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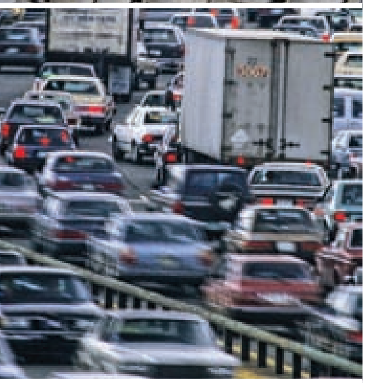

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Because most global warming emissions remain in the atmosphere for decades or centuries, the energy choices we make today greatly influence the climate our children and grandchildren inherit. We have the technology to increase energy efficiency, significantly reduce these emissions from our energy and land use, and secure a high quality of life for future generations. We must act now to reduce dangerous consequences.

Hurricanes in a Warmer World

Exploring the potential causes of increased storm intensity

Hurricanes, typhoons, and cyclones have always bedeviled coasts, but global warming may be making matters worse. Sea level is rising and will continue to rise as oceans warm and glaciers melt. Rising sea level means higher storm surges, even from relatively minor storms, which increases coastal flooding and subsequent storm damage along coasts. In addition, the associated heavy rains can extend hundreds of miles inland, further increasing the risk of flooding.

Recent scientific evidence suggests a link between the destructive power (or intensity) of hurricanes and higher ocean temperatures, driven in large part by global warming. With rapid population growth in coastal regions placing many more people and structures in the path of these tropical cyclones there is a much greater risk of casualties, property damage, and financial hardship when these storms make landfall.

Hurricane Behavior

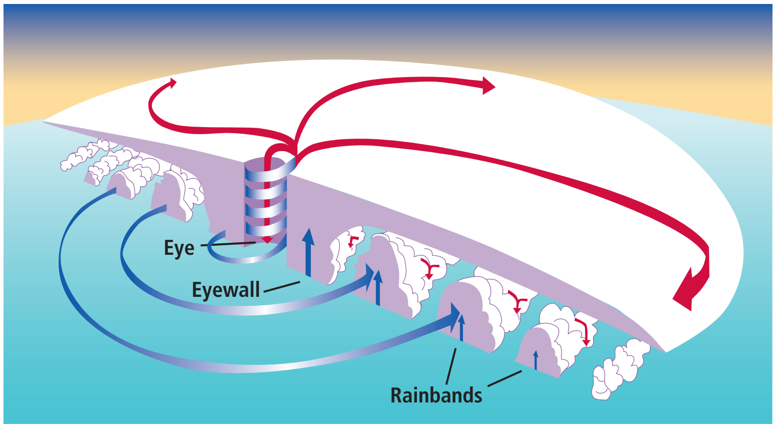
Meteorologists use the term "tropical cyclone" for a closed atmospheric circulation that forms over a tropical or subtropical ocean. Once maximum sustained wind speed exceeds 74 miles per hour these storms are called hurricanes in the Atlantic Ocean, typhoons in the Pacific Ocean, and cyclones elsewhere.

Many factors influence tropical cyclone behavior, but three factors must be present for them to intensify: warm ocean temperatures (hurricanes can occur when surface ocean temperatures exceed about 79 degrees Fahrenheit [26 degrees Celsius]), low vertical wind shear (i.e., no strong change in wind speed or direction), and high humidity. As warm, moist air rises, it lowers air pressure at sea level and draws surrounding air inward and upward in a rotating pattern. As the water vapor-laden air spirals in and rises to higher altitudes, it cools and releases heat as it condenses to rain. This cycle of evaporation and condensation brings the ocean's heat energy into the vortex, powering the storm.

There are several natural factors that can "put the brakes on" a tropical cyclone: moving over colder ocean water; strong winds that churn up colder ocean water; high wind shear that can diminish or destroy the vortex; dry air migrating to the hurricane's core; and moving over land, which creates high frictional drag and deprives the storm of warm ocean "fuel." But as long as conditions are favorable, the storm will thrive.

The Effect of Global Warming

Two factors that contribute to more intense tropical cyclones—ocean heat content and water



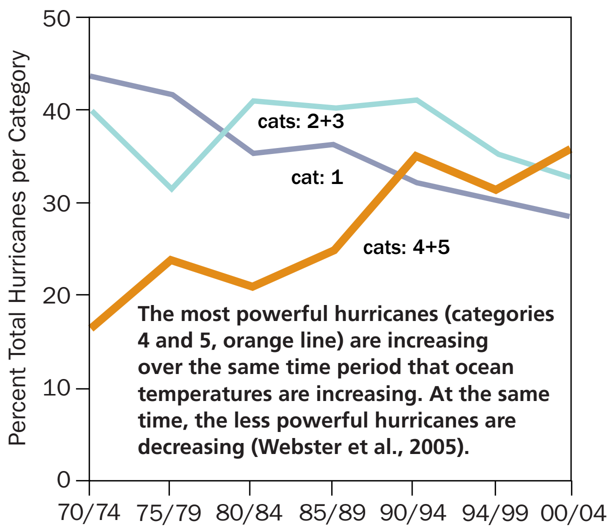
In a tropical cyclone, air rotates inward to the center (or "eye"), then rises to higher altitudes. As warm, moist air rises, the air cools and condenses to rain, releasing heat. This cycle of evaporation and condensation powers the storm.

Adapted from a figure courtesy of NOAA.

vapor—have both increased over the past several decades. This is primarily due to human activities, such as burning fossil fuels and clearing forests, significantly elevating carbon dioxide (CO_2) and other heat-trapping gases that warms the land and ocean and increases evaporation.

The world's oceans have absorbed about 20 times as much heat as the atmosphere over the past half-century, leading to higher temperatures not only in surface waters (e.g., depths of less than 100 feet) but also down to substantial depths, with the most severe warming occurring in the first 1,500 feet below the surface. As this warming occurs, the oceans expand and raise sea level. This expansion, combined with the inflow of water from melting land ice, has raised global sea level more than one inch over the last decade. In addition, observations of atmospheric humidity over the oceans show that water vapor content has increased four percent since 1970; because warm air holds more water vapor than cold air, these findings correlate with an increase in air temperature.

Higher Percent of Category 4 & 5 Hurricanes Worldwide



The most powerful hurricanes (categories 4 and 5, orange line) are increasing over the same time period that ocean temperatures are increasing. At the same time, the less powerful hurricanes are decreasing (Webster et al., 2005).

Recent Scientific Developments

Higher ocean surface temperatures. A 2005 study published in the journal *Nature* examined the duration and maximum wind speeds of each tropical cyclone that formed over the last 30 years and found that their destructive power has increased around 70 percent in both the Atlantic and Pacific Oceans. Another 2005 study, published in the journal *Science*, revealed that the percentage of hurricanes classified as Category 4 or 5 (based on satellite data) has increased over the same period. The findings from both studies correlate with the rise in sea surface temperatures in regions where tropical cyclones typically originate.

Researchers in a 2006 study (also published in *Science*) found, upon reanalyzing early storm track records with modern techniques, that a few category 4 and 5 tropical cyclones may have previously been underestimated. However, it remains to be seen if enough storms would be reclassified to challenge the overall rise in intensity. A 2006 study published in *Geophysical Research Letters,* relying not on storm track records but on global surface wind and temperature records between 1958 and 2001, confirmed the trends identified in the two 2005 studies above and found that a 0.45 °F (0.25 °C) increase in mean annual tropical sea surface temperature corresponded to a 60 percent increase in the tropical cyclone's potential destructiveness.

Researchers have also examined the potential future storm trends. Model simulations show that a one percent annual increase of atmospheric CO_2 concentrations over the next 80 years would produce more intense storms, and rainfall would increase an average of 18 percent compared with present-day conditions.

The influence of regional cycles. Earth's oceans contain various dynamic circulation patterns that influence the distribution of warm and cold water in upper ocean depths. These patterns, or oscillations, last a period of years or even decades. The most well known is the El Niño Southern Oscillation in the Pacific Ocean. The atmospheric conditions described above (e.g., humidity, low wind shear), along with ocean oscillations, are factors that correlate with more intense storms over the short term. Over the long term, however, study findings show that global warming is the overarching factor; initial findings suggest that over the period 1970 to 2004 warmer sea surface temperature is the major factor in the increase in category 4 to 5 hurricanes globally. A study examining the causes of above-average temperatures in the North Atlantic ocean in 2005 indicated about 0.3 °C of the increase arose from ocean oscillations, 0.2 °C from normal weather variations, and 0.45 °C from global warming.

Diminished braking mechanism. Tropical cyclones generate strong winds that mix the ocean's surface waters, churning up colder water from below. This colder water typically serves to weaken a storm; however, if deeper waters become too warm, this natural braking mechanism is diminished. Data from Hurricane Katrina indicate that while sea surface temperature was warm enough for maintaining the hurricane along its entire path, the storm significantly intensified when it hit the deep pools of warm water in the Gulf of Mexico.

Protecting Coastal Communities

Given the loss of life and the huge costs of rebuilding after hurricanes, it is essential to do whatever we can to avoid dangerous warming and protect America's coastal communities for ourselves and our children. This will require a combination of aggressive emission reduction efforts, improved building codes, and the restoration of wetlands, dunes, and barrier islands that can serve as a buffer against rising sea levels and hazardous storm surges.

Union of Concerned Scientists
Citizens and Scientists for Environmental Solutions

Brenda Ekwurzel (Union of Concerned Scientists) prepared this summary with helpful reviews by Kevin Trenberth (National Center for Atmospheric Research) and Kerry Emanuel (Massachusetts Institute of Technology).

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A fully referenced version is available from UCS at *www.ucsusa.org/hurricanepower.*

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