A Parameterization-oriented Approach to Inferring Entrainment Temperature from Altimeter Data: The Impact on Interannual Variability in a Coupled Model

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Abstract

The impact of using Topex/Poseidon/Jason (T/P/J) sea level (SL) data on interannual SST variability is examined using the intermediate ocean model and coupled model (ICM). The T/P/J SL data are used to improve an empirical parameterization of the temperature of subsurface water entrained into the mixed layer (T_e). The improved ocean model is coupled to a statistical atmospheric model that estimates wind stress anomalies from SSTAs. Results are compared using the empirical T_e models constructed from observed T/P/J and simulated sea level data for the periods 1993-2003 (T_e^{obs} and T_e^{mod}, respectively). Using the T_e^{obs} model, the coupled system exhibits more realistic properties of interannual variability (the oscillation period, spatial structure, and temporal evolution), consistent with the 1997-98 El Niño-Southern Oscillation (ENSO) evolution.

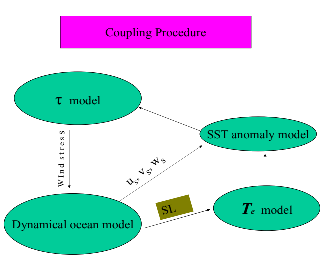
Introduction

T_e is one of the most important factors controlling SST variability in the tropical Pacific and remains a problem area for realistic sea surface temperature anomaly (SSTA) and ENSO simulations in ocean and coupled models. To improve such simulations, an empirical parameterization scheme has been developed for T_e. Previously, SL anomalies were taken from a model simulation forced by observed atmospheric winds and used to parameterize T_e. Model sea level obviously has systematic errors which can degrade SST simulations. Here we have used observed T/P/J sea level data to further improve T_e parameterization and therefore interannual variability simulations in the tropical Pacific. The improved SST model is embedded into an intermediate ocean model (IOM; Keenlyside & Kleeman, 2002), which is further coupled to an atmospheric model for better ENSO simulation.

A coupled atmosphere-ocean model

An intermediate coupled model (ICM) consists of an intermediate dynamic ocean model, a sea surface temperature (SST) anomaly model with an empirical parameterization for T_e, and a statistical atmospheric model that estimates wind stress anomalies from a SVD analysis.

All coupled model components exchange simulated anomaly fields. At each time step, the dynamical ocean model produces anomalous SL, mixed-layer averaged currents (u_s and v_s), and vertical velocity at the base of the mixed layer (w_s). *Te* anomalies are then parameterized from the SL anomalies. These current and *Te* anomalies, together with the prescribed climatology of mean currents and thermal fields, are passed to the SSTA model to calculate SST anomalies. The resultant SST anomaly is then used to calculate wind stress anomalies forcing the dynamical ocean model on the next time step.



An empirical T_e model:

An anomaly model describing SST changes in the mixed layer can be written as (Keenlyside 2001):

$$\frac{\partial T'}{\partial t} = -u'\frac{\partial \overline{T}}{\partial x} - (\overline{u}+u')\frac{\partial T'}{\partial x} - v'\frac{\partial \overline{T}}{\partial y} - (\overline{v}+v')\frac{\partial T'}{\partial y}$$
$$- \left\{(\overline{w}+w')M(-\overline{w}-w') - \overline{w}M(-\overline{w})\right\}\frac{(\overline{T_e}-\overline{T})}{H}$$
$$- (\overline{w}+w')M(-\overline{w}-w')\frac{(T_e'-T')}{H} - \alpha T'$$
$$+ \frac{\kappa_h}{H}\nabla_h\cdot(H\nabla_h T') + \frac{2\kappa_v}{H(H+H_2)}(T_e'-T')$$

T_e: *the Temperature of water entrained into the mixed layer*

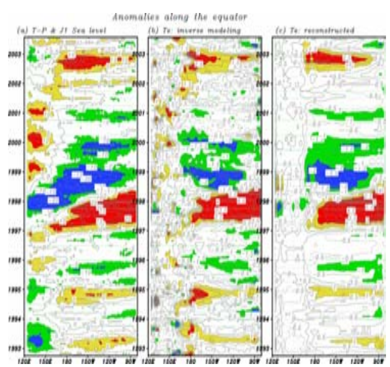
Since its geographic distribution & temporal evolution are not available from observations, T_e anomalies can be parameterized in terms of SL anomalies as follows:

a. Inverse modeling of T_e: Obs. SST & simulated current => SST anomaly model => T_e anomaly fields

b. Statistical relationships between SL and T_e: SVD-based

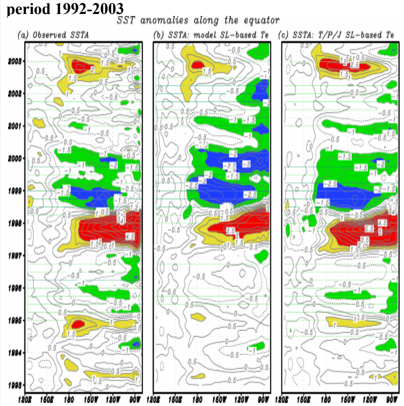
c. Given SL anomalies => T_e => SST calculation

Using model outputs from the FSU run (mean & anomaly currents) and observed SST, T_e anomalies are estimated by inversion of the SST anomaly equation for the period 1978-2003. Then, a SVD analysis of the covariance between anomalies of the estimated T_e and observed T/P/J SL is performed for the period 1993-2003. With 5-modes included, the T_e anomalies can be parameterized in terms of SL anomalies by the SVD technique. Shown below are anomalies along the equator of observed T/P/J SL, inverted T_e and parameterized T_e, respectively.

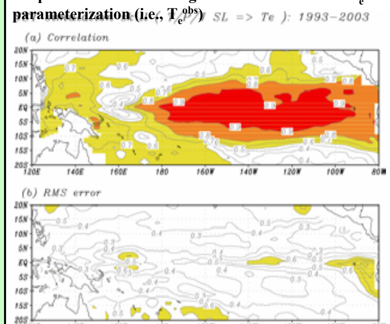


An improved SST simulation

The improved SST model with the empirical T_e parameterization is embedded into an intermediate ocean model (IOM) recently developed by Keenlyside and Kleeman (2002), which is an extension of the McCreary (1981) baroclinic modal model to include varying stratification and nonlinearity. The model is then forced by the FSU winds to produce upper ocean current anomalies, which, together with the T_e anomalies parameterized in terms of SL anomalies, can be used to simulate SST anomalies. The figure below shows the observed (a) and simulated SST anomalies from the T_e^{mod} (b) and T_e^{obs} (c) models along the equator during the period 1992-2003



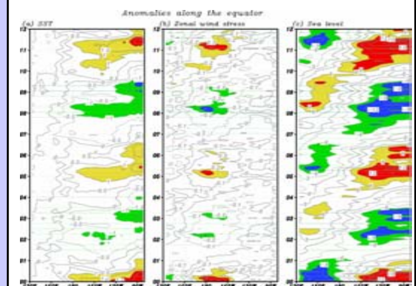
Anomaly correlation and root mean square (rms) between simulated and observed SST anomalies during the period 1993-2003 using *T/P/J* SL data for the T_e parameterization (i.e., T_e^{obs})



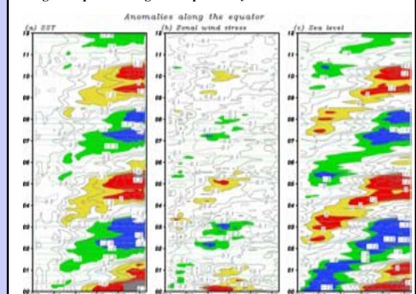
Coupled interannual variability

Using the T_e^{obs} model, the coupled system exhibits more realistic properties of interannual variability (the oscillation period, spatial structure, and temporal evolution), consistent with the 1997-98 El Niño-Southern Oscillation (ENSO) evolution

The figures below show coupled interannual variability of simulated SST (a), zonal wind stress (b), and sea surface height (c) along the equator using the empirical T_e^{mod} model in the ICM.



The figures below show coupled interannual variability of simulated SST (a), zonal wind stress (b), and sea surface height (c) along the equator using the empirical T_e^{obs} model in the ICM.



Concluding remarks

a. **Improved T_e parameterization and SST simulation using observed T/P/J SL data, as compared with those using modeled SL fields previously.**

b. **Improved El Niño simulation when T/P/J SL data are incorporated into a coupled model through the empirical T_e parameterization.**

c. **Combined with traditional data assimilation methods, the proposed T_e parameterization scheme provides a new approach to more effectively use T/P/J SL data in climate studies.**

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