# Seasonality of the Interaction between Convection over the Western Pacific and General Circulation in the Northern Hemisphere①

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ABSTRACT

The seasonality of the interaction between convection over the western Pacific and general circulation in the Northern Hemisphere (NH) is analyzed in the present paper with singular value decomposition (SVD) and empirical orthogonal function (EOF) analysis approaches, based on 500 hPa monthly mean geopotential height data and high-cloud amount data. The analyses demonstrate that coupled dominant patterns in the interaction between the convection over the western Pacific and the general circulation in NH are different in various seasons.

In spring, the convection over the western Pacific is closely related with the western Atlantic (WA) and North Pacific (NP) like patterns of the general circulation in NH, and some associations between the WA and NP like patterns and the El Niño / Southern Oscillation (ENSO) cycle are also existed. The Pacific Japan (PJ) pattern is the dominant pattern in the interaction between the interannual variabilities of the convection over the western Pacific and the general circulation in NH summer. The WA like pattern and 3-4 year period oscillation are also relatively obvious for the summer case. In autumn, the convection over the western Pacific is closely linked with the Eurasian (EU) like pattern and the Atlantic oscillation in the general circulation in NH, it is suggested that in autumn the variation of convective activity over the western Pacific is largely affected by the general circulation anomaly (cold air from high latitudes ) through EU like teleconnection pattern. Abrupt change happened by the end of 1980's in the autumn interaction. The strong interaction between the western Pacific (WP) and EU like patterns in the general circulation in NH and the convection over the western Pacific and a linear trend of increasing of this interaction are also suggested in winter. It is also demonstrated that the interaction in summer and winter is stronger than in the transition seasons (spring and autumn).

**Key words:** Seasonality, Interaction, Convection over the western Pacific, General circulation in the Northern Hemisphere

## I. INTRODUCTION

The interannual and interdecadal climate variabilities are mainly controlled by heat condition anomaly of the global oceans. Most of the warm sea water in the global oceans is concentrated in the warm pool region of the western Pacific with the highest sea water temperature in the global oceans. As the warm pool is located in upward branch of the Walker circulation, through convective activities, the warm pool heats atmosphere and supplies energy to the Walker circulation. It is one of main sources of the atmosphere heat, thus air-sea interaction is very strong in this region. Therefore, the heat condition (convection) in the

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western Pacific plays a very important role in global climate and general circulation variations. Many studies have been carried out in the interaction between the heat condition in the western Pacific and regional or global climate and general circulation variations.

It is found that interannual and intraseasonal variabilities of climate in East Asia and the general circulation in the Northern Hemisphere (NH) in summer are closely linked to convective activities over the tropical western Pacific (Nitta, 1986, 1987; Nitta, et al., 1986; Kurihara and Tsuyuki, 1987; Huang, 1990; Nitta and Hu, 1996). Through analyzing the high–cloud amount (HCA) data derived from the Geostationary Meteorological Satellite (GMS), two dominant fluctuation patterns were found by Nitta (1986). One is north–south oscillation pattern between the subtropical western Pacific near 20°N and middle latitudes across Japan Islands. This pattern is called PJ (Pacific–Japan) pattern by Nitta (1987). The PJ pattern is closely related with extremely hot and cool summers in Japan (Nitta, 1987) and summer drought or flood in regions along the Yangtze River valley in China (Huang, 1990). Recent study of Nitta and Hu (1996) has found that the PJ pattern is the dominant teleconnection pattern affecting the interannual variability of summer climate (temperature and rainfall ) in East Asia. The PJ pattern is closely related to heat source anomaly in the Philippine Sea (Nitta et al., 1986). The investigation of Kurihara and Tsuyuki (1987) with a linear shallow water model suggested that development of barotropical high near Japan is associated with energy dispersion of barotropic Rossby waves excited by intensified convection in north of the Philippines. It is concluded that the PJ pattern mainly is the result of Rossby wave dispersion due to anomalous heating around the Philippines (Nitta, 1987; Kurihara and Tsuyuki, 1987; Huang, 1990). Lau and Peng (1992) believed that the presence of a marginally unstable normal mode of climatological mean flow in the northern summer also plays an important role in forming the teleconnection pattern similar to PJ.

With singular value decomposition (SVD) and a global barotropic spectral model, Hsu (1994) examined the relationship between tropical heating and global tropospheric general circulation in winter. It is suggested that regional tropical heating effects (or convection) can lead to a change in both the zonal–mean and the eddy components of global circulation. Investigation of Li (1990) has shown some evidence of the impact of variation of Asia winter monsoon on tropical convection and ENSO cycle. Analysis of Hu and Huang (1997a) found that there is a linear strengthening trend of the convection over the most tropical oceans in winter in 1980′s. Investigation with observational data and general circulation model (GCM) simulation indicated that there are some associations between the convective activity anomaly over the western Pacific and storm track in North Pacific on time scale of 2–4 years in winter (Hu and Huang, 1997a, 1997b). The center of storm track in North Pacific is strong (weak), eastward (westward), and northward (southward) when the convective activities around the Philippines are strong (weak). The study of Miyazaki (1989) suggested that winter temperature over Japan is highly correlated with the convective activity around the Philippines. At present, the physical mechanism of the winter interaction is still not well demonstrated.

At present, most of these researches are summer case, a few of them are related to winter case. This paper focuses on the difference of the dominant coupled modes in the interaction between convection over the western Pacific and the general circulation in NH in the four seasons. The focus regions of the analysis are the western Pacific for the convection variation and Asia and Pacific for the general circulation variation. The paper is organized as follows. Section 2 describes the data and methods. The analyses of the interaction between the convective activity over the western Pacific and the general circulation in NH in spring, summer, autumn and winter are presented in Sections 3, 4, 5 and 6, respectively. Conclusions and discussions are given in Section 7.

## II. DATA AND METHODS

Monthly mean geopotential height data at 500 hPa (H500) provided by Japan Meteorological Agency (JMA) on a resolution of 5 (latitudes) × 5 (longitudes) from 20°N to the North Pole covering the years 1978 to 1994 are used in the present work. Monthly mean HCA data for the period from April 1978 to February 1995 on a resolution of 3 (latitudes) × 3 (longitudes) derived from GMS are also used in the analyses. Domain of HCA data is from 49°S to 50°N and from 90°E to 171°W. Only the HCA data over oceans are used in the present study as the HCA data coverage are blank in continents during its previous period. HCA data represent quite well the deep convection and monthly mean precipitation in tropics as demonstrated by Maruyama et al. (1986). Normalized seasonal (spring: March, April and May (MAM); summer: June, July and August (JJA); autumn: September, October and November (SON); winter: December, January and February (DJF)) mean data are used in the SVD and empirical orthogonal function (EOF) analyses.

In order to pick up the dominant coupled modes between the H500 in NH and HCA over the western Pacific, SVD is employed. SVD is a powerful tool to isolate the most frequently occurring pairs of patterns in different fields (Bretherton, et al., 1992). SVD analysis is nowadays a routinely used approach to diagnose linear coupled modes in two fields (Bretherton, et al., 1992; Wallace, et al., 1992; Hsu, 1994; Iwasaka and Wallace, 1995; Shen and Lau, 1995; Kachi and Nitta, 1997; Nitta and Hu, 1996). The detailed description about SVD can be found in von Storch and Navarra (1995), Bretherton, et al. (1992), and Wallace, et al. (1992). Only the first SVD coupled patterns and their corresponding time coefficients are presented and analyzed in the following sections. The method of EOF is also employed in this study in order to verify the importance of the dominant SVD mode in the total variation of its corresponding field.

## III. SPRING

EOF and SVD analyses are computed with H500 in NH and HCA over the western Pacific in spring (MAM). Heterogeneous (upper panel) and homogeneous (middle panel) correlation patterns and their corresponding time coefficients (bottom panel) of spring H500 in NH (a) and HCA (b) are shown in Fig. 1. The squared covariance fraction (SCF) of this mode is 33 %, and the correlation coefficient (CC) between the time coefficients of the two fields is 0.82 (Table. 1). The large SCF value implies that this coupled mode reflects one third of the linear interaction between the general circulation and the convection over the western Pacific in spring. The large CC value and similarity between the homogeneous and heterogeneous correlation fields indicate that strong interaction is existed between the general circulation and the convection over the western Pacific in spring. The homogeneous and heterogeneous correlation fields are quite similar to their corresponding first EOF modes (Fig. 2). One of dominant patterns in Fig. 1a and Fig. 2a is the western Atlantic (WA) like pattern in the negative phase, the positive center in the subtropical western Atlantic and the negative center in the northwestern Atlantic, and another dominant pattern is the North Pacific (NP) like pattern in the negative phase, the positive values in North Pacific (40°N, 160°W) and the negative values in the subtropical central Pacific (20°N, 180°). The dominant pattern in Fig. 1b and

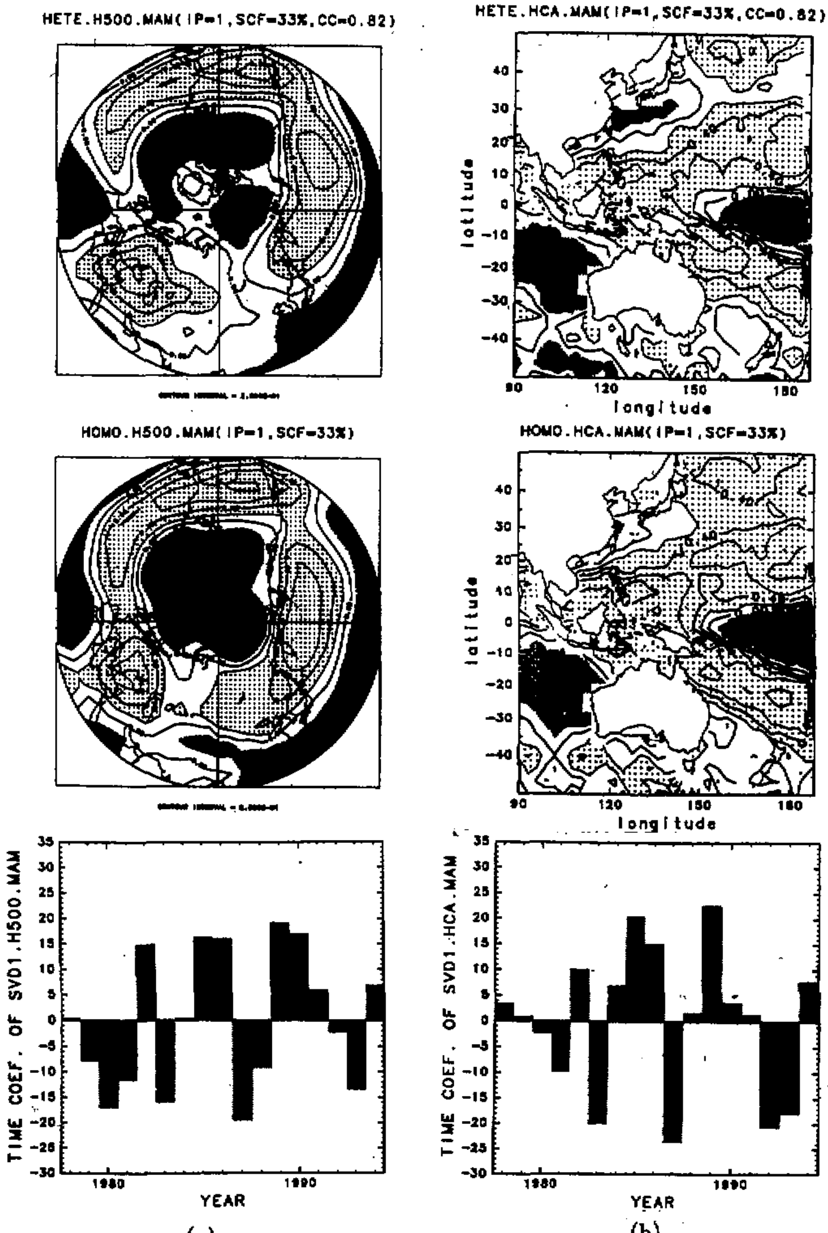


Fig. 1. Heterogeneous (upper) and homogeneous (middle) correlation patterns and their corresponding time coefficients (bottom) for the first SVD mode of H500 in NH (a) and HCA (b) in spring. The quared covariance fraction (SCF) of this mode is 33%. Correlation coefficient (CC) between the time coefficients of the two fields is 0.82. The contour interval is 0.2. Solid (dashed) lines are positive or zero (negative) in the correlation fields. The regions with values less than −0.2 are shaded, and the regions with values larger than 0.2 are dotted.

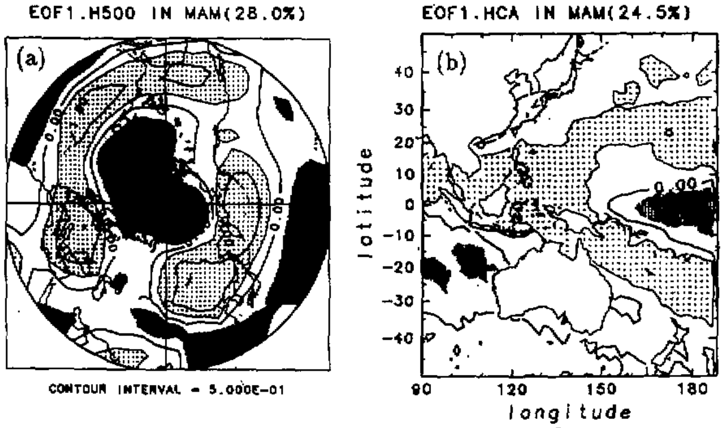


*Fig. 2. The first EOF spatial patterns of H500 in NH (a) and HCA (b) in spring. The contour interval is 0.5. Solid (dashed) lines are positive or zero (negative) in the correlation fields. The regions with values less than −0.5 are shaded, and the regions with values larger than 0.5 are dotted.*

Fig. 2b is a ' horseshoe ' −type pattern, negative values in the tropical central Pacific, positive values by its northern, southern and western sides. This mode is closely related with ENSO cycle. Most of the SVD time coefficients are negative during the mature phase of the El Niño events in spring (for instance, 1983, 1987 and 1992−1993) (Fig. 1).

From the above analyses, it is suggested that the convection over the western Pacific is closely related with the WA and NP like patterns of the general circulation in NH. It is also shown that there is some evidence of the interaction between the WA and NP like patterns and the ENSO cycle (Horel and Wallace, 1981).

## IV. SUMMER

Heterogeneous (upper panel) and homogeneous (middle panel) correlation patterns and their corresponding time coefficients (bottom panel) of summer H500 in NH (a) and HCA (b) are shown in Fig. 3. The SCF of this mode is 35 %, and the CC is 0.93 (Table. 1). The large SCF value implies that this coupled mode reflects more than one third of the linear interaction between the general circulation in NH and the convection over the western Pacific in summer. The values of SCF and CC in Fig. 3 are larger than the corresponding values in Fig. 1 for the spring case (Table 1). It is demonstrated that there is a stronger interaction between the convection over the western Pacific and the general circulation in NH summer than in spring. The homogeneous and heterogeneous correlation fields in Fig. 3 are quite similar to the corresponding first EOF mode of HCA with the opposite polarities (Fig. 4b) and the second EOF mode of H500 (Fig. 4a), respectively. The dominant pattern in Fig. 3 and Fig. 4 is the PJ pattern (Nitta, 1986, 1987), the positive (negative) values in regions from eastern part of China through Japan Islands to North Pacific, and the negative (positive) one by its north and south sides in Fig. 3a, 4a and 4b (Fig. 3b). Therefore, it is demonstrated that PJ pattern is the dominant coupled pattern in the interaction between the interannual variabilities of convection activities over the western Pacific and the general circulation in NH summer, and that the PJ pattern is also one of the very important patterns in the interannual variabilities of

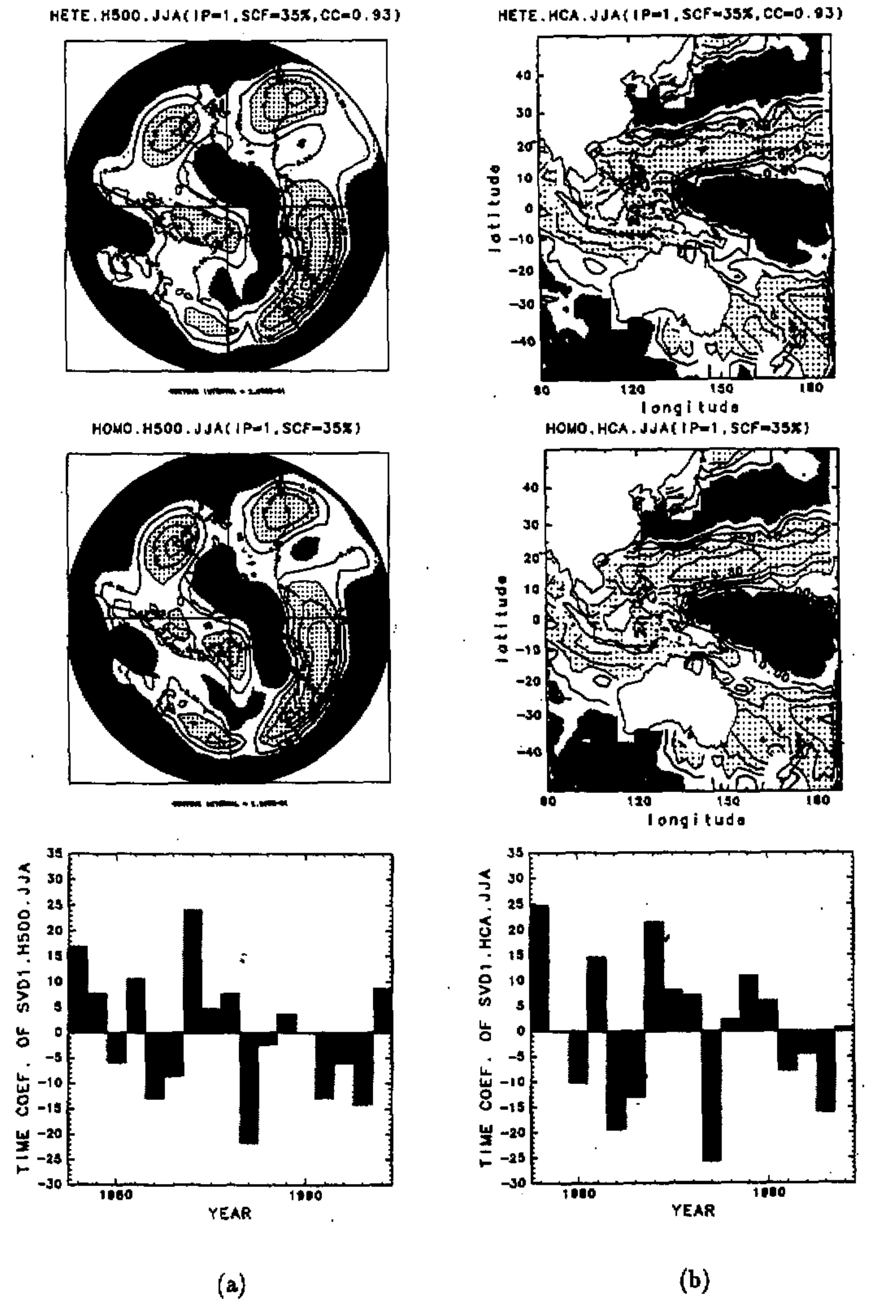


Fig. 3. As in Fig 1, but for summer, SCF = 35%, CC = 0.93.

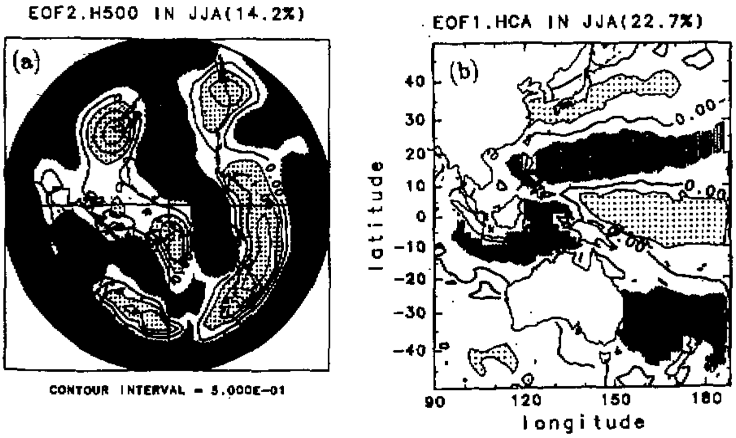


Fig. 4. As in Fig. 2, but for EOF2 of H500 (a) and EOF1 of HCA (b) in summer.

general circulation in NH and the convection over the western Pacific in summer. Nitta (1986, 1987), Nitta et al. (1986), and Huang (1990) pointed out that the formation of *PJ* teleconnection pattern is largely controlled by heat source anomaly in the western tropical Pacific region. There is a strong impact of the PJ pattern on summer temperature anomaly in Japan (Nitta, 1987) and summer drought or flood in regions along the Yangtze River valley in China. Recent study of Nitta and Hu (1996) has demonstrated that the *PJ* pattern is the dominant pattern not only in affecting the summer rainfall anomaly, but also in affecting the summer temperature anomaly in East Asia. In addition, the strong coherent variations in tropics and the WA like pattern are also obvious in the corresponding H500 fields (Fig. 3a and 4a). The 3–4 year period oscillation is obvious in their corresponding time coefficients (Fig.3).

Table 1. The Values of Squared Covariance Fraction (SCF) and the Correlation Coefficient (CC) between the Time Coefficients of the Two Fields of SVD1 in Each Season

| | Spring | Summer | Autumn | Winter |
|---|---|---|---|---|
| SCF | 33% | 35% | 30% | 40% |
| CC | 0.82 | 0.93 | 0.88 | 0.80 |

The present study concludes that the PJ pattern is the dominant pattern in the interaction between the interannual variabilities of the convection over the western Pacific and the general circulation in NH summer. The WA like pattern and 3–4 year period oscillation are also relatively obvious in this interaction.

V. AUTUMN

EOF and SVD analyses in this section, similar to the former two sections, are carried out with the data in autumn (SON). Heterogeneous (upper panel) and homogeneous (middle panel) correlation patterns and their corresponding time coefficients (bottom panel) of H500 in NH (a) and HCA (b) in autumn are shown in Fig. 5. The SCF of this mode is 30 %, and the

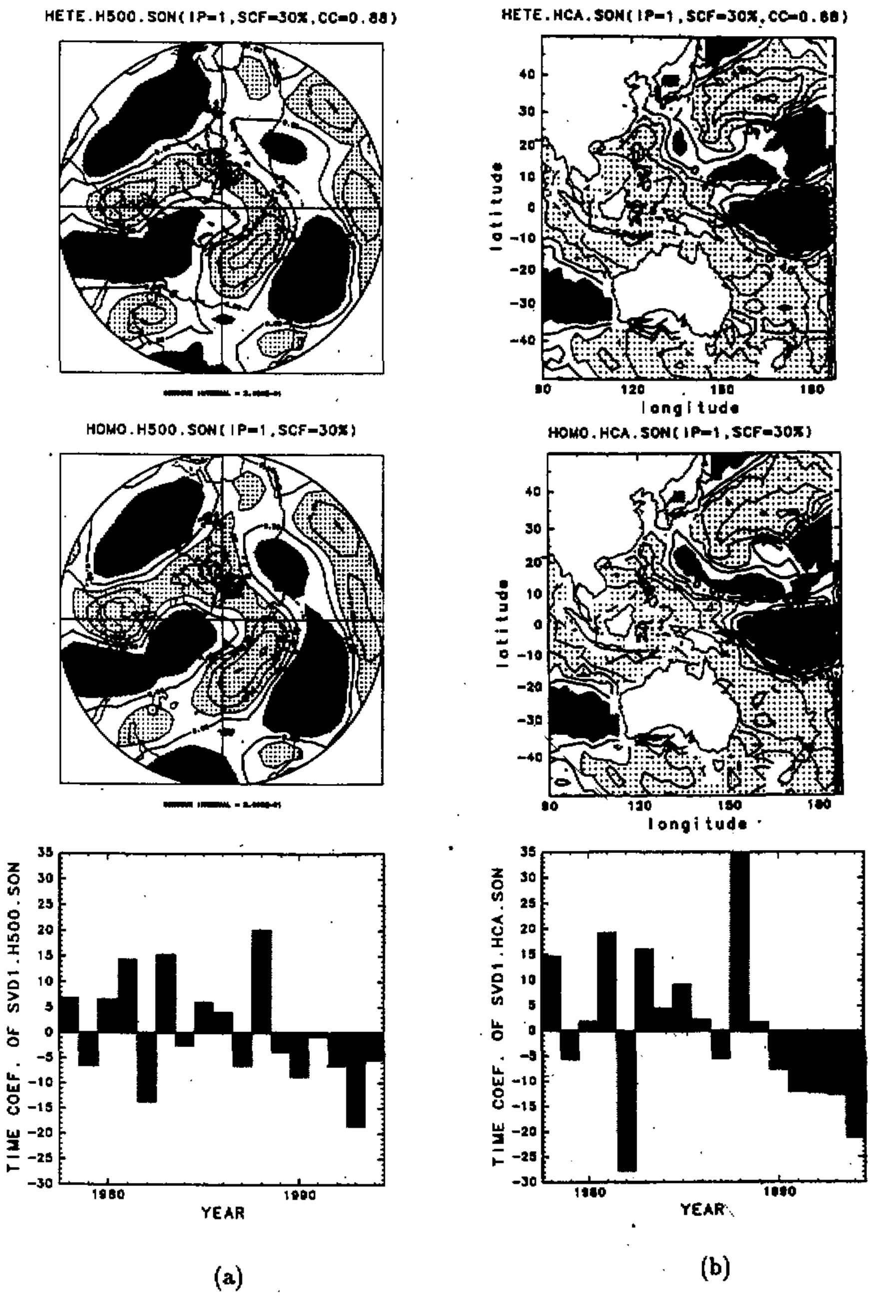


Fig. 5. As in Fig. 1, but for autumn, SCF = 30%, CC = 0.88.

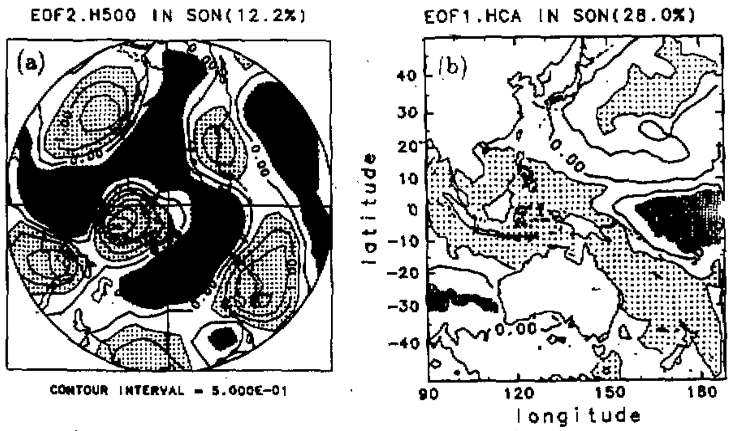


Fig. 6. As in Fig. 2, but for EOF2 of H500 (a) and EOF1 of HCA (b) in autumn.

CC is 0.88 (Table 1). The large SCF value implies that this coupled mode reflects nearly one third of the linear interaction between the general circulation and the convection over the western Pacific in autumn. The values of SCF and CC in Fig. 5 are smaller than the corresponding values in Fig. 3 of the summer case, and similar to those in Fig. 1 of the spring case (Table 1). An EU like pattern is obvious in Fig. 5a, positive values in regions of western Europe and the north side by Mongolia, and negative values in eastern part of Europe and regions around Korea and Japan Islands. It is suggested that in autumn the variation of convective activity over the western Pacific is largely excited by the general circulation anomaly (cold air from high latitudes) through EU like teleconnection pattern. The Atlantic oscillation with negative values in subtropical Atlantic and positive values by the north side is also strong in Fig. 5a. This mode is very similar to the spatial pattern of second EOF mode of H500, except the opposite polarities (Fig. 6a). The corresponding pattern of HCA is positive value regions in south side by Japan, the tropical western Pacific and the most regions around Australia, the negative in the tropical and subtropical central Pacific (Fig. 5b). This mode is analogous to the spatial pattern of first EOF mode of HCA (Fig. 6b). The decadal variability is obvious in its corresponding time coefficients. The positive time coefficients are dominant before the end of 1980's, and the negative dominant in 1990's (Fig. 5). Therefore, there is an obvious change in the interaction between convection over the western Pacific and the general circulation in NH autumn during 1989–1990.

The above analyses indicate that the convection over the western Pacific is closely linked with the EU like pattern and the Atlantic oscillation in the general circulation in NH autumn. Abrupt change occurred in the end of 1980's in the interaction.

## VI. WINTER

Heterogeneous (upper panel) and homogeneous (middle panel) correlation patterns and their corresponding time coefficients (bottom panel) of winter H500 in NH (a ) and HCA (b) are shown in Fig. 7. The SCF of this mode is 40 %, and the CC is 0.80 (Table 1). The large SCF value implies that this coupled mode reflects more than one third of the linear interaction between the general circulation and the convection over the western Pacific in

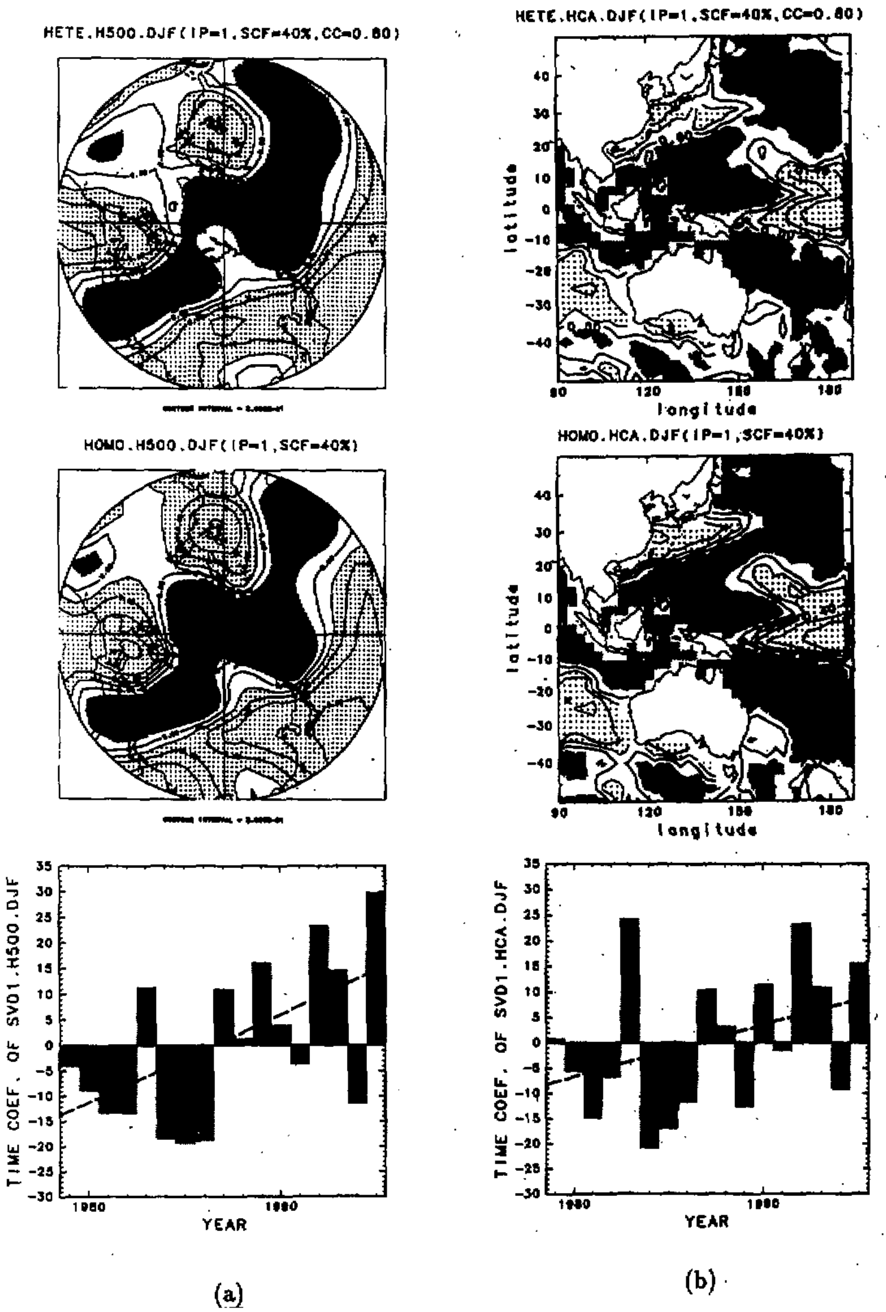


Fig. 7. As in Fig. 1, but for winter, SCF=40%, CC=0.80. The dashed lines in the figures of time coefficients are the linear trend of the time coefficients during 1979–1995, calculated by linear regression.

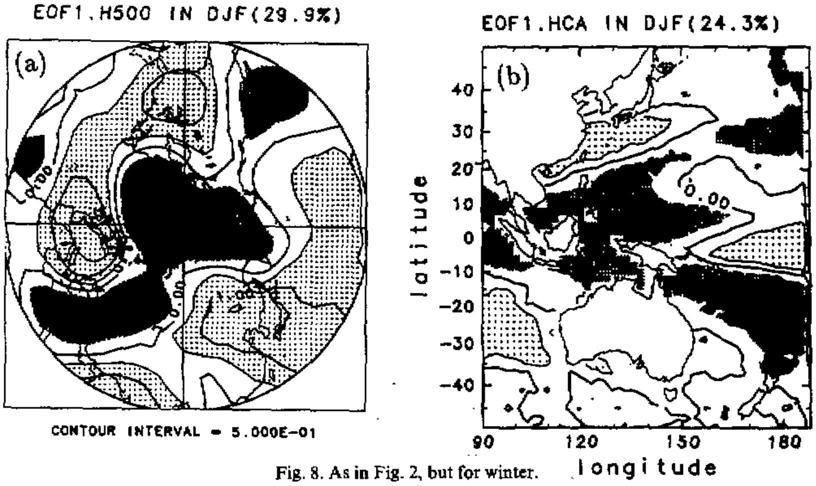


Fig. 8. As in Fig. 2, but for winter.

winter. The value of SCF in winter is the largest value in the four seasons (Table 1). It is indicated that the interaction is the strongest among the interactions between the convection over the western Pacific and the general circulation in NH winter among the four seasons, and it is also demonstrated that the interaction in summer and winter is stronger than in the transition seasons (spring and autumn) (Table 1). The spatial mode of the SVD1 of H500 is dominated by the western Pacific (WP) pattern in negative phase with the positive values in the western Pacific and Asia and negative values in North Pacific, and the EU like pattern in negative phase with positive regions in the western part of Europe and Asia and negative one in the eastern part of Europe (Fig. 7a). This mode is similar to the results of EOF1 for H500 (Fig. 8a) and the results of EOF2 for H500 with opposite signs in Fig. 27b of Wallace and Gutzler (1981), and also similar to the simultaneous correlation field between OLR ( outgoing longwave radiation) and H500 in NH for January during 1975–1987 (see Fig. 4a of Miyazaki (1989)). The spatial distribution of the corresponding first SVD mode of HCA is positive values in regions along the west coast of Pacific and the tropical central Pacific, the negative values in regions around the Philippine Islands and of North Pacific. This negative value regions around the Philippine Islands are nearly exactly similar to the distribution of grid points where the simultaneous correlation coefficient between the temperature over Japan and the OLR in January achieves values greater than 0.63 (seen Fig. 2a of Miyazaki (1989 )). Significant linear increasing trends shown in Fig, 7 are existed in the corresponding time coefficients of SVD1. It is demonstrated that the EU and WP like patterns and the convections over the tropical central Pacific have a linear strengthened trend and the convections over North Pacific and in region around the Philippine Islands have a linear weakened trend in winter. This is coincided with the conclusion about the analysis of OLR given by Hu and Huang (1997a).

From above analyses, the strong interaction between WP and EU like patterns in the general circulation in NH and the convection over the western Pacific in winter is demonstrated. The significant linear increasing trends in their corresponding time coefficients are also revealed.

## VII. CONCLUSIONS AND DISCUSSIONS

The differences of the coupled dominant patterns in the interaction between interannual variabilities of the convection over the western Pacific and the general circulation in NH 500 hPa in the four seasons are analyzed with SVD and EOF analysis approaches, based on 500 hPa monthly mean geopotential height data from March 1978 to December 1994 and high-cloud amount ( HCA ) data from April 1978 to February 1995. EOF and SVD analyses demonstrate that there are strong interaction between the convection over the western Pacific and the general circulation in NH with different coupled dominant interaction patterns in various seasons, and it is an interaction process between the convection over the western Pacific and the general circulation in NH. The main results of the present study are summarized in the following:

(1) In spring, the convection over the western Pacific is closely related with the WA and NP like patterns of the general circulation in NH. There are some associations between the WA and NP like patterns and the ENSO cycle.

(2) The PJ pattern is the dominant pattern in the interaction between the convection over the western Pacific and the general circulation in NH summer. It is also demonstrated that the PJ pattern is one of the very important patterns in the variations of general circulation in NH and the convection over the western Pacific in summer, respectively. The WA like pattern and 3–4 year period oscillation are also relatively obvious in the interaction of this season.

(3) In autumn, the convection over the western Pacific are closely linked with the EU like pattern and the Atlantic oscillation in the general circulation in NH. It is suggested that in autumn the variation of convective activity over the western Pacific is largely excited by the general circulation anomaly (cold air from high latitudes) through EU like teleconnection pattern. Abrupt change occurred by the end of 1980's in this interaction.

(4) The strong interaction between WP and EU like patterns in the general circulation in NH and the convection over the western Pacific in winter is demonstrated. This interaction has a linear trend of increasing.

(5) The interaction in summer and winter is stronger than in the transition seasons (spring and autumn).

The interaction pattern between the convection over the western Pacific and the general circulation in NH varies with season, time and space scales. Only the seasonality of the dominant coupled interaction pattern is preliminary examined in the present paper, and the physical mechanisms and physical processes forming the interaction are unclear and remained as a future subject.

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