NOTES AND CORRESPONDENCE

On the Movement of the "Convection Center" from Summer to Winter Season in the Northern Hemisphere

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1. Introduction

Recently, year to year fluctuation of the atmospheric circulation including the El-Nino Southern Oscillation (ENSO) have attracted much attention and been extensively investigated. Many observational and phenomenological studies have been conducted. However, we should say that we have not yet clarified the physical basis for these interannual fluctuations.

2. What is the substance for the interannual variations?

When we are going to study interannual variations, deviations from the long-term mean field are usually defined to be a component of the interannual fluctuations. This definition of the interannual fluctuation is based on the wave concept in a linear sense. However, the physical meaning and the applicability of this concept is not fully examined.

In general, a linear system consists of free modes and forced modes. In this note, the free mode is defined as

$$\frac{\partial \mathbf{x}}{\partial t} = -i \omega_i \mathbf{x}, \quad i=1, \dots, N. \quad (1)$$

and the forced mode is defined as;

$$\frac{\partial \mathbf{y}}{\partial t} = -i \omega_j \mathbf{y} + F_j^{\text{ext}}(t), \quad j=1, \dots, M, \quad (2)$$

where N and M are a degree of freedom for each mode. In a climate system boundary conditions, which can be considered as an external forcing for the short- and medium-range forecasts, becomes time-dependent variables. As

long as a boundary parameter (X_B) is determined by an atmospheric parameter (X_A), for example,

$$\begin{aligned} \frac{\partial X_A}{\partial t} &= -i \omega_A X_A + \alpha X_B \\ \frac{\partial X_B}{\partial t} &= -i \omega_B X_B + \beta X_A, \end{aligned} \quad (3)$$

these systems are defined to be a free mode, because the forcing does not depend on the external variables.

If we imagine that the interannual variability is governed by the process (1), we have to keep in mind that the restoring force is proportional to the variable itself. Besides the simple oscillatory system, we can consider the coupled linear system (3). In this case, we can generate another frequency by coupling the different modes (Yamagata, 1986).

The other possibility is the sequence of the events; let us assume that phenomena consist of n -events ($X_1, X_2, \dots, X_n$), and that there is a logical sequence of events;

$$X_1 \rightarrow X_2 \rightarrow X_3 \rightarrow X_4 \rightarrow \dots \rightarrow X_n \rightarrow X_1.$$

If it takes τ_j days for X_j to excite X_{j+1} , a period of this event of sequence is a sum of each period, $\sum_{j=1}^n \tau_j$. This example is the explanation of 20 day mode in the northern hemisphere summer monsoon given by Krishnamurti and Bhalme (1976). In conclusion, the process described above is governed by the internal dynamics.

On the contrary, in the case that the external forcing has the periodicity, situation is com-

pletely different: For example, let us assume that system is forced by simple sinusoidal forcing.

$$\frac{\partial Y}{\partial t} = f \sin(\gamma t + \delta), \quad (4)$$

$$Y = -\frac{f}{\gamma} [\cos(\gamma t + \delta)] + Y_0. \quad (5)$$

In this case, the amplitude of Y is independent on the mechanism of the fluctuation. The fluctuation of Y -field is a response to the fluctuation of the source field. In this case, the study of the source field is indispensable.

If these external forcings are the same from year to year and the forced modes are dominant, the interannual variation cannot be expected. However, if in certain instance a forcing is modulated, the large amplitude of the interannual variability is realized. For example, we assume that phase modulation will occur in a certain period in (4). Phase is stochastically modulated at January 1 every year. Results are shown in Fig. 1. Year to year fluctuation is clearly noted. In this case the existence of interannual fluctuations does not necessarily mean the existence of waves in the whole period. Therefore, we should carefully investigate the behavior of the forcing.

In general, the atmospheric circulations can be considered to be the response to the various forcing which is essentially due to the annual cycle of solar radiation. Most of this heating is

absorbed in the surface. Then, this solar energy is carried back to the atmosphere by the convective and radiative processes. Transferred solar energy is used as a forcing to the global atmospheric circulation. In the tropics, most of this part is played by the cumulus convection. In other words, the solar heating in the tropics is mainly realized as the forcing due to the convective heating.

The most significant feature of the convective heating is movability. If the solar heating is uniformly absorbed in the atmosphere, the character of the general circulation will be completely changed. Even though the external forcing is zonally symmetric, the actual forcing for the atmosphere with water (the "aqua" planet) is not zonally symmetric (Hayashi and Sumi, 1986). Therefore, it is essential to investigate the behavior of the convective systems.

To represent the qualitative feature of the convection ensemble in the tropics, the idea of the convection center* is used in this note.

The seasonal cycle of the convection center were recently investigated by Murakami *et al.* (1986) by using the 5 year OLR data. They found the remarkable movement of the convection center which primarily corresponds to the monsoon phenomena over the global domain.

In the northern hemisphere summer, most studies indicate the location of the convection center over the west of Philippines. Fluctuation of the location of the large scale convection center in the northern hemisphere summer seems to be less remarkable. On the contrary, recent study indicated that there are two locations of the convection center over the western and central Pacific Ocean in the northern hemisphere winter corresponding to ENSO events (Lau and Chan, 1983).

Then, it may be questioned how the transition from the summer to the winter occurs in each year? In the ENSO year, does the convection center move from summer to winter regularly, and then from maritime continent to the central Pacific? Or, does it move toward the

Fig. 1 Anomalies of the 50 year time series defined by (5). For details, see the text.

*In this paper, the convection center is defined as the minimum of the velocity potential field of the planetary scale.

central Pacific from the northern summer to winter? These aspects have been investigated by using the FSU global tropical wind data (Krishnamurti *et al.*, 1983).

3. Data and procedures

Data used in this study are the 2.5° by 2.5° longitude-latitude grid data of monthly mean tropical wind from 1965 to 1974 compiled by Krishnamurti *et al.* (1983), whose regions are from 45°N to 25°S between 0° and 360°E . As the data density is a severe problem before FGGE year, the reliability of the analysis should be carefully examined. However, the data density of the RS/RW over the western Pacific region is relatively significant in the world, and the planetary scale aspect of the atmospheric circula-

tion can be discussed by using this dataset.

As we want to investigate the annual march of the large-scale convection features, the appropriate element should be used for them. In this paper, we utilize the term of the "convection center" which represents the action center associated with the relatively large-scale ensemble of the convection. Practically, the position of the convection centers are defined as the location of the minimum of the planetary scale velocity potential fields (χ) derived from the FSU wind data by solving the Poisson's equation ($\nabla^2\chi = D$). In this case, data are limited between 45°N and 25°S . Therefore, we assume $D = 0$ outside the region, and solve the Poisson's eqs. over the global domain. When we checked the effectiveness of this assumption by using ECMWF global

Fig. 2 Velocity potential fields for various methods. Data are the monthly mean field of 200 mb of ECMWF, September, 1980. (Top) is due to the global data, (middle) is due to the assumption that $D = 0$ outside 45°N and 45°S , and (bottom) is due to the assumption that $D = 0$ outside 45°N and 25°S . Unit is $6.3 \times 10^5 \text{ m}^2/\text{s}$.

analysis data, the difference is small (see, Fig. 2). Note that the divergent field is the quantity difficult to obtain. Therefore, the results given in this paper is the qualitative one rather than the quantitative one. Further study is being done by using the more reliable data which have been compiled after FGGE year. The results will be reported in a separate paper.

4. Two states of the annual march of the convection center from summer to winter in the northern hemisphere

The annual march of the convection center due to the ten year averaged divergence field are displayed in Fig. 3. Generally speaking, it lies around the Indonesia – east of New Guinea (Philippines – western Pacific) in the northern hemisphere winter (summer) respectively and moved from the winter position to the summer position and vice versa.

In order to evaluate the effectiveness of the estimate, the areas below 220 W/m^2 in the monthly mean Outgoing Longwave Radiation field from 1974–82 are also displayed in Fig. 4. It also represents the yearly movement between Indonesia – east of new Guinea and Bay of Bengal, and the enhancement of the convection over the Western Pacific Ocean during the summer. We can consider that the general feature given by Fig. 3 and Fig. 4 are similar each other.

Next, we will investigate the interannual fluctuation of the annual march. In Fig. 5, the march of the convection center from July to December between 1965 and 1974 is displayed because we are now interested in the movement from summer to winter. It is clearly understood that there are two groups in these movement; the one is the movement from the

western Pacific to the Indonesia. Another is from the western Pacific to the central Pacific. Especially, it should be noted that the latter case is mostly corresponding to the El Nino years (1965 or 1972).

The effectiveness of the convection center defined above will be examined in the following way. It is most appropriate for the check of this idea to utilize the satellite data. However, they do not exist during this period (1965–74). Instead of these data, we will use typhoon data. It is due to the assumption that in the autumn season the convection activity over the western Pacific region is well correlated with the typhoon activity. Therefore, the convective

Fig. 3 Monthly mean position of convection center averaged between 1965 and 1974.

Fig. 4 Monthly low OLR region (220 w/m^2) averaged between 1985–1982. Top is from January to April, middle is from May to August, and bottom is from September to December.

Fig. 5 Location of convection center from July to December from 1965 to 1974.

activity can be estimated by using the historical record of typhoon activity from 1951–1984 (Xie *et al.*, 1984).

6 hourly typhoon data (pressure, position) were used to determine the convective area associated with the typhoon. Generally, it is difficult to determine the cloud cover by using the surface pressure only. Due to the empirical formula defined for the significant weather chart (JMA, ECC, 1977), the radius of the convective area is assumed by the following simple formula;

$$\begin{aligned} r &= 300 \text{ km} & 970 < p_0 < 1000 \text{ mb} \\ r &= 500 \text{ km} & 940 < p_0 < 970 \text{ mb} \\ r &= 1000 \text{ km} & p_0 < 940 \text{ mb} \end{aligned}$$

Note that these relation simply represents the

qualitative nature that the strong typhoon generally have a large radius.

In Fig. 6 the mean cloud area computed by the above assumption is shown for the El Nino year and the normal year. In the normal year, the convective area due to the typhoon activity lies along 130°E in October and November. On the contrary, the convective area along 140°E is noticeable in the El Nino year. It is shown that the eastward shift of the convection center exists in the El Nino year in October and November. Thus, it is considered that the location of the convection center along the 150°E at October and November in Fig. 5 corresponds to the existence of the typhoon activity over this area.

Generally, it is believed that the typhoon activity is corresponding to the SST. For checking this aspect, the sea surface temperature anomaly from the time averaged values from 125° to 175°E averaged between 10°N and 20°N are computed (figure is not shown). There is no distinct difference between 130°E and 140°E over the western Pacific region. In other words, the eastward shift of the typhoon activity over these region is not directly influenced by the SST there. The shift may be corresponding to the change of the general atmospheric circulations. The shift may also influence the annual march of the convection center. The relation between this shift and ENSO cycle should be further investigated.

5. Summary

Many observations indicate that the atmospheric circulation changes year to year. However, little information is obtained for the physical basis to these interannual variations. Many researchers are thinking that there exists a sort of oscillations whose time-scale or period is more than 1 year. In this case, we have to investigate the process to determine this time-scale. Note that within this concept all variables including boundary conditions are internal variables.

Another possibility is that the interannual variability is due to the interannual fluctuation of the external forcing. Obviously, the external forcing for the climate system is the solar insolation whose variation can be neglected in the time

Fig. 6 Convective area covered by typhoons from September (bottom) to December (top) in normal year (not El Nino; left) and El nino year (right). Data are given four times a day and when the grid point is covered by the typhoon cloud, 1 is added. 4 corresponds to 1 day.

range of interannual variations. However, this forcing for the atmosphere in the tropics is mainly realized in the form of the convective heating. Usually, convection moves according to the seasonal march. However, note that convection can move around in the tropics if boundary conditions do not restrict its movements.

This indicates that there is a possibility of the interannual fluctuation of the external forcing for the atmosphere in spite of the stationary solar heating. Then the interannual variations may be excited by the interannual fluctuations of the forcing. In short, the interannual variations can be considered as the difference of the annual march at each year. For this purpose, the behavior of the convection ensemble has been investigated.

The convective center is defined by the planetary-scale velocity potential field. In a climatological sense, the convection center lies over the maritime continent in the northern hemisphere winter, and over the east of the Philippines in the northern hemisphere summer, and it moves back and forth.

It is shown that there are two types of the movement of the convection center from the summer to the winter: The one is from the western Pacific to the Indochina, and the other from the western Pacific to the central Pacific. This is also corresponding to the eastward shift of the typhoon activity over the Western Pacific in autumn.

This eastward shift of the convection from summer to winter mostly occurred in 1965, 68 and 72 between 1965 and 1974. At the same

time, the eastward shift of typhoon activity is observed in these years. It is also noted that the typhoon activity is closely related to the intra-seasonal variability. In this stage, we cannot conclude that the former results from the latter. Both relations should be carefully examined. However, it should be noted that the eastward shift of the convective activity may result from the change of the global scale circulation. This suggests that the annual march can be modified by the atmospheric circulations. Once the annual march is modified at some instance, then the annual march is going in a different way due to its own dynamics. This may excite the different meteorological fields at a later stage. This possibility should be further investigated.

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北半球の夏から冬へ向けての Convection Center の移動について

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