Observations for Climate: The need for an ocean observing system in the Caribbean and Gulf of Mexico for improving seasonal outlook and intensity forecast of hurricanes

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Abstract

Recent studies using both observations and numerical models have shown that the Atlantic Warm Pool (AWP) - a large body of warm water comprised of the Gulf of Mexico, the Caribbean Sea, and the western tropical North Atlantic - reduces the vertical wind shear and increases the convective available potential energy over the main development region for Atlantic hurricanes, and thus facilitates the formation and development of Atlantic TCs. The AWP also plays an important role in the hurricane track. An eastward expansion of the AWP shifts the hurricane genesis location eastward, decreasing the possibility for a hurricane to make landfall. A large AWP also induces barotropic stationary wave patterns that weaken the North Atlantic subtropical high and produce the eastward steering flow anomalies along the eastern seaboard of the United States. Due to these two mechanisms, hurricanes are steered toward the northeast without making landfall in the United States (Figure 1-3).

Similarly, the Tropical Cyclone Heat Potential (TCHP) - the ocean heat content contained between the sea surface and the depth of the 26°C isotherm - has been shown to play an important role in the intensification of Atlantic TCs. In particular, the intensification (weakening) of Atlantic TCs has been linked with high (low) values of TCHP contained in warm (cold) ocean eddies (Figure 4). The AWP and TCHP are closely related and both show high spatial and temporal variability associated with oceanic mesoscale features.

However, currently, no operational ocean monitoring with *in situ* observations (Argo, drifters, XBTs) exists in the Caribbean and Gulf of Mexico, the crucial core AWP region highly linked to landfalling Atlantic hurricanes (Figure 5). Sea surface height observations derived from satellite altimetry and their statistical correlations with the vertical thermal structure of the AWP are being developed for operational hurricane forecast models to initialize the vertical thermal structure of the ocean models. The results presented here provide the rationale for implementing a sustained *in situ* ocean observing system that can monitor upper ocean thermal structure and resolve mesoscale features in the Caribbean and Gulf of Mexico, the crucial core AWP region, for improving both seasonal hurricane outlook and operational hurricane intensity forecasts.

TC genesis and AWP (1)

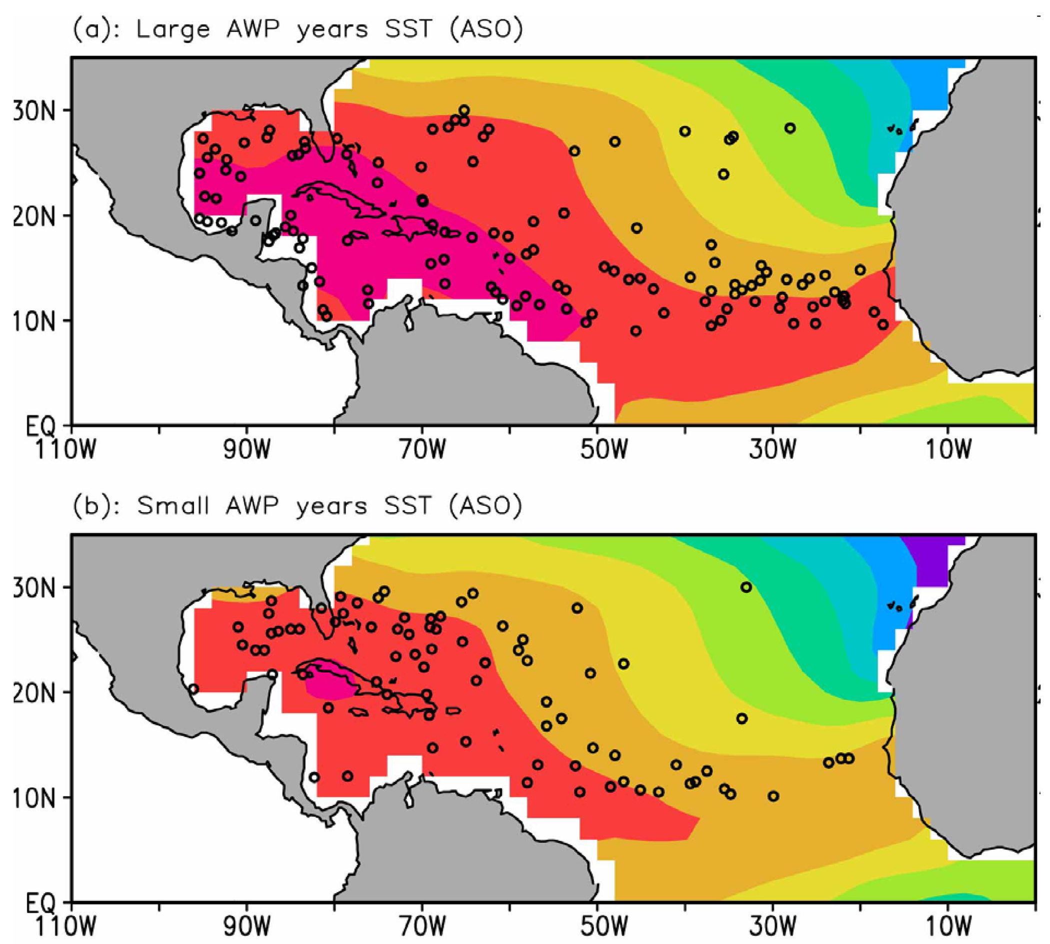

Figure 1. Shown are the TC genesis locations (dots) and SST (shading) for (a) large and (b) small AWP years. An eastward expansion of the AWP during large AWP years shifts the hurricane genesis location eastward, decreasing the possibility for a hurricane to make landfall. The composites of SST for large and small AWP years are computed by using the top and bottom quartiles of the August-October (ASO) AWP index, respectively, based on the data from 1970 to 2009. The dots represent the location of all TCs formed southward of 30°N in large (126 TCs) and small (79 TCs) AWP years.

Hurricane tracks and AWP (2)

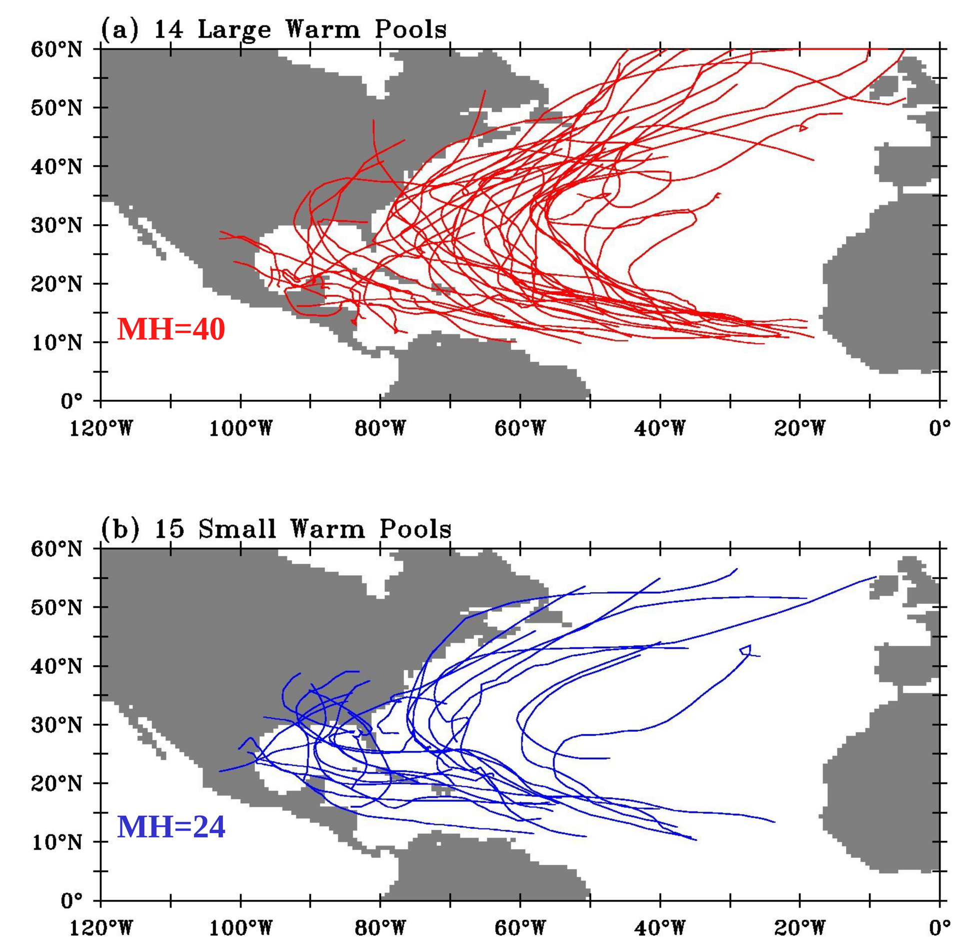

Figure 2. Atlantic major hurricane (Cat. 3 and above) tracks for (a) 14 years of large Atlantic warm pools and (b) 15 years of small Atlantic warm pools. The number of major hurricanes is almost doubled during large AWP years compared to small AWP years. However, the majority of the major hurricanes during large AWP years are steered toward the northeast without making landfall in the United States. As a result, the number of U.S. landfalling major hurricane is not increased during large AWP years compared to small AWP years.

Steering flow and wind shear (3)

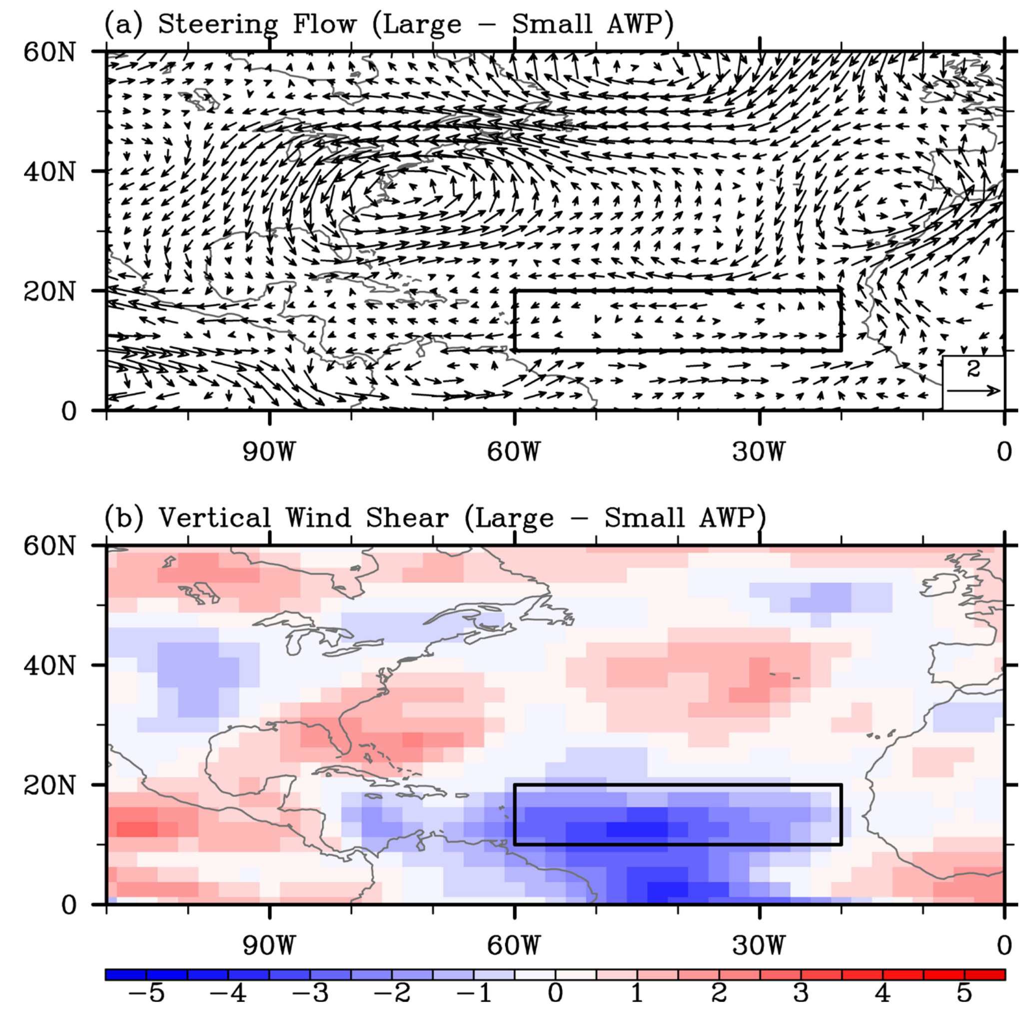

Figure 3. Shown are (a) the TC steering flow anomalies ($\times 10^3$ hPa·ms^{-1}) and (b) vertical wind shear during June–November for large minus small AWP years. A large AWP induces barotropic stationary wave patterns that weaken the North Atlantic subtropical high and produce the eastward steering flow anomalies along the eastern seaboard of the United States. A large AWP also decreases the vertical wind shear over the MDR. The steering flow anomalies are the vertically averaged wind anomalies in 850 hPa to 200 hPa. The vertical wind shear is calculated as the magnitude of the vector difference between winds at 200 hPa and 850 hPa. The box represents the MDR for Atlantic hurricanes.

Tropical Cyclone Heat Potential (TCHP) and Hurricane Intensifications (4)

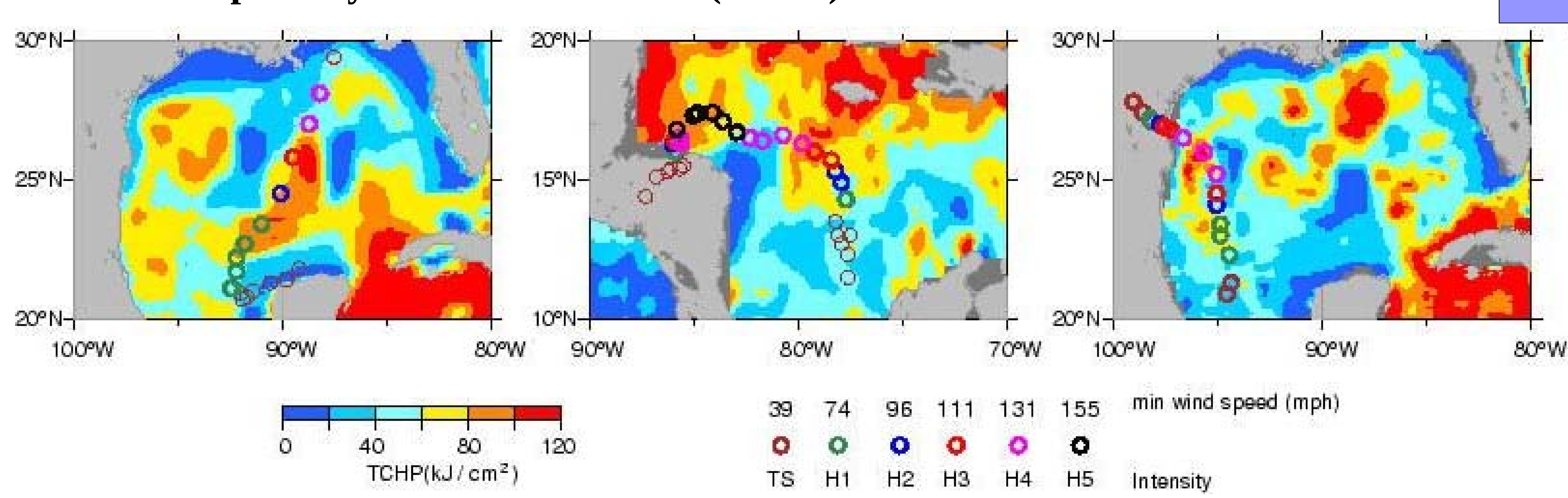

Figure 4. Three examples for the linkage of TCHP to tropical cyclone intensification

Hurricane Opal in the Gulf of Mexico, August-September 1995 (left):
This TC intensified from hurricane-1 (74-95 mph winds) to hurricane-4 (131-155 mph winds) while traveling over a number of warm features in the Gulf of Mexico. In particular, this TC suddenly intensified from hurricane-2 (96-110 mph winds) to hurricane-4 in a period of 10 hours when its track went over a very well defined ring with a mean radius of 150 km that had been shed by the Loop Current. Altimeter-derived fields indicate that the increase in TCHP associated with this warm ring was approximately 30 kJ·cm^{-2}. The most striking information of the ocean conditions during the life span of this hurricane over the Gulf of Mexico was that this warm ring was not detected using the AVHRR-derived sea surface temperature fields.

Hurricane Mitch in the Caribbean Sea, October 1998 (center):
This cyclone intensified from hurricane-2 to hurricane-5 (winds above 155 mph) when it traveled over a region of warm surface waters, experiencing an intensification from hurricane 3 (111-130 mph winds) to 5 with an increase in values of TCHP approximately 80 kJ·cm^{-2} under the track of the TC in 22 hours.

Hurricane Bret in the Gulf of Mexico, August 1999 (right):
This hurricane intensified several times in the SW Gulf of Mexico in a period of approximately 36 hours while traveling over two warm features remnants of one warm ring that had been shed by the Loop Current several months earlier. The increase in TCHP under the track of the TC during this period was approximately 80 kJ·cm^{-2}.

In these cases an association was observed between the increase in TC intensity and a positive anomaly in the value of TCHP under the track of each of the TCs. Preliminary evaluation of the upper ocean thermal conditions during the intensification of 32 of the 36 strongest TCs in the tropical Atlantic from 1993 to 2000 indicates that their intensification can be associated with the passage of their tracks over regions with elevated TCHP of at least 20 kJ·cm^{-2}.

Number of ocean observations (5)

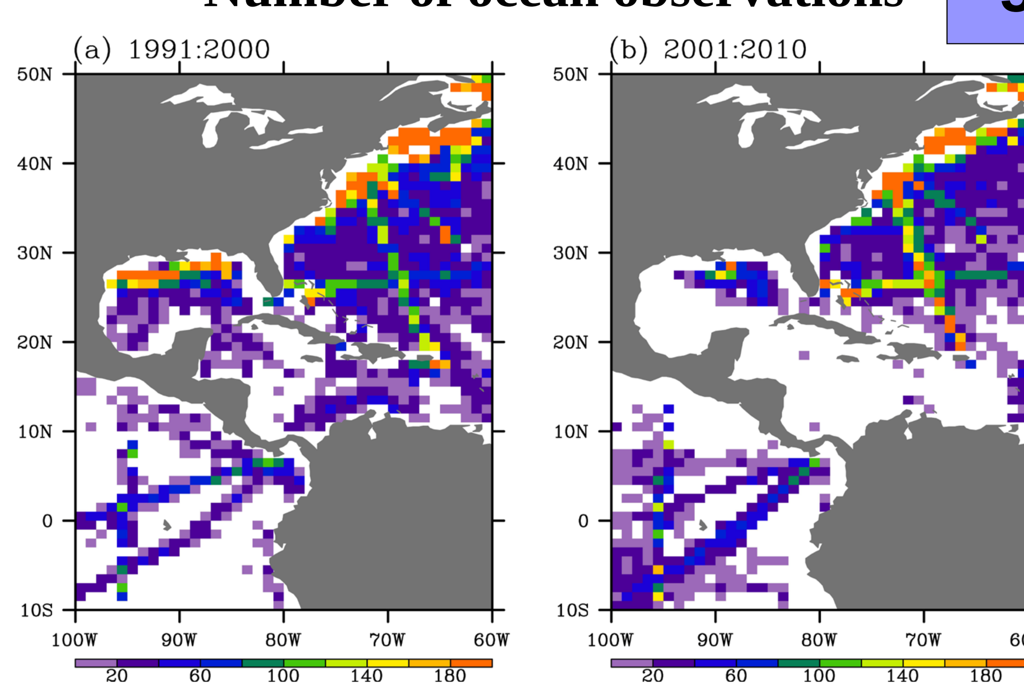

Figure 5. Number of total observations at 100m during (a) 1991-2000 and (b) 2001-2010 for each 1° × 1° grid box obtained from World Ocean Database at NODC. The regions with less than ten observations for the given 10-year periods are white.

Operational hurricane forecast model:
An operational hurricane forecast product of NOAA shows that the 5-day forecast error of SST can be as large as 2°C in the AWP region if the vertical thermal structure of the AWP is not properly initialized with *in situ* observations. However, no operational ocean monitoring with *in situ* observations (Argo, drifters, XBTs) exists in the Caribbean and Gulf of Mexico.

NOAA seasonal hurricane outlook:
The NOAA seasonal outlook for Atlantic basin hurricane activity is set up to forecast a range of expected *number* of tropical storms, hurricanes and major hurricanes. In order to minimize the vulnerability of the society from anomalous weather extremes and to adequately organize the social resources for hurricane preparedness, a much more detailed seasonal outlook of Atlantic hurricane activity, such as storm track, storm formation region, and regional landfalling probability, is required.

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