INVESTIGATING THE CORRELATION BETWEEN HEAT WAVES AND TROPICAL STORMS FOR BROWARD COUNTY: "THE DEADLIEST PLACE IN FLORIDA"

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1. INTRODUCTION

According to the American Meteorological Society (AMS), heat waves (HWs) are defined as "a period of unusually hot, humid and uncomfortable weather." In addition, the National Oceanic and Atmospheric Administration (NOAA) defines it as "a period of unusually warm and unusually humid weather, typically lasting two or more days." In a study developed by Perkins (2015), it is mentioned that at least one definition must be used to evaluate temperature and define HWs. Modern studies suggest that a series of persistent days in which the maximum (T_{max}), minimum (T_{min}) or average (T_{ava}) temperature surpass a specific threshold (limit) is considered a HW. Raghavendra et al. (2019) emphasize that if the T_{max} , T_{mix} or T_{avg} exceeds the 95th percentile for 3 continuous days with an interval of at least 4 uninterrupted days in the same event, this is considered a HW. Keellings and Waylen (2014) established in their studies the 90th percentile of the T_{max} and T_{min} as a common threshold, where the criterion was at least 2 days of temperature above the limit and a separation of at least 4 days below the threshold to be considered an independent event. Nissan et al. (2017) worked with six different binary indicators of extreme heat in Bangladesh, proposing a day-and-night index employing T_{max} , T_{min} and the 95th percentile, where HW conditions were investigated using $T_{max} > T_{max_{95}}$ and $T_{min} >$ $T_{min_{as}}$ for a minimum duration of 3 consecutive days, with the subscript 95 being the 95th percentile of the daily values defined for all days between the years studied. Cloutier-Bisbee et al. (2018) found that from 1950 to 2016, the frequency and duration of HWs exhibited a statistical increase after establishing a climatology and trend analysis of summer HWs at seven major airports in the state of Florida.

Between 2010 to 2020, 215 heat-related deaths occurred in Florida, with 10% of them in Broward County, making it the highest percentage of all counties in the state. In a study developed by Gorucu et al. (2021), it was found that the age of the victims varied between 1 and 98 years, with the elderly aged

65 or over being the group with the highest percentage of deaths (27%). According to the World Health Organization, the impact of this extreme event on health depends on the intensity and duration of the temperature, the acclimatization and adaptation of the population, and infrastructure and preparation. The National Weather Service describes heat as one of the major elements of weather in the United States that results in the deaths of hundreds of people every year.

According to the National Hurricane Center, one of the ingredients for the formation of a Tropical Cyclone (TC) is heat. When heat is added to this type of cyclone, the internal energy and wind speed increase. TCs form in tropical regions with warm waters with temperatures above 80°F or 28°C, sufficient Coriolis force (CF), weak upper air winds, and in addition when other factors are present in the initial disturbance they can intensify. Some of these factors may be; Intertropical Convergence Zone (ITCZ), Monsoon, Madden and Jullian Oscillation (MJO), interaction with mid-latitude cyclones called frontal systems or fronts, sea surface temperature and El Niño Southern Oscillation (ENSO) or La Niña. Klotzbach et al. (2022) identified that the frequency and intensity of TC are increasing in the North Atlantic Ocean between 1990 and 2021, due to favorable atmospheric conditions. Vecchi et al. (2021) revealed that the consequences of this are TC reaching high Saffir-Simpson TC categories (3, 4 or 5). This category defines the storm's development stages, intensity and wind, respectively. Most of these cyclones form in tropical air between 8° and 15° degrees of latitude and continue to propagate to other regions, making Broward County located in southeast Florida, latitude between 25.96°N and 26.36°N, a place susceptible to tropical storms landfall. The Federal Emergency Management Agency (FEMA), National Hurricane Center, National Weather Service and the Storm Prediction Center state that the number of deaths associated with TC and heat waves is increasing over the years, rising concerns among them with this scenario.

In this study, daily data was used to investigate when heat waves occurred in Broward County between the years 1999 and 2022, and whether tropical cyclones hit this same area in the same period. The objective is to verify whether there is any relationship between heat waves and tropical cyclones.

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2. METHOD AND METHODOLOGY

2.1 Area of Study

Broward County (25.96°N, 80.88°W; 26.36°N, 80.02°W), located in the southeastern Florida peninsula, presents four different climate regions according to the Köppen Geiger Climate Classification: tropical rainforest (Af) for the part closer to the coast, tropical monsoon (Am) for the inland region to the middle part of the County, tropical savanna (Aw) from the middle to the west part of the county, and humid subtropical (Cfa) for a northwestern part of the County. The county is strongly influenced by the surrounding bodies of water, local and prevailing winds, atmospheric systems, and ocean currents. The temperature during the coldest month (January) are higher than 15 °C, and in July it is observed the highest temperatures, varying between 27 and 28 °C, however can reach above 37.7 °C, and it considered the wettest place in the United States with a minimum of 50 inches of rain annually (Her, et al., 2020; Raghavendra, et al., 2018; Winsberg (n.d); Black, 1993). Regardless of the maritime climate, heat waves are favorable to occur; however, very few studies have been conducted on this topic.

2.2 Method

For this study, hourly temperature data was downloaded for the year of 2022 from the European Centre for Medium-Range Weather Forecasts (ECMWF) Reanalysis v5 (ERA5) and Florida Automated Surface Observing System Network (ASOS). The objective of this was to validate the reanalysis data. The selected locations (Figure 1) were: Pompano Beach Airpark (PMP) situated in the latitude of 26.2464°N and longitude 80.111°W, Fort Lauderdale Executive Airport (FXE) set in 26.2°N and 80.17°W, Hollywood International Airport (FLL) positioned in 26.07°N and 80.15°W and North Perry Airport (HWO) placed in 25.9995°N and 80.2412°W.



Fig 1. Map of Broward County showing the locations of the four ASOS stations considered in this study (orange dots). Reanalysis data was downloaded for the same locations.

3. RESULTS AND DISCUSSION

In the initial results to find the correlation between observational data and the ERA5 reanalysis for each location, it was identified that FXE presented the best value of 0.9789, followed by PMP as presented the value of 0.9780; FLL had a value of 0.9738, and HWO had the lowest correlation 0.9688. After this verification, with the correlation values approaching almost 1, which is equivalent to 100% accuracy in the compared data. With this, it was proven that the ERA 5 data presented daily temperature values equivalent to the data observed in ASOS. Therefore, reanalysis data was used in this project to help verify the information.

For the second part of the project, an analysis and identification of HW was carried out for the four selected locations in Broward County using a bivariate method that considers the 95th percentile for both daily maximum and minimum temperatures. It was verified 13 HWs in PMP, 10 in FXE, 10 in FLL, and 7 in HWO, with only 3 HWs occurring simultaneously in the 4 locations. These three events happened in the timeframe of August 16th to 21st, 2005; the second case occurred from July 28th to August 6th, 2011; and the third one from September 3rd to 5th, 2020. All the HWs occurred within the hottest months of the year for the state, with most of them taking place in the month of August, and within a negative ENSO phase (La Niña).

It was verified that 5 tropical storms/hurricanes made landfall or crossed Broward County during the study period, however, only Hurricane Katrina (August 23-31, 2005) impacted the county after a HW on August 16-21. It is noteworthy that in the following days, between October 15th and 26th. Hurricane Wilma hit the same county, however no detected. Subsequently, possible HW was connections between hurricanes and heat waves associated with various phenomena were examined, such as fronts (hot sector), ENSO phases and the Madden-Julian phenomenon. According to the Climate Prediction Center, NAO temperatures in 2005 were -2° below average, and in La Niña years the subtropical jet stream shifts position and decreases in intensity leaving the southeastern part of the US, especially the Southeast Florida, Broward County with a dry and hot climate configuration, which is consistent with no injection of moisture from the Pacific Ocean into the upper levels, promoting the heat wave events in the investigated locations. A positive ENSO phase was observed to begin developing near the end of 2005 and mid-2020, years that correspond to the heat wave events that featured hurricane activity in

Florida. An initial analysis of the MJO was considered, which presented a weak oscillation event for August 2005, but is associated with a more cyclostrophic possibility, which is related to an intensification of vorticity in the event of the development of tropical storms and hurricanes. However, more in-depth analysis is needed to gain a better understanding of the possible connections between heat waves and hurricanes, which is the focus of future investigations.

4. Conclusions

In conclusion, ERA 5 reanalysis data proved to be an accurate source to be used in studies associated with heat waves and possible relationship with TC. In all four locations investigated between the years 1999 and 2022 using a bivariate method that considers the 95th percentile for daily maximum and minimum temperatures, PMP had the maximum number of PS, while HWO had the lowest number of events. And only 3 HWs occurred simultaneously in these locations. Most HW occurring in August, and within a negative ENSO phase (La Niña). Among the identified tropical storms/hurricanes that affected this county, only Hurricane Katrina impacted the county after an HW, however in the following days the same location was hit by Hurricane Wilma, but no HW was detected. Future investigations related to HW, TC and other phenomena should be carried out to obtain more information.

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6. Appendix

Year	Name	Туре	Dates	Date of landfall in FL	ENSO (ONI Index)	Location	HW Event	Remarks
1999	Harvey	Tropical Storm	Sep 19 to Sep 22	Sep 21	Strong La Niña	PMP	No	-
						FXE	No	-
						FLL	No	-
						HWO	No	-
1999	Irene	Hurricane (Cat 1)	Oct 12 to Oct 19	Oct 15	Strong La Niña	PMP	No	-
						FXE	No	-
						FLL	No	-
						HWO	No	-
2004	Ivan	Extratropical	Sept 2 to Sept 24	Sep 21	Weak El Niño	PMP	No	LT>Thresh on Sept 3, Sep 13 through Sep 16
						FXE	No	LT>Thresh on Sept 3, Sep 13 through Sep 16
						FLL	No	LT>Thresh on Sep 13 through Sep 16
						HWO	No	LT>Thresh on Sept 3, Sep 13 through Sep 16
2005	Katrina	Hurricane (Cat 1)	Aug 23 to Aug 31	Aug 25	Weak La Niña	PMP	Yes	HT and LT>Thresh on Aug 16 to Aug 21
						FXE	Yes	HT and LT>Thresh on Aug 16 to Aug 21
						FLL	Yes	HT and LT>Thresh on Aug 16 to Aug 21
						HWO	Yes	HT and LT>Thresh on Aug 16 to Aug 21
2005	Wilma	Hurricane (Cat 2)	Oct 15 to Oct 26	Oct 24	Weak La Niña	PMP	No	-
						FXE	No	-
						FLL	No	-
						HWO	No	-

Table 1. Summary of the Tropical Cyclones that made landfall or passed through Broward County, Florida within the years ofthis study. The remarks section shows annotations with the temperature behavior obtained from the initial HW analysis. LT =low temperature, HT = High Temperature, Thresh = 95th percentile for LT/HT, respectively.