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# Interannual vegetation phenology estimates from global AVHRR measurements Comparison with in situ data and applications

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**Abstract**

In a previous paper, we described a procedure to correct the directional effects in AVHRR reflectance time series. The corrected measurements show much less high frequency variability than their original counterparts, which makes them suitable to study vegetation dynamics. The time series are used here to estimate the start and ending dates of the growing season for 18 years from 1982 to 1999. We focus on the interannual variations of these phenological parameters.

A database of in situ phenology observations is used to quantify the accuracy of the satellite-based estimates. Although based on a limited sampling of the Northern mid and high latitudes, the comparison indicates that i) the satellite phenological product contains meaningful information on interannual onset anomalies; ii) there is a higher degree of consistency over regions covered by Broadleaf Forests, Grasses and cereal Crops than over those covered by Needleleaf Forests or Savannas; and iii) the satellite phenological product is of lower quality in regions with mountainous terrain. In favorable conditions, interannual variations of the onset are captured with an accuracy of a few days.

As this satellite-derived product captures the interannual onset variability at ground-truth sites, we confidently use it to larger scales studies. Mapped at a continental scale, the onset anomalies show coherent patterns at the regional (≈ 1000 km) scale for the mid and high latitudes of the Northern hemisphere, which is consistent with a meteorological forcing. In the tropics, there is larger spatial heterogeneity, which suggests more complex controls of the phenology. The relation between vegetation phenology and climate is further investigated over Europe by comparing the variability of the satellite-derived vegetation onset and that of the winter North Atlantic Oscillation index, at a fine spatial scale. The strong correlations observed confirm that this climate forcing parameter explains most of the onset variability over a large fraction of Northern Europe (earlier onsets for positive winter NAO), with lower impact towards the south and opposite effects around the Mediterranean basin. The NAO has a predictive character as the January–February NAO index is strongly correlated with the vegetation onset that occurs around April in Northern Europe.


*Keywords:* Phenology; Vegetation; AVHRR; North Atlantic Oscillation; Directional effects

## 1. Introduction

Plant phenology studies the timing of different stages of vegetation seasonal cycle (such as leaf unfolding, flower first bloom, leaf fall...) in relation with climatic parameters. This research field has draught an intense interest during the last decade in the context of climate change. In particular, an advance in the date of vegetation onset has been observed in the northern latitudes, which was explained as a response to the temperature rising trend, either using remote sensors (Myneni et al., 1997; Zhou et al., 2001) or in situ stations (Beaubien & Freeland, 2000; Chmielewski & Rötzer, 2001; Menzel & Fabian, 1999; Sparks et al., 2000).

Spaceborne measurements such as those provided by AVHRR (Smith et al., 1997), MODIS (Justice et al., 1998), VEGETATION (Maisongrande et al., 2004) or POLDER (Deschamps et al., 1994), contain significant information to study vegetation at the global scale: its distribution, as well as the annual cycles and interannual variations for the various biomes. In addition to the mean trend over long periods traditionally captured by

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remotely sensed time series, interannual anomalies of vegetation dynamics also contain meaningful information on the response of vegetation to meteorological forcing.

In the nineties, several methodological papers, such as Reed et al. (1994), Moulin et al. (1997), White et al. (1997) and Duchemin et al. (1999) presented phenological parameters derived from AVHRR NDVI data. The validation of these parameters, if any, was limited to very few sites, while their temporal and spatial variations were discussed with regards to biome and climate parameters. A major scientific achievement was attained with Myneni et al. (1997) using AVHRR NDVI data, evidencing a lengthening of the growing season over the northern middle latitudes during the 1981–1991 period, in relation with warmer air temperature. Zhou et al. (2001) extended the study of the growing season length variation to the period 1981–1999 over large continental regions (North America versus Eurasia). Asner et al. (2000) related the seasonal NDVI amplitude on Amazon forest to El Niño events and quantified the corresponding interannual variations in terms of net primary production. A finer spatial resolution dataset (0.1°) was derived over Europe by Stöckli and Vidale (2004), they also correlated the vegetation onset with winter temperatures and winter North Atlantic Oscillation index over broad regions. Lately, an 8 km phenology was derived over Siberia using jointly AVHRR NDVI data and short-wave information from SPOT VEGETATION, for the 1982–1999 period (Delbart et al., 2005), exhibiting a very good correlation with in situ observations of the date of leaf onset. The period was extended to 1982–2004 (Delbart et al., 2006), using a specific NDVI threshold for each pixel to derive the onset. The latter was further correlated with El-Niño Southern Oscillation (Vicente-Serrano et al., 2006).

The present paper extends on these works with the objective of a fine-scale phenology description (8 km) at the global scale. It presents a methodology to derive global phenological parameters (dates of vegetation onset and senescence) from AVHRR reflectance time series with an emphasis on the correction of directional effects in the measurements. The phenology parameters are compared with available ground truth and then used in a specific application that illustrates the vegetation response to meteorological forcing at a regional scale and stresses the accuracy and the quality of the data.

## 2. Satellite data and processing

### 2.1. Data

In this paper, we make use of the 8 km Pathfinder AVHRR Land (PAL) reflectances dataset (Smith et al., 1997) in the red and near infrared channels. The daily reflectance measurements have been screened for cloud or snow contamination, corrected for atmospheric absorption and molecular scattering, and then corrected for directional effects (Bacour et al., 2006). The latter correction makes use of biome specific directional signatures based on the prior analysis of surface anisotropy measurements by the POLDER instrument (Bacour & Bréon, 2005), and using the 1 km land cover map used for the MODIS LAI-fAPAR retrieval algorithm (Knyazikhin et al., 1999).

### 2.2. Temporal interpolation

For each of the 8 km pixels, a smooth curve, a mean seasonal cycle and a trend were extracted from the directionally corrected reflectances data, following a temporal interpolation procedure (Thoning et al., 1989). The latter is already summarized in Bacour et al. (2006) (paragraph 4.1) and is then only briefly described here. Given a radiometric signal of interest, its time variation over the 18 year period is first fitted against a second order polynomial and a fourth-order Fourier function: the former represents a crude long-term trend while the harmonic functions catch the common annual cycle. The residuals of this prior fit are then filtered in the frequency domain by two low pass filters : a first cutoff at 80 days filters the short-terms residuals that are then added to the common annual cycle so as to reproduce each of the seasonal cycle over the 18 year period considered; a second cutoff at 667 days filters the long-terms residuals that are added to the second order polynomial to better track the long-term variations of the time series. A time series is hence modeled by a smooth curve, being the sum of the estimated seasonal cycle and long-term trend. The high frequency left in the residuals is considered as noise.

Based on this temporal interpolation procedure, analysis of the modeled reflectance time series in Bacour et al. (2006) shows that the directional signature correction reduces the high frequency variability (noise) by a factor of nearly 2 for most vegetation surfaces. Moreover, the results indicate that the Difference Vegetation Index (DVI), based on a simple difference between the near infrared and red reflectances, contains more information on the vegetation dynamics (i.e. it has a higher Signal to Noise Ratio) than the more widely used NDVI (Normalized Difference Vegetation Index).

### 2.3. Estimate of onset and senescence dates

Phenological estimates were then inferred from the analysis of the modeled DVI time series between 1982 and 1999, at the global scale. For most pixels, the smooth curve shows a well-defined seasonal cycle that can be used to extract the start and end of the growing season. In our processing, these phenology parameters are defined as the dates when the smooth curve crosses the trend curve upward and downward as shown in Fig. 1. This is equivalent to searching for the zeroes of the de-trended time series. Such technique is similar to the 0.5 threshold for the NDVI ratio in White et al. (1997). A small fraction of pixels show more than two intersects for a given year, in which case they were discarded from further processing. As a result, a global dataset of vegetation onset and senescence dates at 8 km resolution is available for the period January 1982 to December 1999 (year 1981 is not considered further as the vegetation cycle is not complete).

We tested several other methods for the determination of phenology dates from the time series:

- In Moulin et al. (1997), the onset date is defined as the date where the derivative of the NDVI time series goes from a null to a positive value.