Misuse of Landfall as a Proxy for Atlantic Tropical Cyclone Activity

Recent studies [Solow and Moore, 2000; Landsea, 2007] have used an assumed constant ratio of landfalling cyclones to all tropical cyclones in the basin to assess potential trends and archive quality for basin-wide North Atlantic tropical cyclones. The underlying assumption is that landfalling storms have been well observed compared with storms over the ocean that do not make landfall. Thus, a trend toward decreasing ratios of landfalling storms is assumed to imply an increasing number of unobserved oceanic storms as we go back in time. The results from these studies depend entirely on the assumption that landfalling ratios are constant over long time periods; yet neither study addressed the veracity of this assumption.

A separate analysis [Mann et al., 2007] has questioned the main conclusion of Landsea [2007] that there is no trend in tropical cyclone numbers. Previous work [e.g., Elsner and Jagger, 2006, and references therein] has shown that changing storm track characteristics that occur with different phases of the North Atlantic Oscillation can lead to variations in the number of hurricanes affecting the United States. Here I show that landfalling ratios are not stationary in time but vary with mean formation locations. Both approaches clearly show that landfall cannot be used to assess basin-wide characteristics.

Figure 1 contains the mainly U.S. landfall ratios relative to all storms taken directly from the National Hurricane Center’s North Atlantic hurricane database (HURDAT) archive [Landsea et al., 2004] together with the landfall ratios derived by Landsea [2007]. Notice that the decline in landfall ratios commenced in the 1930s, well before the satellite era. There also is a long-period variation in landfall ratio, with the early and latter parts of the record being similar and separated by a period of higher ratios. This suggests that it is much more likely that the true record of landfall ratios is not stationary in time and that Landsea’s results are dependent on the chosen time period.

We next break down the data for all Atlantic tropical cyclone genesis locations (Figure 1b) into an eastern and western region with a demarcation at 70°W, chosen to pass through the genesis-free zone in the central Caribbean (see Figure 1c). Genesis frequency was equally divided between the two regions up to 1950. The western region declined steadily from 1940 to 1994, but the eastern region increased only slightly. It is notable that the sharp climatic shifts in the 1930s and the late 1990s identified by Holland and Webster [2007] arose from almost equal increases of eastern and western region developments, not from an eastward shift in genesis locations.

Figure 1b shows that the decline in landfall numbers, and hence ratios (Figure 1a), from 1940 to 1970 was due largely to a decline in storm development in the western Atlantic. The associated spatial changes are illustrated by Figure 1c, and the time series of changes in the regions identified in Figure 1c are in Figure 1d. Notice in Figure 1c the eastward spread of cyclone developments into the equatorial Atlantic, which has been
accompanied by substantial genesis decrease over the Lesser Antilles and the western Caribbean. Thus, there was no net change in overall developments in the southeastern region (Figure 1c). 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 the 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 Sokolow and Moore [2000] and Landsea [2007]. These results support the independent analyses by Neumann et al. [1998] 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. Email: gholland@ucar.edu.

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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; Tenberth 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. Tenberth 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. (a) Ratio of tropical cyclones making landfall from HURDAT and Landsea [2007]. Dots indicate annual values, and solid curves indicate a 9-year running mean, showing the substantial variability of landfalling ratios in time. (b) Smoothed annual tropical cyclone rates (black curve) together with those that form west (blue) and east (red) of 70°W, and landfalling numbers from HURDAT (green). (c) Spatial genesis changes (in 1° Marsden squares) between 1906–1955 and 1956–2005, showing how the decreasing ratios in Figure 1a have resulted largely from a decrease in southwest Caribbean (swest) and Gulf of Mexico (GOM) storm developments. (d) Smoothed time series of cyclone formation rates in the subregions shown in Figure 1c. The series in Figures 1b and 1d have been smoothed with a running 9-year average.