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INTERDECADAL VARIABILITY IN A MODEL ATMOSPHERE

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ABSTRACT: By using the simulation results of an AGCM, which had been run from 1945 to 1993 forced by COADS SST, the interdecadal variability of the model atmosphere was investigated and compared with that of NCEP reanalysis data. It was found that, interdecadal variability exists significantly in both the tropical Pacific wind fields and the mid-high latitude atmospheric circulation of the model atmosphere. The tendency of time variation and spatial distributions of the interdecadal variability of the model atmosphere are basically consistent with observation. Relative to the mid-high latitude atmospheric circulation, the simulation of tropical Pacific wind is more satisfying, which suggests that anomalous variation of SST is still the main factor for the interdecadal variability of tropical Pacific wind. It might have more significant influence on the tropical wind than on the mid-high latitude atmosphere. However, there is still obvious difference between the simulation and observation. They could be attributed to both the simulation capability of the model and absence of other factors in the model which are important for the interdecadal climate variation.

Key words: model atmosphere; SST anomalies; interdecadal variability; mid-high latitude atmospheric circulation; interdecadal variability

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1 INTRODUCTION

As shown in various studies, significant variations exist in the global climate and tropical Pacific SST is one of the important factors influencing the anomaly of interannual climate[1, 2]. Since the 1970's, general circulation models have been used to study anomalous response of the atmosphere on sea temperature and ice coverage given anomalous state of the underlying surface, such as SST anomalies[3]. The Atmospheric Model Intercomparison Program (AMIP), beginning in 1990, concentrates efforts on responses to sea surface temperature and ice coverage to coordinated source of multiple GCMs. The results of quite a number of models are quite successful[4].

Apart from variation on the interannual scale, climate has significant interdecadal variation. Examples can be seen in the intensification of precipitation of the Indian Monsoon, persistent drought in the Sahara region in west Africa starting from the end of 1960's[5-7]. Obvious interdecadal changes are also taking place in the SST of the Pacific Ocean, which experiences a remarkable increase from mid-1970's to 1990's after a relatively stable period in the 1950's and 1960's, in contrast to north Pacific where the SST is significantly decreased[8]. As early as in the 1960's, Namias noted that a long-term (10 years or more) variation exists for the sea level pressure (SLP) in north Pacific, which correlates well with the air temperature in North America[9]. Successively, Kashiwabara[10](1987), Trenbenth[11](1990) and Trenberth[12](1994) pointed out that the SLP was

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anomalously low in north Pacific (but the Aleutian Low is anomalously strong). Such year-to-year changes in SLP as presented above in the north Pacific region are also known as North Pacific Oscillation (NPO), which receives much attention together with the North Atlantic Oscillation (NAO) [13]. It should be pointed out that the NAO and NPO were first put forward in early 1930's as a phenomenon of interannual variability[14], but now they are treated more in the sense of climatic signal across the decade[15].

There are quite a number of factors that could affect the interdecadal variability of the general circulation, like natural and human factors. Only the effects of SST changes in the lower boundary are considered here. Therefore, a general circulation model is forced using the SST data from COADS in 1945 ~ 1993 during integration of nearly 50 years and the result is applied tackling the issue.

Section 2 gives brief account of the model and data. Section 3 studies the interdecadal characteristics of the wind field in the tropical Pacific and general circulation in the mid-and-higher latitudes (citing the region Pacific Ocean through North America) before comparing it with reanalyzed data of NCEP. Section 4 is set for summary and discussions.

2 DATA AND MODEL

2.1 *Data*

(1) Monthly mean anomaly of global sea surface temperature by 1° × 1° and associated climatological field from January 1945 to December 1993 (COADS);
(2) Monthly mean wind fields of reanalyzed 500 hPa and 850 hPa across the globe from January 1949 to October 1998, with horizontal resolution of 2.5° × 2.5°.

For the convenience of discussion, the following indexes are also computed:

① Nino3 index: average of SSTA within the equatorial central and eastern Pacific (90° ~ 150°W, 5°S × 5°N);

②TW2 index: average of 850-hPa zonal wind anomaly within the equatorial central Pacific (180° ~ 140°W, 5°S ~ 5°N);

③ PNA index: PNA = 0.25*[z^*(20 °N,160 °W)-z^*(45 °N,165 °W)+z^*(55 °N,115 °W)-z^*(30 °N,85 °W)].

Specifically, z^* is the anomaly of 500 hPa geopotential height in winter.

2.2 *Description of model*

The climate model employed in the work is a spectral model of global general circulation modified by the Atmospheric Physics Institute of Chinese Science Academy (L9R15 AGCM), which is divided into 9 layers and rhombus-truncated. The resolution is about 7.5° × 4.5° in the horizontal direction (The Gaussian gridpoints are graphed in *Y* direction). The model includes a full set of physical processes, considers real topographic distribution, SST, polar ice, perpetual snow cover, O_3 and CO_2 and incorporates reference atmosphere with standard stratification. Refer to [17] for details of the structure. Using the monthly mean COADS SST over 1945 ~ 1993 as the external forcing field and setting other forcing fields as fixed climatic values, we conducted integration of AGCM for a continuous period of 49 years. The simulations are then used in the analysis followed.

3 ANALYSIS OF SIMULATED RESULTS

3.1 *Interdecadal variation of tropical Pacific wind field*

3.1.1 INTERDECADAL VARIATION OF THE TW2 INDEX

From the TW2 index simulated by AGCM and Nino3 index computed with SST data of COADS, we find that the two are well correlated with each other in temporal variation — westerly (easterly) anomaly is correlated with positive (negative) anomaly of SST by a coefficient of 0.72 (figure omitted). By applying 9-year weighted running mean treatment to the indexes above, we get the variation as shown in Fig.1a and 1b. The interdecadal variation is well illustrated for the TW2 index, basically all negative before 1978 with positive anomaly starting to appear in the end of

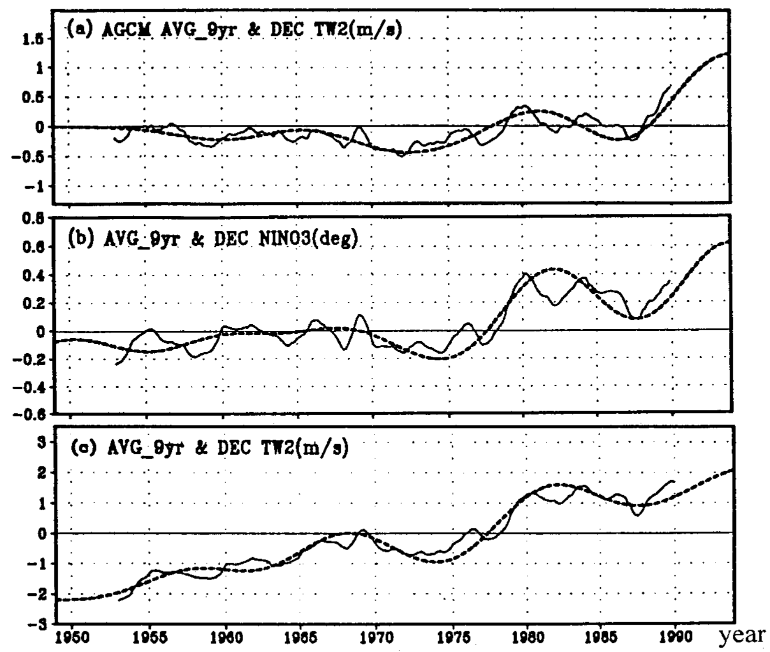

Fig.1 9-year running average (solid line) and low-pass filtered series (thick dashed line) of AGCM TW2 index (a), Nino3 index (b), NCEP TW2 index (c).

1970's, increasing obviously after the end of 1980's. The Nino3 index, treated with running mean, was always in the positive sector after year 1978. Conducting low-pass filter of the TW2 and Nino3 indexes (by eliminating signals with periods less than 9 years), we obtained the series as shown by the dashed lines in Fig.1a and 1b. The interdecadal variation is now much clearer: the SST is negatively anomalous almost all the time and wind field is entirely negatively anomalous (easterly anomalous) before 1977; after 1977, SST stayed within positive anomaly all the time with stronger intensity in the latter period of 1990's (0.6°C) while the TW2 index had alternative anomaly periods of positive in early 1980's, negative in mid-1980's and positive after 1988. The westerly anomaly rapidly increased in the 1990's. In the meantime, consistence is found with temporal variation of TW2 and Nino3 indexes regardless of running mean or low-pass filter. They are correlated by 0.75 and 0.82 respectively, suggesting that the SST variation is still the primary factor that influences the interdecadal variation of tropical Pacific wind fields.

Comparing the TW2 index (derived with NCEP data, figure omitted) with the simulated results, we find that the former is significantly weak, though with highly consistent variation in time (the correlation coefficient being 0.62). Applying similar treatment of 9-year running mean and low-pass filter to the TW2 index of NCEP, we obtained results as shown by the solid and dashed lines respectively in Fig.1c. Although there is some degree of difference between the two, as shown in comparison with Fig.1a, such as strong negative anomaly in TW2 of NCEP in the 1950's and 1960's versus weak negative anomaly in TW2 of AGCM, and a fall to negative zone by the AGCM TW2 versus a reduction but above positive anomaly by the NCEP TW2, in mid-1980's, they are generally the same in the trend of variation (of curves). The year 1977 is a turning point of easterly and westerly anomalies on the interdecadal scale. The coefficients of dashed and sold lines in Fig.1a and Fig.1c are relatively 0.57 and 0.55.

In spite of good simulation of variation tendency of interdecadal signals in the tropical Pacific wind fields by AGCM, differences between simulation and observation are also quite noticeable. The causes may be the property of model itself and lack of factors other than SST in the model. It may be highlighted by the fact that COADS SST does not guarantee stable quality in middle and high latitudes. In fact, the SST is not strong in terms of negative anomaly in the 1950's, which is contrary to strong anomaly of easterly for the same period shown in Fig.1c. In addition, the wind field anomaly in Fig.1a and 1b are generally proportional to the anomaly of SST in magnitude. It is a reasonable simulation. It can then be inferred that the strong easterly anomaly present in the 1950's (Fig.1c) may have been caused by factors other than SST.

3.1.2 EOF DECOMPOSITION OF INTERDECADAL VARIABILITY OF TROPICAL PACIPIC WIND FIELD

First of all, a low-pass filtering is conducted of the zonal wind anomaly at 850 hPa by AGCM to remove signals with periods less than 9 years, i.e. to retain interdecadal signals. Then, the Empirical Orthogonal Function (EOF) is expanded. Fig.2a and 2b give separately the time series and spatial distribution of the first mode of EOF, the latter having an interpretive variance of 43.4%. The temporal variation is basically the same as the interdecadal series (dashed line) of TW2 in Fig.1a, with the major difference being the appearance of positive anomaly in the mid-and-late 1960's. In the spatial distribution, the equatorial west Pacific is in typical out-of-phase relationship with the east Pacific, with the western center, which is stronger, in the equatorial west Pacific (around 165°E) and the eastern one on the coast of South America. The positive anomaly in the western ocean (which can also be negative anomaly) appears to extend southeastward. It is obvious, at least from the simulated results, that the variation is not consistent throughout the Pacific and the changes in wind field are just the reversed in the eastern and western parts with the boundary lying roughly along 135°E.

Fig.3a and 3b respectively give the temporal and spatial distribution of the first mode of interdecadal component of the 850-hPa anomaly provided by NCEP. The contribution of variance from the first mode is 53.4%. Examining the temporal changes, we know that negative (positive) anomaly prevailed before (after) the year 1976, being generally consistent with the interdecadal series (dashed line) of TW2 index in Fig.1c. For the spatial distribution, however, the sign is nearly consistent in the whole equatorial part of the Pacific Ocean with the center across the equator. Analyzing it in association with the temporal series, we know that negative anomaly (easterly anomaly) prevailed before 1976 while positive anomaly (westerly anomaly) dominated after it. It is obvious that the presence of westerly anomaly is favorable for the generation and development of El Niño. It has direct links with frequent and enhancing El Niño events after the 1980's, especially during the 1990's.

Apart from the difference in temporal changes, discrepancies also exist between the simulation and observation concerning the spatial distribution of interdecadal variation of tropical Pacific

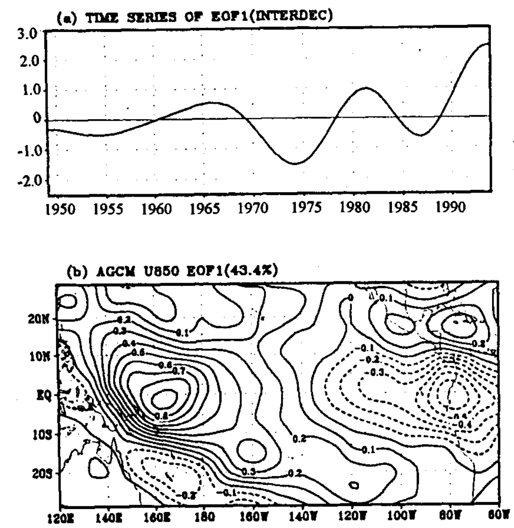

Fig.2 Time series (a), spatial distribution (b) and of the first EOF mode of interdecadal component of 850-hPa zonal wind anomaly simulated by AGCM.

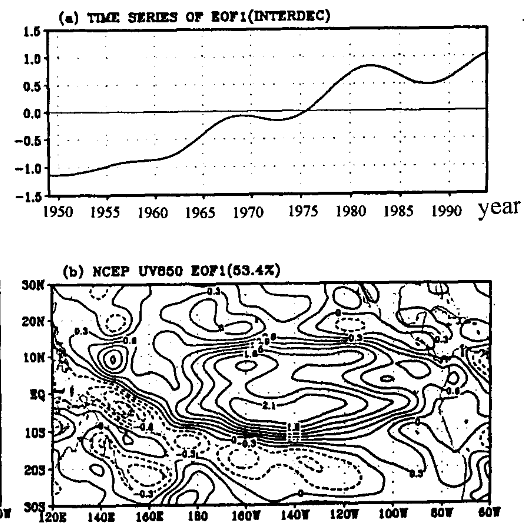

Fig.3 Same as Fig.2 but for that of NCEP data.

wind fields. It is true that the westerly (easterly) anomaly is not moving further enough towards the east in the central and western parts of the ocean due to exaggerated out-of-phase relationship between the east and west Pacific in the simulation. It is inherited with limitations of AGCM itself. Wu et al also found similar phenomena when they studied the distribution of interannual variation of the tropical Pacific wind fields as simulated by the model[18].

It is then drawn from the above discussion that with only SST incorporated the AGCM is normally capable of simulating the tendency of variation and spatial distribution of the interdecadal signals of the tropical Pacific wind fields, though there is difference in intensity (e.g. the 1950's) and some periods of time (e.g. middle part of 1980's) from observation. In addition to the model factor, some other factors other than SST are also controlling the interdecadal variation of the tropical Pacific wind fields.

3.2 *Interdecadal variation of general circulation in middle and high latitudes*

3.2.1 INTERDECADAL VARIATION OF PNA INDEX

First of all, a low-pass filtering is conducted of the geopotential anomaly at 500 hPa to remove signals with periods less than 11 months, i.e. to retain variations above the interannual scale. Then, the PNA index is computed using the equation in Section 2.2.1, which is then treated with 9-year running averaging and low-pass filtering. The results of AGCM and NCEP are shown in Fig.4a and 4b, respectively. The results of 9-year running averaging (upright bars) and low-pass filtering (dashed line) reveal clear patterns of interdecadal variation for the PNA index of the model atmosphere. Positive anomaly appeared in 1969 ~ 1975, 1980 ~ 1986 and negative anomaly in other years of interest. It goes quite consistently with the NCEP result as far as the whole trend of variation is concerned. In Fig.4a and 4b the two dashed-line series are correlated by a coefficient of 0.33, exceeding the 95% significance level. What is insufficient with the simulation is that its sign

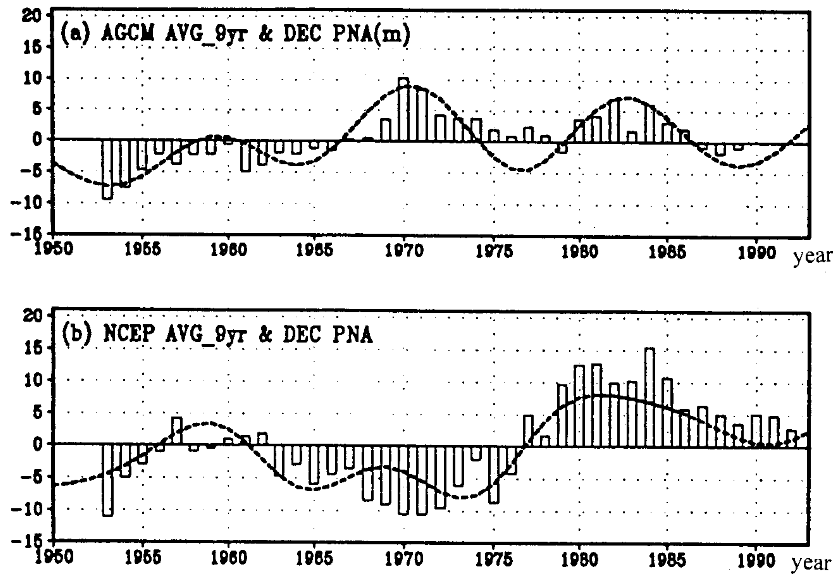

Fig.4 9-year running average (bars) and low-pass filtered series (dashed line) of PNA index simulated by AGCM (a) and NCEP data (b).

is just the opposite of the observation in the 5 to 6 years around the year 1970 while the simulated negative anomaly did not appear until after the year 1975, which is why positive anomaly postponed for 2 to 3 years in the late 1970's. Besides, the positive anomaly ended on an earlier date in the 1980's.

It is now clear that the AGCM is able to simulate the general tendency of interdecadal variation of the PNA index but with much poorer quality as compared to the TW2 index. It is suggested that the simulation of interdecadal variation of general circulation for the mid-high latitude is more difficult than for the tropical Pacific region. It also reflects such a fact: For the interdecadal time scale, the SST anomaly is having more significant influence on the general circulation in the tropical Pacific region than in the mid-and-high latitudes.

3.2.2 EOF DECOMPOSITION OF INTERDECADAL VARIATION OF GENERAL CIRCULATION IN MID-AND-HIGH LATITUDES

A low-pass filtering is conducted of the monthly mean geopotential anomaly at 500 hPa to remove signals with periods less than 9 years, and EOF decomposition is done of geopotential anomaly field for every January of the filtered data. Figs.5a and 5b respectively give the temporal series and spatial distribution of the first mode of EOF. The variance of the first mode contributes by 39.1%. There is not much difference between Fig.5a and Fig.4a (dashed lines) regarding the variation over time, only that positive anomaly prevailed ever after 1980, which is quite close to the result of NCEP (Fig.4b). The only shortage is still the appearance of positive anomaly around 1970 and later occurrence of positive anomaly in the late 1970's. Spatially examined, extensive negative anomaly is found to be over the Pacific Ocean, spanning across the entire North Pacific in the zonal direction. The center is south of the Aleutian Islands in the domain 180° ~ 160°W, 40°N ~ 50°N. Another closed positive anomaly zone is to the northeast with the center over Canada. They have comparable intensity.

With the aim of comparison, Fig.6 gives the result of the first mode of EOF-decomposed interdecadal component of 500-hPa geopotential anomaly field by NCEP. The contribution of variance is 34.1%. Viewing from the temporal changes (Fig.6a), the negative (positive) anomaly prevailed before (after)1977, with the year a turning point. Positive anomaly increased significantly after 1990. Viewing from the spatial distribution, the anomaly was negative in a closed zone that is slightly less than that in Fig.5 with the center a little northward (about 50°N). To its northeast is a closed zone of negative anomaly, too, with higher intensity though, centering on the west coast of Canada. Studying it with time series, we obtained that the geopotential field was relatively low in north Pacific after the year 1977, a fact that is consistent with some other results of analyses[10 - 12].

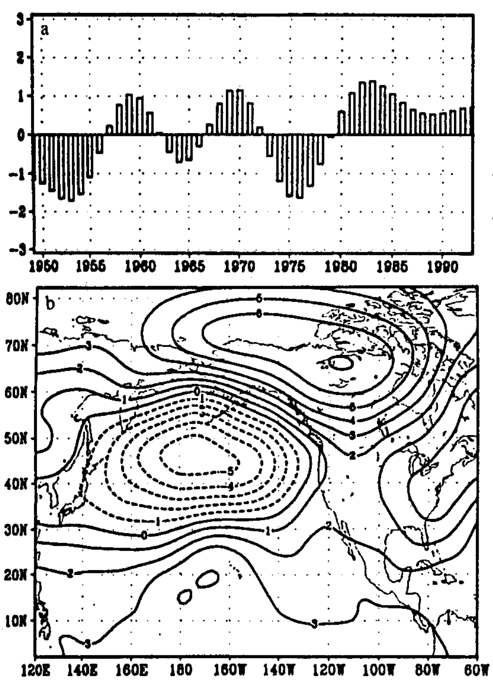

Fig.5 Time series (a), spatial distribution (b) of the first EOF mode of interdecadal component of winter 500-hPa anomaly simulated by AGCM.

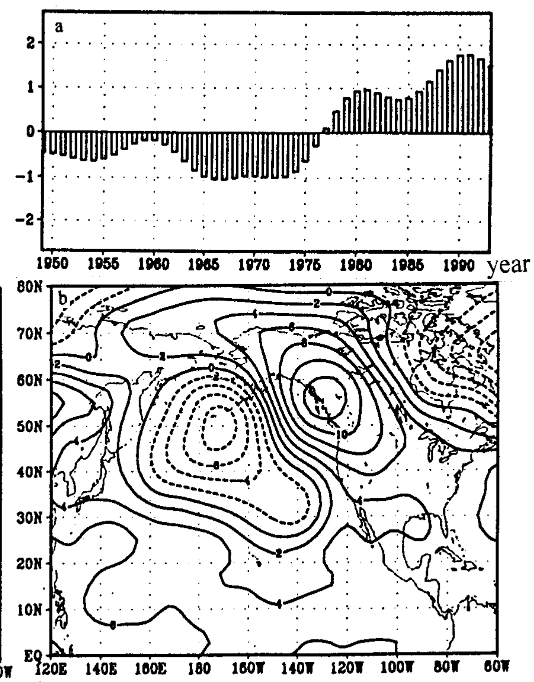

Fig.6 Same as Fig.5 but for that of NCEP data.

It is now obvious that the simulation and observation are very close with regard to the distribution of spatial field of the first EOF mode, despite of slight differences in central location. Nonetheless, they remain far apart in terms of temporal series: Positive anomaly appeared around 1960 and 1970, which did not have counterparts in the NCEP results. In the meantime, the positive anomaly appeared later in the late 1970's.

As shown in the result analyzed above, AGCM gives good simulation of general tendency of spatial distribution and temporal variation of interdecadal general circulation in the winter of Pacific-North America, though with considerable differences in temporal variation for some sections of period between simulation and observation. It indicates that the AGCM is not capable of successfully simulating the interdecadal variation in the general circulation of mid-and-high latitudes if only SST is considered. There must be some other factors in the play, which are of even more outstanding in the tropical Pacific region.

4 CONCLUSION AND DISCUSSIONS

a. In model atmosphere, there is significant interdecadal variation in the wind field of tropical Pacific region and general circulation in the mid-and-high latitudes. The intensity results of AGCM are relatively weak.

b. The AGCM gives good simulation of spatial distribution and tendency of temporal variation for the interdecadal signals of general circulation in the tropical Pacific and mid-and-high latitudes. With regard to variation over time, the simulation is successful in reproducing the shift of the tropical Pacific wind field from easterly anomaly to westerly anomaly in 1977 and that of the PNA index from negative to positive in the late 1970's. In relation to distribution over space, the AGCM is successful in modeling major features of general circulation in the north Pacific region and North America to the northeast. Good simulation is also found with the distribution of wind fields for the central and western parts of tropical Pacific Ocean.

c. Relatively, the simulation of wind fields in tropical Pacific are better than in the mid-and-high latitudes, indicating that SST is still an important factor that influences the interdecadal variation of general circulation in tropical atmosphere. It affects the general circulation in tropical Pacific in a much more significant way than it does in mid-and-high latitude areas.

d. Large difference exists between simulation and observation. It attributes to the property of the general circulation model itself (e.g. for the spatial distribution of tropical Pacific wind field, the simulated easterly or westerly anomaly fail to extend or transmit to the eastern part). The phenomenon also suggests that SST anomaly is only one of the factors that influence the interdecadal variation of general circulation. For a successful simulation of the variation, especially in the mid-and-high latitude regions, other factors as well as SST should be considered comprehensively.

Apart from SST, there are other external factors that could affect the variation of general circulation. They contribute differently on various time scales. The longer the time scale, the more outstanding the slowly-varying factors will be. Variations of such atmospheric components as polar ice and snow cover are of slow processes, which cannot be neglected in terms of their role in the variation of interdecadal climate. Similar numerical experiments should be performed with these factors to understand their role in the variation of interdecadal climate. Depending on oceanic waters, the effect of SST may vary on the interdecadal variability of the atmosphere and simulation with different models may yield different results. There is one more issue that is more fundamental: What is the mechanism responsible for the interdecadal variability of the atmosphere? It is rather difficult, obviously, to give an answer to this question based on what we have known by now. It is, however, one of the hot topics in the international climate research.

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