A GLOBAL COUPLED OCEAN-ATMOSPHERE MODEL OF SHALLOW WATER WAVE AND ITS NUMERICAL EXPERIMENTS

Liu Yimin (刘屹岷), *Jiang Dayong* (姜达雍) and *Yang Meiyu* (杨梅玉)

Academy of Meteorological Science, State Meteorological Administration, Beijing

Received January 14, 1991.

ABSTRACT

A global coupled air-sea model of shallow water wave is developed based on coupled ocean-atmosphere dynamics. The coupling is realized through the air-sea interaction process that the atmosphere acts on the ocean by wind stress and the ocean acts on the atmosphere with heating proportional to sea surface temperature (SST) anomaly. The equation is barotropic primitive one. Response experiments of coupling system are also carried out SSTA in two categories of intensities. Compared with the results of AGCM simulation experiment in which only the dynamic change of air system is considered, it demonstrates that the air-sea interaction between the tropical ocean and the global atmosphere plays a very important role in the evolution of climate system. The results of numerical simulation show that it is encouraging.

Key words: coupled ocean-atmosphere model, numerical experiments, SST, anomalies

I. MODEL

1. *Atmosphere*

The barotropic primitive equations in the spherical coordinates are:

$$\begin{cases} U_t - qHV + m^{-1}(K+gH)_\lambda = -AU, \\ V_t + qHU + n^{-1}(K+gH)_\varphi = -AV, \\ H_t + m^{-1}(HU)_\lambda + n^{-1}(HV)_\varphi = -BH+Q, \end{cases} \tag{1}$$

where q is absolute potential vorticity, U, V are velocities and H potential height, A, B are inverse time scales for Rayleigh friction and Newtonian cooling,Q is the forcing (mass sink or source) term indicating the effect of ocean heat source on the atmosphere. Experiments are carried out in the paper for 500hPa which is different from that of Philander et al. (1984), and let $A=2.0\times10^{-9}$ and $B=6.0\times10^{-9}$.

2. *Ocean*

Oceanic motion in response to a body-force (τ^x, τ^y) is described by the equations:

$$\begin{cases} u_t - qhv + m^{-1}(k+gh)_\lambda = -au+\tau^x, \\ v_t + qhu + n^{-1}(k+gh)_\varphi = -av+\tau^y, \\ h_t + m^{-1}(hu)_\lambda + n^{-1}(hv)_\varphi = -bh, \end{cases} \tag{2}$$

where u, v are sea surface flow fields and h sea surface height. The oceanic motion is also damped by Rayleigh friction (its coefficient is a) and Newtonian cooling (its coefficient is b). τ^x, τ^y are zonal and meridional components of wind stress by surface wind. In our global model, the values of a and b are defined specially considering the boundary effect of sea and land:

$$\begin{cases} a=\begin{cases}3.5\times10^{-5}, & \text{in coastal water}\\ 1.0\times10^{-7}, & \text{in sea water}\end{cases} \\ b=1.0\times10^{-8}. \end{cases} \tag{3}$$

Each continental area in our model, such as North and South America, Asia, Africa, Oceania and north and south poles, is regarded as rectangle.

3. *Air-Sea Coupling*

In our air-sea coupled system, the ocean is driven by the surface winds and the atmosphere is affected by the release of latent heat from the ocean. We assume simply that the changes in the sea surface height h' correspond to SST changes T' and the SST changes, in turn, influence the evaporation which leads to the latent heat release at a suitable height (say, 500hPa) in the troposphere. Thus, the thermodynamical coupling and dynamical coupling are reduced to (Yamagata, 1985; Zebiak, 1982):

$$\begin{cases} (\tau^x,\tau^y)=\nu(U_0,V_0), \\ Q=-\alpha h', \\ \nu=8\times10^{-8}, \\ \alpha=10^{-4}, \end{cases} \tag{4}$$

where U_0, V_0 are the air surface winds, and they are obtained by using the method of parameterization for the model as follows:

$$(U_0,V_0)=0.45(U,V). \tag{5}$$

II. RESULTS OF NUMERICAL EXPERIMENTS

The staggered C grid with $4°\times5°$ is used in the horizontal and the polar ($|\varphi|>80°$) grids are not well-distributed in the meridional direction. The differential equations are written according to conservative principles of total energy and potential enstrophy (Arakawa et al., 1981). Euler backward scheme and centered finite difference scheme are used alternately in the time integration and repeated once hourly. The source terms are computed once hourly. For the area $|\varphi|>70°$, Fourier smoothing has been done to zonal pressure gradient, zonal mass flux and zonal advection term (Jiang and Yang, 1988).

1. *Uncoupling Model*

There is no oceanic heating in the atmospheric model AGCM, i.e., Q is supposed to be zero. The global climate mean data in January (Schutz, 1971) are used as initial fields. The 500 hPa potential height (Fig.1a) and flow field obtained by interpolation are very similar to the observed fields (Fig.1b).

The 30-day integration has been made by using AGCM and the temporal variation of the total kinematic energy during the integration has also been made. The results show that under the situation with frictional drag and without heating, the total energy is stable and descends slightly. These mean that the model suits making climate experiments on short-range climate simulation.

Fig.2 gives the results of the integration in which the winter circulation typical of the Northern Hemisphere is shown. In the high latitudes stronger cyclonic and anticyclonic

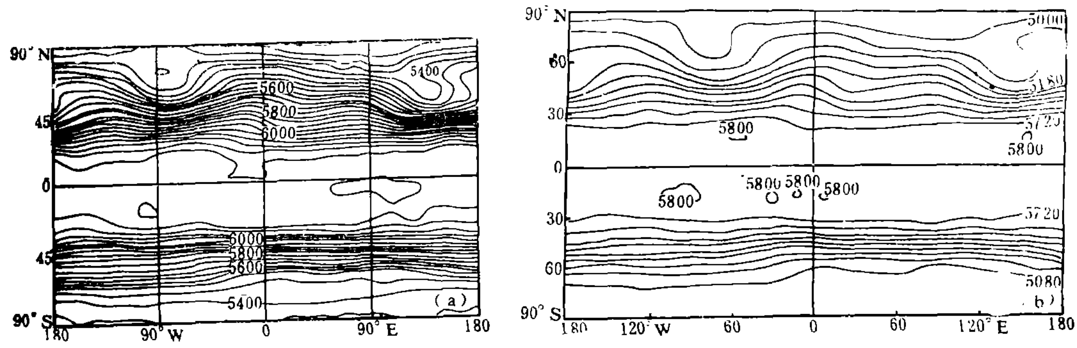
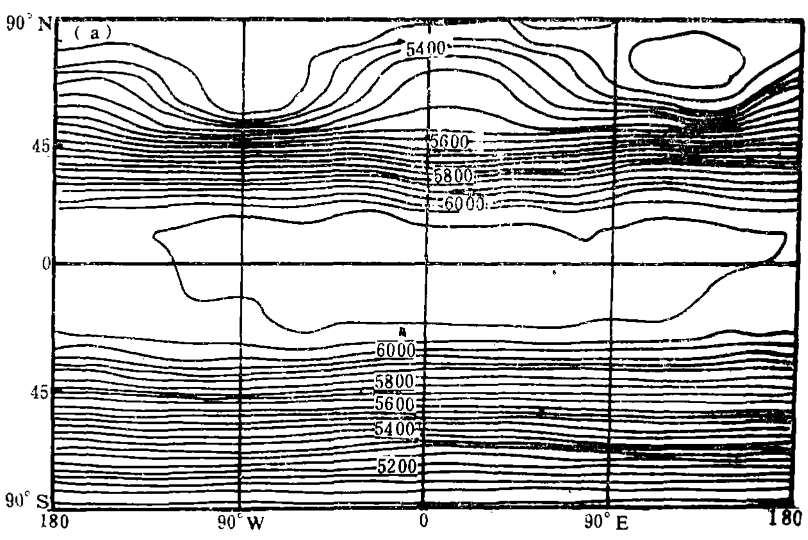


Fig. 1. 500hPa geopotential height in January.
(a)initial field for this study, (b) observed field.

circulations in Fig.2b correspond to the troughs and ridges in Fig.2a. The area of westerly jet is in middle latitudes of the Northern and the Southern Hemispheres. Form 16°S to 4°N there are equatorial easterlies and on its both sides are zonal anticyclonic circulations. A northward cross-equatorial flow about 20° longitude wide is in the central Pacific Ocean. Wave motion is weaker and basically in the state of smooth westerlies in high latitudes of the Southern Hemisphere.

In the ocean model OGCM, the wind stress is computed from the wind of AGCM which is changed daily. The initial ocean field is obtained by integrating one day calm ocean in which the boundary current is considered. The Kuroshio current, the Gulf stream, the Peru current and the easterly equatorial current are well reflected. West wind drift is nearby 50°S. The equatorial current and drift are obviously caused by the wind stress. The magnitude of meridional current is equal to that of zonal current in the middle and high latitudes of the Northern Hemisphere. This is connected with the detaining action of land. After 15 days' integration, the equatorial current is still westward and its zonal component is larger than that in the initial field.



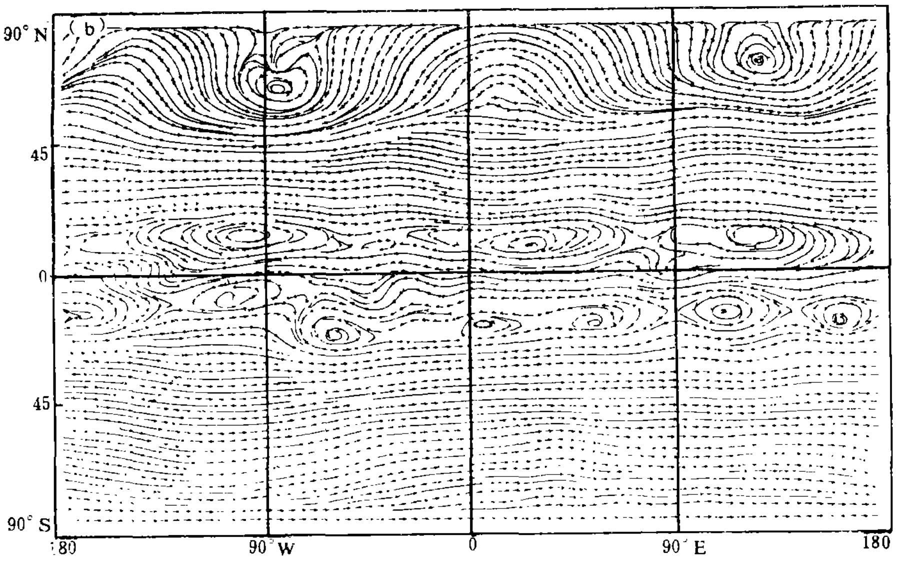


Fig. 2. (a) 500hPa geopotential height after 30 days' integration using the AGCM, (b) same as (a), but for flow field.

2. *Coupling Model and the Response to SSTA*

The 15 days' integration using AGCM and OGCM respectively is used as initial fields of the coupling model COAGCMs. Then 15-day integration is made using the coupled ocean-atmosphere model. Shown in Fig.3 is the 500hPa atmospheric flow field. The waveform of the potential height in middle and high latitudes is close to that in the AGCM. The differences are evident in the flow field. Compared with Fig.2, it shows that two vortex centres of anticyclonic circulation have been formed respectively in the north and south of the equator. The systems' intensities are strengthened and their locations are different with those in Fig.2. The cross-equatorial flow in the equatorial central Pacific Ocean is southward, not northward as in Fig.2. The two-wave pattern is still evident in middle and high latitudes of the Northern Hemisphere, but the intensity and location of the troughs and ridges have been changed because only AGCM is used in simulation. After integration it is shown that the horizontal gradient of the oceanic surface height is increased due to forcing by the wind stress. These indicate that the mechanisms of air-sea interaction involved in the coupled ocean-atomsphere model can influence the location and intensity of the atmospheric altra-long wave, i.e., atmospheric variability and distribution.

To simulate the response of air system to anomaly heating in the coupled air-sea model, two sensitivity tests are made when the El Nino signal appears. One SSTA signal is weaker with a centre of 1.75°C and the other is stronger, similar to the observed one in the 1982—1983 warm episode. Fig.4 is the SST anomalies used in this study. They range from the central Pacific Ocean to the Peru coast.

Fig.5a and b give the 500hPa atmospheric flow field after 15 days' integration with two SSTA respectively. The initial fields are the same as those used in Fig.3. In the height fields, under the forcing of the two heating sources, high pressure areas appear due to the parameterized latent heat in low latitudes. In the stronger heating case, the value of pressure is higher. The difference in high latitudes is small.

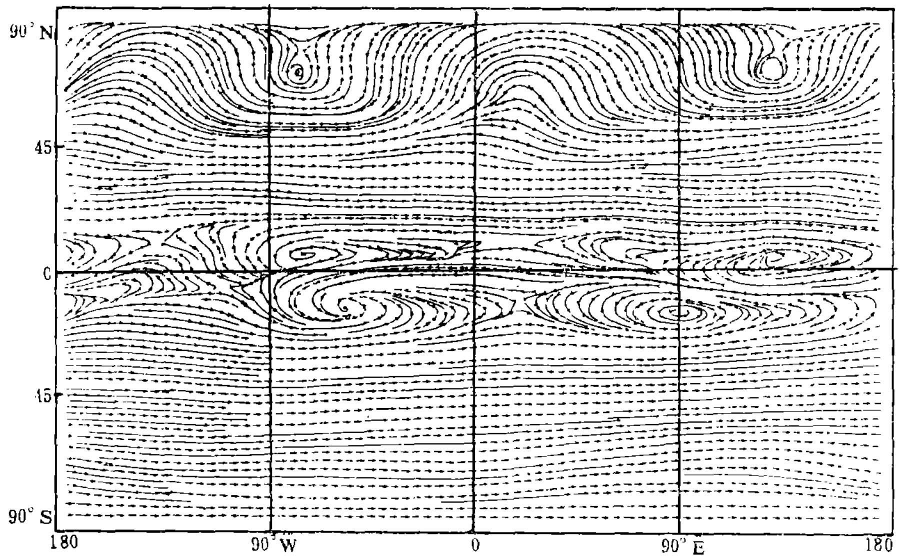


Fig. 3. 500hPa atmospheric flow field using the COAGCMs.

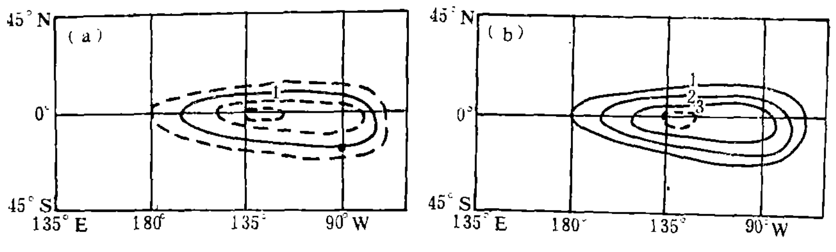


Fig. 4. SST anomalies in the eastern Pacific Ocean (a) $T'_{max}=1.75°C$; (b) $T'_{max}=3.5°C$.

Compared with Fig.3,it shows that,in the case of $T'_{max}=1.75°C$,the intensity of the equatorial anticyclonic circulation is further strengthened and the location changed. Both sides of the equator have been added a small eddy located over the western Pacific Ocean and Australia respectively. Over the eastern Pacific Ocean, the cross-equatorial flow extends southward. It was demonstrated that on short term the atmospheric circulation in low latitudes