Northern Annular Mode Effects on the Land Surface Phenologies of Northern Eurasia

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OVERVIEW

Land surface phenology (LSP) is the spatio-temporal development of the vegetated land surface as revealed by synoptic sensors. Modeling LSP across Northern Eurasia reveals the magnitude, significance, and spatial pattern of the influence of the Northern Annular Mode. Here we fit simple LSP models to two Normalized Difference Vegetation Index (NDVI) datasets and calculate the Spearman rank correlations to link the start of the observed growing season (SOS) and the timing of the peak NDVI with the North Atlantic Oscillation (NAO) and Arctic Oscillation (AO) indices. We investigate the relationships between the Northern Annular Mode and weather station data, accumulated precipitation derived from the CPC Merged Analysis of Precipitation (CMAP) dataset, accumulated growing degree-days (AGDD) derived from the NCEP/DOE II Reanalysis and the number of snow days from the NSIDC.

NORTHERN ANNULAR MODE, NAO & AO

A significant global surface warming trend has been observed over the last 100 years with especially increased warming over the last 50 years (Trenberth et al., 2007). It is estimated that almost half the pronounced recent trend in winter temperature since 1935 (north of 20°N) is due to atmospheric circulation changes (Hurrell, 1996, Serreze et al., 2000).

In addition, the upward trend in the North Atlantic Oscillation over the last 30 years accounts for a large portion of the increase in surface winter temperature in Europe and Asia (north of 40°N, Hurrell, 1996, Hurrell and van Loon, 1997, Thompson et al., 2000, Hurrell et al., 2003).

A mode of climate variability with extensive effects in the Northern Hemisphere, is the Northern Annular Mode (NAM; Thompson and Wallace, 2001), which also goes by the name of the North Atlantic Oscillation (NAO; Hurrell, 1995) or the Arctic Oscillation (AO; Thompson and Wallace, 1998). Wallace and Thompson (2001) describe the Northern Annular Mode as "a planetary-scale pattern of climate variability characterized by an out-of-phase relation or seesaw in the strength of the zonal flow along ~55º and 35ºN and accompanied by displacements of atmospheric mass between the Arctic basin and the mid-latitudes centers ~45ºN."

High values of NAO and AO are associated with warmer and wetter winters, especially in North and Central Europe. The NAO index has been shown to resolve more than 30% of the winter temperature variance in the Northern Hemisphere above 20°N (Hurrell, 1996, Hurrell and van Loon, 1997, Cook et al., 2005). Since the mid-1960s there has been a positive trend in the NAO values which is linked to winter warming over Europe (Cook et al., 2005). In addition, both NAO and AO have been shown to influence strongly the recent warming over Eurasia (Thompson and Wallace, 1998). Atmospheric circulation also plays an important role in snow cover variability. For example, it has been shown that NAO has strong influences on Eurasian winter snow cover (Ogi et al., 2004, Hall et al., 2004). Snow cover and vegetation represent complementary integrated responses of temperature and precipitation in the winter (snow cover) and the remaining part of the year (vegetation).

In addition to forcing meteorological variables such as temperature and precipitation, NAO (AO) has also been linked with interannual vegetation variability as observed by NDVI magnitude (Buermann et al., 2003; Gong and Shi, 2003) and start of season as observed by NDVI (Stöckli and Vidale, 2004). Buermann et al. (2003) demonstrated that the Arctic Oscillation is the main driver for interannual variability in the Northern Hemisphere greenness and that under high AO, warmer and greener spring conditions prevail in Europe and Asian Russia.

Gong and Shi (2003) reported that the nine most important climate indices (including NAO and AO) explain more than half of the interannual variability in NDVI magnitude. Stöckli and Vidale (2004) linked NAO to phenological measurements of averaged regions around Europe and Western Russia. They found strong correlations between winter weather (temperature and precipitation) anomalies and NAO, but only fairly weak correlations ($r^2 = 0.46$) between NAO and start of season.

Under the umbrella of a NEESPI (Northern Eurasian Earth Science Partnership Initiative) project, we investigate the effect of these planetary-scale atmospheric oscillations on land surface phenologies across northern Eurasia.

This study differs from previous studies in three important aspects:

(1) it investigates the correlation between NAO/AO and land surface phenology timings (as opposed to NDVI magnitude),

(2) it focuses on the patterns based on a pixel-by-pixel approach, and

(3) it focuses on Northern Eurasia as a whole, rather than only on the western part of the region.

We examine the magnitude, significance, and spatial pattern of the influences of the NAM on LSPs across Northern Eurasia through analysis of the NAO and AO indices. Based on the new technique of moving-window quadratic models, we determine two characteristics of LSP metrics: (1) the timing of the start of the observed growing season as measured in days of the year, and (2) the timing of the peak of the growing season as measured in accumulated growing degree-days (AGDD). We use Spearman rank correlations to link the fields of LSP model parameter estimates with the NAO and AO indices.

DATA USED

- NCEP-DOE Reanalysis 2 Surface Air Temperature Data (Kanamitsu et al., 2002)
- CPC Merged Analysis of Precipitation (CMAP) Data (Xie and Arkin 1997)
- Northern hemisphere EASE-Grid weekly snow cover (Armstrong and Brodzik, 2005)
- Pathfinder AVHRR Land (PAL) NDVI dataset (James and Kalluri, 1994)
- Global Inventory Monitoring and Modeling Systems (GIMMS) NDVI dataset (Tucker et al. 2005)
- NOAA Climate Prediction Center NAO and AO indices (www.cdc.noaa.gov)
- Global ecoregions of the World Wildlife Fund (Olson et al., 2001).

METHODS USED

I. Basic LSP model in the quadratic form (de Beurs and Henebry 2004, 2005a,2005b,2008):

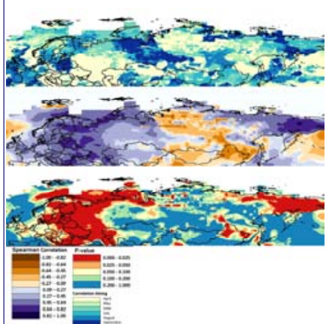
$$NDVI = \alpha + \beta AGDD + \gamma AGDD^2$$

where AGDD are accumulated growing degree-days from 01JAN using a base of 0 °C. Intercept (α) gives NDVI at the start of the observed growing season (SOS). Slope (β) and quadratic parameters (γ) together determine the green-up period, defined as the amount of AGDD (°C) necessary to reach the peak NDVI as follows: *peak position* = $-\beta/2\gamma$.

We fit LSP models for each of the 12 selected years separately (1982-1988 and 1995-1999).

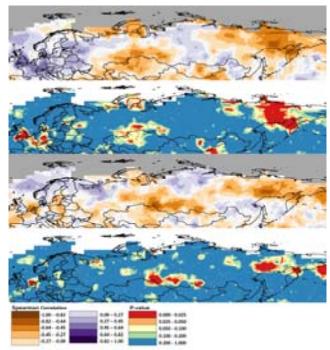
II. We calculate the non-parametric Spearman (rank) correlations and their p-values between LSP SOS, peak position, accumulated precipitation, AGDD measures, and snow days, on the one hand, and the North Atlantic Oscillation (NAO) and Arctic Oscillation (AO), on the other.

NAM EFFECT ON TEMPERATURE



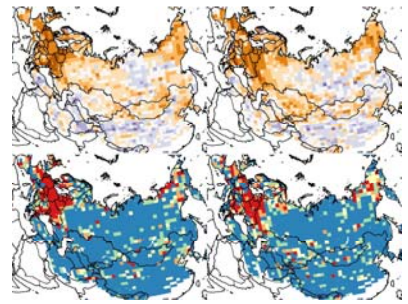
Top panel: The timing of the maximum rank correlation between NAO DJF and AGDD (from the second half of April through the end of September) from NCEP Reanalysis data. Center panel: the magnitude of the maximum rank correlation; Bottom panel: the p-value of the maximum rank correlation. Spatial resolution: 1.875° × 1.91° lat/lon.

NAM EFFECT ON PRECIPITATION



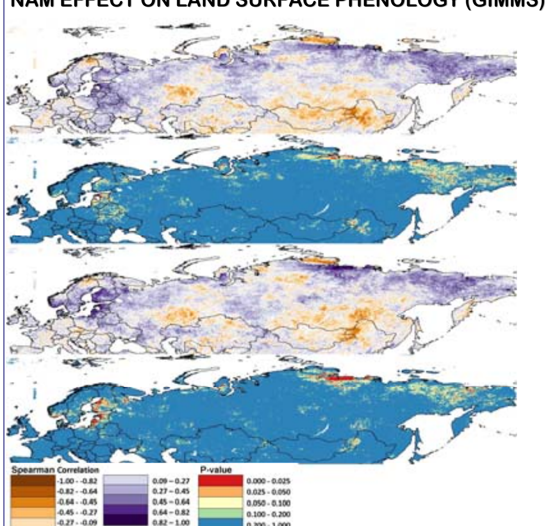
Rank correlation and corresponding p-values between winter NAO and accumulated precipitation data for April (top panel pair) and August (bottom panel pair) from CMAP. Spatial resolution: 2.5° × 2.5° lat /lon.

NAM EFFECT ON SNOW COVER



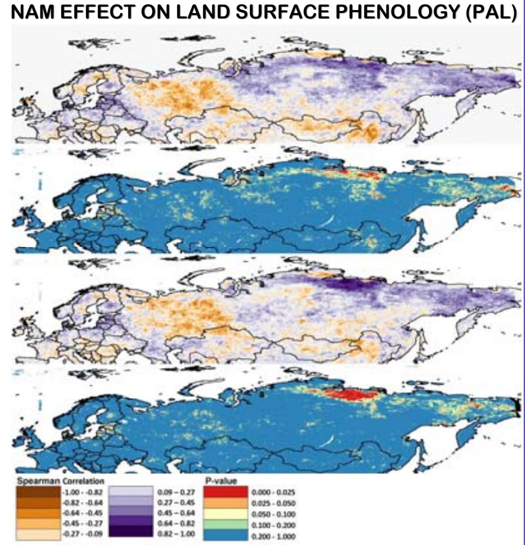
Left top panel: Rank correlation between the number of snow days and NAO DJF. Left bottom panel: the corresponding p-values. Right panels show the rank correlation between the last snow day and NAO DJF. Data from NSIDC. Spatial resolution: 25km × 25km.

NAM EFFECT ON LAND SURFACE PHENOLOGY (GIMMS)



Rank correlation between GIMMS peak position and winter NAO (top panel pair) and winter AO (bottom panel pair). Spatial resolution: 8km × 8km.

NAM EFFECT ON LAND SURFACE PHENOLOGY (PAL)



Rank correlation between PAL peak position and winter NAO (top panel pair) and winter AO (bottom panel pair). Spatial resolution: 8km × 8km.

FINDINGS

- There is widespread influence of the NAM on the land surface phenologies across Northern Eurasia affecting 200-300 Mha.
- There is a significant response of vegetation timing to NAO and AO in Northeastern Russia. This regional response is not as well documented as the European advancement of vegetation in response to NAO and AO. Its appearance supports the NAM paradigm that emphasizes the circumpolar aspect of the AO over the more Euro-centric perspective of the NAO.
- The tundra ecoregions were especially impacted with significant results for about a quarter of the biome.
- The influence of the AO was also extensive (> 130 Mha) for the boreal forests. AO appears to affect the Asian part of northern Eurasia more strongly than NAO, especially for the NDVI peak position as a function of AGDD.
- In general, NAO and AO are considered to emphasize different aspects of the Northern Annular Mode. In this study we found that for vegetation, NAO correlates more strongly with the start of season estimates, while AO correlates more strongly with the peak position.
- The results for both PAL and GIMMS datasets are very similar for the peak position, but the models yield large interannual variability in SOS (data not shown here). Thus, we conclude that peak position might be a more robust aspect of land surface phenology than SOS to link vegetation dynamics to regional and global climate change.
- This research is presented more fully in a paper to appear in *Journal of Climate* (de Beurs and Henebry 2008).

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