Tropical Cyclones and Climate Change

Nick Panico III

MET 295-Spring 2011

Prof. Mandia

Each year hundreds of storm systems develop around the tropical regions surrounding the equator, and approximately 40-50 of these storms intensifies to tropical cyclone levels. The storm names of hurricane, typhoon, and cyclone are given for the respective geographic regions that the storms develop in the Atlantic, Pacific, and Indian Ocean basins. In the Northern Hemisphere, the hurricane season runs from June 1 to Nov. 30, while the Southern Hemisphere generally experiences activity from January to March.

During seasons conducive for development, a tropical cyclone builds energy as it moves across the ocean, sucking up warm, moist tropical air from the surface and dispensing cooler air aloft. Hurricanes often begin their lives as clusters of clouds and thunderstorms referred to as tropical disturbances. These low-pressure areas feature weak pressure gradients and little or no rotation. Most of these disturbances will die out, but a few will reach tropical cyclone status. In these cases, the thunderstorms in the disturbance release latent heat, which warms areas in the disturbance. This results in lowering of the air density inside the disturbance, which further drops the surface pressure. Wind speeds increase as cooler air rushes underneath the rising warm air. This wind is subject to the Coriolis force, so the disturbance begins to rotate. This process continues to build and the incoming winds bring in more moisture, which condenses to form more cloud activity and releases latent heat in the process. The stronger a tropical cyclone gets, the more efficient it is in using the energy from the atmosphere and the ocean.

Global climate change is expected to affect the variables that are important for tropical cyclone formation. Theses variables include temperature and precipitation patterns, oceanic and atmospheric circulation, rates of rising sea level, and the frequency, intensity, timing, and distribution of tropical cyclones. It is expected that tropical cyclones will behave differently in an anthropogenic radiative forcing world.

However, there are climate skeptics that insist that the recent anthropogenic global climate change is nothing short of a complete manipulation of science. Skeptics claim anthropogenic climate change is created for reasons and motivations that go beyond the perimeter of scientific inquiry. The ideology of such an accusation can be portrayed in the statement,

“Hurricanes aren't linked to global warming. According to the National Hurricane Center, storms are no more intense or frequent worldwide than they have been since 1850. Constant 24-7 media coverage of every significant storm worldwide just makes it seem that way."

(Bedard, P. http://www.skepticalscience.com/hurricanes-global-warming.htm)

However, there are still conflicting results regarding this investigation due to fluctuations in the frequency and intensity of tropical cyclones that complicate the detection. Detection is additionally limited by the availability and quality of historical data records of tropical cyclones. Higher confidence in detection will only occur with improved climate models. However, there is strong evidence that climate change will affect tropical cyclones, regardless if the overall frequency is to increase or decrease.

Frequency of tropical cyclone detection is often debated, and used by climate skeptics as a source that no correlation exists between tropical cyclones and anthropogenic climate change. However, other areas of tropical cyclone research clearly indicate that climate skeptics are cherry picking data to create misinformed statements regarding anthropogenic climate change. The Power Dissipation Index (PDI) measures the duration and intensity (wind speed) of storms. The PDI is one variable that presents data that supports tropical cyclones being affected by anthropogenic climate change. Research has found that since the mid-1970s, there has been an overall increase in the energy of storms. The fact that climate skeptics do not ever incorporate such data, in their efforts to show that there is no correlation between tropical cyclones and climate change, illustrates the biased approach that climate skeptics often employ.

Recent research has shown that tropical cyclones are developing with higher wind speeds, and these storms will be more destructive, last longer and make landfall more frequently than in the past. Since this phenomenon is strongly associated with sea surface temperatures, it is reasonable to suggest a strong probability that the increase in storm intensity and climate change is inherently linked. (Cook. J. http://www.skepticalscience.com).

Current future projections based on global climate models (GCM) indicate that greenhouse warming will cause a shift towards stronger storms, with intensity increases of 2-11% by 2100. The models also indicate that average frequency of tropical cyclones will decrease by 6-34%. Substantial increases in the frequency of the most intense cyclones, category 4-5 are expected to increase. An increase in rainfall rates of up to 20% within 100km of the storms center is expected. The magnitude of these projected physical changes and their subsequent impacts on coastal wetlands will vary regionally. (Tropical cyclones and climate change, Knutson, et. al., 2010)

The main challenge for detecting if climate change has a significant role in the systematic complex of tropical cyclones is to determine whether the observed change being discussed exceeds the variability that is expected through natural forcing. Over recent decades sea surface temperatures (SSTs) have increased by several tenths of a degree Celsius in the breeding grounds of tropical cyclone formation. Over the past 50 years there has been a strong correlation of Atlantic tropical cyclone power dissipation and SSTs.

Tropical Atlantic SST has increased more rapidly than tropical mean SST over the last 30 years, and this matches the positive trend that is observed in the Atlantic power dissipation index (APDI) over this period. Climate models indicate that that variability in warming is not strongly influenced by greenhouse gas forcing. Additional evidence of uncertainty in whether past changes in tropical cyclone frequency have exceeded the variability expected through natural forcing comes in several data sets.

A study of 1,500 year record of sediment from a number of sites along the US coast indicates a relatively high frequency of strong Atlantic hurricane landfalls during periods AD 1000-1200, early 1400s, early 1800s, the 1950s, and recent decades. Uncertainties in interpreting storm characteristics from geological sediment and limited spatial coverage exist. Alone, the geological record is not a good indicator of whether or not hurricane frequency changes with climate.

Studies investigating hurricane frequency and climate result in higher levels of confidence when the data included comes from a multitude of sources, not just geological sediment. Michael Mann of Penn State University led one of the studies, regarding hurricane frequency, where his team examined annual storm counts in the Atlantic basin during the past 1,500 years. Since there were no satellites to extrapolate data for the past 1,500 years, the researchers relied on "proxy data," such as sediment records in coastal locations, and large-scale climate factors related to hurricane frequency, such as sea surface temperatures and El Nino.

"Mann's team concluded that while recent tropical cyclone activity has been abnormally high, there was a past period of similarly high activity during medieval times around 1,000 AD. The researchers proposed several factors that might have contributed to the medieval peak, including relatively warm sea surface temperatures in the North Atlantic. Although the study itself did not address the question of whether human activities are behind the recent spike in hurricane activity, it's clear that Mann thinks that may be the case, since the study found a close relationship between sea surface temperatures and storm frequency." (Freedman, A., 2009)

Mann's study is important for tropical cyclone frequency research because it demonstrates that there are past times in history where frequency has increased due to natural forcing. However, when studies of tropical cyclone frequency and anthropogenic climate forcing are investigated, conclusions are not that easy to assess. Reasons are mainly due to the relatively short period of time since the Industrial Revolution.

Adjustments in hurricane counts for possible missing storms has no significant long-term trend ($p>0.05$) on century-scale increases in Atlantic tropical cyclone frequency that is modeled by increases in SSTs. Land-falling tropical cyclones show no long-term increase in the US. However, basin wide hurricane counts do show a significant rising trend but the authors feel this is due to unreliable data that occurs prior to aircraft reconnaissance in 1944. (Tropical cyclones and climate change, Knutson, et. al., 2010)

Recent studies do show that scientists may soon understand tropical cyclone formation well enough to be able to predict the statistical frequency of cyclone occurrence given the state of the climate. It appears that a necessary condition for tropical cyclone formation is the establishment of a low-pressure air parcel that extends through the tropical troposphere and is about 50-100 miles wide.

Thunderstorms that develop within this humid parcel do not produce the dry, cold downdrafts that characterize most storms and which oppose the tendency of evaporation from the ocean to humidify the atmosphere. These downdrafts are determined by the partial evaporation of rain, but within the humid parcel, evaporation is reduced and downdraft formation is inhibited. The formation of these humid parcels appears to be possible through a number of different mechanisms, including the lifting of the tropical boundary layer within a tropical disturbance such as an easterly wave. Humid parcels also form naturally within tropical cloud clusters, by mechanisms that have yet to be determined.

How tropical cyclone frequency can be affected by climate change can be considered by investigating two components: first, by predicting how the prevalence of Gray's necessary conditions will change, and second, predicting how the frequency and strength of potential initiating disturbances will change.

“Elementary considerations suggest that anthropogenic increases in greenhouse gases will reduce the former and increase the latter. Very briefly, the strength of very large-scale tropical circulations such as monsoons and the trade winds are expected to increase. (Although the pole-to-equator surface temperature gradient decreases, gradients at higher altitudes increase and, in the net, the strength of thermally direct circulations increases.) In general, this would be accompanied by an increase in vertical wind shear, particularly in the upper troposphere (wind shear in the lower troposphere actually decreases). This would weigh in favor of fewer cases of tropical cyclogenesis. On the other hand, the more vigorous large-scale circulation might favor more and stronger potential initiating disturbances, such as easterly waves. This would weight in favor of more tropical cyclones. Thus the problem is complex, and simple reasoning produces ambiguous results.” (Emanuel, K., 2006)

Progress has been made in the development of dynamic/statistical models for seasonal tropical cyclone frequency. These models reproduce input features of observed past tropical cyclone variability when forced with historical variations in conditions such as SSTS, large-scale atmospheric winds, moisture, and temperature distributions. Based on current models, late 21st century projections indicate decreases ranging from 6-34% globally, with the Southern Hemisphere falling into the higher end of that range. A decrease in tropical cyclone frequency is expected due to a weakening of tropical circulation that is matched to a decrease in upward deep convection, or an increase in the saturation deficit of the middle troposphere.

Climate models project an increase in both the mean intensities and the frequency of tropical cyclones at higher intensity levels. From 1975 to 2004 there has been a near doubling of category 4 and 5 hurricanes. This study is being contested based on concern that the data shows a skewed “outlook” since the trend is a relatively short record-length relative to multi-decadal variability in the northwest Pacific (ENSO). This demonstrates that current models are still having problems with uncertain relationships between tropical cyclones and climate variability that include factors such as SST distribution and vertical wind shear. However, the most significant changes in intensity are expected for the Atlantic Ocean. Whether this is due to internal or anthropogenic forcing is yet to be determined with any relative high confidence.

The current data regarding tropical cyclones and climate change is consistent with the present scientific outlook on global climate change and anthropogenic radiative forcing. Due to warmer global temperatures it is expected that more water vapor will be displaced into the atmosphere, which will cause greater rainfall amounts found near the center of tropical cyclones. Due to more water vapor present in the atmosphere and warmer sea surface temperatures, hurricanes that do develop, will intensify rapidly. These intensifying storms will make it to higher levels on ranking scales such as the Saffir-Simpson Scale.

While there are still many uncertainties regarding the overall frequency of tropical cyclones, there is higher confidence in increases in globally averaged frequency of the strongest tropical cyclones. Further investigation of global climate change and tropical cyclones is just one piece of the puzzle regarding the need for even further improved climate models. It is important to note that tropical cyclones are not the sole variable that will change due to anthropogenic climate change. The global climate system is an extremely complex intertwined energy system and tropical cyclones are just one small component of that system. Changing behaviors in tropical cyclones should illustrate how complex the climate system is and how susceptible it is too even minute change.

How humans adapt to anthropogenic climate change is crucial to policies that are implemented as the 21st century comes to an end. Should we simply ignore the threat that human beings are having on the environment by believing statements made by climate skeptics? Predictions of future climate are not set in stone because models are limited by significant uncertainties that arise from: (1) the natural variability of climate; (2) our inability to predict accurately future greenhouse-gas and aerosol emissions; (3) the potential for unpredicted factors, such as volcanic eruptions (4) our current incomplete understanding of the "total" climate system. The reliability of climate-model predictions depends directly upon each of these parameters. As each of these parameters is further studied, the better our understanding will be for the forcing that both natural and anthropogenic causes are relative to climate change. This is the reason why the scientific community, policy makers, educators, and the populations of the world have to come together and decide how an extremely important matter such as climate change can be addressed.

Bibliography

Cook, J. http://www.skepticalscience.com. April 2011. http://www.skepticalscience.com/hurricanes-global-warming.htm.

Elsner, J., Kossin, P., Jagger, T. The increasing intensity of the strongest tropical cyclones. 4 September 2008. *Nature* **455**, 92-95.

Elsner, J., Jagger, T. Hurricanes and Climate Change. New York, NY Springer Science, LLC. 2009.

Emanuel, K. A., 2005: Increasing destructiveness of tropical cyclones over the past 30 years. *Nature*, **436**, 686-688.

Emanuel, K. A. http://wind.mit.edu/~emanuel/anthro2.htm. January 2006.

Freedman, A. http://voices.washingtonpost.com. Capitalweathergang. 18 August 2009. http://voices.washingtonpost.com/capitalweathergang/2009/08/new_studies_new_debates_on_hur.html.

Hamilton, J. http://www.npr.org. Recent Hurricanes Not Matched Since Middle Ages. 12 August 2009. http://www.npr.org/templates/story/story.php?storyId=111809658.

Holland, G., Webster, P. Heightened Tropical Cyclone Activity in the North Atlantic: Natural Variability or Climate Trend? Philosophical Transitions of the Royal Society. A. doi:10.1098/rsta.2007.2083. http://atoc.colorado.edu/~whan/ATOC4800_5000/Materials/Hurricane4a.pdf.

Knutson, T. Has Global Warming Affected Atlantic Hurricane Activity? Geophysical Fluid Dynamics Laboratory/NOAA. 3 September 2008. http://www.gfdl.noaa.gov/global-warming-and-hurricanes#section1.

Knutson, T., McBride, L., Chan, C., Emanuel, K., Holland, G., Landsea, C., Held, I., Kossin, J., Srivastava, A., Sugi, M. 10 February 2010. Tropical cyclones and climate change. *Nature Geoscience* 3, 157 – 163.

Landsea, C.W., and W. M. Gray, 1992: The strong association between western Sahel monsoon rainfall and intense Atlantic hurricanes. *J. Climate*, **5**, 435-453.

Mandia, S. http://www2.sunysuffolk.edu/mandias/global_warming/. April 2011.

Vecchi, G., Soden, B. Increased tropical Atlantic wind shear in model projections of global warming. 2007. Geophysical Research Letters, VOL. 34, L08702. http://www.agu.org/pubs/crossref/2007/2006GL028905.shtml.