North Atlantic Oscillation and northern hemispheric warming

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In this paper, the effect of Winter-NAO on northern hemispheric temperature and snow-cover is studied because North Atlantic Oscillation (NAO) fluctuations are strongest in the winter season. The correlation analysis, for the period 1973-2003, suggests that winter-NAO is inversely associated with Northern hemispheric snow-cover from winter through summer and the correlation coefficients are significant at 5% level. Moreover, NAO is showing direct relationship with northern hemispheric temperature during winter season. This relationship is also significant at 5% level. The stability of this relationship is tested and found to be stable. The correlation analysis further suggests that winter-NAO and global temperature difference between land and ocean have direct association, which is significant at 5% level. The effect of rising trend in winter-NAO may have resulted in decreasing northern hemispheric snow-cover, which ultimately results in warming of northern hemispheric temperature. The study suggests that NAO plays an important role in warming of northern hemisphere through decreasing northern hemispheric snow-cover extent.

[Key words: NAO, snow-cover, northern hemisphere temperature, SST, warming, land-ocean temperature, thermal contrast]

Introduction

North Atlantic Oscillation (NAO) is essentially the pressure difference between the Azores High (40°N, 30°W) and the Icelandic Low (63°N, 30°W). According to Hurrell1, when both features are strong, NAO is positive and the strength of westerlies across the Atlantic basin is increased, which is associated with higher European temperatures. A negative phase of NAO is associated with weaker westerly winds and lower European temperatures. Thus, the phase of NAO is directly associated with the temperature over Europe during winter season. Hurrell1 showed that the changes in circulation over the Atlantic have contributed much to the recent wintertime warming across Europe, the coolness over the eastern Mediterranean, and to the very cold conditions over the northwest Atlantic. Hurrell1 also pointed out that temperature variations over North Atlantic region are related to changes in the NAO, while the changes over the North Pacific are linked to the temperature variations in tropics and involve variations in the Aleutian low with teleconnections downstream over North America. Using multivariate linear regression, Hurrell2 further showed that nearly all of the cooling in the northwest Atlantic and the warming across Europe and downstream over Eurasia, since the mid-1970s, results from the changes in the NAO. Thus, the NAO dictates climate variability from the eastern coast of the U.S.A. to Siberia and from the Arctic to the subtropical Atlantic.

In present paper, an attempt has been made to understand the effect of NAO on northern hemispheric temperature. The study is useful in understanding the long-term climatic changes in northern hemisphere in relation to fluctuations in NAO. The probable connection between NAO and Northern Hemispheric temperature can be thought of by considering the effect of NAO on snow-cover extent over northern hemisphere. The snow-cover is an important climate change variable because of its influence on energy and moisture budgets. Snow-cover accounts for the large differences between summer and winter land-surface albedo, both annually and interannually. Snow may reflect as much as 80 to 90% of the incoming solar energy, whereas a snow-free surface such as soil or vegetation may reflect only 10 to 20%. In addition to the albedo effect, snow-cover represents a significant heat sink during the melt period of the seasonal cycle due to a relatively high latent heat of fusion. As a result, the seasonal snow-cover provides a major source of thermal inertia within the total climate system, as it takes in and releases large amounts of energy.

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Bojariu & Gimeno\textsuperscript{3} have explored the relation in the observed data between the Eurasian snow-cover anomalies and the NAO variability on interannual to decadal time scales and suggested that in winter and early spring, NAO influences the extent of snow-cover and the snow-cover affects the atmosphere in the late spring, summer and early autumn leading to a mechanism that seems to be responsible for the multiannual NAO persistence in the last half century. Some earlier studies\textsuperscript{3-7} showed that sub-decadal NAO variation is mostly described by the fluctuation in summer North American snow cover. Some studies\textsuperscript{8-9} show an inverse relationship between winter-NAO and sea-ice in western Baltic. In all these studies\textsuperscript{3-9}, the NAO was considered as an important factor in determining winter weather conditions like temperatures, snow-cover over regions like North America in Europe, Western Baltic etc. However, there is a huge region outside these areas and so the present paper mainly deals with the relationship of NAO with snow-cover over Northern Hemisphere. The study further extends to see the effect of NAO fluctuations on global temperature difference between land and ocean. This is important because northern hemisphere consists of both land and ocean, which responds the NAO fluctuations differently on different scales. It gives the effect of NAO on land-ocean thermal contrast, which is responsible for many weather phenomena like summer monsoon rainfall activity over India.

Materials and Methods

Following data have been used in this study.

1. \textit{North Atlantic Oscillation (NAO)}

Recent North Atlantic Oscillation indices for 1951-2000 have been taken up from web source [http://www.cpc.ncep.noaa.gov]. These NAO indices, which are directly available on the web, are computed as follows:

The NAO patterns were calculated from a Rotated Principal Component Analysis (RPCA) applied to monthly-standardized 500-hPa height anomalies during January 1950–December 2000. To obtain these patterns, ten leading un-rotated modes were first calculated for each calendar month by using the monthly height anomaly fields for the three-month period centered on that month. The NAO indices were calculated by first projecting the standardized monthly anomalies onto the NAO patterns corresponding to that month. The indices were then solved simultaneously using a Least-Squares approach. In this approach, the indices are the solution to the Least-Squares system of equations that explains the maximum spatial structure of the observed height anomaly field during the month. The indices were then standardized for each pattern and calendar month independently.

2. \textit{Northern Hemisphere snow-cover (SNC}_{NH}\textit{)}

Recent northern hemisphere snow-cover data for 1973-2003 have been taken up from web source [http://www.cpc.noaa.gov/data/snow/]. This data, which is directly available on the web, is computed as follows:

During the past few decades, satellite remote sensing has provided important information on hemispheric scale snow extent. Northern hemisphere snow-covered area anomalies, Snow-covered area departures from monthly means for the Northern Hemisphere, 1979-2003, derived from visible (NOAA) and passive microwave (SMMR and SSM/I) satellite sensors were used. The 24-year trend in mean annual snow extent derived from visible and passive microwave satellite data indicates a decrease of approximately 0.4% per year. Precipitation in regions of seasonal snow cover appears to have been constant or increasing slightly over the time period, which leads to conclude that diminishing snow cover is the result of increasing temperatures.

3. \textit{Northern Hemisphere surface air temperature (NHT)}

Recent northern hemisphere surface air temperature data for 1951-2000 have been taken up from [http://cdiac.esd.ornl.gov/trends/temp/jonescru/data.html]. This data, which is directly available on the web, is computed as follows:

The land and marine data components are combined by first interpolating each to the same 5°×5° latitude/longitude grid boxes. Land temperature anomalies were filled where more than four of the surrounding eight 5°×5° grid boxes are present. The hemispheric temperature anomaly time series, which incorporate land and marine data, are continually updated and expanded by Climatic Research Unit (CRU). The land portion of the database from which the time series are computed consists of surface air temperature (SAT) data (land-surface meteorological data and fixed-position weather ship data) from over 3000 station records that have been corrected for non-climatic errors, such as station shifts and/or instrument changes. The number of available stations increases to
over 3000 stations during the 1951-90 period. The marine data used are compiled at the Hadley Centre of the United Kingdom Meteorological Office and consist of sea surface temperatures (SST) that incorporate insitu measurements from ships and buoys.

4. Global Land-Ocean Temperature (GLOT)

Recent global land-ocean temperature data for 1951-2000 have been taken up from [http://www.giss.nasa.gov/data/]. This data, which is directly available on the web, is computed as follows:

The temperature index was formed by combining the meteorological station measurements over land with sea surface temperatures obtained primarily from satellite measurements. Global land-ocean temperature index was calculated with base period 1951-1980. Monthly indices of above-mentioned parameters are available and from these seasonal indices are computed by averaging the appropriate months in the season. The seasons are categorised as:

- Winter = Previous year December, January and February
- Spring = March, April and May
- Summer = June, July and August
- Autumn = September, October and November

Results and Discussion

The winter-NAO is showing increasing trend\textsuperscript{1, 10, 11}. Moreover, in recent 21-year period (1981-2001), the winter-NAO is positive for 15 years and is negative for 6 years only. In view of this increasing trend and recent positive phase of winter-NAO, its relationship with northern hemisphere surface air temperature and snow-cover is studied.

**NAO and NHT in winter season**

In this section, the variability of wintertime NHT in view of the NAO fluctuations (Fig.1) in the same season is discussed. The correlation coefficient between NAO and NHT during winter season, for 1951-2000, is 0.38, which is statistically significant at 5% level. In order to check the stability of the association between NAO and NHT, 30-year running correlation coefficients between them were computed (Fig.2). It suggests that the direct relationship between winter-NAO and winter-NHT is statistically significant at 5% level, from 1959 onward and hence is quiet stable. Thus, the fluctuations in NAO and northern hemispheric temperature are in phase. The probable reasoning for this direct relationship may be as: when NAO is positive then the faster westerlies minimize polar outbreaks, which create above-normal temperatures, especially in winter, which may result in above-normal temperature anomalies over northern hemisphere. Earlier studies have shown the patterns of interannual variability in the Northern Hemisphere wintertime 850-hPa temperature field\textsuperscript{12} and the dynamic contribution to hemispheric mean temperature trends\textsuperscript{13}.

**NAO and snow-cover over Northern Hemisphere (SNCNH)**

An inverse relationship between NAO and SNCNH is statistically significant during winter (at 1% level) and spring (at 5% level) seasons only (Fig. 3A). The correlation coefficients between them, for 30-year period (1973-2003), are -0.47 and -0.45 respectively.

![Fig.1— Interannual variability of NAO and Northern Hemisphere surface air temperature during winter season for 1951-2000.](image)
Further analysis suggests that winter-NAO is inversely associated with SNCNH from winter through summer seasons. This relationship is statistically significant at 1% level for winter snow-cover and at 5% level for spring and summer snow-cover (Fig. 3B). Thus, positive phase of winter-NAO is linked with decrease in northern hemisphere snow-cover from winter through summer. It increases snow-free surface of the Earth, resulting decrease in reflected energy and increase in absorption of solar radiation, which adds heat to the system and thereby causing even more snow to melt. Surface temperature is highly illustrated by the presence or absence of snow-cover, and temperature trends have been shown to be related to changes in snow-cover\textsuperscript{14}.

**Winter-NAO and global land-ocean thermal contrast**

Figure 4 depicts the correlation coefficients of winter-NAO with global land-ocean thermal contrast for the period of 1951-2003. The wintertime NAO is directly associated with global land-ocean thermal contrast for all seasons but statistically significant during winter and spring only. Thus, positive phase of winter-NAO is associated with above-normal thermal contrast, meaning continental warming and ocean cooling. Here continental warming means temperature of the total continent of the earth is rising (the large continental part of the globe lies in the northern hemisphere). Many earlier studies have discussed about global temperature variations\textsuperscript{15-17}.

In view of the positive trend of winter-NAO, there should be continental warming and cooling over ocean. The observed data also suggests that the changes in circulation over the past two decades (1980-2000) have resulted in a surface temperature
anomaly pattern of warming over the continents and coolness over the oceans². This pattern of temperature change has amplified the observed hemispheric-averaged warming because of its interaction with land and ocean; temperature changes are larger over land compared to the oceans because of the small heat capacity of the land.

**Conclusion**

Following conclusions can be drawn from the present study:

1. Positive phase of winter-NAO is associated with northern hemispheric warming. This warming may be due to decreasing northern hemispheric snow-cover from winter through summer. With recent positive phase of winter-NAO, the northern hemispheric warming in winter season is also observed.

2. During winter and spring seasons, the positive phase of NAO is linked with the global continental warming and oceanic cooling.

3. In winter season, NAO seems to contribute global continental warming through northern hemispheric warming and reducing snow-cover over northern hemisphere.

The increasing trend in winter-NAO is linked with decreasing snow-cover extent over northern hemisphere. This decrease in snow-cover extent results in decreasing the reflected energy and increasing the absorption of solar energy. It adds more heat to the Earth-atmosphere system, thereby causing even more snow to melt. This added heat energy to the Earth-atmosphere system affects the land and ocean. Since the response time of land to heat energy is less than the response time of ocean, the continent gets warm more quickly. This may results in large thermal contrast between land and ocean. Thus, a classic positive temperature-albedo feedback mechanism may result in warming of northern hemisphere and decreasing snow-cover extent over northern hemisphere, which may increase the global land temperature, because a large portion of global land is lying in the northern hemisphere.

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**Reference**