Effect of Global Warming on Atlantic Hurricane Activity
By Dean D. Churchill
August 2015
Final Project for UW Data Science 350, 2015.

Introduction

The climatology of tropical cyclonic storms in the Atlantic basin is described using the HURDAT2 track data from The National Hurricane Center. This data set, which covers the period 1851 through 2014, was used to generate descriptive plots of tropical cyclonic storm activity. Global temperature change data, developed as part of the Intergovernmental Panel on Climate Change, were used in a linear regression model with hurricane activity data. A positive correlation between increased hurricane activity and increased global temperatures was observed. This result, which has been discussed in meteorological literature, led to conclusions that a warmer world in the future will be accompanied by more hurricanes. Computational statistics were used to conclude that the warm period since 2000 could not have been explained by random changes of globally averaged temperature.

But before concluding a causal relationship between global warming and enhanced hurricane activity, the meteorology community has often pointed out that the apparent increase in hurricane activity during the later half of the 20th century was due primarily to improvements in observational capabilities – most notably the development of weather imaging satellites.

The R Code

The images in this report can be generated by running my R program, hurtrack_doc.R, in batch mode. The script will download the 2 data sets used – one containing hurricane track data and the other containing globally averaged surface temperature anomalies. The track data will be parsed and persisted. All the graphs and statistical analyses run automatically. The log file, hurtrack_doc.Rout, contains details on the run. If the run completes, "all done!" is the last entry in the log file. Run time is 40 seconds on my iMac. There are some additional images generated that I do not discuss in this report.

Data and Methodology

The U.S. National Hurricane Center (NHC) maintains a database of track and intensities of tropical cyclonic storms that form over the Atlantic Ocean basin. The database is updated annually, and the latest version used for this study was downloaded from
http://www.nhc.noaa.gov/data/hurdat/hurdat2-1851-2014-060415.txt (which is 6 megabytes in size, containing ASCII data records). HURDAT2 contains all records of storms in the Atlantic from 1851 through 2014.

Tropical cyclonic storms have 7 categories of intensity, based on the maximum wind speed observed in the storm. Tropical depressions are the weakest, followed by tropical storms, then hurricanes of category 1, 2, 3, 4, and 5. Category 5 storms are the most devastating, and fortunately, occur least frequently. These categories were computed from the wind speed data using criteria set by NHC.

The HURDAT2 database includes the time, date, latitude, longitude, storm name, maximum wind speed, and minimum pressure, observed every 6 hours. Historical data from the 19th century have been constructed from ship logs of weather observations and from land-based weather stations. Recent data, since the 1960s, have been improved through use of weather satellite imagery to identify and track storm systems.

Globally averaged surface temperatures for the planet have been constructed going back to 1850. These data are available in downloadable format, along with an R program for reading these data. Annual globally averaged surface temperature anomalies were merged with annual counts of tropical storm activity. There are a variety of measures of storm activity used in meteorological literature. Here we do a simple count of the number of observations (generally every 6 hours) of storms, and aggregate into year-long totals.

Climatology of Atlantic Hurricanes

One of the first classic plots of hurricanes is to plot the tracks on a map of all the storms in the record (Figure 1). The storms typically form over the tropical Atlantic, move westward toward Central and North America, and many turn northward then go east out over the North Atlantic. Storms require warm ocean water to form. Thus these storms rarely develop over the higher latitudes nor over land.

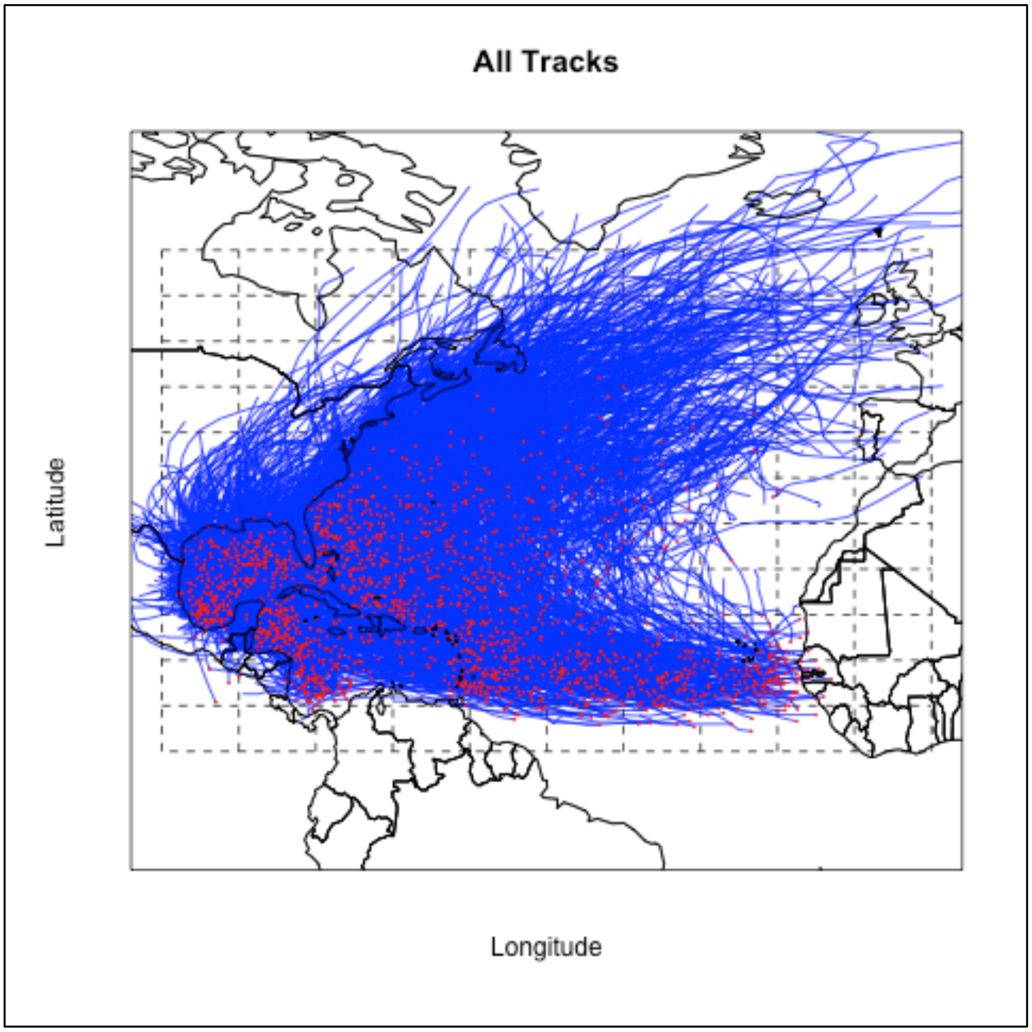

Figure 1. Plot of all storm tracks since 1851. Red dots denotes the starting position of each track.

There are no (or very few) hurricanes along the eastern boundary of the Atlantic ocean because the temperature of the water is too low. Generally hurricanes require water temperatures about 27 deg C or higher to support hurricanes. The flow of air over the tropical Atlantic is dominated by the Bermuda High -- a large cell of dry weather that rotates clockwise, and tends to push storms westward, then northward.

Hurricanes also do not form closer to the equator than about 5 degrees latitude. This is due to the fact that the rotation of the earth around the vertical axis is too weak close to the equator: hurricanes require an initial kick of rotation to get going. At the equator there is no component of rotation in the vertical direction.

The lines in this plot are overlapping each other, making it impossible to visualize where storm activity is more common. An easier way to view this graph is using a heatmap (Figure 2). This shows that Gulf of Mexico, Bahamas, and Western

Caribbean Sea are the hotbeds of storm activity. These areas have relatively warm 28 – 30 deg C sea water during the summer months.

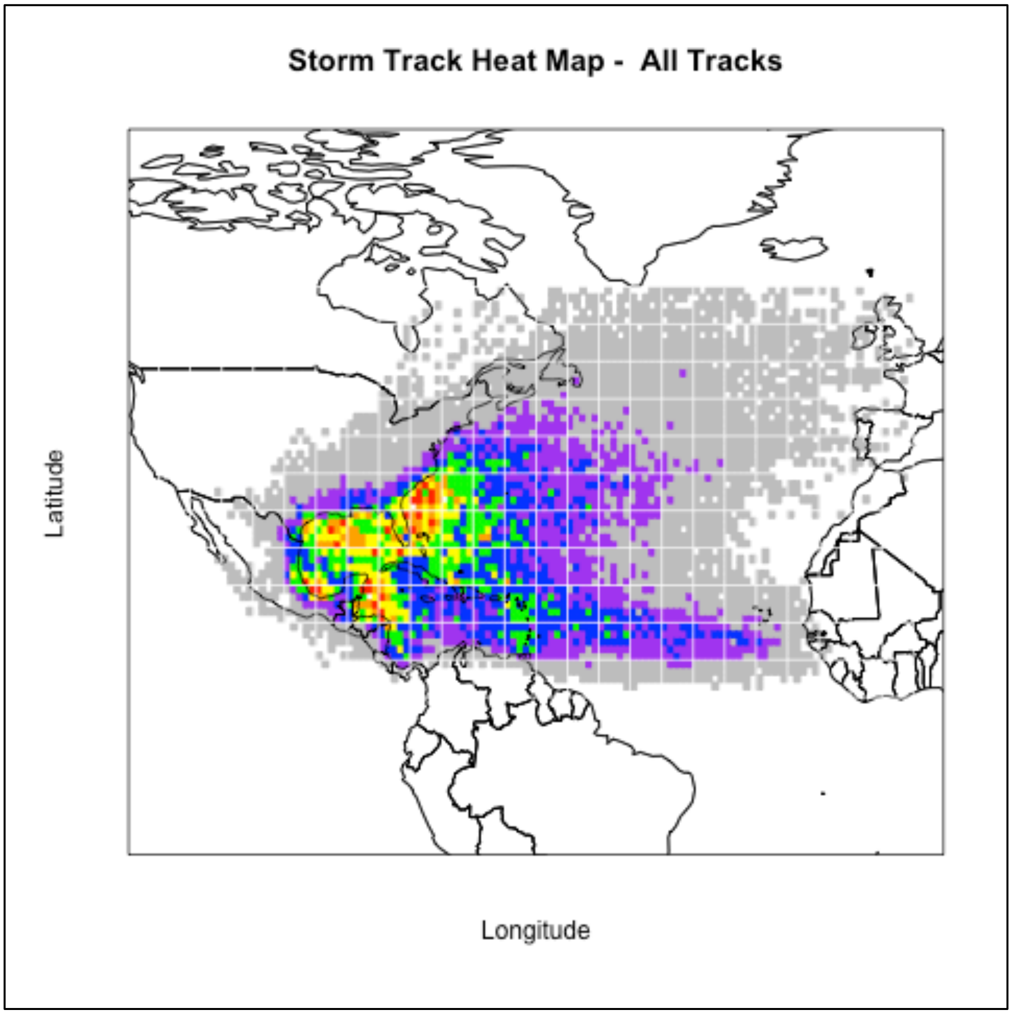

Figure 2. Heatmap of all tropical storm activity. Computed as the sum of all tracks passing through grid boxes 1 deg by 1 deg. Hotter colors denote more frequent storm activity. Cool colors denote less activity.

Figure 3 shows the number of observations of wind speeds, color coded according to the storm classification. Storms are classified as Tropical Depression (TD), Tropical Storm (TS), or Hurricane (Category 1 through 5). Weakest storms are most numerous, intense storm are rare. Category 5 storms in particular are extremely rare.

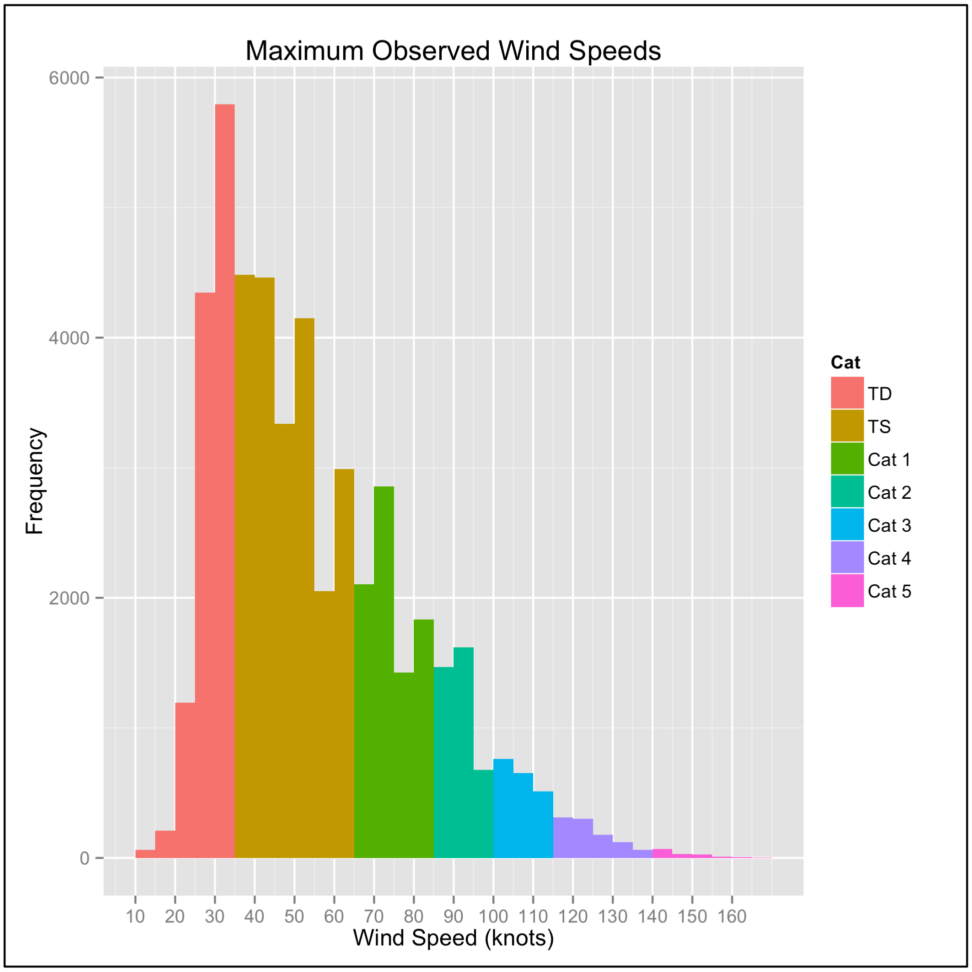

Figure 3. Frequency of storm intensity. Represents all observations in the HURTRACK database. TD = tropical depression, TS=tropical storm, and hurricanes (Cat 1 through Cat 5).

Science of hurricane genesis.

Hurricane form out of thunderstorms over the ocean, in the presence of a pre-existing cyclonic (i.e. rotating) disturbance in the lower atmosphere, combined with high sea surface temperatures, enables the thunderstorms to heat the atmosphere, and cause the air pressure to drop hydrostatically. Visualize that as a column of air warms, the column expands, the air becomes less dense, which means there is less mass in the column, which means that the air pressure at the surface (which responds to the mass of air above it) becomes lower. As the surface pressure falls, wind flows into the lower pressure system from the environment where the pressure is higher. The faster the air flows, the more moisture gets evaporated from the ocean, the more rain is produced by the rising clouds, and more heat gets released by condensation, the more the column of air expands and the pressure drops. This becomes, in the case of a mature hurricane, a positive feedback process. As a result, low pressure is associated with high wind speeds (Figure 4).

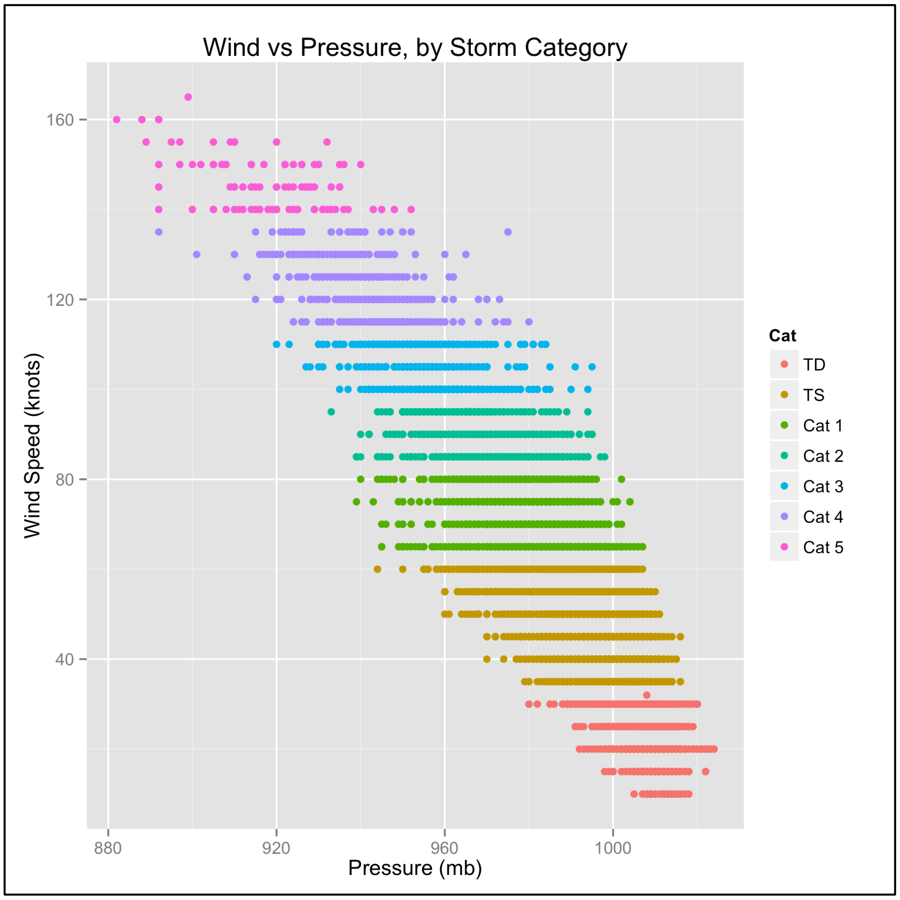

Figure 4. Scattergram of pressure versus wind speed measurements. Wind speed measurements are always rounded off to nearest 5 knots – hence the horizontal lines in the plots. Pressure is measured to the nearest millibar(mb).

The Atlantic hurricane season runs officially from June 1 through November 30 of each year. The peak of the season is early in September, around Labor Day (Figure 5).

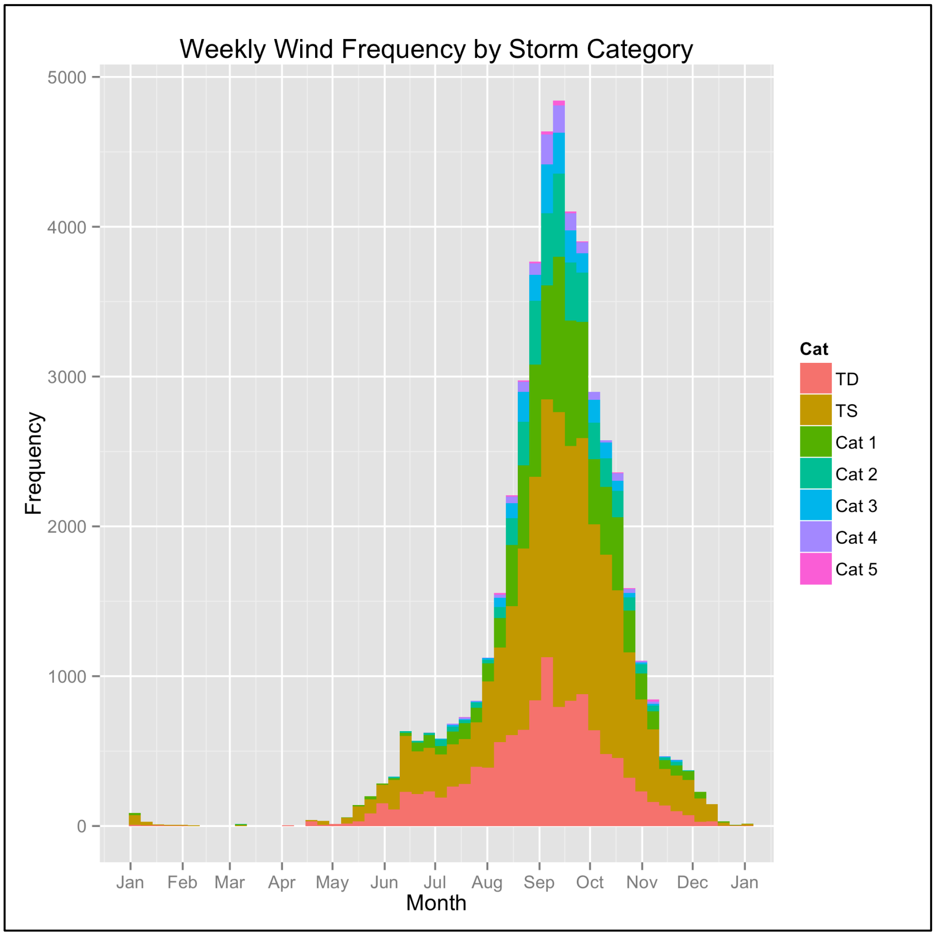

Figure 5. Weekly total storm activity for all track data, categorized by storm classification.

Global Climate Change and Hurricane Activity

A current topic of discussion about hurricanes is whether or not hurricane activity is affected by the increasing global temperatures of the earth. One theory is that a warmer planet will produce warmer oceans, which will produce more hurricanes, or at least hurricanes that are more intense than before.

The classic graph of global temperature change since the mid 1800's shows a warming trend until the 1940s (Figure 6), followed by a cooling trend until 1970, followed by a secular increase in temperature to present day.

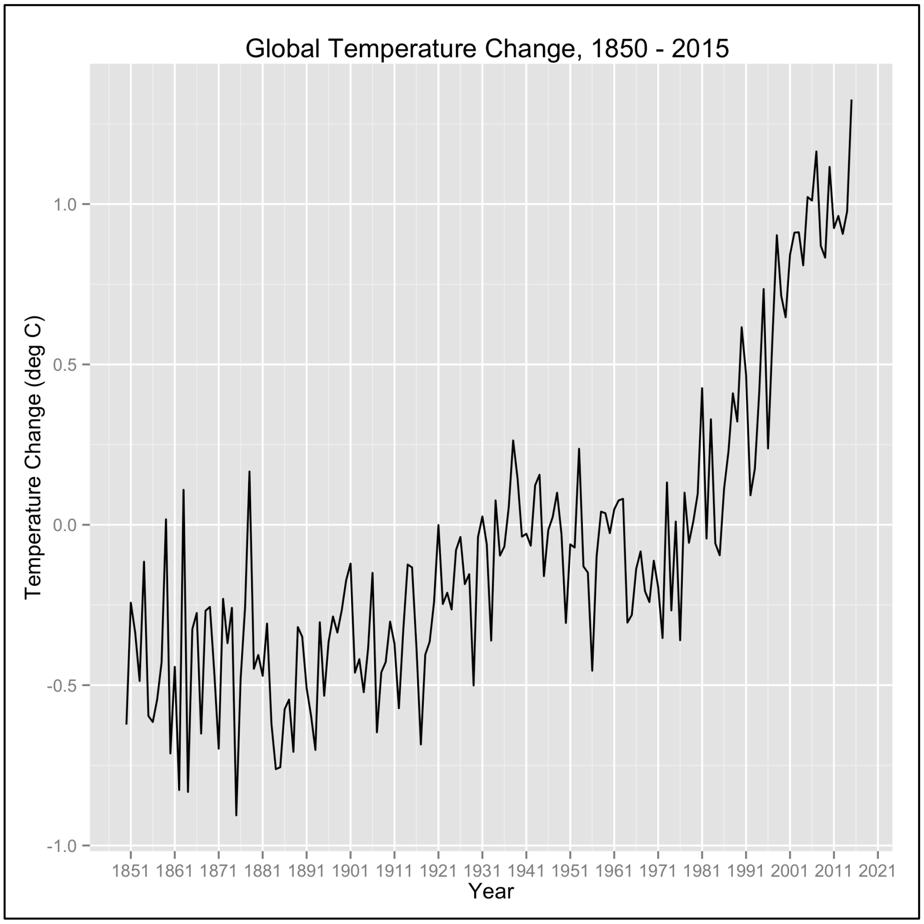

Figure 6. Annual globally averaged surface temperature anomalies (deg C). Anomalies were computed as differences from 1960 - 1990 mean temperature. Data obtained from http://www.cru.uea.ac.uk/cru/data/temperature

Some people are skeptical that this warming trend is for real. Possibly the run up in temperatures over the past 10 years is just a statistical fluke; perhaps all these anomalies are just normally distributed errors, and the world has had a streak of bad luck with many warm years in a row.

To test whether or not these fluctuations are stochastic, I ran a simulation 100,000 times, where I created normally distributed temperature anomalies, from 1850 through 2015, with the same mean and standard deviation as observed in the data of Figure 6. If these fluctuations are indeed randomly distributed, then there should be at least some sequences of fluctuations that have a ten-year-long warm period at the end of sequence at least as warm as that which was observed. After running these simulations, there was not one case where the last 10 years were as warm as observed. So from this computational statistic, I conclude, with a p-value $< 10^{-5}$, that the warming trend observed was not due to random fluctuation.

During this same period tropical cyclonic storm activity has also been increasing (Figure 7).

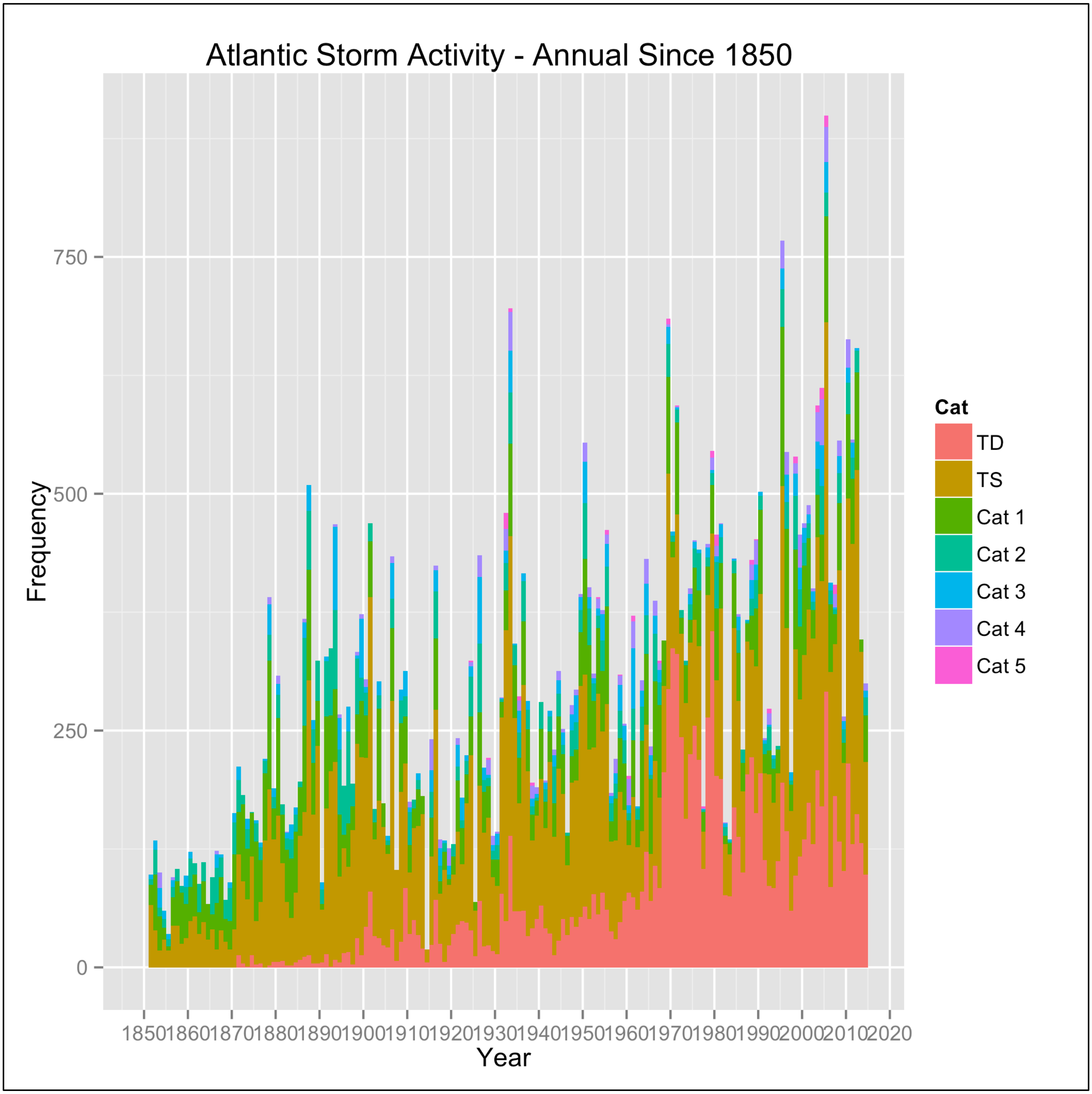

Figure 7. Annual storm activity counts, colored by storm category, 1850 to 2014.

The increase is most prominent in the weakest storms – tropical depressions and tropical storms. That increase is believed to be the result of improved detection, beginning in the 1960s, using weather satellite imagery. Weak, short-lived storms often would live and die at sea without being observed prior to the start of satellite service. Aggregating all these categories of storms into one number for each year produces a set of data that are directly comparable with the global annual temperature changes. The scattergram of these changes, Figure 8, shows a positive correlation between the two. The R^2 value of this line was 0.28.

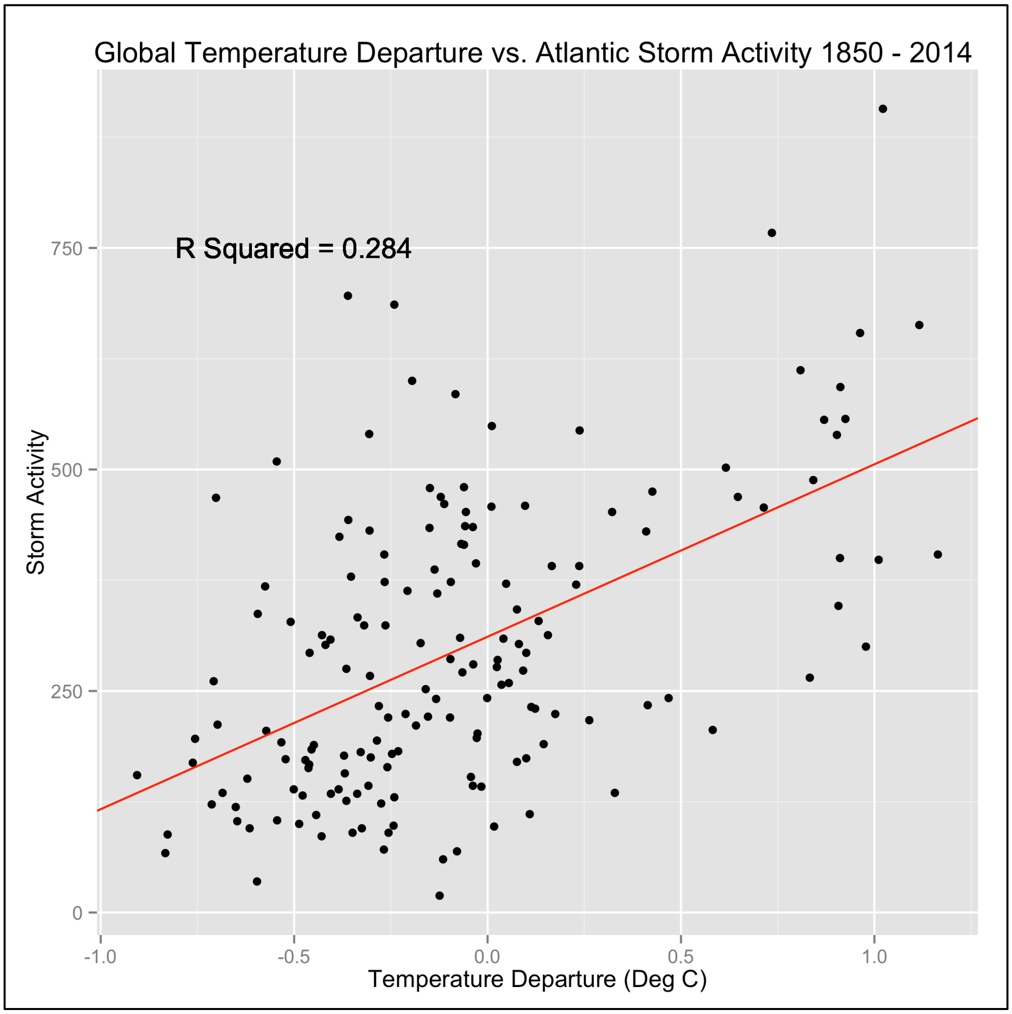

Figure 8. Scattergram of global temperature anomalies and frequency of storm activity. The red line is a linear model best fit.

So these data support the hypothesis that a warmer world supports more hurricane activity. Since this result was first reported in meteorological literature in the 1990s, further work has been done by researchers looking at other ocean basins. The Atlantic is a small ocean, as oceanographers say. Similar track data for the Pacific Ocean and Indian Ocean did not show any increase in storm activity with warmer temperatures.

Hurricanes respond to many more environmental factors than just air temperature. Sea surface temperature, and the depth of the warm water under a storm, environmental wind shear, level of humidity, nearness to land, phase of El Nino and Southern Oscillation are some of the other factors. There has been one study that suggested that a warmer world will support more intense hurricanes in the Indian Ocean, though will not necessarily increase the number of hurricanes. Recent publications have estimated statistically the number of hurricanes that might have formed over the Atlantic and been observed, had satellites and the modern observational network been present in the early parts of the 20th century. Adding in those numbers then removed the apparent increase in storm activity toward the end of the 20th century.