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CLIMATE CHANGE

Can We Detect Trends in Extreme Tropical Cyclones?

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Subjective measurements and variable procedures make existing tropical cyclone databases insufficiently reliable to detect trends in the frequency of extreme cyclones.

Recent studies have found a large, sudden increase in observed tropical cyclone intensities, linked to warming sea surface temperatures that may be associated with global warming (1–3). Yet modeling and theoretical studies suggest only small anthropogenic changes to tropical cyclone intensity several decades into the future [an increase on the order of ~5% near the end of the 21st century (4, 5)]. Several comments and replies (6–10) have been published regarding the new results, but one key question remains: Are the global tropical cyclone databases sufficiently reliable to ascertain long-term trends in tropical cyclone intensity, particularly in the frequency of extreme tropical cyclones (categories 4 and 5 on the Saffir-Simpson Hurricane Scale)?

Tropical cyclone intensity is defined by the maximum sustained surface wind, which occurs in the eyewall of a tropical cyclone over an area of just a few dozen square kilometers. The main method globally for estimating tropical cyclone intensity derives from a satellite-based pattern recognition scheme known as the Dvorak Technique (11–13). The Atlantic basin has had routine aircraft reconnaissance since the 1940s, but even here, satellite images are heavily relied upon for intensity estimates, because aircraft can monitor only about half of the basin and are not available continuously. However, the Dvorak Technique does not directly measure maximum sustained surface wind. Even today, application of this technique is subjective, and it is common for different forecasters and agencies to estimate significantly different intensities on the basis of identical information.

The Dvorak Technique was invented in 1972 and was soon used by U.S. forecast offices, but the rest of the world did not use it routinely until the early 1980s (11, 13). Until then, there was no systematic way to estimate the maximum sustained surface wind for most tropical cyclones.

The Dvorak Technique was first developed for visible imagery (11), which precluded obtaining tropical cyclone intensity estimates at night and limited the sampling of maximum sustained surface wind. In 1984, a quantitative infrared method (12) was published, based on the observation that the temperature contrast between the warm eye of the cyclone and the cold cloud tops of the eyewall was a reasonable proxy for the maximum sustained surface wind.

In 1975, two geostationary satellites were available for global monitoring, both with 9-km resolution for infrared imagery. Today, eight satellites are available with typically 4-km resolution in the infrared spectrum. The resulting higher resolution images and more direct overhead views of tropical cyclones result in greater and more accurate intensity estimates in recent years when using the infrared Dvorak Technique. For example (13), Atlantic Hurricane Hugo was estimated to have a maximum sustained surface wind of 59 m s⁻¹ on 15 September 1989, based on use of the Dvorak Technique from an oblique observational angle. But in situ aircraft reconnaissance data obtained at the same time revealed that the hurricane was much stronger (72 m/s) than estimated by satellite. This type of underestimate was probably quite common in the 1970s and 1980s in all tropical cyclone basins because of application of the Dvorak Technique in an era of few satellites with low spatial resolution.

Operational changes at the various tropical cyclone warning centers probably also contributed to discontinuities in tropical cyclone intensity estimates and to more frequent identification of extreme tropical cyclones (along with a shift to stronger maximum sustained surface wind in general) by 1990. These operational changes include (13–17) the advent of advanced analysis and display systems for visualizing satellite images, changes in the pressure-wind relationships used for wind estimation from observed pressures, relocation of some tropical cyclone warning centers, termination of aircraft reconnaissance in the Northwest Pacific in August 1987, and the establishment of specialized tropical cyclone warning centers.

Therefore, tropical cyclone databases in regions primarily dependent on satellite imagery for monitoring are inhomogeneous and likely to have artificial upward trends in intensity. Data from the only two basins that have had regular aircraft reconnaissance—the Atlantic and Northwest Pacific—show that no significant trends exist in tropical cyclone activity when records back to at least 1960 are examined (7, 9). However, differing results are obtained if large bias corrections are used on the best track databases (1), although such strong adjustments to the tropical cyclone intensities may not be warranted (7). In both basins, monitoring and operational changes complicate the identification of true climate trends. Tropical cyclone “best track” data sets are finalized annually by operational meteorologists, not by climate researchers, and none of the data sets have been quality controlled to account for changes in physical understanding, new or modified methods for analyzing intensity, and aircraft/satellite data changes (18–21).

To illustrate our point, the figure presents satellite images of five tropical cyclones listed in the North Indian basin database for the period 1977 to 1989 as category 3 or weaker. Today, these storms would likely be considered extreme tropical cyclones based on retrospective application of the infrared Dvorak TechTechnique. Another major tropical cyclone, the 1970 Bangladesh cyclone—the world’s worst tropical-cyclone disaster, with 300,000 to 500,000 people killed—does not even have an official intensity estimate, despite indications that it was extremely intense (22). Inclusion of these storms as extreme tropical cyclones would boost the frequency of such events in the 1970s and 1980s to numbers indistinguishable from the past 15 years, suggesting no systematic increase in extreme tropical cyclones for the North Indian basin.

These examples are not likely to be isolated exceptions. Ongoing Dvorak reanalyses of satellite images in the Eastern Hemisphere basins by the third author suggest that there are at least 70 additional, previously unrecognized category 4 and 5 cyclones during the period 1978–1990. The pre-1990 tropical cyclone data for all basins are replete with large uncertainties, gaps, and biases. Trend analyses for extreme tropical cyclones are unreliable because of operational changes that have artificially resulted in more intense tropical cyclones being recorded, casting severe doubts on any such trend linkages to global warming.

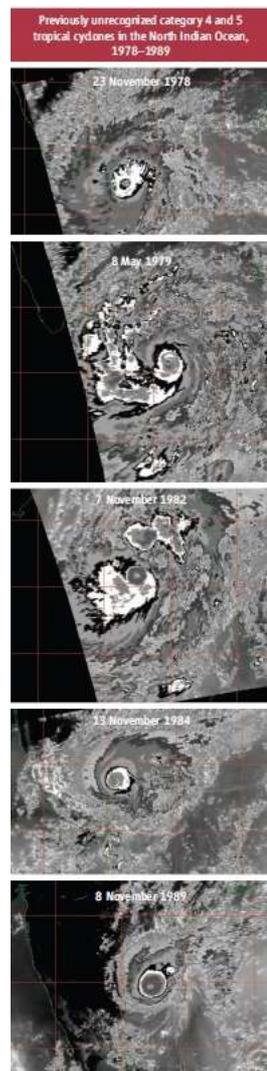
There may indeed be real trends in tropical cyclone intensity. Theoretical considerations based on sea surface temperature increases suggest an increase of ~4% in maximum sustained surface wind per degree Celsius (4, 5). But such trends are very likely to be much smaller (or even negligible) than those found in the recent studies (1–3). Indeed, Klotzbach has shown (23) that extreme tropical cyclones and overall tropical cyclone activity have globally been flat from 1986 until 2005, despite a sea surface temperature warming of 0.25°C. The large, step-like increases in the 1970s and 1980s reported in (1–3) occurred while operational improvements were ongoing. An actual increase in global extreme tropical cyclones due to warming sea surface temperatures should have continued during the past two decades.

Efforts under way by climate researchers—including reanalyses of existing tropical cyclone databases (20, 21)—may mitigate the problems in applying the present observational tropical cyclone databases to trend analyses to answer the important question of how humankind may (or may not) be changing the frequency of extreme tropical cyclones.

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Underestimated storm intensity. The North Indian basin tropical cyclones shown here are listed in the best track data set as category 3 or weaker, but were probably category 4 or 5. Similar underestimates may have been common in all ocean basins in the 1970s and 1980s. Trend analyses for tropical cyclones intensities are therefore highly problematic.