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

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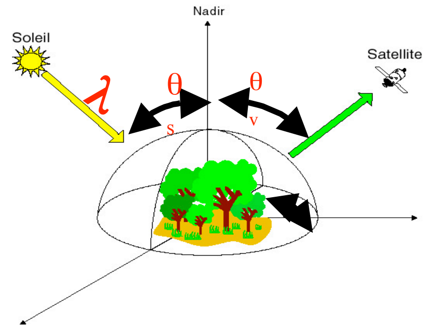
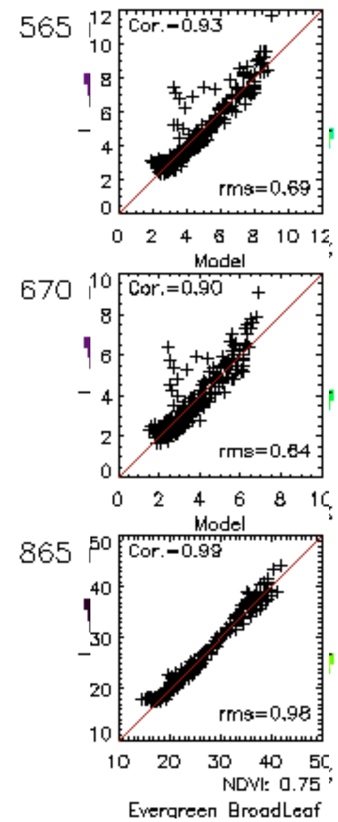
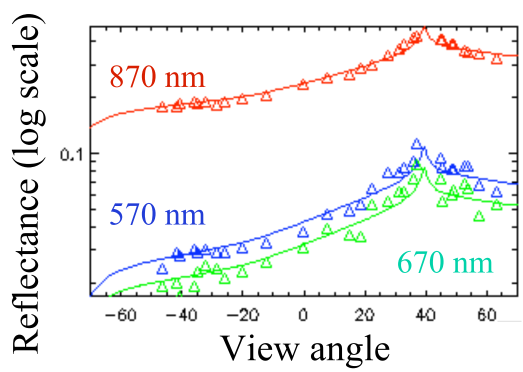
Reflectance directional signatures

- 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





$$R(\theta_s,\theta_v,\varphi) = k_0 + k_1\,F_1(\theta_s,\theta_v,\varphi) + k_2\,F_2(\theta_s,\theta_v,\varphi)$$



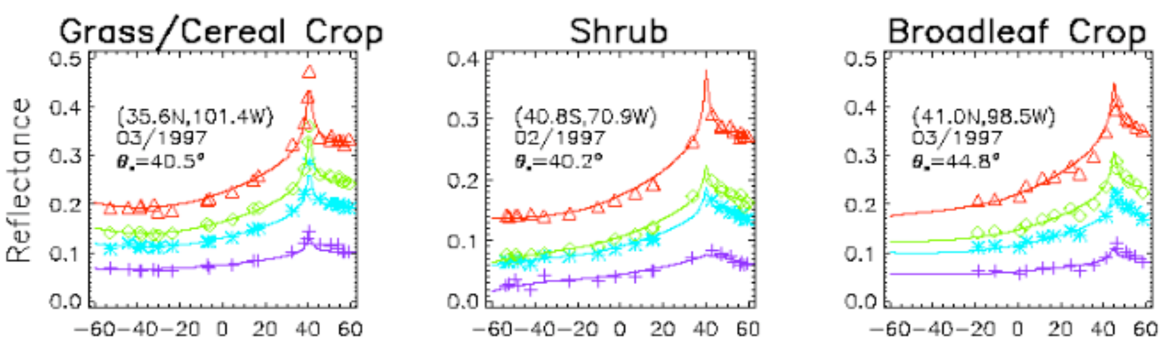
Modeling per biome

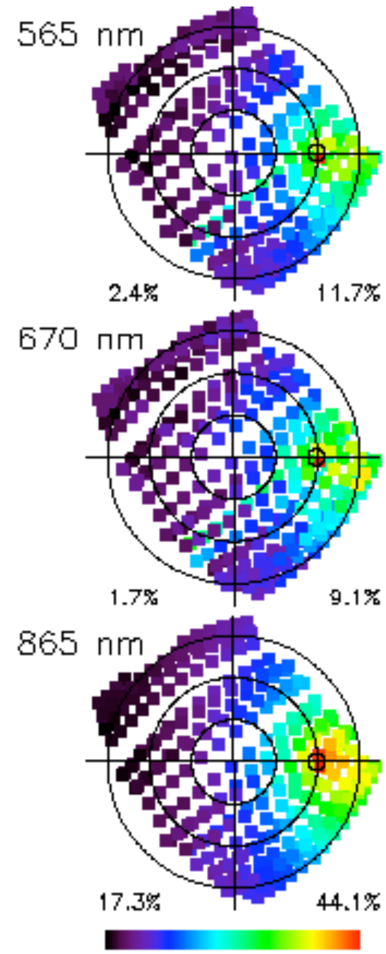
The Bidirectional Signature is

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

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.





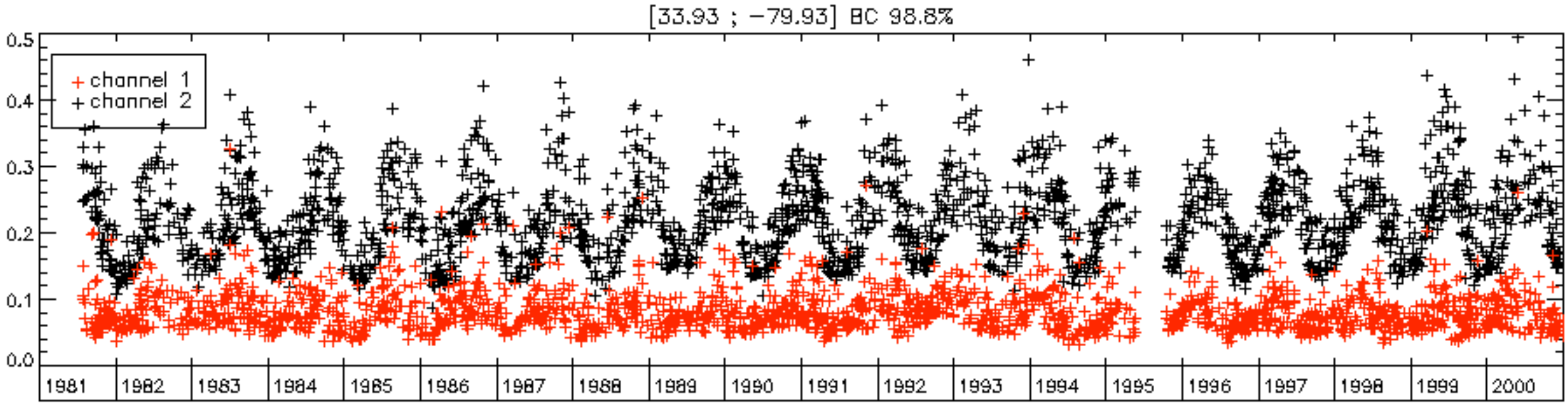
AVHRR time series

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.



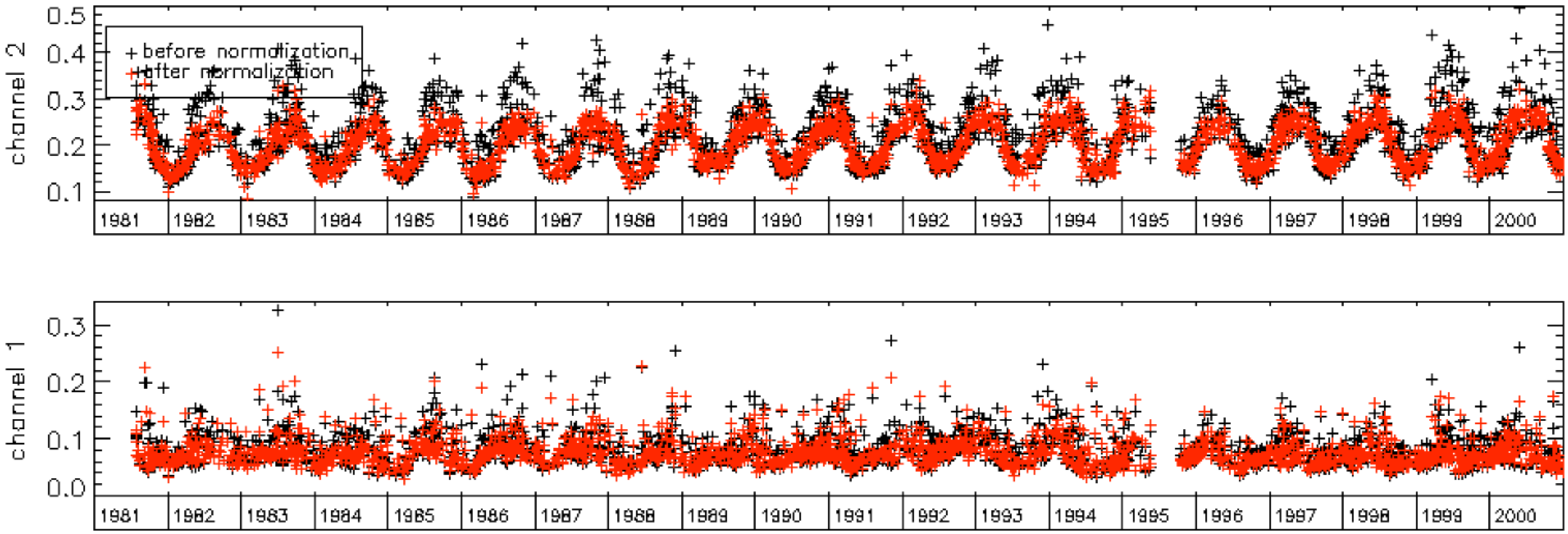
Correction for directional effects

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)

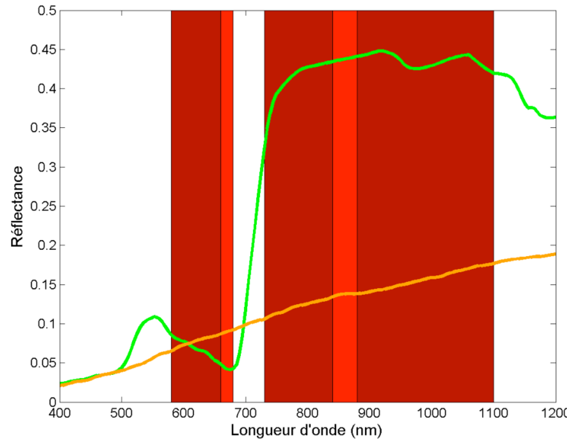
$$R_{cor}(\theta_0,0,0) = R_{mes}(\theta_s,\theta_v,\varphi)\frac{BS(\theta_0,0,0)}{BS(\theta_s,\theta_v,\varphi)}$$

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



NDVI or DVI ?

$$DVI = R_{NearIR} - R_{vis} \qquad NDVI = \frac{R_{NearIR} - R_{vis}}{R_{NearIR} + R_{vis}}$$



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

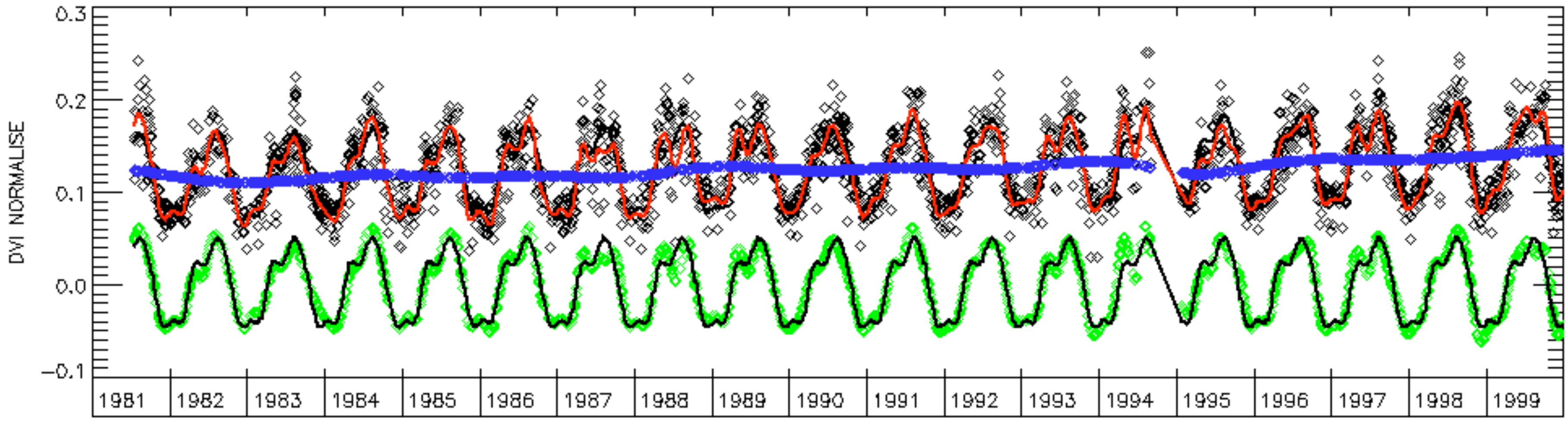
Visible channel is the most affected by atmospheric effects

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)

Smooth curve fit



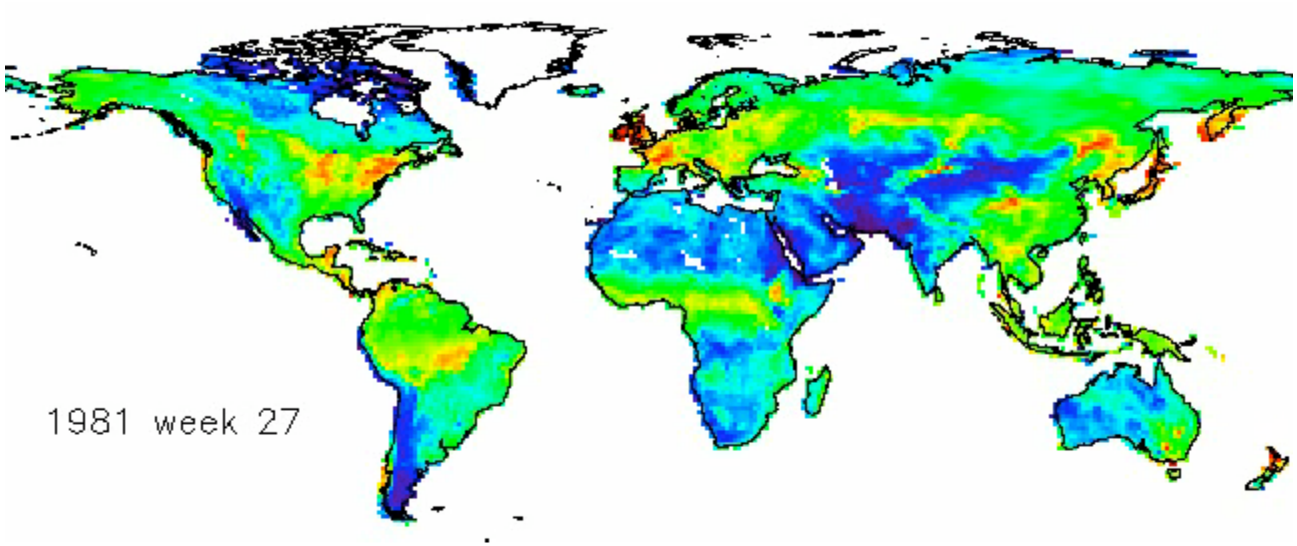
Measured DVI, Trend, Seasonal Cycle, Smoothed Seasonal Cycle, Smooth curve

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

19 years of vegetation dynamic



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

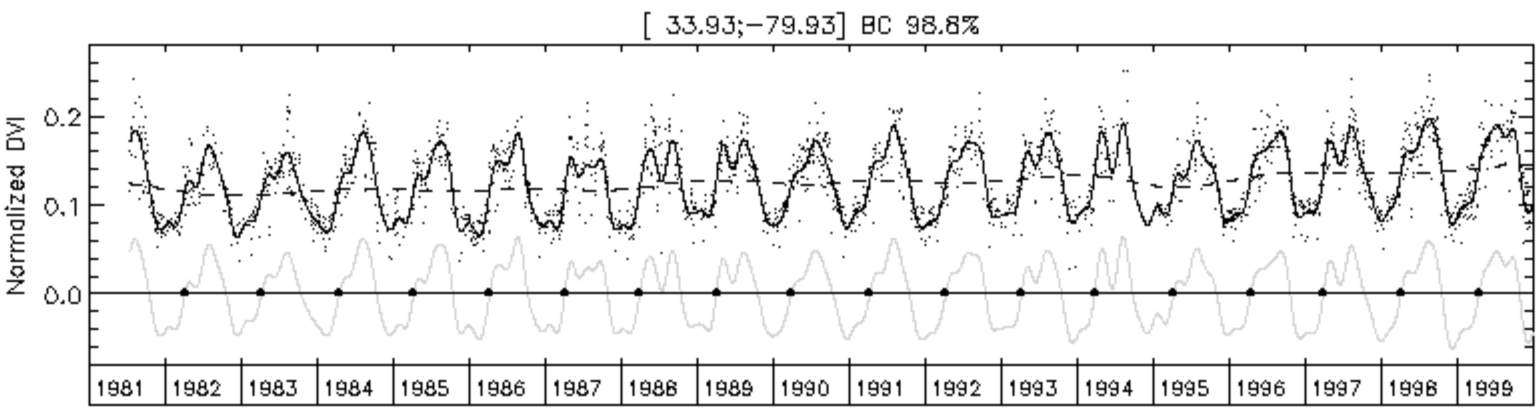
Most vegetated areas show a strong annual cycle of vegetation growth

The dynamic is controlled by temperature, water availability or both.

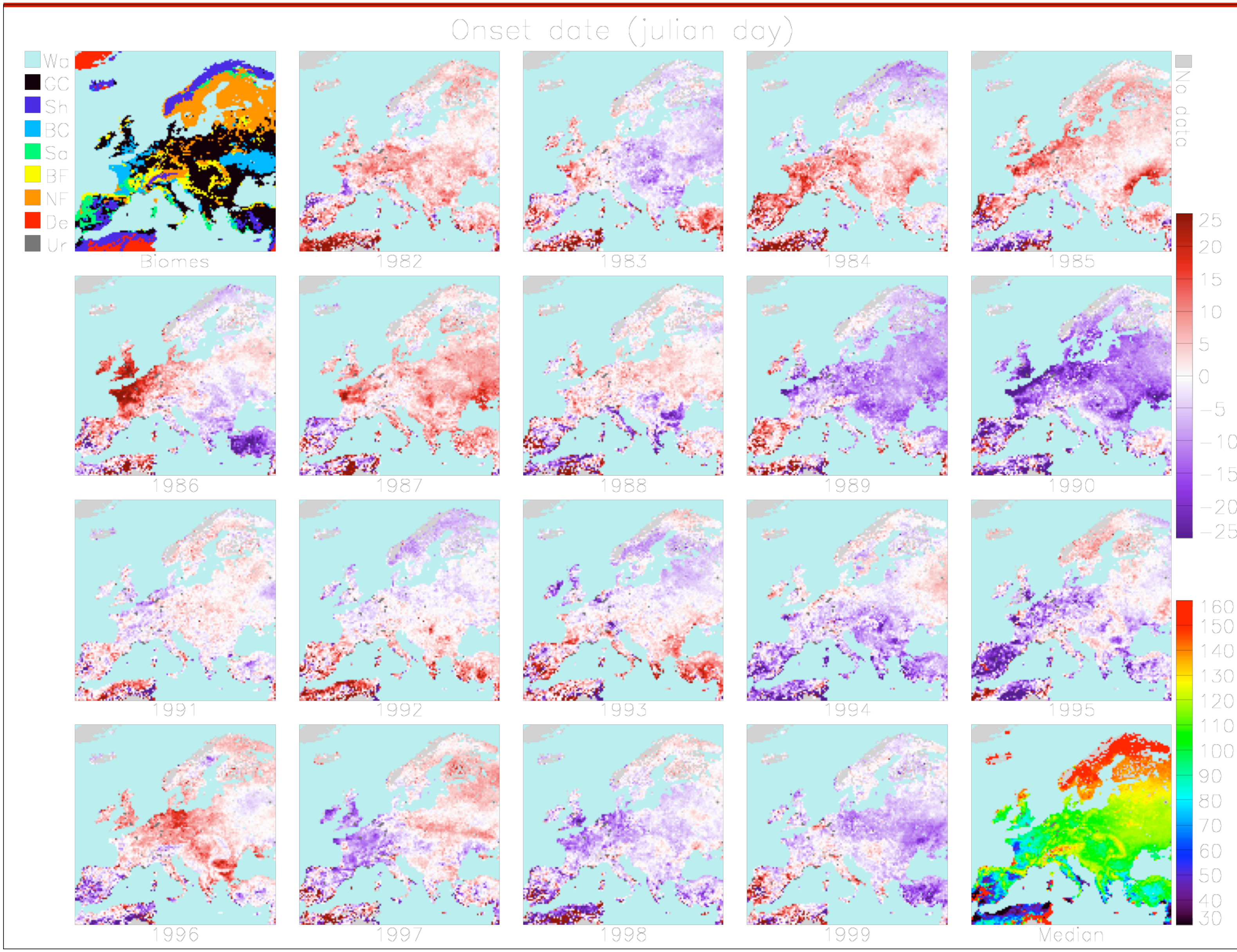
For a given region, the total Carbon uptake is strongly linked to the date of vegetation onset (earlier➔more uptake)

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



+25

0

-25

Anomalies

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

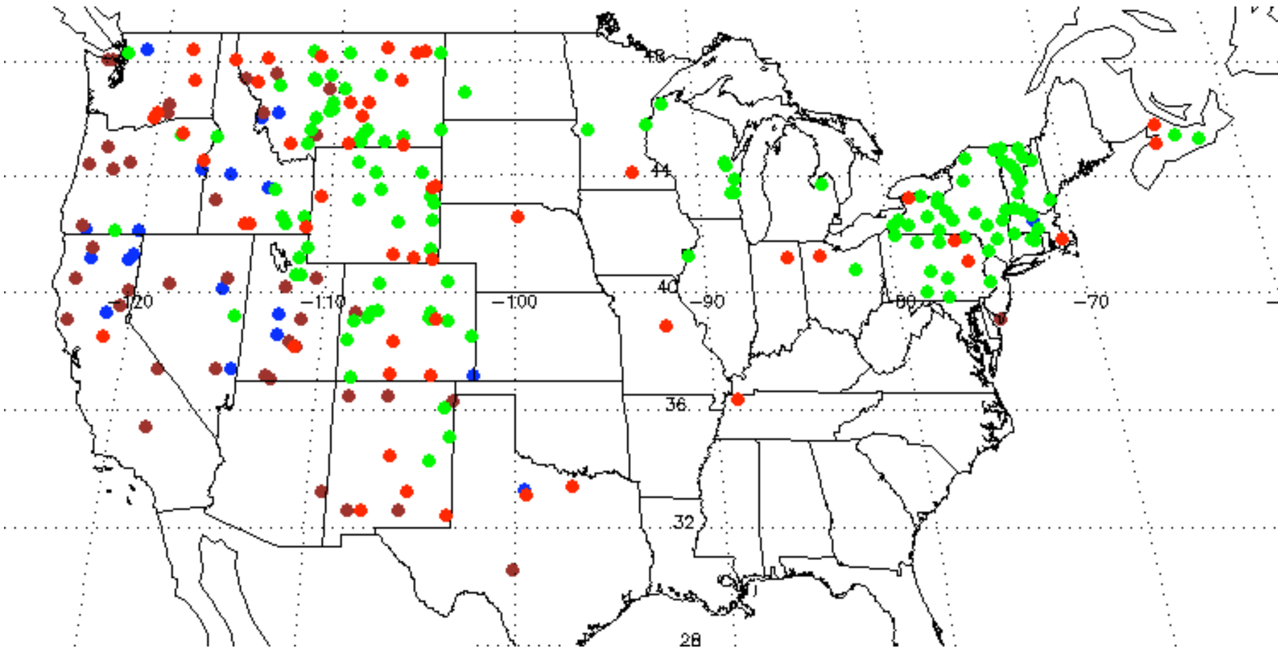
We have found three valid databases for the comparison

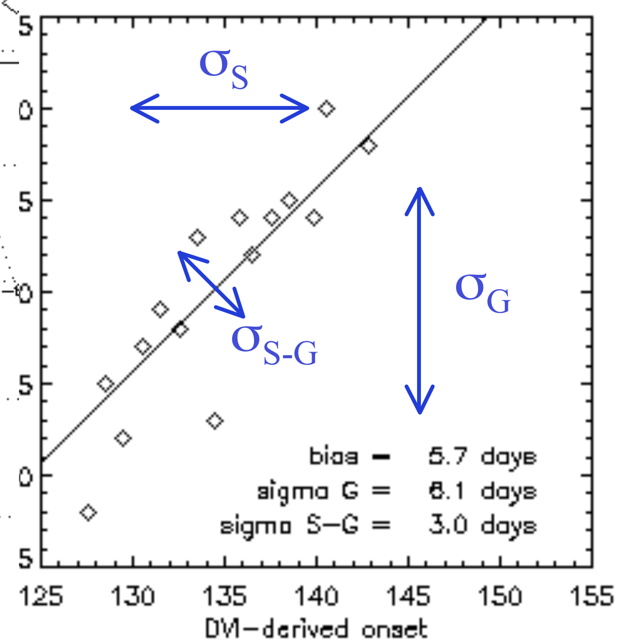
- Lilac phenology at many sites over the United-States
- Onset dates of various trees at a few sites in Switzerland
- Phenology of various trees at a few sites in Siberia

Results over United-States

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

Norfolk, Connecticut



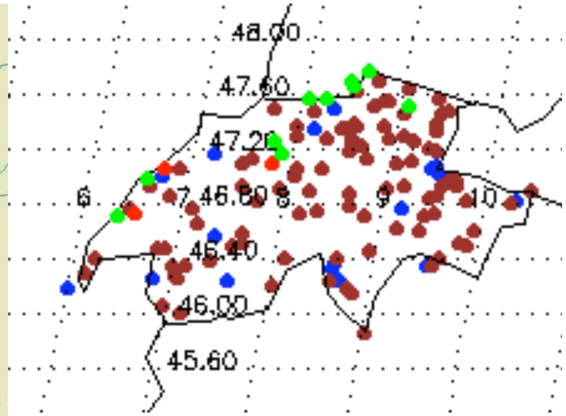


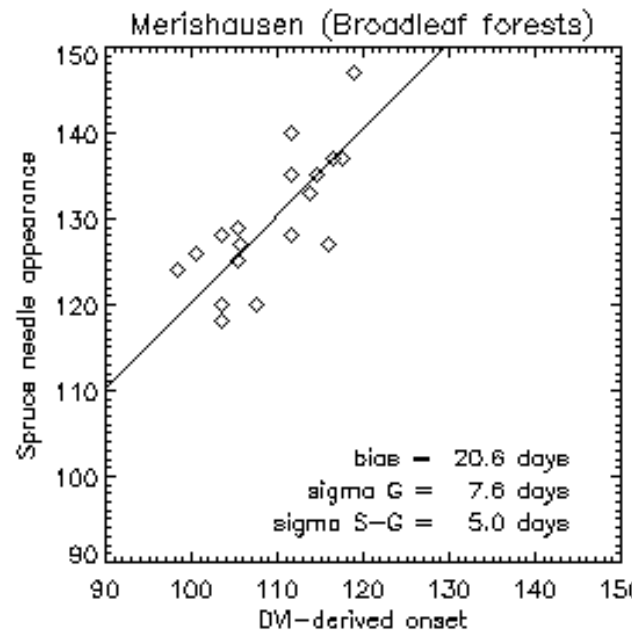
no threshold : $\sigma_{S\text{-}G} < \sigma_G$ $\sigma_{S\text{-}G} > \sigma_G$

SNR threshold: $\sigma_{S\text{-}G} < \sigma_G$ $\sigma_{S\text{-}G} > \sigma_G$

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

Results over Switzerland





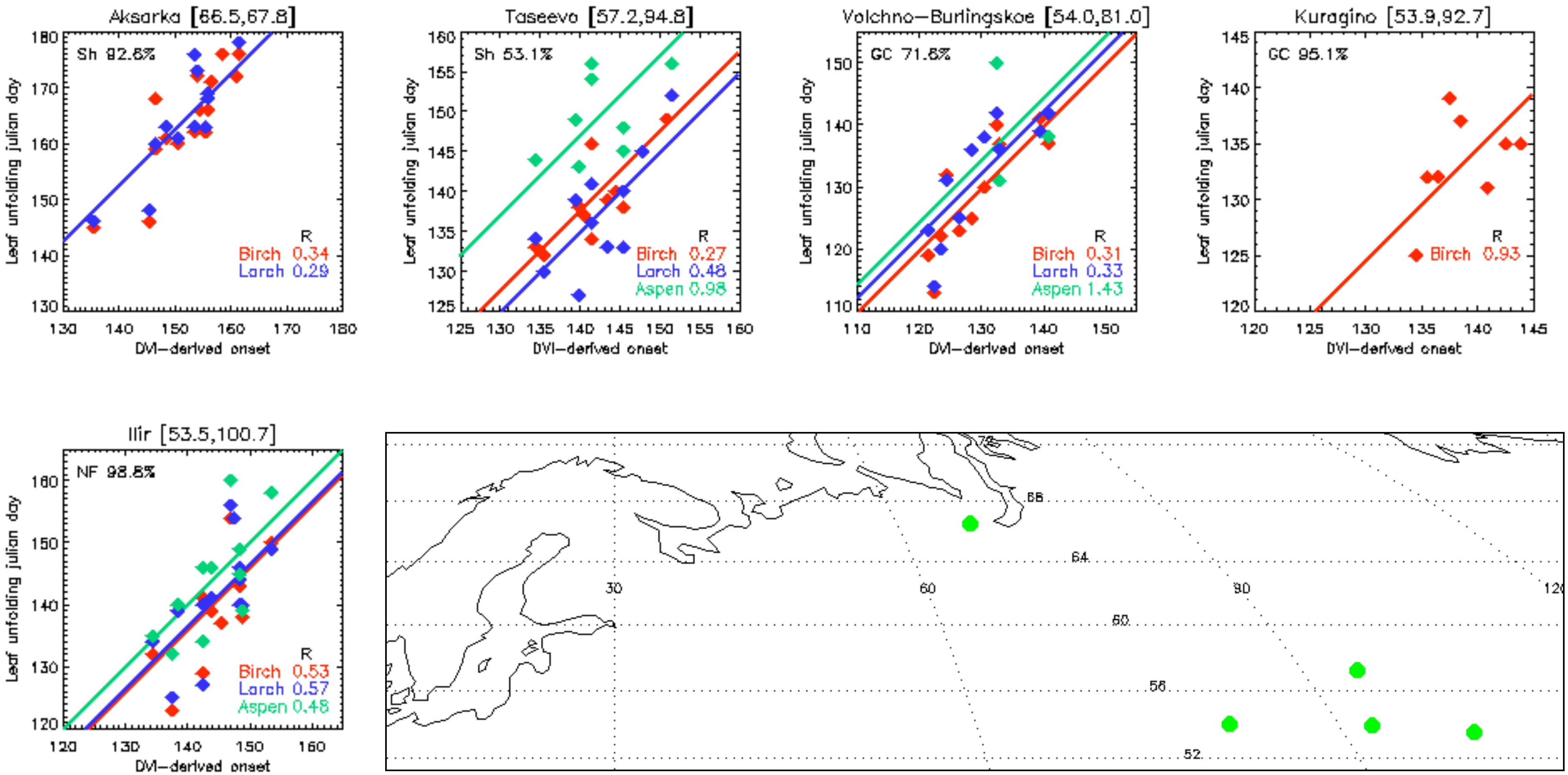
Using quality thresholds, only green stations are selected :
- more than 75% of them with a good correlation
- all are located in the Swiss plain, none in the Alps

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)

Results over Siberia



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

Conclusions on validation

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

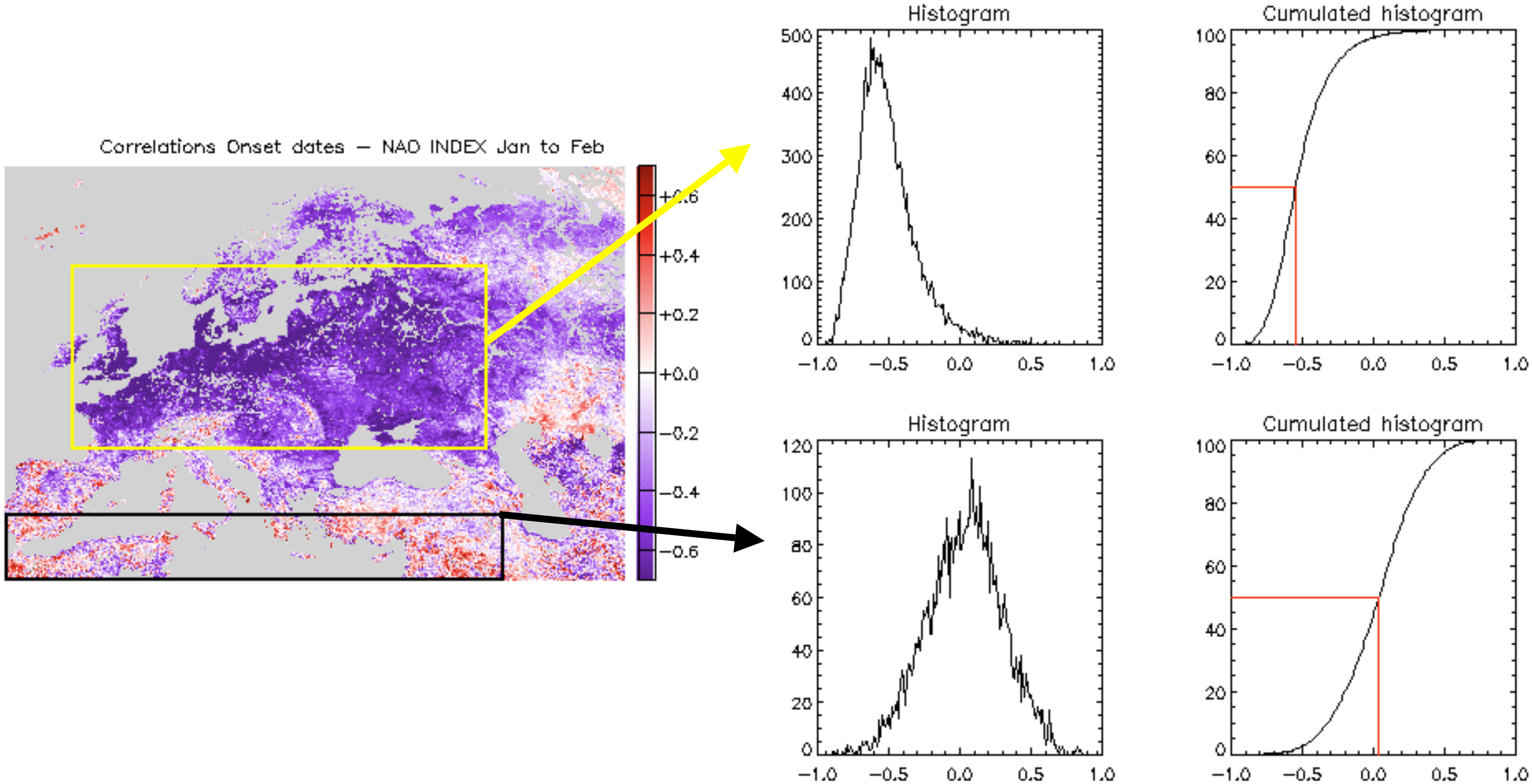
It is based on a spatial average over ≈10x10 km^2 so that a quantitative evaluation against in-situ observation is not possible

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

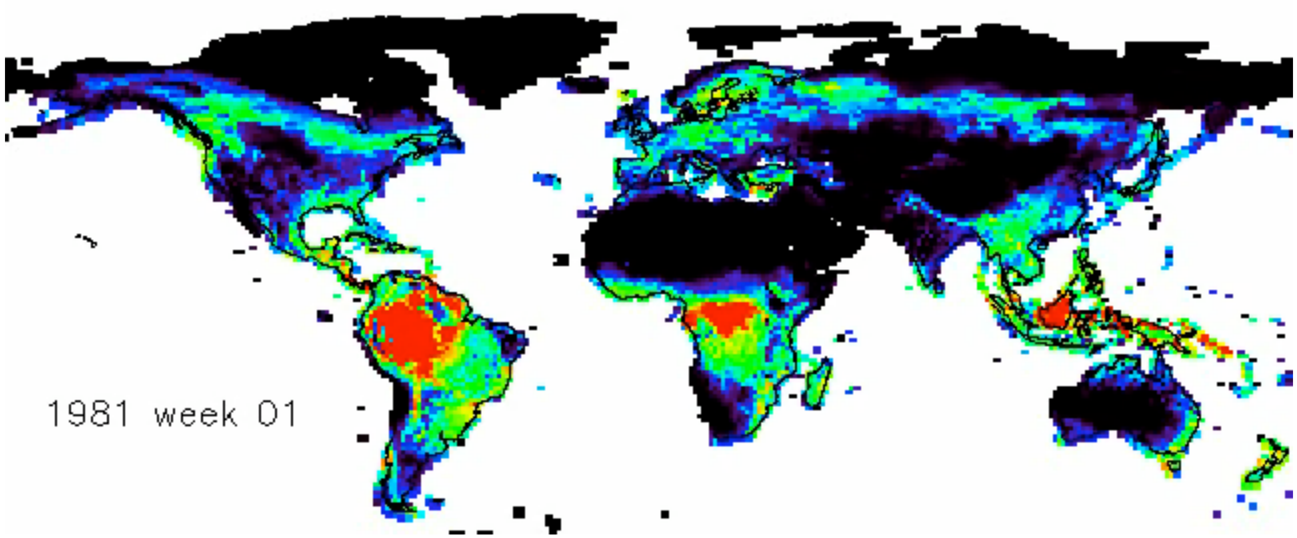
NAO is the difference of surface pressure between Iceland and Azores.
It controls the flow from the Atlantic to Western Europe

There is a strong correlation of winter NAO with Onset Date

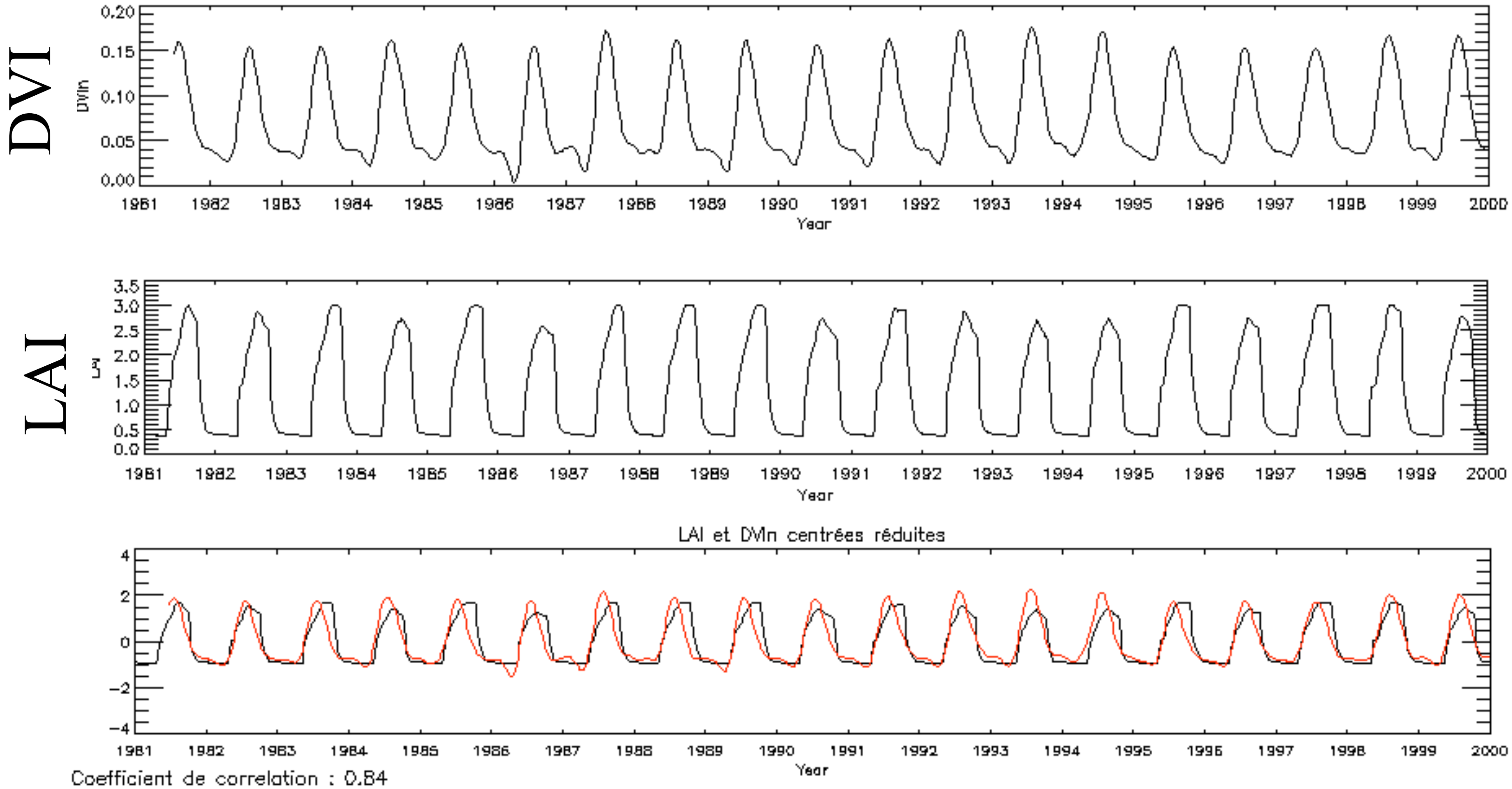


The Orchidée vegetation model

- The model computes the developement of vegetation and the fluxes of energy and mass from the meteorological forcing (temperature, precipitation, radiation)
- 12 Plant Functional Types (PFT)
- Developped at IPSL. 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



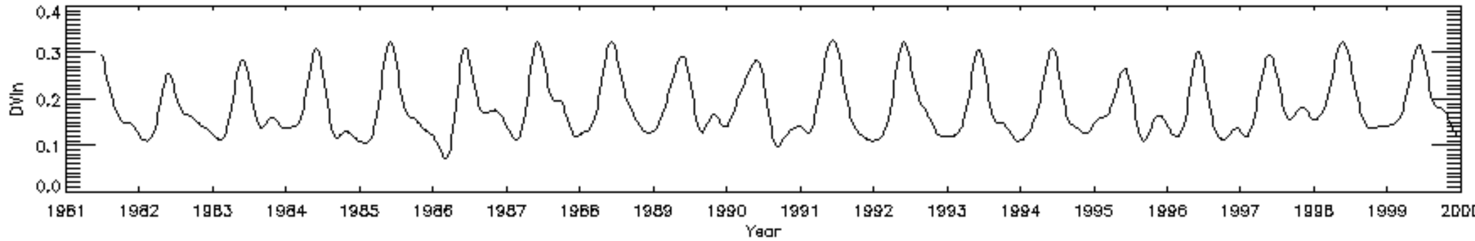
DVI and LAI annual cycles (1/4)



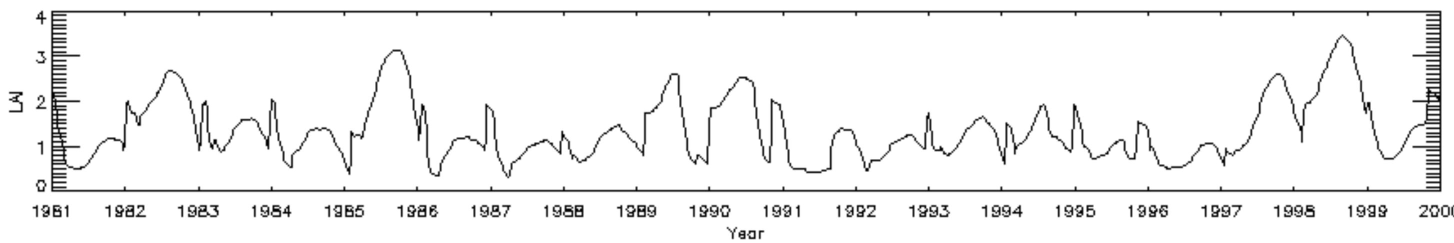
Good coherence of model and satellite time series over Siberia

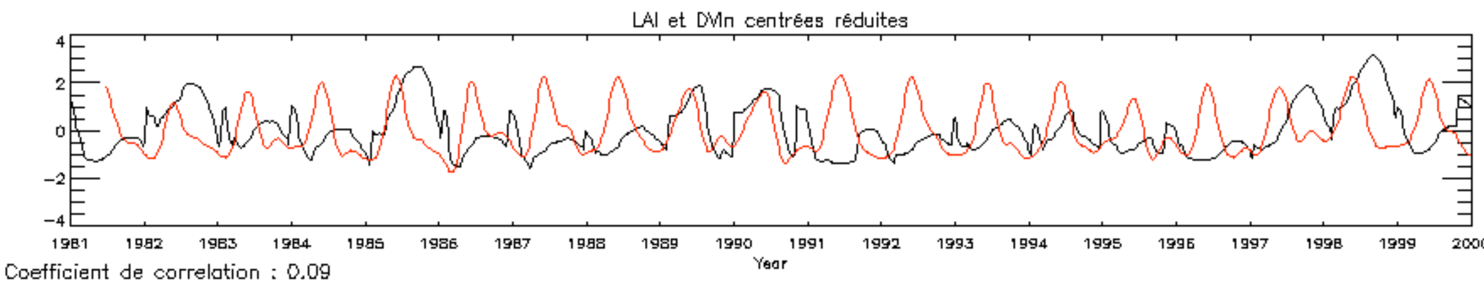
DVI and LAI annual cycles (2/4)

DVI

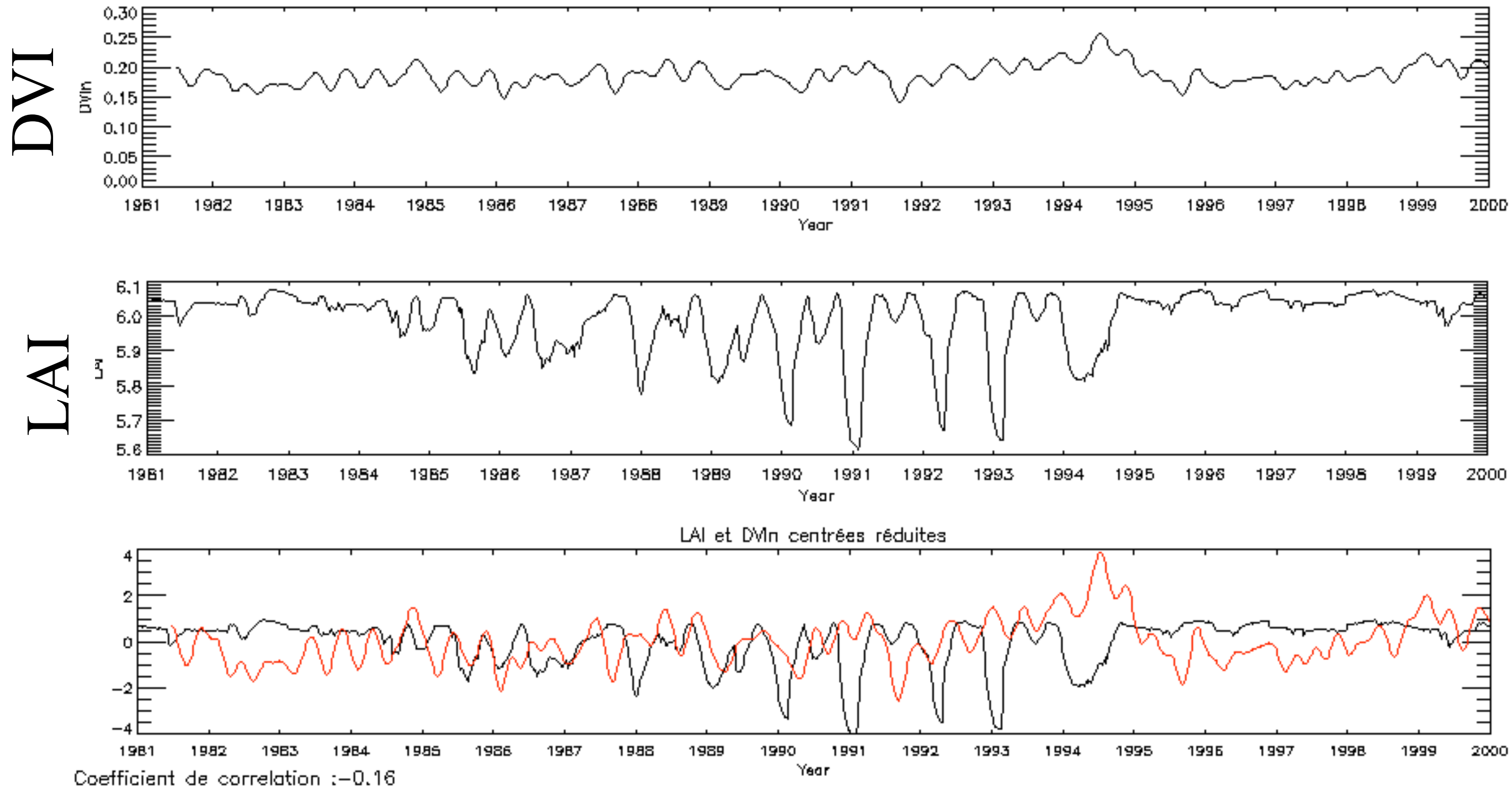


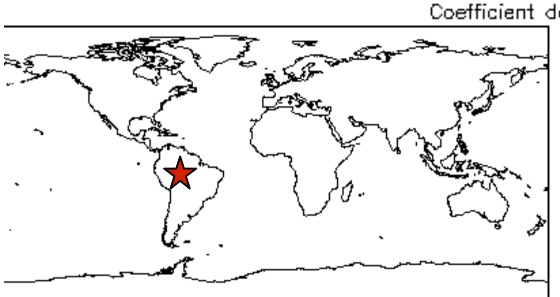
LAI





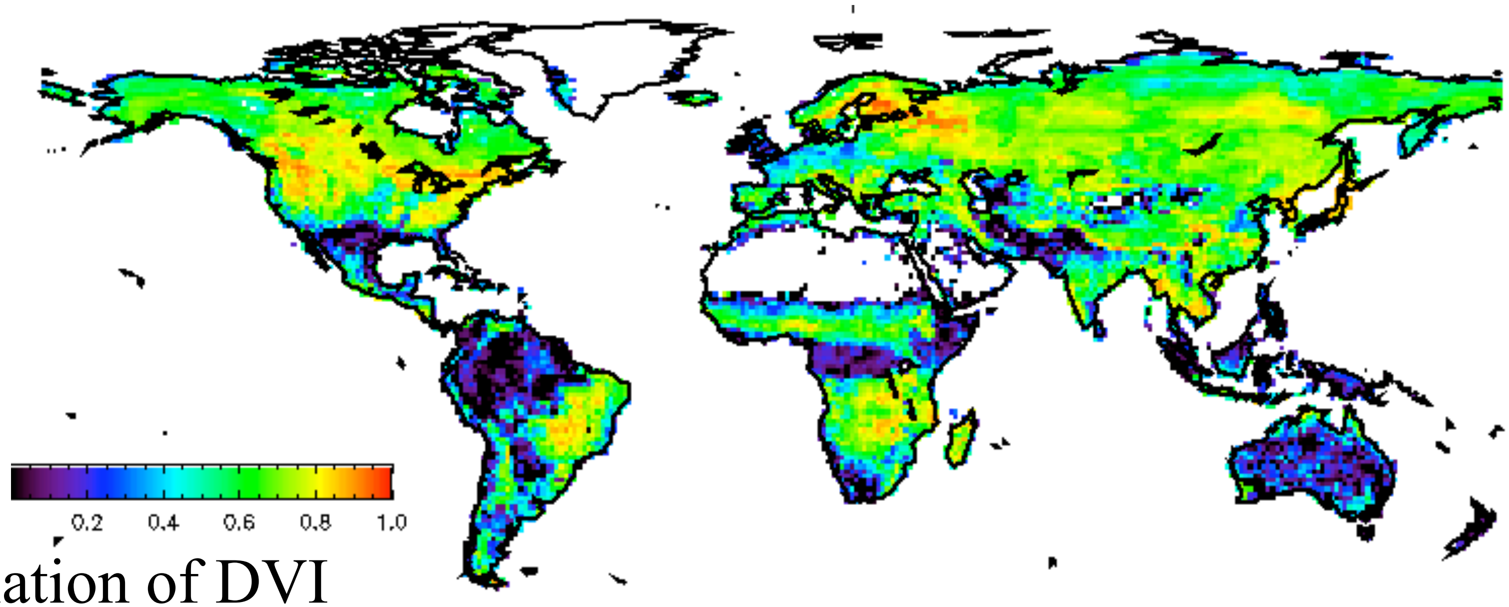
Not that good over UK…





Very poor correlation over Amazonia…
But almost no annual cycle

DVI and LAI annual cycles (4/4)



Correlation of DVI and LAI time series

Poor correlation in areas with limited annual cycle (evergreen forests)
Best over temperate forests

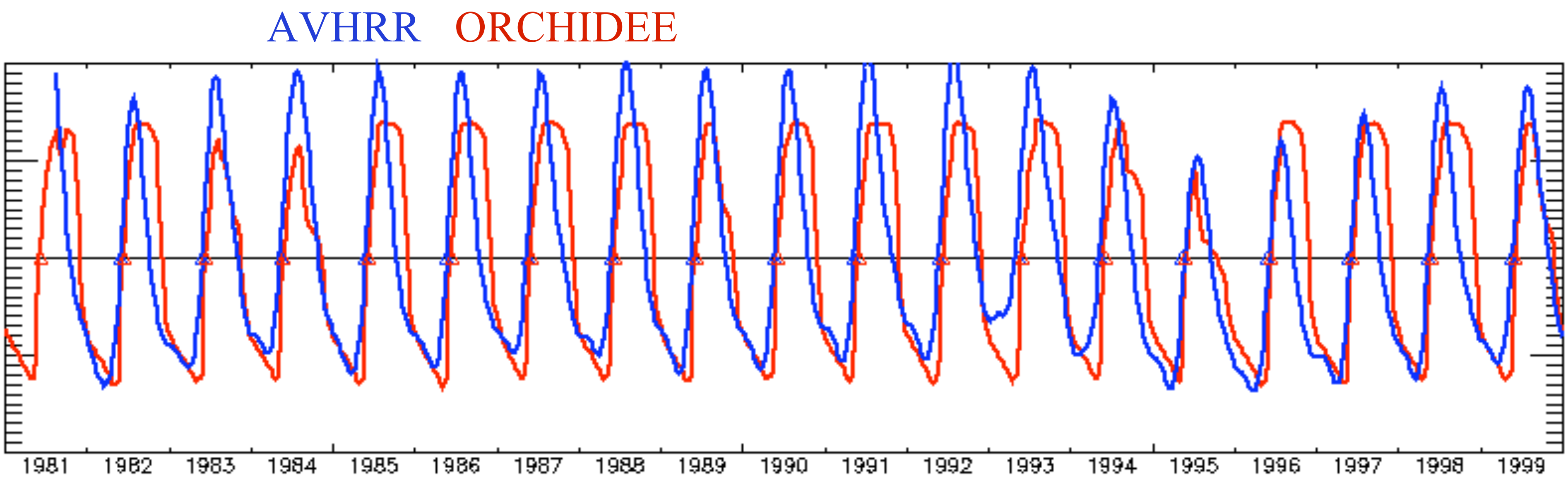
Onset dates based on LAI

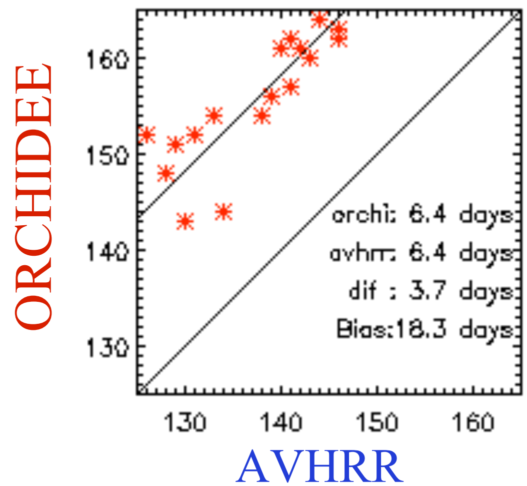
We use the same procedure to extract the onset from the LAI time series

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)



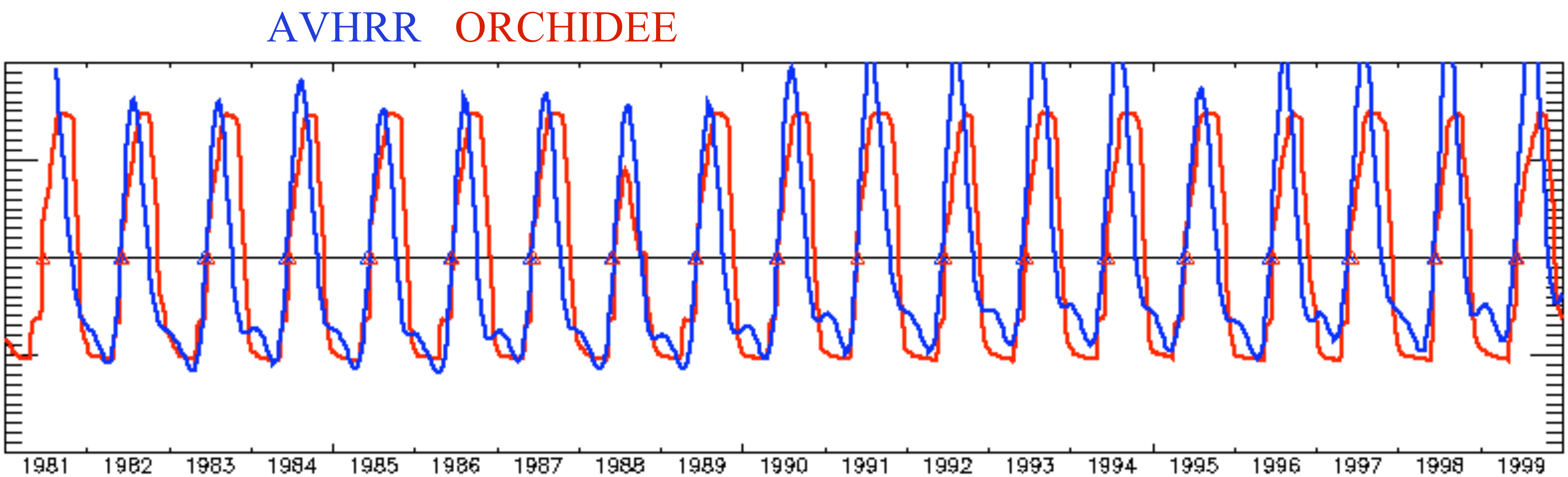


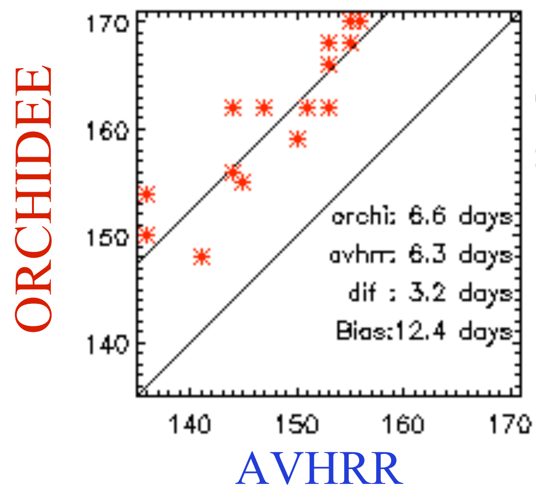
53% Veg Boreal Evergreen

44% C3 Grassland

0% Veg Boreal Deciduous

A few examples (2/4)





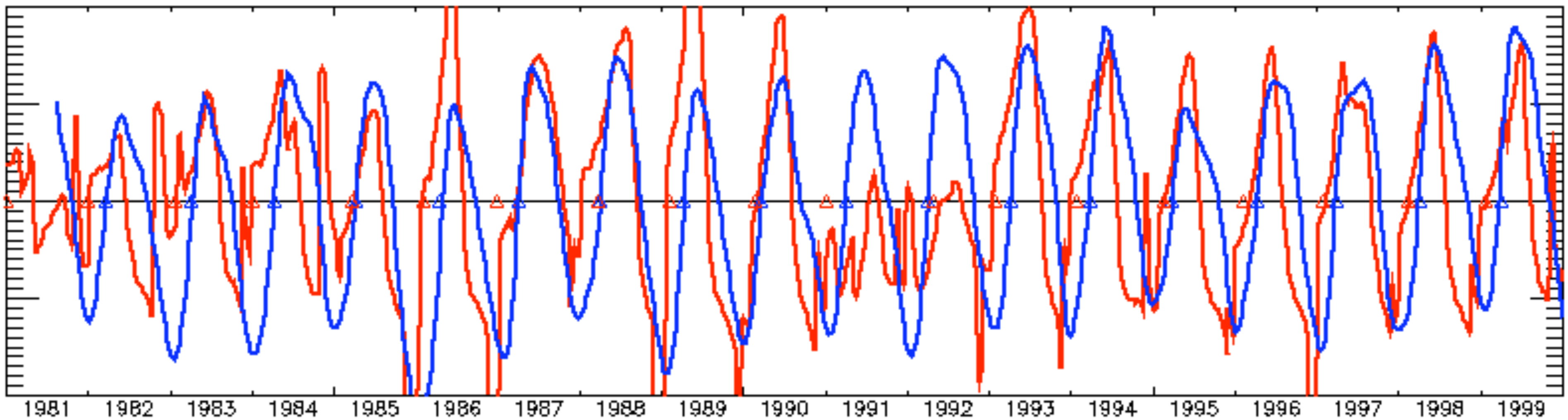
66% C3 Grassland

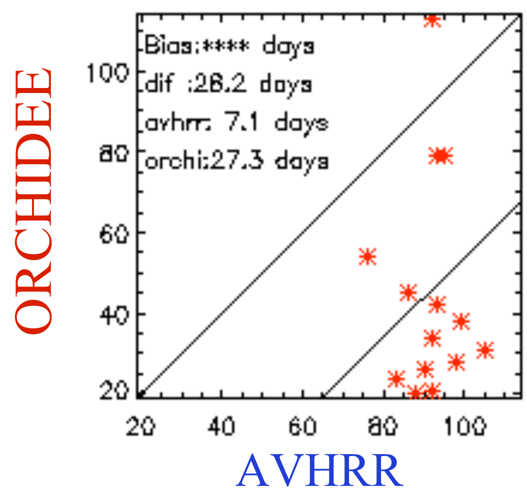
24% Veg Boreal Deciduou

6% Veg Boreal Evergreer

A few examples (3/4)

AVHRR ORCHIDEE





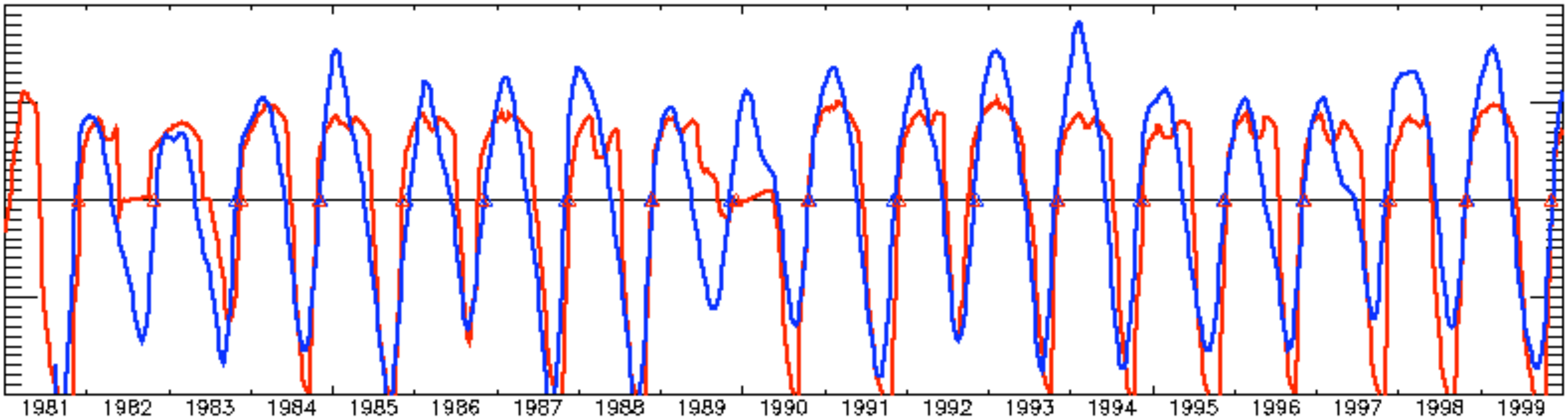
57% C3 Cropland

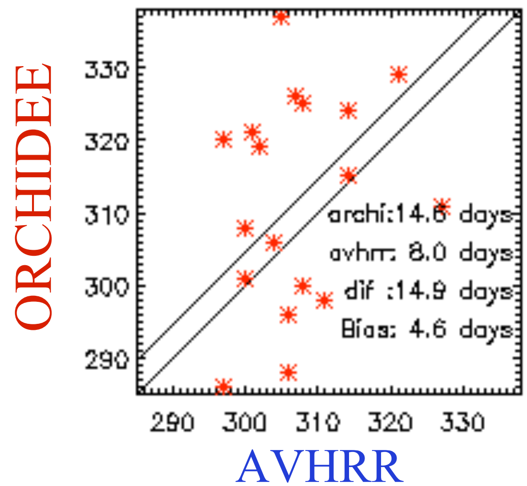
25% Veg Temp Deciduous

7% Veg Temp Evergreen

A few examples (4/4)

AVHRR ORCHIDEE



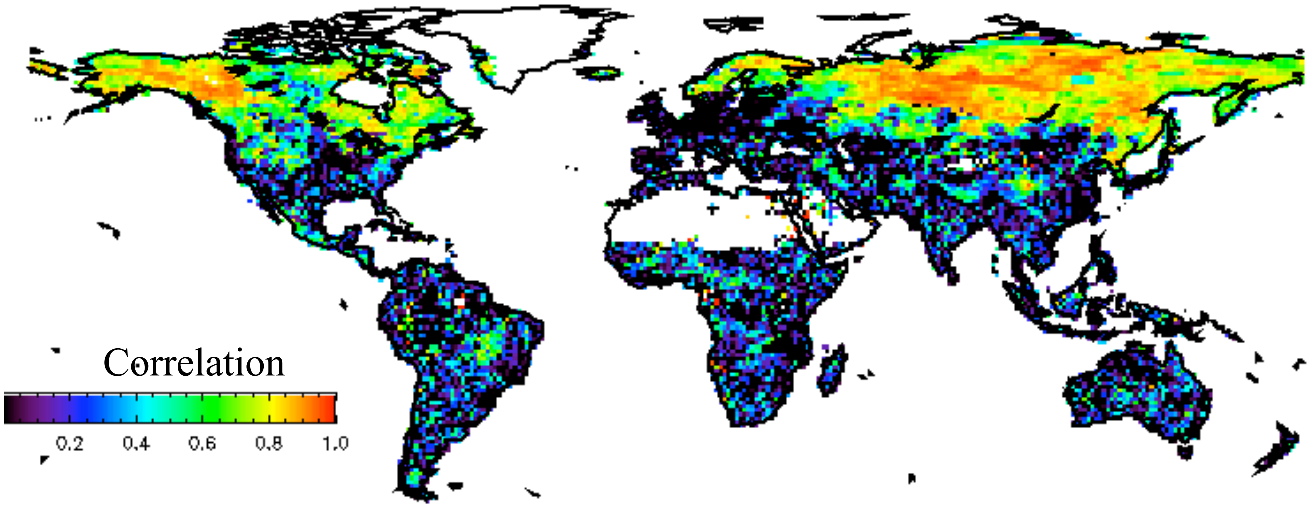


68% C4 Grassland

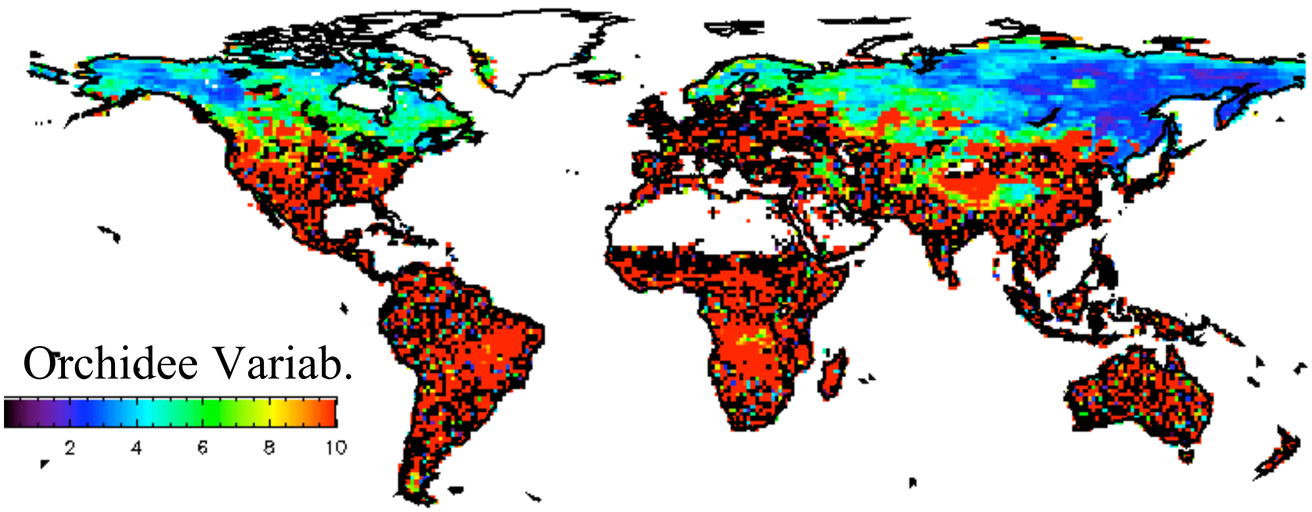
18% Veg Trop Deciduous

10% C4 Cropland

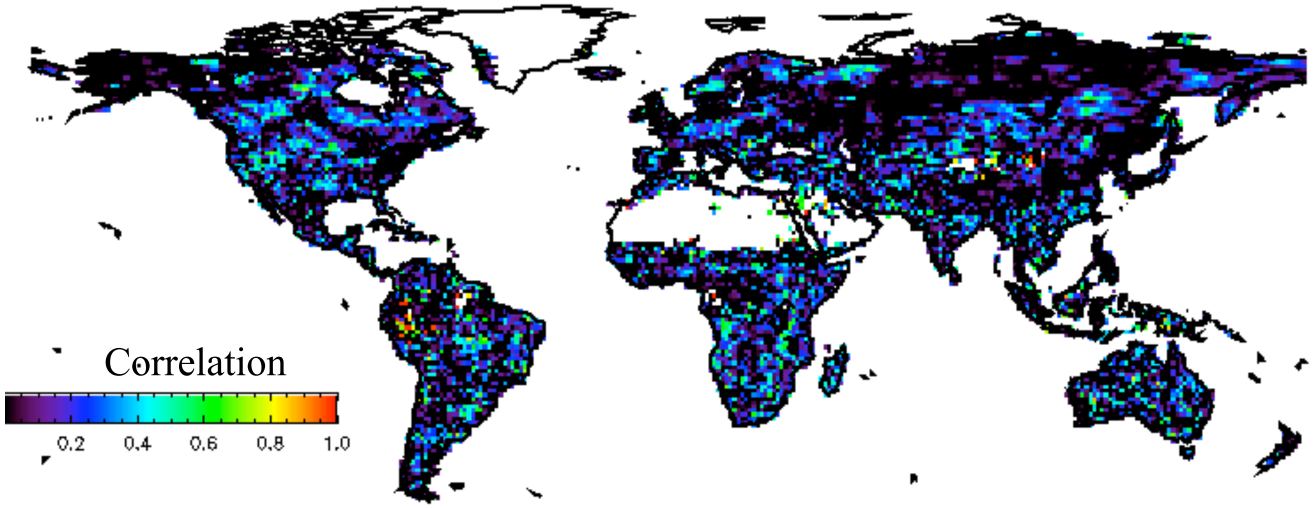
Sat-Model Global Correlation

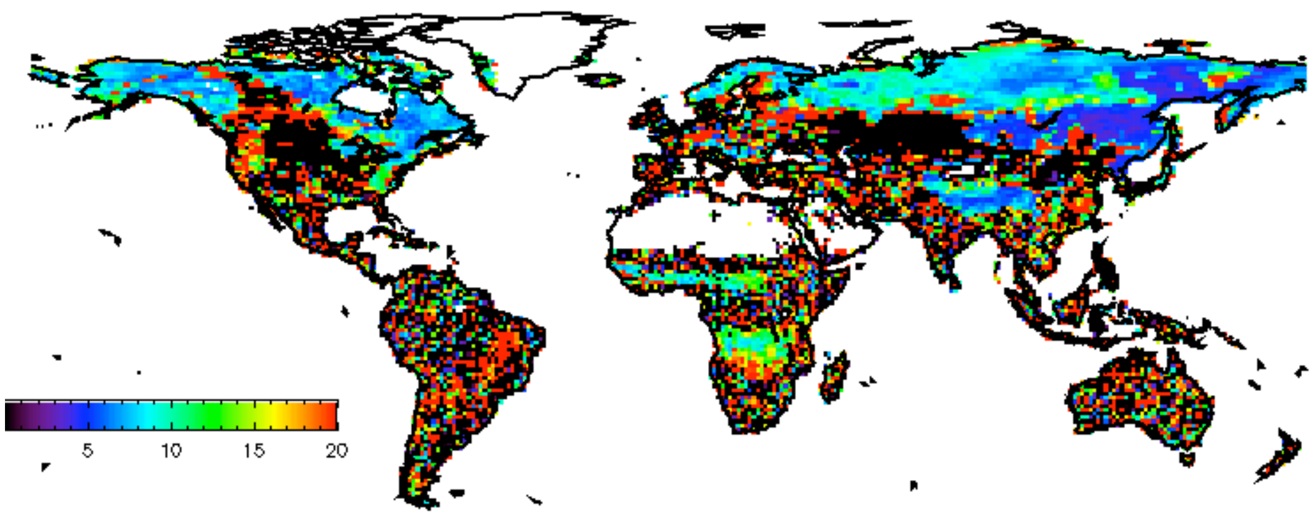


Excellent agreement in high latitude regions. Rather poor everywhere else



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.