Global Monitoring with LoRes EO-Imagery
Time Series Analysis with SPIRITS software

1. VITO’s Remote Sensing Centre (TAP)
2. EU-MARS: Global Agricultural Monitoring
3. FAO-ASIS: Global Drought Monitoring
4. SPIRITS: Introduction & Overview
5. SPIRITS: Some practical exercises
EUROPEAN UNION

BELGIUM

EU-JRC
European Union Joint Research Centre
Ispra - ITALY

UN-FAO
Food and Agriculture Organisation
Rome - ITALY
FLANDRES (Dutch 55%)
WALLONIA (French 35%)

BELGIUM
Area: 30 000 km²
Population: 11 M

BRUSSELS
(200 languages 10%)

EAST
(German)
VITO = Research Institute of Government of FLANDRES Region
- 800 staff members
- 8 “Centres of Expertise”
- Headquarters in MOL (+ 4 other distributed sites)
- Budget 2014: 150 M€ (30% subsidies from government)
VITO-TAP = Centre for Remote Sensing

- 80 staff members
- Budget 2014: 15 M€ (15% subsidies from government)
VITO-TAP: Three Major Domains

**TECHNOLOGY**
- New sensors & platforms
- Flight organisation

**GEODATA**
- CTIV= Centre de Traitement d’Images VEGETATION)
- Pre-processing of raw images (Low → High Resolution)
- Data archiving
- Data dissemination

**APPLICATIONS**
- Extraction of dedicated image information ≈ objectives
- Client-oriented projects (agri-environment)
- Capacity building & training

+ SOFTWARE DEVELOPMENT at all LEVELS
## EO-Data & Scale of Applications

<table>
<thead>
<tr>
<th>RESOL.</th>
<th>VERY LOW</th>
<th>LOW</th>
<th>MEDIUM</th>
<th>HIGH</th>
<th>VERY HIGH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pixel size</td>
<td>±5 km</td>
<td>±1 km</td>
<td>250-500m</td>
<td>20-30m</td>
<td>1-5m</td>
</tr>
<tr>
<td>Frequency</td>
<td>±hour</td>
<td>±1 day</td>
<td>±2 days</td>
<td>2-3 weeks</td>
<td>on demand</td>
</tr>
<tr>
<td>Image size</td>
<td>Earth Disk</td>
<td>2000-4000km</td>
<td>1000-2000km</td>
<td>60-300km</td>
<td>10-20km</td>
</tr>
<tr>
<td>Examples</td>
<td>Geostationaries: MSG...</td>
<td>SPOT-VGT, NOAA-AVHRR</td>
<td>MODIS PROBA-V</td>
<td>Landsat-TM Awiffs, DMC</td>
<td>IKONOS, Quickbird</td>
</tr>
</tbody>
</table>

### Scales:
- **Global** ← **Continental** ← **National** ← **Regional** ← **Field**
POST-PROCESSING
• Thematic analyses & applications
• Monitoring of vegetations/forests/crops
• LU-mapping and area estimation
• Carbon sequestration & Yield forecasting
Global S10 of SPOT-VGT:
- Every 10 days (dekad) a new image
- Global, at 1 km resolution
- April 1998 → May 2014 (> 15 years)

P-Product: partly processed segment

- High accuracy
- Wide user community
- Many applications
**PROBA–V = Follow–up of SPOT–VEGETATION**

- Low budget, sponsored by ESA & BELsപo
- Developed by Belgian companies, maintained by VITO
- Operational since November 2013
- Same features (spatial, spectral) & products as SPOT–VGT
- But three resolutions: 1km, 333m, 100m
Spatial and spectral similarity with VGT

1km → Continuation of SPOT-VGT

300m → Continuation of MODIS/MERIS

100m → Global monthly NDVI-composites
      → NDVI December 2013 (55 GB)
      → Global & dynamic crop mapping!

Zoom on Rice Fields

Mekong Delta - Vietnam
Copernicus Initial Operations

Global Land Service

- Timely production of 14 Global, Biophysical parameters (Vegetation, Radiation, Water)
- Many European partners.
- Data processing, dissemination & archiving by VITO.

Satellite data
Input

Processing and
Archiving

Product
Dissemination

• Timely production of 14 Global, Biophysical parameters (Vegetation, Radiation, Water)
• Many European partners.
• Data processing, dissemination & archiving by VITO.
Aerial photography for Flanders
  • Flights & data acquisition
  • Mobile mapping
  • Storage & analysis (changes)

Hyperspectral domain:
  • Camera development (APEX, MEDUSA)
  • Flights & data acquisition
  • Storage, analysis & distribution

Unmanned Aerial Systems (UAS, drones)
  • Full system development
  • Flights & data acquisition
  • Legal issues
  • Storage & analysis (field-level)
Airborne Campaigns @ VITO
On-going development of PROBA-V2 (alias “GLOBAL-V”)

- Sino-Belgian co-operation (RADI, VITO)
- Focus on 100m, daily, global
- Vis/NIR (VITO) + TIR (China)

Conclusions:

- Developments by TECHNOLOGY
- Daily operation by GEODATA (CTIV)
- Additionally:
  - Data centre with PB capacities
    (1 PB = 1000 TB)
  - Data distribution portals
  - Processing on demand (POD)
  - All data available for APPLICATIONS
Data ingestion & distribution via GEONETCAST

- **Accra, Ghana**
- **Cordoba, Argentina**
- **VITO, Belgium**
VITO-TAP: Three Major Domains

TECHNOLOGY
- New sensors & platforms
- Flight organisation

GEODATA
- CTIV= Centre de Traitement d’Images VEGETATION)
- Pre-processing of raw images (Low → High Resolution)
- Data archiving
- Data dissemination

APPLICATIONS
- Extraction of dedicated image information ≈ objectives
- Client-oriented projects (agri-environment)
- Capacity building & training

+ SOFTWARE DEVELOPMENT at all LEVELS
Focus of this presentation:

• Low Resolution (250m to 5km) but High Frequency
• Spatial Domain: Regions, Continents, Globe
• Two major examples: JRC–MARS and FAO–ASIS
• See later for more details!

Other related activities mentioned for completeness:

• Local applications
• Software development
• Capacity building
• Activities in High Resolution domain
Local Activities in many Countries

- Africa: Kenya, Senegal, Niger, Mozambique, Morocco, ...
- Asia: China, Vietnam,…
- Europe: Belgium, Netherlands, France, Ukraine, Russia, …
• Desert Locust prefer green vegetation
• Satellite products to identify greening areas
• Support FAO and regional analysts
Water quality: Estimation of…
- Suspended particulates
- Chlorophyll
- Dissolved organic matter

Coastal management

Nature conservation
- Habitat mapping
- Forest inventories
- Biodiversity

Agriculture
- Monitoring at field level
- Precision farming
- Disease management
- Estimation of damages (hail, …)
APPLICATIONS: High Resolution (Local)

Crop monitoring at field level:

- Coverage %
- Time series of DMC–Deimos
- Validated with UAV images

Field observations

UAV (2cm)

DMC (22m)
Software development:

- **VGExtract**: Adaptation/reformat of SPOT–VGT syntheses
- **MSG ToolBox**: Pre-processing of MSG data from LandSAF
- **GLIMPSE & SPIRITS**: Generic processing of time series
Others:

- Capacity building & Training sessions
- Websites & WIKIs
- Dedicated data portals
Global Monitoring with LoRes EO-Imagery Time Series Analysis with SPIRITS software

1. VITO’s Remote Sensing Centre (TAP)

2. **EU-MARS**: Global Agricultural Monitoring

3. FAO-ASIS: Global Drought Monitoring

4. SPIRITS: Introduction & Overview

5. SPIRITS: Some practical exercises
**MARS = Monitoring Agricultural Resources**

**Definition:**
- EU-initiative, started in 1989
- Objectives:
  - Standardise AGRO-statistics amongst (always new) EU-states
  - Introduce new techniques (RS, GIS, GPS, …)
- Formerly called “Monitoring Agriculture with Remote Sensing”
- Many sub-actions:
  - Crop yield estimation per administrative region
  - Crop area estimation → area/point frame samplings
  - Control of farmer declarations for area-based primes

**Focus here: Crop monitoring per administrative region**
- Final objective (per region/crop): Production = Area x Mean Yield
- Areas are fixed (too difficult to monitor changes on global scale)
- Estimate Mean Yield per region/crop
- Productions needed for all political decisions
  ≈ import/export, humanitarian aid, …
Overview: Regional crop yield estimation

1. General approach
2. Input data: S10–composites from RS and ancillary info
3. Basic improvements: Flagging, smoothing, …
4. Derived, final information
5. Conclusions
MARS: General approach of EC-JRC

JRC 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
Remote Sensing

Introduction

The remote sensing component of the MCYFS basically involves four actions:

- Data collection: Systematic acquisition of the raw imagery of a number of earth observation (EO) satellites, typically with low resolution but high repetitively.
- Preprocessing: Correction of the raw images for radiometric, atmospheric and geometric effects, and composition of all the corrected images to 10-day to 1-day (or daily) synthetic images (SD)
- Postprocessing: Extraction from the preprocessed SDs of valuable information useful for vegetation and crop monitoring.
- Analysis: Use of this information in the final analysis and decision processes concerning crop monitoring.

Over the years, the systematic ingestion and processing of all the EO data gave rise to a number of "time series" of images, with continuous coverage and daily frequency. In the MCYFS, the series are systematically extended and every day a new set of products is added in real-time (RT). The MCYFS uses the image series in three different ways:

- Qualitative analysis: The mere display of the imagery immediately gives an overview of the general state of the vegetation in a certain area and period. This information is often useful to confirm, adjust, or refute the decisions based on the growth modeling approach.
- Imagery-derived indications can be included in the statistical yield forecasting process.

Sensors

In line with the objectives of JRC-MARS, the remote sensing data must cover Europe and have to be updated at least every ten days to allow monitoring of the relatively fast crop growth dynamics. In the MCYFS, all remote sensing products focus on this ten-day or daily step. Currently, only two types of EO systems can fulfill these requirements:

- Near-polar orbiting satellites equipped with parabolic wide-angle sensors, such as NOAA/AVHRR, SPOT-Vegetation and Terra/A MODIS. These systems provide daily global coverage, at a coarse resolution of about 1 km (250m for MODIS).
- Geostationary satellites, which are fixed above a certain point on the equator, at an altitude of about 36,000 km. MSG (Meteosat Second Generation) hangs above the point with zero longitude and systematically scans the exposed part of the earth surface, mainly Africa and Europe. The image frequency is high (15-30 minutes) but due to the distance, the spatial resolution is very low (3 km per pixel).

In practice, the MCYFS exploits the data of the five different EO systems, listed in the table below.

The processing of the EO data is organized in two parts, namely the pre- and the post-processing.

- Pre-processing: Involves all steps between acquisition of the raw registrations (often called "segments") and the delivery of fully corrected composite images, with a daily (S) or most often 10-day (D) time step. In great lines, this involves the following operations:
  - Geometric corrections: definition of each pixels geolocation and mapping of the entire segment image to a common projection.
  - Radiometric corrections: Calibration and atmospheric correction to obtain surface reflectances (visible channels), brightness temperatures (thermal band).
  - Merging: Coordination of two observations (clouds, shadow, snow and observation error) and modeling of the involved elements in a corrected image, the "composite".
  - Composition: Combining all image segments within a pre-defined period to create a "synthetic" image, corresponding to a composited time (e.g. maximum value) and by excluding the bad observations.

- Post-processing: The preprocessing software is run on LINUX machines. The concentration of individual modules into operational "shells" is realized by the commercial software AgriWeb. The post-processing ingest the SD/SD composite, delivered by the preprocessing, and creates a number of more specific value-added products in the form of images. Qualitative and quantitative data products, such as products and algorithms. The post-processing is performed on Windows PCs with the GULPSSS software (Global Image Processing Software), and ends with the delivery of the final products to JRC.

The processing of the data is described per sensor in the lines below.
Overview: Regional crop yield estimation

1. General approach
2. Input data: S10-composites from RS and ancillary info
3. Basic improvements: Flagging, smoothing, ...
4. Derived, final information
5. Conclusions
Ancillary Data Sets

1. Administrative regions
2. LU-maps
   - GLC2000, GlobCover
   - Crop masks for specific regions
   - IACS parcel maps
3. DB with official crop statistics
   - Areas and yields
   - Per region x crop x year
4. Meteodata - 1.AgroMet
   - Daily, all variables
   - Global at 0.25° from ECMWF
   - Europe at 25km from 4000 stations
   - Belgium at 10km from all stations
5. Meteodata – 2.AeroMet (CVB)
   - For Atmo-correction (SMAC)
   - Water vapour ...
Image Processing: Pre ↔ Post

**POST-PROCESSING**
- Thematic analyses & applications
- Monitoring of vegetations/forests/crops
- LU-mapping and area estimation
- Carbon sequestration & Yield forecasting
HiRes IMGs (10-50m - Local)

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Resolution</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>VGT</td>
<td>GLO</td>
<td>1 km</td>
</tr>
<tr>
<td>METOP</td>
<td>GLO</td>
<td>1 km</td>
</tr>
<tr>
<td>VGT-P</td>
<td>EUR</td>
<td>1 km</td>
</tr>
<tr>
<td>NOAA</td>
<td>EUR</td>
<td>1 km</td>
</tr>
<tr>
<td>MODIS</td>
<td>EUR/IGAD</td>
<td>250m</td>
</tr>
</tbody>
</table>

MSG: EUR(5km) AFR (4km)
Pre-processing: Global SPOT-VGT since 1998

VITO-CTIV=Centre de Traitement d’images SPOT-VEGETATION

Global S10 of SPOT-VGT:
- Every 10 days (dekad) a new image
- Global, at 1 km resolution
- Since 1998 (now more than 15 years)

P-Product:
- partly processed segment

S1: daily synthesis

S10: dekadal synthesis

- High accuracy
- Wide user community
- Many applications
Pre-Processing: European NOAA-AVHRR since 1981

All European data since 1981 at 1 km
Processing by VITO for JRC-MARS

NOAA18-AVHRR, S10 -composite
Dekad 3 of September 2006
Geographic Lat/Lon
• Series of 10-daily composites from March 2007 → Present
• New dekads added in NRT.
• Layers: reflectances, BT, sun/view angles, NDVI, LST, quality information
• Funded by Belgian Science Policy Office (BELSPO)
METOP-AVHRR: Free downloads of $10

Website & Data Portal: http://www.metopS10.vito.be
### METOP-AVHRR: Global S10 from VITO

Each S10-Composite comprises 16 image layers. The lower table gives the SM interpretation. **DT=1 for BYTE, 2 for SHORT INTEGER.**

<table>
<thead>
<tr>
<th>IMAGE</th>
<th>DT</th>
<th>CONTENT</th>
<th>UNIT</th>
<th>Physical Values Y</th>
<th>Scaling</th>
<th>Digital Values V</th>
</tr>
</thead>
<tbody>
<tr>
<td>vvv</td>
<td></td>
<td>CONTENT</td>
<td>UNIT</td>
<td>Y(<em>{lo}) → Y(</em>{hi})</td>
<td>Y = V(<em>{int}) + V(</em>{slo}) * V</td>
<td>V(<em>{lo}) → V(</em>{hi})</td>
</tr>
<tr>
<td>B1_REF</td>
<td>1</td>
<td>R(_{s,RED})</td>
<td>%</td>
<td>0 → 62.50</td>
<td>Y=0.250*V</td>
<td>0 → 250</td>
</tr>
<tr>
<td>B2_REF</td>
<td>1</td>
<td>R(_{s,NIR})</td>
<td>%</td>
<td>0 → 83.33</td>
<td>Y=0.333*V</td>
<td>0 → 250</td>
</tr>
<tr>
<td>B3A_REF</td>
<td>1</td>
<td>R(_{s,SWIR})</td>
<td>%</td>
<td>0 → 62.50</td>
<td>Y=0.250*V</td>
<td>0 → 250</td>
</tr>
<tr>
<td>B4_BT</td>
<td>2</td>
<td>BT-Band 4</td>
<td>K</td>
<td>0 → 3276.7</td>
<td>Y=0.100*V</td>
<td>0 → 32767</td>
</tr>
<tr>
<td>B5_BT</td>
<td>2</td>
<td>BT-Band 5</td>
<td>K</td>
<td>0 → 3276.7</td>
<td>Y=0.100*V</td>
<td>0 → 32767</td>
</tr>
<tr>
<td>NDVI</td>
<td>1</td>
<td>NDVI</td>
<td>-</td>
<td>-0.08 → 0.92</td>
<td>Y=-0.08 + 0.004*V</td>
<td>0 → 250</td>
</tr>
<tr>
<td>LST</td>
<td>1</td>
<td>Land surface temp.</td>
<td>°C</td>
<td>-50 → 75</td>
<td>Y=-50 + 0.5*V</td>
<td>0 → 250</td>
</tr>
<tr>
<td>SZA</td>
<td>1</td>
<td>Sun Zenith Angle</td>
<td>degrees</td>
<td>0 → 125</td>
<td>Y=0.500*V</td>
<td>0 → 250</td>
</tr>
<tr>
<td>VZA</td>
<td>1</td>
<td>View Zenith Angle</td>
<td>degrees</td>
<td>0 → 125</td>
<td>Y=0.500*V</td>
<td>0 → 250</td>
</tr>
<tr>
<td>SAA</td>
<td>1</td>
<td>Sun Azimuth Angle</td>
<td>degrees</td>
<td>0 → 360</td>
<td>Y=1.500*V</td>
<td>0 → 240</td>
</tr>
<tr>
<td>VAA</td>
<td>1</td>
<td>View Azimuth Angle</td>
<td>degrees</td>
<td>0 → 360</td>
<td>Y=1.500*V</td>
<td>0 → 240</td>
</tr>
<tr>
<td>TVO</td>
<td>1</td>
<td>Nr. of Valid obs.</td>
<td>-</td>
<td>1 → 255</td>
<td>Y=V</td>
<td>1 → 255</td>
</tr>
<tr>
<td>TCO</td>
<td>1</td>
<td>Nr. of Clear obs.</td>
<td>-</td>
<td>1 → 255</td>
<td>Y=V</td>
<td>1 → 255</td>
</tr>
<tr>
<td>DAY</td>
<td>1</td>
<td>Day in Dekad</td>
<td>-</td>
<td>1 → 11</td>
<td>Y=V</td>
<td>1 → 11</td>
</tr>
<tr>
<td>ID</td>
<td>2</td>
<td>Segment_ID</td>
<td>-</td>
<td>1 → 32767</td>
<td>Y=V</td>
<td>1 → 32767</td>
</tr>
<tr>
<td>SM</td>
<td>1</td>
<td>Status Map</td>
<td>-</td>
<td>bit-interpretation (see table below)</td>
<td>1 → 255</td>
<td>0</td>
</tr>
</tbody>
</table>

### SMAaption: 16 bit-interpretation

<table>
<thead>
<tr>
<th>Decimal</th>
<th>Bit-Value</th>
<th>Bit7</th>
<th>Bit6</th>
<th>Bit5</th>
<th>Bit4</th>
<th>Bit3</th>
<th>Bit2</th>
<th>Bit1</th>
<th>Bit0</th>
</tr>
</thead>
<tbody>
<tr>
<td>128</td>
<td>1</td>
<td>Land</td>
<td>ValidObs never</td>
<td>never</td>
<td>Good</td>
<td>Cloud or shadow</td>
<td>Cloud</td>
<td>Snow</td>
<td></td>
</tr>
<tr>
<td>64</td>
<td>0</td>
<td>Sea</td>
<td>NoValidObs always</td>
<td>always</td>
<td>Acceptable</td>
<td>none of these</td>
<td>Cloudfree</td>
<td>NoSnow</td>
<td></td>
</tr>
</tbody>
</table>
METOP-AVHRR: examples of global products

September 2010
Dekad 1

NDVI

LST

Clear Observations

Total Observations
Pre-processing: TERRA-MODIS 250m since 2000

- MODIS 250m (RED+NIR $\rightarrow$ fAPAR)
- Pre-processing from L1 (LP-DAAC)
- Europe & IGAD (Horn of Africa)
- Excellent geo-correction
Adaptation of MSG-Products of LSA-SAF

Network of SAFs (Space Application Facility) co-ordinated by EUMETSAT
MSG spatial adaptations: Remap & Join

**SPOT-VGT: NDVI**

**MSG:**

Spatial compatibility with products from other sensors

EUROPE
Inspire-LAE A
5 km

AFRICA
LonLat
4 km

**inputs**
MSG thematic adaptations

Europe (S1/S10):
- ex: end July 2010
- Not shown:
  - Snow cover
  - Tmin, Tmax
- Not entirely filled
- Especially T
- Excellent VEGA
MSG thematic adaptations

Africa: same products, better filled
Method

- Samples from paired S10-observations
- From 12 global S10 of year 2009/2010
- Both of same registration day!
- Both absolutely cloudfree!
- $R^2 = 95\%$, Slope = 1.0
- No improvement “per land cover class”

Residuals due to:

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

METOP is directly available alternative for SPOT-VGT!
Overview: Regional crop yield estimation

1. General approach

2. Input data: S10–composites from RS and ancillary info

3. Basic improvements of S10: Flagging, smoothing, …
   - Flagging
   - Smoothing & Gap filling
   - Addition of fAPAR and DMP

4. Derived, final information

5. Conclusions
Make flagged S10: From...

- EO-IMG
- Associated Status Mask
- External Land/Sea Mask
MARS: Smoothing of VI-profiles

MODIS-250m in IGAD: NDVI of four pixels in 2000-2010
MODIS-250m over the Horn of Africa:

Original and smoothed NDVI for four dekads in 2010

Clouds and missing values replaced by appropriate values.
fAPAR = Fraction of Absorbed PAR (400-700nm) [%]

Reflectances (RED, NIR, …) \rightarrow Neural Network

Sun Zenith/Azimuth Angles \rightarrow fAPAR

View Zenith/Azimuth Angles \rightarrow Cyclopes (INRA-France)

DMP = Dry Matter Productivity [kgDM/ha/day]

fAPAR \rightarrow Monteith-Model

Solar radiation \rightarrow DMP

Tmin/Tmax
MARS: Addition of fAPAR & DMP

Region: The GLOBE
Period: April, 1998, Dekad 1/3
Theme: Fraction of Absorbed Photosynthetically Active Radiation (fAPAR)
Maximum value in period
Source: SPOT-VEGETATION

Region: The GLOBE
Period: April, 1998, Dekad 1/3
Theme: Dry Matter Productivity (DMP)
Mean value in period
Source: SPOT-VEGETATION
Overview: Regional crop yield estimation

1. General approach
2. Input data: S10–composites from RS and ancillary info
3. Basic improvements: Flagging, smoothing, …
4. Derived, final information:
   - Long–Term Statistics & Anomalies
   - Phenological information
   - Clustering
   - RUM–Databases
   - Regional yield assessment
5. Conclusions
### MARS: Long-term Statistics & Anomalies

#### Actual IMGs:
- \( X = \text{NDVI, DMP, ...} \)

- \( \text{Np=36 dekads} \)
- \( \text{12 months} \)

#### Historical Year:
- \( \text{Long-Term Statistics (+ Deciles)} \)

#### DIFh:
- \( \text{Anomaly IMGs} \)
- \( \text{Difference wrt. Historical Year} \)

<table>
<thead>
<tr>
<th>period</th>
<th>1</th>
<th>2</th>
<th>...</th>
<th>( p )</th>
<th>...</th>
<th>( N_p )</th>
</tr>
</thead>
<tbody>
<tr>
<td>year = 1</td>
<td>( X(1,1) )</td>
<td>( X(1,2) )</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>( X(1, N_p) )</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>( y )</td>
<td>...</td>
<td>...</td>
<td>( X(y,p) )</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>( N_y )</td>
<td>( X(N_y,1) )</td>
<td>( X(N_y,2) )</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>( X(N_y, N_p) )</td>
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<th>1</th>
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<th>( p )</th>
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<th>( N_p )</th>
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<tr>
<td>Mean</td>
<td>( \mu_x(1) )</td>
<td>( \mu_x(2) )</td>
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<td>( \mu_x(p) )</td>
<td>...</td>
<td>( \mu_x(N_p) )</td>
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<tr>
<td>Minimum</td>
<td>( \text{Min}_x(1) )</td>
<td>( \text{Min}_x(2) )</td>
<td>( \text{Min}_x(p) )</td>
<td>( \text{Min}_x(N_p) )</td>
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<tr>
<td>Maximum</td>
<td>( \text{Max}_x(1) )</td>
<td>( \text{Max}_x(2) )</td>
<td>( \text{Max}_x(p) )</td>
<td>( \text{Max}_x(N_p) )</td>
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<tr>
<td>St. Dev.</td>
<td>( \sigma_x(1) )</td>
<td>( \sigma_x(2) )</td>
<td>( \sigma_x(p) )</td>
<td>( \sigma_x(N_p) )</td>
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<tr>
<td>( N_{\text{good}} )</td>
<td>( N_x(1) )</td>
<td>( N_x(2) )</td>
<td>...</td>
<td>( N_x(p) )</td>
<td>...</td>
<td>( N_x(N_p) )</td>
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<table>
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<th>...</th>
<th>( N_p )</th>
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<td>year = 1</td>
<td>( A_X(1,1) )</td>
<td>( A_X(1,2) )</td>
<td>...</td>
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<td>...</td>
<td>( A_X(1, N_p) )</td>
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<tr>
<td>...</td>
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<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>( y )</td>
<td>...</td>
<td>...</td>
<td>( A_X(y,p) )</td>
<td>...</td>
<td>...</td>
<td>...</td>
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<tr>
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<td>...</td>
<td>...</td>
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<td>...</td>
<td>...</td>
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</tr>
<tr>
<td>( N_y )</td>
<td>( A_X(N_y,1) )</td>
<td>( A_X(N_y,2) )</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>( A_X(N_y, N_p) )</td>
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</table>
MARS: Long-term Statistics & Anomalies

LTA of 15 Year SPOT-VGT monthly NDVI
Smoothed, monthly MODIS-NDVI: Absolute Difference to LTA → Severe drought in IGAD visible since October 2010
Statistical, non-supervised clustering of the data in a Time Series

- **Calibration (training):** Enhanced ISOclus algorithm
- **Application:** Minimum distance classifier
- **MARS:** Every dekad repeated for several TS (sensors/ROIs/periods)

⇒ Map of homogeneous regions with similar behaviour
**MARS: Regional Unmixed Means (RUM)**

**Principle**

**RUM-FILE:**
- ASCII-TXT
- Comma-separated values
- Each line contains MEAN value of IN-IMG-values of crop pixels in a given GAUL1-region
- Additional items: date, sensor-ID, variable-ID,...

**Works for IN-IMGs with:**
- ordinal variables (NDVI,...)
- categorical variables (“events”)
  → Regional frequencies (ASI)
MARS: Regional Unmixed Means (RUM)

**GLOBAL:**
Regions: FAO-GAUL1 (2688 regions)
Land Use: GLC2000, re-grouped to 5 broad categories

**EUROPE:**
Regions: NUTS2 (600 regions)

Class 12: Cropland
Principle: \( Y = f(X_1, X_2, X_3, \ldots) \)

- \( Y \) = Official yield of given crop in given administrative region
- \( X_n \) = RUM-values of RS-indicators [+ covariates from meteo, model-simulations,…]
- \( f \) = Multiple regression model, Jack-knife calibrated, on data of previous years

Applied on \( X_n \)-data of current year \( \Rightarrow \) Yield Forecasting

**Example from DRAGON-project**
**North China Plain:**

Winter Wheat in 6 districts
- \( X_1 \) = DMP summed over season
- \( X_2 \) = Idem for Temp., Rain
- \( X_3 \) = Chemical fertilizer input

\[ R^2: \quad 85\% \rightarrow 99\% \]
\[ \text{RMSE:} \quad 0.29 \rightarrow 0.06 \text{ Ton/ha} \]
RS-based Index Insurance for IFAD-WFP in SENEGAL:

- Index: Mean fAPAR over season
- Good correlation with yield
- Use relation to define “Trigger”:
  
  If Index of current year < Trigger ⇒ Farmers paid

Also for Ukraine, Morocco,… (SwissRe)
Overview: Regional crop yield estimation

1. General approach
2. Input data: S10-composites from RS and ancillary info
3. Basic improvements: Flagging, smoothing, ...
4. Derived, final information:
5. Conclusions
PER Region/Crop/Year: P [Ton] = Area [ha] x Yield [Ton/ha]

MERITS:
- Drivers:  
  - Static info: Crop areas, soil maps, ...
  - Dynamic: RS-images, meteo-data, official yields
  - Science: Growth model, statistical calibration
- Satisfactory for EU-politics (import/export, human Aid, ...)
- Timely information: Much earlier than “official statistics”

DRAWBACKS:
- Areas assumed “fixed” over years.
- Dynamic mapping needed:  
  - Crops vs. Non-Cropland
  - Better: specific per crop
- EO-systems needed with High Resolution & Frequency
  
  e.g. Proba-V at 100m, Sentinel2 at 10m
Global Monitoring with LoRes EO-Imagery Time Series Analysis with SPIRITS software

1. VITO’s Remote Sensing Centre (TAP)
2. EU-MARS: Global Agricultural Monitoring
3. FAO-ASIS: Global Drought Monitoring
4. SPIRITS: Introduction & Overview
5. SPIRITS: Some practical exercises
Basic Inputs: Time series of S10-composites

North China Plain, NDVI, year 2007

Image of May 2007

- Semi-Arid
- BeiJing
- Southern forest
- Northern forest
- Agri-North
- Agri-South
APPLICATIONS: Low Resolution

JRC–MARS (since 2000)
- NRT-delivery of RS-Information on crop state and yields
- Consortium:
  - Alterra (NL): Modelling
  - MeteoGroup (NL): Meteodatal
  - VITO: RS-data
- JRC: Compilation & Bulletins for...
  - DG-AGRI: Import/export
  - DG-AIDCO: Food security
CropWatch Bulletins:

- Created and distributed by RADI
- Start year:
  - 1998 for China
  - 2013 for the Globe
- Similar to MARS but so far no:
  - crop growth simulations
  - statistical calibration against historical yields
MARS: General approach of EC-JRC

MARS-FOOD
MARS-STAT
AseMARS
GMFS
Asia@ITC
GeoLand

CGMS=Crop Growth Monitoring System

LR Remote sensing → NDVI/DMP

Weather stations → Climate data
Crops → Crop, soil & management parameters
Soils
Agricultural statistics

Crop growth simulation module WOFOST → Calibration

Water balance
Drought events
Calamities
Scenario's

Production

Crop Areas
Crop Yields
MONTEITH-Approach: \[ DMP = R \cdot 0.48 \cdot f_{\text{APAR}} \cdot \varepsilon \left( \frac{T_{\min}}{T_{\max}} \right) \]

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Meaning</th>
<th>Units</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>DMP</td>
<td>Dry Matter Productivity</td>
<td>kgDM/ha/day</td>
<td></td>
</tr>
<tr>
<td>R</td>
<td>Incoming solar radiation (0.2–3.0µm)</td>
<td>J/ha/day</td>
<td>Meteo</td>
</tr>
<tr>
<td>0.48</td>
<td>Fraction of PAR (0.4–0.7µm) in R</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>f_{\text{APAR}}</td>
<td>PAR–fraction absorbed by Vegetation</td>
<td>–</td>
<td>Remote Sensing</td>
</tr>
<tr>
<td>(T_{\min}/T_{\max})</td>
<td>Daily min/max temperature</td>
<td>°C</td>
<td>Meteo</td>
</tr>
<tr>
<td>(\varepsilon)</td>
<td>Efficiency (\approx) Autotrophic respiration:</td>
<td>kgDM/J</td>
<td></td>
</tr>
<tr>
<td></td>
<td>– conversion of absorbed PAR–Energy to carbohydrates</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>– maintenance respiration</td>
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</tbody>
</table>

\[ DMP = DMP_{\text{max}} \cdot f_{\text{APAR}} \]

\[ DMP_{\text{max}} = R \cdot 0.48 \cdot \varepsilon \]
- based on meteodata
- for \(f_{\text{APAR}}=0\)

Dependency of \(DMP_{\text{max}}\) on Temperature and CO2
MARS: Addition of DMP

- DMP$_{\text{max},10}$
- fAPAR$_{10}$
- DMP$_{10}$
Inspect multi-annual VI-profiles per pixel

IMGs with Dates of Start and End of 1 or 2 Seasons in Central Year

Example for NDVI-LTA of SPOT-VGT