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A Change of Large-scale Circulations in the Indian Ocean and Asia Since 1976/77 and Its Impact on the Rising Surface Temperature in Siberia

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Abstract: This study examines the changes of an interdecadal circulation over the Asian continent to find cause of the surface warming in Siberia from 1958 to 2004. According to our study, there is a coherency between a long-term change of sea surface temperature in the Indian Ocean and the rapid increase of air temperature in Siberia since 1976/1977. In this study, we suggest that mean wind field changes induced by the positive sea surface temperature anomalies of the Indian Ocean since 1976/1977 are caused of inter-decadal variations in a large-scale circulation over the Asian continent. It also indicates that the inter-decadal circulation over the Asian continent is accompanied with warm southerly winds near surface, which have significantly contributed to the increase of surface temperature in Siberia. These southerly winds have been one of the most dominant interdecadal variations over the Asian continent since 1976/1977. In addition, we investigated the long-term trend mode of 850 hPa geopotential height data over the Asian continent from the Empirical Orthogonal Function (EOF) analysis for 1958-2004. In result, we found that there was an anomalously high pressure pattern over the Asian continent, it is called 'the Asian High mode'. It is thus suggested that the Asian High mode is another response of interdecadal changes of large-scale circulations over the Asian continent.

Keywords: interdecadal variation, global warming, Asian High mode

Introduction

A lot of global warming signals by greenhouse gas effects have been detected in various fields including the ocean, atmosphere, ecosystem and agriculture, etc.. Among many types of phenomena, the rising surface temperature in Siberia is also one of the most sensitive signals of global warming, which is mentioned in New Scientist, science magazine in August 2005. It is commonly known that the sudden melting of the largest frozen peat bog in Siberia as well as the reduction of snow cover over the Asian continent is due to global warming by greenhouse gases effects. However it is not clear why a degree of climate responses to global warming impacts is locally different.

Some previous studies introduced relationships between a carbon dioxide emission and global warming. Crowley (2000) provided the evidence that cause of the global warming is not due to natural variability (solar activities, volcanism, albedo, aerosols, etc.) but to a carbon dioxide emission by anthropogenic activities. Manabe et al. (1990) showed temporally consistent warm signals in both sea surface temperature in the tropics and surface air temperature in the high-latitudes of the northern hemisphere from a doubling experiment of atmospheric carbon dioxide in the coupled ocean-atmosphere model. Furthermore, Barnett (2001) and Barnett et al. (2005) claimed that anthropogenic forces have affected ocean warming trend over the past 45 years. However, they were not able to account for the processes by which the anthropogenic heat penetrated from the atmosphere to the ocean.

Some authors presented evidence of a significant climate shift since the mid-to-late 1970s, and agrees that mean states shift has influenced the El Niño-Southern Oscillation (ENSO) dynamics in tropics as

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well as the midlatitude monsoon system (Trenberth, 1990; Wang, 1995; Zang et al., 1997; Krishnamurthy and Goswami, 2000). The Sea Surface Temperature (SST) in the tropical Indian Ocean also experienced a warming shift in 1976/1977 (Clark et al., 2000, 2003). Lau and Weng (1999) showed the characteristics of interdecadal variations in global SST anomaly, which can represent a positive SST anomaly pattern in tropical Indian Ocean. Furthermore, Krishnamurthy and Gowami (2000) investigated interdecadal and interannual time-scale circulations in the latitude-height cross-section averaged over 70-120°E, and they discussed relationships between meridional circulation in Indian Ocean and the Indian summer monsoon rainfall. As such, an interdecadal meridional circulation strengthened the Hedley cell in the Indian Ocean. A strong Hedley circulation then induced the weak Indian summer monsoon rainfalls. Lorenz and DeWeaver (2007) found that the poleward shift of the upper level zonal winds in IPCC models, as a global warming is ongoing. Overland et al. (2002) investigated the warming pattern of the lower troposphere from eastern Siberia to northern Canada during spring in the 1990s. They attempted to explain the cause of the temperature increase in this western Arctic as a horizontal heat advection induced by a mean wind shift from anomalous northeasterly flow in the 1980s to anomalous southwesterly flow in the 1990s.

The rising surface temperature in Siberia actually has been influenced by a various causes which include: atmospheric dynamics, chemistry (greenhouse gases effects), surface albedo by both snow melting, etc.. However, the surface temperature in Siberia has remarkably increased since 1976/1977, and the locally non-homogeneous surface warming cannot be perfectly described by chemical reaction or radiation change. The purpose of this study is to reinspect the warming trend of surface temperature in Siberia with an emphasis on large-scale atmospheric dynamics. Firstly, we will show the interdecadal variations of meridional circulations in the Asia-Indian Ocean cross-section, and its impact on the Siberian warming trend in resent are examined in this paper. In chapter 2, we showed long-term warming trends in both the Indian Ocean sea surface temperature and surface air temperature over the Asian continent. These authors suggested that there has been a temporal coherency between long-term warming signals of remote two regions in 1976/1977. Interdecadal variations of meridional circulation in midlatitudes of Asian continent were described in chapter 3, using an eddy fluxes dynamics of large-scale mean flows. In addition, a long-term trend mode in 850 hPa geopotential height of northern hemisphere is also suggested in chapter 4. The last part of this paper contained a brief and some discussion about relationships between the Indian Ocean and Siberia warming. The monthly National Centers for Environmental Prediction and the National Center for Atmospheric Research (NCEP-NCAR) reanalysis É (Kalnay et al., 1996) dataset and the Climate Research Unit (CRU) analysis of the monthly dataset for 1958–2004 were used to analyze the characteristics of interdecadal variations over the Asian continent. In the Ocean, the monthly Extended Reconstructed Sea Surface Temperature (ERSST version 2) data in a 2° by 2° grid resolution was also used (Smith and Reynolds, 2004).

Coherency of Warming Trends in Both Siberia and Indian Ocean

The most serious long-term changes in the Asian continent and Indian Ocean are the increase of Sea Surface Temperature anomalies in the tropical Indian Ocean and the rising surface temperature in Siberia. It is still controversial whether there is a climate regime shift in the whole depths of ocean or to wherever oceans in the mid/late 1970s, but it is surely that Sea Surface Temperature anomalies in the tropical Indian Ocean have increased as well as it has influenced to the Indian Monsoon rainfall change since 1976/1977 (Clark et al., 2003). Meanwhile, the most distinguished long-term change over the Asian continent is the surface warming of the Siberian region in recent. The NewScientist, a science magazine, also reported that

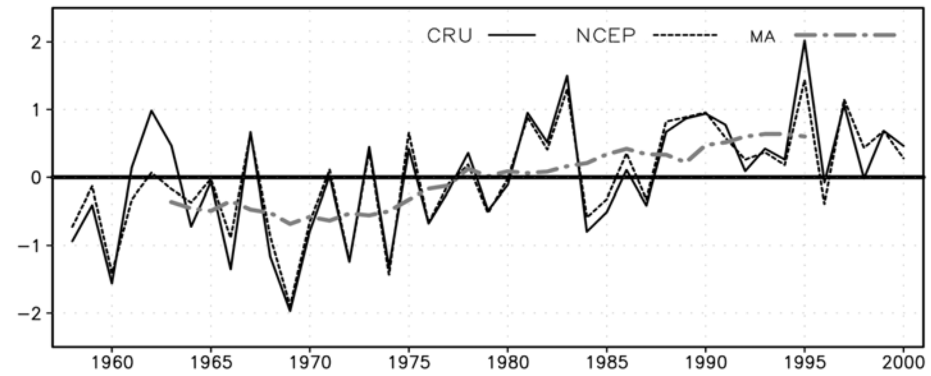


Fig. 1. Time series of temperature anomaly averaged in Siberia (40°N-70°N, 60°E-120°E) for 1958-2000. The solid line and the dotted line indicate the time series of the CRU surface temperature anomaly and the 1,000 hPa temperature anomaly of the NCEP-NCAR reanalysis, respectively. The solid-dotted line denotes the 10-year moving-averaged temperature time series of the CRU data.

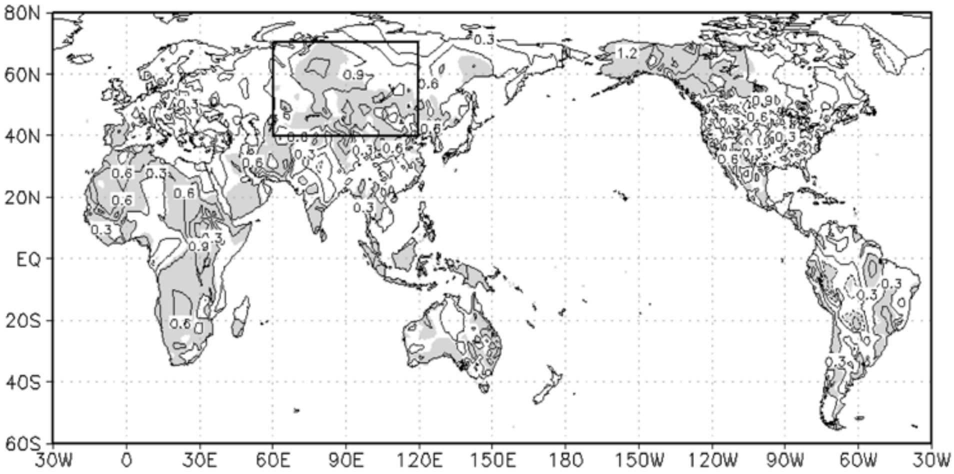


Fig. 2. The difference (°C) between surface temperature averaged for period 1 (1958-1976) and the surface temperature averaged for period 2 (1977-2000) (period 2 minus period 1). A box denotes the warming Siberian region on the Asian continent (40°N-70°N, 60°E-120°E), and Shadings indicate 99% confidence level.

the permafrost of western Siberia is turning into a mass of shallow lakes as the ground melts (in August, 2005).

Figure 1 shows the temperature time series of the CRU (solid line) and the NCEP-NCAR reanalysis (dot line) averaged in Siberia from 1958 to 2000. The solid-dotted line indicates the 10-year time series of the moving-averaged CRU temperature. The Siberian regions is defined as 40°N-70°N, 60°E-120°E, from the Ural mountains to Lake Baikal, in this study, and it is shown as a rectangular box in Fig. 2. The correlation coefficient between the two datasets is +0.95. This result shows that they are highly correlated with each other, and we can confirm the consistency of a surface warming trend among the different temperature datasets. The time series of the 10-year moving-average of CRU temperature data describes that the surface temperature in Siberia has positively changed since 1976/1977. This implies that the surface warming trend in Siberia can be related to the warming shift of Sea Surface Temperature anomalies in the Indian Ocean.

The spatial characteristics of long-term change in surface temperature were also investigated for the

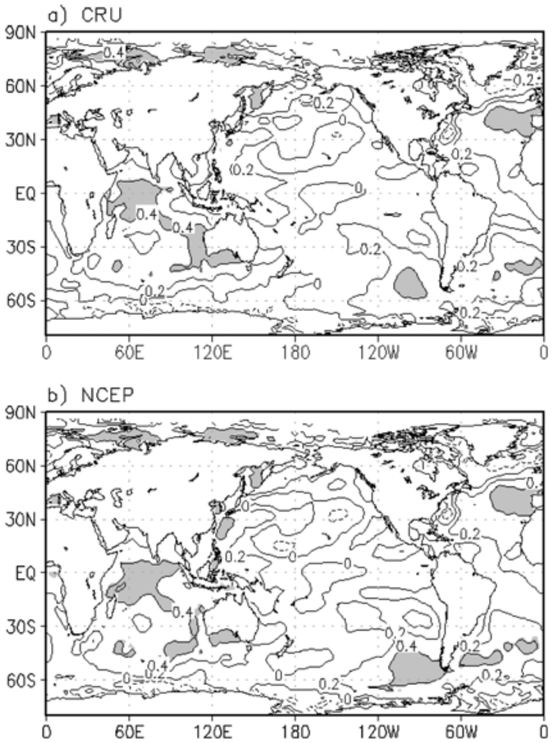


Fig. 3. Correlation coefficients between the time series of the temperature anomaly averaged in the Siberian region and the global ERSST anomalies for (a) CRU analysis, and (b) NCEP-NCAR reanalysis. Shading denotes the 99% confidence level.

period 1958-2000. Figure 2 shows the differences in the CRU surface mean temperature data between two periods: i.e., the temperature averaged for 1977-2000 and for 1958–1976. Strong surface warming signals have appeared in Alaska and western Siberia. The spatial characteristics of the temperature change since 1976/1977 imply that the responses by global warming effects are not homogeneous everywhere, and this means that atmospheric dynamic effects are more important to occur locally serious warming trends than what we think.

Figure 3 shows the correlation coefficient between the temperature anomaly time series in Siberia and the global Sea Surface Temperature anomalies for 1958-2000. There are some similarities between the correlation patterns with the temperature data of the CRU analysis and those with the NCEP-NCAR reanalysis data. A common feature of the two correlation maps is that significantly positive coefficients appear in the Indian Ocean and the northern Atlantic Ocean. The shading denotes a 99% confidence level area. It implies that there is a relationship between the increase of the tropical Indian Ocean Sea Surface Temperature anomalies and the surface warming over the Asian continent.

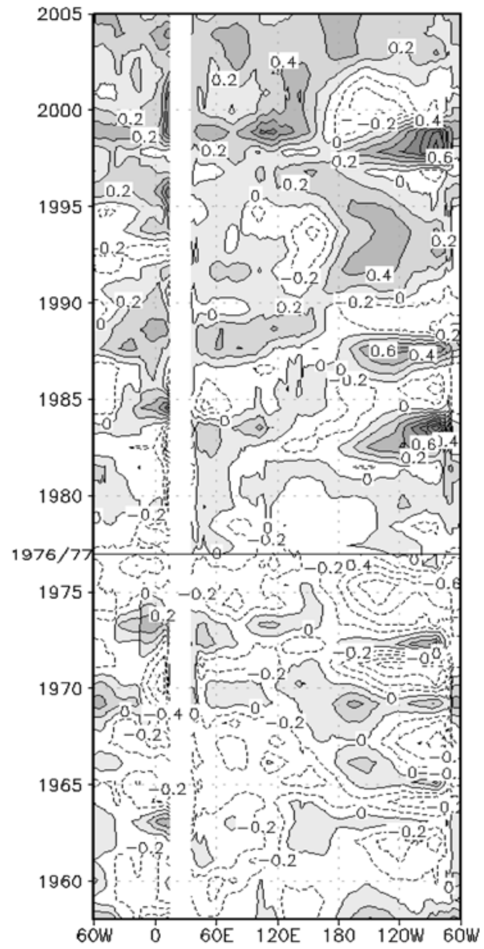


Fig. 4. Hovmöller diagrams of sea surface temperature anomalies (^{o}C) in the tropics (20^{o}N-20^{o}S) for 1958-2004.

Figure 4 shows a Hovmöller diagram of the monthly ERSST anomaly averaged in the tropics (20^{o}N-20^{o}S) from 1958 to 2004. The major characteristics of the tropical SST changes can be summarized as the increase of Sea Surface Temperature anomalies in the Indian Ocean and the occurrences of strong warm events in equatorial Pacific regions since 1976/1977. The distinguished SST changes in the tropics induce an interdecadal time-scaled circulation, and the abrupt changes of the tropical Indian Sea Surface Temperature will be an external forcing to the large-scale circulations in the midlatitudes.

Interdecadal Variations of Large-scale Meridional Circulation Over the Asian Continent

The 'atmosphere bridge' concept devised by Lau and Nath (1996) suggests an understanding of the impact of a tropical Sea Surface Temperature on remote midlatitude circulation in the northern Pacific Ocean. Also, Krishnamurthy and Goswami (2000) suggested that a large-scale circulation coupled with an interdecadal time-scale SST change in the tropics influences the Indian monsoon rainfall circulation. These studies imply that the forcing of an warm Sea Surface Temperature on the atmosphere can significantly control to changes of the Indian Monsoon flows as well as the mid-/high-latitudes mean wind fields. Overland et al. (2002) emphasize that warm advection effects by changes of surface mean winds substantially play important roles for the increase of surface temperature in the high-latitudes. Our analyses were focused on the warming trend of surface temperature in Siberia. Therefore we examine an interdecadal meridional circulation in over the Asian continent which is not only linked between Indian Ocean and Asian continent, but also associated with a warming trend near the surface in Siberia. For a dynamical description, the eddy momentum flux and eddy heat flux are investigated in the latitude-height cross-section over the Asian continent because they are two key components for determining the meridional circulations in the midlatitudes of the Northern Hemisphere.

The differences between the period 1958-1976 and the period 1977-2004 of meridional circulations and temperature in latitude-height cross-sections zonally-averaged in the Asia regions (60^oE-120^oE) were examined (Fig. 5). Differences of mean fields indicate that for the latter period of 1976/1977 minus for the former period. The warming trend of the Indian Ocean SST anomalies since 1976/1977 (shown in chapter 2) induces the strong tropical convections in the Indian Ocean due to sensible hest fluxes in the lower levels, and the release of latent heat by the deep convective activities contributes to the increase in temperature in the upper levels of troposphere over the Indian Ocean. Likewise, these thermal forcings of tropical Sea Surface Temperature in Indian Ocean can also induce a change of the mean wind field changes in the mid-/high-latitudes of the Asian continent, then changes of horizontal wind advection near surface significantly will contribute to the increase of surface temperature in Siberia. In the tropics, and changes of the directly sensible heat fluxes and the latent heat fluxes by the warming trend of Indian Ocean will influence the atmospheric temperature field in the tropics. The difference of mean temperature fields (the shading) in both Fig. 5a and Fig. 5b well describes the positive temperature anomalies by the warm Sea Surface Temperature forcing in the tropical troposphere, and these figures also shows that the increase of surface temperature in Siberia is well accord with the strong southerly winds in the mid-/high-latitudes.

In figure 5a, the stream function lines mean that an ascending motion has strengthened over the warm Indian Ocean for the latter period of 1976/1977. In contrast to, a descending motion is apparent in the mid-to-high levels of abroad subtropics (from 10^oN to 35^oN). The most apparent interdecadal time-scale feature of the stream function lines in mid-latitudes is a strong descending motion in the low-to-mid levels around 40^oN. The Hadley circulation on the interdecadal time-scale, a thermally direct cell, doesn't ideally appear in Fig. 5, but the 200 hPa zonal winds in the latitude-height cross-section shows strong westerlies in 20^oN-40^oN due to meridional temperature gradients, and the core of the upper westerlies are well associated with the position of the maximum temperature gradient (Fig. 5b). Figure 5b also shows

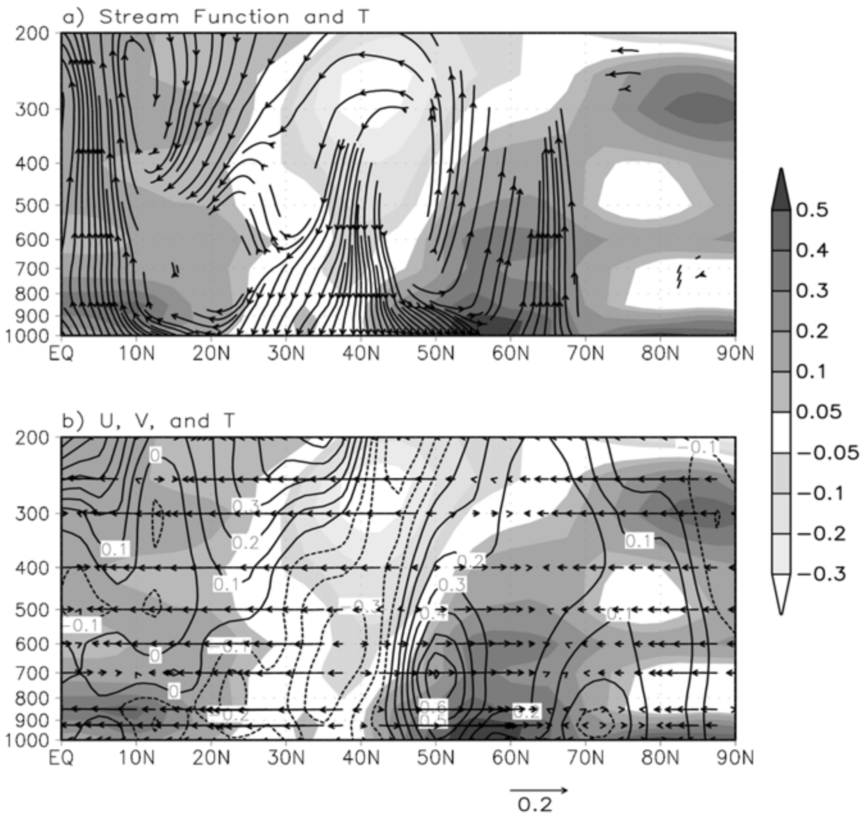


Fig. 5. The latitude-height cross-sections of differences between the period 1958-1976 and the period 1977-2004 for (a) temperature (shading) and stream functions (stream) averaged in the Asia region [60°E-120°E] and for (b) temperature (shading), zonal wind anomaly (line), and meridional wind anomaly vectors (arrow).

low-level westerlies in the northward of the center of the descending motion in the midlatitudes (40°N) and the easterlies in the southward of it, respectively. These characteristics were accorded with surface anticyclone by the anomalous Asian High mentioned in chapter 4.

As a result, we find two characteristics of the interdecadal time-scale relationship between mean temperature field and mean wind field for two different periods; one is that the upper levels westerlies in subtropics for the latter period (form 1977 to 2004) are more stronger than for the former period (form 1958 to 1976) because of the increase of meridional temperature gradients since 1976/1977, and the other is that the rising surface temperature in Siberia is consistent with the characteristics of northward surface wind advections (southerlies) from 40°N to 65°N (Fig. 5).

We have investigated the Ferrel circulation of the midlatitudes, an indirect cell, in the vertical cross-section, for more understanding about an interdecadal variations of large-scale meridional circulation, which has been associated to the change of surface temperature in Siberia since 1976/1977. Generally, the zonal mean momentum equation and the thermodynamic energy equation for quasi-geostrophic motions on the midlatitude β plane can be redefined from the momentum equation and the thermodynamic energy equation, as in the following where N is the buoyancy frequency.

$$\frac{\partial \bar{u}}{\partial t} - f_0 \bar{v} = -\frac{\partial(\overline{u'v'})}{\partial y} + \bar{X} \qquad (1)$$

$$\frac{\partial \bar{T}}{\partial t} + \frac{\bar{w}}{N^2 HR} = -\frac{\partial(\overline{v'T'})}{\partial y} + \frac{\bar{J}}{C_p} \qquad (2)$$

If the zonal-averaged meridional momentum equation approximated by geostrophic balance is combined with the hydrostatic relationship, we can get the following relationship:

$$f_0\frac{\partial\bar{u}}{\partial z}+RH^{-1}\frac{\partial\bar{T}}{\partial y}=0$$

If equations (1) and (2) are rewritten with the continuity equation of $\rho_0\bar{v}=-\frac{\partial\bar{\chi}}{\partial z}$ and $\rho_0\bar{w}=-\frac{\partial\bar{\chi}}{\partial y}$, the diagnostic equation for the stream function ($\bar{\chi}$) is derived by $f_0\frac{\partial}{\partial z}(1)+RH^{-1}\frac{\partial}{\partial y}(2)=0$. We can obtain the mean meridional circulation in terms of $\bar{\chi}$, and this can be used to diagnose the mean meridional circulation qualitatively.

$$\frac{\partial^2\bar{\chi}}{\partial y^2}+\frac{f_0^2}{N^2}\rho_0\frac{\partial}{\partial z}\left(\frac{1}{\rho_0}\frac{\partial\bar{\chi}}{\partial z}\right)$$

$$=\frac{\rho_0}{N^2}\left[\frac{\partial}{\partial y}\left(\frac{\kappa\bar{J}}{H}-\frac{R}{H}\frac{\partial\overline{v'T'}}{\partial y}\right)-f_0\left(\frac{\partial^2\overline{u'v'}}{\partial z\partial y}-\frac{\partial\bar{X}}{\partial z}\right)\right] \tag{4}$$

The left-hand term of the equation (4) is proportional to $-\bar{\chi}$, and the right-hand terms qualitatively state that

$\bar{\chi}\propto-\frac{\partial}{\partial y}$ (diabatic heating)+$\frac{\partial}{\partial y^2}$ (large-scale eddy heat flux)+$\frac{\partial^2}{\partial y\partial z}$ (large-scale eddy momentum flux) $+\frac{\partial}{\partial z}$ (zonal drag force)

In general, the diabatic heating term on the right-hand side of equation (4) plays the most important role in maintaining the Hadley circulation in the tropics, and the meridional indirect circulation in the midlatitudes is significantly controlled by the two eddy terms on the right-hand side, the large-scale eddy heat momentum flux and large-scale eddy momentum flux.

Figure 6 shows interdecadal time-scale variations of (a) the mean eddy heat flux ($v'T'$) and (b) the mean eddy momentum flux ($u'v'$) in the latitude-height cross-sections of the Asian continent. Two eddy fluxes are calculated from multiplying fluctuations of atmospheric variables for 1958-2004, and the mean eddy heat fluxes and the mean eddy momentum fluxes in Fig. 6 are averaged for the latter period (1977-2004). In the equation 4, the eddy heat flux ($\overline{v'T'}$) in the first term of the right-hand side is proportion to negative stream function in the left-hand side of the equation. A stream function ($\bar{\chi}$) is generally decreased in a positive eddy heat flux area, then the positive eddy heat flux makes an anti-clockwise meridional circulation in the two different regions (Fig. 6a). A sinking motion in Fig. 6a will be forced wherever in $\frac{\partial\overline{v'T'}}{\partial y}>0$, and a rising motion wherever in $\frac{\partial\overline{v'T'}}{\partial y}<0$.

The relationship between a stream function and eddy momentum flux is summarized by $\bar{\chi}\propto\frac{\partial\overline{u'v'}}{\partial z\partial y}$; this means that the larger the meridional gradient of the eddy momentum flux ($\frac{\partial\overline{u'v'}}{\partial y}$) as the height increases, the more enhanced the positive stream function value is (the clockwise meridional circulation in Fig. 6b). Likewise, the stream function value is negative when the meridional gradient of the eddy momentum flux is vertically decreased, such as the anti-clockwise meridional circulation in Fig. 6b.

These analyses of large-scale meridional circulation in midlatitudes using the diagnostic equation are very available for a dynamical understanding of real observed circulations. The strong descending motion around 40°N and the ascending motion in 50°N-70°N are well-described by both the eddy momentum flux and eddy heat flux, but we can also find that there is an inconsistency between the eddy heat flux (Fig. 6a) and stream function in midlatitudes (Fig. 5a) in heights over 400 hPa levels of the midlatitudes.

These results mean that the warming shift of SST anomalies in tropical Indian Ocean Sea Surface Temperature since 1976/1977 induces the mean wind field change by the diabatic heating in upper and lower levels of troposphere around tropics. Changes of mean wind field are caused by an enhancement of eddy fluxes in midlatitudes. Although the interdecadal

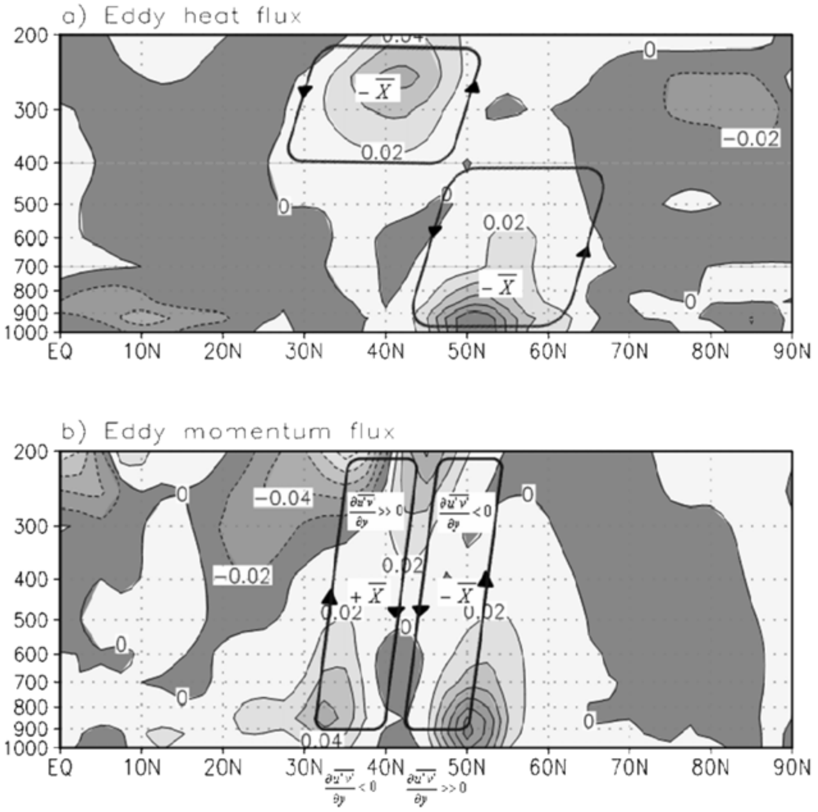


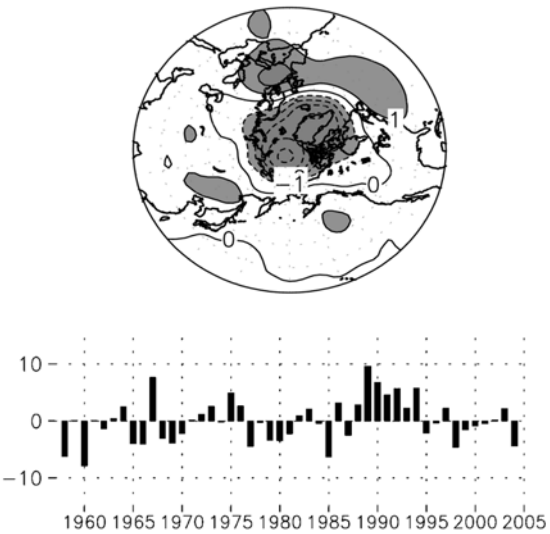
Fig. 6. (a) the latitude-height cross-section of large-scale mean eddy heat fluxes ($\overline{v'T'}$), and (b) the mean eddy momentum flux ($\overline{u'v'}$) averaged in the Asia region [60°E-120°E], The eddy fluxes calculated from multiplying perturbations of atmospheric variables against the mean values for the whole period (1958-2004) and the mean eddy fluxes are averaged for the latter period (1977-2004).

meridional circulation over the Asian continent is derived from a warm Sea Surface Temperature forcing of tropical Indian Ocean, the surface wind changes over the Asian continent have surely contributed to surface warm advections in Siberia since 1976/1977.

An Interdecadal Time-scale High Pressure Anomaly over the Asian Continent

In this chapter, we will suggest a long-term pattern of geopotential height anomalies over the Asian continent, which is associated with the significant interdecadal variation of large-scale meridional circulation in midlatitudes and the rising surface temperature in Siberia. Figure 7 shows the two principal Empirical Orthogonal Function (EOF) modes of the 850 hPa geopotential height anomalies for 1958-2004. The first mode has the spatial pattern of a negative geopotential anomaly core in the North Pole with positive geopotential heights in its surroundings, so it is referred to the ‘AO-type mode’ in here (Fig. 7a). The second mode shows the characteristics of an anomalous high pressure over the Asian continent, and the spatial pattern is very simple, such as an interdecadal time-scale anomalous high pressure in Asia (Figs. 7b); therefore, it is called the Asian High mode in this study. The sum of the variations in the two representative modes accounts for 59% of the total geopotential height variance in the mid-to-high latitudes. We can confirm that the time series of principal components for the anomalous Asian High

a) First mode (45.50%)



b) Second mode (13.33%)

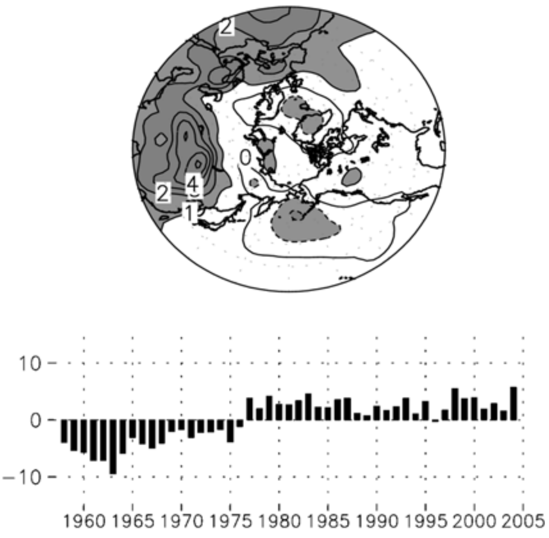


Fig. 7. The principal EOF modes of the 850 hPa geopotential height anomaly for 1958-2004. The upper panel denotes the first mode, and the lower panel the second mode, respectively.

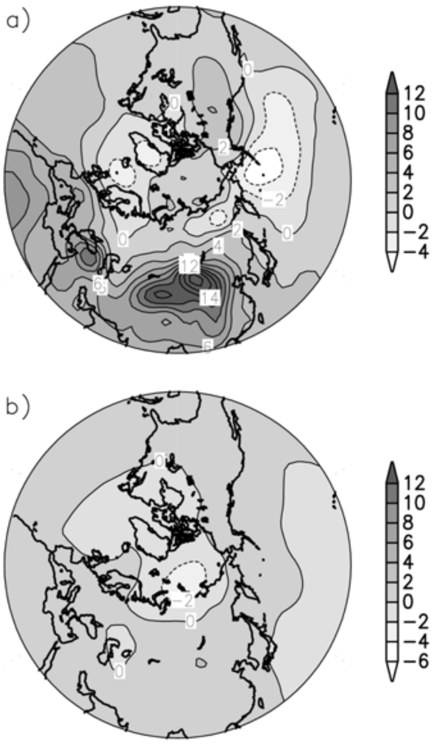


Fig. 8. The composites of the EOF modes for the 850 hPa geopotential height anomalies for 1977-2004. (a) is a composite of the Asian High mode and residual modes except the AO-type mode, and (b) is a composite of the AO-type mode and residual modes except the Asian High mode.

mode has significantly changed from a negative value to a positive value since 1976/1977. This dramatic change of the principal components of in 1976/1977 implies that the anomalous Asian High mode certainly seems to be linked with the interdecadal meridional circulation over the Asian continent. This result suggests that the anomalous Asian High is one of the characteristics of the interdecadal time-scale circulation in the mid/high-latitudes of the Northern Hemisphere.

Composites of the EOF modes, which are eigenvectors that have been multiplied by the principal components, were analyzed to investigate whether another interdecadal time-scale mode is superimposed on the anomalous Asian High mode. Figure 8a shows the summation of all modes for 1977-2004, except the first mode, and Fig. 8b indicates the summation of all modes during the same period, except the anomalous Asian High mode. A strong positive geopotential anomaly over the Asian continent still remains a predominant pattern in Fig. 8a, and this implies that there is no effective mode that contributes to the occurrence of the high pressure anomaly over the Asian continent. Meanwhile, the negative geopotential anomaly of the AO-type mode in the North Pole is very weakened in the composite between the AO-type mode and the residual modes for 1977-2004, except the anomalous Asian High mode (Fig. 8b). This result means that the AO-type mode didn't contribute to the long-term change over the Northern Hemisphere's mid/high latitudes.

Although the center of the anomalous Asian High mode doesn't superimpose over the center of severe warming regions over the Asian continent (shown in Fig. 1), but we also convinces that the Siberia regions has experienced the warm southerly winds near the surface by a horizontal anti-cyclone circulation wind since 1976/1977 (not shown in here). It implies that the surface warm advections over the Asian continent induced by interdecadal circulation changes play more significant roles for the increase of surface temperature in Siberia rather than adiabatic heating or radiation effects. This result is well accorded with the relationship between temperature anomalies and the meridional surface wind in midlatitudes shown in Fig. 5. We suggest that the Asian High mode is another response in geopotential height field to the interdecadal variation of large-scale circulation over the Asian continent since 1976/1977.

Conclusion and Discussion

Until now, this study shows that the coherency between a long-term change of Sea Surface Temperature anomaly in the Indian Ocean and the warming trend of surface temperature in Siberia. A new description of a cause of the surface warming in Siberia on the view of atmospheric large-scale dynamics was attempted by the detail analyses of the interdecadal variations of meridional circulations over the Asian continent. In addition, the anomalous Asian High was suggested as another characteristic of large-scale circulation changes over the Asian continent since 1976/1977.

Our results represent that the positive SST forcing of tropical Indian Ocean on the interdecadal time-scale is still a controllable factor to the meridional circulation changes in between the Indian Ocean and Asian regions. It is also found that the strong surface warm advections over the Asian continent induced by interdecadal time-scale changes of meridional circulation have directly influenced to the rapid rising surface temperature in Siberia since 1976/1977.

Although there is no another evidence, which supports our suggestions, due to a poor performance in mid-/high-latitudes of numerical model, the Global Circulation Model (GCM), we convince that the warm southerly over the Asian continent is absolutely key causes of the rising surface temperature in Siberia since1976/1977. Also, our approach to the Siberian warming by greenhouse gas effects is very useful for understanding of local warming trend in other regions.

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References

Barnett, T.P., 2001, Detection of anthropogenic climate change in the world's oceans. Science, 292, 270-274.

Barnett, T.P., Pierce, D.W., AchutaRao, K.M., Gleckler, P.J., Santer, B.D., Gregory, J.M., and Washington, W.M., 2005, Penetration of human-induced warming into the world's oceans. Science, 309, 270-274.

Clark, C.O., Cole, J.E., and Webster, P.J., 2000, Indian Ocean SST and Indian summer rainfall: Predictive relationships and their decadal variability. Journal of Climate, 13, 2503-2519.

Clark, C.O., Webster, P.J., and Cole, J.E., 2003, Interdecadal variability of the relationship between the Indian Ocean zonal mode and East African coastal rainfall anomalies. Journal of Climate, 16, 548-554.

Crowley, T.J., 2000, Causes of climate change over the past 1000 years. Science, 289, 270-277.

Kalnay, E. and Coauthors, 1996, The NCEP/NCAR 40-Year Reanalysis Project. Bulletin of the American Meteorological Society, 77, 437-471.

Krishnamurthy, V. and Goswami, B.N., 2000, Indian monsoon-ENSO relationship on interdecadal timescale. Journal of Climate, 13, 579-595.

Lau, K.-M. and Weng, H., 1999, Interannual, decadal-interdcadal, and global warming signals in sea surface temperature during 1955-97. Journal of Climate, 12, 1257-

1267.

Lau, N.-C. and M.J. Nath, 1996, The role of the atmospheric bridge in linking tropical Pacific ENSO events to extratropical SST anomalies. Journal of Climate, 9, 2036-2057.

Lorenz, D.J. and DeWeaver, E., 2007, The tropopause height and the zonal wind response to global warming in the IPCC scenario integrations. Journal of Geophysical Research, 112, D10119, doi:10.1029/2006JD008087.

Manabe, S., Bryan, K., and Spelman, M.J., 1990, Transient response of a global ocean-atmosphere model to a doubling of atmospheric carbon dioxide. Journal of Physical Oceanography, 20, 722-749.

Overland, J.E., Wang, M., and Bond, N.A., 2002, Recent temperature changes in the western Arctic during spring. Journal of Climate, 15, 1702-1716.

Smith, T.M. and Reynolds, R.W., 2004, Improved extended reconstruction of SST (1854-1997). Journal of Climate, 17, 2466-2477.

Trenberth, K.E., 1990, Recent observed interdecadal climate changes in the northern hemisphere. Bulletin of the American Meteorological Society, 71, 988-993.

Wang, B., 1995, Interdecadal changes in El Nino onset in the last four decades. Journal of Climate, 8, 267-285.

Zhang, Y., Wallace, J.M., and Battisti, D.S., 1997, ENSO-like interdecadal variability; 1900-93. Journal of Climate, 10, 1004-1020.

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