ITINERIS

Advanced technologies for monitoring and prediction of ground instabilities

Satellite radar interferometry

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Italiadomani

Who I am

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  Earth Science Department of the University of Firenze
PhD in “Earth, environmental and resources sciences”
  University of Naples Federico II
Master in Geological Sciences and Technology in 2012
  University of Firenze
Bachelor in Geological Sciences in 2012
  University of Genoa

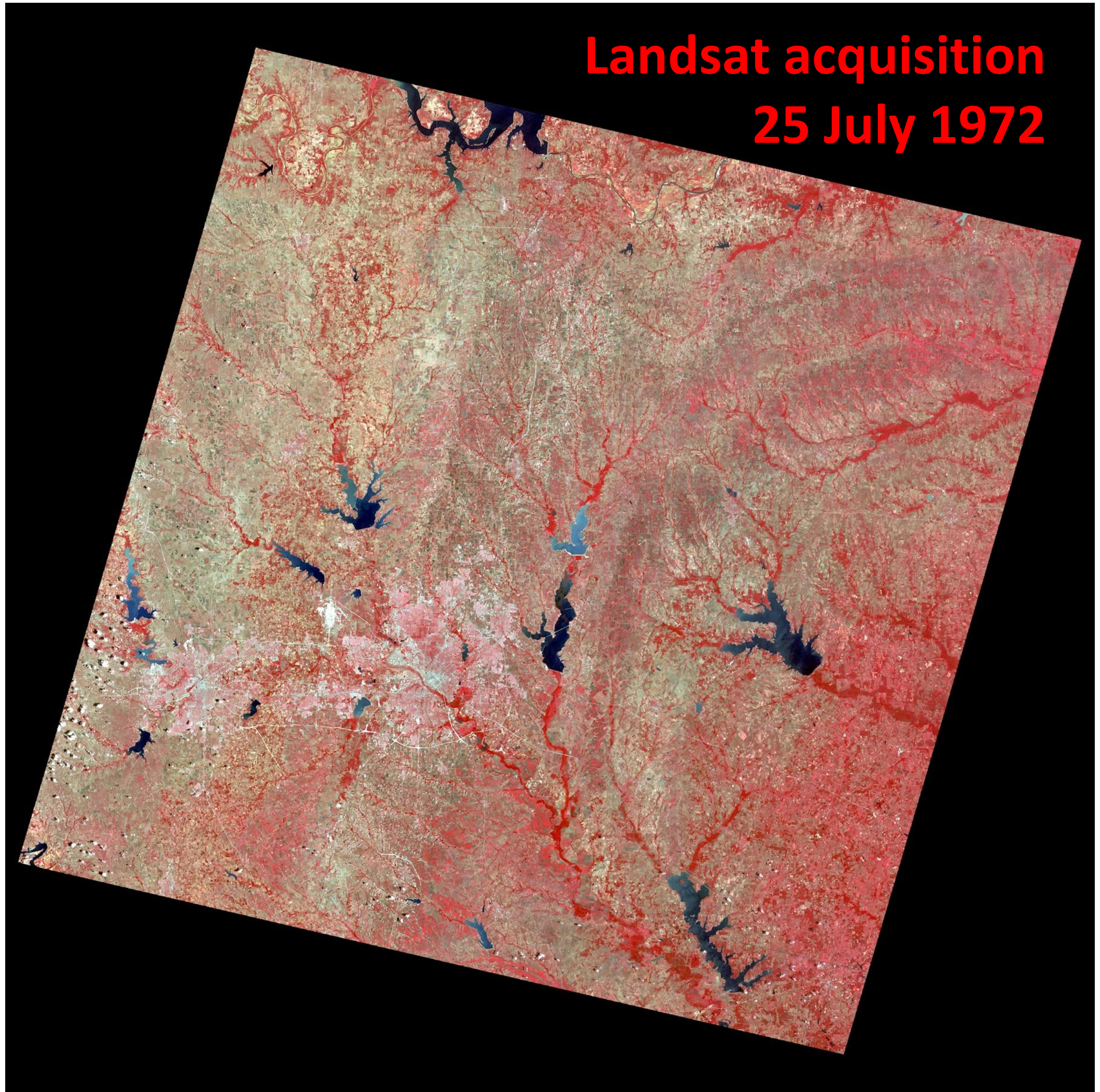
Research interests

Landslides (geomorphological effects, InSAR analysis, triggering causes, induced damage)
Subsidence (InSAR analysis, triggering causes, induced damage)
Geohazards (natural and man-induced)
InSAR monitoring (monitoring of ground deformation in local and over wide areas)
3D reconstruction (PointCloud, geomorphological analysis, volume changes estimation)

Contents

Remote sensing

Remote sensing is the science of acquiring information about the Earth's surface without being in contact with it. Sensing and recording reflected or emitted energy. Processing, analyzing, and applying that information.



Main advantages

Synoptic view

Complementary to ground systems

Systematic acquisition plan

Multispectral ranges

Multitemporal datasets

Large image archives

Multidisciplinary applications

High benefits/cost ratio

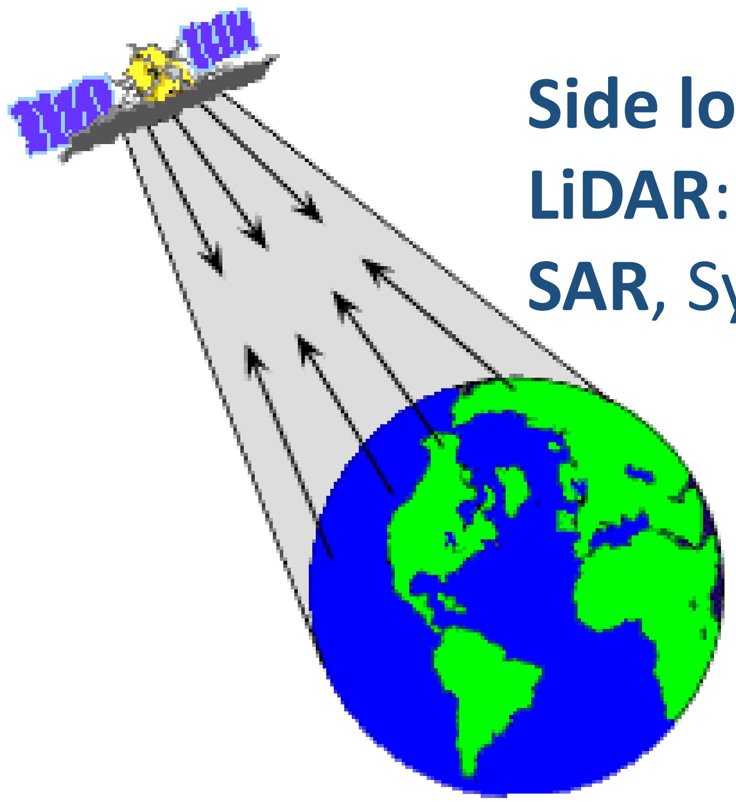
Open data policy

Active and passive sensors

A special mechanical or electronic equipment capable of recording electromagnetic waves reflected or emitted from objects points.

ACTIVE

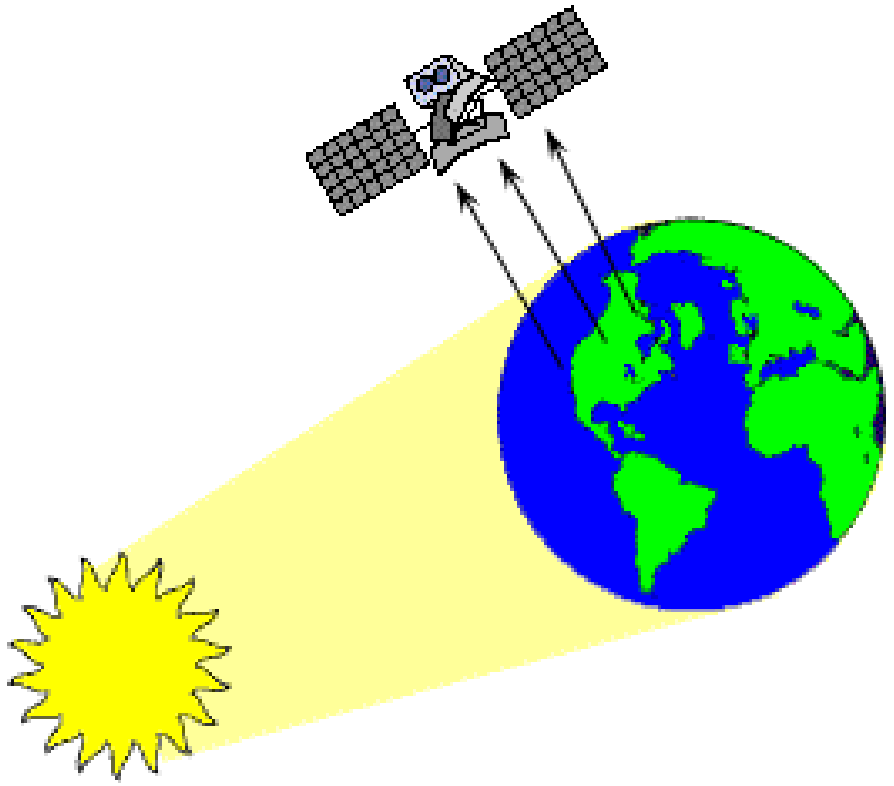
Remote sensing systems which **provide their own energy source for illumination**.
The sensor emits radiation which is directed toward the target to be investigated.
They can operate in any condition of illumination.
They require high amount of energy to operate.



Side looking Radar
LiDAR: laser imaging
SAR, Synthetic Aperture Radar

PASSIVE

Remote sensing systems which **measure energy that is naturally available**.
They use solar radiation as it is reflected (or emitted) from our planet. They depend on the sun.
Passive sensors require much less energy, making them cheaper to operate.



Optical remote sensing:
Hyperspectral
Multispectral: ultra-violet, visible, Infrared.
Thermal

October 1957: launch of the first satellite, the Sputnik 1

Since 1957 were launched more than 15000 satellites by different states and companies

More than the 75% of them are no longer working

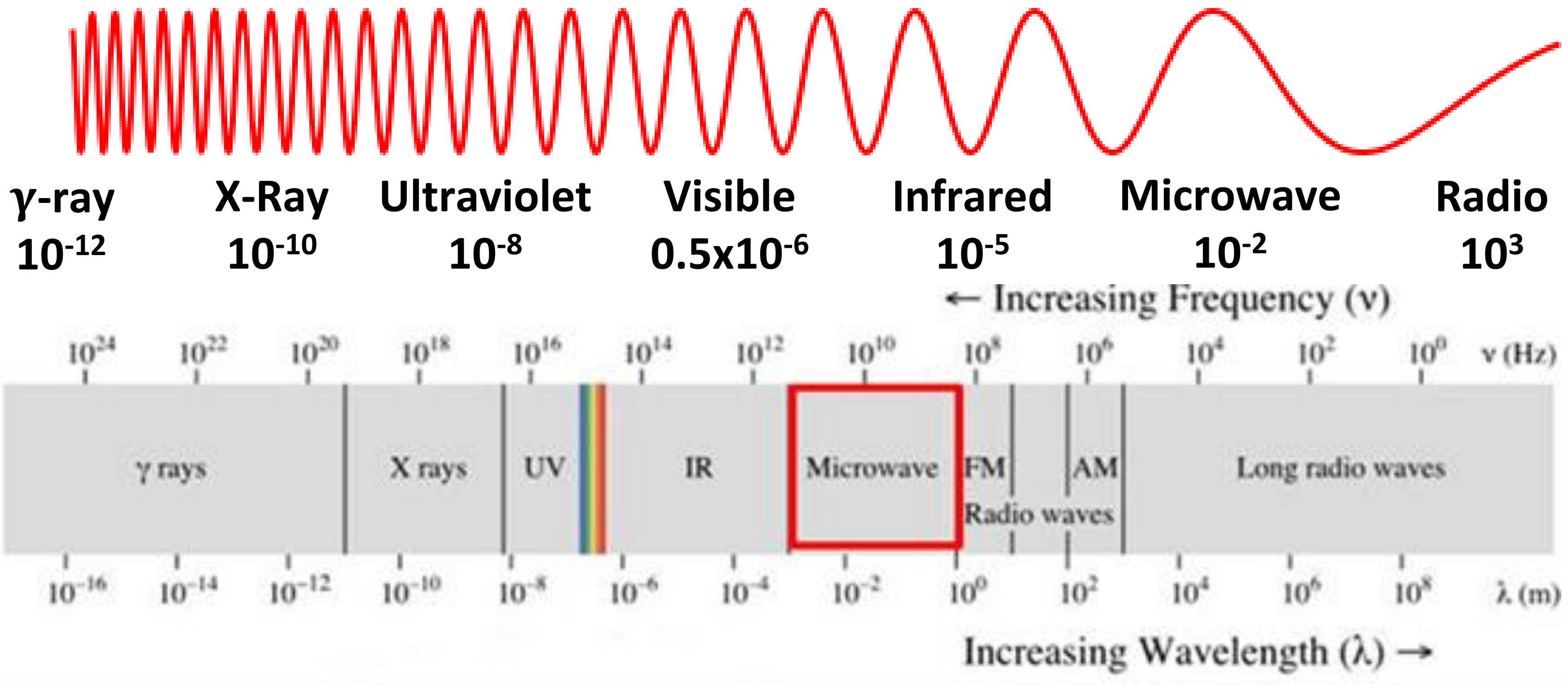
The higher number of operational satellite around the Earth are between 160 ad 2000 km of height with respect to Earth surface

All these satellites have different functions: operational services, telecommunications, civils and military services

ESA SAR products for Interferometry

Contents

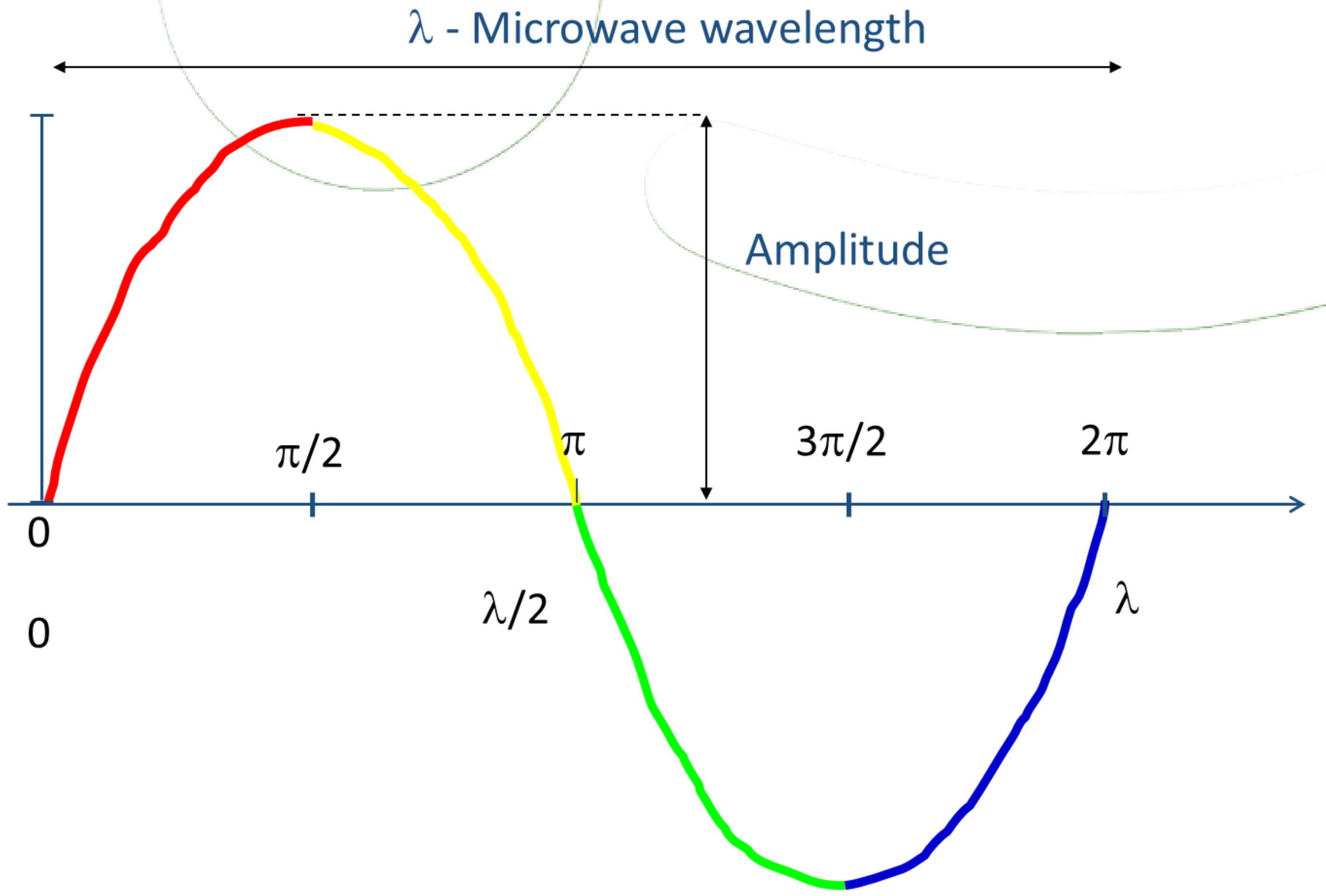
Electromagnetic spectrum



In the electromagnetic spectrum all the possible radiation frequency are present.

Based on the frequency of the wave the ray takes different name.

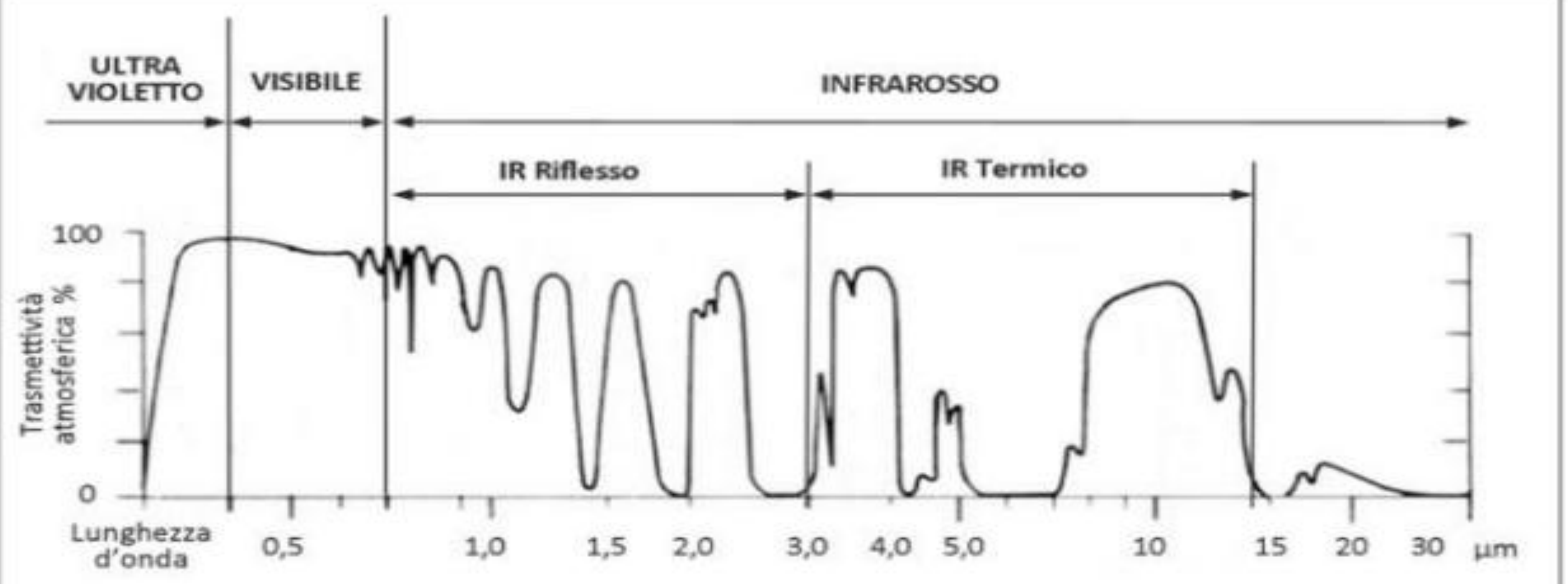
An electromagnetic wave represents the temporal and spatial variations of an electric and a magnetic field in space



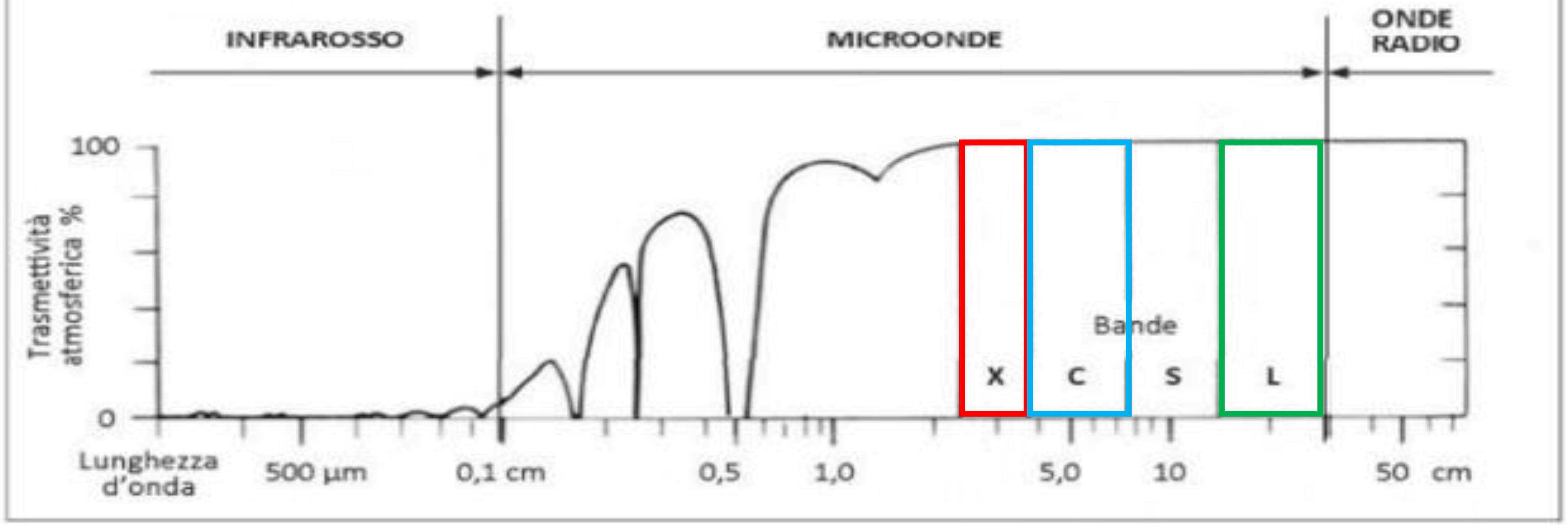
- **Amplitude:** periodic variation over a single period
- **Wavelength** or frequency, i.e. phase: the distance over which the wave's shape repeats.

Atmospheric transmissivity

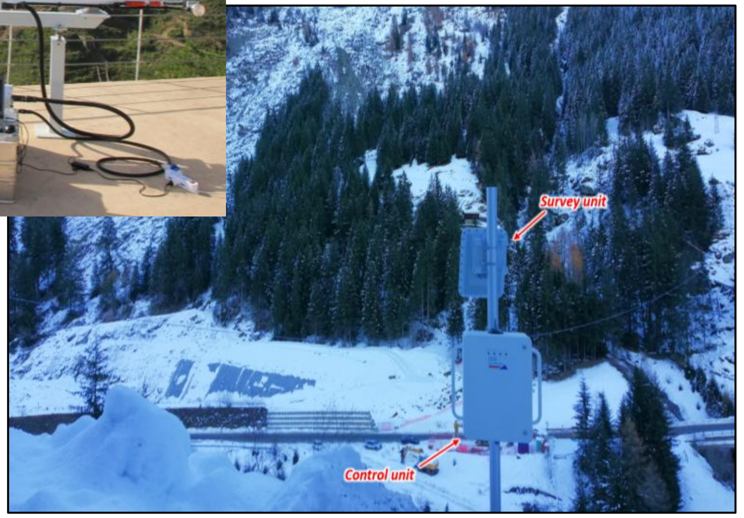
Atmospheric transmissivity



Atmospheric transmissivity



Why radar remote sensing?



- **Active system** - it does not need external sources such as the Sun light;
- Radar systems acquires in **every weather conditions**;
- Radar systems acquires **night and day**
- Satellite radar systems illuminate the scene with **fixed or variable geometries** (side-looking configurations);
- Radar sensor works at the frequency of microwaves that can penetrate through clouds, rain or fog;
- Coherent system: **very precise** measurements of distance variations by means of interferometry

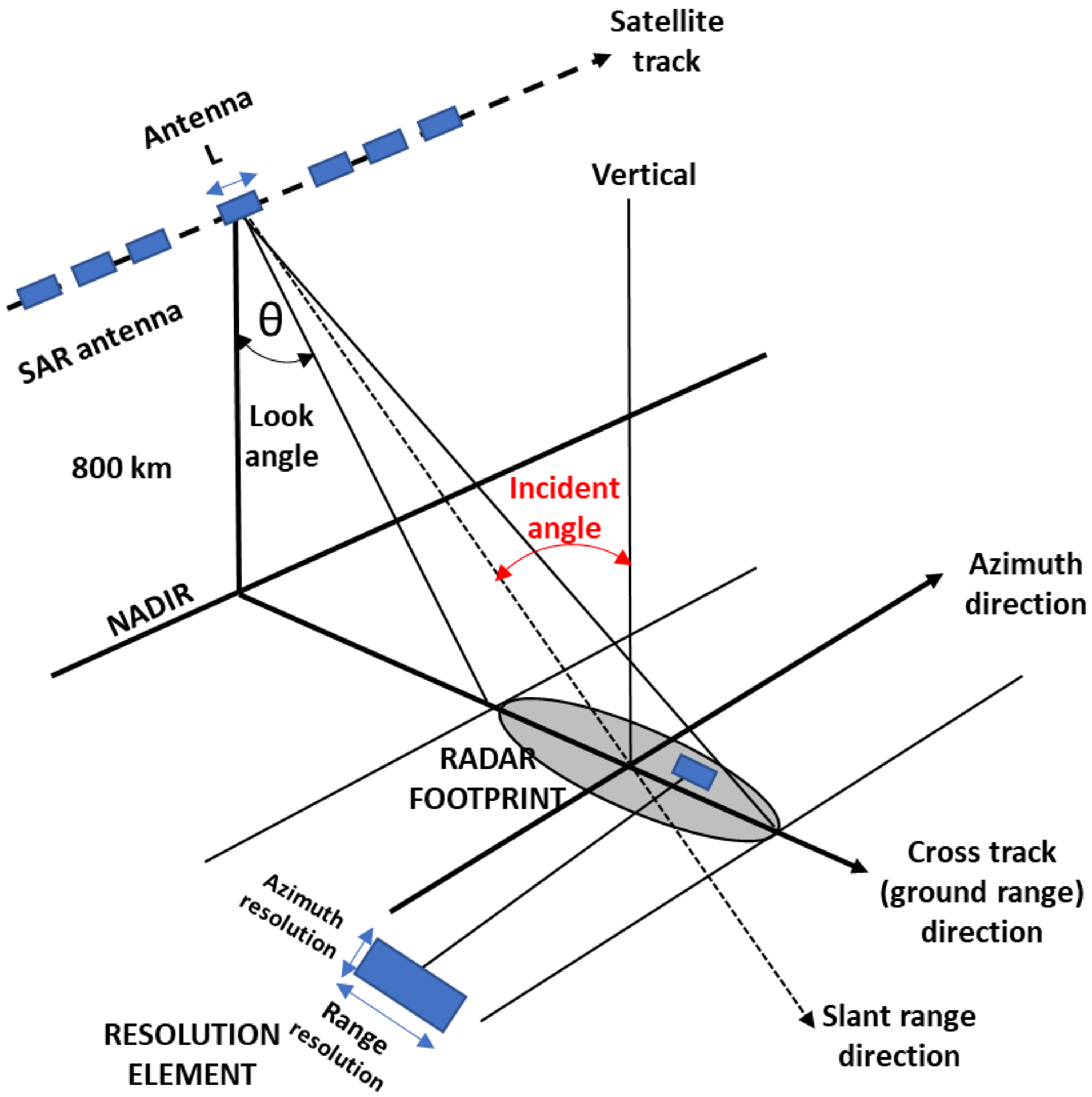
Radar concept: an intiuitive approach

If you are on the boat and you shout, the cliffs will reflect the sound wave.

After some time, you will hear an echo, (not) exactly the same of what you shouted.

Satellite images acquisition

Radio Detection and Ranging (RADAR) is a technique based on the electromagnetic waves that allows determining postion and velocity of fixed and moving targets with high precision



LOS is the Line Of Sight of the satellite

SWAT is the Earth surface enlightened by the microwave beam (LOS direction)

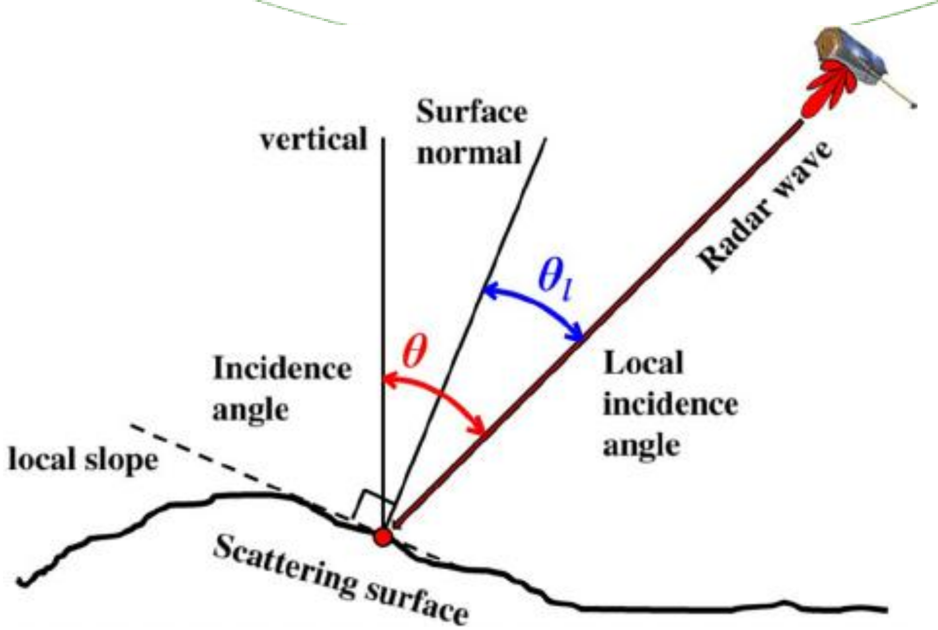
Azimuth range (along-track) is the direction along the trajectory of the sensor

Ground range (across-track) is the direction perpendicular to the Azimuth range

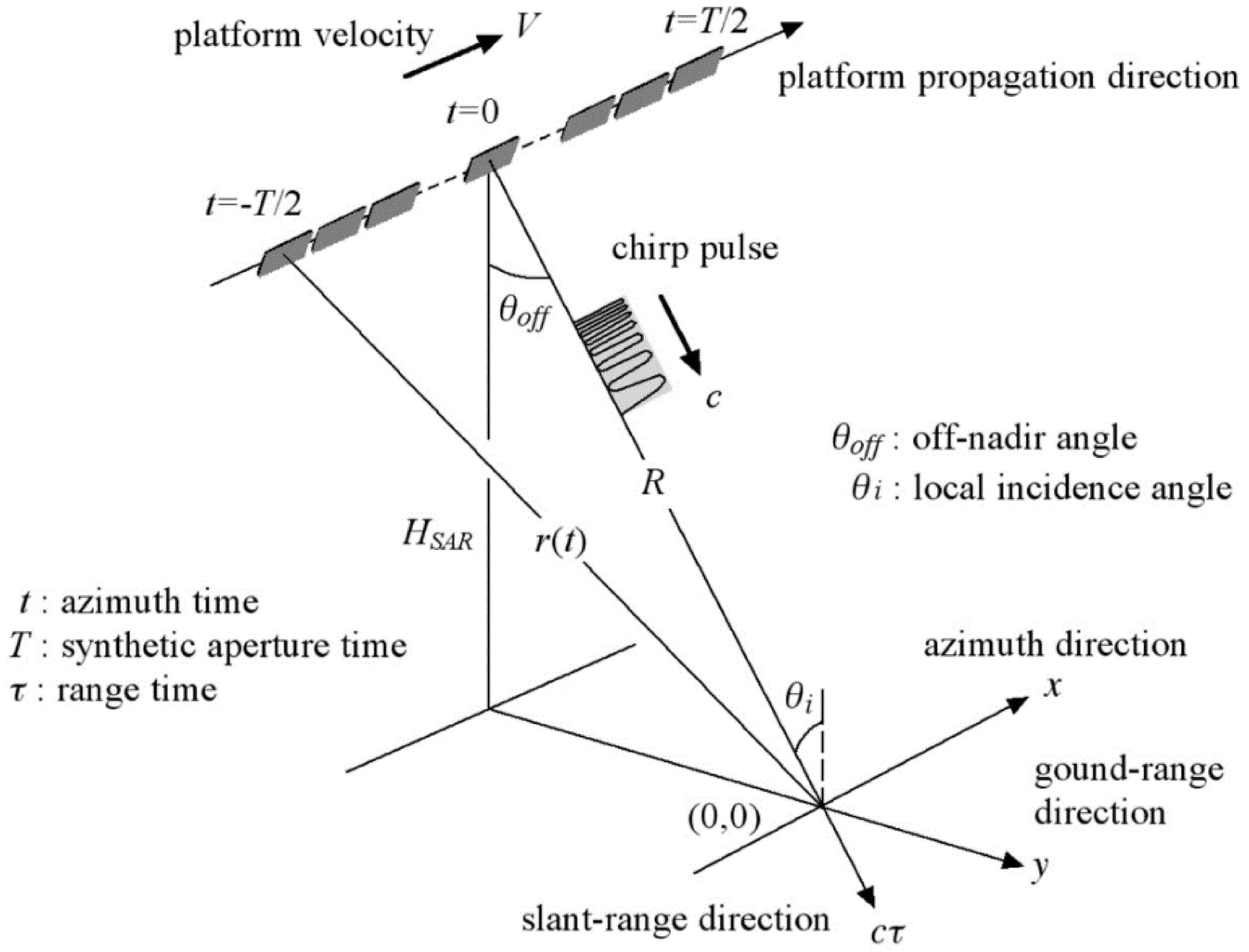
Slant range is the direction between the antenna and the object along the LOS

Incident angle is the angle between the radar wave and the vertical

Local incident angle is the angle between the radar wave and the normal with respect to the ground



The Synthetic Aperture Radar (SAR) is a technique in which the signal processing and the satellite movement during the acquisition is used to improve resolution "synthetizing" a very long antenna.



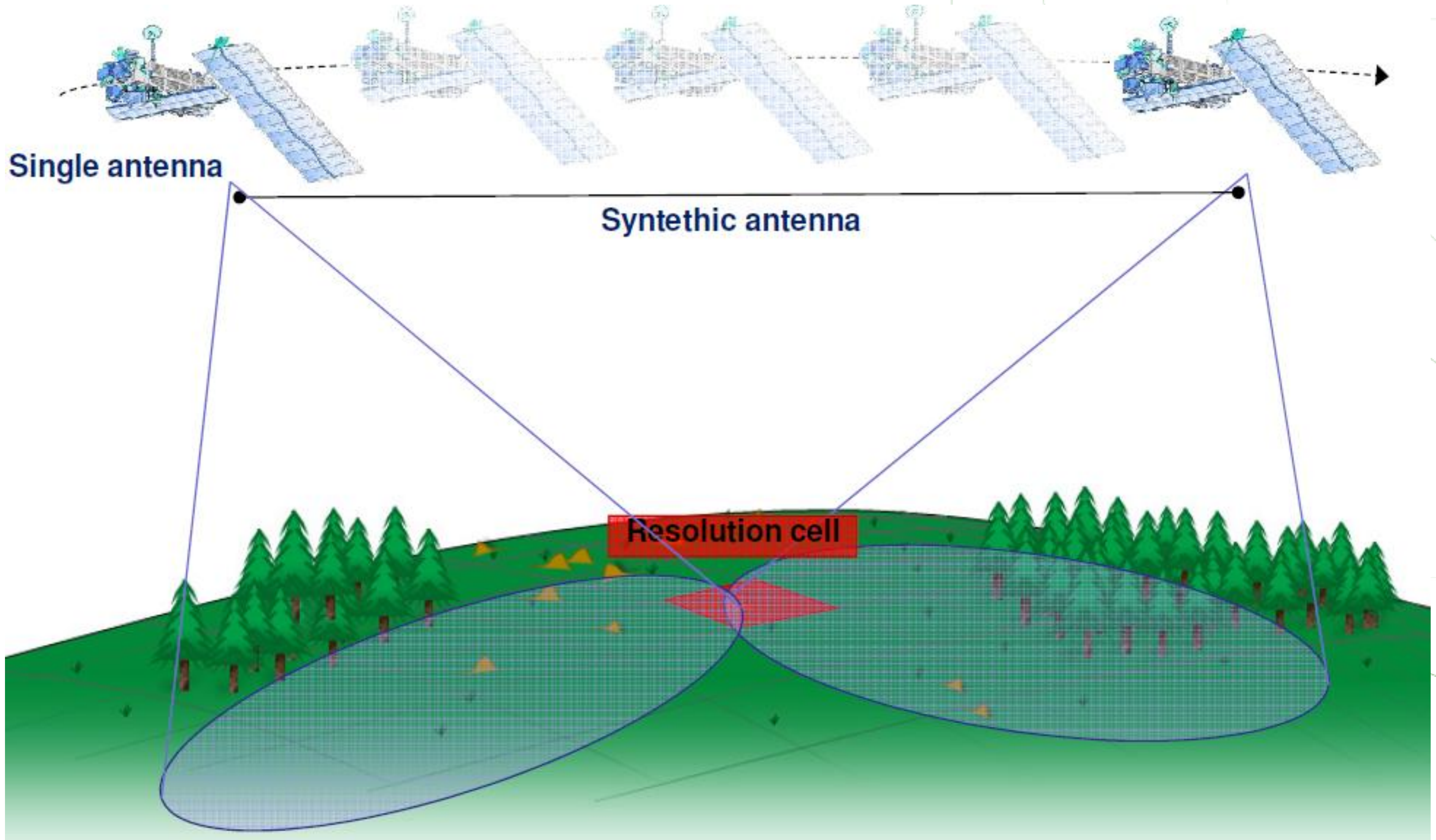
H_{SAR} : height of the SAR platform;

c : velocity of the microwave;

r(t) : slant-range distances at the azimuth time t;

R : slant-range distances at the azimuth when theantenna is nearest to the target at the origin of the ground coordinates (x, y)

Synthetic Aperture Radar (SAR)



The radar looks at the same area from different angles while moving through the platform's trajectory. It is then possible to synthesize a larger antenna by properly combining the different echoes:

- The target is viewed by the radar from the moment it enters the antenna beam to the moment it leaves the antenna beam
    - During this time, it sends back a very large number of echoes
    - Each echo is characterized by the time required for the pulse to travel to the target and back to the radar

Synthetic Aperture Radar: SAR is not an object; it is a way to treat radar echoes

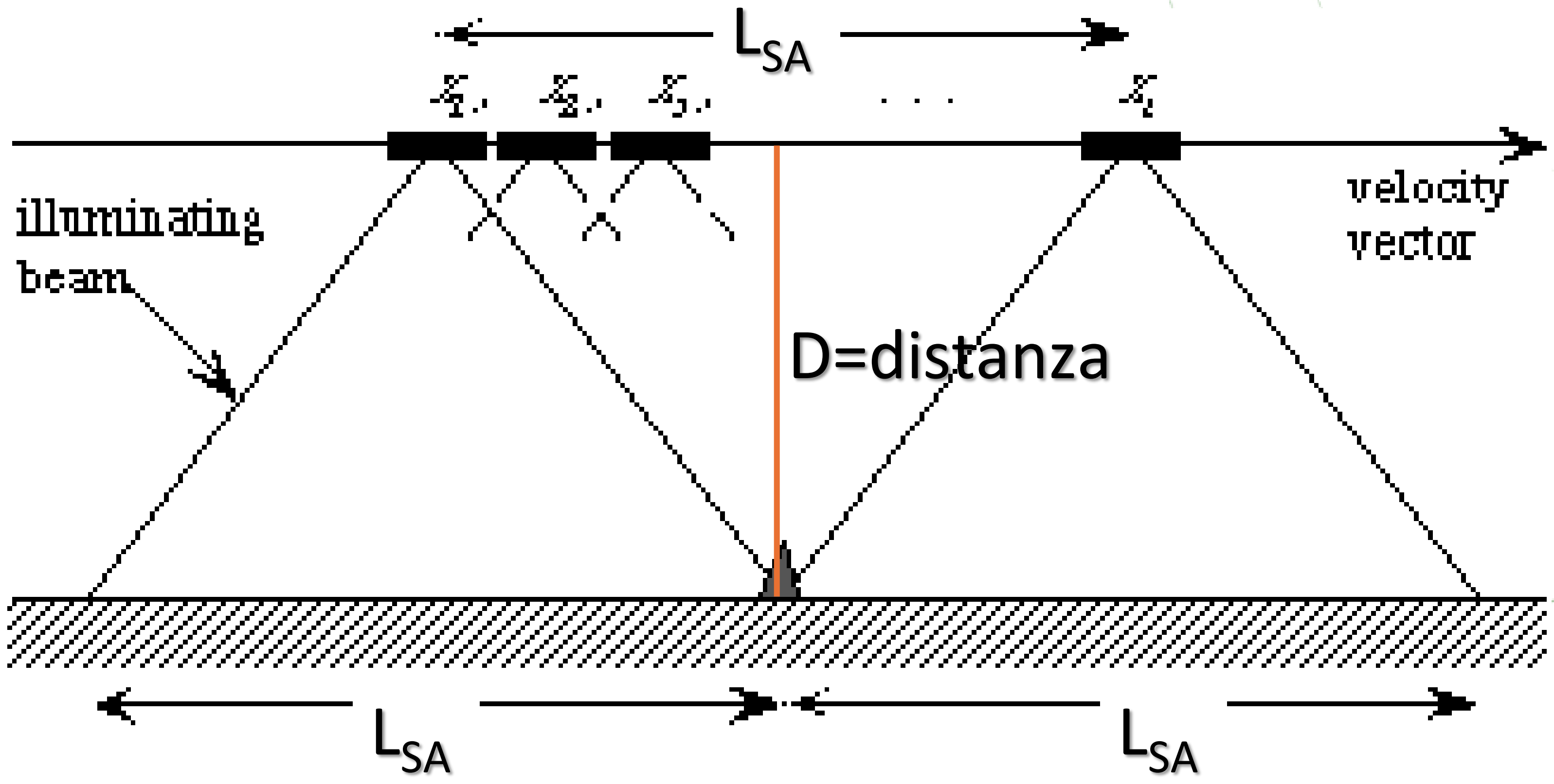
Radar resolution image - Real Radar aperture VS Synthetic Aperture Radar

L_{SA}=lunghezza dell'apertura sintetica

Antenna ad apertura reale

$b=\lambda/L_R$

Lr= lunghezza antenna reale



Tempo di acquisizione

$T=L_{SA}/V$

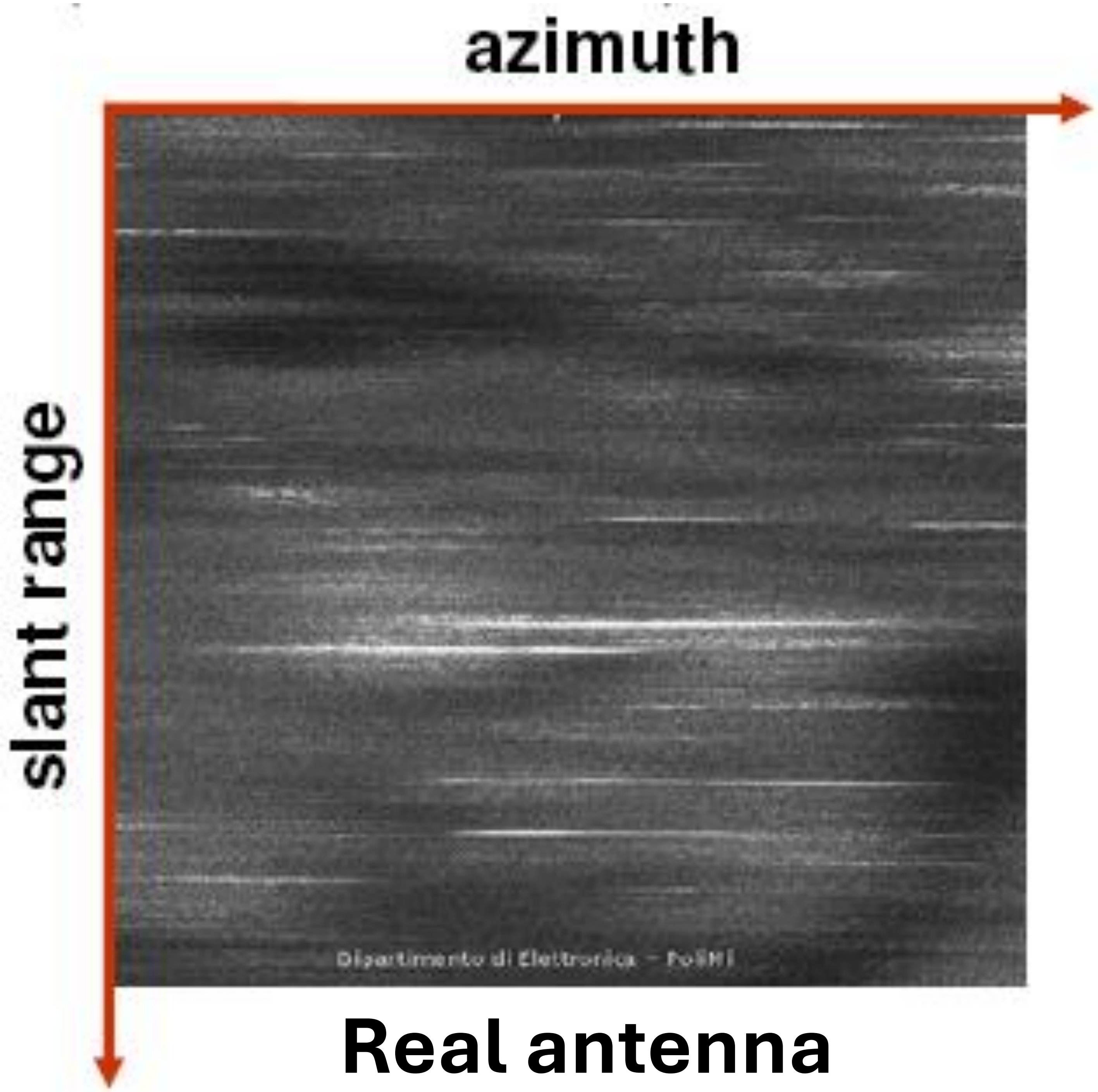
L_{SA} lunghezza antenna sintetica

Risoluzione a terra lungo la direzione di azimut, **R**

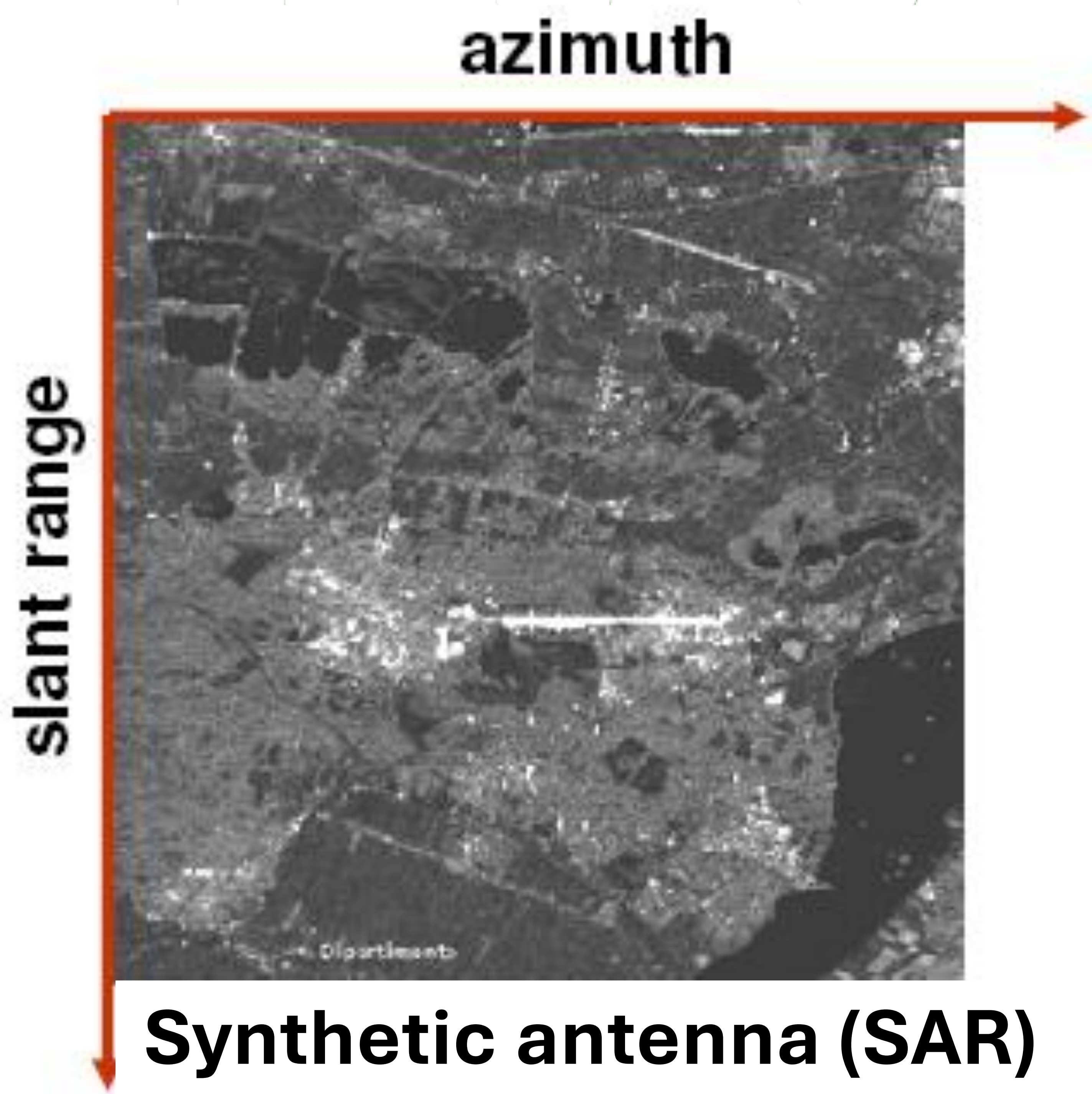
L_{SA}= D * b= **$D\lambda/L_R$**

$$R = \lambda D/2L_{SA} = \frac{\lambda D}{\frac{2D\lambda}{L_R}} = L_R/2$$

Radar resolution image - Real Radar aperture VS Synthetic Aperture Radar



Real antenna



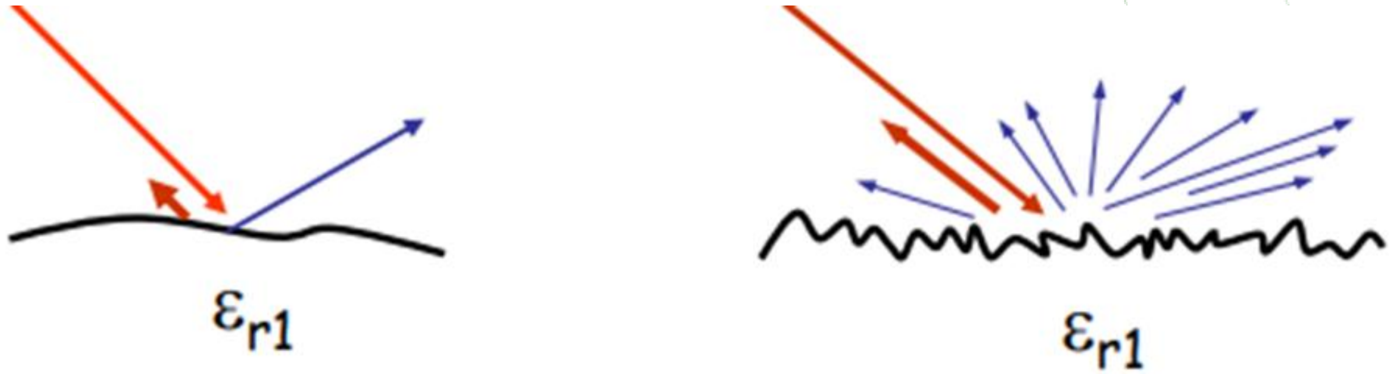
Synthetic antenna (SAR)

The antenna is about some meters and it synthetize a kilometric antenna combinin hundreds of radar eco by a acquisitions from different positions along the radar orbit

Radar signal reflection

- The *radar* sensor sends electormagnetic waves as impulse and then records the signal *backscattered* by elements on the surface
- The echo is different with respect to the emitted wave based on the reflecting element.

Regular surface

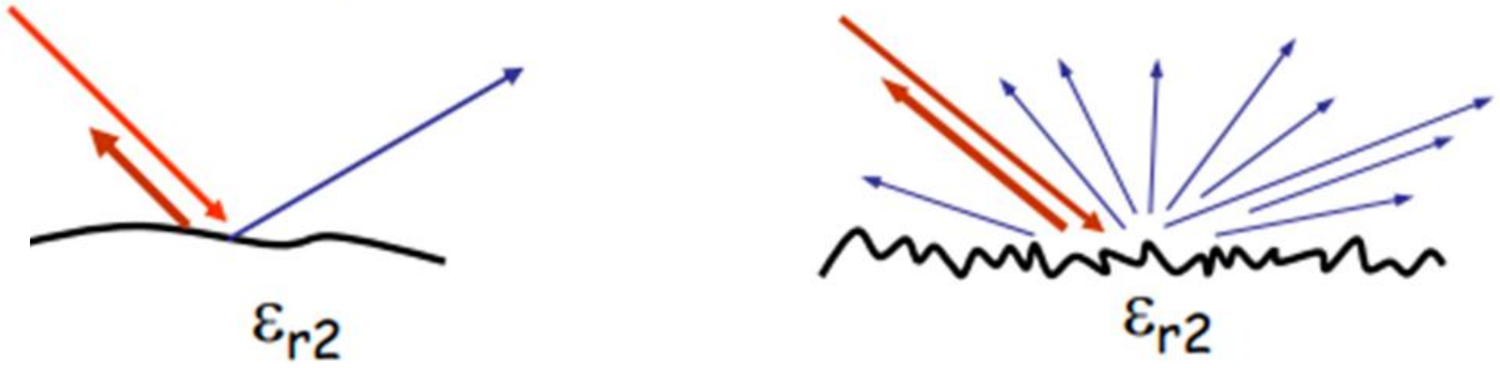


Rough surface

The roughness of the surface with respect to the wavelength manage the reflection pattern

$\varepsilon_{r2} > \varepsilon_{r1}$ Element 2 more humid than the element 1

More humid



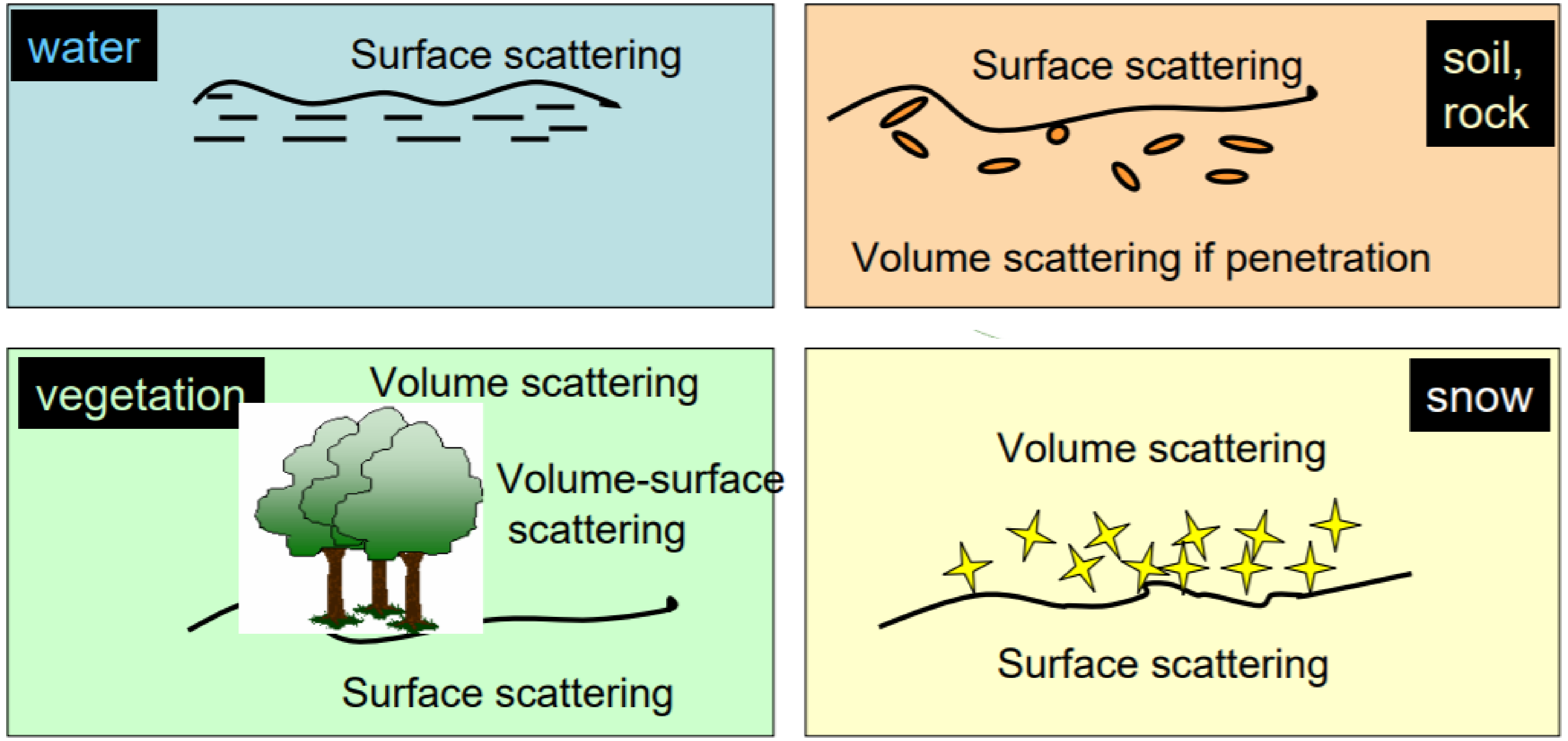
The dielectric constant (depending on the humidity content) of the backscattering element manage the power of the backscattered signal

Radar signal reflection

- Reflecting elements are called ***targets*** o ***scatterers***.
- The backscattered signal by the *targets* captured by the sensor gives back an images, the “radar image”
- The info into the radar image are about the reflectance of the target and the distance to the sensor

(*Intensity* and *Amplitude*, respectively)

Levels of Radar backscatter	*Typical scenario*
• *Very high backscatter (above -5 dB)*	*Man-Made objects (urban)* *Terrain Slopes towards radar* *very rough surface* *radar looking very steep*
• *High backscatter (-10 dB to 0 dB)*	*rough surface* *dense vegetation (forest)*
• *Moderate backscatter (-20 to -10 dB)*	*medium level of vegetation* *agricultural crops* *moderately rough surfaces*
• *Low backscatter (below -20 dB)*	*smooth surface* *calm water, road* *very dry terrain (sand)*



Radar signal reflection

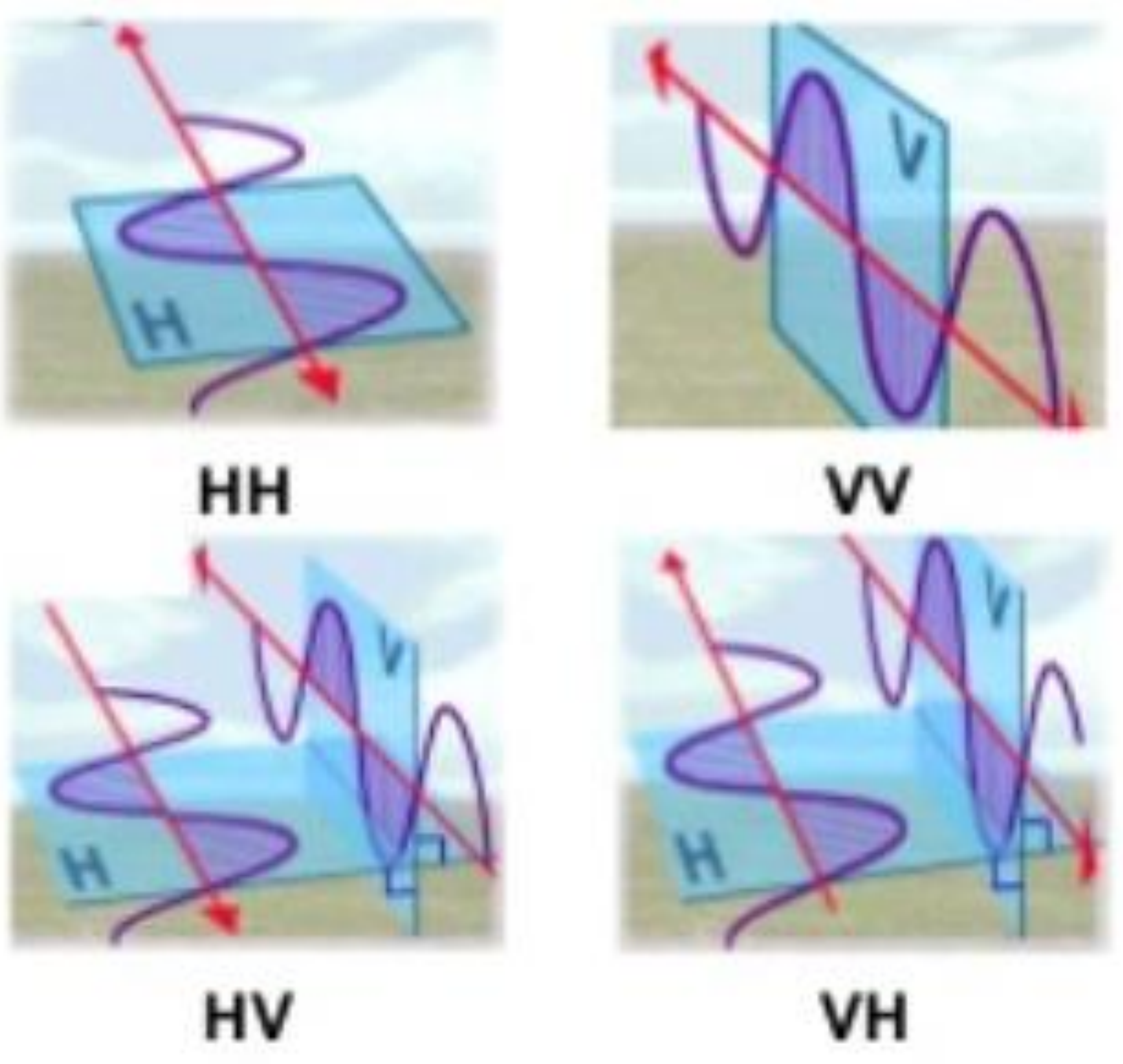
Summarizing, the reflection of the radar signal depends on several parameters of the targets and on the mounted sensors on the satellite:

- Roughness of the surface
- Dielectric constant of the target (e.g., depending on the humidity)
- Incidence angle - local incidence angle
- Frequency/wavelength of the radar signal emitted by the sensor
- Slope of the surface/slope target

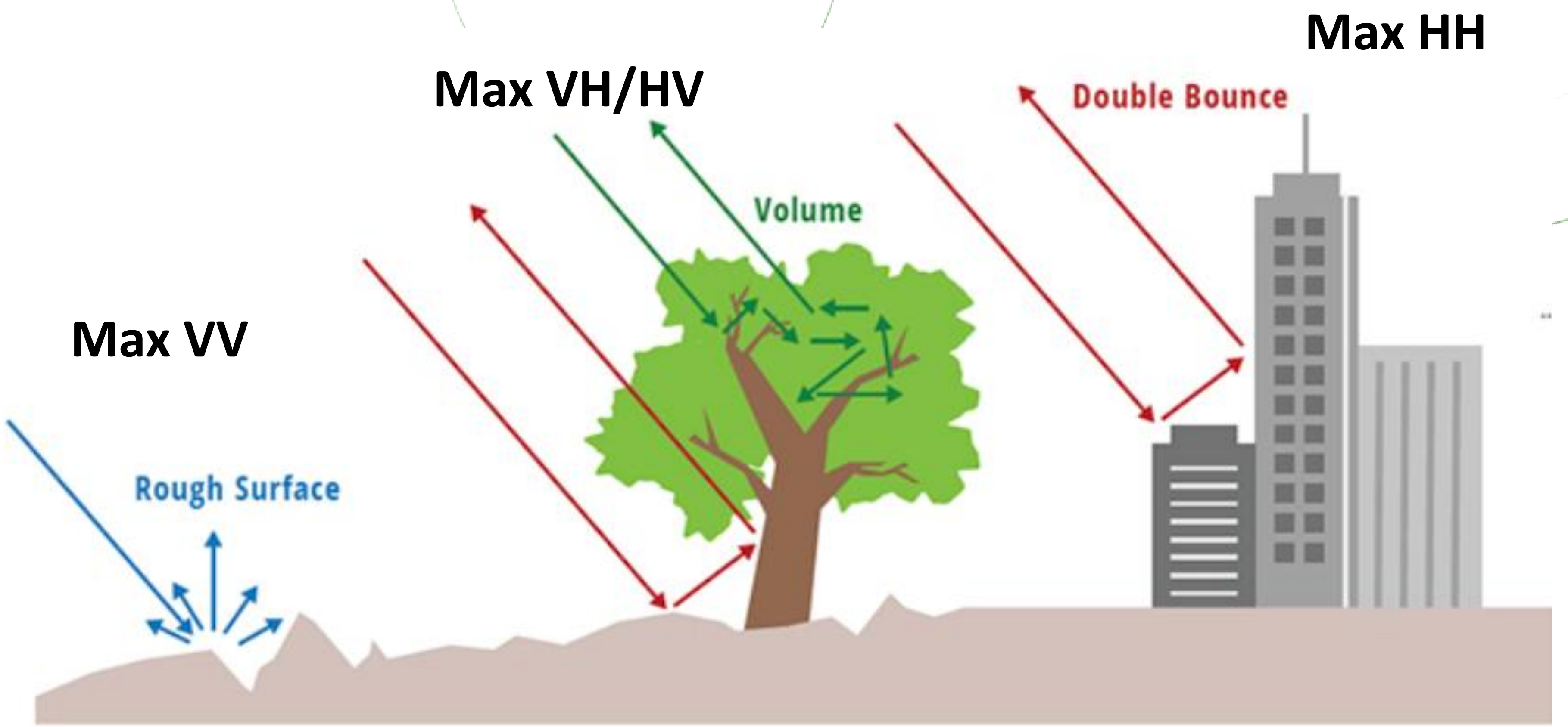
P.s. a single resolution cell of the radar image can contain a single dominant target (e.g., a edifice) or more distributed targets with medium reflectivity.

In the second case, the backscattered signal received by the satellite will be a complex sum of the signal (constructive or destructive) of the individual contributes from the several targets --> ***speckle***

Polarization



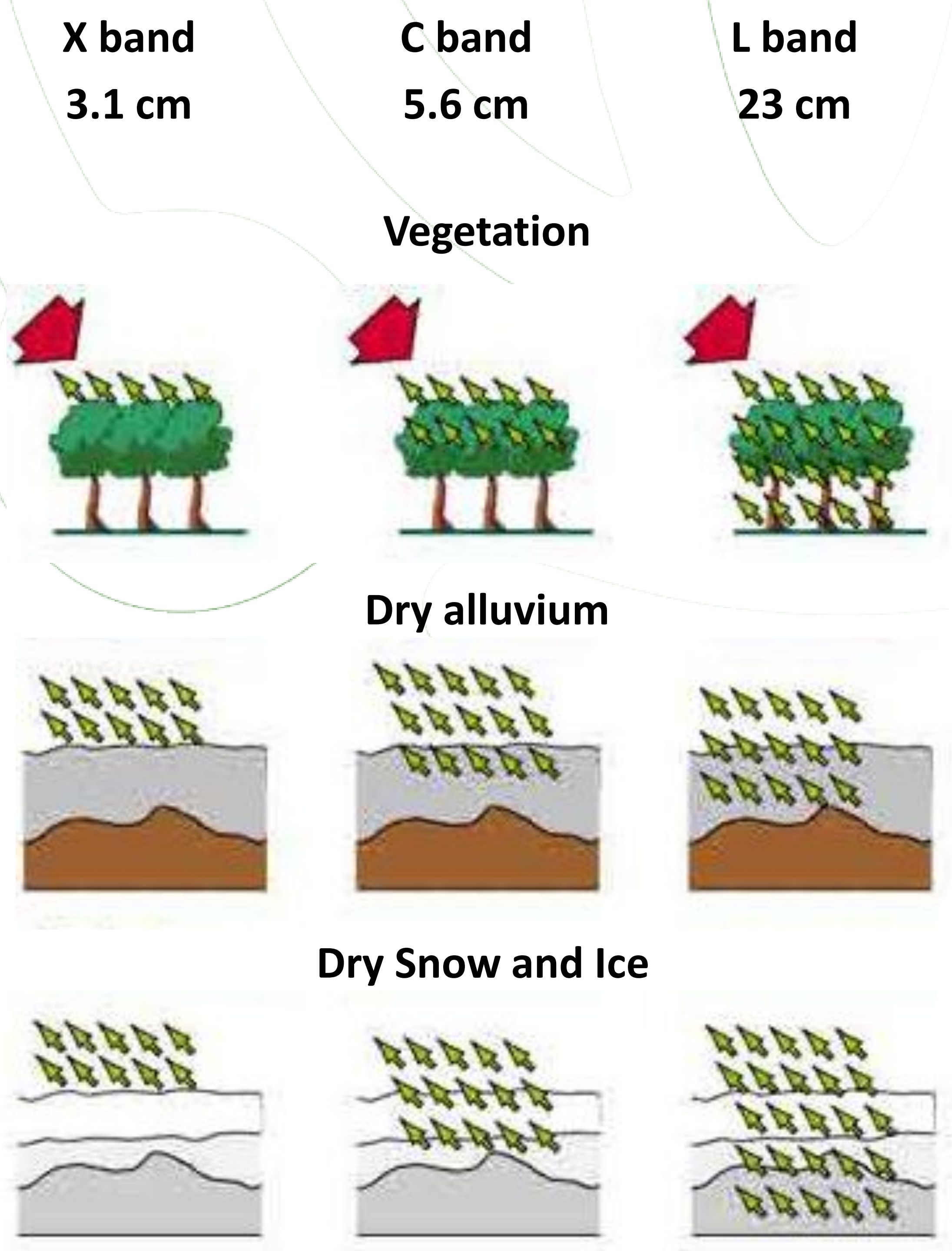
- The polarization is the orientation of the plan into the electromagnetic wave emitted swings
- Different surfaces respond differently to diverse polarizations



Radar satellite signal

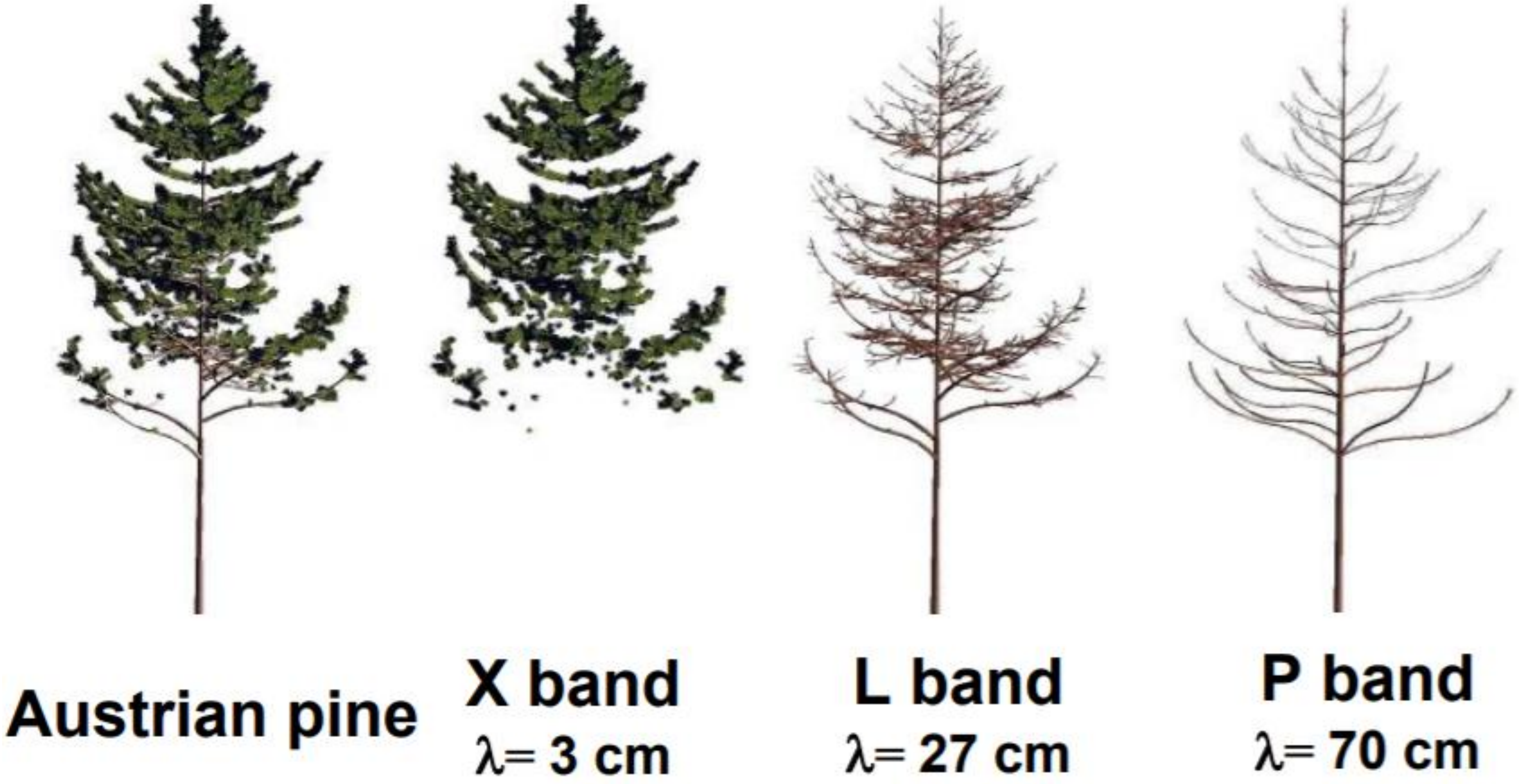
The satellites can acquire the signal with different wavelength depending on the mounted sensor, spectral features and spatial characteristics.

Band	Wavelenght (ƛ, cm)	Frequency (f, MHz)	Satellites
Ka	0.75 - 1.1	40,000 - 26,500	Telecomuncation satellites (Hot Bird constellation)
K	1.1 - 1.67	26,500 - 18,000	
Ku	1.67 - 2.4	18,00 - 12,500	
X	**2.4 - 3.75 CF 3.1**	**12,500 - 8,000**	***COSMO-SkyMed TerraSAR-X PAZ***
C	**3.75 - 7.5 CF 5.6**	**8,000 - 4,000**	***Sentinel-1 (A and B) Radarsat (1 and 2) ENVISAT ERS1/2***
S	7.5 - 15.0	4,000 - 2,000	NISAR
L	**15.0 - 30.0 CF 23.0**	**2,000 - 1,000**	***NISAR JERS ALOS (1 And 2)***
P	30.0 - 100.0	1,000 - 300	BIOMASS



Tree vs wavelenght

What does the signal emitted by the sensor reflect in different wavelength?



The reflecting portion of the tree depends on the wavelength of the radar emitted signal.
Bigger the wavelength, higher the penetration, bigger the info about the crossed material.

SAR archive & in-orbit sensors

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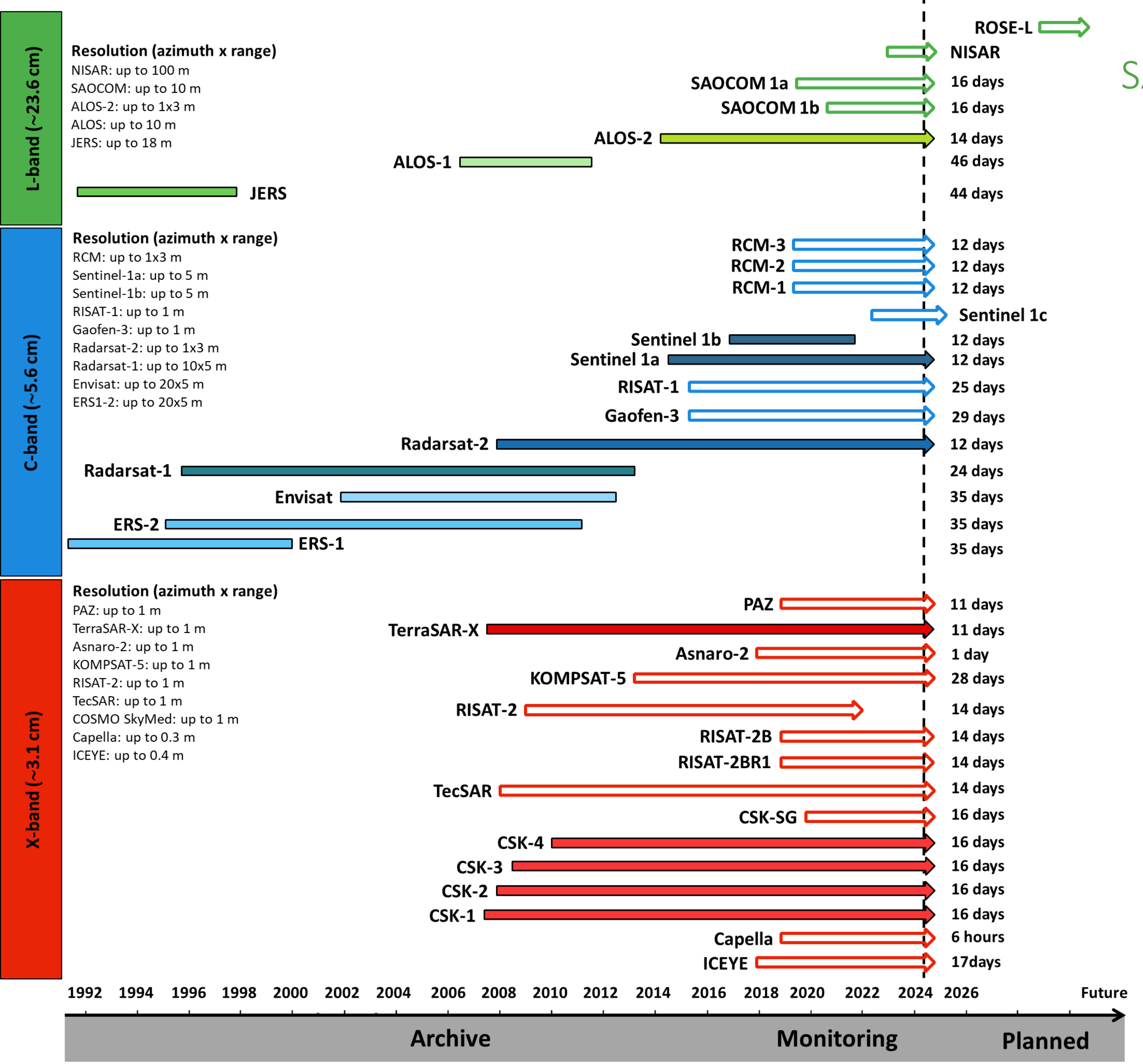
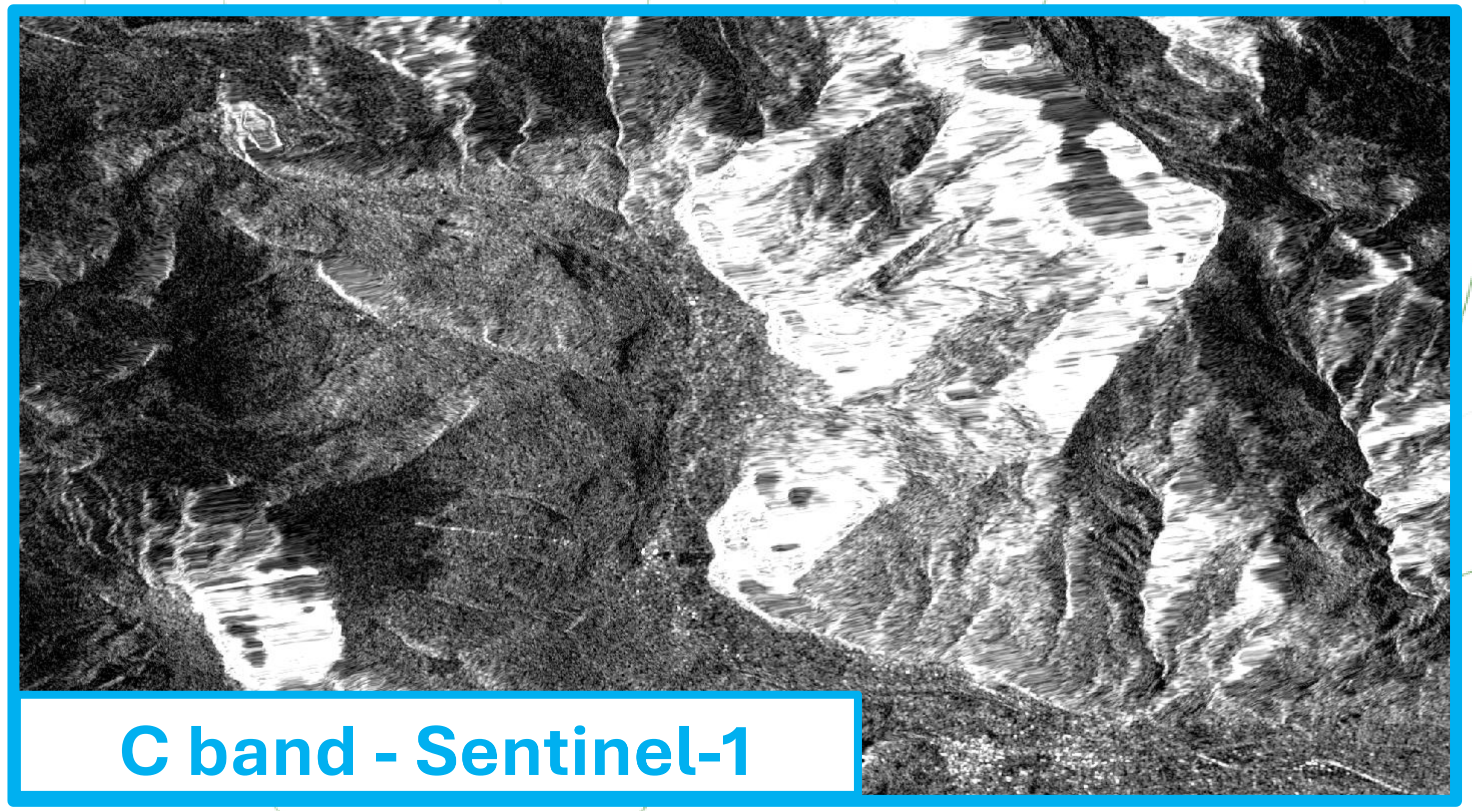
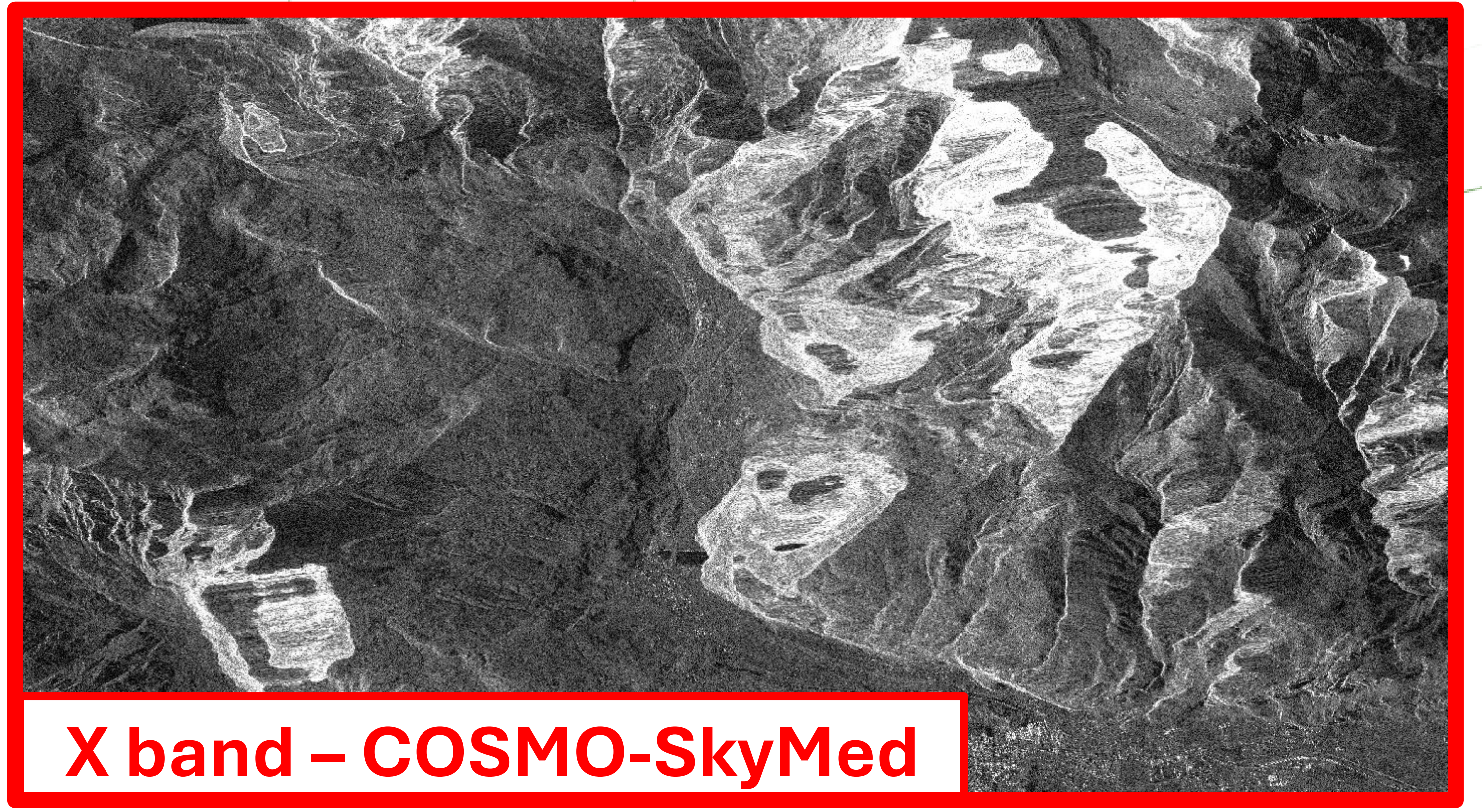




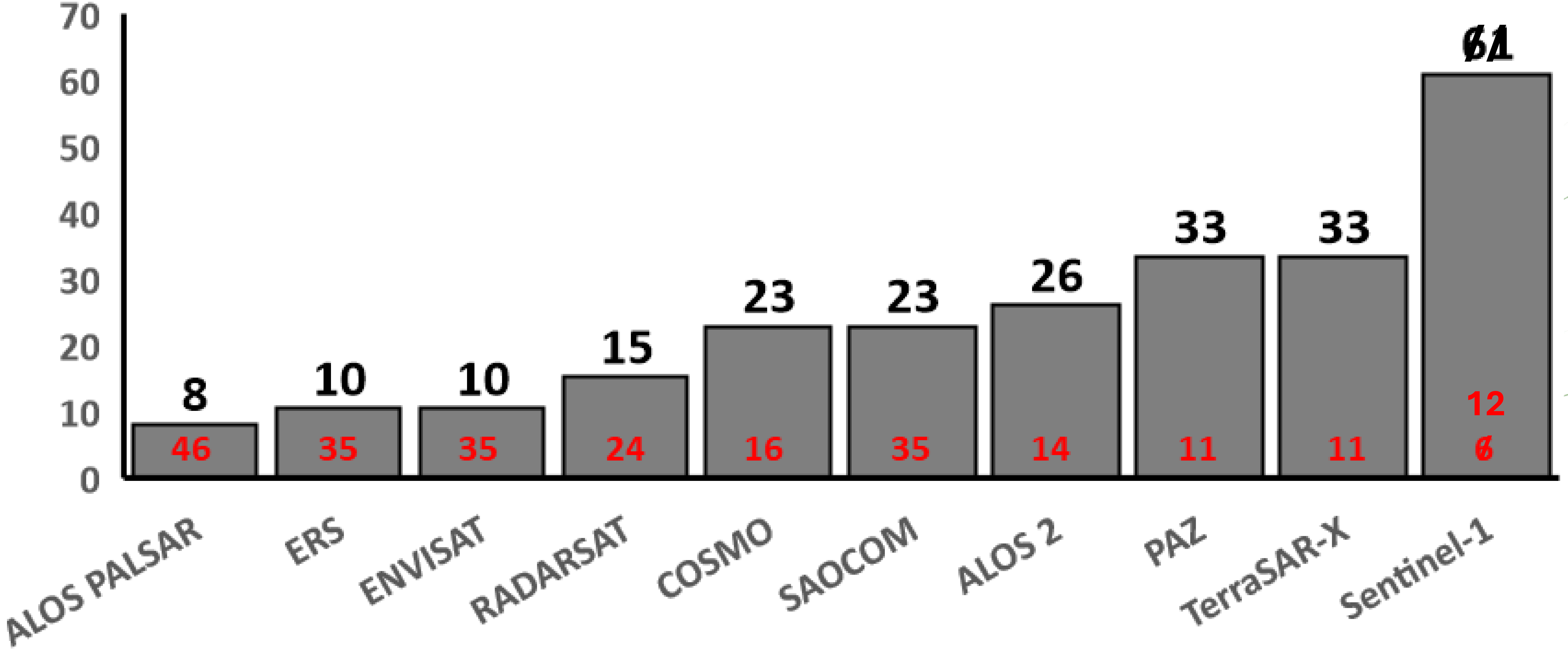
C band - Sentinel-1



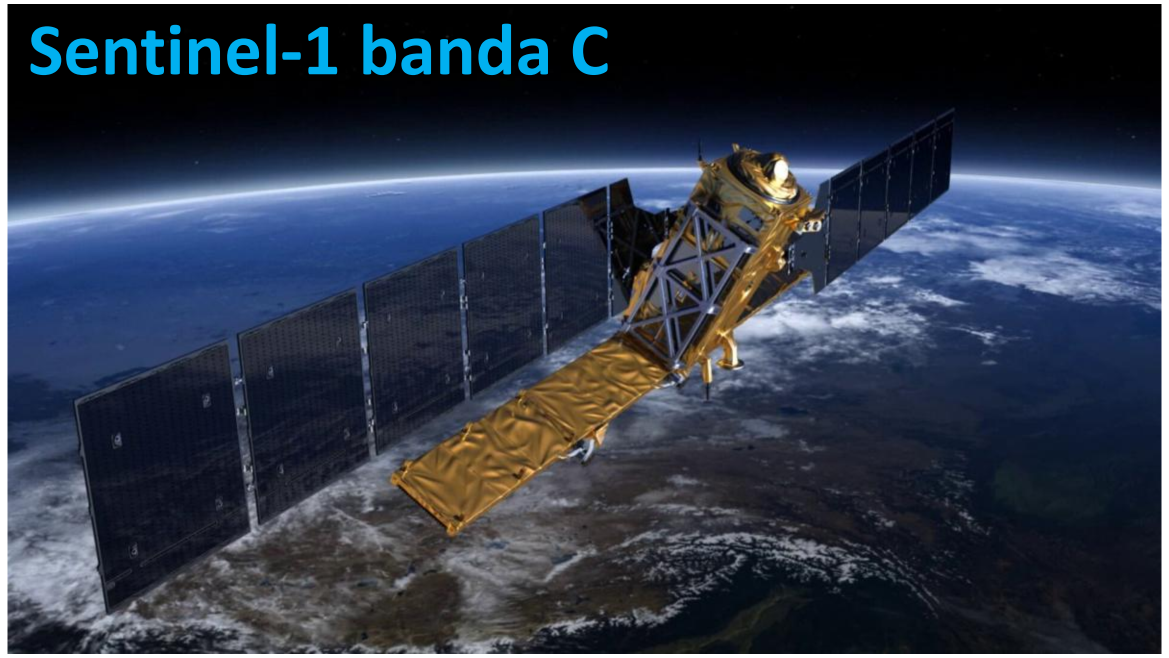
X band – COSMO-SkyMed

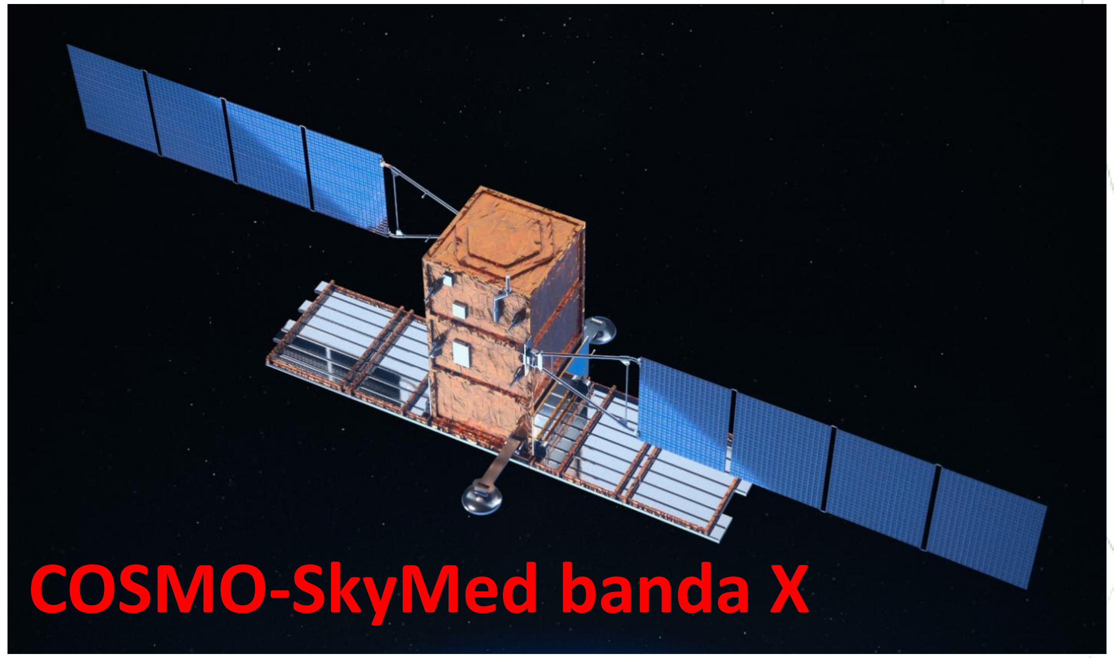
Number of acquisition for year - revisiting time

30/31



Radar sensors - radar ionterpheorometry





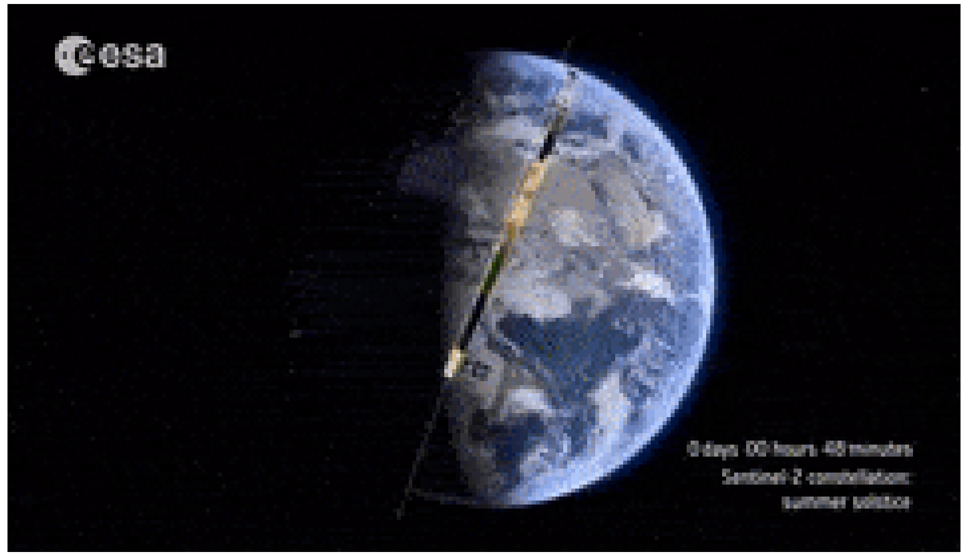
Active sensors: they don’t need of an external source of illumination (as the Sun)

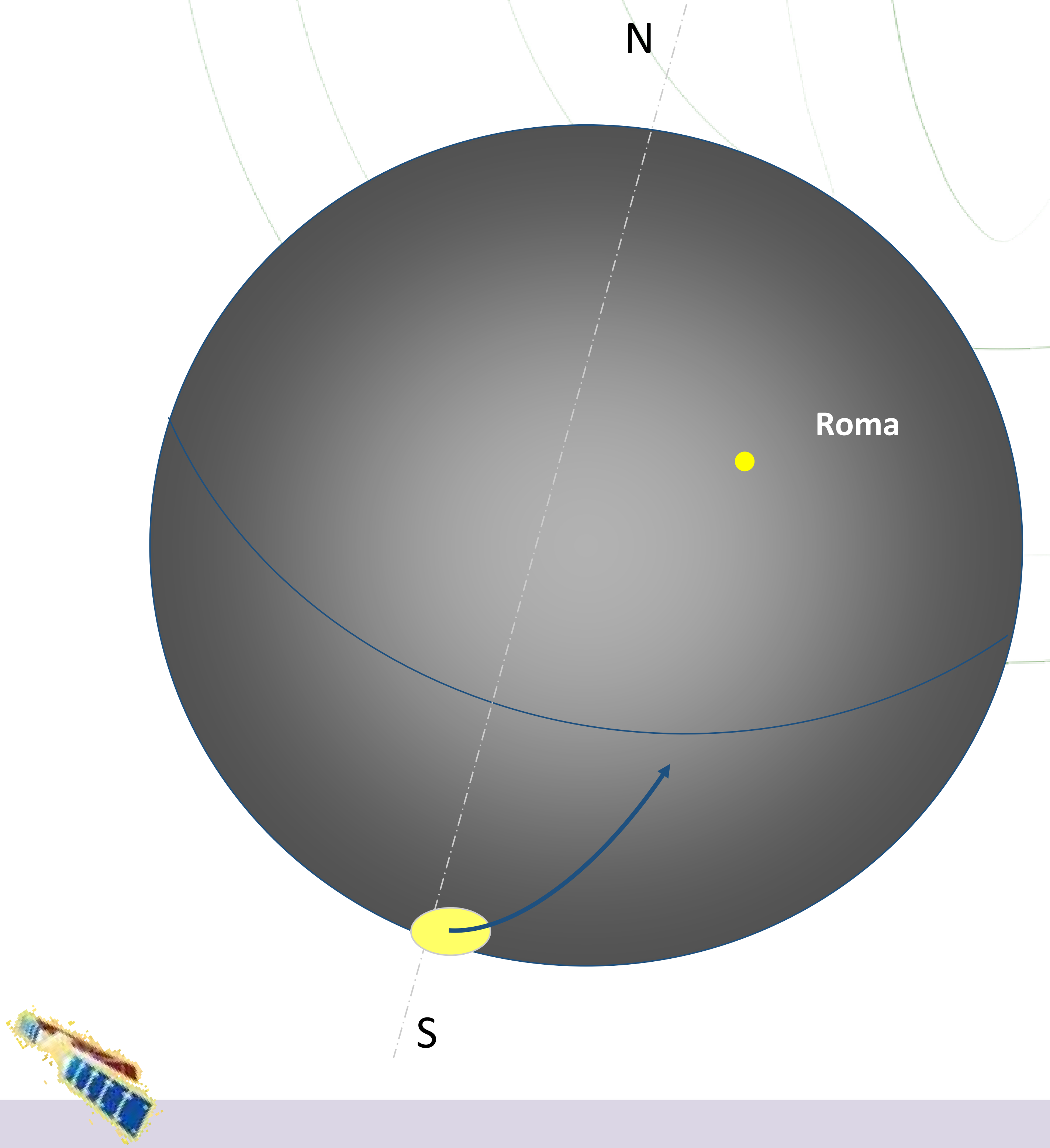
They can acquire in every weather condition

They work in the microwave range of wave frequencies that permits to overpass the clouds, rain and fog for obtaining information over the investigates scenario

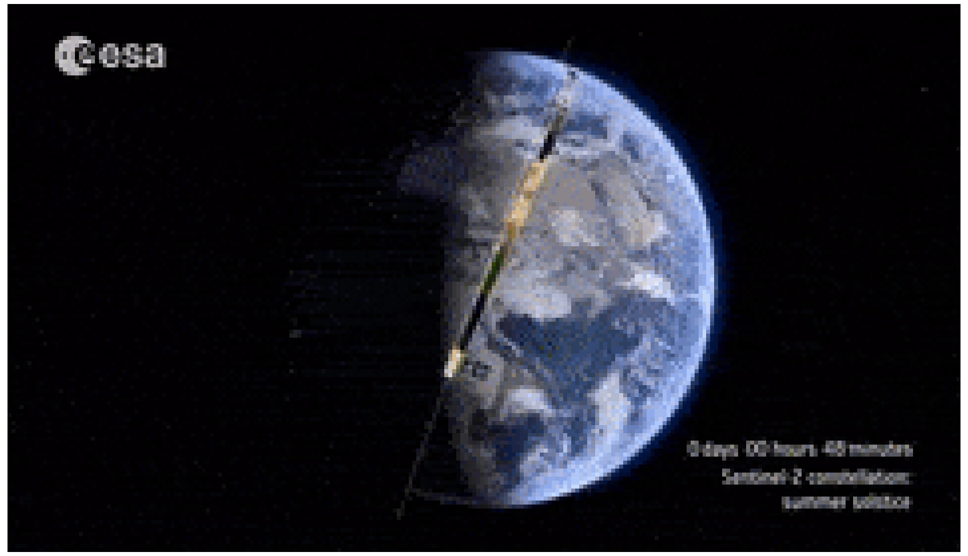
They are coherent systems allowing very precise measures of distance and its variations using the interferometric technique

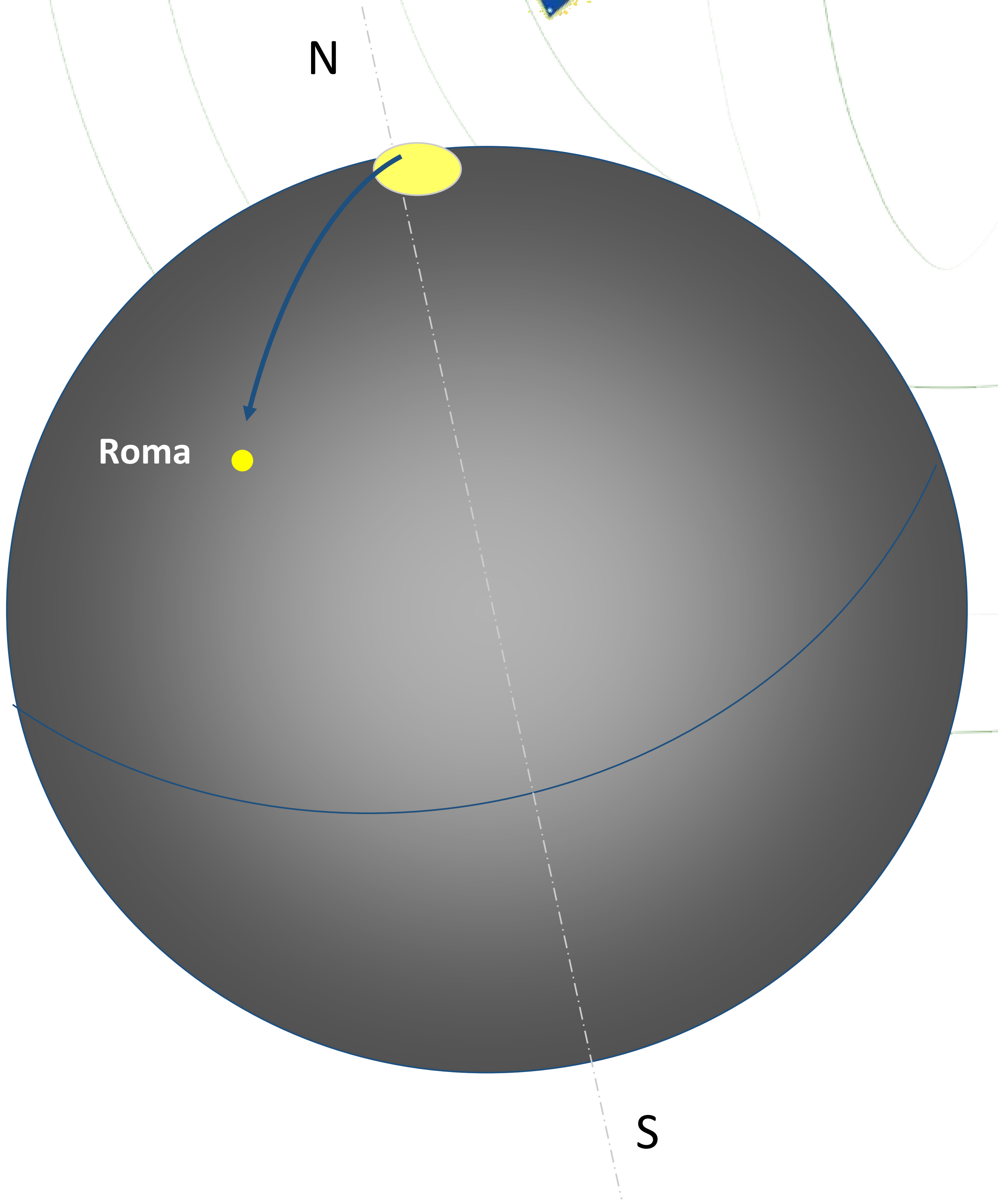
Acquisition in ascending orbit





Acquisition in descending orbit

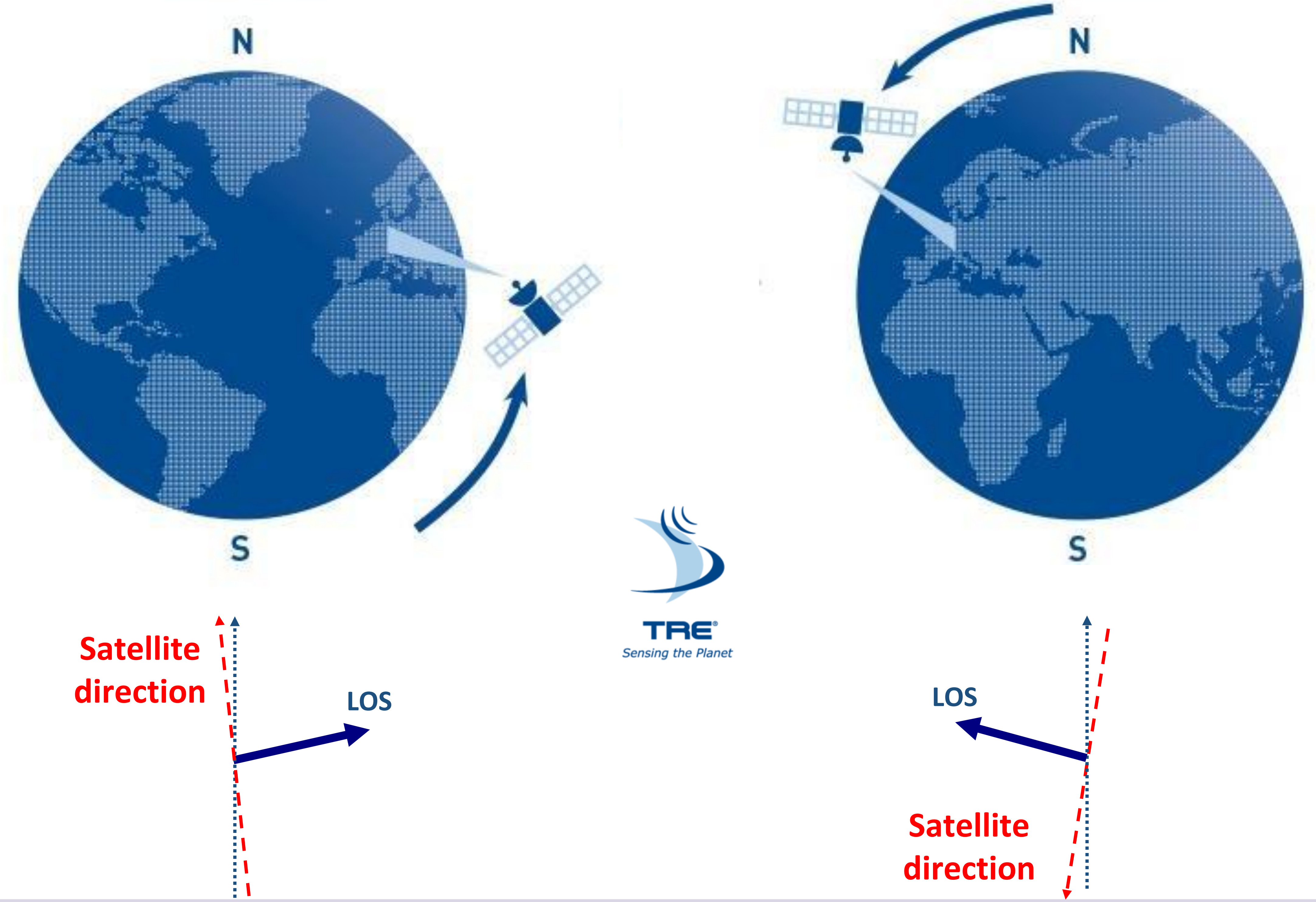




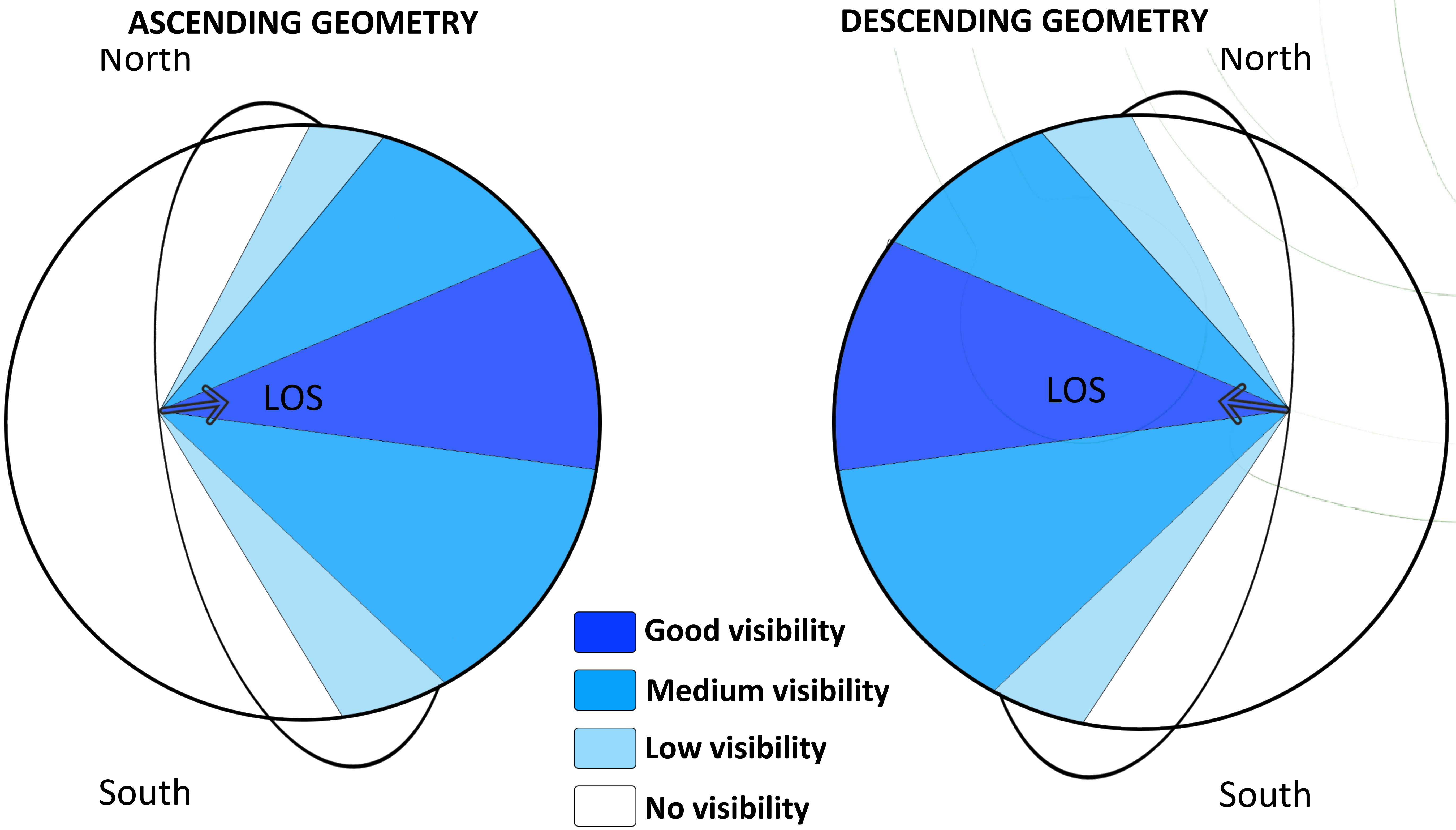
Line of Sight (LoS)

ASCENDING GEOMETRY

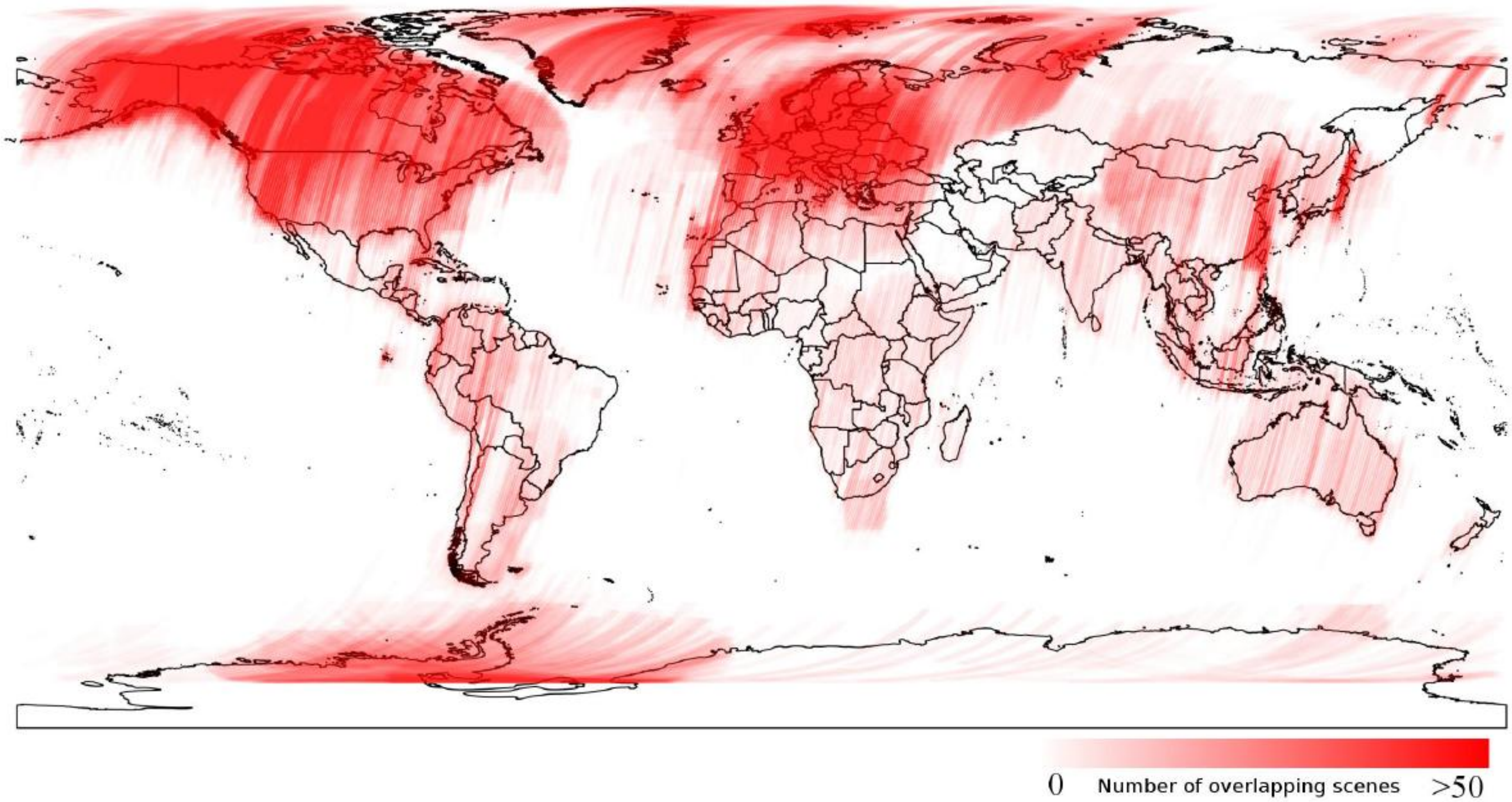
DESCENDING GEOMETRY



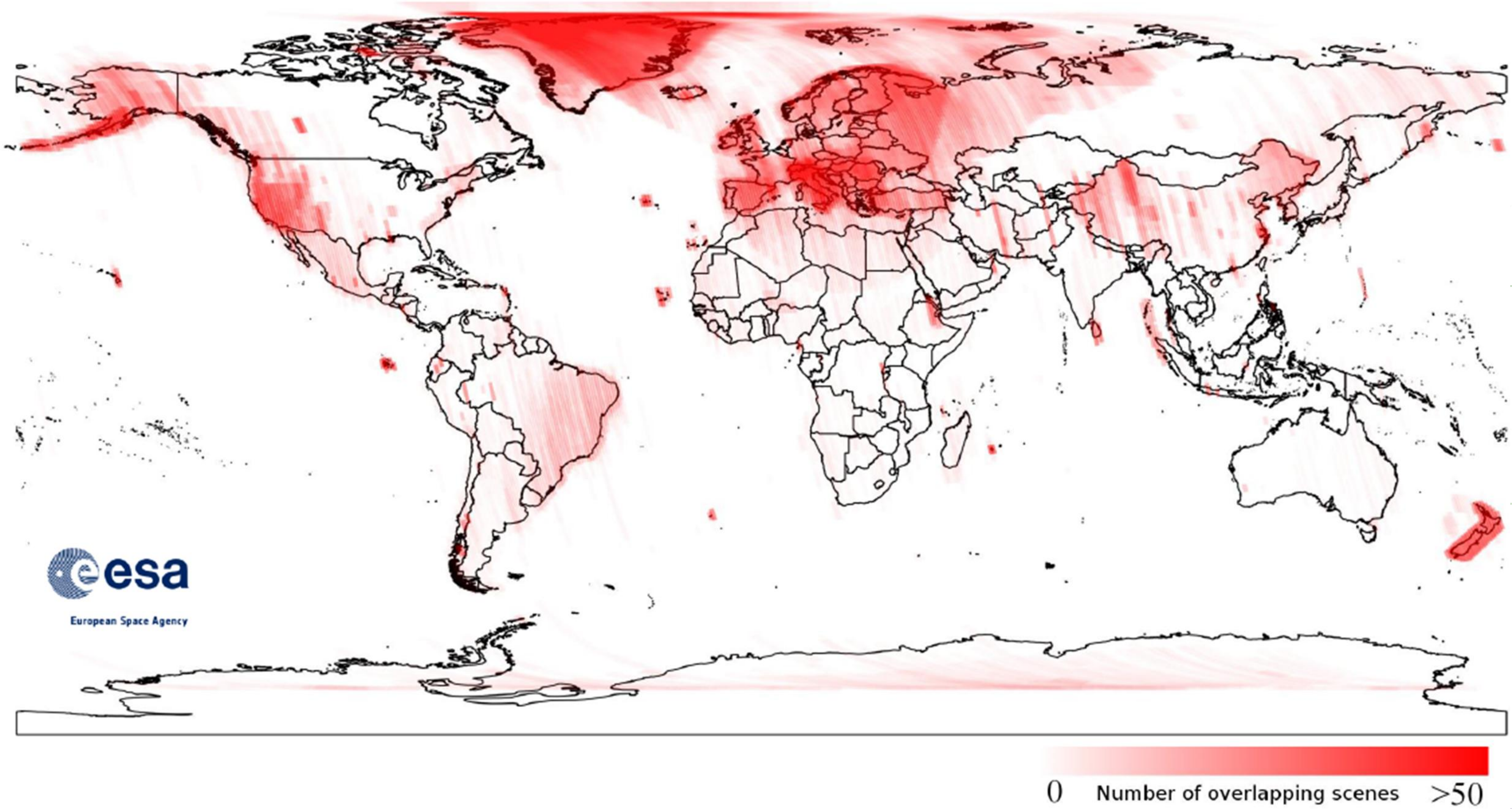
Satellite visibility



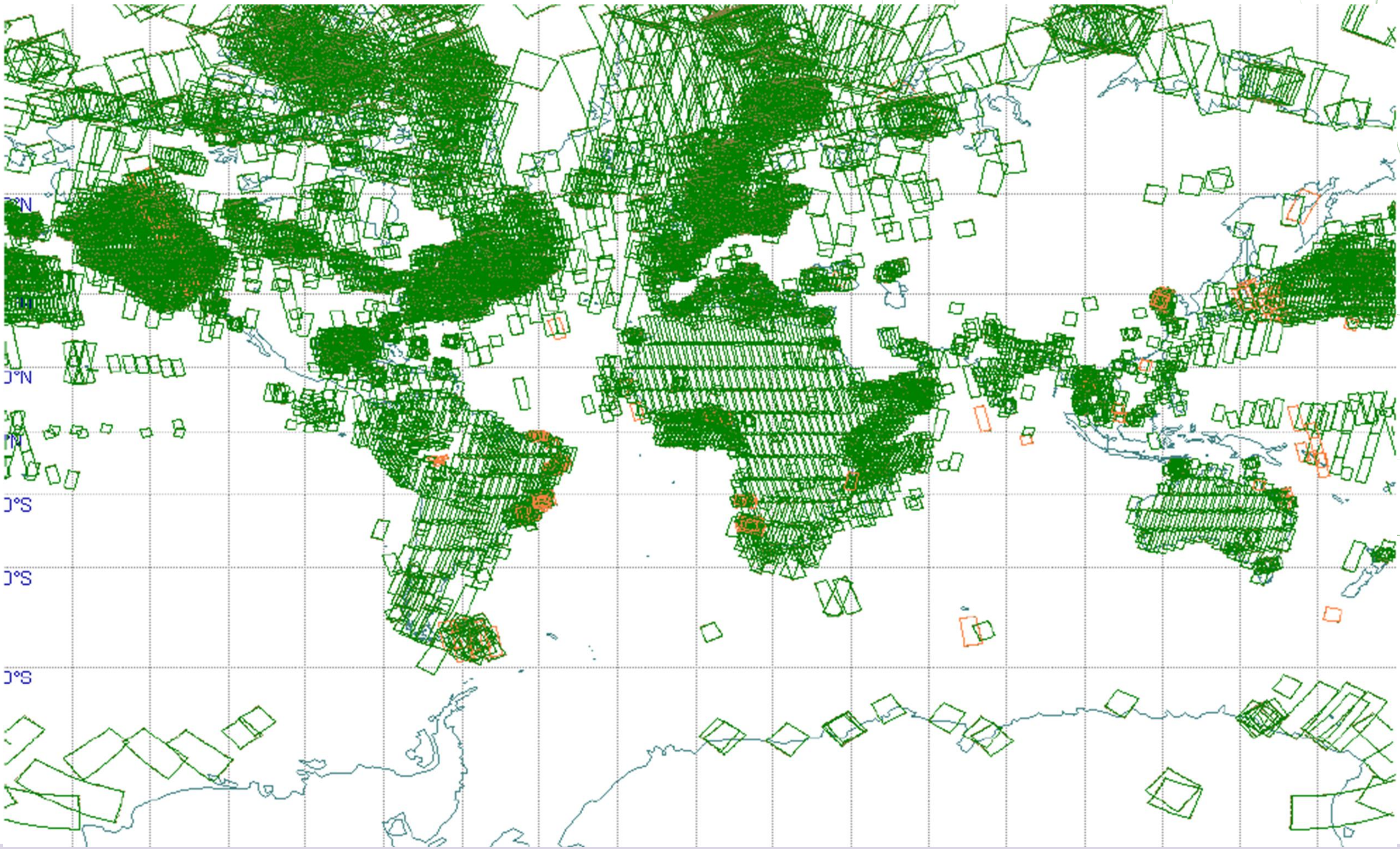
ERS1/2 coverage



ENVISAT coverage

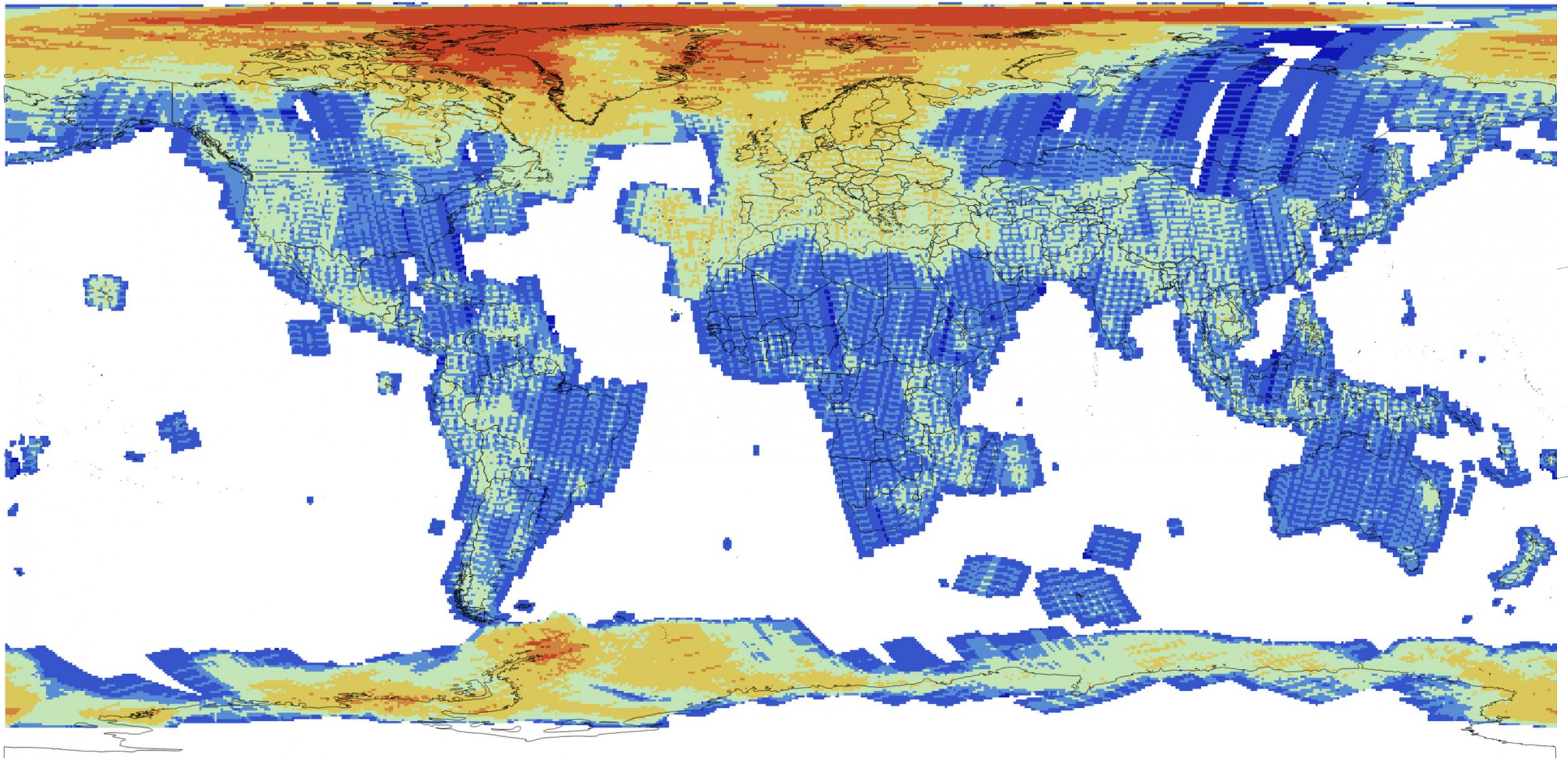


RADASAT-2 coverage



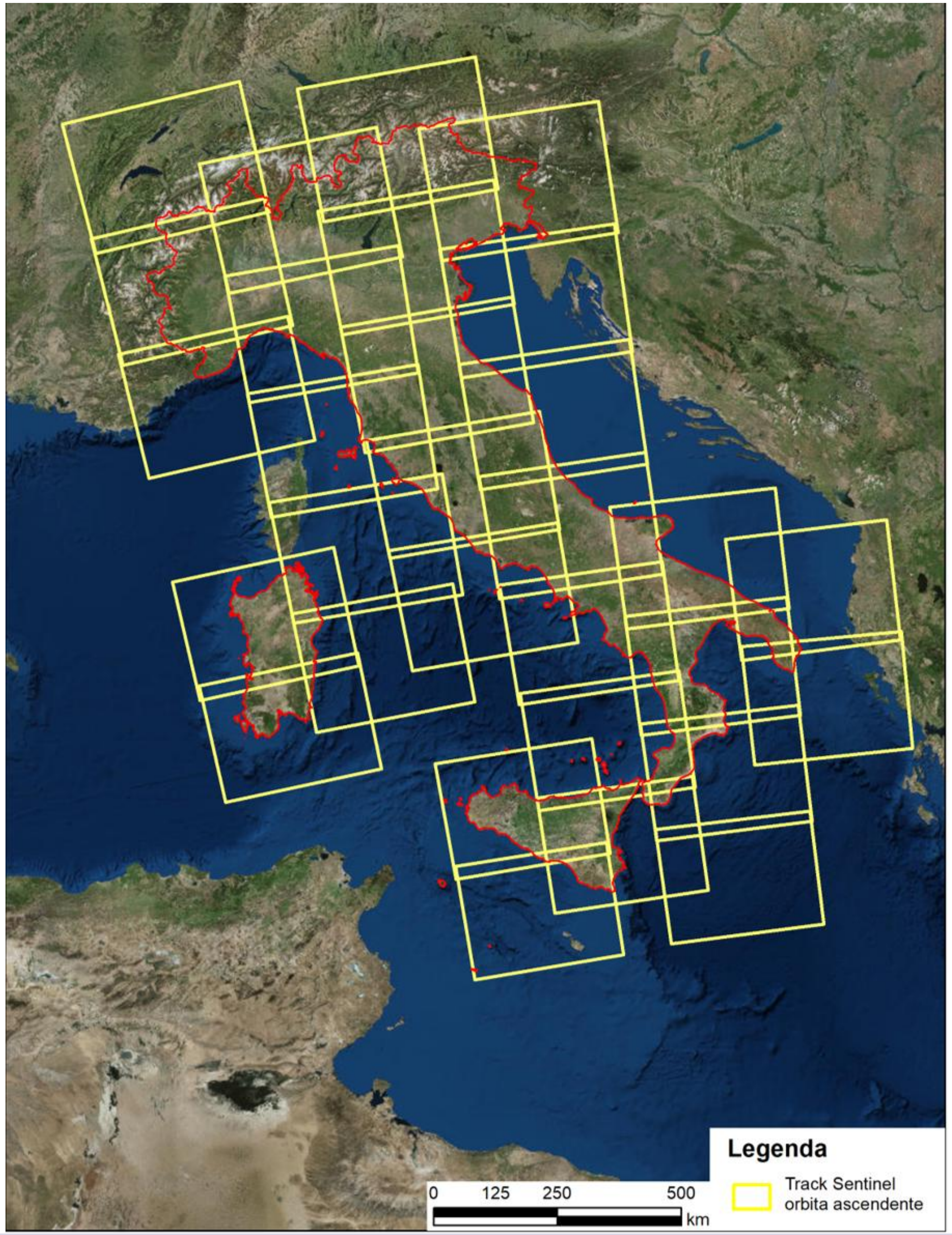
TerraSAR-X coverage

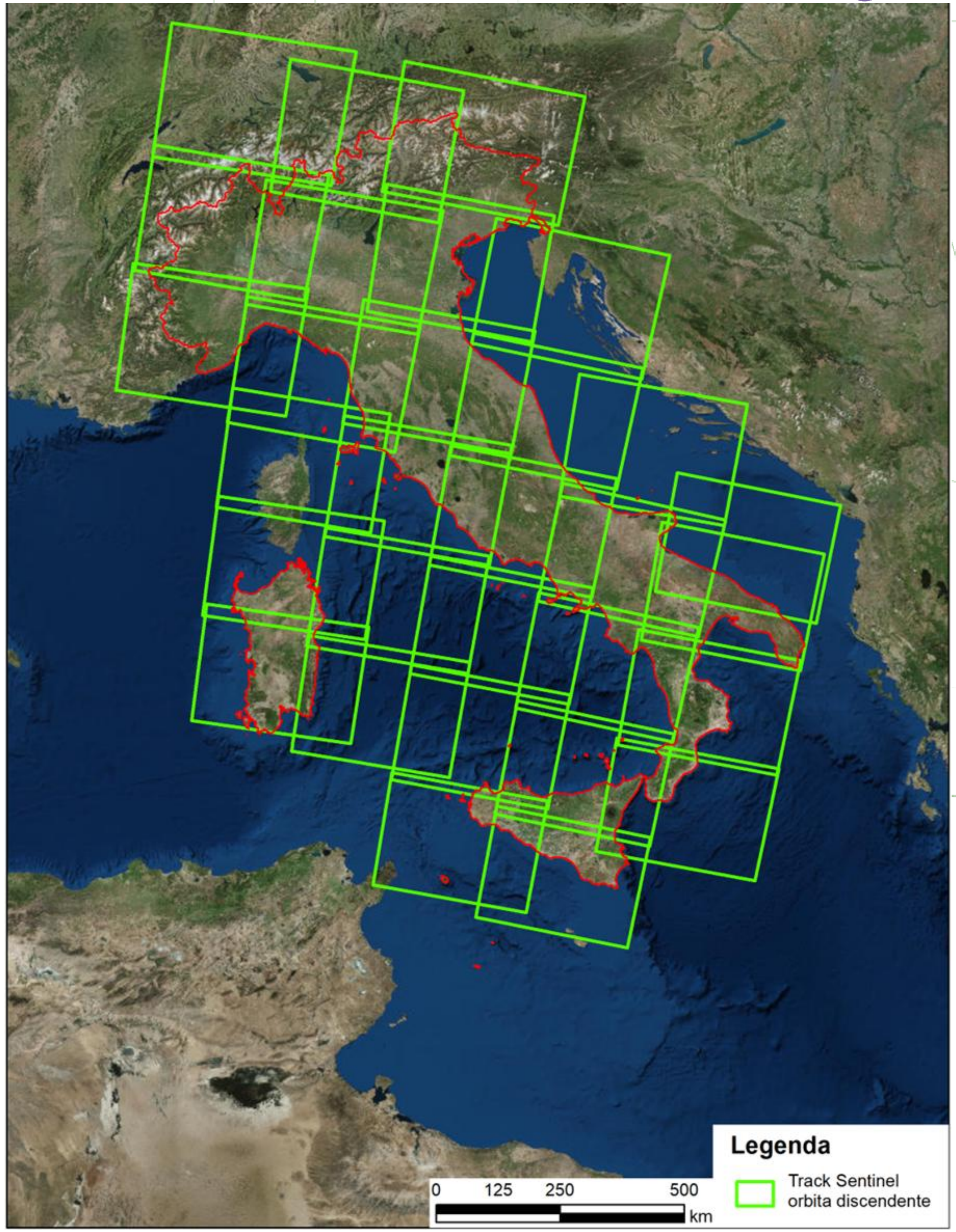
Sentinel-1 coverage



(yet in acquisition)

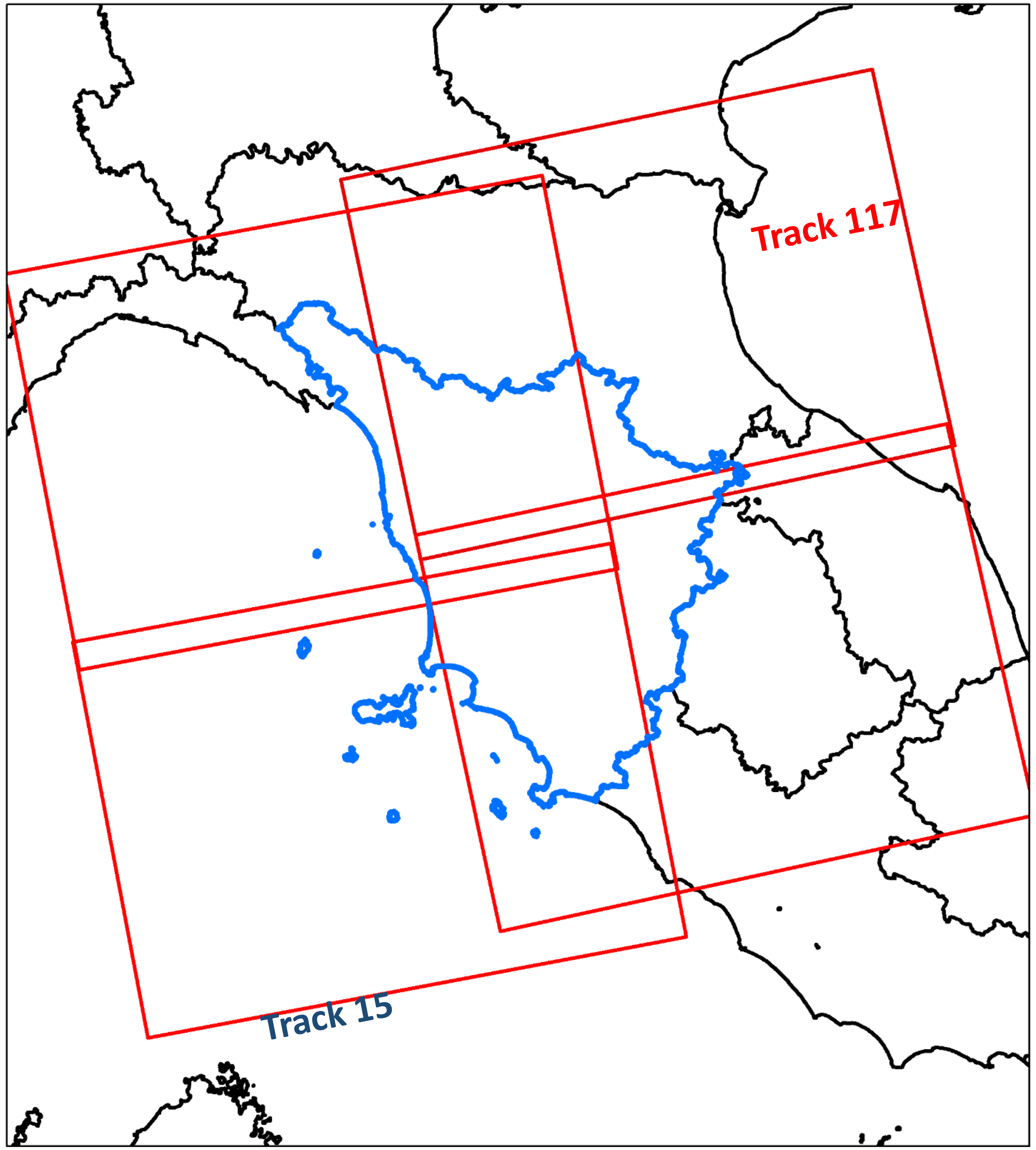
Sentinel-1 coverage



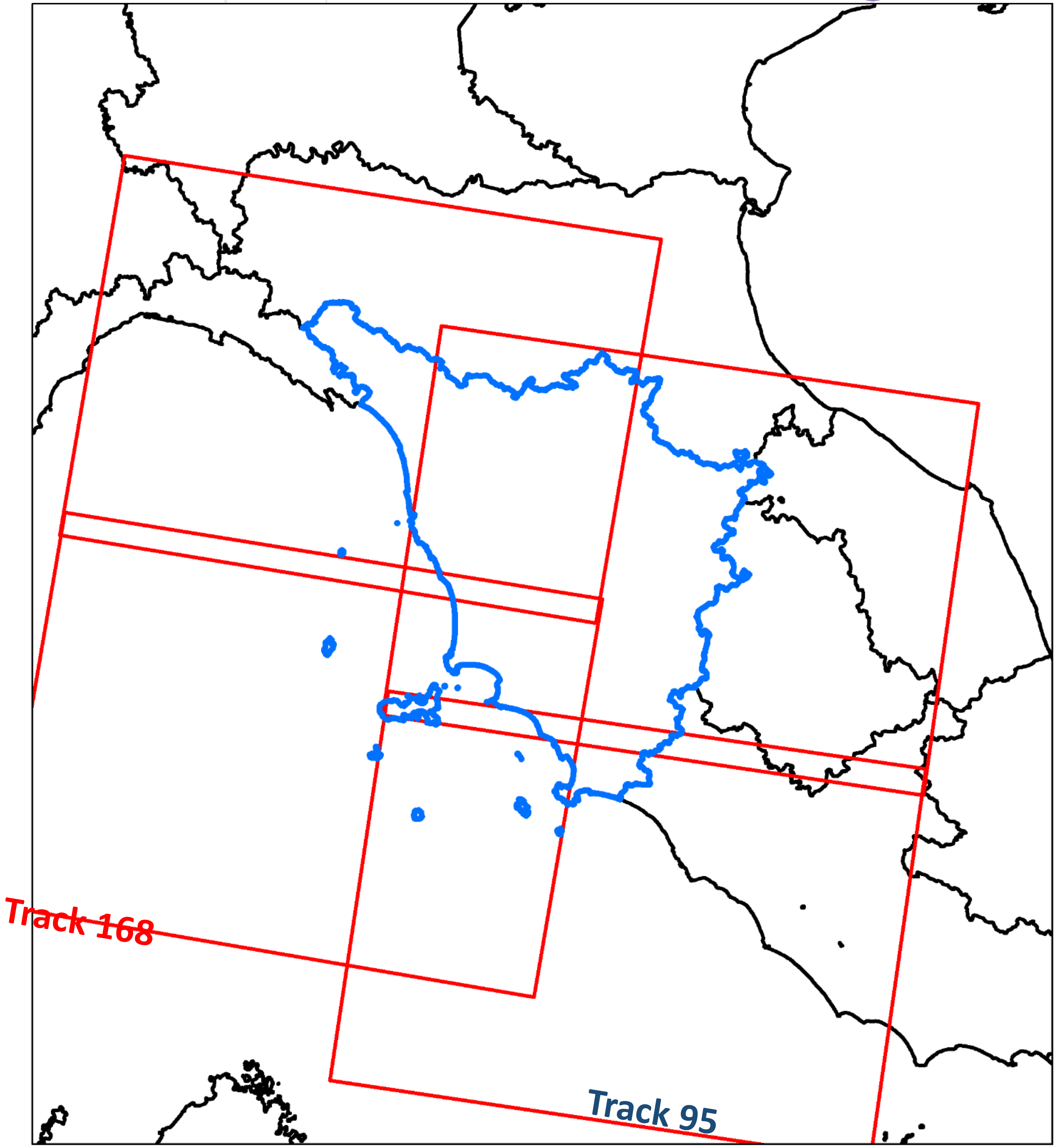


(yet in acquisition)

Sentinel-1 coverage



Ascending geometry



Descending geometry

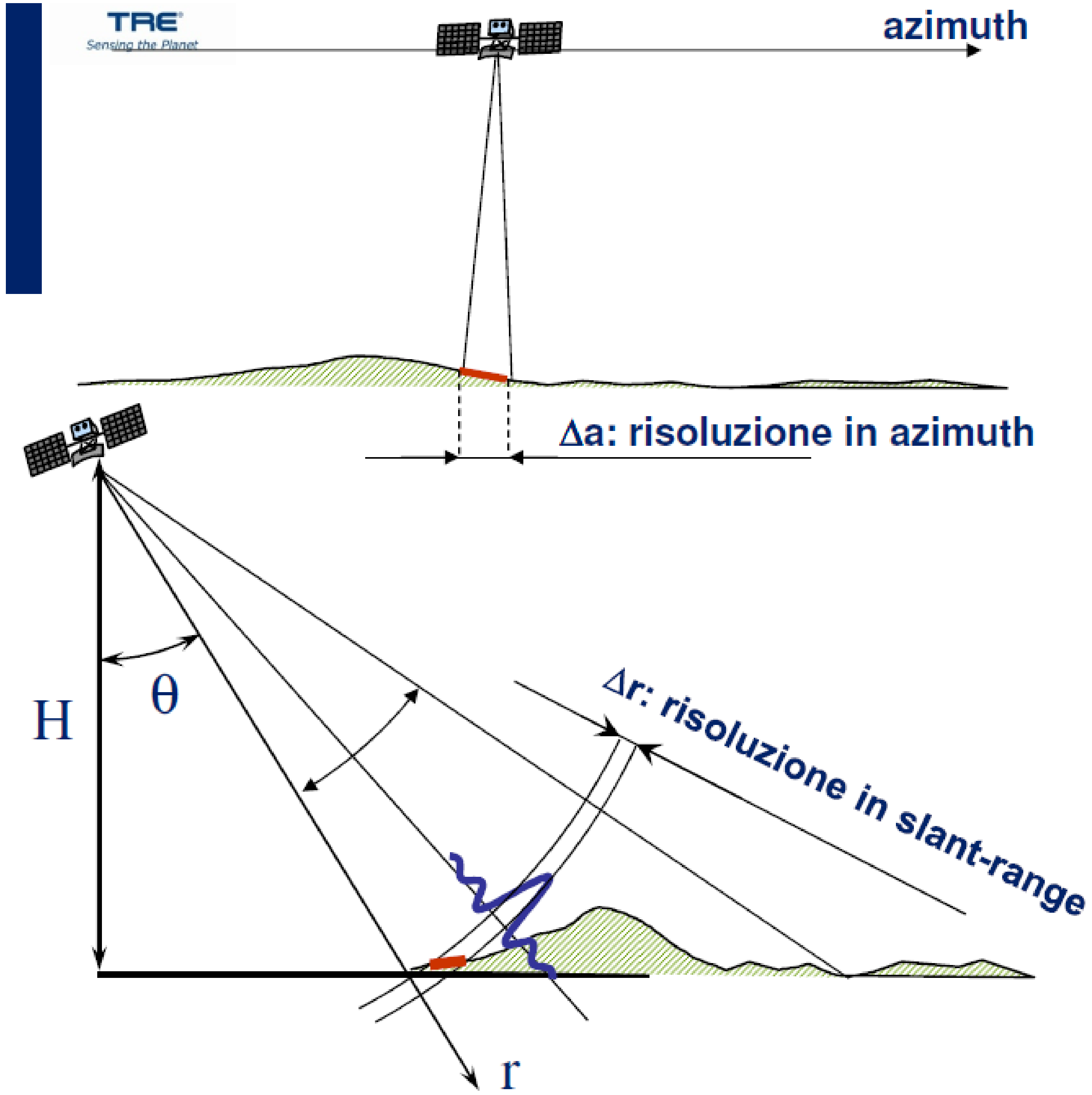
(yet in acquisition)

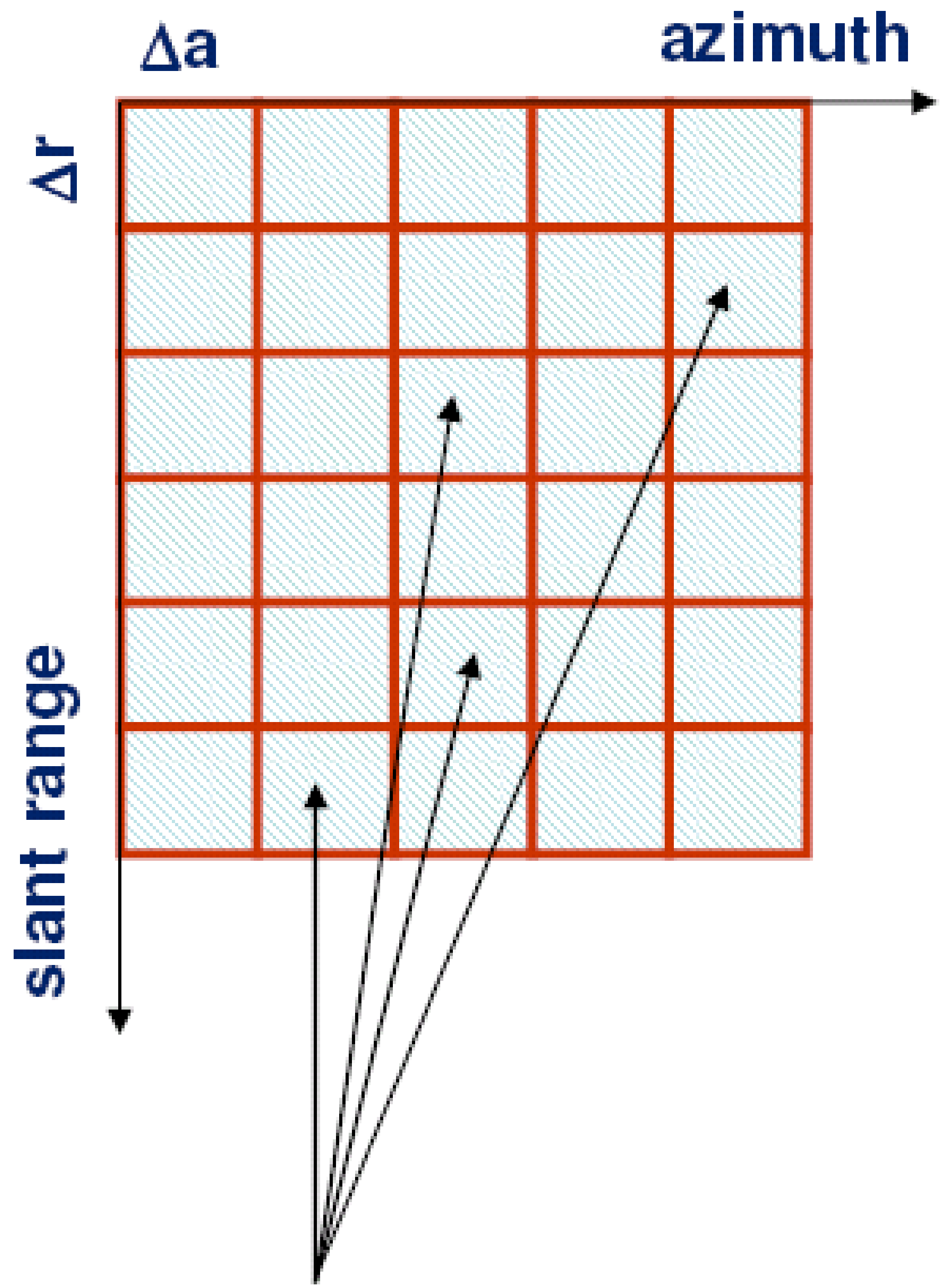
COSMO-SkyMed coverage

Contents

Radar satellite image

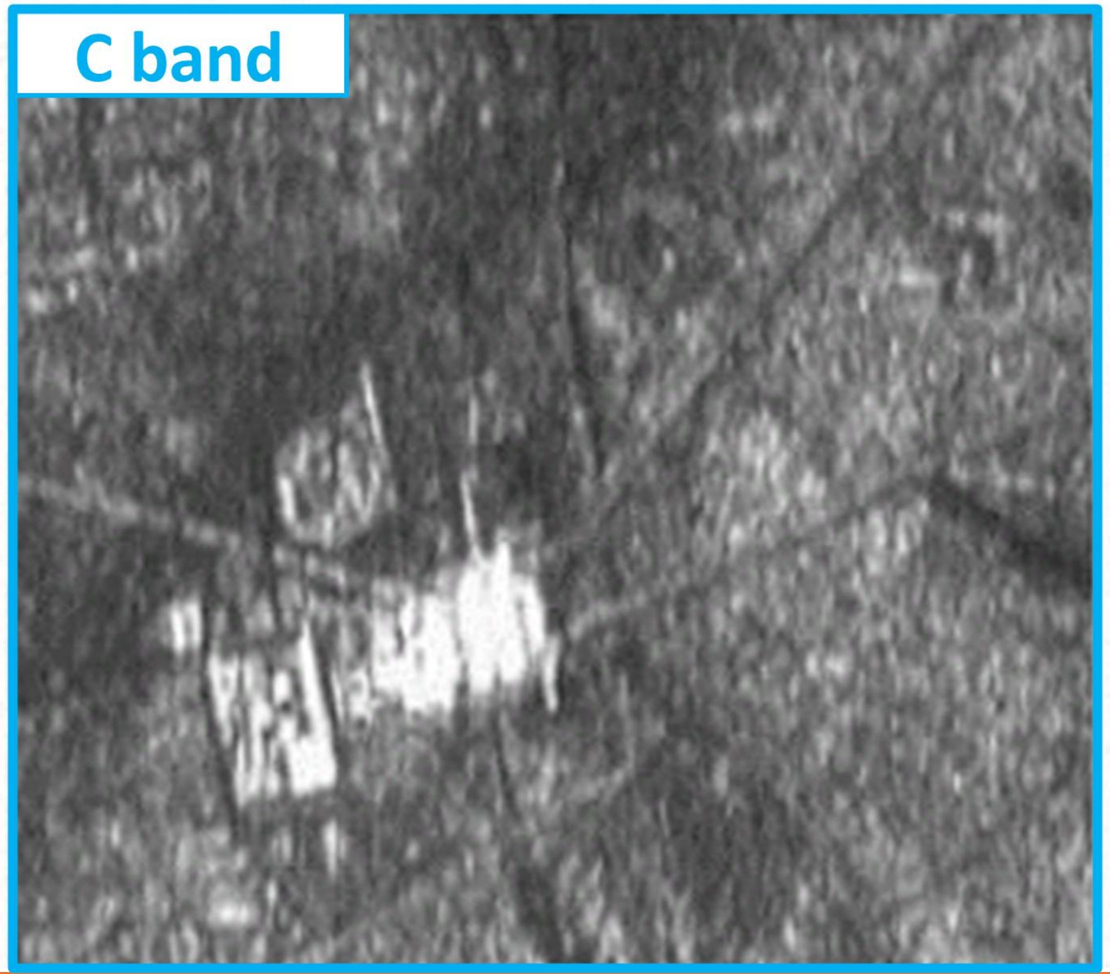
The radar image is **matrix of pixels** like an optical (RGB) image. Each pixel has proper **coordinates** (radar), **dimensions** and **radar information**. Each cell (pixel) has values of **amplitude** and **phase** of the back-scattered signal by targets.





Radar sensors features

Spatial resolution of radar satellite image depends on the characteristics of that sensor (in terms of frequency and wavelength) that has been used for acquisition.



Band	Satellite (samples)	Frequency	Wavelenght	Characteristics	Range x Azimuth
L	Alos PALSAR	1-2 Ghz	22 cm	Wide Swat, Low resolution	10 x 5 m
C	ERS1/2 Envisat Sentinel-1	4-8 Ghz	5,6 cm	Variable Swath (100-250 km) ~10m of resolution	15 x 4 m
X	TerraSAR-X Cosmo SkyMed	8-12 Ghz	3,1 cm	Smaller Swath, Metric resolution	3 x 3 m

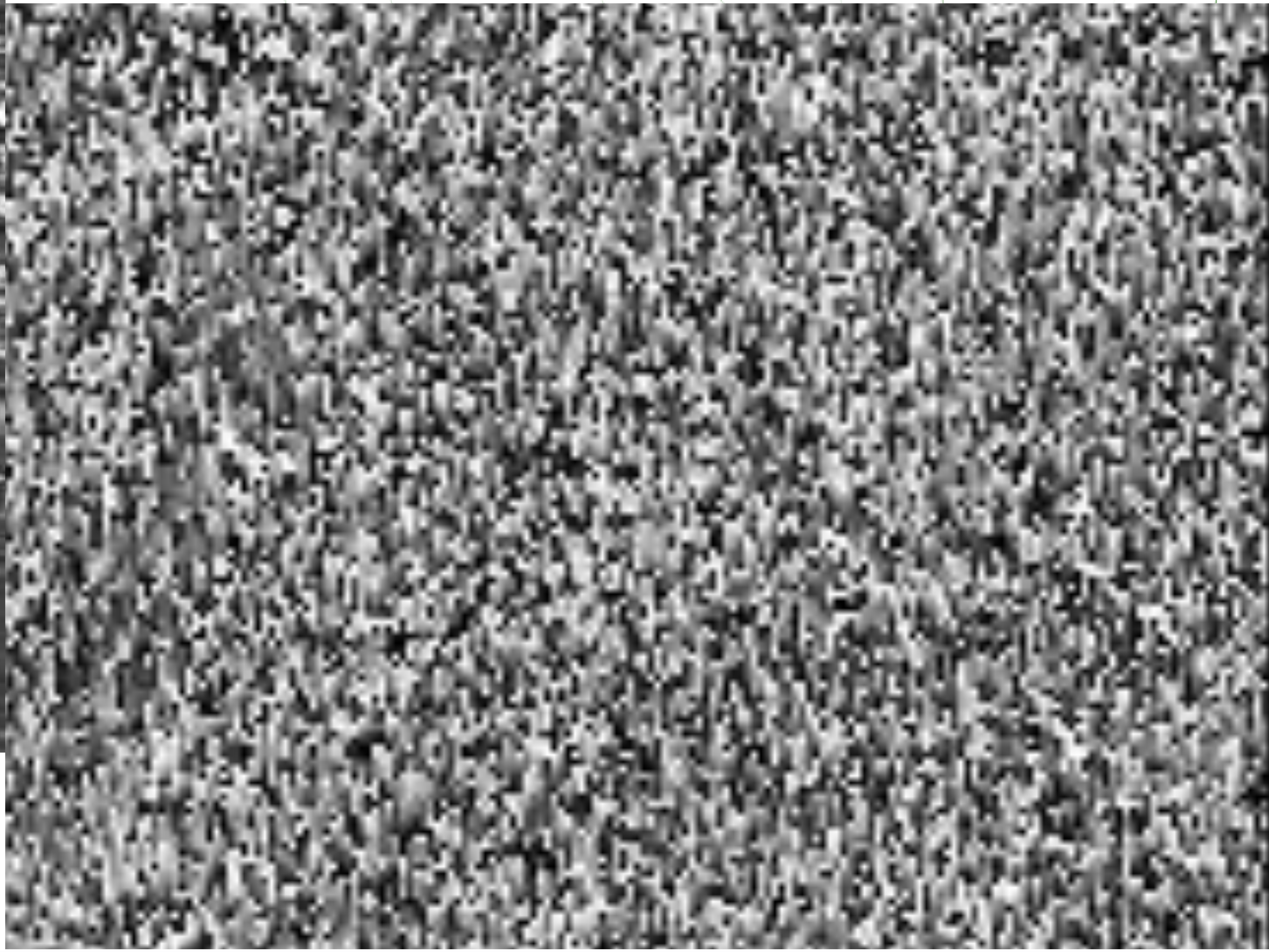
Spatial resolution of radar sensors

ERS1/2 (Banda C)

TerraSAR-X (Banda X)

SAR image contents

Amplitude: pixel values referred to “how much” the target reflect.

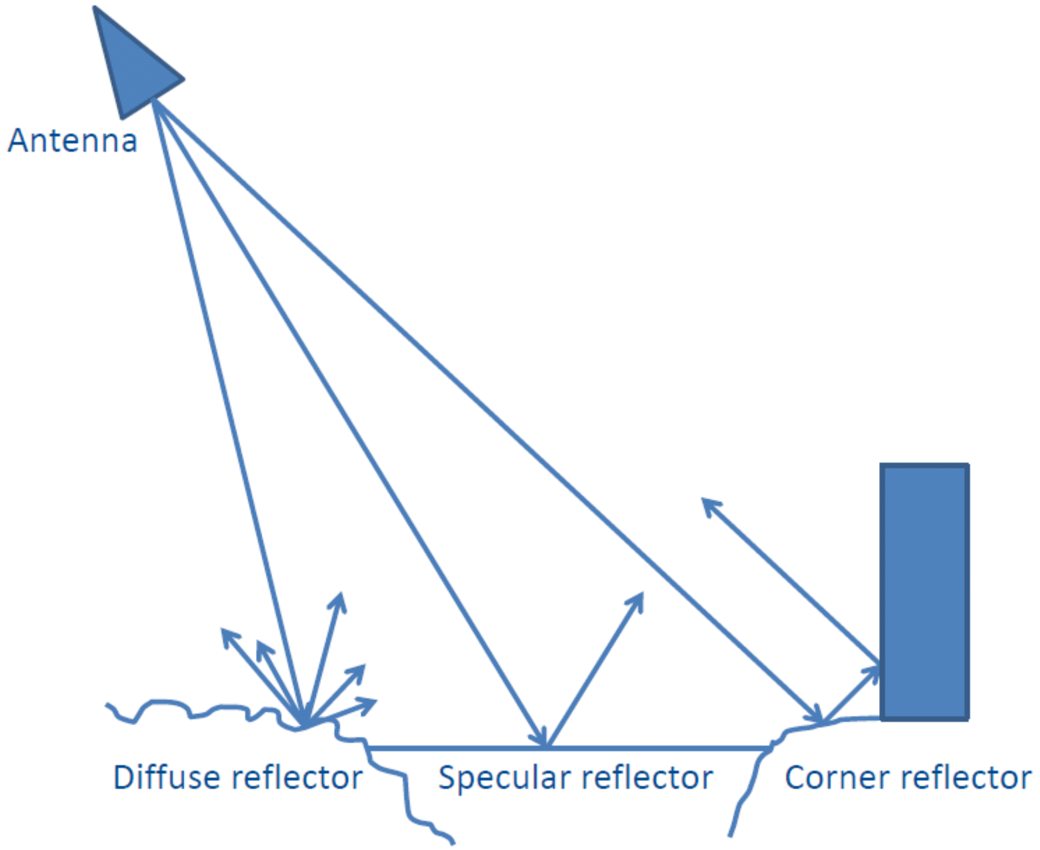


Phase: cell values referred to the distance of the target (measured in π)

SAR image contents - Amplitude

Every pixel of a SAR image contains the back-scattered signal influenced by all the reflecting scatteres in a cell. The reflectivity (back-scattered amplitude) is not influenced by weather conditions and solar illumination.

The intensity of the back-scattered signal depends on the type of target (geometry, temperature, dielectric proprierties).



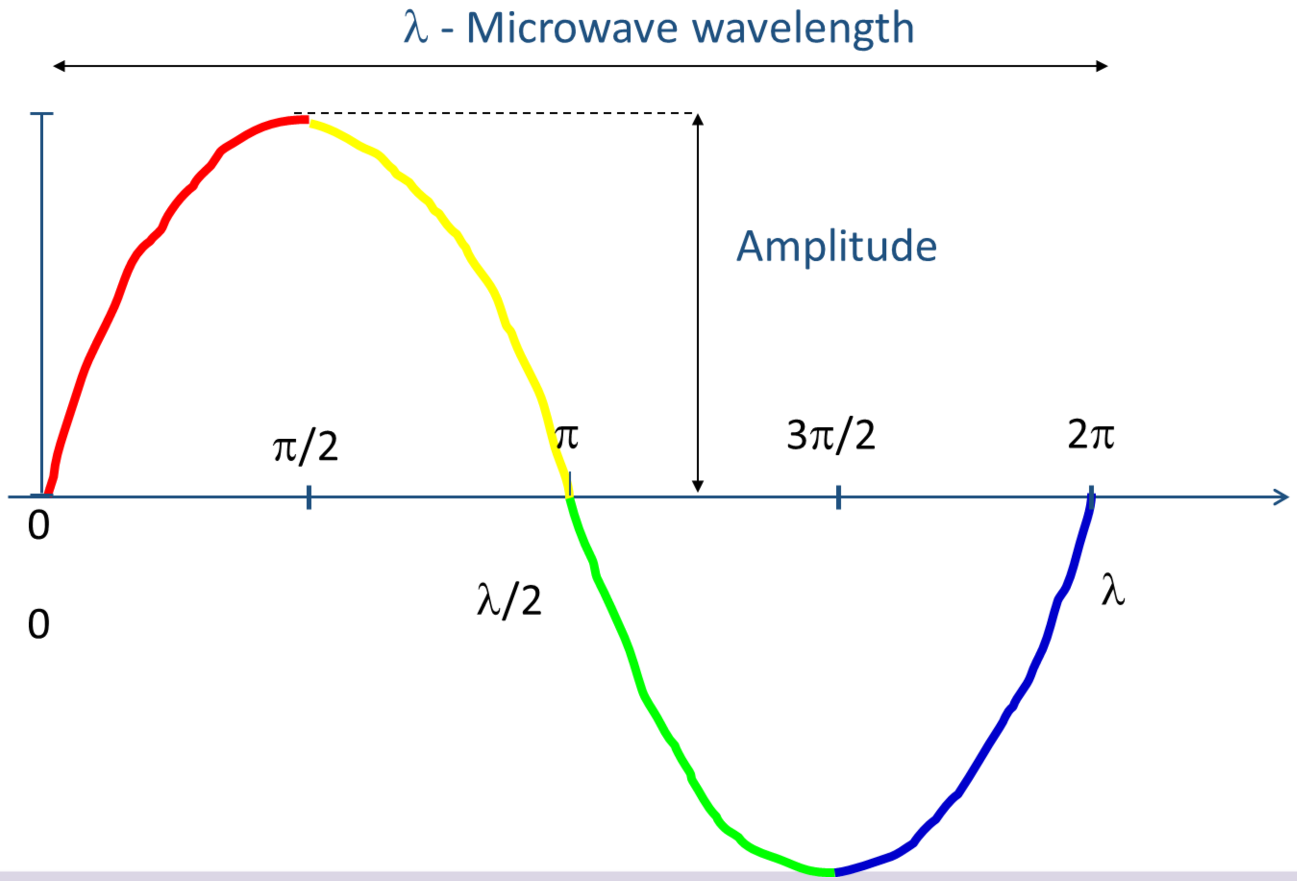
The SAR satellite actually available can collect only a single frequency
This is the reason why the image can be visualized only in gray scale

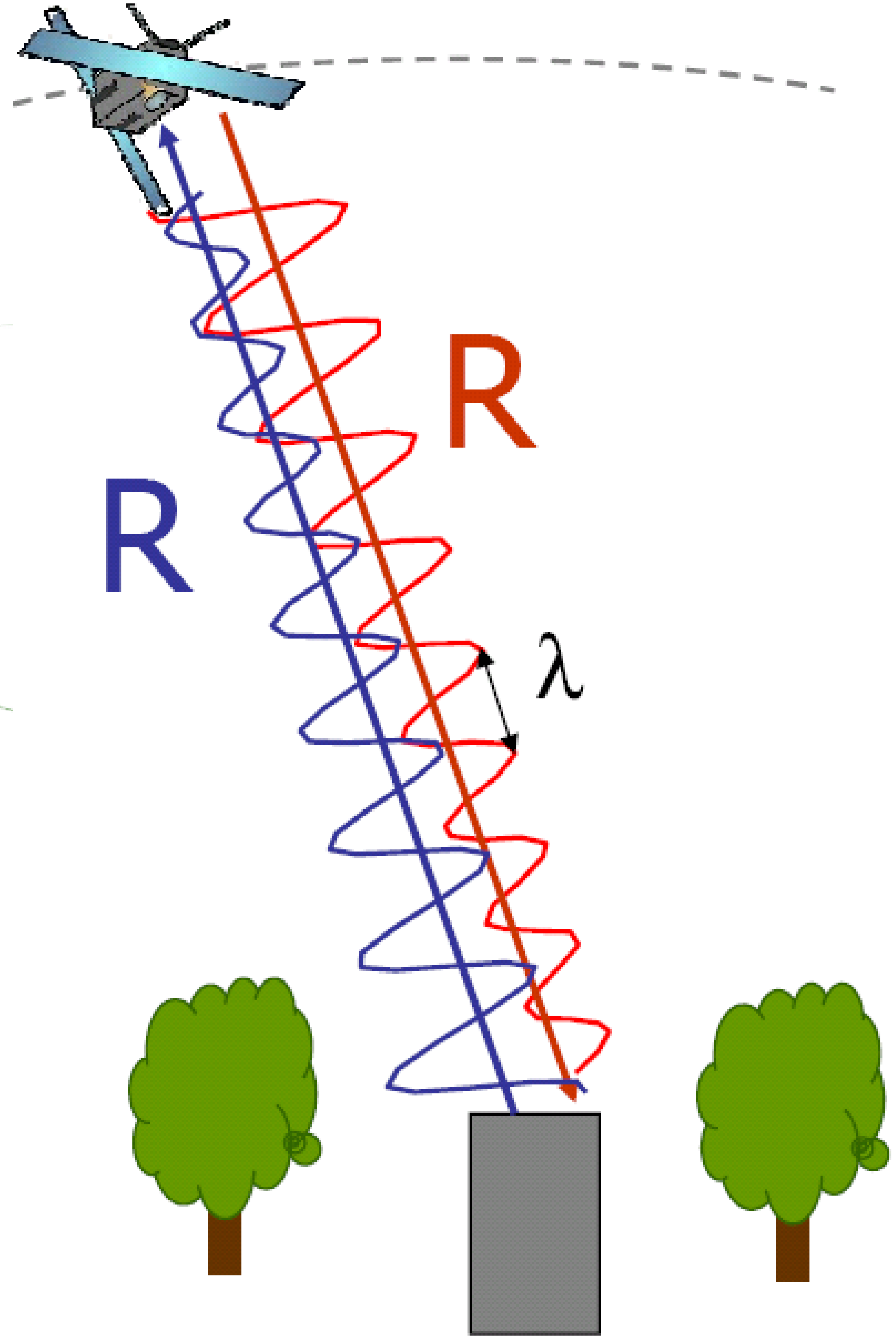
SAR image contents - Phase

- The emitted radar signal reach the target on the ground and then returns to the radar

- The radar signal can be assumed to be a sinusoid wave with wavelength λ.

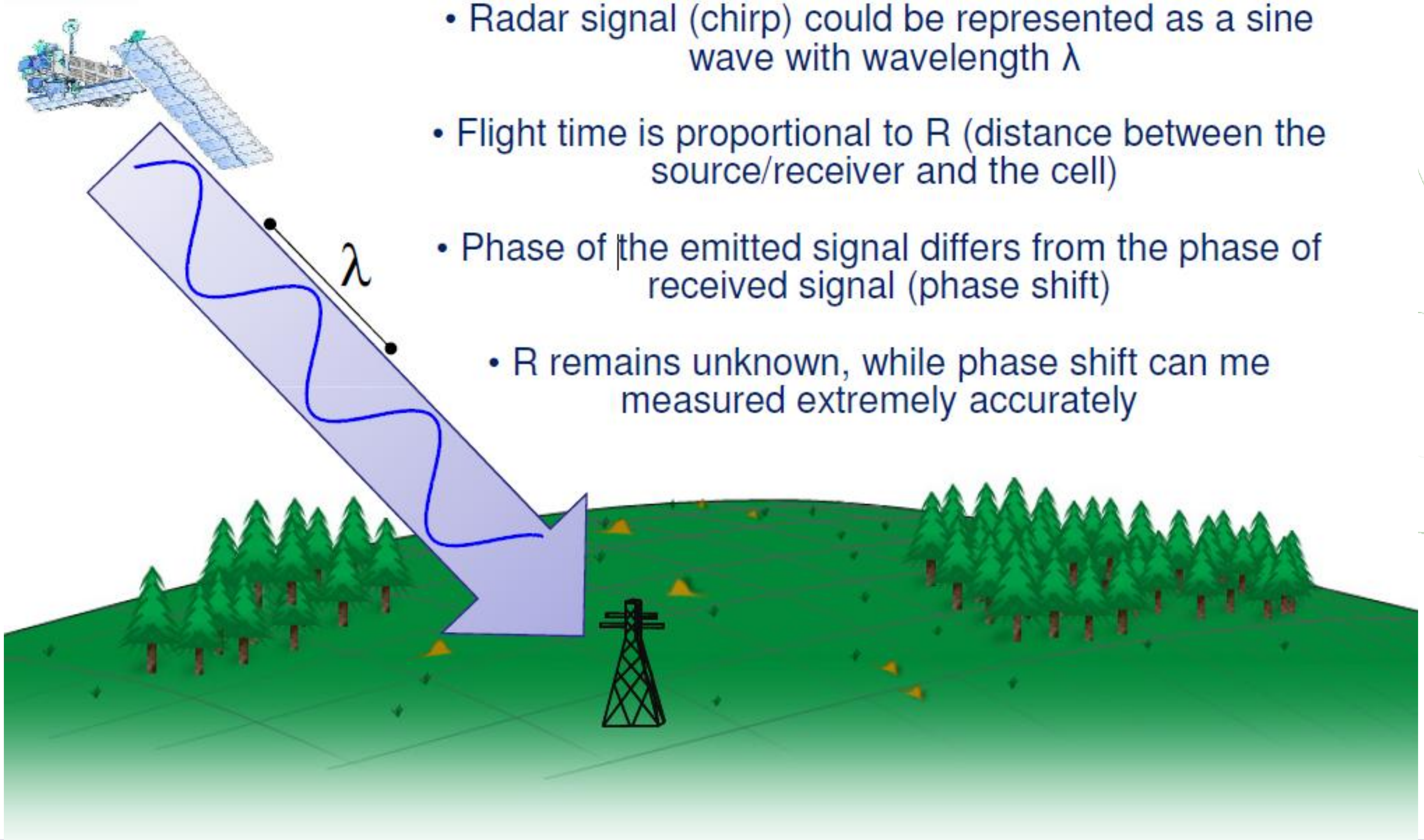
- Based on their distance, the objects (targets) have a peculiar phase radar signal



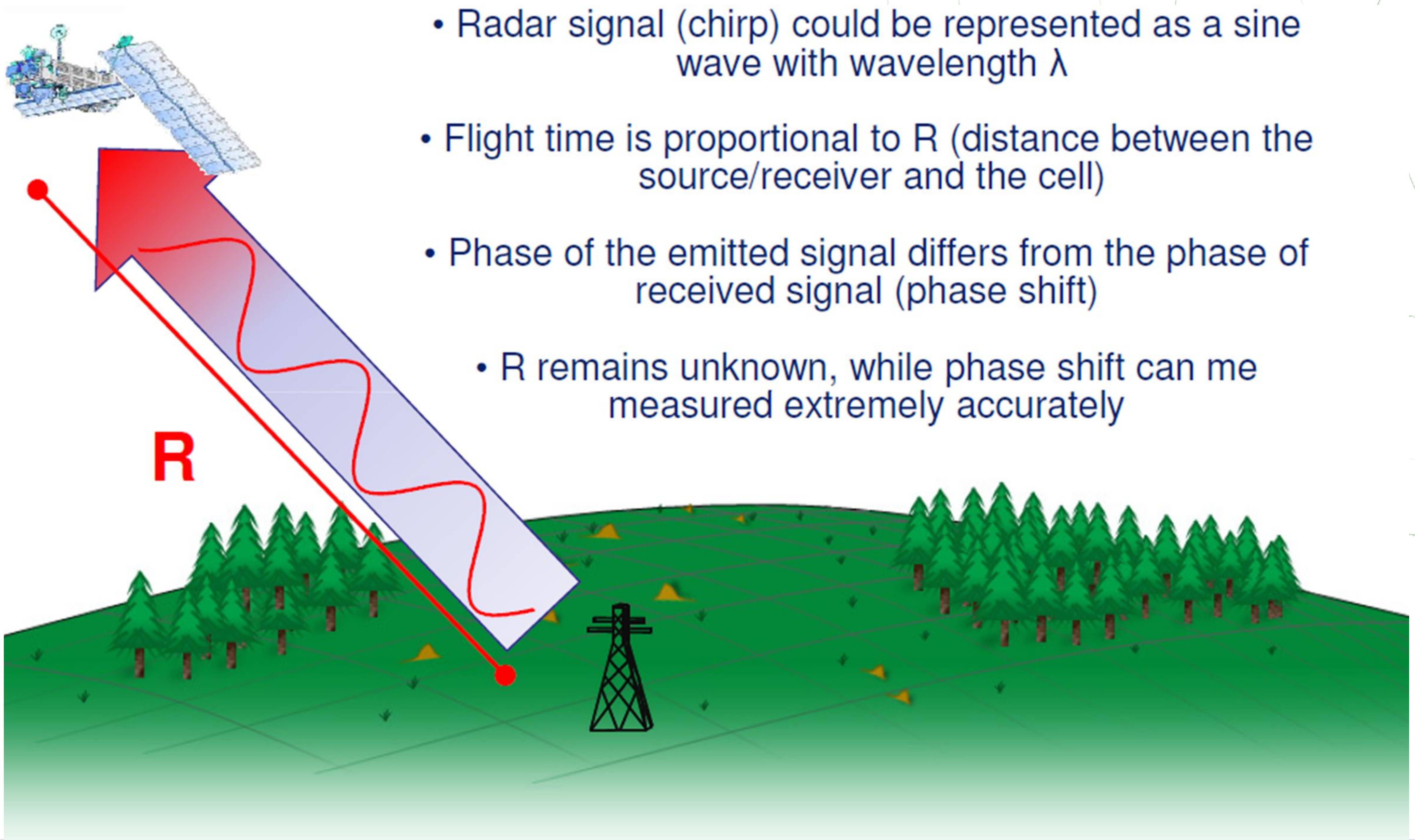


SAR image contents - Phase

- Radar signal (chirp) could be represented as a sine wave with wavelength λ
- Flight time is proportional to R (distance between the source/receiver and the cell)
- Phase of the emitted signal differs from the phase of received signal (phase shift)
- R remains unknown, while phase shift can me measured extremely accurately



SAR image contents - Phase



- Radar signal (chirp) could be represented as a sine wave with wavelength λ
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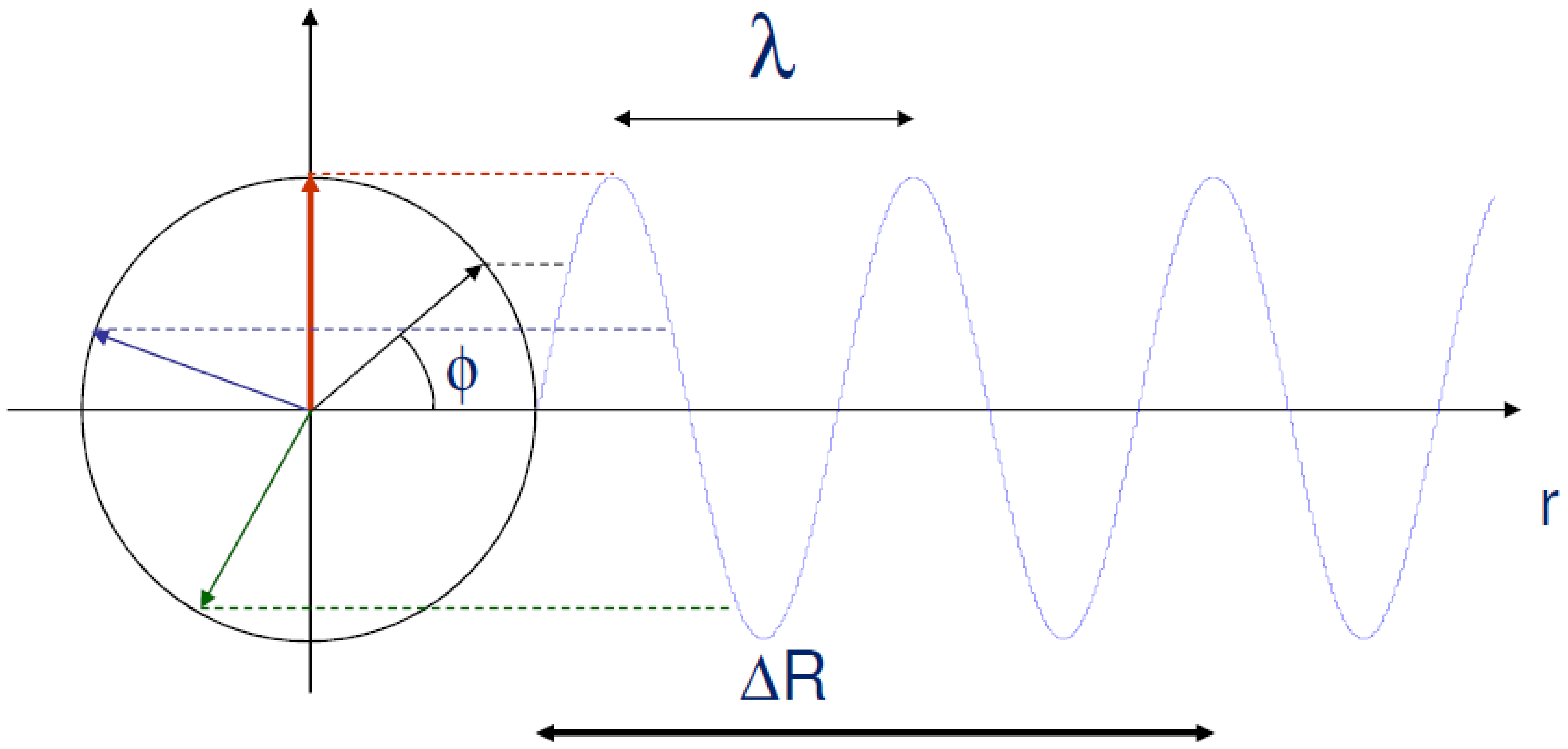
SAR image contents - Phase



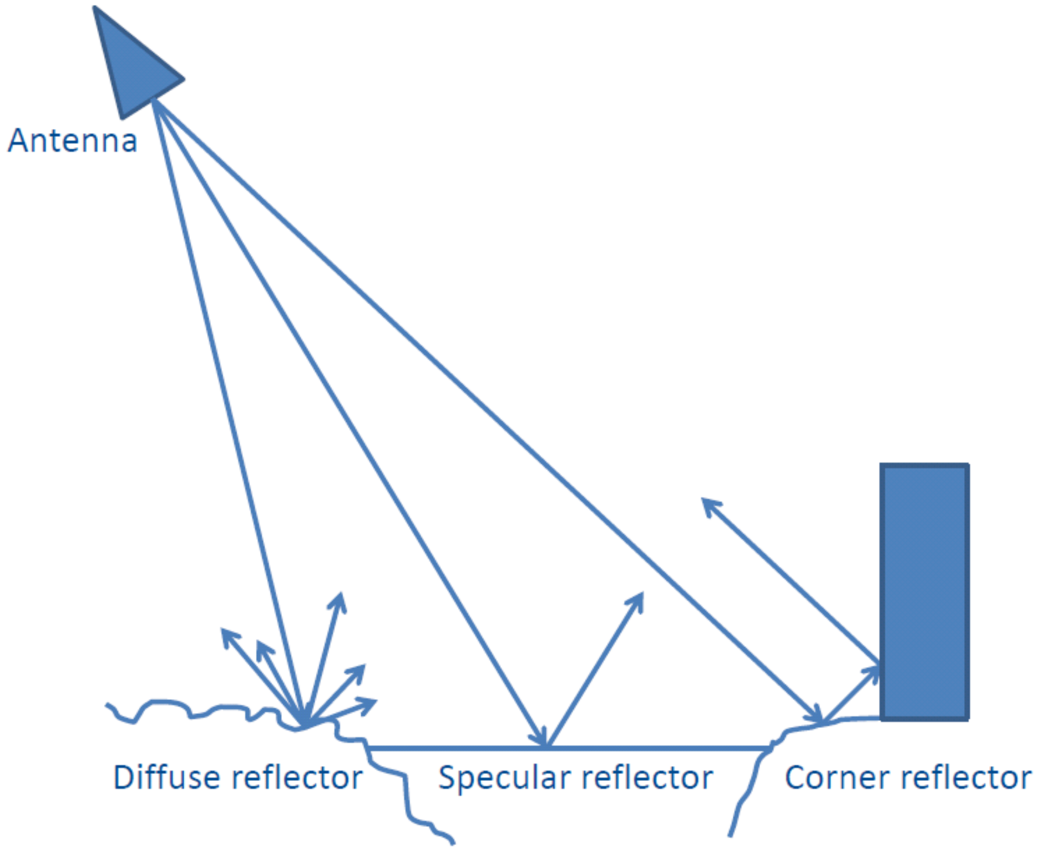
$$\Delta\phi = \frac{2\pi}{\lambda}\Delta R \quad \xrightarrow{\Delta R = 2R} \quad \boxed{\Delta\phi = \frac{4\pi}{\lambda}R}$$

The interferometric phase is proportional to the variation of lenght of the electromagnetic wave

SAR image contents - Amplitude

Every pixel of a SAR image contains the back-scattered signal influenced by all the reflecting scatteres in a cell. The reflectivity (back-scattered amplitude) is not influenced by weather conditions and solar illumination.

The intensity of the back-scattered signal depends on the type of target (geometry, temperature, dielectric proprierties).



SAR image contents - Phase

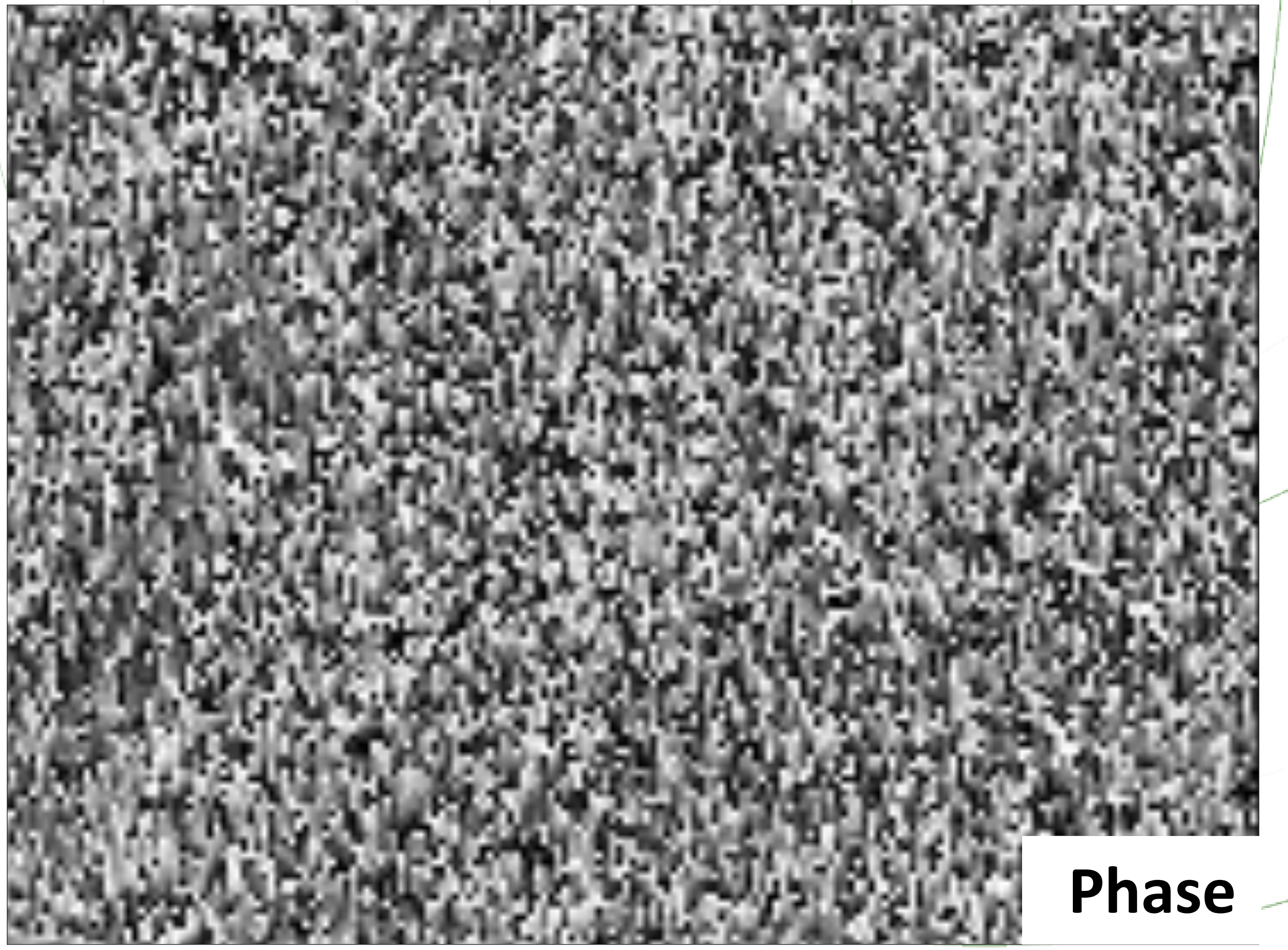
$$\phi = \psi + \frac{4\pi}{\lambda} r \; (+\alpha + noise \;)$$

ψ — Reflectivity of the radar target (geometries, exposition, material)

$\frac{4\pi}{\lambda} r$ — Geometric phase related with the distance of the target and its moving
(λ is the wavelength - r is the radar distance)

α — Atmospheric contribute

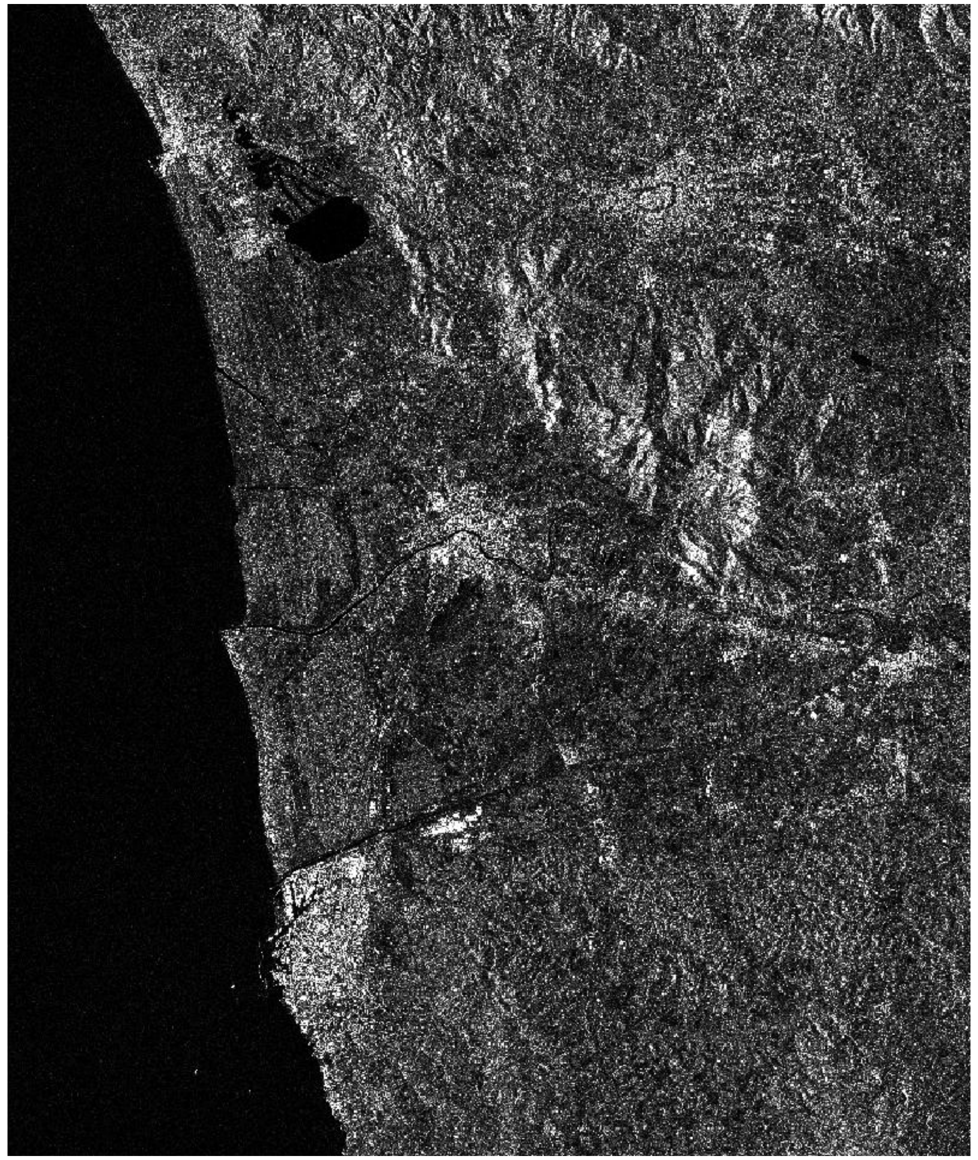
$noise$ — Radar signal noise



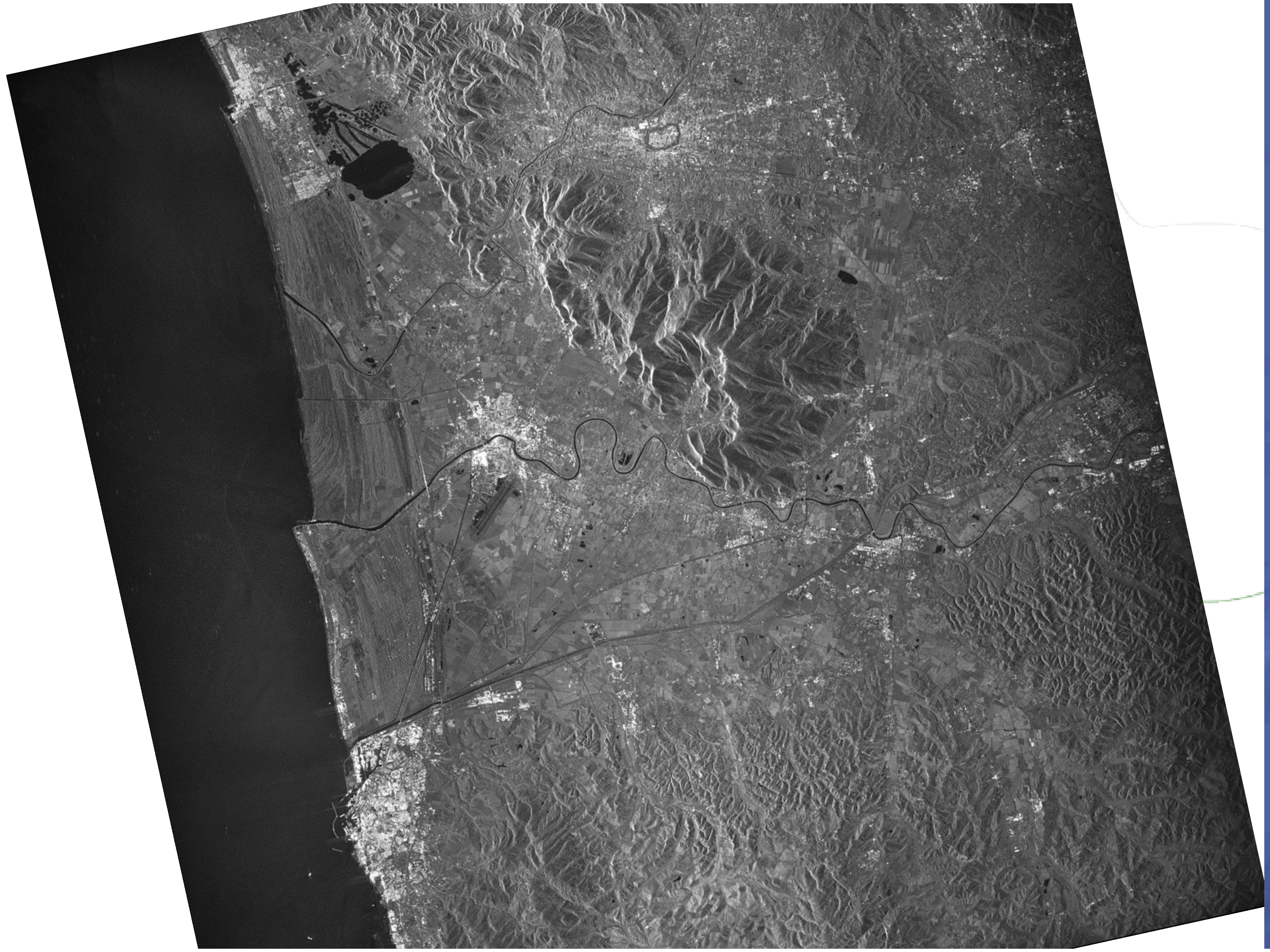
The phase of a single image is useless since the phase image is difficult to understand and the diverse factors of phase contributions are difficult to distinguish from the target reflectivity, atmospheric contribution, topographic effetc and noise

Georeferred SAR image

Sentinel-1 (ESA)
C-band (5.6 cm)

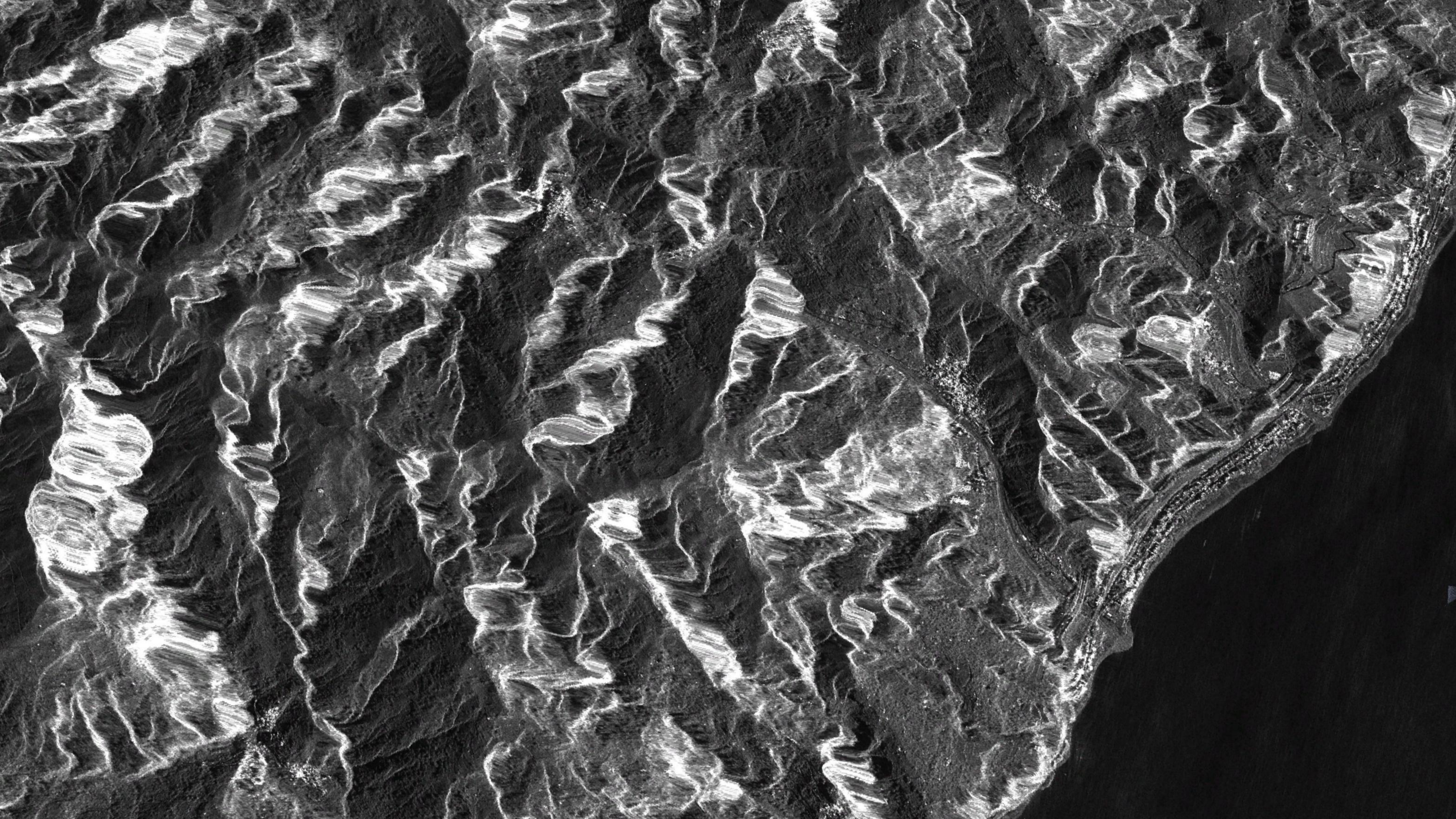


COSMO-SkyMed (ASI)
X-band (3.0 cm)



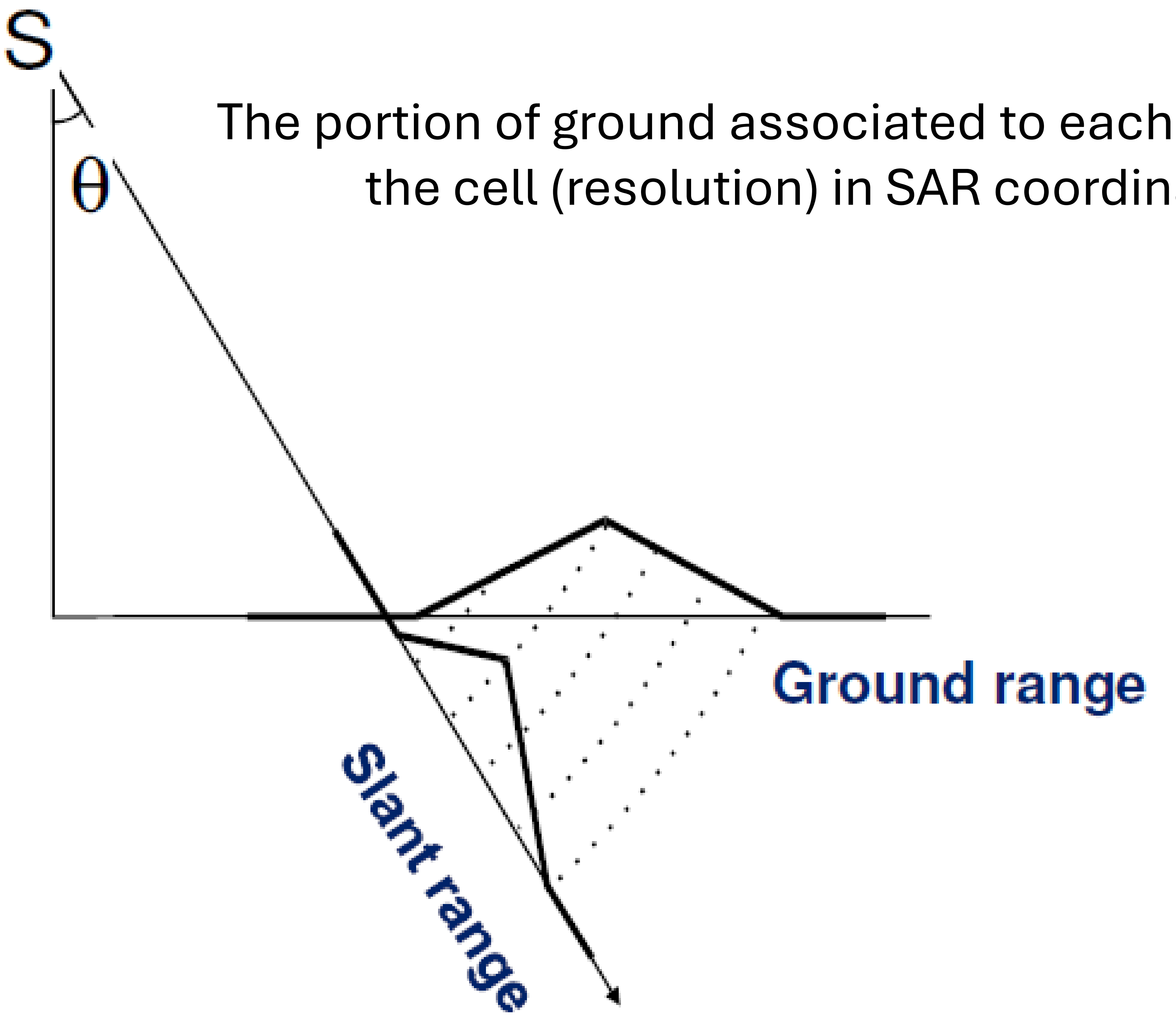
Sentinel-2 (ESA)
Optical image (RGB)

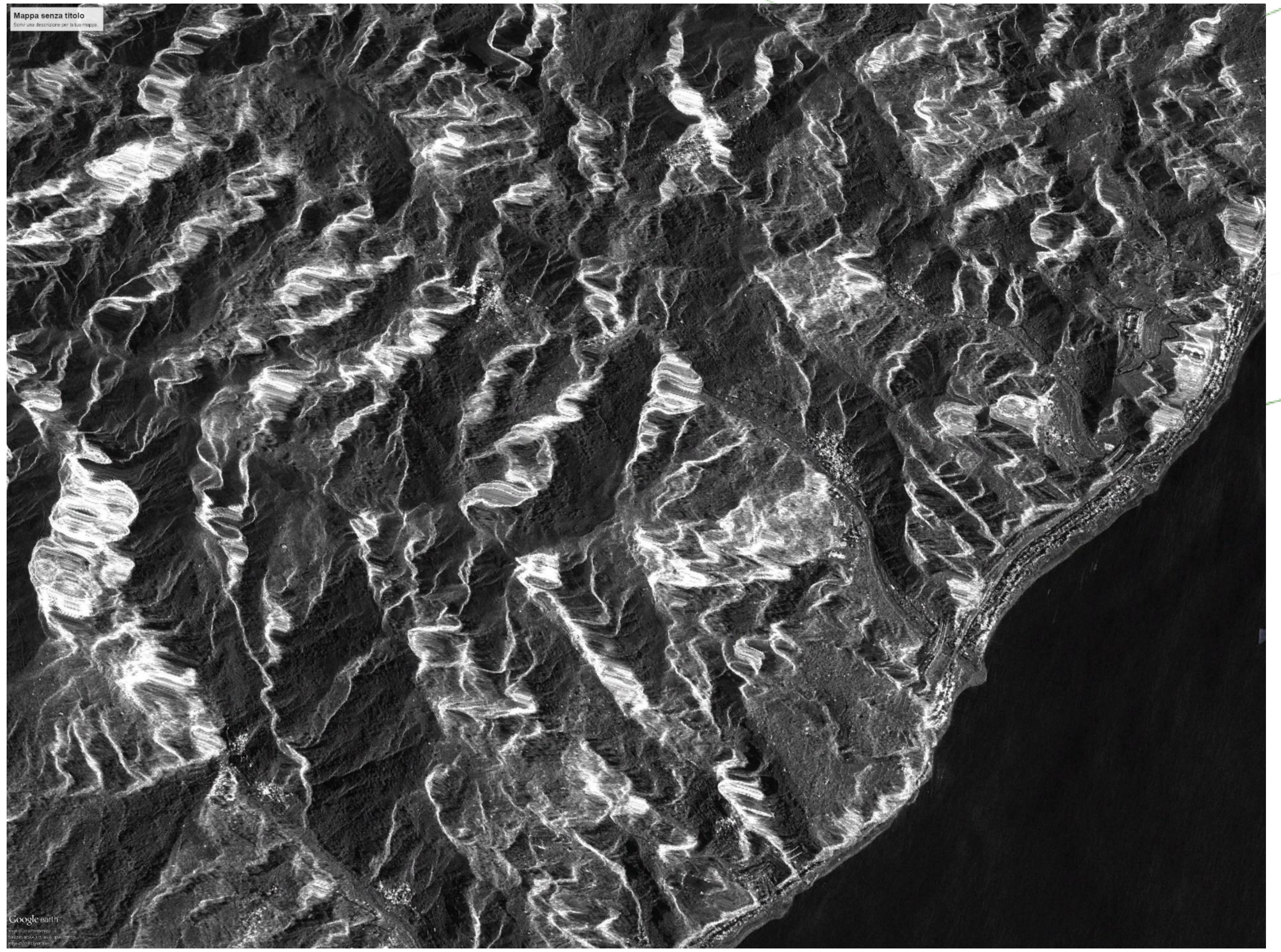
- BLACK: specular reflection (for example the water elements)
- GREY SCALE: several element with various values of reflectivity
- WHITE: high reflectivity (as edifices, outcropping rocks, etc)



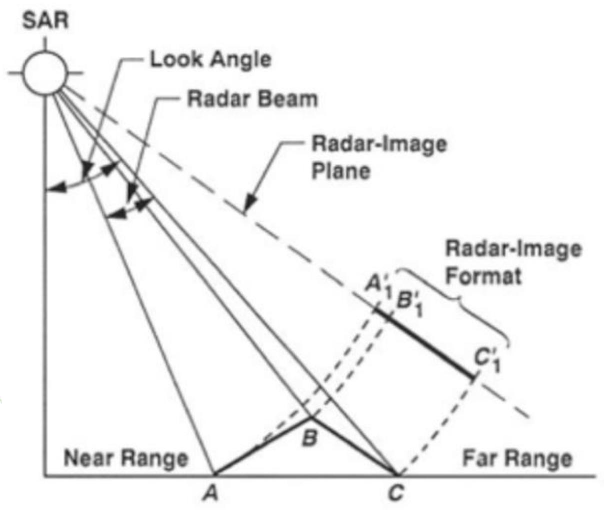
Geometric distortion

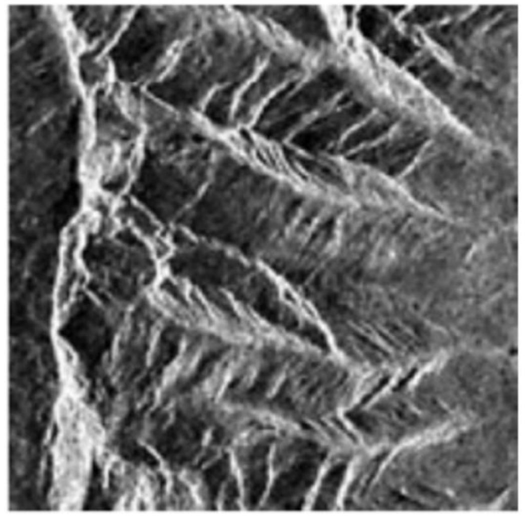
The portion of ground associated to each pixel of the SAR images depends both on the dimension of the cell (resolution) in SAR coordinates (slant range and azimuth) and on the local topography



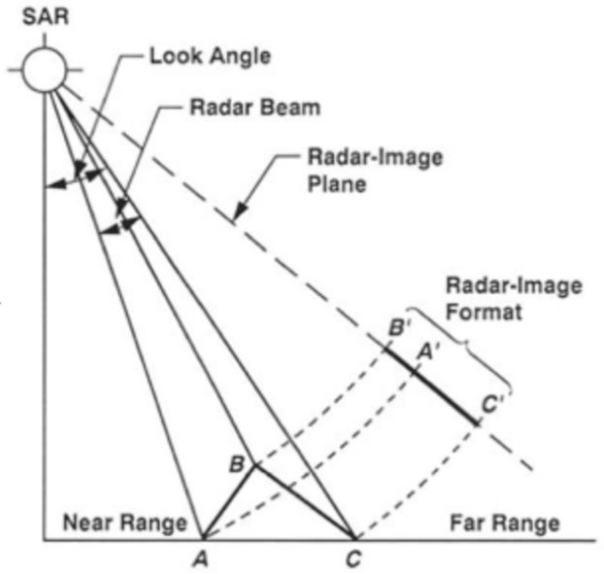


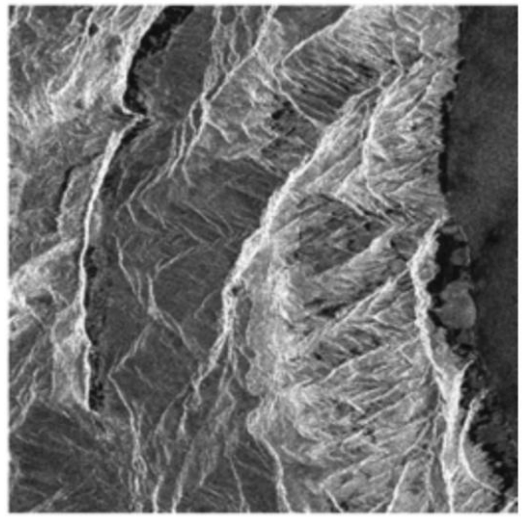
• **Foreshortening**: when the radar beam reaches the base of a tall featured tilted toward the radar (e.g., a mountain) before its top, the foreshortening effect occur. The distance between this two points will appear compressed with respect to the real;



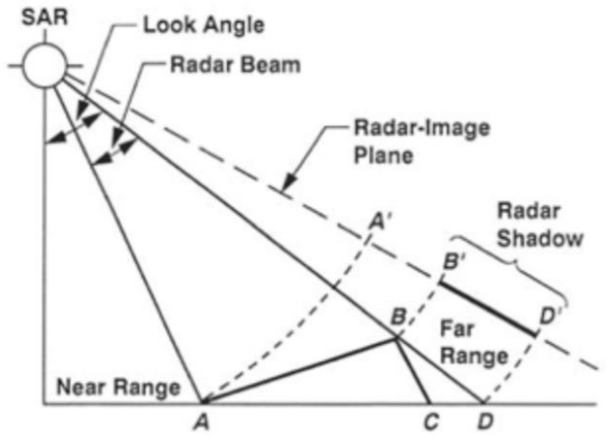


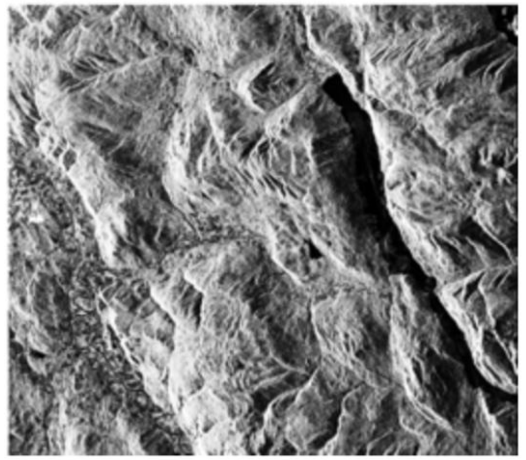
• **Layover**: when the radar beam reaches the top of a tall featured tilted toward the radar (e.g., a mountain) before its base, the layover effect occur. The top of the feature “lays over” its base on the ground projection;





•**Shadowing**: when the radar beam is not able to illuminate a portion of the scene (e.g., steep slope or vertical features), the shadowing effect occur. These portions will appear dark (or completely black).

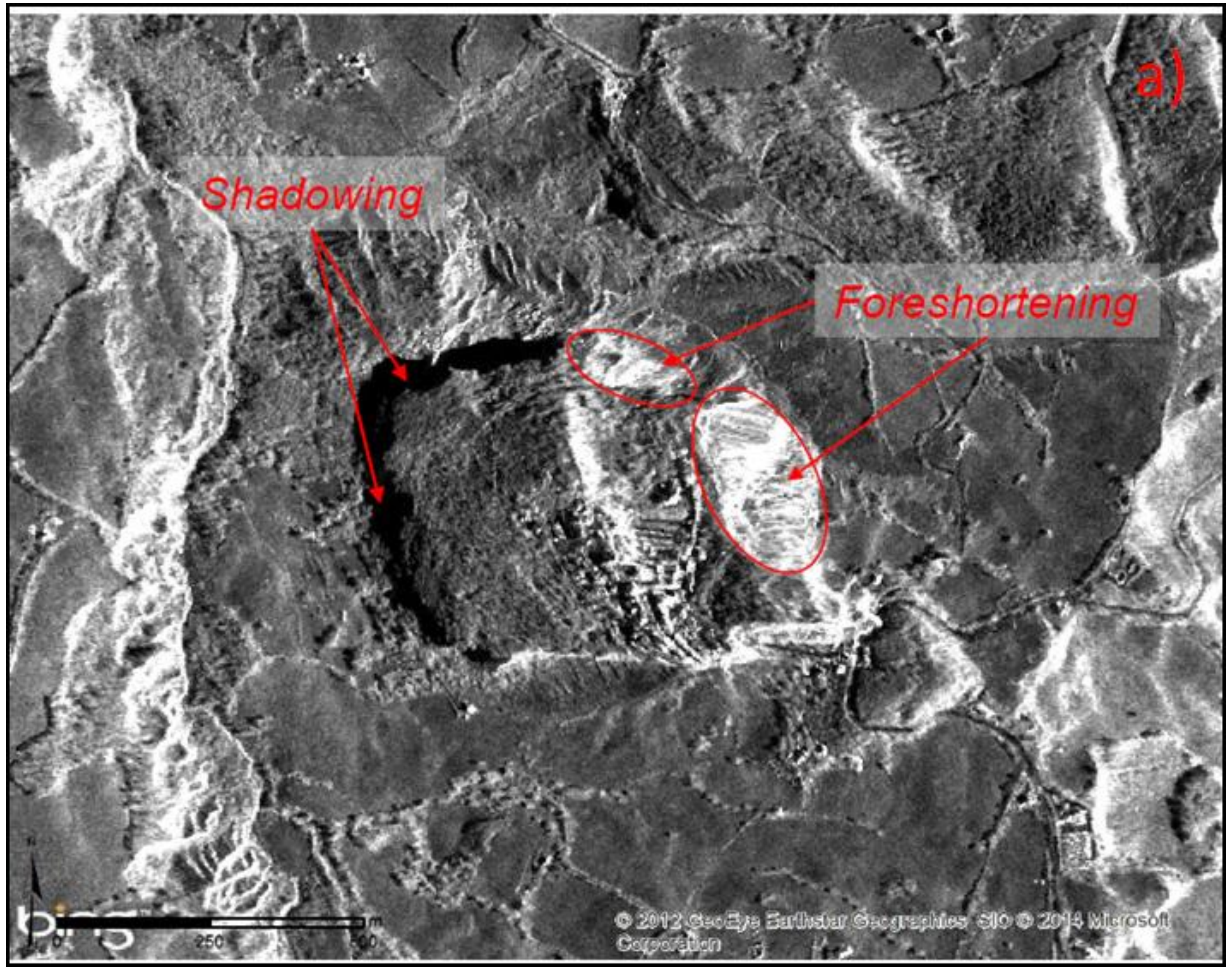




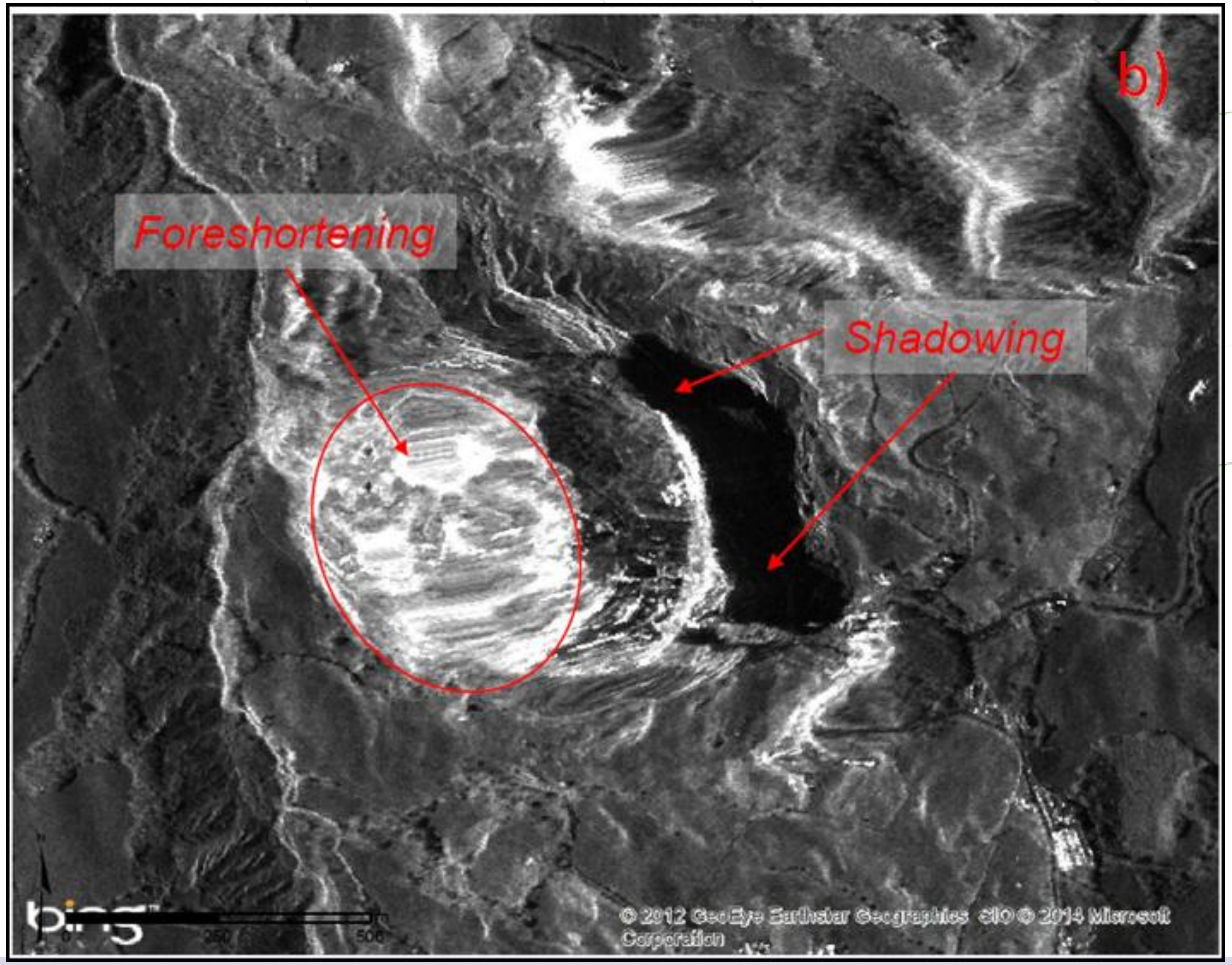
Geometric distortion effects

San Leo Rock Cliff, Emilia-Romagna region (central Italy)

COSMO-SkyMed descending



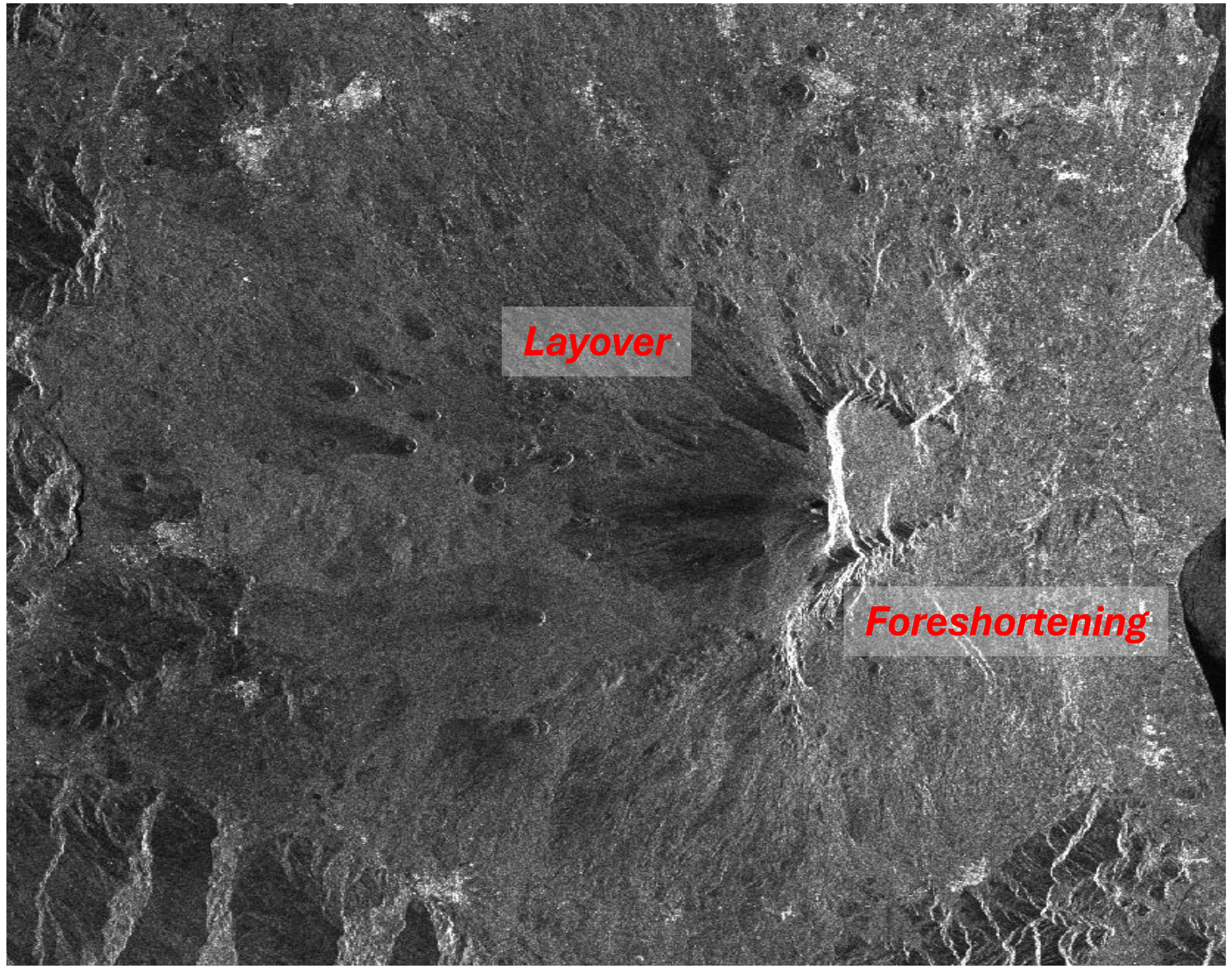
COSMO-SkyMed ascending



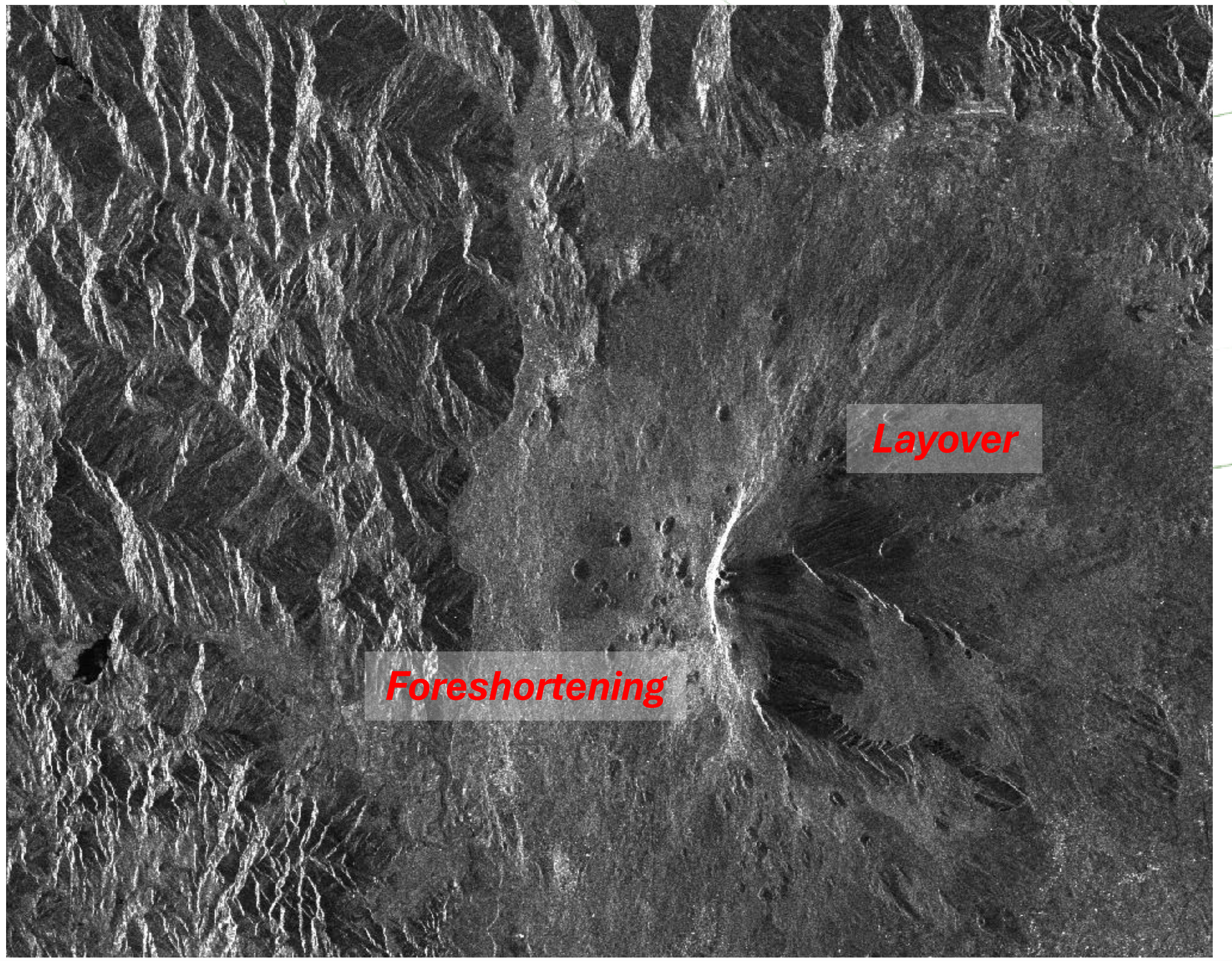
Geometric distortion effects

Etna Volcano, Sicily region (southern Italy)

Sentinel-1 descending

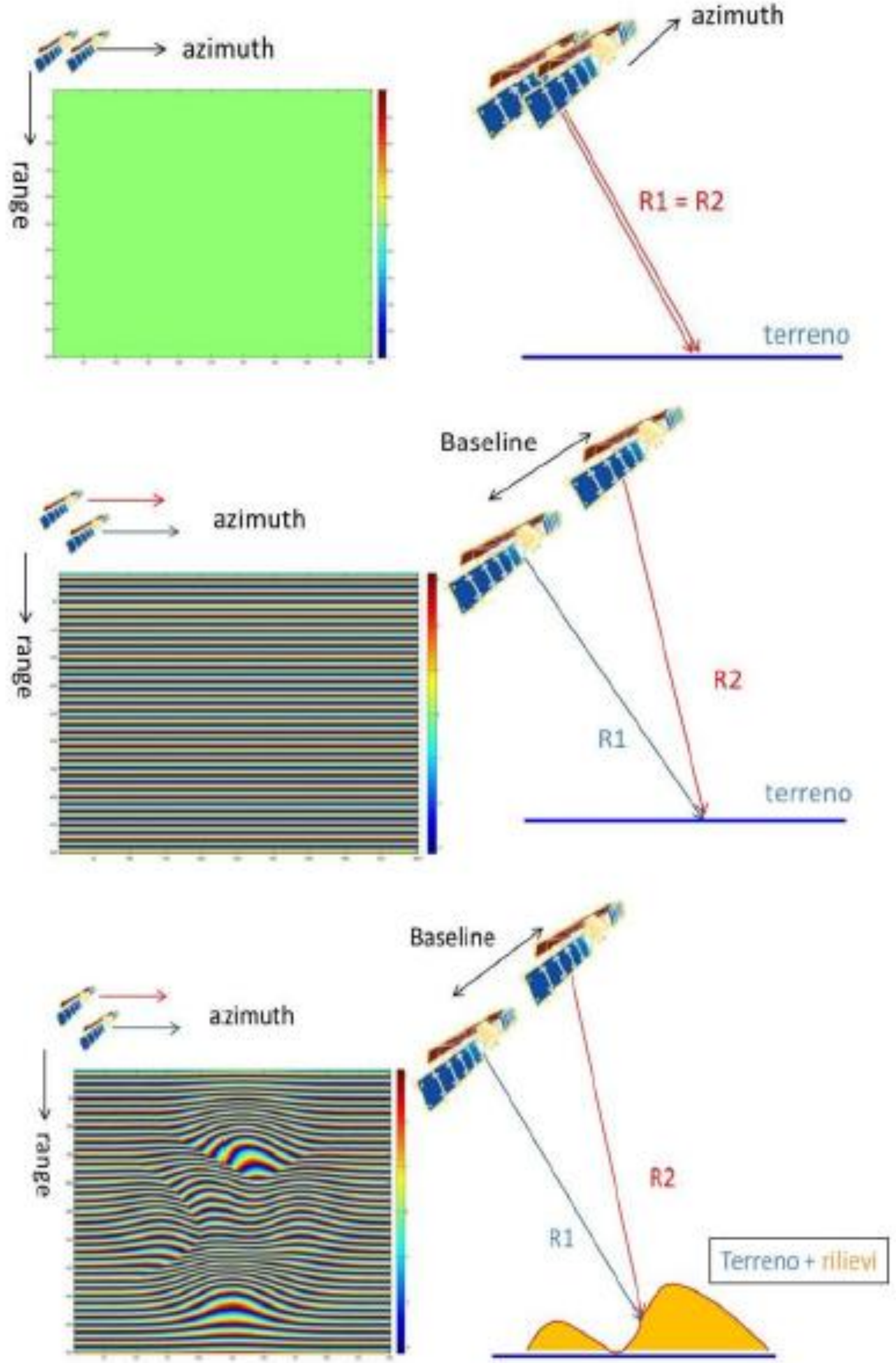


Sentinel-1 ascending



Contents

Differential InSAR (DInSAR)

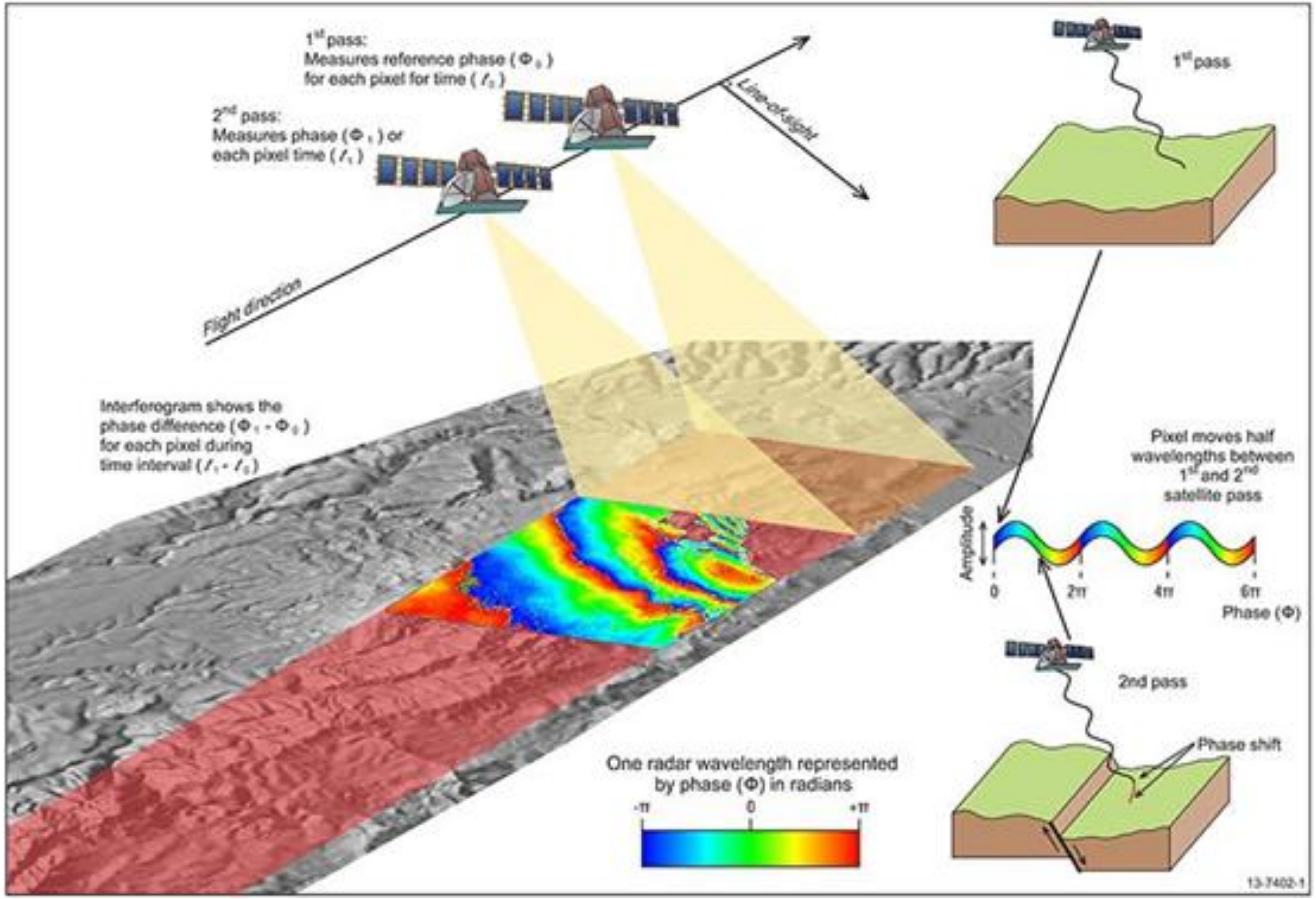


Two images acquired at the same time (Bt =0),
from the same position (Bn =0)
flat terrain, no motion occuring

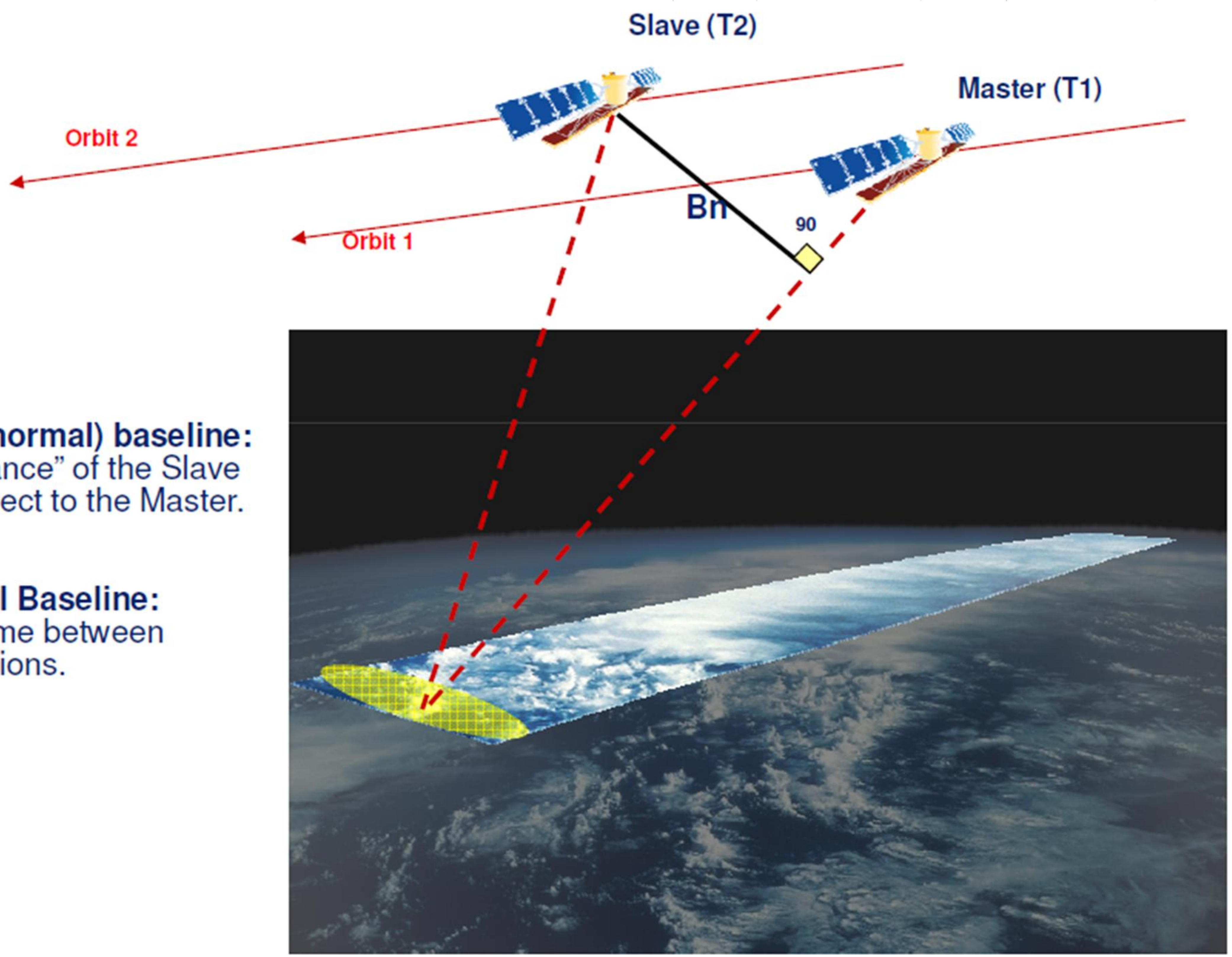
Two images acquired at the same time (Bt =0),
from different positions (Bn ≠0)
flat terrain, no motion occuring

Two images acquired at the same time (Bt =0),
from different positions (Bn ≠0)
not flat terrain, no motion occuring

Differential InSAR (DInSAR)

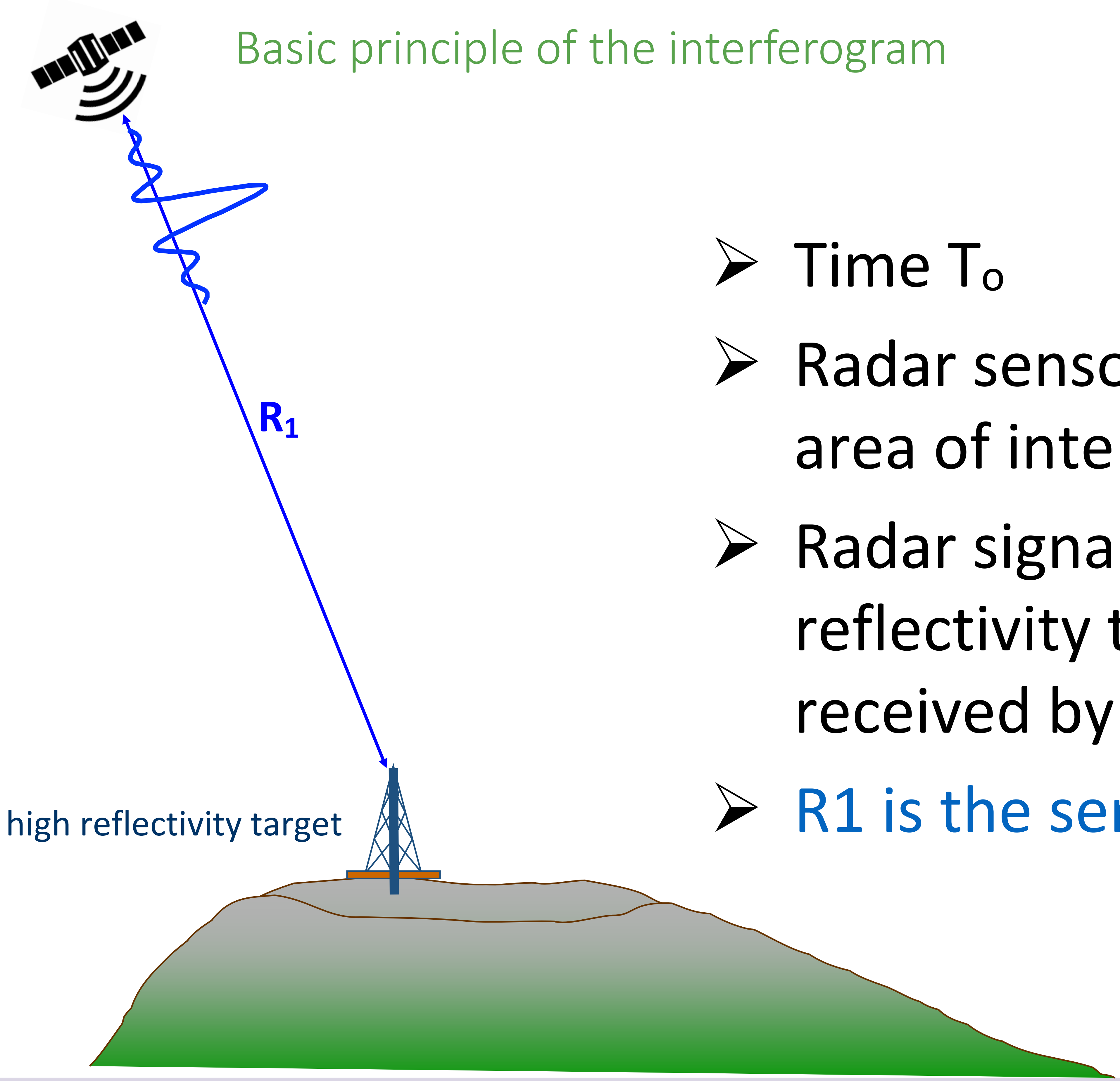


Geometrical and temporal baseline



Bn – Geometrical (normal) baseline:
describes the “distance” of the Slave acquisition with respect to the Master.

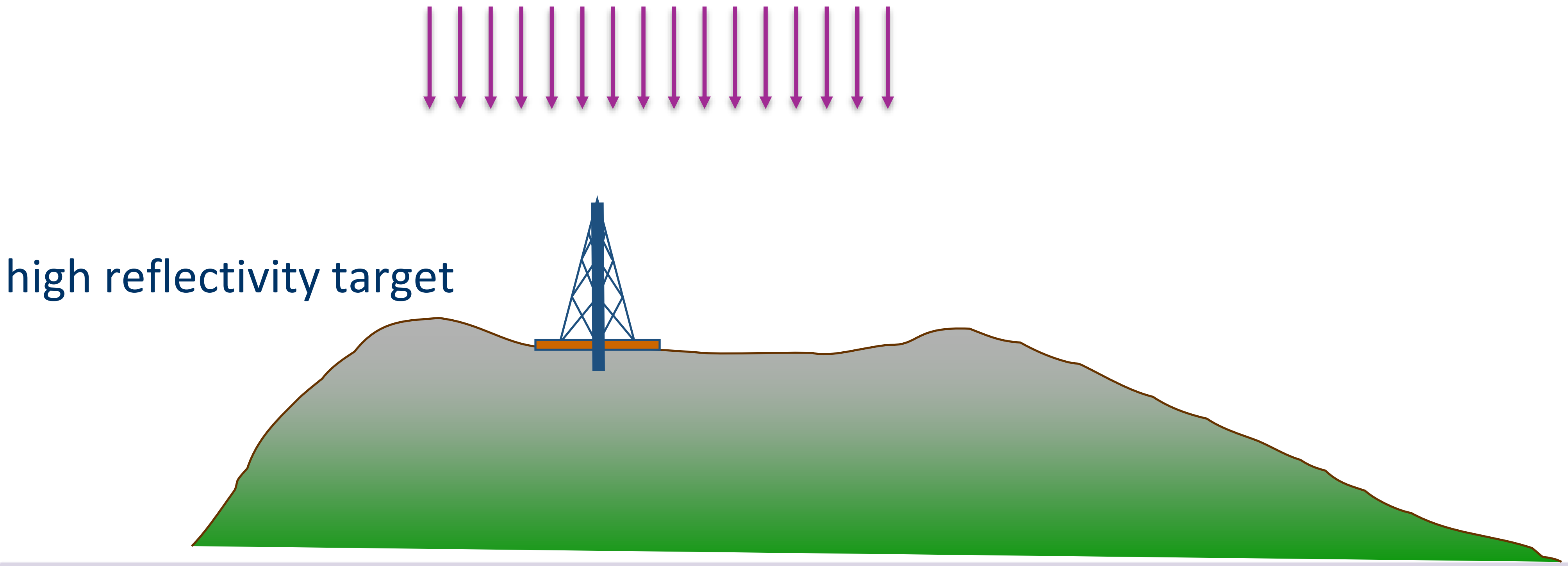
Bt – Temporal Baseline:
difference in time between acquisitions.



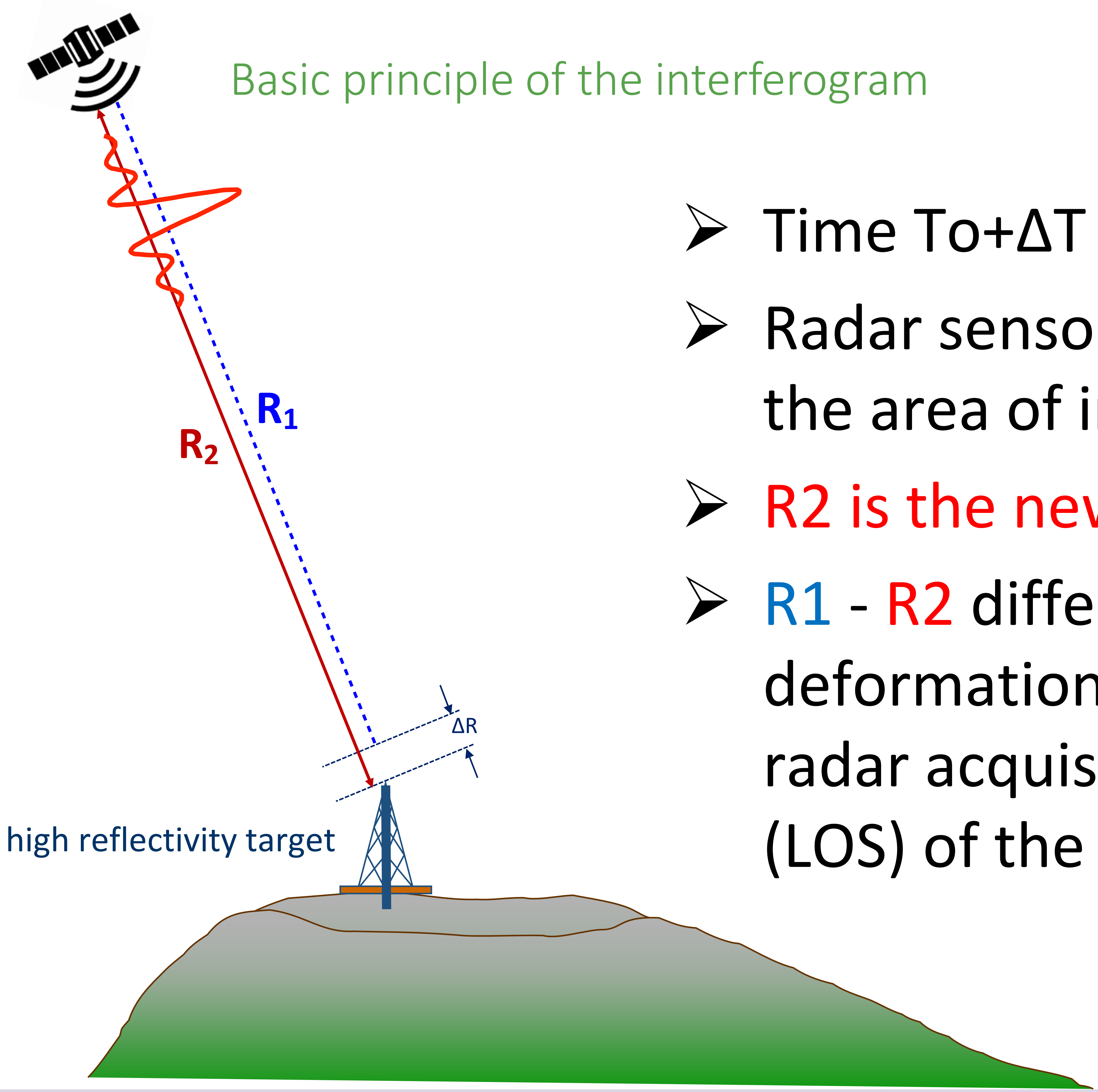
- Time T_o
- Radar sensor send an impulse toward the area of interest
- Radar signal is backscattered by high reflectivity target on the ground and received by the antenna
- R1 is the sensor-target distance

In the time interval ΔT

OCCURRENCE OF GROUND DEFORMATION



Basic principle of the interferogram



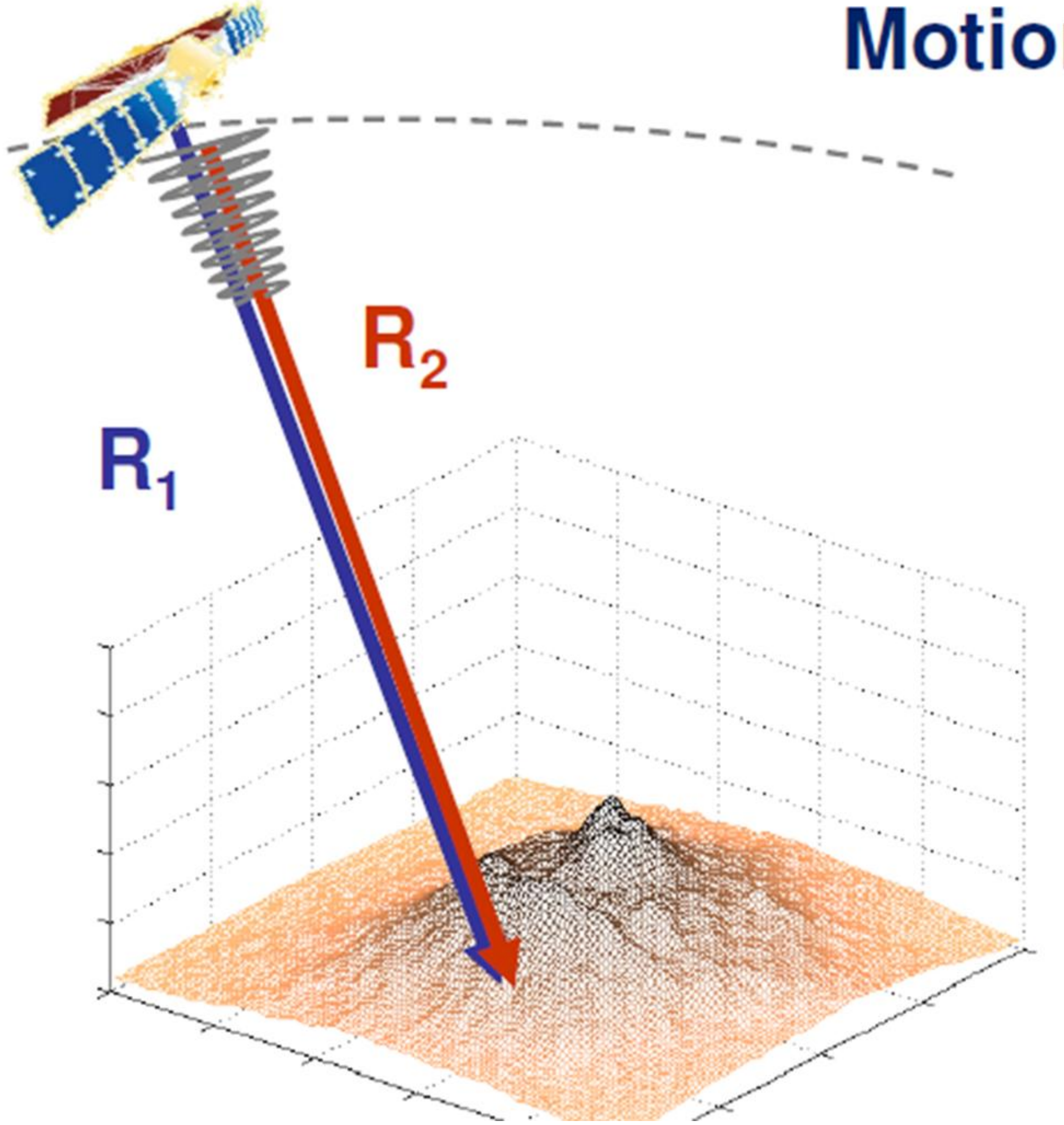
- Time To+ΔT
- Radar sensor send a new impulse toward the area of interest
- R2 is the new sensor-target distance
- R1 - R2 difference is the ground deformation occurred between the two radar acquisitions along the line-of-sight (LOS) of the satellite

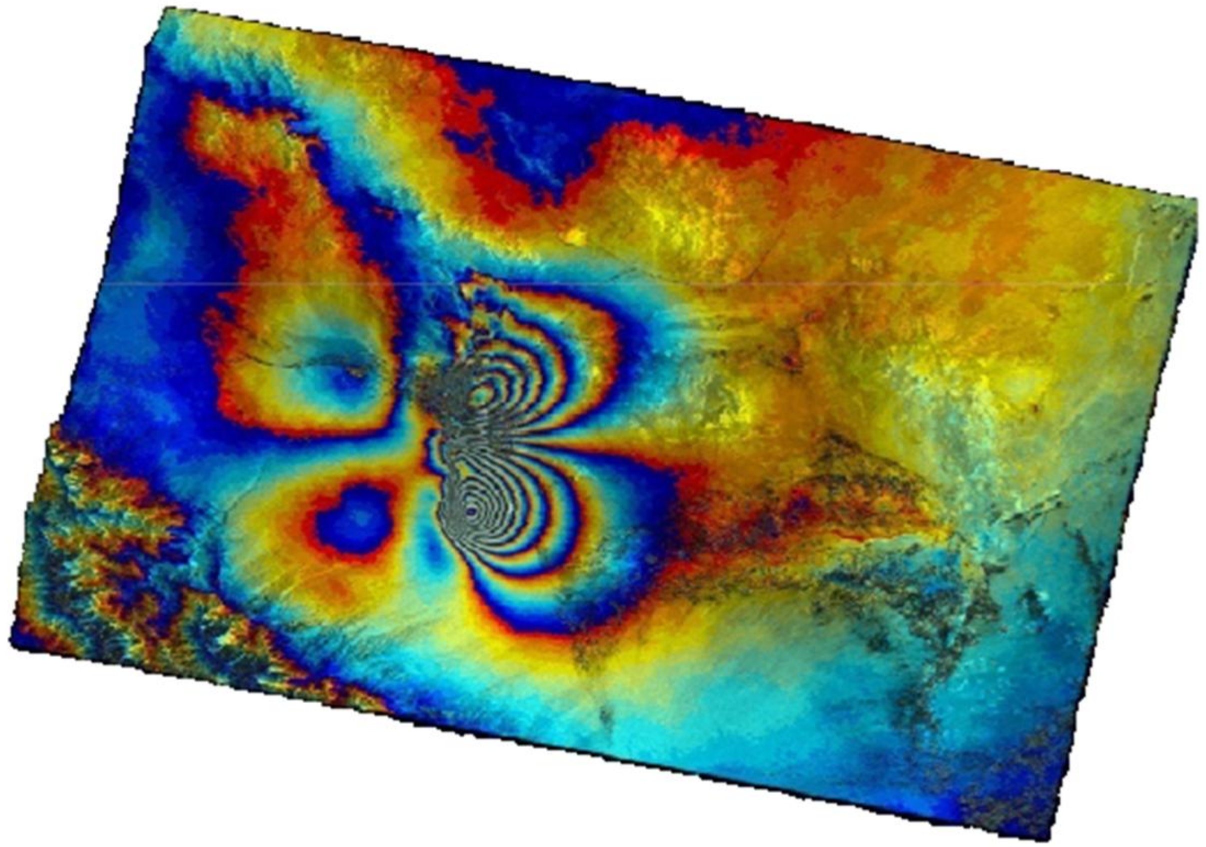
Differential interferometry

SAR interferometry: compare acquisitions

Comparing two acquisitions, on the same area, **NOT** at the same time, acquired from the (almost) same positions

Motion detection





Map of relative displacement, measured through differences in "phase shift"

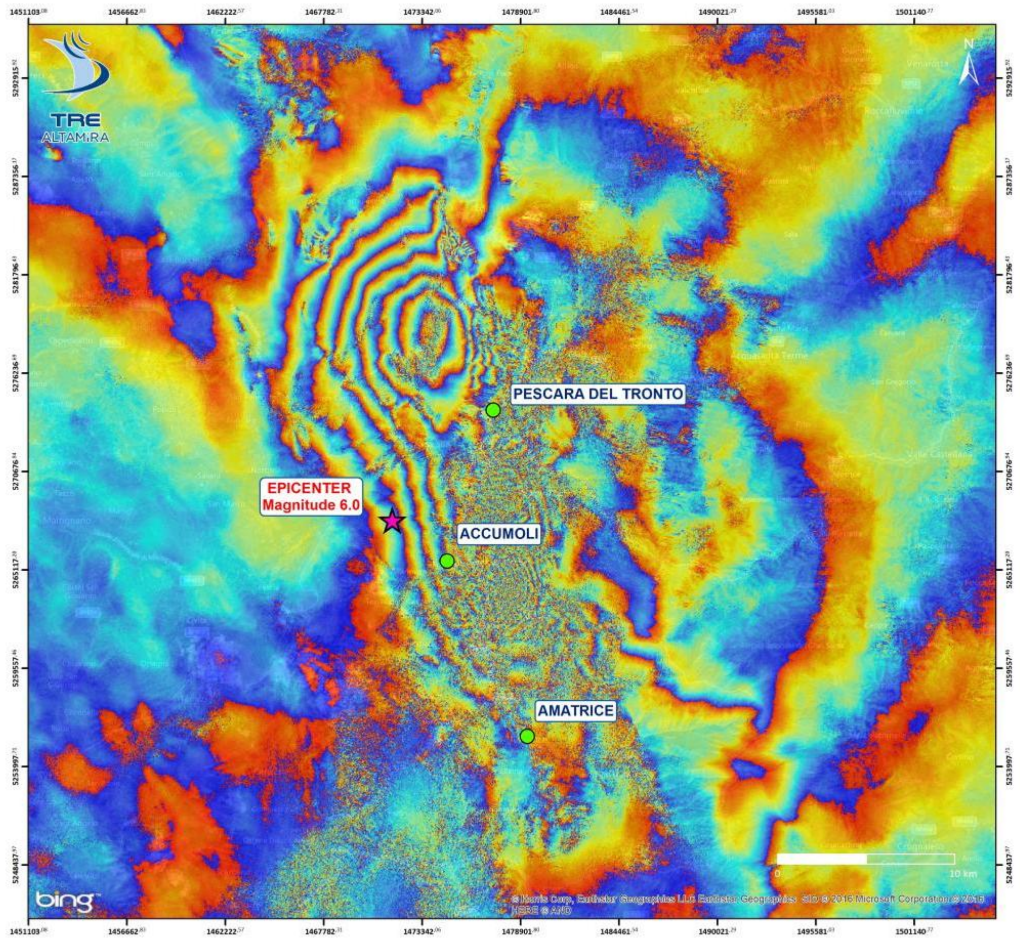
Differential InSAR (DInSAR) components

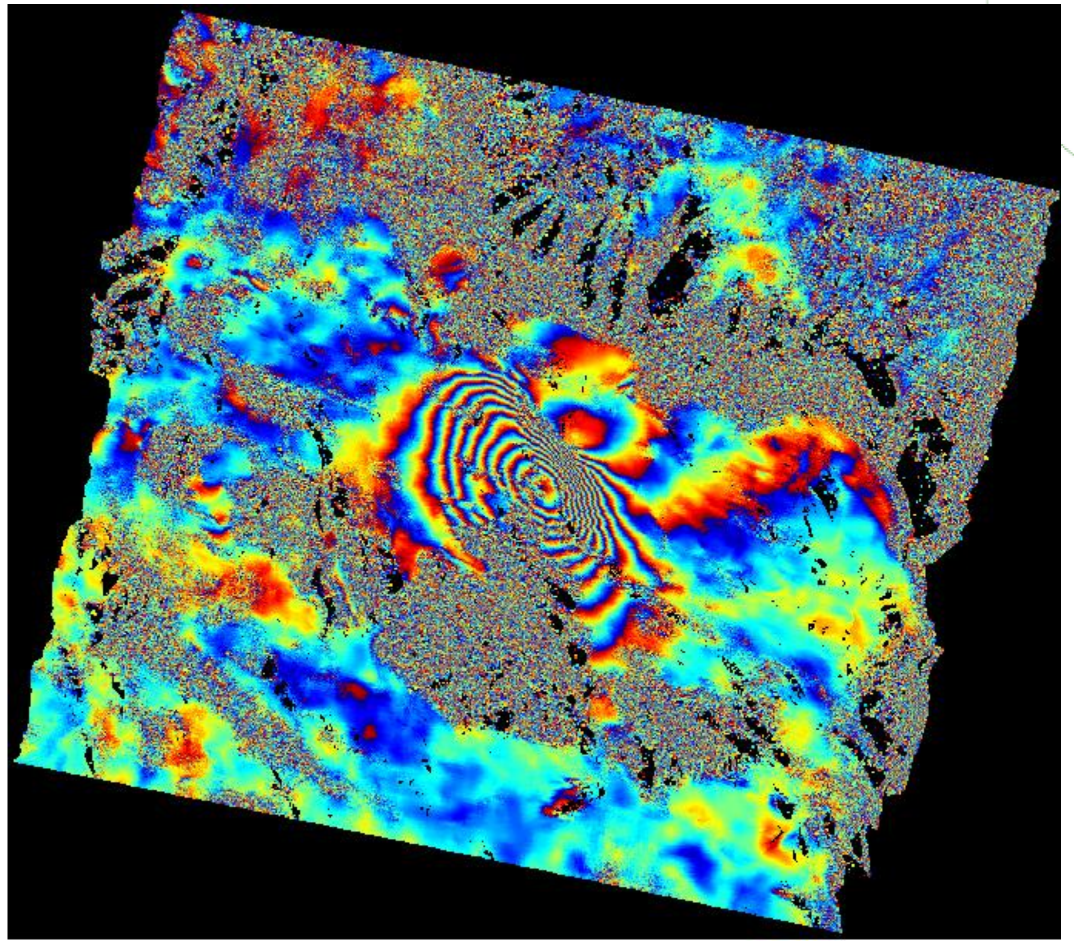
$$\Delta\phi_{int} = \Delta\phi_{displ} + \Delta\phi_{topo} + \Delta\phi_{atm} + \Delta\phi_{flat} + \Delta\phi_{noise}$$

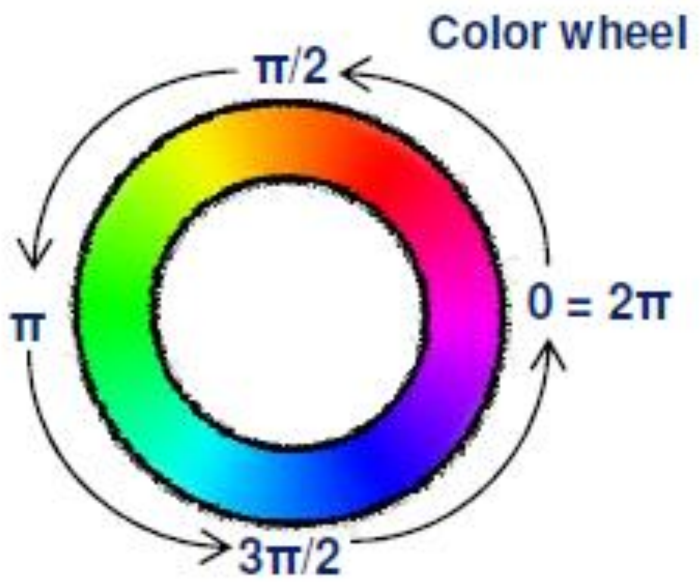
Topografia ($\Delta\phi_{topo}$) — **Atmosfera** ($\Delta\phi_{atm}$) — **Flat-earth** ($\Delta\phi_{flat}$) — **Rumore** ($\Delta\phi_{noise}$)

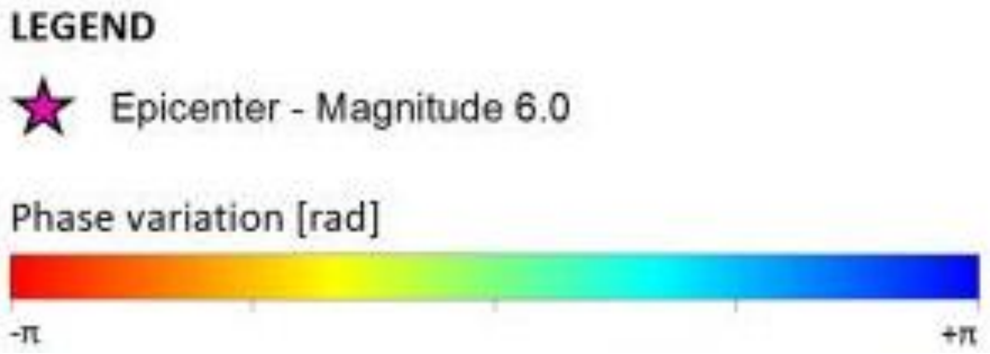
If B_n (*baseline* geometrica) is equal to 0, $\Delta\phi_{topo}$ and $\Delta\phi_{flat}$ are null (as in the GBInSAR sensor)

If B_n is known and a DEM is available, $\Delta\phi_{topo}$ e $\Delta\phi_{flat}$ can be estimated and removbed

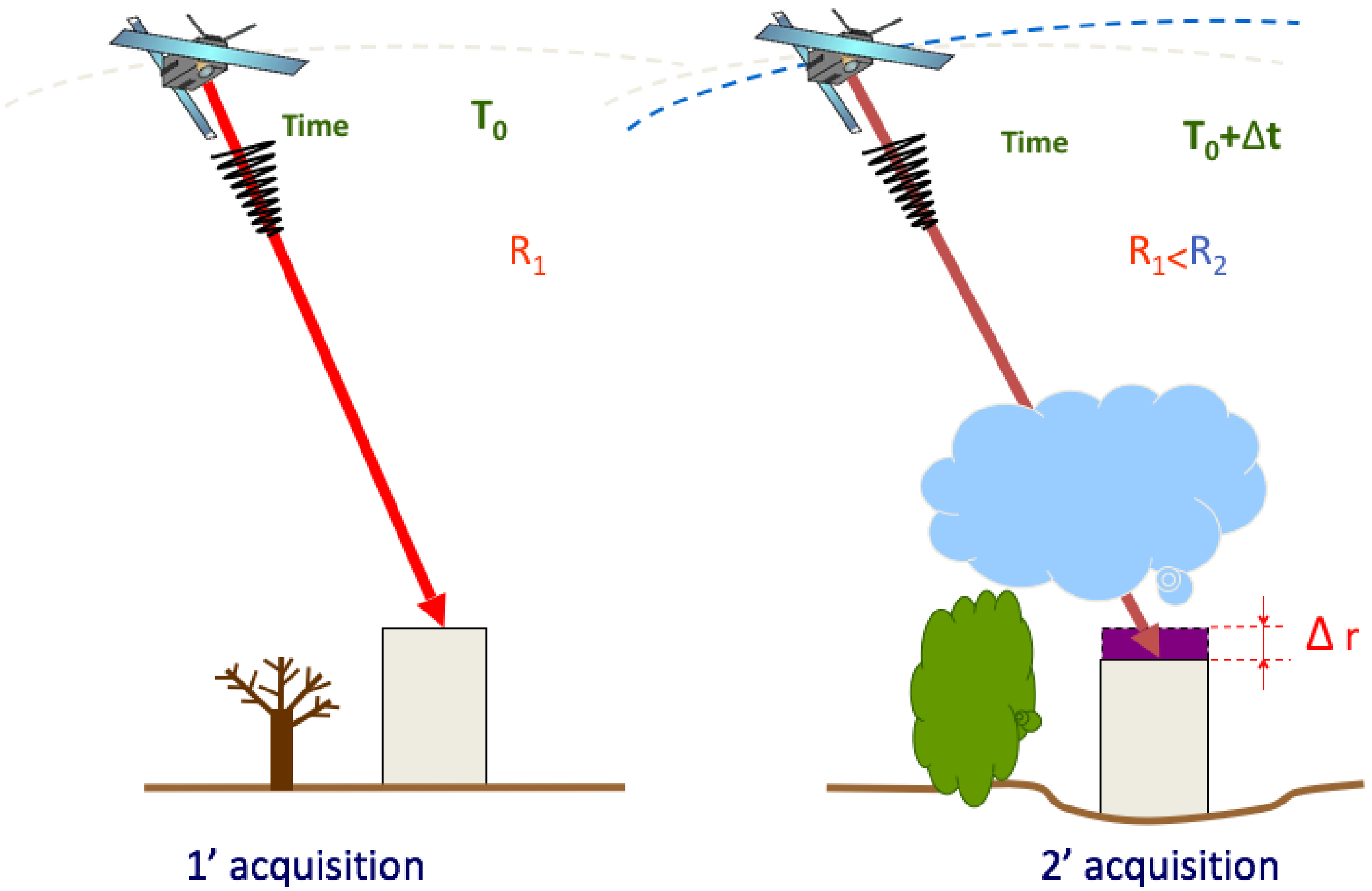








Differential InSAR (DInSAR)



Δt Revisiting time depending on the satellite

Δr Ground displacement

$\Delta \psi$ Reflectivity - should be the same

Δa Atmospheric content - assume to be the same

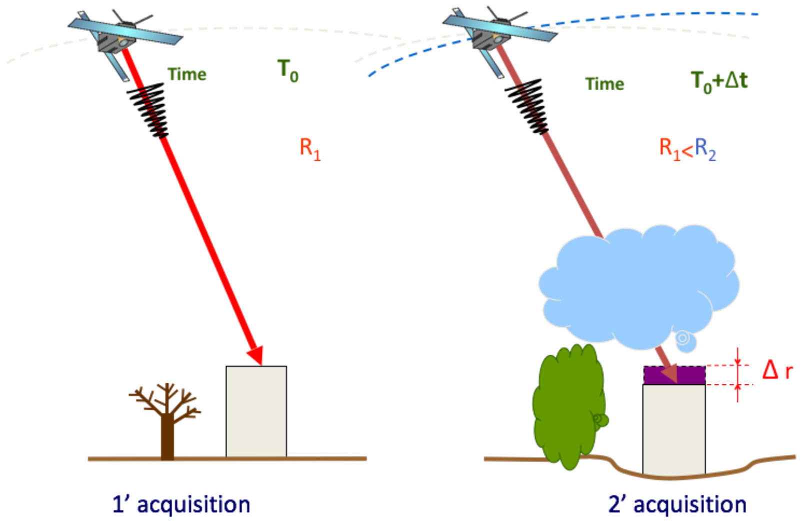
$$\Delta\phi = \Delta\psi + \frac{4\pi}{\lambda} r + \Delta\alpha + noise$$

$$\Delta\phi = \frac{4\pi}{\lambda} r$$

The *noise* can be disregarded if the radar signal is good.

$\Delta\phi = 0 \rightarrow \Delta r = 0$
$\Delta\phi = 2\pi \rightarrow \Delta r = \lambda/2$

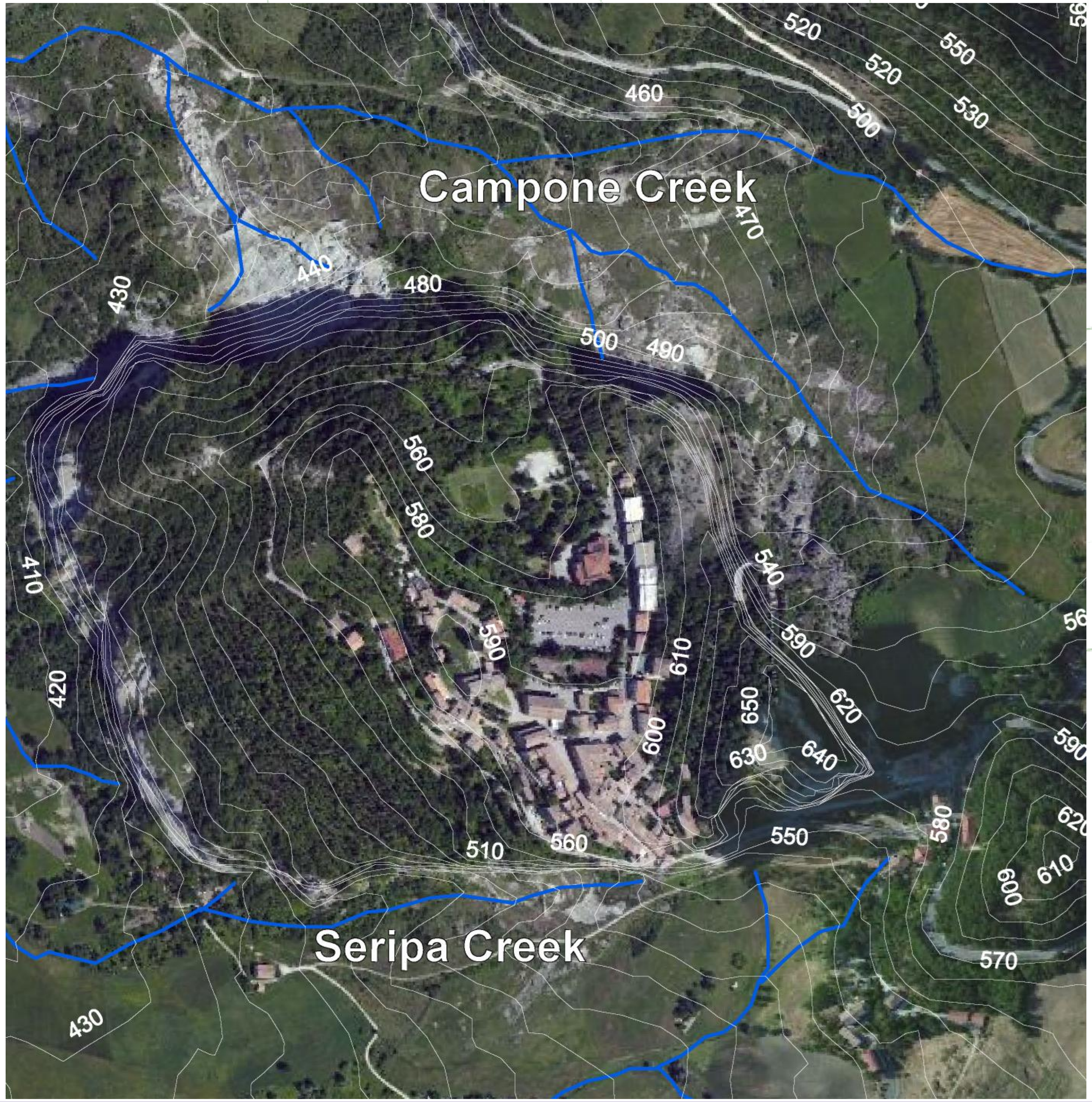
Precision and Accuracy are higher for smaller λ (difference between L-, C- and X- bands)



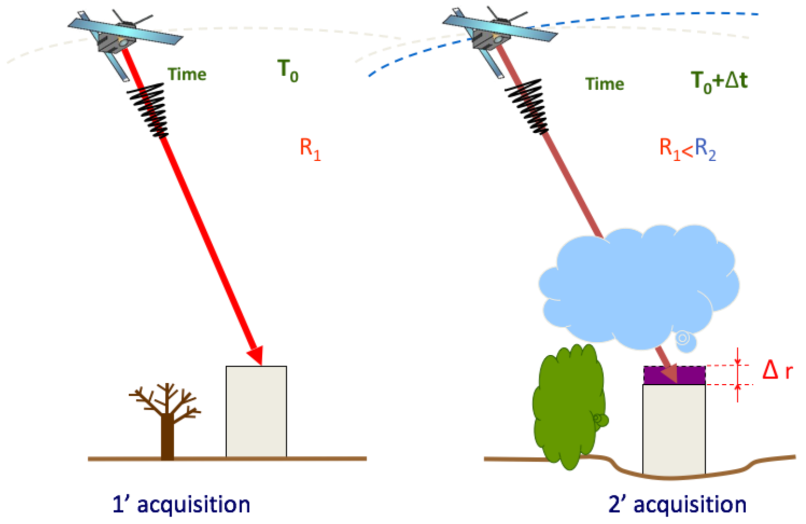
DInSAR examples

Vulcano Fogo, Capoverde (Africa)

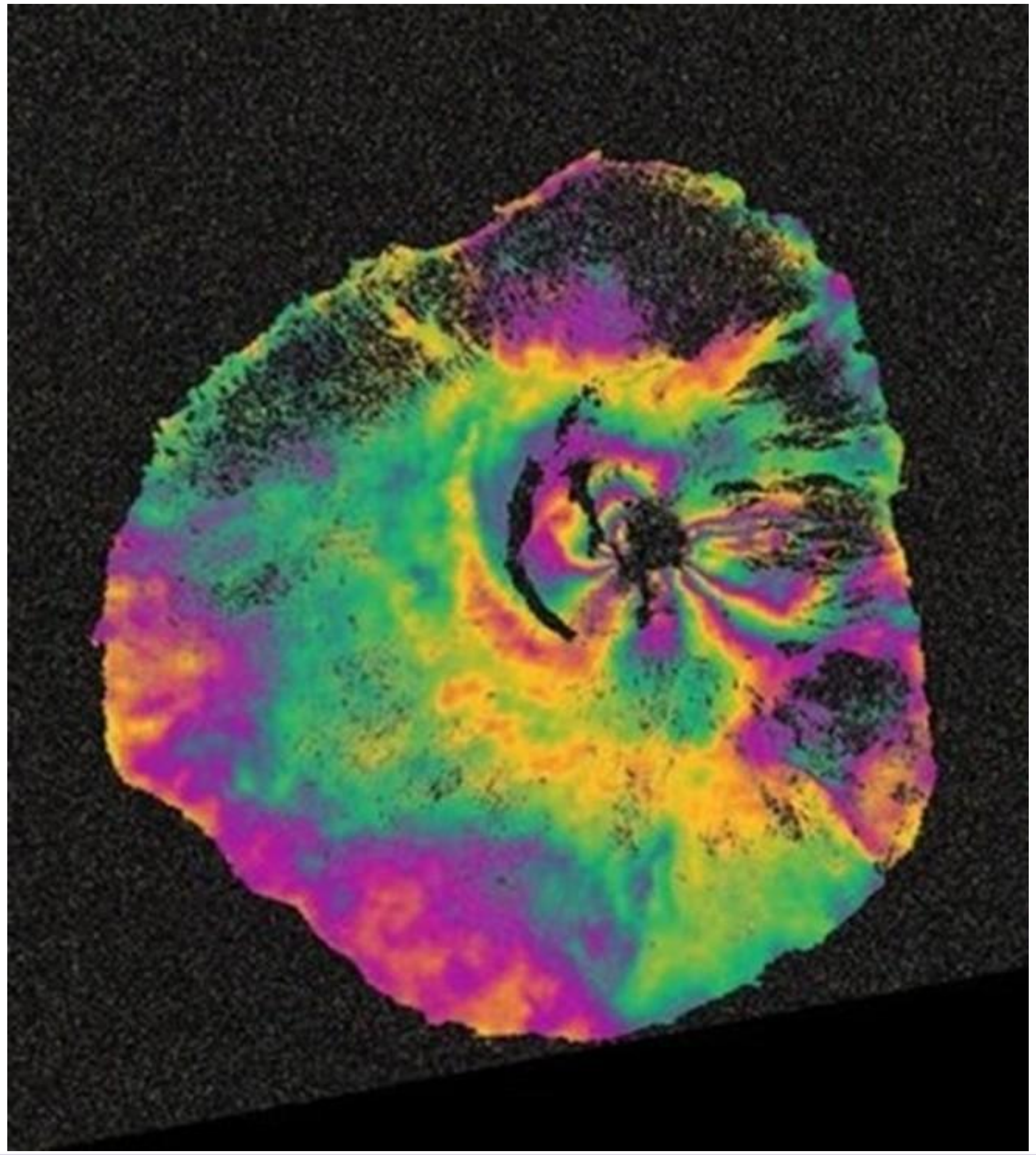
San Leo Rock Cliff, Emilia Romagna, central Italy



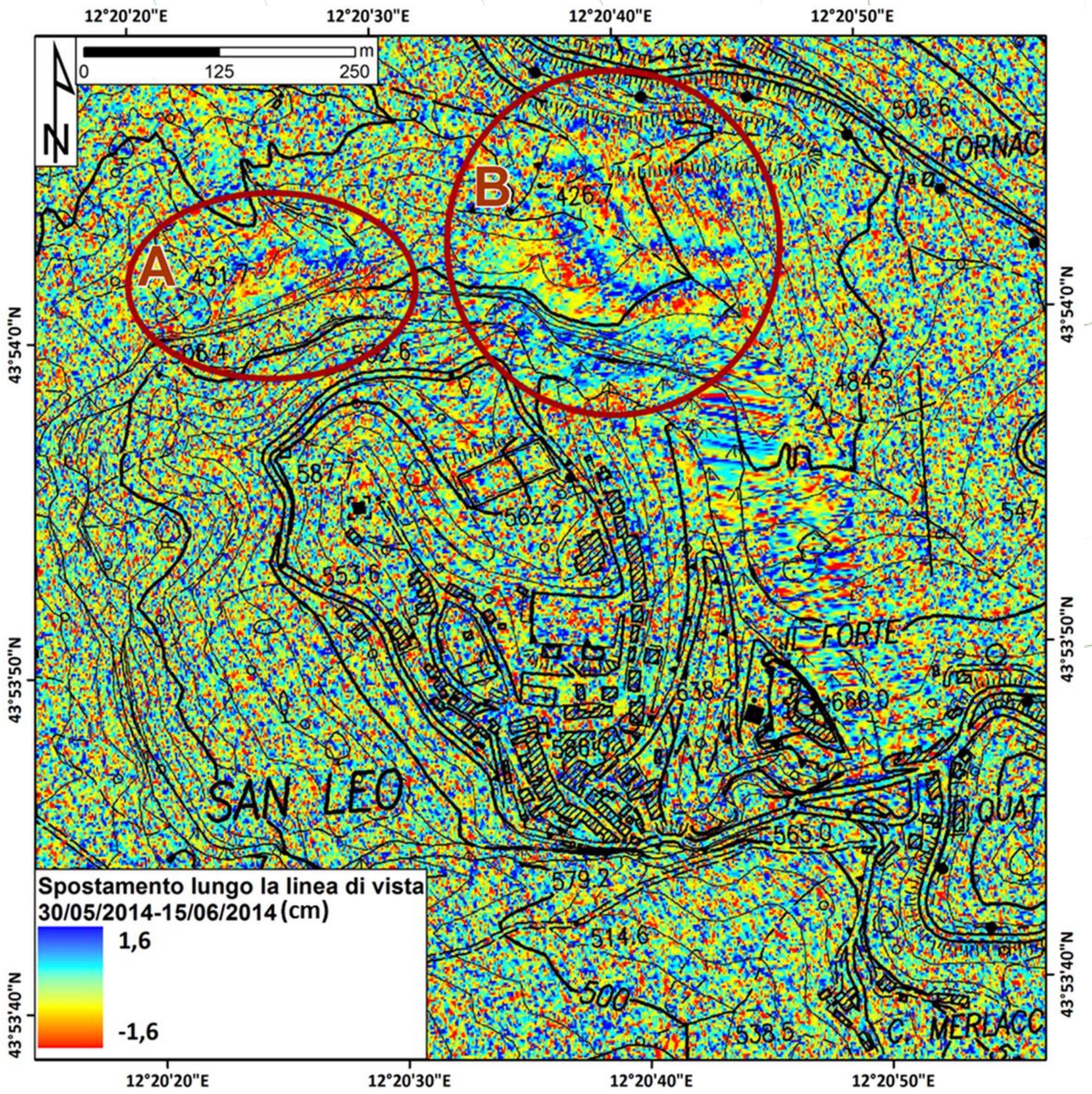
DInSAR examples



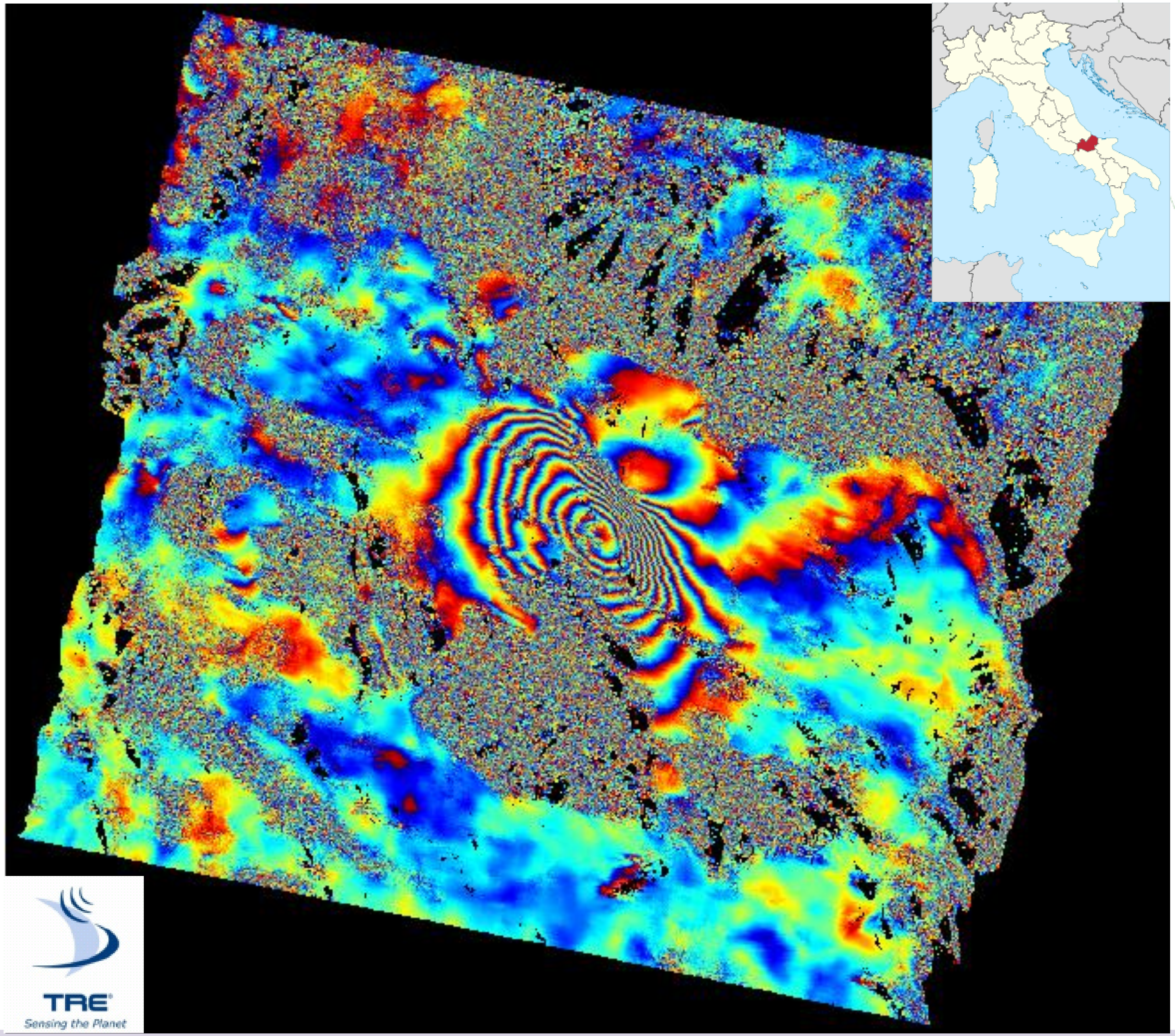
Vulcano Fogo, Capoverde (Africa)



San Leo Rock Cliff, Emilia Romagna, central Italy



L’Aquila earthquake (Italy)



L’Aquila earthquake
Molise region, central Italy
April 9th 2009

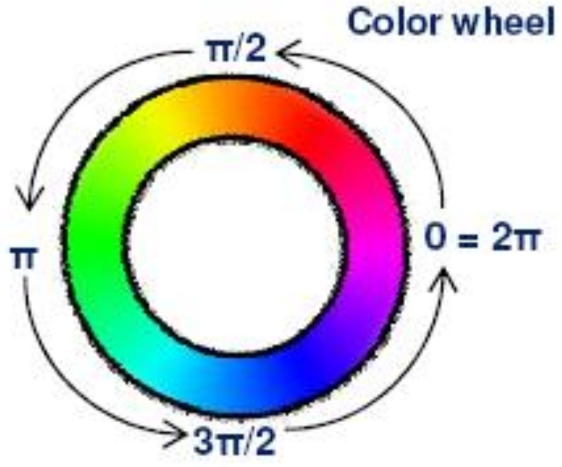
Coseismic ITF

February 2nd 2009

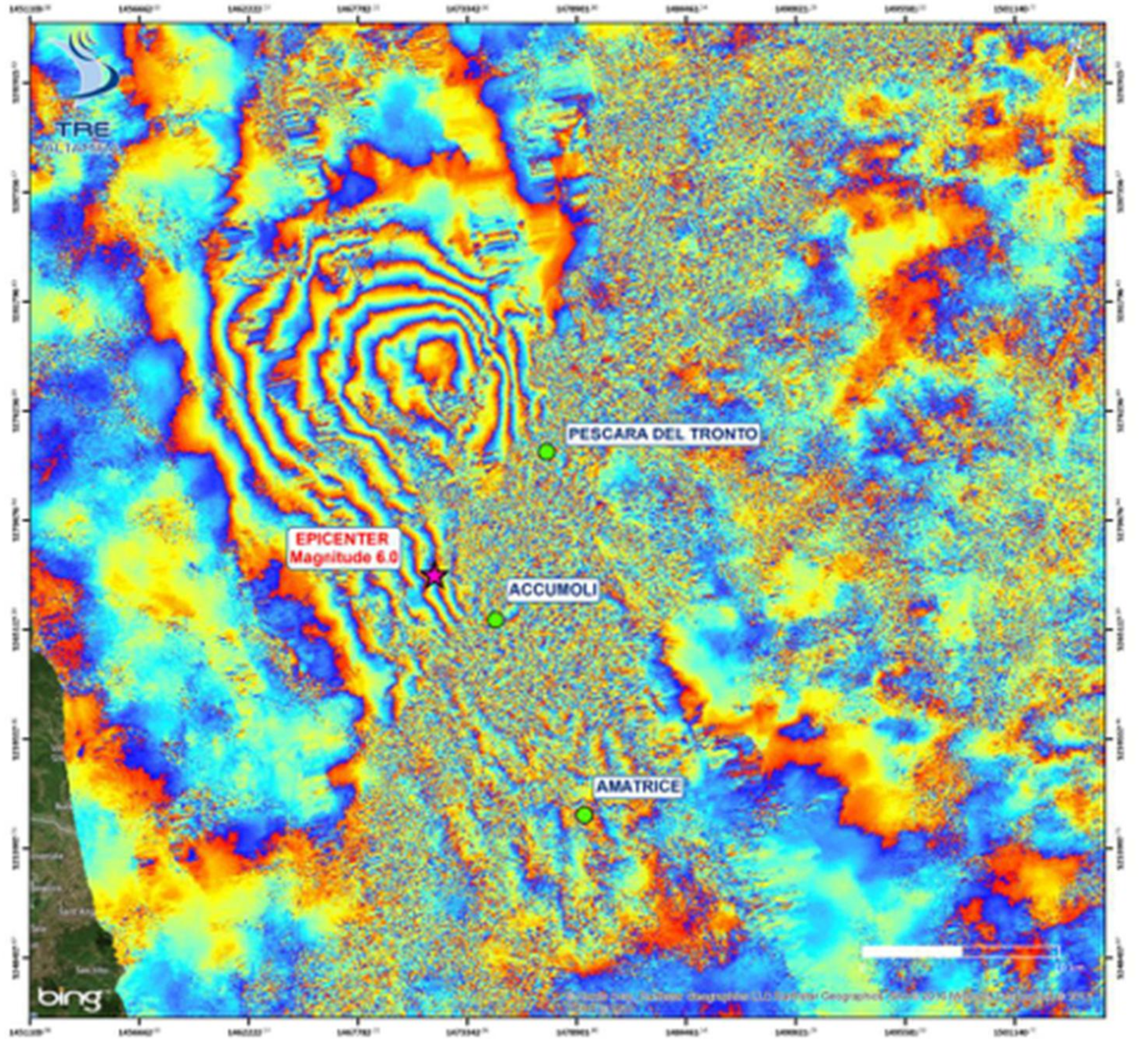
April 12th 2009

Satellite Envisat

Banda C = 5,6 cm



Accumuli earthquake (Italy)

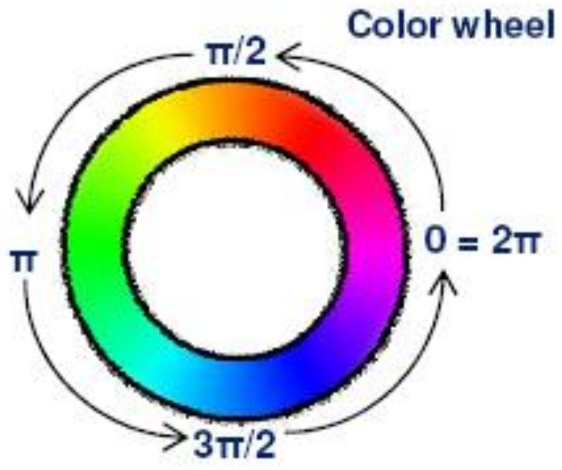


Accumoli - Amatrice earthquake
Lazio region, central Italy
August 24th 2016

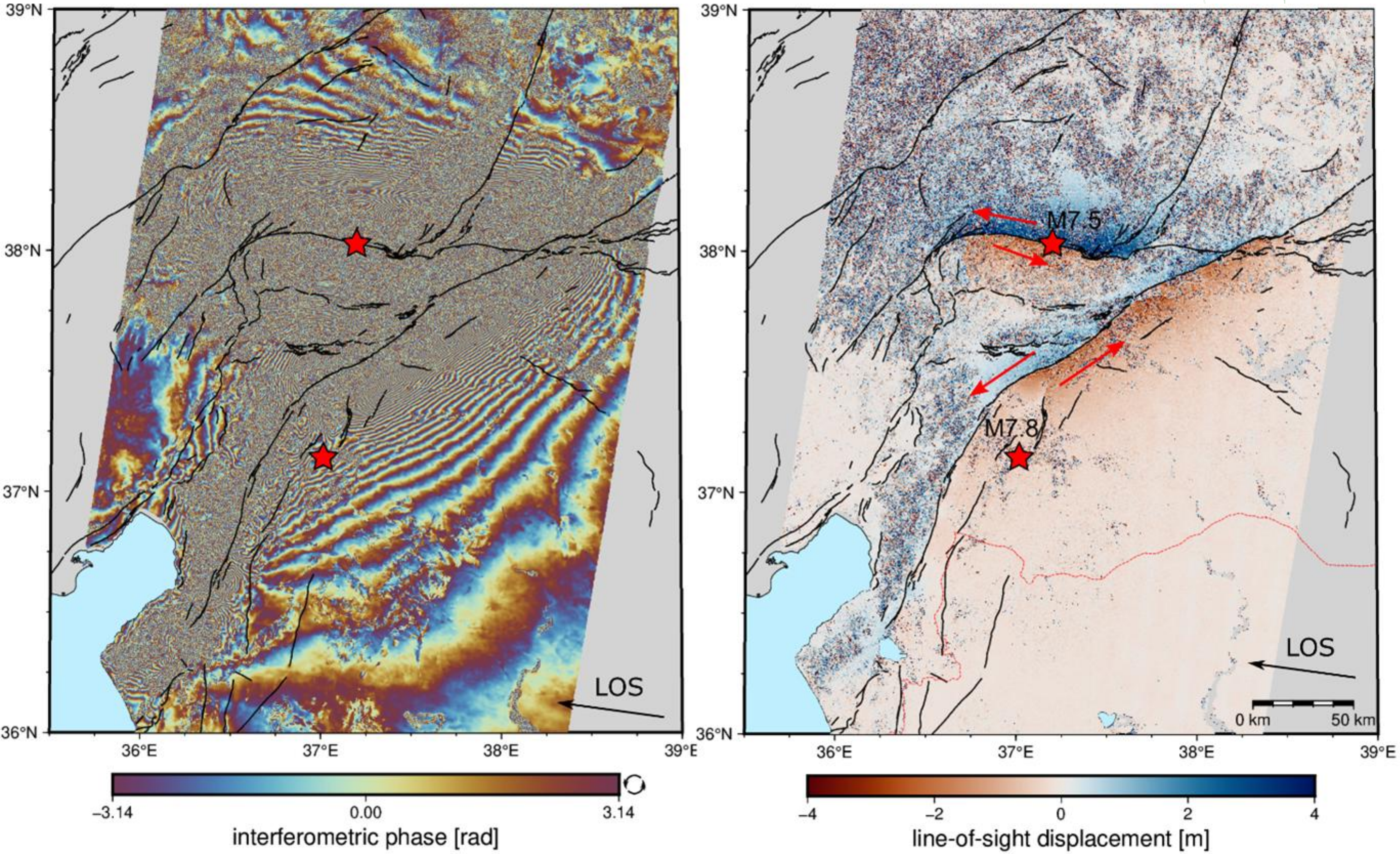
Coseismic ITF

Satellite Sentinel-1

Banda C = 5,6 cm



Turkey-Syria earthquake



Turkey-Syria earthquake

February 5-6th 2023

Coseismic ITF

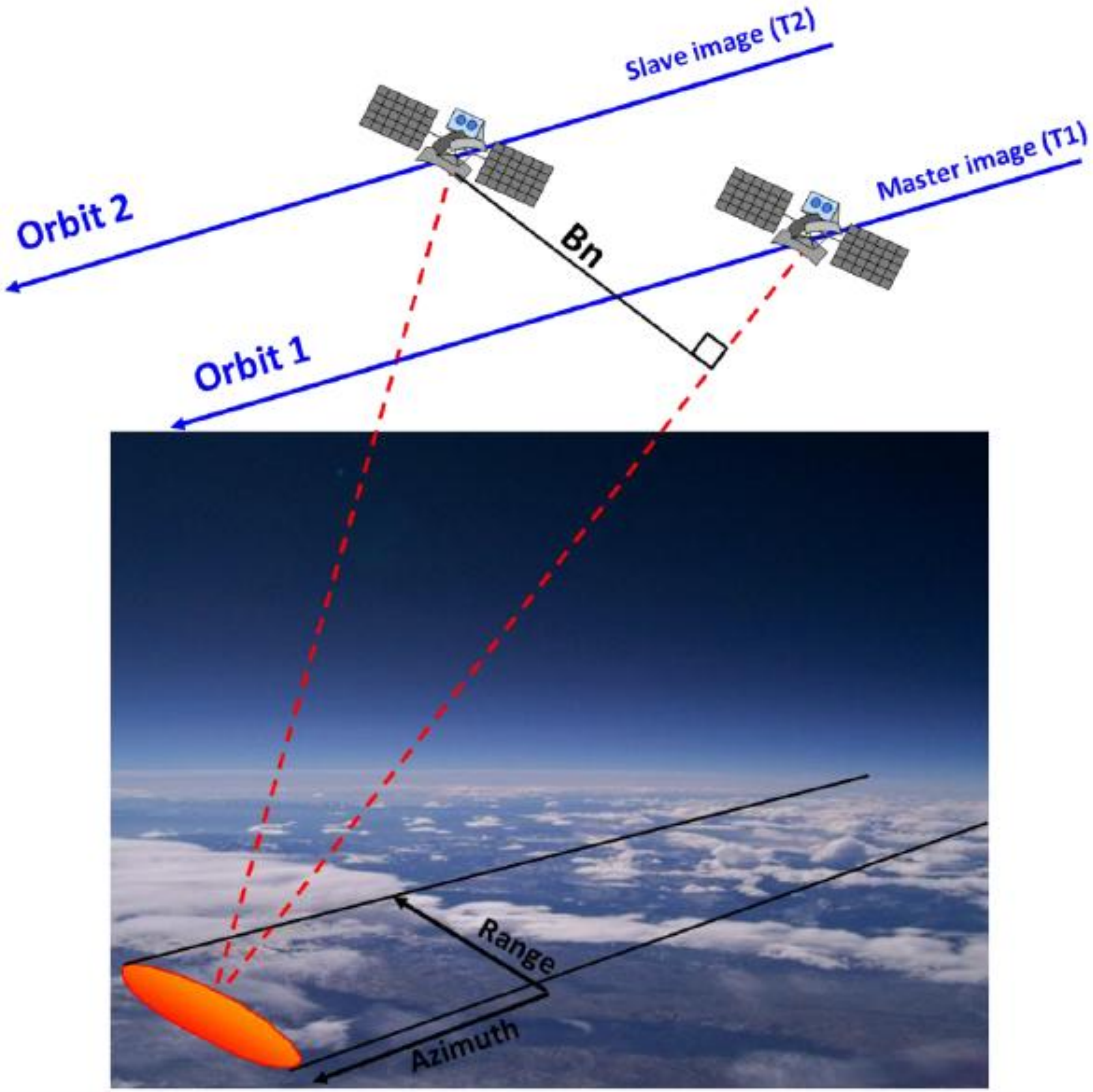
January 29th 2023

February 02nd 2023

Satellite Sentinel-1

Banda C = 5,6 cm

DInSAR limitations



$$\Delta\varphi = \Delta\psi + \frac{4\pi}{\lambda} r + \Delta\alpha + noise$$

Geometric Baseline (Bn): linear distance between master and slave images when shot the same scene.

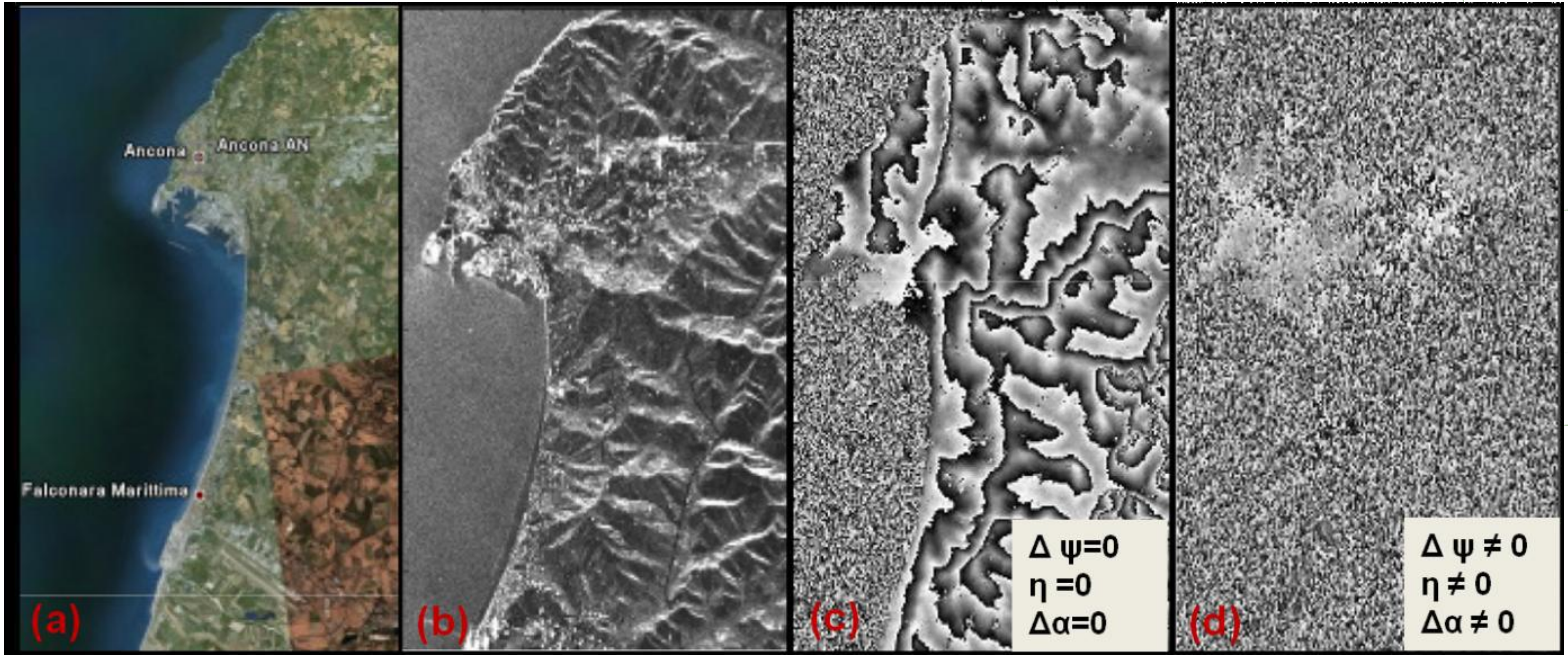
Temporal Baseline (Δt): time span between the slave and master acquisition of the same scene.

Decorrelation: disturb of the radar signal, in phase, based on the type of target reflecting material. High for “natural” soil, low in urban areas.

Atmospheric contributions: based on the weather during the two shots (e.g., humidity, temperature, pressure). If inthe two shot are different a little error will influence the results.

DInSAR limitations

$$\Delta\varphi = \Delta\psi + \frac{4\pi}{\lambda} r + \Delta\alpha + noise$$



Optical image

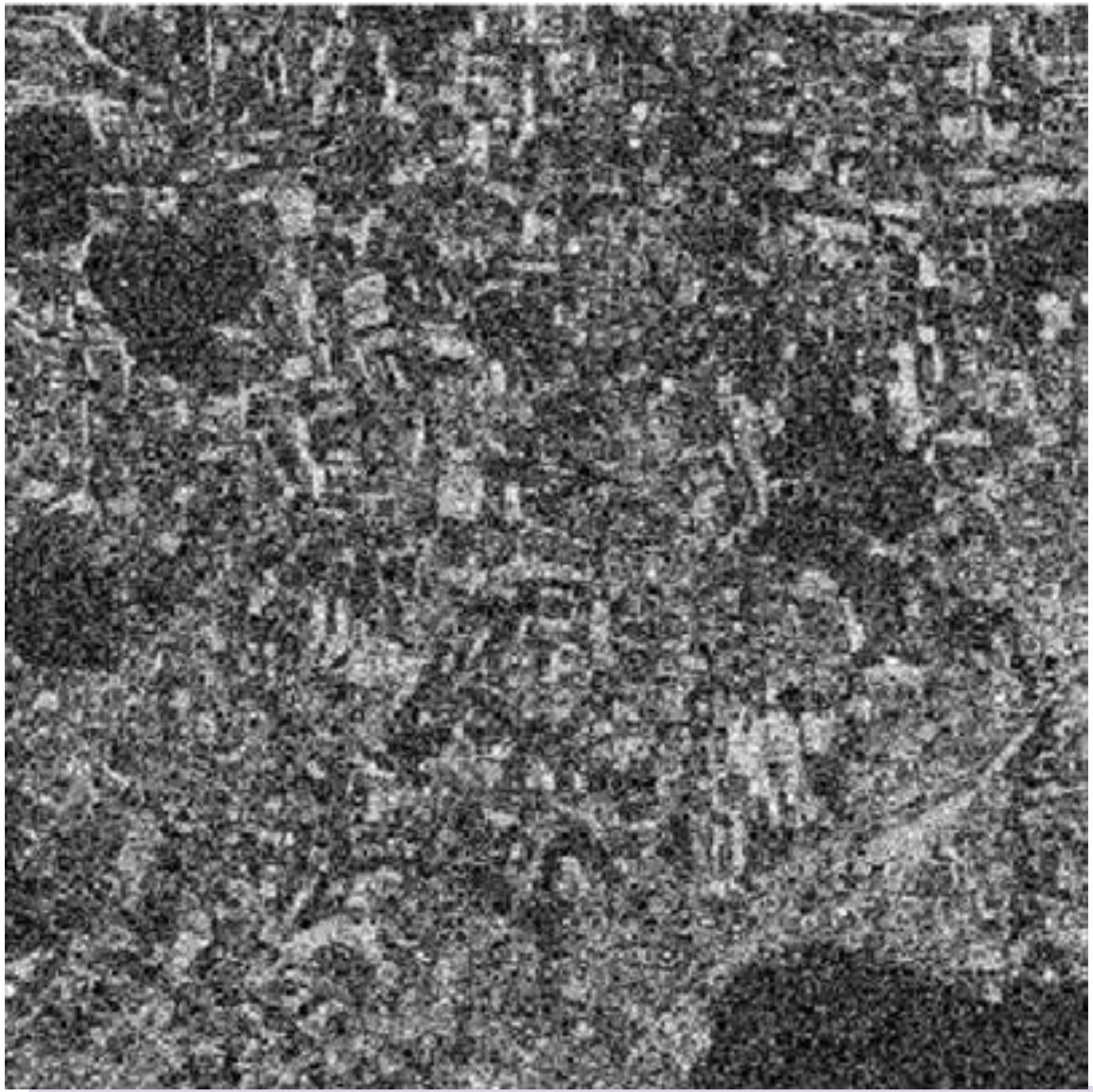
SAR amplitude image

Interferogram
Span of few days

Interferogram
Span of some months

Spatial and temporal decorrelation that caused a loosing of coherence

Coherence

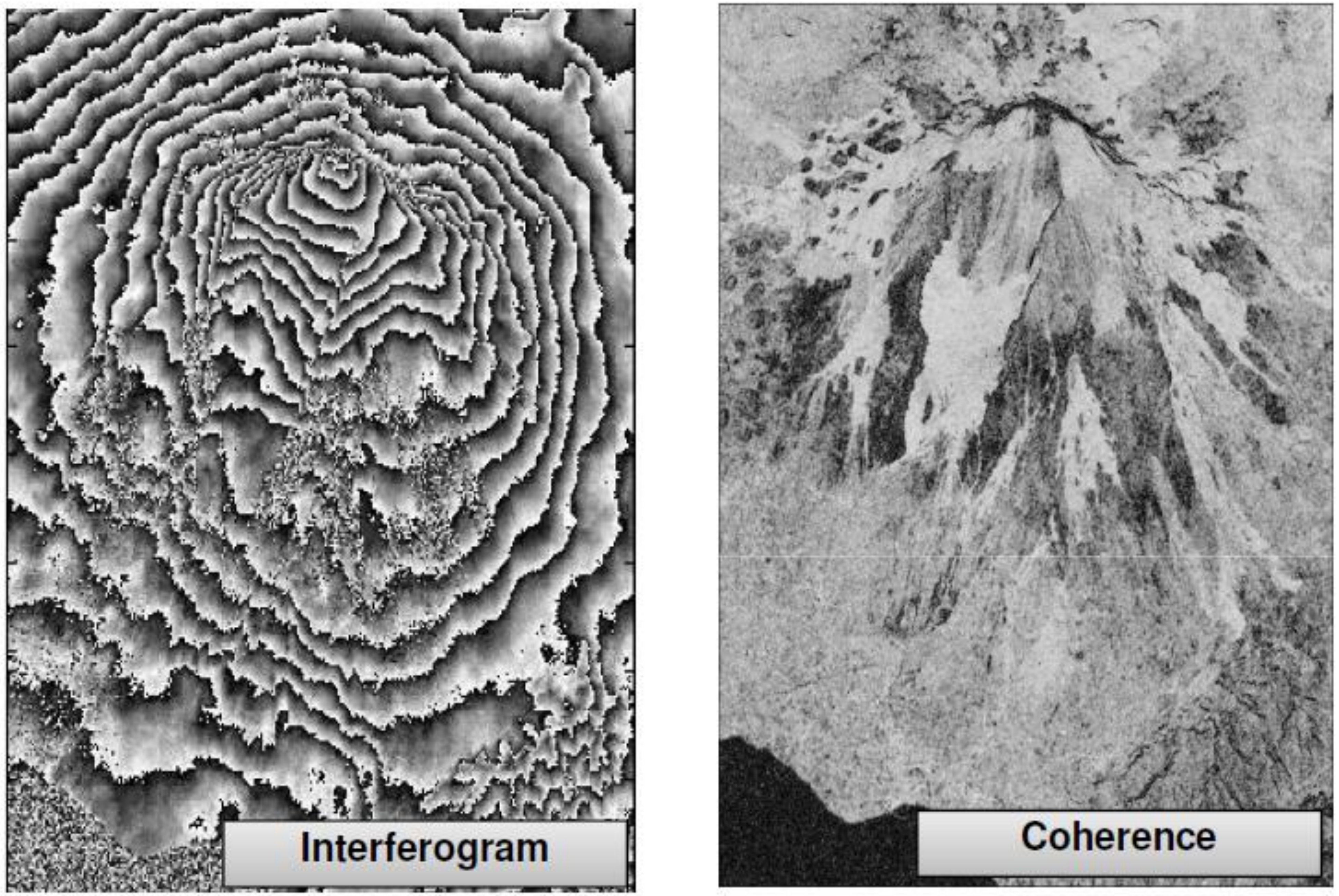


Coherence is a function of surface type, sensor wavelength, interferogram time interval, season, weather/soil moisture etc..

It is limited by working in "coherent" areas of the interferogram.

The longer the time interval of the interferogram (temporal baseline - Bt), the less the coherence of the surfaces and therefore the greater the noise

Interferometric Coherence



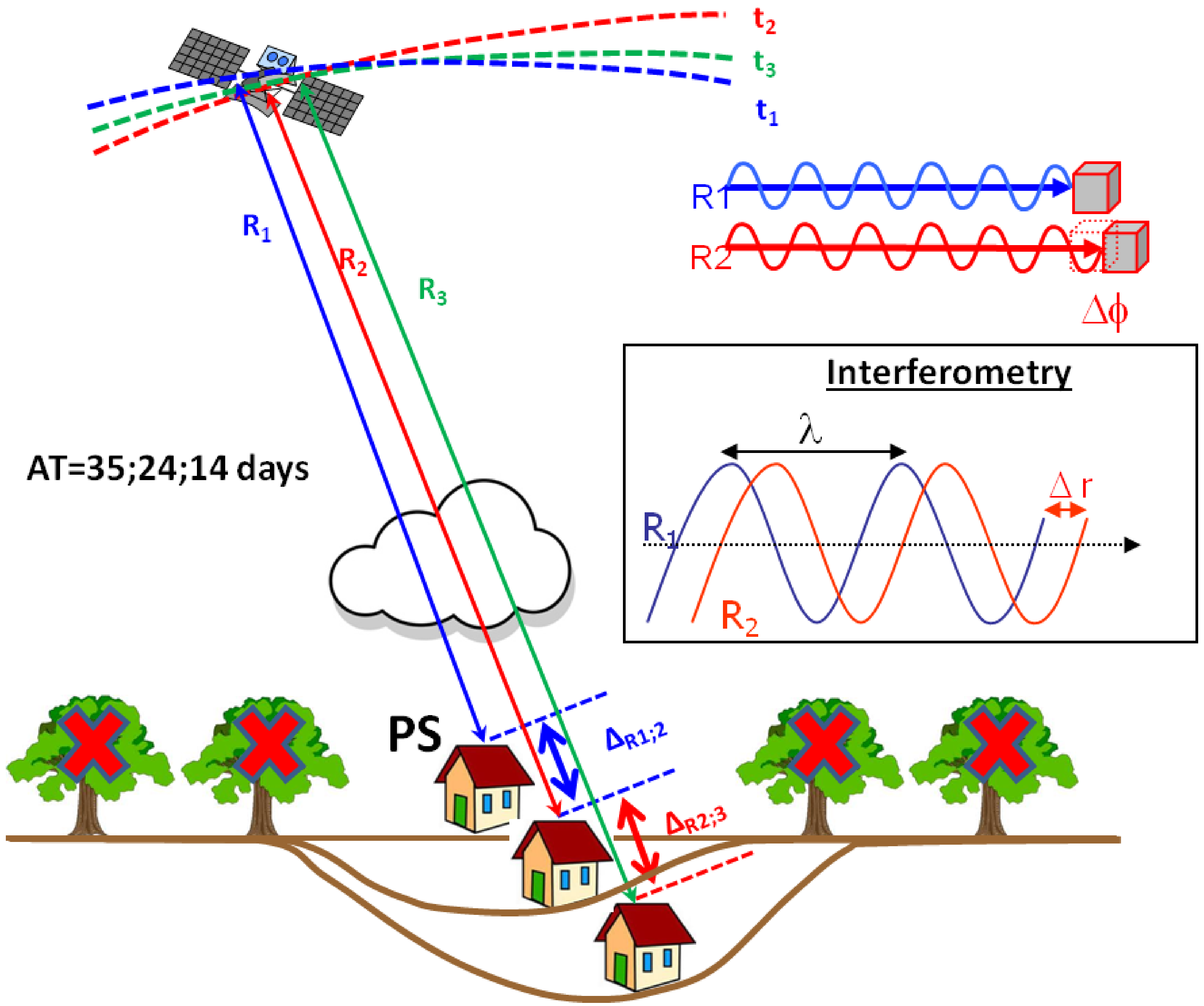
Coherence [γ] refers to the phase stability of each pixel with respect to the neighbors.

$\gamma = 0$ means completely random phase signals(noise)

$\gamma = 1$ complete phase stability (signal)

Contents

Multi-interferometric InSAR



It measures phase differences for each target. The measurament points are called **Persistent Scatterers (PS)**.

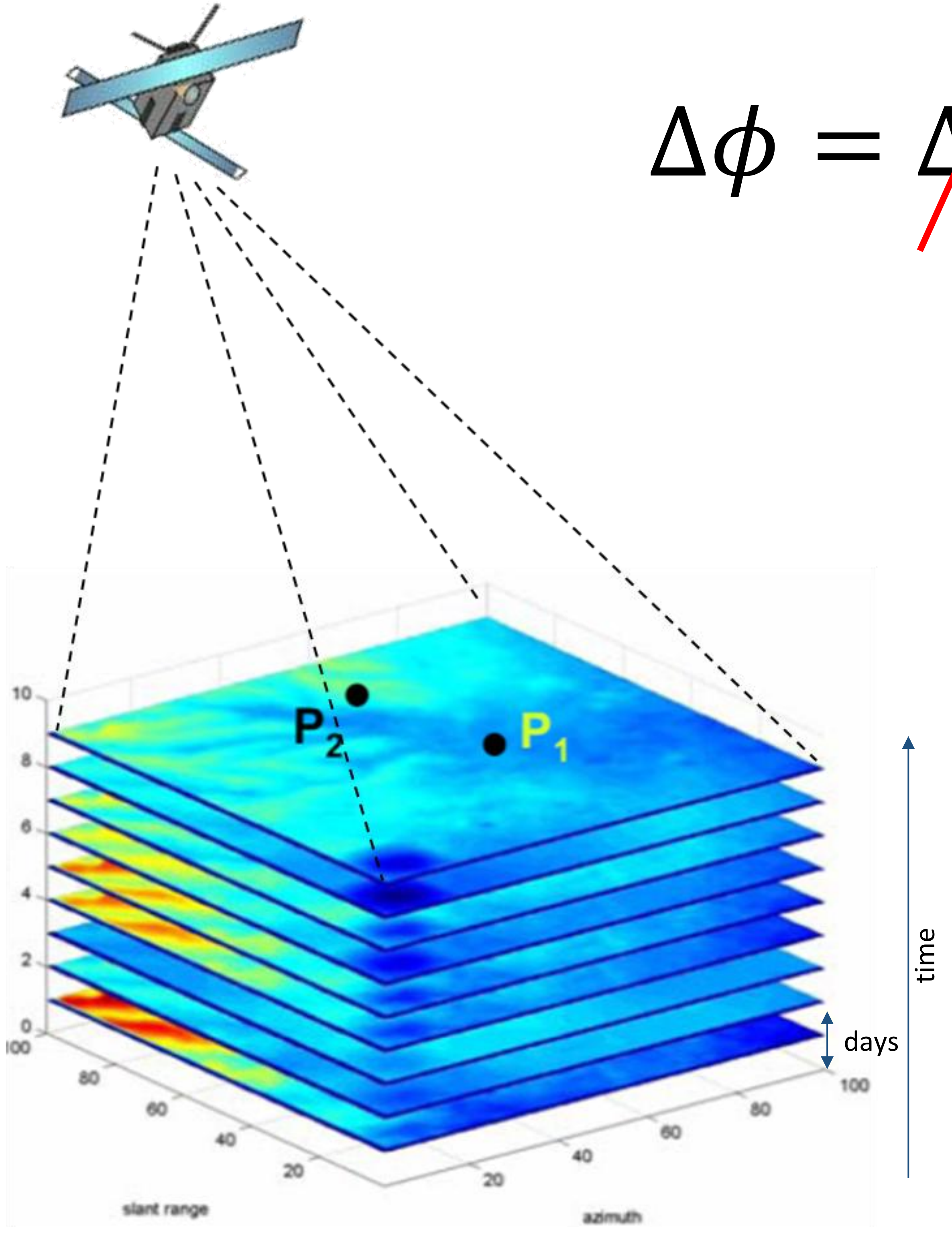
$T_1 - R_1$

$T_2 - R_2 - \Delta_{R1;2}$

$T_3 - R_3 - \Delta_{R2;3}$

- PS are identified by algorithms that analyse several SAR images (at least 30).
- **Displacement** (mm) and **velocity of movement** (mm/year) measured along the LOS direction
- The analysis has to be conducted for each orbit (ascending and descending)

Multi-interferometric InSAR



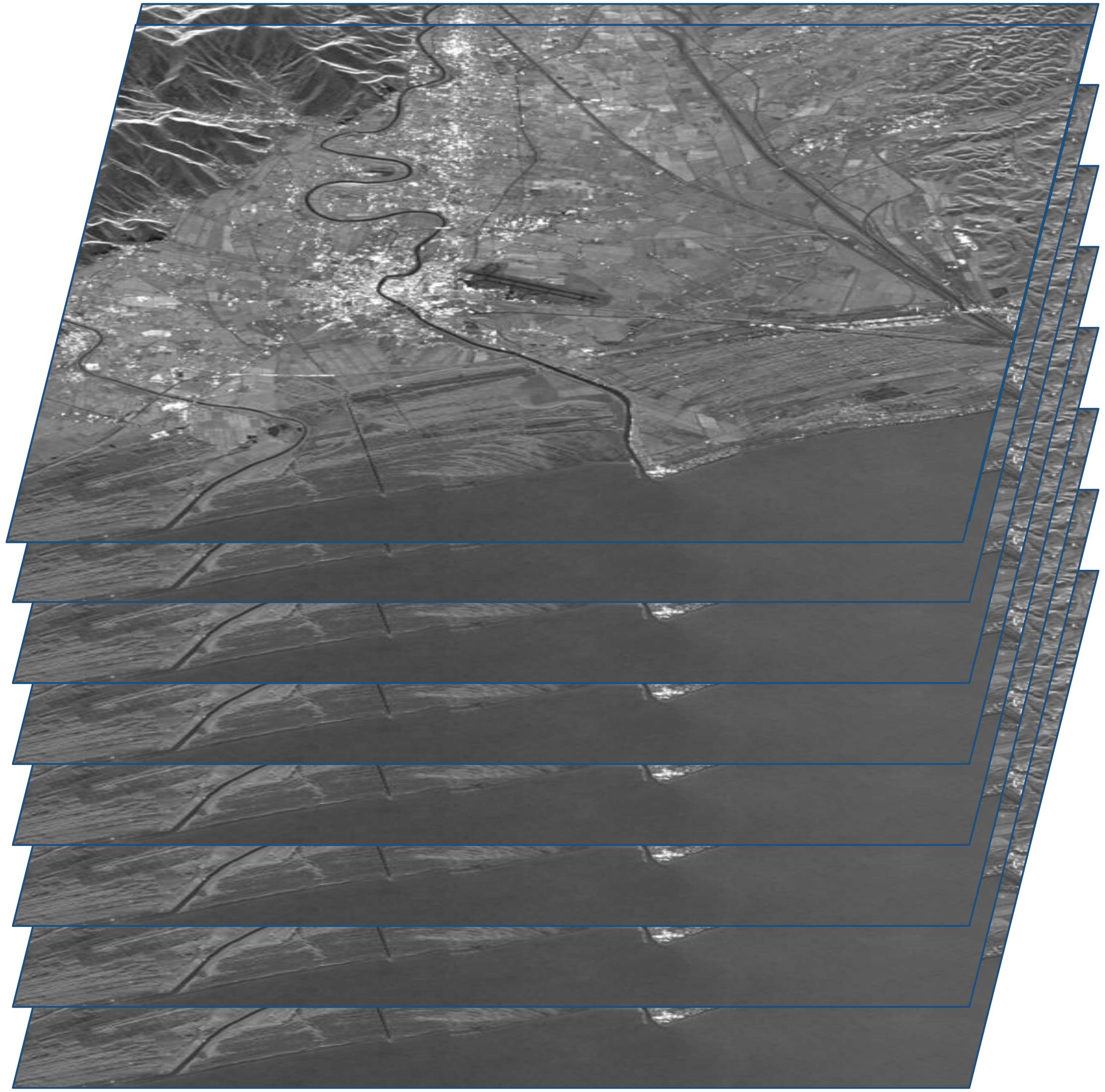
Dataset of SAR images

$$\Delta\phi = \Delta\psi + \frac{4\pi}{\lambda} r + \Delta\alpha + noise$$

- All the measures (displacement or velocity of displacement) are relative to a *reference point*
- Temporally the investigation is limited by the older image (usually the master)
- The reference point is assumed stable according to signal features and geological characteristics. It is manually assigned
- It allows investigating **time-series** (temporal displacement) for each measurement point

Parameter	Precision
Average displacement velocity	< 1mm/year
Single displacement measurement	< 3 mm

Statistical analysis

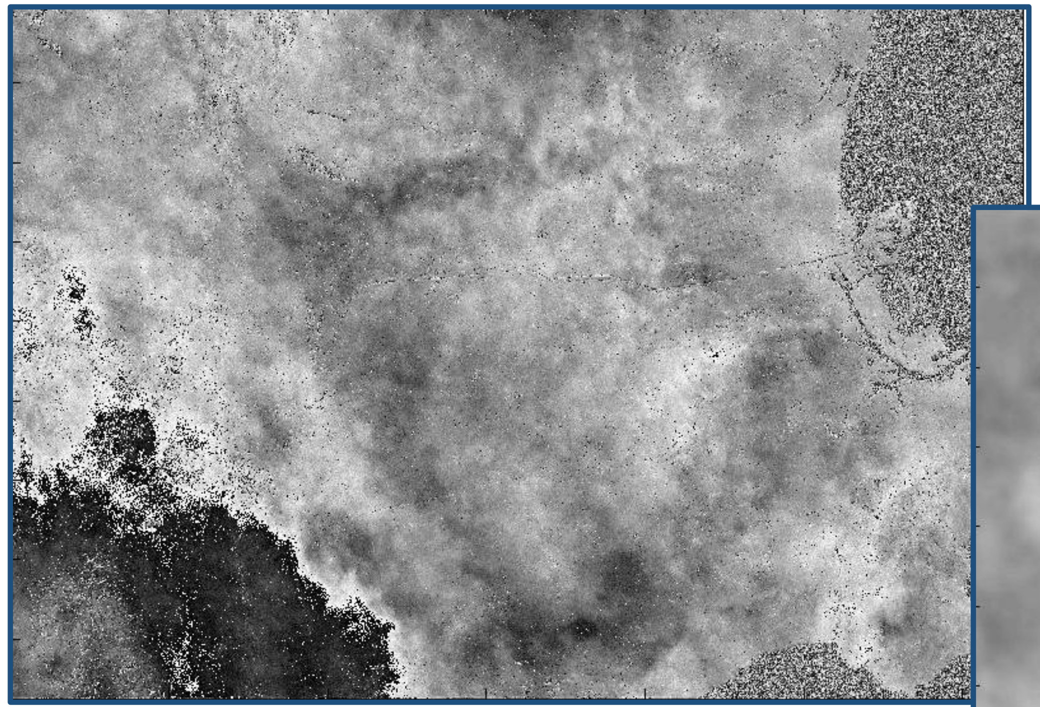


A set of images is selected

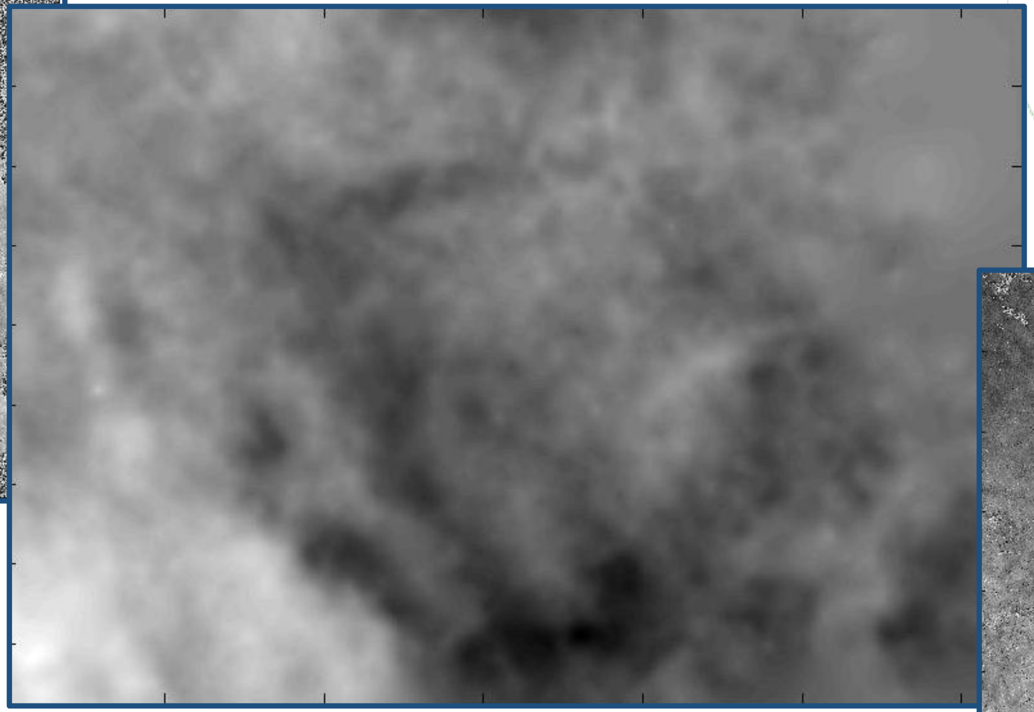
A set of statistics is performed to identify which pixels keep constant reflectivity and coherence up in time

Atmospheric phase screen (APS) is calculated removing from the unwrapped phase, displacement and DEM error contribution:
An **interpolation** (kriging) allow the removal of the APS on all differentials.

$$\Phi = \Phi elevation + \Phi displacement + \Phi atmosphere + \Phi noise$$

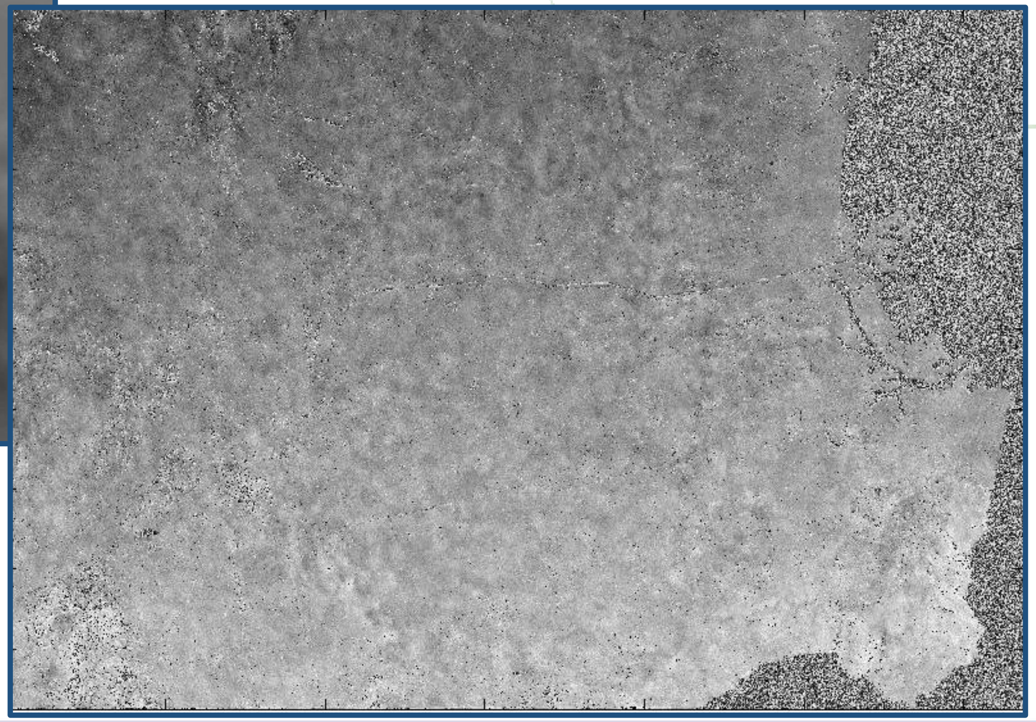


Differential interferogram:
19960406 - 19960405
Bn=87.4 m



Calculated APS

Differential interferogram
"cleaned"



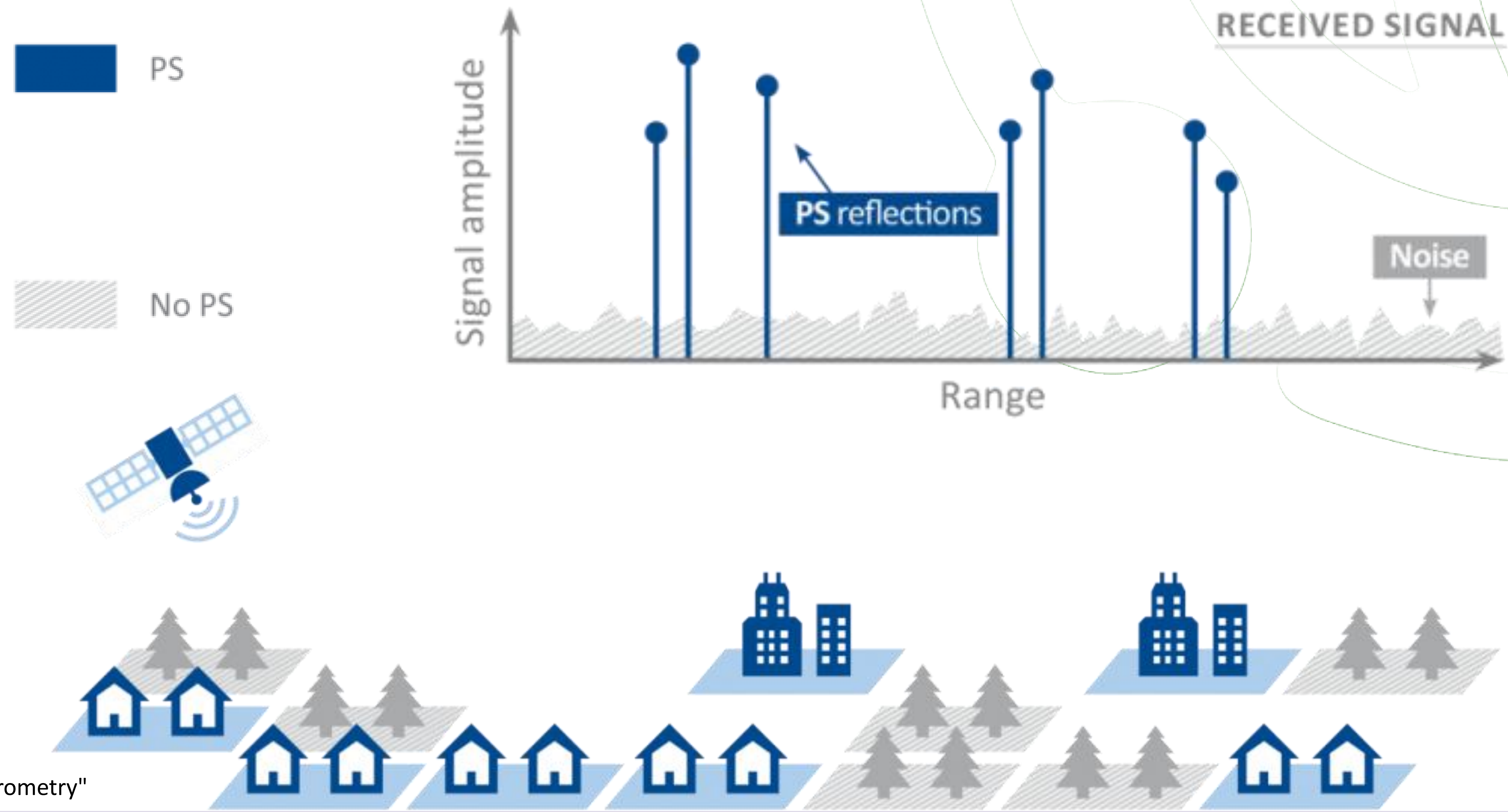
Algorithms

PSI method	Main references
PSInSAR (Permanent Scatterers Interferometry)	Ferretti et al., 2000, 2001
SBAS (Small Baseline Subset)	Berardino et al., 2002
CPT (Coherent Pixels Technique)	Mora et al., 2003; Blanco et al., 2006
Modified SBAS	Schmidt & Burgmann, 2003
IPTA (Interferometric Point Target Analysis)	Werner et al., 2003
SPN (Stable Point Network)	Duro et al., 2003; Crosetto et al., 2008
StaMPS (Stanford Method for Persistent Scatterers)	Hooper et al. 2004
STUN (Spatio-Temporal Unwrapping Network)	Kampes, 2006;
PSP (Persistent Scatterers Pairs)	Constantini et al., 2008, 2014
DePSI (Delft Persistent Scatterer Interferometry)	Ketelaar, 2009
SqueeSAR	Ferretti et al., 2011
WAP (Wide Area Product)	Adam et al., 2011
SARproZ	Perissin & Wang, 2012
MInTS (Multiscale InSAR Time Series)	Hetland et al., 2012
Distributed Scatterers approach	Goel & Adam, 2014
Modified SqueeSAR	Lv et al., 2014
CPS (Cousin PS)	Devanthéry et al., 2014

- The basic concept is the same
- The difference of the algorithms are related to the chosen of the target and the way of the calculation of the feature parameters of the points

PSInSAR - PS

Points with a stable electromagnetic signature in all ITF



Ferretti et al., 2001
"Permanent scatterers in SAR interferometry"

What is Permanent Scatterer?

Elements to which the reflectivity does not change over time

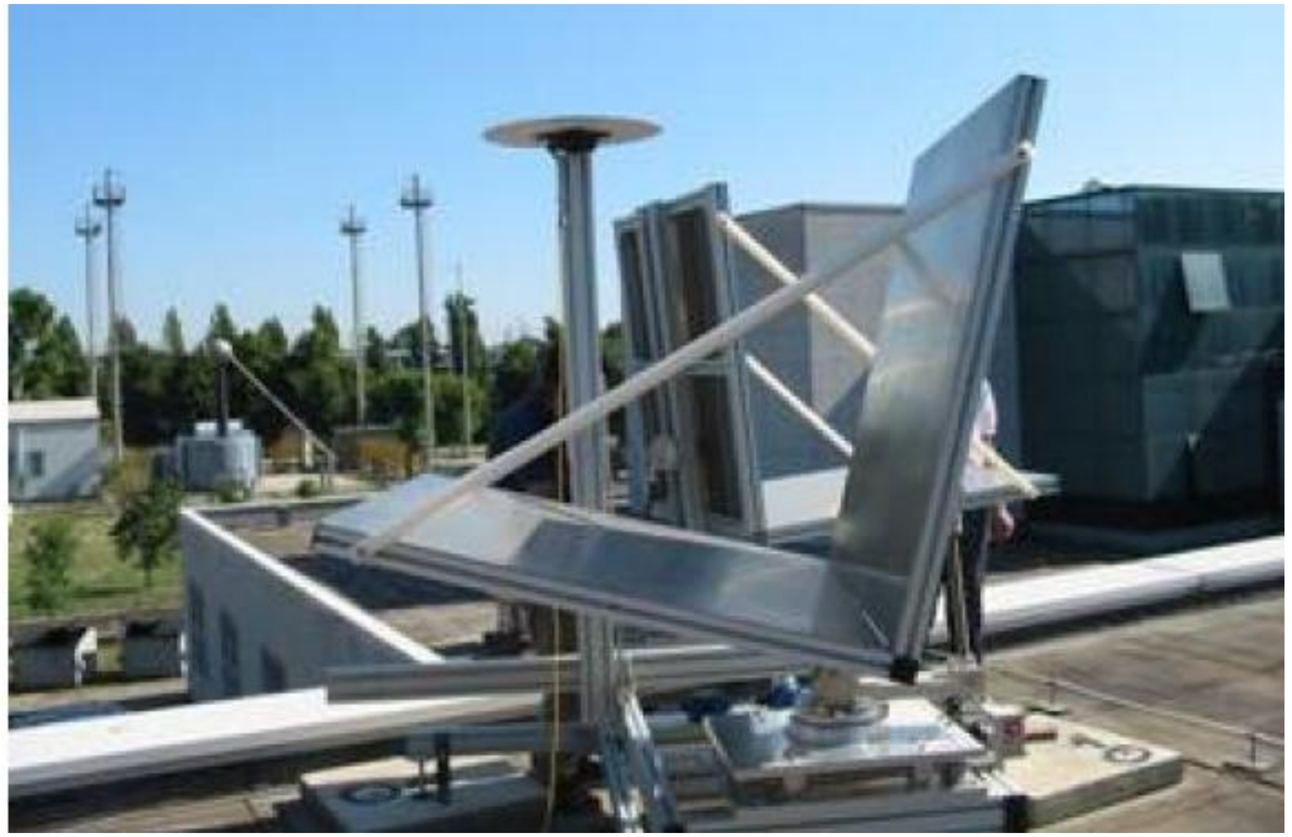
What is NOT Permanent Scatterer?

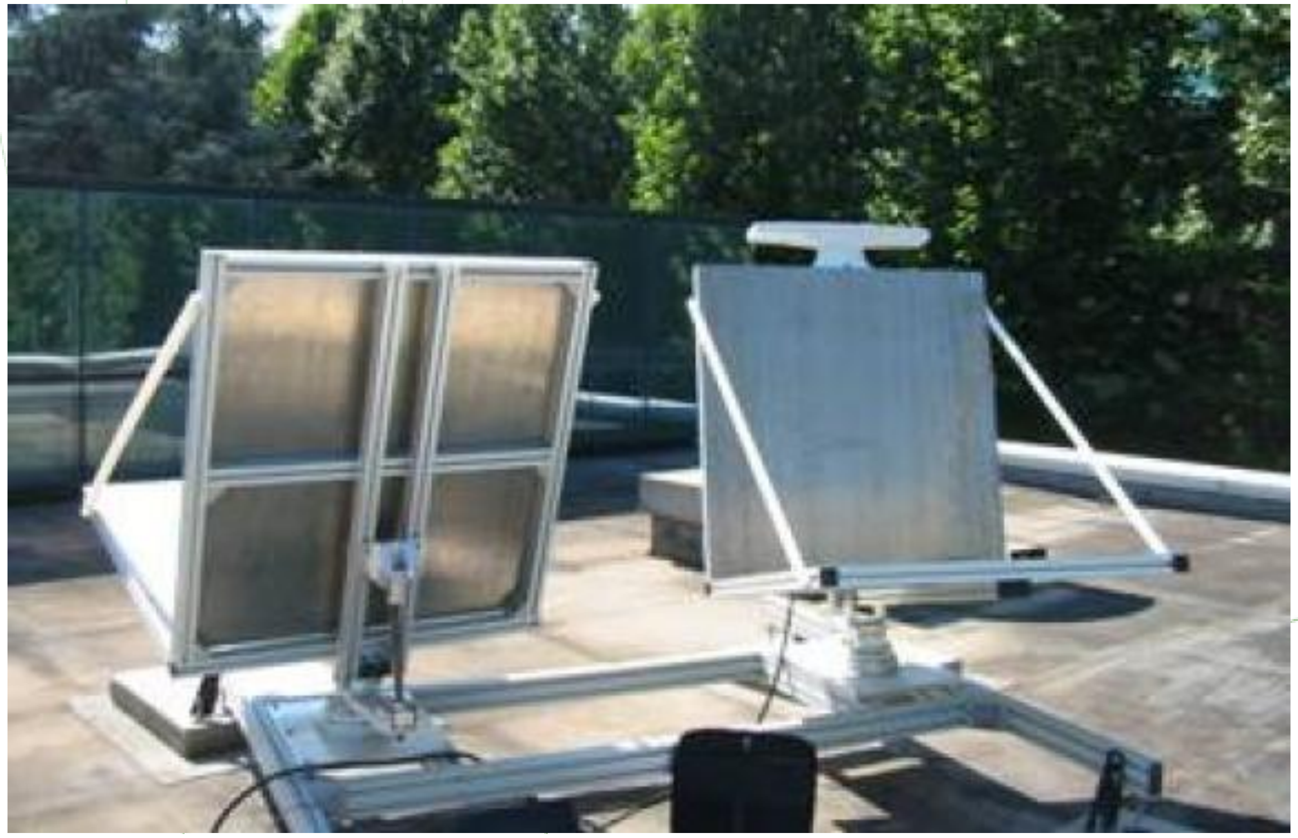


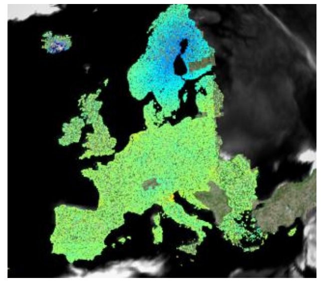


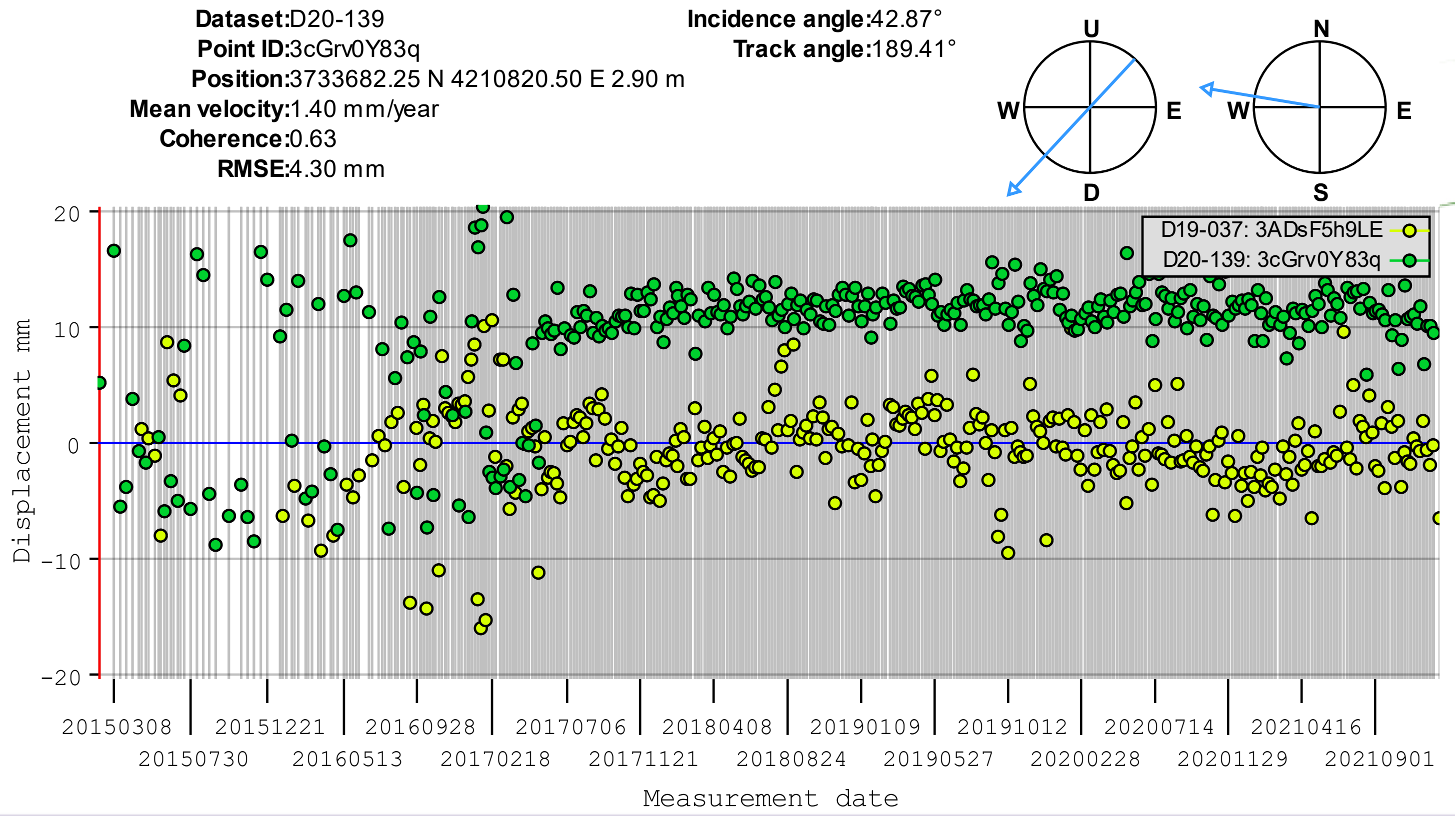

Elements to which the reflectivity does not change over time

Corner Reflector

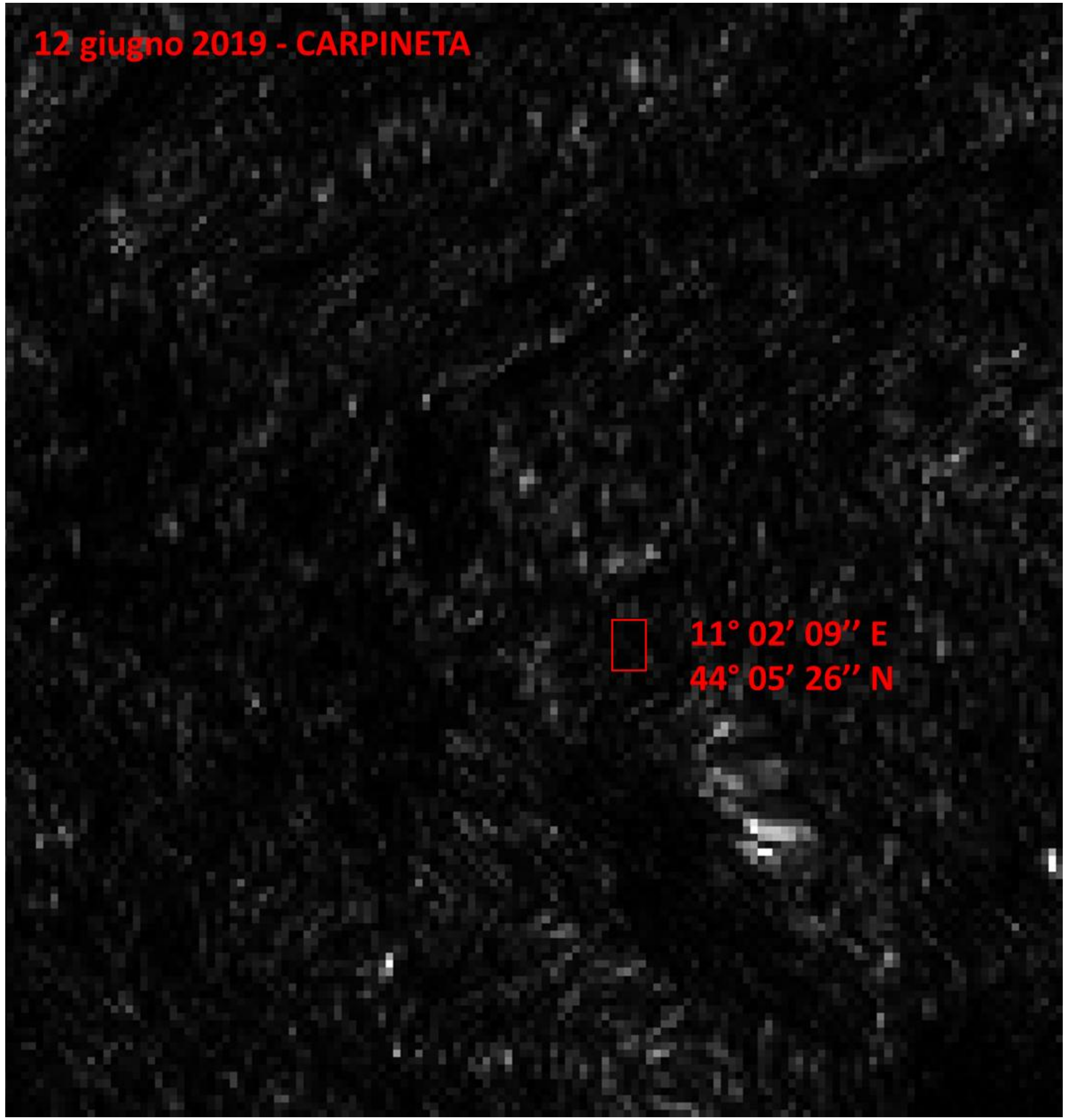


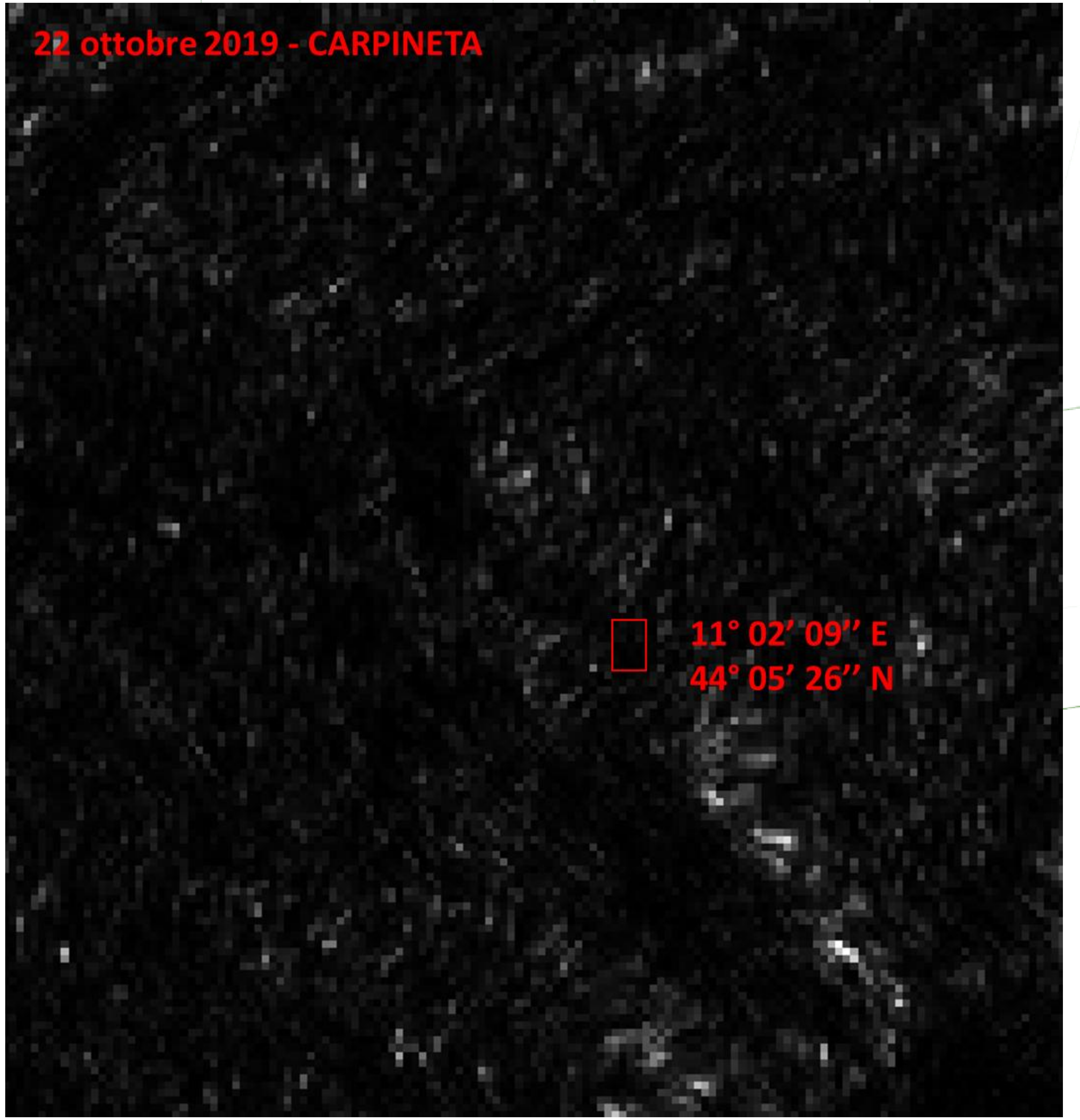




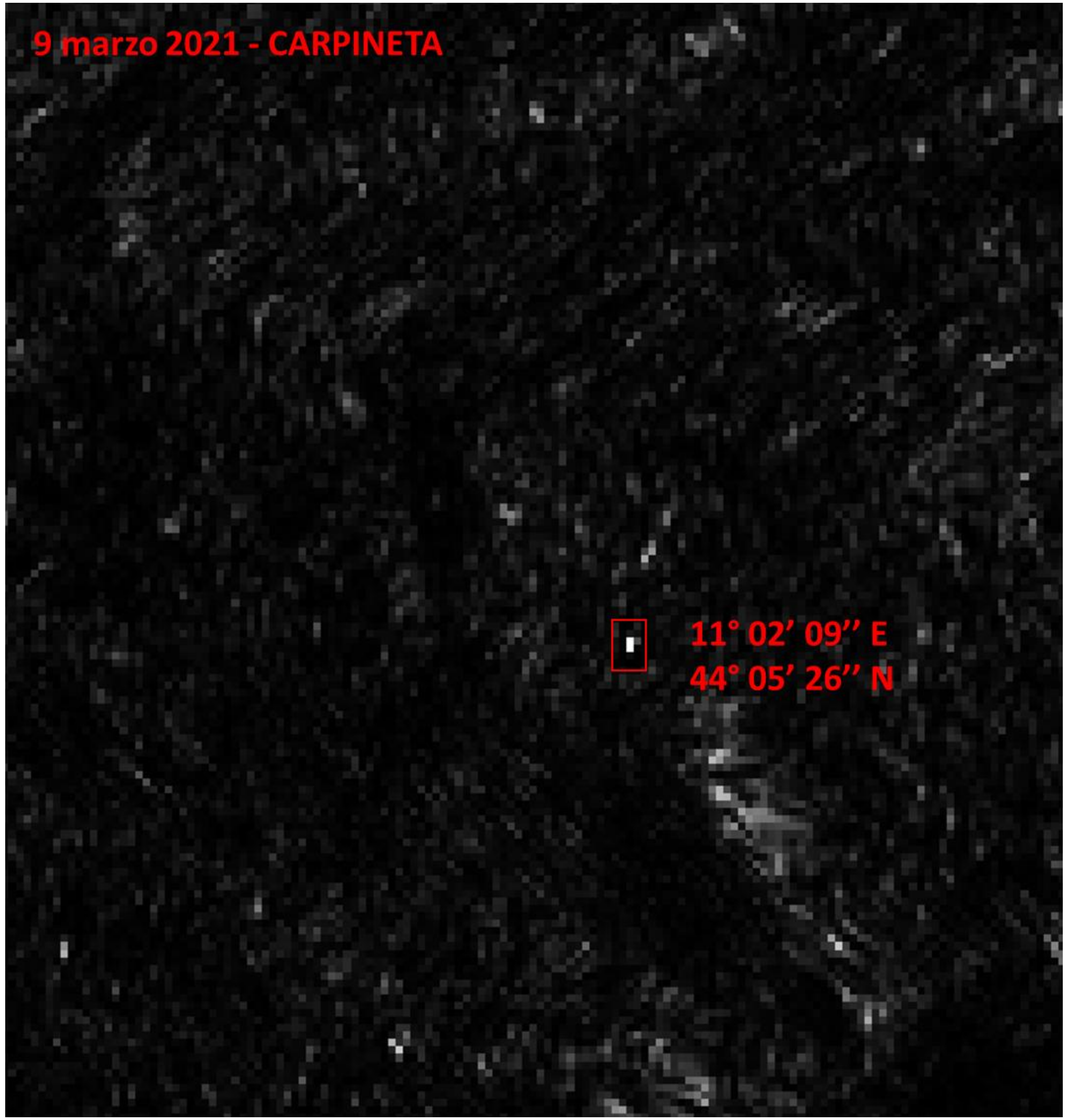


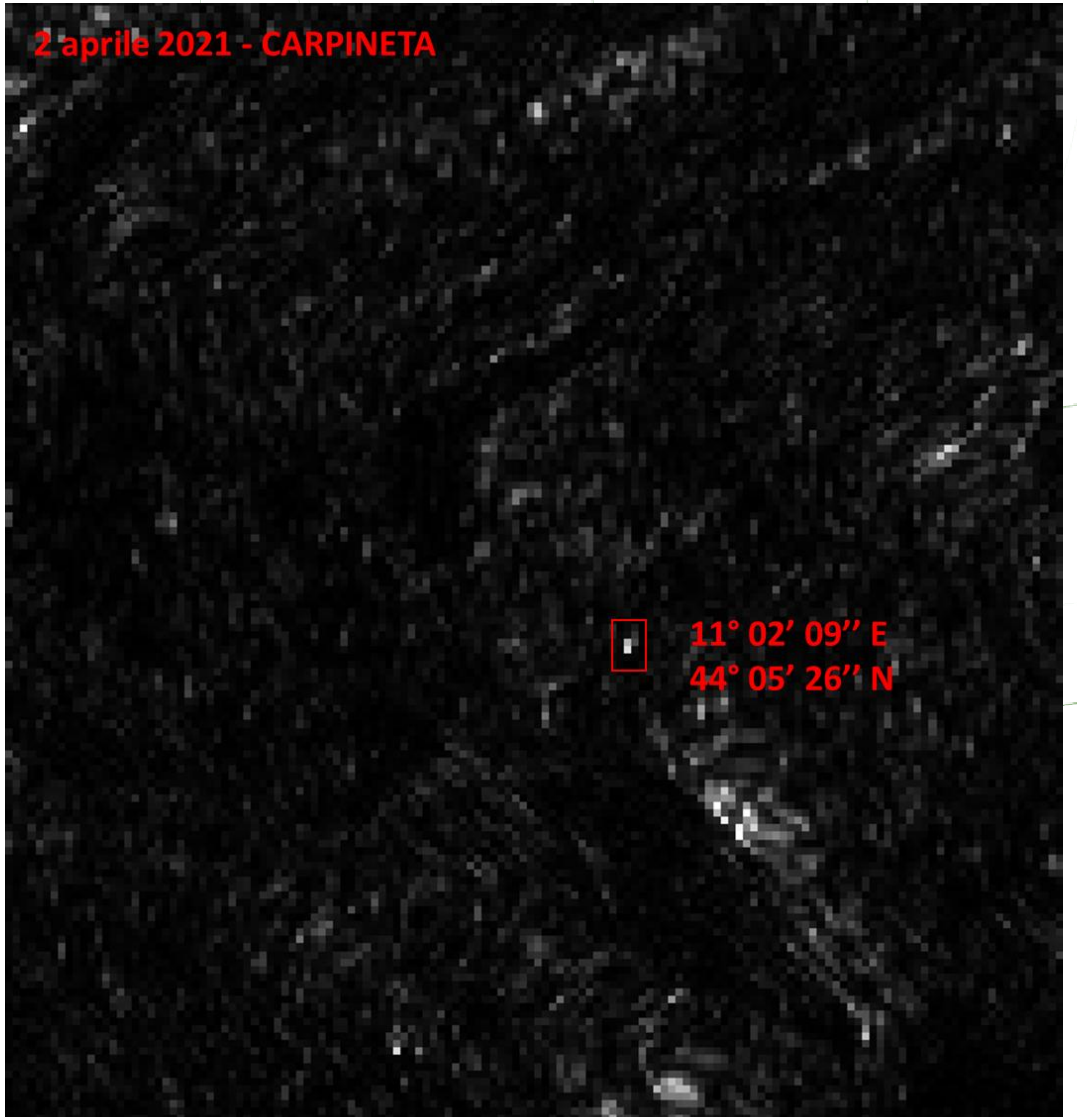
Corner Reflector



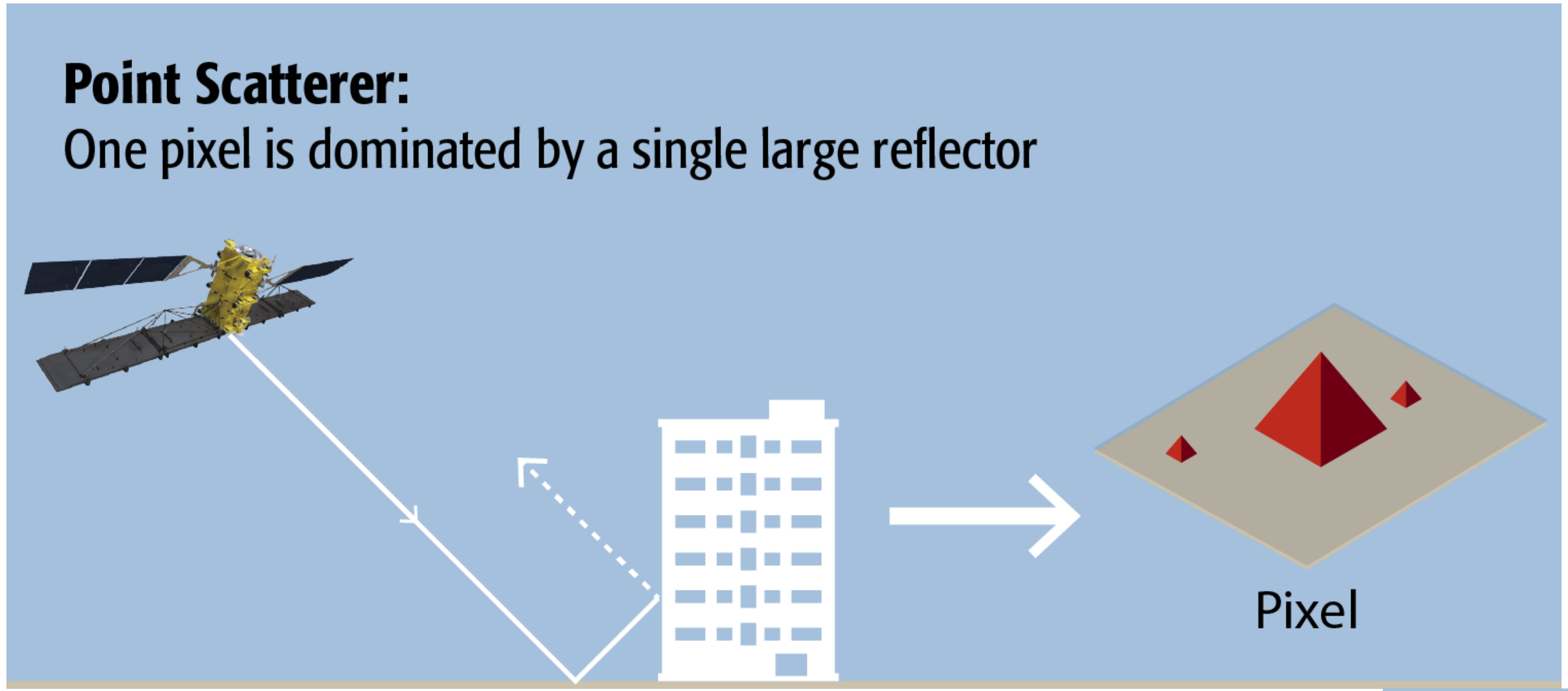


Corner Reflector



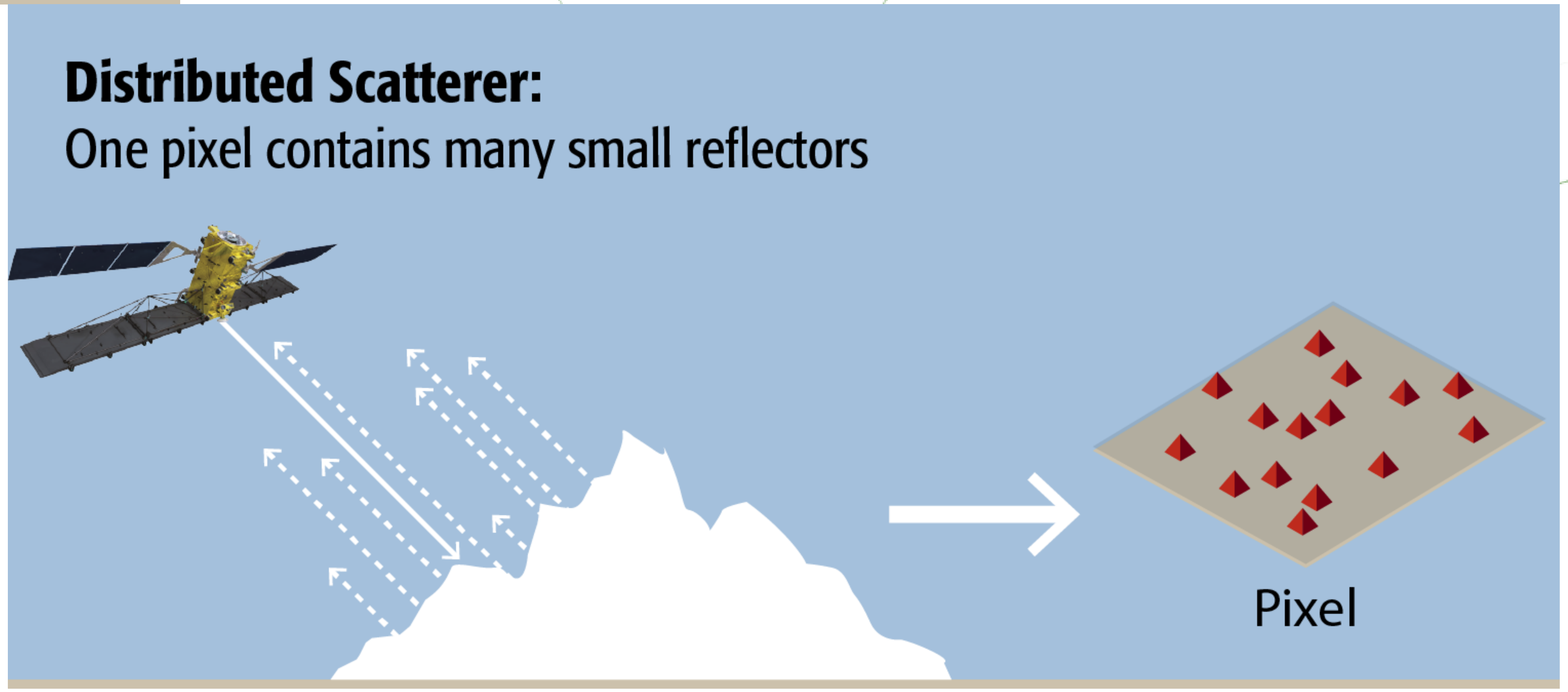


Distributed Scatterers (DS)



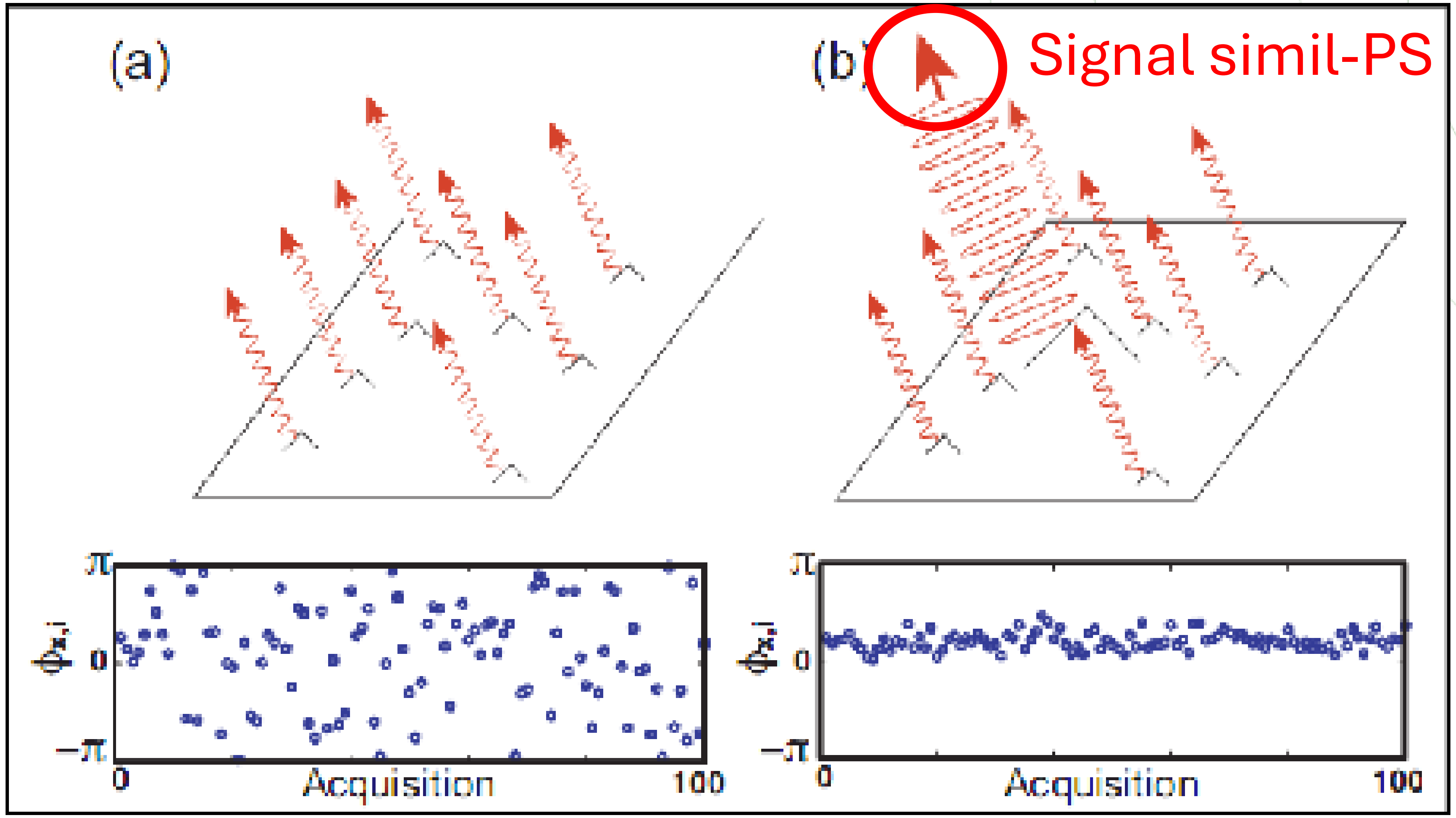
We pass from a puntual target to an aerial one

It permits to enlarge the number of points



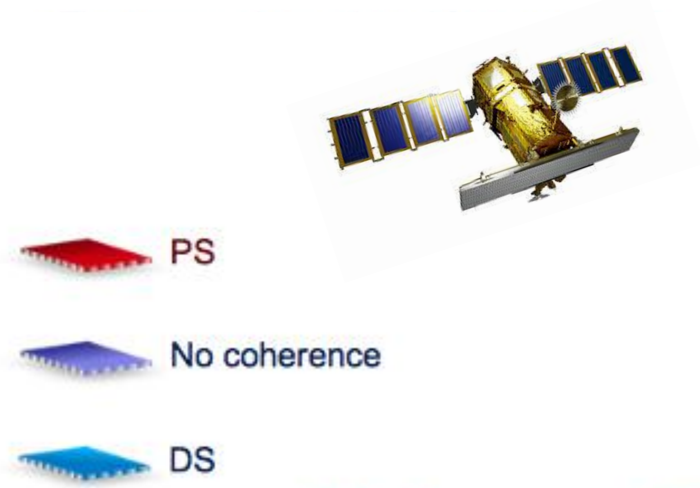
Ferretti et al., 2001
"A new algorithm for processing interferometric data-stacks: SqueeSAR»

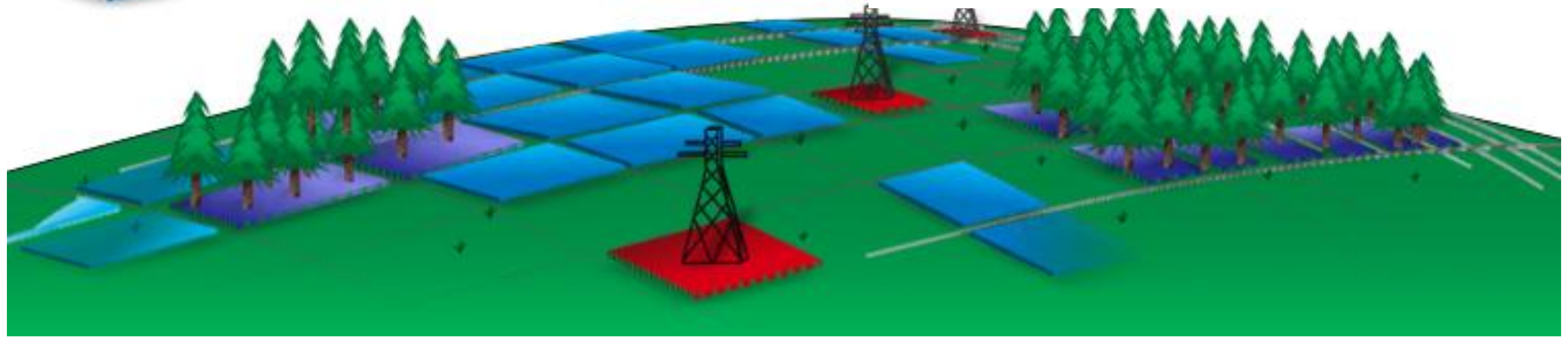
Distributed Scatterers (DS)

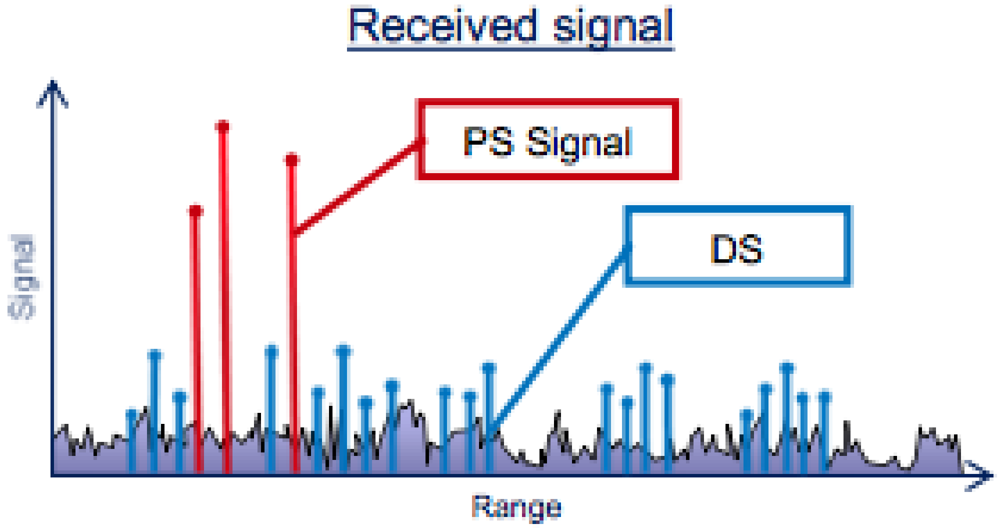


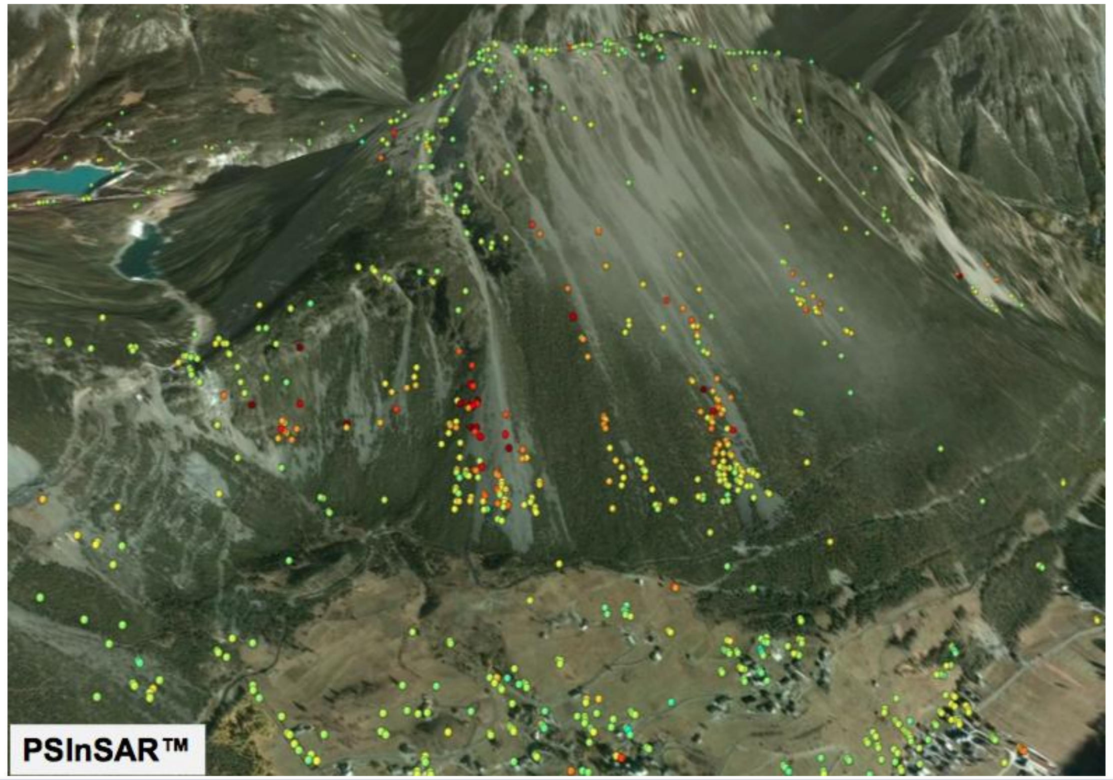
- Identification of points in areas with coherent signal but not so powerful to be a PS, but enough to be recognizable with respect to the envronmental noise;
- According to statistical tests points in small areas with similar backscattered signal are selected;
- This signals are "amplified" (or sqeezed) in order to create/simulate a synthetic PS of an area, thus DS

PSInSAR vs SqueeSAR

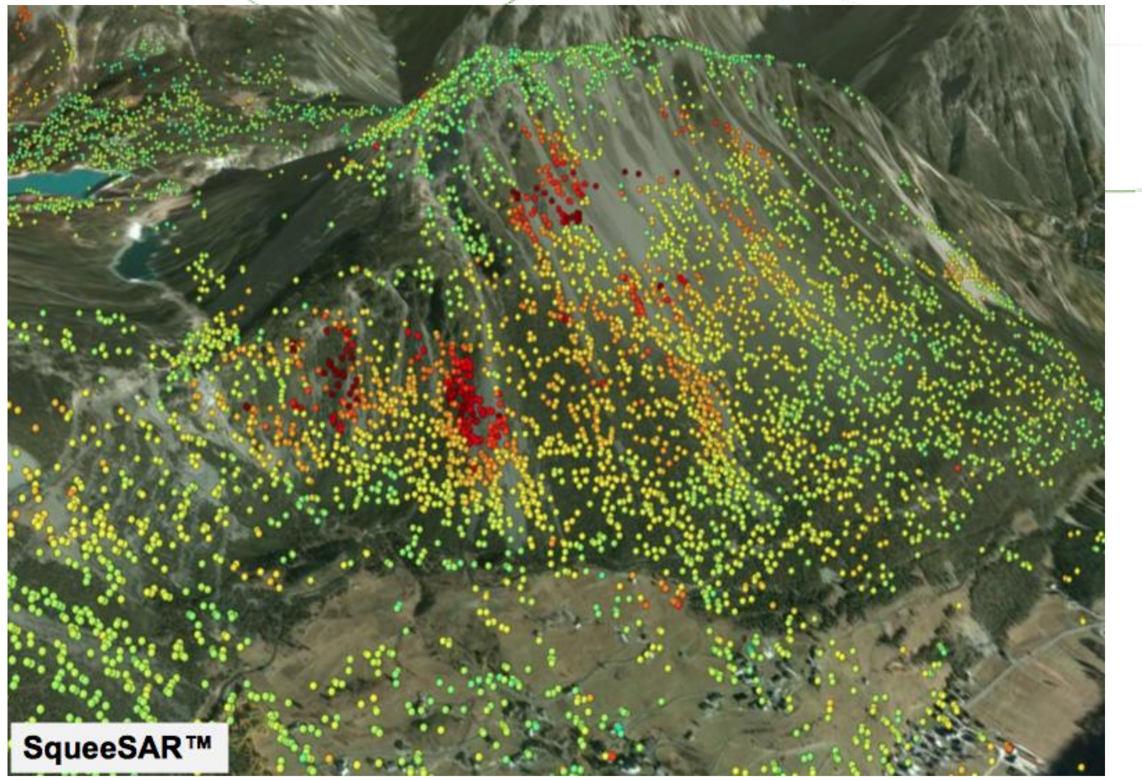








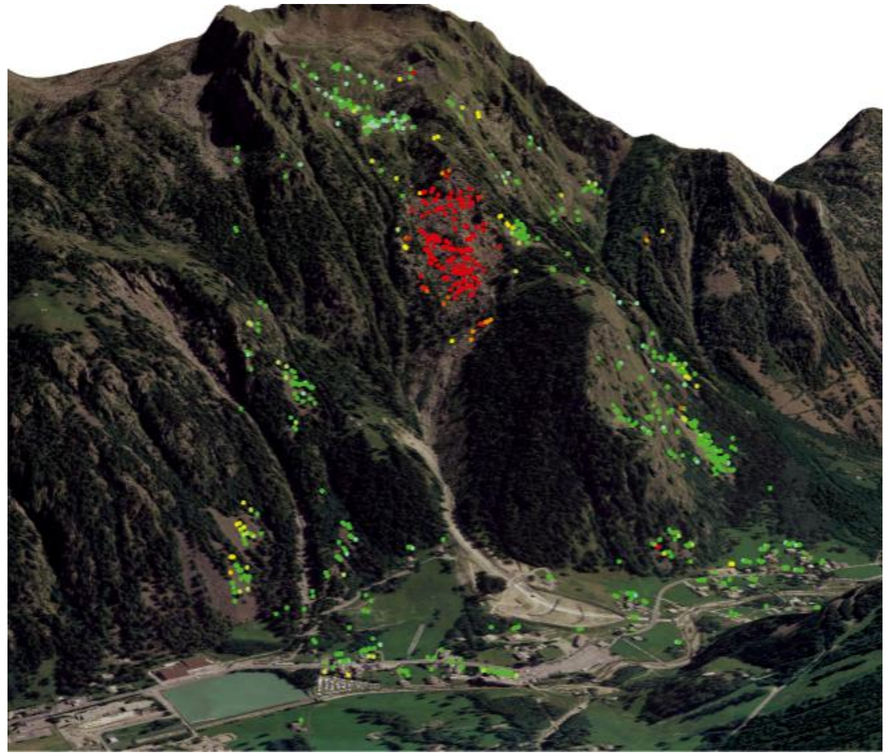
versus

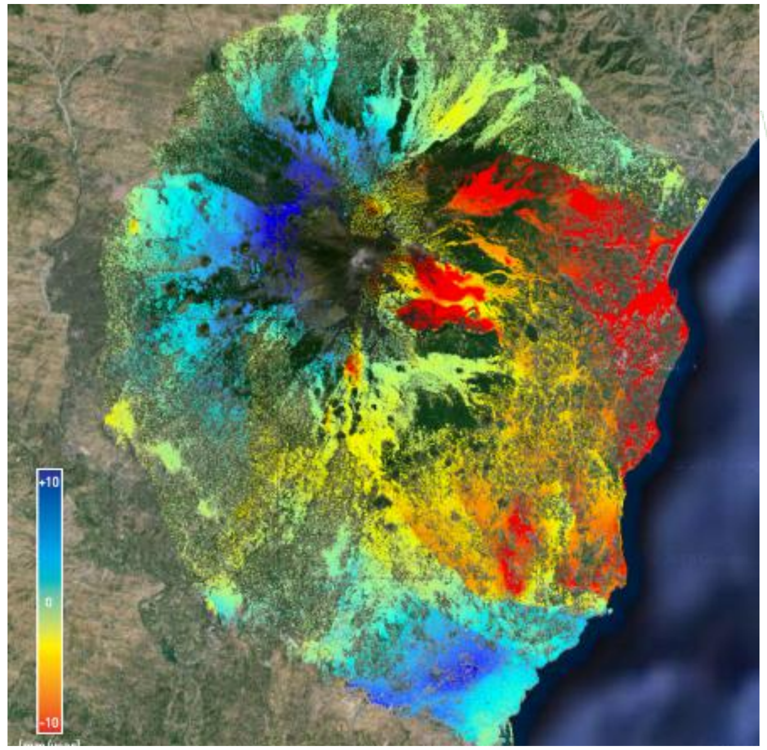


Fields of applications

ITINERIS

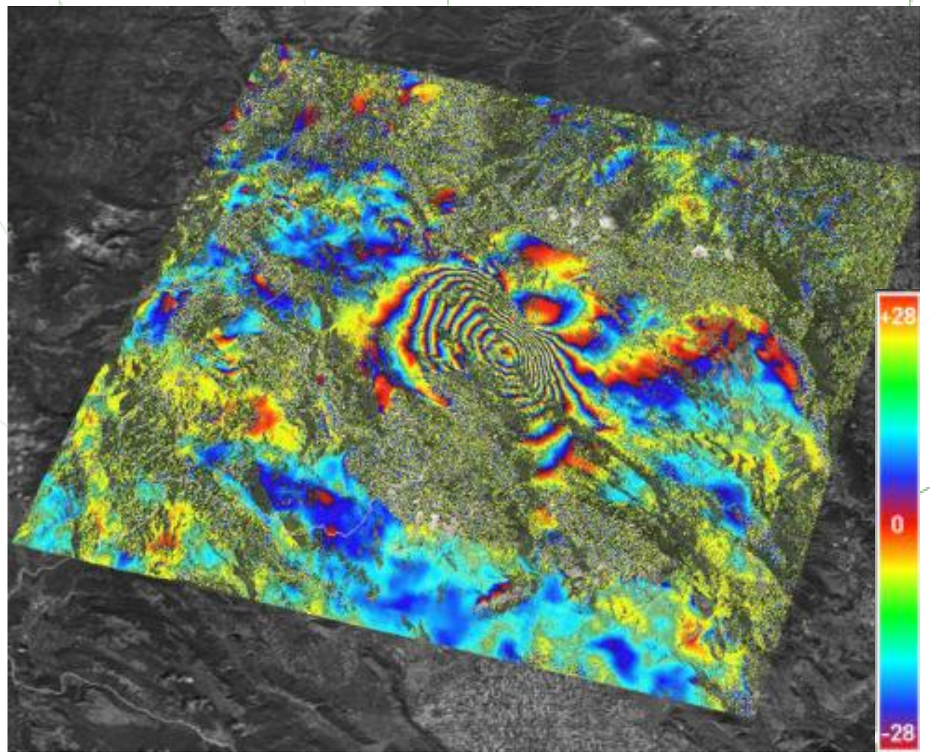
Slow moving landslides

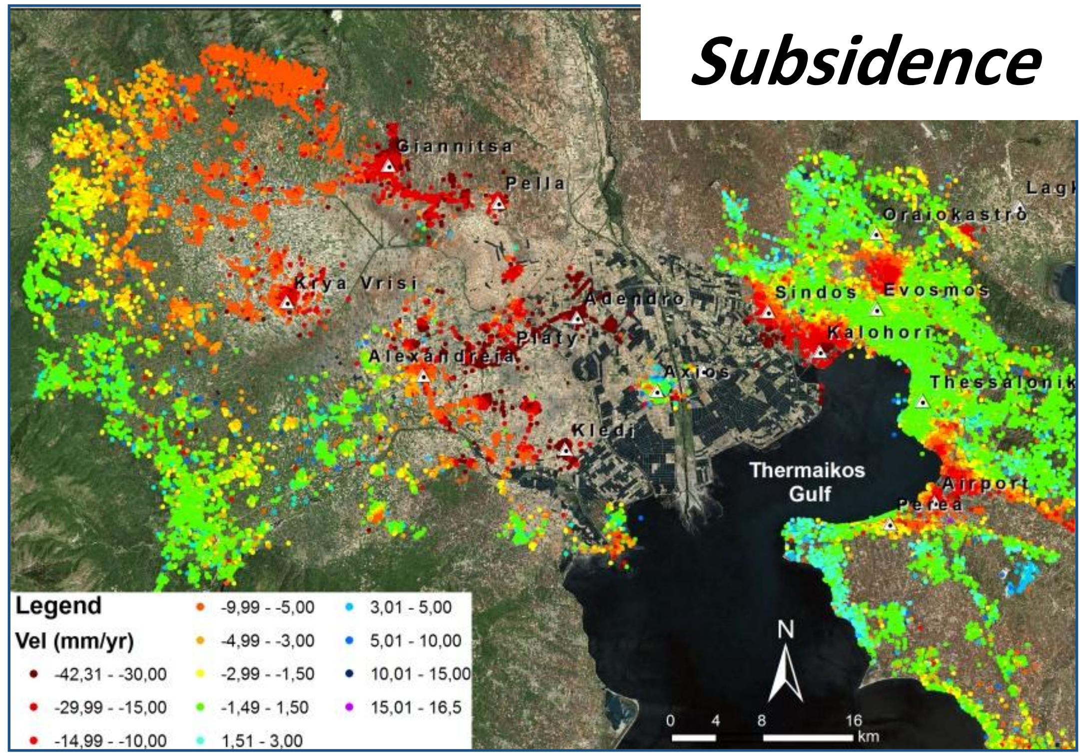




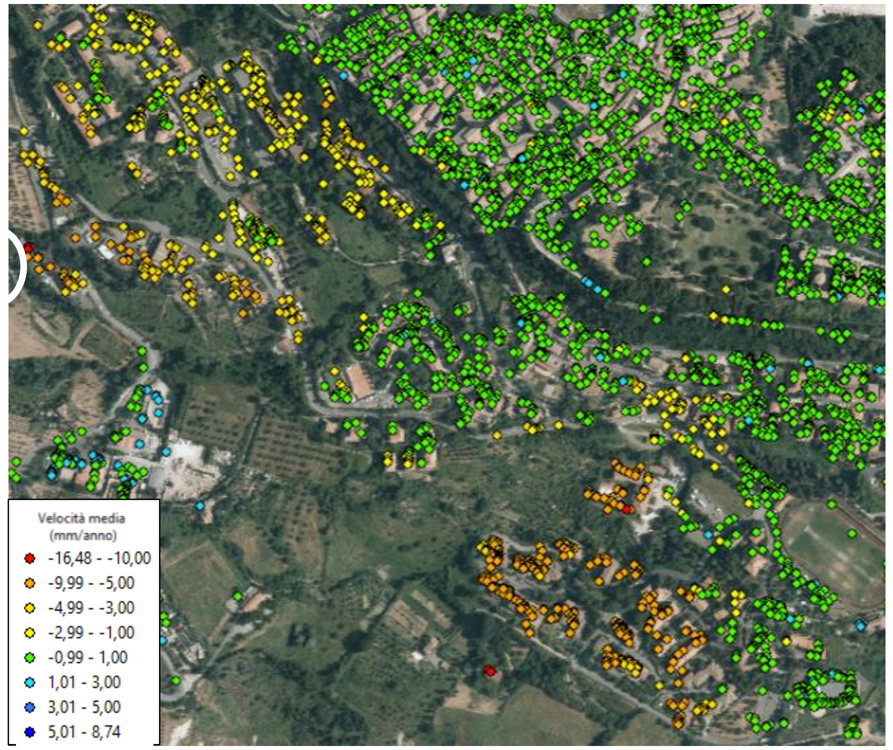
Volcanic deformation

Tectonics



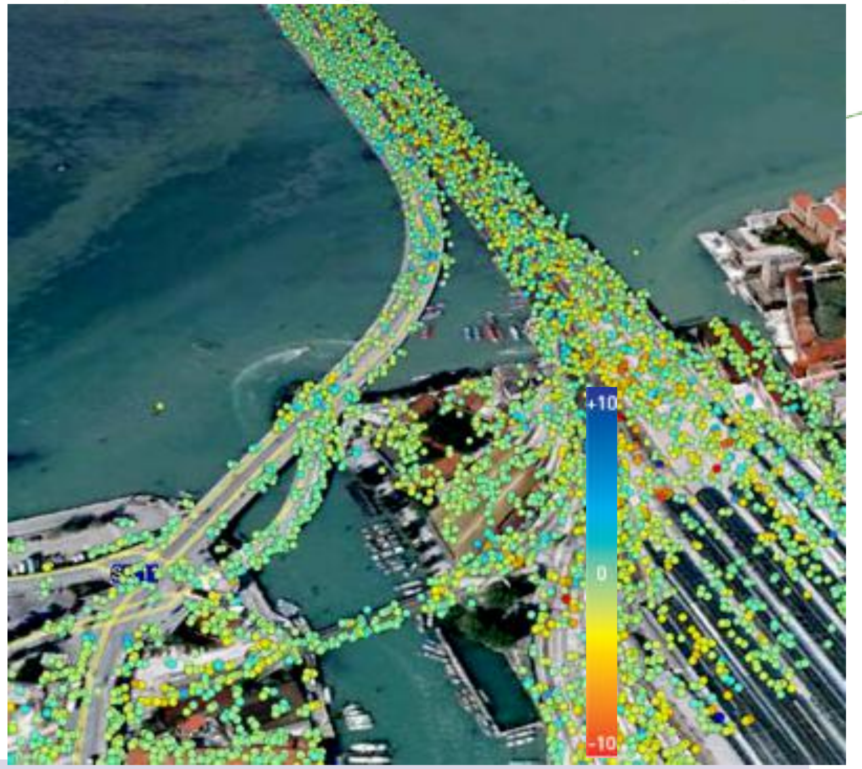


Subsidence

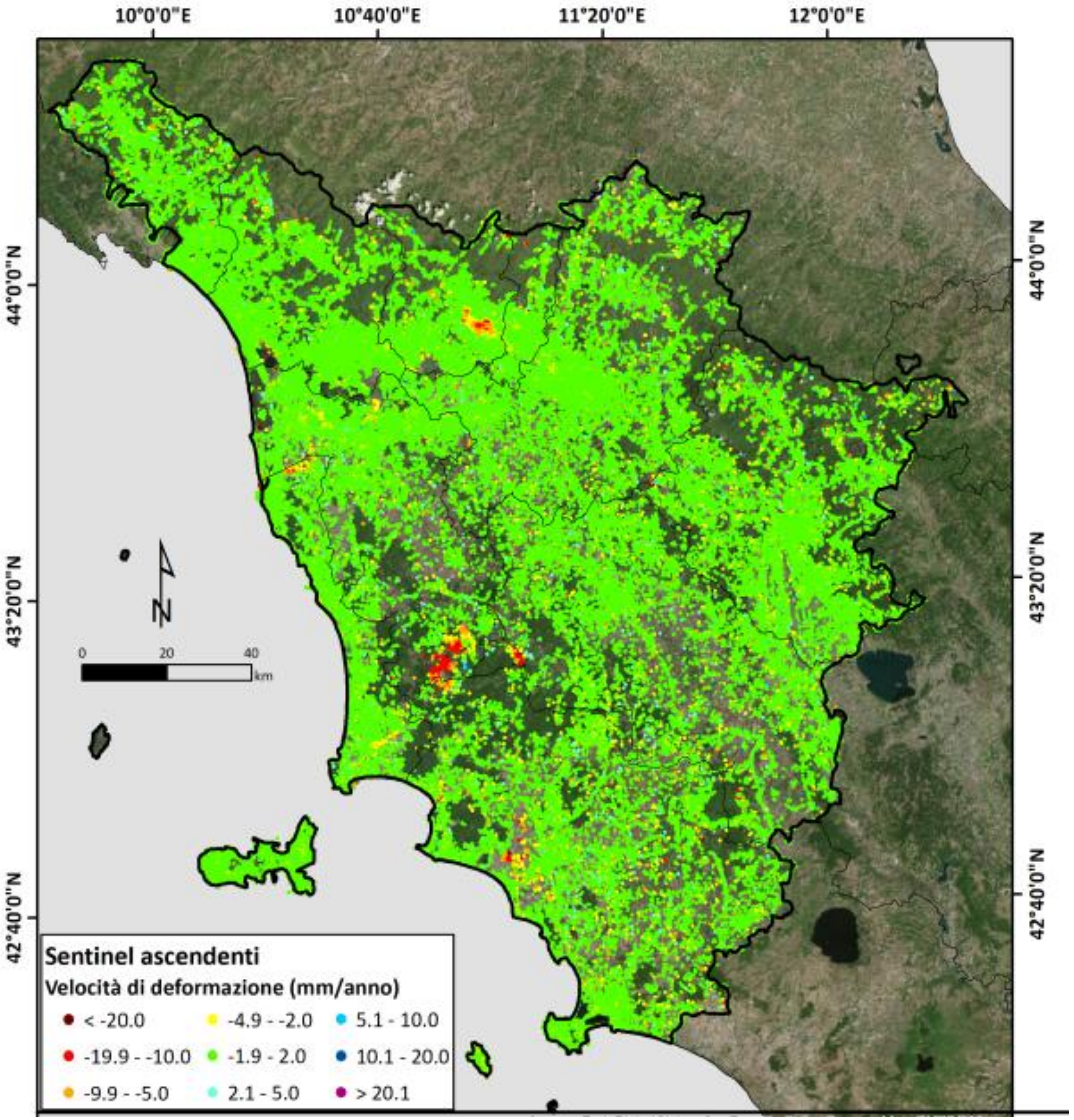


Buildings

Infrastructure



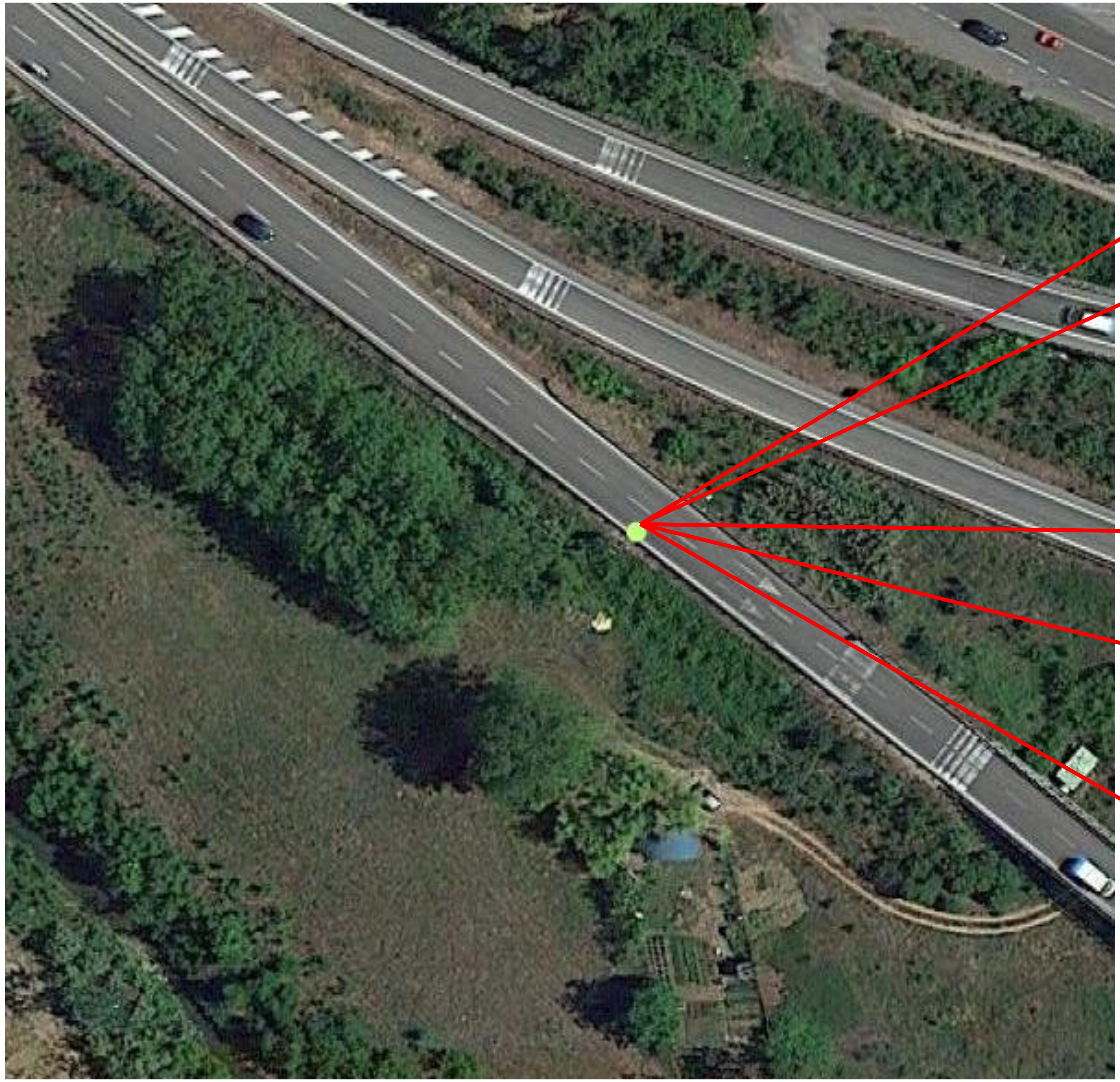
Products of MT-InSAR



The map of velocity classify the single PS based on the annual average velocity value

The value of velocity is calculated based on the linear model

Products of MT-InSAR



1.Identificative code unique of the PS;

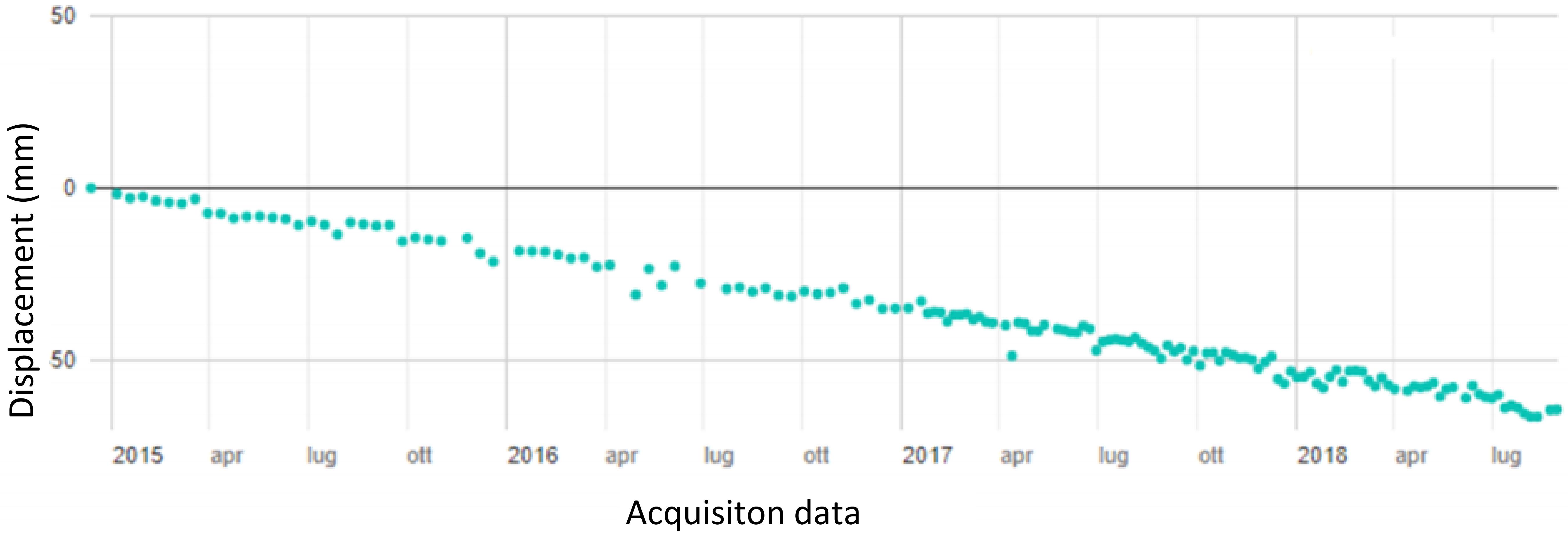
2.Height of the point and its standard deviation. The height is calculated with respect to the DEM used in the procesing of data - metric precision;

3.Velocity of the point and its standard deviation.
Precision: 2 mm/year;

4.Value of **coherence** of the time-series, thus how much it moves from the linear model;

5.Values of displacement of the single acquisistions of the satellite (n column for the Y acquisitions)

Products of MT-InSAR

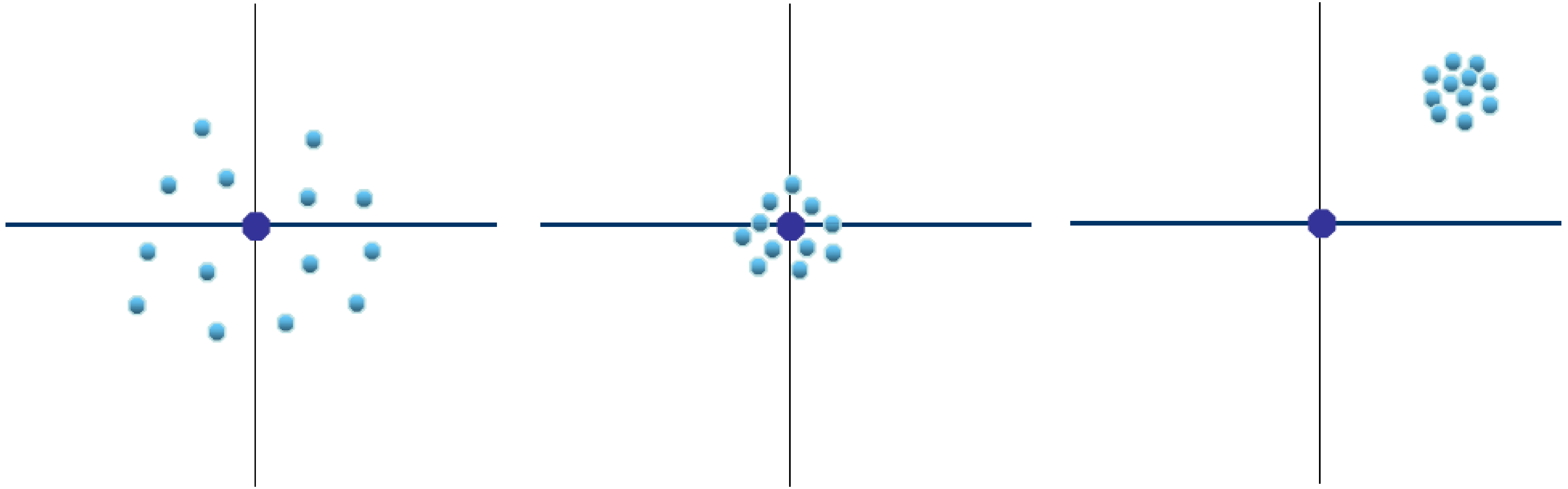


- For each point (PS or DS) is possible to extract the time-series, thus a graph representing the displacement along time
- Each time-serie represents the displacement of the surface, or the target backscattering the signal coherently along time, for the whole period of the datasets of the SAR images processed

Precision and accuracy

The quality of masures depends both on the operator ability and reliability of the used sensors.
A little incertainity is ever present in the estimated measurement values

Accuracy | Precision

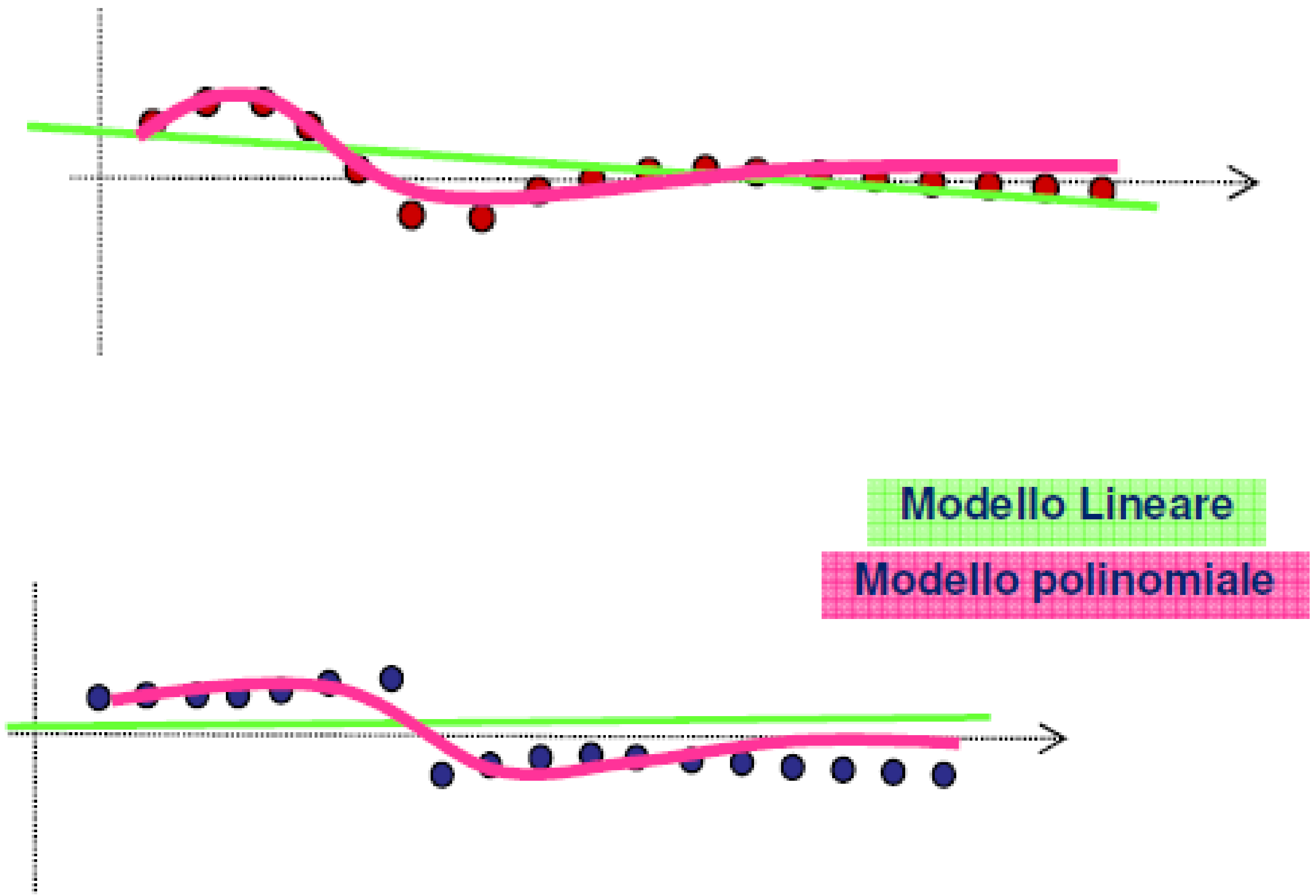


Precision + Accuracy

The accuracy mean the absense of systematic error in measures. High accuracy --> average values close to the real
A measeure is precise when the single measured values are very close to the average of the recorded measures

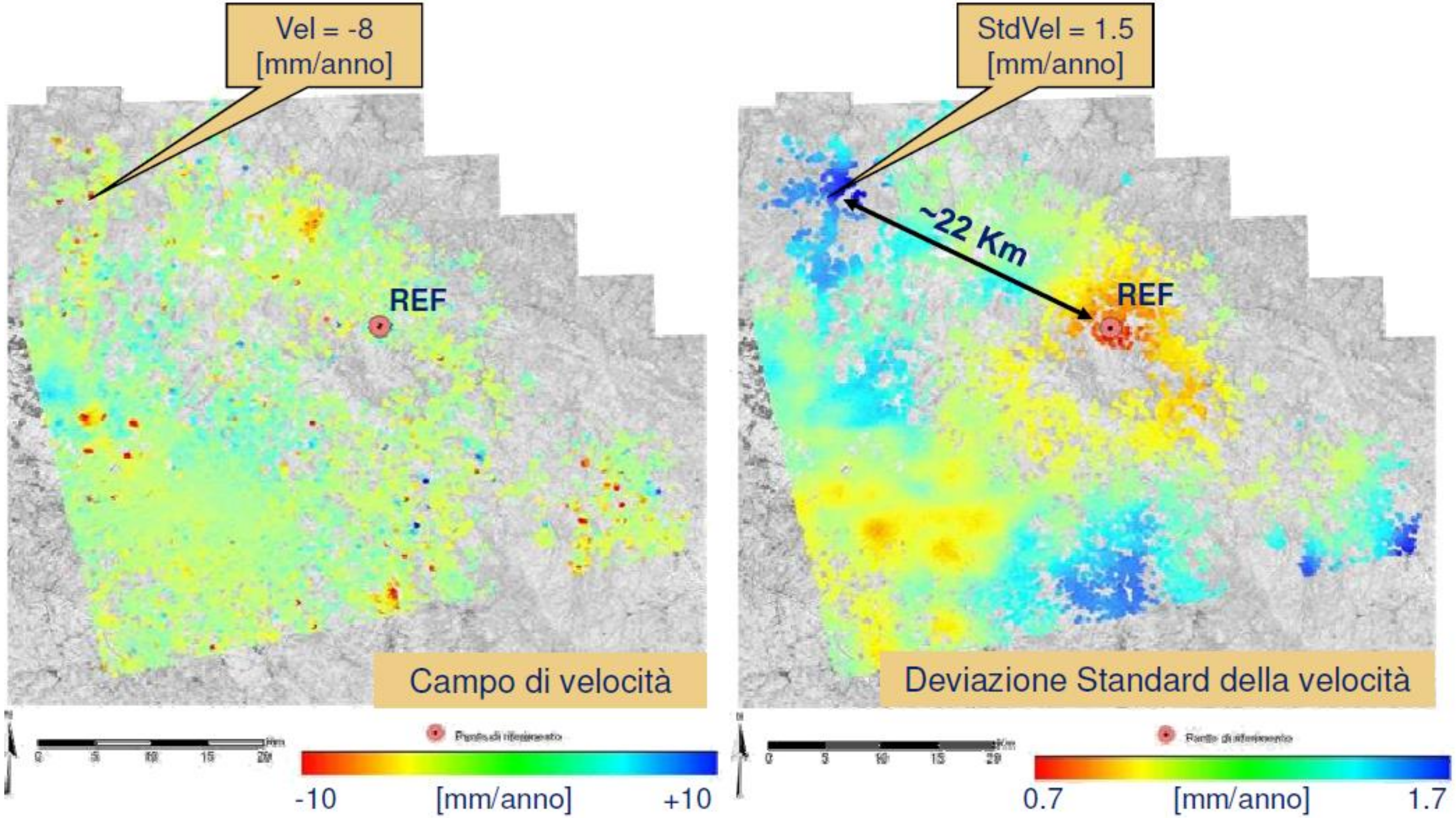
Quality parameters: the coherence

Coherence: evaluate the correspondance between data and displacement model used in the processing.
It assumes values between 0 and 1 (values close to 1 states an high correspondance with the model)
The reliability of the simulation increase with highest number of images into the processed dataset.



Quality parameters: the standard deviation

Standard deviation: it indicates how much the estimation of the difference of velocity of the point moves with respect to the reference point

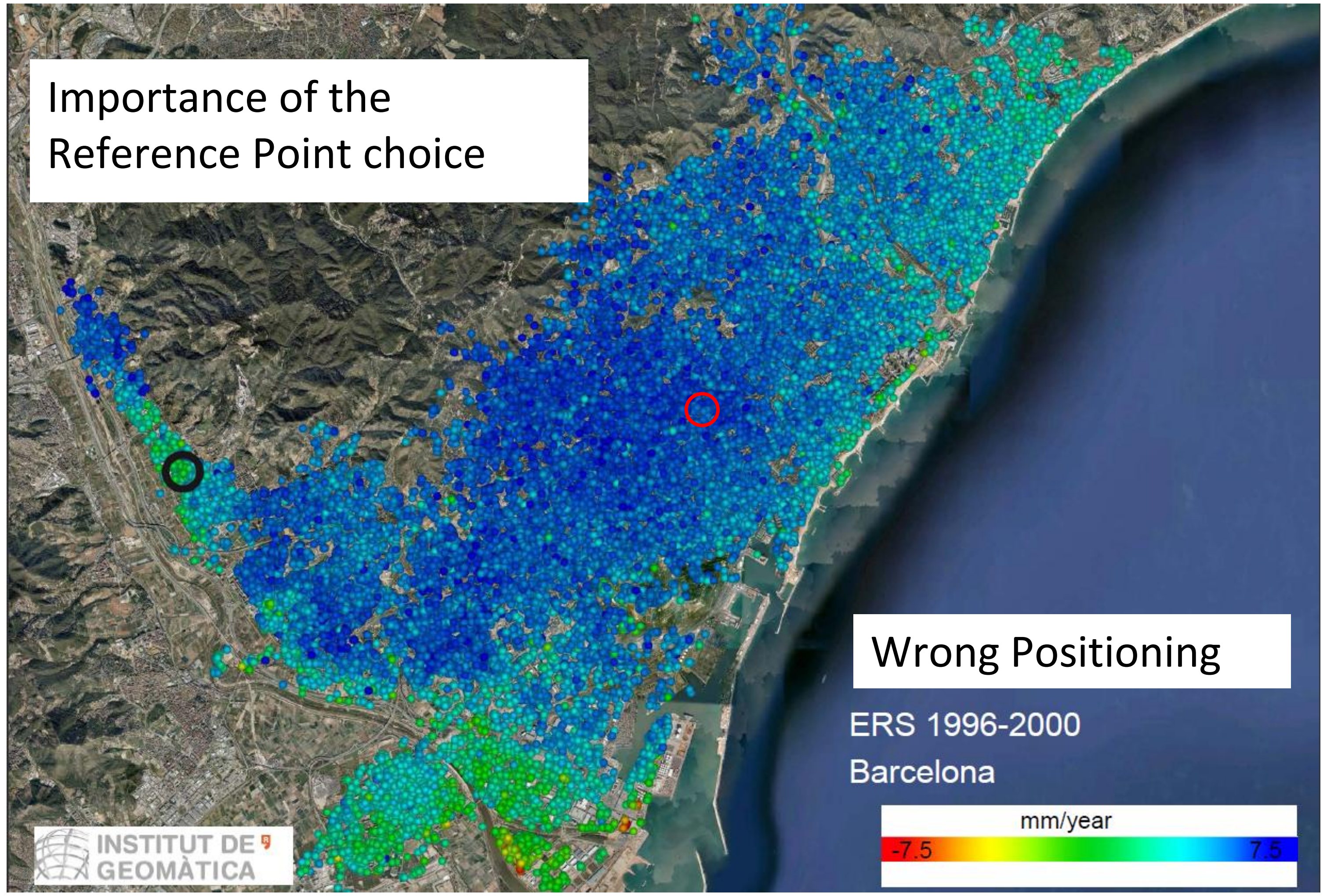


The standar deviation depends on:

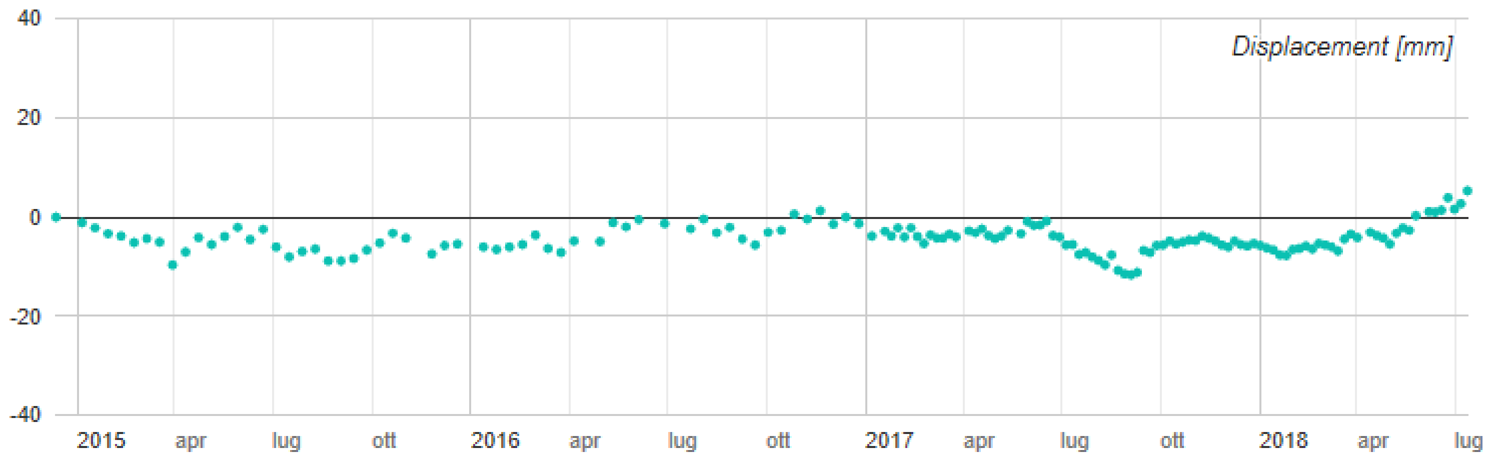
- Distance between the point and the reference point
- Topography of the area of interest

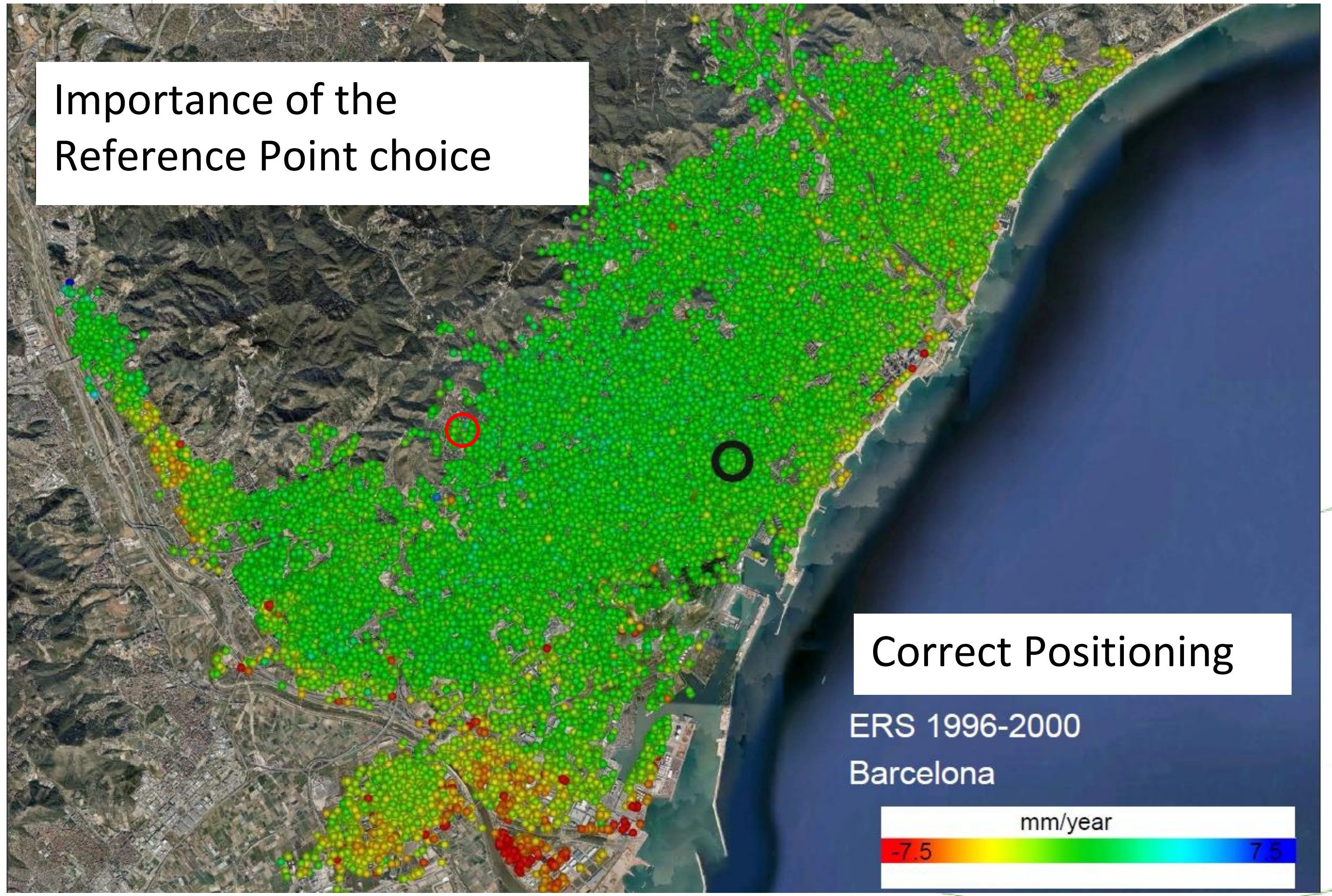
- The interferometric measurements are DIFFERENTIAL (or RELATIVE), thus referred to a common *reference point* for the whole area of interest
- The *reference point* is chosen based on the knowledge of the site, on the ancillary information and the availability of existing monitoring data
- The point MUST be stable (velocity approximately 0 mm/year) and MUST have a very high coherence (> 0.9)
- The interferometric measurements are temporally RELATIVE since referred to a fixed period of time, referred to the oldest processed images

Reference Point

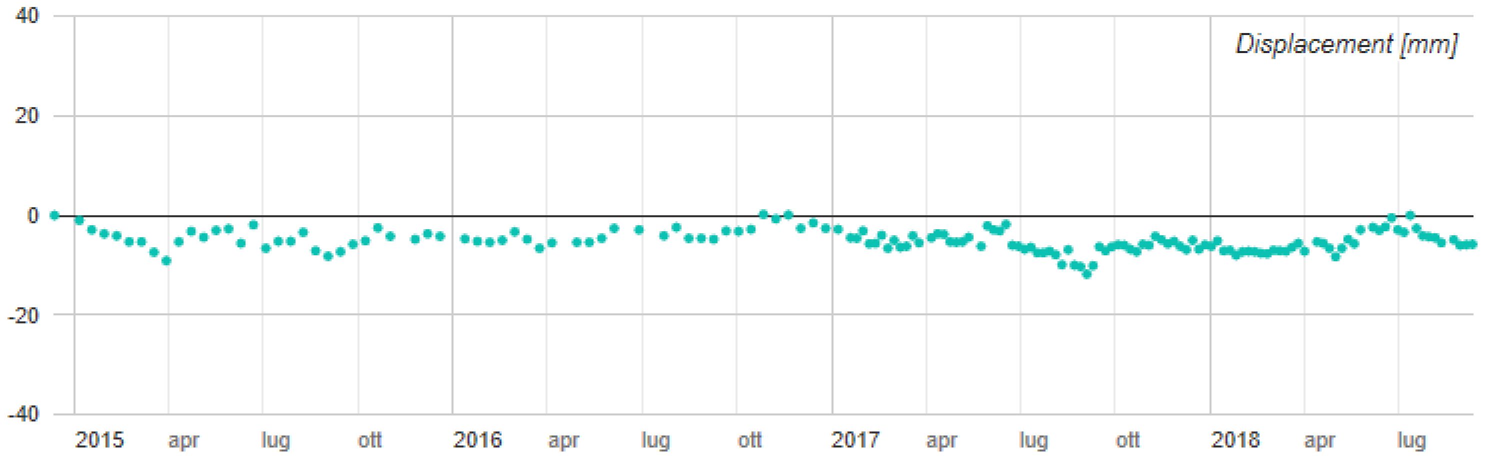


Time Series of the PS in the red circle.
Vel: +3.5 mm/year (uplift) - Coherence: 0.93 (high coherence)

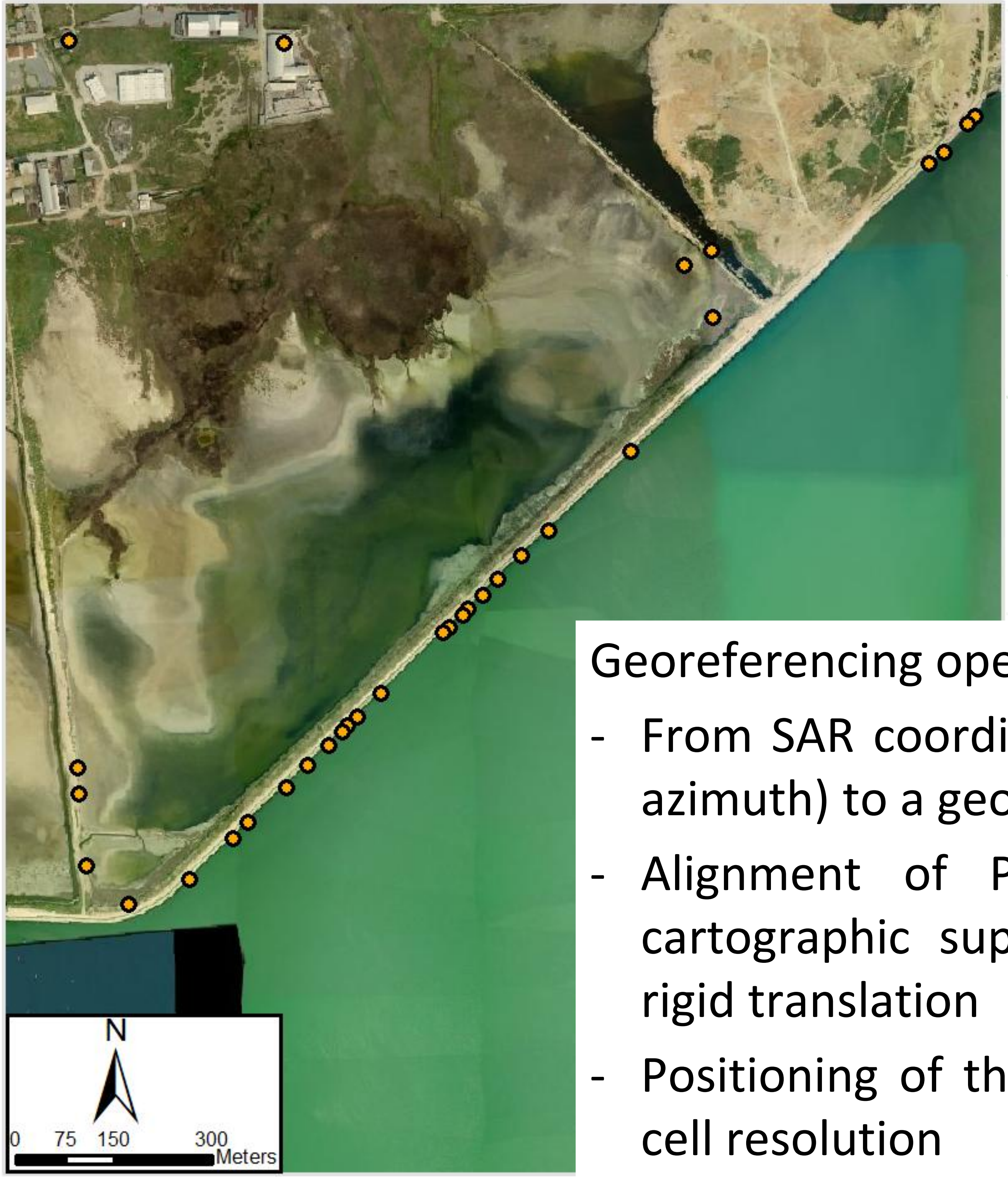




Time Series of the PS in the red circle.
Vel: -0.4 mm/year (stable) - Coherence: 0.91 (high coherence)



Georeferencing precision



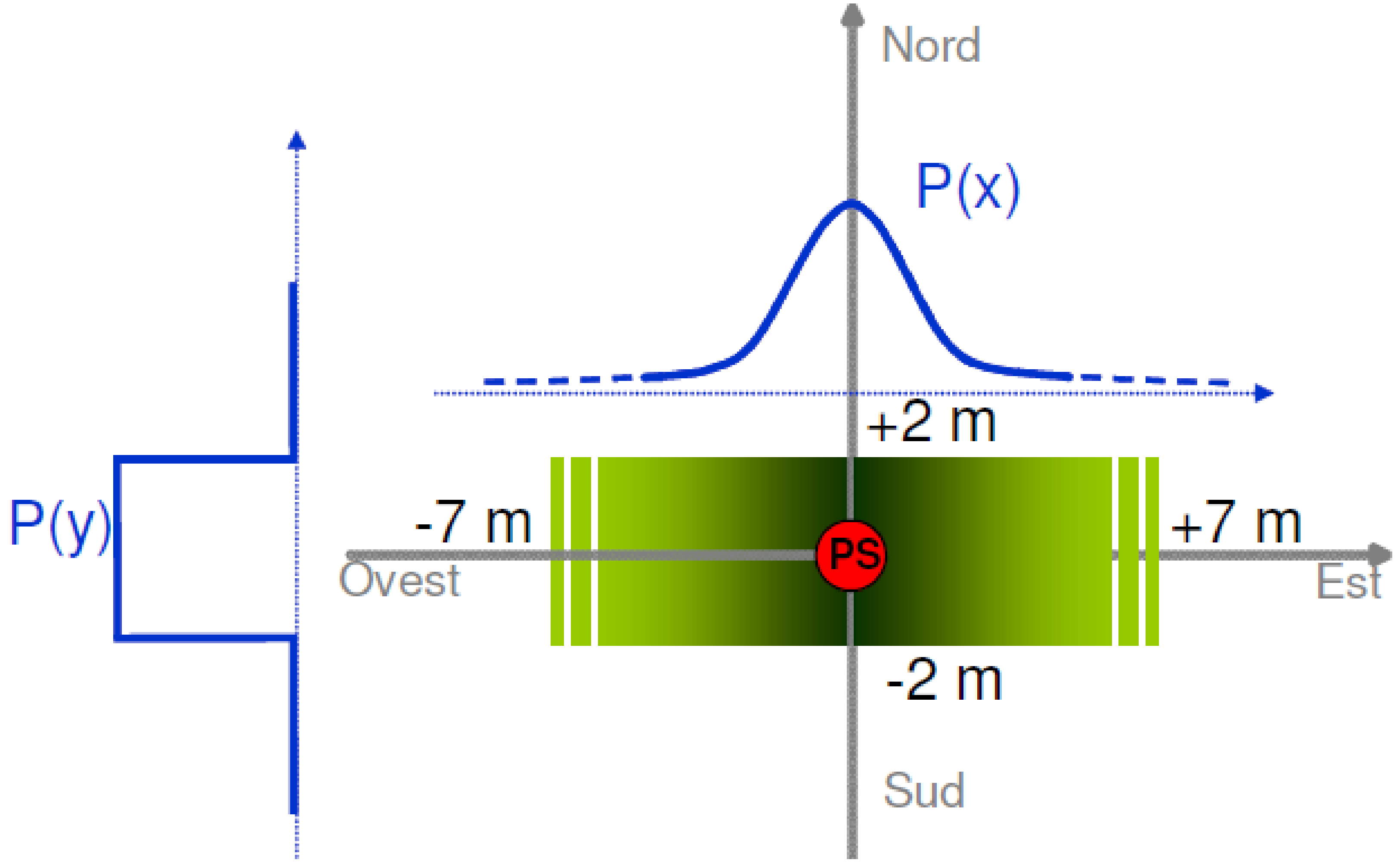
Georeferencing operation:

- From SAR coordinate (slant range and azimuth) to a geographical coordinates
- Alignment of PS on the available cartographic support by means of a rigid translation
- Positioning of the PS into che ground cell resolution

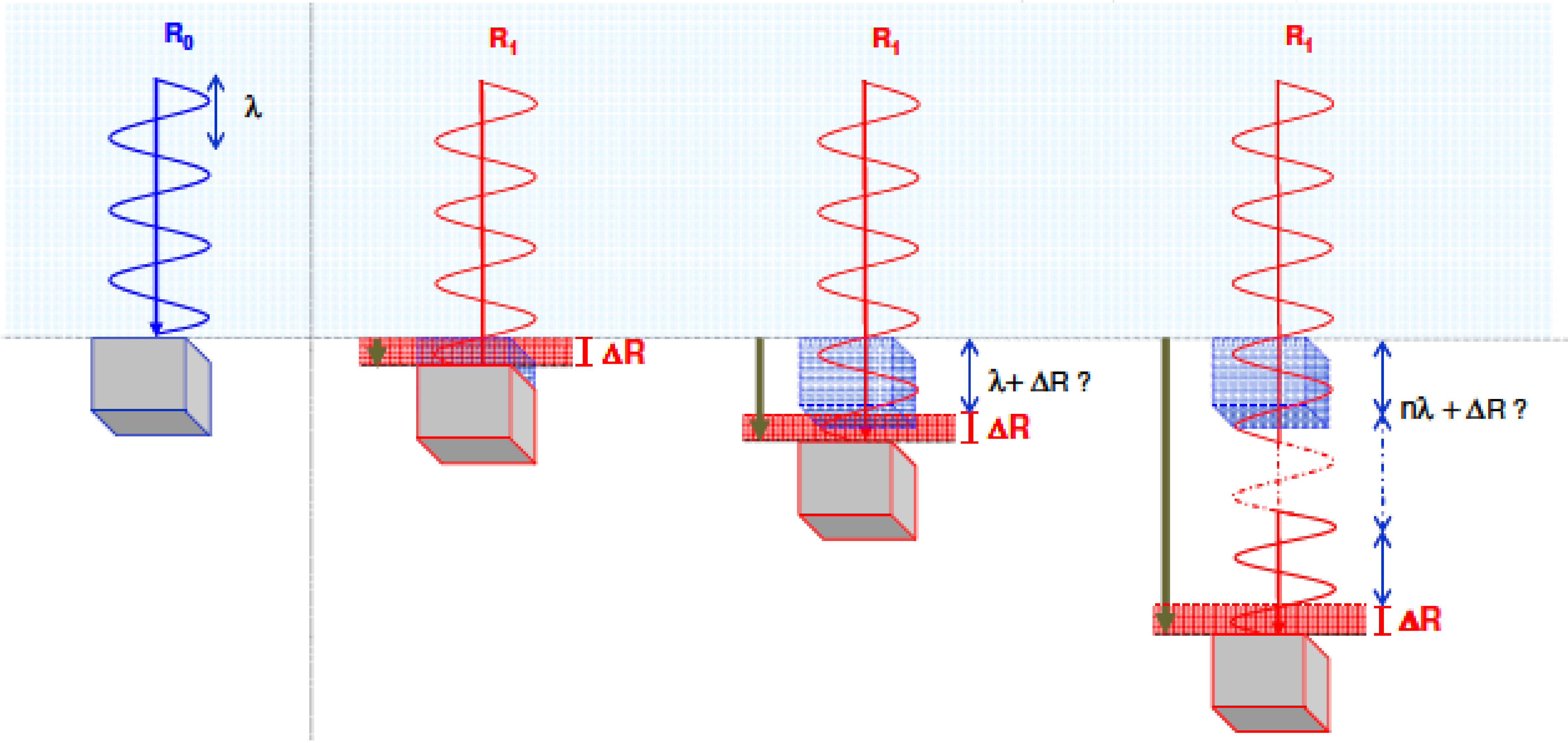
Georeferencing precision

Posizionamento	Est	Nord	Verticale
Banda C Precisione (1σ)	± 7 m	± 2 m	± 1,5 m
Banda X Precisione (1σ)	± 4m	± 1 m	± 1,5 m

Valori tipici per distanze < 1 km dal punto di riferimento per un dataset di almeno 5 anni (satellite banda C)



Measures ambiguity



If the target moves (ΔR) less than to λ/4, the radar system can estimate the displacement without ambiguity.

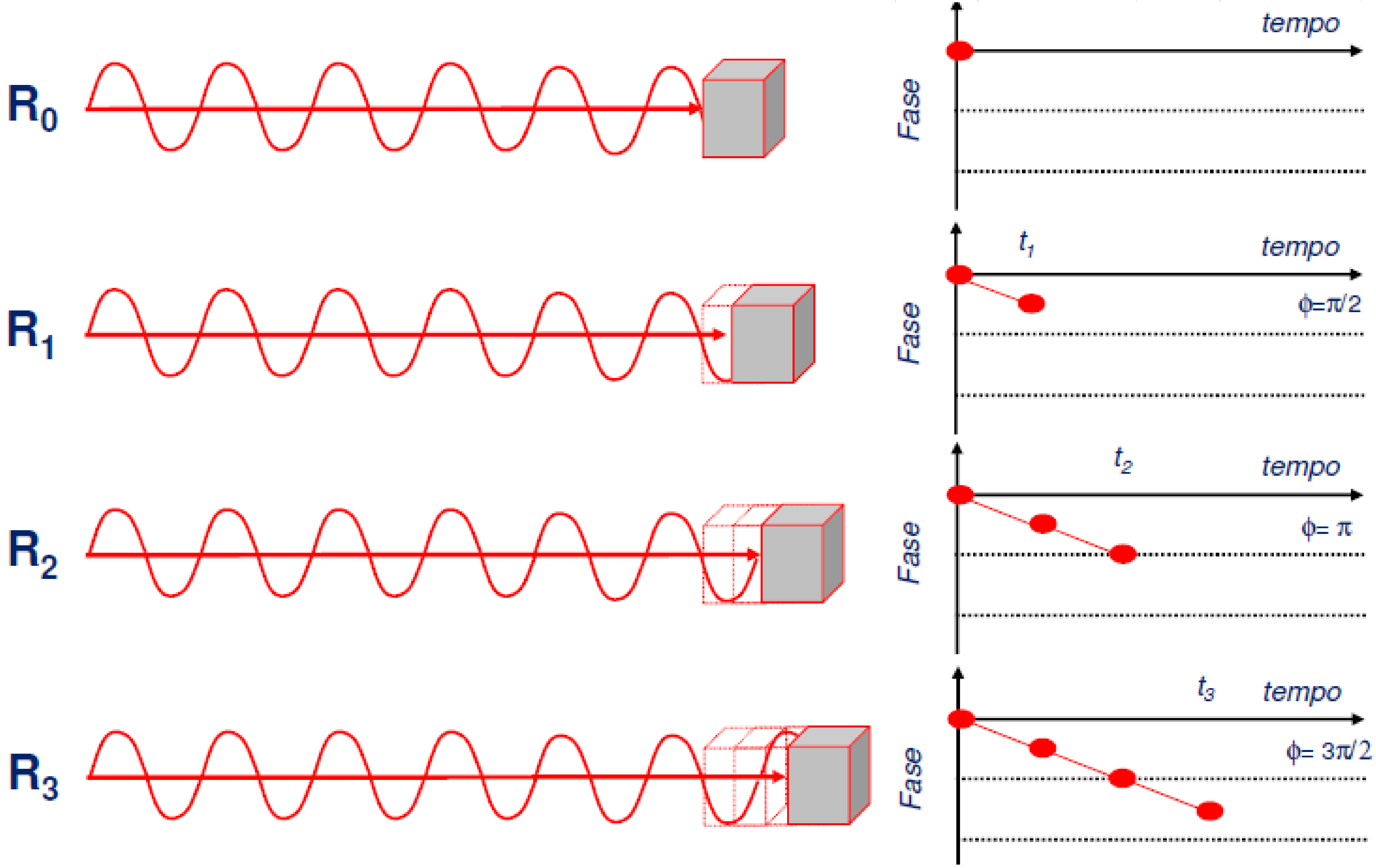
Grater movements can be wrongly estimated.

If the target moves (ΔR) plus 1, 2, n times λ/4 between two subsequent acquisition, the system can estimate a ΔR displacement, but it can not understand the number of complete cycles made by the target.

The sensors can not understand that the electromagnetic wave has made come cycle of phase

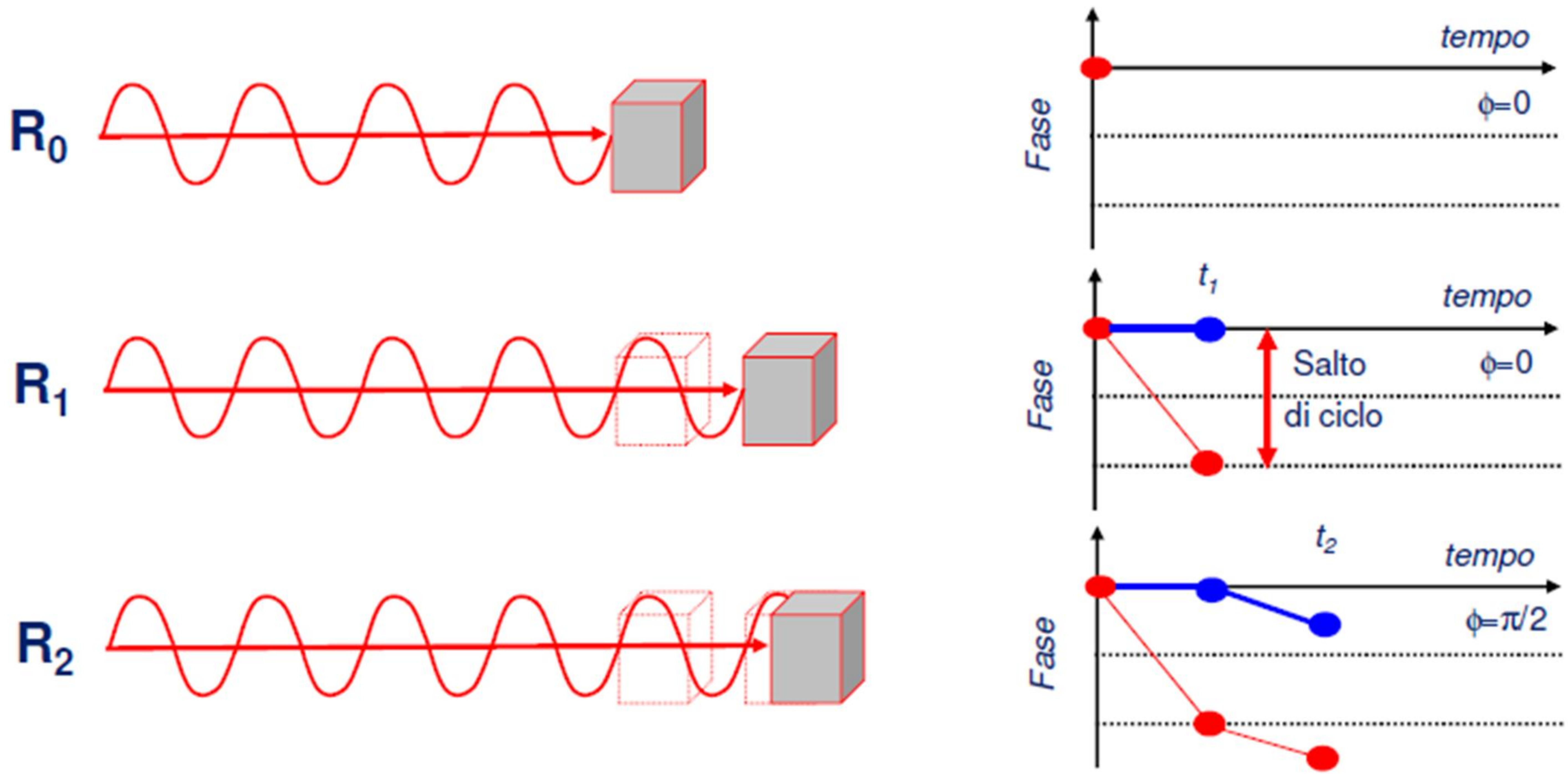
Phase NOT ambuguous

Low movement - High temporal sampling - High density of PS



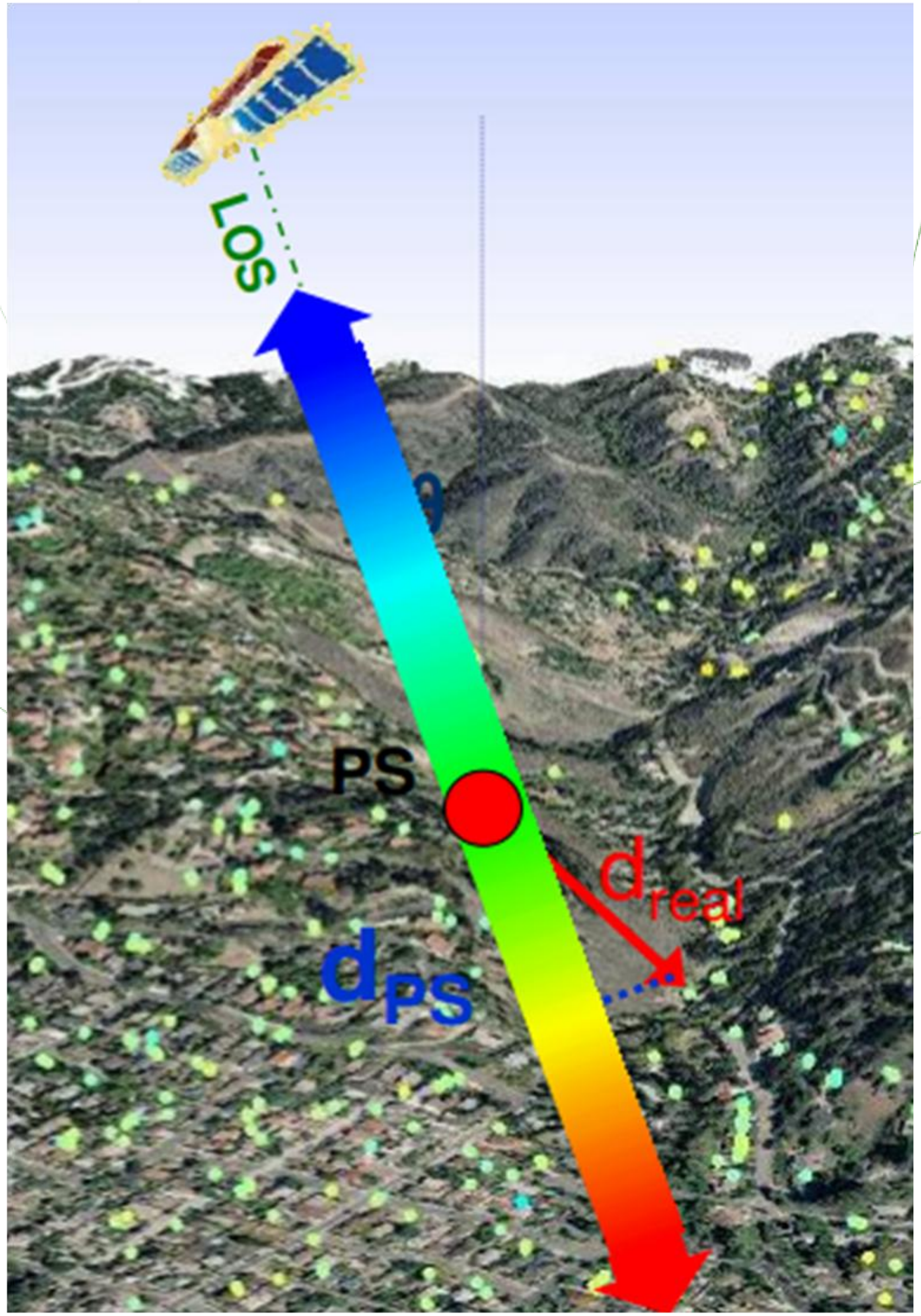
Ambuguous Phase - phase jump

Fast movement - Low temporal sampling - Low density of PS

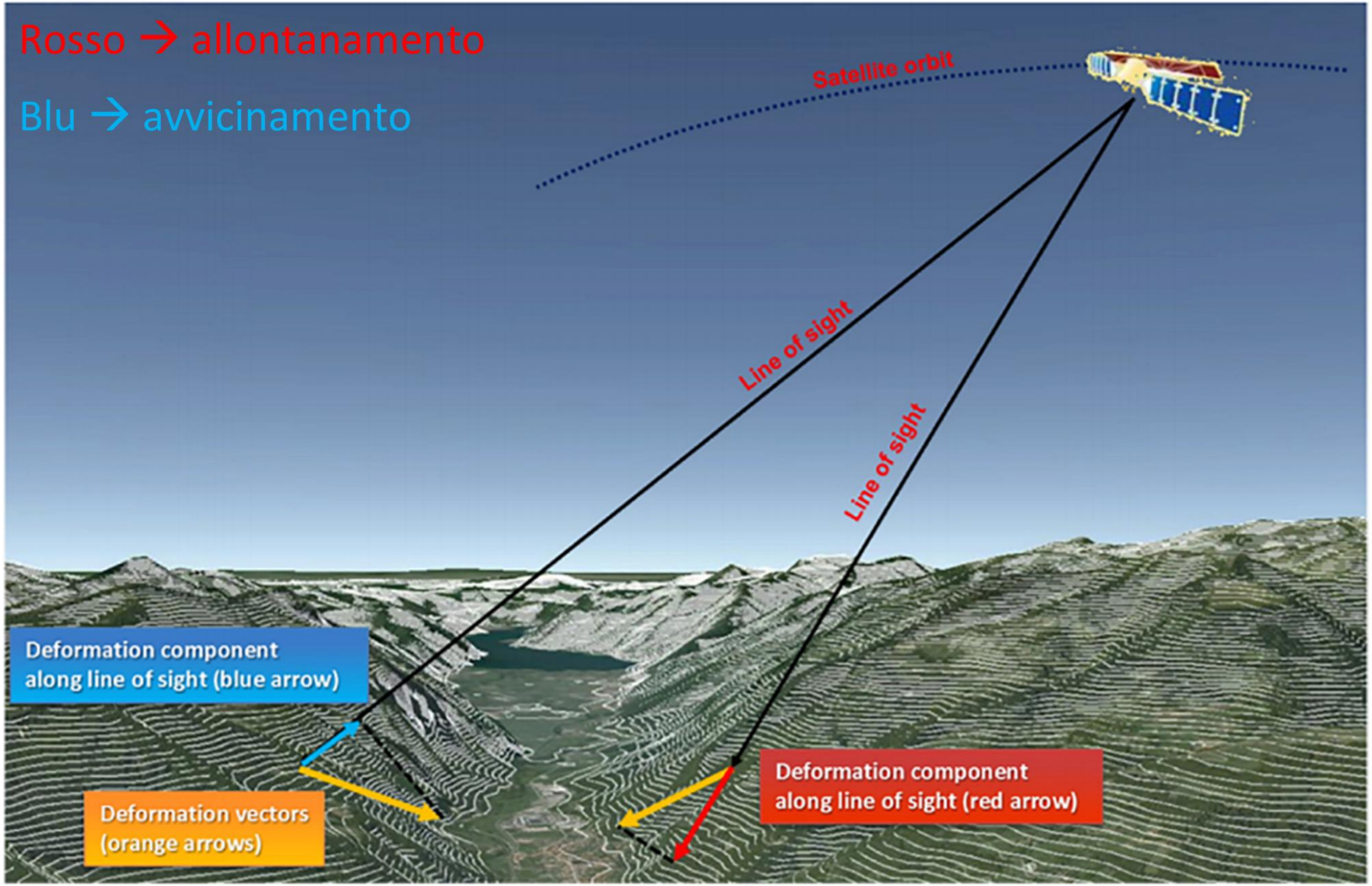


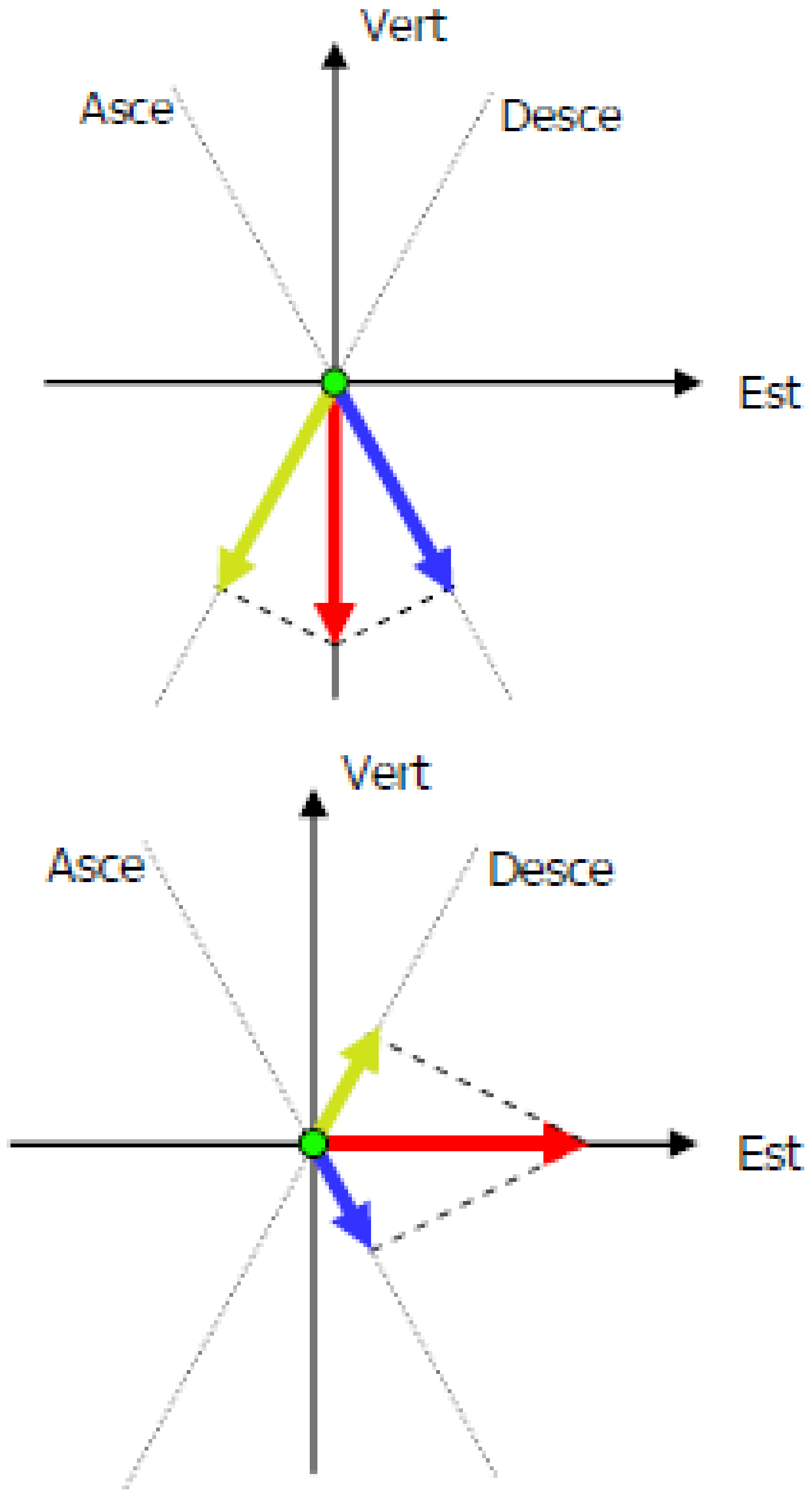
How to read the deformation maps

- **GREEN** represents the "stability" of the point. A range (usually ±2 mm/year) defined on the standard deviation of the datasets is used to set it
- **HOT COLORS** represent a movement of the backscattering element away from the satellite
- **COLD COLORS** represent a movement of the backscattering element towards to the satellite



How to read the deformation maps





$$\lambda/4/\text{Rev.Time}*365$$

Satellite	Maximum velocity detectable
ERS 1/2	14.7 cm/yr
Envisat	21.2 cm/yr
RADARSAT	25.7 cm/yr
TerraSAR-X	35.3 cm/yr
COSMO-SkyMed	42.6 cm/yr
ALOS-2	46.8 cm/yr
Sentinel-1 (6 giorni)	85.2 cm/yr

$\lambda/4$ è intrinsic limit of the interferometric technique

Limitations on velocity

Classe	Descrizione	Danni osservabili	Velocità tipica	Velocità (m/s)
7	Estremamente rapida	Catastrofe di eccezionale violenza. Edifici distrutti per l'impatto del materiale spostato. Molti morti. Fuga impossibile.	> 5 m/s	5
6	Molto rapida	Perdita di alcune vite umane. Velocità troppo elevata per permettere l'evacuazione delle persone.	> 3 m/min	$5 \cdot 10^{-2}$
5	Rapida	Evacuazione possibile. Distruzione di strutture, immobili ed installazioni permanenti.	> 1.8 m/hr	$5 \cdot 10^{-4}$
4	Moderata	Alcune strutture temporanee o poco danneggiabili possono essere mantenute.	> 13 m/mese	$5 \cdot 10^{-6}$
3	Lenta	Possibilità di intraprendere lavori di riabilitazione e restauro durante il movimento. Le strutture meno danneggiabili possono essere mantenute con frequenti lavori di riabilitazione se il movimento totale non è troppo grande durante una particolare fase di accelerazione.	> 1.6 m/anno	$5 \cdot 10^{-8}$
2	Molto lenta	Alcune strutture permanenti possono non essere danneggiate dal movimento.	> 16 mm/anno	$5 \cdot 10^{-10}$
1	Estremamente lenta	Impercettibile senza strumenti di monitoraggio. Costruzioni di edifici possibile con precauzioni.	< 16 mm/anno	

- The maximum velocity that can be measured allow monitoring the slow phenomena
- Subsidence can be monitored, but not sinkhole (maybe previous displacement)
- Only landslides defined as “extremely slow” and “very slow” can be monitored

Landslide classification

Table 5 Summary of the proposed new version of the Varnes classification system. The words in italics are placeholders (use only one)

Type of movement	Rock	Soil
Fall	1. *Rock/ice* fall[a]	2. *Boulder/debris/silt* fall[a]
Topple	3. Rock block topple[a]	5. *Gravel/sand/silt* topple[a]
	4. Rock flexural topple	
Slide	6. Rock rotational slide	11. *Clay/silt* rotational slide
	7. Rock planar slide[a]	12. *Clay/silt* planar slide
	8. Rock wedge slide[a]	13. *Gravel/sand/debris* slide[a]
	9. Rock compound slide	14. *Clay/silt* compound slide
	10. Rock irregular slide[a]	
Spread	15. Rock slope spread	16. *Sand/silt* liquefaction spread[a]
		17. Sensitive clay spread[a]
Flow	18. *Rock/ice* avalanche[a]	19. *Sand/silt/debris* dry flow
		20. *Sand/silt/debris* flowslide[a]
		21. Sensitive clay flowslide[a]
		22. Debris flow[a]
		23. Mud flow[a]
		24. Debris flood
		25. Debris avalanche[a]
		26. Earthflow
		27. Peat flow
Slope deformation	28. Mountain slope deformation	30. Soil slope deformation
	29. Rock slope deformation	31. Soil creep
		32. Solifluction

For formal definitions of the landslide types, see text of the paper.

[a] Movement types that usually reach extremely rapid velocities as defined by Cruden and Varnes (1996). The other landslide types are most often (but not always) extremely slow to very rapid

Hungr et al. (2014)

Landslide classification

Rapid long run out landslides

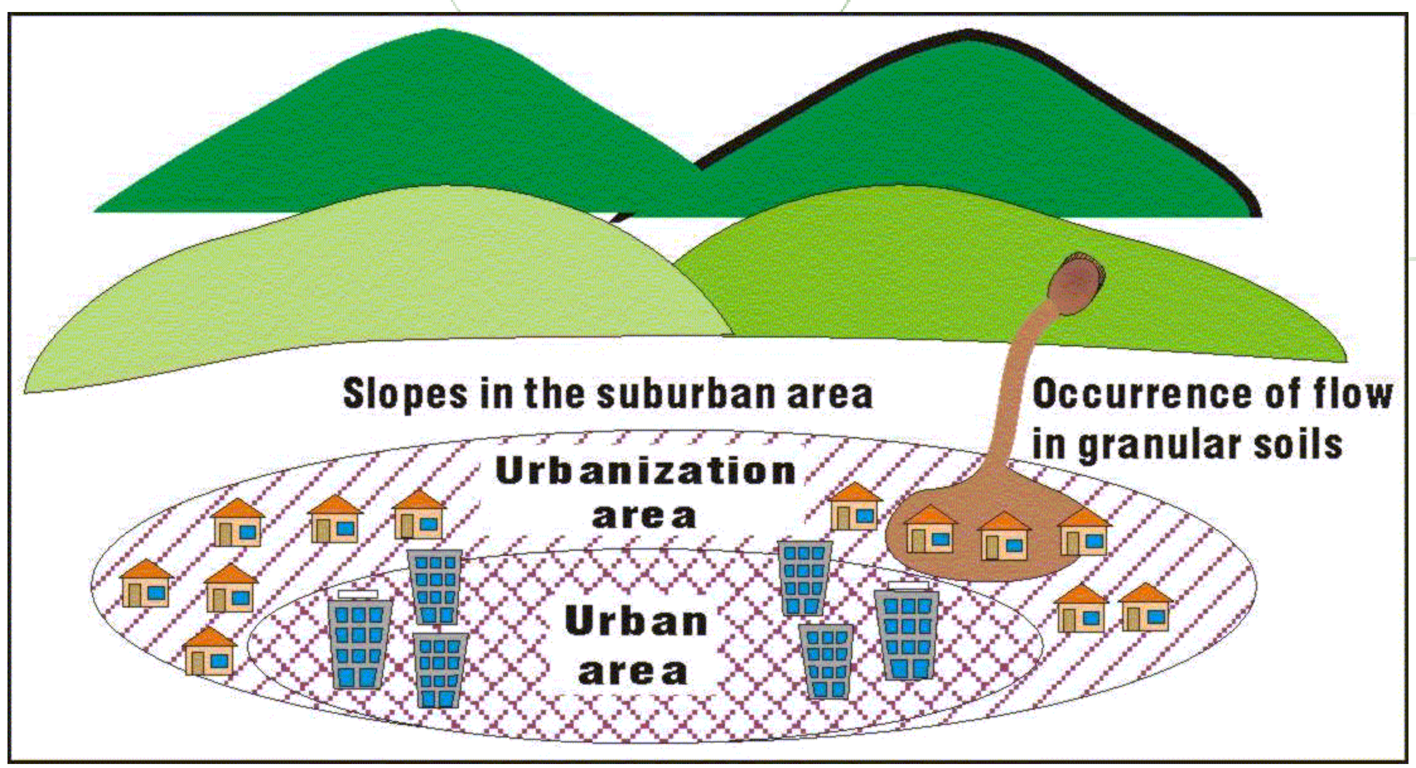
Caused by earthquakes and heavy rainfalls

Characteristics

- Rapid Motion
- Great Impact Force
- Wide Disaster Area

Great number of death

	Rapid - velocity - Slow	
Long run-out distance	Rapid long run-out landslides (liquefied slides, etc)	slow long - traveling landslides (Earth flows, etc)
short-moving landslides	Rapid short-moving landslides (first -time slides)	Slow short - moving landslides (reactivated landslides)



Kyoji Sassa (2001)

Rapid Long-runout

Liquefaction failures
Debris flows
Debris avalanches
Rock avalanches

Slow Long-runout

Reactivations
Earth flows
Mus flows
Mudslides

Rapid Short-runout

1st time failures
Rock falls
Rock slides

Slow Short-runout

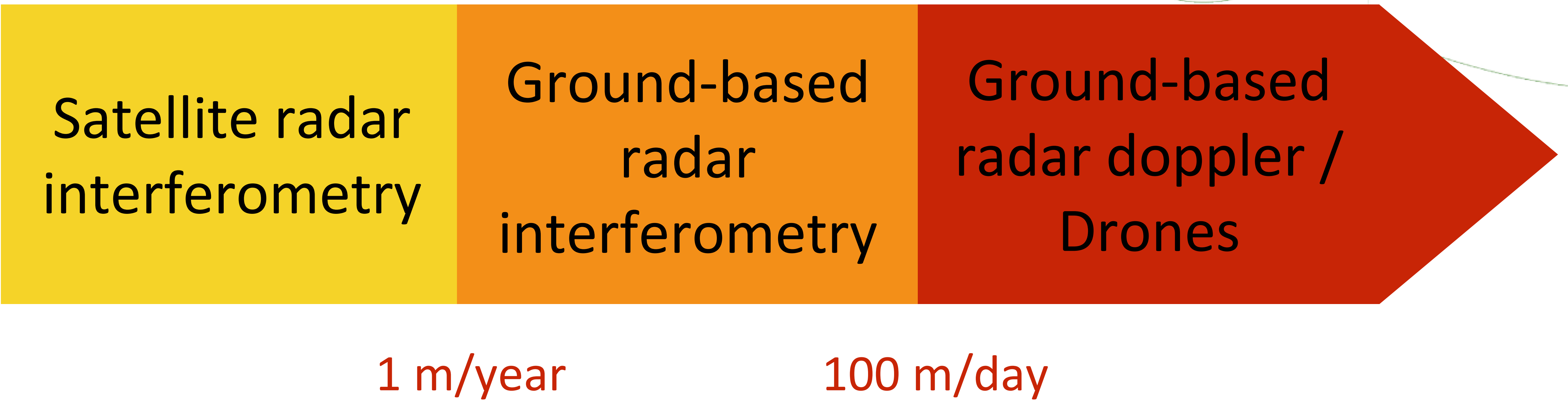
Reactivations
Earth slide
Rock slide

Velocity vs monitoring systems

Table 2 Landslide velocity scale (WP/WLI 1995 and Cruden and Varnes 1996)

Velocity class	Description	Velocity (mm/s)	Typical velocity	Response[a]
7	Extremely rapid	5×10^{3}	5 m/s	Nil
6	Very rapid	5×10^{1}	3 m/min	Nil
5	Rapid	5×10^{-1}	1.8 m/h	Evacuation
4	Moderate	5×10^{-3}	13 m/month	Evacuation
3	Slow	5×10^{-5}	1.6 m/year	Maintenance
2	Very slow	5×10^{-7}	16 mm/year	Maintenance
1	Extremely Slow			Nil

[a] Based on Hungr (1981)



THANKS!

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