InSAR Developments in Belgium

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26 years of Remote Sensing at CSL

1989	SAR1 (ESA)
1990	SAR2 (ESA)
1991	SAR2 (ESA)
1992	SAR2 (ESA), Telsat-1 (BelSPo)
1993	SAR3 (ESA), Telsat-1 (BelSPo)
1994	SAR3 (ESA), Telsat-1 (BelSPo)
1995	SAR4 (ESA), SAR-GSTP (ESA), Telsat-2 (BelSPo), RTP9.1
1996	SAR4 (ESA), SAR-GSTP (ESA), Telsat-3 (BelSPo), RTP9.1
1997	SAR-GSTP (ESA), SAR-DUP (ESA), Telsat-3 à 6 (BelSPo)
1998	SAR-DUP2, Telsat 3 à 6 (BelSPo), FIRST (RW), RTP 9.6 (RW)
1999	SAR-DUP2 (ESA), SAR-DISP (ESA), RTP 9.6 (RW)
2000	SAR-DISP (ESA), SAR-Argentine-1 (BelSPo), RTP 9.6 (RW)
2001	SAR-Argentine-1 à 3 (BelSPo), RTP 9.6 (RW)
2002	SAR-Argentine-1 à 3 (BelSPo)
2003	SAR-Argentine-1 à 3 (BelSPo)
2004	SAR-Argentine-2 à 3 (BelSPo)
2005	SAR-Spacebel (SPB)
2006	SAR-Argentine-1 (BelSPo), MUSIS (SPB)
2007	WIMCA (ESA), MUSAR (BelSPo), GEMITOR (BelSPo), MUSIS (SPB), 3WSA (RW)
2008	WIMCA (ESA), MUSAR (BelSPo), GEMITOR (BelSPo), 3WSA (RW)
2009	WIMCA (ESA), MUSAR (BelSPo), Redu (RSS Redu), 3WSA (RW)
2010	MUSAR (BelSPo)
2011	Argentine 1 (BelSPo)
2012	TreeVol (BelSPo), VI-X (BelSPo), WIMCA II (ESA)
2013	Argentine 2 (BelSPo), OLIVIA (ESA), TransNetAero (INTERREG)
2014	GEPATAR (BelSPo), VNREDSAT 1B (SPB), SAOCOM-CS Phase A/B1 (QinetiQ)
2015	RESIST (BelSPo), MUZUBI (BelSPo)

26 years of Remote Sensing at CSL

FRINGE 99

Advancing ERS SAR Interferometry from Applications towardsOperations

Liège, Belgium,
10 – 12 November 1999

1989	SA
1990	
1991	
1992	
1993	
1994	
1995	SAR- ….1
1996	SA …), RTP9.1
1997	…TP (ESA), SAR-DUP (ESA), Telsat-3 à 6 (**BelSPo**)
1998	SAR-DUP2, Telsat 3 à 6 (**BelSPo**), FIRST (RW), RTP 9.6 (RW)
1999	SAR-DUP2 (ESA), SAR-DISP (ESA), RTP 9.6 (RW)
2000	SAR-DISP (ESA), SAR-Argentine-1 (**BelSPo**), RTP 9.6 (RW)
2001	SAR-Argentine-1 à 3 (**BelSPo**), RTP 9.6 (RW)
2002	SAR-Argentine-1 à 3 (**BelSPo**)
2003	SAR-Argentine-1 à 3 (**BelSPo**)
2004	SAR-Argentine-2 à 3 (**BelSPo**)
2005	SAR-Spacebel (SPB)
2006	SAR-Argentine-1 (**BelSPo**), MUSIS (SPB)
2007	WIMCA (ESA), MUSAR (**BelSPo**), GEMITOR (**BelSPo**), MUSIS (SPB), 3WSA (RW)
2008	WIMCA (ESA), MUSAR (**BelSPo**), GEMITOR (**BelSPo**), 3WSA (RW)
2009	WIMCA (ESA), MUSAR (**BelSPo**), Redu (RSS Redu), 3WSA (RW)
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2015	RESIST (**BelSPo**), MUZUBI (**BelSPo**)

Developments

PRE-PROCESSING

- High-resolution:
  - Stripmap SAR
  - Spotlight SAR
- Medium to low resolution:
  - TOPSAR
  - ScanSAR
- Bistatic SAR

POST-PROCESSING

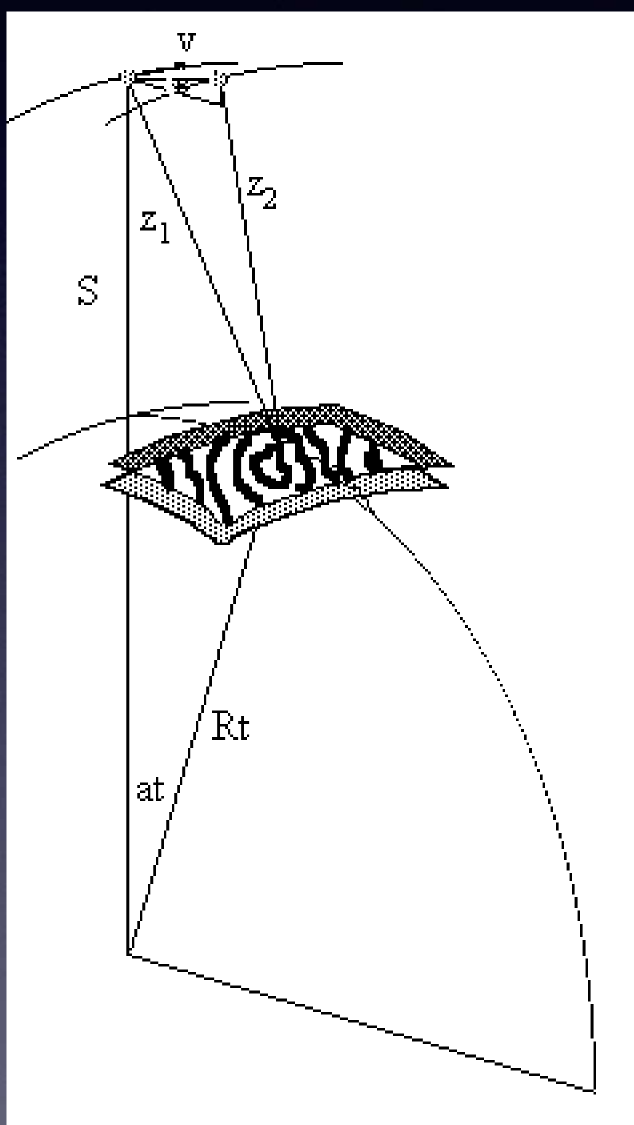
- SAR Interferometry (InSAR)
- Differential Interferometry (DInSAR)
- Polarimetry (PolSAR)
- Polarimetric interferometry (PolInSAR)
- Coherence tracking
- Split Band InSAR
- S1 InSAR

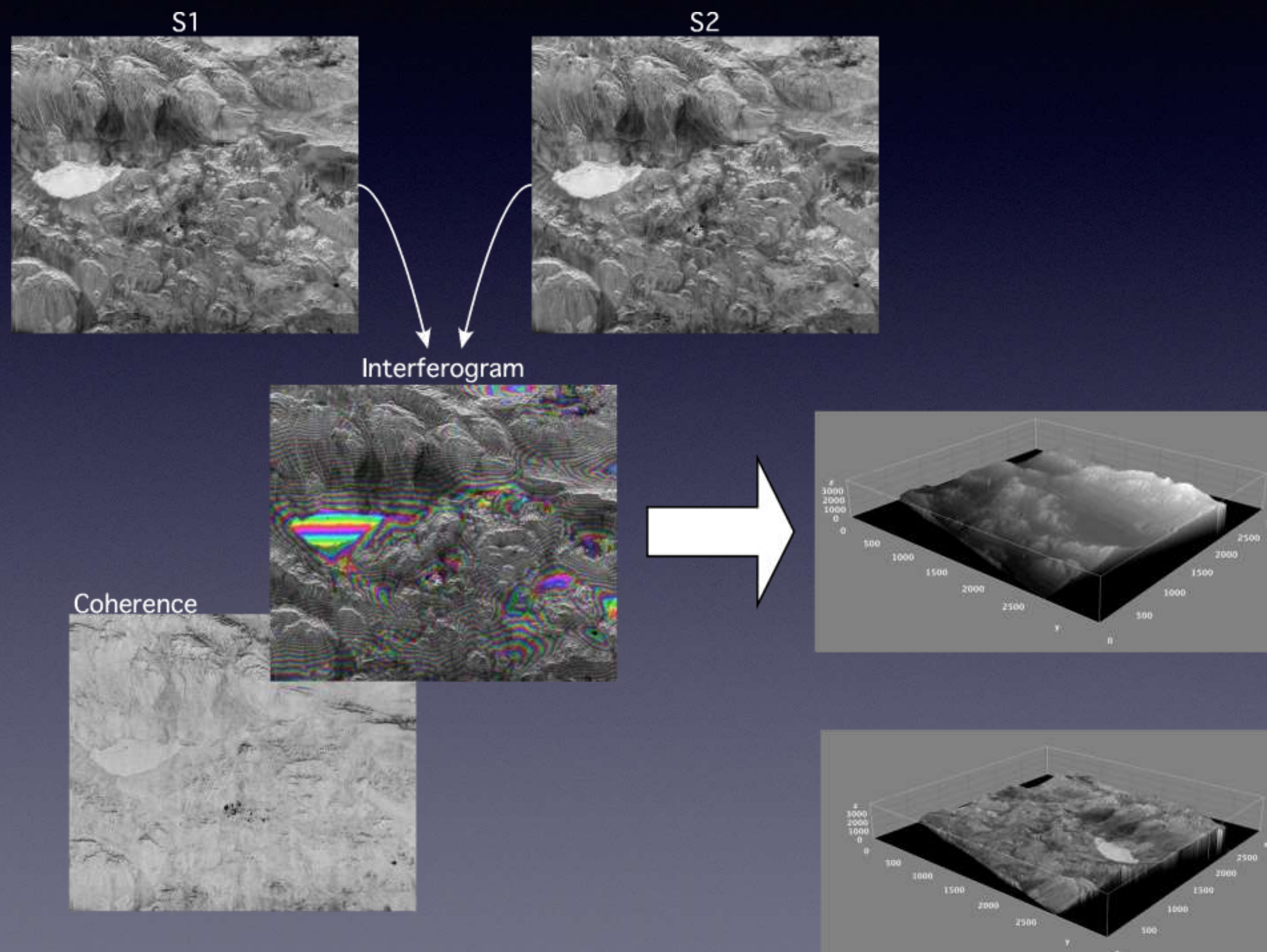
$$pixel = \underbrace{\underbrace{A}_{amplitude}}_{SAR} \; \exp(j \underbrace{\underbrace{\underbrace{\phi}_{phase}}_{InSAR}) \underbrace{\underbrace{\vec{p}}_{polarisation\ state}}_{PolSAR}}_{PolInSAR}$$

InSAR

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

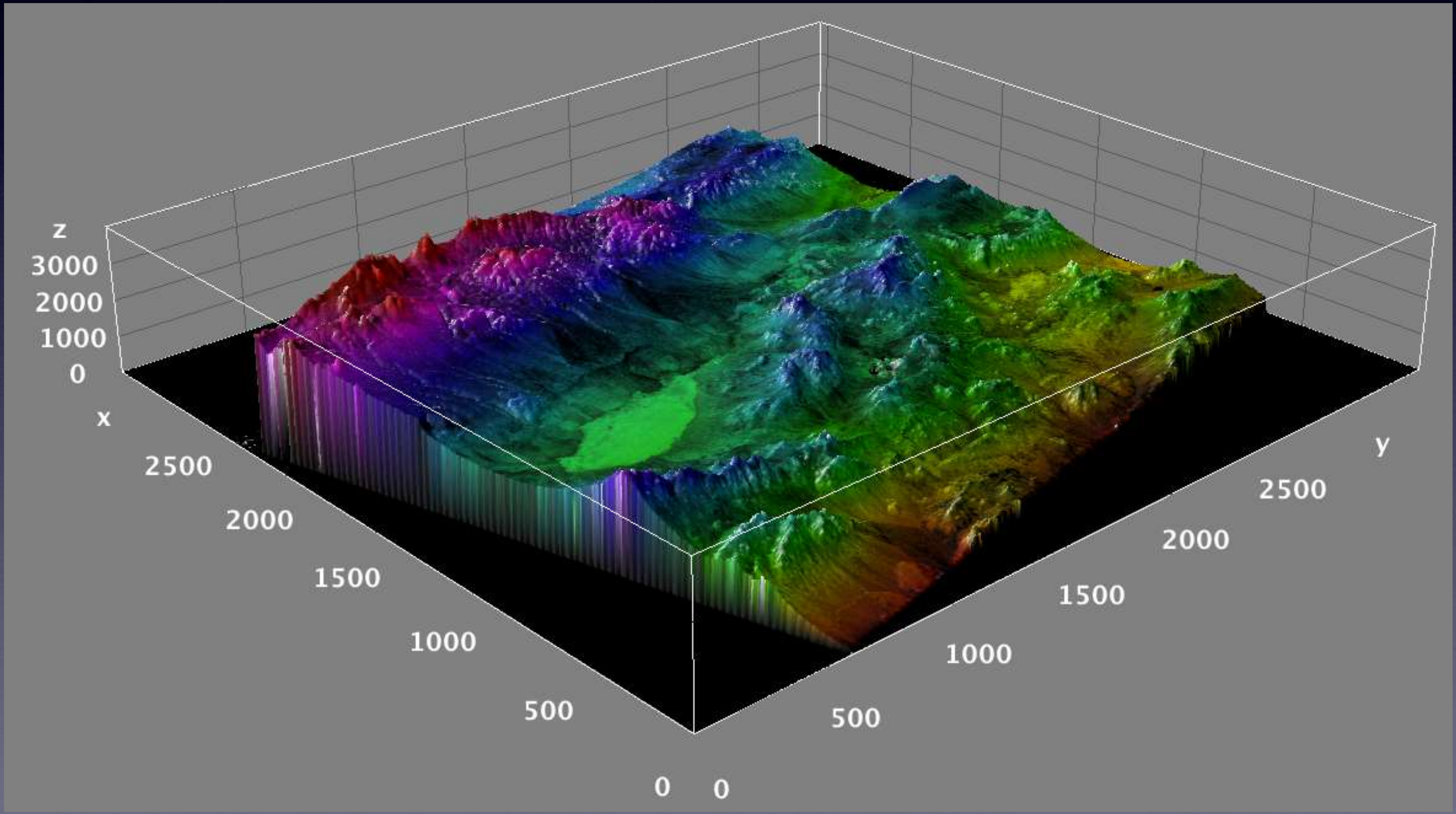
- SAR interferometry scheme:





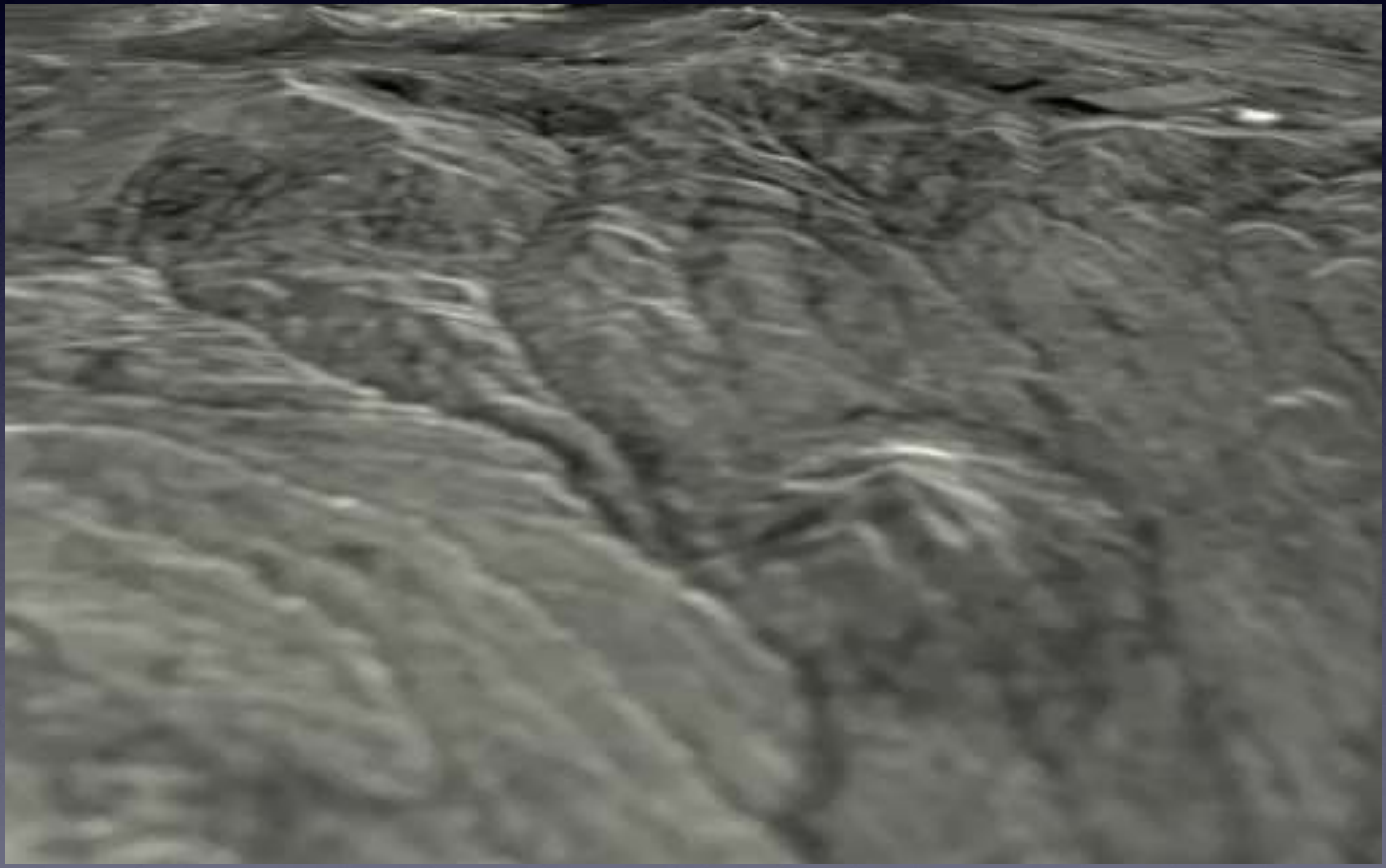
InSAR example

- Example of a Digital Elevation Model obtained by interferometry on the Escondida mine area (Chile)

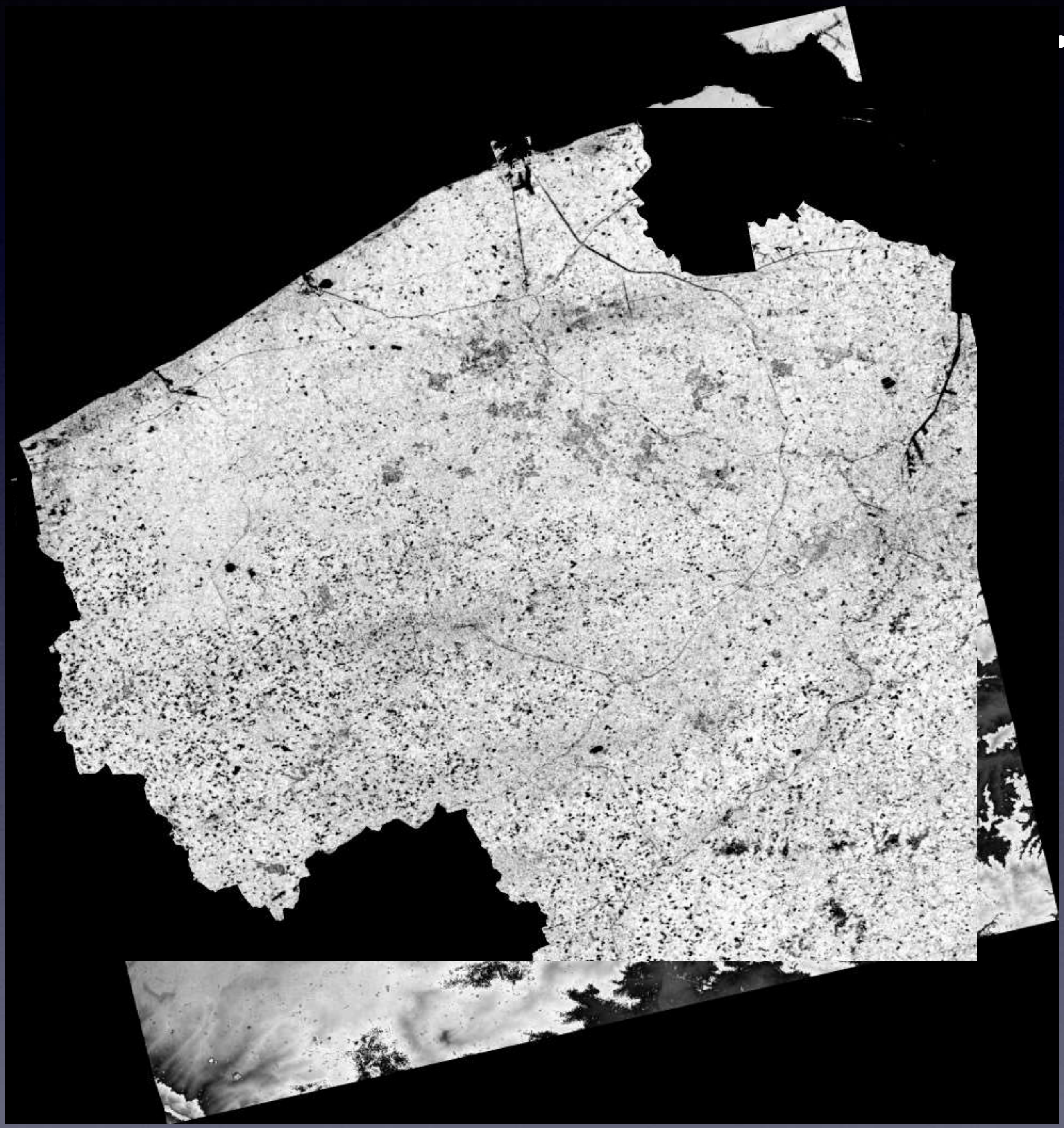


InSAR example

- Example of a Digital Elevation Model obtained by interferometry on the Escondida mine area (Chile)



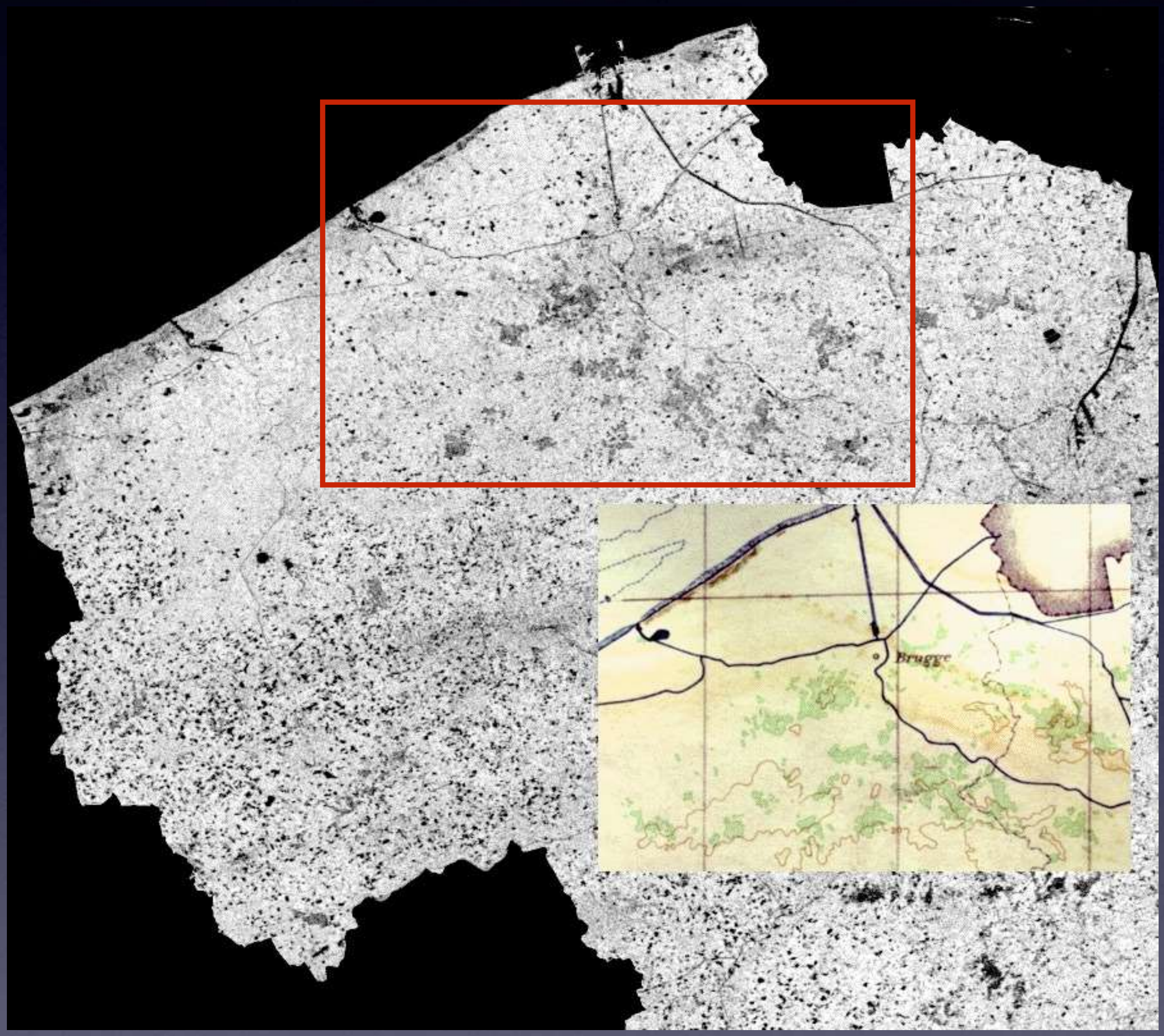
InSAR - Coherence



- InSAR Coherence is a measurement of the “quality” of the interferometric signal

  ✓ Any scene changes between SAR acquisition induces Coherence losses

InSAR - Coherence



- These information losses give themselves information on how the scene is changing

✓ Coherence is an important information channel

  - Human activity
  - Vegetation density
  - Crop stage

Application to crop monitoring

InSAR Coherence for Crop Parameters Monitoring

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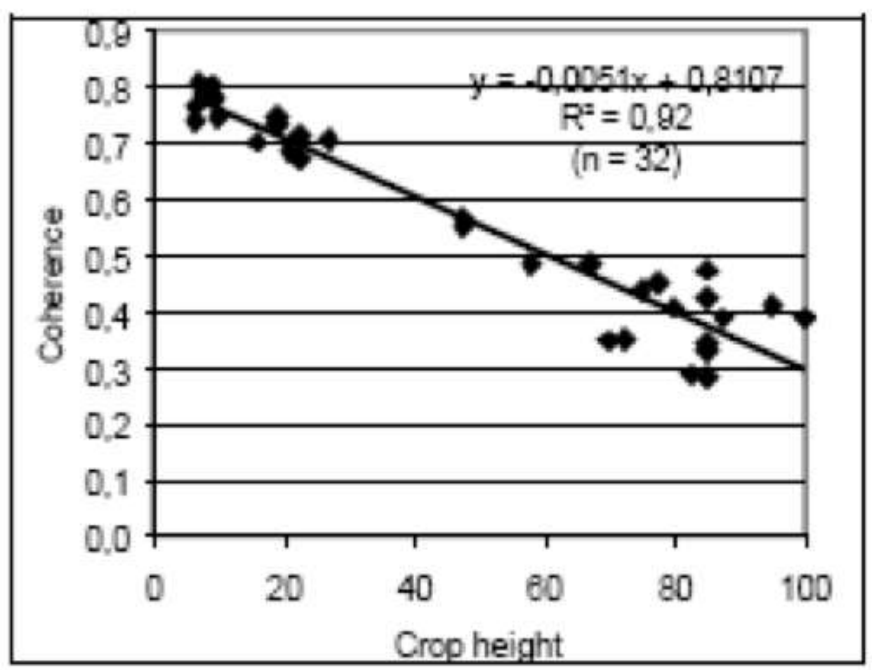
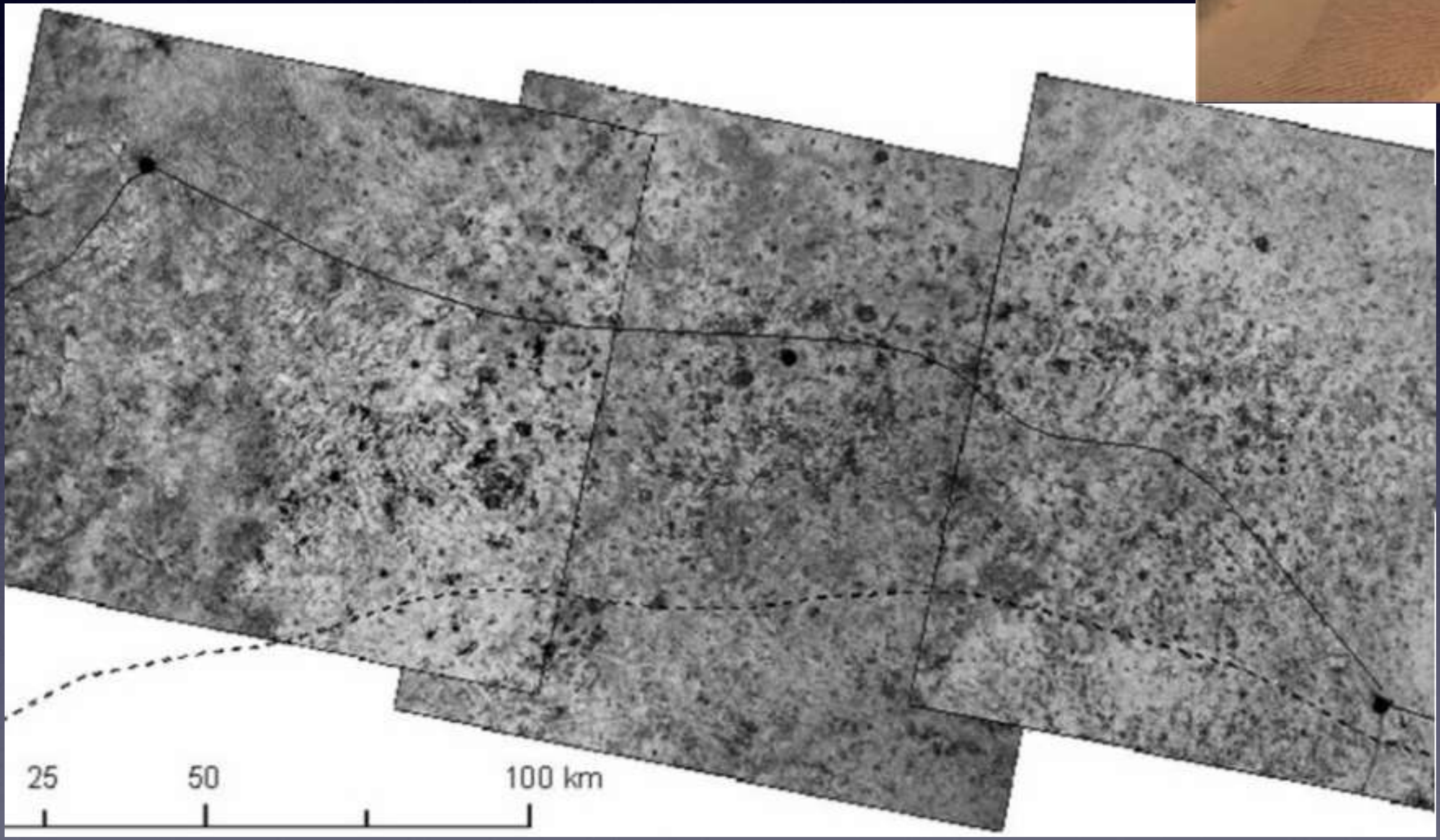


Figure 5: relationship between the tandem coherence and the winter wheat height.

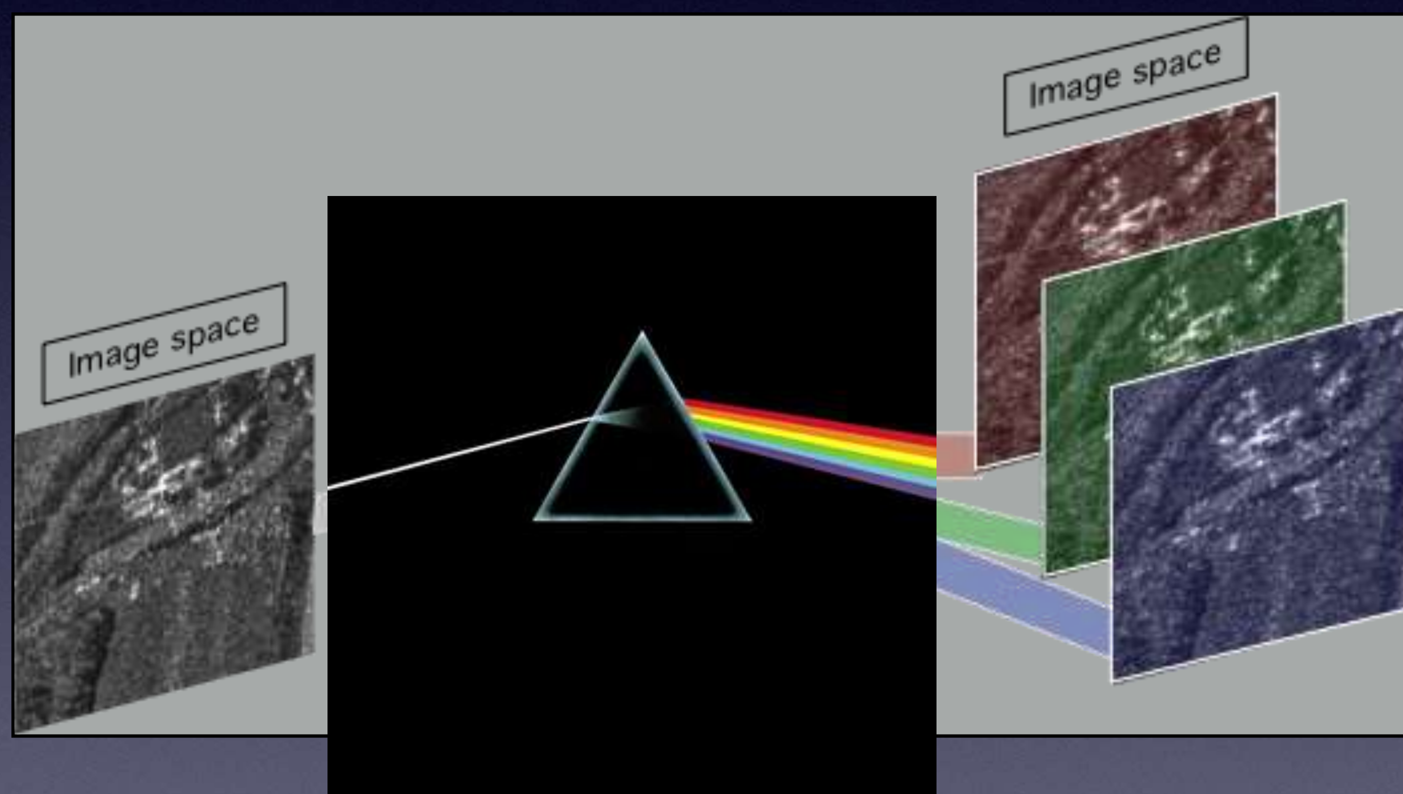
Application to sand dunes movements



Split Band

- Split band principle

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



Split Band

- Spectral coherence

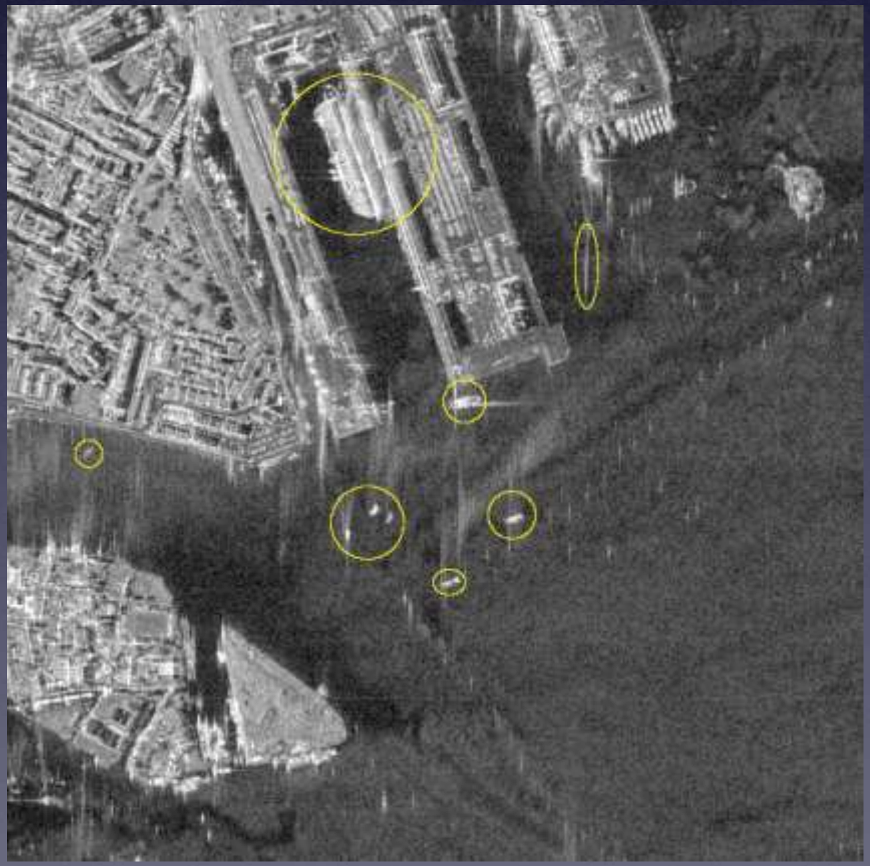
  ➪ Interferometric coherence between sub-images issued from a single acquisition can be measured.

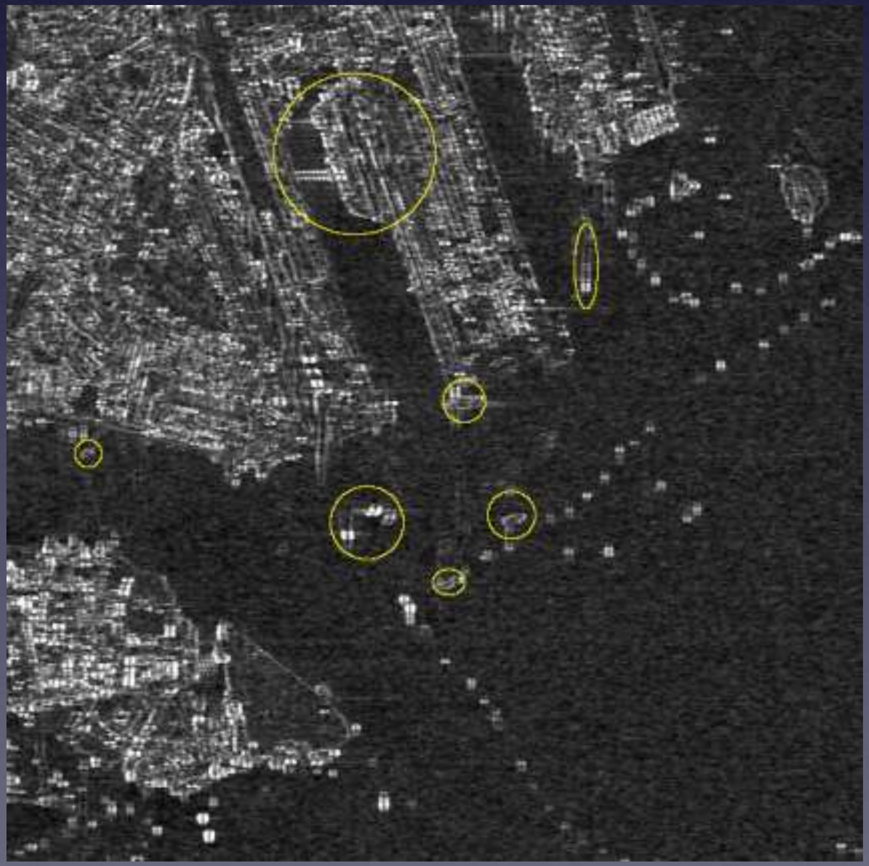
- Split band interferometry

  ✓ Images of an interferometric pair can be split, leading to a stack of interferograms

Spectral coherence

- Spectral coherence applied to vessel tracking:
  - ✓ Border controls
  - ✓ Halieutic reserves management / Fishing monitoring





Left: TerraSAR-X Intensity image of the docks of Venice - Right: Corresponding averaged spectral coherence

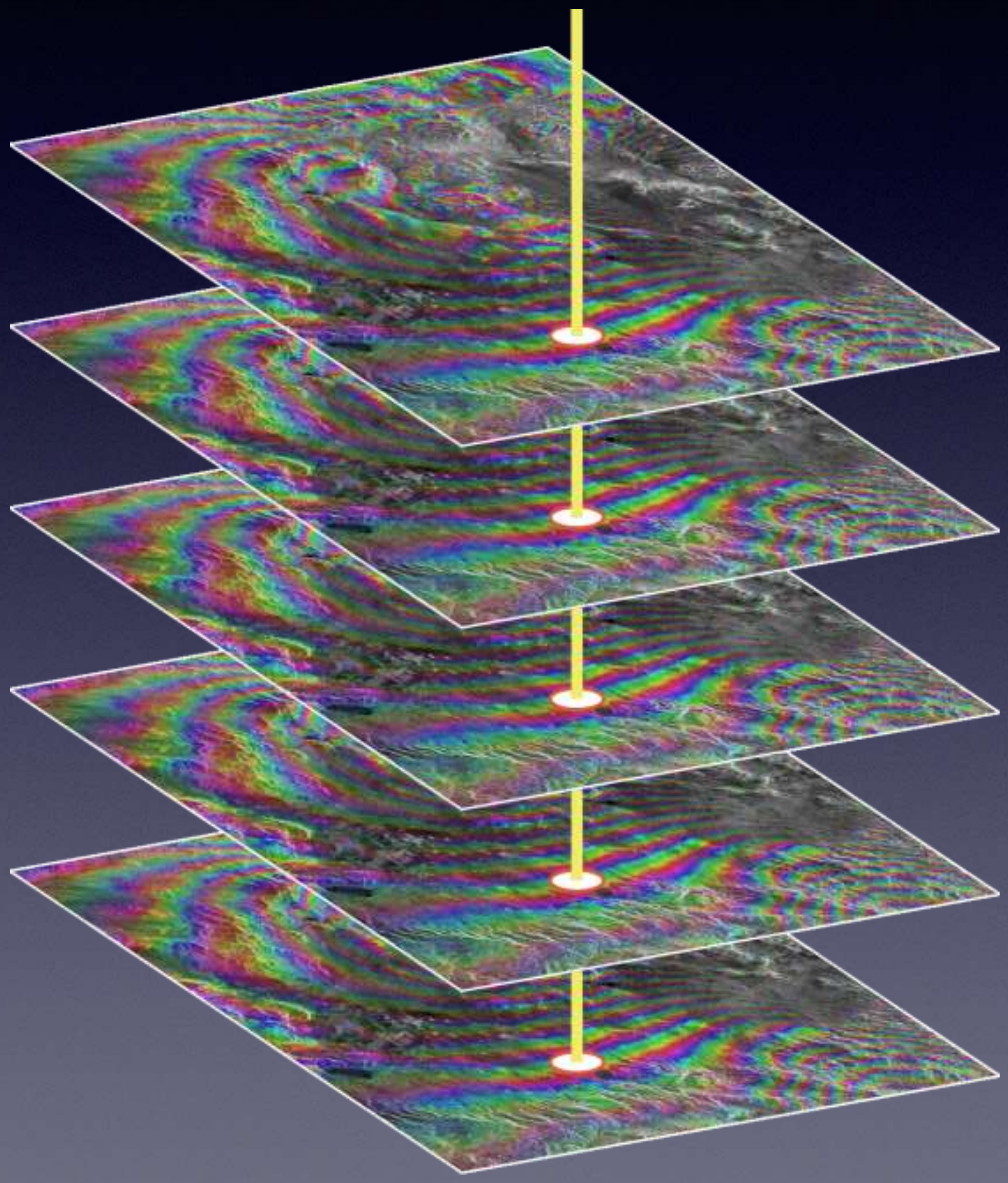
Split Band InSAR (SBInSAR)

- SBInSAR is based on this spectral analysis

  ➪ to generate several InSAR pairs of lower resolution from a single one.

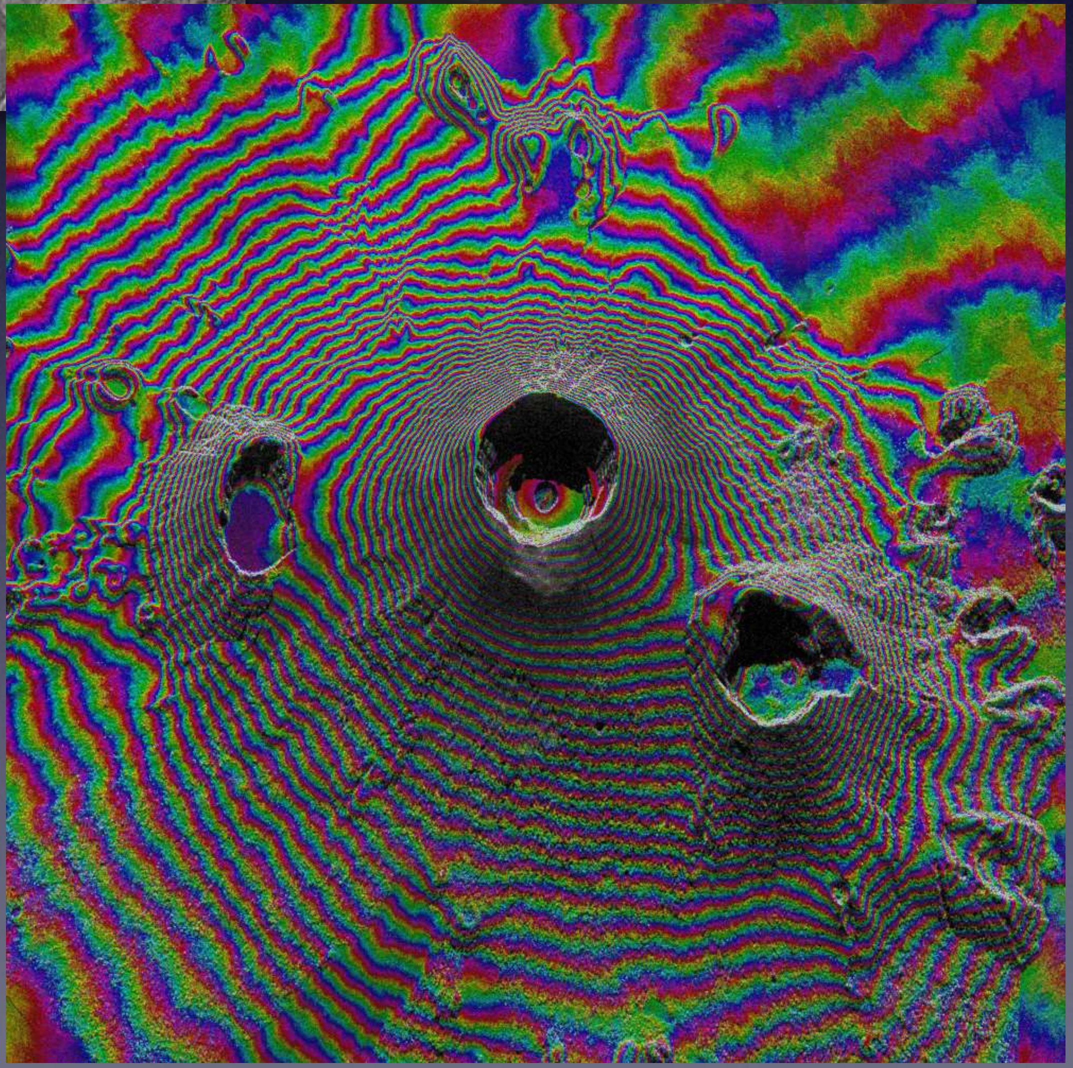
  ➪ Each sub-band interferometric pair leads to an interferogram generated with its own frequency (or wavelength).

  - Fringe rate will vary with respect to wavelength



SBInSAR application example

- Nyiragongo volcano, Kivu basin, East RDC

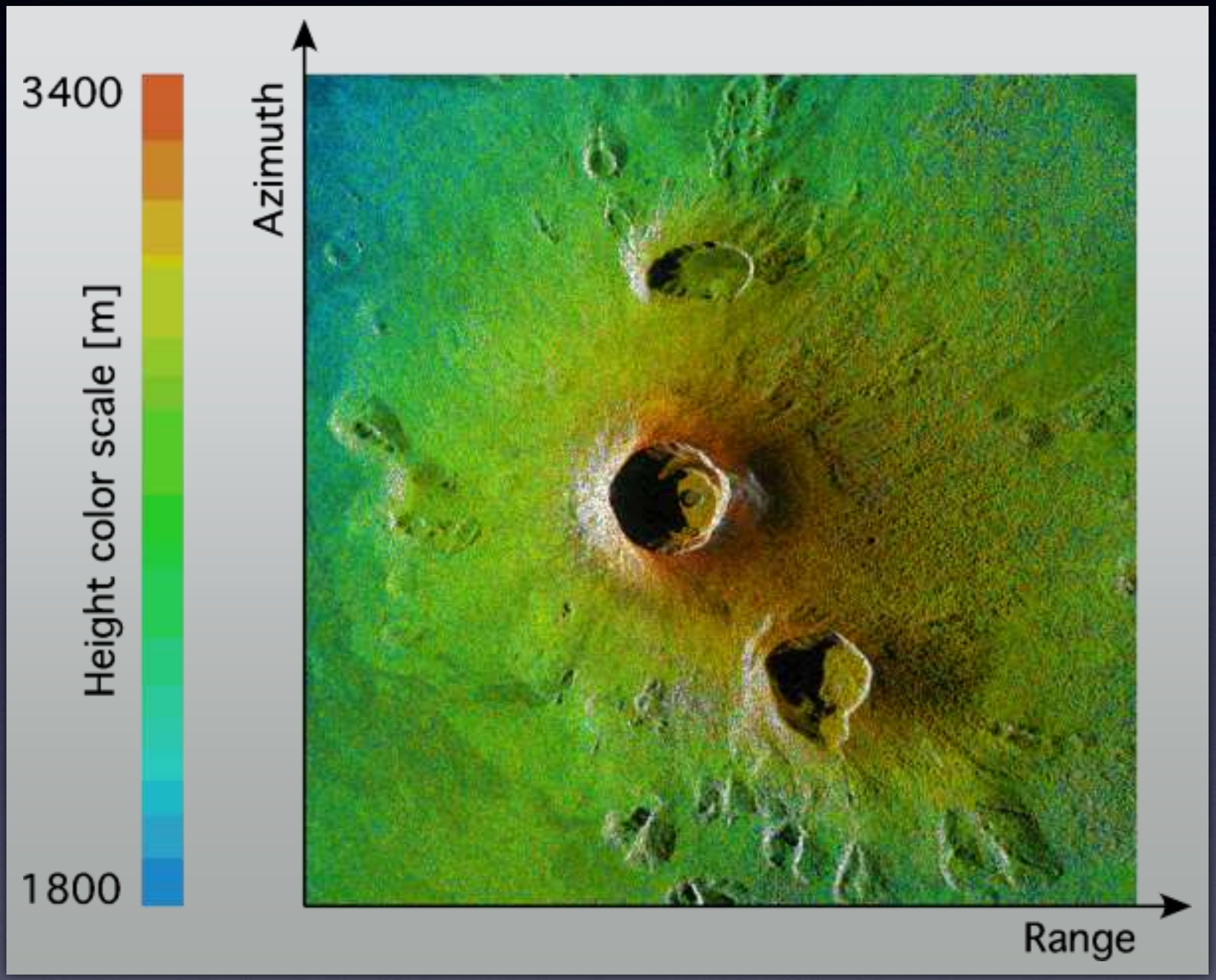


- Objective:
  - ➪ Lava lake and lava deposit monitoring
- Data: TanDEM-X 2012-07-21

SBInSAR application example

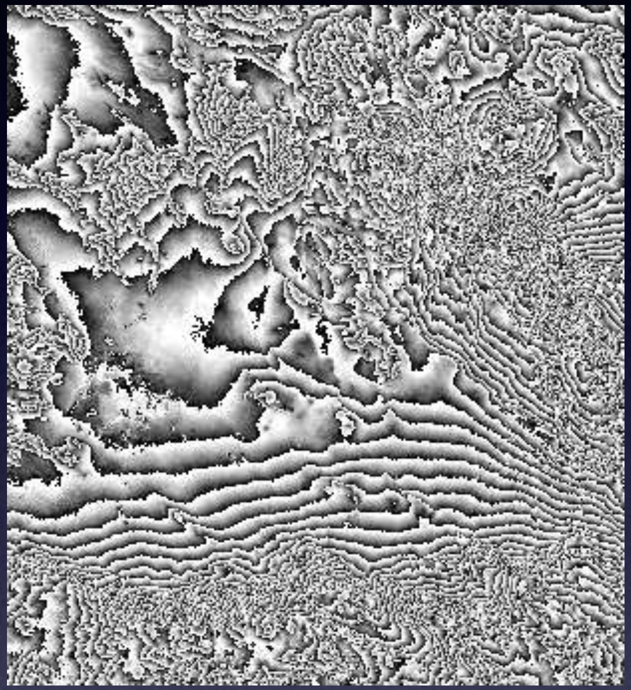
- "Absolute" phase was derived through SBInSAR process and converted into local heights

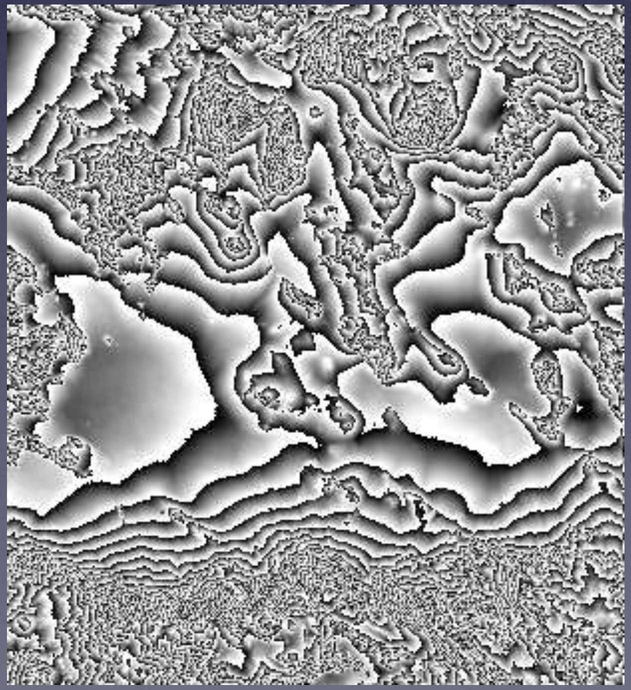
  ➪ Difference between crater rim and lower crater platform P3 was estimated to be of approximately 410m while the expected value is of about 390m.

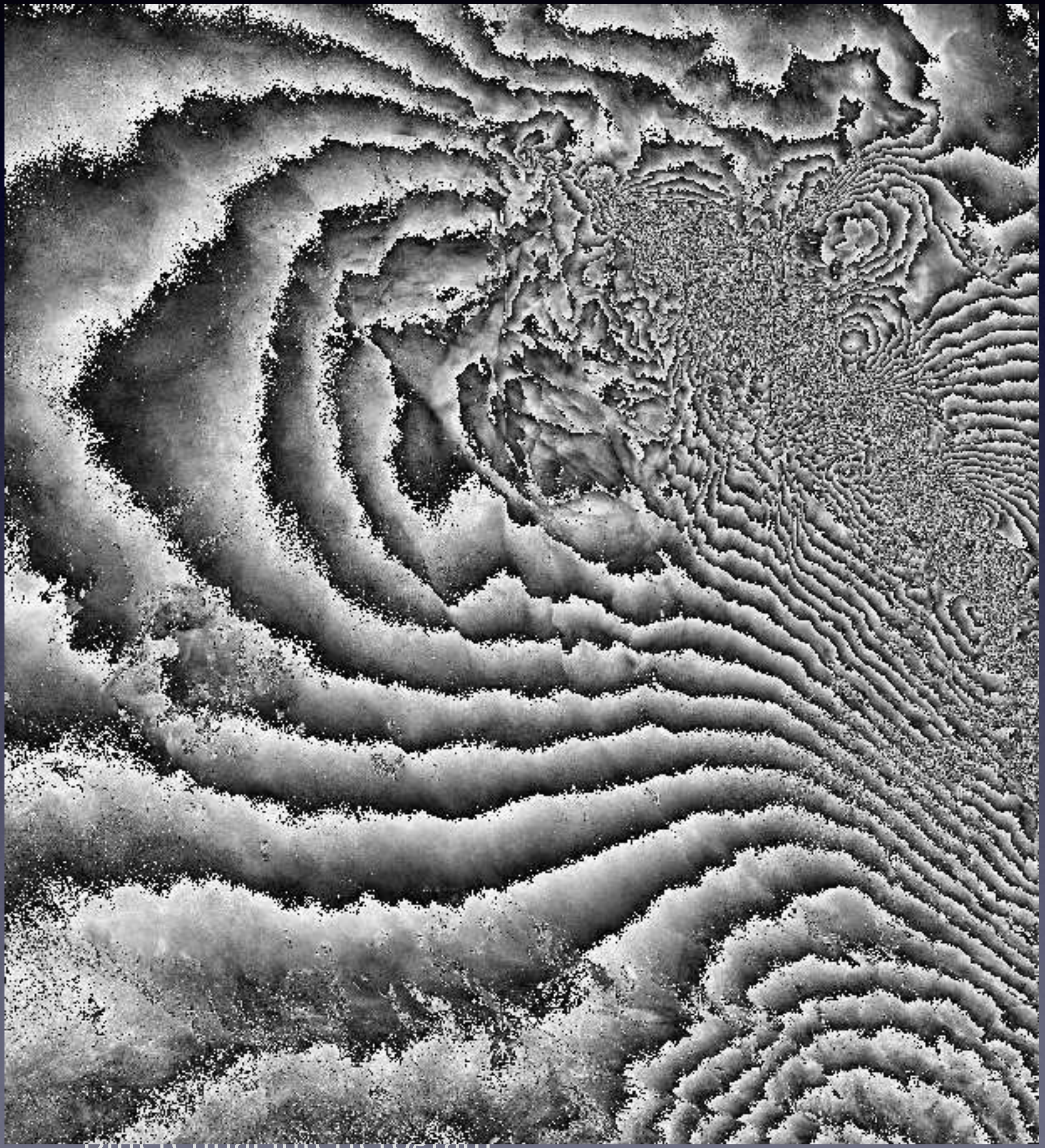


Differential SAR interferometry

- Landers earthquake, 28 juin 1992





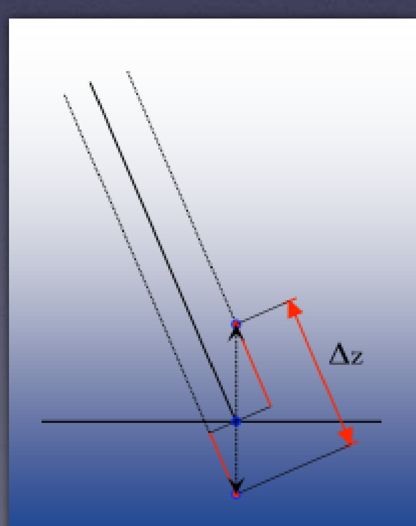


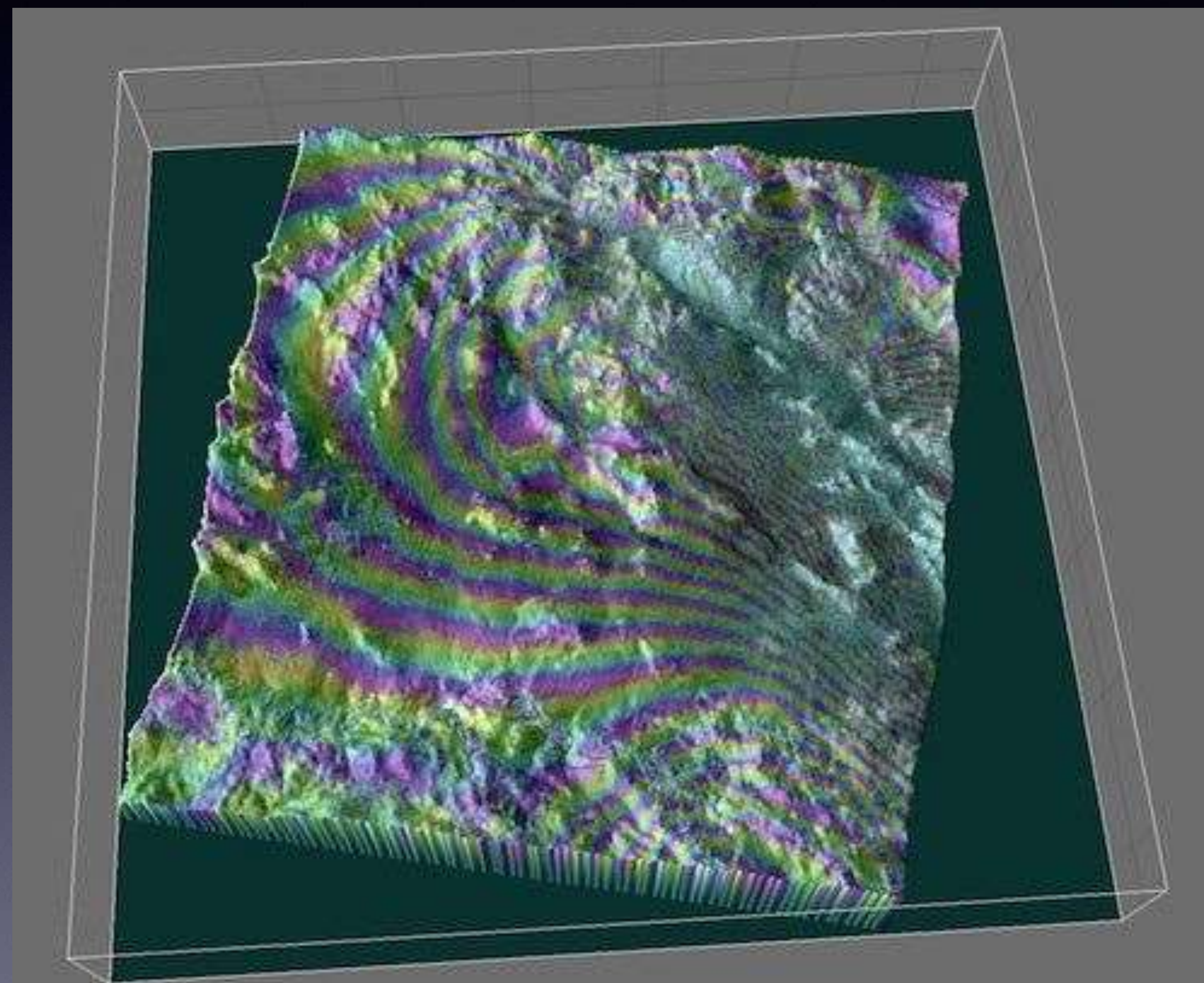
Differential interferogram

Differential SAR interferometry

- Landers earthquake, 28 juin 1992

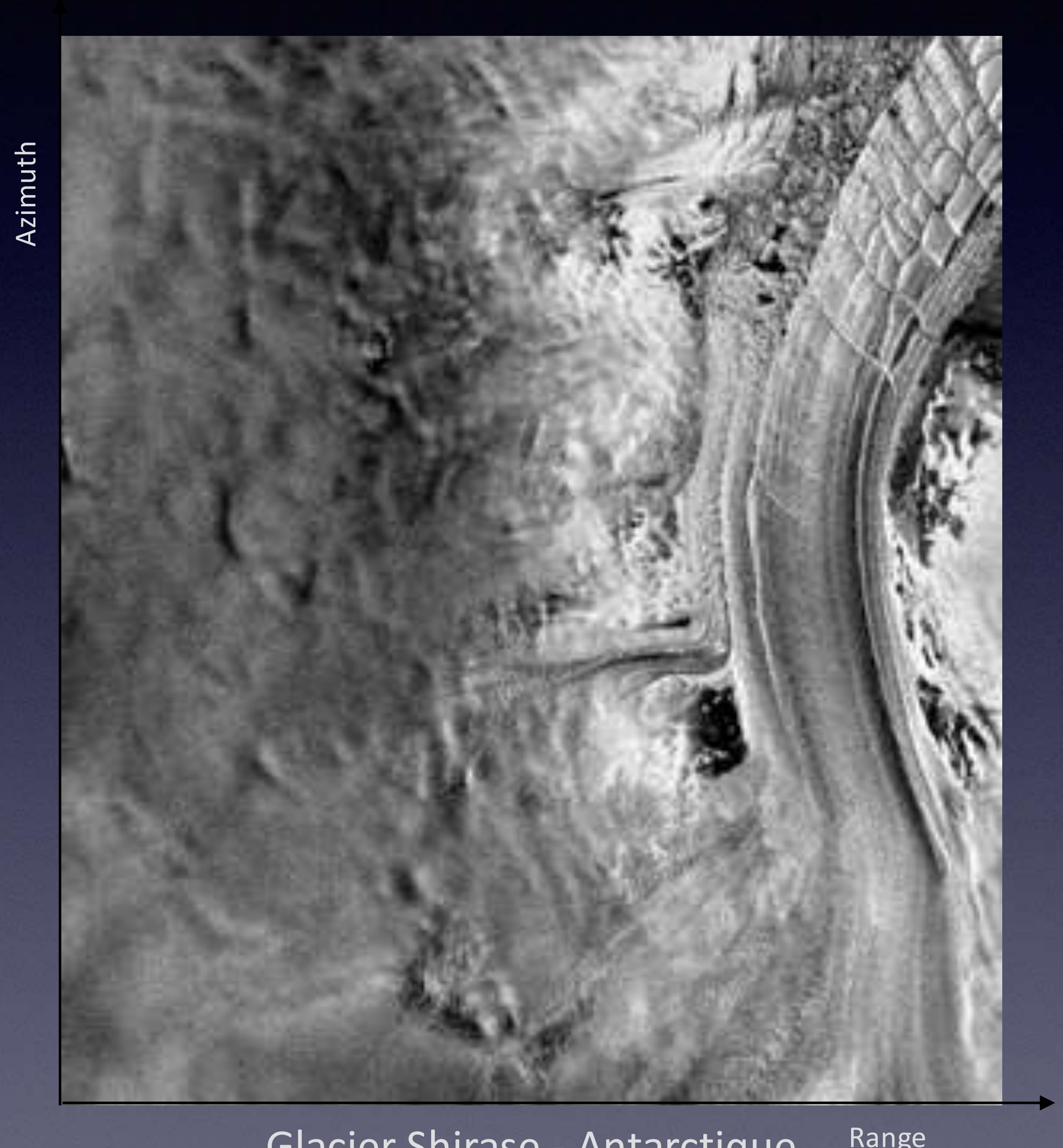
© "Robert A. Eplett/CAL EMA"
California Governor's Office of Emergency Services



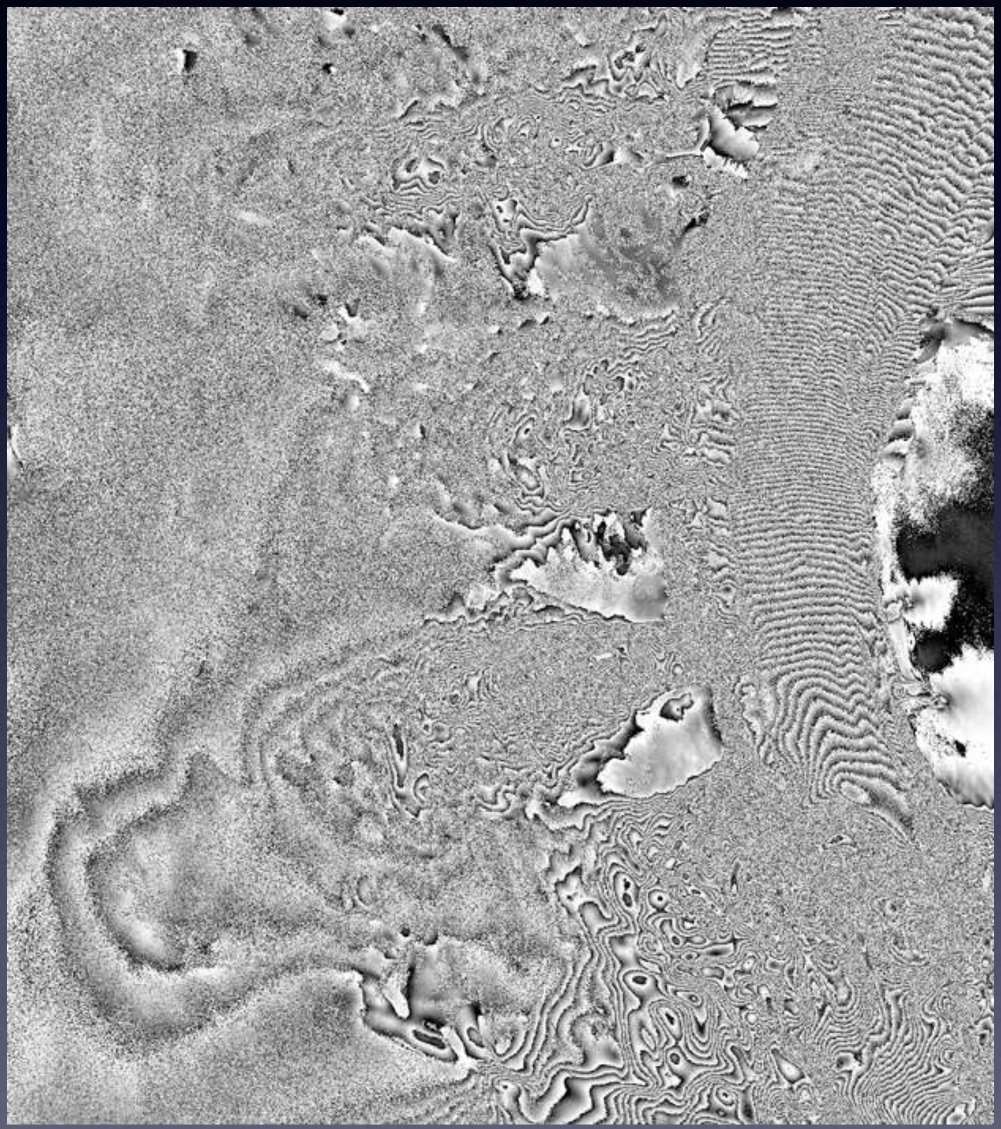


Differential SAR interferometry

- Glacier monitoring: Glacier Shirase - Antarctique



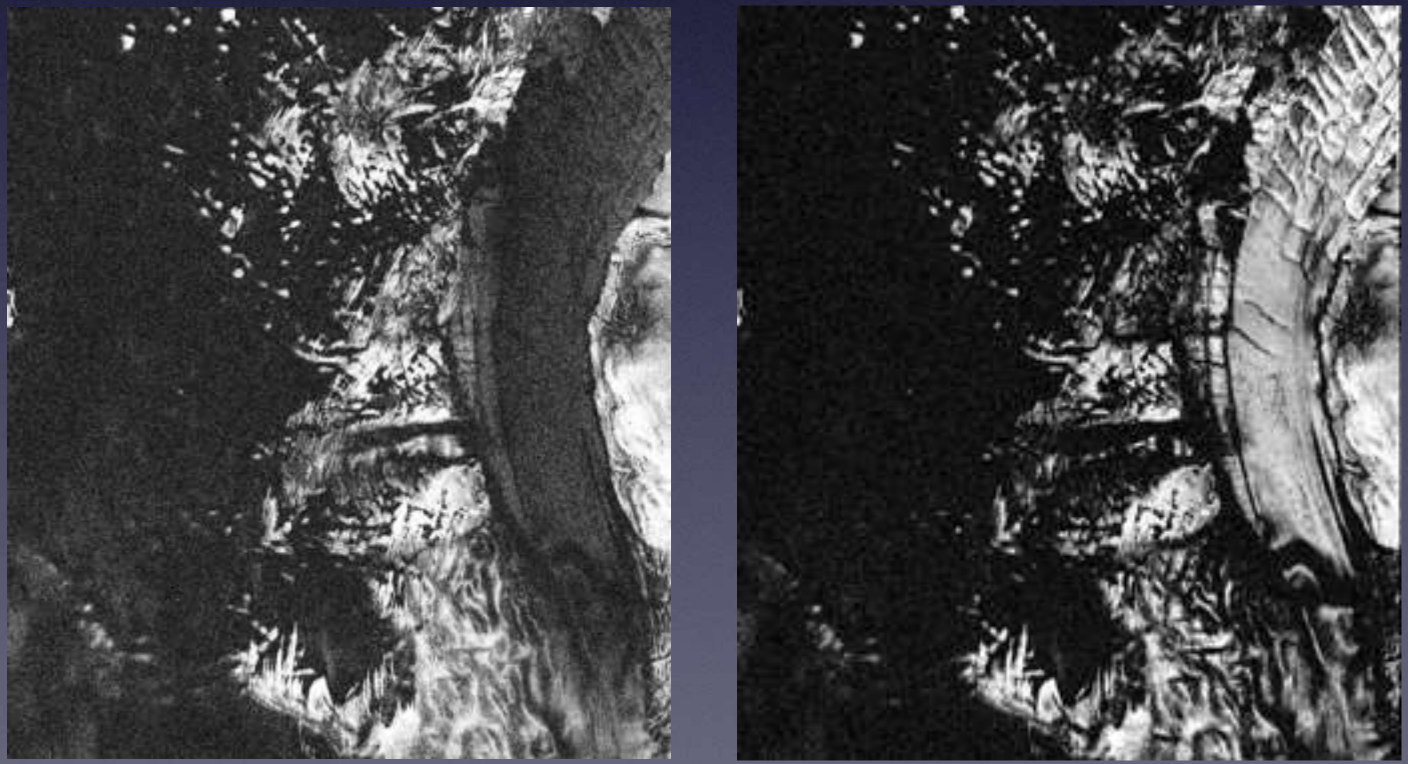
Glacier Shirase - Antarctique
June 2, 1996



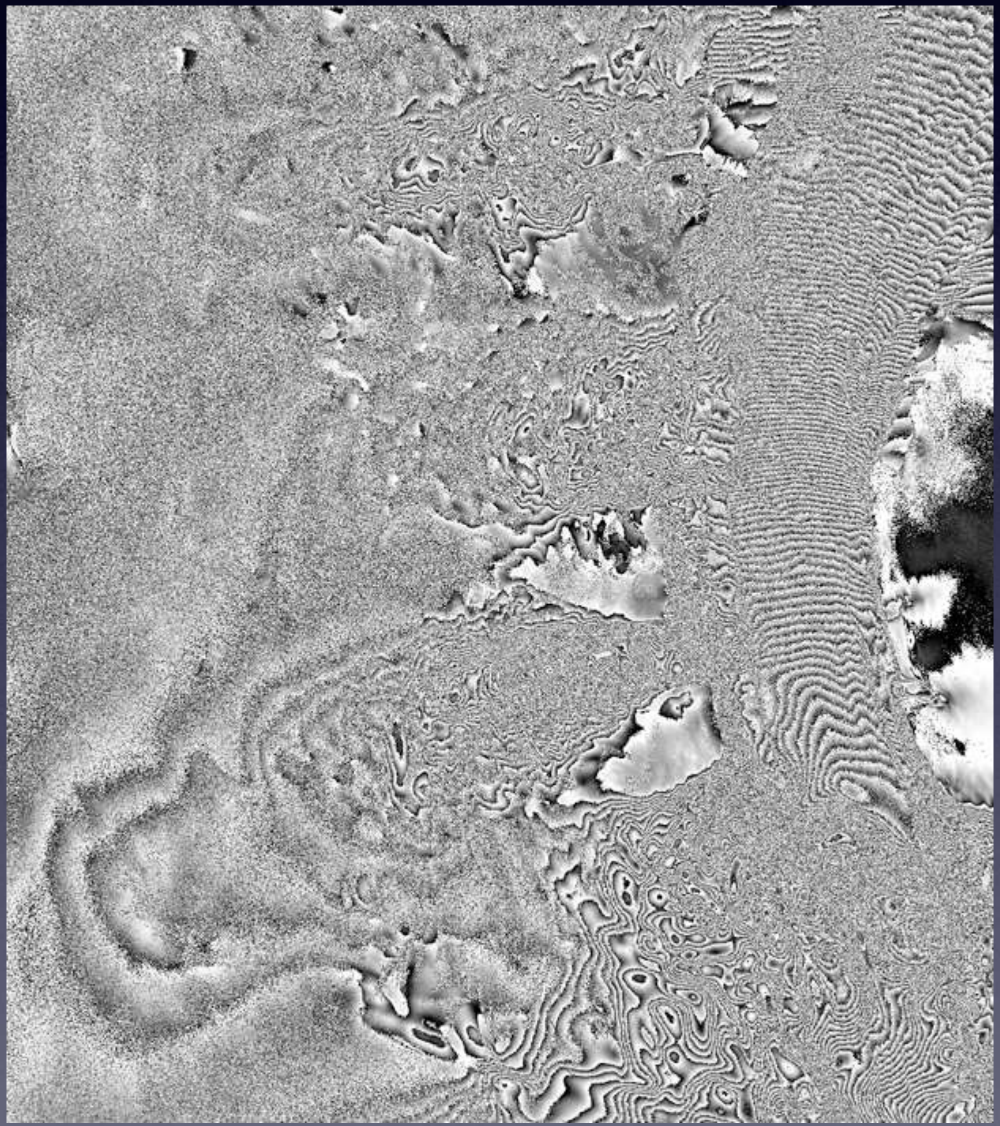
ERS Tandem interferogram
June 2-3,1996

Coherence tracking

- Coherence tracking allows optimizing the signal locally and obtain an estimation of local horizontal displacements along azimuth



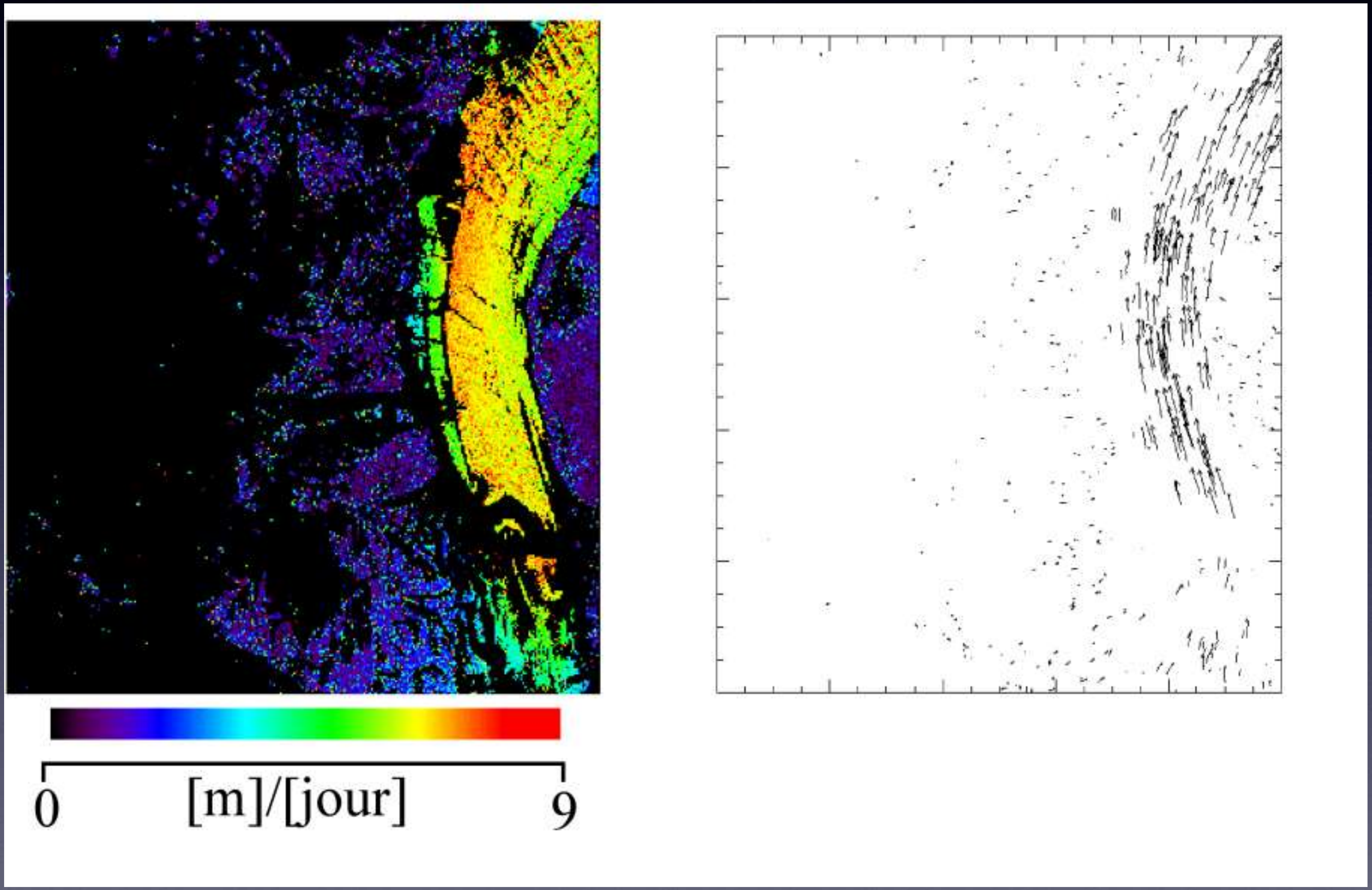
Interferometric coherence before and after tracking
ERS Tandem 2-3 juin 1996



ERS Tandem interferogram
June 2-3,1996

Coherence tracking

- Glacier monitoring : Shiraze glacier - Antarctica



Coherence tracking

SAR Polarimetry

- Quad Pol SAR systems:

  ➡ The signal is sent alternatively along two orthogonal polarizations

  ➡ The backscattered signal is detected along both polarizations

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

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

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

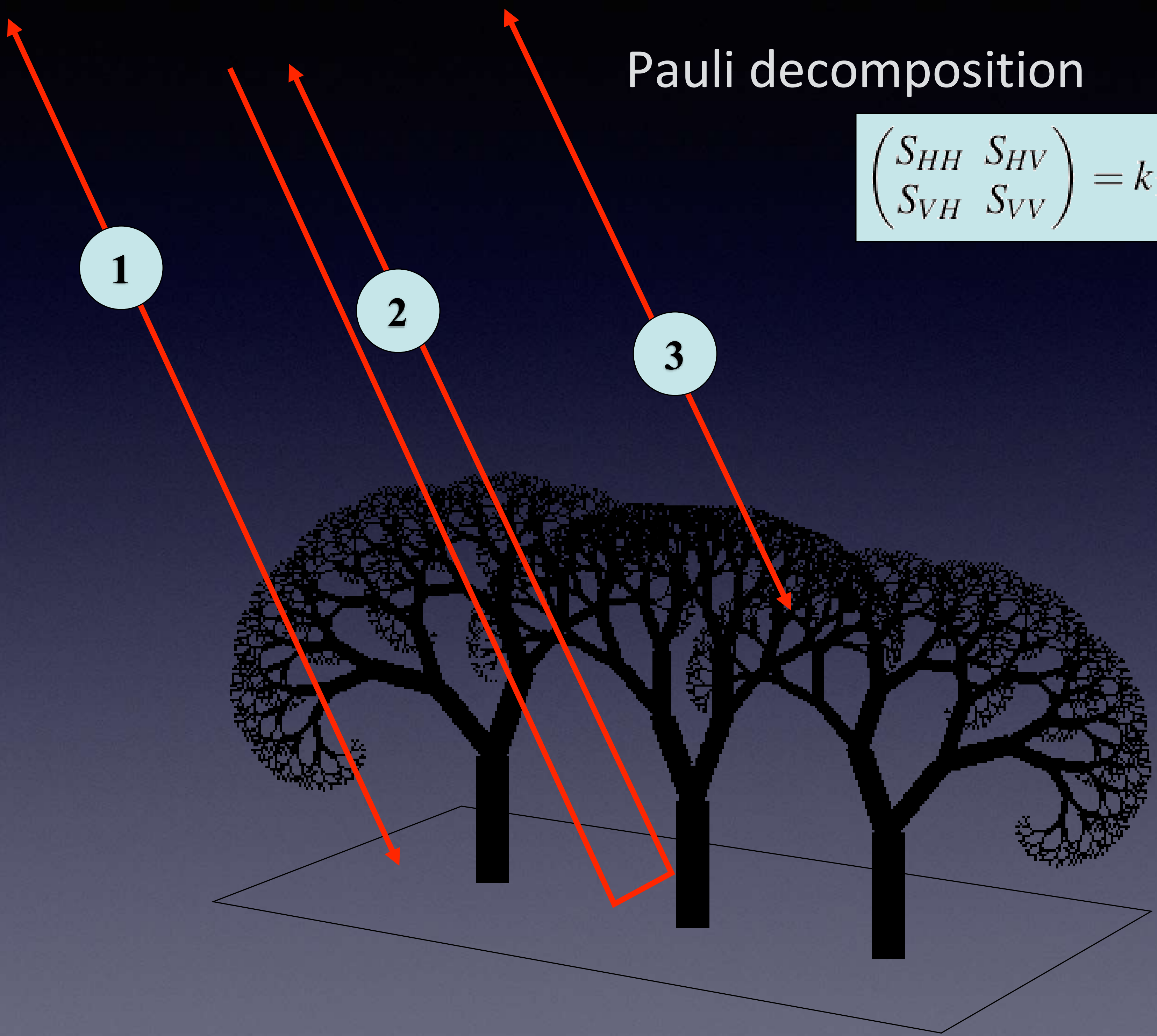
Polarization Synthesis

- Three polarimetric channels per acquisitions : HH, VV and XX (HV or VH)
- Sent and received polarizations can be synthesized
- Some combinations of transmit and received polarizations allow to reveal different elements of the scene

  ➪ Find and represent the most significant combination at a local basis

DLR ESAR Data:
Linear polarization synthesis

Polarimetric Decomposition



Pauli decomposition

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

1 Phase centers corresponding to the 1st scattering mechanism

2 Phase centers corresponding to the 2nd scattering mechanism

3 Phase centers corresponding to the 3rd scattering mechanism

Polarimetric SAR Interferometry

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

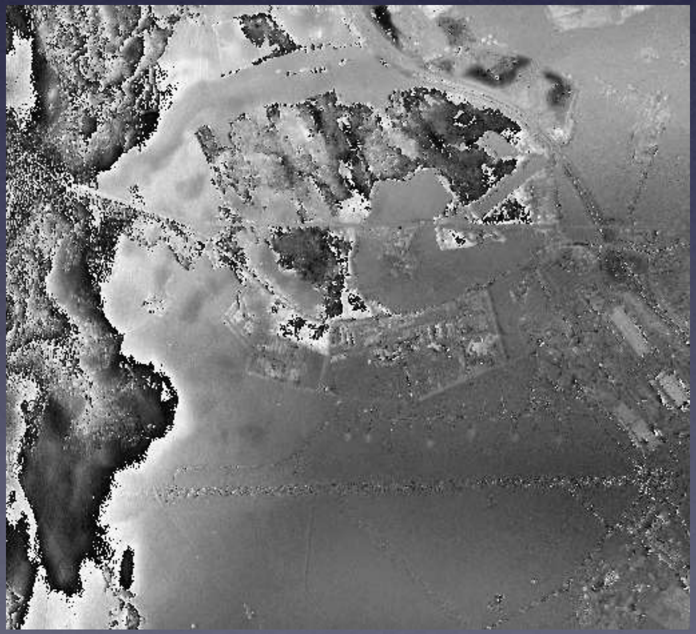
- Objective :

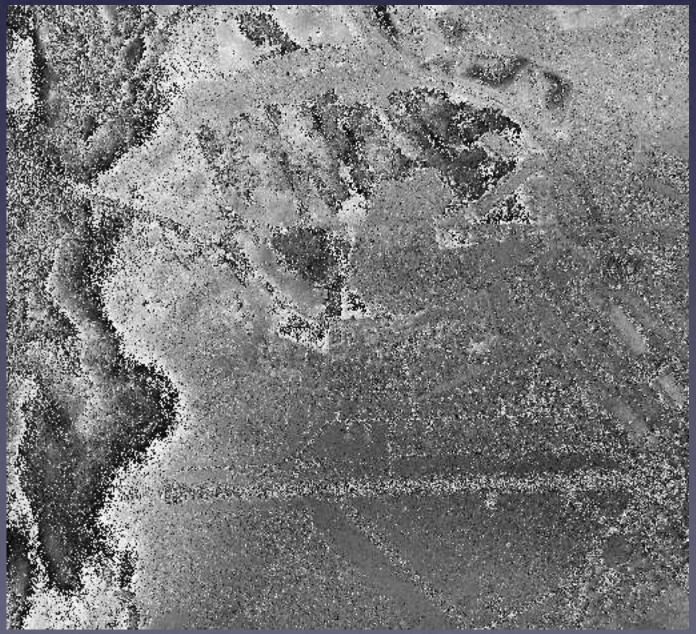
  ➪ Take advantage of polarization synthesis capabilities in order to find the combination of transmit and received polarizations for each acquisition allowing to optimize the interferometric signal locally.

Coherence optimization

Polarimetric SAR Interferometry

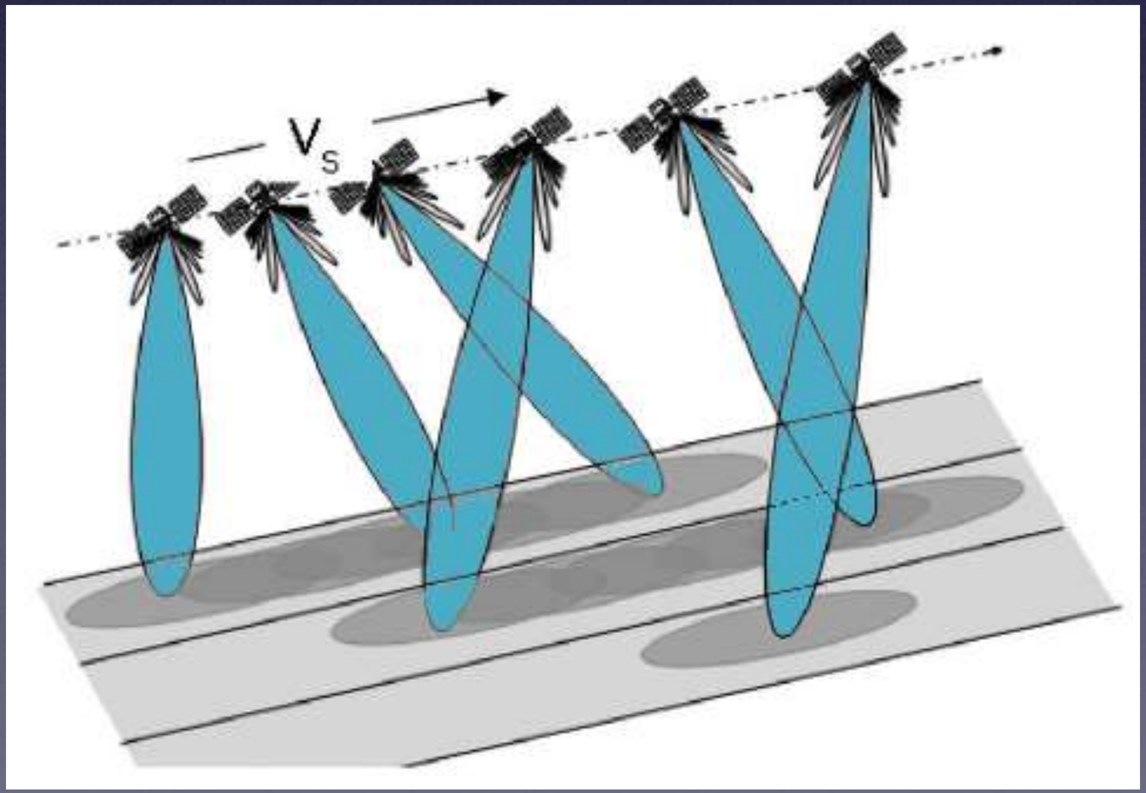
- Coherence optimization leads to :
  - ➪ Three optimized coherences corresponding each to an independant scattering mechanism
  - ➪ Three interferograms corresponding to the mean location of the underlying scattering mechanism center.





TOPSAR interferometry

- TOPSAR = Terrain Observation with Progressive Scans SAR
  - ➪ Antenna steering variation during burst acquisitions
  - ➪ Three sub-swath leading to a 250km coverage in IW mode



TOPSAR interferometry

- Due to variable steering during burst acquisition, corresponding burst of master and slave image of an InSAR pair require a perfect synchronization, i.e., a co-registration of 1/1000 of a pixel…

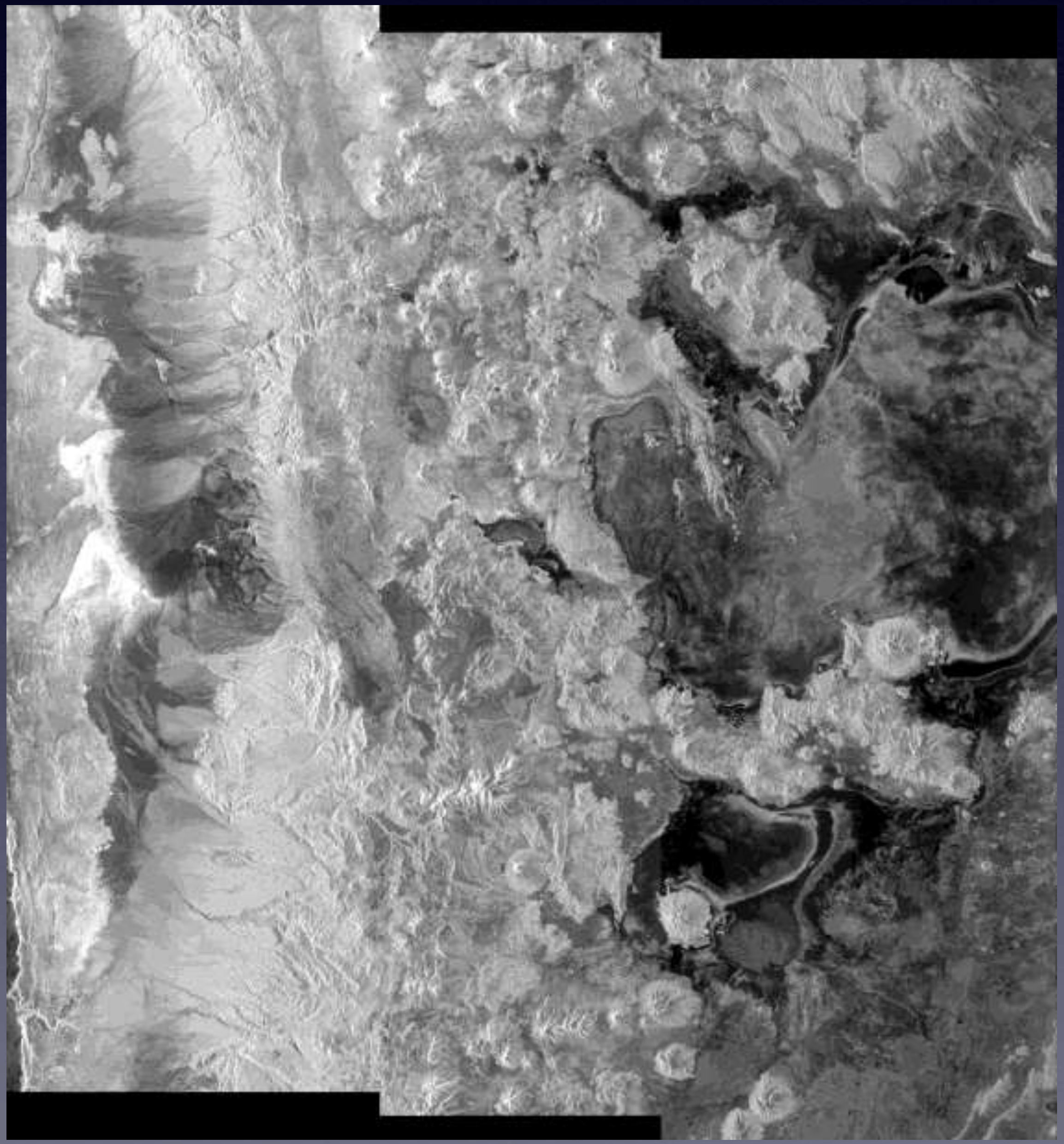
    ✓ Burst synchronization

    ✓ Burst co-registration using Extended Spectral Diversity approach

    ✓ Burst and sub-swath stitching

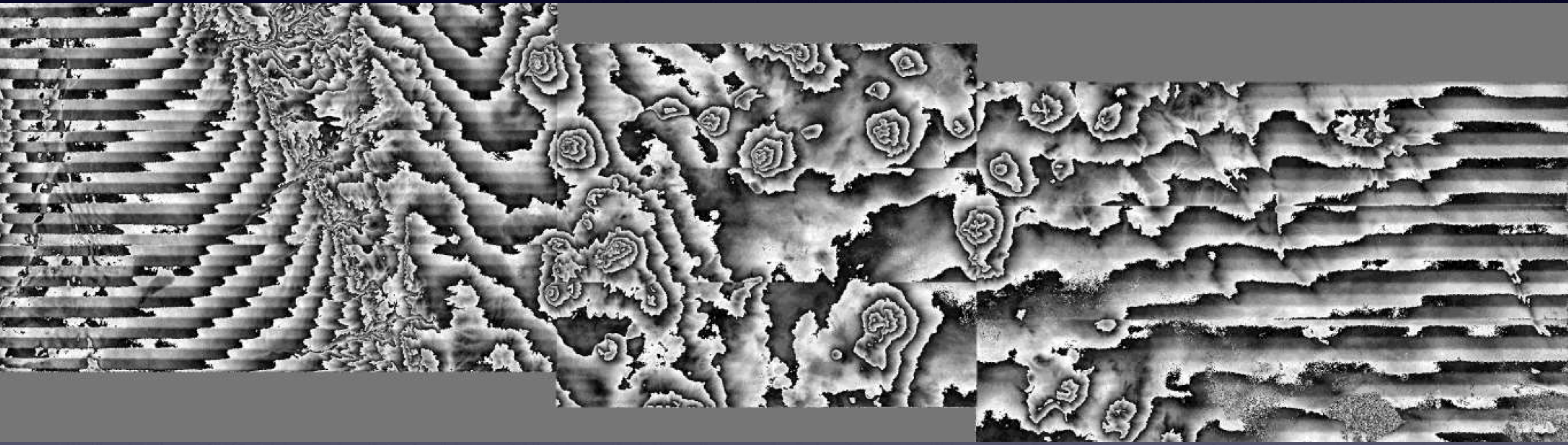
TOPSAR interferometry

- Example 1: Test site : Uyuni, Peru (Salt Flats).
  - ✓ Simulated data set provided by ESA based on RADARSAT 2 TOPSAR data



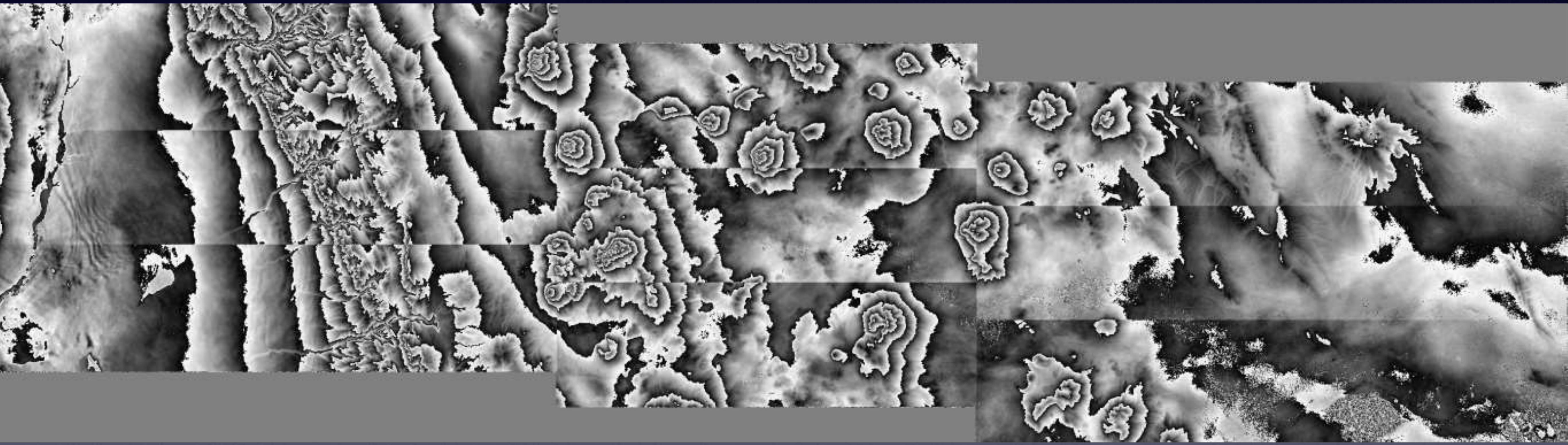
TOPSAR interferometry

- If simply stitching burst and using both image classically to perform InSAR processing, we get aliasing because of the phase ramp present due to antenna steering.



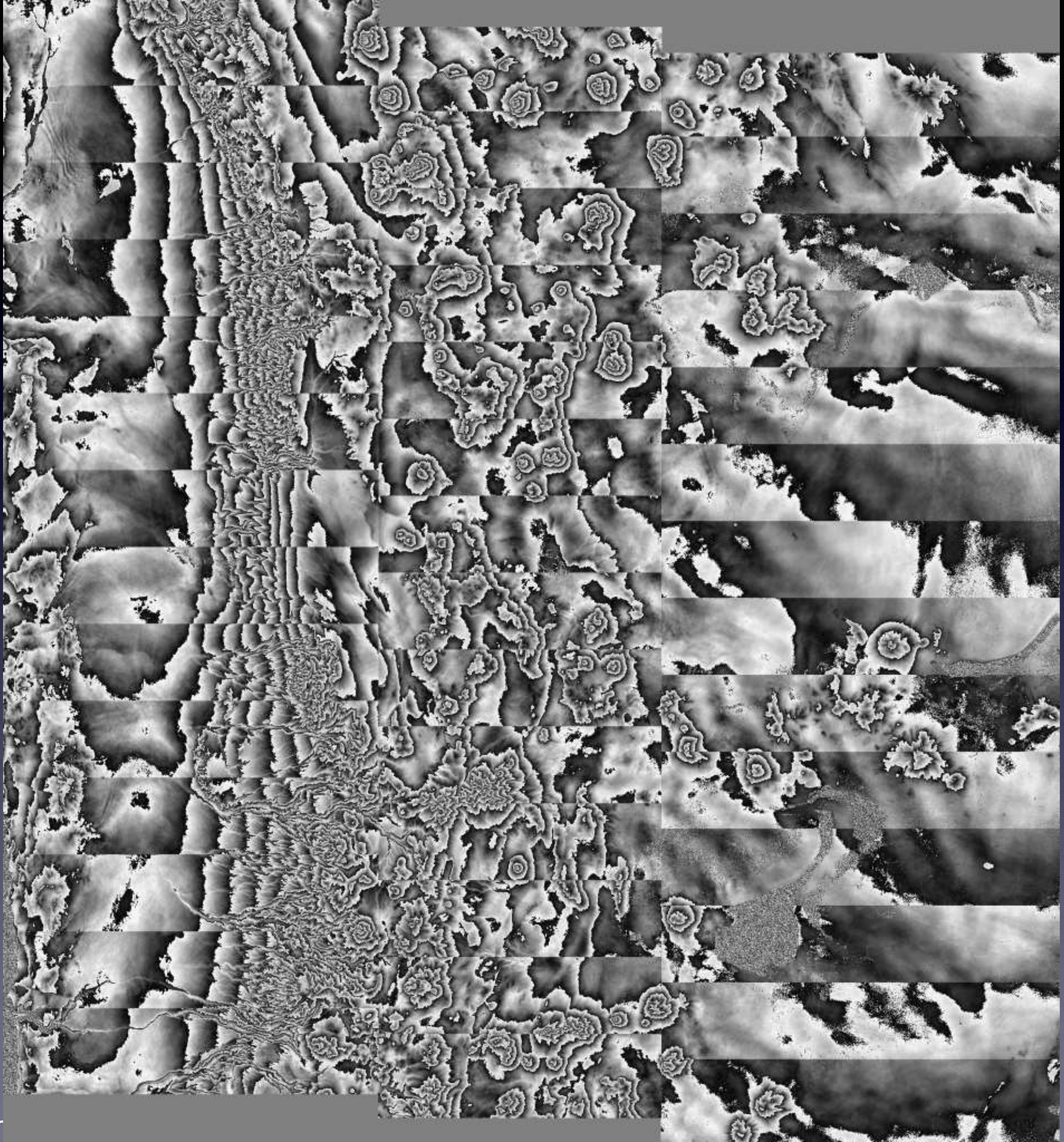
TOPSAR interferometry

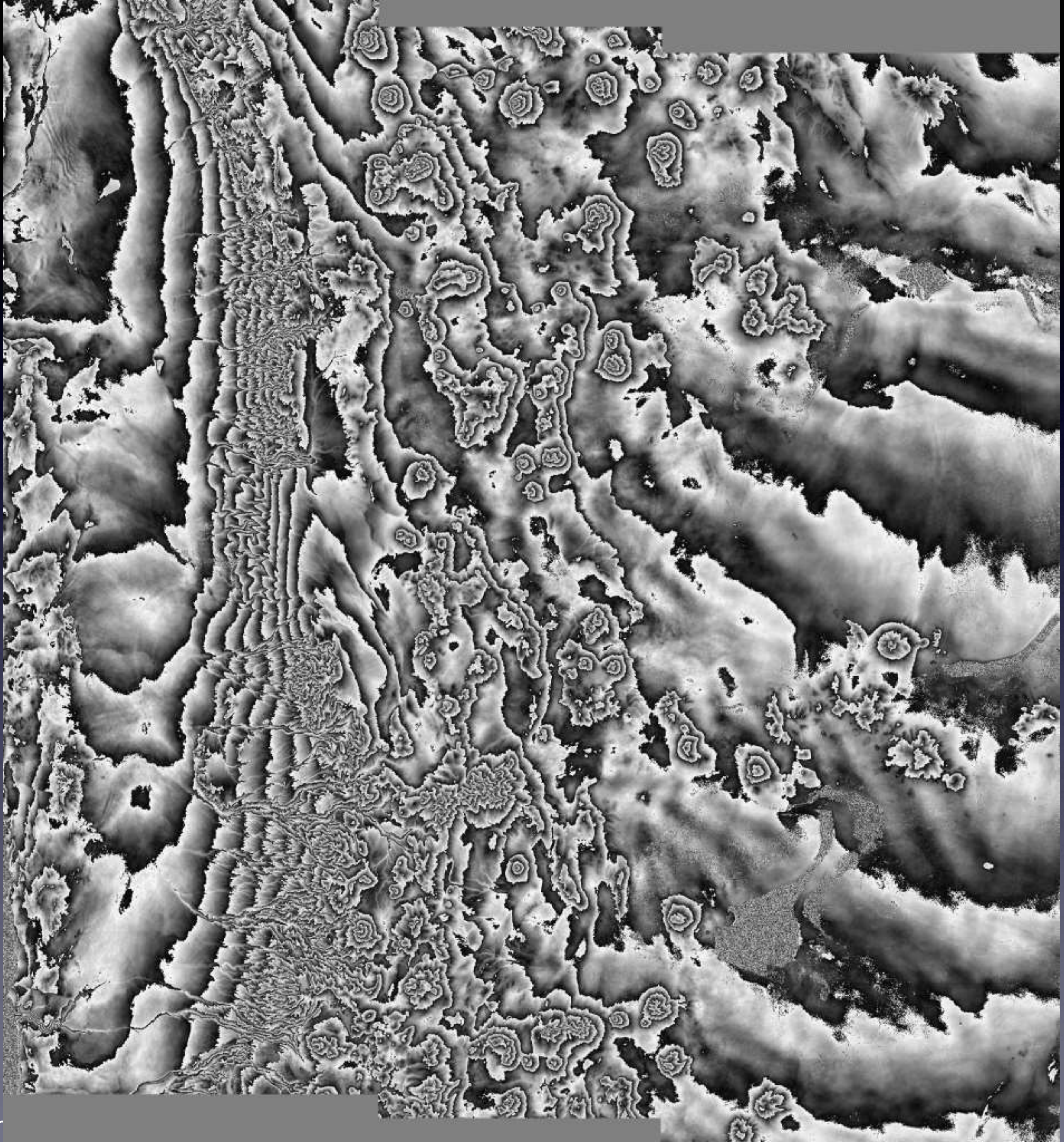
- If removing this phase ramp and if registration burst by burst classically we get:



TOPSAR interferometry

- If applying Extended Spectral Diversity between contiguous burst to reach the required co-registration accuracy, we get:





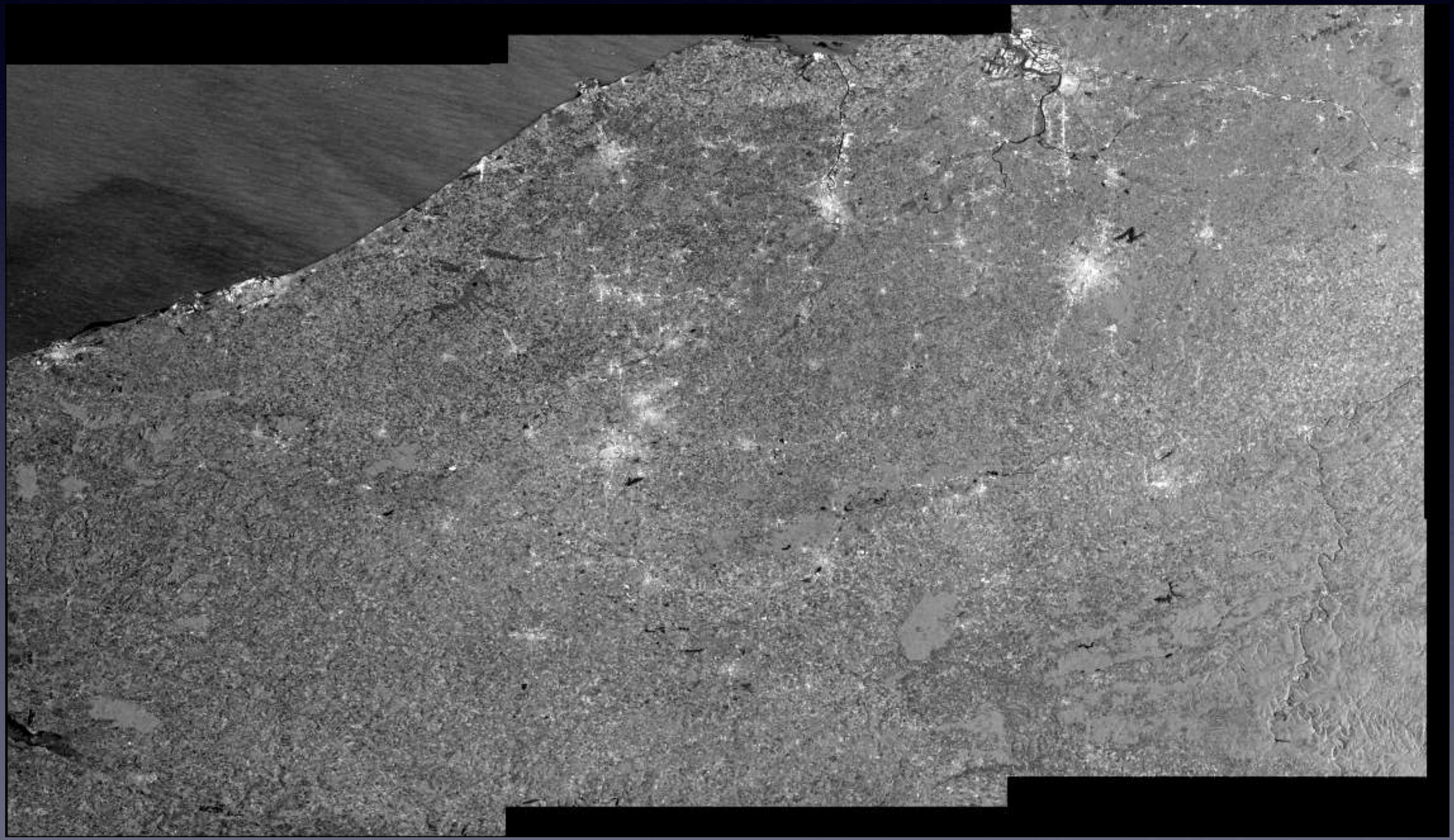
TOPSAR interferometry

- Example 2: Belgium, Sentinel 1 images - March 30, 2015 & April 23, 2015.

  ➪ The underground quarry of La Malogne collapsed on April 23.

TOPSAR interferometry

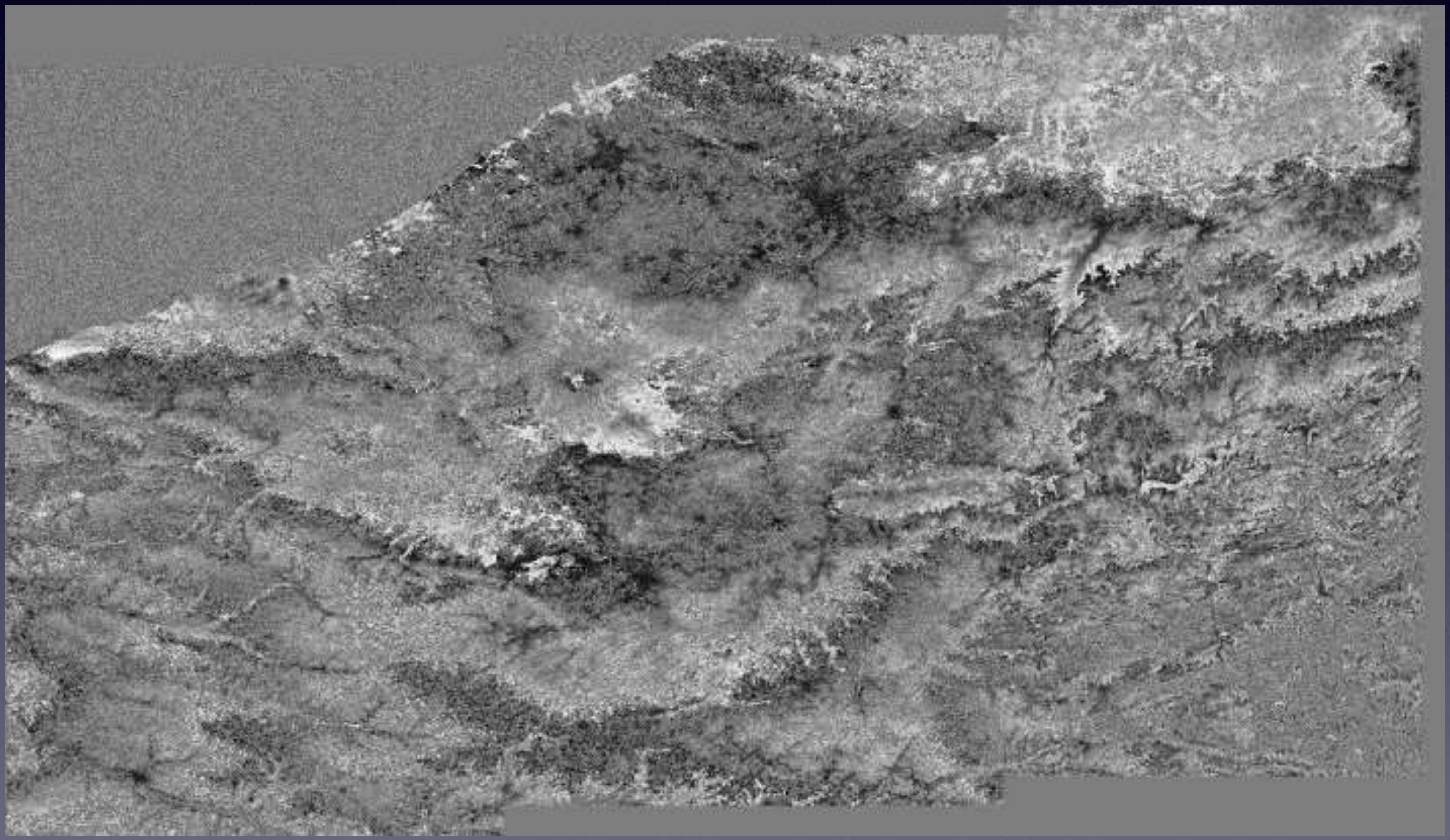
- Example 2: Belgium, Sentinel 1 images - March 30, 2015 & April 23, 2015.



Sentinel 1, March 30, 2015
Descending pass

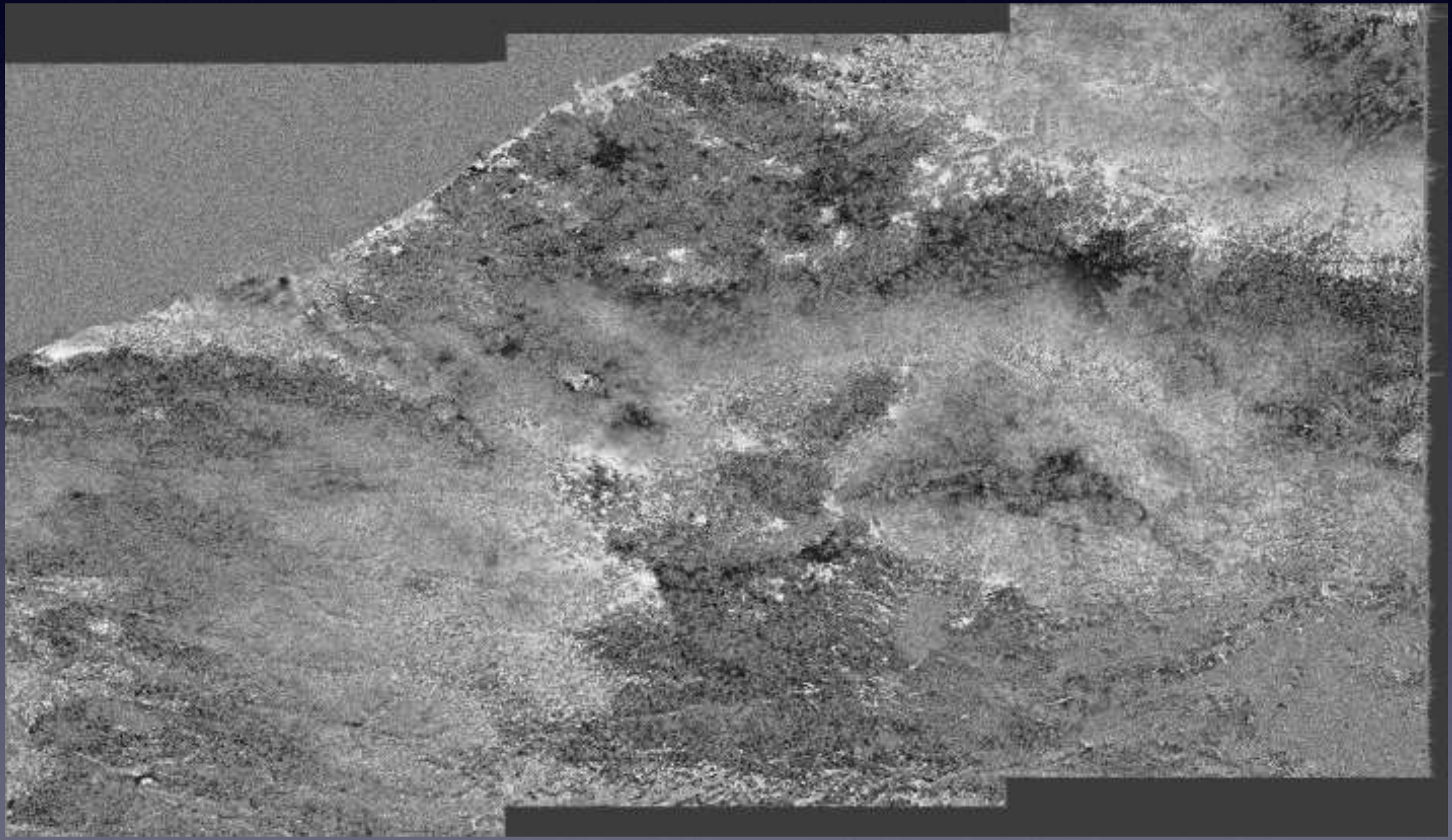
TOPSAR interferometry

- Interferogram



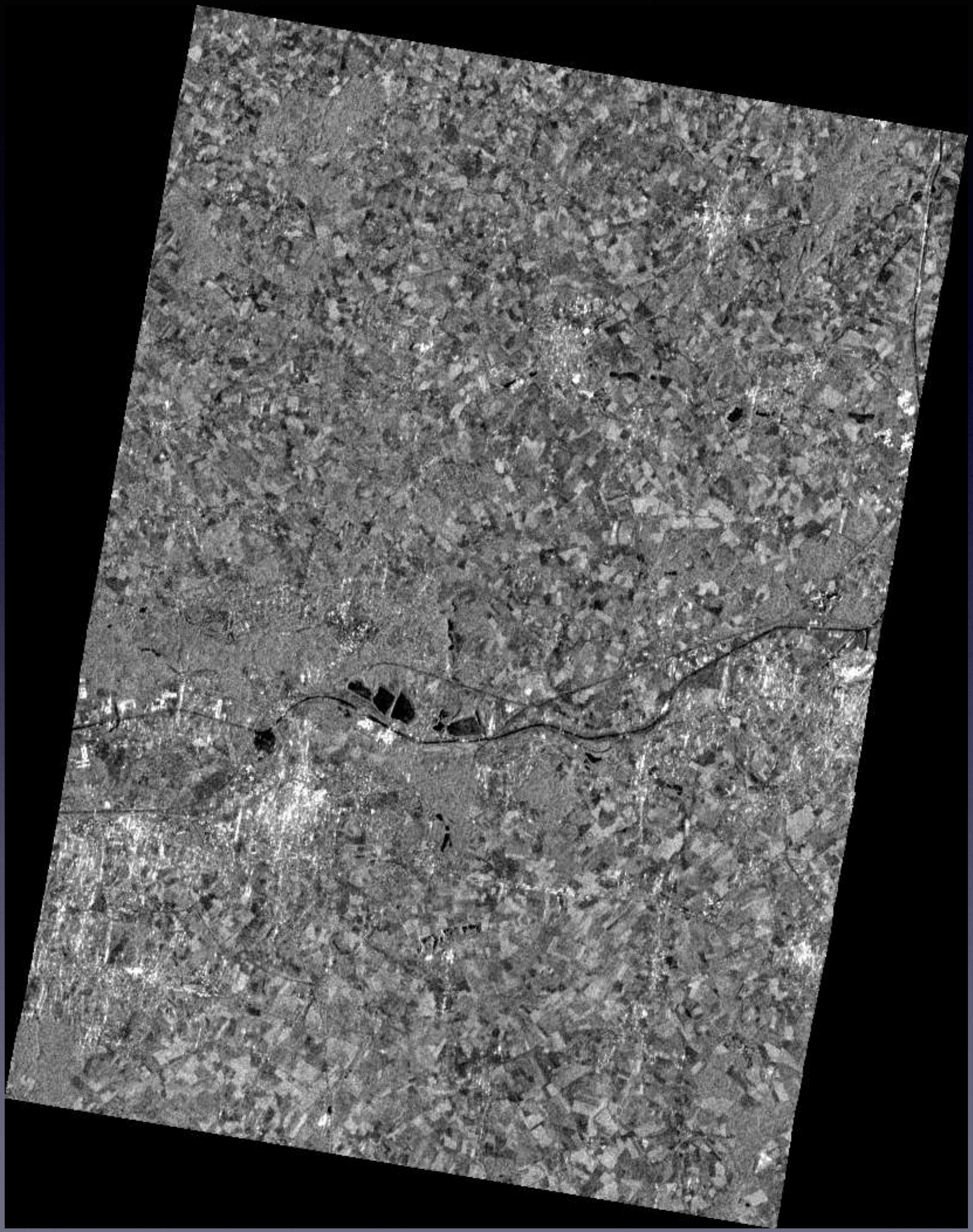
TOPSAR interferometry

- Differential interferomety
  - ➪ Topography was removed using SRTM 1”x1” reference DEM



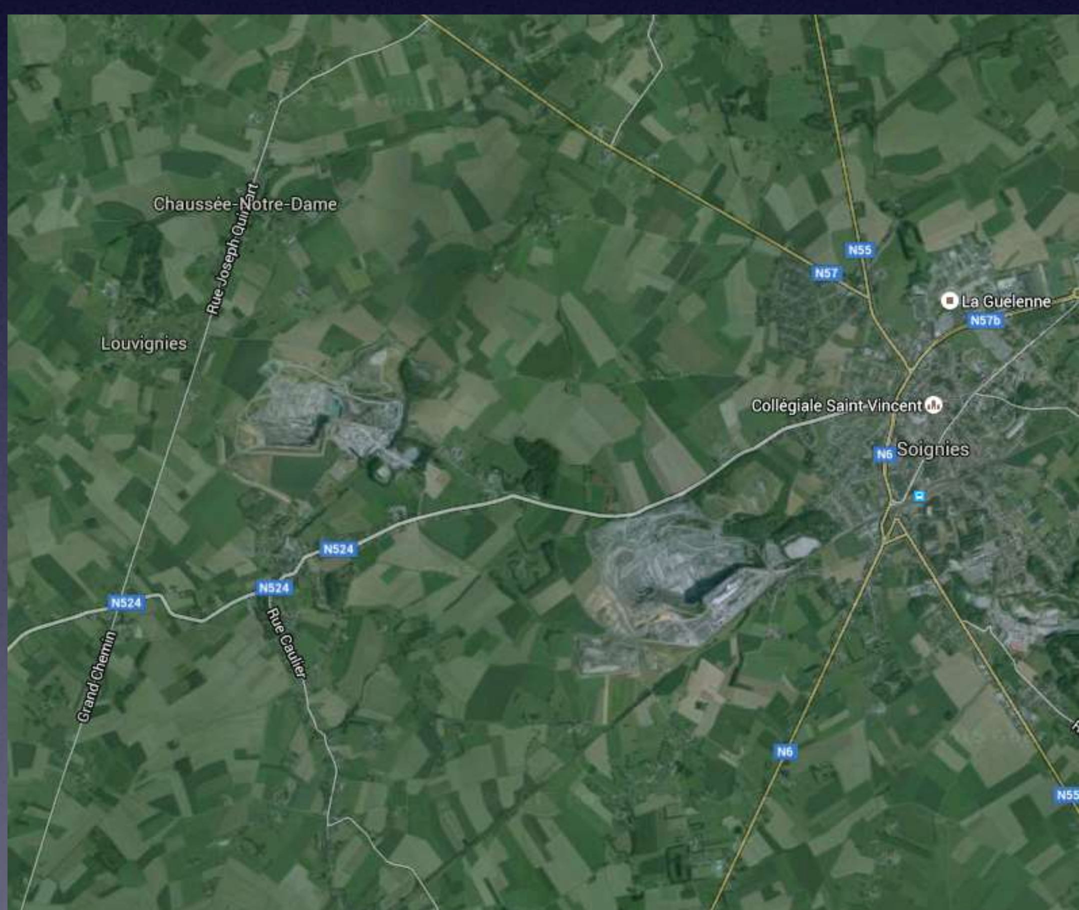
TOPSAR interferometry

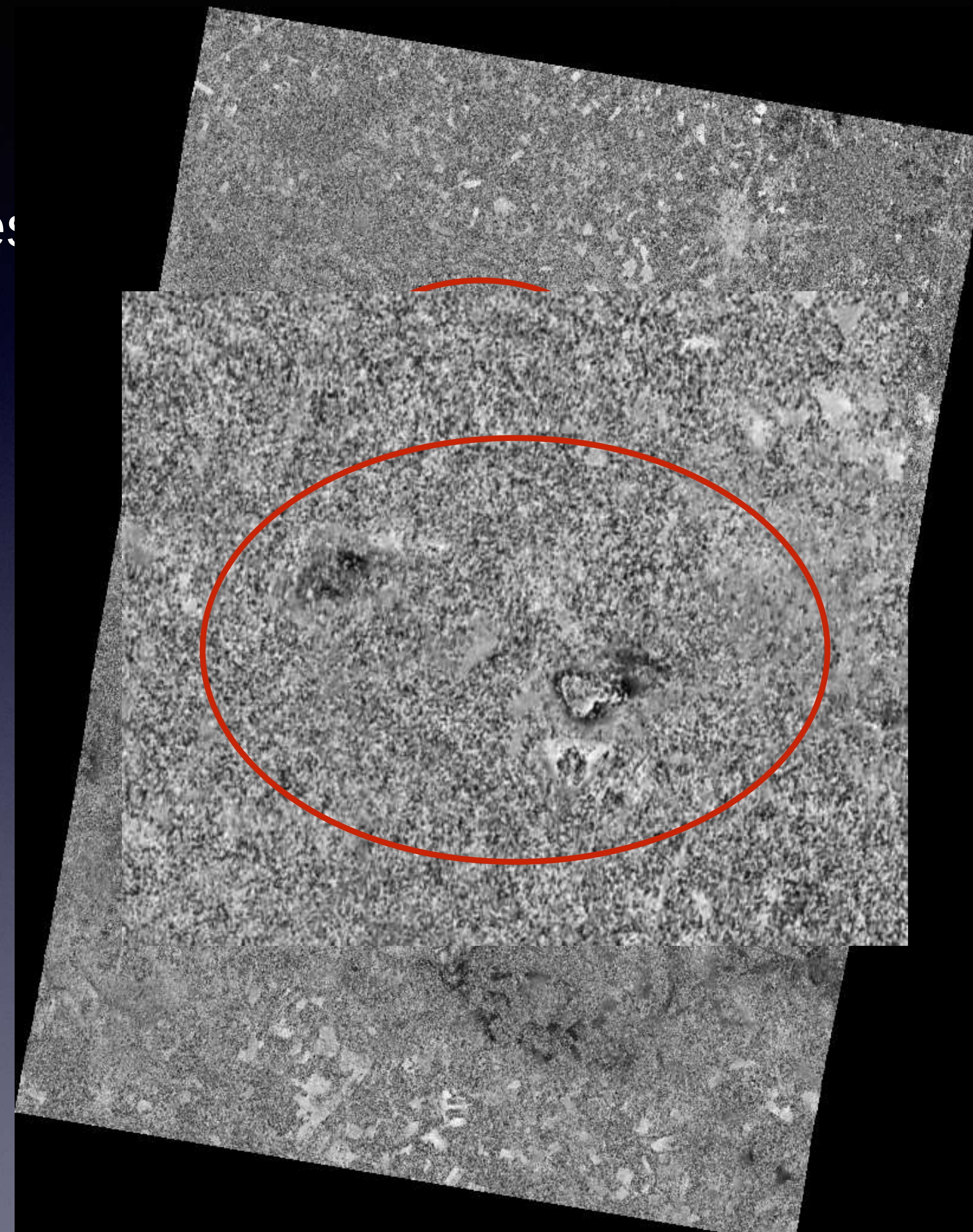
- La Malogne:
  - ➪ Zoom of 5x5 of both master and slave S1 images after « ultra fine registration »
    - 0.8 x 2.78 m ground range - azimuth sampling
  - ➪ InSAR computation using reduction factors of 12 x 4
    - 9.4 x 11.12 m round range - azimuth sampling
  - ➪ Geoprojection in UTM on a 5x5m grid



TOPSAR interferometry

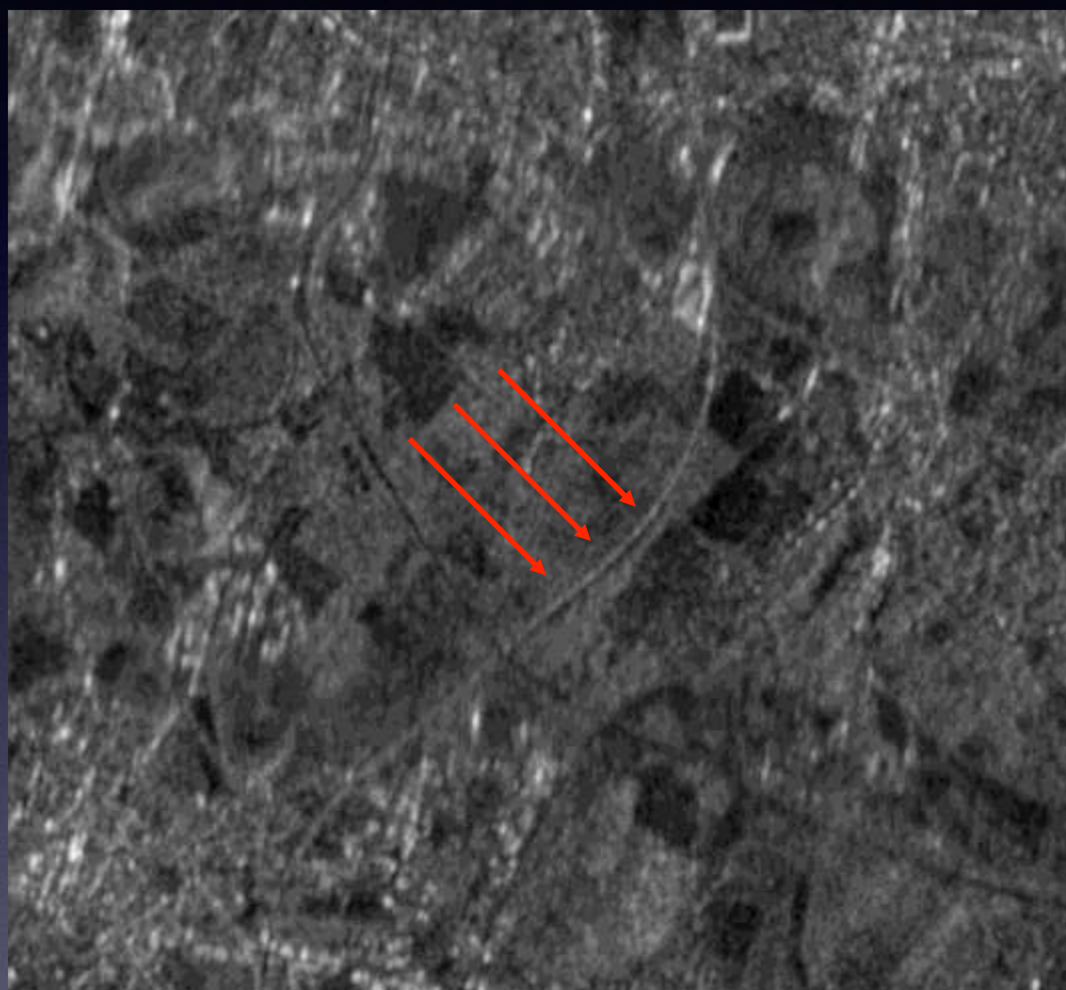
- Presence of some fringes located on open-pit quarries





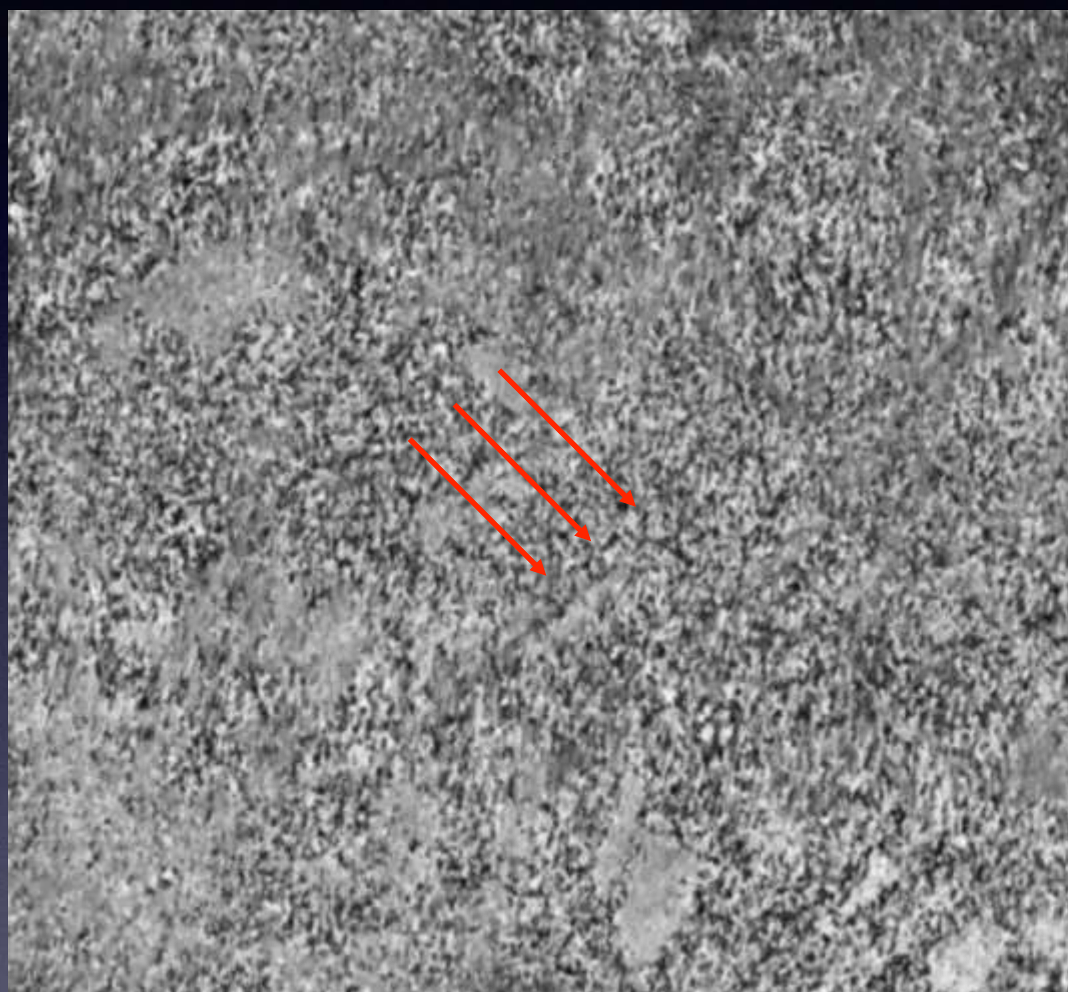
TOPSAR interferometry

- La Malogne



TOPSAR interferometry

- La Malogne



Conclusions

- 26 years of SAR/InSAR developments in Belgium

  ➪ A lot of tools were and are developed:

  ✓ CSL InSAR suite:

  - InSAR/DInSAR/PolSAR/PolInSAR/SBInSAR
  - Coherence/coherence tracking
  - Geo-projection tools

  ➪ Numerous application fields were and are addressed

  ➪ A valuable expertise exists in Belgium