Acquisition of SAR images (SAR : Synthetic Array Radar)

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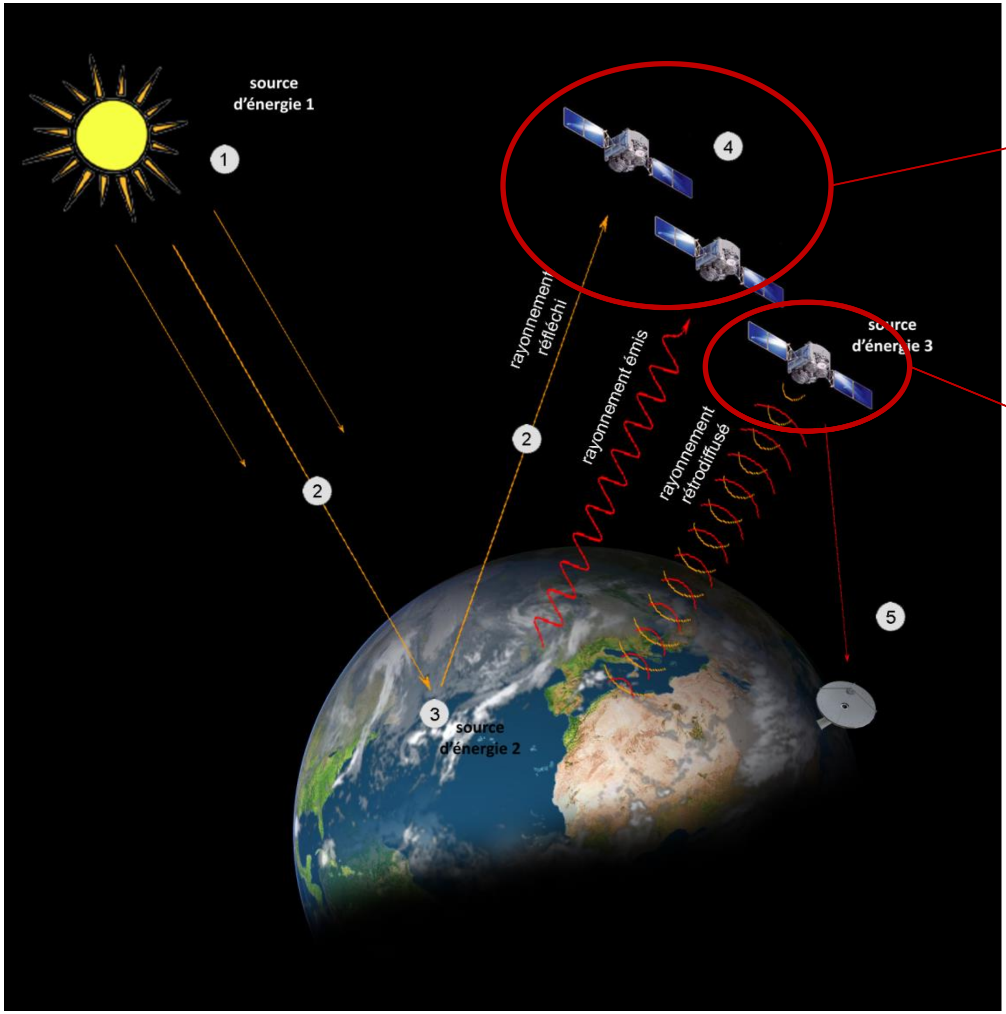
Florence TUPIN

IMA207

Overview

- **Principle of radar acquisition**
- **Examples of SAR images**
- **SAR image acquisition**
  - Range direction and chirp
  - Azimuth direction and synthetic aperture
- **Some SAR systems and applications**

Physic measure



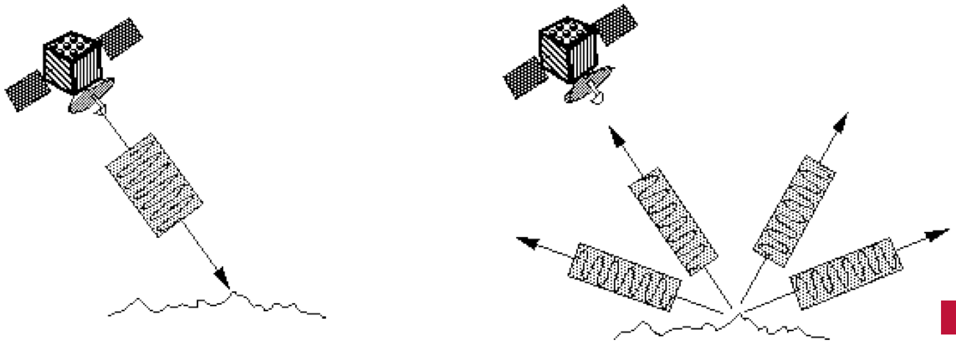
Passive sensors

- Optic domain
- Infra red

Active sensors

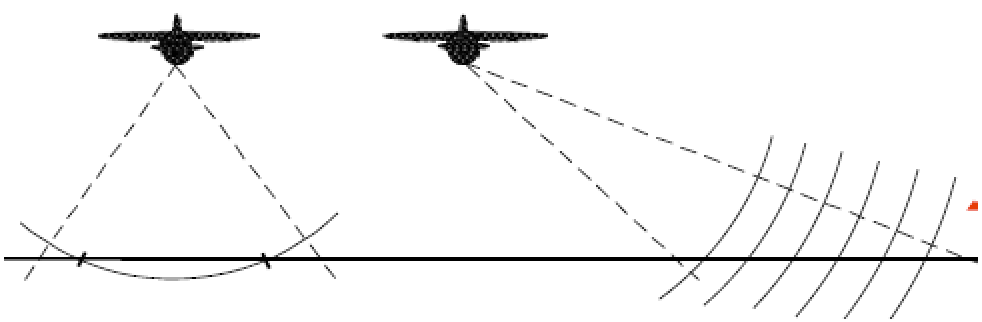
- radar
- lidar

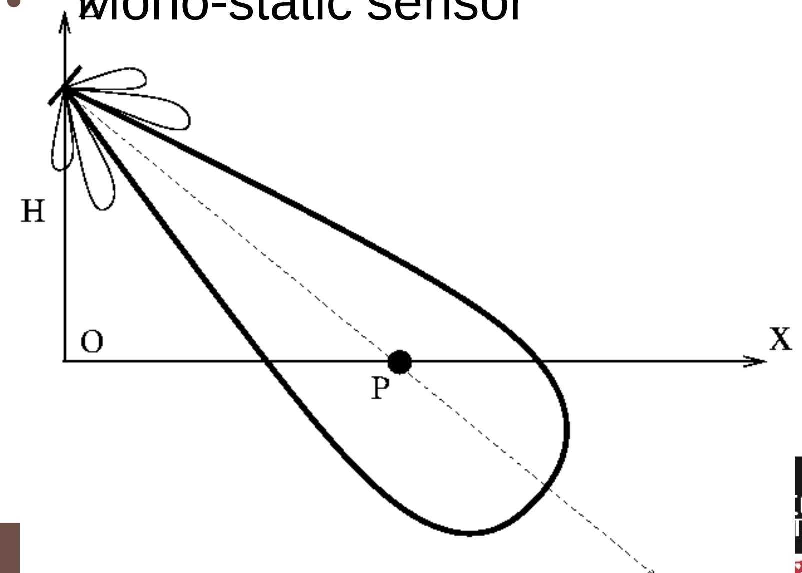
Principle



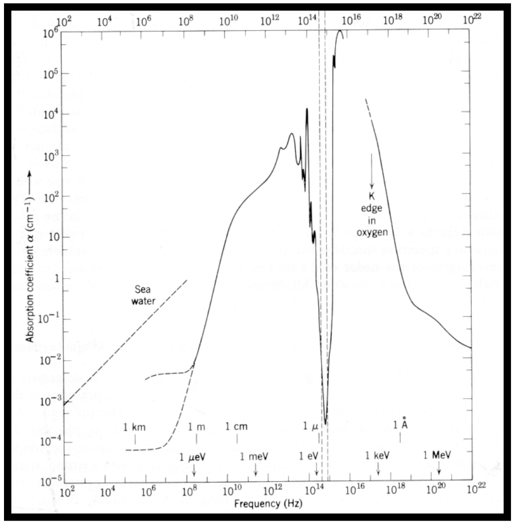
- **Radar imaging :**
  - Emission of E.M. waves
  - Recording of the backscattered signal by the antenna

- **Caracteristics:**
  - Lateral viewing
  - Mono-static sensor

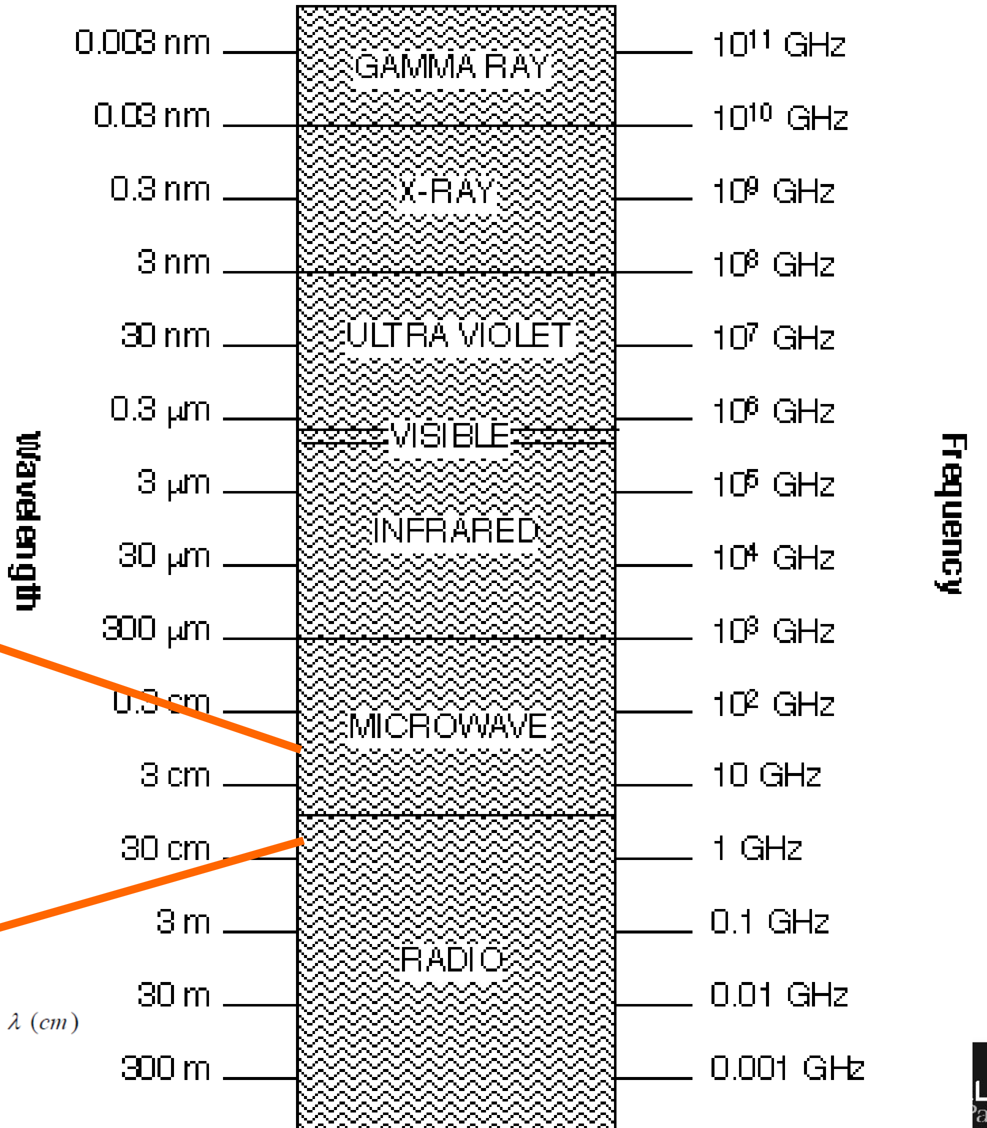




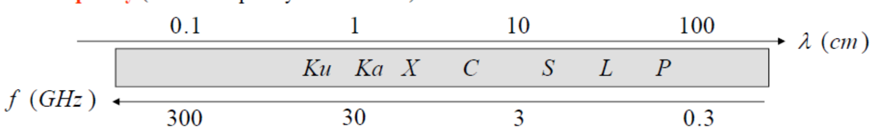
Radar sensors – wavelengths



Radar bands:
- X ~ 2 cm (~ 9 GHz)
- C ~ 5 cm (~ 5 GHz)
- L ~ 20 cm (~ 1 GHz)



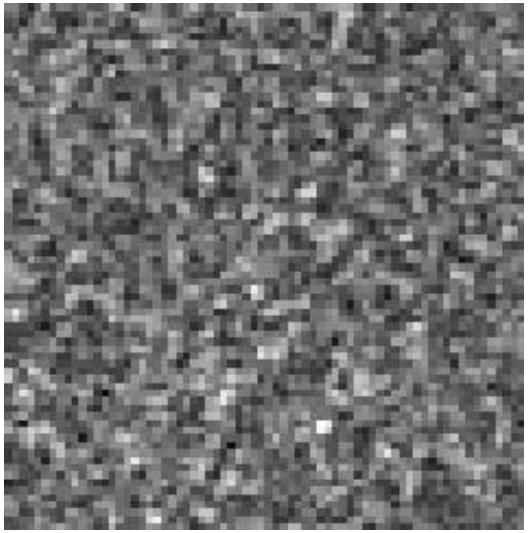
- The **frequency** (carrier frequency + bandwidth)



Why using SAR?

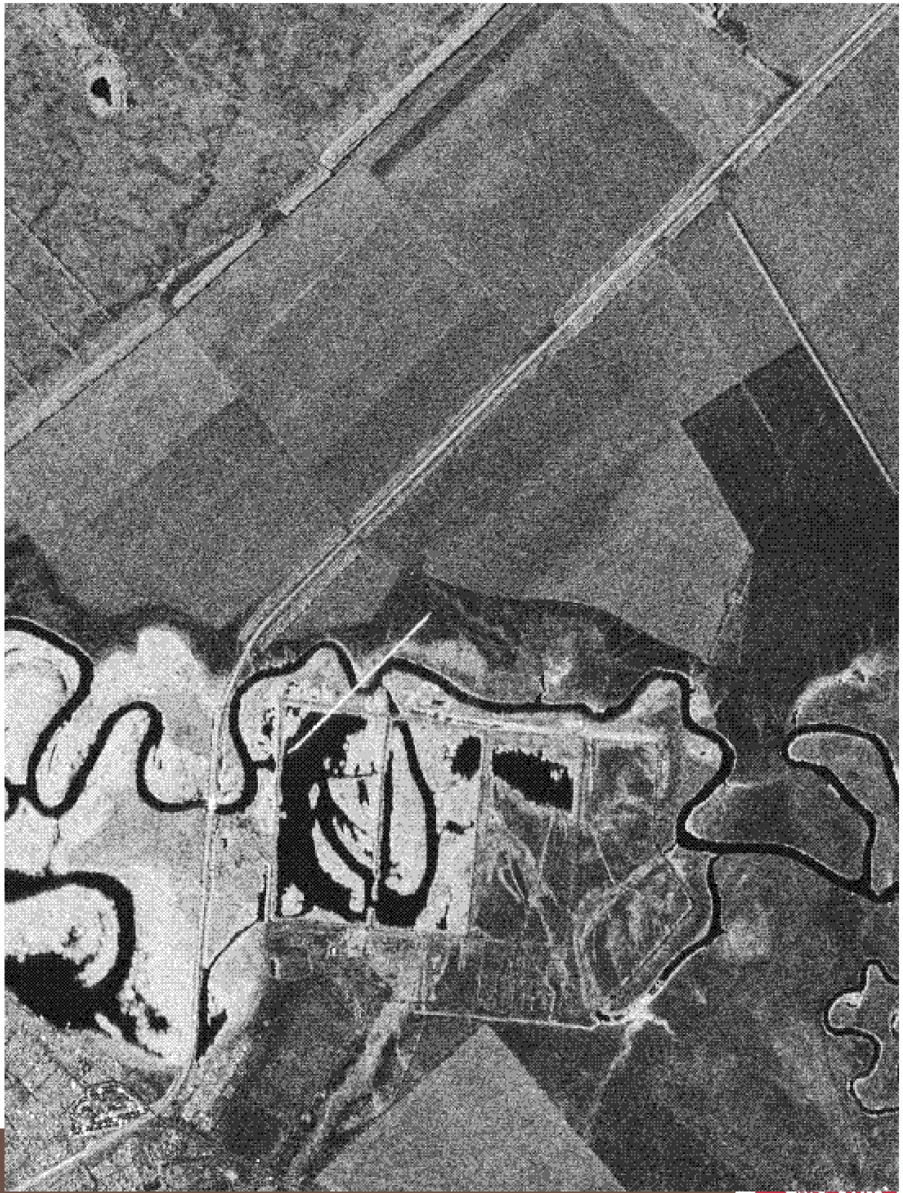
- **Advantages**
  - All time sensor
  - All weather sensor
  - Complementary information compared to optic
    - Sensitivity to different properties of medium
    - Sensitivity to topography
    - Penetration capabilities (subsoil, biomass,…)

- **Drawbacks**
  - Speckle (strong radiometric fluctuations)
  - Sensitivity to geometry



Examples of SAR images

Terrasar-X : first image, june 15th 2007




Friedrichshafen, Allemagne
Image © 2008 GeoContent
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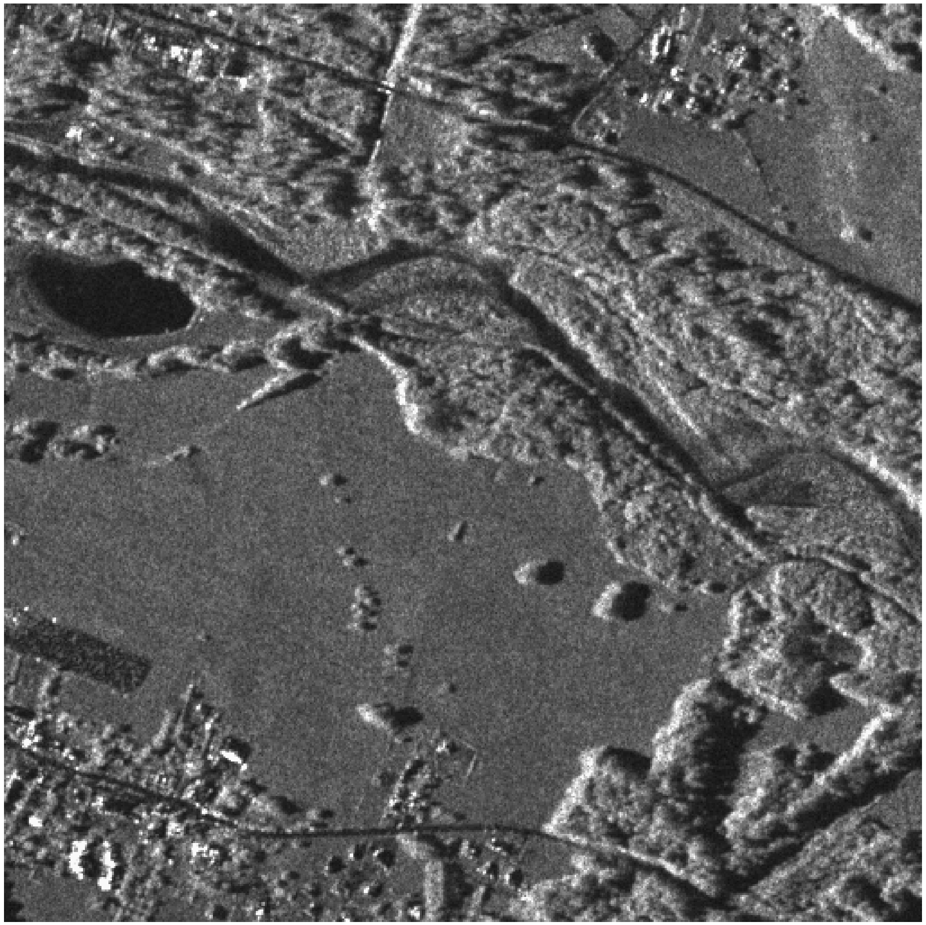
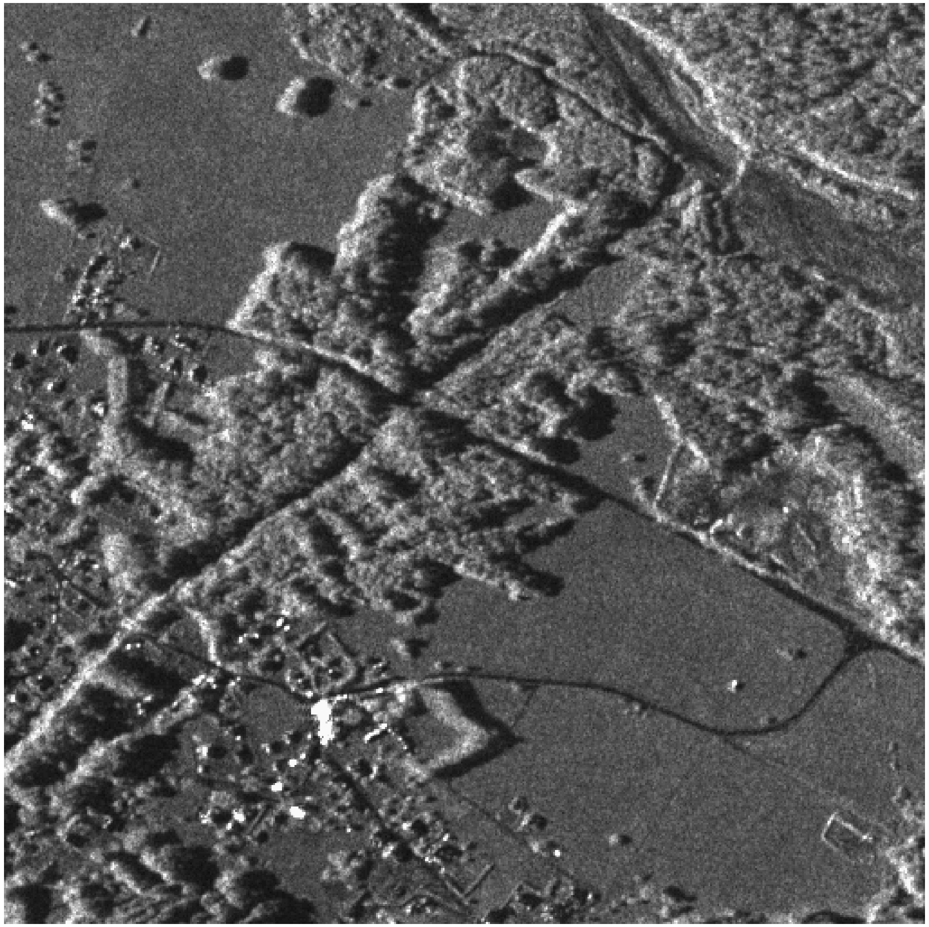
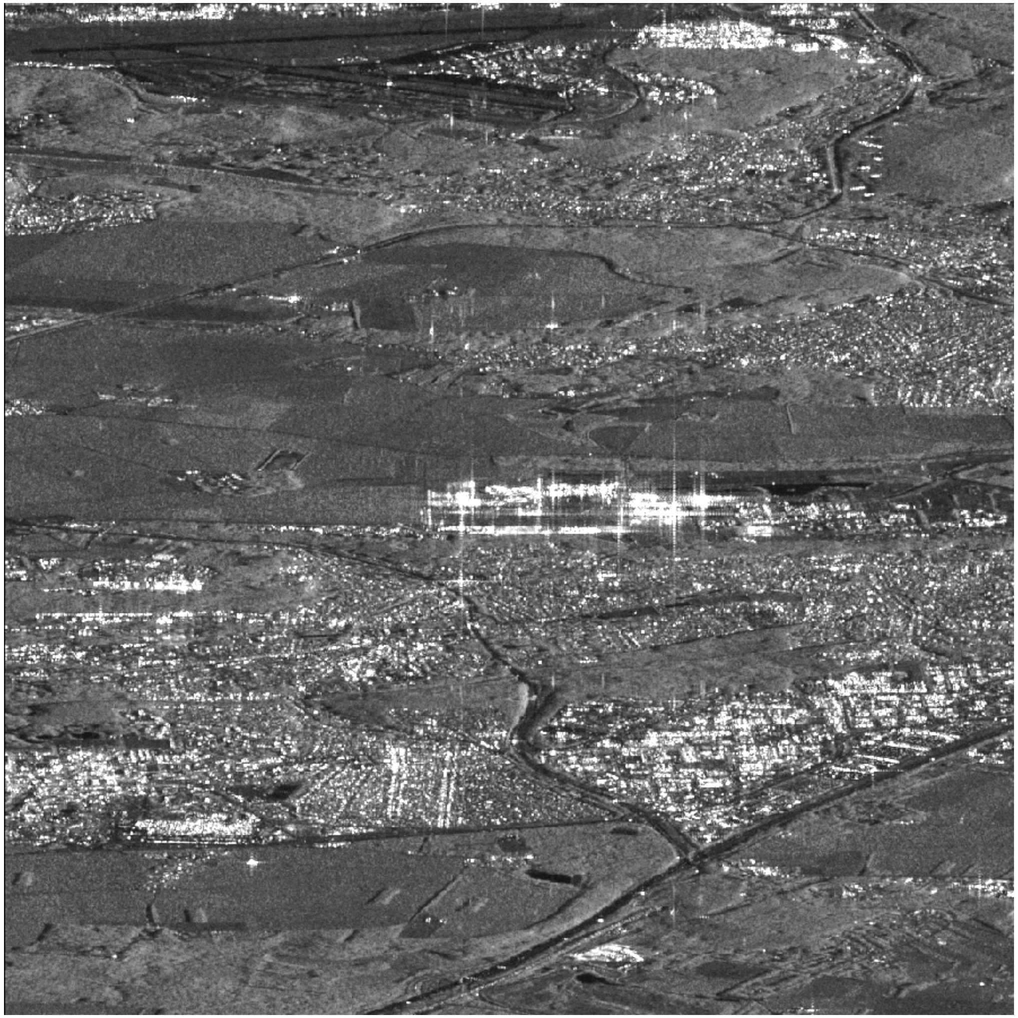
Terrasar-X (~2m) : ideal case (no speckle)



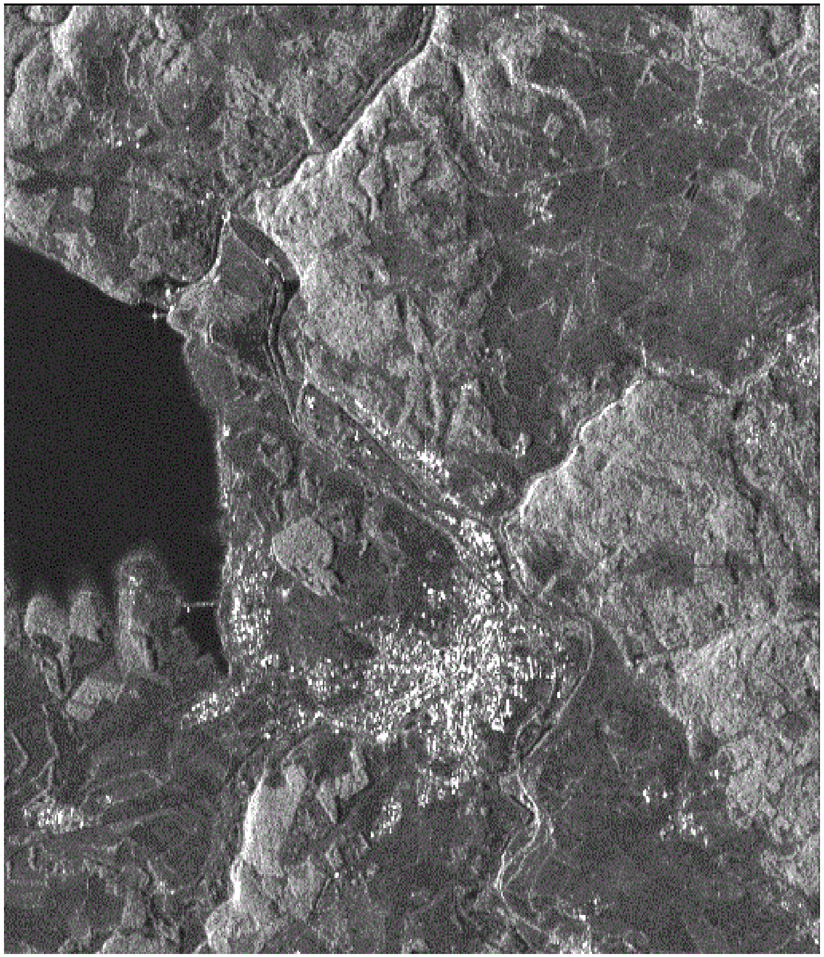
Terrasar-X (~2m) : ideal case (no speckle)

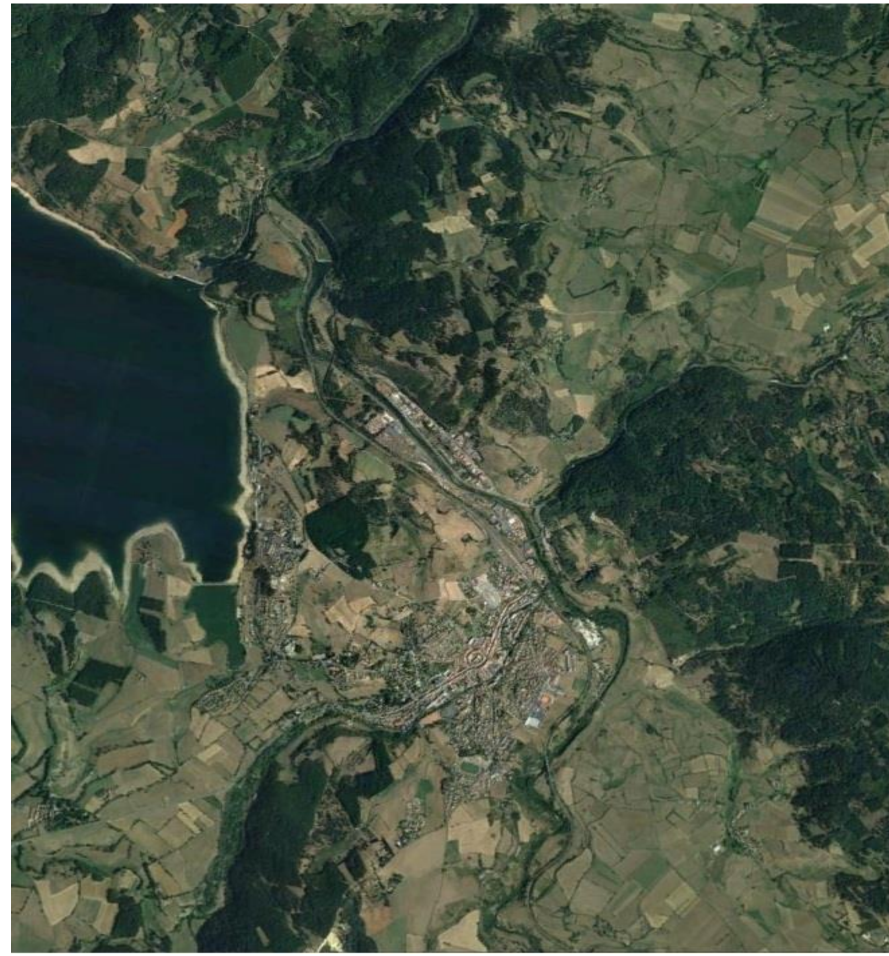


Sentinel image (~4x10m) : ideal case (no speckle)

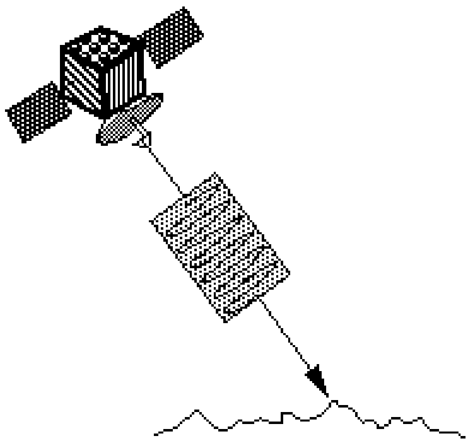


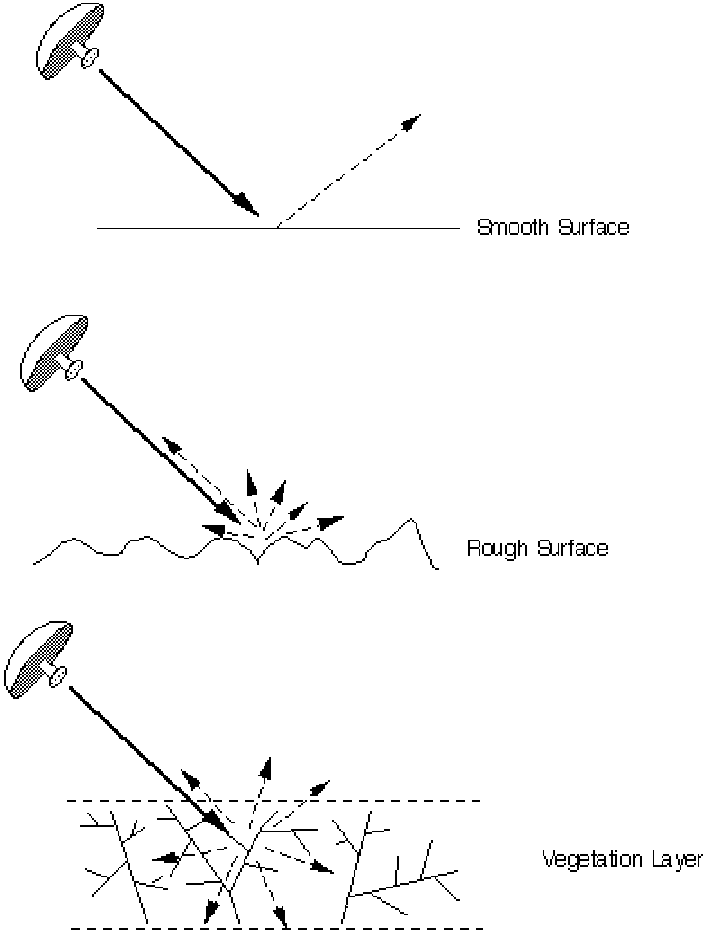
Sentinel-1 : Langogne





Backscattering mechanisms: surface and volume

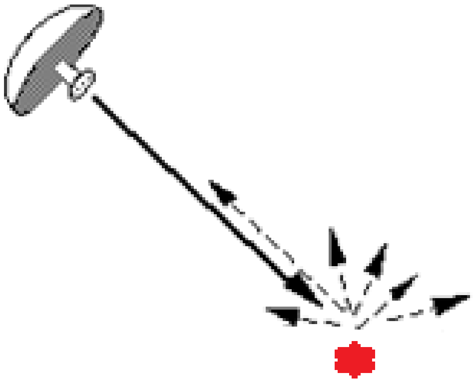




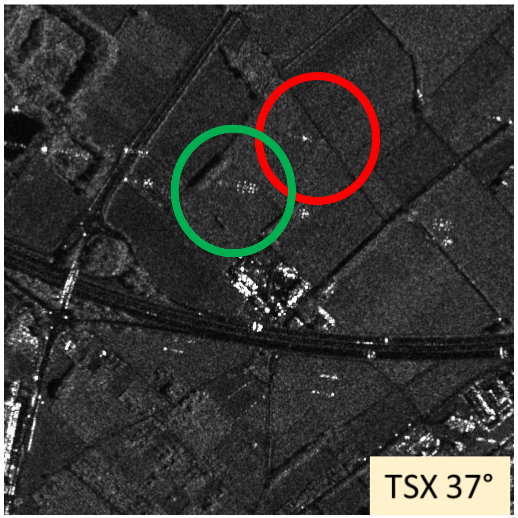
→ Strong influence and the backscattered radiometries

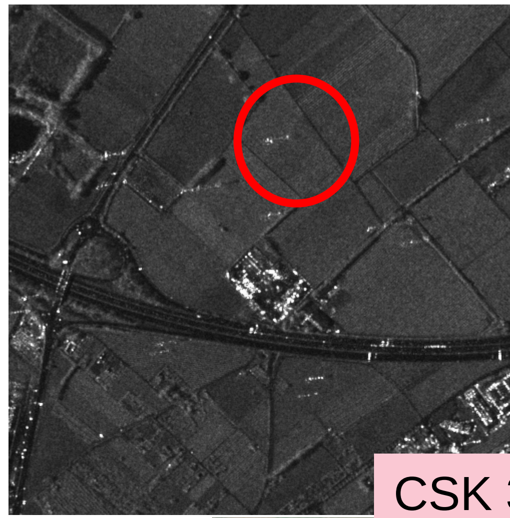
Backscattering mechanisms: metallic objects

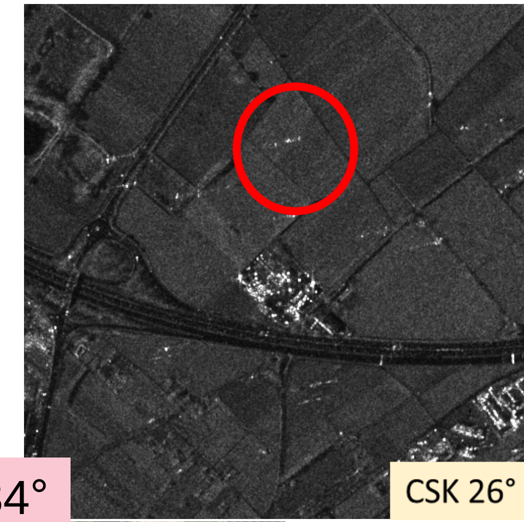
- No propagation in the metal
- Wave fully backscattered



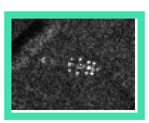
TSX and CSK on Martigny (ideal case):pylons

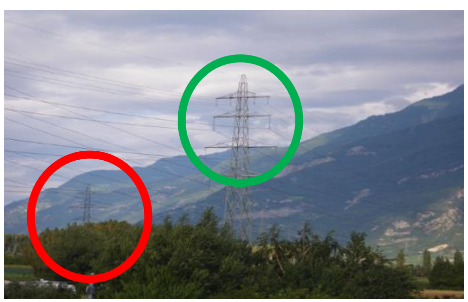




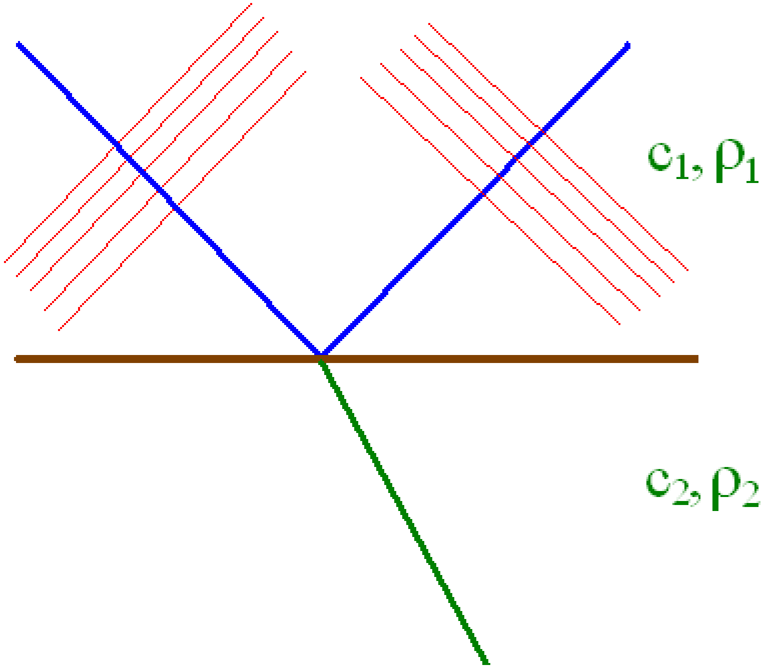


CSK 34°





Dioptre : change of medium

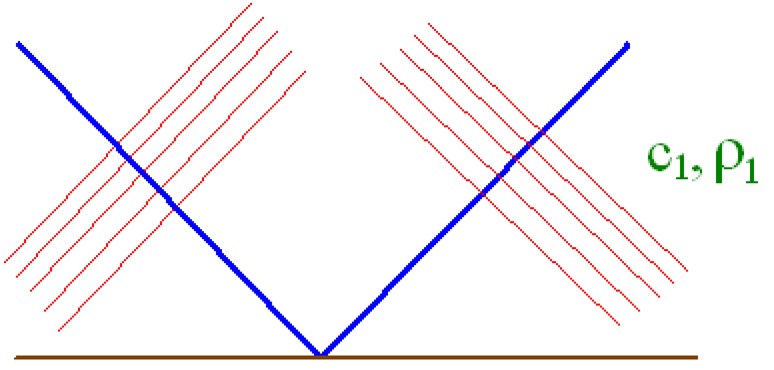


- **Snell Descartes**

$$\theta_1' = \theta_1$$

$$\frac{1}{c_2}\sin\theta_2 = \frac{1}{c_1}\sin\theta_1$$

Dioptre : conductive (metal)

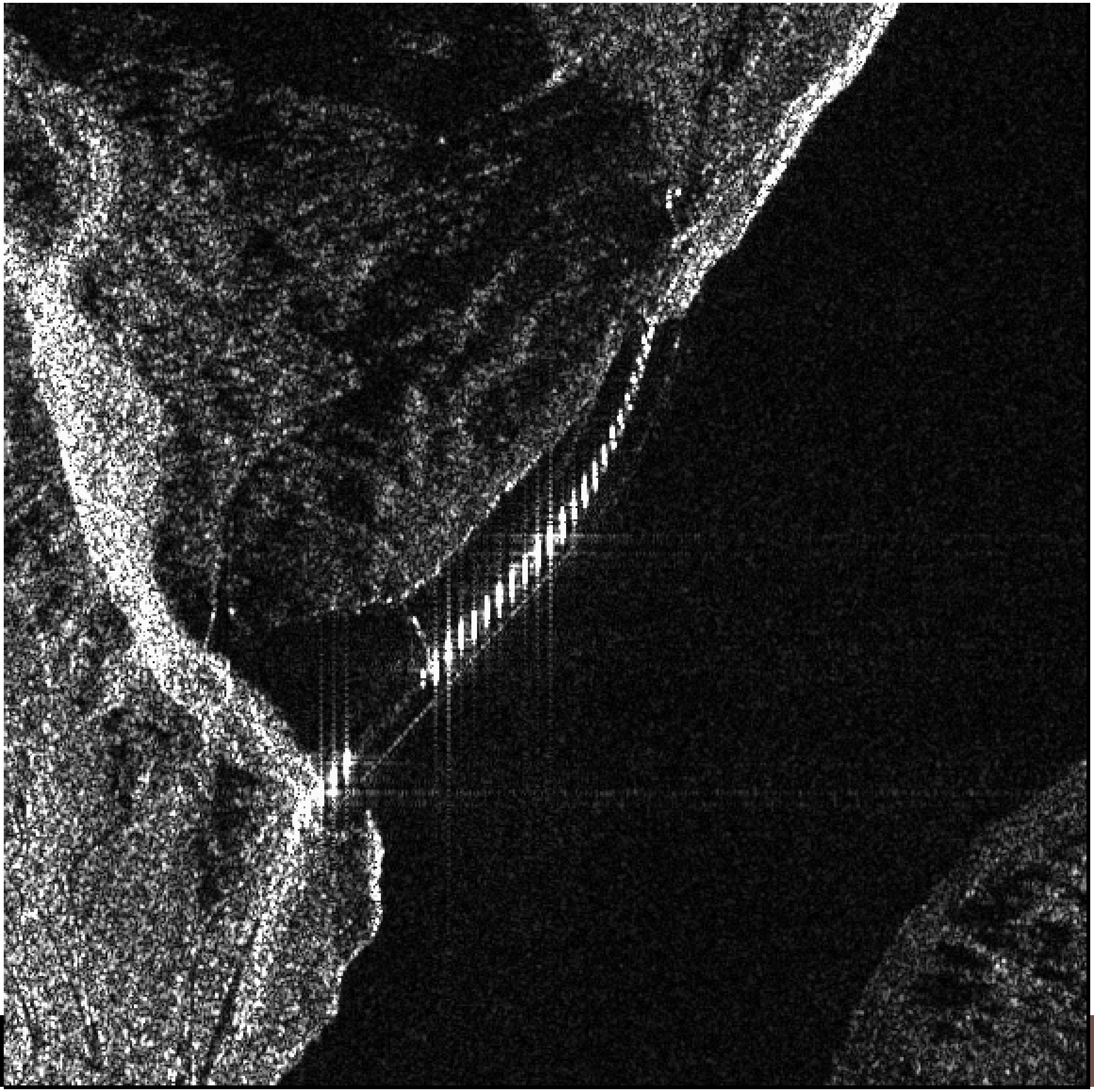


- **Snell Descartes**

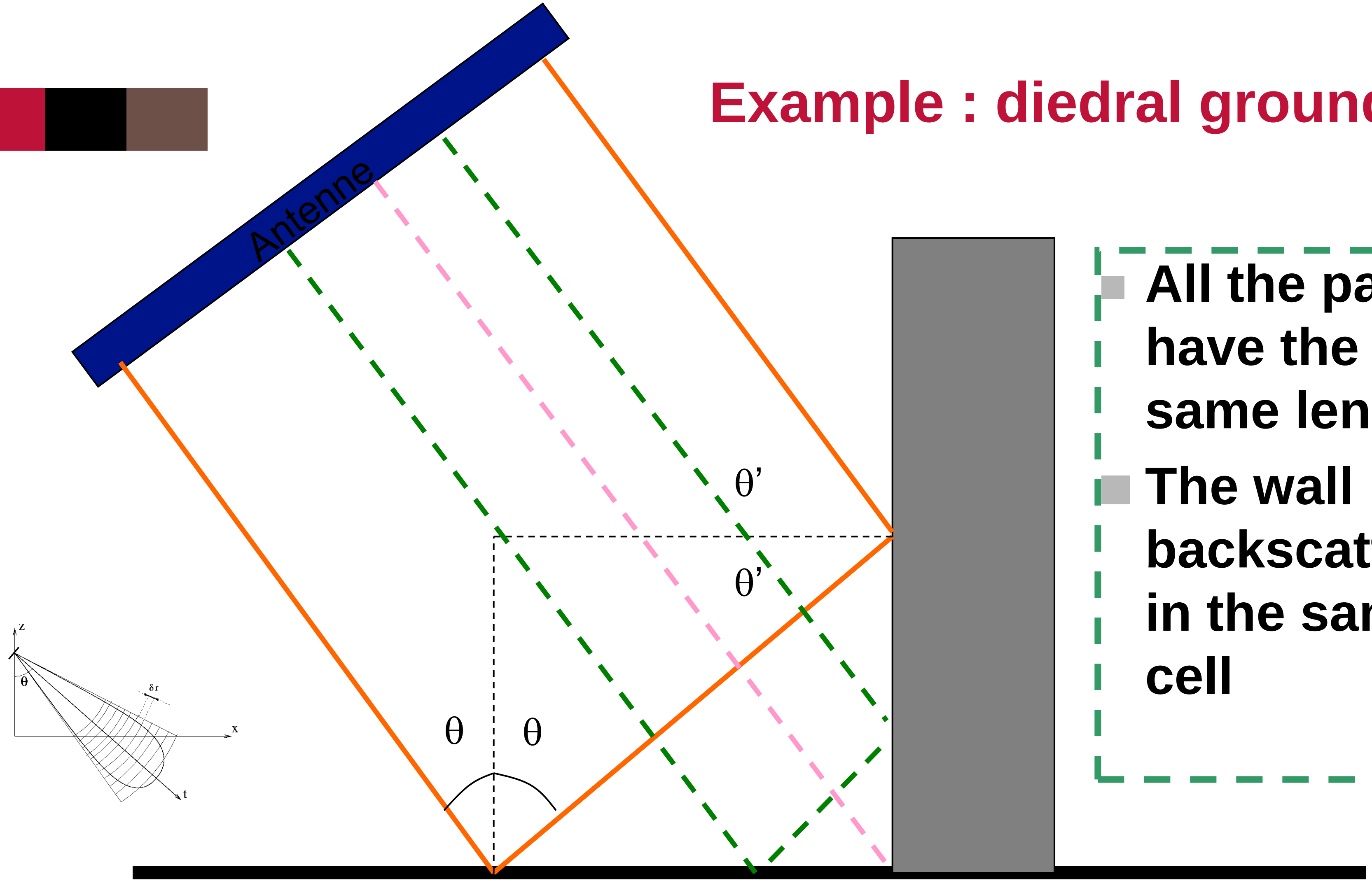
$$\theta_1^{'} = \theta_1$$

- **Only backscattered wave : « full backscattering »**
- **No recorded signal at the emitting antenna**
- **Water is (poorly) conductive**

Roselend lake(Terrasar-X) : black water….



Example : diedral ground/wall



- All the paths have the same length
- The wall is backscattered in the same cell

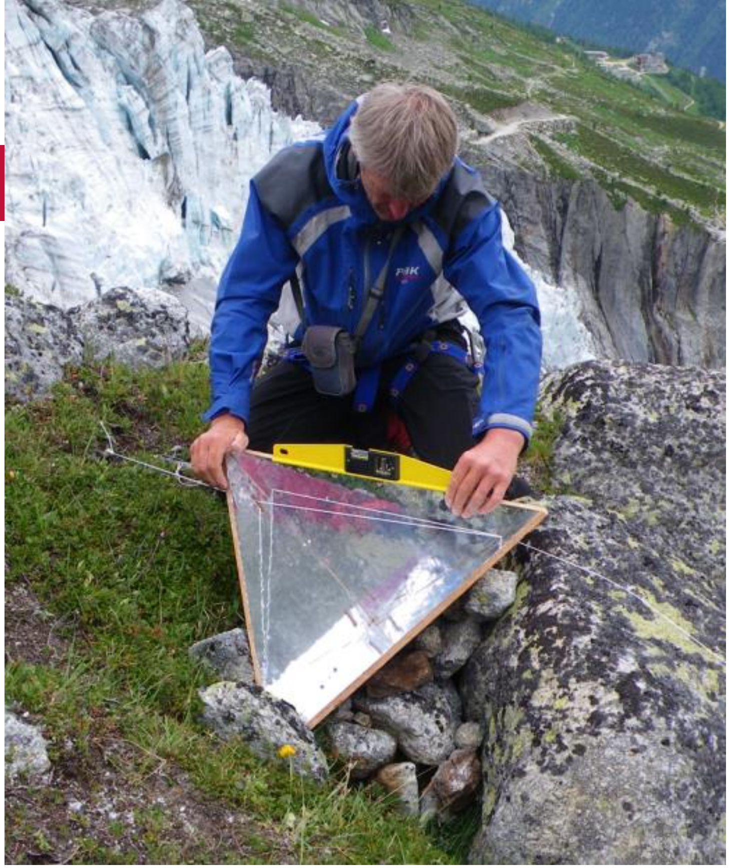
- $2\theta + 2\theta' = \pi$ >> the wave is backscattered towards the sensor

Canonical targets : triedre « corner reflector »

- triedral: 3 sides of length a with 90°
- 3 back. signals
- All the signal back. in the same cell

$$\sigma_{trièdre} = \frac{4\pi a^4}{3\lambda^2}$$

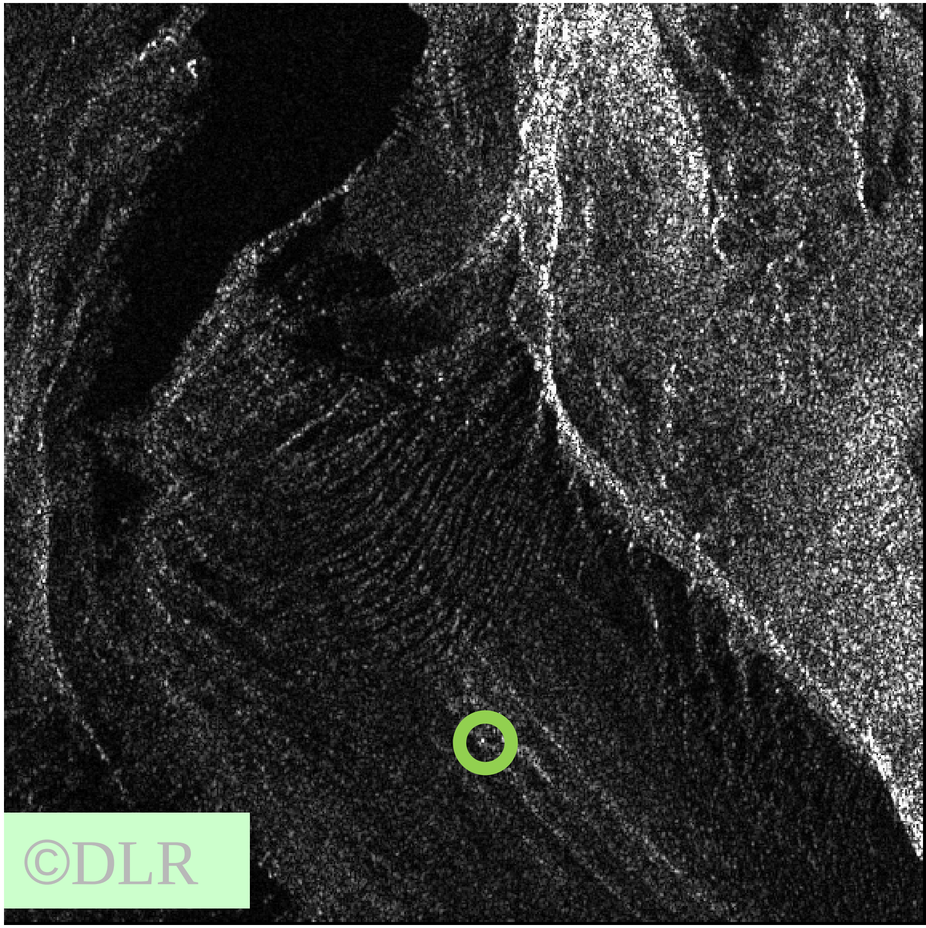
$$\theta_a = \pm 20°$$
$$\theta_b = \pm 20°$$



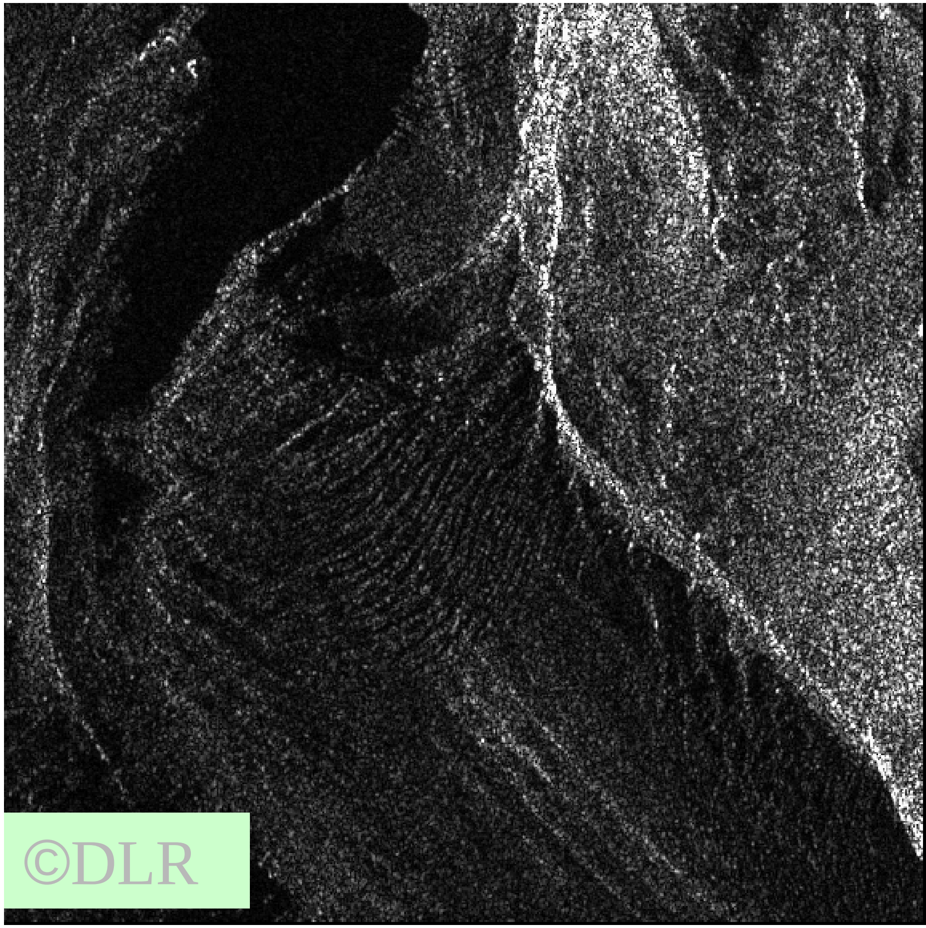
Isolated target

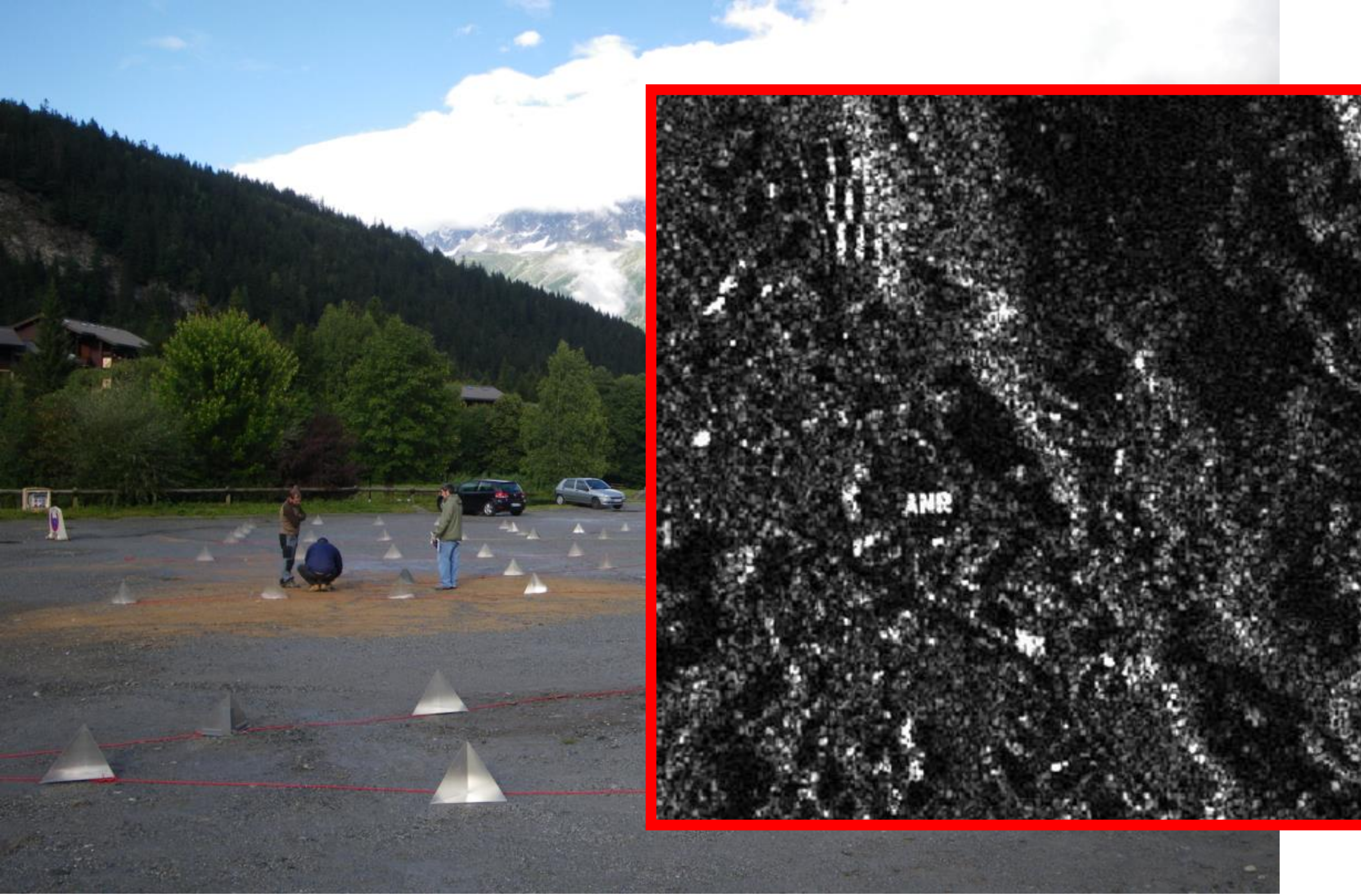
- **Ideal case : « corner reflector »**
  - Almost omnidirectional
  - Prevails all the backscattered signals in the resolution cell

Man-made targets on the glacier



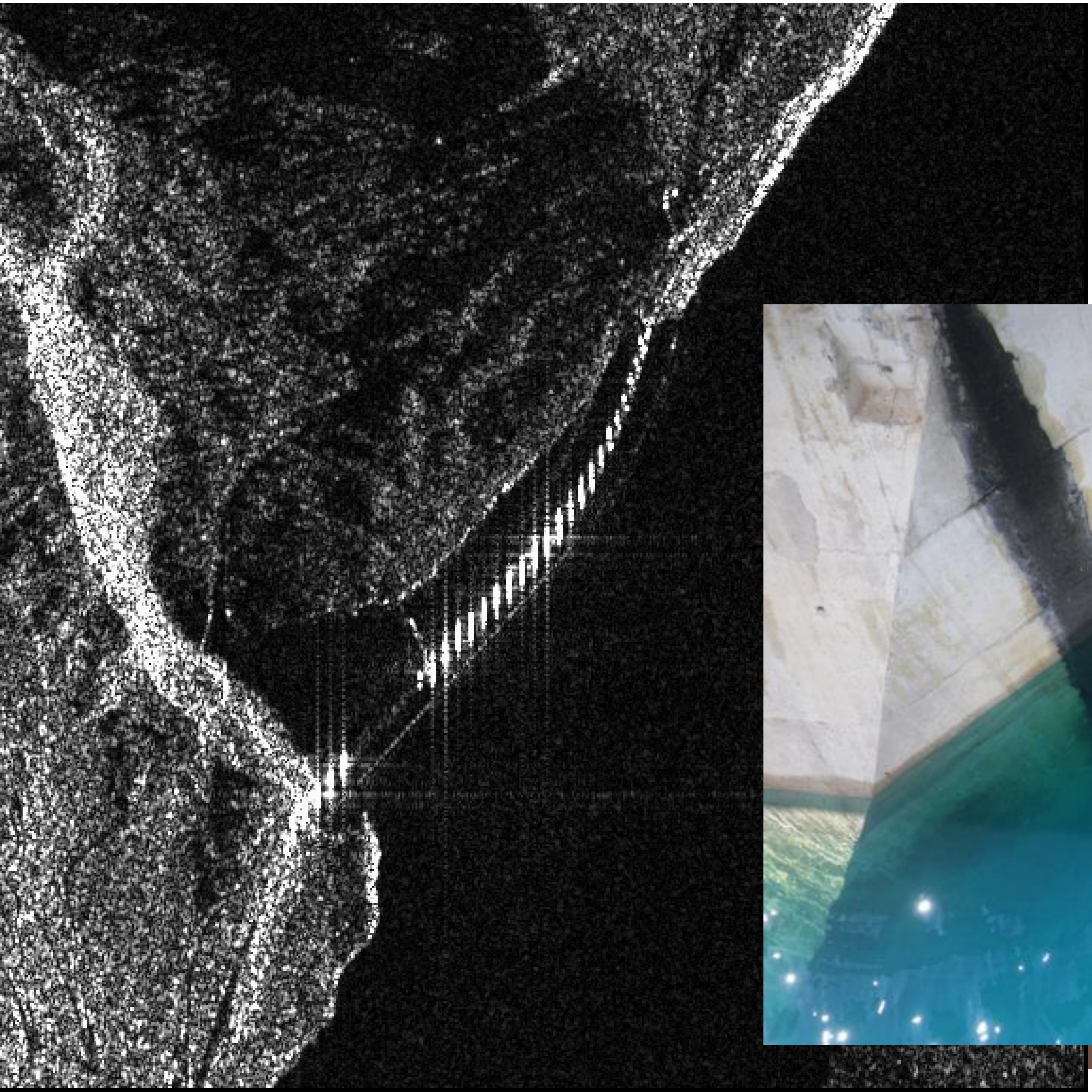
Man-made targets on the glacier





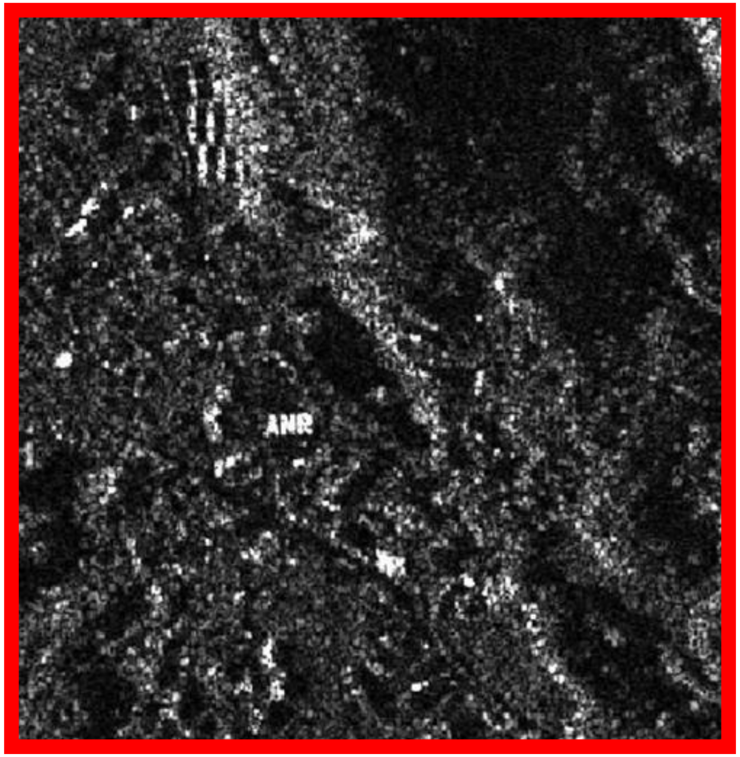
ANR

Man-made targets : suite….
Roselend lake (Terrasar-X)

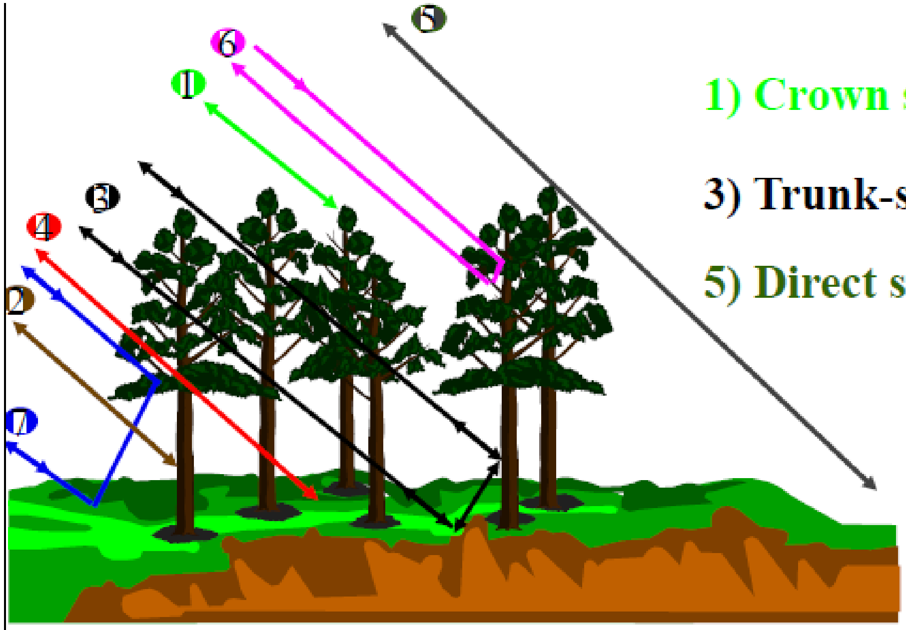


Targets and object appearance

- **Bright targets :**
  - Trihedral / dihedral strucures (man-made objects, urban areas)
- **Surface area:**
  - Depends on the roughness
  - Depends on the geometric configuration
  - Dielectric properties (water content, humidity)
- **Many objects in the resolution cell:**
  - Speckle



Volume scattering mechanisms



Examples of main backscattering mechanisms on the forest

◆ **Volume backscattering** mechanisms generally rely on interaction mechanisms which are highly **complex** and still not well-known. **Main trends**:

- ➔ Backscattering coefficient ↗ when vegetation volume (biomass) ↗
- ➔ Wavelength penetration ↗ when frequency ↘ , i.e. when wavelenght ↗

Backscattering of a cell

$$U_{\omega}(P,t) \approx \frac{1}{R(P)} \iint_{\Sigma} e^{j4\pi \frac{x \sin\theta}{\lambda}} A(x,y)\, ds$$

- **A(x,y) is characteristic of the imaged area**
- **A(x,y) can be complex :**
  - Amplitude : backscattering coefficient
  - Phase : delays or delocalisation inside the pixel
- **→Directivity of the backscattered signal : dépends on A(x,y)**
  - The diagram of the local ground antenna is not known

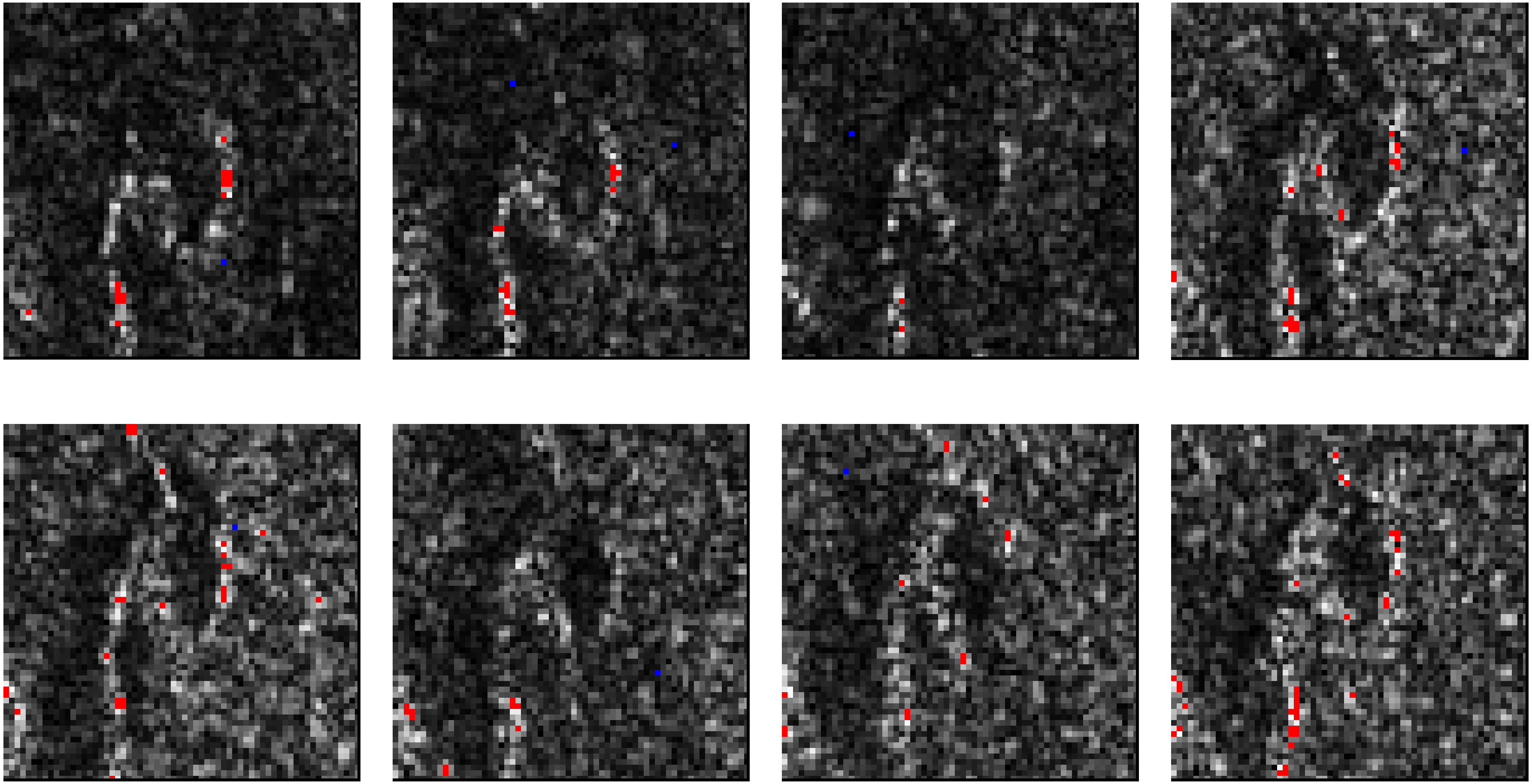
Backscattering of a cell

$$U_\omega(P,t) \approx \frac{1}{R(P)} \iint_\Sigma e^{j4\pi \frac{x \sin\theta}{\lambda}} A(x,y)\, ds$$

- **An object on the ground is defined by its RCS (Radar Cross Section) or SER (Section Efficace Radar) :**
  - Depends on the material (dielectric properties, roughness)
  - Depends on the shape (geometry)
- **SER**
  - ratio between emitted power and backscattered power
  - Depends of the antenna gain

Glacier of Argentière : erratic block

Variable orientation ⇒ variable backscattering

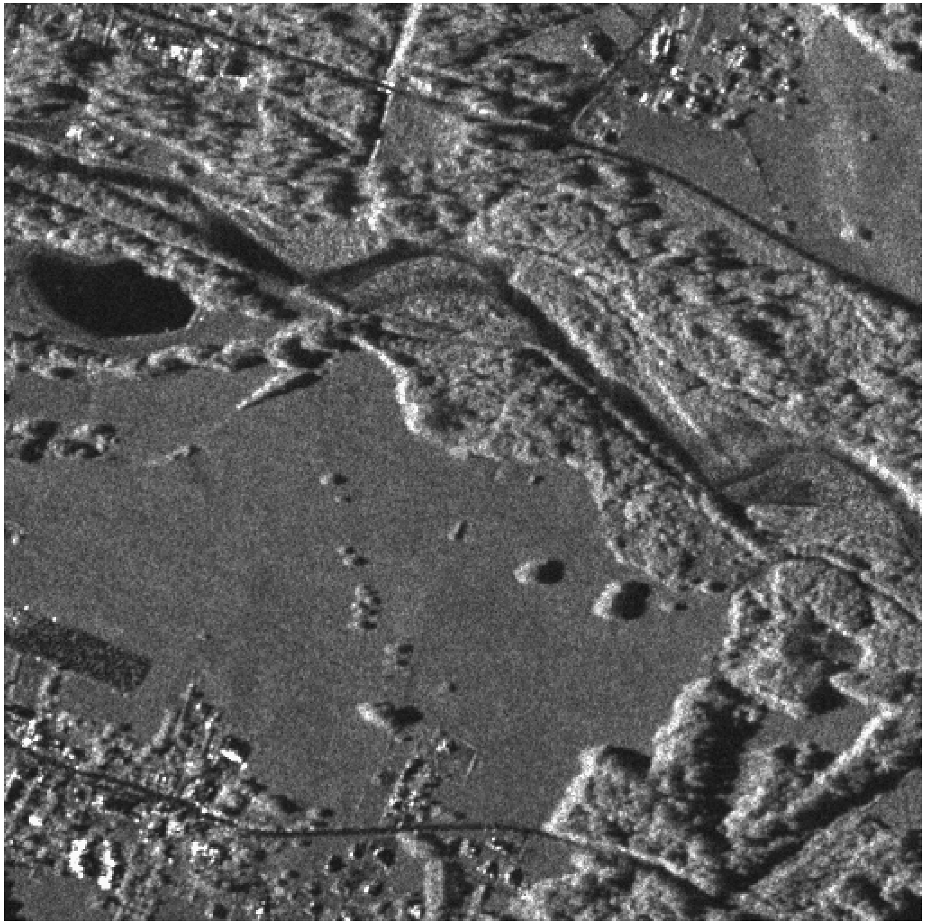


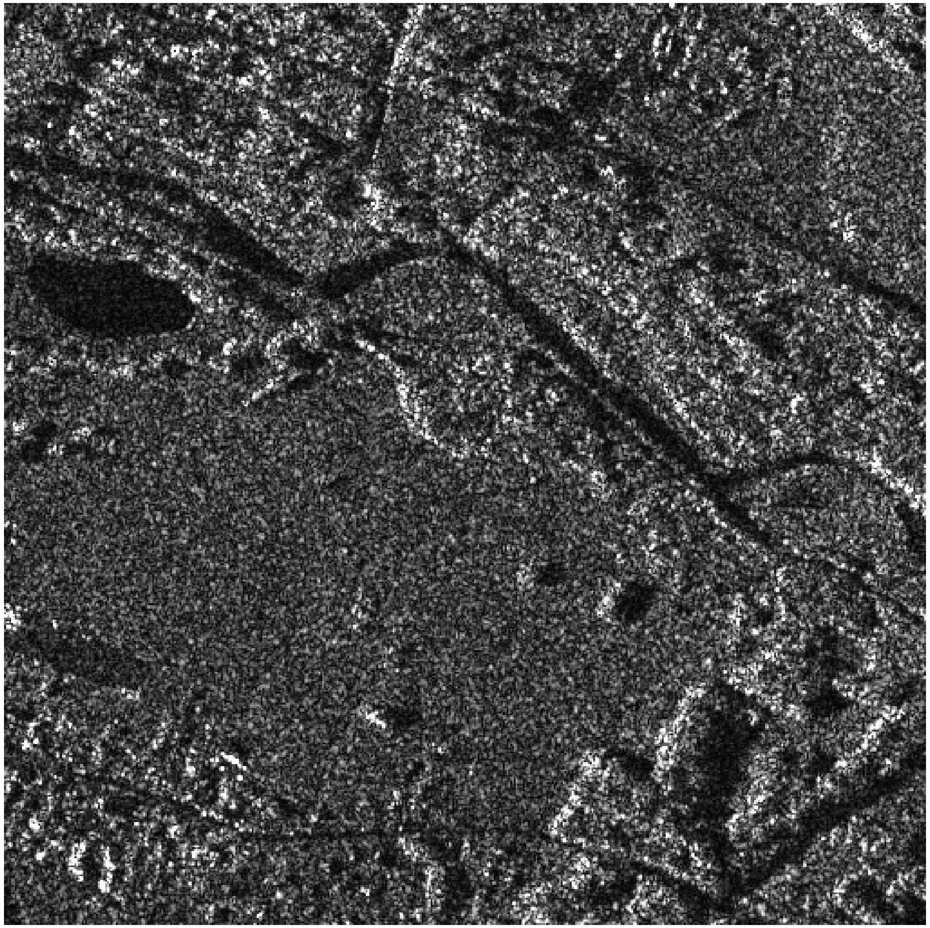
Same incidence angle

Between june and september 2009

Speckle

Image Terrasar-X (~2m) : speckle





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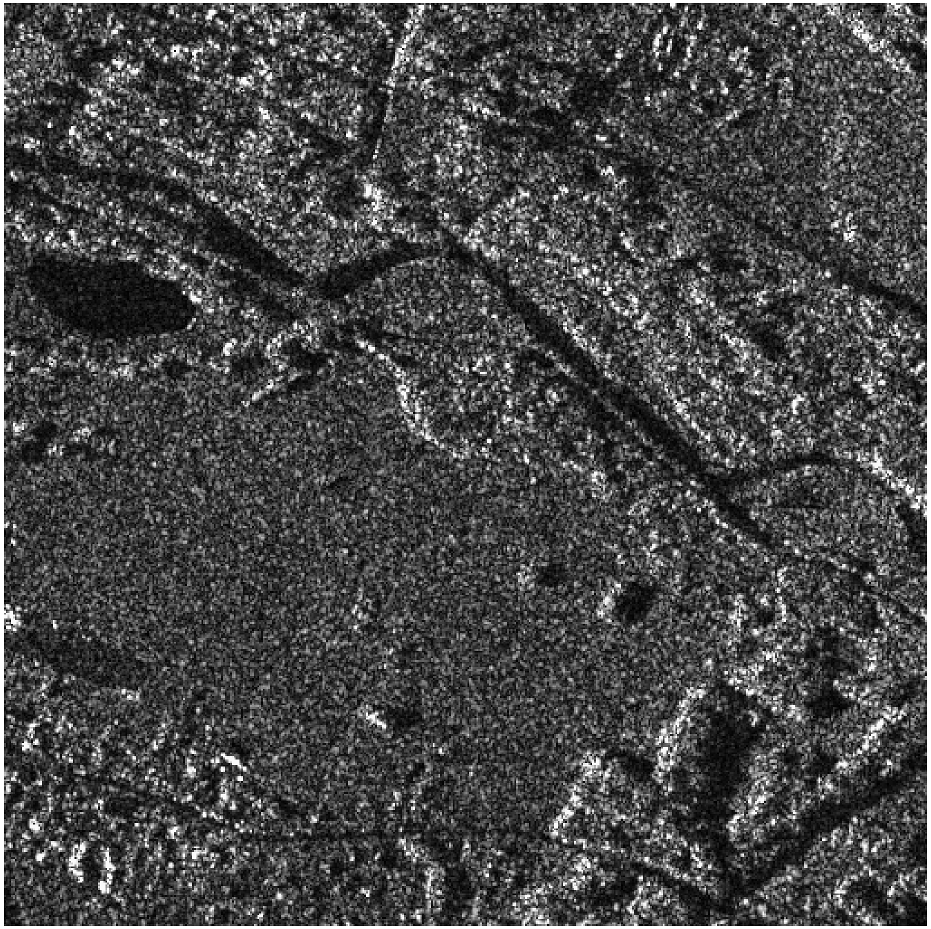
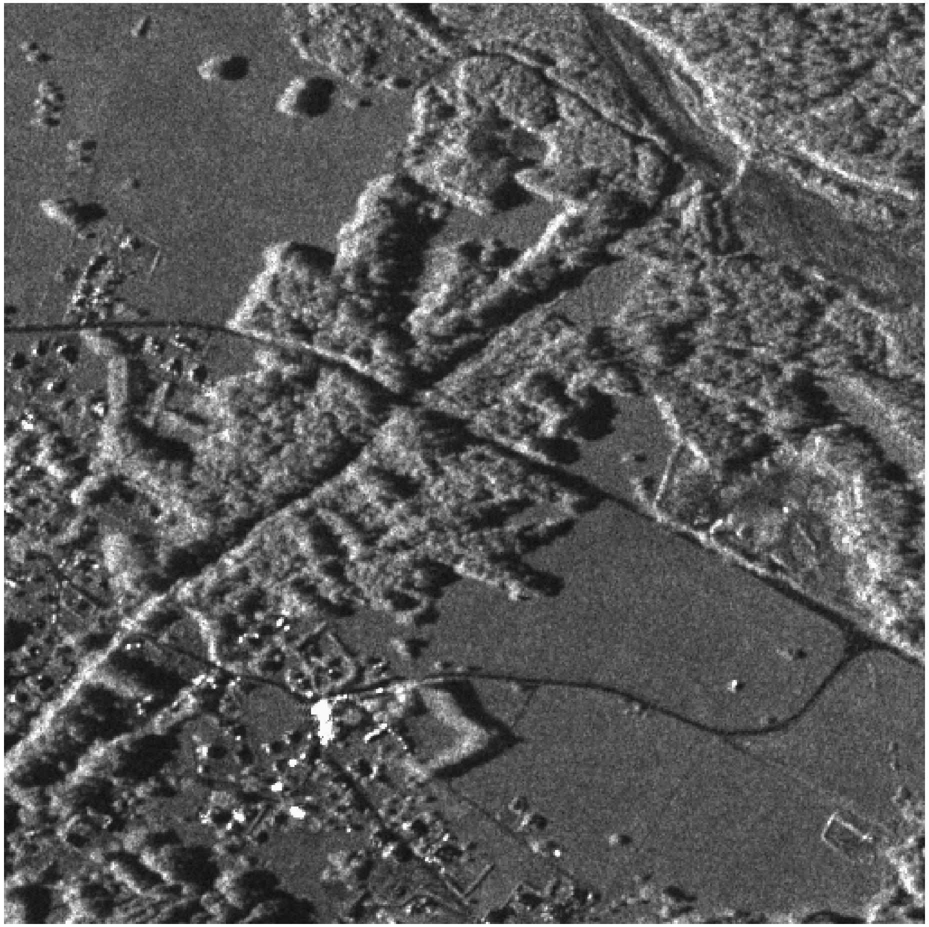


Speckle



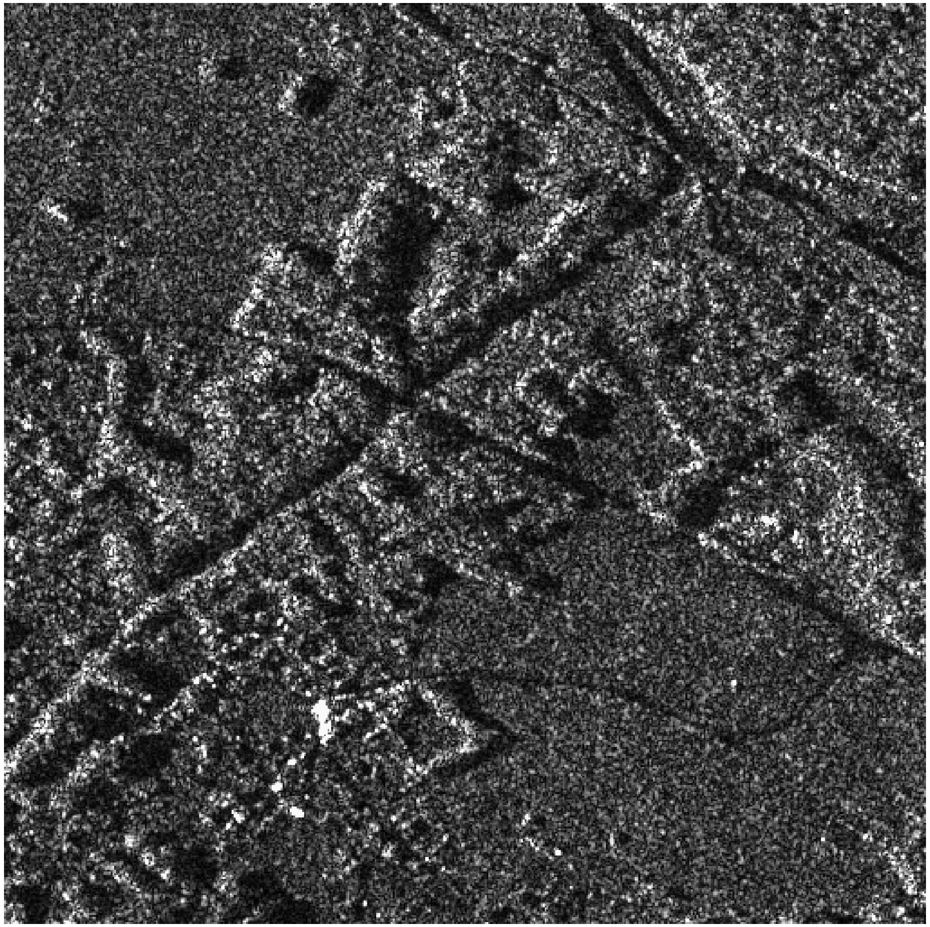
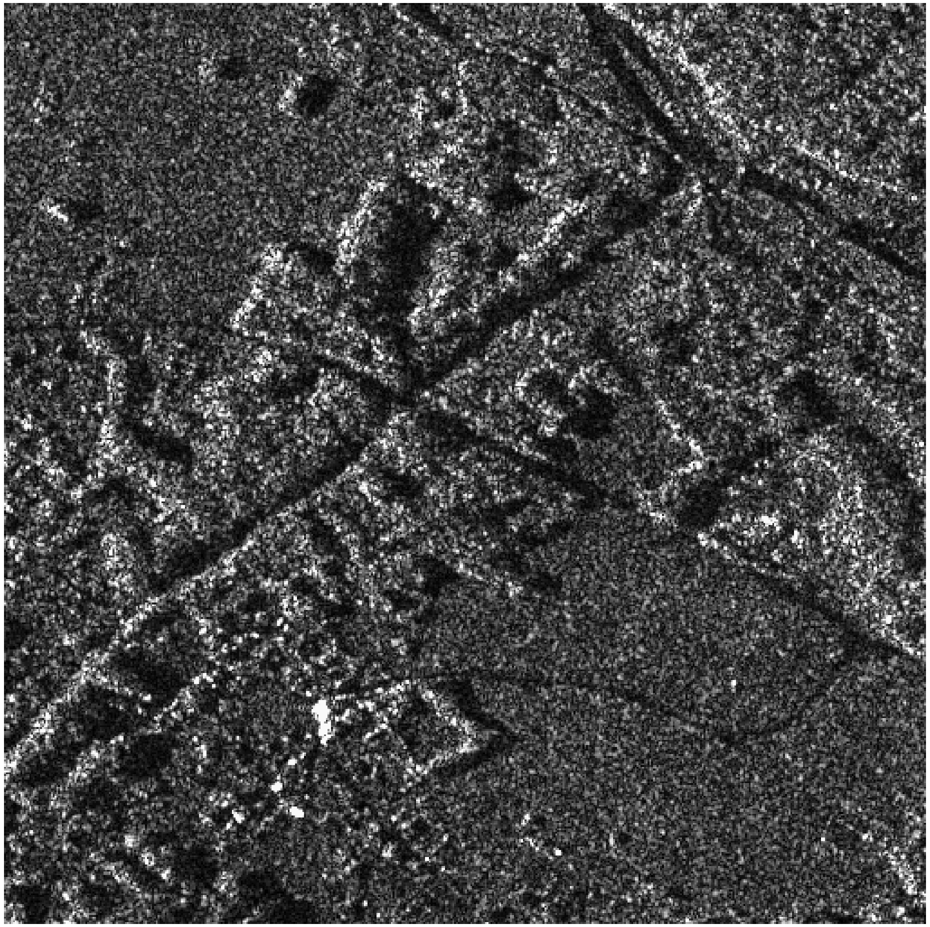
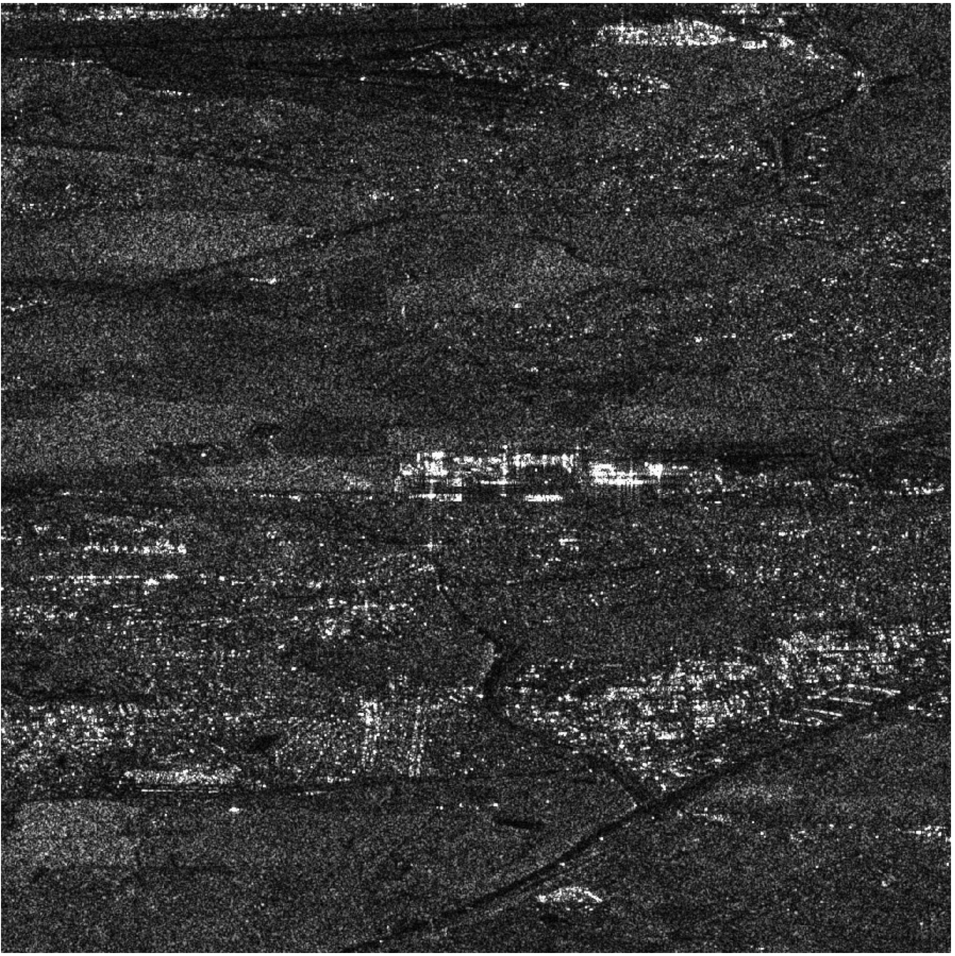


Image Terrasar-X (~2m) : speckle



Speckle (Sentinel, decametric resolution)



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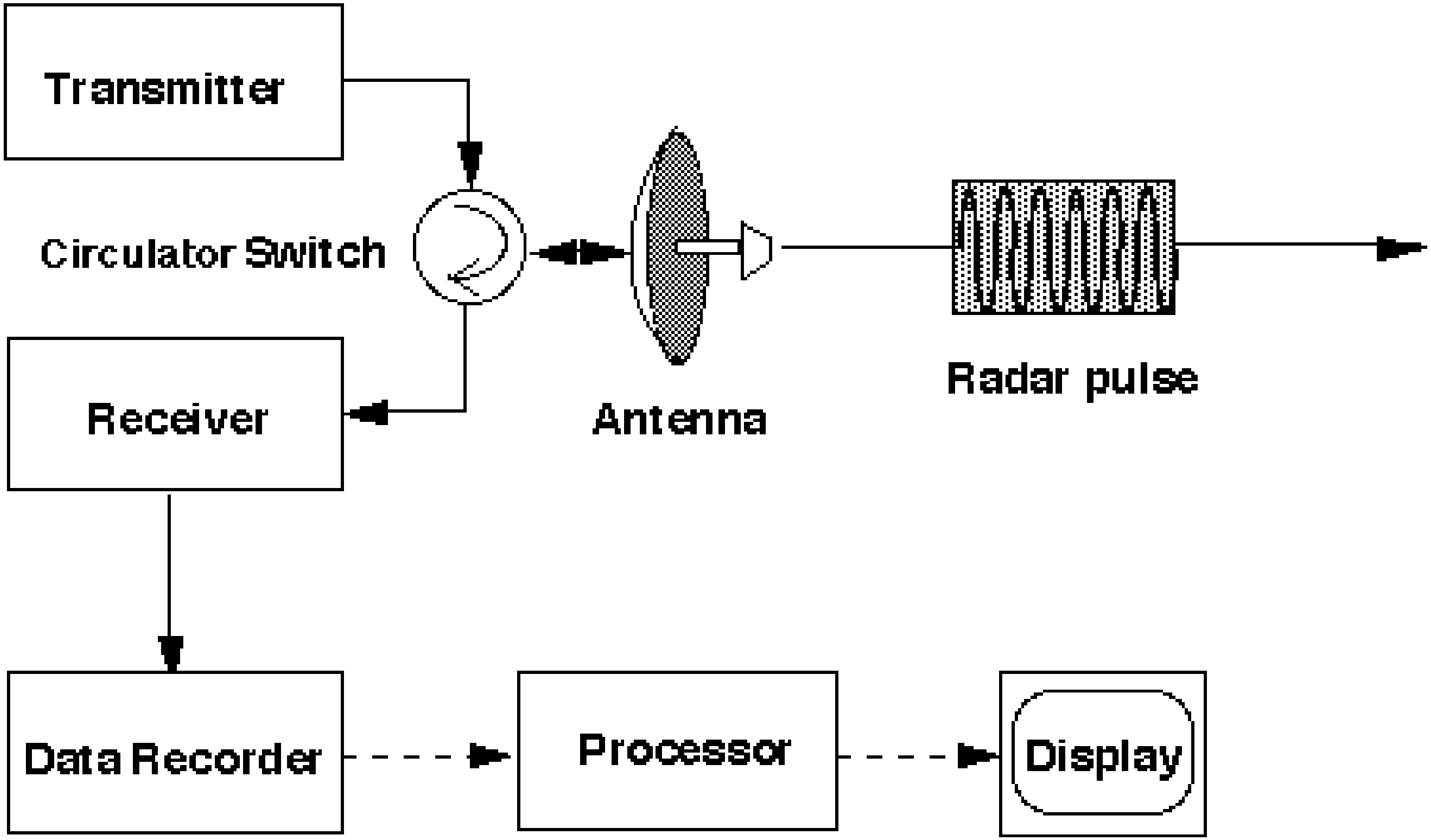
Overview

- **Principle of radar acquisition**
- **Examples of SAR images**
- **SAR image acquisition**
  - Range direction and chirp
  - Azimuth direction and synthetic aperture
- **Some SAR systems and applications**

SAR history

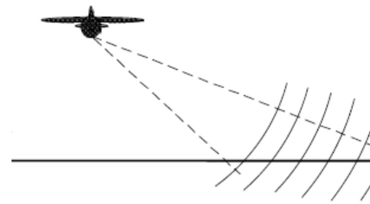
- Principles defined by Wiley (1951)
- Imaging of moon surface (Apollo 17)
- First american experiment SEASAT (1978)
- URSS realizations (Kosmos et Almaz)
- Use of the Shuttle : SIR (1982,1984 et 1994) and SRTM (2000)
- Europe (ESA) : ERS (1991,1995) et Envisat (2002)
- Japan (1992,2006) and Canada (1995)

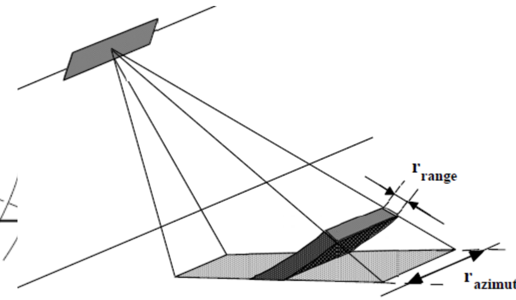
Principles of radar: transmitter and receiver



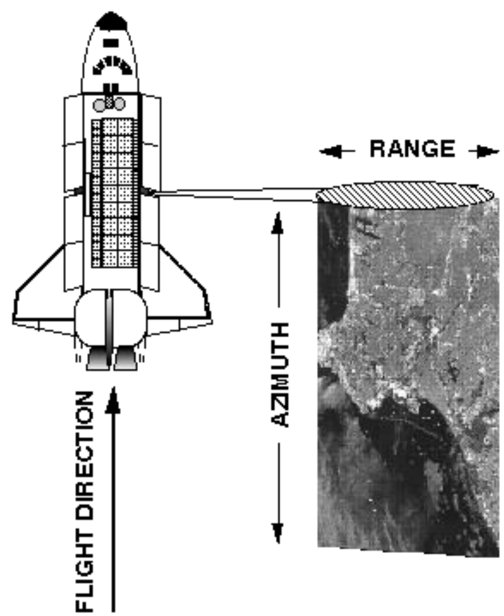
2 principles of SAR acquisition

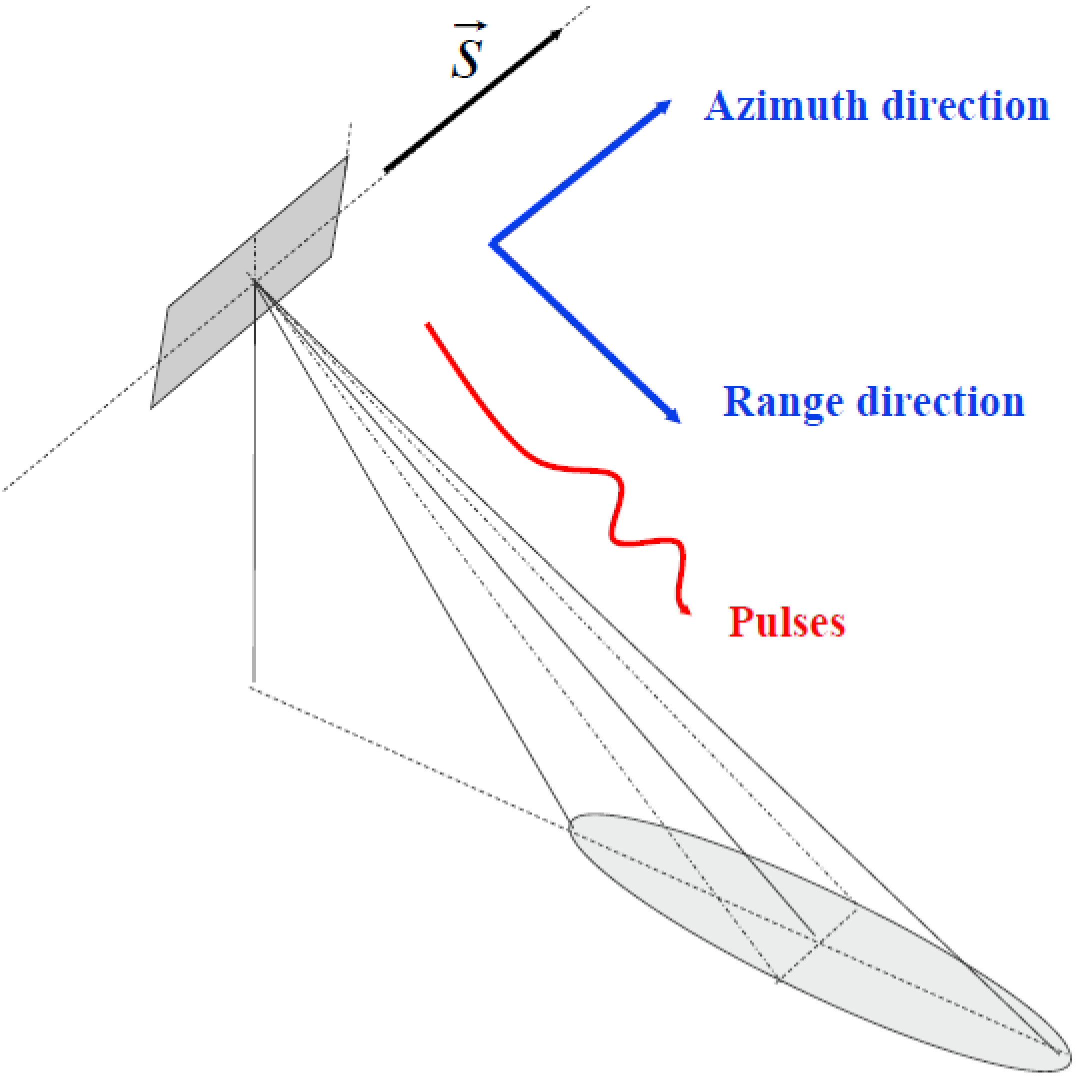
- **Range direction: time (= distance) sampling**
- **Azimuth direction (flight) : antenna spread**



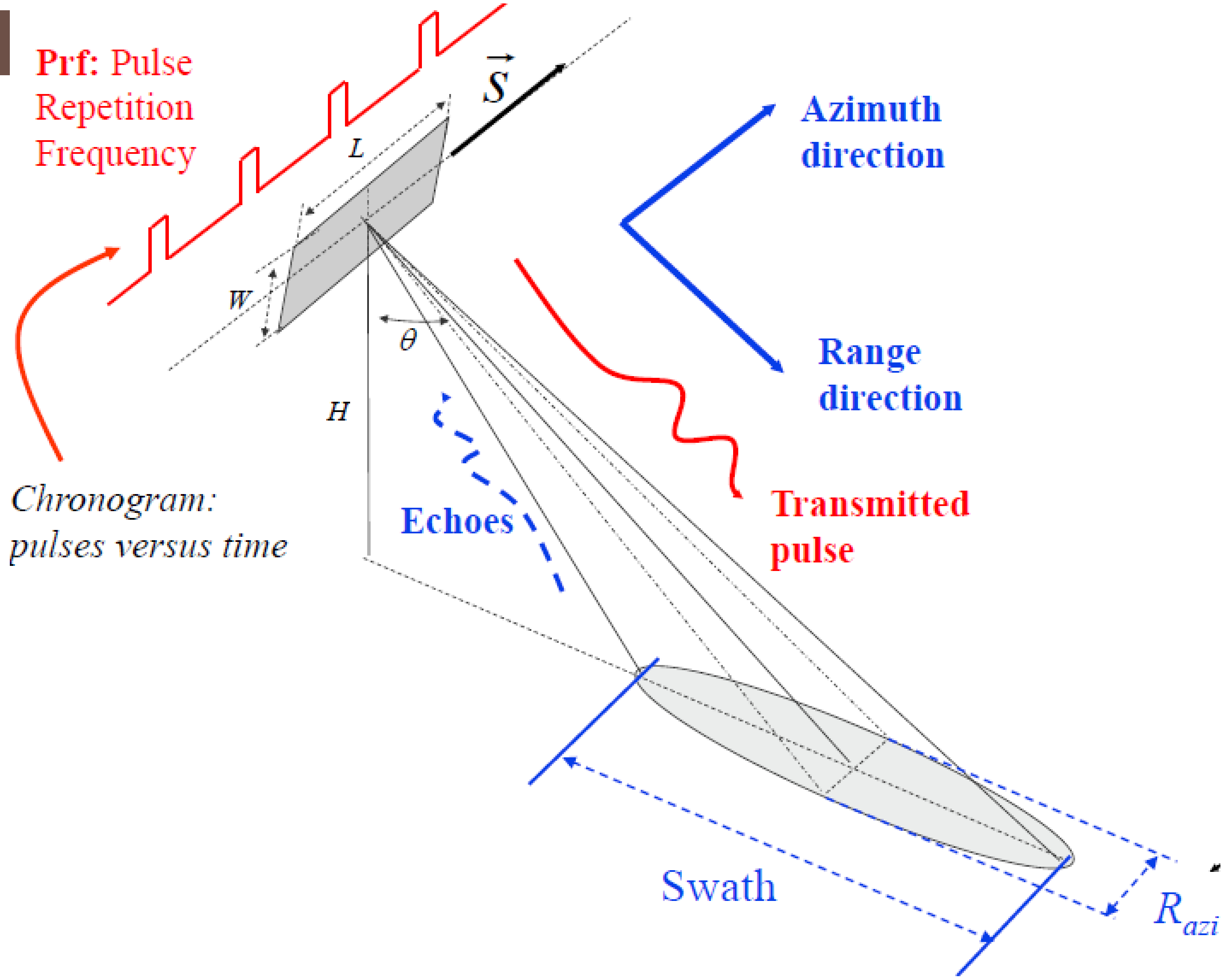


- **Two dimensions :**
  - 1 pulse in range = 1 line
  - Sampling in time = time cell



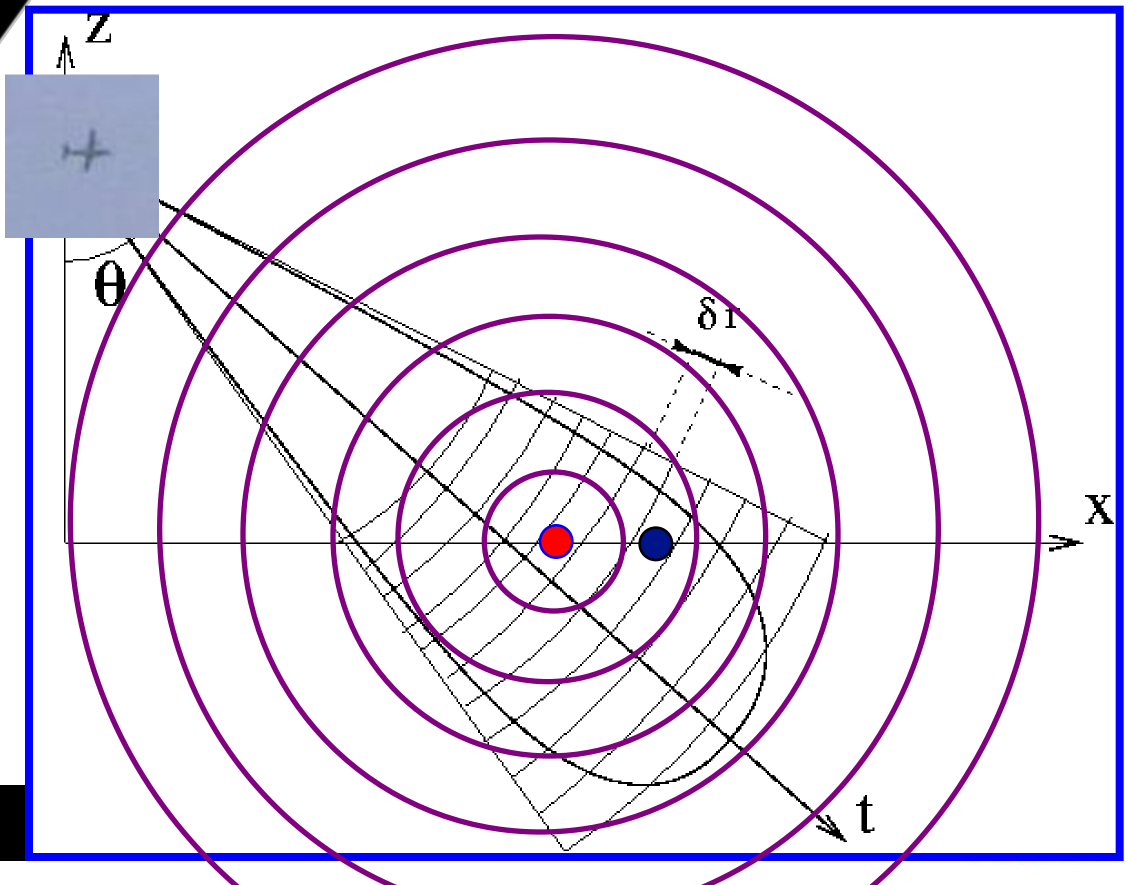


$\vec{S}$
Azimuth direction
Range direction
Pulses

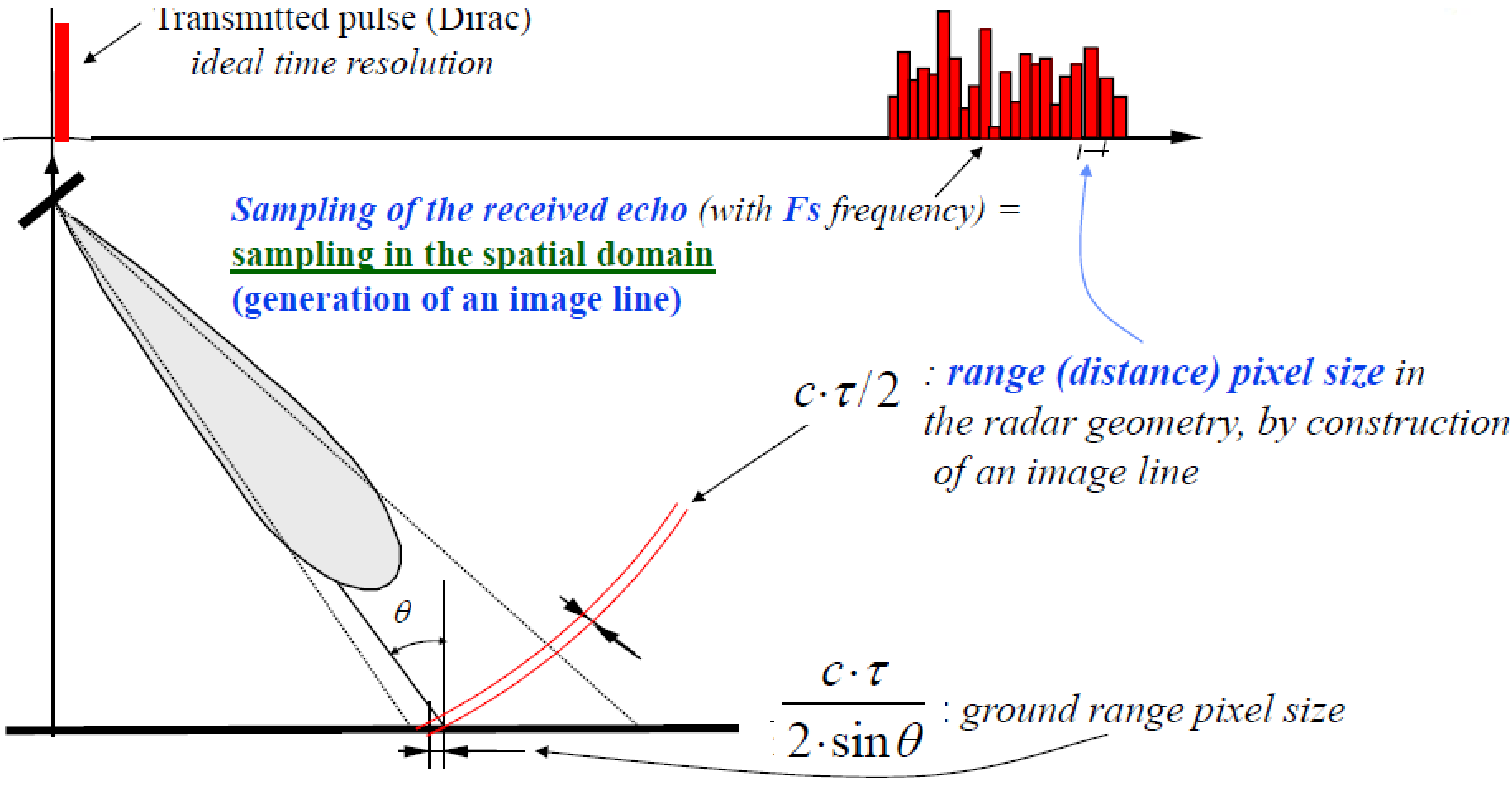

Prf: Pulse Repetition Frequency
Chronogram: pulses versus time
S
L
W
θ
H
Azimuth direction
Range direction
Transmitted pulse
Echoes
Swath
R_{azi}

« Ranging » : Echolocation

- Lateral viewing
- between 20° et 50°

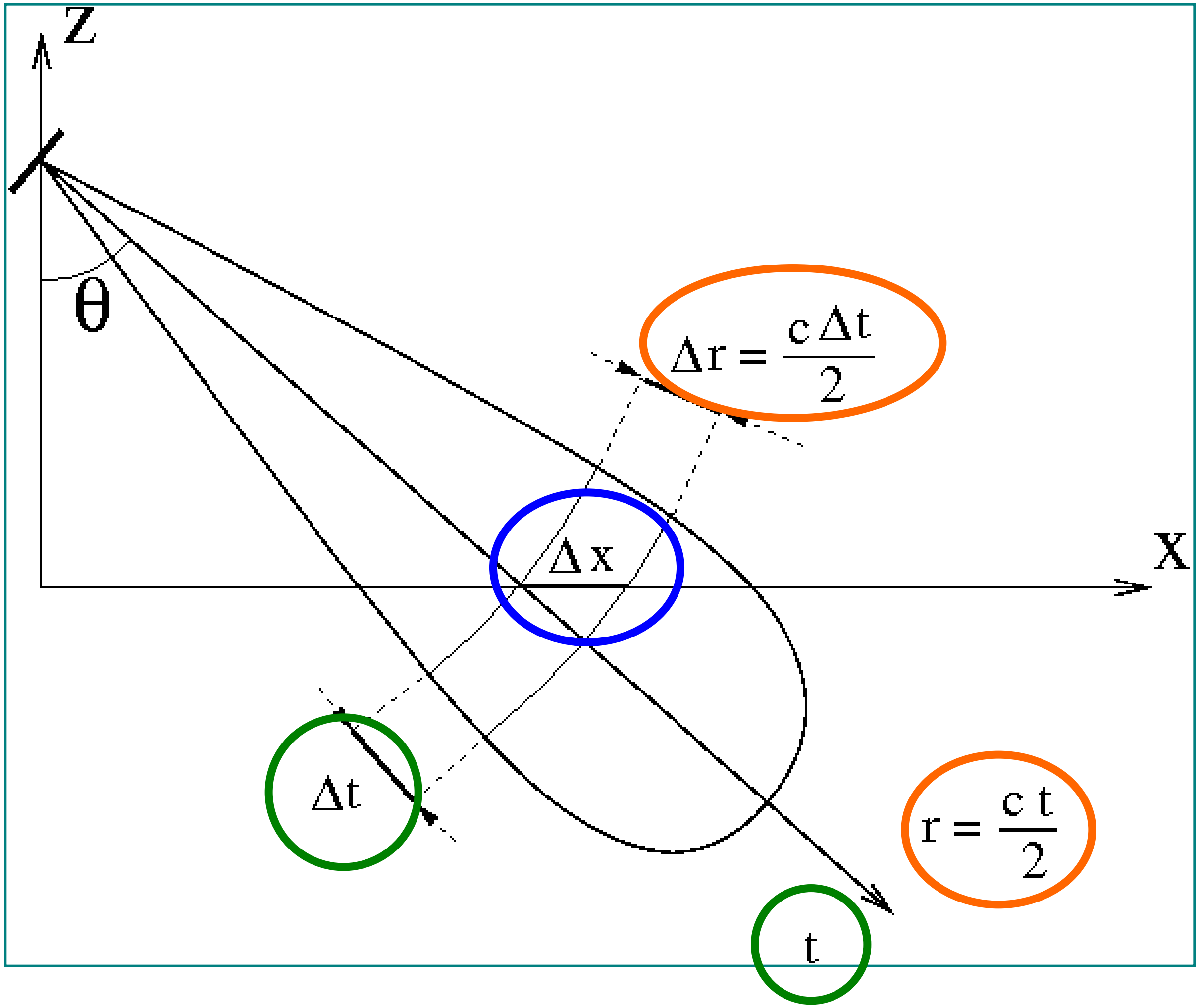


Range cell= Image column



Transmitted pulse (Dirac)
ideal time resolution
Sampling of the received echo (with Fs frequency) =
sampling in the spatial domain
(generation of an image line)
$c \cdot \tau / 2$
: range (distance) pixel size in the radar geometry, by construction of an image line
θ
$\frac{c \cdot \tau}{2 \cdot \sin\theta}$
: ground range pixel size

Sampling (time, range, ground) $\Delta t \leftrightarrow \Delta r \leftrightarrow \Delta x$



- **Time cell:**

$$\Delta t$$

- **Range cell:**

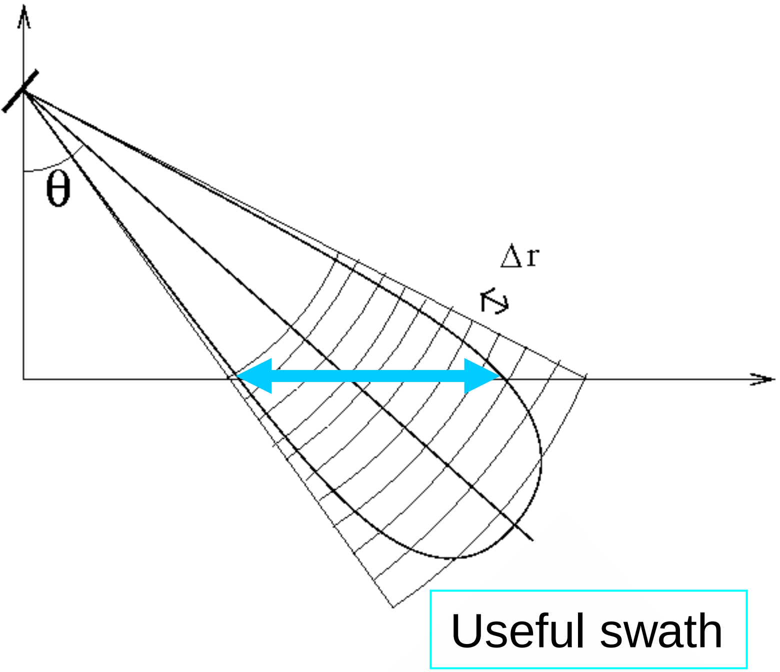
$$\Delta r = \frac{c\,\Delta t}{2}$$

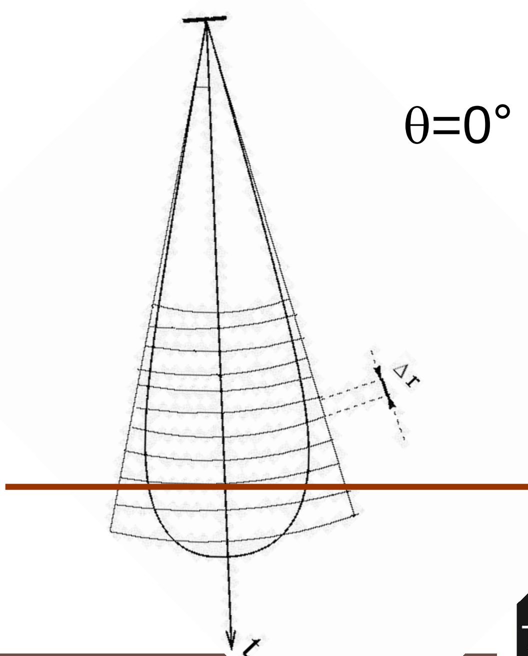
- **Ground range cell**

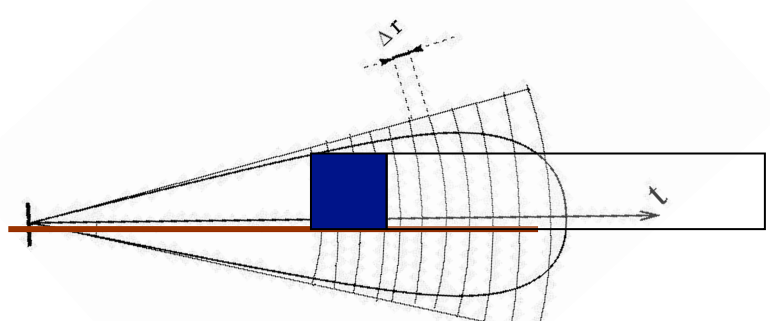
$$\Delta x = \frac{\Delta r}{\sin\theta}$$

Lateral viewing: incidence angle

- **Object location through time**
- **« range cell »**
- **Nadir viewing no possible : 1 cell!**
- **Horizontal viewing: shadows**

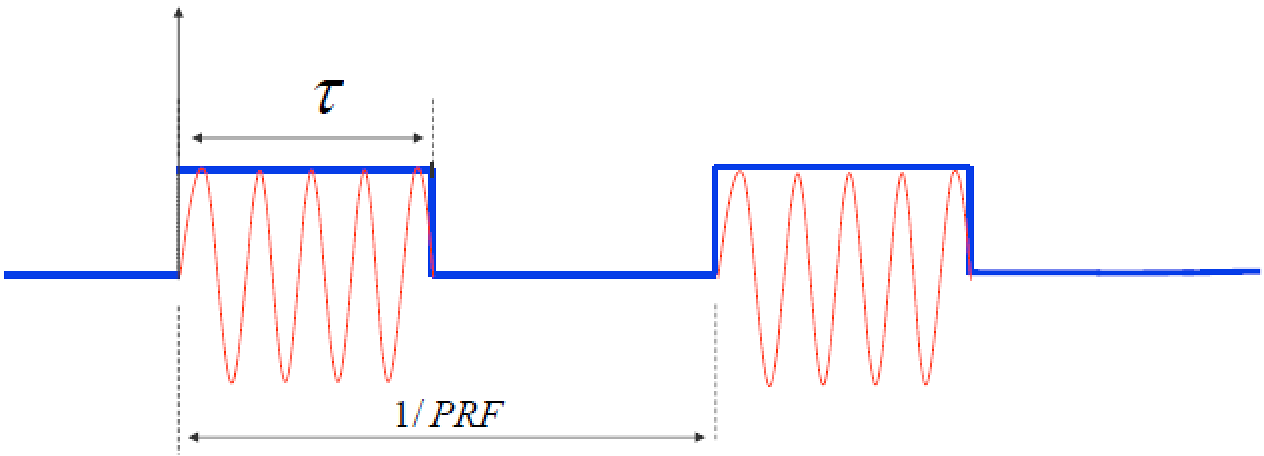


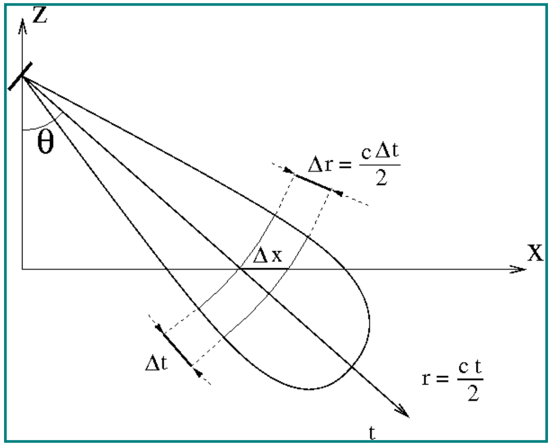




θ=90° : shadow behind the objects

Range resolution





$$t_1 = 2\frac{R_1}{c}$$

$$t_2 = 2\frac{R_2}{c}$$

$$t_2 - t_1 > \tau \iff R_2 - R_1 > \frac{c\tau}{2}$$

- **Resolution:** $\dfrac{c \cdot \tau}{2 \cdot \sin\theta}$
- **ERS :** $\tau \approx 37\ \mu s$ **resolution: a few km (5 km)**

➡ **Improvement of the resolution by chirp emission**

Backscattering of a target

- **Emitted signal:** $s_e(t)$
- **Target at distance *d* :**
  - *Outward :* $$\delta\left(t-\frac{d}{c}\right)$$
- **Target backscattering : *R(t)***
- **Target at distance *d* :**
  - *Backward:* $$\delta\left(t-\frac{d}{c}\right)$$
- **Backscattered signal :** $s_r(t)$

$$s_r(t)=\delta\left(t-\frac{2d}{c}\right)*R(t)*s_e(t)$$

Backscattering of a target

- **Target at distance *d***
- **Backscattering of the target : *R(t)***

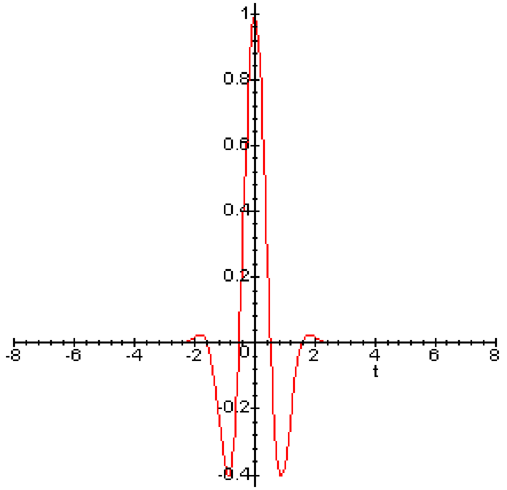
$$s_r(t) = \delta\left(t - \frac{2d}{c}\right) * R(t) * s_e(t)$$

- **Other target at distance *d'***
- **Backscattering of the target : *R'(t)***

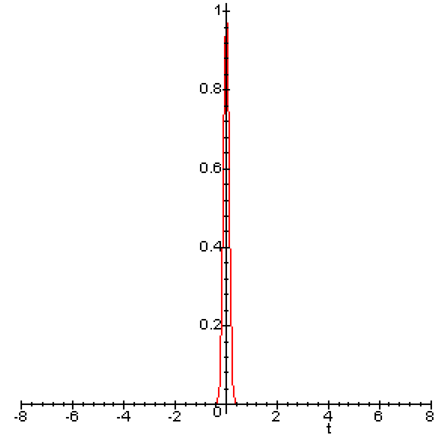
$$s'_r(t) = \delta\left(t - \frac{2d'}{c}\right) * R'(t) * s_e(t)$$

Signal and backscattering

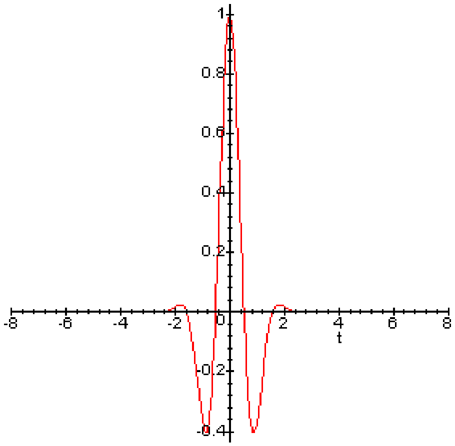
- **Example of « ideal » emitted signal**



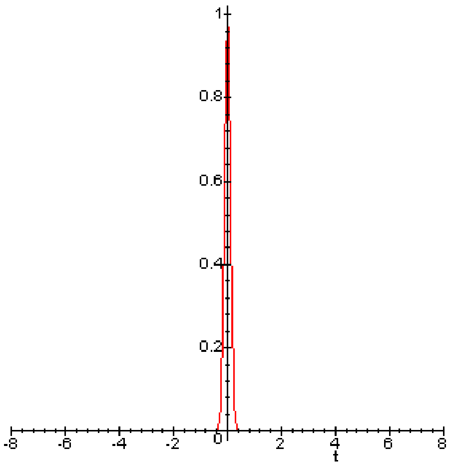
- **Example of « ideal » target**



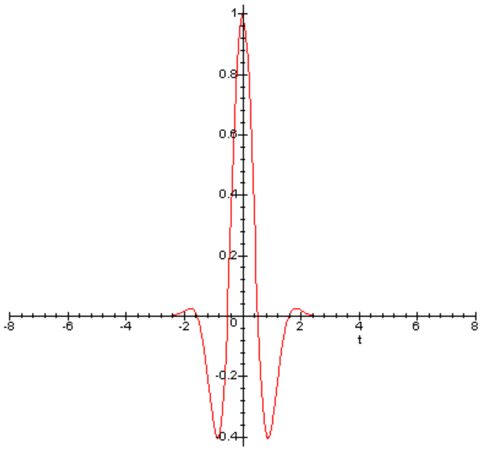
Signal reçu : convolution



*

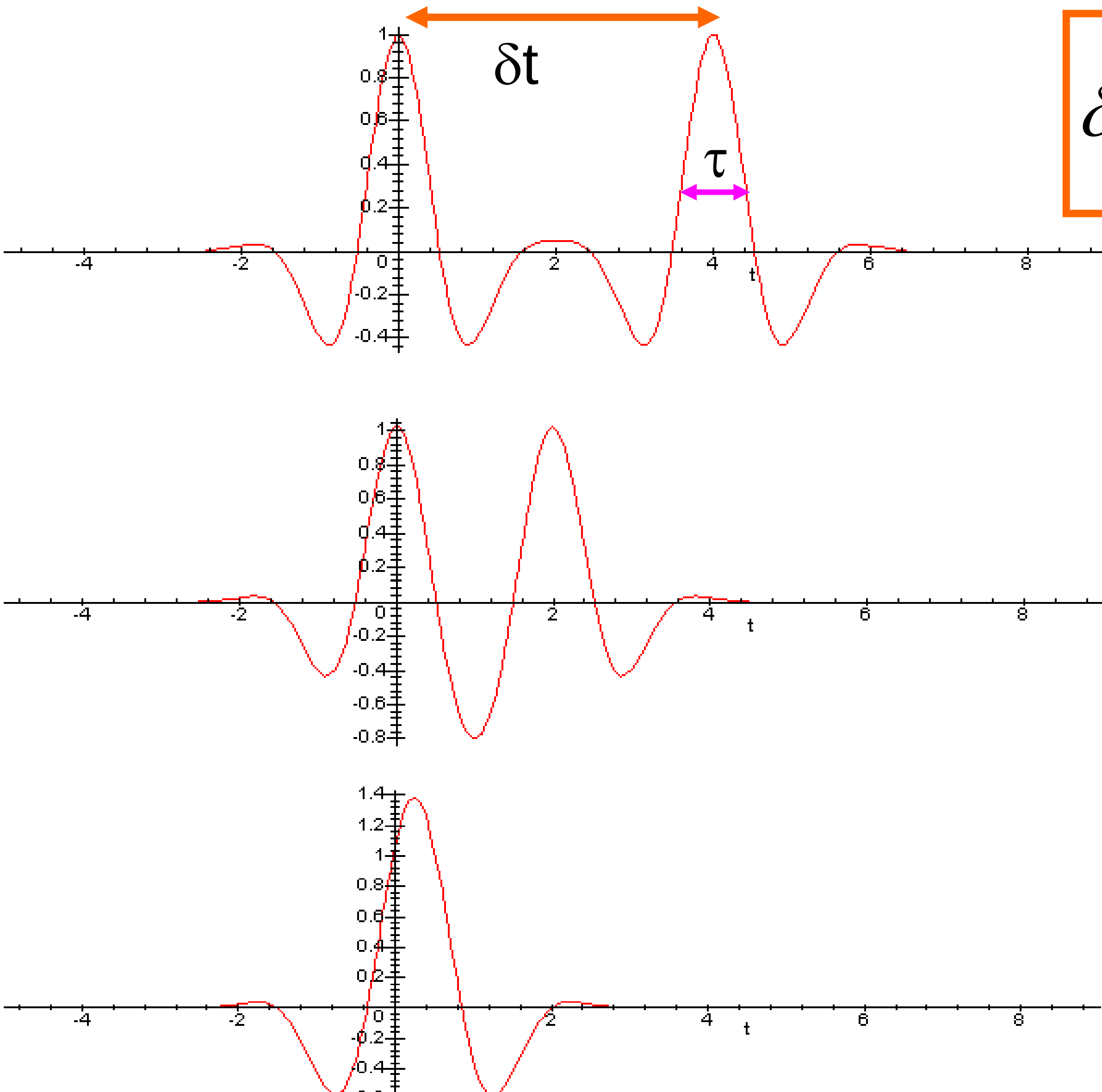


=



$s_e(t)$ $R(t)$ $s_r(t)$

Two targets: radial resolution

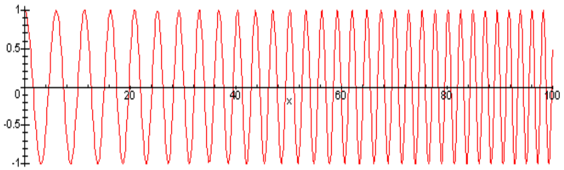


$$\delta t = 2\frac{\delta r}{c}$$

<u>Signal</u> :
choose the shortest τ

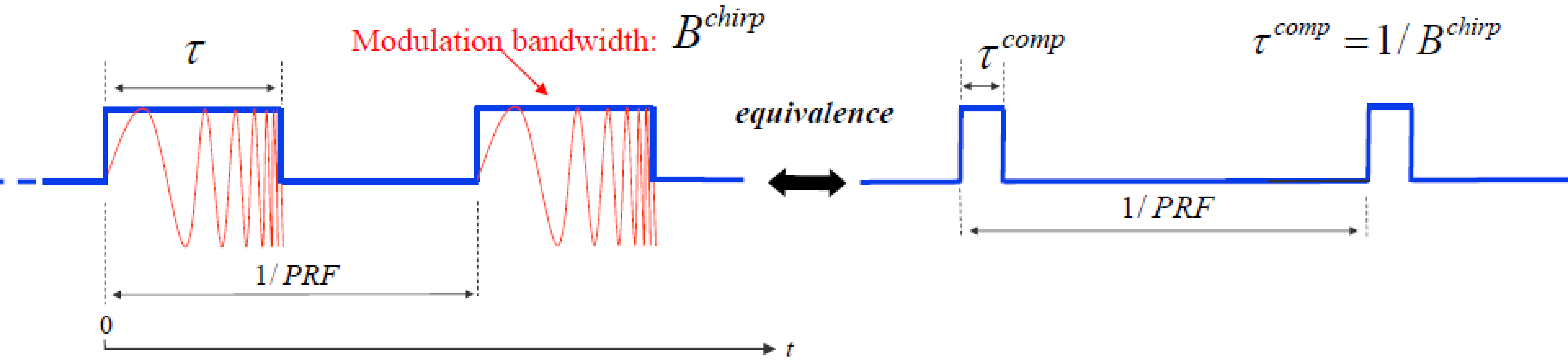
Pulse compression

- **Linearly varying frequency around fo: « modulated frequency» :**
  - Linear term in frequency : f_0
  - Quadratic term in phase : K
- **« *chirp* » of duration T**



$$e^{j2\pi f_0 t} \; e^{j\pi K t^2} \qquad t \in \left[-\frac{T}{2}, \frac{T}{2}\right]$$

Pulse compression



- **Matched filter: short apparent pulse**

$$f_i = \frac{1}{2j\pi}\frac{\partial\varphi}{\partial t} = f_0 + Kt$$

B=KT

$$f_i \in \left[f_0 - K\frac{T}{2},\ f_0 + K\frac{T}{2} \right]$$

Frequency modulation

- **Fourier transform**

$$\mathrm{TF}\left[e^{j\pi K t^2}\right] \approx \sqrt{\frac{j}{K}}\, e^{-j\pi \frac{1}{K} f^2} \qquad f \in \left[-\frac{KT}{2}, \frac{KT}{2}\right]$$

- **Frequential matched filter**

$$\left[\sqrt{\frac{j}{K}}\, e^{-j\pi \frac{1}{K} f^2}\right] \cdot \left[\sqrt{\frac{j}{K}}\, e^{-j\pi \frac{1}{K} f^2}\right]^* = \frac{1}{K} \qquad f \in \left[-\frac{KT}{2}, \frac{KT}{2}\right]$$

- **Inverse Fourier transform**

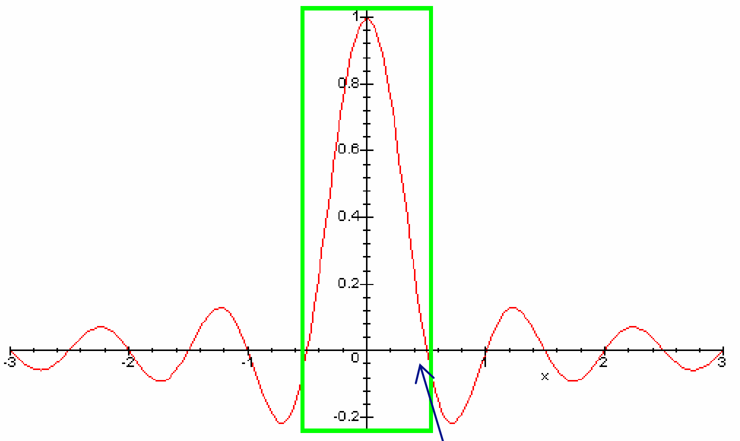
$$\mathrm{TF}^{-1}\left[\mathrm{Id}\right]_{f \in [-0.5, 0.5]} = \frac{\sin(2\pi x)}{2\pi x}$$

Result of the matched filter

$$e^{j2\pi f_0 t} \; e^{j\pi K t^2} \qquad t \in \left[-\frac{T}{2}, \frac{T}{2}\right]$$

- **Chirp of duration *T*, of bandwith B=*KT*, « sinc » :**

$$\propto \frac{\sin(\pi KT\,t)}{\pi KT\,t}$$



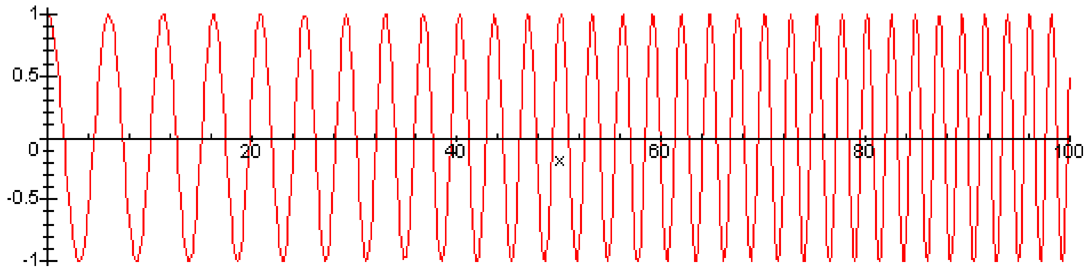
$$\tau_0 = \pm \frac{1}{KT}$$

$$\tau = \frac{1}{KT} = \frac{1}{KT^2} T$$

Compressed pulse and chirp

- **Emission of a linearly modulated frequency with Bandwith B=KT**
- **Equivalent to a duration τ**
- **Compression factor KT^2**

$$s_r(t) * s_e^*(-t) = \delta\left(t - \frac{2d}{c}\right) * R(t) * s_e(t) * s_e^*(-t)$$
$$= \delta\left(t - \frac{2d}{c}\right) * R(t) * \text{sinc}$$



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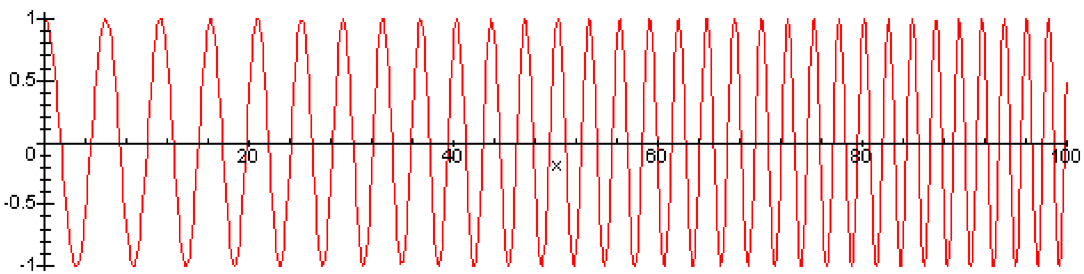
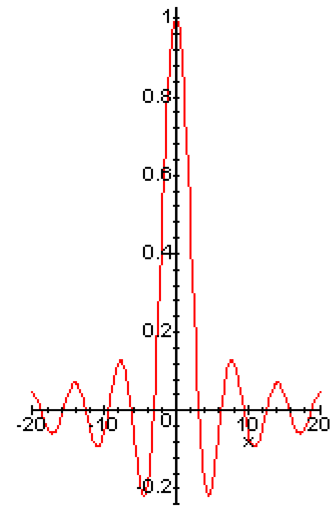




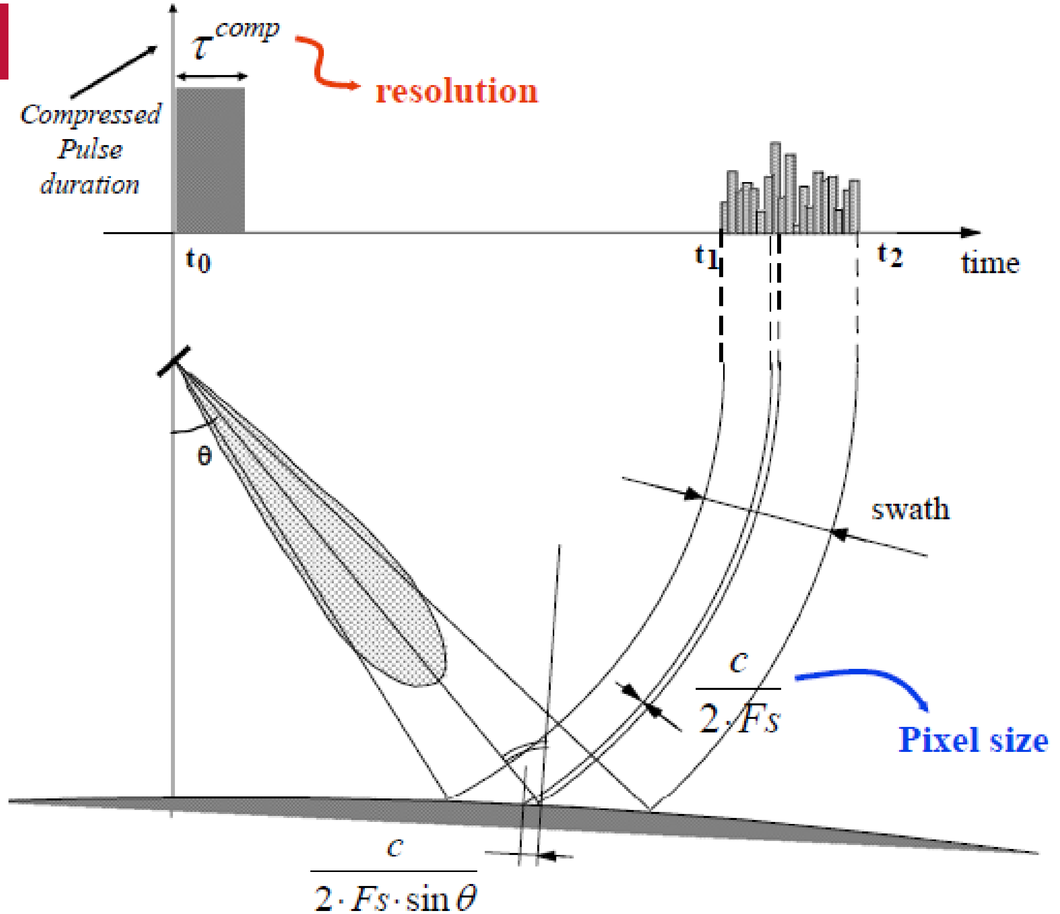
Conclusion on range resolution

- **The radial resolution of a SAR sensor depends on the bandwith**

$$B = \frac{1}{\tau}$$

	Bandwith	« range » resolution
ERS	15.55 MHz	9,6m
Radarsat 1	30 MHz	5m
Terrasar-X	150 MHz	1m

$$\delta r = \frac{c\tau}{2} = \frac{c}{2B}$$



Numerical example: ERS

$$Fs = 18.96\ MHz$$

$$Pixel_{slant\_range} = 7{,}9\ m$$

$$Pixel_{ground\_range} = 26\ to\ 18\ m$$

$$B = 1/\tau^{comp} = 15.5\ MHz$$

$$Res_{slant\_range} = 9.7\ m$$

$$Res_{ground\_range} = 22\ to\ 32\ m$$

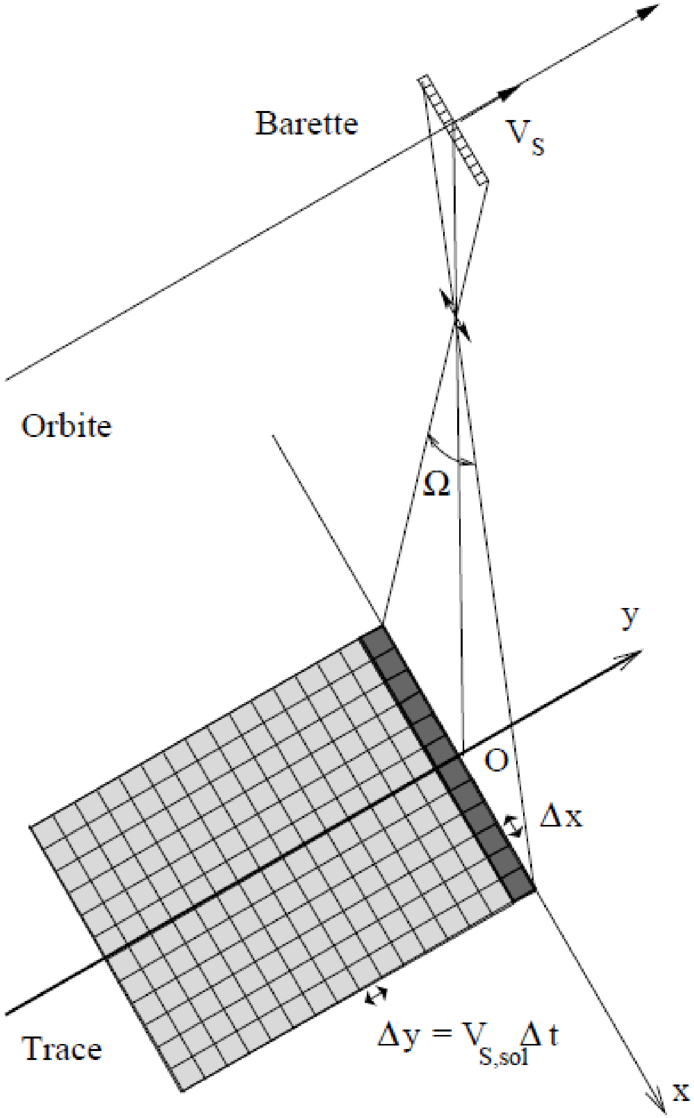
- **The pixel size is defined by the sampling frequency Fs**
- **The range resolution is defined by the modulation Bandwidth B^{chirp}**

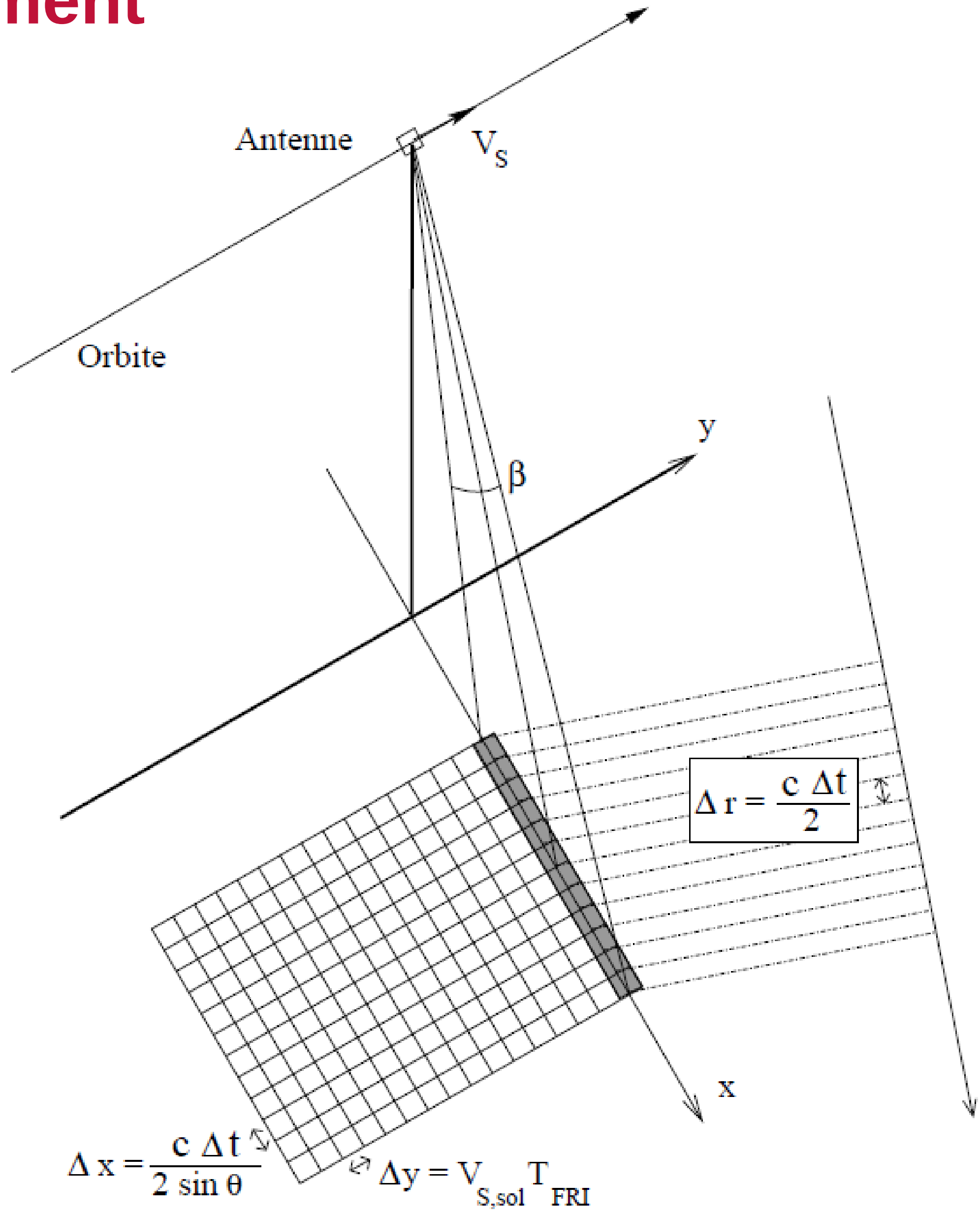
The pixel size is generally "built" slightly smaller than the resolution: Fs≥Bchirp

Overview

- **Principle of radar acquisition**
- **Examples of SAR images**
- **SAR image acquisition**
  - Range direction and chirp
  - Azimuth direction and synthetic aperture
- **Some SAR systems and applications**

Image by movement





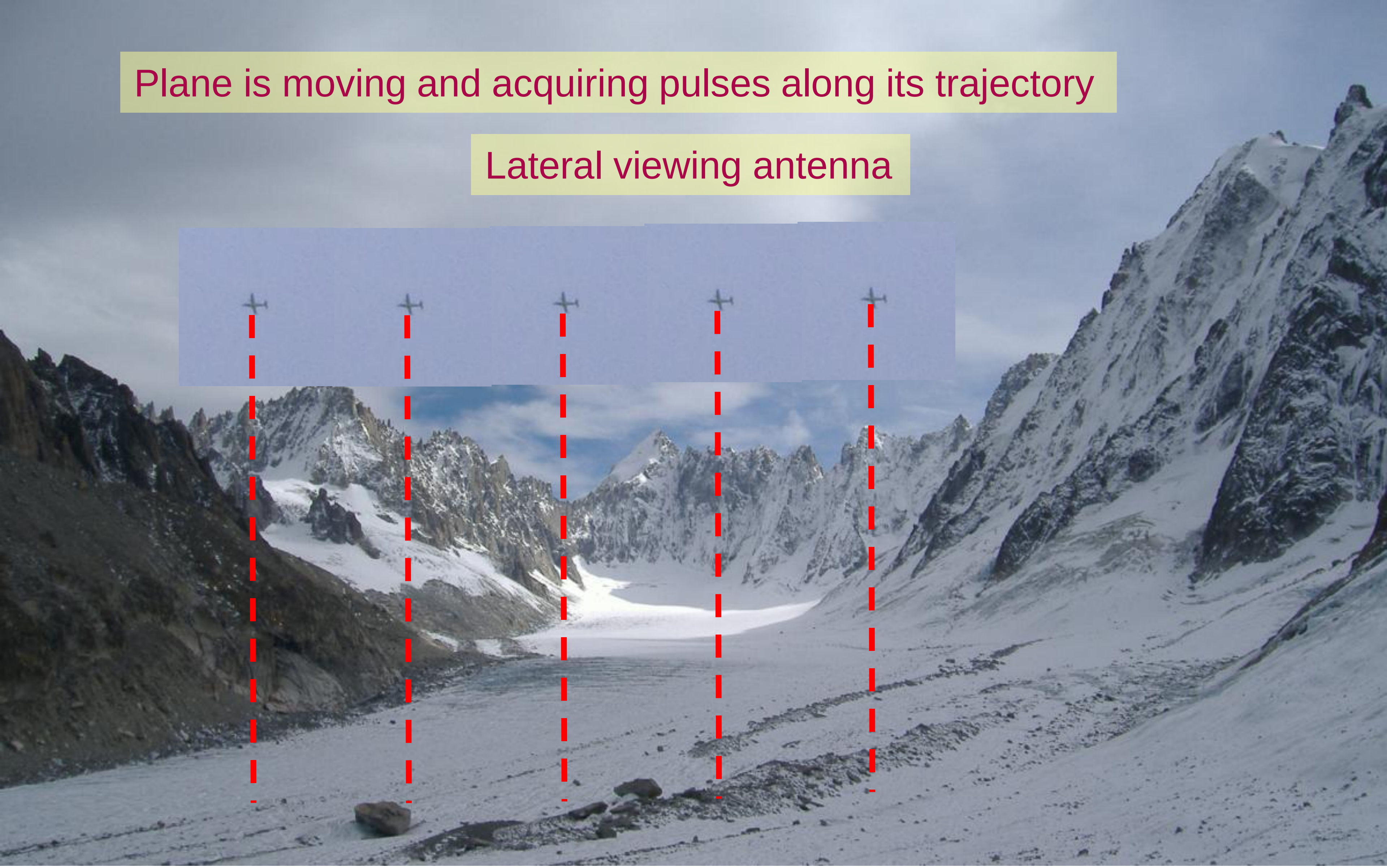
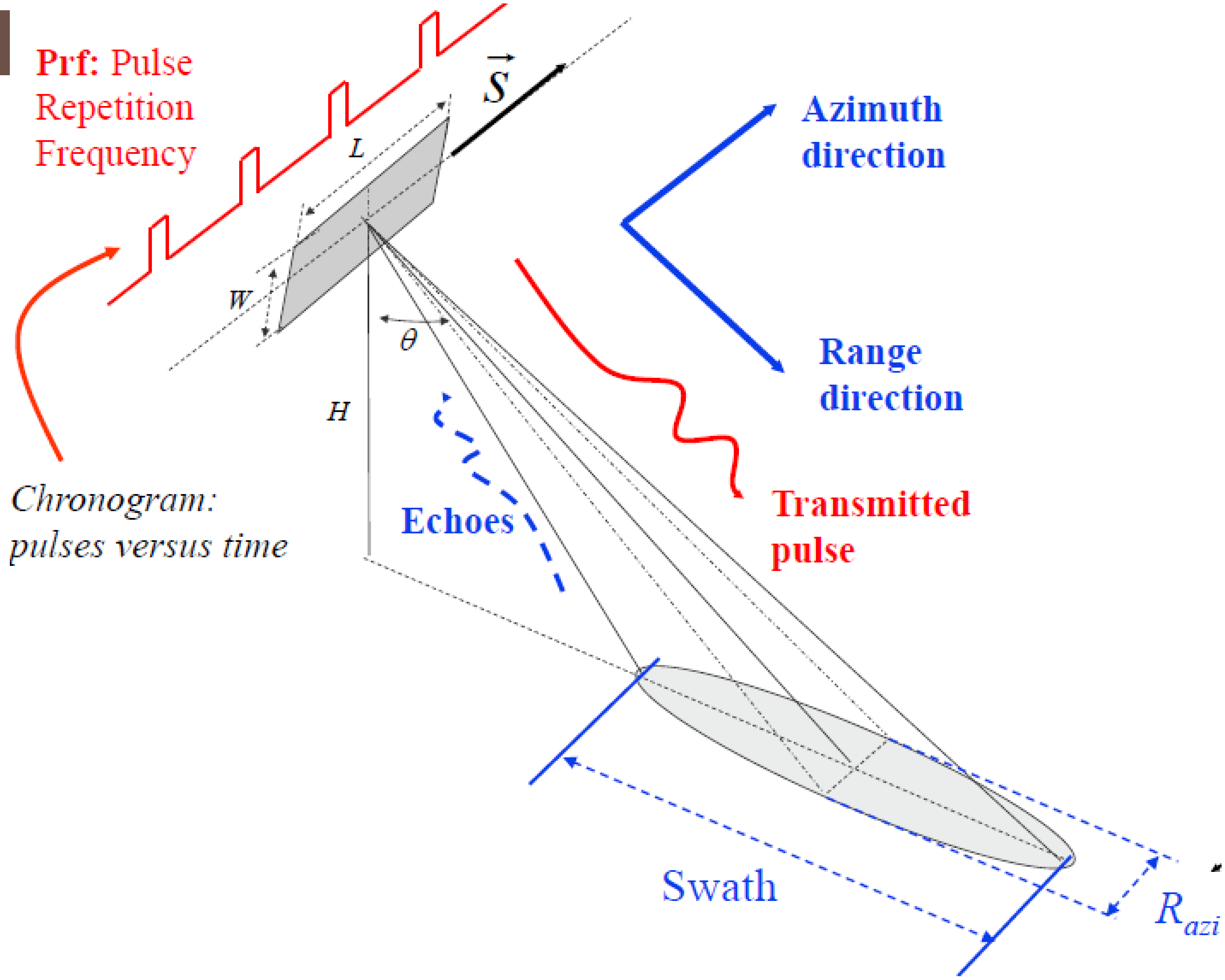
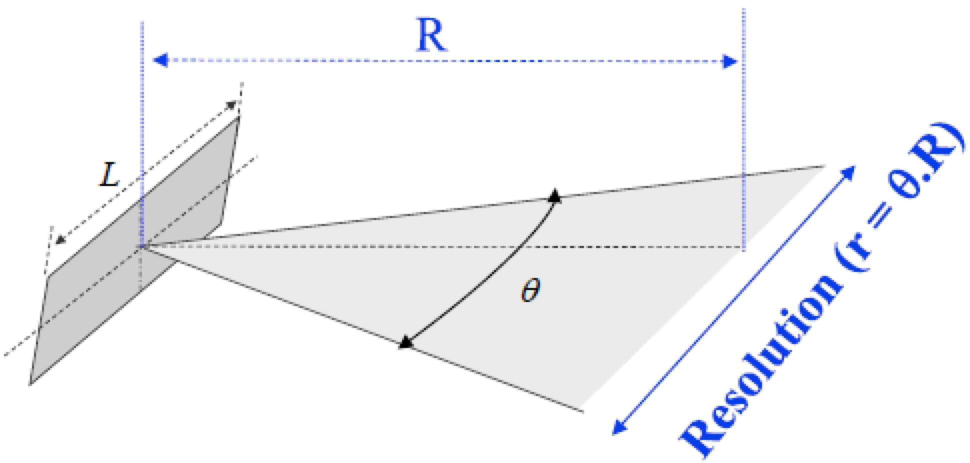

Plane is moving and acquiring pulses along its trajectory
Lateral viewing antenna

Image lines


Prf: Pulse Repetition Frequency
L
W
θ
H
S
Azimuth direction
Range direction
Transmitted pulse
Echoes
Chronogram: pulses versus time
Swath
R_{azi}

Antenna and swath

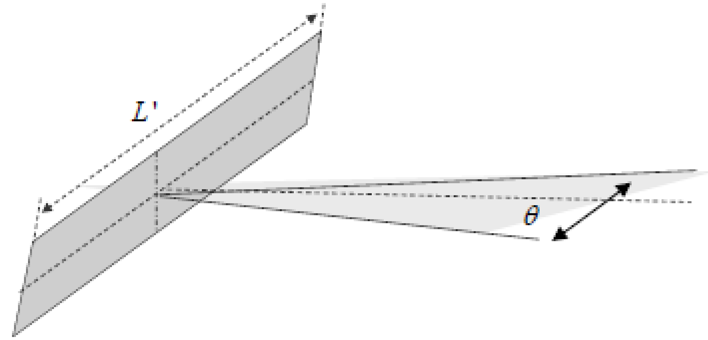


$$\theta = \frac{\lambda}{L}$$

Wavelength

Antenna length (horizontal direction)

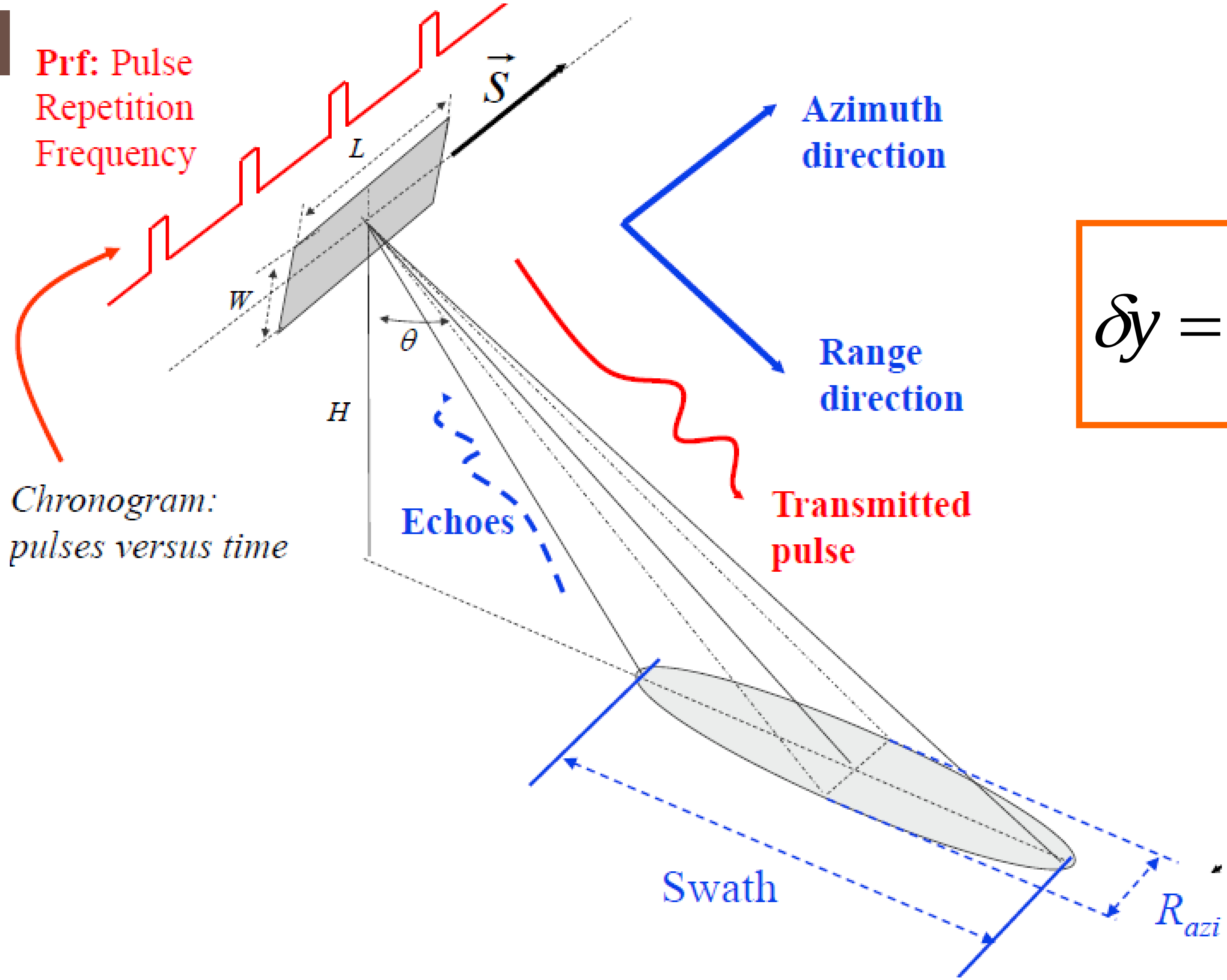
Angular aperture (horizontal plane)



➡ The larger the antenna, the narrower the aperture (resolution ↘)

Numerical example:

L ≈ 4m, R ≈ 4 km (airborne radar), λ ≈ 3 cm (X band) ➔ **resolution ≈ 30 m**

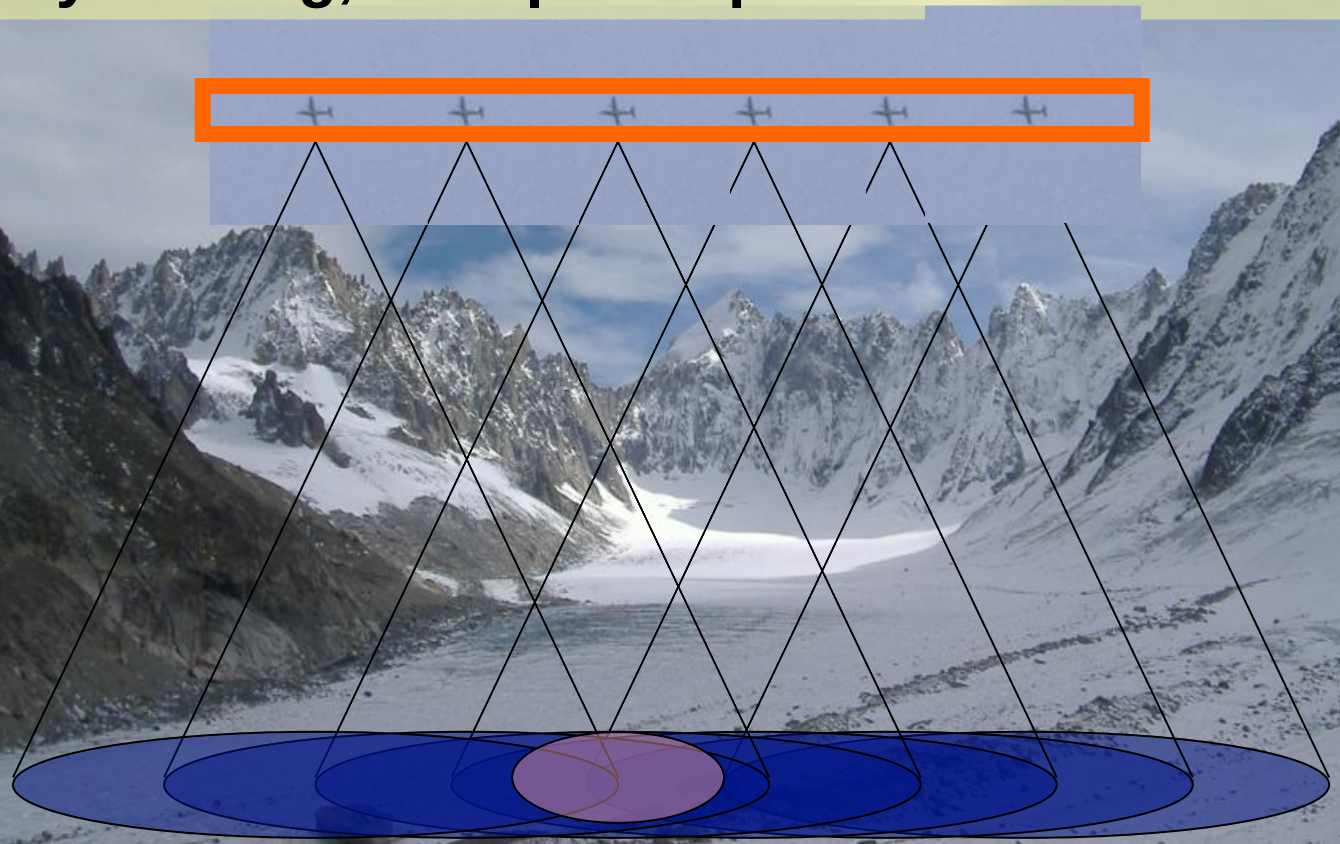


$$\delta y = \frac{\lambda D}{L}$$

Real antenna is too small

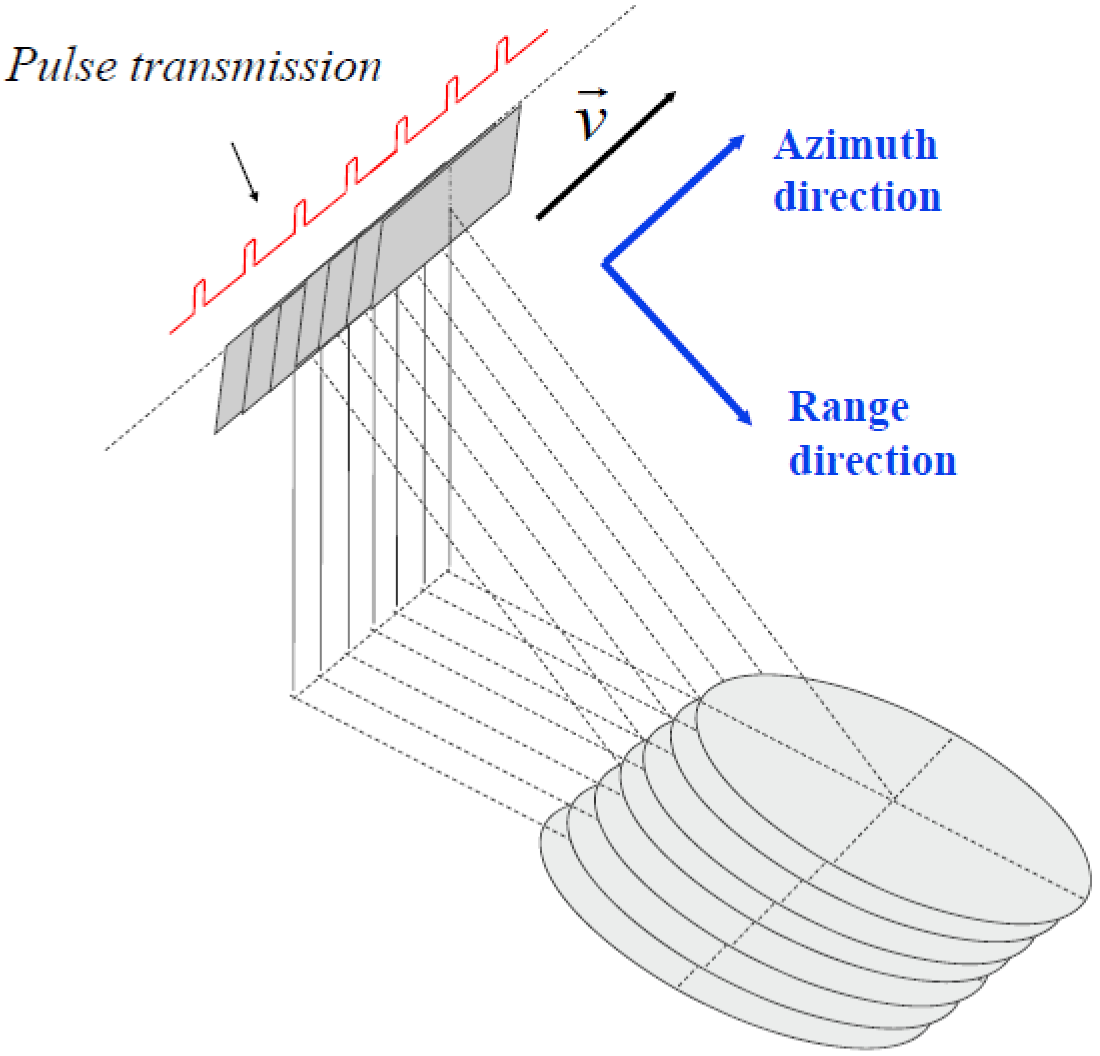
→ It measures a too big area

By moving, multiple acquisitions of the same point



A same point is seen by different antenna positions

The synthetic antenna « sees » a small area

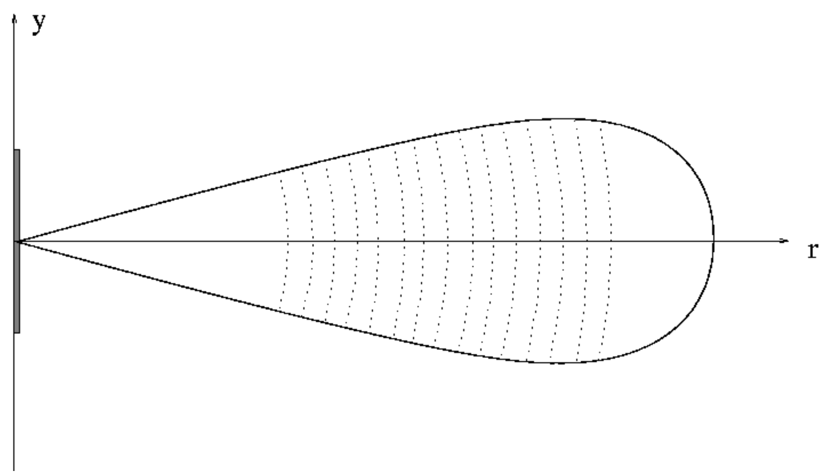


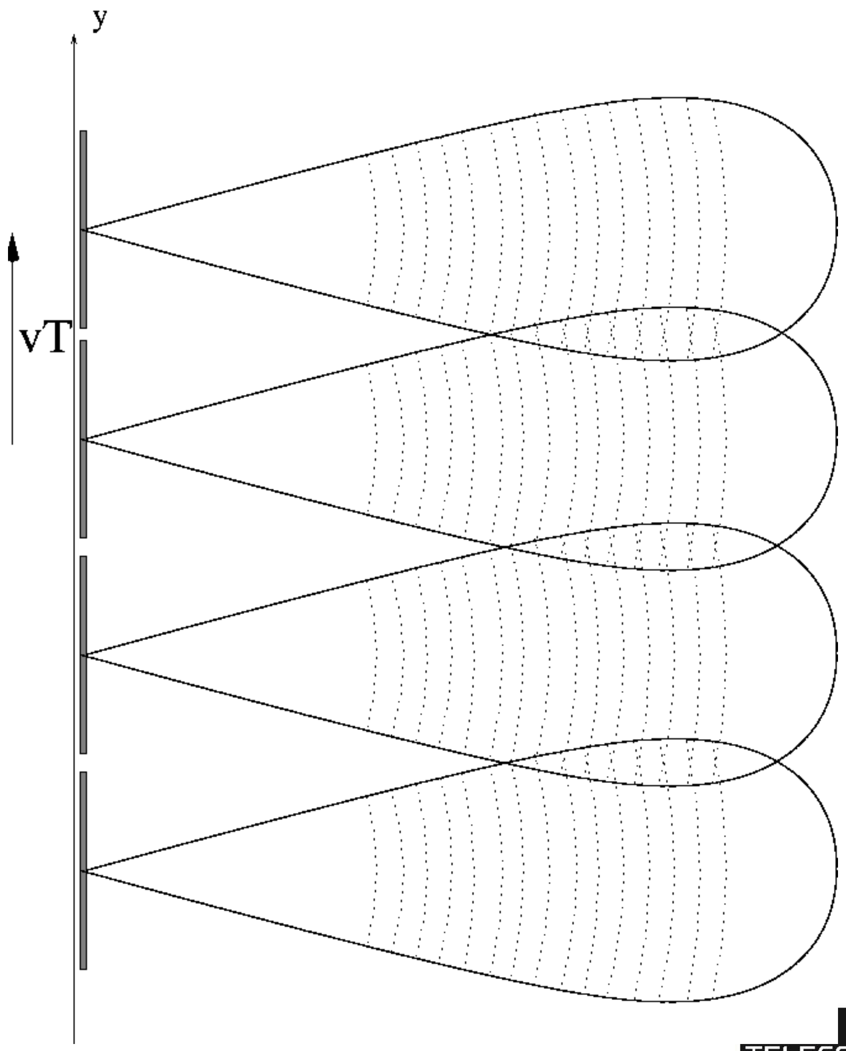
The antenna progression along the orbit allows to observe **each given point at different times**

⬇

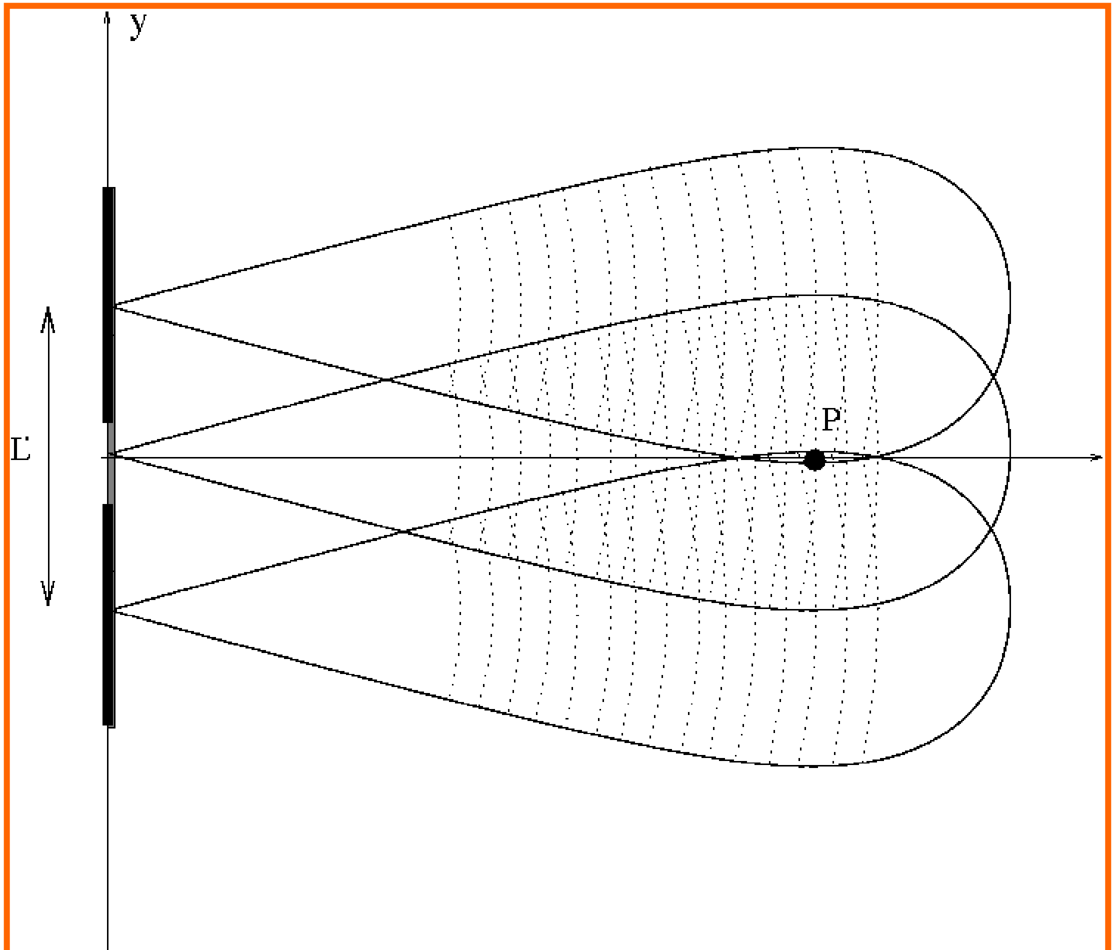
Resolution improvement in the **azimuth** direction

Synthetic antenna
Uses the movement of the sensor





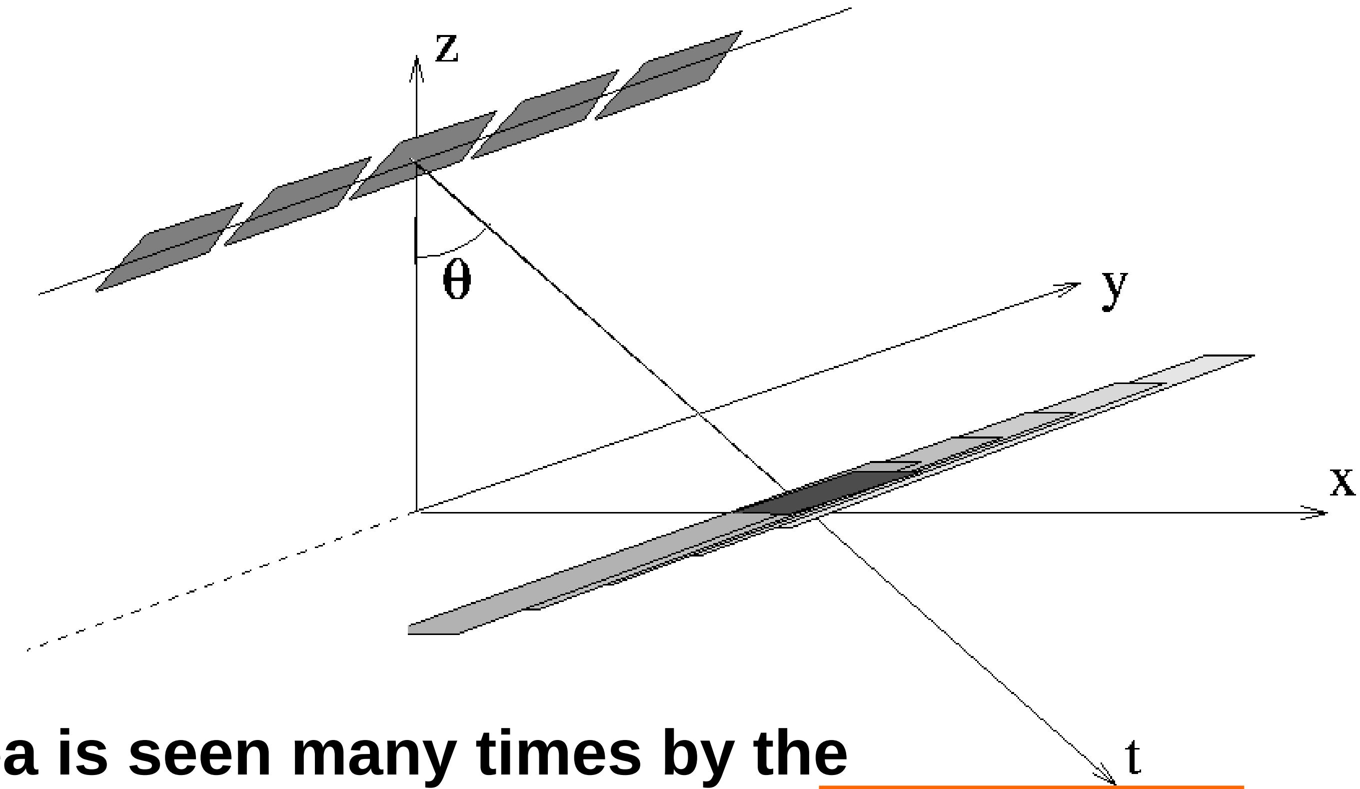
Visibility of a target in the swath



- **Point P is seen along the distance L'**
- **L' = 2 δy**

$$\delta y = \frac{\lambda D}{L}$$

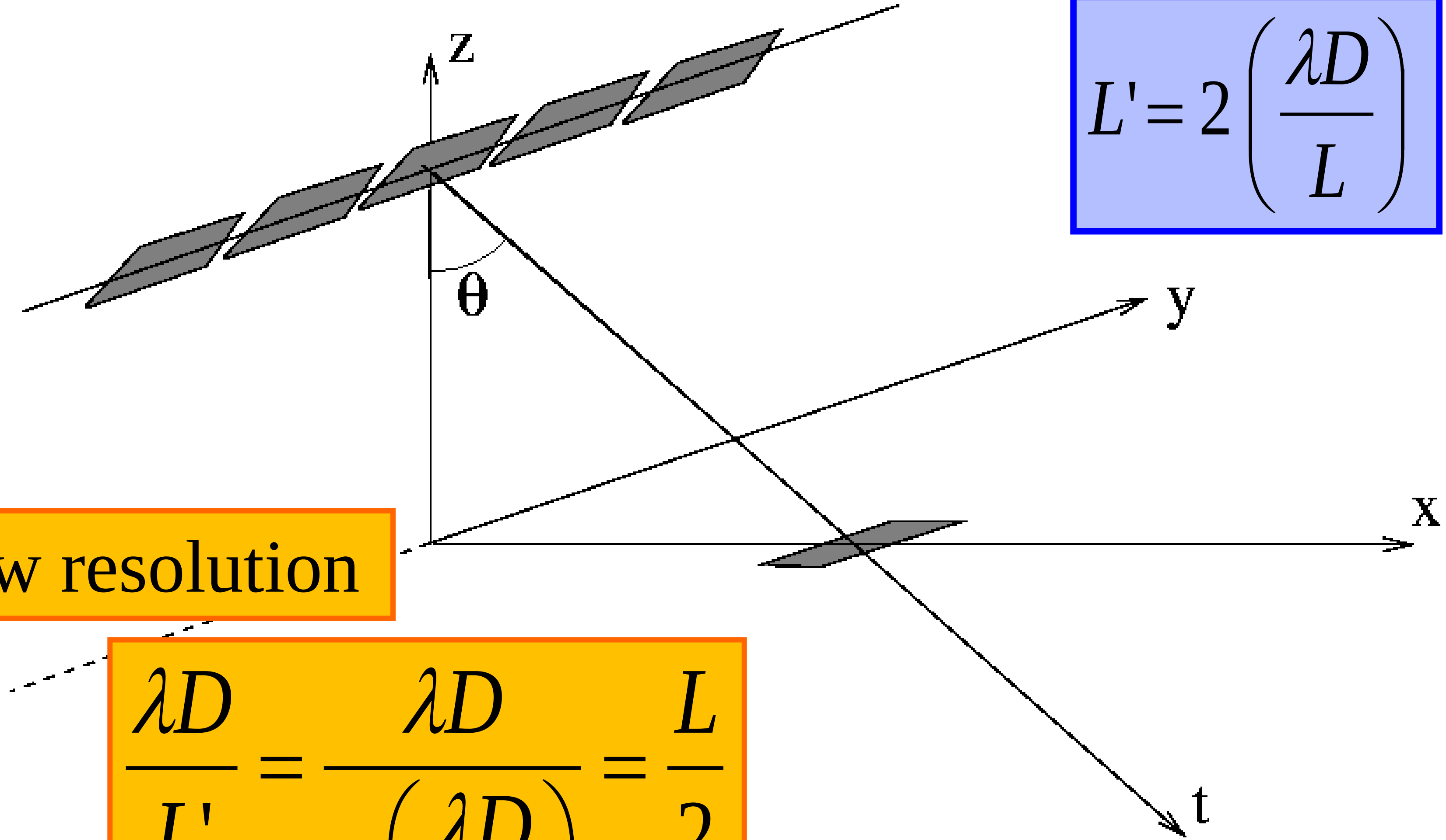
Synthetic aperture



- A same area is seen many times by the sensor
- Visibility length= synthetic aperture

$$L' = 2\left(\frac{\lambda D}{L}\right)$$

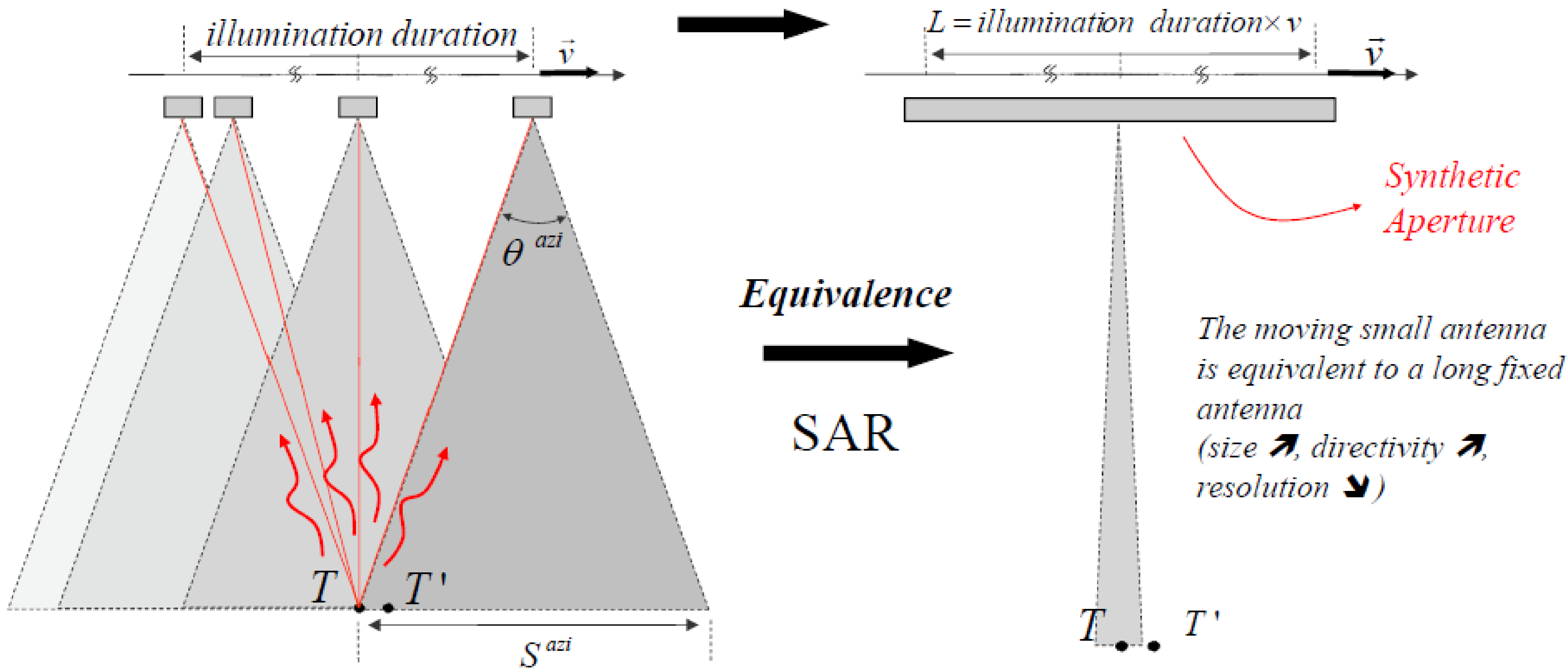
Creating an antenna of size L’



$$L' = 2\left(\frac{\lambda D}{L}\right)$$

New resolution

$$\frac{\lambda D}{L'} = \frac{\lambda D}{2\left(\frac{\lambda D}{L}\right)} = \frac{L}{2}$$



Coherent adding of successively received echoes → Resolution gain in the azimuth direction (**Ex: ERS: 5 km → 5 m**)

The compression rate Na equals the **number of coherently added echoes** (complex addition). It is
he resolution gain in the azimuth direction

SAR resolution

- **Depends only on the antenna size L**

$$\text{Resolution : } \quad \boxed{\delta y = \frac{L}{2}}$$

- **Does not depend on the distance to the target !!**
- **Does not depend on the wavelength**

- **Illumination time depends on L et λ**

Dimension de l'antenne synthétique

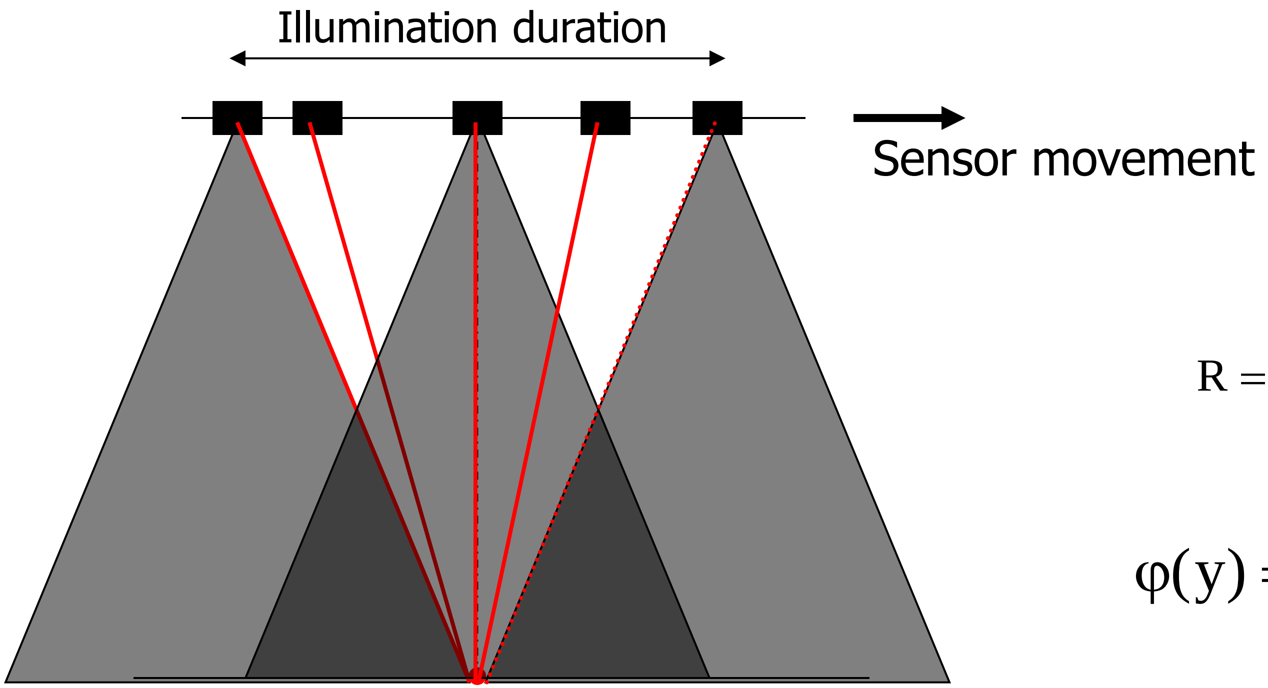
$$L_S = \frac{2\lambda D}{L}$$

$$\omega = \frac{2\lambda}{L}$$

	L (m)	λ (cm)	ω	D (km)	L_S (km)
ENVISAT (θ=30°)	10	5,66	0,324°	912	10,32
CSK (θ=30°)	5,7	3,1	0,311°	714	7,76
TSX (θ=30°)	4,8	3,1	0.370°	593	7,65
ALOS (θ=30°)	8,9	23,5	1.513°	799	42,2

Synthetic aperture and signal processing

Sensor trajectory, target plan



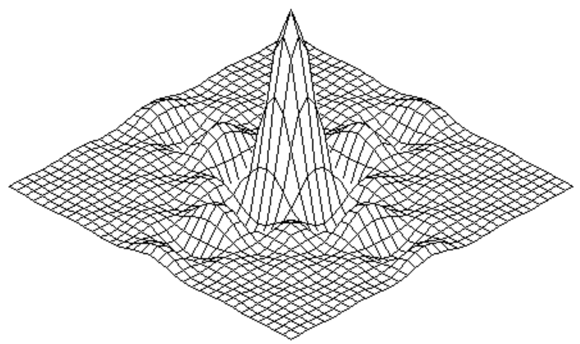
$$R = R_0 + \frac{y^2}{2R_0}$$

$$\varphi(y) = \frac{2\pi y^2}{\lambda R_0} + k$$

$$f(y) = \frac{2y}{\lambda R_0}$$

Linearly varying frequency: « modulated frequency» !
« natural » chirp in azimuth direction : matched filter

Summary of SAR imaging: chirp + synthetic aperture



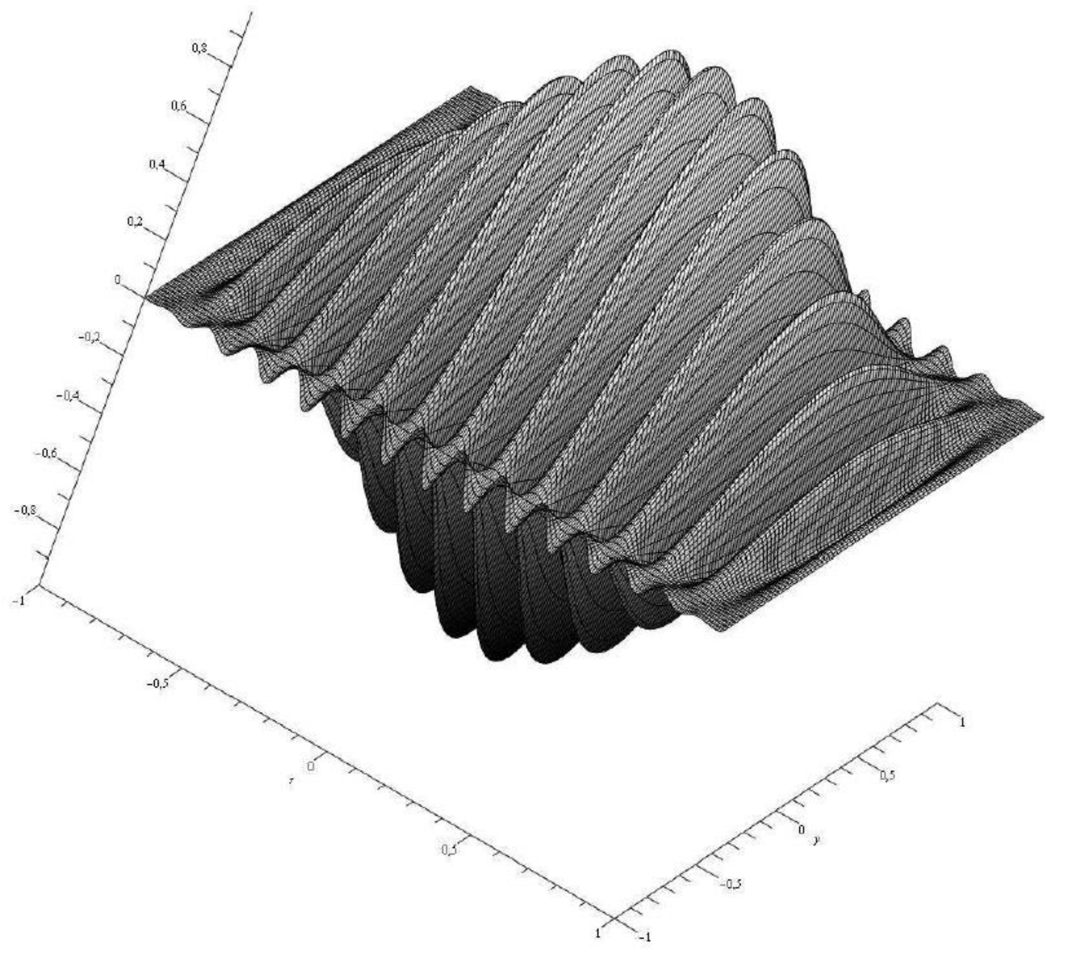
- **Range: pulse compression and matched filter**
- **Azimuth: natural chirp and matched filter = big synthetic aperture**
- **PSF :**
  - Cardinal sinus in range
  - Cardinal sinus in azimuth

$$PSF \propto \frac{\sin(\pi B t)}{\pi B t} \frac{\sin(\pi B_y y)}{\pi B_y y} \propto \frac{\sin(\pi B_r r)}{\pi B_r r} \frac{\sin(\pi B_y y)}{\pi B_y y}$$

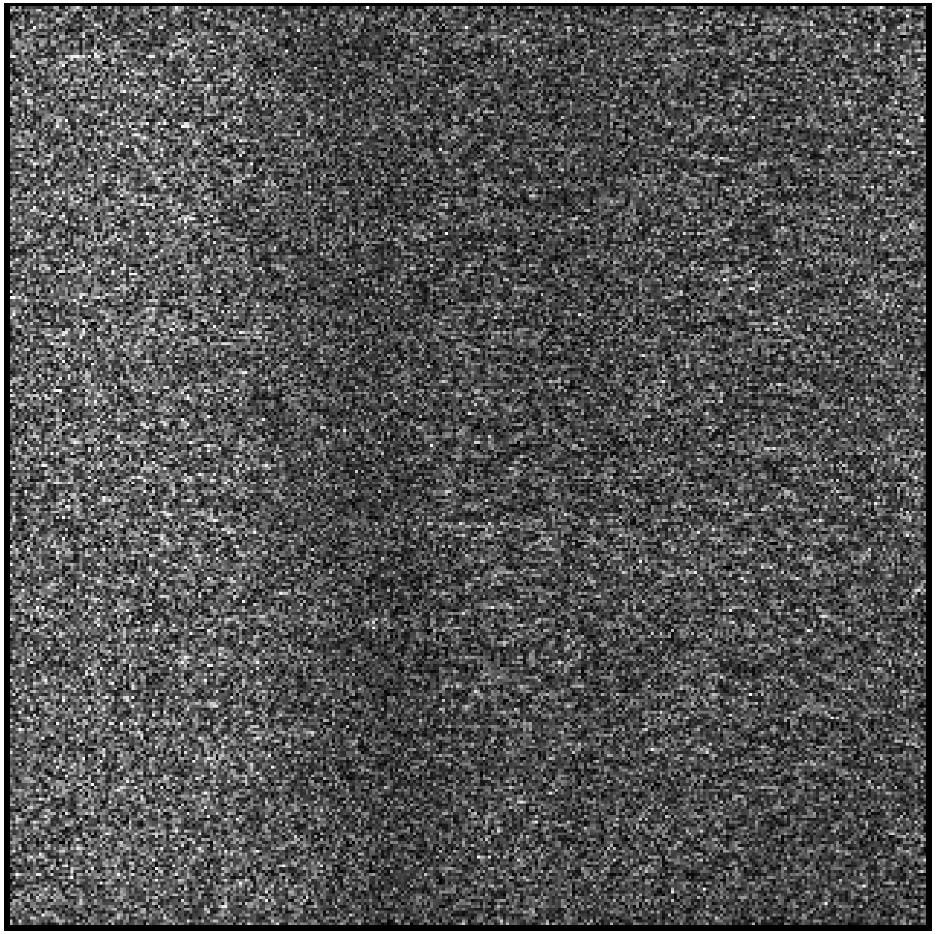
$$B_r = \frac{2B}{c}$$

$$B_y = \frac{2\lambda}{L_S}$$

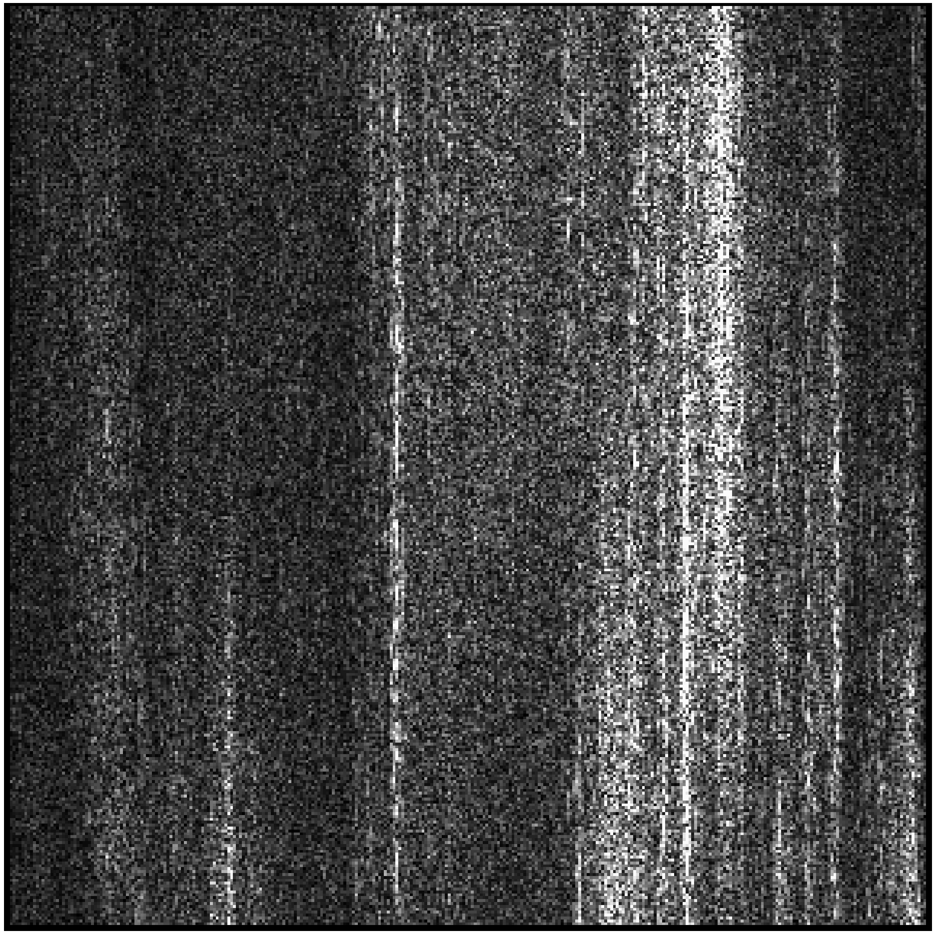
Carrier frequency + cardinal sinus (Ox et Oy)



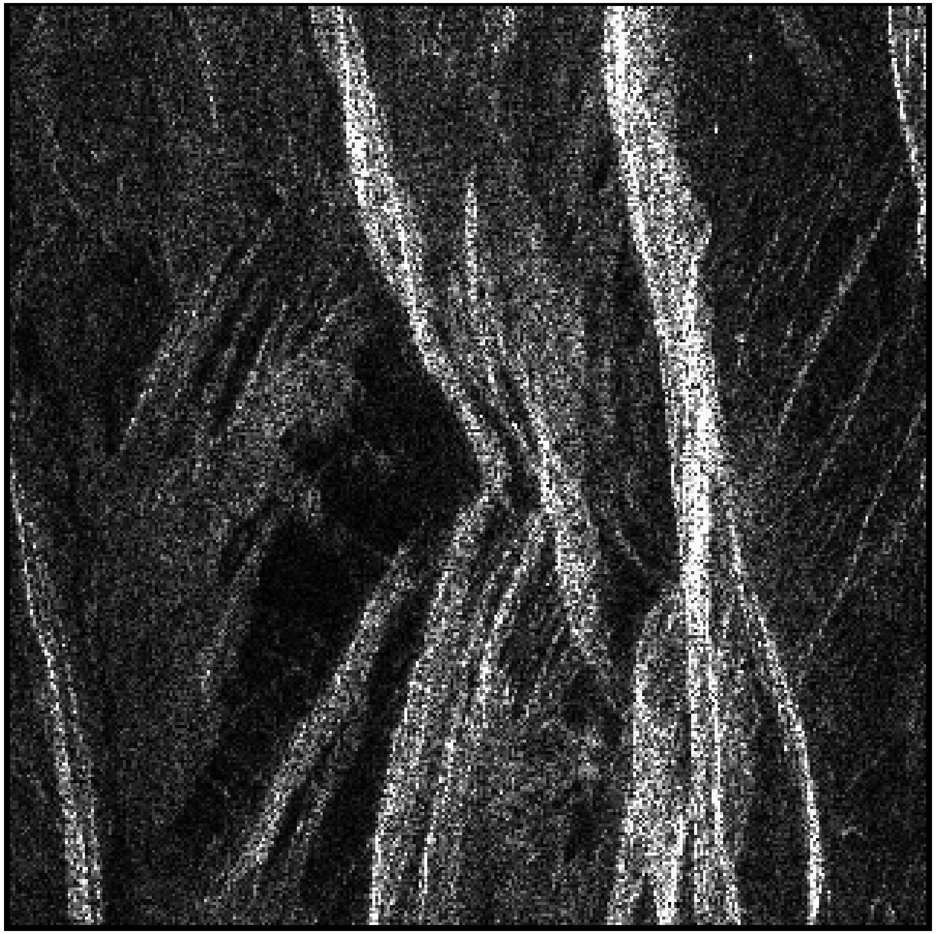
Example of SAR data : RAW data (km res)



Matched filter in range direction (chirp)



Matched filter in azimuth direction (synt. aperture



Overview

- **Principle of radar acquisition**
- **Examples of SAR images**
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  - Azimuth direction and synthetic aperture
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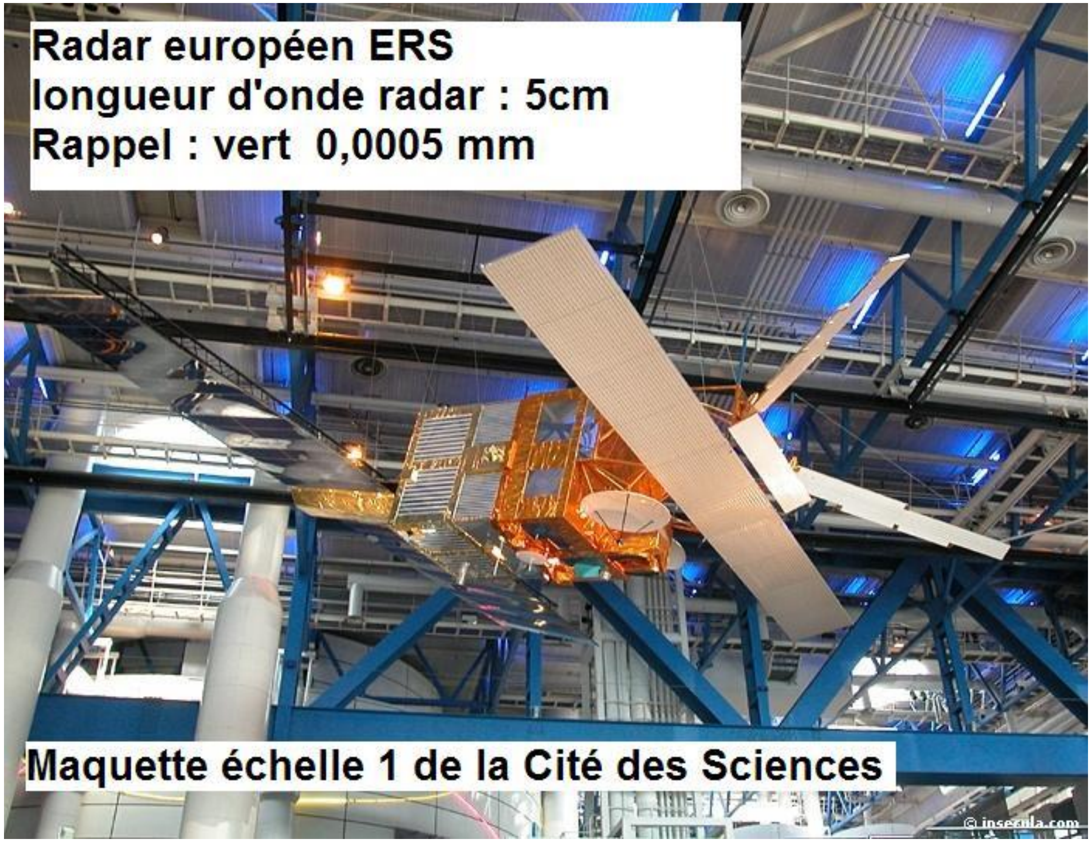
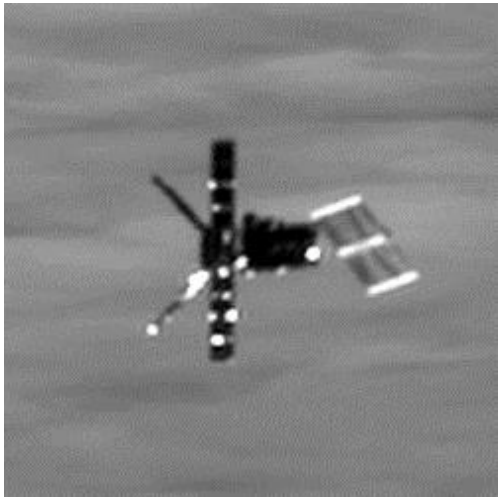
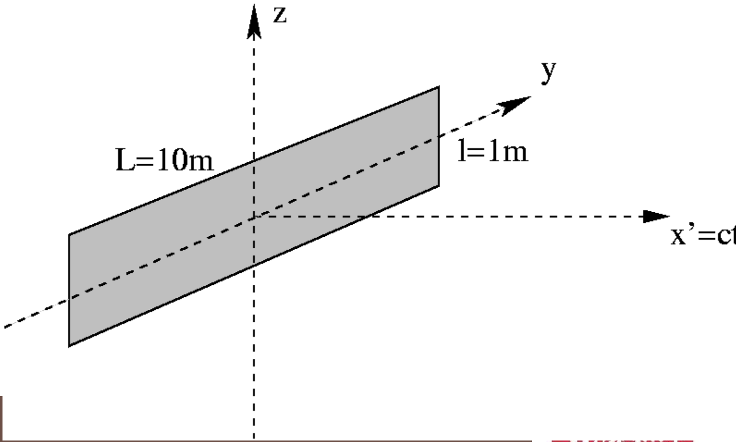
ERS-1



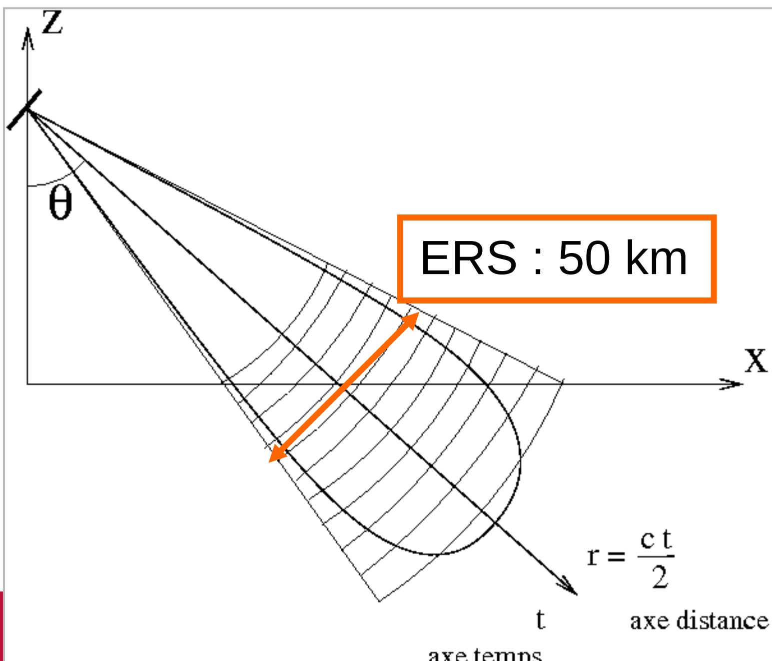


Antenna of 1m x 10m
10 panels



Emitting – receiving antenna

$$\delta z = \frac{\lambda D}{l}$$



- **« antenna swath »**
- **Shape of the antenna**

  - D : around 1000 km
  - λ : a few cm
  - L : limited size

  - → resolution of RAR (real aperture radar) : a few km

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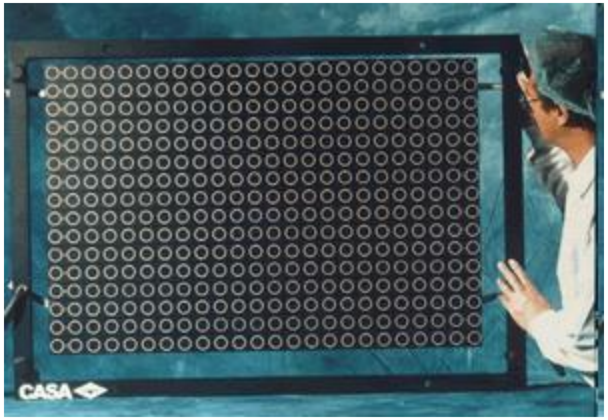
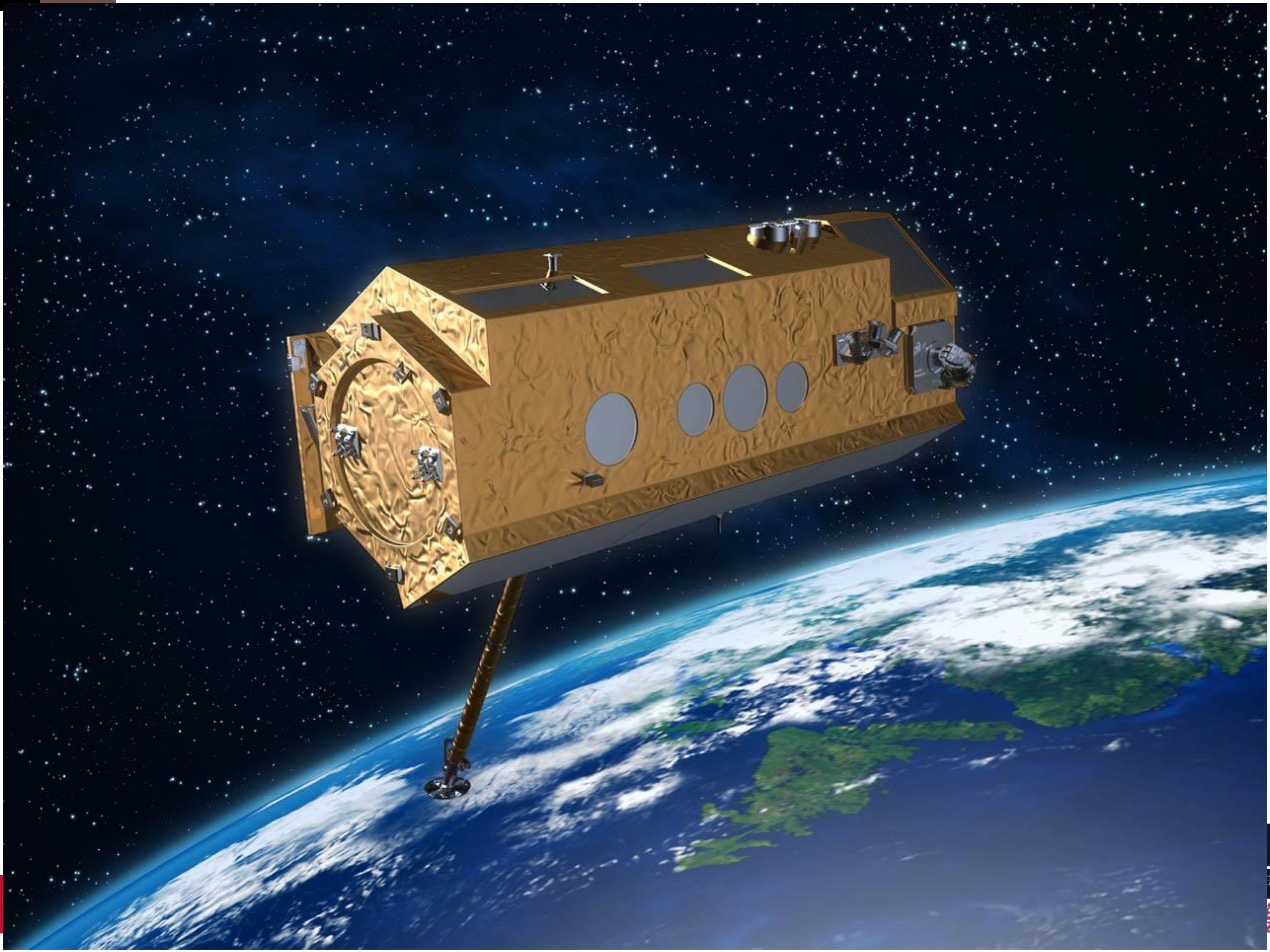
ENVISAT : from antenna to « phased array »



- **16 modules for a tile**
  - A tile : 0,65m x 1m
- **4 tiles for a panel**
  - A panel : 1,30m x 2m
- **5 panels on ASAR**
  - Antenna : 1,30m x 10m
- **320 modules**
  - Choice of the phase for each module

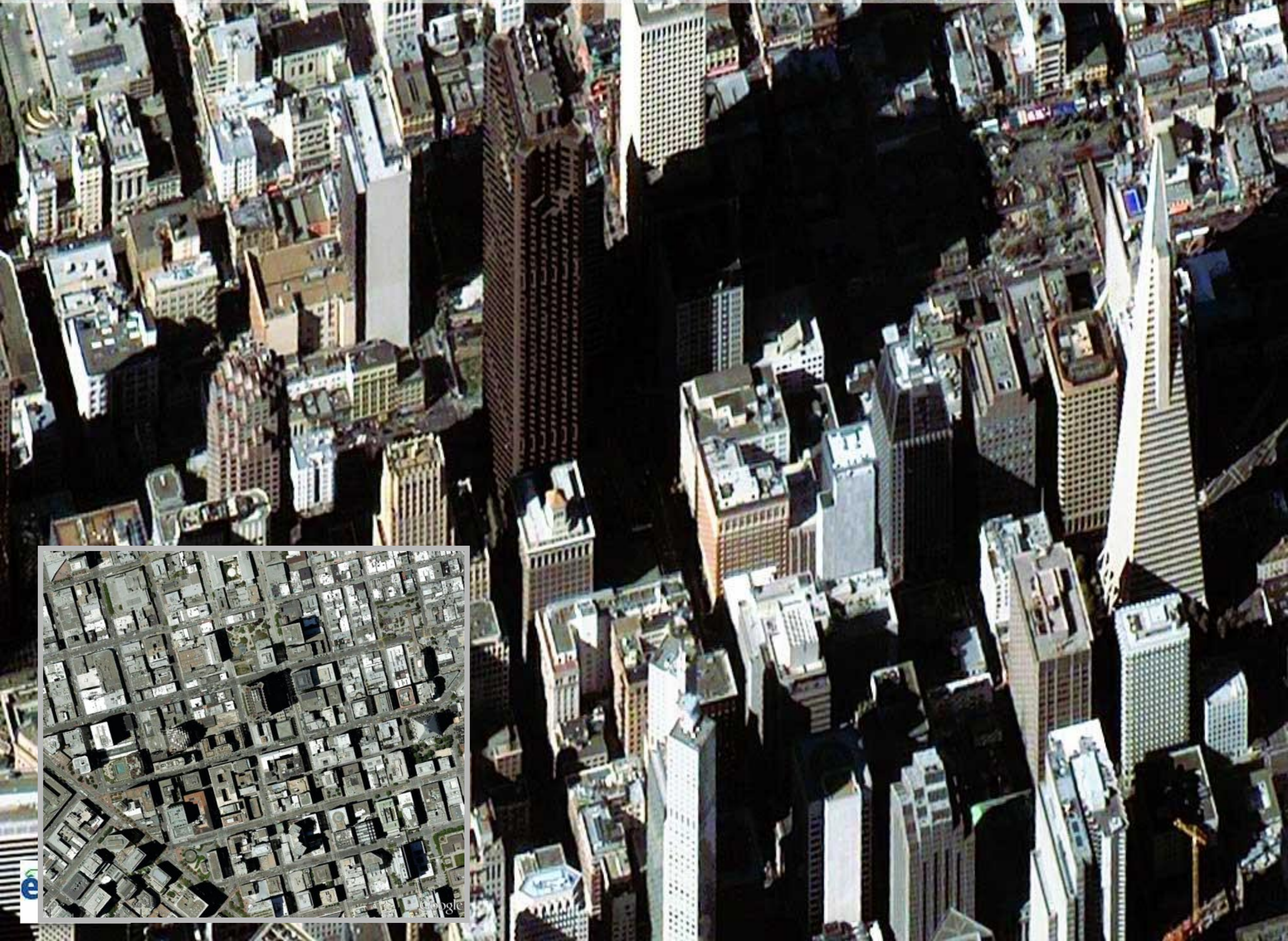
Terrasar-X (DLR)



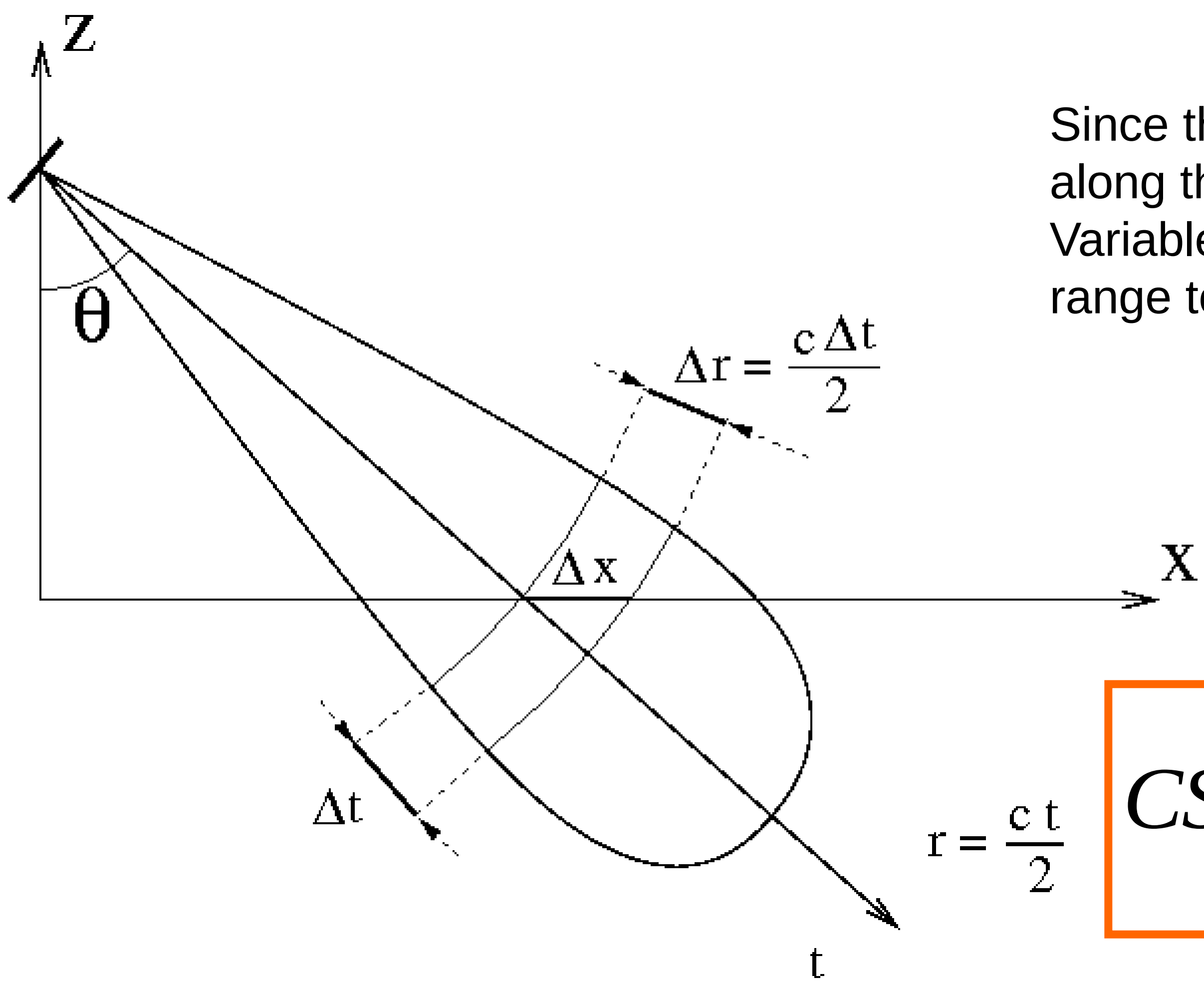
Geometry of SAR images

Consequences of lateral viewing

QuickBird San Francisco, December, 2001 Pan-sharpened



Influence of lateral viewing

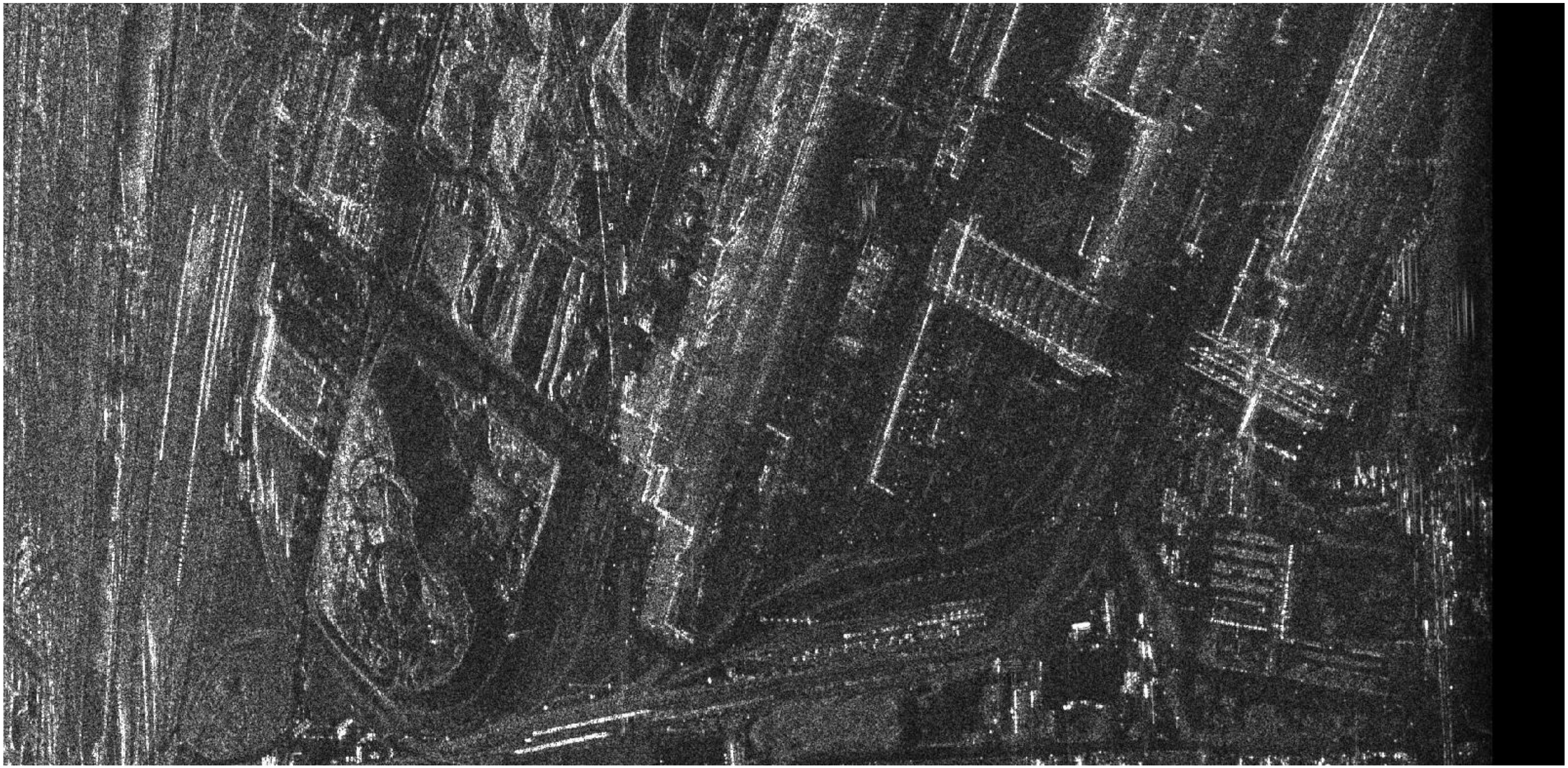


Since the incidence angle varies along the swath:
Variable resolution from near range to far range

$$CS = \Delta x = \frac{\Delta r}{\sin(\theta)}$$

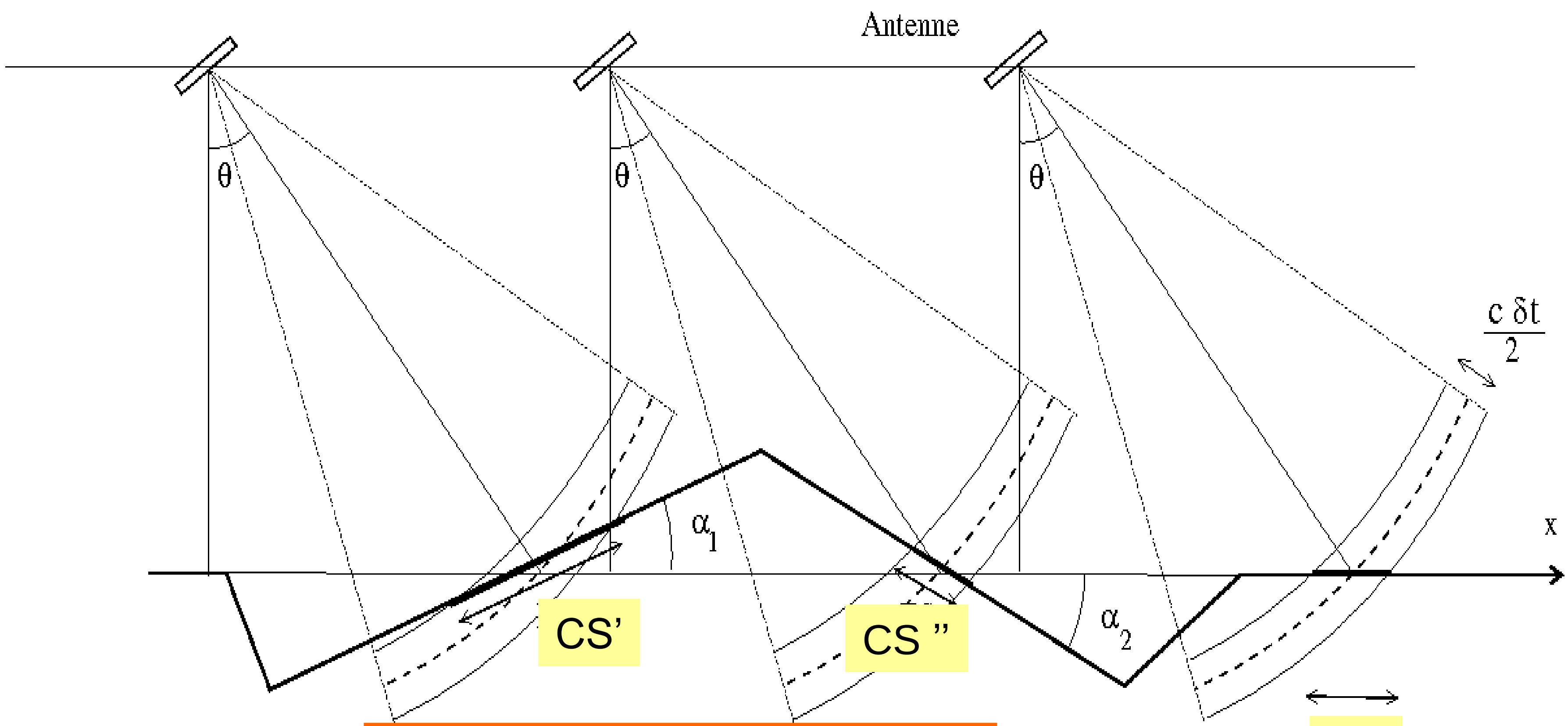
Geometrical distorsions
Variable incidence angle: variable resolution

θ=6°, dx θ=60°, dx/10



Airborn system: same δr, variable δx along the swath

Influence of relief on cell size



$$CS(\alpha) = \frac{\Delta r}{\sin(\theta - \alpha)}$$

Effets de la variation de la case sol en fonction de la pente locale : le Cap Vert

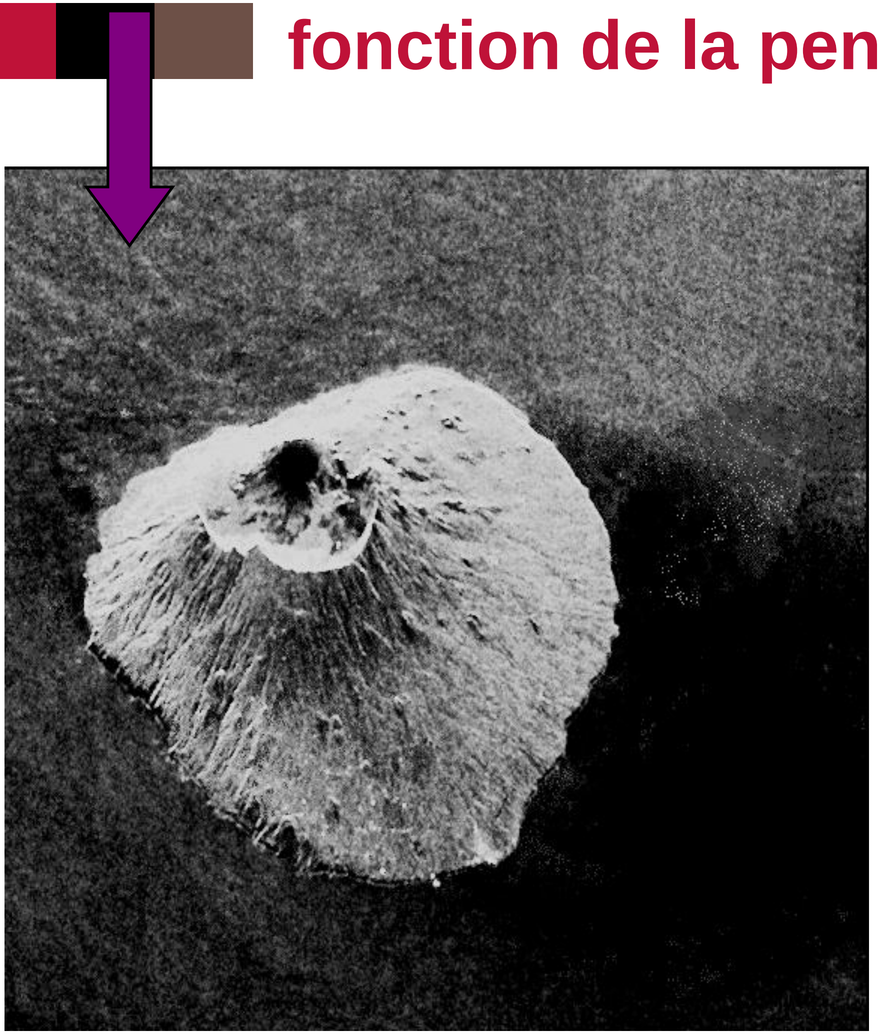
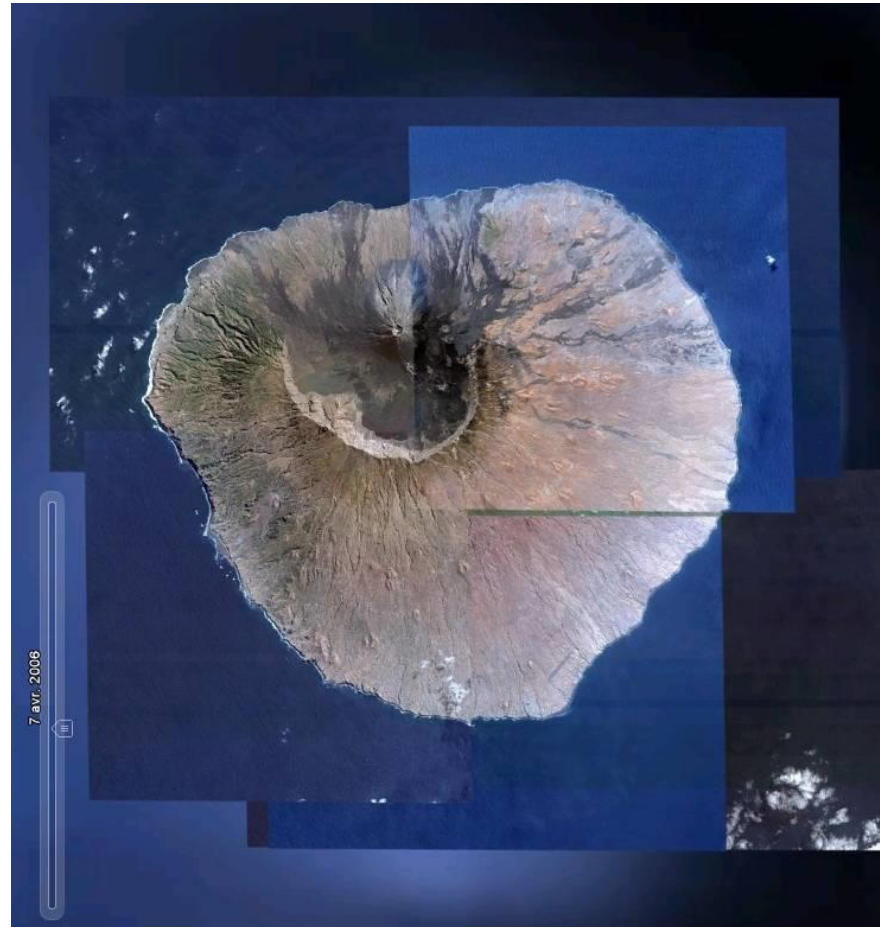
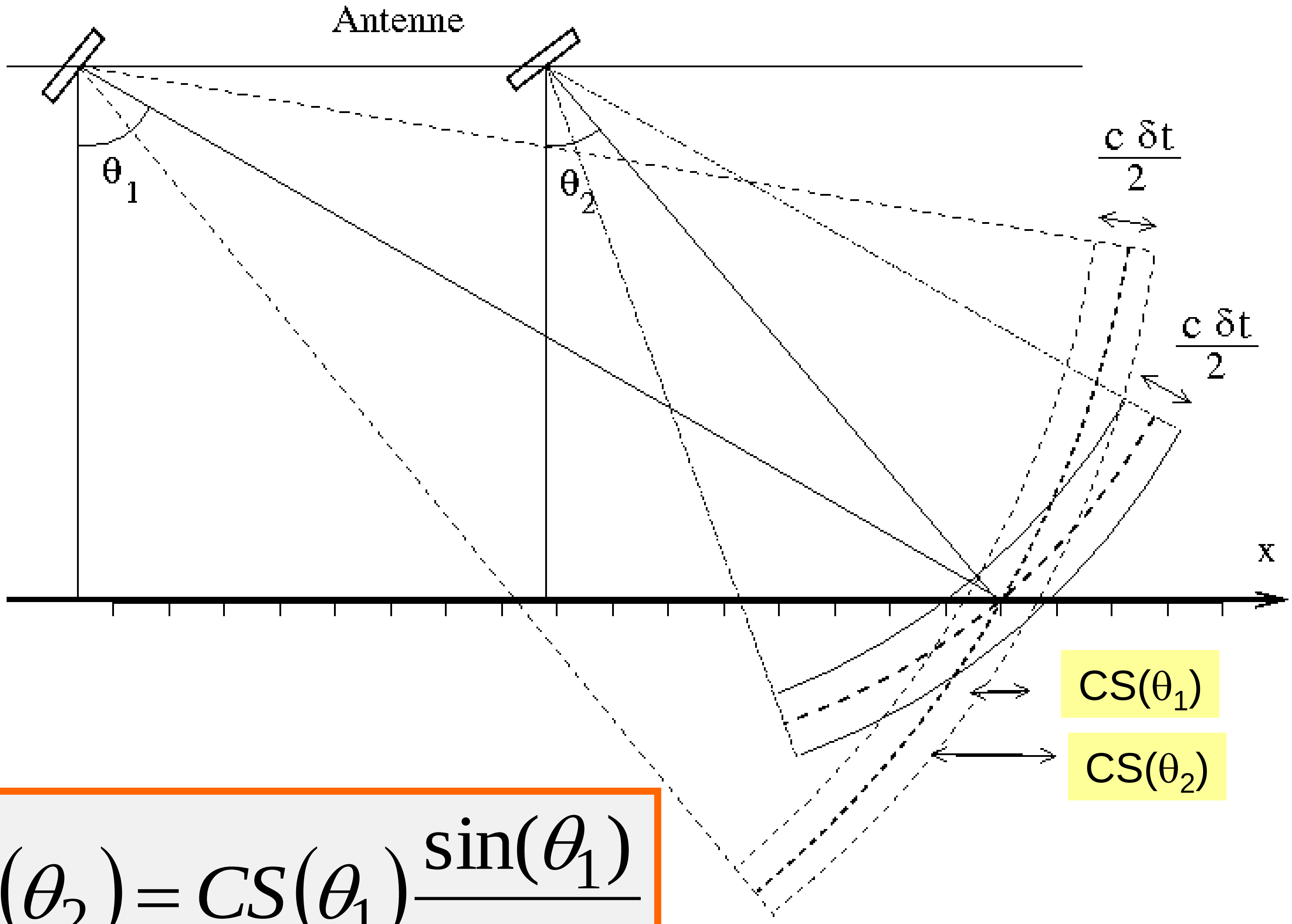


Image ERS



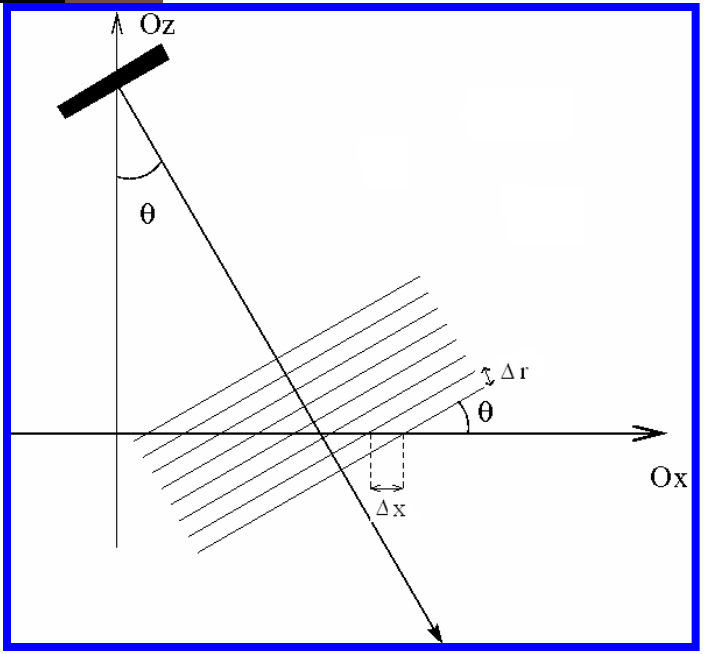
Mosaïque sur Google

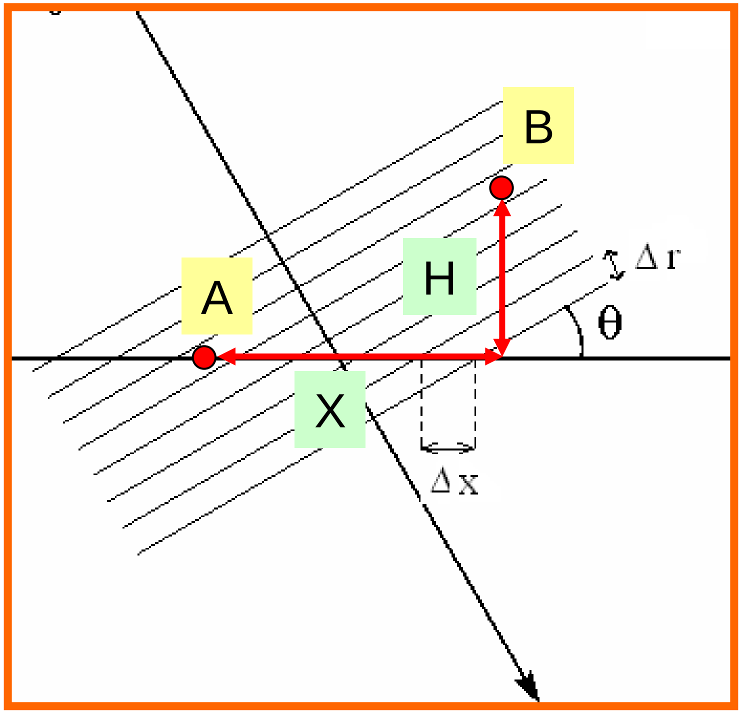
Cell size and local slope



$$CS(\theta_2) = CS(\theta_1)\frac{\sin(\theta_1)}{\sin(\theta_2)}$$

Ground range: Case $\alpha = \theta$





- Range cell : Δr
- Ground range : Δx
- Influence of local slope

- A and B in the same range cell
- Relation between X, H et θ

$$\tan\theta = \frac{H}{X}$$

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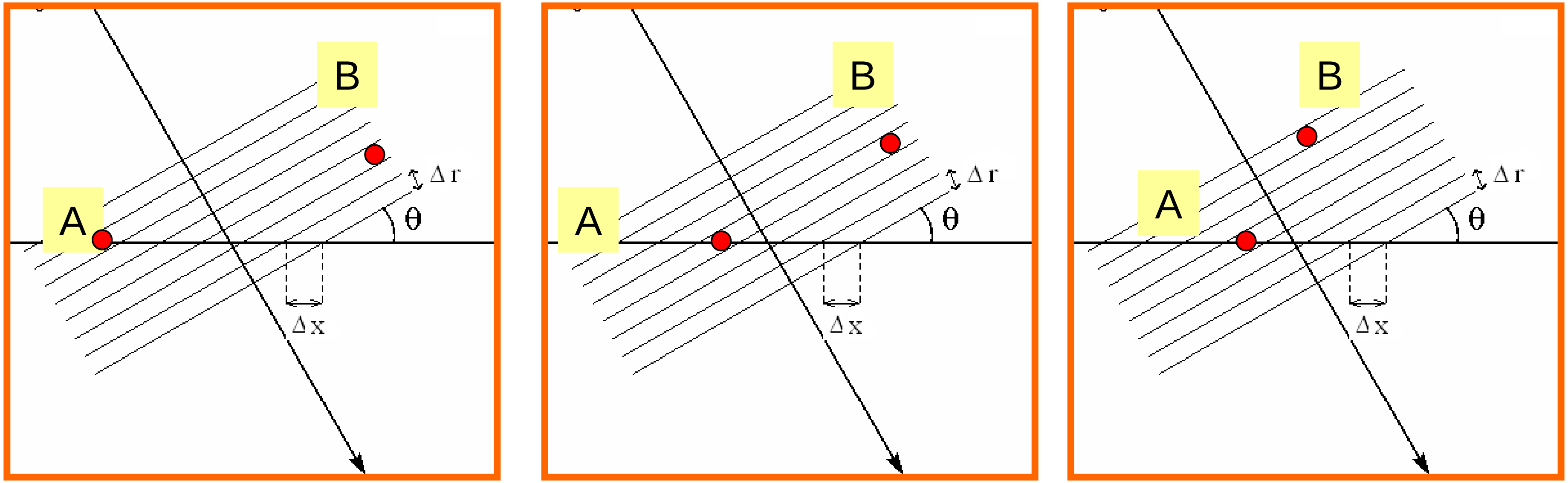
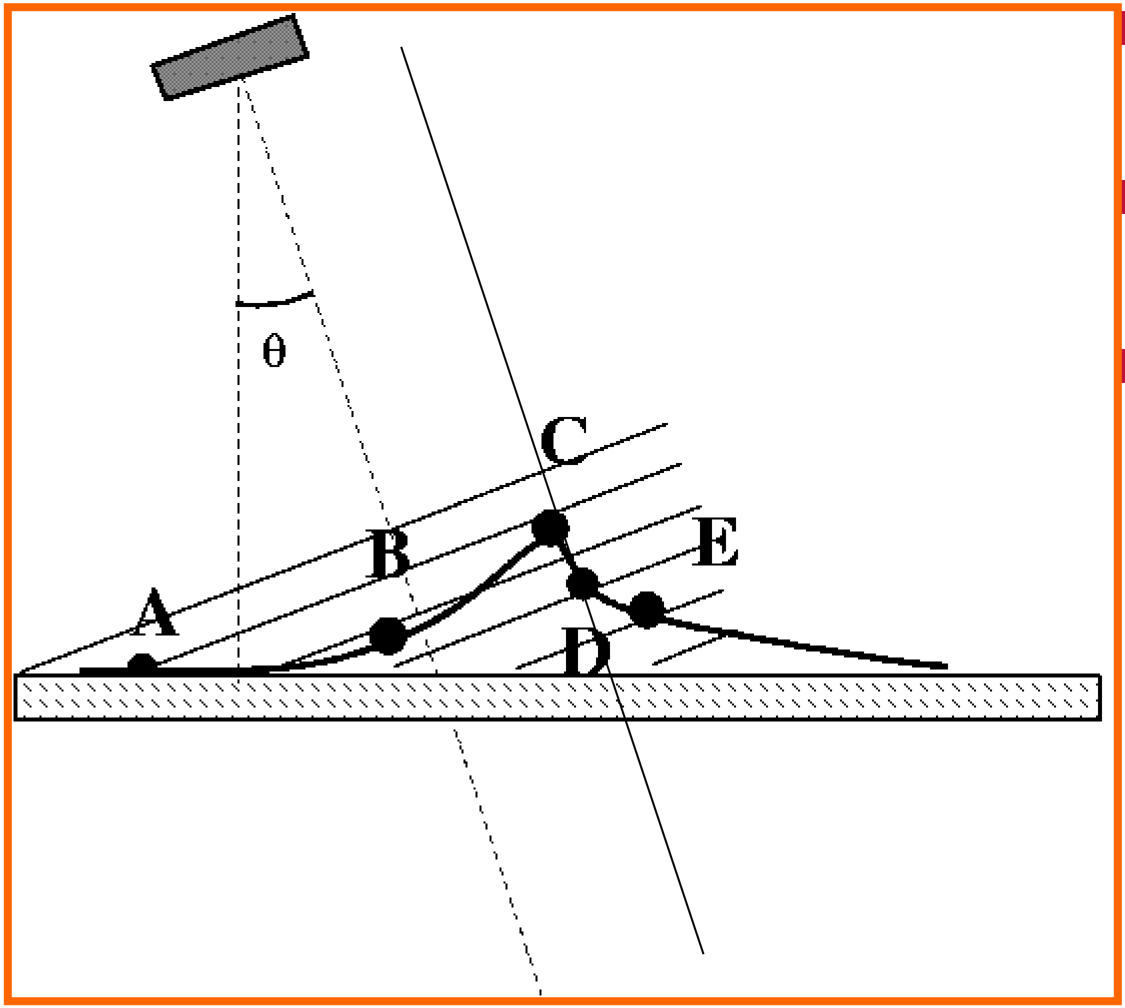
Relief – lay-over



- **Weak slope : A first, then B**
- **Slope = incidence angle: A and B in the same cell**
- **Strong slope : B first, then A : <u>« lay-over »</u>**
  - Lay-over condition: $H > X \tan\theta$

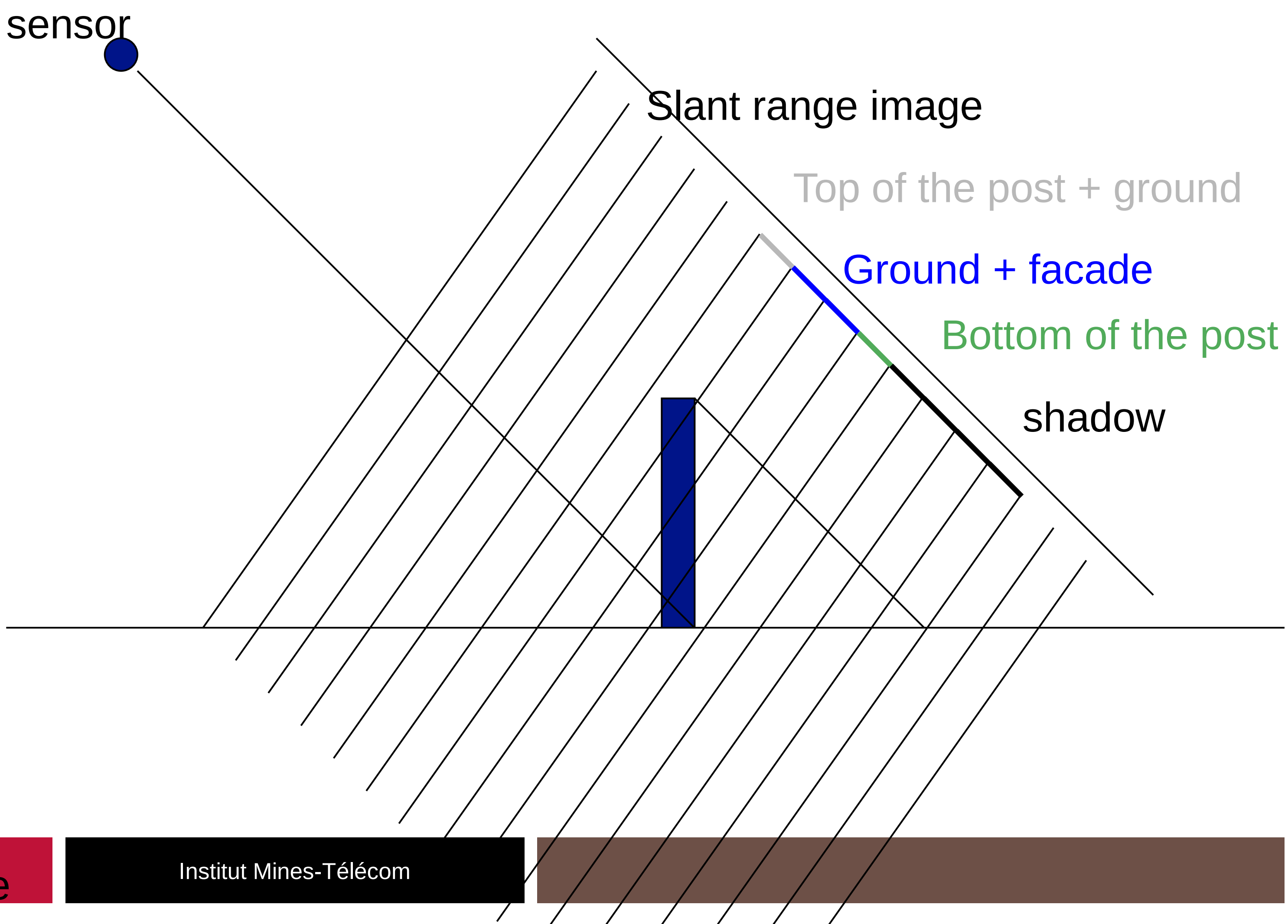
Geometric distorsions: Lay-over / shadow



- **Lay-over: C and A**
- **Inversion: C before B**
- **Shadow: D**

Geometrical distorsions
Lay-over / shadow

- **Example of a vertical post**



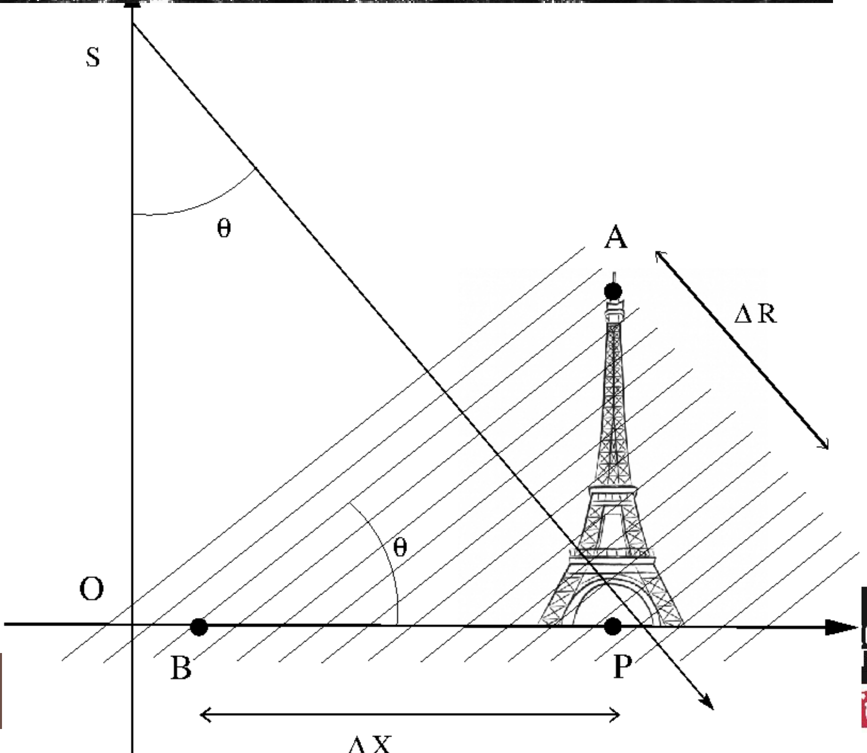
Eiffel tower

Lateral viewing

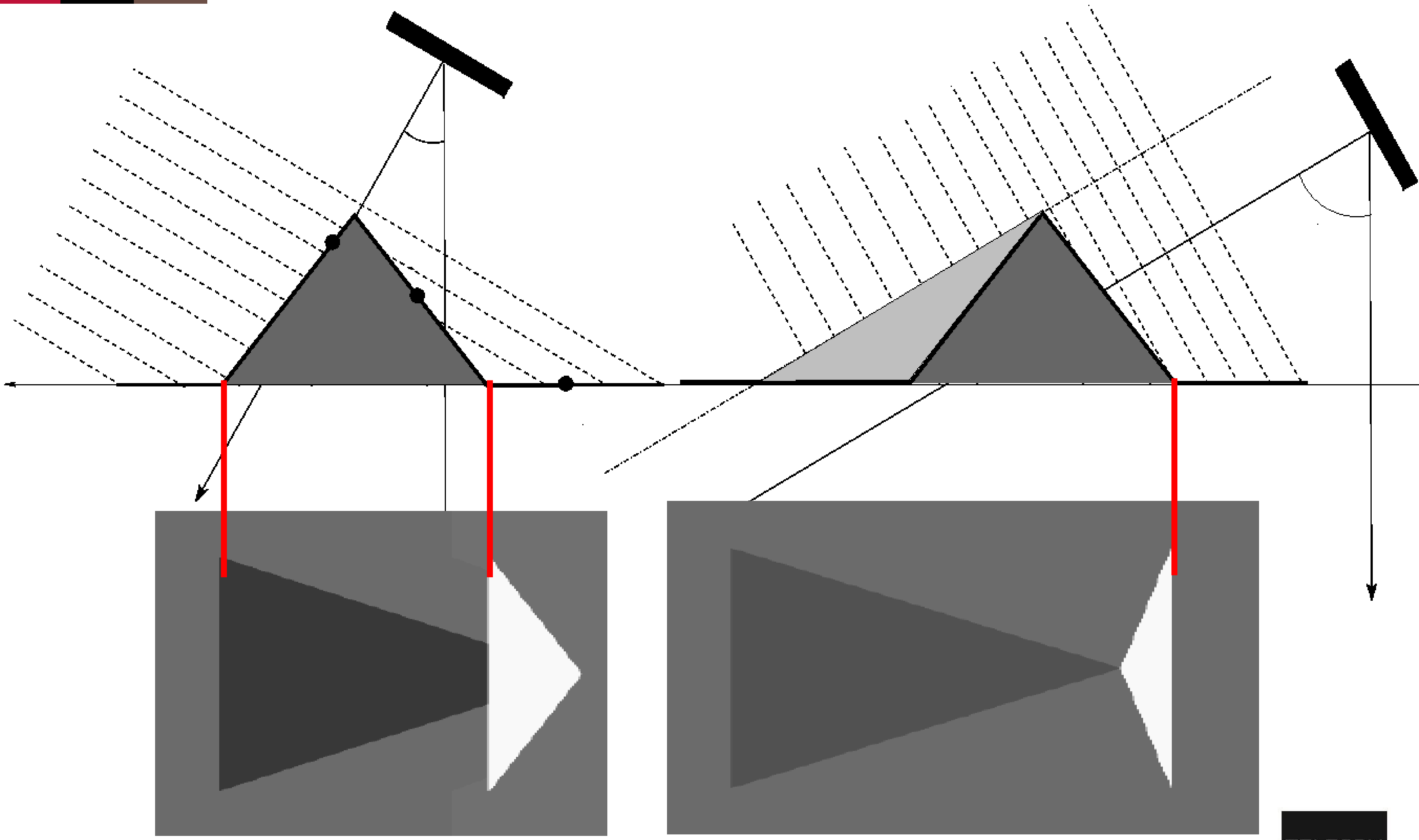
- **Terrasar-X, θ~34°**
- **Relationship between h and BP**

$$H = \frac{\Delta X}{\tan\theta}$$

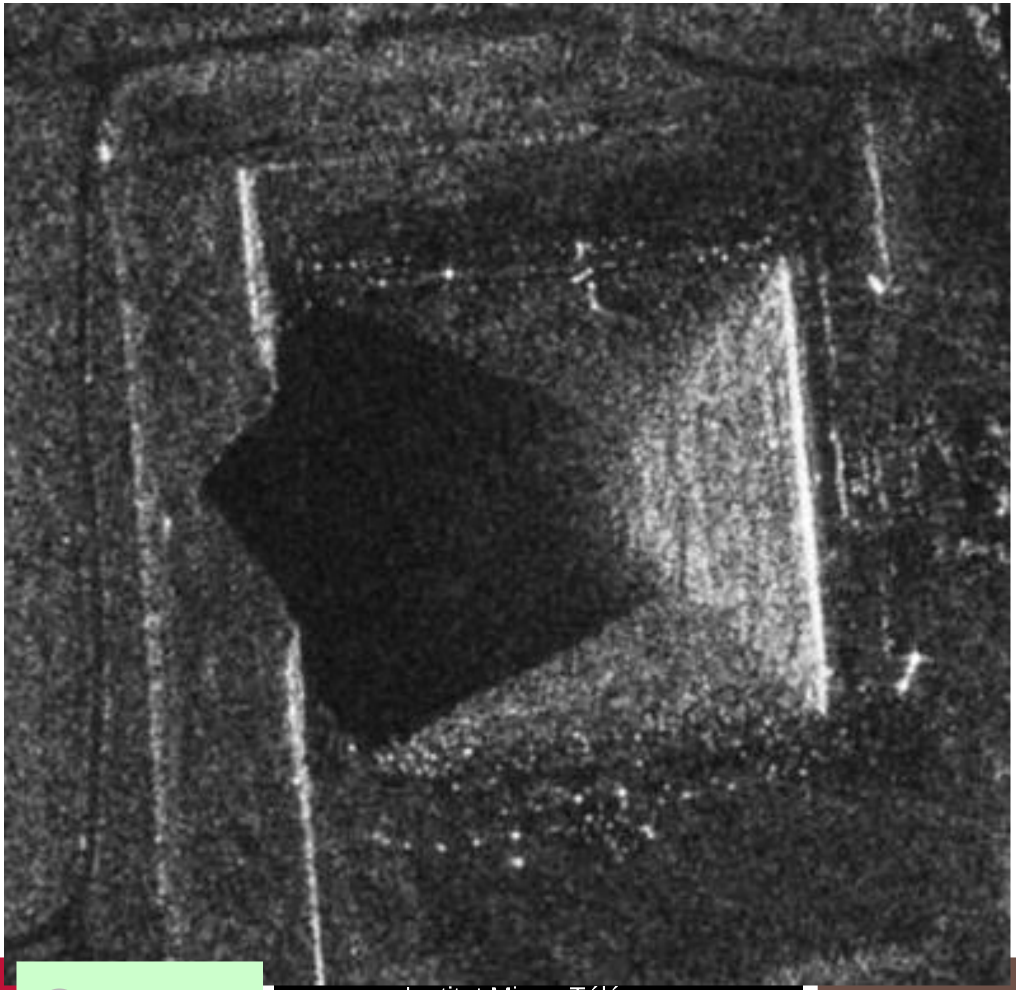
$$H = \frac{\Delta R}{\cos\theta}$$

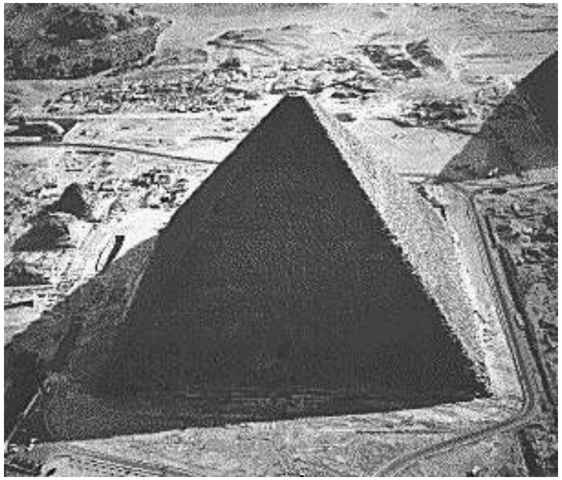


Pyramide 30° and 60°



TERRASAR-X :Gizeh

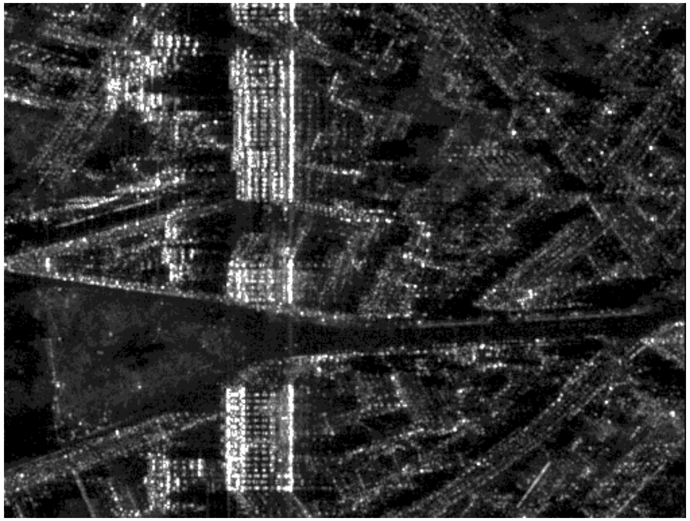


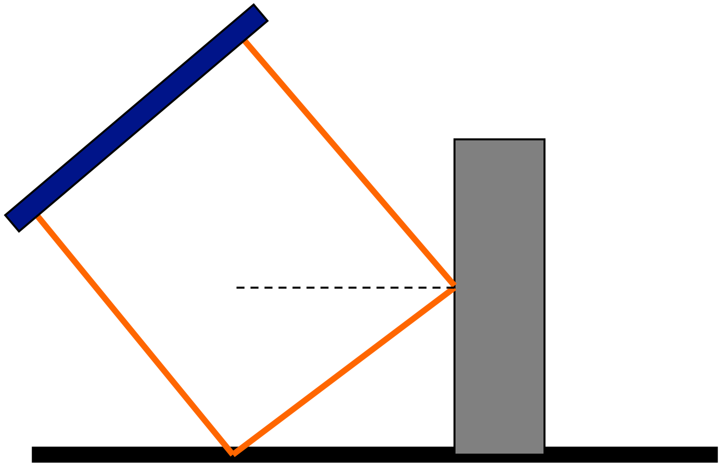


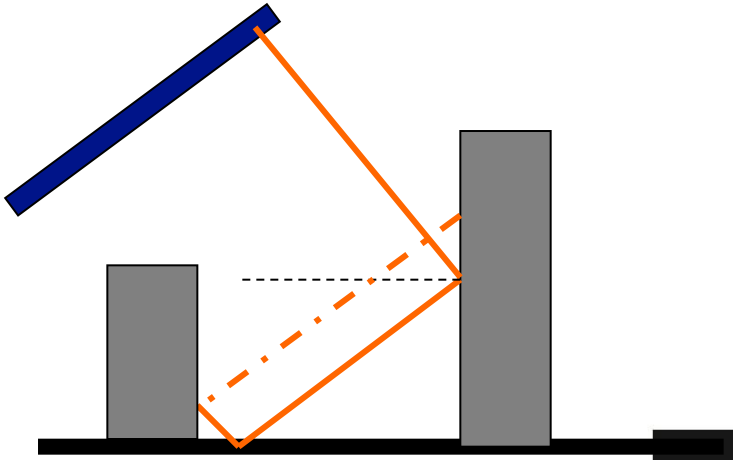
- **Side : 232m**
- **Height : 146m**
- **Slope : 51°**
- **Incidence : 53°**

Gizeh : incidence 40°

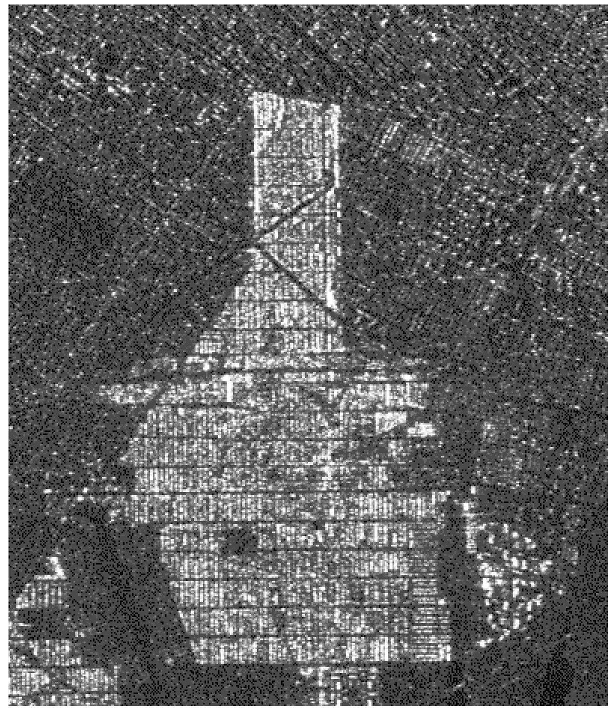
Urban areas







Influence of the viewing direction



X-SAR image of Brooklyn, New-York, resolution 6.5m

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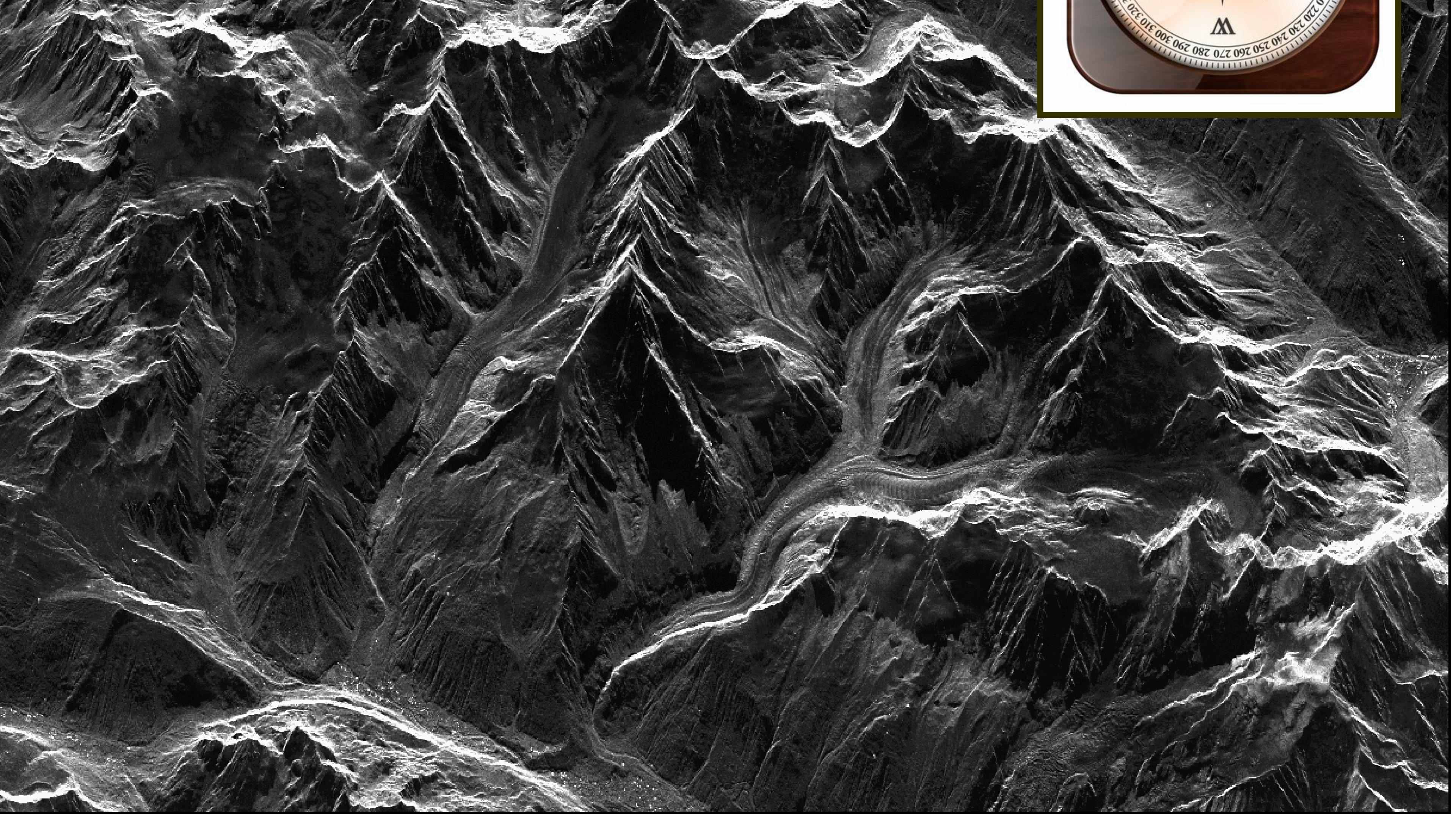
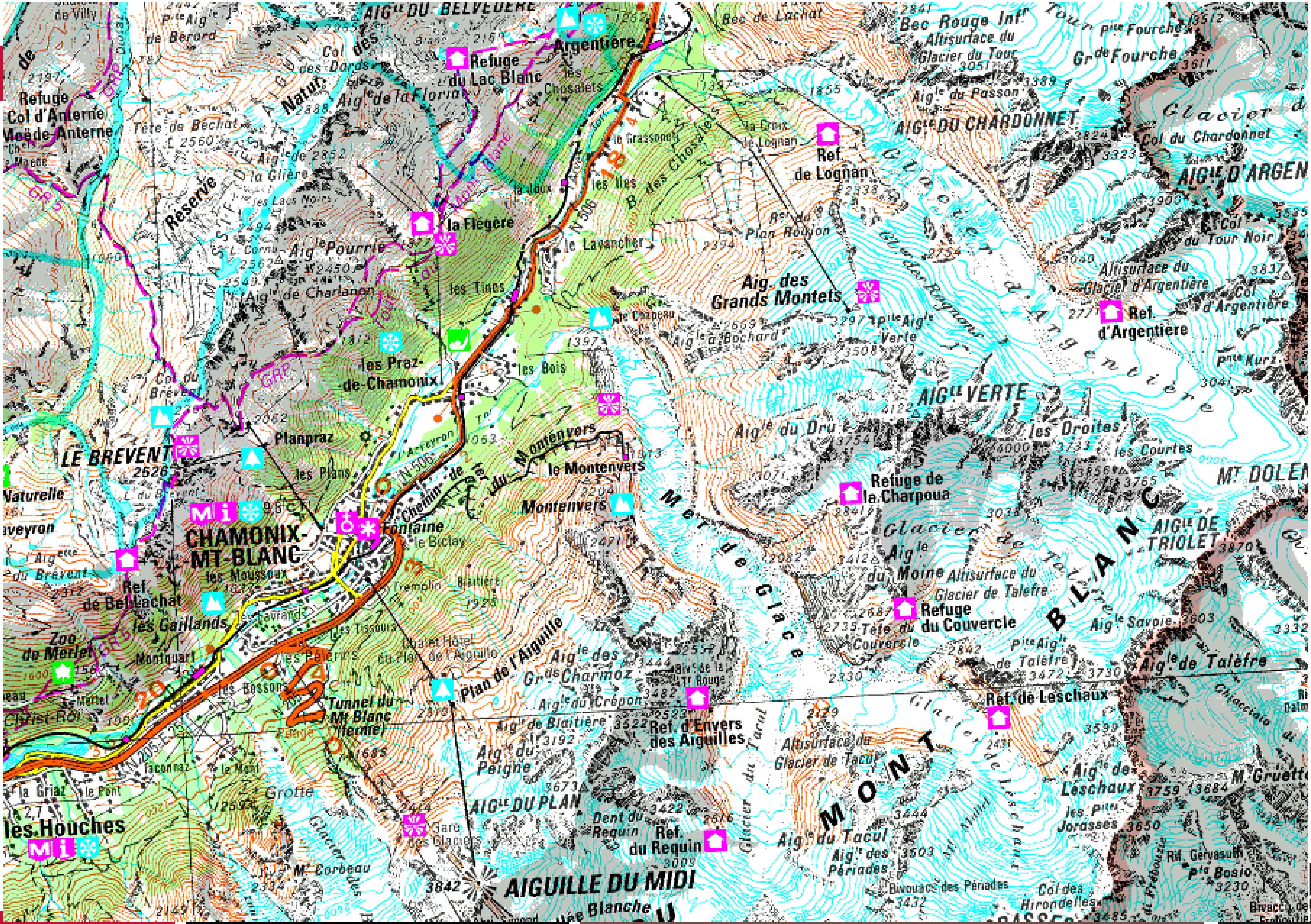
31 déc. 2006
Image © 2010 GeoEye
Image © 2010 IGN-France
Google

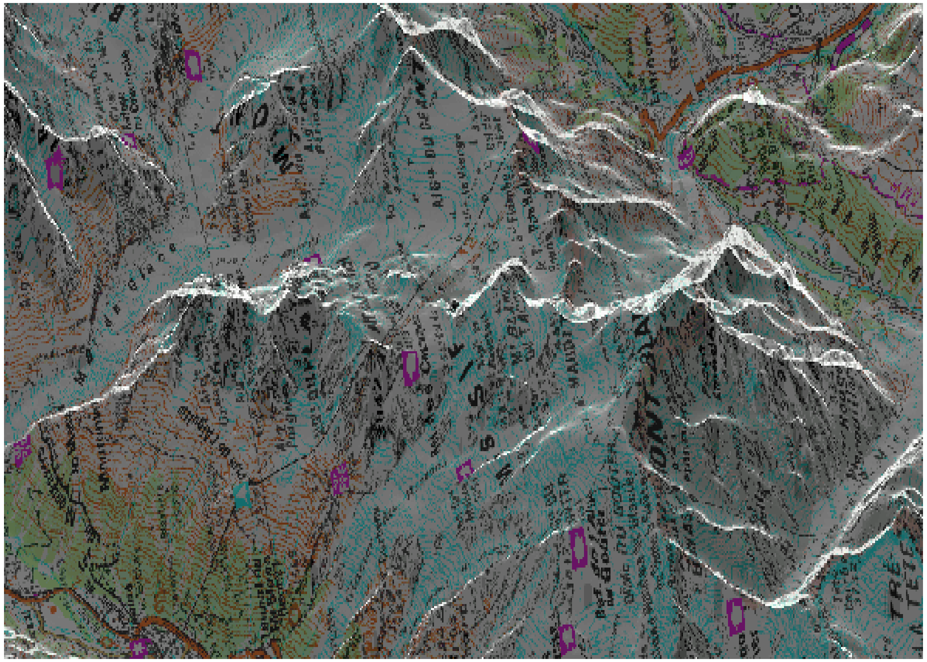
Terrasar-X
Descending pass





AIGLE DU BELVÉDÈRE
Argentière
Refuge du Lac Blanc
Refuge Col d'Anterne
Aigle de la Floria
Bec Rouge Infr
Grde Fourche
AIGLE DU CHARDONNET
Col du Chardonnet
AIGLE D'ARGEN
Ref de Lognan
Réserve
la Flégère
Aigle Pourrie
Aigle de Charlanon
le Lavancher
Aig. des Grands Montets
Ref. d'Argentière
les Praz-de-Chamonix
AIGLE VERTE
Aigle du Dru
les Droites
les Courtes
LE BRÉVENT
2526
Planpraz
le Montenvers
Montenvers
Refuge de la Charpoua
MT DOLEN
CHAMONIX-MT-BLANC
AIGLE DE TRIOLET
Mer de Glace
Ref. de Bel Lachat
les Gaillands
Refuge du Couvercle
Zoo de Merlet
Plan de l'Aiguille
Aigle des Grds Charmoz
Tunnel du Mt Blanc
Ref. de Leschaux
Ref. d'Envers des Aiguilles
MONT BLANC
Aigle de Talèfre
les Houches
AIGLE DU PLAN
Ref. du Requin
Aig. du Tacul
AIGUILLE DU MIDI
3842

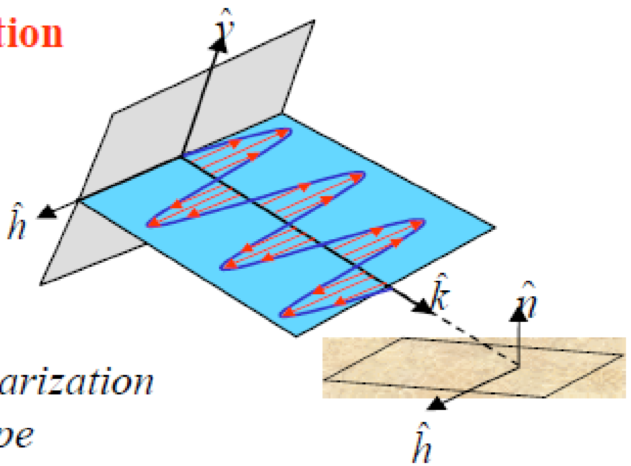
Terrasar-X and map + simulated radiometry (SAR geometry)



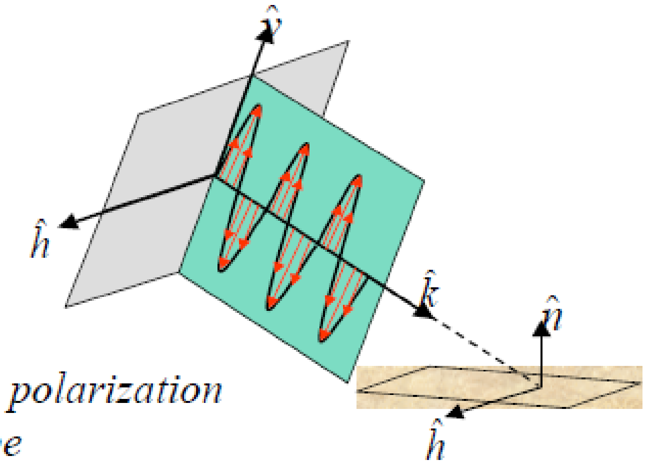
Polarimetry

Polarimetry

- The **polarization**



Horizontal polarization
RADARSAT type



Vertical polarization
ERS type

- **Fully polarimetric sensor :**
  - Emission H or V
  - Reception H or V
  - Scattering vector $\boldsymbol{k} = (z_{hh}, z_{vv}, \sqrt{2} z_{hv})^t$
- **Backscattered signal**
  - Depends on the mechanisms inside the resolution cell (dihedral back., volumic,…)

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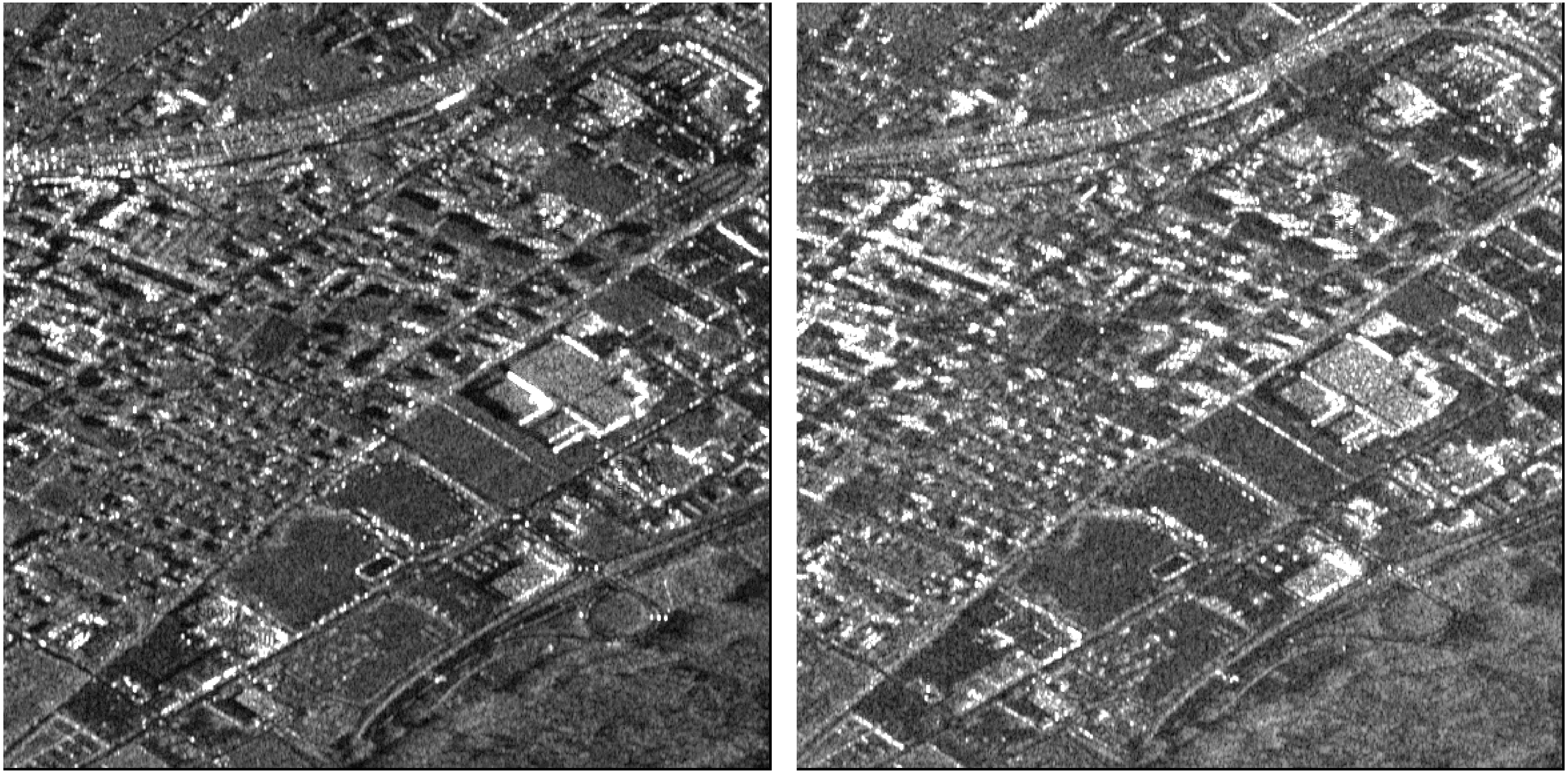
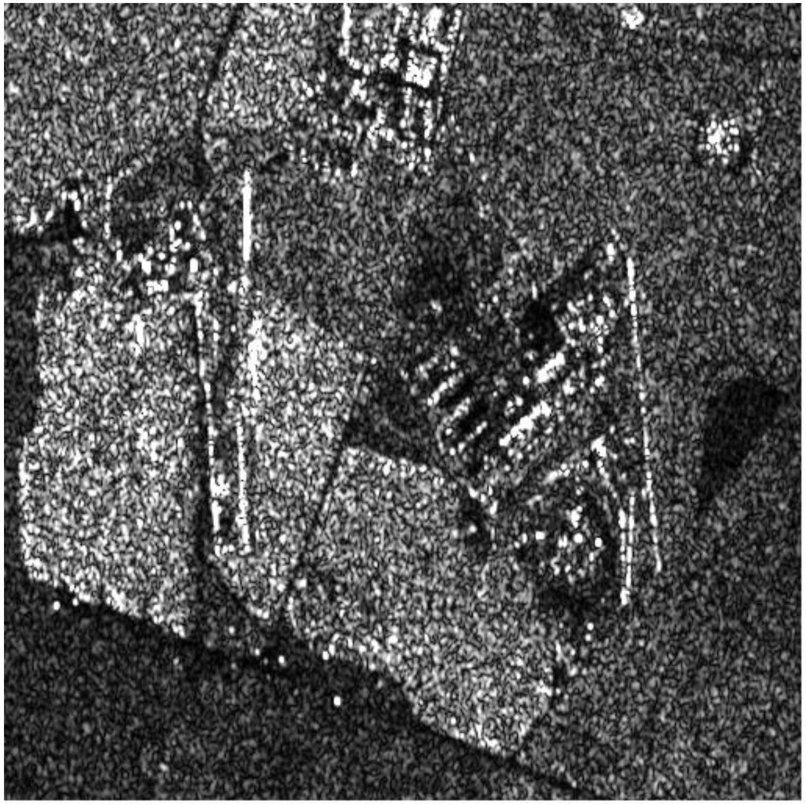
Comparison between HH and HV images



Composition of TerraSAR-X images HH and HV polarizations

Polarimetry

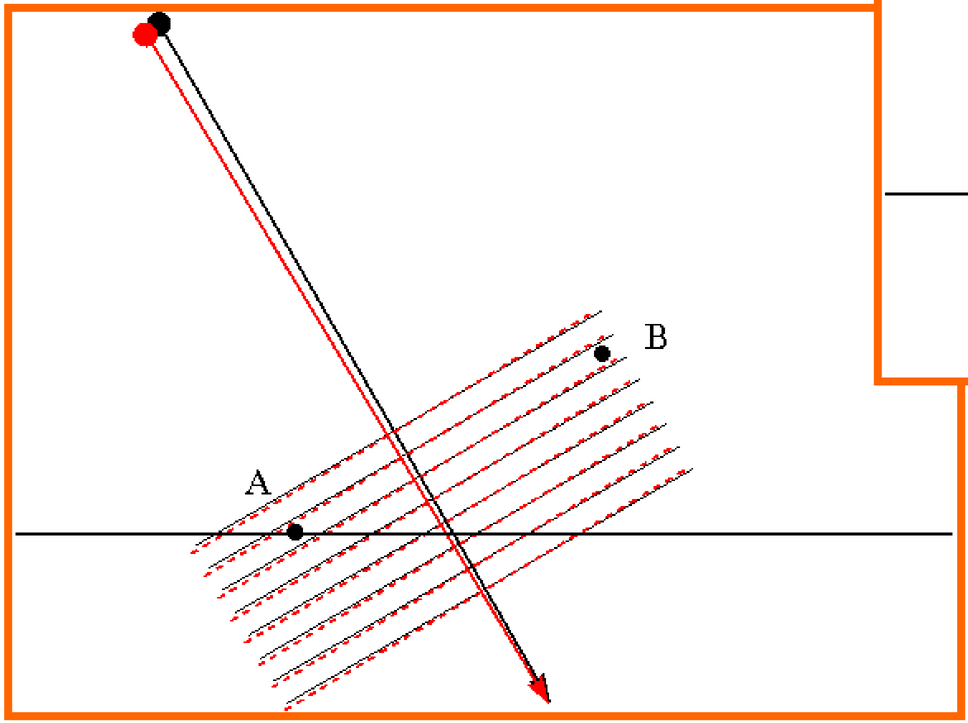
- **Sensitivity of the signal**

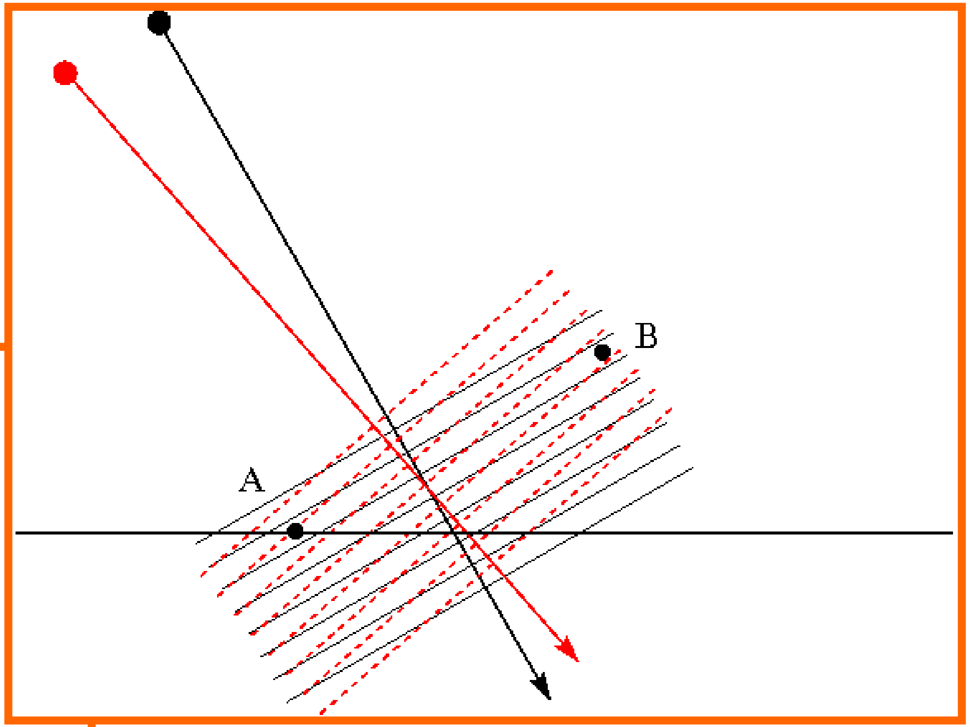


Polarisation HH

Polarisation VV

Interferometry

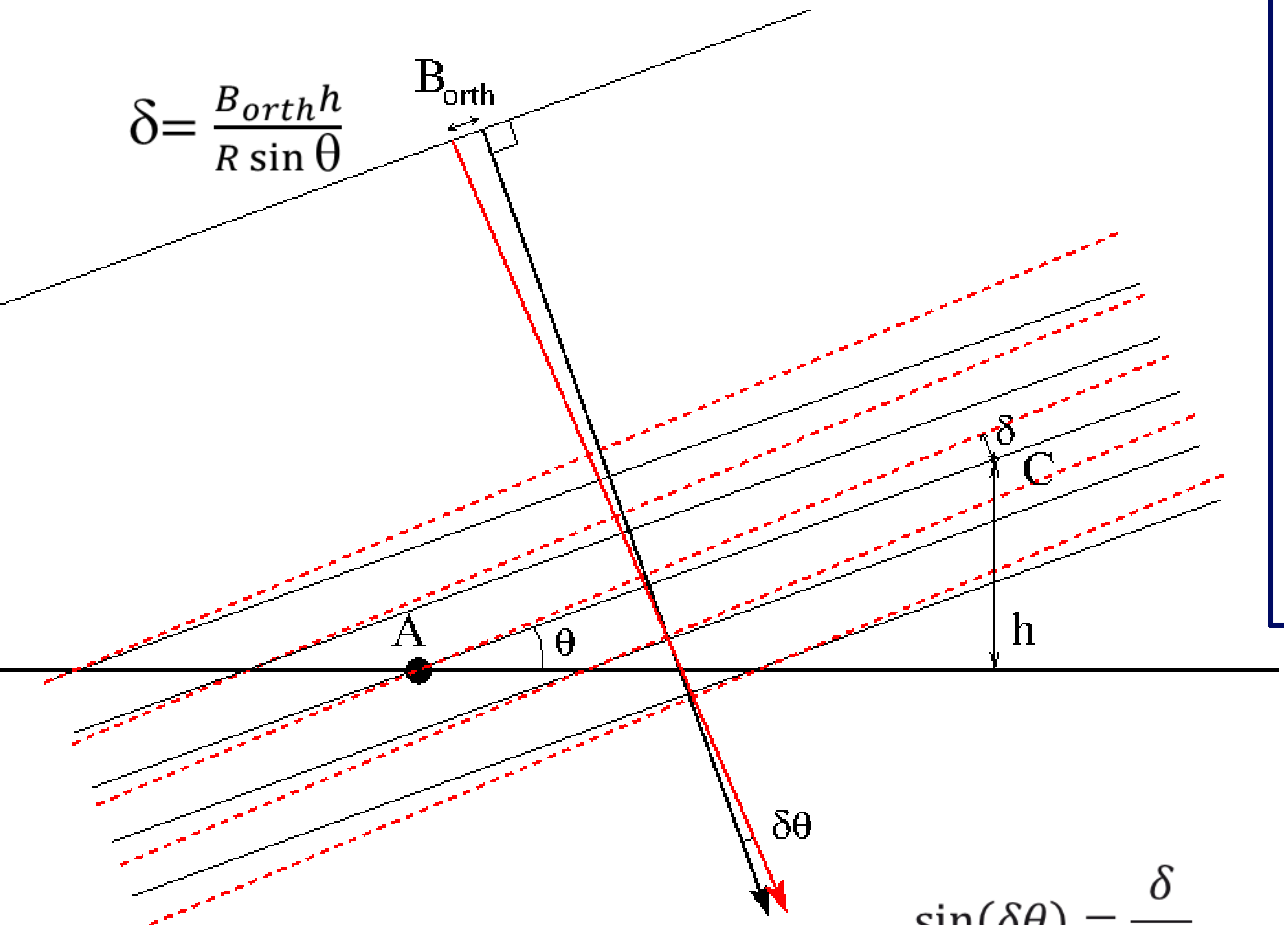




Big baseline:
radargrammetry

Small baseline :
interferometry

(3) Interferferometry - principle



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

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

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

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

$$\sin(\delta\theta) = \frac{\delta}{AC}$$

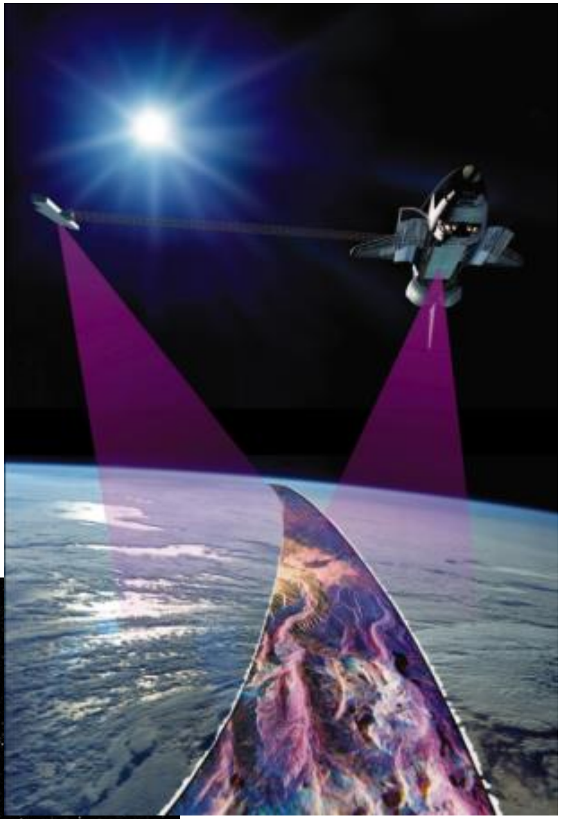
$$\sin(\delta\theta) = \frac{Borth}{R}$$

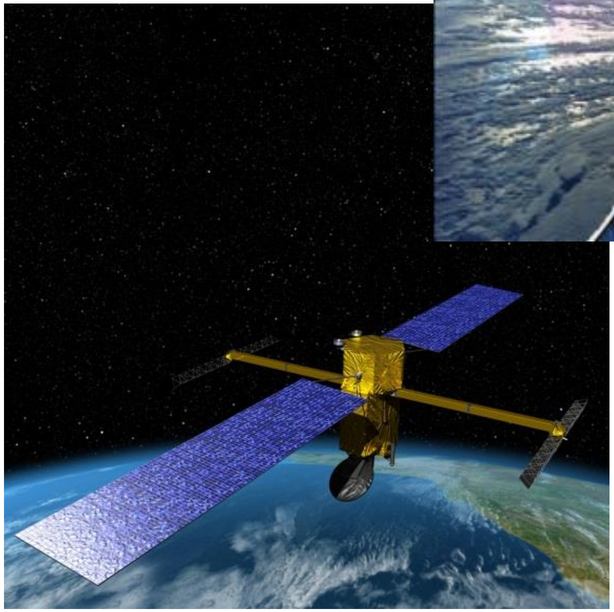
Interferometry - principle

- **Interferometric processing chain**
  - Acquisition of 2 SAR images in interferometric configuration
  - Fine registration of the 2 images
  - Computation of the phase difference
  - Phase unwrapping

Interferometry – Main steps

- **Acquisition of 2 SAR images in interferometric configuration**
  - Repeat pass interferometry
    - Same orbit, same incidence angle, time revisit
  - Single pass interferometry
    - SRTM (Shuttle Radar Topographic Mission)
    - Airborne acquisitions
    - TanDEM-X / TerraSAR-X
    - *SWOT*





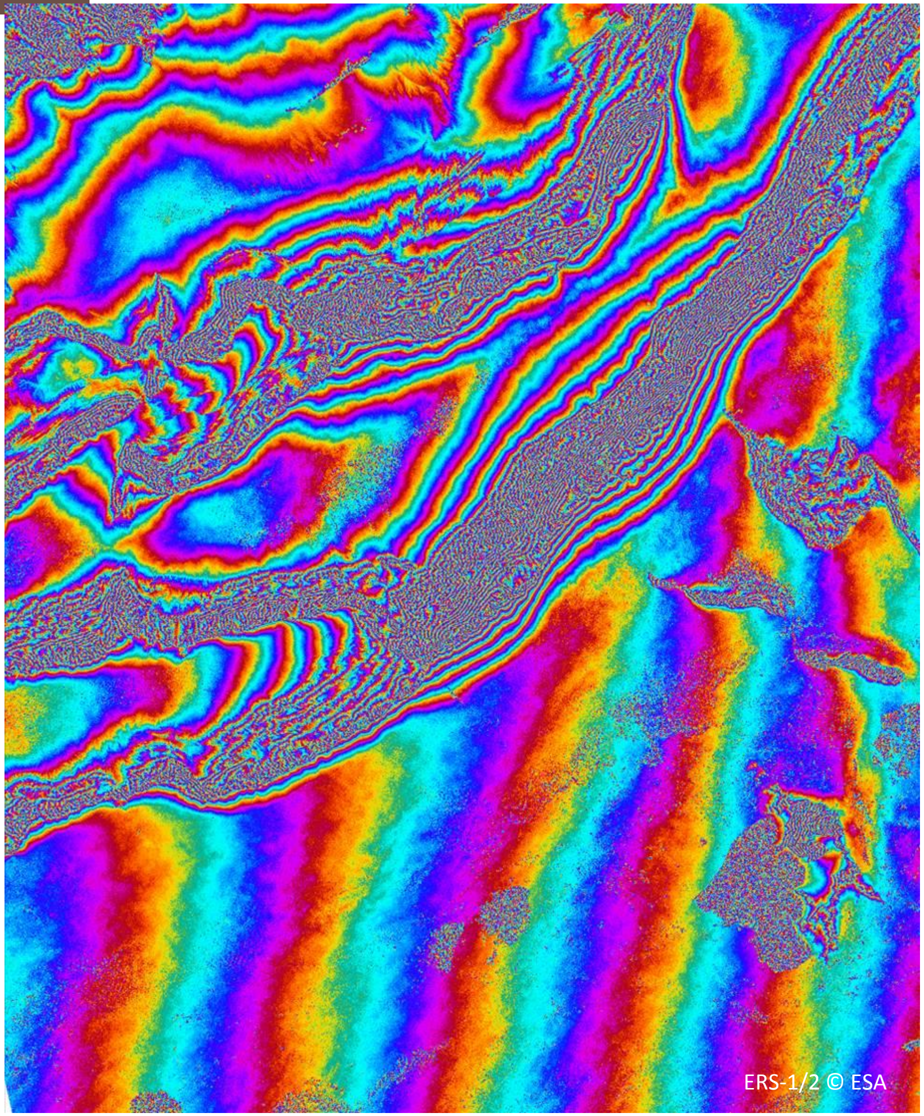
ERS SAR

Image

Bachu, China

approx. 100 km × 80 km

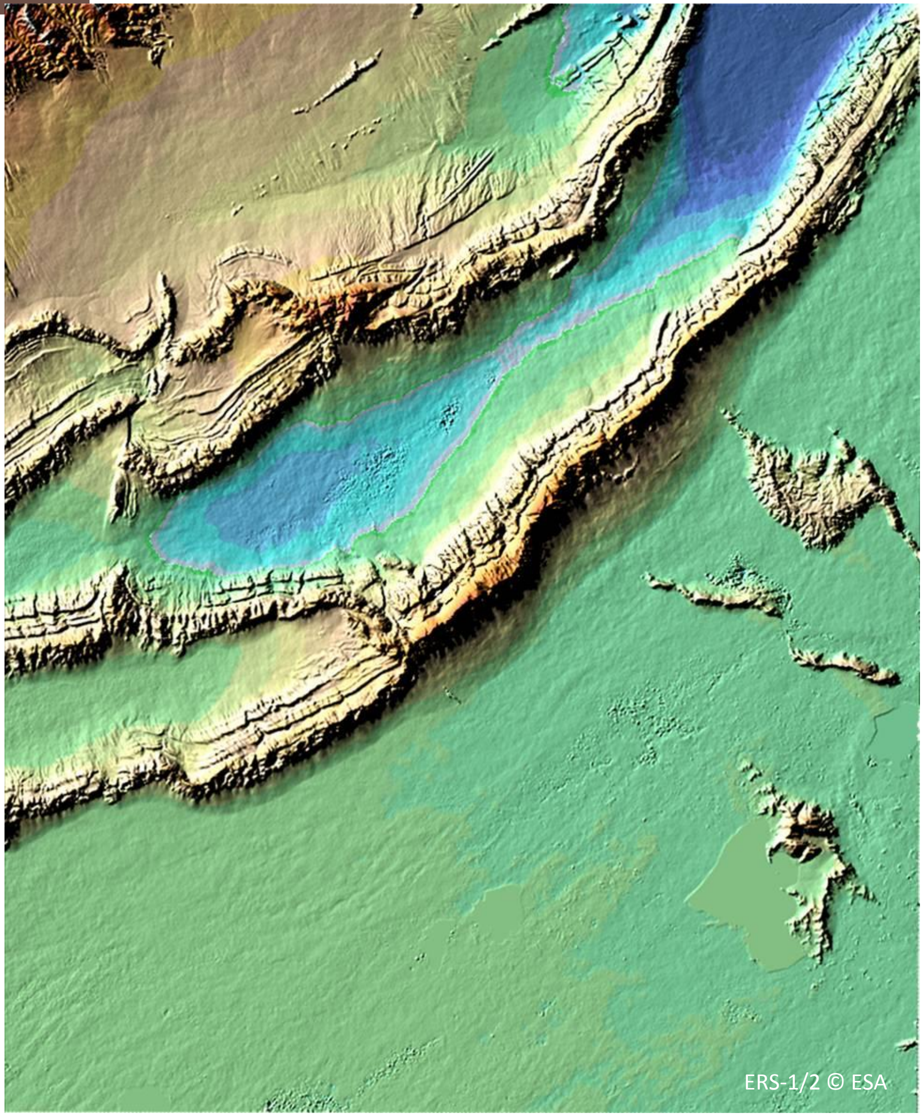
Interferometric Phase



Bachu, China

approx. 100 km × 80 km

InSAR DEM (ERS-1/2)



Bachu, China

approx. 100 km × 80 km

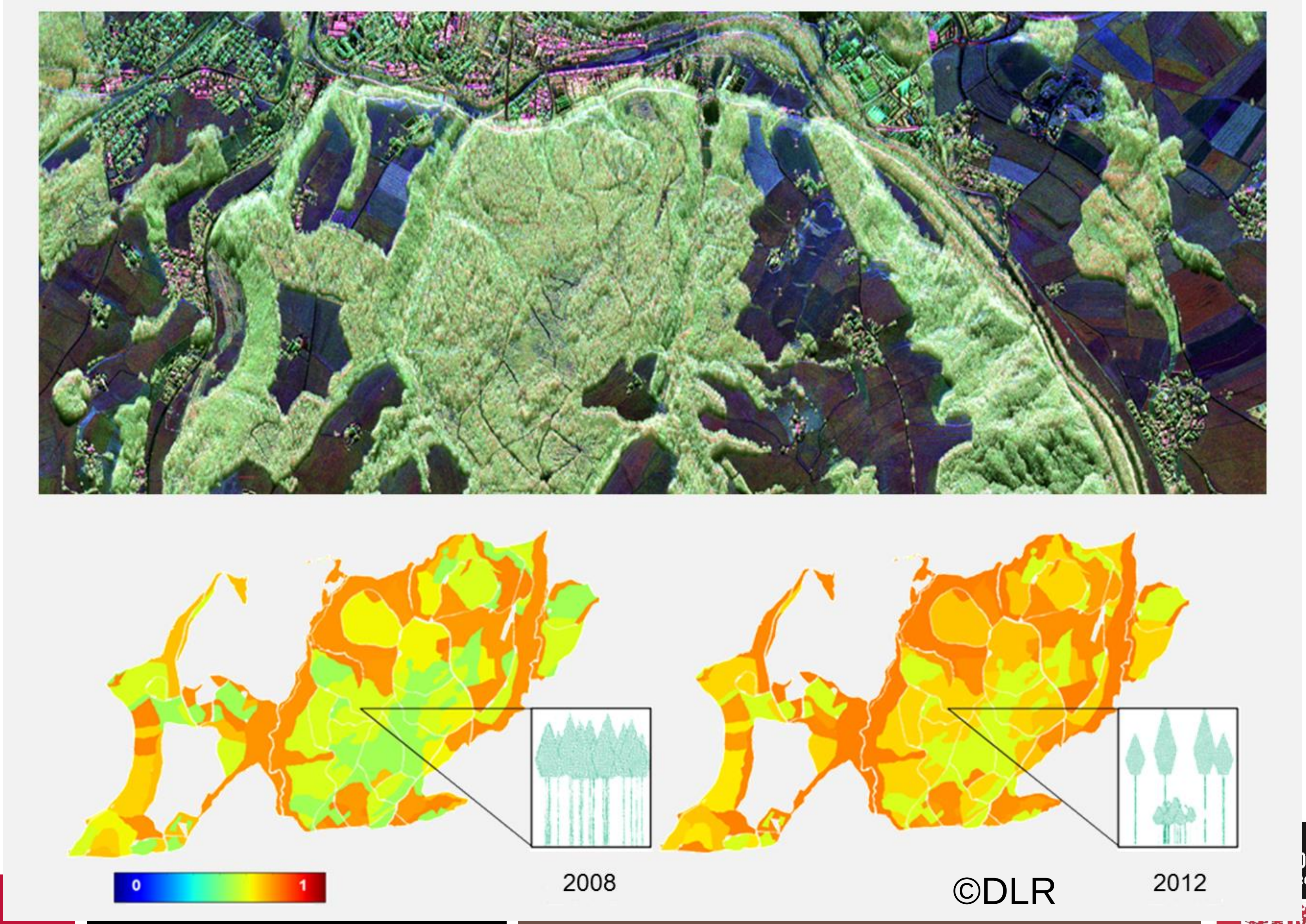
Use of SAR data

Use of SAR data

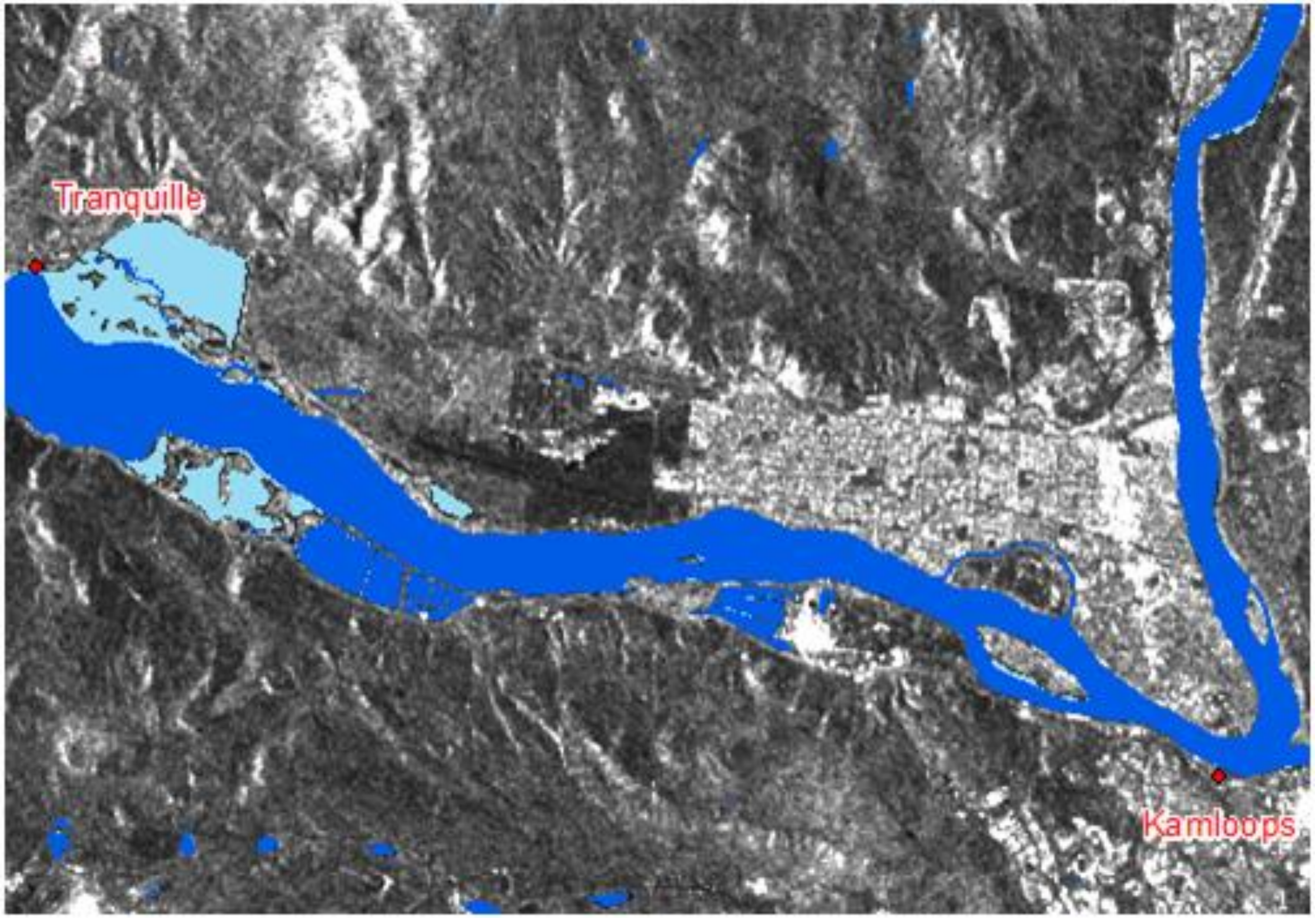
- **Land applications**
  - Agriculture and vegetation monitoring
  - Urban areas monitoring
  - Disaster management
  - Defense and security
  - Digital terrain modeling *(interferometry)*
  - Ground movement monitoring *(interferometry)*
- **Ocean aplications**
  - Specific processing (Doppler analysis) for sea surface current
  - Ice monitoring (ice state and movement)
  - Ship detection and supervision
  - Pollution detection

Agriculture monitoring (polarimetry)

BIOMASS measurement



Flood monitoring



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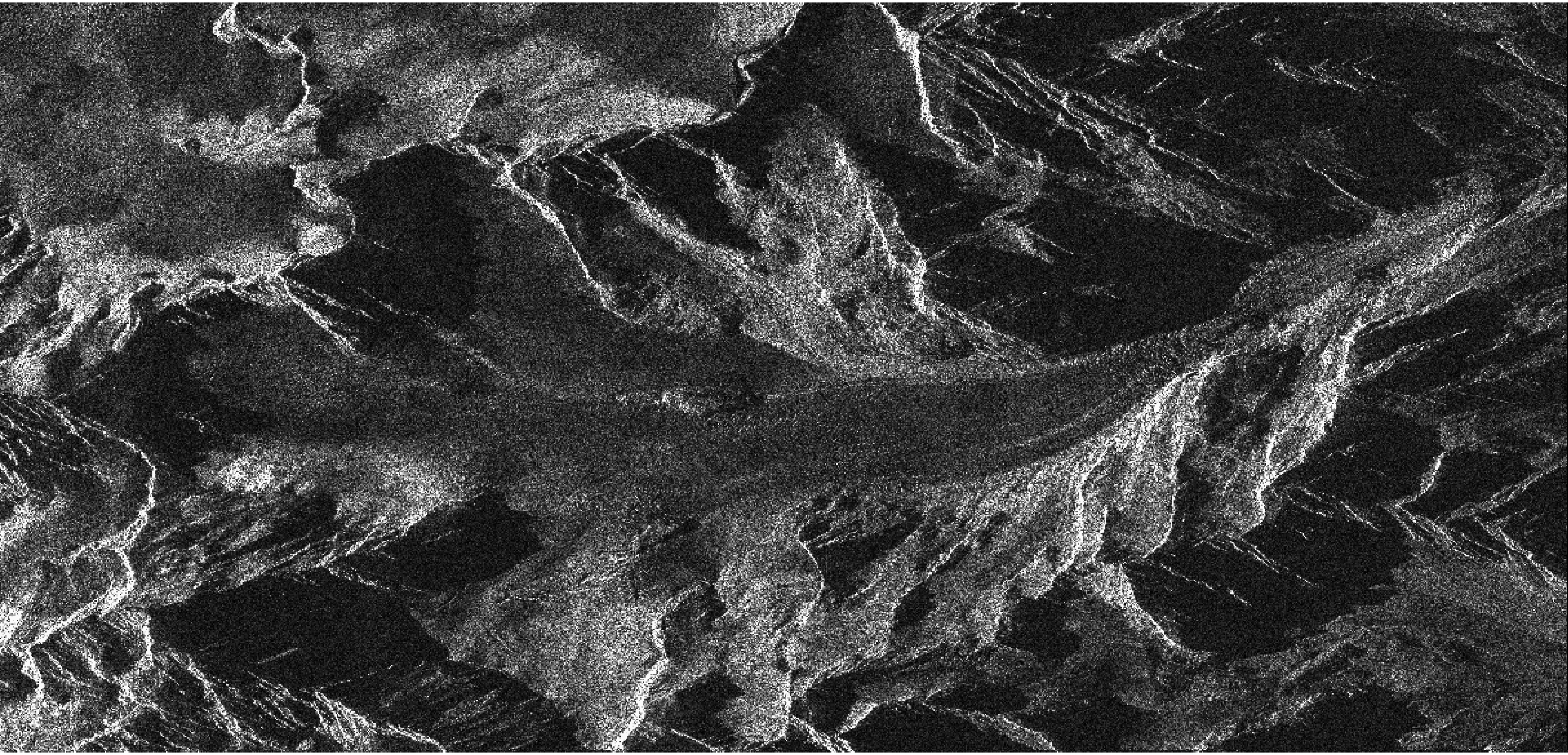
Séisme Sendaï

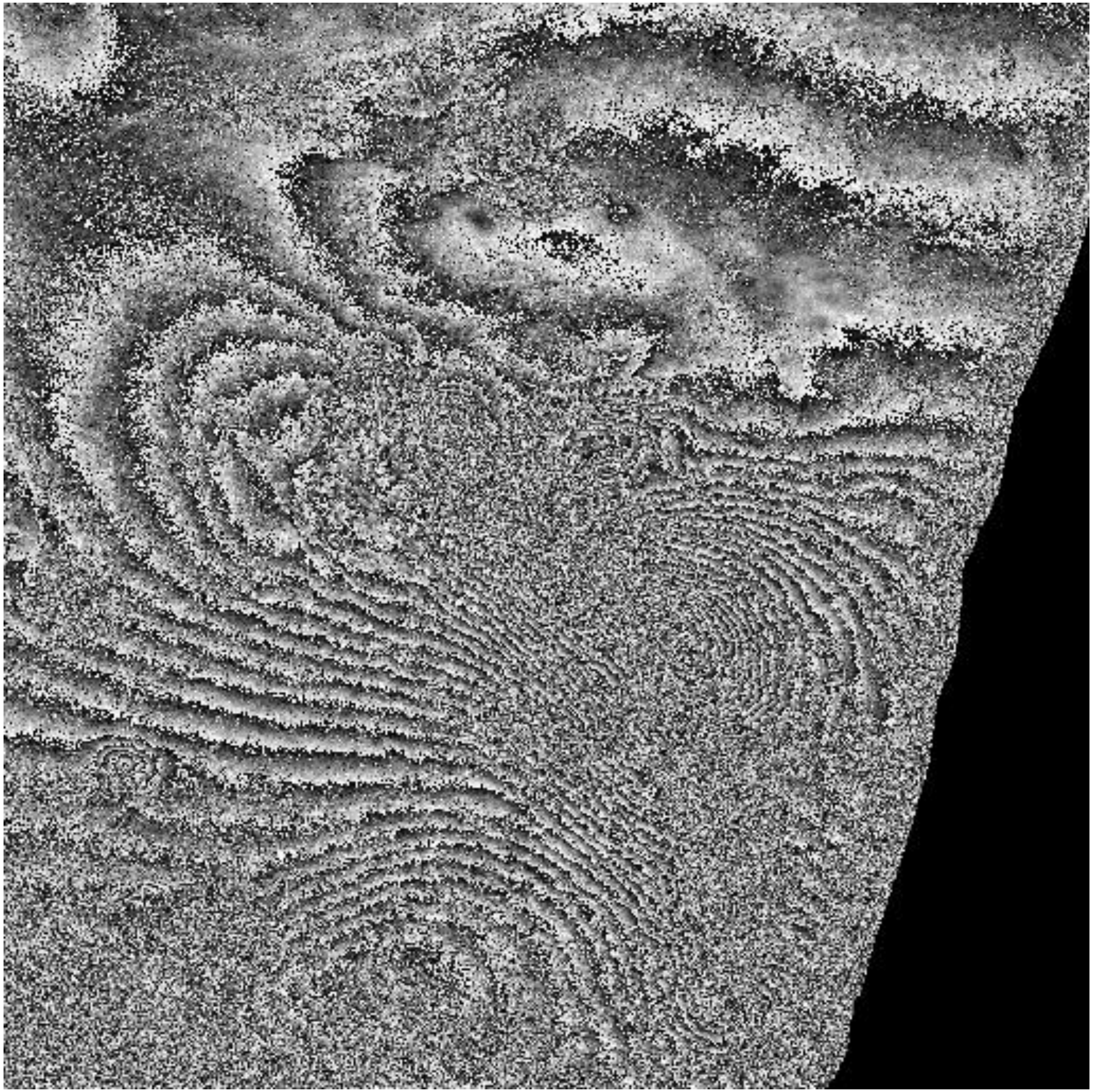
Avant

Après

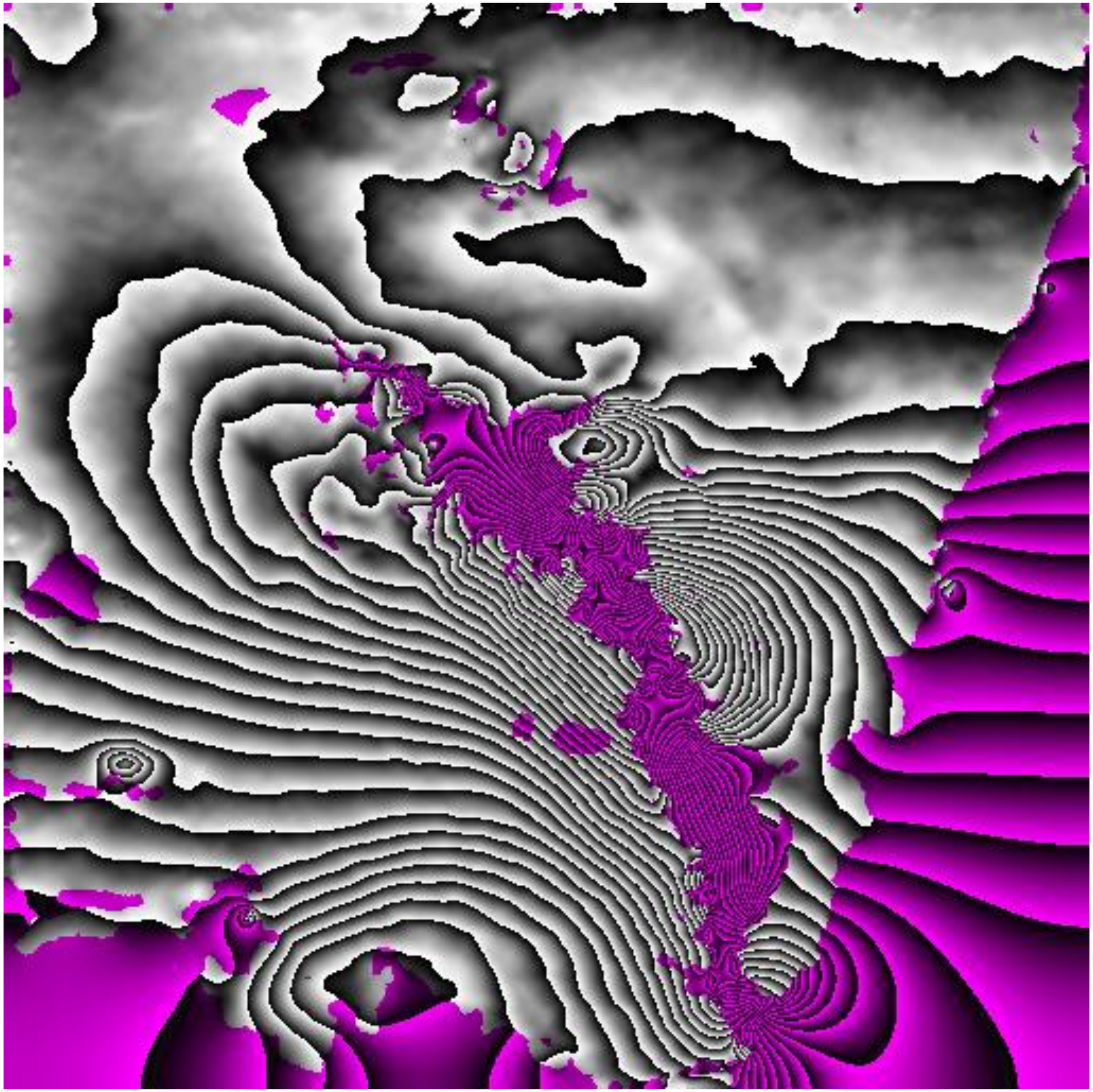
- **Positionnement quasi parfait des images RSO**

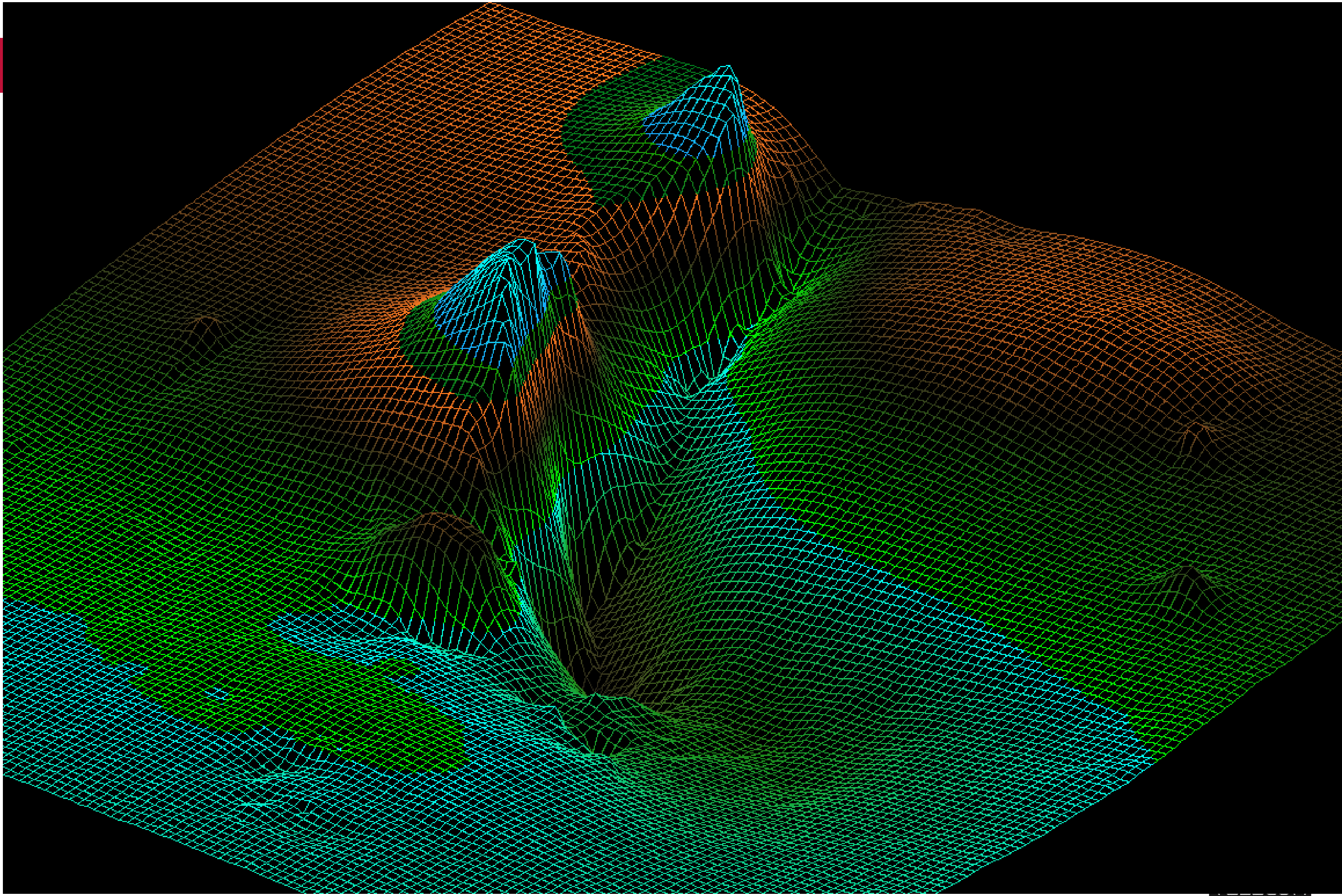
Glacier de Saleina
Uniquement visible sur passes ascendantes
Evolution entre mai 2009 et octobre 2009



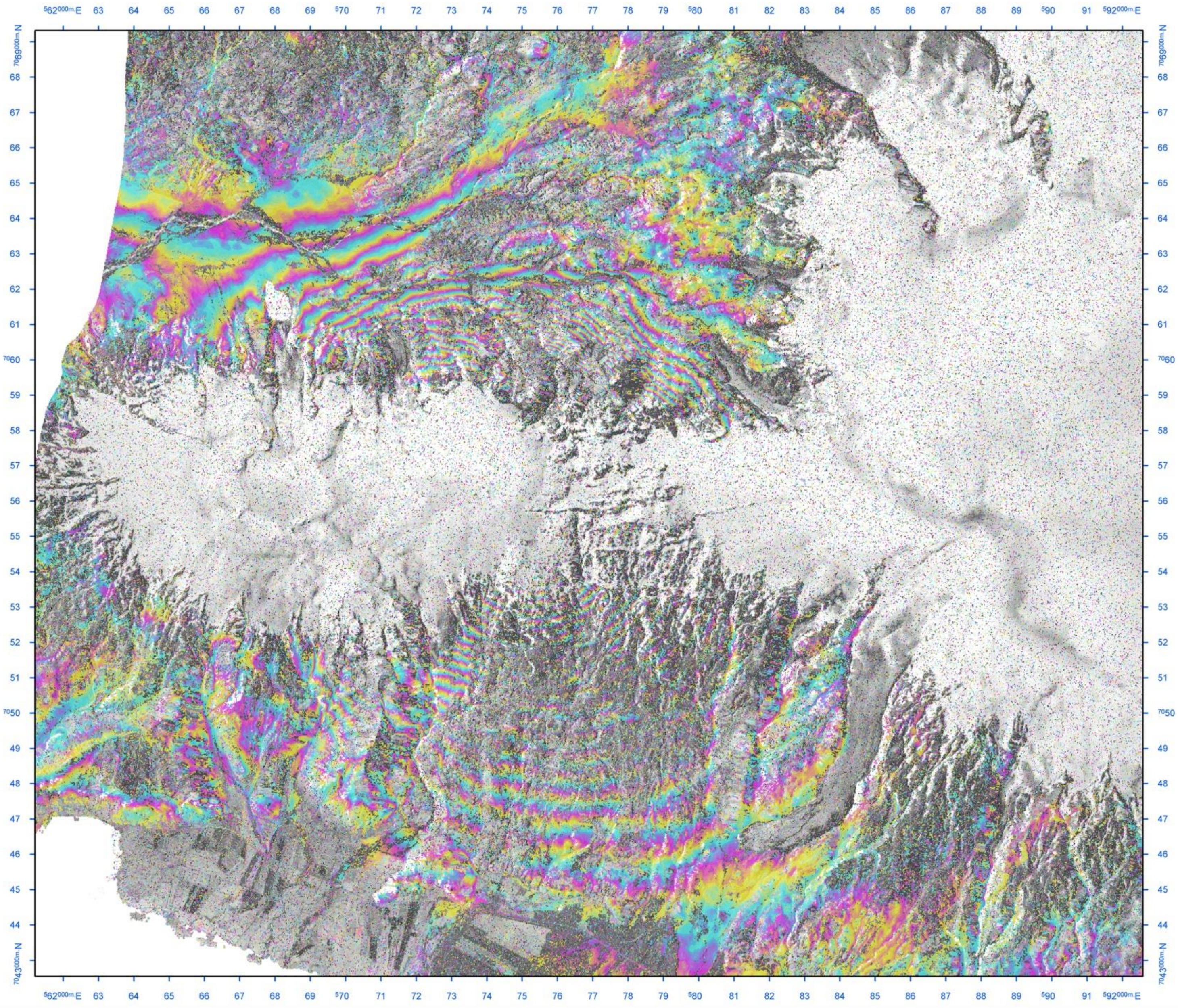


e différentiel @CNES, faille des Landers





Eyjafjallajokull (Iceland) - Deformation Monitoring



infoterra
an EADS Astrium company

TerraSAR-X
Differential SAR-Interferometry

Location of Scene:

Line-of-sight (LOS) change

-Pi Pi

ASTER GDEM used for topographic phase reduction.

ASTER GDEM is a product of METI and NASA

Satellite Image/Processing Information

Acquisition Period	18.06.2009 - 11.04.2010
Number of Scenes	2
Satellite	TerraSAR-X
Imaging Mode	StripMap
Ground Resolution	~4 m
Polarisation	HH
Incidence Angle	~37°
Pass Direction	Descending
Sample Acquisition Date	18.06.2009
Sample Acquisition Time (UTC)	07:48:52
BAFA Release	415-12.00-1104250 - 426-12.00-1104261

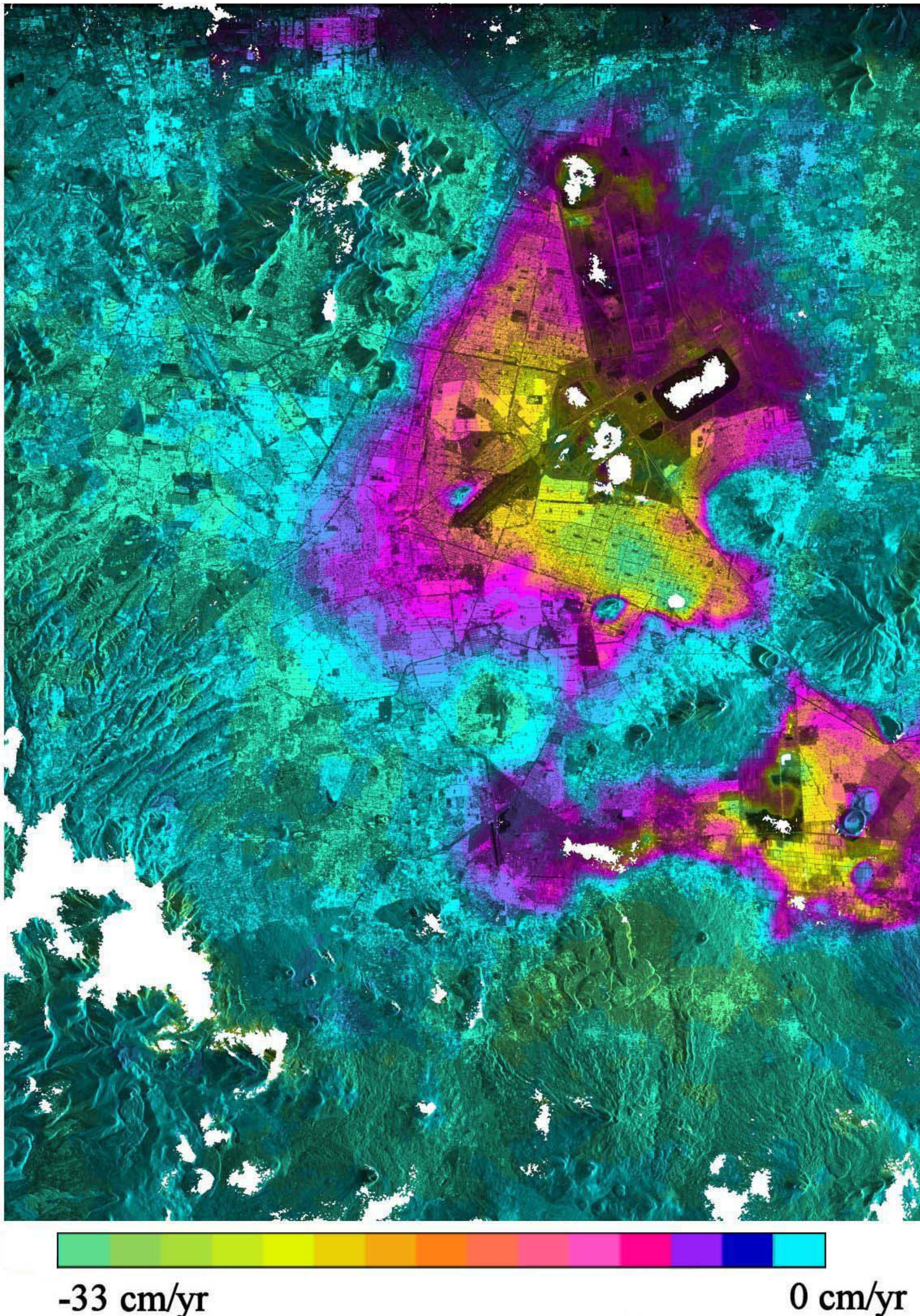
0 0,5 1 2 3 4 5 6 7 8
Kilometers

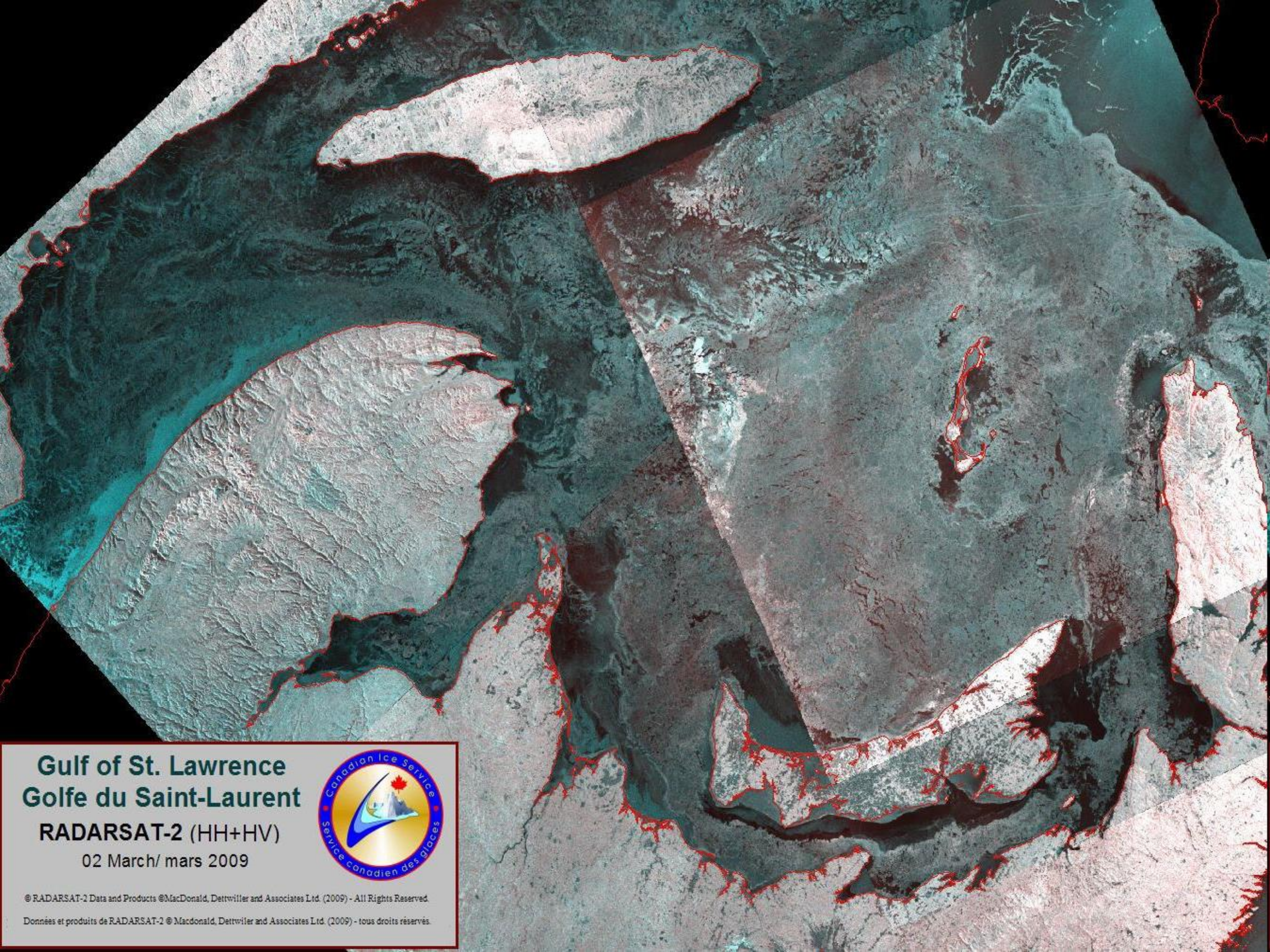
Map Projection

Geographic	**Universal Transverse Mercator**
Ellipsoid: WGS 84	Ellipsoid: WGS 84
Datum: WGS 84	Datum: WGS 84
	Zone: 27N

TERRASAR-X SERVICES

Date of Map generation: 2010-05-21; Map template version: 1


-33 cm/yr
0 cm/yr


Gulf of St. Lawrence
Golfe du Saint-Laurent
RADARSAT-2 (HH+HV)
02 March/ mars 2009
Canadian Ice Service
Service canadien des glaces
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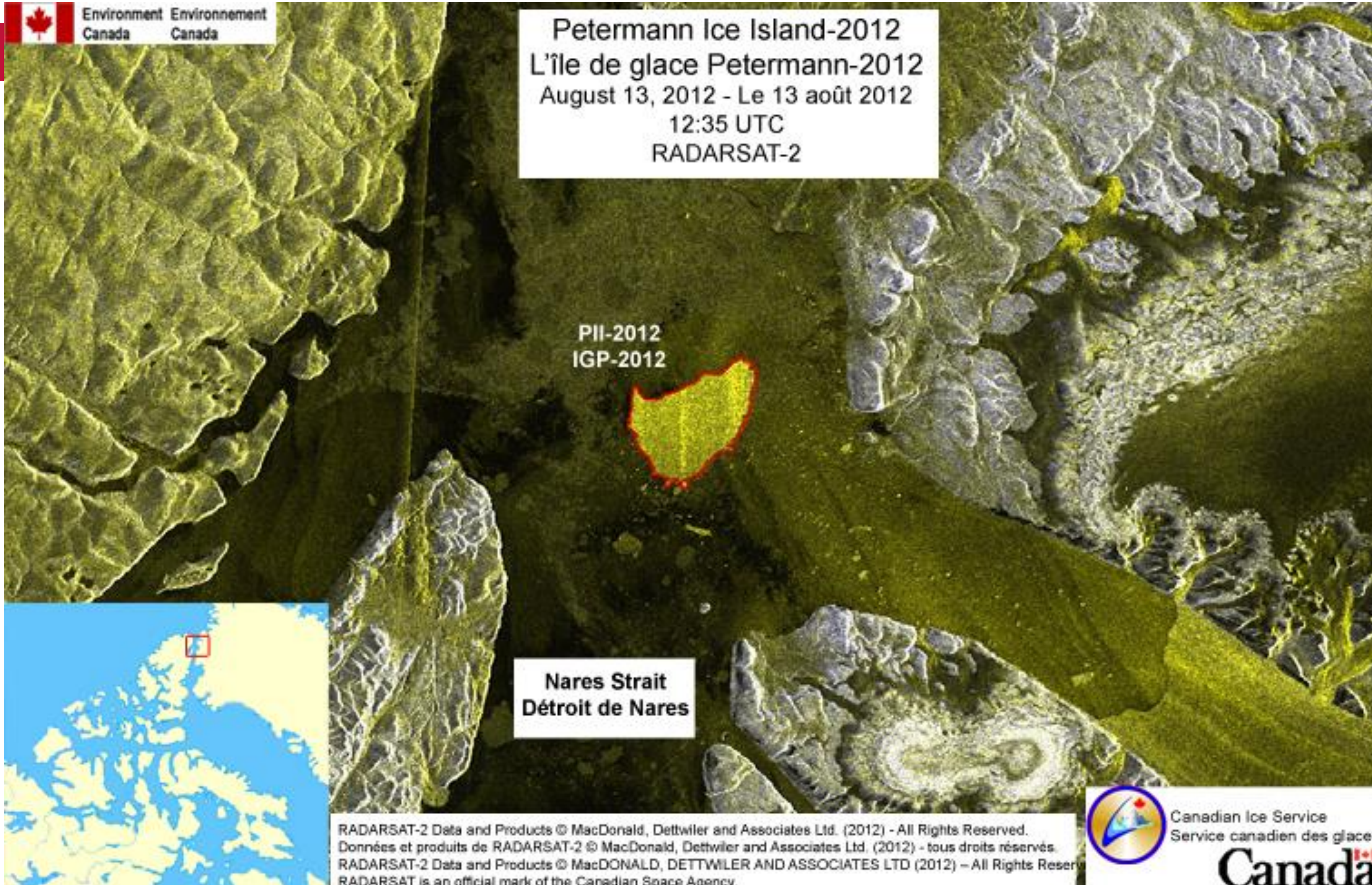
Environment Canada
Environnement Canada
Petermann Ice Island-2012
L'île de glace Petermann-2012
August 13, 2012 - Le 13 août 2012
12:35 UTC
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