Analysis of anomalously low surface air temperature in Northern Hemisphere during 2009/2010 winter

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1. Introduction

During the winter season of 2009-2010, an extraordinarily serious low-temperature disaster impacted mid an high latitudes in Northern Hemisphere (NH), especially in the areas of middle Russia, eastern Mongolia, northern China and the east coast of North America. Severe snowstorms were associated with the anomalously low temperature and caused enormous personnel casualties and economic loss. The low temperature is inconsistent with the recent warming trend, therefore, it is worth examining the causes for such temperature anomalies.

The Northern Hemisphere Annular Mode (NAM) which dominates the monthly mean anomalous flow in the NH has been gradually recognized and concerned (Thompson and Wallace, 1998，2000；Li and Wang, 2003a, b). The NAM is zonally symmetric in the sea level pressure (SLP) field associated with a north-south redistribution of atmospheric mass between mid and high latitudes (Lorenz, 1951).

A lot of research has been done to investigate the impacts of the NAM on the regional climate in the NH, such as the temperature (Gong et al., 2001), precipitation (Yang et al., 2008) and sandstorms (Ding et al., 2005). However, few studies focus on the planetary-scale impacts of the NAM and the associated mechanisms.

Starting with the analysis for the winter of 2009-2010, we aim to investigate the influence of the NAM on the hemispheric climate and present the mechanism for the planetary-scale impact.

2. Data and Methodology

Atmosphere reanalysis data are obtained from NCEP/NCAR (Kalnay et al., 1996) for the period of 1948-2010. The base period is 1958-2000.

The NAM index (NAMI) is defined as the difference in the normalized monthly zonal-mean SLP between 35°N and 65°N (Li and Wang, 2003).

The linear correlation, linear regression and composite analysis are adopted in this study.

3. Atmospheric Anomalies during 2009/10 winter

Spatial Patterns of surface air temperature (SAT) and circulation anomalies

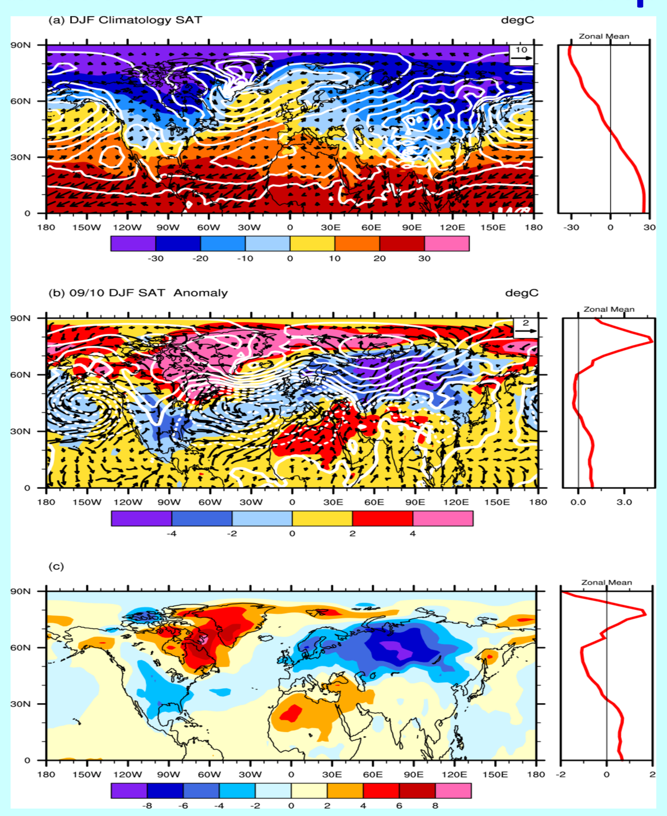

Fig. 1 (a) Climatological winter (December to February) mean SAT (color shadings, units: °C), SLP (contours, units: hPa) and surface winds (vectors, units: m s-1) (left) and the zonal mean profile of SAT (right); (b) same as (a), but for the anomalies during 09/10 winter; (c) SAT differences (units: °C) between 09/10 winter and the average for last 15 winters (1994/95 — 2007/08) (left) and its zonal mean profile (right). Contour intervals for SLP are 5 hPa(a) and 1 hPa(b)

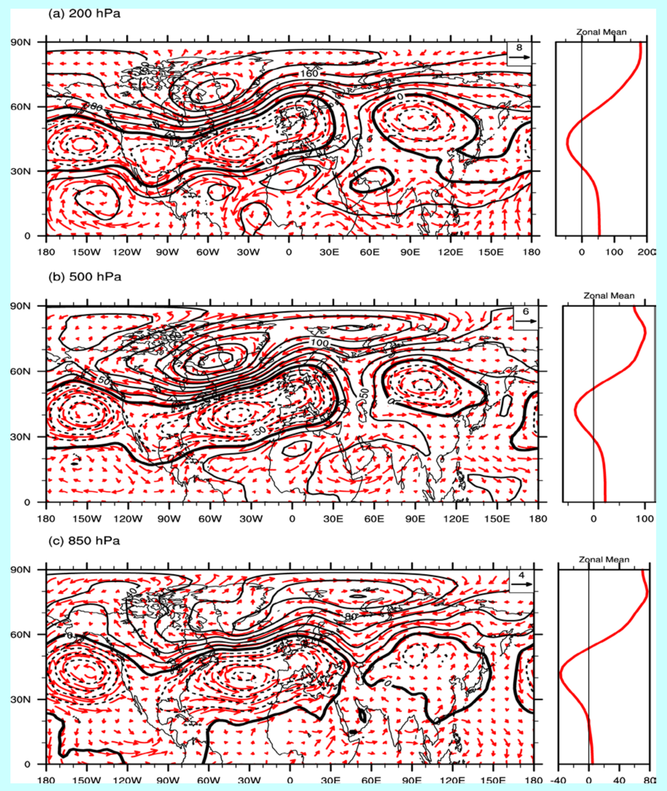

Fig. 2 Anomalous winter mean geopotential high (contours, units: gpm), and winds (vectors, units: m s-1) during 09/10 winter at (a) 850 hPa, (b) 500 hPa, and (c) 200 hPa, respectively

2009/10 winter is a typical negative NAM winter!

4. Planetary-scale Impact of NAM

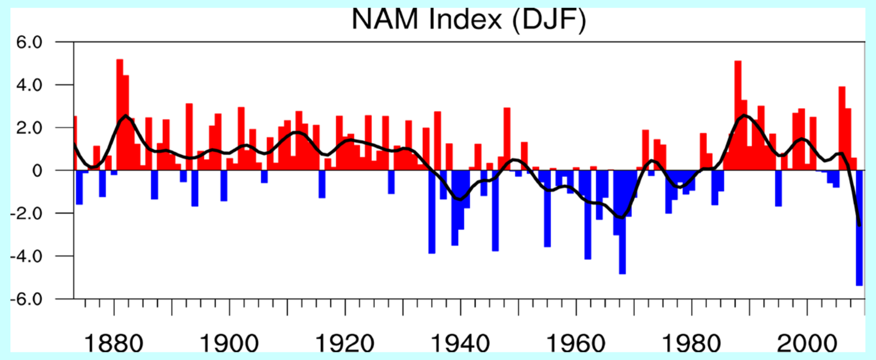

Fig. 3 Time series of the winter NAMI for the 1873/74-2009/10 period. The bold line represents decadal variation obtained using a 9-point Gaussian-type filter

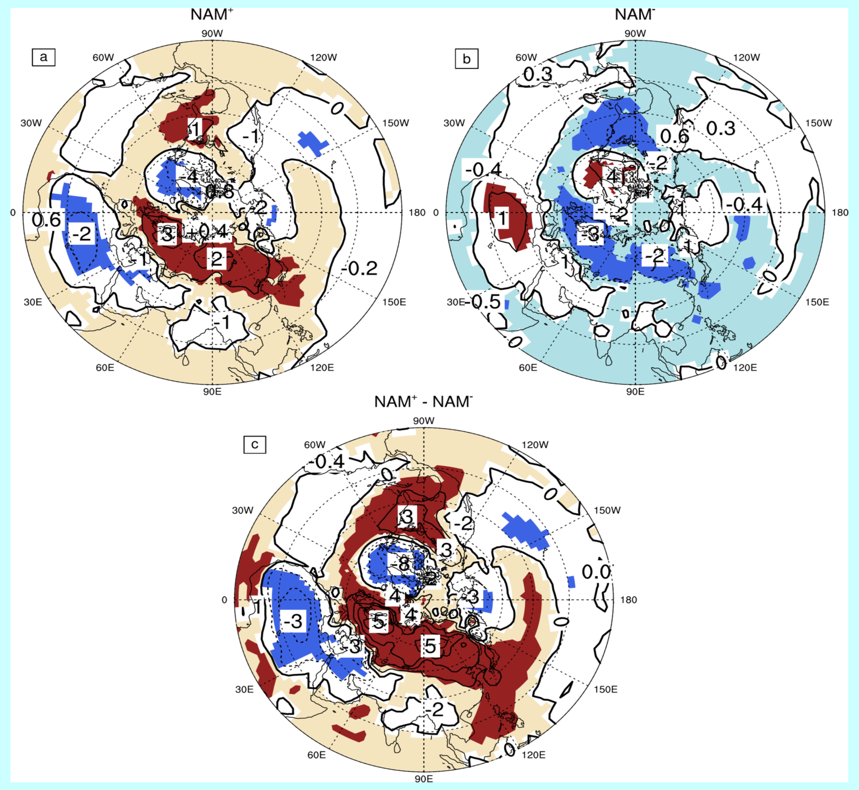

Fig. 4 Composite of Northern Hemisphere SAT (units: °C) for (a) typical positive NAM (NAM+) winters and (b) typical negative NAM (NAM-) winters; (c) composite differences in SAT between NAM+ and NAM- cases. The dark and light shaded areas are significant at the 95% and 90% confidence level, respectively

Quasi-annular belts of SAT anomalies

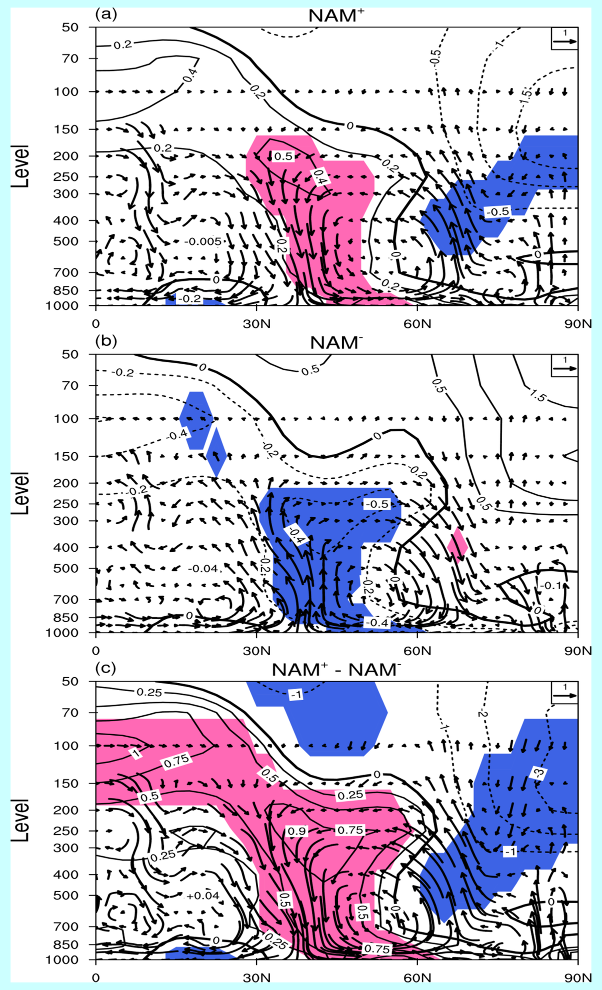

Fig. 5 Composite of meridional circulation (vectors, vectors in units of m s-1 for the meridional wind and cm s-1 for the vertical velocity) and zonal-mean air temperature (contour, units: °C) for (a) NAM+ and (b) NAM- winters; (c) composite differences in meridional circulation and zonal-mean air temperature between NAM+ and NAM- cases. The shaded areas are significant at the 95% confidence level for zonal-mean air temperature

5. Physical Process - Temperature Advection

$$\frac{\partial T}{\partial t}+\frac{u}{a\cos\varphi}\frac{\partial T}{\partial\lambda}+\frac{v}{a}\frac{\partial T}{\partial\varphi}+w\frac{\partial T}{\partial z}-\frac{1}{\rho c_p}\frac{dp}{dt}=\frac{1}{c_p}\dot{Q}$$

$$\frac{W}{H}\sim10^{-6}<<\frac{U}{L}\sim10^{-5}$$

scale analysis

$$\frac{\partial T}{\partial t}=-\frac{u}{a\cos\varphi}\frac{\partial T}{\partial\lambda}-\frac{v}{a}\frac{\partial T}{\partial\varphi}$$

$$\frac{T'}{\overline{T}}\sim10^{-2}<<\frac{U'}{\overline{U}}\sim10^{-1}<<1$$

linearization

$$-\frac{u'}{a\cos\varphi}\frac{\partial\overline{T}}{\partial\lambda}-\frac{v'}{a}\frac{\partial\overline{T}}{\partial\varphi}$$

zonal mean

$$\frac{\partial[T]'}{\partial t}=-\frac{[v]'}{a}\frac{\partial\overline{[T]}}{\partial\varphi}$$

Meridional temperature advection (MTA) induced by the meridional wind (V) plays an important role in the variation of zonal-mean air temperature.

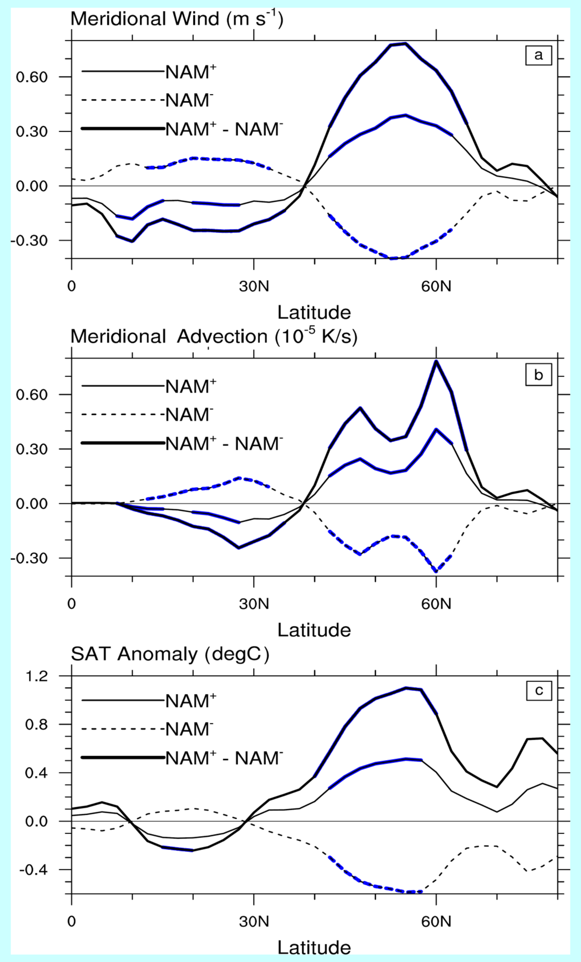

Fig. 6 Composite of zonal-mean (a) V, (b) MTA and (c) SAT for NAM+ (solid thin line) and NAM- (dash thin line) winters; composite difference (solid thick line) in zonal-mean (a) V, (b) MTA and (c) SAT between NAM+ and NAM- winters. Blue lines denote regions above 95% significance levels

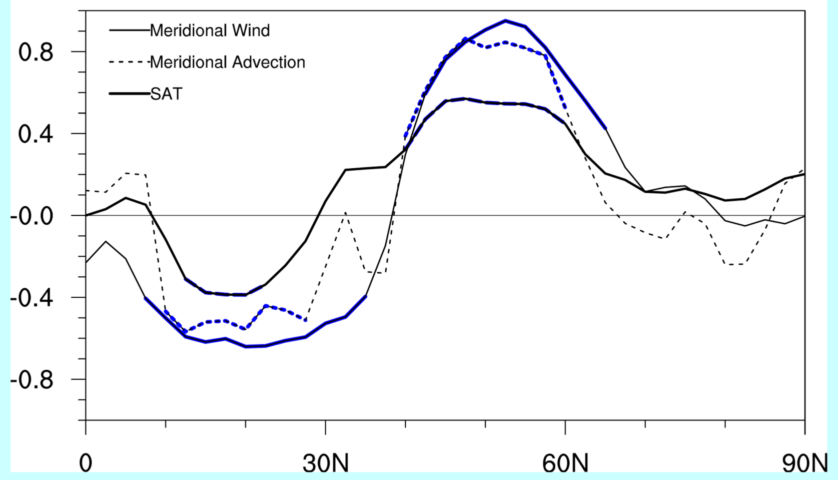

Fig. 7 Correlations between NAMI and zonal-mean V (solid thin line), MTA (dash thin line) and SAT (solid thick line). Blue lines denote regions above 95% significance levels

6. NAM and SAT at Mid-Latitudes

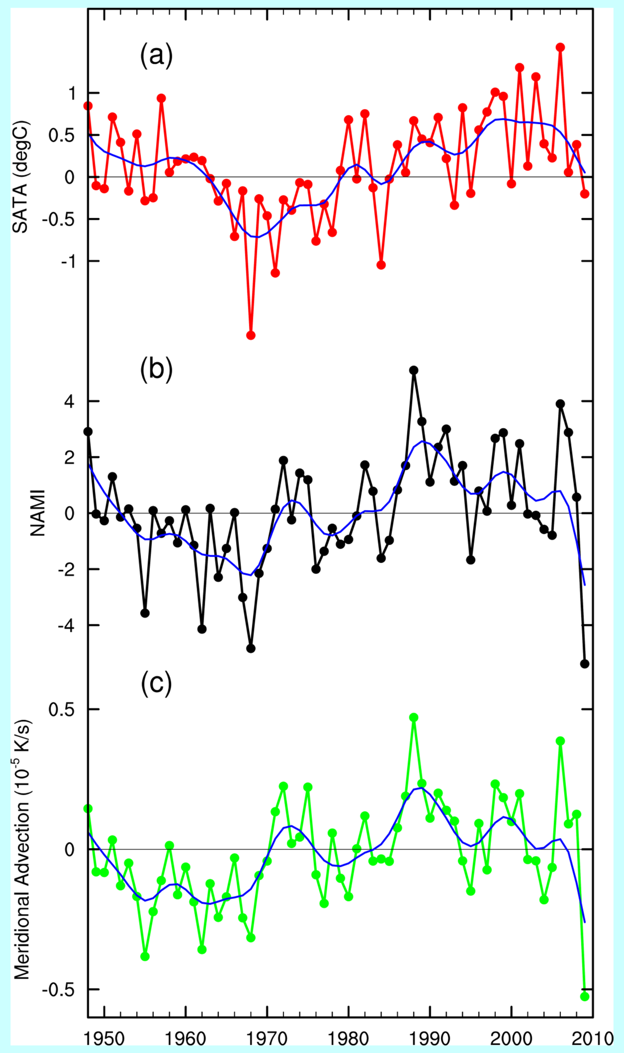

Fig. 8 Time series of (a) mid-latitudes (35°- 60°N) averaged SAT, (b) NAMI and (c) mid-latitudes averaged MTA. The blue lines represent decadal variation obtained using a 9-point Gaussian-type filter

r(SAT, NAM) = 0.56 (0.64), where the value in parentheses are based on decadal anomalies

For mid-latitudes, we have:

$$SAT=0.16\times NAMI+0.11$$

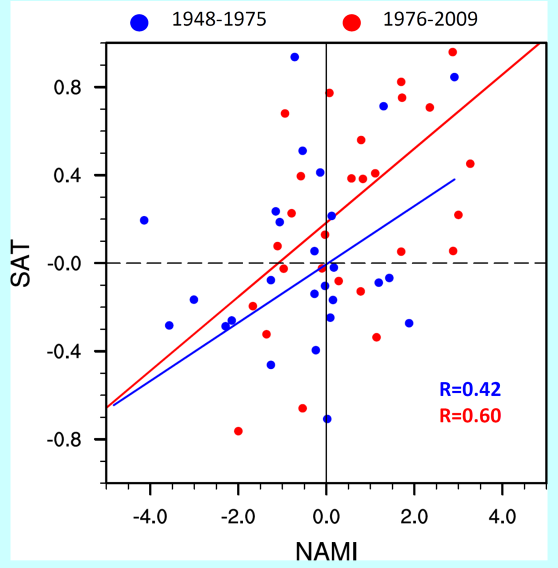

Fig. 9 Scatterplot of winter mid-latitudes averaged SAT against NAMI over the periods of 1948-1975 (blue) and 1976-2009 (red)

7. Conclusion

1. The anomalously low surface air temperature occurred at mid-latitudes in the NH during 2009/10 winter. The coldest SAT anomalies (SATA) were located in Eurasia and eastern USA, and in some regions the SATA exceeded -4°C. Compared with the average for last 15 years, the SAT at middle latitudes decreased almost 1°C, and in Eurasia the SAT even decreased 8°C. The associated circulation patterns resembled those of a typical negative NAM winter, indicating a connection between the SAT and the NAM.

2. The SAT pattern related to the NAM is quasi-annular, resulting in a significant relationship between the zonal-mean air temperature and the NAM. This indicates that the NAM has a planetary-scale impact on the NH climate. The Ferrel Cell becomes stronger (weaker) for the NAM+ (NAM-) winters, leading to south (north) surface wind anomalies at mid-latitudes.

3. The simplified formula for the thermal equation shows that the MTA induced by the meridional wind plays an important role in the variation of zonal-mean air temperature. Observational analysis shows that significant positive (negative) MTA anomalies are usually associated with NAM+ (NAM-) which can cause the warmer (colder) SAT at mid-latitudes.

4. A robust change occurred in the interannual relationship between mid-latitudes SAT and the NAM in the middle 1970s.

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Acknowledgement:

The travel to WCRP OSC is supported by Asia-Pacific Network for Global Change Research.

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