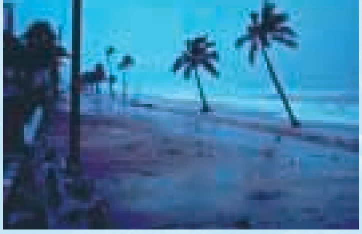

Using satellite altimetry

to identify regions of hurricane intensification

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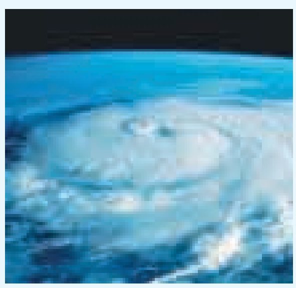
The role of the ocean in hurricane formation is largely recognized and accepted. The formation of hurricanes has been linked to the sea surface temperature and values of this parameter higher than 26°C or so have been shown to be a necessary but insufficient condition for hurricane cyclogenesis. Additionally, the intensification of hurricanes involves a combination of favorable atmospheric conditions such as trough interactions and vertical shear. In this scenario, the upper ocean thermal structure was thought to play only a marginal role in hurricane intensification. However, after a series of events where the sudden intensification of hurricanes occurred when their path passed over oceanic warm features, it is now being hypothesized that the upper ocean plays an important role in this process.

A warm ring has been linked to the intensification of hurricane Opal in the Gulf of Mexico during October 1995 [Shay et al., 2000]. During this month, the sea surface temperature was homogeneous throughout the region, as revealed by AVHRR imagery (not shown here). On the other hand, the sea height field derived from satellite altimetry revealed that the Loop Current and a warm ring were located right under the track of this storm when it suddenly intensified. A detailed study of the oceanic and atmospheric conditions revealed that the integrated vertical temperature area under the track of this hurricane was at least partially responsible for its rapid intensification. Model studies [Hong et al., 2000] also showed that there could have been a possible link between the intensification of this storm and the same warm features.

Although sea surface temperature provides a measure of the surface ocean conditions, it tells us nothing about the subsurface ocean thermal structure in the first tens of meters. It is known that the oceanic skin temperature drops when the sea surface is affected by strong winds, creating a well-mixed layer to depths of several tens of meters. At the end, the tropical storm will be traveling above the water, with a mixed layer temperature similar to the skin sea surface temperature. Quantifying these effects on the intensification of hurricanes is important for advance warning in coastal communities. The above studies and hypothesis provide the basis and motivation to investigate and monitor the upper ocean thermal structure, which has become a key element in the study of hurricane-ocean interaction with a view to predicting sudden hurricane intensification. These

Altimeter data are used here to investigate the relationship between hurricane intensification and upper ocean thermal structure under the storm track. Preliminary results show that the intensification of most hurricanes in the tropical Atlantic and Gulf of Mexico during the period 1993-2000 are linked to the variability of the integrated vertical temperature under the storm track.



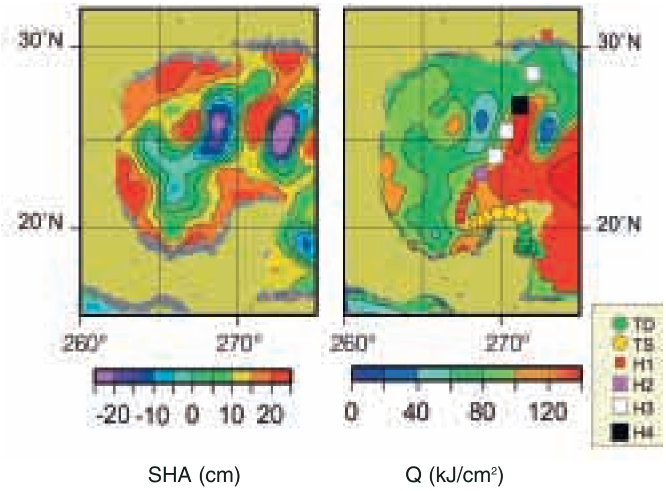


Figure 1. Altimeter-derived sea height anomaly (SHA) and hurricane heat potential (Q) during October 1995. The track of hurricane Opal is superimposed, indicating its evolving intensity from tropical depression (TD) to tropical storm (TS) and hurricane 1 through 4 (H1-H4)

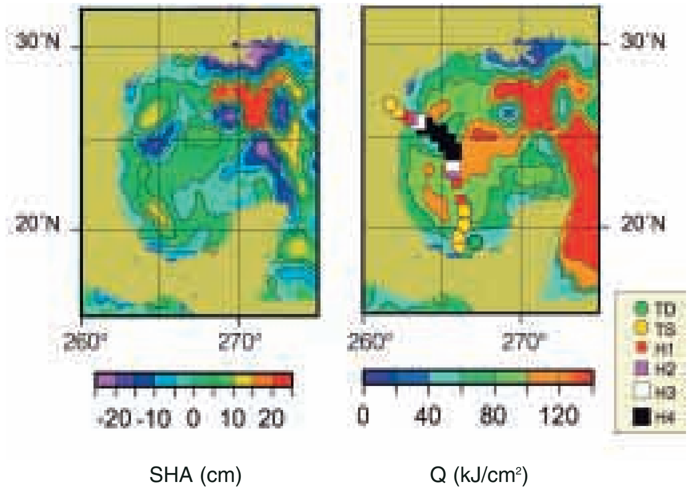


Figure 2. Altimeter-derived sea height anomaly (SHA) and hurricane heat potential (Q) during August 1999. The track of hurricane Bret is superimposed, indicating its evolving intensity from tropical depression (TD) to tropical storm (TS) and hurricane 1 through 4 (H1-H4)

warm features, mainly anticyclonic rings and eddies, are characterized by a deepening of the isotherms towards their centers with a markedly different temperature and salinity structure than the surrounding water mass. The objective of this effort is to apply a methodology that uses climatological and satellite altimetry data to a) monitor the hurricane heat potential field, and b) investigate any possible link between this parameter and the intensification of hurricanes during the period 1993-2000.

Hurricane heat potential

Merged data from three altimeters (Topex/Poseidon since 1993, ERS-2 since 1995 and GFO since 1998) are used to generate sea height anomaly (SHA) fields. The depth of the 26°C isotherm is estimated using a two-layer model reduced-gravity approximation [Goni et al, 1996]. This value, together with the sea surface temperature and the climatological values of the mixed layer depth, is also used to construct synthetic vertical temperature profiles. The hurricane heat potential, a parameter introduced by Leipper and Volgenau [1972], is proportional to the integrated vertical temperature from the sea surface to the depth of the 26°C isotherm. Consequently, regions of higher sea surface temperature and the 26°C isotherm have higher hurricane heat potential than their surrounding waters. The tropical North Atlantic Ocean, the Caribbean Sea and the Gulf of Mexico are regions where hurricanes build and intensify. Here, the ocean dynamics are highly variable in space and time and characterized by the presence of warm currents, meanders and eddy formation, often with very high hurricane heat potential values during the summer months. This study links the intensification of several major hurricanes in the tropical Atlantic, Caribbean Sea and Gulf of Mexico to regions with high hurricane heat potential. Data from hurricanes with strength 2 or more in the tropical North Atlantic, Caribbean Sea and Gulf of Mexico between 1993 and 2000 were analyzed. Results indicate that in 31 out of 36 cases hurricane intensification can be linked to an increase in the values of hurricane heat potential of approximately 30 kJ/cm^2 under the storm track. Two typical examples were hurricanes Opal and Bret in the Gulf of Mexico, where storms suddenly intensified when traveling into areas of higher hurricane heat potential (see Figures 1 and 2).

This work emphasizes the investigation of the upper ocean thermal structure using satellite altimetry. However, a thorough investigation is still needed, using in-situ data and theoretical models, to better evaluate the relative importance of the ocean in the hurricane intensification process. Hurricane heat potential is estimated in near-real time during each hurricane season and posted on the NOAA/AOML website at:

http://www.aoml.noaa.gov/phod/cyclone/data/

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