An investigation of very low frequency sea level change using satellite altimeter data

R.S. Nerem [1], G.T. Mitchum [2],
B.S. Giese [3], E.W. Leuliette [1],
D.P. Chambers [4]
[1] (CCAR, USA)
[2] (University of South Florida, USA)
[3] (Texas A&M University, USA)
[4] (Center for Space Research, USA)

With 8 years of precise satellite altimeter data from TOPEX/POSEIDON, and the prospect of the continuation of this time series by Jason-1, we now have a data set of sufficient length to begin studying very low frequency (VLF) sea level variations. The objective of this investigation is to obtain a better understanding of VLF sea level variations by analyzing TOPEX/POSEIDON and Jason-1 altimeter data using both advanced statistical analysis techniques and numerical ocean modeling. With the addition of a few years of Jason-1 measurements, we should soon be able to make quantitative estimates of the rate of sea level rise due to climate change.

The success of the TOPEX/POSEIDON (T/P) altimeter mission has created a revolution in oceanography. T/P allows entirely new types of oceanographic problems to be addressed that were impossible with previous missions. Among many accomplishments, T/P has provided measurements of global mean sea level variations at 10 day intervals with a precision of 4 cm, more than sufficient to detect the very low frequency (VLF) changes associated with climate change given a sufficiently long time series and accurate monitoring of the instrument calibration. More importantly, T/P makes it possible to geographically map the spatial variations of VLF sea level [Nerem et al., 1999; Cabanes et al., 2001], though a better characterization and understanding of these patterns is still sought. It is difficult to detect the geographic “fingerprint” of long-term climate change signals using altimeter data from a single satellite mission such as T/P, because the mission length will probably be insufficient to easily differentiate these signals from interannual and decadal variations. Therefore, a multi-decadal time series of sea level derived from several altimeter missions will likely be required. Nevertheless, in the interim, the interannual to decadal VLF signals which T/P has detected over the last 8 years are of great interest in themselves because of what we can learn about short-term climate change. As the T/P mission generates a longer time series, much better separation of the interannual, decadal, and secular sea level signals will be possible. In addition, as we develop a better understanding of the interannual to decadal sea level variations, this will also help us identify the long-term climate change signals. Thus, it is the VLF sea level change currently being observed by T/P at interannual periods and longer which are the subject of this investigation [Nerem and Mitchum, 2000a; 2000b].

The primary objective of this investigation is to obtain a better understanding of the factors contributing to the VLF sea level changes observed by T/P and Jason-1. Part of our investigation considers the measurement/data analysis issues associated with accurately measuring VLF sea level change using satellite altimeter data. These issues include monitoring the altimeter calibration behavior, errors in the measurement corrections, and new data analysis techniques for extracting VLF changes. We have employed the global tide gauge network to develop better estimates of the behavior of the T/P altimeter calibration (figure 1), which complements other on-going calibration studies (e.g. the Harvest platform). Tide gauge data are an important resource, not only for instrument calibration, but also for tying different altimeter missions together, and understanding the sea level variations observed in the relatively short altimetry record in the context of the tide gauge observations of sea level rise over the last century [Mitchum, 1997]. We have also been stuyding the importance of a well defined terrestrial reference frame in this context, and especially the maintenance of this reference frame

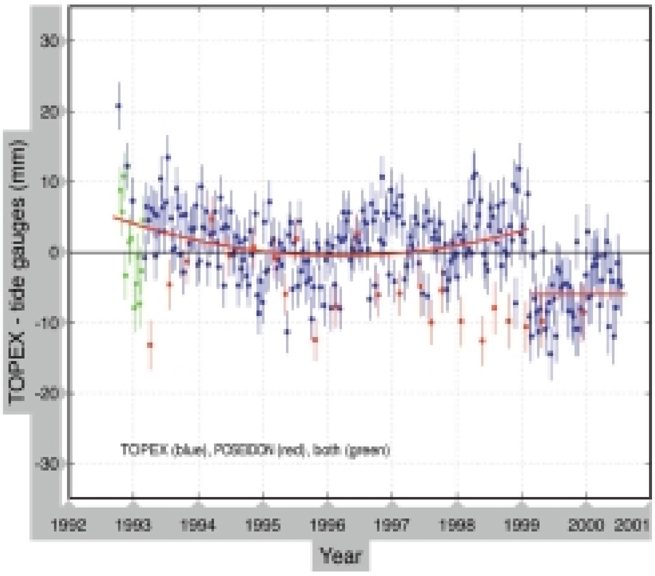

Figure 1: 10 day estimates TOPEX and POSEIDON altimeter calibration estimates computed from altimeter minus tide gauge sea level differences [Mitchum, 1994; 1998; 2000].

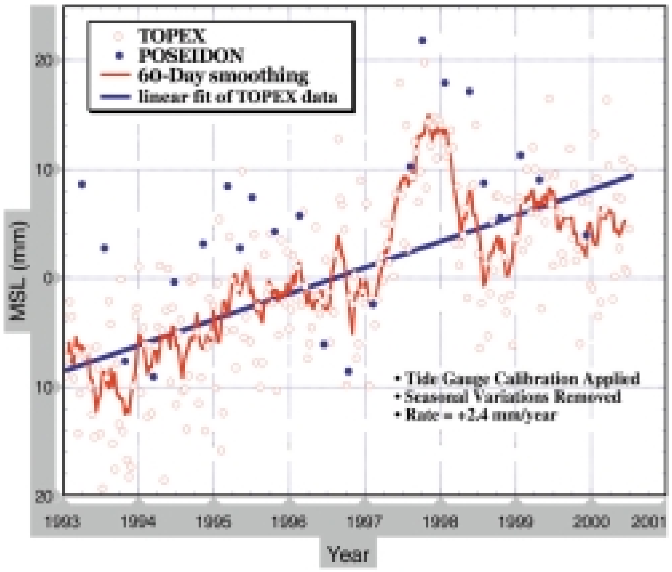

Figure 2: Variations in global mean sea level [Nerem, 1995a, 1995b; Nerem et al., 1999] from the TOPEX and POSEIDON altimeters after calibrating the measurements with the tide gauge calibration factors shown in figure 1. The dots show the 10 day sea level estimates, and the line is the same after smoothing with a 60 day boxcar filter.

over the several decades of precise altimetry required to detect climate change signals [Nerem et al., 2000]. With appropriate monitoring of the altimeter calibration, we can more confidently use statistical analysis techniques (e.g. filtering theory, principal component analysis, etc.) to extract and characterize the VLF sea level changes contained in the altimeter data records [Nerem et al., 1997; 1999].

Figure 2 shows variations in global mean sea level observed over the first 8 years of the T/P mission [Nerem et al., 1999]. The 15-20 mm rise, and subsequent fall, of mean sea level during the 1997-1998 ENSO event was interesting in itself, but also somewhat dissappointing since it will require us to have a much longer time series of altimeter measurements in order to average through the ENSO events and detect the true long term change. Our investigation is focused on gaining an understanding of the observed VLF sea level changes, which is important for studies of short-term climate change, and also has implications for uncovering the long-term climate change signal imbedded in the relatively short altimetry time series.
We have compared the observed VLF sea level changes to various in-situ measurements (e.g., SST, hydrography, tide gauges) (figure 3) and numerical ocean models in order to evaluate possible causes for the observed variations, such as changes in heat content [Chen et al., 1998; Minster et al., 1999], hydrologic contributions [Chambers et al., 2000], large scale ENSO responses [Nerem et al., 1999], etc. We are also assimilating the altimeter data into a modified MOM2 ocean model in an attempt to simulate the observed VLF variations.
These simulations are a powerful tool for studying the factors driving the VLF changes [Nerem et al., 1999].

Unquestionably, in explicitly focusing on the longest time scales possible, this investigation addresses a difficult objective given the relatively short time series of precise satellite-observed sea level. However, with 8 years of data in hand, and the prospect of the Jason-1 continuing this record, this is an excellent time to study of VLF sea level changes. We have planned a comprehensive effort employing multi-mission satellite altimetry, tide gauge data, models of sea level change, and advanced statistical analysis techniques that has an excellent chance of significantly advancing our understanding of VLF sea level change and its causes. Also, the team has been explicitly chosen in order to bring different areas of expertise to bear on the problem, including members with experience in geodesy and oceanography, and in data analysis and numerical modeling.

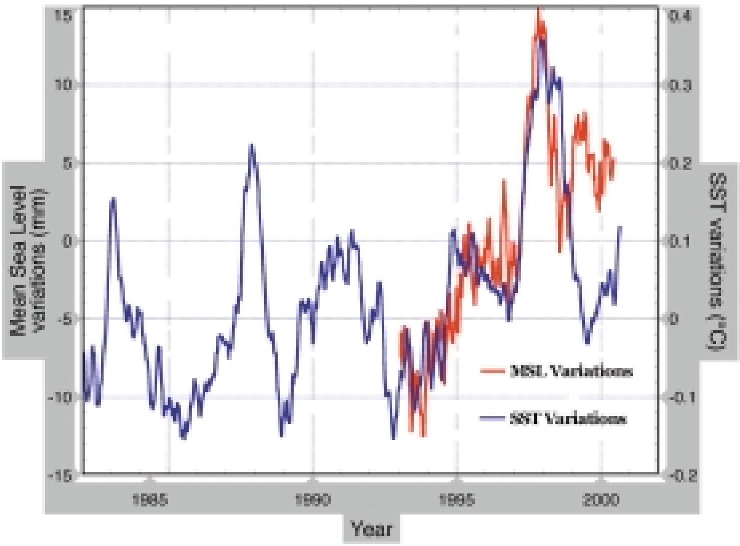

Figure 3: Comparison of variations in global mean sea level (red) [Nerem et al., 1999] and global mean sea surface temperature (blue) [Reynolds and Smith, 1994], both smoothed with a 60 day boxcar filter (seasonal variations removed).

References

Cabanes C., A. Cazenave, C. Le Provost, 2001: Sea level change from TOPEX/ POSEIDON altimetry for 1993-1999 and possible warming of the southern oceans, *Geophys. Res. Lett.*, 28 (1), 9-12.

Chambers D.P., J. Chen, R.S. Nerem, B.D. Tapley, 2000: Interannual mean sea level change and the Earth's water mass budget, *Geophys. Res. Lett.*, 27 (19), 3073-3076.

Chen J.L., C.R. Wilson, D.P. Chambers, R.S. Nerem, B.D. Tapley, 1998: Seasonal global water mass budget and mean sea level variations, *Geophys. Res. Lett.*, 25 (19), 3555-3558.

Minster J.F., A. Cazenave, Y.V. Serafini, F. Mercier, M.C. Gennero, P. Rogel, 1999: Annual Cycle in Mean Sea Level from TOPEX/POSEIDON and ERS-1: Inference on the Global Hydrological Cycle, *Global and Planetary Change*, 20, 57-66.

Mitchum G.T., 1994: Comparison of TOPEX sea surface heights and tide gauge sea levels, *J. Geophys. Res.*, 99 (C12), 24,541-24,554.

Mitchum G.T., 1997: A Tide Gauge Network for Altimeter Calibration, in *IGS/PSMSL Sea Level Workshop, edited by R. Neilan, P. Woodworth,* and P. Van Scoy, Jet Propulsion Laboratory, Pasadena, California.

Mitchum G.T., 1998: Monitoring the Stability of Satellite Altimeters with Tide Gauges, *J. Atmos. and Oceanic Tech.*, 15 (June), 721-730.

Mitchum G.T., 2000: An Improved Calibration of Satellite Altimetric Heights Using Tide Gauge Sea Levels with Adjustment for Land Motion, *Marine Geodesy*, 23, 145-166.

Nerem R.S., 1995a: Global Mean Sea Level Variations from TOPEX/ POSEIDON Altimeter Data, *Science*, 268, 708-710.

Nerem R.S., 1995b: Measuring global mean sea level variations using TOPEX/POSEIDON altimeter data, *J. Geophys. Res.*, 100 (C12), 25,135-25,152.

Nerem R.S., K.E. Rachlin, B.D. Beckley, 1997: Characterization of Global Mean Sea Level Variations Observed by TOPEX/POSEIDON Using Empirical Orthogonal Functions, *Surveys in Geophys.*, 18, 293-302.

Nerem R.S., B.J. Haines, J. Hendricks, J.F. Minster, G.T. Mitchum, W.B. White, Improved determination of global mean sea level variations using TOPEX/ POSEIDON altimeter data, *Geophys. Res. Lett.*, 24 (11), 1331-1334, 1997.

Nerem R.S., D.P. Chambers, E.W. Leuliette, G.T. Mitchum, B.S. Giese, 1999: Variations in Global Mean Sea Level Associated with the 1997-98 ENSO Event: Implications for Measuring Long Term Sea Level Change, *Geophys. Res. Lett.*, 26 (19), 3005-3008.

Nerem R.S., R.J. Eanes, J.C. Ries, G.T. Mitchum, 2000: The Use of a Precise Reference Frame for Sea Level Change Studies, in *Towards and Integrated Global Geodetic Observing System (IGGOS)*, edited by R. Rummel, H. Drewes, W. Bosch, and H. Hornik, pp. 8-12, Springer-Verlag, Munich.

Nerem R.S., G.T. Mitchum, 2000a: Observations of Sea Level Change from Satellite Altimetry, in *Sea Level Rise: History and Consequences*, edited by B.C. Douglas, M.S. Kearney, and S.P. Leatherman, pp. 121-163, Academic Press.

Nerem R.S., G.T. Mitchum, 2000b: Sea Level Change, in *Satellite Altimetry and Earth Sciences*: A Handbook of Techniques and Applications, edited by L. Fu, and A. Cazenave, pp. 329-349, Academic Press.

Reynolds R.W., T.S. Smith, 1994: Improved global sea surface temperature analysis, *J. Climate*, 7, 929-948.

Corresponding author:
R.S. Nerem
Colorado Center for Astrodynamics Research and Department of Aerospace Engineering Sciences, University of Colorado at Boulder
UCB431, Boulder
Colorado 80309-0431 - USA
E-mail: nerem@colorado.edu