and the western Caribbean. Thus, there was no net change in overall developments in the southeastern region (Figure 1d). A separate study, under preparation by me and collaborators, will ascribe the western Caribbean decrease and the majority of the eastward spread to circulation changes associated with the expansion of the North Atlantic warm pool.

It is logical that part of the eastward spread in Figure 1c arose from weaker developing systems in the far eastern equatorial North Atlantic not being well analyzed in early years. However, the large reduction in Lesser Antilles developments (Figure 1c) indicates that most of these early-year systems simply were picked up later in their lifetimes. This is supported by the observation that the genesis intensity over the Lesser Antilles was substantially higher at approximately 20 meters per second prior to 1955 compared with approximately 10 meters per second after 1956. Thus, missing early stages of far eastern storms did not have a great impact on observed numbers of tropical cyclones, as shown in Figure 1b.

To conclude, the decrease in landfall ratio leading up to the satellite era was part of a long-period cycle in which late nineteenth century values were similar to those of today. This decrease arose largely from a similar decrease of tropical cyclone developments in the well-observed western Caribbean and southern Gulf of Mexico regions, and it cannot be ascribed to unobserved eastern region tropical cyclones. It thus appears to be a real feature and not an analysis artifact.

This finding also is supported by other studies, such as that of *Elsner* [2003], which suggest that there are large-scale shifts in tropical cyclone tracks and development regions. Landfall ratios cannot be assumed to be constant in time and cannot be used to infer missing data in earlier years, or to adjust the historical time series as suggested by *Solow and Moore* [2000] and *Landsea* [2007]. These results support the independent analyses by *Neumann et al.* [1999] and *Chang and Guo* [2007], who estimate early twentieth century missing storms at around one to two per year declining to zero by 1960. Follow-on studies will address the physical mechanisms that cause these changes.

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Author Information

Greg J. Holland, National Center for Atmospheric Research, Boulder, Colo.; E-mail: gholland@ucar.edu.

Atlantic Tropical Cyclones Revisited

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Vigorous discussions have taken place recently in *Eos* [e.g., *Mann and Emanuel*, 2006; *Landsea*, 2007] and elsewhere [*Emanuel*, 2005; *Webster et al.*, 2005; *Hoyos et al.*, 2006; *Trenberth and Shea*, 2006; *Kossin et al.*, 2007] regarding trends in North Atlantic tropical cyclone (TC) activity and their potential connection with anthropogenic climate change. In one study, for example [*Landsea*, 2007], it is argued that a substantial underestimate of Atlantic tropical cyclone counts in earlier decades arising from insufficient observing systems invalidates the conclusion that trends in TC behavior may be connected to climate change. Here we argue that such connections are in fact robust with respect to uncertainties in earlier observations.

Several recent studies have investigated trends in various measures of TC activity. *Emanuel* [2005] showed that a measure of total power dissipation by TCs (the power dissipation index, or PDI) is highly correlated with August–October sea surface temperatures (SST) over the main development region (MDR) for Atlantic TCs over at least the past half century. Some support for this conclusion was provided by *Sriver and Huber* [2006]. *Webster et al.* [2005] demonstrated a statistically significant increase in recent decades in both the total number of the strongest category cyclones (categories 4 and 5) and the proportion of storms reaching hurricane intensity. *Hoyos et al.* [2006] showed that these increases were closely tied to warming trends in tropical Atlantic SST, while, for example, the modest decrease in vertical wind shear played a more secondary role. *Kossin et al.* [2007] called into question some trends in other basins, based on a reanalysis of past TC data, but they found the North Atlantic trends to be robust.

A number of recent studies have found these trends likely linked in large part to anthropogenic climate change. *Mann and Emanuel* [2006] found long-term August–October MDR SST trends to be driven primarily by a combination of large-scale SST increases and regionally enhanced anthropogenic aerosol cooling over the North Atlantic. *Trenberth and Shea* [2006] also concluded that tropical Atlantic SST trends have been driven by large-scale anthropogenic warming. While these latter studies relied upon an empirical separation of forced and internal variability subject to alternative interpretations [e.g., *Zhang et al.*, 2007], *Santer et al.* [2006] arrived at a similar conclusion using an entirely different model-based detection and attribution approach.

Mann and Emanuel [2006] and *Holland and Webster* [2007] furthermore noted a close statistical relationship between long-term MDR SST trends and annual total TC counts. More recently, *Landsea* [2007] has argued that such relationships are an artifact of a substantial historical undercount bias in early Atlantic TC counts based on the assumption that a substantial fraction of TCs went unnoticed because they did not make landfall. We argue below that Landsea's argument does not stand up to scrutiny.

The sharp simultaneous increases in TCs and MDR SST during the 1930s and 1990s occur during intervals for which there are no known changes in observing practices [*Holland and Webster*, 2007], which makes the argument for a role of undercount bias less plausible. Second, the approach used by *Landsea* [2007] seeks to correct the record of annual total TC counts based on the assumption that the true percentage of TCs making landfall is constant over time. However, the reported genesis locations are expanding eastward with time along with the greater rate of SST warming in the eastern portion of the tropical Atlantic [*Holland and Webster,* 2007]. Moreover, it is well known [e.g., *Elsner*, 2003] that climate phenomena such as the North Atlantic Oscillation (NAO) and El Niño–Southern Oscillation (ENSO), themselves subject to low-frequency variability and

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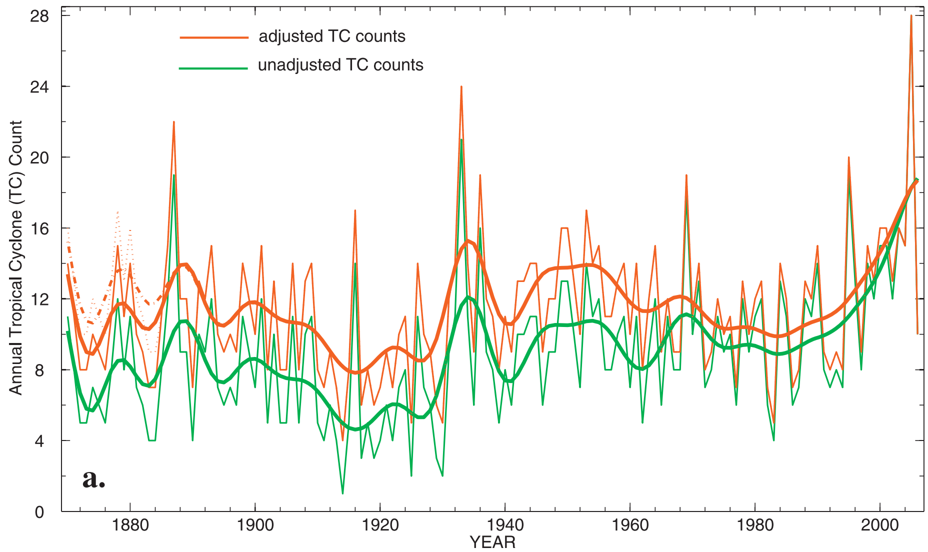

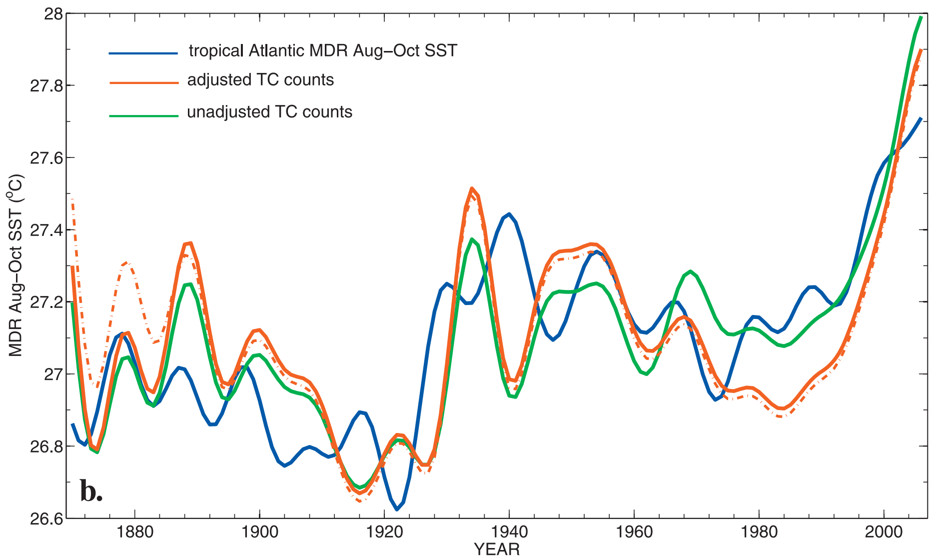

Fig. 1. Long-term tropical cyclone (TC) numbers and their relationship with main development region sea surface temperature (SST). (a) Annual TC numbers (annual mean, thin curve; decadally smoothed, bold curve) from 1870 to 2006. Compared are raw TC counts from Jarvinen et al. *[1984] (green) and adjusted counts (red) as described by* Landsea *[2007]. The dashed versions of the red curves shown prior to 1886 demonstrate the impact of assuming an additional pre-1886 increase in undercounts as discussed in text. (b) Comparison of decadal trends (1870–2006) in tropical North Atlantic August–October SST (blue) with TC counts (raw, green; adjusted, solid red; additional pre-1886 adjustment included, dashed red). The TC series have been centered to have the same mean and scaled in order to have the same decadal variance as the SST series. SST data are from the HadISST2 observational data set [*Rayner et al., *2003]. Note (Figure 1a) that the specific observation of anomalous TC counts over the past decade is robust with respect to whether or not the adjustments suggested by* Landsea *[2007] are adopted. Note also (Figure 1b) that the close relationship between long-term changes in TC counts and tropical North Atlantic August–October SST is robust with respect to such considerations.*

long-term trends, have a significant influence on the prevailing trajectories of Atlantic TCs. Finally, independent reanalyses of the long-term record [*Chang and Guo*, 2007; T. Knutson and G. Vecchi, personal communication, 2007; G. J. Holland and P. J. Webster, personal communication, 2007] suggest a substantially smaller undercount bias than does *Landsea* [2007], and sparse observations can also lead to overcounting when a single event is counted as two or more events.

These misgivings notwithstanding, we will assume for the purpose of discussion that the *Landsea* [2007] undercount estimates are correct. Following *Landsea* [2007], we adopt an undercount of 3.2 TCs prior to 1966 and an undercount of one TC from 1967 to 2002. While left unquantified by *Landsea* [2007], we additionally allowed for an even higher undercount (five TCs) prior to 1886 based on *Landsea et al.* [2004]. The qualitative nature of the long-term TC trends, including the anomalous nature of the recent decadal trend, clearly is insensitive to whether or not these adjustments are adopted (Figure 1a).

Moreover, the tight relationship on decadal timescales between the MDR SST and TC count series is insensitive to the adjustments (Figure 1b). The correlation between the decadally smoothed MDR SST and TC count series over 1870–2006 using the unadjusted TC record is $r = 0.76$ (58% shared variance) and is only slightly lower using the adjusted record ($r = 0.68$; 47% shared variance) including if the additional pre-1886 adjustment is made ($r = 0.63$; 40% shared variance). In each case, the correlation is significant at well above the 99% confidence level.

While we agree with *Landsea* [2007] that the true undercount bias is likely to be more complex than can be accounted for with such simple adjustments, we stress that the time history of the undercount bias would have to bear an uncanny (inverse) resemblance to tropical Atlantic SST variations to fortuitously yield the observed close relationships between SST and TCs.

In summary, the adjustments argued for by *Landsea* [2007], even if correct, would not change any of the primary conclusions of recent studies suggesting a measurable increase in various measures of Atlantic TC activity, a connection of this increase with warming SSTs, or the likely causal connection of warming SSTs with anthropogenic climate change.

We appreciate the efforts of investigators [e.g., *Kossin et al.*, 2007] who have undertaken the laborious and important task of reanalyzing the historical record of tropical cyclone activity. We caution, however, that researchers should not overstate the impact of existing uncertainties on our ability to discern certain key long-term trends in tropical cyclone activity.

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Author Information

Michael E. Mann, Pennsylvania State University, University Park; E-mail: mann@psu.edu; Kerry A. Emanuel, Massachusetts Institute of Technology, Cambridge; Greg J. Holland, National Center for Atmospheric Research, Boulder, Colo.; and Peter J. Webster, Georgia Institute of Technology, Atlanta.

NEWS

In Brief

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Islands uncovered by melting polar ice Thawing glaciers north of Norway's Svalbard archipelago have revealed at least two unmapped and unclaimed islands, one roughly the size of a basketball court, according to a 20 August Reuters report. In addition, information released in August by the U.S. National Snow and Ice Data Center indicated that with one month left in the melting season, Arctic sea ice is already below the record minimum. "Reductions of snow and ice are happening at an alarming rate," said Norwegian Environment Minister Helen Bjoernoy. She suggested that these observations may indicate that the loss of sea ice is perhaps accelerating faster than predicted by the Intergovernmental Panel on Climate Change, which warned in February that summer sea ice could almost vanish by the end of this century.

Indian oil company joins efforts to reduce methane emissions The Oil and Natural Gas Corp, Ltd. (ONGC), headquartered in Dehradun, India, has joined seven U.S. and Canadian oil and natural gas companies as a partner in a U.S. Environmental Protection Agency program to reduce greenhouse gas emissions. EPA's Natural Gas STAR International Program aims to reduce methane emissions from the oil and natural gas sector while delivering more gas to markets around the world. With this partnership, ONGC agrees to implement emissions reduction practices and to submit annual reports on progress achieved; EPA agrees to assist ONGC with training technicians in new cost-effective technologies that will help achieve target emissions. The Natural Gas STAR International Program is administered under the Methane to Markets Partnership, a group of 20 countries and 600 companies across the globe that since 2004 has volunteered to cut methane emissions. More information on EPA's agreement with ONGC can be found at http://www.epa.gov/gasstar/index.htm; information about the Methane to Markets Partnership can be found at http://www.methanetomarkets.org.

—Mohi Kumar, Staff Writer