Delayed impact of the North Atlantic Oscillation on biosphere productivity in Asia

Guiling Wang
Department of Civil and Environmental Engineering, University of Connecticut, Storrs, Connecticut, USA

Liangzhi You
The International Food Policy Research Institute, Washington, DC, USA

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[1] This study examines the relationship between the North Atlantic Oscillation (NAO) and vegetation productivity in Asia inferred from both provincial crop yields data in China and satellite-derived Normalized Difference Vegetation Index data. Our finding suggests that vegetation productivity in northern Asia during the main growing season correlates significantly to NAO, with a surprising long delay of 1.5 years. Correlation at shorter time lags, which was the focus of previous studies, is weak and not significant between the NAO index and vegetation activities in Asia. This suggests the existence of a so-far unrecognized mechanism that carries the NAO signal for multiple years. The lagged vegetation response also provides the potential for NAO to serve as a predictor for crop yields in China. INDEX TERMS: 0315 Atmospheric Composition and Structure: Biosphere/atmosphere interactions; 1615 Global Change: Biogeochemical processes (4805); 1630 Global Change: Impact phenomena; 1833 Hydrology: Hydroclimatology; 1851 Hydrology: Plant ecology. Citation: Wang, G., and L. You (2004), Delayed impact of the North Atlantic Oscillation on biosphere productivity in Asia, Geophys. Res. Lett., 31, L12210, doi:10.1029/2004GL019766.

1. Introduction

[2] The North Atlantic Oscillation (NAO) refers to an oscillation in the gradient of atmospheric pressure between the high pressure center near the Azores and the low pressure center near Iceland on the Atlantic [Hurrell, 1995, 1996]. NAO and the northern annular mode (NAM) [Thompson and Wallace, 1998], which is a highly zonally symmetric north-south oscillation in atmospheric mass between the polar region and mid-latitudes of the northern hemisphere, may be considered as two paradigms of the same phenomenon [Wallace, 2000]. Through its impact on atmospheric circulation, this oscillation system regulates climate variability in most of the Northern Hemisphere, with a particularly strong impact over Eurasia in winter [Hurrell, 1995, 1996]. During the positive phase of NAO, the pressure gradient between the Icelandic low and the Azores high is larger than normal, causing both the cyclonic and anti-cyclonic winds to become stronger than normal. This leads to enhanced mid-latitude westerly winds across the North Atlantic that brings with it the mild air from the ocean, causing warmer winters downwind in Europe and part of North Asia. During the negative phase of NAO these anomalies reverse.

[3] As the biosphere responds to climate variations, the NAO signal propagates into both marine and terrestrial ecosystems, causing widespread NAO-related flora and fauna patterns [Straile and Adrian, 2000; Thompson and Ollason, 2001; Attrill and Power, 2002; Beaugrand et al., 2002; Lucht et al., 2002]. Although the NAO-related temperature pattern extends far eastward into northern Asia [Visbeck et al., 2001], few ecological responses in Asia have been documented. Recently, several studies analyzed the temporal variability of vegetation activities at the hemispheric scale, thus shedding lights on the response of terrestrial biosphere in Asia to NAO [Los et al., 2001; Russell and Wallace, 2004; Buermann et al., 2003; Gong and Shi, 2003]. However, because NAO has been considered primarily as an atmospheric phenomenon with little persistence, these studies typically focused on either the concurrent season or the season(s) immediately following the NAO anomalies. Based on the current notion of the NAO phenomenon, a time lag longer than a few months in vegetation response is neither expected nor easily explained. In this study we will show that the vegetation response time in Asia is even longer, at a surprising 18 months. Here we investigate the impact of NAO on the productivity of vegetation in Asia at various time lags, and with a special focus on the primary growing season when things matter the most. We infer vegetation productivity from both the yearly crop yield data from China and the satellite-derived monthly Normalized Difference Vegetation Index (NDVI). NDVI is a commonly used proxy for leaf area index and productivity.

2. Data and Methodology

[4] The provincial crop yield data was provided by the Chinese Academy of Agricultural Science. It spans the 19-year period 1979–1997, and includes data for seven crops: rice, wheat, maize, sorghum, millet, potato, and soybean. The monthly NDVI data was derived from the Advanced Very High Resolution Radiometer, and provided by the Earth Observing System Data and Information System Distributed Active Archive Center at NASA’s Goddard Space Flight Center. It spans the period 1982–2000, and covers the globe with a 1-degree spatial resolution.

[5] There are several commonly used indices for the phase and polarity of NAO. These include the PC-based NAO index derived using principal component analysis of the sea level pressure field north of 20°N over the Atlantic sector, and the station-based NAO index derived from the
3. Results

[9] The relationship between yearly crop yields and the NAO index in the immediately preceding winter (i.e., with NAO leading crop activities by a few months) is not significant in all provinces of China. It is the criteria 2) and 3) that are violated here. While the correlation based on raw data is significant, detrending the data destroyed the correlation. This indicates that a spurious correlation was caused by the presence of a secular trend in both time series. This statement holds for all seven types of crops we have data for.

[10] However, we found a significant correlation between the yield of several grain crops and the NAO index when increasing the time lag by one year, i.e., when the crop yield is paired with the winter NAO index of the previous year (Figure 1). For example, the crop yields of 1997 are linked with the NAO index during the extended winter of 1996 (defined as December 1995 through March 1996). This means that NAO leads crop activities by approximately 18 months depending on the growing season of individual crops. Figure 1 indicates that the positive phase of NAO favors several crops in China during the second growing season following NAO anomalies. These crops include maize, millet, sorghum, and wheat. It is clear from Figure 1 that the delayed crop response is limited to the provinces in northern China. Although this south-north contrast is consistent with the fact that climate variability in northern Asia is related to NAO, documented climate responses take place in the same winter as the NAO anomalies or in the subsequent spring [Hurrell, 1995, 1996; Wang and Schimel, 2003]. The long-lagged correlation may suggest the existence of a so-far unrecognized mechanism in the climate system that carries multiple year memory about the NAO signal.

Figure 1. Correlation coefficients between winter NAO index and crop yields in China provinces based on raw data (a, c, e, g) and based on detrended data (b, d, f, and h), with a time lag of approximately 1.5 years. The crops include maize (a and b), sorghum (c and d), millet (e and f), and wheat (g and h). The 5% significance level for the correlation coefficient corresponds to 0.39. See color version of this figure in the HTML.
[11] The significant NAO-crop association in Figure 1 spans majority of the main producing area of China. During the period 1979–1997, more than 70% of China’s maize production comes from provinces where our analysis indicates a significant link between NAO and maize yield. This number is more than 75% for sorghum, and about 60% for millet. For wheat, the three provinces of significant correlation (Jilin, Liaoning, and Inner Mongolia) cover the main growing area of spring wheat. Winter wheat, with a growing season approximately from October to May, does not seem to respond to NAO. Note that in northern China, the approximate growing season is from June to September for maize, from June to October for both millet and sorghum, and from March to October for spring wheat. The common growing season among the crops that do respond to NAO is from summer to early fall.

[12] Two regions of significant correlation between NAO and NDVI are identified, and the correlation coefficients are positive for both. One is the west Europe where a response to NAO is found in NDVI of the concurrent winter and the subsequent spring (February–May) and diminishes after May (Figure 2). This is expected since concurrent and slightly lagged warming in that region was linked to NAO. The NAO-induced warming enhances vegetation growth and causes early snow melting, both contributing to higher NDVI in early spring [Myneni et al., 1997; Zhou et al., 2001]. Note that at this time lag, the NAO signal is not significant in Asia.

[13] The other region includes northern Africa and a large part of Asia, where the NAO signal is detected in the NDVI data during the second growing season following the winter of NAO anomalies (Figure 3). The correlation is spatially coherent and temporally persistent, lasting from July to October. On average, vegetation productivity lags NAO by approximately 18 months. This region of significant correlation in northern Asia covers the Northeast and North China Plains, the main producing areas of China where crop yields are linked to NAO at approximately the same time lag (Figure 1). In contrast, the relationship between the NAO index and NDVI in the immediately following growing season (corresponding to an approximate time lag of 6 months) is very weak and not significant. This lack of correlation at shorter time lags is consistent with the results from the crop data.

[14] To further establish the case of a lagged relationship between NDVI and the NAO, in Figure 4 we present the correlation coefficients between the NAO anomaly in each winter (from December of year -1 to March of year 0) and the NDVI index in each month of year 0, year 1, and year 2 averaged over an example area in Asia. Here years -1, 0, 1 and 2 refer to the previous, current, first subsequent and second subsequent years relative to the time of the NAO anomaly, respectively. It is clear from Figure 4 that the peak correlation occurs during year 1, from July to October, with a time lag of ~18 months. Correlation at other time lags is much weaker and not significant.

[15] Comparing the NAO-crop relationship and the NAO-NDVI relationship identifies three common characteristics. First, the time lag between the NAO index and NDVI is approximately the same as that between the NAO index and crop yield. Second, the time of significant NAO association identified from the NDVI data (i.e., July–October) cover most of the growing season of the crops for which our crop data establishes a delayed response to NAO. Third, the region of significant NAO-NDVI correlation in Asia covers the northern China where crop yield data suggests a response of crop productivity to NAO. These three factors together suggest that the crop yield data from China and the satellite NDVI data are consistent. They both indicate a significant response of vegetation productivity in Asia to the NAO system with a time delay of one and half years. The lack of a discernable secular trend in the NDVI data and its presence in the crop yield data may arise from possible changes of the crop carbon allocation favoring reproduction as a result of the increasing use of fertilizers.

4. Discussions

[16] In the past, NAO has been considered primarily as an atmospheric phenomenon, and its impact on climate vari-
ability takes place primarily during the concurrent winter. The significant response of vegetation productivity in Asia to NAO with a delay as long as 1.5 years is therefore very intriguing. According to the NDVI data, this lagged response in vegetation is widespread across North Africa and Asia, indicating that the lasting memory may reside in some large scale forcing. One suspect is the ocean. From Figure 3 it seems that the strong NAO-NDVI correlation kicks off near Siberia in July off the Arctic coast. We therefore speculate that the Arctic Ocean may play a role.

Another important pathway is through carbon and nutrient cycling that responds to NAO-induced climate anomalies. Biochemical responses to climate are able to cause a lagged correlation between ecosystem productivity and climate variability at the global scale [Schimel et al., 1996; Braswell et al., 1997].

Regardless what the underlying mechanism may be, the delayed vegetation response to NAO has significant implications scientifically and beyond. Studies linking carbon dynamics to modes of atmospheric circulation [e.g., Russell and Wallace, 2004; Reichenau and Esser, 2003] should take into account this delayed response in carbon assimilation. The impact of NAO on flora works up the food web and may lead to some so-far unidentified or unexplained fauna patterns in Asia. In addition, the relationship documented here provides the potential for the NAO index to serve as a predictor for long-range forecast of several grain crops yields in China. However, there are past examples where a correlation varies significantly with time [Wang, 2003]. As always, the application of a correlation for prediction purpose should take with caution.

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