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H. Rigorous Open-Ocean Validation of TOPEX/POSEIDON Sea Level in the Western Equatorial Pacific: J. Picaut, A. J. Busalacchi, T. Delcroix, and M. J. McPhaden

1. Rationale

The TOPEX/POSEIDON mission is projected to yield a 2-cm sea-level accuracy for studying meso- and large-scale phenomena. Such an accuracy is a minimum to quantify low-latitude surface currents, owing to the vanishing Coriolis force toward the equator.

In light of the Geosat mission, all in-situ sea-level estimates will result in an error of 3 to 7 cm. These estimates rely on various techniques of measurement, which indeed are subject to specific limitations. Sea level, deduced from island tide gauge data, is contaminated by current–island and shelf effects. Dynamic height time series, obtained from mooring, XBT, CTD, and IES data, capture only the steric sea-level contribution. Moreover, the significance of the series is altered by technical constraints such as reference level, the use of mean TS, and inadequate time/vertical sampling. Thus, there is a fundamental difference between the anticipated TOPEX/POSEIDON accuracy and our present observational means for validation.

At the recent TOPEX/POSEIDON meeting in Toulouse (October 1991), it was quite obvious that the TOPEX/ POSEIDON Project has no present plans for the validation of open-ocean sea-level variability. As a contribution to the TOPEX/POSEIDON Verification Phase, we propose an experiment which would provide sea-level measurements in the western equatorial Pacific with a 1-cm accuracy. It would be the only rigorous open-ocean validation study being sponsored by the TOPEX/POSEIDON Project. The experiment would be conducted during the 6-month Verification Phase. It would strongly benefit from the scientific and logistic aspects of the TOGA–COARE unprecedented ocean–atmosphere experiment (e.g., half of the total cost of the proposed experiment is already funded as part of TOGA–COARE).

Space agencies such as NASA and CNES are often criticized for their practice of launching hardware into space at the expense or elimination of adequate in situ validation. In recognition of this, NASA Headquarters management has stated that going into the Earth Observation Satellite (EOS) era there will need to be increased reliance on interagency and international collaboration and cost sharing. This is particularly acute for ocean remote sensing where the logistics of in situ validation could prove prohibitive. Our proposed efforts are in direct response to the need for rigorous open-ocean validation of the TOPEX/POSEIDON altimeter-data retrievals. By leveraging existing observational programs, there is considerable interagency and international cost sharing. If we were unable to exploit these existing programs in the western Pacific, the true cost of this validation effort would increase by $300K and therefore would be cost prohibitive.

2. The Experiment

Two existing TOGA–Terre Atmosphère Océan (TAO) ATLAS moorings (Figure V-3), located at 2°S, 156°E and 2°S, 165°E, will be outfitted with additional dedicated instruments especially designed to capture sea level with a 1-cm accuracy at two TOPEX/POSEIDON crossover points. A series of surface-to-bottom temperature and salinity sensors along the mooring lines will provide the steric part of sea-level changes. The barotropic part will be deduced from bottom-pressure sensors. The atmospheric pressure effect will be estimated from surface-pressure sensors.

The two different sites are located in very different geographical settings. The 2°S, 165°E mooring is anchored on an abyssal plain (4400 m) far from a coast, whereas the 2°S, 156°E mooring is situated on the Ontong Java Plateau (1750 m) near the Kilinailau trench and at little more than a radius of deformation (400 km) from New Ireland and Bougainville islands. Sea-level intercomparison between these two different sites will provide essential information on bottom-induced barotropic and baroclinic effects and on-island, sea-mount, and trench geoid effects.

This is a critical experiment for the TOPEX/POSEIDON program, and the two sites are also necessary for redundancy in the event that one of the moorings is damaged or lost. Mooring losses are infrequent, but they nonetheless must be considered in designing any field program relying on moored instrumentation. In TOGA–TAO, over 30 moorings are presently maintained across the equatorial Pacific, and there are plans to expand this array to almost 70 moorings in the next 2 years. Loss of a single mooring in this array would represent only 3% of the data from the present array. For the TOPEX/POSEIDON validation study based on only one mooring, loss of that mooring would represent 100% of the data. Moreover, mooring losses are generally higher in the COARE region than elsewhere because of intensive commercial fishing by nations bordering the western Pacific. Thus, to ensure that our efforts produce at least one 6-month validation data set from the western Pacific, it is essential to fully instrument two sites (with backup flotation and double releases on each).

Historical background exists for the 2°S, 165°E original site, because numerous cruise and ATLAS mooring data have been collected since 1985. The data gathered at this site were used to evaluate Geosat in 1986–87 and also in a statistical study for the proposed experiment. The 2°S, 156°E ATLAS mooring, installed in September 1991, has the advantage of being situated at the center of the COARE Intensive Flux Array. This array will provide unprecedented ocean–atmosphere measurements, especially during the Intensive Observation Phase (IOP, November 1992–February 1993). From the ocean side, the measurements consist mainly of temperature, salinity, current, and turbulence taken from ships (8 to 15), moorings (30), and drifters (approximately 50). In the atmosphere, temperature, humidity, pressure, wind, rain, and radiation will be measured from numerous instruments installed on islands, ships, dropsondes, airplanes, and satellites. All these data will be made available to the COARE scientists in a timely manner (3 to 6 months) after the IOP. The TOPEX/POSEIDON Project will have lost a tremendous one-time opportunity if it does not take advantage of this suite of measurements for validation in the western equatorial Pacific.

In August–September 1992, the 2°S, 165°E and 2°S, 156°E ATLAS moorings will be replaced during the SURTROPAC-17 and COARE 156-3 cruises on board the French R/V Le Noroit (the original 2°S, 165°E mooring will be shifted to 164.5°E under a TOPEX/POSEIDON crossing point). Both moorings will be completed with additional sensors along the line and surface- and deep-pressure gauges as needed for the proposed experiment. All corresponding data will be retrieved in March 1993, at the end of the French COARE–POI cruise. The timing of this experiment is thus concomitant with the TOPEX/POSEIDON Verification Phase.

The present design of ATLAS thermistor chain moorings includes 11 temperature sensors in the upper 500 m and a meteorological unit. The daily averaged data are transmitted via ARGOS and sent on GTS. Estimates of 0/500-dbar dynamic height, derived only from these temperature measurements, will be compared in near-real time with TOPEX/POSEIDON sea level. This proposed work will be done for the 2°S, 15°E and 2°S, 164.5°E sites and also for the 30 to 50 TOGA–TAO ATLAS moorings located over the whole equatorial Pacific. However, due to the previously discussed limitations, these estimates of sea level will certainly result in a 4- to 7-cm error.

To obtain the 1-cm sea-level accuracy (total steric and pressure contributions), a series of additional temperature, salinity, and pressure sensors will be installed for the 2°S, 156°E and 2°S, 164.5°E sites, with 0.25- to 5-min time resolution to adequately resolve high-frequency waves. The number of additional temperature and salinity sensors is determined through a sampling study based on 13 (57) deep CTD casts made at (around) 2°S, 165°E over the last 6 years. Surface dynamic heights relative to the bottom are calculated from a series of discontinuous T,S points taken on the CTD profiles at the sensors' depths and compared to their values using the complete CTD profiles. Different calculations, made with various array designs, result in a standard error of 0.6 dyn cm for the following array. Because of important salinity variations in the first 500 m (Figure V-4), 10 SEACAT (T,S) units are needed between the ATLAS temperature sensors, themselves completed with interpolated salinity. From 500 m to bottom (1750 m at 2°S, 156°E; 4400 m at 2°S, 164.5°E), the salinity variations are small enough to use 7 (10) miniature temperature recorders (MTRs) and a mean T,S relationship. BPRs (bottom pressure gauges) will be installed near the two moorings and will result in a 0.3- to 0.5-cm barotropic sea-level accuracy, after pressure drift corrections. Flotation (Benthos) balls together with additional acoustic releases will complete the two ATLAS lines to recover all equipment (therefore the data) if the surface toroid happens to disappear because of vandalism, mechanical failure, or hurricane.

3. Participants

Although the participants are all members of the same TOPEX/POSEIDON scientific team, the intended validation experiment is separate from our existing TOPEX/POSEIDON science project and is submitted in recognition that the TOPEX/POSEIDON Project has no apparent plans for open-ocean validation of the TOPEX/POSEIDON altimeter retrievals. A notable advantage of the proposed work stems from the complementary backgrounds and expertise of the four participants (in situ and satellite observation analysis, and numerical ocean modeling) and from their ability to cooperate for the last 5 to 10 years.

Two members of the proposed work team have been for several years PIs of the TOGA–TAO mooring network in the western equatorial Pacific. This network, functional for TOGA objectives, was made possible by cooperation between ORSTOM and NOAA/PMEL. Modelling, in situ, and satellite data intercomparison extended this efficient collaboration to NASA/GSFC.

All members are strongly involved in the TOGA–COARE field and model studies, which enable them to have unlimited access to the corresponding ocean–atmosphere data set.

4. Data Processing and Analysis

Temperature and salinity data from SEACAT units will be calibrated with CTD measurements taken during the TOGA–COARE experiment and processed at ORSTOM–Noumea. Data from the ATLAS thermistor chains, MTR, and BPR will be prepared at NOAA/PMEL.

Time series of TOPEX/POSEIDON sea-level anomalies provided by the TOPEX/POSEIDON Verification Team will be compared to sea level derived from surface-to-bottom dynamic height and bottom pressure time series. The relative importance of pressure and steric components will be studied in conjunction with water masses, ocean bottom, and geoid variations.

Empirical and theoretical mode decompositions will be performed to determine the major modes of variation in the vertical structure. Models will then be used to retrieve subsurface and deep-ocean information from TOPEX/POSEIDON sea-level measurements.

Precise and continuous (time/depth) unprecedented T,S data will provide fruitful information relevant to TOGA–COARE objectives (e.g., barrier-layer, heat, and salt advection).

Differences between TOPEX/POSEIDON sea level and our rigorous in situ steric and pressure sea level could be used by TOPEX/POSEIDON engineers to refine instrumental and geophysical altimeter calibrations using all atmospheric and oceanic data collected during TOGA–COARE.