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Information retrieval by implicit inversion

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Frascati, 3 August 2006

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Outline

1. Spectral signatures of vegetation and other geophysical media
2. Principles of optimal environmental indicator design
3. Optimal FAPAR estimation
4. Performance evaluation
5. Applications

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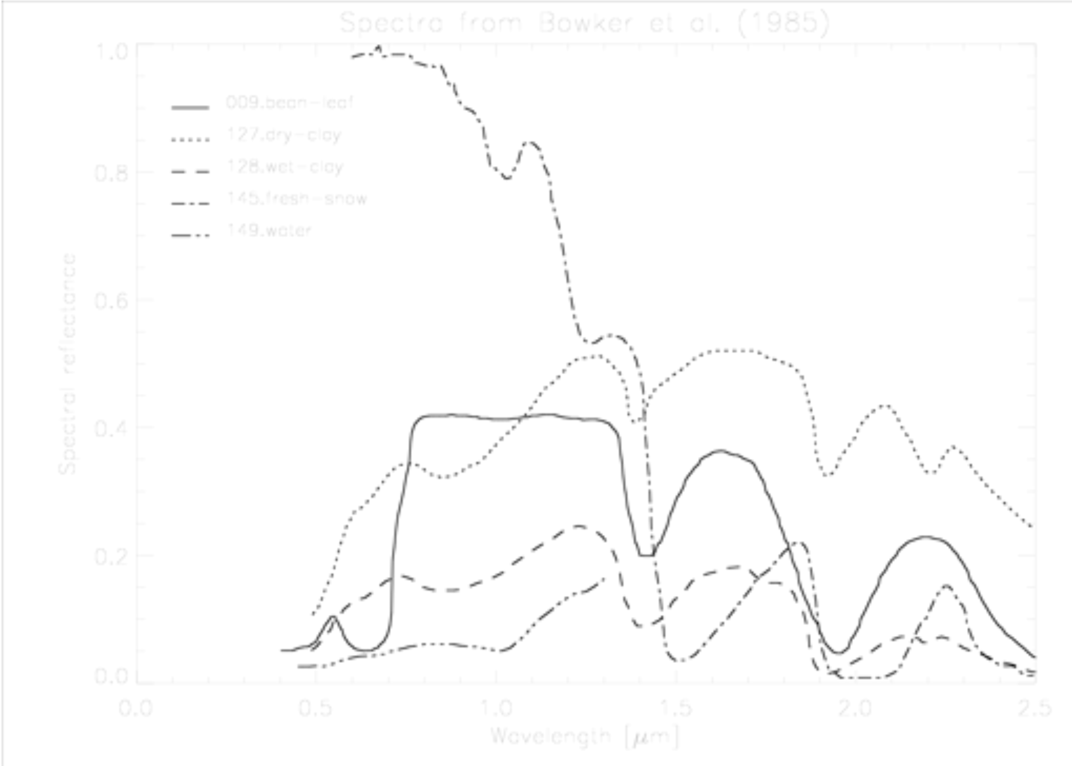
Typical surface spectral signatures

- Leaves
  - § Visible: pigment absorption
  - § NIR: cell structure
  - § MIR: water and cellulose absorption
- Soils
  - § chemical composition
  - § structure
  - § water content
- Water
  - § sediments
  - § dissolved organic matter
  - § chlorophyll
- Snow and ice
  - § grain size
  - § age



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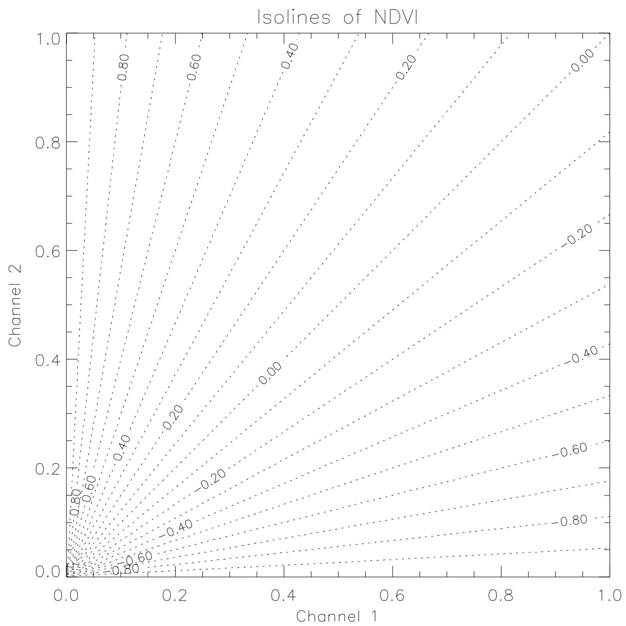
Normalized Difference Vegetation Index

- NDVI is defined as

$$NDVI = \frac{\rho_{NIR} - \rho_{RED}}{\rho_{NIR} + \rho_{RED}}$$

- where
  - § ρ_{RED} is the target reflectance in the red spectral band
  - § ρ_{NIR} is the target reflectance in the red spectral band
- Historically, NDVI
  - § was introduced to exploit early (2-bands) sensors such as ERTS and AVHRR
  - § is neither a geophysical variable nor optimized for any particular purpose



- Proper interpretation: The higher the NDVI, the higher the probability that the target contains vegetation

Limitations of vegetation indices

- NDVI is sensitive to various perturbing factors, including:
  - atmospheric constituents (aerosols, water vapor)
  - directional effects (targets are spectrally anisotropic)
  - soil color changes (e.g., as a function of water content)
- Numerous authors have attempted to modify the NDVI formula
  - Cottage industry of vegetation indices: PVI, SAVI, ARVI, and the like
  - These indices generally exhibit some improvement in one respect at the expense of some degradation in another respect
- Vegetation indices have been largely abused by attempting to correlate them with LAI, FAPAR, biomass, precipitations, herbivore density, etc
- When applied to data from different sensors, these formulae yield incompatible results because of differences in
  - orbits, time of passage at the Equator, Sun and view angles, etc
  - spectral bands, calibration and performances of various sensors
- All these drawbacks have long been exhaustively described in the literature
- The only rational approach to address all issues at once is to design quantitative indicators through a rational methodology

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Optimal VI design (0)

- For the purpose of demonstration only, consider a sensor with only 2 spectral bands (RED and NIR), such as AVHRR
- Require an indicator that is sensitive to the amount of vegetation and insensitive to the usual perturbing factors (soil wetness, atmospheric effects, etc)
- Show graphically the process of environmental indicator design (isoline bending) and the necessary compromises

Ref: Verstraete, M. M. and B. Pinty (1996) 'Designing optimal spectral indices for remote sensing applications', IEEE Transactions on Geoscience and Remote Sensing, 34, 1254-1265.

Optimal VI design (1)

- Idealized full canopy:
  - full absorption in the RED
  - full reflection in the NIR
- Formula:

$$IVI_1 = \sqrt{\rho_{RED}^2 + (1 - \rho_{NIR})^2}$$

- Remaining issues:
  - index diminishes with vegetation amount

$$IVI_1 = 1 - \sqrt{\rho_{RED}^2 + (1 - \rho_{NIR})^2}$$

  - Isolines are equally spaced but physics tells us of non-linear reflectance response to vegetation amount

Ref: Verstraete, M. M. and B. Pinty (1996) 'Designing optimal spectral indices for remote sensing applications', IEEE Transactions on Geoscience and Remote Sensing, 34, 1254-1265.

Optimal VI design (2)

- Idealized full canopy:
  - Non-linear index to ensure linear response to variable of interest
- Formula:

$$IVI_2 = \frac{1}{\rho_{RED}^2 + (1 - \rho_{NIR})^2}$$

- Remaining issue:
  - Vegetation is not perfectly absorbing in the RED or reflecting in the NIR

Ref: Verstraete, M. M. and B. Pinty (1996) 'Designing optimal spectral indices for remote sensing applications', IEEE Transactions on Geoscience and Remote Sensing, 34, 1254-1265.

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Optimal VI design (3)

- Realistic full canopy:
  - Typical reflectance and absorption coefficients
- Formula:

$$IVI_3 = \frac{1}{(c_r - \rho_{RED})^2 + (c_n - \rho_{NIR})^2}$$

- Remaining issue:
  - What about sensitivity to soil changes?

Ref: Verstraete, M. M. and B. Pinty (1996) 'Designing optimal spectral indices for remote sensing applications', IEEE Transactions on Geoscience and Remote Sensing, 34, 1254-1265.

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Optimal VI design (4)

- Insensitivity to soil (only):
  - § Wet soils darken in both spectral bands about equally
- Formula:

$$IVI_4 = \rho_{NIR} - \rho_{RED}$$

- Remaining issue:
  - § Combine sensitivity to vegetation and insensitivity to soil changes

Ref: Verstraete, M. M. and B. Pinty (1996) 'Designing optimal spectral indices for remote sensing applications', IEEE Transactions on Geoscience and Remote Sensing, 34, 1254-1265.

Optimal VI design (5)

- Optimal index for both vegetation and soils:
  - Product of IVI3 and PVI
- Formula:

$$IVI_5 = \frac{PVI}{(c_r - \rho_{RED})^2 + (c_n - \rho_{NIR})^2}$$

where

$$PVI = \frac{1}{\sqrt{a^2 + 1}}(\rho_{NIR} - a\rho_{RED} - b)$$

is the Perpendicular Vegetation Index

- Remaining issue:
  - What about sensitivity to atmospheric effects?

Ref: Verstraete, M. M. and B. Pinty (1996) 'Designing optimal spectral indices for remote sensing applications', IEEE Transactions on Geoscience and Remote Sensing, 34, 1254-1265.

Optimal VI design (6)

- Insensitivity to water vapour (only):
  - Atmospheric humidity affects only the NIR channel
- Formula:

$$IVI_6 = 1.0 - 0.22\rho_{RED}$$

- Remaining issue
  - Combining all requirements so far

Ref: Verstraete, M. M. and B. Pinty (1996) 'Designing optimal spectral indices for remote sensing applications', IEEE Transactions on Geoscience and Remote Sensing, 34, 1254-1265.

Optimal VI design (7)

- Optimal index for:
  - maximum sensitivity to vegetation
  - minimum sensitivity to soils and water vapour
- Formula:

$$IVI_7 = \frac{PVI \times (1.0 - 0.22\rho_{RED})}{(c_r - \rho_{RED})^2 + (c_n - \rho_{NIR})^2}$$

- Remaining issue:
  - What about sensitivity to aerosols?
  - etc…

Ref: Verstraete, M. M. and B. Pinty (1996) 'Designing optimal spectral indices for remote sensing applications', IEEE Transactions on Geoscience and Remote Sensing, 34, 1254-1265.

Summary of requirements and constraints

- Scientific requirements
  - § Generate a product highly sensitive to a specific vegetation property
    - well-identified, carefully selected biophysical variable (FAPAR, LAI, biomass, height…)
    - measurable in the field
    - directly usable in a model or application
    - with a documented accuracy
  - § Generate a product as insensitive as possible to perturbing processes
    - atmospheric effects (e.g., aerosols and gaseous constituents)
    - directional effects
    - soil composition, texture and water content
  - § Design a family of compatible algorithms
    - each optimized for a particular platform and sensor (SeaWiFS, MERIS, VGT, MISR, MODIS, …)
    - generating demonstrably coherent products
- Operational constraints
  - § Limited computational load
  - § Estimation on the basis of simultaneous spectral measurements only
  - § Taking full account of the specifications of each platform and sensor
  - § Suitable to monitor vegetation changes in space or in time

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Practical implementation

- Selection of the biogeophysical variable:
  - LAI: Leaf Area Index (m^2 m^{-2})
  - Difficulties in estimating LAI, saturation
  - PAR: Photosynthetically Active Radiation (~400 to 700 nm)
  - FAPAR: Fraction of Absorbed Photosynthetically Active Radiation
  - Measure of plant productivity, mostly in top canopy layer
- Instruments:
  - SeaWiFS (1997-2005)
  - MERIS (2002-present)
  - others: MISR, MODIS, VEGETATION, GLI, etc
- Assumptions:
  - Blue channel to correct for atmospheric effects (mostly aerosols)
  - Canopy anisotropy represented by standard RT models
  - Soil types represented by a database of typical values

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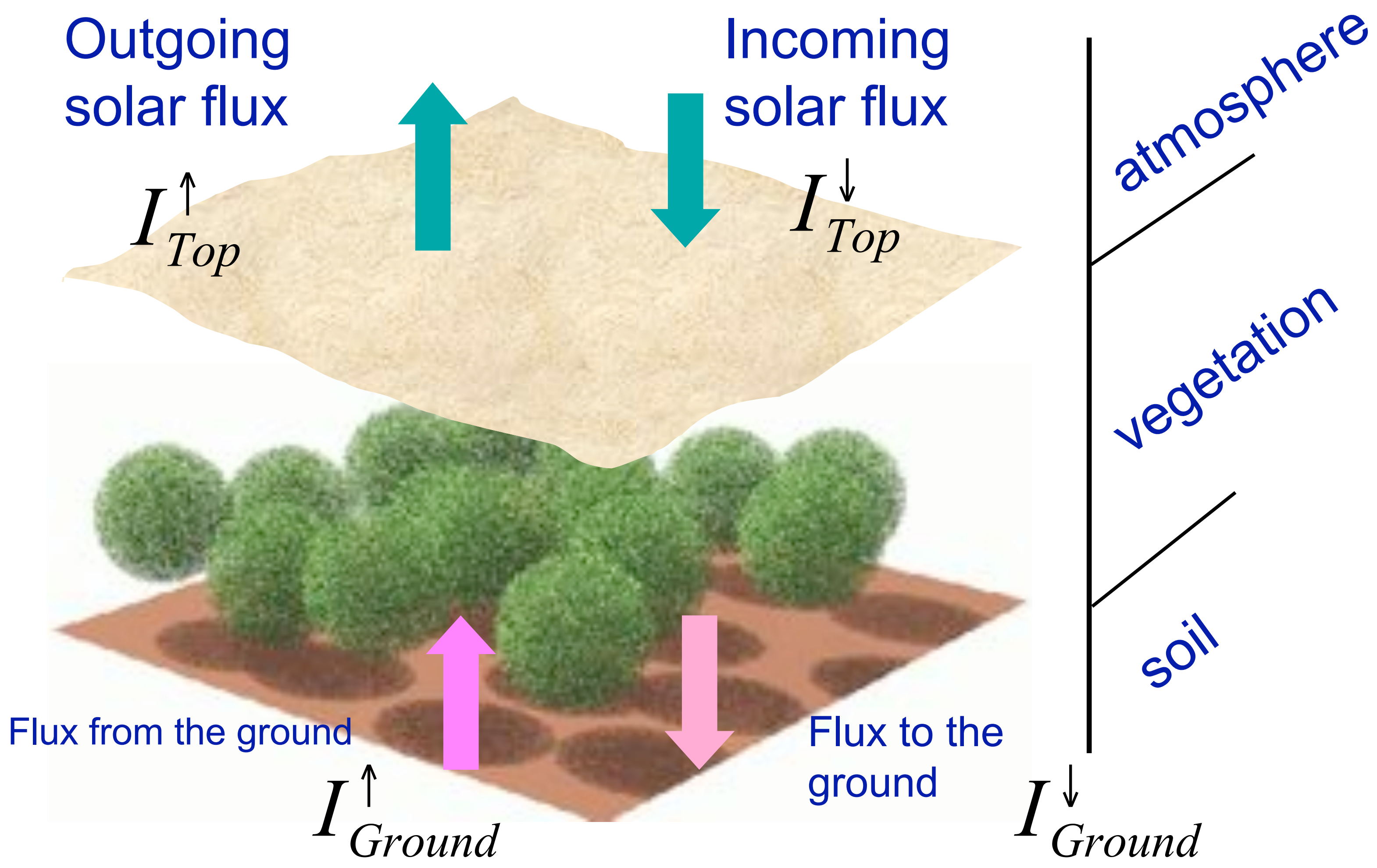
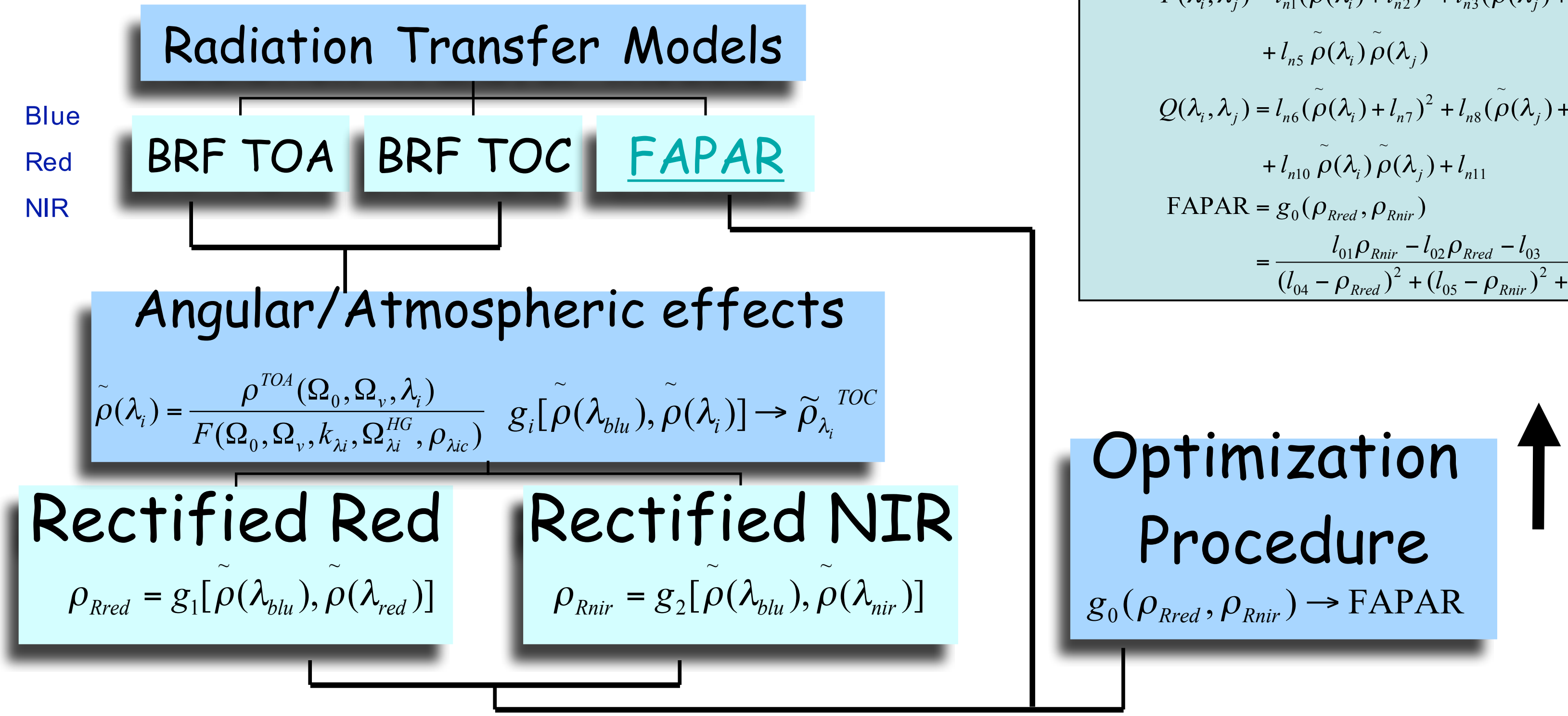
What is FAPAR?



$$FAPAR = ((I^{\downarrow}_{Top} + I^{\uparrow}_{Ground}) - (I^{\downarrow}_{Ground} + I^{\uparrow}_{Top})) / I^{\downarrow}_{Top}$$

Algorithm optimization



$$g_n[\tilde{\rho}(\lambda_i), \tilde{\rho}(\lambda_j)] = P(\lambda_i, \lambda_j) / Q(\lambda_i, \lambda_j)$$

$$P(\lambda_i, \lambda_j) = l_{n1}(\tilde{\rho}(\lambda_i) + l_{n2})^2 + l_{n3}(\tilde{\rho}(\lambda_j) + l_{n4})^2 + l_{n5}\, \tilde{\rho}(\lambda_i)\, \tilde{\rho}(\lambda_j)$$

$$Q(\lambda_i, \lambda_j) = l_{n6}(\tilde{\rho}(\lambda_i) + l_{n7})^2 + l_{n8}(\tilde{\rho}(\lambda_j) + l_{n9})^2 + l_{n10}\, \tilde{\rho}(\lambda_i)\, \tilde{\rho}(\lambda_j) + l_{n11}$$

$$\mathrm{FAPAR} = g_0(\rho_{Rred}, \rho_{Rnir}) = \frac{l_{01}\rho_{Rnir} - l_{02}\rho_{Rred} - l_{03}}{(l_{04} - \rho_{Rred})^2 + (l_{05} - \rho_{Rnir})^2 + l_{06}}$$

Ref: Verstraete and Pinty (1996) and Gobron et al. (2000), IEEE TGRS

Accuracy improvement (1)

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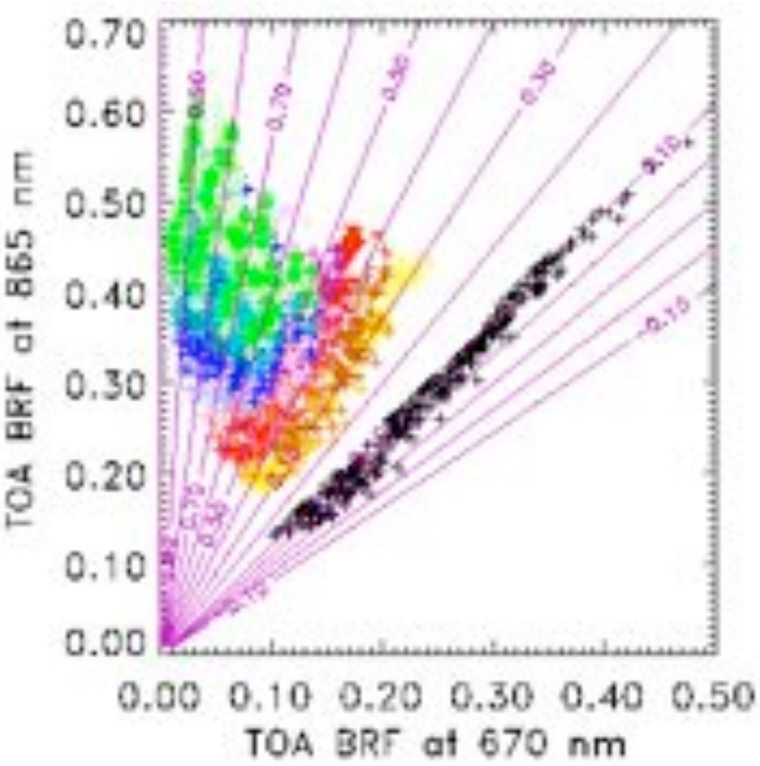
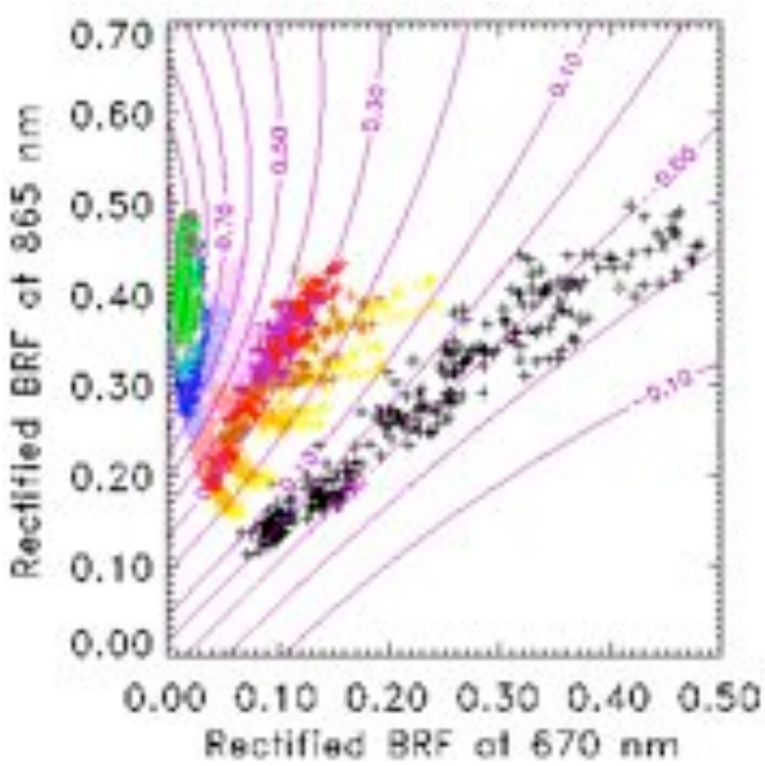
NDVI **VGT** **OVNI**

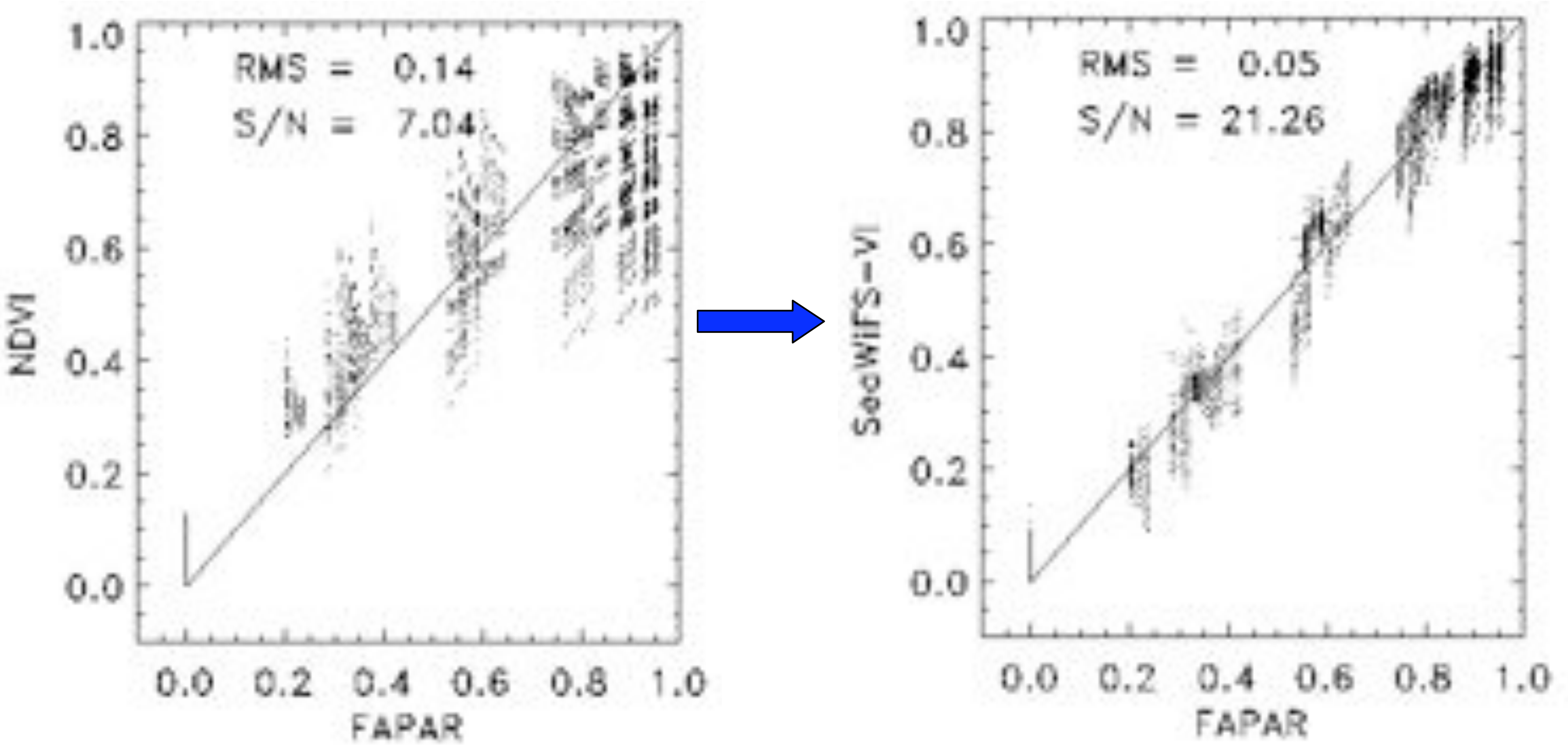




Ref: Gobron et al. (2000), IEEE TGRS

Accuracy improvement (2)

NDVI **SeaWiFS** **SGVI**



Ref: Gobron et al. (2000), IEEE TGRS

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Algorithm utilization

Satellite Data

Blue
Red
NIR

BRF TOA

Observation

Sun

Angular/Atmospheric `Rectification'

$$\tilde{\rho}(\lambda_i) = \frac{\rho^{TOA}(\Omega_0,\Omega_v,\lambda_i)}{F(\Omega_0,\Omega_v,k_{\lambda i},\Omega^{HG}_{\lambda i},\rho_{\lambda ic})}$$

Rectified Red

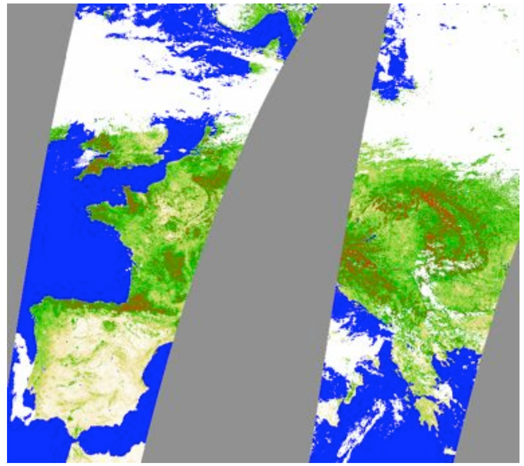
$$\rho_{Rred} = g_1[\tilde{\rho}(\lambda_{blu}),\tilde{\rho}(\lambda_{red})]$$

Rectified NIR

$$\rho_{Rnir} = g_2[\tilde{\rho}(\lambda_{blu}),\tilde{\rho}(\lambda_{nir})]$$

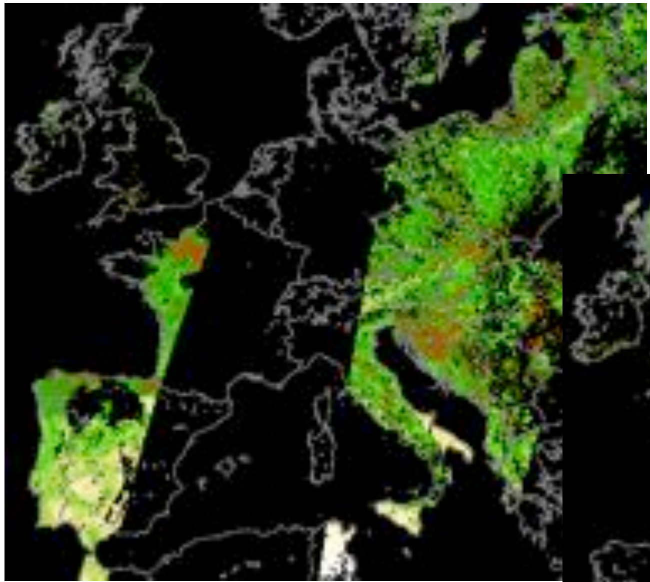
Compute Fapar

$$FAPAR = g_0(\rho_{Rred},\rho_{Rnir})$$

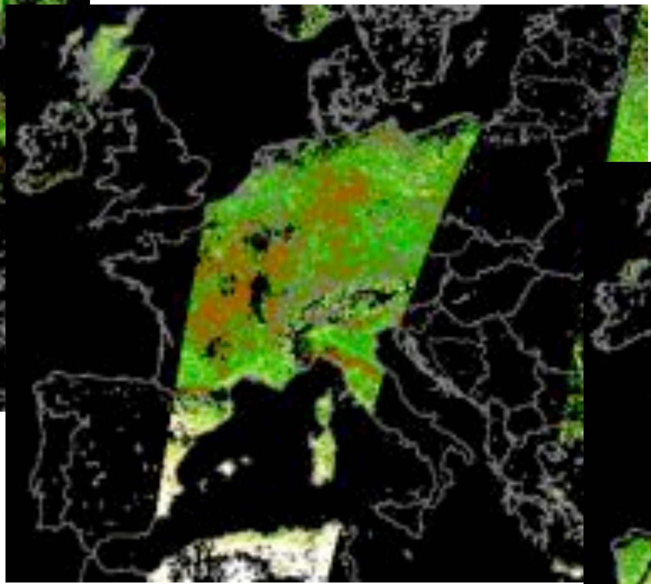


Ref: Gobron et al. (2000), IEEE TGRS

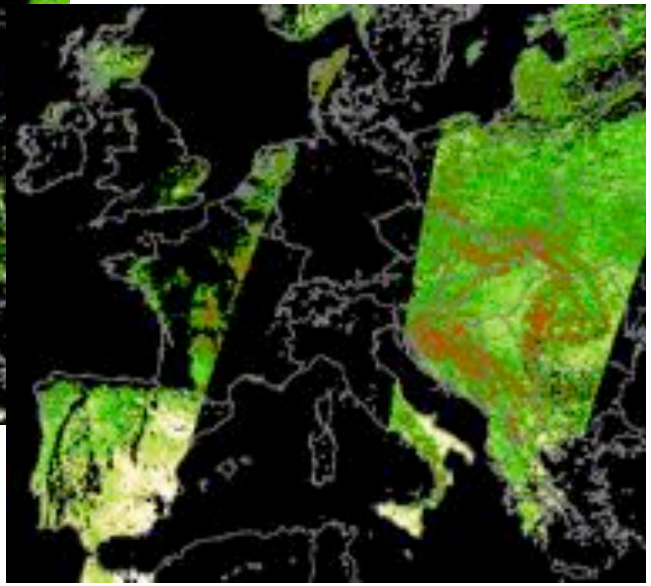
Daily observations



1 June 2000

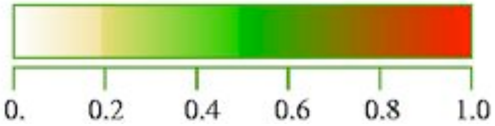


2 June 2000



3 June 2000

FAPAR:



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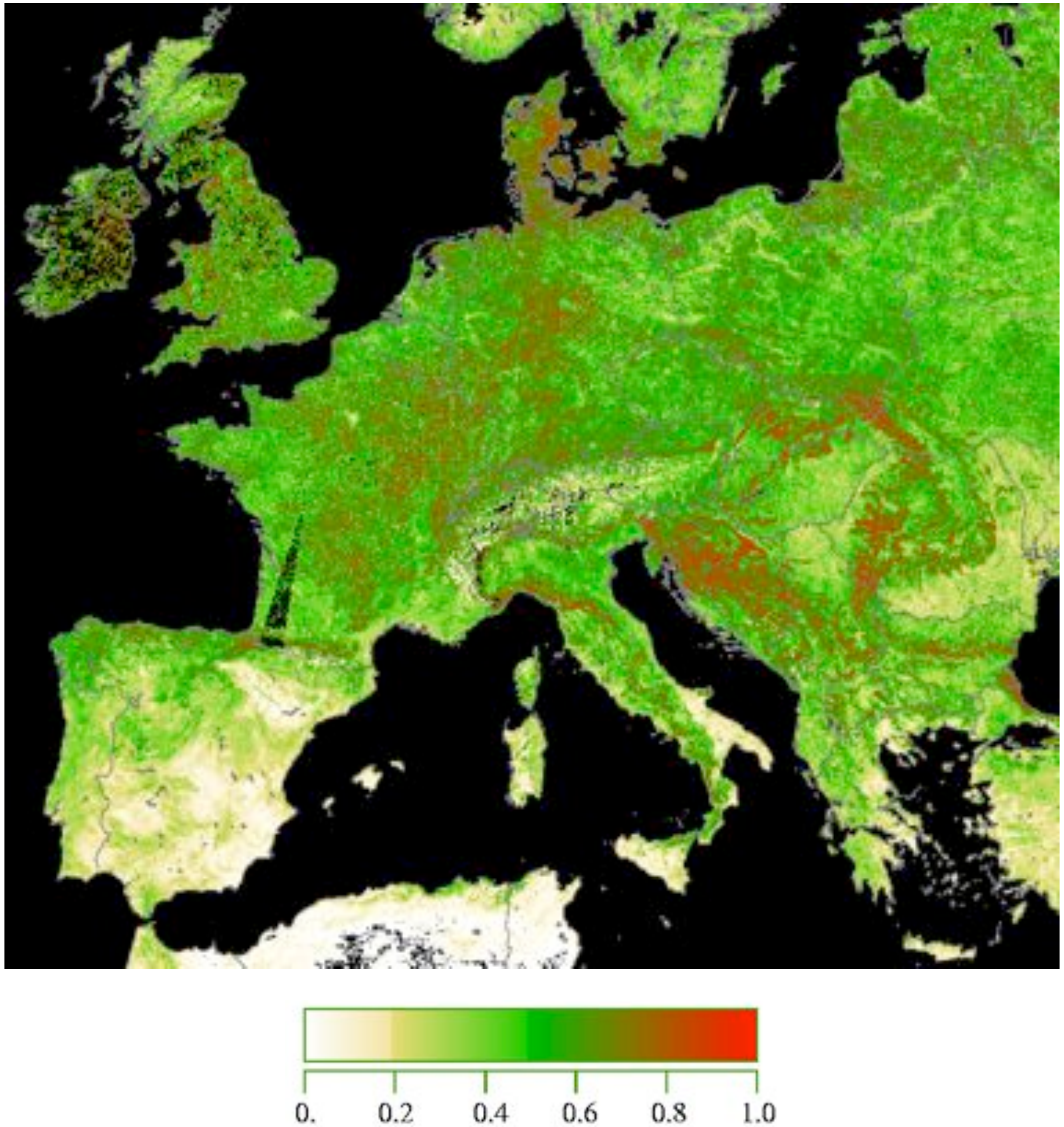
Decadal composite



1 – 10 June 2000

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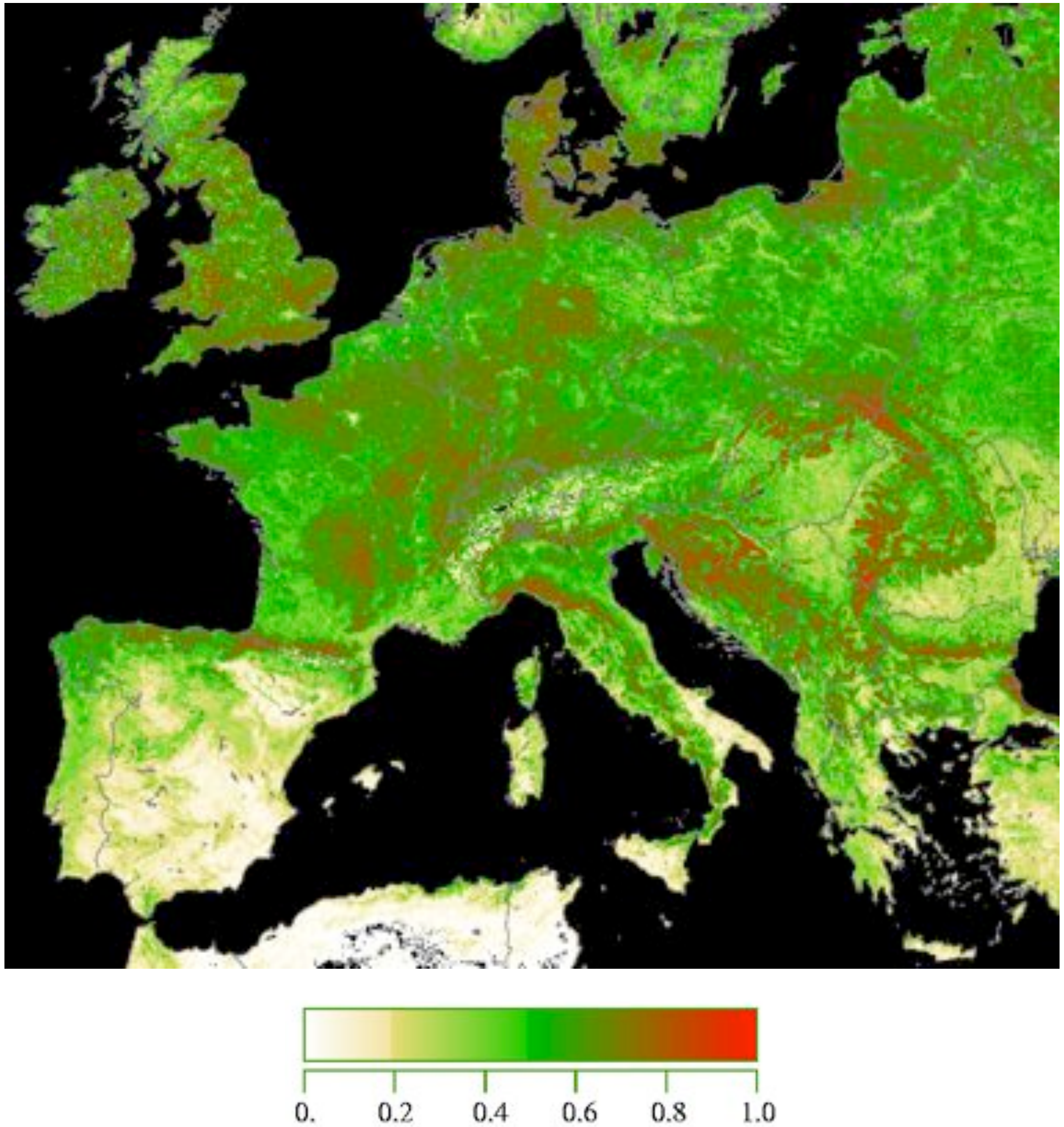
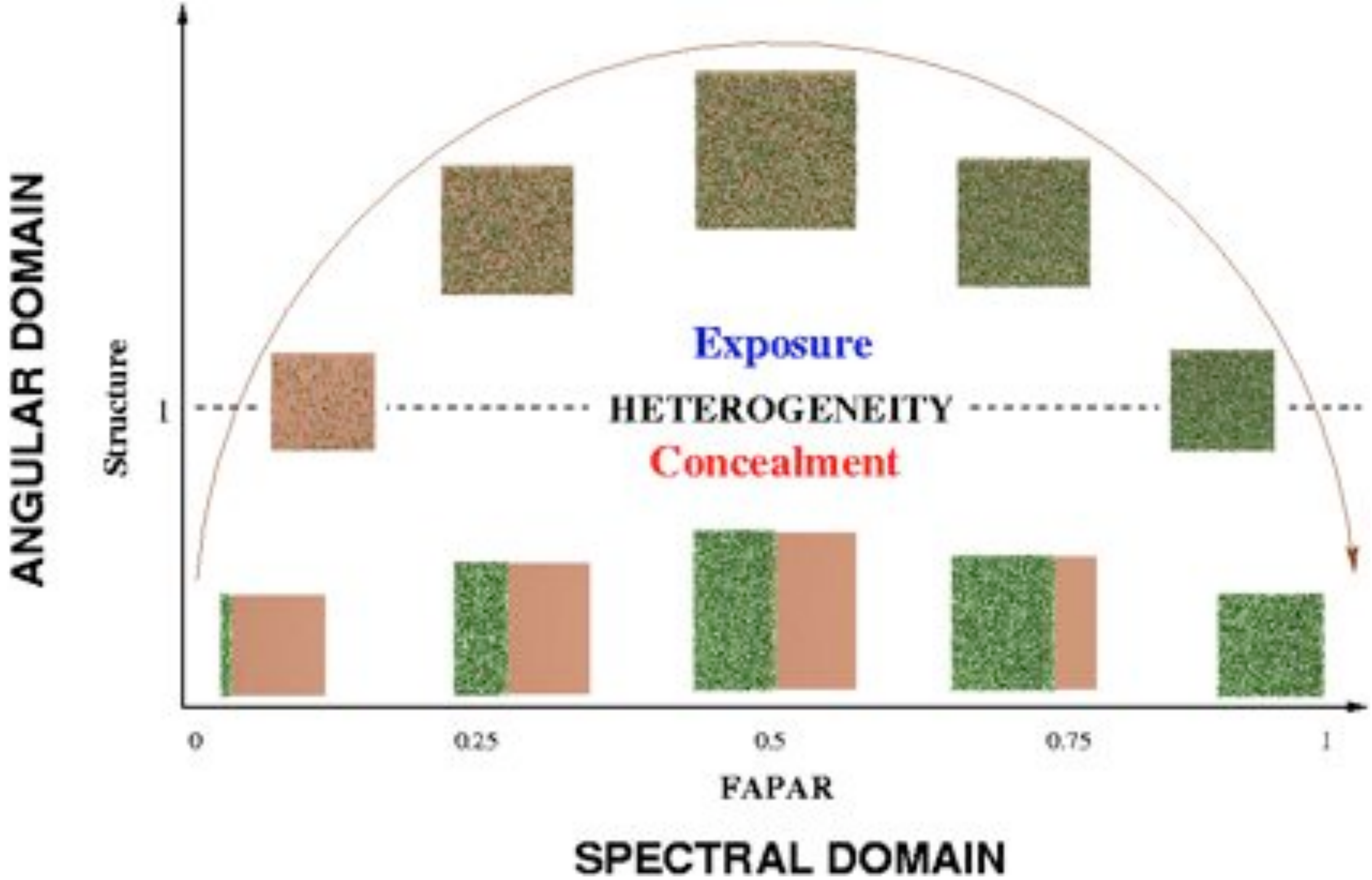
Monthly composite



1 – 30 June 2000

Using spectral and directional information



Ref: Pinty, B. et al. (2002) 'Uniqueness of Multiangular Measurements, Part 1: An Indicator of Subpixel Surface Heterogeneity from MISR', *IEEE Transactions on Geoscience and Remote Sensing*, MISR Special Issue, **40**, 1560-1573.

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MERIS FAPAR product

esa

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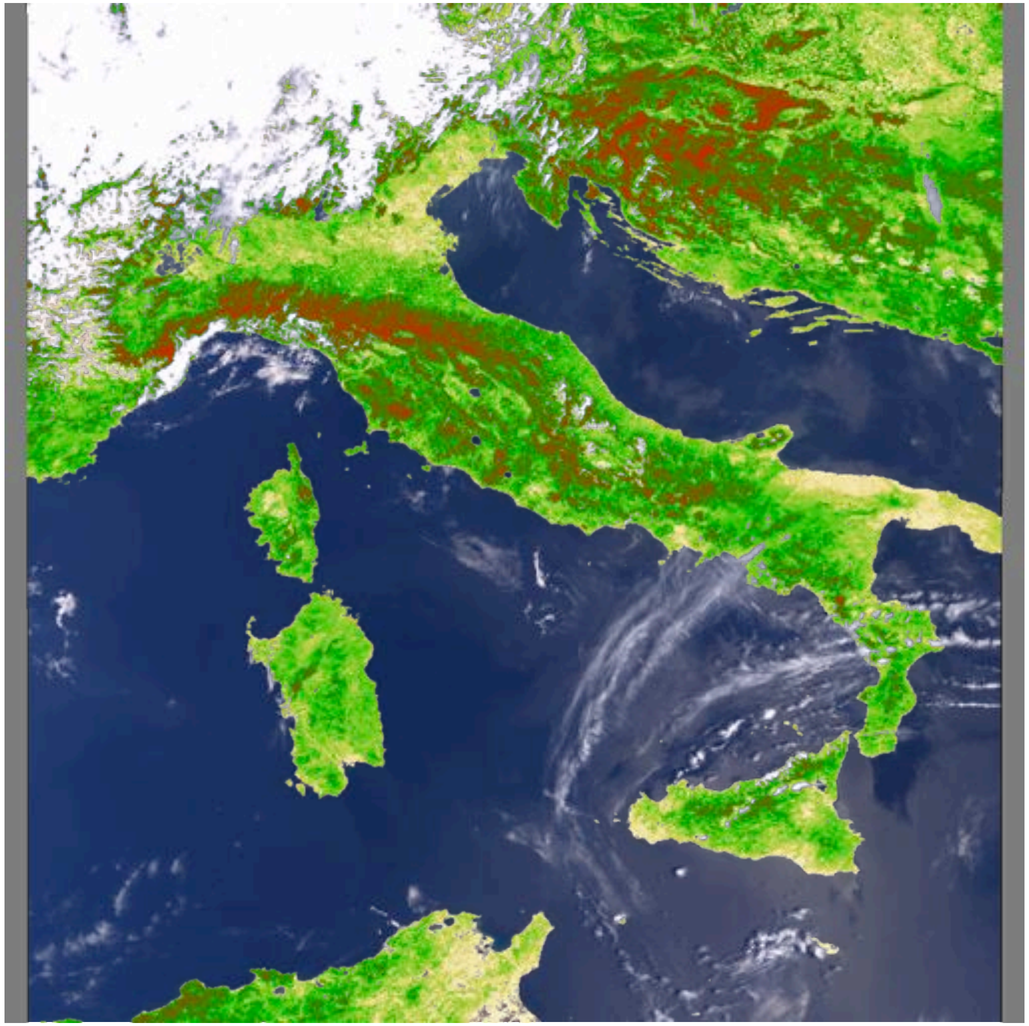
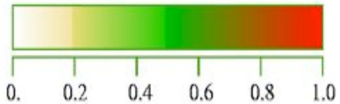
CARING FOR THE EARTH



FAPAR
Fraction of Absorbed Photosynthetically Active Radiation



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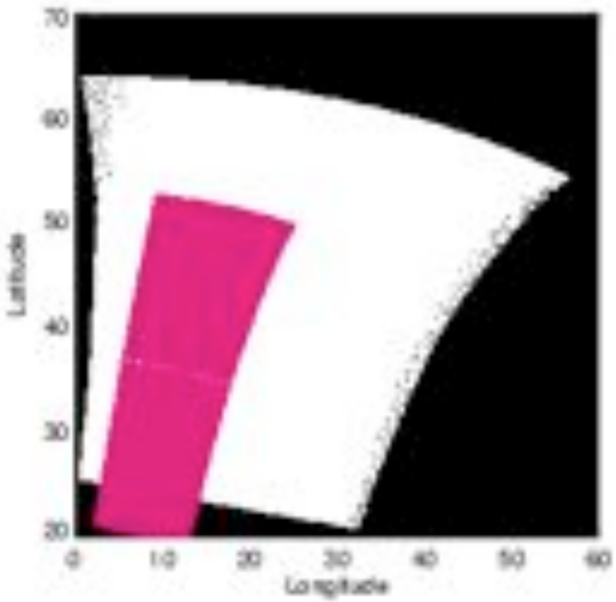
FAPAR products comparison

03 August 2002



Ref: Gobron, N. et al. (2002) 'MERIS Land Algorithm: preliminary results', in *Proceedings of the ENVISAT Validation Workshop*, Frascati, Italy, ESA **SP 53**.

Remapping: MERIS → SeaWiFS

9:32

9:43

MERIS browse

Geographical domain sampled by both MERIS & SeaWiFS

MERIS data re-mapped into the SeaWiFS orbit

11:12

11:23

SeaWiFS browse

MERIS vs. SeaWiFS

Orbit 1579

@ 09:48

(Push-broom)

SeaWiFS

@ 11:17

(Scanner)

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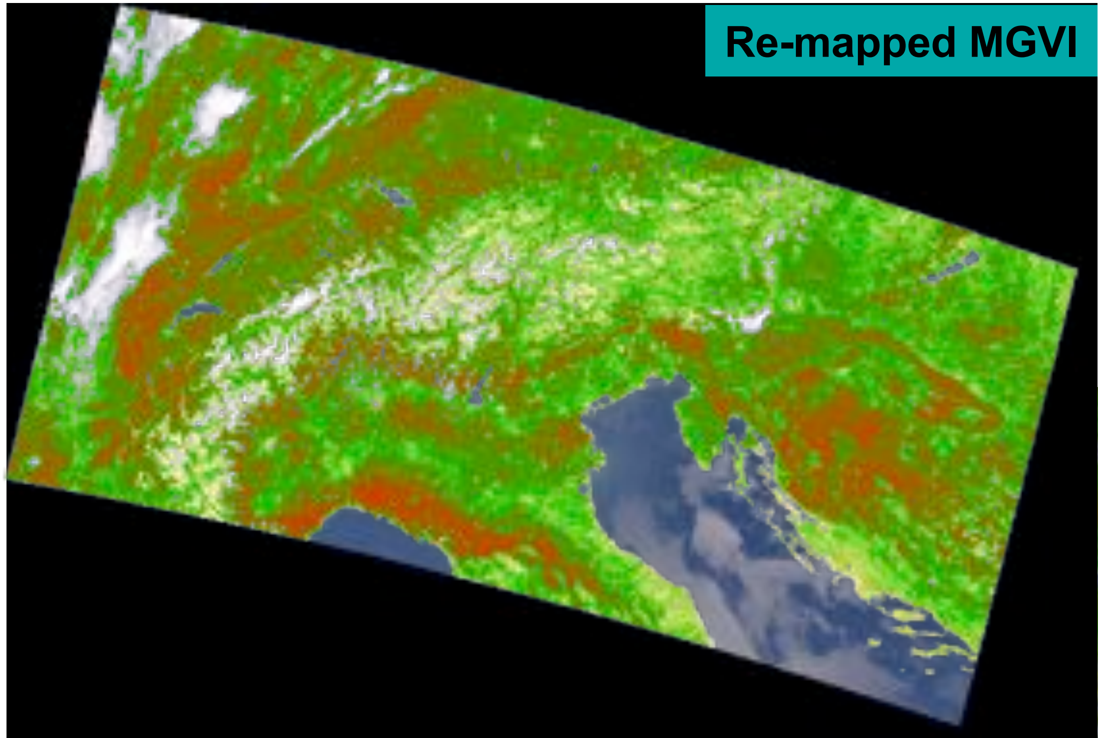
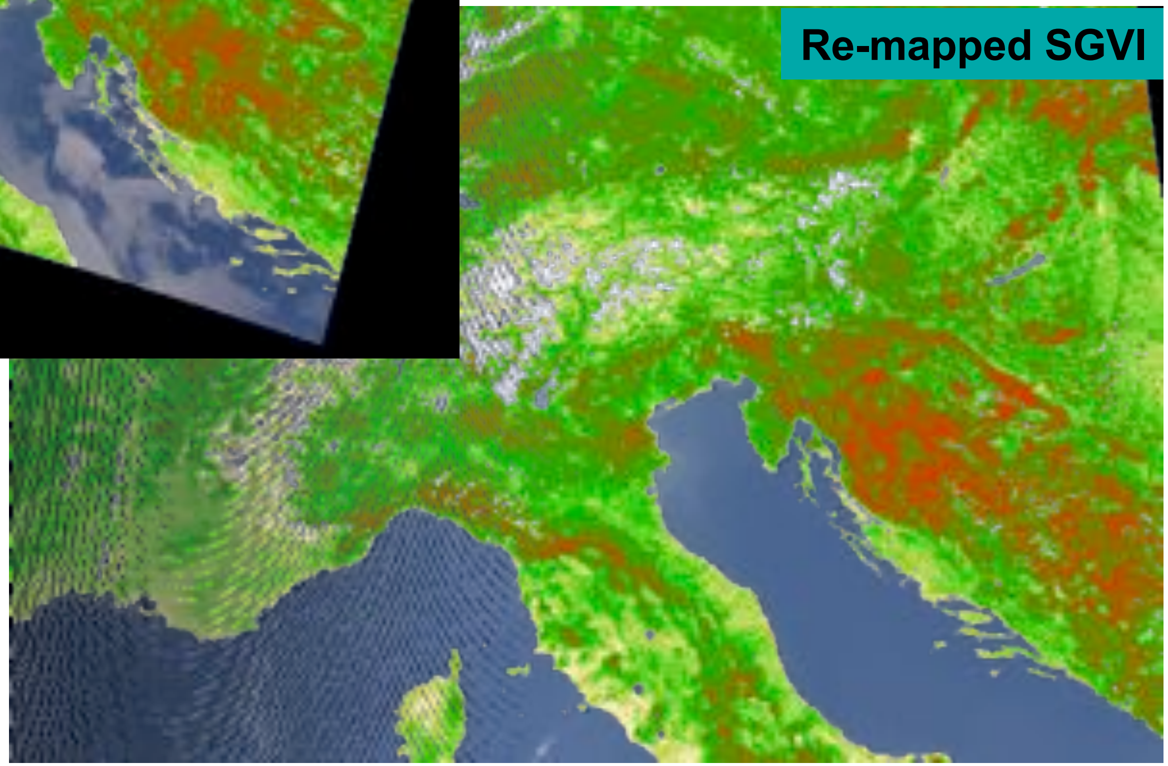
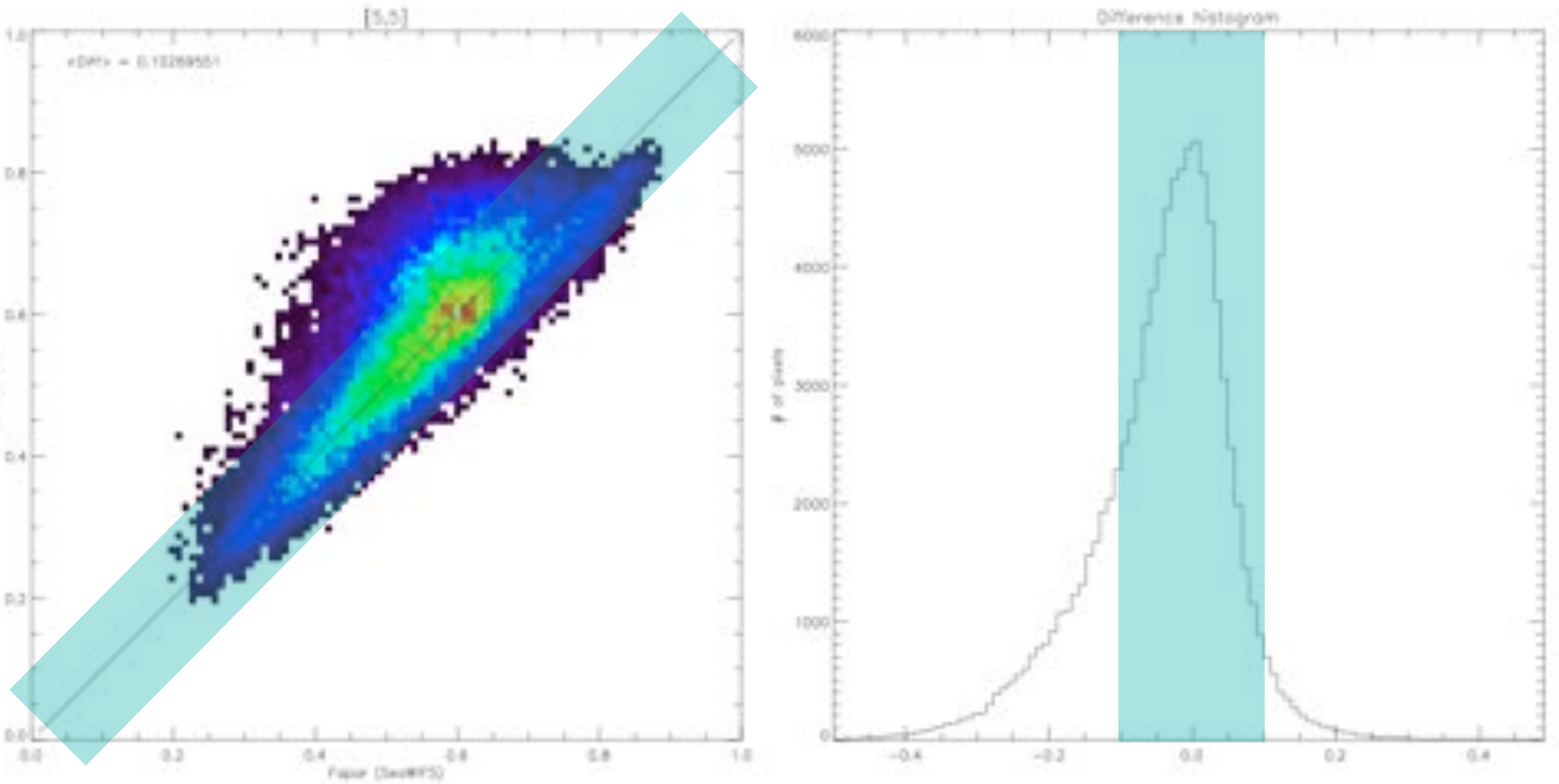
MGVI vs. SGVI (1)

2002/06/19





MGVI vs. SGVI (2)



2002/06/19

Ref: Gobron, N. et al. (2002) 'MERIS Land Algorithm: preliminary results', in *Proceedings of the ENVISAT Validation Workshop*, Frascati, Italy, ESA **SP 53**.

MGVI vs. SGVI (3)

Ref: Gobron et al. , 2003, EUR Report 20764 EN.

MGVI vs. SGVI (4)

Ref: Gobron et al. , 2003, EUR Report 20764 EN.

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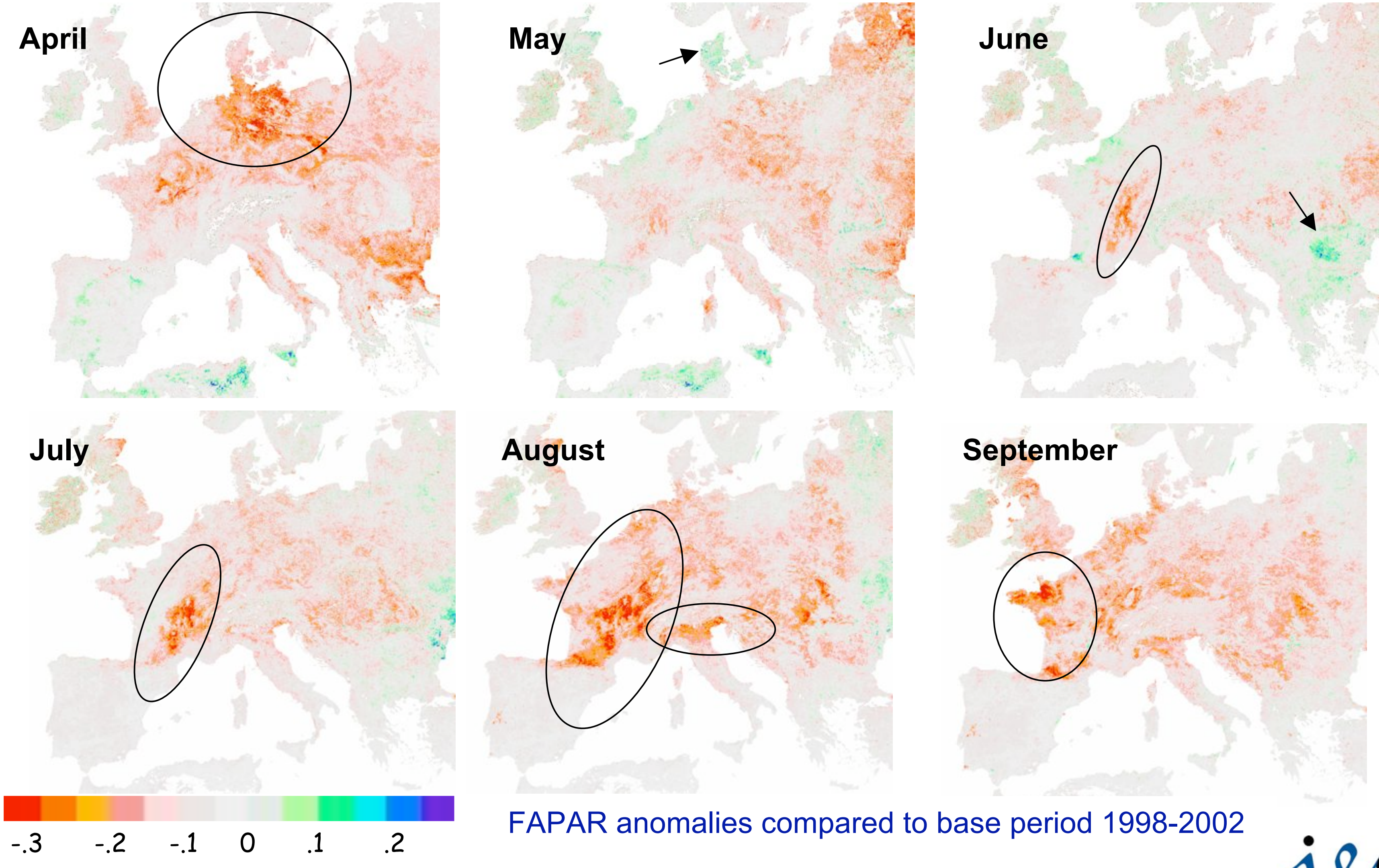
2003 European drought detection (1)



FAPAR anomalies compared to base period 1998-2002

Ref: Gobron, N. et al. (2005) 'The state of vegetation in Europe following the 2003 drought', *International Journal of Remote Sensing*, **26**, 2013-2020.

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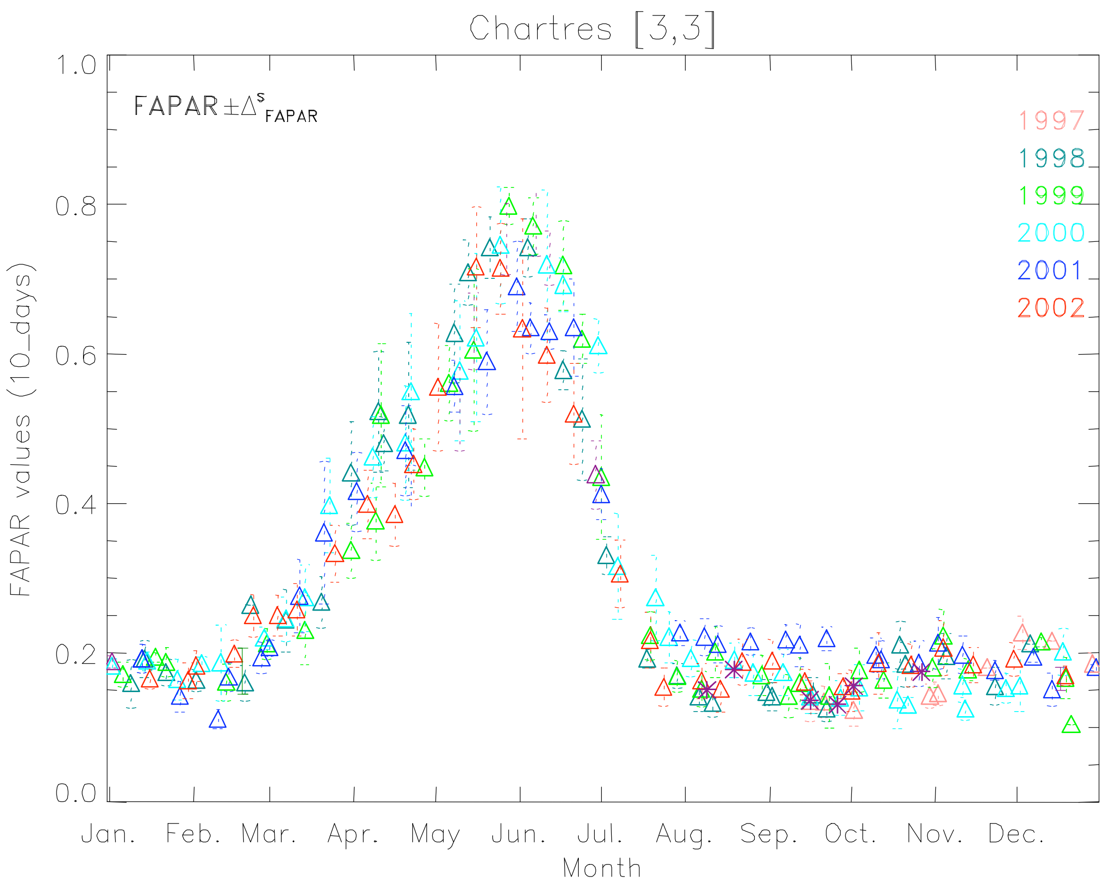
2003 European drought detection (2)



Ref: Gobron, N. et al. (2005) 'The state of vegetation in Europe following the 2003 drought', *International Journal of Remote Sensing*, **26**, 2013-2020.

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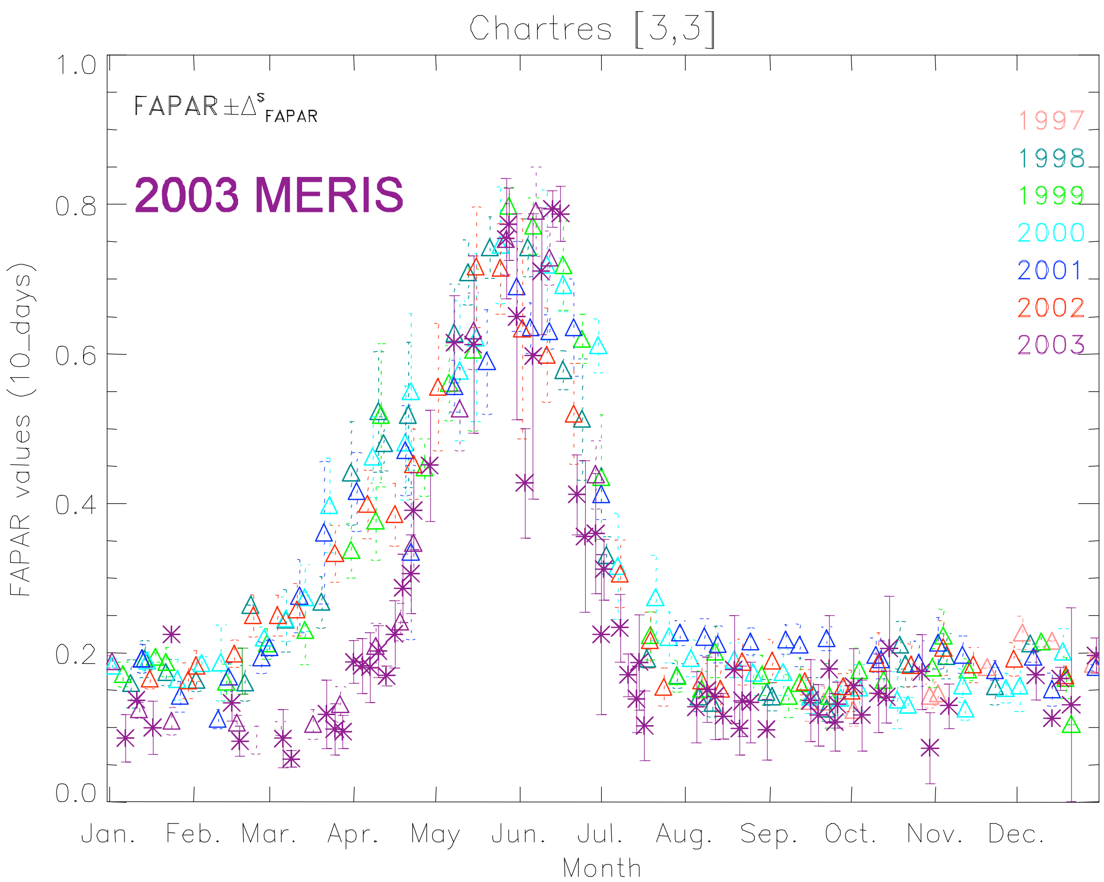
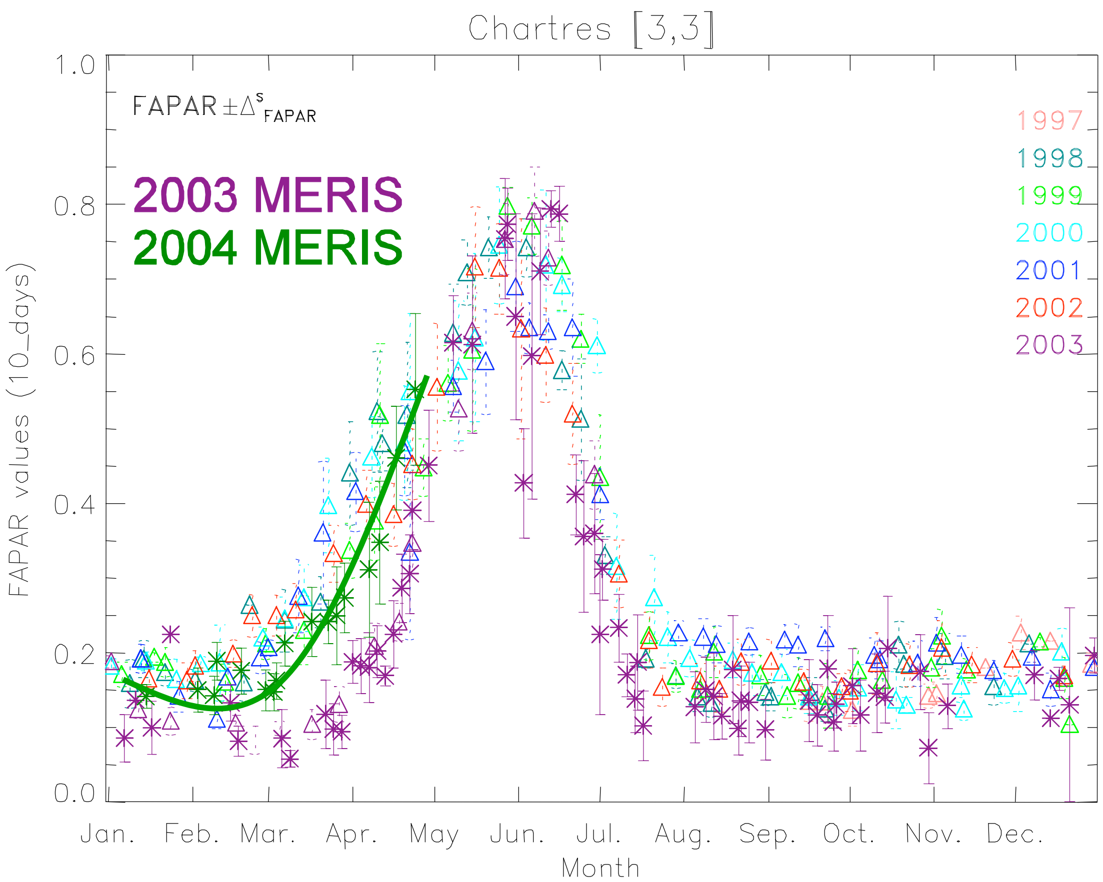
2003 European drought detection (3)



Ref: Gobron, N. et al. (2005) 'The state of vegetation in Europe following the 2003 drought', *International Journal of Remote Sensing*, **26**, 2013-2020.

2003 European drought detection (4)



Ref: Gobron, N. et al. (2005) 'The state of vegetation in Europe following the 2003 drought', *International Journal of Remote Sensing*, **26**, 2013-2020.

Characterizing growing seasons (1)

- Objectives:
  - Detect if the observed ecosystem exhibits a seasonal pattern or not
  - Objectively quantify the start and end of each growing season
- Challenges:
  - Missing values
  - No or multiple growing seasons per year
  - Unexpected events (e.g., fire)
- Approach:
  - Fit S-shaped curves through the data for successive positions of a moving window, then analyze the results
- Outcomes:
  - Estimates of start, end and length of growing season each year
  - Additional environmental indicators: value of FAPAR at the peak of the season and integrated value over the season

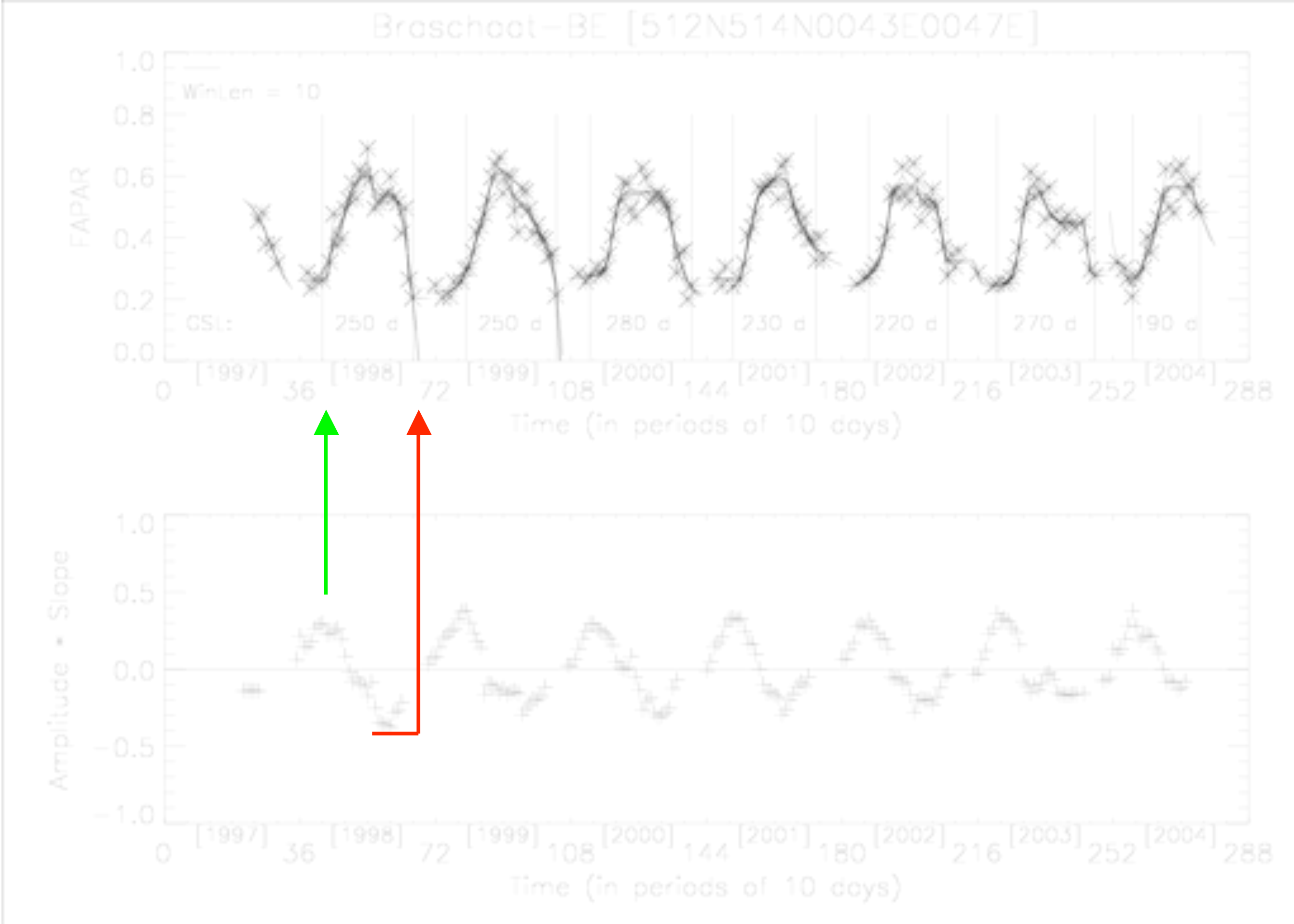
Characterizing growing seasons (2)

- Parametric sigmoid model:

$$y = \frac{a}{1 + \exp(-b(x - c))} + d$$

- Definitions:
  - § The start of the growing season is deemed to occur, within a given 12-month period, on the first decade with valid FAPAR observations within the moving window period for which the absolute value of the model amplitude parameter *a* is maximal and the slope parameter *b* is positive
  - § The end of the growing season is deemed to occur, within a given 12-month period, on the last decade with valid FAPAR observations within the moving window period for which the absolute value of the model amplitude parameter *a* is maximal and the slope parameter *b* is negative

Characterizing growing seasons (3)



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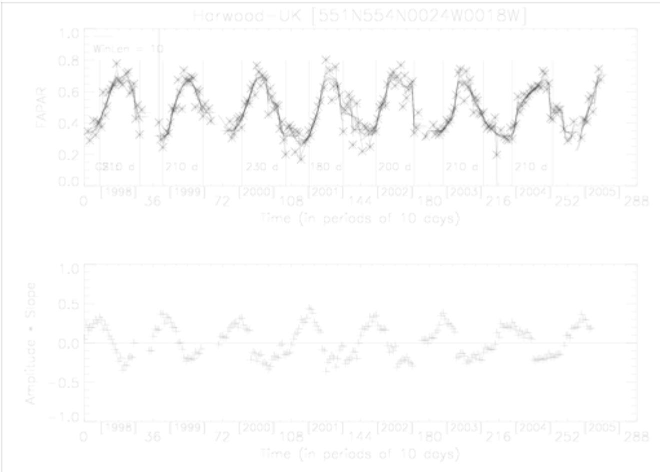
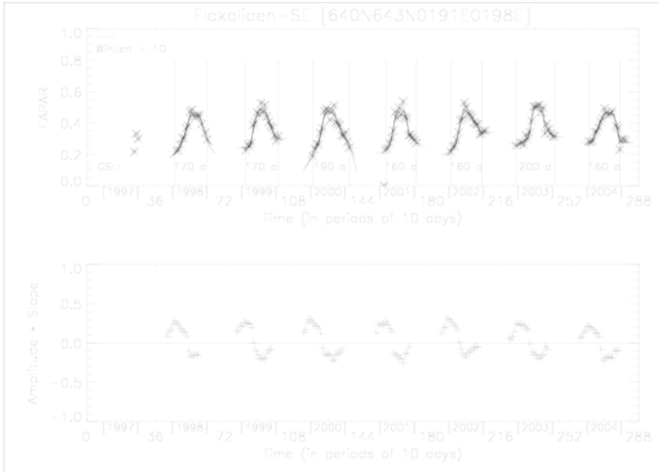
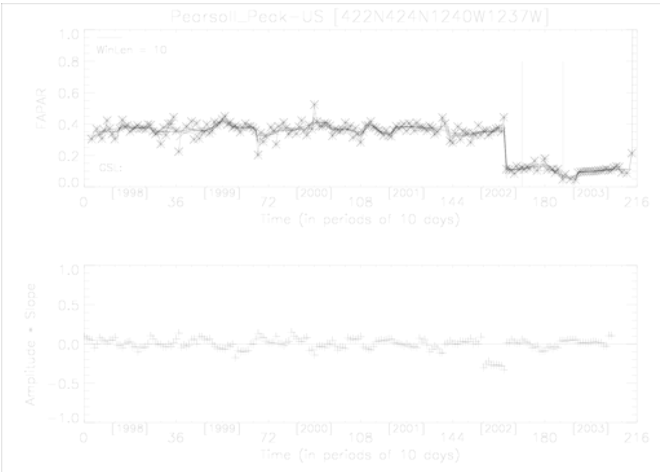
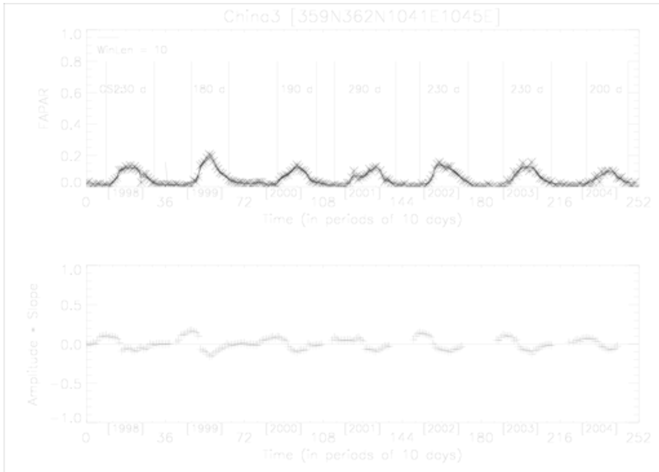
Characterizing growing seasons (4)










"That's all Folks!"