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Reflecting on the First Three Years of TOPEX/POSEIDON

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The U.S./France TOPEX/POSEIDON (T/P) satellite, in orbit since August 1992, is the first global ocean observing system specifically designed to study ocean dynamics. The satellite uses a state-of-the-art radar altimeter system to determine the sea level—the height of sea surface relative to a reference ellipsoid—with an unprecedented accuracy. It is supplying a

made by *Wunsch and Stammer* [1995]. A major characteristic of the spectrum is a ridge of variance at the annual period for wavelengths ranging from 500 to 10,000 km. Appreciable energy levels are revealed at shorter periods as well. The spatial pattern of the annual cycle was studied by many investigators. A hemispheric asymmetry in the amplitude is ob-

Fu, 1995]. At lower frequencies, the large-scale variability exhibits predominantly westward phase propagation, a characteristic of Rossby waves. At high latitudes, the phase speeds of these waves are found to be 2–3 times faster than theoretical predictions based on standard theory [*Chelton and Schlax*, 1996]. This indicates that the response of high-latitude ocean to tropical events such as El Niño is much faster than previously thought. In the Antarctic Circumpolar Current, evidence of eastward propagation due to the effect of mean flow on Rossby waves was reported for the first time [*Hughes*, 1995].

T/P is leading to many new findings about the energetics of ocean currents. *Qiu* [1995] reported a linear increase in eddy energy south of the Kuroshio Extension as a result of conversion of mean flow kinetic energy via instability.

generally less than the observation by a factor of 2 or more. The discrepancy is most pronounced in eddy-rich regions, but its causes

between the western equatorial Pacific and the eastern Indian Ocean. The comparison with the Davao-Darwin sea level index indi-

hydrographic estimates at scales larger than about 2500 km (R. Rapp, personal communication, 1996). The T/P results have thus provided

These sea level changes at interannual timescales make it impossible to use the current data set to detect long-term sea level rise caused by possible global warming, and it underscores the need for acquiring a multidecadal, multimission time series of altimeter data of T/P quality.

The patterns of sea level change shown in Figure 1 are the leading mode of variability after the annual and semiannual signals are removed from the data. This mode of sea level change is coherent in space and time with the sea surface temperature (SST) signal, which was rising at a globally averaged rate of 0.07°C/year during 1993–1994 [*Nerem*, 1995]. This suggests that the sea level signal is probably related to the warming of the ocean. Taking the higher rate of sea level rise of 4–6 mm/year, the sea level to SST drift ratio is 6–9 cm/°C. Given typical values of the seawater thermal expansion coefficient and assuming that the SST drift signal is correlated with the temperature evolution below the surface, this ratio typically requires a temperature change over a layer 300–450 m thick. This seems large, since the timescale of these observed variations is short compared to the timescale needed for heat invasion in such a layer. Of course, SST may be a poor indicator of subsurface signals, especially in the tropics. However, taking the lower bound of the estimated sea level rise at 2 mm/year, only a layer of 150 m would need to be heated, which is more realistic. The correlation between sea level and SST signals is encouraging and indicates that actual oceanographic interannual variations are being observed.

T/P data suggest that the seasonal variation of the mean sea level is very small. Yet, mean SST shows a seasonal signal of 0.5°C in amplitude, which should induce a seasonal steric height signal of the order of 5 mm amplitude (assuming an average mixed layer depth of 50 m). However, seasonal water mass transfer to

this steric height effect. In fact, T/P data might provide useful information on the latter, which is poorly known.

Future Work

NASA plans to operate the T/P satellite through at least 1998, providing up to 6 years' worth of data. Among many fruitful applications of this growing data set, an enterprise should develop in which the data are used with computer models for routine global ocean analysis and predictions. To make a real impact on understanding the global ocean change and its role in climate, global observing systems of the quality of T/P need to be maintained in the future. The dynamic boundary condition for ocean circulation provided by altimetry is crucial for a global climate observing system. A follow-on mission to T/P is currently being developed by France and the United States with its launch planned for 1999.

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