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NOTES AND CORRESPONDENCE

Characteristic Features of Recent Abrupt Changes in Winter Circulation Revealed by a General Circulation Model

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Abstract

Two noticeable abrupt changes in Northern Hemispheric winter circulation have occurred in recent decades, one around 1977 and the other around 1989. In the 1970s occurrence, changes in equatorial sea surface temperatures (SSTs) occurred concurrently with those in mid-latitude atmospheric circulation. In the case of the late 1980s, however, no important variation in SSTs was seen in the equatorial regions. In order to identify the differences in the characteristics of the changes in circulation between the two cases, observed 500 hPa heights were compared to simulations with an atmospheric general circulation model (GCM) that used observed SSTs as surface boundary conditions. The results of simulation suggest that the change in circulation in the late 1980s was not the direct response to the changes in SSTs, but can rather be characterized as a triggered planetary scale internal mode of variability in the winter atmosphere.

1. Introduction

An important change in winter circulation occurred in the mid-1970s (*e.g.*, Nitta and Yamada, 1989; Trenberth, 1990, Kachi and Nitta, 1997). The most prominent feature of this sudden change in circulation was that sea level pressure and 500 hPa geopotential height decreased over the North Pacific region concurrently with an increase in sea surface temperatures (SSTs) over the equatorial Pacific. More recently, since the very late 1980s, sea level pressures over the North Pacific sector, which had been in the lower regime since 1977, recovered to their normal state (Trenberth and Hurrell, 1994). The more recent abrupt change was, however, not limited to the Pacific sector but it rather extended over wide regions of the Northern Hemisphere. For example, it included a decrease in sea level pressure over the polar region (Walsh, 1996), a decrease in sea ice concentration over the sea of Okhotsk (Tachibana *et al.*, 1996), a high value of the North Atlantic Oscillation (Hurrell, 1995), and high surface air temperatures over the East Asian sector (Yatagai and Yasunari, 1994). In considering the cause of the recent decrease in north polar sea ice, Maslanik *et al.* (1996) noted a coincidence between the lowering of the Arctic sea level pressures and a highly unusual extended El Nino/ Southern Oscillation (ENSO) event from 1990–1995 (Trenberth and Hoar, 1996). However, lagged correlation analysis (Koide and Kodera, 1997) suggests the relationship

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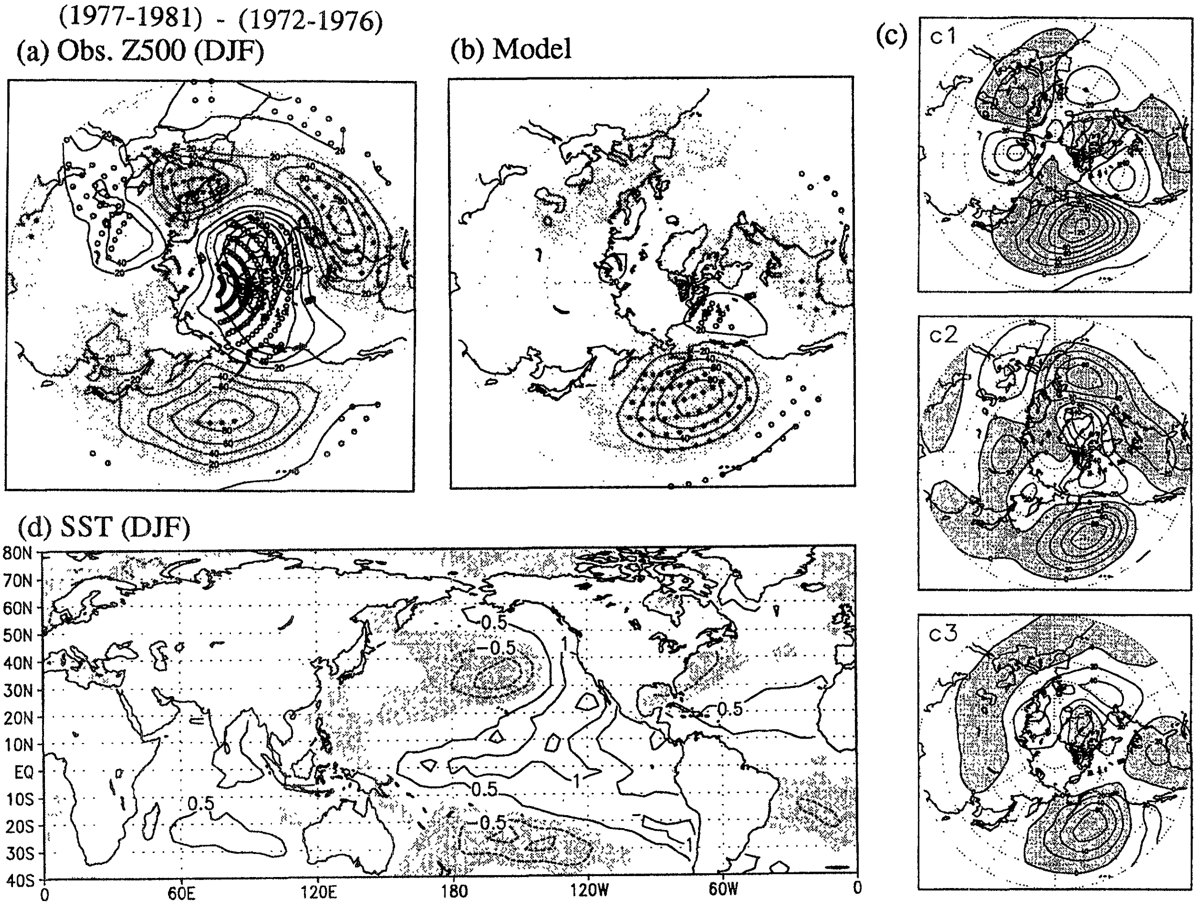

Fig. 1. Epoch differences between two periods (1977–1981) and (1972–1976). (a) Observed difference in winter mean 500 hPa geopotential height. (b) Same as (a) except for ensemble mean of 3 model simulations. (c) Same as (b) except for the 3 individual runs (c1, c2, c3). (d) Same as (a) except for winter mean SST. Contour interval is 20 m for (a), (b), and (c), but 0.5 K for (d). Negative values are shaded. Zero contour line is suppressed in (a), (b), and (d).

of the midlatitude circulation and equatorial SSTs between the 1970s and late 1980s is quite different.

Concerning the origin of the abrupt change in the 1970s, it has been demonstrated by general circulation models (GCM) that the circulation changes over the North Pacific regions originated from changes in diabatic heating due to anomalous equatorial SSTs (*e.g.*, Graham, 1994; Graham *et al.*, 1994; Kawamura *et al.*, 1995, 1997b). The aim of the present study is to determine, using the results of simulations with a GCM, whether or not the abrupt change in the Northern Hemispheric winter circulation that occurred in the late 1980s was also due to equatorial SST anomalies as was the case in the 1970s.

2. Data

The simulated data used in the present study is the same as was used in the model experiments by Kawamura *et al.* (1995, 1997b) and Sugi *et al.* (1997), in which the Japan Meteorological Agency (JMA) global model (JMA, 1993) was integrated for 34 years from 1955 through 1988 using observed near-global SSTs compiled by the U.K. Meteorological Office. These experiments included three integrations of GCM from different initial conditions. Details of the experiments can be found in Kawamura *et al.* (1995, 1997b) and Sugi *et al.* (1997). More recently, model integrations have been extended until the end of 1993 (Kawamura *et al.*, 1997a). These integrations are used in the present study. Observed monthly mean 500 hPa geopotential height data compiled by the JMA are used for comparison with the model simulation. It should be noted that in the present study, winter mean data are calculated by averaging December, January, and February mean data, with the winter designated as falling under the year corresponding to January.

3. Results

During the recent decades, two large changes in circulation between five year periods before and after the winters (A) 1977 and (B) 1989 can be seen in the expansion coefficients of singular value decom-

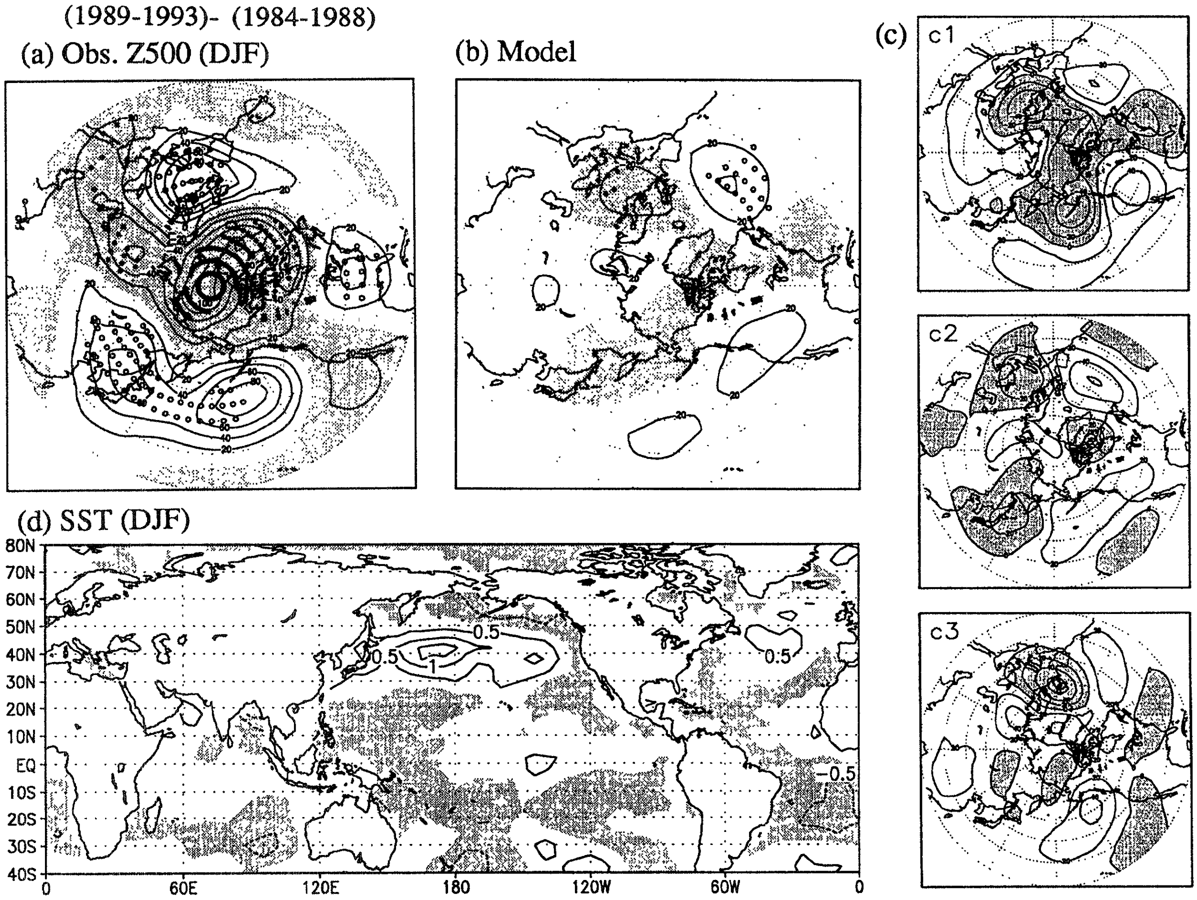

Fig. 2. Same as Fig. 1, except for the epoch difference is between (1989–1993) and (1984–1988).

position (SDV) of winter mean 500 hPa geopotential height and SST (Koide and Kodera, 1997). According to their results, we focus our attention on these two periods in the present study.

Figure 1a shows the difference in observed winter mean 500 hPa height between the two periods: 1977–1981 and 1972–1976. According to the Student-t statistics, grid points where the difference of means between the two periods are significantly different from zero with 95 % confidence level are indicated by open and solid circles for positive and negative values, respectively. The same epoch difference was also calculated for simulated 500 hPa height, which was constructed using the ensemble mean of 3 model runs from different initial conditions (Fig. 1b). The individual members of the ensemble mean can be found in the right-hand panels in Fig. 1c, (c1, c2, and c3).

A large decrease in 500 hPa height on the order of 80 m is observed over the North Pacific sector after 1977, although it is only marginally significant (Fig. 1a). As already shown by Kawamura *et al.* (1995), the model results (Fig. 1b) reproduce well a decrease over the North Pacific regions. It should be noted that in the case of model results although simulated decrease over the Pacific regions has similar magnitude as that observed, interannual variability being attenuated as a result of ensemble mean, statistical significance is greatly increased.

For the changes over the North Atlantic sector, while the observational results also exhibit large variation in 500 hPa height (Fig. 1a), no significant changes are found in the model results (Fig. 1b). Visual inspection of the results of the 3 individual model runs (Fig. 1c) reveals that model response is stable only over the North Pacific-American sector. The decreased height over the North Pacific sector is reproduced well in all 3 runs (at about −110 m, −80 m, and −60 m), while a decrease over the North Atlantic region is found only in the 2nd run (Fig. 1c-2). In the other two runs, an increase of height is found instead. In the case of the 1970s change, it should also be remembered that a large increase in equatorial SSTs occurred concurrently with the changes in extratropical 500 hPa height (Fig. 1d).

The same analysis in Fig. 2 is repeated for the change in the 1980s. Epoch differences for the 5 year periods between 1989–1993 and 1984–1988 are shown in Fig. 2. Similar magnitude changes in observed 500 hPa height (Fig. 2a), as in the 1970s, with opposite polarity anomalies (+80 m), are found over the North Pacific sector. In fact, this increase in height corresponds to the end of the deeper Aleutian low regime, which began in the winter of 1977 (Trenberth and Hurrell, 1994). Compared to the observations, the model response is quite small, not only over the North Pacific sector but over all the Northern Hemisphere (Fig. 2b). In most places, the variation hardly exceeds 40 m. Visual inspection of the individual runs (Fig. 2c) reveals that negative and positive values are respectively found over the Europe and Atlantic sector in all three runs (Fig. 2c), where simulated height differences are significant (Fig. 2b). The model responses are, however, much smaller (30–60 m) than in the 1970s (60–120 m). Furthermore, the spatial pattern does not correspond to the observations (Fig. 2a). It should also be noted that little change is found in the equatorial SSTs (Fig. 2d), even though the changes in the mid-latitude SSTs are comparable to or even greater than in the 1970s (Fig. 2d).

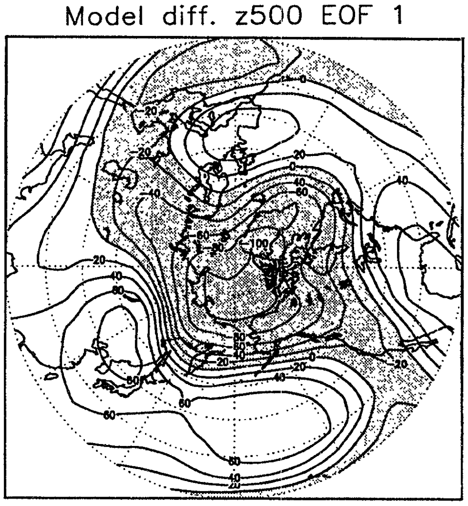

Fig. 3. First EOF of the difference field of the winter mean 500 hPa height between each pair of the 3 model simulations. Contour interval is 20 (unit is arbitrary) and negative values are shaded.

4. Discussions and concluding remarks

The present model simulation reproduces the observed features of the atmospheric circulation change in the 1970s over the northeastern Pacific sector. In the case of the 1980s, however, practically none of the observed aspects are simulated. This large contrast in model simulation performance can be attributed to differences in SST changes between the two cases. Large changes in equatorial SSTs accompanied the circulation change in the 1970s, while such changes are absent in the 1980s (*cf.* Figs. 1d and 2d).

Concerning the spatial distribution of the simulated abrupt changes, in the 1970s large variations in extratropic circulation were limited over the North Pacific-North American sector. This can be interpreted as a result of propagation of Rossby waves forced by anomalous heat sources due to the changes in equatorial Pacific SSTs (*e.g.*, Karoly *et al.*, 1989). In the 1980s, although observed changes in sea level pressure are found over the North Pacific sector (Trenberth and Hurrell, 1994) important variations are also found over the midlatitude of Atlantic-Eurasian sector and polar regions, as mentioned in the introduction. Therefore, if the failure of the model simulation is due to an erroneous response of the GCM to changes in SSTs, one can at least say that in case of the 1980s change the atmosphere should not be forced in a similar manner as in the 1970s. Hence, it is necessary to identify the characteristics of the changes in circulation produced at the end of the 1980s.

So far, analyses have been conducted to isolate atmospheric variability forced by changes in diabatic heating due to anomalous SSTs. For this reason, an ensemble mean of three runs integrated from different initial conditions is employed to attenuate internal variability in the atmosphere. In the following, internal variability in the model atmosphere is briefly examined by looking at the differences between each of the model runs, which differ only in initial conditions. In order to identify the most dominant internal mode of variability in the model, EOF analysis is conducted. Figure 3 shows the first mode of the EOF of the differences in the winter mean 500 hPa height between each of the 3 runs. The analysis is based on the correlation matrix calculated from 114 months (3×38 winters) of data. The first EOF explains 12 % of the total variance.

Visual inspection of Figs. 3 and 2a reveals a striking similarity in the spatial distribution of variation. Negative values are found in the polar regions, which extend toward the west Asian and north African regions. Positive anomalies are extended along the mid-latitudes. They are particularly strong over the Europe, East Asia, eastern North Pacific, and southeastern U.S. sectors. It should also be noted that the planetary scale internal mode of variability presented in Fig. 3 is not peculiar to the present model. A similar pattern of internal variability is also identified in different GCMs (see *e.g.*, Kodera *et al.*, 1996; Harzallah and Sadourny, 1995).

This similarity of patterns between Figs. 3 and 2a suggests that the abrupt change in late 1980s is, in fact, strongly related to the planetary scale internal mode of variability of the atmosphere. However, a question arises: if the variation is due to the internal dynamics of the atmosphere, then this mode of variability should be expected to appear randomly from one year to the next. Why has the occurrence frequency of this mode changed between the periods before and after the winter of 1989? Did this happen by chance, or did some small change in external forcing modify the occurrence frequency of the internal mode of variability (Palmer, 1993)?

The results of simulations with the JMA GCM suggest that the change in circulation during the mid 1970s over the North Pacific regions can be understood as response due to the anomalous equatorial SSTs. In contrast, the change in the late 1980s has a different character. It may be considered as a triggered planetary scale internal mode of variability in the winter atmosphere. And the GCM failed to reproduce such variation. This does not, however, exclude the possibility that the change in the 1980s was triggered by anomalous SSTs in the mid-latitudes or some other area. The failure of the simulation could be simply due to the deficiency of the JMA GCM. In fact, Latif *et al.* (1996) showed that mid-latitudes SST can trigger a large change in mid-latitude circulation, although other studies (Lau and Nath, 1994; Graham *et al.*, 1994) suggest a minor role of the mid-latitude SSTs.

It should also be noted that in the present study, climatological sea ice extent is used for surface boundary conditions. Thus, it is also necessary to examine whether they are important. In any case, the response of the atmosphere to the boundary forcing is highly nonlinear, so that simulated results may be highly dependent on the model used. Therefore, intercomparison of simulations by different models is strongly desired.

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大気大循環モデルにより明らかにされた近年の冬期循環場の急激な変化の特徴

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近年、北半球冬期の大気循環場に2度にわたる急激な変化が1977年、1989年付近を中心とし見られた。1970年代の大気の変動には熱帯の海面水温の変化が伴っているのに反し、1980年代終わりの変動には、熱帯の海面水温には顕著な変化は見られない。この、2度の大気循環場の変動の違いの特徴を捕らえるため、観測された海面水温の変化を下部境界条件として用いた大気大循環モデル実験で再現された500 hPa高度場と観測とを比較して調べた。その結果、1980年代の変動は、海面水温の変化により直接的に強制されているというより、むしろ、冬の大気場に特徴的な内部変動が何かによって誘引されたというような特徴を示している。