→ 6th ESA ADVANCED TRAINING COURSE ON LAND REMOTE SENSING

Agriculture Monitoring

[D4T1b]

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European Commission Joint Research Centre

European Commission

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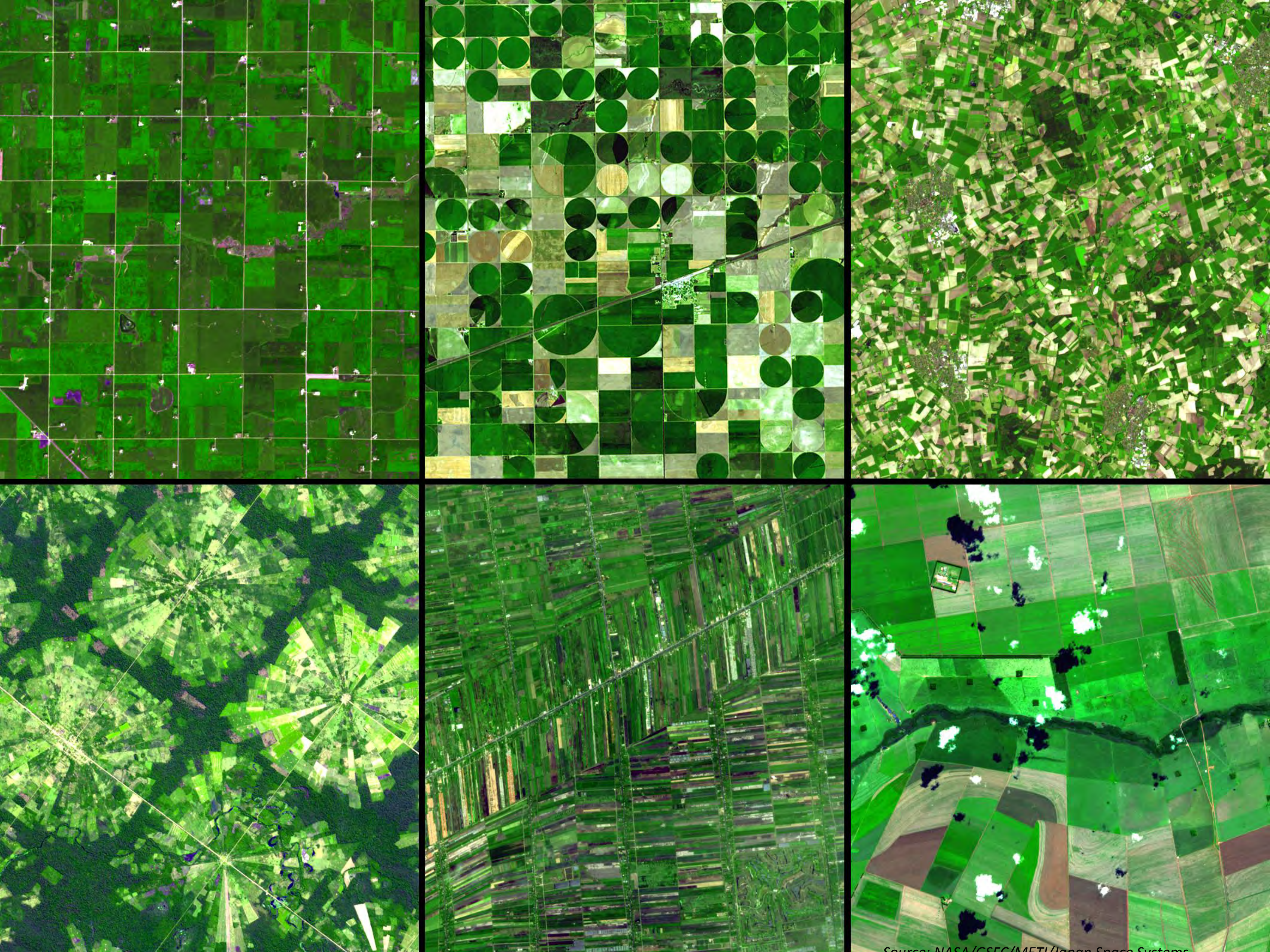
Why do we monitor agriculture (with satellite EO)?

- Precision farming
- Inform commodity brookers
- Assess agro-ecosystem sustainability
- Monitor agricultural resources
- Contributing to ensure food security by anticipating shortages
- …



Source: NASA/GSFC/METI/Japan Space Systems

Outline of this course

1. What do we want to know when monitoring agriculture?

2. What information can we derive from (optical) remote sensing?

3. The requirements of remote sensing observation for agricultural monitoring

4. Thinking differently to extract more from current EO systems

5. Some insights into operational crop monitoring systems

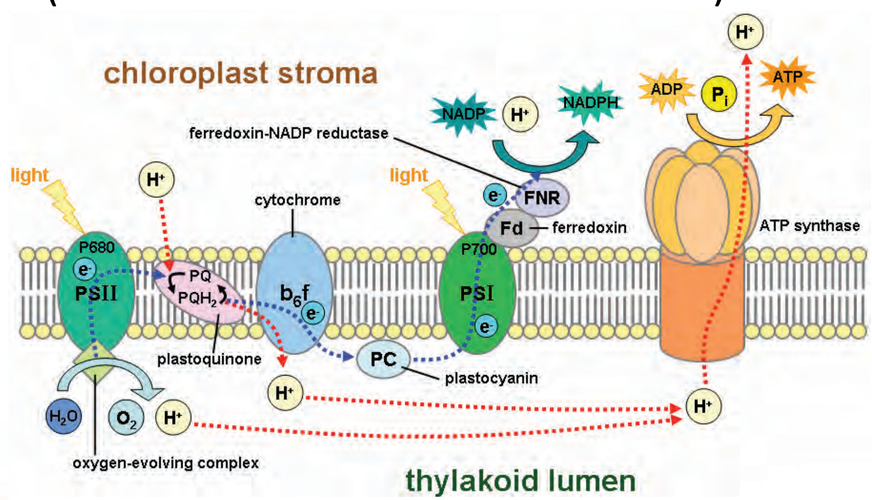
WHAT DO WE WANT TO KNOW?

Photosysthesis

The process by which plants convert light energy into chemical energy stored in carbohydrate molecules synthesized from carbon dioxide and water

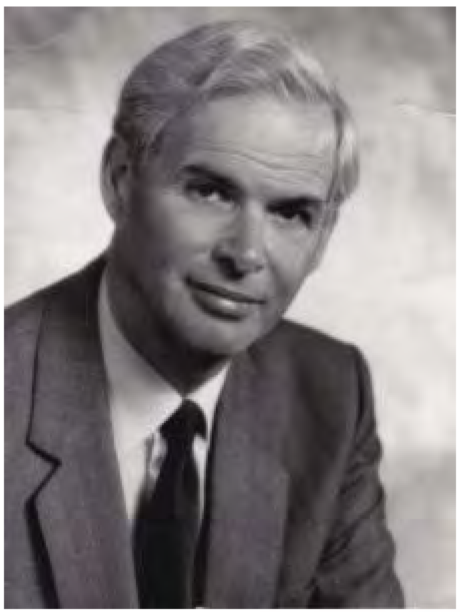
$$\underbrace{6CO_2}_{\text{Carbon dioxide}} + \underbrace{6H_2O}_{\text{Water}} \xrightarrow{\text{Light}} \underbrace{C_6H_{12}O_6}_{\text{Sugar}} + \underbrace{6O_2}_{\text{Oxygen}}$$

(remember the PHOTOSYSTEMS ?)



Plant productivity

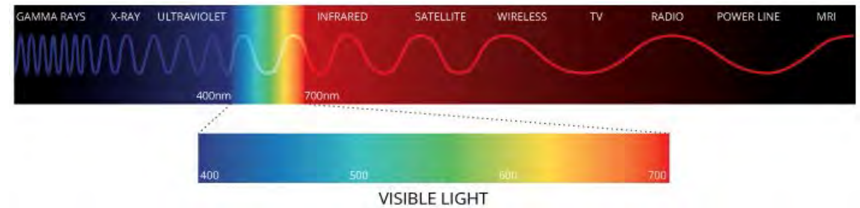
Gross Primary Productivity (GPP): How much matter (usually carbon) is a plant canopy (e.g. a field) accumulating per unit area per unit time [g C m-2 s-1]



Monteith approach:

Monteith, J. L. (1977). Climate and efficiency of crop production in Britain. Philosophical Transactions of the Royal Society B: Biological Sciences, 281(980), 277–294.

$$GPP = PAR \times fAPAR \times LUE$$



PAR, APAR and fAPAR

Source: *http://www.fondriest.com/environmental-measurements/parameters/weather/photosynthetically-active-radiation/*

Photosynthetically Active Radiation (PAR):

Radiation between 400 and 700 nm that photosynthetic organisms are able to use in the process of photosynthesis. It coincides with visible light

[Units: µmol photons m−2 s−1]

Absorbed PAR (APAR):

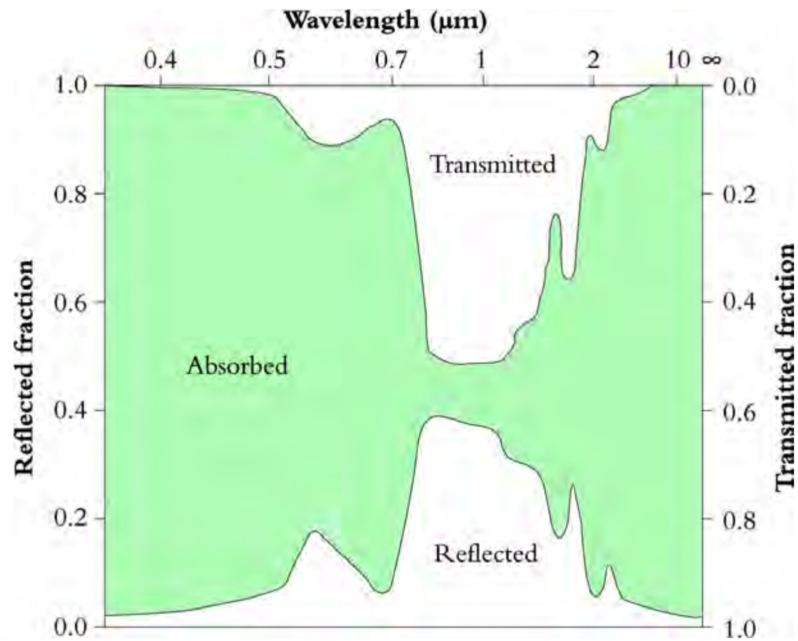
Quantity of PAR absorbed by the plants

Often considered equal to *intercepted* PAR

Fraction of APAR (fAPAR):

Normalized variable between 0 and 1

fAPAR = APAR/PAR



Source: Plants in Action, published by the Australian Society of Plant Scientists, http://plantsinaction.science.uq.edu.au/edition1/

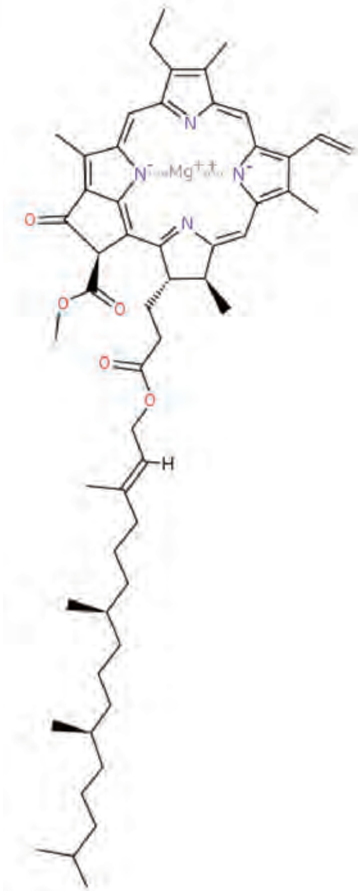
Chlorophyll concentration

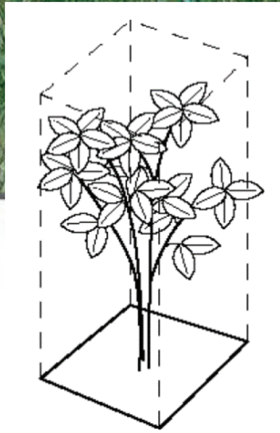
Molecule responsible for energy capture from photons

⇒ [Chl] is another indicator of GPP

Majority of leaf nitrogen is contained in chlorophyll molecules

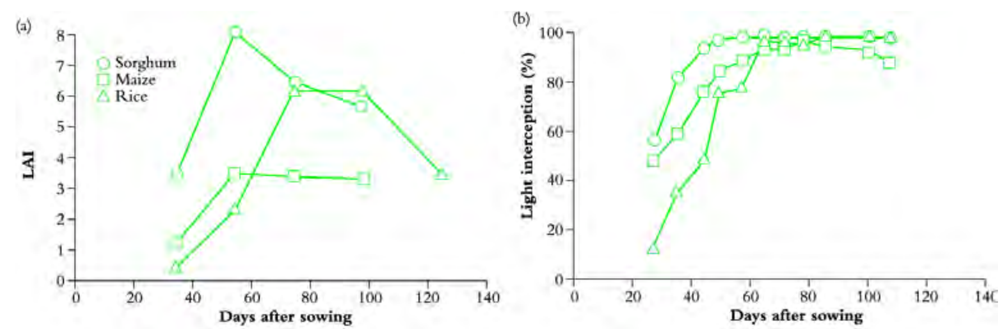
⇒ Low [Chl] can indicate nitrogen deficiency





Leaf Area Index (LAI)

Defined as half the total developed area of green leaves per unit of ground horizontal surface area [units: m2 m-2]



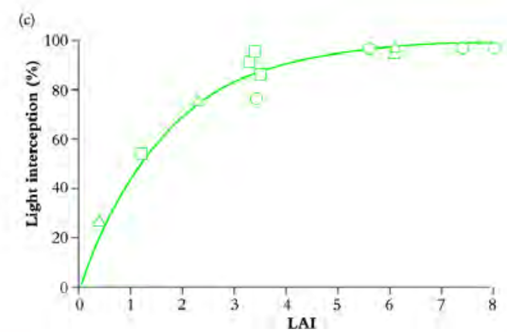
Useful to describe light interception
$I = I_0 e^{-kLAI}$

Interface between atmosphere and vegetation.

Variants:

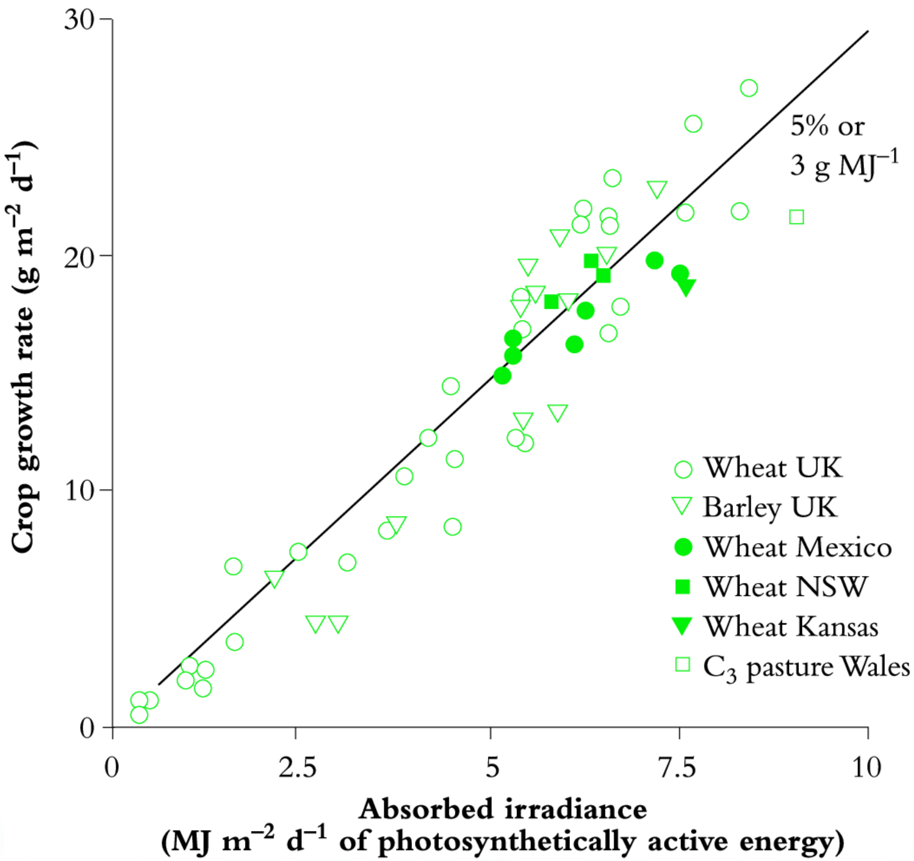
Plant area index (PAI): includes projected area of all plant organs (leaves, stems, ears, trunks…)

Green area index (GAI): like PAI but only for green elements



Source: Plants in Action, published by the Australian Society of Plant Scientists, http://plantsinaction.science.uq.edu.au/edition1/

Light use efficiency (LUE)



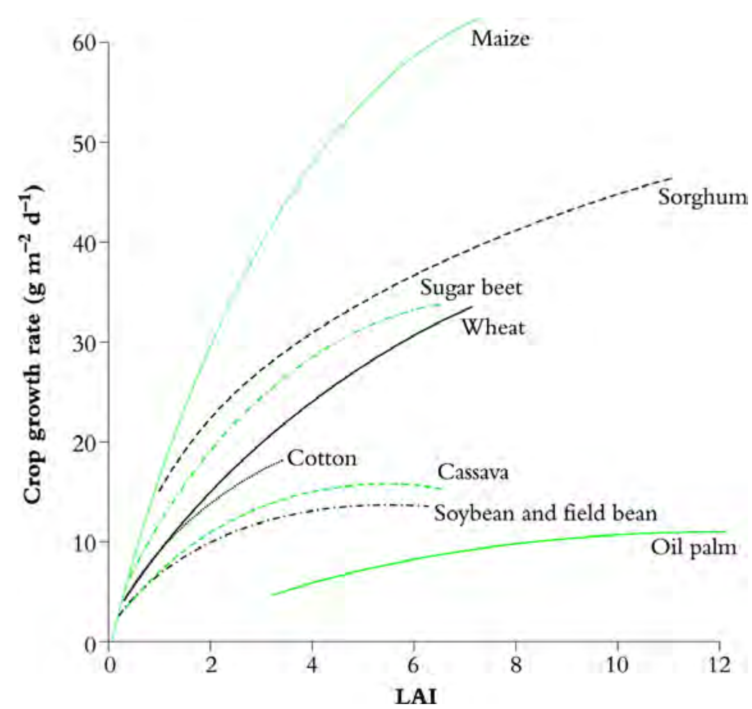


Table 6.12 Communities of crop plants vary widely in their efficiency of light utilisation for dry matter production (ε) due to differences in canopy architecture, photosynthetic attributes and respiratory losses

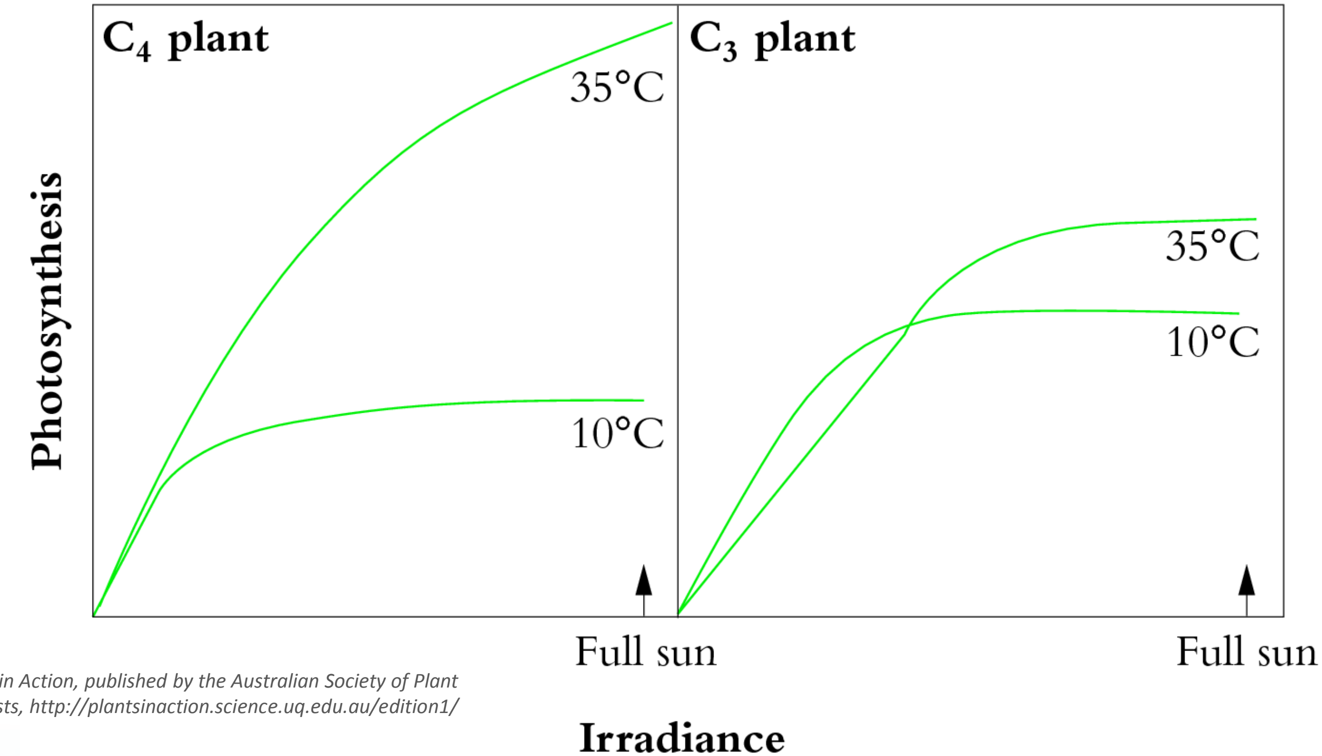
Crop species	ε (g MJ^{-1})
Rice (*Oryza sativa*)	4.15
Maize (*Zea mays*)	3.40
Sweet potato (*Ipomea batatas*)	3.06
Kale (*Brassica oleracea*)	2.65
Sunflower (*Helianthus annuus*)	2.59
Cotton (*Gossypium hirsutum*)	2.52
Sub. clover (*Trifolium subterraneum*)	1.63
Soybean (*Glycine max*)	1.29

(Based on Warren Wilson 1969)

Source: Plants in Action, published by the Australian Society of Plant Scientists, http://plantsinaction.science.uq.edu.au/edition1/

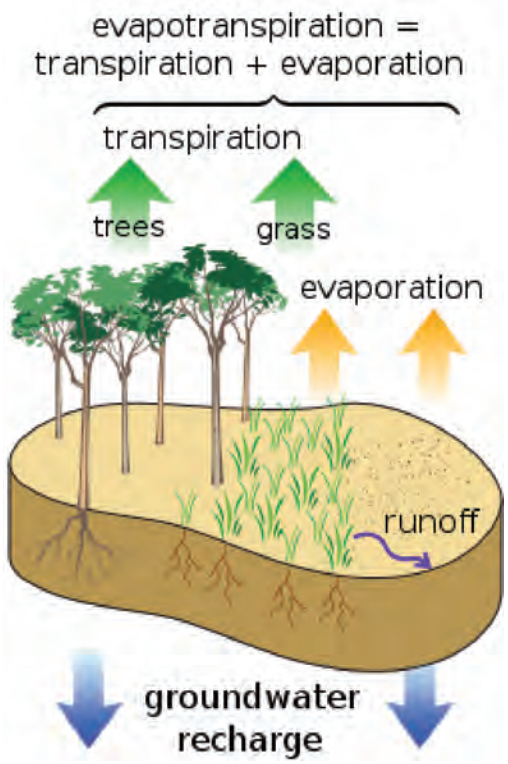
Light use efficiency (LUE)

Can be influenced by water availability, plant type, [CO2], temperature…



Source: Plants in Action, published by the Australian Society of Plant Scientists, http://plantsinaction.science.uq.edu.au/edition1/

Evapotranspiration (ET) or Latent Heat



Penman-Monteith equation

$$ET_o = \frac{0.408\Delta\left(R_n - G\right) + \gamma \frac{900}{T+273} u_2 \left(e_s - e_a\right)}{\Delta + \gamma\left(1 + 0.34 u_2\right)}$$

Priestly-Taylor equation

$$\mathrm{ETp} = \alpha \frac{\Delta}{\Delta + \gamma} (\mathrm{Rn} - \mathrm{G}) \qquad [1]$$

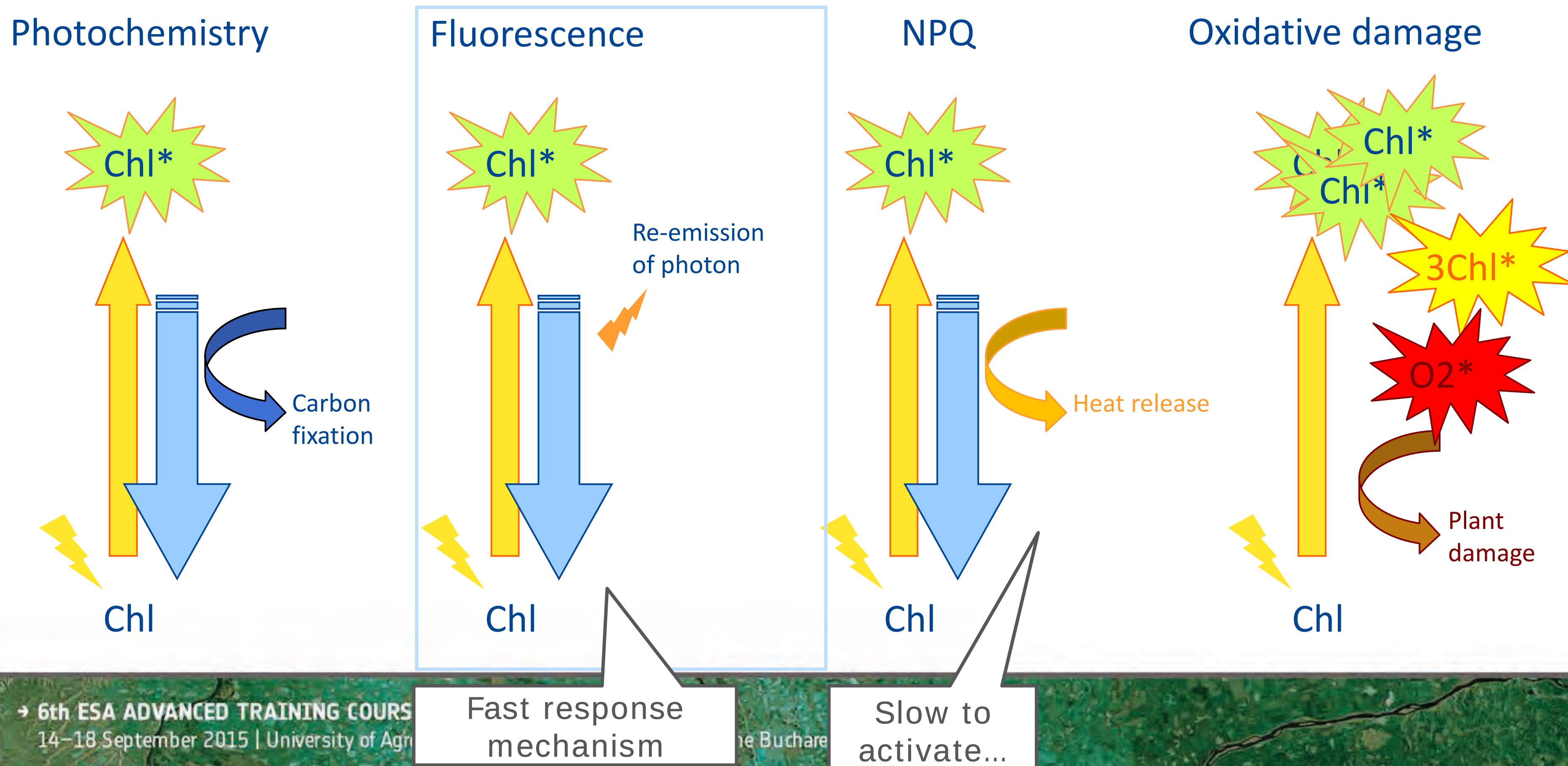
Soil moisture

The volumetric (or gravimetric) quantity of water in the soil available to the plant

Optical/Thermal Group	
D4T1b Agriculture Monitoring G. Duveiller (JRC, Italy)	8:30 - 9:30 9:30 - 9:45 9:45- 10:00 10:00 - 10:15
D4P1b Agriculture Monitoring G. Duveiller (JRC, Italy)	10:45 -11:45 11:45 - 12:15 12:15 - 12:45
D4T2b Soil Moisture & Water Resources B. Su (ITC, The Netherlands)	14:15 - 15:30
D4P2b Soil Moisture & Water Resources B. Su (ITC, The Netherlands)	16:00 - 18:00

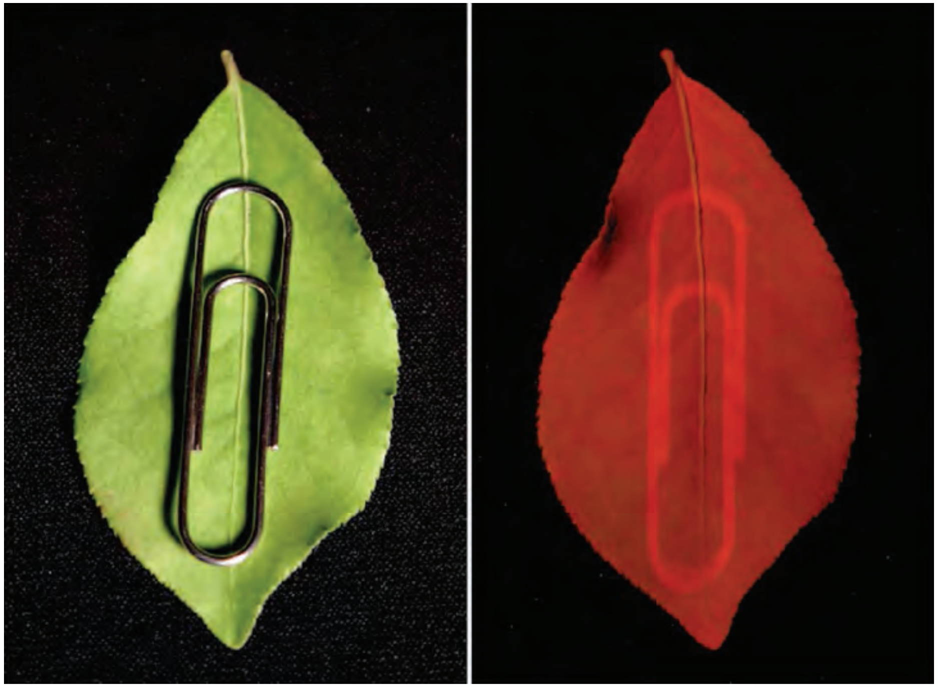
Sun induced chlorophyll fluorescence (SIF)

The various fates of exited chlorophyll…



Increase of light conditions

1. Sunfleck on shadowed leaf
2. PSII saturate
3. SIF increases fast to evacuate excess Chl*
   – corr(SIF,GPP)<0
4. SIF goes back down as photosynthesis rate increases
   – (NPQ eventually kicks in)
5. SIF stabilizes and then remains proportional to PSII yield
   – corr(SIF,GPP)>0



http://www.nightsea.com/articles/fluorescence-photography-illuminates-chlorophyll/

Sun induced fluorescence (SIF)

- Emitted by the photosynthetic machinery itself (by PSII)
- Responds **instantaneously** to perturbations in the environmental conditions such as light and water stress
- This allows to translate effects of stress which do not necessarily cause a **reduction of Chl or LAI**
- Can provide early and direct diagnostic of functional status of vegetation… a **proxy for photosynthetic activity**… i.e. for gross primary productivity (GPP)

Back to productivity and crop yield

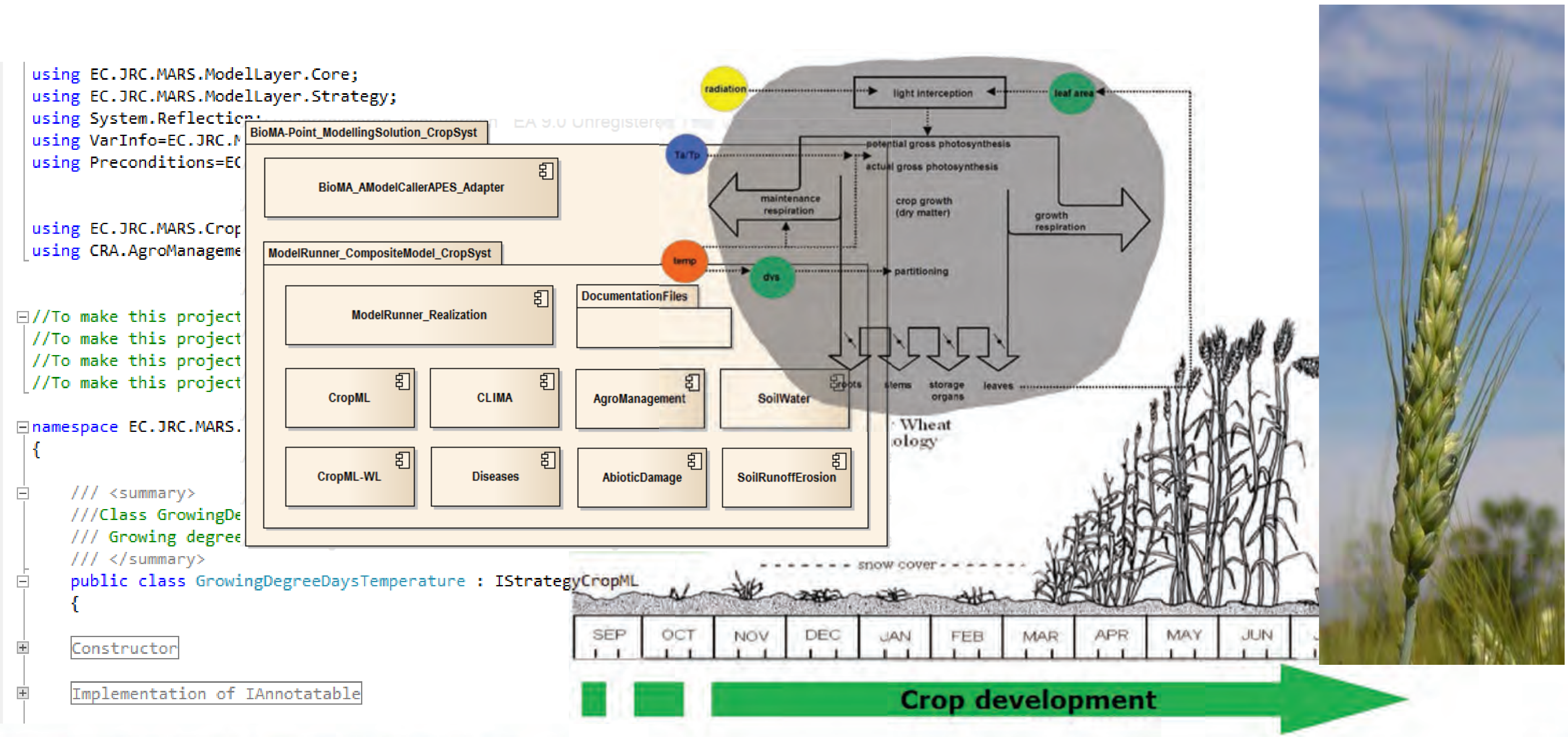
Net Primary Productivity (NPP): NPP = GPP – autotrophic respiration

Dry Matter Productivity (DMP): Generally same as NPP, considering respiration proportional to GPP, and changing units to [kgDM/ha/day]

Crop yield = NPP * Harvest Index

Requires taking into account the partitioning of biomass into different pools… or more specifically, to the pool that is harvested.

Crop growth modelling …



Crop growth modelling …

- Crop growth models (CGMs) resume our understanding of physiological processes
- They vary in their complexity, but often they require several driving meteo variables and they have many internal parameters that must be fixed.
- Punctual models built based on field trials. Spatial extension possible but complicated by the necessary input data + modeling assumptions.
- Some examples include WOFOST, STICS, DSSAT, CERES, APSIM, ORYZA …
- Simpler models (that may be easier to spatialize) include SAFYE, GRAMI

Phenology

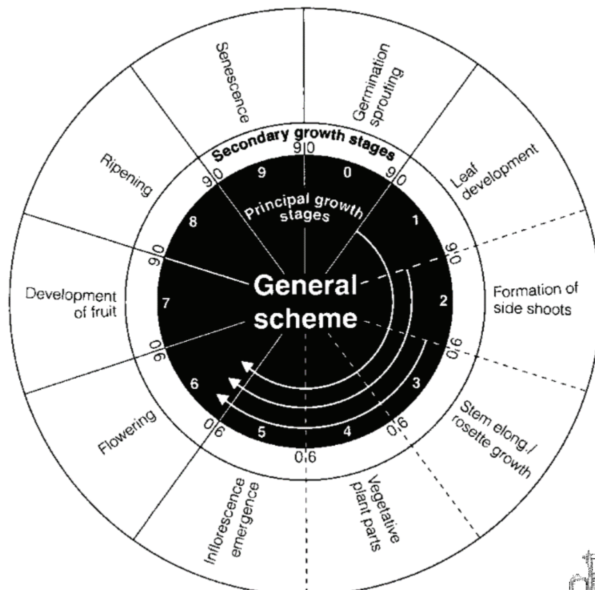
The timing of specific development stages of the canopy, e.g: emergence, anthesis (flowering), maturity…

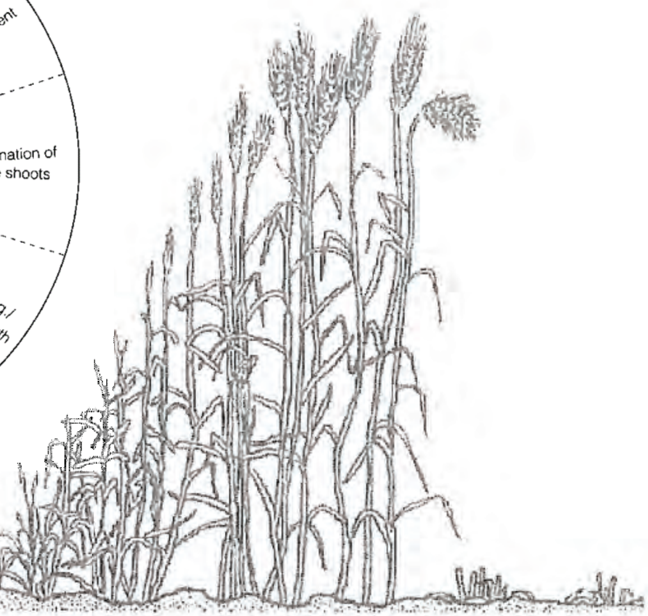
The extended BBCH-scale, for specific crops

Cereals Witzenberger et al., 1989; Lancashire et al., 1991

Phenological growth stages and BBCH-identification keys of cereals
(wheat = *Triticum* sp. L., barley = *Hordeum vulgare* L., oat = *Avena sativa* L., rye = *Secale cereale* L.)

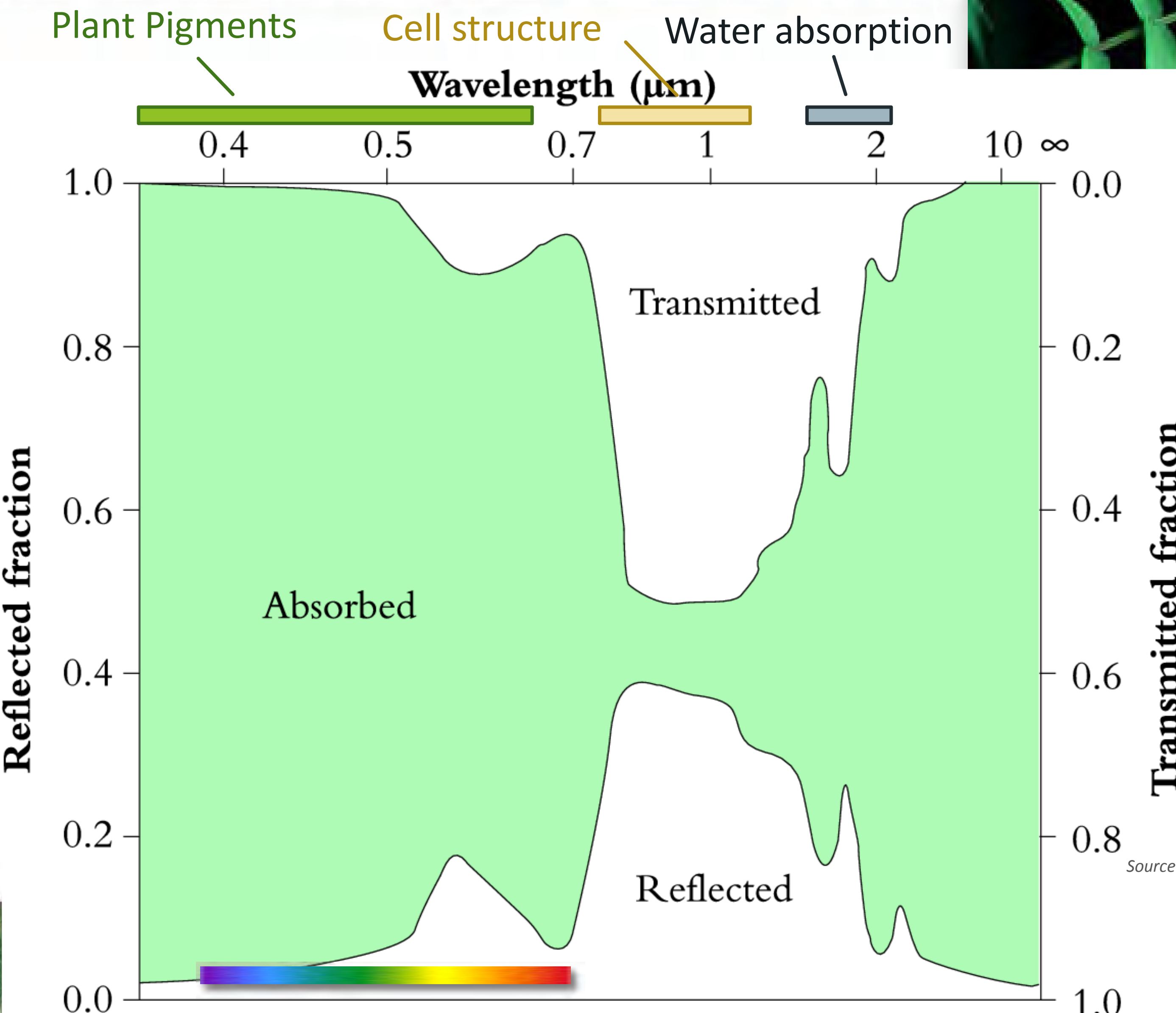
Code	Description
Principal growth stage 0: Germination	
00	Dry seed (caryopsis)
01	Beginning of seed imbibition
03	Seed imbibition complete
05	Radicle emerged from caryopsis
06	Radicle elongated, root hairs and/or side roots visible
07	Coleoptile emerged from caryopsis
09	Emergence: coleoptile penetrates soil surface (cracking stage)
Principal growth stage 1: Leaf development[1,2]	
10	First leaf through coleoptile
11	First leaf unfolded
12	2 leaves unfolded
13	3 leaves unfolded
1 .	Stages continuous till . . .
19	9 or more leaves unfolded
Principal growth stage 2: Tillering[3]	
20	No tillers
21	Beginning of tillering: first tiller detectable
22	2 tillers detectable
23	3 tillers detectable

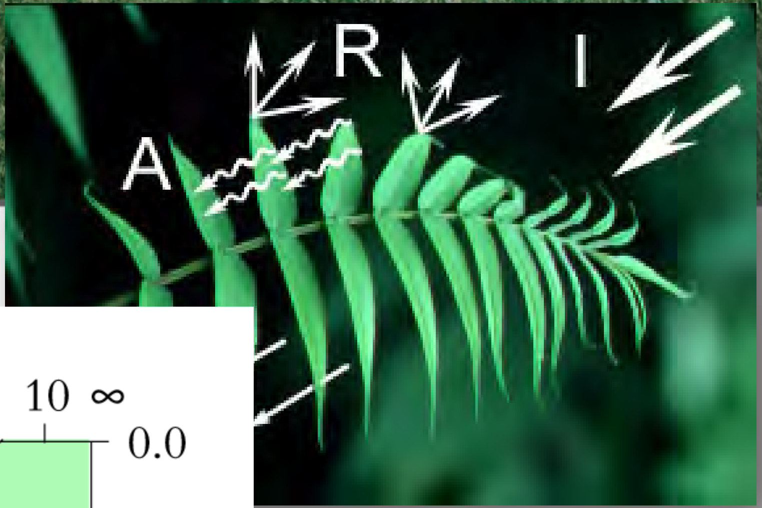




WHAT INFORMATION CAN WE RETRIEVE FROM REMOTE SENSING?

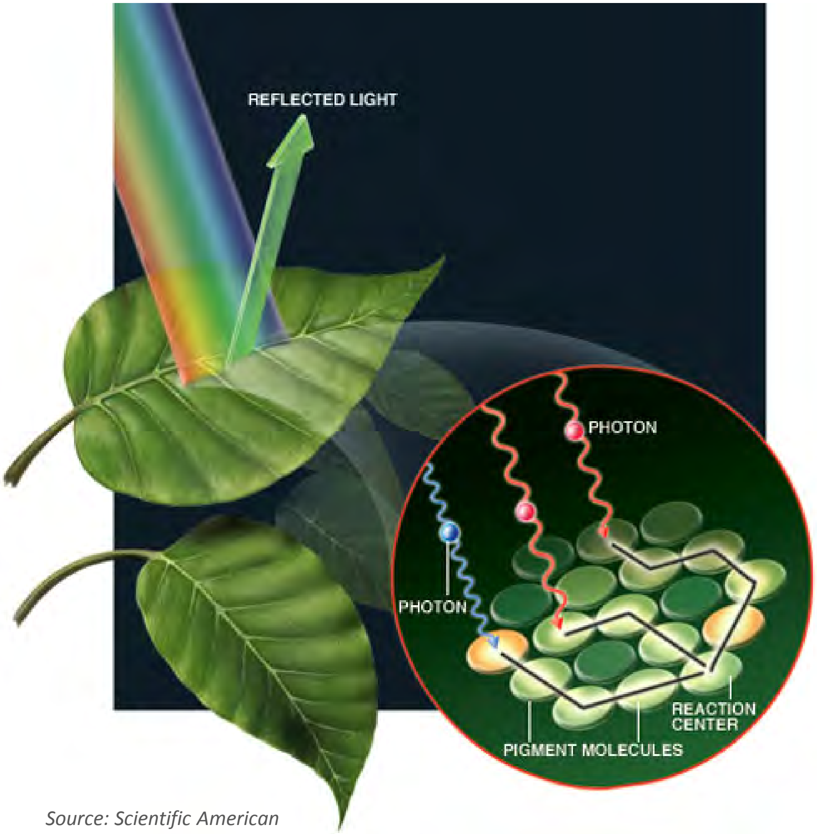
Spectral properties of vegetation



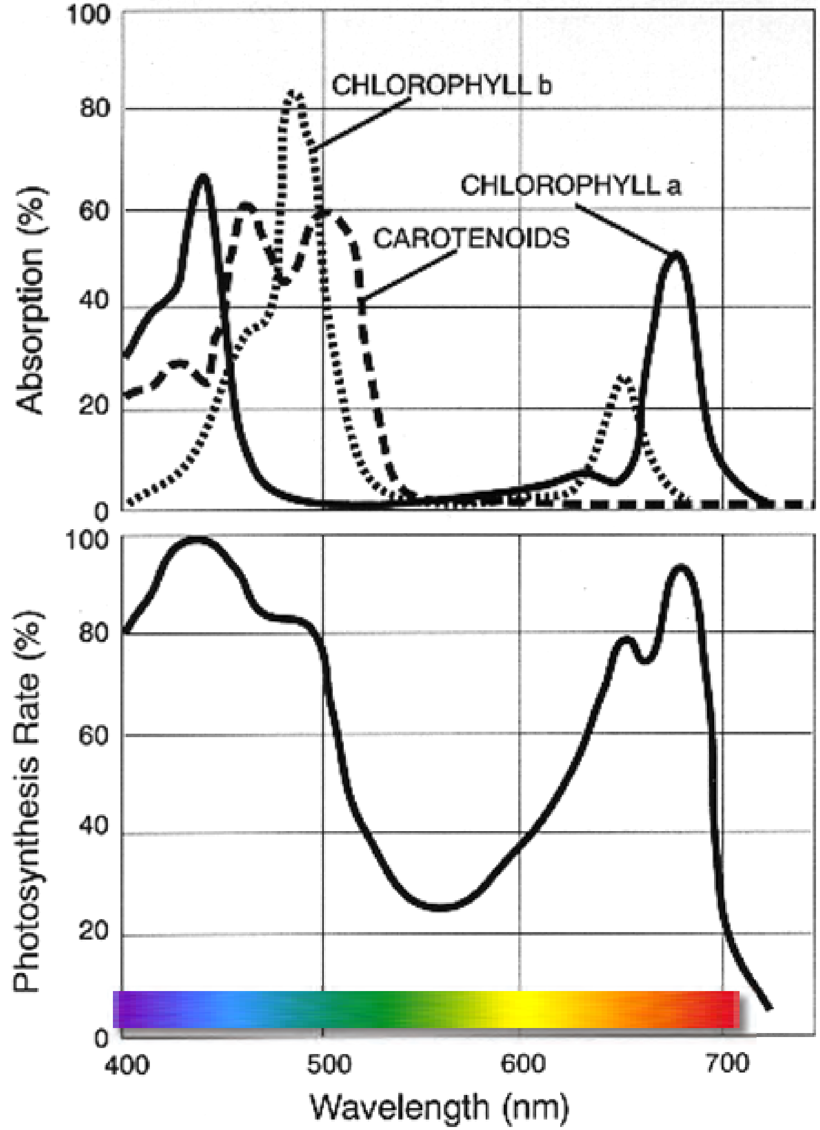


Source: Plants in Action, published by the Australian Society of Plant Scientists, http://plantsinaction.science.uq.edu.au/edition1/

Plant pigments

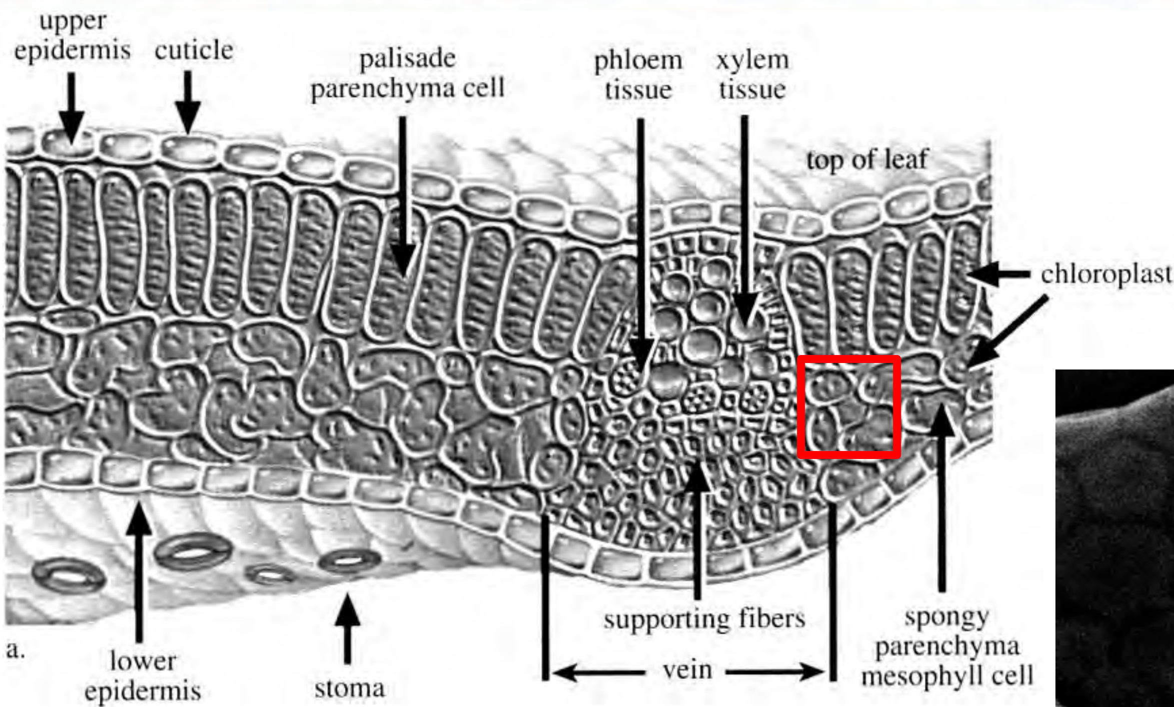


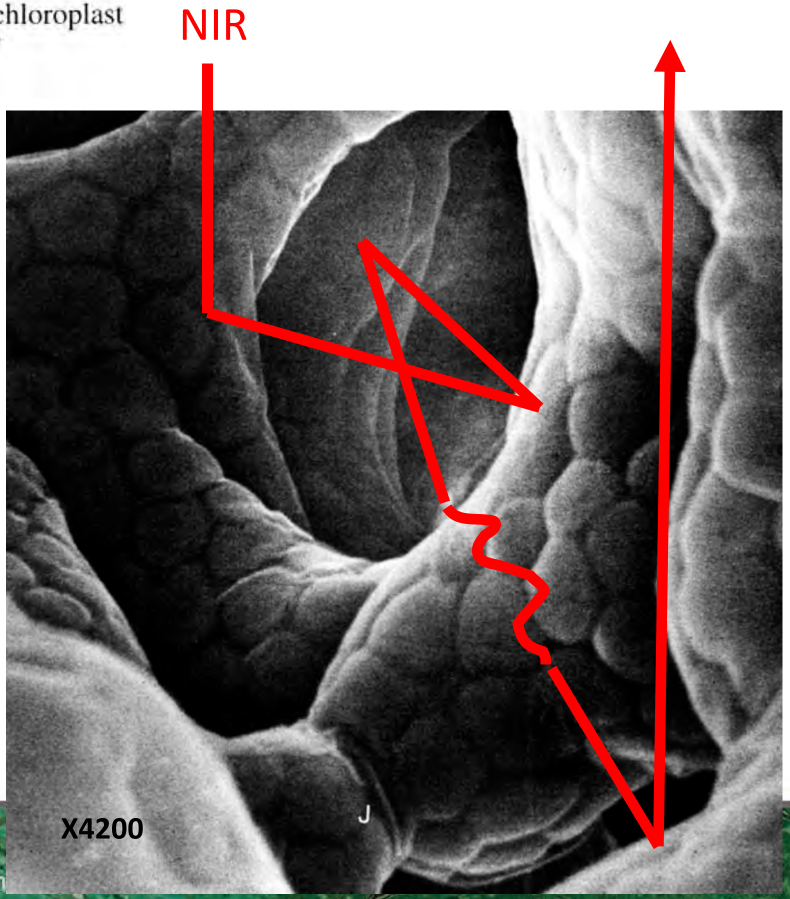
Source: Scientific American



Source: http://www.life.uiuc.edu/govindjee/paper/gov.html, from "Concepts in Photobiology: Photosynthesis and Photomorphogenesis", Edited by GS Singhal, G Renger, SK Sopory, K-D Irrgang

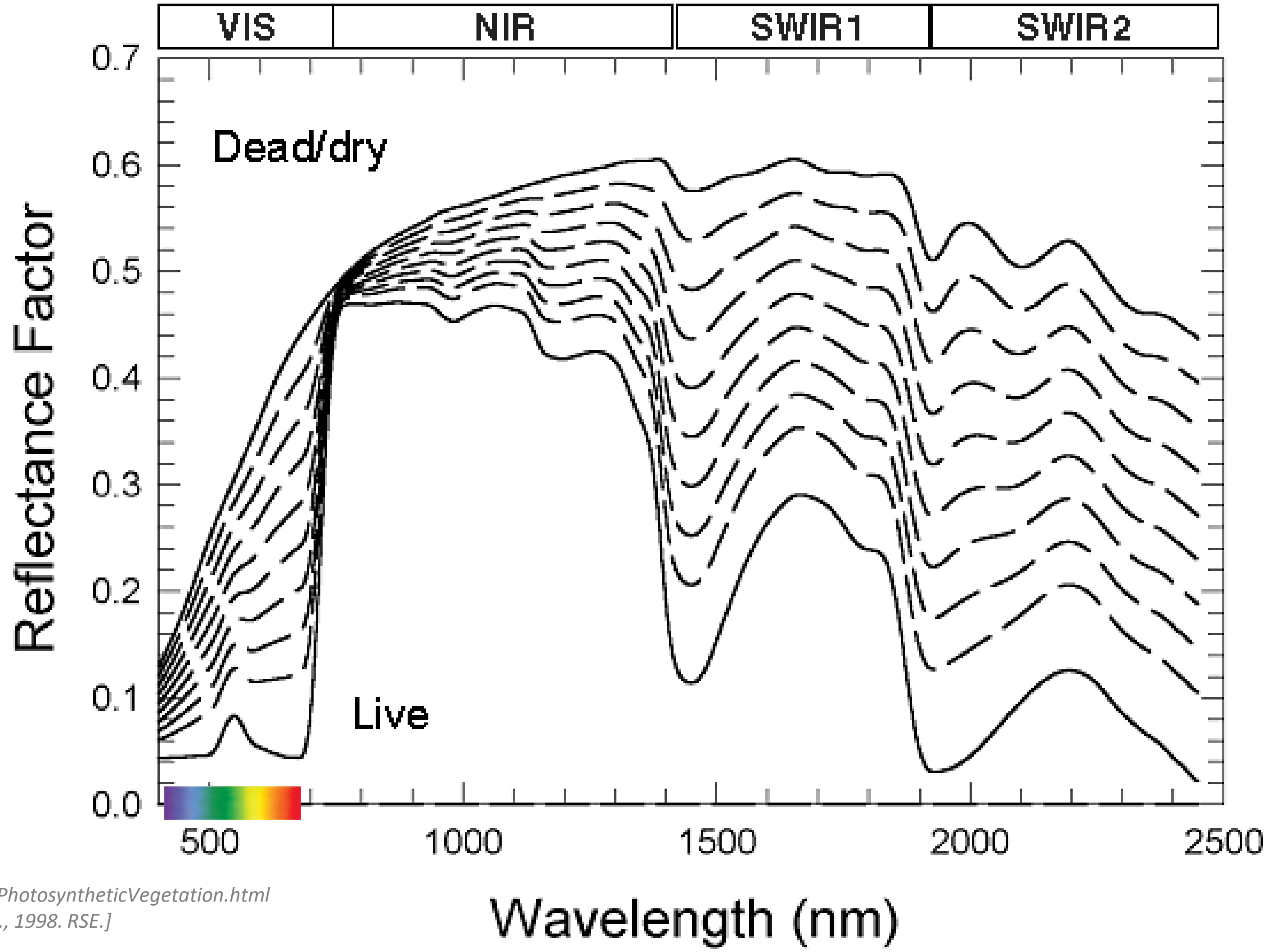
Cell Structure





Cell structure strongly scatters NIR radiation to prevent cell damage

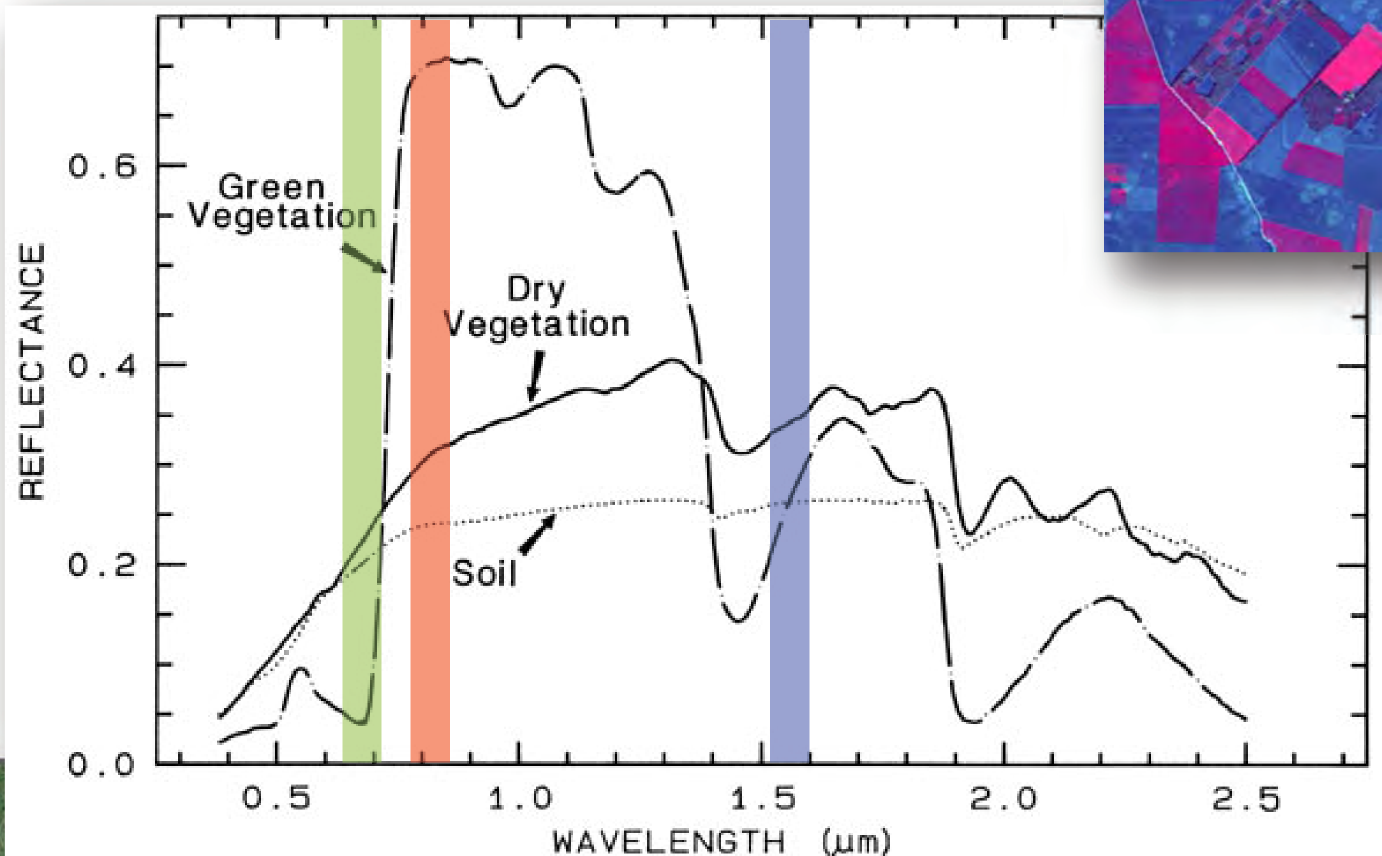
Absorption from water in the plants

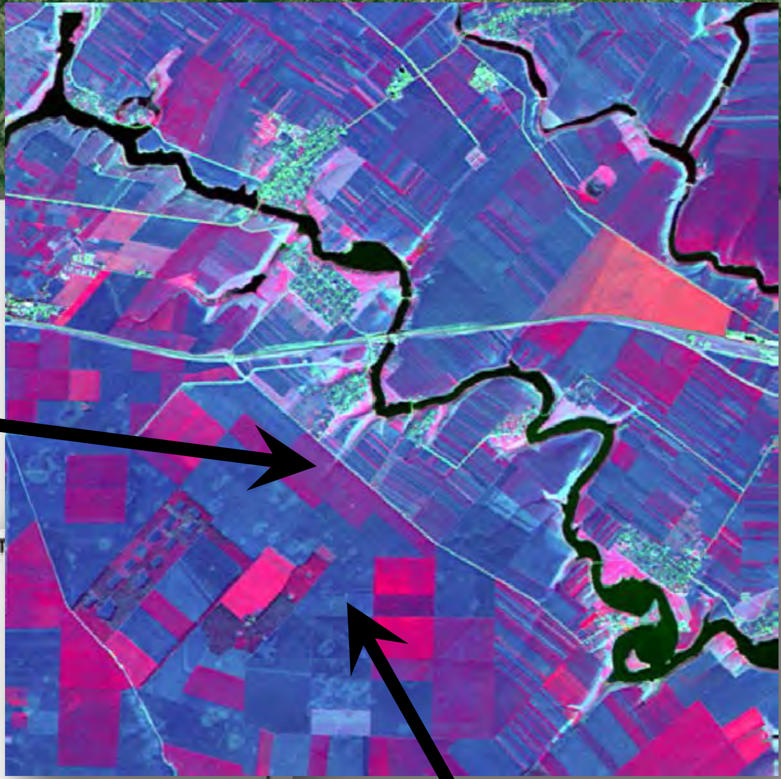


Source: http://www.exelisvis.com/docs/NonPhotosyntheticVegetation.html [incorrectly cited as coming from: Asner, G.P., 1998. RSE.]

Observing crop from space

– A typical ag. Landscape in a temperate climate





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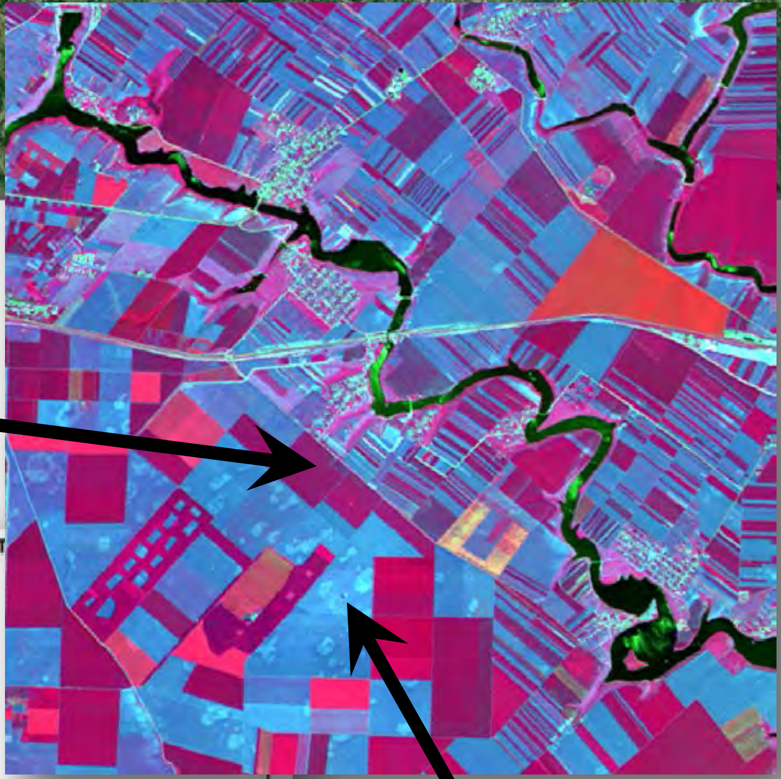

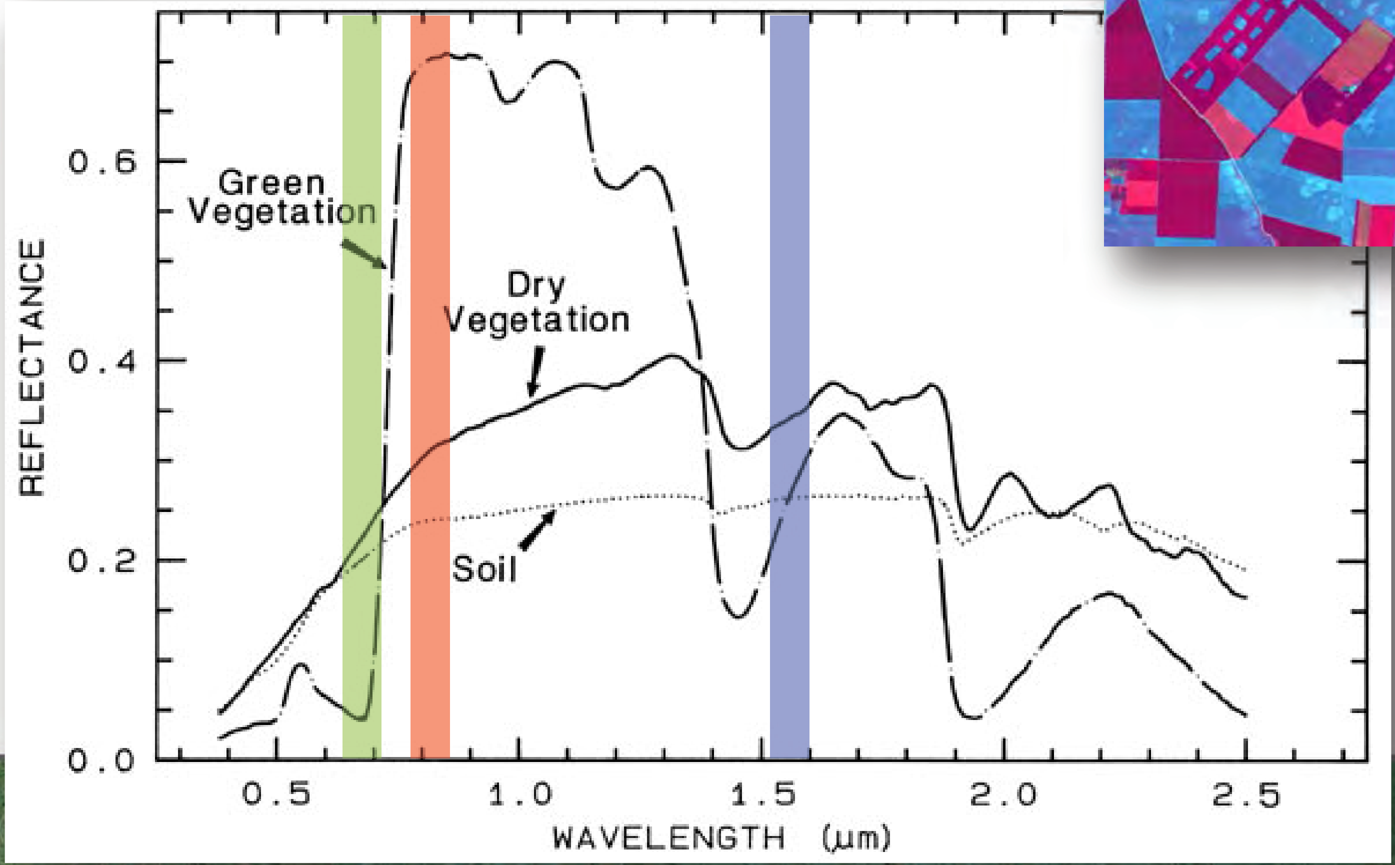

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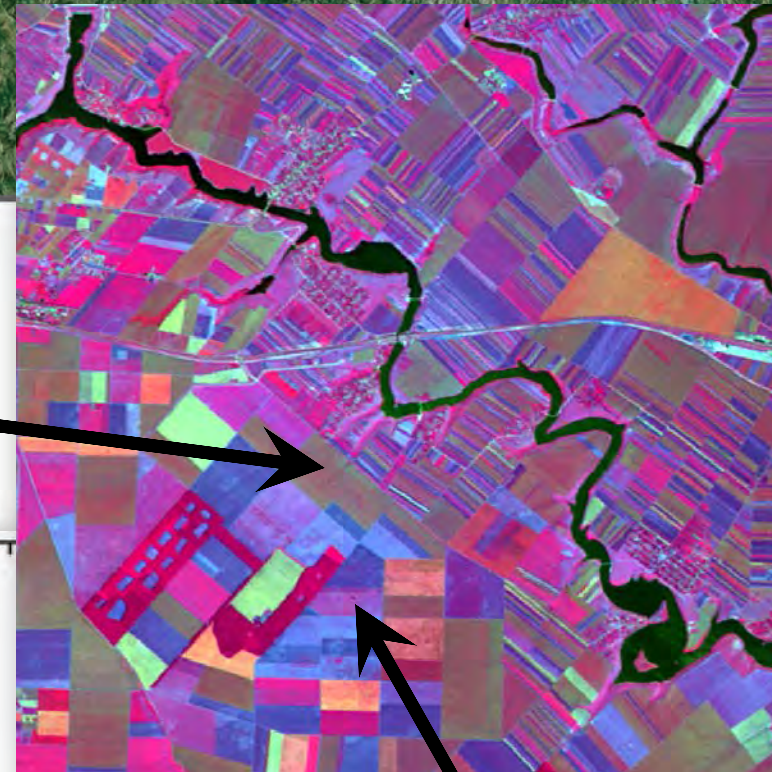

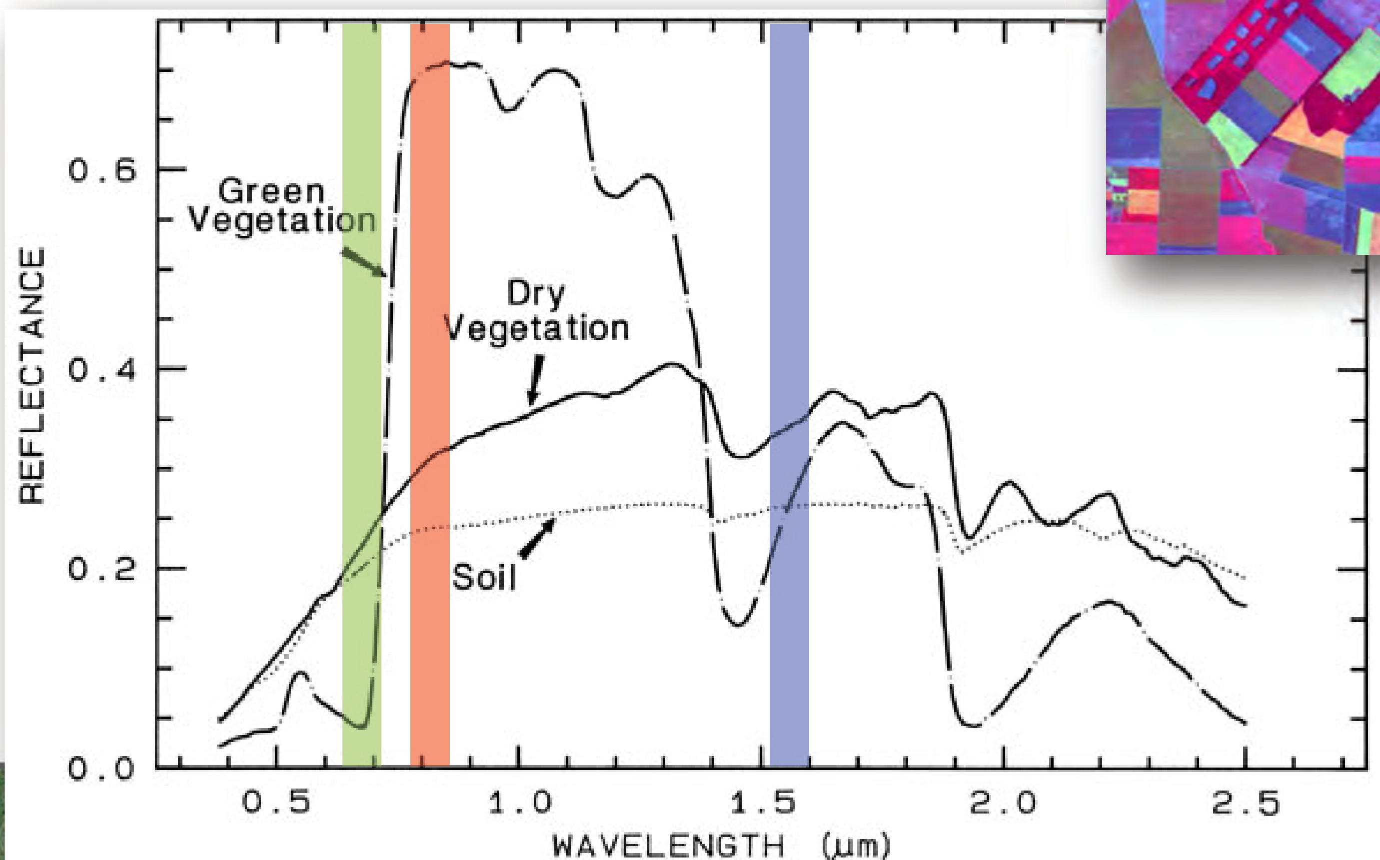

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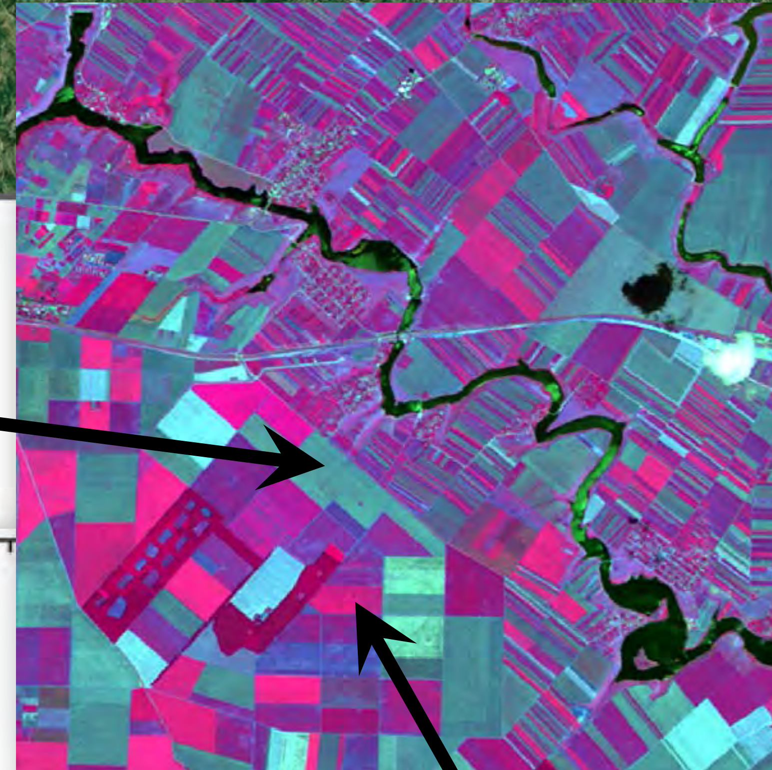
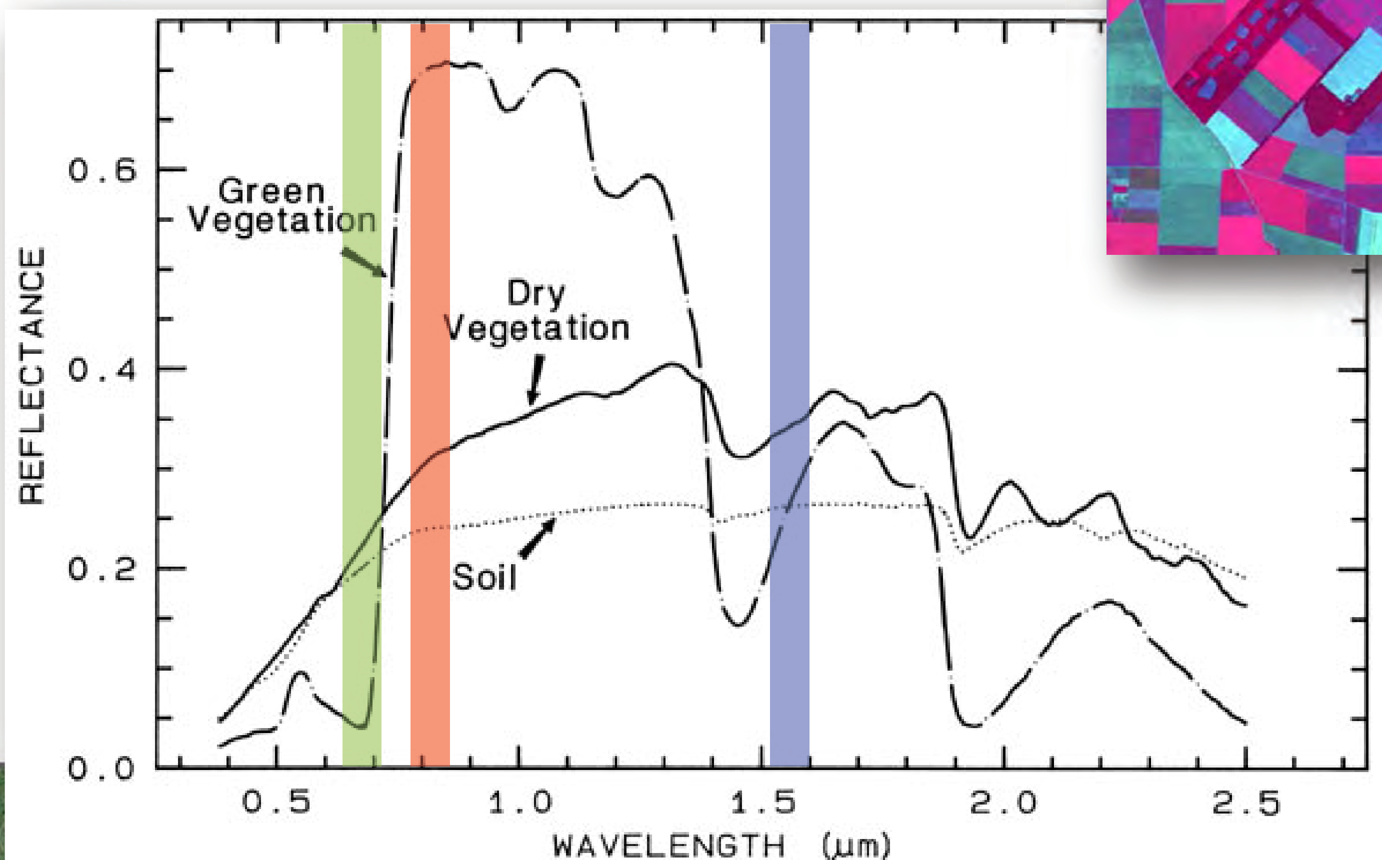




Vegetation indices

- Convenient way to resume information
- Exploit the particular spectral properties of vegetation
- Depend on spectral response of the sensors (which changes even for bands with same names)
- Potentially unlimited number of combinations

Indice	Abréviation	Équation	Auteur et année
Ratio Vegetation Index	RVI	$\frac{\mathrm{R}}{\mathrm{NIR}}$	Pearson and Miller, 1972
Vegetation Index Number	VIN	$\frac{\mathrm{NIR}}{\mathrm{R}}$	Pearson and Miller, 1972
Transformed Vegetation Index	TVI	$\sqrt{\mathrm{NDVI}+0.5}$	Rouse et al., 1974
Green Vegetation Index	GVI	$(-0.283\mathrm{MSS4}-0.660\mathrm{MSS5}+0.577\mathrm{MSS6}+0.388\mathrm{MSS7})$	Kauth and Thomas, 1976
Soil Brightness Index	SBI	$(0.332\mathrm{MSS4}+0.603\mathrm{MSS5}+0.675\mathrm{MSS6}+0.262\mathrm{MSS7})$	Kauth and Thomas, 1976
Yellow Vegetation Index	YVI	$(-0.899\mathrm{MSS4}+0.428\mathrm{MSS5}+0.076\mathrm{MSS6}-0.041\mathrm{MSS7})$	Kauth and Thomas, 1976
Non Such Index	NSI	$(-0.016\mathrm{MSS4}+0.131\mathrm{MSS5}-0.425\mathrm{MSS6}+0.882\mathrm{MSS7})$	Kauth and Thomas, 1976
Soil Background Line	SBL	$(\mathrm{MSS7}-2.4\mathrm{MSS5})$	Richardson and Wiegand, 1977
Differenced Vegetation Index	DVI	$(2.4\mathrm{MSS7}-\mathrm{MSS5})$	Richardson and Wiegand, 1977
Misra Soil Brightness Index	MSBI	$(0.406\mathrm{MSS4}+0.600\mathrm{MSS5}+0.645\mathrm{MSS6}+0.243\mathrm{MSS7})$	Misra et al., 1977
Misra Green Vegetation Index	MGVI	$(-0.386\mathrm{MSS4}-0.530\mathrm{MSS5}+0.535\mathrm{MSS6}+0.532\mathrm{MSS7})$	Misra et al., 1977
Misra Yellow Vegetation Index	MYVI	$(0.723\mathrm{MSS4}-0.597\mathrm{MSS5}+0.206\mathrm{MSS6}-0.278\mathrm{MSS7})$	Misra et al., 1977
Misra Non Such Index	MNSI	$(0.404\mathrm{MSS4}-0.039\mathrm{MSS5}-0.505\mathrm{MSS6}+0.762\mathrm{MSS7})$	Misra et al., 1977
Perpendicular Vegetation Index	PVI	$\sqrt{(\rho_{sol}-\rho_{végé})^2_{R}+(\rho_{sol}-\rho_{végé})^2_{NIR}}$	Richardson and Wiegand, 1977
Ashburn Vegetation Index	AVI	$(2.0\mathrm{MSS7}-\mathrm{MSS5})$	Ashburn, 1978
Greenness Above Bare Soil	GRABS	$(\mathrm{GVI}-0.09178\mathrm{SBI}+5.58959)$	Hay et al., 1979
Multi-Temporal Vegetation Index	MTVI	$(\mathrm{NDVI(date\ 2)}-\mathrm{NDVI(date\ 1)})$	Yazdani et al., 1981
Greenness Vegetation and Soil Brightness	GVSB	$\frac{\mathrm{GVI}}{\mathrm{SBI}}$	Badhwar, 1981
Adjusted Soil Brightness Index	ASBI	$(2.0\ \mathrm{YVI})$	Jackson et al., 1983
Adjusted Green Vegetation Index	AGVI	$\mathrm{GVI}-(1+0.018\mathrm{GVI})\mathrm{YVI}-\mathrm{NSI}/2$	Jackson et al., 1983
Transformed Vegetation Index	TVI	$\frac{(\mathrm{NDVI}+0.5)}{\lvert\mathrm{NDVI}+0.5\rvert}\sqrt{\lvert\mathrm{NDVI}+0.5\rvert}$	Perry and Lautenschlager, 1984
Differenced Vegetation Index	DVI	$(\mathrm{NIR}-\mathrm{R})$	Clevers, 1986
Normalized Difference Greenness Index	NDGI	$\frac{(\mathrm{G}-\mathrm{R})}{(\mathrm{G}+\mathrm{R})}$	Chamard et al., 1991
Redness Index	RI	$\frac{(\mathrm{R}-\mathrm{G})}{(\mathrm{R}+\mathrm{G})}$	Escadafal and Huete, 1991
Normalized Difference Vegetation Index	NDVI	$\frac{(\mathrm{NIR}-\mathrm{R})}{(\mathrm{NIR}+\mathrm{R})}$	Rouse et al., 1974
Perpendicular Vegetation Index	PVI	$\frac{(\mathrm{NIR}-a\mathrm{R}-b)}{\sqrt{a^2+1}}$	Jackson et al., 1980
Soil Adjusted Vegetation Index	SAVI	$\frac{(\mathrm{NIR}-\mathrm{R})}{(\mathrm{NIR}+\mathrm{R}+\mathrm{L})}(1+\mathrm{L})$	Huete, 1988
Transformed SAVI	TSAVI	$\frac{[a(\mathrm{NIR}-aR-b)]}{(R+a\mathrm{NIR}-ab)}$	Baret et al., 1989
Transformed SAVI	TSAVI	$\frac{[a(\mathrm{NIR}-aR-b)]}{[R+a\mathrm{NIR}-ab+X(1+a^2)]}$	Baret and Guyot, 1991
Atmospherically Resistant Vegetation Index	ARVI	$\frac{(\mathrm{NIR}-\mathrm{RB})}{(\mathrm{NIR}+\mathrm{RB})}$ $\mathrm{RB}=\mathrm{R}-\gamma(\mathrm{B}-\mathrm{R})$	Kaufman and Tanré, 1992
Global Environment Monitoring Index	GEMI	$\mathrm{GEMI}=\eta(1-0.25\eta)-\frac{(\mathrm{R}-0.125)}{(1-\mathrm{R})}$ $\eta=\frac{[2(\mathrm{NIR}^2-\mathrm{R}^2)+1.5\mathrm{NIR}+0.5\mathrm{R}]}{(\mathrm{NIR}+\mathrm{R}+0.5)}$	Pinty and Verstraete, 1992
Transformed Soil Atmospherically Resistant Vegetation Index	TSARVI	$\frac{[a_{rb}(\mathrm{NIR}-a_{rb}\mathrm{RB}-b_{rb})]}{[\mathrm{RB}+a_{rb}\mathrm{NIR}-a_{rb}b_{rb}+X(1+a_{rb}^2)]}$	Bannari et al., 1994
Modified SAVI	MSAVI	$\frac{2\mathrm{NIR}+1-\sqrt{(2\mathrm{NIR}+1)^2-8(\mathrm{NIR}-\mathrm{R})}}{2}$	Qi et al., 1994
Angular Vegetation Index	AVI	$\tan^{-1}\left\{\frac{\lambda_3-\lambda_2}{\lambda_2}[\mathrm{NIR}-\mathrm{R}]^{-1}\right\}+\tan^{-1}\left\{\frac{\lambda_2-\lambda_1}{\lambda_2}[\mathrm{G}-\mathrm{R}]^{-1}\right\}$	Plummer et al., 1994

How to retrieve biophysical variables from RS?

Empirical methods

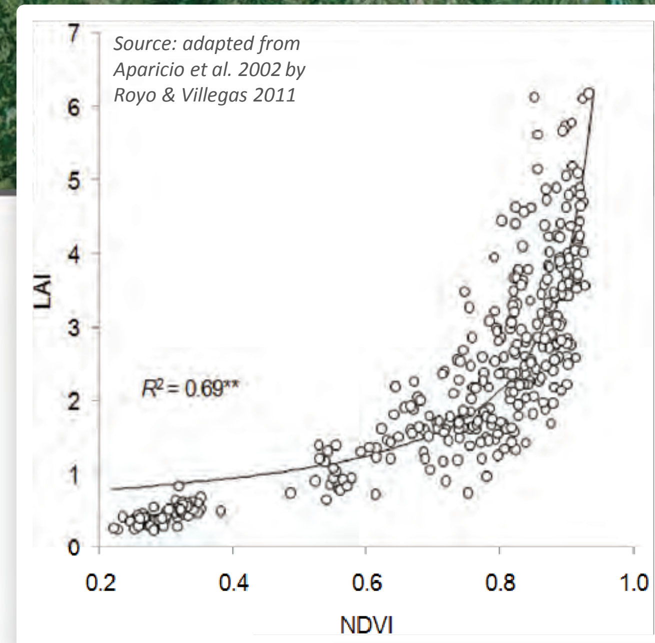
- Establishment of a statistical relationship between VI or ρ and field measured biophysical variables

- Require intensive field measurements for calibration and validation

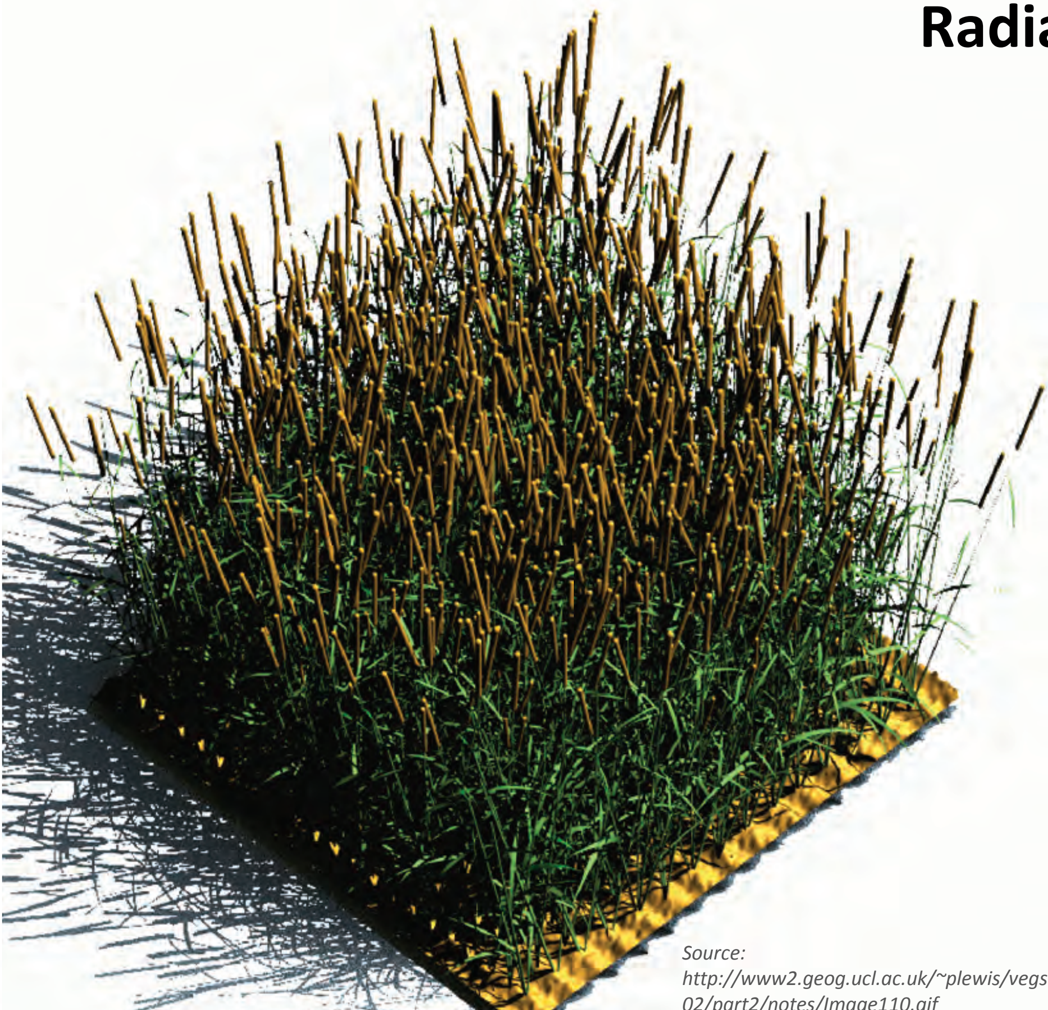
- Relation is typically limited to large geographic extent

Physical methods

- Based on model inversion…



Radiative Transfer Models…



Source:
http://www2.geog.ucl.ac.uk/~plewis/vegsci2002/part2/notes/Image110.gif

They provide an explicit physical connection between the observed remote sensing signal and the target (Houborg et al. 2015)

RTMs can be quite descriptive or abstract, depending on the needs.

Source:
http://fapar.jrc.ec.europa.eu/WWW/Data/Pages/FAPAR_Software/Images/semi-discrete.gif

PROSAIL RTM

Combination of:

- PROSPECT leaf model (Jacquemoud & Baret, 2009)
- SAIL canopy model (Verhoef, 1984, 1985)

- Simple
- 10 variables
- Perhaps the most used in the literature

Table 1
Main variables of PROSAIL.

Model	Symbol	Quantity	Unit
PROSPECT	N	Leaf structure parameter	–
	C_{ab}	Chlorophyll $a+b$ content	$\mu g\ cm^{-2}$
	C_w	Equivalent water thickness	cm
	C_m	Dry matter content	$g\ cm^{-2}$
	C_{bp}	Brown pigments content	–
SAIL	LAI	Leaf area index	–
	LIDF*	Leaf inclination distribution function	–
	s_L	Hot spot parameter	–
	ρ_s	Soil reflectance assumed Lambertian or not	–
	SKYL	Ratio of diffuse to total incident radiation	–
	sza or θ_s	Solar zenith angle	deg
	vza or θ_v	Viewing zenith angle	deg
	raa or φ_{sv}	Relative azimuth angle	deg

*Several functions have been proposed to define the LIDF: polynomial, ellipsoidal or elliptic distribution characterized by an average leaf angle (ALA), Beta distribution characterized by two parameters (a and b).

Remote Sensing of Environment 113 (2009) S56–S66

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journal homepage: www.elsevier.com/locate/rse

ELSEVIER

PROSPECT + SAIL models: A review of use for vegetation characterization

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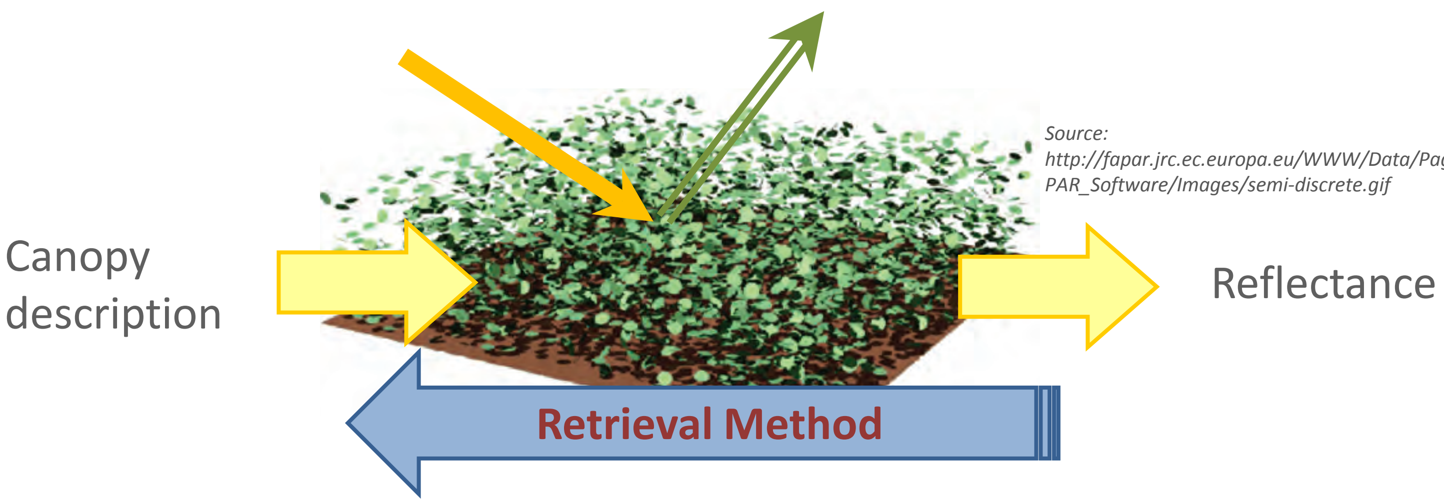
How to retrieve biophysical variables from RS?

Physical methods

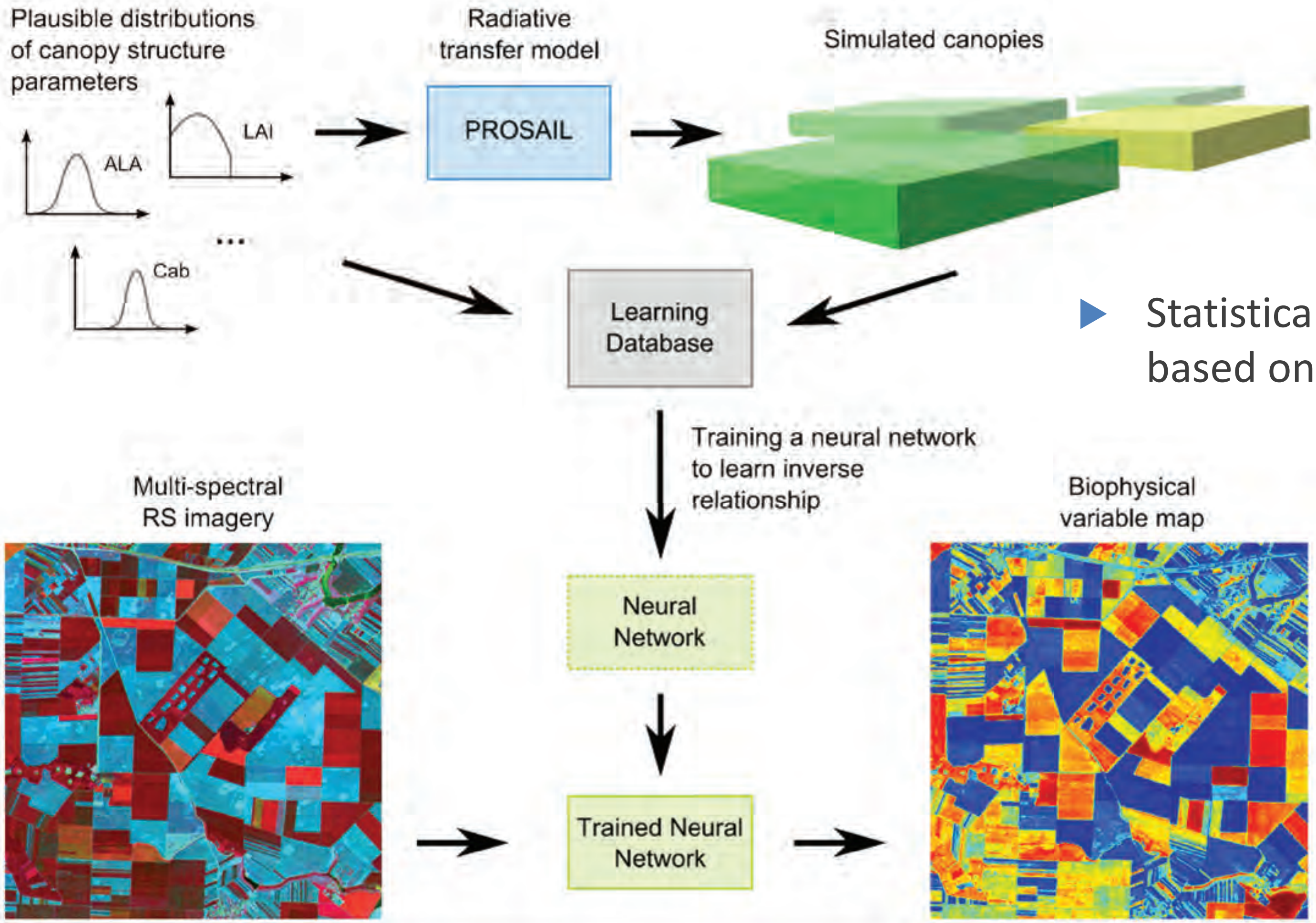
- Replacement of field measurements by radiative transfer models (RTMs)
- Mathematical inversion necessary, but difficult because it is an ill-posed problem



Source: http://fapar.jrc.ec.europa.eu/WWW/Data/Pages/FAPAR_Software/Images/semi-discrete.gif

- Method is transportable across landscapes as long as RTM is valid

Example of a hybrid inversion method using PROSAIL and NNT



- Statistical relationship based on RTM results

Example of a global product built using such method: GEOV1

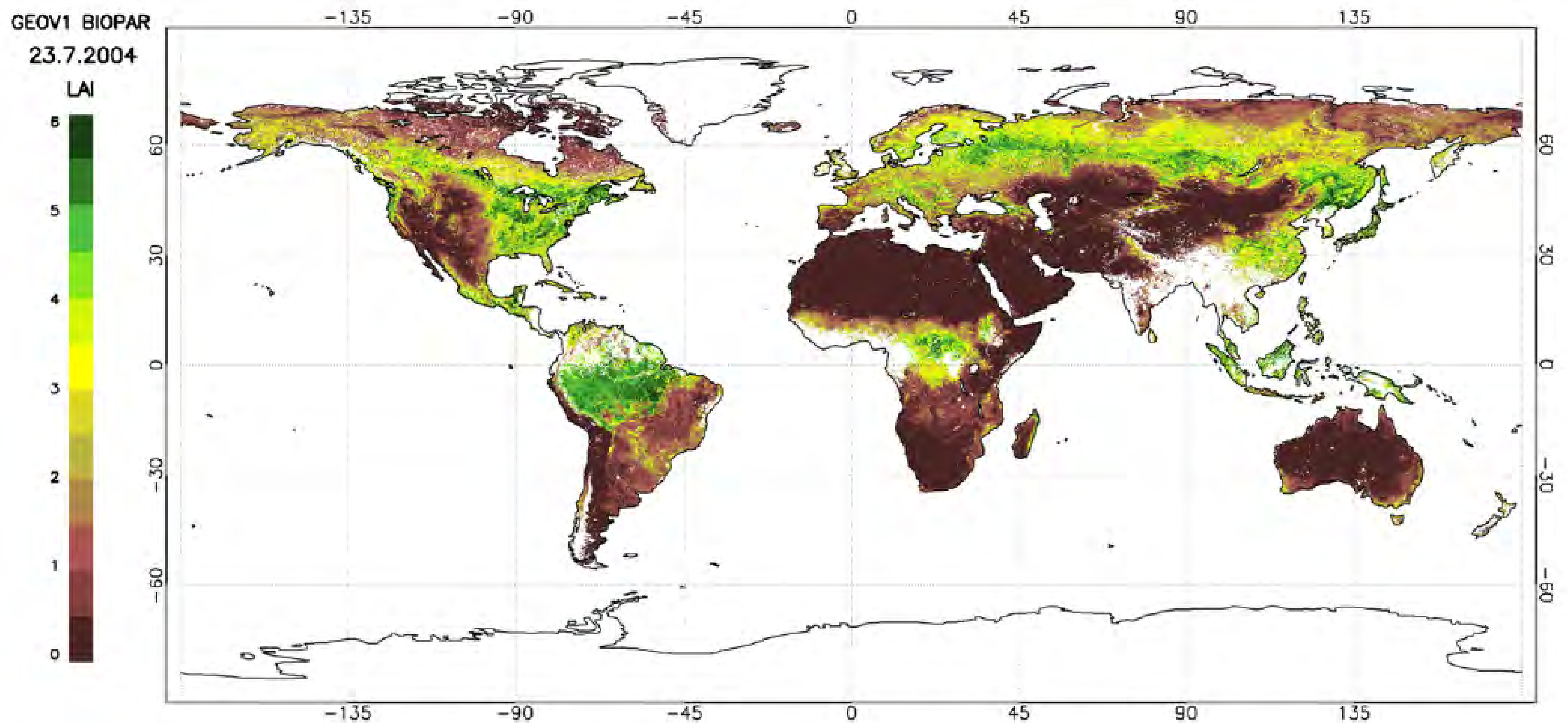
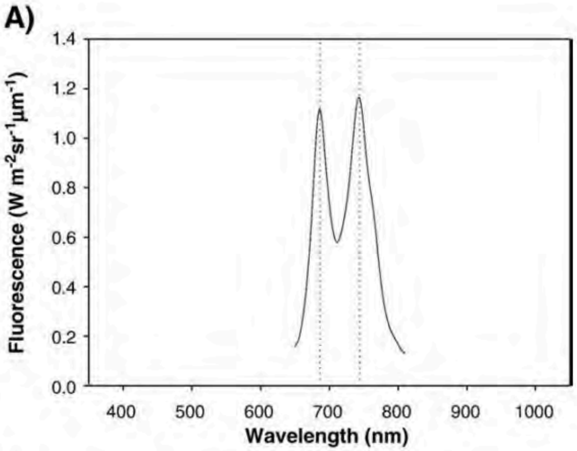
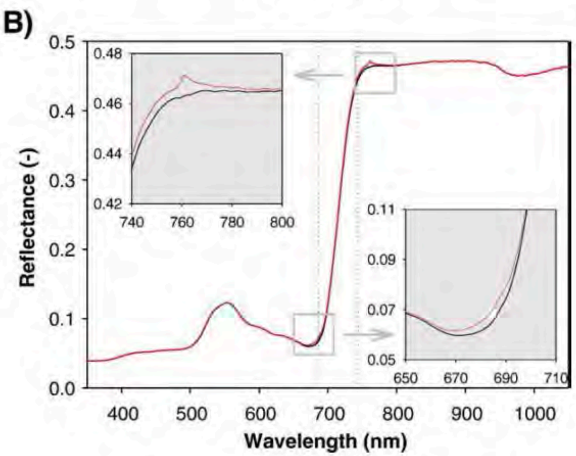


Fig. 1. GEOV1 LAI global map corresponding to the 23rd of July of 2004.

Please cite this article as: Camacho, F., et al., GEOV1: LAI, FAPAR essential climate variables and FCOVER global time series capitalizing over existing products. Part 2: Validation..., *Remote Sensing of Environment* (2013), http://dx.doi.org/10.1016/j.rse.2013.02.030

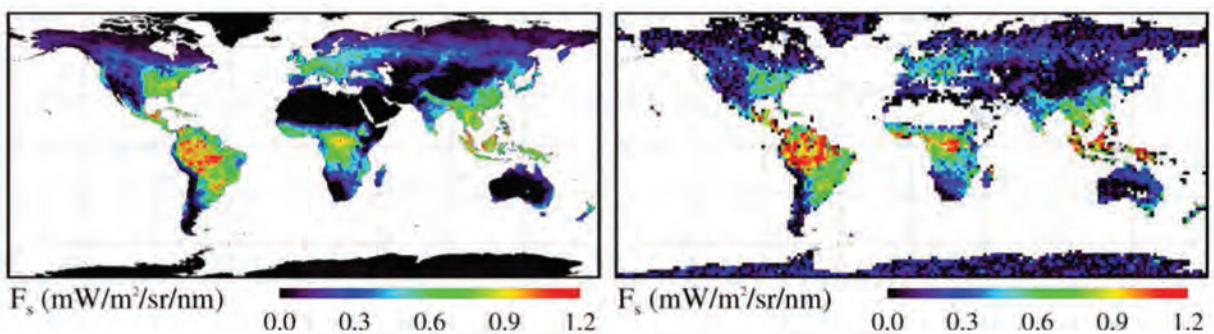
The complexity of retrieving SIF results in coarse resolution





Source: Meroni et al. 2009. RSE, 113, 2037-2051

- Only Only 1-5% of the reflected signal !!!
- Yet, can be measured (passively) thanks to telluric O2 absorption bands and sophisticated radiative transfer inversion
- Global datasets now available for 2007 onwards
- Downscaling to finer resolution is coming…



(c) GOME-2 (left) and GOSAT (right), Annual 2009

Source: Joiner et al. 2013. Atmos. Meas. Tech., 6, 2803–2823

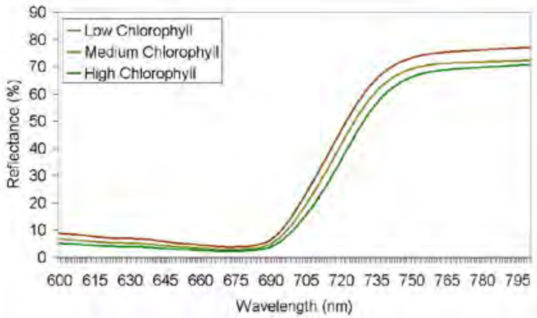
Others useful parts of the spectrum…

Photochemical Reflectance Index (PRI): Normalized difference between leaf reflectance at 531 nm and a reference wavelength (~550 nm) (Gamon et al. 1992)

⇒ Related to xanthophyll cycle

⇒ can serves as proxy for LUE

Source : http://www.seos-project.eu/modules/agriculture/agriculture-c01-s02.html



Bands in the RED EDGE: region of rapid change in reflectance of vegetation between red and near infrared (690-730 nm)

⇒ recognized as key for improving chlorophyll retrieval capacity

⇒ Sentinel-2 has 2 bands in the red edge

Thermal Infra Red (TIR): particularly sensitive to stomatal behaviour, as canopy temperatures will respond directly to water stress through induced stomatal closure and decreased evaporative cooling (Houborg et al. 2015)

Using thermic with VIs together

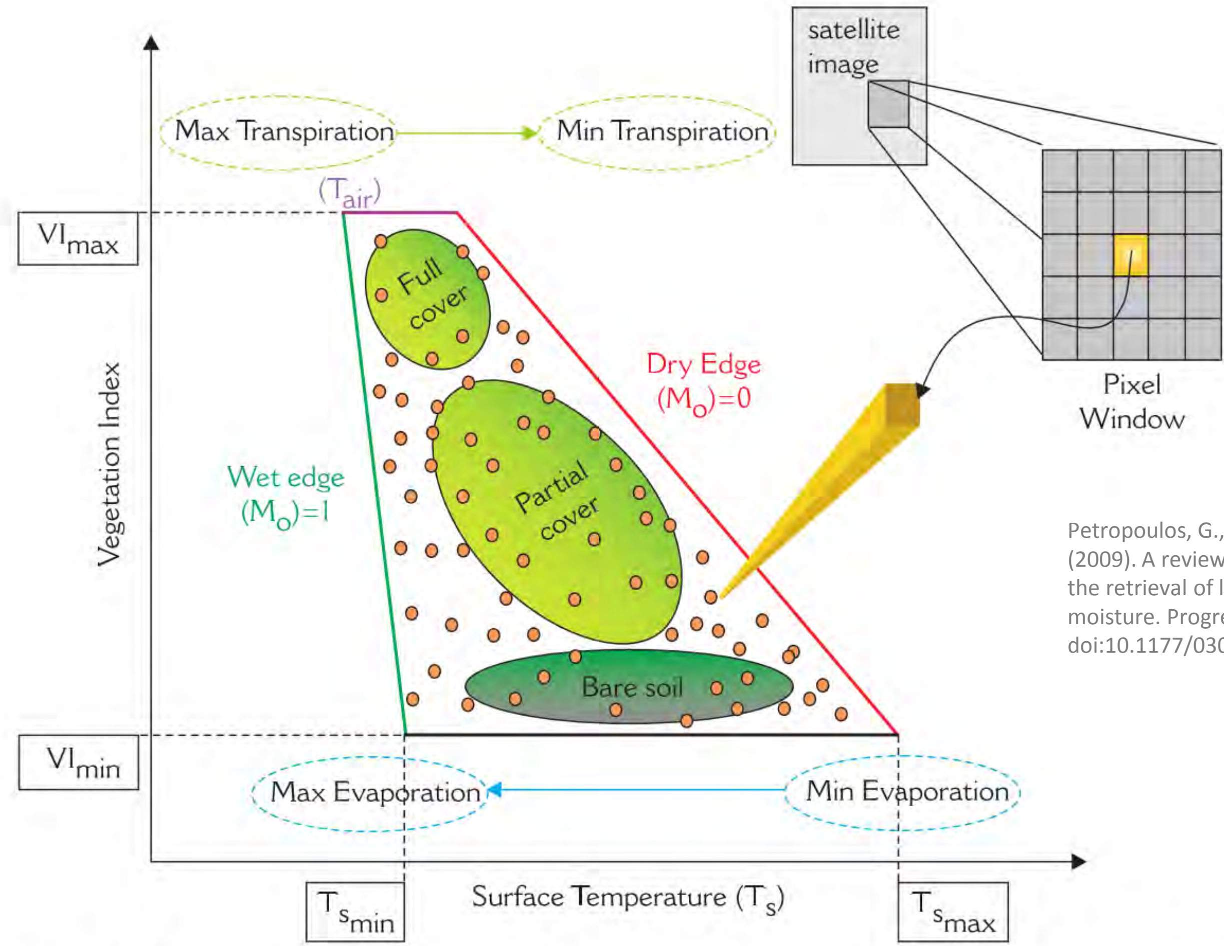


Figure 1 Summary of the key descriptors and physical interpretations of the T_s/VI feature space or 'scatterplot'

Source: Synthesized from previous works of Lambin and Ehrlich (1996), Sandholt *et al.* (2002) and Nishida *et al.* (2003a; 2003b).

Petropoulos, G., Carlson, T. N., Wooster, M. J., & Islam, S. (2009). A review of Ts/VI remote sensing based methods for the retrieval of land surface energy fluxes and soil surface moisture. Progress in Physical Geography, 33(2), 224–250. doi:10.1177/0309133309338997

WHEN and WHERE?

Balancing the requirements in terms of temporal and spatial resolution for agriculture monitoring

Balance in the type of information we need…

How often?
[Temporal resolution]

What temporal coverage?
[Archive length]

How detailed?
[Spatial resolution]

What geographic extent?
[Swath]

How precisely?
[Radiometric resolution]

Where in the EM spectrum?
[Spectral resolution]

At what angle?
[Angular resolution]

How often? [Temporal resolution]

Near real-time (NRT) high temporal frequency data to detect changes in crop status

- agro events happen in the order of 7 days

Many observations potentially discarded (clouds, angles, etc.)

- we need as many observations as possible

* Ideally all individual observations should be available instead of predefined temporal composites

How detailed? [Spatial resolution]

Mixed pixels are ambiguous and complicated to unmix due to:

- potential temporal shifts between winter and summer crops
- adjacent crops change with rotations

Spatial resolution needs to be fine enough to have a crop specific signal

But not too coarse to limit

- unnecessary noise
- excessive computations

Spatial requirements will vary according to landscape complexity (e.g. Duveiller & Defourny 2010, RSE)

What geographic extent? [Swath]

Localized precision agriculture?

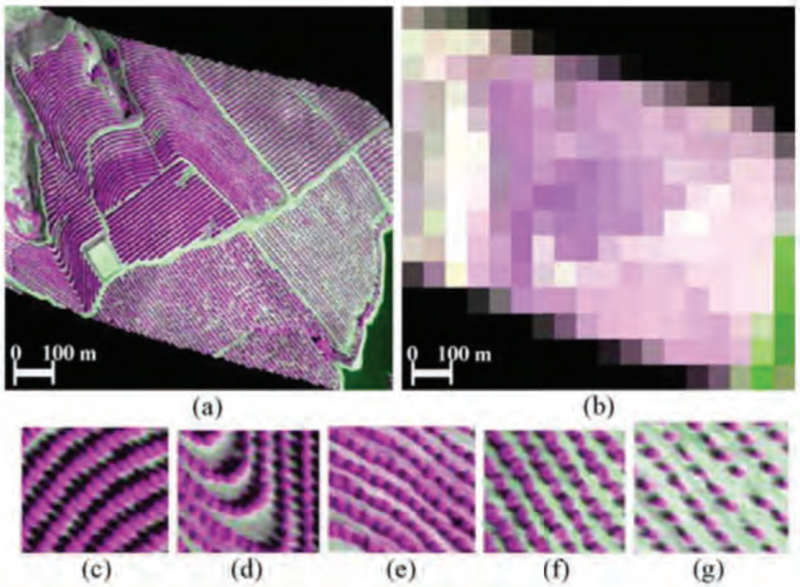
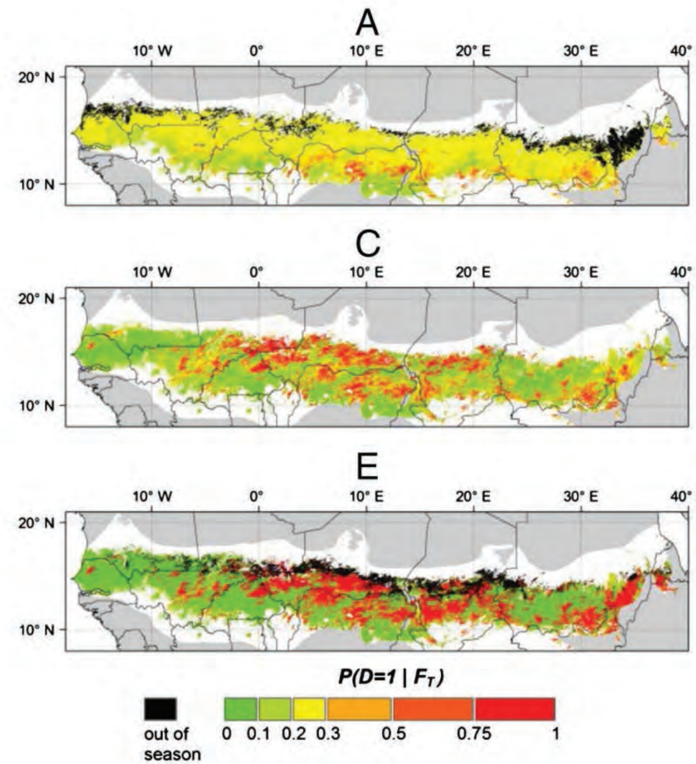


Fig. 1. (a) Airborne hyperspectral imagery acquired with the micro-Hyperspec VNIR sensor on board a UAV yielding 40-cm resolution. (b) Resampled to 50-m pixels to assess the aggregation effects on fluorescence retrieval. (c)–(g) Complexity of planting grids/orientations. Images are shown in color composites using green, red, and NIR bands.

Zarco-Tejada, P. J., Suarez, L., & Gonzalez-Dugo, V. (2013). Spatial Resolution Effects on Chlorophyll Fluorescence Retrieval in a Heterogeneous Canopy Using Hyperspectral Imagery and Radiative Transfer Simulation, 10(4), 937–941.

… or global/regional ag. Monitoring?



Meroni, M., Fasbender, D., Kayitakire, F., Pini, G., Rembold, F., Urbano, F., & Verstraete, M. M. (2014). Early detection of biomass production deficit hot-spots in semi-arid environment using FAPAR time series and a probabilistic approach. Remote Sensing of Environment, 142, 57–68. http://doi.org/10.1016/j.rse.2013.11.012

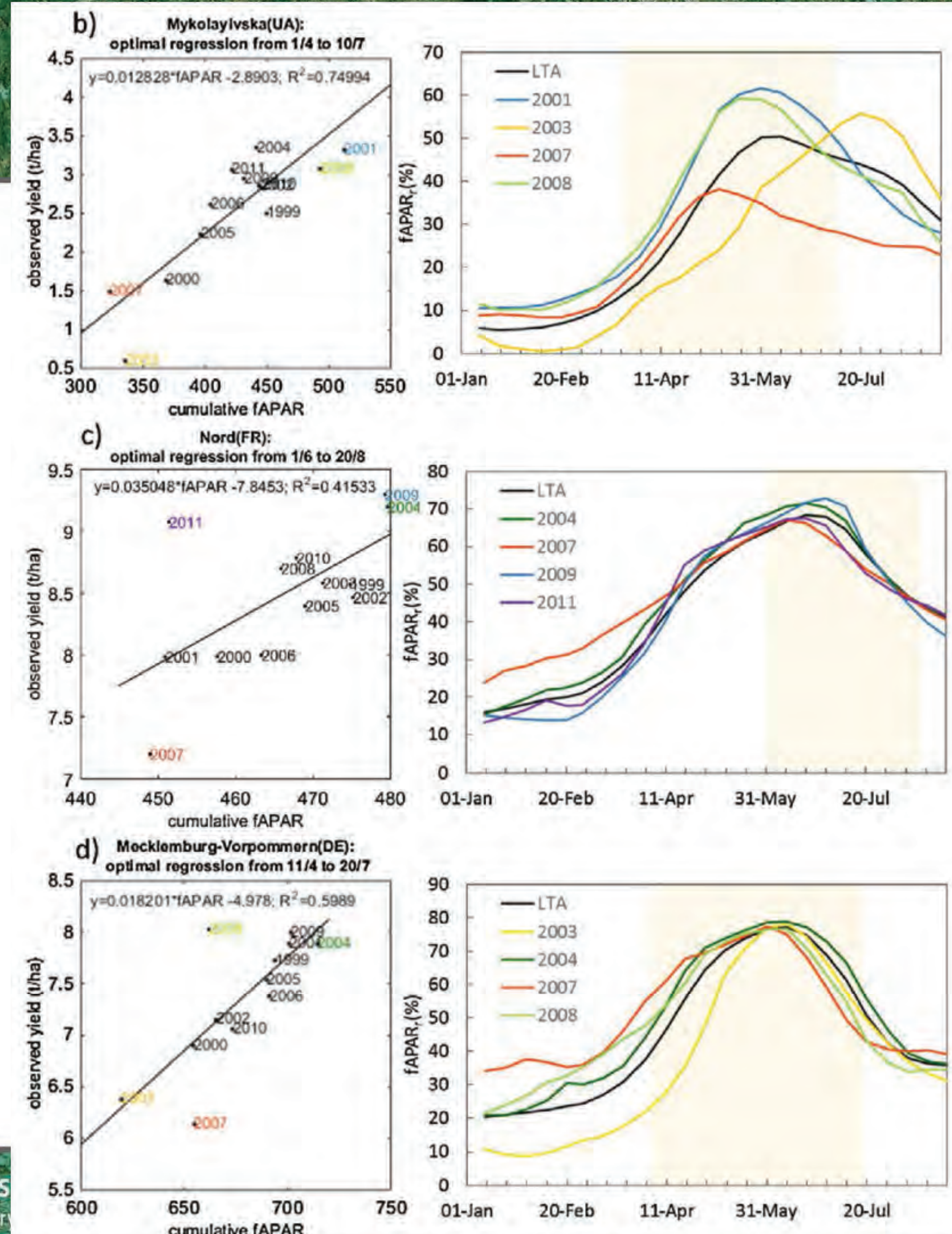
What temporal coverage? [Archive length]

Many applications require comparing with past events to characterize:

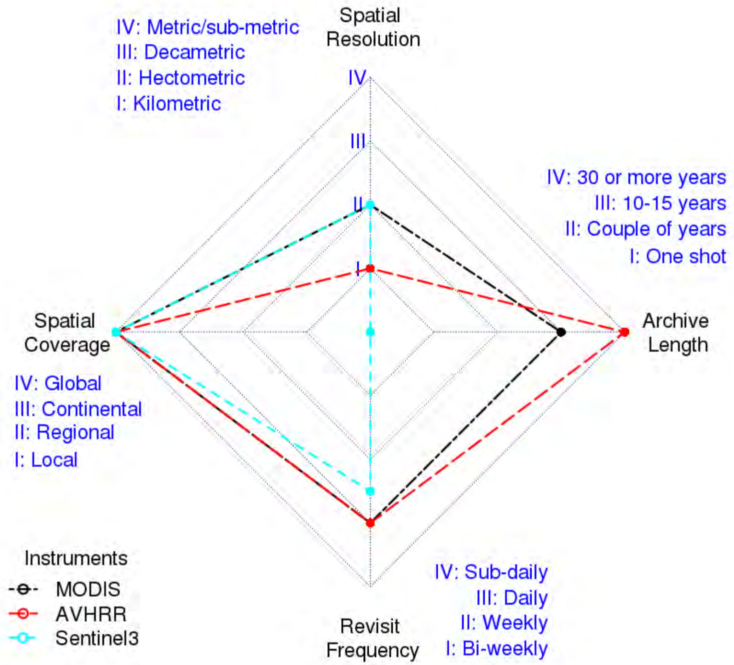
- similar years
- anomalies
- trends

Need for longest possible archives…

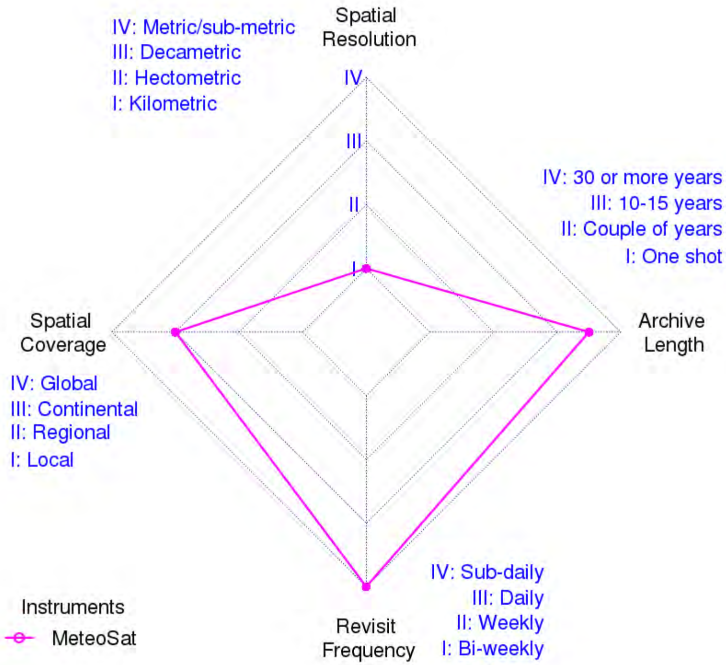
López-Lozano, R., Duveiller, G., Seguini, L., Meroni, M., García-Condado, S., Hooker, J., … Baruth, B. (2015). Towards regional grain yield forecasting with 1km-resolution EO biophysical products: Strengths and limitations at pan-European level. Agricultural and Forest Meteorology, 206, 12–32. doi:10.1016/j.agrformet.2015.02.021

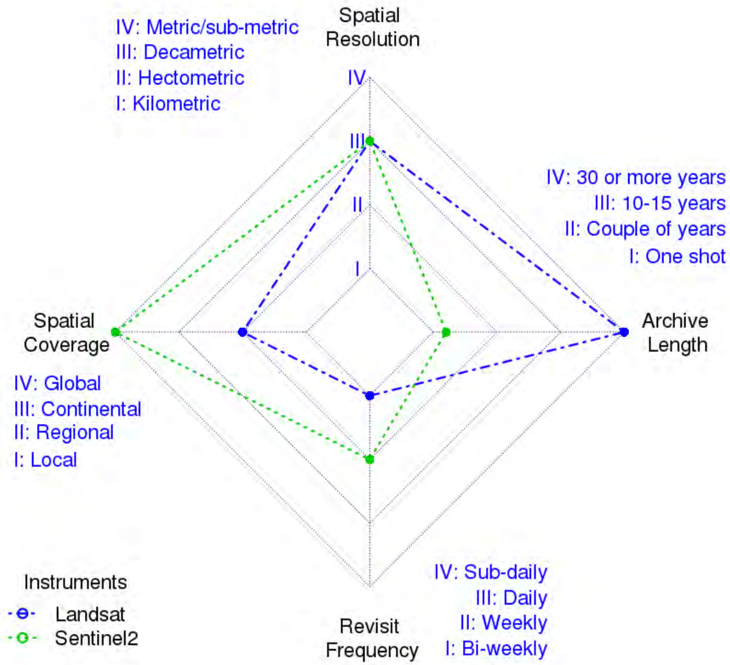


We can resume our 4 “dimensions” into a “spider-plot”



We can resume our 4 “dimensions” into a “spider-plot”





Is ‘coarse’ spatial resolution obsolete?

- Sentinel2A + Sentinel2B should provide 5 days revisit…
- Combination with Landsat 8 will increase frequency even more…
- Solutions like Google Earth Engine (GEE) allow managing such heavy loads of data

Increase in observation capacity + spatial resolution

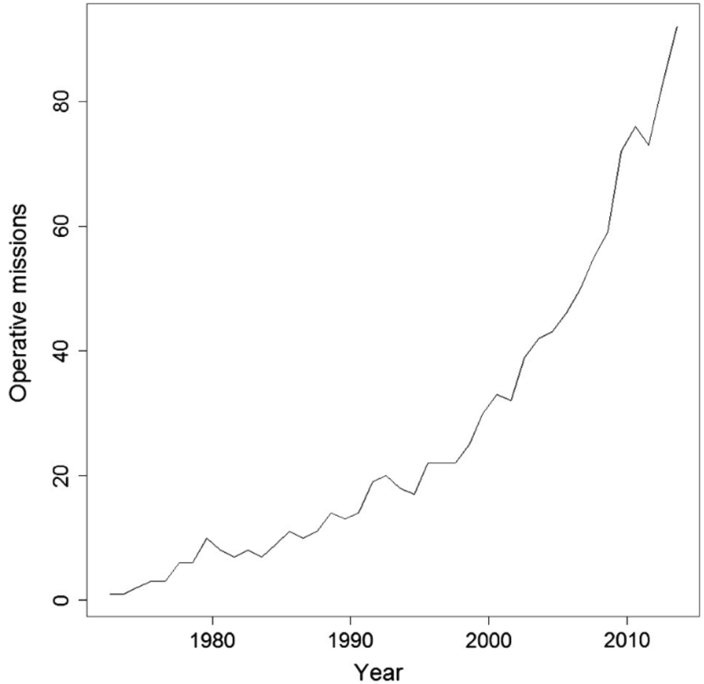


Fig. 2. The number of near-polar orbiting, land imaging civilian satellites operational as of 1st August 1972 to 2013.

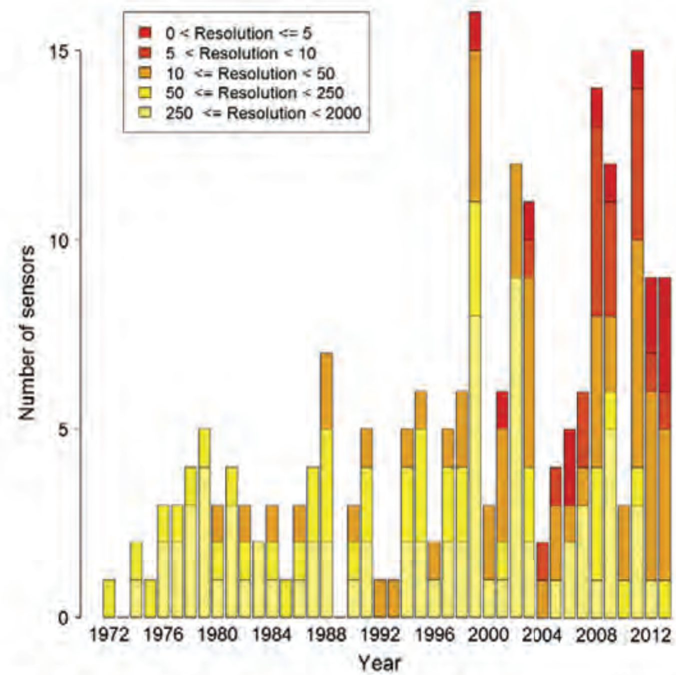
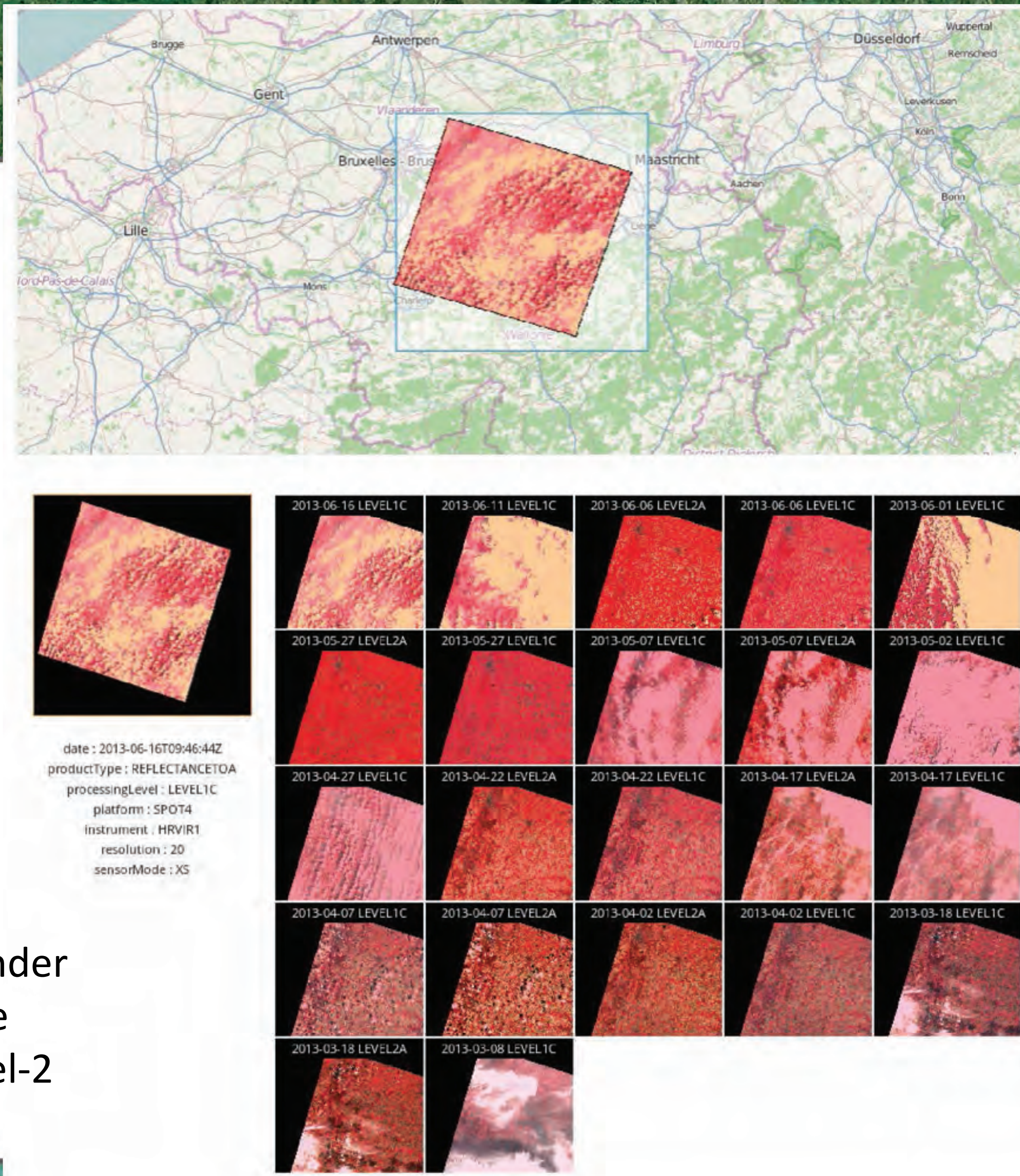


Fig. 9a. Number of multispectral sensors at different spatial resolutions flying on near-polar orbiting, land imaging civilian satellites per year.

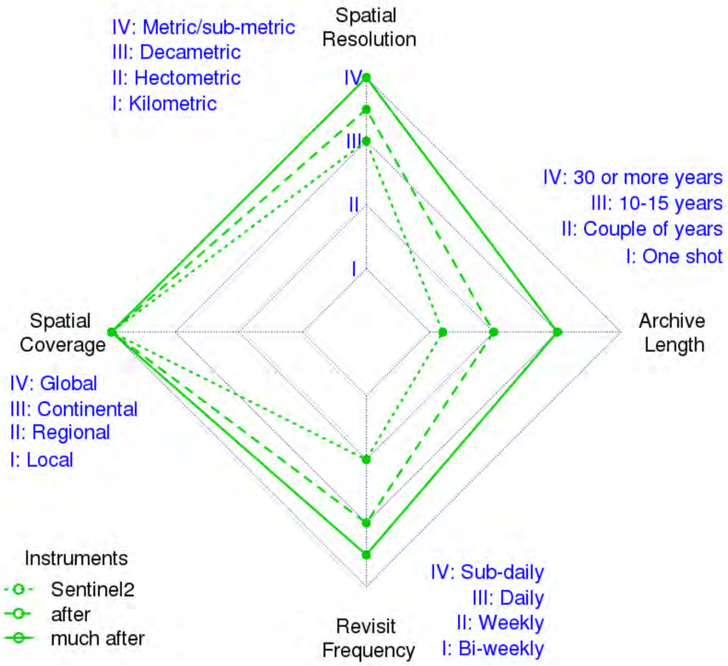
Belward, A. S., & Skøien, J. O. (2014). Who launched what, when and why; trends in global land-cover observation capacity from civilian earth observation satellites. ISPRS Journal of Photogrammetry and Remote Sensing, 103, 115–128. doi:10.1016/j.isprsjprs.2014.03.009

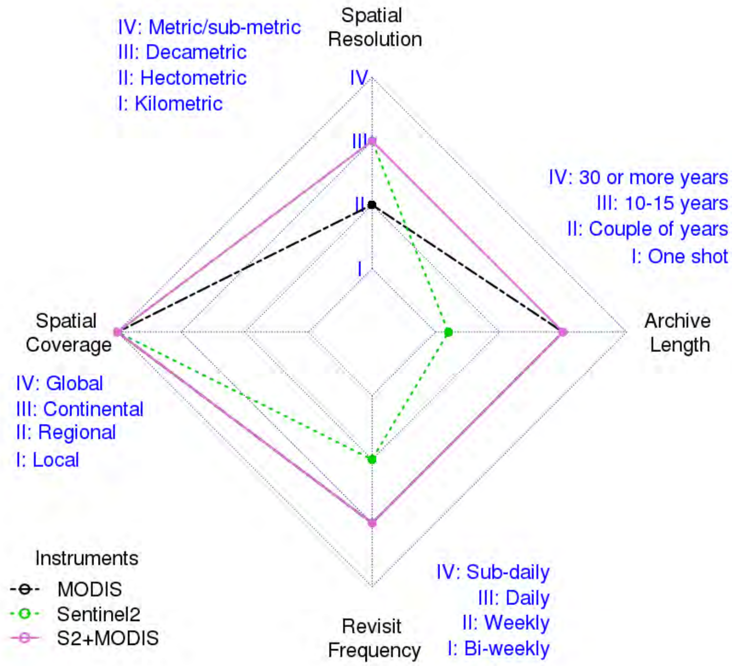
Clouds are still an issue and will remain an issue …



Imagery for a site in Belgium proposed by CNES and CESBIO under SPOT4/TAKE5 initiative to provide data with similar specs to Sentinel-2

Possible strategies…





Wait for an archive to be constituted… … or use existing data synergistically

Dealing with data smartly
in the context of Ag. monitoring

Suggestions for better synergetic use of various data

- Prefer inter-operable products instead instrument specific ones
  - $\Rightarrow$ Help building consistent long term data records
  - $\Rightarrow$ Eases the use of data from different sensors
- Change resolutions intelligently
  - $\Rightarrow$ Use spatial (or spatio-temporal) image segmentation for high spatial resolution
  - $\Rightarrow$ use all daily data to smooth in time and avoid pre-defined temporal composites
- Try to get more out of coarser pixels
  - $\Rightarrow$ Spatio-temporal data fusion with fine resolution
  - $\Rightarrow$ Select spatial samples of adequate pixels
- Combine RS info with crop growth models

Trying to get more from coarse pixels: data fusion

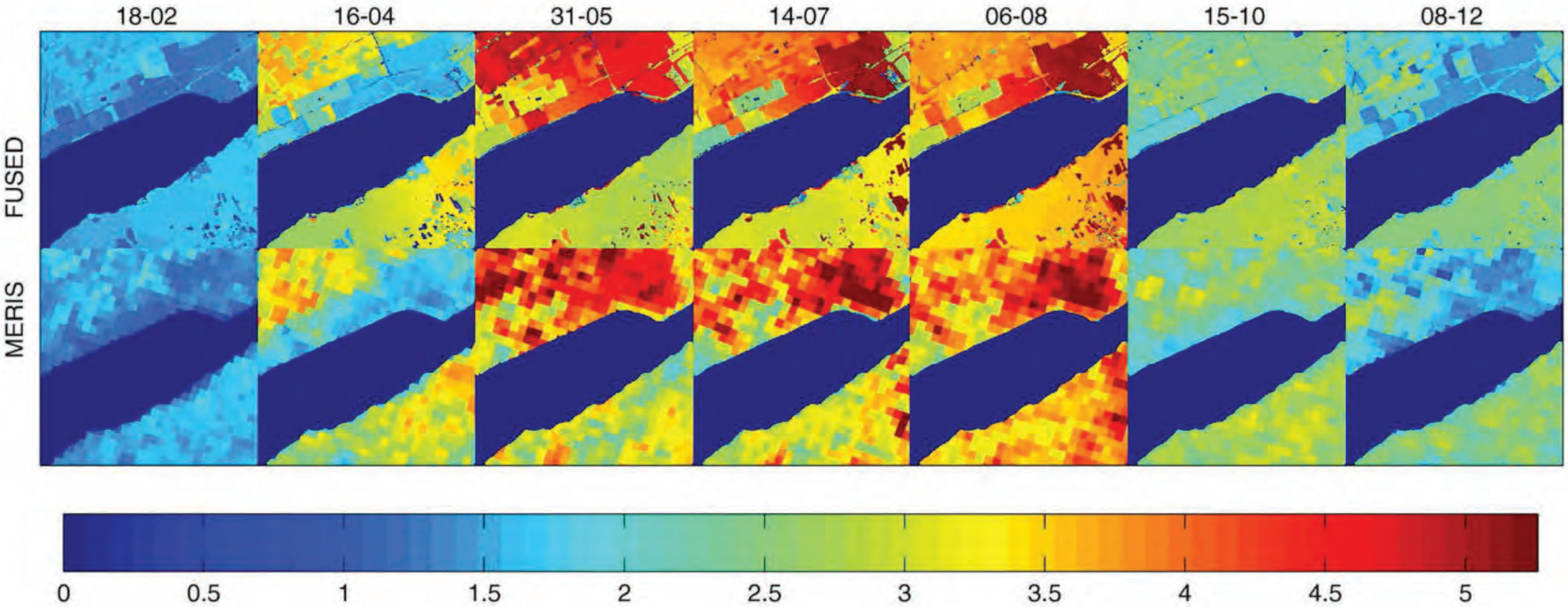


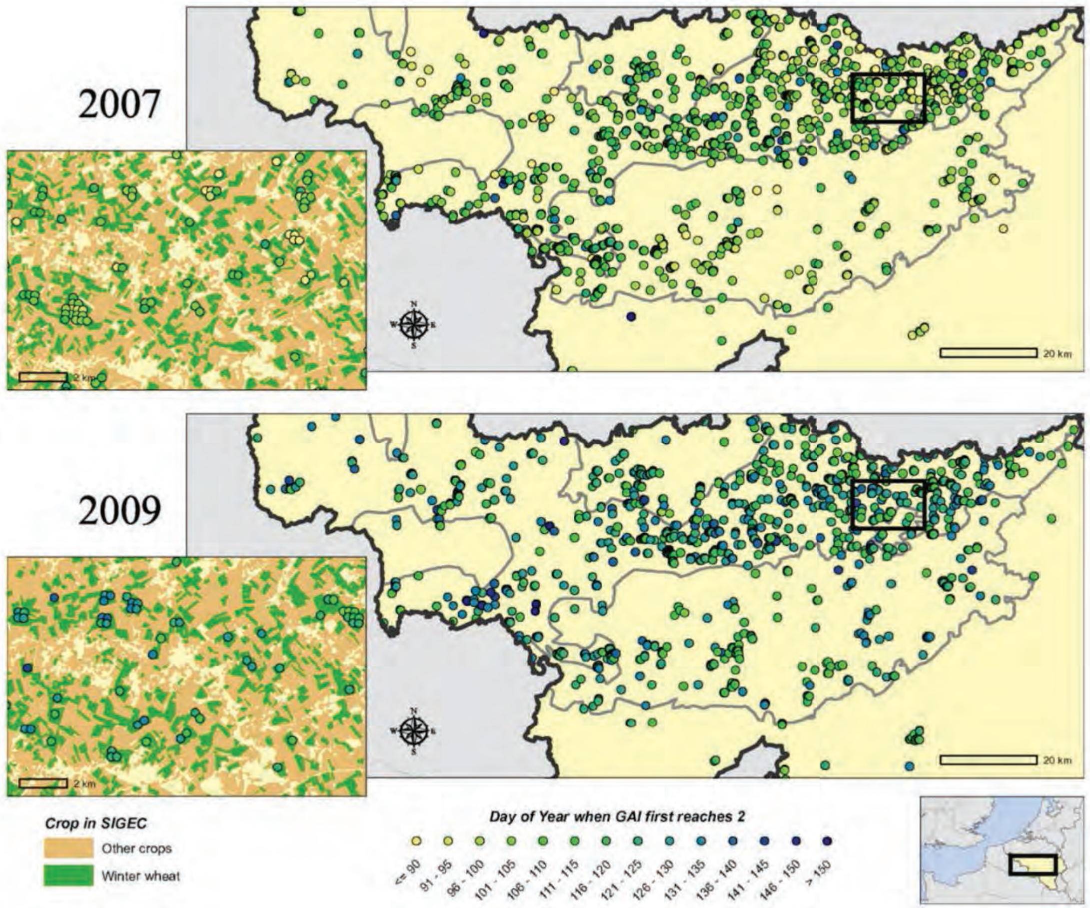
Fig. 9. Temporal evolution of MTCI values for fused (top) and MERIS (bottom) data.

Zurita-Milla, R., Kaiser, G., Clevers, J. G. P. W., Schneider, W., & Schaepman, M. E. E. (2009). Downscaling time series of MERIS full resolution data to monitor vegetation seasonal dynamics. Remote Sensing of Environment, 113(9), 1874–1885. http://doi.org/10.1016/j.rse.2009.04.011

Trying to get more from coarse pixels: selecting a spatial sample

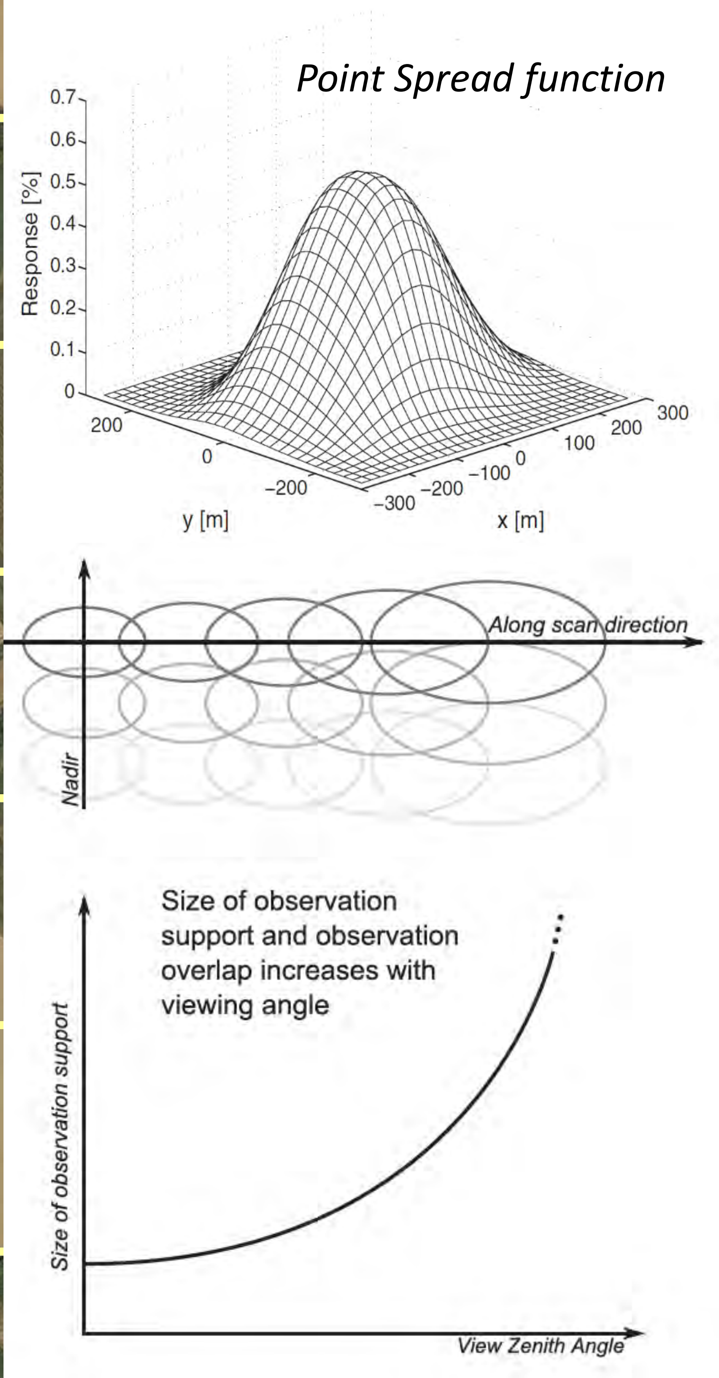
Only pixels falling adequately in the target fields are used to represent the dynamics at regional level

Unlike fusion, requires no (or just limited) high spatial info



Duveiller, G., Baret, F., & Defourny, P. (2012). Remotely sensed green area index for winter wheat crop monitoring: 10-Year assessment at regional scale over a fragmented landscape. Agricultural and Forest Meteorology, 166-167, 156–168. http://doi.org/10.1016/j.agrformet.2012.07.014


What many people THINK is in a pixel
What may actually be in a pixel


Point Spread function
Response [%]
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
200
0
−200
y [m]
300
200
100
0
−100
−200
−300
x [m]
Along scan direction
Nadir
Size of observation support and observation overlap increases with viewing angle
Size of observation support
View Zenith Angle

Crop identification by exploiting the multi-angularity of the temporal signal

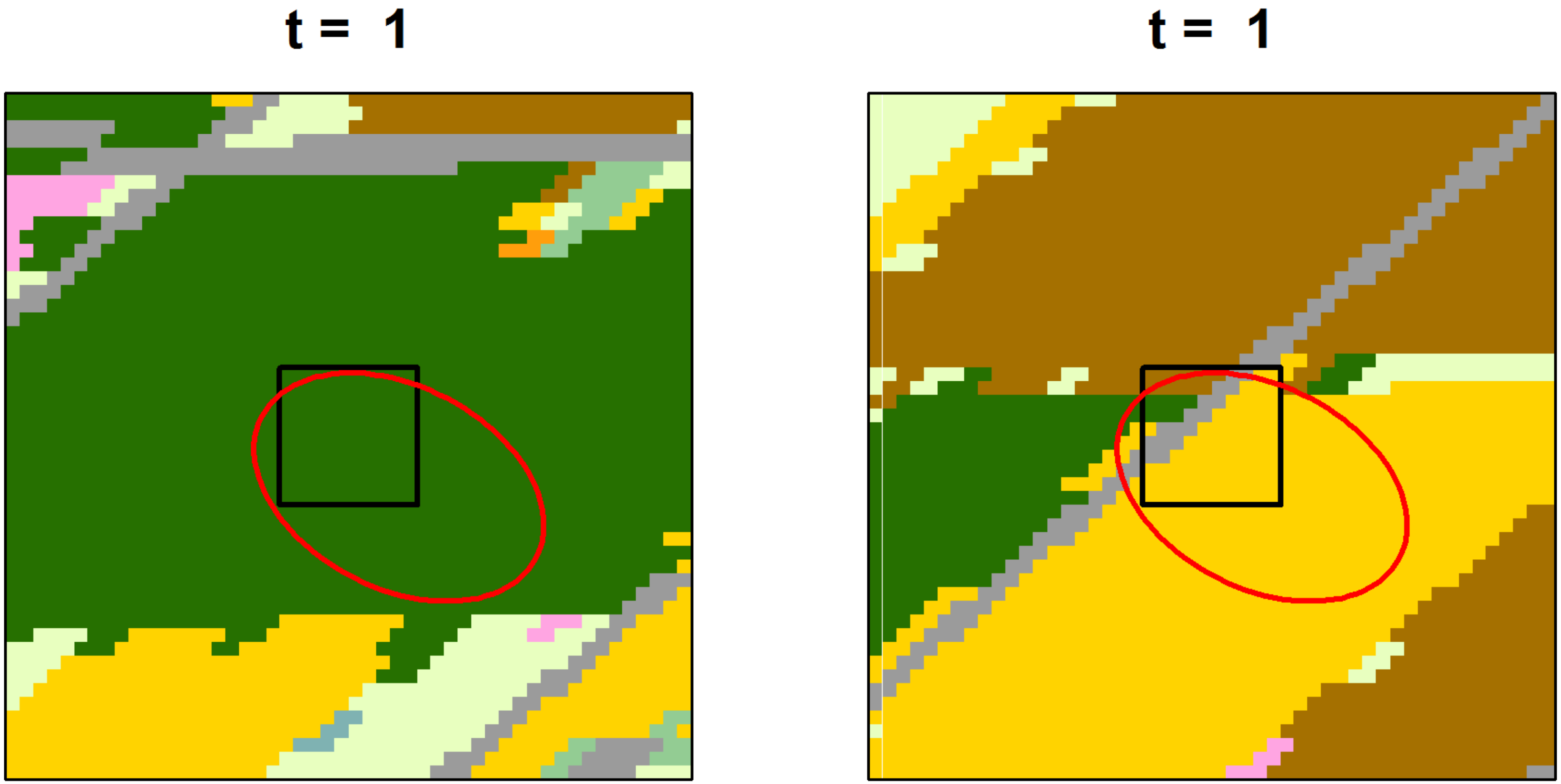
Duveiller, G., Lopez-Lozano, R., & Cescatti, A. (2015). Exploiting the multi-angularity of the MODIS temporal signal to identify spatially homogeneous vegetation cover: A demonstration for agricultural monitoring applications. Remote Sensing of Environment, 166, 61–77. http://doi.org/10.1016/j.rse.2015.06.001

Example with MODIS:

- Revisit orbit cycle is 16 days
- The footprint changes every day during that period
- Potentially 2 observation per day
- The same area is not sampled in every consecutive day !

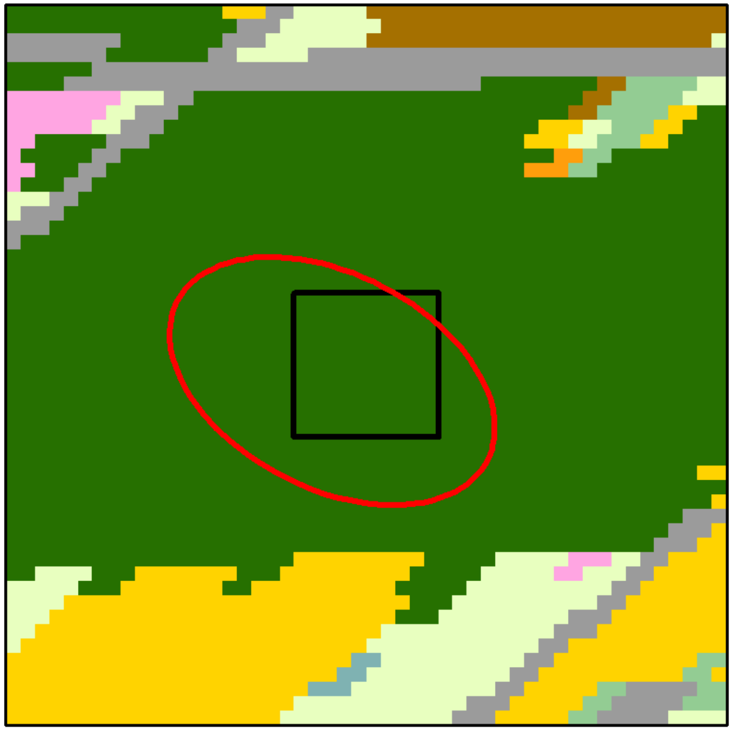
Objective: exploit this property to identify crop specific time series

Sampling the grid cell vicinity

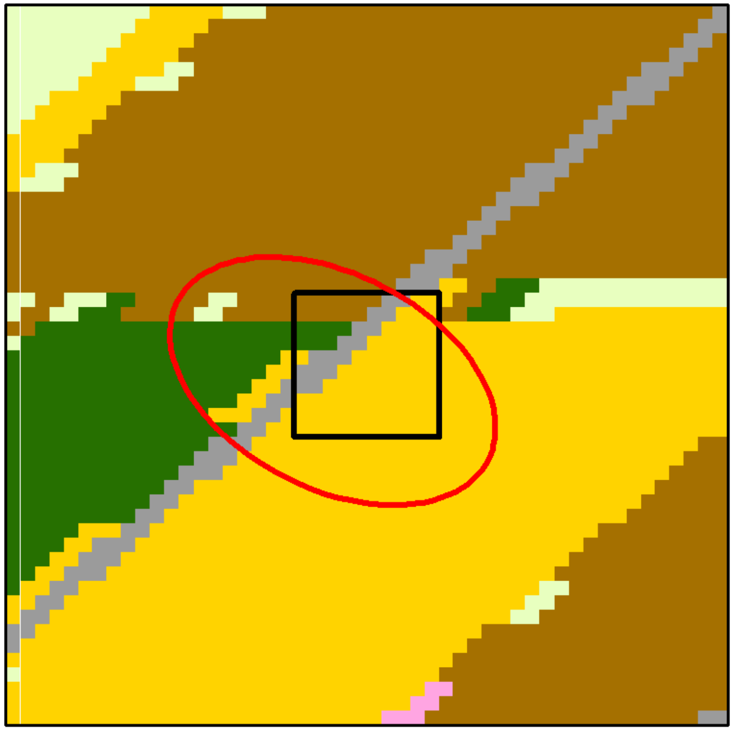


Sampling the grid cell vicinity

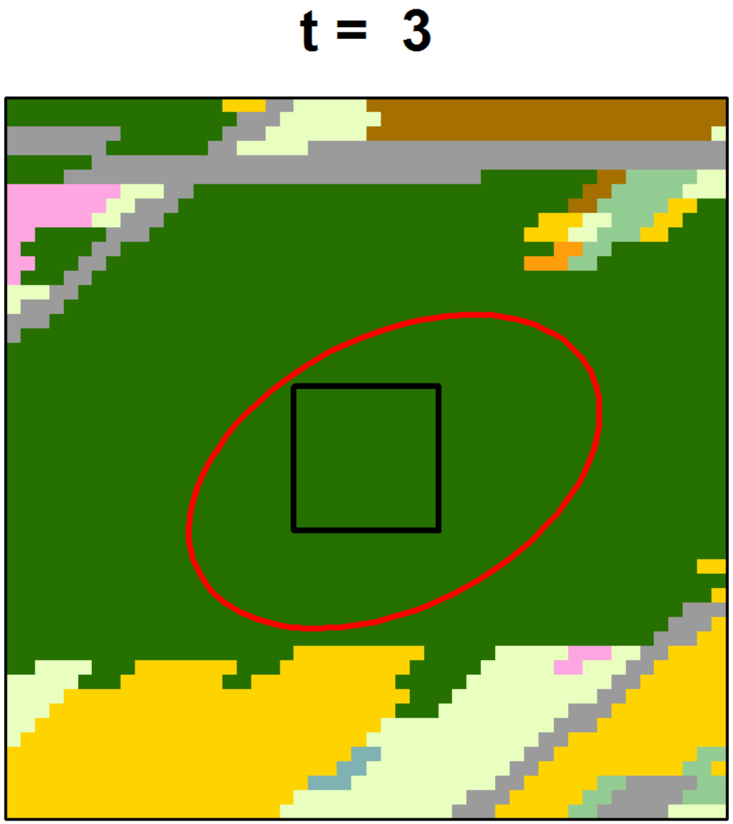
t = 2

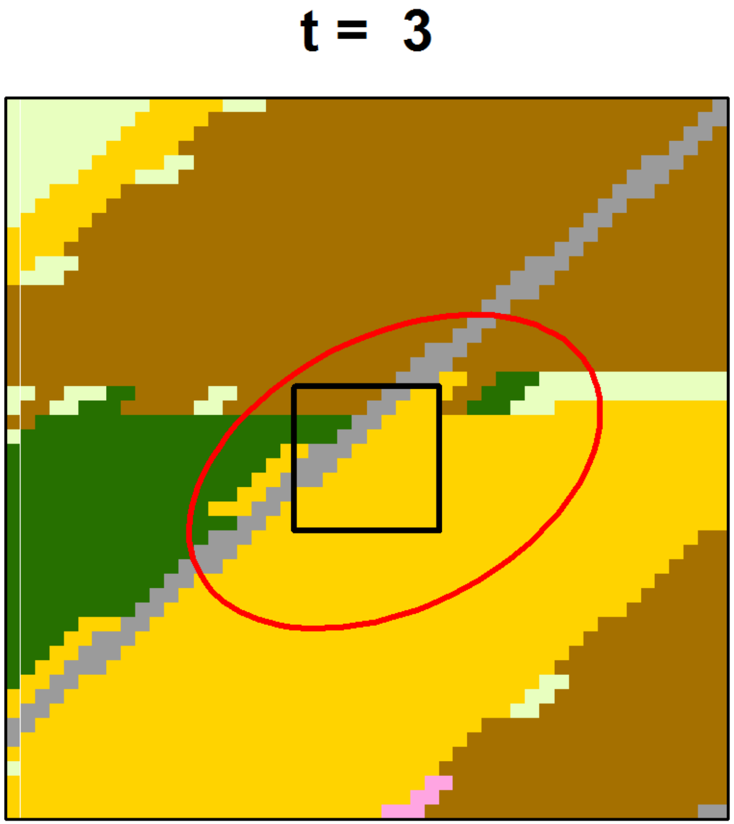


t = 2



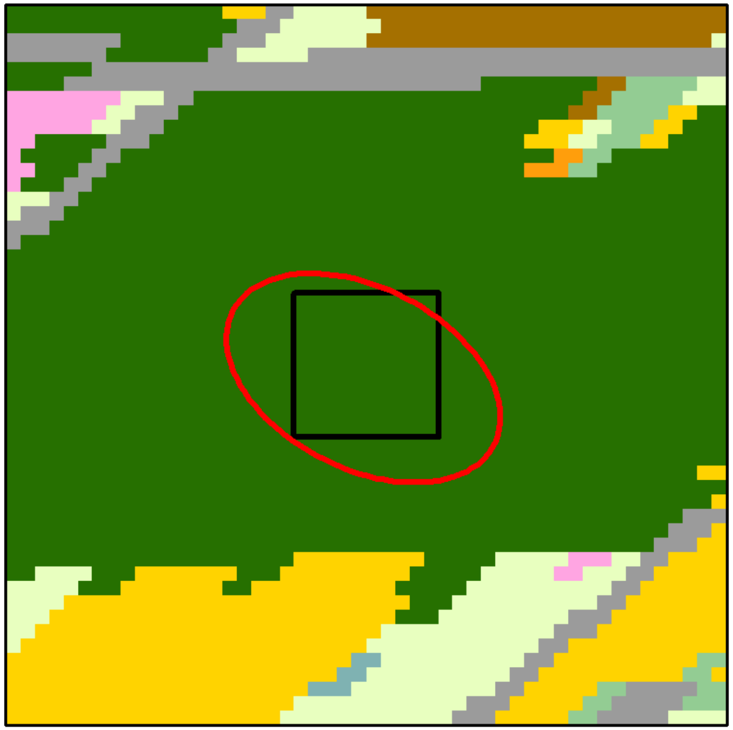
Sampling the grid cell vicinity



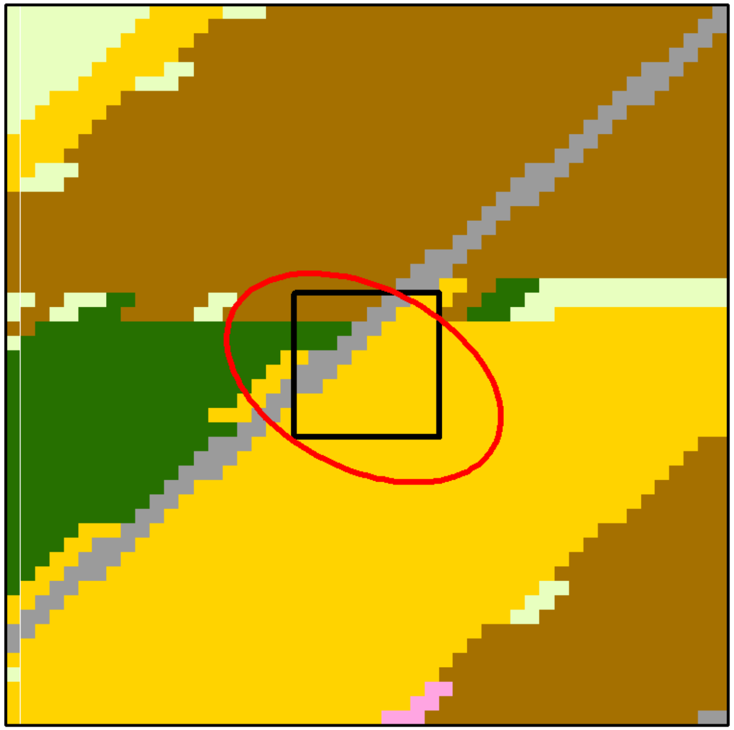


Sampling the grid cell vicinity

t = 4

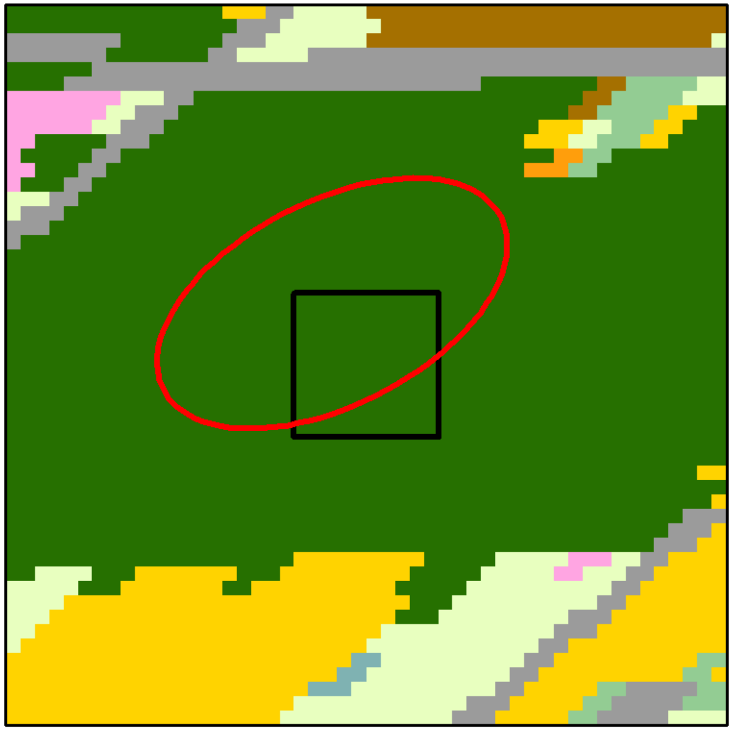


t = 4

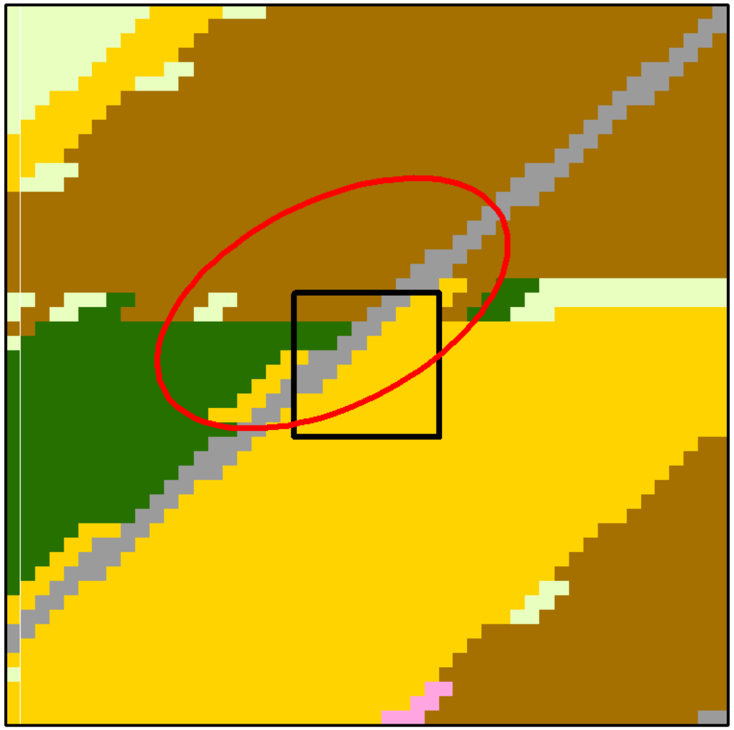


Sampling the grid cell vicinity

t = 5

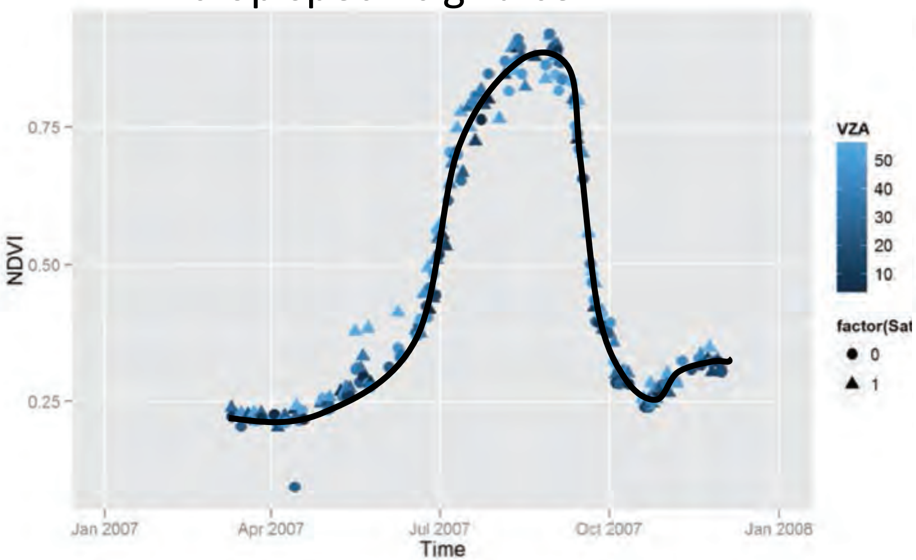


t = 5

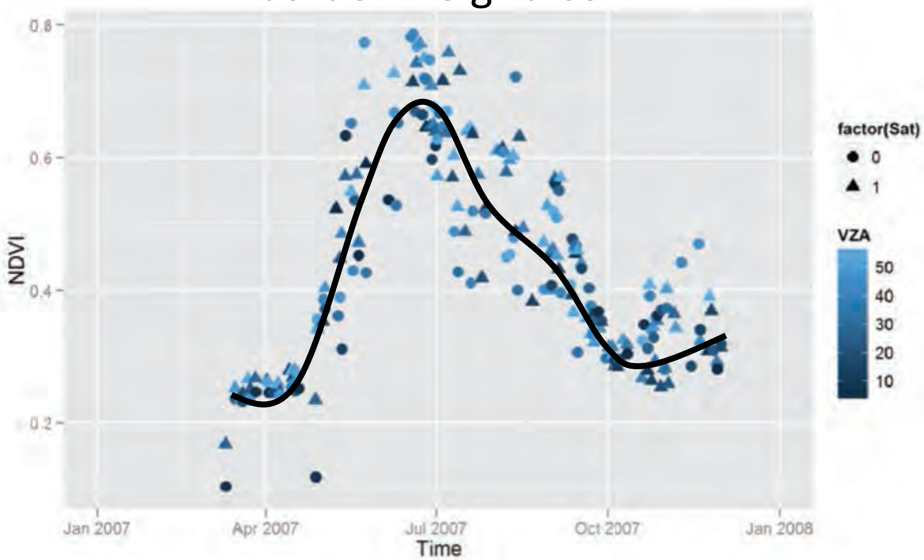


Estimating the target's homogeneity

A crop specific grid cell



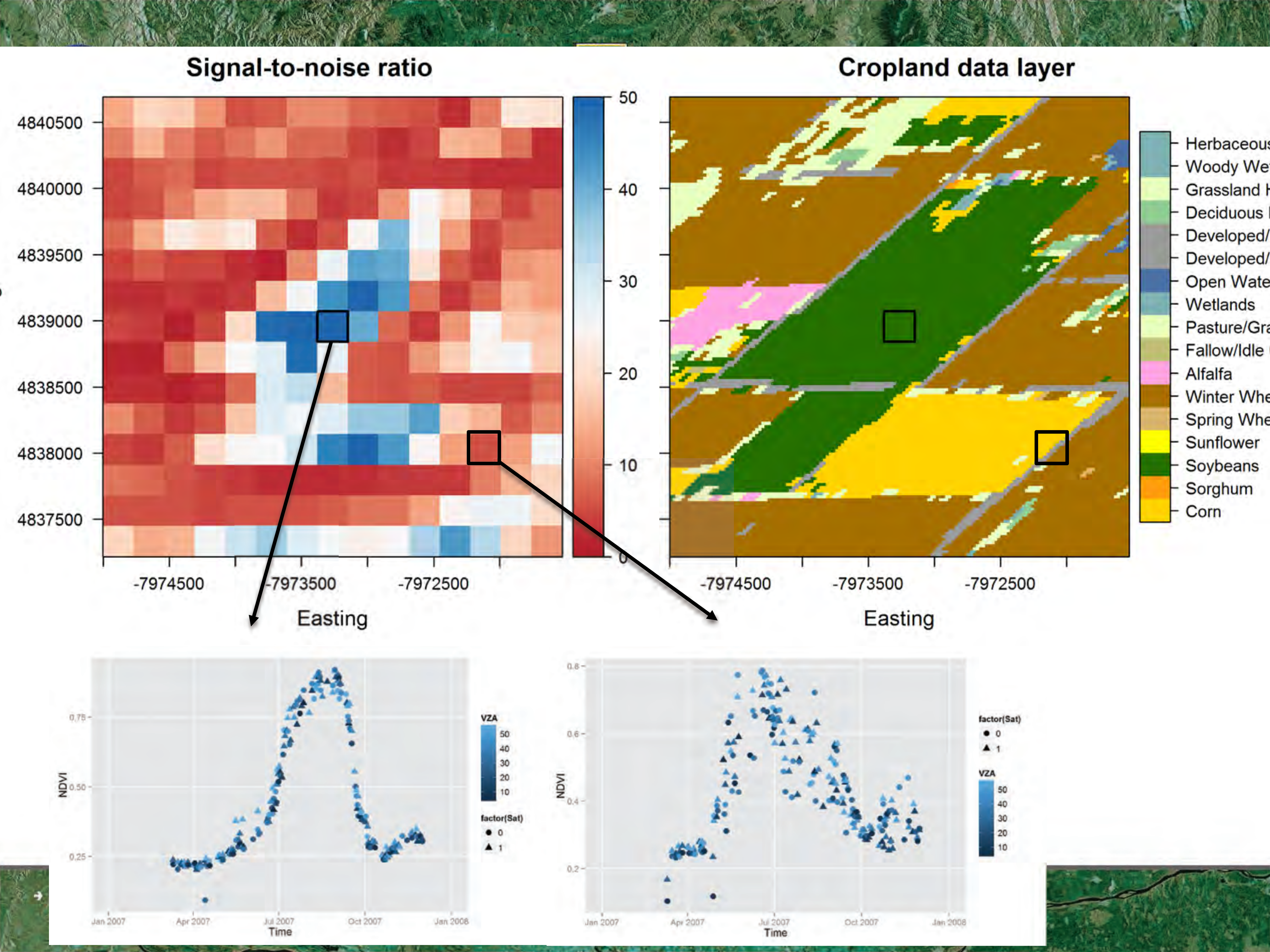
A borderline grid cell



Signal can first be smoothed based on all filtered observation (including high angles)

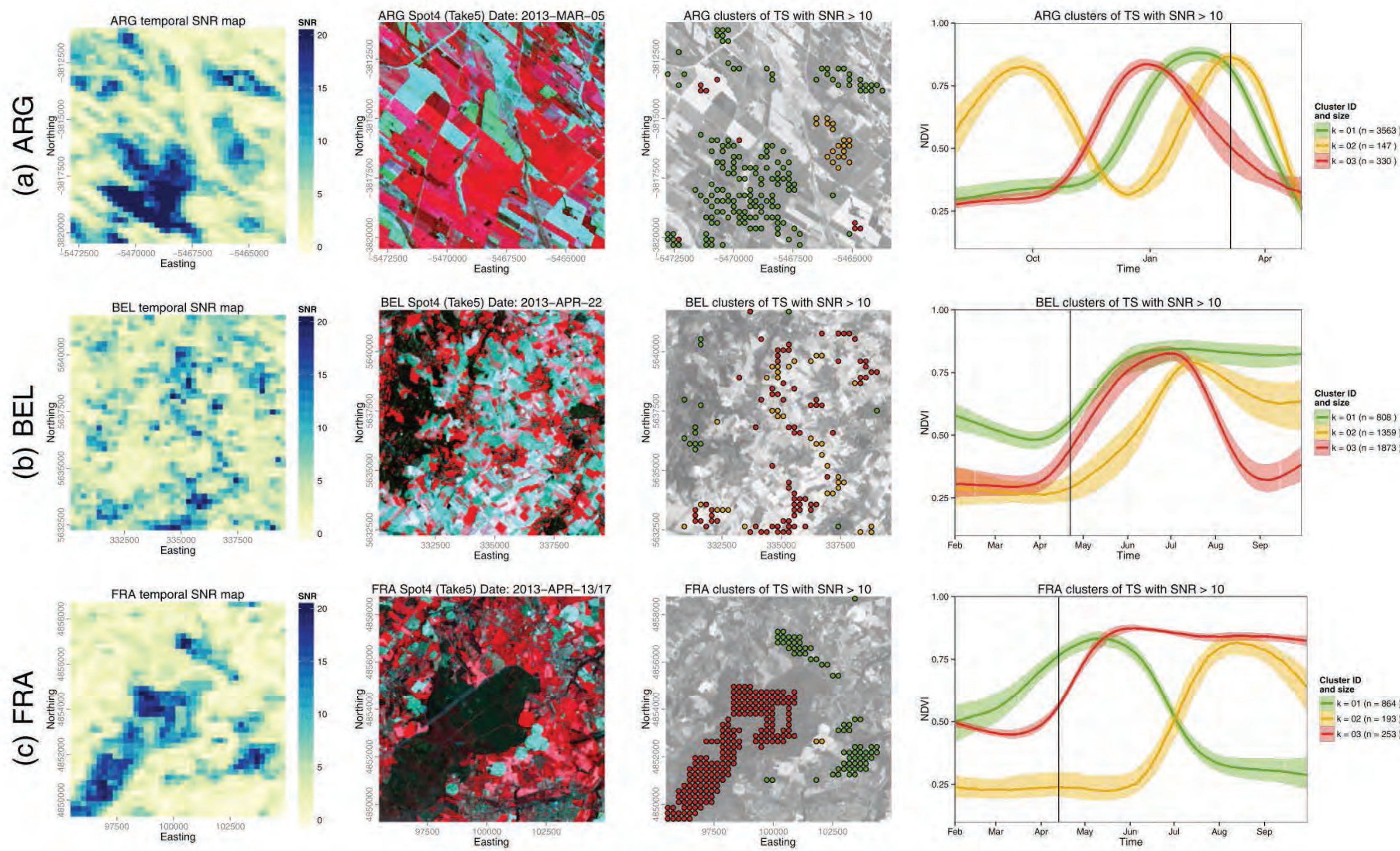
Temporal signal to noise ratio can be calculated as:

$$SNR = Var(signal)/Var(noise)$$



Signal-to-noise ratio
Cropland data layer
4840500
4840000
4839500
4839000
4838500
4838000
4837500
50
40
30
20
10
0
-7974500
-7973500
-7972500
Easting
Herbaceous
Woody We
Grassland
Deciduous
Developed/
Developed/
Open Wate
Wetlands
Pasture/Gra
Fallow/Idle
Alfalfa
Winter Whe
Spring Whe
Sunflower
Soybeans
Sorghum
Corn
NDVI
Time
VZA
factor(Sat)
Jan 2007
Apr 2007
Jul 2007
Oct 2007
Jan 2008

Method applied to identify 'pure-enough' crop pixels over various landscapes



Duveiller, G., Lopez-Lozano, R., & Cescatti, A. (2015). Exploiting the multi-angularity of the MODIS temporal signal to identify spatially homogeneous vegetation cover: A demonstration for agricultural monitoring applications. Remote Sensing of Environment, 166, 61–77. http://doi.org/10.1016/j.rse.2015.06.001

Combine RS info with crop growth models: Smoothing data based on simple crop model

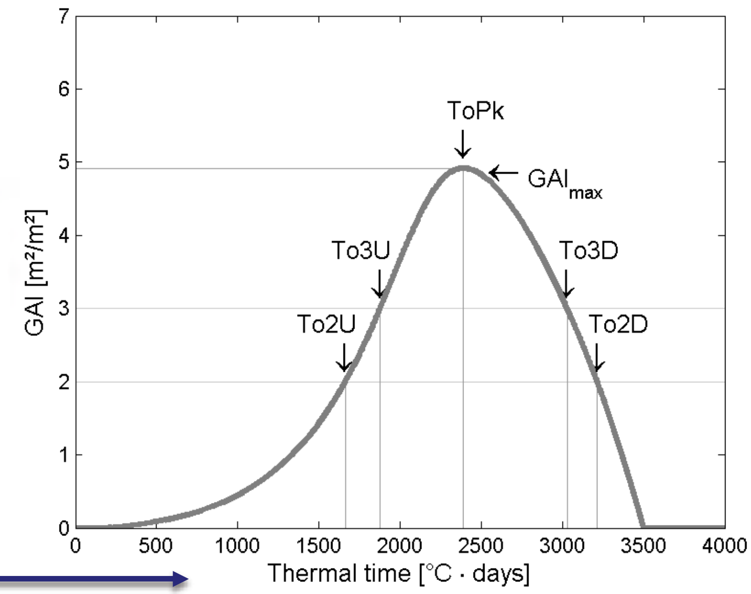
Can be retrieved from RS

Growth

$$GAI(tt) = k \cdot \left[\frac{1}{\left(1 + e^{-a(tt - T_0 - T_a)}\right)^c} - e^{b(tt - T_0 - T_b)} \right]$$

Senescence

Thermal time

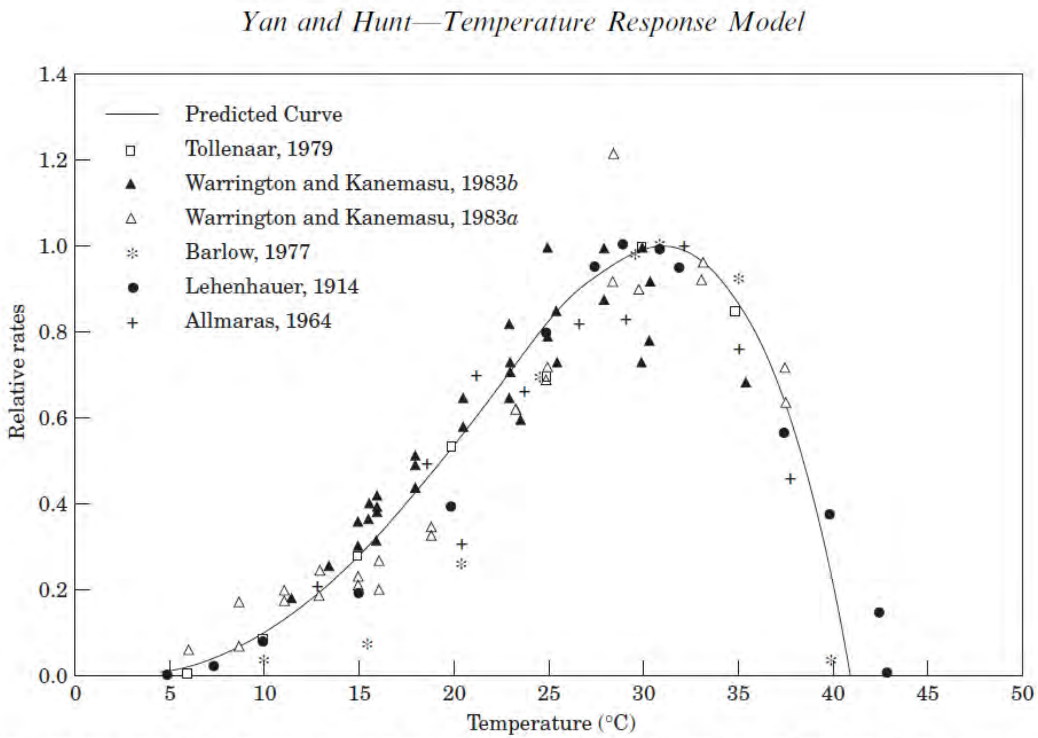


Canopy Structure Dynamic Model (CSDM)

Koetz, B., Baret, F., Poilve, H., & Hill, J. (2005). Use of coupled canopy structure dynamic and radiative transfer models to estimate biophysical canopy characteristics. Remote Sensing of Environment, 95(1), 115–124.

Plants grow faster over a given temperature range

Yan, W., & Hunt, L. A. (1999). An Equation for Modelling the Temperature Response of Plants using only the Cardinal Temperatures. Annals of Botany, 84(5), 607–614. doi:10.1006/anbo.1999.0955



Measured relative rates of all development or growth of maize, together with predicted relative rates based on a single curve with $T_{max} = 41$ and $T_{opt} = 31$ °C.

$$r = R_{max}\left(\frac{T_{max} - T}{T_{max} - T_{opt}}\right)\left(\frac{T - T_{min}}{T_{opt} - T_{min}}\right)^{\frac{T_{opt} - T_{min}}{T_{max} - T_{opt}}}$$

Note: this is crop specific…

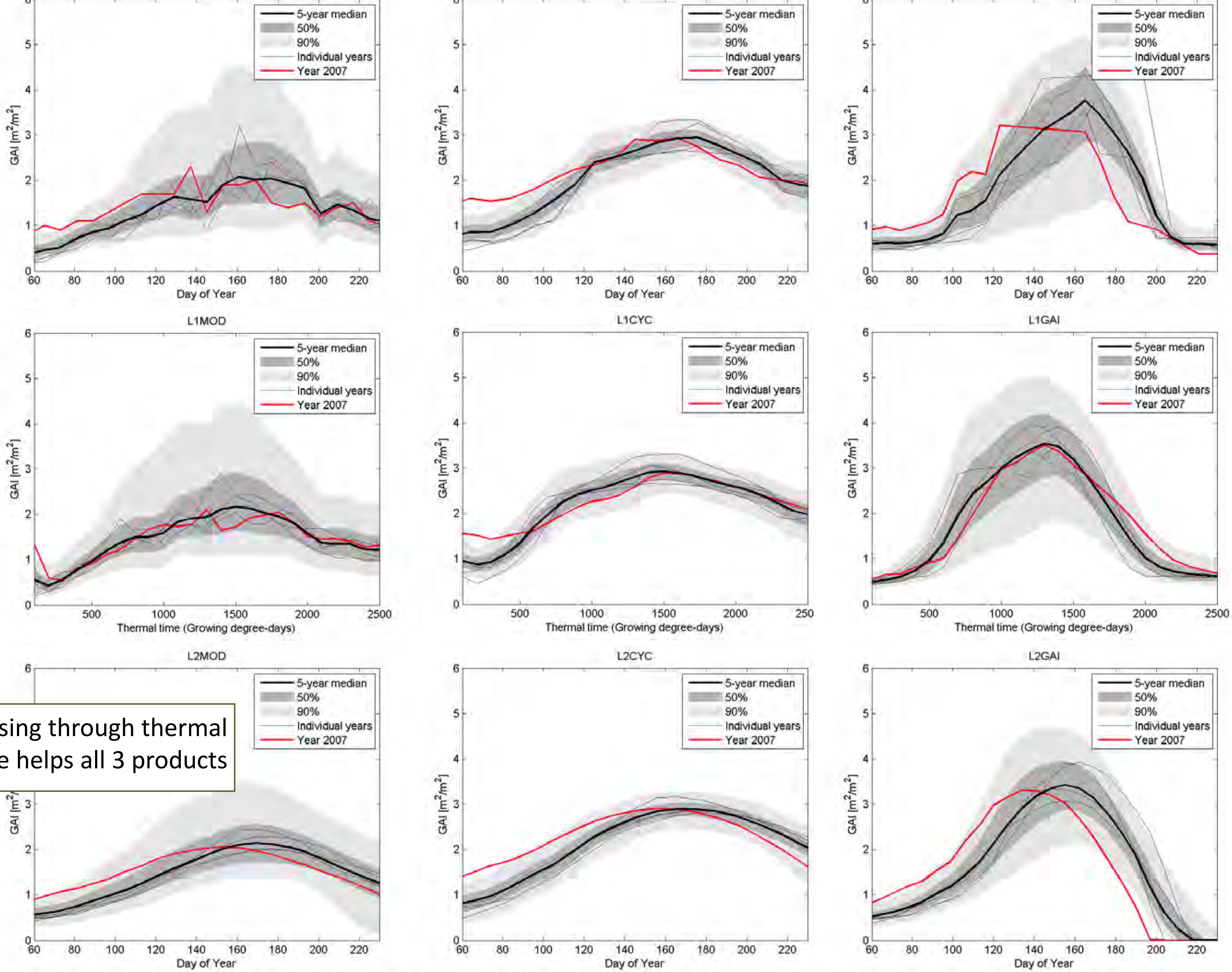
Thermal time

- Simple practical approach to change the time axis...
  - Like dynamical time warping (DTW)

- Sum of growing degree days (GDD) above a given base temperature

$$\mathrm{tt} = \sum_{i=t_1}^{t_2} \left[\frac{(T_{\mathrm{max},i} + T_{\mathrm{min},i})}{2} - T_{\mathrm{base}} \right]$$

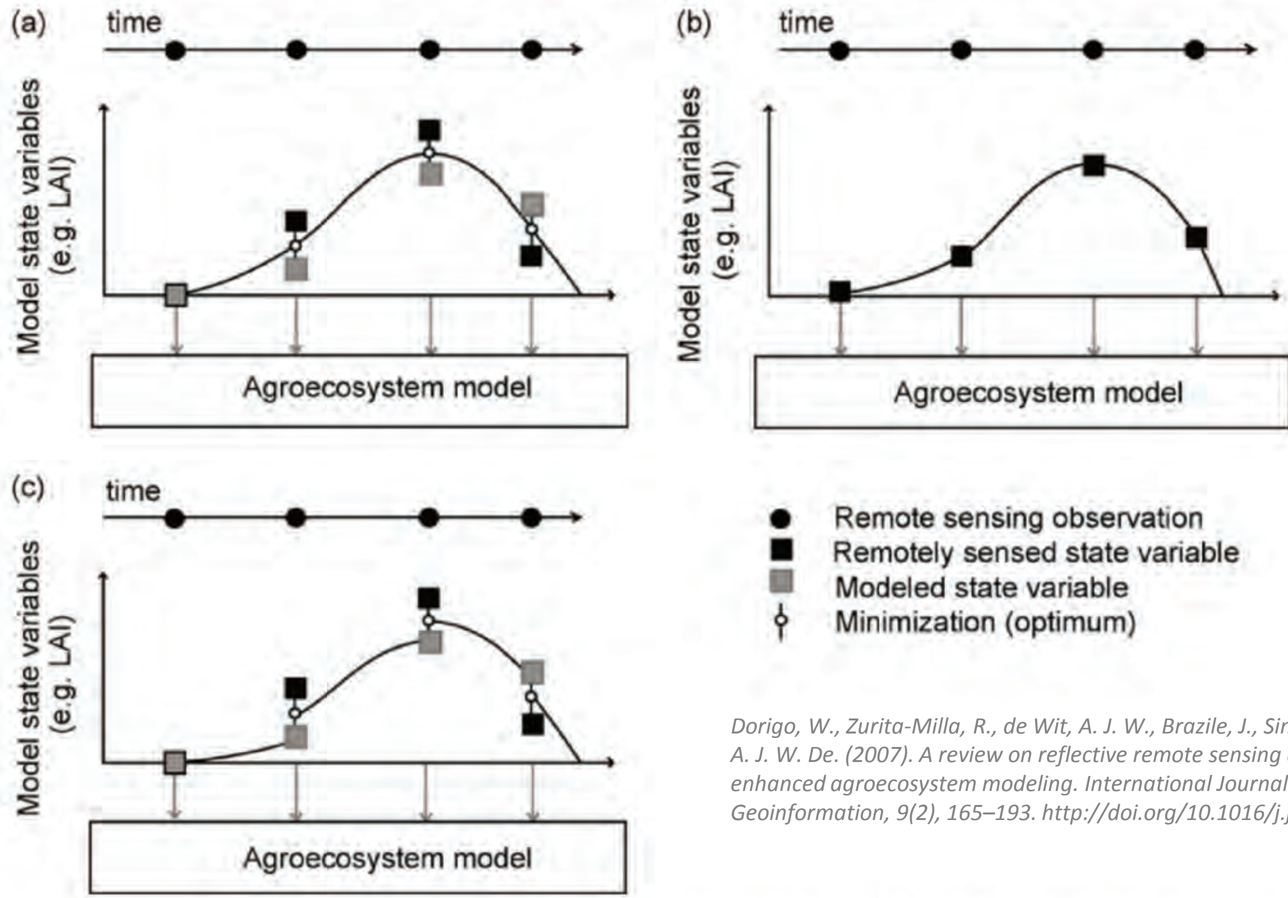
- There are variants:
  - Removing base temp from min and max (see Mcmaster & Wilhelm, 1997)
  - Using more cardinal temperatures (as in Yan & Hunt, 2009)



Passing through thermal time helps all 3 products

Duveiller, G., Baret, F., & Defourny, P. (2013). Using Thermal Time and Pixel Purity for Enhancing Biophysical Variable Time Series: An Interproduct Comparison. IEEE Transactions on Geoscience and Remote Sensing, 51(4), 2119–2127. http://doi.org/10.1109/TGRS.2012.2226731

Combine RS info with crop growth models: Data assimilation

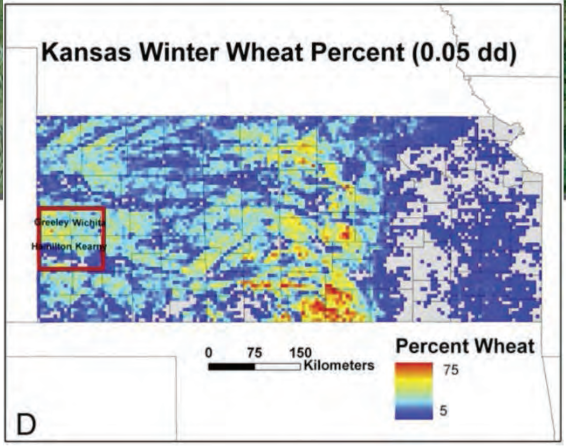


Dorigo, W., Zurita-Milla, R., de Wit, A. J. W., Brazile, J., Singh, R., Schaepman, M. E. E., & Wit, A. J. W. De. (2007). A review on reflective remote sensing and data assimilation techniques for enhanced agroecosystem modeling. International Journal of Applied Earth Observation and Geoinformation, 9(2), 165–193. http://doi.org/10.1016/j.jag.2006.05.003.

Fig. 7. Schematic representation of different methods for the assimilation of remotely sensed model state variables in agoecosystem models: (a) 'calibration', (b) 'forcing', and (c) 'updating' (adapted from Delécolle et al., 1992).

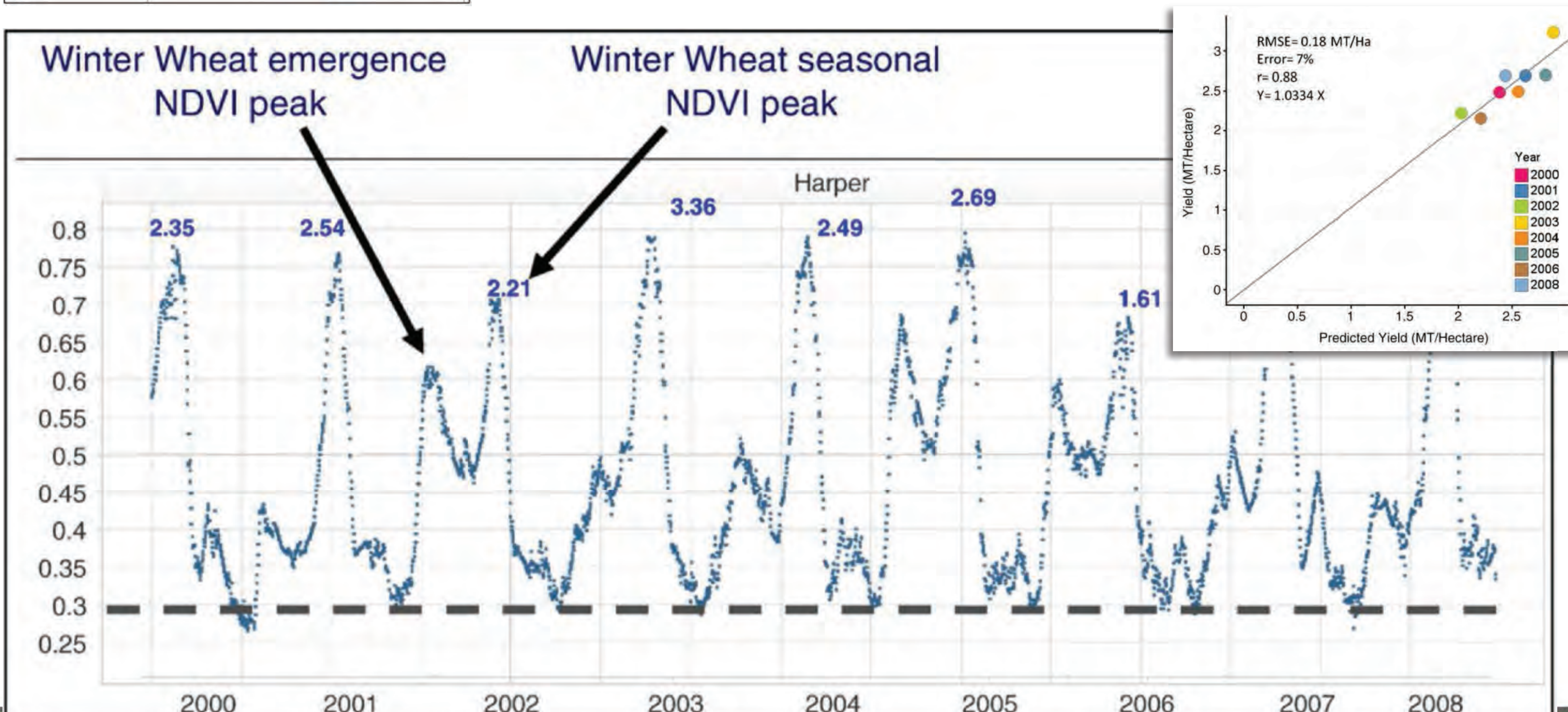
AGRICULTURAL MONITORING:
EXAMPLES OF METHODS AND SYSTEMS

The challenge of crop yield forecasting…



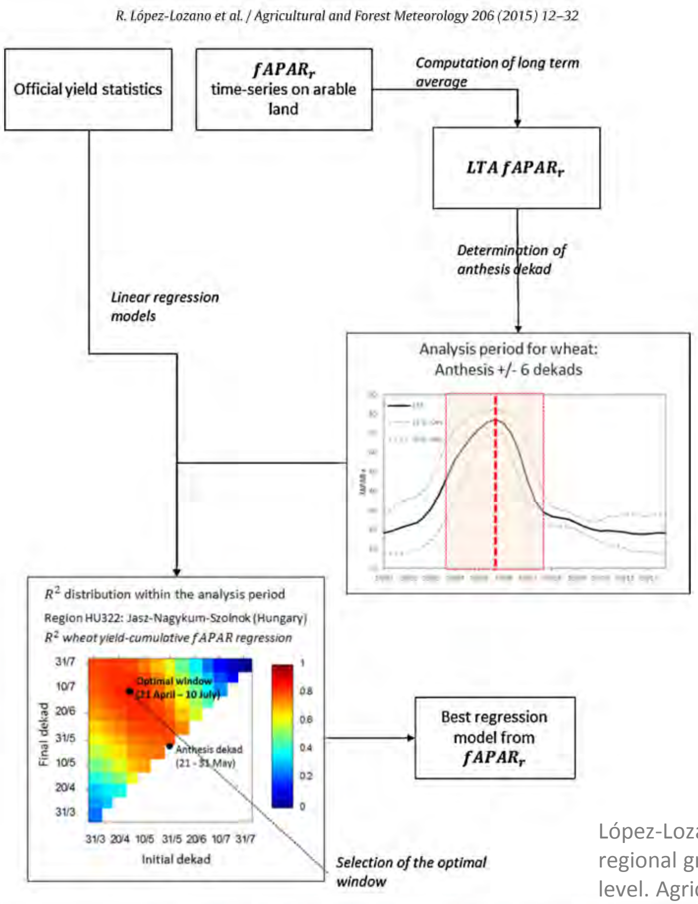
Regression based on peak of coarse NDVI

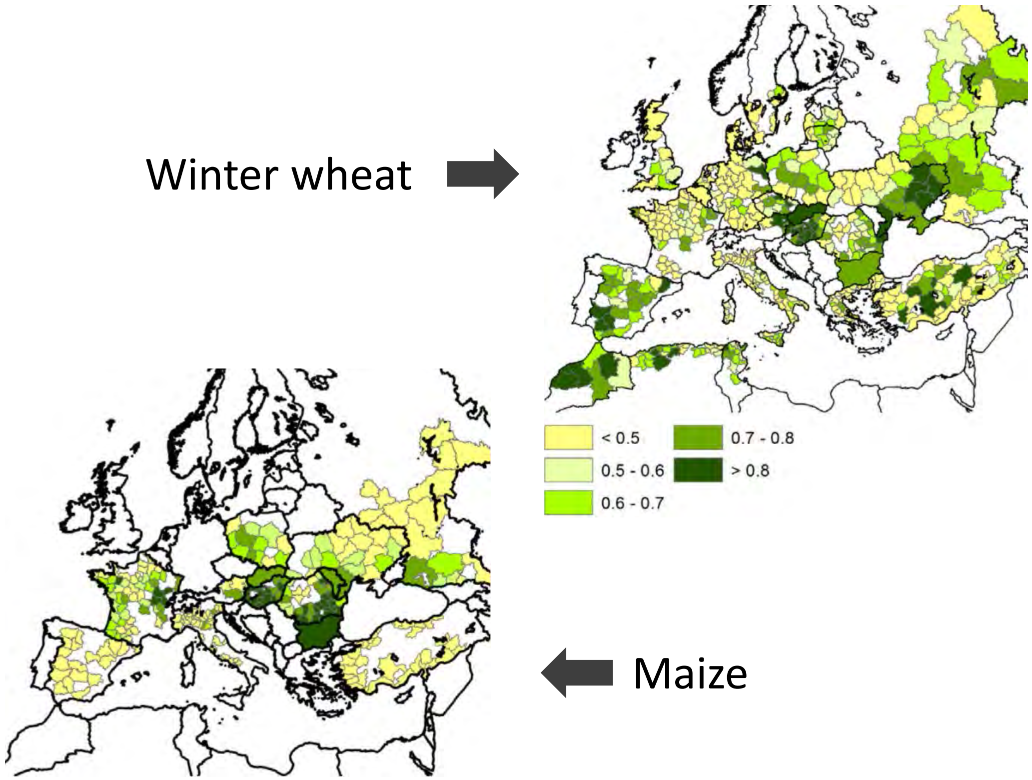
Becker-Reshef, I., Vermote, E., Lindeman, M., & Justice, C. (2010). A generalized regression-based model for forecasting winter wheat yields in Kansas and Ukraine using MODIS data. Remote Sensing of Environment, 114(6), 1312–1323. http://doi.org/10.1016/j.rse.2010.01.010



Results can be obtained earlier in the season by using thermal time: see Franch et al. (2015)

Exploring correlations between yield times series and fAPAR

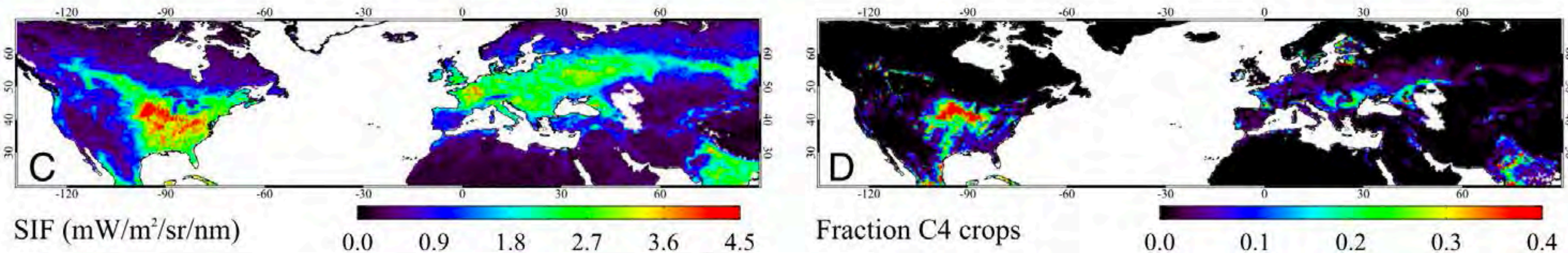


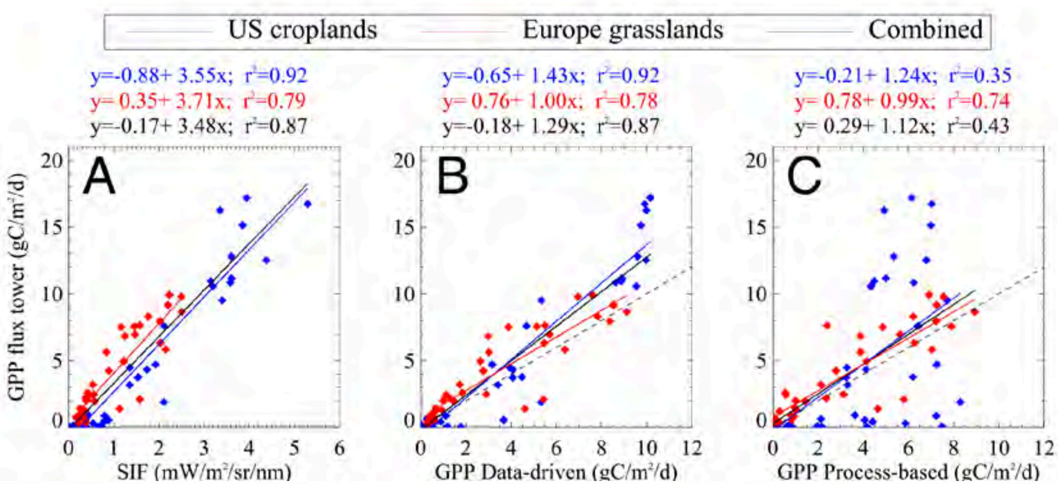


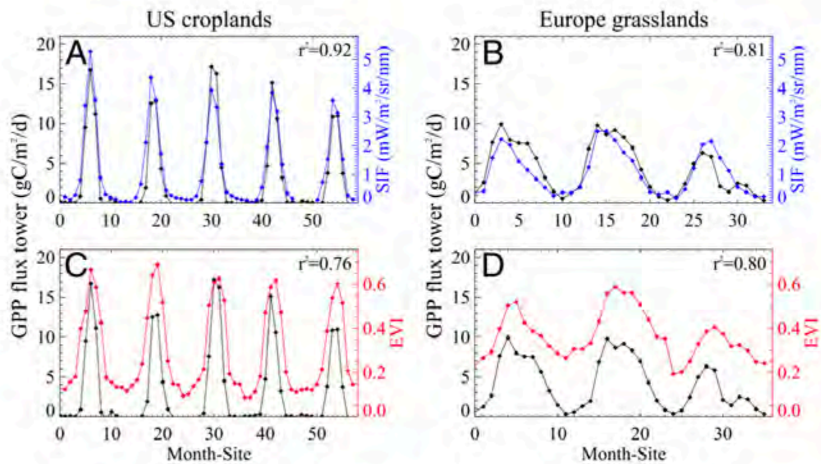
López-Lozano, R., Duveiller, G., Seguini, L., Meroni, M., García-Condado, S., Hooker, J., … Baruth, B. (2015). Towards regional grain yield forecasting with 1km-resolution EO biophysical products: Strengths and limitations at pan-European level. Agricultural and Forest Meteorology, 206, 12–32. doi:10.1016/j.agrformet.2015.02.021

Some promising early results on the empirical use of SIF

Guanter, L., Zhang, Y., Jung, M., Joiner, J., Voigt, M., Berry, J. A., … Griffis, T. J. (2014). Global and time-resolved monitoring of crop photosynthesis with chlorophyll fluorescence. Proceedings of the National Academy of Sciences. doi:10.1073/pnas.1320008111



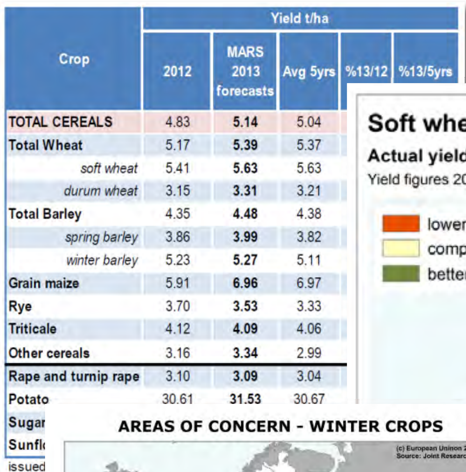




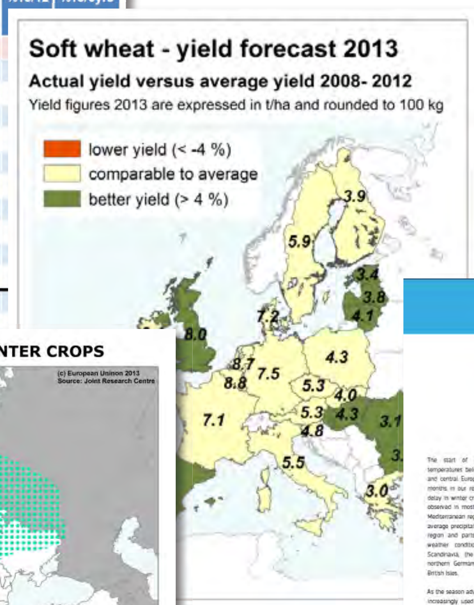
Source: Guanter et al. 2014. PNAS

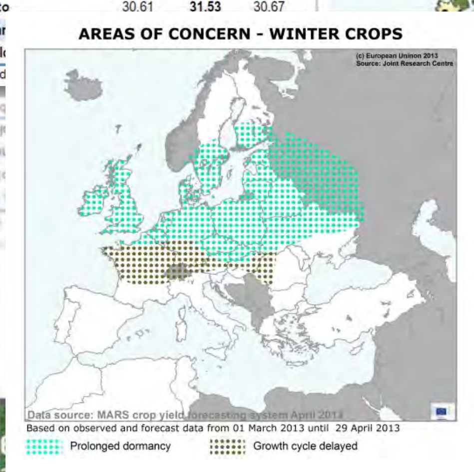
MARS Crop yield forecasting system (MCYFS)

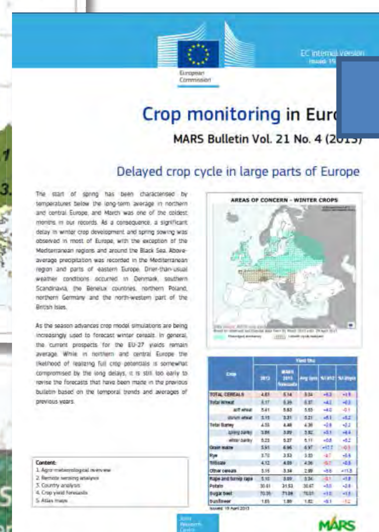
Operational service to provide agriculture intelligence for major crops for EU decision making process on market intervention and policy support



Crop	Yield t/ha 2012	MARS 2013 forecasts	Avg 5yrs	%13/12	%13/5yrs
TOTAL CEREALS	4.83	5.14	5.04		
Total Wheat	5.17	5.39	5.37		
soft wheat	5.41	5.63	5.63		
durum wheat	3.15	3.31	3.21		
Total Barley	4.35	4.48	4.38		
spring barley	3.86	3.99	3.82		
winter barley	5.23	5.27	5.11		
Grain maize	5.91	6.96	6.97		
Rye	3.70	3.53	3.33		
Triticale	4.12	4.09	4.06		
Other cereals	3.16	3.34	2.99		
Rape and turnip rape	3.10	3.09	3.04		
Potato	30.61	31.53	30.67		

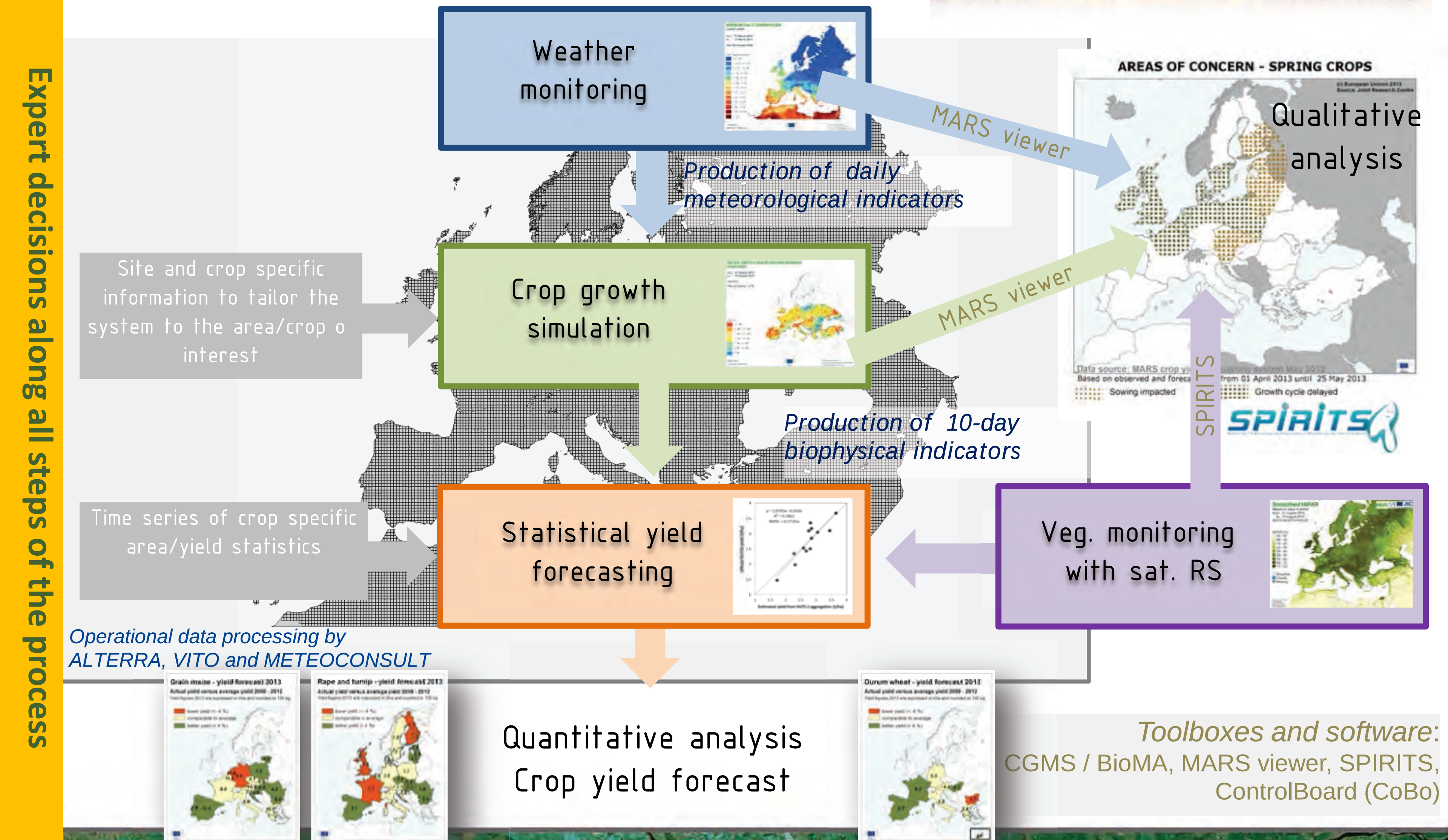


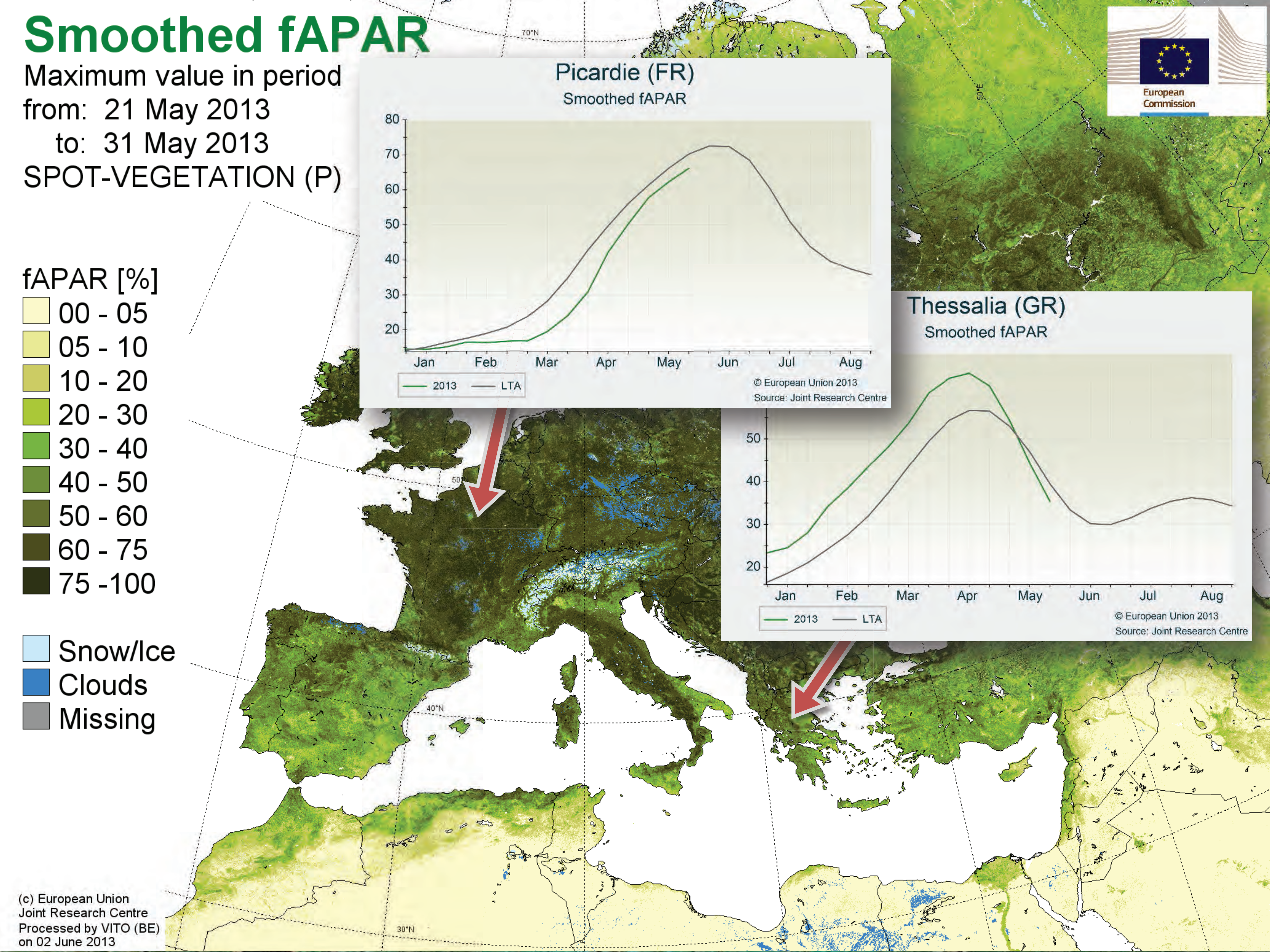


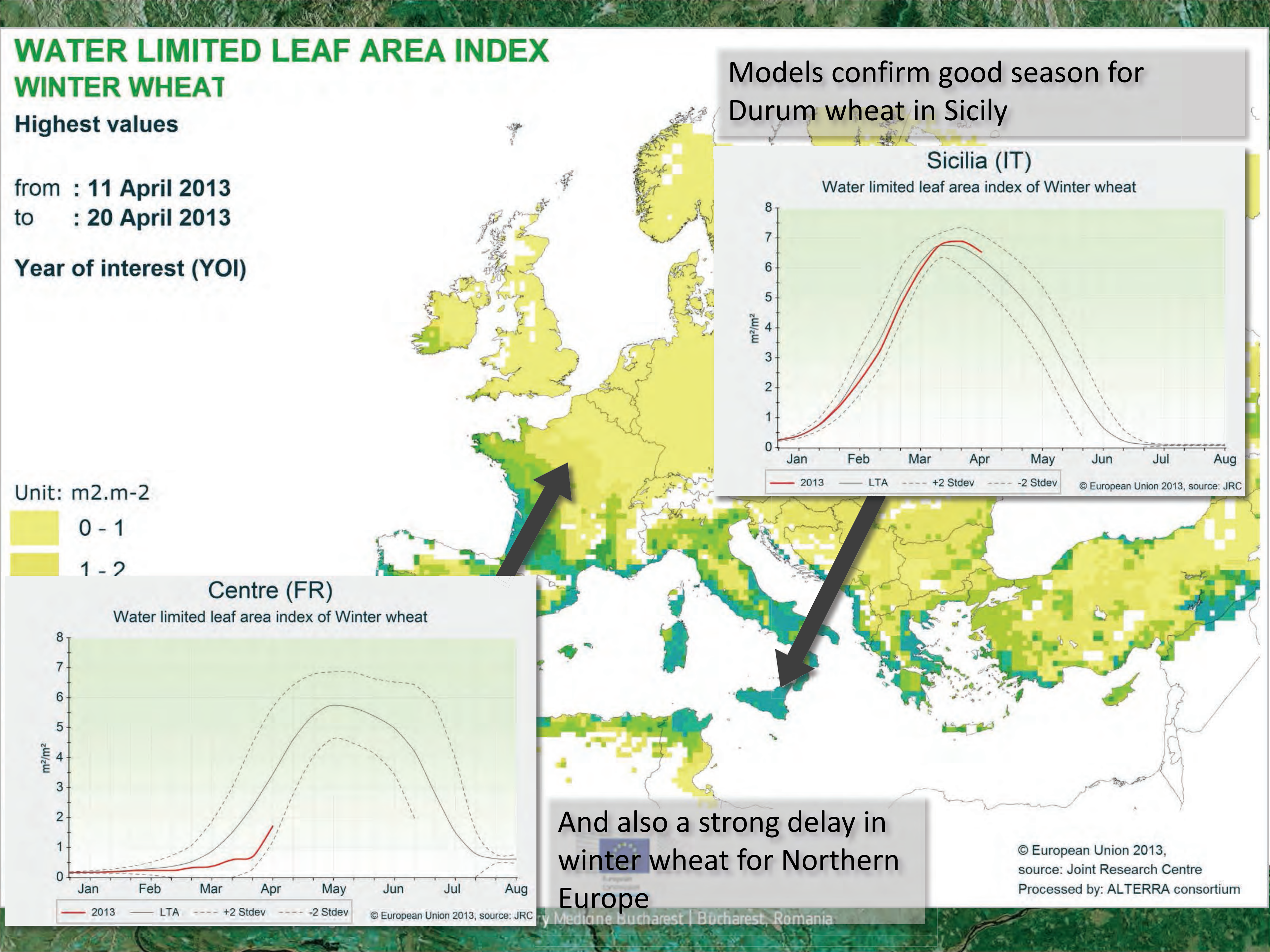


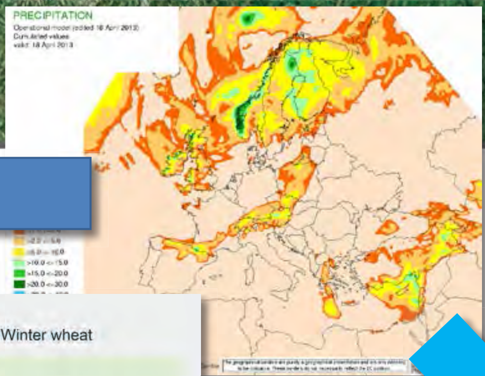
Decision Makers

MCYFS - a model and data driven decision support system

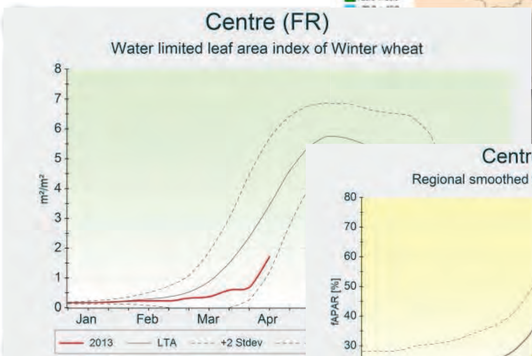


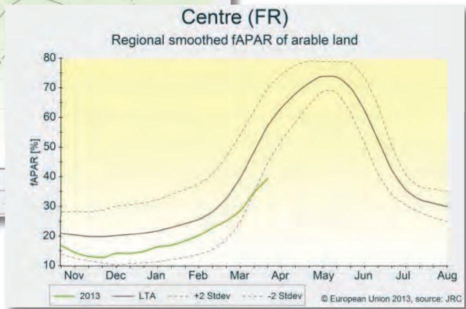

Smoothed fAPAR
Maximum value in period
from: 21 May 2013
to: 31 May 2013
SPOT-VEGETATION (P)
fAPAR [%]
00 - 05
05 - 10
10 - 20
20 - 30
30 - 40
40 - 50
50 - 60
60 - 75
75 -100
Snow/Ice
Clouds
Missing
Picardie (FR)
Smoothed fAPAR
80
70
60
50
40
30
20
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
2013
LTA
© European Union 2013
Source: Joint Research Centre
Thessalia (GR)
Smoothed fAPAR
50
40
30
20
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
2013
LTA
© European Union 2013
Source: Joint Research Centre
70°N
50°N
40°N
30°N
50°E
European Commission
(c) European Union
Joint Research Centre
Processed by VITO (BE)
on 02 June 2013


WATER LIMITED LEAF AREA INDEX
WINTER WHEAT
Highest values
from : 11 April 2013
to : 20 April 2013
Year of interest (YOI)
Unit: m2.m-2
0 - 1
1 - 2
Models confirm good season for Durum wheat in Sicily
Sicilia (IT)
Water limited leaf area index of Winter wheat
m²/m²
0
1
2
3
4
5
6
7
8
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
2013
LTA
+2 Stdev
-2 Stdev
© European Union 2013, source: JRC
Centre (FR)
Water limited leaf area index of Winter wheat
m²/m²
0
1
2
3
4
5
6
7
8
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
2013
LTA
+2 Stdev
-2 Stdev
© European Union 2013, source: JRC
And also a strong delay in winter wheat for Northern Europe
© European Union 2013,
source: Joint Research Centre
Processed by: ALTERRA consortium
Bucharest | Bucharest, Romania

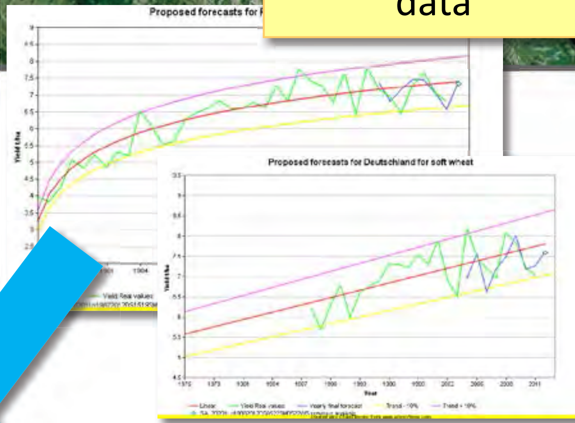


Indicators



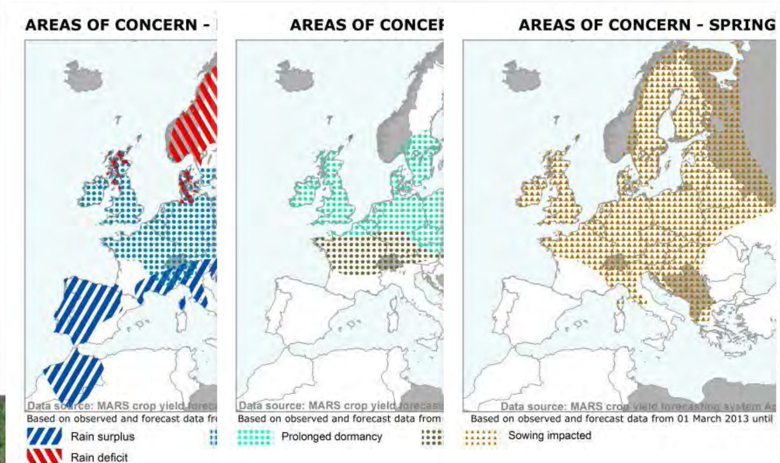


Historical yield data



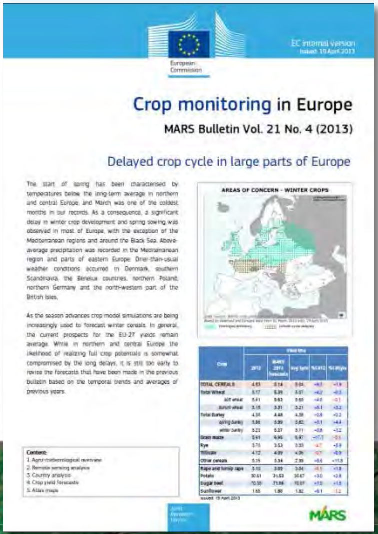
TEAM of ANALYSTS

MARS Bulletin



Crop	Yield t/ha 2012	MARS 2013 forecasts	Avg 5yrs	%13/12	%13/5yrs
TOTAL CEREALS	4.83	**5.14**	5.04	+6.3	+1.9
Total Wheat	5.17	**5.39**	5.37	+4.2	+0.3
soft wheat	5.41	**5.63**	5.63	+4.0	-0.1
durum wheat	3.15	**3.31**	3.21	+5.1	+3.2
Total Barley	4.35	**4.48**	4.38	+2.8	+2.2
spring barley	3.86	**3.99**	3.82	+3.1	+4.4
winter barley	5.23	**5.27**	5.11	+0.8	+3.2
Grain maize	5.91	**6.96**	6.97	+17.7	-0.1
Rye	3.70	**3.53**	3.33	-4.7	+5.9
Triticale	4.12	**4.09**	4.06	-0.7	+0.9
Other cereals	3.16	**3.34**	2.99	+5.6	+11.5
Rape and turnip rape	3.10	**3.09**	3.04	-0.1	+1.8
Potato	30.61	**31.53**	30.67	+3.0	+2.8
Sugar beet	70.35	**71.06**	70.01	+1.0	+1.5
Sunflower	1.65	**1.80**	1.82	+9.1	-1.2

issued: 19 April 2013



USDA United States Department of Agriculture
Foreign Agricultural Service

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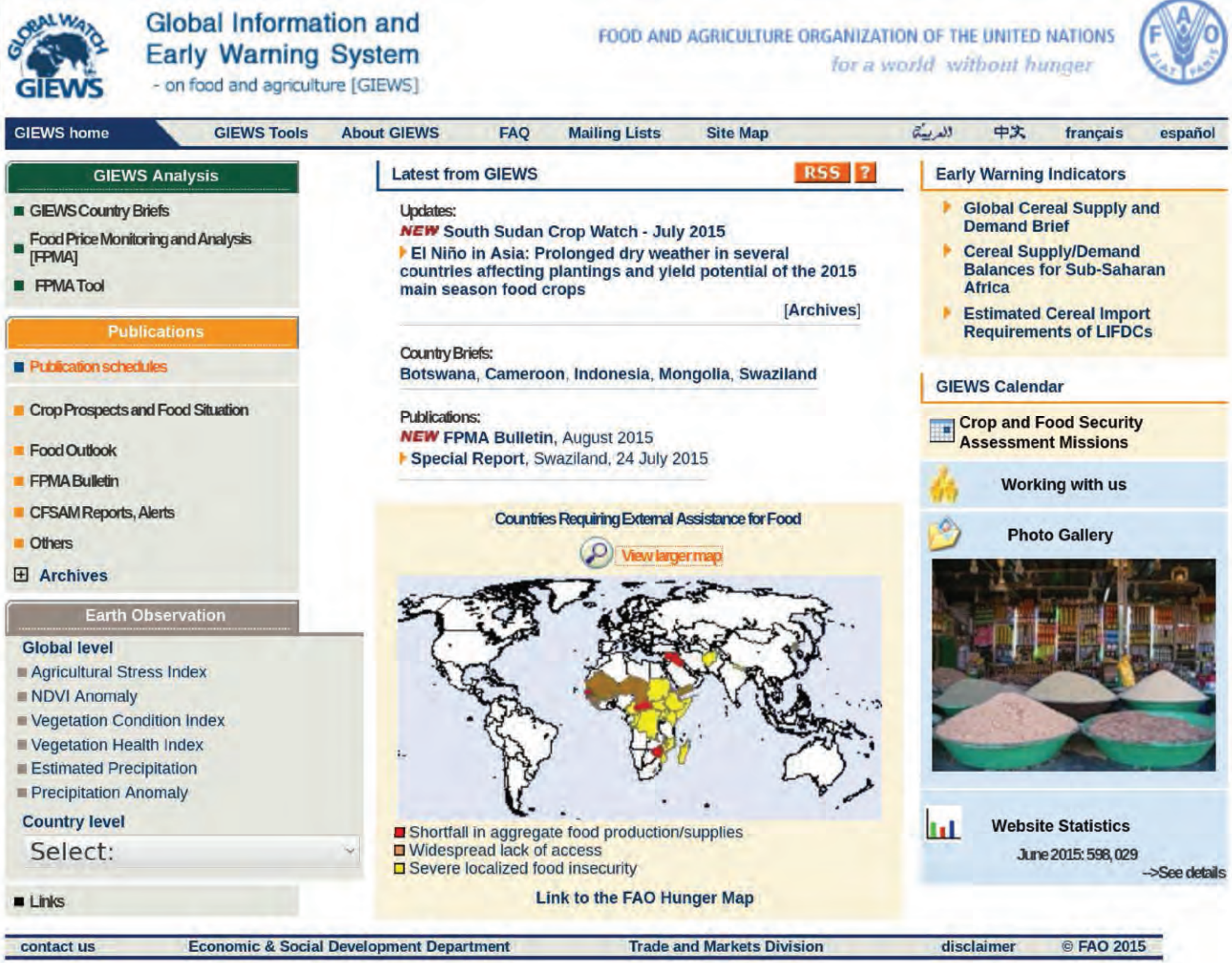
http://www.pecad.fas.usda.gov/

Chinese CROPWATCH system

http://www.cropwatch.com.cn



http://www.fao.org/giews/english/index.htm

GEOGLAM

http://www.geoglam-crop-monitor.org/

GEOGLAM
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Crop Monitor reports are released with the AMIS Market Monitor bulletin and reflect crop conditions as of the 28th of each month.

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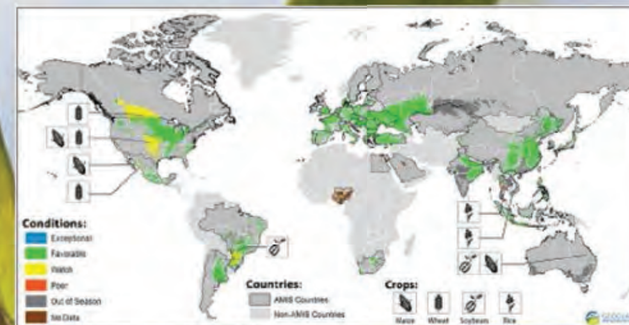

About the GEOGLAM Initiative

The Group on Earth Observations, a partnership of governments and international organizations, developed the Global Agricultural Monitoring (GEOGLAM) initiative in response to the growing calls for improved agricultural information. The goal of GEOGLAM is to strengthen the international community's capacity to produce and disseminate relevant, timely and accurate forecasts of agricultural production at national, regional and global scales through the use of Earth Observations (EO), which include satellite and ground-based observations. This initiative is designed to build on existing agricultural monitoring programs and initiatives at national, regional and global levels and to enhance and strengthen them through international networking, operationally focused research, and data/method sharing.

Both GEOGLAM and AMIS were endorsed by the G20 Heads of States' Declaration (Cannes, November, 2011), when GEOGLAM was tasked to "coordinate satellite monitoring observation systems in different regions of the world in order to enhance crop production projections and weather forecasting data." Within this framework, GEOGLAM developed the Crop Monitor reports, which provide global crop condition assessments in support of the AMIS market monitoring activities.

GEOGLAM Global Agricultural Monitoring | GEO GROUP ON EARTH OBSERVATIONS

Thank you for your attention…

Contact:

gregory.duveiller@jrc.ec.europa.eu