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Changes in land surface temperatures and NDVI values over Europe between 1982 and 1999

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Abstract

We used land surface temperature (LST) algorithms and NDVI values to estimate changes in vegetation in the European continent between 1982 and 1999 from the Pathfinder AVHRR Land (PAL) dataset. These two parameters are monitored through HANTS (Harmonic ANalysis of Time Series) software, which allows the simultaneous observation of mean value, first harmonic amplitude and phase behaviors in the same image. These results for each complete year of data show the effect of volcanic aerosols and orbital drift on PAL data. Comparison of time series of HANTS cloud-free time series with the original time series for various land cover proves that this software is useful for LST analysis, although primarily designed for NDVI applications. Comparison of yearly averages of HANTS LST over the whole Europe with air temperature confirms the validity of the results. Maps of the evolution for both parameters between periods 1982/1986 and 1995/1999 have been elaborated: NDVI data show the well confirmed trend of increase over Europe (up to 0.1 in NDVI), Southern Europe seeing a decrease in NDVI (−0.02). LST averages stay stable or slightly decrease (up to −1.5 K) over the whole continent, except for southern areas for which the increase is up to 2.5 K. These results evidence that arid and semi-arid areas of Southern Europe have become more arid, the rest of Europe seeing an increase in its wood land proportion, while seasonal amplitude in Northern Europe has decreased.

Keywords: NDVI; LST; Europe; Pathfinder AVHRR Land dataset; HANTS

1. Introduction

NDVI data collected by AVHRR sensor, aboard NOAA satellites, have been widely used to study vegetation answer to global warning (Bogaert et al., 2002; Myneni et al., 1997; Tucker et al., 2001; Zhou et al., 2003; Zhou et al., 2001), principally through GIMMS (Global Inventory Mapping and Monitoring Studies) dataset. The preference of GIMMS dataset over Pathfinder AVHRR Land (PAL) database is due on one hand to the correction of volcano aerosols (Vermote & El Saleous, 1994) emitted by El Chichón from March to April 1982 and Mount Pinatubo in June 1991, and on the other hand to the correction of the dependence to solar zenith angles (Pinzon et al., 2004). Nevertheless, the authors used PAL images for this work, since GIMMS dataset is limited to NDVI data, while PAL images contain NDVI images as well as reflectances and radiometric temperatures, from which land surface temperature (LST) can be retrieved (Sobrino & Raissouni, 2000).

The PAL dataset used in this present work is composed of 10-day composite images. NDVI values during each 10-day period are used for the compositing technique, called Maximum Value Composition (MVC). This technique consists in selecting the highest value of NDVI during each 10-day period for each pixel, which removes most of the cloudy pixels (Holben, 1986). PAL dataset is corrected from atmospheric effects using a Rayleigh correction following the work of Gordon et al. (1988), including a correction for ozone absorption, following McPeters et al. (1993). No geometrical correction was applied to PAL dataset, for the reason that illumination and viewing angle data are not available at continental scale.

Since the availability of PAL and GIMMS datasets, NDVI data has been proven useful to detect variations in vegetation activity. Zhou et al. (2001) evidenced a persistent increase in

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NDVI values for most of Eurasia between 1981 and 1999, while North America showed a more fragmented pattern of change. This work also pointed out increases in the length of the growing season over Eurasia (18±4 days) as well as North America (12±5 days). Bogaert et al. (2002) evidenced the greening trend over Eurasia as persistent and spatially extensive and connected, while long-term greening trend over North America was more fragmented spatially, with a mixture of short- and long-term greening trends. Zhou et al. (2003) related statistically these changes mainly to climate, except during winter, for which low significances were obtained. These results confirm also the work of Myneni et al. (1997), which linked this increase in vegetation (between 45 and 70°N) with variations in the seasonal cycle of atmospheric CO_2. Delbart et al. (2005) pointed out that over boreal regions, methods to determine the length of growing season from NDVI values were inaccurate, and that the use of normalized difference water index (NDWI) should be preferred. As regards European continent, Maselli (2004) evidenced NDVI decreases in a protected coastal area in Italy, especially for the coniferous forest in summer and early fall, which were correlated to winter rainfall decreases.

These results obtained by remote sensing methods confirm works carried out at ground level. For example, Ahas et al. (2002) showed advances in spring phases in Western and Central Europe of four weeks between 1951 and 1998, while Eastern Europe spring phases were delayed up to two weeks. The highest advances in spring phases were linked to earlier disappearance of snow cover, while the variations between Eastern and Western Europe trends are explained by a phenological difference. This work left out Fennoscandian regions, for which Tømmervik et al. (2004) identified an increase in forest coverage in detriment of lichen-dominated areas over the period 1960–2000, principally due to intensive grazing by reindeer population in the period 1961–1987, which removed the lichen barrier for germination of birch seeds.

Land surface temperature analyses are more seldom, the research being focused on the determination of the best algorithms for its retrieval. Reviewing the different methods, Qin et al. (2004) evidenced Sobrino et al. (1994) method as the more accurate when additional information (like in situ measurements of total atmospheric water vapor content) was lacking. Han et al. (2004) identified Ulivieri et al. (1994) algorithm as best over Canadian boreal forest. Multitemporal analyses are in their premises, mainly because of the orbital drift effect, which prevents the use of PAL record from applications. This orbital drift effect causes temperatures to decrease steadily during activity periods of the different NOAA satellites (Price, 1991). Short LST time series have been used to relate climatic anomalies (El Niño/La Niña) and forest fires (see Manzo-Delgado et al., 2004).

Joint analyses of LST and NDVI have already been conducted (Nemani & Running, 1997), but only on short periods of time, also because of the orbital drift effect. Nevertheless, joint analysis of NDVI and LST showed to be of great significance, since they facilitate the identification of changes in land occupation and surface conditions (Nemani et al., 1993), by differentiating seasonal changes from changes in land occupation (Nemani & Running, 1997). NDVI and land surface temperature behaviors have also been proven to be partially correlated (Kaufmann et al., 2003): an increase in NDVI values during summer (greater proportion of vegetation) will result in lower land surface temperatures, while higher NDVI values during winter (smaller snow extent) will result in an increase in LST.

This paper aims at evidencing the interest of HANTS (Harmonic ANalysis of Time Series) software for harmonic analysis of LST, and its combined use for LST and NDVI parameters for better detection of changes over the European continent. HANTS software is used here to perform the detection of cloud contaminated pixels, through a harmonic analysis of the time series. This harmonic analysis is carried out after removal of the outliers (identified as cloud-contaminated), which is the main difference of this approach with former similar ones (see for example Sellers et al., 1994). This results in obtaining cloud-free time series without the usual gaps due to the removal of the cloud contaminated pixels identified by different tests (see Cihlar, 1996; Saunders & Kriebel, 1988).

This work is divided into three parts. First, the methodology to obtain land surface temperatures from PAL data is presented, with a brief description of HANTS software, which will be used to conduct a harmonic analysis of NDVI and LST evolution, through the determination of yearly averages and first harmonic amplitudes and phases. Then, NDVI and LST evolutions will be presented, and, in a third part, HANTS performances for LST analysis will be discussed, as far as changes in Europe from 1982 to 1999. In this study, quantitative changes in average values of NDVI and LST might be affected by the already mentioned orbital drift effect, nevertheless they are presented here, as well as first harmonics changes in amplitude and phase. The influence of the orbital drift on amplitude and phase values should be lesser, because the analysis is conducted yearly: this means that evolution related to satellite changes will appear mainly in the yearly average value.

2. Methodology

The algorithms used to estimate land surface temperature are adapted from Sobrino and Raissouni (2000). This estimation is based on the previous determination of emissivities in thermal wavelengths and atmospheric water vapor content. NDVI and LST evolution during the whole extent of PAL database are studied here with the help of HANTS software (Verhoef et al. (1996)), which conducts a yearly harmonic analysis through a previous cloud filtering.

2.1. Land surface temperature

Land surface temperature (T_s) is estimated using the following formula:

$$T_s = T_4 + 1.40 \cdot (T_4 - T_5) + 0.32 \cdot (T_4 - T_5)^2 + 0.83 + (57 - 5W) \cdot (1 - \varepsilon) - (161 - 30W) \cdot \Delta\varepsilon \quad (1)$$