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Estimating the ocean flow field from combined sea surface temperature and sea surface height data

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Final Project Report

This project was part of a previous grand at MIT that was moved over to the Scripps Institution of Oceanography together with the PI. The the final report provided here is concerned only with the work performed at SIO since January 2000.

The primary focus of this project was the study of the three-dimensional, absolute and time-evolving general circulation of the global ocean from a combined analysis of remotely sensed fields of sea surface temperature (SST) and sea surface height (SSH). The synthesis of those two fields was performed with other relevant physical data, and appropriate dynamical ocean models with emphasis on constraining ocean general circulation models by a combination of both SST and SSH data.

The central goal of the project was to improve our understanding and modeling of the relationship between the SST and its variability to internal ocean dynamics, and the overlying atmosphere, and to explore the relative roles of air-sea fluxes and internal ocean dynamics in establishing anomalies in SST on annual and longer time scales. An understanding of those problems will feed into the general discussion on how SST anomalies vary with time and the extend to which they interact with the atmosphere.

The data sets analyzed as part of this project were the Reynolds and Smith (1994) SST analysis as provided by the National Center for Environmental Prediction (NCEP) on a weekly basis, and 10-day averaged SSH fields observed by the TOPEX/POSEIDON altimeter mission. We used those fields alone for data-based studies and in combination with NCEP surface forcing fields. We also used them in combination with a numerical model in model-data assimilation approaches. A first publication from that analysis was published in 2001 (*Leeuwenburgh and Stammer*, 2001; see attached copy). In that paper, we investigate regional and global-scale correlations between observed anomalies in sea surface temperature and height. A strong agreement between the two fields is found over a broad range of latitudes for different ocean basins. Both time-longitude plots and wavenumber-frequency spectra suggest an advective forcing of SST anomalies by a first-mode baroclinic wave field on spatial scales down to 400 km and time scales as short as 1 month. Even though the magnitude of the mean background temperature gradient is determining for the effectiveness of the forcing, there is no obvious seasonality that can be detected in the amplitudes of SST anomalies. Instead, individual wave signatures in the SST can in some cases be followed over periods of two years.

The phase relationship between SST and SSH anomalies is dependent upon frequency and wavenumber and displays a clear decrease of the phase lag toward higher latitudes where the two fields come into phase at low frequencies. Estimates of the damping coefficient are larger than generally obtained for a purely atmospheric feedback. From a global frequency spectrum a damping time scale of 2-3 month was found. Regionally results are very variable and range from 1 month near strong currents to 10 month at low latitudes and in the sub-polar North Atlantic. Strong agreement is found between the first global EOF modes of 10 day averaged and spatially smoothed SST and SSH grids. The accompanying time series display low frequency oscillations in both fields.

We recently started to investigate the quality of the TRMM SST field (TMI) as provided by F. Wentz. A first analysis addressed the quality of this new SST fields. As shown by *Stammer, Wentz and Genteman* (2002a) the TMI fields, depite there lower spatial resolution, are superior to the Reynolds and Smith SST fields due to a lesser degree of averaging or smoothing (see also *Stammer, Wentz and Genteman*; 2002b). The paper provides a comparison between recent SST observations obtained from the TRMM microwave imager with the commonly used *Reynolds and Smith* (1994) SST analysis and in situ data that highlight the significant improvement of microwave SST observations above what can be obtained from infrared technology. The largest benefit of the microwave technology clearly comes from the unprecedented near all-weather sampling of ocean phenomena that yields measurements of the oceans SST without the heavy smoothing in space and time that traditionally is being applied to close data gaps resulting from clouds and lead to fields that resolve only features on spatial scales larger than approximately 1000km wavelength.

Our comparison of the new TMI fields with the *Reynolds and Smith* (1994) analysis results in a global mean offset of 0.18°C and a global STD difference of 0.54°C. However, regionally we find STD differences between both SST fields that reach 1°C or more, a number that is significantly larger than the error specification of either data set alone. We obtain global STD differences between *Reynolds and Smith* (1994) and in situ data of 0.55°C as compared to only 0.45 °C from TMI fields. Moreover, *Reynolds and Smith* (1994) uncertainties are highly time dependent and spatially varying, revealing a clear seasonal cycle with amplitudes varying by 0.35°C around 25°latitude on the annual cycle in both hemispheres. Of concern is also the apparent drift in the *Reynolds and Smith* (1994) analysis with respect to in situ measurements to in situ observations that shows a relative cooling of about 0.2°C over 3 years over parts of the southern hemisphere where interannual SST changes actually show the opposite trend.

To provide an example of spatial variations in the new SST fields, Fig. 1 displays typical difference fields between TMI and Reynolds observations from eastern tropical Pacific and the Indian Ocean along with the individual TMI and *Reynolds and Smith* (1994) fields. Differences of ± 2°C and more are quite common over large fractions of the panels. In the Arabian Sea every year a distinct eddy-like feature appears in the Somali Basin in late summer that is usually being referred to as the "Great Whirl". An anomalous dipole mode in the Indian Ocean SST field with warmer than normal water in the western Indian Ocean and cooler than normal waters in the eastern basin are believed to be responsible for heavy rain fall over east Africa and a weaker monsoon over the Indian continent (*Webster et al.*, 1999; *Murtugudde et al.*, 2000; *Saji et al.*, 1999). Detailed information about SST variations are therefore critical for many countries around the Indian Ocean. As can be seen from Fig. 1a the TMI data from late September of 1998 show a filament of cold water reaching from the coast of Somali into the Somali basin as is typical for the development of the Great Whirl. At the same time the northern Arabian Sea is characterized by a ridge of warm water reaching zonally across the basin. Both features are fairly underrepresented in the respective *Reynolds and Smith* (1994) field (Fig. 1c) and exist there only on large spatial scales. Accordingly, the difference field

Fig. 1

is dominated by those and other similar small-scale features that represent real physical signals in the TMI data (Fig. 1e).

A second example is provided from the eastern tropical Pacific from 15. September, 1999. In this region cold water appears first near the continental coats and then propagates westward along the equator. Those phenomena are associated with instability events of the regional circulation that are usually referred to as tropical instability waves (TIW). Both the cold tongue and the smaller-scale anomalies associated with the instability waves are clearly visible in the temperature anomalies from the 15th of September, 1999 (Fig. 1b). Note again the cold small-scale SST anomalies in the TMI field close to the Central American continent as they result from the Tehuanapec and Papagayo wind jets and related mixing and up-welling. Again all those smaller-scale structures associated with ocean dynamics are severely under-represented in the *Reynolds and Smith* (1994) field.

Dynamical features present in SST fields are thus preserved in an unprecedented way and open up completely new ways of analyzing and understanding SST anomalies and their relation to ocean dynamics (*Leeuwenburgh and Stammer*, 2002).

Purely empirical studies, such as described above, are a necessary first step to test the remote sensing data against in-situ ocean observations and against models of the upper ocean physics build into general circulation models. To study the impact of SST data on the estimated state monthly mean SST data (Reynolds and Smith, 1994) have been included in the estimation procedure as part of this project. Results summarized in Stammer et al. (2002a,b,c) show that the overall model-data misfit is substantially reduced through the inclusion of SST data, especially when a full KPP mixed layer model was used.

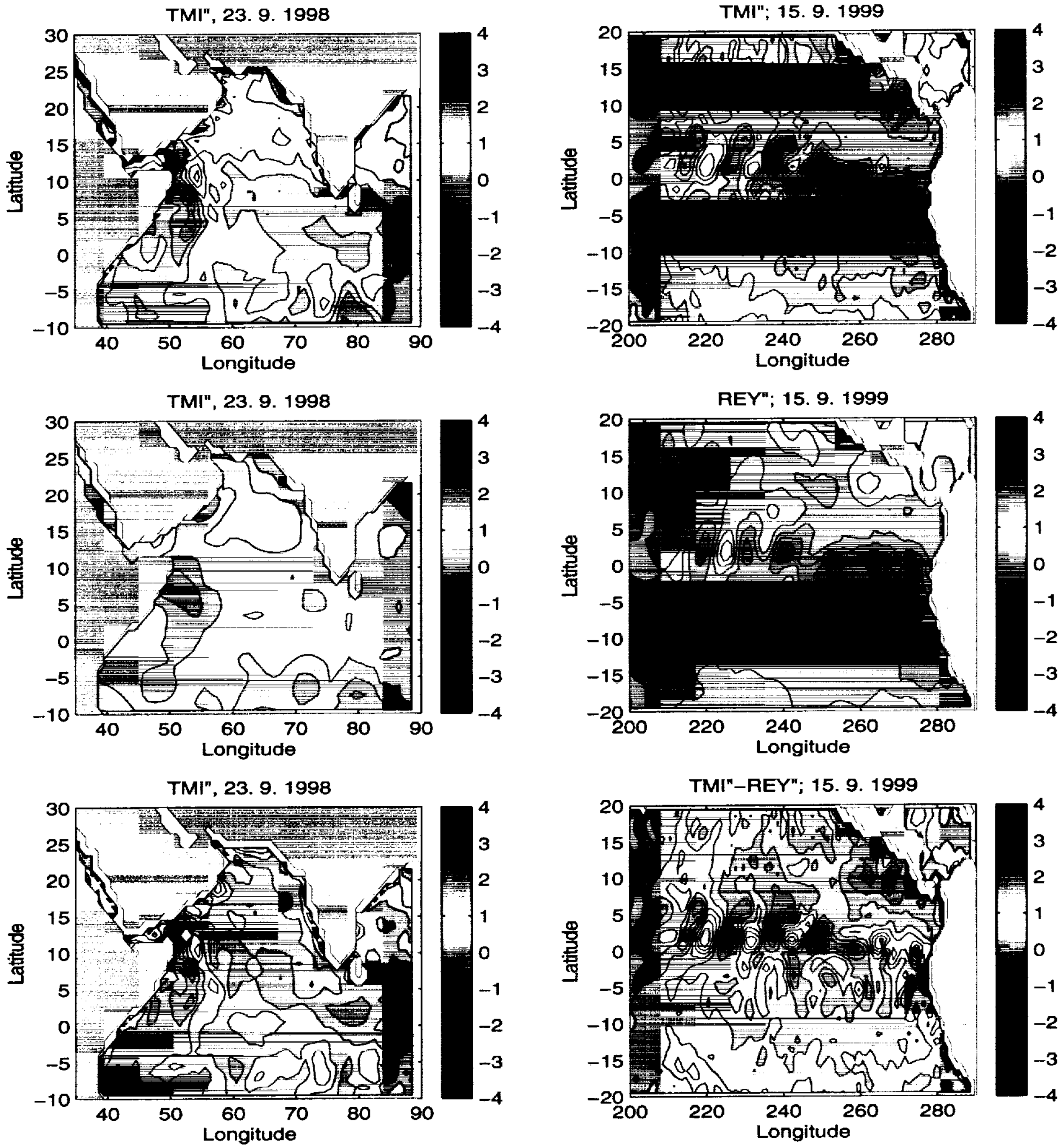

Figure 1: Top: non-seasonal TMI SST anomalies shown (left) from the 23. September, 1998 in the Indian Ocean, and (right) from the 15. September, 1999 in the tropical Pacific. Middle: similar fields, but from the *Reynolds and Smith* (1994) analysis. Bottom: difference fields TMI - RS94. Contour interval: 0.5°C in all panels.

References

Leeuwenburg, O., and D. Stammer, 2000: Ocean Currents Affect Sea Surface Temperature, *J. Phys. Oceanogr.*, 28, Part 2, 2340–2358.

Leeuwenbourgh, O., and D. Stammer, 2002: Rossby Waves Observed Through new TMI SST Fields, in preparation.

Reynolds, R. W., and T. M. Smith, 1994: Improved global sea surface temperature analysis using optimum interpolation. *J. Climate*, 7, 929–948.

Stammer, D., F. Wentz and C. Gentemann, 2001: Validation of new Microwave SST measurement for climate purposes, *Journal of Climate*, submitted for publication.

Stammer, D., F. Wentz and C. Gentemann, 2002: New microwave SST measurement for climate research, *Bulletin of the American Meteorological Society*, to be submitted for publication.

Stammer, D., C. Wunsch, R. Giering, C. Eckert, P. Heimbach, J. Marotzke, A. Adcroft, C.N. Hill, and J. Marshall, 2002, The global ocean circulation during 1992 –1997, estimated from ocean observations and a general circulation model, *J. Geophys. Res.*, in press.

Stammer, D., C. Wunsch, R. Giering, C. Eckert, P. Heimbach, J. Marotzke, A. Adcroft, C.N. Hill, and J. Marshall, 2001: Volume, Heat and Freshwater Transports of the Global Ocean Circulation 1992 –1997, Estimated from a General Circulation Model Constrained by WOCE Data, submitted for publications.

Stammer, D., K. Ueyoshi, W.B. Large, S. Josey and C. Wunsch, 2002, Global sea surface flux estimates obtained through ocean data assimilation, *Bulletin of the American Meteorological Society*, submitted for publication, 2001.