Interannual variability of the atmosphere/snow interaction over the Eurasian continent during the spring season and its relation to the monsoon period

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Abstract

Interannual variability of the spring snow cover over the Eurasian continent and its relevance towards the following monsoon season has been investigated using the NOAA/ NESDIS northern hemisphere weekly snow-cover chart and in-situ measurement of snow- depth derived from the Historical Soviet Daily Snow Depth Version 2 (HSDSD) dataset. Interannual variability of snow cover in the western Russian region has a strong correlation with the January NAO (North Atlantic Oscillation) and a signal of a strong positive/negative NAO remains as a emanating early/late snow melt in the region which persists until April. While NAO itself has little or no auto-correlation for period longer than 1 month, a consistent lag correlation was seen, where an EU-like wave-guide pattern following the NAO dipole matures during March, which in turn allows an anomalous heat advection from the Atlantic to alter the land surface condition. In the following April, a barotropic atmospheric anomaly responsible for the adiabatic heating in the region can be seen. While such large-scale atmospheric teleconnection can be seen accompanying the snow anomaly, its effect can no longer be seen past May, which could suggest that its influence towards the monsoon onset or its maturity can be marginal.

Keywords; Snow cover, snow melt, North Atlantic Oscillation

1. Introduction

Interannual variability of snow extent over the Eurasian continent during the winter season has long been considered to have a possible impact towards the climatic conditions of the subsequent seasons. The so called "Blanford hypothesis" suggests an inverse relationship between the winter and spring snow accumulation over the Himalayas and the subsequent monsoon rainfall over India. This relation was later supported by Hahn and Shukla (1976) where they used satellite derived snow area data to show a statistically significant negative correlation against the Indian monsoon rainfall. Extending this result to a continental scale, Bamzai and Shukla (1999) showed that the inverse correlation between the IMR exists only over the western European region during late winter, and over the western Russian plains during early spring.

On the other hand, snow extent in this region is under strong influence of the atmospheric variability such as the North Atlantic Oscillation (NAO). Based on an EOF analysis, Clark et al. (1999) showed three distinct atmospheric patterns where each has a different impact towards the snow extent, one of which is the NAO. Saito et al. (2003) showed that the dominant mode of atmospheric variaibility (the Arctic Oscillation, or the NAO) has strong correlation with the snow extent over the Eurasian continent which lasts up to April. Also, Robock et al. (2004) showed that strength of winter NAO may have an influence towards the snow extent and soil moisture of the region which propagates eastward and lasts until April. Hori and Yasunari (2003) also showed that the influence of NAO towards snow extent during Jan. is limited to the European region, and has a lag effect emanating northeastwards until April. While some studies suggests that the effect NAO may remain as a climatic memory in the snow cover until summer (Ogi 2004), other studies showed that early/late snow cover does not last through May, and its ability to alter the state of the monsoon may be relatively small (Ueda et al. 2003; Shinoda 2001). Also, Hori and Yasunari(2003) showed that the NAO influence towards the snow extent can be seen regardless of the state of the monsoon, which suggests that the given correlation may be accidental, with no physical background. The objective of this study is to build upon Hori and Yasunari(2003) to describe the atmospheric variabilities accompnying the snow melt over the Eurasian continent during early spring.

2. Data and Methods

Two types of snow data are used throughout this study. The Historical

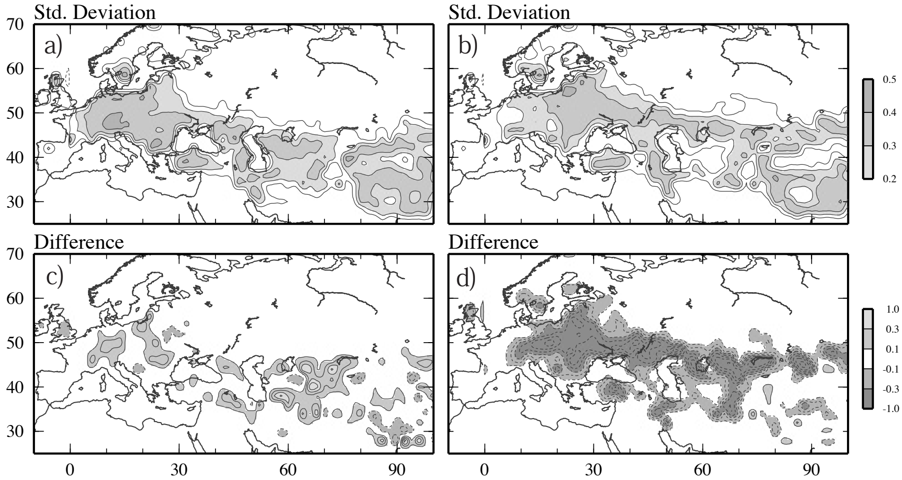

Fig1: a) Interannual standard deviation of snow extent on Jan. for the 1972-2002 period. b) same as a) but for Mar. c) Climatological snow extent difference for the first half and second half of the month of Jan. d) same as c) but for Mar.

Soviet Daily Snow Depth (Version 2.0) is used for in-situ measurement of snow amount. NOAA/NESDIS Northern Hemisphere Snow Cover Chart is used for continent-wide snow content estimation. The original dataset is comprised of gridded digital data of 2x2 degrees. Snow extent climatology was created using a 30-year weekly averages of NOAA/NESDIS snow cover dataset.

Also, daily data from the NCEP/NCAR Reanalysis dataset is used from 1972-2002. to create the monthly and weekly atmospheric datasets.

3. Results

The climatological feature of the springtime snowmelt over the Eurasian continent is assesed using a 30 year averaged snow extent data. Figure 1. shows the interannual standard deviation of snow extent during Jan. and Mar. Also shown is the variability in snow extent within each month, by taking the difference of the climatological snow extent between the first half of the month against the latter half. In January, the tnterannual variability of snow extent is large over the European region while in March, the region with maximum variability shifts north-eastward to the western Russian plains. However, snow extent difference within the first and second half of the month is small in January, which suggests that the existence of snow is interannual by nature rather than by seasonal change of snow extent.

Next, the seasonal change of atmospheric variables during the snow melt season is presented. Figure 2. shows a longitude-time section of SLP, 850hPa v-wind, 850hPa wind vectors and snow extent averaged over the region of 45-55N. The onset of southerly is clearly shown over 20-60E during late February through April, accompanied by a rapid snow melt in the region. This is consistent with the findings of Ueda et al. (2003) where they showed that the snow variability during early March through April is governed by the climatological southerly onsetting in early March in the region of 30-60E.

Such southerly wind is in conjunction with the climatological westward extension of the Siberian High (SH). During early March, the intensity of the Iceland low weeakens while the strength of the SH intensifies, which creates a strong pressure gradient in the lower troposphere which maintains the strong southerly in 20-60E.

On the other hand during January, westerly wind is predominant over the climatological snow extent region, suggesting the interannual variability of NAO playing a strong role in determining the existance of snow in the region.

To investigate the interannual variability of snow melt during these two seasons, we create two indieces of snow extent. We define the the first index as the snow extent averaged over 45-55N, 0-30E at week 1-3 as the Eurasian-Index (Eu-index), and the second index as the snow extent over 45-55N, 20-60E during weeks 8-12 as the Western-Russian index(WR index).

Figure 3. shows the timeseries of the two indices, from 1972-2002. The Eu index has a strong correlation with the January NAO index, which is consistent with previous studies (Hori 2003, Robock 2003). The March index shows strong interannual variability along with a notable decadal variability where the index shifts around 1986/87. Correlation with March NAO index is better for the latter period, which is consistent

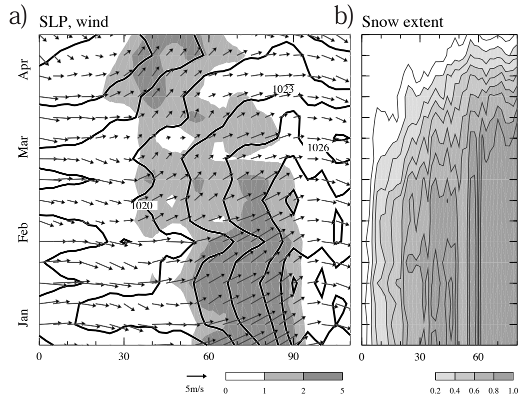

Fig2: a) Climatological SLP (contours) and 850hPa v wind (shades) and wind vectors averaged over 45-55N. b) climatological snow extent over the same latitude zone.

with the findings of Saito et al. (2004) where the covariability of the snow cover between the winter season and the spring season changed in the mid-'80s.

To investigate the atmospheric variabilities corresponding to each indices, a composite analysis between the high years and low years of each indices is given. The WR-index is devided into two periods of 1972-1986, and 1987-2002, and normalized for each period to derive the high years and low years. The composite differnence for SLP, snow extent and 850hPa wind is given in figure 4.

In figure 4 (a), the dipole structure of the NAO is clearly seen. The snow extent anomaly is confined to the European region where the warm maritime advection in conjunction with the NAO westerly is strongest. While strong westerly anomalies are seen over the inland region of the Eurasian continent, no significant difference in snow extent anomaly can be seen.

During March, the atmoshpheric patterns differs between the two defined periods. In the first period of 1972-1986, a weak positive SLP anomaly can be seen over the climatologocal center of the SH, while a negative anomaly can be seen over the western Russian plains. The negative SLP anomalies signifies a late IL retreat, and the overall pressure gradient in the region becomes strong in the WR index region. Strong southwesterly anomaly can be seen over the region, with an negative snow extent anomaly corresponding to less snow can be seen. The SLP anomaly over the Atlantic ocean basin shows no NAO like features, which suggests weak correlation with the NAO.

The second period of 1987-2002 shows a negtive SLP anomaly in central Eurasia corresponding to the weakened westward extention of the SH. A positive SLP anomaly is over the european region, accompanied by a westerly anomaly extending from the Atlantic ocean towards the western Russian plains. A weak dipole anomaly is present in the Atlcntic which suggests moderate correlation with the NAO. Strong northwesterly anomaly is present over the snow extent anomaly over 20-50E, and southwesterly anomaly is present over the 50-80E region.

It is clear from the figure that the January snow extent is mostly governed by the NAO variabliity. March variability has shown a distinct decadal whift in the mid 1980s, where IL/SH pressure gradien t becam e weaker, and warm advection accompanied by the anomalous westerly by the March NAO has become dominant. It should be noted that the area of the snow anomaly mostly overlaps between the two periods, and notable change exists only the controling atmospheric anomalies.

To show the change in snow extent persistence betwwen the two periods, composite difference of snow extent for the subsequent seasons is given in figure 5. In the 1972-1986 period, snow extent anomaly propagates northwards with sustained intensity, which suggests strong correlation with the subsequent seasonal change of the snow extent. The snow extent anomaly persists through April, until mid May, but diminishes after June (figure now shown).

In the 1986-2002 period, snow anomalies extends more eastwards. However, the anomaly becomes weaker in the subsequent weeks, and the anomaly does not persist beyond April.

This suggests that the atmospheric control over the snow extent has become weaker in the recent years, where a snow anomaly, once formed do not persist through the spring season.

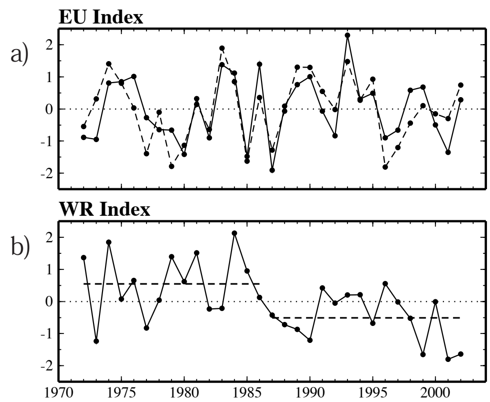

Fig3: a) Timeseries of snow extent averaged over 0-20E, 45-55N for Jan. (solid line), NAO index for Jan. (dashed line). b) snow extent averaged over 30-60E, 45-55N for Mar.

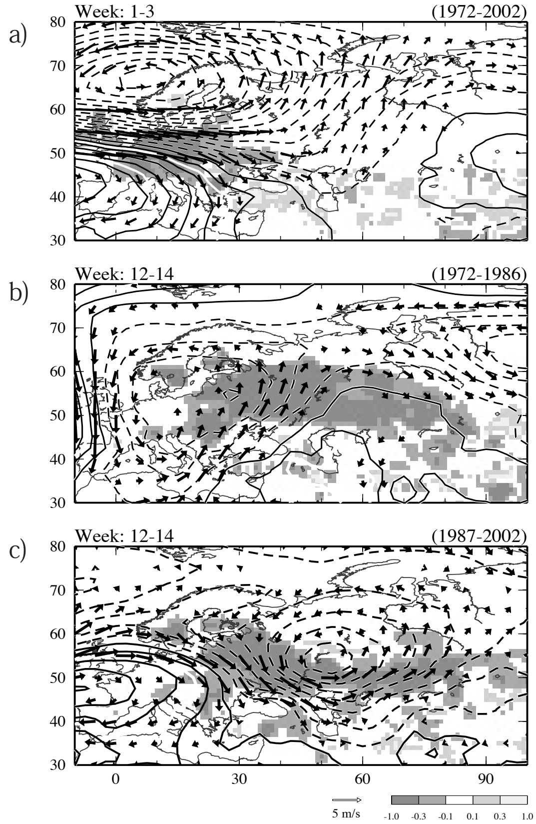

Fig4: Composite difference of SLP (contour), snow extent anomalies (shades) and 850hPa wind vector for a) high/low years of Eu-index during weeks 1-3. Period is from 1972-2002, b) same as a) but for WR-index for weeks 12-14, peiod is 1972-1986, c) same as b) but for period of 1986-2002.

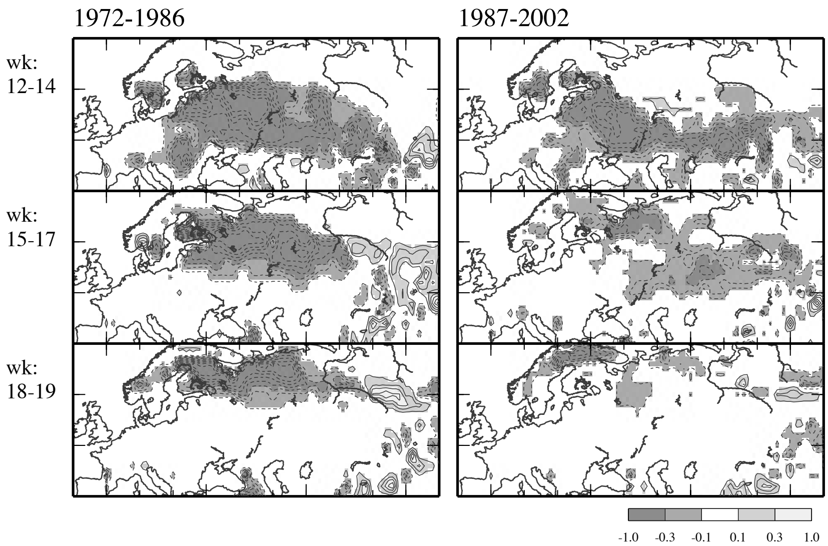

Fig5: a)-c) Composite difference of snow extent for high/low years of WR-index during for the period of 1972-1986, b) same as a) but for period of 1987-2002.

4. Discussions

The climatological and interannual variability of the Eurasian snow melt and its corresponding atmospheric patterns are investigated throughout this study. It is found that January snow extent is confined to the European region by the influence of the NAO, whereas the March snow extent is mostly influenced by the climatological southerly maintained by the IL/SH pressure gradient wind in the lower troposphere. The march snow extent variability shows a distinct shift towards a lesser snow amount during the mid 1980s, with a higher correlatioin with the March NAO in the later period. Composite analysis revealed that the March snow extent was mostly influenced by the amplitude of the IL/SH gradient during the 1972-1986 period, while the amplitude of the westerly advection accompnying the March NAO was dominant in the 1987-2002 period.

While In general, NAO shows no memory beyond 1 month, in the recent years, a high correlation can be seen between the January and March NAO which gived leads to the high persistance of snow extent anomaly during these seasons.

Some studies argues the recent strong correlation between the January NAO and the Indian monsoon rainfall (Chang et al. 2001; Robock et al. 2003), but such correlations callapsed during the mid-1990s (figure not shown) and it is suggested that the NAO may not have a dominant influence towards the monsoon.

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