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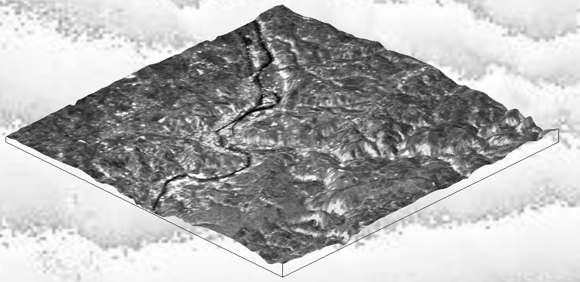
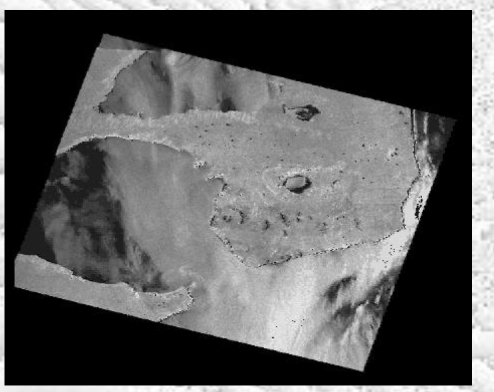
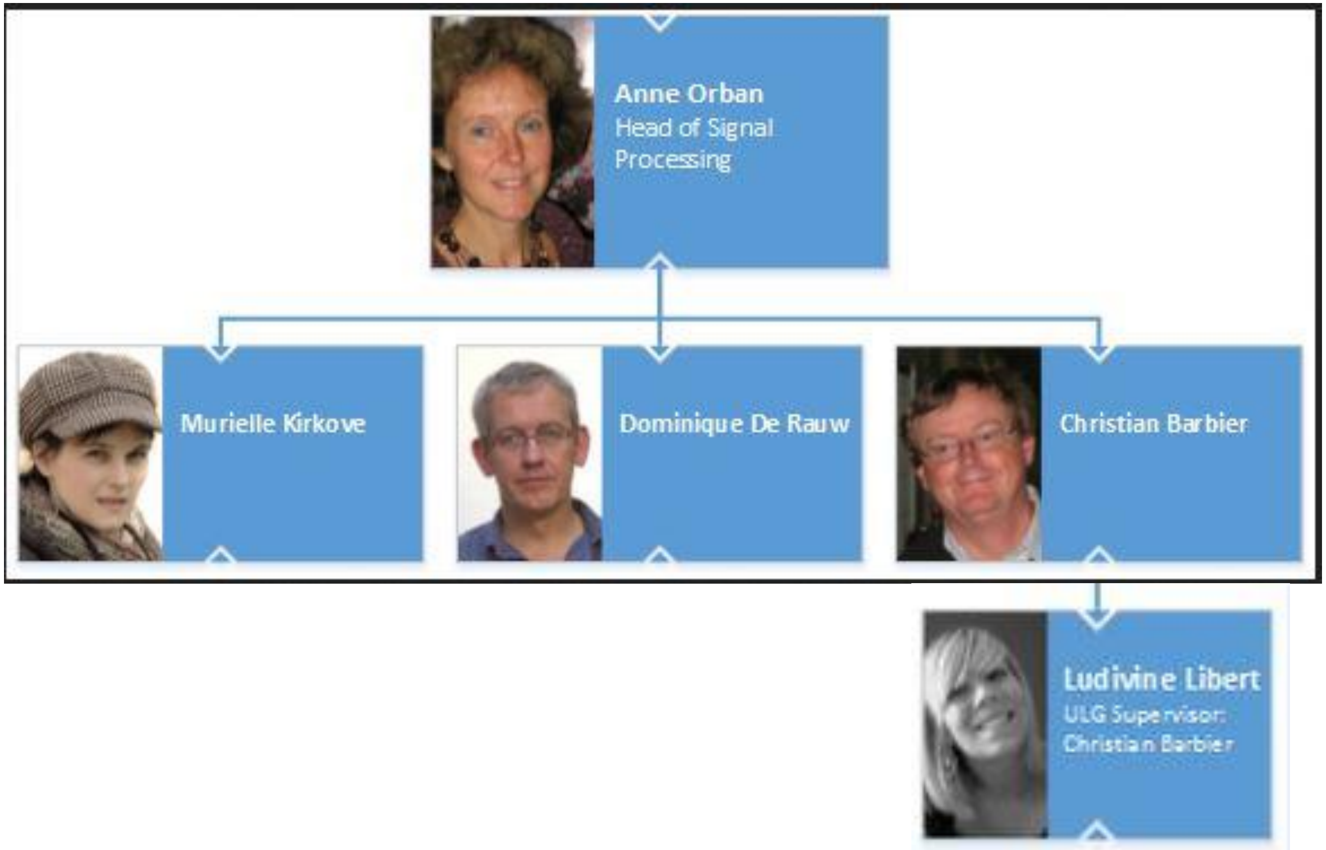
Signal Processing Laboratory

Anne Orban





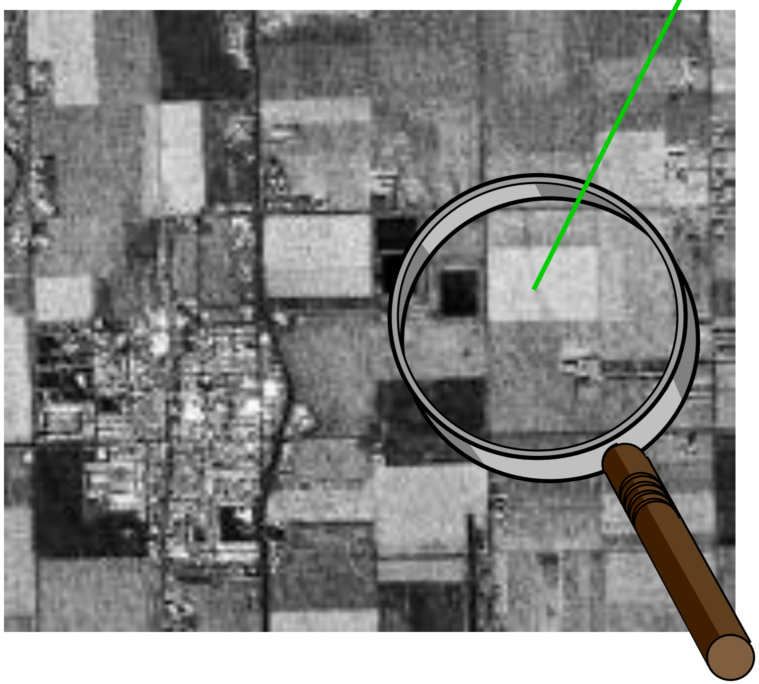

Anne Orban
Head of Signal Processing
Murielle Kirkove
Dominique De Rauw
Christian Barbier
Ludivine Libert
ULG Supervisor: Christian Barbier

SAR: A Pictorial Résumé

$$pixel = \underbrace{\underbrace{A}_{amplitude}}_{SAR} \exp(j \underbrace{\underbrace{\phi}_{phase}}_{InSAR}) \underbrace{\underbrace{\vec{p}}_{polarisation\ state}}_{PolSAR}$$

$$\underbrace{phase \quad polarisation\ state}_{PolInSAR}$$

focusing | *post-processing*



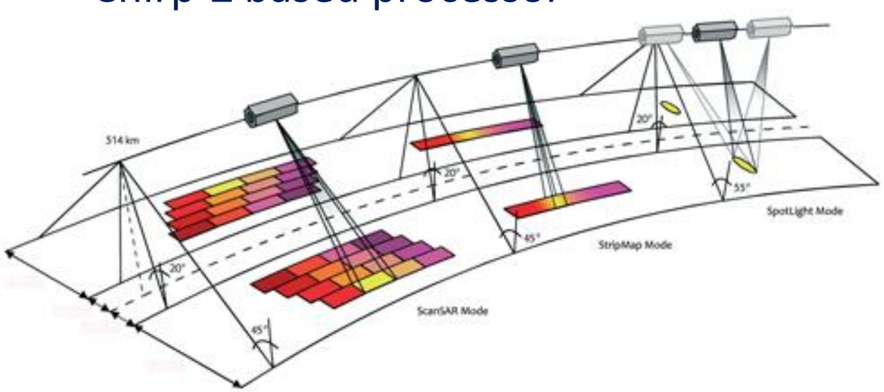
Every pixel tells a story

PRE-PROCESSING:
SAR focusing

- SpotLigth SAR: High resolution
- Stripmap SAR: Medium resolution
- ScanSar & TopSAR: Low resolution

Different approaches of azimuth focusing

- w-k processor
- Chirp scaling processor
- Chirp-Z based processor



POST-PROCESSING:
Application oriented

- SAR Interferometry (InSAR)
- Geocoding & Geoprojection
- Differential SAR interferometry (DInSAR)
- Coherence Tracking
- SAR Polarimetry (PolInSAR)
- SAR Polarimetric Interferometry (PolInSAR)
- Multi-Chromatic Analysis
- Spectral Coherence
  erferometry (SBInSAR)

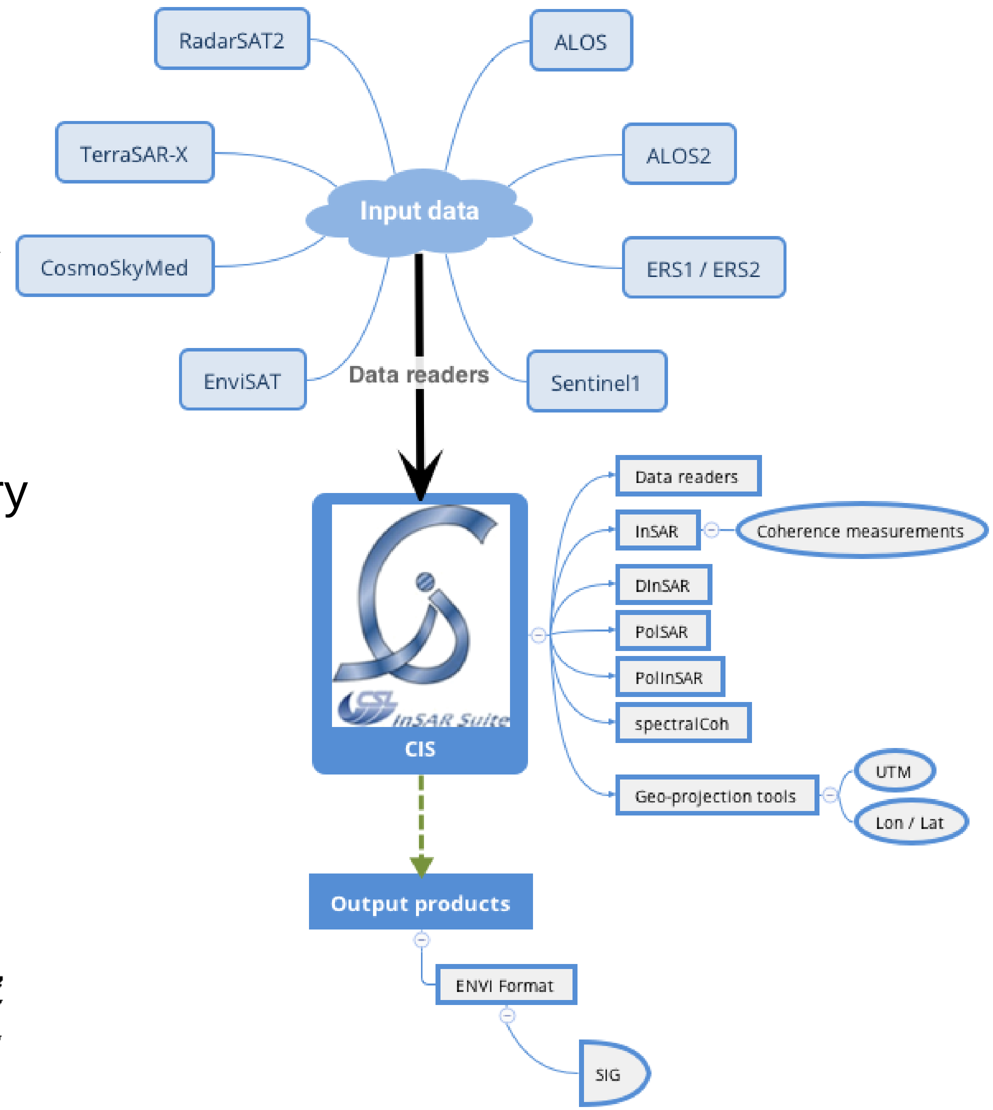
InSAR Suite

POST-PROCESSING: Application oriented

- SAR Interferometry (InSAR)
- Geocoding & Geoprojection
- Differential SAR interferometry (DInSAR)
- Coherence Tracking
- SAR Polarimetry (PolInSAR)
- SAR Polarimetric Interferometry (PolInSAR)
- Multi-Chromatic Analysis
- Spectral Coherence
- Split-Band Interferometry (SBInSAR)

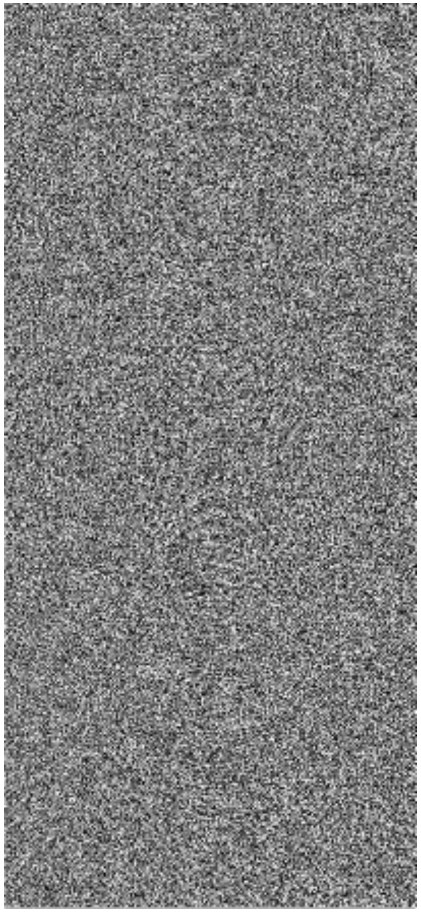
$$pixel = \underbrace{\underbrace{A}_{amplitude}}_{SAR} \exp(j \underbrace{\underbrace{\phi}_{phase}}_{InSAR}) \underbrace{\underbrace{\vec{p}}_{polarisation\ state}}_{PolSAR}$$

$$\underbrace{\phi \quad \vec{p}}_{PolInSAR}$$



SAR Focusing

$$pixel = A\, exp\ (j\,\phi)\ \vec{p}$$

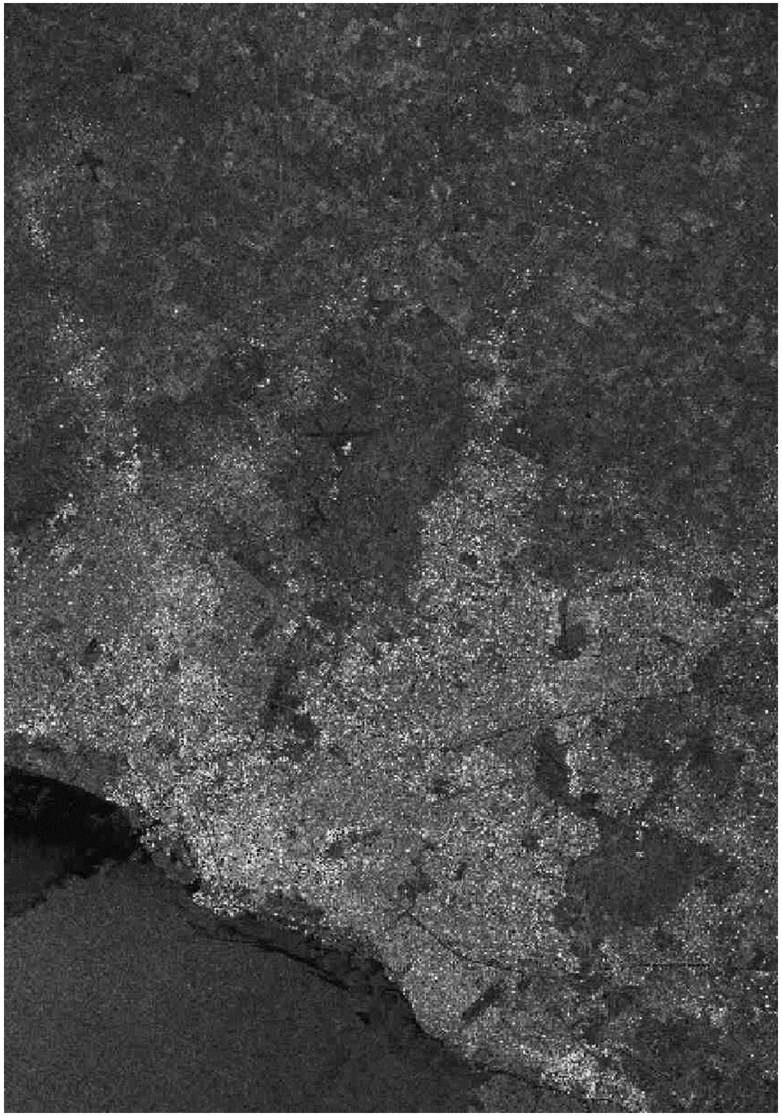


The raw image

The focused image

$$pixel = A \exp(j\,\phi)\,\vec{p}$$

Buenos Aires from Space



ERS raw data

-

processed at Cordoba ground station

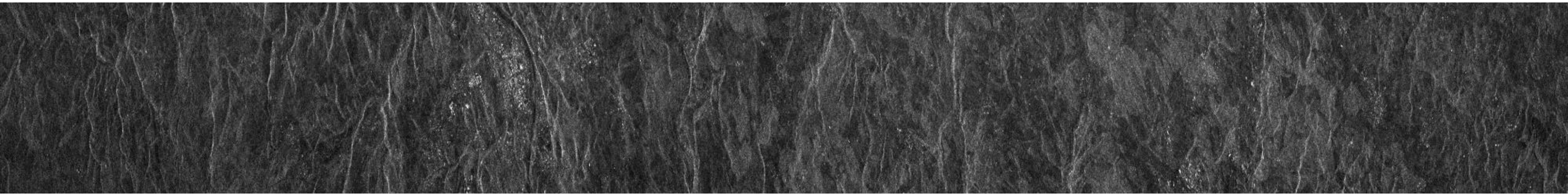
-

CSL processor

$$pixel = A\, exp\, (j\, \phi)\, \vec{p}$$

Recent development:

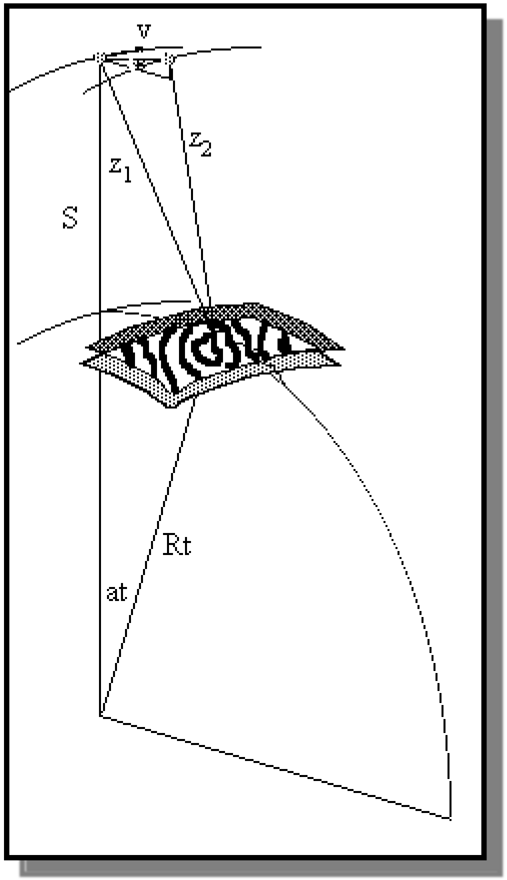
A part (burst) of a focused Sentinel-1 raw data: TopSAR Processor



TopSAR mode: Antenna steered not only in range but also in azimuth

Incident beam moving from backward to forward and at different ranges on the ground → wide ground swath

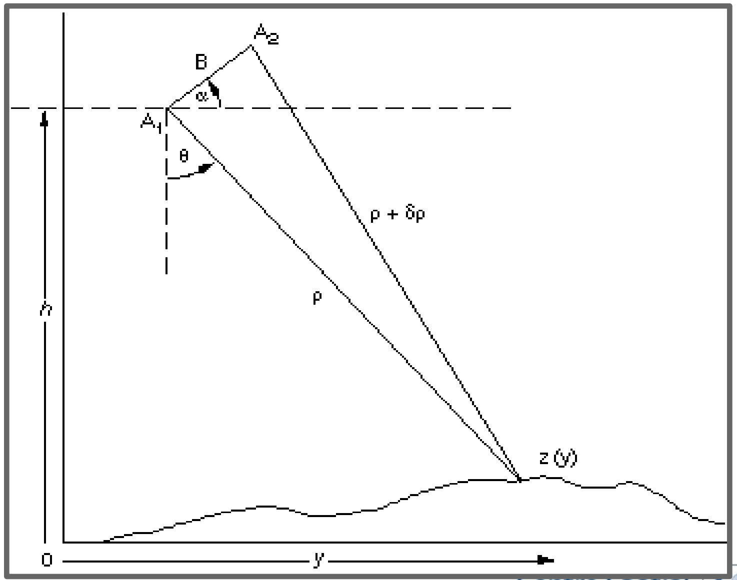
$$pixel = A\exp\left(j\phi\right)\vec{p}$$



- Sar Interferometry aims:
  - To produce **Digital Elevation Models**
  - To perform **coherence analysis for change monitoring and multi-chromatic analysis**

  to obtain scene characteristics:

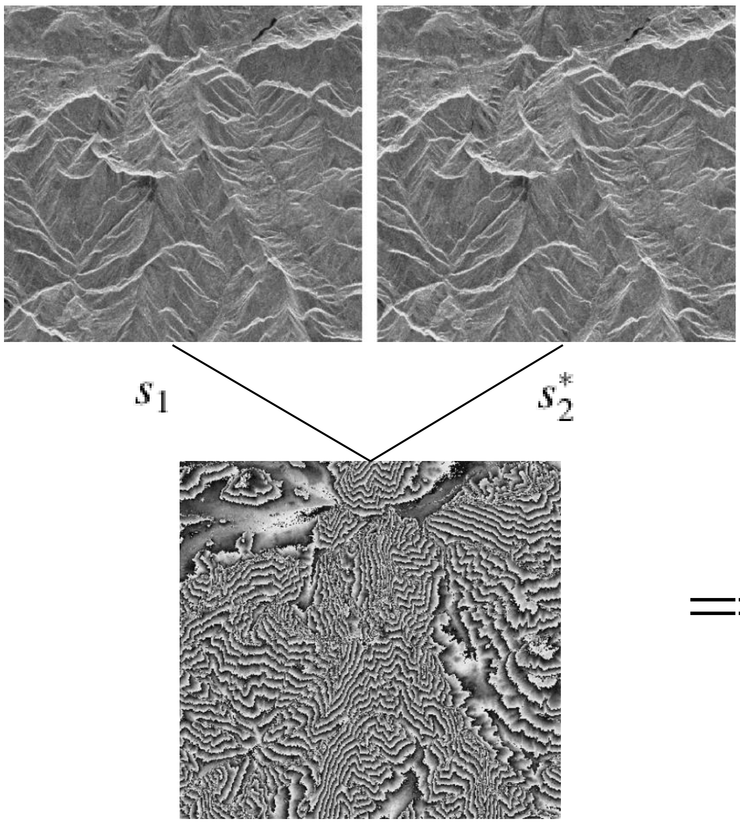
  - Soil moisture
  - Crop stage
  - Land use
  - Human pressure
  - Forest fires
  - land slides
  - floods
  - ...



Digital Elevation Models

$$pixel = A\, exp\,(j\phi)\,\vec{p}$$

Pass 1 Pass 2



Interference pattern

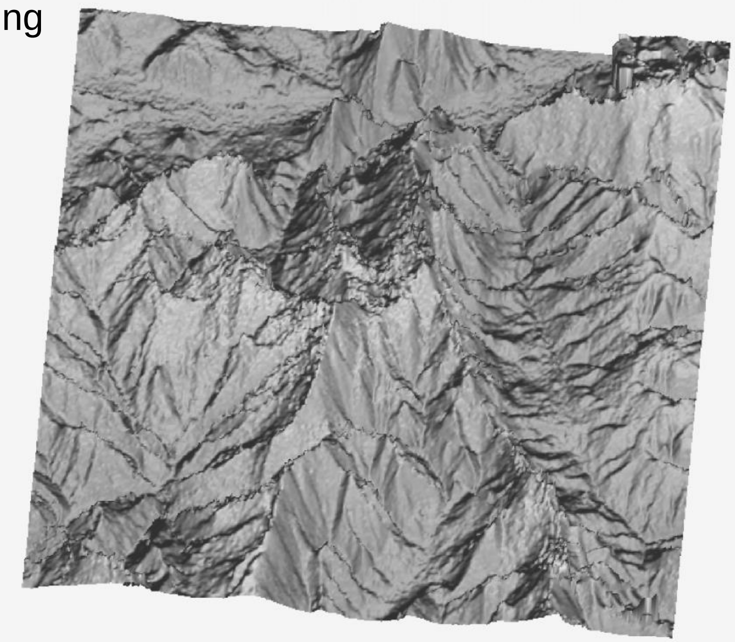
$$\gamma = \frac{|\langle s_1 s_2^* \rangle|}{\sqrt{\langle s_1 s_1^* \rangle \; \langle s_2 s_2^* \rangle}}$$

InSAR Processing steps:

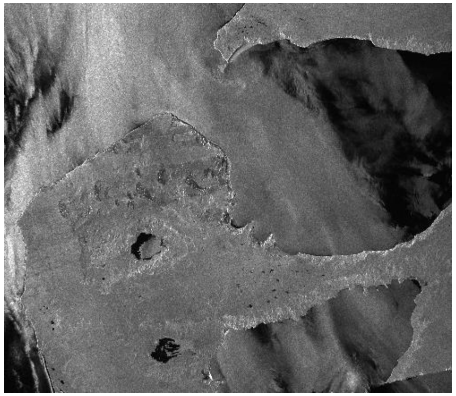
- Co-registration
- Interpolation
- InSAR product generation
  - Amplitude/intensity images
  - Coherence image
  - Interferogram
- Phase unwrapping
- Geo-projection

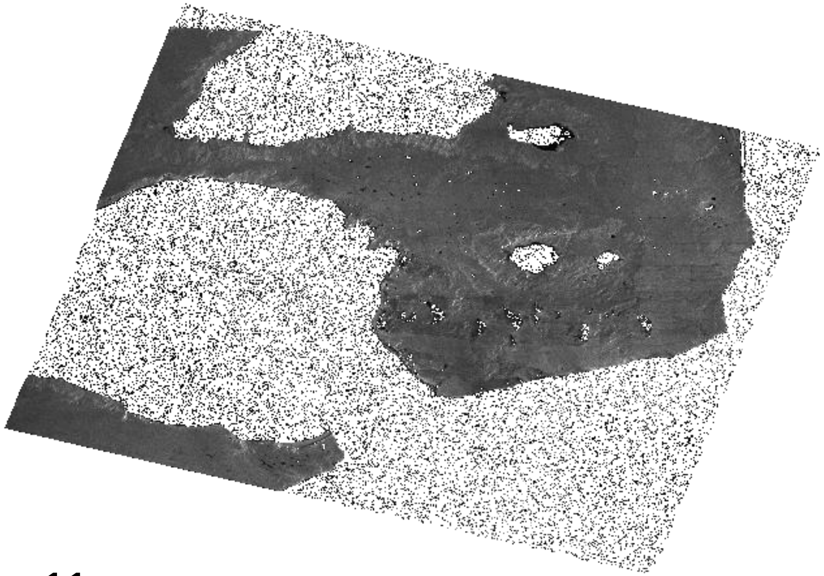
==>

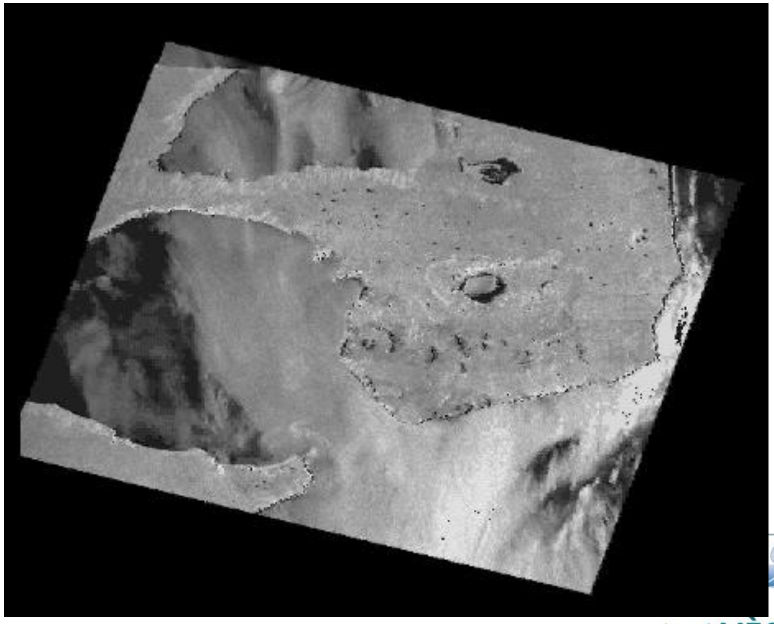
DEM



Example : The Peninsula Valdes



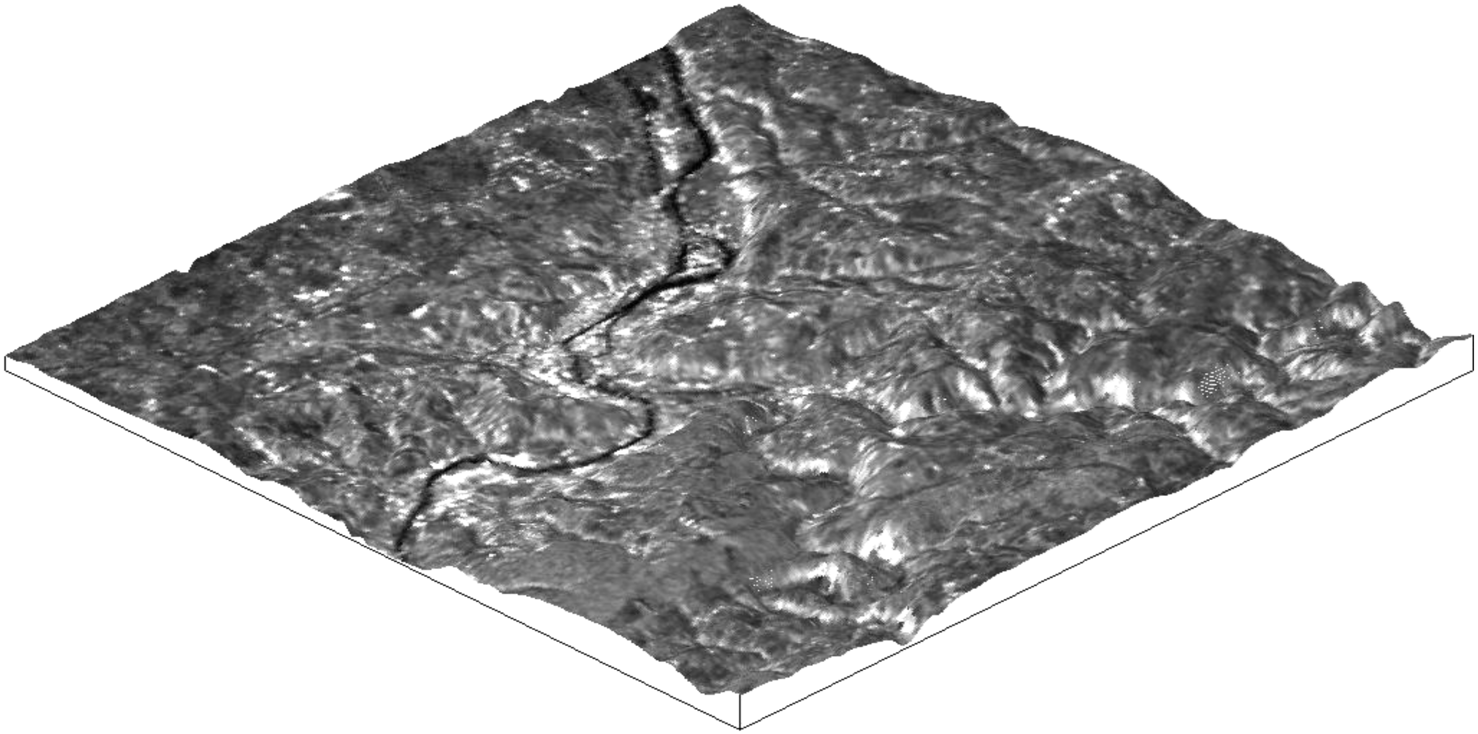




$$pixel = A\exp(j\phi)\,\vec{p}$$

Digital Elevation Models

DEM of the region of Liege (ERS1-ERS2 tandem pair)



A relief map of the Liège region, obtained by applying the interferometric technique to one ERS-1 image and one ERS-2 image (ESRIN Contract Nr. 12159/96/I-HGE "Quality Assessment of InSAR Topographic Mapping").

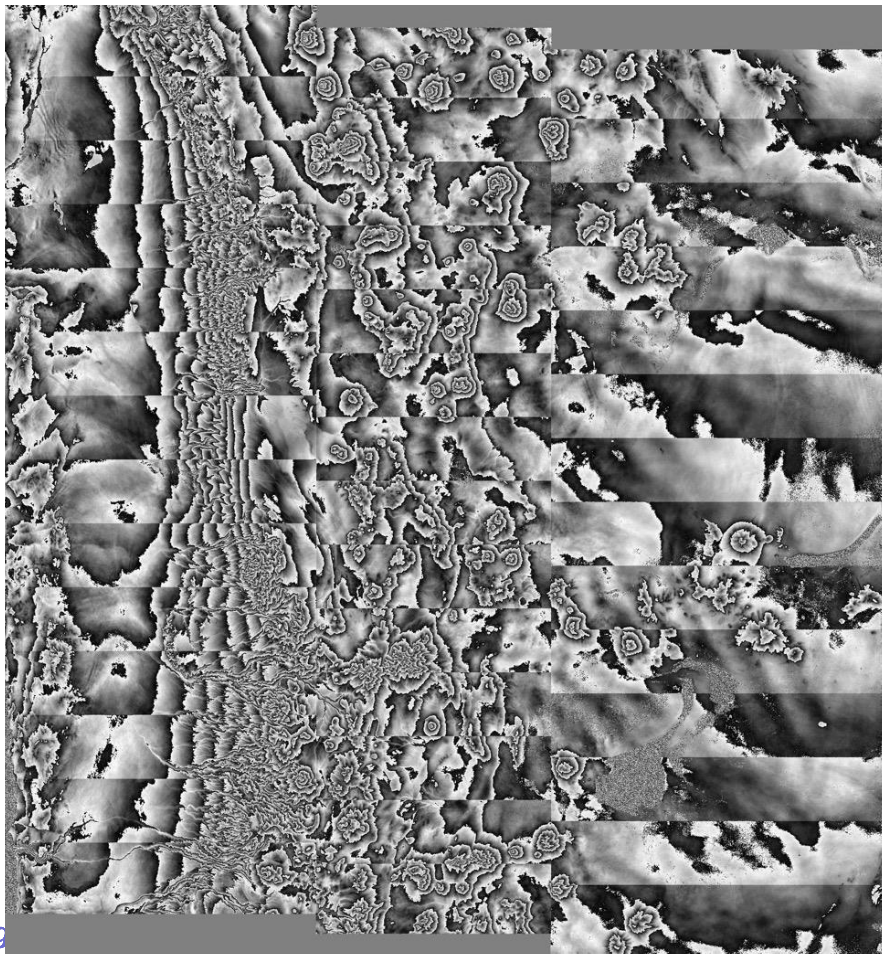
SAR Post-Processing: Wide-Swath InSAR

$$pixel = A\, exp\ (j\phi)\ \vec{p}$$

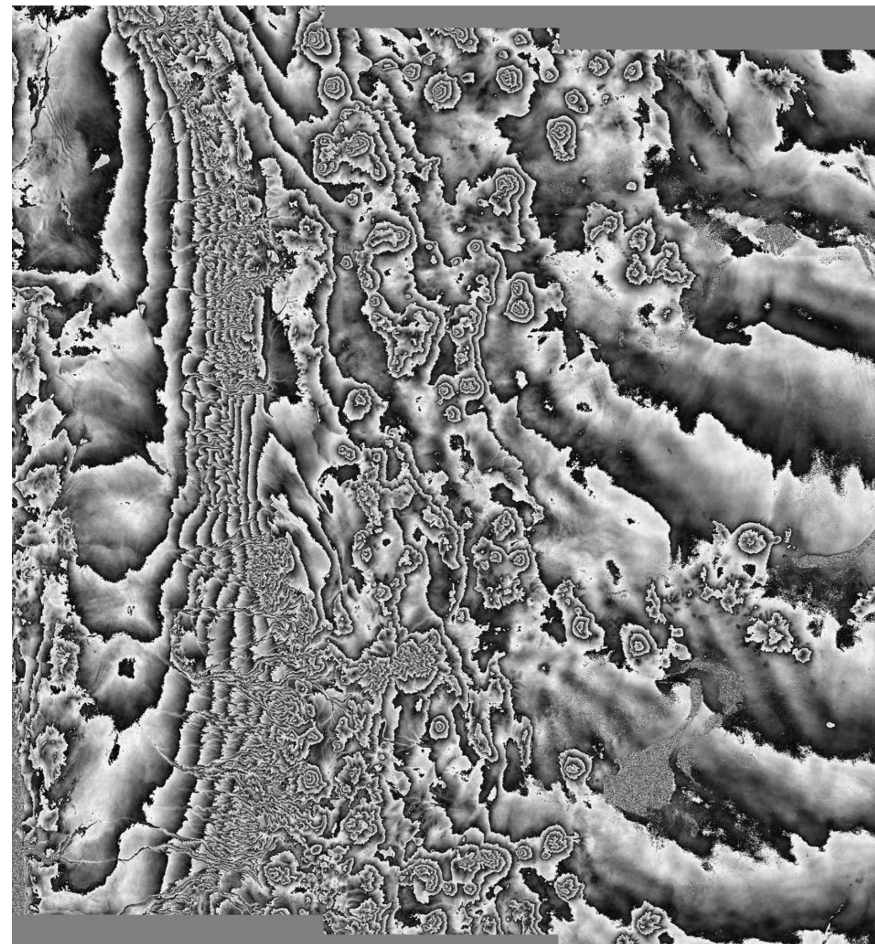
Recent development:

Wide-swath SAR: burst acquisition

Interferogram from a S1 TopSAR pair



After burst synchronization

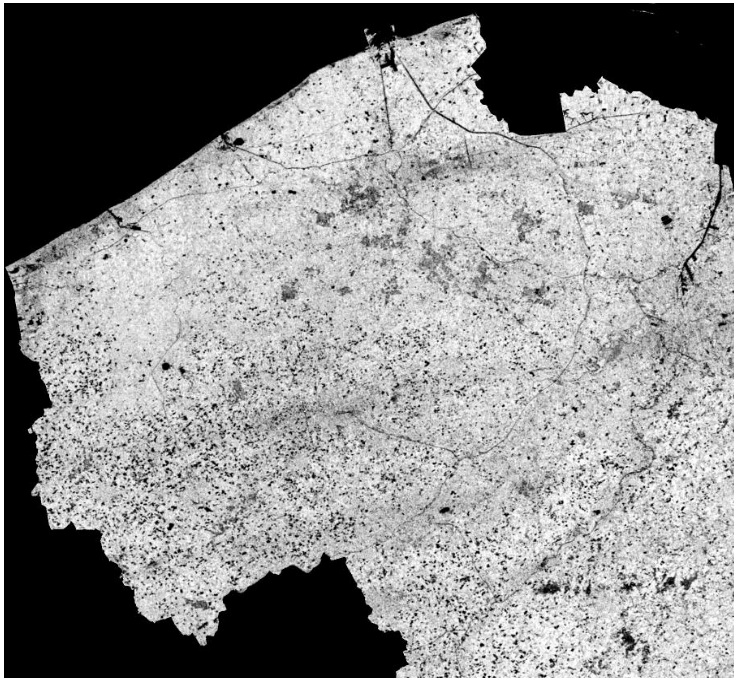


$$pixel = A\,exp\,(j\phi)\,\vec{p}$$

InSAR for Change Detection

Temporal Coherence follow-up as a tool for change monitoring

Interferometric coherence map of InSAR pair over Belgium



- *InSAR Coherence losses between the 2 SAR acquisitions is an important information channel on how the scene is changing:*
  - *Human activity*
  - *Vegetation density*
  - *Crop stage*

$$pixel = A\,exp\,(j\phi)\,\vec{p}$$

Coherence-Based Change Detection

Temporal Coherence follow-up

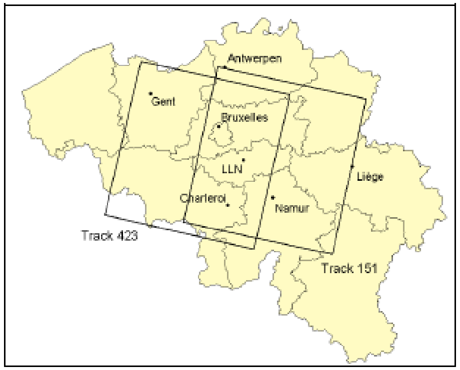
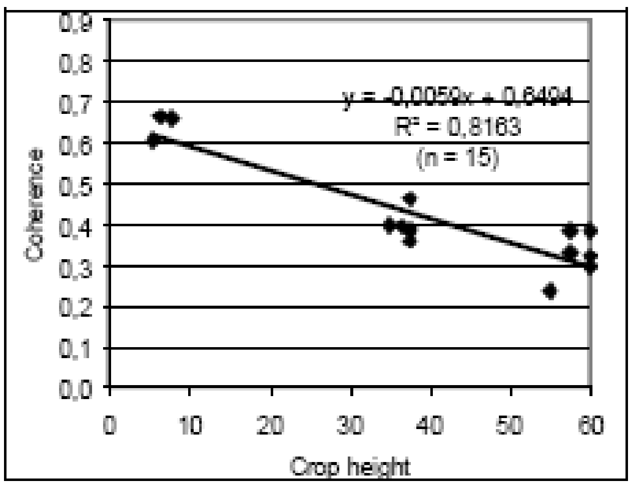


Figure 1: Localisation of the two set of images over the study area.

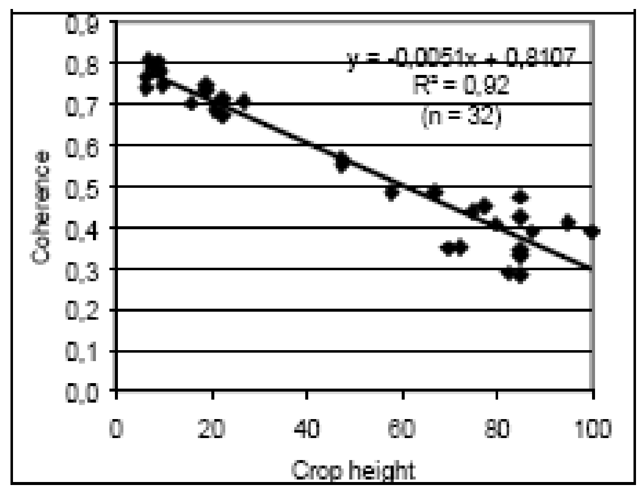
Relationship between plant height and coherence evolution with time (ex: potato and winter wheat).

Mean error of 7 cm seems compatible with information requirements for a crop monitoring system.

Results



Linear regression between the tandem coherence and the potato height.

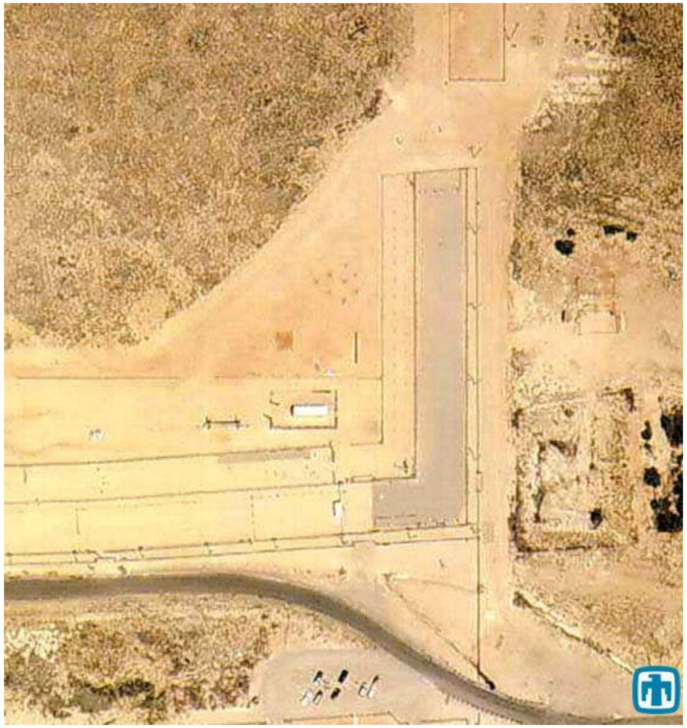


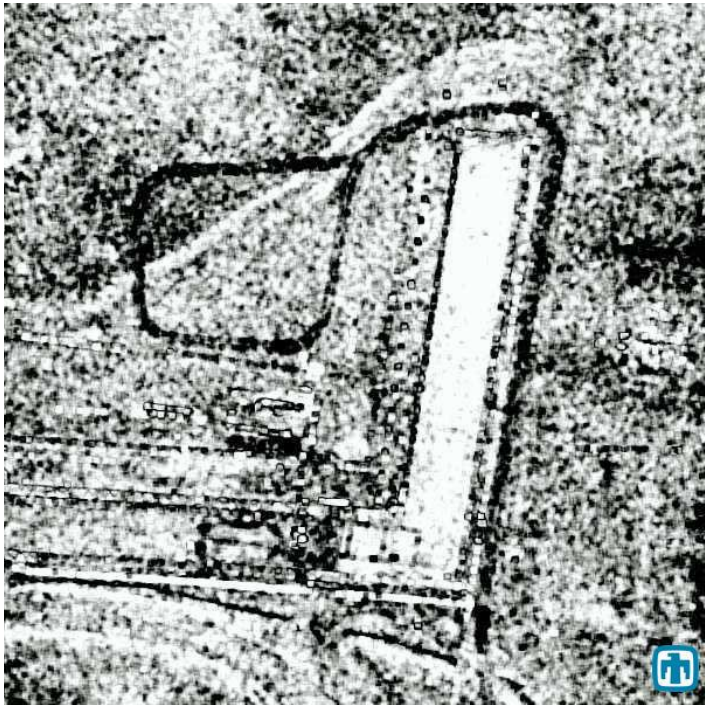
relationship between the tandem coherence and the winter wheat height.

$$pixel = A\,exp\;(j\phi)\;\vec{p}$$

Coherence-Based Change Detection

An Example of change ….





Optical image

InSAR coherence showing vehicle tracks

Coherence-Based Change Detection: Recent example

Greenland wildfire

First observed on July 31, 2017

Coherence-Based Change Detection: Recent example

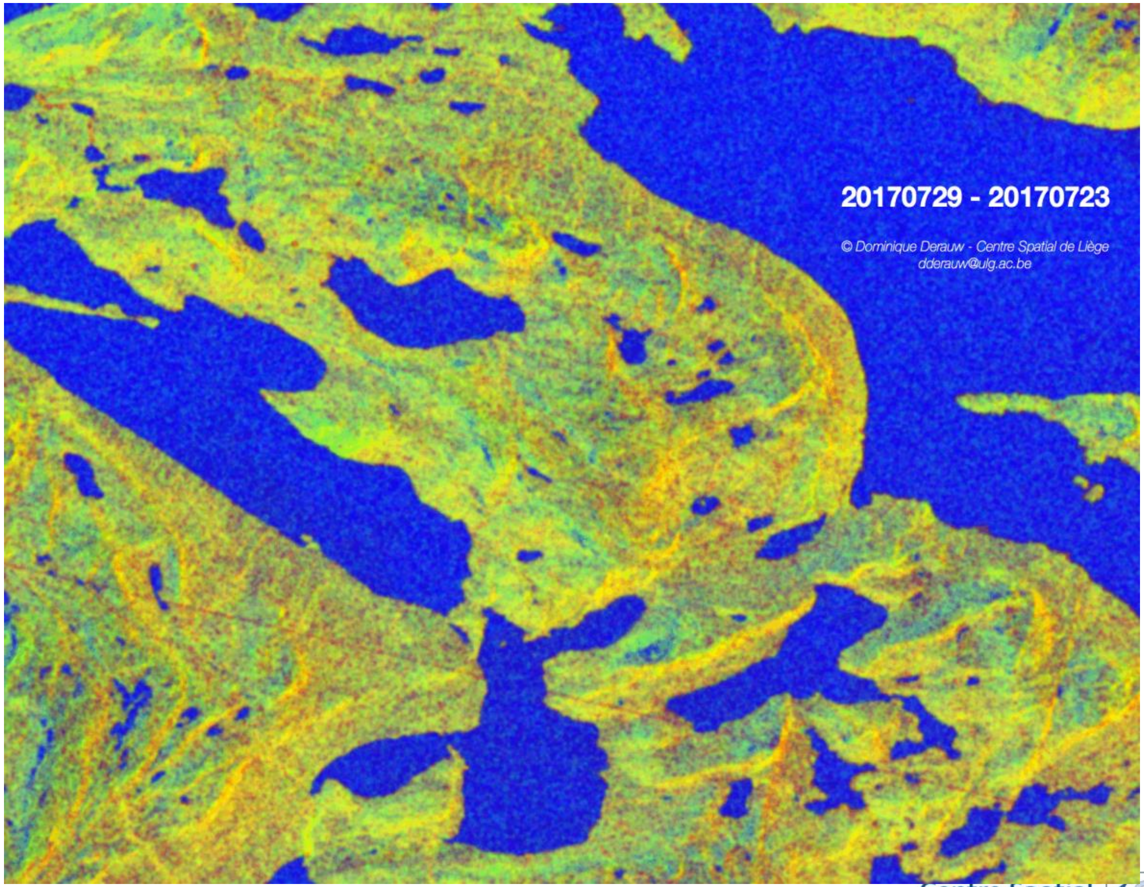
Greenland wildfire - **Sentinel2** observation (8 August)

$$pixel = A\,exp\,(j\phi)\,\vec{p}$$

Coherence-Based Change Detection: Recent example

Greenland wildfire - **Sentinel1** observations

Fire extension monitoring using **6-days Sentinel1A - Sentinel1B coherence** layers



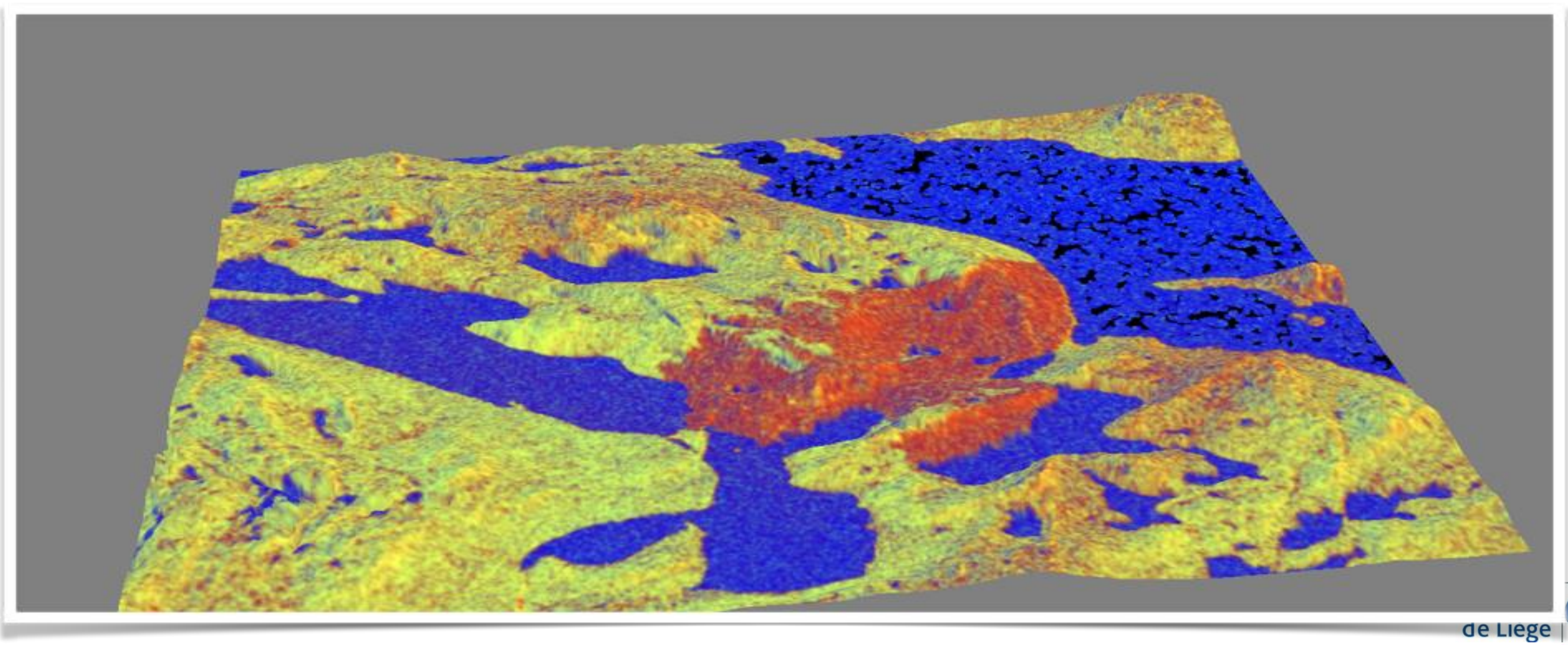
$$pixel = A\,exp\,(j\phi)\,\vec{p}$$

Coherence-Based Change Detection: Recent example

Greenland wildfire - Sentinel1 observations

- Fire full extension on August 17, 2017

➡Estimated burnt surface: 21.8 km^2

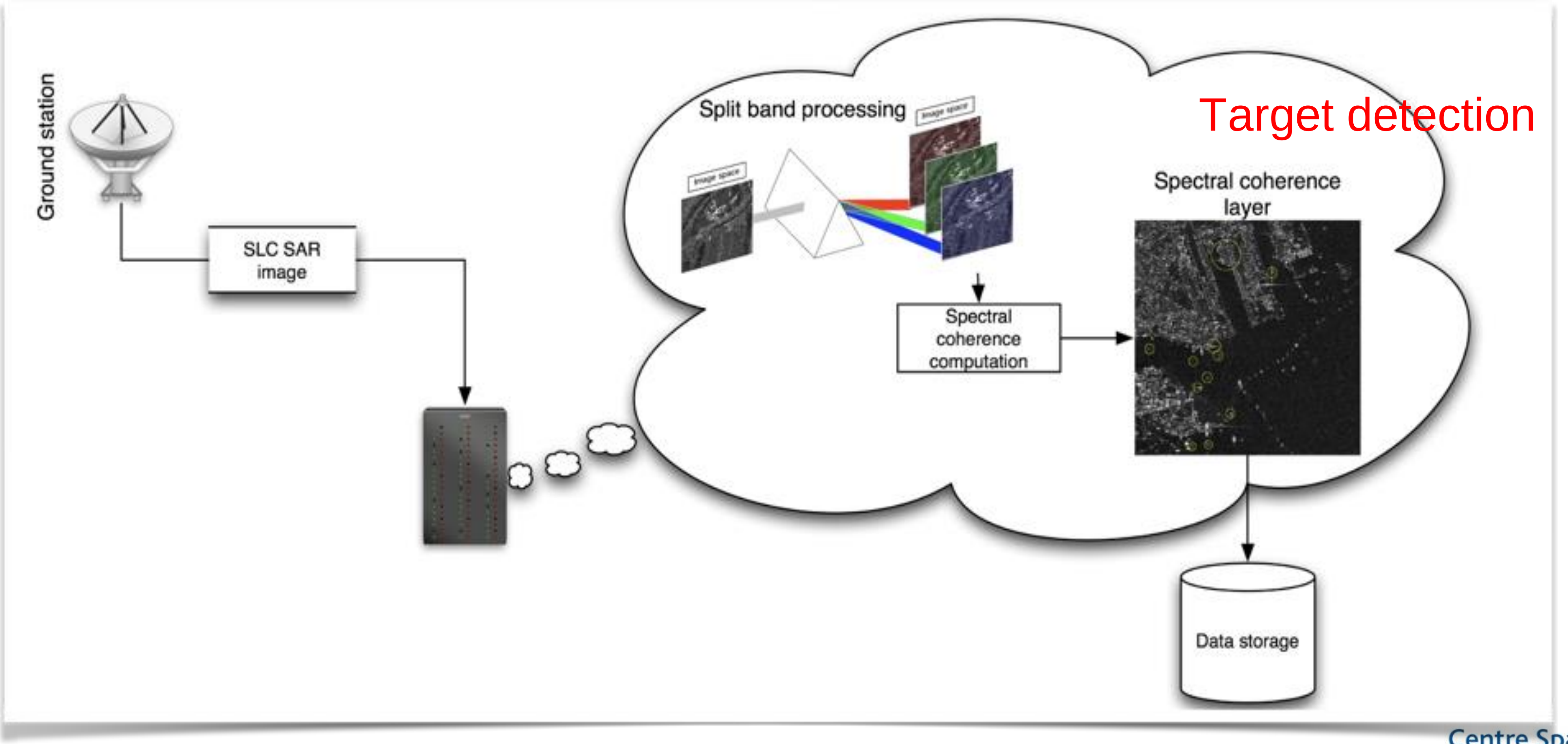


Wide-band Interferometry between sub-bands

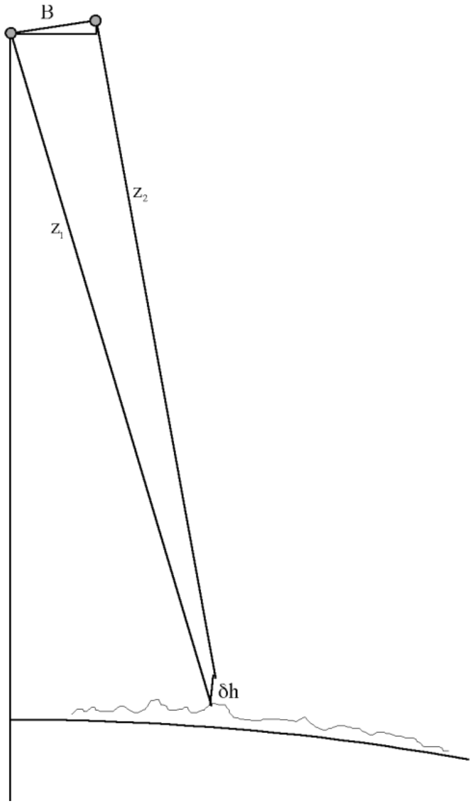
$$pixel = A \exp(j\phi)\,\vec{p}$$

Spectral coherence estimation

Target detection



$$pixel = A\,exp\,(j\phi)\,\vec{p}$$



- **Differential SAR Interferometry** aims to retrieve information not related to the topography:

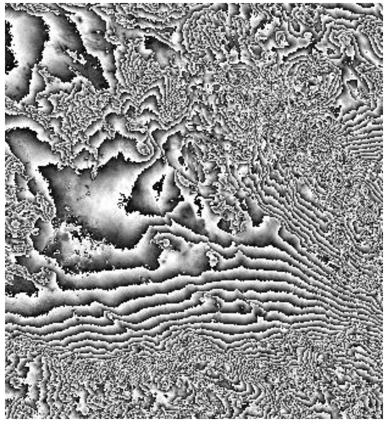
To measure and monitor local displacements

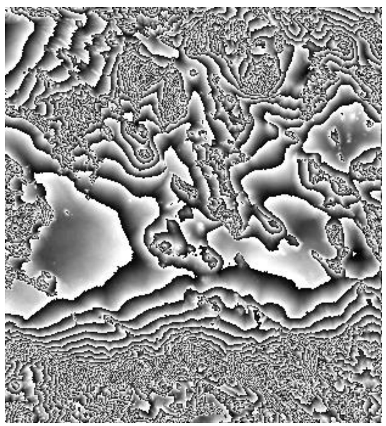
- Cities subsidence due to
  - Excessive water pumping
  - Mining activities
  - …
- Dykes monitoring
- Glaciers
- …

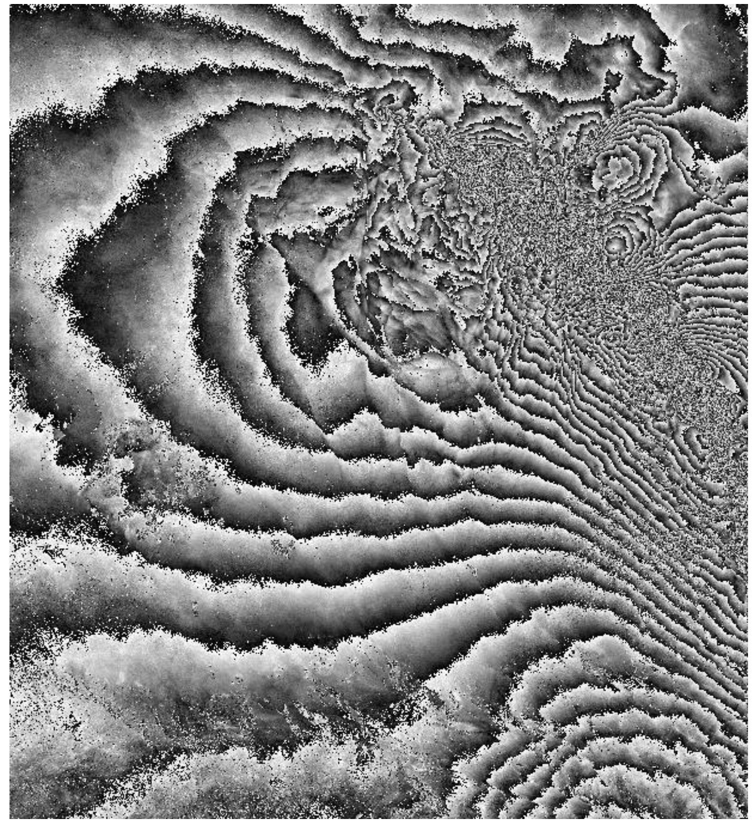
$$pixel = A\, exp\ (j\phi)\ \vec{p}$$

Interference pattern of terrain displacement:

The example of the Landers earthquake





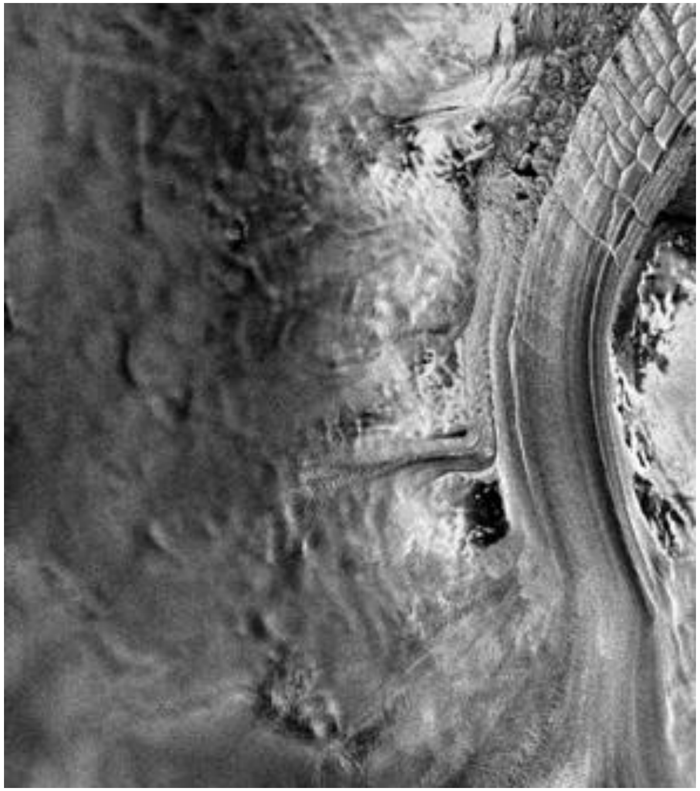


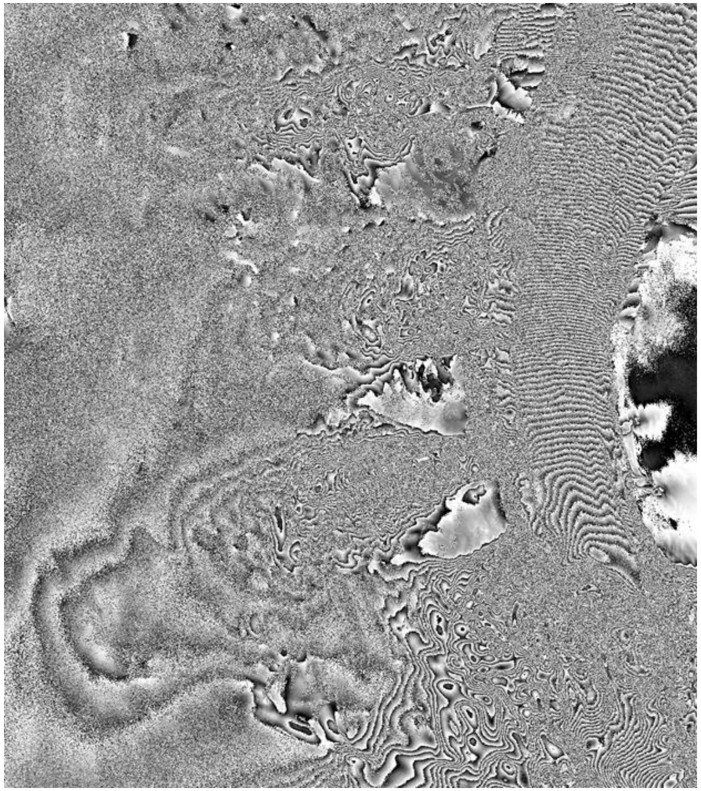
Detectable displacements of 28mm

A spectacular result of radar interferometry : the interference pattern reflects the terrain displacements due to the Landers (California) earthquake in June 1992. Displacements of only 28 mm can be detected despite of the altitude (800 km) from which the images were acquired. The fracture fault can be seen on the right, where the fringe density is the highest. This interferogram covers an area of 50 km x 50 km (SSTC Contract No T3/12/012 "Neotectonic Study in Hill and Mountain Countries : an Interferometry Application").

$$pixel = A \exp(j\phi)\ \vec{p}$$

Glacier monitoring : Shiraze glacier - Antarctica



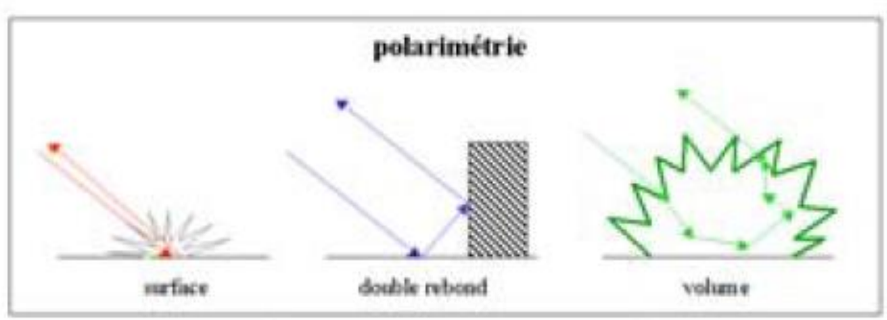


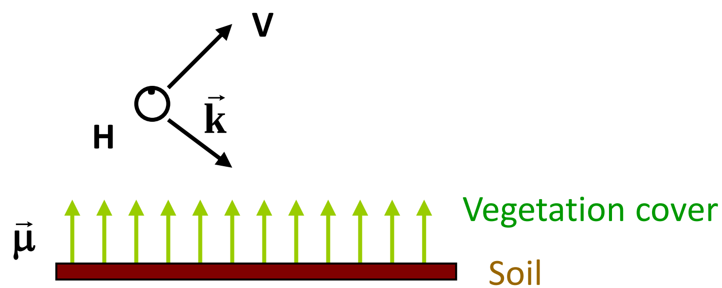
$$pixel = A\,exp\;(j\,\phi)\,\vec{p}$$

Polarimetric SAR ⟶ information on scattering mechanisms

- In full-polarimetric SAR systems, the signal is **sent and received** alternatively along **two orthogonal polarizations** (Horizontal and Vertical)
- The system allows getting **four polarization scheme in a single acquisition**
- The complete scattering matrix is obtained

$$\begin{pmatrix} E_H^r \\ E_V^r \end{pmatrix} = \frac{e^{-jk_r}}{k_r} \begin{pmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{pmatrix} \begin{pmatrix} E_H^t \\ E_V^t \end{pmatrix}$$





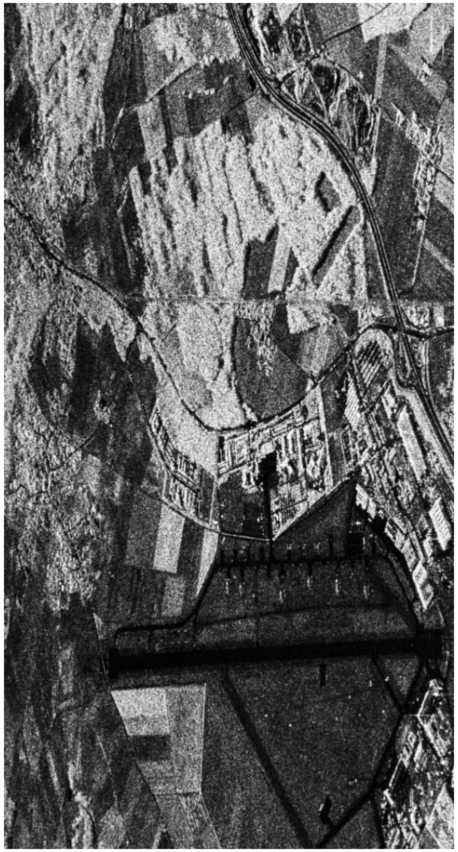
$$U_{int} = -\vec{\mu}.\vec{E}$$

Allows classification of scatterers

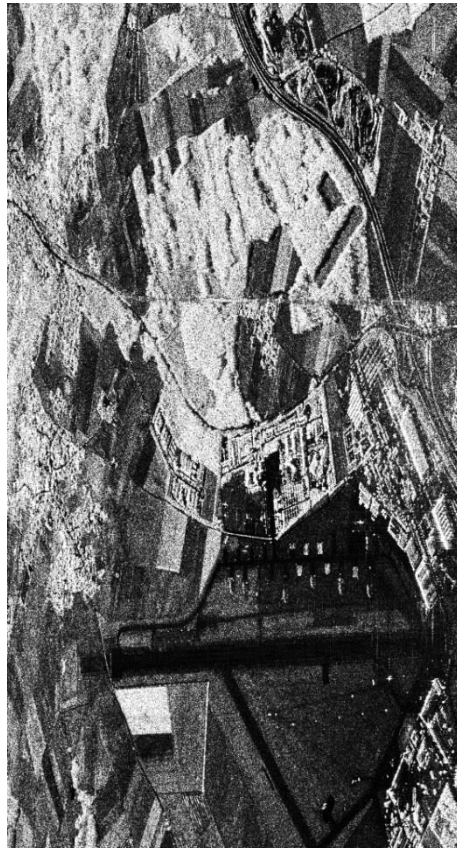
$$pixel = A\,exp\;(j\,\phi)\,\vec{p}$$

Polarimetric SAR:

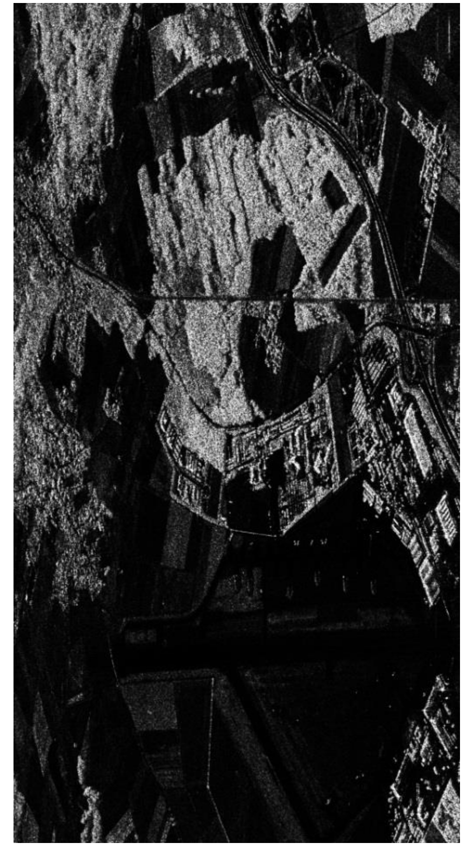
Information on scattering mechanisms



VV



HH



HV

Example: VV, HH and HV images

(Images produced at CSL, ESAR polarimetric data provided by the DLR)

Polarimetric Decomposition for classification

- Several decompositions are possible
  - **Example: Pauli decomposition**

$$\begin{pmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{pmatrix} = k_1 . \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} + k_2 . \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix} + k_3 . \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}$$

$$\Longrightarrow \overrightarrow{k} = \begin{pmatrix} k_1 \\ k_2 \\ k_3 \end{pmatrix} = \frac{1}{2} \begin{pmatrix} S_{HH} + S_{VV} \\ S_{HH} - S_{VV} \\ S_{HV} + S_{VH} \end{pmatrix}$$

$$[T] = \overrightarrow{k} . \overrightarrow{k}^{\dagger}$$

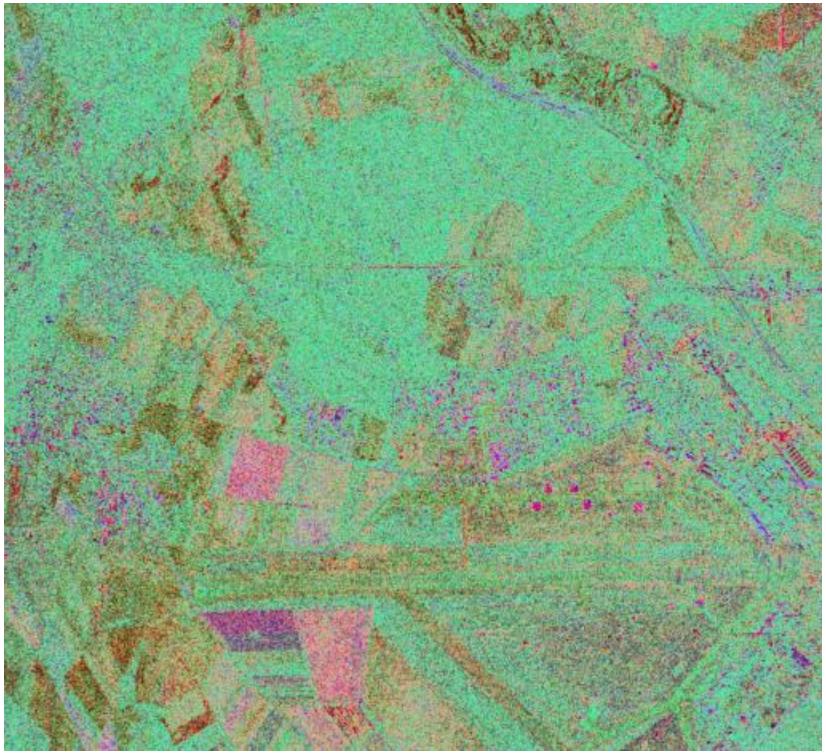
Pauli decomposition colored representation

$$pixel = A\, exp\ (j\,\phi)\,\overrightarrow{p}$$

Polarimetric Decomposition for classification

– **H-A-α Decomposition**

- Based on the eigen vectors decomposition of the coherency matrix : the so called HAα decomposition revealing different backscattering processes

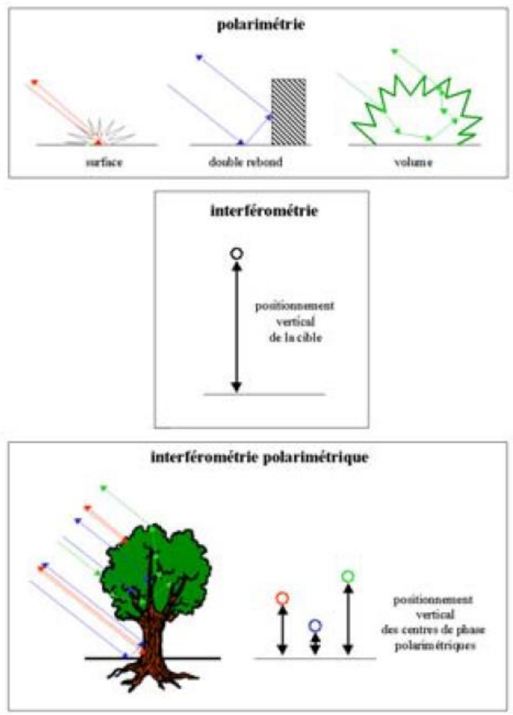


Anisotropy = Red Entropy = Green
Alpha = Blue

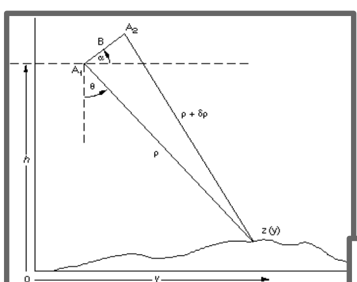
$$pixel = A\,exp\,(j\,\phi)\,\overrightarrow{p}$$

InSAR + PolSAR → PolInSAR processing

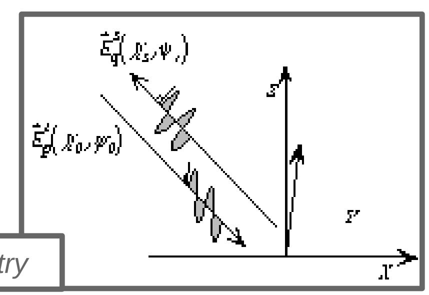
provides a combined sensitivity to the **vertical distribution of scattering mechanisms**.



- Improvement of scatterers classification
- Forest height retrieval



SAR interferometry



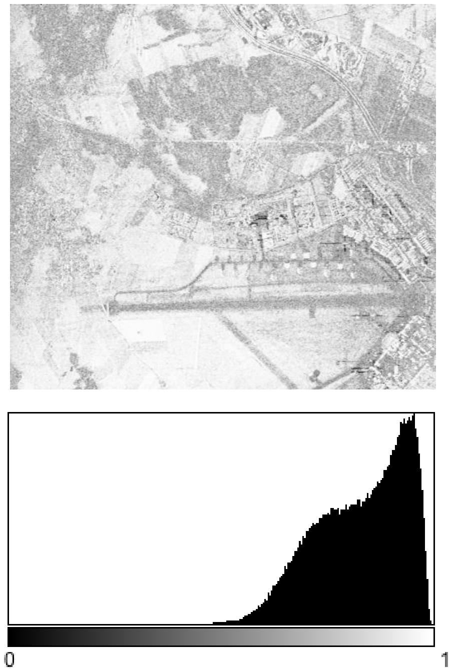
SAR polarimetry

SAR Post-Processing: PolInSAR

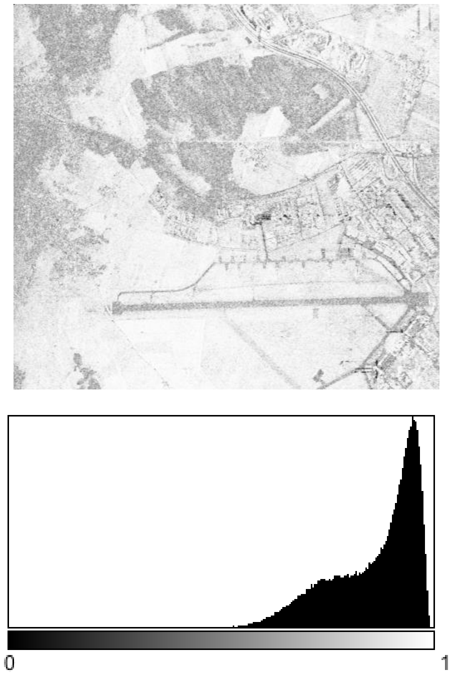
$$pixel = A\,exp\,(j\,\phi)\,\vec{p}$$

- Each SAR acquisition of an interferometric pair is made of three polarimetric channels (HH, VV and HV)

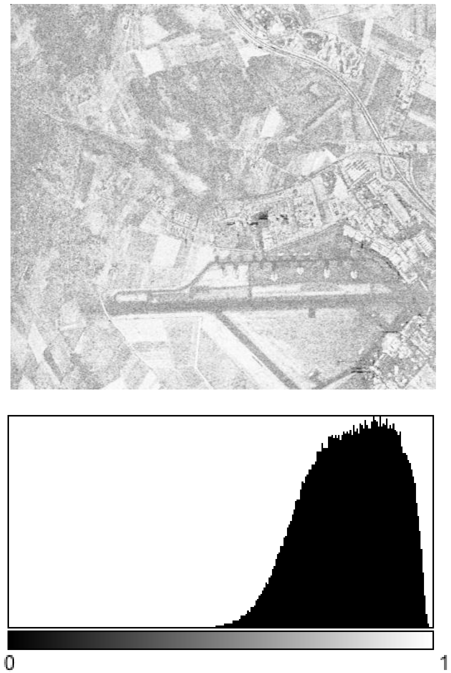
==> HH_HH, VV_VV and HV_HV interferograms/coherence maps



Count: 237568 Min: 0.135
Mean: 0.828 Max: 0.996
StdDev: 0.109 Mode: 0.955 (4246)
Bins: 256 Bin Width: 0.004



Count: 237568 Min: 0
Mean: 0.862 Max: 0.996
StdDev: 0.103 Mode: 0.951 (7148)
Bins: 256 Bin Width: 0.004



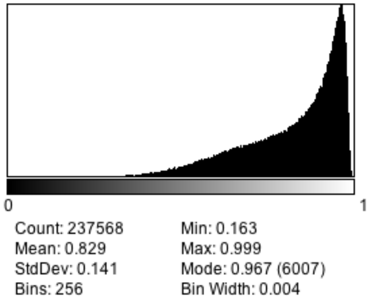
Count: 237568 Min: 0.113
Mean: 0.804 Max: 0.996
StdDev: 0.102 Mode: 0.877 (3181)
Bins: 256 Bin Width: 0.004

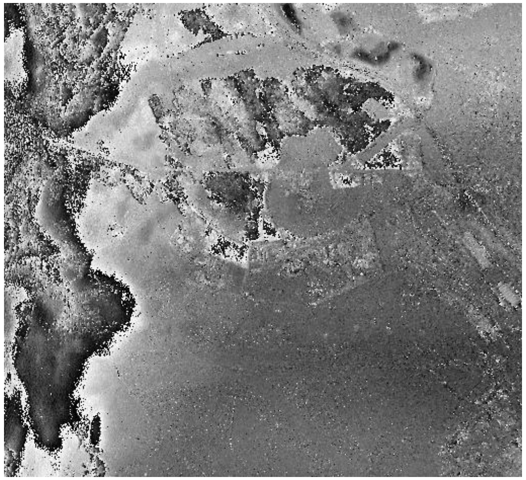
Coherence optimization by eigenvalue decomposition

$$pixel = A\,exp\,(j\phi)\,\vec{p}$$

Find the 3 orthogonal scattering mechanisms that optimize the coherence locally

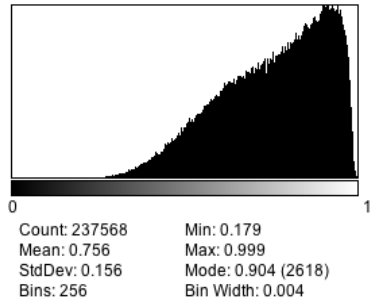
First optimum coherence & interferogram





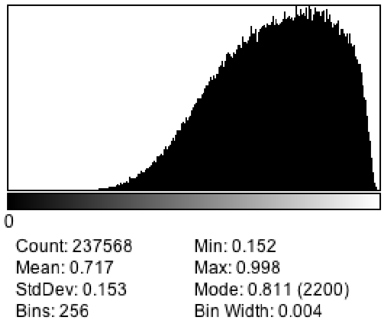
opt1

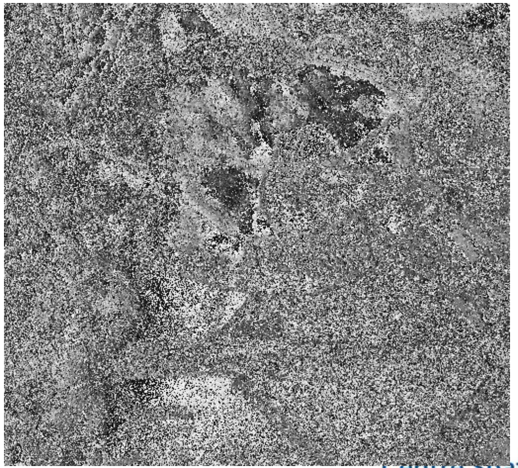
Second optimum coherence & interferogram



opt2

Third optimum coherence & interferogram

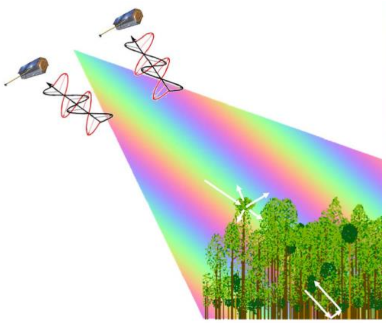




opt3

Forest Height Retrieval

$$pixel = A\,exp\,(j\phi)\,\vec{p}$$



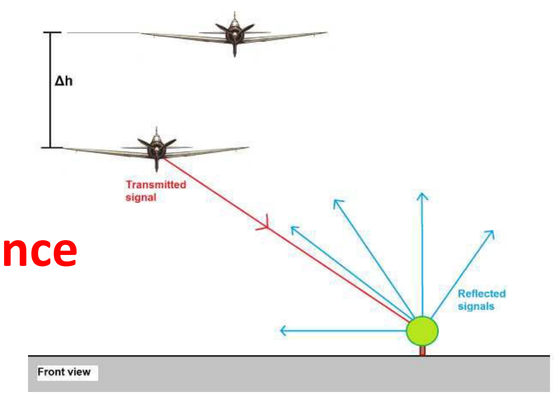
+ *allometric relationship for estimation of biomass*

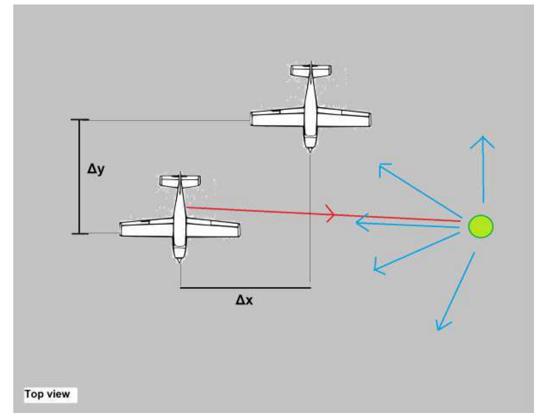
Fig. 3. *Forest heights derived from the Pol-InSAR technique overlaid on a Google map from Traunstein, Germany (forest height retrieval based on two fully-polarimetric L-band data sets acquired by DLR's airborne E-SAR system).*

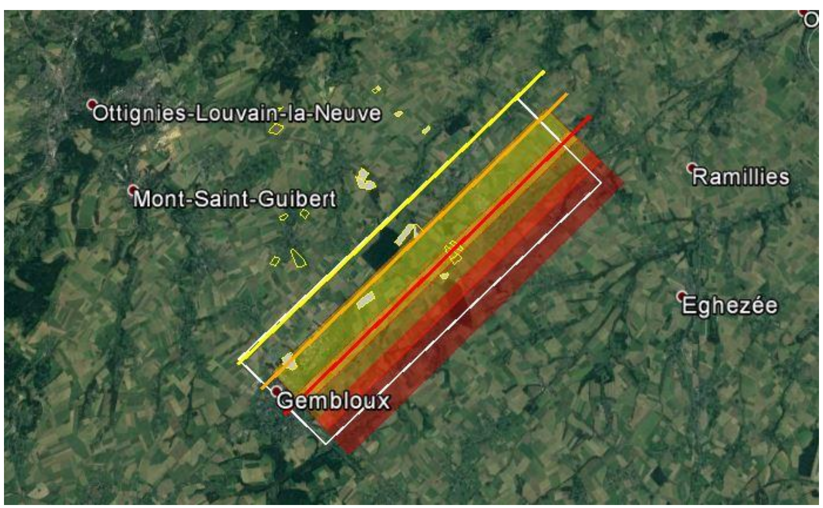
BelSAR : an Airborne Campaign for L-Band Full-Polarimetric and Interferometric Bistatic SAR Measurements over Belgium

for applications in

- **agriculture**
- **soil moisture**
- **bistatic SAR science**







5 flights covering one vegetation growth season

Others Activities and Development

Combining **Radar** and **VIS-NIR** data**:**

soil moisture, hydric stress, irrigation monitoring…

Hyperspectral Data

- **Post-processing :**
  - Atmospheric /radiometric/geometric corrections
- **Exploitation** (support to bio-certification, portable spectrometer)

Development of **synergy** between **geo-positioning and remote sensing data**

Academic / industrial training

Academic at Liege University:

- ***Remote Sensing***
- ***Cosmology***
- ***Observing the Earth from Space***
- ***Internship***
- ***Seminars on Topical Issues***

Lectures and B2B

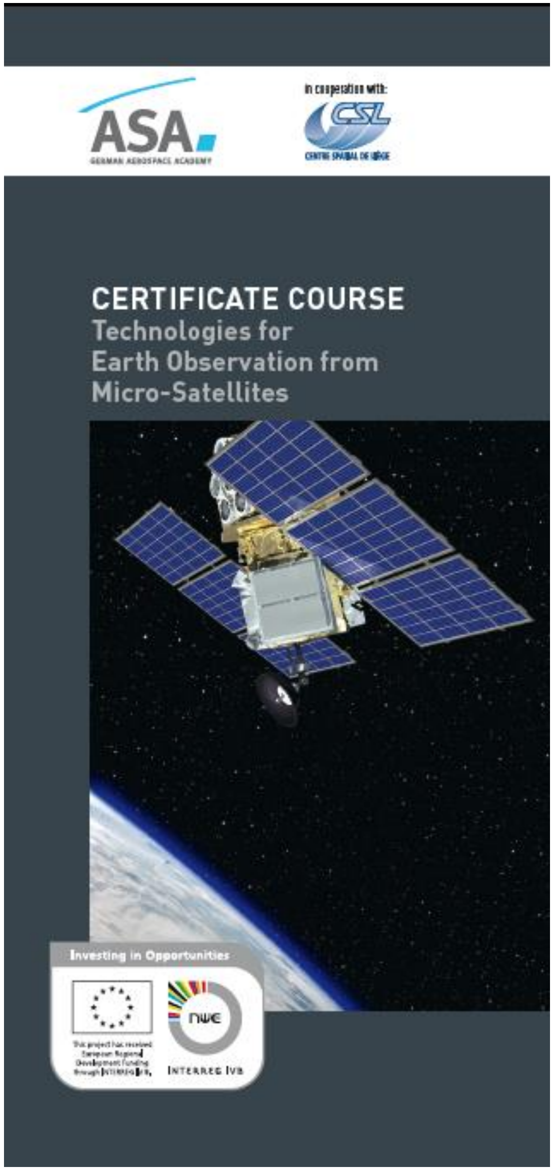
- ***Santiago University (Chili)***
- ***Belspo,***
- ***Argentine,***
- ***WAN,***
- ***Algérie…***

FabSpace 2.0 – Open innovation, Earth Observation Data Exploitation

TransNetAero
transnational network of aerospace regions

ASA
GERMAN AEROSPACE ACADEMY

Certificate Course on Technologies for Earth Observation from µ-Satellites



Academic / industri

TransNetAero
transnational network of aerospace regions

ASA
GERMAN AEROSPACE ACADEMY

Certificate Course on Technologies for Earth Observation from µ-Satellites

Specific training

The MEANS

- **The lancher**
  - The rocket
  - The engines
  - The propergols
- **The satellite**
  - Orbit
  - Attitude control
  - Electrical power
  - Thermal control
  - Telecommunications
  - Data processing
  - Payload
- **The ground segment**
  - Mission control
  - Data transmission and reception
  - User segment
- **Management**
  - The project and its management
  - The phases of a space project
  - Reviews
  - Documentation
  - PA/QA
  - Configuration management
- **Ground tests**
  - Thermal vacuum tests
  - Mechanical and acoustical tests
  - Electromagnetic tests

The OBSERVABLES

- **The space environment**
  - Components
  - Effects
- **The Earth**
  - Remote sensing bases
  - Image processing
  - Remote sensing applications :
    - Cartography
    - Géology
    - Urban
    - Vegetation
    - Atmosphere
    - Oceans and coastal zones
    - Risk management

Specific equipment

Computers:

- 4 iMac 27”
- 1 MacBook Pro
- Exploitation system : MacOS10.12

Mass memory Stations:

- 1 Synology DS1515 + 9Tb effective (18Tb in RAID)
- 1 LaCIE 2big 2 x 3 Tb

Centre Spatial de Liège
Université de Liège

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Thank you