E-AGRI – Workshop, Rabat 12-14 October 2011
Crop Yield Forecasting based on Remote Sensing

Low resolution remote sensing data for crop yield assessment in the E-AGRI study areas of Morocco and HuaiBei-China

Herman Eerens, VITO-Belgium

A. INTRODUCTION
1. VITO-TAP & MARSOP-project
2. Sensors & PRE-processing
3. POST-Processing & Products
4. SPIRITS software

B. VGT-DATA FOR E-AGRI
1. HuaiBei
2. Morocco

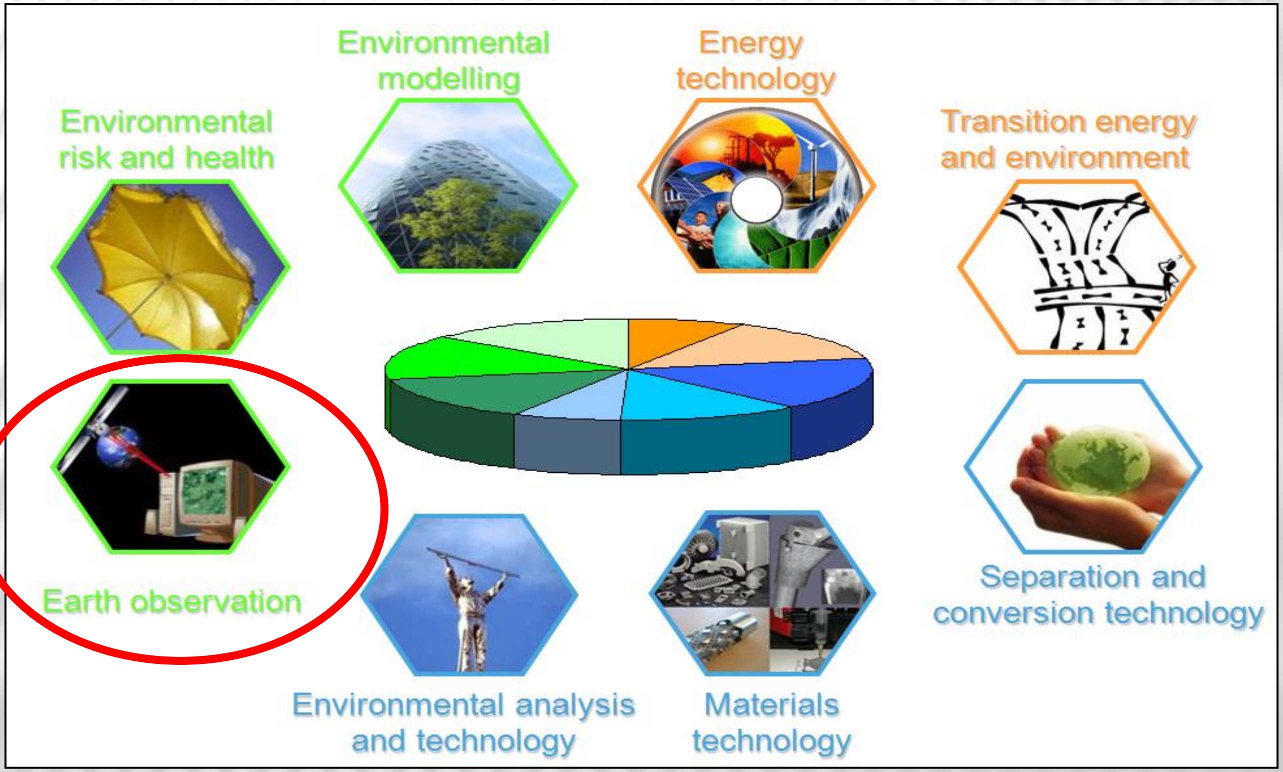
C. SIMILARITY ANALYSIS for MOROCCO

D. CONCLUSIONS

VITO: Vlaamse Instelling voor Technologisch Onderzoek
Flemish Institute for Technological Research

Research Institute of Flemish Government (Flanders = Northern Region of Belgium)

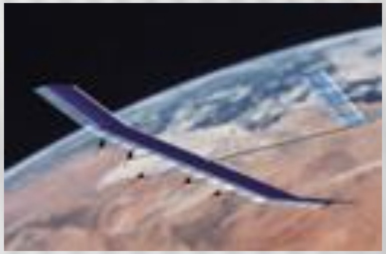
- 600 staff members
- 90 M€ revenue in 2010: 40% from government(s), 60% own projects
- 8 "Centres of Expertise" dealing with new materials, environmental issues, …, RS



VITO: Vlaamse Instelling voor Technologisch Onderzoek
Flemish Institute for Technological Research

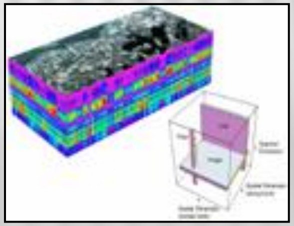
TAP: Centre for Earth Observation

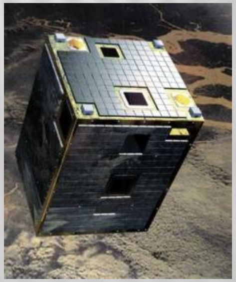
- 70 staff members
- 20 M€ revenue in 2010: 20% from VITO, 80% own projects
- Units:
  - CTIV = SPOT-VEGETATION processing/archiving unit
  - ***Global vegetation unit***
  - Aerial photography
  - Local hyperspectral applications (CASI, APEX, ...)
  - UAV: Unmanned Aerial Vehicles
  - Camera design: Medusa (UAV), APEX,…
  - Proba-V: follow-up of SPOT-VGT



Global Vegetation Unit

- 14 staff members
- Estimation / mapping of Crop Areas and Yields
  at Regional to Global scales
- Major projects:
  MARSOP, GMFS, Geoland2, DevCoCast,..., E-AGRI





MARSOP-Contracts since 2000

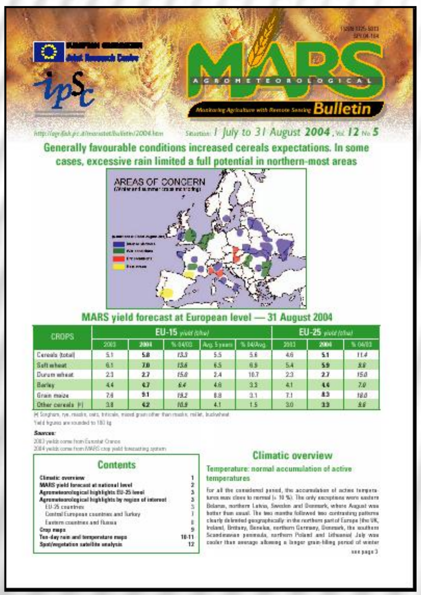
METEOCONSULT
Daily MeteoData

ALTERRA
CGMS-Results

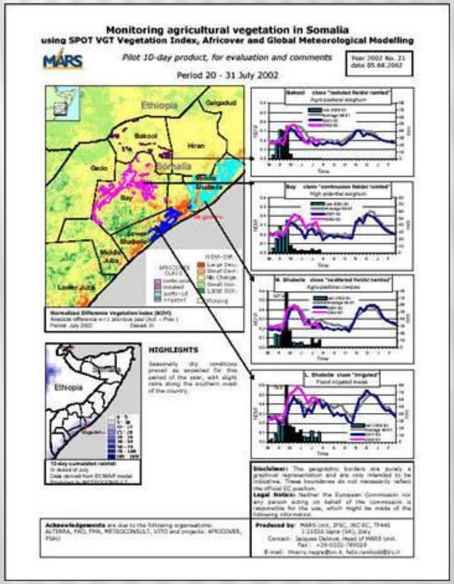
VITO
RS-Products

JRC-IES-MARS (Monitoring Agricultural ResourceS)

Agri4Cast *FoodSec*



Website & DB-Viewers
http://www.marsop.info



DG-AGRI *Scientific users* *DG-AIDCO/RELEX*

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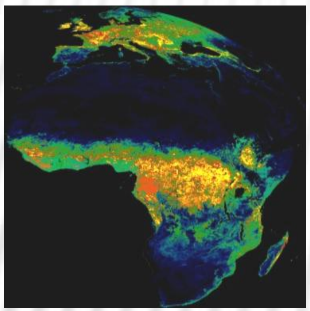
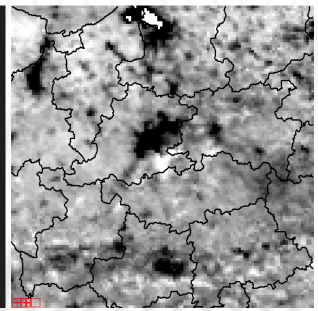
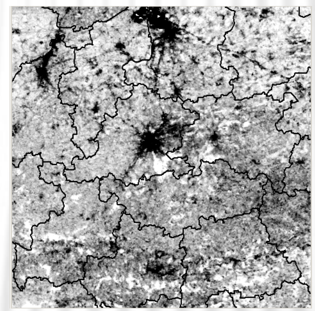
Types of RS-images used in MARSOP

RESOLUTION	Very Low	Low	Medium	High	Very High
Pixel size	3-5km	± 1 km	250-500m	20-30m	1-5m
Frequency	15’	± 1 day	± 2 days	2-3 weeks	on demand
Image size	10 000km	± 3000km	± 1500km	60-200km	10-20km
Examples	MSG GOES	SPOT-VGT AVHRR	MODIS MERIS-FR	SPOT-HR, Landsat	IKONOS, Quickbird


MSG (3 km)


VGT (1 km)


MODIS (250 m)


Landsat (30m)


IKONOS (4m)

SENSOR	Since	GLOBAL	EUROPE	OTHER
SPOT-VGT	1998	X	X	6 ROIs
NOAA-AVHRR	1981		X	
METOP-AVHRR	2007	X	X	
MODIS-250m	2000		X	IGAD
MSG-SEVIRI	2005		X	Africa

Huaibei covered by SPOT/METOP, Kenya also by MODIS, Morocco by all

PRE-Processing ⇔ POST-Processing

SATELLITE

INGEST (FTP, Eumetcast)

RAW DATA
(segments)

Corrections→ Composit

LINUX/C++/AppWorx

- Calibration
- Geo-correction
- Atmo-correction
- Cloud/snow detection
- S10-compositing

Walter Heyns
Bart Ooms

CONTINENTAL/GLOBAL S10-COMPOSITES

JRC, Alterra, …

DISSEMINATE

INFORMATION
(IMG, QLK, RUM)

All further operations …

Windows/GLIMPSE/BAT

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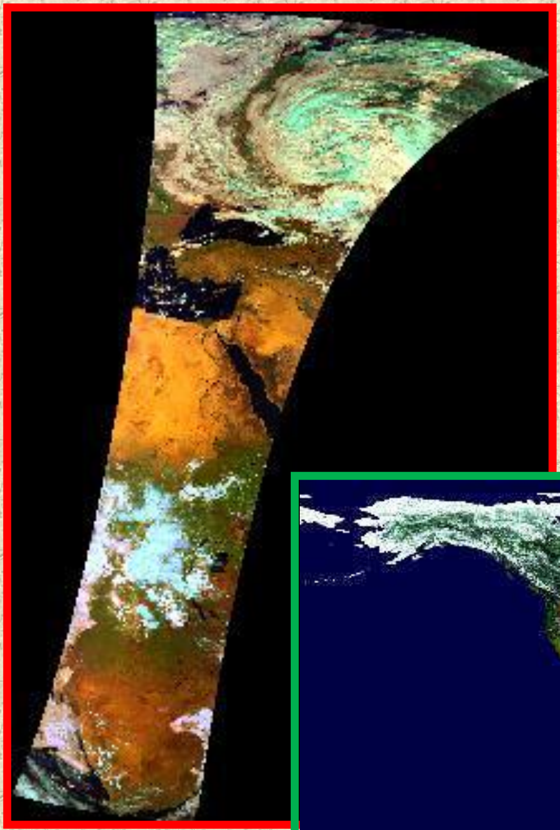
Dominique Haesen

SPOT-VGT: 1km, since 1998, PRE-processing by VITO-CTIV



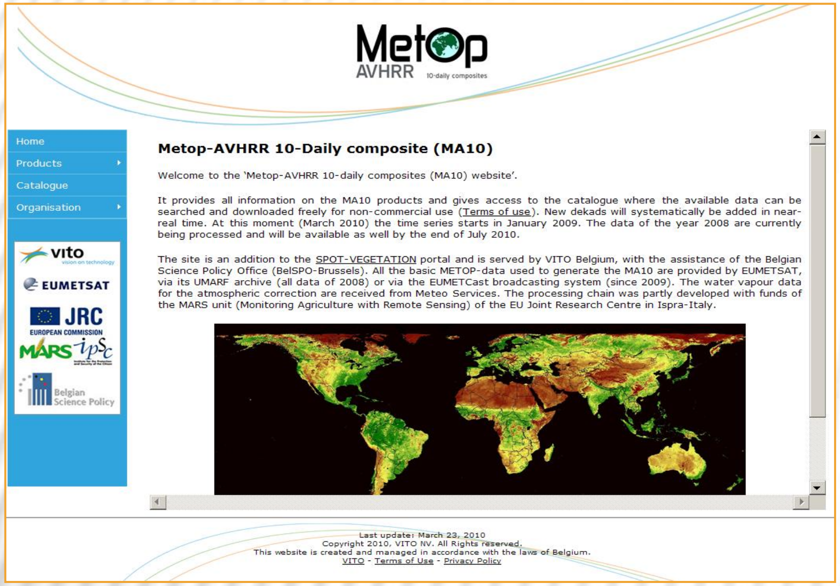
P-product ("Segment")
= Corrected Individual registrations

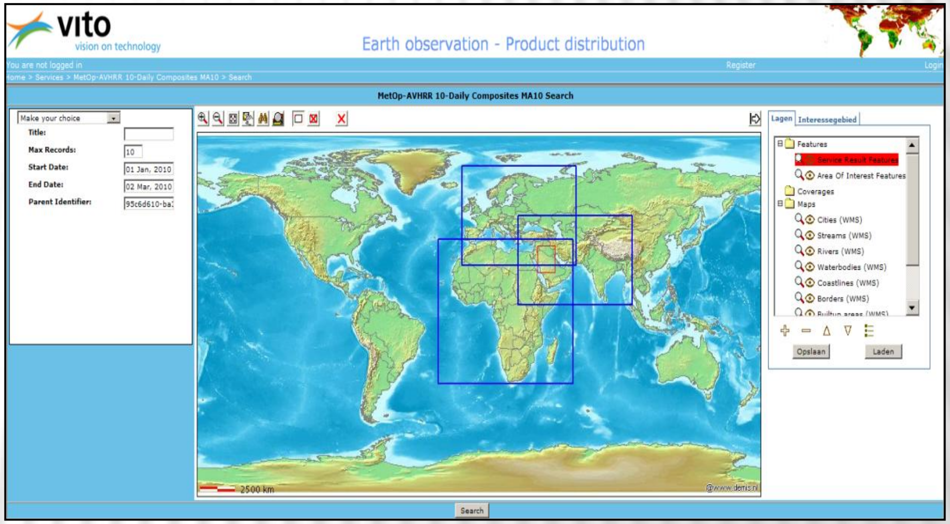
S10-product (10-Daily Synthesis/Composite)
Global, per pixel the best-available observation

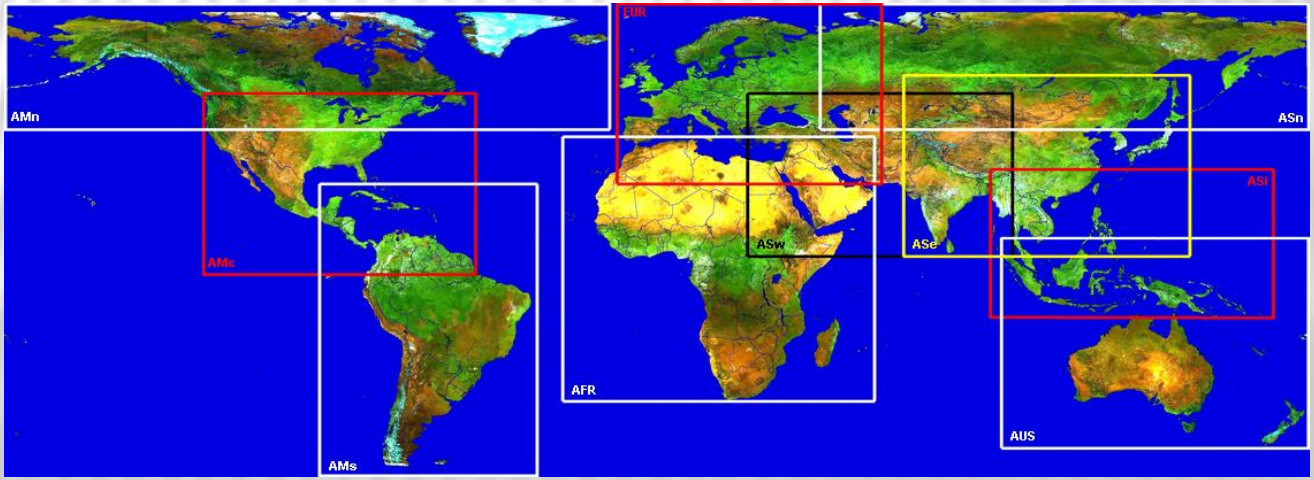
VGT-S10: - Geographic Lon/Lat at 1°/112 resolution (± 1 km along equator/meridians)
- 11 "layers": reflectances, NDVI, angles, status map, registration date
- Available after 1-2 days ⇒ **Purchased from CTIV for MARSOP**

METOP-AVHRR: 1km, since 2007, global archive in compressed form

Website & Data portal
http://www.metopS10.vito.be

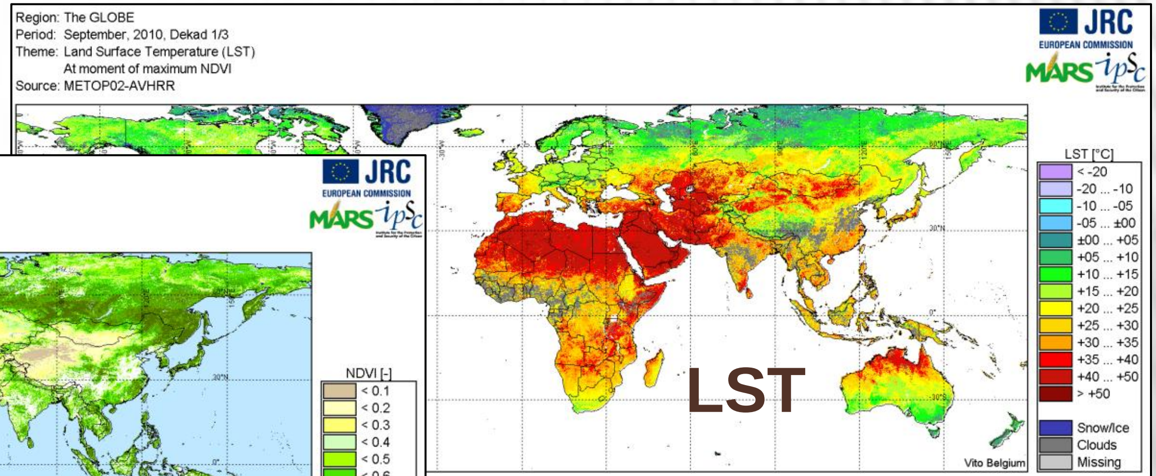


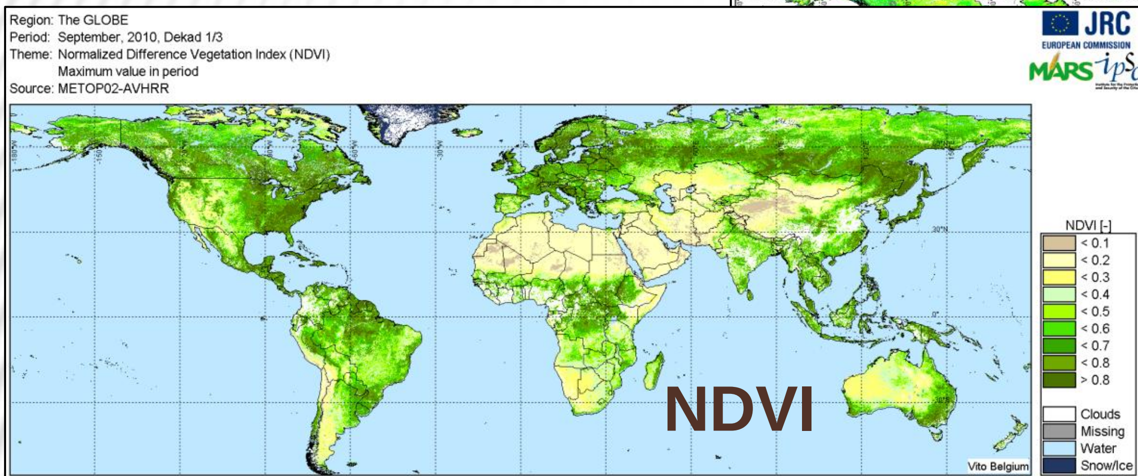


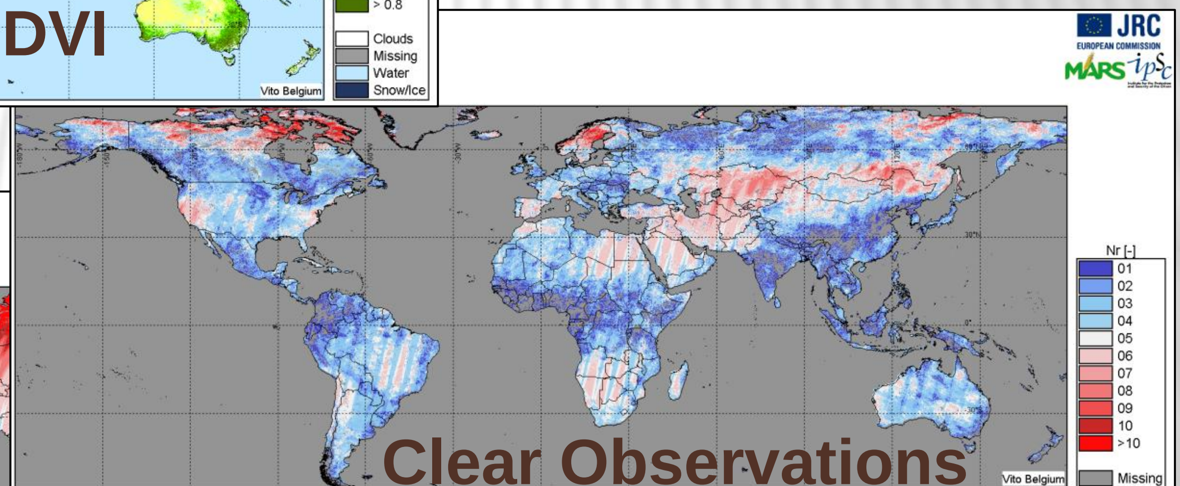


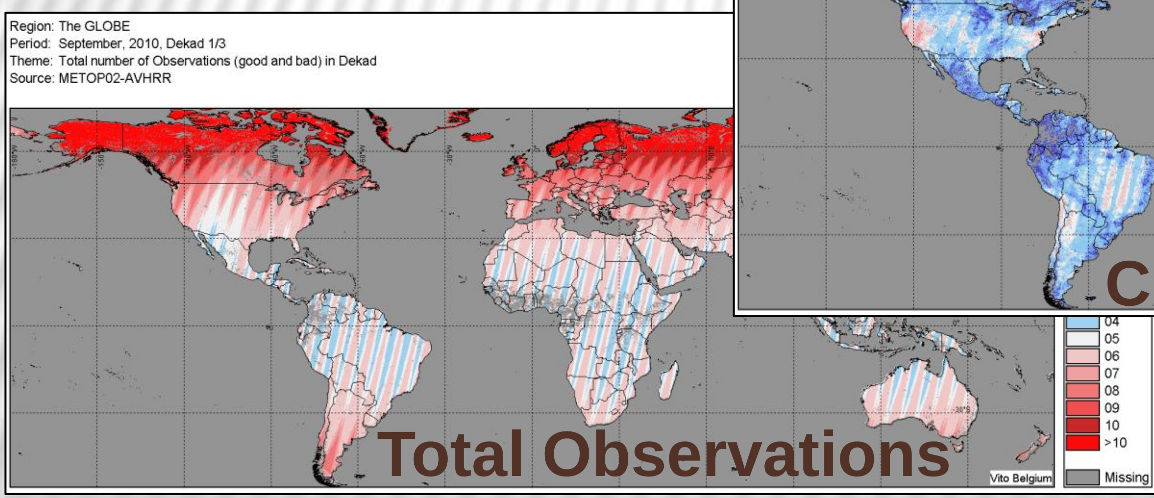
METOP-AVHRR: 1km, since 2007, global archive in compressed form

September 2010 Dekad 1







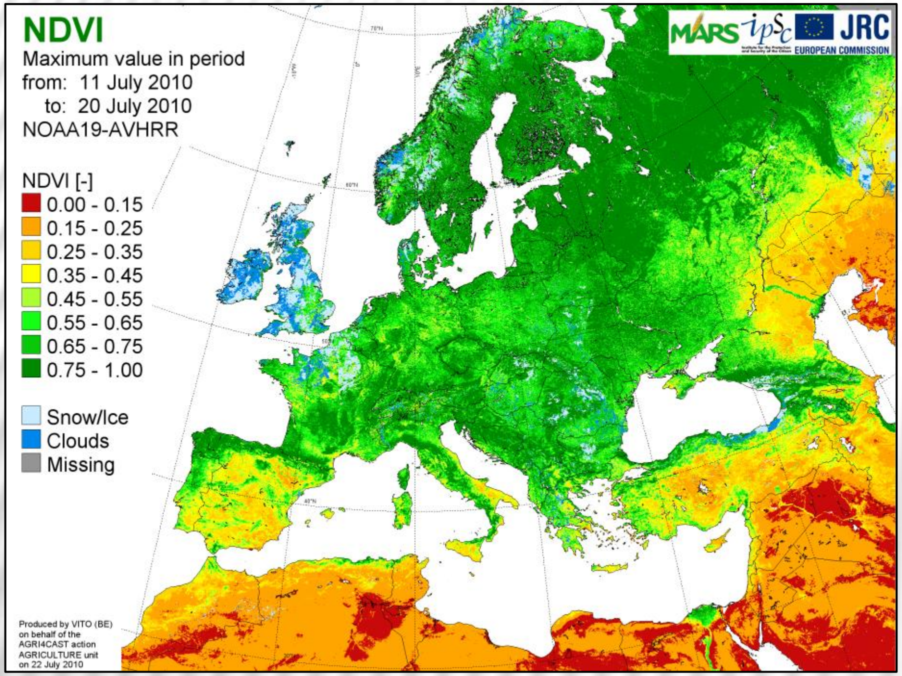


NOAA-AVHRR ⇔ METOP-AVHRR

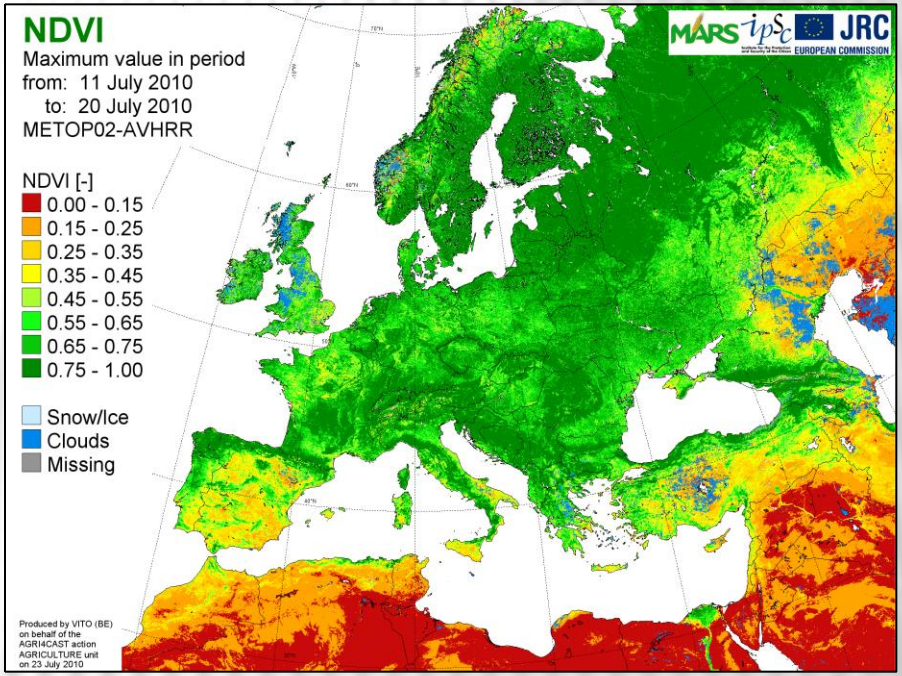
NDVI-S10 for Dekad 1 of September 2008

Remapped to INSPIRE-LAEA (1km)

NOAA-AVHRR (noon)



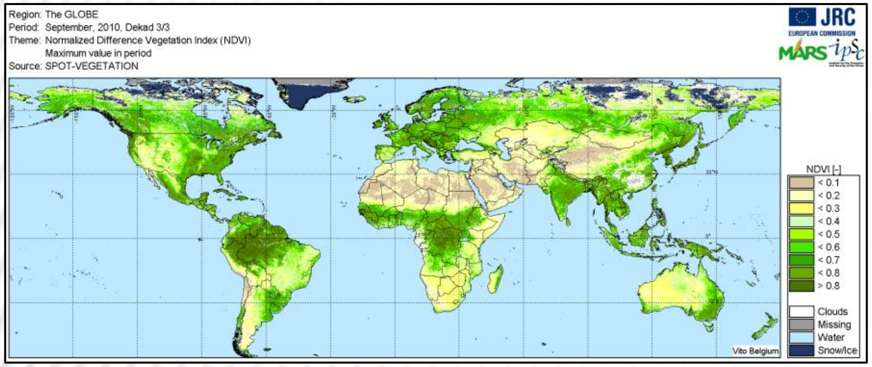
METOP-AVHRR (morning)

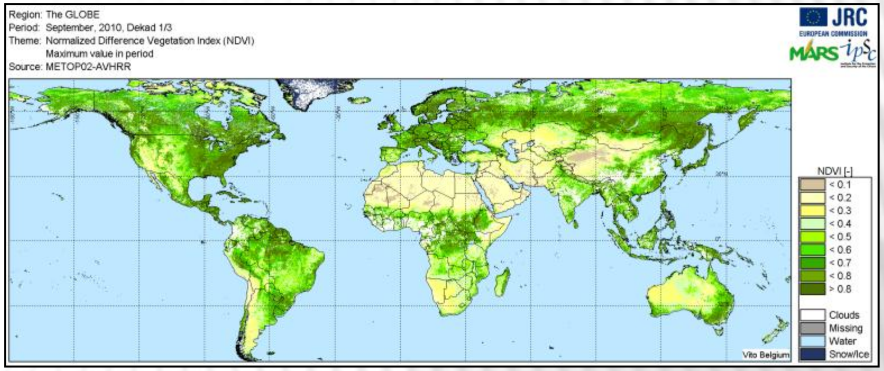


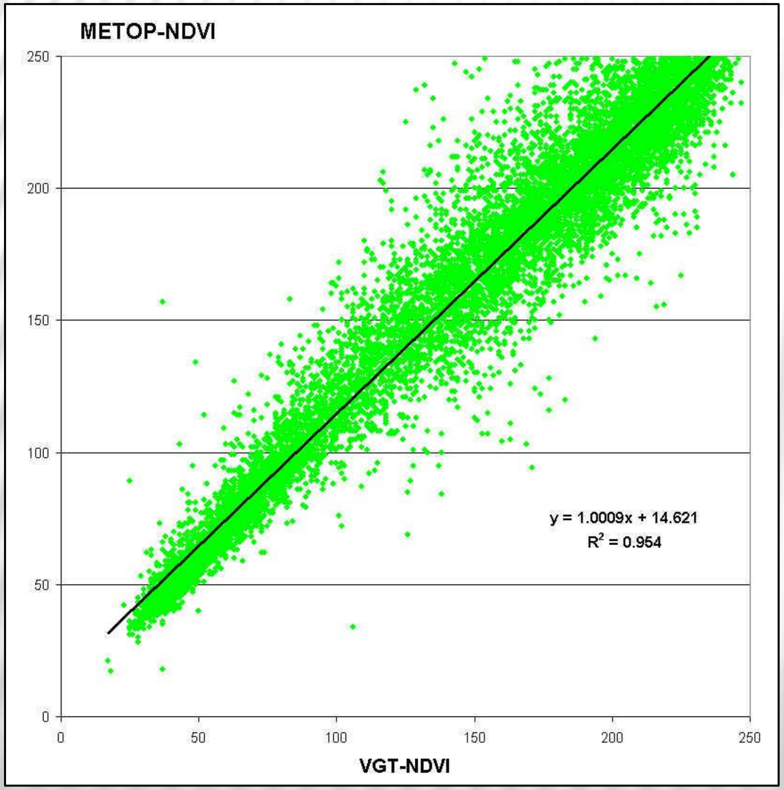
MARSOP:

- *Archive of NOAA-AVHRR over Europe since 1981*
- *But METOP-AVHRR (since 2007) is better*

SPOT-VGT ⇔ METOP-AVHRR







Method

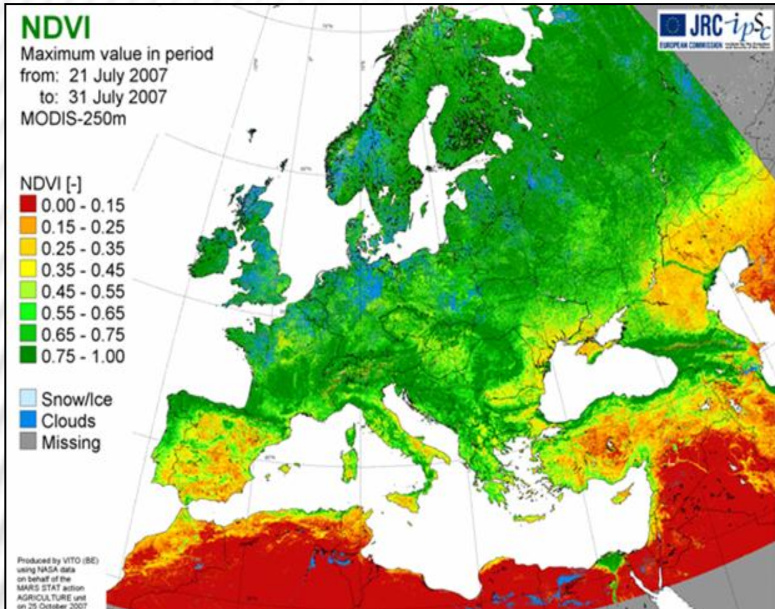
- Samples from paired observations
- From 12 global S10 of year 2009/2010
- Both cloudfree
- Both of same registration day !
- R^2 = 95%
- No improvement “per land cover class”

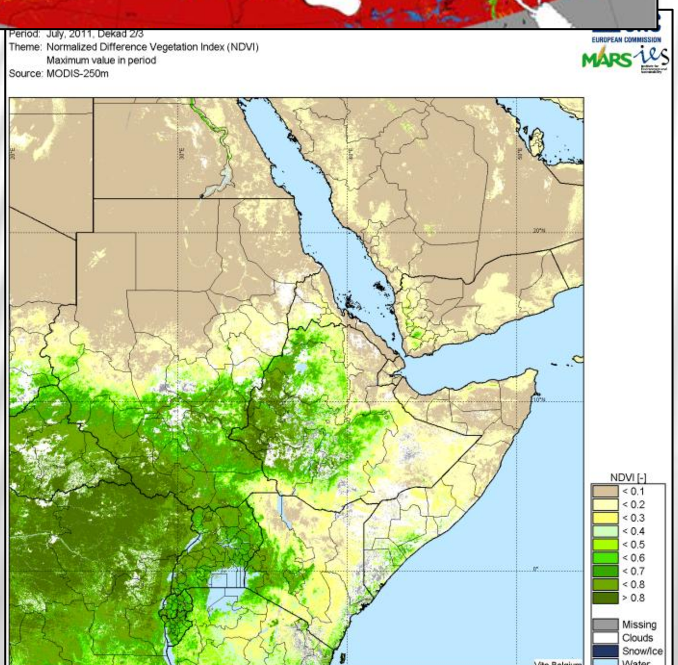
Residuals due to:

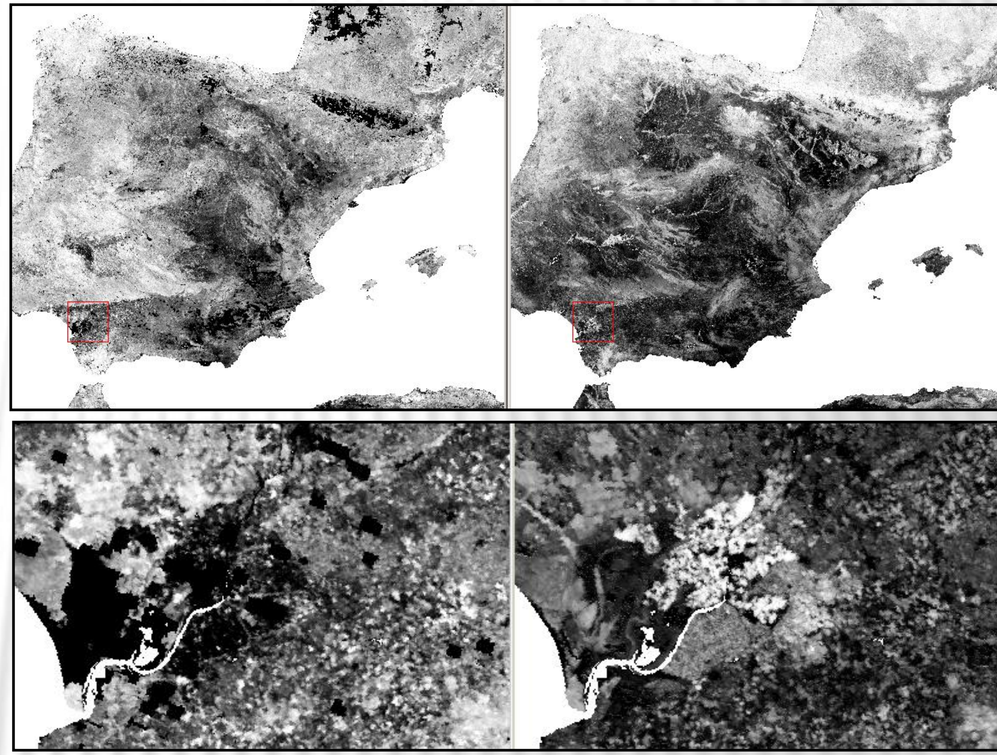
- METOP 1h earlier than VGT
- Different geometries
- Different spectral response
- Etc.

Conclusion: if SPOT-VGT fails, METOP is directly available alternative !

TERRA-MODIS: 250m, since 2000, Europe & IGAD







January 2007 July 2007

MSG-SEVIRI: since 2005, Europe (5km) & Africa (4km)

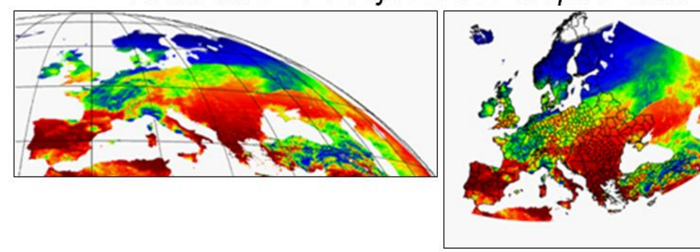
Geostationary MSG
Registration
↓
EUMETSAT (GE)
Pre-processing
↓
LAND SAF (PT)
Derived land products
↓
VITO (BE)
Remap, 1/10-daily images
↓
JRC-MARS (IT)
Crop monitoring

Basic chain at VITO (AseMARS 2005)

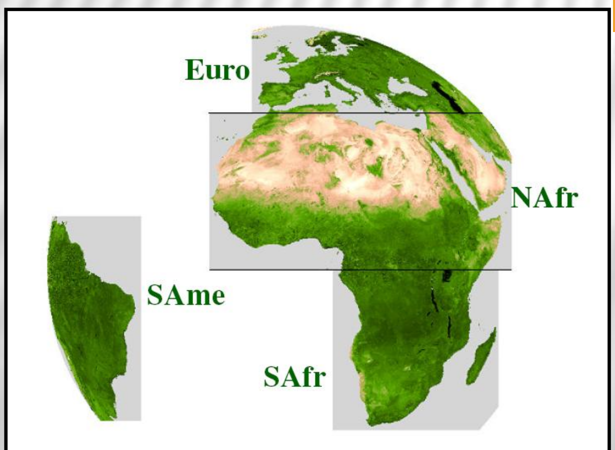
Land SAF (IM)
↓ *sFTP*
HDF-5
↓ *Reformat*
ENVI-IMG's
↓ *Snow, Albedo LAI, fAPAR fCover* / *Composit: LST, Radiation, ET*
Daily IMG's
↓ *Map: AF4 (Lon/Lat) EU5 (Inspire)*
Daily IMG's → **DATABASE**
↓ *Composit*
10-Daily IMG's → *Extract* → **DATABASE**

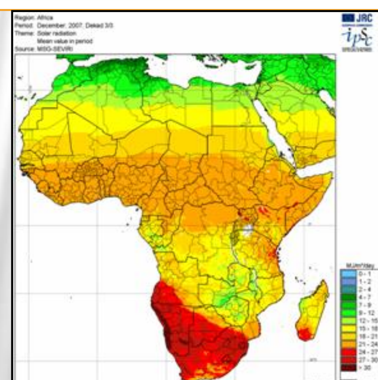
Daily Composits:
- Radiation, LST, ET
- D0 6hUTC → D1 6hUTC
- LST→T_{min}, T_{mean}, T_{max}
- Sunshine duration: from cloud mask

RAW IMG → Projected to Inspire 5km

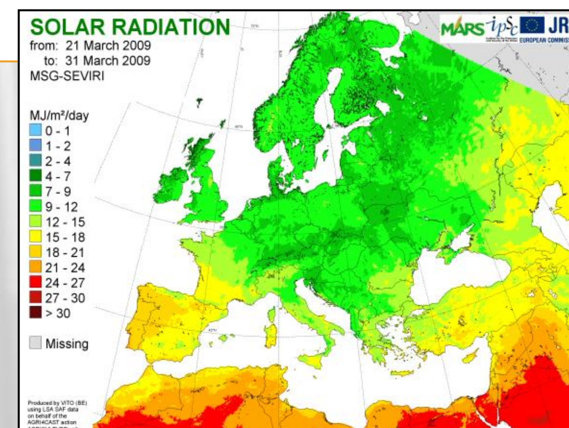


Four zones of LSA SAF



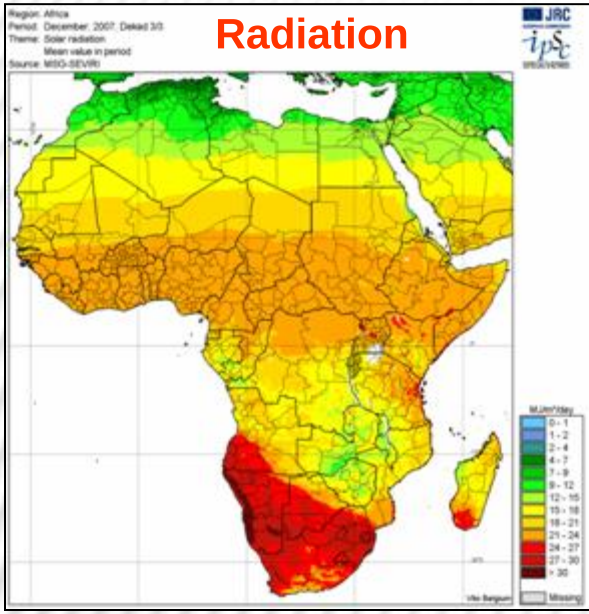


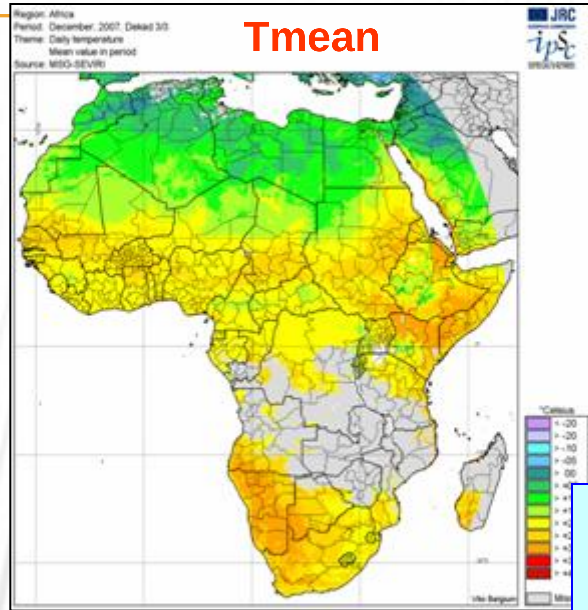
AF4: Africa at 4 km

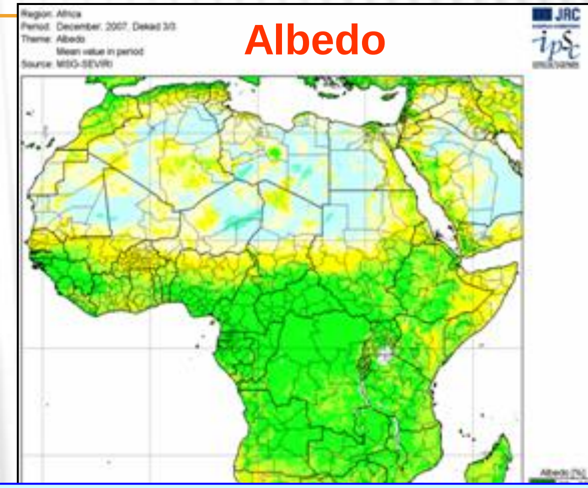


EU5: Europe at 5 km

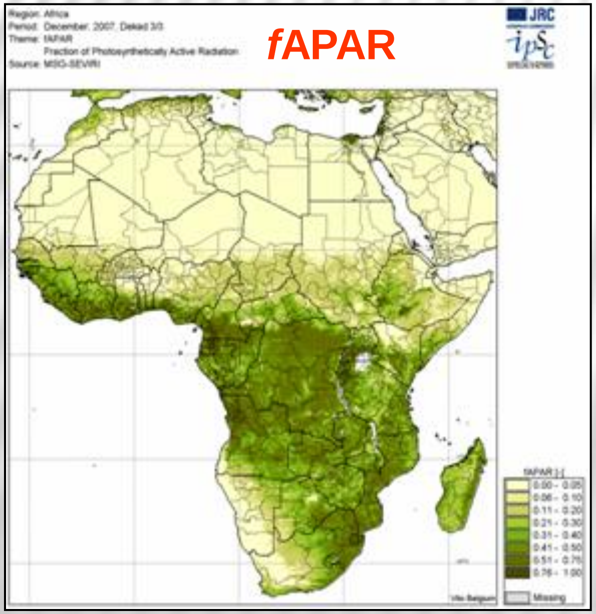
MSG-SEVIRI: since 2005, Europe (5km) & Africa (4km)

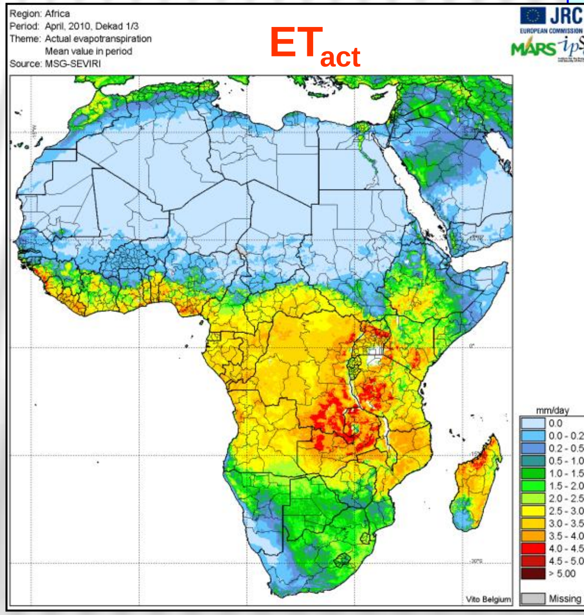


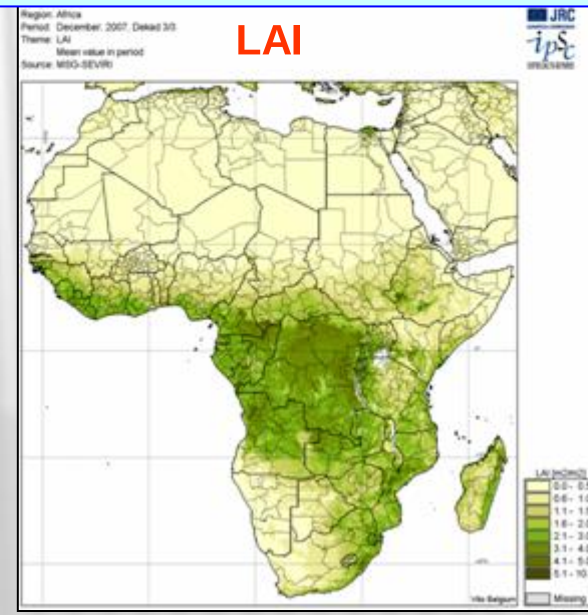




Examples for
2007, December, Dekad 3







METEO-data

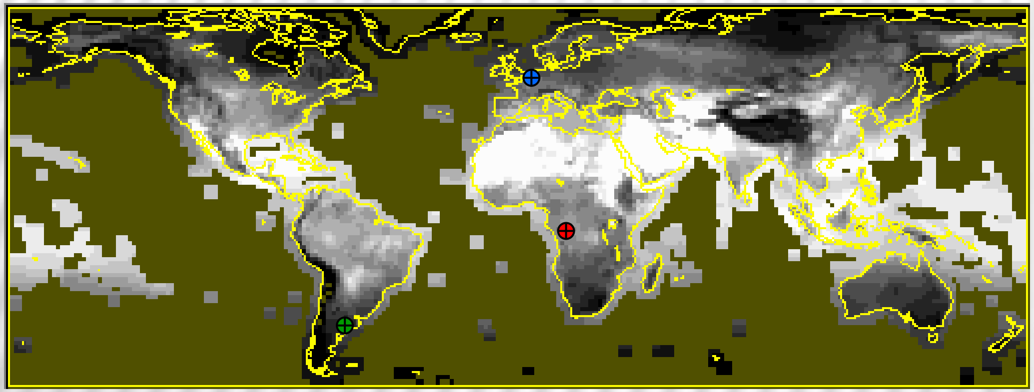
A. Gridded data for correction of SAT-IMGs → PRE-processing

- Global total water vapour (every 6h) from ECMWF 1.0°
- Climatologies for ozone, aerosols

B. Gridded daily AGROMET-data → POST-processing

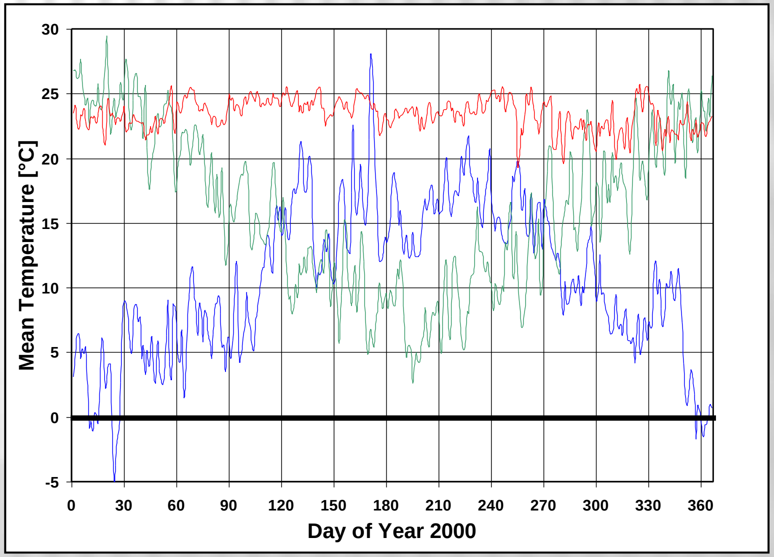
- T_{min}, T_{max}, radiation, ET, precipitation, …
- Global from MeteoConsult (source=ECMWF) 0.25°
- Europe from CGMS/Alterra (source=station data) 25 km

Daily, global Data, interpolated to grid of 0.25°-resolution (ECMWF)



1 July 2000: Mean Daily Temperature [°C]

Brussels	(51°N, 4.5°E)
Buenos Aires	(36°S, 60°W)
Kinshasa	(4.5°S, 15°E)



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INGEST (FTP, Eumetcast)

RAW DATA
(segments)

Corrections→ Composit
LINUX/C++/AppWorx

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DISSEMINATE

INFORMATION
(IMG, QLK, RUM)

All further operations …
Windows/GLIMPSE/BAT

2

Herman Eerens
Dominique Haesen

CONTINENTAL/GLOBAL S10-COMPOSITES

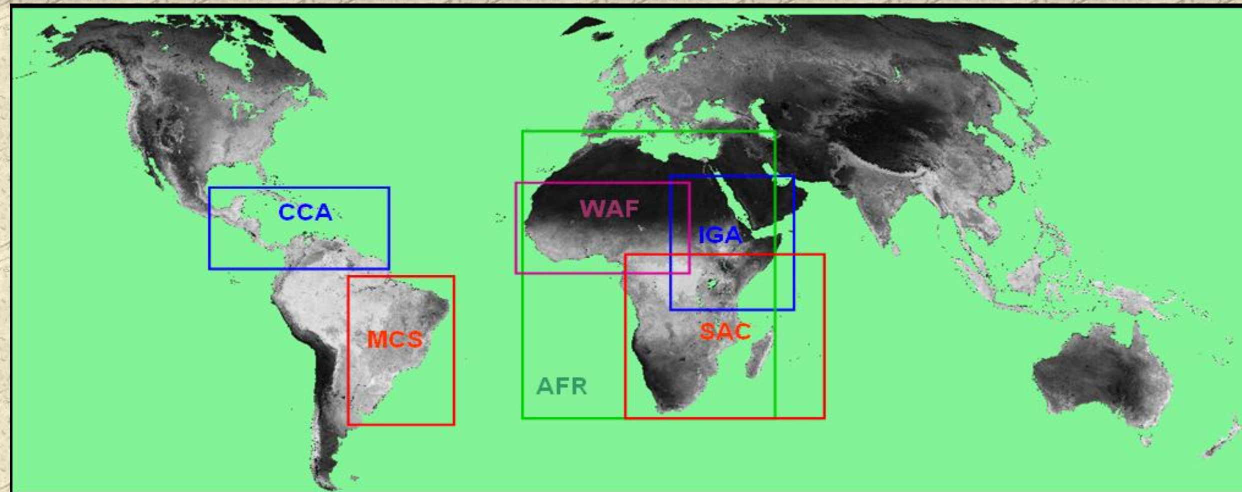
POST-processing operations – starting from the S10-composites

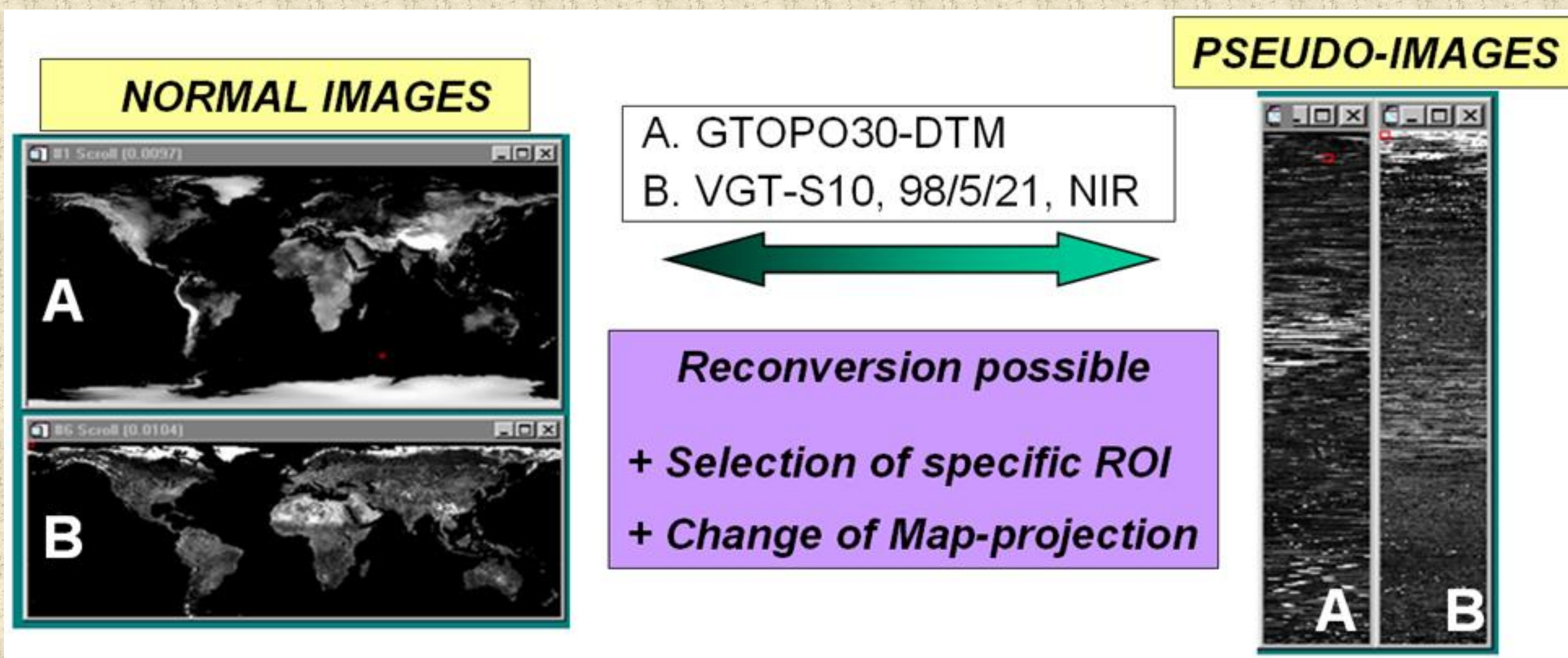
1. **Spatial operations**
   - Compression of global images to PI-format (Pseudo-Images)
   - Extract ROI from global imagery
   - Thinning (global VGT/METOP at 21 km)
   - Remap (e.g. all European data in INSPIRE-LAEA)
2. **Thematic operations: add S10-images with…**
   - LST (only for NOAA/METOP-AVHRR)
   - fAPAR (fraction absorbed radiation in 400-700 nm)
   - DMP = *f*(fAPAR, meteo) ~ Monteith-approach
3. **Time series operations - 1. Within a single year**
   - Monthly S30-composites
   - Cumulative values
   - Smoothing of time series
   - Phenology
   - ISO-clustering
4. **Time series operations - 2. Over the years**
   - Images with long-term statistics ("historical year")
   - Anomalies
   - Similarity analysis → See later!
5. **Extraction of RUM-databases (Regional Unmixed Means)**

POST-processing – Spatial operations for the global VGT/METOP

ROIs

- GPI: Global, 1km, PI
- GLD: Global, 21km, NI
- 1km NI: AFR, IGA, WAF, SAC, MCS, CCA



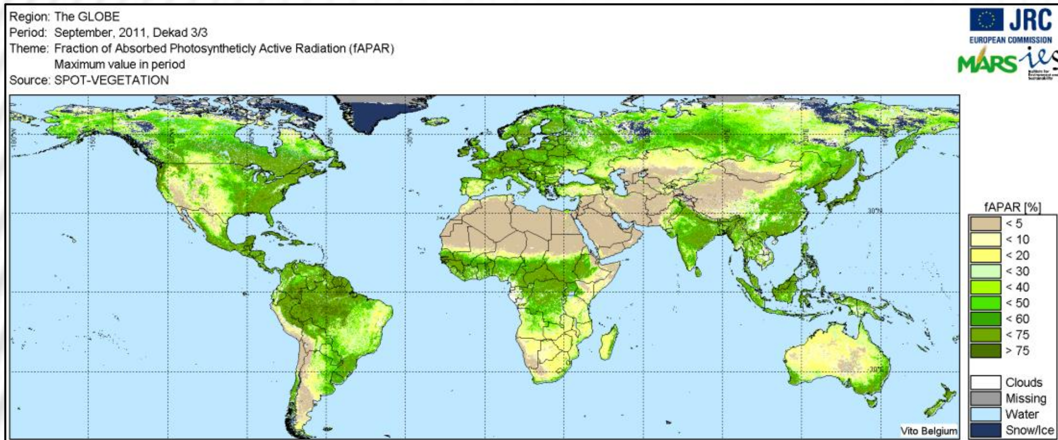


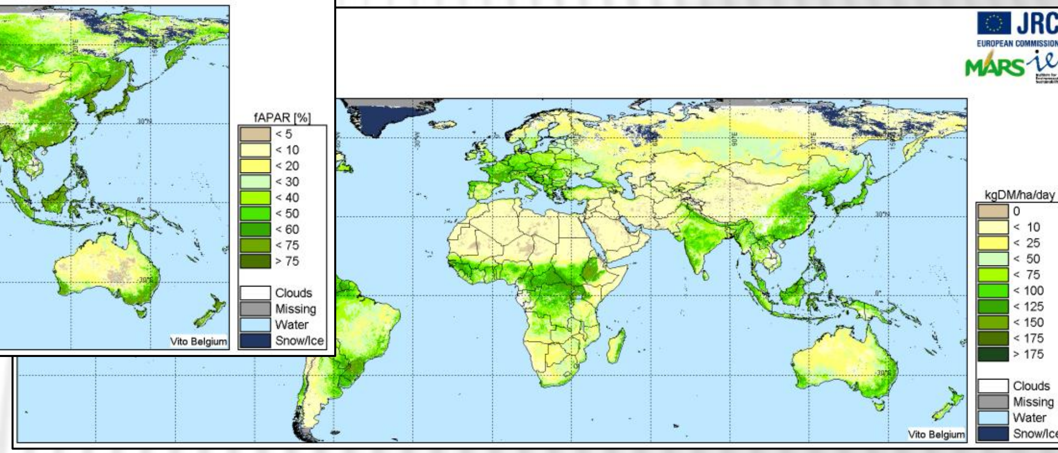
POST-processing – fAPAR & DMP

Fraction of absorbed PAR (400-700nm)

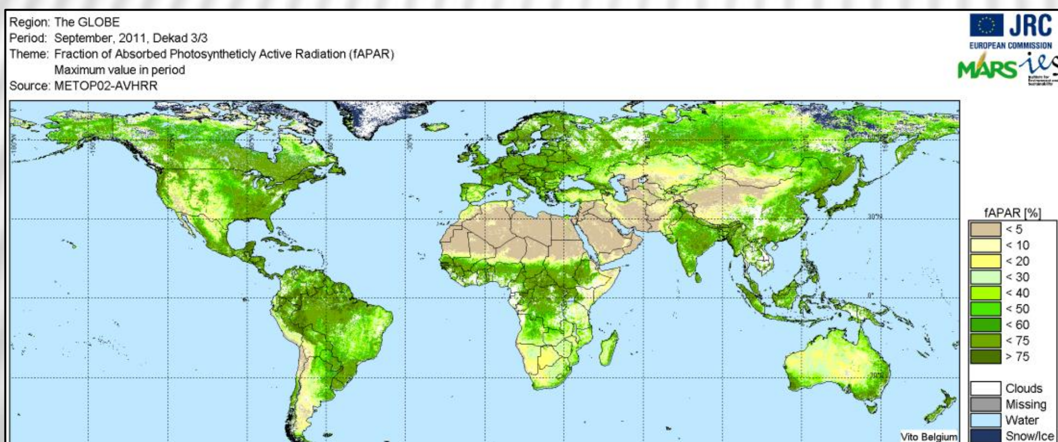
Dry Matter Productivity kgDM/ha/day

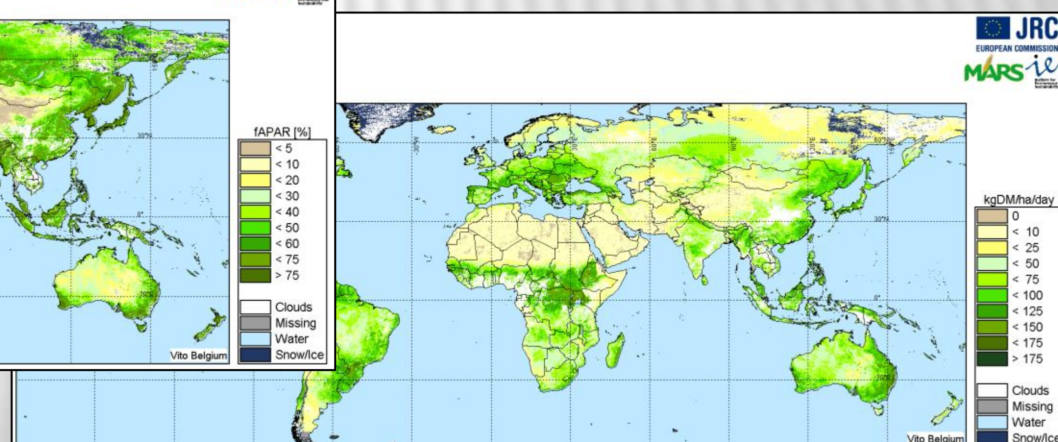
SPOT-VGT





METOP-AVHRR



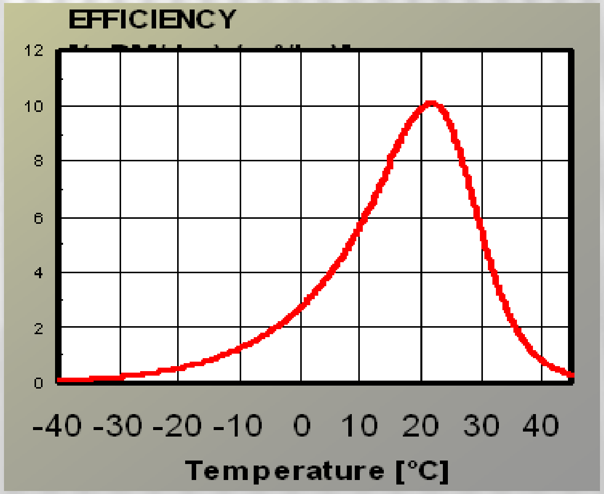


POST-processing – Dry Matter Productivity (DMP)

MONTEITH-Approach: $DMP = R \cdot 0.48 \cdot fAPAR \cdot \varepsilon\,(T_{min}/T_{max})$

Symbol	Meaning	Units	Source
DMP	Dry Matter Productivity	kgDM/ha/day	
R	Incoming solar radiation (0.2–4.0 µm)	J/ha/day	Meteo
0.48	Fraction of PAR (0.4–0.7µm) in R	–	
fAPAR	PAR-fraction absorbed by Vegetation	–	Remote Sensing
T_{min}/T_{max}	Daily min/max temperature	°C	Meteo
ε	Efficiency-term:	kgDM/J	

- conversion of absorbed PAR-Energy to carbohydrates $= f(T_{24})$
- autotrpohic maintenance respiration $= f(T_{12})$



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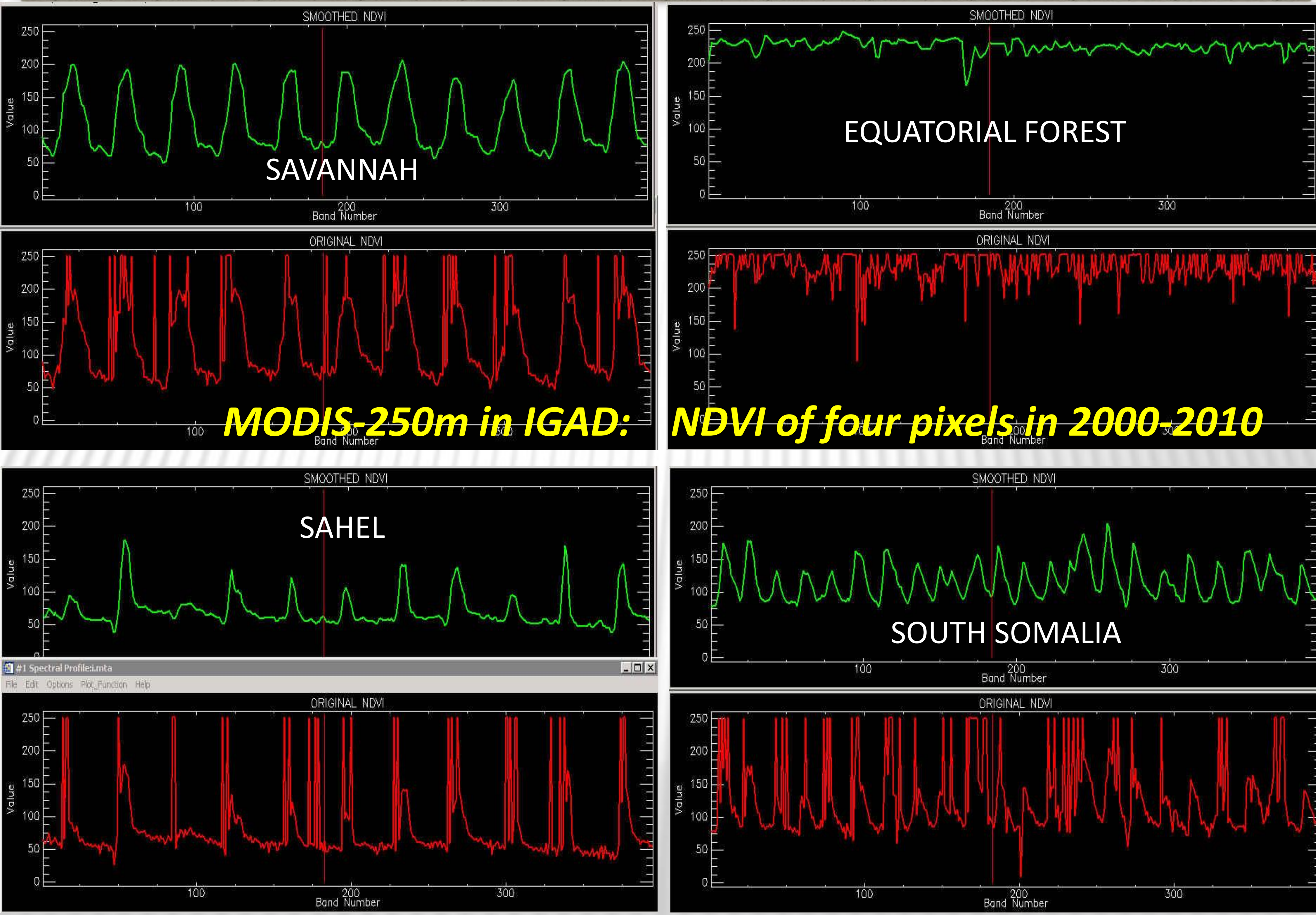
POST-processing – Smoothing of time series (NDVI, fAPAR,…)



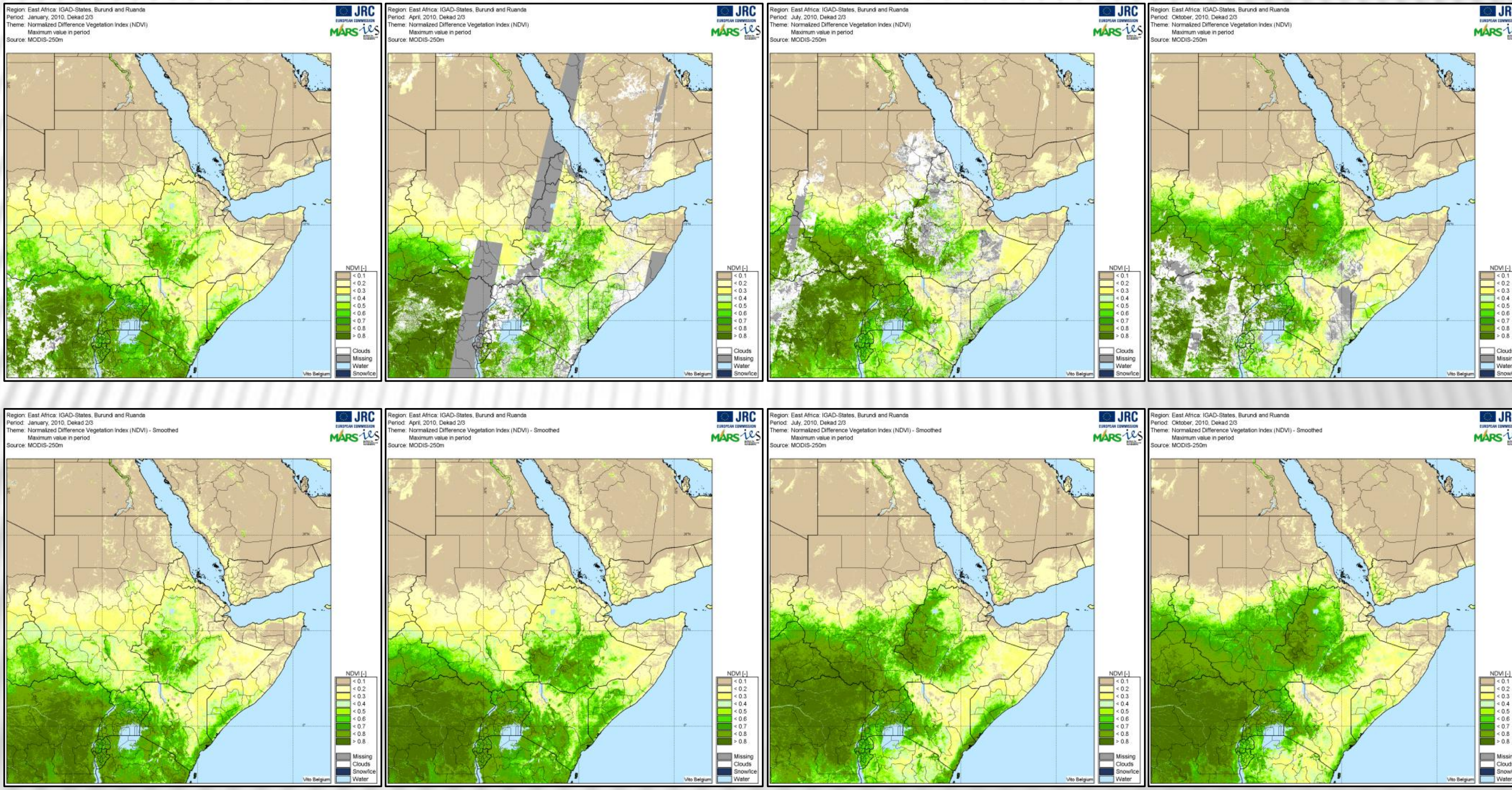
POST-processing – Smoothing of time series (NDVI, fAPAR,…)

MODIS-250m in IGAD: NDVI of four Dekads in 2010

JANUARY *APRIL* *JULY* *OCTOBER*

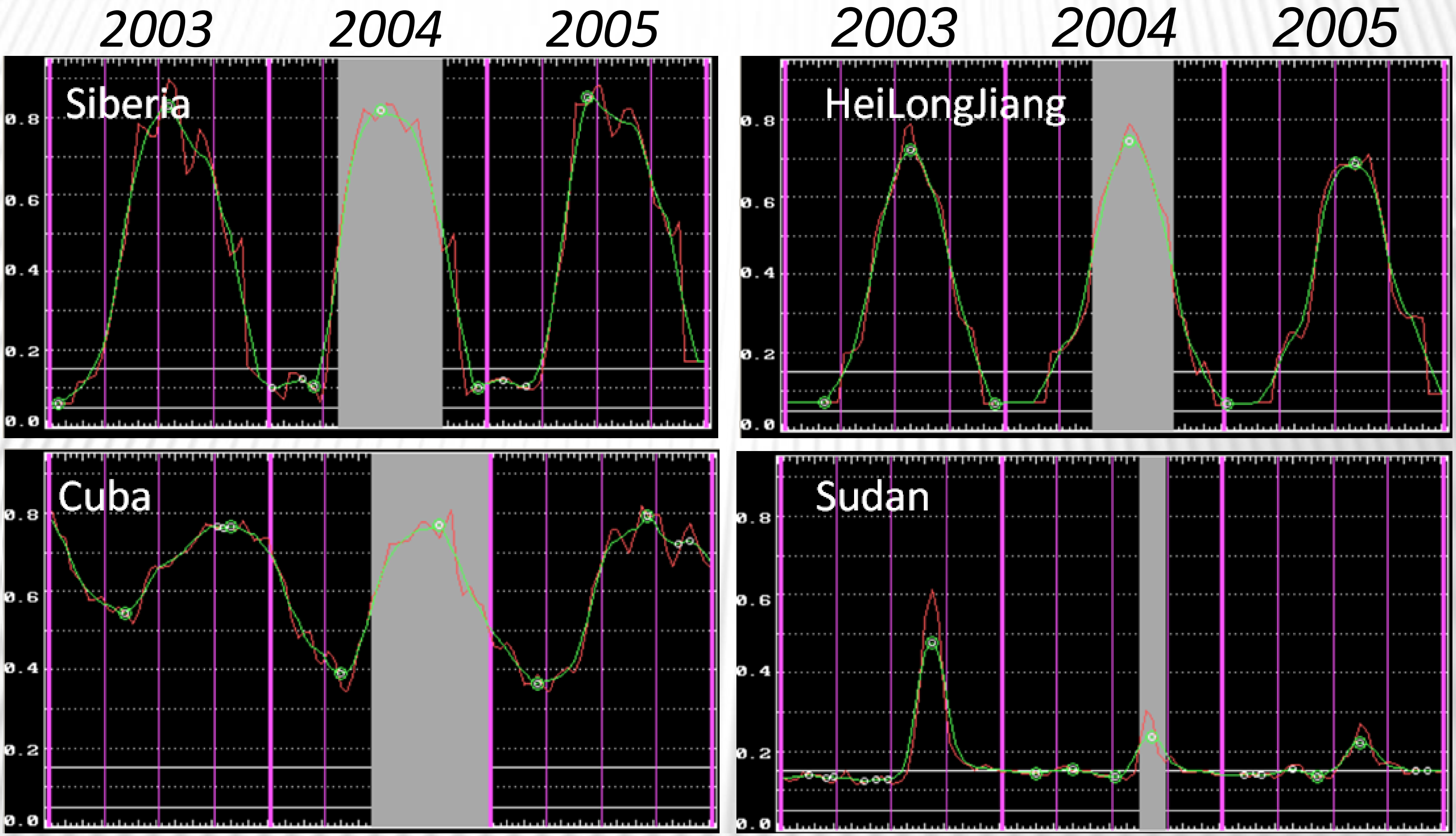
RAW

SMOOTHED



NB: - Significant improvement (even missing dekads replaced)
- Idem for b-fAPAR (and derived y-DMP)

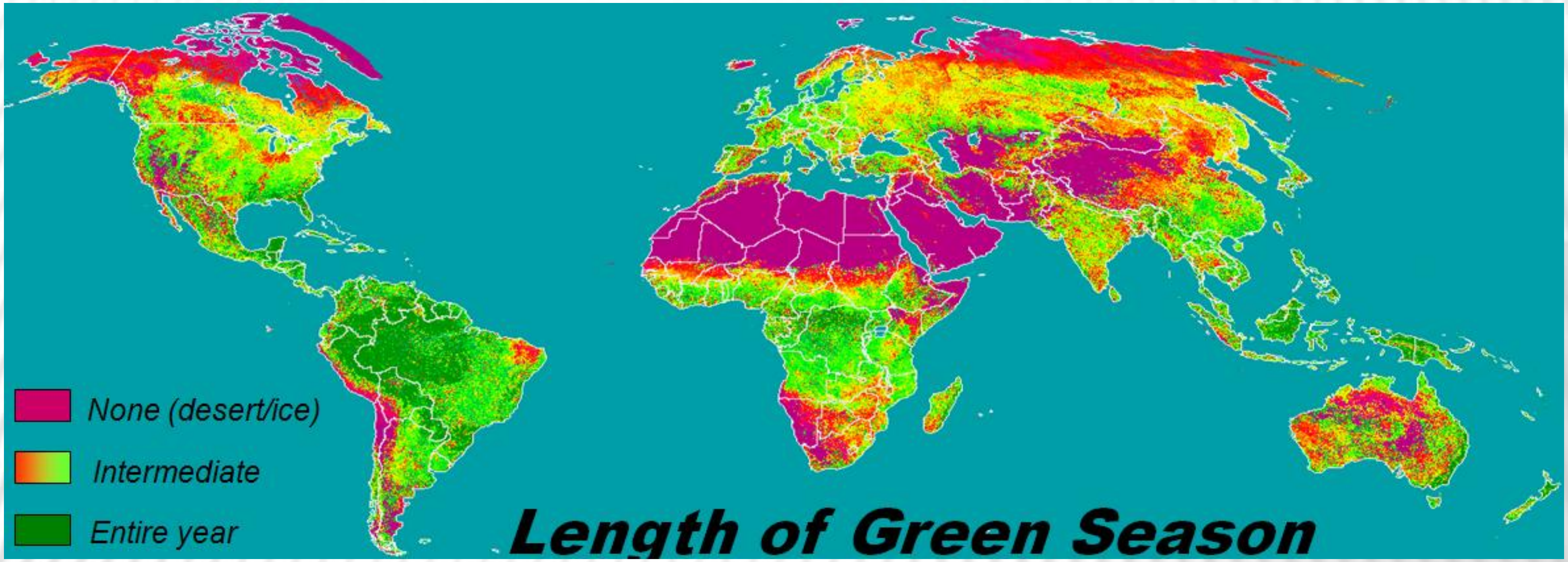
POST-processing – Phenology (start/end/length of the growing season)

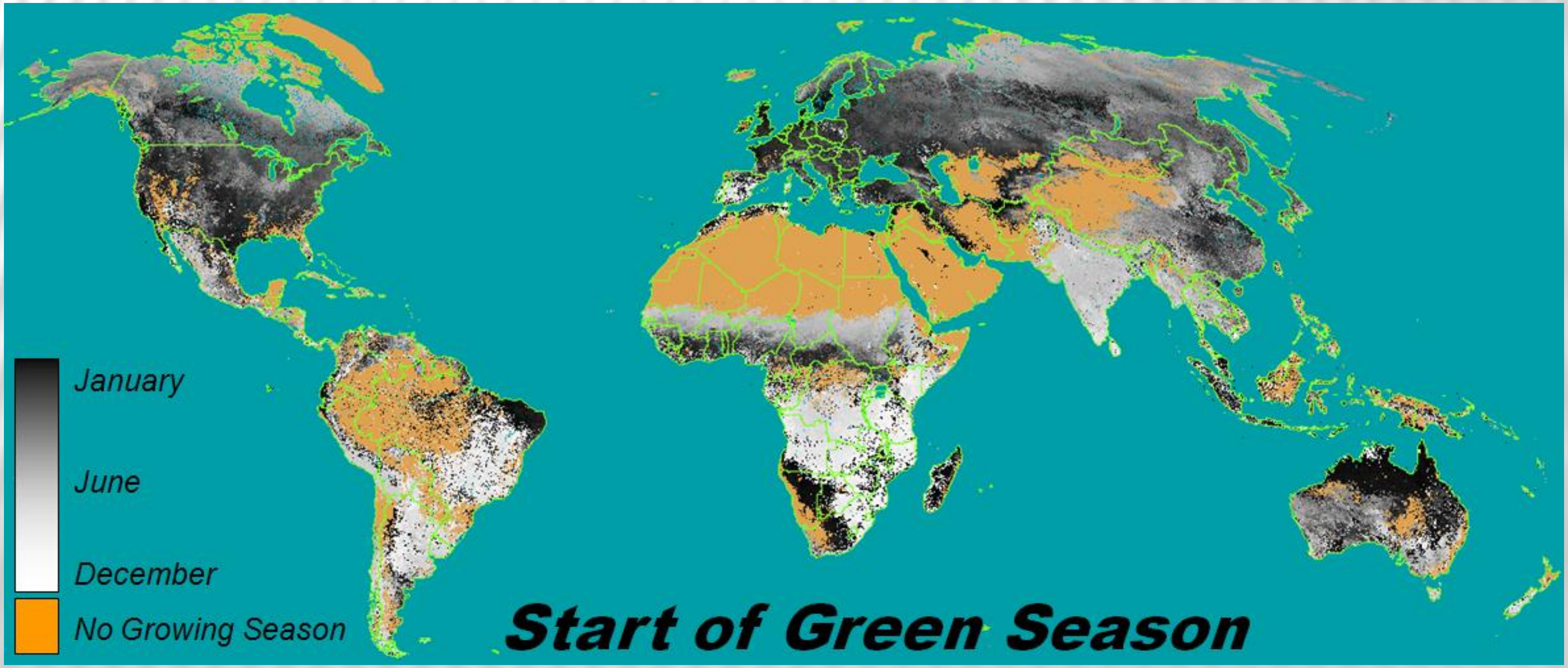


GLD (VGT, global, 21km), NDVI, Years 2003-2005 (focus on 2004)

- **Smoothed NDVI (modified SWETS)**
- **Further smoothed with 5-dekads running mean**
- White block = main green season (only 2004)

POST-processing – Phenology (start/end/length of the growing season)

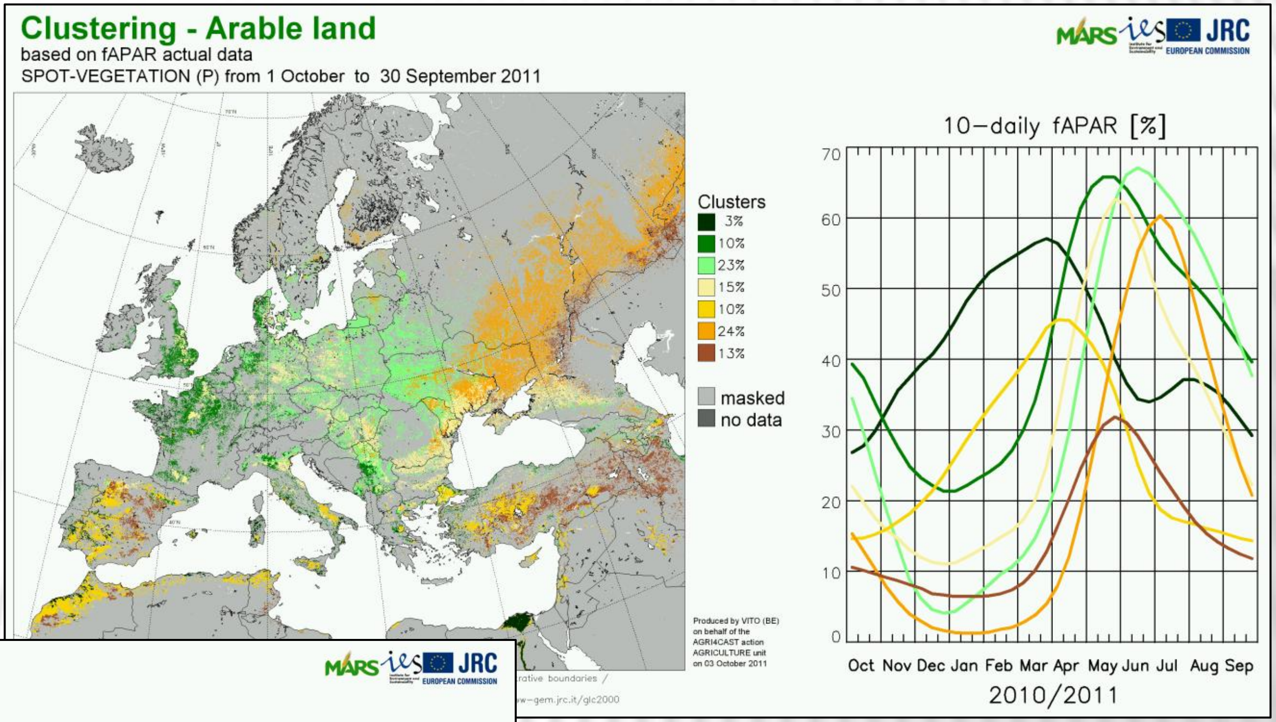


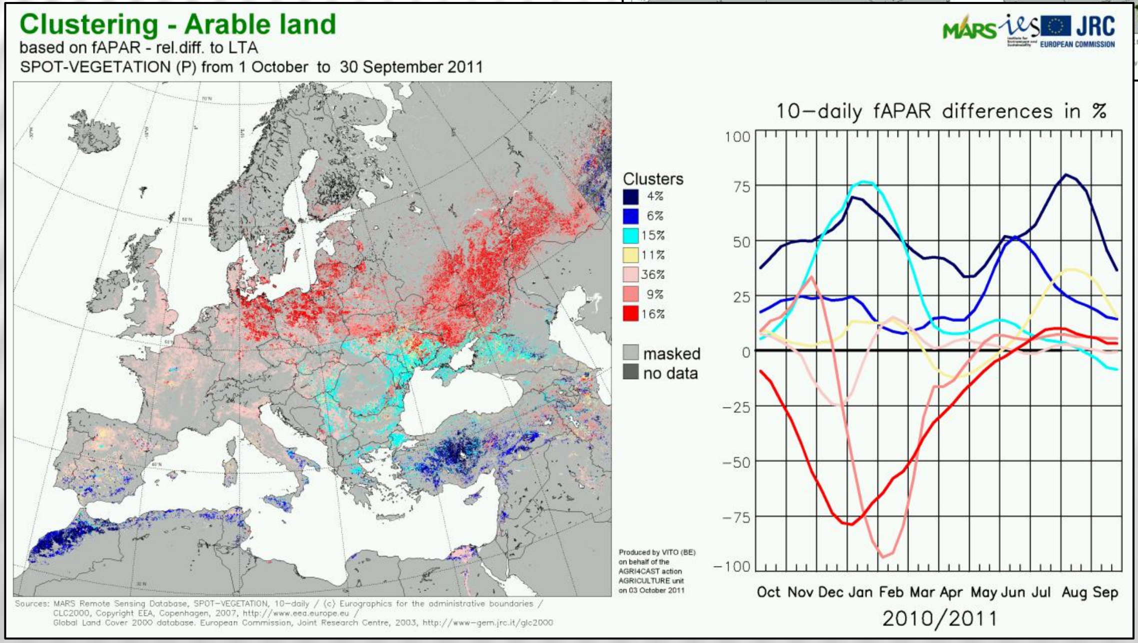


POST-processing - ISO-clustering

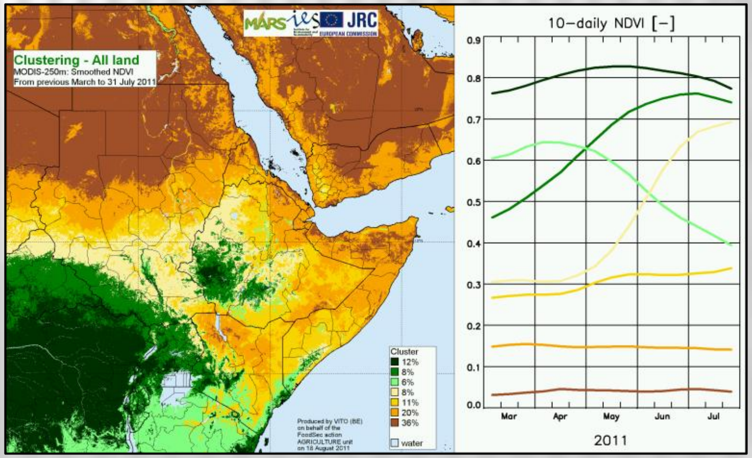
EUROPE:16 analyses/dekad

- For two time series:
  - October→ Present
  - March → Present
- For NDVI & fAPAR
- Actual values & Differences
- For cropland & pastures





Trial for IGAD (all pixels)



POST-processing operations – starting from the S10-composites

1. **Spatial operations**
   - Compression of global images to PI-format (Pseudo-Images)
   - Extract ROI from global imagery
   - Thinning (global VGT/METOP at 21 km)
   - Remap (e.g. all European data in INSPIRE-LAEA)
2. **Thematic operations: add S10-images with…**
   - LST (only for NOAA/METOP-AVHRR)
   - fAPAR (fraction absorbed radiation in 400-700 nm)
   - DMP = *f*(fAPAR, meteo) ~ Monteith-approach
3. **Time series operations - 1. Within a single year**
   - Monthly S30-composites
   - Cumulative values
   - Smoothing of time series
   - Phenology
   - ISO-clustering
4. **Time series operations - 2. Over the years**
   - Images with long-term statistics ("historical year")
   - Anomalies
   - Similarity analysis → See later!
5. **Extraction of RUM-databases (Regional Unmixed Means)**

POST-processing – Historical Year & Differences/Anomalies

period	1	2	…	*p*	…	N_p
year = 1	X(1,1)	X(1,2)	…	…	…	X(1, N_p)
…	…					…
y	…			**X(*y*,*p*)**		…
…	…					…
N_y	X(N_y,1)	X(N_y,2)	…	…	…	X(N_y, N_p)

Actual IMGs:

X=NDVI,DMP,…

Np=36 dekads

12 months

Period	1	2	…	*p*	…	N_p
Mean	$\mu_x(1)$	$\mu_x(2)$	…	$\boldsymbol{\mu_x(p)}$	…	$\mu_x(N_p)$
Minimum	$Min_x(1)$	$Min_x(2)$		$\mathbf{Min_x(p)}$		$Min_x(N_p)$
Maximum	$Max_x(1)$	$Max_x(2)$		$\mathbf{Max_x(p)}$		$Max_x(N_p)$
St. Dev.	$\sigma_x(1)$	$\sigma_x(2)$		$\boldsymbol{\sigma_x(p)}$		$\sigma_x(N_p)$
N_{good}	$N_x(1)$	$N_x(2)$	…	$\mathbf{N_x(p)}$	…	$N_x(N_p)$

Historical Year:

Long-Term Statistics (+ *Deciles*)

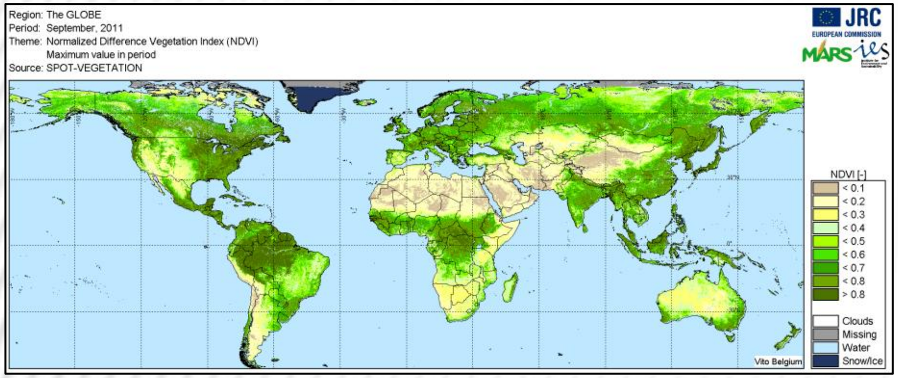
period	1	2	…	*p*	…	N_p
year = 1	$D_X(1,1)$	$D_X(1,2)$	…	…	…	$D_X(1, N_p)$
…	…					…
y	…			$\mathbf{D_X(y,p)}$		…
…	…					…
N_y	$D_X(N_y,1)$	$D_X(N_y,2)$	…	…	…	$D_X(N_y, N_p)$

DIFh:

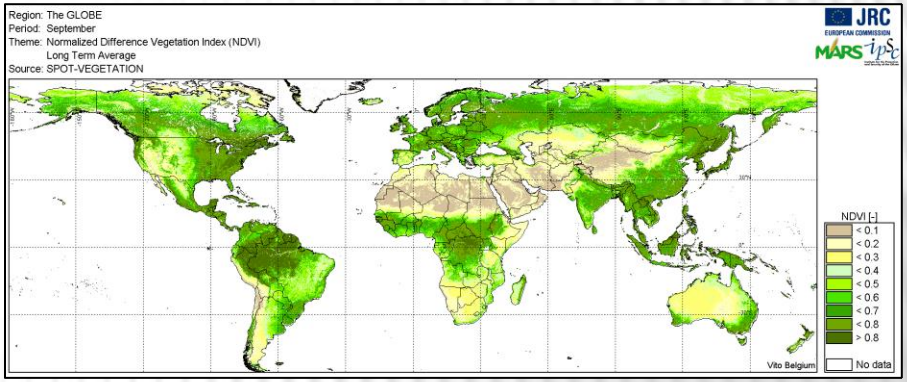
Difference IMGs with regard to Historical Year

POST-processing – Historical Year & Differences/Anomalies

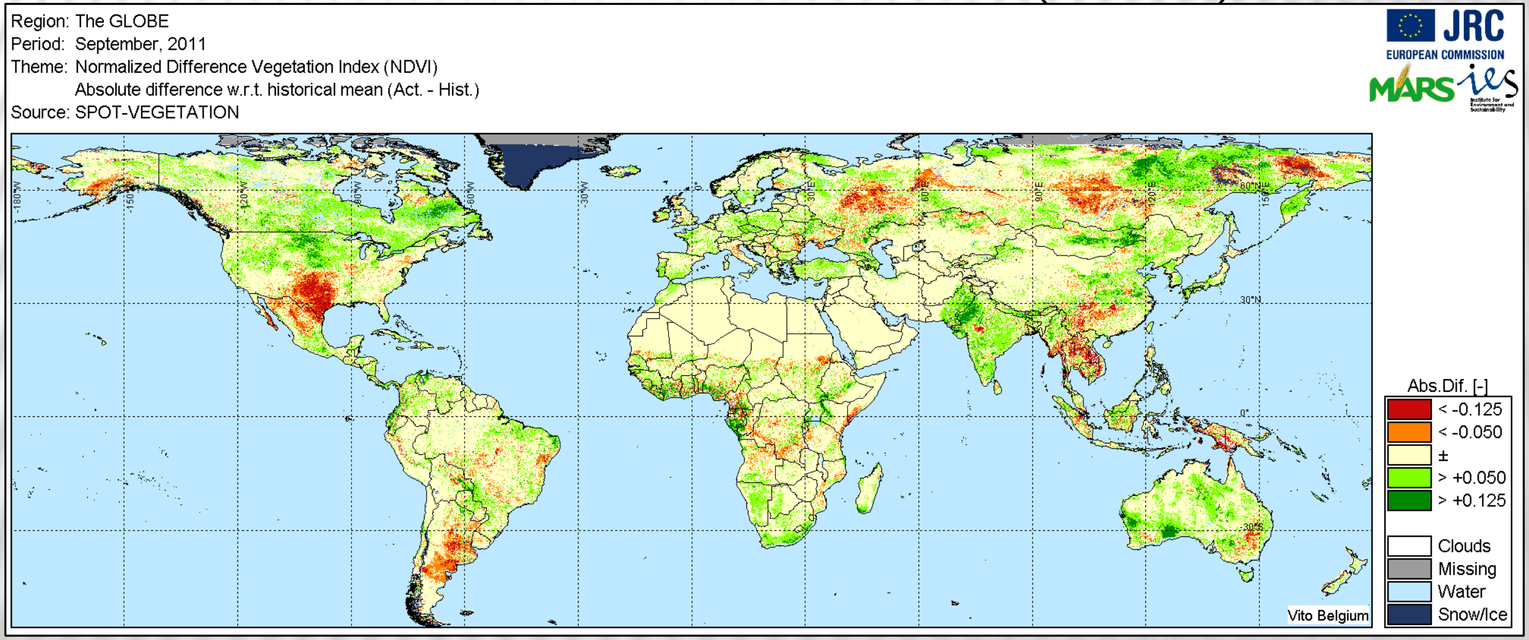
A. NDVI SEPTEMBER 2011



B. MEAN NDVI for SEPTEMBER (1999-2010)



C. NDVI-ANOMALY for SEPTEMBER 2011 (C = A - B)



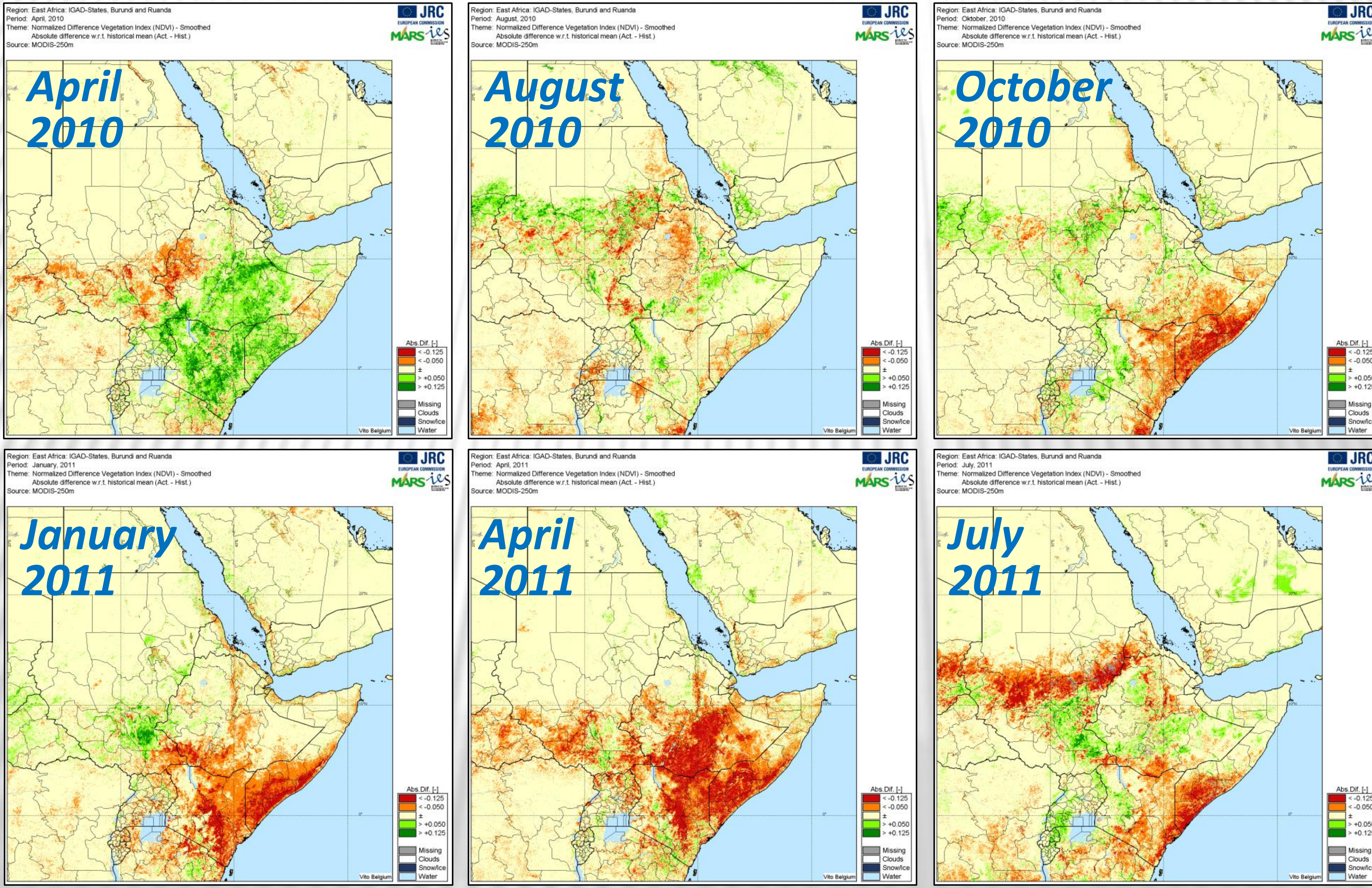
POSITIVE: **North US, Canada, W.Europe, S.Africa, India, N.China, Australia**

NEGATIVE: **SE US, Argentina, parts of Russia, SE-Asia, Somalia**

POST-processing – Historical Year & Differences/Anomalies

Absolute Difference of smoothed, monthly k-NDVI to Historical Year

→ Severe drought in IGAD visible since October 2010



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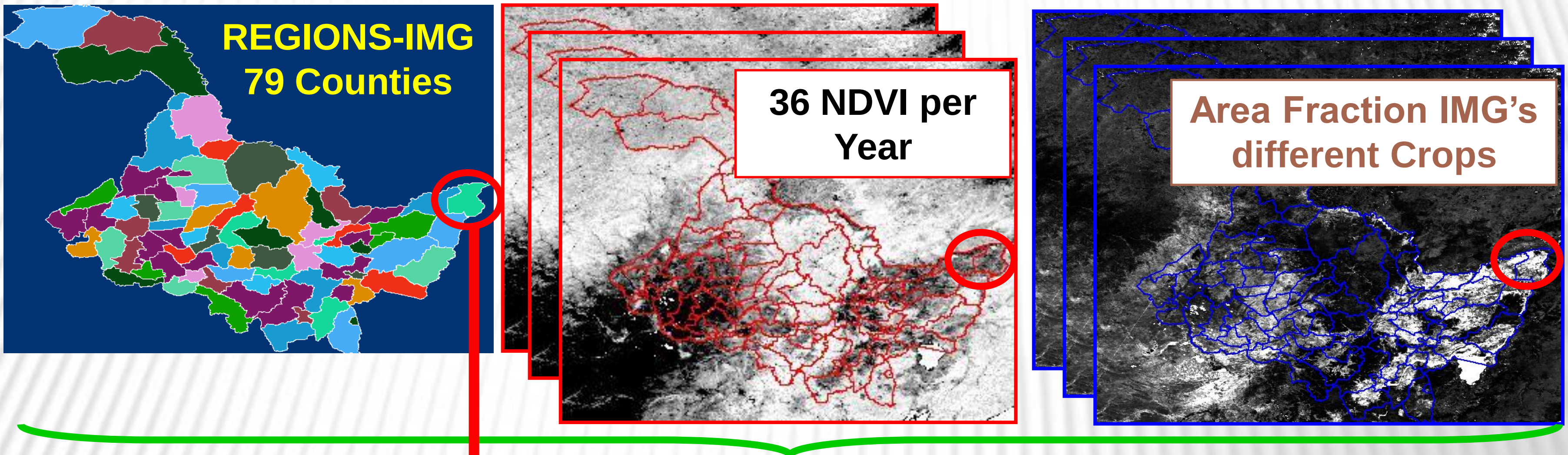
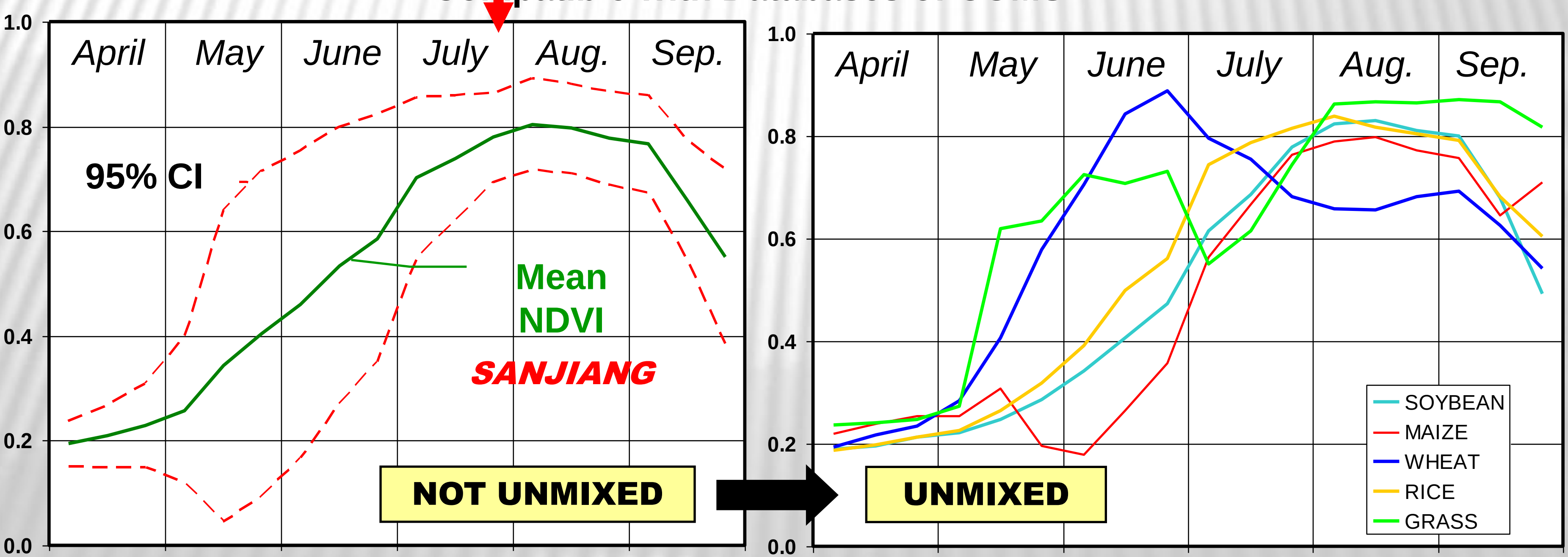
POST-processing – RUM-databases (Regional Unmixed Means)

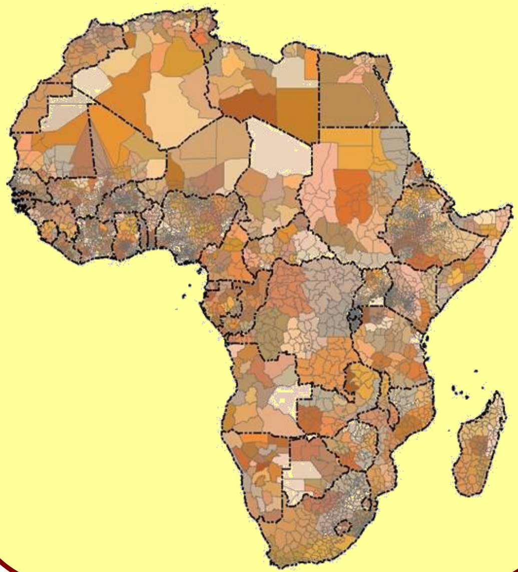


UNMIXING ⇒ <u>Database</u> with specific profiles per Region, Year and Crop
Compatible with Databases of CGMS

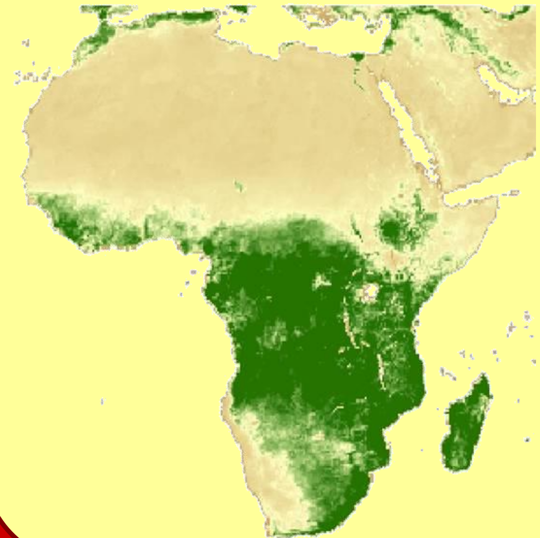


POST-processing – RUM-databases (Regional Unmixed Means)

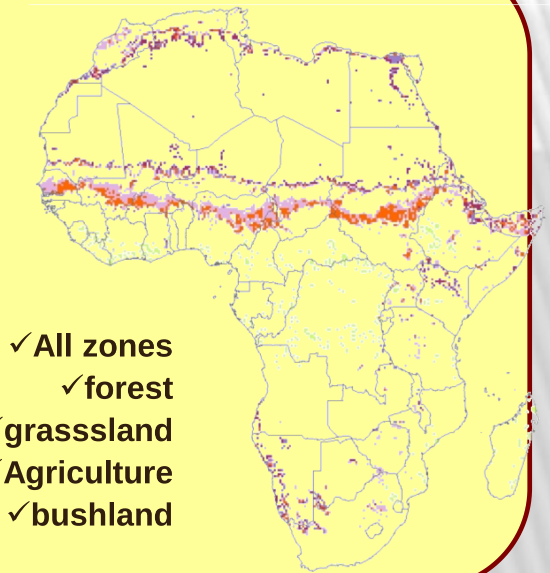
Administrative boundaries



SPOT-VGT images



Landcover



- ✓All zones
- ✓forest
- ✓grasssland
- ✓Agriculture
- ✓bushland

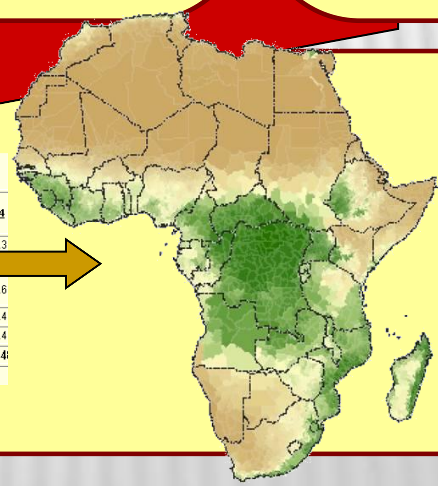
“RUM” database – regional unmixed

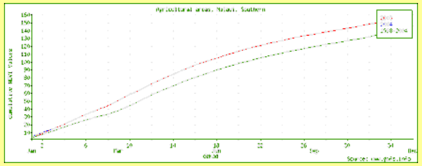
Statistics for : 2003, MWI, Northern

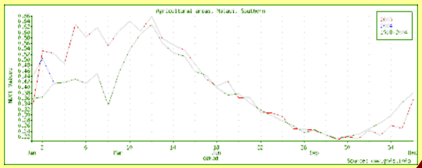
Figures indicate the dry matter productivity in Kg/ha/day. Colum 1-36 indicate decade 1 to decade 36*.

Country	ADMIN LEVEL 1	ADMIN LEVEL 2	ADMIN LEVEL 3	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Malawi	Northern	Chitipa		0.48	0.67	0.64	0.64	0.68	0.76	0.74	0.64	0.61	0.62	0.55	0.52	0.63	0.69	0.60	0.60	0.46	0.42	0.51	0.44	0.48	0.43	0.42	0.3
Malawi	Northern	Karonga		0.55	0.70	0.65	0.60	0.65	0.72	0.72	0.63	0.60	0.62	0.60	0.60	0.64	0.64	0.61	0.65	0.52	0.46	0.49	0.45	0.49	0.45	[illegible]	[illegible]
Malawi	Northern	Nkata-Bay		0.62	0.74	0.62	0.48	0.71	0.73	0.74	0.63	0.56	0.64	0.55	0.62	0.76	0.74	0.63	0.74	0.47	0.59	0.49	0.52	0.61	0.51	0.59	0.6
Malawi	Northern	Rumphi		0.47	0.69	0.66	0.60	0.66	0.75	0.78	0.66	0.57	0.70	0.62	0.65	0.70	0.70	0.65	0.67	0.48	0.50	0.51	0.47	0.53	0.43	0.45	0.4
Malawi	Northern	Mzimba		0.43	0.63	0.56	0.47	0.63	0.67	0.67	0.53	0.51	0.63	0.61	0.62	0.63	0.63	0.58	0.59	0.44	0.46	0.45	0.43	0.45	0.41	0.40	0.4
Mean				**0.51**	**0.686**	**0.626**	**0.558**	**0.666**	**0.726**	**0.73**	**0.618**	**0.57**	**0.642**	**0.586**	**0.602**	**0.672**	**0.68**	**0.614**	**0.65**	**0.474**	**0.486**	**0.49**	**0.462**	**0.512**	**0.446**	**0.466**	**0.44**

* 1 decade is a ten-days synthesis of the dry matter productivity values.

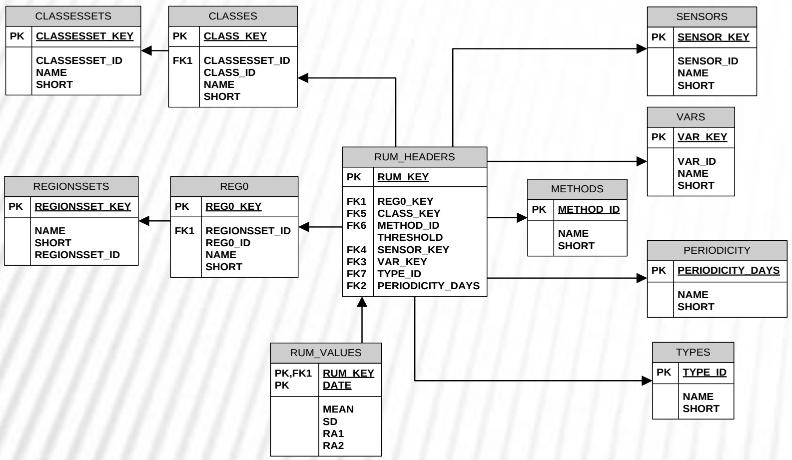




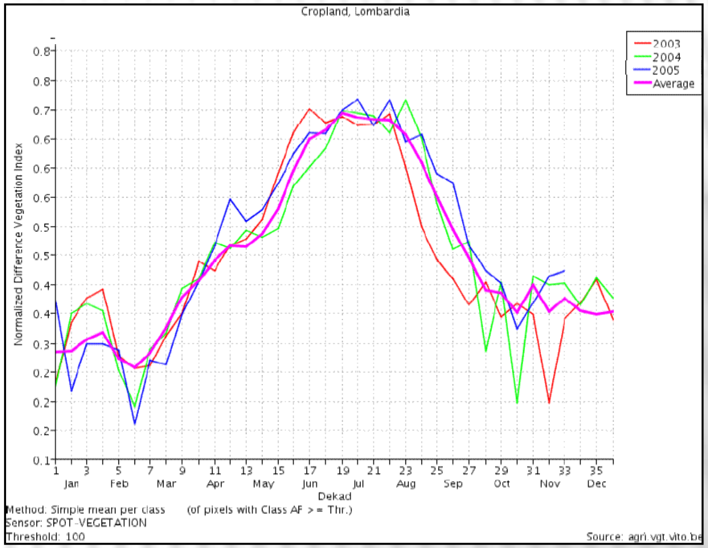


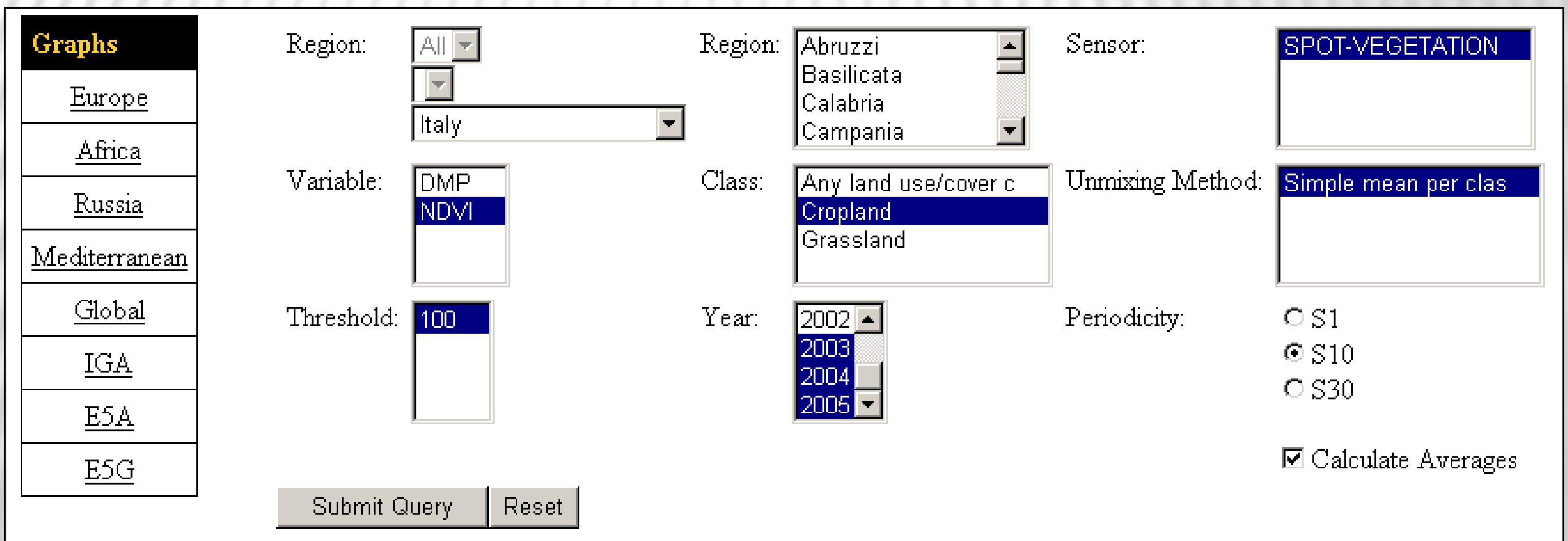
POST-processing – RUM-databases in MARSOP

ORACLE DATABASE



RUM-profiles



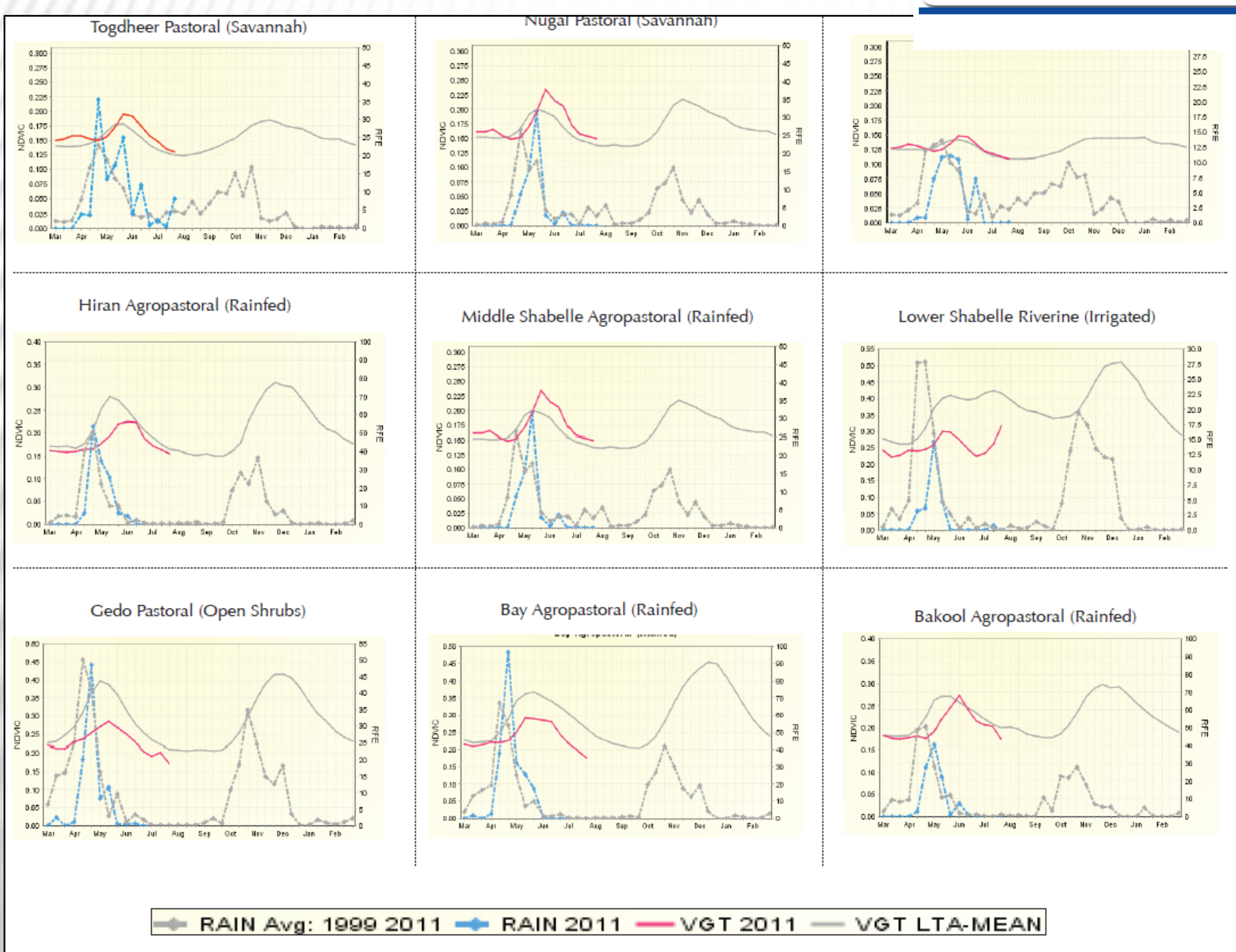


MARSOP-VIEWER

POST-processing – RUM-databases (Regional Unmixed Means)

OPERATIONAL USE for

- Crop monitoring
- Yield estimation



E-AGRI – Workshop, Rabat 12-14 October 2011
Crop Yield Forecasting based on Remote Sensing

Low resolution remote sensing data for crop yield assessment in the E-AGRI study areas of Morocco and HuaiBei-China

Herman Eerens, VITO-Belgium

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1. VITO-TAP & MARSOP-project
2. Sensors & PRE-processing
3. POST-Processing & Products
4. SPIRITS software

B. VGT-DATA FOR E-AGRI
1. HuaiBei
2. Morocco

C. SIMILARITY ANALYSIS for MOROCCO

D. CONCLUSIONS

PRE-Processing ⇔ POST-Processing

SATELLITE

INGEST (FTP, Eumetcast)

RAW DATA
(segments)

Corrections → Composit

LINUX/C++/AppWorx

- Calibration
- Geo-correction
- Atmo-corrections
- Cloud/snow detection
- S10-compositing

Walter Heyns

Bart Ooms

JRC, Alterra, …

DISSEMINATE

INFORMATION
(IMG, QLK, RUM)

All further operations …

Windows/GLIMPSE/BAT

2

Herman Eerens

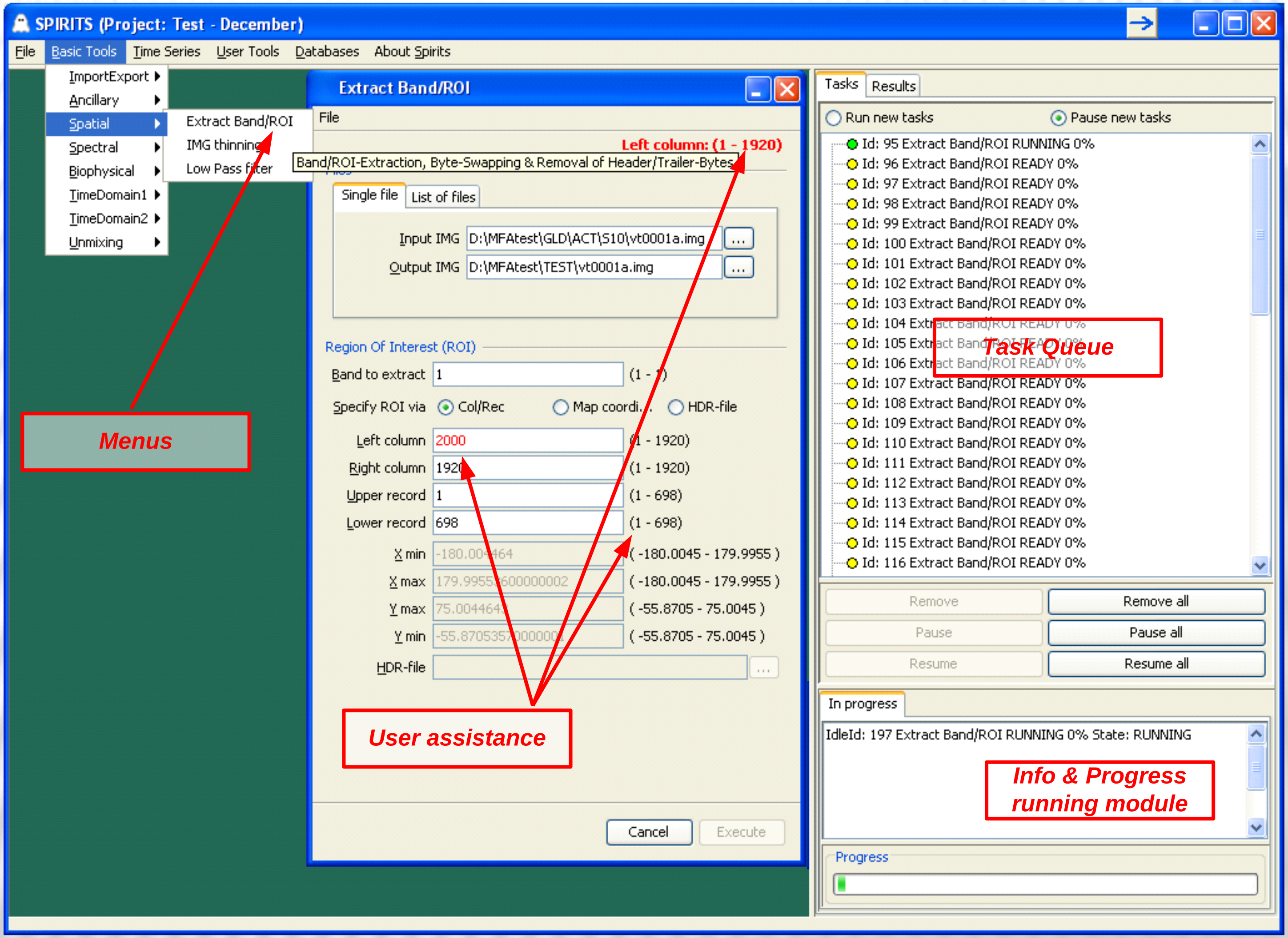
Dominique Haesen

CONTINENTAL/GLOBAL S10-COMPOSITES

SPIRITS software

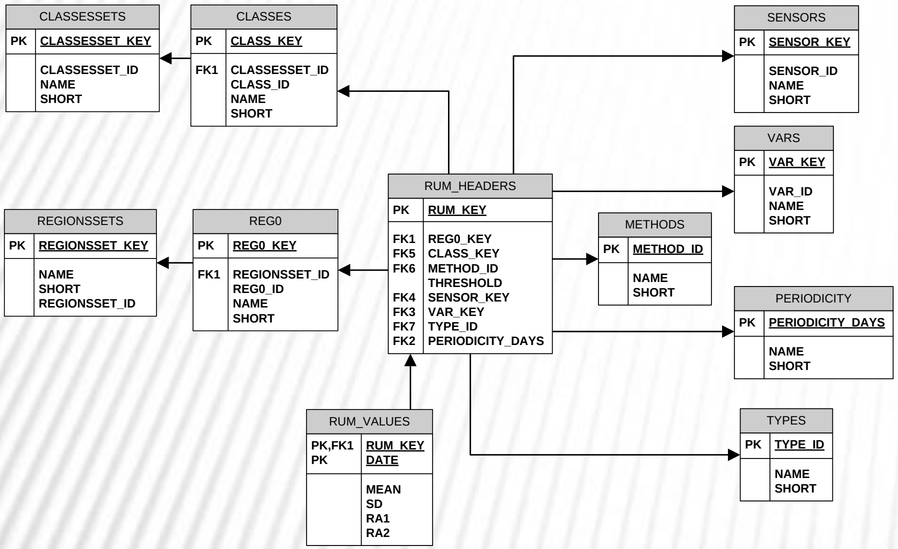
- **GLIMPSE = Global Image Processing Software**
  - Set of programs for image processing, mainly for:
    - *Post-processing in MARSOP*
    - *Time series analysis*
    - *Classification (HiRes/Hard, LoRes/Soft)*
  - Extension to commercial packages IDRISI and ENVI
  - ANSI-C for DOS
- **SPIRITS = Software for the Processing and Interpretation of RS Image Time Series:**
  - Windows GUI in JAVA with C-modules of Glimpse & many others
  - Functionalities
    - *Time series analyses*
    - *Import/Export (format conversions)*
    - *Vector-raster conversion*
    - *RUM-database & viewer*
    - *Quicklook generator*
    - *Workflow tool to incorporate user-defined modules*
  - Collaboration with JRC-MARS, Freely available.
  - **September 2012**: First official release, incl. manual & tutorial

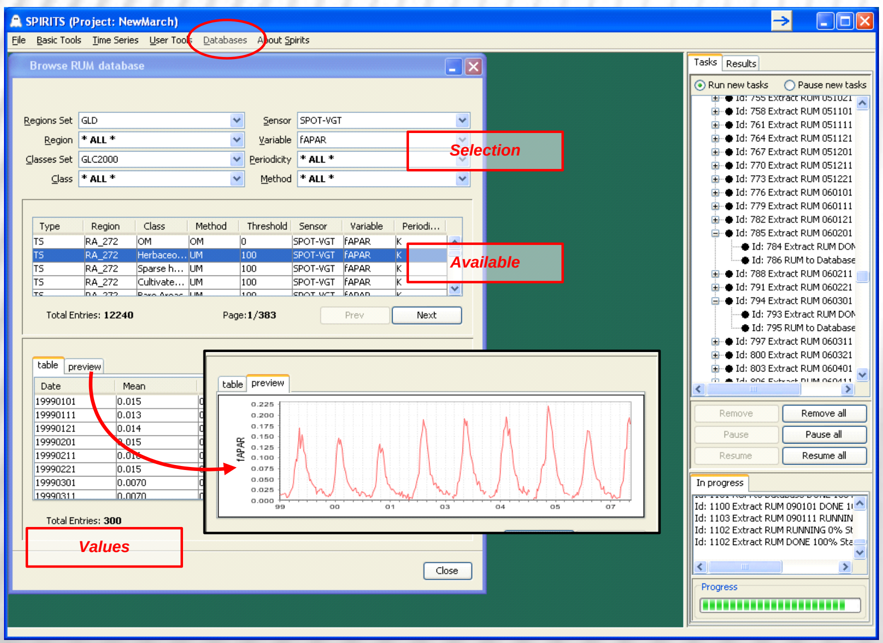
SPIRITS software



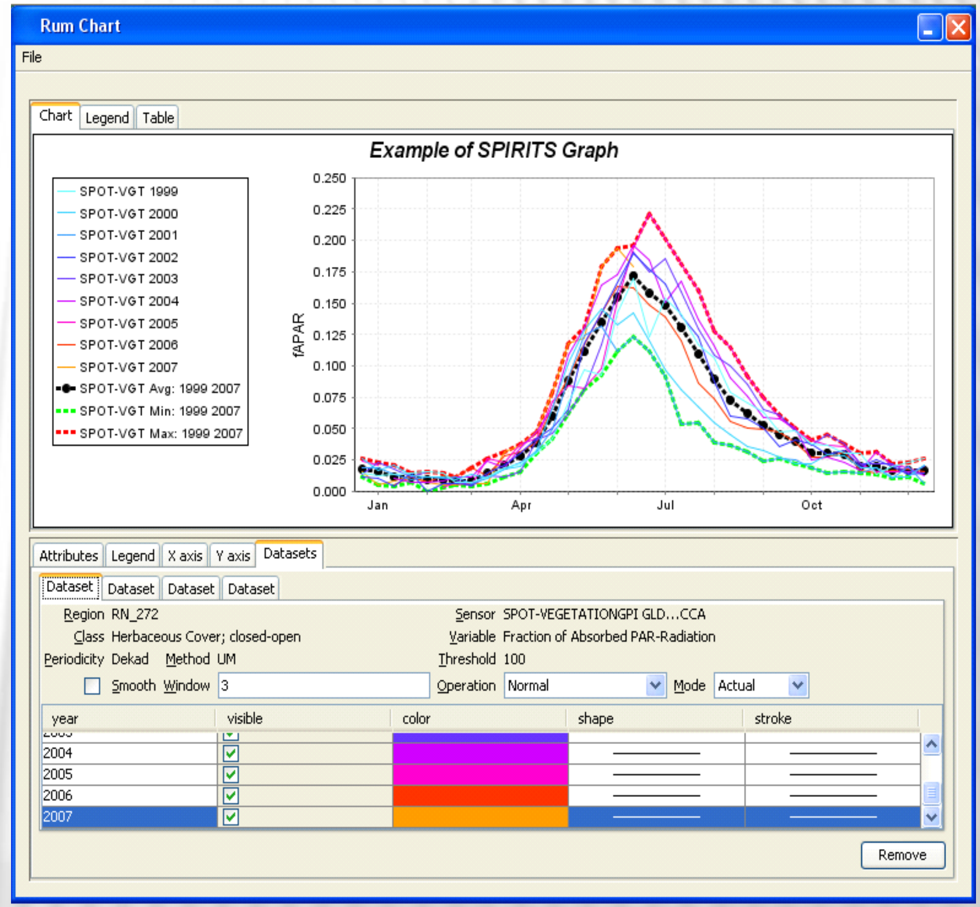
General overview of the SPIRITS GUI

SPIRITS software: RUM-database & viewer





The database browser

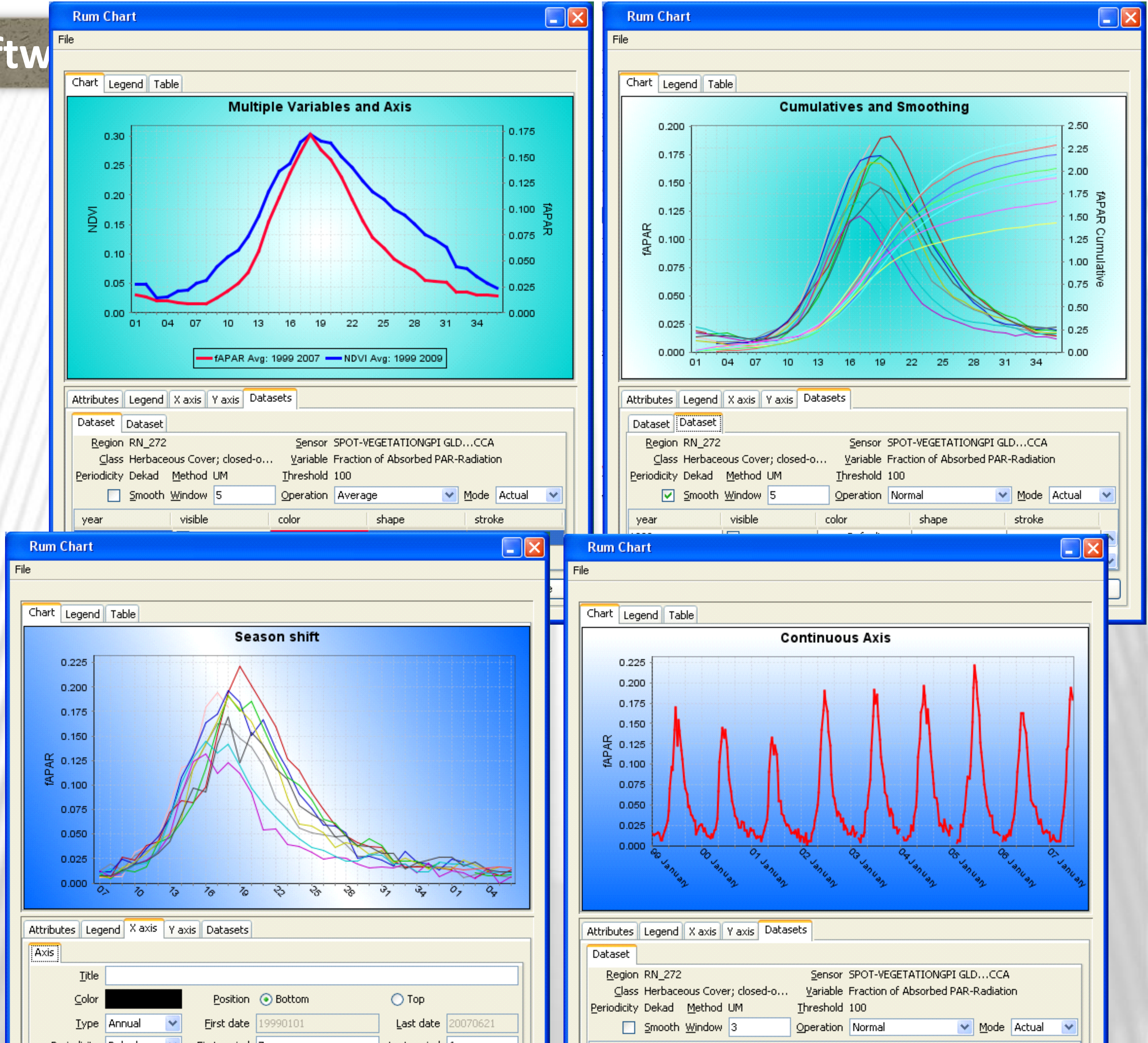


The database viewer

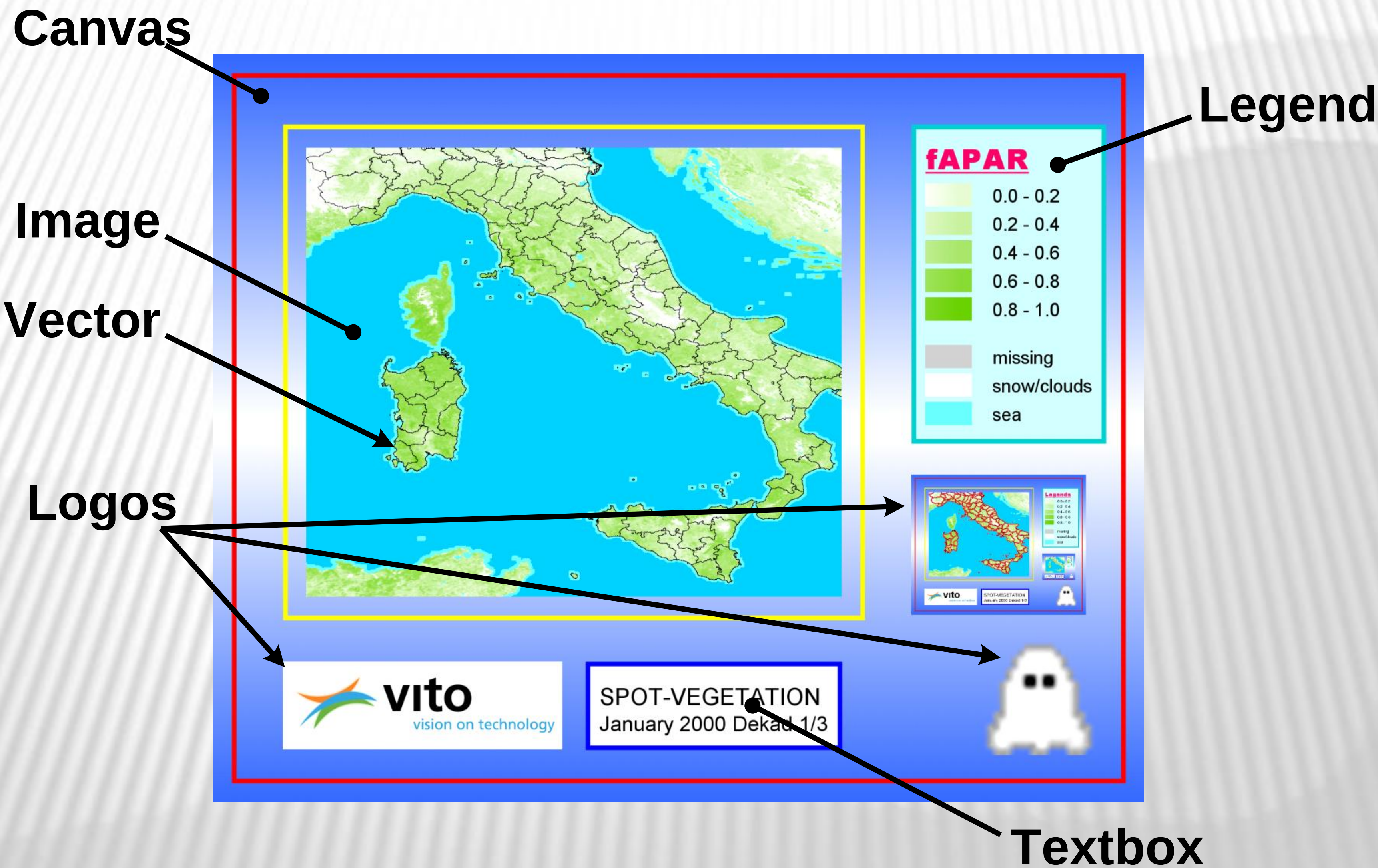
SPIRITS softw

Database Viewer:

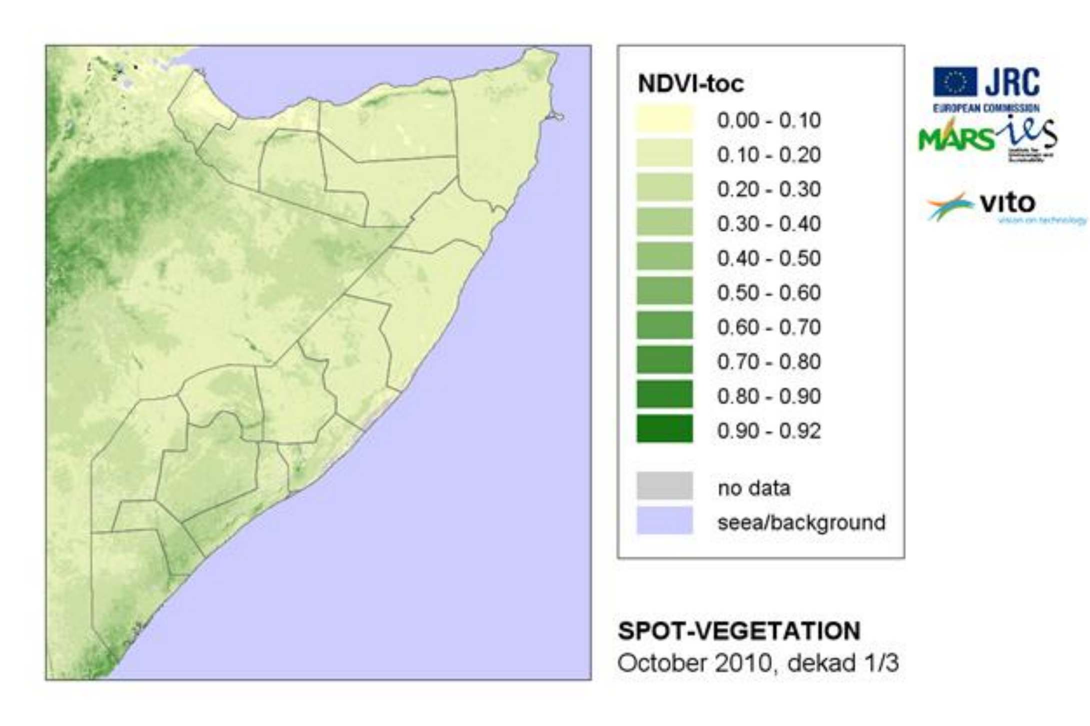
More examples

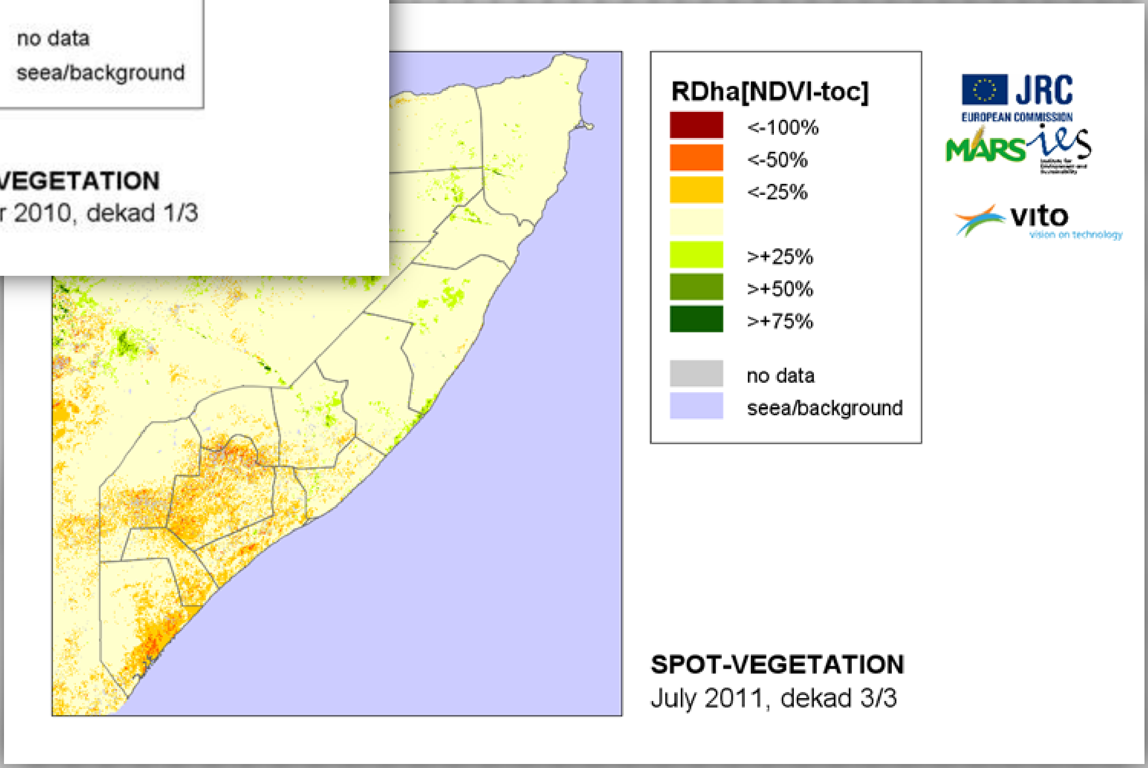


SPIRITS software: QuickLook generator



SPIRITS software: QuickLook generator





Low resolution remote sensing data for crop yield assessment in the E-AGRI study areas of Morocco and HuaiBei-China

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2. Morocco

C. SIMILARITY ANALYSIS for MOROCCO

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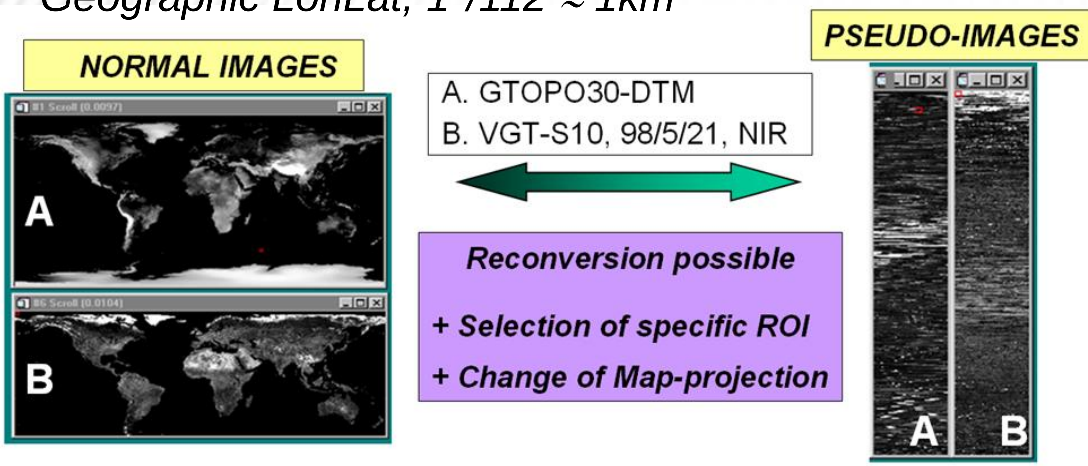
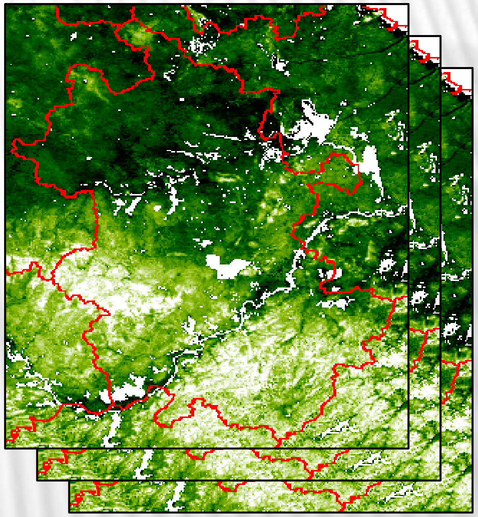
E-AGRI sites: VGT-data

Global archive of SPOT-VGT

Geographic LonLat, 1°/112 ≈ 1km

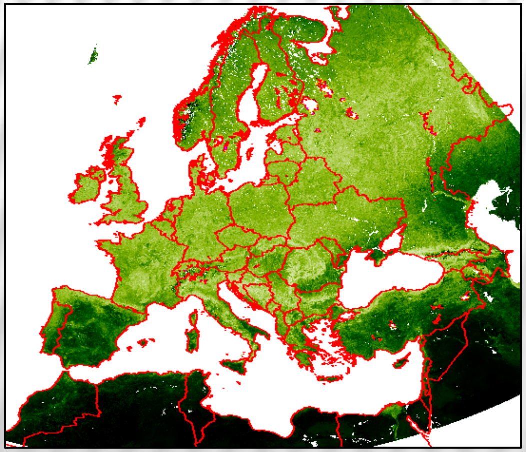


HuaiBei

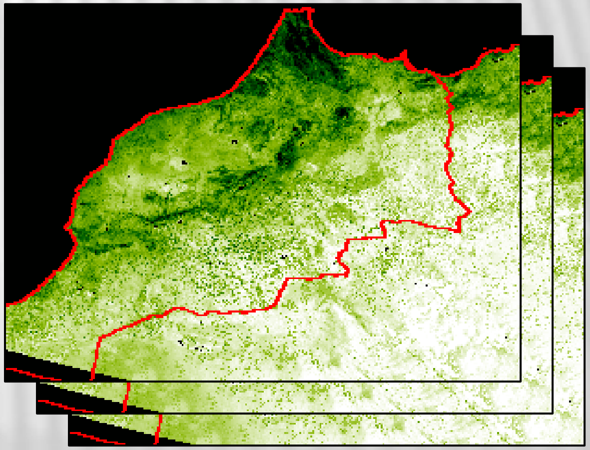


European archive SPOT-VGTp

Lambert Azimuthal Equal Area,1km



Morocco



Always: Jan. 1999 → Dec. 2010 = 12 years = 432 dekads

E-AGRI sites: VGT-data

Prepared VGT-data for HuaiBei & Morocco:

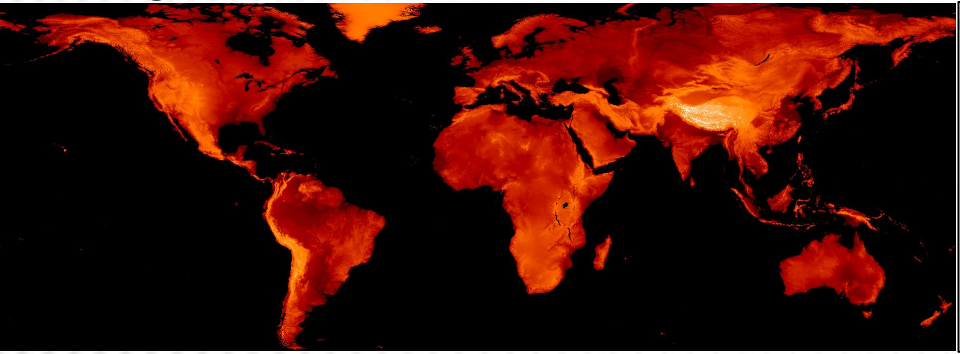
1. Always 5 different “variables”

VARIABLE	ORIGINAL	SMOOTHED
NDVI	i-NDVI	k-NDVI
fAPAR	a-fAPAR	b-fAPAR
DMP		y-DMP

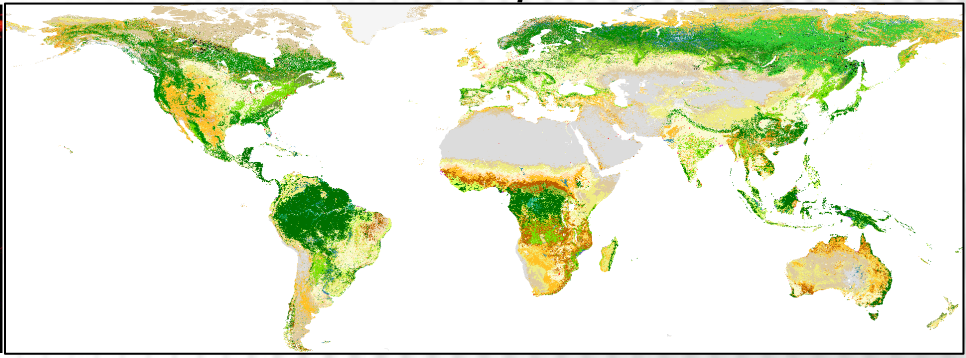
2. Always 432 dekads: Jan. 1999 → Dec. 2010 = 12 years

E-AGRI sites: Global ancillary data at 1km resolution

Digital Terrain Model GTOPO30

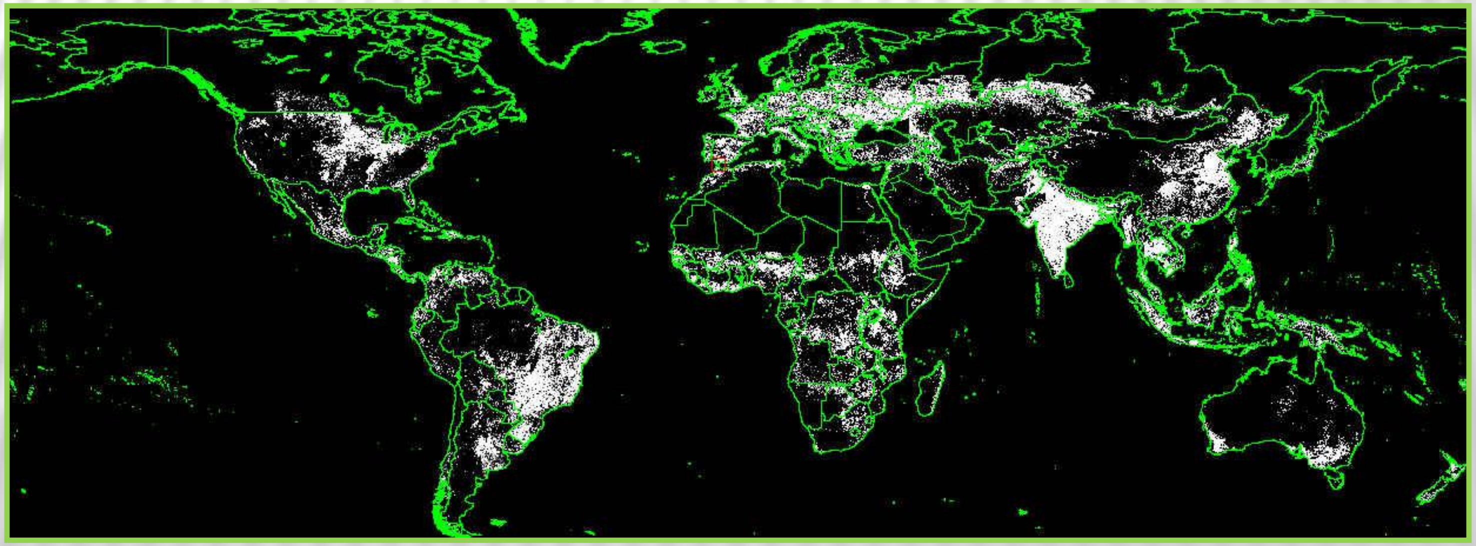


Land Cover Map GLC2000

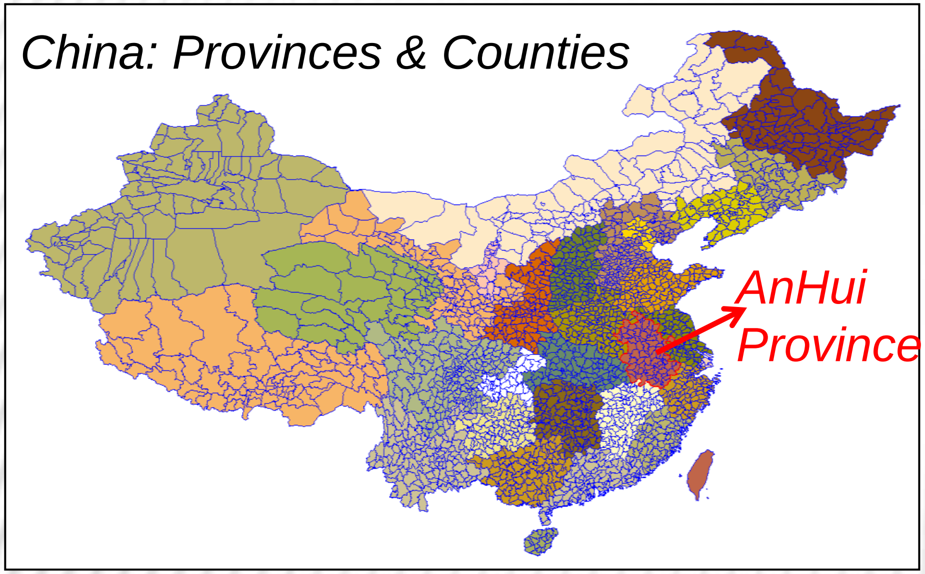


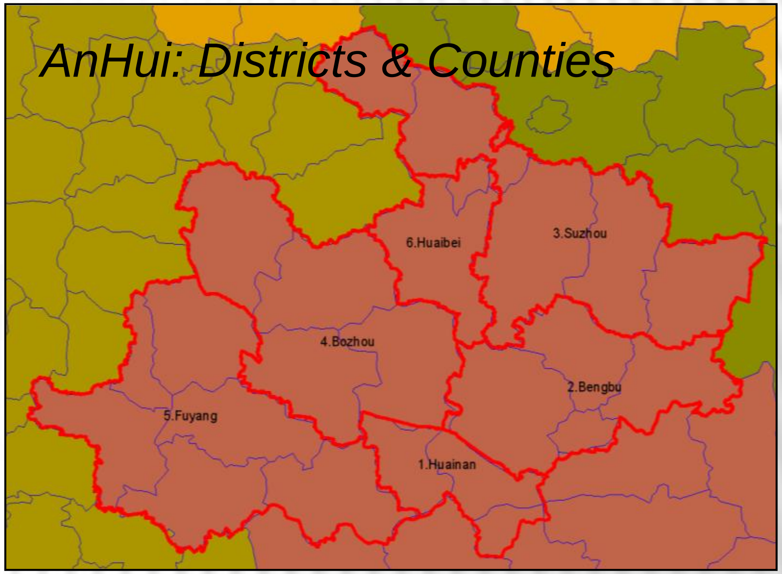
Cropland AFI (Area Fraction Image) from JRC-MARS

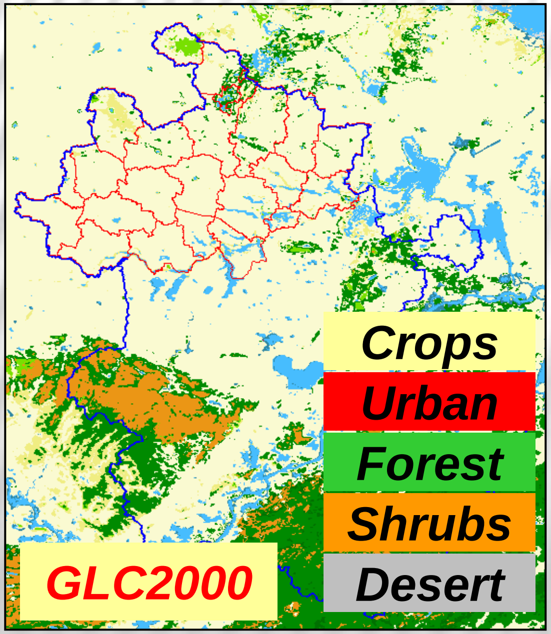
From GlobCover V2.2, CORINE-2000, AfriCover, the SADC data set and the USGS Cropland Use Intensity data set

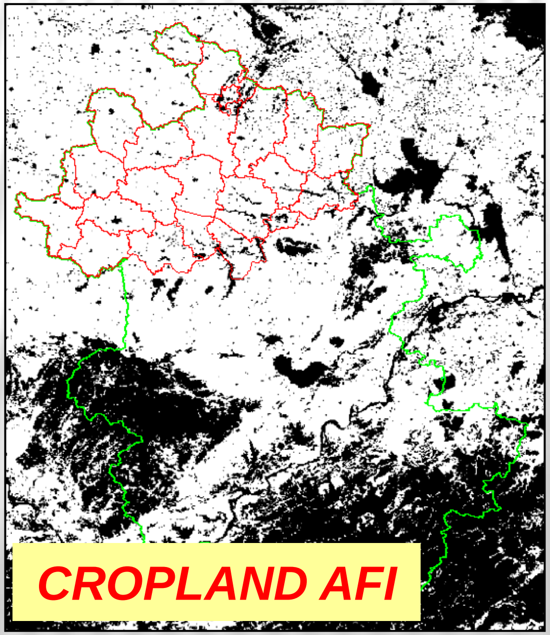


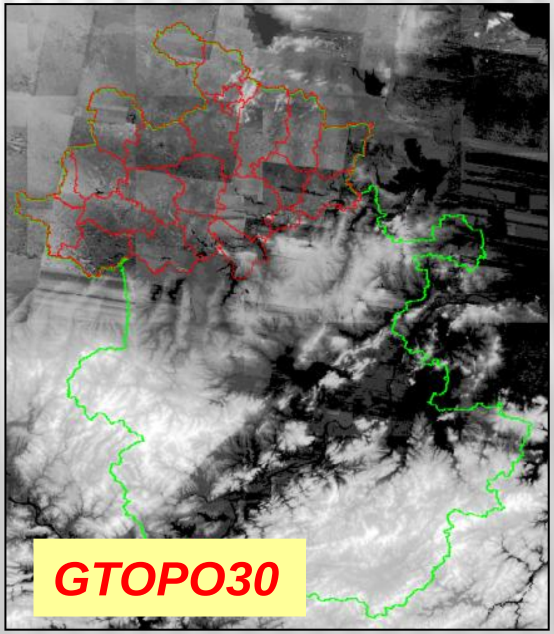
E-AGRI sites: HuaiBei-China











E-AGRI sites: HuaiBei-China

Wheat Yield of 6 cities in huaibei plain (2009-2000) (tons/hectare)

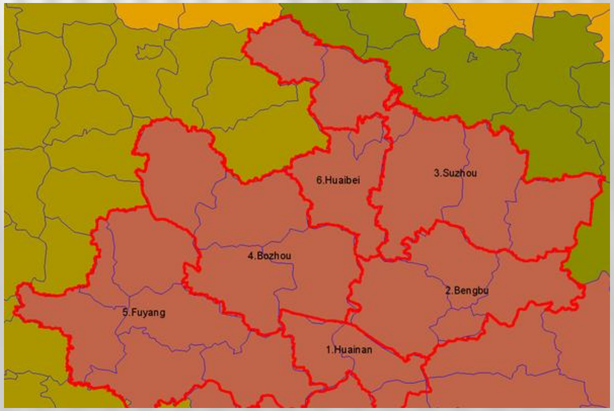
Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Huaibei city	3.694532	5.26904	4.657383	4.279428	5.377414	5.329523	6.051492	5.868251	6.434996	6.396739
Bozhou city	4.168311	5.157282	4.568276	4.406571	5.614608	5.525788	5.936209	5.882021	6.776365	6.817511
Suzhou city	3.67048	4.967319	4.263909	3.847727	5.355147	4.947669	5.794227	5.501471	5.940689	5.882017
Bengbu city	4.071628	4.220557	4.141661	2.68131	5.103099	5.054757	5.637738	5.47541	5.871898	5.876093
Fuyang city	4.256466	4.882748	4.008668	3.38595	5.303458	4.865835	5.364304	5.493151	6.075007	6.097501
Huainan city	3.395472	2.887137	3.994712	2.443591	4.949499	4.852663	5.466248	5.344601	5.704192	5.875177

Maize Yield of 6 cities in huaibei plain (2009-2000) (tons/hectare)

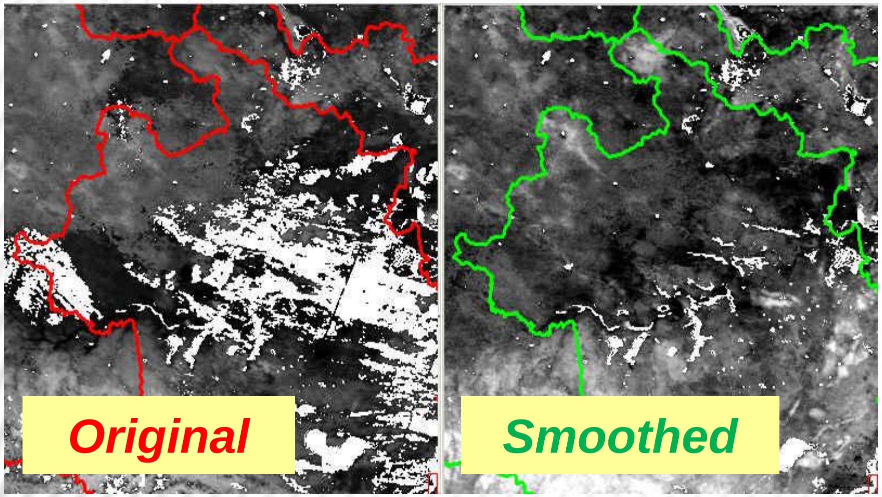
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Huaibei	4.979049	5.387977	3.030687	2.988436	5.92802	4.877846	6.139996	4.460011	4.656074	5.46403
Bozhou	5.154946	4.685217	2.599905	2.609596	5.87187	5.129987	6.131353	5.080324	5.710643	6.081848
Suzhou	5.703472	6.092365	3.070503	3.092463	6.017741	4.743201	5.927312	4.350705	4.895685	5.278532
Bengbu	5.317024	5.431771	3.089918	2.853913	5.781421	4.326433	5.562113	4.102673	4.980076	5.081796
Fuyang	4.966968	4.186786	2.299194	1.914315	5.836133	4.680154	6.069689	4.030725	5.44339	5.496973
Huainan	5.293478	5.342378	2.77879	3.007667	5.717396	5.005746	5.174083	4.818352	5.125043	2.019199

Provided by Chinese colleagues:
Official yield statistics for Wheat and Maize
Year 2000 – 2009
For six districts ‘(“cities”) in HuaiBei

NB: Beware the Region_ID numbers



E-AGRI sites: HuaiBei-China

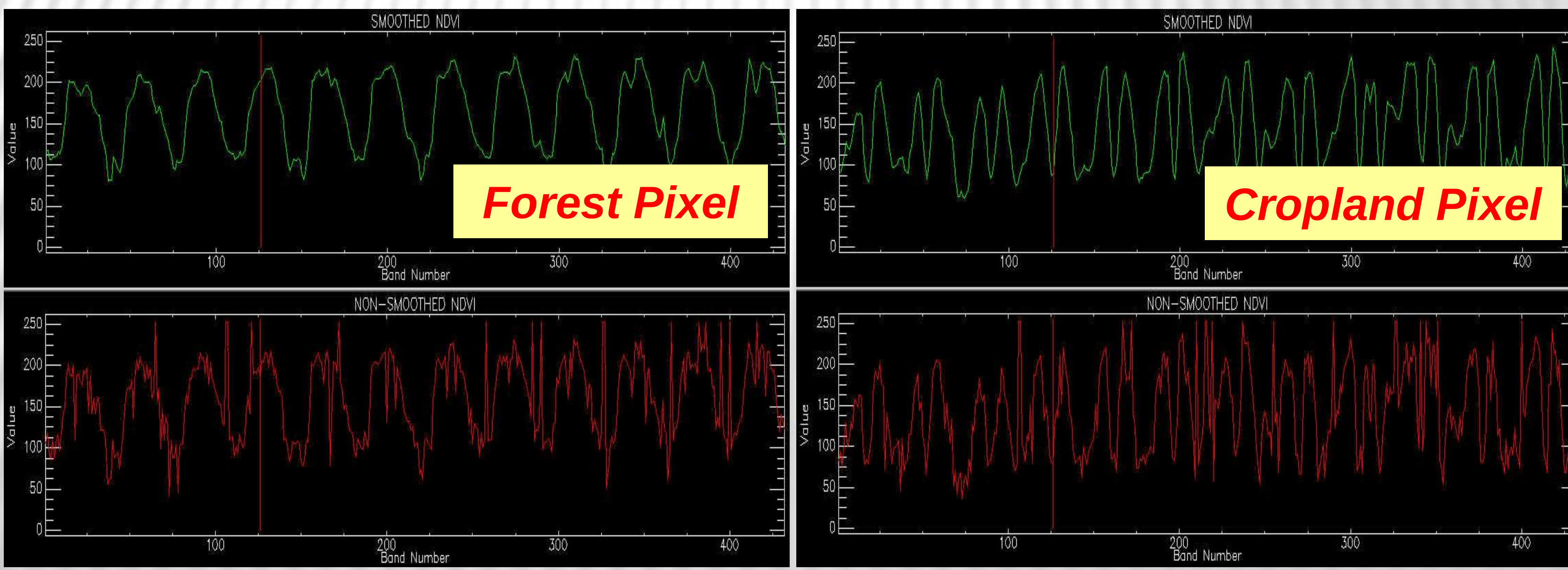


Effect of the smoothing for NDVI:

- *Original i-NDVI (left):*
  - *- missing values*
  - *- non-detected clouds.*
- *Smoothed k-NDVI (right)*
  - *- looks much better.*

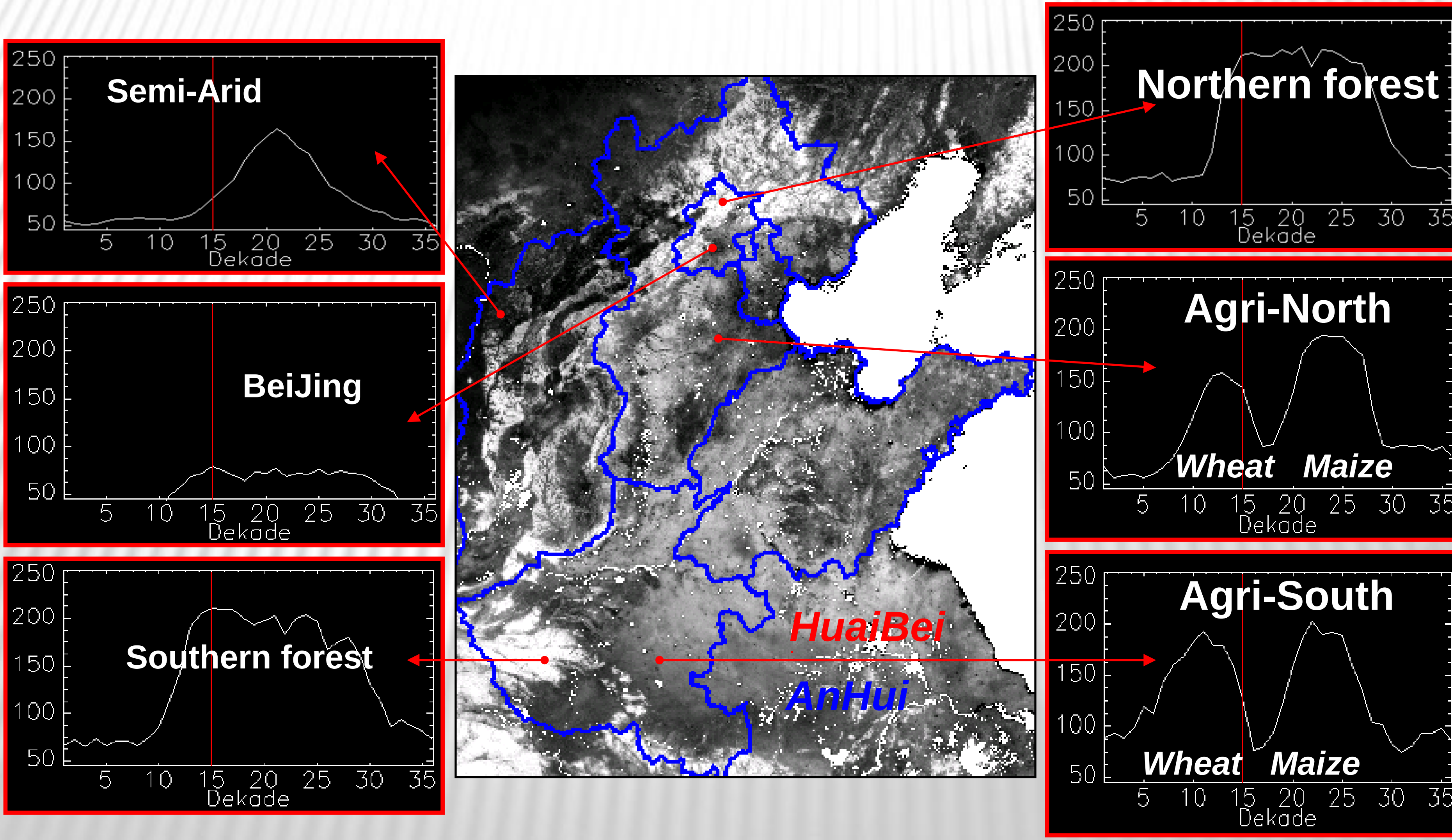
Smoothed

Original

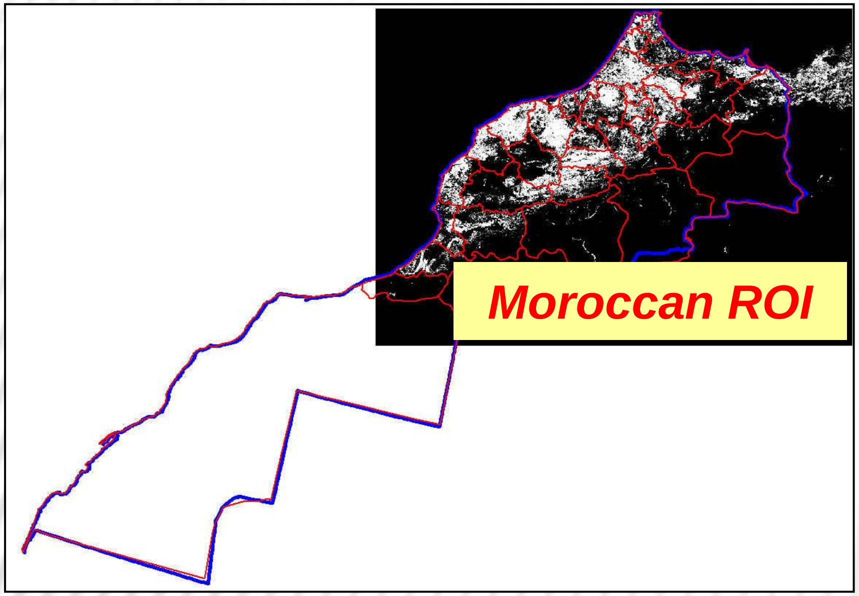


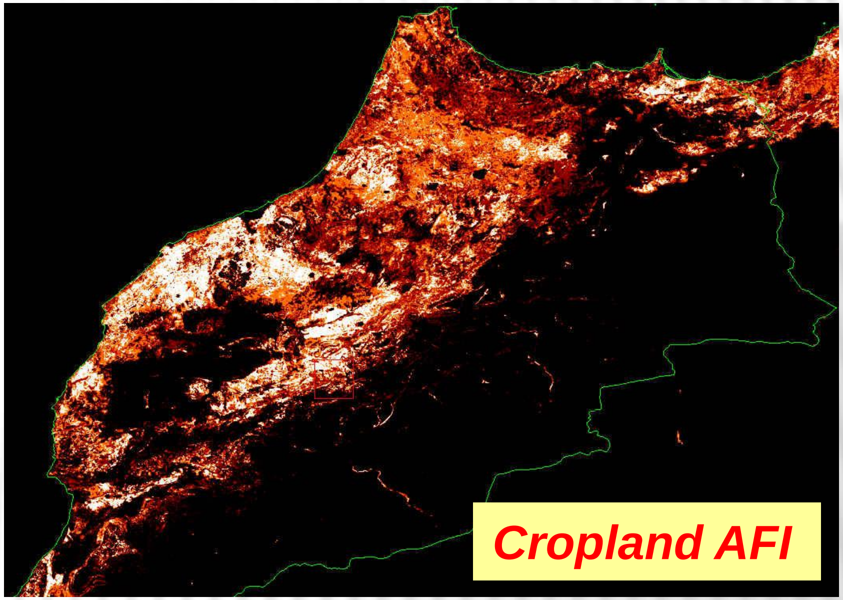
E-AGRI sites: HuaiBei-China - Phenology

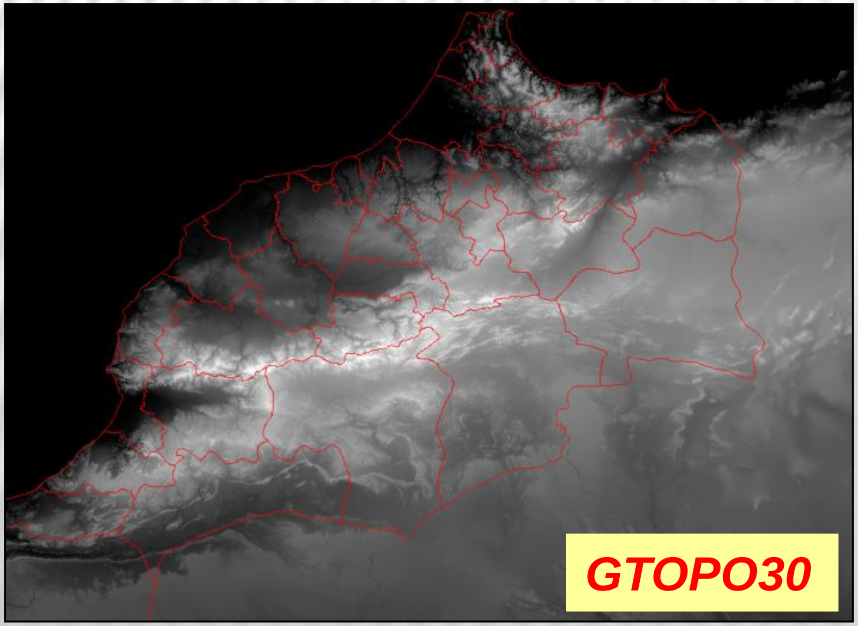
North China Plain: typical NDVI profiles

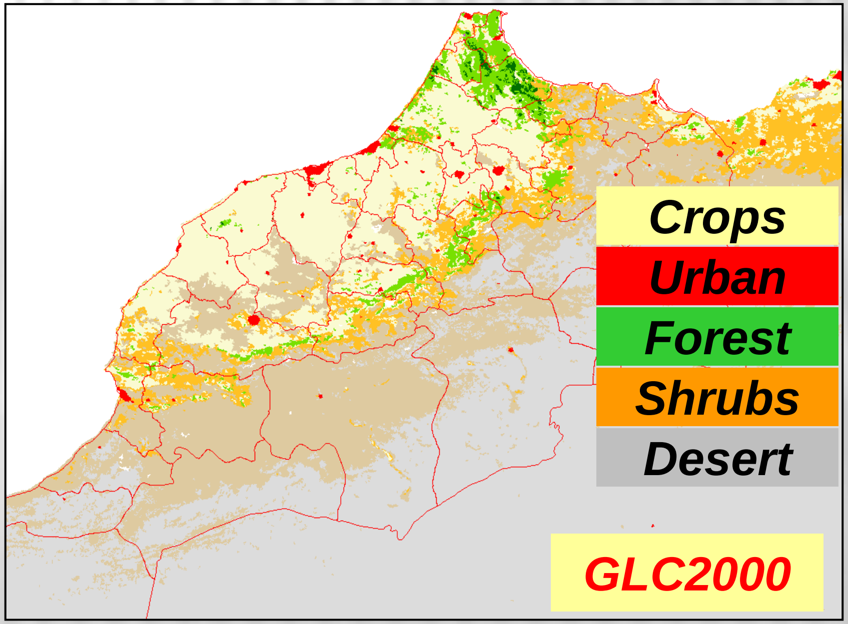


E-AGRI sites: Morocco

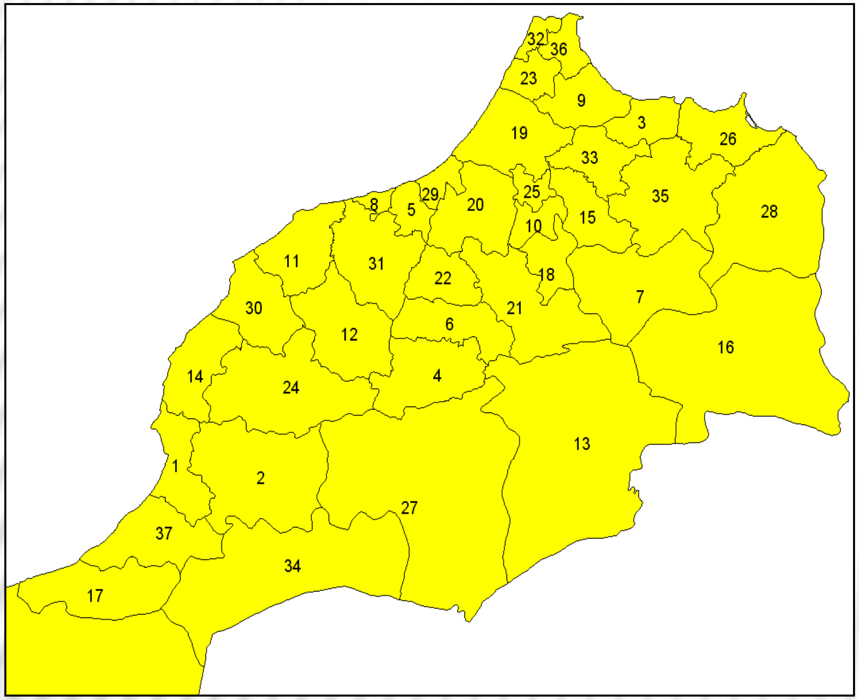








E-AGRI sites: Morocco



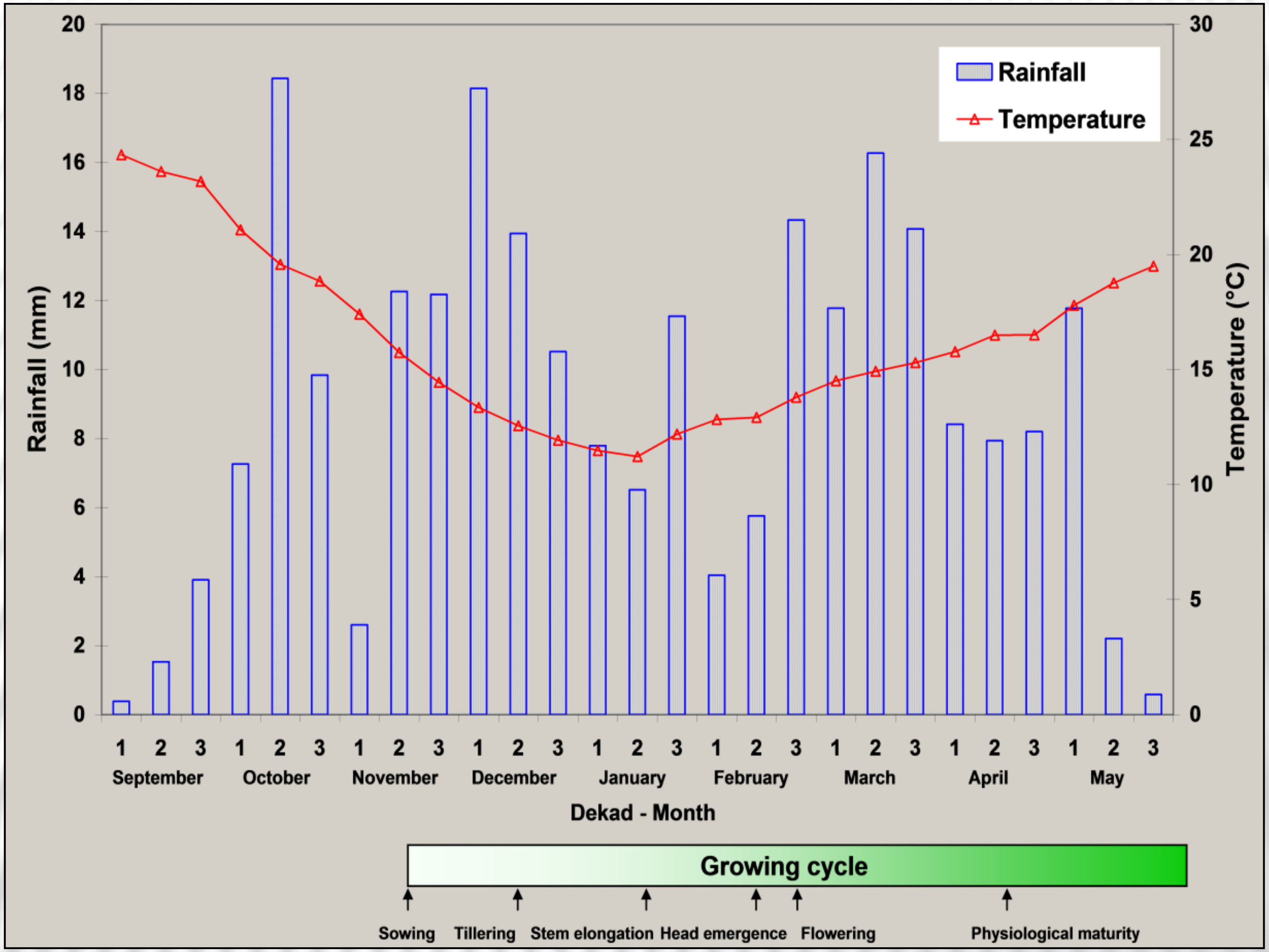
Official yield statistics for:

- *4 crops:*
    - *Durum wheat*
    - *Soft wheat*
    - *Barley*
    - *All autum-sown cereals*
- *32 years (1979-2010)*
- *38 provinces*

NB: Beware the Region_ID numbers

ID	NAME	ID	NAME	ID	NAME	ID	NAME
1	AGADIR	11	EL JADID	21	KHENIFRA	31	SETTAT
2	TAROUDAN	12	EL KELAA	22	KHOURIBG	32	TANGIER
3	AL HOCEI	13	ERRACHID	23	LARACHE	33	TAOUNATE
4	AZILAL	14	ESSAOUIR	24	MARRAKEC	34	TATA
5	BEN SLIM	15	FES	25	MEKNES	35	TAZA
6	BENI MEL	16	FIGUIG	26	NADOR	36	TETOUAN
7	BOULEMAN	17	GUELMIM	27	OUARZAZA	37	TIZNIT
8	CASABLAN	18	FRANE	28	OUJDA	38	LAAYOUNE
9	CHEFCHAO	19	KENITRA	29	RABAT		
10	EL HAJEB	20	KHEMISSE	30	SAFI		

E-AGRI sites: Morocco - Phenology



Phenology of wheat in Morocco .

February-March is the most crucial period for all cereals.

(figure provided by Riad Balaghi of INRA-Maroc).

E-AGRI sites: RUM-databases for HuaiBei & Morocco

ADMIN. REGIONS
- *Morocco:*
  - *37 Provinces*
  - *Country*
- *China:*
  - *6 districts*
  - *HuaiBei*

CROPLAND AFI

Select only pixels with 100% Cropland

VGT-IMAGES
- *432 dekads (12 years)*
- *5 variables*

RUM-database (example/extract)

Reg_ID	Year	Dek	i-NDVI	a-fAPAR	k-NDVI	b-fAPAR	y-DMP
1	1999	1	0.214	9.820	0.229	10.880	13.9
1	1999	2	0.231	11.690	0.242	11.820	14.2
1	1999	3	0.257	13.210	0.263	13.310	20.2
1	1999	4	0.266	14.130	0.279	14.570	22.2
1	1999	5	0.282	15.370	0.288	15.720	27.9
...	...	...	...	...	...	...	...
1	2010	36	0.277	16.520	0.298	18.100	35.0
37	1999	1	0.177	7.060	0.194	8.560	10.5
...	...	...	...	...	...	...	...
37	2010	36	0.341	19.970	0.344	19.910	21.5

E-AGRI sites: RUM-databases for HuaiBei & Morocco

Further database manipulations:

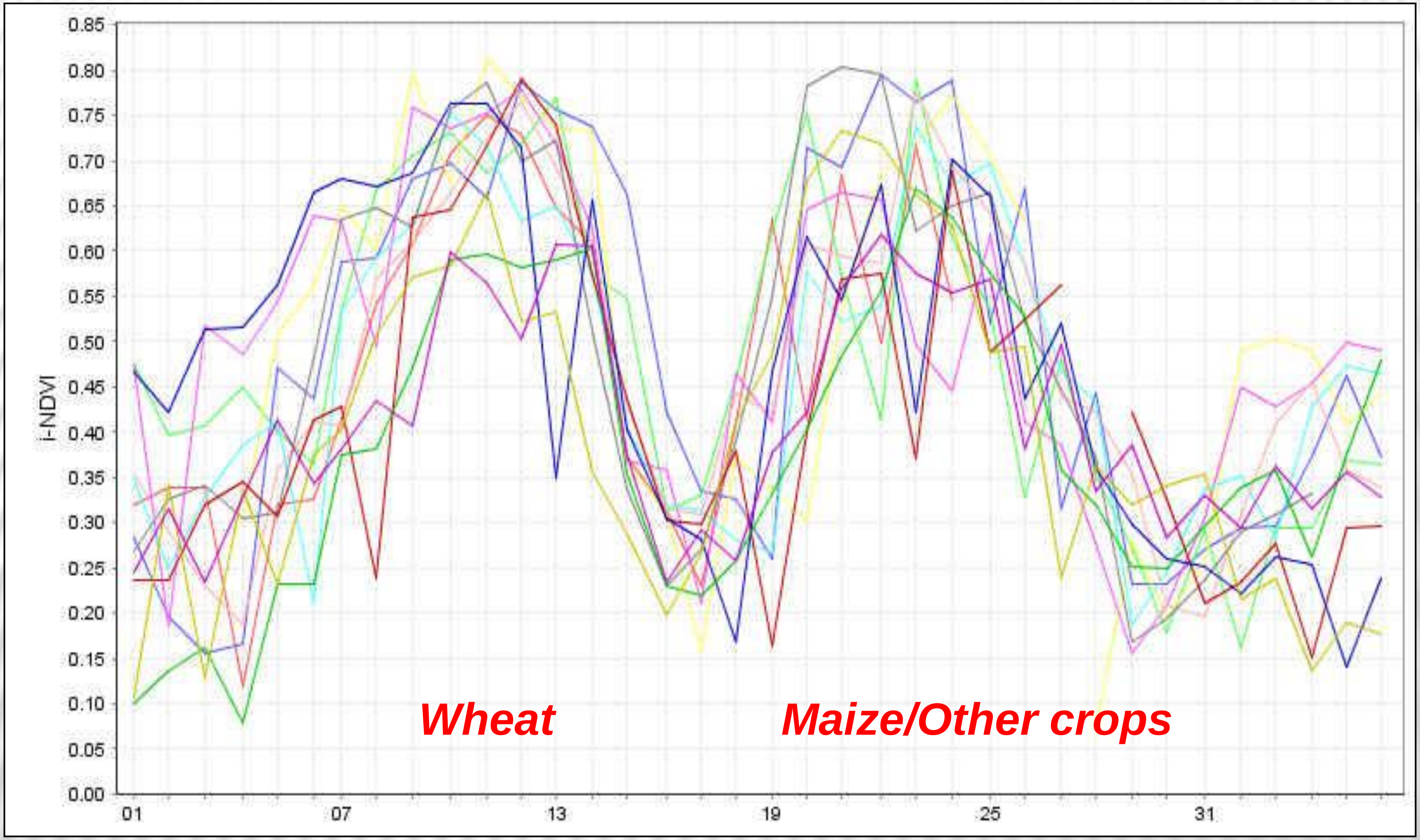
- *Inference of mean RUM-values over critical period (e.g. Feb.-March)*
- *Addition of official yields (Region_ID numbers!)*

Two examples

Reg_ID	Year	Mean k-NDVI Feb-Mar	Barley Yield Qx/ha
1	1999	0.300	4.1
2	1999	0.267	8.5
3	1999	0.308	8.6
...	...	...	...
37	1999	0.564	4.2
1	2000	0.222	7.1
...	...	...	...
37	2009	0.608	12.0
...	...	...	...
36	2010	0.526	17.7
37	2010	0.439	10.2

Year	February			March			Wheat Yield (100 x Kg/ha)		NDVI Feb.-March
	1	2	3	1	2	3			
2000	0.3530	0.3850	0.4150	0.4570	0.4890	0.5030	7.4		0.4337
2001	0.4920	0.4780	0.4450	0.4010	0.3650	0.3390	4.0		0.4200
2002	0.4900	0.5080	0.5050	0.5000	0.4850	0.4580	10.7		0.4910
2003	0.4060	0.4200	0.4320	0.4410	0.4570	0.4650	11.7		0.4368
2004	0.5190	0.5310	0.5450	0.5540	0.5550	0.5420	16.2		0.5410
2005	0.5060	0.5130	0.5240	0.5330	0.5330	0.5280	18.4		0.5228
2006	0.4580	0.4590	0.4680	0.4850	0.4930	0.4950	8.9		0.4763
2007	0.5070	0.5330	0.5530	0.5710	0.5800	0.5730	19.7		0.5528
2008	0.3710	0.4020	0.4190	0.4300	0.4250	0.4040	6.1		0.4085
2009	0.5220	0.5280	0.5340	0.5330	0.5100	0.4870	13.3		0.5190
2010	0.5390	0.5520	0.5600	0.5630	0.5600	0.5450	21.0		0.5532

E-AGRI sites: RUM-database for HuaiBei



RUM-profiles of the non-smoothed i-NDVI
for one of the counties in the HuaiBei zone.
The different lines represent the subsequent years (1999-2011).

E-AGRI sites: RUM-databases for HuaiBei & Morocco

CONCLUSIONS:

- *RUM-databases can be used for yield assessment:*
  - *Evaluation/validation of different procedures*
  - *Application to the current year*
- *Standarisation needed:*
  - *Format of tables with official statistics and RUM-values*
  - *Region_ID numbers (to avoid confusion!)*
- *Research topics*
  - *Which is best variable: i/k-NDVI, a/b-fAPAR, y-DMP?*
  - *Which dekad(s) in year must be considered $\approx$ critical period?*
  - *Work per province/district or directly on national level?*
  - *Etc.*

$\Rightarrow$ ***See other presentations***

Low resolution remote sensing data for crop yield assessment in the E-AGRI study areas of Morocco and HuaiBei-China

Herman Eerens, VITO-Belgium

vito
vision on technology

A. INTRODUCTION
1. VITO-TAP & MARSOP-project
2. Sensors & PRE-processing
3. POST-Processing & Products
4. SPIRITS software

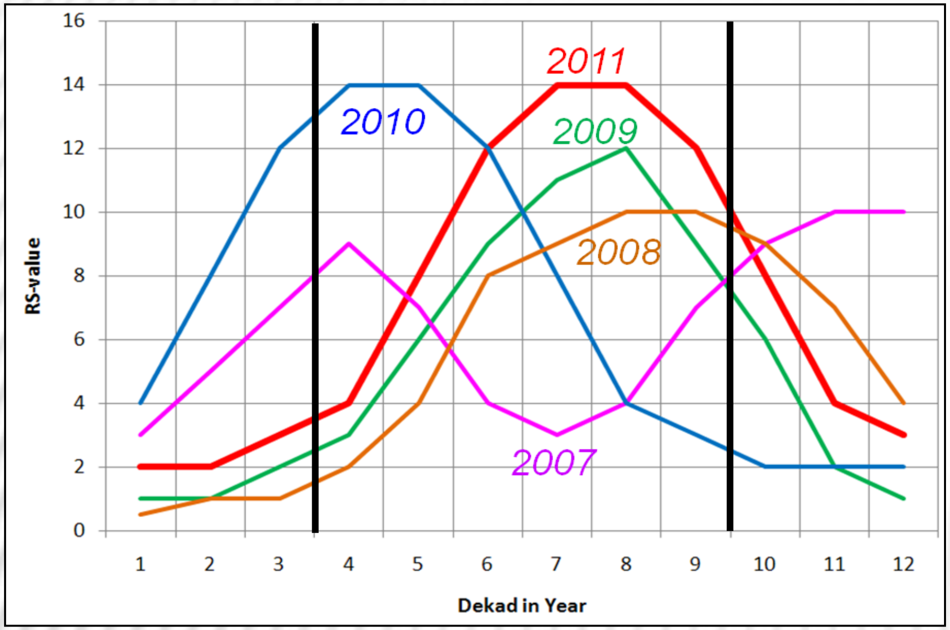
B. VGT-DATA FOR E-AGRI
1. HuaiBei
2. Morocco

C. SIMILARITY ANALYSIS for MOROCCO

D. CONCLUSIONS

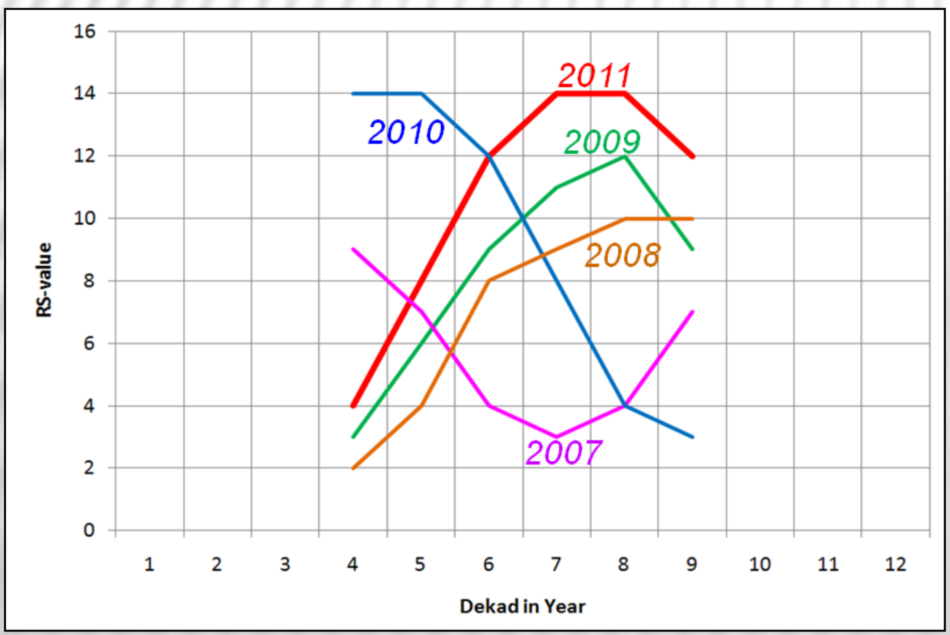
E-AGRI
E-Agriculture

SIMILARITY ANALYSIS: Principle



Pixel profiles
of any RS-variable (NDVI, fAPAR,…)
for different years

Dekads 4-9 = critical growth period



Basic version (no shifts)

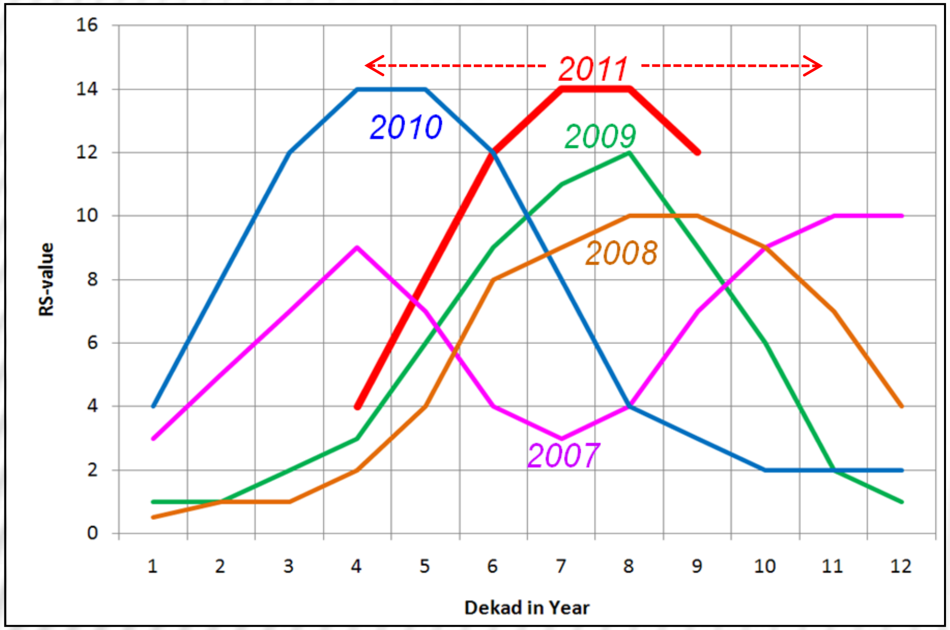
Compare "target year" (2011)
with other years.

Always compute RMSE.

Most similar year=with lowest RMSE

In this example: 2009

SIMILARITY ANALYSIS: Principle



Version with dekadal shifts

Compare "target year" (2011) with other years.

Shift target series (6 dekads) back- and forward over n dekads (here n=3)

Always compute RMSE.

Most similar year &shift = the one with lowest RMSE

*In this example: **similar year=2010, shift = -3** (i.e. 2011 is later than 2010)*

Underlying idea: account for inter-annual phenological shifts.

Program SIMILI:

- *Input images = time series of NDVI, fAPAR,… (different years/dekads)*
- *Critical period (e.g. February-March)*
- *Output images: most similar year, RMSE + optionally dekadal shift*

SIMILARITY ANALYSIS: Principle

MARSOP-EUROPE: Every dekad 16 similarity analyses:

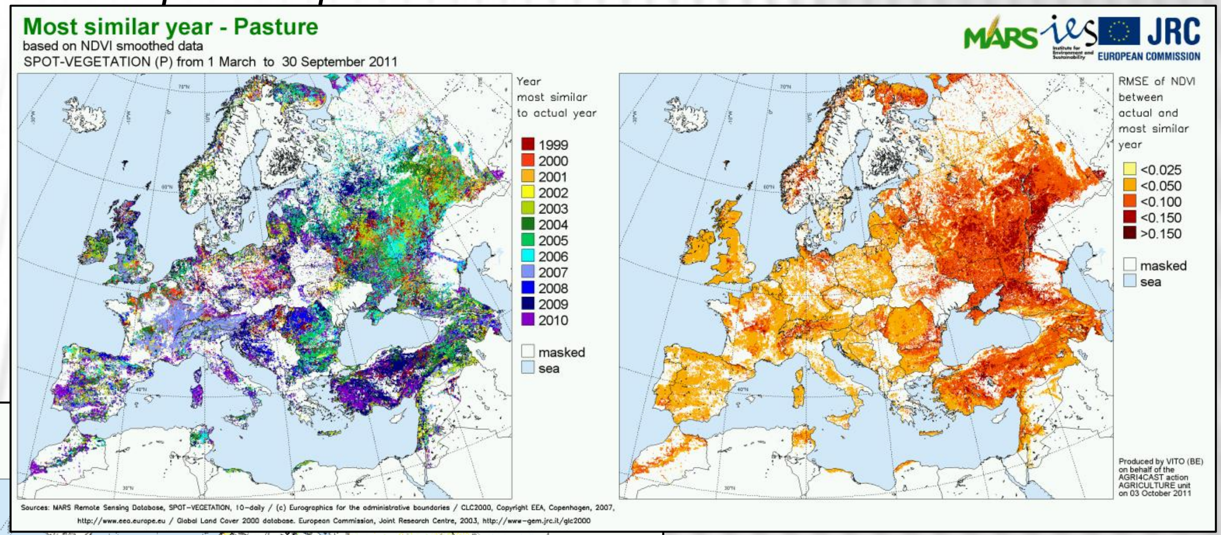
- *Time series from previous October/March → present*
- *Smoothed NDVI & fAPAR*
- *Without shifts and with shifts over ± 6 dekads*
- *Seperately for two subsets of pixels: cropland & pastures*

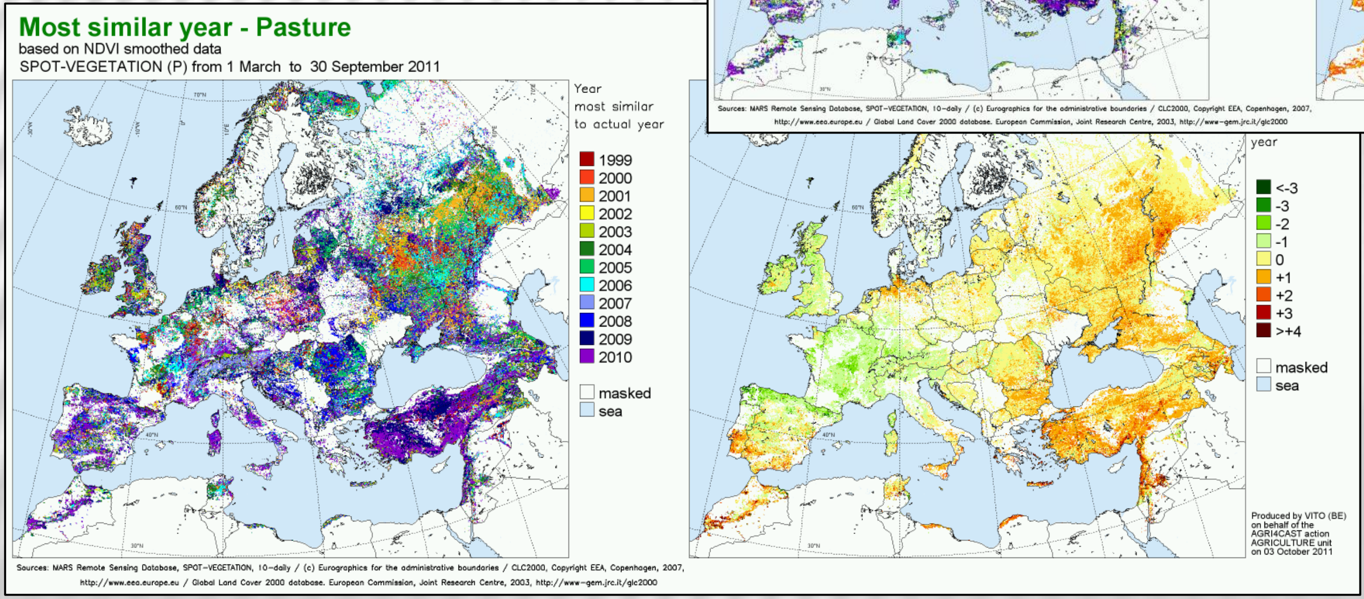
NDVI March to September

Pastures

No shifts

Most similar year & RMSE





NDVI March to September

Pastures

Shifts of ± 6 dekads

Most similar year & Shift

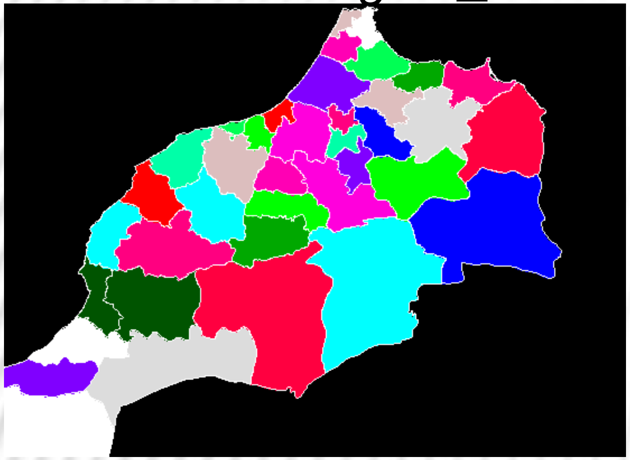
W.Europe: early

E.Europe: late

SIMILARITY ANALYSIS: Translation into yields

Program SIM2YLD: Three inputs

IMG with Region_IDs



Most similar year to 2010

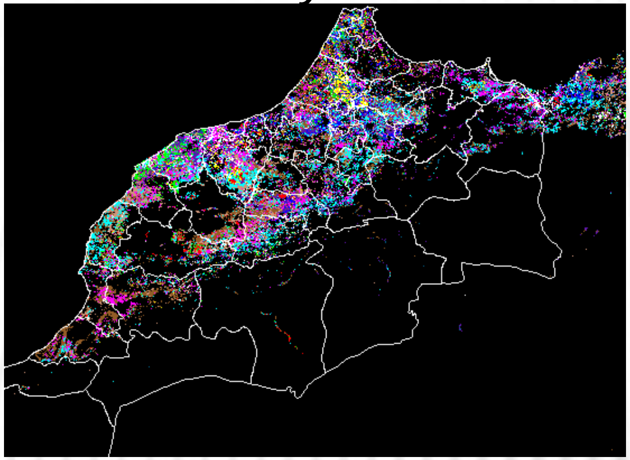


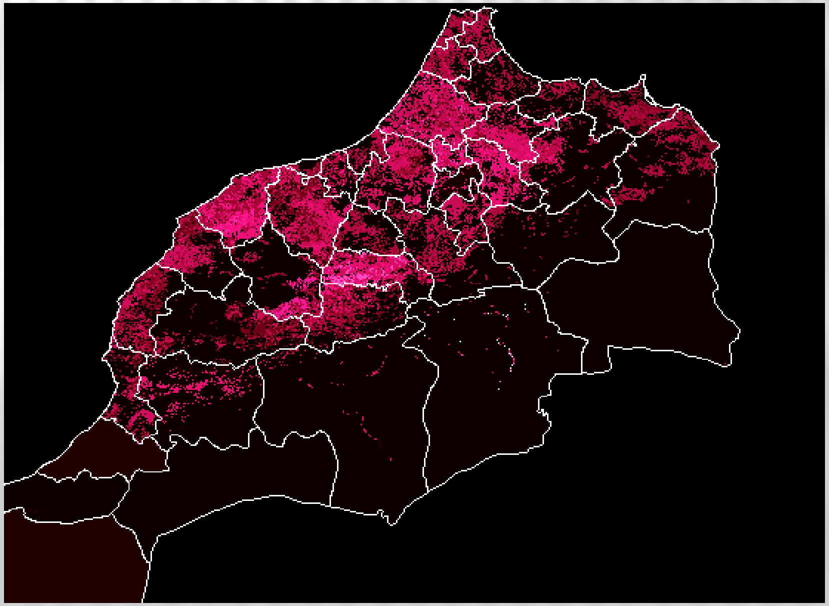
Table with Crop Yields

Reg_ID	Year	Yield
1	1999	4.1
2	1999	8.5
...	...	...
37	1999	4.2
1	2000	7.1
...	...	...
37	2009	12.0
...	...	...
37	2010	10.2

One output image:

Estimated yield per pixel

- *For concerned crop (see table)*
- *For concerned year (2010) = "Target year" of SIMILI*



SIMILARITY ANALYSIS: Two application modes

A. Yield forecasting for current year

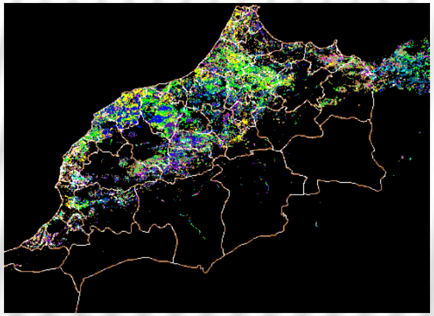
- *Apply SIMILI on images of current year (= “target year”)*
- *SIM2YLD gives crop yields per pixel, using statistics of previous years*
- *Derived RUM-databases give mean yield per province/district*

B. Testing & Evaluation

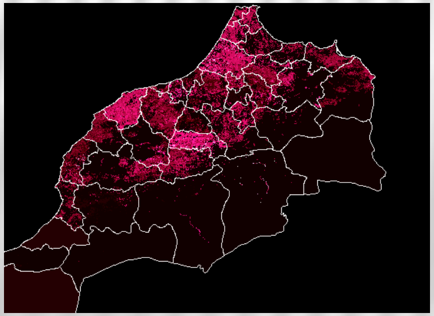
- *Repeat SIMILI and SIM2YLD for all available years*
- *Extract RUM-databases*
- *Compare estimated vs. official yields (linear regression & R^2)*

1999

Most similar year

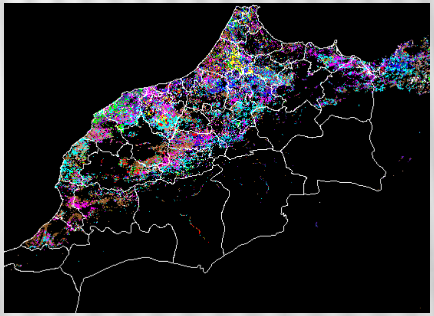


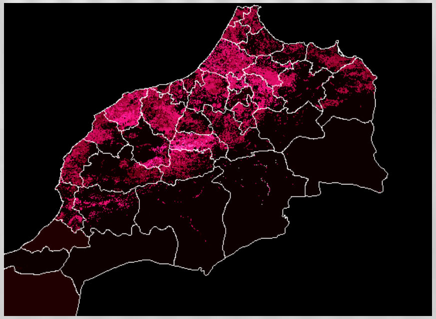
Estimated Yield Durum wheat



Idem for years 2000-2009

2010





SIMILARITY ANALYSIS: Example of yield forecasting

GMFS Global Monitoring for Food Security

Crop Yield and Vegetation Monitoring

Nairobi 26/10/2011 http://www.gmfs.info

Yield Estimation based on Low Resolution Monitoring

Context: Non Parametric Yield Forecast
Similar Years to Yield estimate

Similarty Analysis :
- CROP MAP !
- for each pixel the most similar year is found
-Display classified map
-Per ADMIN percentage

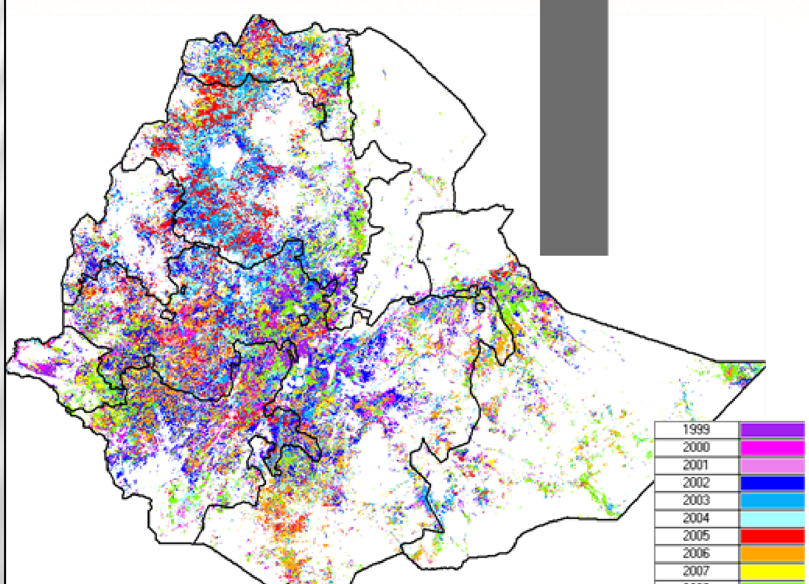


TABLE1: Percentage of similar year to 2009 per administrative area

		1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	
Addis Ababa	ETH001	10%	9%	0%	8%	14%	8%	6%	10%	10%	23%	100%
Amhara	ETH003	7%	2%	1%	12%	23%	19%	21%	2%	6%	8%	100%
Harari	ETH007	36%	3%	9%	2%	25%	4%	0%	8%	12%	2%	100%
Oromiya	ETH008	9%	4%	8%	17%	11%	13%	9%	13%	7%	9%	100%
Somali	ETH009	6%	4%	8%	9%	9%	10%	4%	15%	4%	31%	100%
Southern	ETH010	10%	5%	7%	20%	7%	10%	8%	12%	6%	15%	100%
Tigray	ETH011	4%	2%	1%	11%	20%	17%	17%	6%	15%	6%	100%

TABLE2: WHEAT yield statistics from CFSA

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Addis Ababa	11.97	11.69	11.815	11.94	12.45	18.71	17.32	13.87	17.32	13.87
Amhara	7.38	9.4	10.36	8.87	12.93	14.5	15.24	15.94	15.24	15.94
Harari	6.08	6.37	12.43	6.37	12.43	12.43	12.43	11.16	12.43	11.16
Oromiya	13.23	13.27	14.12	12.04	18.82	17.02	18.17	17.64	18.17	17.64
Somali	7.73	4.9	5.2	7.98	16.27	9.55	7.32	4.46	7.32	4.46
South Gonder	5.59	6.28	7.31	8.91	8.78	7.54	8.48	10.41	8.48	10.41
Tigray	10.3	8.95	9.78	6.56	13.15	9.79	13.32	14.79	13.32	14.79

TABLE3 = TABLE1 X TABLE2: Test of calculation of the estimated WHEAT yield for 2009

		1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	Calculated yield for 2009
Addis Ababa	ETH001	1.25	1.07	0.00	0.98	1.73	1.48	1.10	1.45	1.81	[illegible]	14.08
Amhara	ETH003	0.49	0.15	0.08	1.10	2.91	2.71	3.25	0.32	0.98	[illegible]	13.21
Harari	ETH007	2.20	0.18	1.09	0.14	3.07	0.48	0.00	0.92	1.43	[illegible]	9.70
Oromiya	ETH008	1.13	0.57	1.12	2.07	2.12	2.14	1.57	2.27	1.33	[illegible]	15.97
Somali	ETH009	0.46	0.22	0.40	0.72	1.51	0.91	0.31	0.68	0.26	[illegible]	6.85
Southern	ETH010	0.53	0.34	0.52	1.80	0.65	0.77	0.65	1.21	0.49	[illegible]	8.53
Tigray	ETH011	0.45	0.18	0.09	0.71	2.65	1.71	2.24	0.90	2.04	[illegible]	11.87

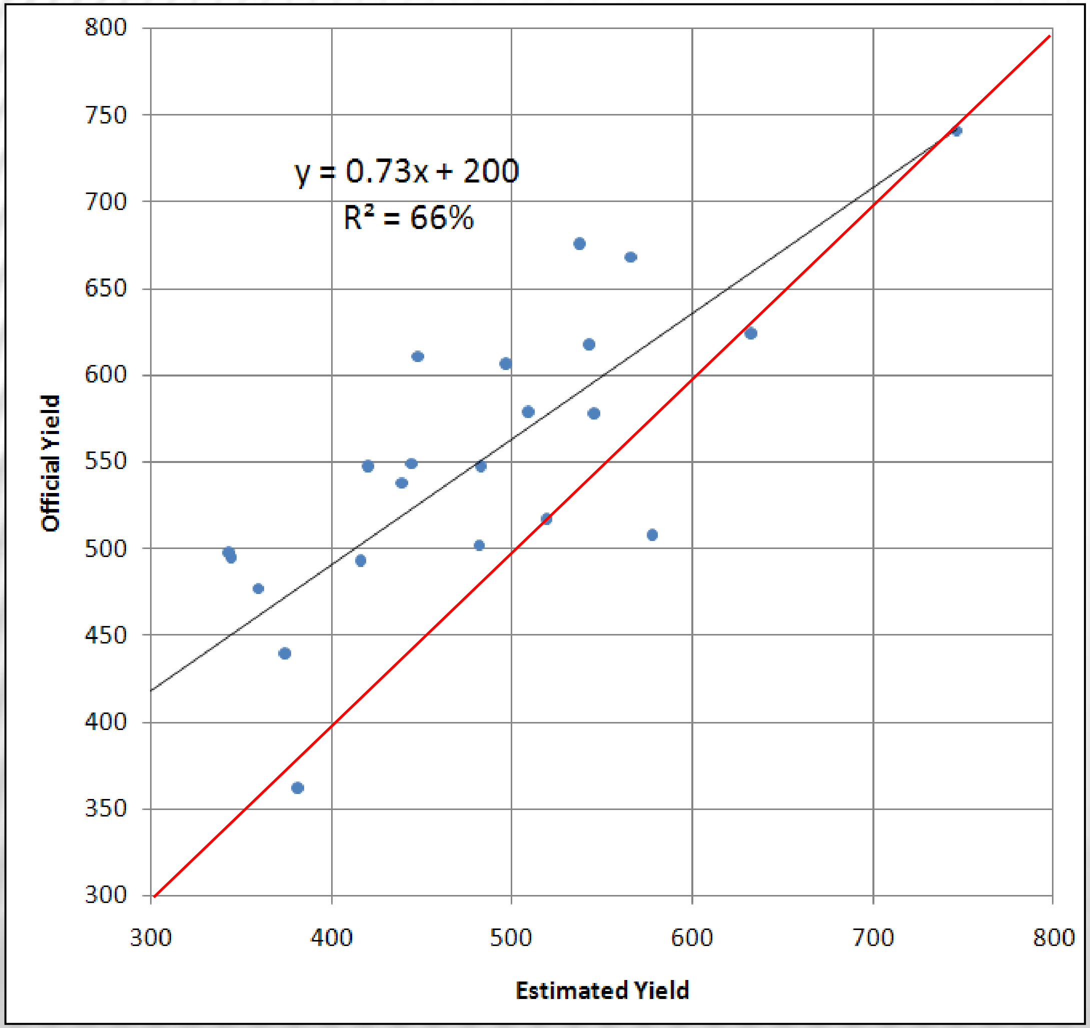
Source: Sven Gilliams (GMFS)

SIMILARITY ANALYSIS: Example of evaluation for 1 year

Millet yield in 2010 for 23 Level2 administrative regions in Niger

Based on SPOT-VGT (1999-2010) + crop mask

+ Comparison with official yields of 2010



Good relationship (R^2=66%)

Better than standard regression approaches.

But underestimation!

Can be corrected via this regression.

Source: Antoine Royer (GMFS) & Djabi Bakary (Ulg)

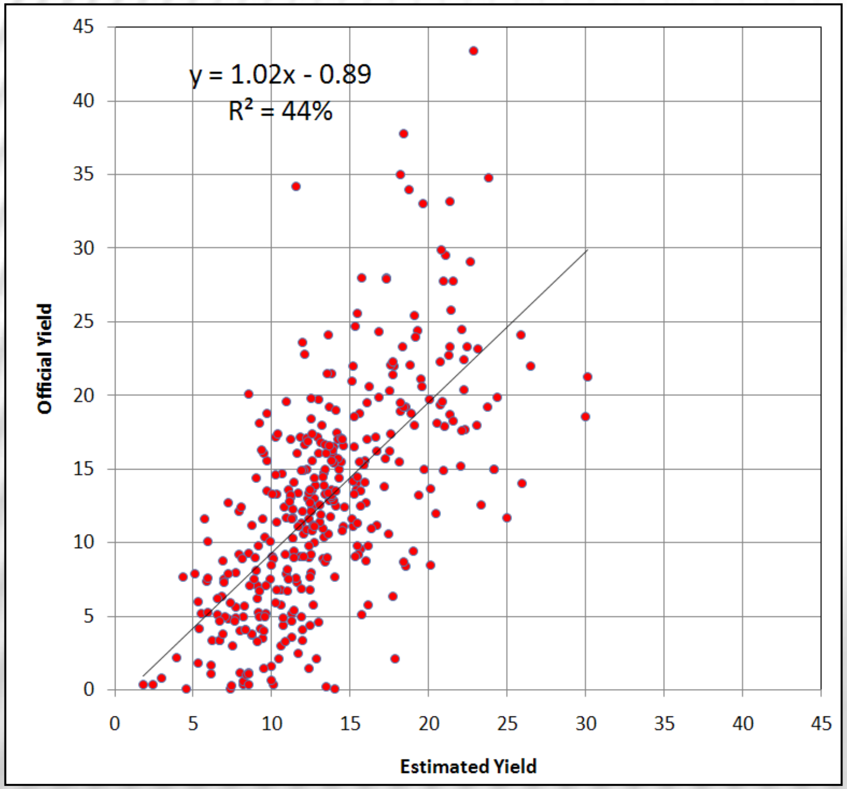
SIMILARITY ANALYSIS: Results for Morocco

SIMILI for 12 years of k-NDVI (1999-2010), only 100% cropland pixels

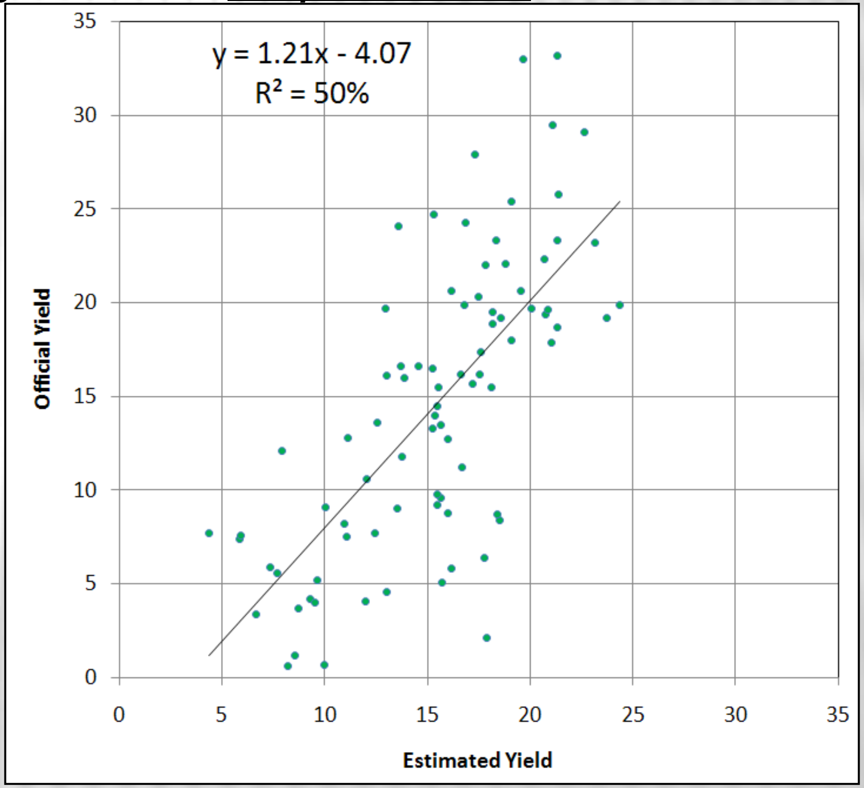
Target series = February-April (9 dekads), shift allowed of ± 3 dekads

SIM2YLD for DURUM WHEAT

RUM-database with mean estimated yields for 37 provinces



All 37 provinces



7 most productive provinces

NB: Regression ≈ Diagonal

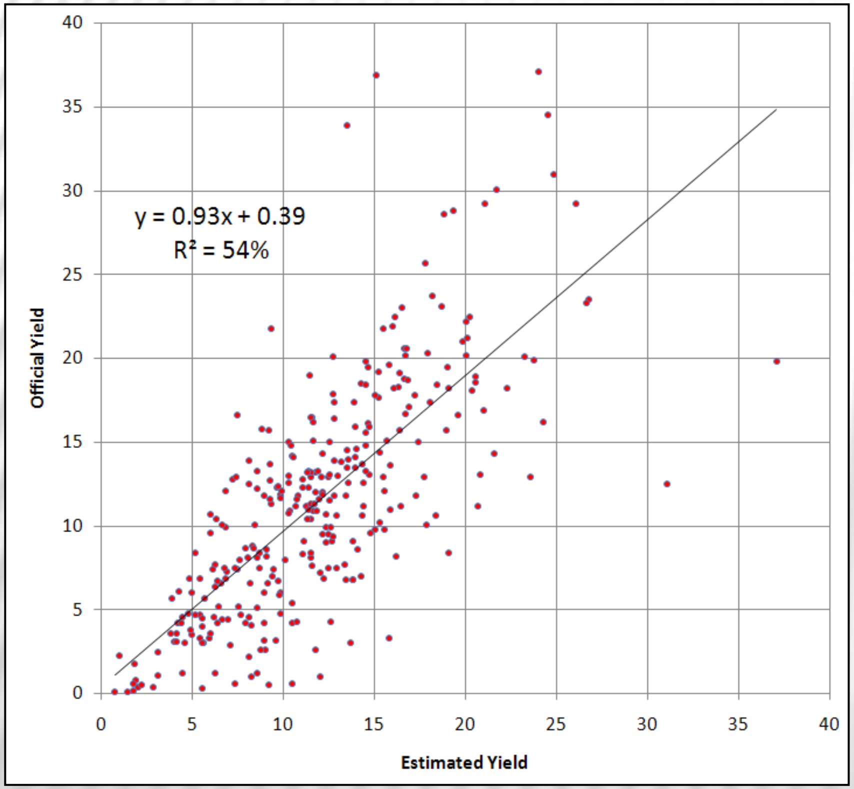
SIMILARITY ANALYSIS: Results for Morocco

SIMILI for 12 years of k-NDVI(1999-2010), only 100% cropland pixels

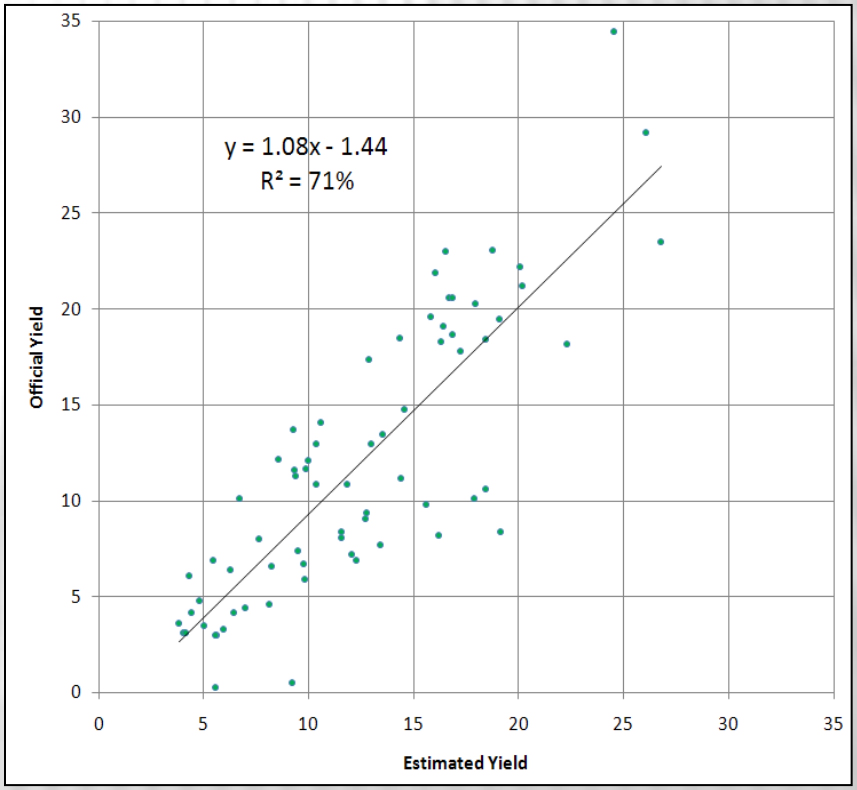
Target series = February-April (9 dekads), no shift allowed

SIM2YLD for AUTUMN CEREALS

RUM-database with mean estimated yields for 37 provinces



All provinces



7 most productive provinces

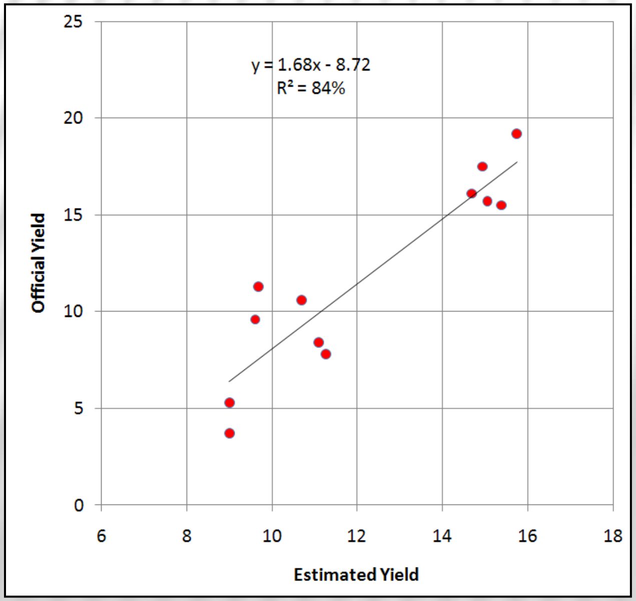
NB: Regression ≈ Diagonal

SIMILARITY ANALYSIS: Results for Morocco

SIMILI for 12 years of k-NDVI(1999-2010), only 100% cropland pixels
Target series & shifts: variable
SIM2YLD for 4 different crops
RUM-database with mean estimated yields at NATIONAL LEVEL

R^2-values in % (true vs. Estimated yields)

SHIFT	NONE		± 3 DEKADS	
CROP	FEB-MARCH	FEB-APRIL	FEB-MARCH	FEB-APRIL
Durum wheat	68	76	70	***82***
Soft wheat	68	76	67	***78***
Barley	61	***81***	59	72
Aut. cereals	72	***84***	65	80



Autumn cereals

Feb-April, no shifts

R^2=84%

NB: Regression ≠ Diagonal

SIMILARITY ANALYSIS: Results for Morocco

National level
4 crops merged

$R^2 \approx 75\%$

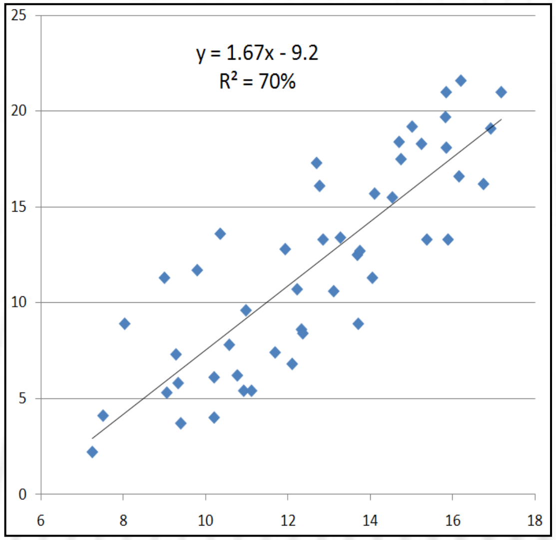
February-March

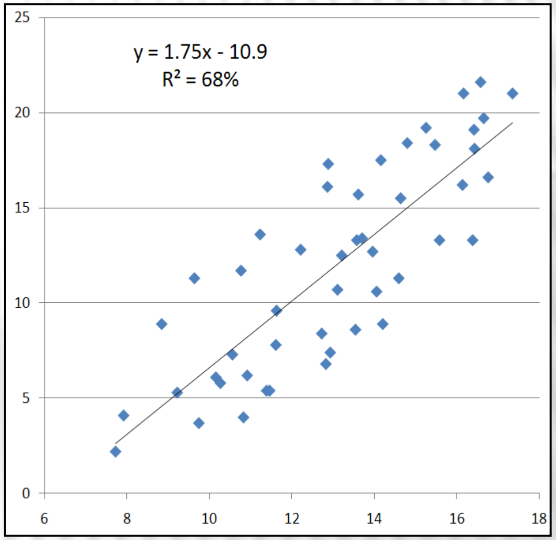
Always: Offcial vs. Estimated Yield

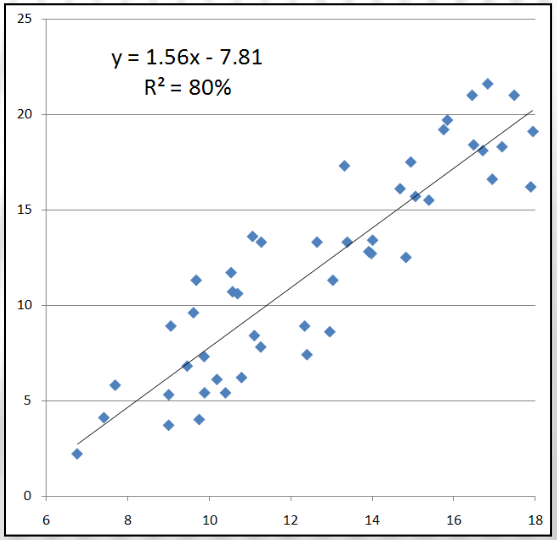
February-April

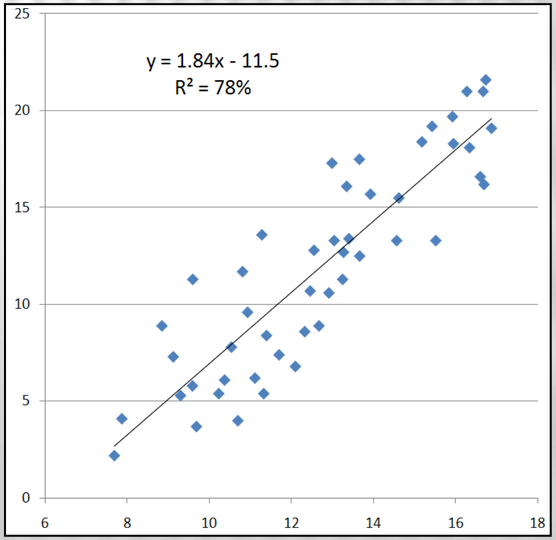
No shifts

Shifts of ± 3 dekads









NB: Regression line $\neq$ Diagonal

SIMILARITY ANALYSIS: Some conclusions

PRO:

- Simple, intuitive and straightforward approach
- Sequence of 3 image operation: SIMILI, SIM2YLD, RUM-extraction
- No “higher statistics” needed
- Some satisfied users: GMFS, Niger, Belgium, …

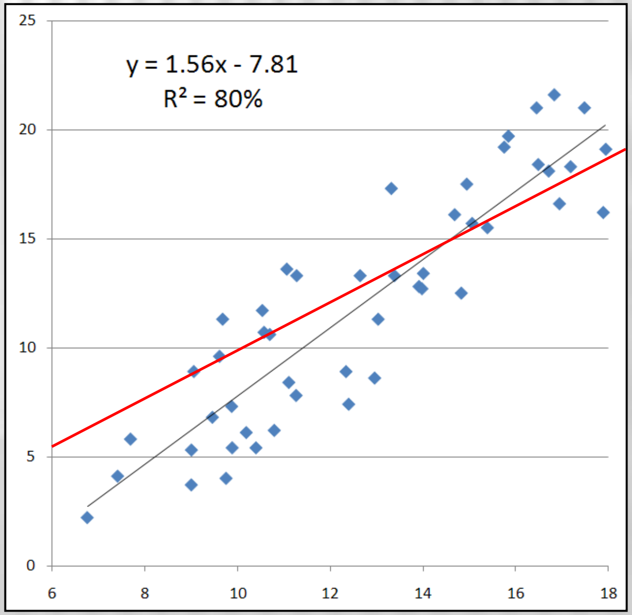
CONTRA:

- Less accurate than classical approach ??? (see Riad B.)
- By definition: yield forecasts are limited to MIN/MAX of official yields

  $\Rightarrow$ If current year is exceptionally bad/good

  $\Rightarrow$ This also explains why regression line $\neq$ diagonal

  $\Rightarrow$ Overestimation for bad cases, underestimation for good cases



Improvements of the procedure

- weight the years ≈ RMSE
- use detrended official yield data

Low resolution remote sensing data for crop yield assessment in the E-AGRI study areas of Morocco and HuaiBei-China

Herman Eerens, VITO-Belgium

CONCLUSIONS

1. **Via JRC/VITO MARSOP3-project**
   - Image archives of VGT, NOAA, METOP, MODIS, MSG
   - Capacity to quickly extract all data of new ROIs
2. **SPIRITS software**
   - All analyses on time series of images
   - Basic input data: JRC, VITO, GeoNetCast
   - Release: September 2012 (+manual/tutorial), freely available
3. **E-AGRI**
   - Data prepared for Morocco and HuaiBei (first attempt)
   - Future: more sensors, Kenya,…?
   - More official yields needed for HuaiBei
   - Standardisation needed for official yields (add Region_ID)
   - Improve AGRO-mask→ crop/year-specific (≈ area estimates)
4. **SIMILARITY ANALYSIS**
   - Use NOAA-AVHRR: since 1981 but lower quality (more gaps)
   - Improvements of the procedure
   - Compare with outcomes of regression-method, CGMS,…

E-AGRI – Workshop, Rabat 12-14 October 2011
Crop Yield Forecasting based on Remote Sensing

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A. INTRODUCTION
1. VITO-TAP & MARSOP-project
2. Sensors & PRE-processing
3. POST-Processing & Products
4. SPIRITS software

B. VGT-DATA FOR E-AGRI
1. HuaiBei
2. Morocco

C. SIMILARITY ANALYSIS for MOROCCO

D. CONCLUSIONS

Thank You