Altimetric Ocean Heat Content Monitoring for the Study of Landfalling U.S. West Coast Winter Storms

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Introduction

The human and economic impact of severe landfalling winter storms on the U.S. West Coast are comparable on an annual average to the human and economic impact of earthquakes. Like hurricanes, the prediction of these storms is hindered because they develop over the ocean where observations are sparse.

During the NOAA California landfalling Jets Experiment (CALJET) in the winter of 1997–1998, data was collected in regions where additional and/or improved observations could potentially help downstream forecasts. One of the regions of sensitivity, found by an adjoint analysis using the MM5 numerical weather model, was the temperature in the lower atmosphere 1000 km off the California coast. One of the objectives of CALJET was to determine the sensitivity of landfalling storms to the upper-ocean thermal structure, which is still very much a work in progress. In the winter of 1997–1998, NOAA-P3 aircraft were used to perform AXBT surveys in the region to profile the oceanic mixed-layer.

In this poster, we present preliminary comparisons of altimetry-based upper-ocean heat content estimates with *in situ* measurements from this study. An extended heat content time series in the study region spanning the entire TOPEX/POSEIDON (T/P) mission is used to put into context the warmer conditions that were observed, associated with the 1997–1998 El Niño. Special attention is focused on the mesoscale oceanographic component of heat content to determine the sampling required to adequately monitor the upper-ocean heat content in the region. Results from this study will contribute to the NOAA Pacific landfalling Jets (PACJET) Experiment [1], a follow-on to CALJET, planned for the winter of 2000–2001.

An Infrared satellite image of a Pacific storm on 3 February 1998 that caused flooding rains, hurricane force winds, and heavy surf during CALJET is shown in Figure 1.

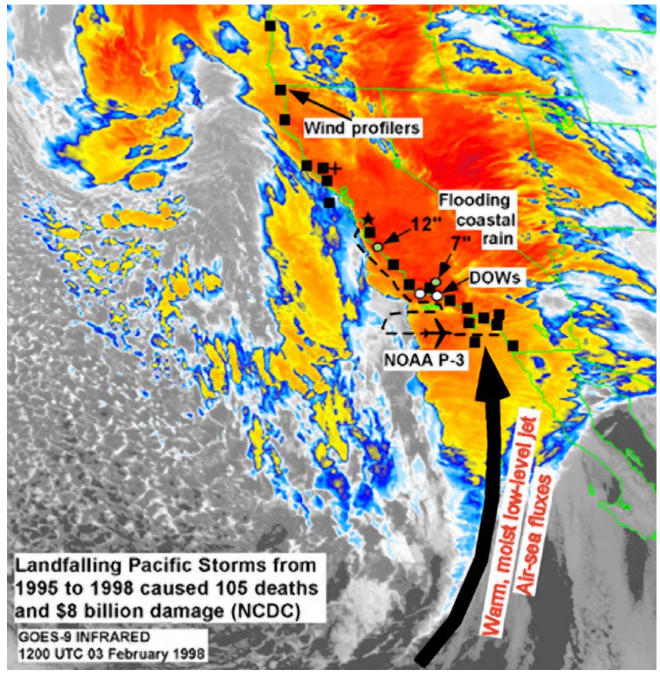

Figure 1. Infrared satellite image of the 3 February 1998 storm (courtesy of ETL/NOAA).

Current research and operational models rely on satellite-based sea surface temperature (SST) measurements and climatology-based SST measurements. The goal of the current work is to create a procedure whereby altimetry-based heat content estimates can be used to accurately monitor the upper-ocean heat content off the West Coast of the U.S. The ultimate objective is to develop a near real-time capability for estimating the upper-ocean thermal structure from altimetry for input into research and operational forecast models.

Methods

Three synoptic AXBT surveys were performed from aircraft to collect upper-ocean temperature profiles off the West Coast of the U.S. during the winter of 1997–1998. The spatial extent of the AXBT deployments in the analysis region of interest (ROI) are shown in

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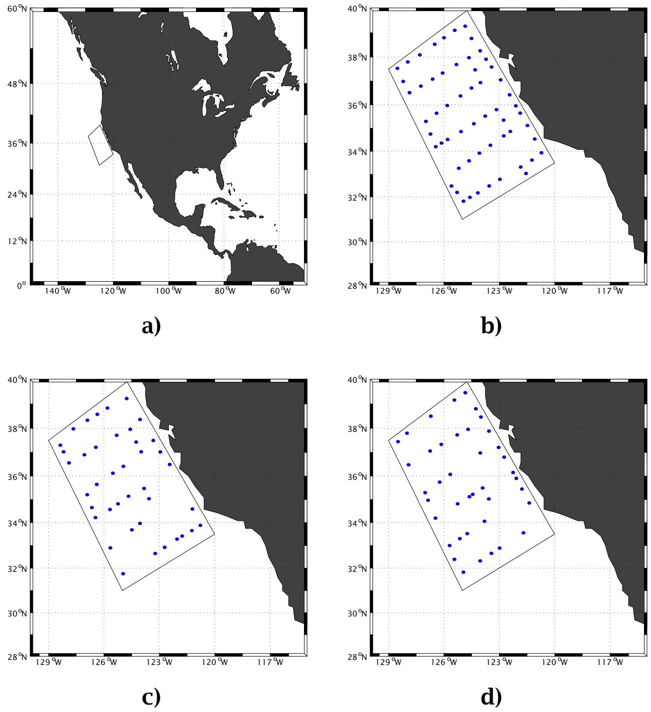

Figure 2. The map in (a) is an overview of the analysis region of interest (ROI). Measurement locations for (b) Jan. 20, (c) Feb. 11, and (d) Feb. 26.

Figure 2. Three sets of altimetry-based sea surface height anomalies (SSHA), and the AXBT data, were used to compute the upper-ocean heat content for 0 to 350 meters in depth. The AXBT heat content were computed directly from the temperature profiles. Altimetry-based heat content estimates were made using a linear relationship between ocean geopotential anomaly and heat content deviations from the mean using the World Ocean Atlas 1998 (WOA 1998) climatology [2,3]. The climatological mean heat content also was used to reference the heat content determined from AXBTs to a long-term mean.

Three altimetry data sets are compared in this study. The first altimetric data set was based on TOPEX data alone. The second altimetric data set was obtained by "blending" TOPEX and ERS-2 altimeter data with an emphasis on retaining the longer wavelength oceanographic signals accurately measured by T/P and the mesoscale signal sampled by both the T/P and ERS-2 satellites (blended TOPEX/ERS) [4]. The third data set is an operational data set that is produced by heavily filtering and combining and ERS-1 and ERS-2 altimetry data with an emphasis on retaining only mesoscale structure (mesoscale TOPEX/ERS) [5].

No *in situ* measurements of salinity were made during the aerial surveys. Since climatology-based salinity corrections do not significantly improve altimetry-based heat content estimates, none were applied [6].

Table 1. Correlation coefficients for all dates.

	AXBT	TOPEX	BTE	MTE
AXBT	1	0.53	0.72	0.37
TOPEX	0.53	1	0.79	0.22
BTE	0.72	0.79	1	0.48
MTE	0.37	0.22	0.48	1

Results

Three analysis dates were chosen to compare the AXBT heat content with the altimetry-based heat content. The three chosen dates each consisted of more than thirty points and spatially covered the majority of the ROI. Altimetry data was interpolated to the dates and to the locations of the AXBT data.

Figures 3 to 5 show maps of heat content estimates for each analysis date, comparing the altimetry-based heat content estimates with the AXBT heat content for the upper 350 meters of the ocean in the ROI. Visual inspection of the heat content anomaly maps reveals a rather good correlation between the blended TOPEX/ERS and AXBT heat content.

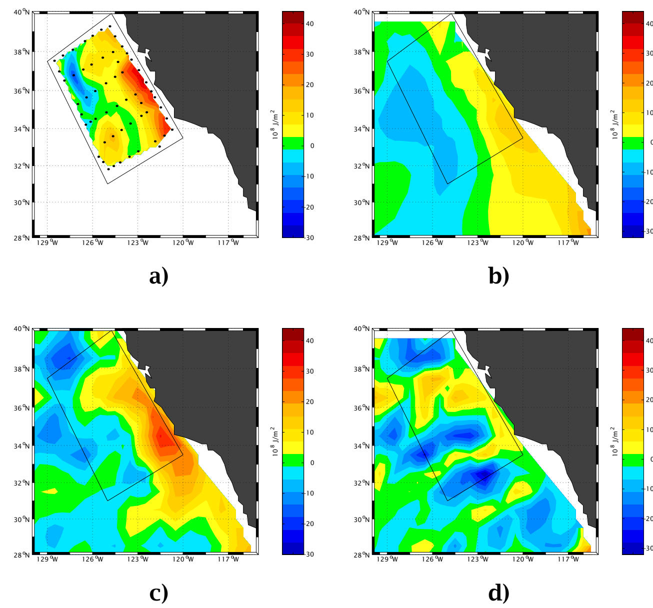

Figure 3. Heat Content Anomaly (HCA) maps for Jan. 20. (a) *In situ* AXBT, (b) TOPEX, (c) blended TOPEX/ERS, and (d) mesoscale TOPEX/ERS.

The scatter plot in Figure 6(b), AXBT and the blended TOPEX/ERS, shows the best correlation, which is confirmed in Table . The correlation between the AXBT and blended TOPEX/ERS heat content is 0.72, inferring that 51% of the variance in the AXBT heat content is represented by the blended TOPEX/ERSheat content estimate.

Tables through show the correlation coefficients for the three analysis dates taken separately. In each case, the blended TOPEX/ERS heat content estimate has the best correlation to the AXBT heat content, highlighting the importance of resolving the mesoscale circulation

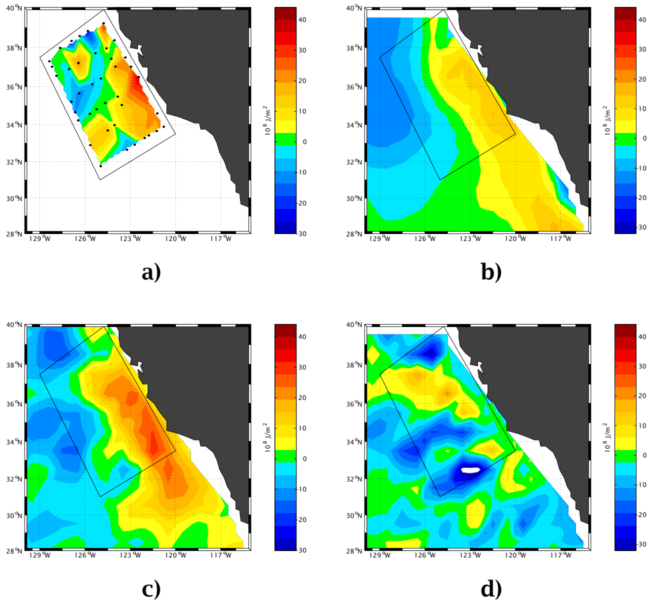

Figure 4. Heat Content Anomaly (HCA) maps for Feb. 11. (a) *In situ* AXBT, (b) TOPEX, (c) blended TOPEX/ERS, and (d) mesoscale TOPEX/ERS.

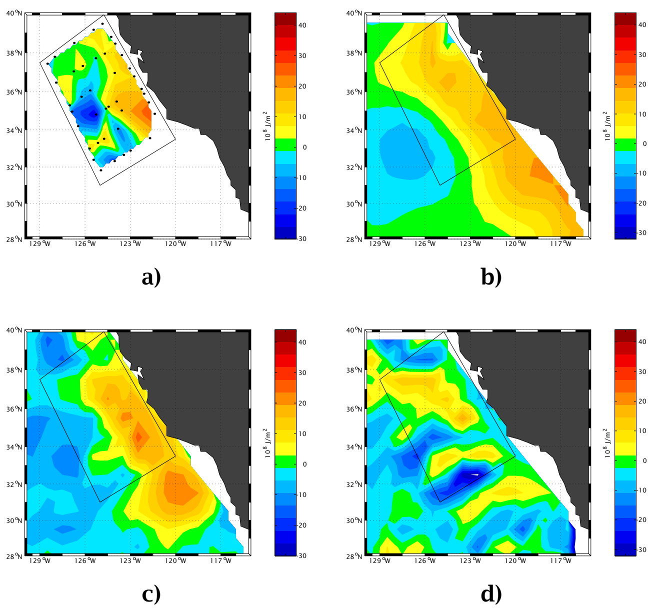

Figure 5. Heat Content Anomaly (HCA) maps for Feb. 26. (a) *In situ* AXBT, (b) TOPEX, (c) blended TOPEX/ERS, and (d) mesoscale TOPEX/ERS.

when estimating heat content in the ROI.

The spatial mean heat content in the ROI over six years, 1993 through 1998, is shown in Figure 7. The TOPEX heat content varies the most, a result of under sampling of the mesoscale in the region. The TOPEX and the blended TOPEX/ERS series capture seasonal changes well, including the 1997–1998 El Niño and a smaller spike in heat content near the time of the 3 February 1998 storm.

Figure 8 is a zoomed-in view of the mean heat content times series, with the addition of the AXBT mean heat content for the three analysis dates. The AXBT points

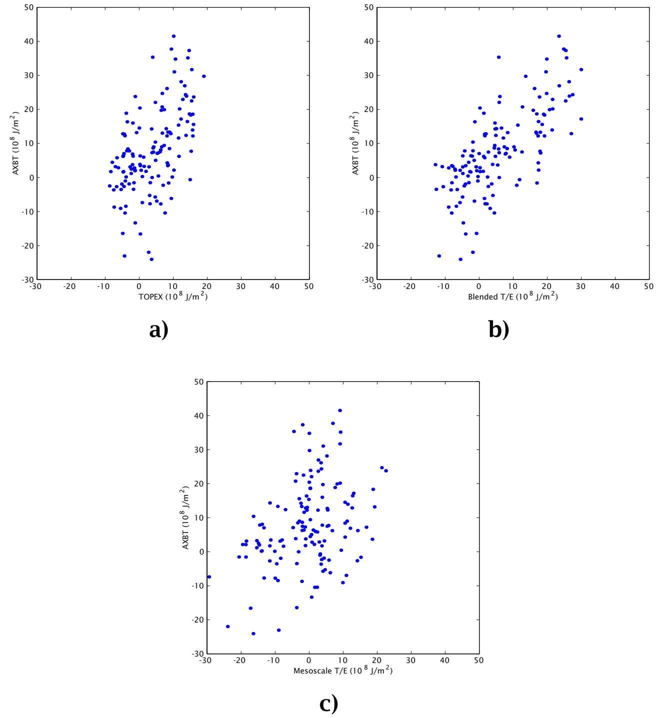

Figure 6. HCA scatter plots for all analysis dates combined. (a) AXBT vs. TOPEX, (b) AXBT vs. blended TOPEX/ERS, and (c) AXBT vs. mesoscale TOPEX/ERS.

Table 2. Correlation coefficients for Jan. 20.

	AXBT	TOPEX	BTE	MTE
AXBT	1	0.76	0.78	0.40
TOPEX	0.76	1	0.84	0.23
BTE	0.78	0.84	1	0.52
MTE	0.40	0.23	0.52	1

Table 3. Correlation coefficients for Feb. 11.

	AXBT	TOPEX	BTE	MTE
AXBT	1	0.57	0.69	0.37
TOPEX	0.57	1	0.92	0.17
BTE	0.69	0.92	1	0.47
MTE	0.37	0.17	0.47	1

Table 4. Correlation coefficients for Feb. 26.

	AXBT	TOPEX	BTE	MTE
AXBT	1	0.58	0.74	0.38
TOPEX	0.58	1	0.79	0.24
BTE	0.74	0.79	1	0.45
MTE	0.38	0.24	0.45	1

are shown with error bars, which form a 95% confidence interval about the mean heat content for each date. The mean heat content for the AXBT and blended TOPEX/ERS data correspond favorably.

In Figure 9, the altimetry-based mean heat content is shown for the span of time where all three altimetry data sets are available.

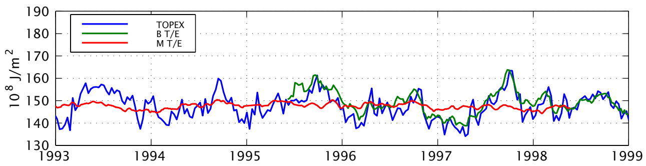

Figure 7. Time Series of the spatial mean heat content in the analysis region.

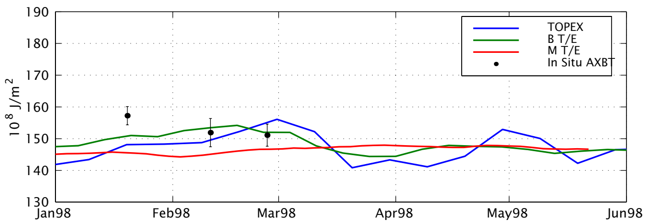

Figure 8. Time Series of the spatial mean heat content in the analysis region, during 1998. The error bars on the AXBT points form the 95% confidence interval about the mean heat content.

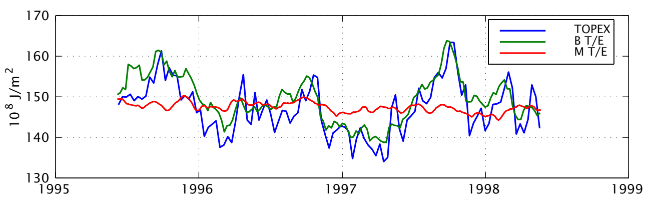

Figure 9. Time series of the spatial mean heat content in the analysis region, comparing the altimetry estimates over a 2.5 year span.

Summary

Altimetry-based heat content estimates were computed using TOPEX and ERS satellite data. The heat content estimates were computed for the upper 350 meters of ocean in the ROI. The altimetry-based heat content estimates were compared with *in situ* AXBT data that was taken during surveys in the winter of 1997–1998. Current findings:

- Altimetry-based heat content estimates in the ROIwere well correlated with the three *in situ* AXBT analysis dates.
- The blended TOPEX/ERS data seems to match the *in situ* AXBT analysis dates the best of the three altimetry data sets.
- It is likely that some combination of altimetry-based heat content estimates could be made available in near real-time for input into research models during PACJET.

Planning of the aerial surveys for PACJET is currently underway. Because the altimetry-based heat content estimates can be used in lieu of *in situ* data sampled by aerial surveys, the necessity of large-scale synoptic aerial surveys during PACJET is no longer an issue. Focused aerial surveys of evolving winter storm systems, however, are planned during the winter 2000-2001 experiment. We hope to coordinate deployment of a limited number of AXBTs on altimeter satellite ground tracks during these flights, which would be used to further validate altimetry-based heat content estimates in the region.

References

[1] Ralph, Martin, "The Pacific Landfalling Jets Experiment (PACJET) and a Long-Term Effort to Improve 0–24 Hour West Coast Forecasts," PACJET Program Document, January 27, 2000, `http://www.etl.noaa.gov/programs/pacjet/pacjet.shtml`.

[2] Hendricks, James R., *Global Sea Level Rise and Upper Ocean Heat Storage Estimates From* TOPEX/POSEIDON *Satellite Altimetry*, Doctoral Dissertation, University of Colorado at Boulder, 1996.

[3] Chambers, Don P., ; *et al.*, "Long-Period Ocean Heat Storage Rates and Basin-Scale Heat Fluxes from TOPEX," *Journal of Geophysical Research*, Vol. 102, No. C5, 1997, pp. 10525–10533.

[4] Leben, Robert R., *et al.*, "Reduction of Long Wavelength Errors in ERS-2 Satellite Altimetry Data Using Crossover Difference Detrending and TOPEX/POSEIDON Data," *in preparation*, 2000.

[5] Lillibridge, J., *et al.*, "Real-Time Altimetry from ERS-2," *Proc.* 3*rd* ERS *Symp.,* Florence, Italy, March 1997.

[6] Sato, Olga T., *et al.*, "Importance of Salinity Measurements in the Heat Storage Estimation from TOPEX/POSEIDON," *Geophysical Research Letters*, Vol. 27, No. 4, 2000, pp. 549–551.

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