GEOPHYSICAL RESEARCH LETTERS, VOL. 35, L23705, doi:10.1029/2008GL036012, 2008

Click Here for Full Article

Is the North Atlantic hurricane season getting longer?

James P. Kossin[1]

Received 14 September 2008; revised 28 October 2008; accepted 5 November 2008; published 9 December 2008.

[1] In the 2008 North Atlantic hurricane season, July was anomalously active with four tropical storms, of which two intensified to become hurricanes. The 2007 season experienced an uncommon May storm and an equally uncommon December storm. The 2005 season was the most active in the secular record, and was also anomalously active during the typically quiescent early and late portions of the season. This recent increase in early- and late-season activity has raised questions about the effect that climate change may be having on the length of the hurricane season. Here I report on the observed trends in the annual distribution of North Atlantic tropical storm formation events and their relationship with tropical Atlantic sea surface temperatures (SST). I find an apparent tendency toward more common early- and late-season storms that correlates with warming SST, but the uncertainty in these relationships is high.
Citation: Kossin, J. P. (2008), Is the North Atlantic hurricane season getting longer?, *Geophys. Res. Lett.*, *35*, L23705, doi:10.1029/2008GL036012.

1. Introduction

[2] The official North Atlantic hurricane season begins on 1 June and ends on 30 November, and although tropical storms are occasionally observed to form outside of this period, the vast majority (97–98%) of tropical storms form within these months. The historical peak in tropical storm formation occurs in early September while June and November storms are relatively rare. This distribution of tropical storm formation events in the Tropical North Atlantic Ocean is well known (Figure 1). The shape of the distribution is modulated by the evolution of the tropical environment that storms are spawned in, with the most conducive conditions typically occurring in early September, coinciding with the peak in event frequency. These environmental conditions include sea surface temperature (SST), among other factors such as vertical wind shear, low-level vorticity (a measure of local rotation of low-level winds), and relative humidity [*McBride and Zehr*, 1981]. If the environment changes so that it becomes more conducive to storm formation over a longer portion of the year, then the distribution shown in Figure 1 should exhibit shape changes, particularly within the tails of the distribution.

[3] One simple, but limited way to consider these changes is by sampling the extrema of the distribution from each year and forming time series of these singular annual values. When this is performed, the time of occurrence of the first and last annual formation events exhibit decreasing and increasing trends, respectively, suggesting that the length of the hurricane season is increasing (Figure 2). Interpretation of such an analysis is constrained, however, by the marked reduction in degrees of freedom that such a sampling imposes, and the method does not address the larger question of how the overall distribution of events is changing. Here this constraint is overcome by applying the method of quantile regression to test for changes in the distribution of North Atlantic tropical storm formation events and their relationship with SST variability.

2. Results

[4] The observed trends in tropical Atlantic SST averaged over each hurricane season (Figure 3) show the warming that has occurred in the region south of 30° North latitude and east of 75° West longitude, an area within the main tropical storm formation region. To identify changes in the annual distribution of tropical storm formation dates that may be associated with the warming in this region, the method of quantile regression [*Koenker and Hallock*, 2001; *Elsner et al.*, 2008] is applied (Figure 4). The quantiles represent thresholds within the distribution. For example, 20% of the formation dates occur earlier than the date at the 0.2 quantile. The trends shown in Figure 4 represent changes in these quantile thresholds with time. Here a negative trend indicates that the threshold for that quantile

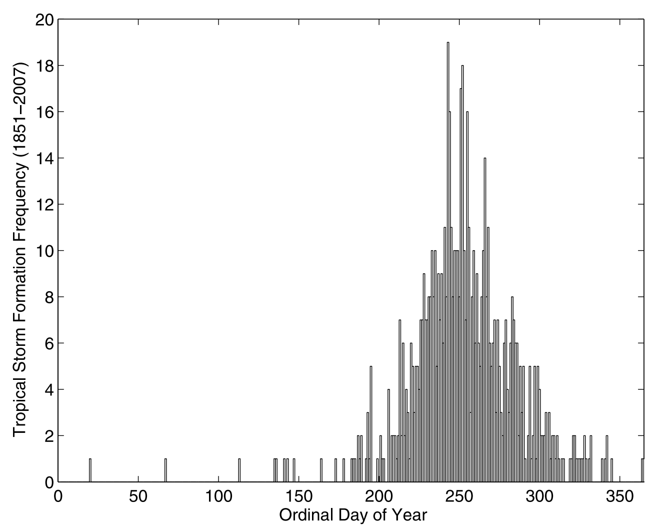

Figure 1. Frequency distribution of North Atlantic tropical storm formation events in the main formation region south of 30° North latitude and east of 75° West longitude. A formation event is defined as the day when a tropical depression first achieves an intensity of 35 kt (17 m s^{-1}). Events are identified using the historical "best track" hurricane record.

[1]Cooperative Institute for Meteorological Satellite Studies, University of Wisconsin-Madison, Madison, Wisconsin, USA.

0094-8276/08/2008GL036012$05.00

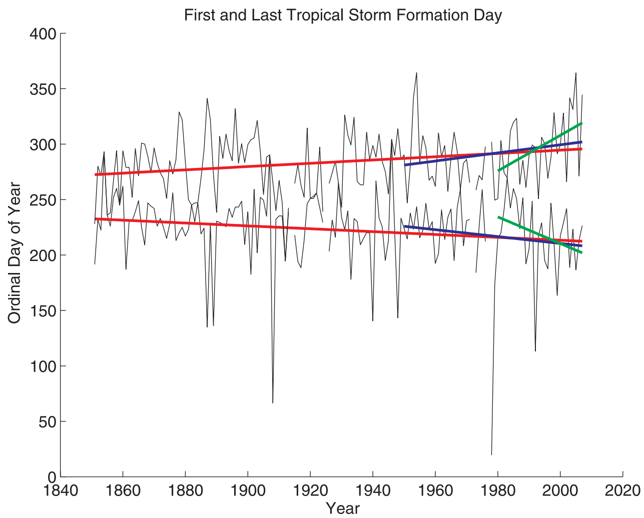

Figure 2. Time series of the first and last tropical storm formation event each year in the region south of 30° North latitude and east of 75° West longitude (black lines). For reference, linear trends are shown for the periods 1851–2007 (full record, red), 1950–2007 (aircraft reconnaissance era, blue), and 1980–2007 (modern satellite era, green).

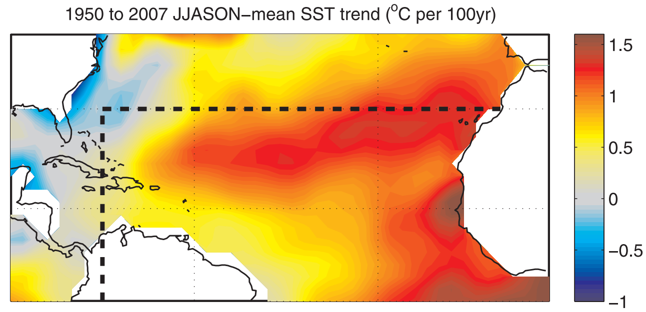

Figure 3. Observed sea surface temperature (SST) trends during the official North Atlantic hurricane season (June–November) for the period 1950–2007. Units are °C per century. The dashed rectangle denotes the tropical storm formation region south of 30° North latitude and east of 75° West longitude. Data are from the NOAA Extended Reconstructed Sea Surface Temperature V3 product [*Smith et al.*, 2008].

is moving toward earlier dates, and a positive trend indicates change toward later dates. During the period 1851–2007 (comprising the complete North Atlantic "best track" record), the median formation date has remained essentially fixed, as indicated by a nearly zero trend at the 0.5 quantile. However, the date marking the threshold of the earliest 5th percentile exhibits a negative trend of roughly 1.3 days per decade. Similarly, the date marking the threshold of the latest 5th percentile exhibits a positive trend of roughly 1.0 day per decade. Note that the trends deduced from the method of quantile regression are not sensitive to outliers in comparison to trends based on ordinary least-squares regression. The inclusion or omission of the outlier formation dates seen in Figure 2 does not measurably affect the results shown in Figure 4. The level of confidence that the trends in the tails of the distribution shown in Figure 4 are different than zero is about 85%, which does not indicate a highly robust signal emerging from the interannual to multidecadal variability of the historical record of formation dates.

[5] When considering the full best track record, there is potential for non-physical trends to be introduced by the continuing improvements in our ability to accurately identify storm formation. To mitigate this, all analyses are repeated for the periods 1950–2007 and 1980–2007. The first period comprises years with active aircraft reconnaissance, and the second comprises years that are representative of present technology. It is unlikely that storm formation would be systematically missed within these periods [*Vecchi and Knutson*, 2008], and accurate identification of formation events can be assumed to be optimal in the later period due to the nearly continuous day and night coverage by infrared instruments on geostationary satellites. Here it should also be noted that the analyses in this work are not highly sensitive to the potential errors that may exist in the recorded formation date for any individual storm. The

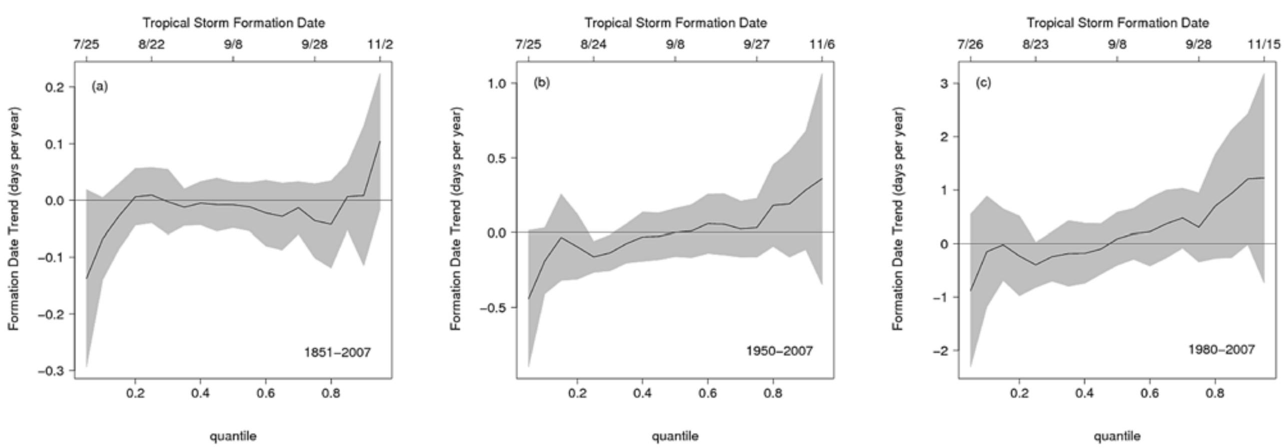

Figure 4. Trends in tropical storm formation dates, in the region south of 30° North latitude and east of 75° West longitude, at the 0.05–0.95 quantiles. Trends are based on the periods (a) 1851–2007, (b) 1950–2007, and (c) 1980–2007. The dates (month/year) associated with the 0.05, 0.25, 0.50, 0.75, and 0.95 quantiles for each period are shown on the top axis (these threshold dates are based on the full sample for each period). Shading denotes the 90% confidence interval.

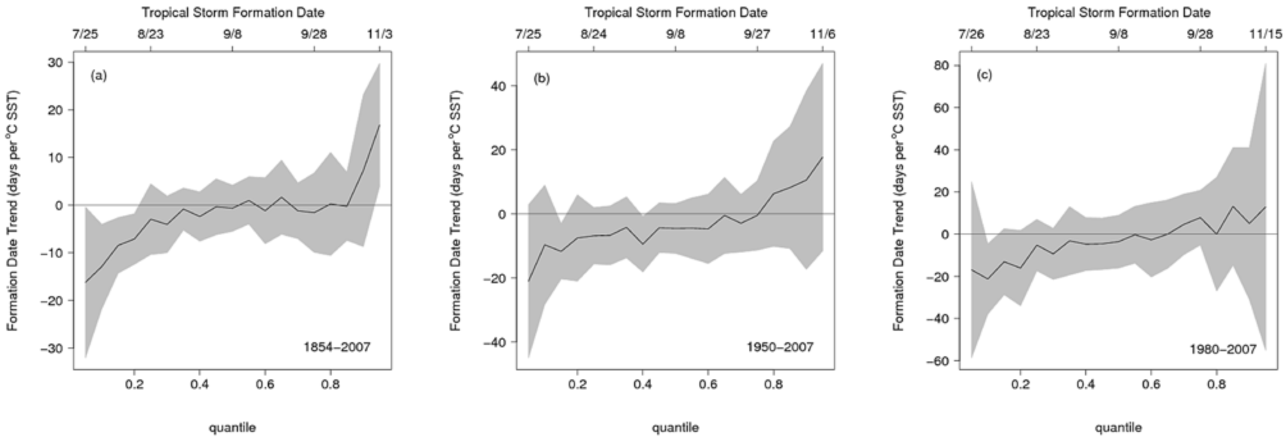

Figure 5. Relationship between changes in the distribution of tropical storm formation dates and May SST variability in the region south of 30° North latitude and east of 75° West longitude. The NOAA Extended Reconstructed Sea Surface Temperature V3 product spans the period 1854 to present.

magnitude of these errors may be as large as a few days on either side of the date in the best track record, but it's the *interstorm* formation dates and their range that largely control the distribution.

[6] Figures 4b and 4c show trends in the formation date distribution for the later best track periods. Analogous to the complete best track period, the median date has remained essentially fixed at September 8th, but the change in thresholds for the earliest and latest percentiles indicate a general broadening of the season. The magnitudes of the trends are between 5 and 10 days per decade, and the level of confidence is between 80% and 90%.

[7] To better quantify the relationship between the distribution of tropical storm formation event dates and SST variability within the region of warming SST, quantile regression is repeated with a measure of SST in place of year. Here SST is averaged over the region of warming (Figure 3) in the month of May, prior to the June start of the official hurricane season. This value provides a good proxy for SST variability in all months of the North Atlantic hurricane season. The correlations of May SST with June, July, August, September, October, and November SST in this region over the period 1854–2007 are 0.93, 0.87, 0.82, 0.79, 0.72, and 0.70, respectively. The following results don't change significantly when season-mean (June–November) SST is used in place of May SST. Figure 5 demonstrates a relationship between changes in the distribution of tropical storm formation event dates and SST variability within the region of warming SST. In all periods, warmer springtime SST is associated with a lengthening of both the early and late season. An increase of 1°C corresponds to a marked shift of the earliest and latest quantiles by as much as 20 days. Again, the confidence in these trends is sometimes low, but the results are consistent between time periods and suggestive of changes in the distribution of formation dates associated with local climate variability.

3. Concluding Remarks

[8] This short note reported on changes in the distribution of tropical storm formation dates in the tropical North Atlantic. Quantile regression was applied to historic best track data to objectively measure changes within the distribution, and identify uncertainties in the magnitude of these changes. A consistent signal emerged that suggests the season has become longer as the earliest formation dates of the season have become earlier and the latest dates have become later. While the sign of these trends remain consistent when different periods are considered, the uncertainty is sometimes high. Similarly, the trends were shown to be related to local SST variability with warmer SST consistently associated with a longer hurricane season. The analyses presented here show how storm formation dates have been changing within the historical hurricane record, but cannot be used to directly implicate cause for these changes or to accurately predict future changes. The relationship with SST is suggestive of a larger link to climate variability, but no explicit link to human-induced global warming can be inferred from this study.

[9] **Acknowledgments.** I'm grateful to Matt Sitkowski and Dan Vimont for their creative input. This work is funded by the NOAA CCDD ARC program and the Risk Prediction Initiative of the Bermuda Institute of Ocean Sciences. The NOAA ERSST V3 data were provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their web site at http://www.cdc.noaa.gov/. Quantile regressions were performed using the software environment R (http://www.r-project.org) and the quantile regression package quantreg (R package version 4.17; http://www.r-project.org).

References

Elsner, J. B., J. P. Kossin, and T. H. Jagger (2008), The increasing intensity of the strongest tropical cyclones, *Nature*, *455*, 92–95.

Koenker, R., and K. F. Hallock (2001), Quantile regression, *J. Econ. Perspect.*, *15*, 143–156.

McBride, J. L., and R. Zehr (1981), Observational analysis of tropical cyclone formation. Part II: Comparison of non-developing versus developing systems, *J. Atmos. Sci.*, *38*, 1132–1151.

Smith, T. M., R. W. Reynolds, T. C. Peterson, and J. Lawrimore (2008), Improvements to NOAA's historical merged land–ocean surface temperature analysis (1880–2006), *J. Clim.*, *21*, 2283–2296.

Vecchi, G. A., and T. R. Knutson (2008), On estimates of historical North Atlantic tropical cyclone activity, *J. Clim.*, *21*, 3580–3600.

J. P. Kossin, Cooperative Institute for Meteorological Satellite Studies, University of Wisconsin-Madison, 1225 West Dayton Street, Madison, WI 53706, USA. (kossin@ssec.wisc.edu)