National Centre for Earth Observation
NATURAL ENVIRONMENT RESEARCH COUNCIL

UNIVERSITY OF LEICESTER

esa

→ 8th ADVANCED TRAINING COURSE ON LAND REMOTE SENSING

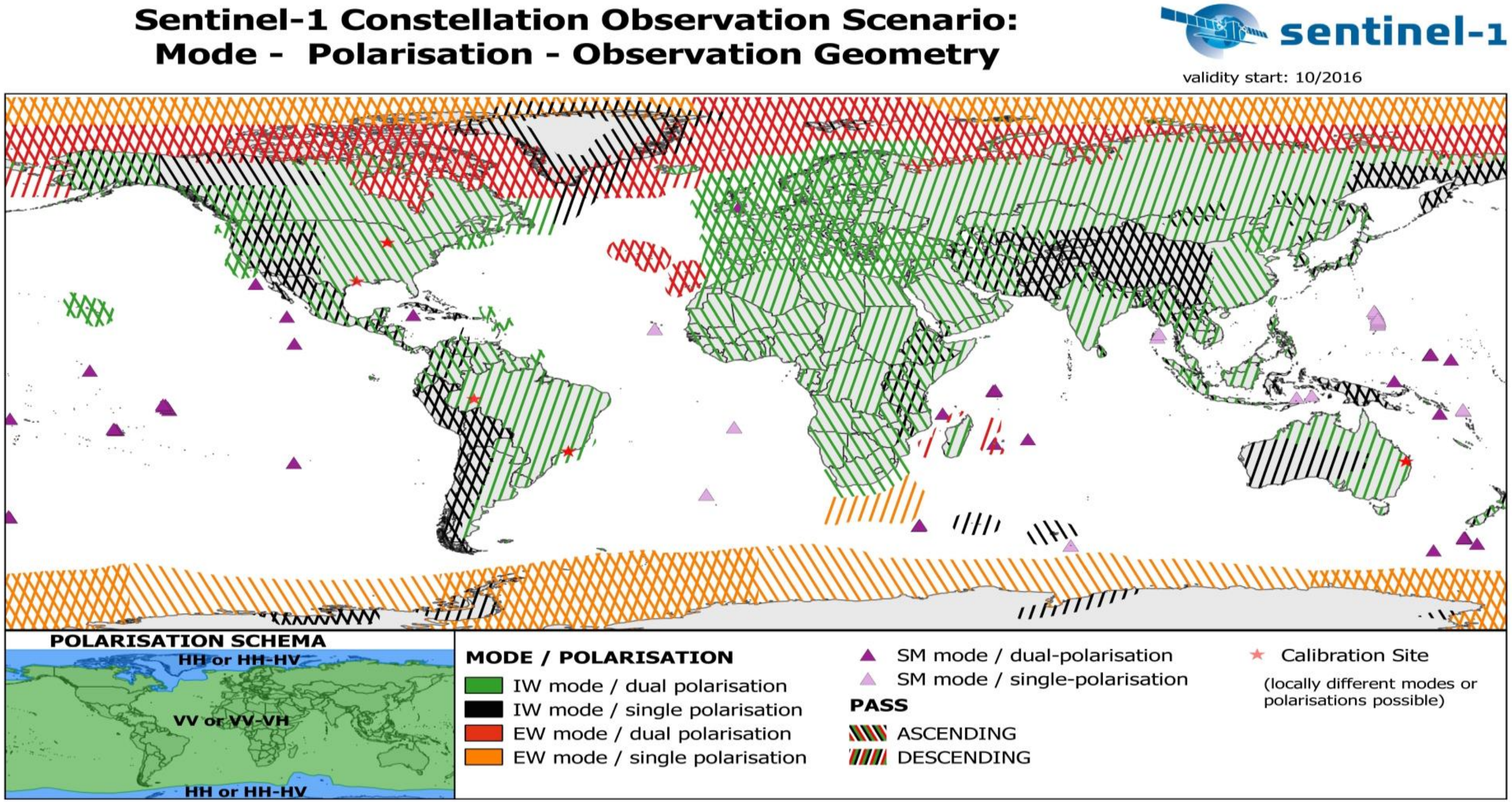
10–14 September 2018
University of Leicester | United Kingdom

Multitemporal analysis of SAR data

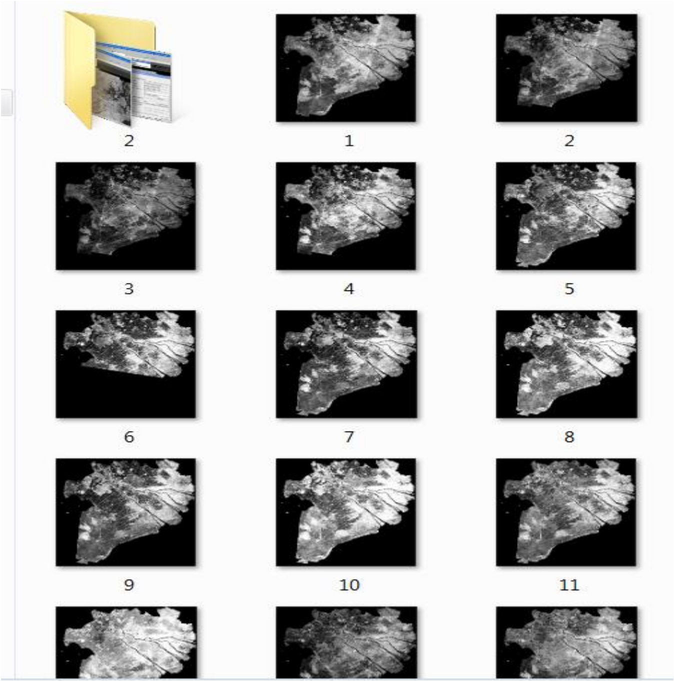
Thuy Le Toan

11/09/2018

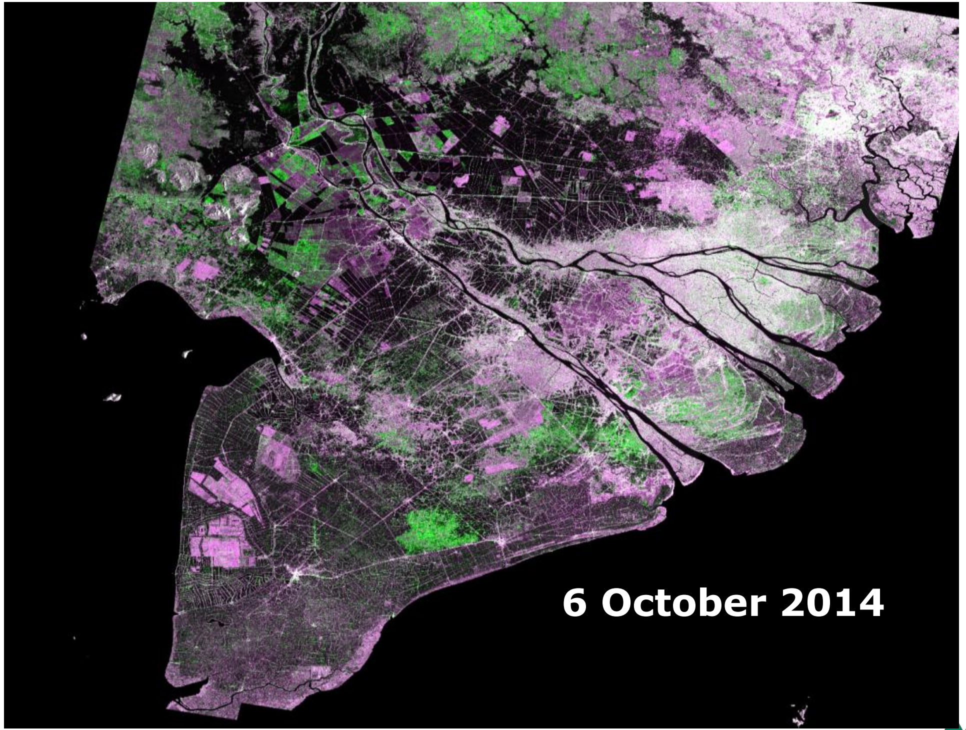
With Sentinel-1, systematic multitemporal SAR images are now available worldwide



No cloud cover on SAR images



S1 over S Vietnam: every 12 /6 days



Why to use multitemporal SAR images ?

1. To detect changes in the observed area:

- change due to vegetation growth, soil moisture, freeze/thaw
- flooding, deforestation…

2. To have more measurements to enhance processing methods:

- to discriminate objects /surface types with different temporal variations

  Surface types classification

- to reduce the speckle effect by using differenes in speckle distribution (of homogeneous area) on different temporal images

  Speckle filtering

Focus of the lecture: observation of vegetation

1. Time series of S1 for deforestation monitoring

2. Time series of S1 for agriculture monitoring with emphasis on rice

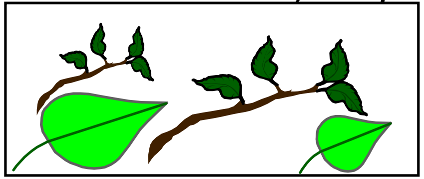
Forest Multitemporal Analysis
Deforestation monitoring using Sentinel-1

Thuy Le Toan

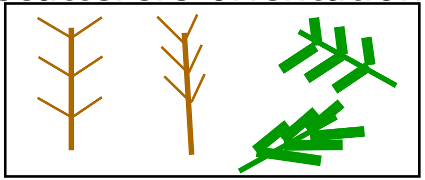
What cause temporal variations in SAR measurements

Vegetation properties

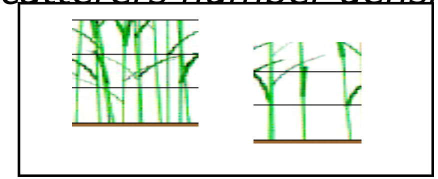
scatterers size,shape



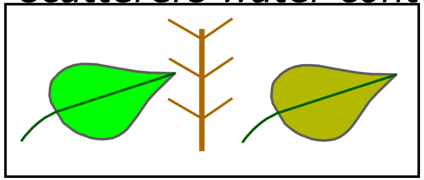
scatterers orientation



scatterers number density

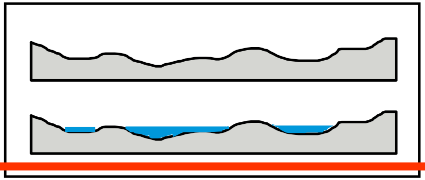


scatterers water content



Ground properties

soil moisture & surface roughness



Natural changes

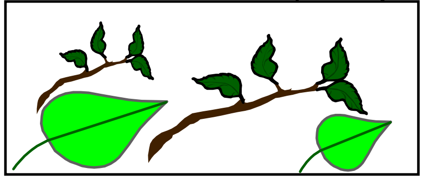
- Change with vegetation growth
- Diurnal and seasonal change
- Wind, rain, temperature effects
- …

- Rain, inundation effects
- Freeze/thaw
- Weathering effects
- ..

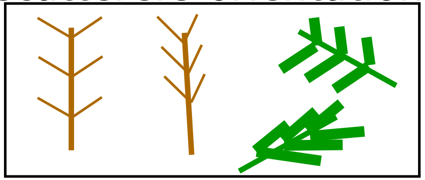
What cause temporal variations in SAR measurements

Vegetation properties

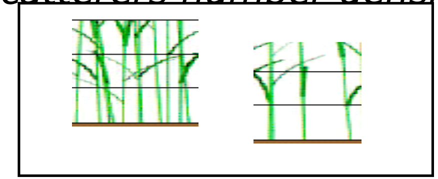
scatterers size,shape



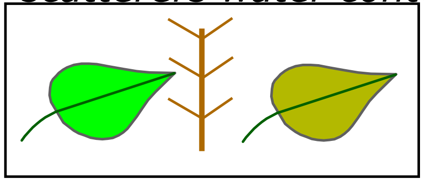
scatterers orientation



scatterers number density

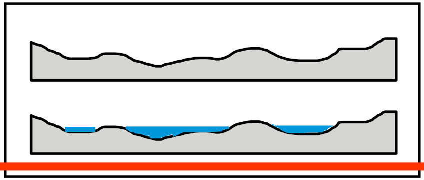


scatterers water content



Ground properties

soil moisture & surface roughness



Disturbances

- Change in scatterers density (degradation)
- Change in scatterers orientation (wind throw)
- Changes in water content (fire)
- All scatterers removed (clear cutting)
- ...

- Soil surface with post deforestation debris
- ...

Deforestation monitoring using S1 data

- Optical data hampered by cloud cover
- L-band SAR available widely in mosaic but one a year
- Other SAR data (TerraSAR-X, CosmoSkymed, Radarsat) limited by their cost and small coverage
- Sentinel-1: only source of SAR data available globally at short repeat observation interval

→ Sentinel-1 for observation of forest areas prone to deforestation

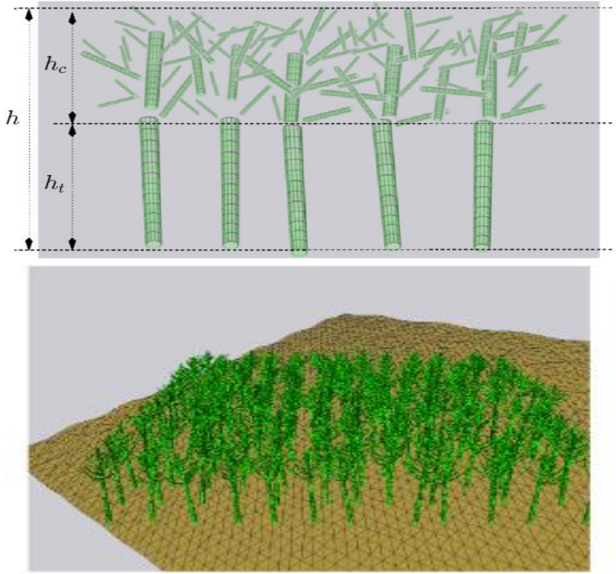
Early detection of deforestation

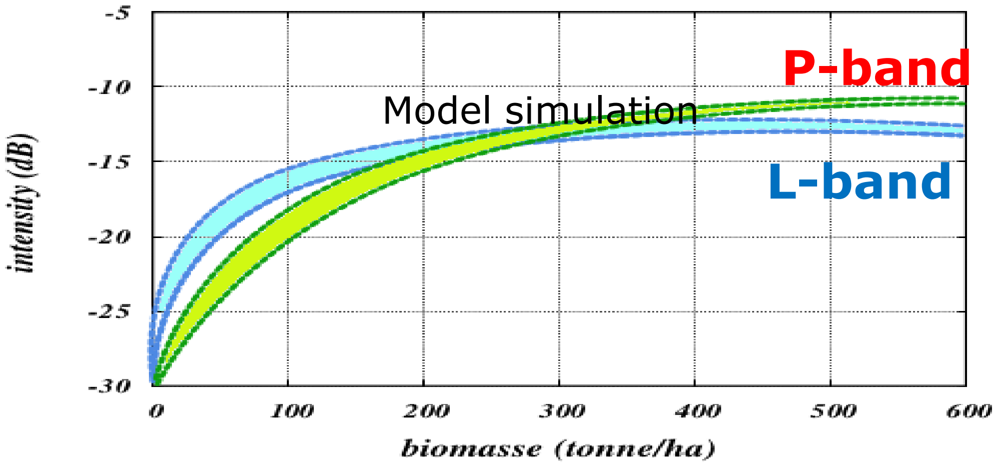
Monitoring of logging activity

Deforestation monitoring: to detect change in backscatter

At low frequency: L and P-band

Physical modelling at P, L, C, X band

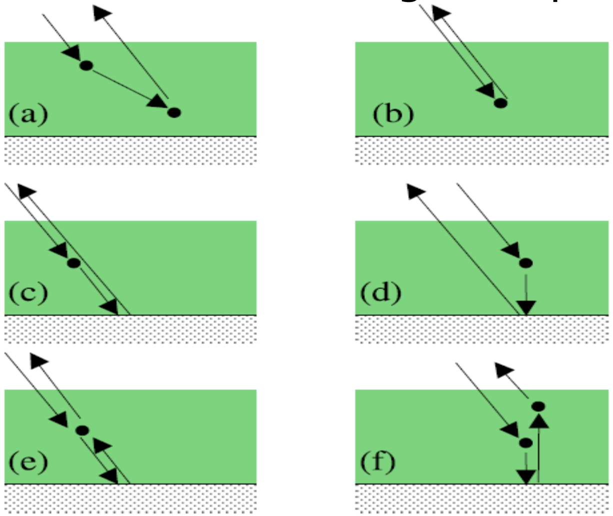




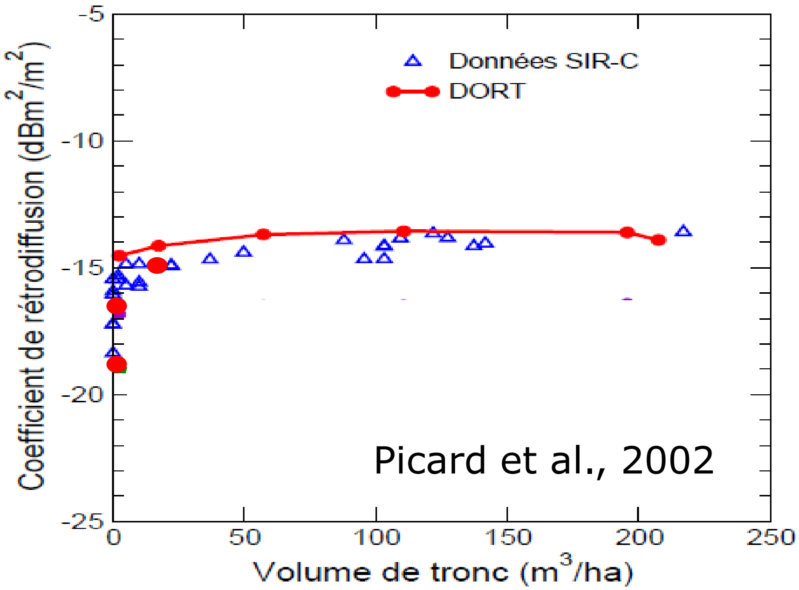
→ Contrast between mature forest and bare ground is very high:
> 15 dB at P-band and >10 dB at L band

At C-band, small contrast between forest and deforested area

Mechanisms contributing to depolarization



At C band



→ Contrast between mature forest and bare ground is small, 1-3 dB, depending on surface properties

→ Sensitivity to forest biomass negligible or very low

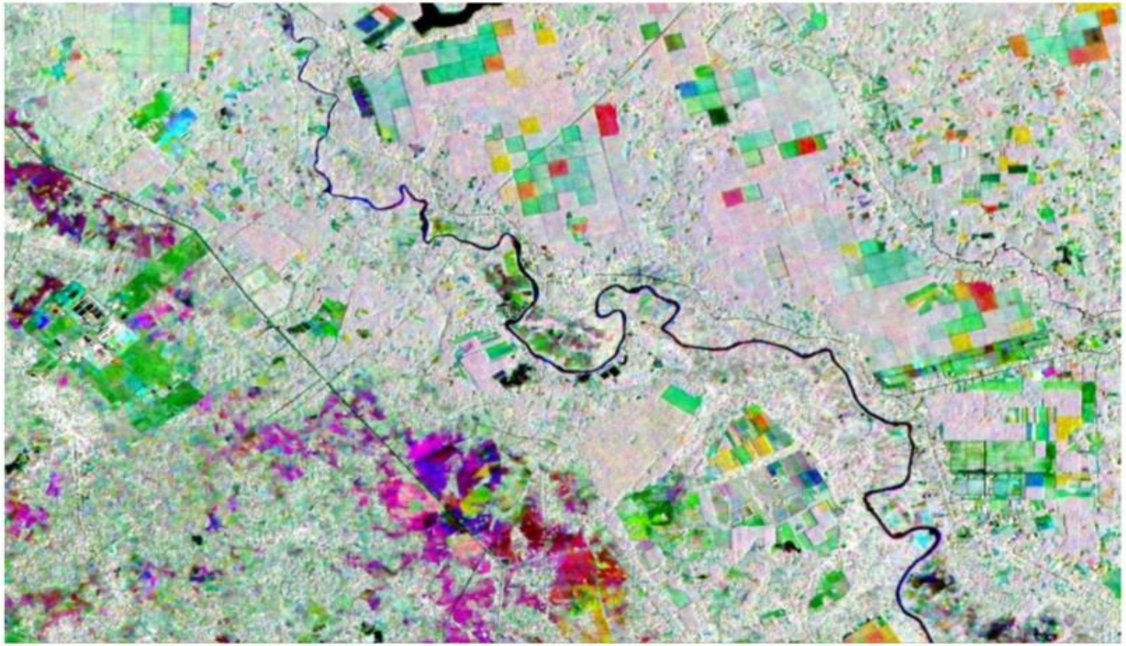
Multitemporal forest monitoring with Sentinel-1

Rubber plantation area near Dầu Tiếng
(Bình Dương Province)

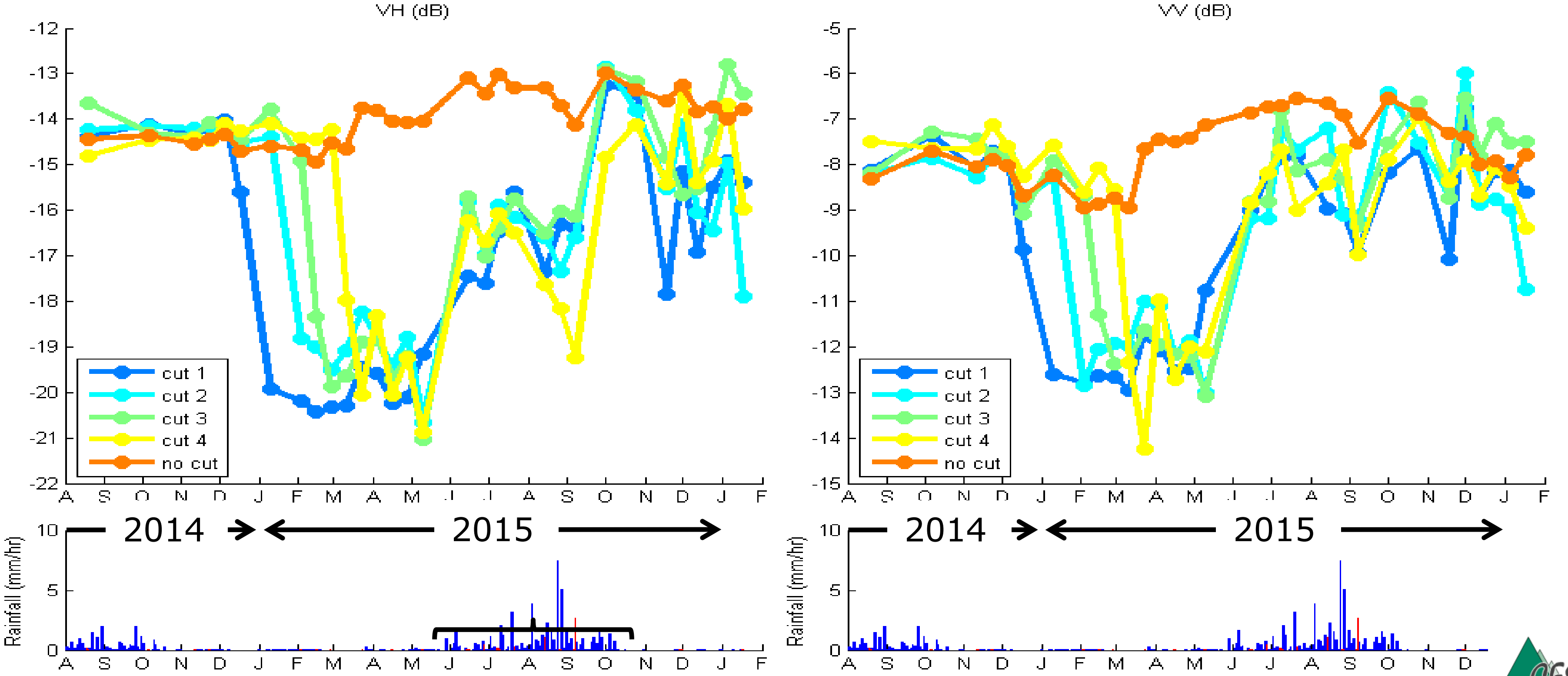
78 Sentinel-1 images (VH and VV) have been acquired in this area between October 2014 and 12 March 2017

- Almost every 12 days until September 2016
- Almost every 6 days after October 2016, when Sentinel-2B entered its operational phase

Multitemporal forest monitoring with Sentinel-1



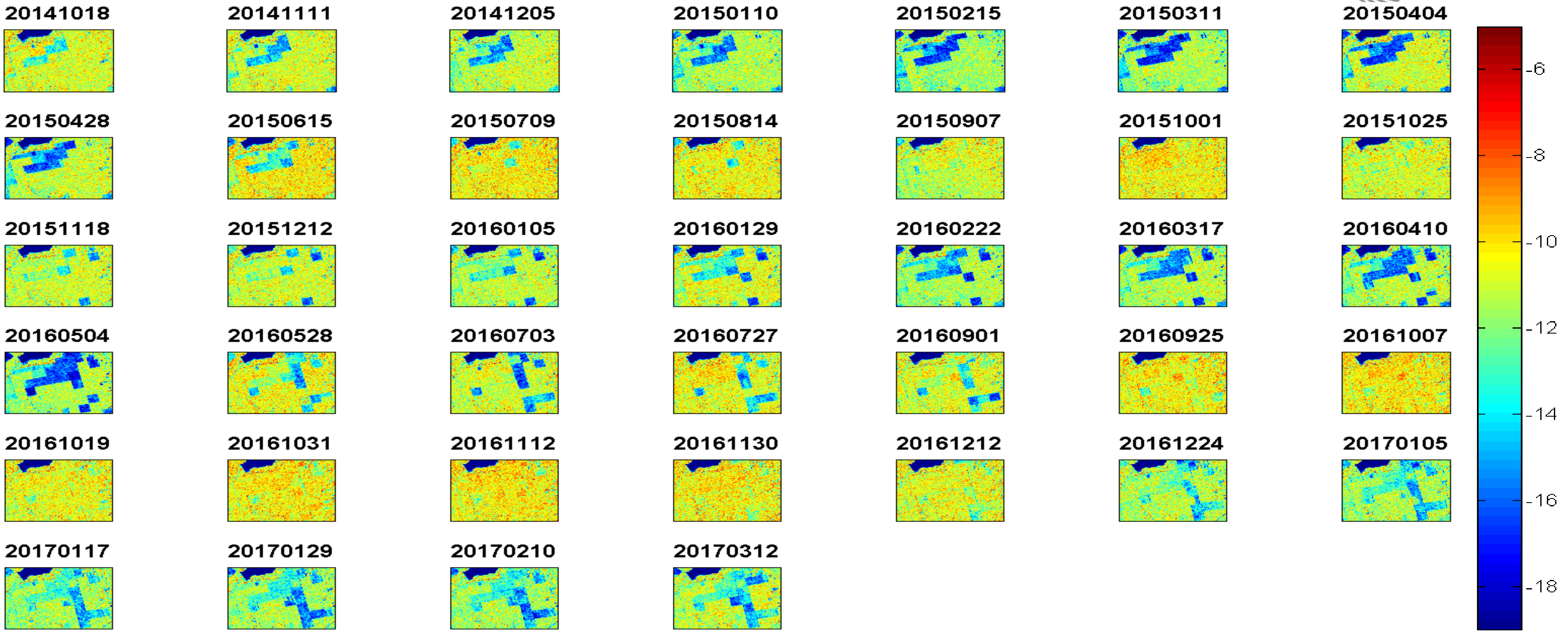
Color composite image from VH backscatter
R (3 Feb 2015), G (26 Aug 2015), B (17 Jan 2016)
(Bouvet et al., 2017)



VH (dB)
VV (dB)
cut 1
cut 2
cut 3
cut 4
no cut
2014
2015
Rainfall (mm/hr)
A S O N D J F M A M J J A S O N D J F

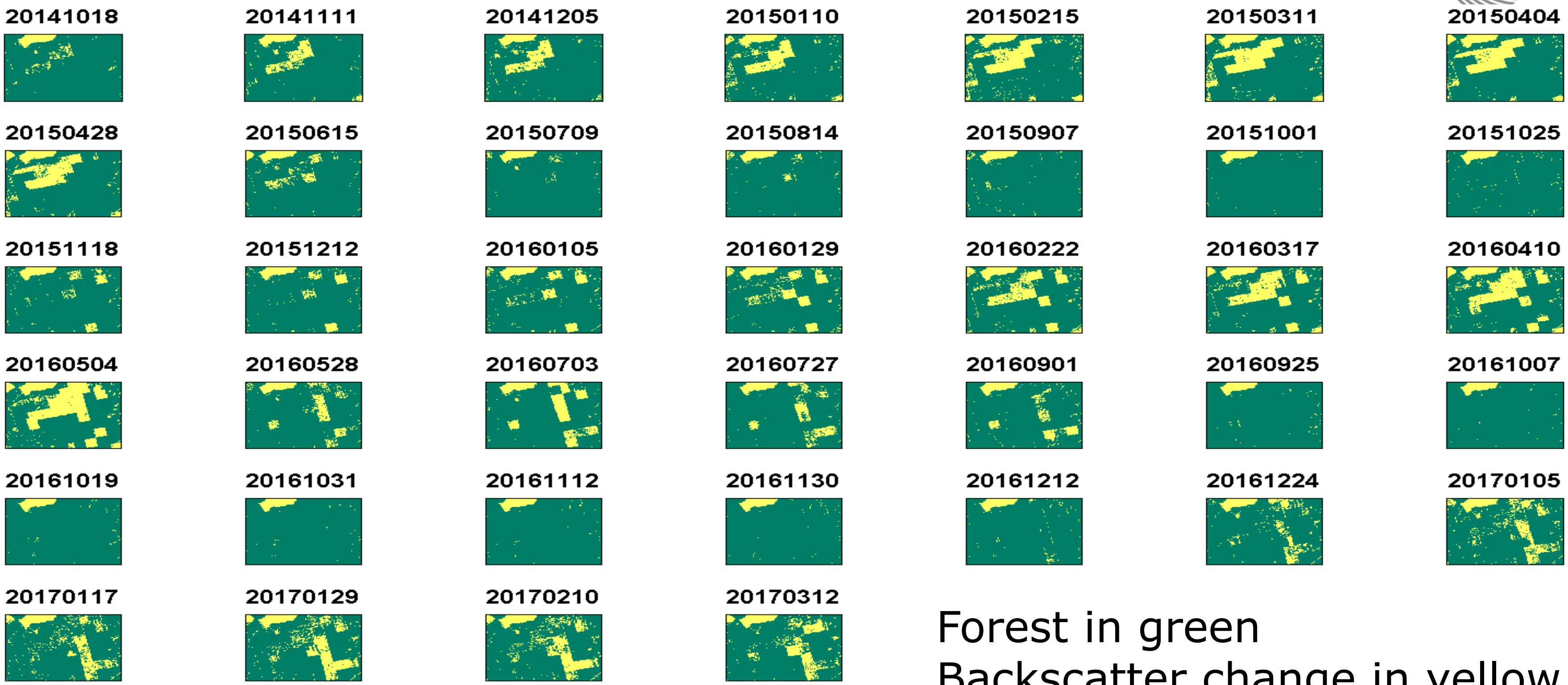
Wet season:

γ^0_{VH}



78 dates are available between October 2014 and April 2017. Only every second image is shown here.

Forest/Non-Forest from γ^0_{VH}

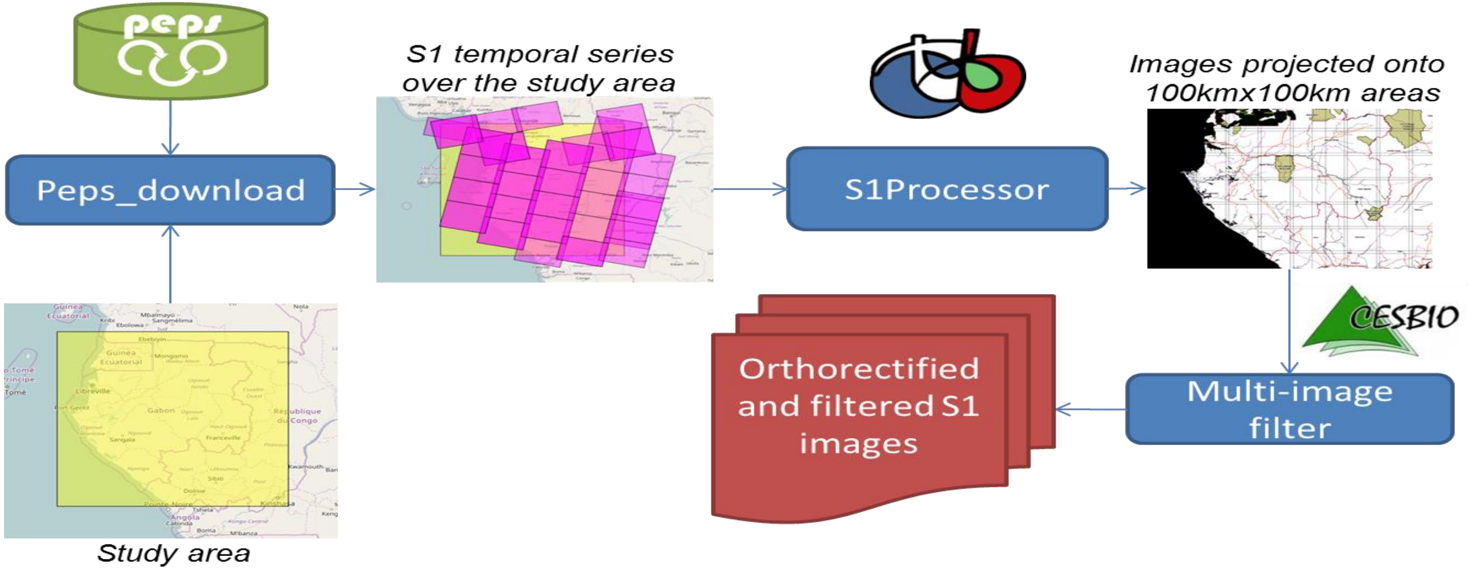


Forest in green
Backscatter change in yellow

→ Need time series for disturbance detection

A CNES-CESBIO processing chain to handle the large amount of S1 data

Generation of stacked time series from a set of downloaded pre-processed images

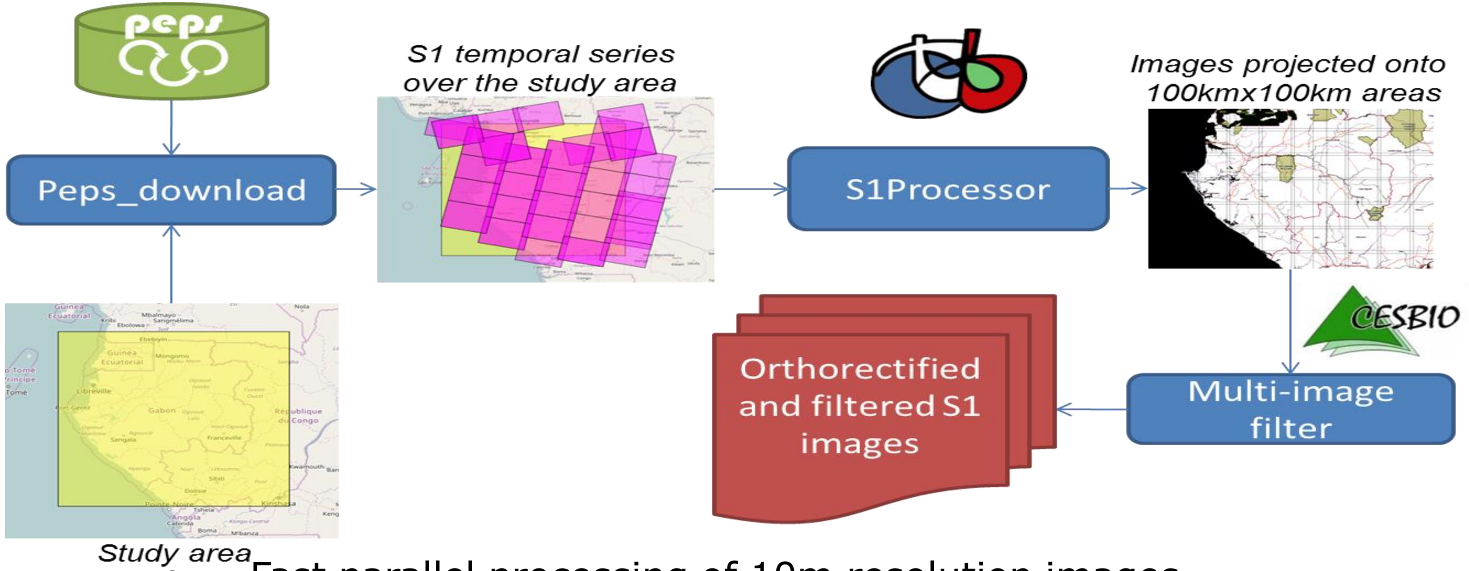


PEPS: CNES platform that provides free access to data from the Sentinel satellites

OTB Orfeo ToolBox: CNES open source for state-of-the-art remote sensing

A CNES-CESBIO processing chain to handle the large amount of S1 data

Generation of stacked time series from a set of downloaded pre-processed images



- Fast parallel processing of 10m resolution images
- Automatically downloads, calibrates, orthorectifies and filters speckle noise
- Multi-image filtering particularly adapted to dense time series
- Images subset directly superposed to Sentinel-2 100x100 km^2 tiles

Forest cover change with C-band SAR time series

Input data:

- Sentinel-1 time series (every 6-12 days)
- Ancillary data to mask out non-forest areas

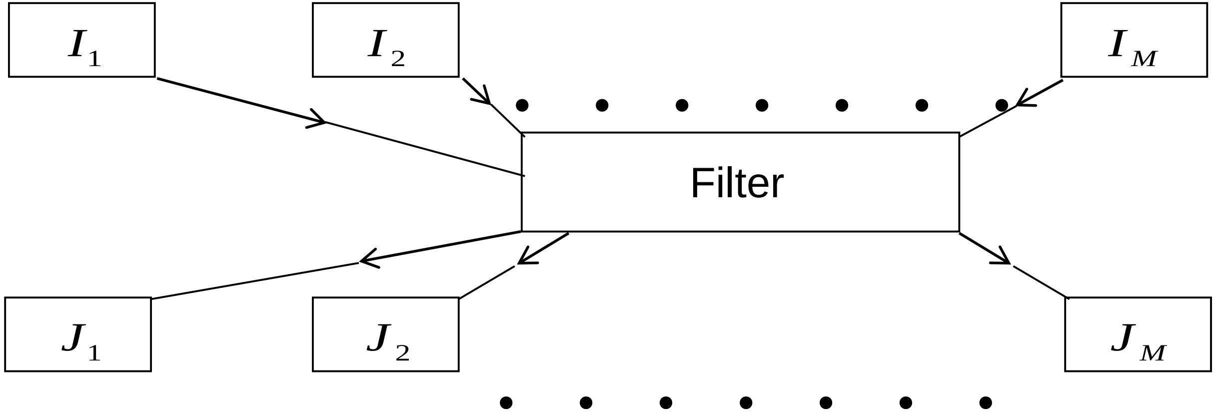
Software:

- Pre-processing chain: Python/OrfeoToolBox
- Coding software: Python, Matlab,…
- GIS software for visualisation: QGIS, ArcGIS,…

Use of multi-images for speckle filtering

Original Images

Filtered images



Purpose of filter:

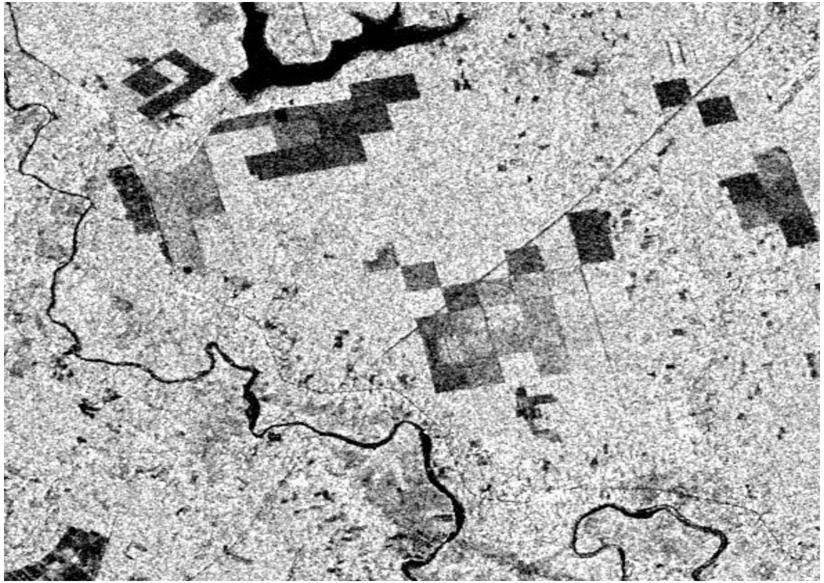
(1) Preserve radiometry $\Rightarrow$ unbiased

$$\langle I_k(x,y)\rangle = \langle J_k(x,y)\rangle \qquad 1 \leq k \leq M$$

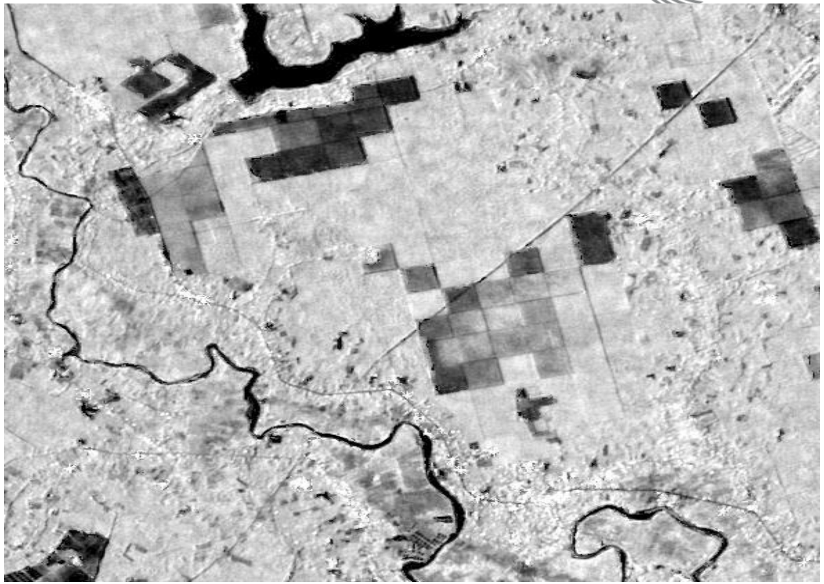
(2) Minimise the variance of J_k

Lopes & Bruniquel, 1997
Quegan & Yu, 2001

Speckle filtering



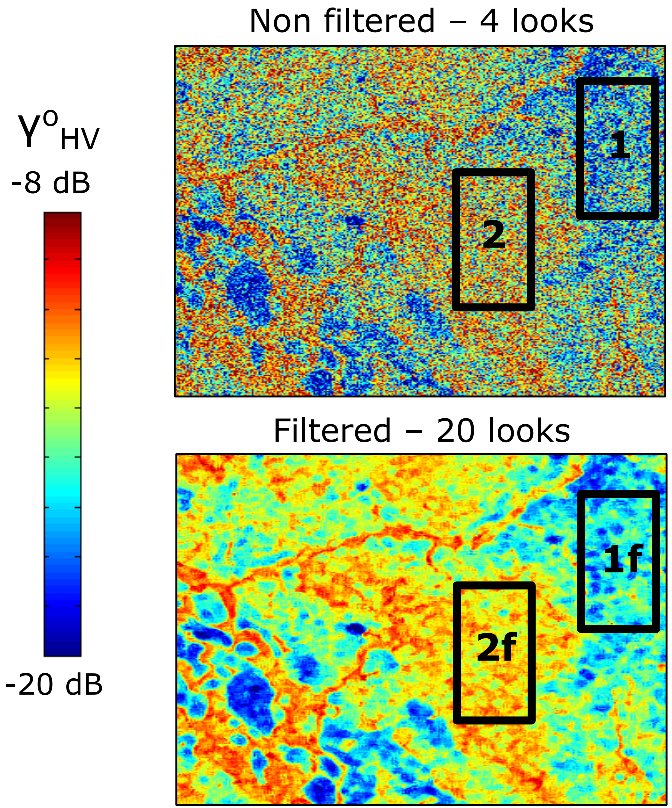
Sentinel-1 image before filtering



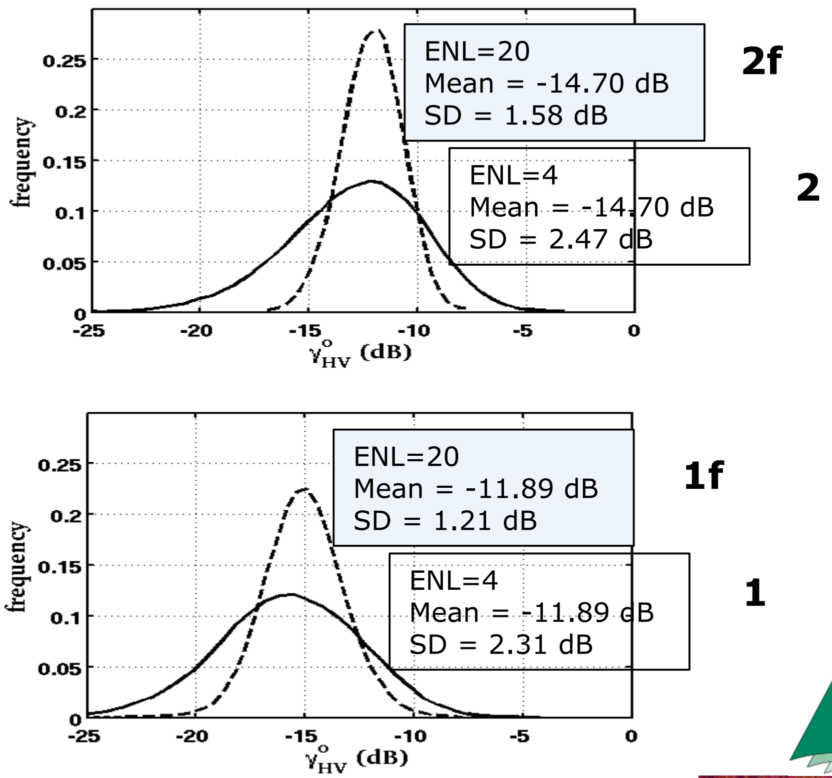
Sentinel-1 after filtering

- Speckle effect is reduced
- Spatial resolution is preseved
- Speckle reduction is enhanced with increasing number of images

Multi-image filtering reduces variance and preserves radiometry



Mermoz et al., 2016



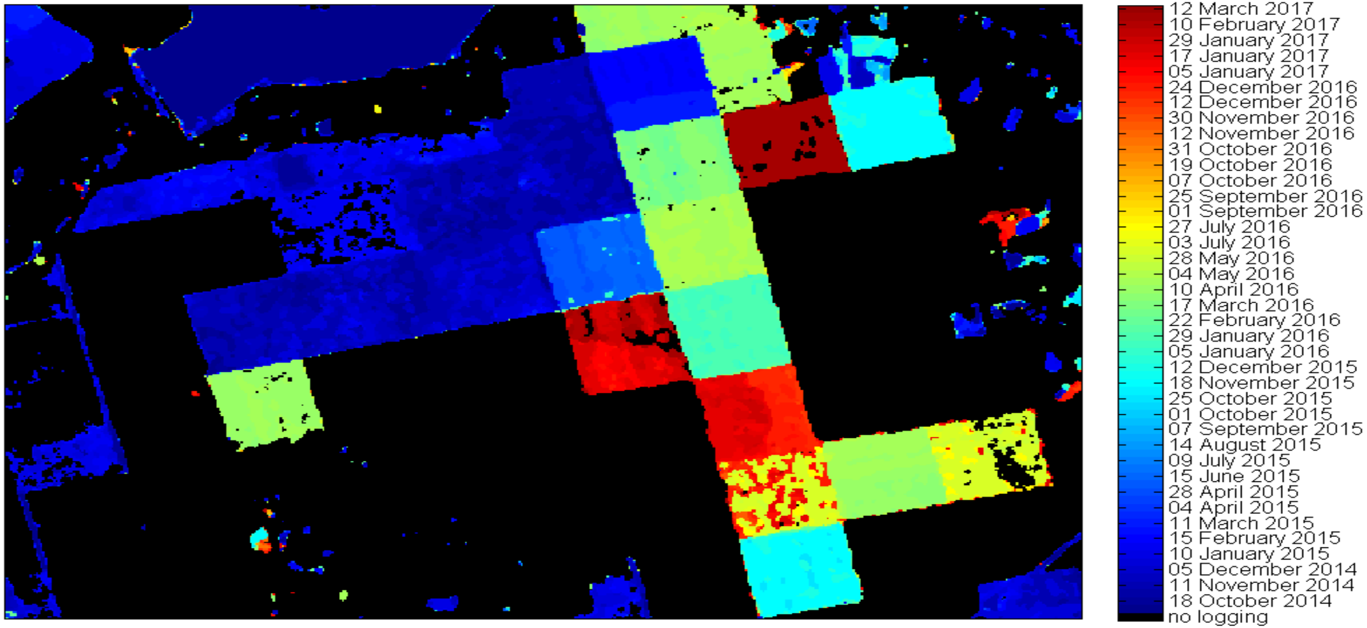
Thuy Le Toan

Results in Vietnam: monitoring clear-cutting

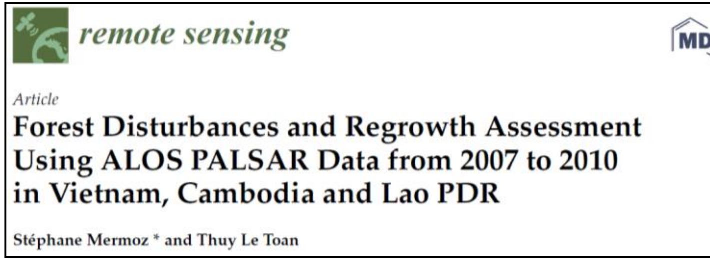
Rubber plantations in southern Vietnam

Detection of the first date where change occurs

Logging date



- Using backscatter change detection (Mermoz and Le Toan, 2016)
- Confirmation by backscatter variance after the disturbance (Bouvet et al.,2018)

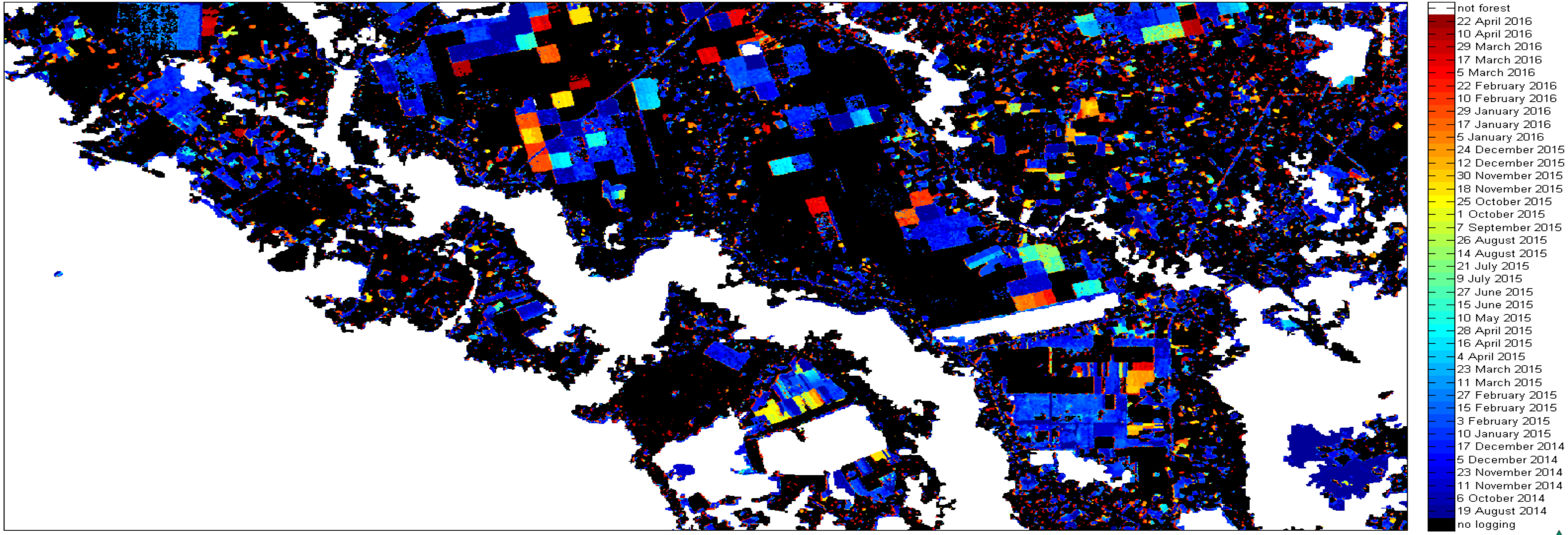

remote sensing

Article

Forest Disturbances and Regrowth Assessment Using ALOS PALSAR Data from 2007 to 2010 in Vietnam, Cambodia and Lao PDR

Stéphane Mermoz * and Thuy Le Toan

Logging date map between October 2014 and April 2016



Question: time series of Sentinel-1 can be used to detect forest disturbances globally ?

Clear cutting for rubber plantation in Cambodia and Vietnam

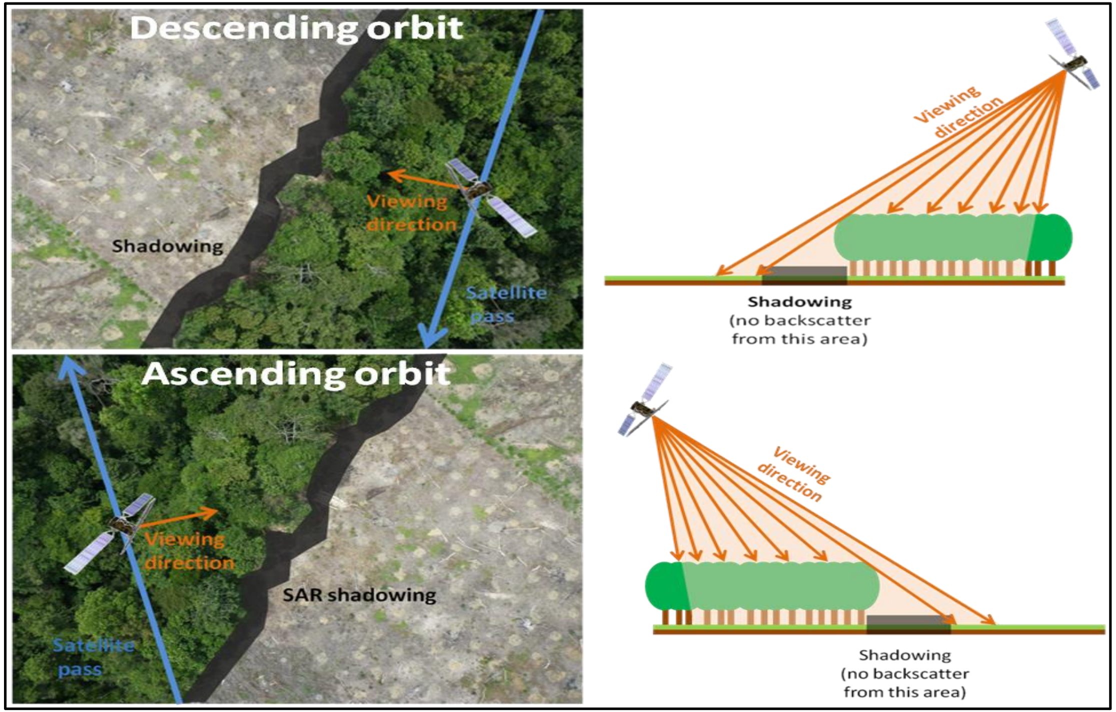
Clear cutting In Peru

Disturbance detection performance depends strongly on the disturbed area

- Vegetation type
- Dimension of the disturbed area
- Environment conditions: rain, seasonality
- Post-disturbance state of the area
- Topography

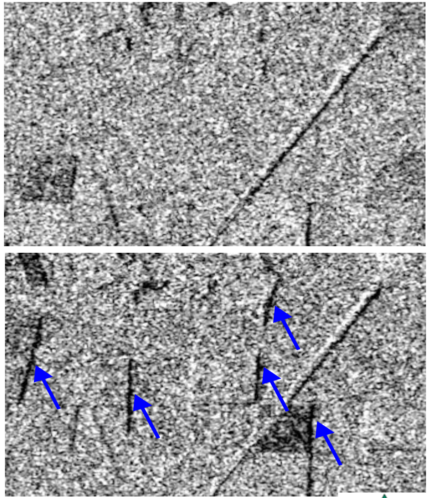
→ Need to develop other disturbance indicators to complement backscatter change

Need for additional deforestation indicators: the shadow effect



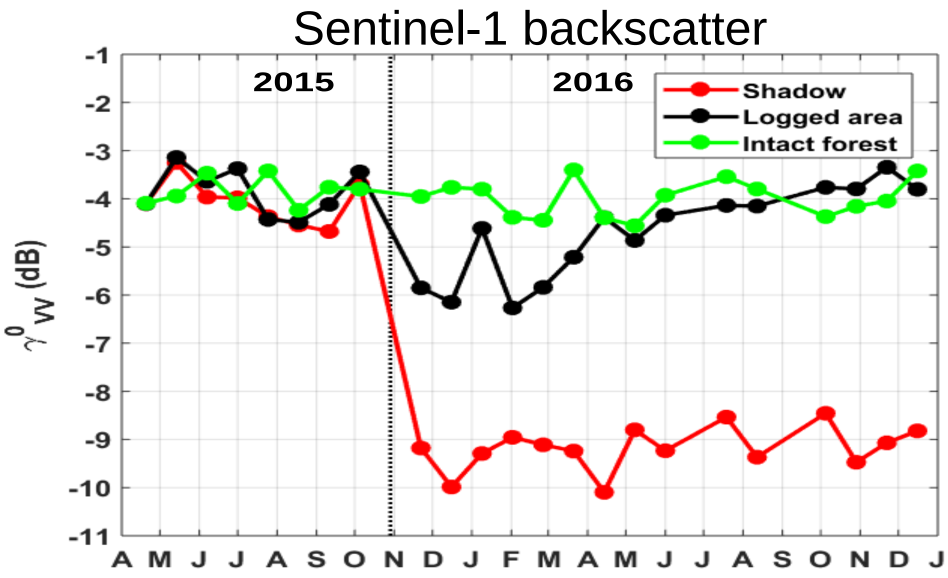
When deforestation occurs, shadows (dark areas) are created in SAR images at the edges of the deforested patches:

10 May 2015



1 October 2016

Need for additional deforestation indicators: the shadow effect



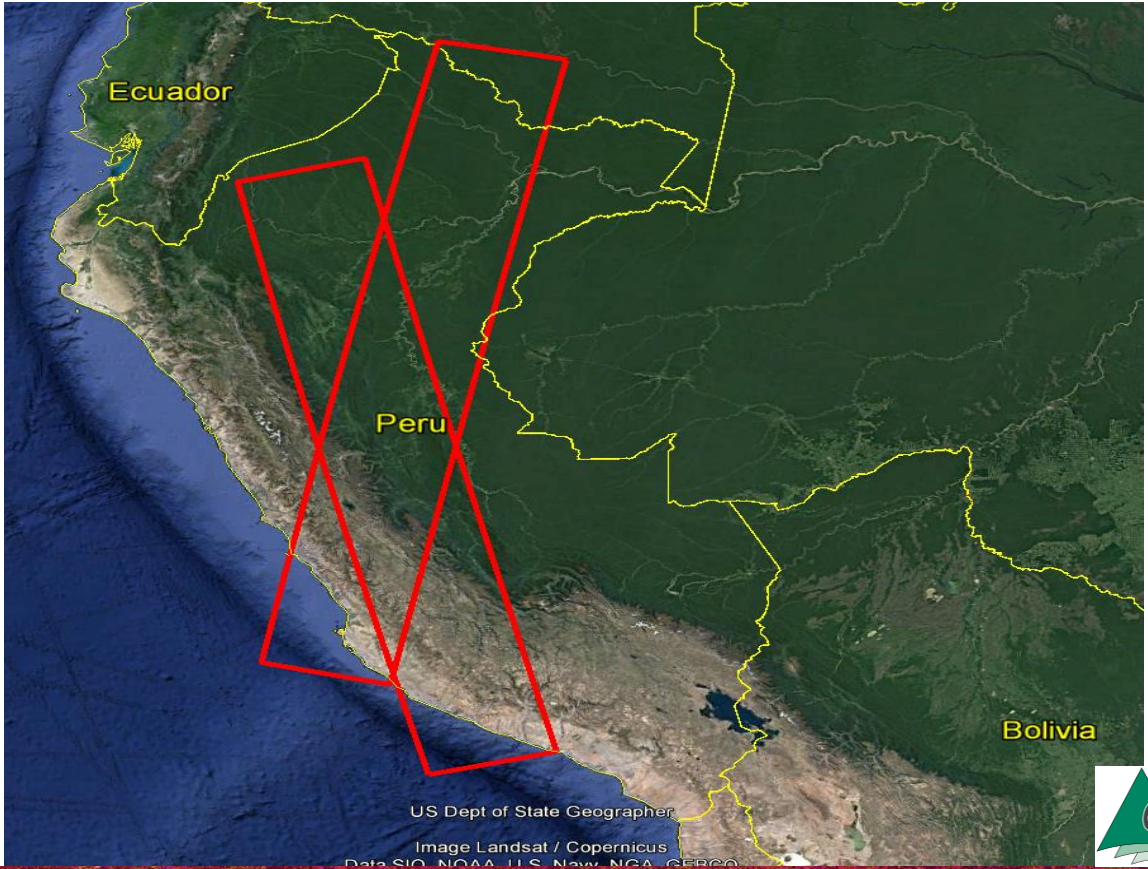
⇨Shadows are reliable, persistent indicators of deforestation

In this example, logging occurs in October-November 2015

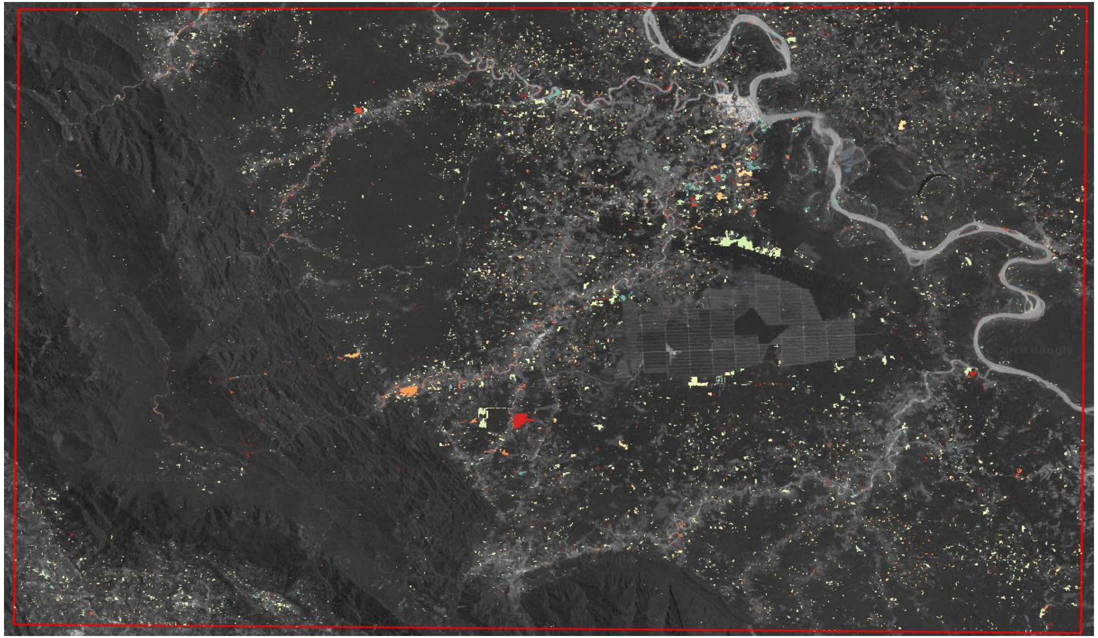
The temporal backscatter profile of :

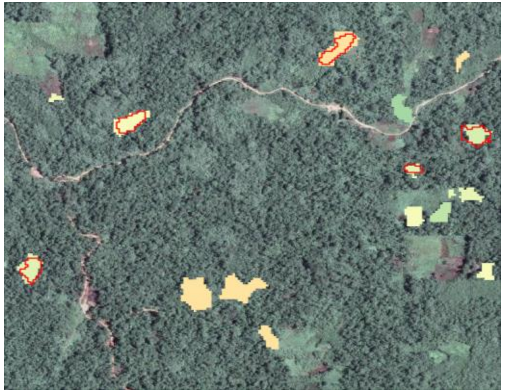
- **Intact forest** close to the disturbance area (in green): shows a stable backscatter
- **Logged area** (black): moderate decrease (~2.5dB), but post-disturbance backscatter then gradually increase to its original level
- One of the edges of the logged patch: **shadow** appears (red), drastic backscatter decrease (~5dB), with no apparent evolution after

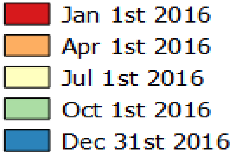
Disturbance detection enhacement by using ascending & descending orbits



Results of deforestation monitoring in Peru



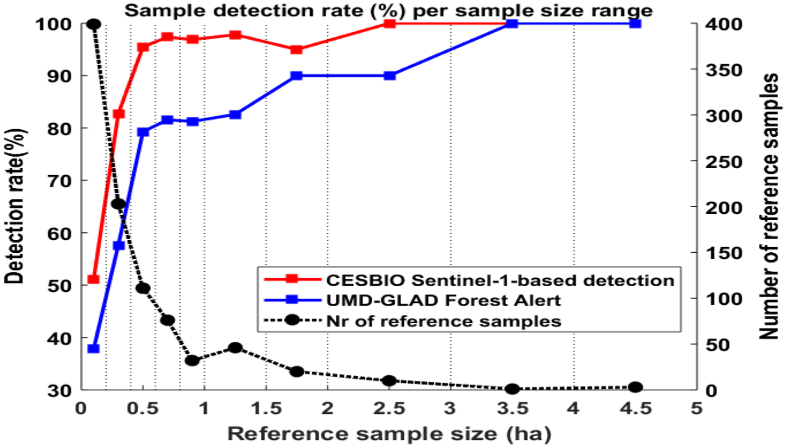


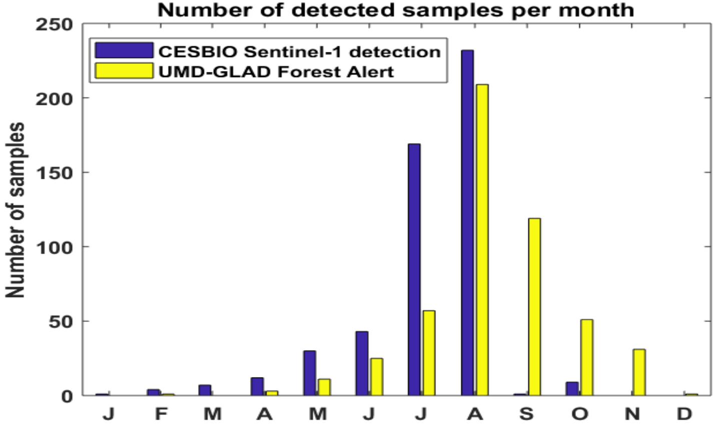


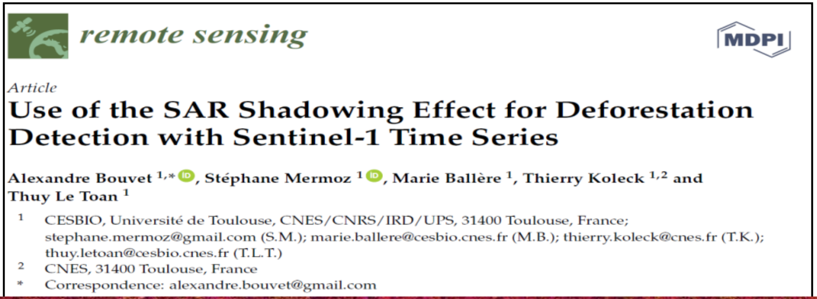
About 8 600 ha deforested in one year (over a 600 000 ha area).

Results of deforestation monitoring in Peru

Comparison with optical-based (Landsat) detection (UMD-GLAD Forest Alert)






remote sensing

MDPI

Article

Use of the SAR Shadowing Effect for Deforestation Detection with Sentinel-1 Time Series

Alexandre Bouvet [1,*], Stéphane Mermoz [1], Marie Ballère [1], Thierry Koleck [1,2] and Thuy Le Toan [1]

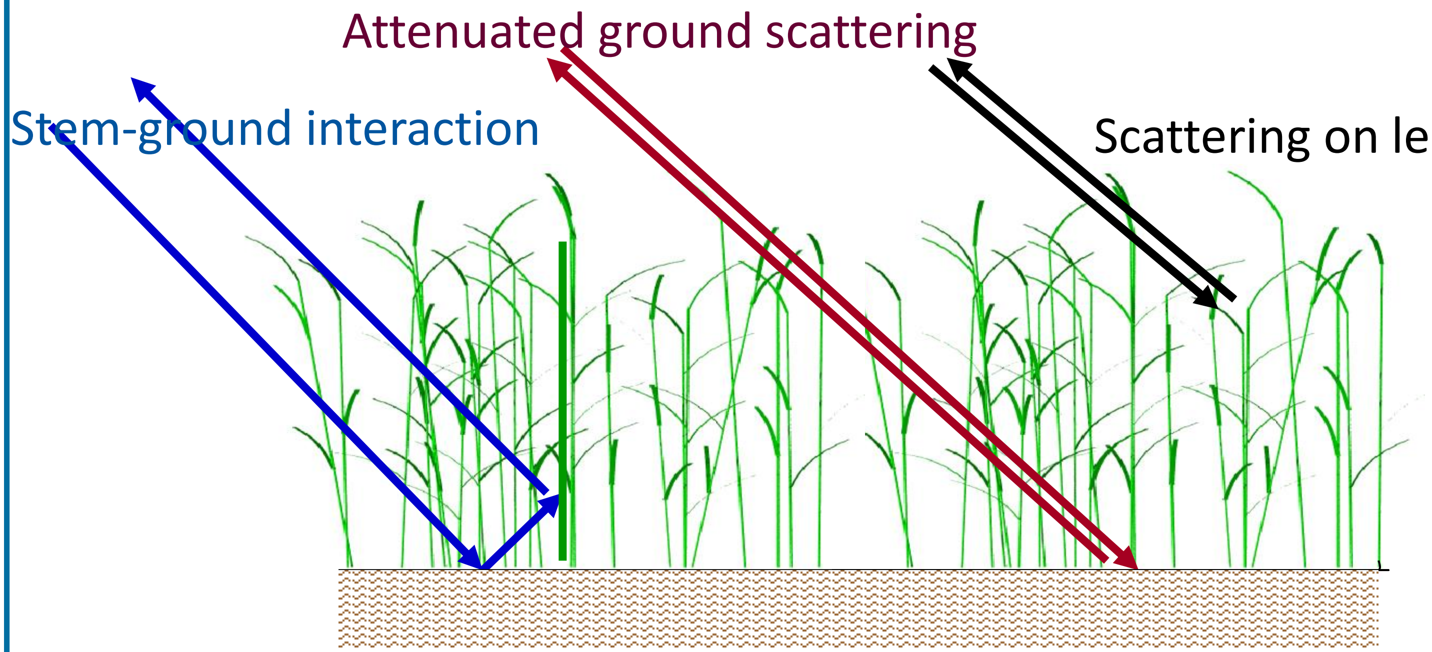
1 CESBIO, Université de Toulouse, CNES/CNRS/IRD/UPS, 31400 Toulouse, France; stephane.mermoz@gmail.com (S.M.); marie.ballere@cesbio.cnes.fr (M.B.); thierry.koleck@cnes.fr (T.K.); thuy.letoan@cesbio.cnes.fr (T.L.T.)

2 CNES, 31400 Toulouse, France

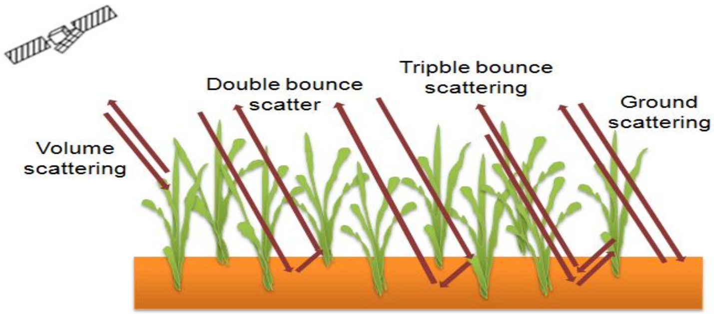
* Correspondence: alexandre.bouvet@gmail.com

Agriculture Multitemporal Analysis

Scattering from a cereal canopy



Backscattering from agricultural fields



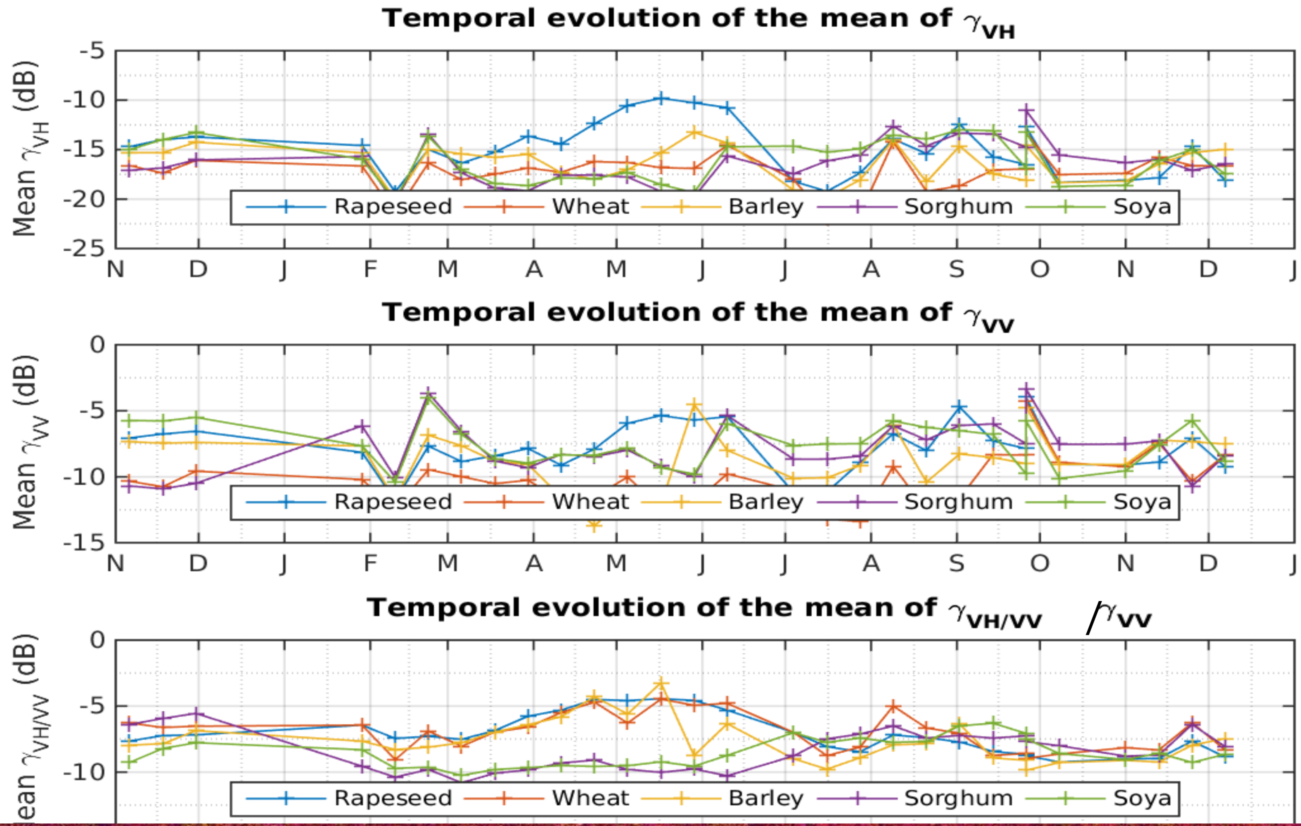
The backscattering from an agricultural field depends on interaction mechanisms, and is governed by:

- The vegetation biomass and structure, which depend on : species, varieties, density, growth stage, growth status
- Soil moisture (rainfall, irrigation), soil surface roughness
- The radar frequency, polarisation, and incidence angle

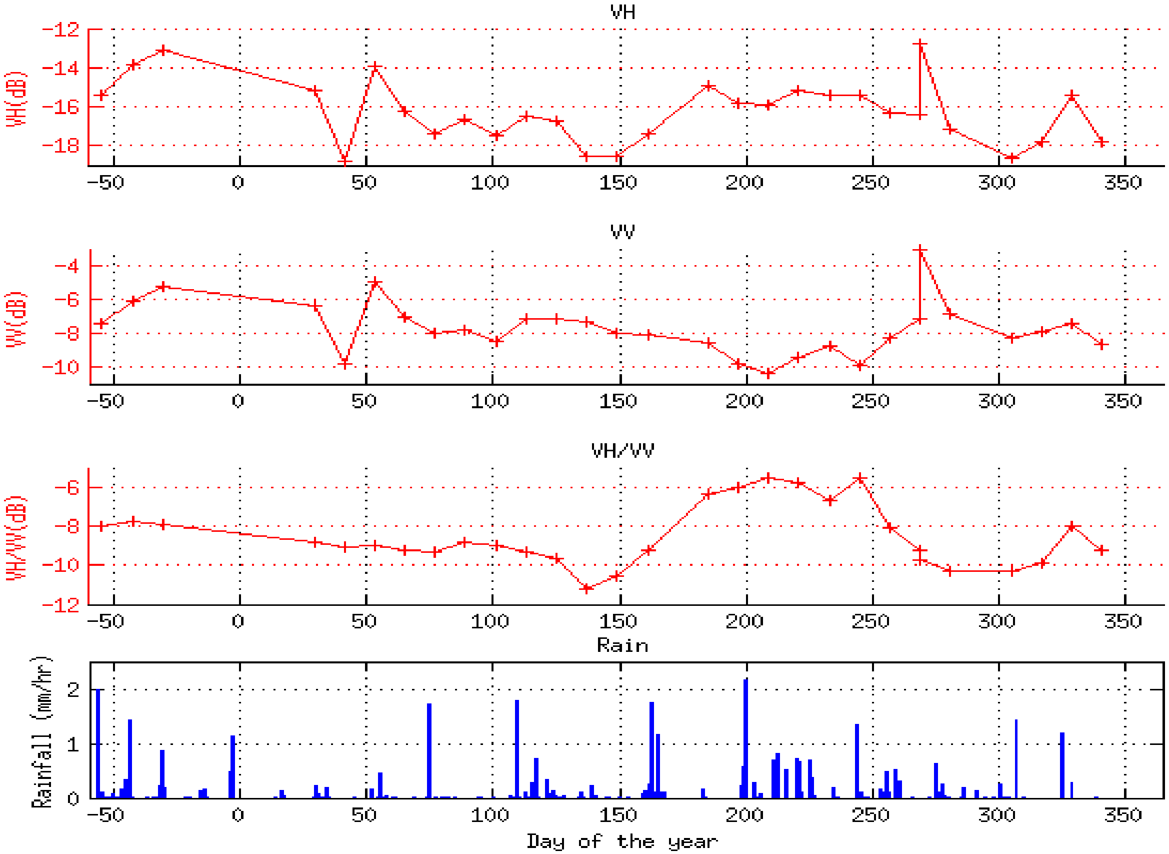
→ **Strong temporal variation during the crop season**
→ **SAR time series necessary in agriculture applications**
→ **For Sentinel-1, use of 2 polarisations (VH+VV)**

Crop types have different temporal backscatter evolution

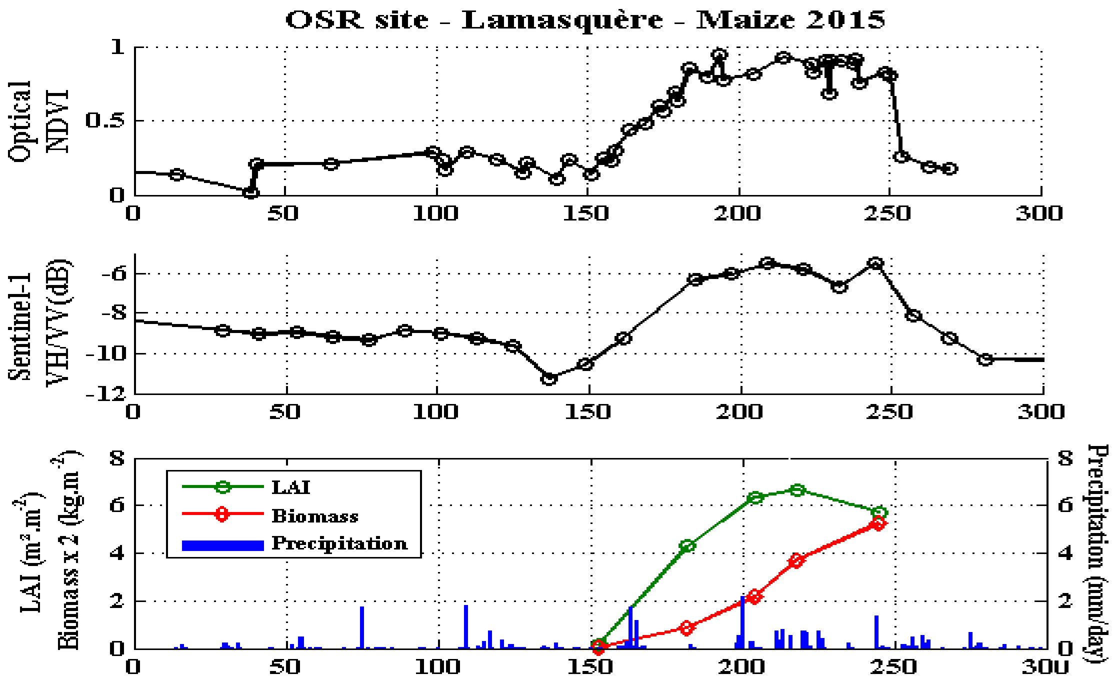
November 2014 to December 2015, South West France



Maize (corn)

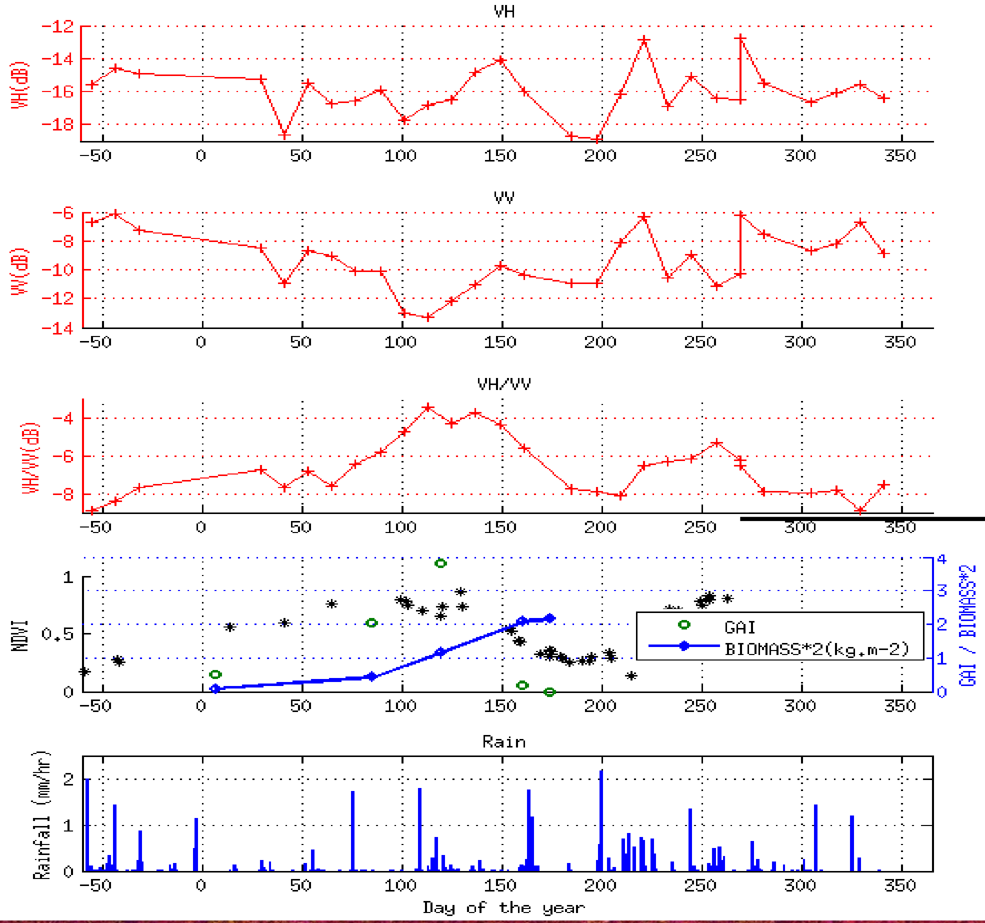

VH
VH(dB)
-12
-14
-16
-18
VV
VV(dB)
-4
-6
-8
-10
VH/VV
VH/VV(dB)
-6
-8
-10
-12
Rain
Rainfall (mm/hr)
2
1
0
-50
0
50
100
150
200
250
300
350
Day of the year

VH/VV strongly correlated to optical NDVI (LAI)



Veloso et al, 2017

Barley



Identification of secondary cover

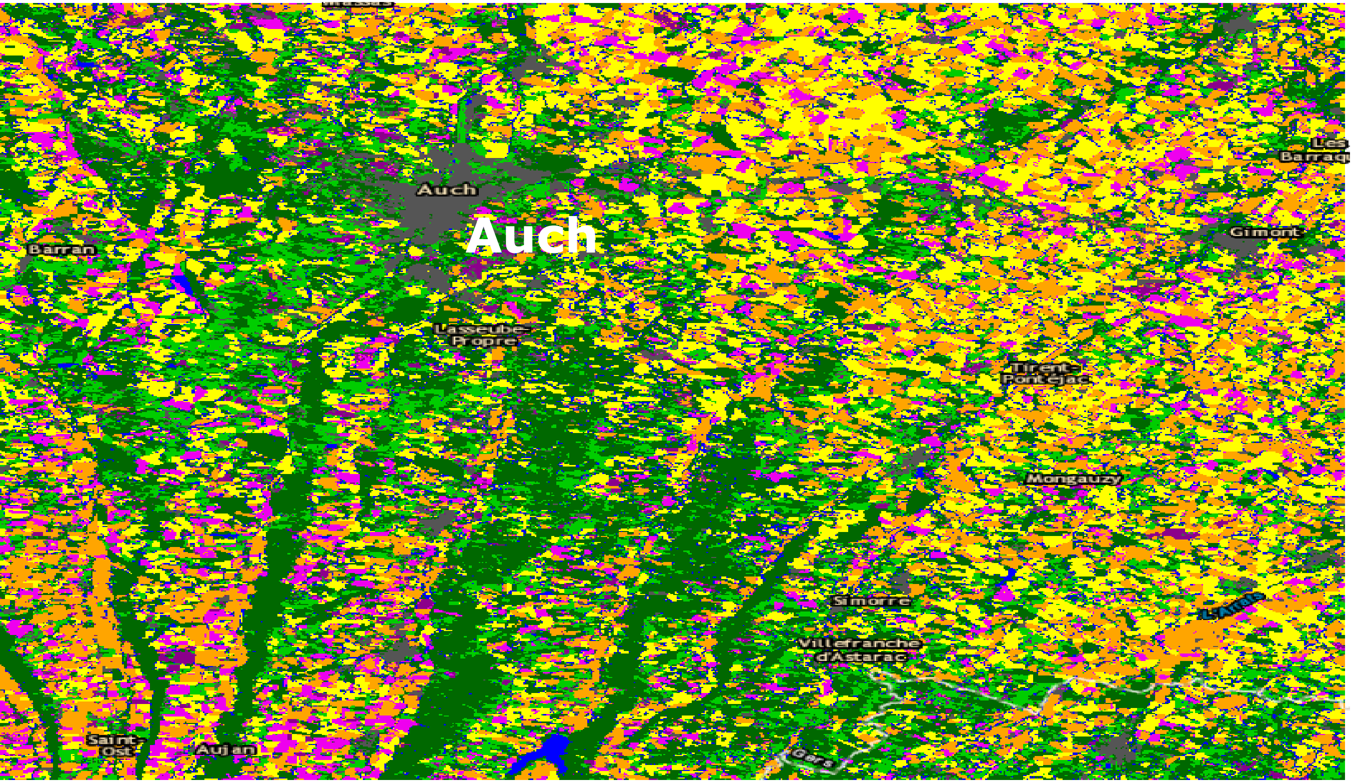
Land use and Crop mapping using Sentinel-1

ID	DATE	ID	DATE
1	06/03/2015	12	09/08/2015
2	18/03/2015	13	21/08/2015
3	30/03/2015	14	02/09/2015
4	11/04/2015	15	14/09/2015
5	23/04/2015	16	26/09/2015
6	05/05/2015	17	08/10/2015
7	17/05/2015	18	01/11/2015
8	29/05/2015	19	13/11/2015
9	10/06/2015	20	25/11/2015
10	16/07/2015	21	19/12/2015
11	28/07/2015		

g

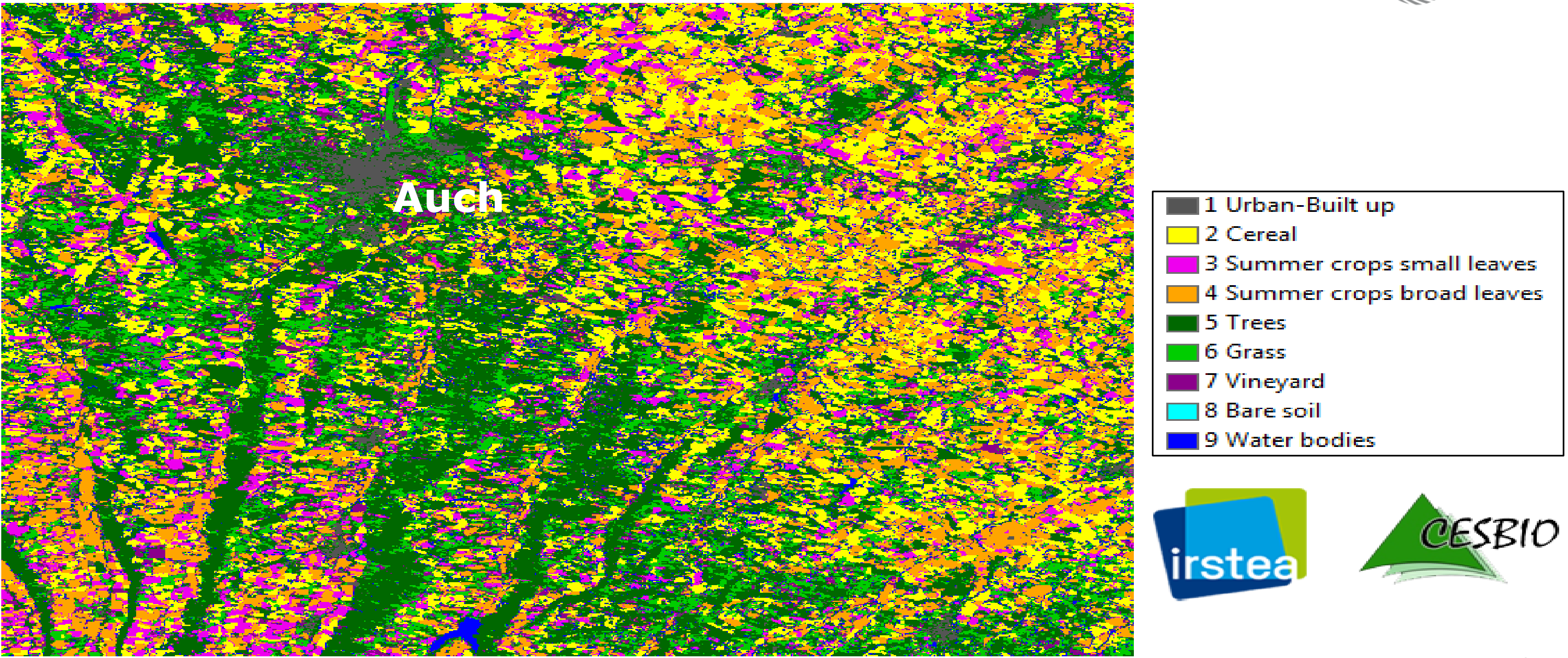
ID	DATE	ID	DATE
1	12/03/2015	11	10/07/2015
2	24/03/2015	12	22/07/2015
3	05/04/2015	13	15/08/2015
4	17/04/2015	14	27/08/2015
5	29/04/2015	15	08/09/2015
6	11/05/2015	16	20/09/2015
7	23/05/2015	17	02/10/2015
8	04/06/2015	18	19/11/2015
9	16/06/2015	19	13/12/2015
10	28/06/2015		

Reference LULC map using optical and ground data



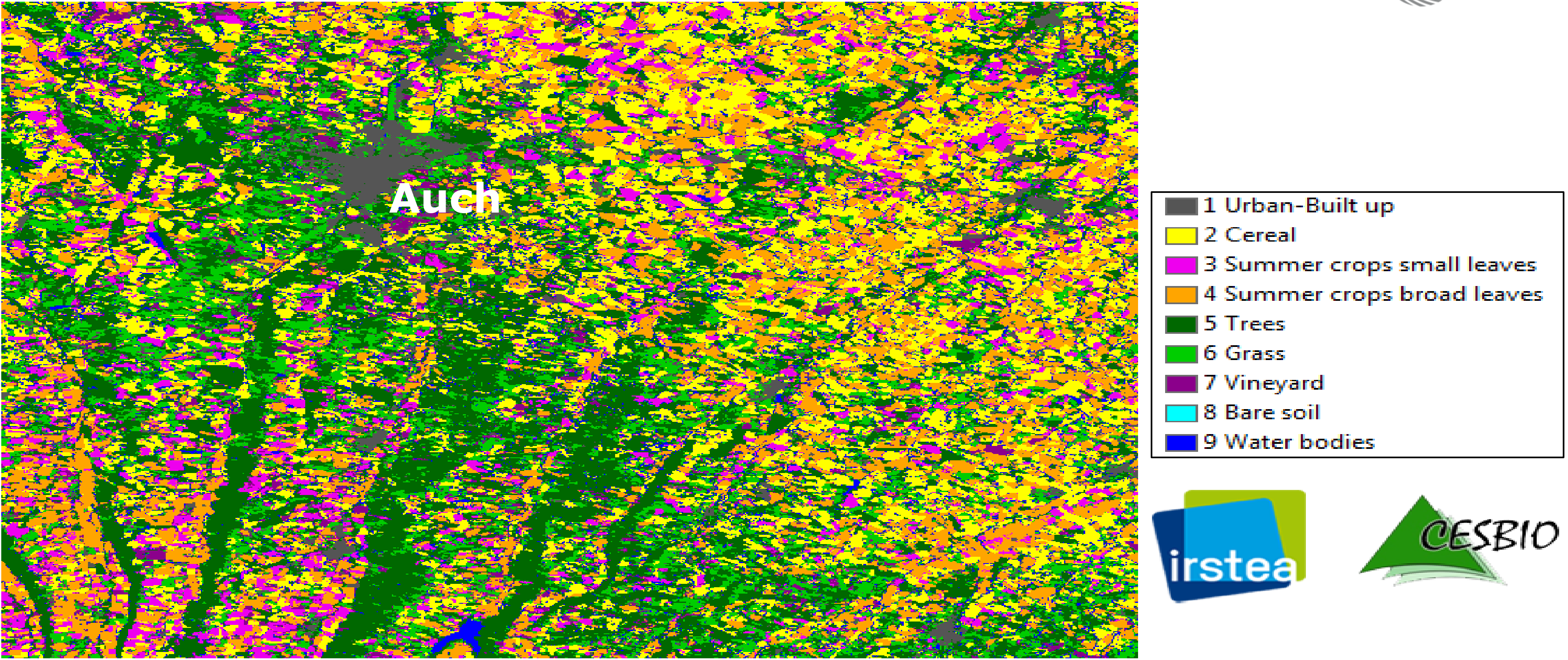
1	Urban-Built up
2	Cereal
3	Summer crops small leaves
4	Summer crops broad leaves
5	Trees
6	Grass
7	Vineyard
8	Bare soil
9	Water bodies

Crop mapping using Sentinel-1 (intensity, multidates)



Overall accuracy: 82%, Kappa Coef. = 0.79

Crop mapping using intensity and InSAR coherence time series Sentinel-1 data



Overall accuracy: 89%, Kappa Coef. = 0.86

Rice monitoring using Sentinel-1

Rice is the most critical staple food for more than half of humanity, with the majority in developing world (90% in Asia)

- Among EO data, SAR data have been proved efficient for rice monitoring since late 80's , but applications have been hampered by lack of systematic and cost effective data
- Sentinel-1 represents unpreceding opportunity for operational rice monitoring applications
- R&D Demonstrator projects were urgently needed with the launch of Sentinel-1 in April 2014

The GEORICE Project

innovators

Understanding and meeting the user needs

1. **Main requirements :**

   Rice sown and harvested area, rice **cropping density**, rice production

   → for statistics at administrative units (province, region, country)

   Rice **status**, **growth anomaly**

   → for early qualitative information on future production

2. **Other requirements**:

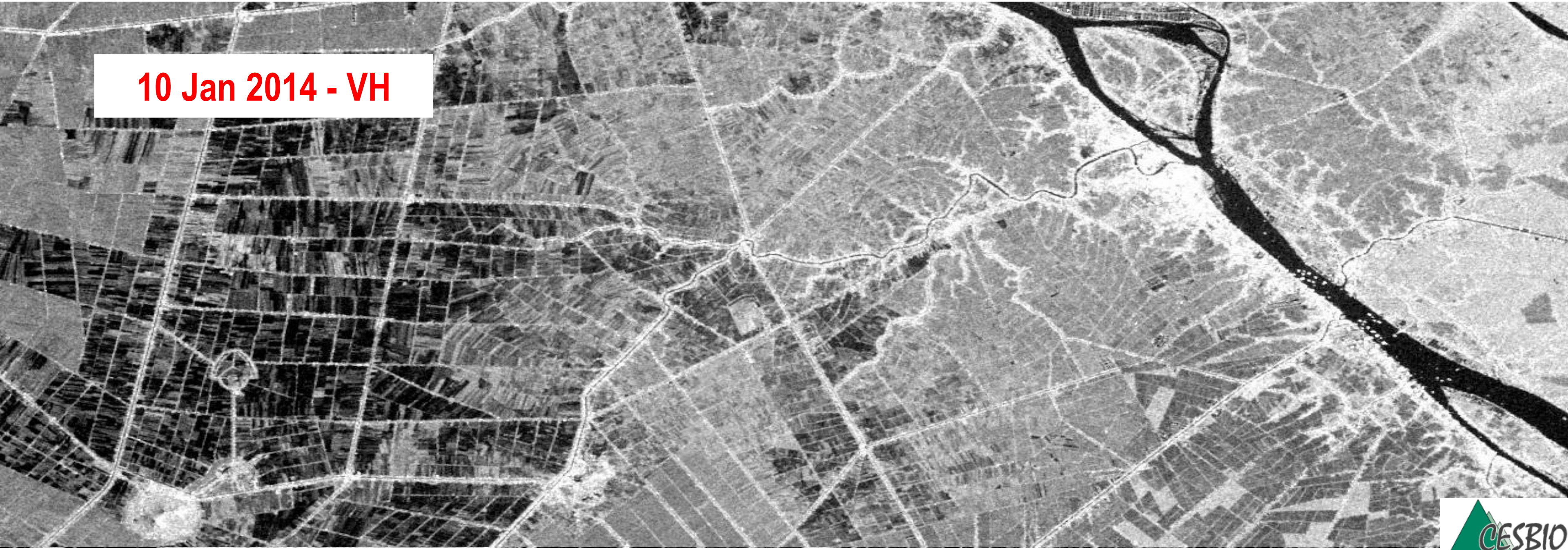
   Rice phenology: to manage irrigation, fertilisation, pesticide, and combined with weather forecast, for disaster mitigation

   Rice sowing date: for planning of irrigation, treatment, harvest

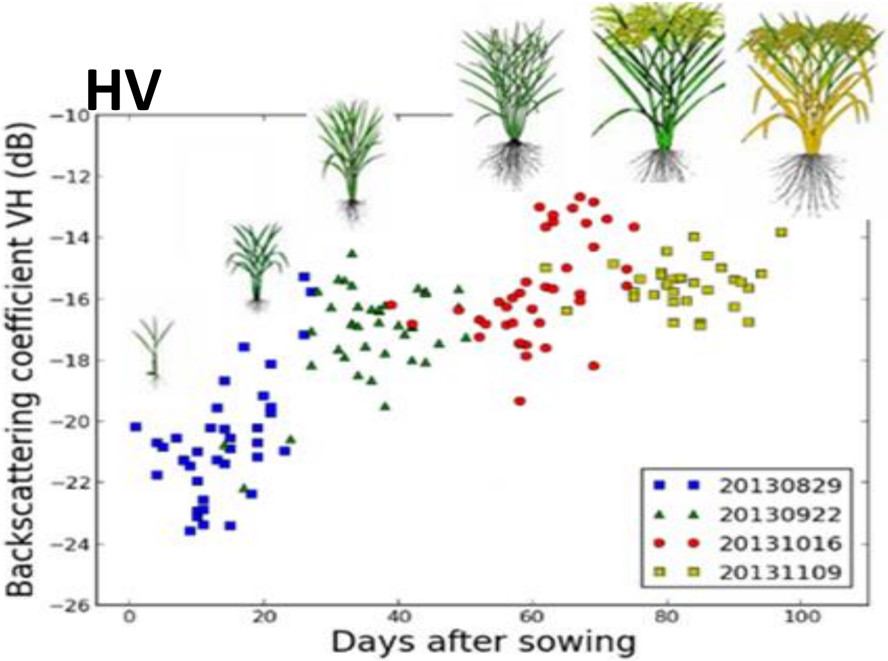
   Rice varieties: for market information

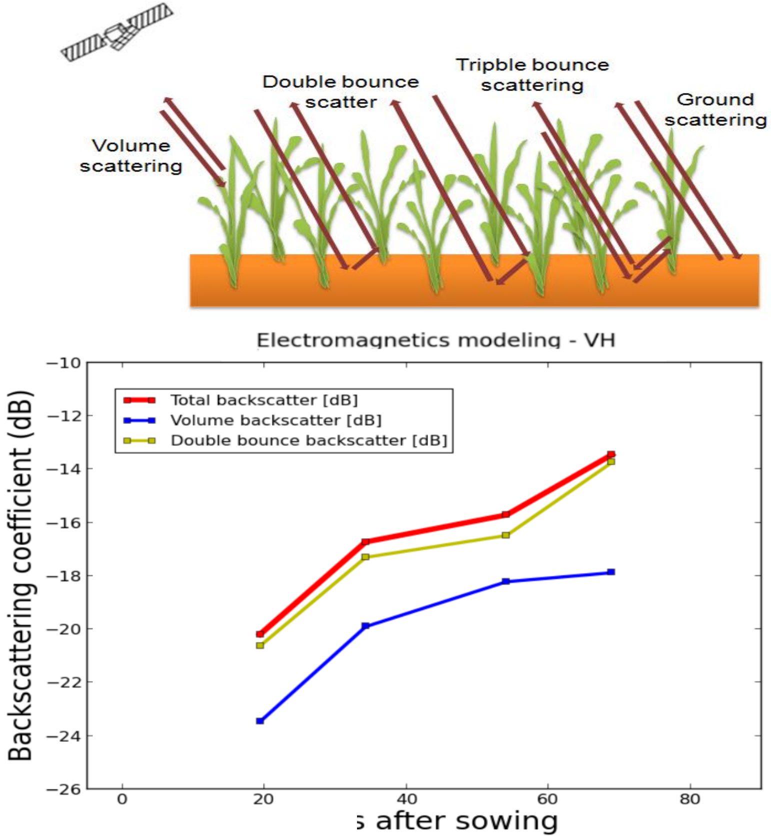
   Field water status: for irrigation planning, water consumation

Rice growth monitoring with Sentinel-1 radar data time series



Understandig rice backscatter temporal evolution





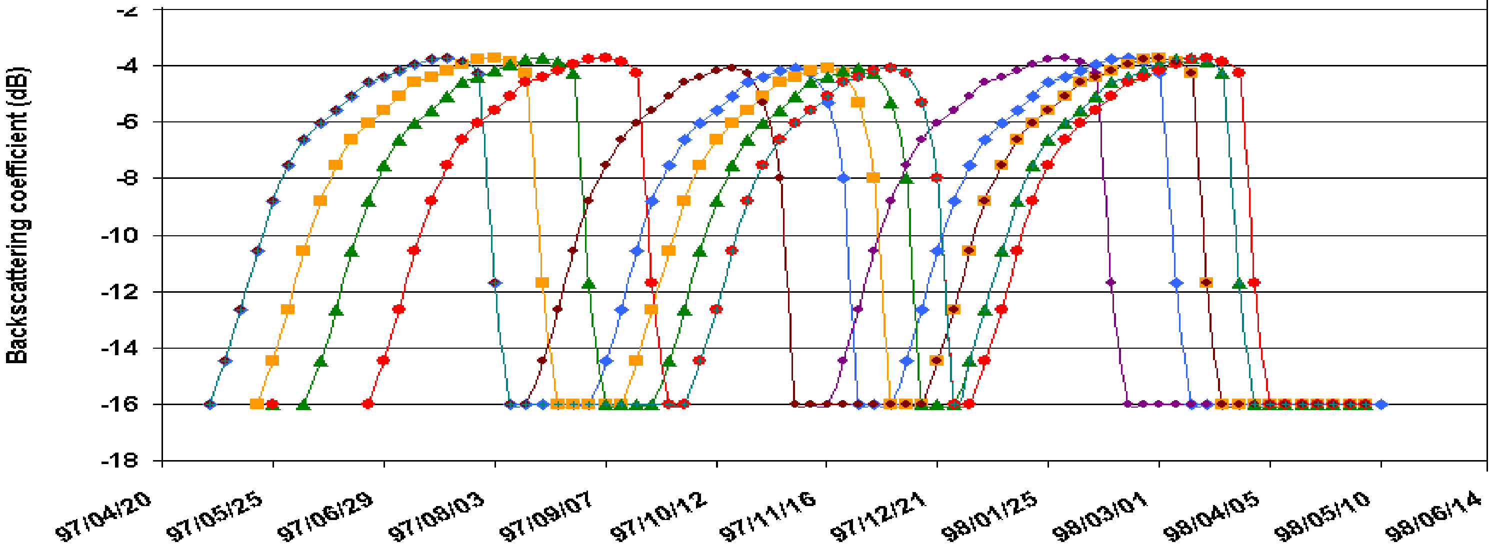
→ ***Use temporal change for rice mapping***

Derivation of sowing date, rice biomass

At a given date, rice fields can have a large range of backscatter

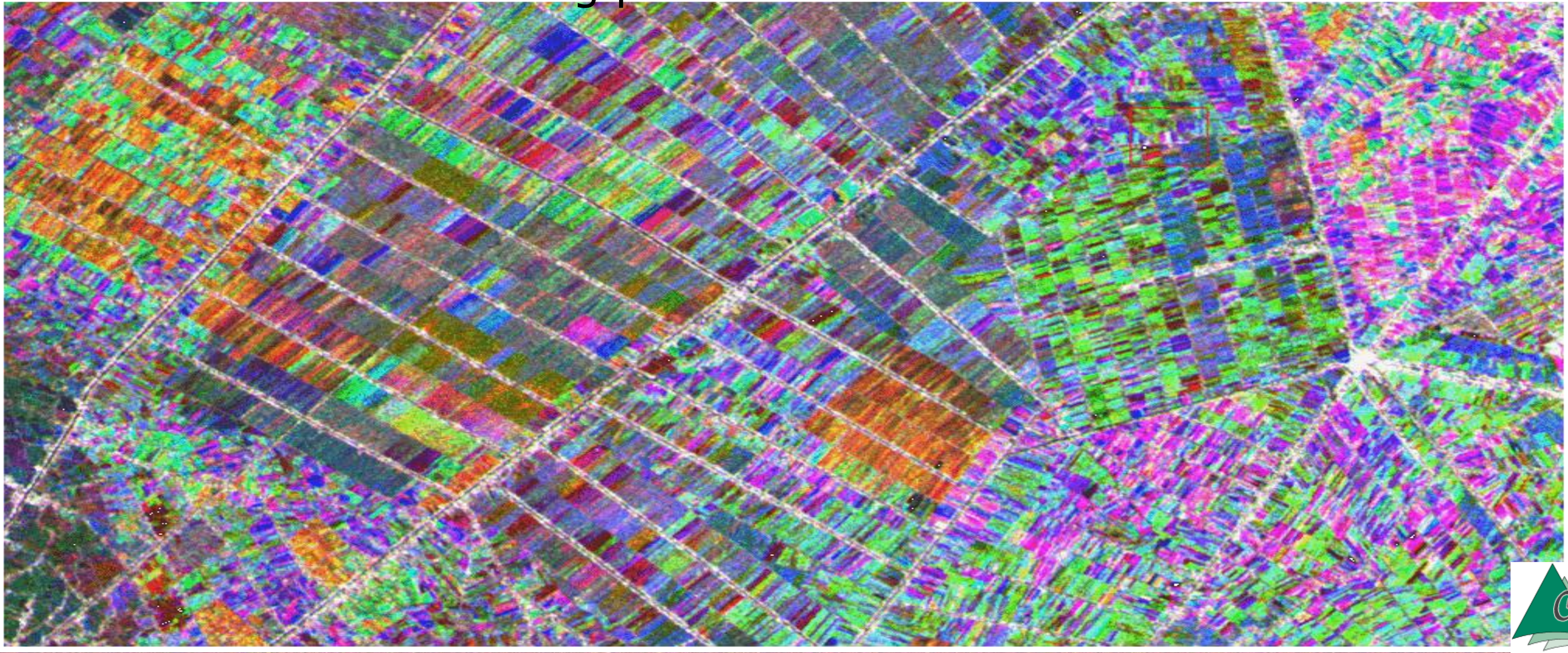
1. Strong temporal variation of the radar backscatter of rice fields
2. Non uniform crop calendar of adjacent fields

Simulation of the C-band backscatter of the 3 crops per year in the Mekong Delta



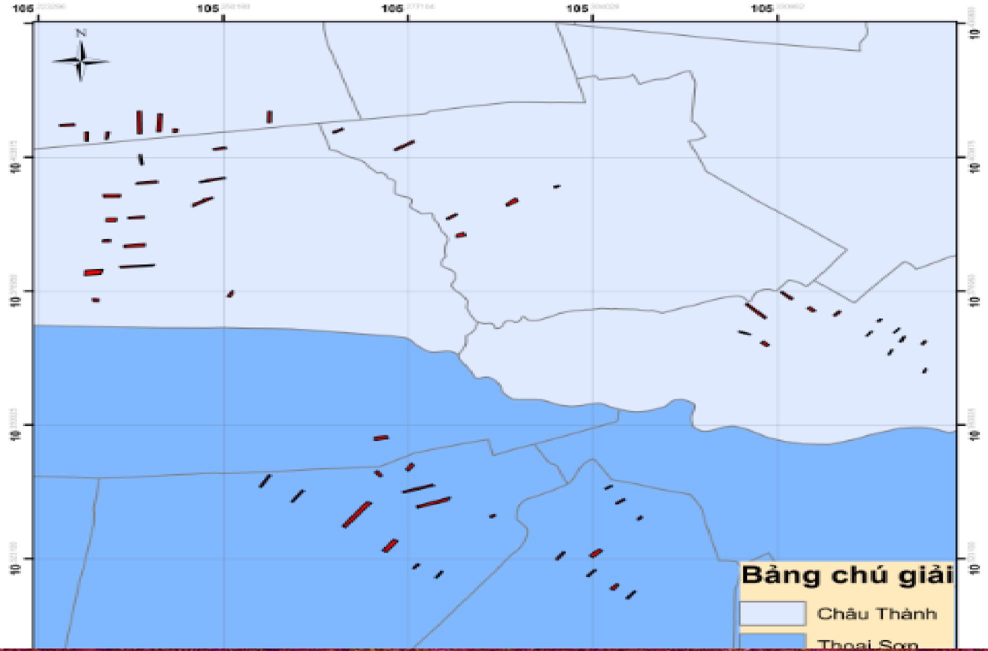
Technical challenges in using standard classification methods

Examples of RGB combinations of different dates of Sentinel-1 over rice fields in the An Giang province



In situ data for understanding of the radar backscatter and algorithm development

40 /60 sampling fields have been surveyed in 2015/16 in An Giang at the same dates of S1.

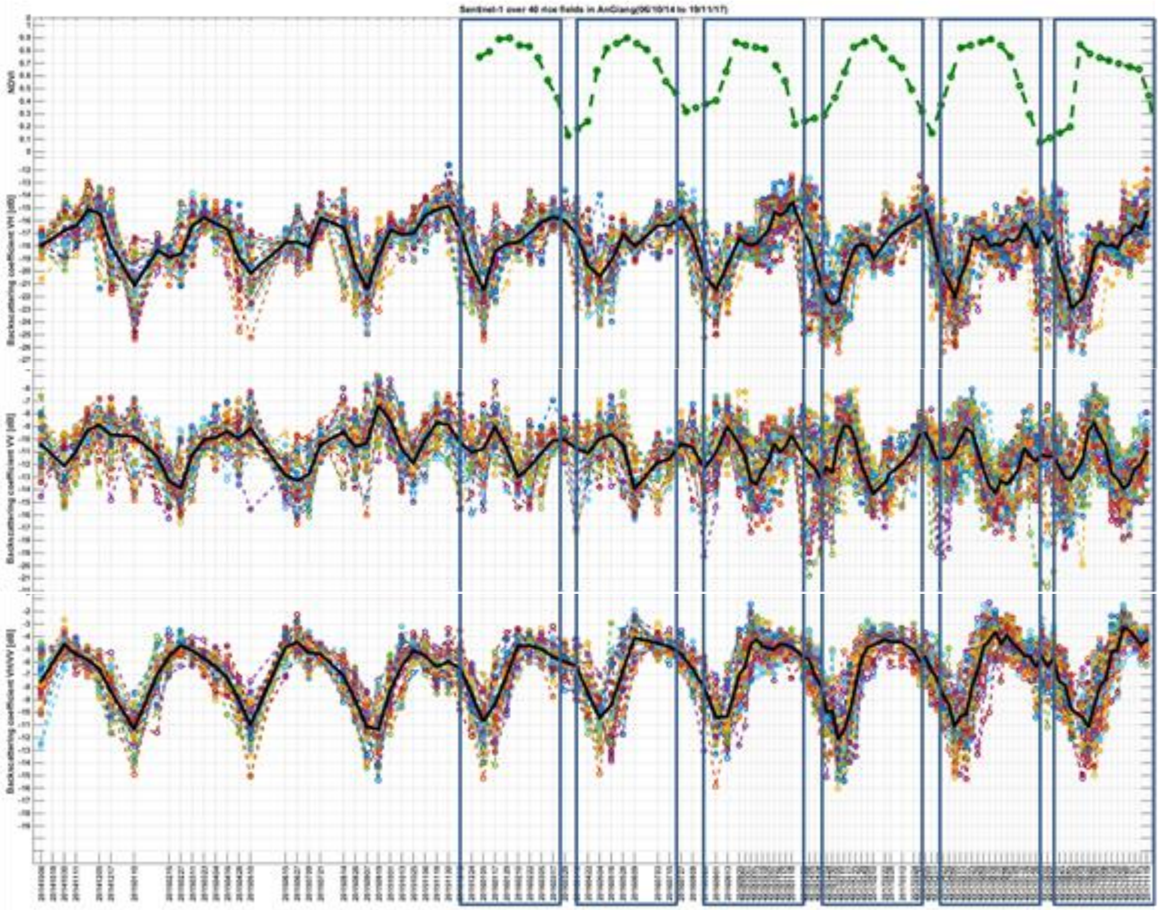


Survey by the University of An Giang
In collaboration with the VNSC /STAC)
and CESBIO

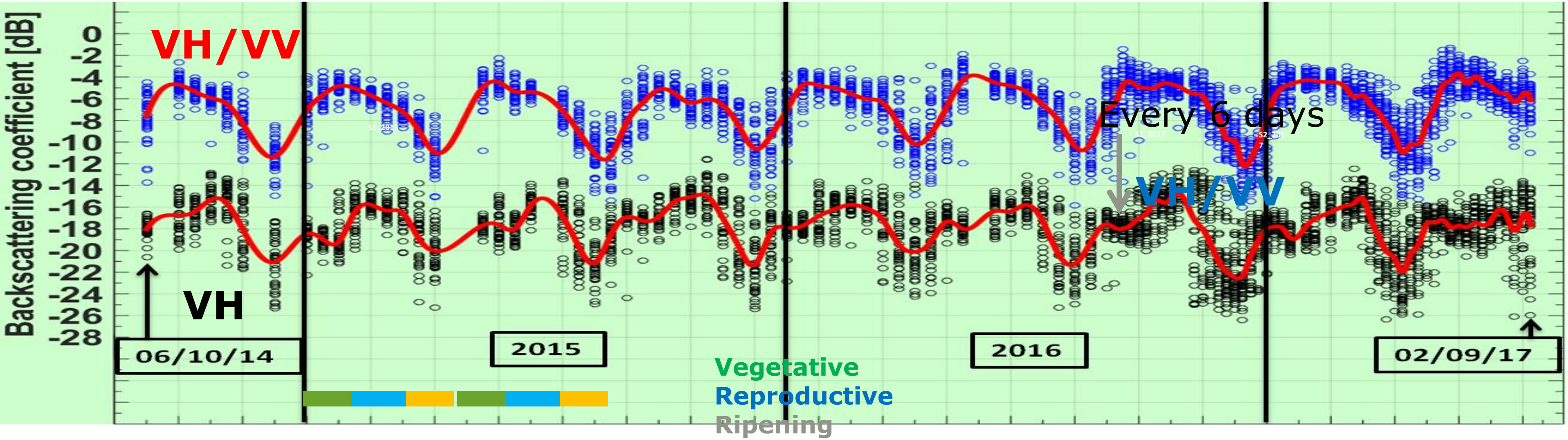
General:
Day of sowing
Rice varieties
Planting density
Harvest date
Rice Yield

Intensive information:
Phenological stage
Height
Biomass
Soil condition

Multi-year analysis of rice backscatter



Sentinel-1 backscatter time series of rice fields



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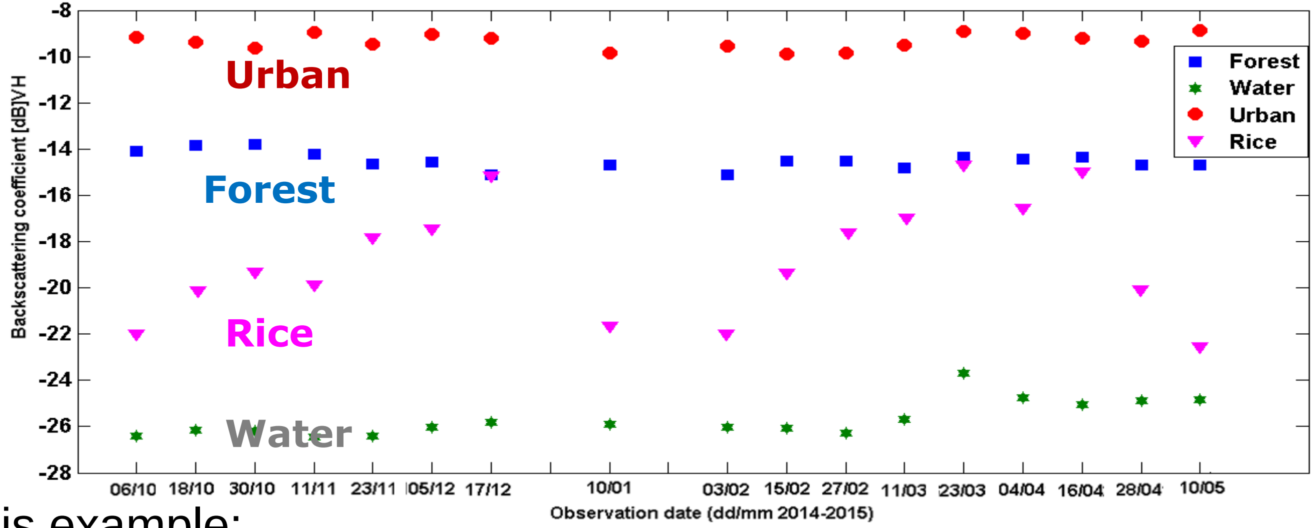
Maximum temporal change as rice/non rice indicator



In this example:

Rice: Maximum temporal change: 5 à 8 dB

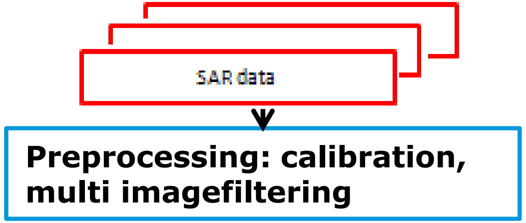
Urban : < 1 dB; (VH >-11 dB)

Water: < 2 dB; (VH <-24dB)

Forest: < 1.5 dB

A simple rice mapping algorithm

Hoa Phan et al., 2017



6 images of SENTINEL-1 for mapping of Autum-Winter rice in 2014
19/08, 31/08, 12/09, 24/09, 06/10

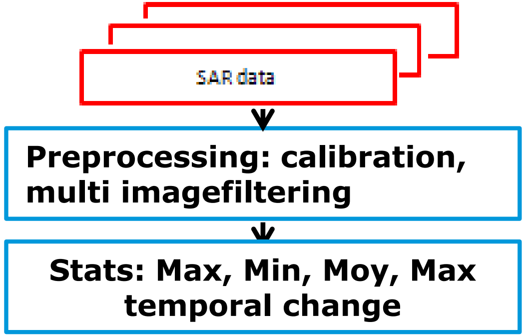
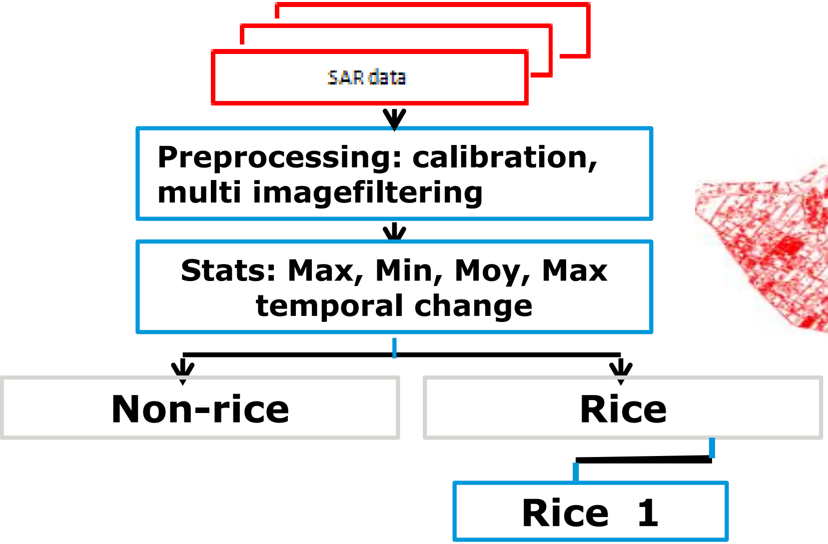
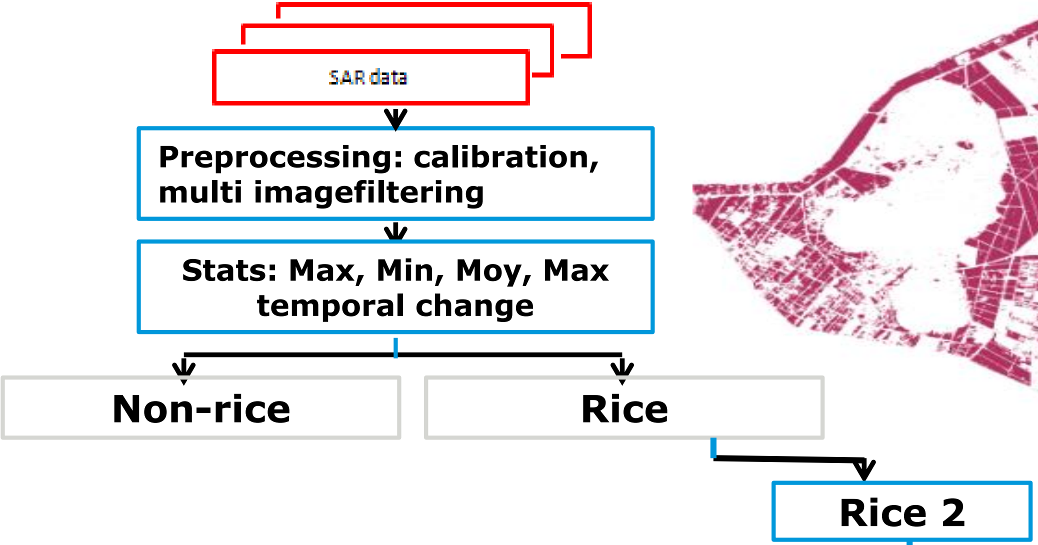


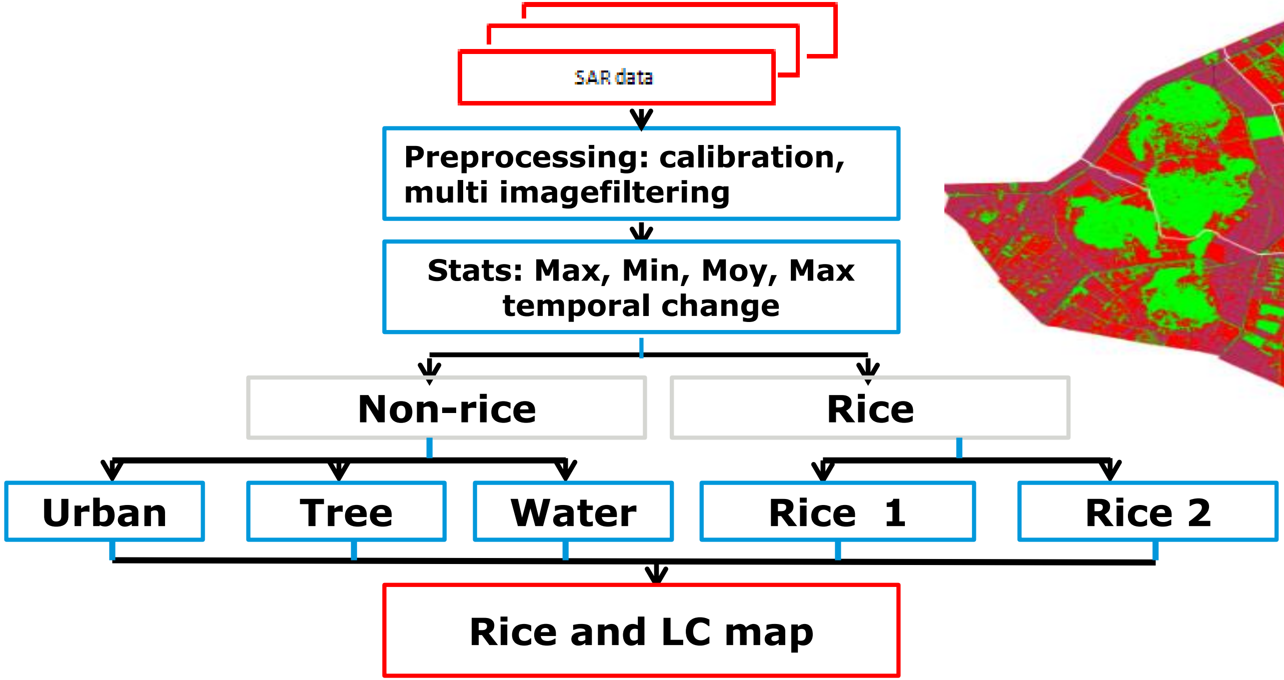
Image of maximum temporal change
Black: small change
White: large change

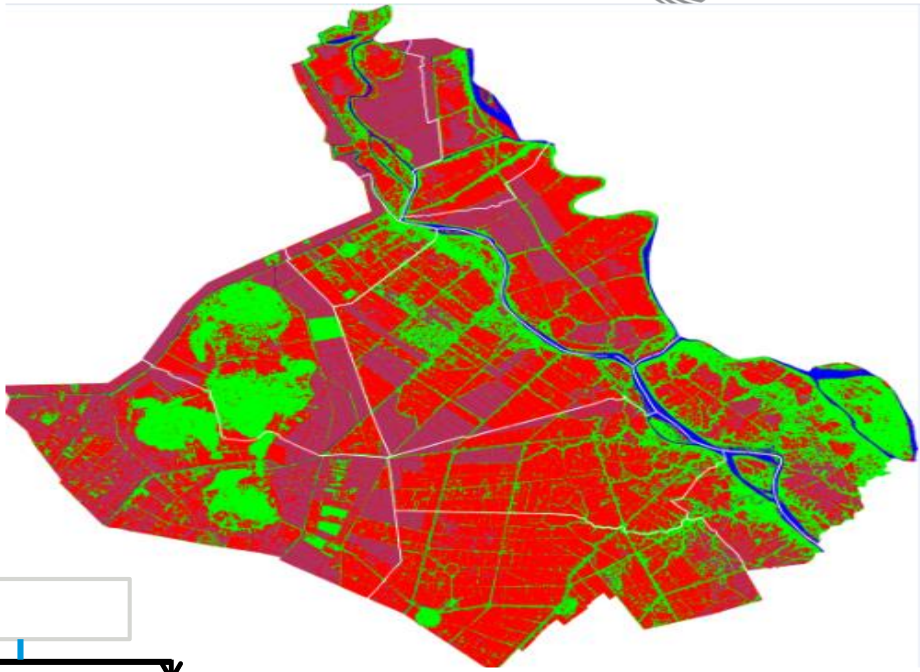


Rice of Autumn-Winter 2014



Rice of Winter Spring 2005





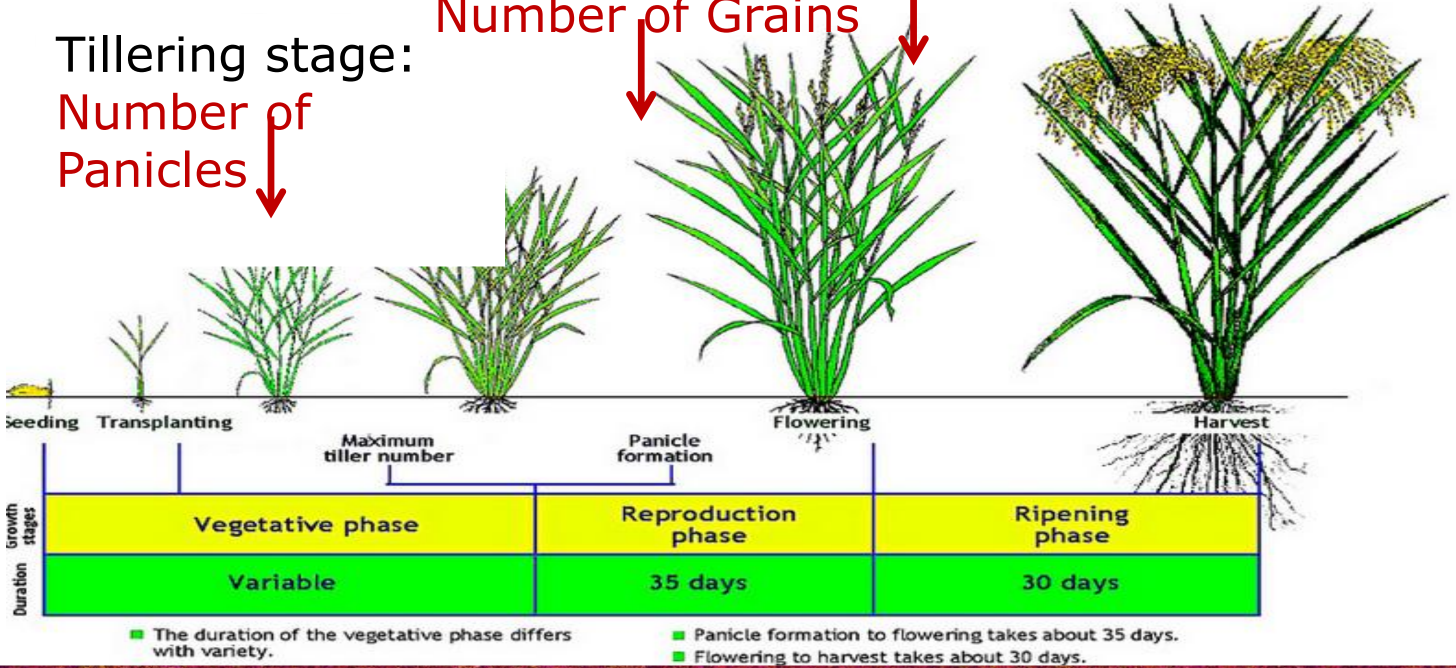
Red: Rice in Autumn-Winter 2014
Violet: Rice in Winter Spring 2015

Detection of rice phenology

Grain Filling Stage:
Weight of Grains

Panicle formation:
Number of Grains

Tillering stage:
Number of
Panicles



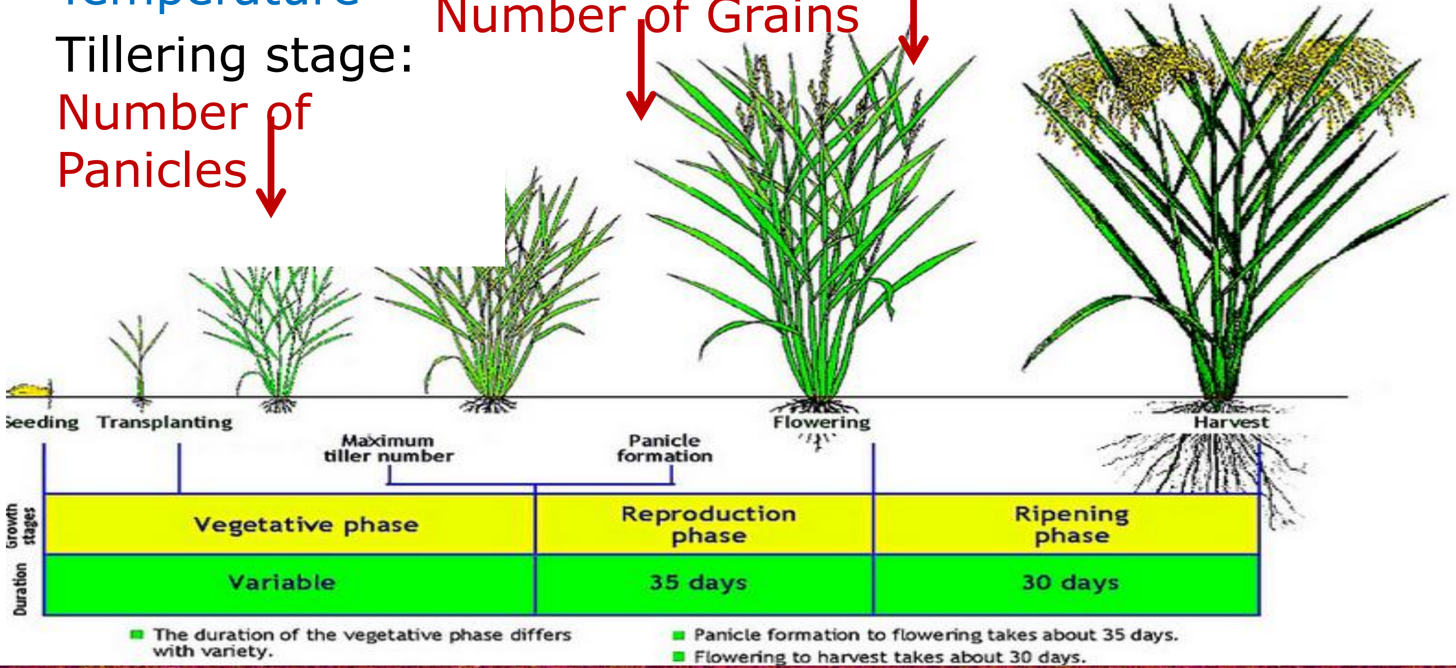
Detection of rice phenology

Needed: Solar Radiation
Temperature

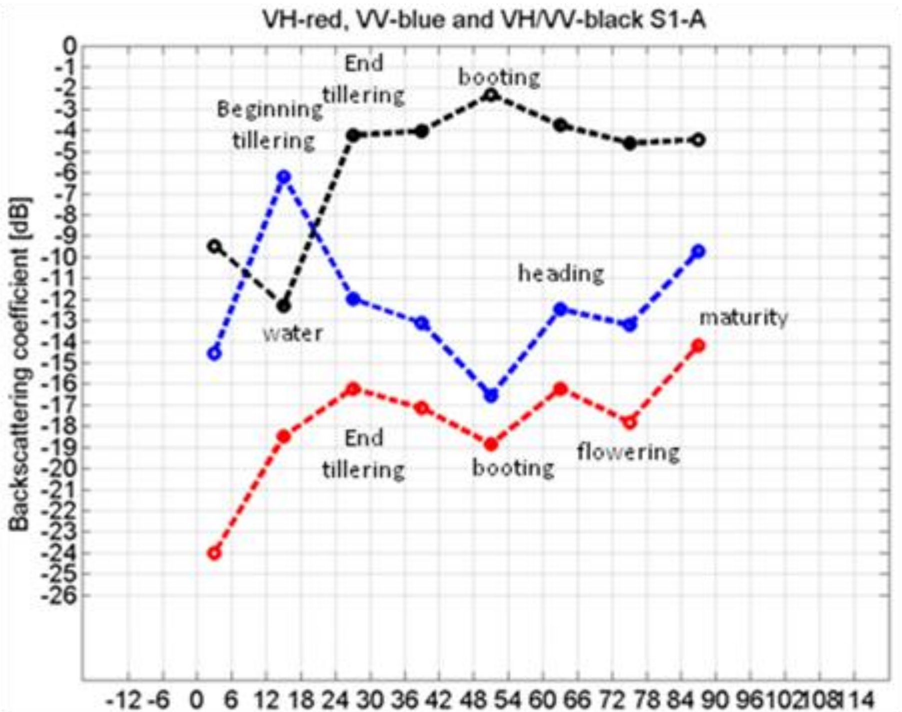
Tillering stage:
Number of Panicles

Water
Panicle formation:
Number of Grains

Water
Solar Radiation
Grain Filling Stage:
Weight of Grains



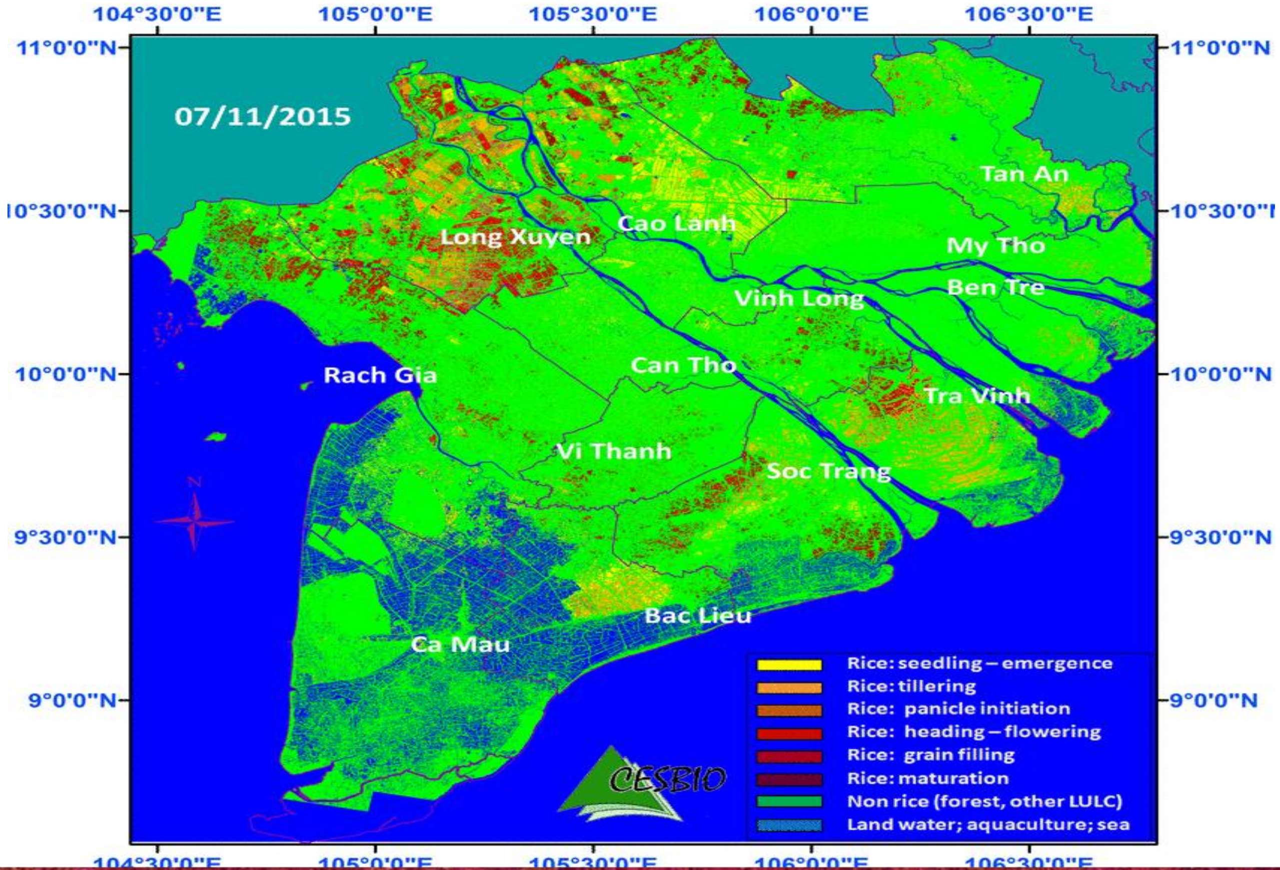
Detection of rice phenology



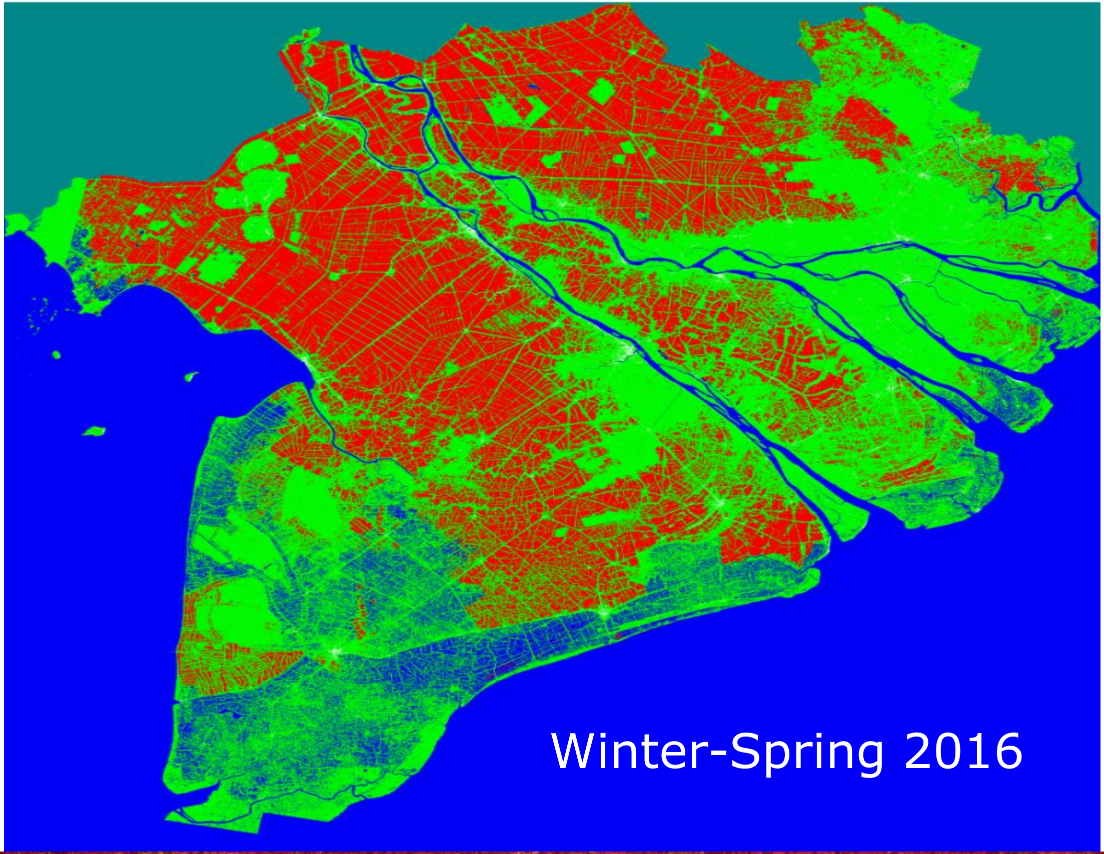
Sowing | Beginning tillering-Water | End of tillering | Booting | Flowering | Milky stage

Thuy Le Toan

Monitoring rice phenology using Sentinel-1



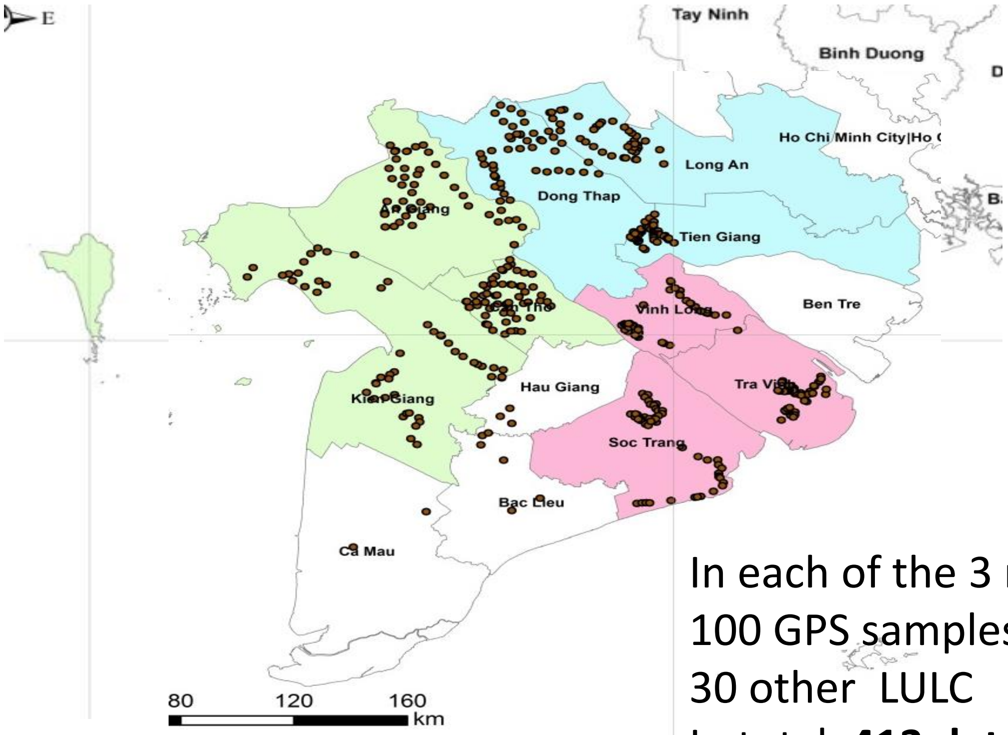
Map and Statistics



By March 2016:
1,39 M ha of rice grown area

The prevision of the Ministry of Agriculture And Rural Development For Winter-Spring rice **1.56 M ha**

Data for rice/non rice validation



In each of the 3 major rice regions in the Mekong delta

100 GPS samples of rice planting areas +

30 other LULC

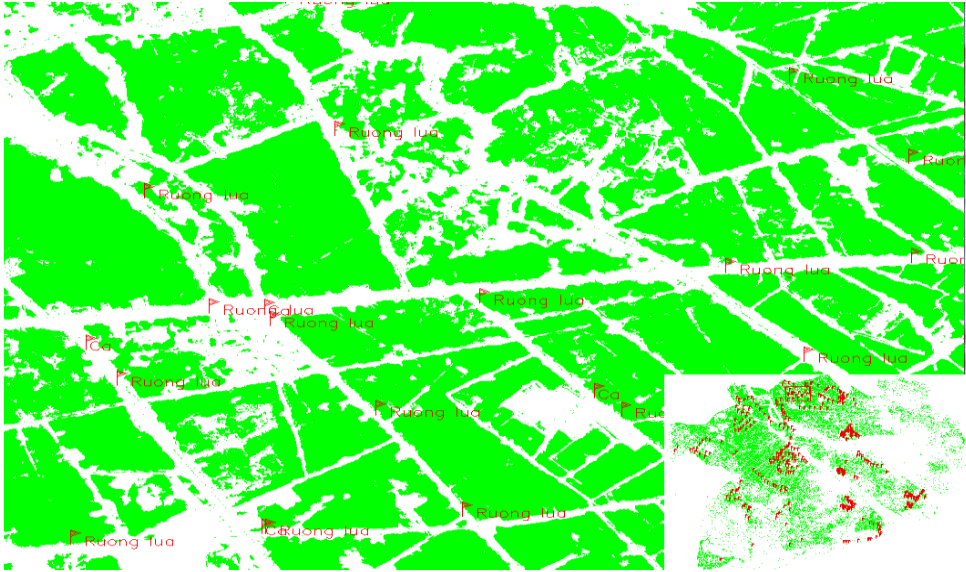
In total, **413 data points** for S1 acquisition date

Rice/non rice detection performance

Detection of rice planting area during the season

	Ground survey		S1 product
Rice	299		293
No-rice in the season	23	114	120
Other LULC	91		
Total	413		

The Mekong Delta: 413 independent check points: 98%.

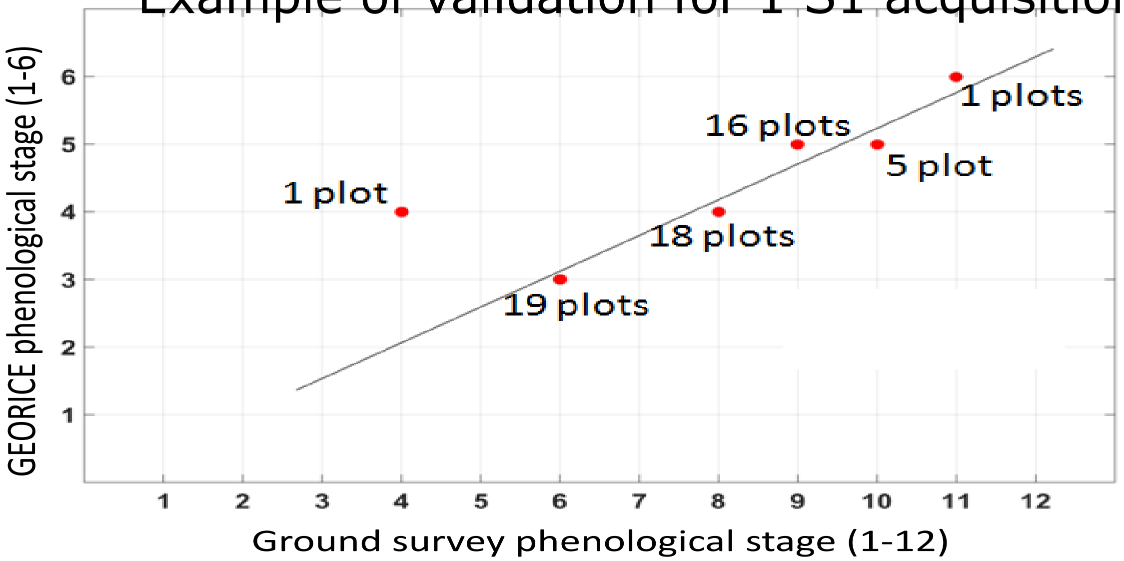


Error sources:

1. The precision of the GPS coordinates
2. The selected time interval for rice

Rice phenology validation

Example of validation for 1 S1 acquisition



Only 1 plot out of 60 was erroneous **(98.3%).**

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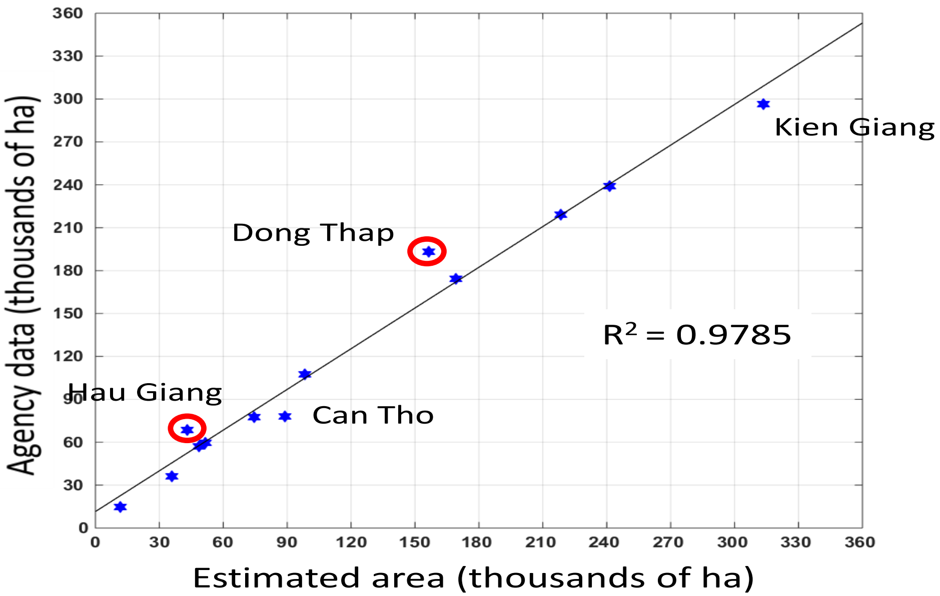
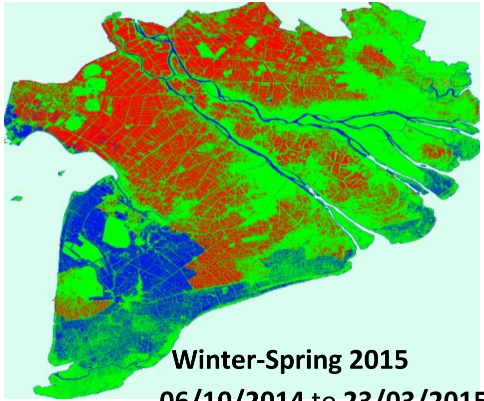
Rice area statistics

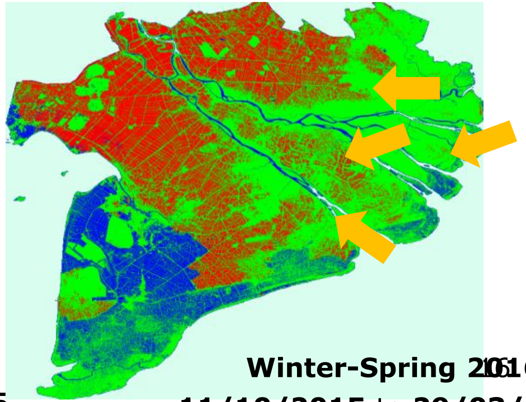


Rice area extent for Summer-Autumn 2016 crop in the Mekong Delta Comparison GEORICE estimates and Agency statistical data

Map and Statistics



Winter-Spring 2015
06/10/2014 to 23/03/2015



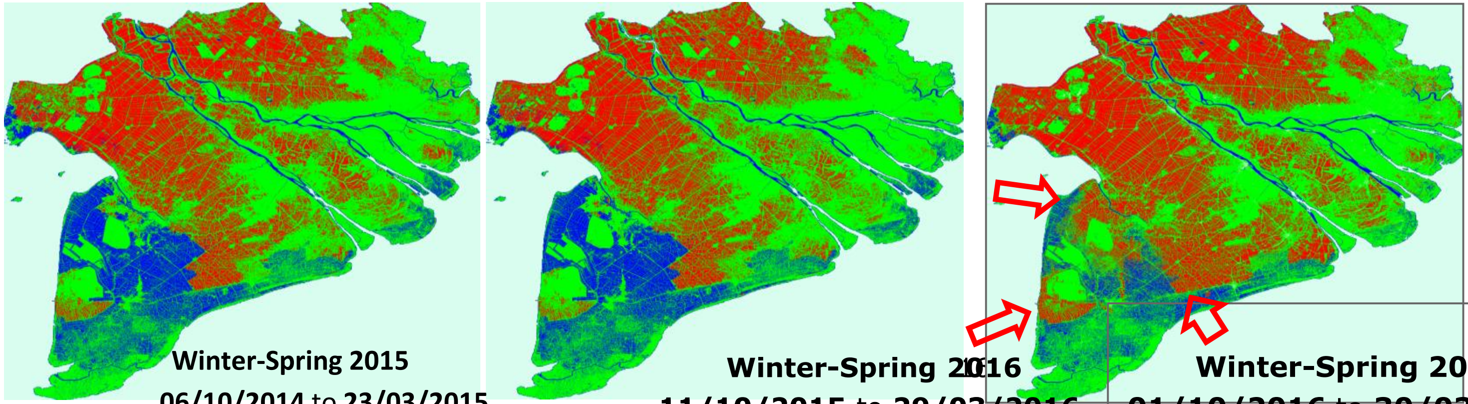
Winter-Spring 2016
11/10/2015 to 29/03/2016

- **Decrease of Winter-Spring rice area in 2016 compared to 2015**

(decrease of **276,000** ha or 16.7% ; i.e. 1.39M ha vs 1.67M ha) caused by **shortage of water** and **saline water intrusion (El Niño effect)** .

Official report by Vietnam MARD 2017:
The severe drought and salinity intrusion strongly affected 11 of the 13 provinces in the MRD. Rice areas affected by drought and salinity intrusion rapidly increased from 139,000 ha in mid March 2016 to ***224,552*** *ha by mid April 2016.*

Map and Statistics



Winter-Spring 2015
06/10/2014 to 23/03/2015

Winter-Spring 2016
11/10/2015 to 29/03/2016

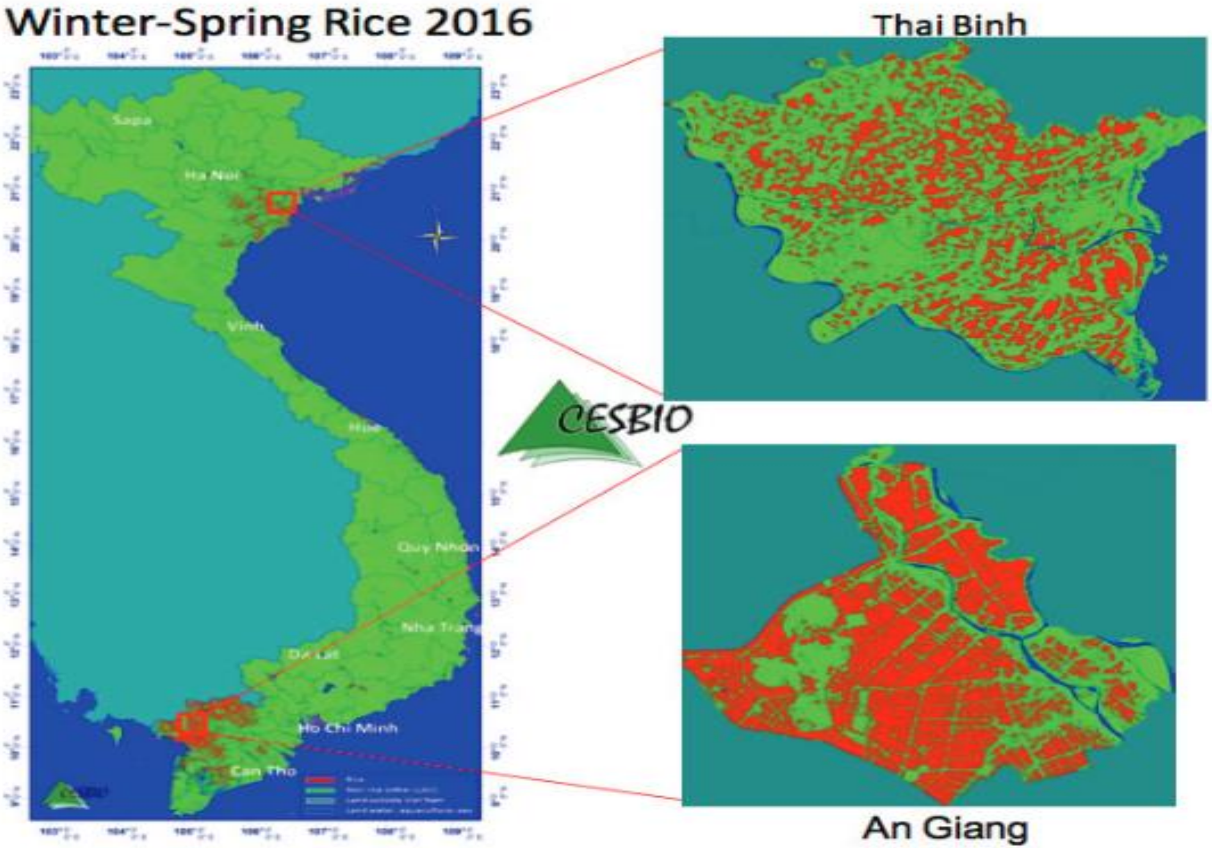
Winter-Spring 2017
01/10/2016 to 30/03/2017

- **Increase of Winter-Spring rice area in 2017 compared to 2016, 2015**

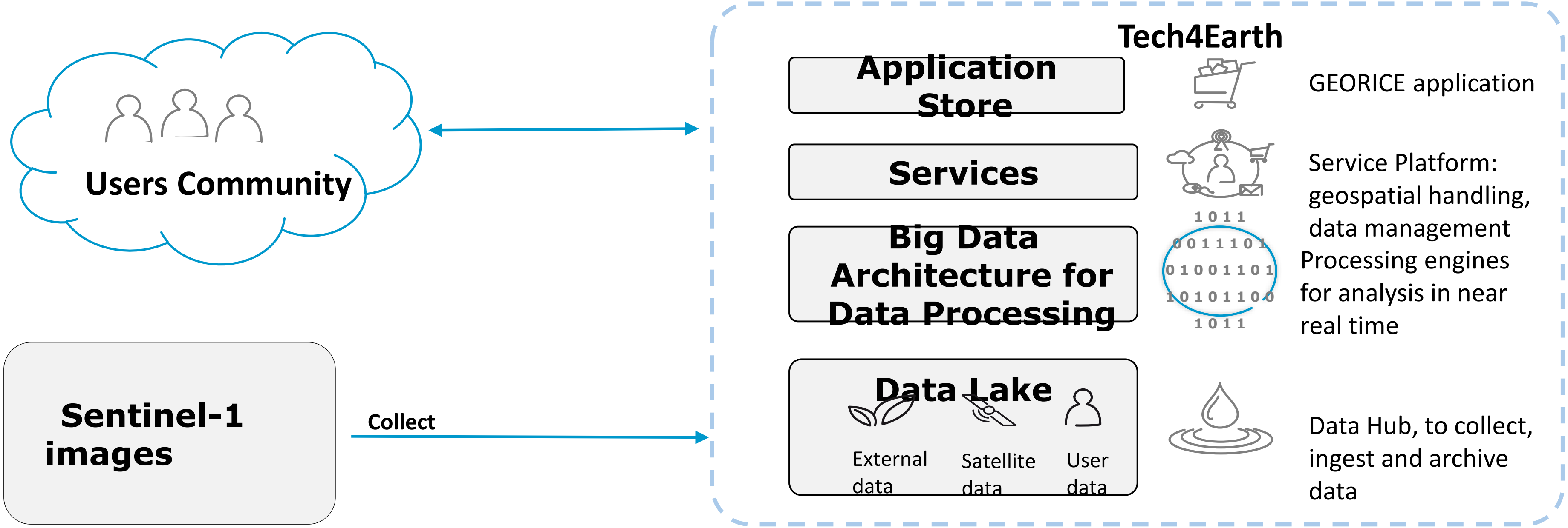
(More fields planted with rice and conversion of aquaculture. Among causes: shortage of rice production in 2016 and increase of rice price in 2016)

Mapping at country scale

Test of wall-to-wall national mapping using S1

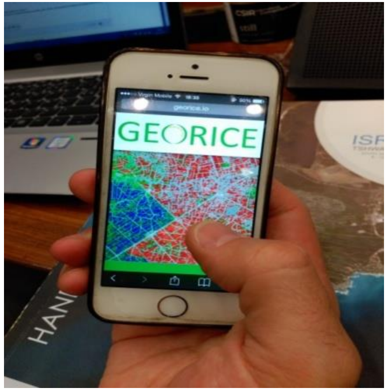


Challenge in multitemporal analysis: big data
→ Towards operational implementation



Challenge in multitemporal analysis: big data
→ Towards operational implementation

Users Community



Sentinel-1 images

Collect

Tech4Earth

Application Store		GEORICE application
Services		Service Platform: geospatial handling, data management
Big Data Architecture for Data Processing	1 0 1 1 / 0 0 1 1 1 0 1 / 0 1 0 0 1 1 0 1 / 1 0 1 0 1 1 0 0 / 1 0 1 1	Processing engines for analysis in near real time
Data Lake External data · Satellite data · User data		Data Hub, to collect, ingest and archive data

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CESBIO

Summary

1. Two applications derived from multitemporal analysis of SAR data have been presented: deforestation monitoring, and agricultural crop monitoring,

2. Understanding of the causes of change in the radar backscatter can help to derive methods relevant to the application,

3. Further development integrating different sources of data (optical, radar) will enhance the application results

4. Techniques to handle large amount of data are being developed, and there is a need to have methods adapted to the users