ECAS 2022

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Proceeding Paper

Climatological Variations in the Intensity of Tropical Cyclones Formed over the North Atlantic Basin Using the Hurricane Maximum Potential Intensity (HuMPI) Model †

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† Presented at the 5th International Electronic Conference on Atmospheric Sciences, 16–31 July 2022; Available online: https://ecas2022.sciforum.net/.

Abstract: In this study, we investigated the variations in the intensity of the tropical cyclones (TCs) formed in the North Atlantic basin from 1982 to 2021, based on the outputs from the Hurricane Maximum Potential Intensity (HuMPI) model. To feed HuMPI, we computed the annual Sea Surface Temperature (SST) as the SST average from 1 June to 30 November using the Daily Optimum Interpolation SST database. The information for all major hurricanes (MHs, category 3+ on the Saffir-Simpson wind scale) was from the HURDAT2 dataset. While the trend ($p < 0.05$) in the mean maximum potential intensity (MPI) was approximately 1.14 m/s per decade for the maximum sustained wind speed and −1.57 hPa/decade for the minimum central pressure, the MHs intensity did not exhibit any statistically significant trend. The behaviour of the MPI could be explained by the increase ($p < 0.05$) of the SST at a rate of 0.20 °C/decade. In addition, the increase of the TCs intensity in the last 20 seasons (2002–2021) concerning the period 1982–2001 was quite similar for MHs and MPI, being an increase of 3.89% and 3.20% for the mean maximum wind speed, respectively. Meanwhile, the minimum central pressure decreased by about 0.36% in both cases. This latter result is promising for investigating the changes in the TC intensity in global warming based on the HuMPI model.

Keywords: tropical cyclones; potential intensity; climatology; HuMPI

Academic Editor: Anthony Lupo

Published: date: 14 July 2022

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1. Introduction

Tropical cyclones (TCs) generally provoke casualties and economic losses in tropical regions due to the combined effect of strong winds, heavy rainfall, flash flooding, landslides and storm surge [1–4]. The population in coastal areas and small islands are often the most affected by the impact of TCs. The TCs hazard mainly depends on the number of people exposed, their vulnerability [2], intensity and trajectory of the storm. Therefore, the accurate prediction of TC track and intensity is crucial for reducing the negative impact of TCs and associated phenomenons [5].

According to Knapp et al. [6], approximately 90 TCs globally are formed every year, of which ~16.7% occur over the North Atlantic (NATL) basin. Despite the long-term (since 1851) dataset of TCs records in the NATL basin, the inhomogeneities in the methods to observe TCs notably limits the detection of climatic signals in the TC intensities [7]. Therefore, the influence of the climate change on TC activity is uncertain [2].

Some authors [8–12] have investigated trends in TC activity. Klotzbach and Landsea [9] found an insignificant upward trend in the proportion of Category 4–5 hurricanes on the Saffir-Simpson wind scale. Kossin et al. [10], using TC records from the ADT-HURSAT dataset from 1979 to 2017, revealed a significant trend in the percentage of major hurricanes (MHs, Category 3+ on the Saffir-Simpson wind scale). Pérez-Alarcón et al. [11] detected a significant increasing trend in tropical storms but not in TCs with hurricane category. Most recently, Klotzbach et al. [12] investigated the global TC trends from 1990 to 2021, founding a significant decrease in the global number of hurricanes.

In this study, we aim to investigate the climatological variations in the intensity of TCs formed in the NATL basin from 1982 to 2021 thought the Hurricane Maximum Potential Intensity (HuMPI) [13] model simulations.

2. Data and Methods

In this work, we only considered the TCs that reached the MH intensity, for which MPI is most relevant.. The information on TCs was retrieved from the Atlantic Hurricane Database (HURDAT2) [14] developed by the United States National Hurricane Center and also hosted in the International Best Track Archive for Climate Stewardship version 4 [15].

To compute the TCs' maximum potential intensity (MPI), we used the HuMPI model [13,16]. In addition, the annual average Sea Surface Temperature (SST) extracted from June to November from the Daily Optimum Interpolation SST database v2.1 [17] was used to feed HuMPI.

We also averaged the lifetime maximum intensity (LMI; maximum wind speed (MHs_{vmax}), and minimum central pressure (MHs_{pmin})) of all MHs every year to investigate the annual changes in the mean LMI. Additionally, the annual SST was average in the box delimited by 5–30° N in latitude and 10–100° W in longitude, as shown in Figure 1. Similarly, we calculated the mean annual MPI for the potential maximum wind speed (MPI_{vmax}) and potential minimum central pressure (MPI_{pmin}). We focused our study in this region (5–30° N in latitude and 10–100° W in longitude, red box in Figure 1) based on all MHs commonly reached the LMI in this area.

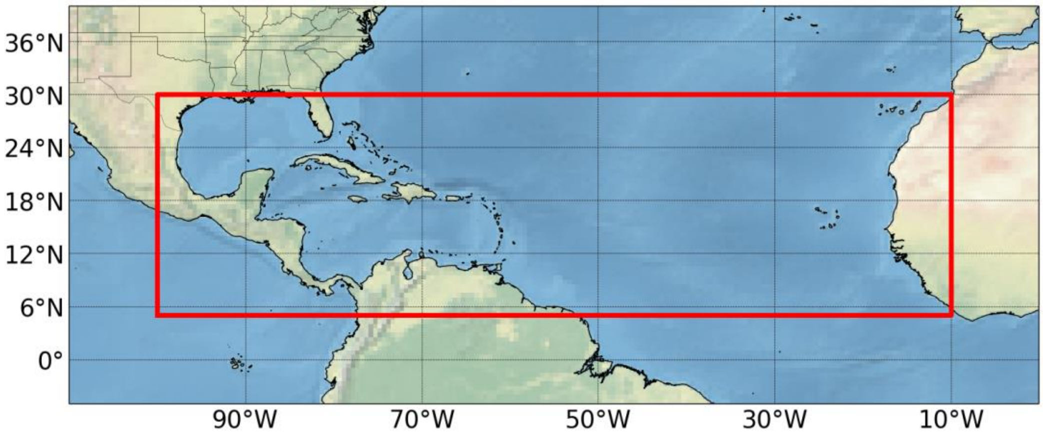

Figure 1. The red box (5–30° N in latitude and 10–100° W in longitude) delimits the area in which the annual mean Sea Surface Temperature and the Maximum Potential Intensity were computed.

3. Results and Discussion

The average SST in the red box shown in Figure 1 exhibits a significant ($p < 0.05$) increasing trend of 0.20 °C/decade, as revealed in Figure 2. This result agrees with the findings of Taboada and Anadón [18], who pointed out an SST rising at a rate of 0.25 °C/decade from 1982 to 2010; and Pérez-Alarcón et al. [13], who found an upward trend of SST of 0.23 °C/decade from 1980 to 2019. Overall, linear trends in the average SST revealed a widespread process of warming during the last four decades in the region of the NATL basin, where TCs commonly reach their LMI, in agreement with Taboada and Anadón [18].

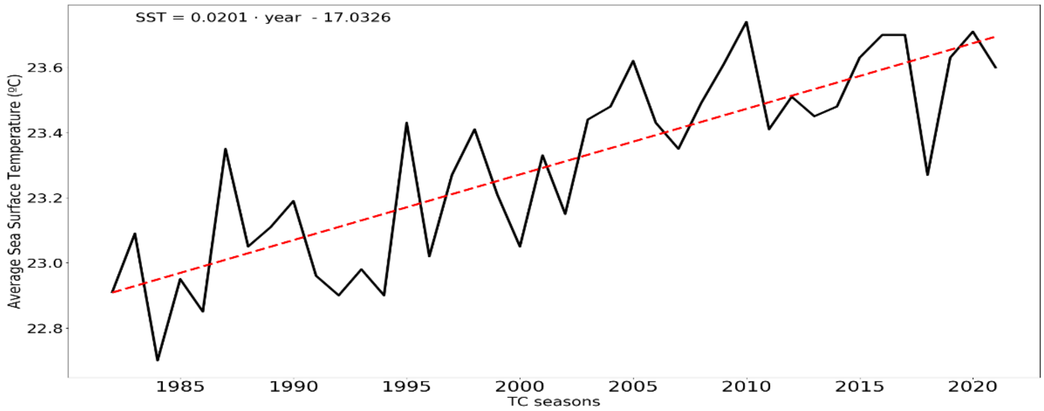

Figure 2. Annual averaged SST in the red box showed in Figure 1. The red dashed line denotes the trend line statically significant at 95%.

Despite the warming of the NATL basin, the intensity of MHs did not show any statistically significant trend, as revealed in Figure 3a for the maximum wind speed and Figure 3b for the minimum central pressure. Nevertheless, the mean potential maximum wind speed exhibit an upward trend of 1.14 m/s per decade (Figure 4a) and the potential minimum central pressure shows a decreasing trend of 1.57 hPa/decade (Figure 4b). The behaviour of the MPI is linked with the SST trend, as the HuMPI model establishes the SST as the primary source of energy for the TCs intensification.

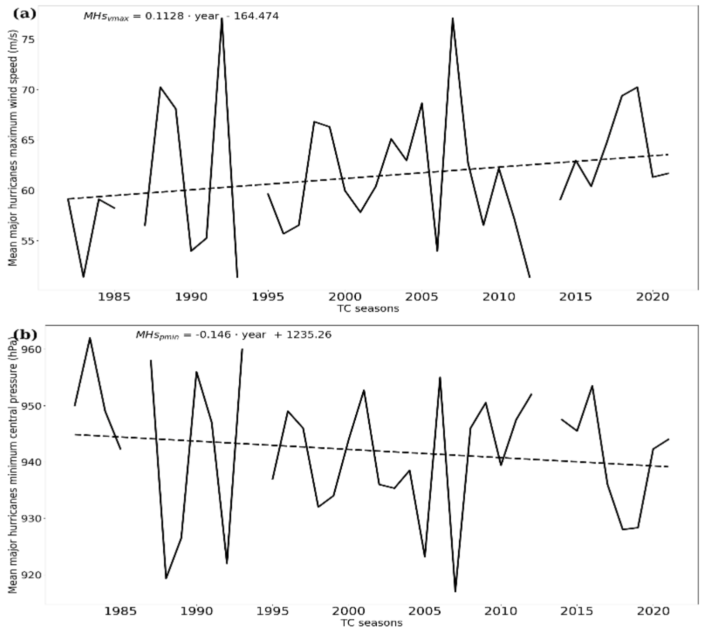

Figure 3. Annual averaged of (**a**) maximum wind speed and (**b**) minimum central pressure for the major hurricanes based on HURDAT2 database. The black dashed line represents the linear trend ($p > 0.05$). The discontinuities in the black solid lines denotes TCs season without major hurricanes.

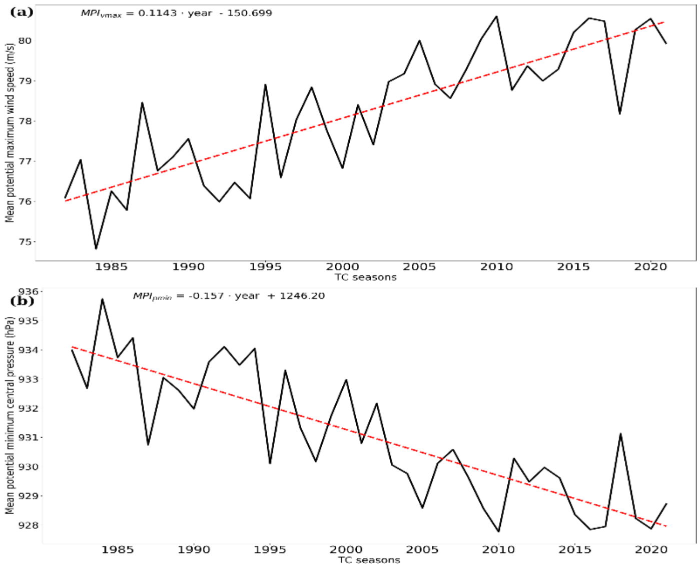

Figure 4. Annual averaged of (**a**) potential maximum wind speed and (**b**) potential minimum central pressure based on the HuMPI model outputs. The red dashed line represents the linear trend statistically significant at 95%.

We additionally separated the analysis into two periods of 20 years each (the first 1982–2001 and the second 2002–2021) and then computed the changes in the mean MHs intensity and MPI in the 2002–2021 period concerning the period 1982–2001. Figure 5 shows the percentage of increment of SST, maximum wind speed and decrease of the minimum central pressure. From Figure 5, the SST in the last 20 years is, on average, approximately 1.85% higher than the mean SST in the period 1982–2001. Interestingly, changes in the MHs' intensity and the MPI are almost similar. The maximum wind speed of MHs increased by 3.89%, while the potential maximum wind speed increased by 3.20%. For the minimum central pressure, both MHs and MPI, the decrease in the last two decades accounted for 0.36%.

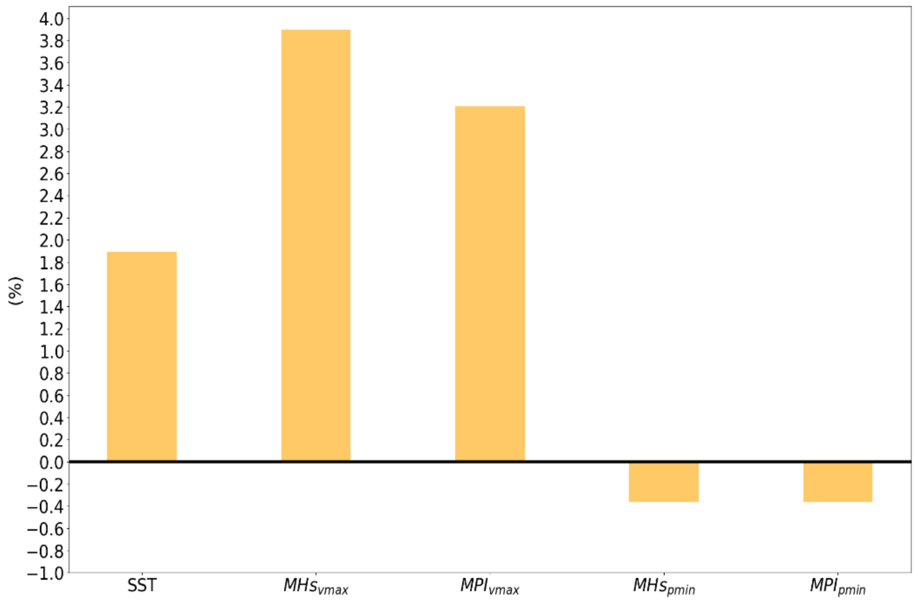

Figure 5. Changes (in percentage) of the mean Sea Surface Temperature, major hurricanes intensity and maximum potential intensity in the period 2002–2021 concerning the period 1982–2001.

4. Conclussions

While the mean intensity of major hurricanes did not show any statistically significant trend in the North Atlantic basin, the maximum potential intensity from HuMPI model outputs revealed an increasing trend in the maximum wind speed of 1.14 m/s per decade and a downward trend in the minimum central pressure or 1.57 hPa/decade. In addition, the mean maximum wind speed in the period 2002–2021 has increased by 3.89% for MHs and 3.20% for MPI concerning the period 1982–2001. Our results are promising to investigate the changes in the intensity of tropical cyclones due to global warming.

Author Contributions: A.P.-A. conceived the idea of the study; A.P.-A. and J.C.F.-A. processed the data and made the figures; A.P.-A. wrote the manuscript. All authors analyzed the results and revised the final version of the manuscript. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable

Informed Consent Statement: Not applicable

Data Availability Statement: The HURDAT2 database can be freely downloaded from https://www.nhc.noaa.gov/data/#hurdat (accessed on 25 April 2022). The Daily Optimum Interpolation Sea Surface Temperature database is available at https://www.ncdc.noaa.gov/oisst (accessed on 16 April 2022), while the Python code from HuMPI model can be obtained from https://doi.org/10.5281/zenodo.6475215 (accessed on 20 April 2022) or directly from the Github repository at https://github.com/apalarcon/HuMPI-master (accessed on 20 April 2022).

Acknowledgments: The authors acknowledge the availability of public datasets from the National Hurricane Center and the NOAA/NCDC.

Conflicts of Interest: The authors declare no conflict of interest.

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