Application of Altimetry to Tropical Ocean Modeling and Climate Prediction

--- A New OSTST Project

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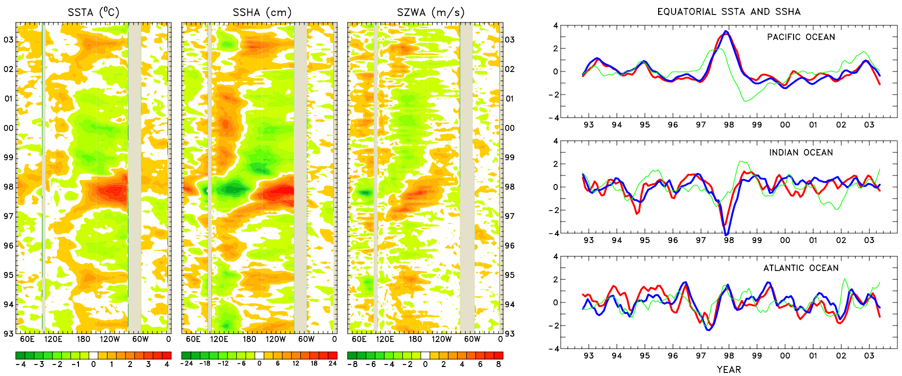
Introduction

Application of satellite remote sensing to climate study is still in its infancy, largely due to the limitation of data record being too short. Now that the combined T/P and Jason altimeter data set has become more than a decade long, we should be able to evaluate the impact of these data on a large range of time scales and in a systematic and quantitative manner. More importantly, we should further explore the possibility of applying these high-quality, high-resolution observations to real-time ocean modeling and climate prediction. This study focuses on the tropical oceans for two reasons: First, there are large interannual-to-decadal fluctuations in these oceans which have strong influences on regional and global climate; and second, altimetry data are likely to have a major impact here because of the important role of sea level in tropical ocean dynamics and climate variability. We will pay attention to climate fluctuations in all three tropical oceans, including the tropical Pacific El Niño-Southern Oscillation (ENSO), the tropical Atlantic variability which consists of an equatorial ENSO-like mode and an interhemisphere mode, and the tropical Indian variability which is dominated by a prominent Indo-Pacific mode. A hierarchy of model experiments, using an intermediate coupled model, an ocean general circulation model, and a hybrid coupled model, along with the Kalman filters for data assimilation, will be carried out to achieve our goals.



▲ **LEFT:** Anomalies of sea surface temperature (SSTA), sea surface height (SSHA) and surface zonal wind averaged 5^0S-5^0N for global equatorial oceans from 1993 to 2003. SSTA is from Reynolds analysis, SSHA from TP, and SZWA from a satellite scatterometer product that combines ERS-1, ERS-2 and QuikSCAT data. **RIGHT:** Zonal gradients of Reynolds SSTA (red) and TP SSHA (blue), and zonally integrated TP SSHA (green) in the equatorial Pacific (upper panel), Indian (middle panel), and Atlantic (lower panel) Oceans, as a function of time. The gradients are defined as the difference between the average values in two 10^0x10^0 boxes at the eastern and western ends of each ocean. All variables are normalized by their respective standard deviation.

Hypotheses

Based on theories, observational evidences, and previous empirical and modeling studies of the tropical climate variability, we have the following working hypotheses:

(1) Sea level contains the memory of the tropical Pacific ocean-atmosphere coupled system. Assimilating altimeter sea level data for model initialization can largely improve ENSO prediction. Of particular importance are the sea level variations in the western tropical Pacific, which serves as a long-lead precursor for El Niño/La Niña.

(2) Ocean dynamics, and hence sea level variations, play a significant role in the tropical Atlantic variability (TAV), which includes an interhemisphere decadal mode and an ENSO-like interannual mode. Analyzing and assimilating altimetry as well as historic sea level data will improve our understanding of TAV and its predictability.

(3) The dominant interannual variability in the tropical Indian Ocean region is part of a tropical Indo-Pacific mode (TIPM), which is characterized by opposite zonal gradients of sea level (and SST) in the Indian and Pacific Oceans. Better understanding of TIPM will lead to improved climate prediction in both oceans.

Objectives

The focus of this research is tropical climate prediction. Prediction is probably the most important purpose of developing models and observing systems; it is also the ultimate test for theories and models. In general, our objectives are:

(1) To investigate the dynamical aspects of the short-term climate changes in the tropics, with emphasis on the effects of sea level (thermocline depth) fluctuations;

(2) To evaluate the impact of the TP and Jason altimeter sea level data on global tropical ocean modeling and climate prediction on interannual to decadal time scales;

(3) To develop and implement advanced data assimilation techniques and procedures for coupled ocean-atmosphere models with particular attention to altimeter data; and

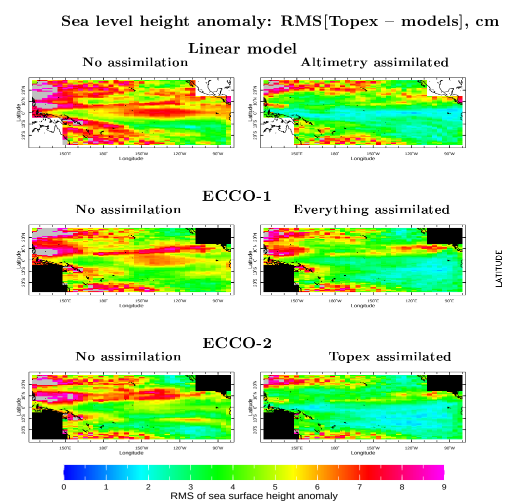
(4) To apply the TP and Jason data to operational forecasts of short-term climate changes in the global tropics, with particular emphasis on ENSO.

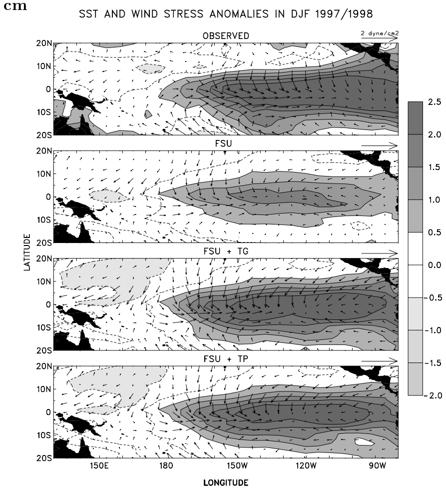
Approaches

(1) Three Models: An intermediate coupled model (LDEO5), an ocean general circulation model (LOAM), and a hybrid coupled model (LOAM plus a multivariate statistical atmosphere).

(2) Data Assimilation: Kalman filters implemented with both reduced space approximation (e.g., Cane et al., 1996; Kaplan et al., 2003) and ensemble approach (e.g., Evensen, 1994; van Leeuwen, 1999; Keppenne, 2000).

(3) Modeling strategy:
- **a) Process experiments (recharge paradigm, TAV, TOPM, inter-basin connection, etc., using various models);**
- **b) Impact experiments (twin-model experiments with and without assimilating altimetry data for all models);**
- **c) Sensitivity experiments (effects of mission transitions, and mean state correction using gravity mission data);**
- **d) Forecast experiments (real-time forecasts on a monthly basis with altimeter data assimilated).**





▲ **Preliminary Results: impact of sea level data assimilation.** **LEFT:** Root-mean-square errors between the TP altimetry (Cheney et al., 1994) and the model simulated sea level anomalies with and without data assimilation, for the linear tropical Pacific model of Cane and Patton (1984) and the MIT global OGCM in ECCO1-2 projects. **RIGHT:** Observed and forecast SST and wind stress anomalies in DJF 1997-98. Forecasts were made two seasons in advance, with only FSU winds, FSU winds plus tide gauge (TG) sea level, or FSU winds plus TP sea level for model initialization (Chen , 2001).