

Climate Change and Tropical Cyclones

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### Abstract

Studies about whether or not there is a linkage between anthropogenic climate change and changes in tropical cyclones behaviour are relatively recent. They are mostly based on recorded historical data in order to identify past changes and likely trends; and on system modelling with the aim to predict future behaviours. Most of the studies consulted for this paper agree that a warmer world will not likely interfere in the frequency of tropical cyclones (i.e. number of occurrences). The regions hit will also remain the same. However, changes in climate patterns may likely result in more intense hurricanes, and also cause changes on their travel speeds and duration over the land. The outcomes, such as coastal flooding and heavy rain, are expected to be intensified due to climate change. The economic losses will likely be increased. Nevertheless, no ultimate conclusions can be reached due to the lack of longer and wider records. Longer observations and a better understanding of tropical cyclone systems are required.

*Keywords:* hurricanes, global warming.

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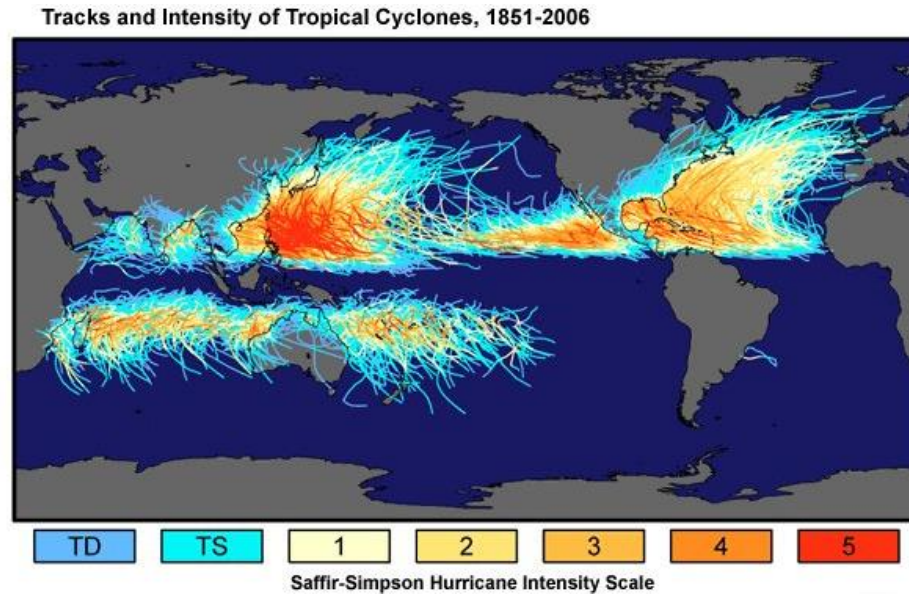
### Introduction

Since the devastation caused by Hurricane Katrina in 2005, tropical cyclones have been a topic of considerable repercussion in the media, with particular attention paid to the possible influence of anthropogenic climate change on Tropical Cyclones behaviour (Pielke, 2007). Whether global climate change interferes in patterns of tropical cyclones activity is a much-debated issue among the academic community. Both the interference on the number of tropical cyclones, on their path and on their intensity are being strongly discussed. This discussion has been fuelled by the increased frequency and intensity of observed hurricanes since 1995 (Goldenberg et al. 2011) and the overwhelming nature of the North Atlantic hurricane season in 2005 (Gualdi, 2007).

A tropical cyclone is a strong low-pressure system that forms over tropical or sub-tropical sea waters. Depending on the region of the planet, a tropical cyclone may be called a hurricane (North Atlantic Ocean and Eastern Pacific Ocean), a typhoon (Western Pacific Ocean), or a cyclone (Indian Ocean) (University of Rhode Island, 2010-2015). A few main conditions must be met in order to allow a tropical cyclone to form:

- i. SST reaching 26°C or more, in order to meet the ocean heat supply demand (Bengtsson, 2007);
- ii. Low vertical wind shear (Bengtsson, 2007), to allow the convective cloud cells to provide energy for the cyclones effectively (Shultz, Russel and Espinel, 2005);
- iii. Moist layers at mid-troposphere elevations to enhance thunderstorm formation (Shultz, Russel and Espinel, 2005);
- iv. Coriolis force to create and sustain the spin (Bengtsson, 2007).

Figure 1 below depicts the global occurrences and tracks of tropical cyclones, accompanied by their intensities under the SaffirSimpson hurricane intensity scale, for the period of 1851-2006.



*Figure 1.* Global distribution of observed occurrence of tropical cyclones, transitioning and hybrid cyclones related to the energy scale according to SaffirSimpson hurricane intensity scale. The isolated track on South Atlantic basin refers to life cycle of hurricane Catarina in March 2004. Figure by Rohde, R (2006). Retrieved from <https://earthobservatory.nasa.gov/images/7079/historic-tropical-cyclone-tracks>.

According to Shultz, Russell and Espinel (2005), patterns of human behaviour relate with physical forces to determine the epidemiology (i.e. patterns, causes and effects) of a tropical cyclone. Henderson-Sellers et al. (1998) point out the increasing human vulnerability to tropical cyclones due to the increasing population in coastal areas. Also, economic losses are rising as it is possible to see a rapidly increasing number of buildings and infrastructure in hurricane-prone areas. More than enhancing their own vulnerability, human beings may also be responsible for strengthening tropical cyclones due to its interference on the Earth's climate patterns.

The production of greenhouse gases by human activity can be defined as anthropogenic climate change (Global Greenhouse Warming). Since the 1700s, people have increased the amount of carbon dioxide (CO<sub>2</sub>) in the atmosphere by 40 per cent, and also other greenhouse gases in different percentages (The United States Environmental Protection Agency, 2016). IPCC (2007) advocates that the observed changes in the amounts of greenhouse gases detected in the air in such a short period of time could not be a result of natural conditions alone. Most of the CO<sub>2</sub> emissions, for instance, are related to fossil fuel burning in order to produce energy (Global Greenhouse Warming). IPCC, in its 4<sup>th</sup> Climate Change Report (2007), released data showing that eleven of the twelve warmest years ever instrumentally recorded (since 1850) were those between 1995 and 2006.

One of the most important components of the global climate system is the oceans due to their capacity of maintenance and alleviation of climate variability (Barnett, Pierce and Schnur, 2001). Moreover, ocean surface temperatures are extremely relevant to the formation of tropical cyclones, as discussed in past paragraphs. Thus, anthropogenic climate change

influences on surface seawater temperatures (SST) may be deeply deemed on studying the relationship between global warming and hurricanes.

Levitus et al. (2000) conducted an observational study that concluded that all world's oceans, over the 45 years prior to the study, are increasing in heat content of the upper part. Another study, carried out by the National Oceanic and Atmospheric Administration - NOAA (2016), has concluded that from 1901 through 2015, surface seawater temperatures have increased at an average rate of 0.13°F per decade and will continue to rise. According to the same source, the three last decades have been marked by the highest sea surface temperatures ever recorded in history. These changes, however, are regional. Whereas temperature is rising in most parts of the world's ocean, in others, such as specific regions of North Atlantic, it is cooling (EPA).

Understanding the relationship between tropical cyclones and climate change, and identifying trends and patterns of behaviour is definitely a hard task. It is difficult to distinguish which changes in hurricane behaviour are caused by anthropogenic climate change, directly or indirectly, and which ones are only results of the regular fluctuation on the occurrences of tropical cyclones. Thomas et al. (2017) pointed out the influence of natural variabilities such as the Atlantic Multi-Decadal Oscillation (AMO) and the El Niño Southern Oscillation. According to the University of Rhode Island (2010-2015), "hurricane activity varies by season and also due to weather and climate patterns that vary on time scales of weeks to years to decades". For Bengtsson (2007), longer records of reliable observations than those currently available are required to reach better conclusions. Trend detection is hampered by several limitations of global historical records of tropical cyclones (Knutson et al. 2010).

Despite the difficulties involved, much research has been already done, presenting some good and reliable results. The majority of them are based on system modelling, which allows the assessor to simulate different future scenarios based on baseline data. Most of the models are based on anthropogenic greenhouse gases emissions data. Besides, academic research is also relying on recorded data, in order to identify changes and trends in tropical cyclones occurrence, intensity and frequency over the past years.

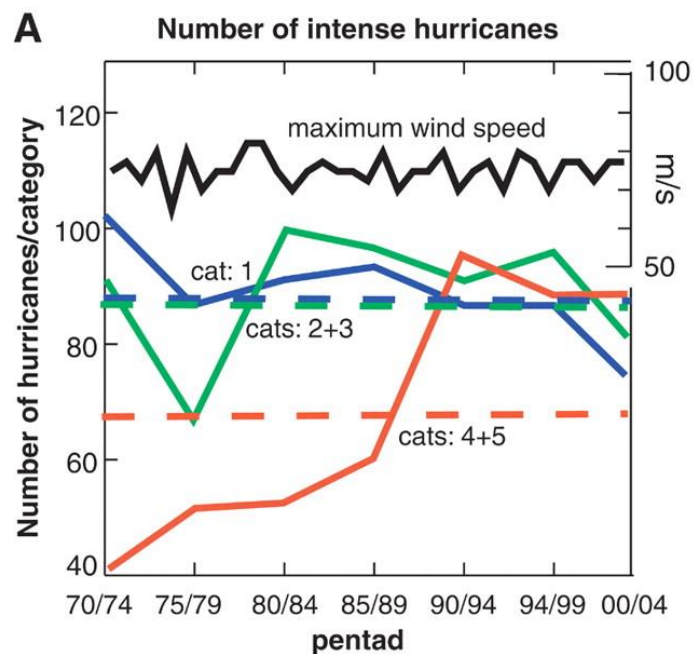
The next section intends to gather together and discuss diverse sources of research, in order to understand what are the conclusions already made about the topic, and also what else should be done in future research to increase the quantity and quality of data regarding the relationship between climate change and tropical cyclones.

### Discussion

According to National Geographic (2010), climate change is slowly interfering on sea surface temperatures (SST), but its results are already able to be noticed in the form of rising strength of tropical storms and hurricanes. Despite all uncertainties related to the effects of climate change on natural disasters, experts mostly agree that global warming outcomes, such as sea level rise, warming oceans, and hotter air, may likely interfere on the behaviour of tropical cyclones (Hood, 2017).

The Geophysical Fluid Dynamics Laboratory of Princeton University (2019) has reached some results. According to their research, i. sea level rise, which has a substantial human contribution, may be causing higher storm surge levels for tropical cyclones that do occur; ii. tropical cyclone rainfall rates will likely increase due to increased warming and atmospheric moisture content; iii. tropical cyclone intensities will likely increase on average, globally; iv. global tropical cyclones reaching category 4 and 5 will likely increase due to anthropogenic warming.

A bibliographic and data review conducted by Knutson et al. (2010) has concluded no significant changes in the frequency of tropical storms and hurricane numbers from 1970 to 2004. Another study, developed by Walsh, Nguyen and McGregor (2004) has concluded, by modelling, the same as Knutson et al. (2010) about the number of occurrences in a warmer world. However, their results also show an increase in the numbers of intense storms (i.e. those which winds reaching high speeds) and also in storms with lower central pressures. Caesar et al. (2018) support Walsh, Nguyen and McGregor (2004) modelling conclusions. They have found, by observing recently recorded data, that storms with maximum wind speeds of 175 km/h have increased, storms of 200 km/h have doubled, and those of 250km/h and more have tripled. Furthermore, the recent years have been marked by tropical storms with the highest wind speeds on record, such as the globally strongest one Patricia (2015) (Caesar et al. 2018). Webster et al. (2005) have developed a graph (Figure 2), based on historical data recorded from 1970 to 2004, that supports the argument that the number of intense storms has been increasing over the last decades.



*Figure 2.* The number of intense hurricanes, from 1970 to 2004. Each curve represents different categories of tropical cyclones. Dashed lines show average numbers of hurricanes for each category. The bold curve is the maximum wind speed observed globally. From 'Changes in Tropical Cyclone Number, Duration, and Intensity in a Warming Environment', by Webster et al., 2005, <http://science.sciencemag.org/content/sci/309/5742/1844/F4.large.jpg?width=800&height=600&carousel=1>.

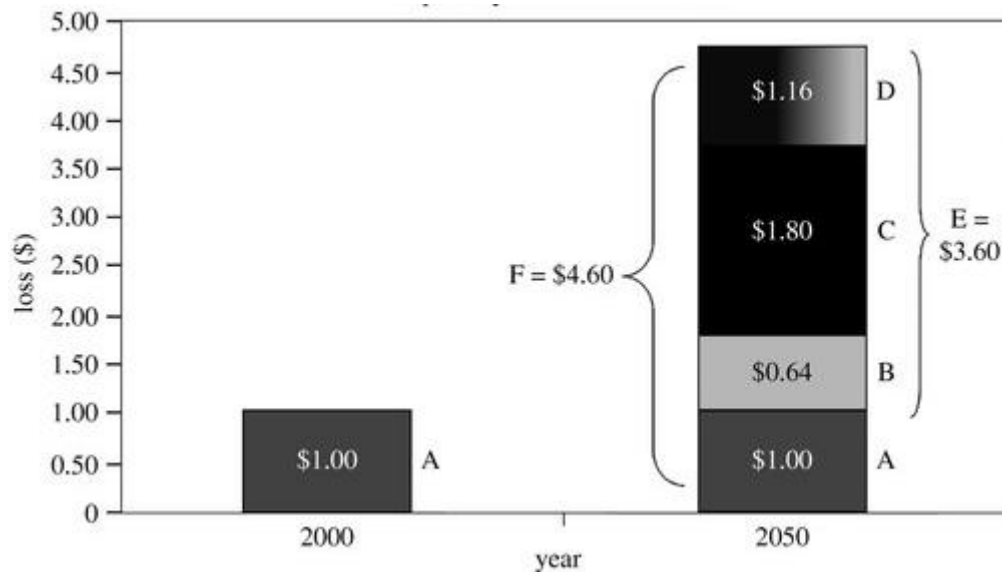
In Figure 2, it is possible to see that the number of tropical cyclones of categories 4 and 5 has been increasing over the last years. Meanwhile, the number of low categories tropical cyclones has not changed significantly. For Webster et al. (2005), global data indicate a 30-year trend toward more intense hurricanes. However, they have also highlighted that longer global data records are necessary before reaching any definitive conclusions.

In accordance with Henderson-Sellers et al. (1998), the regions affected by tropical cyclones are not expected to change significantly under a warmer world. Their travel speeds, on the other hand, are getting lower due to warming, and are expected to be even more reduced in the next years as a result of climate change (Kossin, 2018). While the cyclone travel speed gets lower making the system to move in a slow pace across the landscape, the wind speed within the storm remains high, resulting in heavy rains to last longer over land (Welch, 2018). Thus, the duration of tropical cyclones is expected to increase.

Not only climate change interferences on tropical cyclones intensity, on the number of occurrences, and on their path are being discussed by the scientific academy. The influence of climate change on the outcomes of a hurricane is also an important topic, maybe even more than those discussed in the past paragraphs since they directly affect people and the economy. IPCC (2014) highlights the relationship between climate change and rising sea-levels. Coastal flooding risks related to tropical cyclones may be strongly increased by rising sea-levels, and since flooding is considered one of the most destructive results of a hurricane, people living in coastal areas will be highly threatened.

Heavy rainfall related to tropical cyclones is potentially devastating because it could result in huge floods, as Hurricane Harvey proved in 2017 (Thomas et al. 2017). Climate change is linked with increases in extreme precipitation since warmer air is able to carry more moisture (Natural Academy of Science, 2016). Thus, tropical cyclones heavy rains could be intensified by ongoing changes in the Earth's climate.

Pielke (2007) has conducted an interesting study in order to understand how climate change can influence on tropical cyclones' damage costs. In his modelling, after consulting several data from past research and ten different specialists, he has assumed that tropical cyclones intensities will increase by 18% by 2050 due to climate change; population/wealth will increase by 180% above 2000's levels, and damage is proportional to the cube of the intensity (Pielke, 2007). Beginning in the year 2000, considering each \$1,00 (one American dollar) in losses from Tropical Cyclones, Pielke's results for 2050 are depicted in Figure 3.



*Figure 3.* Tropical cyclone losses in 2050. A, baseline loss in 2000; B, climate change effect on baseline conditions; C, additional loss due to greater population and wealth; D, climate change effect on additional loss. E, total damage increases; F, total damage. From ‘Future economic damage from tropical cyclones: sensitivities to societal and climate changes’, by R. A. Pielke, 2007, <https://royalsocietypublishing.org/doi/full/10.1098/rsta.2007.2086>.

According to the graph and Pielke’s interpretation of it, for each dollar of economic loss in 2000, an additional \$3.60 of loss would occur in 2050, under pre-defined conditions. Thus, the total costs for tropical cyclone damage in 2050 would be \$4.60, or 4.6 times more than 2000’s damages. It is important to highlight that Pielke has considered vulnerability reduction policy’s effects on his modelling (Pielke, 2007).

#### Final Considerations

According to the information presented in the past sections, some considerations about how tropical cyclones are being influenced by anthropogenic climate change have been reached (a - f).

- a. The number of occurrences of tropical cyclones is not expected to increase in a warmer environment;
- b. The intensity of tropical cyclones has been increasing over the last few decades and is expected to continue increasing due to climate change. Thereby, categories 4 and 5 hurricanes are expected to happen more frequently than in the past;
- c. Both the regions affected by tropical cyclones and their path are not expected to change significantly;
- d. Tropical cyclones are expected to travel slower, thereby lasting longer over the land, which could result in long-durations heavy rainfalls;



e. Hurricane outcomes, such as storm surges, heavy rains and coastal flooding are expected to be intensified by a warmer atmosphere, rising temperatures of the sea surface, and also higher sea levels;

f. Economic losses tend to increase due to more intense tropical cyclones, higher coastal populations and increasing wealth.

In summary, climate change may be considered an important factor of influence on tropical cyclones behaviour, which may negatively affect people who live in hurricane-prone areas. Increasingly intensity of tropical cyclones, associated with longer durations and even more hazardous outcomes will increase the risk on already over-populated and vulnerable coastal areas. The integration of climate adaptation and disaster risk reduction at national and community levels may help to better prepare countries for cyclones (Climate Analytics, 2018), leading to the development of more resilient societies (Bacmeister et al., 2016).

After all, it is important to understand that all the information presented in this paper is based on recorded data from the past, and modelling predictions for the future. As already said, available data records are not long or reliable enough to reach any definitive conclusions about the relationship between climate change and tropical cyclones. A better understanding of storm systems and wider, longer sets of data are required in order to increase the reliability of predictions.

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