Comparison of Sea Surface Temperatures (SST) in the Atlantic During the Formation of Rapid Intensification Hurricanes

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Abstract

Warmer sea surface temperatures (SST's) have become more common as global warming accelerates. As a consequence, more major hurricanes are reaching rapid intensification (RI) each season. This research intends to investigate the relationship between warm SST's and the extreme intensification of tropical cyclones in the North Atlantic basin. The six RI hurricanes used for this study were categorized between stable RI and unstable RI, where stable RI indicates a consistent and prolonged increase in maximum sustained winds and unstable RI indicates a short period of increase in the maximum sustained winds. The images used for this investigation were captured with the Advanced Very High Resolution Radiometer (AVHRR) sensor, between the years 2010 and 2023. The SST was calculated using the ENVI software. There was no significant trend found in warm SST having an effect on stable or unstable RI hurricanes. Nonetheless, this does not imply that warm SST has no contribution in RI. For further research, it is suggested to choose a larger sample size spanning from before the 21st century and validate calculated SST with bouy temperature measurements.

I. Introduction

The Atlantic Hurricane Season has taken a turn for the worse in the last few decades. Scientists have demonstrated an increasing trend in the intensification of hurricanes in the North Atlantic basin [1][2]. This is due to the fact that global warming and greenhouse gas emissions have elevated sea surface temperatures (SST) since the late 1800's [2]. Therefore, rapid intensification (RI) hurricanes have become the norm every single year. Rapid intensification hurricanes are defined as major tropical cyclones (category 3 or more in the Saffir-Simpson scale) to have an increase in maximum sustained winds of 30 knots (kt) or more in the span of 24 hours or less [3].

Some specific conditions need to be present in order for these hurricanes to have RI. A major contributing factor is warm SST. An average of 26.5℃-27.5℃ has been observed to be the SST range for tropical cyclone genesis [4]. In some extreme cases, SST has exceeded these temperatures by a few degrees Celsius. This increased warming has led to the RI of several devastating hurricanes in the Caribbean and Southeastern U.S. Thus, this research project intends to study the SST of six RI tropical cyclones from 2010 to 2023 utilizing the Advanced Very High Resolution Radiometer (AVHRR) sensor and the ENVI software to process the images. It is relevant to note that our analysis did not take into account other factors that promote or degrade RI, such as wind shear, eyewall replacement, dry air masses, etc.

II. Methodology

The selected region of study is a portion of the ocean in the North Atlantic shown in Figure 1. Hurricanes that develop in this region can affect the island of Puerto Rico, a factor that made this area interesting to this research.

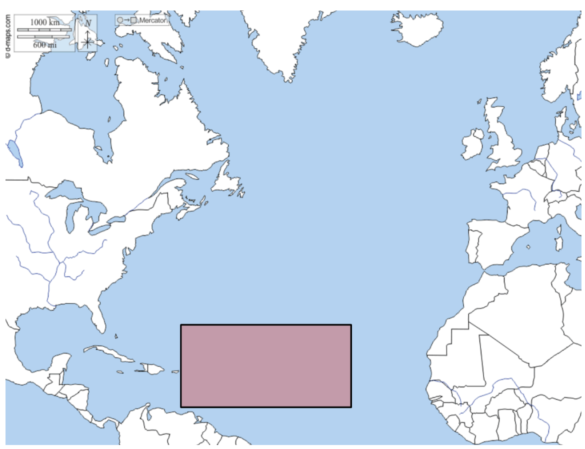

Figure 1 Region of study.

After the area was chosen, six major hurricanes, from the years 2010 to 2023, were selected and divided based on the following criteria: unstable RI and stable RI. Hurricanes classified as having a stable RI were hurricanes that had an uninterrupted period of rapid intensification for twelve hours or more. Hurricanes classified as having unstable RI were hurricanes that had much shorter periods of rapid intensification. With that criteria being set, and with the help of Google Docs [5] and Microsoft Excel [6], the chosen hurricanes with stable RI were Igor (category 4) [7], Sam (cat. 4) [8], Lee (cat. 5) [9], and the hurricanes with unstable RI were Larry (cat. 3) [10], Teddy (cat. 4) [11], and Danny (cat. 3) [12].

The Advanced Very High Resolution Radiometer (AVHRR) sensor was chosen for this study for its capacity to measure SST using bands 3, 4, and 5 (all thermal bands). These images were obtained from the NOAA CLASS database [13] and chosen two to three days prior (depending on the condition of the image) to study the sea surface condition before the hurricane passed and to avoid having the hurricane covering the image, something that hinders SST calculations. SST, in degrees Celsius (°C), was then calculated using the ENVI AVHRR Sea Surface Temperature (SST) tool. After SST was calculated, the images were georeferenced and masked to eliminate unwanted values, such as clouds and land. Each mask had a minimum of 20 °C, to only take into consideration expected and realistic SST measurements. The maximum of each mask depended on the maximum temperature calculated, to add more visual contrast between values. Once this processing was completed, a color scheme, a color bar, a grid, and a north arrow were added for more visual appreciation.

III. Results

Stable RI hurricanes:

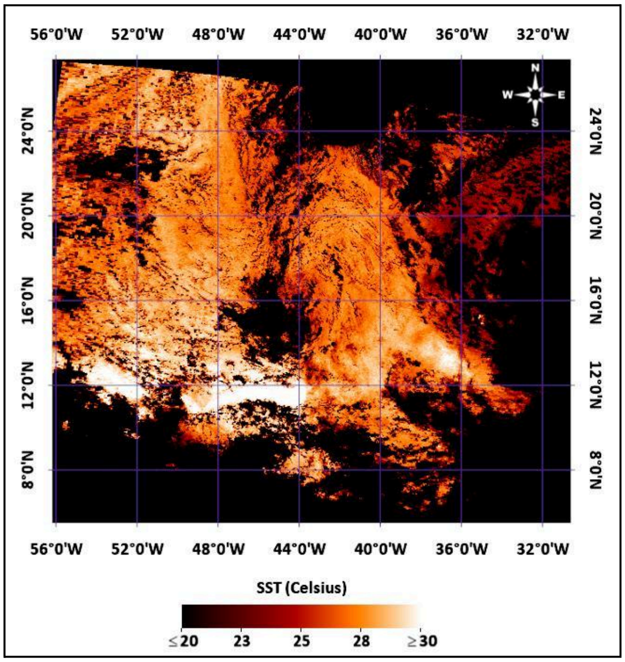

Figure 2 Calculated SST for Hurricane Igor.

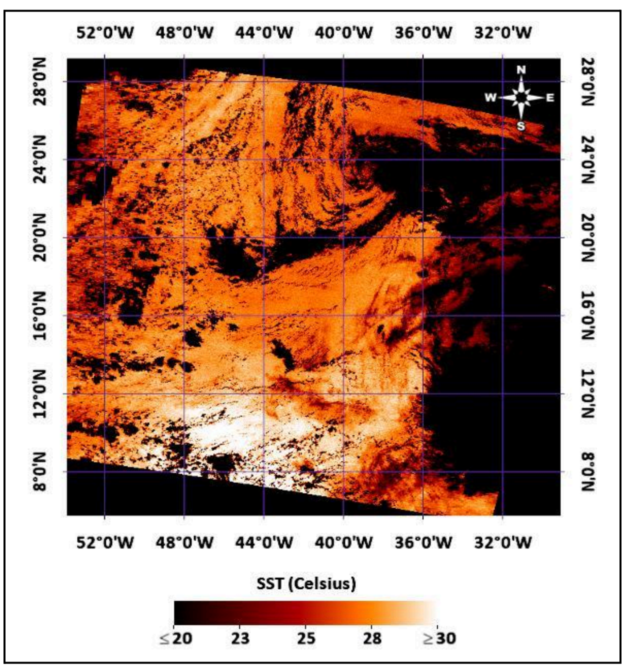

Figure 3 Calculated SST for Hurricane Sam.

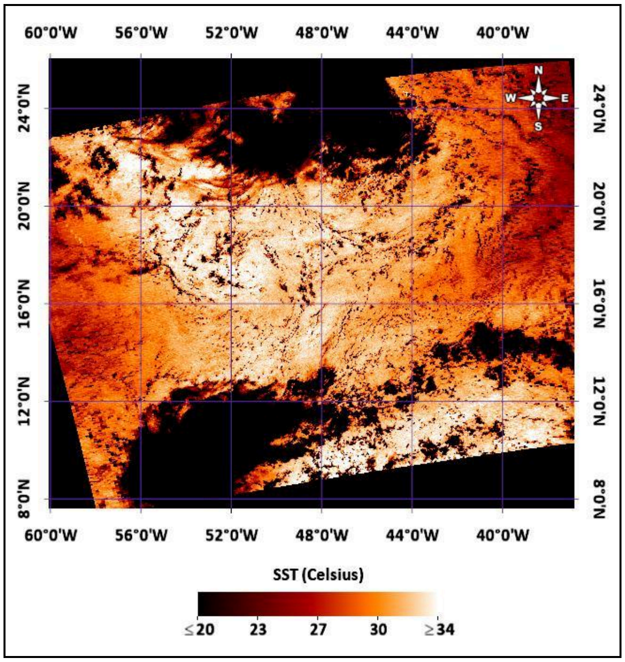

Figure 4 Calculated SST for Hurricane Lee.

Unstable RI hurricanes:

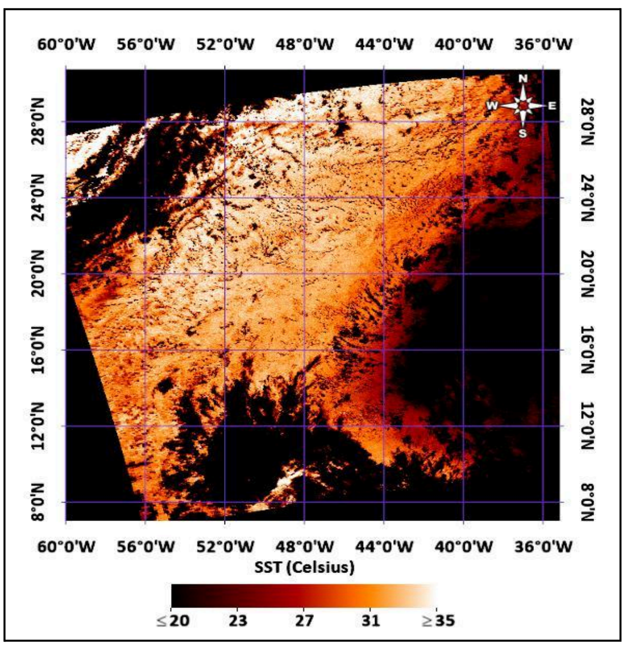

Figure 5 Calculated SST for Hurricane Danny.

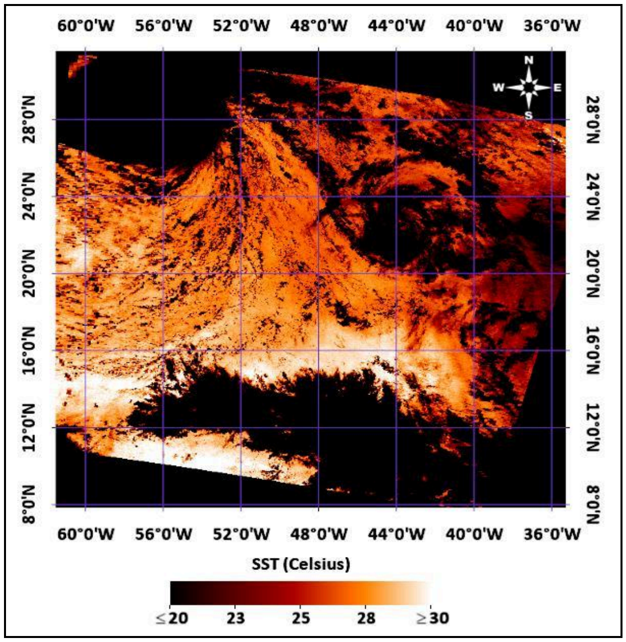

Figure 6 Calculated SST for Hurricane Teddy.

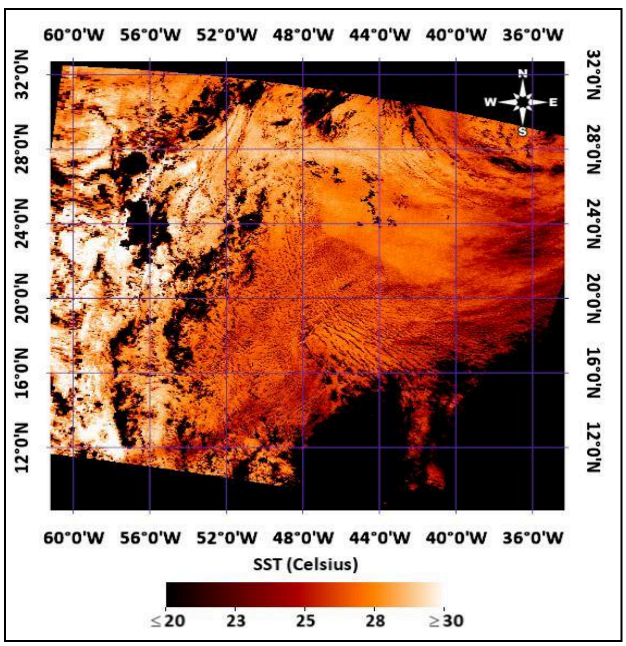

Figure 7 Calculated SST for Hurricane Larry.

Table 1 All studied hurricanes with their category, date, maximum SST found, and maximum wind speed recorded.

Hurricane	Category	Date	Maximum SST Recorded (°C)	Maximum Wind Speed (kt)
Igor	4	8-21 September 2010	29.31	135
Sam	4	22 September- 5 October 2021	29.30	135
Lee	5	5-16 September 2023	33.62	145
Danny	3	18-24 August 2015	35.05	110
Teddy	4	12-23 September 2020	29.50	120
Larry	3	31 August-11 September 2021	29.00	110

IV. Discussion

The analysis of sea surface temperatures (SST) during the formation of rapid intensification (RI) hurricanes in the North Atlantic basin revealed many interesting things. Despite the expectation of warmer SSTs playing a significant role in RI, this study did not find a direct correlation between warm SST and the categorization of hurricanes into stable RI or unstable RI. This unexpected result may have come from various factors that could have influenced both the SST measurements and the RI process of each hurricane.

One notable challenge encountered in this study was the presence of clouds in the satellite images used for the SST calculations. Cloud cover can obscure the ocean's surface, leading to inaccurate SST measurements. Another thing to take into consideration is sun radiation, which is influenced by cloud cover and atmospheric conditions. At specific angles, the sun radiation can harshly reflect off of the sea and into the sensor, effectively saturating its readings and contributing to potential discrepancies in the results.

Furthermore, it is essential to consider other atmospheric and oceanic variables that affect RI, such as wind shear, Saharan Air Layer (SAL) intrusion, and the presence of dry air masses, as was the case for hurricanes Danny (SAL), Teddy (SAL), and Larry (wind shear). These factors can disrupt the intensification process and probably contributed to the classification of these hurricanes into the unstable RI categories. Future research should aim to incorporate these variables into the analysis to gain a more comprehensive understanding of RI dynamics.

During further analysis of the sea surface temperatures (SST's), colder sections of water were observed near the areas where hurricanes were approaching from the east. One possible explanation for these colder waters is the vertical shifting of the ocean surface caused by the passage of hurricanes. As hurricanes intensify, they can induce vertical mixing of cooler water from deeper ocean layers, leading to reductions in SST. However, it is also possible that these colder areas result from increased atmospheric noise close to the hurricanes, which may interfere with accurate SST measurements.

V. Conclusions

The study aimed to explore the relationship between warm sea surface temperatures (SST) and the rapid intensification (RI) of hurricanes in the North Atlantic basin. While the expectation was for warmer SSTs to significantly influence RI, the findings did not directly support this hypothesis. Despite the unexpected results, several other things were found during their analysis. This research underlines the complicated nature of hurricane dynamics and the many variables that need to be considered to understand it. Further research with a larger sample size, an extended period of time, and incorporating other variables would give a better understanding of how these natural phenomena work. For research that continues this work, some recommendations are expanding the scope of study, validating results with buoy or ship data, mitigating the impact of atmospheric noise, and collaborating with other disciplines to better the analysis. Future research that takes this into consideration could advance our understanding of RI hurricanes and contribute to the pursuit of knowledge.

VI. Recommendations

A larger sample of hurricanes spanning a longer period of time with a larger region of study could provide better conclusions regarding this type of research. Another recommendation could be to consider incorporating additional atmospheric and oceanic variables, such as wind shear and SAL intrusion, into the analysis to better understand RI dynamics. In addition, finding a method of tracing the hurricane's trajectories in the images to see the portion of sea surface through which they passed, can give a better understanding to what SST the hurricane encountered, since the images are just of the general area. Also, finding more ways of validating results with buoy and/or ship data besides the Tropical Cyclone Reports would give the research more credibility since the SST calculations can give erroneous results. Another thing that could be added is to investigate methods for mitigating the impact of atmospheric noise on the SST calculations to improve data accuracy and to collaborate with other teams to integrate expertise from meteorology and oceanography for a better analysis of the results.

VII. References

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