Diagnostic Study on Seasonality and Interannual Variability of Wind Field①

Xue Feng (薛　峰), Zeng Qingcun (曾庆存)

LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing 100029

(Received December 30, 1998; revised February 28, 1999)

ABSTRACT

Based on NCEP / NCAR reanalysis data during 1980–1994, seasonality and interannual variability of the horizontal wind field are studied. It is shown that: (1) In the lower troposphere, there exist regions with maximum of seasonality in the tropics, the subtropics and high latitudes, which is called the tropical, subtropical and temperate–frigid monsoon region respectively. In the upper troposphere, the subtropical monsoon combines with the tropical monsoon as a nonseparably planetary monsoon system. In the stratosphere, there is a belt with very large seasonality in each hemisphere caused by the inversely seasonal circulation and by the establishment and collapse of the night jet. (2) Seasonal variation of the large–scale monsoon may generally be attributed to that of the zonal wind, however, seasonal variation of the meridional wind is of great importance in East Asian monsoon region. (3) In monsoon region, interannual variability of the atmospheric general circulation is closely related to seasonal variation of monsoon, while in the tropical Pacific, it may considerably be influenced by the external factors such as sea surface temperature (SST) anomalies associated with El Nino or La Nina event. Moreover, interannual variability undergoes a pronounced annual cycle.

Key words: Atmospheric general circulation, Seasonality, Interannual variability, Monsoon

1. Introduction

Though seasonal variation of the atmospheric general circulation is mainly caused by that of the solar radiation, its distributions are inhomogeneous over the globe, for instance, it is more significant in monsoon region than in any other regions. In a traditional sense, monsoon summarizes all drastic seasonal variations in the tropics and subtropics (e.g., India and East Asia). Besides the classic monsoon regions, there exist some other regions over the globe, where the seasonal variation is clear or even drastic. In order to describe quantitatively seasonal variation of the atmospheric general circulation, a new method was adopted by Zeng et al. (1994, 1998) to define seasonality, the results in an individual year show that besides the classic monsoon region, there exist two regions with large seasonality over the subtropics and high latitudes in the lower troposphere, which are called subtropical monsoon region and temperate–frigid monsoon region respectively (Zeng et al., 1998). But from the viewpoint of climatology, the result in an individual year should further be examined using multi–year data. Moreover, what is the relation between seasonal variation and intra–annual variation of

①Supported by "Research on the formation mechanism and prediction theory of heavy climatic disasters in China" and the NSF key project on "Analysis on Seasonal Variation and Interannual Variability of the Atmospheric General Circulation" (No. 49735160).

the atmospheric general circulation? The above questions will be studied in this paper.

According to the method defined by Zeng et al. (1994), NCEP / NCAR reanalysis data during 1980–1994 are used to calculate seasonality and interannual variability of the horizontal wind field, their distributions are systematically analyzed. Based on this, we attempt to discover some rules of seasonal and interannual variations of the atmospheric general circulation and possible links between them, so as to provide some observational basis on dynamical research of seasonal and interannual variations of the atmospheric general circulation and short–range climate prediction. Section 2 outlines the data and methodology, Section 3 and Section 4 analyze the distributions of seasonality and interannual variability respectively, and finallly, we summarize the main results in Section 5.

2. Data and methodology

The data used in this paper are NCEP / NCAR reanalysis data, covering the period from 1980 to 1994, the meteorological element is the monthly mean horizontal wind field. The horizontal resolution of the data is 2.5° longitude by 2.5° latitude, in the vertical direction, eight levels are selected, i.e., 850 hPa, 700 hPa, 500 hPa, 300 hPa, 200 hPa, 100 hPa, 50 hPa and 10 hPa.

After Zeng et al. (1994,1998), the normalized seasonality is defined as follows:

$$\delta = \| F_s - F_w \| / \| \bar{F} \|,$$

where F is the meteorological element, here F is the horizontal wind field, i.e., $F \equiv \vec{V} = u\vec{i} + v\vec{j}$, $\bar{F}$ is the annual mean of F, and F_s, F_w are the value of F in summer and winter respectively, which is taken as the mean of June, July and August and that of December, January and February. $\| A \|$ is the norm of A, i.e.,

$$\| A \| = [\iint_S |A| dS]^{1/2},$$

where S denotes the computational domain, which is taken as an area with 10° latitude × 10° longitude.

Interannual variability is calculated by the following method, if F_{ij} represents the value of F in the ith year and the jth month (or season), interannual variability is defined as mean variance Δ_j,

$$\Delta_j = [\sum_{i=1}^{I} (F_{ij} - \bar{F}_j) / I]^{1/2},$$

where I is the total years (15 years in this paper).

In order to compare with the above normalized seasonality, standard deviation is also adopted to evaluate interannual variation, i.e.,

$$\tilde{\Delta}_j = \Delta_j \sqrt{F_j}.$$

3. Seasonality

Figure 1 shows seasonality of the horizontal wind field averaged from 1980 to 1994 at 850 hPa. It is shown that there are three maxima of δ in both hemispheres, the maxima of δ in the tropics concede with the tropical monsoon region, forming a wide region west of the dateline, east of the tropical Africa, south of the North Australia and north of the coastal

East Asia, in particular, δ reaches its largest value in Asian–Australian monsoon region, with the two centers in the western Pacific warm pool and the tropical Indian Ocean; In the subtropics particularly in the subtropical Pacific, there are also maxima of δ with the value smaller than that in the tropics, which have close relationships with seasonal migration of the subtropical highs; In high latitudes, the maxima of δ correspond to seasonal variation of storm tracks of the westerlies. Broadly speaking, as already noted by Zeng et al. (1998), the above three regions with large seasonality form three evident monsoon regions in the lower troposphere, i.e., the tropical monsoon region, the subtropical monsoon region and the temperate–frigid monsoon region. It is also noticed that the maximum of δ from Iran to Tibetan Plateau is false since the earth's surface is higher than 850 hPa there.

At 500 hPa (Fig.2), there are still maxima of δ in the above three latitudes. In comparison with the lower level, the maxima of δ in Asia–Australia are somewhat weakened, but the value of δ in Atlantic Ocean is substantially enhanced. Besides, over the latitudes between the tropics and the subtropics, the zonal range of maxima of δ increases gradually while the meridional range deminishes, making the distributions be belt–shaped. Meanwhile, the subtropical branch tends to approach the tropical one with height, in the tropics and the subtropics at 300–200 hPa (figure not shown), there are only two maxima of δ, the tropical

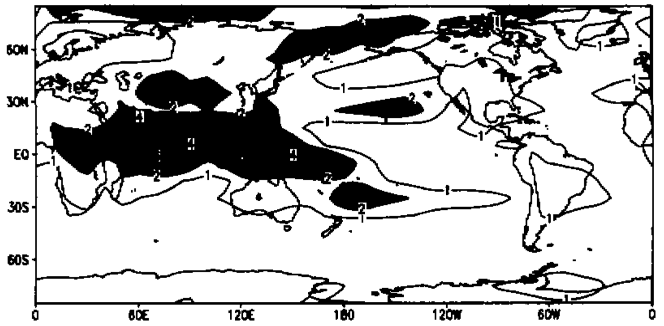

Fig. 1. Seasonality at 850 hPa for the horizontal wind averaged over 1980–1994.

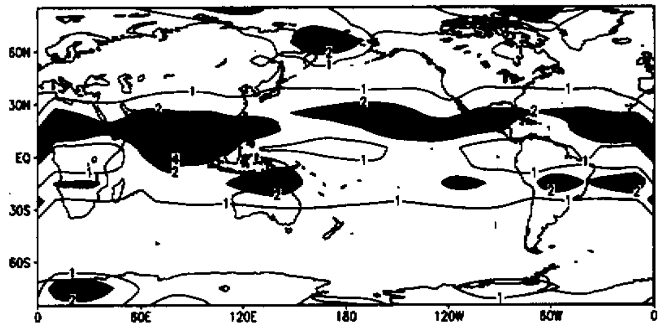

Fig. 2. As in Fig.1, but for 500 hPa.

monsoon and the subtropical monsoon have merged into a single whole, which is the so-called planetary monsoon. Moreover, while the maxima of δ in high latitudes still appear at 100 hPa, the value of δ is gradually reduced from the lower level to the upper level. From above analysis, it is concluded that seasonal variation of the atmospheric general circulation possesses a significant baroclinity. In general, the distribution of δ in the troposphere is much similar to that in the individual year obtained by Zeng et al. (1998).

In the stratosphere, δ is much larger than that in the troposphere. Due to the opposite circulation between summer and winter in the middle stratosphere at 50 hPa, (figure not shown), there is a well-defined belt with maximum of over latitudes between the tropics and subtropics in each hemisphere, the northern belt is much stronger than the southern one. At 10 hPa, i.e., in the high stratosphere (Fig. 3), there is also a well-defined belt located in 20–50°N and 30–40°S respectively. It is noted that there exists a night jet in winter over middle and high latitudes which will break down after the late spring, therefore, the maximum of δ in the high stratosphere is located more poleward than that in the middle stratosphere.

A further analysis shows that the distribution of δ of the zonal wind (u component) bears a resemblance to that of the horizontal wind, thus seasonal variation of the large-scale atmospheric general circulation (large-scale monsoon) is basically due to that of the zonal wind . Different from u, the distributions of δ for the meridional wind generally scatter in the north-south direction, for instance, at 850 hPa (Fig. 4), there are maxima of δ in east Asian monsoon region, Eurasia in mid and high latitudes and region from Arabian Sea to West Asia, there are also some secondary maxima in the subtropics and high latitudes of both hemispheres. It is worth noting that due to seasonal migration of the western Pacific subtropical high, δ reaches its largest value in East Asian monsoon region with the center in the western Pacific warm pool and it is even larger than the seasonality of u in most East Asian monsoon region, showing that v plays an important role in seasonal variation of East Asian monsoon. In fact, in East Asian monsoon region, since north-west wind and north-east wind prevail in winter, and south-west wind and south-east wind prevail in summer, the seasonal variation of v is quite large. Webster and Yang (1992) defined a monsoon intensity index associated with the zonal wind, which is widely used in monsoon research. Based on above analysis, it is evident that the definition is only suitable for the tropical monsoon, but it cannot be extended to East Asian monsoon region.

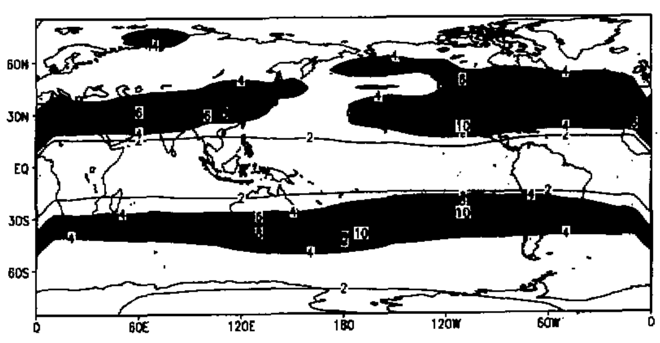

Fig. 3. As in Fig. 1, but for 10 hPa.

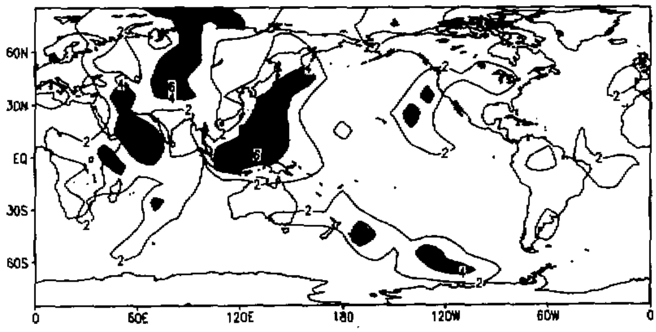

Fig. 4. Seasonality at 850 hPa for the meridional wind averaged over 1980–1994.

There exists a clear interannual variation for seasonality of the atmospheric general circulation, the distribution of its interannual variability, i.e., $\Delta(\delta)$ is much similar to that of δ. Taking 850 hPa as an example (Fig. 5), there are maxima of δ corresponding to those of δ in the tropics, the subtropics and high latitudes, respectively. In another word, both seasonality and its interannual variability reach the largest value in monsoon region, therefore, monsoon plays a role in interannual variation of the atmospheric general circulation. the difference is that δ in the tropics is much larger than that in high latitudes, but δ in the northern high latitudes is comparable to or even larger than that in the tropics, this kind of distribution is also apparent at the other levels of the troposphere. Furthermore, the distribution of δ in each year during 1980–1994 displays a clear interannual variation (figures not shown), for example, in 1983 (strong El Nino year), seasonality at 850 hPa in Asian monsoon region particularly in coastal East Asia is much weaker than that in the normal year, therefore, the seasonal variation of Asian monsoon is reduced by El Nino event, this result is in good agreement with the result by numerical simulation that Asian monsoon is weak in El Nino years (Ju and Slingo, 1995; Lau and Bua, 1998).

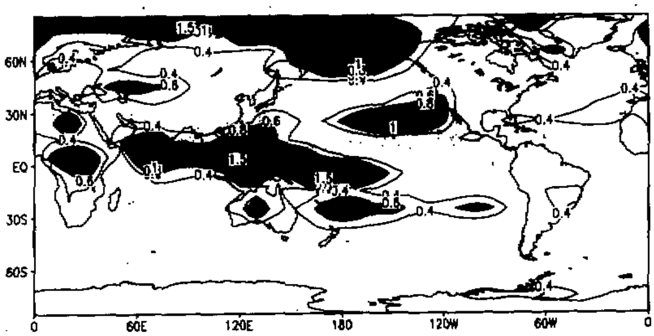

Fig. 5. Interannual variability of seasonality of the horizontal wind at 850 hPa.

4. Interannual variability

In order to compare with the above normalized seasonality, standard deviation is used to express interannual variability of the atmospheric general circulation. We calculated interannual variability of the horizontal wind including monthly mean $\tilde{V}_m$ in each month, seasonal mean in $\tilde{V}_s$ each season and annual mean $\tilde{V}_y$. It is found that the distributions of interannual variability of the horizontal wind for 12–month mean $\sum_{j=1}^{12} \bar{\lambda}(\tilde{V}_{mj})/12$, 4–season mean $\sum_{j=1}^{4} \bar{\lambda}(\tilde{V}_{sj}/4)$, and annual mean $\bar{\lambda}(\tilde{V}_y)$, are generally similar, showing that all these three time scales including monthly mean, seasonal mean and annual mean can reflect the signals of interannual variation of the atmospheric general circulation, but interannual variability generally decreases with the mean time scale, i.e., $\bar{\lambda}(\tilde{V}_m) > \bar{\lambda}(\tilde{V}_s) > \bar{\lambda}(\tilde{V}_y)$.Taking 12–month mean interannual variability of monthly mean wind at 500 hPa as an example (Fig. 6), it is shown that there are maxima of $\bar{\lambda}$ in Asian–Australian monsoon region,the tropical and the subtropical eastern Pacific, the subtropical Atlantic and high latitudes, in particular, its largest value is located in the tropical eastern Pacific and the western Pacific warm pool. Compared with Fig.2, we find that the distribution of $\bar{\lambda}$ is similar to that of δ over most regions except in the tropical eastern Pacific and the west Pacific warm pool, indicating that there are close relationships between seasonal variation and interannual variation of the atmospheric general circulation in monsoon region. On the other hand, since El Nino or La Nina occurs in the tropical eastern Pacific and Walker circulation ascends in the western Pacific warm pool, the atmospheric general circulation over the tropical Pacific is driven by SST anomalies, as a consequence, interannual variability reaches its maximum in these two regions. This result indicates that interannual variability caused by the external factors such as SST anomalies associated with El Nino or La Nina event is possibly larger that caused by the internally seasonal variation in the atmosphere. The relationship between interannual variation and seasonal variation needs further studies.

The distribution of interannual variability in each month shows that it undergoes a pronounced annual cycle (figure not shown). Due to baroclinity of seasonal variation of the atmospheric general circulation, there are differences at different levels, but interannual

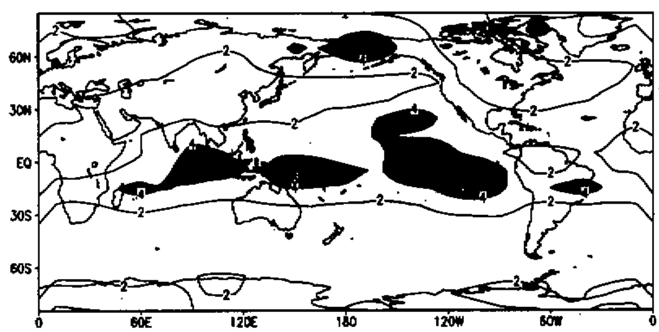

Fig. 6. 12–month mean interannual variability of the monthly mean horizontal wind at 500 hPa.

variability decreases from winter to summer over most regions. Moreover, the distribution of seasonal variation of interannual variability is generally similar to that of 12–month mean interannual variability montioned above, this reflects close relationships between interannual variation and seasonal variation of the atmospheric general circulation in another aspect.

5. Summary

In this paper, NCEP/NCAR reanalysis data during 1980–1994 are used to calculate seasonality of the horizontal wind field, it is found that in the lower troposphere, in addition to the classic tropical monsoon region, there are regions with maximum of seasonality in the subtropics and in high latitudes respectively, due to seasonal migration of the subtropical highs and seasonal variation of storm tracks of the westerlies, in a general sense, they can be called the subtropical and temperate–frigid monsoon region respectively. The subtropical monsoon tends to approach the tropical one with height and eventually the tropical monsoon and subtropical monsoon merge into a whole planetary monsoon system in the upper troposphere. In the stratosphere seasonality is much larger than that in the troposphere, besides this, there is a well–defined belt with very large seasonality in each hemisphere caused by the opposite circulation between summer and winter and by the establishment and collapse of the night jet. In general, the baroclinic structure of seasonal variation of the atmospheric general circulation reflects the interaction between the lower levels and higher levels of the atmosphere or between the troposphere and the stratosphere.

Seasonality of the large–scale monsoon may generally be attributed to that of the zonal wind because the atmospheric general circulation is dominated by its zonal component. In some regions such as East Asian monsoon region, however, the meridional wind plays an important role in seasonal variation of East Asian monsoon, hence the monsoon intensity index defined by Webster and Yang (1992) is not suitable for East Asian monsoon. In order to accurately depict the intensity change of East Asian monsoon, it is evident that the zonal and the meridional wind must be considered simultaneously.

The result also shows that interannual variation of the atmospheric general circulation is closely related to seasonal variation of monsoon in monsoon region. In the tropical Pacific, however, interannual variation caused by the external factors such as SST anomalies associated with El Nino or La Nina event is possibly larger than that caused by the internally seasonal variation in the atmosphere. In addition to observational analysis, it is necessary to study their detailed relationships by numerical modeling. The numerical experiment for this purpose is now underway.

REFERENCES

Ju J., and J. Slingo, 1995: The Asian summer monsoon and ENSO, *Quart J. Roy Meteor. Soc.*, **121**, 1133–1168.

Lau K. M., and W. Bua, 1998: Mechanisms of monsoon–southern oscillation coupling: insights from GCM experiments, *Climate Dyn.*, **14**, 759–779.

Webster P.J., and S. Yang, 1992: Monsoon and ENSO: Selectively interactive systems, *Q. J. R. Meteorol. Soc.*, **118**, 877–926.

Zeng Q. C., Zhang B. L., Liang Y. L., and Zhao S. X., 1994: Asian summer monsoon– A case study, *Proceedings of the Indian National Sciences Academy*, **60**, Part A, No.1, 81–96.

Zeng Q. C., and Zhang B. L., 1998: Seasonal variation of the atmospheric general circulation and monsoon, *Chinese J. Atmos. Sci.*, **22**, 805–813.