Changes in the Atmospheric Circulation over the North Pacific-North America Area since 1950

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Abstract

In this study, we examine the interdecadal changes over the North Pacific area of sea level pressure and 500-mb height for the winters 1950–1988. Since most of the variance ($\sim 95\%$) of these two variables' asymmetric component is explained by the long-wave regime (wavenumbers 1–4), interdecadal changes in this wave regime are used for discussion. The major findings are (1) that the interdecadal changes of sea level pressure and 500-mb height were nearly barotropic and took place on the scale of the quasi-stationary long waves; (2) that the pattern of interdecadal 500-mb height change was spatially in quadrature with the 39-winter mean; and (3) that falls/rises of sea level pressure and 500-mb height in the Pacific were associated with the intensification/weakening of the lower-latitude westerlies. Version 1 of the Community Climate Model (CCM) of the National Center for Atmospheric Research (NCAR) was used to perform two numerical experiments in which the sea surface temperature (SST) anomalies in the North Pacific during the decades 1950–1959 and 1979–1988 (with respect to the 39-winter (1950–1988) mean SST) were imposed on the climatological SST of the NCAR CCM1 perpetual January control experiment. It was demonstrated that with the numerical simulations, the observed interdecadal changes of the atmospheric circulation reported in this study were apparently associated with the interdecadal changes of the tropical and extratropical North Pacific SST.

1. Introduction

In the past decade, several studies have dealt with interdecadal climate variability. Hense *et al.* (1988), showed that the average temperature and moisture content in the middle tropical troposphere had increased over the previous twenty years; and Posmentier *et al.* (1989) pointed out that sea surface and surface air temperatures of the tropical Pacific had been increasing since 1960. Contrasting surface temperature and 700-mb height between two periods (1947–1966 and 1969–1980), Douglas *et al.* (1982) found that both variables decreased over the North Pacific from the former to the latter period. Their results were later confirmed by Jones (1988) and Folland and Parker (1988). Nitta and Yamada (1989) also compared the interdecadal changes in sea-surface temperature, surface pressure, and 500-mb height for the period 1957–1987, reaching the same conclusion as these studies. Trenberth (1990) analyzed sea level pressure and surface air and sea temperature over the past five decades and found that in the decade ending in 1988, the surface tem-

perature increased in Alaska and decreased over the North Pacific, and the pressure in the Aleutian low dropped significantly. Trenberth's finding suggests that circulation regimes change over the North Pacific. Knox *et al.* (1988) examined the decadal variation of the 500-mb height in the Northern Hemisphere for the period 1946–1985 and identified two contiguous climate regimes (1946–1962 and 1963–1985) with a fairly abrupt transition in 1962–1963. Shabbar *et al.* (1990) made a further effort to explore the spatial structure change of the 500-mb height between these two subclimate regimes. They found that the pattern of change resembled the Pacific-North America (PNA) teleconnection pattern, with a sign reversal associated with the change of climate regime.

Recent interdecadal change in the atmospheric circulation over the North Pacific is thus well documented, and Douglas *et al.* (1982), Nitta and Yamada (1989), Trenberth (1990) and Shabbar *et al.* (1990) all suggested that the change of geopotential height and low-tropospheric temperature in the North Pacific is linked to the PNA pattern. It was demonstrated analytically by Hoskins and Karoly (1981) and observationally by Wallace and

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Fig. 1. (a) The sea level pressure of the long wave regime (wavenumbers 1–4) averaged over 39 winters (1950–1988): $\bar{P}_L(SL)$; (b) the first decadal (1950–1959) mean of the $P_L(SL)$ departure from $\bar{P}_L(SL)$: $\Delta\bar{P}_{LF}(SL)$; and (c) the last decadal (1979–1988) mean of the $P_L(SL)$ departure from $\bar{P}_L(SL)$: $\Delta\bar{P}_{LL}(SL)$. The contour interval is 4 mb for (a) and 1 mb for (b) and (c). The boxes denote the Tibetan Plateau.

Gutzler (1981) that the PNA pattern is primarily a train of stationary *barotropic* Rossby waves. This barotropy of the vertical structure is well established for the interannual variation of the atmospheric circulation associated with the El Nino/Southern Oscillation (ENSO) events but not for the interdecadal changes of the atmospheric circulation. We intend to show this barotropic nature of the low-frequency changes by analyzing the sea-level pressure and 500-mb height fields of the National Meteorological Center (NMC) for 1950–1988. Because the data were extracted from the monthly-mean NMC octagonal-grid analyses and interpolated onto a $5^\circ \times 5^\circ$ grid, the analysis is limited to the area north of 20°N . The PNA teleconnection pattern is a manifestation of the quasi-stationary long waves, and we shall therefore focus our analysis on the long-wave (wavenumbers 1–4) regime.

It is well understood that the PNA pattern associated with the ENSO is a response of the extratropical circulation to anomalously high or low sea-surface temperatures (SST) over the equatorial Pacific. Although interdecadal changes of the atmospheric circulation in the North Pacific-North America region may resemble the interannual changes during the ENSO extremes, previous studies have not concluded whether the former changes can be induced by a mechanism similar to that associated with the ENSO. In view of the coincidence between the observed interdecadal changes in the atmospheric circulation over the North Pacific-North America area and in the SST, we suggest that the simultaneous interdecadal changes in equatorial SST

and atmospheric circulation are connected. To substantiate this suggestion, and to point to the equatorial SST changes as a possible cause of the extratropical circulation changes a numerical study was pursued with Version 1 of the Community Climate Model (CCM) of the National Center for Atmospheric Research (NCAR) and the SST of the Comprehensive Ocean-Atmosphere Data Set (COADS).

2. The changes in the circulation

During northern winter (December–February), the mean sea-level pressure pattern north of 20°N contains the Siberian high, the Aleutian low, the Canadian high, the Icelandic low, and part of the subtropical ridge (Fig. 1a). In the troposphere (Fig. 2a), major troughs are located near the east coasts of Asia and North America and major ridges near the west coasts of North America and Europe; a minor trough also extends from eastern Europe to the Mediterranean. A west wind maximum in the troposphere is associated with each of the three climatological troughs (Fig. 3a). A comparison between the mean fields of sea-level pressure and upper-level height (Figs. 1a and 2a) shows that the troughs and ridges lean westward from the vertical; that is, they are baroclinic. These long-term-mean features are evident in the deviations from the latitude mean of sea-level pressure, $\bar{P}_L(SL)$, (Fig. 1a), in the 500-mb height, $\bar{Z}_L(500\text{ mb})$ (Fig. 2a) of the *long-wave regime*, and in the 500-mb geostrophic wind (Fig. 3). The maps are based on the pressures and heights in the first four zonal harmonic waves, which explain about 95 % of the mean spatial variance of sea-level

Fig. 2. (a) The 500-mb height of the long wave regime (wavenumbers 1–4) averaged over 39 winters (1950–1988), $\bar{Z}_L$ (500 mb); (b) the first decadal (1950–1959) mean of the Z_L (500 mb) departure from $\bar{Z}_L$ (500 mb); $\Delta\bar{Z}_{LF}$ (500 mb); and (c) the last decadal (1979–1988) mean of the Z_L (500 mb) departure from $\bar{Z}_L$ (500 mb): $\Delta\bar{Z}_{LL}$ (500 mb). The contour interval is 40 m for (a) and 10 m for (b) and (c). The boxes denote the Tibetan Plateau.

Fig. 3. (a) The 39-winter (1950–1988) mean isotachs of the geostrophic wind at 500 mb $|\bar{V}(500\text{ mb})|$; (b) the first decadal (1950–1959) deviations from the 39-winter mean; and (c) the last decadal (1979–1988) deviation from the 39-winter mean. The contour interval is 5 ms^{-1} for (a) and 1 ms^{-1} for (b) and (c).

pressure and 500-mb height north of 20°N in winter.

To illustrate the interdecadal variability of the large-scale circulation in winter, time series of sea level pressure and 500-mb height are shown in Fig. 4 for three regions which represent the centers at sea level of the Siberian high, of the Aleutian low, and of the North American ridge. These areas are not the centers of the 500-mb height features even though they straddle them; they are, however, the

centers of change in both sea-level pressure and 500-mb height (Figs. 1b, 1c and Figs. 2b, 2c). In Fig. 4, P_L (SL) and Z_L (500 mb) increased linearly over Asia and North America but decreased over the North Pacific; the linear change over the latter region was about 5 mb and 100 m in the last four decades, and the trends have the same sign in P_L (SL) and Z_L (500 mb). Note that although sea-level pressure and 500-mb height are well associated at

Fig. 4. The time series of area-mean $P_L(SL)$ and $Z_L(500\text{ mb})$ over three areas: (a) and (d), the center of the Siberian high; (b) and (e), the center of the Aleutian low; and (c) and (f), the North American ridge. The straight lines are linear trends.

all frequencies over the ocean, it is only the lowest frequencies (trend) that are associated over the continents, which is consistent with the vertical structure of the interannual fluctuations of geopotential height found by Blackmon *et al.* (1979).

Shown in Fig. 5 are time-longitude sections of the linear trend in $P_L(SL)$, $Z_L(500\text{ mb})$, and $1000/500\text{ mb}$ thickness at 50°N ; the most marked interdecadal variability occurred in the Pacific longitudes. Surprisingly, the variations of $P_L(SL)$ and $Z_L(500\text{ mb})$ are spatially stationary and vertically synchronous. The latter characteristic is further substantiated by the consistent variations in the thickness $\Delta Z(500\text{ mb}) [= Z(500\text{ mb}) - Z(1000\text{ mb})]$ (Fig. 5c), and both $\bar{P}_L(SL)$ and $\bar{Z}_L(500\text{ mb})$. As suggested by Fig. 4, the interdecadal variation in the atmospheric cir-

culation over the North Pacific is almost *barotropic*. This observation is corroborated by the departures of the first and last decadal winter averages of $\bar{P}_L(SL)$ and $\bar{Z}_L(500\text{ mb})$ from the 39-winter mean in Figs. 1b, 1c and Figs. 2b, 2c. As noted, the baroclinity of the quasi-stationary long waves is reflected in their westward tilt from the vertical. A westward tilt, however, is not evident in the decadal winter anomalies and the interdecadal change of the large-scale circulation is thus nearly barotropic. It is, in addition, on the scale of the mean long waves and thus fits Hoskins and Karoly's (1981) description of the structure of the Pacific-North America teleconnection pattern.

Another interesting feature of the first and last decadal winter anomalies of $\bar{P}_L(SL)$ and $\bar{Z}_L(500\text{ mb})$

Fig. 5. Time-longitude sections at 50°N of (a) $P_L(SL)$, (b) $Z_L(500\text{ mb})$, and (c) thickness between 1000 mb and 500 mb $\Delta Z(500\text{ mb})$, smoothed by the linear trend. The contour interval is 1 mb for (a) and 10 m for (b) and (c).

mb) is that the anomalies are in spatial quadrature with the long-term-mean 500-mb height because the anomalies are barotropic and the mean baroclinic. The anomalies are not in quadrature with the mean sea-level pressure but are either in-or 180 degrees out-of-phase with it.

3. Numerical Simulations

As mentioned in the Introduction, Hense *et al.* (1988), Posmentier *et al.* (1989), and Nitta and Yamada (1989) found an increase in the surface temperature over the tropical Pacific during recent decades. Furthermore, Douglas *et al.* (1982), Folland and Parker (1988), and Trenberth (1990) noted that the temperature over the North Pacific Ocean had fallen during the past several decades. As the low-latitude temperature rose, the meridional contrast in sea-surface temperature (SST) in the Pacific concurrently increased during the period. Woodruff *et al.* (1987) have compiled the Comprehensive Ocean-Atmosphere Data Set (COADS), which includes the SST over most parts of the world's oceans for the past one hundred years. Woodruff *et al.*'s SST departures from the 1950–1988 winter (December–February) mean for two decades (1950–1959 and 1979–1988), Fig. 6, coincide with the SST changes found by previous studies cited here. In fact, the structure of the decadal SST anomalies shown in Fig. 6 resembles the first principal eigenmode of Nitta and Yamada's (their Fig. 1a) empirical orthogonal function (EOF) analysis of the SST during the period 1950–1987.

The SST anomalies associated with the warm extreme of the ENSO consist of a warm tongue extending from the eastern to the central Pacific along the equator (Rasmusson and Carpenter, 1982). In Fig. 6, the later decade has mainly *positive* SST anomalies in the tropics, whereas the earlier decade has almost all *negative* tropical anomalies. The anomalies in 1979–1988 thus resemble those in a warm extreme of the ENSO. It was demonstrated by numerical studies, *e.g.*, Blackmon *et al.* (1983), that changes in the PNA pattern are associated with SST anomalies in the equatorial central Pacific. Geisler *et al.* (1985) showed with a sophisticated climate model, and Branstator (1986) with a simple barotropic model, that changes in the mean long waves during a warm event are not sensitive to the longitudinal location of the equatorial SST anomaly center in the Pacific. Later, imposing the real-time SST from 1969 to 1990 on the general circulation model of the Japan Meteorological Research Institute, Kitoh (1991) was able to generate the decadal variation of the simulated climate with a time scale of about ten years. Both Kitoh and Yamagata and Matsumoto (1992), argued that the anomalous SST warming over the western tropical Pacific may be responsible for the decadal change over the Pacific. Because of previous numerical simulations of the atmospheric circulation change associated with the ENSO suggestions of the decadal variation of atmospheric circulation, we suggest that the decadal changes of the atmospheric circulation over the North Pacific-North America region may result from the interdecadal changes in the

Fig. 6. The first decadal (1950–1959) mean of the sea surface temperature (SST) departure from the 39-winter (1950–1988) mean SST, and (b) the second decadal (1979–1988) mean of the SST departure from its 39-winter mean. The SST anomalies shown here were compiled by Woodruff *et al.* (1987) and updated at the National Center for Atmospheric Research. The contour interval is 1°C , and the negative SST anomalies are shaded.

SST (Fig. 6). This suggestion can be tested by numerical simulations in a sophisticated climate model with the SST anomalies shown in Fig. 6. We have used the Community Climate Model (CCM) of the National Center for Atmospheric Research (NCAR) for the test, and the results are presented in the next section.

3.1 Model and Experiments

Version 1 of the NCAR CCM was used in this study. Williamson *et al.* (1987) have given a detailed description of this model. It was developed in terms of the primitive equations in a sigma coordinate system. In accordance with Bourke *et al.* (1977) and McAvaney *et al.* (1978), the momentum equations are not directly used in the NCAR CCM1 model; instead, the model uses the vorticity and divergence equations that are derived from them. The model includes detailed parameterizations of subgrid-scale processes. For example, the convective adjustment scheme designed by Manabe (1965) and the cloud/radiation scheme by Ramanathan *et al.* (1983) are incorporated into the model. Climatological sea-surface temperatures compiled by Alexander and Mobley (1976) are imposed over the oceans, while instantaneous surface temperatures over land

are calculated by the surface-energy balance equation of Halloway and Manabe (1971). The model is global and is formulated in the horizontal domain with spherical harmonics of rhomboidal 15 truncation. The model has twelve vertical levels, with σ equal to 0.991, 0.926, 0.811, 0.644, 0.500, 0.355, 0.245, 0.165, 0.110, 0.060, 0.025, and 0.009 from bottom to top.

The perpetual January simulation of 1200 days with the NCAR CCM1 is used as the control experiment. The initial data for this perpetual January simulation were produced by a sequence of perpetual January experiments based upon successive modifications to Version O of the NCAR CCM (Pitcher *et al.*, 1983) which formed the preliminary version of CCM1. Conditions at the end of the last simulation with the preliminary version of CCM1 became the standard January initial conditions for CCM1 and were used for the perpetual January simulations. In order to test the hypothesis that the interdecadal changes in the stationary eddies described in Section 2 are associated with changes in the SST over the North Pacific (Fig. 6), two sensitivity experiments were performed with the NCAR CCM1 and with the standard January initial conditions of the CCM1. We imposed the two decadal (1950–1959 and 1979–1988) SST departures (Fig. 6) from the 39-winter (1950–1988) mean on the climatological SST used in the perpetual January simulation. Let us designate these two experiments as LLM and LFM, respectively. It is our experience (Chen and Branstator, 1991) that it takes more than 100 days for the NCAR CCM to reach its equilibrium state with significant changes in the initial conditions, particularly in high latitudes and in the stratosphere. Therefore, the two experiments with the LLM and LFM SST anomalies were integrated over 400 days. The stationary eddies of the control and the two sensitivity experiments were obtained from the last 200-day (Day 201–400) mean fields. The responses of the model stationary eddies to interdecadal changes in the North Pacific SST are illustrated by contrasting the 200-day mean height fields in the LLM and LFM and the control experiments.

3.2 Experiment Results

The observed interdecadal changes of the quasi-stationary long waves to be simulated are summarized by the following:

- The changes in sea-level pressure and 500-mb height took place on the scale of the mean long waves and resemble the PNA teleconnection pattern over the Pacific-North America region.
- The pattern of 500-mb height change was spatially in quadrature with the 39-winter mean but in phase with the change of sea-level pres-

Fig. 7. (a) The 500-mb height of the long-wave regime (wavenumbers 1–4) averaged over day 201–400 of the NCAR CCM1 perpetual January simulation: $\bar{Z}_{LM}$ (500 mb); (b) the departure of the corresponding 500-mb height in the first sensitivity experiment (first decadal) from $\bar{Z}_{LM}$ (500 mb): $\Delta\bar{Z}_{LFM}$ (500 mb); and (c) the departure of the corresponding 500-mb height in the second sensitivity experiment (last decadal) from $\bar{Z}_{LM}$ (500 mb): $\Delta\bar{Z}_{LLM}$ (500 mb). The contour interval is 50 mb for (a) and 10 m for (b) and (c).

sure, and the changes in the troposphere were therefore barotropic.

Since the post processor of the climate model does not provide mean sea-level pressure, we prepared only the 500-mb height anomalies for verification. Moreover, in order to explore the baroclinicity of the model stationary eddies and the possible barotropic nature of the model stationary-eddy response to the interdecadal changes in the SST over the North Pacific, we also present the 850- and 200-mb height anomalies, Z_{LM} (850 mb) and Z_{LM} (200 mb), instead of vertical cross-sections at a given latitude.

The stationary troughs and ridges are reflected in negative and positive $\bar{Z}_L$ (500 mb) anomalies. Comparison between the observed $\bar{Z}_L$ (500 mb) (Fig. 2a) and the model $\bar{Z}_{LM}$ (500 mb) (Fig. 7a) indicates that the position of the troughs and ridges over the North Pacific-North America region are well simulated by the NCAR CCM1. As noted above, the long-wave, stationary eddies are baroclinic. Although the model mean sea-level pressure is not available, the westward tilt of the model waves can be seen by comparing $\bar{Z}_{LM}$ (850 mb) (Fig. 8a) and $\bar{Z}_{LM}$ (200 mb) (Fig. 9a). Both the locations of the positive and negative latitude anomalies and the westward tilt of the quasi-stationary eddies are reasonably simulated by the model.

For convenience of discussion, let us denote $\Delta\bar{Z}_{LFM}(\) = \bar{Z}_{LFM}(\) - \bar{Z}_{LM}(\)$ and $\Delta\bar{Z}_{LLM}(\) =$

$\bar{Z}_{LLM}(\) - \bar{Z}_{LM}(\)$. In other words, $\Delta\bar{Z}_{LFM}(\)$ and $\Delta\bar{Z}_{LLM}(\)$ are responses of the model long-wave stationary eddies to the first and last decadal SST departures (Figs. 6a and 6b, respectively) from the 39-winter mean (not shown). As revealed from Fig. 7, magnitudes of $\Delta\bar{Z}_{LFM}$ (500 mb) and $\Delta\bar{Z}_{LLM}$ (500 mb) at their centers are generally somewhat larger than the observed $\Delta\bar{Z}_{LF}$ (850 mb) (Fig. 2b) and $\Delta\bar{Z}_{LL}$ (500 mb) (Fig. 2c). Otherwise, horizontal structures of $\Delta\bar{Z}_{LFM}$ (500 mb) and $\Delta\bar{Z}_{LLM}$ (500 mb) resemble those of $\Delta\bar{Z}_{LF}$ (500 mb) and $\Delta\bar{Z}_{LL}$ (500 mb), respectively, over the North Pacific-North America region. The interdecadal changes of the atmospheric circulation over this region during 1950–1988 are thus well simulated by the NCAR CCM1 forced with the changes of the SST in this period. The observed changes of the atmospheric circulation in the North Pacific-North America region are barotropic. By contrasting Figs. 7–9, we can easily see that either $\Delta\bar{Z}_{LFM}(\)$'s or $\Delta\bar{Z}_{LLM}(\)$'s exhibit similar structures at the three levels. Apparently, the structure of the change in the model stationary eddies is barotropic as well.

4. Concluding Remarks

The mean sea-level pressure and 500-mb height fields during 1950–1988 show systematic interdecadal changes over the North Pacific-North America region. The pattern of these changes resembles

Fig. 8. Same as Fig. 7, but for 850 mb. The contour interval is 30 m for (a), and 10 m for (b) and (c).

Fig. 9. Same as Fig. 8, but for 200 mb. The contour interval is 60 m for (a) and 20 m for (b) and (c).

the PNA teleconnection pattern; it is almost barotropic and spatially in quadrature with the climatological eddies. In the past four decades, the SST in the tropical and northern Pacific Ocean also underwent a systematic change, which suggests that the interdecadal changes in the atmospheric circulation might be related to the changes in the SST. To test this hypothesis, Version 1 of the NCAR Community Climate Model (CCM1) was used to perform

two sensitivity experiments in which the SST anomalies in the first and the last decade of the period 1950–1988 were imposed on the climatological January SST used in the control experiment of the NCAR CCM1 (the perpetual January climate experiment). Comparing the two sensitivity experiments with the control experiment, it is seen that the major observed features of interdecadal change in the atmospheric circulation were

well simulated by the two sensitivity experiments. Therefore, we conclude that interdecadal changes in the atmospheric circulation over the North Pacific-North America region during 1950–1988 were linked to the changes in the Pacific SST.

The major efforts of current climate research are focused on the global climate change stimulate a surge of studies in the interannual variation of the atmospheric circulation, particularly associated with ENSO. However, our understanding of interdecadal changes in the atmospheric circulation is still very limited at this stage, although the numerical experiments of this study reveal a possible influence of the interdecadal changes of the Pacific SST on those changes in the atmospheric circulation. There are a lot of questions concerning interdecadal changes that lie ahead of us. For example, since there is a feedback interaction between the atmosphere and ocean, do interdecadal changes in the former cause those changes in the latter? Besides the North Pacific-North America region, do interdecadal changes occur in other parts of the globe? Do interdecadal changes also happen in the stratosphere? It is our hope that success of our simple numerical experiments would call more attention to this area, especially after the NMC reanalysis data (Kalnay and Jenne, 1991) become available.

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Reference

- Alexander, R.C. and R.L. Mobley, 1976: Monthly average sea-surface temperatures and ice-pack limits on a 1° global grid. *Mon. Wea. Rev.*, **104**, 143–148.
- Blackmon, M.L., J.E. Geisler and E.J. Pitcher, 1983: A general circulation model study of January climate anomaly patterns associated with interannual variation of equatorial Pacific sea surface temperatures. *J. Atmos. Sci.*, **40**, 1410–1425.
- Blackmon, M.L., R.A. Madden, J.M. Wallace and D.S. Gutzler, 1979: Geographical variations in the vertical structure of geopotential height fluctuations. *J. Atmos. Sci.*, **36**, 2450–2466.
- Bourke, W., B. McAvaney, K. Prui and R. Thurling, 1977: Global modeling of atmospheric flow by spectral methods. *Methods in Computational Physics*, Vol. 17, General Circulation Models of the Atmosphere, Academic Press, 267–324.
- Branstator, G., 1985: Analysis of general circulation model sea surface temperature anomaly simulations using a linear model. Part I: Forced solutions. *J. Atmos. Sci.*, **42**, 2225–2241.
- Douglas, A.V., D.R. Cayan and J. Namias, 1982: Large-scale changes in North Pacific and North America weather patterns in recent decades. *Mon. Wea. Rev.*, **112**, 1851–1862.
- Folland, C.K. and D. Parker, 1988: Observed variations of sea surface temperature. *Proc. NATO Advanced Research Workshop on Climate-Ocean Interaction*, Oxford, England, September 1988, Kluwer Academic Press.
- Geisler, J.E., W.L. Blackmon, G.T. Bates and S. Mu noz, 1985: Sensitivity of January climate response to the magnitude and position of equatorial Pacific sea surface temperature anomalies. *J. Atmos. Sci.*, **42**, 1037–1049.
- Hense, A., P. Krahe and H. Flohn, 1988: Recent fluctuations of tropospheric temperature and water vapor content in the tropics. *Meteor. Atmos. Phys.*, **38**, 215–227.
- Halloway, J.L., Jr. and S. Manabe, 1971: Simulation of climate by a global general circulation model, 1, Hydrological cycle and heat balance. *Mon. Wea. Rev.*, **99**, 335–370.
- Hoskins, B.J. and D.J. Karoly, 1981: The steady linear response of a spherical atmosphere in thermal and orographic forcing. *J. Atmos. Sci.*, **38**, 1179–1196.
- Jones, P.D., 1988: Hemispheric surface air temperature variations: Recent trends and an update to 1987. *J. Climate*, **1**, 654–660.
- Kalnay, E. and R. Jenne, 1991: Summary of the NMC/NCAR reanalysis workshop of April 1991. *Bull. Amer. Meteor. Soc.*, **72**, 1897–1904.
- Kitoh, A., 1992: Interannual variations in an atmospheric GCM forced by the 1970–1989 SST. Part II: Low-frequency variability of the wintertime Northern Hemisphere extratropics. *J. Meteor. Soc. Japan*, **63**, 271–291.
- Knox, J.L., K. Higuchi, A. Shabbar and N.E. Sargent, 1988: Secular variation of Northern Hemisphere 50 kPa geopotential height. *J. Climate*, **1**, 500–511.
- Manabe, S., J. Smagorinsky and R.F. Strickler, 1965: Simulated climatology of a general circulation with a hydrological cycle. *Mon. Wea. Rev.*, **93**, 709–798.
- McAvaney, B.J., W. Bourke and K. Puri, 1978: A global spectral model for simulation of the general circulation. *J. Atmos. Sci.*, **35**, 1557–1583.
- Nitta, T. and S. Yamada, 1989: Recent warming of tropical sea surface temperature and its relationship to the Northern Hemisphere circulation. *J. Meteor. Soc. Japan*, **67**, 375–383.
- Pitcher, E.J., R.C. Malone, V. Ramanathan, M.L. Blackmon, K. Puri and W. Bourke, 1983: January and July simulations with a spectral general circulation model. *J. Atmos. Sci.*, **40**, 580–604.
- Posmentier, E.S., M.A. Cane and S.E. Zebiak, 1989: Tropical Pacific climate trends since 1960. *J. Climate*, **2**, 731–736.
- Rasmusson, E.M. and T.H. Carpenter (1982): Variations in tropical sea surface temperature and surface wind fields associated with the Southern Oscillation/El Niño. *Mon. Wea. Rev.*, **110**, 354–384.
- Shabbar, A., K. Higuchi and J.L. Knox, 1990: Regional analysis of Northern Hemisphere 50 kPa geopotential heights from 1946 to 1985. *J. Climate*, **3**, 543–557.

- Trenberth, K.E., 1990: Recent observed interdecadal climate changes in the Northern hemisphere. *Bull. Amer. Meteor. Soc.*, **71**, 988–993.
- Wallace, J.M. and D.S. Gutzler, 1981: Teleconnections in the geopotential height field during the Northern Hemisphere winter. *Mon. Wea. Rev.*, **109**, 784–812.
- Williamson, D.L., J.T. Kiehl, V. Ramanathan, R.E. Dickinson and J.J. Hack, 1983: Description of NCAR Community Climate Model (CCM1). NCAR Technical Note, NCAR/TN-285+STR, 112 pp.
- Woodruff, S.D., R.J. Slutz, R.L. Jenne and P.M. Steurer, 1987: A comprehensive ocean-atmosphere data set. *Bull. Amer. Meteor. Soc.*, **68**, 1239–1250.
- Yamagata, T. and Y. Masumoto, 1992: Interdecadal natural climate variability in the western Pacific and its implication in global warming. *J. Meteor. Soc. Japan*, **70**, 167–175.

北太平洋–北米域における 1950 年以降の大気循環変動

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この研究では、北太平洋領域での 1950–1988 冬の地上気圧及び 500 mb 高度の 10 年スケールの変動を調べた。この 2 変数の非対象成分の殆ど (–95%) は長波 (波数 1–4) で説明されるため、この波数での 10 年スケールの変動を議論の対象とした。主として次のことが見いだされた。(1) 地上気圧と 500 mb 高度の 10 年スケールの変動はほぼ順圧的で順定常的な長波で起きている。(2) 10 年スケールの 500 mb 高度の変動のパターンは、39 冬期平均のパターンの位相と 90 度ずれている。(3) 太平洋における地上気圧と 500 mb 高度の下降と上昇は、より低緯度の西風の強化と弱まりに伴っている。

NCAR の CCM.V1 を用いて、気候値の SST を与え 1 月を持続させた基準実験に対して、1950–1959 年及び 1979–1988 年の (1950–1988 年 39 冬期平均からの) 偏差を与えて数値実験を行った。この数値実験によって、この研究で報告された大気循環の 10 年スケールの変動は、10 年スケールの熱帯・温帯北太平洋の海面水温変動に関連していることが証明された。