Formations Universitaires

Samedi 4 Mai 2019, Port-au-Prince, Haiti

Initiation imagerie radar (SAR)

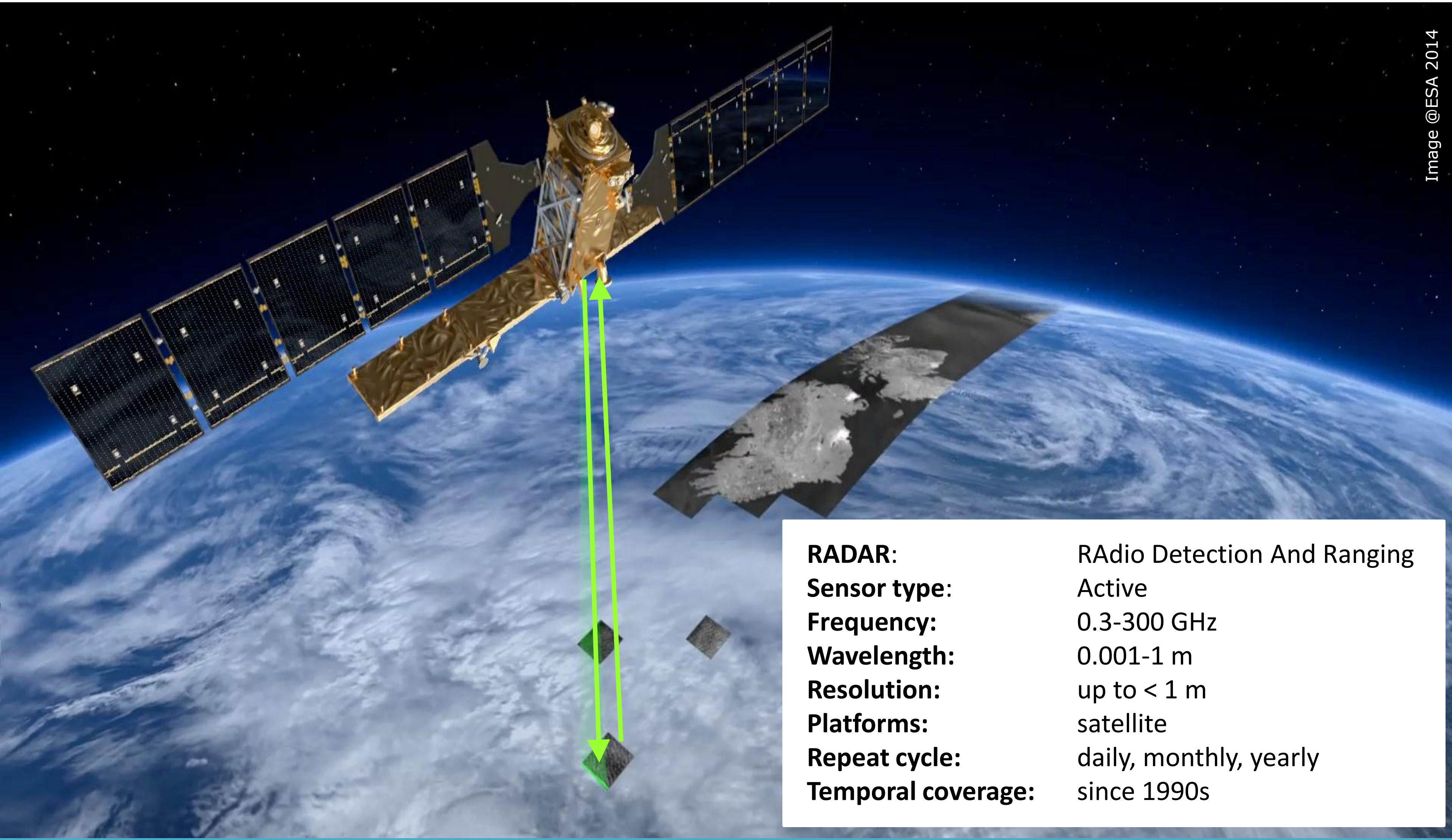
Dr. Francesca Cigna, Dr. Deodato Tapete

Italian Space Agency (ASI), Scientific Research Unit

Presentation outline

- **Synthetic Aperture Radar (SAR)**
- **Principles of SAR imaging**
- **Microwave bands & active sensors**
- **SAR image processing methods**
  - ❑ Change detection
  - ❑ Interferometric SAR (InSAR)
  - ❑ Persistent Scatterer Interferometry (PS-InSAR)
- **Available SAR data** (focus on Sentinel-1 & COSMO-SkyMed)
- **Q&A**

Synthetic Aperture Radar (SAR) imagery



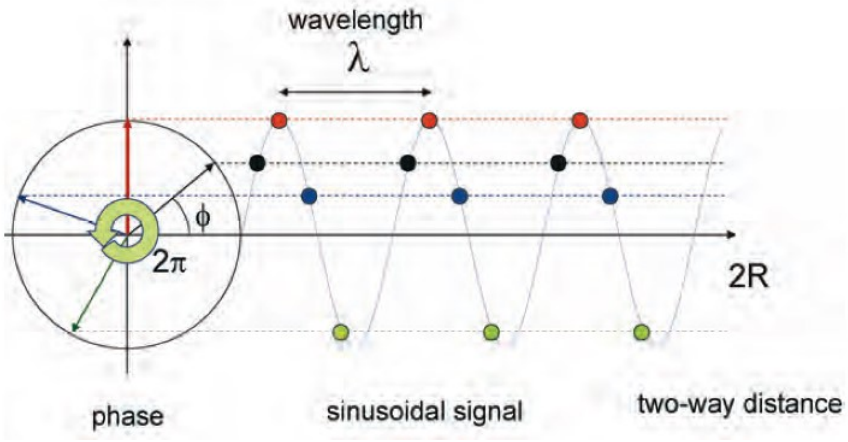
RADAR:	RAdio Detection And Ranging
Sensor type:	Active
Frequency:	0.3-300 GHz
Wavelength:	0.001-1 m
Resolution:	up to < 1 m
Platforms:	satellite
Repeat cycle:	daily, monthly, yearly
Temporal coverage:	since 1990s

Information content of SAR images

Agenzia Spaziale Italiana

- **Amplitude**

Measure of the strength of a signal, in this context the height of the electromagnetic wave.

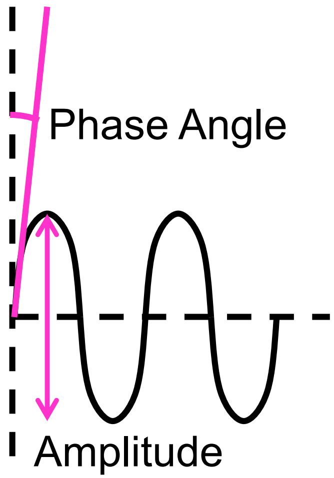


Relationship with backscattering properties of the <u>scatterers</u> on the ground

- **Phase**

Property of a periodic phenomenon (electromagnetic wave) referred to an arbitrary origin. Expressed in degrees or radians.

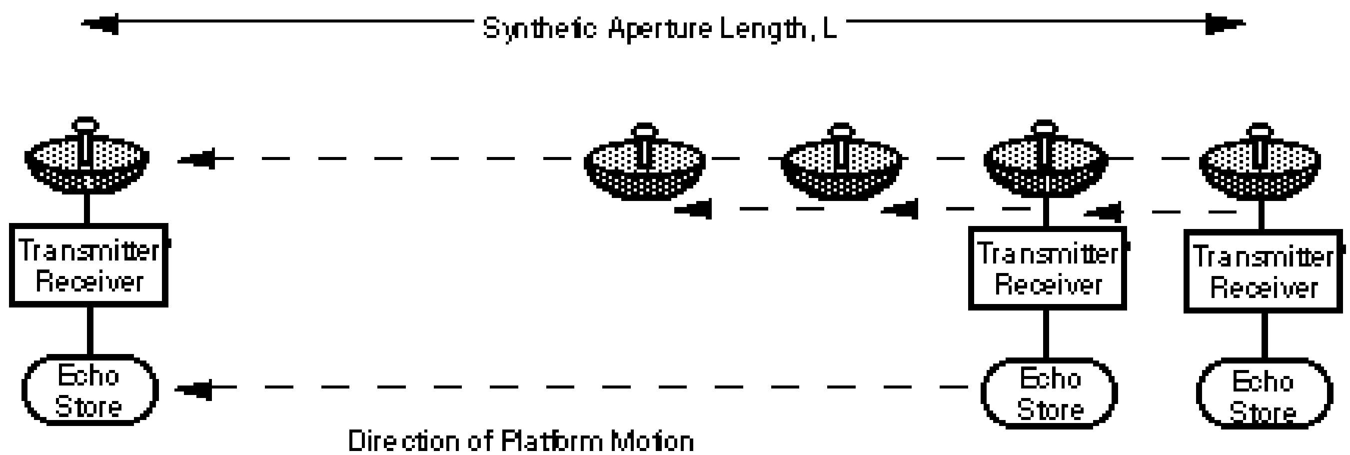
It is the information used in SAR Interferometry (InSAR)



Synthetic Aperture Radar (SAR) imagery

Objective: to produce an antenna larger than the physical one onboard the radar platform

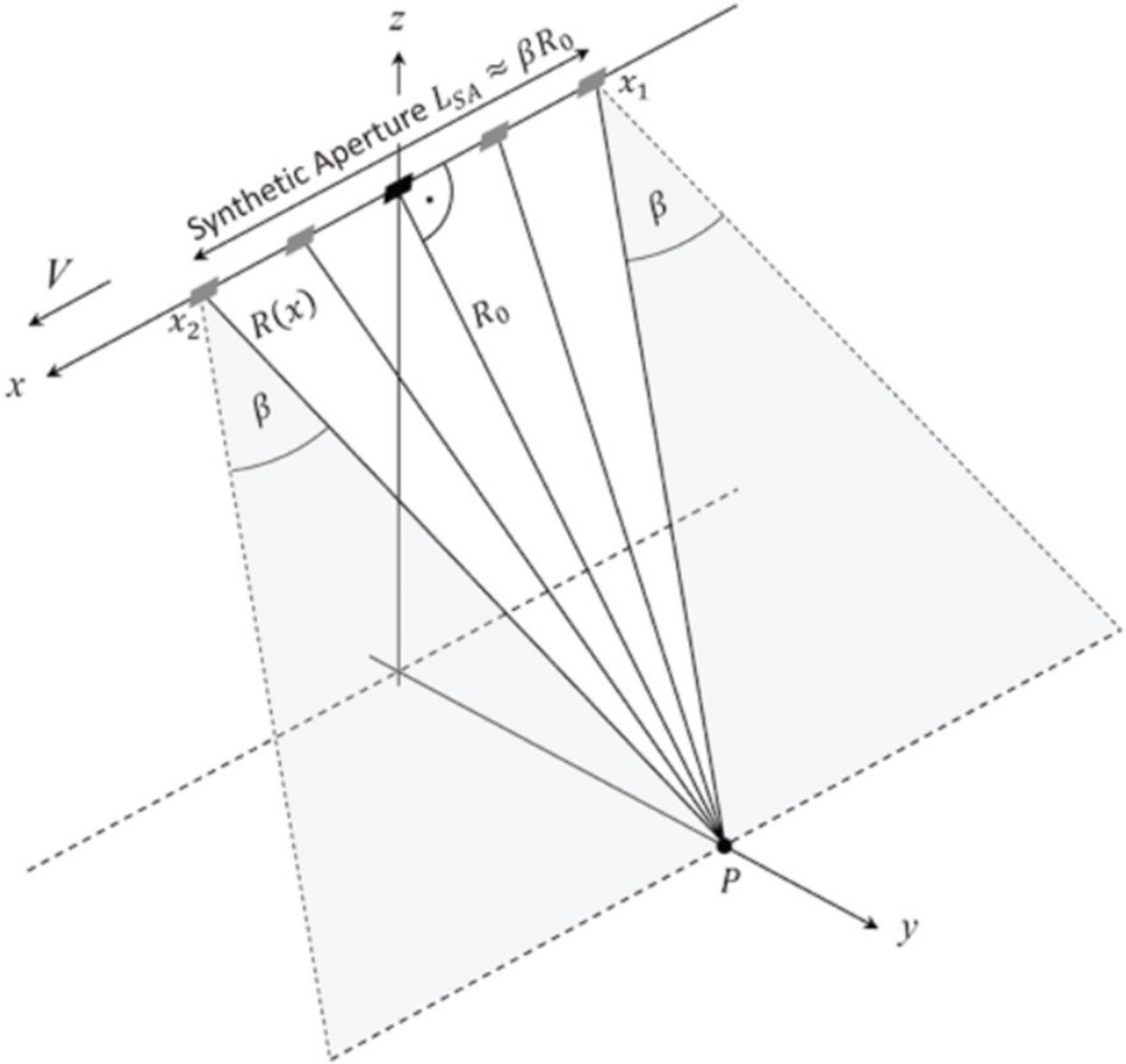
- As the sensor moves along its motion direction, a pulse is transmitted at each position and return echoes are recorded



ESA Earthnet Online (2013)

Same principle for all the types of platform (space-borne, air-borne, ground-based SAR)

In the case of a space-borne SAR sensor

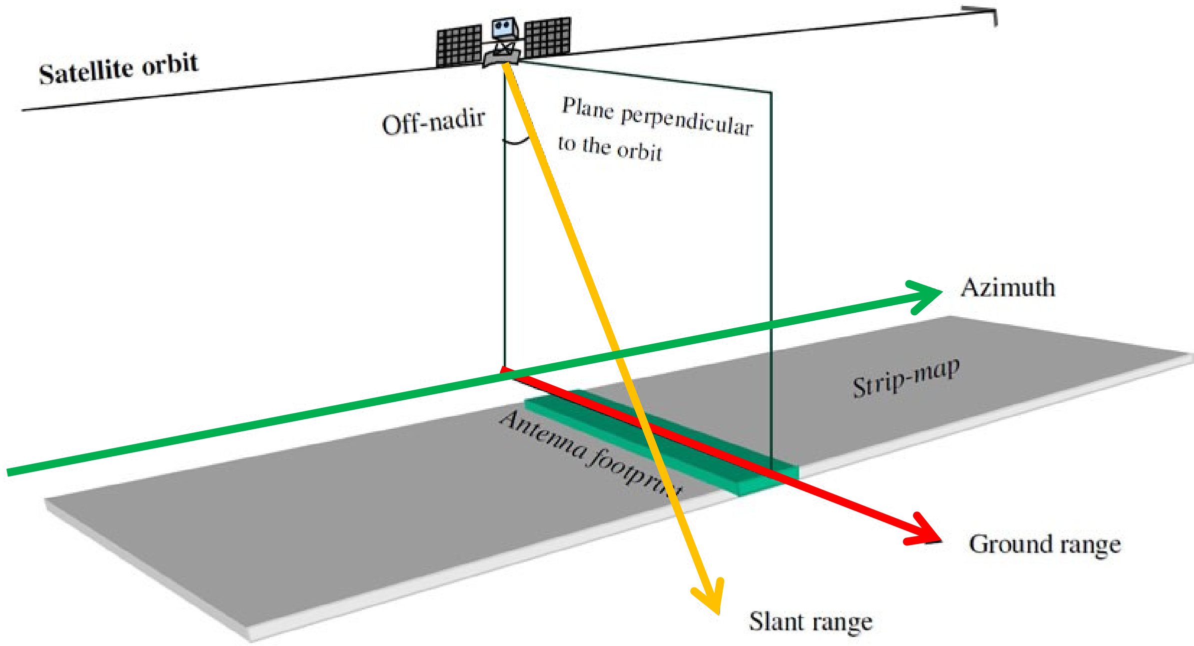


Space-borne SAR imaging – basic terminology

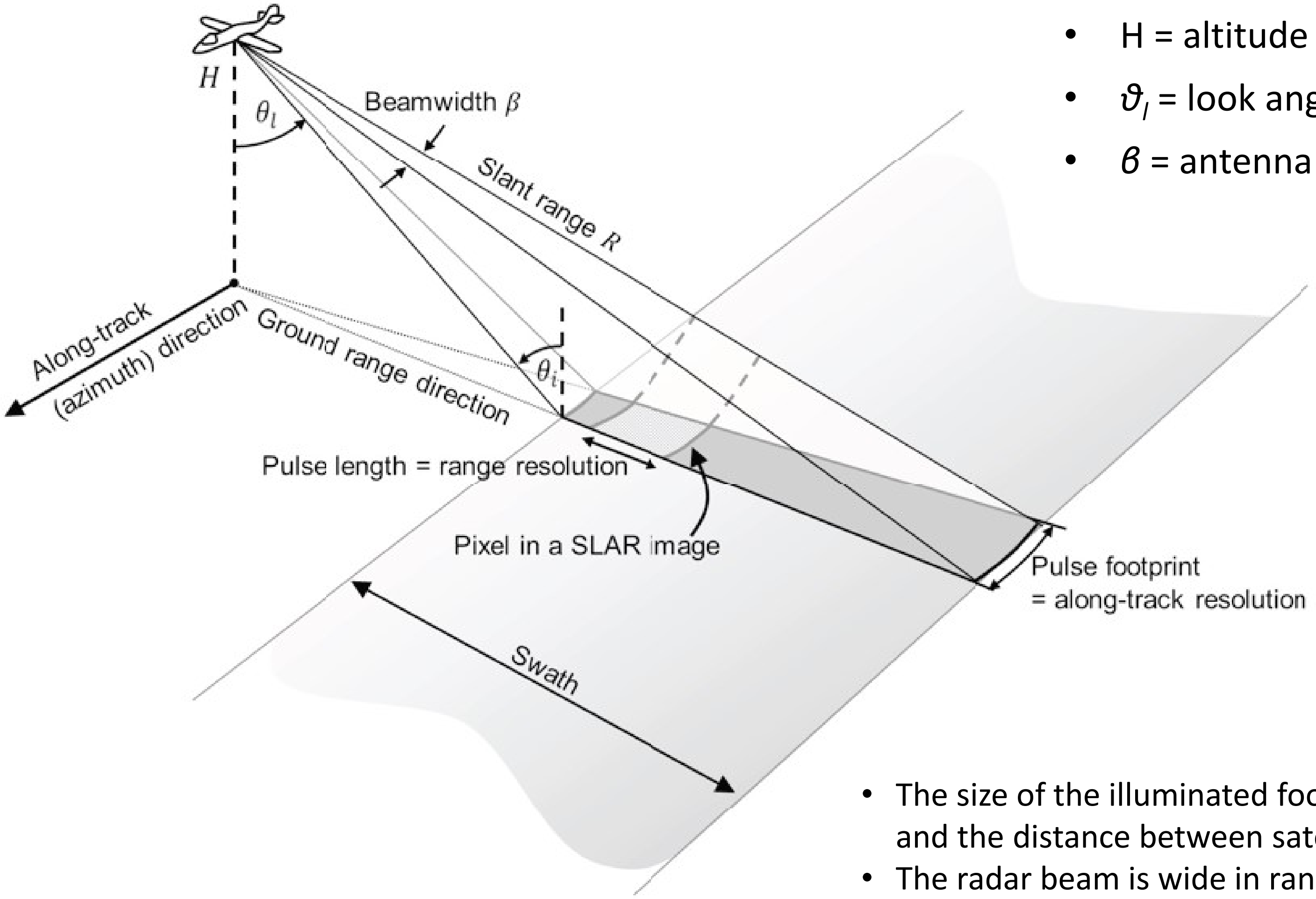
- direction (i.e. **azimuth** direction, flight track)
- direction (i.e. ground **range** direction)
- (i.e. **slant-range** direction)
- Off-nadir angle (or look angle, ϑ_l): inclination of the antenna with respect to the nadir (typical range 20-50°)

The figure is based on the assumption that Earth surface is flat!

Under this assumption, look angle, ϑ_l = incidence angle, ϑ_i



Azimuth (along-track) and Range resolution

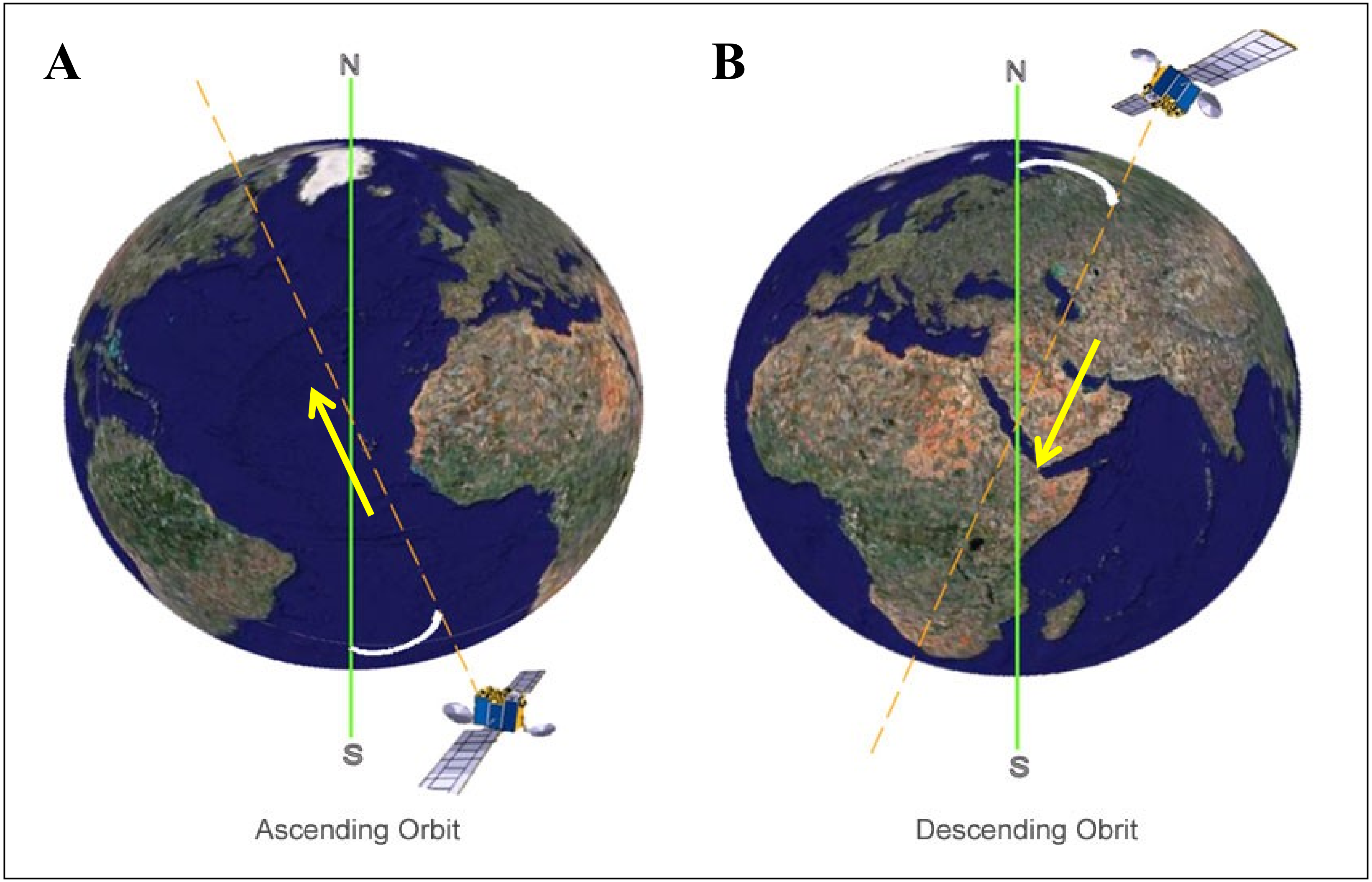


- H = altitude H
- ϑ_l = look angle
- β = antenna beam-width

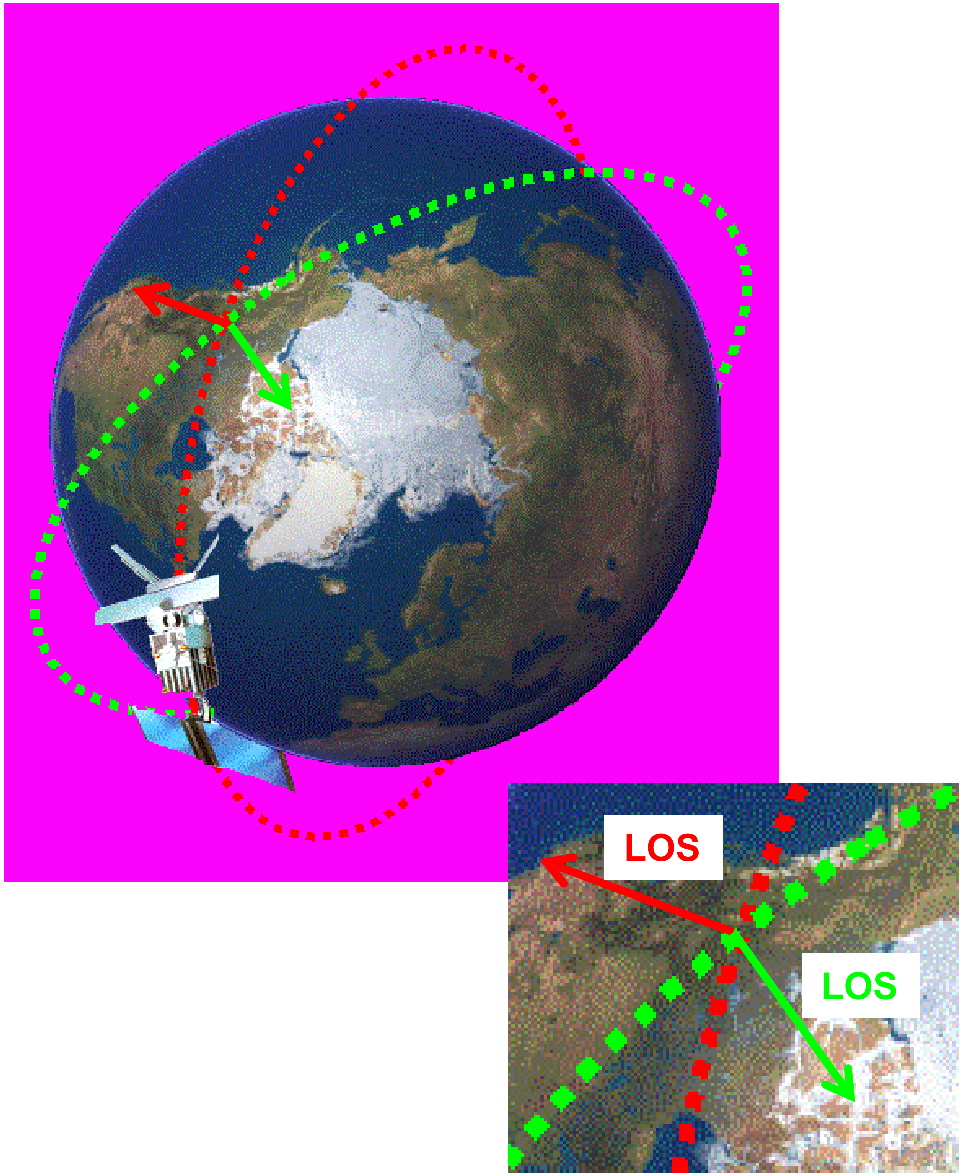
- The size of the illuminated footprint is defined by β and the distance between satellite and ground R
- The radar beam is wide in range direction but narrow in azimuth

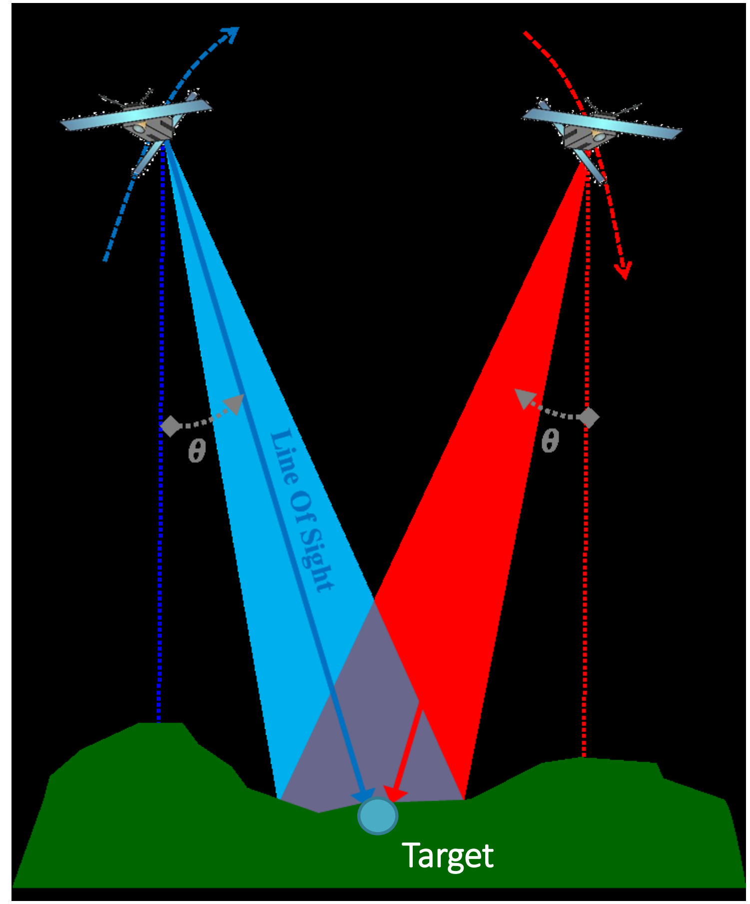
SAR Handbook: Comprehensive Methodologies for Forest Monitoring and Biomass Estimation. Eds. Flores, A., Herndon, K., Thapa, R., Cherrington, E. NASA. 2019. DOI: 10.25966/hbm1-ej07

Ascending and descending passes



Complementary observation geometries



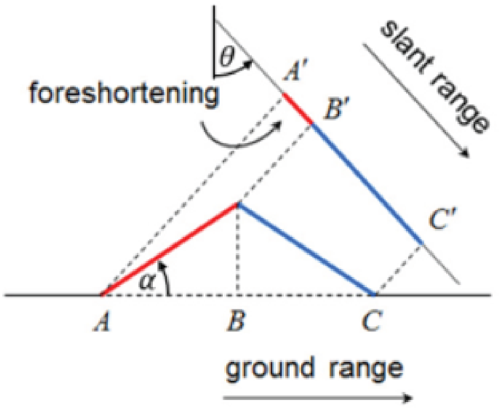


Slant-range distortions

Agenzia Spaziale Italiana

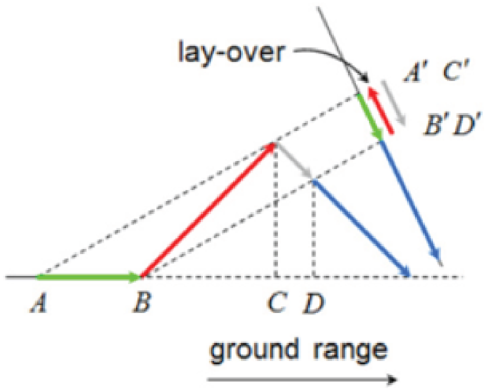
FORESHORTENING

- Sensor-facing slope foreshortened in image
- Foreshortening effects *decrease* with increasing look angle



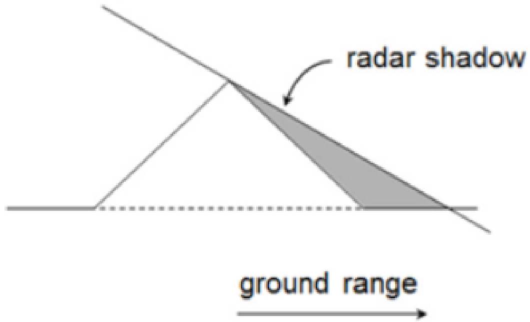
LAYOVER

- Mountain top overlain on ground ahead of mountain
- Layover effects *decrease* with increasing look angle



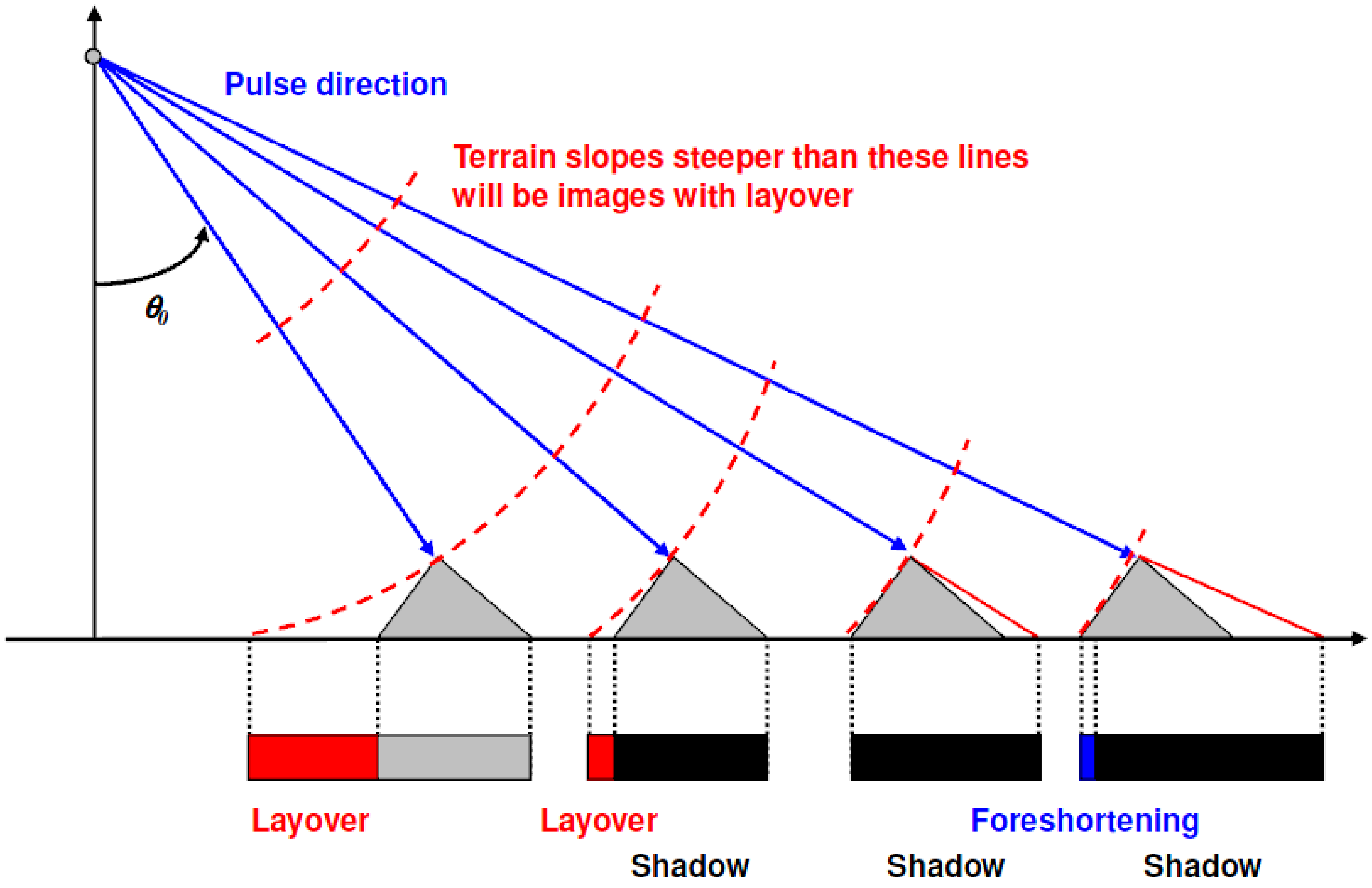
SHADOW

- Area behind mountain cannot be seen by sensor
- Shadow effects *increase* with increasing look angle



Slant-range distortions over mountainous regions

Agenzia Spaziale Italiana

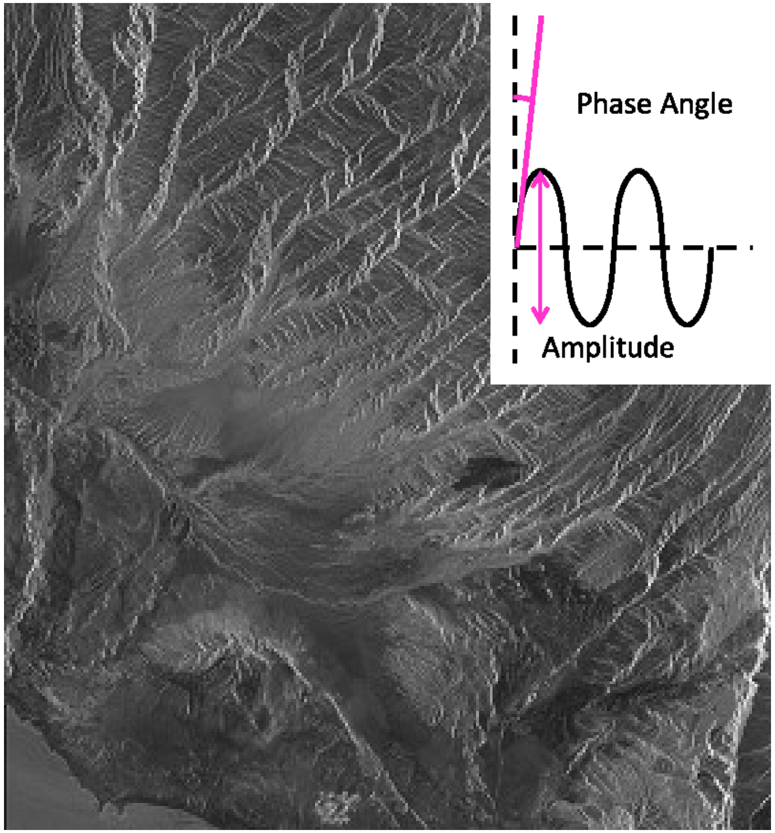


SAR amplitude

Amplitude is the **strength of the radar signal backscattered to the sensor**

It can be calculated by combining real (Q) and imaginary (I) parts of the complex radar signal

Amplitude $A = \sqrt{(I^2 + Q^2)}$



Amplitude can be transformed into physical units → **σ^0** (sigma nought) or radar backscatterer

σ^0 depends on:

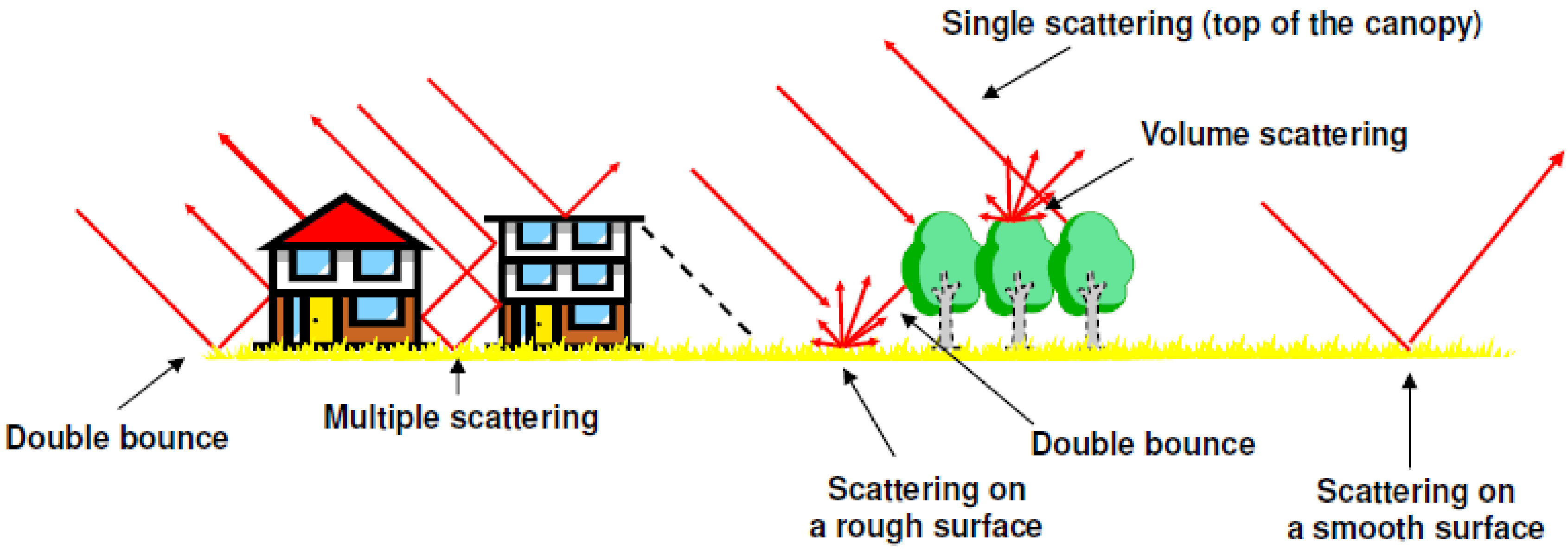
- λ, wavelength
- Polarization
- ϑ, incidence angle

properties of the radar signal

- Roughness
- Shape
- Dielectric properties

properties of the scattering surface

Radar backscattering mechanisms



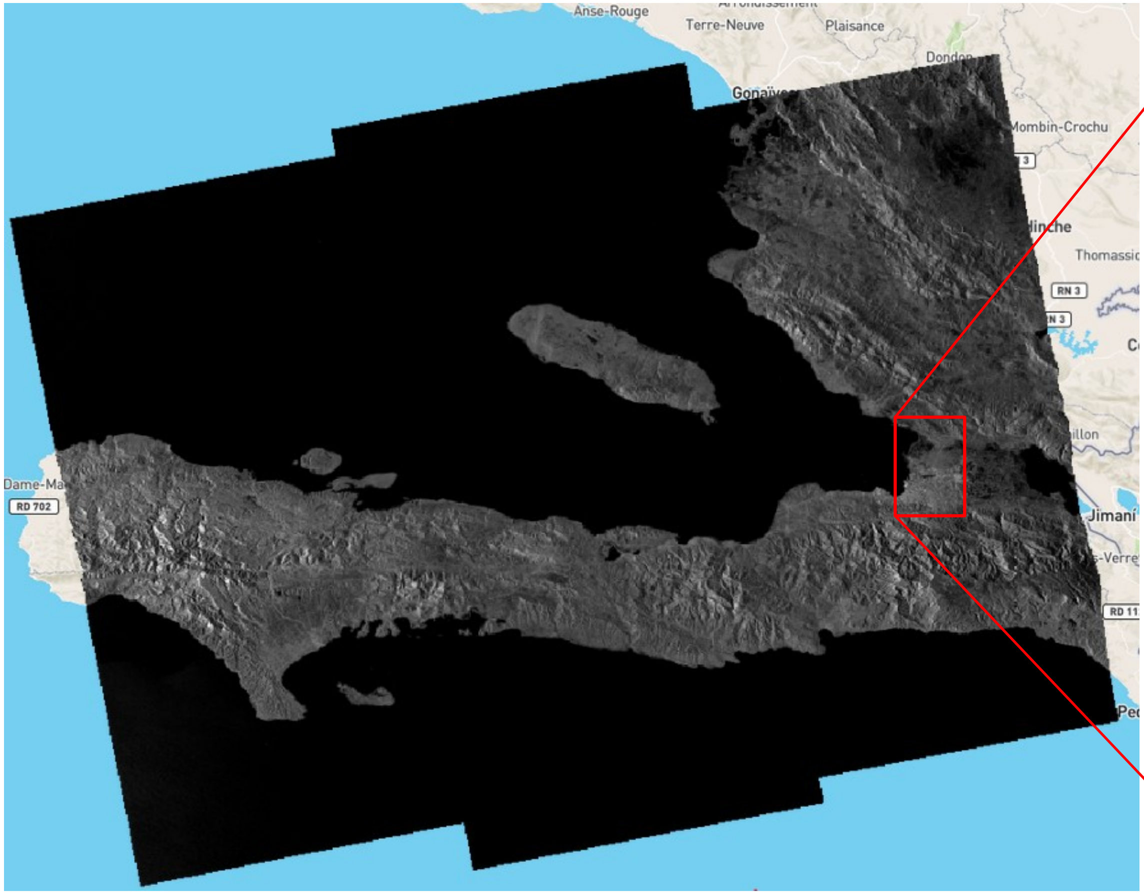
Effect of soil properties:

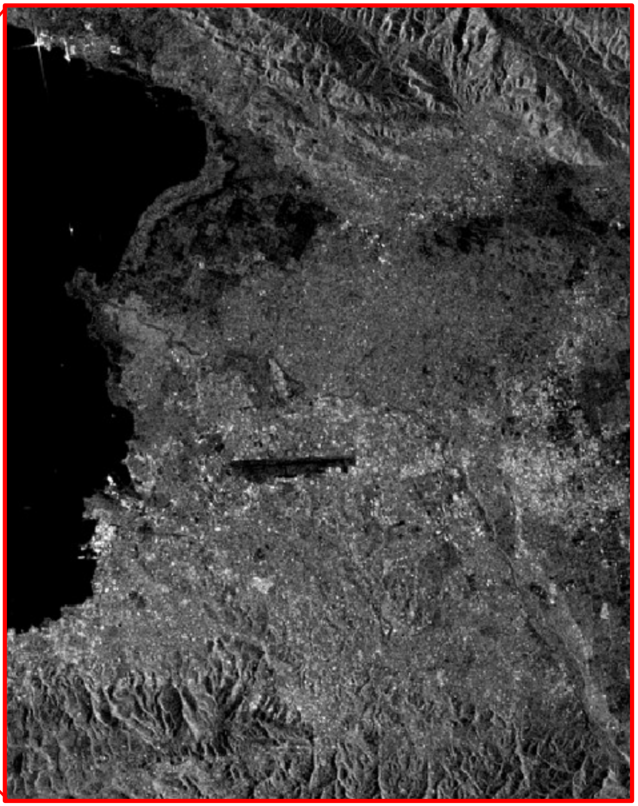
- **Dry** soil: depending on radar wavelength, some of the incident radar energy can penetrate into the soil surface (less backscattered signal)
- **Wet** soil: large difference in dielectric properties between water and air results in higher backscattered signal
- **Flooded** soil: specular reflection, low backscattered signal, dark appearance in SAR image

Examples of SAR images over Haiti

SAR amplitude information (normalized **radar backscatter**, sigma nought - $\boldsymbol{\sigma^0}$)

Sentinel-1 SAR image acquired on 25 March 2019





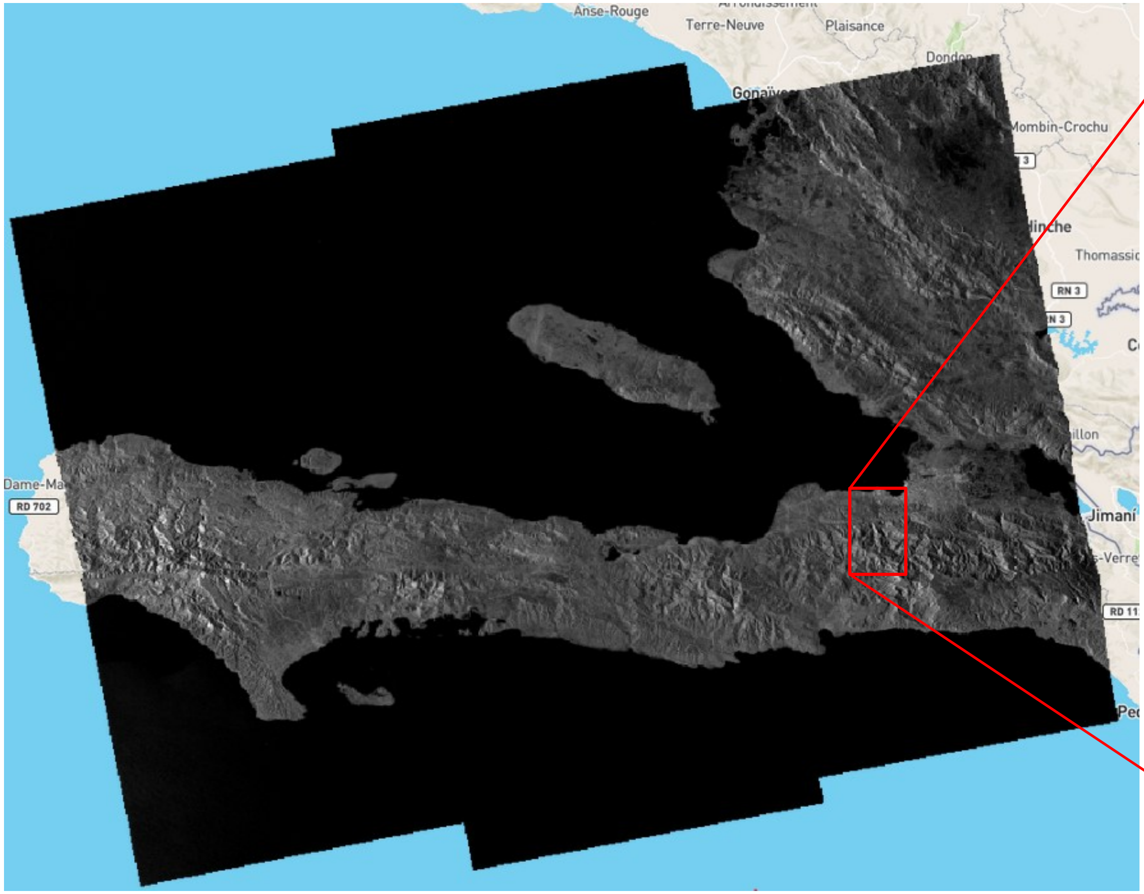
Port-au-Prince

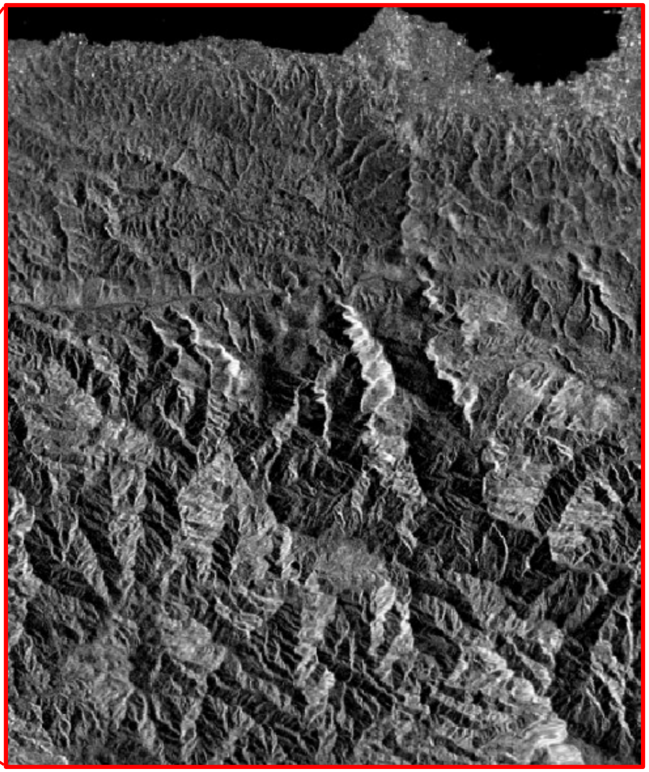
Examples of SAR images over Haiti

Agenzia Spaziale Italiana

SAR amplitude information (normalized **radar backscatter**, sigma nought - **σ^0**)

Sentinel-1 SAR image acquired on 25 March 2019





Topographic distortions

Radar bands (wavelength - λ)

Agenzia Spaziale Italiana

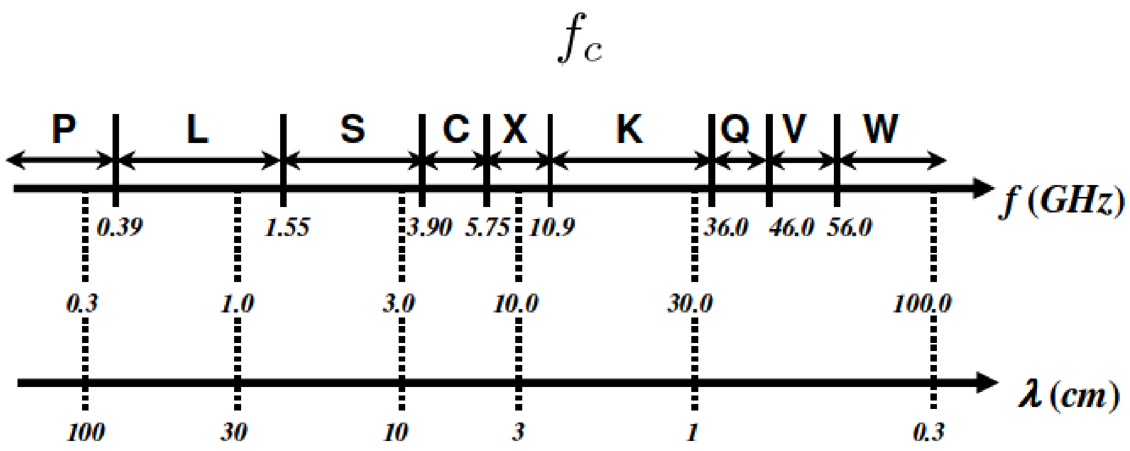
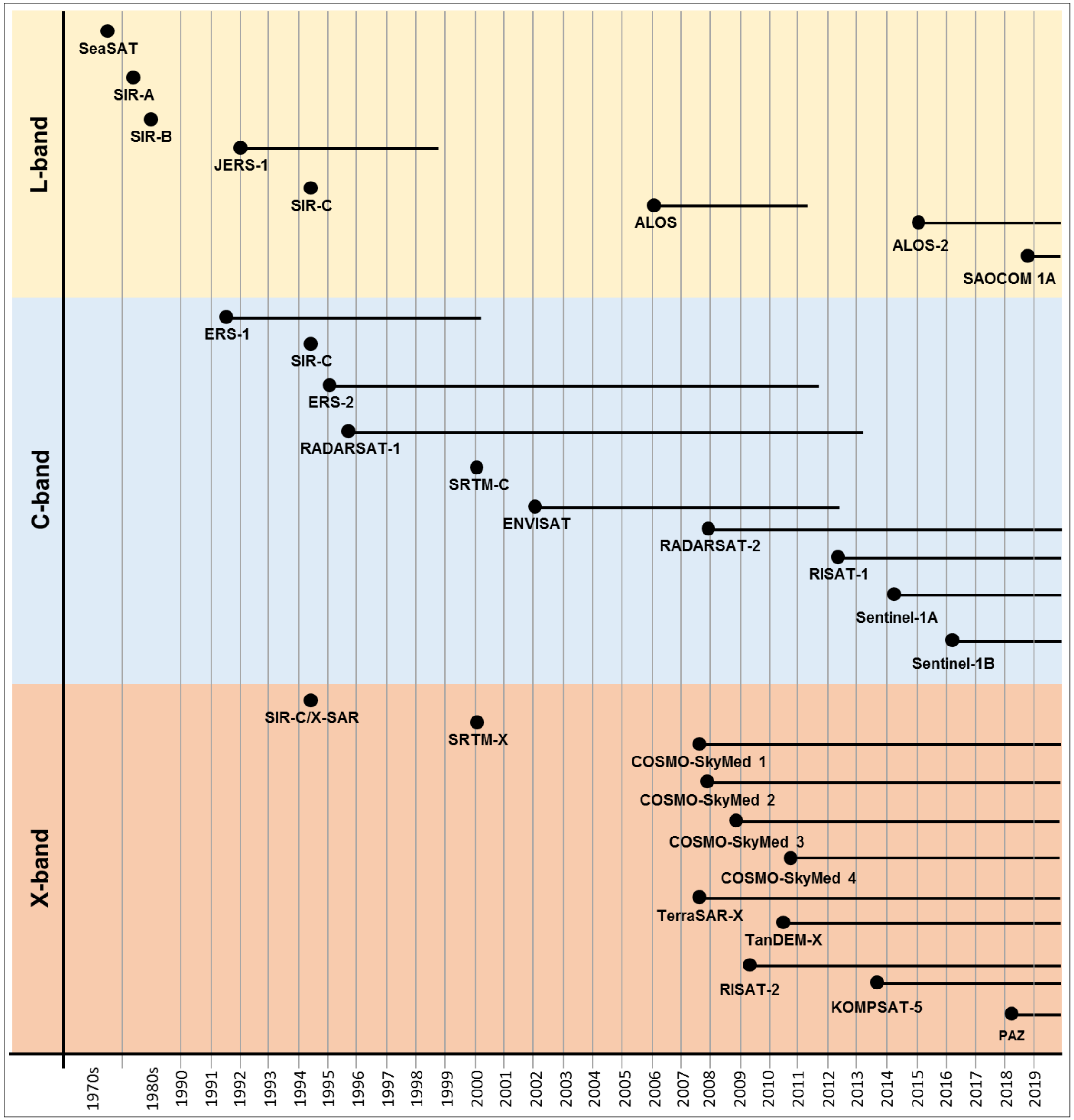


Table 1. SAR bands and frequencies.

Name	Nominal frequency range	Wavelength range	Specific bands used in SARs
VHF	30–300 MHz	10–1 m	138–144 MHz, 216–225 MHz
P (UHF)	300–1000 Mhz	100–30 cm	420–450 MHz, 890–942 MHz
L	1–2 GHz	30–15 cm	1.215–1.4 GHz
S	2–4 GHz	17–7.5 cm	2.3–2.5 GHz, 2.7–3.7 GHz
C	4–8 GHz	7.5–3.75 cm	5.25–5.925 GHz
X	8–12 GHz	3.75–2.5 cm	8.5–10–68 GHz
Ku	12–18 GHz	2.5–1.67 cm	13.4–14.0 GHz, 15.7–17.7 GHz
K	18–27 GHz	1.67–1.11 cm	24.05–24.25 GHz
Ka	27–40 GHz	1.11–0.75 cm	33.4–36.0 GHz
V	40–75 GHz	0.75–0.40 cm	59–64 GHz
W	75–110 GHz	0.40–0.27 cm	76–81 GHz 92–100 GHz
Millimetre	110–300 GHz	2.7–1.0 mm	

Past and present SAR space missions

As of 1st April 2019



Agenzia Spaziale Italiana

λ = 15-30 cm

f = 1-2 GHz

λ = 3.75-7.5 cm

f = 4-8 GHz

λ = 2.5-3.75 cm

f = 8-12.5 GHz

An introduction to SAR image processing methods

Agenzia Spaziale Italiana

- **Amplitude change detection**
  - Environmental monitoring
  - Land use land cover (LULC) mapping
  - Land surface processes mapping
    - Flooded areas
    - New or moving landslides

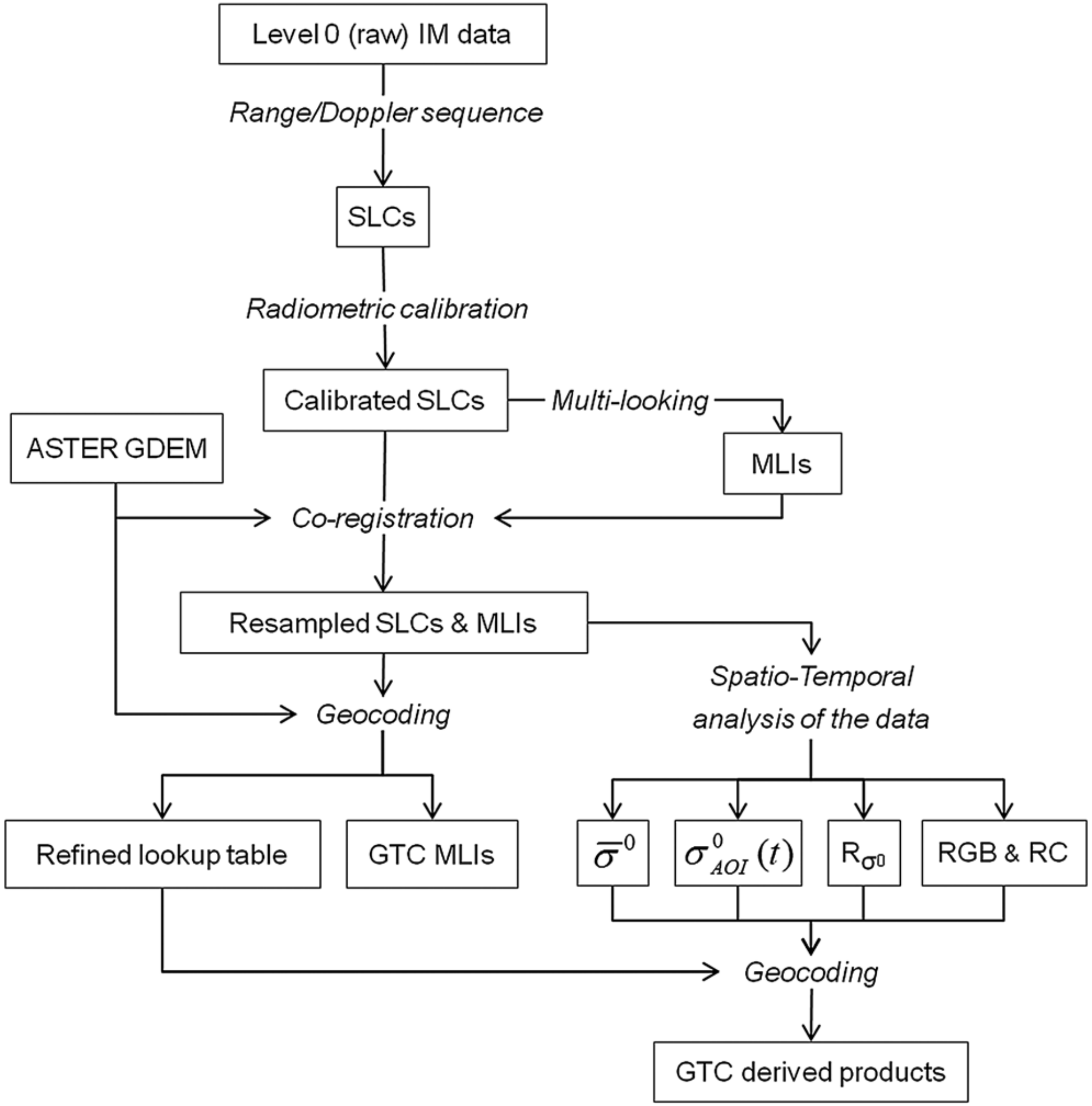
- **Interferometric SAR (InSAR)**
  - Seismic deformation
  - Regional ground deformation

- **Persistent Scatterer Interferometry (PS-InSAR)**
  - Regional to local ground deformation
  - Building collapses
  - Subsidence monitoring

Examples of applications in the next ppt!

Amplitude change detection

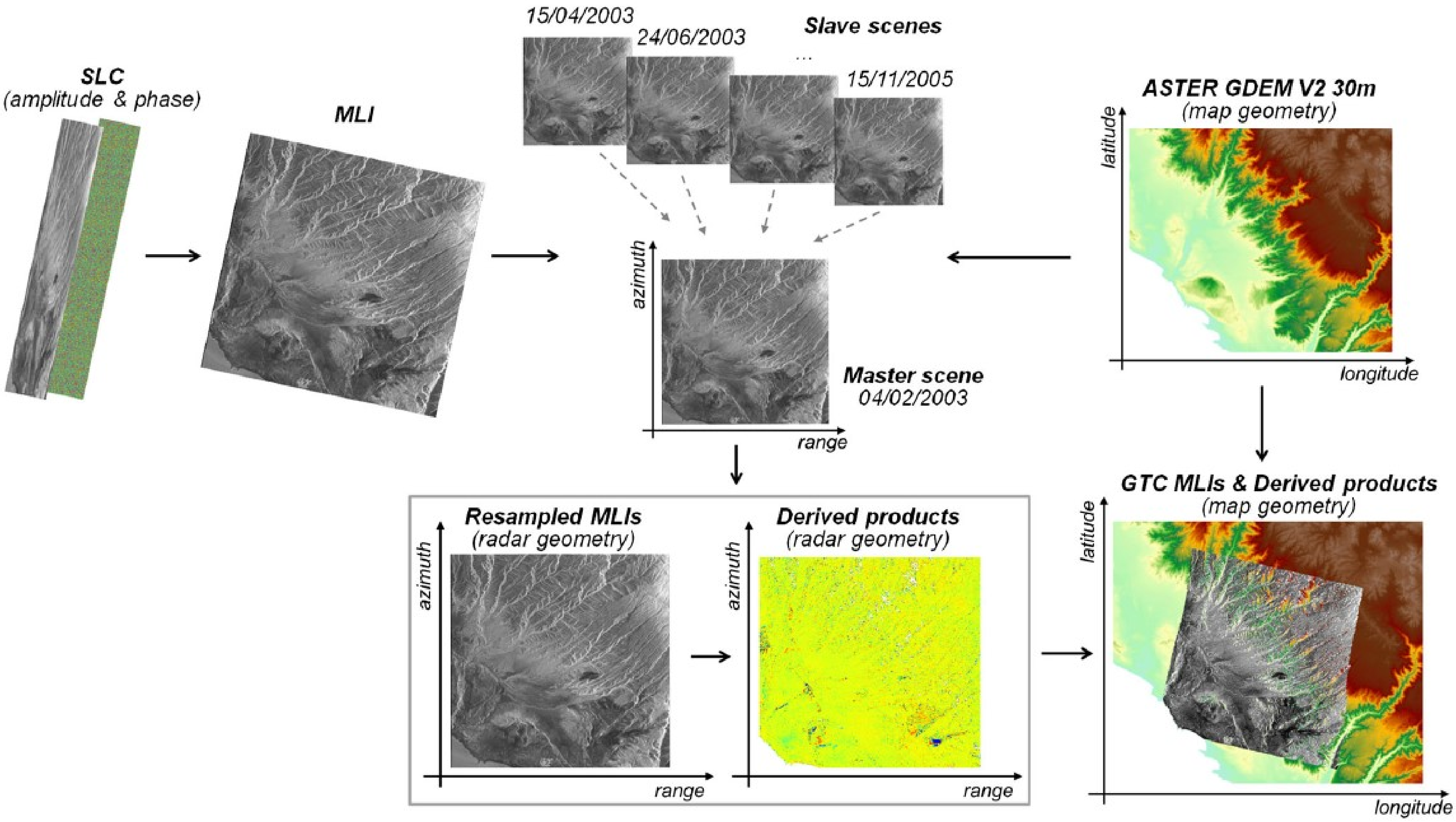
Agenzia Spaziale Italiana



Cigna et al. (2013) doi: 10.1002/arp.1451

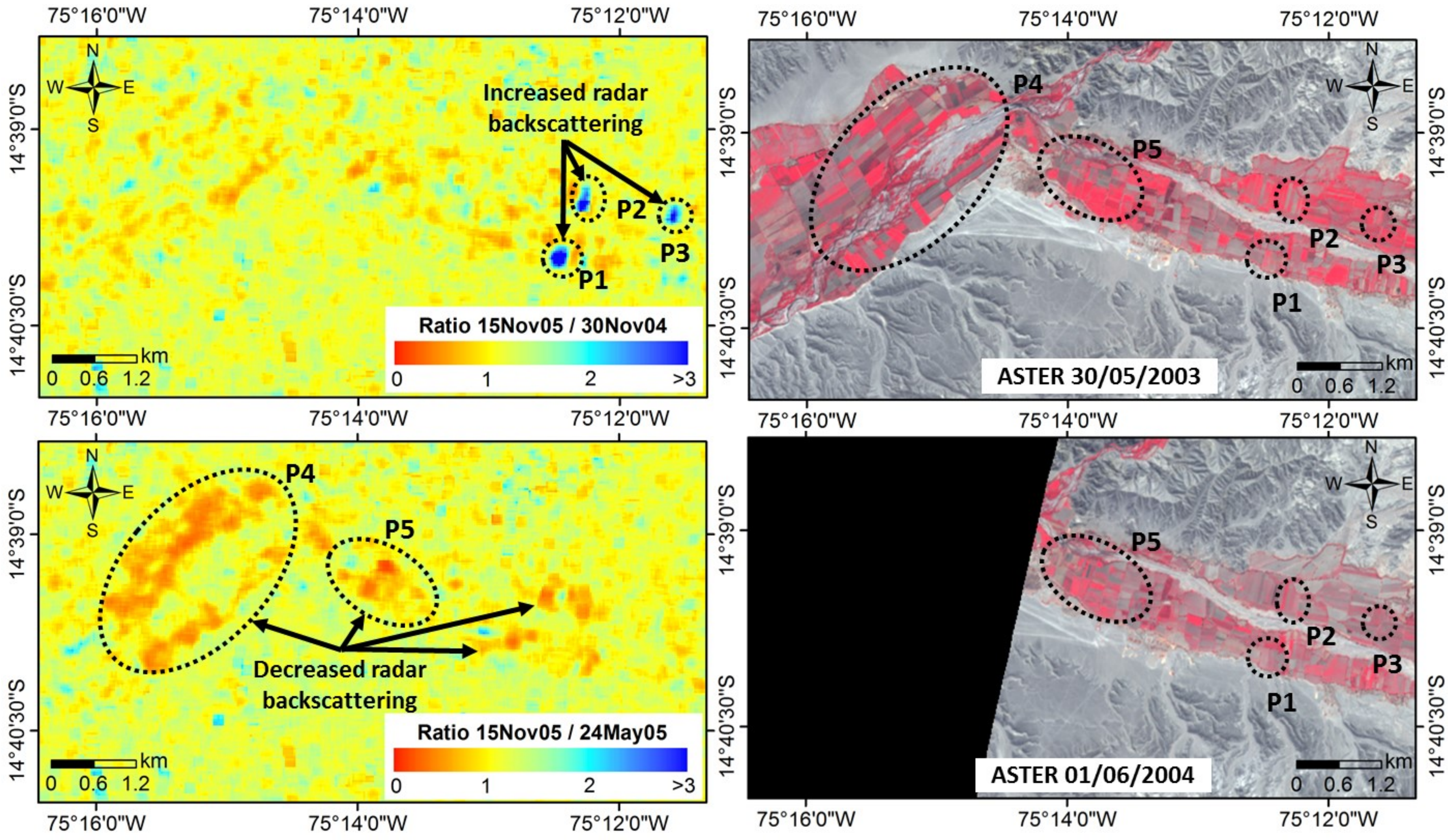
Amplitude change detection

Agenzia Spaziale Italiana



Tapete et al. (2013) doi: 10.1002/arp.1449

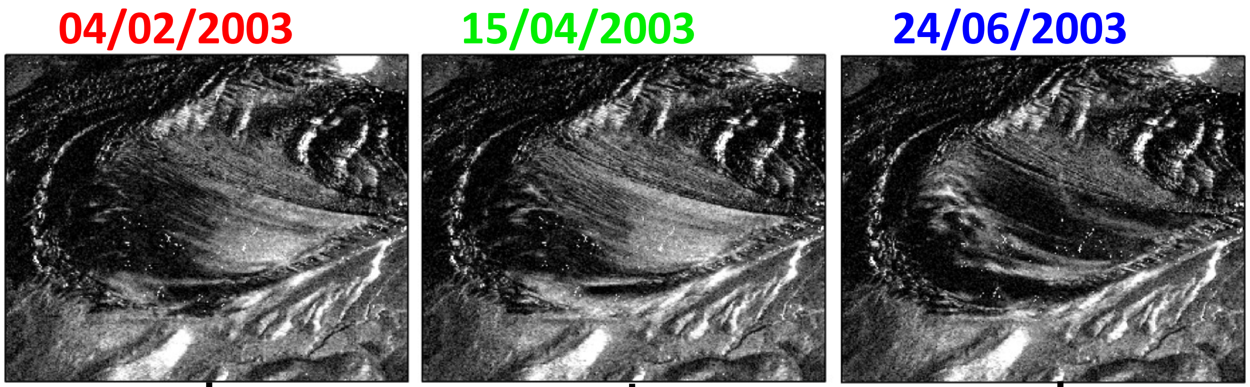
Change detection for environmental monitoring



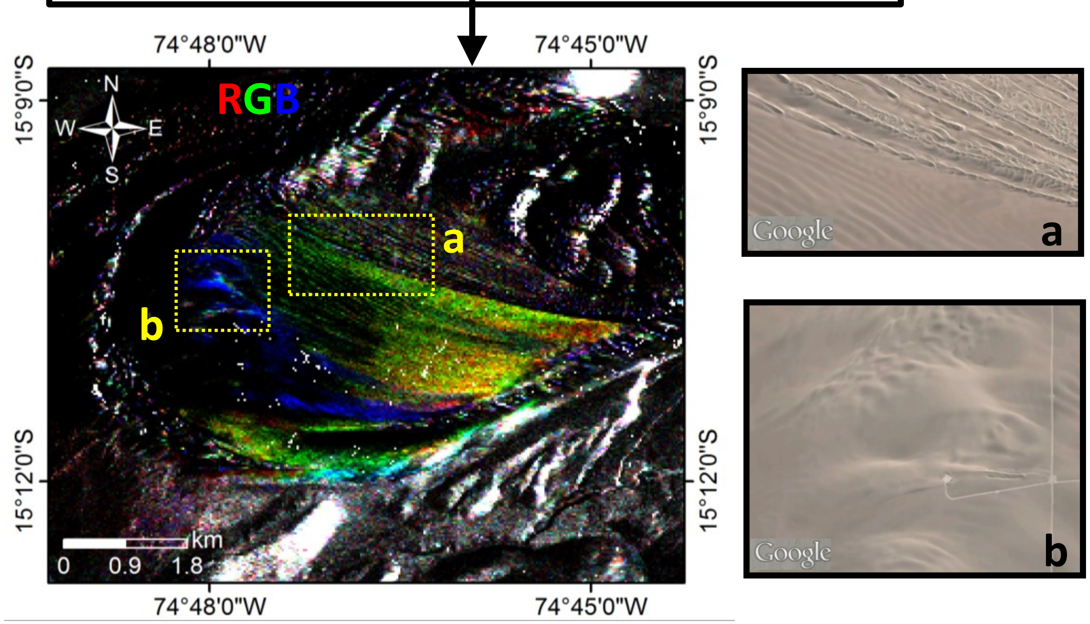
Change detection for environmental monitoring

Agenzia Spaziale Italiana

Surface processes and mass movements



SAR colour composite

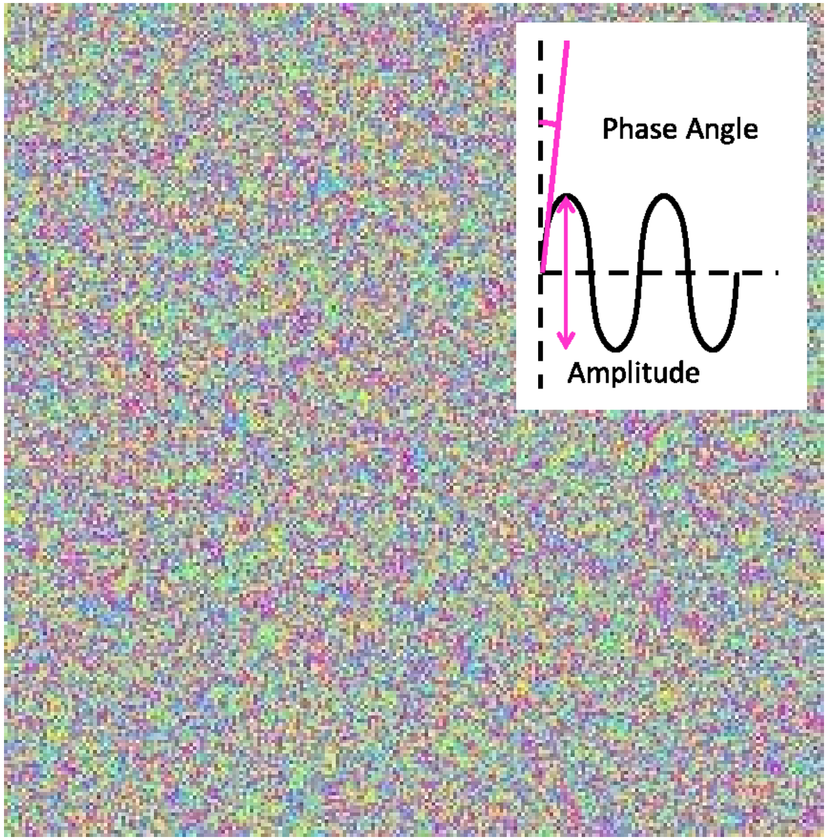


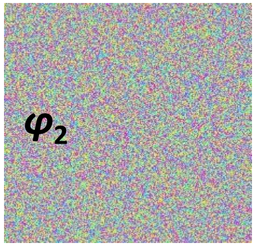
Wind/rain-driven morphological changes and mass movements cause local alterations of the backscattering coefficient

SAR phase

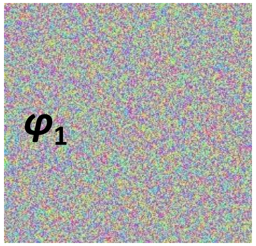
The phase of the radar signal backscattered to the sensor depends on the sensor-target distance

Phase $\varphi = \arctan[I/Q]$ [0-2π]

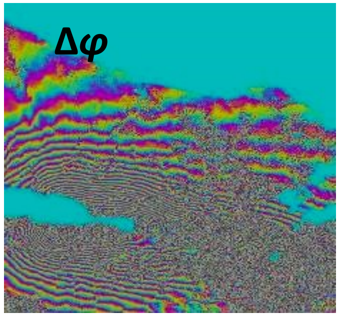




−



=



Interferogram

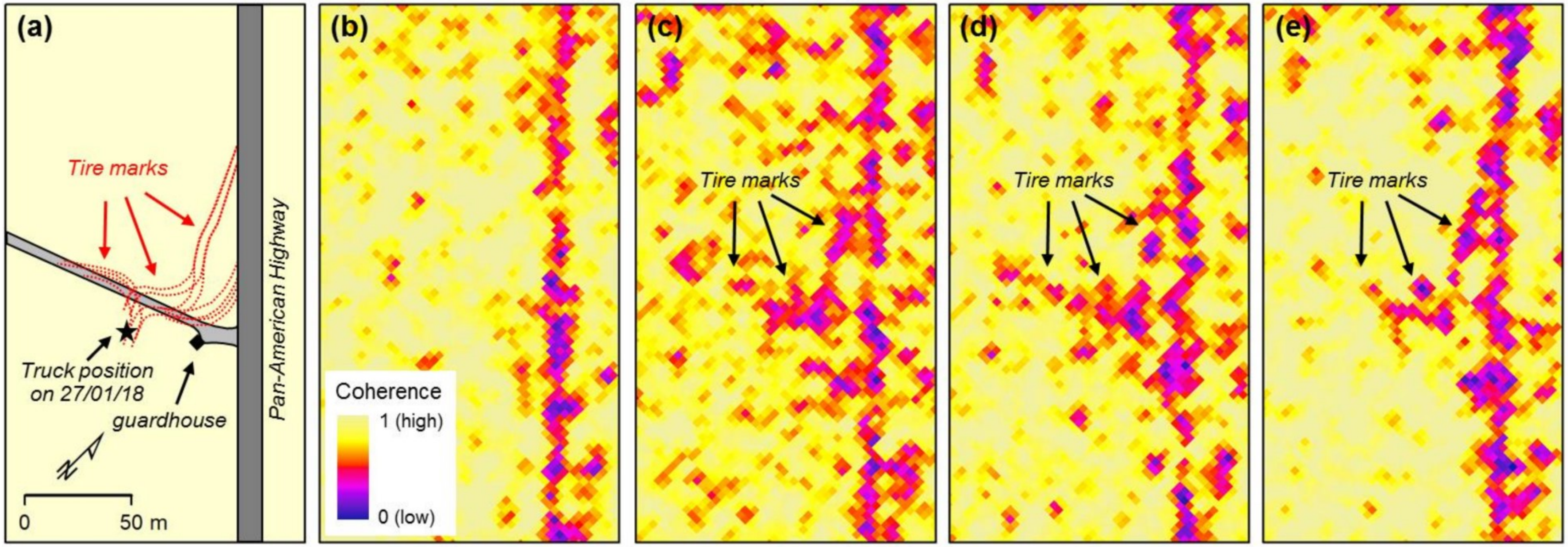
$$\Delta\varphi_{int} = \Delta\varphi_{geom} + \Delta\varphi_{topo} + \Delta\varphi_{def} + \Delta\varphi_{atm} + \Delta\varphi_{noise}$$

Change detection based on "coherence"

Coherence (γ) is a measure of interferometric phase correlation and quantifies the degree of correlation between phase and amplitude information of two SAR images
γ = 0 indicates no coherence and γ = 1 a perfect correlation

Useful to map changes in surface properties due to natural and anthropogenic disturbance

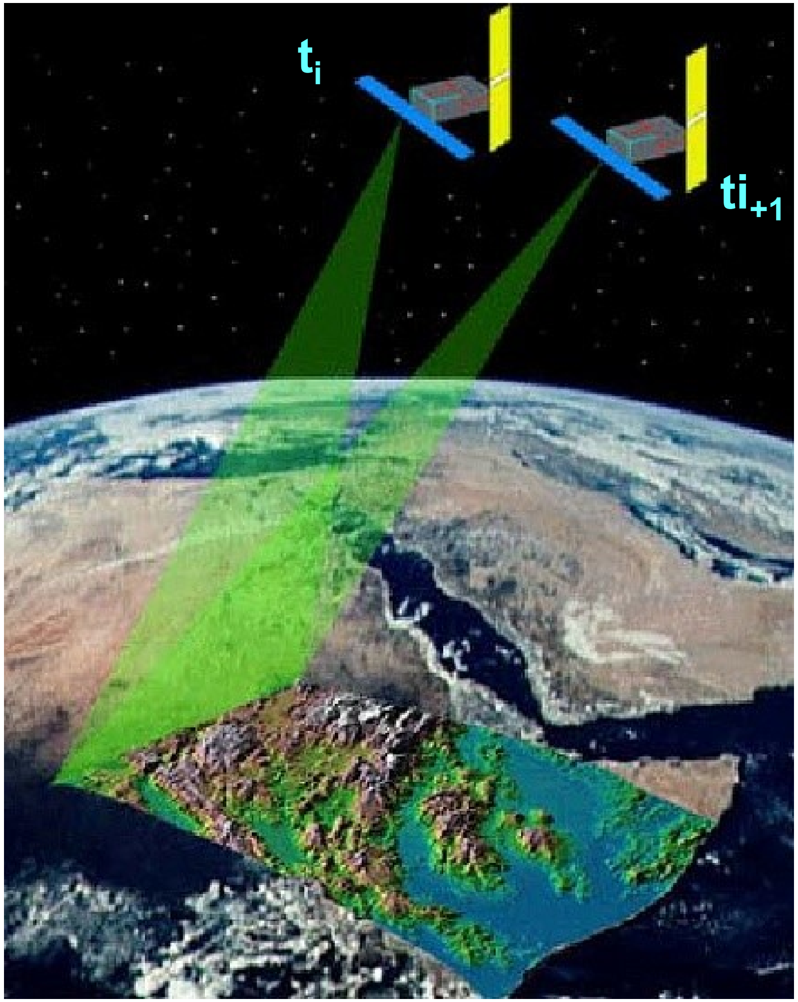
Example in Peru using COSMO-SkyMed data at 3 m resolution



Interferometric SAR (InSAR)

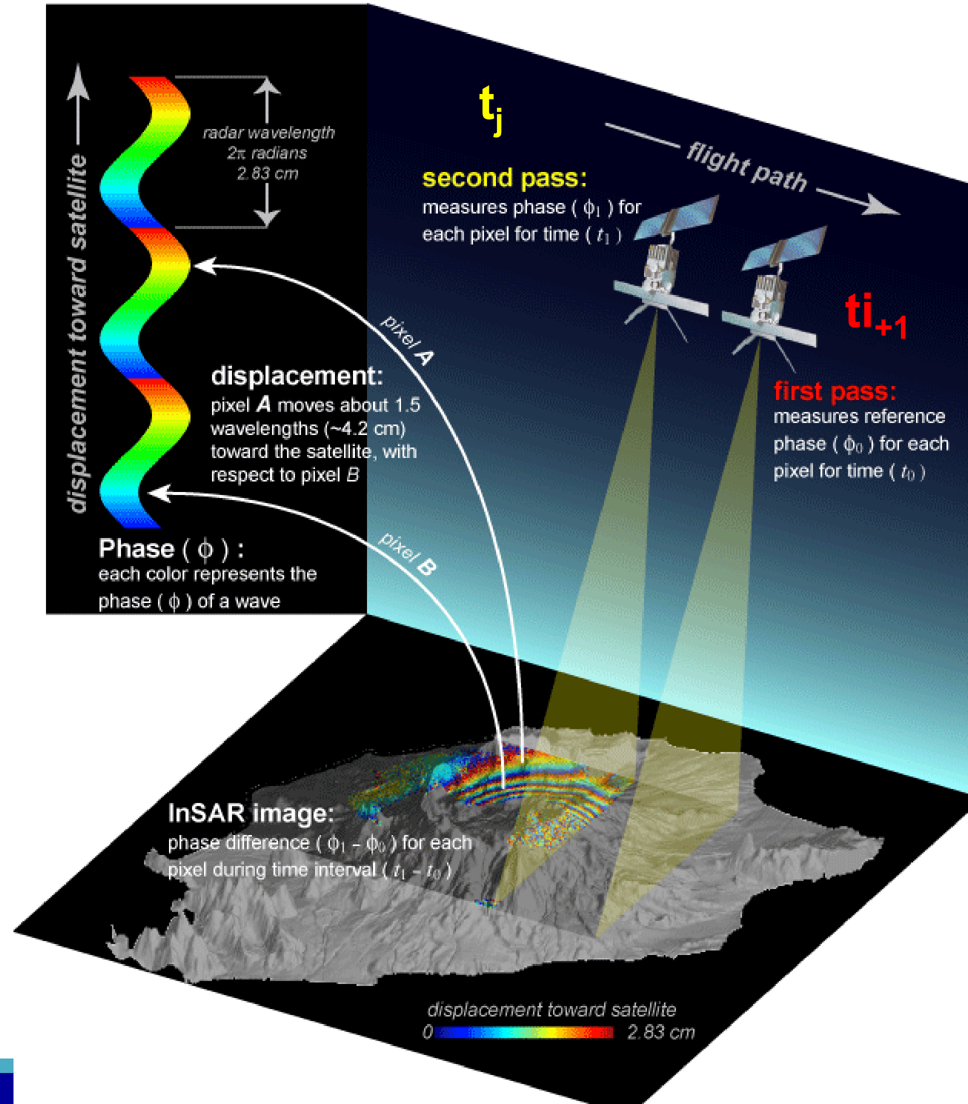
Agenzia Spaziale Italiana

http://nova.stanford.edu



DEM generation

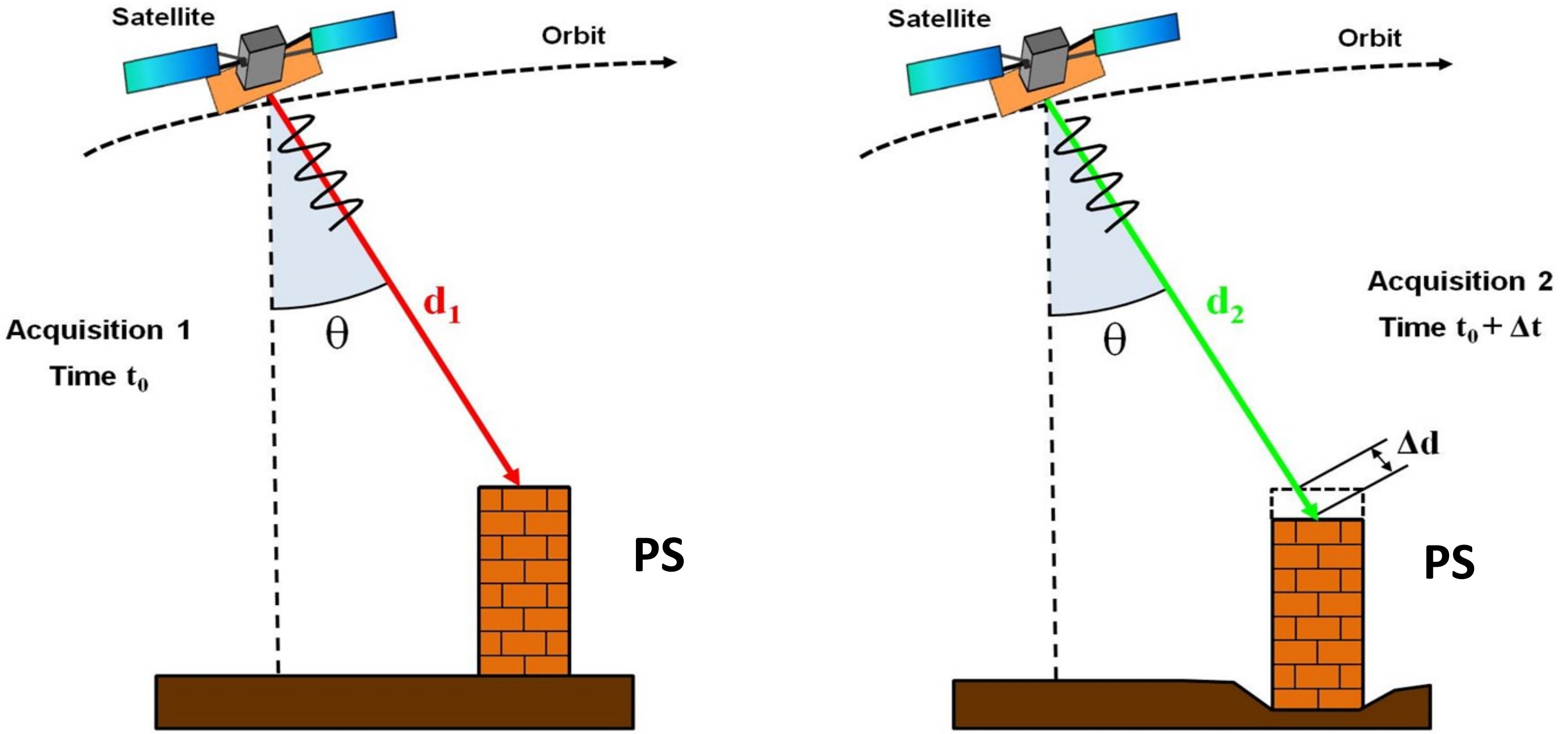
Ground motion monitoring



www.insar.sk

Interferometric SAR (InSAR)

Differential InSAR

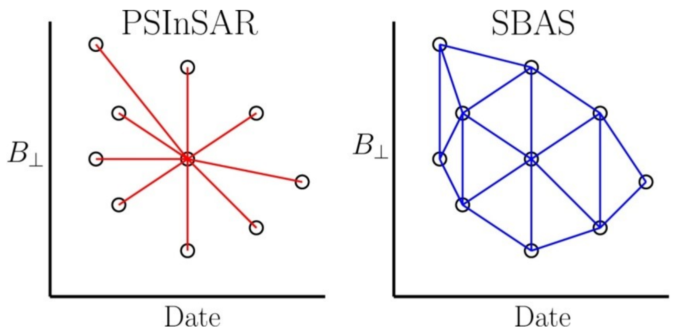


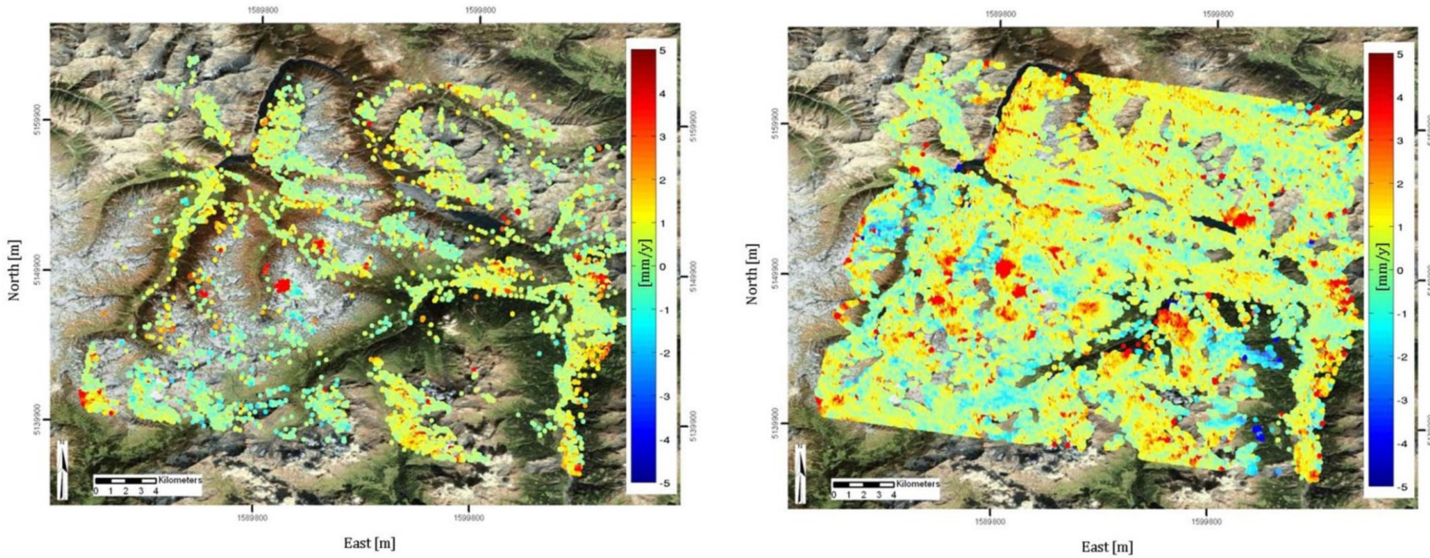
The displacement of targets on the ground that are characterised by persistent backscattering to the radar sensor (i.e. **Persistent Scatterer, PS**) can be tracked with millimeter precision

InSAR processing – deformation time series

Agenzia Spaziale Italiana

- Exploit long SAR data stacks (> 25 images)
- Estimate of object displacement and/or deformation
- Different approaches for processing
    - Small Baseline Subset (SBAS)
    - Persistent Scatterer Interferometry (PSI)



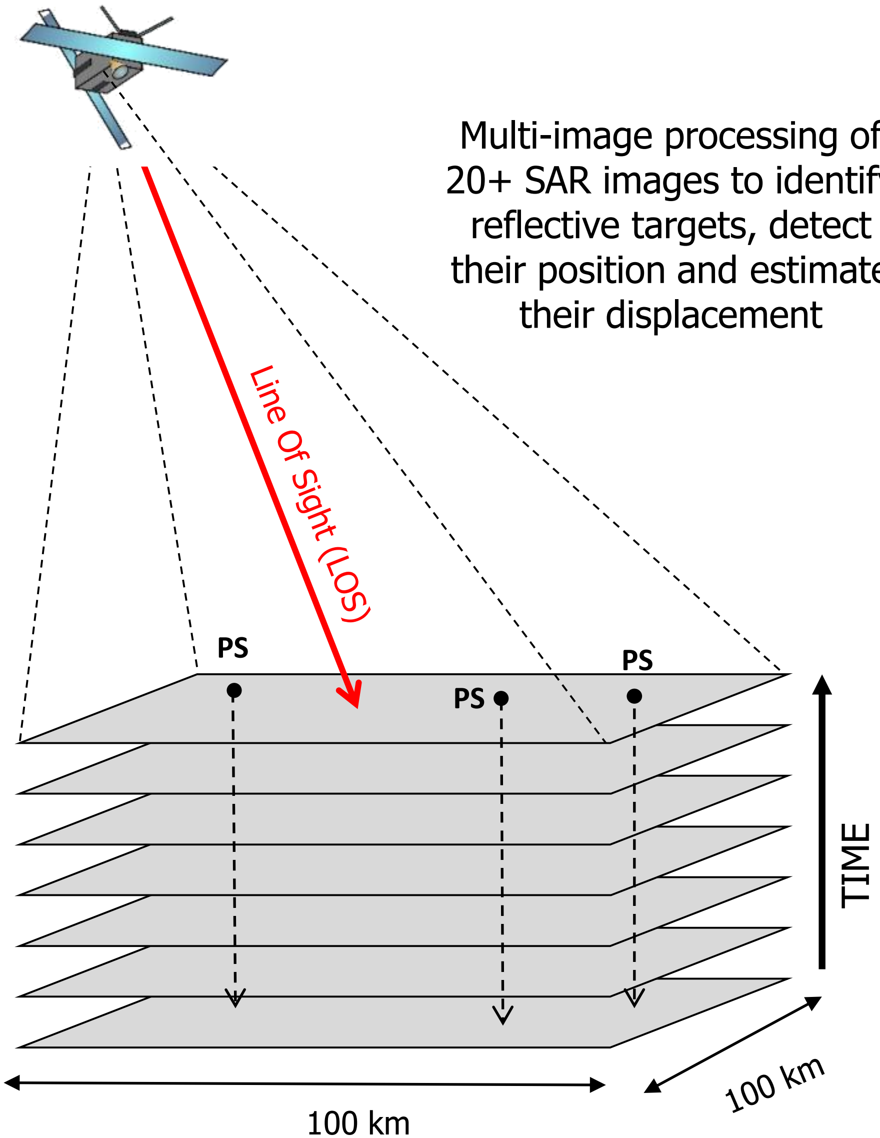


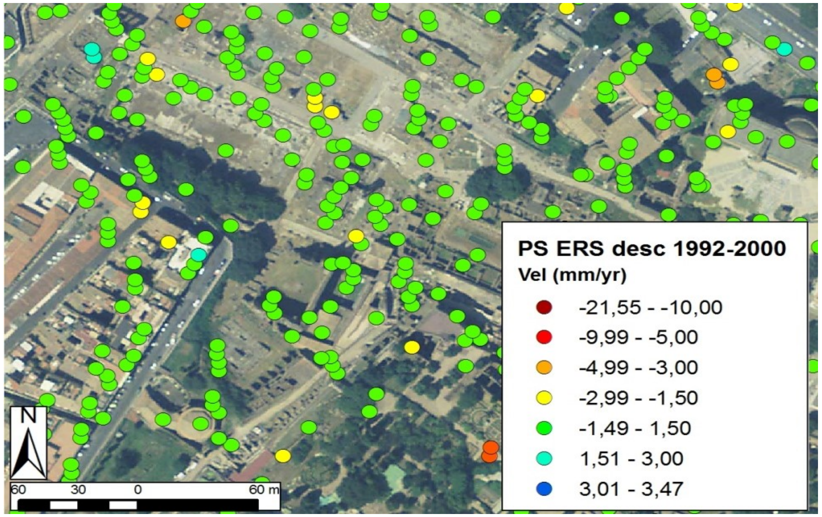
(a) (b)

Comparison between the LOS velocity map [mm/yr] estimated by applying the (a) PSInSAR and the (b) SqueeSAR algorithms to process 65 RADARSAT data (Ferretti et al., 2011). Spatial density of measurement points increases from 85 PS/km^2 to 450 MP/km^2.

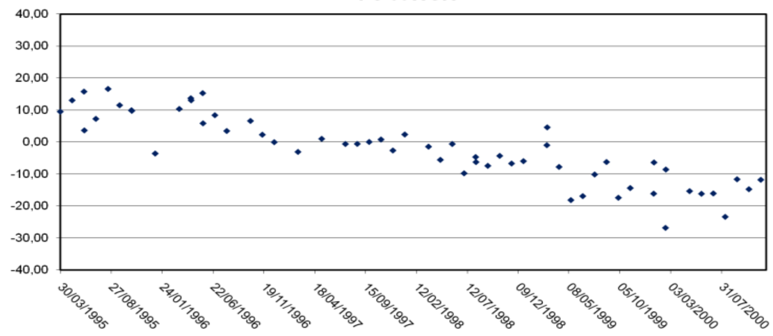
Persistent Scatterer Interferometry (PS-InSAR)

Multi-image processing of 20+ SAR images to identify reflective targets, detect their position and estimate their displacement





Annual LOS deformation rate
(precision up to ~0.1 mm/yr)



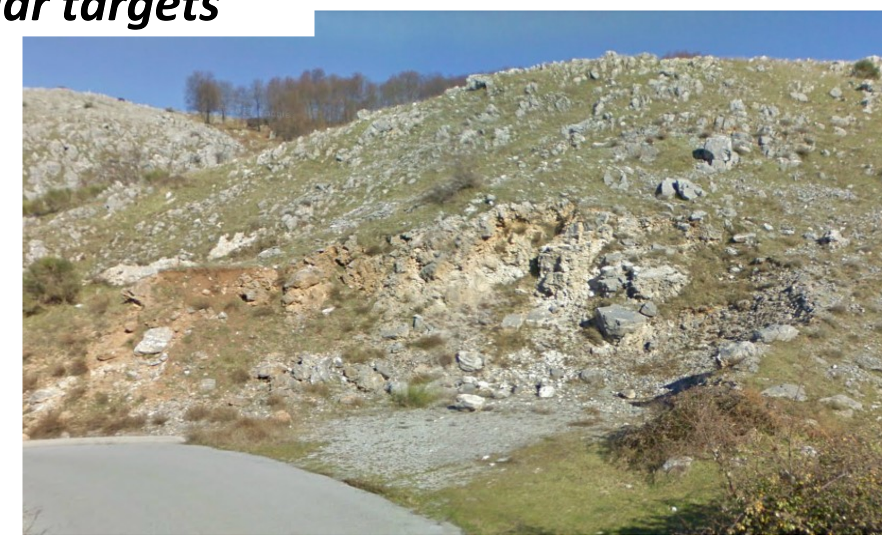
Displacement time-series
(precision up to ~1 mm)

Persistent Scatterer Interferometry (PS-InSAR)

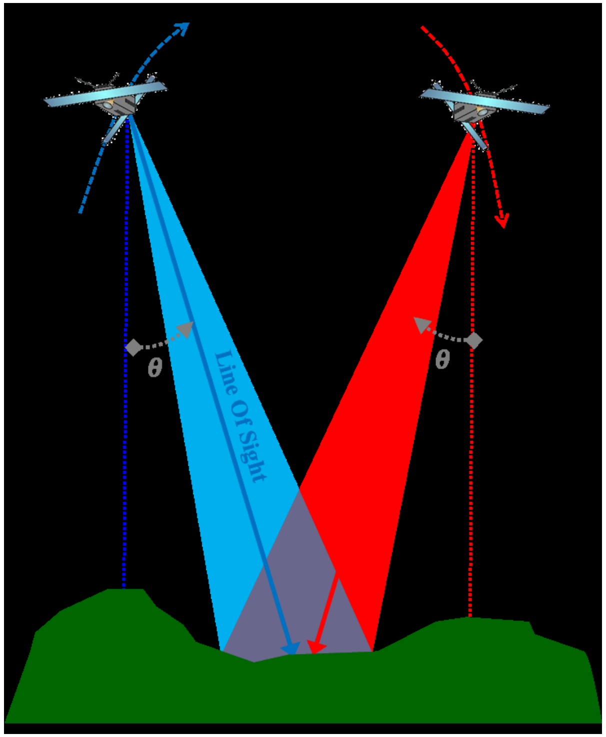


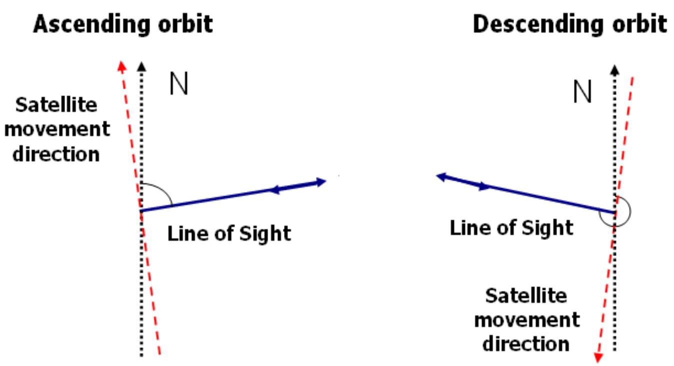

“Natural” radar targets





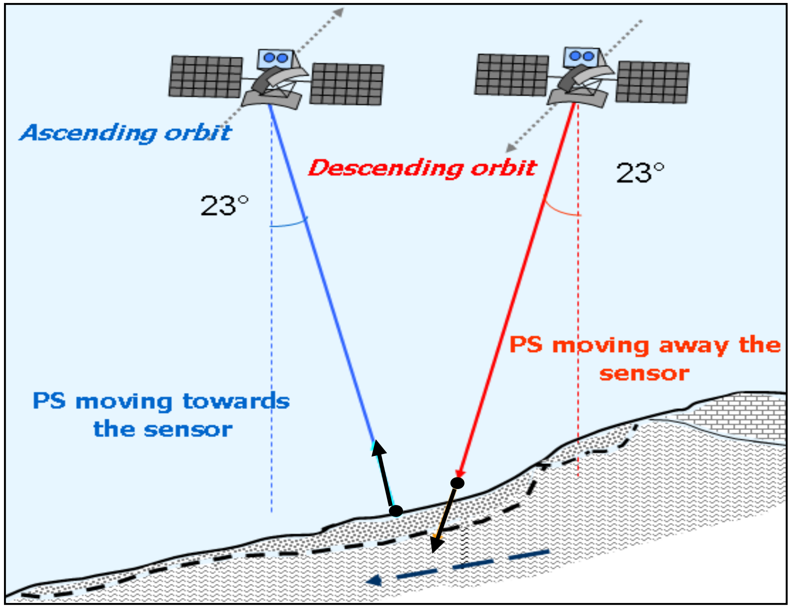
Observation geometry: ascending and descending





InSAR provides estimates of ground displacement along the satellite **Line Of Sight** (LOS)

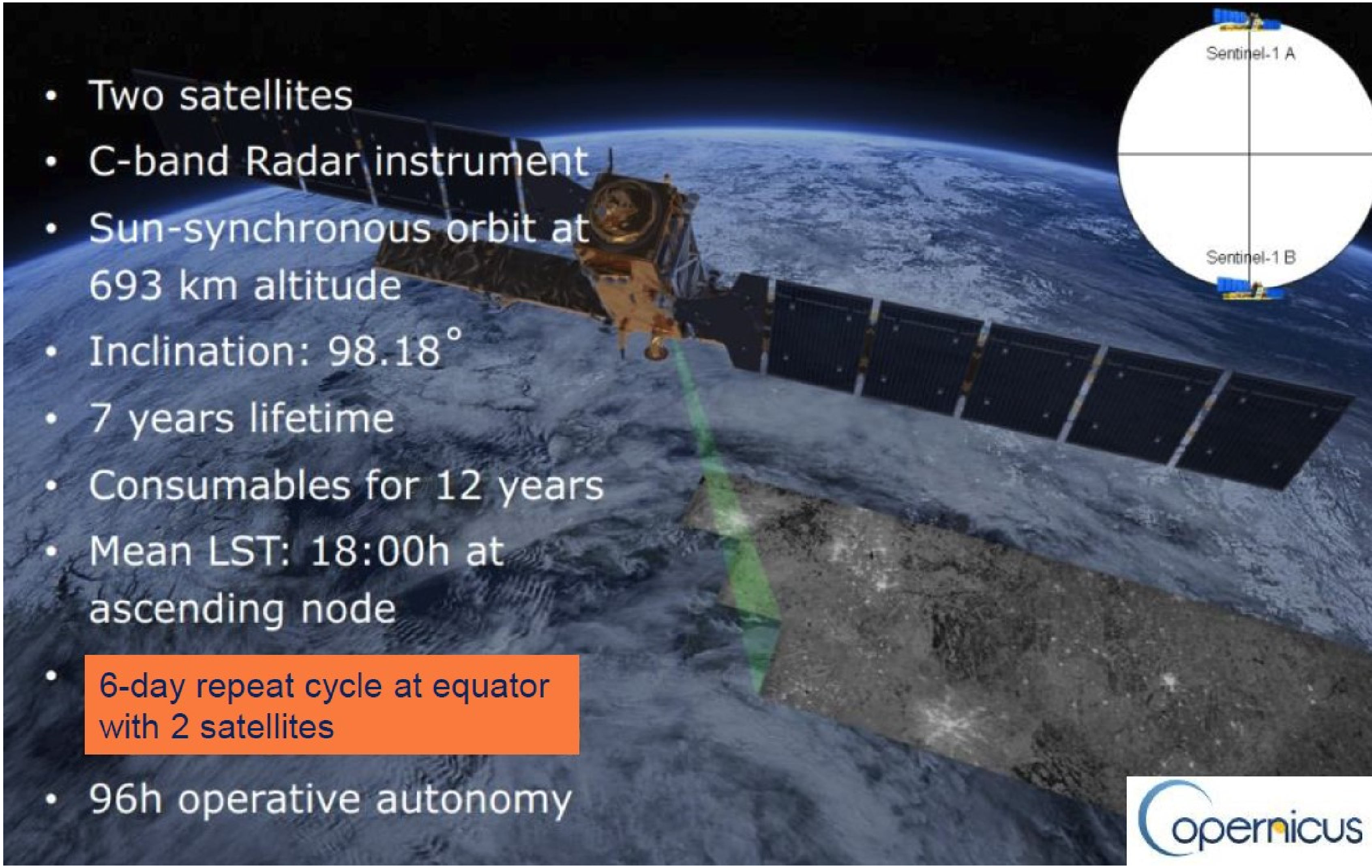
The same area can be investigated using two different geometries: **ascending** & **descending** mode



Landslide motions mainly occur along the steepest slope direction, and can be seen as movements away or towards the satellite, depending on the mode used

Copernicus Sentinel-1 mission overview

Agenzia Spaziale Italiana

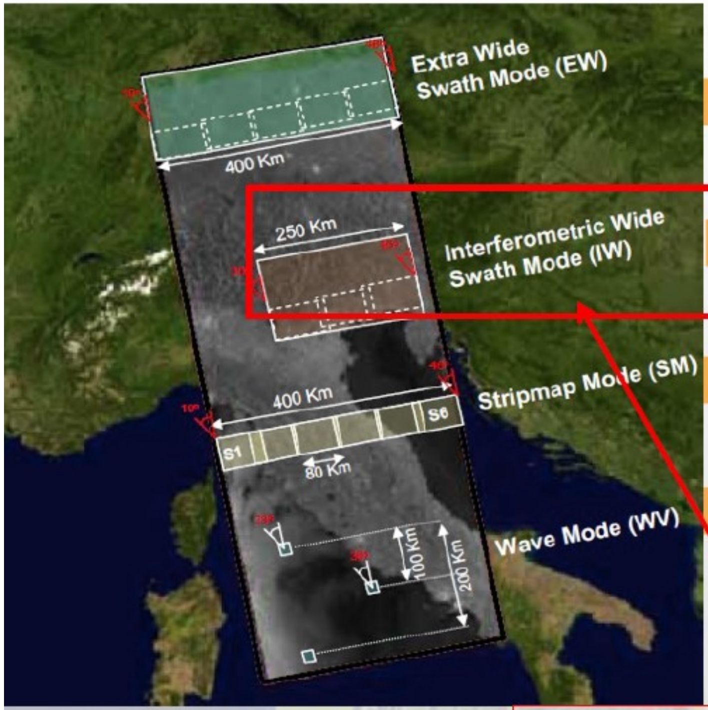


- Two satellites
- C-band Radar instrument
- Sun-synchronous orbit at 693 km altitude
- Inclination: 98.18°
- 7 years lifetime
- Consumables for 12 years
- Mean LST: 18:00h at ascending node
- 6-day repeat cycle at equator with 2 satellites
- 96h operative autonomy

Copernicus

Copernicus Sentinel-1 operational modes

Agenzia Spaziale Italiana



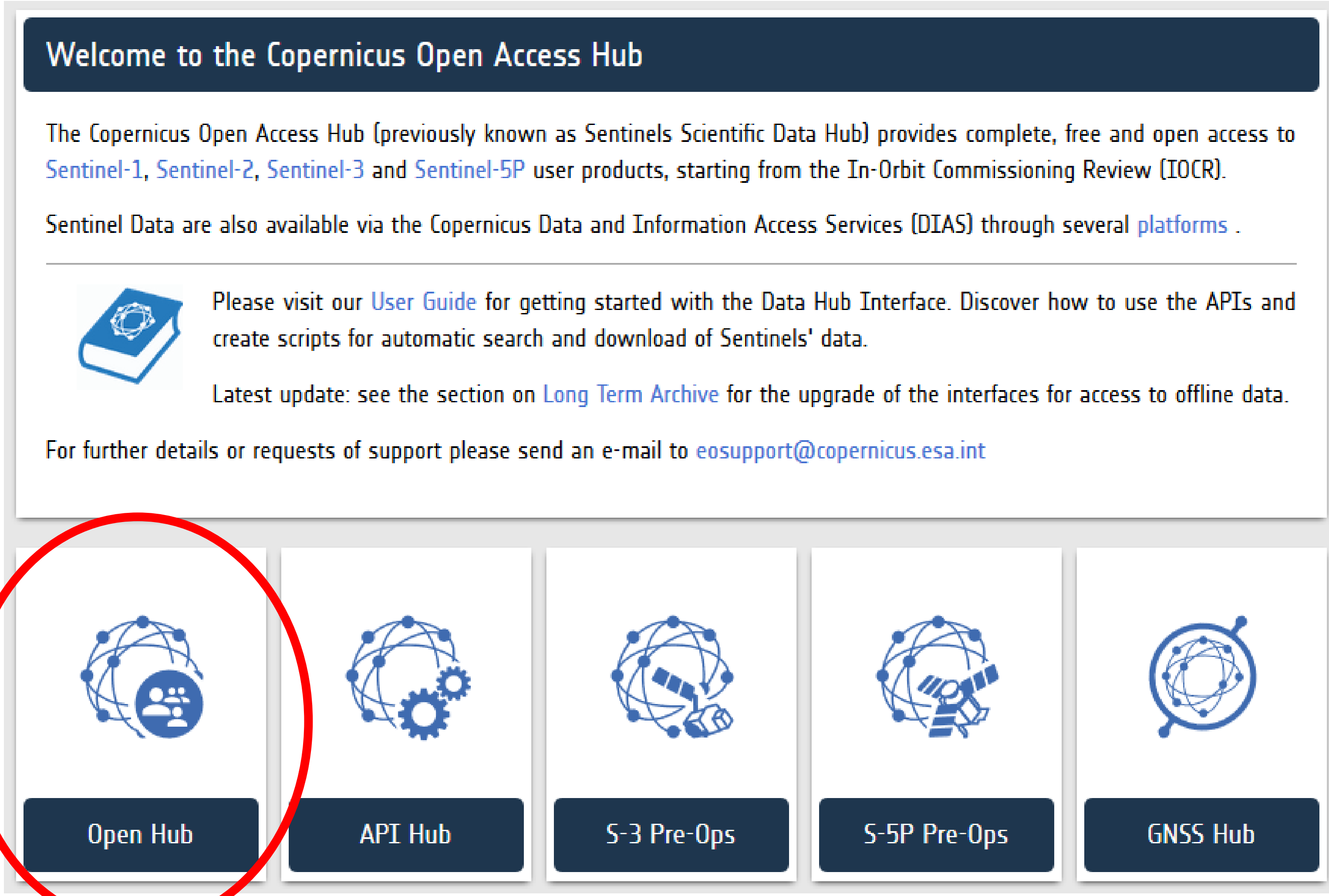
Resolution (1 look)	Swath Width	Polarisation
20 x 40 m²	> 400 km	HH+HV or VV+VH
5 x 20 m²	> 250 km	HH+HV or VV+VH
5 x 5 m²	> 80 km	HH+HV or VV+VH
5 x 5 m²	20 x 20 km² at 100 km spacing	HH or VV

Main mode over land

- **Daily coverage of high priority areas, e.g. Europe, Canada, shipping routes**

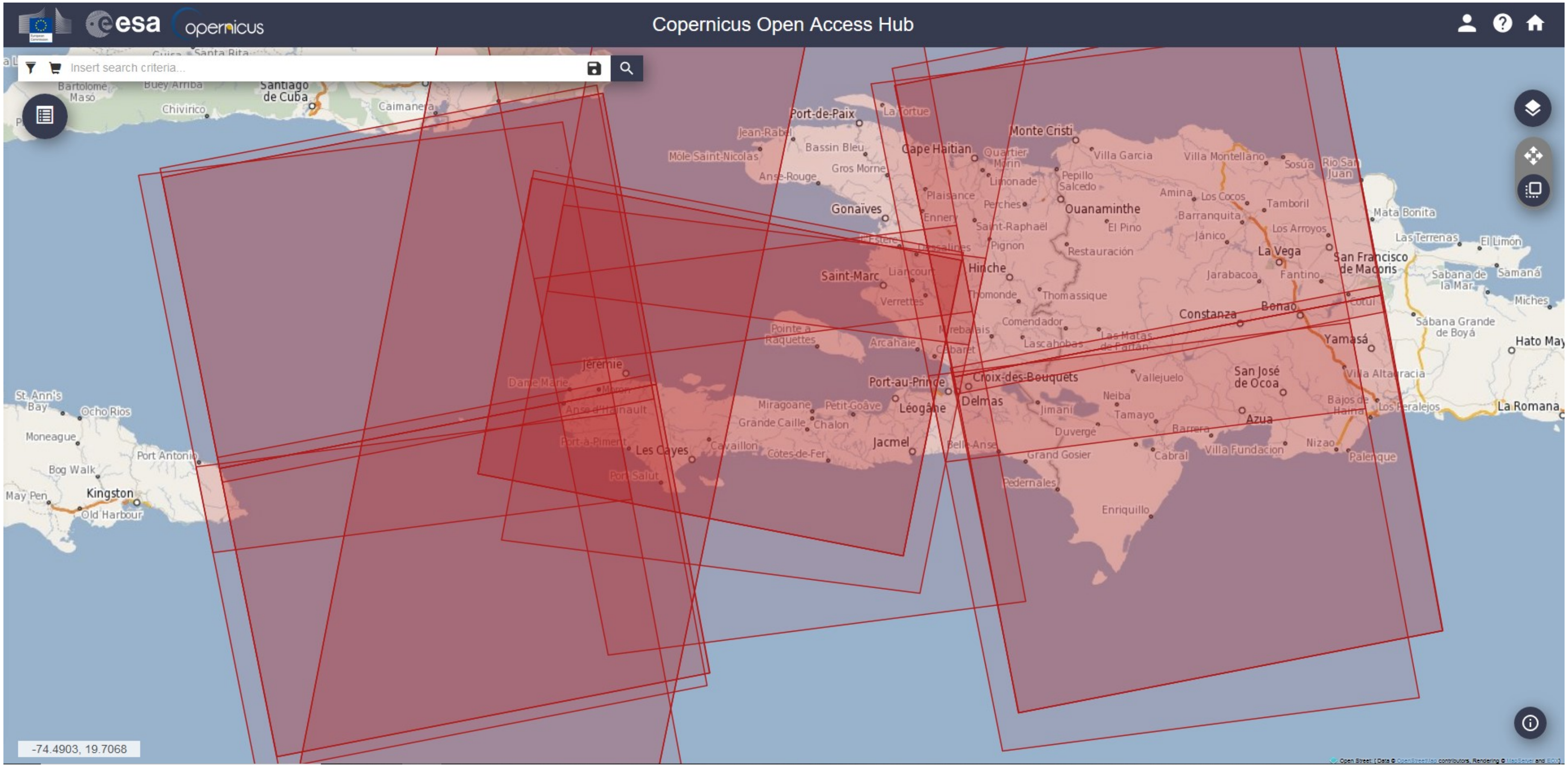
Sentinel-1 Data Access
https://scihub.copernicus.eu/

Agenzia Spaziale Italiana



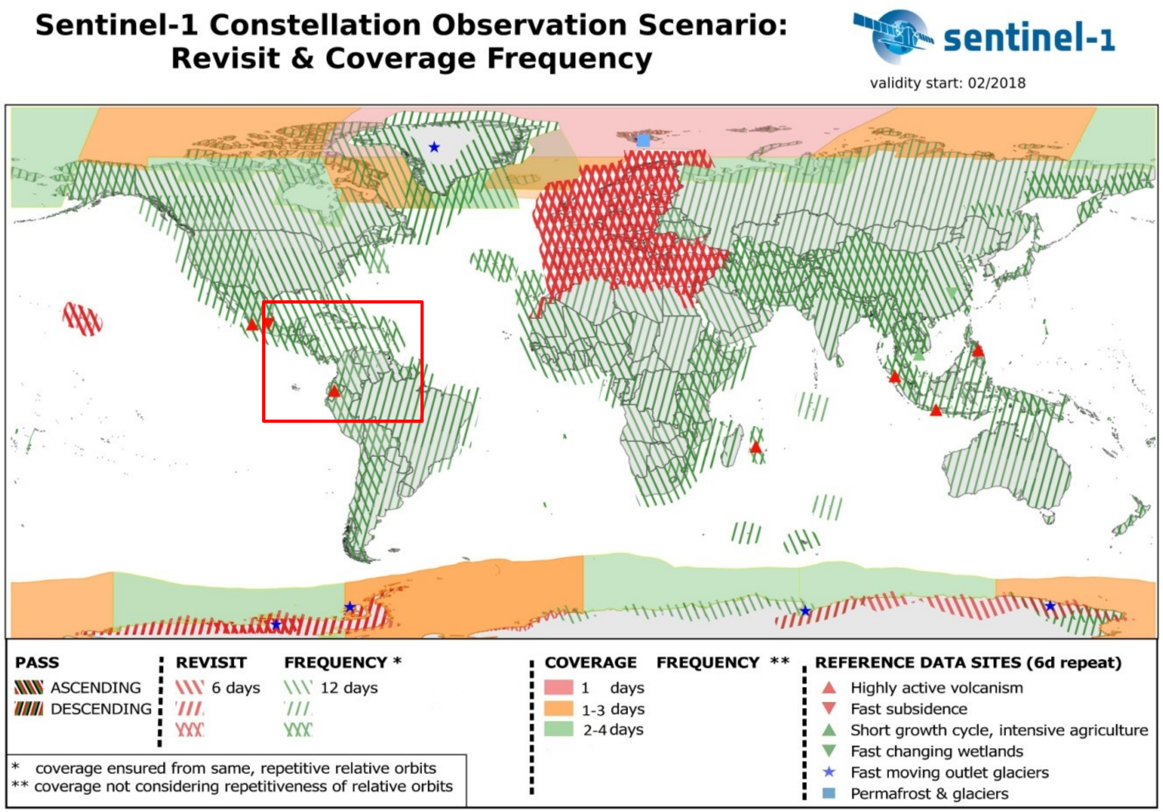
Sentinel-1 Data Access
https://scihub.copernicus.eu/

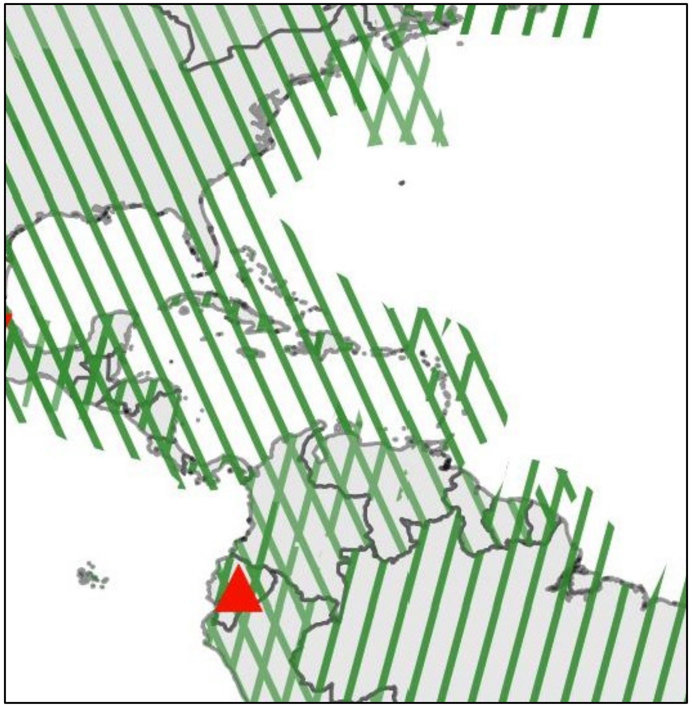
Agenzia Spaziale Italiana



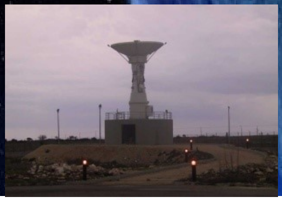
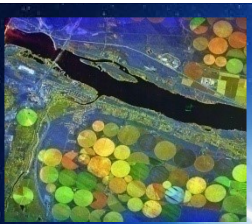
For example, Sentinel-1 catalogue over southern Haiti (January – April 2019)

Sentinel-1 Observation Scenario over Haiti





The COSMO-SkyMed PROGRAMME


- The main Italian investment in Space System for Earth Observation
- A National Program conceived by Italian Space Agency (ASI) and funded by It. Ministry of Research & It. Ministry of Defence

DUAL USE SYSTEM

- Managed by ASI in cooperation with the It. MoD
- Developed by the Italian National Industry

SINCE MAY 2011 THE ITALIAN COSMO-SkyMed FOUR SAR SATELLITES CONSTELLATION IS FULLY OPERATIONAL

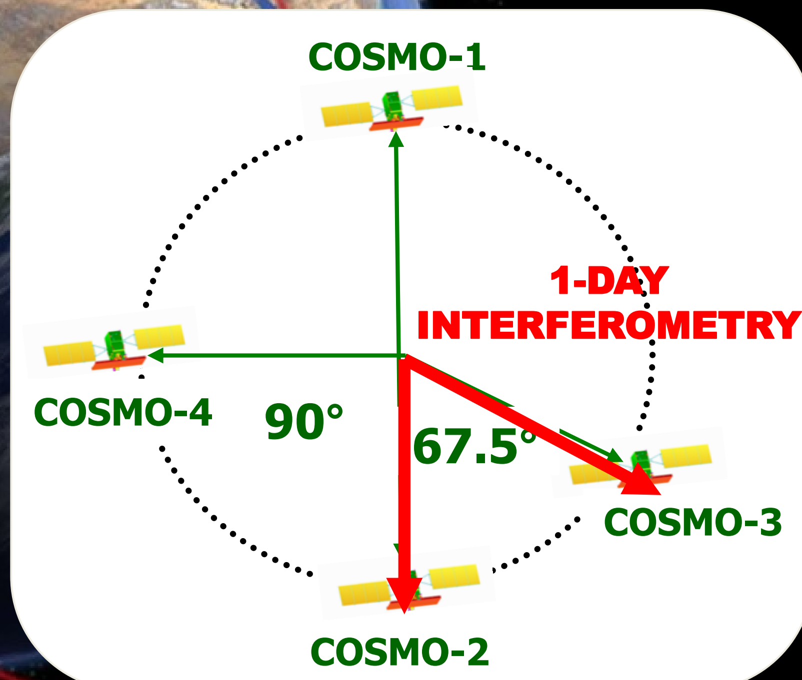
NO OTHER 4 SAR SATELLITES CONSTELLATION TODAY ON THE EO OPERATIONAL SCENE

8 JUN. - 2007
COSMO-1

9 DEC. - 2007
COSMO-2

25 OCT. - 2008
COSMO-3

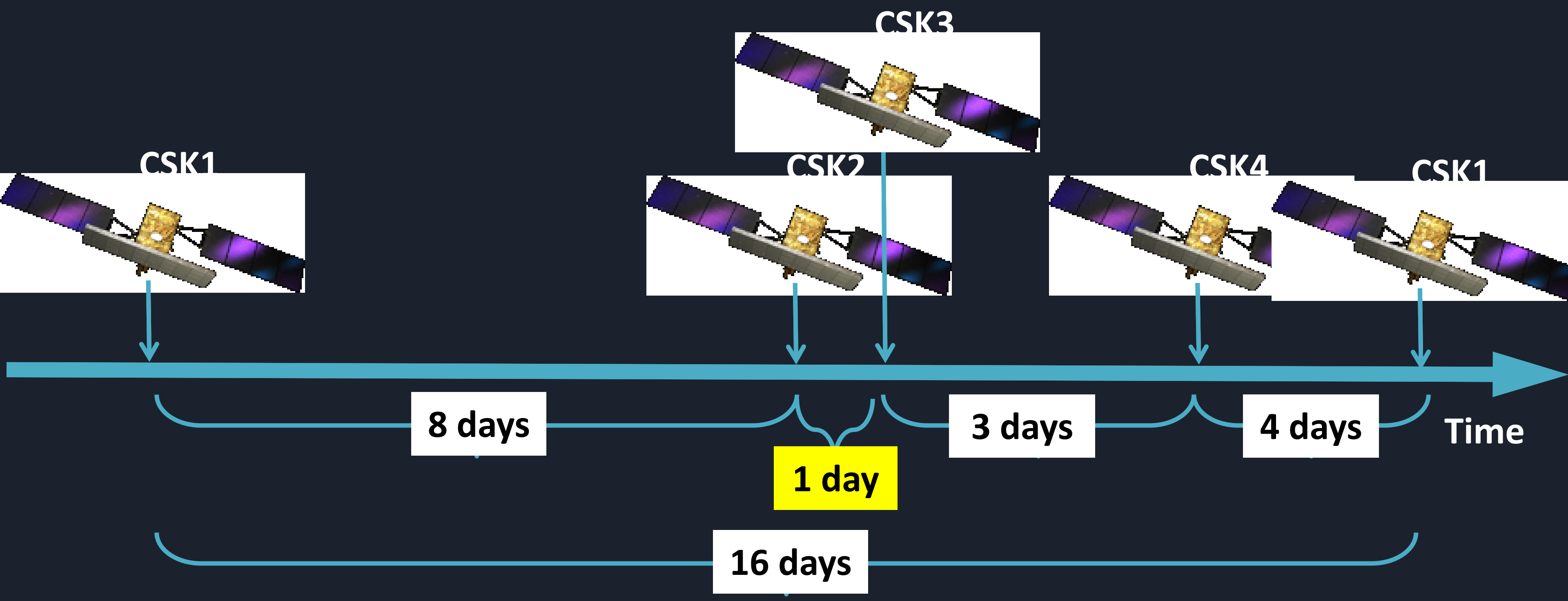
5 NOV. - 2010
COSMO-4



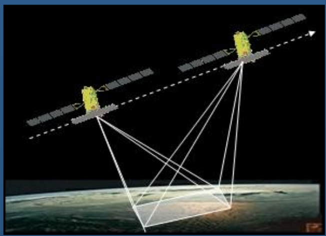
Revisiting time & constellation deployment

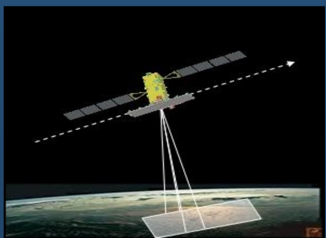
Agenzia Spaziale Italiana

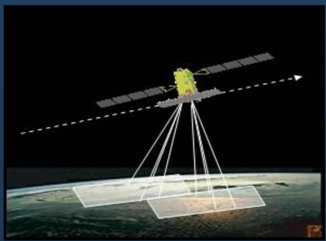
MAIN INTERFEROMETRIC COUPLES

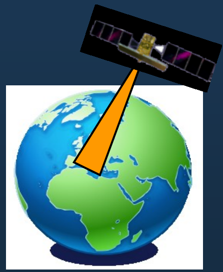


MULTI-MODE ACQUISITION CAPABILITY









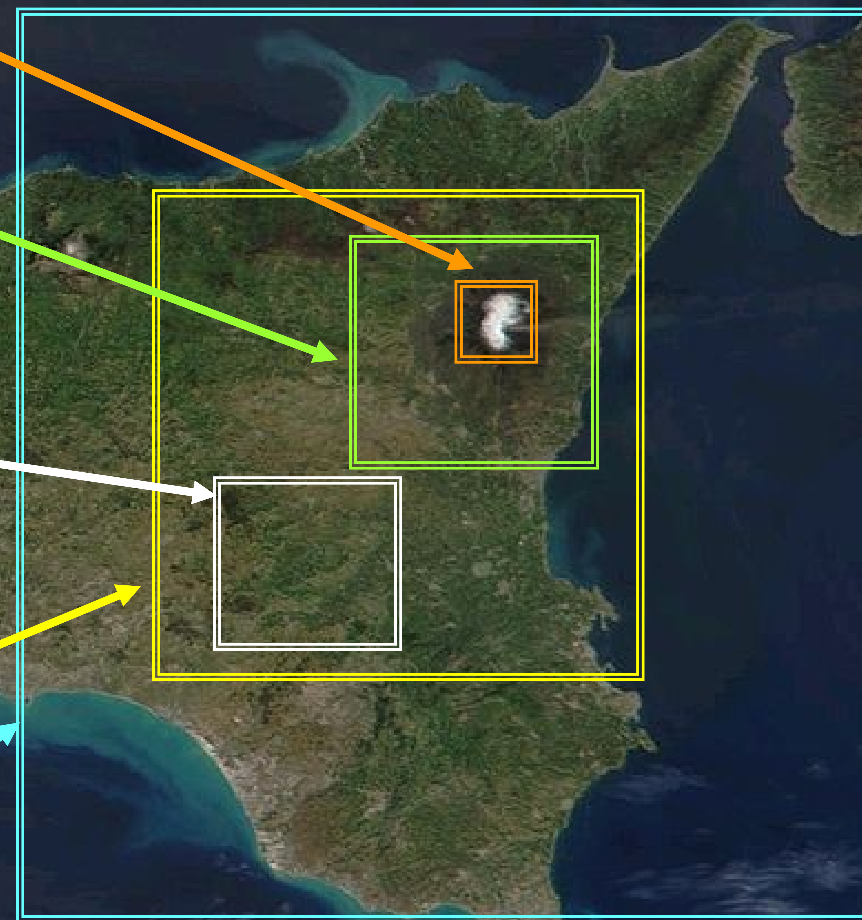
SPOTLIGHT
10 Km X 10 Km
1 m Resol.

STRIPMAP - HIMAGE
40 Km X 40 Km
3 m Resol.
Single pol. HH or
VV or VH or VV

STRIPMAP – PING PONG
30 Km X 30 Km
15 m Resol.
Alternating pol. HH/VV
or HH/HV or VV/VH

SCANSAR WIDE
100 Km X 100 Km
30 m Resol.

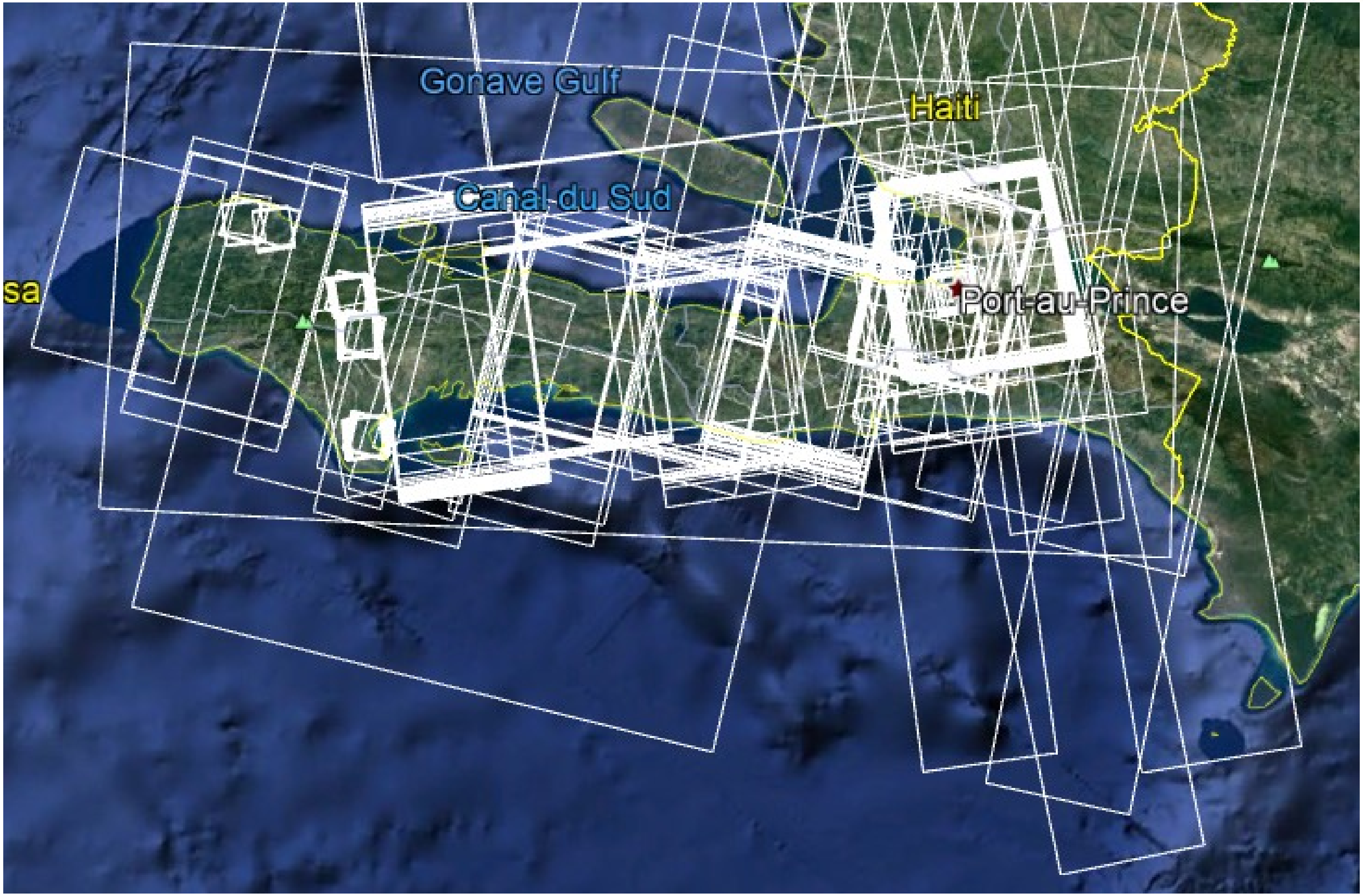
SCANSAR HUGE
200 Km X 200 Km
100 m Resol.



WIDE FIELD

NARROW FIELD

COSMO-SkyMed over southern Haiti



COSMO-SkyMed data accessibility (generally)

www.asi.it

INSTITUTIONAL USERS

ASI supports the INSTITUTIONAL (incl. SCIENTIFIC) data exploitation

agenzia spaziale italiana

COSMO-SkyMed Catalogue

e-geos
AN ASI / TELESPAZIO COMPANY

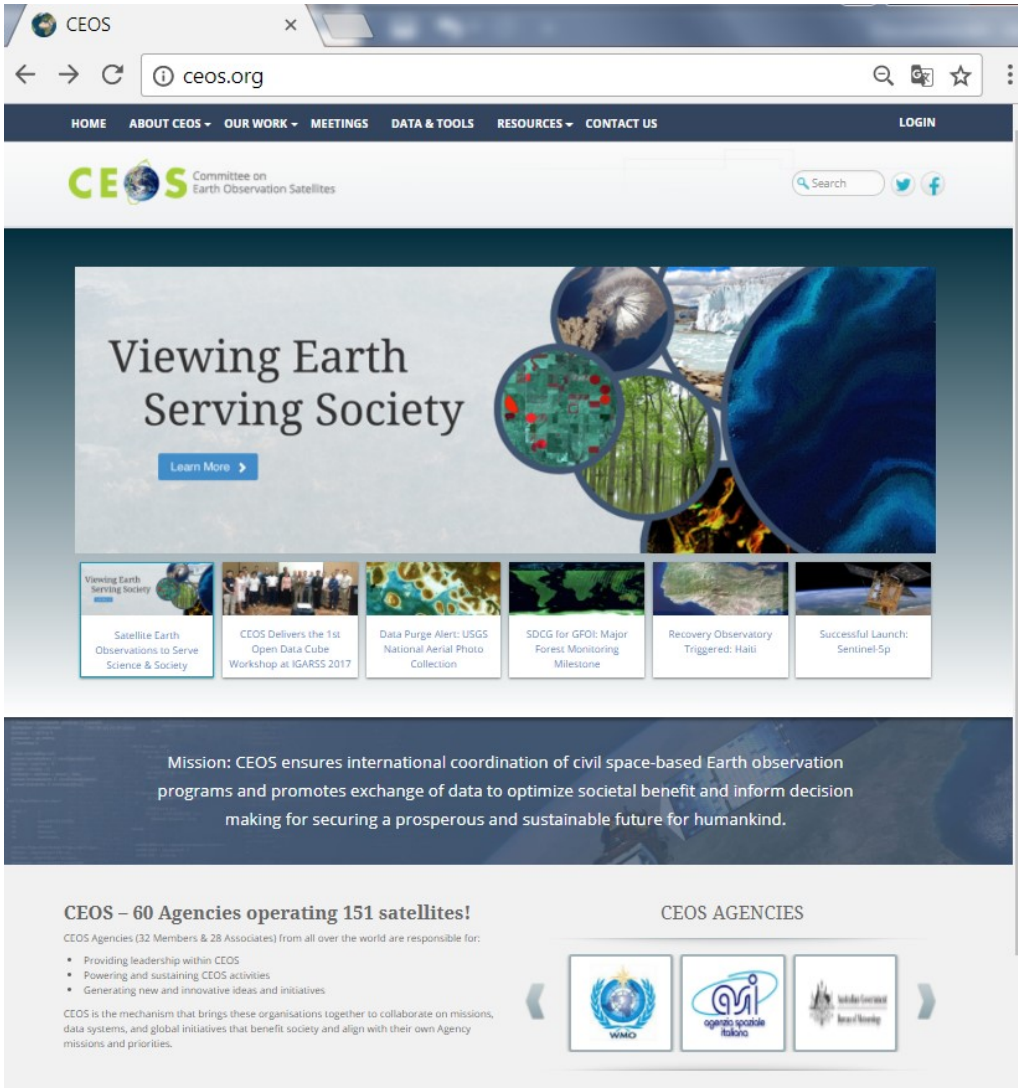
COMMERCIAL USERS

e-geos
UNA SOCIETÀ ASI/TELESPAZIO

e-GEOS supports the COMMERCIAL data exploitation

www.e-geos.it

Through Committee on Earth Observation Satellites



CEOS
http://ceos.org/

Working Group on Disasters
http://ceos.org/ourwork/workinggroups/disasters/

THANK YOU FOR YOUR ATTENTION!

Dr. Francesca Cigna, Dr. Deodato Tapete

Scientific Research Unit

Italian Space Agency (ASI)

francesca.cigna@asi.it deodato.tapete@asi.it