# Combining Altimetric Height with Broadscale Profile Data:
# A Technique for Estimating Subsurface Variability

*Josh Willis, Dean Roemmich, Bruce Cornuelle*

*jkwillis@ucsd.edu, droemmich@ucsd.edu, bcornuelle@ucsd.edu,*

*Scripps Institution of Oceanography*

## Introduction

Present large-scale, *in situ* measurement programs, including the broadscale XBT network, undersample the temporal and spatial variability of the world ocean. In contrast, the TOPEX/Poseidon (T/P) altimeter record provides improved resolution of horizontal and temporal variability, but no information about vertical temperature structure. By combining the altimeter data with *in situ* XBT profiles, a dataset can be produced which maintains the high resolution of the altimeter and also provides information about changes in vertical structure.

## Data

The technique described here was developed using data from the Tasman Sea region shown in Figure 1. Three distinct data sets are considered: high-resolution XBT (HRX) transects, broadscale XBT profiles, and T/P altimetric height. The HRX transects were repeated quarterly and had a probe spacing of 10 to 100 km. These transects were used to compare upper-ocean temperature variability and altimetric height over a large range of horizontal scales. Historical salinity was used to calculate 0/800 m steric height for all XBT profiles. All anomalies are relative to a time-mean (climatology) and seasonal cycle.

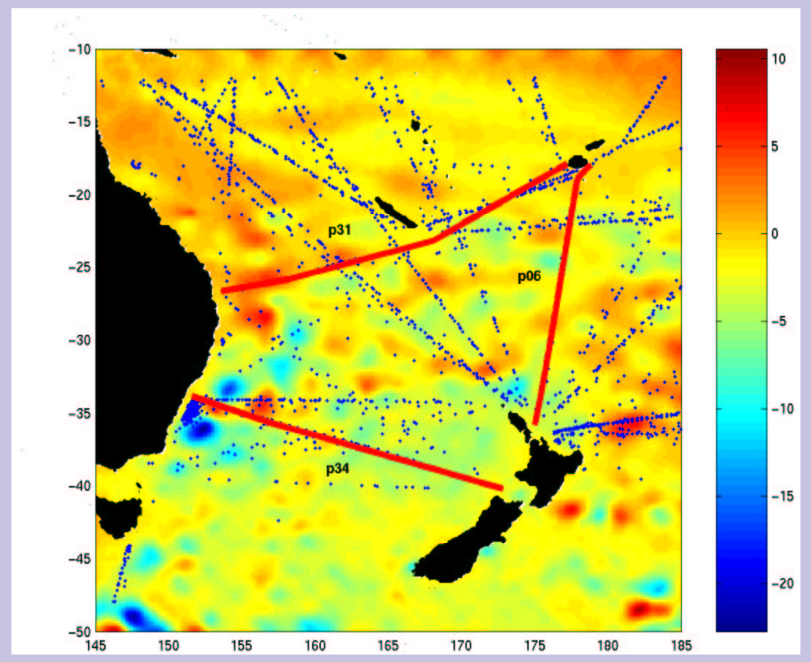


**Figure 1.** Tasman Sea region. Red lines show WOCE HRX transects. Blue dots show locations of all available XBT profiles for 1995. Background shows a 1-year time-mean (1995) of T/P altimetric height in cm.

## Technique

A large portion of the sea-surface height variability measured by the altimeter is caused by changes in density in the top-most kilometer of the water column. These upper-ocean density changes are expressed as 0/800 m steric height anomalies calculated from the XBT profiles. Because steric height is strongly correlated with heat content, maps of heat content and storage can be inferred from an estimate of steric height.

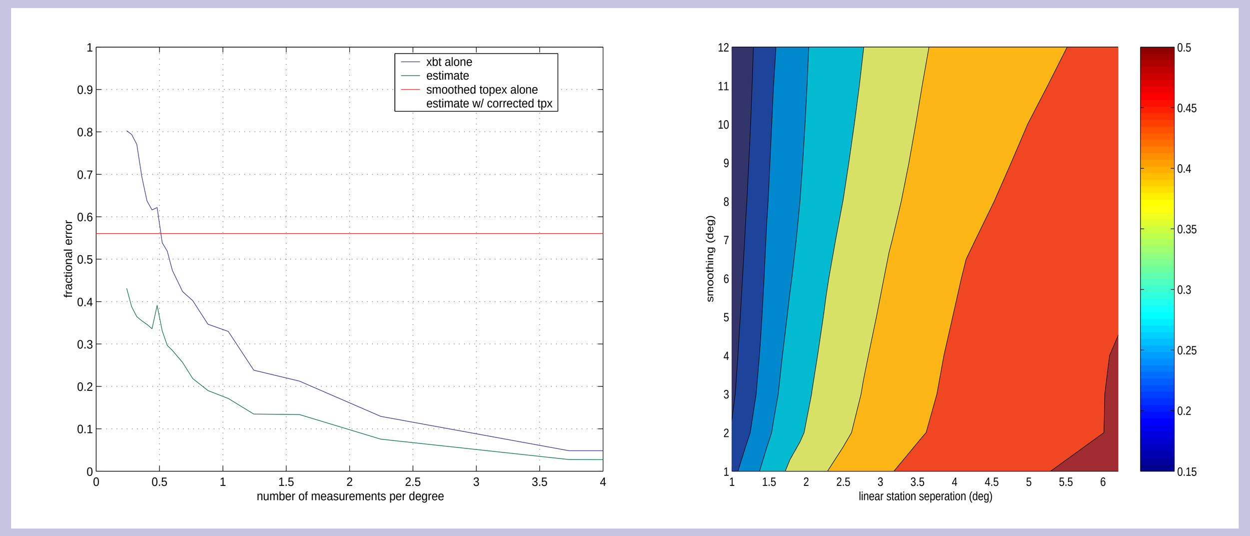
Maps of steric height are estimated using altimetric height data by calculating the difference between the steric height anomaly measured at each XBT location and the altimetric height anomaly interpolated to the same position. This difference field is then smoothed and objectively mapped. It is then applied as a 'correction' to a similarly smoothed map of altimetric height. This is equivalent to using altimetric height as the *a priori* guess in an objective map of steric height:

$$\langle estimate \rangle = \langle (steric\ height - altimetric\ height) \rangle + \langle altimetric\ height \rangle,$$

where < > denotes mapping. The error due to undersampling is confined to the difference field which has less variance than the altimetric height or steric height fields. This means that an estimate formed this way will have less error than an estimate using either data set alone (see Figure 2).

**Figure 2.** Fractional error in estimates of 0/800 m steric height along P31 averaged over 25 repeats of the transect. Undersampling was simulated by leaving out data along the track when estimating steric height. The result was then compared with the "true" field which kept the full resolution of the transects. **a).** Fractional error in three different estimates of steric height. Blue: estimate formed from subsampled XBT data alone. Red: estimate formed from altimetric height alone (note, since there is no need to subsample the T/P data set, this line is constant). Green: estimate using difference method. The "true" field was considered to be the field formed by retaining all of the XBT data and smoothing with a 10 degree along-track filter. **b).** Fractional error in difference method versus sampling resolution and smoothing length. Note that for a given data resolution, averaging or smoothing over a large region does not significantly reduce the error.

**a)** **b)**



## Subsurface Quantities

### Heat Content

Changes in steric height are very closely related to changes in heat content over the same part of the water column. A simple linear regression was used to convert steric height anomalies into changes in upper-ocean heat content. By allowing the regression coefficients to vary slightly with latitude, most of the variability in heat content could be predicted using steric height anomalies as shown in Figure 3.

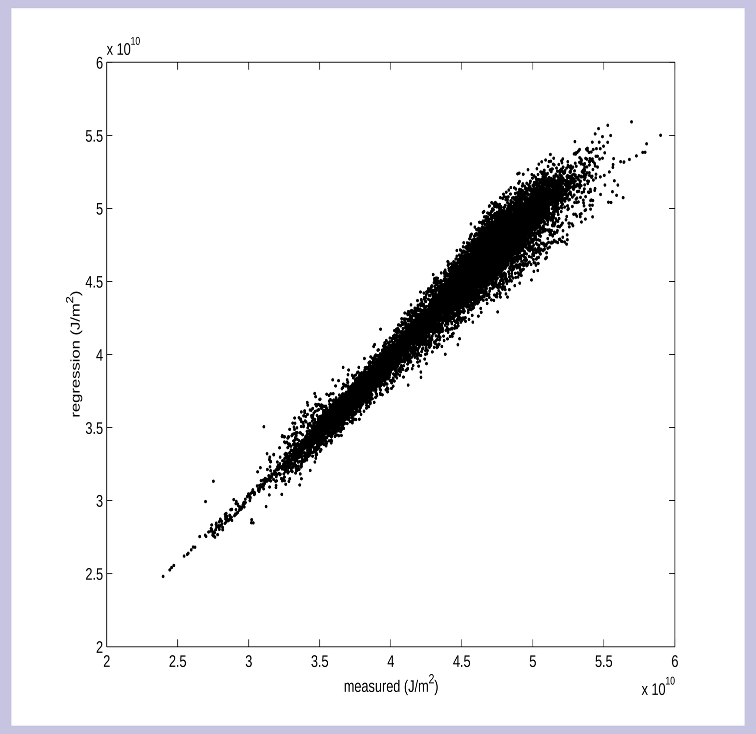


**Figure 3.** Heat content calculated using linear regression onto steric height vs. measured heat content for all profiles in study.

### Temperature

In the region of study, changes in sea surface height are dominated by temperature changes which are coherent over most of the upper 800 m of the water column. A large portion of subsurface temperature variability can be estimated by a linear regression of the form: $T(z) = \alpha(z) * (T/P)$. This altimeter-based estimate of subsurface temperature variability can be used to supplement *in situ* measurements from XBT profiles in the following way:

$$T_{estimate}(z) = \langle T_{xbt}(z) - \alpha(z) * (T/P) \rangle + \langle \alpha(z) * (T/P) \rangle,$$

where each depth is mapped separately. This is analogous to the 'difference estimate' of steric height discussed in the Technique box. Figure 4 shows the error in estimating subsurface temperature using various methods. The difference estimate gives the smallest error even with the modest probe spacing of 1 profile every 3° longitude.

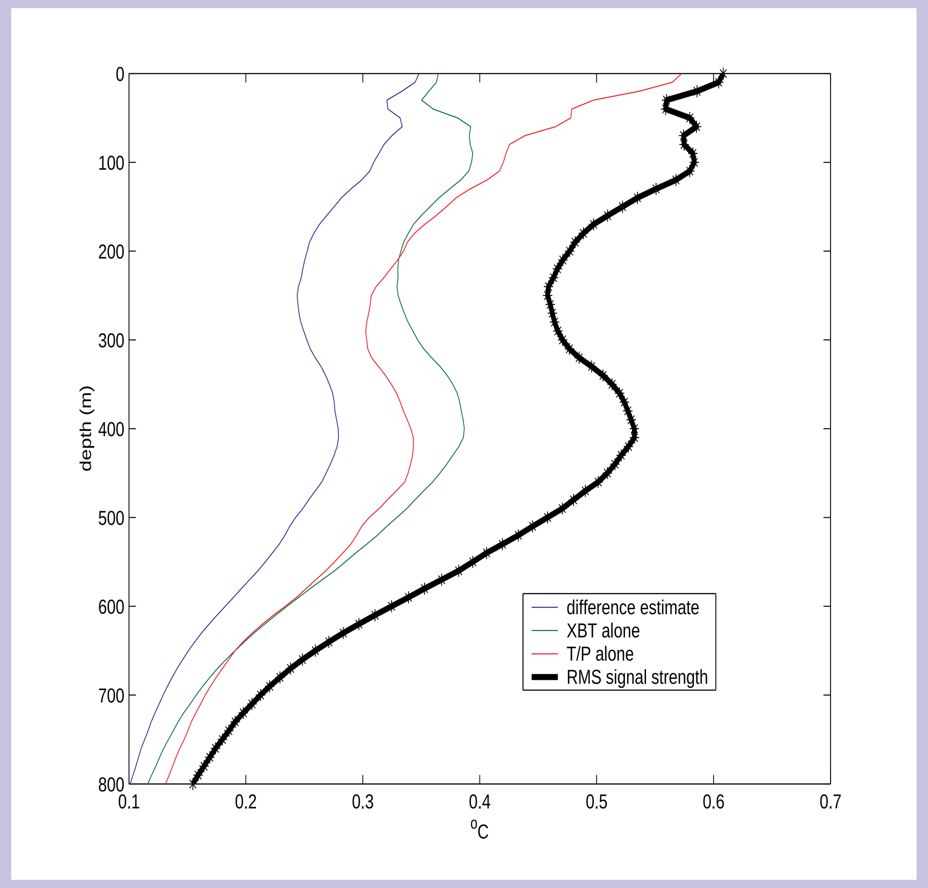
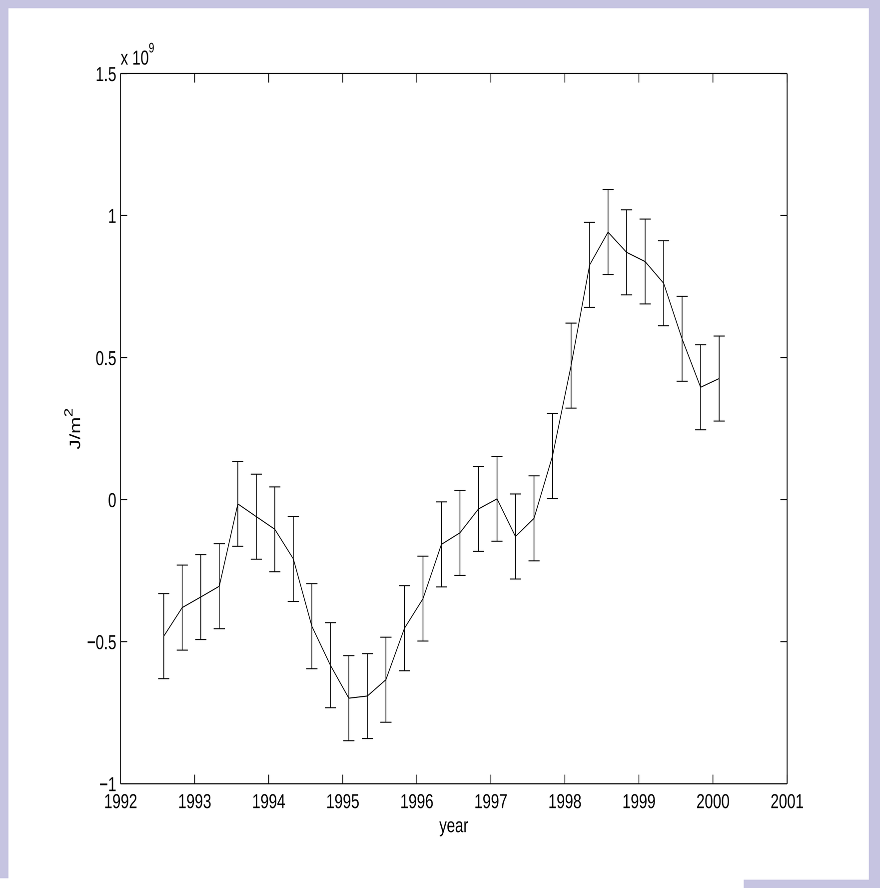



**Figure 4.** Blue: RMS error in predicting subsurface temperature anomaly using 'difference estimate'. Green: Error using XBT data alone. Red: Error using altimetric height alone. Thick black: RMS signal strength of temperature variability. All curves are averaged over 25 transects of P31. A climatology and seasonal cycle were removed. The 'difference' and 'XBT alone' estimates were subsampled to 1 profile every 3° of longitude.

## Results

A time series of the steric height anomaly field was calculated over the entire region of Figure 1 from late 1992 through 2000. The maps were made with a one year time window and smoothed over three degrees. Maps of heat content and subsurface temperature were then calculated. Figure 5 shows the time series of upper-ocean heat content of the box enclosed by the HRX sections. The interannual variability is quite large. The peak at the end of 1998 corresponds to an anomalous warming of about 35 $W/m^2$ over the year. The error bars translate to about 5 $W/m^2$ in the heat storage. The cause of this feature can be seen in Figure 6 to be a positive anomaly intruding down from the north in 1998. Figure 6 shows a time series of temperature maps at 400m.

**Figure 5.** Heat content of the box enclosed by the HRX sections. Error bars are estimated to be about 30% of the strength of the signal.



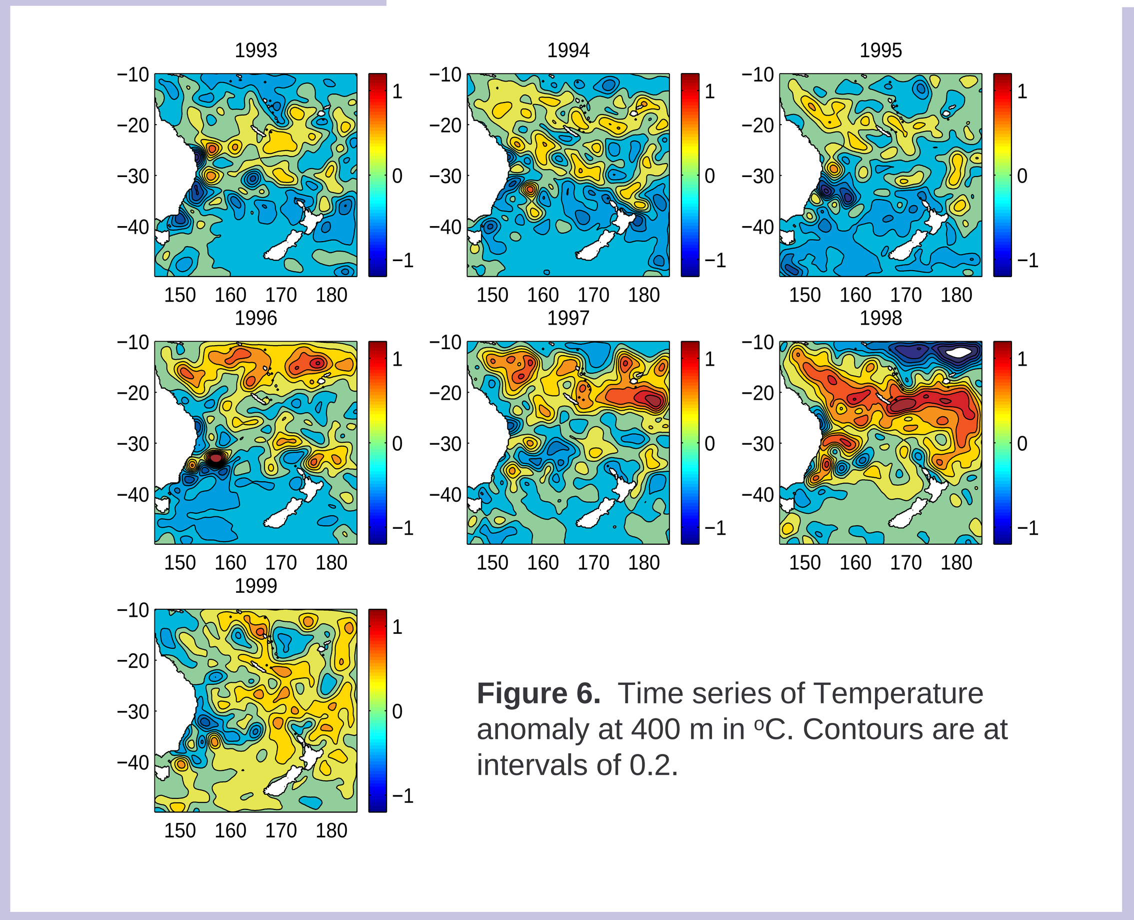



**Figure 6.** Time series of Temperature anomaly at 400 m in °C. Contours are at intervals of 0.2.

## Summary

Data from the TOPEX/Poseidon altimeter record can be combined with *in situ* data to improve estimates of variability in upper-ocean steric height, heat content and subsurface temperature. Subsurface temperature variability can be estimated with an accuracy of about 0.3 °C. Heat storage can be estimated over large areas with an RMS error of about 5 $W/m^2$ in well-sampled regions such as the Tasman Sea.