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14. ABSTRACT

The objective of this program is to analyze data from the deployment of a class of low-cost instruments that were deployed into hurricanes during the Coupled Boundary Layer Air Sea Transfer (CBLAST) initiative. Measurements of the air-sea interface in very high sea states present a difficult challenge for both remote sensing techniques and in-situ moored or shipboard instrumentation. With significant effort and cost, moorings and surface buoys can be designed to withstand the rigors of the sea-surface during these conditions. However, the statistical nature of very high wind events such as hurricanes, typhoons, and large winter storms requires that moorings be deployed over long periods of time in order to raise the probability of the instrumentation being in the right place and at the right time. The recent improvement of synoptic, predictive models of storm events now presents the opportunity for adaptively sampling the upper ocean during storms through strategic placement of light-weight, low-cost instrumentation in the path of incoming storm events.

15. SUBJECT TERMS

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CBLAST data analysis: Air-sea interaction floats

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LONG-TERM GOALS

Our goal is to better understand air-sea fluxes and oceanic response during extreme wind events using in-situ measurements.

OBJECTIVES

The objective of this program is to analyze data from the deployment of a class of low-cost instruments that were deployed into hurricanes during the Coupled Boundary Layer Air Sea Transfer (CBLAST) initiative. Measurements of the air-sea interface in very high sea states present a difficult challenge for both remote sensing techniques and *in-situ* moored or shipboard instrumentation. While the satellite-based remote-sensing techniques generally lose accuracy in high sea-states due to a lack of understanding of the physics of the parameter that is measured and inverted (ie. microwave scattering, EM bias, passive microwave), *in-situ* measurements are difficult due to the environmental loading placed on the instrumentation and survivability of moorings. Shipboard instrumentation in high sea-states is either too costly for long-term measurements or presents a danger to the personnel onboard the vessel. With significant effort and cost, moorings and surface buoys can be designed to withstand the rigors of the sea-surface during these conditions. However, the statistical nature of very high wind events such as hurricanes, typhoons, and large winter storms requires that moorings be deployed over long periods of time in order to raise the probability of the instrumentation being in the right place and at the right time. The recent improvement of synoptic, predictive models of storm events now presents the opportunity for adaptively sampling the upper ocean during storms through strategic placement of light-weight, low-cost instrumentation in the path of incoming storm events.

APPROACH

Our approach to developing an instrument capable of air-sea interaction measurements in extreme environmental conditions is based on the addition of a few, low-cost instruments integrated into profiling SOLO floats that are modified for missions restricted to the upper ocean. The SOLO, a predecessor to the ALACE type float, is now a mature technology (Davis et al, 1991) which has been produced in very large numbers as part of the WOCE program. The profiling ability of the float is accomplished by changing the float’s volume and buoyancy through the pumping of hydraulic fluid from an internal reservoir to an external bladder. Historically, the floats have been able to sample profiles of temperature and measure sub-surface currents by remaining at a pre-programmed depth where the float is neutrally buoyant.

Under this project, we developed additional capabilities for the standard SOLO profiler for it to undertake missions specific to studying the air-sea boundary during the hurricane high wind/wave conditions. Modifications to the float included

a) The use of a new gear motor to allow efficient pump operations in the intended depth range of 0-200m as opposed to the normal ARGO 2000m depth cability
b) Orbcomm data telemetry system
c) Design of a new top cap which housed an onboard acoustic altimeter for measuring waves and bubble cloud depths, a passive hydrophone recording system for measuring the ambient noise field, and a CTD.
d) A robust air-deployment system certified for C130J aircraft.

The mission designed for the CBLAST hurricane float is shown in figure 1 and includes the following:

- Profile temperature and salinity to 200m which we anticipate is below the mixed layer
- Rise to a neutrally buoyant depth of O(30-50)m and park enter a 'hovering' routine. While at this depth, the acoustic ambient noise field and surface wave field is sampled using the sonar altimeter, pressure sensors, and accelerometers.
- Profile to surface to obtain GPS position and transmit data to satellites. Simultaneously burst sample the conductivity and temperature probes at the surface to measure entrained air and temperature fluctuations.
- Repeat cycle every 4 hours for 200 dives.

Nine floats were deployed into the path of Hurricane Frances in 2004 with a cross track spacing of 35km and an along track spacing of 50km. All floats survived their deployment, and were recovered by ship approximately 30 days later. Figure 2 shows the initial float locations, their trajectories, and the paths of Hurricanes Frances and Jeanne.

WORK COMPLETED & PRELIMINARY RESULTS

Our initial focus with the data sets have been to evaluate the quality of the data from the CTD, the sonar altimeter, and the passive acoustic measurements. Our findings are that generally all the data are useful with the caveat that some variables sampled will need careful interpretation. In particular, we have found that digital noise contaminated portions of the ambient sound recordings, which will require conditional averaging of the uncontaminated records of the computed noise spectrum. These findings have resulted in significant changes to the hardware of the ambient sound processor boards for future deployments. In addition, some drift was found in the pre/post calibrations of the conductivity sensor which will need to be accommodated for in subsequent processing.

Analysis work that has been completed includes:

- HWINDS reanalysis data has been obtained and gridded to each float location. HWINDS provides a consistent method to retrieve wind speed estimates as a function of time and space and the arbitrary float locations.
- Waves processing. Time series of the surface waves have been computed from the sonar data at each float location during Hurricane Frances. Surface waves are sampled at 2Hz for twenty

minutes every 4 hours. Bulk surface wave statistics (significant wave height, 1-D wave spectrum, peak period, and similar) have been computed for each float record. The nine float array allows us to examine spatial gradients of the surface waves as the storm propagates through the sampling region. Figure 3 shows an example surface wave time series during 25m/s winds. Present work is focused on a statistic analysis of the measured surface waves (eg – direct computation of surface waves through zero-crossing analysis) to examine the distribution of rogue waves and their relation to the forcing and quadrants of the storm. Initial findings indicate several instances of individual waves exceeding the commonly accepted rogue wave definition of two times the significant wave height.

- Bubble layer depth. During periods of high seastate, significant concentrations of bubbles are injected into the upper layer of the ocean. Due to the acoustic impedance differences between air and water, bubbles are very efficient scatterers of sound and provide a target for the upward looking sonar. Our analysis of the sonar data shows that at the highest seastates, the sonar reflects from the base of a bubble layer that is 1-10m in depth and that oscillates with the orbital velocity of the surface waves. Understanding the depth of this layer has important implications due to the dynamic impacts to the upper ocean (eg – a void fraction of 10^{-4} has similar impacts to the density as a 1 degree C change in temperature) and to the fluxes of gases across the air-sea interface. We have analyzed all the sonar data from the float array, and have found that the bubble layer depth scales with U^3, implying a scaling relationship between the flux of energy and the potential energy of the entrained air. Figure 4 shows all data measured during Fabian and the U^3 relationship using HWINDS wind estimates.
- Heat Content, heat fluxes, and mixing. The CTD data obtained from the storm have been analyzed to examine the changes in the hurricane heat potential and the spatial gradients of this parameter. We find that the heat content has short decorrelation scales over the spatial size of the array deployed, with significant changes in heat content in the regions exposed to the eyewall as opposed to those to the right of the storm. For examples, a float 100km to the right of the eyewall (max winds of 35 m/s) floats experienced very little heat loss, while floats that penetrated the eyewall (winds in excess of 50 m/s) observed heat losses of 60-70 $kJcm^{-2}$. We also find that the bulk of these heat losses are after the passage of the storm which is consistent with the previous findings of D'Asaro which illustrates the importance of storm induced shear motions in mixing deeper/cooler water towards the surface. Figures 5 and 6 illustrate the conditions measured at a float which remained operational while the eye of Frances passed overhead. The results of this effort resulted in a joint publication with other CBLAST PIs D'Asaro, Sanford, and Niiler.
- Scripps graduate student Sarah Zedler successfully defended her Ph.D. thesis in 2008, with the resultant publication "The ocean's response to Hurricane Frances and its implications for drag coefficient parameterization at high wind speed" being accepted for publication in the Journal of Geophysical Research.

IMPACT/APPLICATIONS

The demonstration of our ability to air-deploy an autonomous platform using military aircraft should provide a number of additional of scientific and applied applications that are of DOD interest. The ability to receive time series of in-situ measurements of oceanic conditions during storm events should also be of interest to operational weather models that the assimilation of oceanic data. Our analysis of the surface conditions measured during the storms should provide useful data sets that can be used in activities to define the operational envelopes of surface ships that might be exposed to tropical storms.

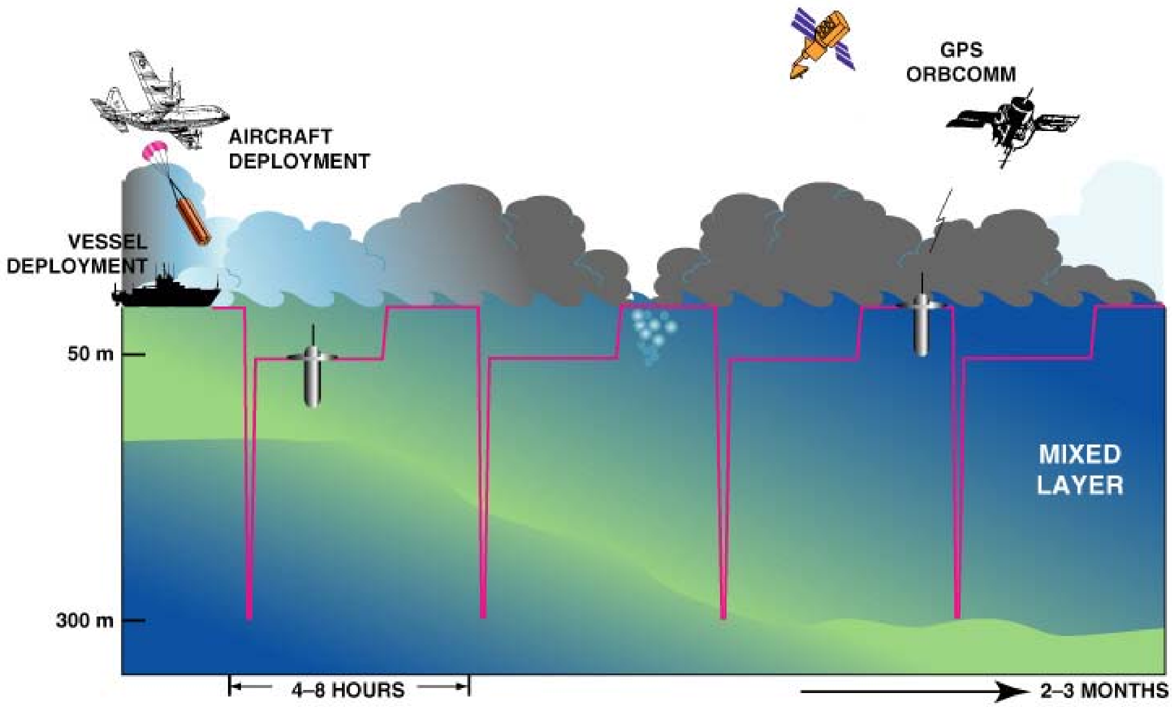
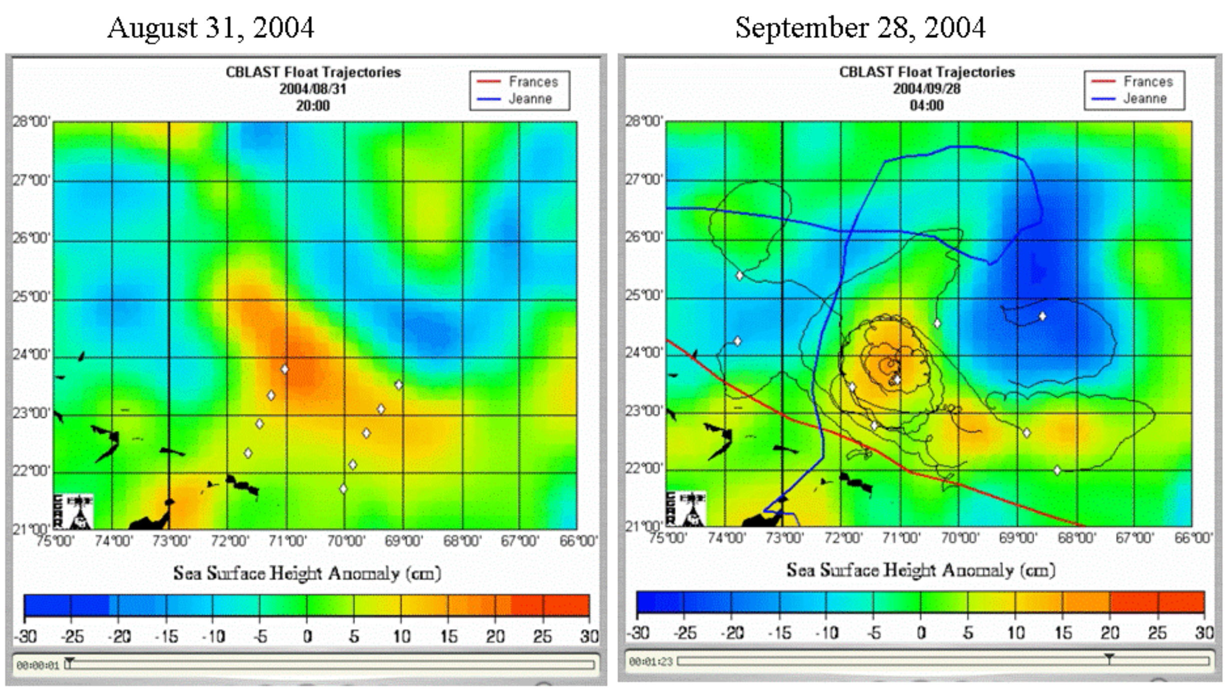


Figure 1. A schematic of the mission schedule for the CBLAST HURRICANE SOLO FLOAT. While at hover depth, the system measures surface waves and the ambient noise field. Conductivity, temperature and depth is measured during the decent portion of the cycle.



Blended altimetry from Colorado Center for Astrodynamics Research, Univ. Colorado, Boulder
http://e450.colorado.edu/realtime/gsfc_global-real-time_ssh/

Figure 2. Left. The initial float deployment locations overlaid onto maps of a sea hurface height anomaly map created through blended altimetry. Right. The trajectories of the floats over the 29 day deployment and tracks of hurricanes Frances and Jeanne. The array was designed to measure oceanic response during Frances (red line), with two of the floats passing through the eyewall.

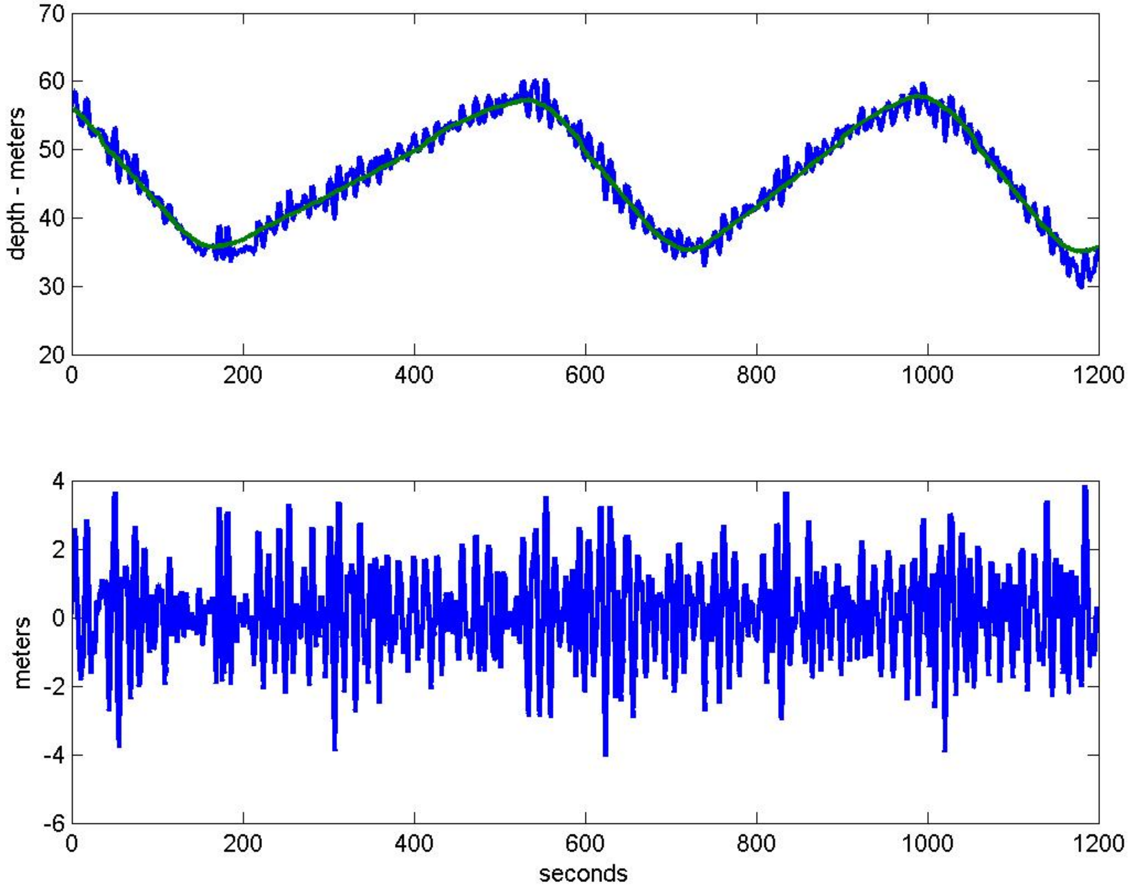


Figure 3. Top. A twenty minute time series of vehicle depth while the vehicle in is hover mode. The sawtooth shape are from active buoyancy corrections the vehicle makes to stay within a pre-determined hover range programmed into the vehicle. The green line is the pressure derived distance to the free surface and blue line is the range measured with the upward looking sonar. While the pressure signal of the surface waves is small since they attenuate with depth, the time series illustrates the sonars ability to remotely measure the surface waves. Bottom. Time series of the free surface computed using simple filtering techniques applied to the pressure and sonar signals. Wind speed estimates using HWINDS reanalysis at the time of these measurements is 25 m/s. The significant wave height and peak period measured by the float at this time is 5.1m and 12.8 seconds respectively.

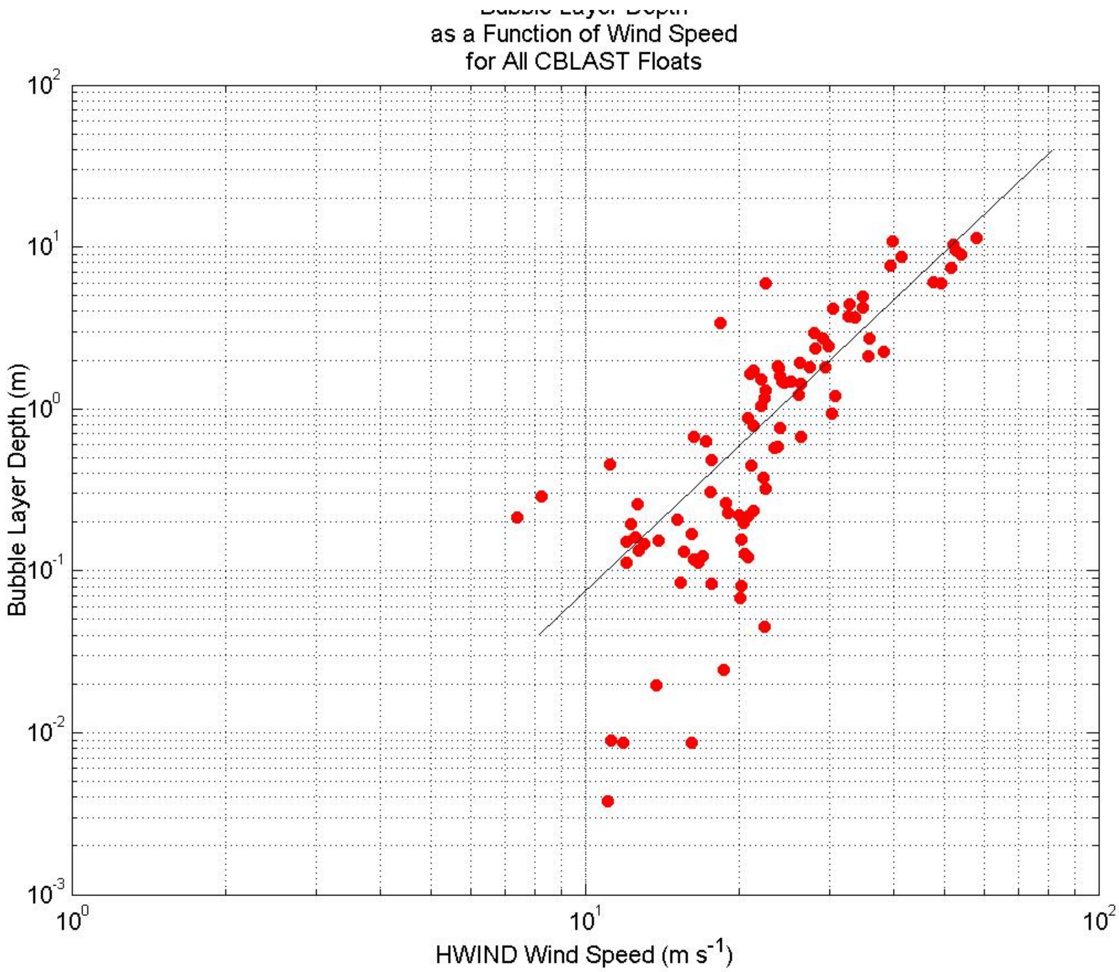


Figure 4. Bubble layer depth measured by the CBLAST float sonar versus surface wind speed estimates from the HWIND reanalysis. The bubble layer depth is a twenty minute average of the difference in free surface derived from the vehicle's pressure sensor and upward looking sonar. At high seas states, the sonar reflects off the base of the bubble cloud, providing a means for estimating the depth of this layer. The reference line illustrates that the depth of this layer scales with the cube of the wind speed.

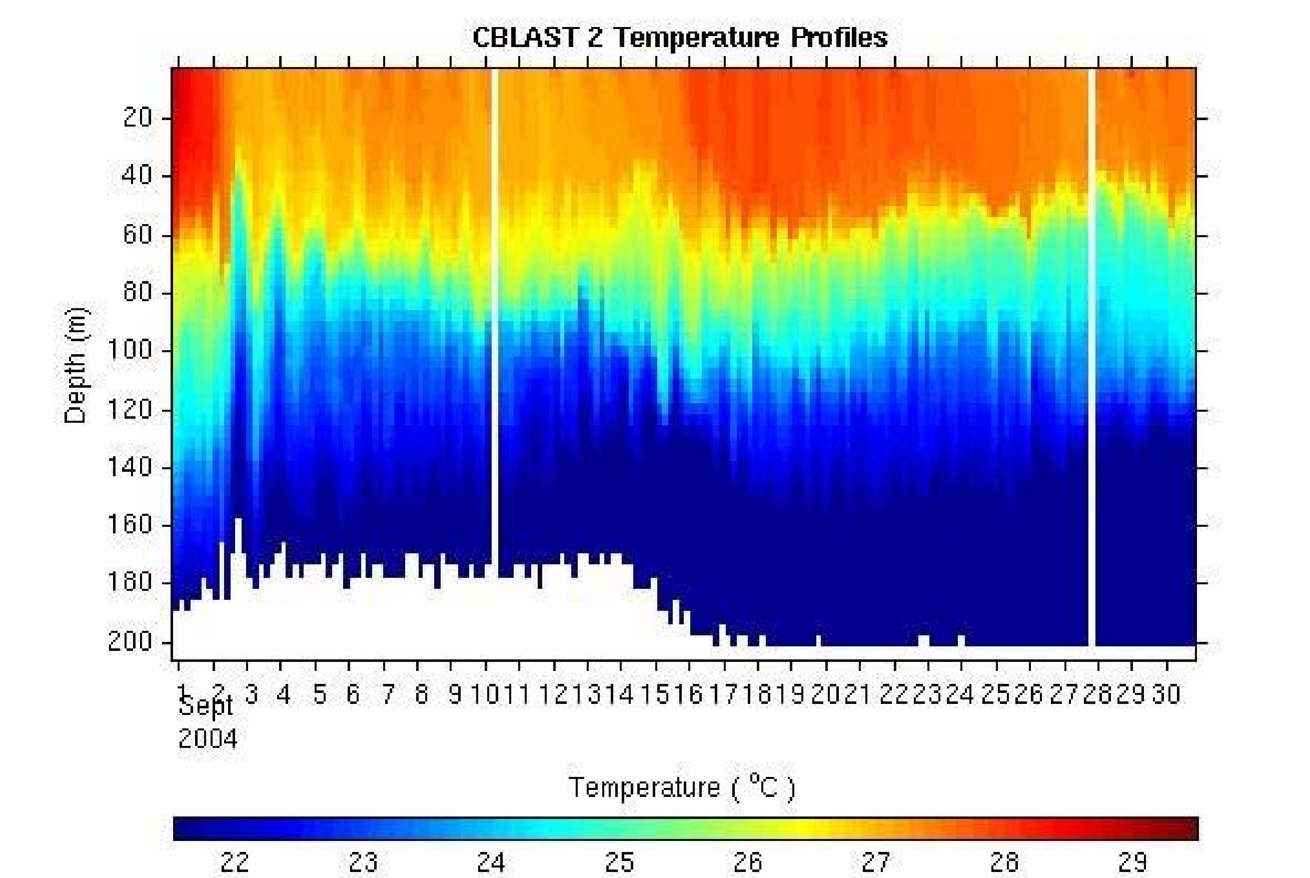


Figure 5. Time series of upper ocean temperatures profiled by CBLAST profiling float #2 during Hurricane Frances. This float was deployed in a location that passed through the eyewall of this strong storm. Apparent in the figure is the rapid uplift of the isotherms during the passage of the eye of the storm and the subsequent inertial motions of the mixed layer depth. The two floats which passed through the eye experience very similar responses, while floats that did not pass through the eye had a reduced oceanic response.

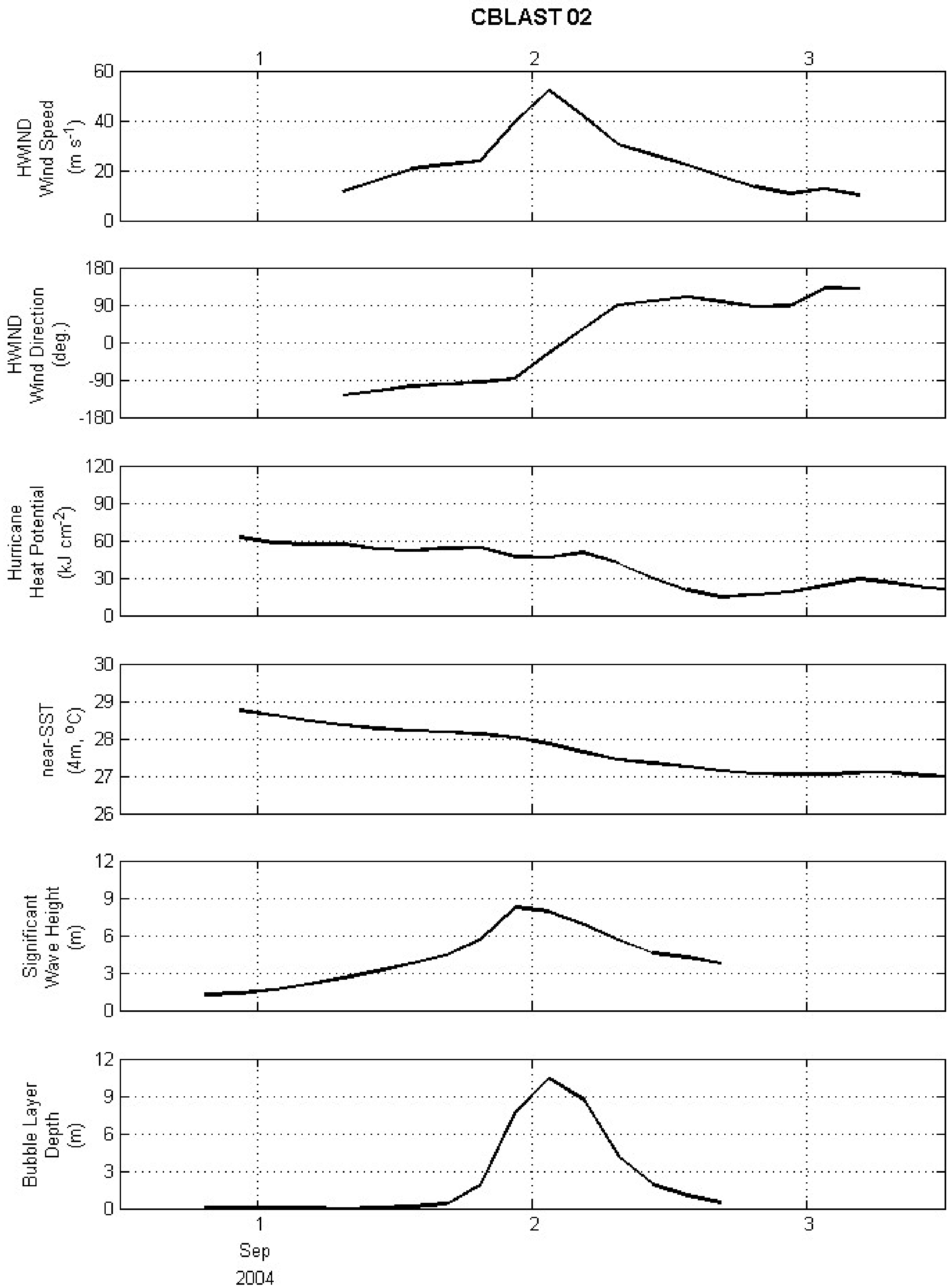


Figure 6. A summary time series of the conditions measured by CBLAST float #2 (see Figure 5). The top two plots are the HWINDS wind speed and direction for reference. The time series illustrate how the majority of the cooling takes place after the storm leaves the region. Also of note is how the significant wave height peaks before the storm while the depth of the bubble layer has zero phase lag with the maximum winds.