Application of TOPEX/POSEIDON Altimetry Measurements to Observational and Modeling Studies of the Low-Frequency Upper Ocean Mass and Heat Circulation in the Tropical Pacific

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I. Introduction

The importance of the El Niño/Southern Oscillation (ENSO) phenomenon in year-to-year variations of the Earth's climate is now recognized. This phenomenon is characterized by the huge transport of mass and heat over the tropical Pacific basin; this transport drastically modifies ocean-atmosphere interactions. Despite the concentration of in situ measurements in the tropical Pacific Ocean during the first five years of the Tropical Ocean and Global Atmosphere (TOGA) international program, synoptic measurements of currents over the whole ocean are still lacking. Since these currents are in quasi-geostrophic equilibrium at low frequency, their intensity and corresponding variation could be monitored from dynamic height topography and hence from satellite altimetry. In turn, accumulation of measurements during TOGA and the ongoing TOGA–Coupled Ocean-Atmosphere Experiment (COARE) in the western Pacific, will help tremendously in calibrating altimetry measurements.

The main purpose of the proposed work is to describe the seasonal and interannual variability of the upper ocean mass and heat transport in the tropical Pacific and to understand the mechanisms responsible for these transports. This will be done through a combination of experimental and modeling approaches. Remotely sensed sea level and derived currents, observed on the basin scale, will be compared, analyzed, and combined with routine and enhanced in situ measurements of thermal and current fields, as well as with model solutions forced by satellite-derived estimates of momentum and heat fluxes. The practical scientific rationale for this work stems from the unique data sets collected by (or easily available to) the investigator's team, and from the team members' complementary backgrounds (physical oceanography and meteorology) and expertise (in situ and satellite-observation analysis and numerical ocean modeling).

II. Research Plan

Our investigation will first evaluate and, we hope, improve sea level and surface current data derived from TOPEX/POSEIDON measurements. As part of the prelaunch studies, preliminary calculations were performed using data from the first 22 cycles of the Geostat Exact Repeat Mission (November 1986 through November 1987). The corresponding altimetry sea level has been compared with various in situ estimates of sea level in the western equatorial Pacific (Delcroix et al., 1991). These sea level estimates were dynamic heights calculated from thermistor-chain mooring measurements, conductivity/temperature/depth (CTD) cruise measurements, and expendable bathythermograph (XBT) measurements taken as part of the tropical Pacific Ship-of-Opportunity Programme (SOP). Furthermore, a comparison between in situ currents, measured from moorings and drifting buoys (Figure 1), and altimetry-derived surface currents demonstrates that a reasonable estimate of zonal current at the equator can be obtained from altimeter data (Picaut et al., 1990).

The previous intercomparison will be extended to the complete data set of the Geosat altimeter (up to January 1989) and later to the improved TOPEX/POSEIDON altimeter.

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Since 1987, the number of in situ measurements in the tropical Pacific Ocean has increased. As part of the TOGA–TAO (Tropical Ocean Atmosphere) array, there are presently 19 Autonomous Line Acquisition System (ATLAS) thermistor-chain moorings in the tropical Pacific (Hayes et al., 1991). The TOGA current-meter mooring array now includes five equatorial moorings (World Climate Research Programme (WCRP), 1990a), and more TOGA cruises have been conducted recently in the tropical Pacific. The launch of TOPEX/POSEIDON in mid-1992 will greatly benefit from the TOGA–COARE in the Western Pacific (WRCP, 1990b). The COARE Intensive Observation Period (IOP, November 1992 through February 1993), embedded in a period of enhanced monitoring, will provide the best ocean and atmosphere data set for altimeter calibration in the tropics. The present investigators are involved in this international experiment. The ATLAS–TAO and current-meter arrays will be augmented in the COARE domain (10°N to 10°S, 140°E to 180°); CTD and current profiler cruises will be conducted during the IOP. Drifting buoys will be launched in the COARE domain. Thermosalinographs, added on the corresponding moorings and on the XBT-SOP, will enable a better estimate of dynamic height from temperature profiles. In addition, the expected continuation of the TOGA moored current-observing array and the anticipated deployment of 65 ATLAS moorings within the equatorial Pacific wave guide to complete the TOGA–TAO array will provide an excellent in situ verification data set for TOPEX/POSEIDON until the termination of TOGA (December 1994).

After being evaluated and improved, the altimetery estimates of sea level and derived surface current will be used to describe and understand the four-dimensional variability of mass and heat transport in the tropical Pacific Ocean. Various fields of oceanic parameters and ocean-forcing functions will be first produced over the whole tropical Pacific on similar grid size. When possible, these fields will be conducted on a finer grid over the COARE domain. Filtering in space and time of the original altimeter data and an objective analysis procedure will be improved according to results of previous evaluations. Sea level and surface geostrophic current fields will be produced over the tropical Pacific basin, probably on a weekly basis. The method developed by Deleroix and Gautier (1986) will be corrected from salinity variation in the surface layer to derive the heat content field from the sea level field. Salinity fields will thus be constructed from all available sources (at the surface from SOP measurements and, if feasible, from the satellite estimate of precipitation, and near the surface from CTD cruises and moorings). The satellite surface heat flux field will be provided, following the procedure developed by Gautier (1984) and improved in the ongoing Tropical Heat Exchange Programme (THEP). Finally, as a major atmosphere tropical ocean forcing function, gridded wind stress fields derived from various data sets (e.g., ship measurements, moorings, and satellite estimates) and operational analyses will be generated and/or assembled by the present investigators.

Descriptive and statistical studies of the aforementioned fields will be a first step toward a better comprehension of the seasonal and interannual variation of mass and heat transport in the tropical Pacific. Following a prelaunch study (Deleroix et al., 1991), special emphasis will be placed upon the importance of Kelvin and Rossby waves on the redistribution of mass and heat in the tropical Pacific. Besides, modeling experiments will be conducted to gain a more rigorous mechanistic interpretation of these variations and to construct, on a global grid, subsurface temperature and current information that could not be provided from satellite and sparse in situ measurements alone. The availability of such subsurface information, especially for currents, would greatly improve the potential of the TOPEX/POSEIDON satellite measurements.

To address this last goal, we will start by calculating the low-order vertical model structure from sea level and a few subsurface temperatures demonstrated by Hayes et al. (1985). The structure will be tested at sites with sufficient relevant observations (e.g., sea level, CTD, and mooring data); if successful, the results will be applied to the whole tropical Pacific. The modeling component of this proposition will use two ocean models. Busalacchi and O'Brien (1981) were the first to demonstrate that wind-driven linear model results can account for a significant portion of the El Niño variations in dynamic topography and sea level. An updated multivertical mode version of this model (Busalacchi et al., 1990) will be used to describe and interpret the strictly dynamic response to the tropical Pacific Ocean.

The hydro- and thermodynamic response will be inferred from a reduced gravity primitive-equation model consisting of several layers in the vertical and a surface mixed layer with active thermodynamics. This model will be forced by surfacing fluxes of momentum and heat. Comparison will be made with direct current measurements and altimeter-derived surface currents to identify and quantify where and when geostrophic contributions are important, and, by so doing, provide a determination of where altimeter-derived geotrophic currents can be used with confidence to describe the ocean circulation. Given sea level altimetry and our numerous in situ observations, model data assimilation is probably the best way to extend the satellite information in the subsurface layer.

Thus, prior to launch, assimilation schemes for sea level and sea surface temperature will be implemented and tested. Error analysis would be an important aspect of this task since it would determine the accuracy of such extrapolation. Finally, and given the near real-time availability of many of our in situ and satellite data, forecast studies would be attempted with both ocean models.

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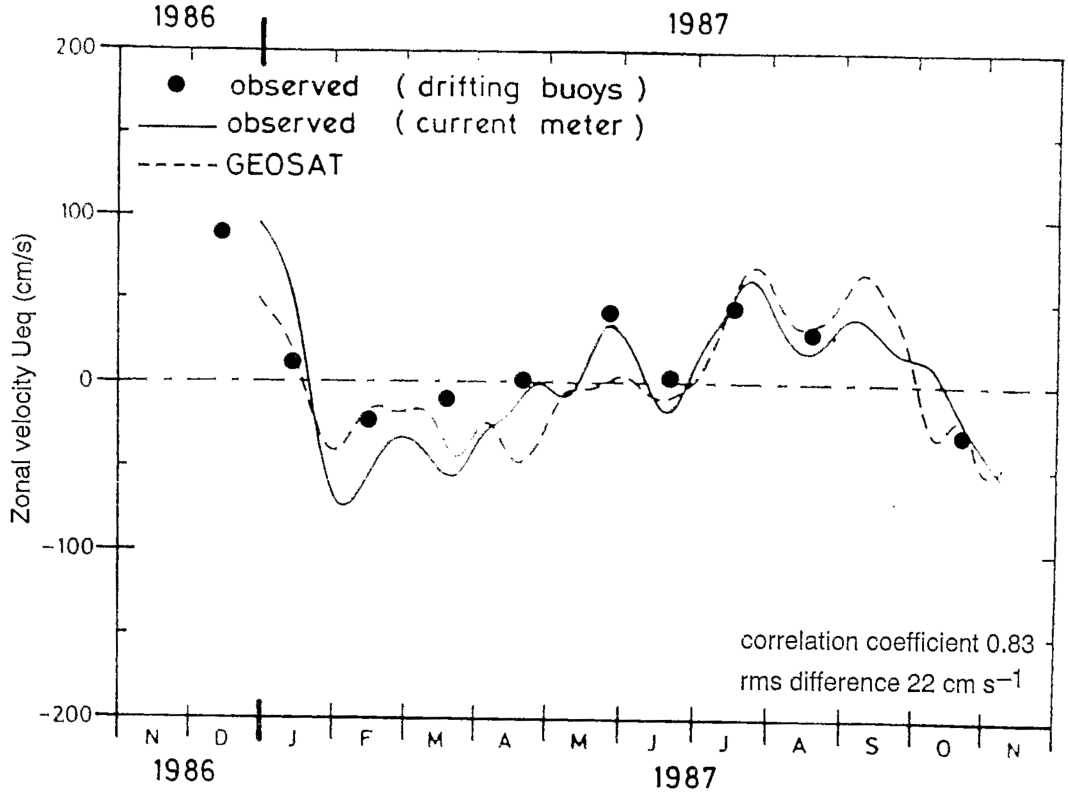

Figure 1. Low-pass-filtered geostrophic zonal flow estimated from Geosat altimeter data (dashed) and near-surface zonal flow measured directly from an equatorial mooring at 165°E (solid line). The dot represents the monthly mean surface current derived from drifting buoys within a 162°E to 167°E, 1°N to 1°S box.