HURRICANES AND GLOBAL WARMING

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An interdisciplinary team of researchers survey the peer-reviewed literature to assess the relationships between global warming, hurricanes, and hurricane impacts.

Debate over climate change frequently conflates issues of science and politics. Because of their significant and visceral impacts, discussion of extreme events is a frequent locus of such conflation. Linda Mearns, of the National Center for Atmospheric Research (NCAR), aptly characterizes this context: "There's a push on climatologists to say something about extremes, because they are so important. But that can be very dangerous if we really don't know the answer" (Henson 2005). In this article we focus on a particular type of extreme event—the tropical cyclone—in the context of global warming (tropical cyclones are better known in the United States as hurricanes, i.e., tropical cyclones that form in the waters of the Atlantic and eastern Pacific oceans with maximum 1-min-averaged surface winds that exceed 32 m s^{-1}).

In our discussion we follow distinctions between event risk and outcome risk presented by Sarewitz et al. (2003). "Event risk" refers to the occurrence of a particular phenomenon, and in the context of hurricanes we focus on trends and projections of storm frequencies and intensities. "Vulnerability" refers to "the inherent characteristics of a system that create the potential for harm," but are independent from event risk. In the context of the economic impacts of tropical cyclones vulnerability has been characterized in terms of trends in population and wealth that set the stage for storms to cause damage. "Outcome risk" integrates considerations of vulnerability with event risk to characterize an event that causes losses. An example of outcome risk is the occurrence of a $100 billion hurricane in the United States. To calculate such a probability requires consideration of both vulnerability and event risk. This article discusses hurricanes and global warming from both of these perspectives.

EVENT RISK. At the end of the 2004 Atlantic hurricane season, many scientists, reporters, and

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policymakers looked for simple answers to explain the extent of the devastation, which totaled more than $40 billion according to the National Hurricane Center. Some prominent scientists proposed that the intense 2004 hurricane season and its considerable impacts, particularly in Florida, could be linked to global warming resulting from the emissions of greenhouse gases into the atmosphere (e.g., Harvard Medical School 2004; NCAR 2004). But the current state of climate science does not support so close a linkage (Trenberth 2005).

Tropical cyclones can be thought of to a first approximation as a natural heat engine or Carnot cycle (Emanuel 1987). From this perspective global warming can theoretically influence the maximum potential intensity of tropical cyclones through alterations of the surface energy flux and/or the upper-level cold exhaust (Emanuel 1987; Lighthill et al. 1994; Henderson-Sellers et al. 1998). But no theoretical basis yet exists for projecting changes in tropical cyclone frequency, though empirical studies do provide some guidance as to the necessary thermodynamical and dynamical ingredients for tropical cyclogenesis (Gray 1968, 1979).

Since 1995 there has been an increase in the number of storms, and in particular the number of major hurricanes (categorys 3, 4, and 5) in the Atlantic. But the changes of the past decade in these metrics are not so large as to clearly indicate that anything is going on other than the multidecadal variability that has been well documented since at least 1900 (Gray et al. 1997; Landsea et al. 1999; Goldenberg et al. 2001). Consequently, in the absence of large or unprecedented trends, any effect of greenhouse gases on the frequency of storms or major hurricanes is necessarily very difficult to detect in the context of this documented variability. Perspectives on hurricanes are no doubt shaped by recent history, with relatively few major hurricanes observed in the 1970s, 1980s, and early 1990s, compared with considerable activity during the 1940s, 1950s, and early 1960s. The period from 1944 to 1950 was particularly active for Florida. During that period 11 hurricanes hit the state, at least one per year, resulting in the equivalent of billions of dollars in damage in each of those years (Pielke and Landsea 1998).

Globally there has been no increase in tropical cyclone frequency over at least the past several decades (Webster et al. 2005; Lander and Guard 1998; Elsner and Kocher 2000). In addition to a lack of theory for future changes in storm frequencies, the few global modeling results are contradictory (Henderson-Sellers et al. 1998; Houghton et al. 2001). Because historical and observational data on hurricanes and tropical cyclones are relatively robust, it is clear that storm frequency has not tracked recent tropical climate trends. Research on possible future changes in hurricane frequency due to global warming is ambiguous, with most studies suggesting that future changes will be regionally dependent, and showing a lack of consistency in projecting an increase or decrease in the total global number of storms (Henderson-Sellers et al. 1998; Royer et al. 1998; Sugi et al. 2002). These studies give such contradictory results as to suggest that the state of understanding of tropical cyclogenesis provides too poor a foundation to base any projections about the future. While there is always some degree of uncertainty about the future and model-based results are often fickle, the state of current understanding is such that we should expect hurricane frequencies in the future to have a great deal of year-to-year and decade-to-decade variation as has been observed over the past decades and longer.

The issue of trends in tropical cyclone intensity is more complicated, simply because there are many possible metrics of intensity (e.g., maximum potential intensity, average intensity, average storm lifetime, maximum storm lifetime, average wind speed, maximum sustained wind speed, maximum wind gust, accumulated cyclone energy, power dissipation, and so on), and not all such metrics have been closely studied from the standpoint of historical trends, due to data limitations among other reasons. Statistical analysis of historical tropical cyclone intensity shows a robust relationship to the thermodynamic potential intensity (Emanuel 2000), suggesting that increasing potential intensity should lead to an increase in the actual intensity of storms. The increasing potential intensity associated with global warming as predicted by global climate models (Emanuel 1987) is consistent with the increase in modeled storm intensities in a warmer climate, as might be expected (Knutson and Tuleya 2004). But while observations of tropical and subtropical sea surface temperature have shown an overall increase of about 0.2°C over the past ~50 years, there is only weak evidence of a systematic increase in potential intensity (Bister and Emanuel 2002; Free et al. 2004).

Emanual (2005) reports a very substantial upward trend in power dissipation (i.e., the sum over the lifetime of the storm of the maximum wind speed cubed) in the North Atlantic and western North Pacific, with a near doubling over the past 50 years (Webster et al. 2005). The precise causation for this trend is not yet clear. Moreover, in the North Atlantic, much of the recent upward trend in Atlantic storm frequency and intensity can be attributed to large multidecadal fluctuations. Emanuel (2005) has just been published as of this writing and is certain to motivate a healthy and robust debate in the community. Other studies that have addressed tropical cyclone intensity variations (Landsea et al. 1999; Chan and Liu 2004) show no significant secular trends during the decades of reliable records.

Because the global earth system is highly complicated, until a relationship between actual storm intensity and tropical climate change is clearly demonstrated and accepted by the broader community, it would be premature to conclude with certainty that such a link exists or is significant (from the standpoints of either event or outcome risk) in the context of variability. Additionally, any such relationship between trends in sea surface temperature and various measures of tropical cyclone intensity would not necessarily mean that the storms of 2004 or 2005 or their associated damages could be attributed directly or indirectly to increasing greenhouse gas emissions.

Looking to the future, global modeling studies suggest the potential for relatively small changes in tropical cyclone intensities related to global warming. Early theoretical work suggested an increase of about 10% in wind speed for a 2°C increase in tropical sea surface temperature (Emanuel 1987). A 2004 study from the Geophysical Fluid Dynamics Laboratory in Princeton, New Jersey, that utilized a mesoscale model downscaled from coupled global climate model runs indicated the possibility of a 5% increase in the wind speeds of hurricanes by 2080 (Knutson and Tuleya 2004; cf. Houghton et al. 2001). Michaels et al. (2005) suggest that even this 5% increase may be overstated, and that a more realistic projection is on the order of only half of that amount. Even if one accepts that the Knutson and Tuleya results are in the right ballpark, these would imply that changes to hurricane wind speeds on the order of 0.5–1.0 m s^{-1} may be occurring today. This value is exceedingly small in the context of, for example, the more than doubling in numbers of major hurricanes between quiet and active decadal periods in the Atlantic (Goldenberg et al. 2001). Moreover, such a change in intensities would not be observable with today's combination of aircraft reconnaissance and satellite-based intensity estimates, which only resolves wind speeds of individual tropical cyclones to—at best—2.5 m s^{-1} increments.

VULNERABILITY AND OUTCOME RISK.

Understanding of trends and projections in tropical cyclone frequencies and intensities takes on a different perspective when considered in the context of rapidly growing societal vulnerability to storm impacts (Pielke and Pielke 1997; Pulwarty and Riebsame 1997). There is overwhelming evidence that the most significant factor underlying trends and projections associated with hurricane impacts on society is societal vulnerability to those impacts, and not the trends or variation in the storms themselves (Pielke and Landsea 1998). Growing population and wealth in exposed coastal locations guarantee increased economic damage in coming years, regardless of the details of future patterns of intensity or frequency (Pielke et al. 2000). Tropical cyclones will also result in death and suffering, in less developed countries in particular, as seen in Haiti during Hurricane Jeanne (cf. Pielke et al. 2003).

Over the long term the effects of changes in society dwarf the effects of any projected changes in tropical cyclones according to research based on assumptions of the Intergovernmental Panel on Climate Change (IPCC), the scientific organization convened to report on the science of climate change. By 2050, for every additional dollar in damage that the IPCC expects to result from the effects of global warming on tropical cyclones, we should expect between $22 and $60 of increase in damage due to population growth and wealth (Pielke et al. 2000). The primary factors that govern the magnitude and patterns of future damages and causalities are how society develops and prepares for storms rather than any presently conceivable future changes in the frequency and intensity of the storms. Consider that if per capita wealth and population grow at a combined 5% per year, this implies a doubling in the real costs of hurricanes about every 15 years. In such a context, any climate trend would have to be quite large to be discernible in the impacts record.

With no trend identified in various metrics of hurricane damage over the twentieth century (Pielke and Landsea 1998), it is exceedingly unlikely that scientists will identify large changes in historical storm behavior that have significant societal implications. In addition, looking to the future, until scientists conclude a) that there will be changes to storms that are significantly larger than observed in the past, b) that such changes are correlated to measures of societal impact, and c) that the effects of such changes are significant in the context of inexorable growth in population and property at risk, then it is reasonable to conclude that the significance of any connection of human-caused climate change to hurricane impacts necessarily has been and will continue to be exceedingly small.

CONCLUSIONS. To summarize, claims of linkages between global warming and hurricane impacts are premature for three reasons. First, no connection has been established between greenhouse gas emissions and the observed behavior of hurricanes (Houghton et al. 2001; Walsh 2004). Emanuel (2005) is suggestive of such a connection, but is by no means definitive. In the future, such a connection may be established [e.g., in the case of the observations of Emanuel (2005) or the projections of Knutson and Tuleya (2004)] or made in the context of other metrics of tropical cyclone intensity and duration that remain to be closely examined. Second, the peer-reviewed literature reflects that a scientific consensus exists that any future changes in hurricane intensities will likely be small in the context of observed variability (Knutson and Tuleya 2004; Henderson-Sellers et al. 1998), while the scientific problem of tropical cyclogenesis is so far from being solved that little can be said about possible changes in frequency. And third, under the assumptions of the IPCC, expected future damages to society of its projected changes in the behavior of hurricanes are dwarfed by the influence of its own projections of growing wealth and population (Pielke et al. 2000). While future research or experience may yet overturn these conclusions, the state of the peer-reviewed knowledge today is such that there are good reasons to expect that any conclusive connection between global warming and hurricanes or their impacts will not be made in the near term.

Yet, claims of such connections persist (cf. Epstein and McCarthy 2004; Eilperin 2005), particularly in support of a political agenda focused on greenhouse gas emissions reduction (e.g., Harvard Medical School 2004). But a great irony here is that invoking the modulation of future hurricanes to justify energy policies to mitigate climate change may prove counterproductive. Not only does this provide a great opening for criticism of the underlying scientific reasoning, it leads to advocacy of policies that simply will not be effective with respect to addressing future hurricane impacts. There are much, much better ways to deal with the threat of hurricanes than with energy policies (e.g., Pielke and Pielke 1997). There are also much, much better ways to justify climate mitigation policies than with hurricanes (e.g., Rayner 2004).

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