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# Year 1 Report: Eastern Pacific Ocean Heat Content Estimates For SHIPS Forecasts

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**Introduction:** Over the past ten months of the grant, the effort has focused on processing data and synthesizing data sets discussed in Section I of the grant and building a realistic climatology. The approach includes satellite data, XBT data (including moored data in the EPAC such as TAO arrays), and exploring climatologies such as the US Navy's Generalized Digital Environmental Model (GDEM) in building a suitable hurricane season climatology for EPAC.

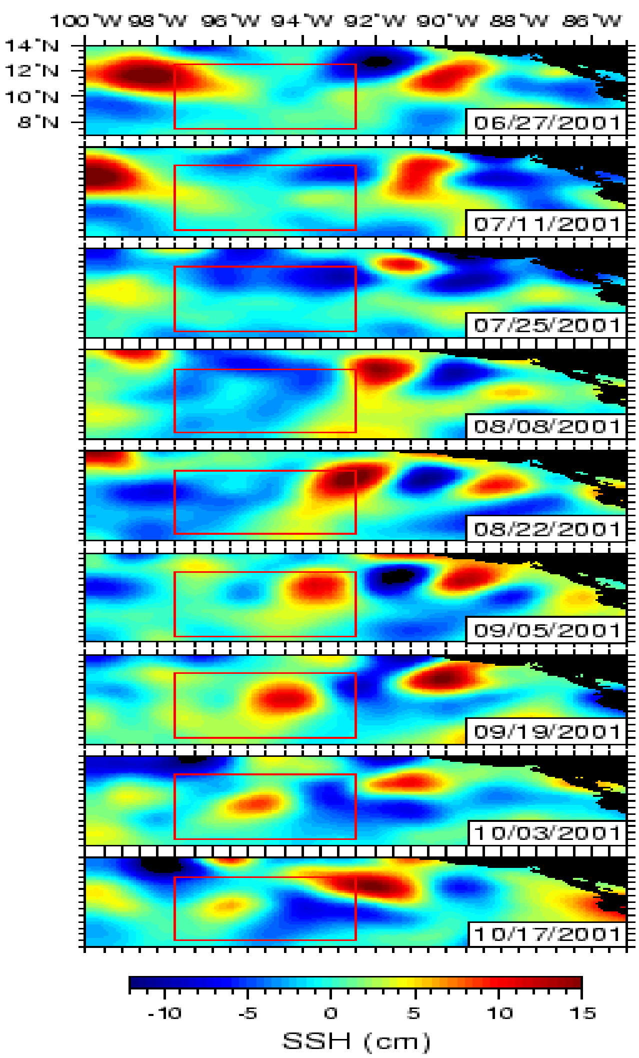


Fig 1: SSH field (cm) in the EPAC relative to the EPIC domain in summer 2001.

**1. Altimetry:** TOPEX/ Poseidon (T/P) and Jason-1 altimeter measures the sea level every 9.9 days along repeat ground-track spaced 3° longitudinally at the Equator. ERS-2 mission and Geosat Follow-On-Missions (GFO) have repeat tracks of 35 and 17 days, respectively. The availability of a merged SSH data is shown in Figure 1 for a merged product (http://www.jason.oceanobs.com/html/donees/produits/satellites_{uk}.html) for an altimetry product available 1992-2005 from AVISO. Weekly SSHs track eddies from Aug through Oct 2001 using the product during the EPIC field program (Fig 1). By the time the eddy reaches the center of the EPIC domain, it starts to spin down in strength. The ring pathway, tracked over a three-month period based successive images, suggests that the warm features move at 13 to 15 $cm\ s^{-1}$ towards the west southwest and have OHC heat content values of more than 50 $kJ\ cm^{-2}$ (Fig.2).

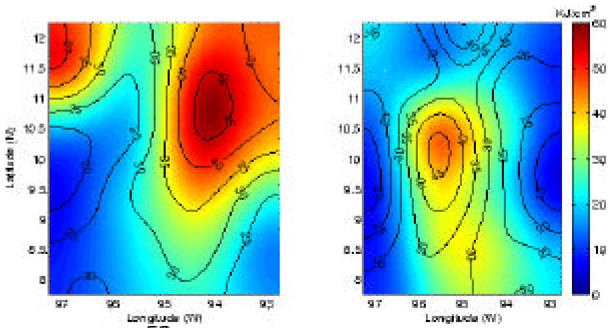

Fig 2: OHC (kJ $cm^{-2}$) from *in situ* profiles during EPIC in Sept (left) and Oct (right**).**

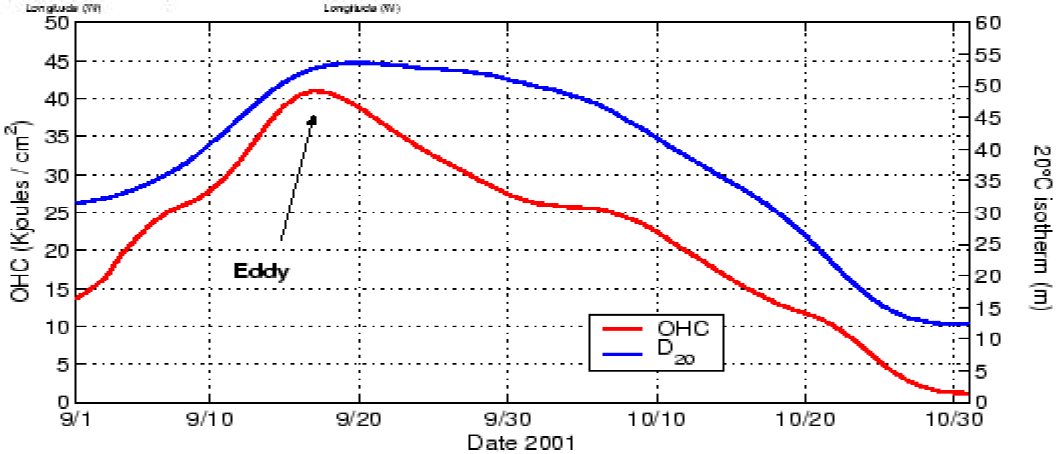


Fig 3: OHC (kJ $cm^{-2}$) and Depth of the 20°C isotherm (m) determined from the TAO mooring at 10°N95°W during Sept and Oct of 2001 during the EPIC field program**.**

**2. Mooring Data:** Time series of thermal structure measurements from TAO moorings in the EPAC deployed as part of the long-term monitoring by PMEL have been processed. As shown in Figure 3, here is an example of depressed thermocline (i.e. 20°C isotherm depth) that occurs during the passage of a warm core eddy at 10°N and 95°W. At this position, the OHC values exceeded 40 kJ $cm^{-2}$ as the eddy began to spin down and weaken, consistent with Figures 1 and 2.

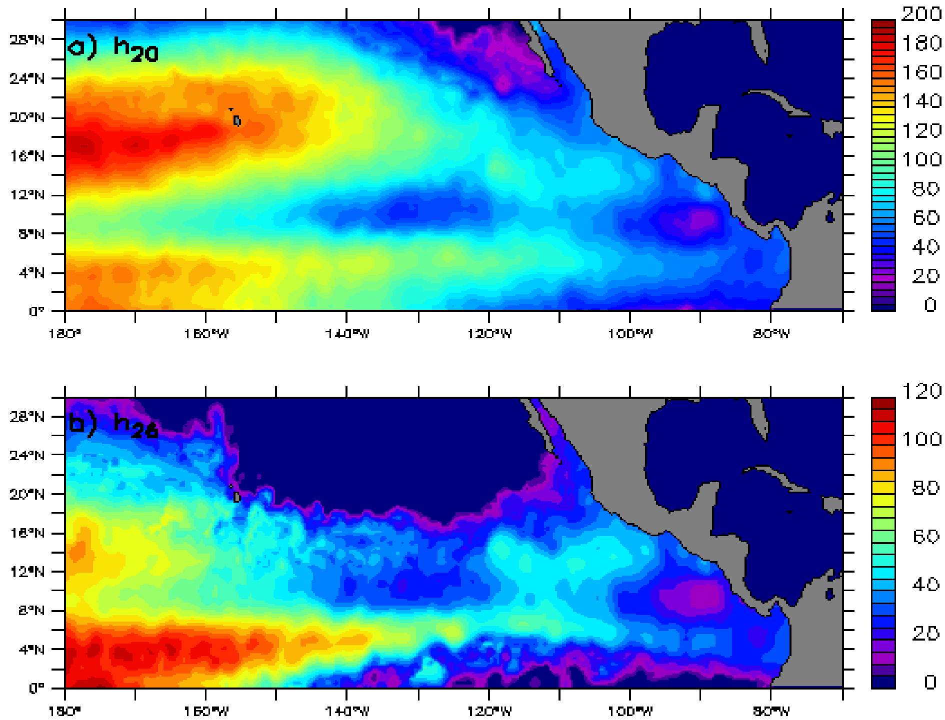


Figure 4: Depths (m) of the mean a) 20°C and b) 26°C isotherms based on an average of the GDEM (**V3**) from May through October.

**3. GDEM:** This climatology is being used for the grant. While the analysis has focused on the **Version 3**, we are comparing the fields to those from **Version 2.5** (used for the Atlantic Ocean Basin) to ensure consistency between the two basins. As shown in Figure 4, the mean depths of the 20° and 26°C isotherms are based on an average over a hurricane season (May through October) using temperature profiles at 0.5° resolution in the EPAC. Notice that the general shoaling of the isotherm depths from west to east forces tighter vertical gradients in the warm pool's upper ocean thermal structure. Generally, the 20°C isotherm depths range from 30 to 50 m compared to more than 100 m west of 140°W. The corresponding 26°C mean isotherm depth ranges between 15 to 25 m in the warm pool (12°N, 95°W) and north of 20°N, the 26°C isotherm shoals to the surface. This surface shoaling, known as ventilating of the 26°C isotherm, implies that once a TC reaches that area, they will begin to lose their oceanic heat source and presumably begin to weaken. A second aspect of this area is that the buoyancy frequencies at the base of the ocean mixed layer (OML) exceed 20 cycles per hour.

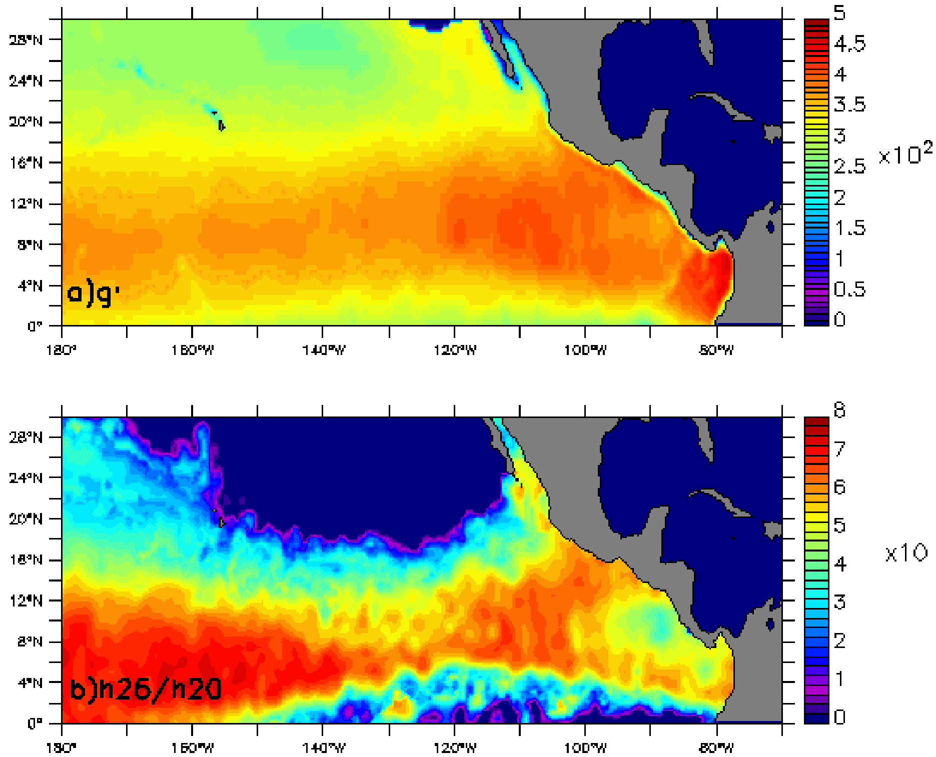


Figure 5: a) Reduced gravity (g' x $10^2$ m $s^{-2}$) and b) ratio of the 26°C and 20°C isotherm depths for the EPAC hurricane season based on **GDEM V3**.

As per the two-layer model, reduced gravity (g') distribution (density difference between upper and lower layer multiplied by the acceleration of gravity) and the ratio between the 26°C and 20°C isotherm depths are shown in Fig. 5. East of 120°W, reduced gravities are about 5 x $10^{-2}$ m $s^{-2}$, which is indicative of the strong stratification of the EPAC. West of this longitude, g' decreases to about 3.5 x $10^{-2}$ m $s^{-2}$ whereas towards the northern part of the domain, reduced gravities decrease to about 2 x $10^{-2}$ m $s^{-2}$. For example, in the area of hurricane Norbert experiment (84), the observed buoyancy frequency was 11 cycles per hour (cph) compared to more than 20 cph in the warm pool. Such spatial variations have a pronounced impact on cooling and the cold wake or trail left behind by the hurricane. In general, the strong stratification in the warm pool often precludes a strong internal wave wake left behind by hurricanes. During

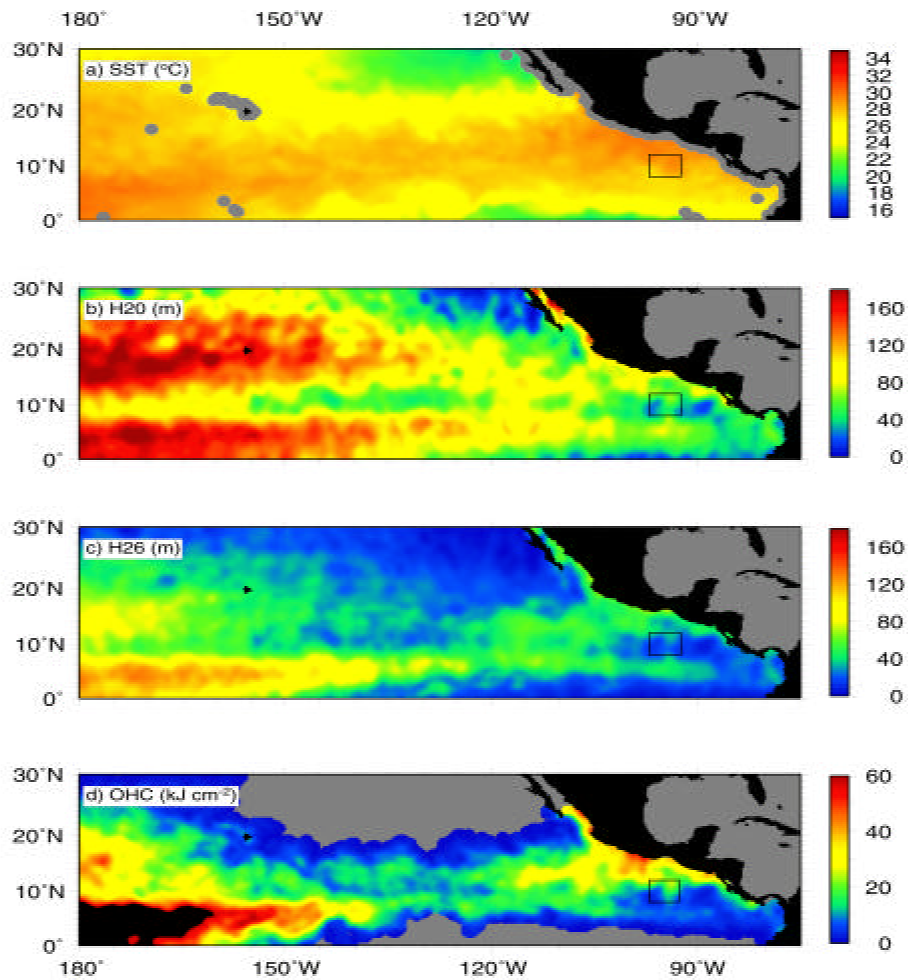


Figure 6: a) SST (°C) , b) $h_{20}$ (m), c) $h_{26}$ (m), and d) OHC (kJ cm$^{-2}$) in the EPAC for 15 Sept 2001 during the EPIC field program as depicted by the black box centered at 10°N and 95°W.

hurricane Juliette in 2001 (not shown), the cold wake of SSTs exceeding 4°C only began towards the north and west of the warm pool. One area that we are looking into is the depth of the 26°C isotherm at 95°W and 10°N. Observed profiles and time series measurements from TAO mooring suggest that the ratio between these depths should be more on the order of 0.45 to 0.5 in the warm pool as opposed to climatology suggesting 0.3. One possibility for this discrepancy is how the vertical interpolation is handled in the region of strong vertical gradients (linear versus spline fits).

**4. OHC Estimation:** As shown in Figure 6, the OHC is estimated using **GDEM V3** climatology from Figures 4, 5 using the surface height anomaly (SHA) and TMI-derived Sea-Surface Temperature (SST) fields for mid-September 2001. Observed SSTs in the warm pool were warmer than those indicated by TMI by about 0.5°C based on observed profiles. The approach uses SHA from T/P, GFO, and ERS-2 altimetry data (not blended AVISO in Figure 1) where repeat tracks are 9.9, 17 and 35 days for T/P, respectively. These fields are blended and objectively analyzed to a 0.5° grid from the coast to 180°W and from the equator to 30°N and are then combined to estimate isotherm depths and OHC. As shown in Fig. 6a, the warm SSTs exceeded 27.5°C north of the equatorial cold tongue and extended longitudinally from the coast to 180°W. Cooler SSTs are observed north of 20°N, and decrease to below 26°C at about 24°N. The mean 20°C isotherm depths suggest a general shoaling from west to east to a relative minimum of about 40 m in the EPIC domain. Notice the general shape of this minimum that apparently was affected by a warmer feature between the two cold cells (Fig. 6b). This may be a manifestation of the Costa-Rica Dome which is a semi-permanent feature of the EPAC due to the cyclonic mean wind stress curl. The 26°C isotherm depths also show a similar pattern except that the relative minimum is about 20 to 25 m. Finally, the resultant OHC distribution shows values of ~50 kJ $cm^{-2}$ at ~14°N and 95°W. As suggested by Figure 2, a key issue is the OHC distribution within the EPIC domain should have a similar value but is actually 10 to 15 kJ $cm^{-2}$ less than observed However, satellite-derived OHC and isotherm depths have a similar pattern to those observed, but are underestimated. *Thus, we are examining the details between the observed versus satellite-derived distributions of these fields and the differences between* ***GDEM V2.5 and V3 climatologies.***

**Comparison to Observations**: As shown in Figure 7, observed profiles from the *NCAR G-130* aircraft (4 flights) and *R/V Ron Brown* are compared to October profiles from the **GDEM-V3**. There is reasonably good agreement between 1.5°N and 9°N for the thermal structure except that the isothermal depths in the upper ocean are less than those observed from 6 to 9°N. Salinity structure indicates significant variability in the upper ocean due in part to horizontal advection by currents and precipitation patterns associated with the ITCZ. However, salinity gradients in the upper ocean differ significantly between 6°N and at the equator. Buoyancy frequencies (N), vertical gradient of density (temperature and salinity), indicate that climatology underestimates the density gradients and hence buoyancy frequency by 3 to 5 cph. Observed profiles support the larger values of N as expected due to the smoothing in various climatologies compared to realistic observed thermal and salinity structure in the upper ocean.

**Summary:** Over the ten months of the grant, we have made progress on developing the climatology for the EPAC using **GDEM V3** (and comparing them to **V2.5**). Presently, we are making detailed comparisons to observed profiles as well as estimates of the isotherm depths and OHC fields from the EPIC experiment and time series from the TAO moorings (10°N). We anticipate that these comparisons will be concluded within the next few months to improve the climatology for the EPAC in meeting Objectives I and II as part of this NOAA Joint Hurricane Testbed grant. Ms Jodi Brewster assumed the position vacated by Mr. Tom Cook last fall, has now learned about the OHC estimation process and the web site and has increased her productivity in working with Mr. Cook and with Ms Michelle Mainelli at TPC.

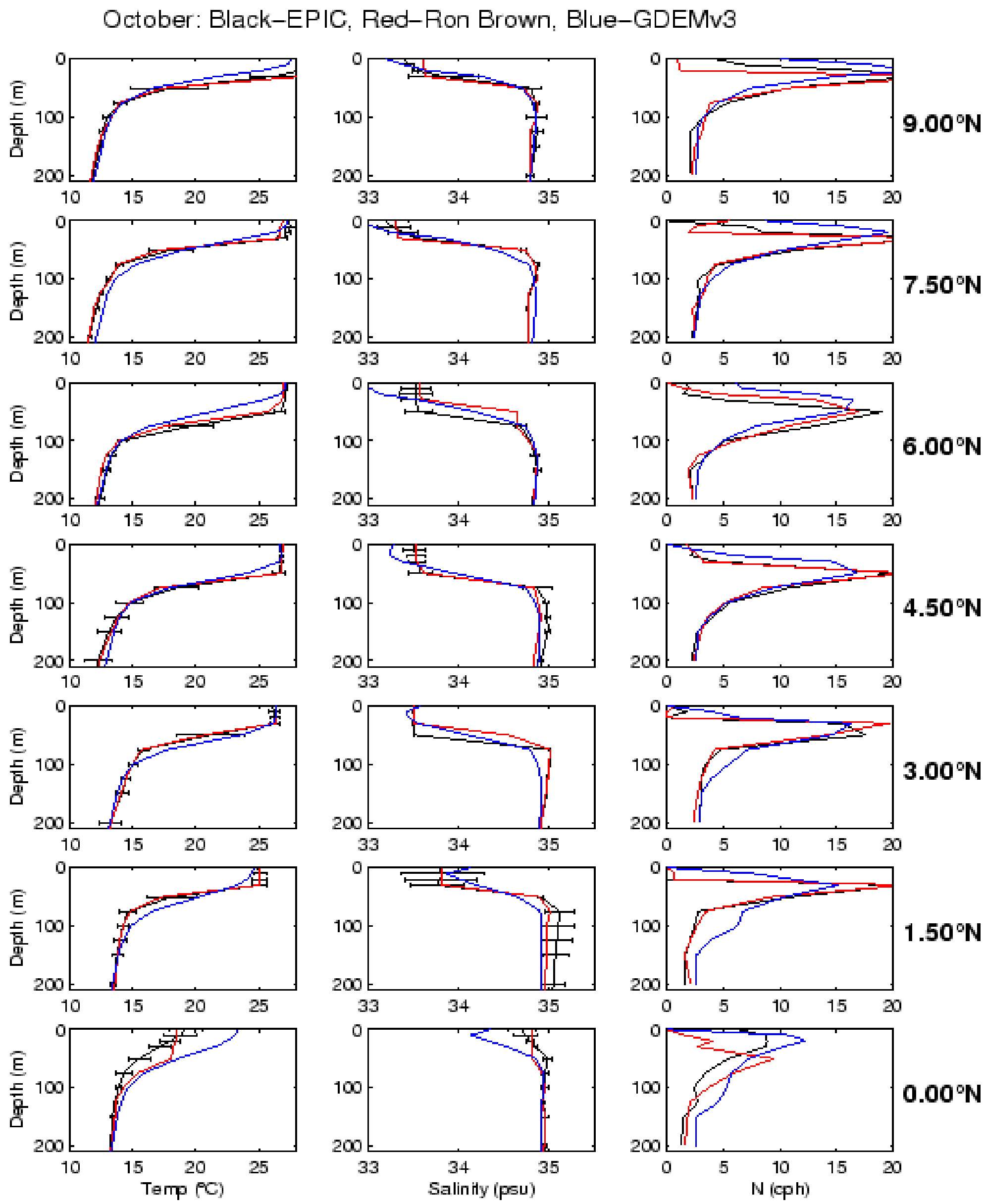


Figure 7: Comparison of T(z) (°C : left), S(z), (psu: center) and N(z) (cph: right) from 9°N to the equator in early October 2001 between Airborne eXpendable Conductivity Temperature and Depth profiles (black), *Ron Brown* (red) and **GDEM V3** (blue). Equatorial transects are based on four sets of AXCTDs along 95°W allowing the uncertainty bars to be estimated.

**Timeline:** We are following the revised timeline and delivery schedule:

A. February 06: Synthesis of data sets in Section I of proposal

1. Radar altimetry; and
2. XBT transect data;
3. Data Bases (GDEM)

B. August 06: From latest GDEM, develop:

1. Isotherm Depths/Reduced Gravities
2. SHA and Upper Layer Thickness
3. OHC Estimation
4. Comparison to In situ measurements

C: February 07: Seasonal Climatology (to TPC) as per Section II of proposal

D: May-Oct 07: Monitoring and Daily Estimates for SHIPS