Using 20 years of AVHRR data to assess the impact of the North Atlantic Oscillation on European vegetation

Célia Gouveia [a,b,]*, Ricardo M. Trigo[b] and Carlos C. DaCamara[b,c]

[a] Escola Superior de Tecnologia, Instituto Politécnico de Setúbal, Campus do IPS, Estefanilha, Setúbal, Portugal – cgouveia@est.ips.pt
[b] Centro de Geofísica da Universidade de Lisboa, Ed. C8, Campo Grande, 1749-016 Lisboa, Portugal
[c]Instituto de Meteorologia, Rua C ao Aeroporto, 1749-077, Lisboa, Portugal – carlos.dacamara@meteo.pt

Abstract –We use Normalized Difference Vegetation Index (NDVI) retrieved between 1982 and 2001 from the AVHRR instrument. The year-to-year variations of vegetation greenness in Europe were estimated and related the North Atlantic Oscillation - NAO. Here, we intend to show the sequence of intermediate relevant physical mechanisms responsible for the changes induced in vegetation by the NAO. Therefore, upper level atmospheric circulation and surface climatic impacts were assessed by computing maps of correlation coefficient between NAO and a number of suitable meteorological variables. The most relevant results observed are obtained for the winter-spring seasons, where the positive phase of winter NAO signal is associated with positive temperature anomalies throughout most of northern Europe while it is associated with negative precipitation anomalies in the western Mediterranean. Naturally, these conditions favor (hinder) vegetation growth above (below) normal green vegetation cover conditions over large regions of northern Europe (Iberia and Northern Africa).

Keywords: Land cover types, NDVI, NAO, climate variability, correlation.

1. INTRODUCTION

Over the last 25 years, the temperature of northern latitudes has risen by 0.8 ºC, with a longer active growing season as a consequence of an early spring and delayed autumn and, consequently an increase on photosynthetic activity of vegetation, detectable by changes in NDVI. These changes have been shown to be related with changes in near surface climatic variables such as land surface temperature for vegetated areas (Myneni et al., 1995, Zhow et al., 2001). Associated with this high latitude warming it a significant reduction in annual snow cover has been detected, induced by an early disappearance of snow in spring. These changes have affected the global carbon cycle, but there is no evidence that increases in the atmospheric concentration of CO2 are responsible for the increases in NDVI described above (Kaufmann et al., 2002).

This study analyses the relation between satellite-based measures of vegetation greenness and climate over European region. For this purpose, we use the NDVI, retrieved between 1982 and 2001 from the AVHRR instrument (Pathfinder data set). The effects of orbital drift and sensor changes on channel 1 and 2 reflectances and NDVI from the PAL data set were recently investigated and based on theoretical and statistical analyses it has been concluded that this data was not corrupted significantly by these effects (Kaufmann et al., 2000). The year-to-year variations of vegetation greenness in both northern and southern European sectors were estimated and related to the dominant mode of climate variability in the northern hemisphere, namely the North Atlantic Oscillation - NAO. Therefore, atmospheric circulation and climatic impacts were assessed by computing maps of correlation coefficients between NAO and different variables, namely low tropospheric temperature and geopotential height as well as land surface air temperature, radiation, evaporation, precipitation and soil moisture.

A significant influence of NAO, associated to spatial patterns of variation of different climatic fields, on the NDVI in the European North Atlantic region was found. The most outstanding results were found for spring and autumn seasons. Baltic Sea area and Central Europe are the regions presenting maximum response for spring patterns, whereas the Black Sea area reveals a maximum response for other seasons. It was also found that during the springtime period, spatio-temporal structures of vegetation activity at the hemispheric scale are highly correlated with overlying patterns of surface temperature, downward radiation flux and evaporation rate.

2. DATA AND METHODS

We used the monthly Normalized Difference Vegetation Index (NDVI) data set at 8-km resolution from Pathfinder Advanced very High Resolution Radiometer (AVHRR) Land Data provided by NASA Earth Science Enterprise. The data for Eurasian and North Atlantic regions cover the area between 15 W to 50 E and 30N to 70 N and respect to the 20-year long period from 1982 to 2001.

The NDVI data captures the contrast between red and near-infrared reflection of solar radiation by vegetation that is indicative of the amount of green leaf area. (Myneni et al, 1995). It has been shown that the NDVI related to the amount of energy absorbed by leaf pigments such as chlorophyll and therefore is closely correlated with the fraction of photosynthetically active radiation absorbed by plant canopies, leaf area, leaf biomass and potential photosynthesis (Asrar et al., 1984; Myneni et al, 1995).

This data set (NDVI) is particularly useful for studies of temporal and interannual behaviour of surface vegetation and for developing surface background characteristics for use in climate modeling. Monthly and seasonal anomalies were computed for NDVI and the seasonal composites were obtained for the standard seasons: Winter (DJF), Spring (MAM), Summer (JJA) and Fall (SON). We computed a grid point correlation between seasonal anomalies of NDVI and NAO for the 20 year study period 1982 to 2001. Many studies have shown some temporal delay in the relationship between NDVI and meteorological data, namely precipitation, soil moisture and temperature (Lei Ji et al 2004, Lotsch et al 2003, Di et al 1994, Buermann et al 2003).

All meteorological data used in this study are large-scale gridded data retrieved from the National Centers for Environmental Prediction (NCEP/NCAR) Reanalysis data sets for the period 1982-2001. The Reanalysis data were derived through a consistent assimilation and forecast model procedure that incorporated all available weather and satellite information. Monthly values of SLP, 500 hPa geopotencial height, precipitation and evaporation rates, trophosferic and 850 hPa temperatures, downward radiation flux, net long wave radiation, specific humidity and soil were extracted for the NCEP 2.5º latitude by 2.5º longitude grid, for the area 30-70º N, 15º W-50º E. Monthly and seasonal averages were obtained for the same seasons previously described for NDVI. Monthly and seasonal anomalies were computed for all these variables.

Taking into account the predominance of the NAO pattern during the boreal winter, we computed grid point correlations between NAO and large scale atmospheric data (2.5º lat by 2.5º lon). Following the approach of Buermann et al. (2003), we have also performed grid point correlations between the NAO index and the NDVI anomaly values (8km by 8km) using contemporaneous (non lagged) and lagged values. The advantage of this type of analysis is related to the capacity of highlighting any potential spatial patterns of direct and/or precedent correlations between the NAO and meteorological (MET) or NDVI anomalies (Buermann et al., 2003). However, unlike these authors we found interesting non lagged correlation values for autumn and spring. Therefore, in this work we limited the amount of graphics and analyses to the best results, respecting to the following combinations:

I. NAO(DJF) – MET(DJF).
II. NAO(JFM) – NDVI(MAM)
III. NAO (MAM) – NDVI(MAM)
IV. NAO(JJA) – NDVI (JJA)
V. NAO(SON) - NDVI(SON)

In order to estimate the statistical significance for these correlation values, we assume that each season represents an independent event within a Gaussian distribution. For the 20 year study period under consideration, this result in 18 degrees of freedom with corresponding 95% significance levels of 0.44 and 99% significance levels of 0.56, based on a two tailed t-test statistics (Wilks, 1995).

3. RESULTS

Spatial patterns of simple correlations between the NAO index and NDVI anomalies for the selected area and for the 1982-2001 period are presented in Fig. 1. Correlation analysis shows positive correlations values over Central Europe for combinations II and III (spring), more pronounced for II.

The region with the highest positive correlation (range between 0.6 and 0.8) may be observed around the Baltic countries. For these maps, the largest negative correlations are located over the southwestern Iberian Peninsula and northwestern Africa, with values around –0.5, However, it is over Iceland that the strongest negative correlation values may be observed, with some pixels presenting values near –0.8.

An interesting spatial pattern is found over the Iberian Peninsula, with positive correlations (~ 0.4) scattered near the French border and along Mediterranean coast and negative correlations (~ -0.5) clustered in the southwest. These patterns for spring are similar to those recently obtained by other authors (e.g. Vicente-Serrano and Heredia-Laclaustra, 2004; Buermann et al., 2003) but with higher correlations values, namely in Baltic countries. Furthermore, dipolar pattern in Iberian Peninsula and negative correlations in Iceland were not identified in that study.

The pattern for combination III shows lower correlations throughout the European continent, but with still significant negative (positive) values over Russia (Poland, Ukraine).

The pattern obtained for combination IV (summer) shows the highest negative correlations values (-0.5) over central Europe, north-western France, Great Britain, Denmark, Sweden and Adriatic countries. The highest positive correlations values is found in south-eastern Iberian Peninsula, north-western Africa, Norway and the countries in west part of Caspian Sea. Again it is possible to identify a dipolar pattern over the Iberian Peninsula, but with swapped signs relatively to those found in spring, i.e. with positive correlations in south and east parts and negative correlations in north and west parts. This pattern is also similar to the pattern found by Buermann et al. (2003), but with lower correlations in Central Europe and northern countries of Black Sea (see Fig. 4). On the other hand, they have not found significant correlations in the Iberian Peninsula.

Another interesting spatial pattern is found for combination V (autumn), where the highest negative correlation values are located over land around the Black Sea, Iberian Peninsula and Northeastern Scandinavia, with particularly significant values ranging from –0.5 to –0.8.

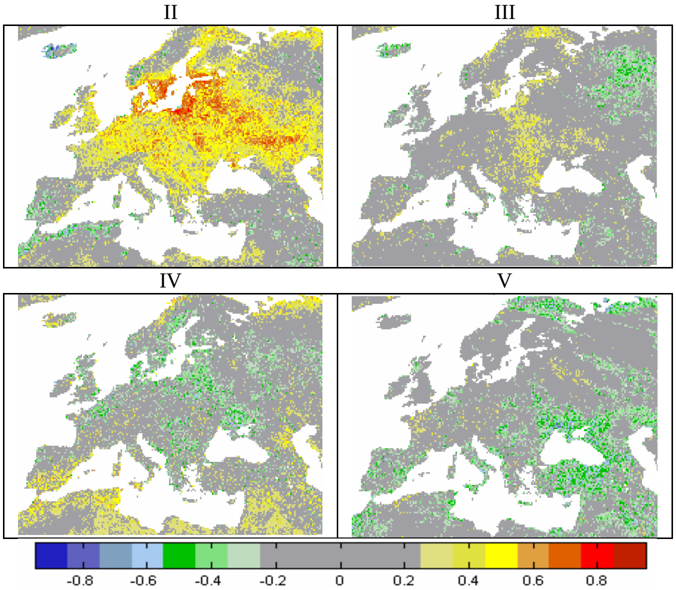

Figure 1. Patterns of simple correlation between three months average of North Atlantic Oscillation (NAO) and NDVI anomalies, for the period of 1981-2000 and for combinations II, III, IV and V.

Then we computed correlation patterns between seasonal averages of the NAO index and corresponding averages of relevant fields, namely: surface temperature, 1000 hPa geopotential height, downward radiation flux, net long wave radiation, evaporation and precipitation rates, specific humidity. Note that for panels in Fig. 2 we only present the grid point correlations for combinations I, II and IV. However, taking into consideration the different nature of the impact of NAO on “water-related” variables, we also present the grid point correlations for combinations I, III and V (Fig. 3). Generally speaking, temperature, potential evaporation and precipitation rate, soil moisture and specific humidity figures show a dipolar pattern with maximum positive (negative) correlation values located over Northern Europe (Southern Europe and North Africa) (Figs. 2a, 2e, 3a, 3b e 3c). A dipole pattern, but with swapped dipole signals may be found for the 1000 hPa geopotencial height, downward radiation flux and net long wave radiation (Figs. 2b, 2c and 2d).

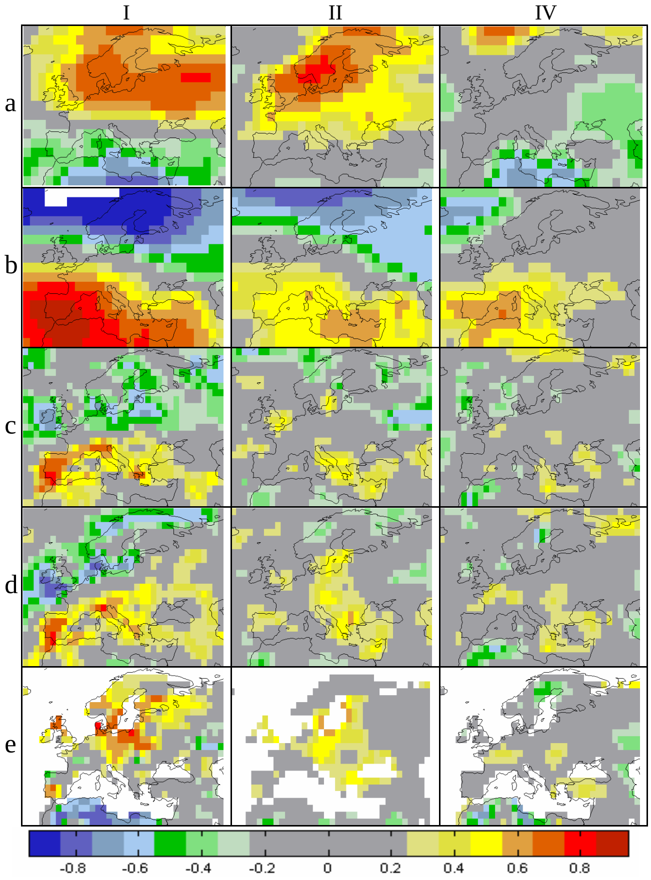

Figure 2. Patterns of simple correlation between three month average for the period of 1981-2000 and for combinations I, II and IV of North Atlantic Oscillation (NAO) and a) seasonal temperature; b) 1000 hPa geopotencial height; c) downward radiation flux ; d) downward net long wave radiation and e) potential evaporation rate.

It is now widely accepted that the NAO influences the European temperature field mostly by advection of heat by anomalous mean flow (Trigo et al., 2002). Several studies confirm that the NAO controls the storm track along the North Atlantic area and namely during the negative phase, where a more southerly track is found, bringing more clouds to the southern Europe (Trigo et al., 2004). During the positive phase a reduction of the cloud cover occurs in this area, which corresponds to an increase of net long wave radiation, at the same time there is an increase of cloud cover over central Europe (Trigo et al, 2002, 2004). During the negative phase of NAO the increase of clouds over the southern Europe, corresponds to an increase of net of short wave radiation. As the evaporation rate depends strongly on latent heat and air speed, it is possible to see some similarities between this variable and temperature and net long wave radiation (Fig. 2e).

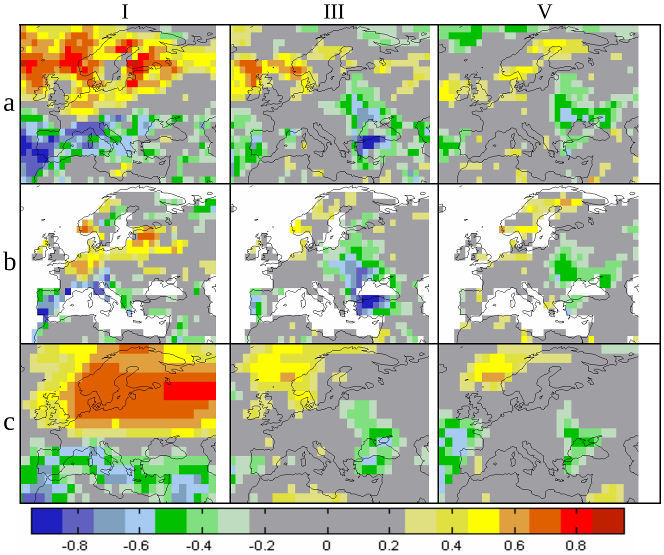

Figure 3. Patterns of simple correlation between three months average for the period of 1981-2000 for combinations I, III and V of North Atlantic Oscillation (NAO) and a) precipitation rate; b) soil moisture and c) specific humidity.

Recent studies have shown that the positive phase of the NAO index in spring implies an increase of temperature and of net long wave radiation which implies an increase in potential evaporation rate, a reduction of snow depth and an increase in vegetation production (e.g. Buermann et al., 2003, Vicente-Serrano and Heredia-Laclaustra, 2004). Nevertheless, this increase in vegetation production will only happen when there is enough water to allow vegetation activity and photosynthetic process. Otherwise, thermal increase will have negative consequences on vegetation production due the more stressful water conditions (Vicente-Serrano and Heredia-Laclaustra, 2004). Therefore, in areas where the correlation values between NDVI and NAO are higher (e.g. Baltic Countries and Sweden) correspond to regions where the influence of the NAO pattern in “water-related” variables is not so relevant.

Finally, for summer and autumn seasons it is possible to observe that during the positive phase of NAO there is a reduction in precipitation (and “water-related” variables) that implies a reduction in vegetation greenness, namely in the areas where the radiation and evaporation are higher, i.e., countries around the Black Sea.

Next we investigated how the upper-air patterns associated with this mode of hemispheric-scale climate variability are related to the low level temperature and geopotencial height. The spatial patterns of simple correlation between seasonal temperature anomaly at 850 hPa level and geopotencial height at 500 hPa and seasonal averages of the NAO index are presented in Fig. 4 for combinations I (4a) and II (4b). As seen before, warmer (cooler) surface conditions are associated with positive (negative) height anomalies (Figs. 2a and 2b), indicating that there is an equivalent barotropic structure to the overlying atmosphere (Thompson and Wallace, 2000). Several studies have shown that additional linkages between the upper-air teleconnection features and surface temperature signatures are associated with changes in storm tracks, surface fluxes, baroclinic wave activities and blocking patterns (Trigo et al., 2002). As seen in Fig. 4 the patterns are not so intense and the pattern for spring is very similar to the NDVI pattern. Hence it appears that the upper-air teleconnections patterns provide a bridge between remote forcing fields and the surface temperature and NDVI fields.

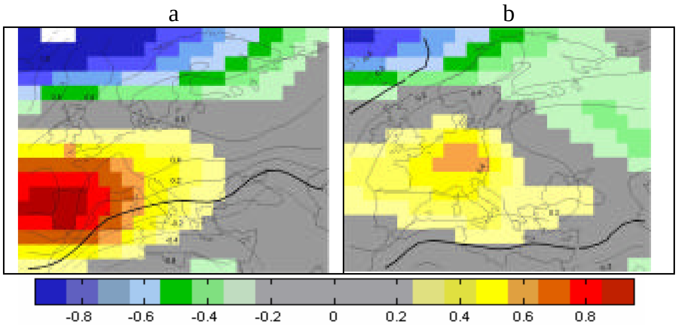

Fig. 4. Patterns of simple correlation between seasonal 850 hPa temperature 500 hPa geopotencial height and NAO anomalies for the period of 1982-2001 and combinations I (a) and II (b). The filled colour contour represents the correlation for 500 hPa geopotencial height and the contour lines represent the 850 hPa temperature. Bold line represents the null correlation and dashed lines the negative correlations.

The spatial patterns of simple correlation between the seasonal meteorological field anomalies and seasonal averages of the NAO, demonstrate the dominant influence of the NAO on surface variables that are key parameters for vegetation growth. The correlation patterns between the NAO index and NDVI anomalies are consistent with the patterns between the NAO index and meteorological field anomalies. These patterns are spatially more coherent in the spring period, when warm temperature, highest net long wave radiation, highest evaporation rate and less snow deep in Eurasia are linked to enhanced greenness, associated with the positive phase of NAO. In contrast, the decline in greenness in Central Europe during the summer is probably a result of reduced summer and spring time precipitation and specific humidity associated with the positive phase of NAO.

5. CONCLUSIONS

A significant influence of the NAO on the NDVI in the European North Atlantic region was found in this study. The NAO associated spatial patterns of variation of different meteorological fields were also identified. These spatial patterns present a dipolar structure at the European scale, resembling the NAO-precipitation and NAO-temperature spatial patterns (Trigo et al., 2002). For winter patterns the areas having maximum response are the Iberian Peninsula, the Northern British Isles, the Scandinavia area and the Baltic Sea area. For spring patterns the areas having maximum response are the Baltic Sea area and Central Europe. For the remaining seasons the area that presents maximum response is confined to the Black Sea.

It is found that during the critical springtime period, spatio-temporal structures in hemispheric scale vegetation activity are highly correlated with overlying patterns of surface temperature, downward radiation flux, evaporation rate. The results also indicate that hemispheric-scale upper-air circulation patterns associated with NAO are partly responsible for the correlation between year to year changes in spring greenness in the north. During the positive phase of NAO, warmer and greener spring conditions prevail in Eurasia. Interestingly over the last two decades the NAO was more often in its positive phase compared to longer historical records (Thompson et al, 2000; Trigo et al., 2002). In addition, this period was also characterised in northern latitude by a more persistent vegetative activity in Eurasia (Zhou et al, 2001).

7. REFERENCES

Asrar,G., Fuchs, M., Kanemasu, E.T., Hatfeld, J.L., 1984. “Estimating absorbed photosynthetic radiation and leaf area index from spectral reflectance in wheat”. Agronomy Journal, v.76, p.300-306,

Buermann, W., Anderson, B., Tucker, C. J., Dickinson, R. E., Lucht, W., Potter, C. S., and Myneni,R. B., 2003. “Interannual covariability in Northern Hemisphere air temperatures and greenness associated with El Niño-southern oscillation and the Arctic Oscillation”. J. Geophys. Res. 108 D13, doi: 10.1029/2002JD002630.

Di, L., Rundquist D. C., and Han, L., 1994. “Modeling relationships between NDVI and precipitation during vegetation growth cycles”. Int. J. Remote Sens., vol. 15, no. 10, pp. 2121-2136.

Dong, J., Kaufmann, R.K., Myneni, R.B., Tucker, C.J., Kauppi, P.E., Liski, J., Buermann, W., Alexeyev, V. & Hughes, M.K., 2003. “Remote sensing estimates of boreal and temperate forest woody biomass: carbon pools, sources, and sinks”. Remote Sensing of Environment 84(3): 393-410.

Lei Ji; Peters, A.J. , 2004. “Forecasting vegetation greenness with satellite and climate data”. Geoscience and Remote Sensing Letters, IEEE,Volume: 1, Issue: 1, Jan. 2004 Pages:3 – 6

Lotsch,A., Y. Tian, M.A. Friedl, and R.B. Myneni., 2003. “Land cover mapping in support of LAI/FPAR retrievals from EOS-MODIS and MISR: Classification methods and sensitivities to errors”. Int. J. Remote Sensing. 24, 1997-2016.

Myneni, R. B., F. G. Hall, P. J. Sellers, and A. L. Marshak, 1995 “The interpretation of spectral vegetation indexes,” IEEE Trans. Geosci. Remote Sensing, vol. 33, pp. 481-496, Mar.

Thompson, David W. J. and Wallace, J. M., 2000. “Annular Modes in the Extratropical Circulation. Part I: Month-to-Month Variability”, Journal of Climate: Vol. 13, No. 5, pp. 1000–1016

Trigo R.M., Osborn T.J., Corte-Real J.M., 2002. “The North Atlantic Oscillation influence on Europe: climate impacts and associated physical mechanisms”. Climate Research, 20, 9-17.

Trigo R.M., Pozo-Vazquez D., Osborn T.J, Castro-Diez Y., Gámis-Fortis S., Esteban-Parra M.J. 2004. “North Atlantic Oscillation influence on precipitation, river flow and water resources in the Iberian Peninsula”. Int. J. Climatology. 24, 925-944.

Vicente-Serrano, S. M. and Heredia-Laclaustra, A, 2004. “NAO influence on NDVI trends in the Iberian peninsula (1982-2000)”. Int. J. of Remote Sensing. Volume 25, Number 14 / July 20,pp. 2871 – 2879

Zhou, L., Tucker, C.J., Kaufmann, R. K., Slayback, D., Shabanov, N.V., & Myneni, R. Bl, 2001. “Variations in northern vegetation activity inferred from satellite data of vegetation index during 1981 to 1999”. J. Geophys. Res., 106(D17): 20069-2008

Wilks, D. S., 1995. “Statistical Methods in Atmospheric Sciences”. Academic Press.