14D.3 HURRICANE HEAT POTENTIAL VARIABILITY FROM IN SITU AND RADAR ALTIMETRY MEASUREMENTS

Lynn K. Shay*, S. Daniel Jacob[1], Thomas M. Cook[1], Michelle M. Mainelli[2], Sean R. White[3], Peter G. Black[3], Gustavo J. Goni [4], Robert E. Cheney [5]
[1] RSMAS/MPO, University of Miami, Miami, FL
[2] NOAA/NWS, Tropical Prediction Center, Miami, FL
[3] NOAA/AOML, Hurricane Research Division, Miami, FL
[4] NOAA/AOML, Physical Oceanography Division, Miami, FL
[5] NOAA/NESDIS, Laboratory for Satellite Altimetry, Silver Spring, MD

1. BACKGROUND

Research flights over the Loop Current in the eastern Gulf of Mexico have been conducted on the NOAA WP-3D aircraft over the past few seasons. Grids of Airborne eXpendable Current Profilers (AXCPs), Airborne eXpendable Conductivity Temperature and Depth (AXCTDs) profilers and Airborne eXpendable Bathythermographs (AXBTs) were deployed during both quiescent atmospheric conditions as well as during the passage of storms. Success rates exceeded 80%, including the deployment of the new AXCTDs, which provide conductivity (salinity) and temperature profiles to 1000 m with accuracies of about 0.05 ppt and resolution of ±0.03 ppt over 1 m vertical scales.

The objective of this brief note is to use these profiler measurements to estimate upper ocean heat potential and compare them to those determined from satellite altimetry. Leipper and Volgenau (1972) suggested that the integrated thermal structure to the depth of the 26°C isotherm represents a source of heat for hurricanes. Shay *et al.* (2000) documented the amount of heat loss using pre and post heat potential estimates based on radar altimetry estimates from the NASA TOPEX mission (Cheney *et al.*, 1994). In this study, this satellite approach uses fields from TOPEX and ERS-2 and a gradient method between the surface and the depth of 26°C isotherm to estimate heat potential within the context of a two-layer model (Goni *et al.*, 1997). Measurements in the Gulf of Mexico's Loop Current represents a good test case given large heat potential gradients on the periphery of this deep oceanic heat reservior.

2. IN SITU MEASUREMENTS

As shown in Fig. 1, integrated oceanic heat potential were analyzed using temporal and spatial scales derived form the hurricane Gilbert (1988) data set. As the depth of the 26°C isotherm depicts the top of the cooler thermocline water, subtropical water is distributed over deep layers (≈ 130 m deep) compared to 35 to 40 m in the Gulf Common water. Given these differing depths, observed heat potential estimates of 130 KJ cm^{-2} in the Loop Current and warm core ring (WCR) were well above those values in the Gulf Common water. Notice that the integrated heat potential estimates suggest a value of 1 KJ cm^{-2} m^{-1} in the Loop Current.

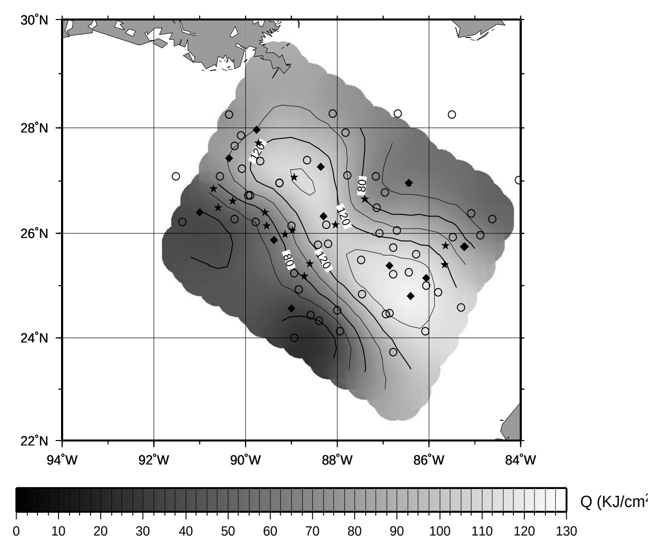

Figure 1: Ocean heat potential (gray) and isotherm depth of the 26°C water (contour: m) based on AXCPs (star), AXCTDs (diamond), and AXBTs (circle) deployed in the eastern Gulf of Mexico in Aug 99 from a NOAA WP-3D flight.

3. RADAR ALTIMETRIC ESTIMATES OF HEAT POTENTIAL

The TOPEX radar altimeter measures the sea level

* *Corresponding Author Address: Lynn K. Shay, MPO, RSMAS, 4600 Rickenbacker Causeway, Miami, FL 33149. email: nick@erg.rsmas.miami.edu.*

beneath its groundtrack at 7 km intervals every 9.9 days where adjacent tracks are separated by about 3° (300 km) in longitude. By contrast, the repeat cycle for ERS-2 is 35 days, but with a horizontal resolution of less than 100 km. These data are corrected for solid and ocean tides, wet and dry tropospheric effects, ionospheric processes, electro-magnetic bias and inverse barometric corrections (Cheney *et al.*, 1994). Using the parameter matrix scheme of Mariano and Brown (1992), and parameters from the hurricane Gilbert, the surface height anomaly (SHA) fields from TOPEX and ERS-2 data set were objectively analyzed. These analyzed altimeter-derived SHA data calibrated by hydrographic data (i.e. temperature and salinity climatology) are a proxy to monitor the upper layer thickness based on a two-layer model approximation where the 20°C isotherm separates the lower and upper layers. The choice of the 20°C isotherm depth is appropriate for the two-layer ocean in that it separates two layers of differing densities as previously observed. Thus, the depth of the 20 and 26°C isotherms may be monitored from the altimeter-derived SHA field.

The depth to which the temperature exceeds 26°C is the *hurricane heat potential* (Leipper and Volgenau 1972). Given vertical structure measurements, the heat potential is

$$Q = \rho_1 c_p \int_{d_{26^\circ C}}^{\eta} \Delta T dz, \qquad (1)$$

where η is the sea surface and $d_{26^\circ C}$ is the depth of the 26°C isotherm, c_p is specific heat at constant pressure and ρ_1 is the density of the upper ocean layer. In warm baroclinic structures, $d_{26^\circ C}$ is distributed over deep layers ranging from 100 to 140 m deep. If vertical structure measurements are available, equation (1) is solved by vertical integration. However, *in situ* data are not always available in storms, and in the summer months the spatially uniform SSTs are above 29°C with little thermal contrast in the Gulf of Mexico. Thus, the heat potential derived from radar altimeters represents an opportunity to know the positions of these heat sources relative to the storm track. If Δz is taken as $d_{26^\circ C}$ isotherm, the gradient method is:

$$Q = 0.5 \rho_1 c_p \Delta T (\eta + d_{26^\circ C}) \qquad (2)$$

where ΔT is the temperature difference between the SST obtained from Reynolds SST analysis and 26°C. The gradient (2) and integral (1) methods are used to estimate heat potential from radar altimeter and *in situ* data. Essentially, the approach is area underneath the curve. Based on regression analyses, the slope was 0.95 between the satellite derived gradient method and the integrated thermal structure. The bias from the fit is -12 KJ cm^{-2}. Thus, by multipling the altimeter data (0.95) and subtracting 12 KJ cm^{-2}, satellite-inferred values converge towards observed heat potential. As more data becomes available from aircraft, autonomous profiling floats, etc., the heat potential and depth of the $26°C$ isotherm inferred from satellite measurements will be improved.

4. SUMMARY

Implicit in the refinement of satellite algorithms is the acquisition of high-quality ocean structure measurements before, during and after hurricane passage using aircraft expendables and autonomous profiling floats. Not only are *in situ* data important in refining the satellite-based heat potential estimates for guidance in intensity predictions (see Mainelli *et al.* this issue) but they are needed to resolve the horizontal gradients where intensification seems most likely to occur in hurricanes (Shay *et al.* 2000; Mainelli-Huber 2000).

Acknowledgments: Research effort has been supported by the National Science Foundation through grant ATM-01-08218 to the Division of Meteorology and Physical Oceanography at the Univerisity of Miami's Rosenstiel School of Marine and Atmospheric Science. We are grateful for the efforts of the pilots, technicians, engineers and scientists at NOAA's Aircraft Operations Center (AOC) and Hurricane Research Division (HRD).

5. REFERENCES

Cheney, R., L. Miller, R. Agreen, N. Doyle, and J. Lillibridge, 1994: TOPEX/POSEIDON: The 2-cm solution. *J. Geophys. Res.*, **99**, 24555-24563.

Goni, G. J., S. L. Garzoli, A. Roubicek, D. B. Olson, and O. B. Brown, 1997: Agulhas ring dynamics from TOPEX/Poseidon satellite altimeter data. *J. Mar. Res.*, **55**, 861-883.

Leipper, D., and D. Volgenau, 1972: Hurricane heat potential of the Gulf of Mexico. *J. Phys. Oceanogr.*, **2**, 218-224.

Mainelli-Huber, M., 2000: The upper ocean's role on tropical cyclone intensity. **MS Thesis**, Rosenstiel School of Marine and Atmospheric Science, University of Miami, Miami, FL 33149, 89pp.

Mariano, A. J., and O. B. Brown, 1992: Efficient objective analysis of heterogeneous and nonstationary fields via parameter matrix. *Deep Sea Res.*, **39A**, 1255-1271.

Shay, L. K., G. J. Goni, and P. G. Black, 2000: Effects of a warm oceanic feature on hurricane Opal. *Mon. Wea. Rev.*, **128**, 1366-1383.