Analysis of inter-annual variations of the vegetation phenological state from AVHRR time series. Comparison with modelling results

Fabienne Maignan, Cédric Bacour, François-Marie Bréon

Laboratoire des Sciences du Climat et de l'Environnement, France
Reflectance directional signatures

Reflectance of natural targets varies with the observing geometry

We have used measurements from the POLDER satellite to study the magnitude and variability of the angular signatures

BRDFs can be accurately reproduced by a simple analytical model of the form

\[ R(\theta_s, \theta_v, \varphi) = k_0 + k_1 F_1(\theta_s, \theta_v, \varphi) + k_2 F_2(\theta_s, \theta_v, \varphi) \]
Modeling per biome

The Bidirectional Signature is

$$BS(\theta_s, \theta_v, \varphi) = 1 + \frac{k_1}{k_0} F_1(\theta_s, \theta_v, \varphi) + \frac{k_2}{k_0} F_2(\theta_s, \theta_v, \varphi)$$

Within a given biome, the variability of the directional signature is rather small

We defined “typical” directional signature (i.e. $k_1/k_0$ and $k_2/k_0$) for each biome.
Use Pathfinder AVHRR Land (PAL) time series

Period 1981-1999, daily, 8 km resolution. Geocoded and calibrated data, corrected for molecular scattering and ozone absorption

Focus on channel 1 (visible) and 2 (near IR). Other channels for cloud detection

Pre-processing: Cloud detection, correction for water vapor absorption.
Correction for directional effects

Puts the reflectance measurements in a standard observation geometry

Makes use of the directional signatures derived from POLDER observations (sun at 40°, satellite at nadir)

\[ R_{\text{cor}}(\theta_0, 0, 0) = R_{\text{mes}}(\theta_s, \theta_v, \varphi) \frac{BS(\theta_0, 0, 0)}{BS(\theta_s, \theta_v, \varphi)} \]

The normalized time series show much less high-frequency variability than the original measurements:
NDVI or DVI?

The near-IR channel contains most of the information on the vegetation dynamic.

Visible channel is the most affected by atmospheric effects.

NDVI corrects partially for directional effects, which is one reason for its wide use.

The DVI appears less affected by atmospheric effects.

When an explicit directional correction is available, it appears better than the NDVI (significantly larger signal to noise on the time series).
Analysis of various frequencies in the data provides the trend, the seasonal cycle and a smooth curve. The RMS difference between the measured DVI and the smooth curve is a quantification of the noise. The signal is the amplitude of the seasonal cycle, or the trend, or the inter-annual variations of the smooth curve.
The data processing provides a global view of vegetation dynamic for 19 years. Suitable to analyze inter-annual variations in relation with meteorology or climate forcings. In the following, we focus on the onset of vegetation growth although many other applications are possible.
Vegetation onset

Most vegetated areas show a strong annual cycle of vegetation growth. The dynamic is controlled by temperature, water availability or both.

For a given region, the total Carbon uptake is strongly linked to the date of vegetation onset (earlier \(\rightarrow\) more uptake).

From our DVI time series, we estimate the vegetation onset as the date when the smooth curve crosses the trend upward.

A small fraction of sites have a seasonal cycle not suitable for such procedure (double crosses).
Results over Europe

Onset date (Julian day)

Mean Onset Date
Validation of onset date estimate

Maps of onset date anomalies show **coherent patterns** at the 500-1000 km scale, consistent with meteorological forcing. Since all pixels are processed independently, it is a strong indication that there is **some information in the satellite product**.

Further validation requires comparison with in-situ observations. Difficult task because of:
- In-situ data availability
- Spatial heterogeneity
- Mix of various vegetations with different phenologies

We have found **three valid databases** for the comparison:
- Lilac phenology at many sites over the United-States
- Onset dates of various trees at a few sites in Switzerland
- Phenology of various trees at a few sites in Siberia
Results over United-States

Schwartz, M.D. & Caprio, J.M.
North American Lilac database

Norfolk, Connecticut

no threshold : $\sigma_{S-G} < \sigma_G$ $\sigma_{S-G} > \sigma_G$
SNR threshold: $\sigma_{S-G} < \sigma_G$ $\sigma_{S-G} > \sigma_G$

High correlation between in-situ and satellite derived onset dates.
Results over Switzerland

Using quality thresholds, only green stations are selected:
- more than 75% of them with a good correlation
- all are located in the Swiss plain, none in the Alps

Poor correlation between in-situ and satellite derived onset dates.
Further analysis show a large variability of in-situ observations.
Interpreted as the result of large height variations within short distances
(very heterogeneous pixels)
High correlation between in-situ and satellite derived onset dates.

**Results over Siberia**
Conclusions on validation

The satellite products contain some information on the onset date (not just noise).

It is based on a spatial average over \( \approx 10 \times 10 \text{ km}^2 \) so that a quantitative evaluation against in-situ observation is not possible.

Several sites, in homogenous areas, show an excellent correlation. The standard deviation of the difference between the in-situ and the satellite derived date is a few days (depending on location and vegetation type).
Correlation with NAO over Europe

NAO is the difference of surface pressure between Iceland and Azores. It controls the flow from the Atlantic to Western Europe. There is a strong correlation of winter NAO with Onset Date.

![Map of correlations between Onset dates and NAO index from January to February.](image)

![Graphs showing histograms and cumulative histograms.](image)
The Orchidée vegetation model

The model computes the development of vegetation and the fluxes of energy and mass from the meteorological forcing (temperature, precipitation, radiation)

12 Plant Functional Types (PFT)

Developed at IPSL. [http://orchidee.ipsl.jussieu.fr](http://orchidee.ipsl.jussieu.fr)

We use the LAI as a proxy of the vegetation dynamic

The onset date is selected as the date when the LAI crosses upward the annual mean
DVI and LAI annual cycles (1/4)

Good coherence of model and satellite time series over Siberia
DVI and LAI annual cycles (2/4)

Not that good over UK...
DVI and LAI annual cycles (3/4)

Very poor correlation over Amazonia...
But almost no annual cycle
Poor correlation in areas with limited annual cycle (evergreen forests)
Best over temperate forests
Onset dates based on LAI

We use the same procedure to extract the onset from the LAI time series. A bias may be expected. Is there a proper consistency between the onset derived from the model and that observed from satellite?
A few examples (1/4)

AVHRR ORCHIDEE

[60.0N, 121.0W]
A few examples (2/4)

AVHRR ORCHIDEE

[62.0N, 76.0E]
A few examples (3/4)

AVHRR  ORCHIDEE

[45.0N, 0.0E]
A few examples (4/4)

AVHRR  ORCHIDEE

[19.0S, 52.0W]

68% C4 Grassland
18% Veg Trop Deciduous
10% C4 Cropland

archi: 14.6 days
avhrr: 8.0 days
dif: 14.9 days
Bias: 4.6 days
Sat-Model Global Correlation

Excellent agreement in high latitude regions. Rather poor everywhere else.
Phénologie : dates de sénescence

No agreement on senescence
Conclusions

We suggest a method for the correction of directional effects in low-resolution Earth reflectance measurements.

The application of the method to AVHRR time series provides higher signal to noise observations.

These time series are used to extract the onset of vegetation growth, which is one proxy of the forcing of climate on photosynthesis.

Good coherence with in situ observations over homogeneous areas.

Surprisingly high correlation with NAO over Northern and Eastern Europe.

The Orchidee vegetation model show the same patterns of onset date anomalies in Boreal regions, but not over the rest of the World.

We have evidence several deficiencies in the Orchidee time series.