Tour des méthodes de mesure d'élévation par imagerie SAR : de la radargrammétrie à la tomographie

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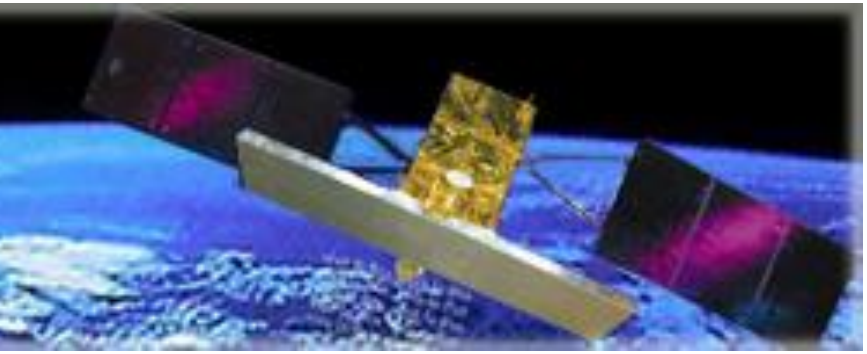
Télécom ParisTech – LTCI

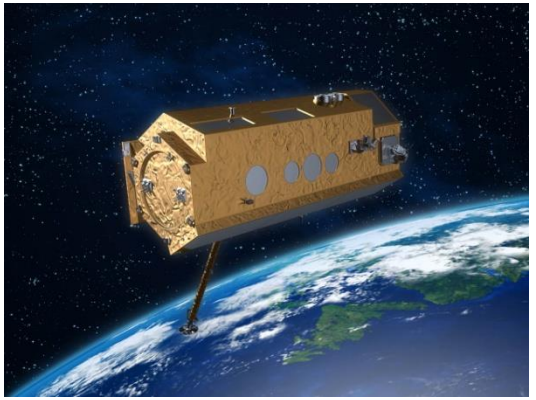
Journée thématique du PNTS –
Observation et modélisation de structures 3D des enveloppes superficielles
16 mars 2017

Context

- **Golden age of SAR sensors: improved spatial, polarimetric and temporal resolutions**

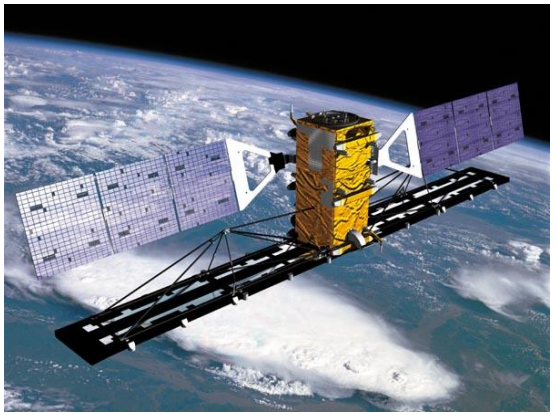


CSK



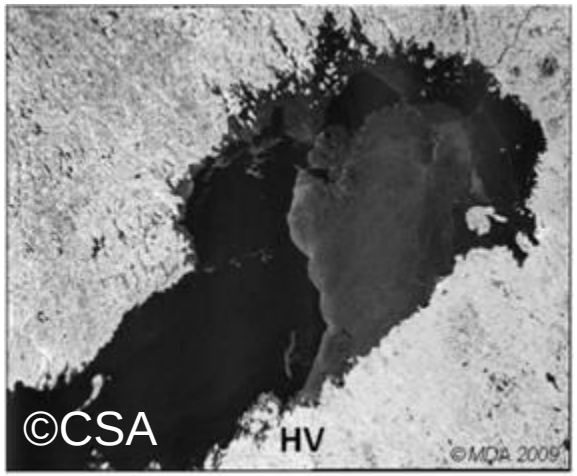
TerraSAR-X

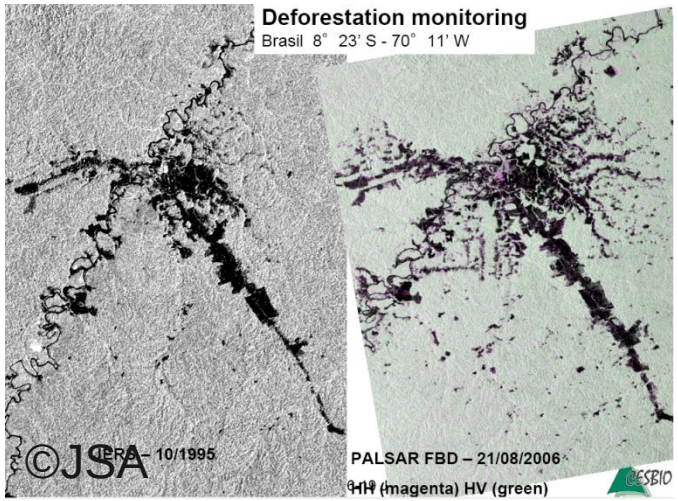
Sentinel I

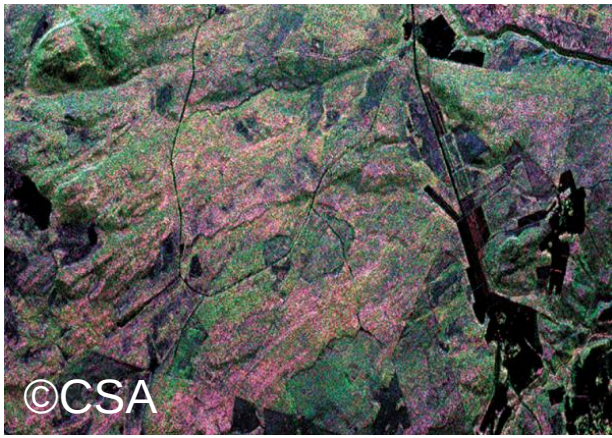


RadarSAT-2

Context


©CSA
HV
©MDA 2009


Deforestation monitoring
Brasil 8° 23' S - 70° 11' W
©JSA
PALSAR FBD – 21/08/2006
HH (magenta) HV (green)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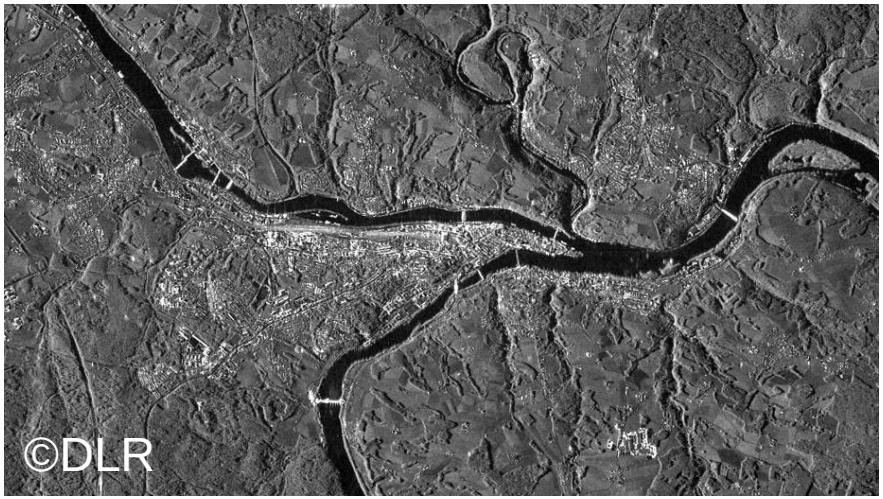
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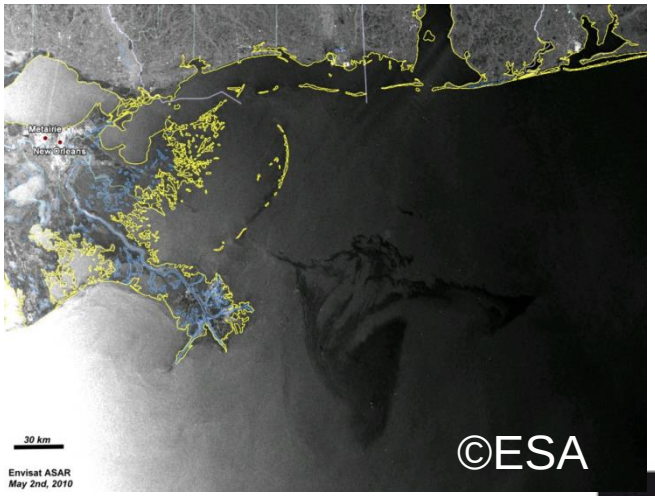
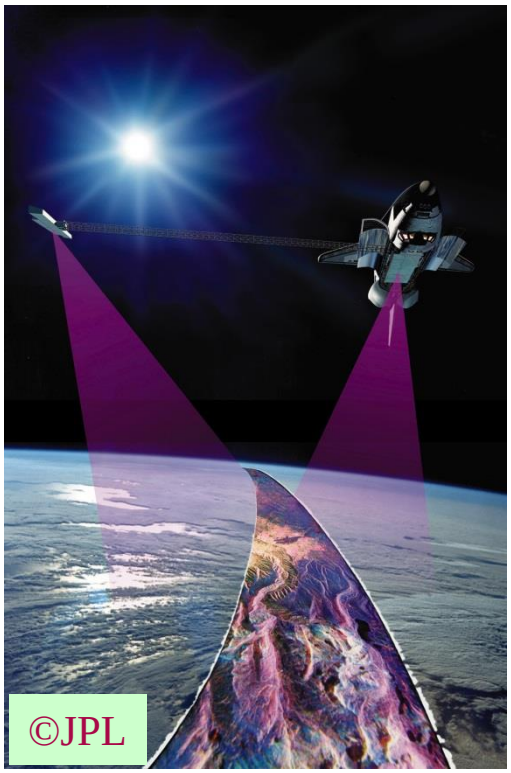
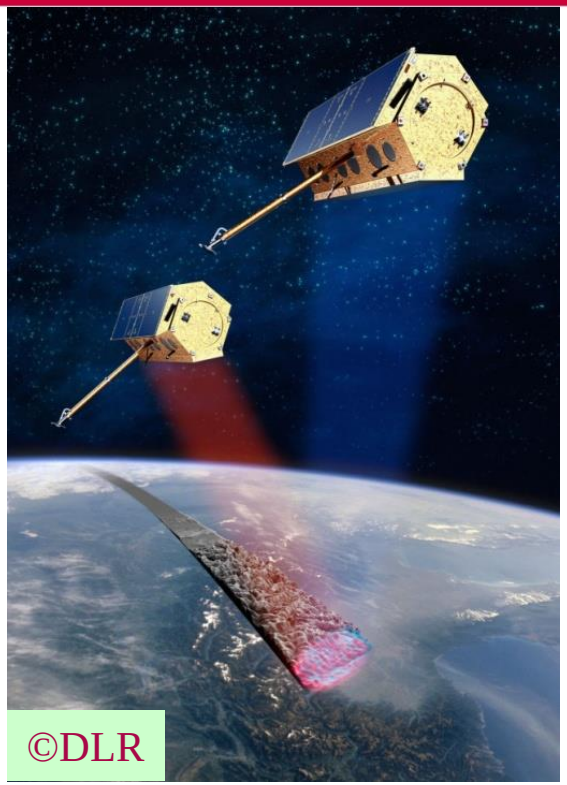
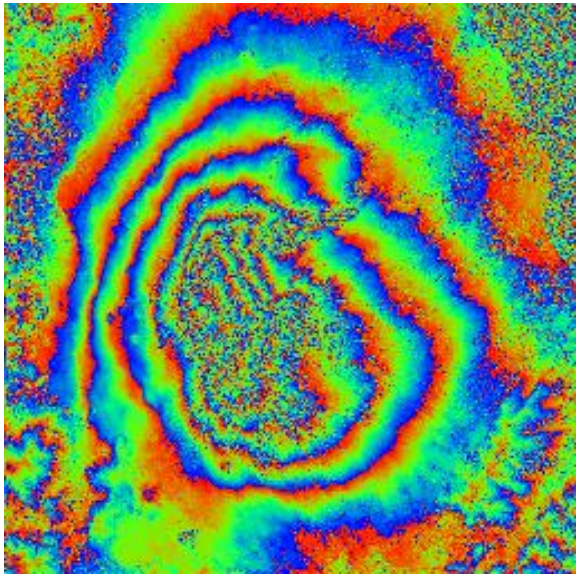
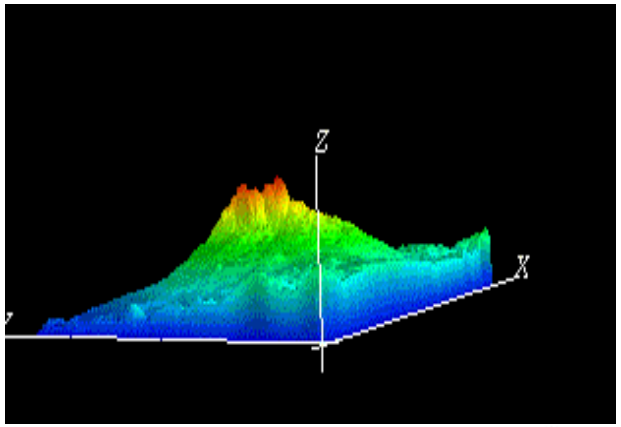

30 km
Envisat ASAR
May 2nd, 2010
©ESA

Context









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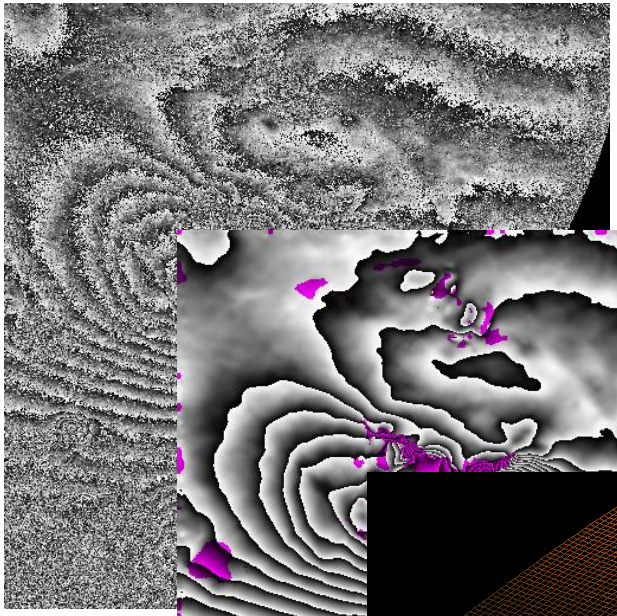
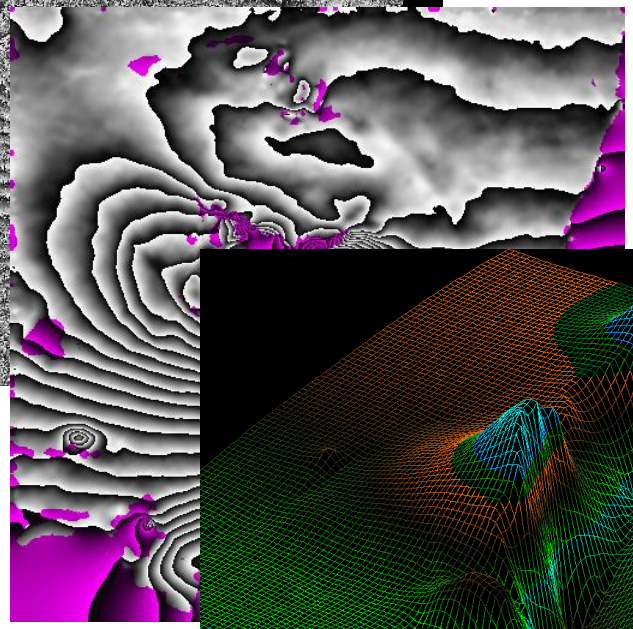
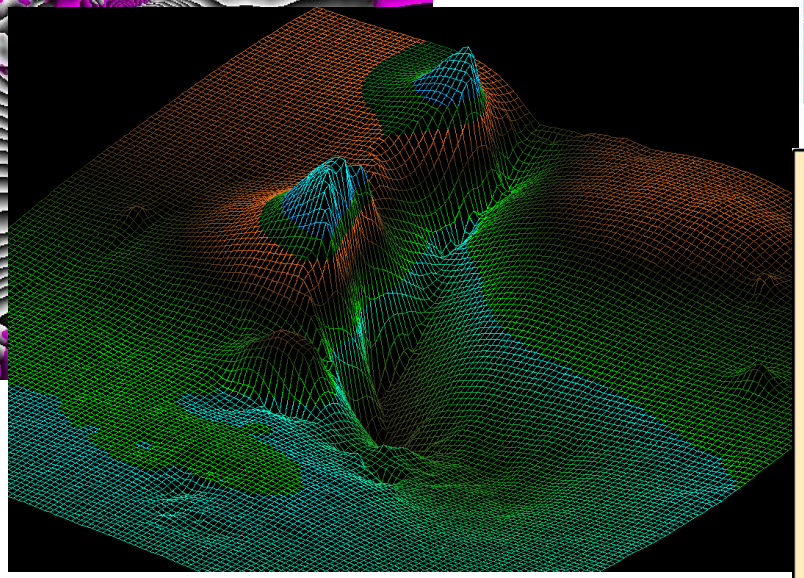
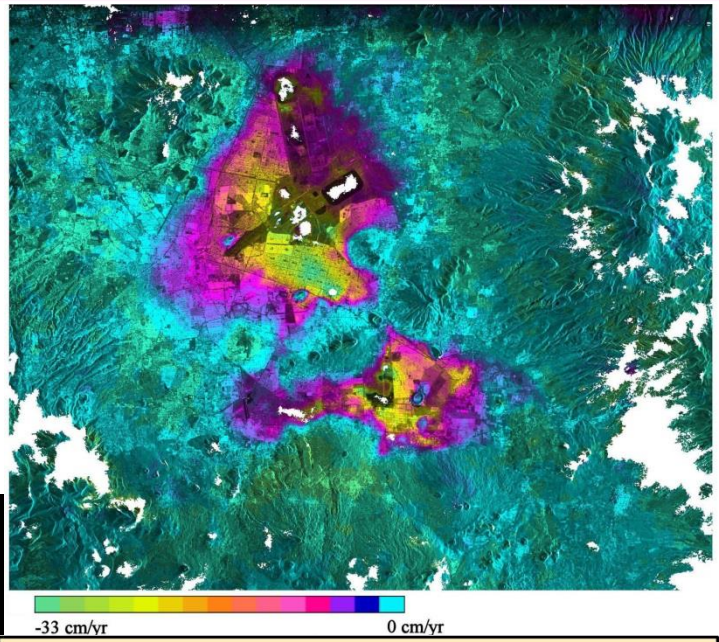
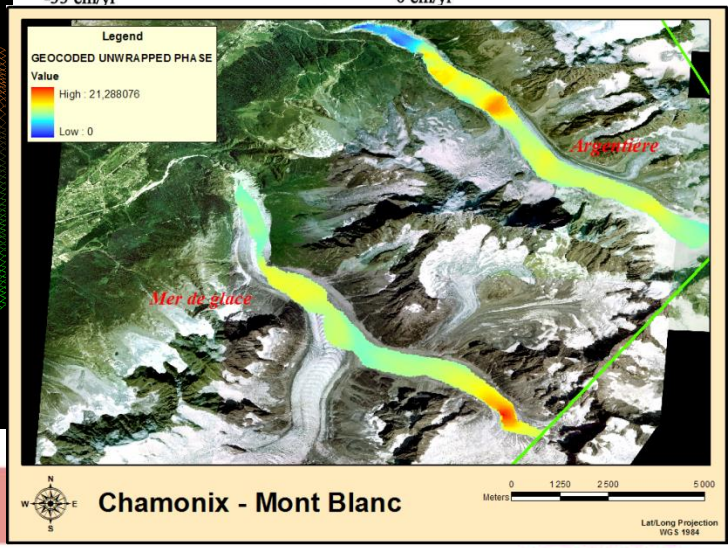
Context








-33 cm/yr
0 cm/yr

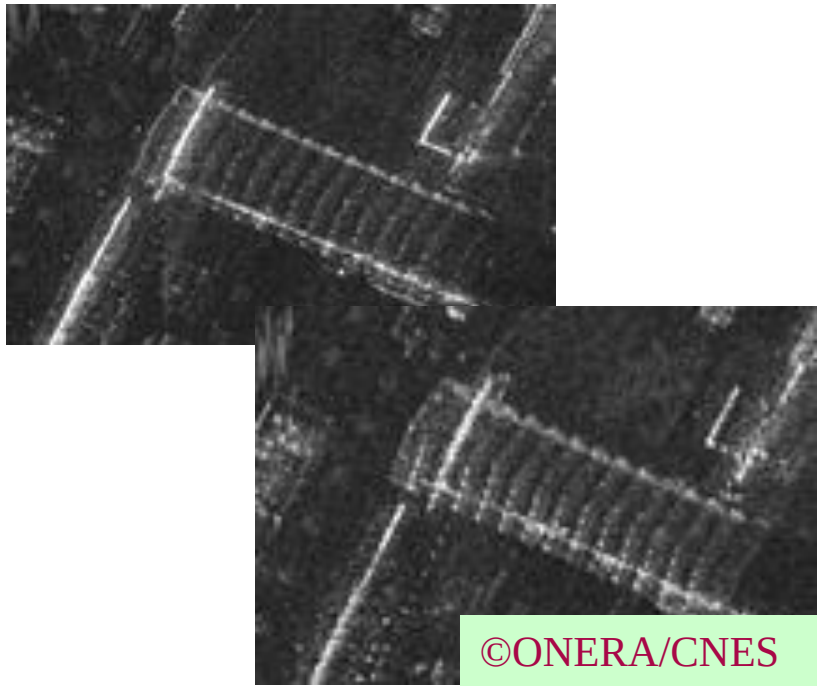

Legend
GEOCODED UNWRAPPED PHASE
Value
High : 21,288076
Low : 0
Argentière
Mer de glace
N
W
E
S
0
1250
2500
5000
Meters
Chamonix - Mont Blanc
Lat/Long Projection
WGS 1984

Overview

- **How recovering elevation information ?**
  - Radargrammetry
  - Interferometry
  - Tomography
- **Focus on urban areas**
  - Geometric limits
  - Use of external information
- **How helping with image processing ?**
  - Data and prior models
  - Fusion of information
- **Conclusion**

Data acquisition

- **SAR signal: complex signal**
  - Amplitude: backscattering coefficient of the scene
  - Phase: linked to the geometry



- **Elevation: *1*, 2 or more images**
  - *Radarclinometry (amplitude)*
  - Stereoscopy (amplitude)
  - Interferometry (phase)
  - Tomography (n-D phase)

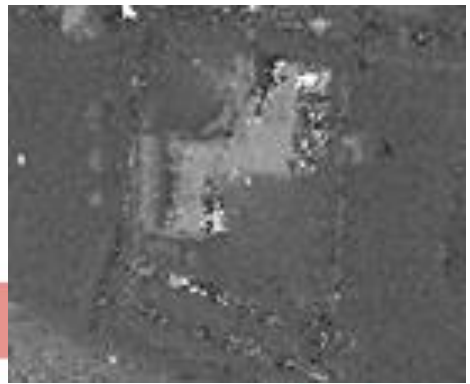
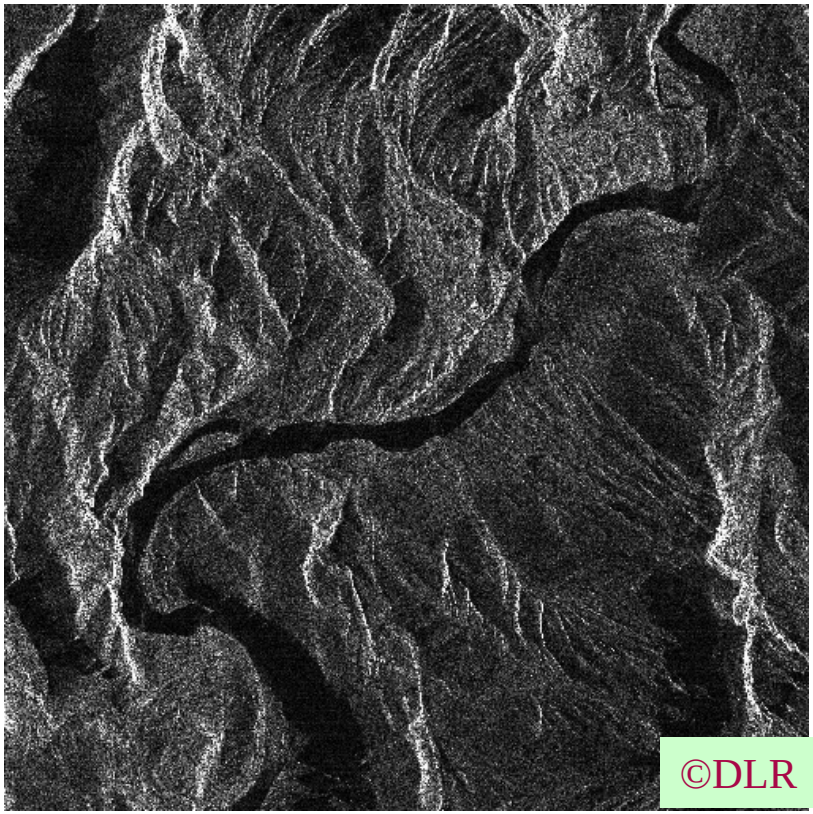
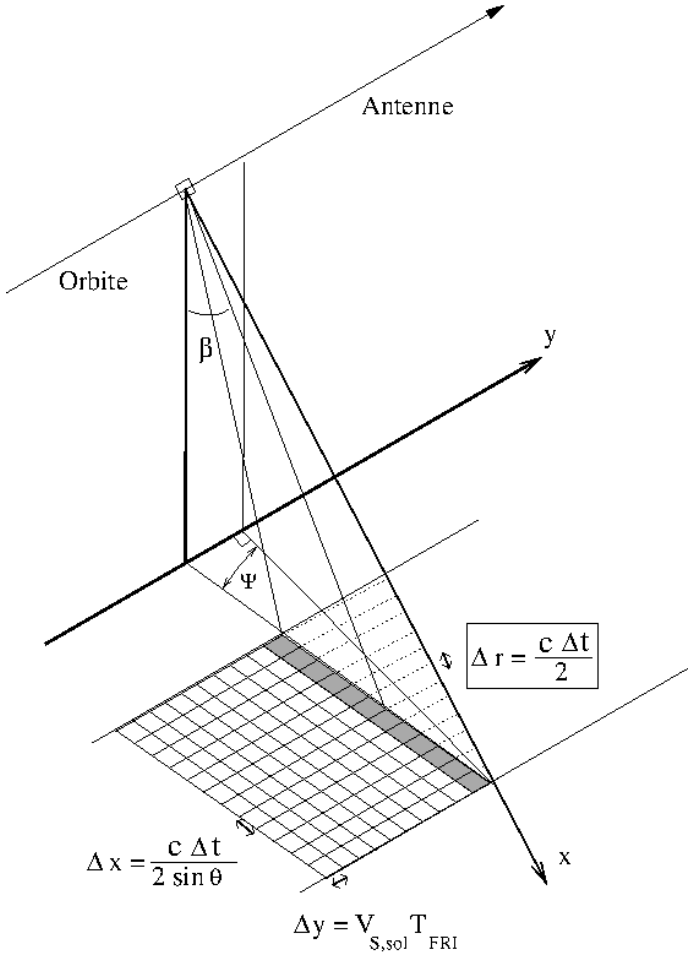


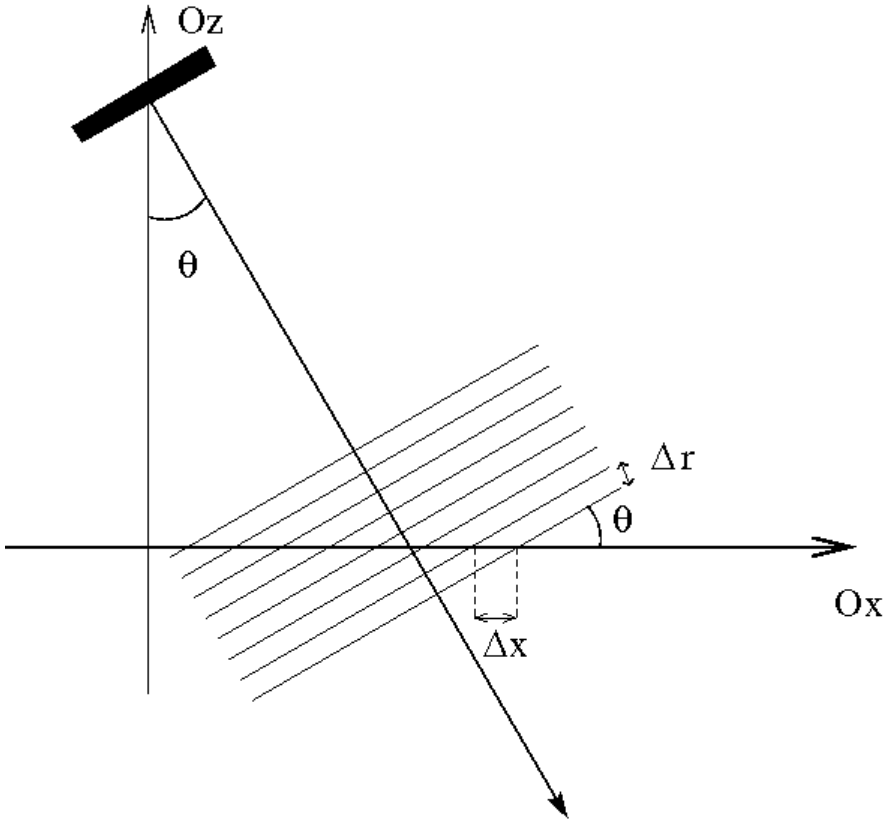
Image Terrasar-X



- Visée latérale : effets liés au relief
- Imagerie cohérente : chatoiement
- Réponse (RCS) pour des longueurs d'onde centimétriques

Construction d'une image Radar

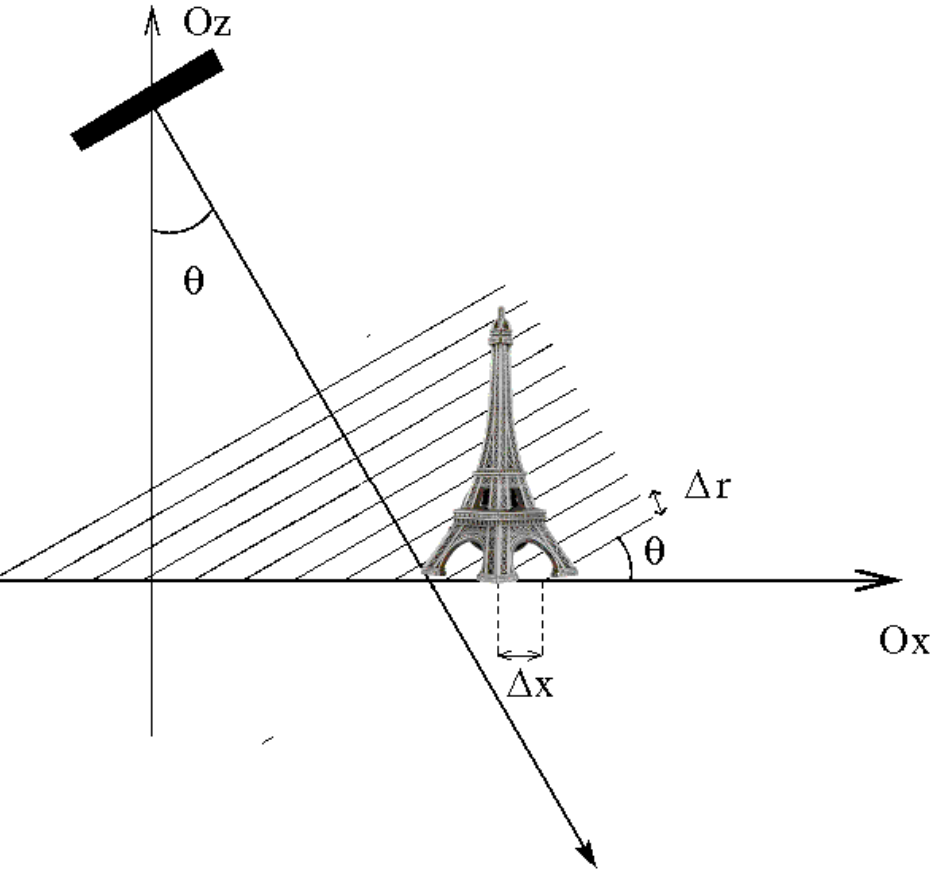


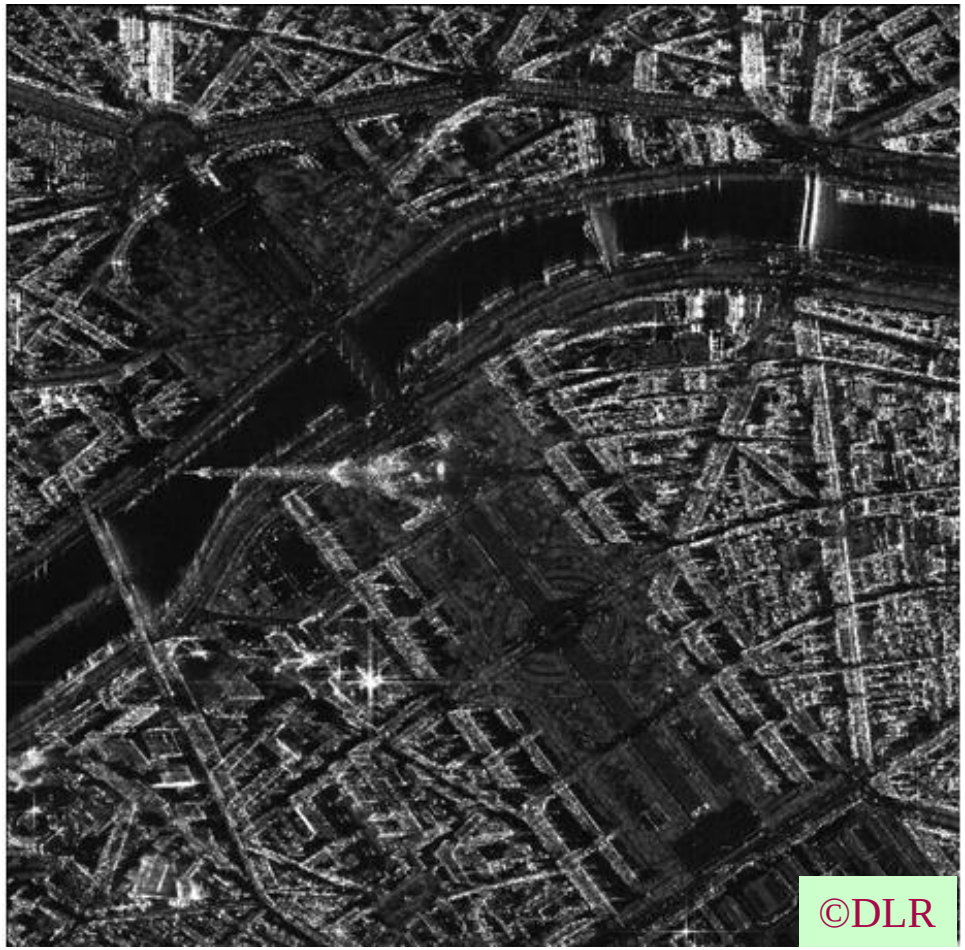


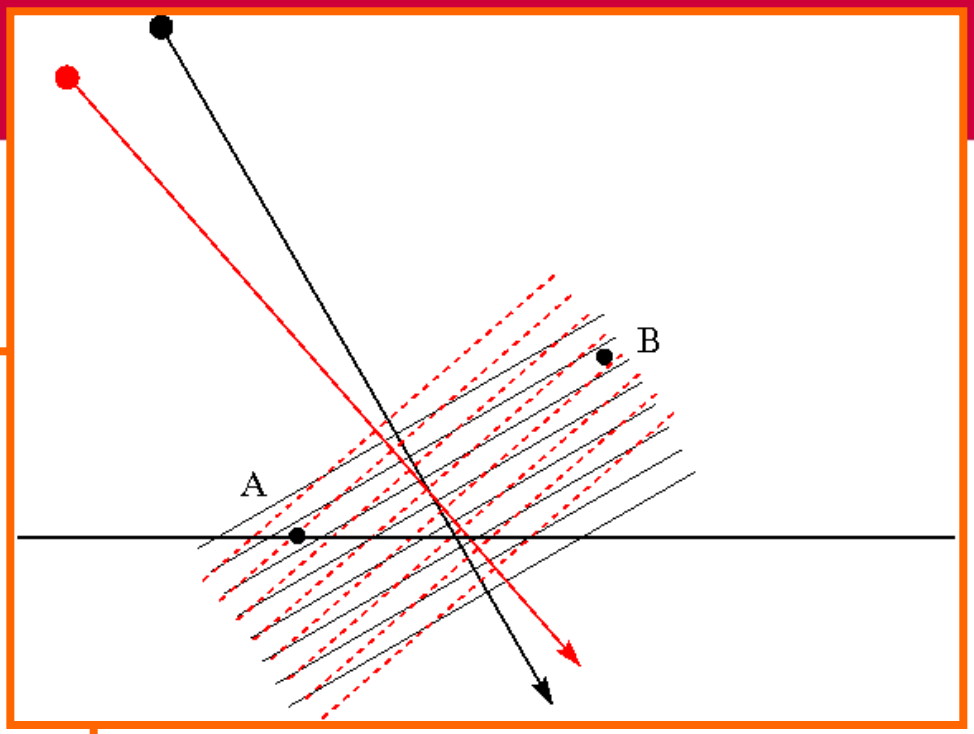
Tout est géométrie !!

Acquisition SAR

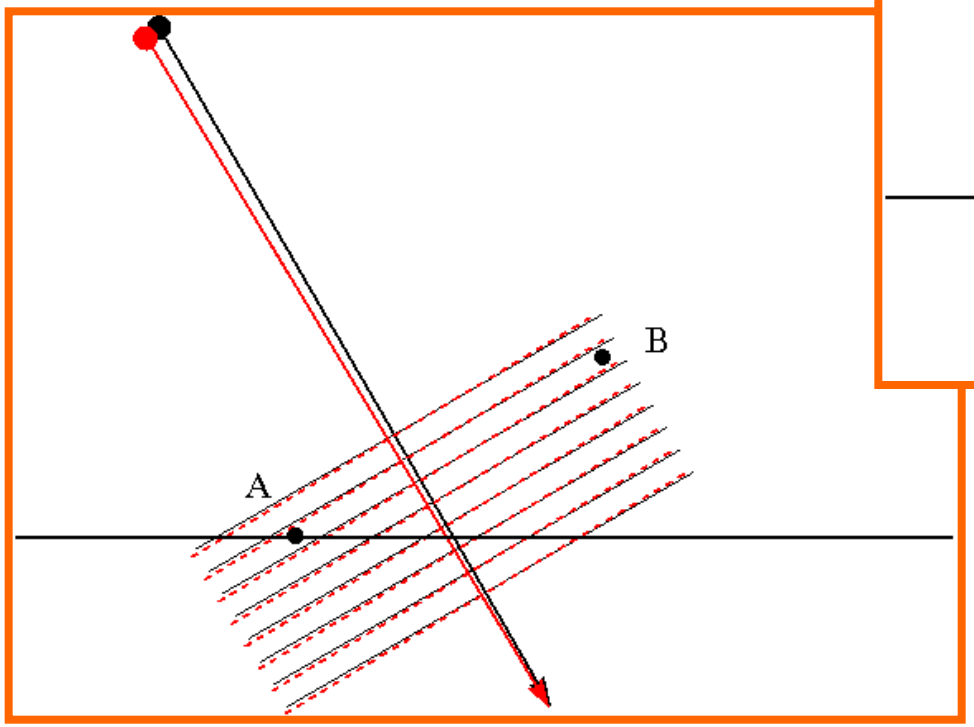
- **Terrasar-X, θ~30°**





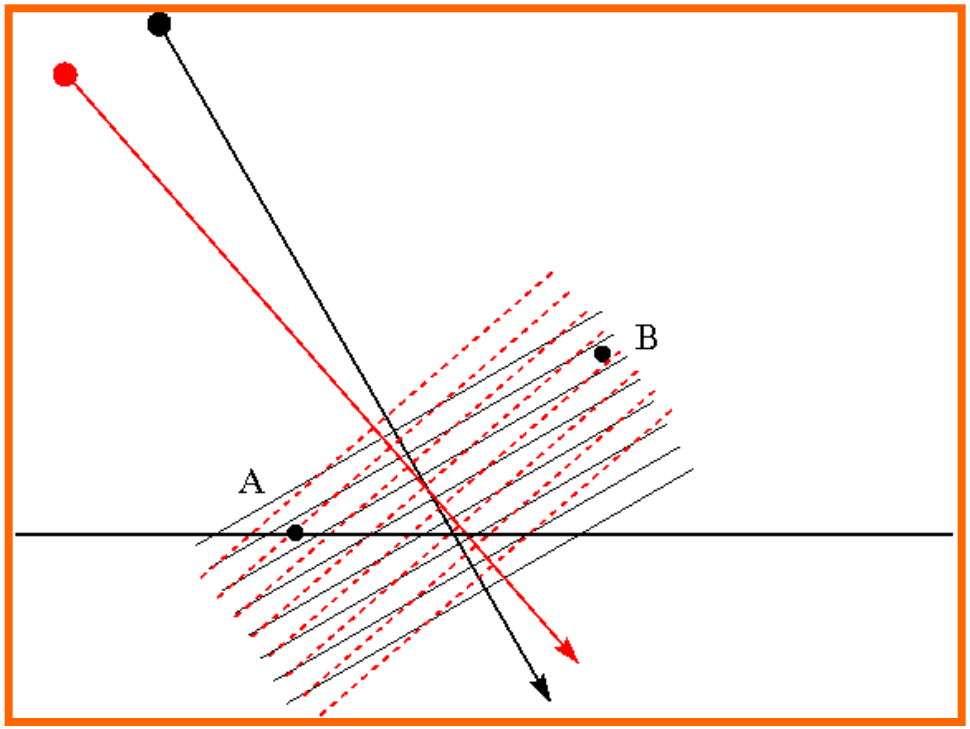


Grande base :
Radargrammétrie



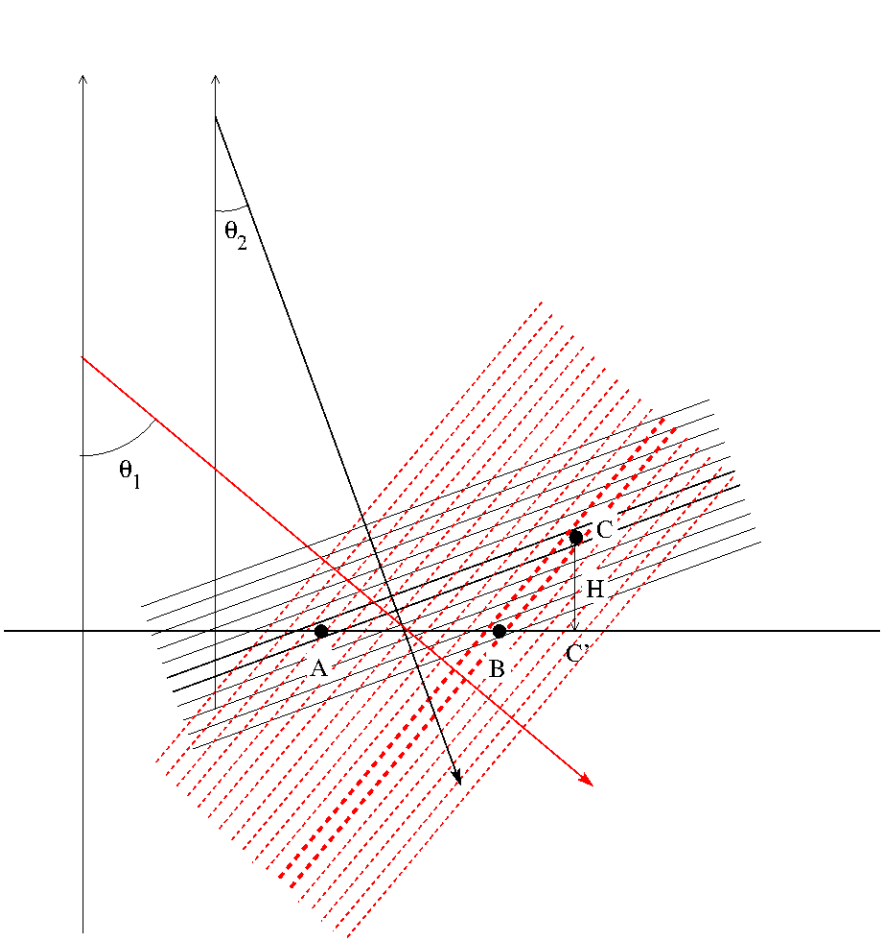
Petite base :
Interférométrie

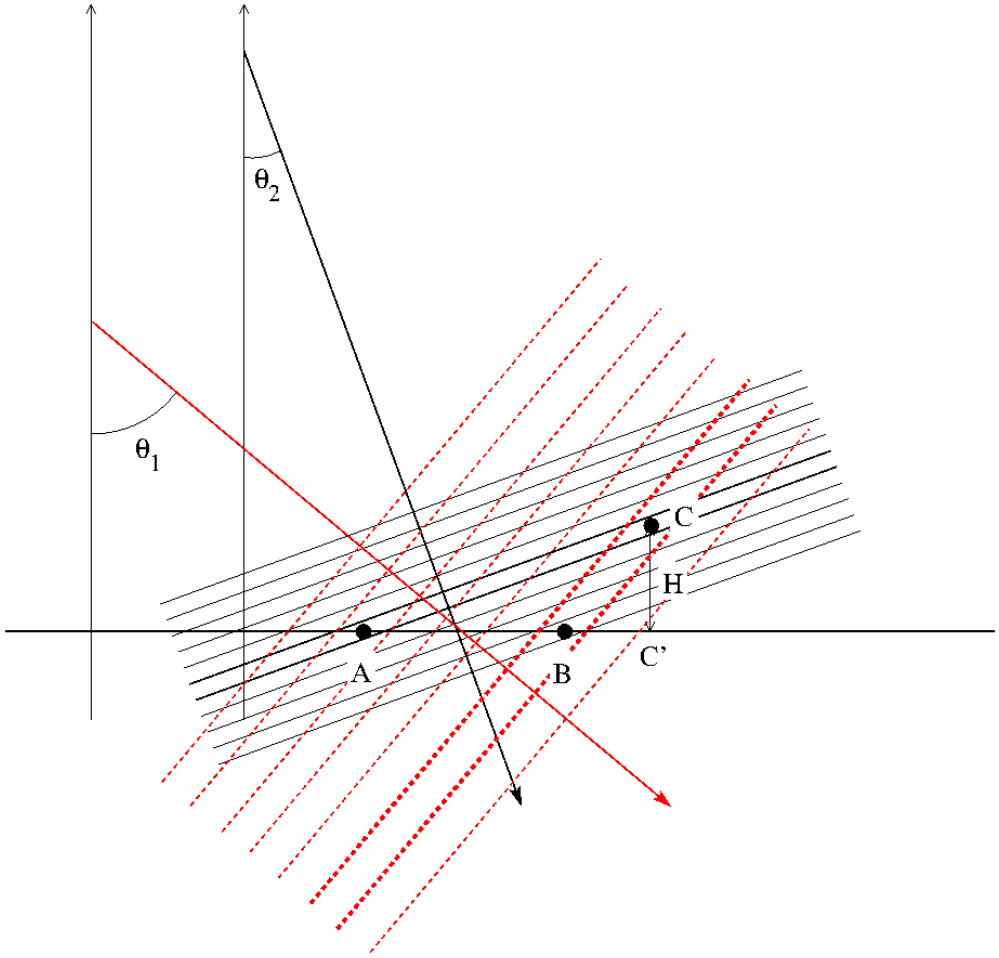
Grande base
Deux antennes avec des incidences différentes



- Deux objets A et B
- Dans la même case distance pour l'antenne noire
- Dans deux cases distance de l'antenne rouge !!
- →stéréoscopie

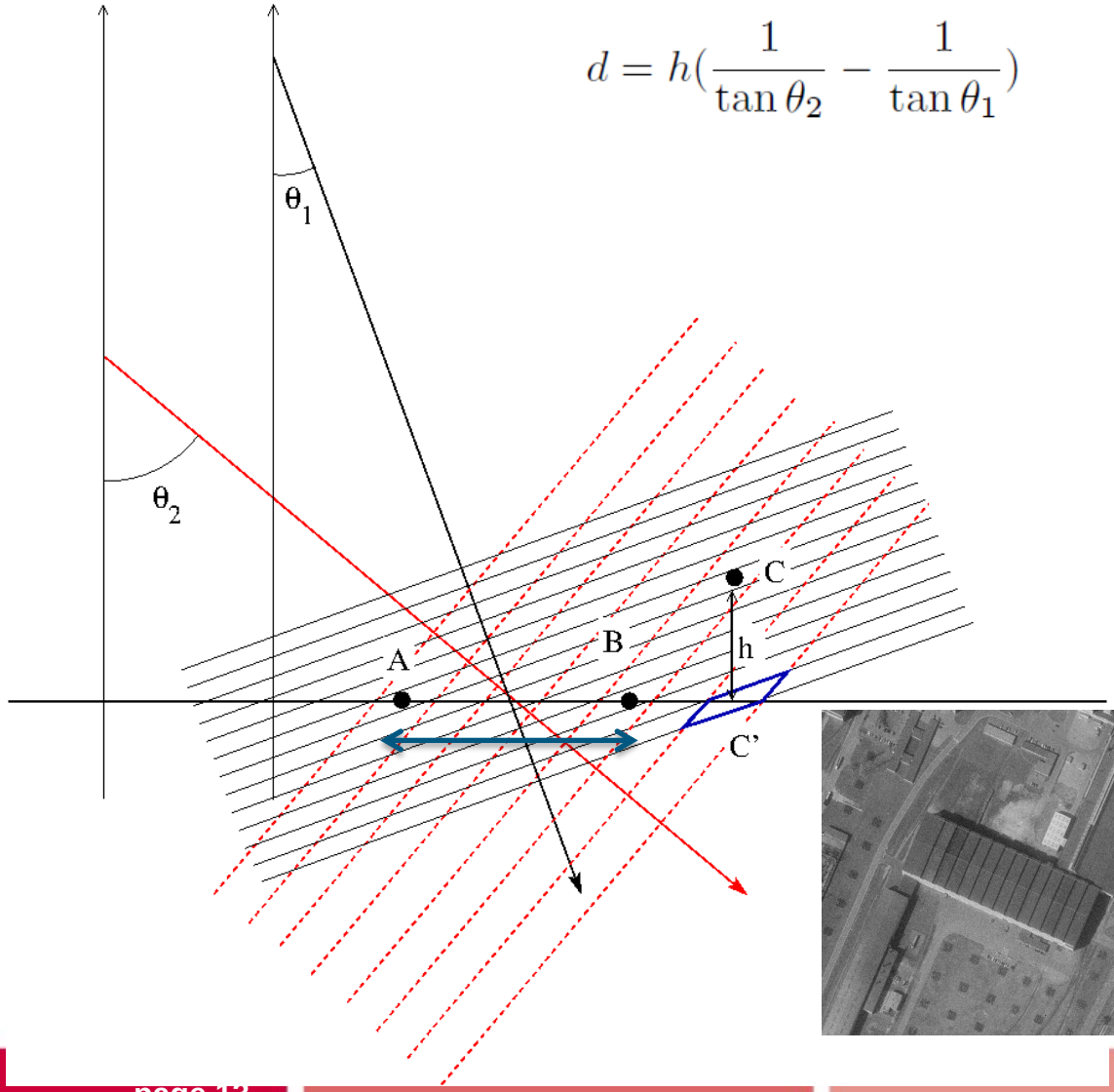
Recalage : même pixel sol

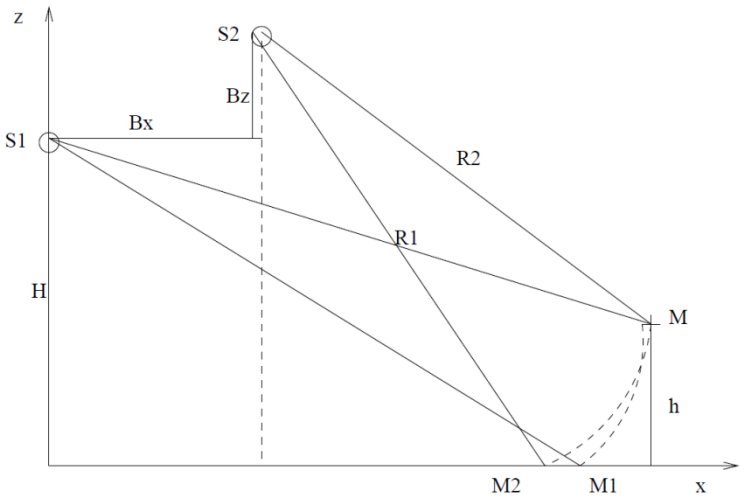


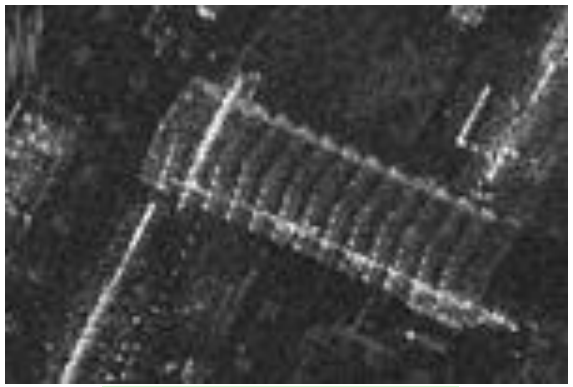


Radargrammétrie

$$d = h(\frac{1}{\tan\theta_2} - \frac{1}{\tan\theta_1})$$

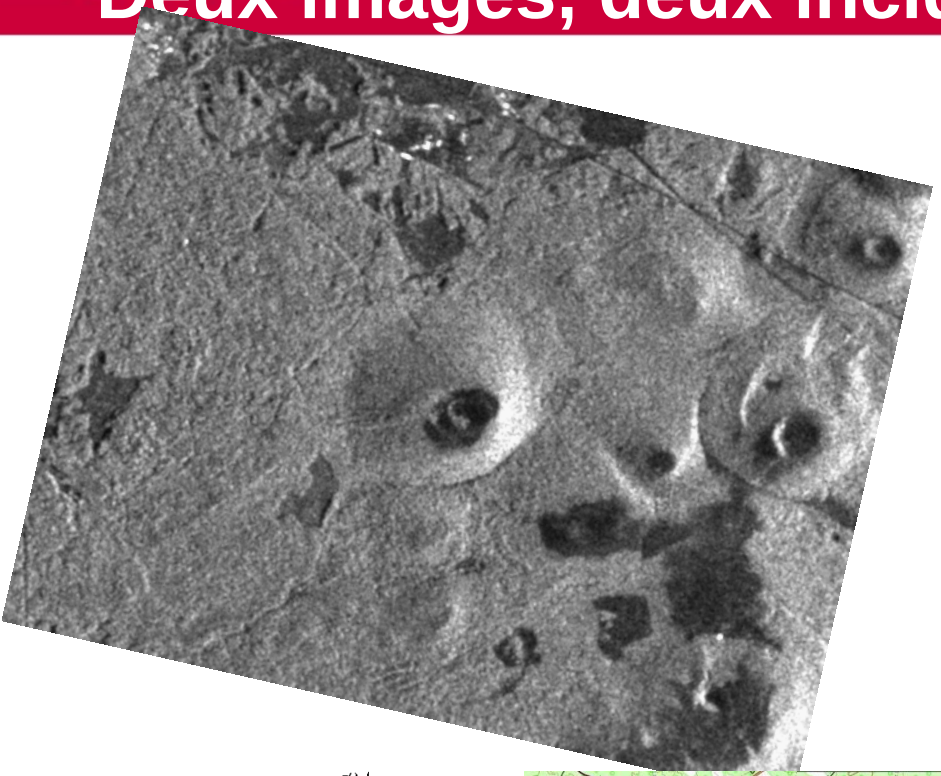




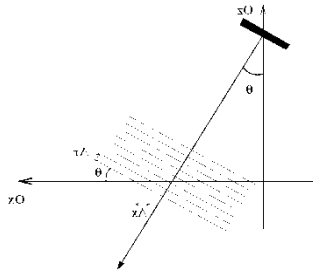


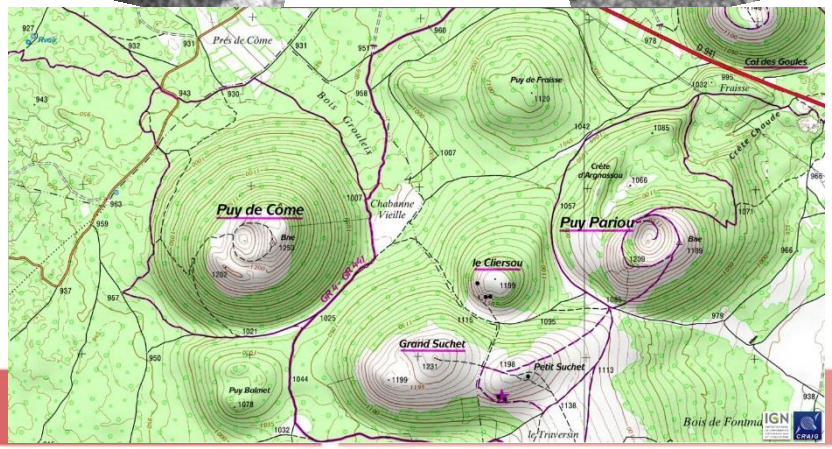
©ONERA/CNES

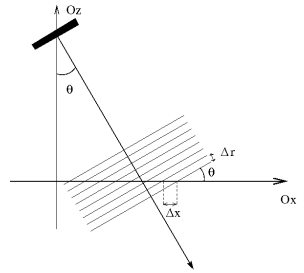
Deux images, deux incidences



©ESA







Images Sentin

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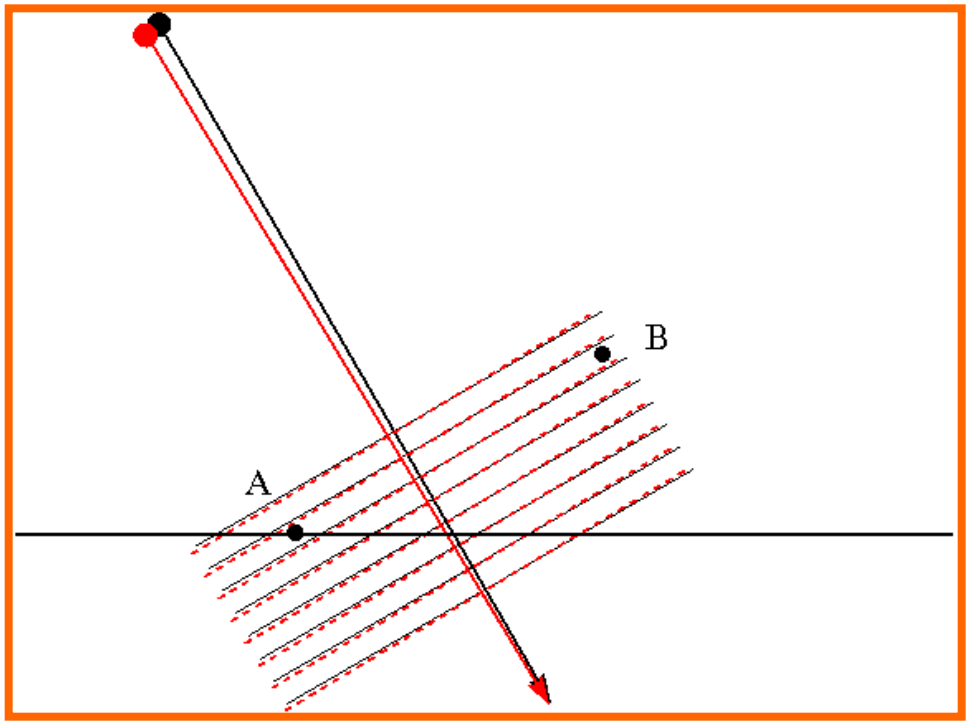
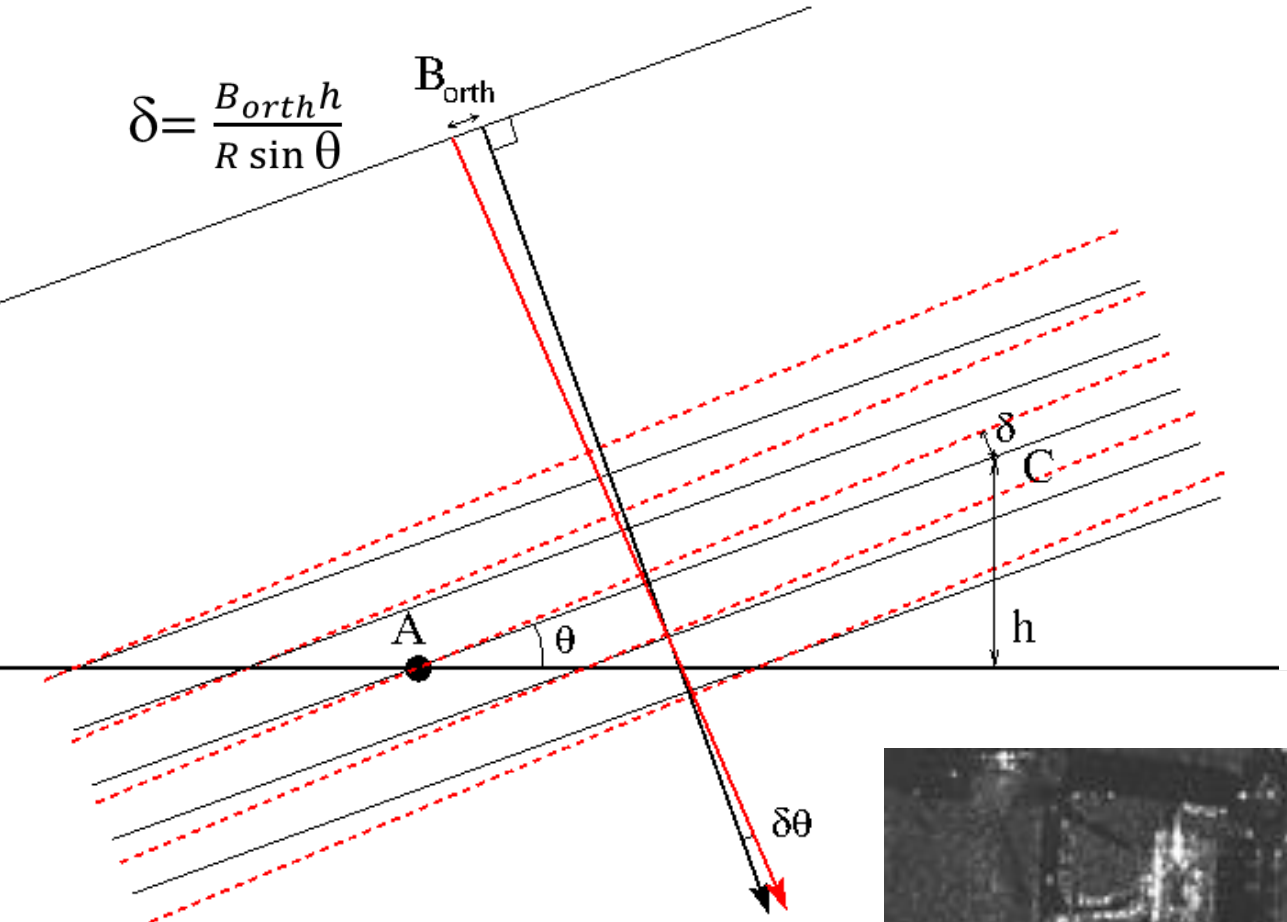
Petite base :
deux antennes avec presque la même incidence



- Deux objets A et B
- Dans la même case distance pour l'antenne noire
- Dans la même case distance de l'antenne rouge
- → interférométrie

Interférométrie

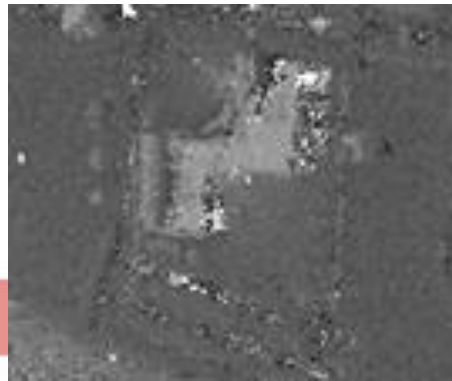


$$\phi = \frac{4\pi R}{\lambda} + \phi_{pr}$$

$$\phi_2 - \phi_1 = \frac{4\pi(R_2 - R_1)}{\lambda} = \psi_{1,2}$$

$$\psi_{1,2} = \frac{4\pi B_{\perp 1,2}}{R \sin(\theta) \lambda} h$$

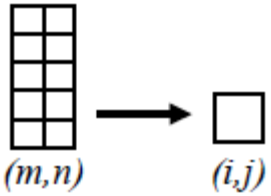
$$\psi_{1,2} = \alpha_{geom_{1,2}} h$$



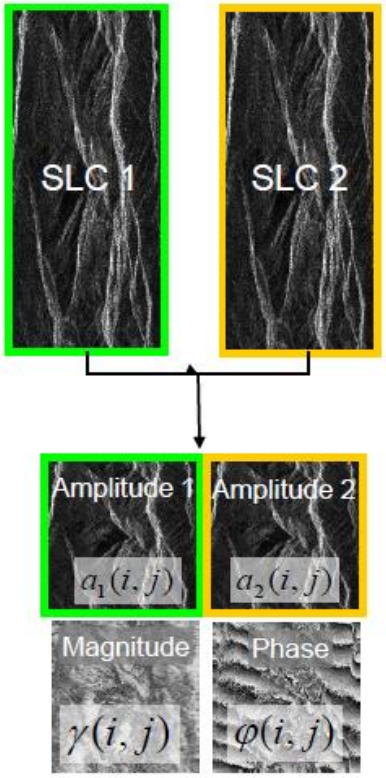
SAR interferometric data

- **Interferometry:**

$$z_1(m,n) = A_1(m,n)e^{i\phi_1(m,n)}$$
$$z_2(m,n) = A_2(m,n)e^{i\phi_2(m,n)}$$

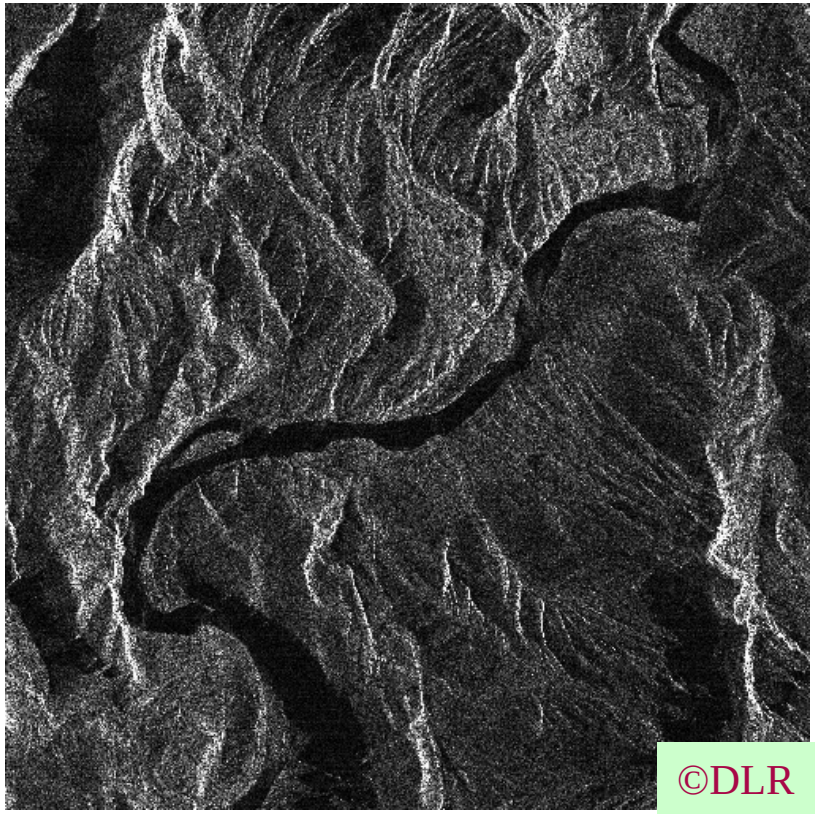


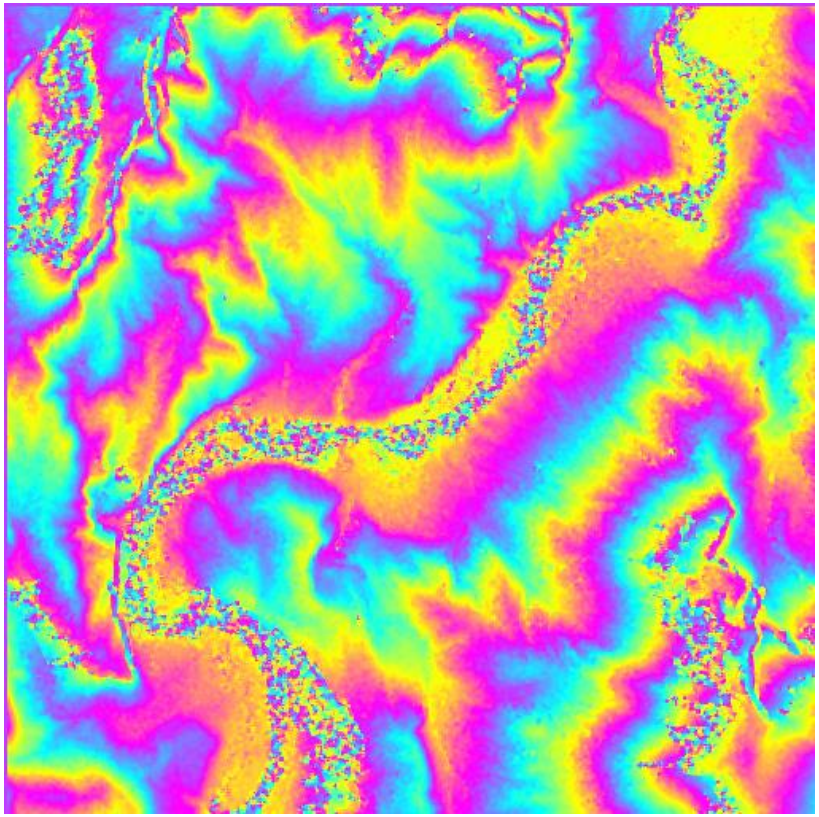
$$\gamma(i,j)e^{i\phi(i,j)} = \frac{\sum_{(m,n)} z_1(m,n)z_2^*(m,n)}{\sqrt{\sum_{(m,n)} |z_1(m,n)|^2}\sqrt{\sum_{(m,n)} |z_2(m,n)|^2}}$$



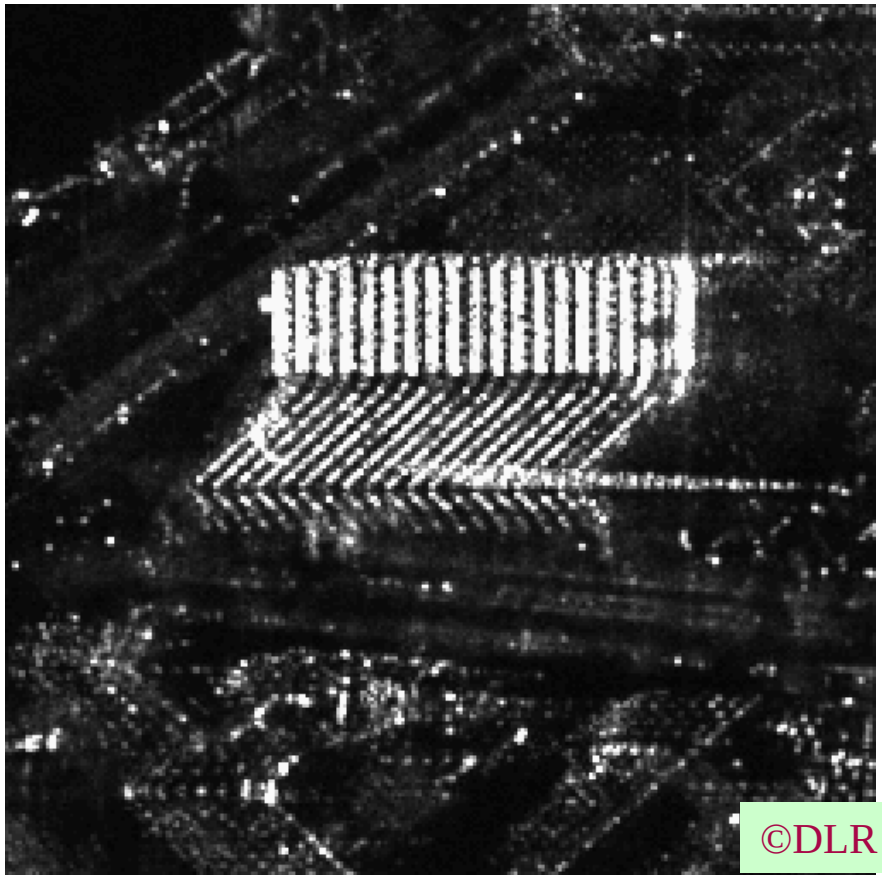
- **Multi-temporal InSAR:**
  - Topography + displacement (D-InSAR)
  - Perturbations:
    - Phase decorrelation noise
    - Systemic errors (atmosphere, orbit,…)

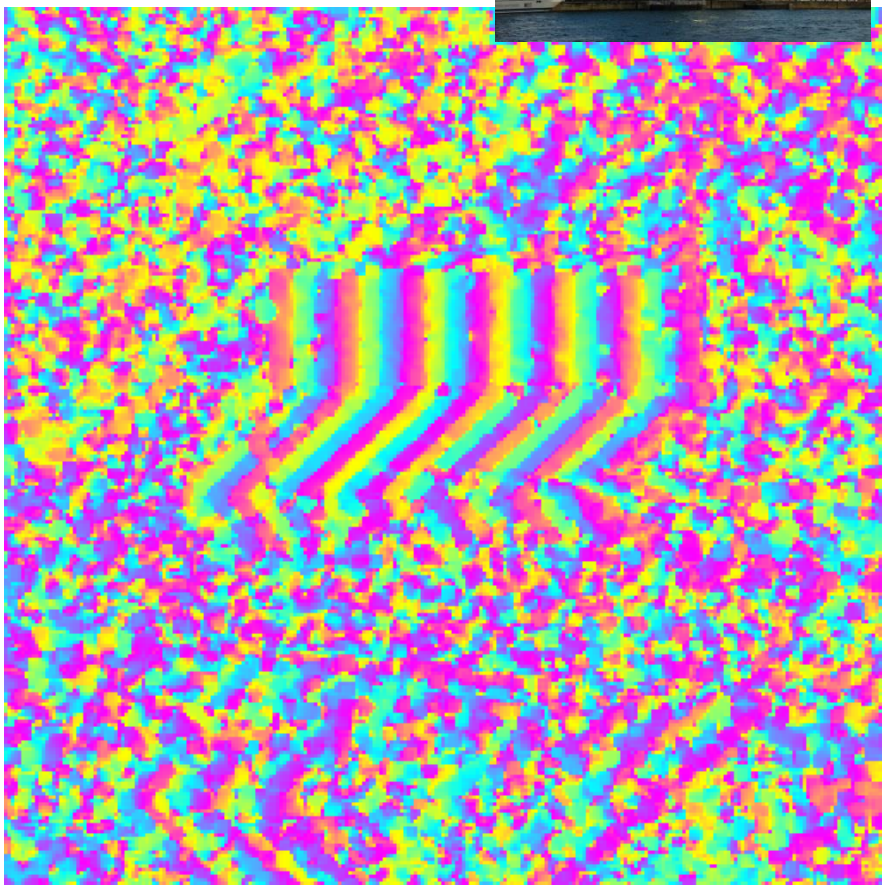
Mesure du relief
Grand canion du Colorado





Tour Mirabeau (70m)
Mesure de $\delta\varphi$





Environ 6 franges : Base orthogonale de 473m. Altitude estimée : 69m

Comparaison - intérêts / limites

Radargrammétrie

- Mise en correspondance *éparse*
- Variations de rétrodiffusion en fonction de l'angle
- Précision de reconstruction

$$\epsilon \approx \frac{1}{\sin(\delta\theta)}$$

Interférométrie

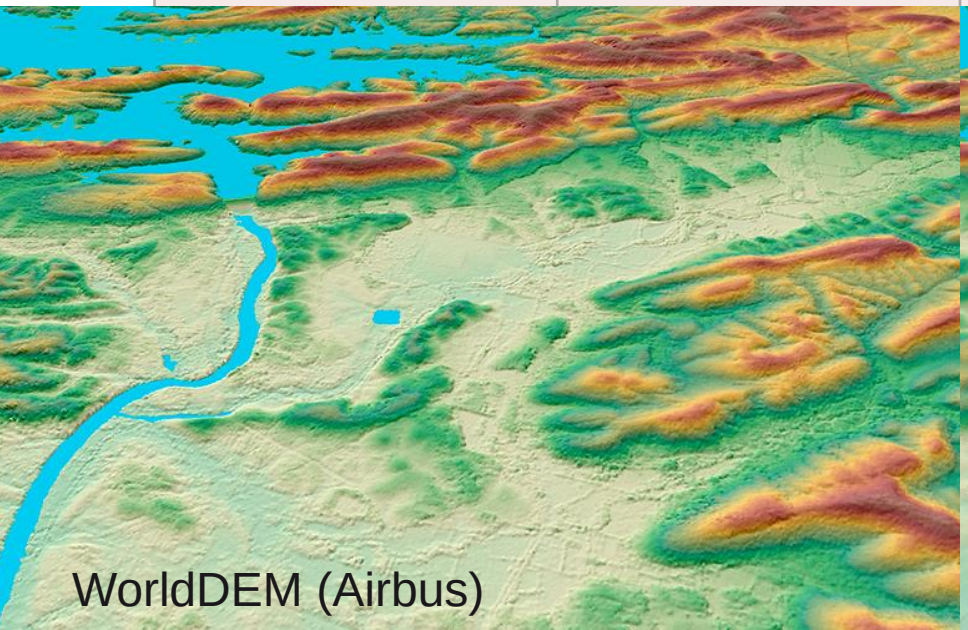
- Mise en correspondance *dense*
- *Décorrélation* spatiale, temporelle, perturbations atmosphériques
- Difficultés de *déroulement* de la phase (altitude d'ambiguïté)

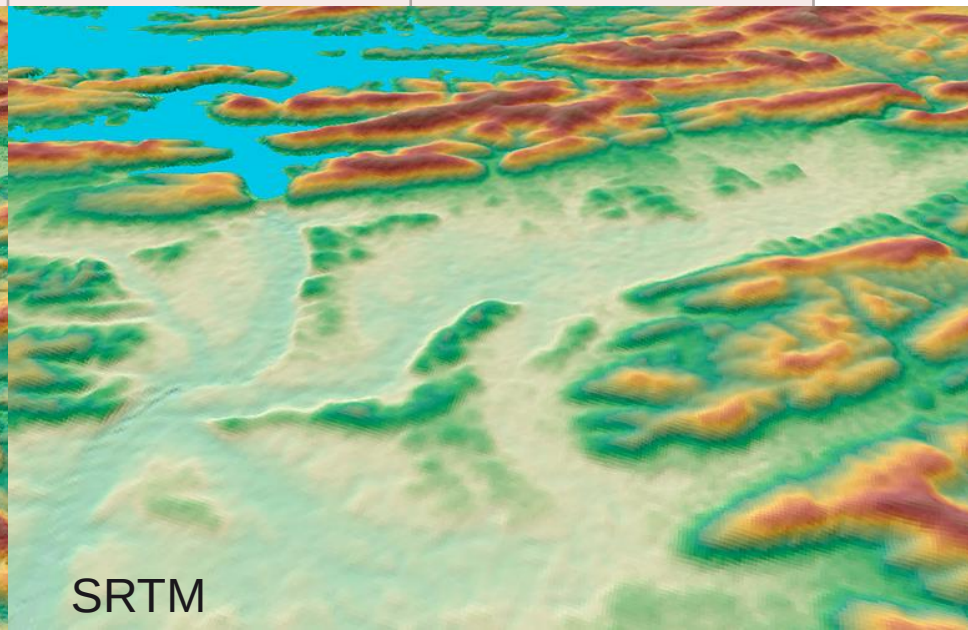
$$h_{amb} = \frac{\lambda R \sin\theta}{2B_{\perp_{1,2}}}$$

$$\sigma_h = \sigma_\psi \frac{h_{amb}}{2\pi}$$

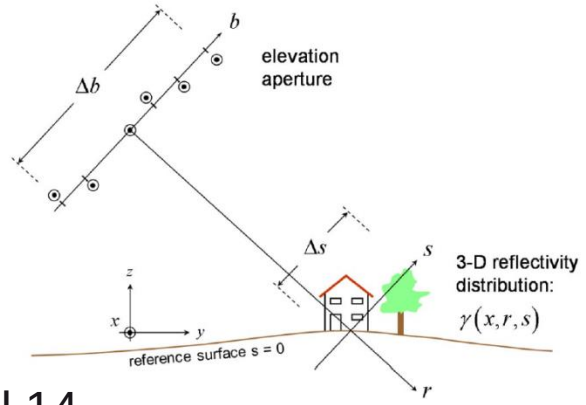
Reconstruction 3D - MNT

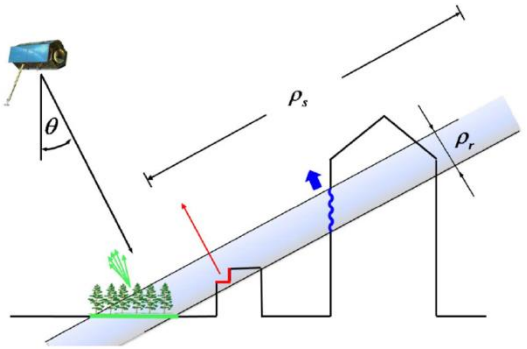
Mission	mode	Précision planimétrique	Précision altimétrique
SRTM (2000)	Bande X Interféro mono-passe	60m (30m)	16m abs. 10m rel.
TanDEM-X WorldDEM	Interféro mono-passe + mult-passe	12m	4m abs. 2m rel.





Tomographie SAR

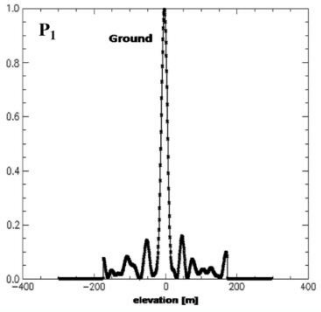


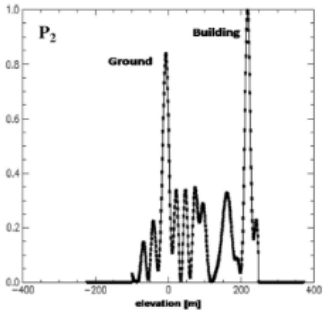


Zhu et al.14

$$g_n = \int_{\Delta s} \gamma(s) \exp(-j2\pi\xi_n s)\, ds, \qquad n = 1, \ldots, N$$

$$\mathbf{g} = \mathbf{R}\boldsymbol{\gamma}$$

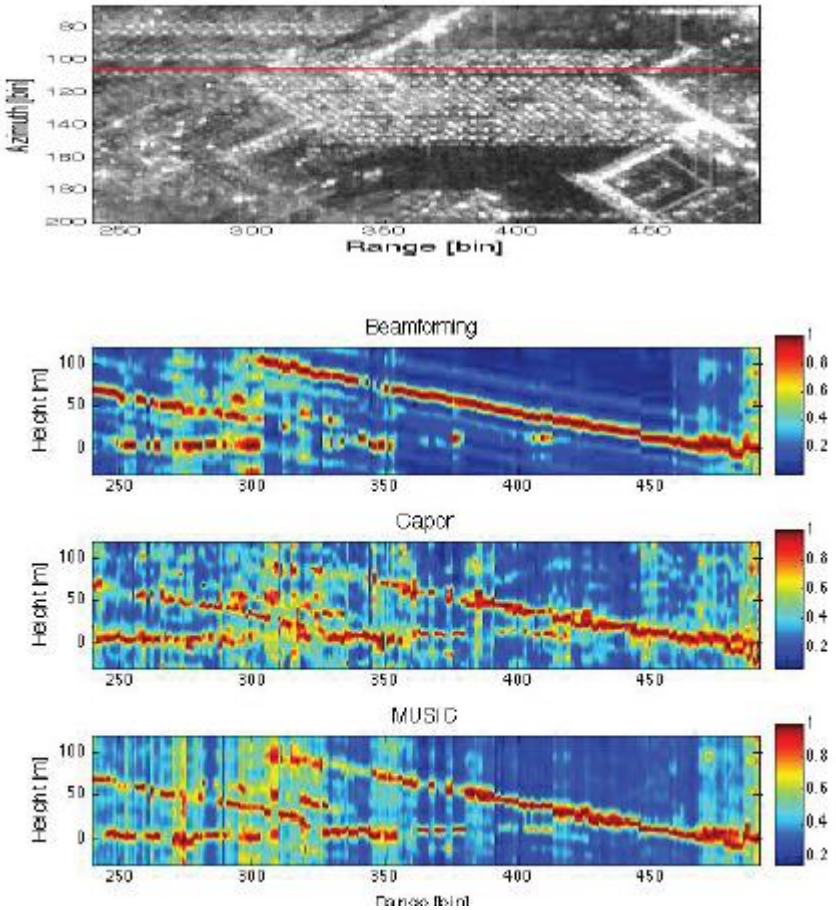


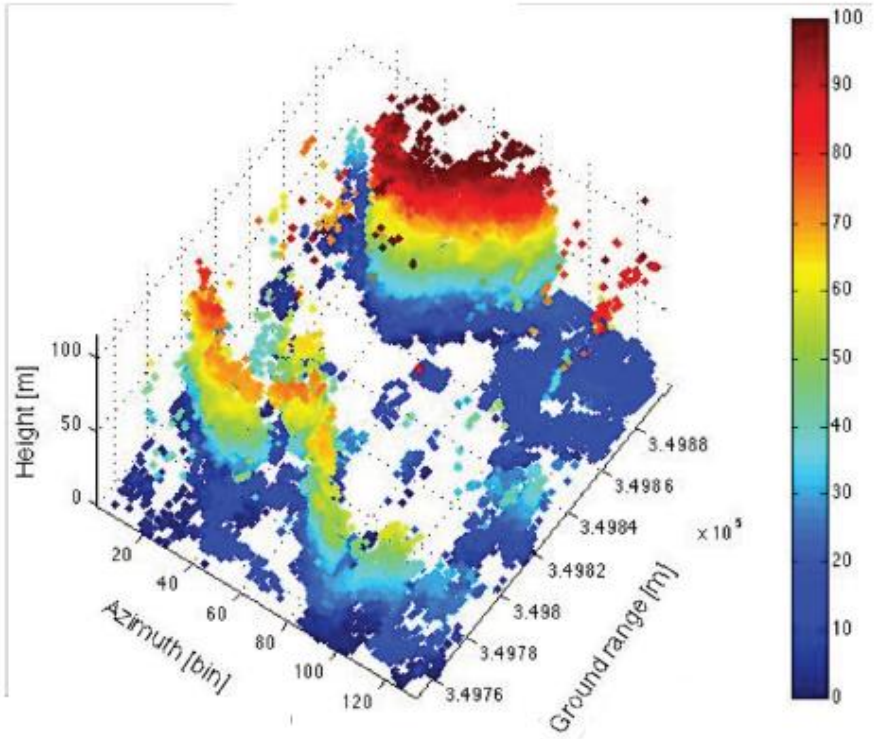


Méthodes d'inversion:

- Méthodes d'analyse spectrale
- Méthodes parcimonieuses

SAR tomography

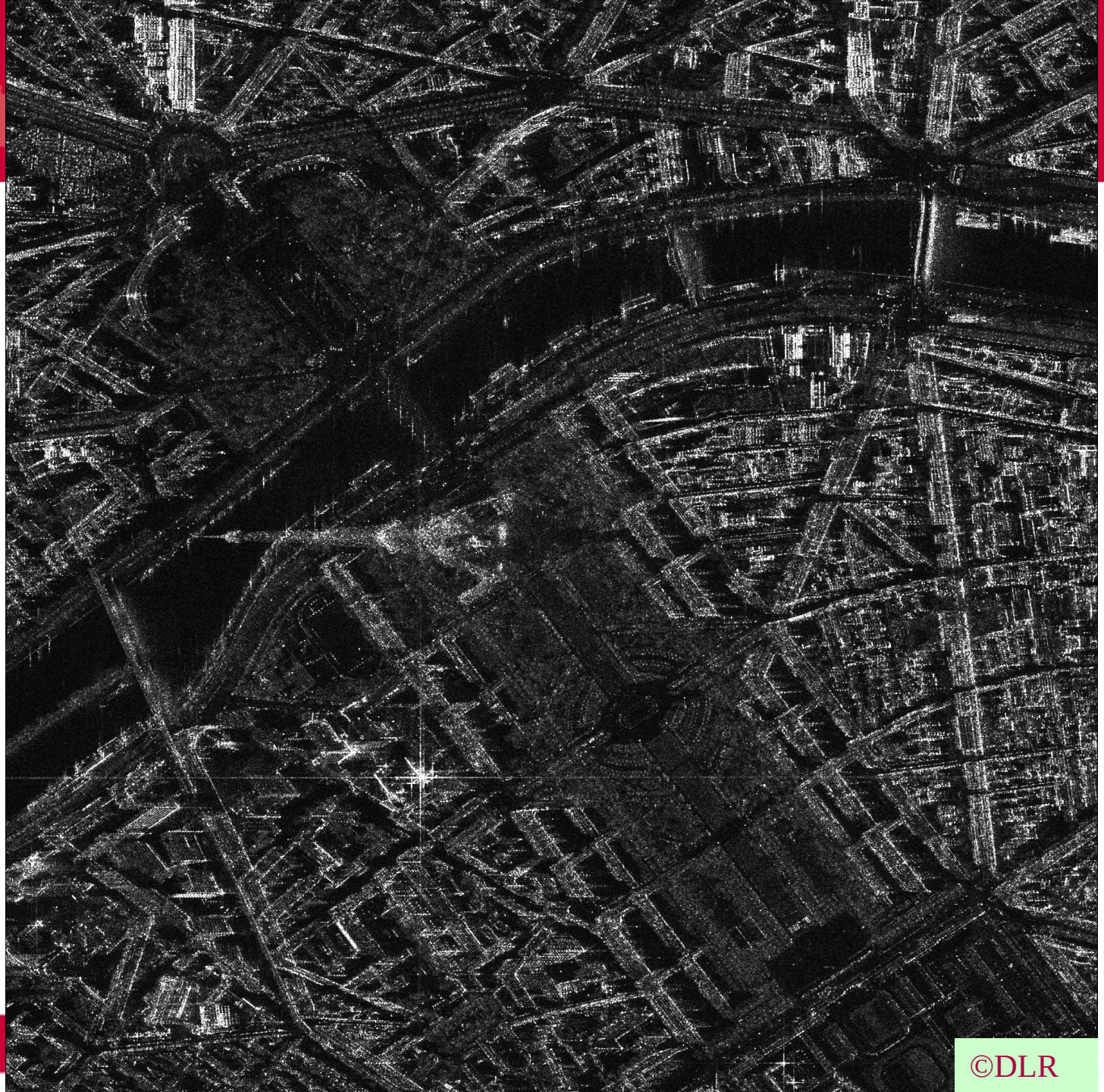




Porfiri et al., Multitemp 2015

Overview

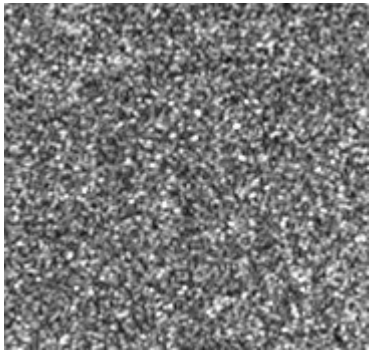
- **How recovering elevation information ?**
  - Radargrammetry
  - Interferometry
  - Tomography
- **Focus on urban areas**
  - Geometric limits
  - Use of external information
- **How helping with image processing ?**
  - Data and prior models
  - Fusion of information
- **Conclusion**

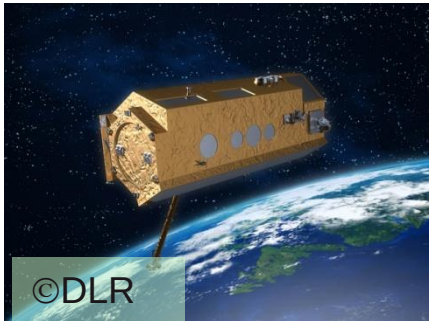


TerraSAR-X
DLR project
LAN 176

Urban areas

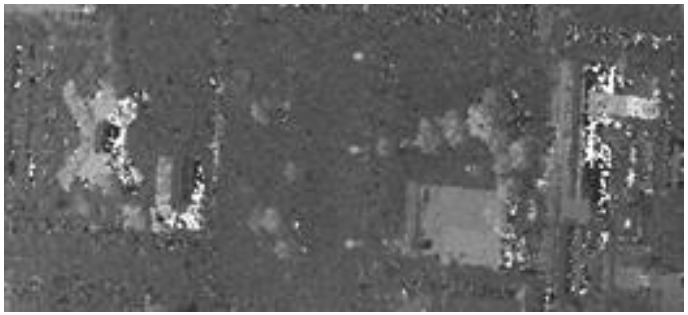
- **SAR images :**
  - Speckle noise
  - Strong influence of geometry (incidence angle / object geometry)



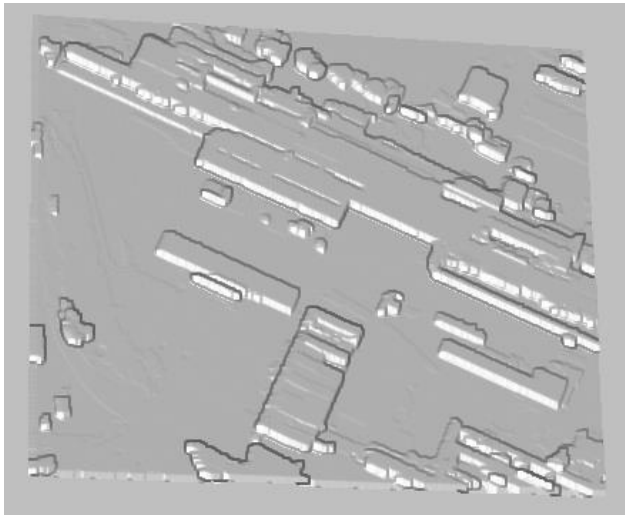


Challenges of urban areas

- **Geometric difficulties**
  - Shadow areas
  - Overlay areas



- **Solutions**
  - Multi-aspect images (asc/desc)
  - SAR tomography
  - Combination with other data (SAR, optic)
  - Image processing methods



Overview

- **How recovering elevation information ?**
  - Radargrammetry
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- **Focus on urban areas**
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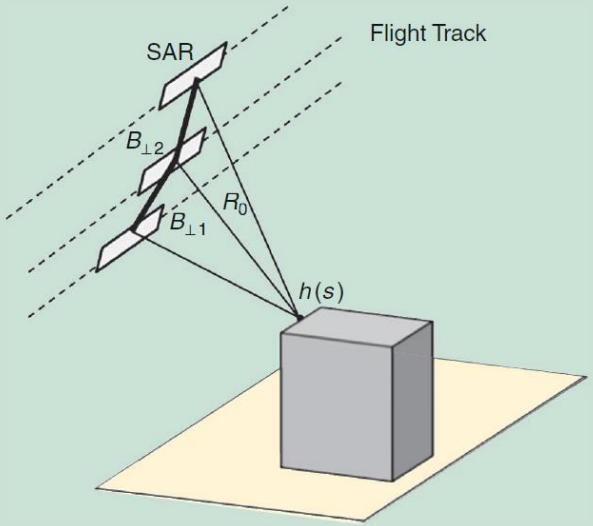
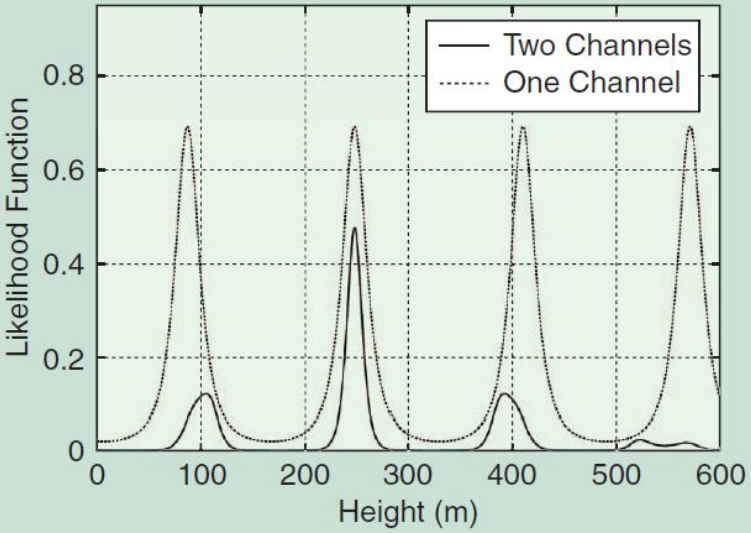
  - Fusion of information
- **Conclusion**

Multi-channel InSAR data



Baselice et al., IEEE SP 2014



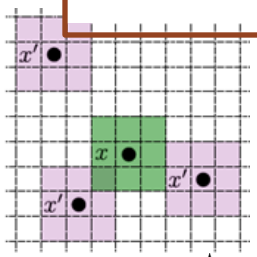
Baselice et al., IEEE SP 2014

$$\boldsymbol{\Sigma} = R \begin{pmatrix} 1 & \gamma_{1,2}\exp(j\psi_{1,2}) & \cdots & \gamma_{1,D}\exp(j\psi_{1,D}) \\ \gamma_{1,2}\exp(-j\psi_{1,2}) & 1 & & \gamma_{2,D}\exp(j\psi_{2,D}) \\ \vdots & & \ddots & \vdots \\ \gamma_{1,D}\exp(-j\psi_{1,D}) & \gamma_{2,D}\exp(-j\psi_{2,D}) & & 1 \end{pmatrix}.$$

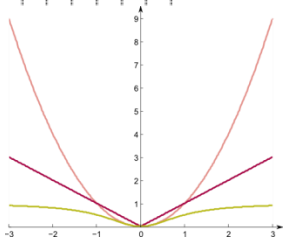
Image processing methods

- **Formulation of a global optimization problem:**

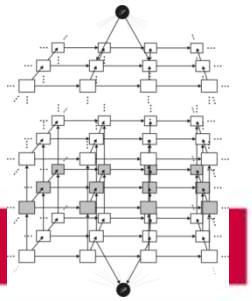
$$\hat{\boldsymbol{h}}^{(\text{R-NL})} = \arg\min_{\boldsymbol{h}} \; -\sum_i \lambda_i \log\det(\boldsymbol{\Sigma_i}(h_i)) + \lambda_i \text{tr}(\boldsymbol{\Sigma_i}(h_i)^{-1}\boldsymbol{C}_i) \; + \sum_{(i,j)} |h_i - h_j|$$



- **Likelihood term: exploiting image redundancy**
  - NL-SAR based regularization



- **Prior term: exploiting elevation regularity**
  - Enforce smooth reconstruction with discontinuities



- **h optimization: graph-cut based algorithm**

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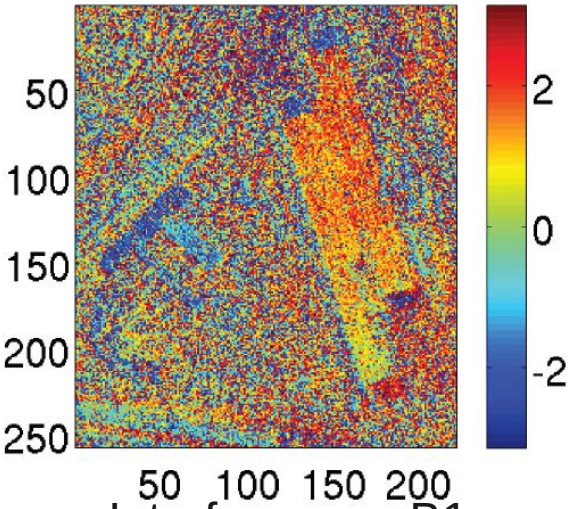
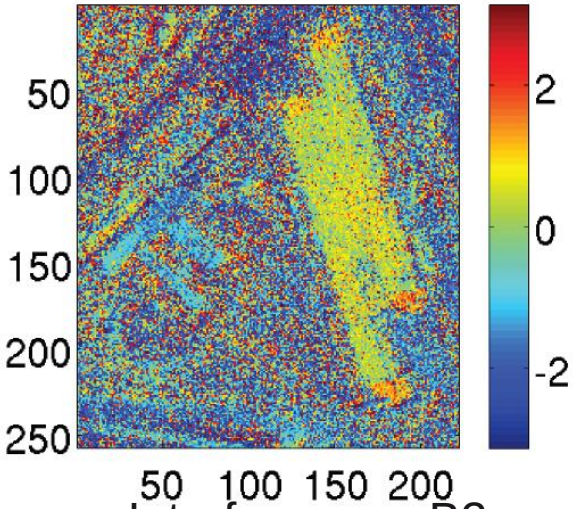
Multi-baseline InSAR

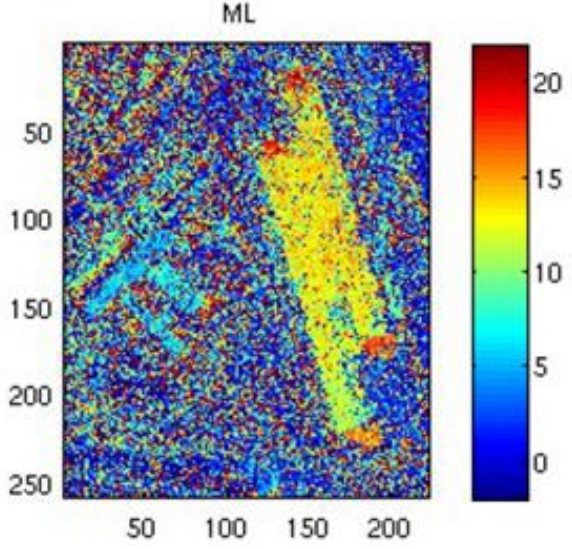


Interferogram B1

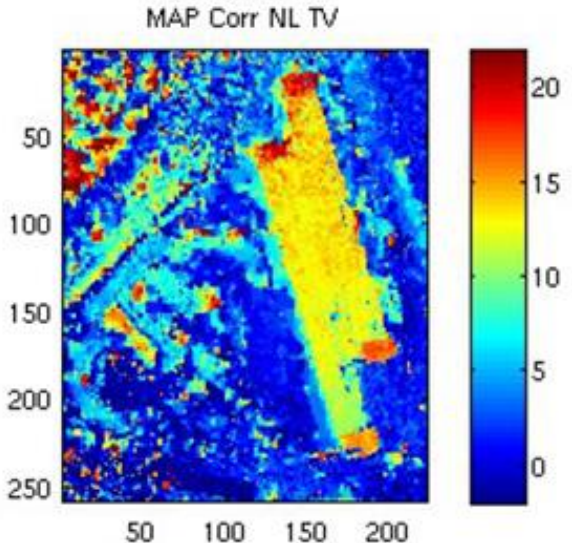


Interferogram B2

Non-local + total variation regularization (3 CSK data) [Deledalle et al. 2015]



Without regularization



With regularization

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Conclusion

- **Well-established approaches:**
  - Differential interferometry and « permanent scatterer » -like methods
  - Multi-aspect fusion
- **Still challenging**
  - Dealing with few interferograms
  - Obtaining a dense reconstruction
  - Combining with other data

Références (1)

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- H. Sportouche, F. Tupin and L. Denise, *Extraction and 3D Reconstruction of Isolated Buildings in Urban Scenes from High-Resolution Optical and SAR Spaceborne Images,* , IEEE Transactions on Geoscience and Remote Sensing, 2011
- L. Denis, F. Tupin, J. Darbon and M. Sigelle, *Joint Regularization of Phase and Amplitude of InSAR Data: Application to 3D reconstruction*, IEEE Transactions on Geoscience and Remote Sensing, November 2009
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- Radargrammetric Processing for 3-D Building Extraction from High-Resolution Airborne SAR Data, E. Simonetto, H. Oriot, H. cantalloube, IEEE TGRS 2005
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- [Porfiri et al., 2015] Building profile reconstruction using TSX time series and tomographic technniques, Multitemp 15