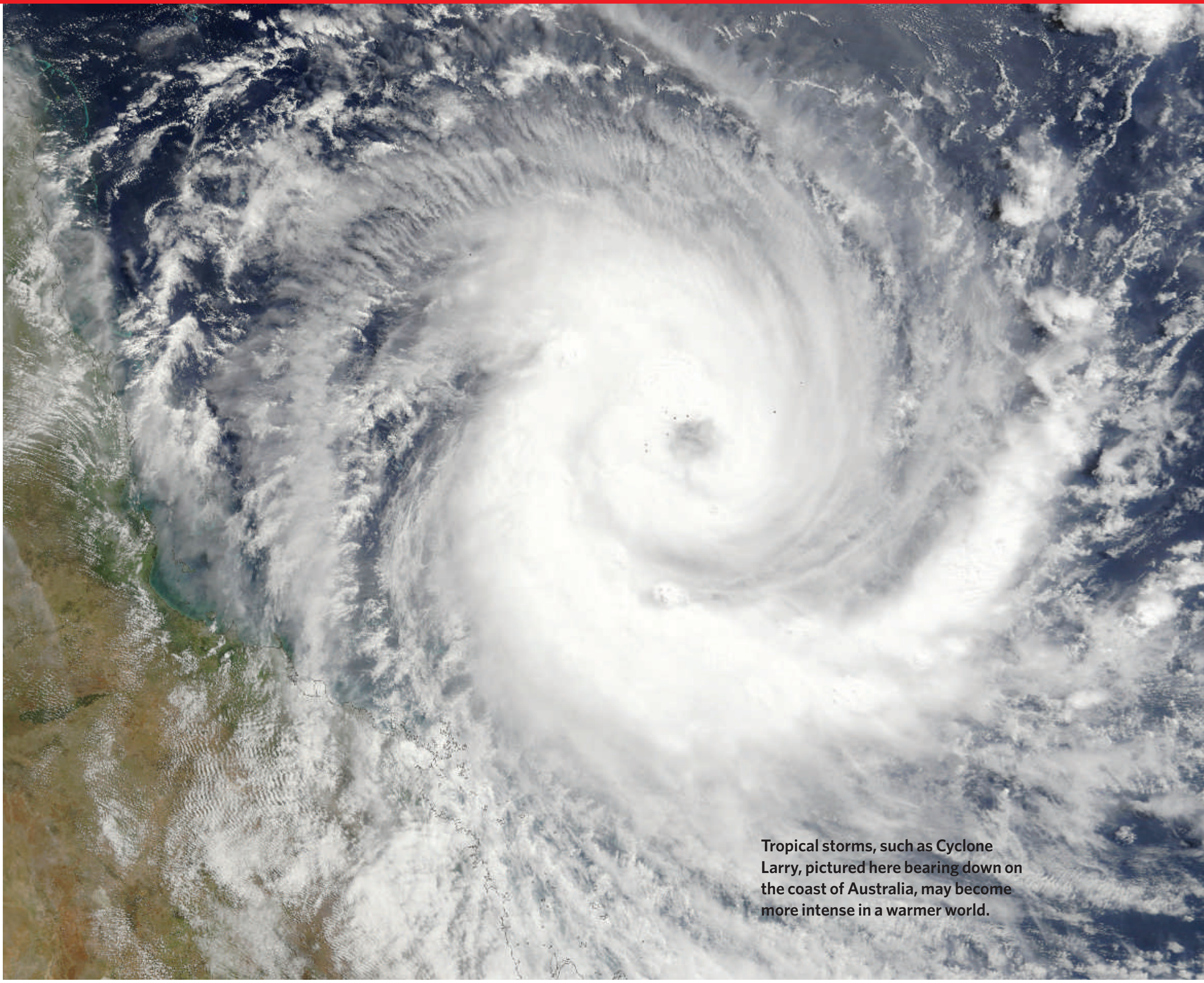


Tropical storms, such as Cyclone Larry, pictured here bearing down on the coast of Australia, may become more intense in a warmer world.

Bad weather ahead

Scientists and policymakers are battling over whether global warming is making hurricanes more destructive. **Alexandra Witze** ventures into the heart of the storm.

It remains the worst tempest in written history. In November 1970, a tropical storm strengthened into a cyclone in the Bay of Bengal. It slammed into what is now Bangladesh, killing up to half a million people. But just try digging up specific data about it. You won't find it. In the database of Indian Ocean storms, the wind speeds for this particular cyclone are listed as zero.

For storm researchers, this is a wearily familiar tale. The historical data on tropical cyclones are notoriously patchy. Some gaps are down to irregularities in the measurements collected during past storms. Others are caused by plain old human error. The Bangladesh cyclone, for example, happened during a period when databases from two government agencies were being merged and data were lost in the transition.

Today, increasingly sophisticated satellite imagery makes gaps less likely. But researchers still wrestle with the imperfect historical record — especially if they are trying to understand whether global warming is making cyclones more intense. Some argue that such a claim is hard to prove if major storms of the past aren't on record.

As the 2006 hurricane season gets under way in the Atlantic basin, few issues could be hotter than the relationship between global warming and tropical storms. Forecasters predict that things won't be as bad as 2005, which saw a record 28 named storms in the Atlantic and probably more than US$100 billion in damages (see 'The season ahead'). But authorities are looking to scientists to tell them whether 2005 is an example of a hurricane season that we will have to get used to.

At first glance, a link between cyclones and global warming seems to makes sense. Tropical cyclones are born over the oceans, where masses of rotating air pick up ever more energy from warm surface water. Once the winds in the mass reach 33 metres per second, a tropical cyclone is born. In the northwest Pacific, it's called a typhoon; in the Atlantic and northeast Pacific, a hurricane; elsewhere, a cyclone.

But only recently have scientists come up with the data that suggest global warming makes cyclones more intense. Two major studies laid the groundwork last year. In the first, published in August, atmospheric scientist Kerry Emanuel proposed that hurricanes had grown more intense over the past 30 years, most likely because of increasing sea surface temperatures[1]. Emanuel, of the Massachusetts Institute of Technology, developed an index to describe how destructive a storm could be, and found that the wrecking power of storms correlated strongly with sea surface temperature.

Tempests of doom

The second paper[2] came in September, soon after Hurricane Katrina had killed more than 1,800 people along the US Gulf Coast. A team led by Peter Webster, of the Georgia Institute of Technology in Atlanta, studied the occurrence of storms rated at the higher end of a strength-categorization scale called the Saffir–Simpson scale.

Hurricanes are ranked from 1 to 5 on the scale: storms with wind speeds reaching 33 metres per second are at the low end of category 1, and the threshold wind speed for a category 5 storm is 67 metres per second (or 241 kilometres per hour). Hurricane Katrina was category 5 when over the Gulf of Mexico, and had weakened to category 3 when it slammed into the Gulf Coast. Webster's team reported that there has been a rise in the number of category 4 and 5 storms in the past 35 years, in nearly all of the world's ocean basins[2].

Together, the Emanuel and Webster papers kick-started fresh efforts in a previously obscure corner of meteorology. A veritable flood of findings has emerged; some preliminary work was presented in April at a meteorology meeting in Monterey, California[3]. "We've moved forward immensely since last June," says Greg Holland, a co-author on the Webster paper and a meteorologist at the National Center for Atmospheric Research in Boulder, Colorado.

Yet many research areas remain untapped. One major unknown, experts say, is how hurricanes interact with the ocean — not just form above it. "Right now, almost everyone attacks the problem as hurricanes responding passively to climate change," says Emanuel. "They are active players." Hurricanes leave a trail of cold water in their wake — which is not currently accounted for in most climate models.

Other researchers point to the need to better understand the factors affecting hurricane intensities. They hope that data from last year's 'hurricane-hunter' flights will help[4]; these involved forecasters flying into the heart of Atlantic hurricanes to find out what drives changes to their intensity. And mysteries still surround the issue of how hurricanes form in the first place. Indeed, one speaker, David Nolan of the University of Miami, Florida, drew a crowd in Monterey with his provocatively titled talk, 'Could hurricanes form from random convection in a warmer world?' (His answer: 'no'.)

> **"The name-calling has got to stop."** — Max Mayfield

Given that more research is obviously needed, how should scientists best direct their efforts to get useful answers as soon as possible? Many echo the adage that the past is the key to the present, and argue that far more time and money need to be spent on paleotempestology — the study of past hurricanes, as recorded in geological deposits. Studies that look back as far as several thousand years ago could help resolve the frequency with which hurricanes form, or at least make landfall in certain regions of the world. These would provide an invaluable measure of 'normal' patterns against which to weigh modern trends.

Perhaps most crucially, meteorologists say, the renewed interest in hurricanes could inspire researchers to work on improving the historical record of storms. It is possible to go back through the database and re-assess each storm with modern eyes, making sure its strength and trajectory are analysed by the same standard as more recent storms. That's what Christopher Landsea, a meteorologist at the National Hurricane Center in Miami, has been doing for the Atlantic hurricane database, which contains measurements on storms dating back to 1850.

Elusive evidence

Re-analysing past measurements is one thing. But the biggest problem, says Landsea, is in having to work with a lopsided data set. If you knew what was in sausages, you wouldn't want to eat them, he says; likewise the historical record shouldn't be trusted. For instance, Hurricane Wilma garnered headlines last summer when it was recorded to have the lowest central pressure — another measure of storm intensity — of any known hurricane in the Atlantic basin. Yet Wilma "was sampled just about every hour of its existence", says Landsea. Compare that, he says, to a tropical storm such as Carol, which moved up the US eastern seaboard for days in 1954 but was sampled only seven times over its lifetime.

The picture gets even bleaker in the world's other ocean basins. In a recent informal study, Landsea looked through satellite images of storms in the northern Indian Ocean. From these pictures, he estimated that the storms should have been rated as category 4 or 5; they were recorded as being of lower intensities at the time. Landsea says that if these storms are missing from the records, how is it possible to conclude that hurricane intensities are increasing because of global warming? They could be,

T. BLACKWOOD/AFP/GETTY

Entire plantations were wiped out when Cyclone Larry (left) struck land earlier this year.

BETTMANN/CORBIS

Destructive force: a cyclone that hit what is now Bangladesh in 1970 killed up to half a million people.

he says; it's just impossible to tell.

Webster disagrees: "Chris has found several category 4s and 5s we missed in the early 1970s; he has to find 152 for us to be wrong." And Emanuel adds that, although one can argue about the particular number of hurricanes in a particular year, his measure of hurricane intensity still correlates strongly with sea surface temperature — no matter how many storms there are in a particular year.

Divided opinion

The disagreement echoes deep battle lines between several camps, many of which have been re-ignited by the recent studies. A flurry of critiques has appeared in *Science* and *Nature*, as well as in the blogosphere. The debate has got personal at times, and few are happy about it. "The name-calling has got to stop," says Max Mayfield, director of the National Hurricane Center in Miami.

In one recent paper, longtime climate-change sceptic Patrick Michaels and colleagues argue that rising sea surface temperature no longer affects the intensity of a hurricane once its winds have reached speeds of more than 50 metres per second[5].

In another, Philip Klotzbach of Colorado State University in Fort Collins writes that there is no strong correlation between hurricane energy and sea surface temperature in most of the world's ocean basins — and that Webster's and Emanuel's results are due mostly to the patchiness of data sets prior to the mid-1980s (ref. 6). And the *Bulletin of the American Meteorological Society* has hosted a feisty back-and-forth, spearheaded by policy expert Roger Pielke Jr of the University of Colorado. He calls links between hurricanes and global warming "premature".

For many, the stakes could not be higher. Knowing where and how often storms might strike is crucial for shaping government policies. Exploding populations in coastal zones place ever-greater numbers of people at risk — a fact noted by some policy experts, who say that the apparent increase in hurricane destructiveness seen in the past few years is down to the fact that more people are living in at-risk areas[7].

Preliminary studies by other groups seem to bear out Webster's and Emanuel's conclusions. A new study of Indian Ocean hurricanes, presented at the Monterey meeting, suggests that there has indeed been an increase in category 4 and 5 storms in the region — and few Indian Ocean storms are missing from the database. And using a data set of global storms that occurred between 1958 to 2001, scientists from Purdue University in West Lafayette, Indiana, have found the same overall increase in storm destructiveness in recent years — particularly after 1985 (ref. 8).

Worse to come

Other scientists are turning to computer models for possible answers to questions, such as how much will sea surface temperature rise, and exactly how will that influence hurricane formation? Computer models suggest that sea surface temperatures in the Atlantic hurricane-forming region could warm by 2 °C by 2100. They also suggest that if this rise occurs, maximum wind speeds could increase by 6% (ref. 9). It may not sound like much, but damage from hurricanes rises in proportion to the cube of the wind speed.

"The warming we've seen to date is just the tip of the iceberg."
— Thomas Knutson

So far, the world's oceans haven't seen anything close to a 2 °C warming — just a 0.5 °C rise since 1970. "The warming we've seen to date is really just the tip of the iceberg," says Thomas Knutson, a climate modeller at the Geophysical Fluid Dynamics Laboratory in Princeton, New Jersey.

Predicting future hurricane activity will also require greater understanding of how natural climate fluctuations interact with global warming. For example, the El Niño Southern Oscillation, a pattern of temperature fluctuations in the tropical Pacific ocean, can affect the formation of hurricanes in certain regions, as can volcanic eruptions.

For people living in vulnerable coastal regions, answers to the debates can't come soon enough. In the United States, last year's destruction has prompted a new round of calls for hurricane preparedness and mitigation measures. New Orleans, the city devastated by Katrina, is slowly being rebuilt with higher levees to keep storm surges out. And while researchers argue over the details of databases and data analysis, residents are girding for another six months of uncertainty. ■

Alexandra Witze is *Nature*'s chief of correspondents for America.

THE SEASON AHEAD

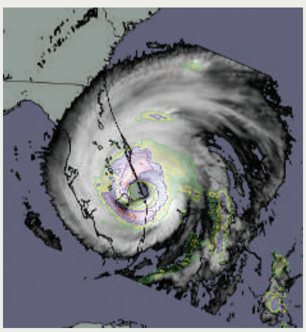
Given all the attention to Atlantic Ocean hurricanes, it's hard to remember that only 11% of the world's tropical cyclones occur there.

In 2005, that attention seemed warranted. Seven hurricanes made landfall in the United States. Katrina killed 1,800 people. There were so many storms that the National Hurricane Center ran out of alphabetized names and started giving them Greek names instead.

Experts say the United States should prepare for more of the same. The latest predictions suggest that sea surface temperatures in the region where hurricanes are born are running higher than average. The National Oceanic and Atmospheric Administration predicts that there will be up to 16 named storms in the Atlantic this season, with up to ten becoming hurricanes. William Gray, a forecaster at Colorado State University, and his colleagues have predicted 17 named storms, with nine of them hurricanes.

Not everyone agrees on the significance of such numbers. Gray, for his part, is one of the most vocal critics of a possible link between hurricanes and global warming. He argues that the Atlantic is seeing nothing more than a peak in a regular cycle of activity. The 1950s and 1960s were active decades; in the 1970s, things quietened down. Activity picked up again in 1995 and has increased ever since.

NASA



Others disagree with Gray. "We may have quiet years, but right now it doesn't look like a quiet decade," says Kerry Emanuel, a hurricane expert at the Massachusetts Institute of Technology.

For this year, coastal residents should pay close attention to what happens in the next two months. Roughly 90% of the Atlantic's hurricane activity takes places after 1 August, says Eric Blake of the National Hurricane Center in Miami. Adding sea surface temperature data from June and July should radically improve forecasts for this coming season, he says — letting people know how much 2006 will look like 2005. **A.W.**

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