Monitoring Vegetation Dynamic from Space

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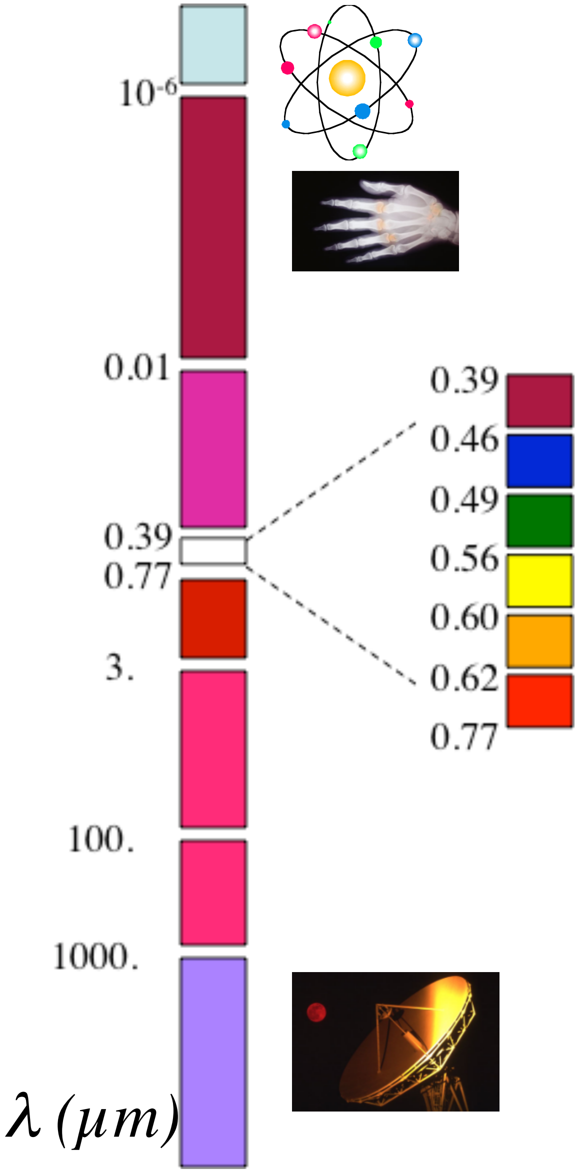
Questions

- What is the global distribution of vegetation ?
- How much Carbon is there within vegetation ?
- What are the processes that control the growth and decay of vegetation ?
- What is the impact of anthropogenic activities on vegetation distribution and dynamic ?
- What is the response of vegetation to meteorological forcing (drought, heat…) ?
- Are there trends in vegetation cover and dynamic ?
- Is it possible to predict agriculture yields ?

Parameters to be measured

- Vegetation cover
- Photosynthetic activity
- Structure parameters (height, density, mass)
- Temperature
- Water content
- Fluxes of mass (H_2O, CO_2…) and energy (radiation, sensible heat)

Several spectral ranges…



Visible / near IR (0.5-1 µm) :
Photo-synthetic activity

Thermal IR (4-12 µm) :
Temperature

MicroWave : Water content, biomass

This presentation focuses on the visible / near IR range

Basic principle…

Chlorophyll absorbs sunlight at wavelengths < 0.7 µm.

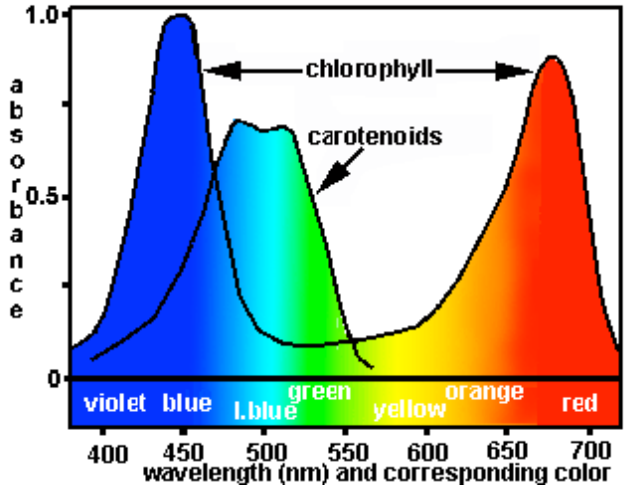
Several pigments. Max absorption in blue and red parts of the spectrum

Consequences for active vegetation

Reflectance higher in green than blue or red.

Reflectance much higher in near IR (>0.75 µm) than in red (<0.7 µm)

No such spectral features for non vegetated surfaces



Basic principle (2/2)…

Reflectance spectrum of bare soil is fairly smooth.

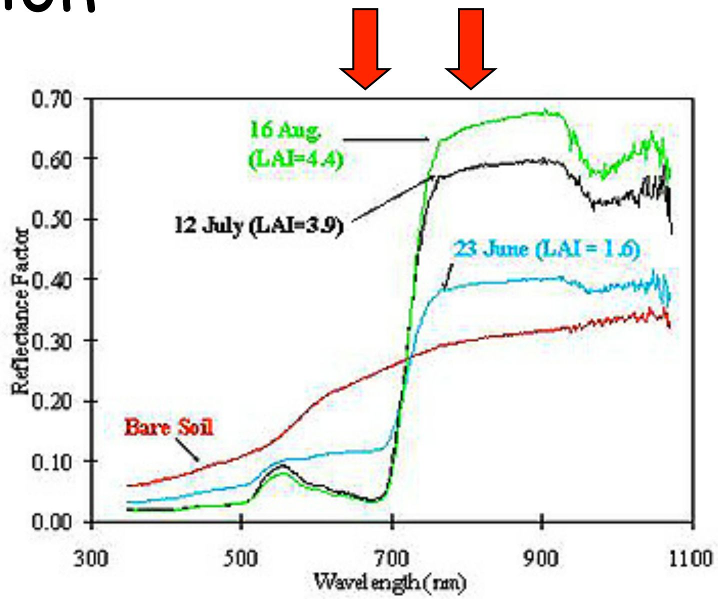
That of vegetation shows a rapid increase around 0.7 μm.

The difference between two reflectance measurements at 0.65 and 0.8 μm is an indication of the presence of active vegetation

Active vegetation indices:

$$NDVI = \frac{R_{NIR} - R_{red}}{R_{NIR} + R_{red}}$$

$$EVI = \frac{R_{NIR} - R_{red}}{R_{NIR} + 6R_{red} - 7.5R_{blue} + 1}$$



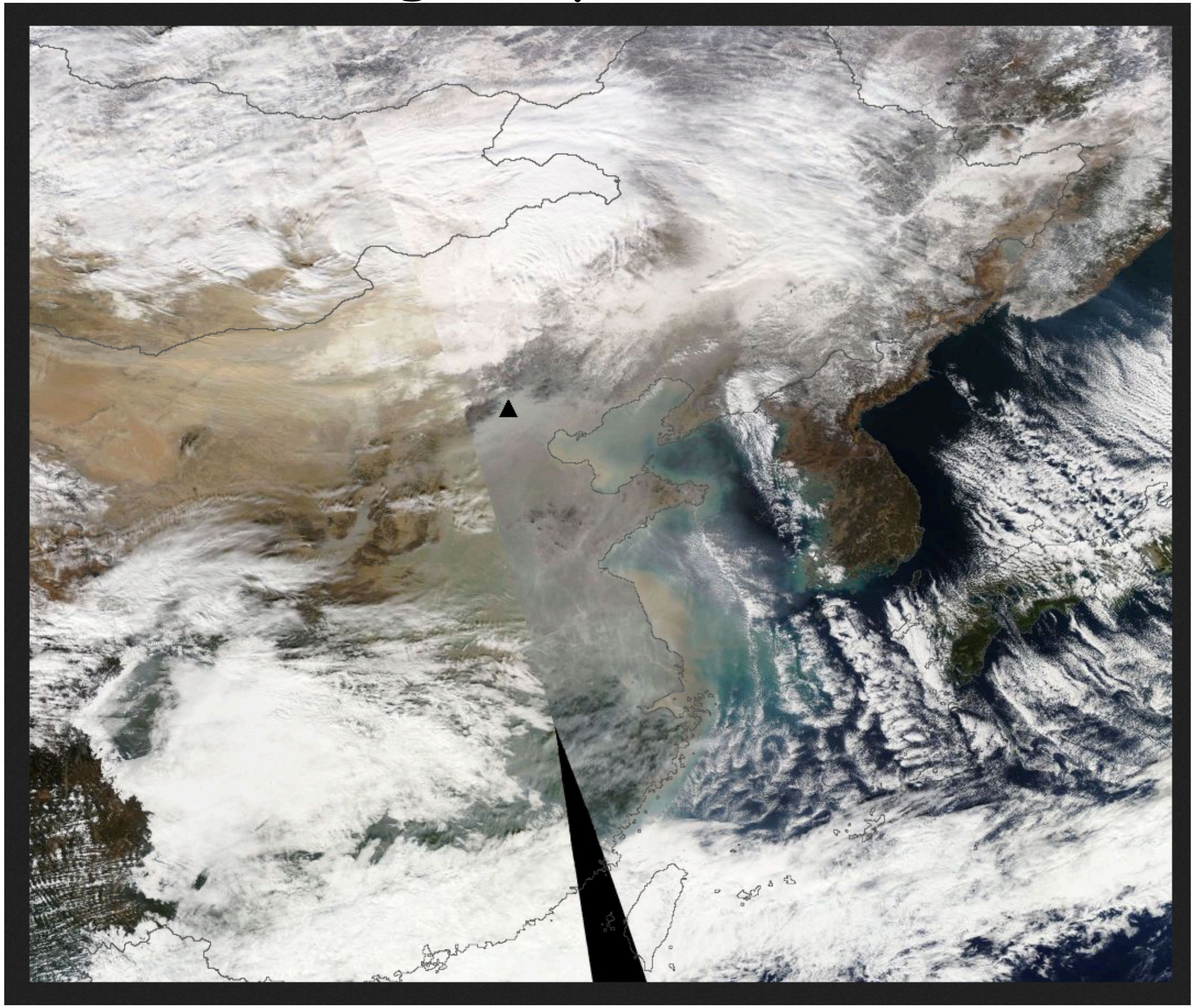
Difficulties…

Clouds and aerosols have a large impact on the measurements

Clouds must be detected and rejected

The impact of aerosols on the measurements must be corrected

The corrected data (surface reflectance) sometime show artefacts (poor correction)



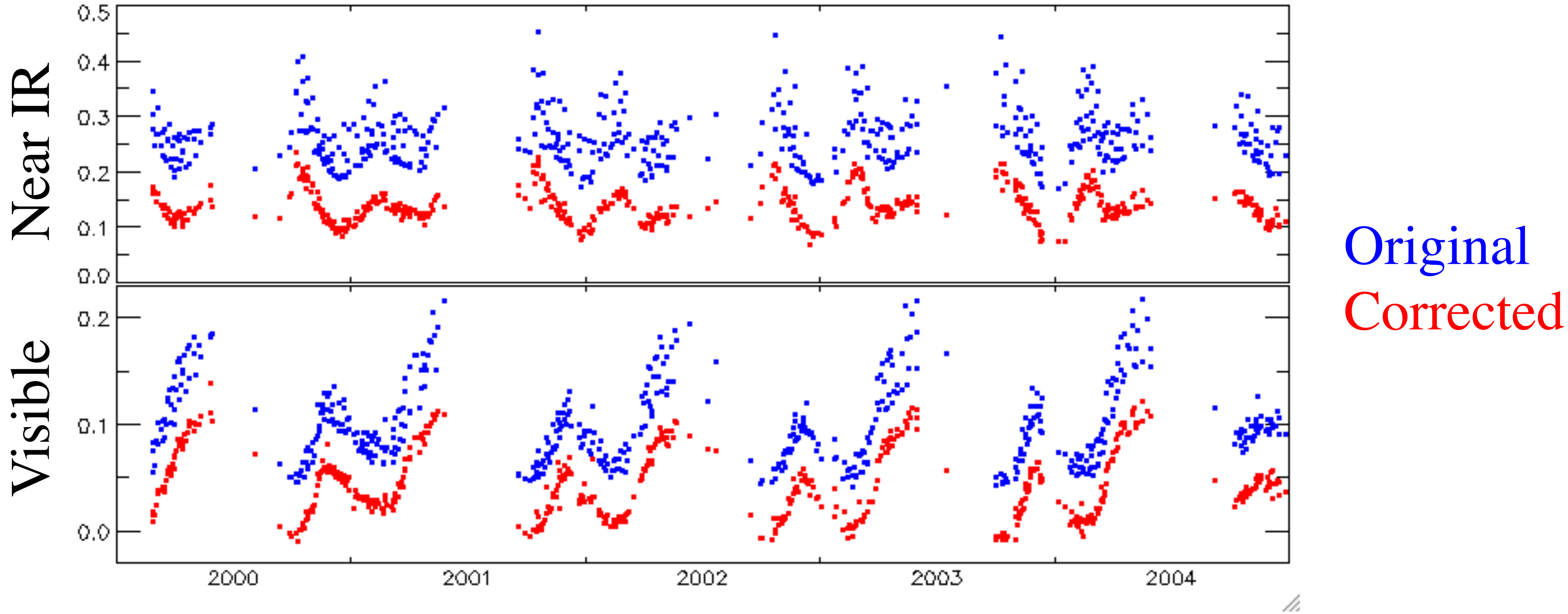
Reflectance time series

Reflectance time series show high-frequency variability

The "noise" is partly due to directional effects.

Selection of specific geometries decreases temporal coverage

Can we correct for the directional effect and retain the original temporal resolution ?

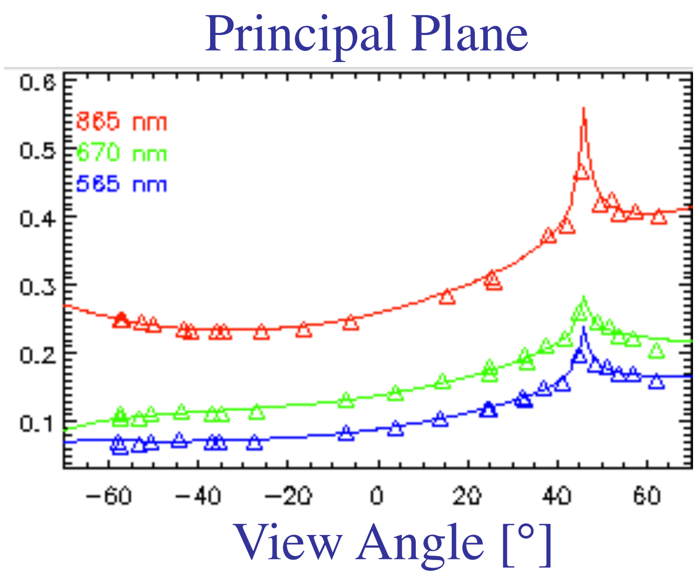


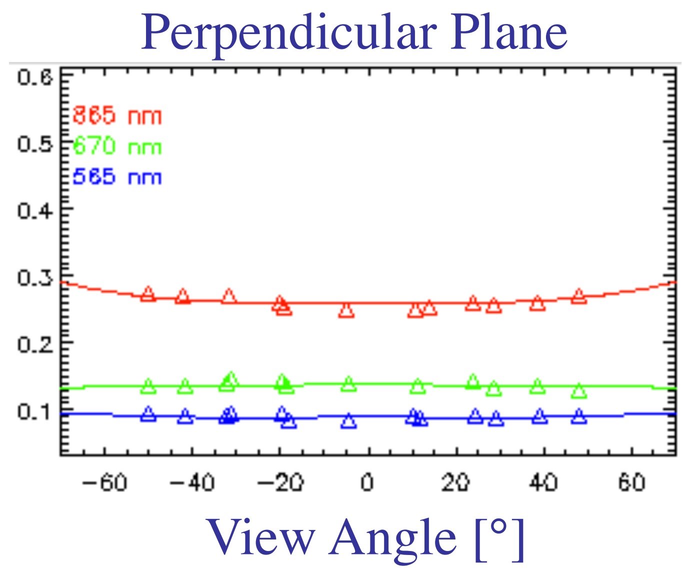
Parasol: "Full" BRDF measurements

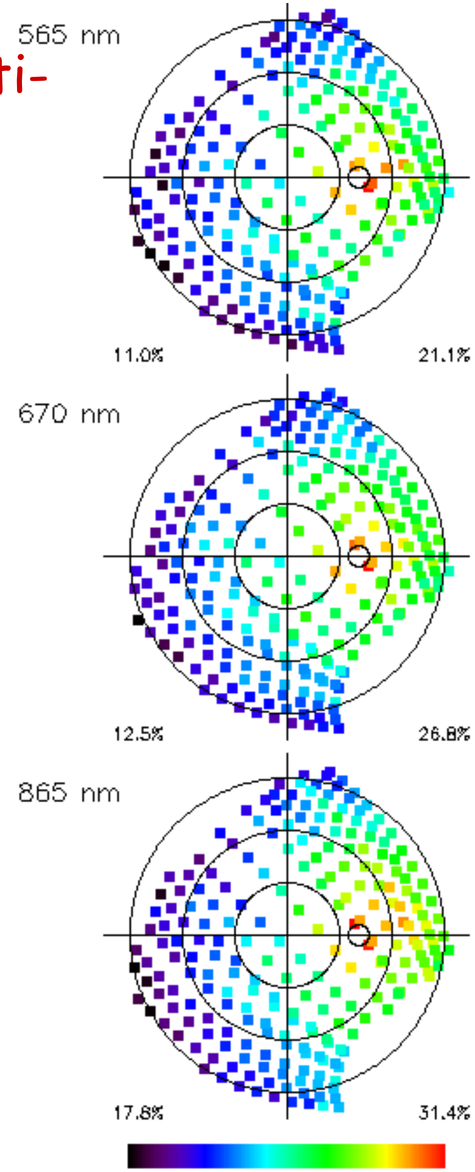
The POLDER instrument onboard PARASOL provides multi-directional measurements of the Earth Reflectances.

These are used for

- BRDF modeling
- Albedo estimate
- Surface characteristics







Maignan et al., *Rem. Sens. Env.*, 2004

Analytical models of BRDF

Linear models :

$$\rho\,(\theta_s,\,\theta_v,\,\phi) = k_0 + k_1\,F_1(\theta_s,\,\theta_v,\,\phi) + k_2\,F_2(\theta_s,\,\theta_v,\,\phi)$$

Several choices for F_1 and F_2

- F_1: Model surface effects (soil roughness)
- F_2: Model volume effects (R.T. within canopy)

Analysis of the hot spot have lead to a modification of F_2

$$F_2^{New} = F_2^{Old}\left(1 + \frac{1}{1+\xi/\xi_0}\right)$$

Non linear models :

RPV [Rahman, Pinty, Verstraete]:

$$\rho\left(\theta_s,\theta_s,\phi\right) = \rho_0\left[\left(\cos\theta_s + \cos\theta_v\right)\left(\cos\theta_s\cos\theta_v\right)\right]^{k-1} P(\xi)\left(1+R(\xi)\right)$$

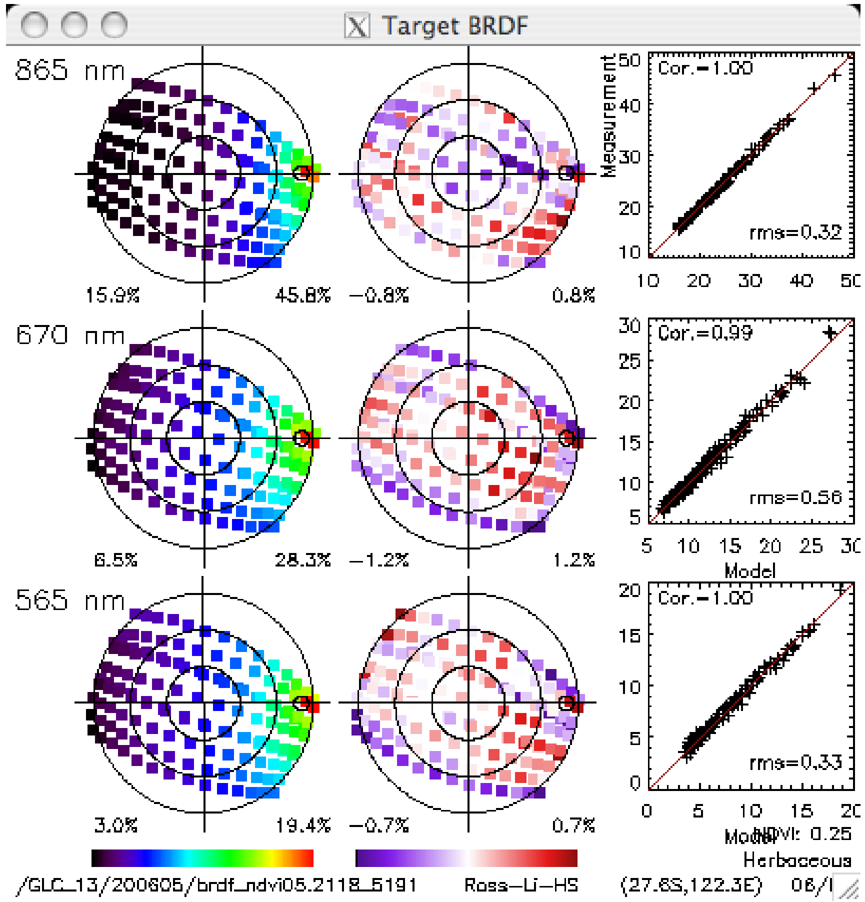
Engelsen : log-linearized version of RPV

Maignan et al., *Rem. Sens. Env.*, 2004

A BRDF database

We have developped a database of reflectance measured by Parasol over a wide range of viewing geometries

- Corrected for atmospheric effects (transm. and scat.)
- Sorted by surface type
- Selected "best" targets
  - Homogeneity
  - Many obs. over the year
  - "Clean" measurements
- Simple format, limited volume
- Display and analysis tool



Available from http://postel.mediasfrance.org

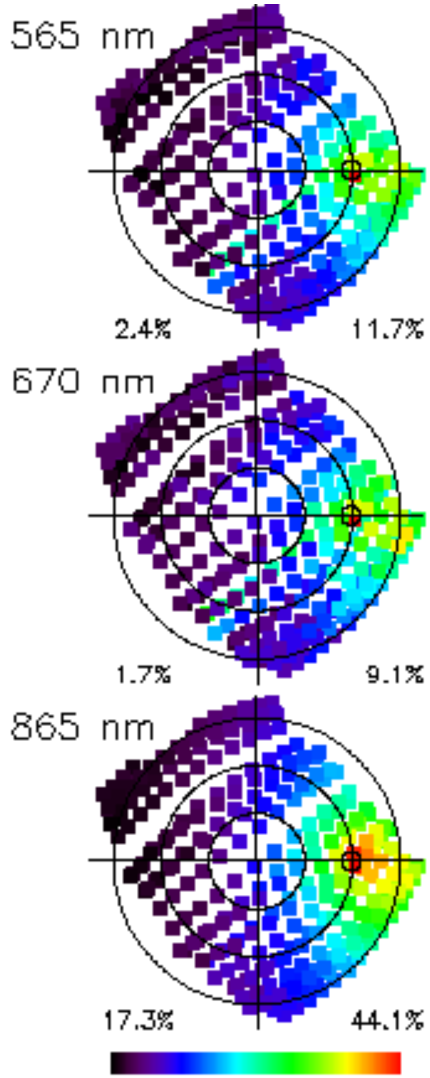
Modeling per biome

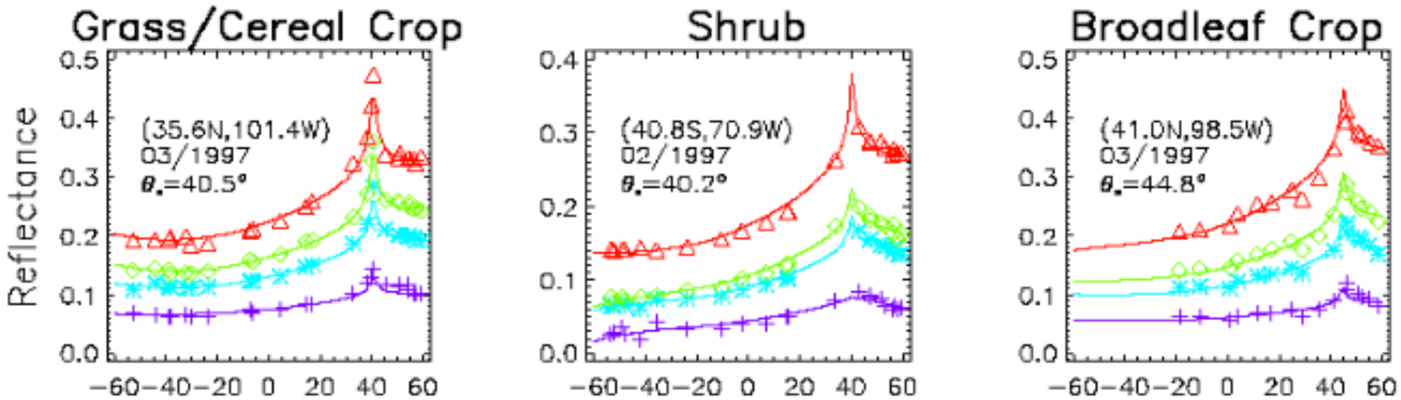
The Bidirectional Signature is

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

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.





Bacour & Bréon., *Rem. Sens. Env.*, 2005

Invert BRDF parameter per pixel

Assuming that we have a time series of reflectance acquires in varying geometries, one can invert the model, without an assumption of target stability.

Search for BRDF parameters (V: k_1/k_0, R: k_2/k_0) that minimize the high frequency variations of the time series of ρ(t), after directional correction

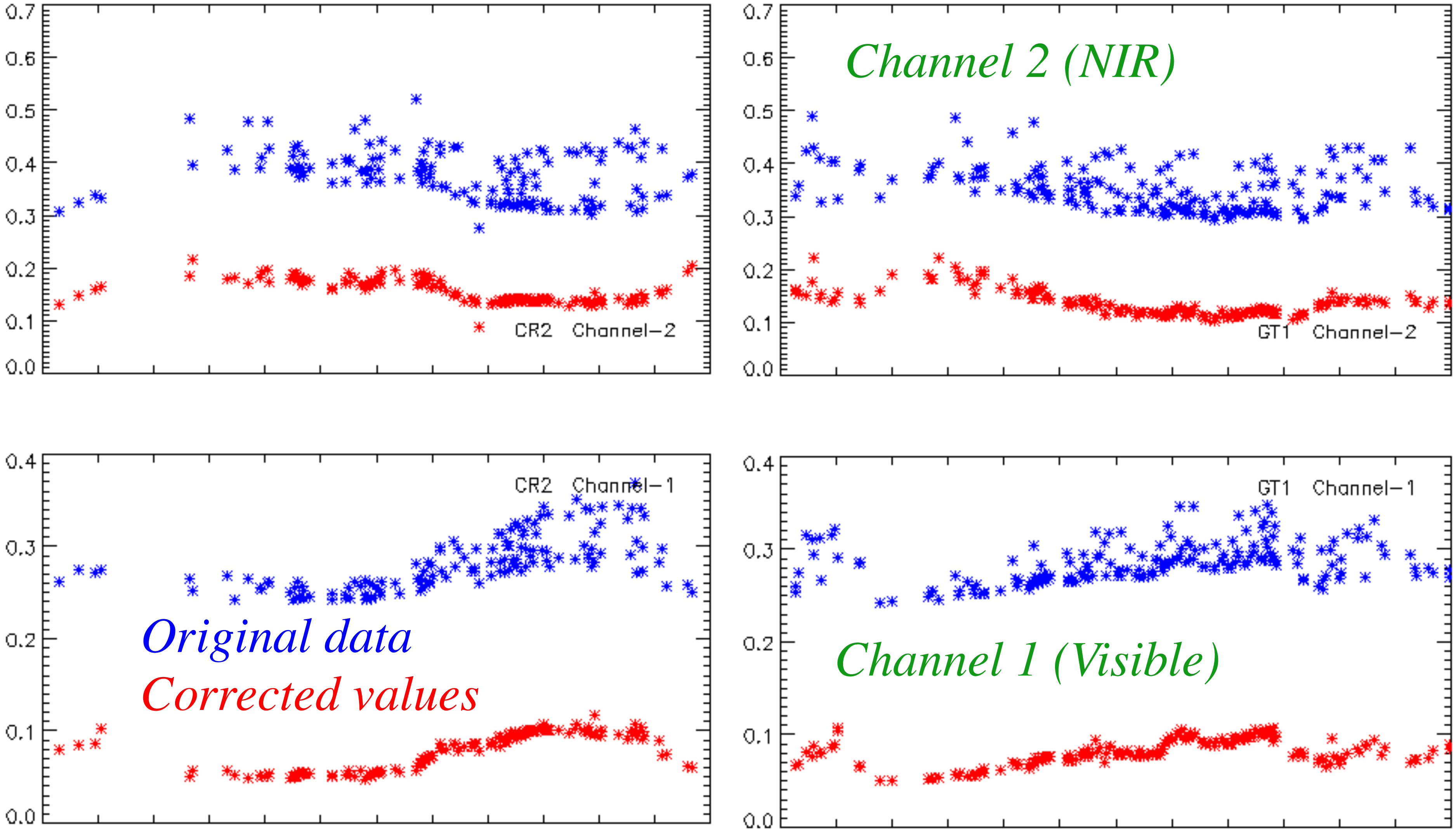
$$M=\sum_{i=1}^{N-1}\frac{\left(\rho_{i+1}\left[1+VF_1^{i}+RF_2^{i}\right]-\rho_i\left[1+VF_1^{i+1}+RF_2^{i+1}\right]\right)^2}{day^{i+1}-day^{i}+1}$$

There is an analytical solution for the optimal (V, R)

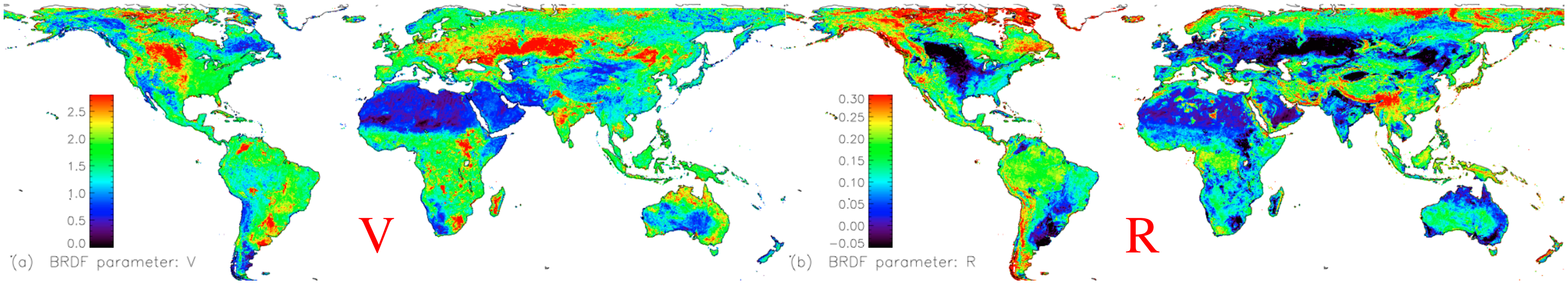
$$\begin{pmatrix}\sum_{i=1}^{N-1}\Delta^i\rho F_1\,\Delta^i\rho F_1 & \sum_{i=1}^{N-1}\Delta^i\rho F_1\,\Delta^i\rho F_2\\ \sum_{i=1}^{N-1}\Delta^i\rho F_1\,\Delta^i\rho F_2 & \sum_{i=1}^{N-1}\Delta^i\rho F_2\,\Delta^i\rho F_2\end{pmatrix}\otimes\begin{pmatrix}V\\R\end{pmatrix}=\begin{pmatrix}-\sum_{i=1}^{N-1}\Delta^i\rho\,\Delta^i\rho F_1\\ -\sum_{i=1}^{N-1}\Delta^i\rho\,\Delta^i\rho F_2\end{pmatrix}$$

Vermote et al., *IEEE TGARS*, 2008

Results…


0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
CR2 Channel−2
Channel 2 (NIR)
GT1 Channel−2
0.4
0.3
0.2
0.1
0.0
CR2 Channel−1
Original data
Corrected values
GT1 Channel−1
Channel 1 (Visible)

Spatial structures of BRDF model

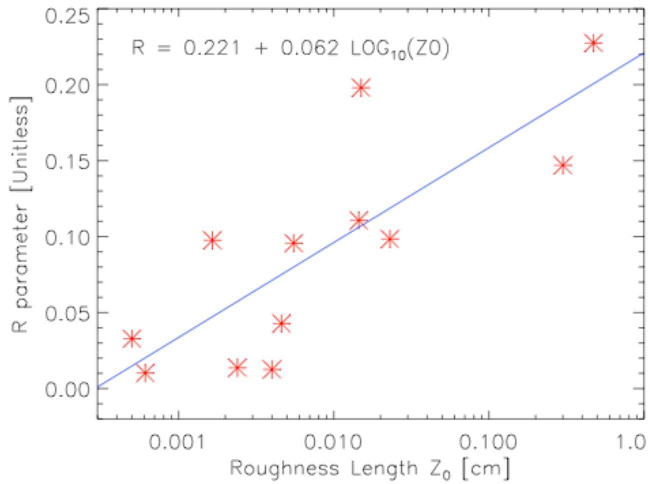


$$\rho(t,\theta_s,\theta_v,\varphi) = \rho_0(t)\left[1 + R\,F_1(\theta_s,\theta_v,\varphi) + V\,F_2(\theta_s,\theta_v,\varphi)\right]$$

There are some well-defined spatial structures that can be related to the surface cover.

Over desert areas, R can be linked to the surface roughness

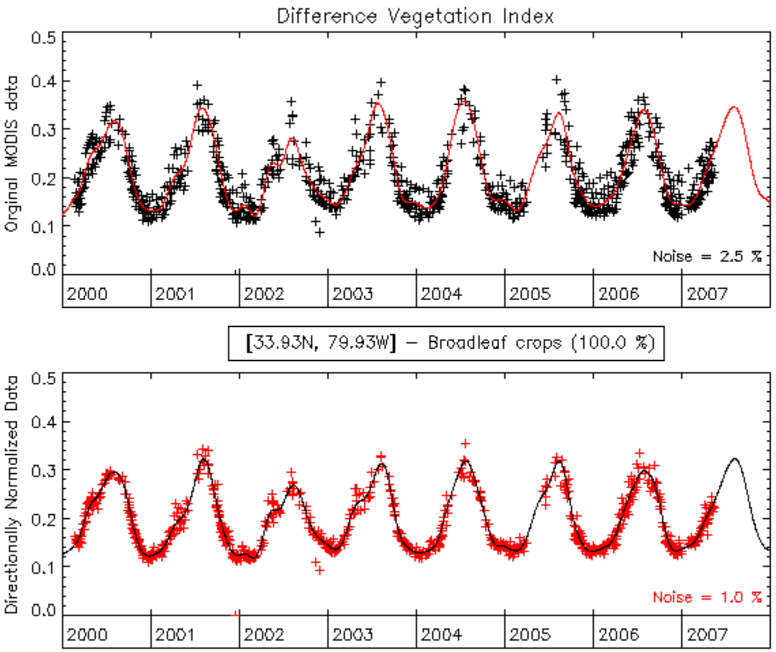
A proper interpretation is still needed…

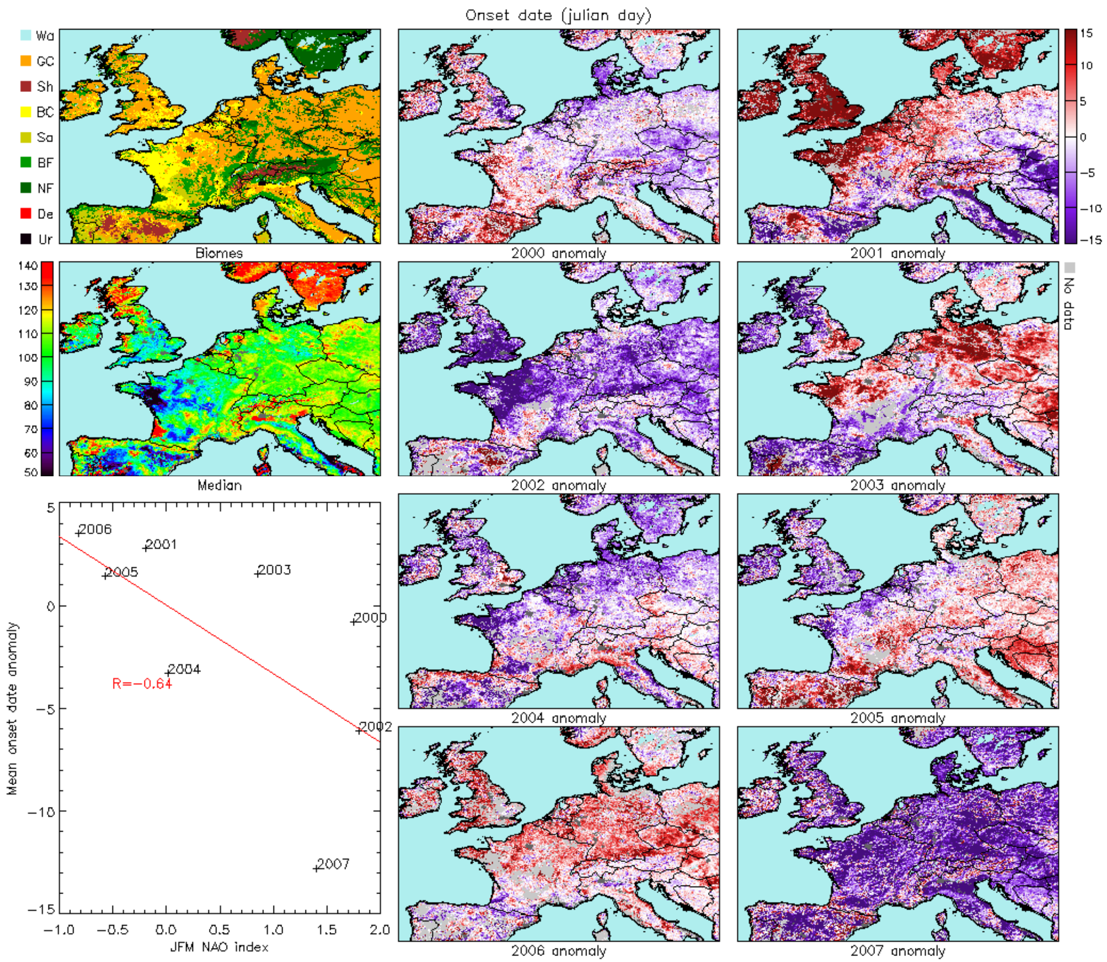


Vermote et al., *IEEE TGARS*, 2008

Application: Vegetation Phenology

The corrected time series are cleaner than their original counterpart and can be used to extract “fine” signal

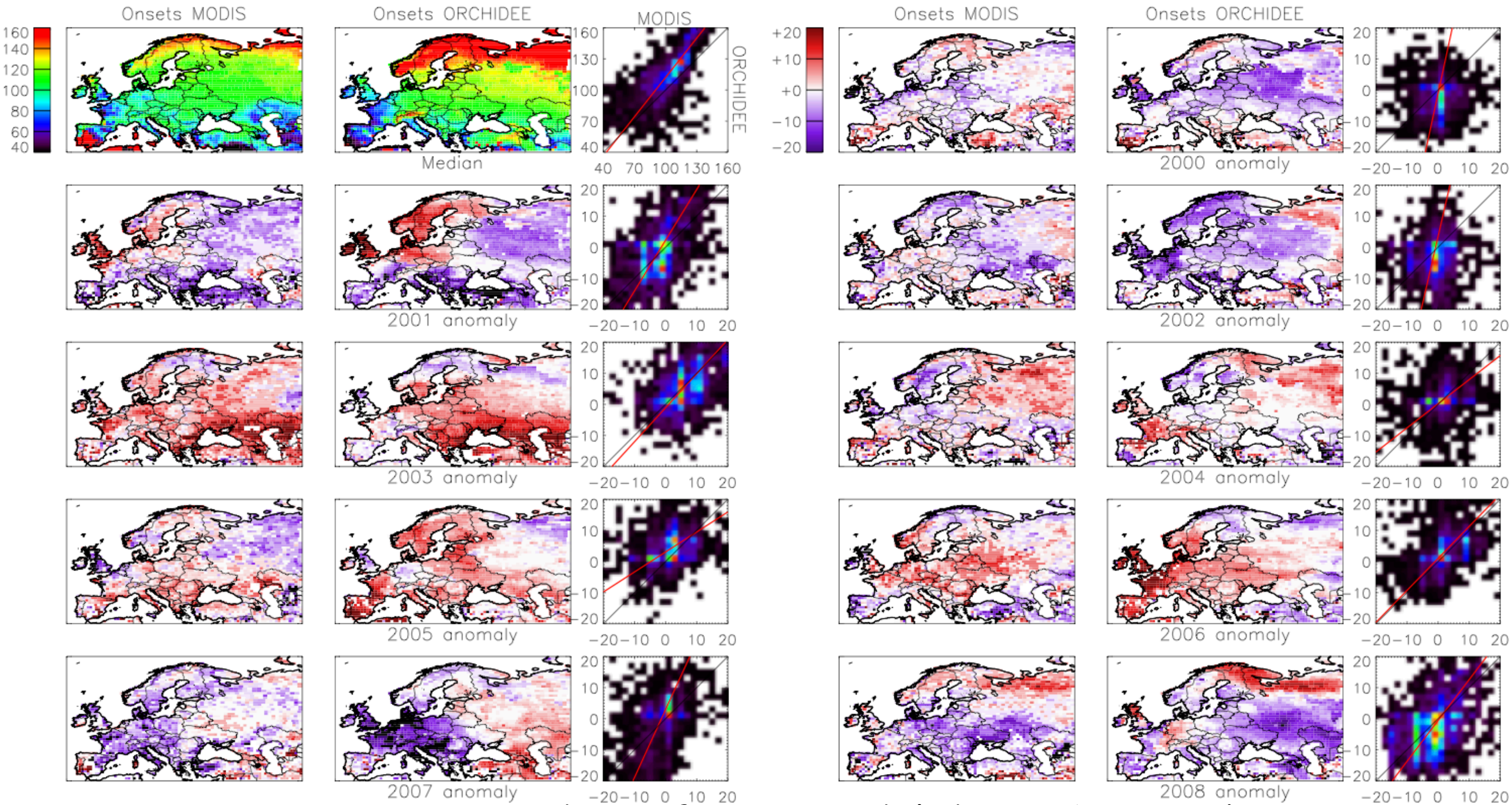




Here, analysis of interannual anomaly of vegetation onset, in relation to North Atlantic Oscilation

Maignan et al., *Rem. Sens. Env.*, 2007

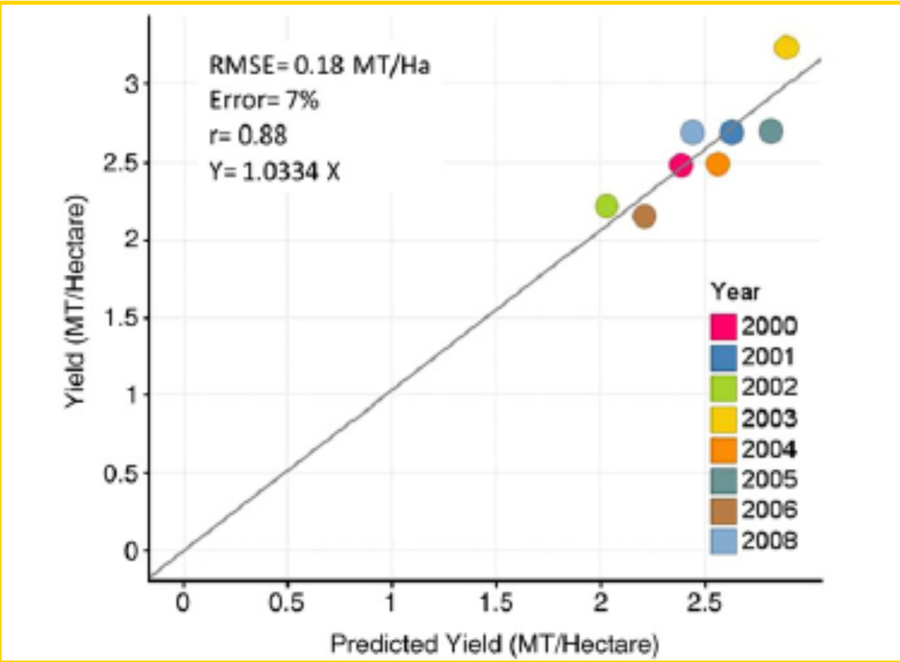
Validate a vegetation model

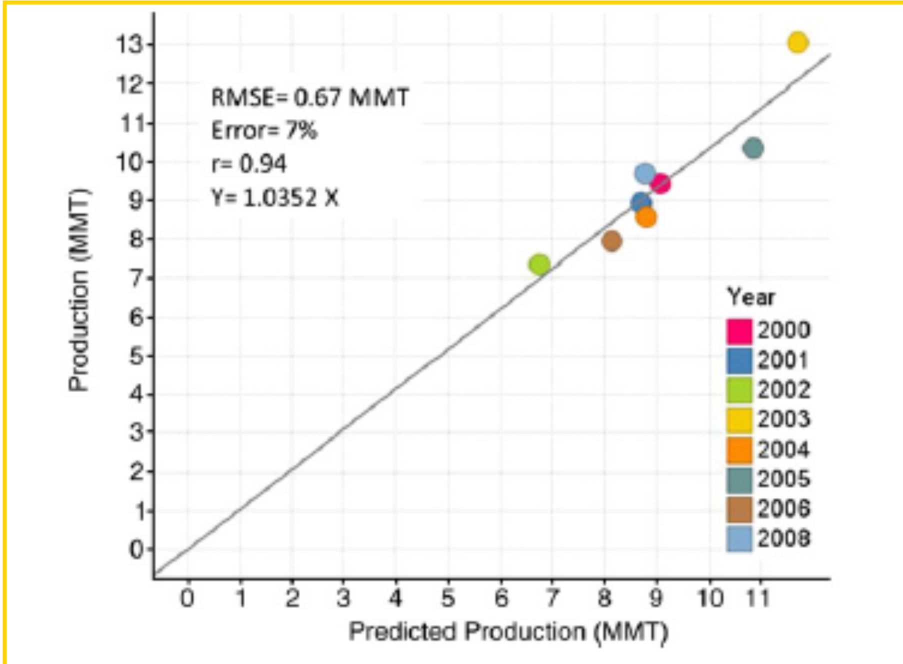


Compare vegetation onset dates from a model driven by weather to MODIS observations. Data assimilated to constrain model parameters.

Estimate crop yield

Corrected reflectance time series are used to identify max NDVI
Crop yield is estimated as a function of the max NDVI and surface fraction of winter wheat





The method was calibrated and validated over Kansas (see above)
It shows similar results over Ukraine, and makes it possible to estimate yield several weeks before harvest.

Becker-Reshef et al., *Rem. Sens. Env.*, 2007

Why focus on Amazonia ?

*Large source of **biodiversity** facing numerous dangers:*

- degradation (deforestation, fires)

- climatic change (droughts)

Carbon cycle point of view:

*- Intact forests are a **carbon sink** at present (Phillips et al., 2008)*

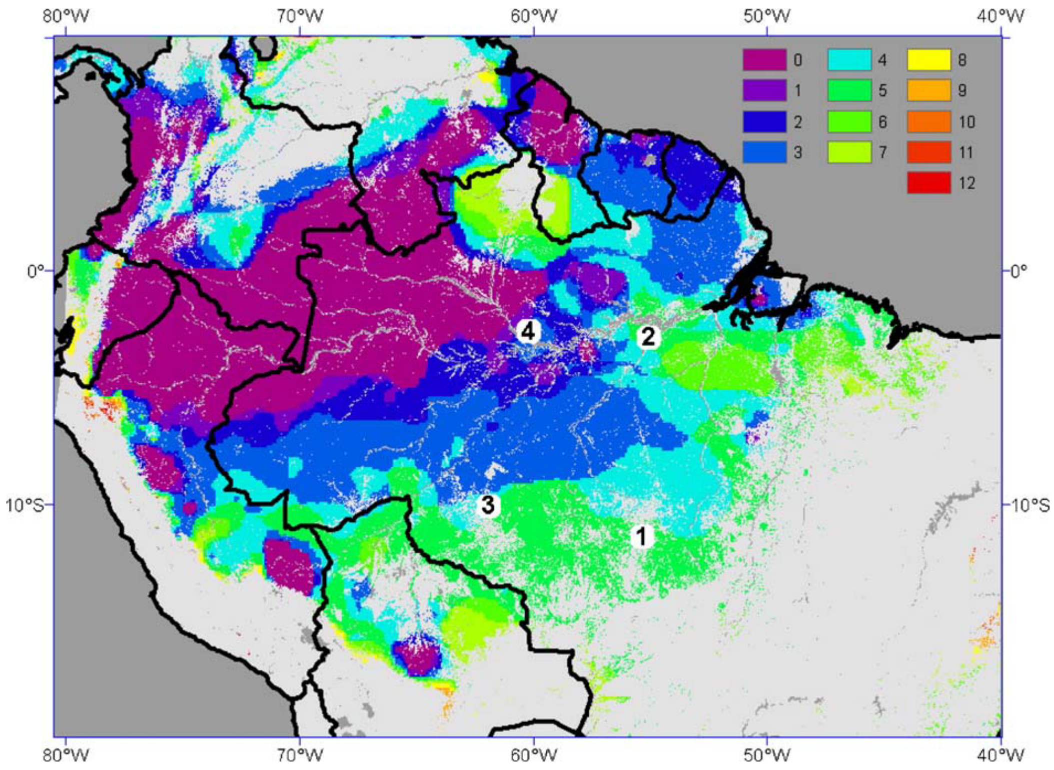
- Will they turn into a source?

***Poorly known**:*

- few in situ measurements

- contrasted models results (questioned predicted die-back in the 21st century)

Remote sensing of Amazonia



Number of dry months over the evergreen forest

Xiao et al. (2006)

Amazonia is particularly difficult for remote sensing because

- Frequent cloud cover

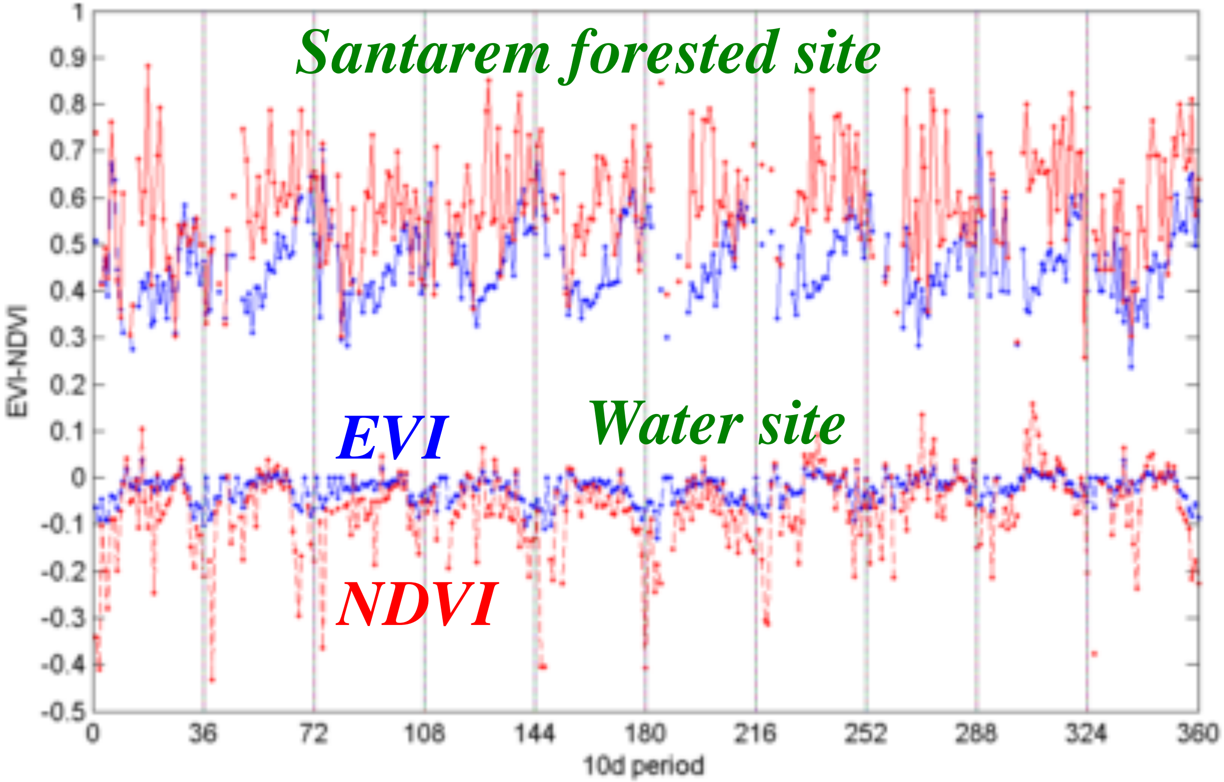
- Large aerosol load during the dry season (fires)

NDVI vs EVI

EVI is designed to :

- *minimize atmospheric contamination and soil background effects,*
- *exhibits less saturation for high LAI.*

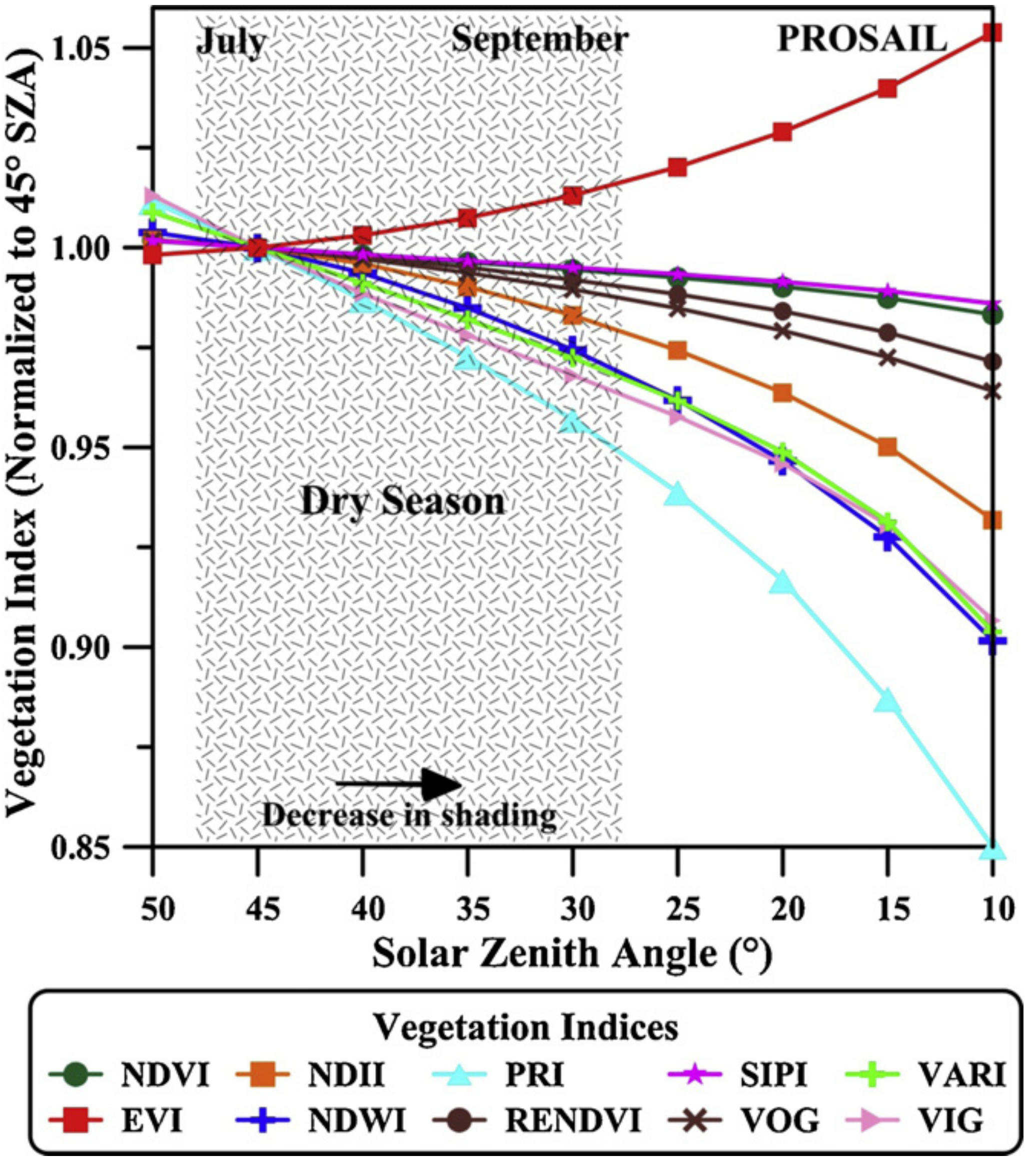
SPOT-VGT 1 km data



Moreau et al. (2010)

The water EVI remains stable as expected (no vegetation activity) whereas the water NDVI exhibits atmospheric contamination (undetected clouds, aerosols).

Directional effect on Veg Ind.



Galvao et al. (2012)

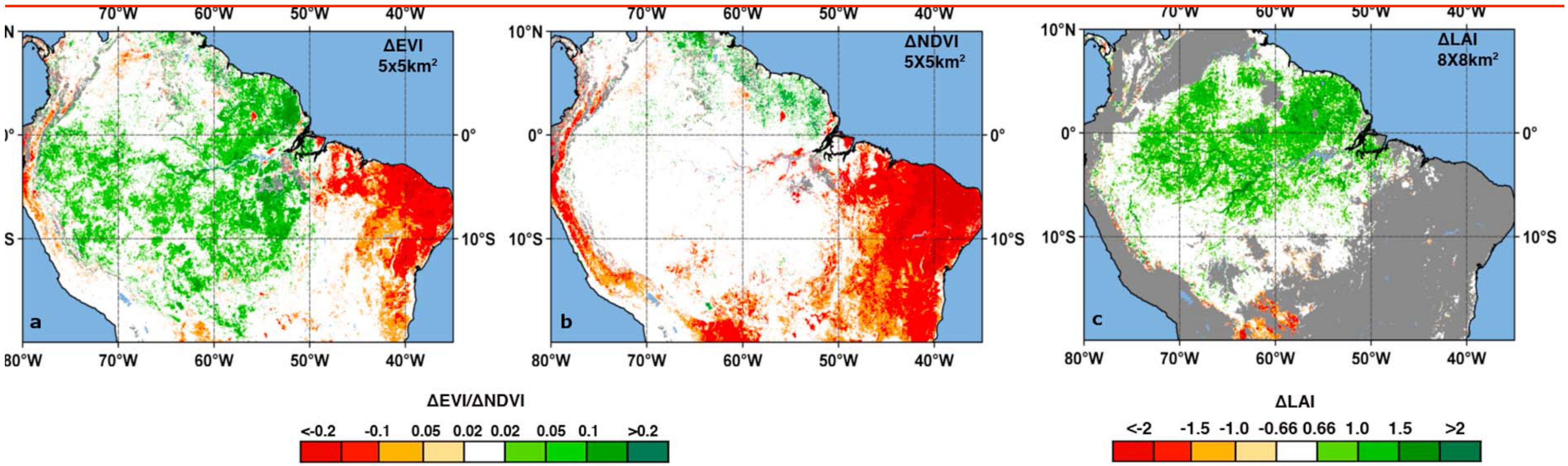
LAI=5

nadir viewing

Analysis of the impact of the reflectance directional signatures on the various Vegetation Indices proposed in the litterature

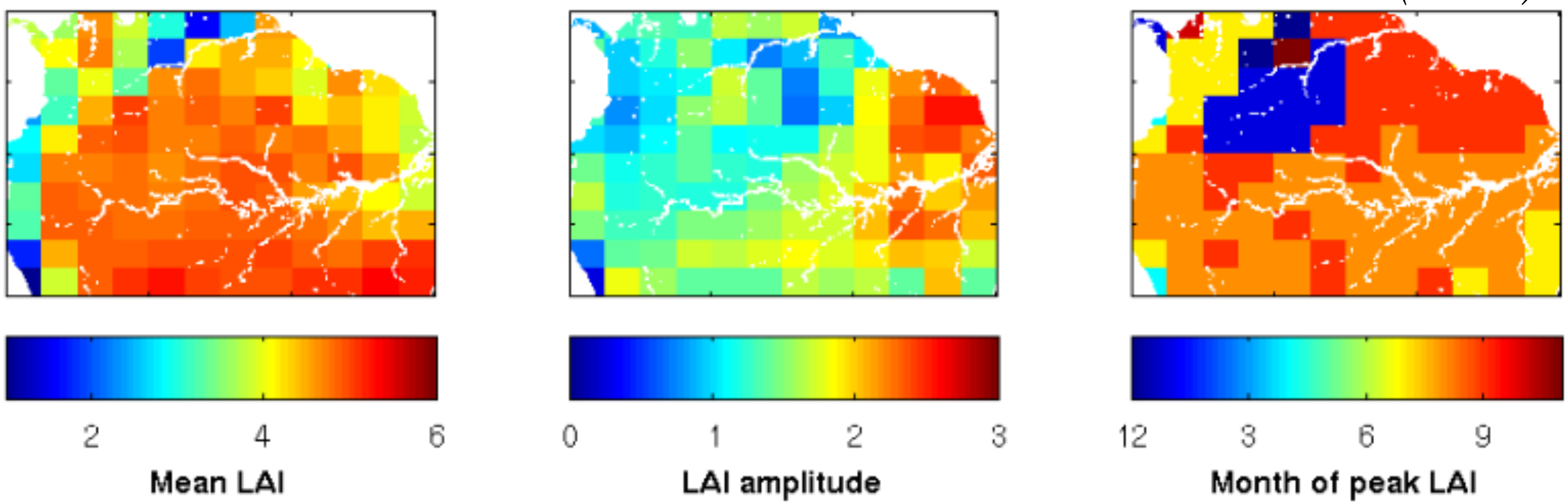
EVI is more anisotropic than NDVI. It needs a correction.

Seasonal cycles at basin's scale (MODIS data)

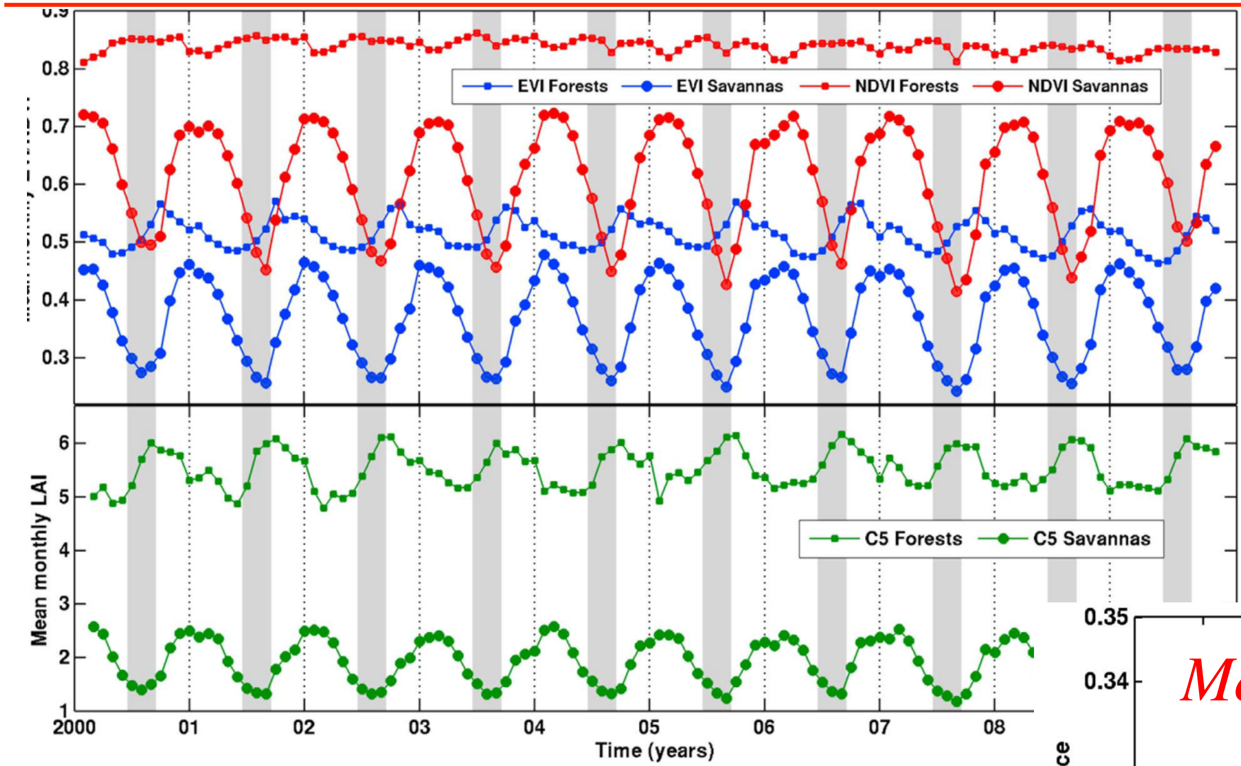


Samanta et al. (2012)

Caldararu et al. (2011)



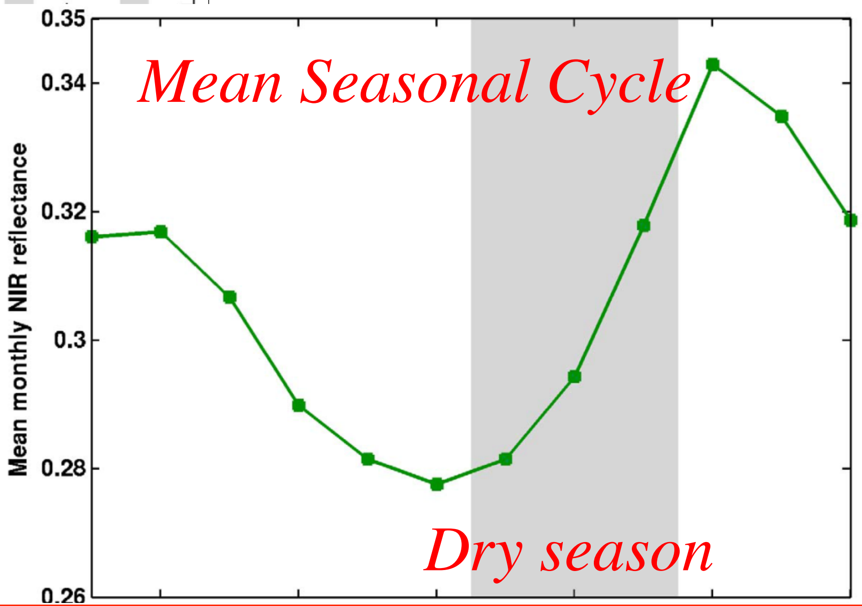
Greening during dry season



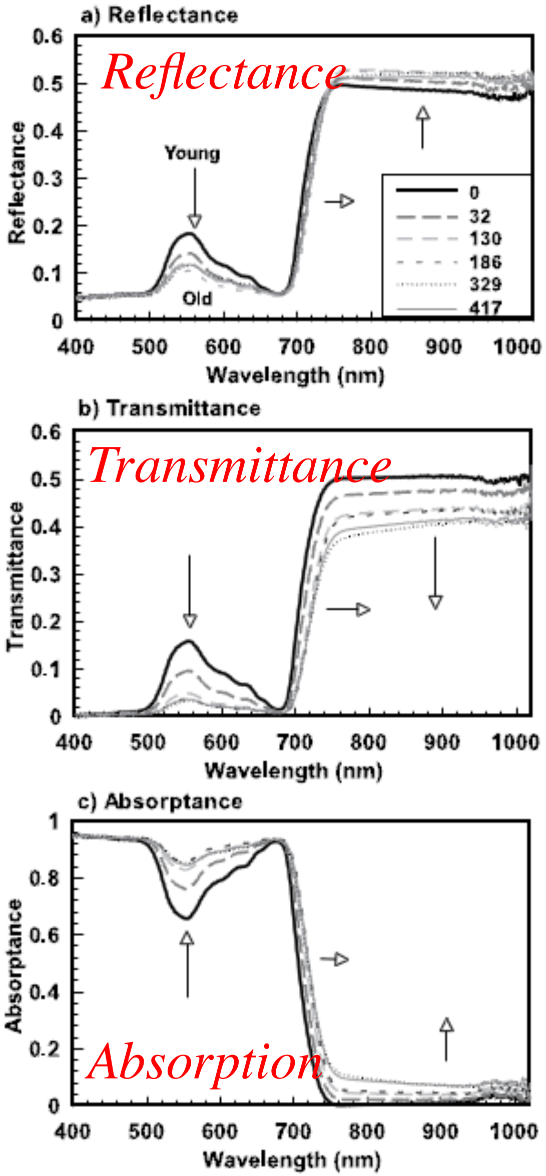
Monthly time series of EVI, NDVI and LAI over forests with statistically significant green-up of forest during dry season

Samanta et al. (2012)

Monthly NIR reflectance over Amazon forests, with statistically significant ***green-up from June to October****. The* ***dry season, July to September****, is shaded.*



Optical properties of leaves



over the first 6 months:

- *decreased transmittance and increased absorptance in the visible and NIR,*
- *decreased visible and increased NIR reflectance*

over the last 9 months:

- *increased NIR absorptance (epiphylls and necrosis)*

→ *decreased NIR reflectance at the canopy scale*

Roberts et al. (1998)

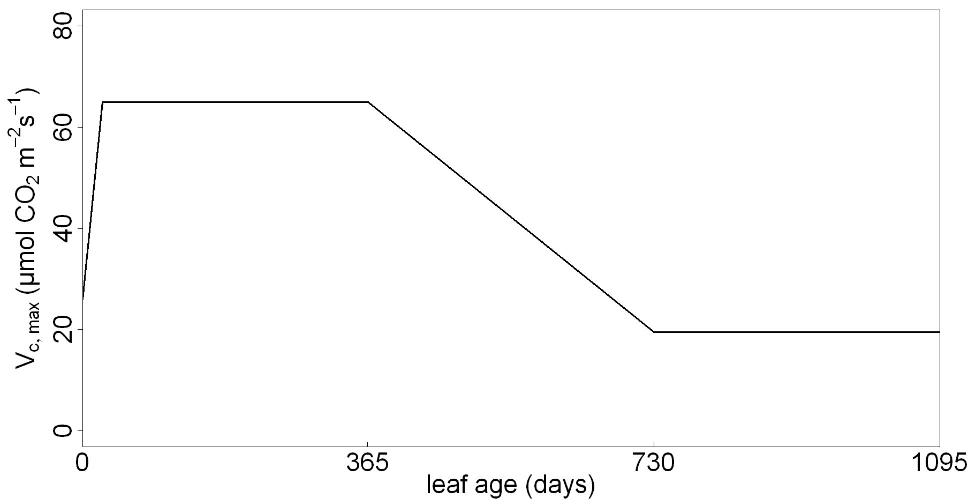
Understanding processes

EVI and LAI exhibit a peak during the dry season (<100 mm/month).

***Radiation** is the main driver of the Amazon forest seasonal dynamics.*

*Trees do not suffer from hydric stress during the dry season because they have **deep roots** to access water in deep soil.*

*At the end of the wet season, trees shed old leaves and produce **new leaves with higher photosynthetic capacities**.*



Example of a modeled leaf photosynthetic capacity ($V_{c,max}$) determined as a function of leaf age

de Weirdt et al. (2012)

*These results are in coherence with **in situ** measurements (FLUXNET, leaf litterfall) and **model** results.*

Ten relevant papers (among many)

Asner (1998): Biophysical and Biochemical Sources of Variability in Canopy Reflectance

Bradley et al. (2011): Relationships between phenology, radiation and precipitation in the Amazon region

Caldararu et al. (2011): Inferring Amazon leaf demography from satellite observations of leaf area index

de Almeida Castanho et al. (2012): Accounting for spatial variation in vegetation properties improves simulations of Amazon forest biomass and productivity in a global vegetation model

Galvao et al. (2012): View-illumination effects on hyperspectral vegetation indices in the Amazonian tropical forest

Phillips et al. (2008):The changing Amazon forest

Poulter and Cramer (2009): Satellite remote sensing of tropical forest canopies and their seasonal dynamics

Richardson et al. (2013): Climate change, phenology, and phenological control of vegetation feedbacks to the climate system

Roberts et al. (1998): Spectral changes with leaf aging in Amazon caatinga

Samanta et al. (2012): Seasonal changes in leaf area of Amazon forests from leaf flushing and abscission

Conclusions

Satellite remote sensing is a great tool for the monitoring of vegetation dynamic

Difficult data processing is necessary to extract quantitative information

- Cloud detection and rejection
- Correction for atmospheric absorption and scattering
- Normalization for directional effects

We have developed models and tools to quantify the directional signatures from reflectance time series.

Applications include phenology monitoring, crop yield estimate, and understanding of vegetation growth processes

Remote sensing data must be coupled with vegetation modelling for an estimate of parameters than cannot be observed (fluxes, underground biomass…)