Response Process of Ocean to Atmospheric Forcing and Optimal Response Frequency in the CZ Ocean Model

Ni Yunqi (倪允琪), Zou Li (邹 力) and Wu Aiming (吴爱明)
Department of Atmospheric Sciences, Nanjing University, Nanjing 210093
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ABSTRACT
Ocean response to atmospheric forcing in the CZ ocean model is analyzed. The results show that Nino 3 index from the CZ ocean model driven by linear composite of biennial, ENSO and even annual time scale wind stress anomalies is consistent well with composite of responding two or three components of observed Nino 3 index during the El Nino period while the La Nina phenomena cannot be reproduced by the linear composite. It implies that linear response process for ocean response to atmospheric forcing is dominated during the El Nino period while nonlinear response might be main process during the La Nina period.

Simulated results also suggest that optimal response frequency of the CZ ocean model is the frequency lower than annual variability and ocean response to the atmospheric forcing with annual time scale can give rise to incorrect signal–errors in the simulated SSTA field.

Key words: Response process, Atmospheric forcing, Simple ocean model, Linear interaction

I. INTRODUCTION
ENSO events may be a three time–scale process in which there is annual cycle, quasi–biennial oscillation and low–frequency scale with 3–7 year period (Barnett, 1991). Spectral analysis of tropical variables such as SST, SLP and zonal surface wind often show the peaks associated with these two longer time scales. (Lau and Sheu, 1988; Rasmusson et al., 1990). However, Van Loon and Shea (1985), Lau and Sheu (1988) found a remarkably strong nonlinear interaction between a QB time scale (≈ 25 months period) and a longer (LF) time scale (≈ 50 months). Barnett (1991) pointed out that ENSO is partially due to a nonlinear interaction between the two bands. Therefore, the question is why the CZ ocean model forced by observed wind stress anomalies can simulate the observed SSTA in the tropical Pacific, which is a linear, reduced gravity model. Obviously, the above question refers to the following questions: 1) which one is more important to produce ENSO events in the tropical Pacific, nonlinear or linear interaction between the time scales? 2) which one is dominated for the ocean response to atmospheric forcing, linear process or nonlinear process? In order to answer the above questions, the relation between the time scales and response process of ocean to atmospheric forcing is respectively investigated.

Models and data are described in Section 2. EOF analysis of observed and simulated SSTA is displayed in Section 3. In Section 4, linear response process and nonlinear influence of ocean to atmospheric forcing are analyzed and optimal response frequency in the CZ ocean model is given in Section 5. The last section is summary and conclusions.
II. DESCRIPTION OF MODEL AND TREATMENT OF DATA

1. Atmospheric Component of the CZ Model

The Cane–Zebiak atmospheric model starts with the governing dynamical equations which describe a linear, steady state anomaly circulation with a prescribed tropospheric vertical structure on an equatorial beta plane (Zebiak, 1986), Rayleigh friction and Newtonian cooling are included. The heating parameterizations in the model include a component which depends on the anomaly of sea surface temperature (SSTA), in which the climatological SST is incorporated, and a component which depends on the convergence of total surface winds. The latter component involves an iterative scheme which includes feedback onto the surface wind field.

The wind stress was generated from a thirteen–year (1979–1991) integration of the model using observed SST anomalies.

2. Ocean Component of the CZ Model

The Cane–Zebiak ocean model, which is described in more detail in Zebiak and Cane (1987), covers the Pacific basin from 124°E to 70°W and from 29°S to 29°N. The dynamics of the model starts with the linear reduced–gravity model, which produces only depth–averaged baroclinic currents. A shallow friction dominated (Ekman) layer of 50 m is introduced to simulate the surface intensification of wind–driven currents in the real ocean. By using Rayleigh friction layer are linear. The pressure gradient in the surface layer varies only with thermocline depth in this model, which neglects the influence of any temperature changes occurring in the surface layer alone.

The equation describing the evolution of temperature anomalies in the model surface layer includes three–dimensional temperature advection by both the specified mean currents and the calculated anomalous currents. The assumed surface heat flux anomaly is proportional to the local SST anomaly, acting always to adjust the temperature field towards its climatological mean state, which is specified from observations.

Thirteen-year (1979–1991) integrations of the CZ ocean model have been carried out, each forced by a different set of wind stress anomalies. The first of these consisted of the observed wind stress anomalies from the FSU analysis (Goldenberg and O'Brien, 1981) for the period 1979–1991, with detrending and smoothing as described in Cane et al. (1986), while the other consisted of model generated wind stress anomalies by the CZ atmospheric model for the same thirteen years.

The four–pole low pass filter (Kaylor, 1977) is used to filter the observed and simulated wind stress anomaly with the frequency we need. The filter is a fairly sharp low–pass filter with a half–power. Thus, periods shorter than that we don’t need are effectively filtered out, while longer periods are retained.

To obtain annual variability, biennial oscillation and ENSO signal (periods longer than two years), the filter procedure is as follows:

1) The filter is used to filter the period equal or shorter than biennial oscillation, therefore, ENSO signal is obtained and it is referred to as A;

2) The filter is used to filter the period equal or shorter than annual variability and it is referred to as B. A is subtracted, then, from B the biennial oscillation is obtained;

3) The filter is used to filter the periods shorter than annual variability and it is referred to as C. B is subtracted, then from C the annual variability is obtained.

Power spectrum analysis for signal A, (B–A), and (C–B) shows that the annual