The frequency and duration of U.S. hurricane droughts

Timothy Hall¹ and Kelly Hereid²

¹NASA Goddard Institute for Space Studies, New York, New York, USA, ²ACE Tempest Re, Stamford, Connecticut, USA

Abstract As of the end of the 2014 hurricane season, the U.S. has experienced no major hurricane landfall since Hurricane Wilma in 2005, a drought that currently stands at 9 years. Here we use a stochastic tropical cyclone model to calculate the mean waiting time for multiyear landfall droughts. We estimate that the mean time to wait for a 9 year drought is 177 years. We also find that the average probability of ending the drought with a major landfall in the next year is 0.39 and is independent of the drought duration, as one would expect for a Bernoulli process.

1. Introduction

U.S. coastal communities have suffered the effects of several hurricanes in recent years, including Ike (2008), Irene (2011), and Sandy (2012). However, not since Hurricane Wilma in 2005 has a major hurricane made U.S. landfall, defined as having Saffir-Simpson scale 3 or higher at landfall (maximum 1 min sustained wind speeds of 178km/h or higher). This 9 year drought (2006–2014 inclusive) is unprecedented in the historical record, as documented in National Hurricane Center’s Hurricane Database (HURDAT) [Jarvinen et al., 1984] back to 1851, beating the previous 8 year record, 1861–1868. It has occurred despite many of the intervening years being active by measures such as total storm count, major storm count, accumulated cyclone energy (ACE), and major landfalls on Caribbean Islands.

The major landfall drought is undoubtedly fortunate for coastal populations. A detrimental effect, however, may be a sense of complacency. During this period reinsurance premiums and return rates on catastrophe bonds have dropped (insuracelinked.com/still-falling), even while the population and property in harm’s way continues to surge [Pielke et al., 2008]. Many factors affect the reinsurance and catastrophe bond industry, but it is likely that a long period without costly wind-driven losses has helped depress premiums and rates by causing a perception of reduced U.S. hurricane hazard [Meyer, 2012]. If this perception is misplaced, then a new major landfall will cause disproportionate hardship.

In this paper we use a stochastic tropical cyclone (TC) model to estimate the mean waiting time for long hurricane landfall droughts and the mean time to the next major landfall. In section 2 we discuss our methods, and in section 3 we present our results. We conclude in section 4 with a discussion on what, if anything, the current drought says about U.S. hurricane hazard.

2. Methods

The reliable historical record of U.S. hurricane landfalls dates back to the midnineteenth century [Jarvinen et al., 1984]. This is not sufficiently long to estimate the waiting time for long landfall droughts. Instead, we employ a statistical-stochastic tropical cyclone (TC) model to generate an event set of synthetic TCs much longer than the historical record and analyze landfall droughts in this synthetic set. A number of such models exist that are used in public and private sector catastrophe risk assessments [Emanuel et al., 2006; Vickery et al., 2006; Rumpf et al., 2007; Bonazzi et al., 2014]. Here we use the model of Hall and Jewson [2007] and Hall and Yonekura [2013], which is constructed using publicly available 1950–2012 archived data on tropical cyclones (HURDAT) [Jarvinen et al., 1984] and depends on two indices of climate variation: sea surface temperature (SST) in the subtropical North Atlantic compared to the global tropical mean and the state of El Niño/Southern Oscillation (ENSO). Hall and Yonekura [2013] have shown that the model reproduces well the statistics of historical TC landfalls. In particular, they show that when the model is used to simulate the HURDAT historical period multiple times, the set of wind speed return period curves at
landfall bounds the directly computed HURDAT return period curve at all intensities [from Hall and Yonekura, 2013, Figure 10]. This is true on a regional basis, as well as over the full U.S. Gulf-Atlantic coast.

For this study we simulate 1000 times the period 1950–2012, where each simulation is a stochastic generation of TCs forced by the 1950–2012 historical time series of the models independent variables. We then place these one thousand 63 year simulations in sequence, creating a 63,000 year set of TCs. From this set we compute the rates of TCs crossing 19 U.S. states (TX, LA, MS, AL, FL, GA, SC, NC, VA, MD, DE, PA, NJ, NY, CT, RI, MA, NH, and ME) having intensities above specified thresholds. A TC is counted as having crossed a state if its center spends at least 1 h over the state. By direct counting of simulation years with and without such events, we estimate statistical properties of strings of years without events.

We define an N year drought to be a string of N consecutive years without a hurricane of specified intensity crossing any of the states. There are different ways to quantify landfall droughts. Here we ask two questions: (1) What is the mean time to wait for an N year drought? (2) N years into a drought, what is the mean time to next landfall? We answer these questions as functions of N, landfall intensity, and landfall region.

3. Results

Figure 1 shows the waiting time for major landfall droughts as a function of drought duration for the full U.S. Gulf and East Coast (all 19 states) and three coastal subregions. We estimate the waiting time of a 9 year plus drought (e.g., the 2006–2014 period) of major U.S. landfall to be 177 years. Subregions have shorter waiting times; it is easier to have a drought of a specified duration on a smaller target. To a good approximation, the waiting time can be estimated by making the assumption that the presence or absence of landfalls in a year is a Bernoulli process. Such a process has a mean waiting time of $A_N = (P^{-N} - 1)/(1 - P)$, where $P$ is the probability of no landfall [e.g., Feller, 1968, chap. 13, section 7]. This is plotted in Figure 1 using $P = 0.64$, the fraction of years in HURDAT 1851–2012, and $P = 0.62$, the fraction in HURDAT 1950–2012. (The TC model’s $P$ from the multiple 1950–2012 simulations is 0.61, very similar.) Also plotted is an estimate of the mean waiting time obtained by directly counting landfalls in
HURDAT 1851–2012, along with associated 90% confidence bounds from a generalized jackknife procedure.

Figure 2 shows the full-coast waiting time, now for five landfall intensities, Saffir-Simpson category 1 or greater (Cat1+) through landfalls at category 5 (Cat5). The more intense the landfall, the lower the rate, and the shorter the wait for a drought. Note that if the annual rate approaches zero (the probability of zero landfall approaches one), then \( A_N \sim N \). In this case, since there is never an event, it is only necessary to wait \( N \) years for an \( N \) year drought. This limiting case is also shown in Figure 2. The TC model predicts about a 0.05 annual rate of a U.S. Cat5 landfall; i.e., a 0.95 annual probability of zero such landfalls. The mean Cat5 waiting time begins to diverge visibly from zero-landfall limit in Figure 2 around \( N = 10 \) years. The last Cat5 U.S. landfall was Hurricane Andrew in 1992, a 22 year drought as of the end of the 2014 season.

In the other extreme, the TC model predicts a 0.23 annual probability of zero Cat1+ landfalls. (Direct analysis of HURDAT is very similar, 0.22.) A long Cat1+ drought is unlikely. The model predicts an average wait of 10,000 years for a 6 year Cat1+ drought. We are currently not in a Cat1+ drought. Hurricane Arthur, a 2014 Cat1 landfall, ended the 1 year Cat1+ drought of 2013, which followed the two Cat1+ landfalls (Isaac and Sandy) in the 2012 season.

We now ask the question, given a current \( N \) year drought, what is the probability that it will end next year? Figure 3 shows the probability of a U.S. landfall in the next year as a function of current drought duration for three intensity thresholds, Cat2+, Cat3+, and Cat4+. There is little dependence on \( N \). The probability for a landfall next year is approximately independent of the time since last landfall, as would be expected for a Bernoulli process. Given these probabilities and assuming Bernoulli, the mean wait time to next landfall is simply \( P/(1 - P) \), which yields 0.3 years, 0.7 years, 1.6 years, 4.4 years, and 19.2 years for Cat1+ through Cat5+. Direct counting of model landfall droughts yields nearly identical values.

Finally, we examine the sensitivity of landfall probabilities and drought wait times to the simulation period. The results of Figures 1–3 were obtained from repeated simulation of 1950–2012. We also perform repeated simulations of the more recent period 1995–2012, which is known to have more North Atlantic hurricane activity. That is, we use the same model built in 1950–2012 observations and drive it repeatedly with the 1995–2012 historical SST and ENSO time series. Figure 4 plots the annual probability of one or more Cat3+ landfalls on the five regions and full coast for 1950–2012 (blue) and 1995–2012 (red). (bottom) Fractional difference.
and Atlantic 1950–2012 to 1995–2012. The increase is not uniform but is instead concentrated on the Gulf and Florida [Hall and Yonekura, 2013]. The 1995–2012 probability for no Cat3+ landfalls in a year is 0.59. The corresponding wait time for a 9 year drought during this period is 242 years, compared to 176 years for the 1950–2012 period.

4. Discussion

The current 9 year U.S. Cat3+ hurricane landfall drought is a rare event. By our estimates here the wait time for such a drought is 177 years, on average. Should we conclude anything from this? Has some characteristic of hurricane climate changed in a sustained, predictable way leading to fewer U.S. major landfalls? The case remains open. But several observations point to the current drought being more a case of good luck than any shift in hurricane climate.

1. Despite the U.S. drought, the seasons since 2005 have displayed average energy. The 2006–2014 annual mean ACE is 97 (10^4 kt^2), compared to a 1951–2000 mean of 93.
2. There has been no shortage of major hurricanes. The years 2008, 2010, and 2011 had 5, 5, and 4 hurricanes reach Cat3 status, respectively, and the 9 year period 2006–2014 averaged 2.7 major hurricanes annually, about equal to the annual average since 1950.
3. There has been no shortage of Cat3+ landfalls on Caribbean and Mexican coastlines. Cuba, only a few degrees latitude south of Florida, has experienced five Cat3+ landfalls since 2005 (Dean, Paloma, Ike, Gustav, and Sandy), well above its long-term rate.
4. There have been two U.S. landfalls that were almost Cat3: Hurricane Gustav (2008) made Louisiana landfall with maximum 1 min sustained wind speeds of 170km/h, compared to the 178/km/h Cat3 threshold. Hurricane Ike (2008) made Texas landfall with 175km/h wind speeds.

A hurricane climate shift protecting the U.S. during active years, even while ravaging nearby Caribbean nations, would require creativity to formulate. We conclude instead that the admittedly unusual 9 year U.S. Cat3+ landfall drought is a matter of luck.

References