Sentinel-2: A New Perspective for Research and Operational Applications in the Areas of Agriculture and Environment


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Early work exploited mainly NOAA/AVHRR and geostationary satellite data (GOES, METEOSAT, …) :

- These meteorological satellites provide high temporal sampling required by weather monitoring operational goals

- Despite difficult issues regarding calibration, geometric registration, directional effects and drifting orbits, cloud screening, …, the land surface scientific community performed many studies which benefit of:
  - continental/global coverage,
  - high temporal sampling,
  - continuity over more than 30 years

Thanks to these pioneer work and the raising climate change concerns, missions and sensors devoted to global land monitoring were funded: VEGETATION, MODIS, MERIS
30 years of research with mutitemporal NOAA/AVHRR data

Northern hemisphere greening : Myneni et al, 1997

NDVI, LAI and precipitation anomalies in Sahelian semi-arid area : strong correlation with peak annual rainfall anomalies (Ganguly et al. 2008)
Annual NPP from TURC model driven with ECMWF analysis. Unit is g[C].m\(^{-2}\).

Estimated global NPP: 66.2 Gt C/yr for 1998
Scale and ground resolution issue

SPOT-VEGETATION, Modis, Meris, global coverage, revisit 1-3 days

SPOT, Landsat limited coverage, revisit 16-26 days

Surface directionnal effects
The need of combining high ground resolution, and high temporal sampling

Scientific point of view:

- Understanding and modeling of ecosystems functioning require to account for the high heterogeneity of land surfaces.

Application point of view:

- World population increase: more food has to be produced and in the same time the impact on the environment shall be minimized/decreased.

  - Ground resolution should allow to monitor individual fields and provide information for precision farming practices: <30 m (10m).

  - Revisit time should allow to monitor vegetation growth: one “clear” image every 5 to 10 days.
New missions

■ Venus: scientific mission
  - About 140 sites over the world
  - One image every two days over about 100 sites
  - 10 m resolution, field of view 27 km
  - Multispectral camera, 12 spectral bands, blue -> near infrared,
  - Constant view angle
  - Launch: 2014

■ Sentinel-2: operational mission
  - Global coverage
  - 1 image every 5 days with 2 satellites
  - 13 spectral bands, blue -> SWIR
  - 10-60 m resolution, field of view 290 km
  - Launch 2013

■ Landsat LDCM, SPOT 6,7, Sentinel 1 & 3 …
Contribution to the Venüs and Sentinel-2 preparation
The Observatoire Spatial Régional (OSR)

- Started in 2001
- Objectives:
  - Research on the functioning of land surface: water and carbon fluxes, land cover/use, crop monitoring, …
  - Calibration/validation of EO algorithms and products
  - Experimentation to prepare new EO missions (SMOS, Venüs, Sentinel-2)

- Approach: Long Term Experiment
  - Routine in situ measurements: fluxes at the soil/vegetation/atmosphere interface, LAI, biomass, etc
  - Systematic acquisition of one cloud free high resolution satellite image (SPOT, Formosat) every month since 2002
  - Partnerships with local actors
  - Distribution of the data through internet OGC services (ongoing work)

- A regional component of the French Land Thematic Centre (LTC)
- CESBIO : a member of the LTC network of scientific expert laboratories
OSR: In situ measurements

Lewis Radiometer (SMOS)
Mean and standard deviation of monthly NDVI over a 50x50 km area, in 2002 and 2003
Simulation of Venus level 1, 2, 3 products performed with FORMOSAT 2 images:
- 8m resolution, 1 day repeat cycle, 4 spectral bands, constant viewing angle

Level 1:
Top of the Atmosphere reflectances calibrated & geocoded (orthoimage)

Level 2:
Single date surface reflectances after cloud masking and atmospheric correction

Level 3:
10 days time composite of level 2
Venµs products : geometry

Simulation with FORMOSAT 2 images

Accurate image registration is of paramount importance when using time series

Spec: 3m multitemporal (1/3rd pixel)

Method: automatic registration using correlation with a reference image

Data will be provided with the user preferred projection

Registration accuracy measured on a time series (in pixel)

80 images, Morocco, Nov 2005-Nov 2006
30% cloudy
The worst absolute location error is less than 0.4 pixels for 90% of points

(BAILLARIN et al., IGARSS 2008)
Venüs combines 2 methods for clouds detection

- Multi temporal analysis of the surface reflectances
- Clouds altitude detection by stereoscopy, computation of the location of clouds shadows
Venµs combines 2 methods for clouds detection

Multi temporal analysis of the surface reflectances

Clouds altitude detection by stereoscopy, computation of the location of clouds shadows
Venus products: Atmospheric corrections
Results for aerosols

Retrieved Aerosol Optical Depth (@ 550 nm)
Retrieved AOT

Estimation of aerosol optical depths

20050524

1st TOA image: Initialization
Impact of constant view angle

Wheat field – Yaqui
Mexico

Venüs: constant view angle ⇒ Smooth time series
EXAMPLES OF USE OF HIGH QUALITY TIME SERIES

Preparation of Venµs and Sentinel-2 missions with SPOT and Formosat-2

> 1 image per month
Formosat-2 time series
Yaqui, Mexico

December 12
December 23

Formosat-2 time series
Yaqui, Mexico

20071223
January 3

Formosat-2 time series
Yaqui, Mexico
Formosat-2 time series
Yaqui, Mexico

January 8

20080108
January 13
Formosat-2 time series
Yaqui, Mexico

January 18

20080118
Formosat-2 time series
Yaqui, Mexico

January 29

20080129
Formosat-2 time series
Yaqui, Mexico

February 4

20080204
Formosat-2 time series
Yaqui, Mexico

February 9

20080209
Image time series: \( \Rightarrow \) Vegetation development monitoring

- Takes into account the specific development of each field
Classes are separated using their temporal and spectral profiles

Formosat-2 “True” colours
Classes are separated using their temporal and spectral profiles.

Formosat-2 “True” colours.
- **Solving Corn/Sunflower confusions**
- **More classes:** distinction between silage and grain corns
- **Characterization of the heterogeneity**
Land cover and land use mapping: support to decision making and monitoring public policies

Sustainable development indicators:
- Arable and permanent crop land
- Land use change
- Proportion of land area covered by forests
- Fragmentation of habitat

Land cover is a prerequisite for most applications

All data from the Cesbio’s regional observatory (OSR)
Towards near real time land cover mapping

Multidate and « Real time » land cover maps using the clear images acquired from the start of growing Season

In May, 90% of Maize is well classified

=> Irrigation water forecast
Leaf Area Index 2007

20060217

(Demarez et al. 2008)
Estimation of crop water requirements

Meteorological forcing: SAFRAN

Land cover map

Remote sensing time series

Reference Potential Evapotranspiration

Crop Coefficient $K_c(t)$

well watered grass

well watered crop optimal agronomic conditions

Crop Potential Evapotranspiration $ET_c$

$ET_c(t) = K_c(t,\text{crop}).ETP_{ref}(t)$

(Allen et al. 1998 FAO n°56)

( = crop water requirement )
Crop Potential Evapotranspiration ETc in 2002 (water requirement)
Monthly cumulated irrigation

Zoom over a 5x5 km window

2002
April  May  June  July  August

2003

20  40  60  80  100  120  140  160  180
mm
Evapotranspiration, soil moisture, biomass: validation

- \( \text{RMSE}_{\text{ETR}} = 0.93 \text{ mm} \)
- \( \text{RRMSE}_{\text{ETR}} = 26\% \)

- \( \text{RMSE}_{H_1} = 0.031 \text{ m}^3\text{.m}^{-3} \)
- \( \text{RMSE}_{H_2} = 0.025 \text{ m}^3\text{.m}^{-3} \)
Irrigation at regional scale

Volumes consommés SAFYE (en hm$^3$)

- SAFYE > AEAG
- SAFYE = AEAG
- SAFYE < AEAG

Histogram:
- Volumes régionaux AEAG
- Volumes régionaux estimés

2006: 6.8%
2007: -9.3%
2008: -3.3%
2009: -10.1%
Driving a Soil-Vegetation-Atmosphere transfer model with LAI derived from Formosat

Map of Soil Type

Map of Soil Water Content for 10/09/06

- 0.17 - 0.24
- 0.24 - 0.27
- 0.27 - 0.29
- 0.29 - 0.31
- 0.31 - 0.34
Snow cover monitoring and snow melt modeling

High resolution Formosat-2 image over the Atlas mountain, Morocco (February 2008)

Snow cover evolution as a function of time and altitude (winter 2004-2005)

Snow melt and stream flow modeling

Respective contribution of rainfall and snow to the flow of two rivers
Additional information from Radar
Assessment of straw & residues management

Radar data only: very useful for this survey because it guarantees data coverage even if cloudy period (soil preparation occurs in autumn in less than 3 weeks in our area)

Bande C, Polar VV (14/07/2010)
Bande X, Polar HH (15/07/2010)
Bande C, Polar HV (14/07/2010)

Winter wheat straw

After disking

F. Baup, R. Fieuzal
Conclusions (1)

- Multi-Temporal Remote Sensing Images allow to develop quality products for new or more reliable applications.

- Venµs is a scientific mission: limited number of sites, continuity is uncertain, maybe with Mistigri/Tirex mission: same concept + Thermal infrared @50m.

- The European Sentinel-2 mission will provide global coverage of high resolution superspectral data, every 10 days with one satellite and every 5 days with two satellites.
  
  ⇒ One clear image every 15 to 30 days.

- Combination of optical and radar data should provide more operational services:
  - Sentinel 1: radar band C every 12 (6) days, 5-40 m
  - Sentinel 2: solar channels, every 10 (5) days, 10-60 m, global
  - Sentinel 3: solar channels, every 2 days, 300 m, global.
An increased number of EO satellites provide more and more images. However, combination of all this data is not an easy task: registration, calibration, spectral bands, viewing angles, cost and operational process to collect the data.

- Registration of the images should be better than 1 pixel (multitemporal, multispectral.)
- Constant viewing angles make image registration but also atmospheric correction easier, and reduce surface directional effects.
- Mission continuity and systematic coverage of large (global) areas is crucial.
- Efficient processing and distribution ground segment.

Need for agriculture: 1 clear image every 5 to 10 days.

- A dedicated mission would be more efficient and easy to manage: a 2 days global systematic revisit with ~15-20 m resolution can be achieved with 3 satellites (CNES' study), 1 day with 6 satellites.
- Need to work on the combined use of optical and radar data in order to build truly operational services.
Thank you

And many thanks to the colleagues from CNES and CESBIO and to the partners in France, Morocco and Mexico