Perspectives on focused workshop questions regarding past economic impacts of storms or floods

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1. According to research currently available, what factors account for the increased costs of disasters in recent decades?

a. Hurricanes

For the case of U.S. landfalling hurricanes, Pielke and Landsea (1998) make a strong case that societal factors such as increasing population in coastal areas affected by hurricanes, increases in value of structures in those areas, and inflation are the key drivers of increased economic damages from hurricanes in recent decades. In contrast, changes in U.S. landfalling hurricane climate appear to play a more minor role. A recent key analysis on the latter influence is Landsea's (2005) U.S. Power Dissipation Index (PDI) for landfalling tropical cyclones (TCs) since 1900, updated through 2005 (Fig. 1). This TC climate metric shows no strong evidence for an upward trend during the 20th century, although 2004 and 2005 appear as strong outliers at the end of the series. Landsea (2005) comments that 1886, although not shown on the figure, is estimated to be comparable to 2004 and 2005, again emphasizing the limited evidence for a long-term trend in this metric at this time.

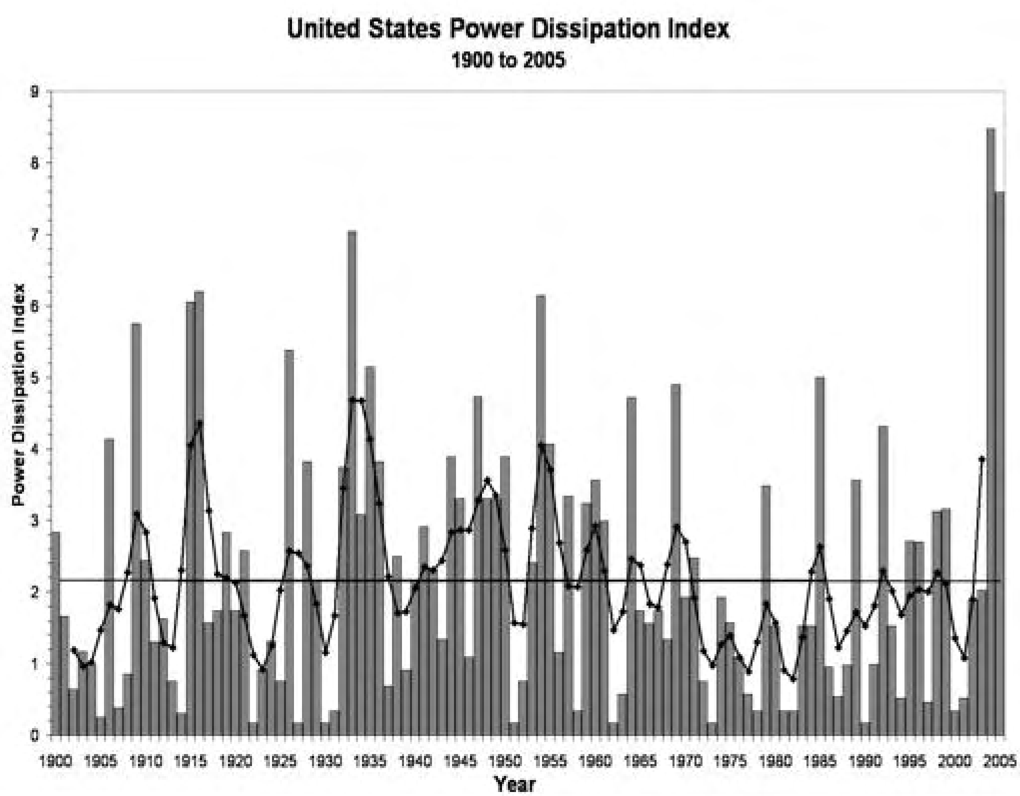

Fig. 1. Power Dissipation Index (PDI) for continental United States, 1900-2005 in units of m^3s^{-3}, multiplied by 10^{-5}. Based on all tropical storms, subtropical storms, and hurricanes at time of impact. Black curve smoothed with two passes of 1-2-1 filter. From Landsea (2005).

The absence of a strong trend is noteworthy given indications of a century-scale SST warming trend in the tropical Atlantic Main Development Region (e.g., Fig. 2, see also Knutson et al., 2006), and of possible SST-correlated upward trends in Atlantic *basin-wide* TC counts and storm maximum PDI (Figs. 3 and 4, Emanuel 2006). Interestingly, the U.S. landfalling PDI also does not clearly show the pronounced multi-decadal modulation seen in the basin-wide Atlantic PDI (Fig. 5) and major hurricane counts (not shown) since the late 1940s. Although the current "active era" of Atlantic hurricane activity apparently began in 1995, only during 2004 and 2005 did the U.S. landfalling PDI reach or exceed the strong levels that occurred several times in the first half of the 20th century (Fig. 1).

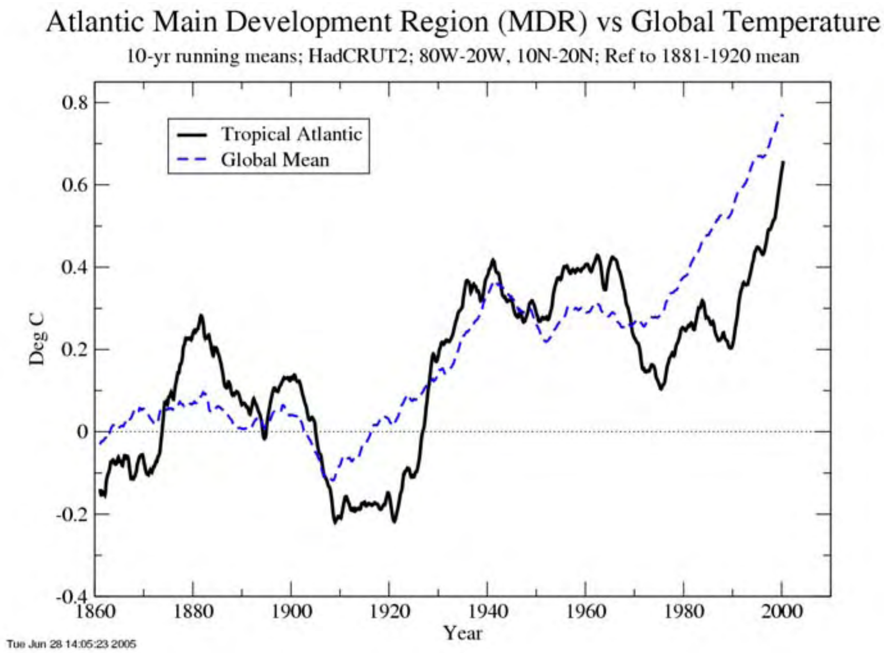

Fig. 2. Atlantic Main Development Region (MDR) surface temperature vs global mean surface temperature. MDR region defined as 80W-20W, 10N-20N. 10-yr running annual means, referenced to 1881-1920 are plotted.

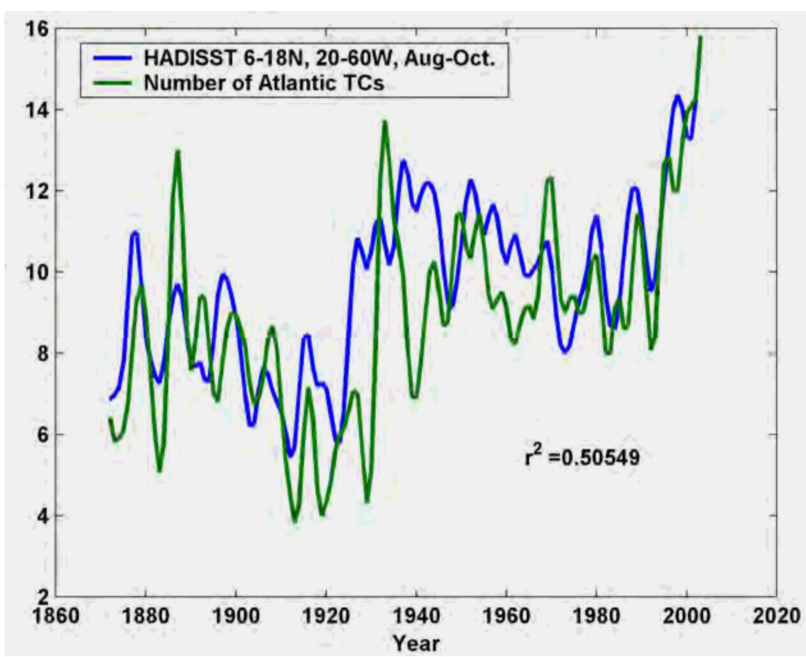

Fig. 3. Annual number of Atlantic tropical cyclones (smoothed) versus sea surface temperature (Aug. – Oct.) in the tropical Atlantic (6-18N, 20-60W). Source: Emanuel 2006.

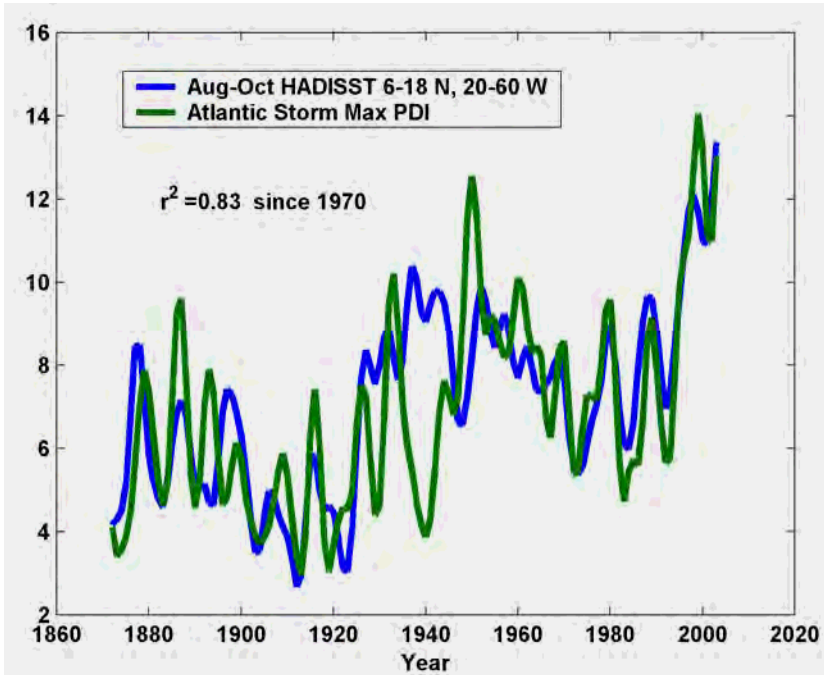

Fig. 4. Storm maximum power dissipation index (one value per storm) for the Atlantic basin versus sea surface temperature (Aug. – Oct.) in the tropical Atlantic (6-18N, 20-60W). Values scaled by arbitrary constants to show correlation of curves. Source: Emanuel 2006).

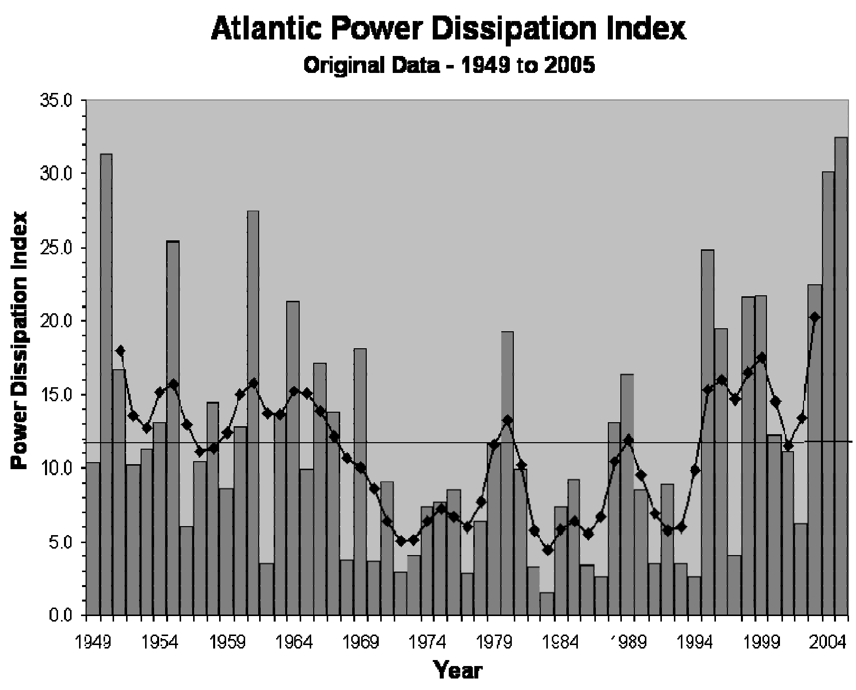

Fig. 5. Atlantic Power Dissipation Index (PDI) from Landsea (2005) using no correction of early period wind intensities, in contrast to Emanuel (2005). Values multiplied by 10^{-6}, in units of m^3sec^{-3}.

Thus, while there is debate about whether there is a century-scale trend in various Atlantic basin-wide TC measures (e.g., Emanuel 2006; Landsea, personal communication 2006), there does not appear to be any real debate about the lack of trend to date in U.S. landfalling PDI statistics. A key question to resolve is why this is the case. Emanuel (2005b) raises a fair point that U.S. landfalling storms are only a small fraction of all Atlantic hurricanes so that a basin wide index is based on about 100 times more data than the U.S. landfalling PDI. This means that the failure to see a trend in the U.S. landfalling PDI may be a signal to noise issue, with a possible underlying trend masked by the high noise levels and limited sample size for U.S. PDI. On the other hand, the sensitivity of hurricane intensity to sea surface warming implied in the Emanuel (2005a) results exceeds by a factor of 6 the sensitivity inferred from the Knutson and Tuleya's (2004) idealized hurricane modeling study, which found a sensitivity of about 4% per degree Celsius SST increase. In a recent examination of Atlantic potential intensity data since about 1980, the discrepancy with our modeling work appears to be about a factor of 4, and that discrepancy might be partly attributable to a general reduction of surface wind speeds in the basin over time (Emanuel 2006).

In summary, in attributing the sharp rise in U.S. hurricane damages to various factors, the U.S. landfalling PDI results to date do not support a clear role for century-scale climate change in the observed damage trend.

b. Floods

Concerning possible trends in damaging floods, Milly et al. (2002) tentatively detected an upward trend (Fig. 6) in the global frequency of "great floods" (100-year floods on river basins larger than 200,000 km^2). In their climate-model-based estimates of sensitivity of great-flood rates to an idealized quadrupling of atmospheric CO2, the most sensitive regions were in the high latitudes and the tropics (Fig. 7). Milly et al. (2005) presented evidence that the global pattern of 20th-century trends in mean annual streamflow was partially controlled by forced climate change, although trends in any single region generally could be explained by internal variability. The latter study lends some credibility to climate models' retrospective and prospective estimates of flood risk.

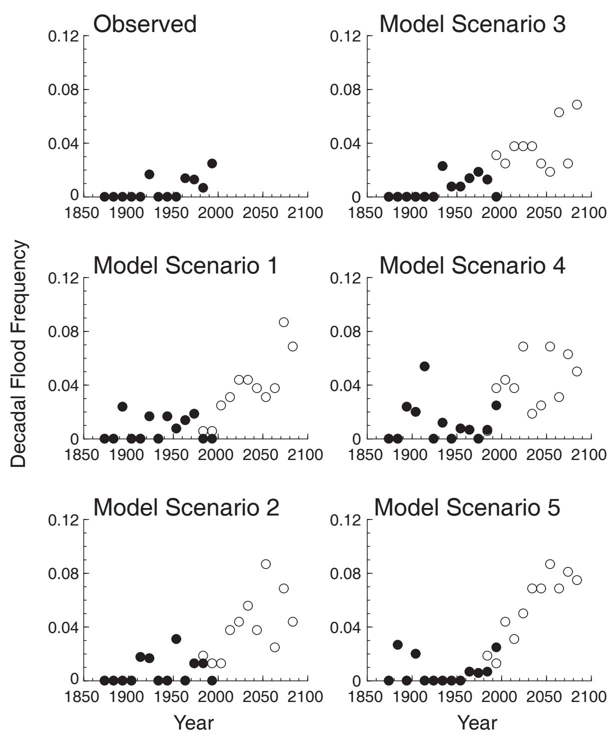

Fig. 6. Decadal extratropical flood frequencies for observations (upper left) and a series of climate model experiments with the GFDL R30 coupled climate model forced by historical estimates of greenhouse gases and direct effect of sulfate aerosols, with +1%/yr CO2 forcing for post-2000. The flood frequency is defined as the number of events exceeding the 100-yr discharge divided by the number of station years of observations. In modeled output, filled circles are obtained with station starting and ending dates as in observations, while open circles are obtained with all stations continuing operation once begun. Source: Milly et al. 2002.

Milly, Figure 2

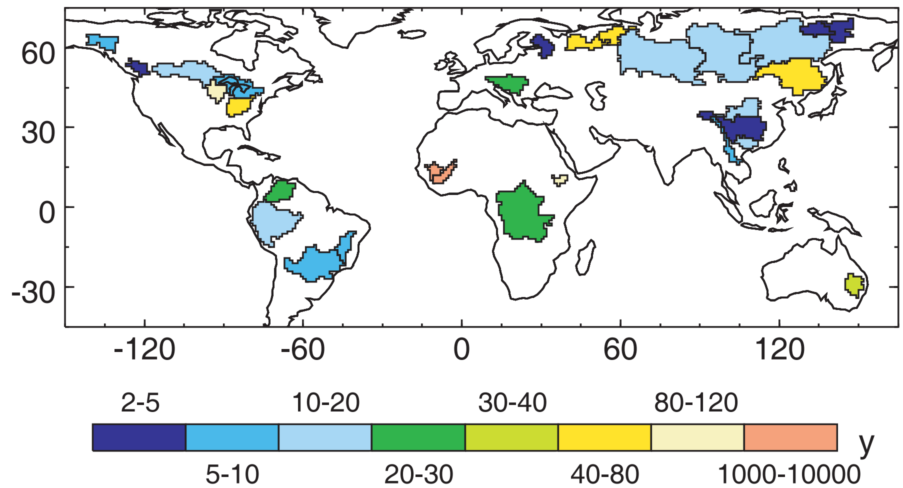

Fig. 7. Map showing gauged drainage areas and flood-risk sensitivities. Color indicates the modeled return period, under idealized CO_2 quadrupling, of the flood magnitude associated with a 100-year flood before the CO_2 increase. Source: Milly et al. 2002).

Groisman et al. (2005) present evidence for increasing occurrence of intense precipitation events (upper 0.3%) for many extratropical regions, but they note that it is difficult to relate the changes in very heavy precipitation directly to changes in flooding. Knutson and Tuleya's (2004) simulations of hurricanes under CO2-warmed climate conditions, with a 20% increase in storm core rainfall for a 1.75°C SST warming, suggests the possibility of a future trend in hurricane-related precipitation rates. Groisman et al. (2004) report that no change can be detected at this time in hurricane-related precipitation along the southeast coast of the U.S. However, they did not assess whether the *per storm* precipitation has changed. Local precipitation totals from hurricanes are strongly influenced by the storm translation speed as well as storm-relative precipitation rates.

Pielke and Downton (2000) find that both precipitation increases and societal factors (population and wealth) have contributed to the increase in U.S. flood damages in recent decades. They found that 2-day heavy rainfall events and the number of wet days were two climate statistics that were more closely linked to flood damage than other measures they examined. They noted a trend, correlated to the increase in these precipitation measures, in damage per capita, but not in damage per unit wealth.

In summary, the analyses by Milly et al. and Pielke and Downton suggest that climate factors may be at least partially responsible for the observed increase in flood occurrence and flood damages in recent decades, although based on the latter study of U.S. damages, societal factors are likely to be most important.

2. What are the implications of these understandings, both for research and policy?

Societal factors (coastal population growth, increased development of more expensive infrastructure at the coast, etc.) have almost certainly been the key drivers of the strong, systematic rise in total U.S. hurricane damages over the past several decades. One implication of this is that research to understand these drivers and how to best reduce vulnerability to hurricane damage is a worthwhile undertaking. There is probably much "low-hanging fruit" to be harvested in this regard, if the goal is to reduce the aggregate amount of hurricane damage in the future, relative to a "business as usual" scenario. Consumers, businesses (e.g., insurers) and policymakers could benefit from such studies, particularly since wide-spread adoption of damage-reducing preventative measures will likely require proactive measures from these stakeholders.

The possibility of substantial long-term increases in historical PDI in several basins, including the Atlantic, and the possibility of even greater increases in the future imply that this topic also deserves considerable attention from the hurricane and climate research communities at this time. The lack of a long-term trend in U.S. landfalling TC statistics could reflect a signal-to-noise issue, as Emanuel (2005b) suggests, or could be indicative of greater data problems in the basin-wide statistics as compared to the U.S. landfalling TC statistics. In general, the causes of the differing behavior between all-basin and landfalling TCs need to be resolved.

Despite the evidence that societal factors have almost certainly been the key drivers of the sharp rise in total hurricane damages in the U.S. in recent decades, there is some ambiguity arising regarding the interpretation of the past two very damaging seasons. In addition, the (highly uncertain) future projections of increases in hurricane intensities and perhaps other TC metrics imply that climate change could lead to additional damage potential for whatever coastal infrastructure exists at a given point in the future. For example, Emanuel (2005a) reports roughly a doubling of PDI accumulated over the Atlantic and Northwest Pacific basins in the last 30 years, associated with roughly an 0.5ºC SST increase. If future PDI changes were to scale with future SST changes in that manner, it seems likely that a climate change signal in landfalling PDI will eventually emerge, even for the U.S. landfalling hurricanes, unless there is a strong mitigating effect from changes in storm tracks, or other factors. It is important to note that SST increases in the Atlantic during the 21st century are likely to be much more substantial, perhaps by a factor of four (e.g., Knutson and Tuleya 2004), than the warming that occurred in the 20th century. Future sea level rise associated with anthropogenic climate warming, a process which apparently has a very long equilibration time scale (e.g. centuries to millennia) will almost certainly further exacerbate coastal flooding problems from a given hurricane to some degree, unless substantial damage mitigation steps are undertaken. Subsiding land in some coastal regions due to various natural and anthropogenic influences can also exacerbate this problem.

From a research perspective, the implications include the need for improved climate-quality monitoring and for improved historical and "paleoclimate-proxy" tropical cyclone data bases. These will provide better information for assessing future changes, and more reliable statistical assessments of past changes in hurricane activity, including land fall, in all basins. Specific examples include the need to reanalyze tropical cyclone data bases in all basins, and not just the Atlantic. Greater efforts should be made to provide researchers with access to original "raw" historical observations rather than derived quantities, concerning past tropical cyclones (Emanuel, personal communication). Consideration should be given to initiating or resuming aircraft reconnaissance of hurricanes outside of the Atlantic basin. For example, aircraft reconnaissance was conducted in the NW Pacific basin beginning in the 1940s, but was discontinued in 1987. Aircraft reconnaissance could provide more reliable intensity estimates than are now possible using satellite-only methods. Another example is paleotempestology research, which attempts to use information in the geological record, such as overwash deposits in near coastal lakes, to infer pre-historic hurricane activity.

In general, hurricane-climate research is expected to progress most rapidly when a combination of theory, modeling, and observations are brought to bear on the problem.

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