NUMERICAL STUDY OF OROGRAPHIC INFLUENCE ON LOW FREQUENCY OSCILLATION

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ABSTRACT

Orographic effects on monthly-and seasonal-scale low frequency oscillation are investiged in terms of a five-level global spectral model with a triangle truncation at wavenumber 10 that contains relatively full physical parameterization, followed by analysis and comparison of the lowpass filtered data separately obtained from models with and without orography. Results show that remarkable seasonal characteristics are displayed in the orographic forcing-generated low frequency wavetrain on monthly and seasonal scales. It is found that the Northern Hemisphere summer orography-produced tropical heating acts as source of the low-frequency wavetrain for both hemispheres. Besides, the simulations indicate that the orographic wavetrain perturbation can give rise to the anomaly in the equatorial zonal flow, whose transient forcing will cause a new wavetrain in the Southern Hemisphere, thus completing the cross-equatorial propagation of the northern wave in interhemispheric action.

Key words: spectral model, orographic influence, low-frequency oscillation, tropical convection

I. INTRODUCTION

Since Charney and Eliassen (1949) investigated atmospheric response to large-scale orographic features and thermal forcings, many researchers have directed their efforts at the impact of massive mountains on atmospheric circulation and examined their orographic role in generation of seasonal mean circulation by means of linear and nonlinear models. By use of a barotropic model, Grose and Hoskins (1979) first made an approach to the propagation of two-dimensional Rossby waves across spheric surface in a set of simple orographic conditions. Hoskins and Karoly (1981) employed a multilevel model to explore it with the discovery of two wavetrains forming downstream the orographic forcing region, one (of low wavenumber) travelling poleward and the other (of high wavenumber) equatorward in bifurcation at 40°N, resulting in a blocking downstream the orographic feature, where a anticyclonic vortex is seen poleward of a cyclonic gyre. Huang and Gumbo (1982) also reported features of orographic stationary waves travelling towards low latitudes. All of the work above-mentioned indicate the role played by orographic features in genesis of a steady wavetrain.

Using low-order global spectral models with and without orography involved, Ni et al. (1988) and Ni and Zhang (1991) examined in detail the effects of a giant orographic terrain on seasonal mean circulation, transportation of heat, momentum and moisture, conversion of atmospheric energies and Asian summer monsoon. Their findings all clearly point to the essential role of orography in generation of mean circulation, transfer of physical quantities and conversion of energy and its innegligible effect on the intensity and position of the monsoon. More recently, Ni et al. (1991) and Zhang et al. (1991) discovered remarkable seasonality and interannual variability in the low-frequency osillation (LFO) and strong intraseasonal (30—60 days) oscillation produced by their models. The results lead us to consider what role the orography plays in the genesis and propagation of LFOs in the low-order spectral models. For this reason, further analysis is performed of the simulations given by the models with and without a mountain terrain involved in an attempt to investigate the orographic effects on LFOs.

Ⅱ. BRIEF DESCRIPTION OF MODEL IN USE AND EXPERIMENTAL SCHEMES

A brief description is given of the low-order global spectral model for the reanalysis. For further details the reader is referred to Otto-Bliesner et al. (1982).

The model has in a σ-coordinate five equi-spaced levels from surface to atmospheric top ($\sigma = p/p^*$ with p^* for surface pressure) with rigid-lid boundary conditions, i. e. , $\sigma = 0$ at $\sigma = 0$. The basic dynamic and thermodynamic formulation is a complete set of equations of vorticity and horizontal divergence, continuity with surface pressure derived from integration, vapor and thermodynamic expression, to which equations of statics and σ vertical velocity diagnosis are added.

The model variables are expressed by the spheric function horizontally expanded with triangle truncation at wavenumber 10. A semi-implicit scenario for time integration is used with a step of 90 minutes.

Parameterizations involve long-and short-wave radiations, large-scale condensation and convection, vertical and horizontal diffusion of momentum, heat and moisture. Included in the model are huge mountains and conditions of such underlying surfaces as SST, sea ice, albedo and snow line. Two schemes are formulated for the modelling.

Scheme Ⅰ (with mountains available, MEXP for short) is based on spectral truncation and expansion of data at 1 °× 1 ° latitude / longitude grids to be directly used as lower boundary condition. Scheme Ⅱ (without mountains, NMEXP) includes no effect of any major orography with other conditions remaining the same as Scheme Ⅰ.

For MEXP the long-term mean January boundary conditions and external forcing are considered with initial integration at the isothermal of 240°K, calm and dry atmosphere and constant sea-surface pressure (1013. 25 hPa) and duration of 6. 5 years. The latest 5 - year output is analysed as MEXP result . Then NMEXP is run for

2.5 years with the identical initial and boundary conditions, followed by lowpass filtering and analysis of the last-year simulation, which is then compared to the first-year one for difference calculation , thereby examining the orographic effects on the modelling.

Ⅲ. SEASONAL CHARACTERISTICS OF MOUNTAINS—FORCED LFOs

Fig. 1 is a plot of winter 300 hPa height difference (subtraction of the Northern Hemisphere winter mean for MEXP in the first model year from the average for NMEXP in the same period, the same below). It is clear that two wavetrains are excited by the Tibetan Plateau in the hemisphere; one travels to the northeast from the west of the plateau, turns to the southeast around the polar region and moves into the tropical central/eastern Pacific while the other heads east off the plateau before recurving into the western Pacific at low latitudes. Both of them cross the equator about the dateline into the other hemisphere with one going over the antartic and arriving in the southern Indian Ocean and the other makes its way into the tropical eastern Pacific and follows a great circle route to the tropical Indian Ocean. They are two of the wavetrains with higher wavenumbers that perform cross-equatorial propagation.

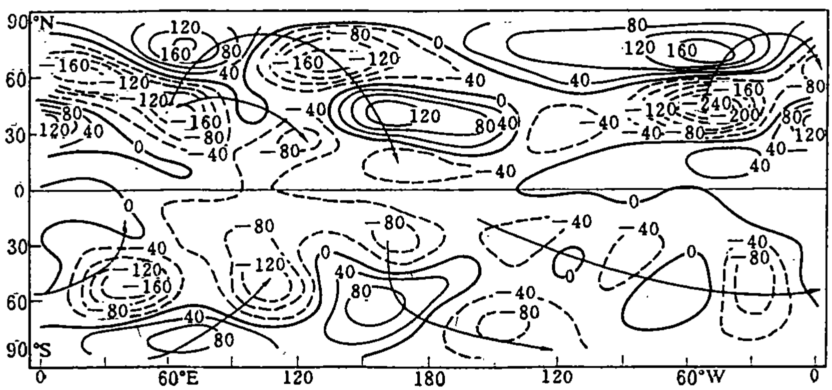

Fig. 1. Simulated 300 hPa geopotential height difference (MEXP minus NMEXP) with contour interval of 40 gpm.

Studying the figure (omitted) of the Northern Hemisphere 300 hPa flow difference, it is clearer that the plateau-originated wavetrains are exactly corresponding with those of Fig. 1. Additionally, one of them acts as a cyclonic difference perturbation as it reaches the northern tropical central/western Pacific, enhancing the equatorial westerly difference flow; owing to the transient lateral forcing of the equatorial zonal flow a corresponding cyclonic disturbance is formed in the Southern Hemisphere that moves across the southern part of South Pacific in a great circle route.

In Fig. 1, a wavetrain is observed to the east of the Rocky Mountains that first travels northward and then to the southeast, suggesting that the differences in orientation, shape and altitude for the Tibetan Plateau and the Rockies are responsible for the varied impact on low frequency wavetrains.

In the Southern Hemisphere, as the Andes is the only major massive orographic feature the orography-forced low frequency wavetrains are significantly weaker than those in the Northern Hemisphere. Nevertheless, a wavetrain is seen on the east side of the Andes that porpagates through the southern South Atlantic and coincides with the eastern branch of the cross-equatorial wavetrains, running into the tropical Indian Ocean.

Comparing Fig. 1 with the figure (omitted) of the 850 hPa geopotential height difference reveals identical (opposite) signs of disturbances in the Southern Hemisphere and northern areas close to the equator at both 850 and 300 hPa, suggesting well-defined characteristics equivalent of barotropicity (baroclinicity).

Fig. 2 presents the northern summer 300 hPa height difference, from which one can see that the perturbation amplitude is much stronger in the Southern than in the Northern Hemisphere. The northern wavetrain travels northeast from the equatorial western Pacific, turning towards the southeast in the Bering Strait, entering into northern South America and further the equatorial western Atlantic while the southern wavetrain propagates southeast from the equatorial western Pacific into high latitudes, then passing through the southern Indian Ocean, turning towards northeast and finally returning to the equatorial western Pacific.

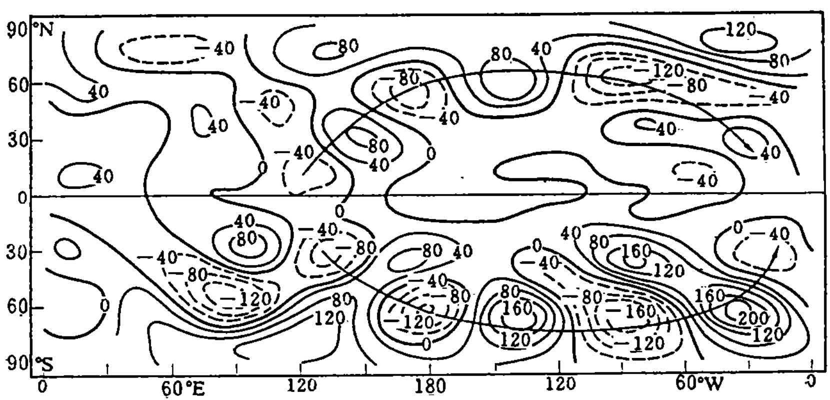

Fig. 2. Simulated 300 hPa geopotential height difference in northern summer.

The more complicated pattern of mountains-induced LFOs in the transitional periods of spring and autumn as shown in Figs 3 and 4 is due to the mixture of low-frequency wavetrains produced by both orographic effect of massive terrains (Tibetan Plateau and Rocky Mountains) and consequent differential heating effect over the tropical Pacific and Atlantic (as given by difference in convective activity of the experiments).

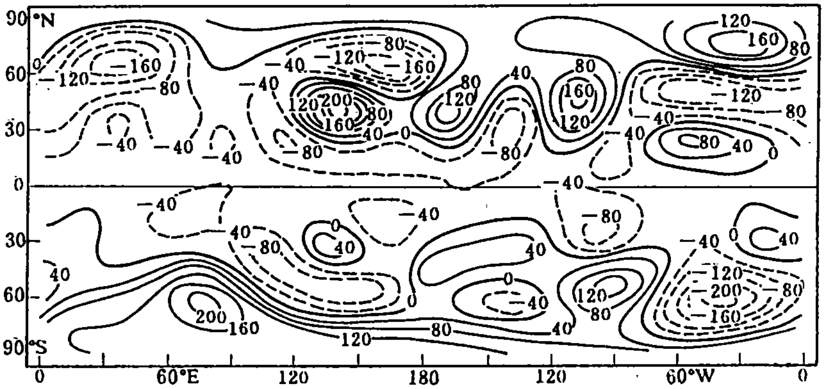

Fig. 3. The same as in Fig. 2 except for spring.

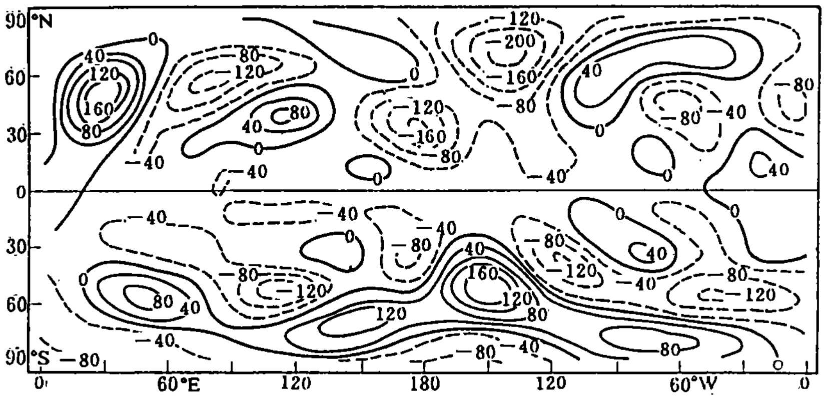

Fig. 4. The same as in Fig. 2 except for autumn.

The foregoing evidence clearly suggests that effects of the northern orographic terrain on the low-frequency wavetrain display pronounced seasonality: the mountains-associated waves are predominant in winter; the wavetrains are prevalent in summer which are related to the forcing of convection-given heat sources inside the tropical model atmosphere under the orographic influence; in the transitional seasons of spring and fall, a more intricate pattern of the low frequency disturbance is generated out of direct orographic forcing and the convective heating under the mountains effect. In contrast, the orographic low-frequency wavetrain is faint in the Southern Hemisphere and the tropical heating variability-caused forcing due to the mountains and cross-equatorial northern wavetrain are responsible in great measure.

Ⅳ. GEOGRAPHIC INFLUENCE OF LOW-LATITUDE HEAT SOURCES/SINKS

In tropics, since the heat source (sink) distribution generally corresponds to low-

(high-) level convergence and high-level (low-level) divergence fields of the divergence wind component, it is reasonable to represent the distribution with the aid of the field of the component.

The NMEXP-simulated winter 300 hPa divergence wind field (Figure omitted) illustrates that the model heat sources indicated by high-level divergence and low-level convergence are over the northern central Pacific and southern tropical Atlantic while the sinks are observed on the west side of the Tibetan Plateau and in the west of the northern Atlantic (both figures not shown). The difference (MEXT-NMEXP) in the northern winter 300 hPa divergence wind is depicted in Fig. 5, which shows that the orography is responsible for the difference flow with low (high) divergence (convergence) on the west side of the plateau, or a stronger heat sink therein as viewed from the perspective of the NMEXP model results, with weaker sources in East Asia and central parts of the tropical western and North Pacific and a still weaker one in the North American eastern coast. Evidently, the Tibetan Plateau exerts more significant effect on the divergence wind field than the Rocky Mountains , and the southern mountains influence the field weakly. Following Hoskins and Karoly, one can see clearly the feeble effect of the orography on the redistribution of the winter tropical heating sources (based on the source pattern from MEXP vs NMEXP). It follows that the northern winter direct orographic forcing is responsible principally for the wavetrain.

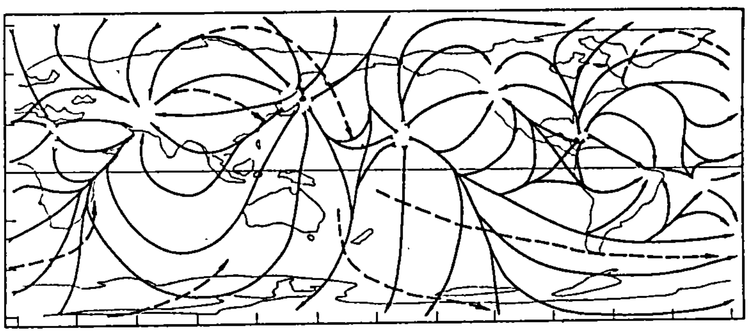

Fig. 5. The simulated 300 hPa differences of divergence wind field (M—NM) in the winter. Solid lines are streamlines, dash lines are wave paths.

The summer NMEXP-simulated 300 hPa divergence wind (Figure not shown) show that the tropical central Pacific remains a strong heat-source seat which, differing from the northern winter case, shifts its core to northern tropics around the dateline from the southern low latitudes around 150°W and a marked heat-sink area over the western Indian Ocean (Figure omitted). Fig. 6 delineates the difference in 300 hPa divergence wind for the northern winter, exhibiting a significant source over South Asia to the equatorial western Pacific. The formation is likely to be dependent upon the enhanced monsoon meridional circulation with the Tibetan effect, thereby so intensifying the equatorial E—W directed circulation and equatorial western Pacific convection that the latter belt becomes a heat source with respect to the NMEXP outcome, a conclusion that agrees well with the study on the orographic influence on summer monsoon (Ni et al. , 1986). As such, the genesis of this source bears a direct relation to the plateau. Referring to Fig. 2, we see that this source belt is located just in the seat of origin of wavetrains each observed in one hemisphere for the northern summer. It can be inferred therefore that the two wavetrains are produced largely by low-latitute heating under the influence of the plateau for the northern summer, a result that is in agreement with the theory on thermal forcing-generated waves (Hoskins and Karoly).

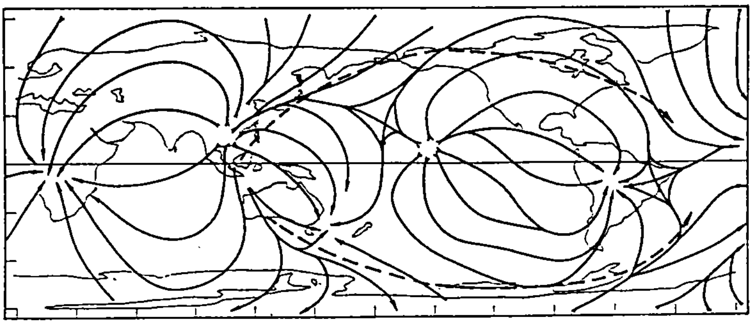

Fig. 6. Same as in Fig. 5 except for summer.

V. CONCLUDING REMARKS

From the foregoing analysis, we come to the following conclusions.

a. The orographic effects on the low-frequency wavetrains at monthly and seasonal scales are featured by appreciable seasonality. In the northern winter the Tibetan Plateau excites two wavetrains, one on the west side travelling northeast, turning southeast around the arctic and moving into the tropical mid/western Pacific, and the other marching eastward and then entering into the low-latitude western Pacific, both of which cross the equator about the dateline, with one passing through the antarctic and then entering the southern Indian Ocean, and another going along a great circle route into the tropical Indian Ocean from the low-latitude eastern Pacific. The courses of the features of Tibetan origin are controlled by dynamic effects of lateral forcing of zonal flow transiency. Additionally, a Rockies-associated wavetrain coincides with the one of higher wavenumber of Tibetan origin. In this season, a wavetrain related to the Andes chain coincides with the eastern-branch cross-equatorial one, propagating through the South Atlantic into the Indian Ocean. In the northern summer, affected in the equatorial western Pacific by the plateau with each running into a hemisphere, the wavetrains modify the climate on a global basis. Moreover, orographic low-frequency waves in spring and fall have more complex patterns and hence differ strongly.

b. The orographic forcing gives rise to low-frequency wavetrains in two ways: i) of direct forcing, the example being the waves in the northern winter; ii) of orography-associated heat source/sink distribution, the example being the wavetrain in the northern summer that comes from the forcing of low-latitude heating anomaly caused by the Tibetan Plateau.

c. The extensive mountains have pronounced influence on the pattern of heat sources/sinks in the tropics. In the northern winter a more vigorous sink region shows up on the west side of the plateau and sources are located in East Asia and the tropical western Pacific; in summer a stronger orography-influenced source area is formed over South Asia and the tropical western Pacific, which is perhaps the leading origin of bi-hemispheric low-frequency wavetrains for the northern summer.

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