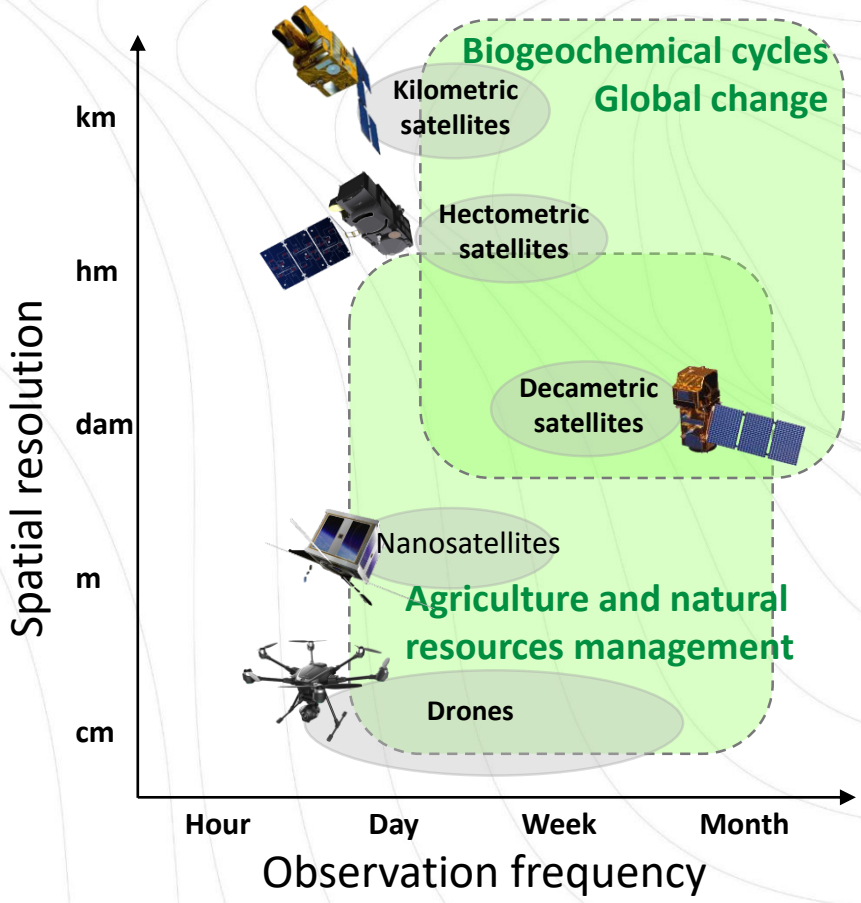
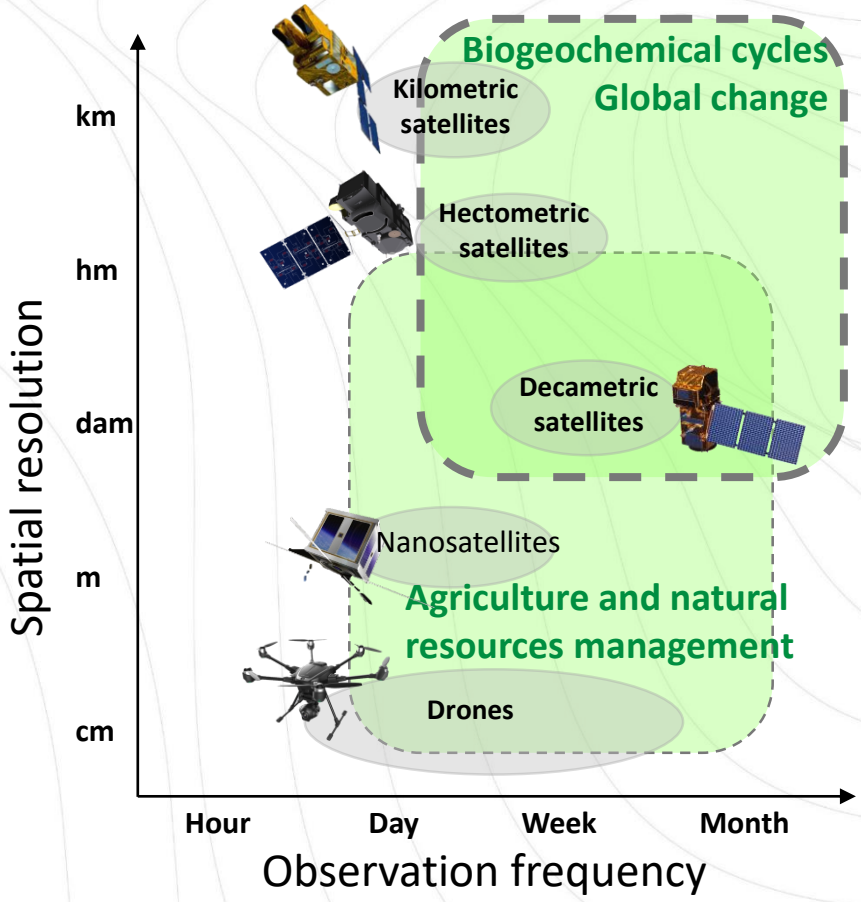
CGLS and THEIA Biophysical Vegetation Variables

Aleixandre Verger

CIDE Centro de Investigaciones Sobre Desertificación
CSIC
CREAF


Biogeochemical cycles
Global change
Kilometric satellites
Hectometric satellites
Decametric satellites
Nanosatellites
Agriculture and natural resources management
Drones
km
hm
dam
m
cm
Spatial resolution
Hour
Day
Week
Month
Observation frequency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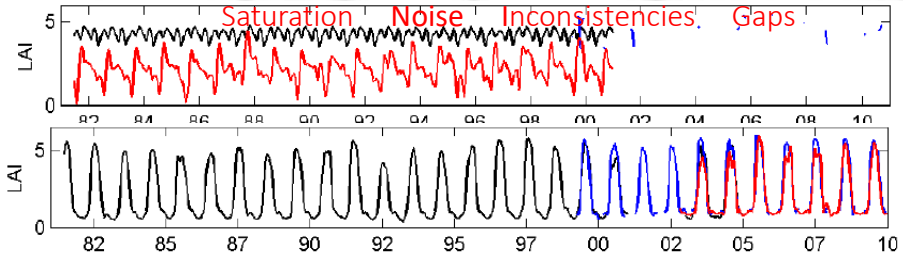
OSS NC
OBSERVATION SPATIALE AU SERVICE DE LA NOUVELLE-CALÉDONIE

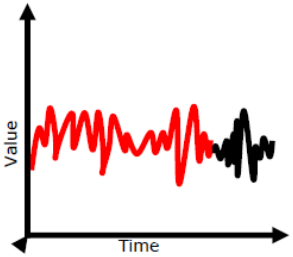
DATA REQUIREMENTS

Free / accessible / open



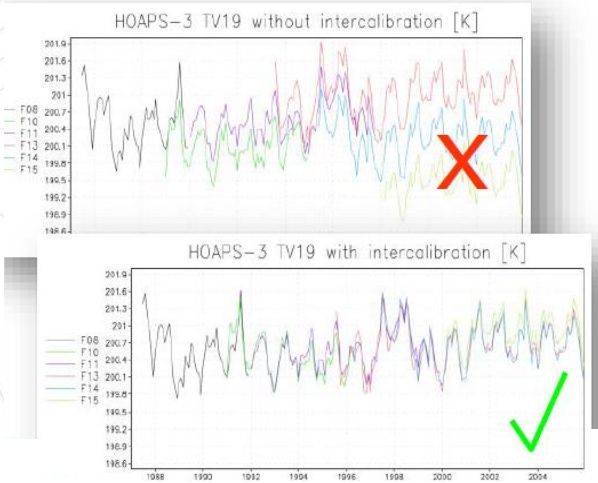
Continuity & Gap free

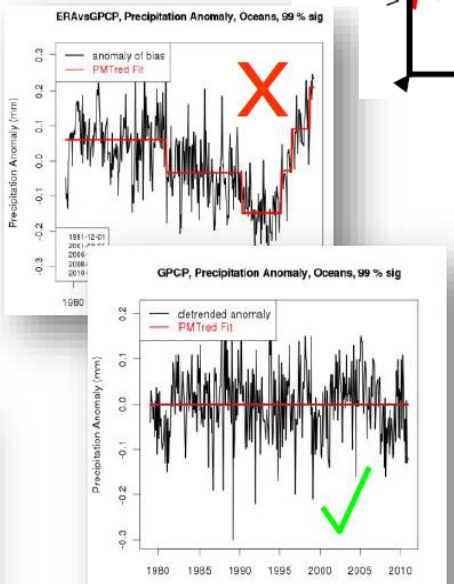
Consistency
Stability



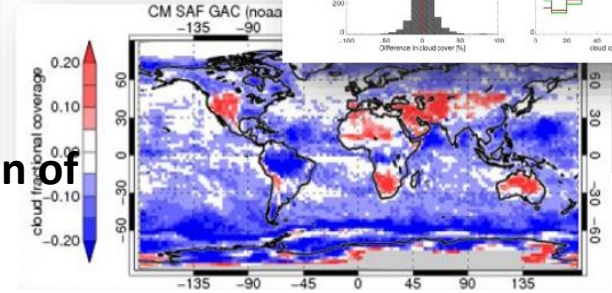
Sufficiently long time series

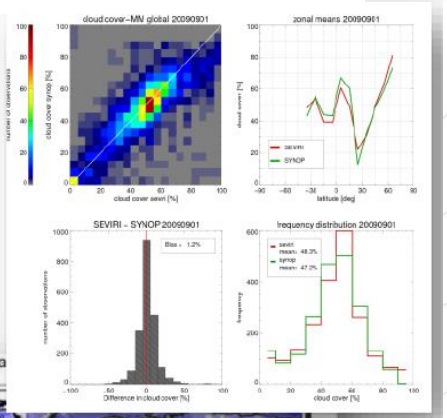
Calibrated





Quality controlled





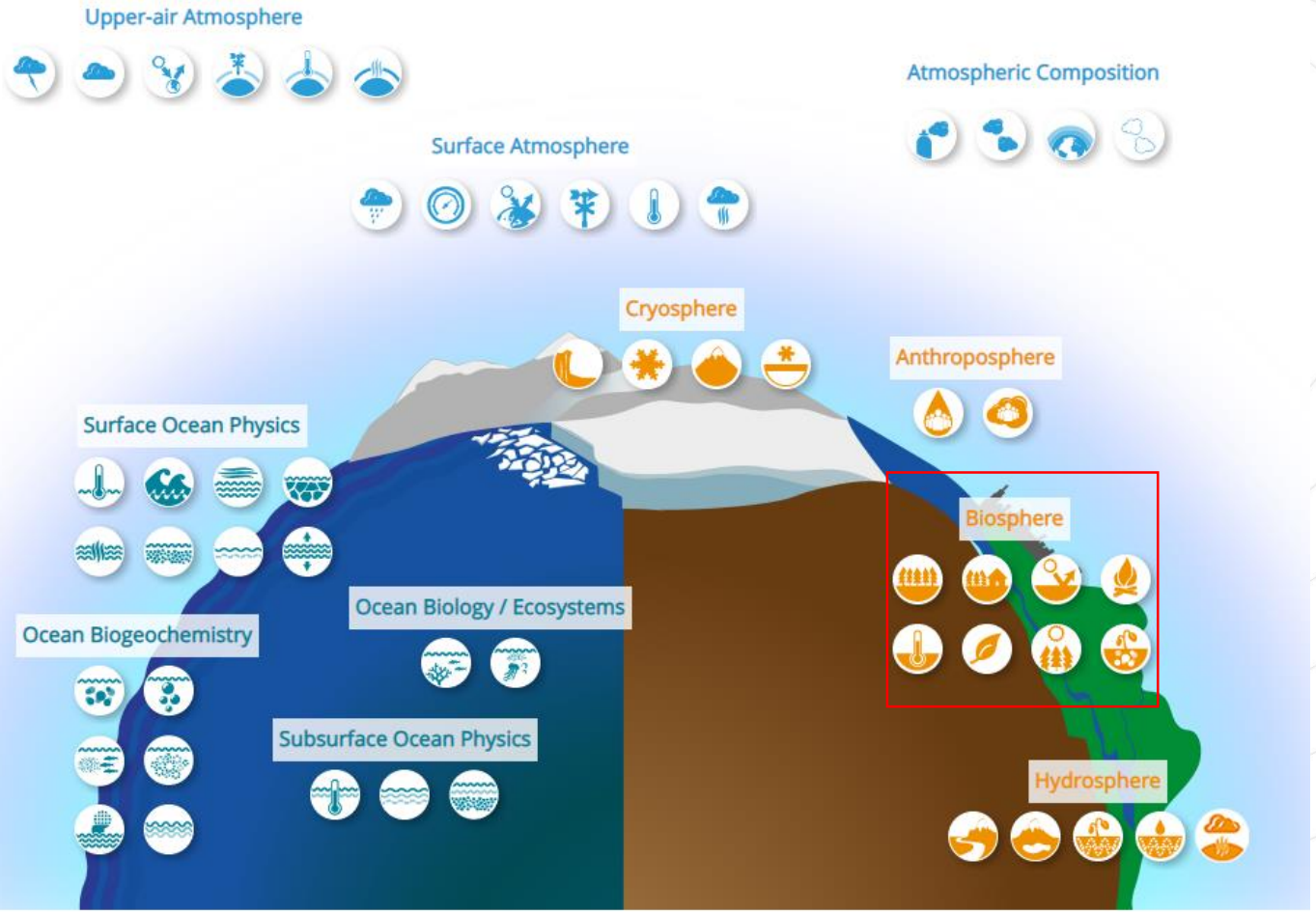
Characterization of uncertainties
Traceability

Essential Climate Variables

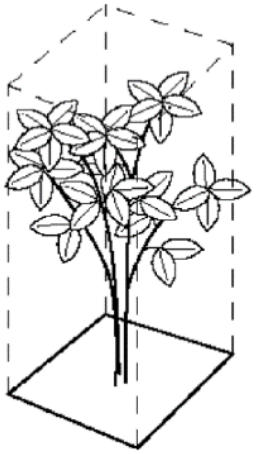
ECVs – variables that allow characterizing & following the Evolution of the **Earth's Climate**

Biosphere

- Above-ground biomass
- Albedo
- Evaporation from land
- Fire
- Fraction of absorbed photosynthetically active radiation (FAPAR)
- Land cover
- Land surface temperature
- Leaf area index
- Soil carbon
- Soil moisture



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]

Interface between atmosphere and vegetation.

	Only leaf	All vegetation elem.
Green+non green	LAI	PAI
Green	GLAI	GAI

Destructive measurements

+ leaf clumping

Upward looking
Indirect methods
DHP, LAI2000, TRAC…

downward looking
Indirect methods
Remote Sensing …

PAR, APAR, fAPAR, LUE

Photosynthetically Active Radiation (PAR):

Radiation between 400 and 700 nm that photosynthetic organisms are able to use in the process of photosynthesis.

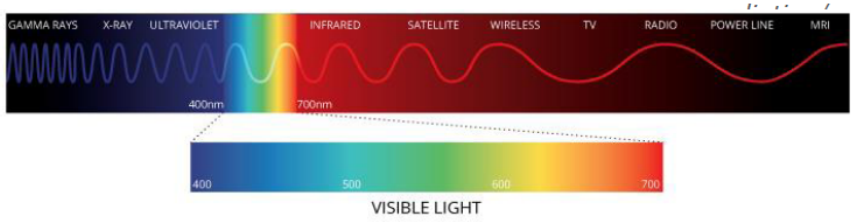
Coincides with visible light [Units: µmol photons m−2 s−1]

Absorbed PAR (APAR):

Quantity of PAR absorbed by the plants

Often considered equal to *intercepted* PAR

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



Fraction of APAR (fAPAR):

Normalized variable between 0 and 1

fAPAR = APAR/PAR

Light use efficiency (Monteith approach)

Canopy productivity = Radiation interception * Radiation use efficiency

GPP=PAR x fAPAR x LUE

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COPERNICUS GLOBAL LAND SERVICE

Copernicus Europe's eyes on Earth — Land Monitoring Service

ATMOSPHERE MONITORING

MARINE ENVIRONMENT MONITORING

LAND MONITORING

CLIMATE CHANGE

EMERGENCY MANAGEMENT

SECURITY

ART GEODEV Nouvelle Calédonie

COPERNICUS GLOBAL LAND SERVICE

Copernicus Europe's eyes on Earth — Land Monitoring Service

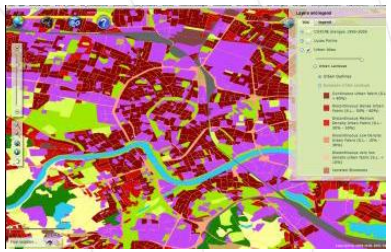
LAND MONITORING

EEA

JRC EUROPEAN COMMISSION

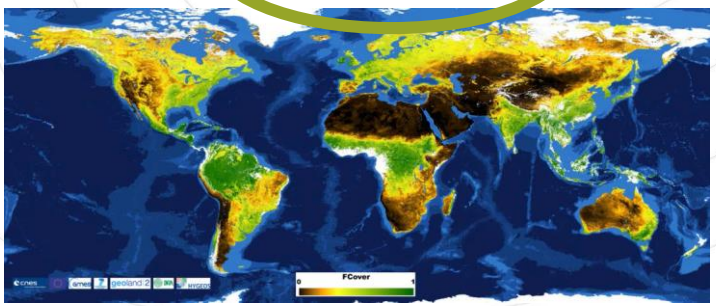
IN-SITU

LOCAL



PAN-EUROPEAN

GLOBAL



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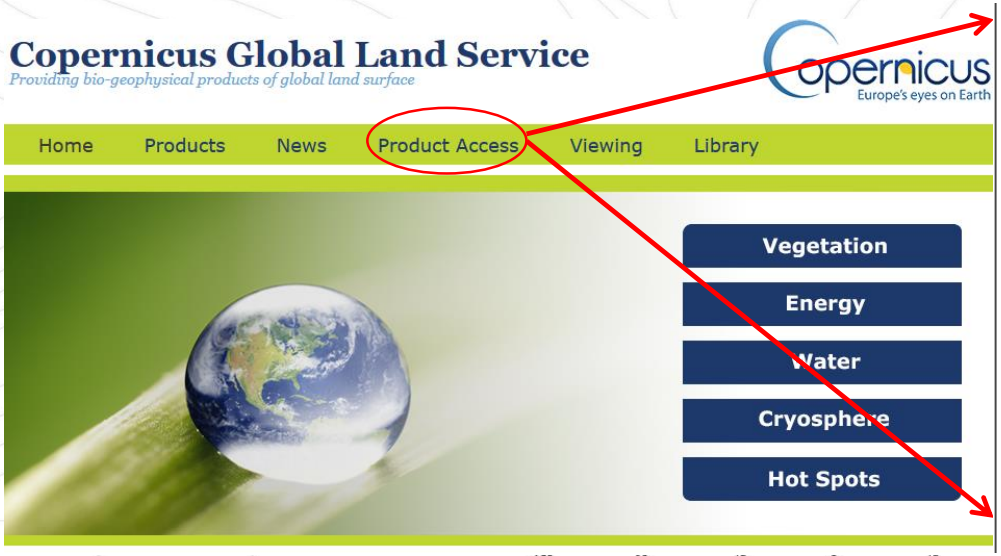
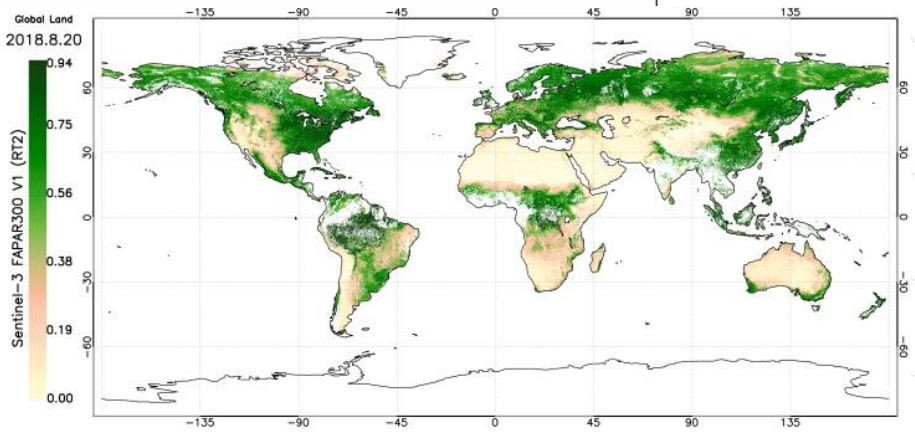
COPERNICUS GLOBAL LAND SERVICE

Copernicus Europe's eyes on Earth — Land Monitoring Service

http://land.copernicus.eu/global





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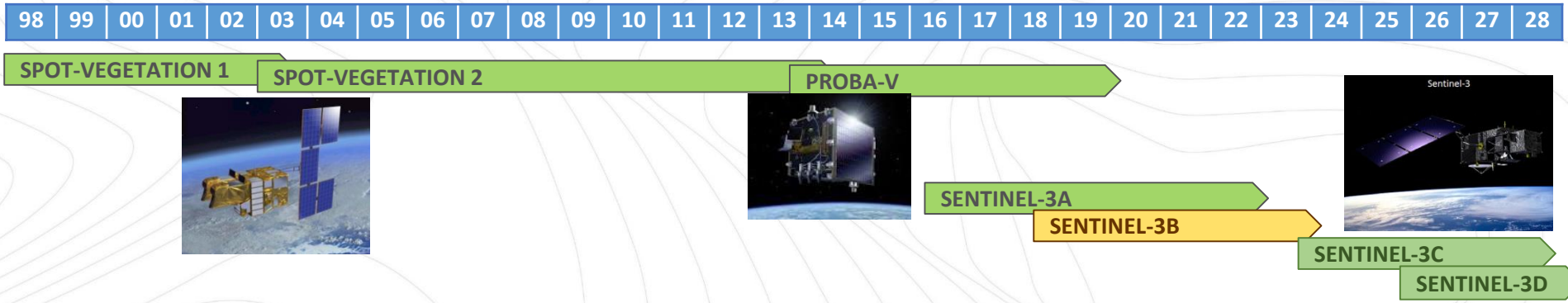
COPERNICUS GLOBAL LAND SERVICE

Copernicus = operational program, not a project



- **Need for global ECVs LAI, fAPAR (& fCOVER)**
  - **long, consistent, stable and continuous time series** for documenting anomalies and trends in global change
  - **near real time estimates**
    - Operational users
    - Decision makers
- **Continuous quality control**

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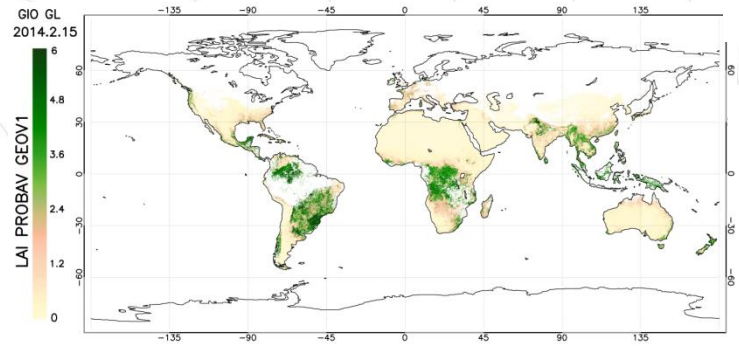
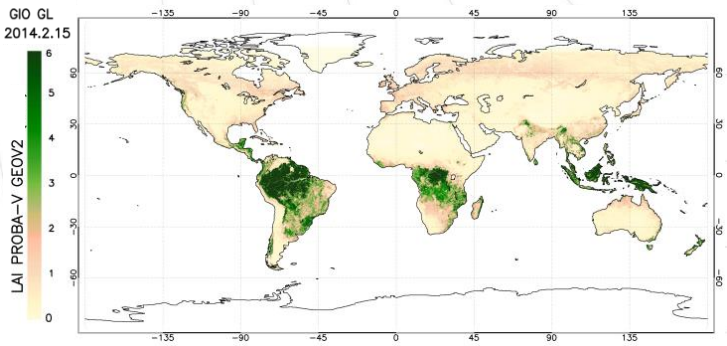
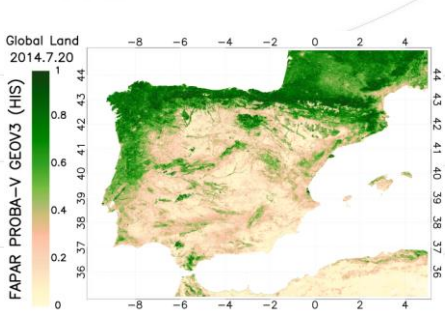
CGLS LAI, FAPAR & FCOVER GEOVx Products

Version	Sensor	Spatial resolution	Input	Temporal smoothing	Gap filling	NRT	Main improvement
1km V1	SPOT/VGT PROBA-V	1km	30-day VIS/NIR/SWIR TOC	Reflectance level	✗	✗ 12-day lag	Accuracy
1km V2	SPOT/VGT PROBA-V	1km	Daily VIS/NIR/SWIR TOC	Product level	✓	✓	NRT, temporal consistency & product completeness
300m V1	PROBA-V, OLCI/S3	1/3km	Daily VIS/NIR TOC	Product level	✗	✓	NRT, Spatial resolution



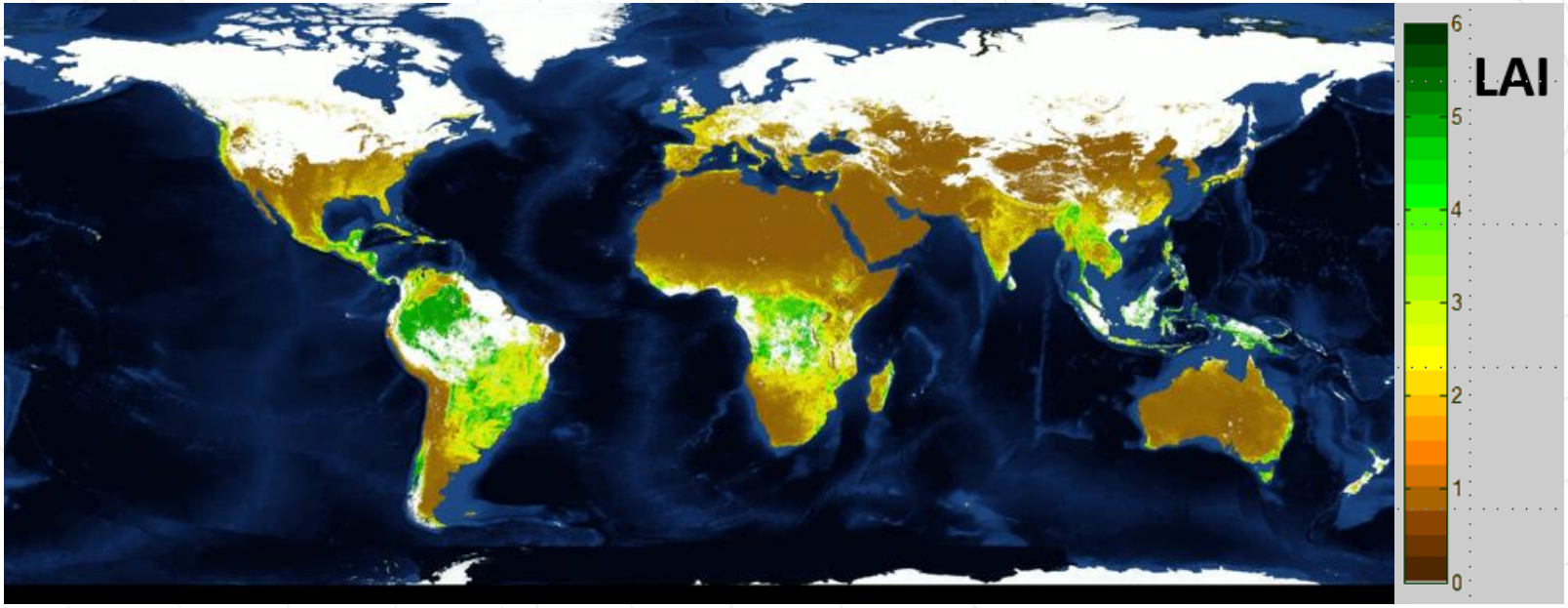




ART GEODEV Nouvelle Calédonie

1 km V1: Long term monitoring & improved accuracy

✓20 years via SPOT/VGT & PROBA-V



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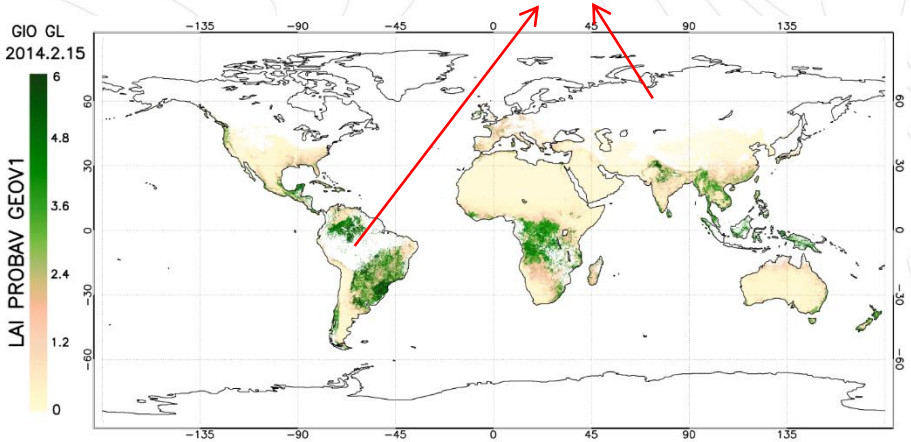
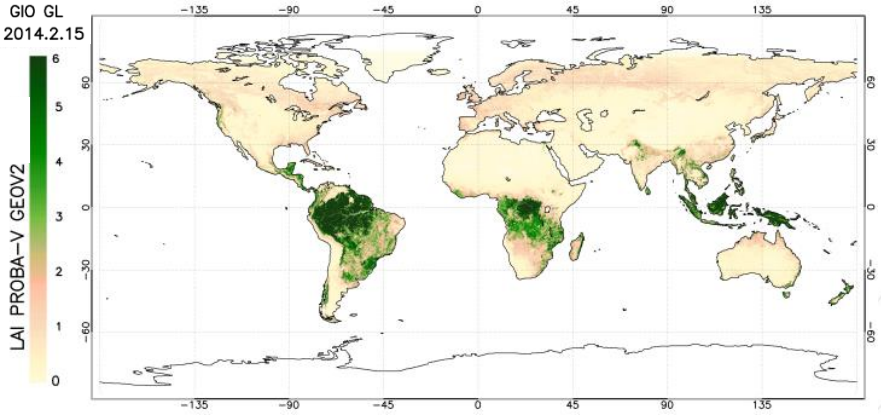
1KM V2: NRT & PRODUCT COMPLETENESS

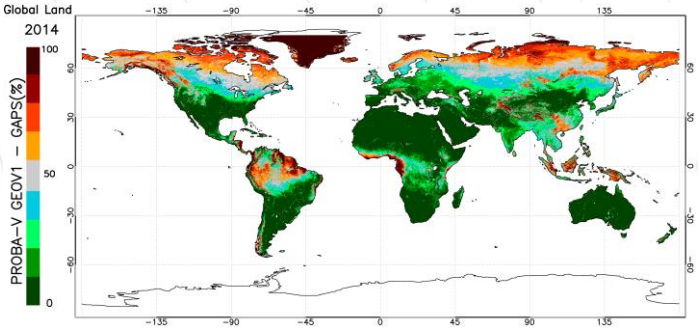
✖ **1km V1 - Missing data** in the tropics and at high latitudes in winter time



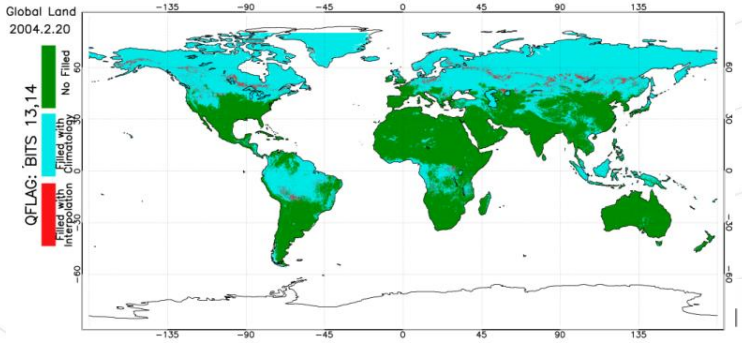
✓ 1km V2 - Products with **no gaps**



Spatial distribution of missing values



Filled with climatology



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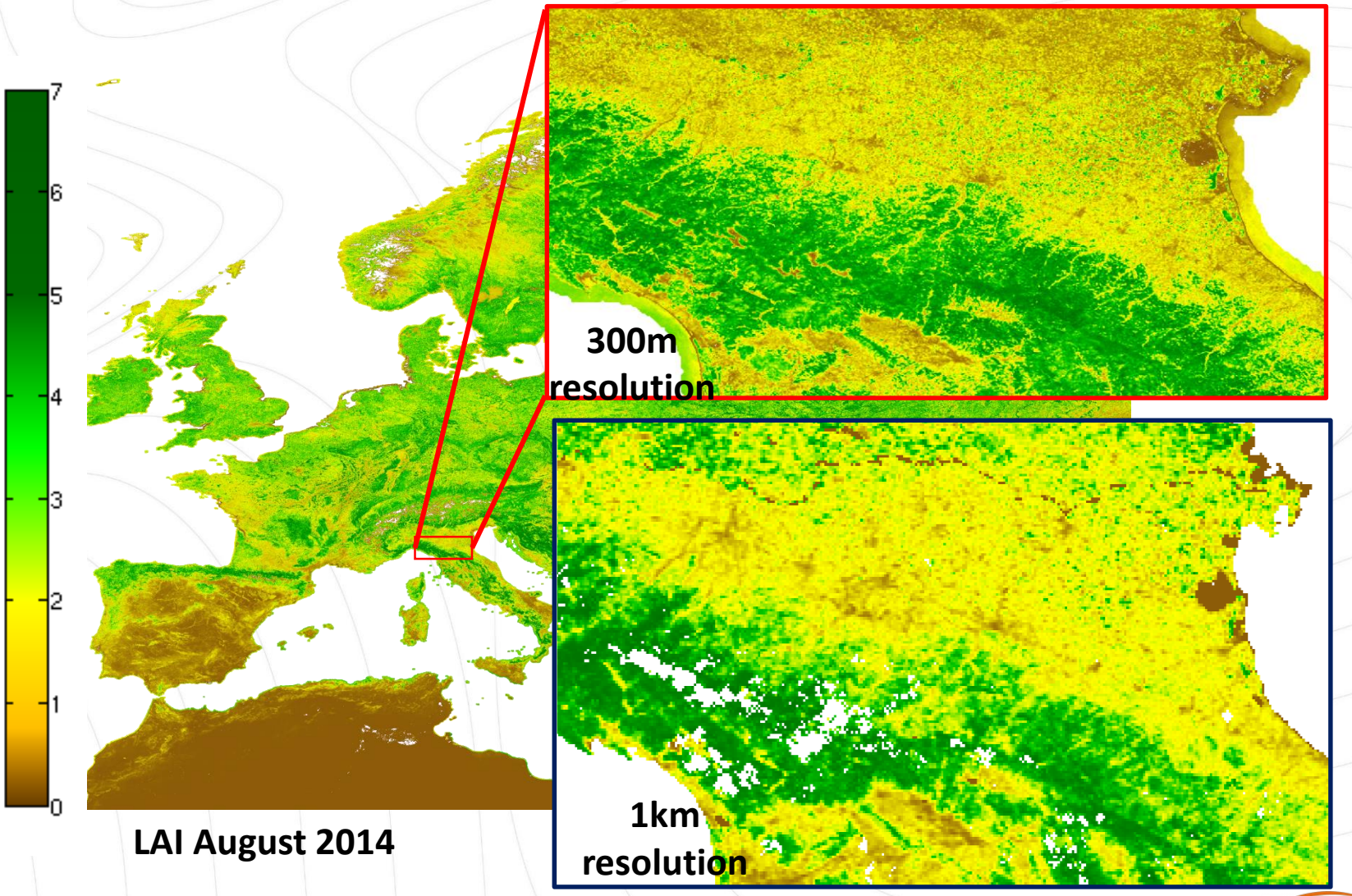
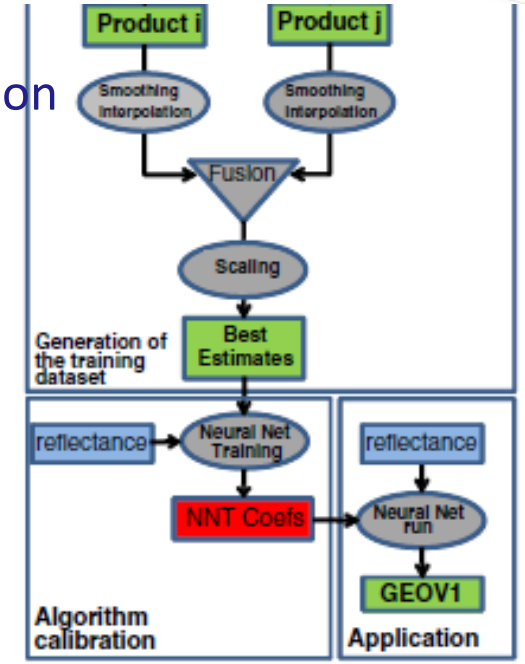
300m V1 : Improved spatial resolution



Nouvelle Calédonie ART GEODEV

LAI, FAPAR AND FCOVER RETRIEVAL ALGORITHMS: GENERAL PRINCIPLES

GEOVx LAI/FAPAR/FCOVER products are derived from neural networks trained with VGT reflectance data and the fusion of existing MODIS & CYCLOPES products



1km V1

10-day TOC-r reflectances

Neural Networks

Dekadal Product

1km V2 & 300m V1

Daily TOC reflectances and angles

STEP A

Neural Networks

Daily Product

STEP B

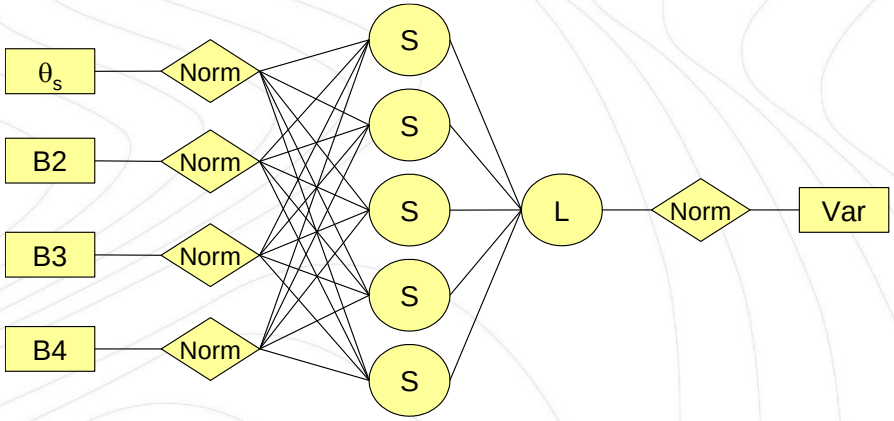
Compositing, Smoothing (& Gap Filling)

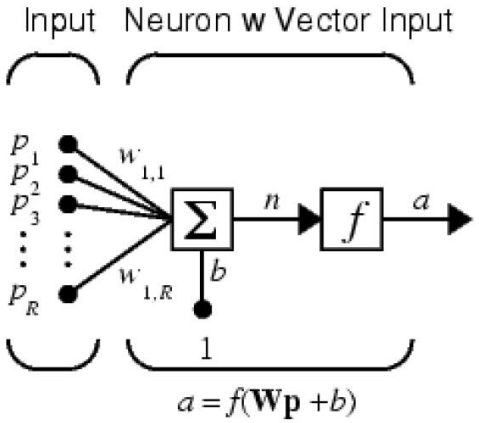
Dekadal Product

Neural Networks

Artificial Neural Networks (ANN)

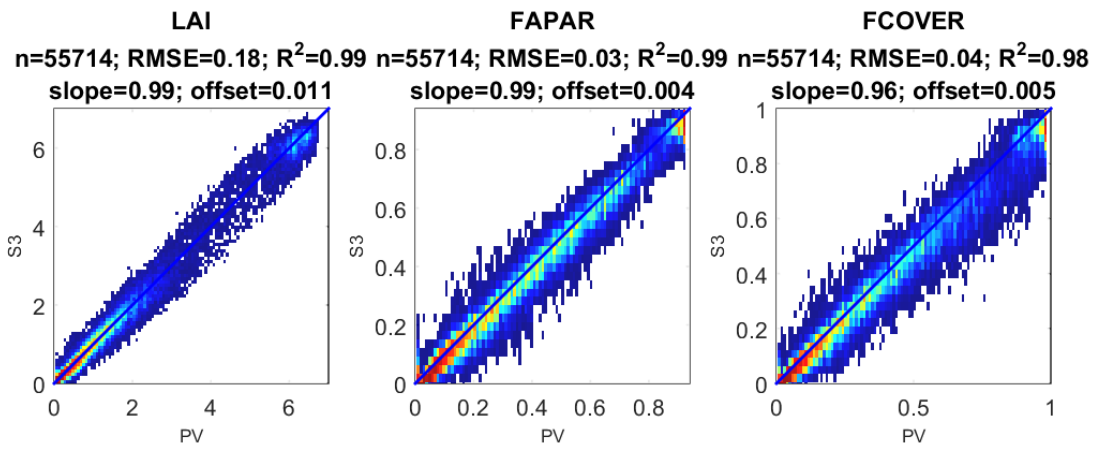
Ensemble of elementary functions (neurons) characterized by weights, bias, transfer function





Where

R = number of elements in input vector



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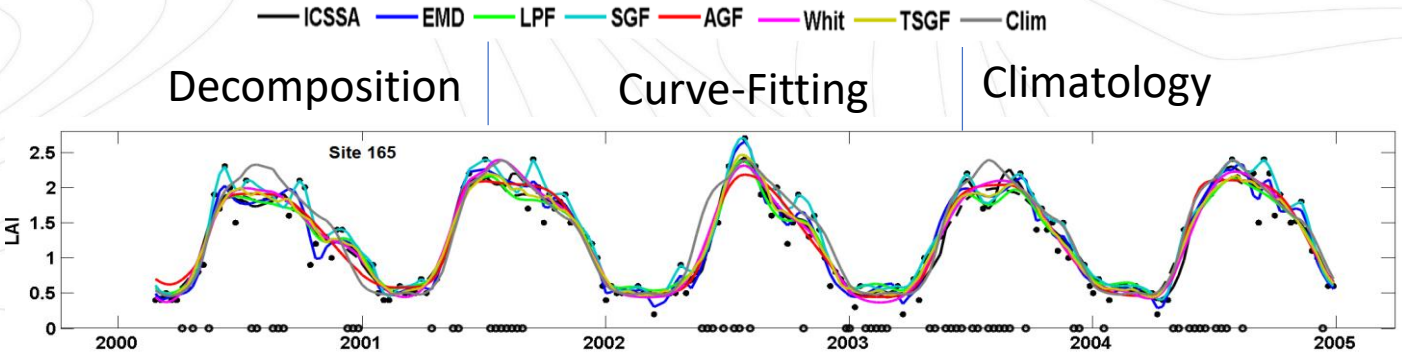
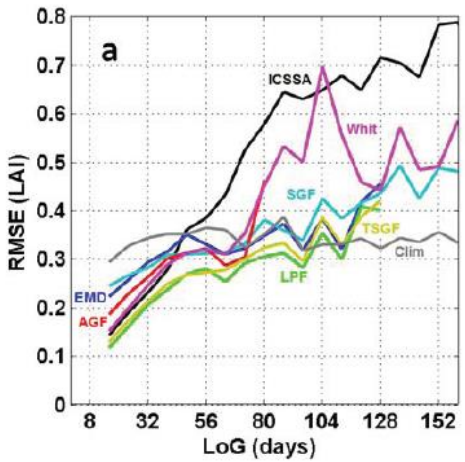
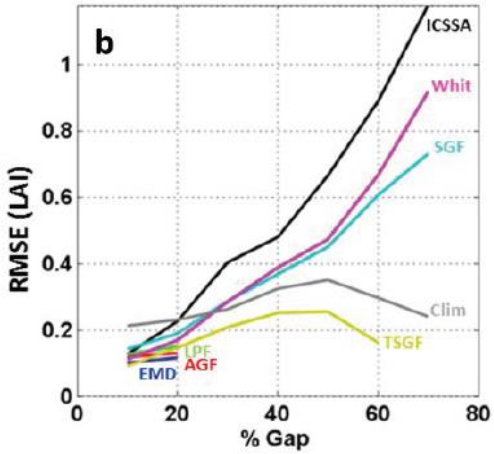
Temporal smoothing

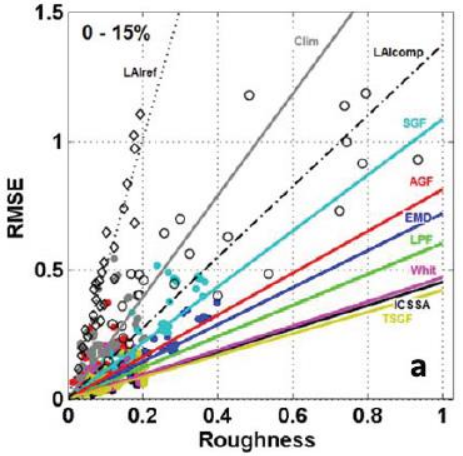
Adaptive polynomial fitting

Compositing window length (15-60 days) depends on available daily estimates (5 at each half-window)





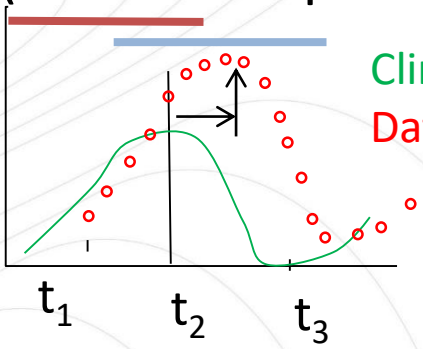




Kandasamy et al. 2013, *Biogeosciences*

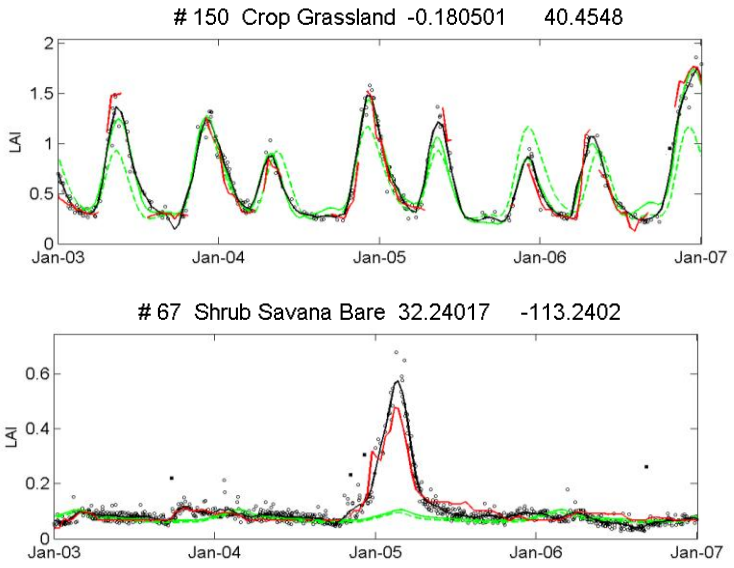
Gap filling

- **1km V2**: use of the interannual climatology for filling gaps (linear interpolation if climatology not available)



CACAO: Consistent Adjustment of the Climatology to Actual Observations

Verger et al. 2013, *IEEE TGRS*



CACAO cannot predict atypical seasonality from the climatology

Product values not affected when enough valid data

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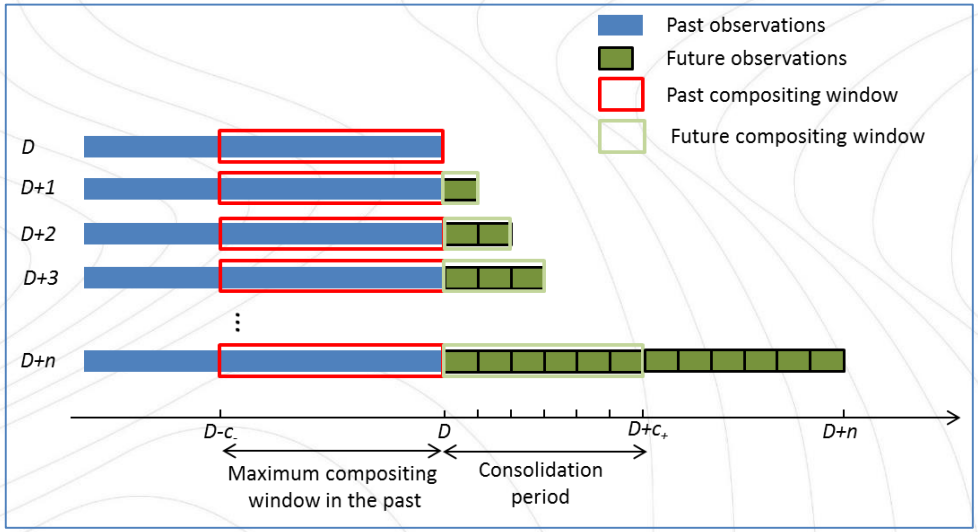
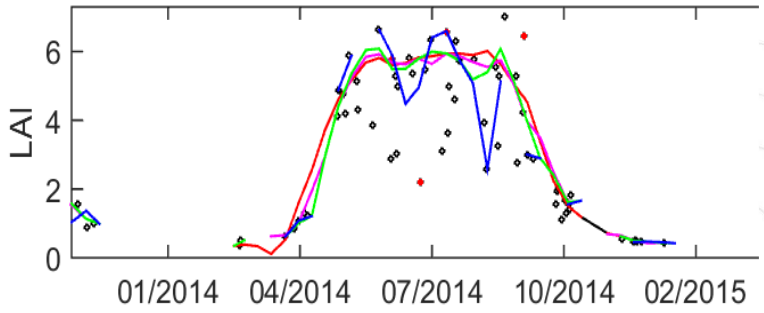
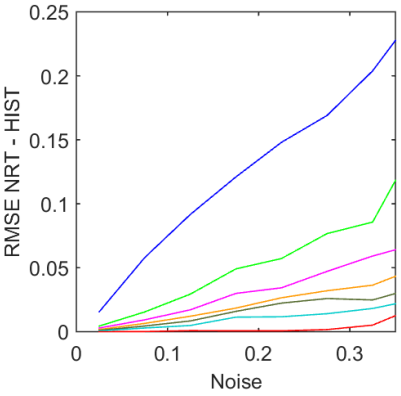
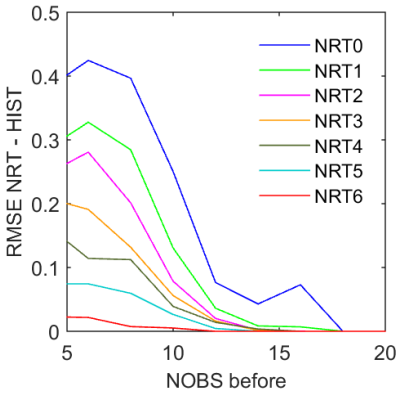
OBSERVATION SPATIALE AU SERVICE DE LA NOUVELLE-CALÉDONIE

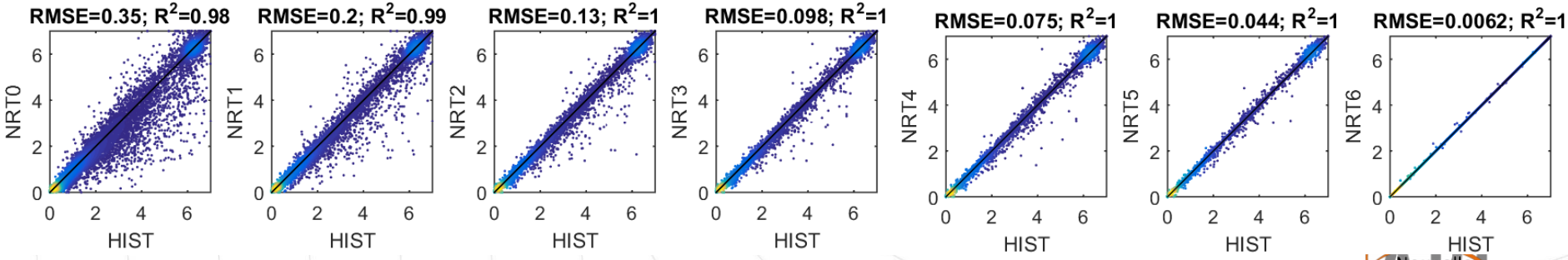
NEAR REAL TIME PROCESSING







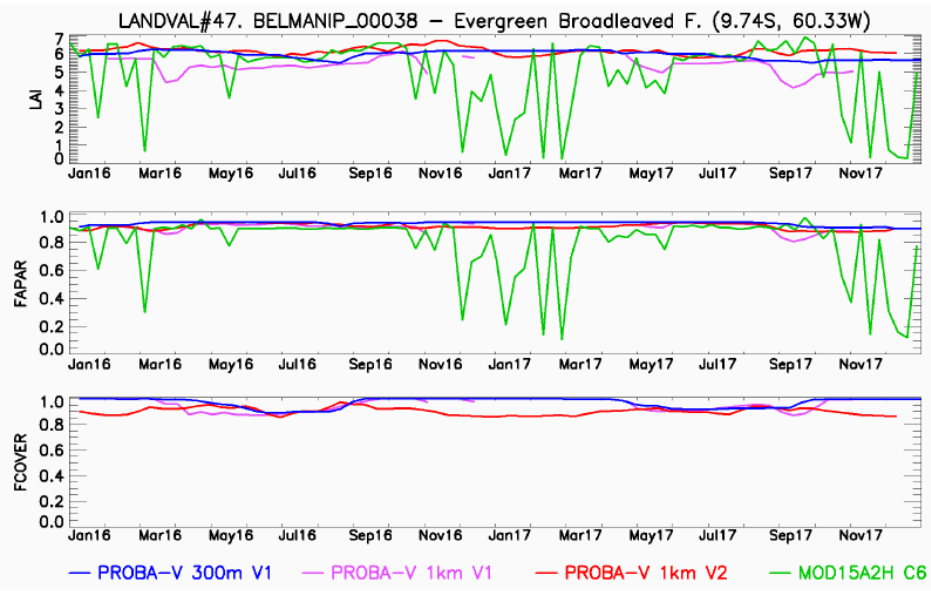


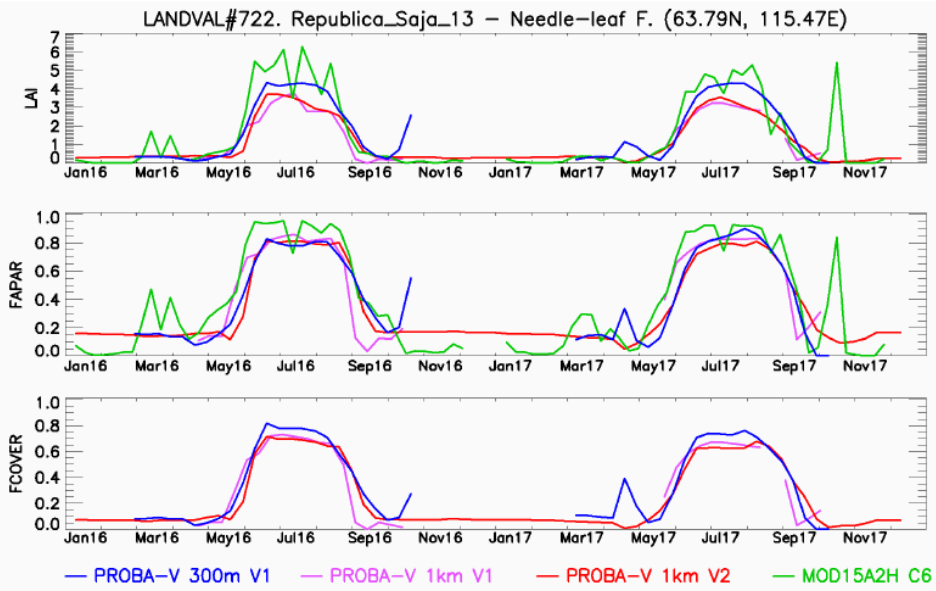


Nouvelle Calédonie
AKT GEODEV

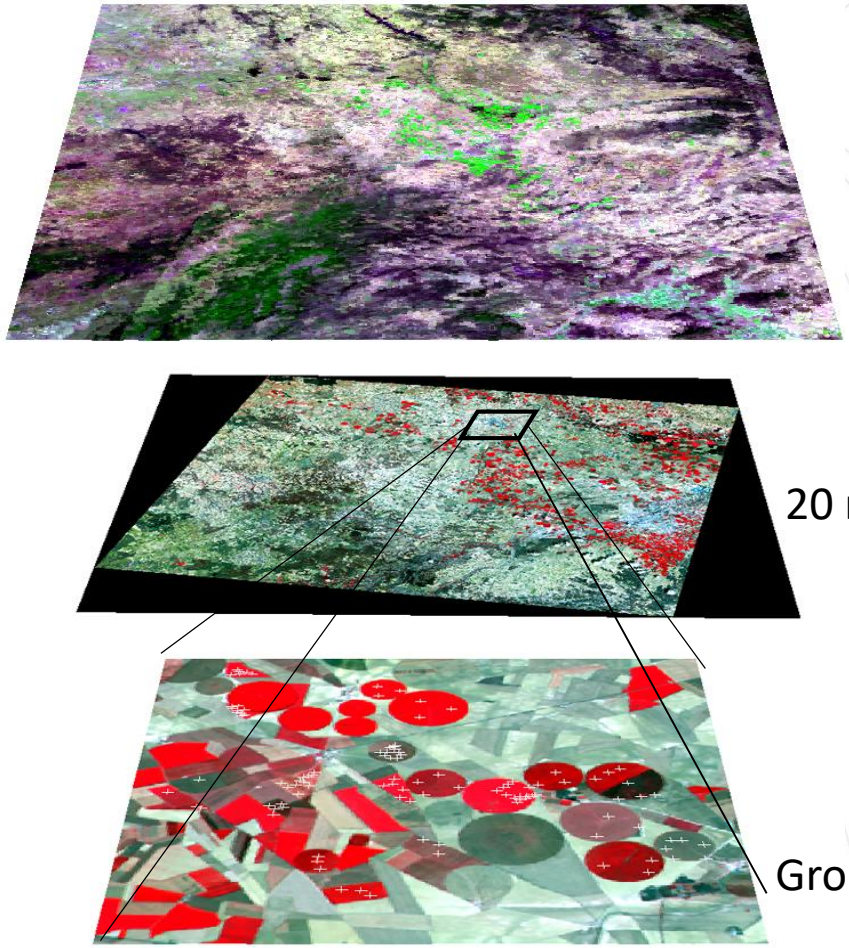
TEMPORAL CONTINUITY AND CONSISTENCY

- ***1km V2 & 300m V1:***
  - *Good temporal consistency, smooth profiles, removing some artifacts present in V1, with better inter-annual precision (same sensor)*
- ***1km V2:***
  - *Temporal continuity (no missing data)*





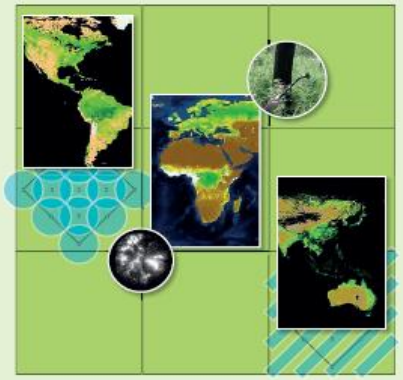
Validation: Bottom up approach



Committee on Earth Observation Satellites
Working Group on Calibration and Validation

Land Product Validation Sub-Group

Global Leaf Area Index Product Validation Good Practices



Version 2.0

January, 2014

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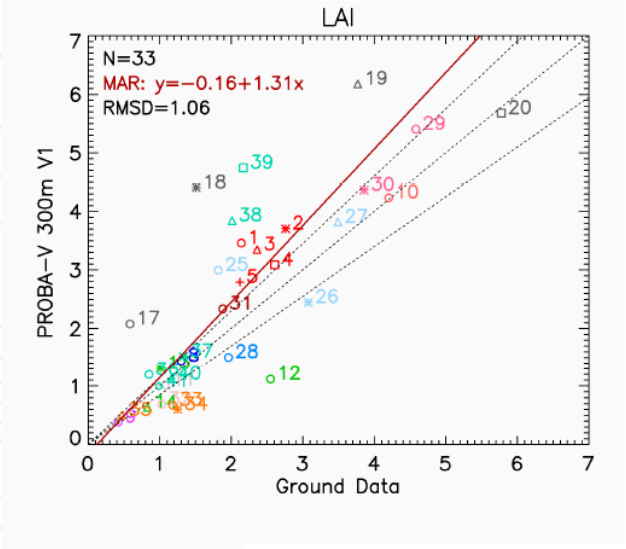
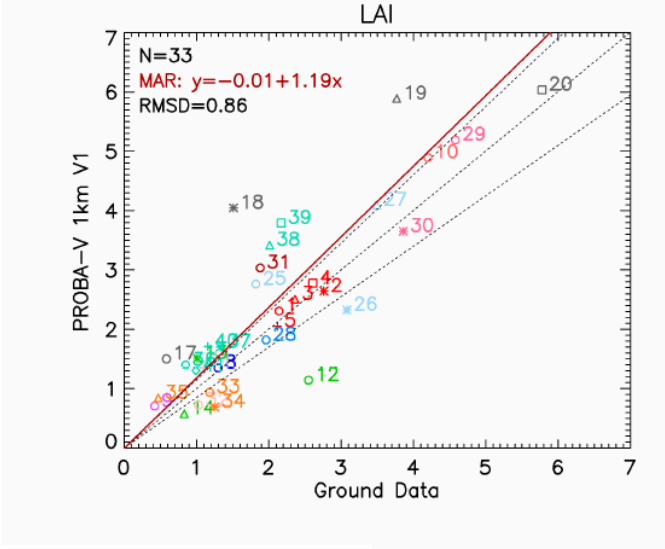
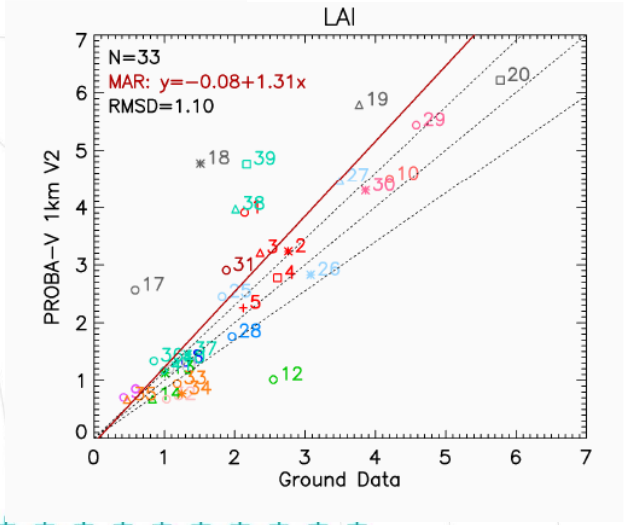
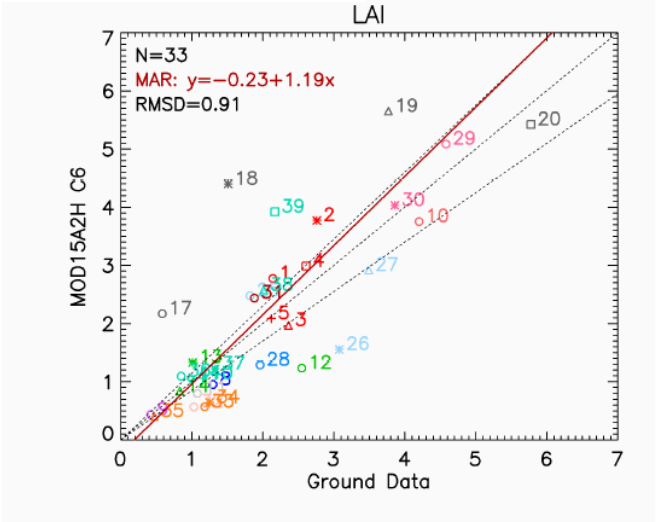
Accuracy assessment: comparison with ground measurements





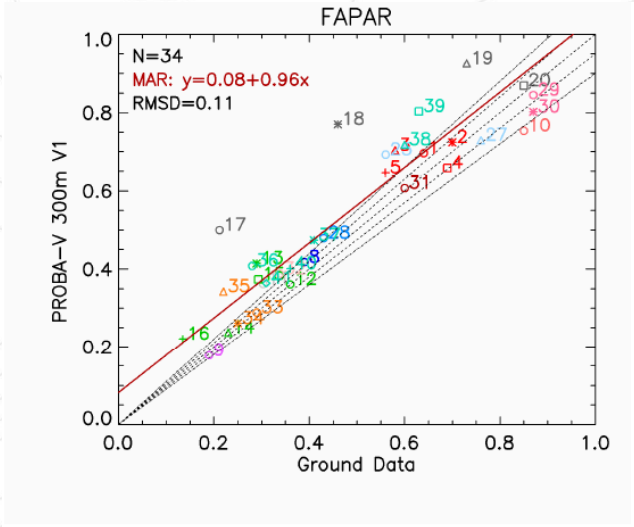




- Pshenichne
- Merguellil
- 25Maya_1
- 25Maya_2
- Rasasca
- LaReina_1
- Barrax
- Albufera
- Ottawa
- Capitanata
- San_Fernando
- Callelongo
- Maraqua
- Liria
- Moncada
- Ahspect

Fuster et al. 2020, Remote Sensing

Accuracy assessment: comparison with ground measurements



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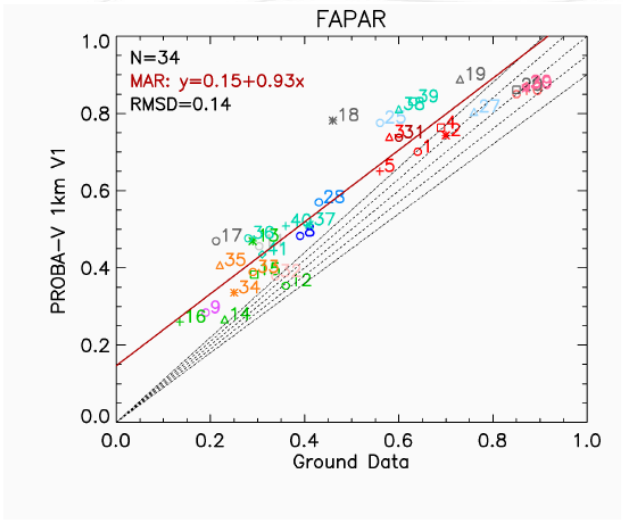

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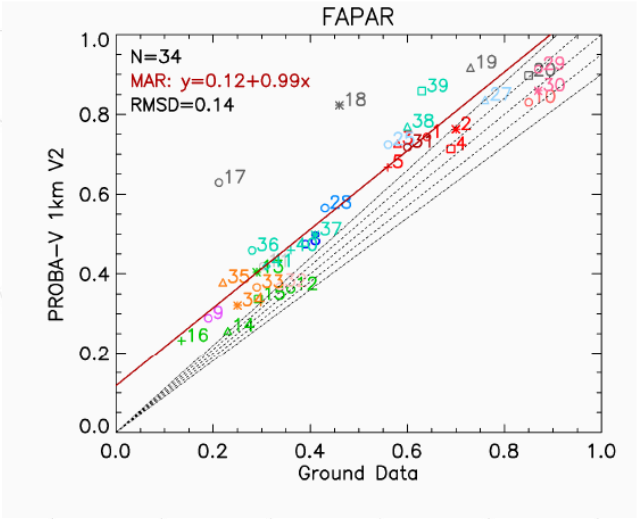

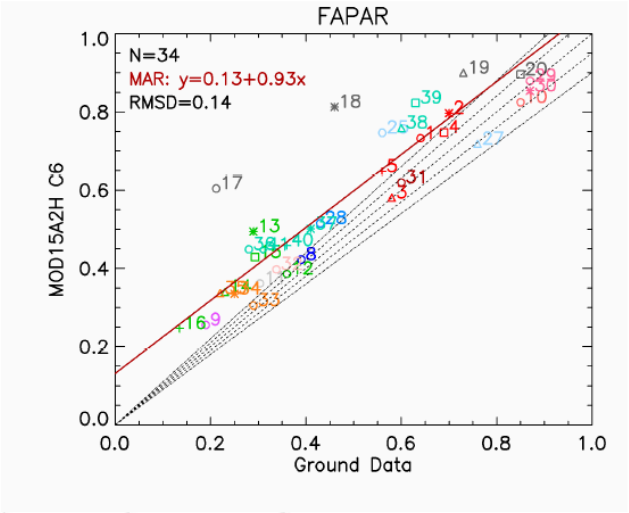

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Fuster et al. 2020, Remote Sensing

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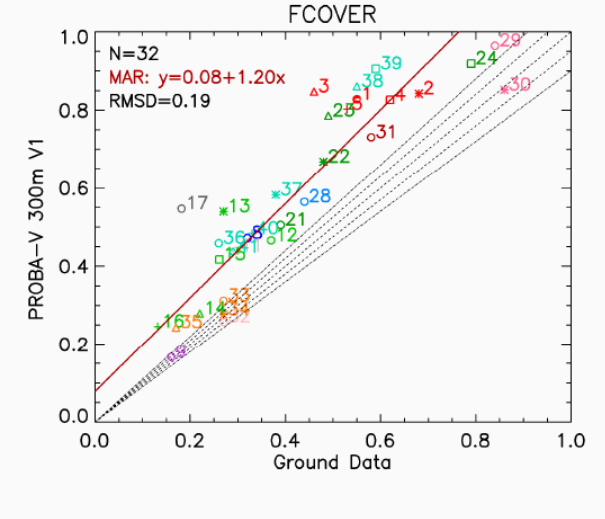

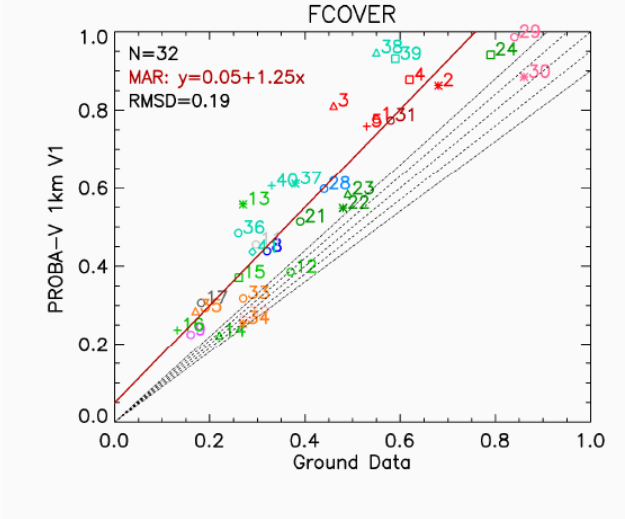

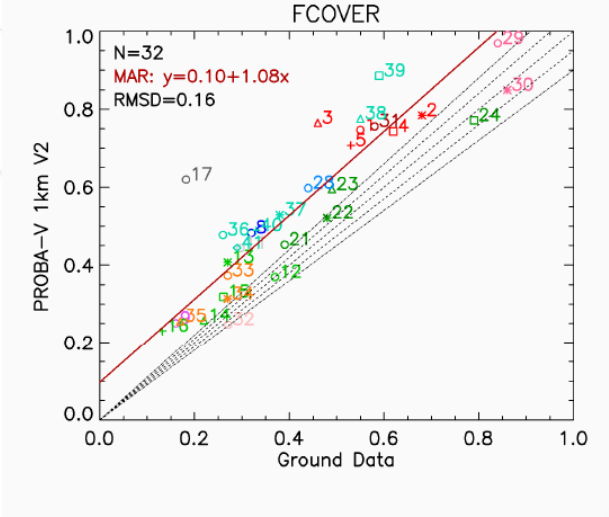

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Fuster et al. 2020, Remote Sensing

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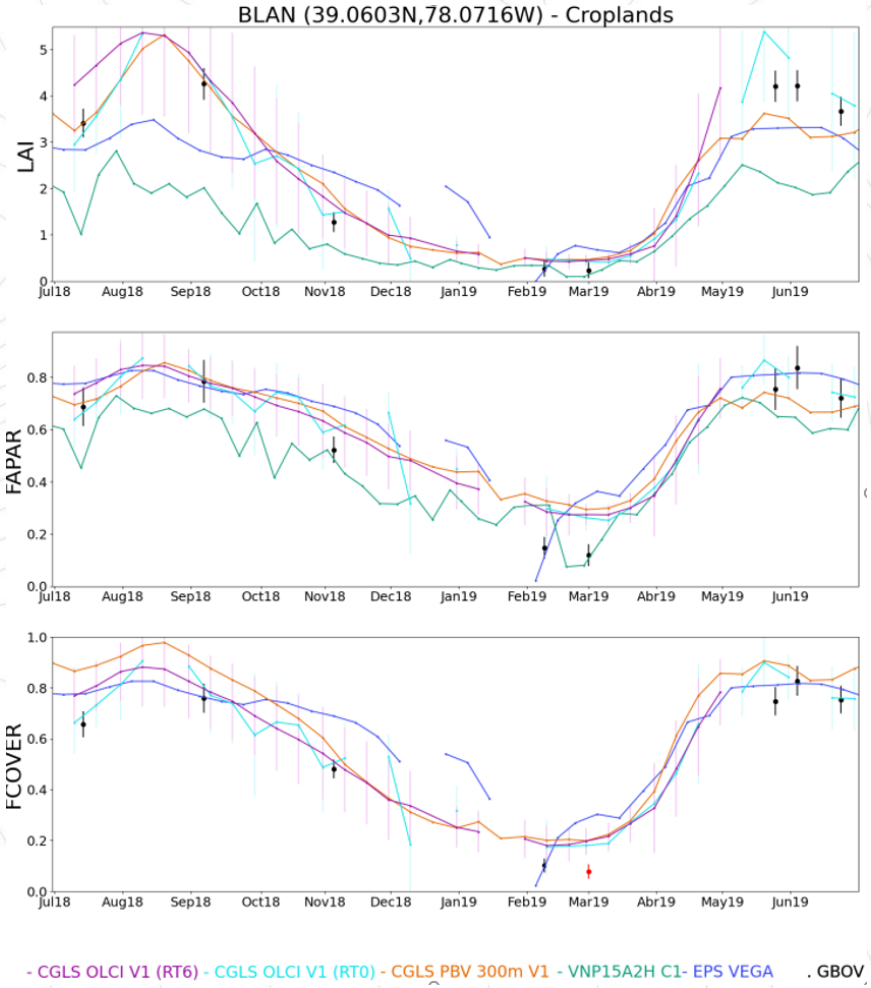
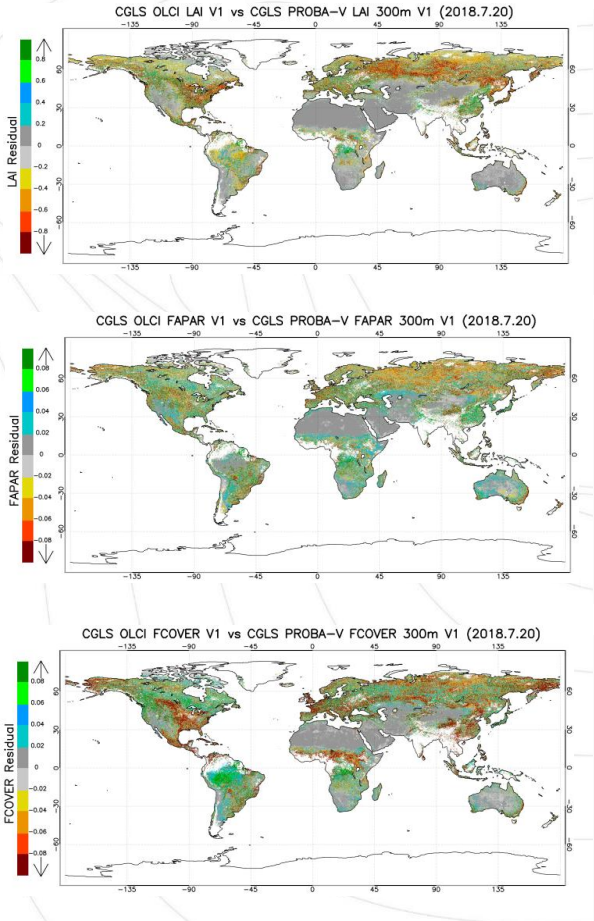
Continuity with Sentinel-3





Sanchez, 2021, CGLS QAR

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GEOV2-AVHRR: Long-term Global Vegetation Monitoring

Same principles of CGLS 1km v2

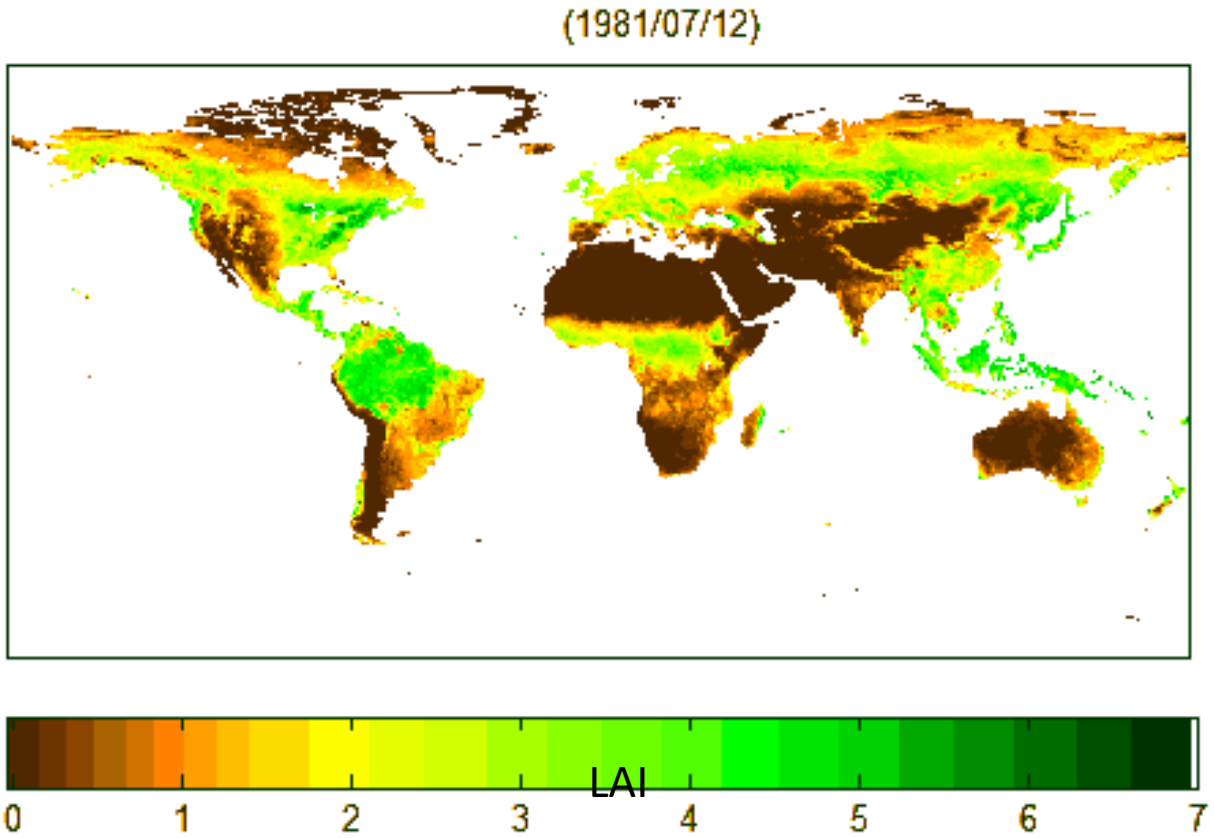
40+ years of LAI, fAPAR & FCOVER AVHRR time series

0.05° (4km) – 0.5° products every 10 days at the global scale

Théia Pôle thématique surfaces continentales

CREAF

INRAE



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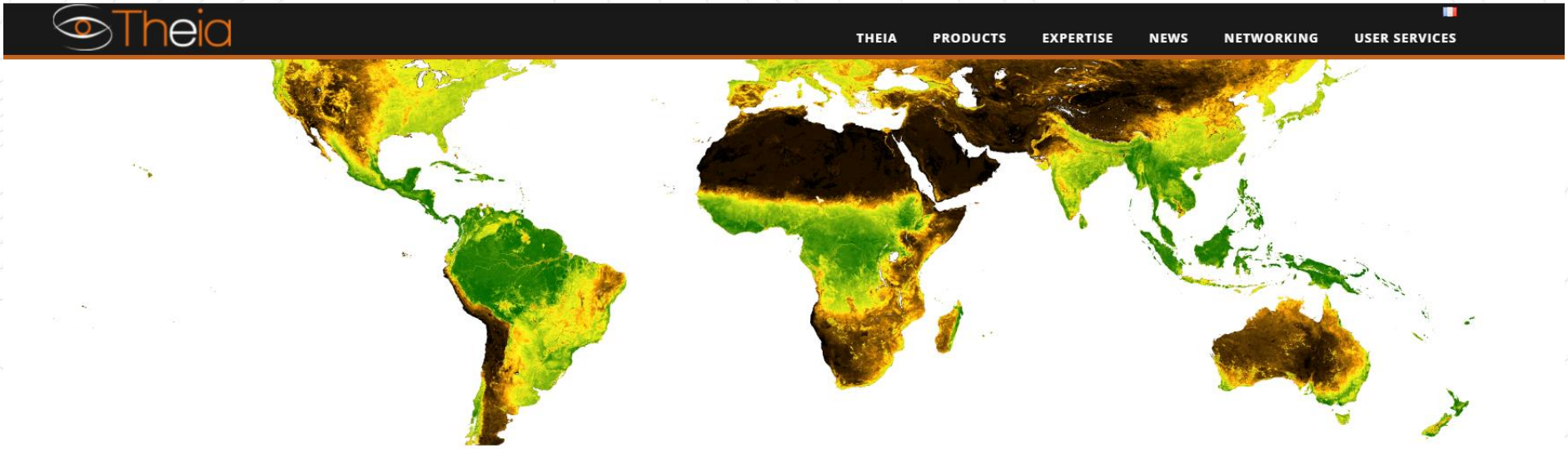
DATA ACCESS AND DOCUMENTATION

https://www.theia-land.fr/en/product/series-of-vegetation-variables-avhrr



Data access and documentation

https://www.theia-land.fr/en/product/series-of-vegetation-variables-avhrr

https://postel.theia.cnes.fr/atdistrib/postel/client/#/products?startDate=1980-01-01&productType=Vegetation&completionDate=2

Theia Land Data Centre

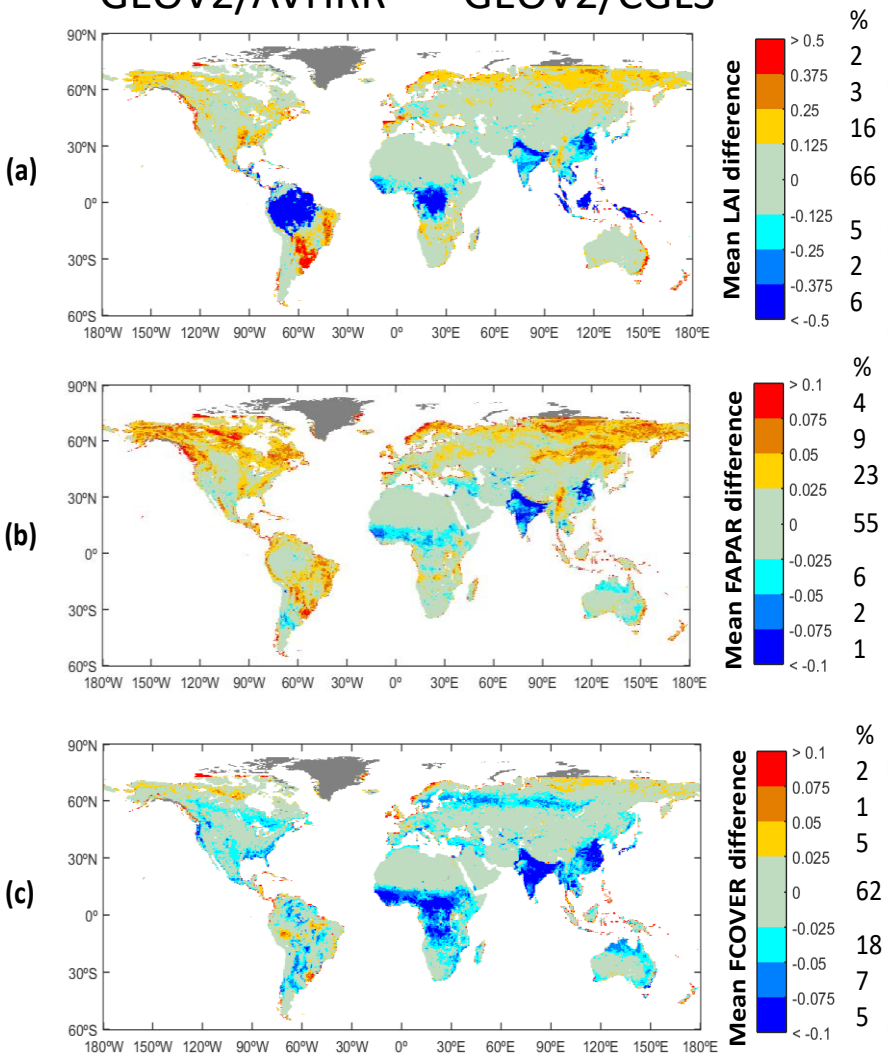
Start Help verger@creaf.uab.cat 0

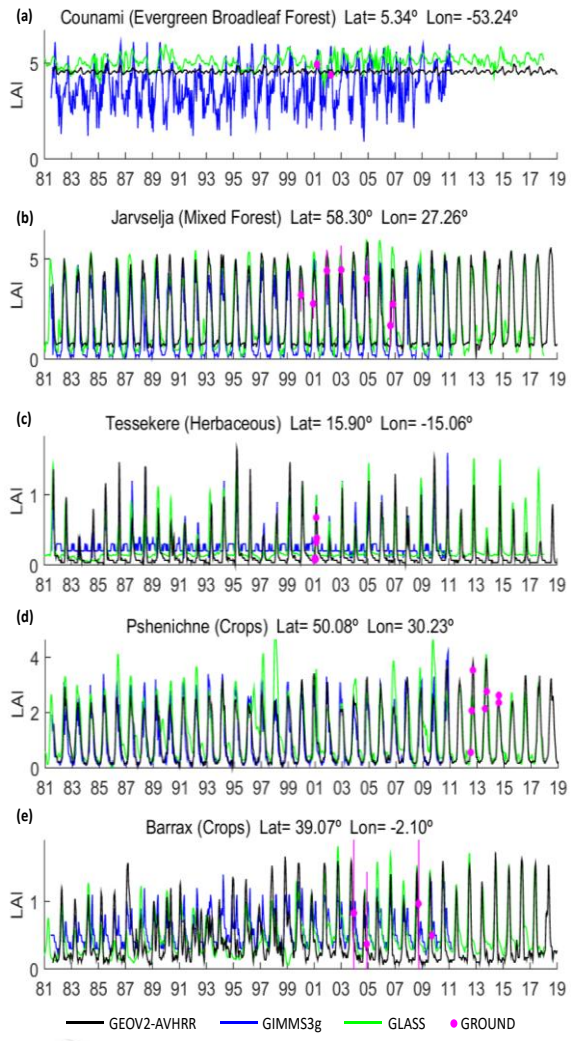
Add checks to cart

date	type	project	instrument	parameter	archive	actions
2018-12-25	Vegetation	GEOV2-GCM	AVHRR	FAPAR	/vegetation/fapar/GEOV2-GCM/data/THEIA_GEOV2-GCM_R01_AVHRR_FAPAR_20181225.h5.gz	add to cart
2018-12-25	Vegetation	GEOV2	AVHRR	Fcover	/vegetation/fcover/GEOV2/data/THEIA_GEOV2_R01_AVHRR_FCOVER_20181225.h5.gz	add to cart
2018-12-25	Vegetation	GEOV2	AVHRR	LAI	/vegetation/lai/GEOV2/data/THEIA_GEOV2_R01_AVHRR_LAI_20181225.h5.gz	add to cart
...						
1981-08-25	Vegetation	GEOV2	AVHRR	Fcover	/vegetation/fcover/GEOV2/data/THEIA_GEOV2_R01_AVHRR_FCOVER_19810825.h5.gz	add to cart
1981-08-25	Vegetation	GEOV2	AVHRR	FAPAR	/vegetation/fapar/GEOV2/data/THEIA_GEOV2_R01_AVHRR_FAPAR_19810825.h5.gz	add to cart
1981-08-25	Vegetation	GEOV2-GCM	AVHRR	LAI	/vegetation/lai/GEOV2-GCM/data/THEIA_GEOV2-GCM_R01_AVHRR_LAI_19810825.h5.gz	add to cart

VALIDATION AND QUALITY ASSESSMENT

GEOV2/AVHRR — GEOV2/CGLS

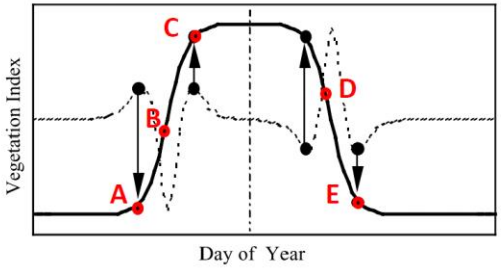


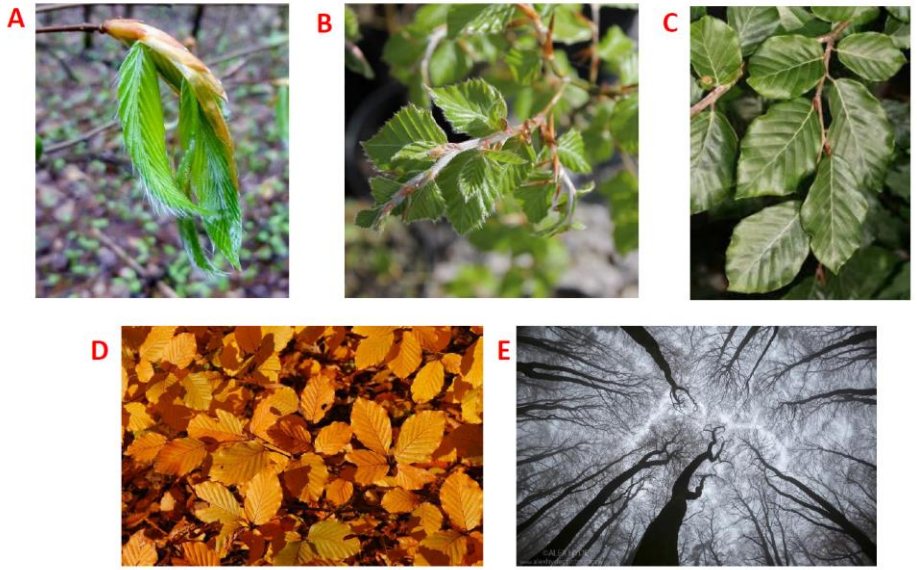


Applications: Land Surface Phenology

Identification of phenophases

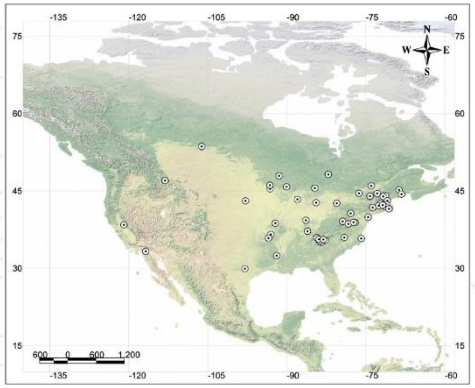
Phenophase: An observable stage or phase in the annual life cycle of a plant

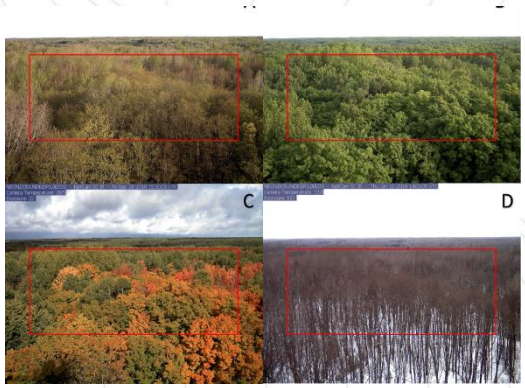


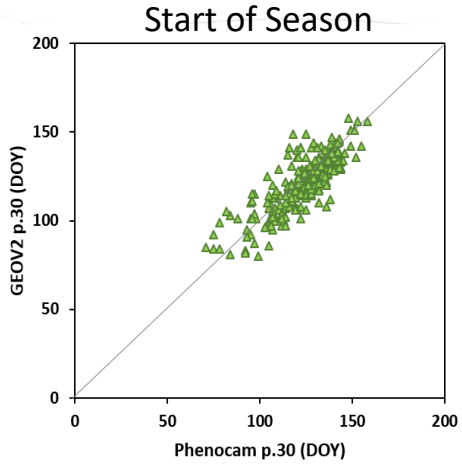


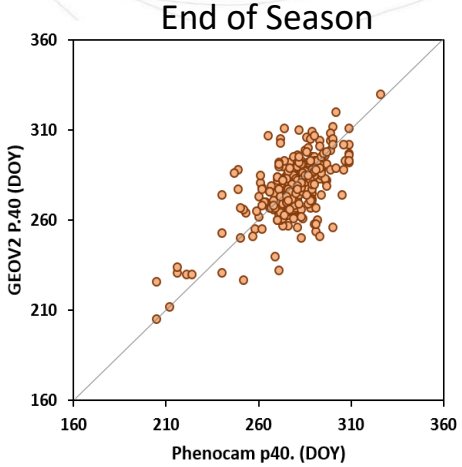
LSP → Phenophase

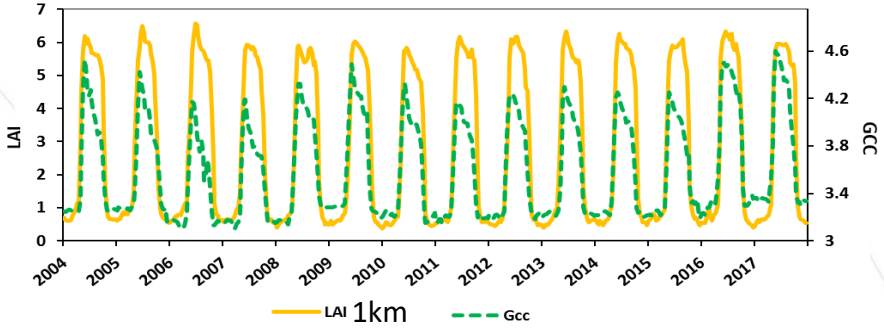
Applications: Land Surface Phenology











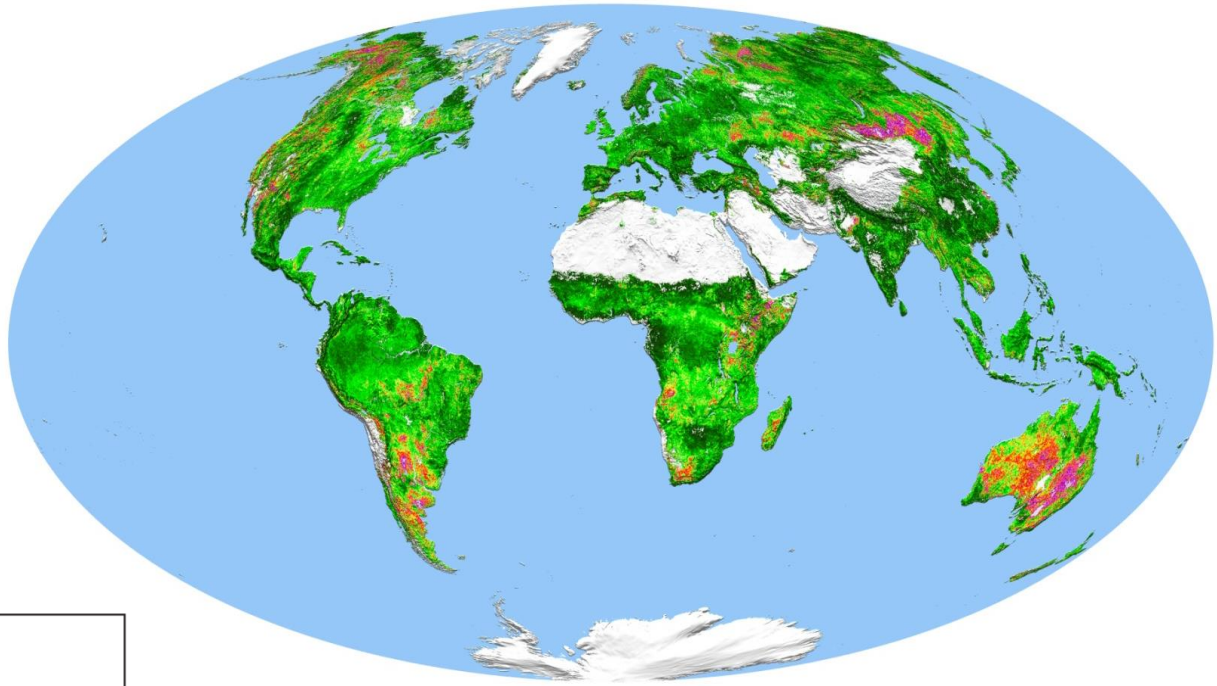
LAI 1km GEOV2

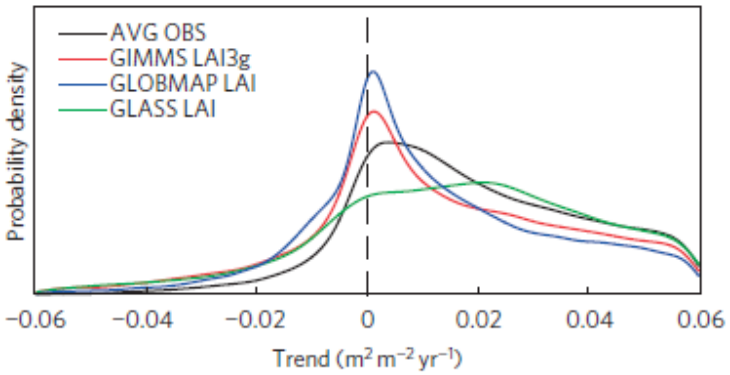
Bornez et al. 2020, Remote Sensing

Applications: Global Change

Greening trend

25-50% greening, 4% browning





Zhu et al. Nature Climate Change, 2016

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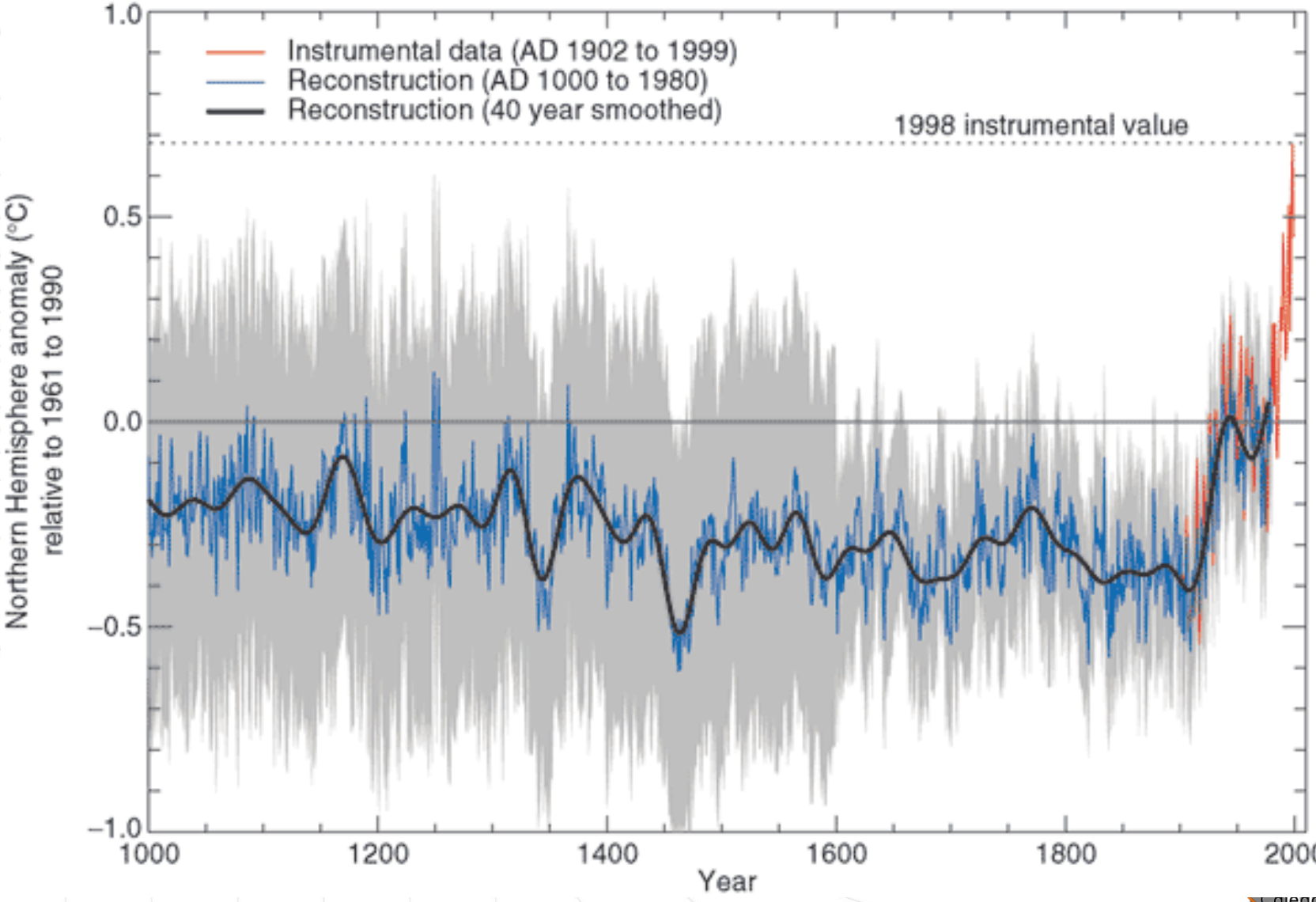
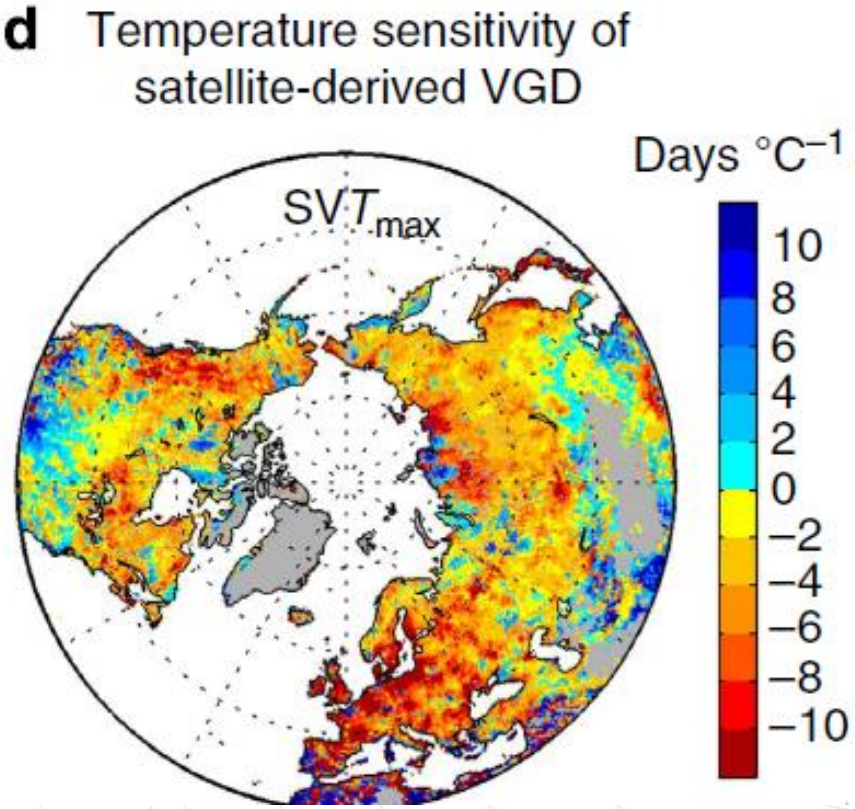
…with warming



…that advances the leaf onset



Leaf onset in the northern hemisphere triggered by daytime temperature

Piao et al. Nature Communications, 2015

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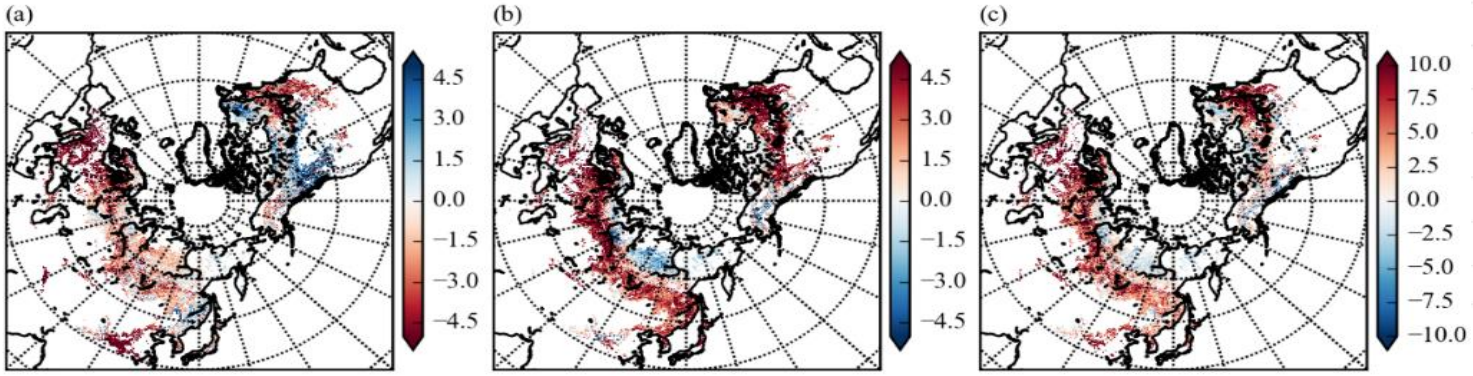
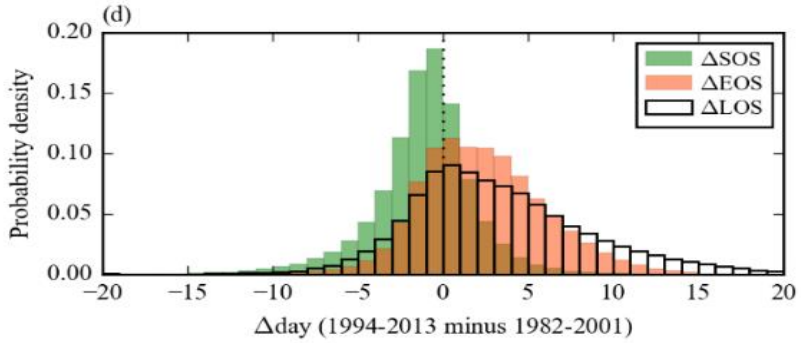
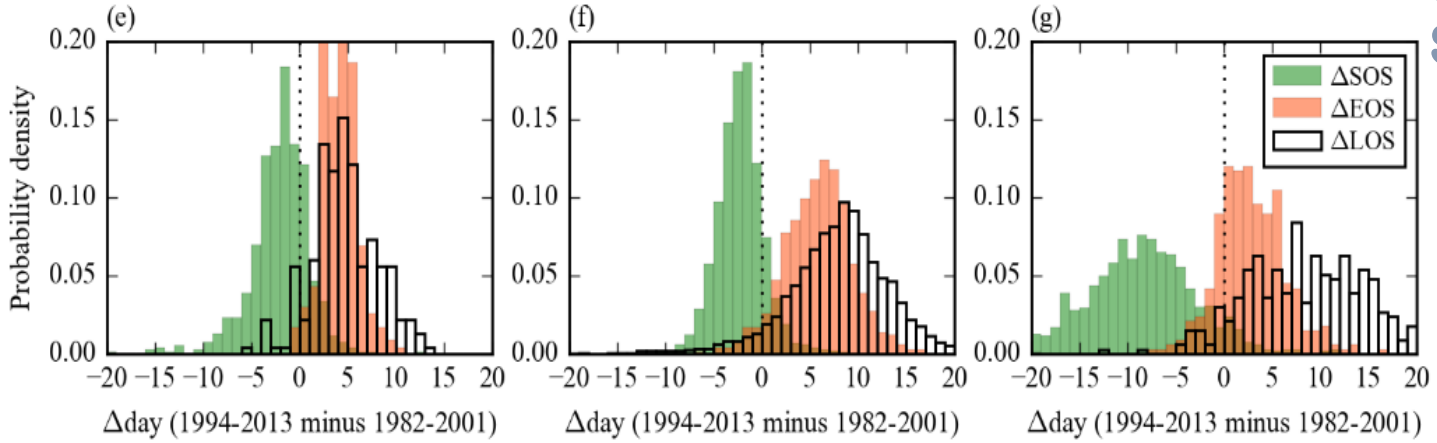
…delays the end of season



Remote sensing data Northern latitudes



Ground data US, Germany and Switzerland



Jong et al. Nature Com. 2017

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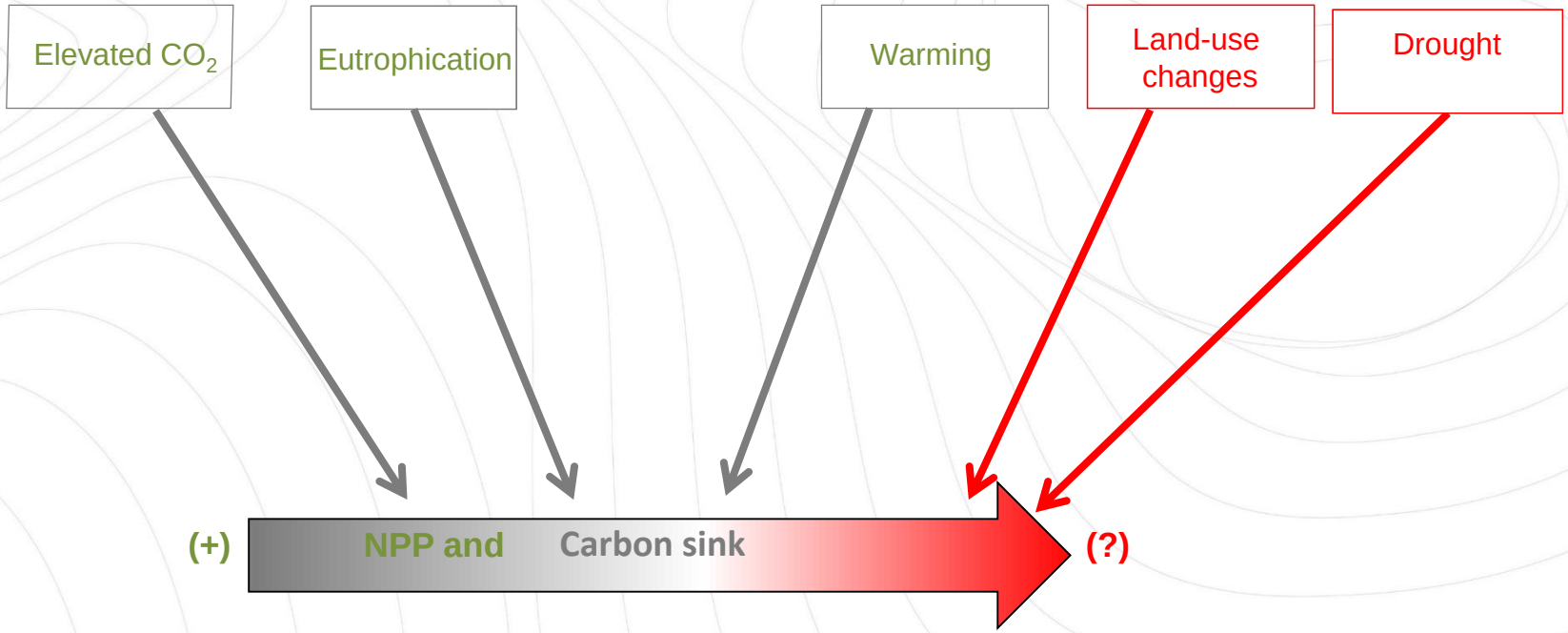
So yes, the fertilization of the biosphere increases NPP and carbon sinks



….for how long?

Drought-Induced Reduction in Global Terrestrial Net Primary Production from 2000 Through 2009

Maosheng Zhao* and Steven W. Running

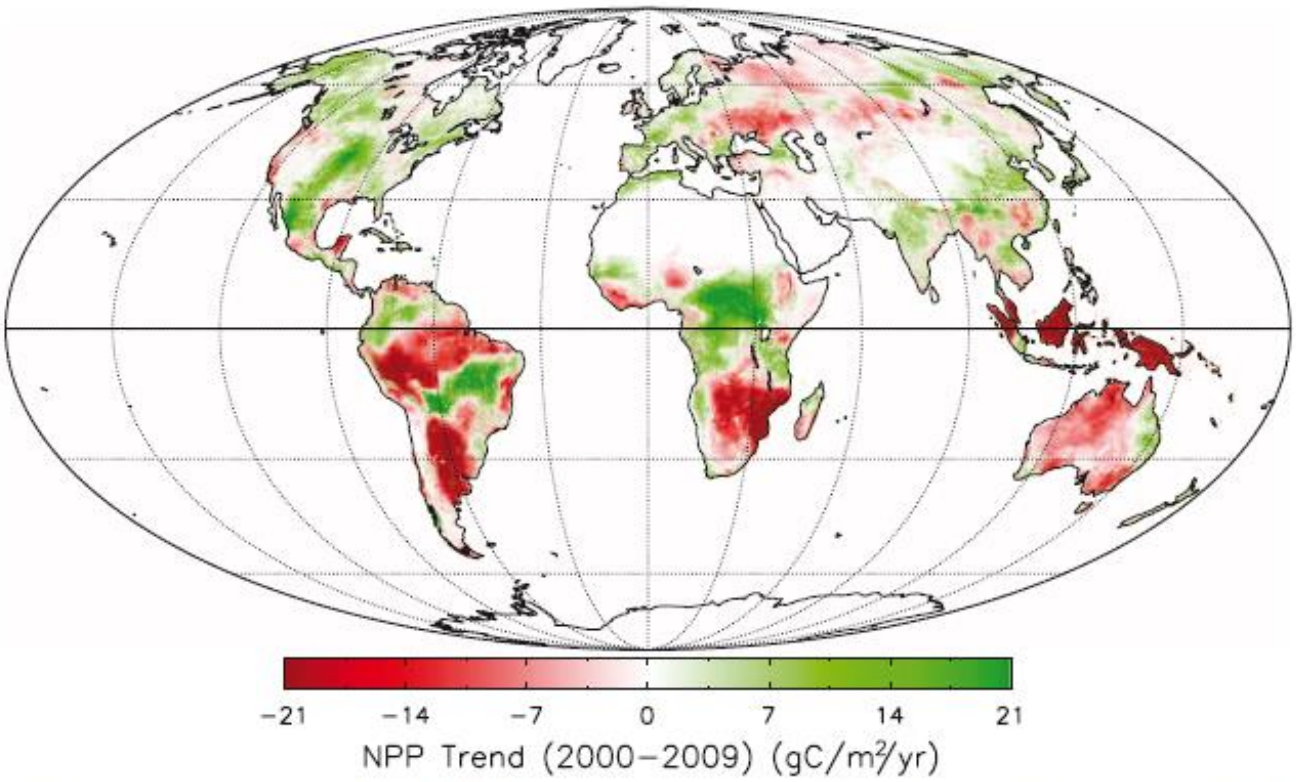


Fig. 2. Spatial pattern of terrestrial NPP linear trends from 2000 through 2009 (SOM text S1) (*8*, *10*).

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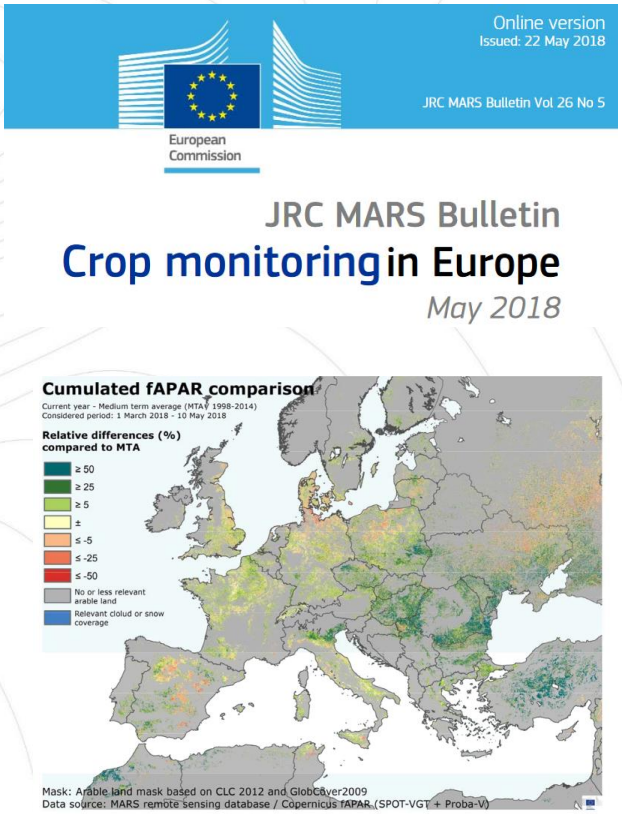
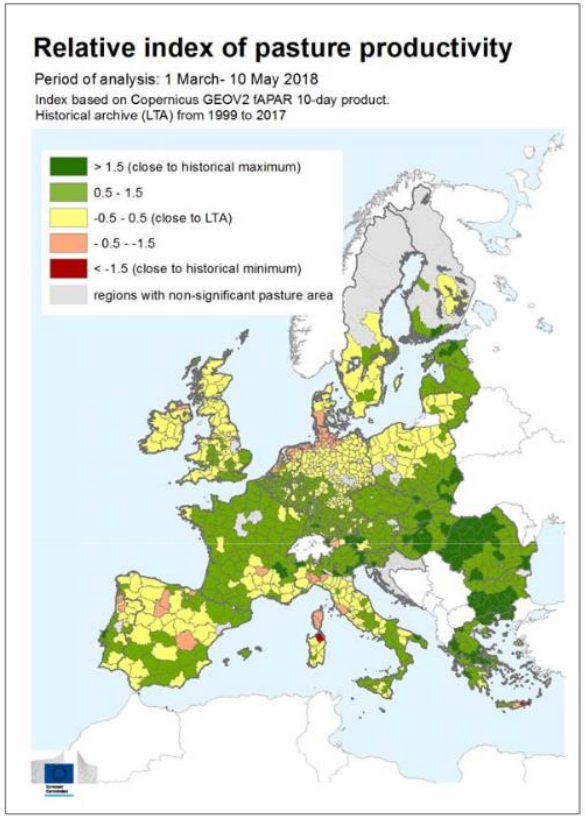
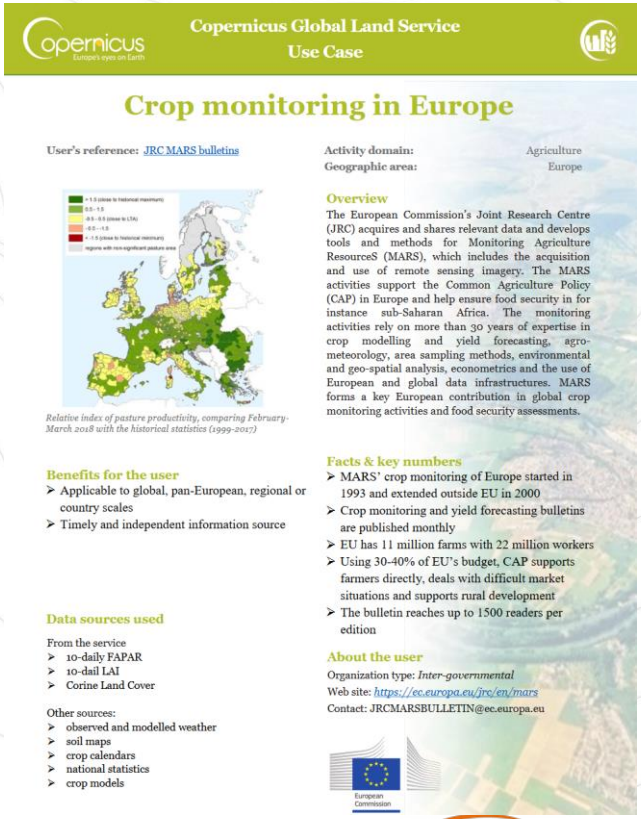
Operational Applications: Crop Monitoring

Use of fAPAR 1km V2 for crop monitoring

Copernicus Europe's eyes on Earth — Land Monitoring Service







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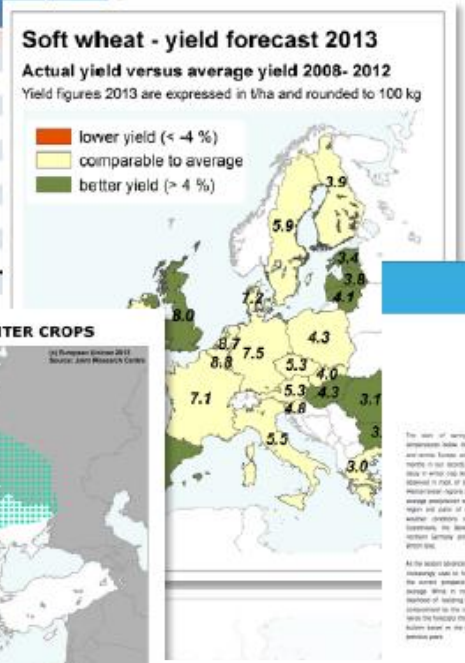
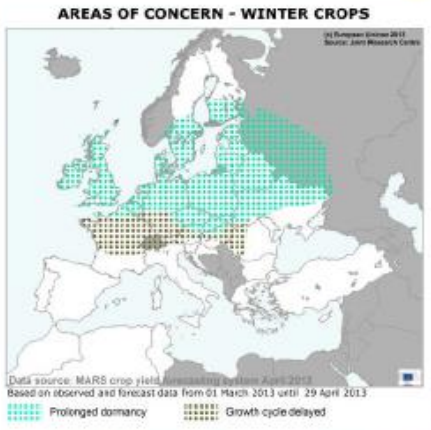
Operational Applications: Crop Monitoring

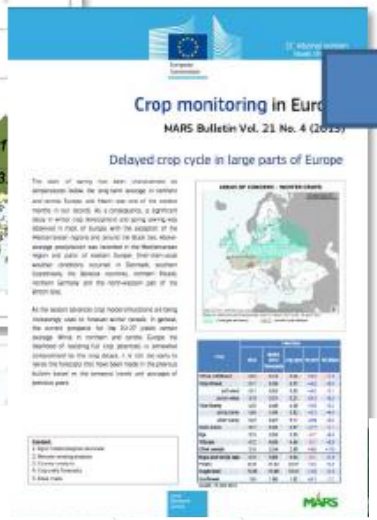
MARS Crop yield forecasting system (MCYFS)

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	31.51	30.67		



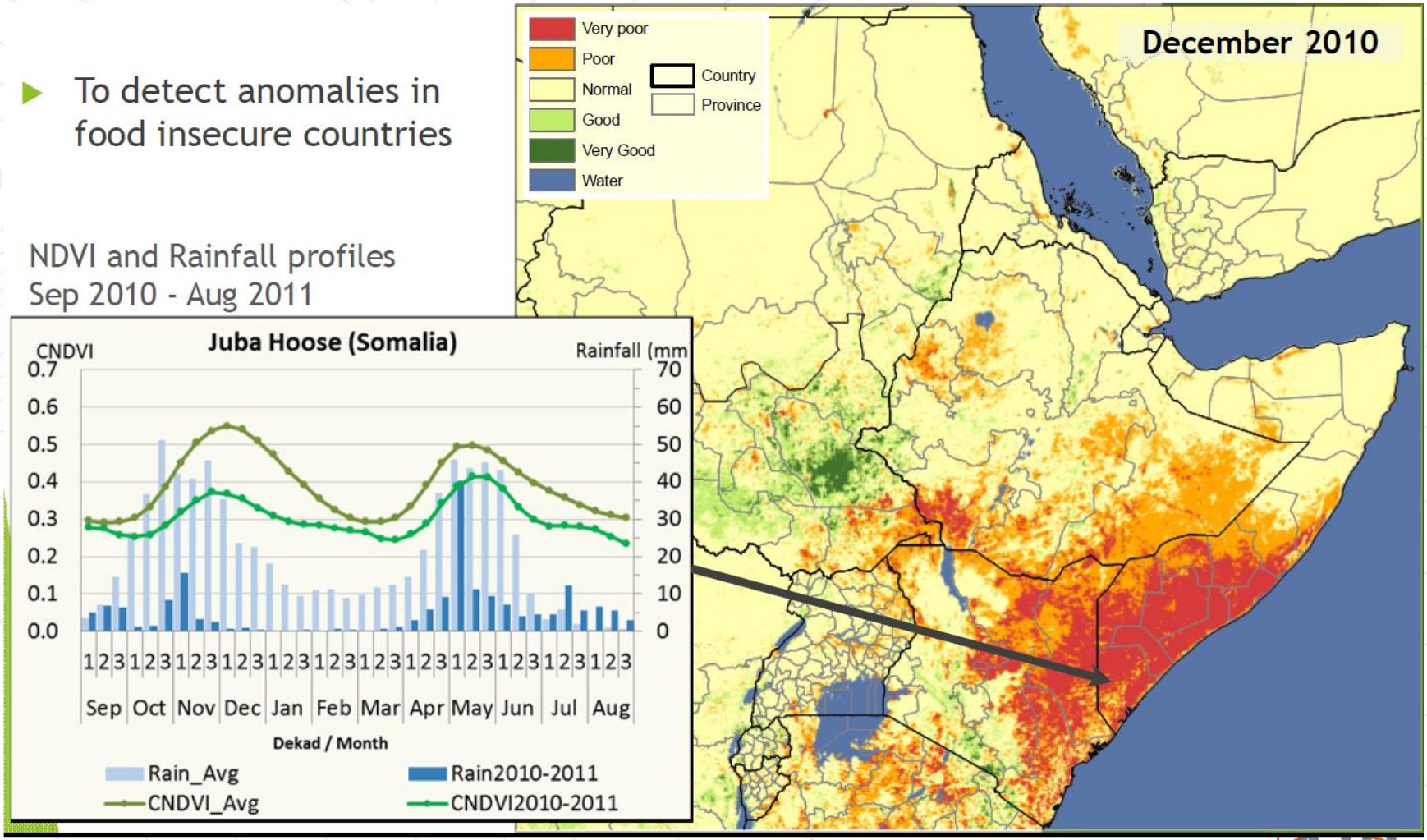




Decision Makers

Operational Applications: Food Security

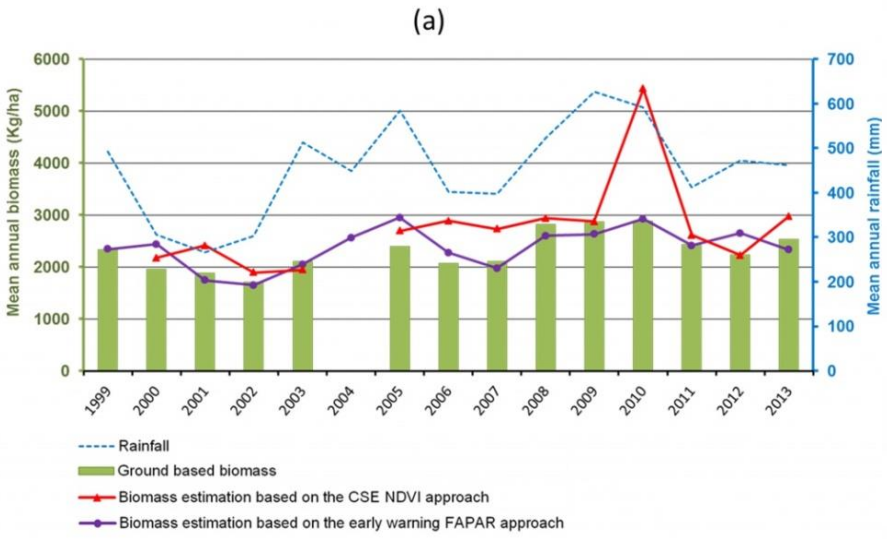
- To detect anomalies in food insecure countries

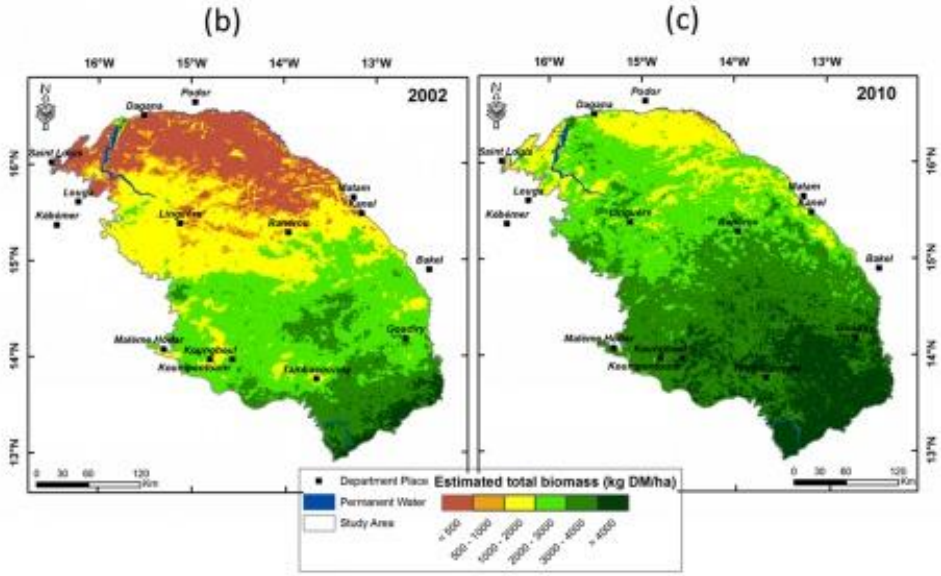


NDVI and Rainfall profiles
Sep 2010 - Aug 2011

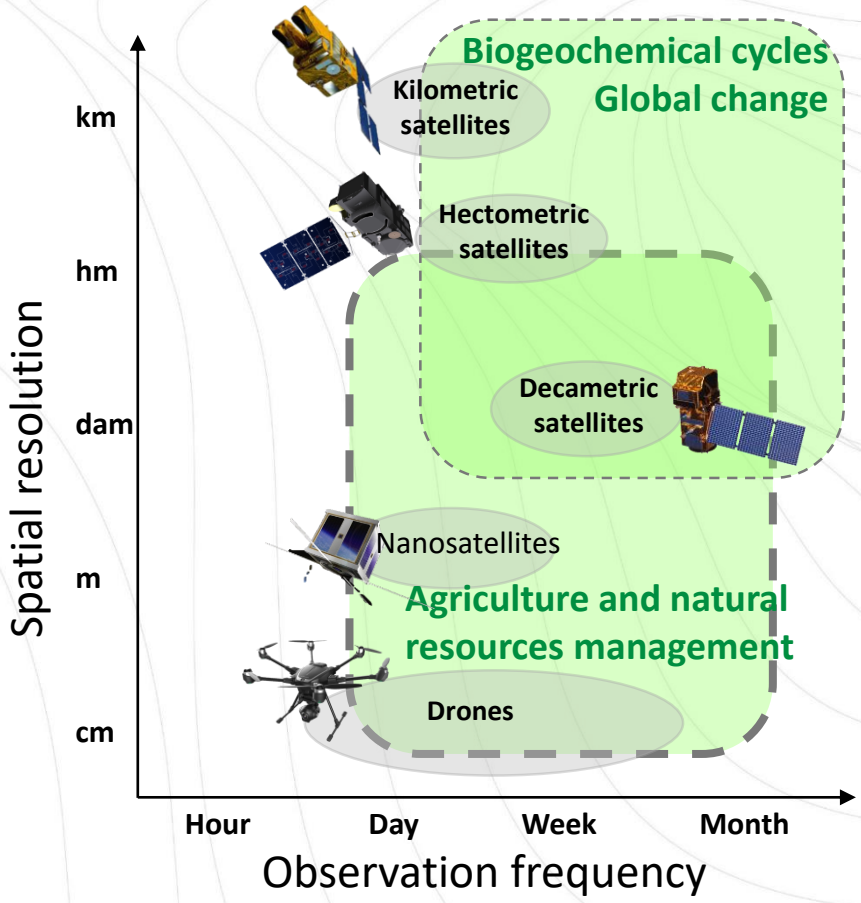
Operational Applications: Food Security

Pasture productivity for grazing livestock (Senegal)





Diouf et al. 2015, Remote Sens


Biogeochemical cycles
Global change
Kilometric satellites
Hectometric satellites
Decametric satellites
Nanosatellites
Agriculture and natural resources management
Drones
km
hm
dam
m
cm
Spatial resolution
Hour
Day
Week
Month
Observation frequency

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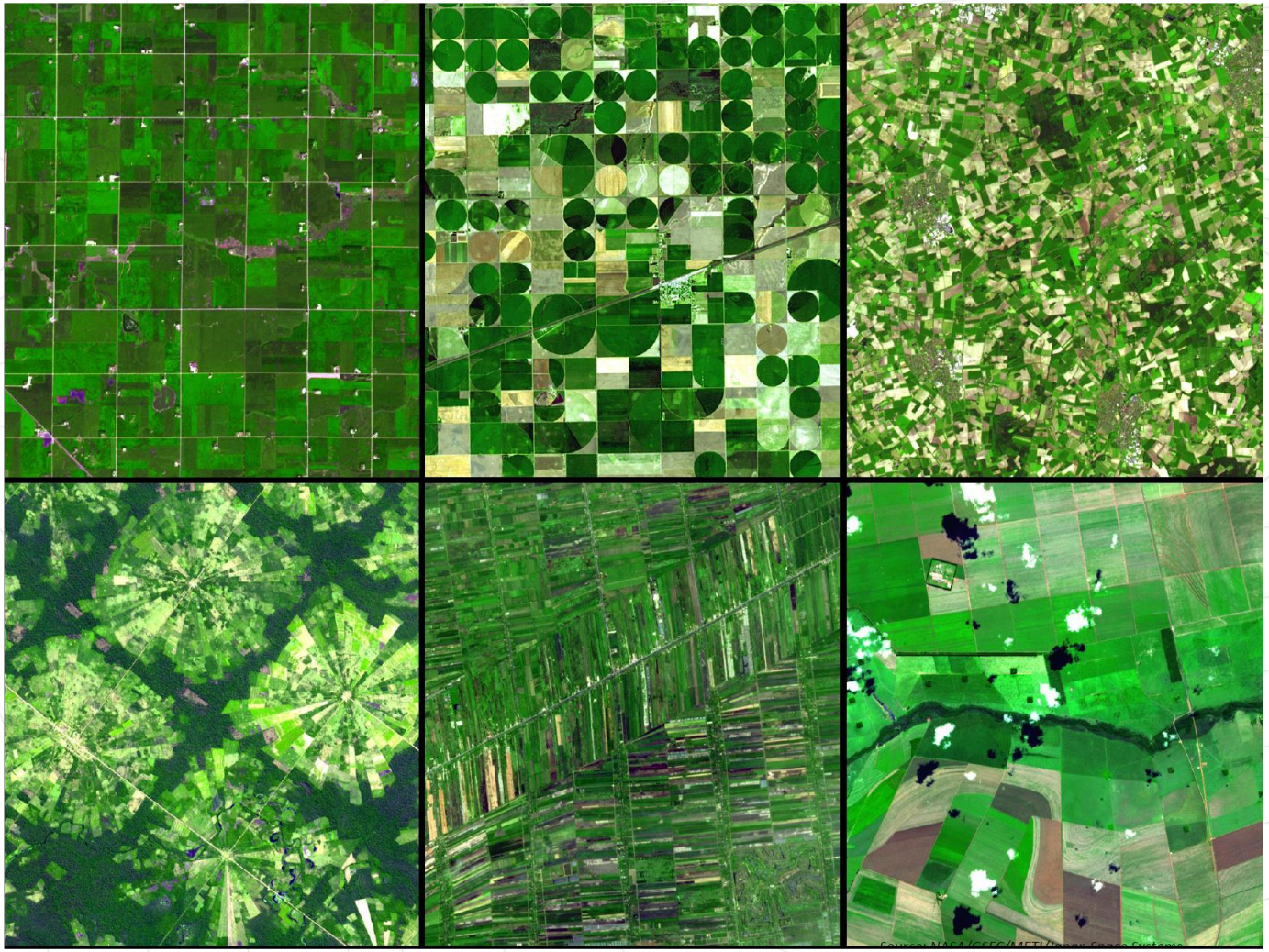
Decametric resolution allowing field monitoring



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5km

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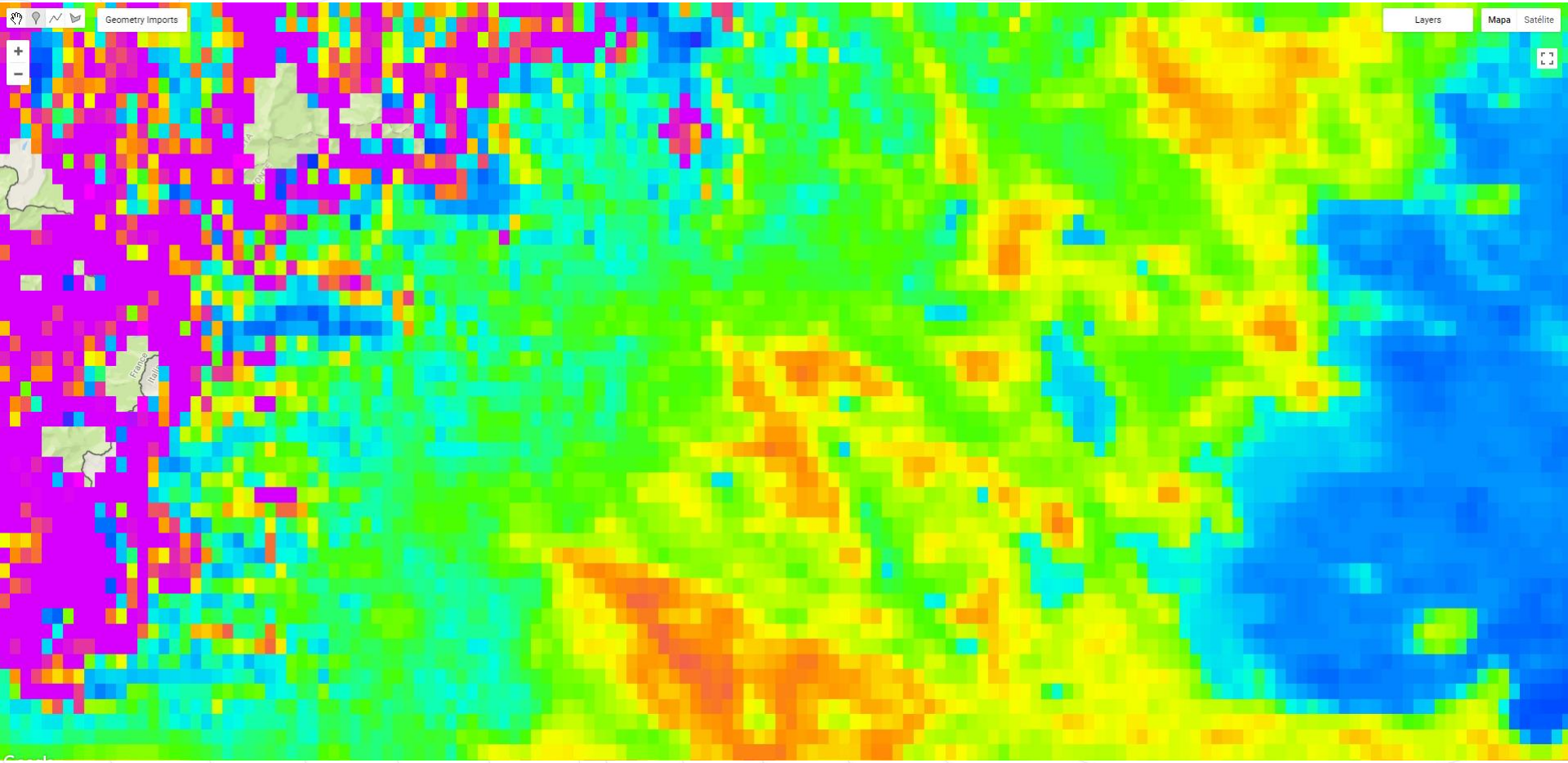

5km

SoS 2017 **Proba-V 1km**

Start of Season (day of year)

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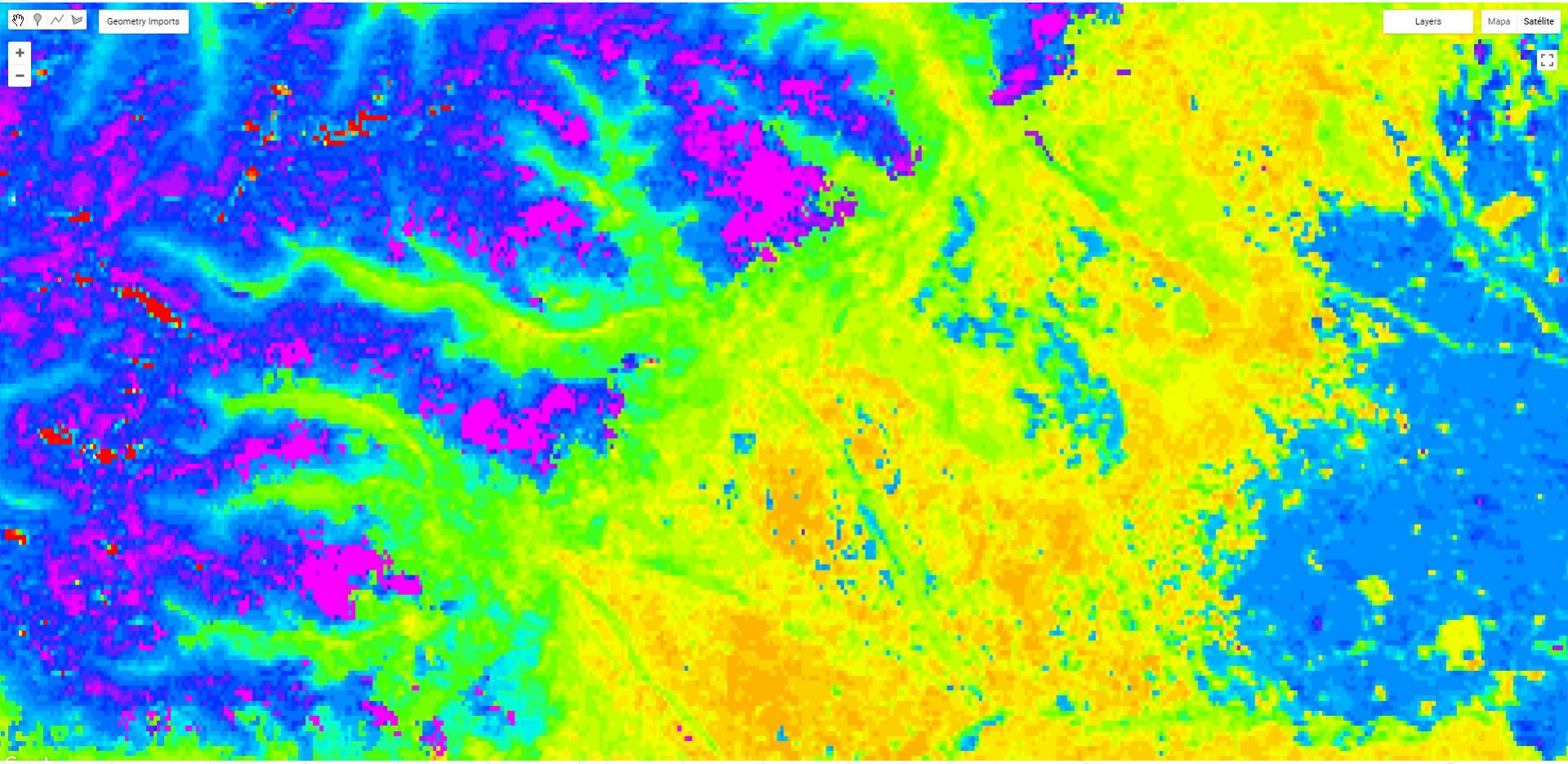

5km

SoS 2017 **Proba-V 333m**

Start of Season (day of year)

ART Nouvelle Calédonie GEODEV

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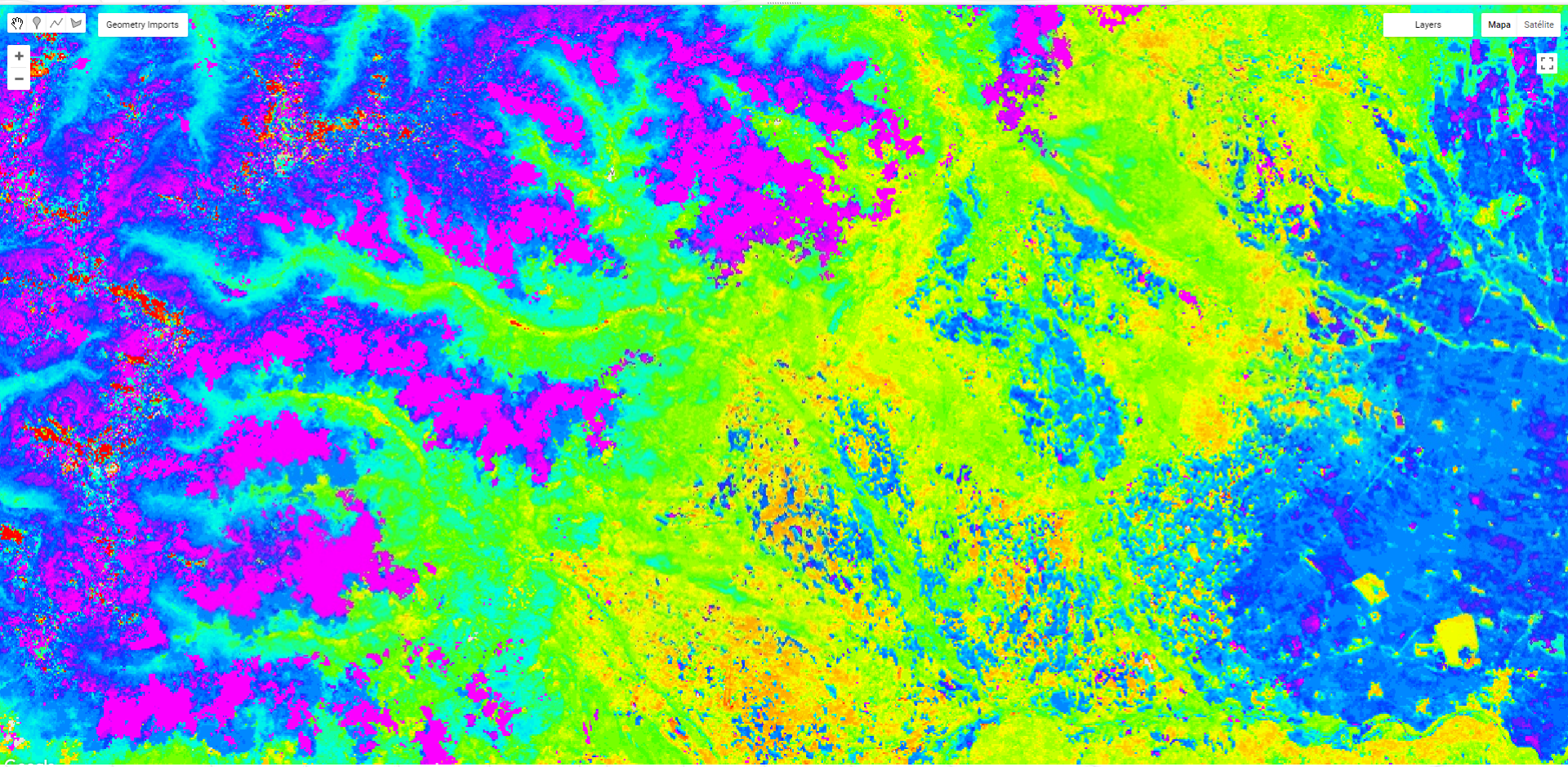

5km

SoS 2017 **Proba-V 100m**

Start of Season (day of year)

30 75 180

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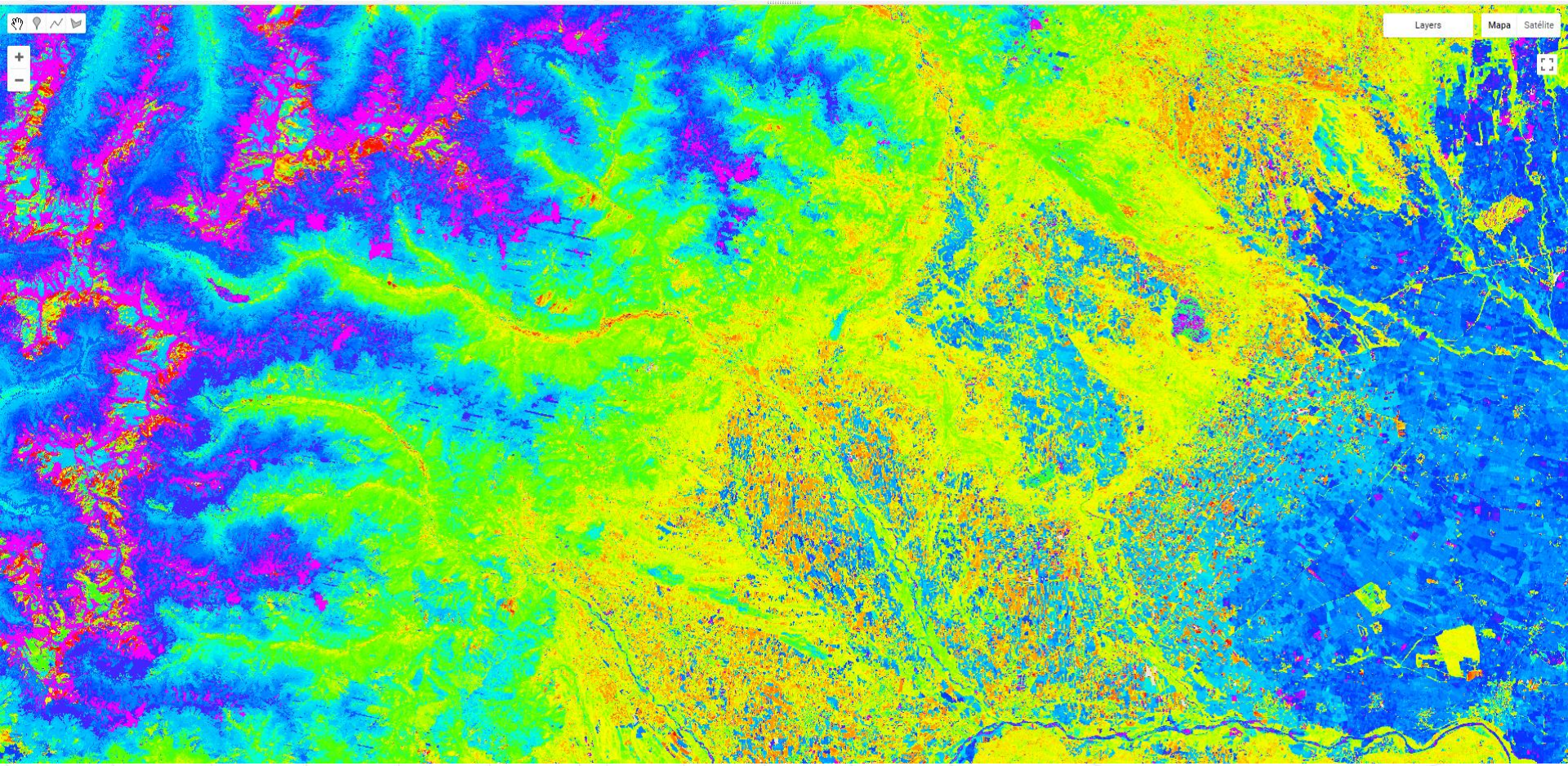

5km

SoS 2017 **S2 and L7-8 10m**

Start of Season (day of year)
30 75 180

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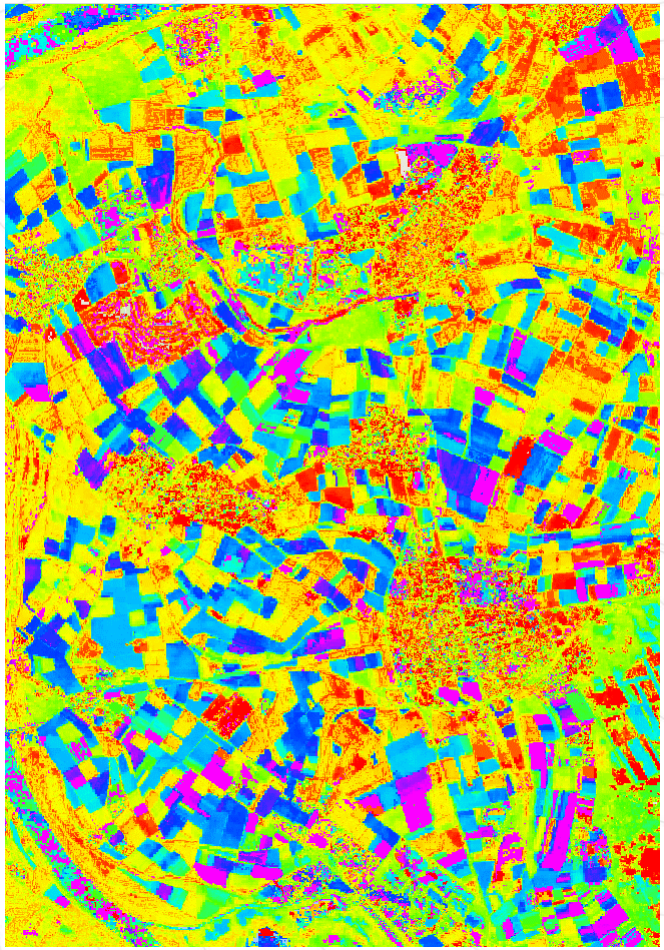
Worms (Germany)



SoS 2017 S2 & L7-8 (10m)

1km

Descals et al. 2020, Remote Sensing

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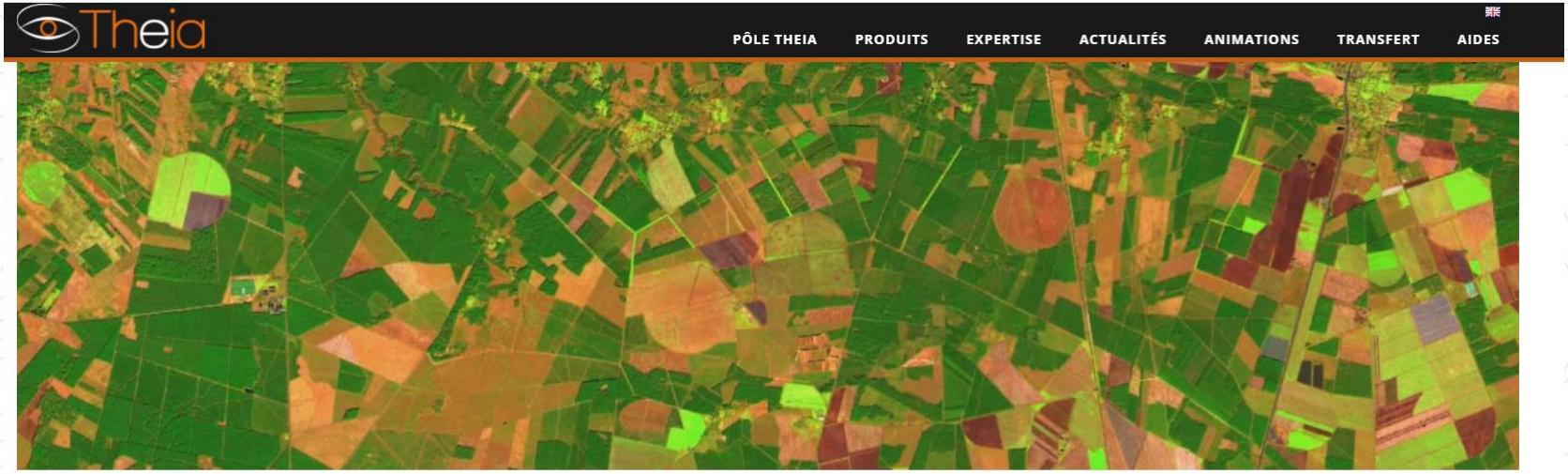
CES Biophysical Variables From S2



CES VARIABLES BIOPHYSIQUES VÉGÉTATION

#CENTRE D'EXPERTISE SCIENTIFIQUE #CES EN PROTOTYPAGE

CES EN PROTOTYPAGE

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INRAE | Capte

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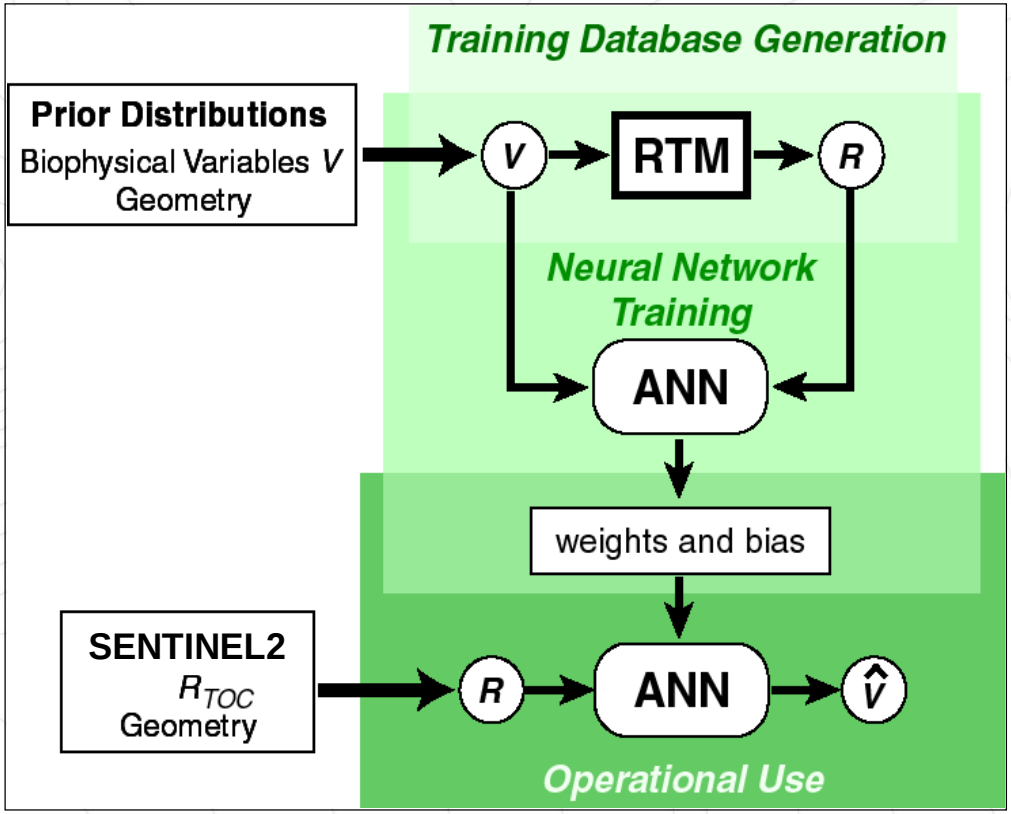
ART GEODEV Nouvelle Calédonie

CES Algorithm

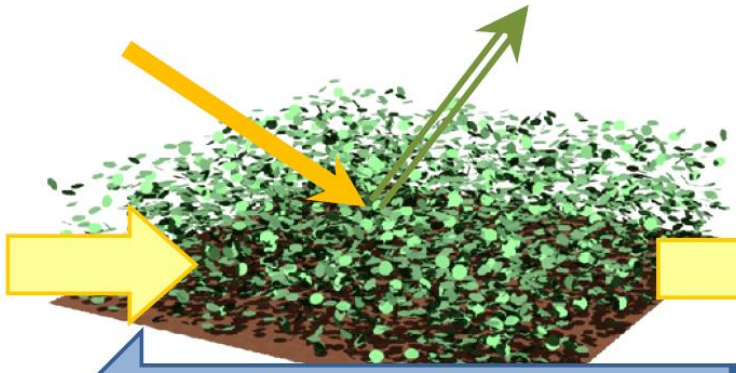


- **RTM= PROSAIL model**
  1D – Turbid medium
- **Inputs (20m)**
  Reflectances + geometry (cosine)

Acronym	Central (nm)	Width (nm)	Spatial resolution (m)
B3	560	35	10
B4	665	30	10
B5	705	15	20
B6	740	15	20
B7	783	20	20
B8a	865	20	20
B11	1610	90	20
B12	2190	180	20

- Biophysical Variables: GAI, fAPAR, fCover
  Canopy Chlorophyll Content, Canopy Water Content

Radiative Transfer Model

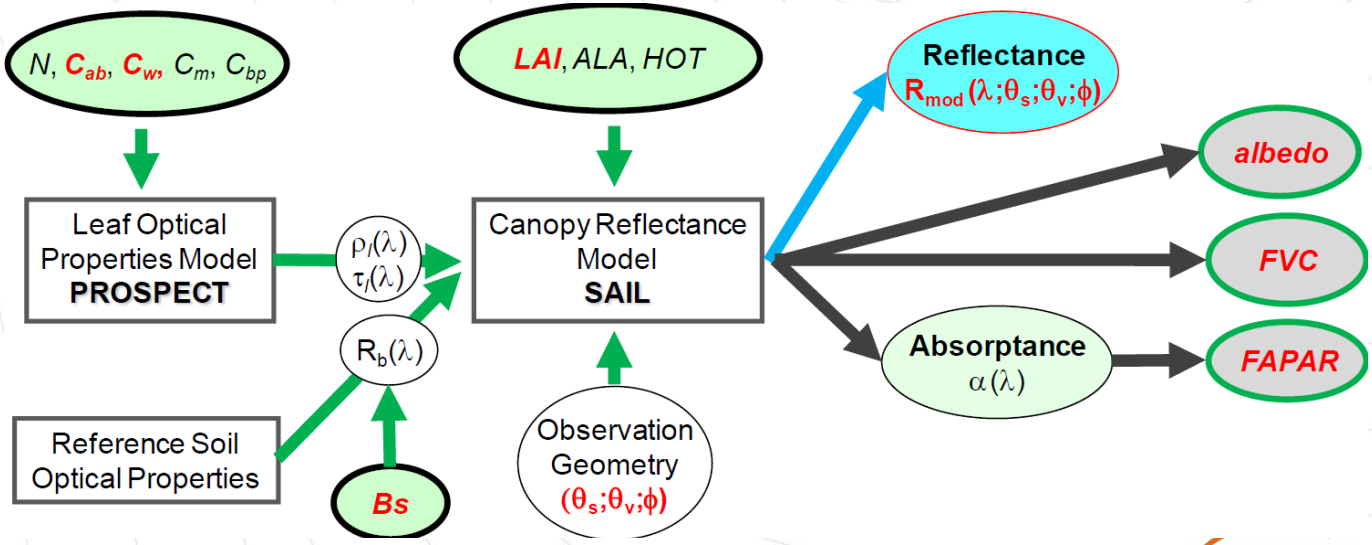


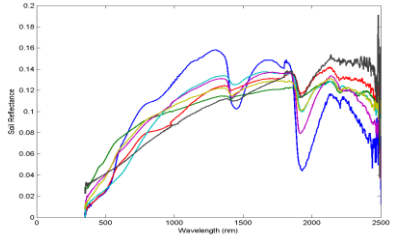
Source:
http://fapar.jrc.ec.europa.eu/WWW/Data/Pages/FAPAR_Software/Images/semi-discrete.gif

Canopy description

Reflectance

Retrieval Method





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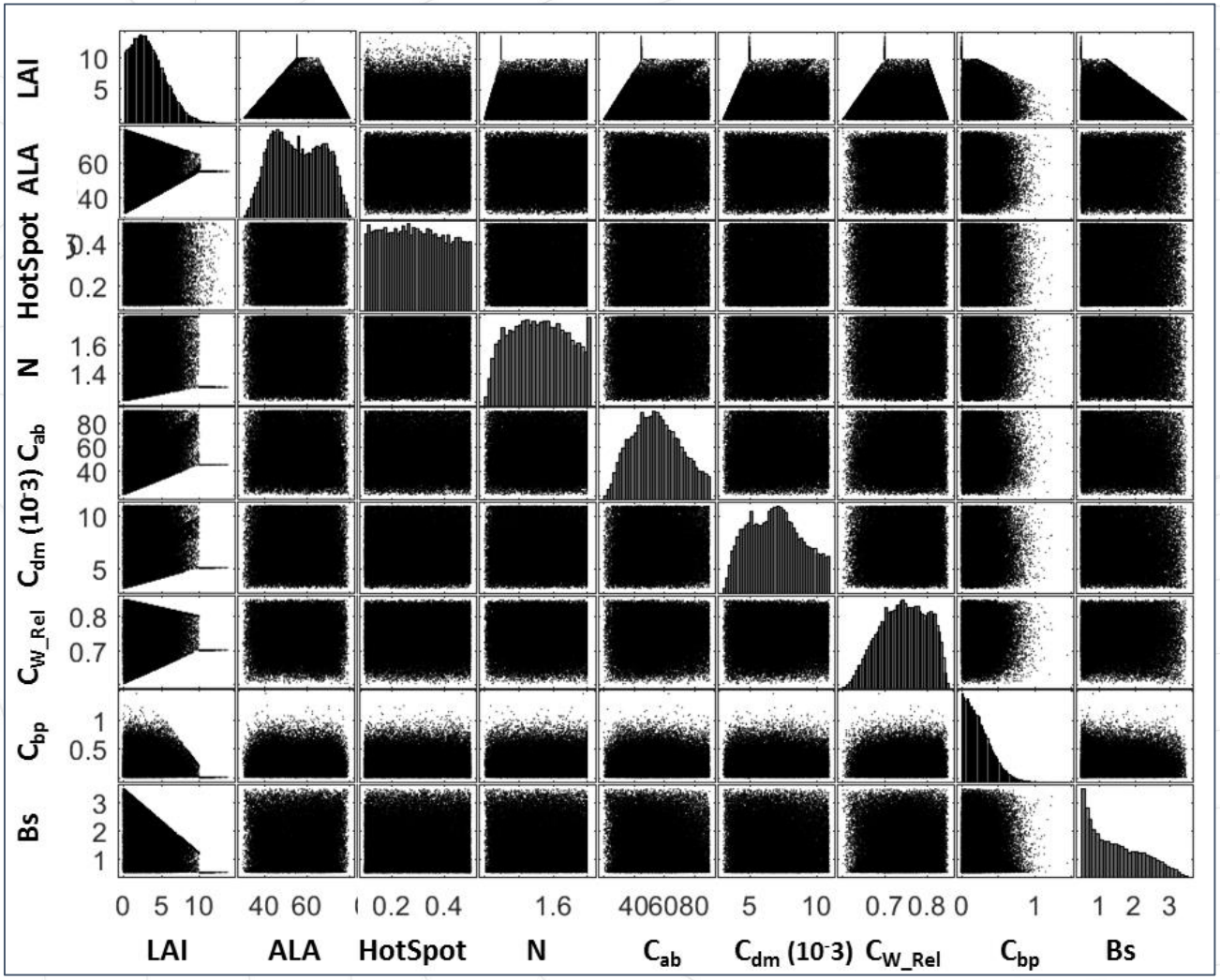
Optimizing the Training Dataset

- Distribution of variables
  - Prior Distributions & Co



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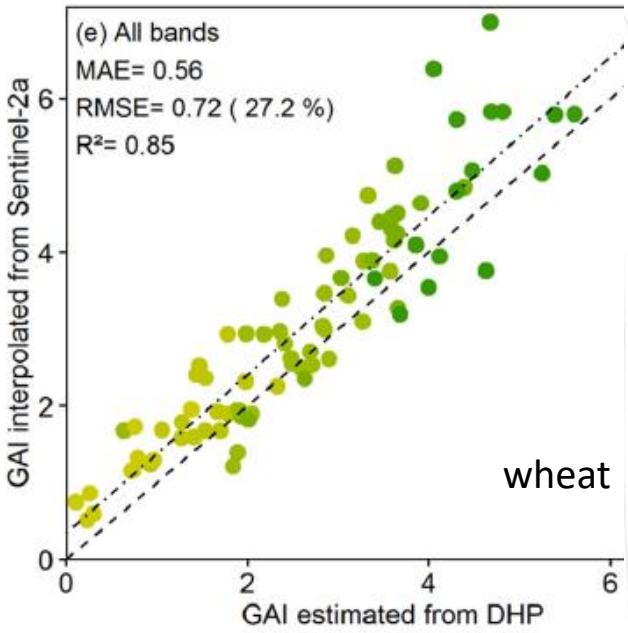
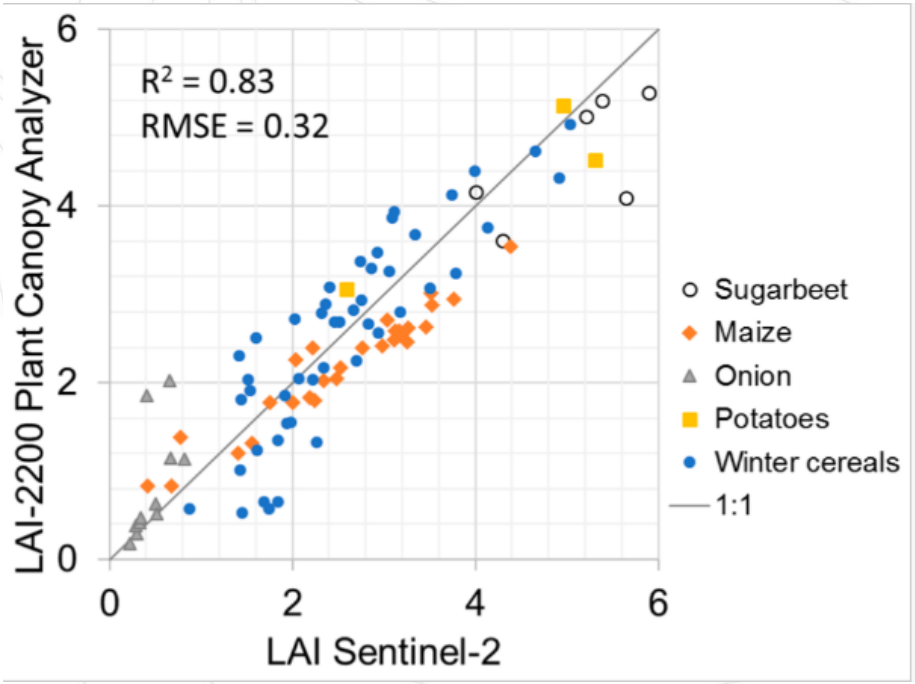
Accuracy assessment: comparison with ground measurements



From Delloye et al, RSE, 2018



From Vuolo et al, RS, 2016

Conclusions

- **ECVs LAI & fAPAR (and fCOVER)**
  - Time series (1981 - present) with 10-day frequency at the global scale
  - Validated, associated with QA and quality uncertainties
  - Freely available
- **1km V2 CGLS**
  - Improved continuity, smoothness and near real time projection vs 1km V1
- **300m V1 CGLS**
  - Improved spatial resolution
- **Importance of validation/calibration activities**
  - Quantification of accuracy of estimates
  - - x - = + fusing products, ensemble estimation
- **Importance of temporal compositing**
  - Adaptive length of compositing window
  - Outlier rejection
  - Use of climatology as background for gap filling and short term projection
- **Same principles for the generation of AVHRR LAI/fAPAR products within THEIA**
  - Continuous and consistent long time series over the last 40 years
- **Continuity of products with S3 and next missions**
  - Need overlap period between sensors!! (at least one year)
- **Long, consistent and continuous time series for documenting anomalies and trends in global change**
- **Near real time estimates**
  - Operational users
  - Decision makers
- **Importance of decametric missions (S2) for agriculture and natural resources management**
- **20m CES LAI, FAPAR, FCOVER, CCC, CWC**