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High Speed Solar Wind Influence on NAO Index and Surface Temperature on Earth

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Abstract: The most important role in the atmospheric circulation in the Northern hemisphere plays the North Atlantic Oscillation (NAO). The NAO index changes the surface air temperature in a typical pattern. This research is about high speed solar wind streams (HSSWS) and their influence on the atmospheric circulation. The NAO index increases when a HSSWS reaches the Earth in all studied cases and this leads to typical surface air temperature changes in short term scale.

Key words: high speed solar wind, NAO index, NAM index

Introduction

Atmospheric circulation is the system of large scale atmospheric motions over the Earth. These motions are due to the different heating of Earth's surface. Heated air at the Equator rises and starts moving north and south towards the poles. The rotation of the Earth causes Coriolis force which deviates the moving air from the Equator to the right in the Northern hemisphere and to the left in the Southern hemisphere. At latitude of about 30° the air moves to east in both hemispheres. It cools, sinks to the surface and forms a zone with higher atmospheric pressure there. Because of that, the air starts moving toward the lower air pressure at the Equator along the surface on one side, and toward higher latitudes, on the other. The part of the atmospheric circulation from the Equator to 30^0 and backwards is called Hadley cell (one Hadley cell for the Northern hemisphere and another one for the Southern hemisphere).

The air masses at about 60° latitude are still sufficiently warm and moist. The air rises and moves toward the pole through the upper troposphere. At the pole it is already cooled and descends, forming a cold dry high pressure area. Then the air masses move away from the pole along the surface but twisting to the west because of the Coriolis force. The circulation of the air from the pole to 60° latitude and backwards is called Polar cell (one Polar cell for each hemisphere).

The Hadley cell and the Polar cell are thermally direct – they exist because of the differences in the surface air temperature. The Ferrel cell (again one in the Northern and one in the Southern hemisphere) is a secondary cell, dependent on the Hadley and the Polar cells. It is a result of high and low pressure areas in the latitudes between 30° and 60°. Unlike the Hadley and the Polar cells, this cell is not truly closed because of the sharp variations in direction of the surface winds.

Due to the landscape, the zones of different air pressure are localized in centers of action (Marshall, 2007).

The most important role in the atmospheric circulation in the Northern hemisphere plays the North Atlantic Oscillation (NAO). The structure of the NAO comes from the internal nonlinear atmospheric dynamics. The NAO refers to a redistribution of atmospheric mass between the Arctic and the subtropical Atlantic and is responsible for the changes of the mean wind speed and direction over the Atlantic (Hurrell, 2002). For a quantity representation of the NAO, the NAO index is used. It is equal to the normalized mean sea level pressure anomalies between Azores high and Icelandic low pressure in the Atlantic Ocean. When the NAO index is positive, the dominant circulation is zonal (from east to west). This carries warm and humid air from the Atlantic and causes mild and humid weather in Europe and Asia. When the NAO index is negative, the circulation is predominantly meridional (north – south). This leads to colder winter and hotter summer in Europe and the west part of Asia (Hurrell et al., 2003).

The Northern Annular Mode (NAM-index) stands for the whole Northern hemisphere and for different altitudes. It characterizes the variations in the strength of the polar vortex. The NAM is a hemispheric-scale pattern, characterized by synchronous fluctuations in pressure of one sign over the northern polar cap and of opposite sign at lower latitudes (Baldwin and Dunkerton, 2001).

This study is for the influence of the high speed solar wind streams (HSSWS) on the NAM index. HSSWSs come from solar coronal holes – open magnetic field regions. The plasma of the streams (mainly consisting of electrons, protons and helium nuclei) is characterized by high speed, low temperature and low density. When facing the Earth, the HSSWSs cause long but not very strong geomagnetic storms. The most solar coronal holes occur during sunspot declining and minimum phase so this is the period of the solar cycle when more HSSWSs come to Earth (Gosling, 2010).

Eddy (1976) found a relationship between the solar activity and the Earth's climate connecting the Maunder Minimum with the so-called Little Ice Age period in northern Europe. Another research shows a connection between the solar cycle length and the temperature of the Northern hemisphere (Friis-Christensen and Lassen, 1991). Lundstedt (1984) and Tinsley (2000) showed that the solar wind modulates the global electric circuit, causing changes in tropospheric temperature and atmospheric circulation. Furthermore, the evolution of the NAO index follows both the electric field strength of the solar wind and the planetary magnetospheric K_p index general features with linear correlation coefficients 0.62 between NAO and the electric field and 0.57 between NAO and K_p (Boberg and Lundstedt, 2002).

Recent studies show higher values of NAM in years with frequent high speed solar wind events (Georgieva et al., 2012). All these results motivate for investigating the connection between HSSWSs and parameters of the atmospheric circulation in short term time scale (several days).

Table 1. Some characteristics of the studied HSSWSs

	NAO	Max plasma speed, km/s	Max Kp	Max Dst
09.01.2003	-1.01	467	4	-31
08.12.2003	0.65	821	5.7	-51
20.12.2003	-0.03	628	4.7	-25
15.01.2004	-2.32	642	4.7	-57
28.01.2004	-2.35	672	4.7	-65

Data and methods

There are different definitions for high speed solar wind and respectively, different lists of events. The criteria used here include an increase of the solar wind velocity by at least 100 km/s in no more than one day to at least 500 km/s for at least 5 hours, accompanied with low proton temperature and low density (Georgieva et al., 2008). The studied events took place in years 2003 and 2004 when the solar cycle was on its declining phase and the HSSWSs were the dominant agent of solar activity. The events were chosen to be distinct from other solar activity manifestations (for at least 5 days after the HSSWS coronal mass ejections or another HSSWSs not to be observed) and to be in winter in the Northern hemisphere because of the significant changes of the NAO index during this time of the year (Hurrell, 2003). Five events were studied as three of them occurred while the NAO index was close to zero in the day the HSSWS reached the Earth, and in the other two the NAO index was much less than zero. In table 1 are shown the dates when the streams reach the Earth, the values of the NAO index in these days, the maximum solar wind speed and the greatest values of the K_P and D_{st} indices during the event.

The data for the high HSSWSs is taken from the National space science data center (http://omniweb.gsfc.nasa.gov/form/dx1.html) and cross-checked with the Coronal hole history at http://www.solen.info/solar. The data for the atmospheric parameters is from ftp://ftp.ncdc.noaa.gov/pub/data/gsod/.

The duration of the selected high speed solar wind events is several days so data was taken for one day

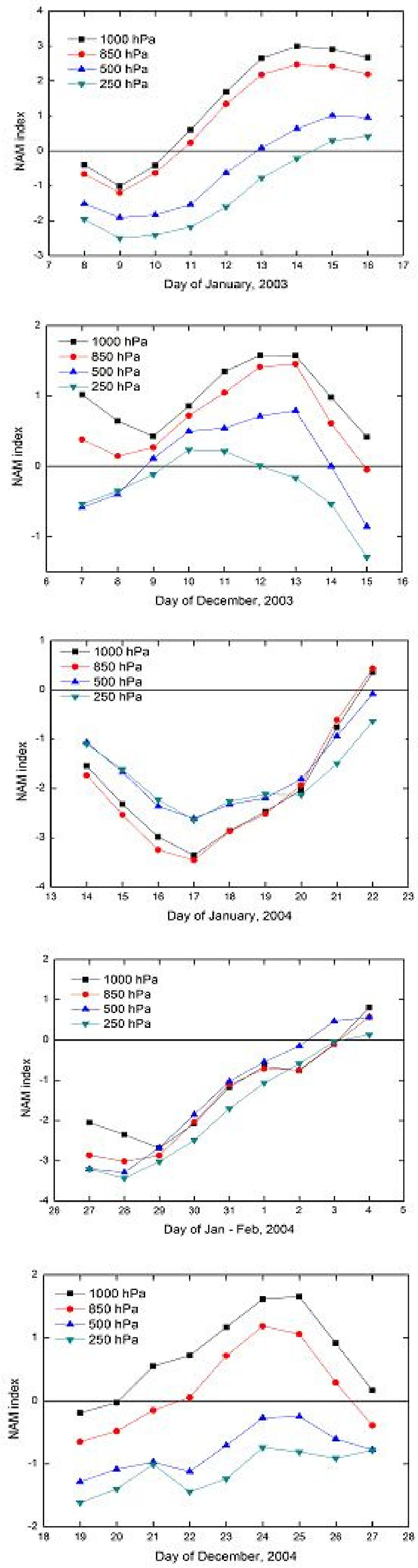

Figure 1. The change of the NAM at four different altitudes after 5 HSSWS that reach the Earth. The NAM increases in all cases studied for at least 4 days.

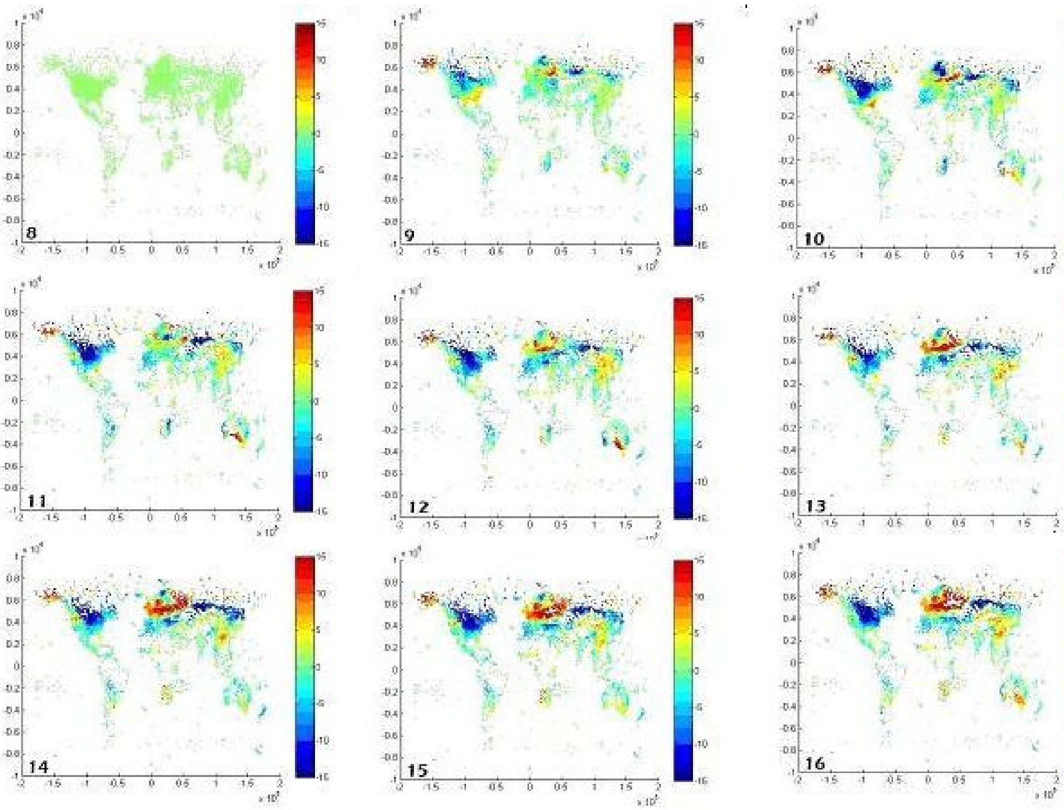

Figure 2. The color coded plots of the daily averaged surface temperature difference between days after a HSSWS reached the Earth (on 9 January 2003) and the day before that. The scale is in °C. The NAO index starts from nearly zero (-1.01 at the day of the event).

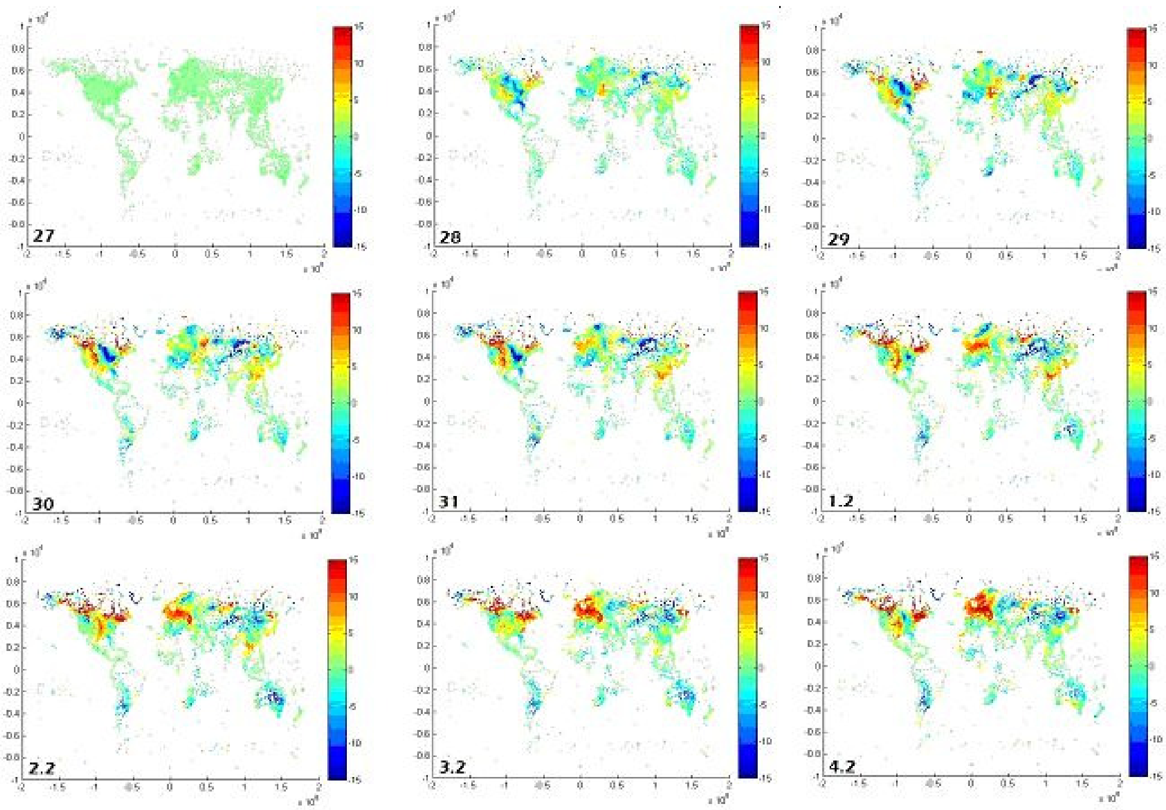

Figure 3. The color coded plots of the daily averaged surface temperature difference between days after a HSSWS reached the Earth (on 28 January 2004) and the day before that. The scale is in °C. The NAO index starts from a strongly negative value (-2.35 at the day of the event).

before and eight days after the stream came on Earth. The difference between the daily averaged temperatures for each day of the event and the day before the event for over 9000 worldwide stations is calculated and its color-coded value is plotted as a function of latitude and longitude in Figs. 2 and 3.

For the same period of time (9 days) the NAM index is plotted for four tropospheric altitudes – 1000 hPa, 850 hPa, 500 hPa and 250 hPa (the pressure is 250 hPa at approximately 10 km altitude – the upper end of the troposphere). The values of the NAM index are taken from
http://www.nwra.com/resumes/baldwin/nam.php.

Results and conclusions

The value of the NAM index at 1000 hPa is approximately equal to the value of the NAO index. As shown in Fig. 1, the general trend of the NAM index for the different altitudes is increasing. In some of the cases (8 December 2003 and 15 January 2004) the first one or two days after the arrival of the HSSWS the NAO index decreases but after that starts increasing for at least 4 days. No difference is observed between the behavior of the NAO (and NAM) index when the value of the NAO starts from approximately zero or from significantly below zero.

In Fig. 2 is plotted the color coded difference between the daily averaged temperature as a function of latitude and longitude for the HSSWS that reached the Earth on 9 January, 2003. The temperature in the day before the event is taken as a "zero" and in the other plots is the difference between the temperature for the day and this "zero" day. The temperature in East Europe increases and on 13 January the warm air spreads over most of the European continent, except for the Mediterranean where the temperature decreases significantly from 12 January. On 15 January the warm wave from Europe reaches the west part of Asia. For the studied period in the central and east parts of Asia the temperature decreases. The same trend is observed in the central and east parts of South America.

This event represents the first case of HSSWSs – with positive NAO index in the day of the event. The plots for the other two studied cases – 8 December and 20 December 2003, are similar to these presented here.

In Fig. 3 is plotted the same color coded temperature difference for the HSSWS on 28 January 2004. For the first three days the surface air temperature in the Mediterranean decreases. On 31 January (the NAO index reaches -1.17) the temperature in west Europe starts increasing and this quickly spreads over the whole continent by the end of the studied period. On 4 February the NAO index reaches a positive value of 0.81. In the east parts of North America the temperature increases and stays that way until the end of the period.

According to Hurrell (2002) positive NAO index leads to low pressure anomalies in the Icelandic region and high pressure anomalies across the subtropical Atlantic which means anomalous northerly flow across western Greenland, Canadian Arctic and the Mediterranean. This decreases the temperature in the east parts of North America, Greenland and the Mediterranean and increases the temperature in Europe and parts of Asia. The present research confirms this particular temperature pattern in short term time scale, while Hurrell made his conclusions using monthly averaged data.

Seppälä et al. (2009) conclude that geomagnetic activity may play a role in modulating wintertime surface air temperatures. They found different winter surface air temperature patterns in years with high and low geomagnetic activity, with the differences similar to the differences between positive and negative NAM index. The difference in the NAM index between the two cases is positive and statistically significant. They commented that the resemblance of the surface air temperature patterns in the Northern hemisphere to the typical cell-like NAM pattern may indicate a common mechanism between the NAM and the temperature changes induced by geomagnetic variations.

The research of Seppälä et al. (2009) was made for low annular average solar radio flux at 10.7 cm (F10.7) which is typical for the solar cycle minimum phase. Richardson et al. (2000) estimated that 70% of the geomagnetic activity in solar cycle minimum phase is due to HSSWSs. So, the main drivers of geomagnetic activity in the research of Seppälä et al. are HSSWSs.

The presented here study follows the changes in NAM as a result of HSSWSs and supports the hypothesis that the effect of the streams modify the atmospheric circulation as characterized by the NAM and the NAO index, and as a result the temperature pattern is changed.

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