INTRODUCTION TO SAR REMOTE SENSING

Theory and applications

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About TARGETS

The implementation of remote sensing techniques is a function of what needs to be observed. For instance, the orbit parameters are related to monitoring requirements. So, the Earth can be observed at different scales.

about SENSORS

In remote sensing, the device used to acquire data i.e. to measure the radiation arriving to the satellite instrument, is usually referred to as a **"sensor"**.

about INFORMATION TO KNOWLEDGE

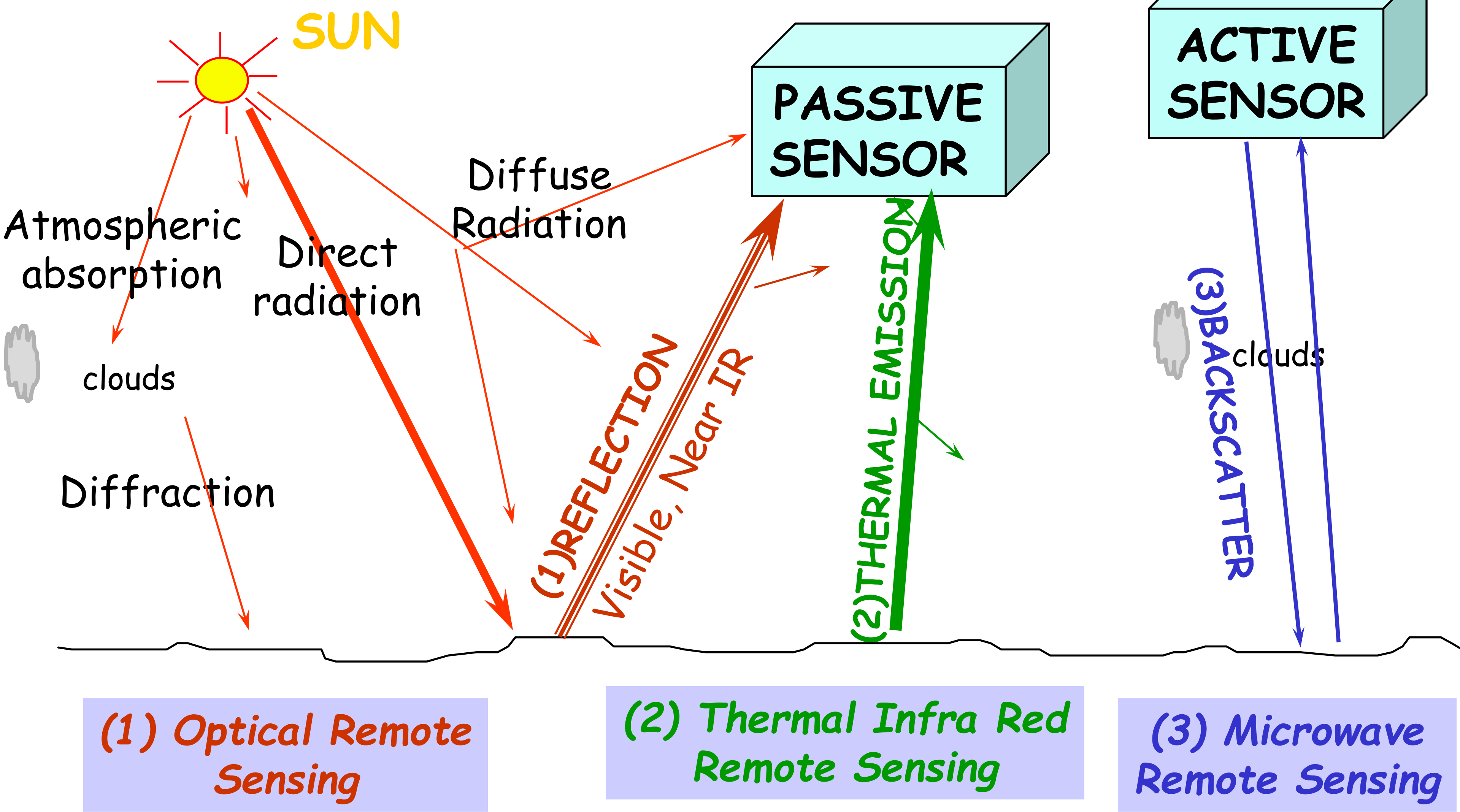
In remote sensing, it is very important to understand the data provided by sensors in order to interpret them properly.

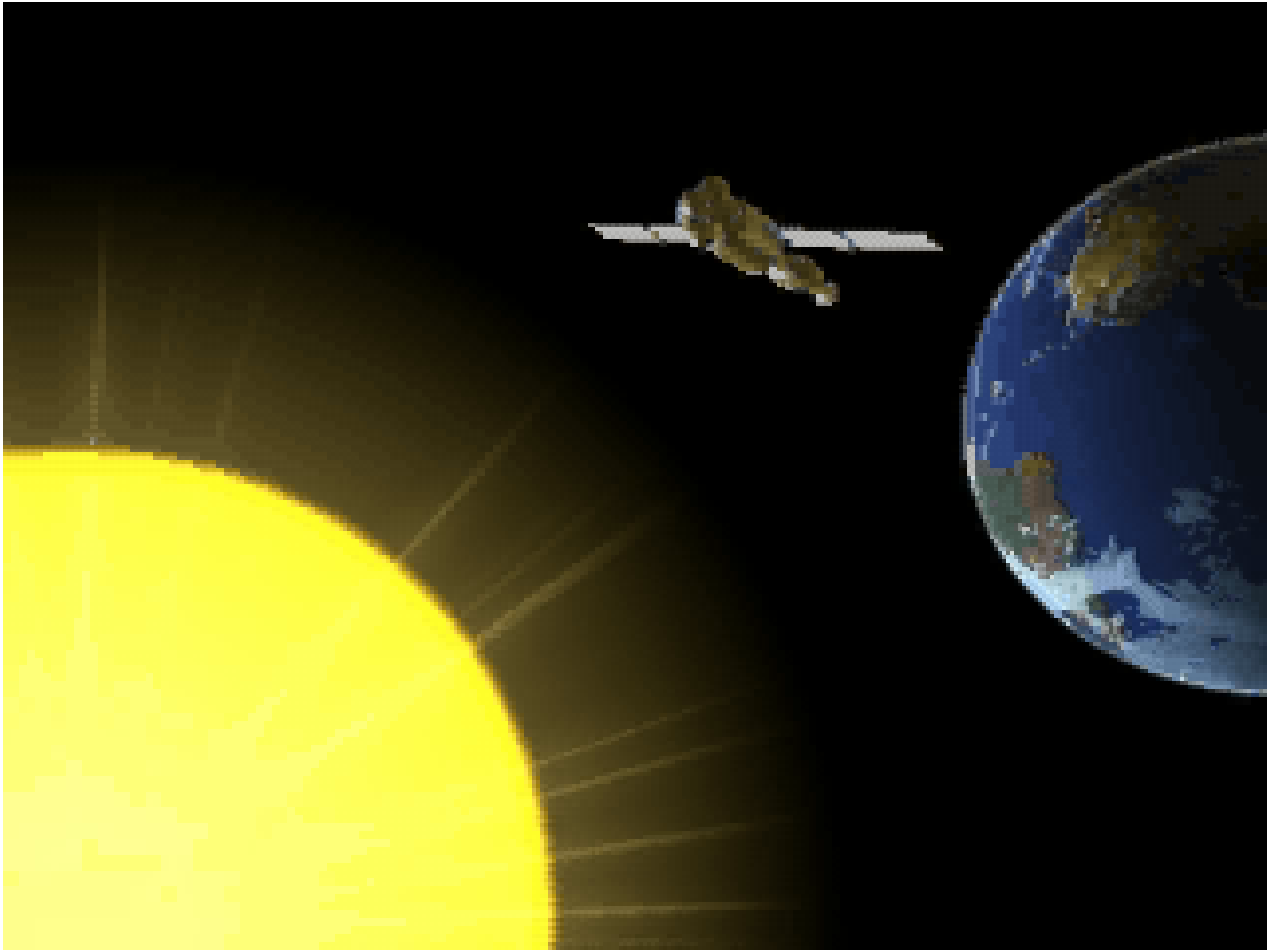
Introduction to Radar satellites

Today, satellites are very common platforms used in remote sensing; they carry a great diversity of sensors, often specialised to observe specifically the weather, landscapes or natural disasters, vegetation; some are even capable of “seeing” through clouds or acquiring imagery at night.

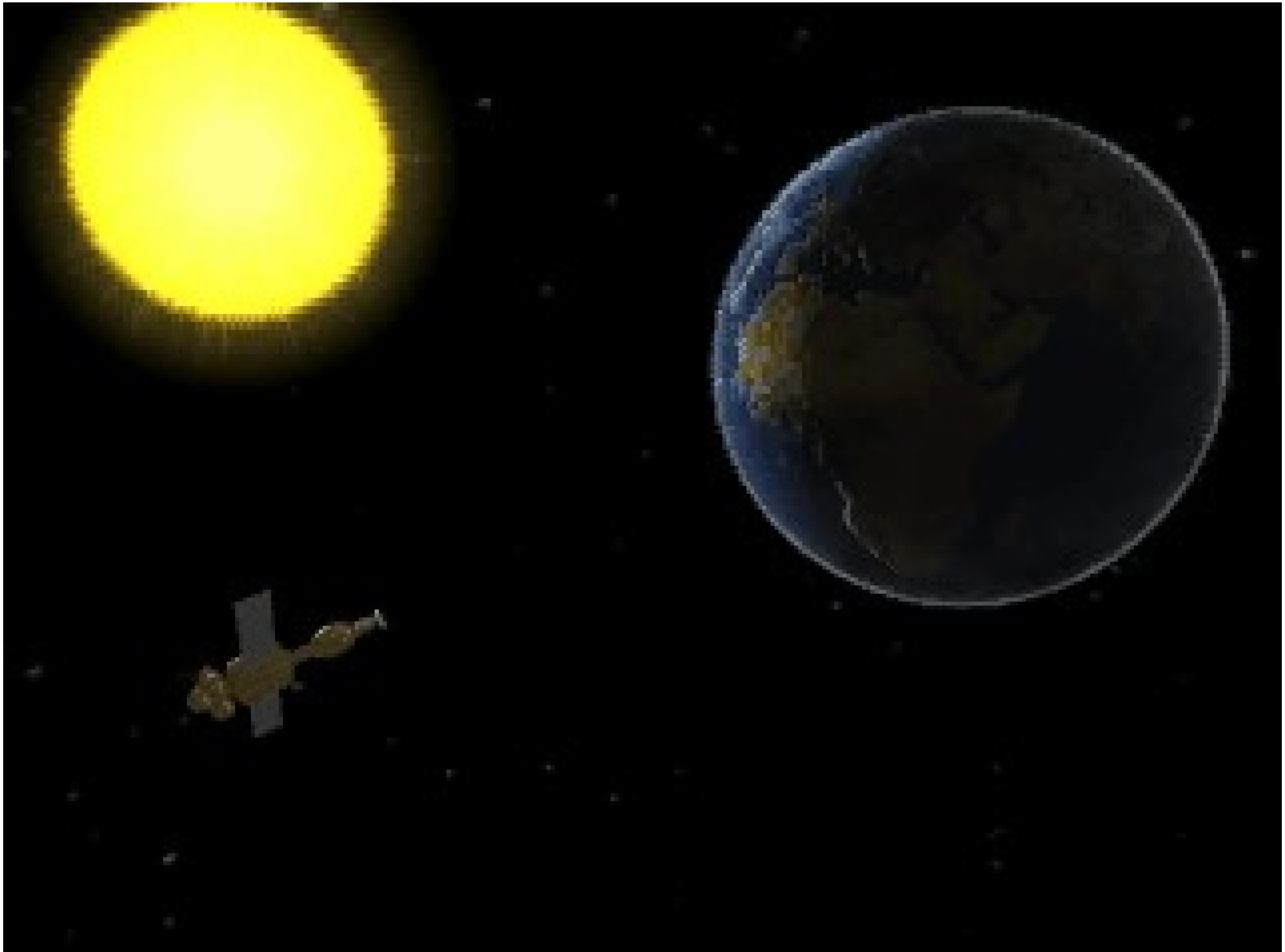
General remote sensing principles

Sensors : Optical, Thermal and Microwave

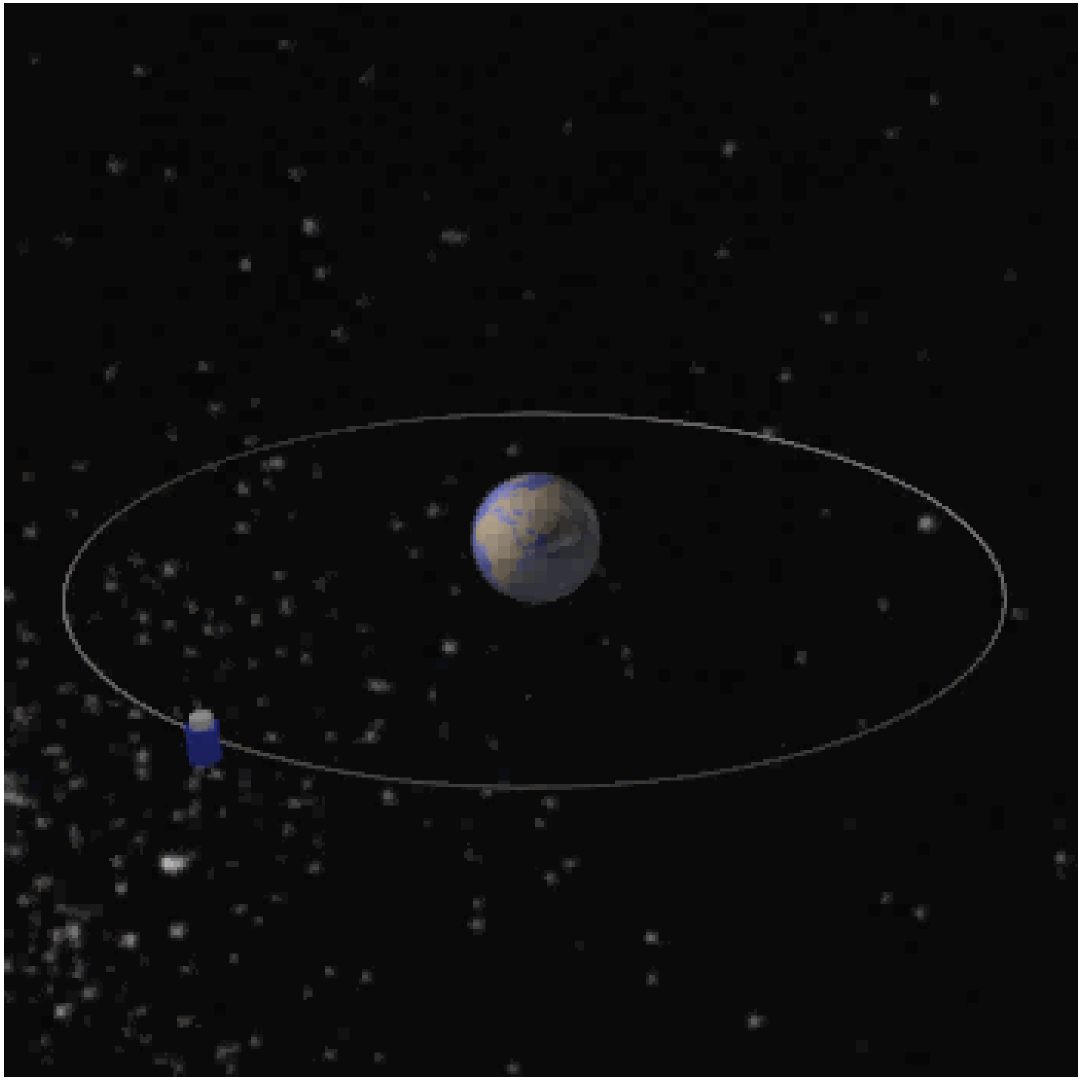




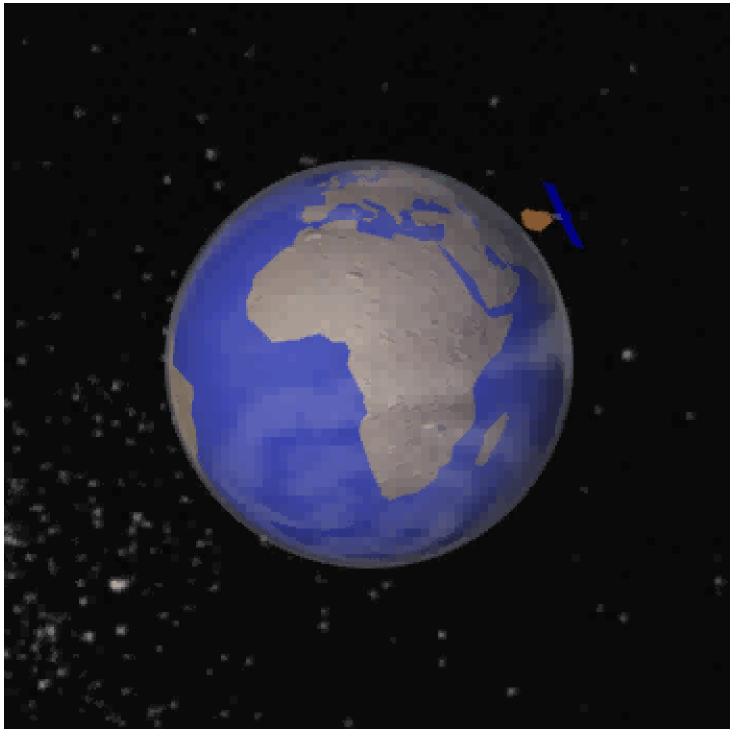
Passive system

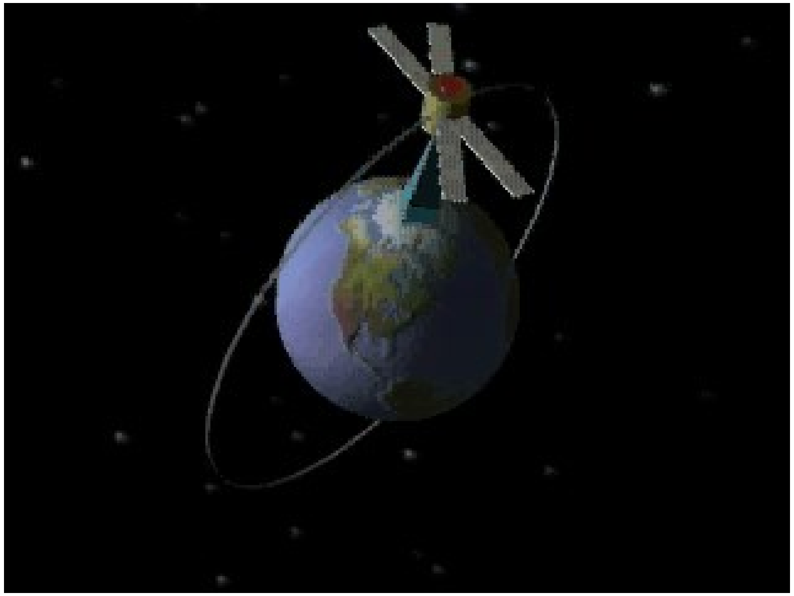


Active system

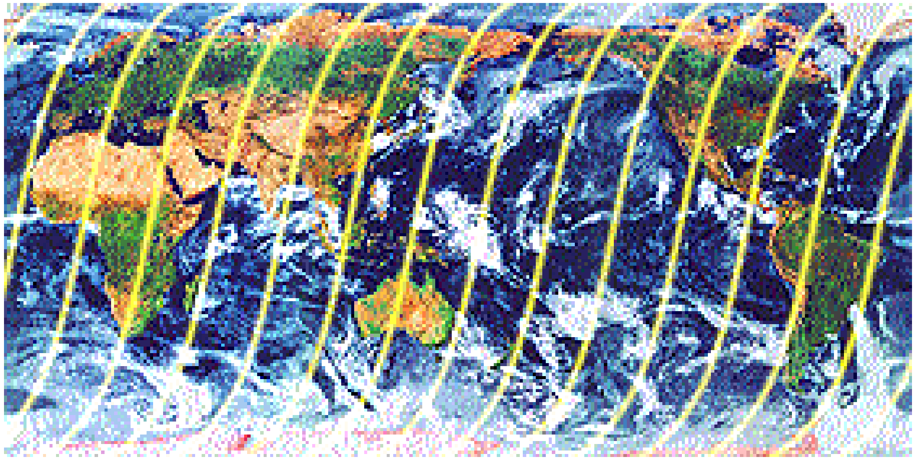


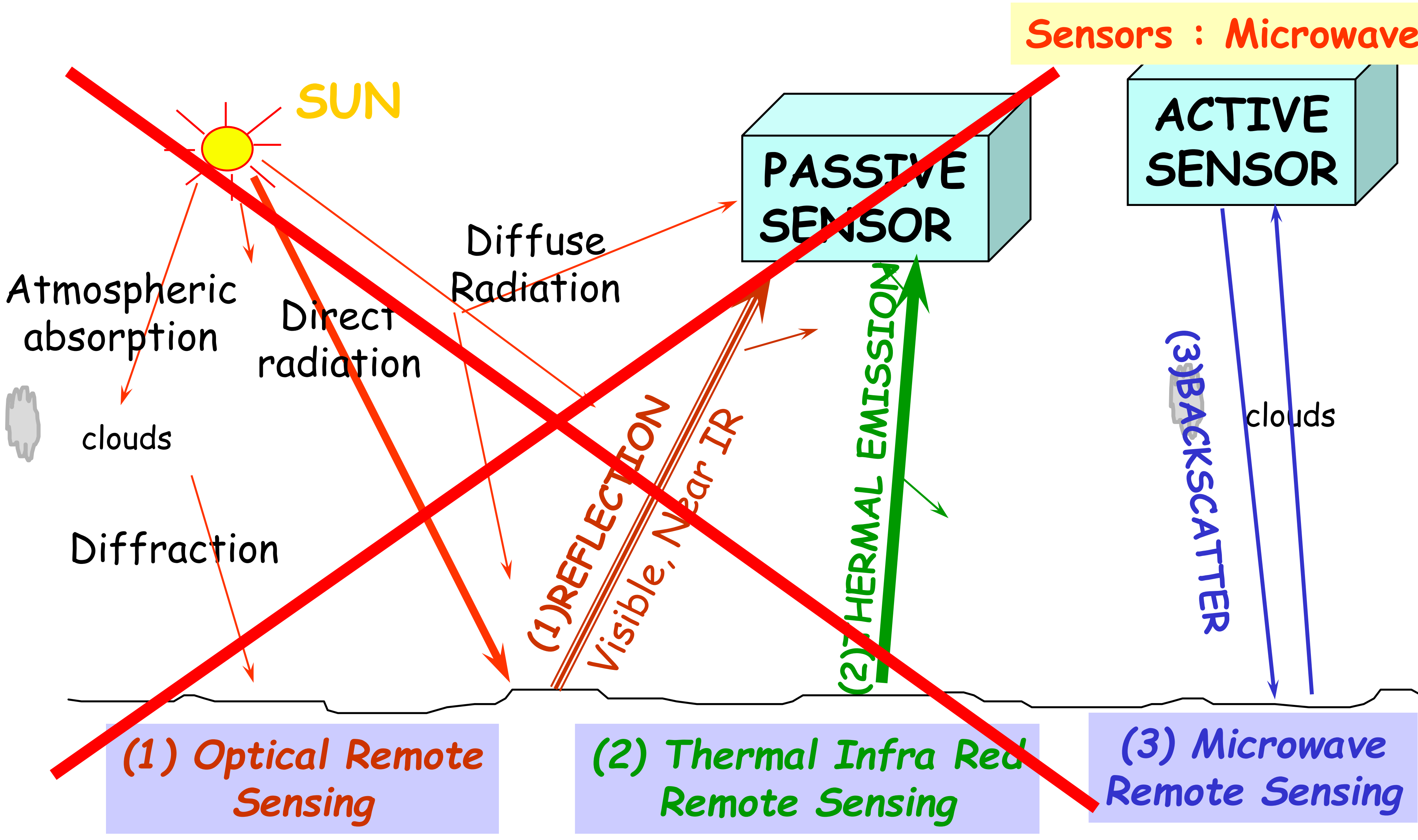
The geostationary orbit is quasi circular at 36000km altitude. One period lasts 24h, hence the satellite moves at the same angular speed as the Earth. The satellite seems fixed with respect to an observer on ground.





Polar orbit





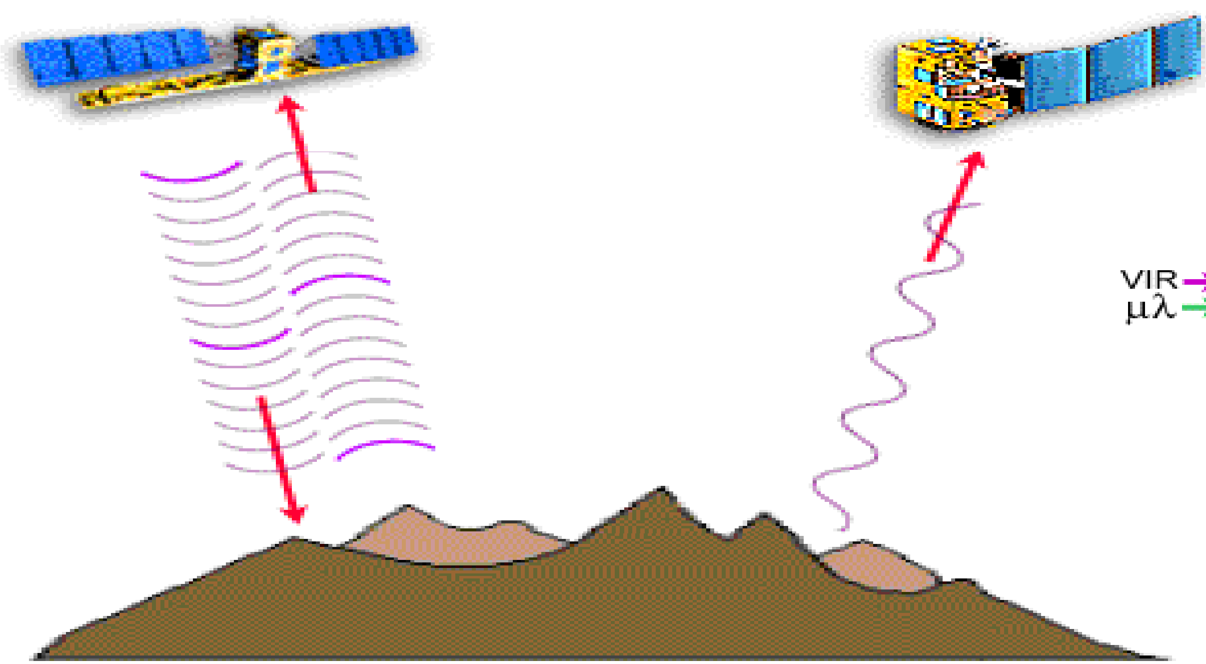
Sensors : Microwave
SUN
PASSIVE SENSOR
ACTIVE SENSOR
Diffuse Radiation
Atmospheric absorption
Direct radiation
clouds
Diffraction
(1)REFLECTION
Visible, Near IR
(2)THERMAL EMISSION
(3)BACKSCATTER
clouds
(1) Optical Remote Sensing
(2) Thermal Infra Red Remote Sensing
(3) Microwave Remote Sensing

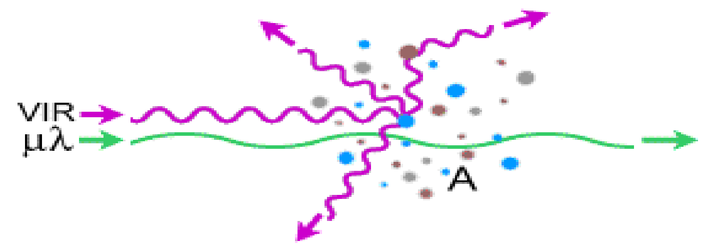
RADAR Concept

A radar transmits electromagnetic waves in form of pulses and records the echoes scattered back by objects encountered by the waves along their path.

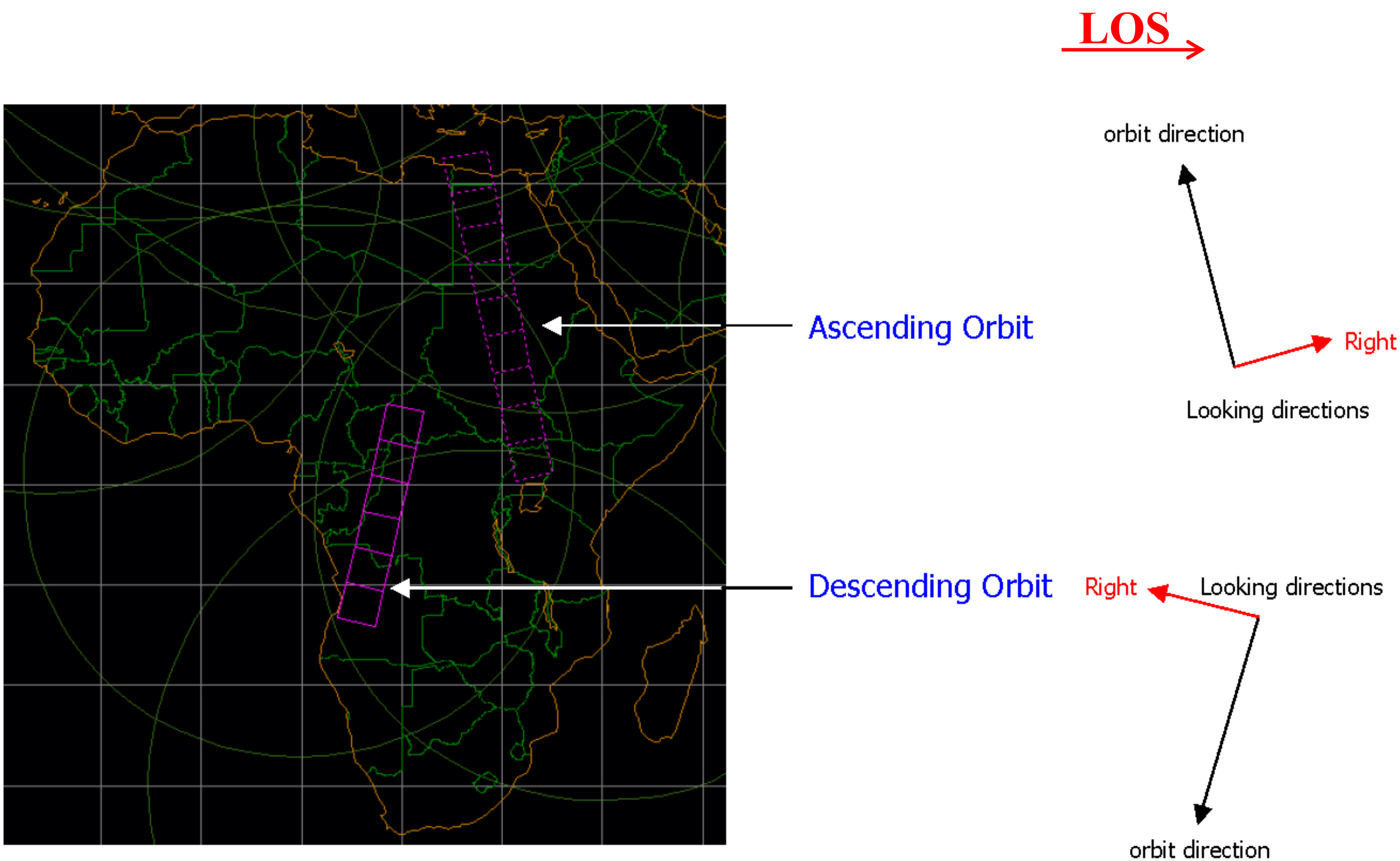
The echoes are a modified version of the transmitted pulse. Depending on the object scattering back the pulses, the echoes recorded by the radar are different (more or less energy, particular phase value etc.).

Radar can always acquire, i.e. it does not suffer from cloud cover, fog and day-night cycle





Satellite Orbits



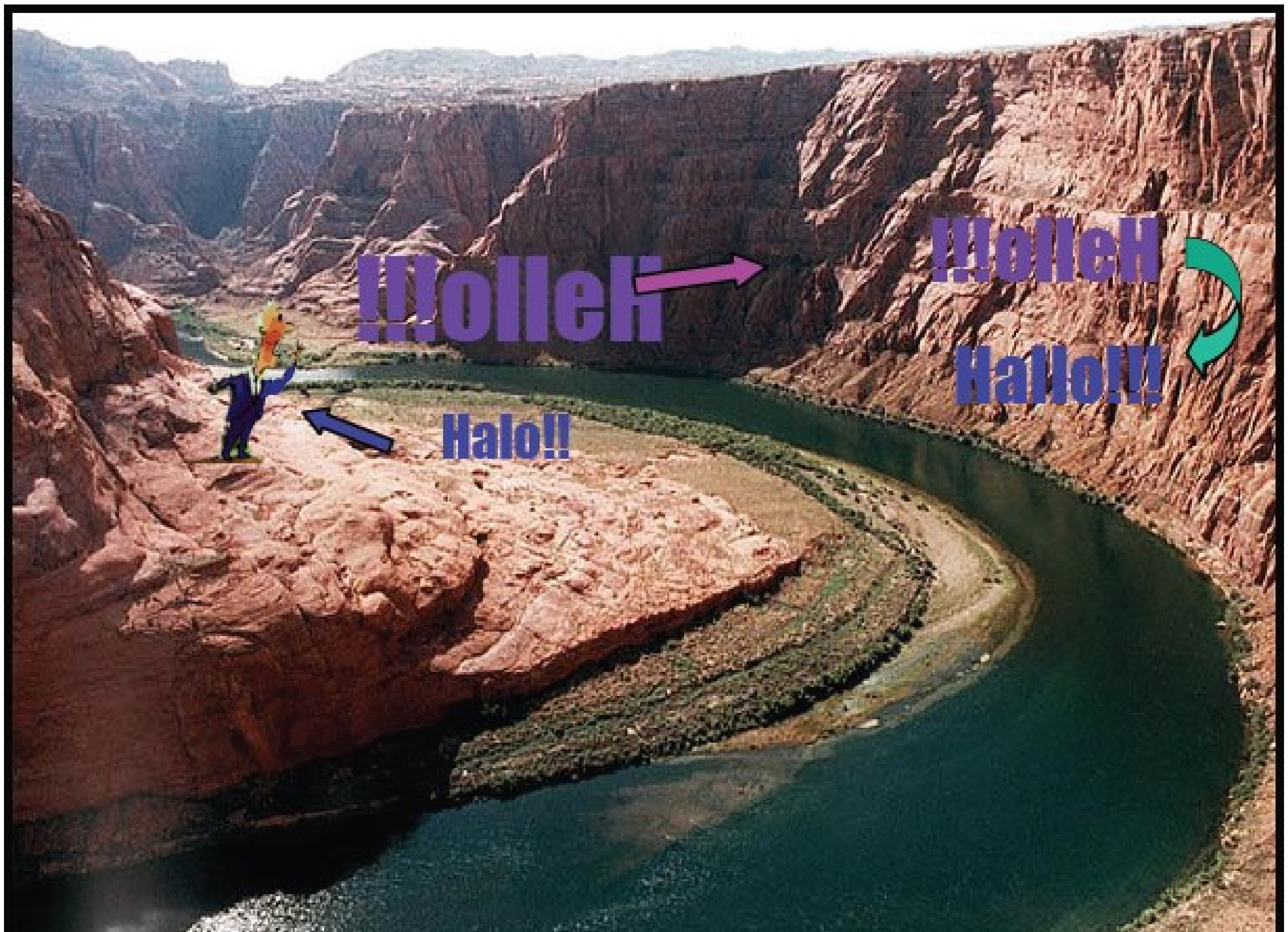
Sun synchronous orbits at about 785 km allow systematic revisiting times with different viewing geometries (descending & ascending modes)

SAR Basics

Imaging radar is an active sensor that alternatively sends out microwaves in form of pulses and records the echoes scattered back by objects hit by the waves along their traveling path.
The objects are also commonly referred to as **targets or scatterers.**

RADAR Concept

Imagine you are in the Grand Canyon and you shout. The cliffs will reflect the sound wave. After some time you will hear an echo, which is not exactly the same compared to what you shouted. This is the “principle” of a RADAR!



Synthetic Aperture Radar - SAR

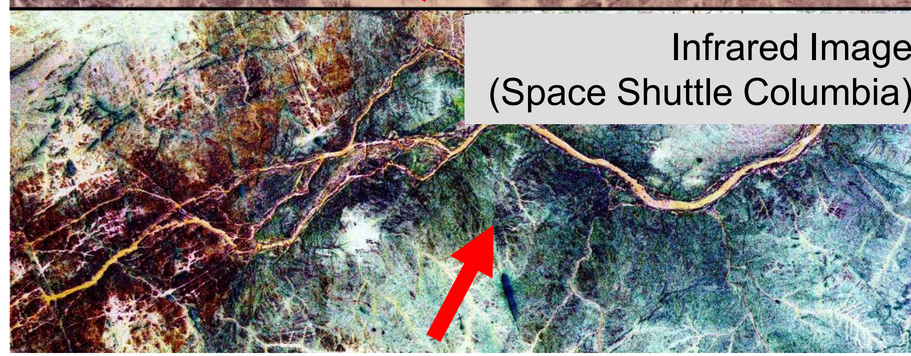
- active ⇒ independent of sun illumination
- microwave ⇒ penetrates clouds and (partially) canopy, soil, snow

  wavelengths:
  - X-band: 3 cm
  - C-band: 6 cm
  - L-band: 24 cm
- coherent ⇒ interferometry, speckle
- polarization can be exploited
- spatial resolution:
  - space-borne: 5 m - 100 m (TerraSAR-X: ≈1 m)
  - air-borne: > 0.2 m

Motivation for Earth Observation with SAR

- **Complementary information to optical sensors**
  - *Scattering at different wavelengths, polarisations,...*
- **Independent of weather**
  - *Imaging also with clouds, rain, ...*
- **Independent of daylight**
  - *Imaging during night, polar winter, ...*
- **New generation of products**
  - *Elevation models, deformation...*

©NASA



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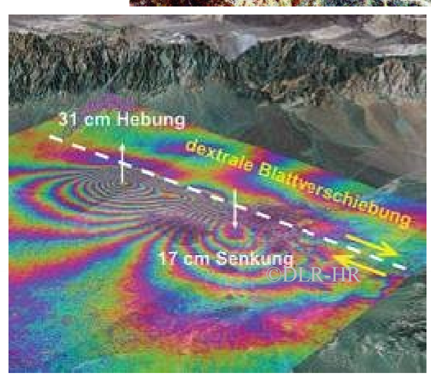

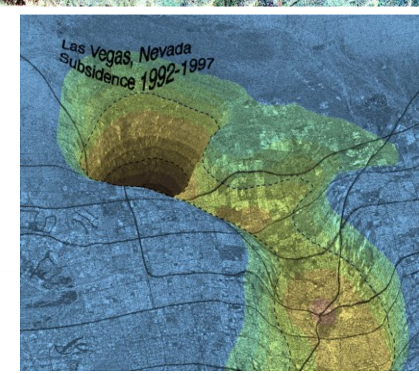

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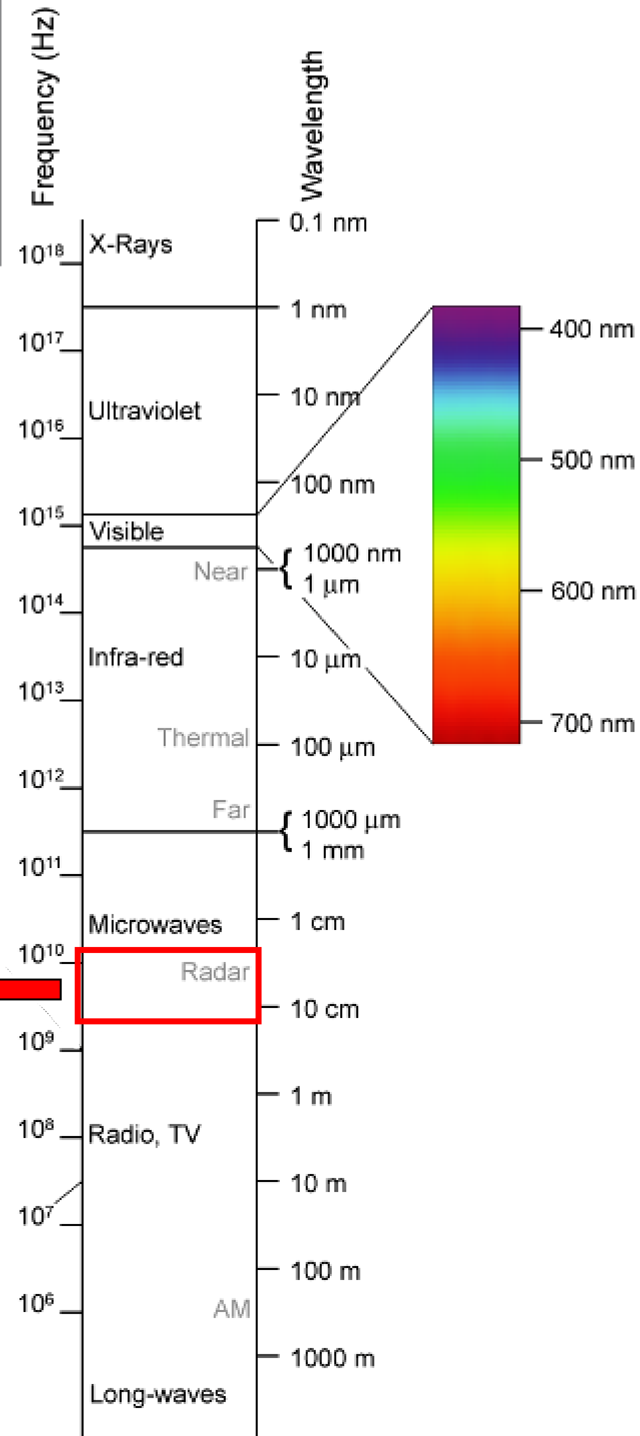
The electromagnetic

Synthetic Aperture Radar (SAR)



SAR Systems – Carrier Frequencies

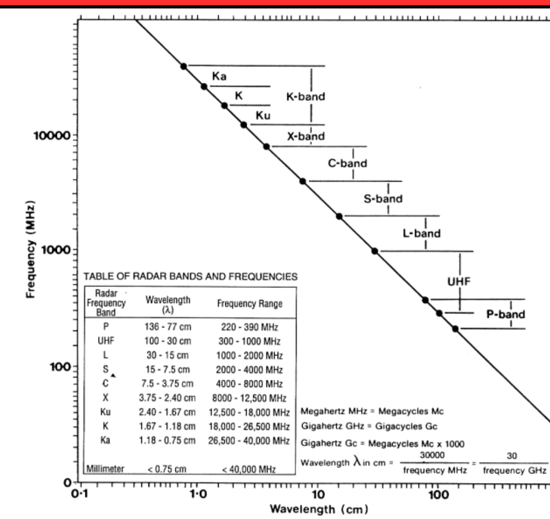
SAR sensors uses the microwave portion of the electromagnetic spectrum, from a frequency of 0.3 GHz to 300 GHz, or in wavelength terms, from 1 m to 1 mm.

Band	Frequency	Wavelength
VHF	30-300 MHz	10-1 m
P-band	280-390 MHz	107-77 cm
UHF	300 MHz – 1GHz	100-30 cm
L-band	1-2 GHz	30-15 cm
S-band	2-4 GHz	15-7.5 cm
C-band	4-8 GHz	7.5-3.75 cm
X-band	8-12.5 GHz	3.75-2.40 cm

Yellow background: Airborne SAR systems

Red background: Airborne & Spaceborne SAR systems

Spaceborne SAR need high frequency to see through the Ionosphere



Microwave Frequency and Wavelength Bands

band	frequency f_0		wavelength $\lambda = c/f_0$		typical application
Ka	27 – 40	GHz	1.1 – 0.8	cm	airport surveillance
K	18 – 27	GHz	1.7 – 1.1	cm	little used (H_2O absorption)
Ku	12 – 18	GHz	2.4 – 1.7	cm	**satellite altimetry**
X	8 – 12	GHz	3.8 – 2.4	cm	**SAR**, marine radar, weather radar
C	4 – 8	GHz	7.5 – 3.8	cm	**SAR**, weather radar
S	2 – 4	GHz	15 – 7.5	cm	long-range weather radar
L	1 – 2	GHz	30 – 15	cm	**SAR**, traffic control
P	0.3 – 1	GHz	100 – 30	cm	experimental SAR

Tab. 1: © TUM

Main satellites carrying SAR sensors

ENVISAT ASAR was a spaceborne SAR operated by the European Space Agency (ESA).

ERS-1 and ERS-2 SAR were also operated by ESA. The two satellites have been in operation since 1991 and 1995 respectively.

SENTINEL 1 A & B (ESA, Copernicus program)

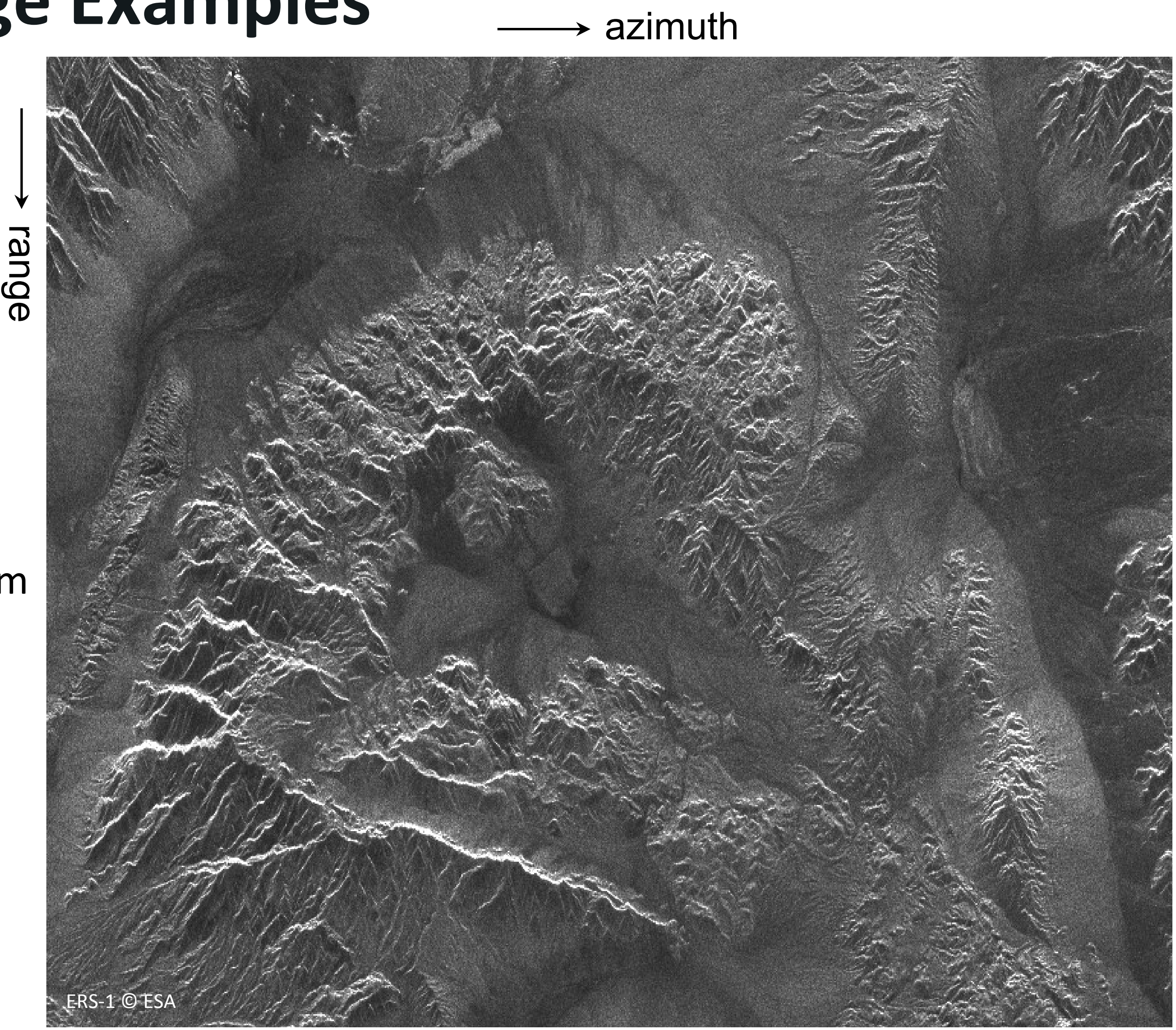
RADARSAT-1 and 2 are spaceborne SAR operated by the Canadian Space Agency (CSA).

ALOS-PALSAR 2 is a SAR L- band operated by the Japanese Space Agency

COSMOS SKY_MED is a X band operated by Italian Space Agency for civil protection purposes.

TERRASAR-X is a X band operated by DLR

SAR Image Examples



Sensor: ERS-1

Mojave Desert
CA, USA

Size ≈ 40 km x 40 km

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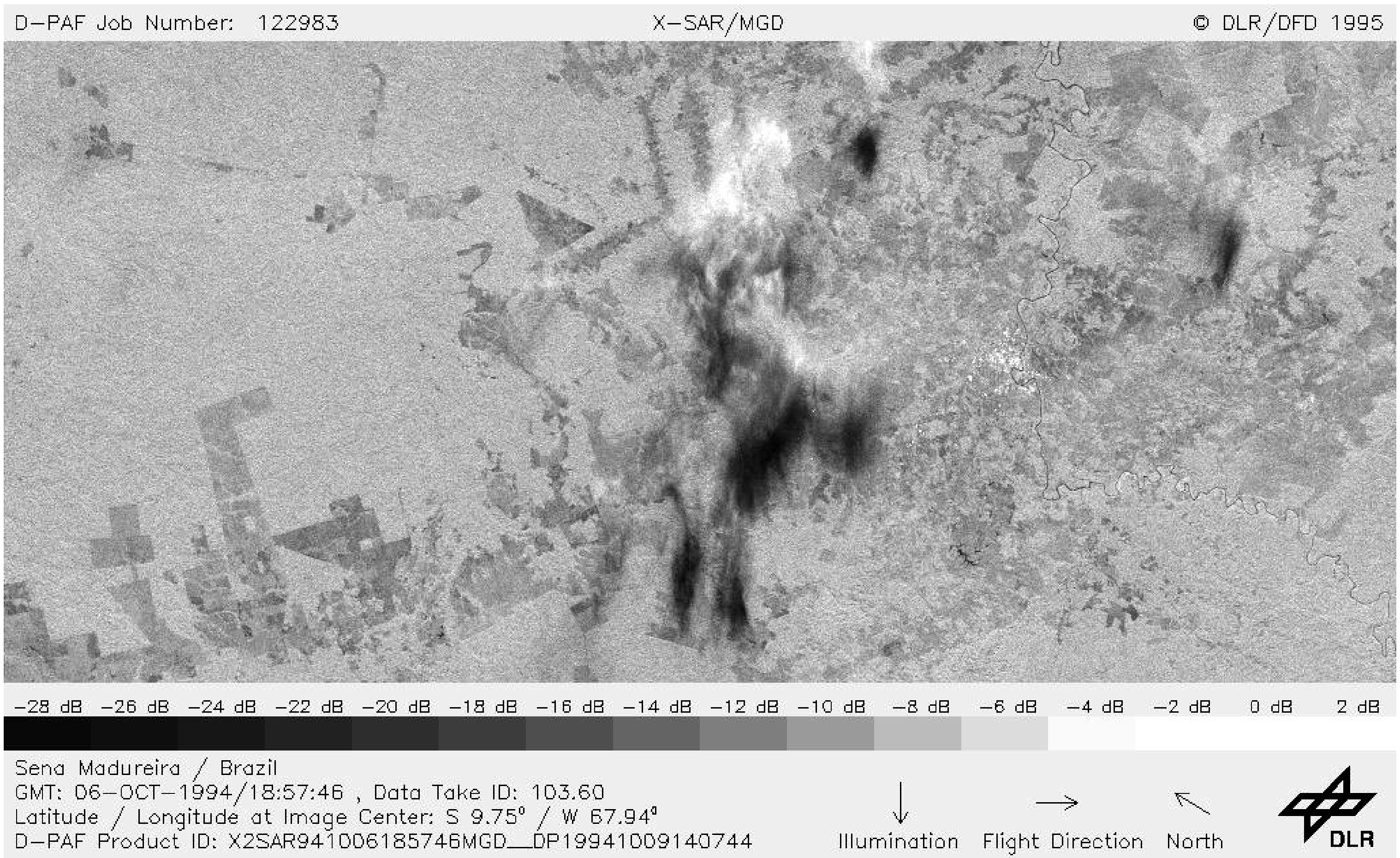
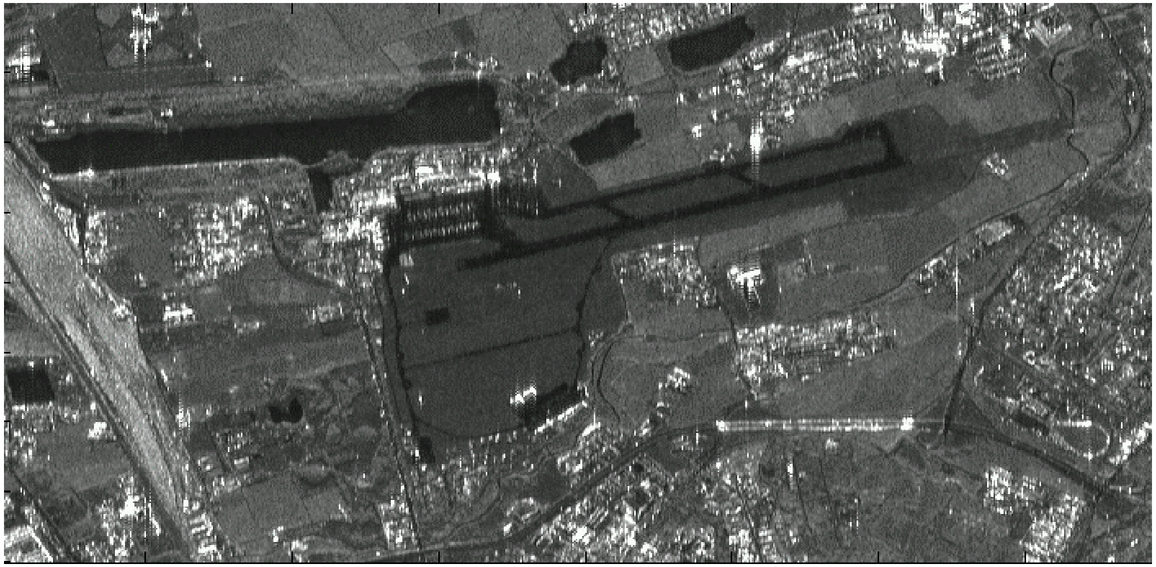
Heavy Clouds and Rain Cells in X-Band SAR Images

→ Only visible at short wavelengths and extreme conditions



SAR vs OPTICAL



ERS-2 SAR detected image of the Linate Airport in Milan (Italy)

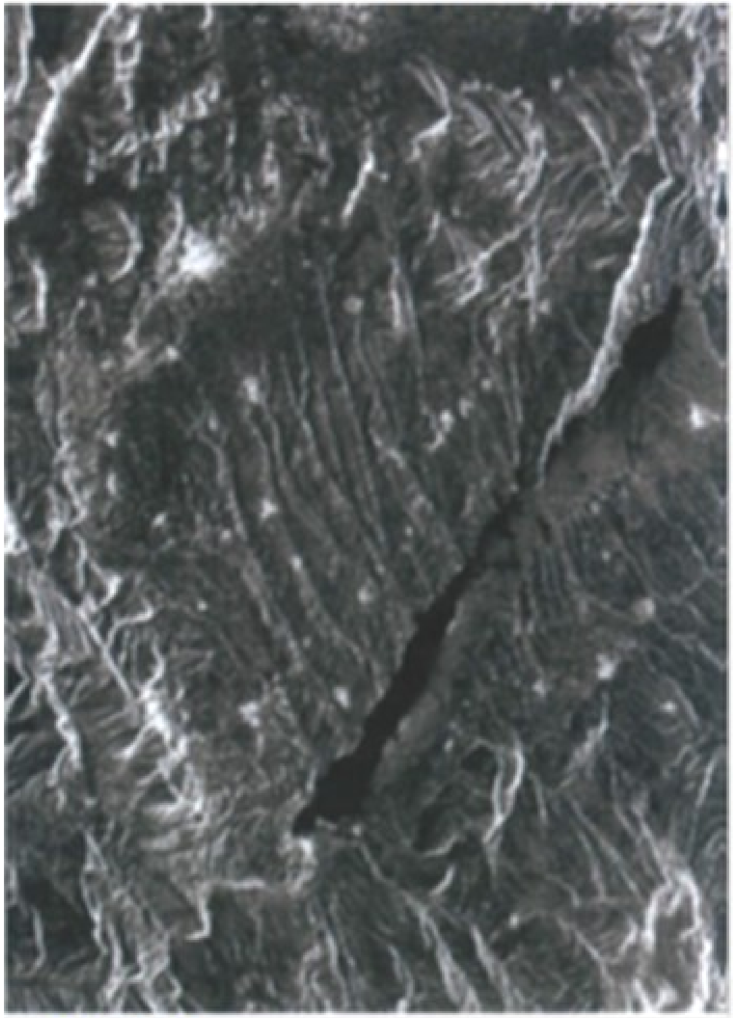
Optical image taken from SPOT satellite.

INQUA

IUGS UNESCO IGCP 567

Earthquake Archaeology

Introduction to SAR image



ERS-1 image

Landsat FCC

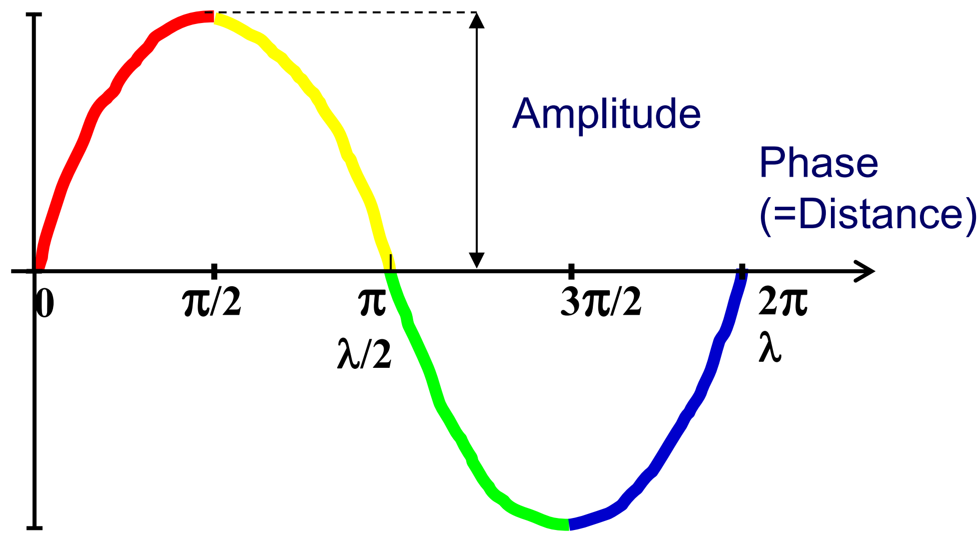
Electromagnetic Wave

An electromagnetic wave represents the temporal and spatial variations of an electric and a magnetic field in space, characterized by its *amplitude* and *wavelength or frequency (i.e. phase)*

An electromagnetic wave can be mathematically represented by a complex number in the form

$$A \cdot e^{j\varphi}$$

where
A is the amplitude of the wave, expressing the energy of the wave
φ is the phase, i.e. a term related to the wavelength, giving the path traveled by the wave (in the 0, 2 π interval)



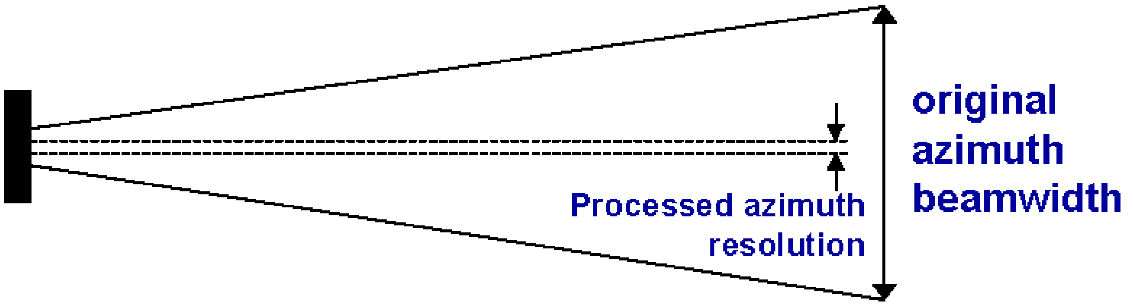
λ - Microwave wavelength

SAR Concept

SAR takes advantage of the Doppler history of the radar echoes generated by the forward motion of the flying to synthesize a large antenna.

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 (1000-2000 per sec). Each echo is characterized by the time required for the pulse to travel to the target and back to the radar.

This allows to synthesize the echoes together resulting to a high azimuthal resolution despite a physically small antenna.



This is the concept of Synthetic Aperture Radar – SAR

SAR is not an object, it is a way to treat RADAR echoes!

2-D Raw Data Matrix

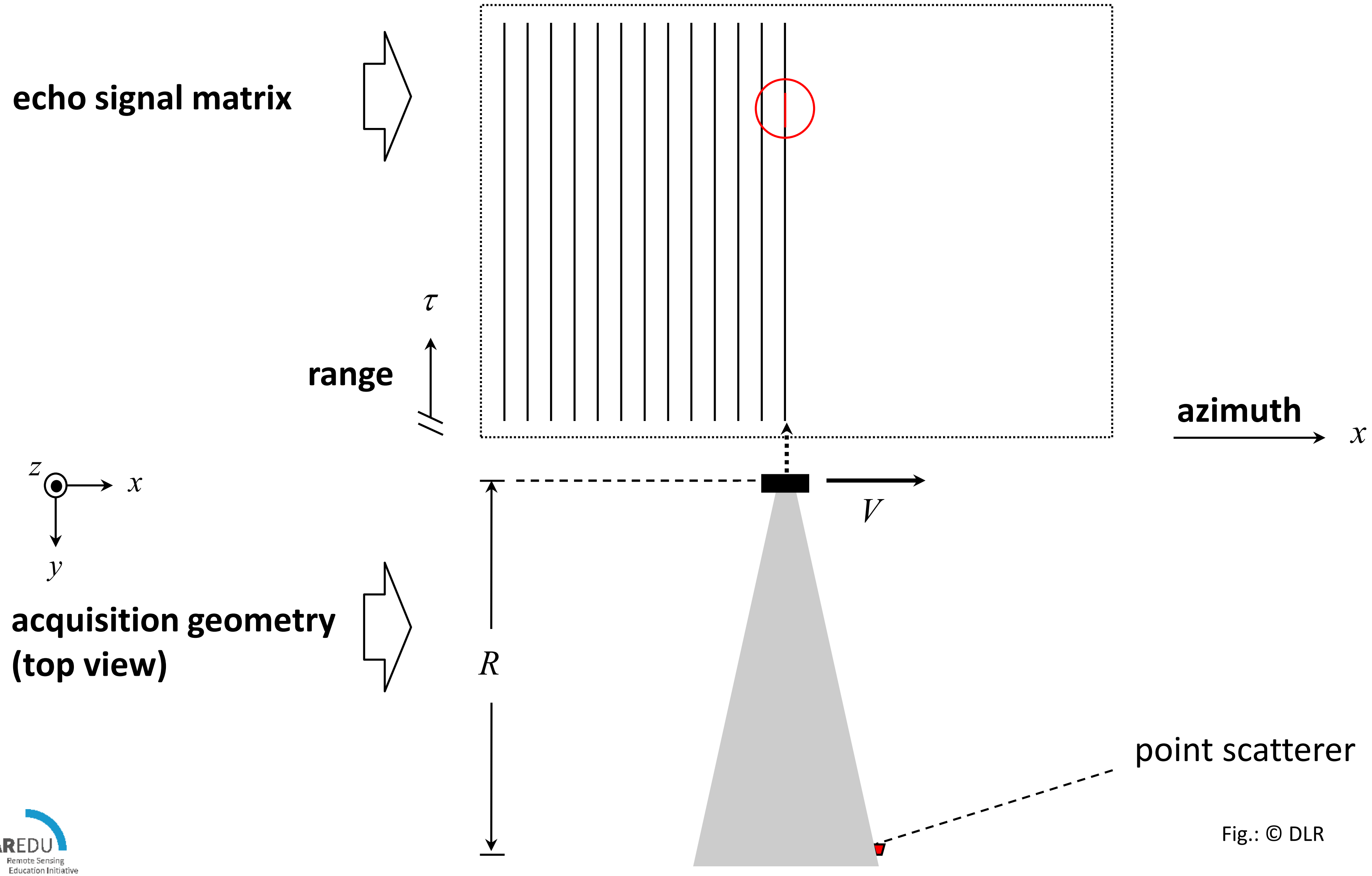


Fig.: © DLR

2-D Raw Data Matrix

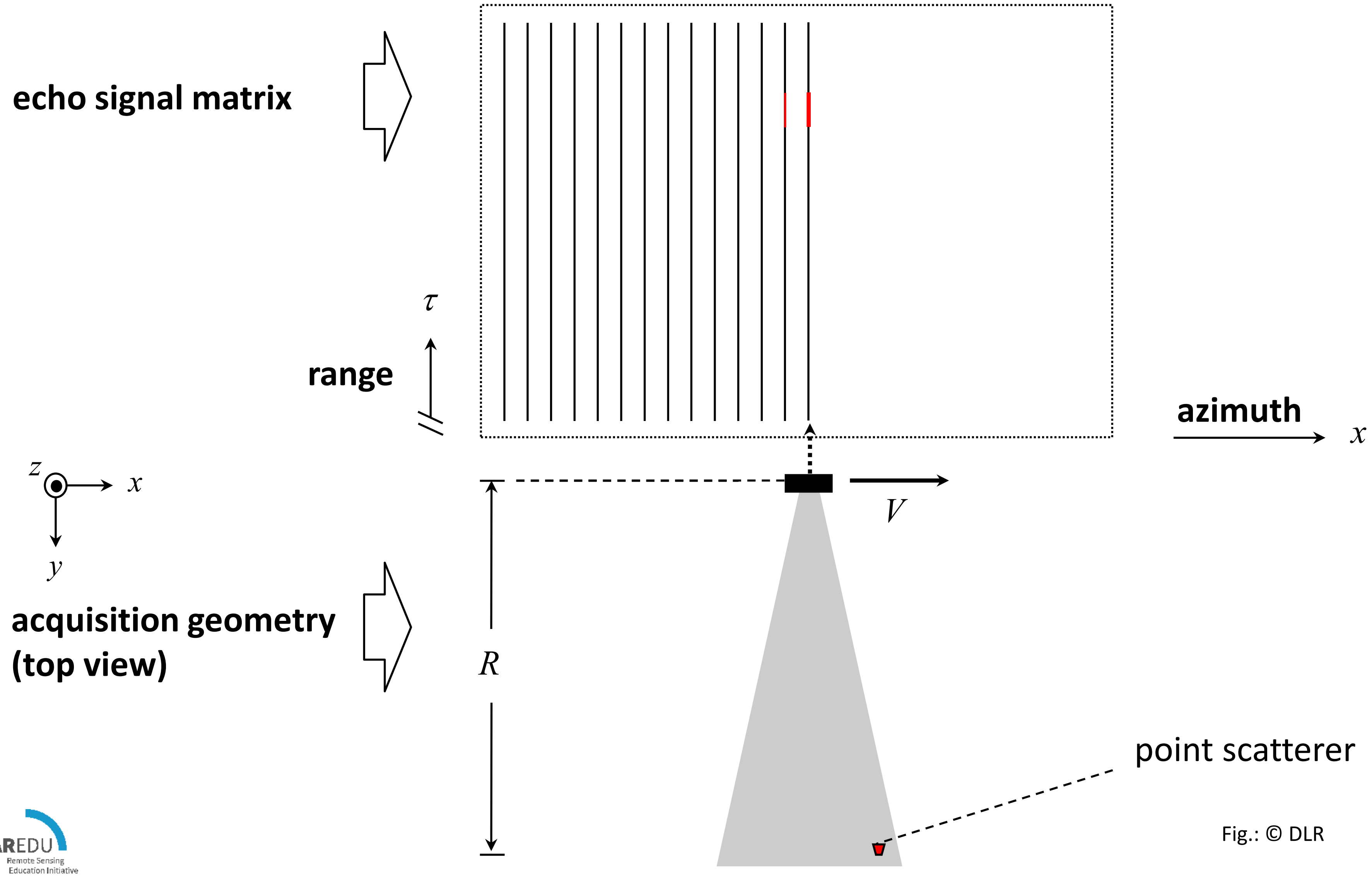


Fig.: © DLR

2-D Raw Data Matrix

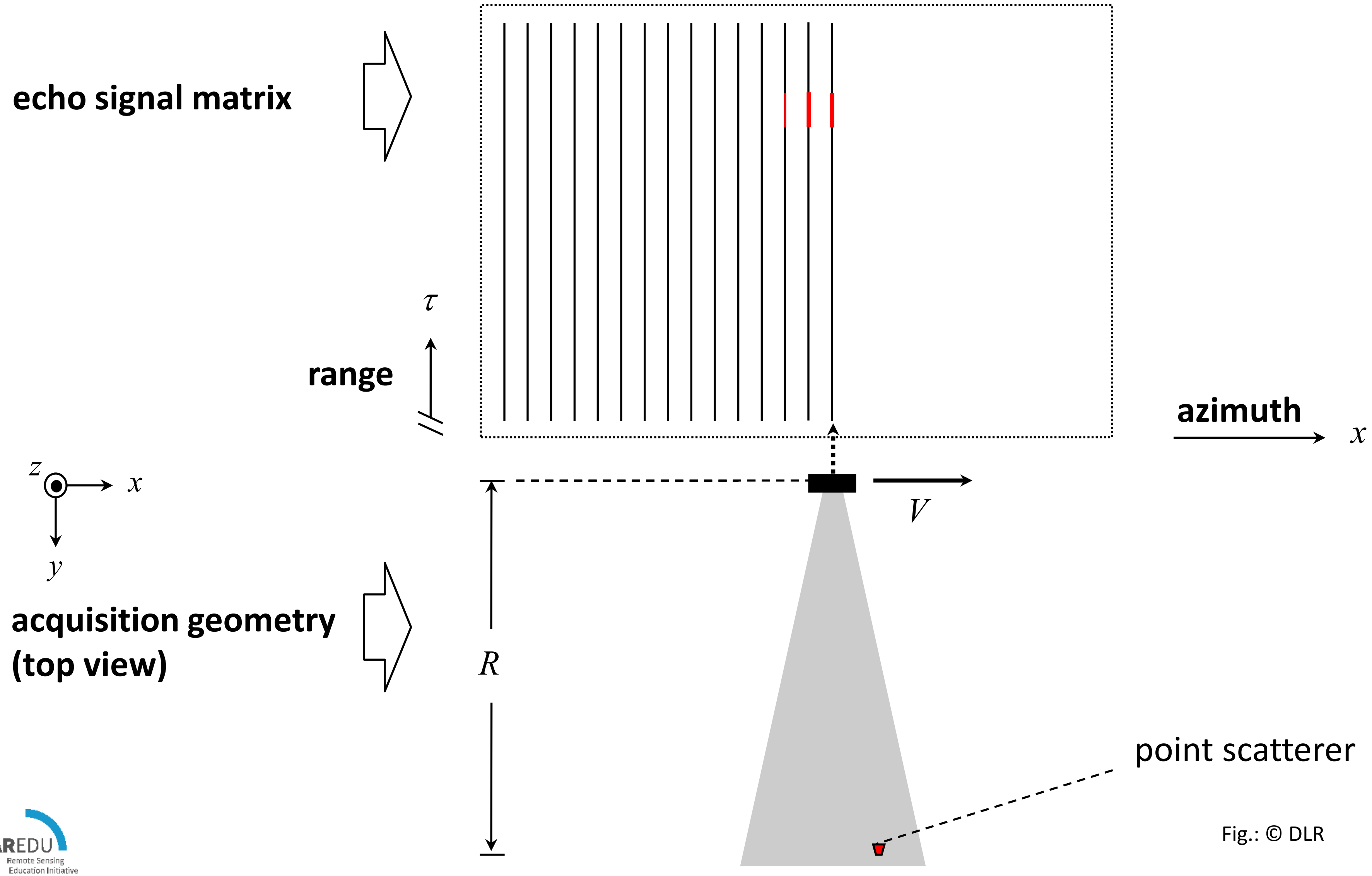


Fig.: © DLR

2-D Raw Data Matrix

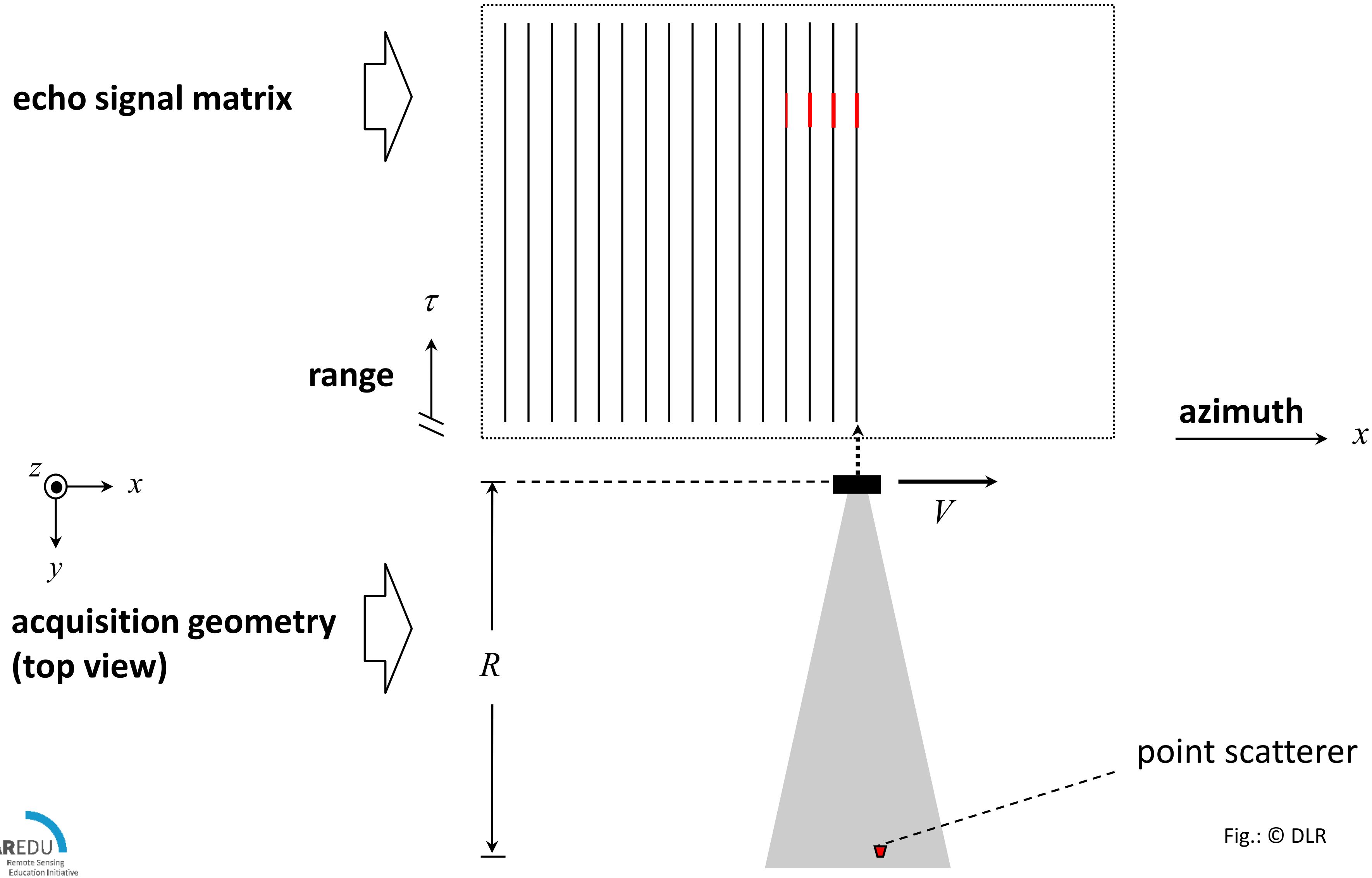


Fig.: © DLR

2-D Raw Data Matrix

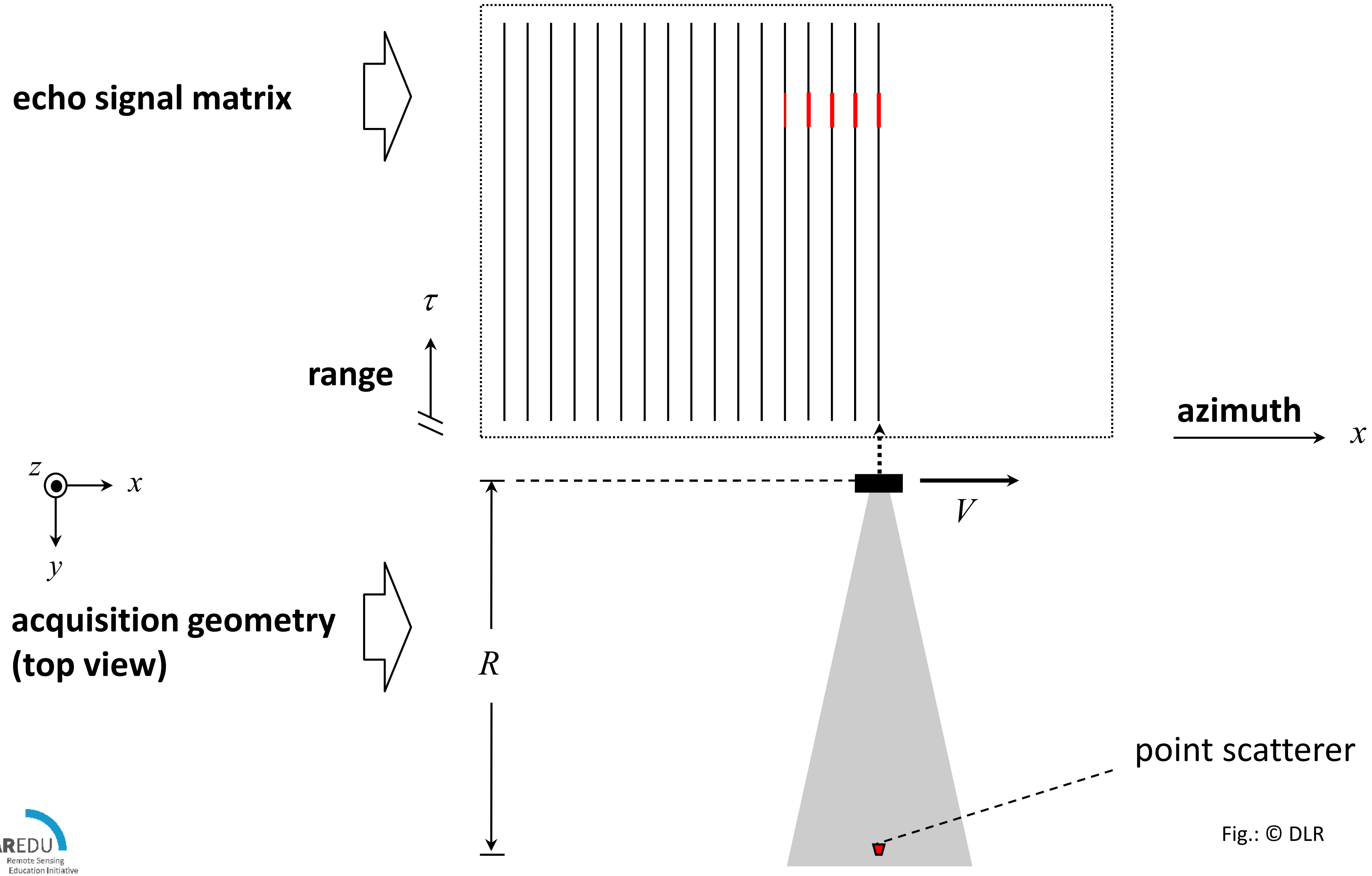
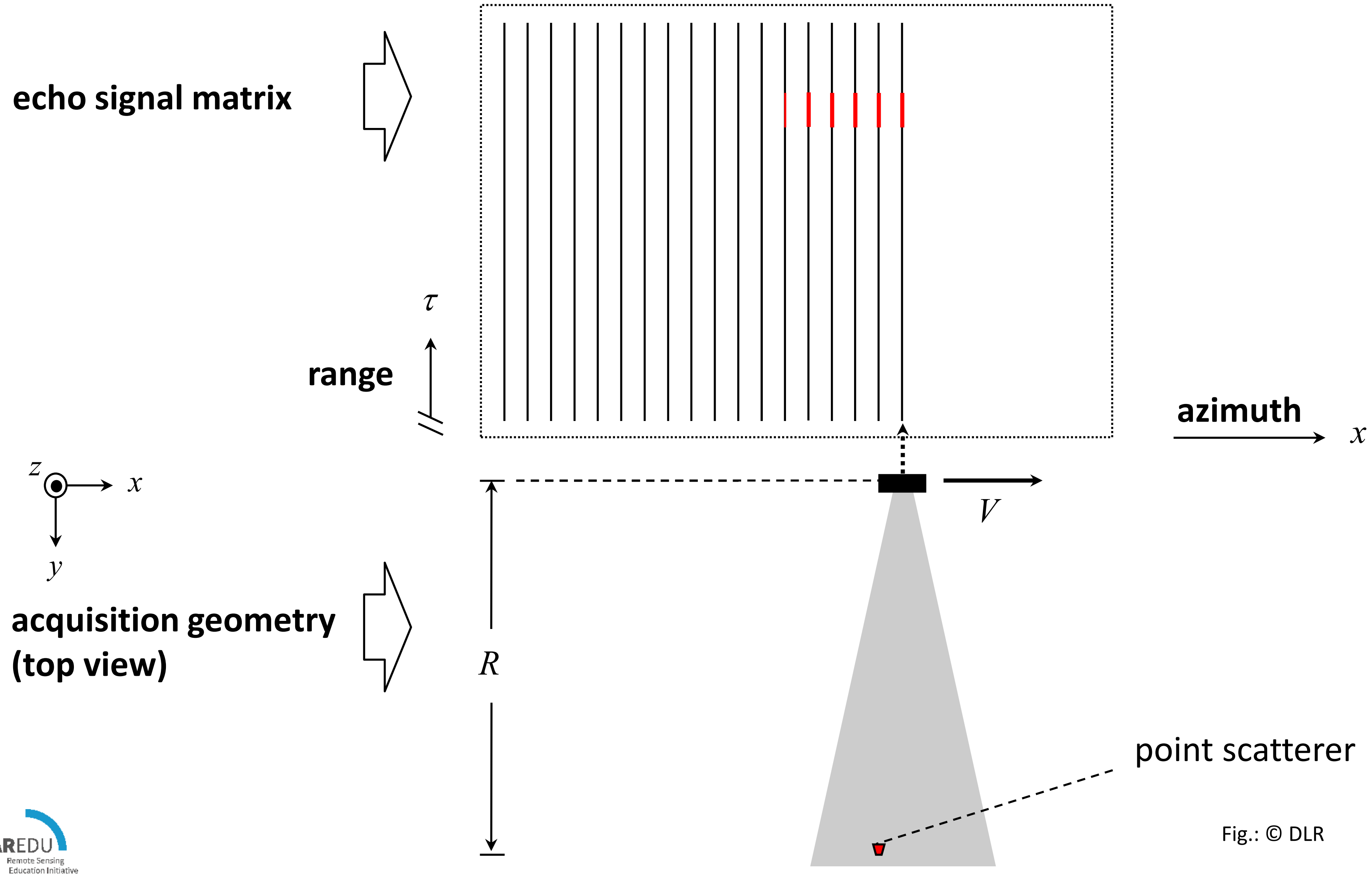


Fig.: © DLR

2-D Raw Data Matrix



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2-D Raw Data Matrix

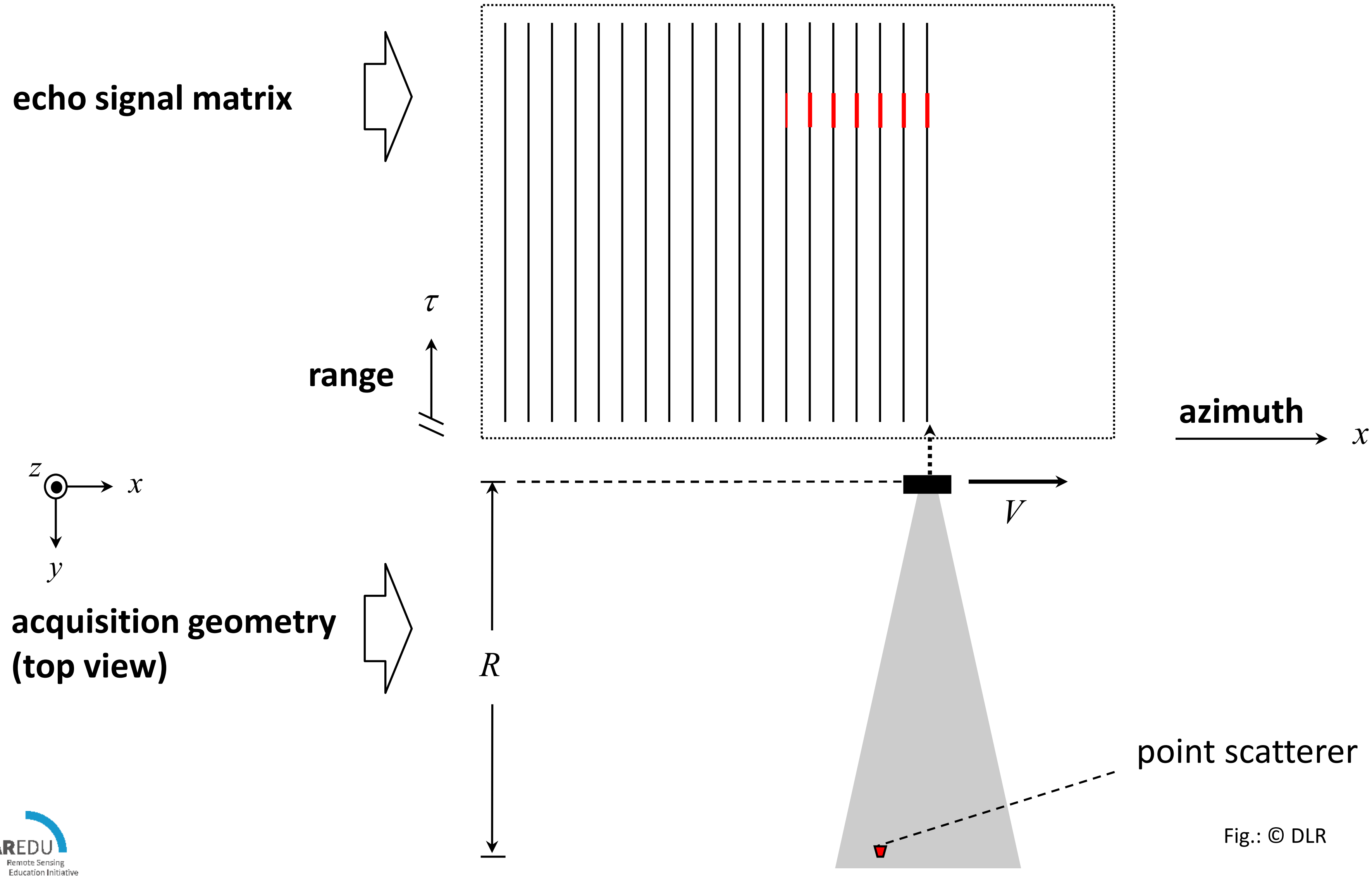

Fig.: © DLR

2-D Raw Data Matrix

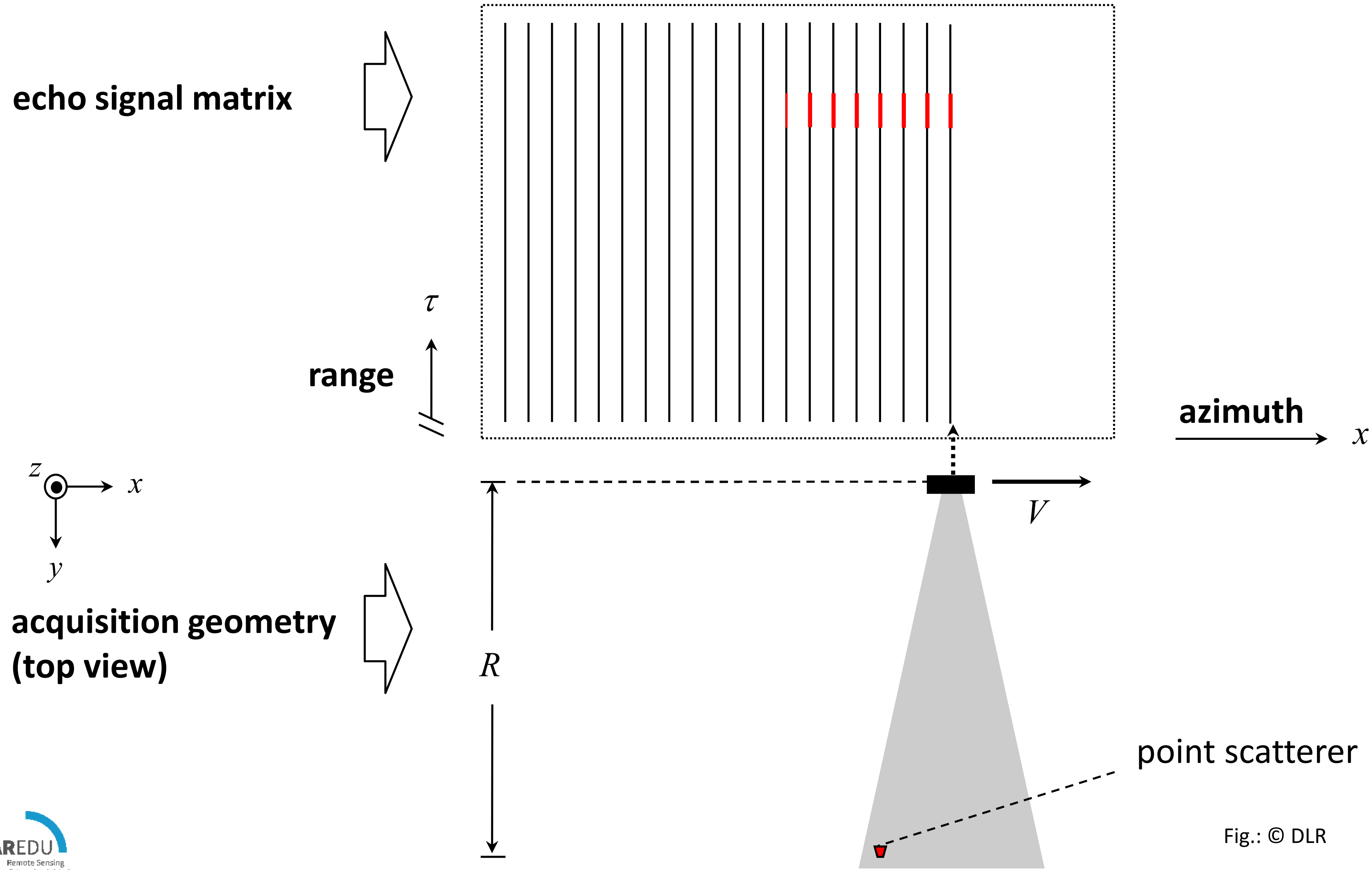

Fig.: © DLR

2-D Raw Data Matrix

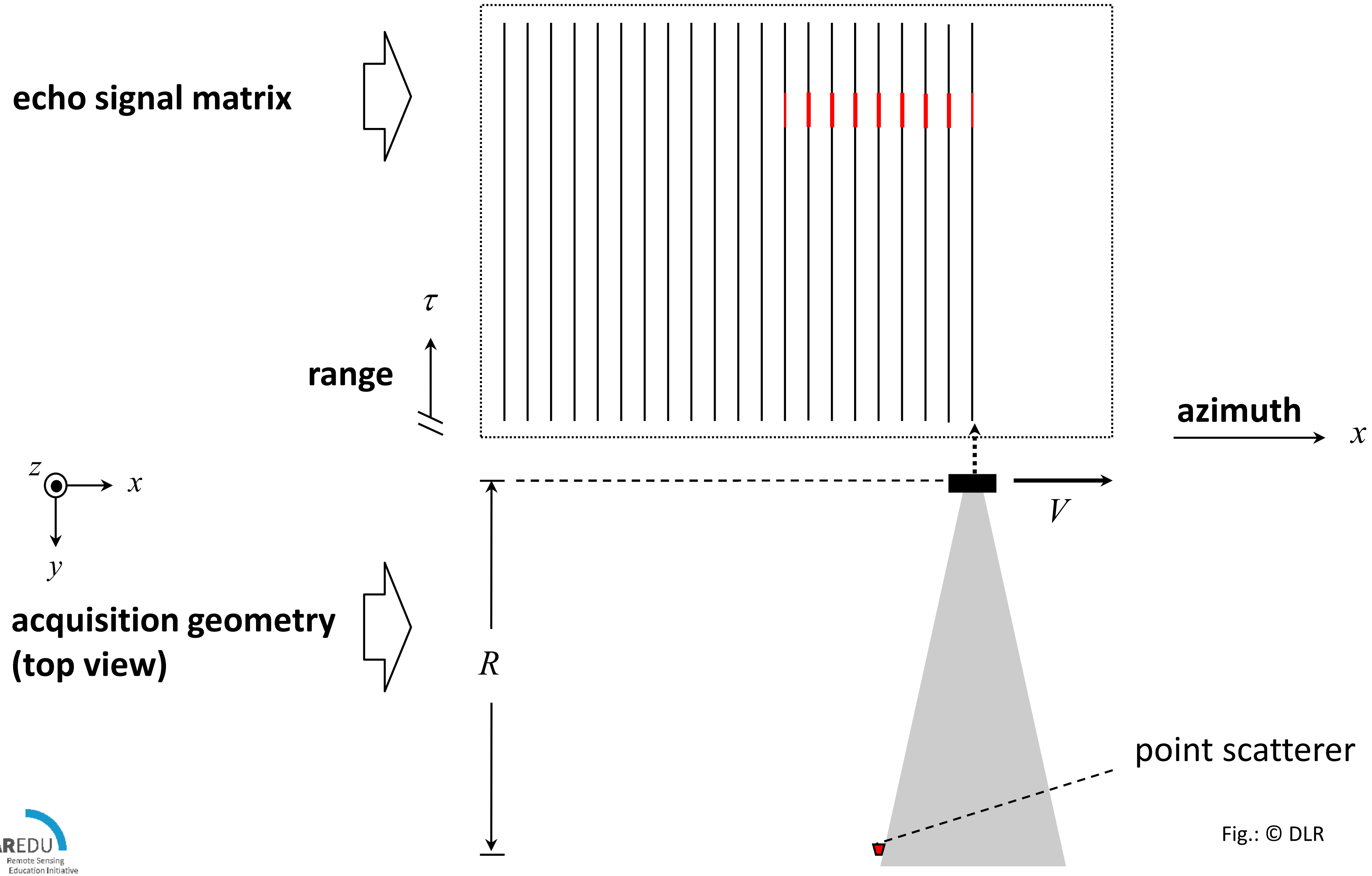

Fig.: © DLR

2-D Raw Data Matrix

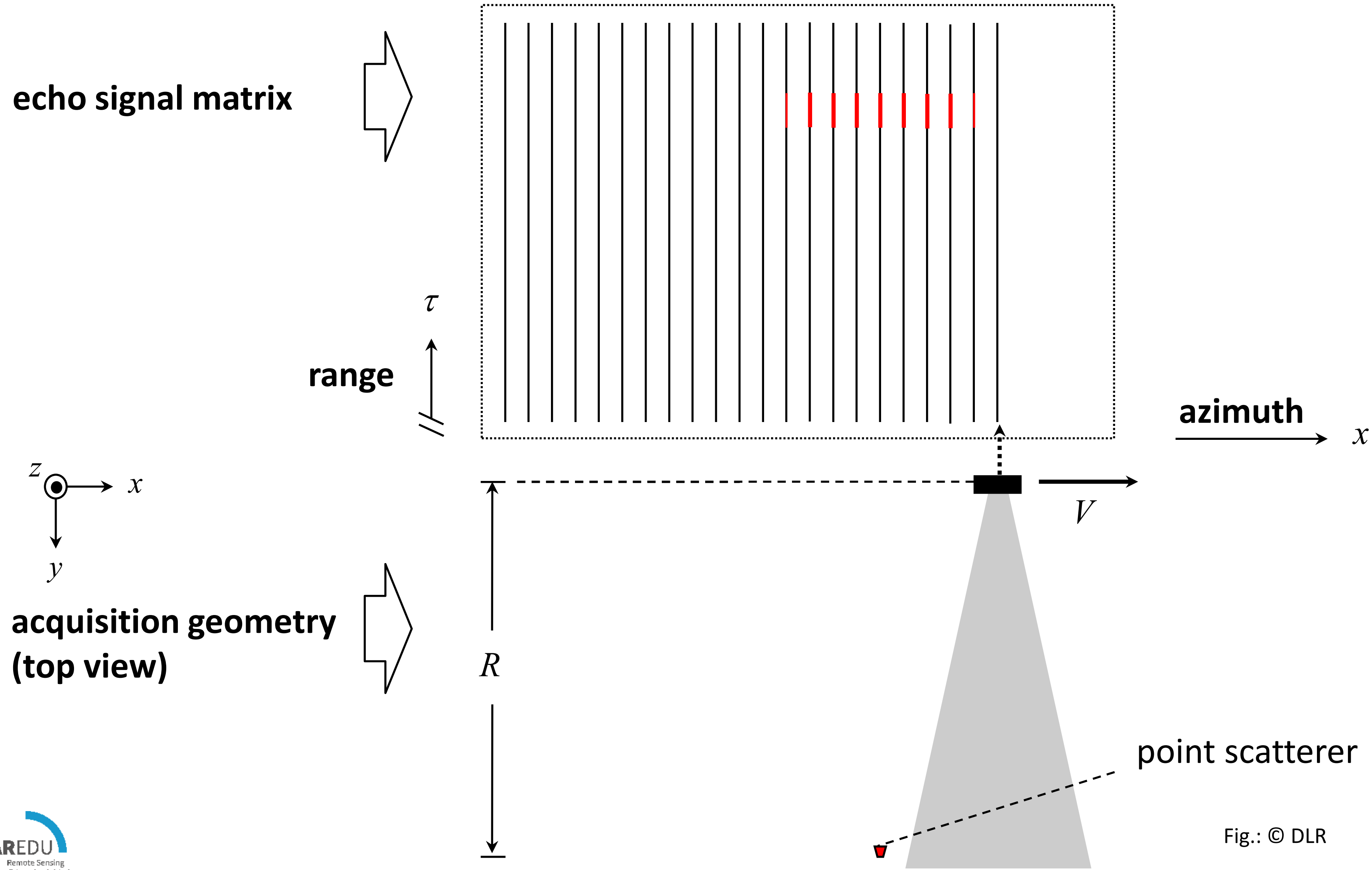

Fig.: © DLR

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RADAR Amplitude and Phase – Single Target

The signal backscattered to the RADAR is a complex quantity consisting of

Amplitude and **Phase**

- The amplitude of the signal depends on the scattering strength of the target
- This is related to the power scattered back toward the sensor

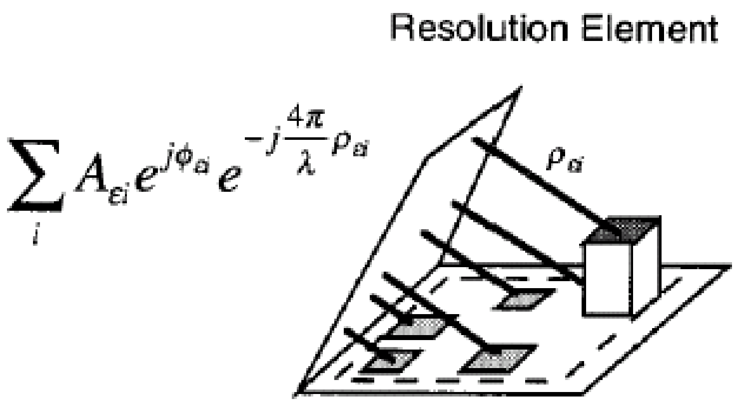
- The phase is primarily related to the two-way path distance (2R) between the radar and the target
- In addition a phase offset can be introduced by the scattering. This term depends on the specific target.
- The phase has values in the interval 0 - 2π

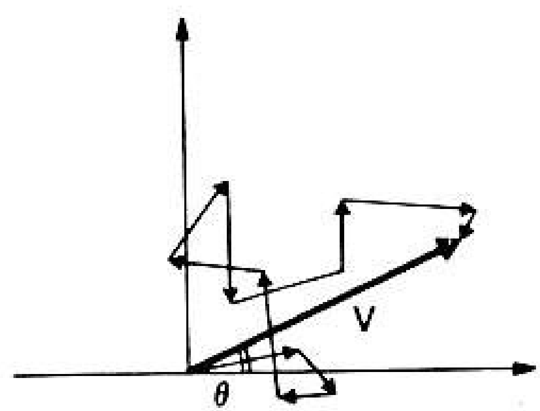
$$\varphi = -\frac{2\pi}{\lambda} \cdot 2R + \varphi_{scatter} = -\frac{4\pi}{\lambda} R + \varphi_{scatter}$$

RADAR Amplitude and Phase – Distributed Targets

Let us now consider the case of several targets in a resolution cell (e.g. trees, buildings, poles etc.)

If a resolution cell contains few up to several hundredths targets, the signal received results from the coherence (=complex) sum of the contributions from the individual targets





The amplitude is related to scattering strength of the scatterers but also their mutual position. In this way signals tend to sum up or cancel out.

The phase of each target is deterministic (distance to the radar) but becomes random in the 2π interval because the coherent sum of the individual targets

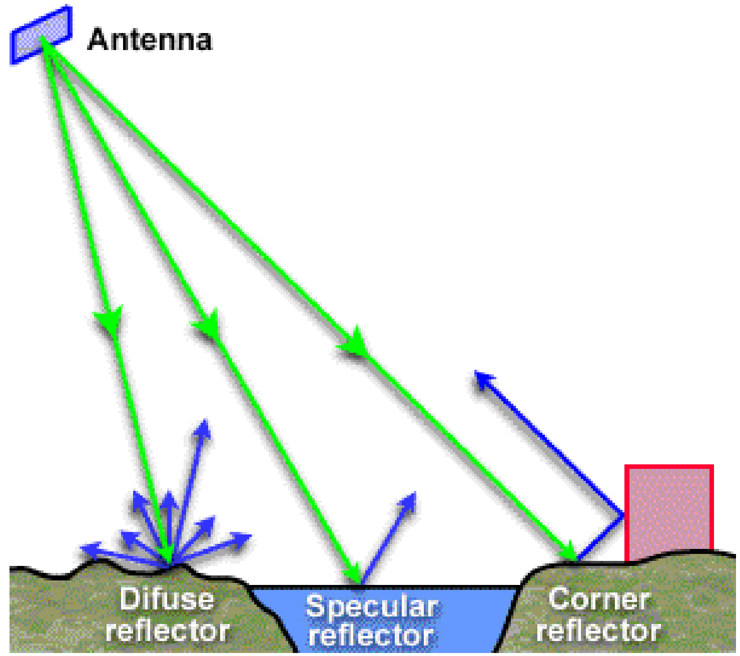
This effect is called speckle (= salt and pepper)

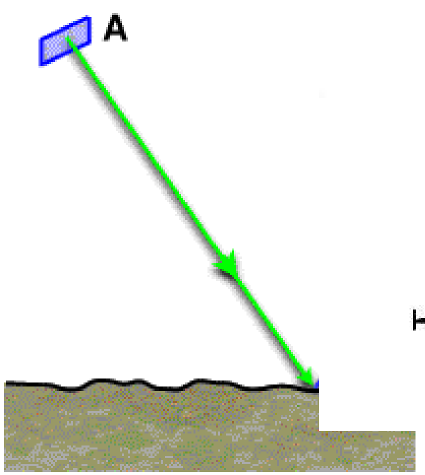
RADAR Scattering

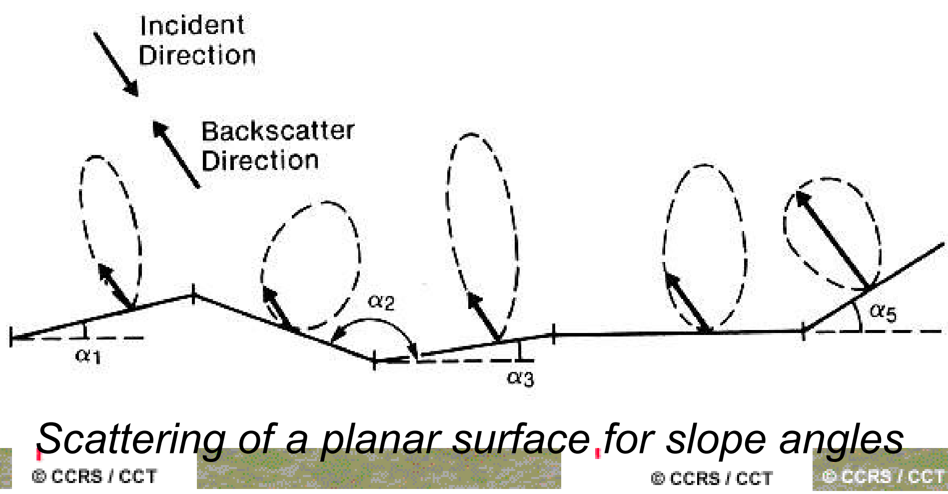
Surface Roughness:
Backscattering increases with roughness

Incidence Angle (Topography) :
Viewing geometry affects the signal

Dielectric Constant (Moisture content) :
Backscattering increases with moisture

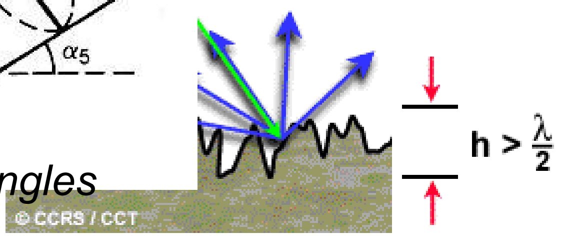




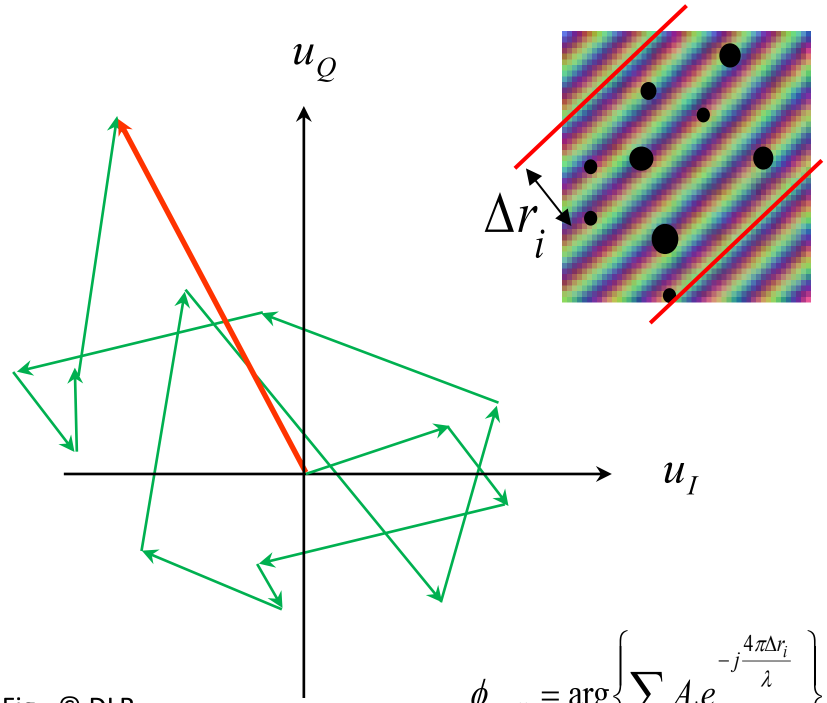


Scattering of a planar surface for slope angles

Scattering of a planar surface for different roughnesses



Speckle "Noise"



$$\phi_{scatt} = \arg\left\{ \sum A_i e^{-j\frac{4\pi\Delta r_i}{\lambda}} \right\}$$

Fig.: © DLR

- Random positive and negative interference of wave contributions from the many individual scatterers within one resolution cell
  - Varying brightness from pixel to pixel even for constant σ_0

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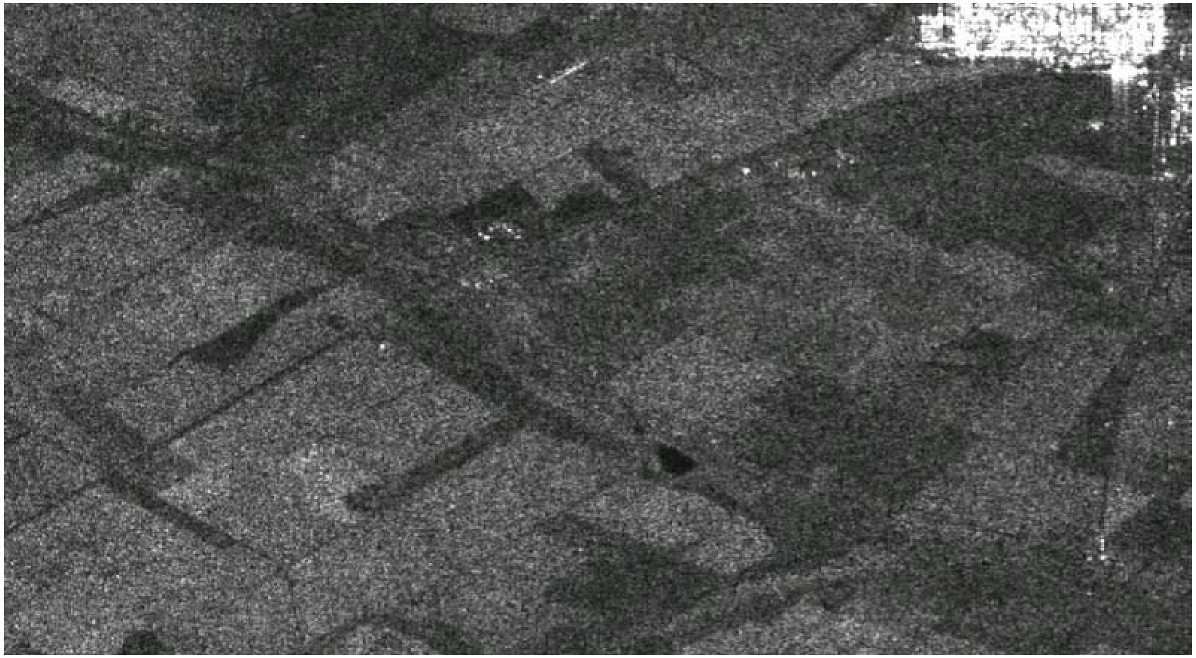
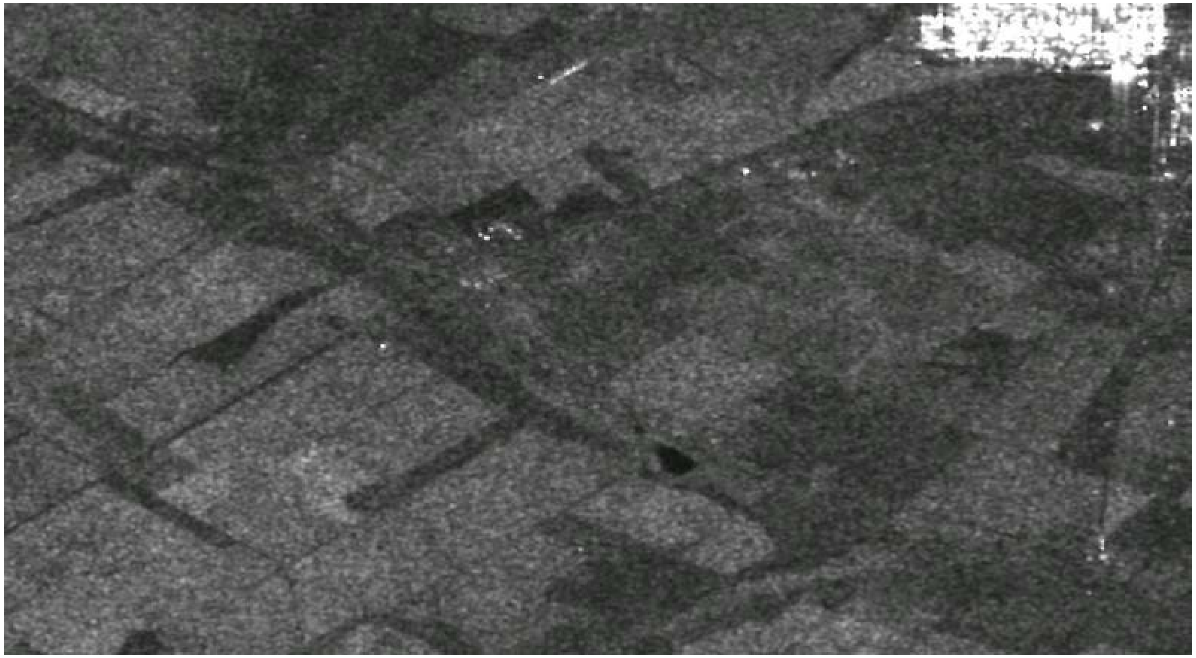
Speckle

Images obtained from coherent sensors such as SAR system are characterized by speckle.

This is a spatially random multiplicative noise due to coherent superposition of multiple backscatter sources within a SAR resolution element.

In other words, speckle is a statistical fluctuation associated with the radar reflectivity (brightness) of each pixel in the image of a scene.





Example for Bayesian Speckle Reduction

original SAR image
SAR data © AeroSensing GmbH

speckle filtered
Bayesian algorithm

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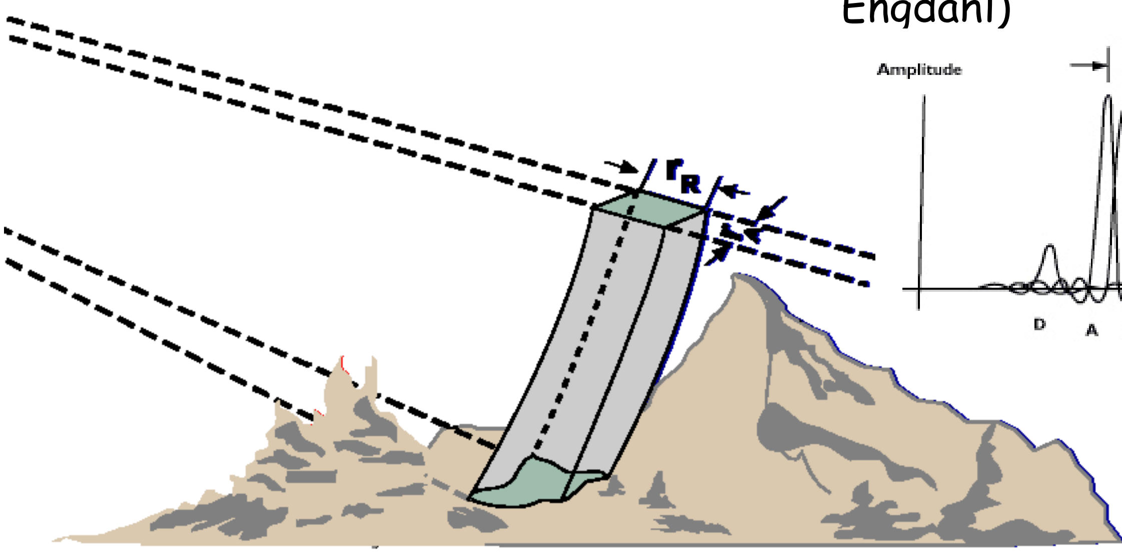
SAR Resolution

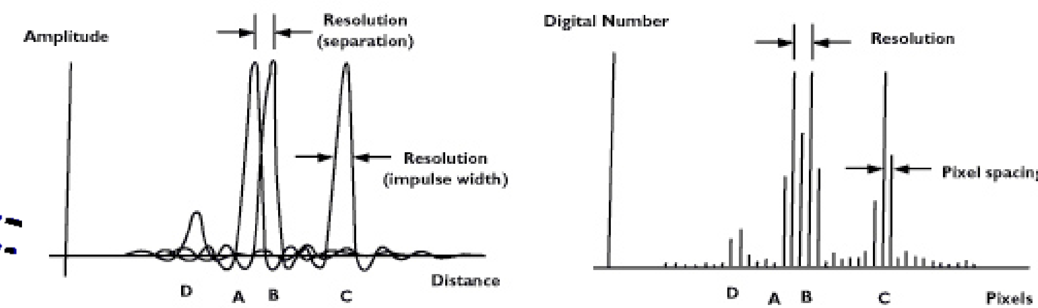
Since SAR is an active system, the actual sensor resolution has two dimensions, **range resolution** and **azimuth resolution**. The SAR Resolution Cell dimension (SRC) in azimuth is not equal to the corresponding slant range.

Resolution of a SAR sensor should not be confused with **pixel spacing** (step) which results from sampling done by the SAR image processor.

The terrain is imaged in each SRC depends on local topography and is called Ground Resolution Cell (GRC).

For side-looking radars resolution is loosely defined as the minimum distance at which the radar can discriminate between two closely spaced scatterers with responses of approximately equal strength (M. Engdahl)



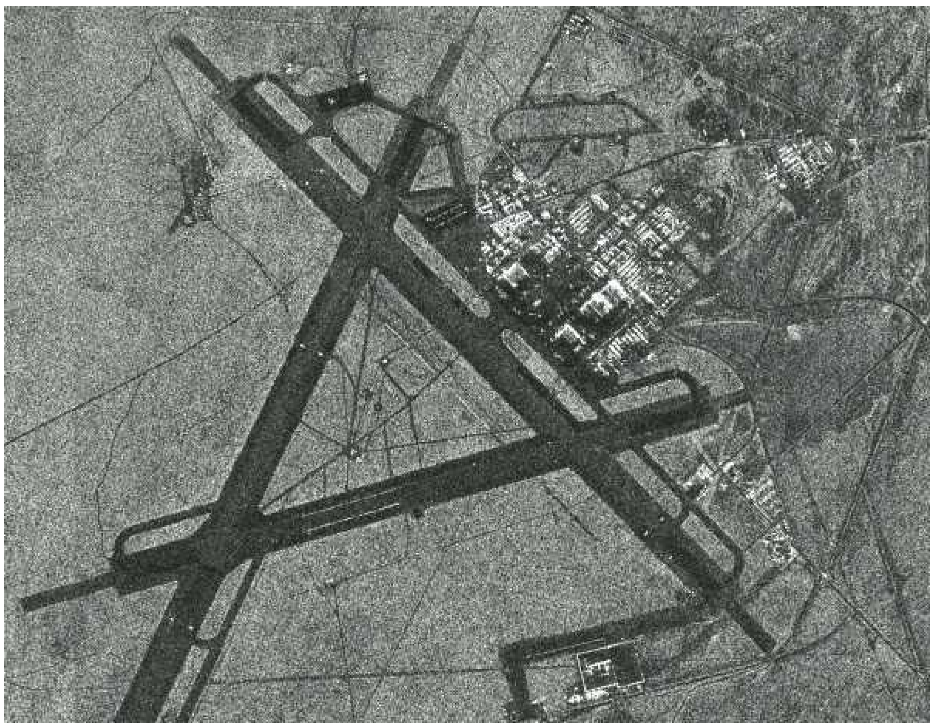


Resolution differs from pixel size, which is related to how densely the scene reflectivity has been sampled.

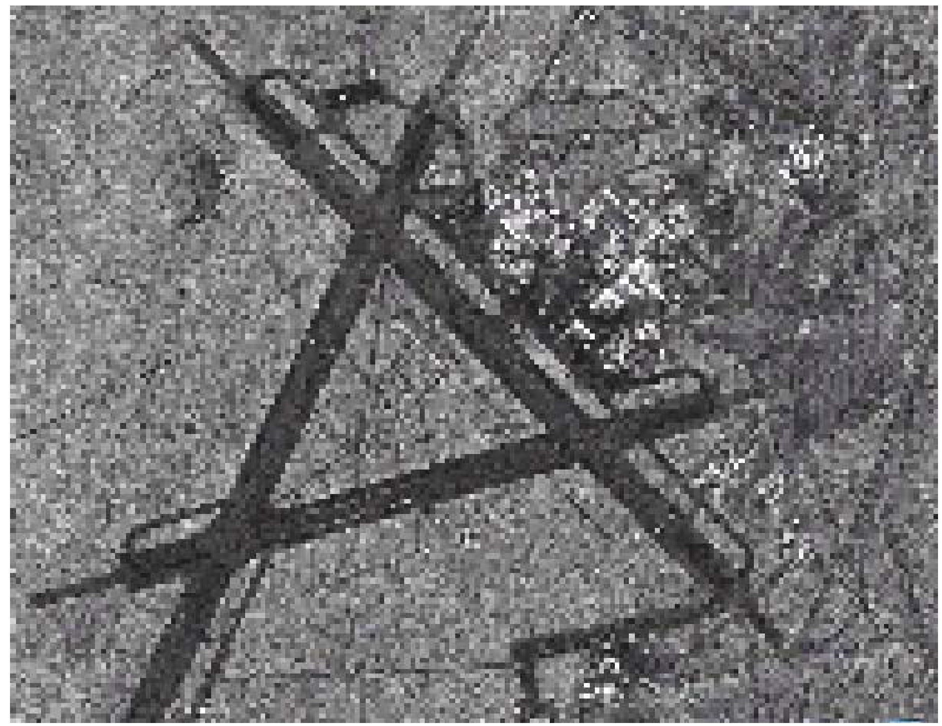
SAR Resolution

The general trend of the aerospace industry is towards SAR sensors featuring an ever increasing spatial resolution and shorter temporal sampling

RADARSAT-2 Fine Beam (3m)



ERS-2 SAR (20m)

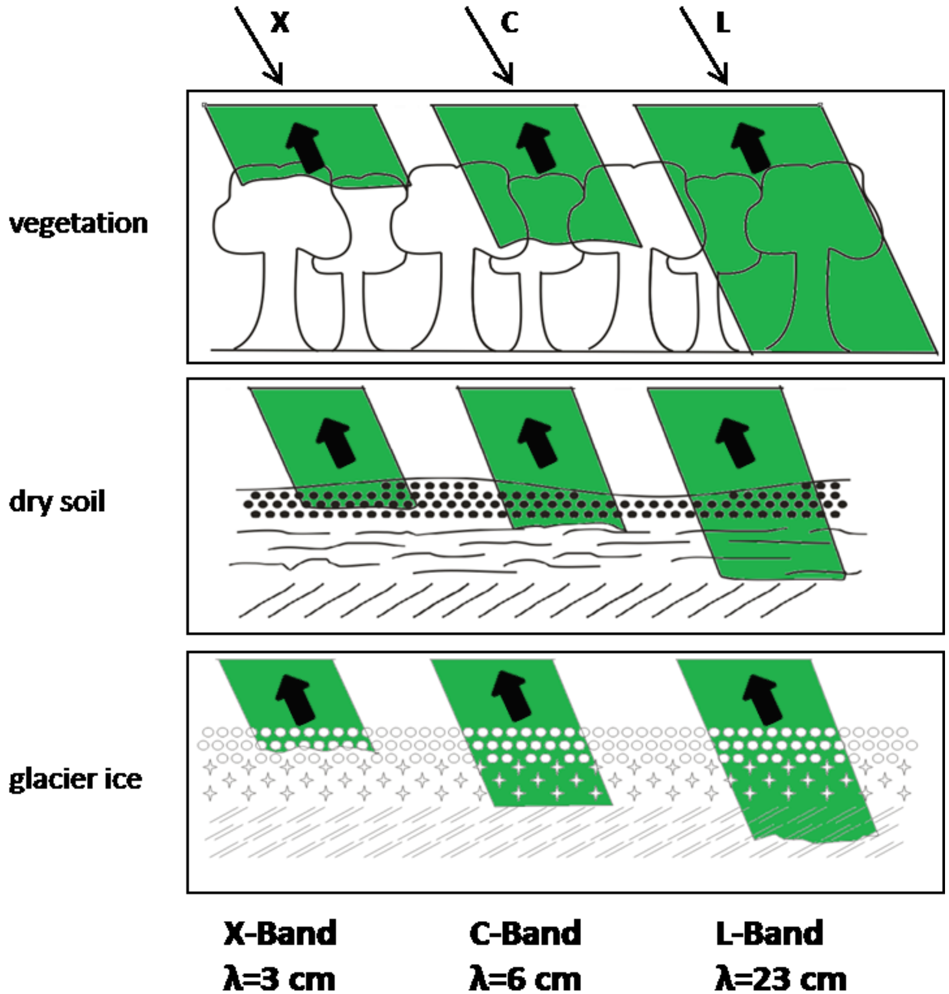


Towards a better spatial and temporal resolution

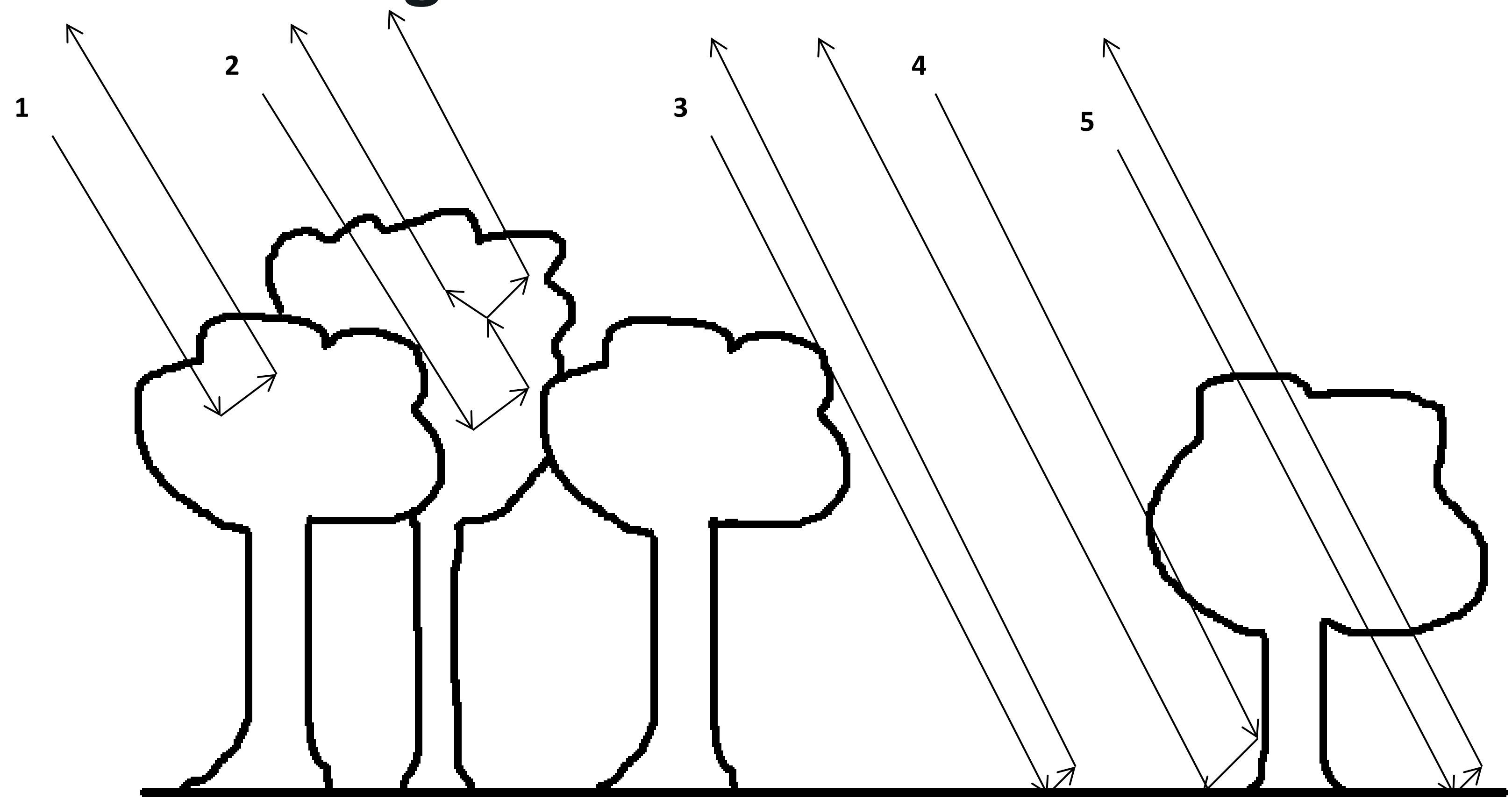
Frequency vs. SAR Penetration

Depending on the frequency waves can penetrate into the vegetation and, on dry conditions, to some extent, into the soil (for instance dry snow or sand).

Generally, the longer the wavelength, the stronger the penetration into the target is.



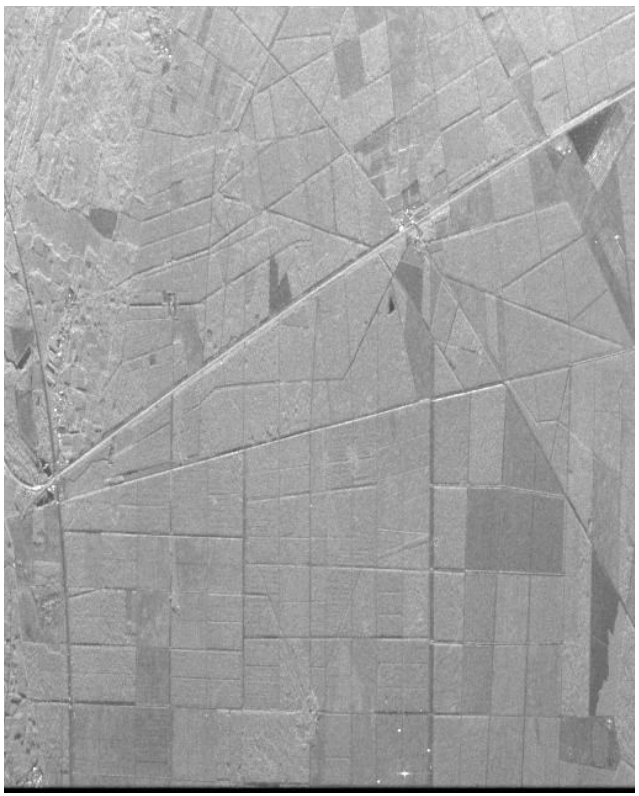
Scattering Mechanisms in Forests



1: direct single scatter
2: multiple bounce
3: direct ground reflection
4: double bounce trunk - ground
5: attentuation of ground scatter by canopy

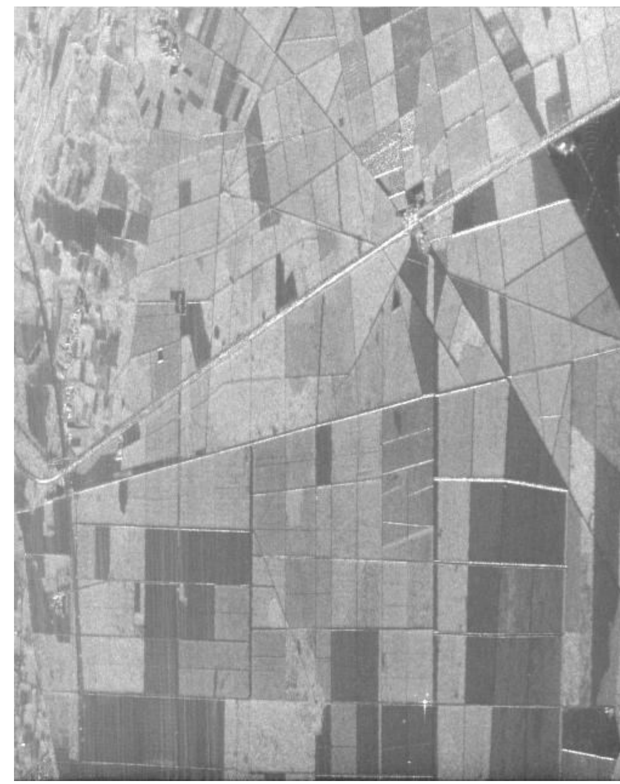
Fig.: © DLR

Frequency Comparison: Vegetated Area
LandesForest, France



C-Band (5.7 cm)

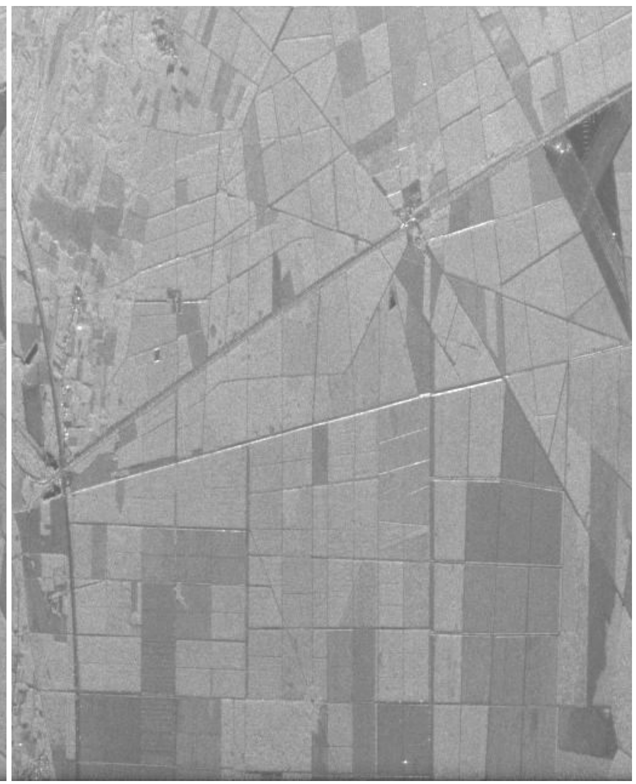
L-Band (24 cm)



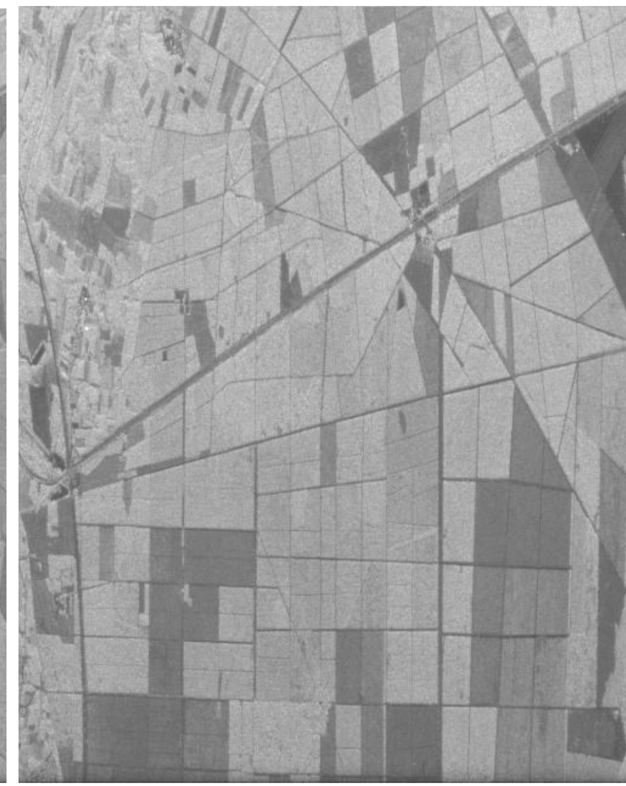
P-Band (68 cm)

Vegetation Scattering L-band Polarization Comparison

HH



VV



HV

RAR Imaging Geometry

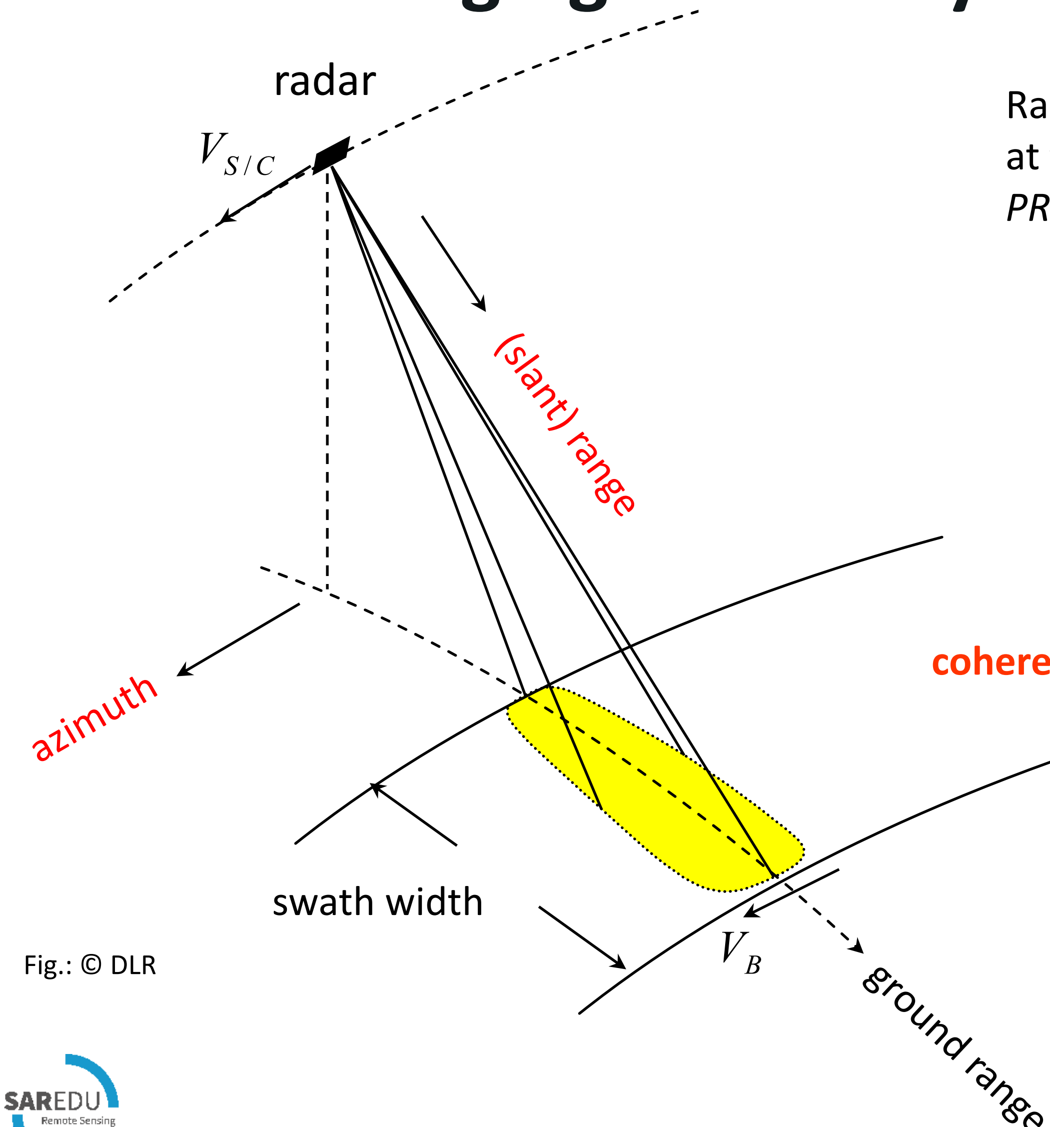


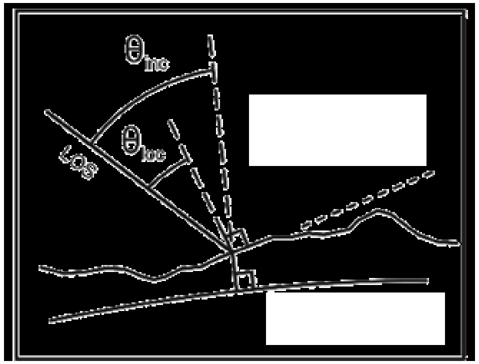
Fig.: © DLR

Radar transmits pulses and receives echoes at the rate of the pulse repetition frequency:
PRF $\cong$ 1000 - 4000 Hz

range: radar principle = scanning at speed of light

azimuth: scanning in flight direction at V_B plus aperture synthesis (holography)

coherent imaging: complex-valued pixels contain amplitude (brightness) and phase information



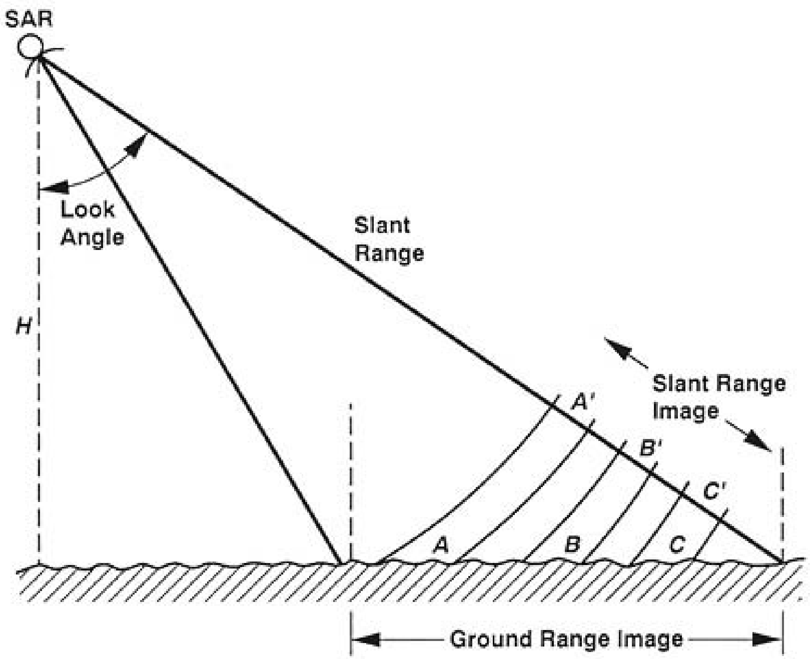
Slant vs. Ground Range Geometry

Slant range

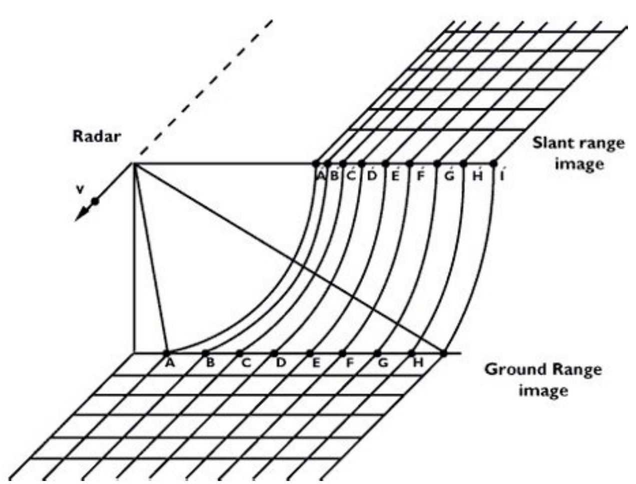
This is the natural radar geometry in which an image is acquired.

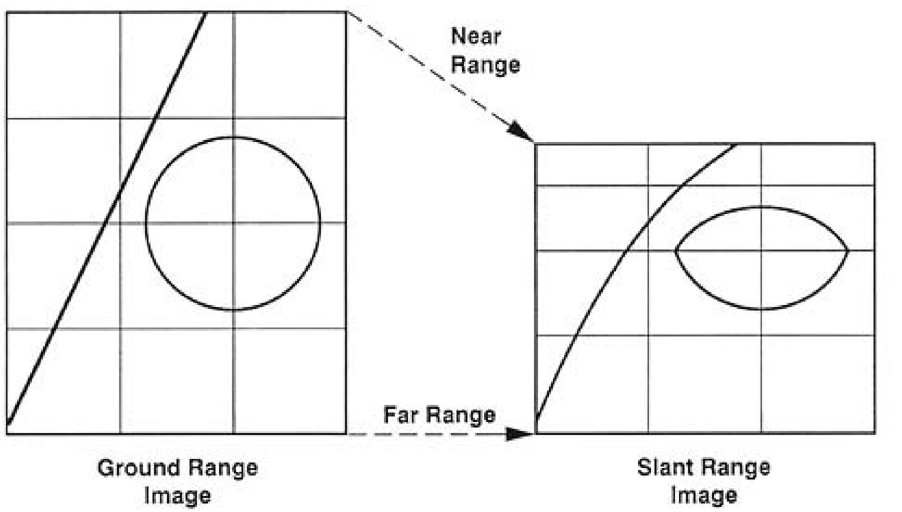
Ground range

This is the true geometry of the image



Images in slant range will appear “compressed” in the range direction

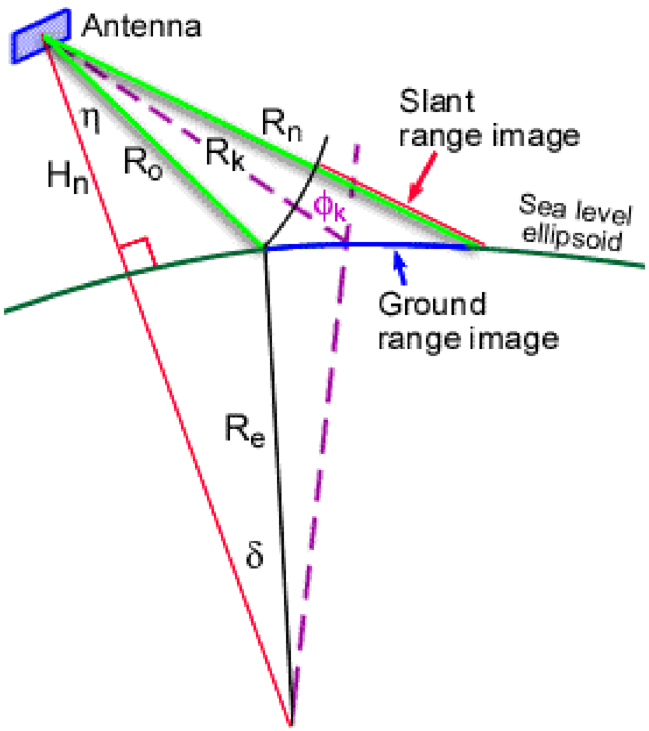


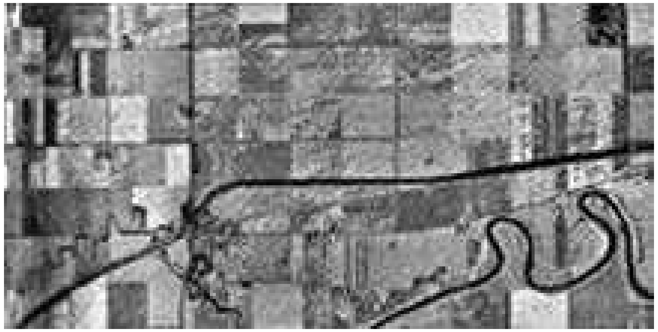


Slant vs. Ground Range Geometry

Transformation of an image from slant to ground range geometry is based on trigonometry.

Knowledge of the platform height, H, and incidence angle allows correction of slant-range geometry, where targets in near range appear compressed with respect to those in far range.





Slant range geometry

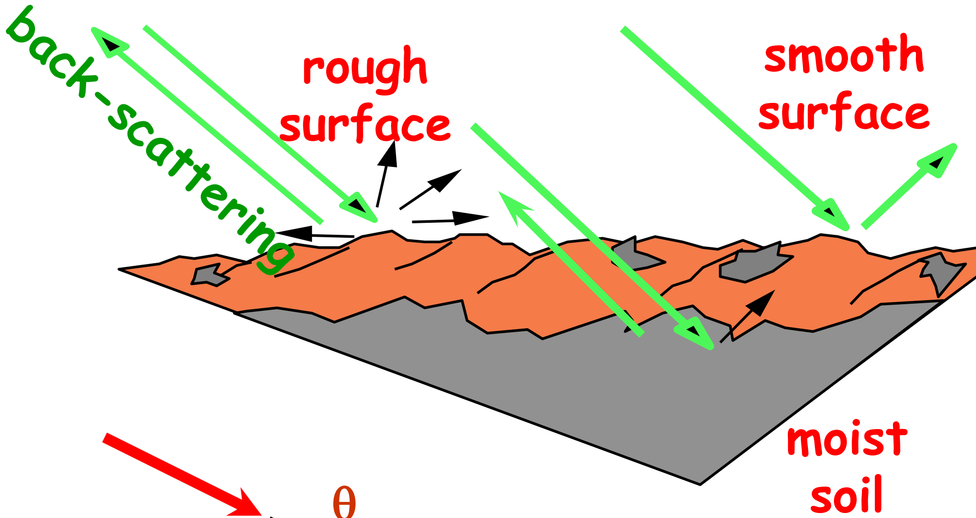
Ground range geometry

Radar remote sensing principles

Geophysical characteristics and back-scattering

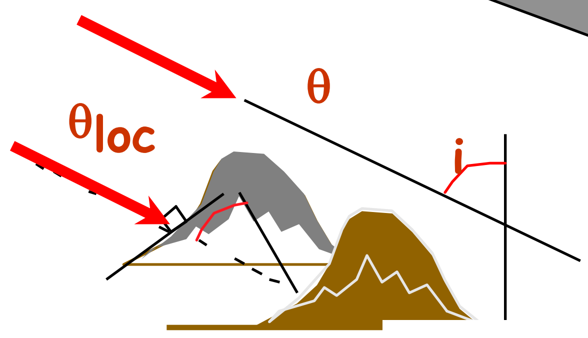
RADAR remote sensing is a technique that provides information on the physical characteristics of the earth's surface, mainly:

- Surface Roughness:
  Back-scattering
  increases with roughness



- Moisture content :
  Back-scattering
  increases with moisture

- Topography :
  Viewing geometry
  affects the signal



Harokopio University of Athens
Department of Geography
Φringe Team

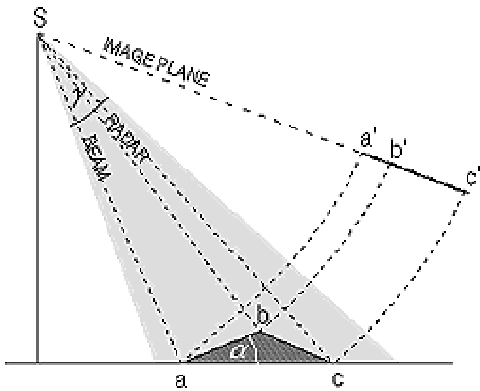
Geometric Distortions

Minor differences in elevation can cause considerable relief induced range distortions.

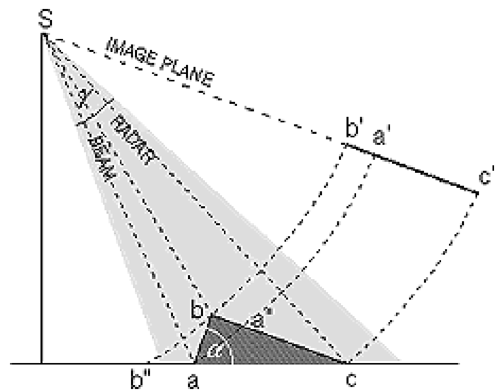
Foreshortening alters the distance of two regions in areas with slopes

Layover occurs when multiple regions are at the same slant range

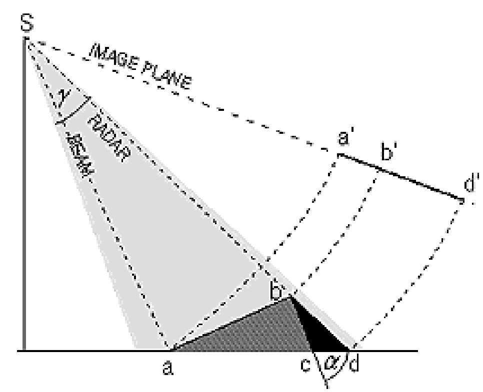
Shadow occurs because of occlusion by terrain



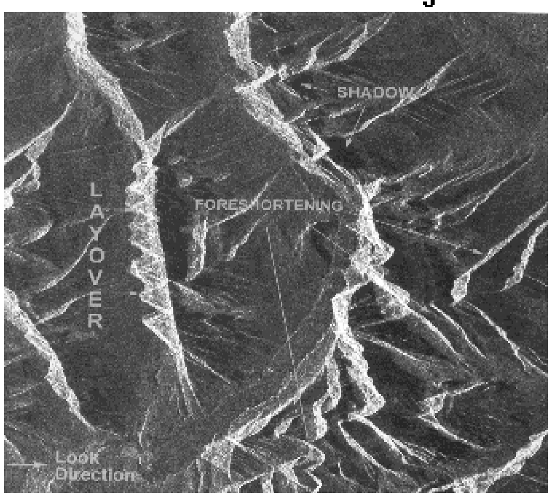
Foreshortening



Layover



Shadowing



Layover is an extreme case of foreshortening, where the slope is bigger than the radar look angle (θ).

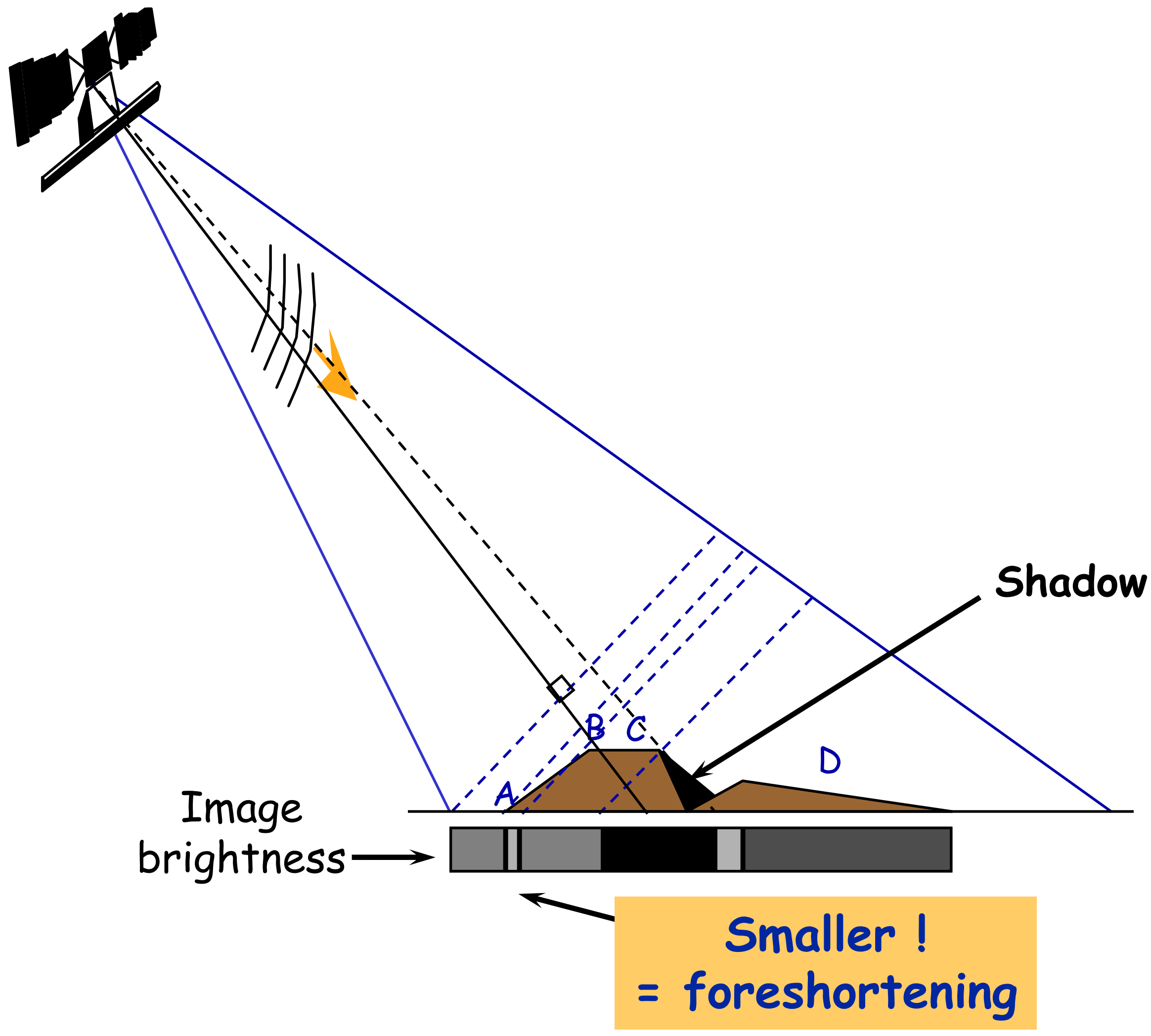
Layover and shadow lead to missing data in regions with steep sloped terrain.

Influence of topography

Problems of:
- **Shadows**
- **Foreshortening**
- **Layover**

(extreme case of foreshortening, topography is inverted)

Use of DEM to correct !



Geometry of SAR Images - Shadow

→ Steep slopes oriented away from the SAR return no signal

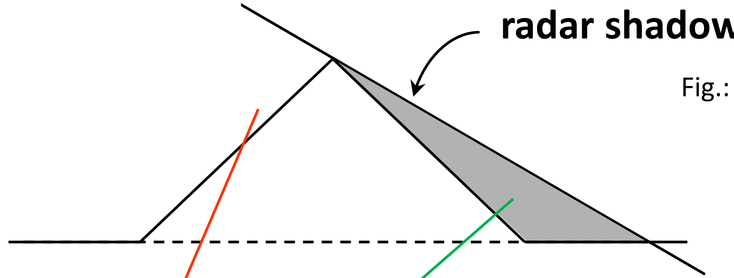
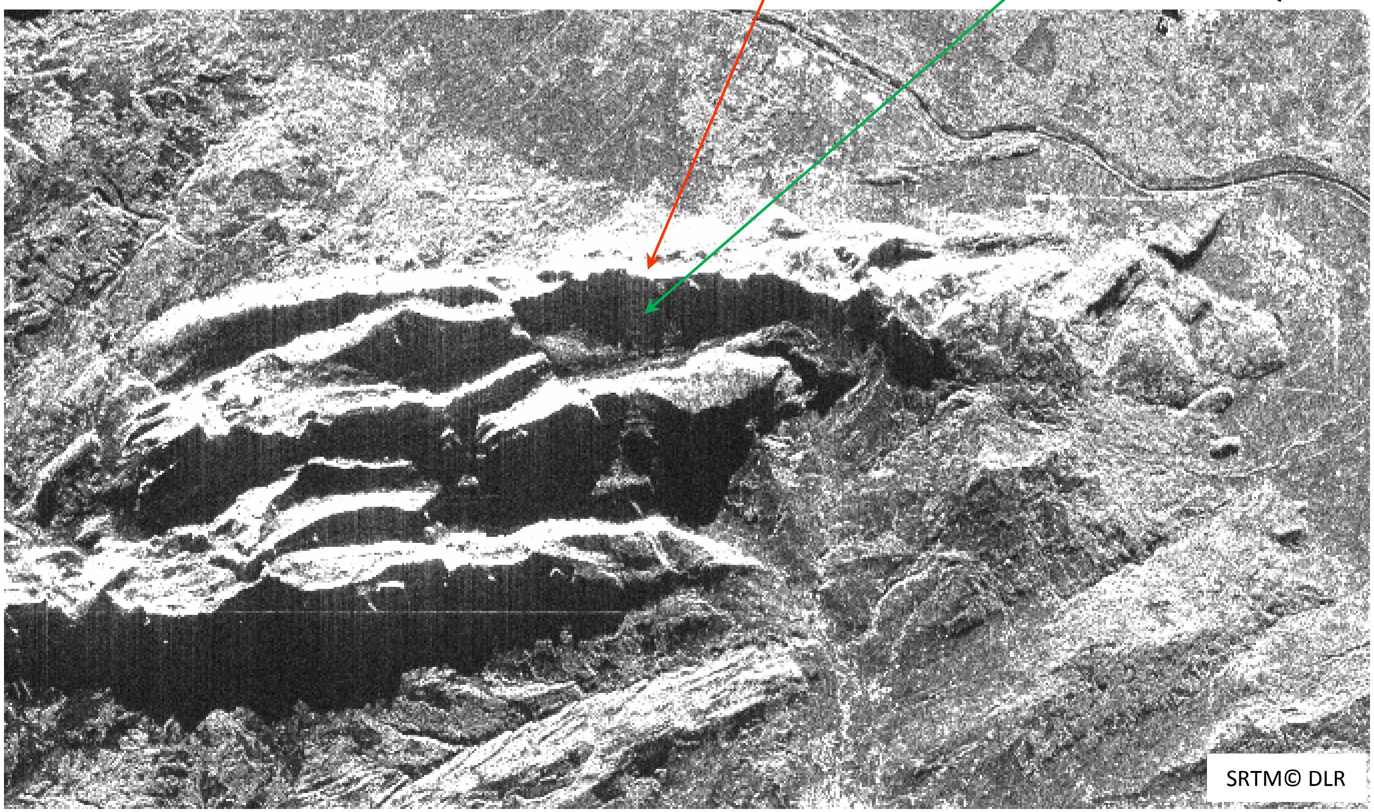


Fig.: © DLR

→ azimuth

↓ range

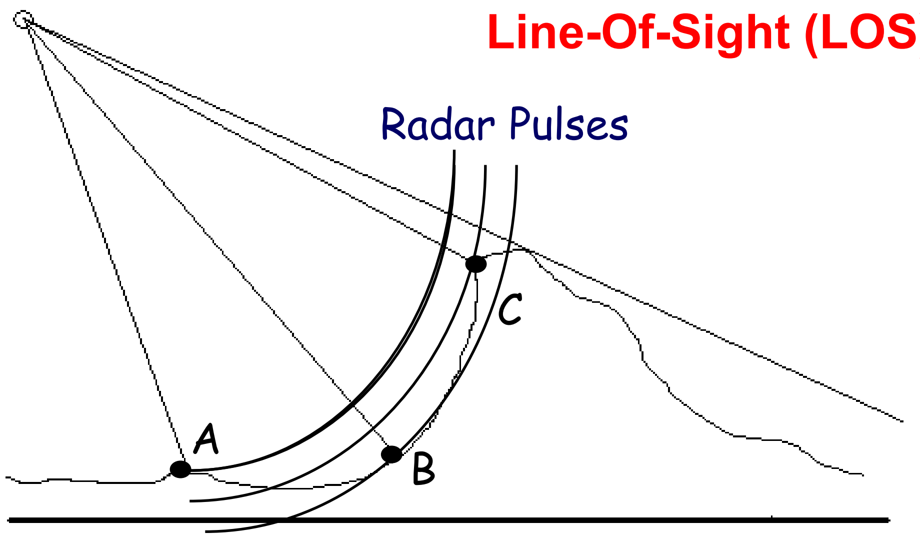


SRTM/X-SAR

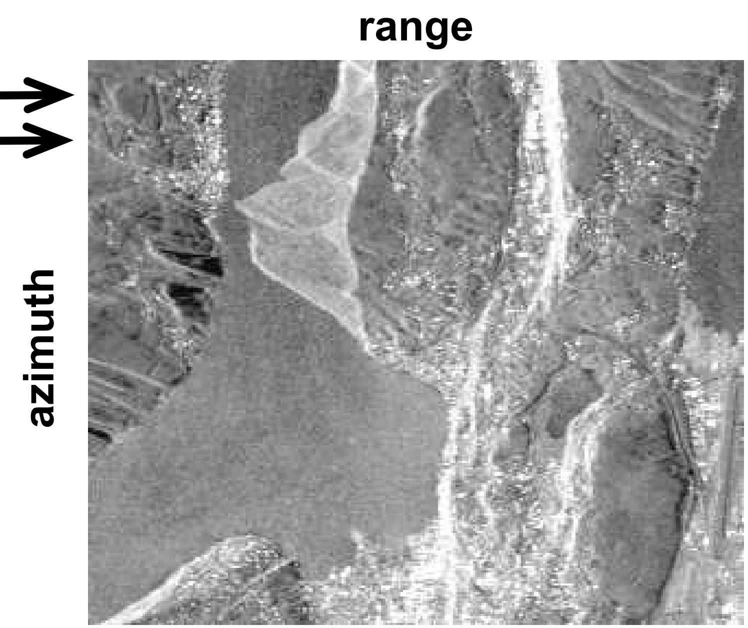
$\theta = 54$ deg

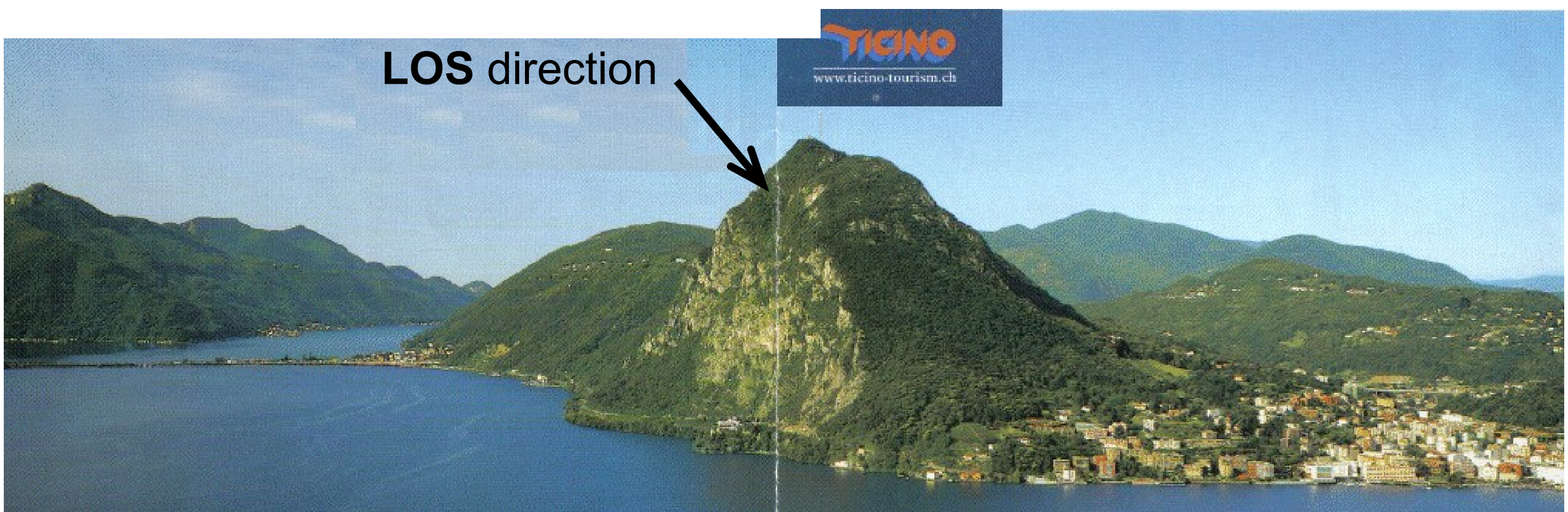
SAREDU Remote Sensing Education Initiative

Example of Layover



Line-Of-Sight (LOS)





Lugano, Switzerland, and the Monte San Salvatore

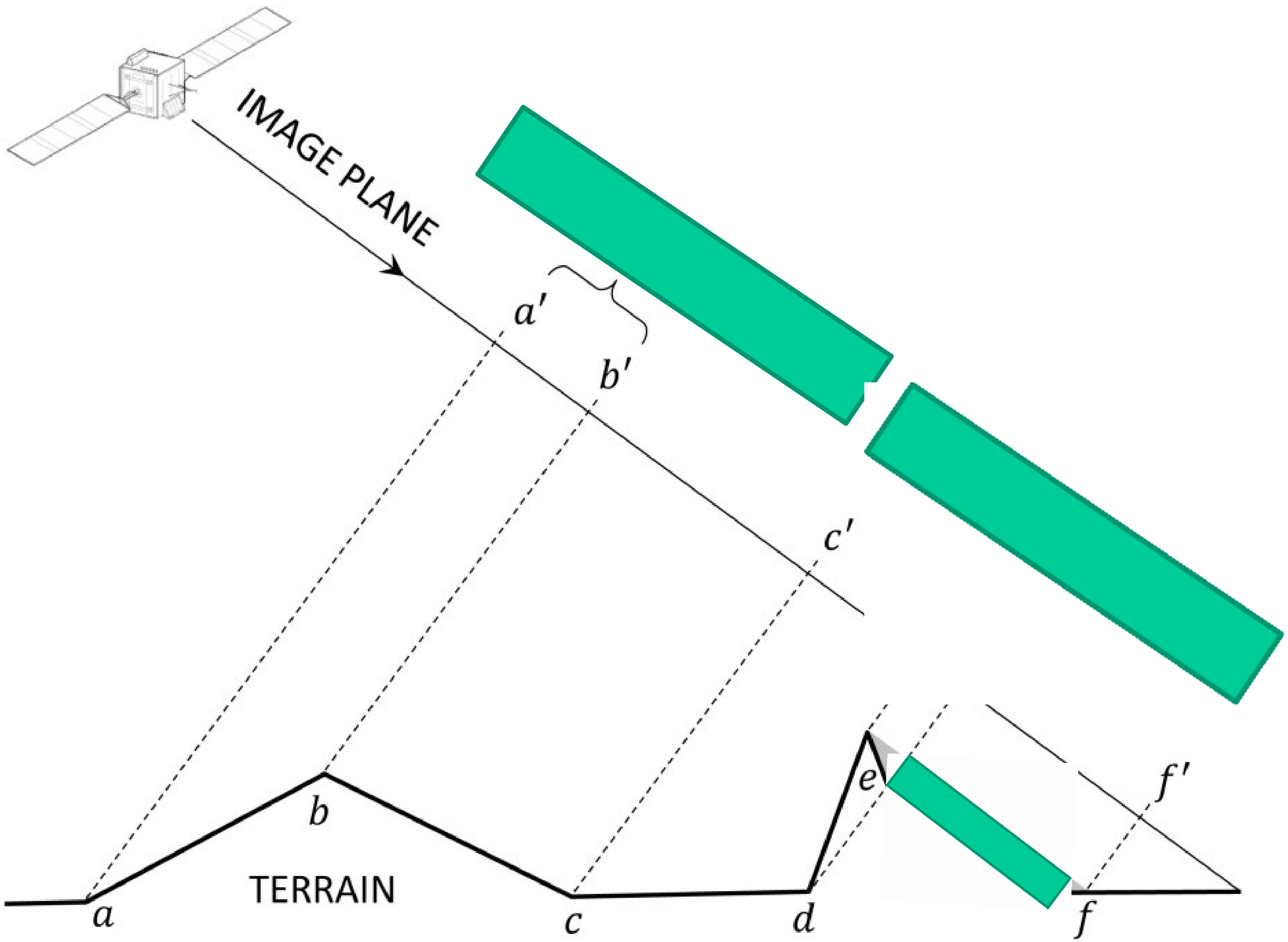
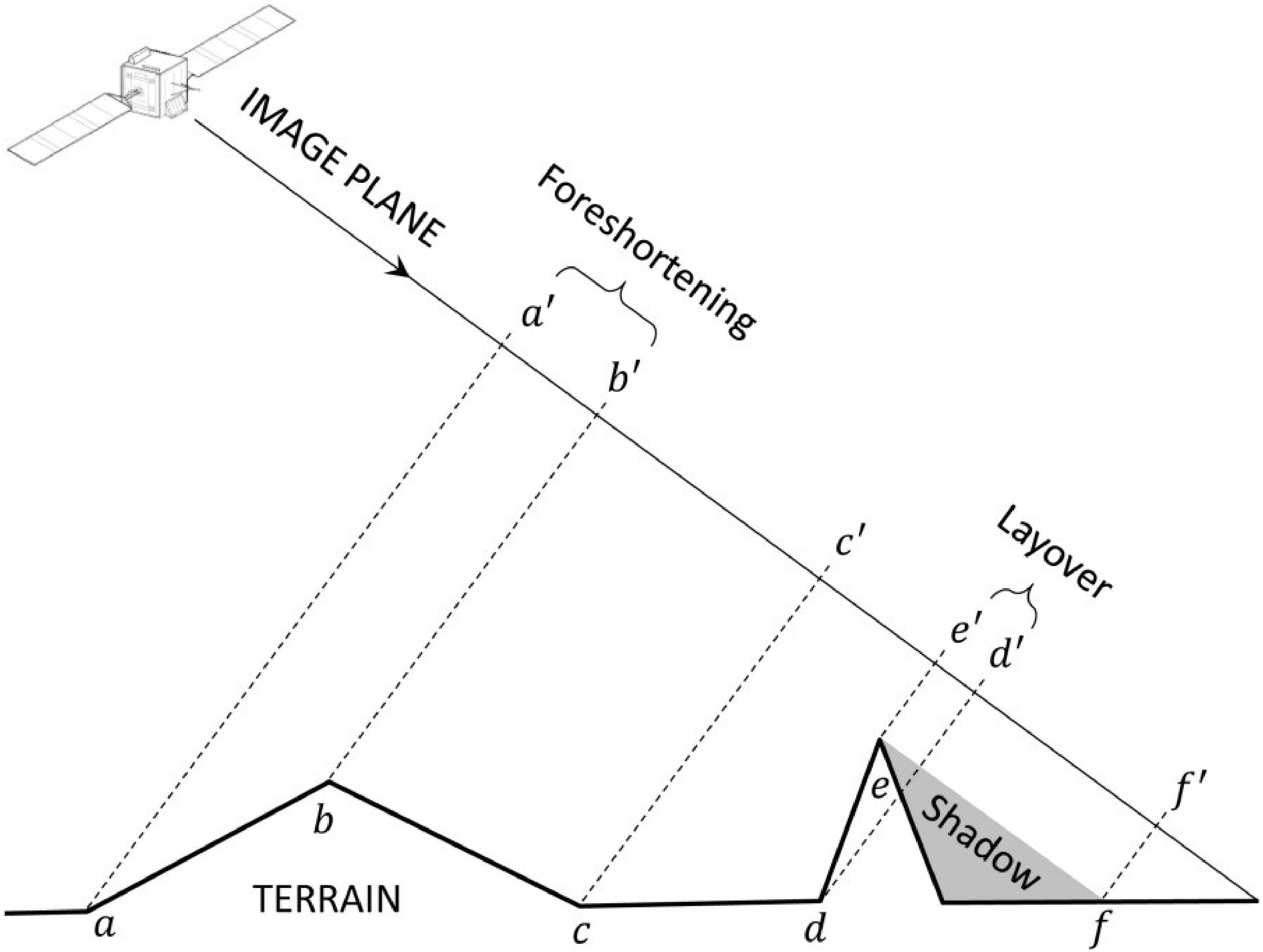


IMAGE PLANE
a′
b′
c′
f′
a
b
c
d
e
f
TERRAIN



© C. Stewart

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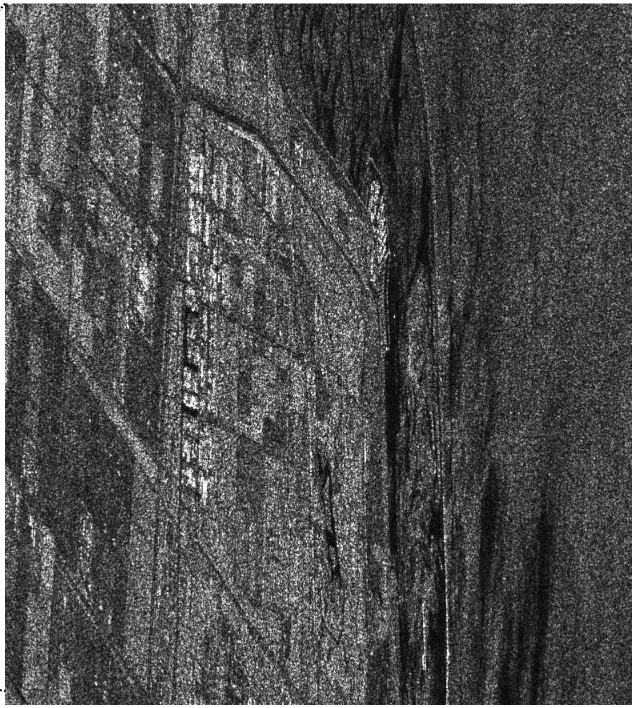
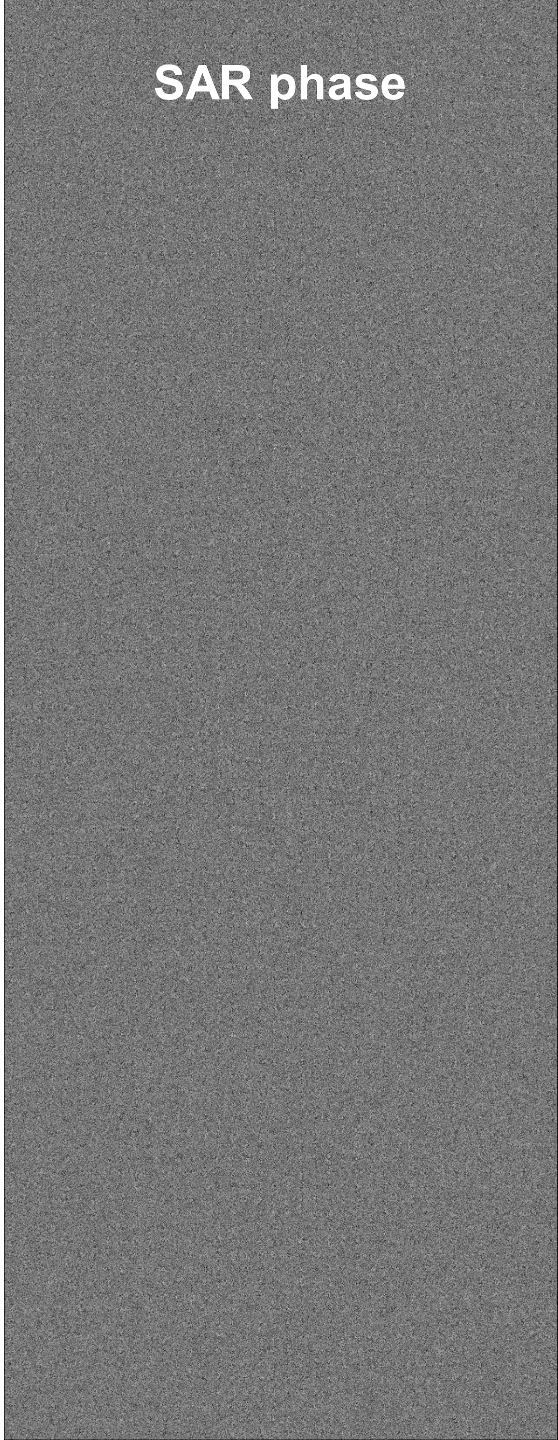
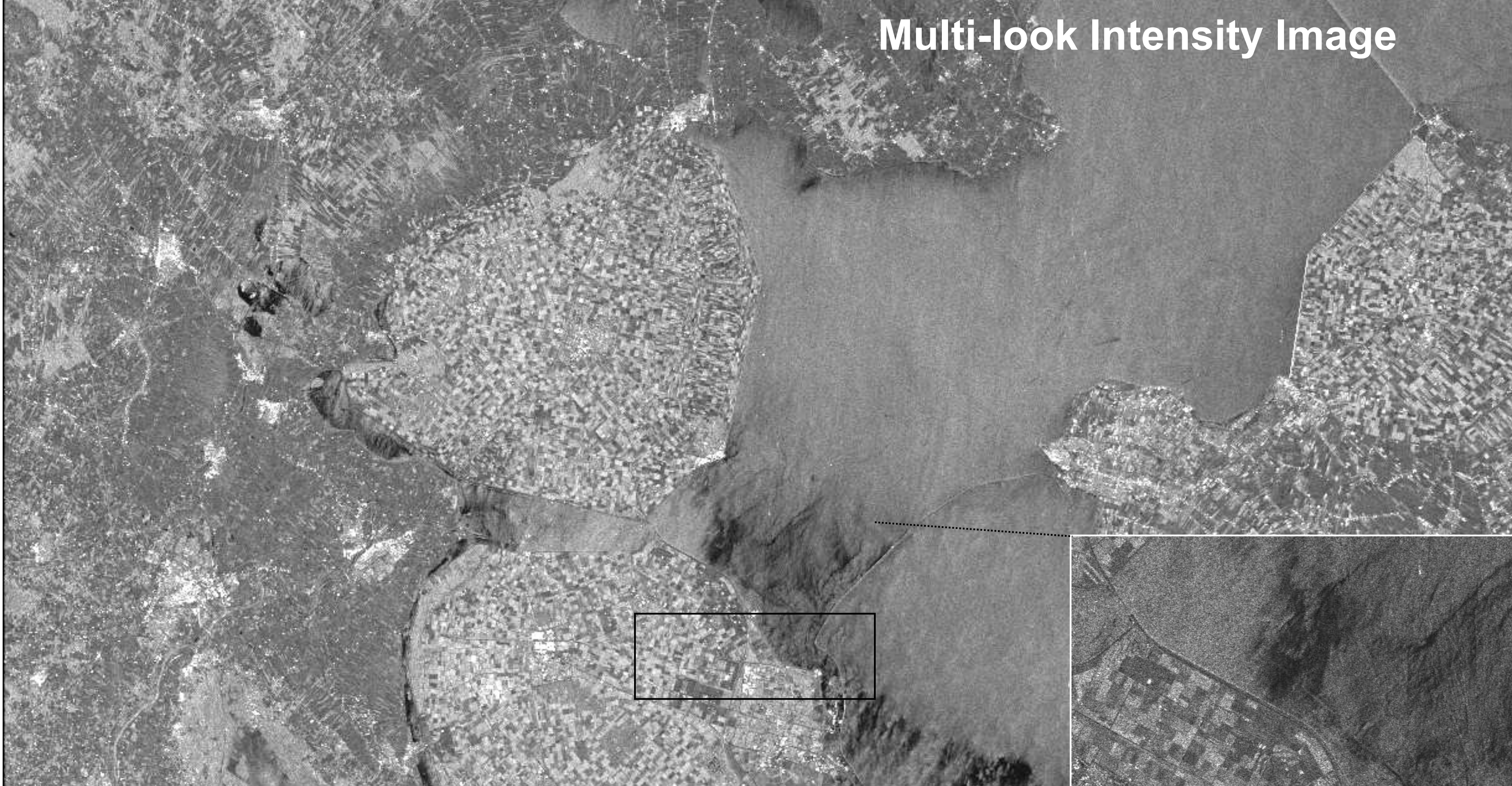
SAR SLC imagery

Believe it or not this is an area in the Netherlands!!

The images appear stretched because the pixel size in range (20 m) is 5 times bigger than in azimuth (4 m)







Now you know can see how this area
in the Netherlands looks like!!

Because of the 1:5 ratio between pixel sizes, a
multi-look factor of 1x5 has been applied. The
result are squared pixels with 20m x 20m pixel size

Current and old Civil Spaceborne SARs

satellite	owner	band	resolution	look angle	swath	lifetime
ERS-1	ESA	C	25 m	23°	100 km	1991-2000
ERS-2	ESA	C	25 m	23°	100 km	1995-2012
Radarsat-1	Canada	C	10 m - 100 m	20°- 59°	50 - 500 km	1995-2013
ENVISAT	ESA	C	25 m - 1 km	15°- 40°	100 - 400 km	2002-2012
ALOS	Japan	L	10 m -100 m	35°- 41°	70 - 360 km	2006-2011
Cosmo	Italy	X	ca. 1 m - 16 m	…	…	2007-
TerraSAR-X & TanDEM-X	Germany	X	1 m - 16 m	15°- 60°	10 - 100 km	2007/2010-
Radarsat-2	Canada	C	3 m - 100 m	15°- 59°	10 - 500 km	2007-
ALOS-2	Japan	L	3 m – 100 m	8°-70°	25 – 350 km	2014-
Sentinel-1	ESA	C	5 m – 50 m	20°-46°	20 - 400 km	2014-

History of SAR missions

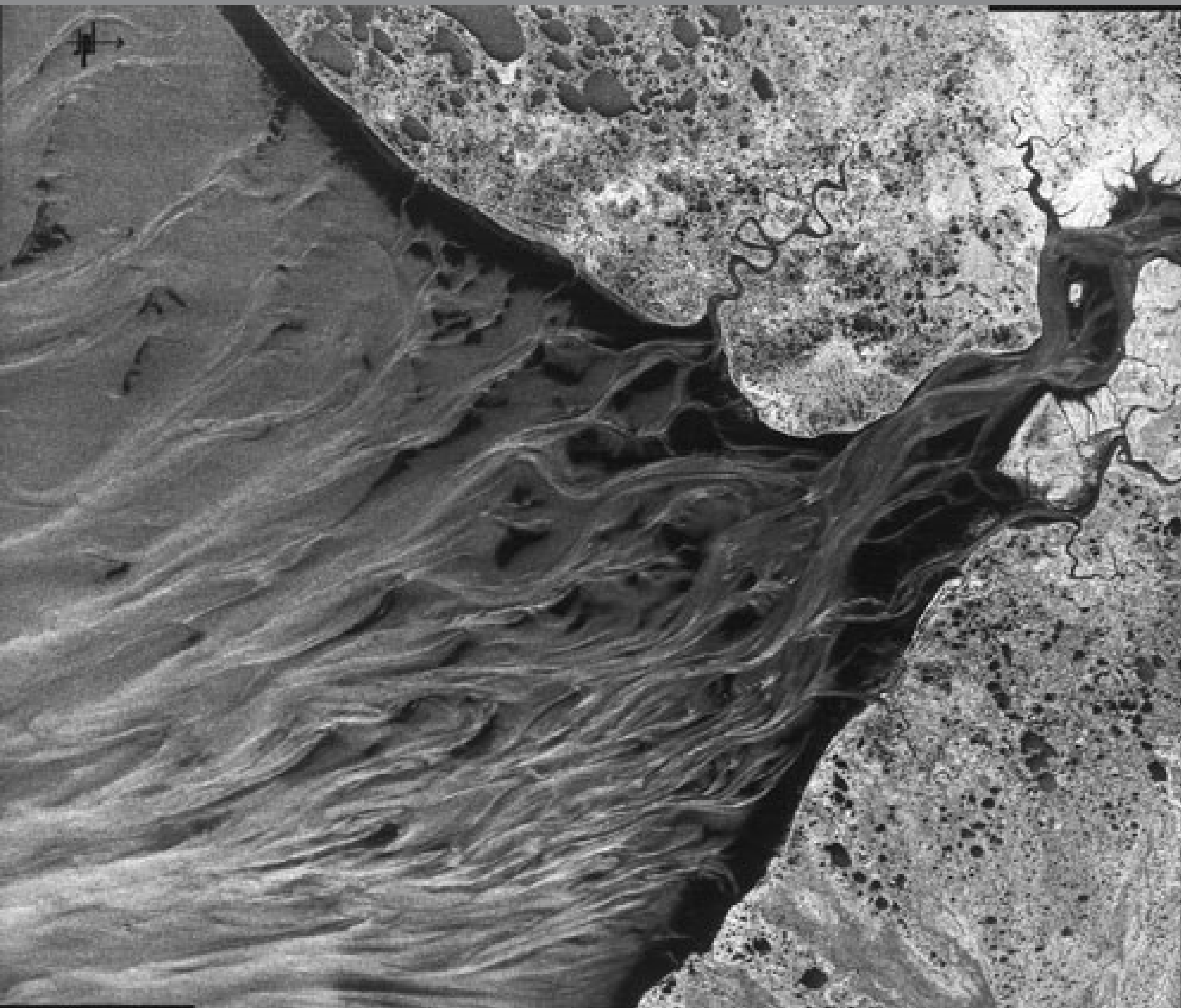
Chris Stewart, RSAC c/o ESA

SEASAT the First Civilian Spaceborne SAR (1978)

Orbit Parameters
Altitude:805 km circular
Inclination:108 degrees
Repeat Period:100 min (14 orbits a day)

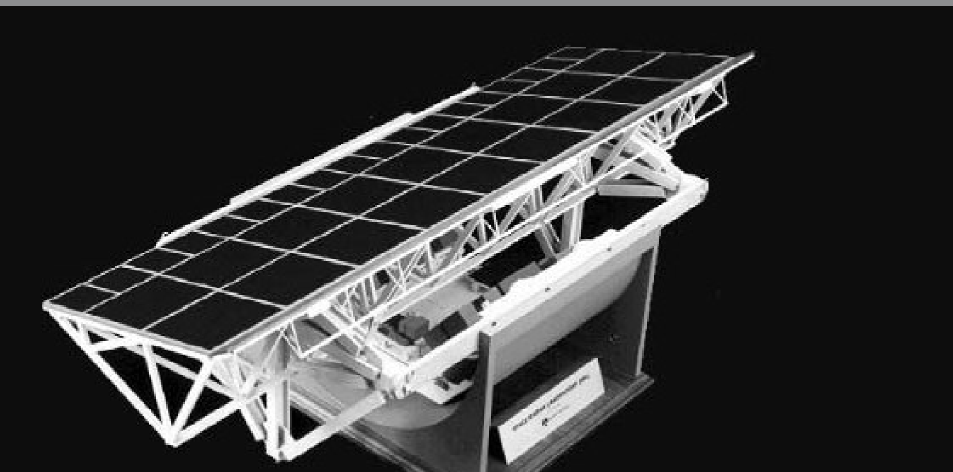
Spacecraft Statistics
Weight:2,290 kg
Length:12.2m
Diameter: 1.5m max.
SAR antenna: 2.1 x 10.7m

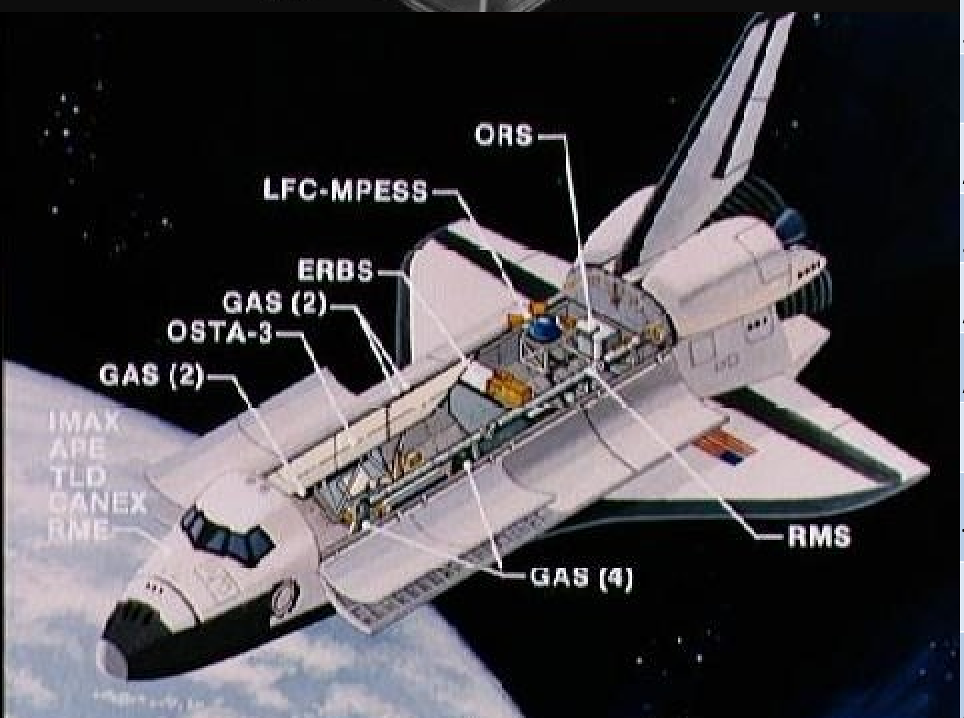
Instrument :
L Band (23 cm-1.27Ghz)
Polarization : HH
Central Incidence : 20°
Ground resolution : 25 m (4 looks)
Swath Width: 100 km



This SAR image is of the Kuskokwim River delta, Western Alaska. It was taken by Seasat on July 13, 1978. The patterns are formed by river water flowing around sand bars. The pock-marked land is covered by small permafrost lakes.

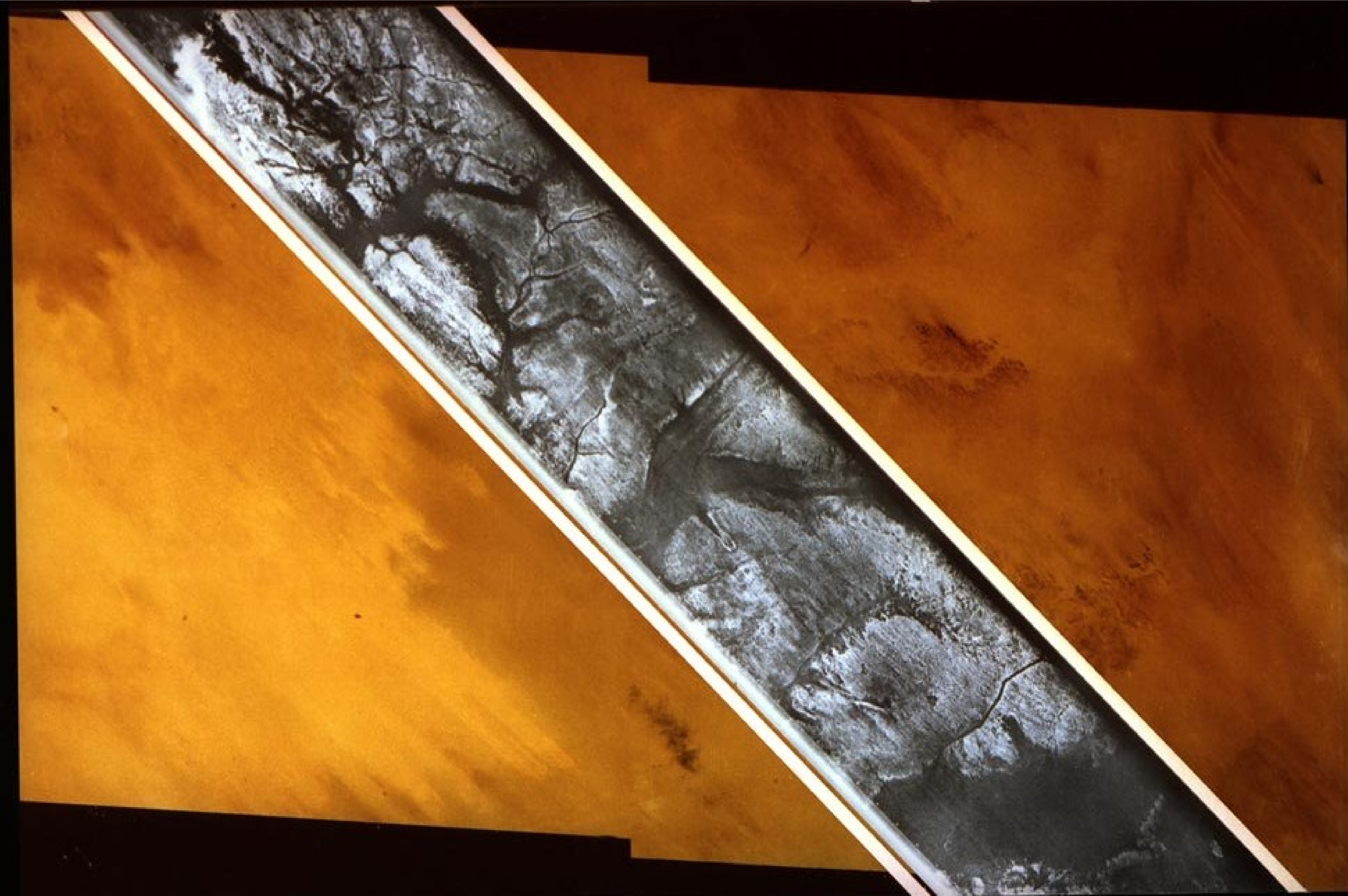
Shuttle Imaging Radar Missions
SIR- A & B (1981 & 1984)



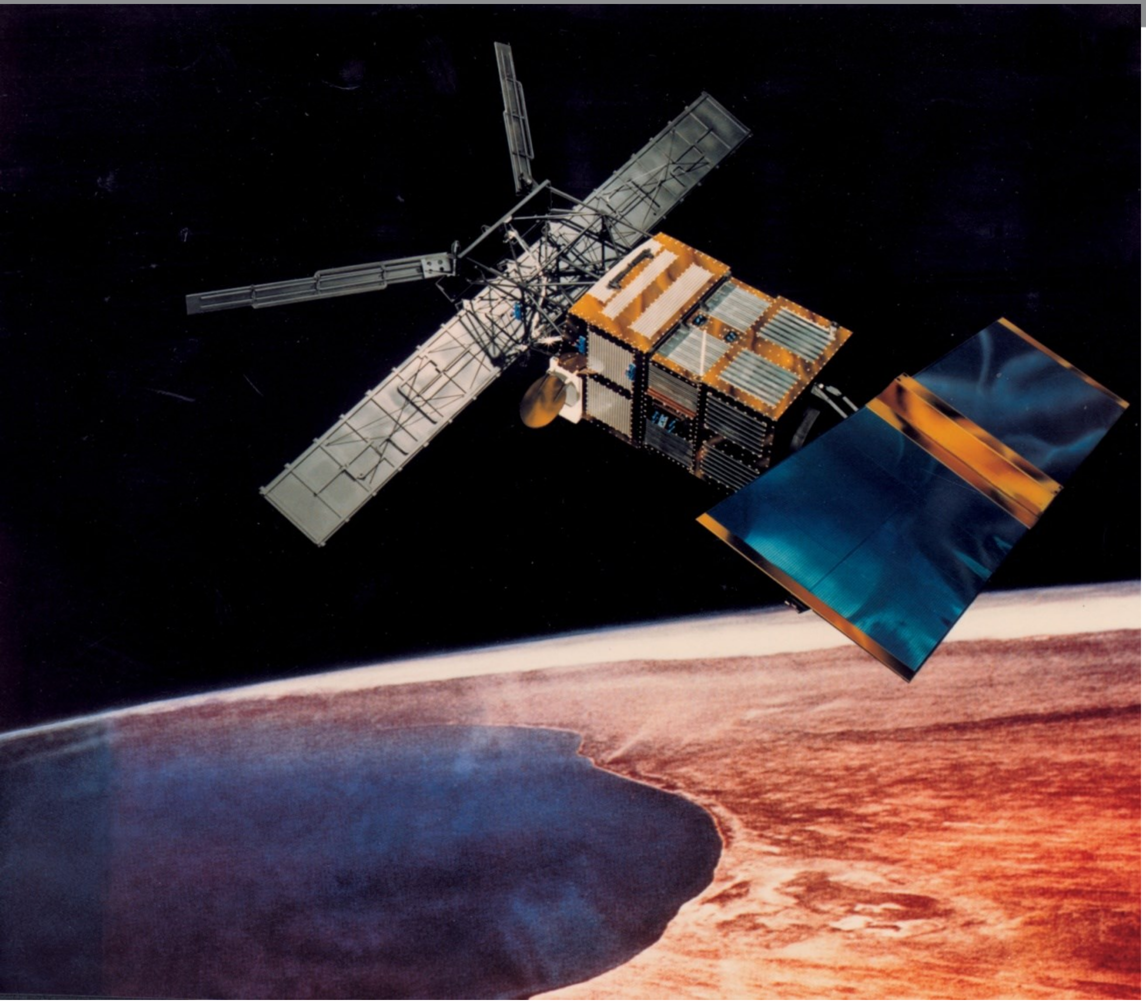


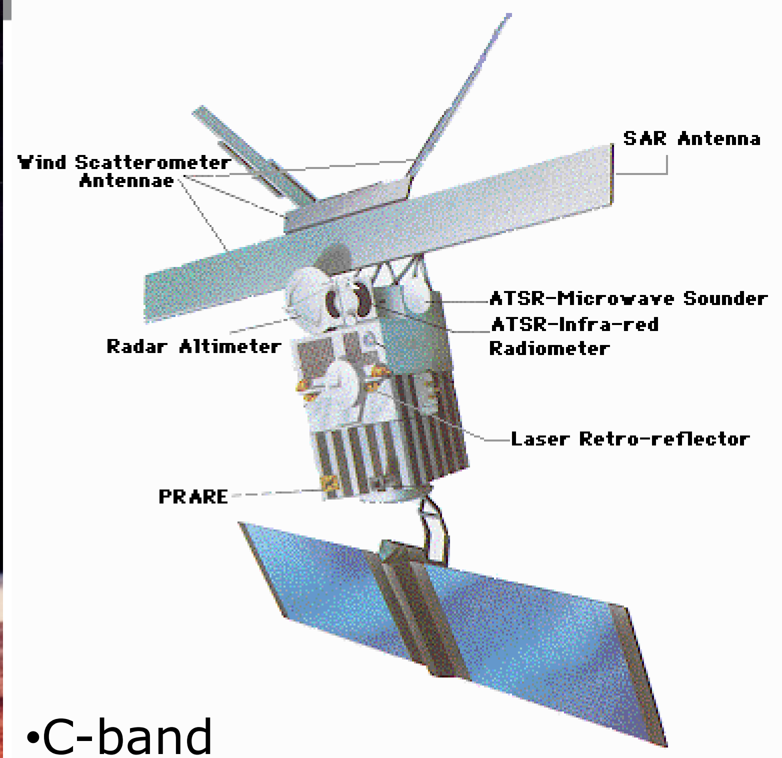
SIR-B	Parameters
Shuttle Orbital Altitudes	360, 257, 224 km
Shuttle Orbital Inclination	57 degrees
Mission Length	8.3 days
Radar Frequency	1.275 GHz (L-band)
Radar Wavelength	23.5 cm
System Bandwidth	12 MHz
Range Resolution	58 to 16 m
Azimuth Resolution	20 to 30 m (4-look)
Swath Width	20 to 40 km
Antenna Dimensions	10.7 m x 2.16 m
Antenna Look Angle	15 to 65 degrees from vertical
Polarization	HH
Transmitted Pulse Length	30.4 microseconds
Minimum peak power	1.12 kW
Data recorder bit rate (on the ground)	30.4 Mbits/s

SIR-A sees "radar rivers"

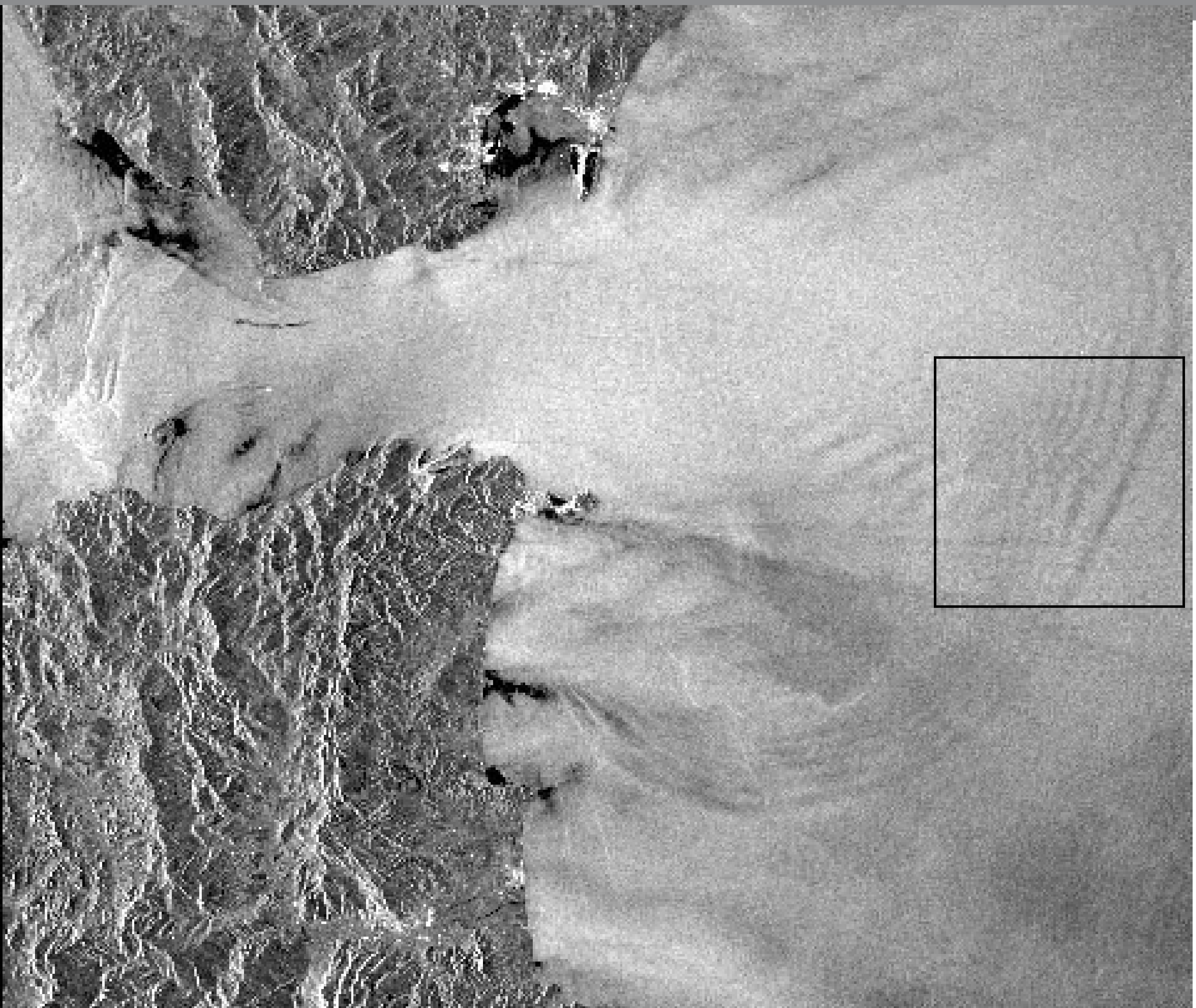


ERS-1 (ESA 1991-2000)





- C-band
- Moderate Swath & Resolution
- Single Polarisation (VV)
- Successful Operations
- Excellent Data Quality
- Application Development
- Emerging Market



The ERS-1 SAR scene below is from the Strait of Gibraltar, and was acquired on 22:39 UTC on July 30, 1993.

JERS-1 (NASDA, Japan 1992)

Instrument :	Orbit :
L Band (1.2 GHz)	Repeat Period : 44 days
Polarization : HH	Local crossing time : 10:45
Central Incidence : 35°	
Ground resolution : 18 m (3 looks)	
Swath Width: 75 km(offset from Nadir: 400km)	

Shuttle Imaging Radar Missions (1981-2000) (JPL USA)

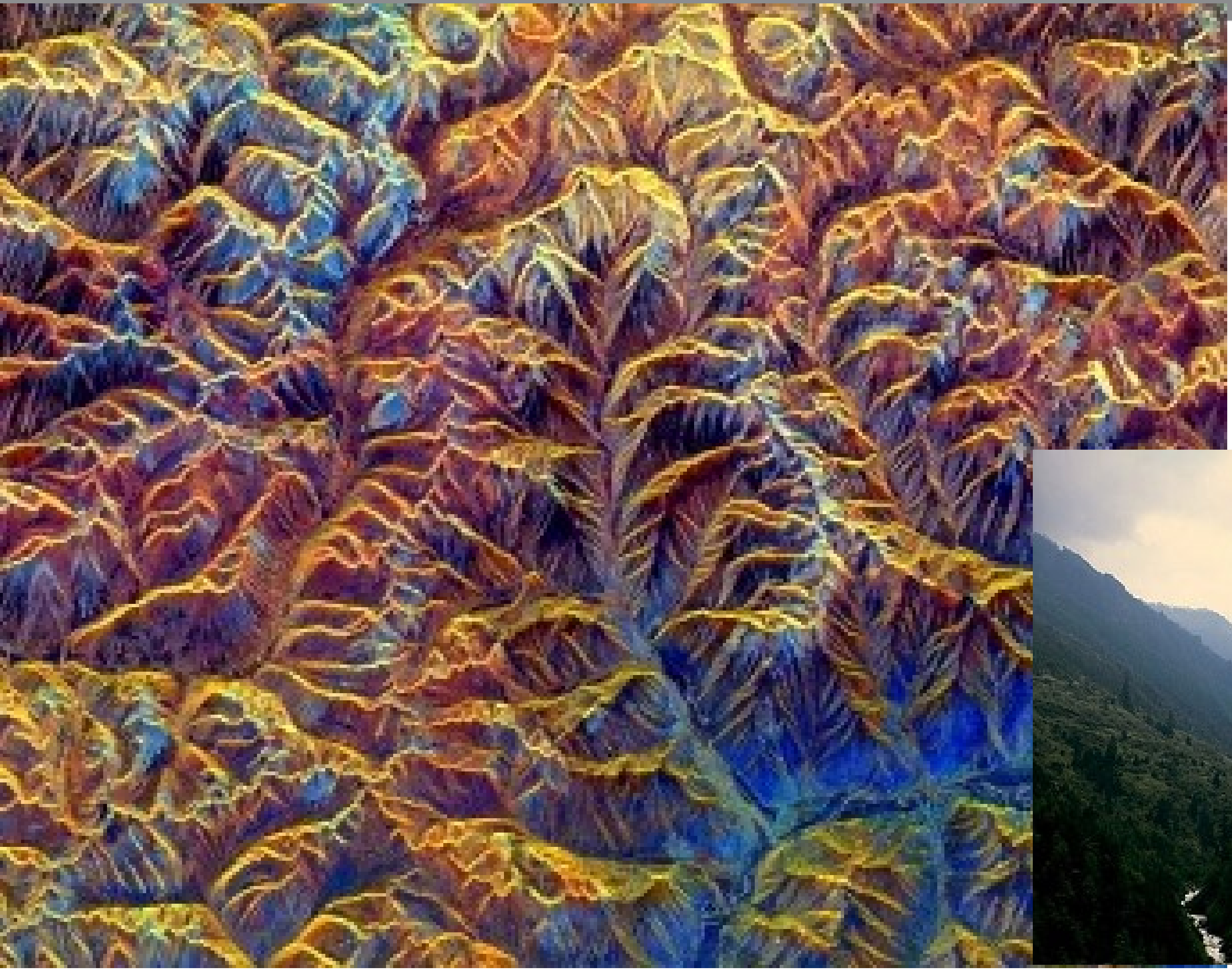
SIR-C/X-SAR

(Endeavour shuttle, 1994)

Instrument :

L Band (1.25 GHz)
C Band (5.3 GHz)
Polarisation : Fully Polarimetric
Incidence : 20° - 55°

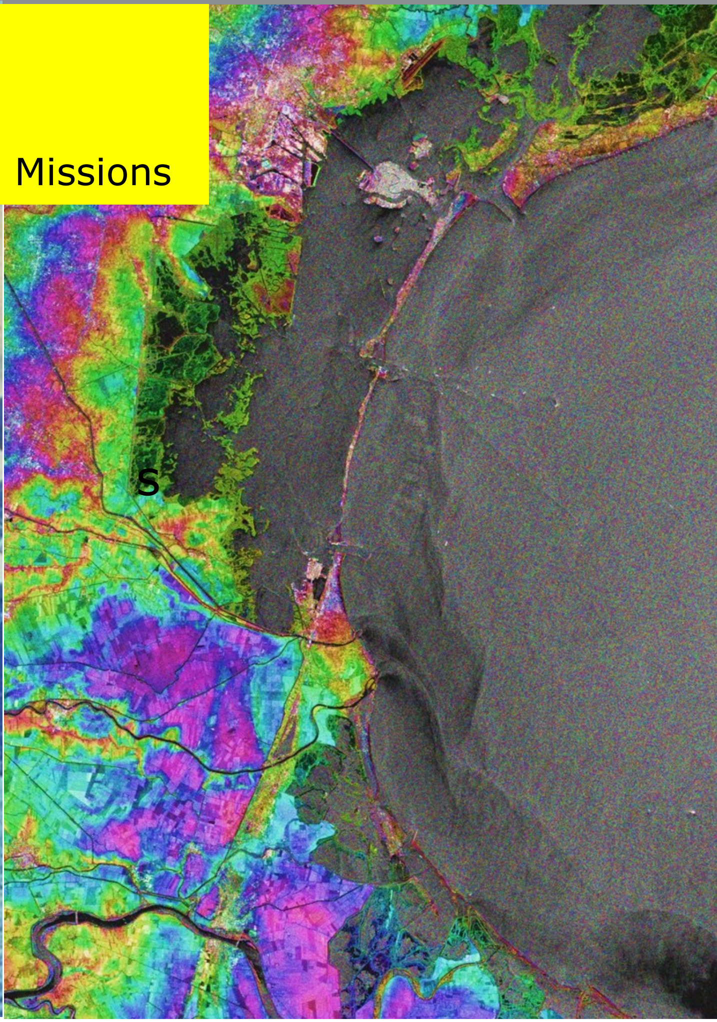
X Band (9 GHz)
Polarisation : VV
Incidence : 20° - 55°



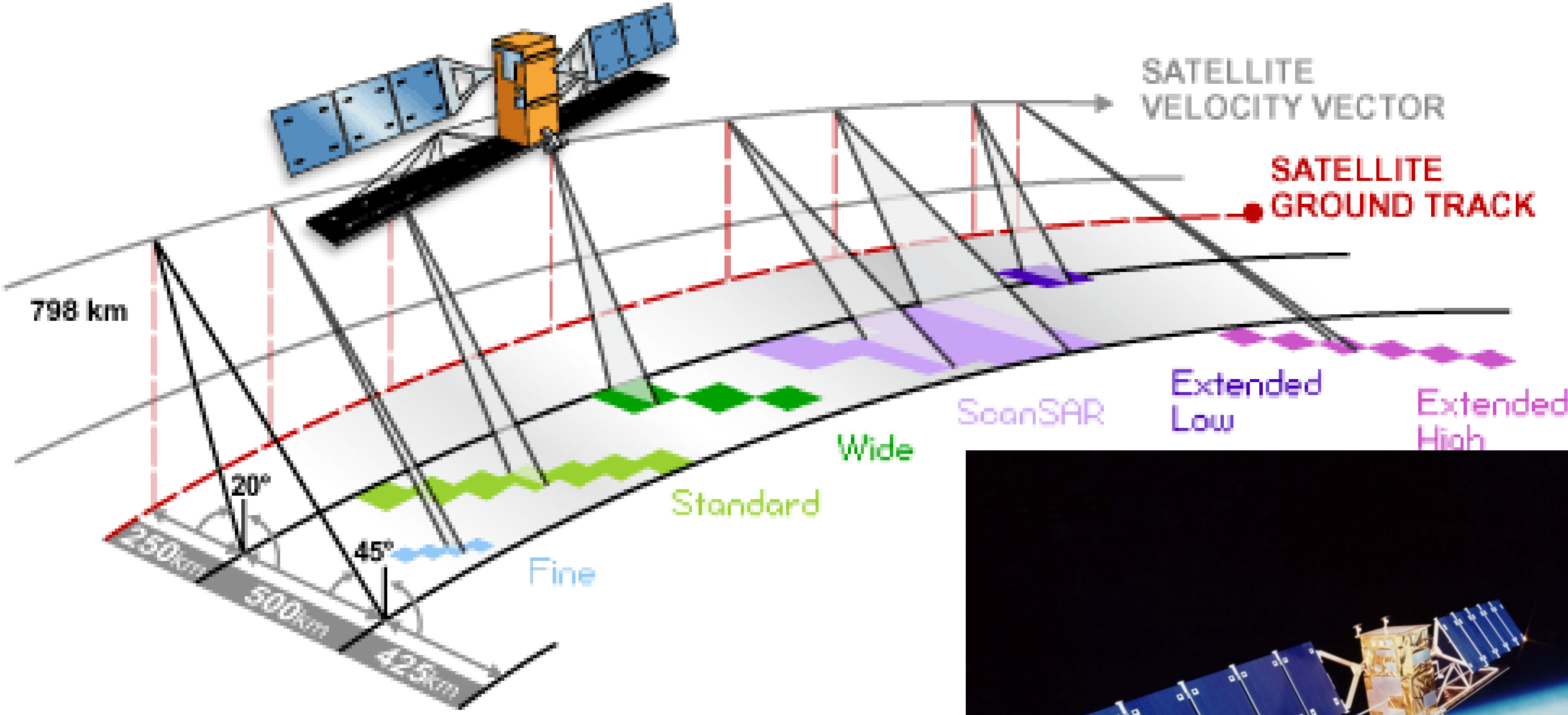
Tibet seen by SIR-C/X-SAR). The various colors assigned to the radar frequencies and polarizations are to map the distribution of different rock types.

ERS-2 1995-2011

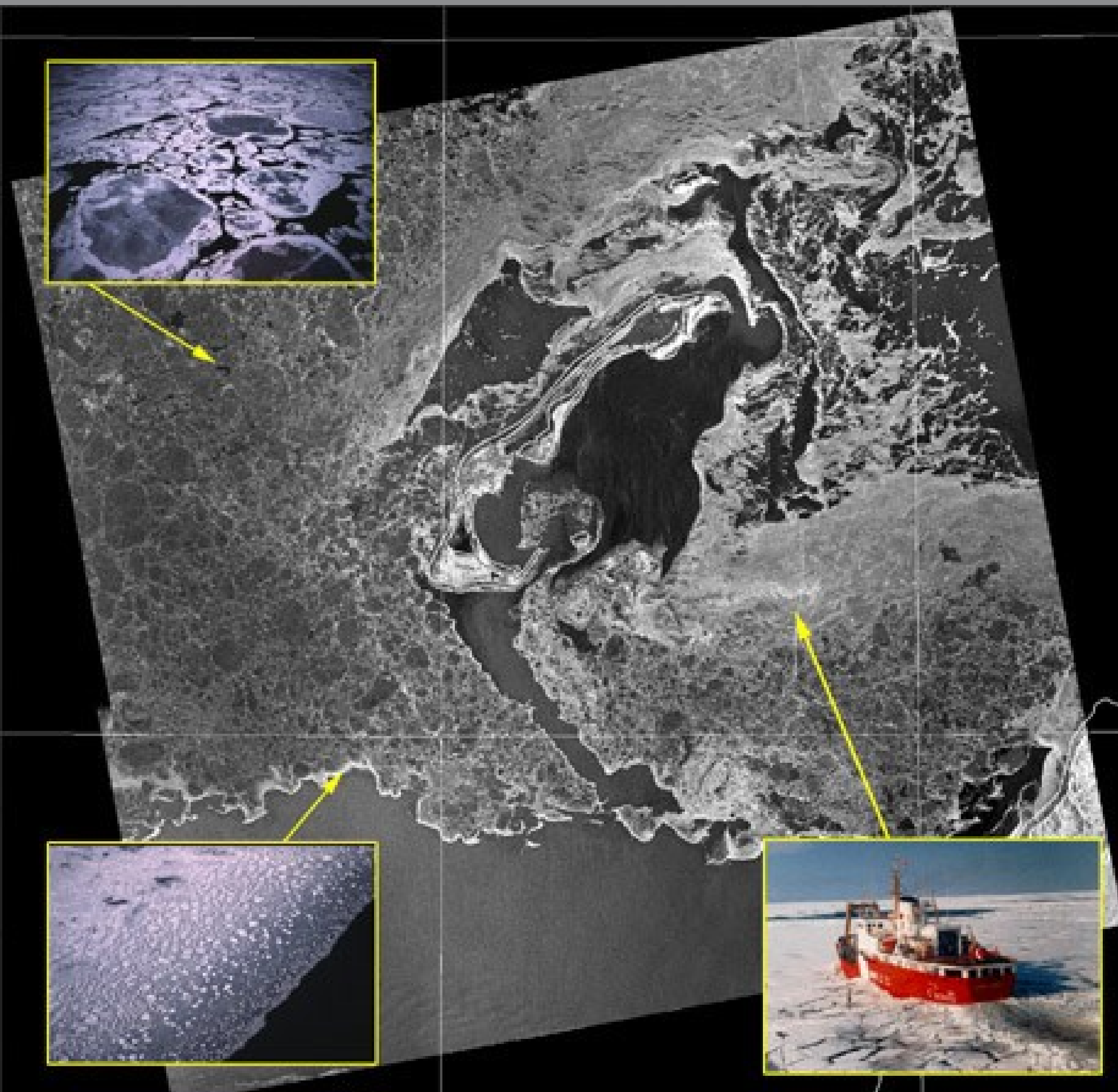
Same SAR as ERS-1
Continuity of Data Supply
Tandem Operation
Importance of Temporal Dimension
Funding Issues for (Pre-) Operational Missions



RADARSAT-1, Canada CSA 1995



RADARSAT-1 Ice Monitoring

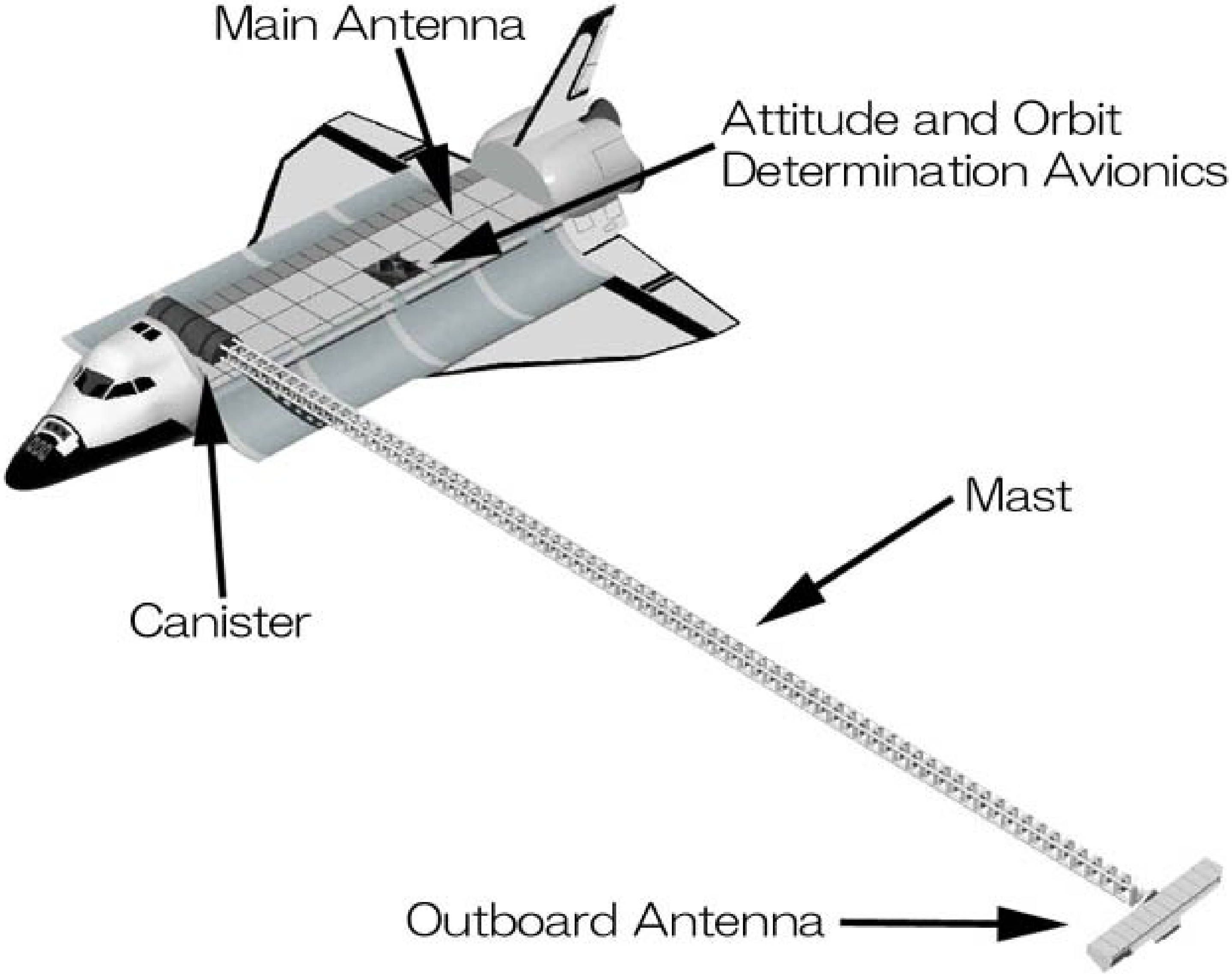


RADARSAT provides routine surveillance of the entire Arctic region.

This helps track sea ice distribution, identify various types of ice, and produce daily ice charts.

The information is used for planning safe shipping routes and supply operations for offshore exploration platforms or ocean research stations.

Shuttle Radar Topographic Mission SRTM (2000)



The Shuttle Radar Topography Mission (SRTM) obtained elevation data for a high-resolution digital topographic database of Earth.
SRTM flew onboard the Space Shuttle Endeavour during an 11-day mission in February of 2000.

SRTM DEM + Landsat overlay: San Andreas Fault, Los Angeles

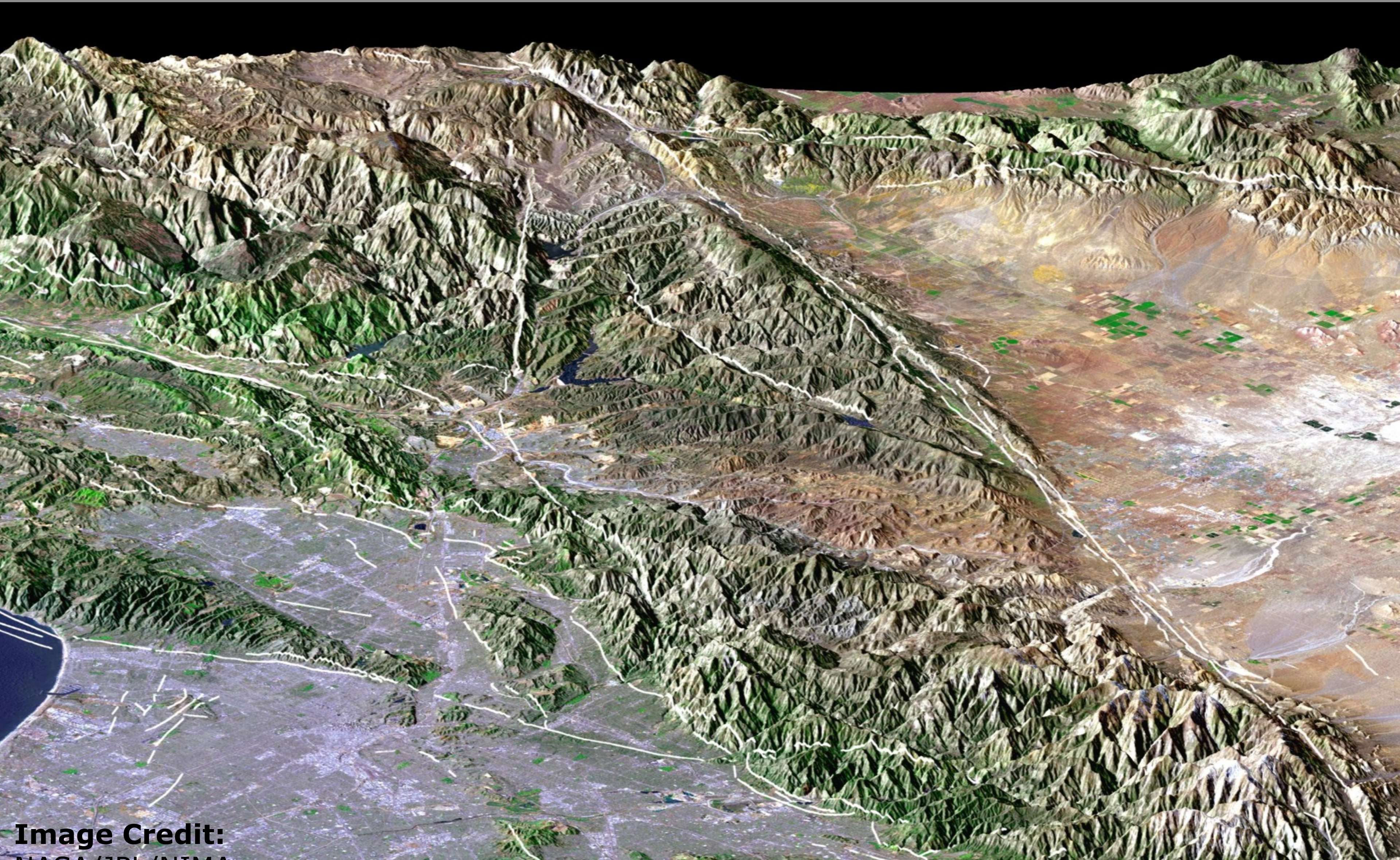


Image Credit:
NASA/JPL/NIMA

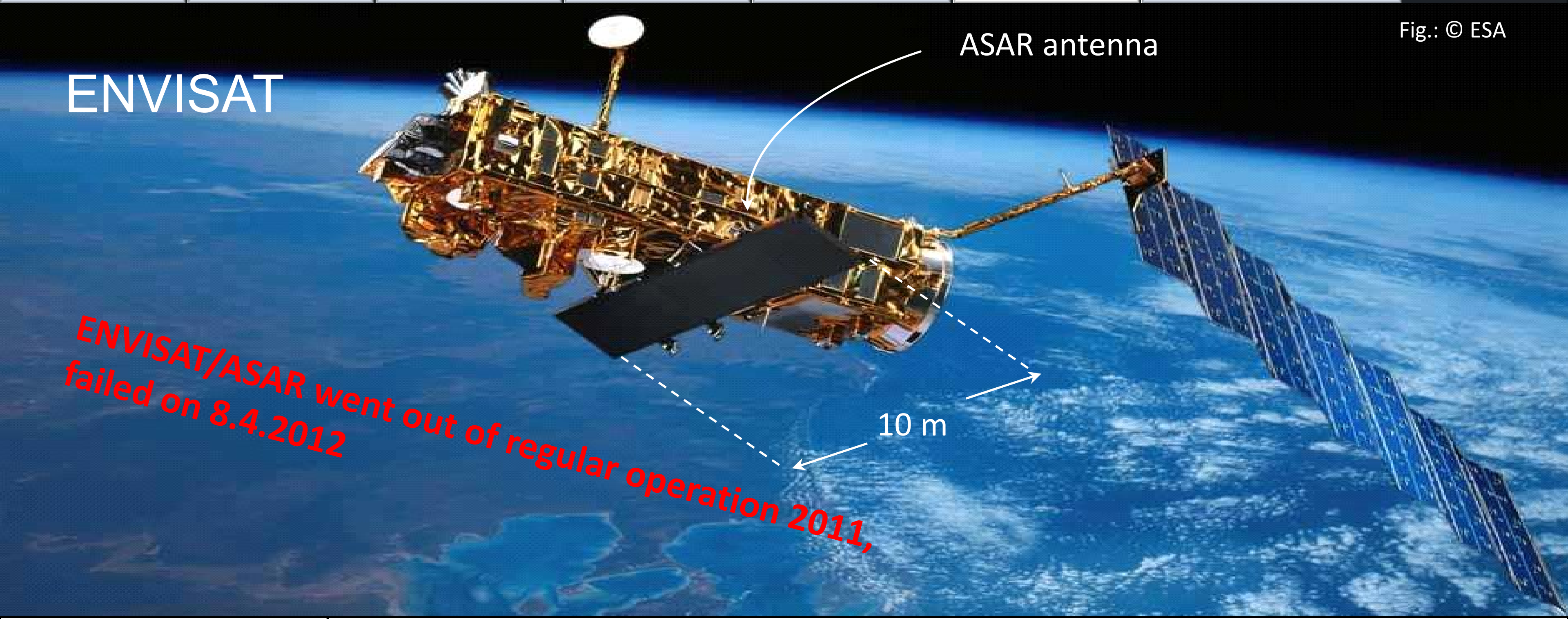
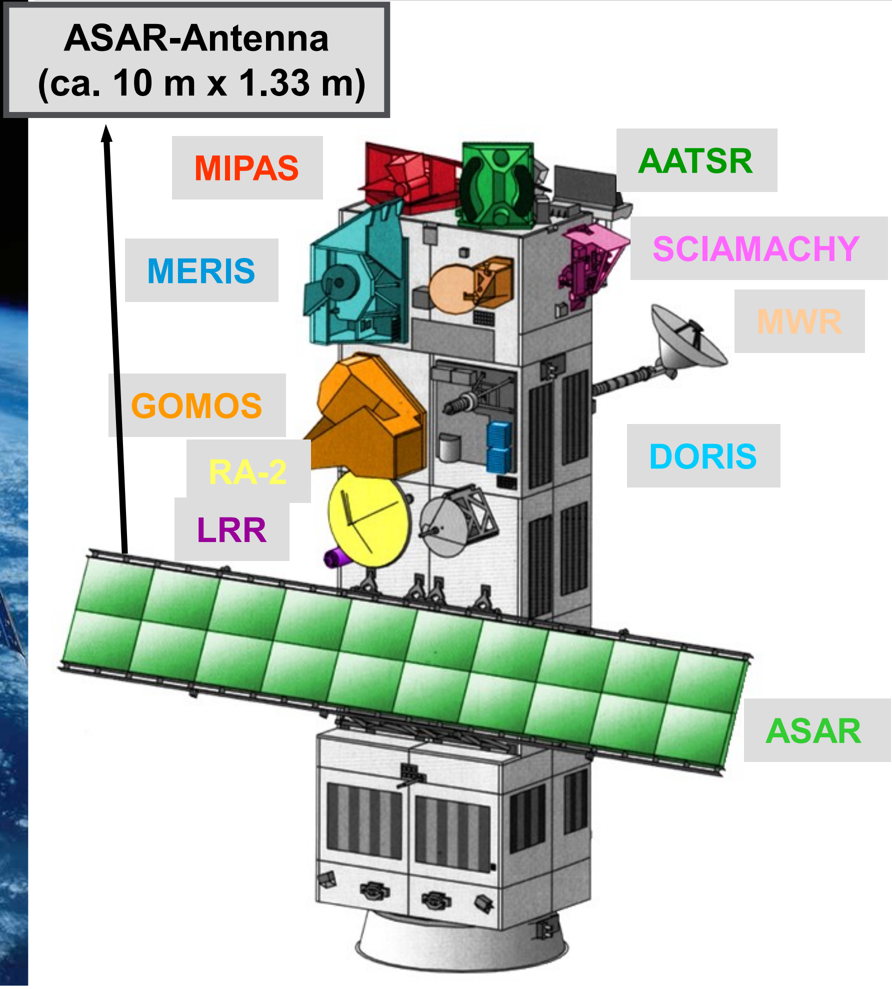


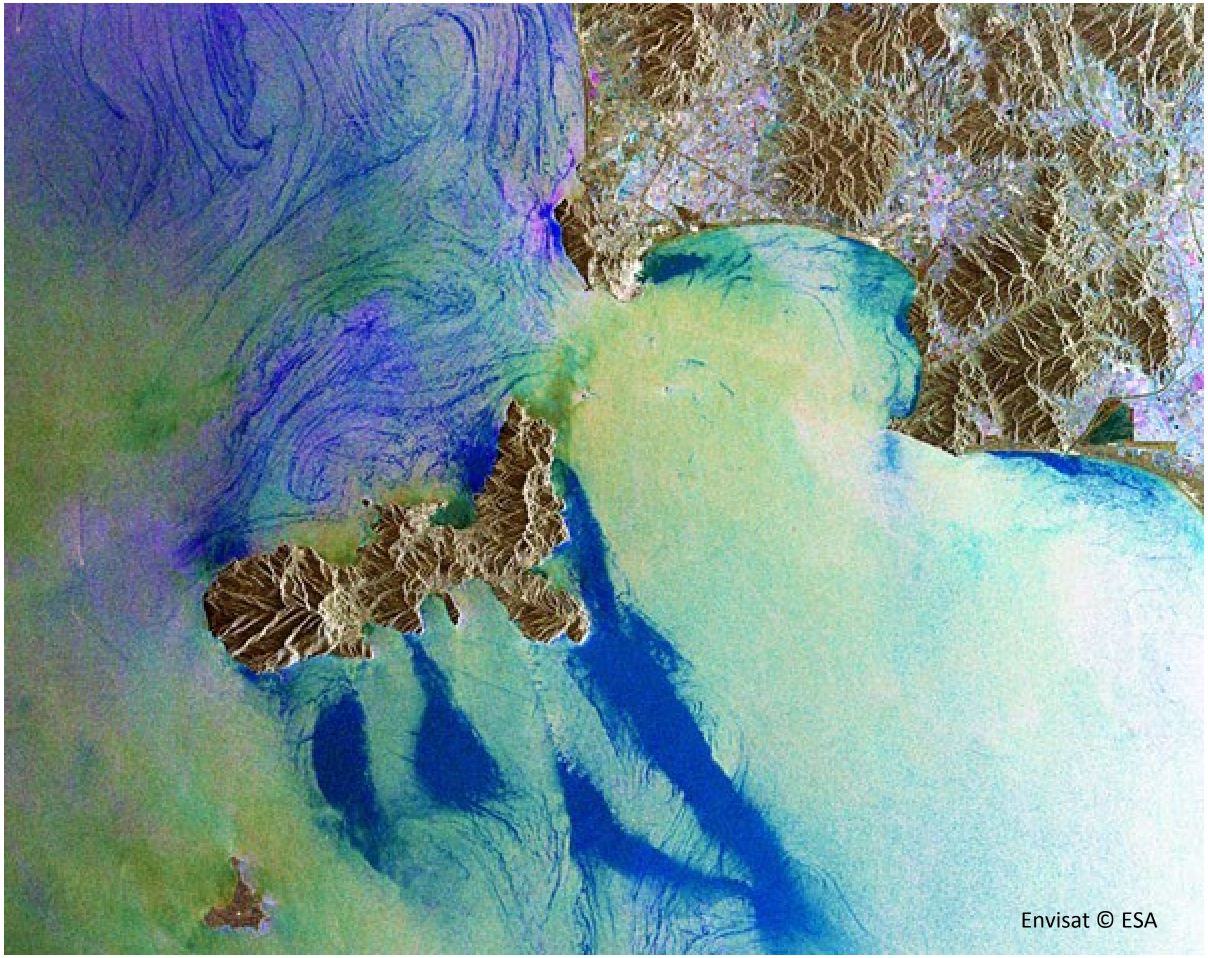
Image Mode (IM)	Spatial resolution of approximately 30 m (for precision product). VV or HH polarisation from any of 7 selectable swaths. Swath width approx. 56-100km.
Alternating Polarisation Mode (AP)	Spatial resolution of approximately 30 m (for precision product). HH/VV, HH/HV, or VV/VH polarisation pairs. Two co-registered images per acquisition, from any of 7 selectable swaths.
Wide Swath Mode (WS)	Spatial resolution of approximately 150 m by 150 m 400 km by 400 km wide swath image. VV or HH polarisation.
Global Monitoring Mode (GM)	Spatial resolution of approximately 1000 m by 1000 m. Up to a full orbit of coverage. HH or VV polarisation.
Wave Mode (WV)	Small imagette (dimensions range between 10 km by 5 km to 5km by 5km), esp. for ocean monitoring. May be positioned anywhere in an Image Mode swath. HH or VV polarisation may be chosen.

ENVISAT / ASAR (ESA 2002)



ENVISAT – ASAR: Elba (IT)

Multitemporal compilation of three Envisat radar images acquired on 29-11-2008, 7-2- 2009 and 21-8-2010.



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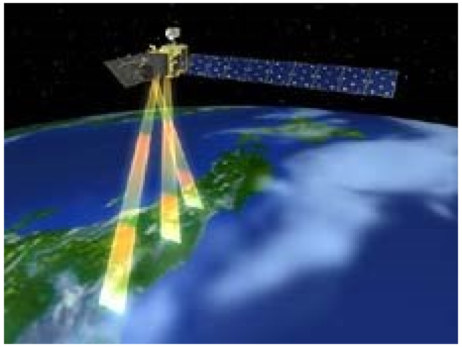
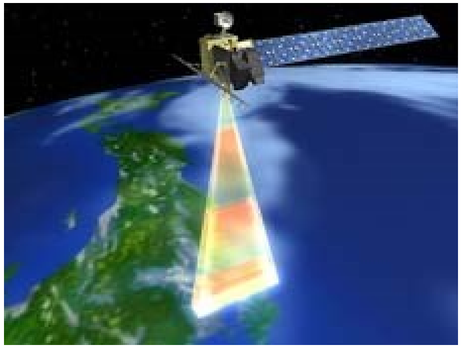
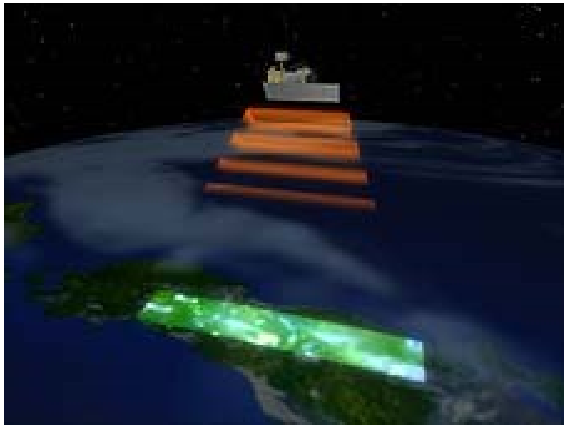
ALOS

- **ALOS-Satellite:** three remote-sensing instruments
- **PRISM**:
  3 High-resolution(monochrome) images (also for DEMs)
- **AVNIR-2**:
  Multi-band(color) images, capability of pointing
- **PALSAR**:
  Cloud-free, Day-and-Night radar sensor

ALOS failed 12.5.2011!







Major Specifications of PALSAR		
Observation Mode	High Resolution	SCANSAR
Frequency	L-band (1.27GHz)	
Polarization	HH,VV,HH&HV, VV&VH	HH,VV
Spatial Resolution	10m	100m
Number of Looks	2	8
Swath Width	70km	250x350km
Off-nadir Angle	10 - 51 deg	
NEsigma0	Approx. -23dB	

Figures: ©JAXA

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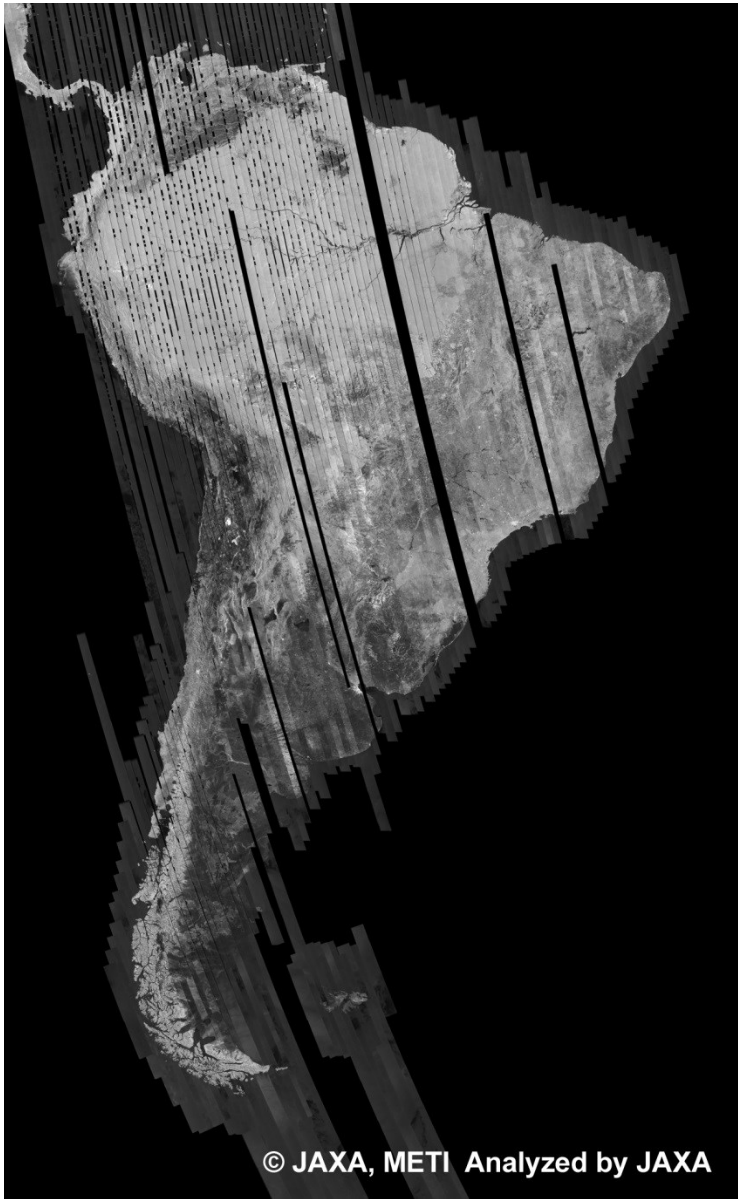
ALOS – PALSAR

500m Browse Mosaic of South America (FBS/HH Ascending)
for cycle40 (Dec. 16, 2010 ~ Jan. 30, 2011)
→ Forest / biomass mapping



From: http://www.eorc.jaxa.jp/ALOS/en/img_up/mosaic_500_c40.htm

RADARSAT-2 Quad Polarisation

The colour composite of a Radarsat-2 polarimetric radar image acquired over the Flevoland test site in the Netherlands on 4 April 2009. The different colours reflect the type and condition of the land cover. Field boundaries are clearly visible in this area, which is mostly agricultural. The dark areas correspond to water surrounding this area of reclaimed land, the very bright areas to urban settlements and the pink/blue area to middle-left is a nature reserve.

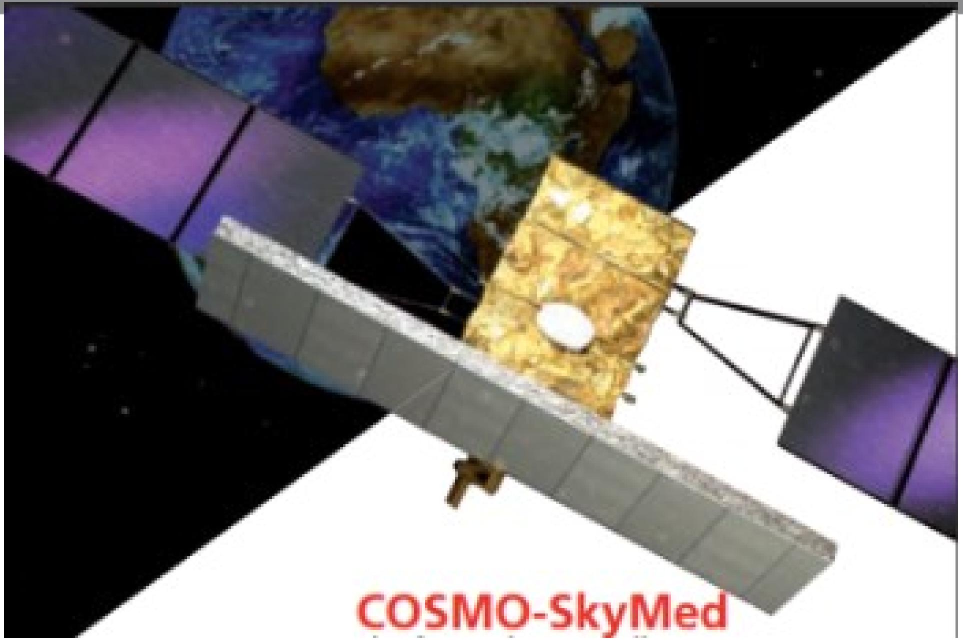
COSMO-SkyMed (ASI 2007)

First generation
• Four COSMO-SkyMed X band satellites
Integration with other missions
• Two SAOCOM L-band satellites
Second Generation
• COSMO-SkyMed second generation being developed by ASI and Italian Ministry of Defense (launching by 2014), will guarantee innovation and continuity with the current system

• 400 MHz chirp bandwidth
• 1m resolution from 25° to 59° incidence angle
• Image size 10 x 10 km @ 1m resolution

With 4 satellites
• At equator 4 images per day
• At 40° latitude, every 7 hours (average)

An image will be made available 24 to 48 hours after the request has been approved

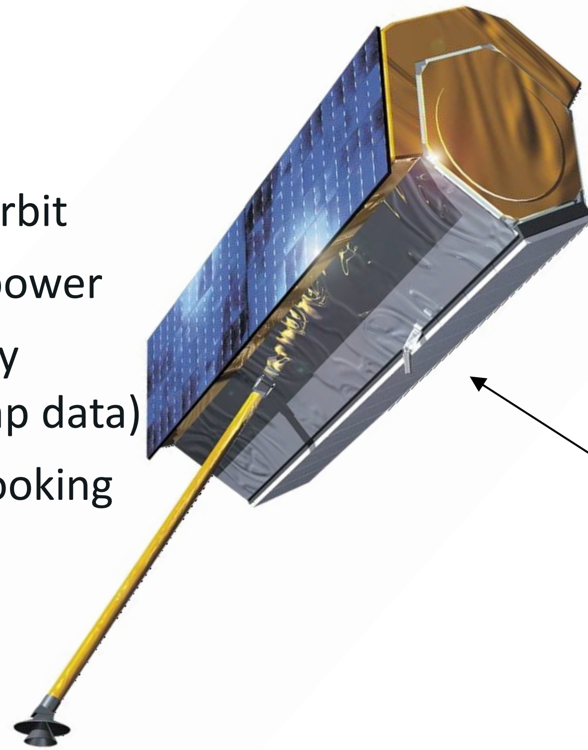


With 4 satellites up to 1800 images per day
Daily scenario example:
• 300 Spotlight-2 = 30,000 km² at 1m resolution
And
• 1,500 Stripmap = 2,400,000 km² at 3m resolution

COSMO-SkyMed & San Francisco

TerraSAR-X Satelli

- **Satellite**
- 514 km altitude
- 11 days repeat orbit
- 800 W average power
- 320 Gbit memory
  (600 s of stripmap data)
- Rollable to left looking



300 MBit/s downlink

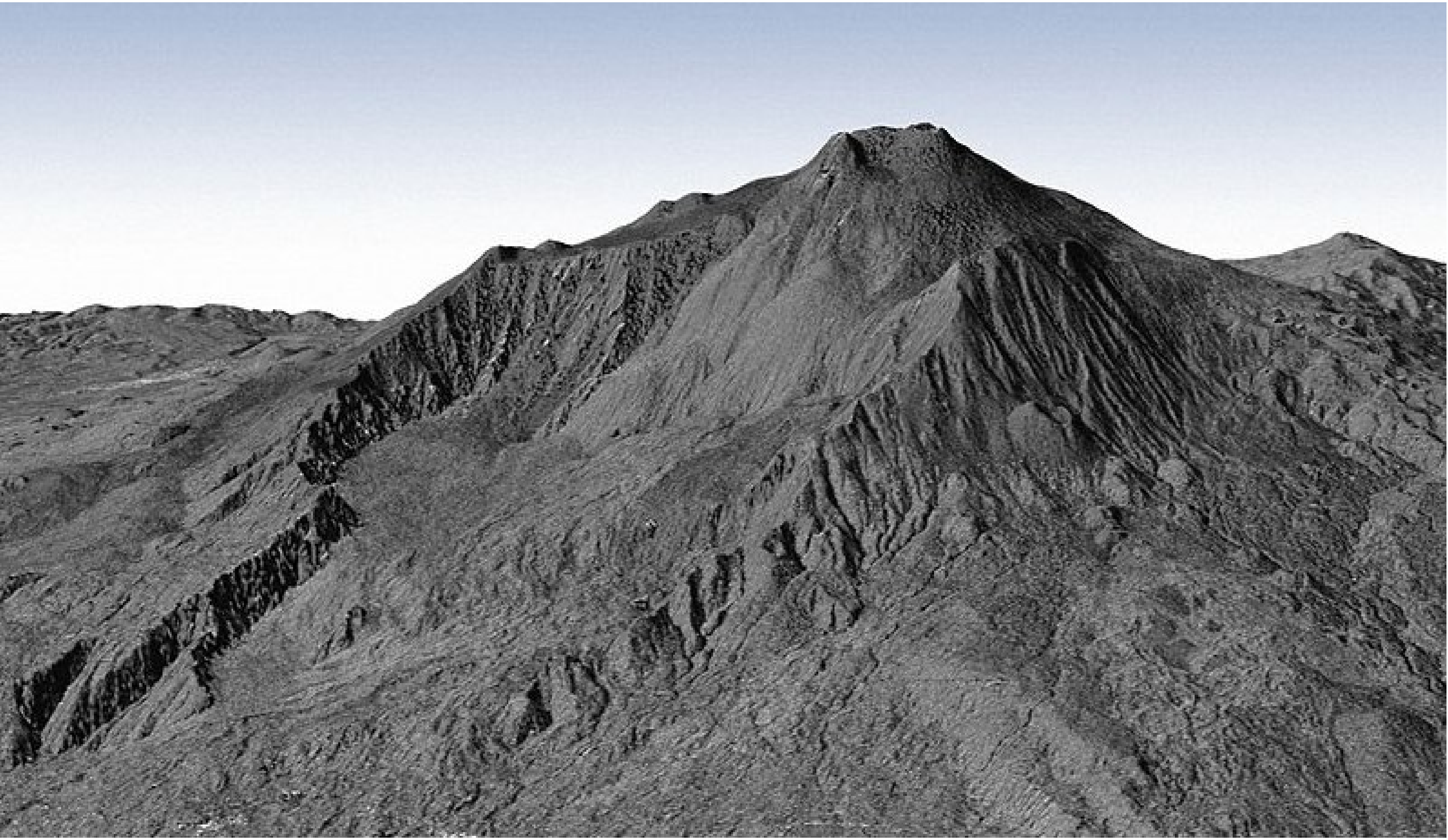
Active array SAR antenna

- 384 sub-arrays
- 150 MHz bandwidth (300 MHz)
- right looking
- >100 elevation beams
  - ScanSAR
- > 100 azimuth beams
  - Spotlight
- transmit and receive in H or V
  - Dual polarization
- experimental dual receive antenna & redundant receiver
  - Quad polarization
  - GMTI

Fig.: © DLR

TerraSAR-X at Farnborough Airshow

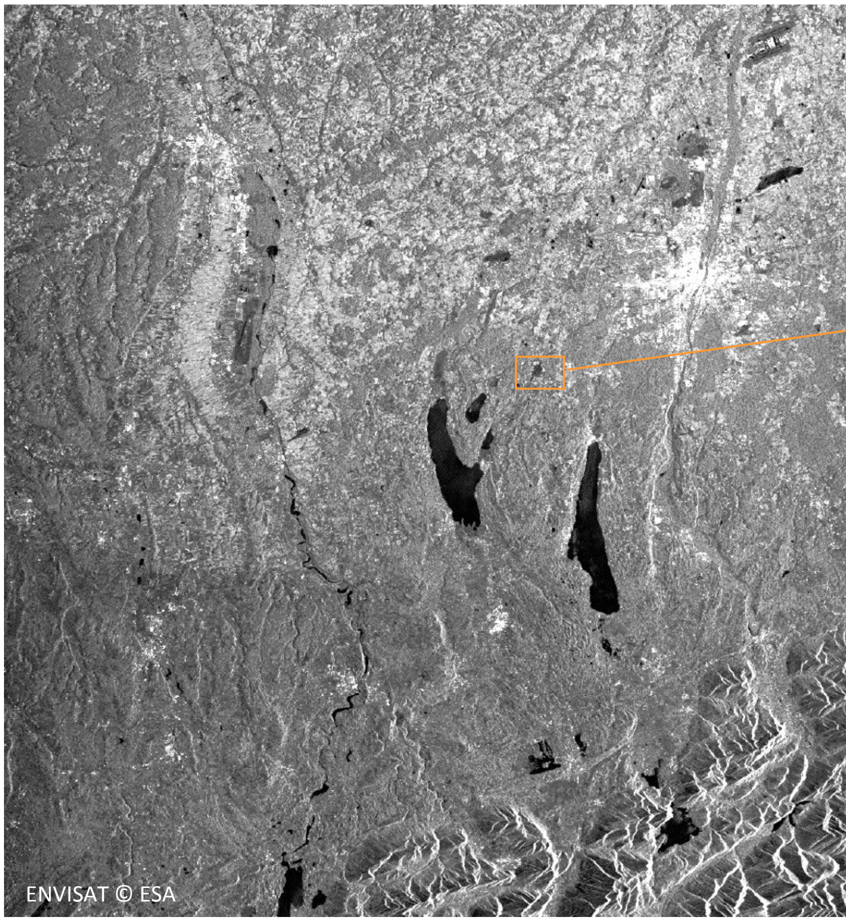
Tandem-X (2010)
Etna

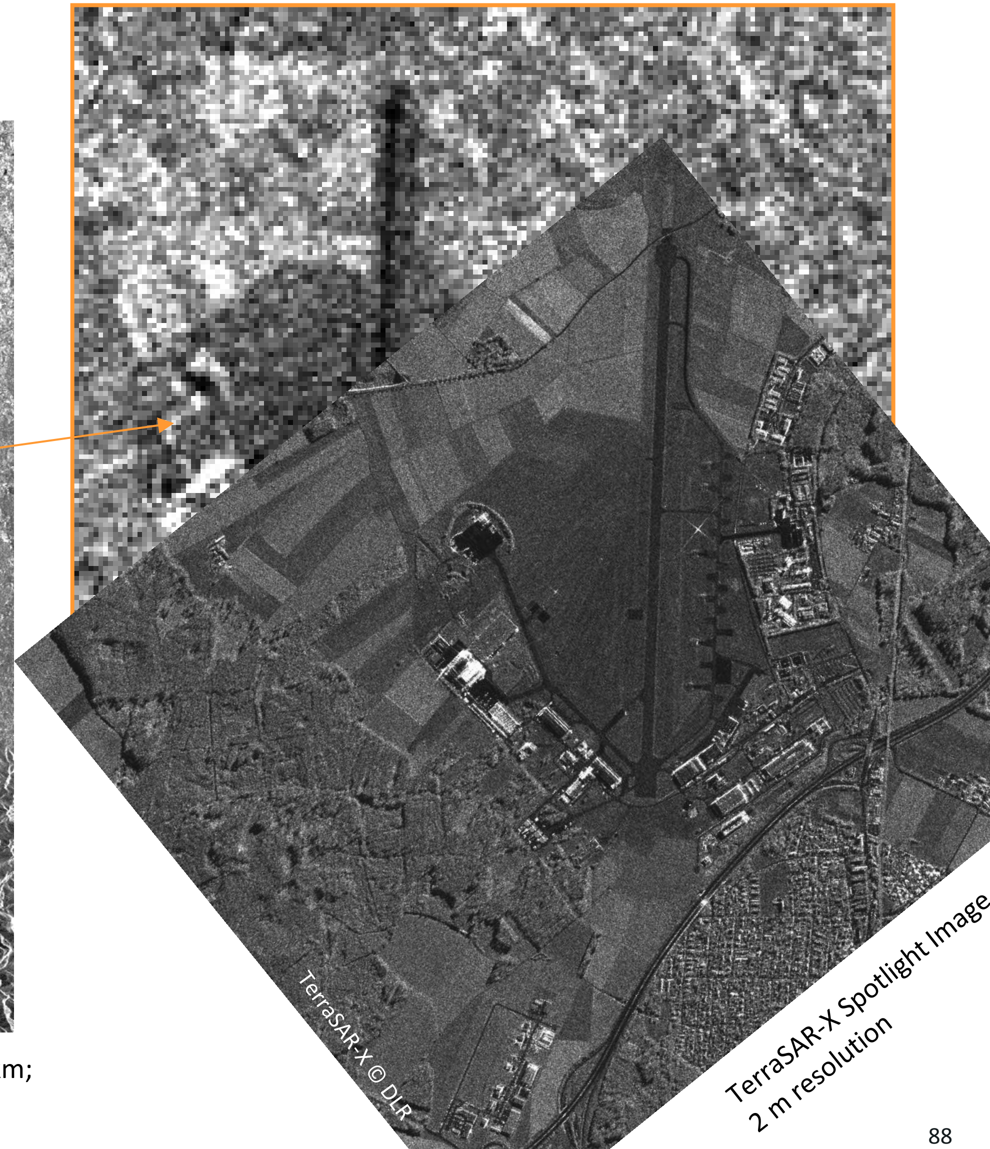


TerraSAR-X Image Examples

SAREDU Remote Sensing Education Initiative

SAR Application Example: Mapping





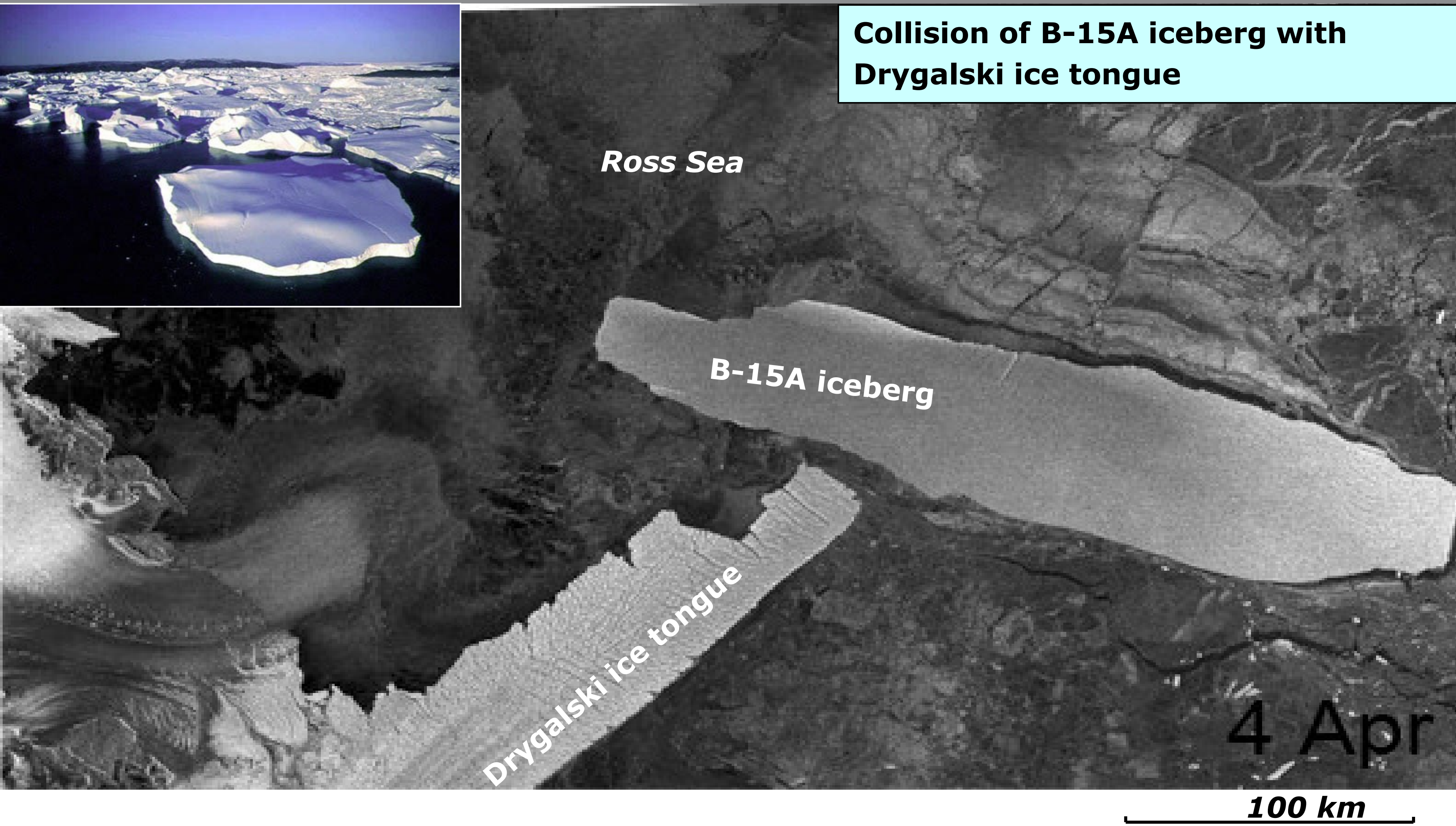
ENVISAT / ASAR IM 2 Oberpfaffenhofen 100 km x 100 km;
25 m resolution (© ESA)

SAREDU Remote Sensing Education Initiative

Examples of applications

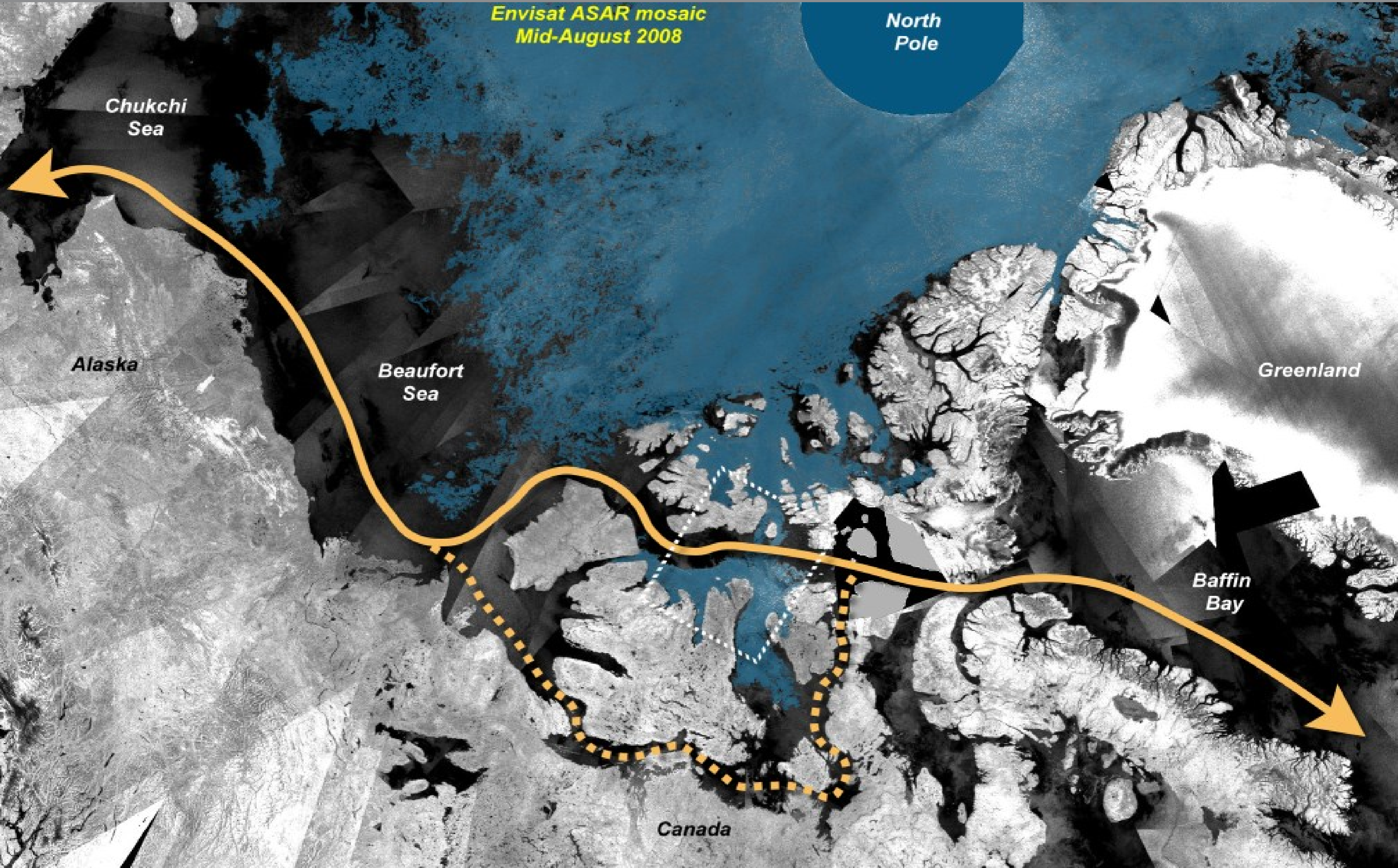
Ice Monitoring

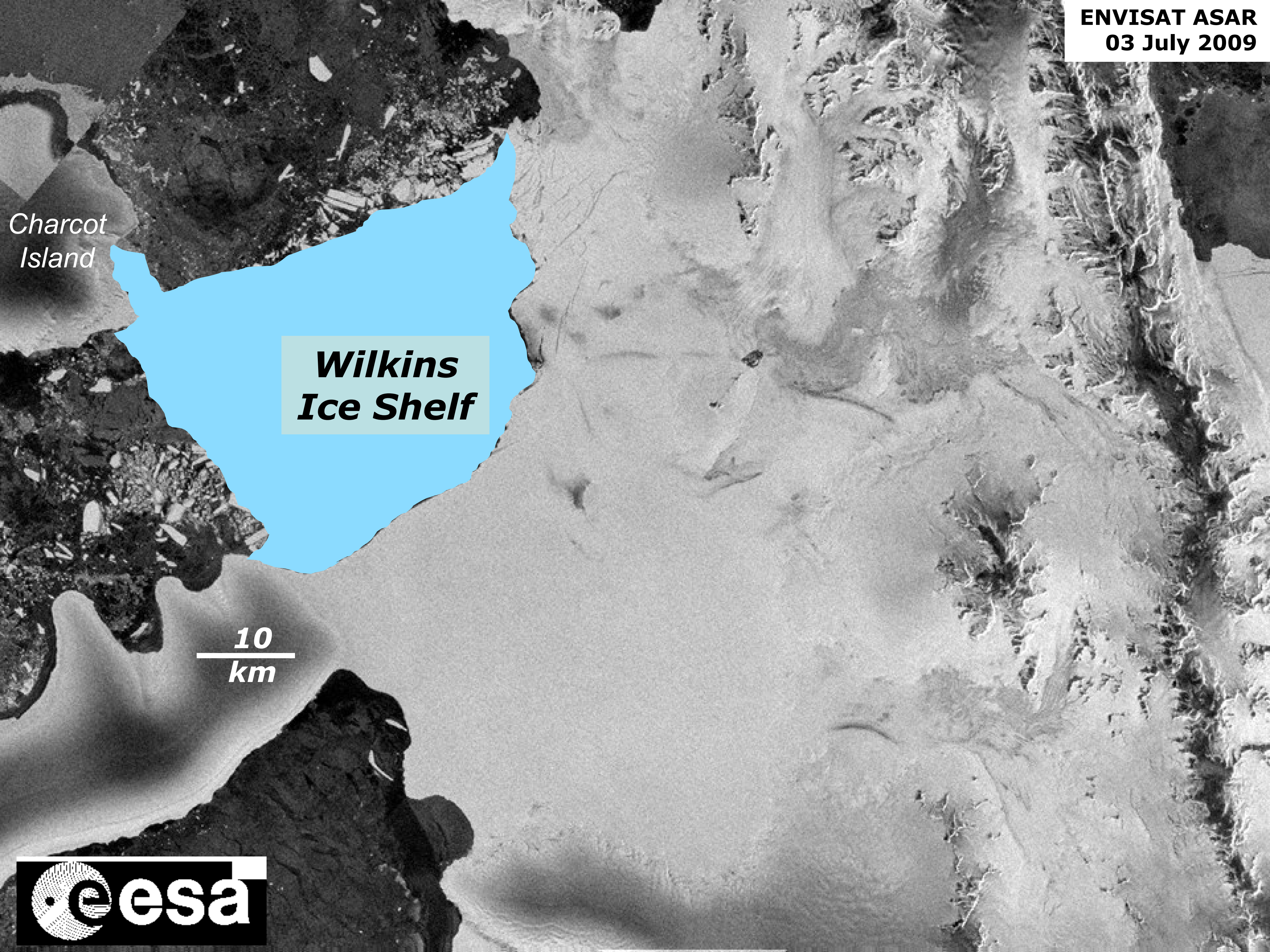
Antarctica April 2005



Collision of B-15A iceberg with Drygalski ice tongue

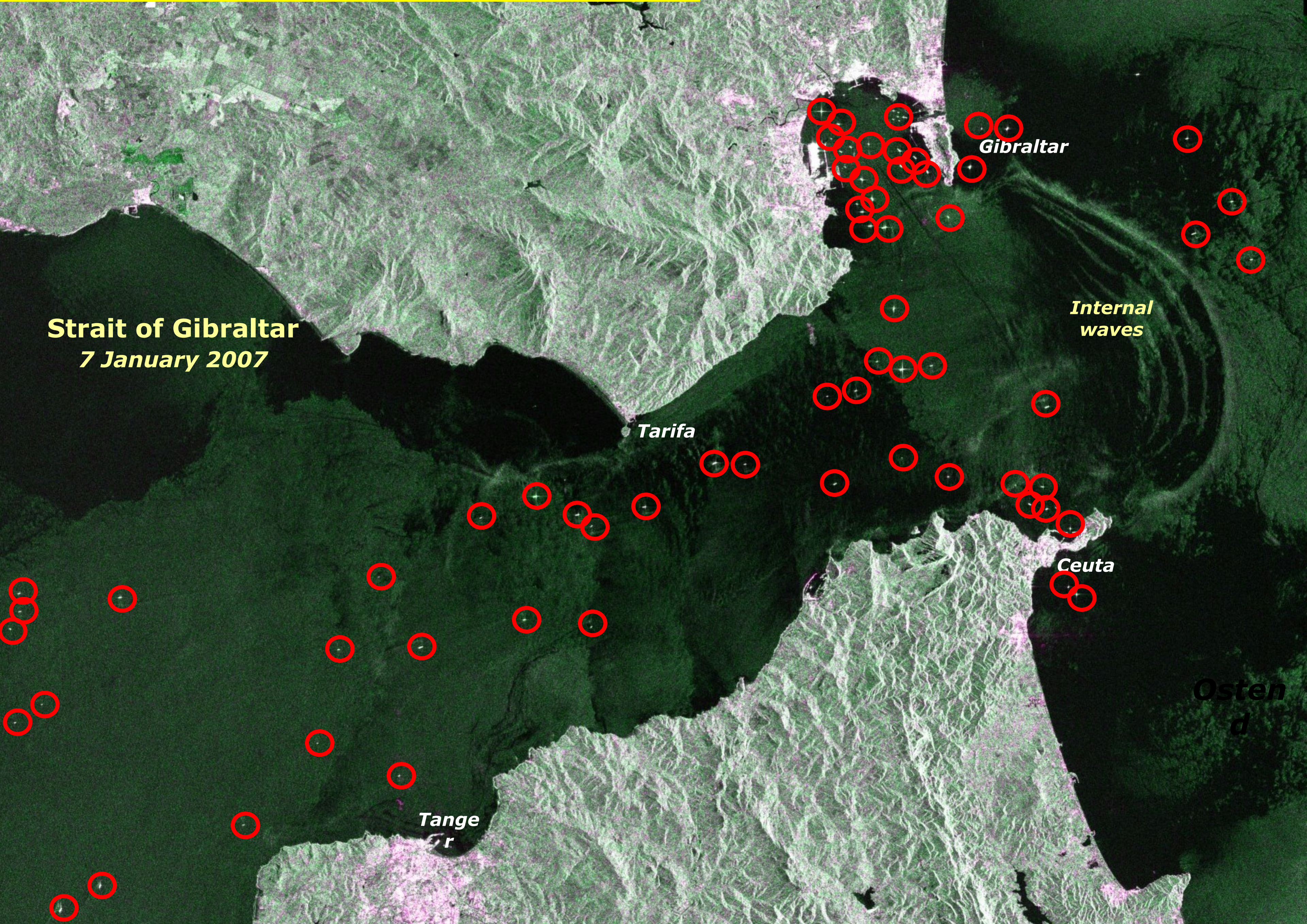
European Space Agency


Envisat ASAR mosaic
Mid-August 2008
North
Pole
Chukchi
Sea
Alaska
Beaufort
Sea
Greenland
Baffin
Bay
Canada

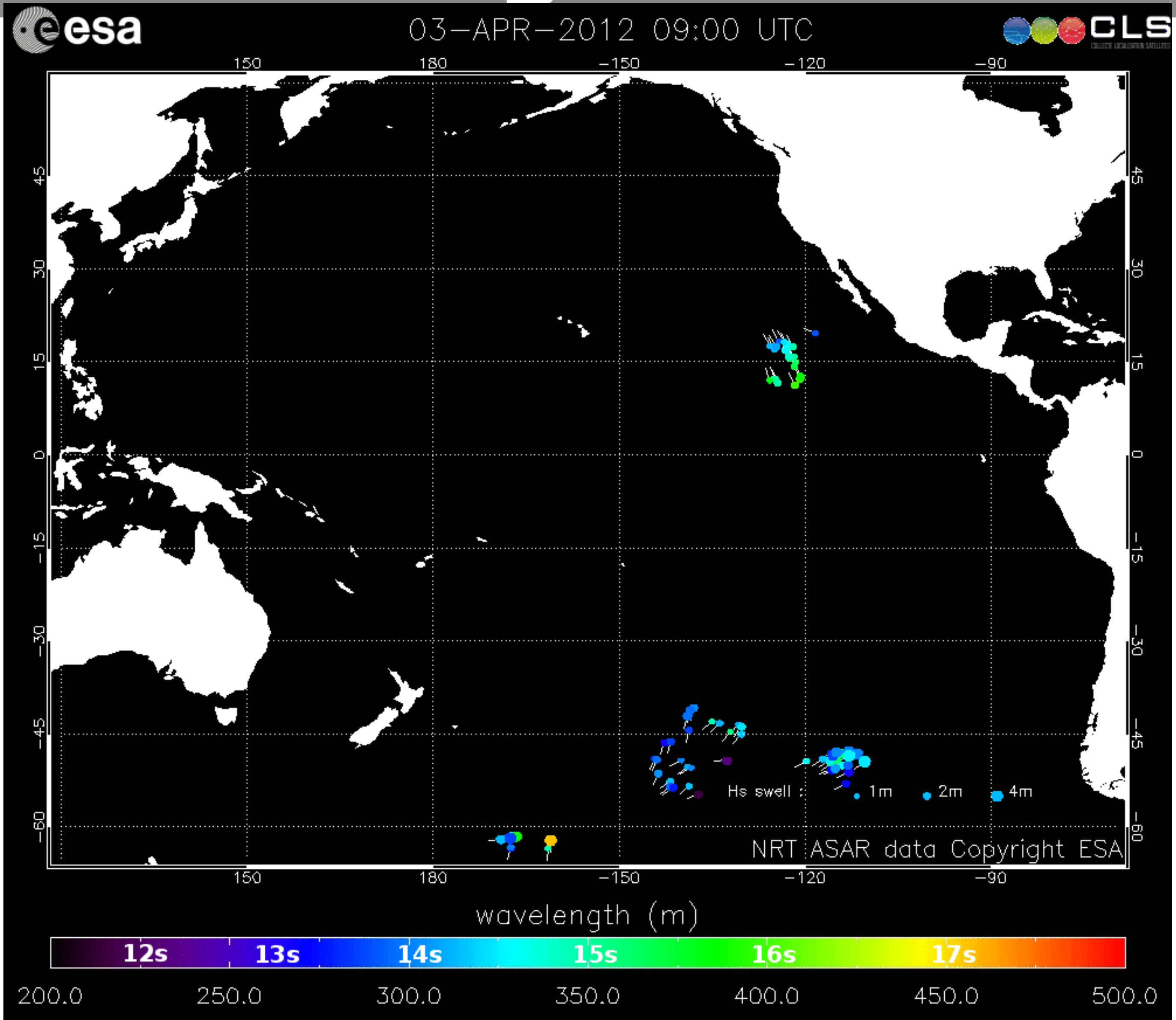

ENVISAT ASAR
03 July 2009
Charcot
Island
Wilkins
Ice Shelf
10
km
esa

Marine Applications

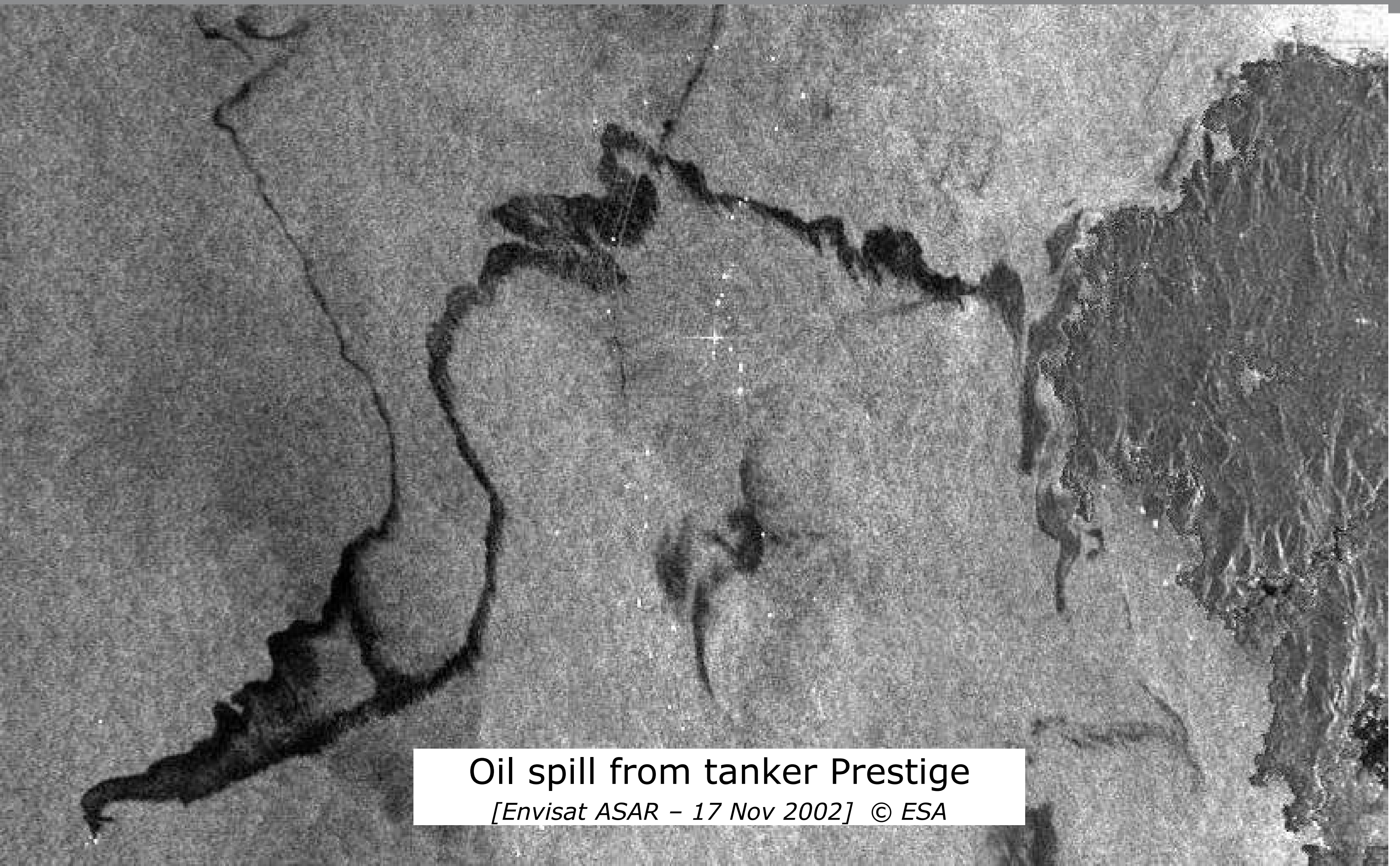
ENVISAT/ASAR Ship Detection



ASAR Ocean Wave Forecasting



SAR applications for disaster management: Oil Spills

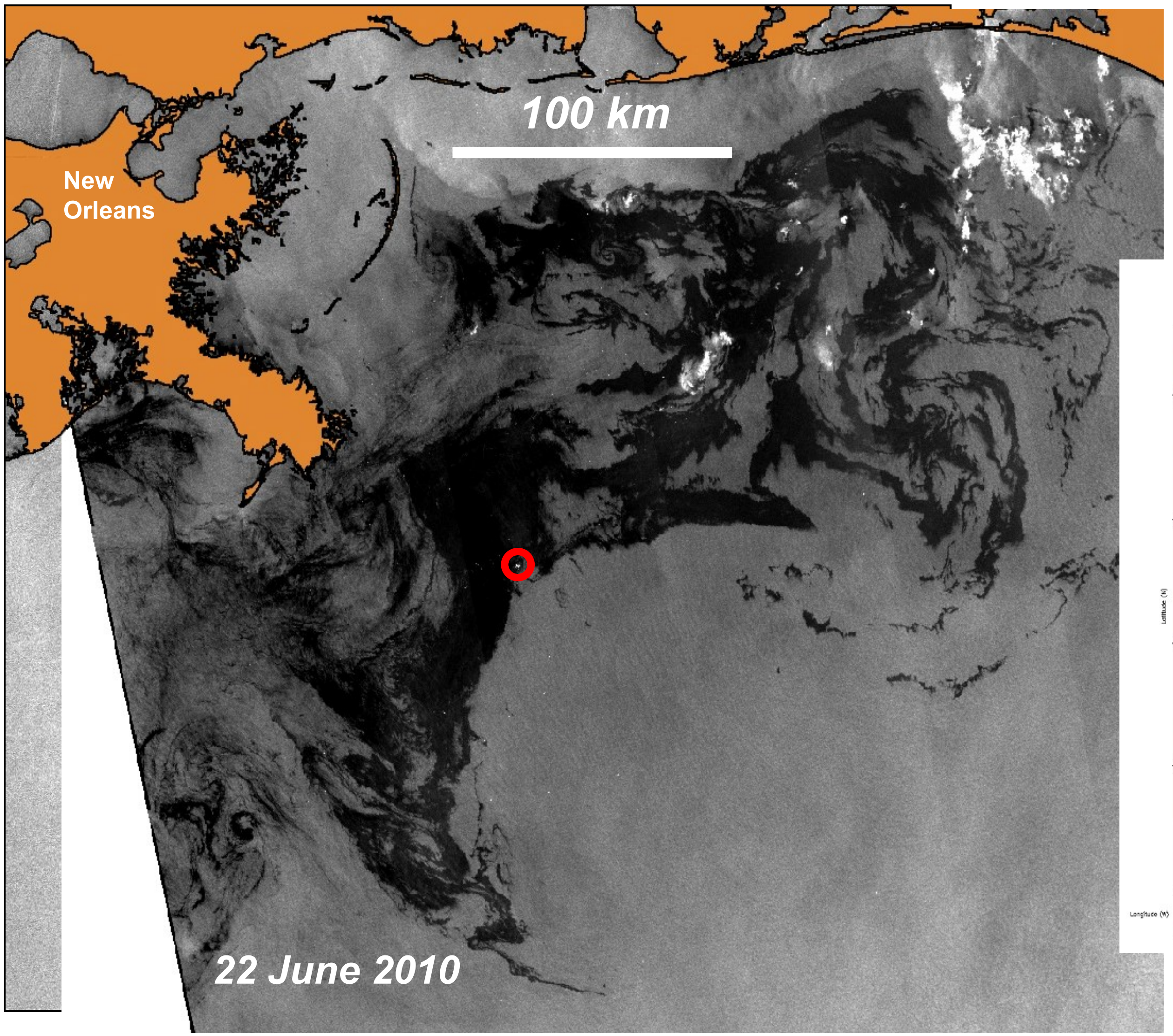


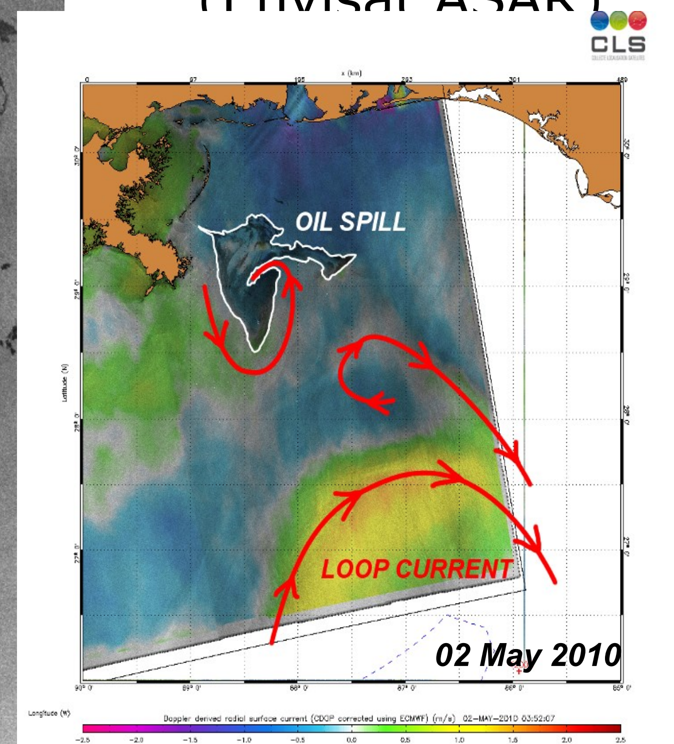
Oil spill from tanker Prestige

[Envisat ASAR – 17 Nov 2002] © ESA

The Louisiana Oil Spill disaster from space

(Envisat ASAR)





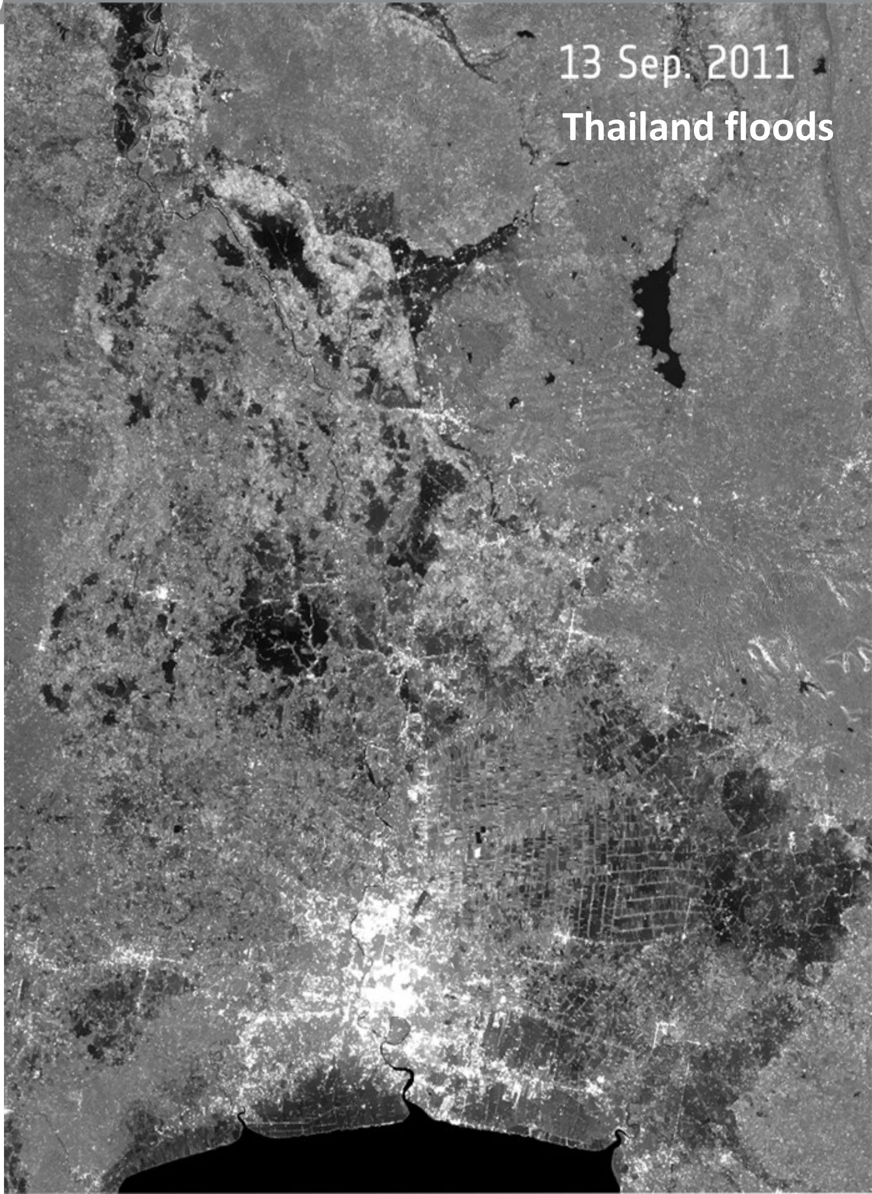
Floods

SAR Flood Monitoring

Envisat was activated 370 times for the Charter on Space and Major Disasters

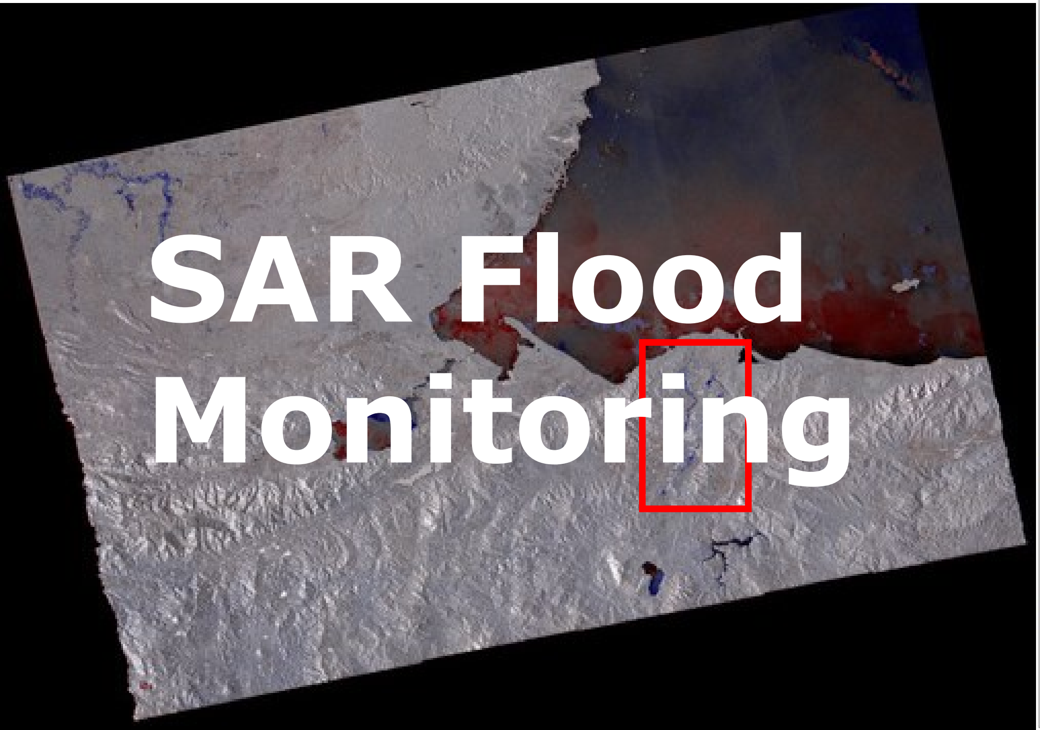
Recent Envisat ASAR activation :

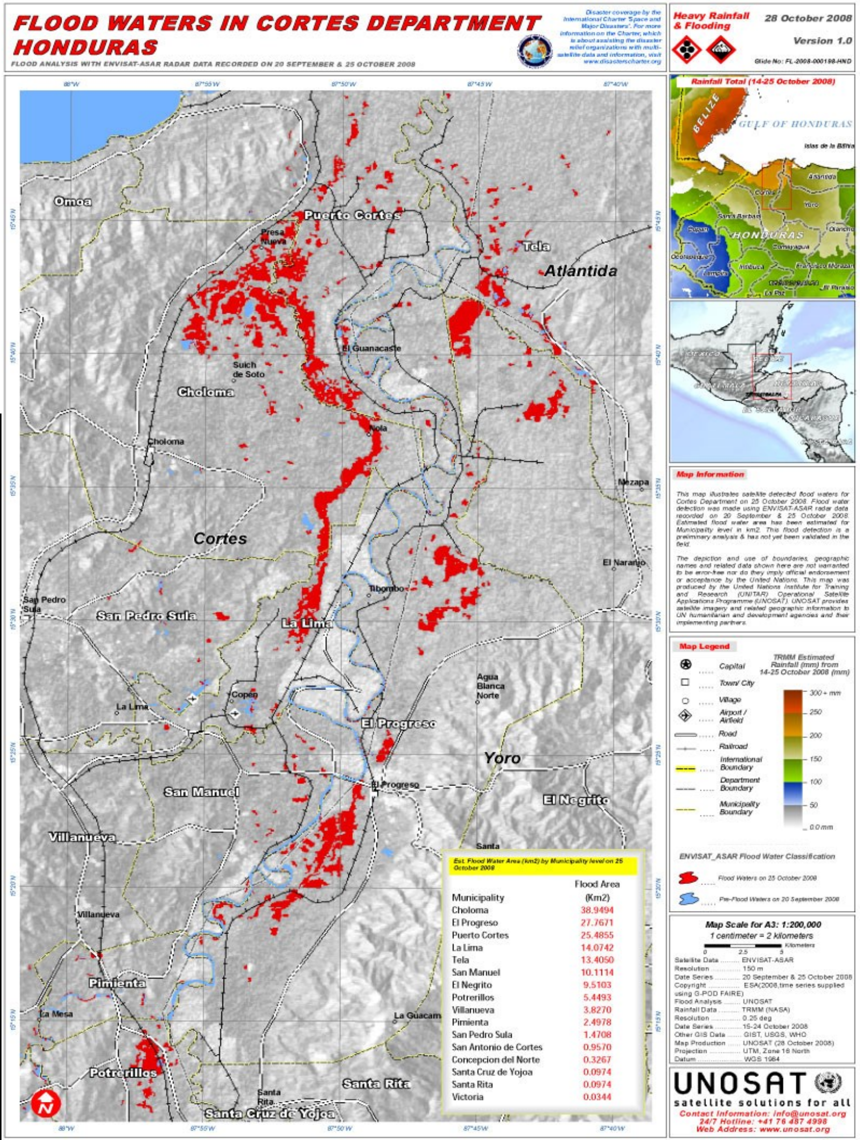
Emergency area	*Disaster type*	*Date*	*Authorized User*
Nigeria	Flood	29-Aug-11	National Emergency Management Agency (NEMA)
Japan	Flood/ Landslide	04-Sep-11	JAXA on behalf of Cabinet Office JAPAN
Cambodia	Flood	12-Oct-11	UNITAR/UNOSAT on behalf of UN OCHA
New Zealand	Oil Spill	12-Oct-11	USGS
Thailand	Flood	17-Oct-11	Asia Disaster Reduction Centre (ADRC)
Vietnam	Flood	17-Oct-11	Asia Disaster Reduction Centre (ADRC)
El Salvador	Flood	19-Oct-11	UNITAR/UNOSAT on behalf of UN OCHA
Chile	Volcano	27-Oct-11	SIFEM (Sistema Federal co Emergencias)
Ghana	Flood	28-Oct-11	UNOOSA
Philippines	Flood	19-Dec-11	Asia Disaster Reduction Center (ADRC)
Brazil	Flood	07-Jan-12	Ministry of Defense from Brazil
Madagascar	Flood	13-Feb-12	COGIC
Perú	Flood	21-Feb-12	SIFEM
Algeria	Flood	26-Feb-12	Algerian Space Agency
Madagascar	Flood	01-Mar-12	COGIC
Ecuador	Flood	09-Mar-12	USGS on behalf of SNGR/Ecuador



Flooding in Honduras. Charter activated 27th Oct 2008

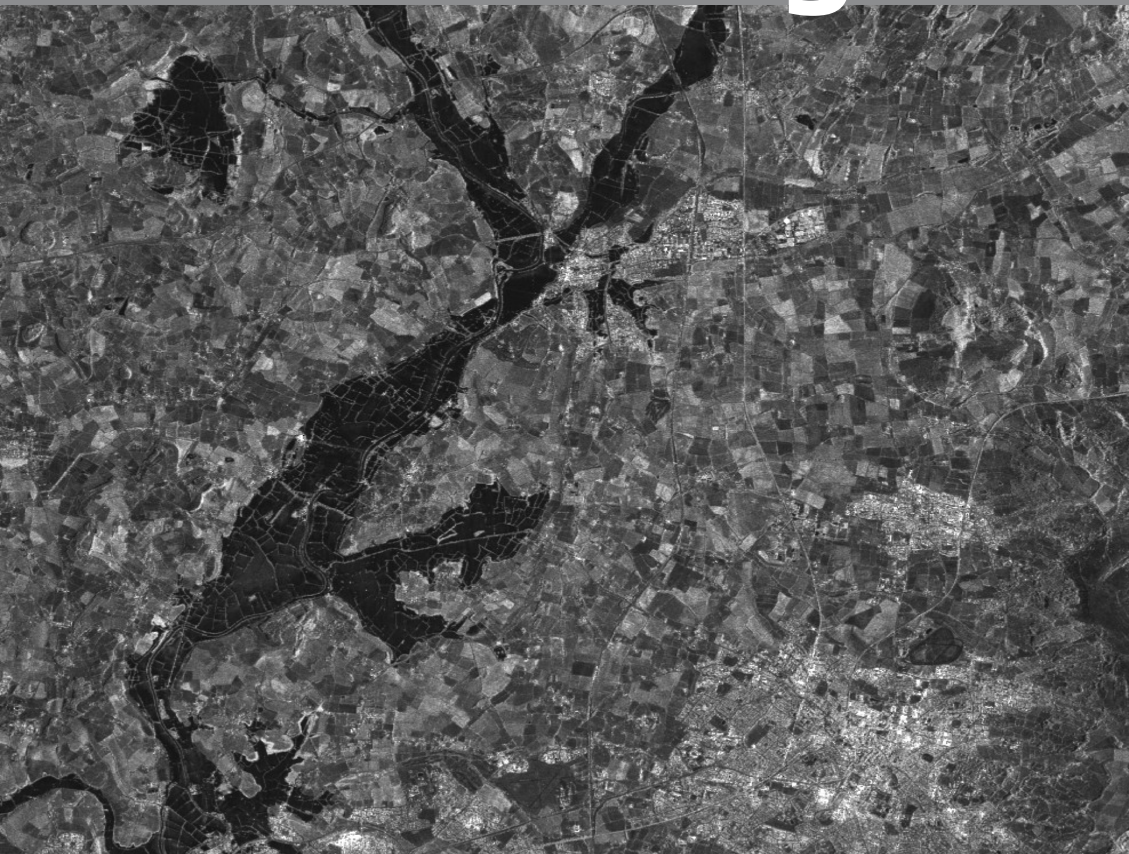
Map produced in **less than 3 hours after activation**

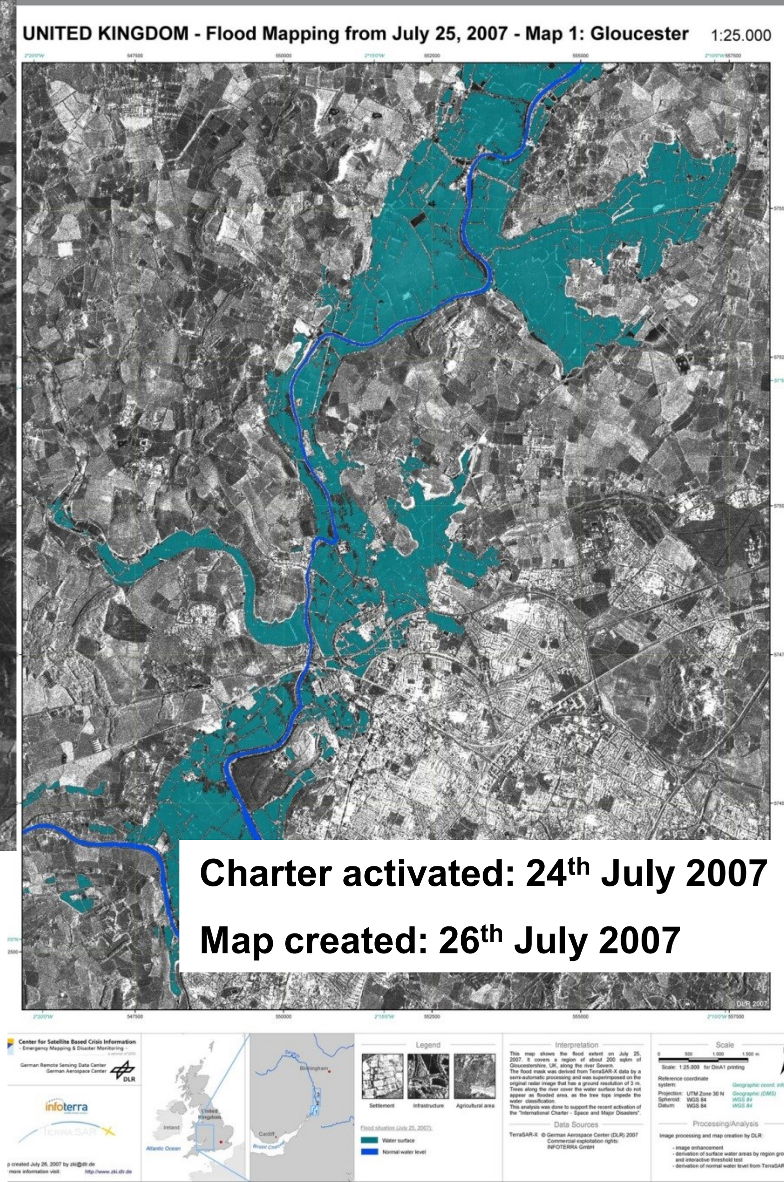




Municipality	Flood Area (Km2)
Choloma	38.9494
El Progreso	27.7671
Puerto Cortes	25.4855
La Lima	14.0742
Tela	13.4050
San Manuel	10.1114
El Negrito	9.5103
Potrerillos	5.4493
Villanueva	3.8270
Pimienta	2.4978
San Pedro Sula	1.4708
San Antonio de Cortes	0.9570
Concepcion del Norte	0.3267
Santa Cruz de Yojoa	0.0974
Santa Rita	0.0974
Victoria	0.0344

SAR Flood Monitoring



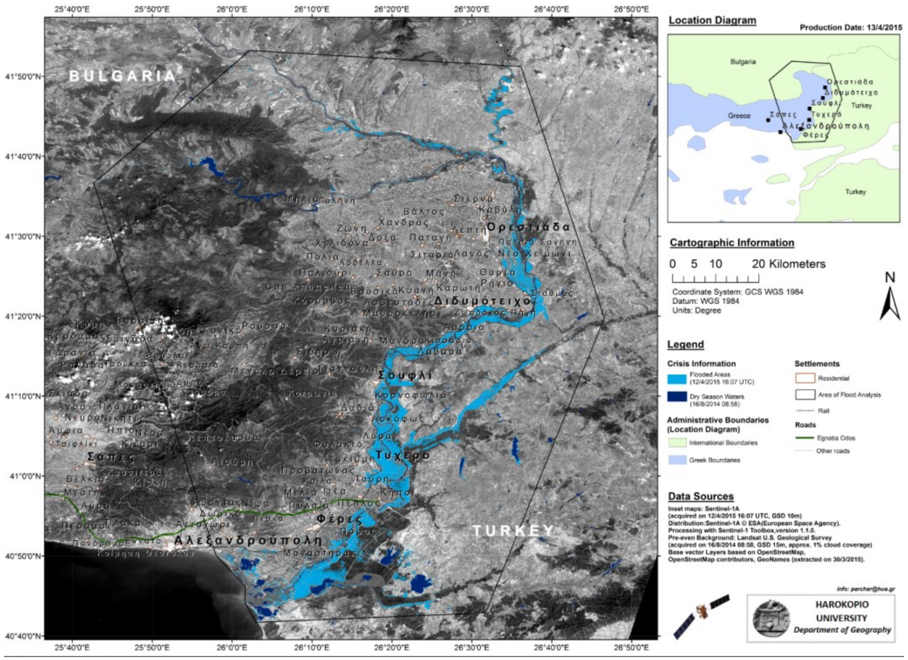


Charter activated: 24th July 2007

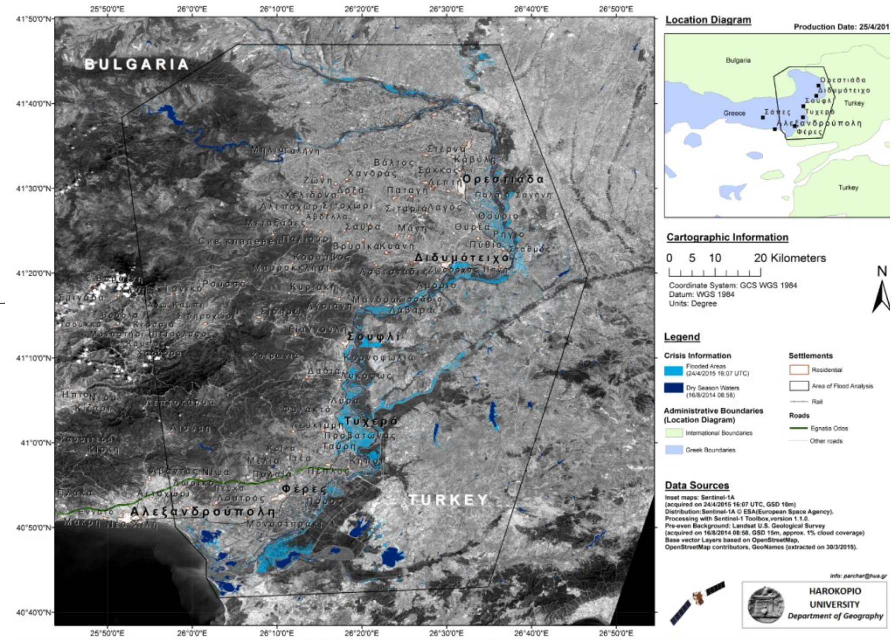
Map created: 26th July 2007

TerraSAR-X data (3m resolution) used in Charter Call

Evros-GREECE/ Flood, 12/4/2015



Evros-GREECE/ Flood, 24/4/2015



SAR applications for disaster management: volcano monitoring

ERS SAR image data acquired during the period 1992-2000 have been used to reconstruct the deformations, in the direction towards the satellite, of the Volcano Mount Etna.

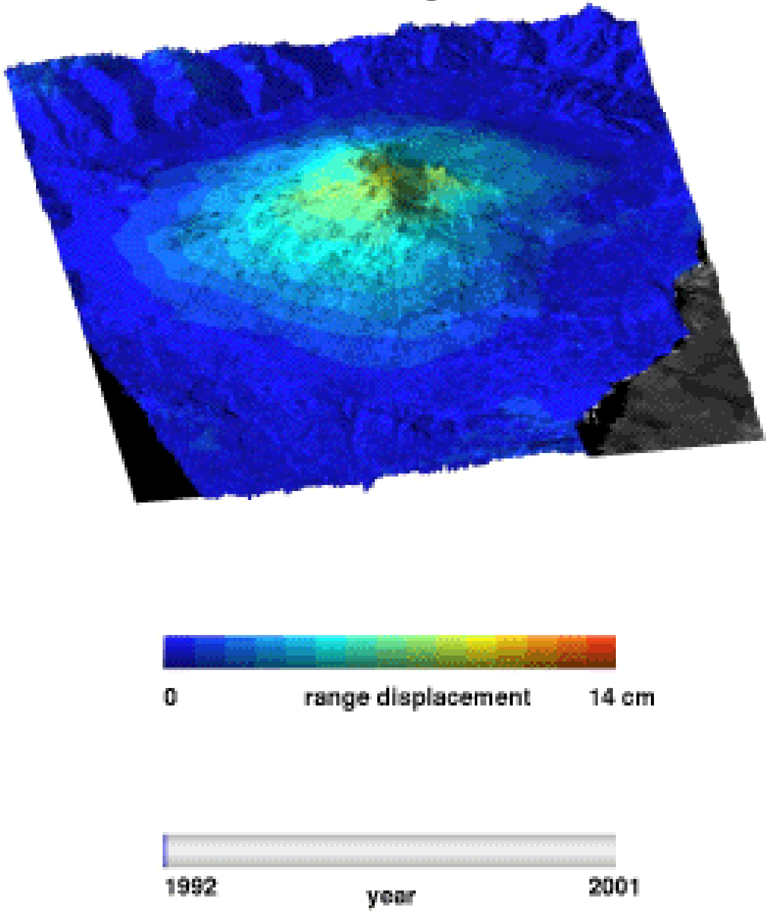
Inflation and deflation episodes are visualised by changes in colour scale.

Work carried out for the Project ESA context Cat-1 n. 1127

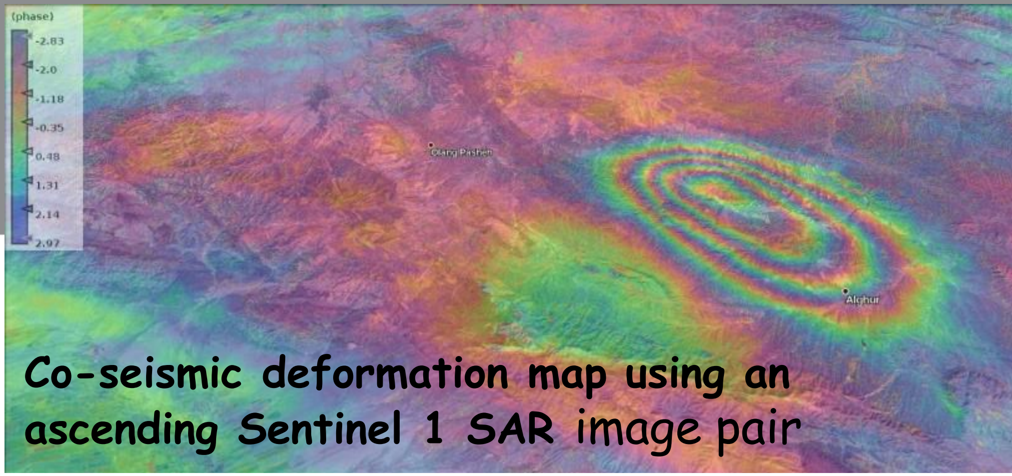
PI: Paul Lundgren JPL,USA

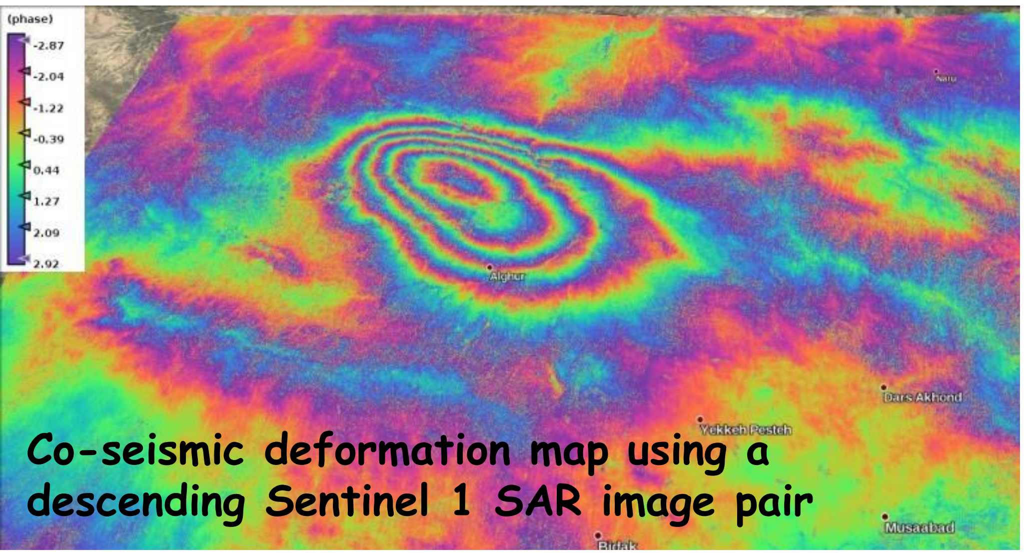
CoI: Riccardo Lanari CNR, Napoli

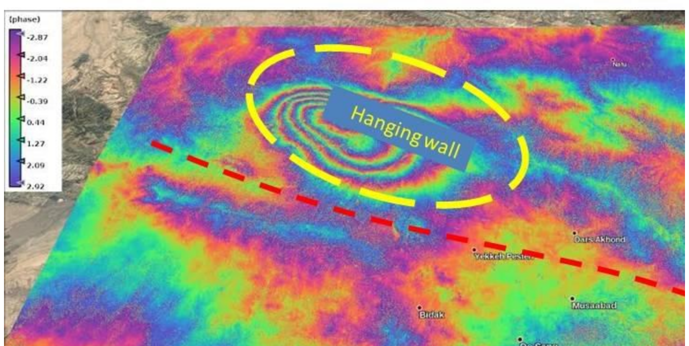
The breathing of Etna



Earthquakes





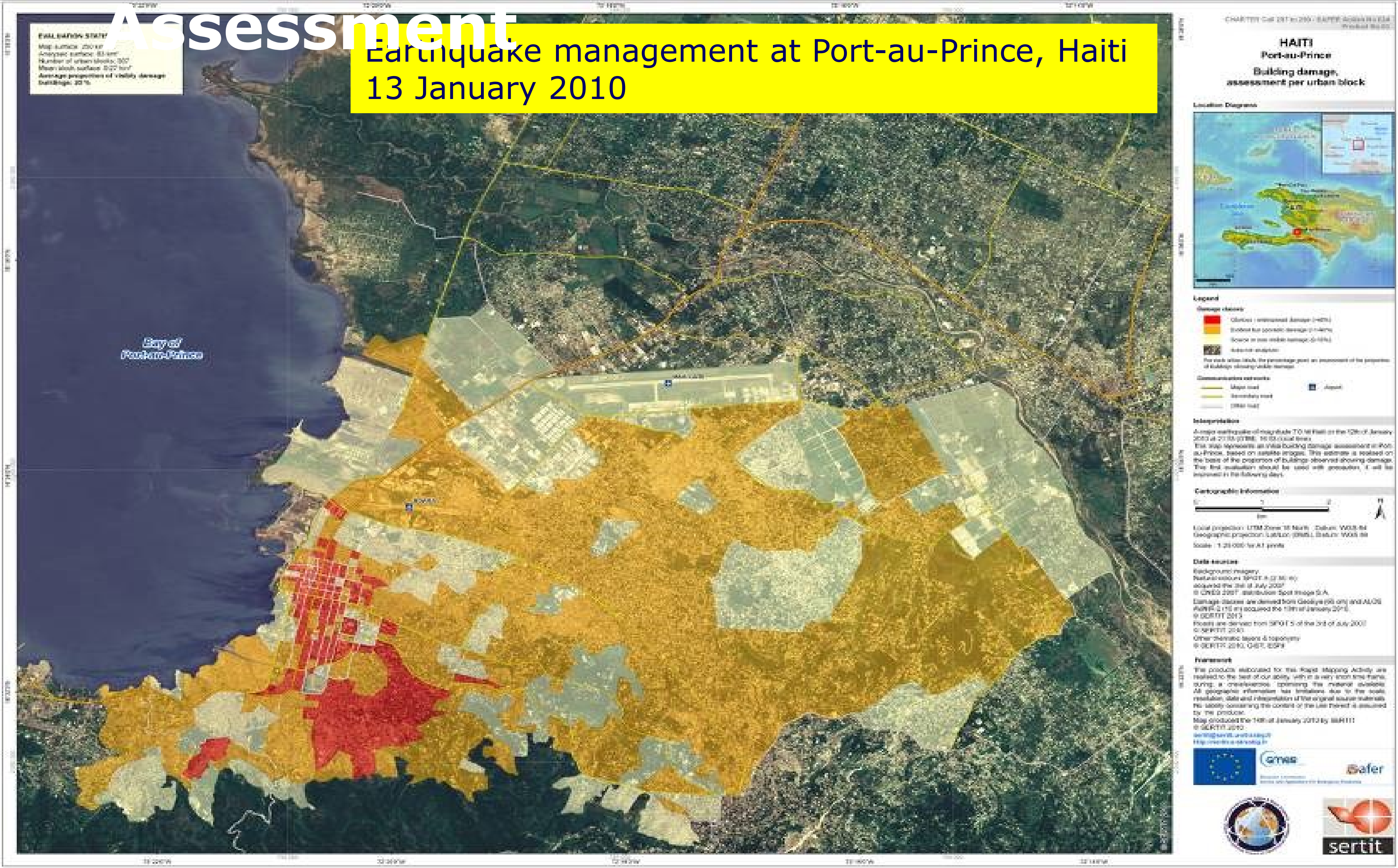


Doghaleh Fariman, NE Iran earthquake, Mw6.1, 5 April 2017. Two co-seismic wrapped interferometric maps were created using ascending (24/3/2017 - 5/4/2017) and descending (25/3/2017 – 6/4/2017) Sentinel 1 SAR scenes. The s/w for processing was SNAP.

Both deformation maps show negative values of phase indicating movement towards the satellite, case that means it is a block pushed up. The lobe of the fringes (in total 4-5 fringes), taken in consideration the above information, coincides with the hanging wall of the reverse fault.

SAR Support for Earthquake Damage Assessment

Earthquake management at Port-au-Prince, Haiti
13 January 2010

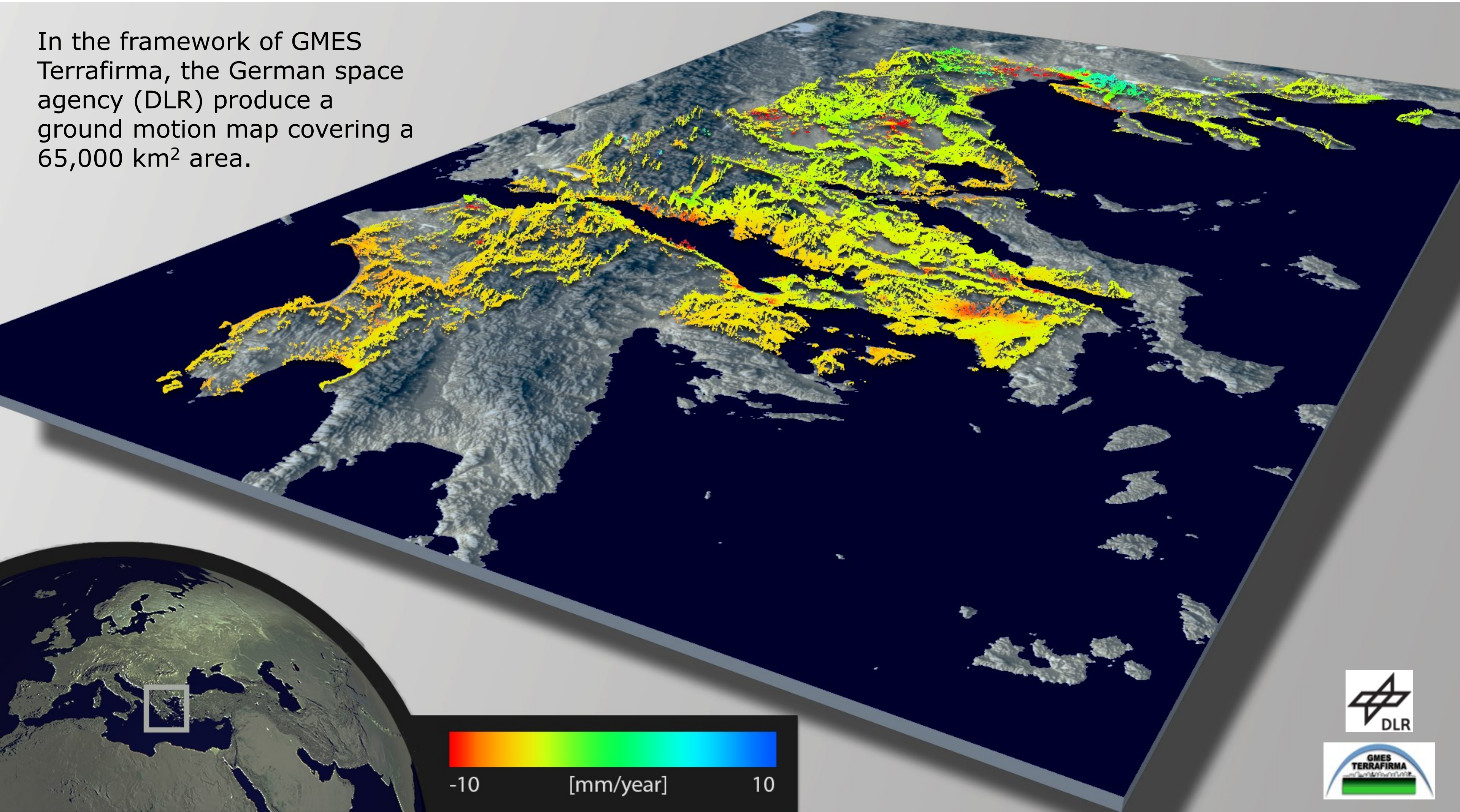


Subsidence Measurement

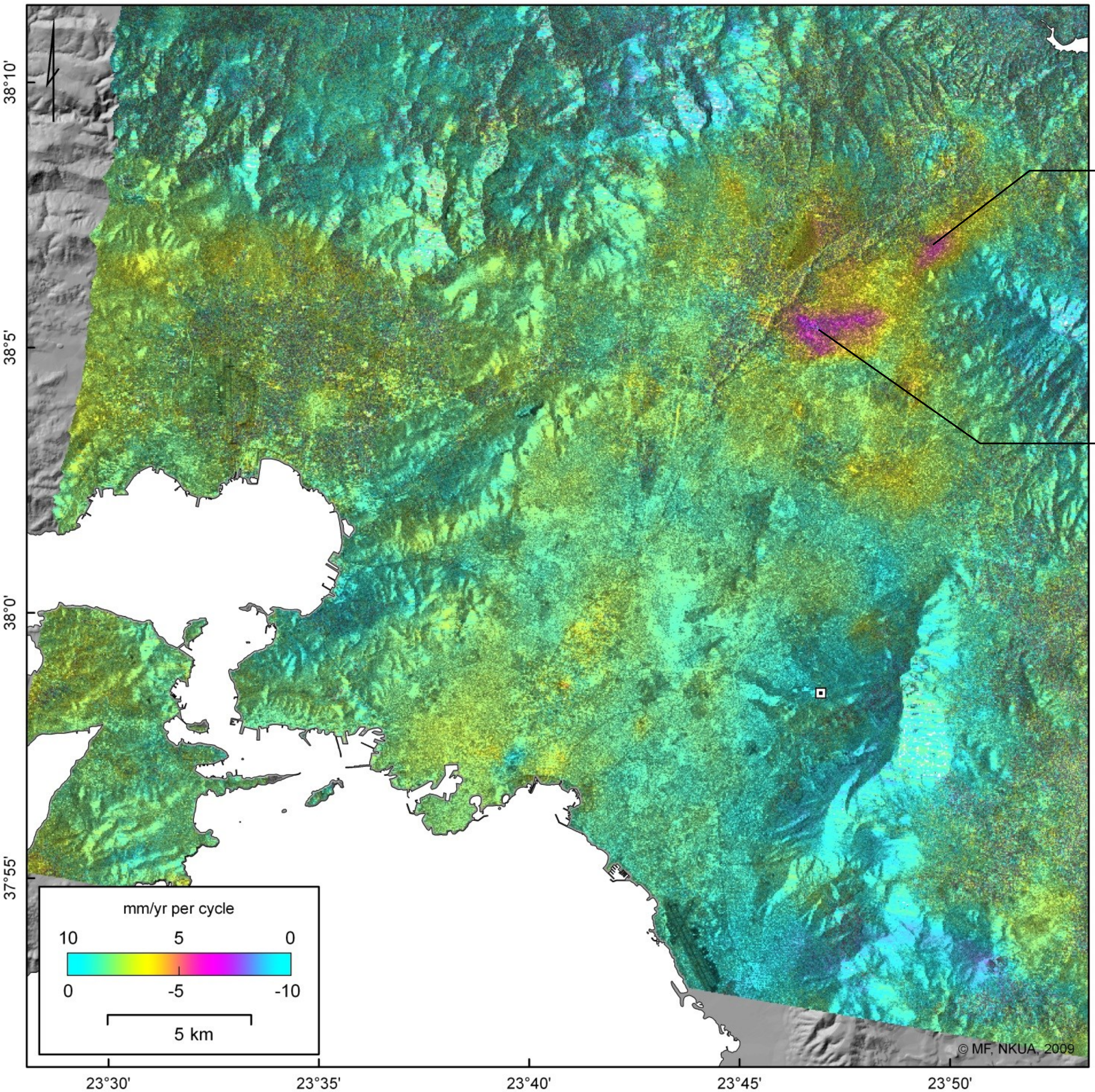
Wide Area Product (WAP)
Mapping half of Greece

The future of ESA's **Terrafirma project** (www.terrafirma.eu.com), a Pan-European ground motion hazard information service.

In the framework of GMES Terrafirma, the German space agency (DLR) produce a ground motion map covering a 65,000 km² area.



Ρυθμοί Παραμόρφωσης Περιόδου 1992-1999

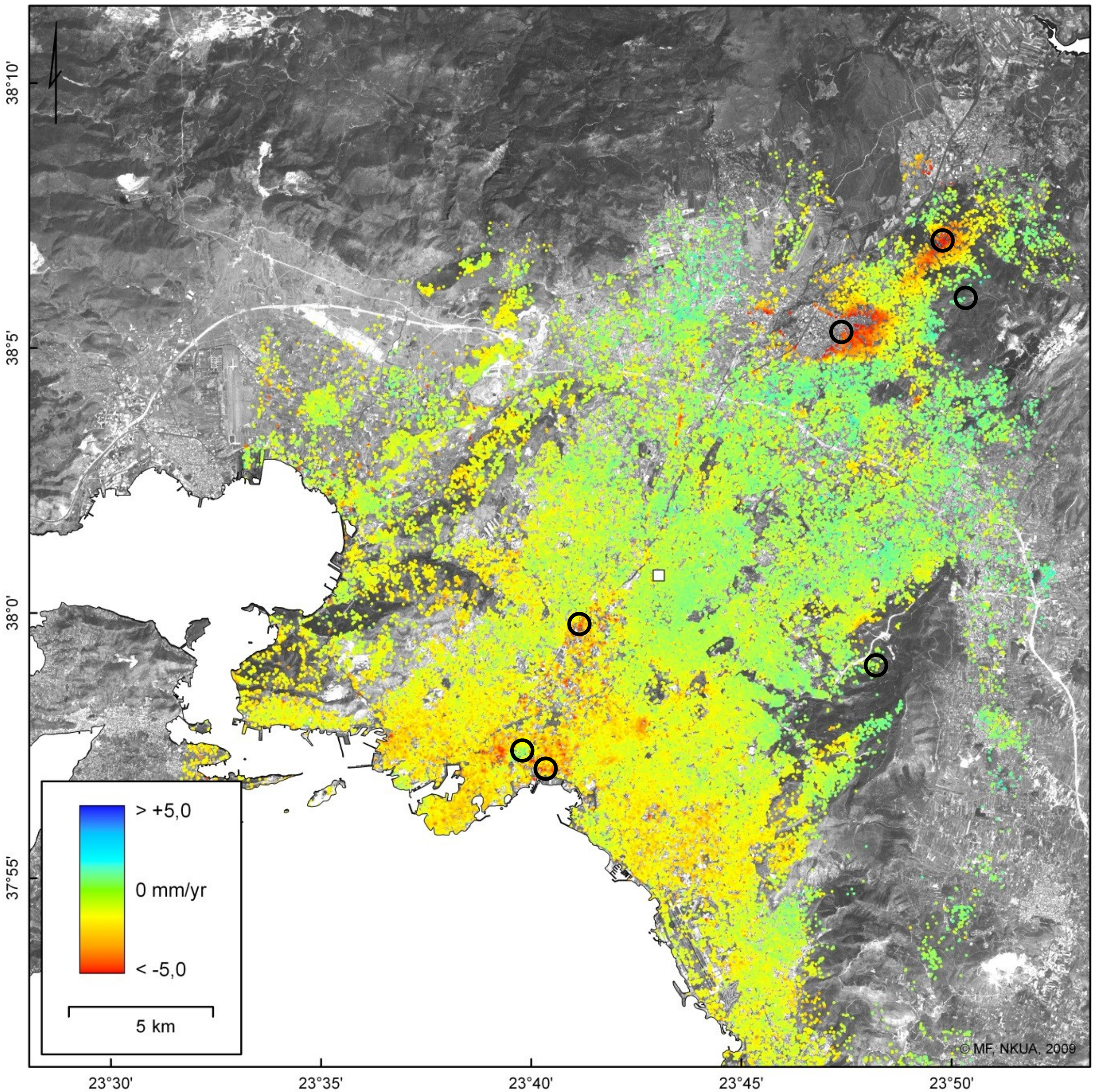


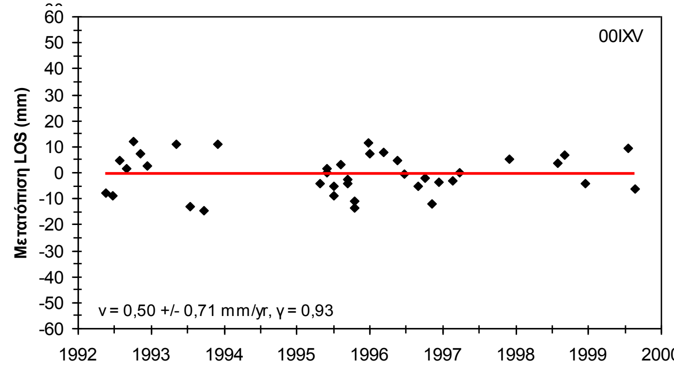
Εκάλη
-7,0 ±0,5
mm/yr

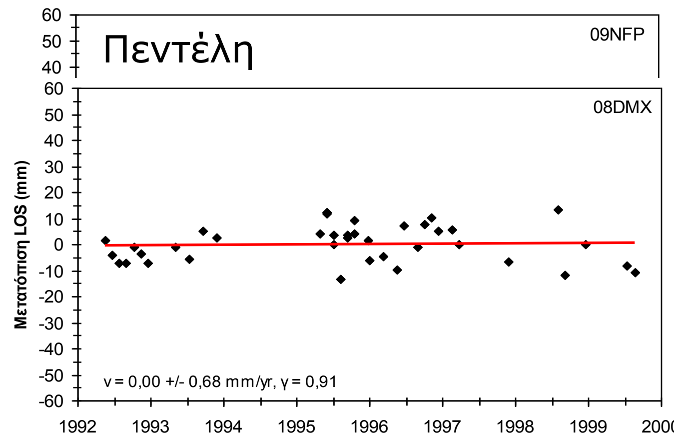
Νέα Κηφισιά
-9,5 ±1,0
mm/yr

Foumelis, Michael. "Human induced groundwater level declination and physical rebound in northern Athens Basin (Greece) observed by multi-reference DInSAR techniques." *Geoscience and Remote Sensing Symposium (IGARSS), 2012 IEEE*

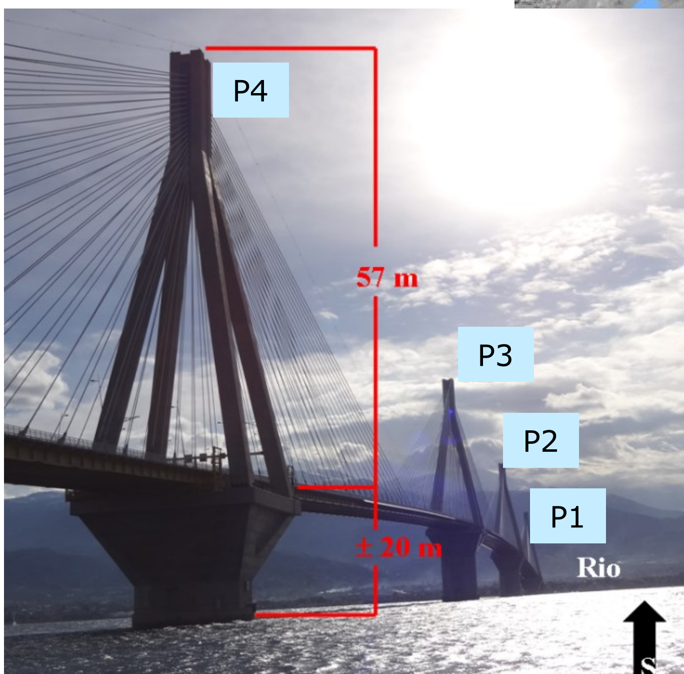
ESA TERRAFIRMA



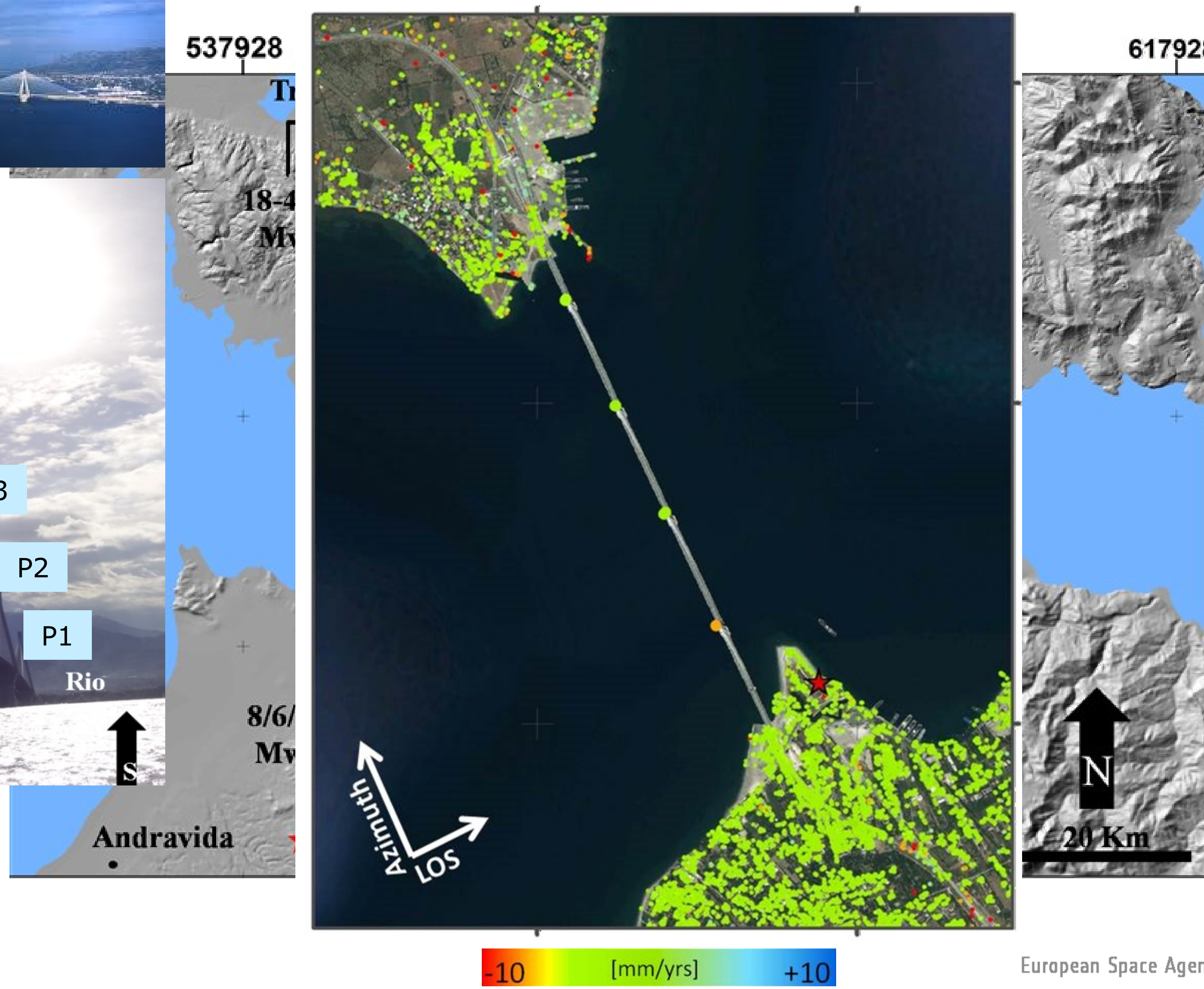




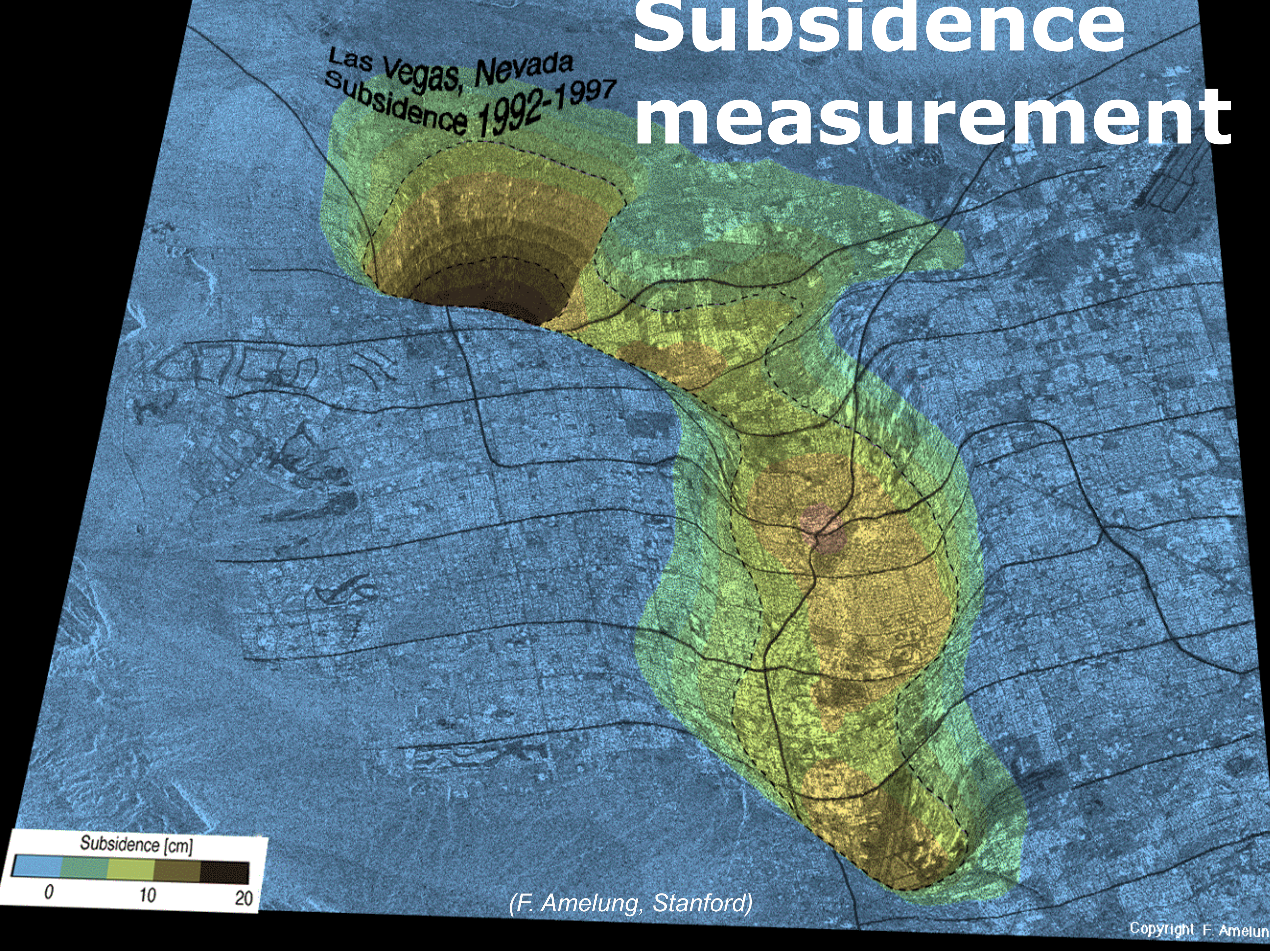
Critical Infrastructure Monitoring
Rio – Antirio Bridge (Greece)



Credits: HUA

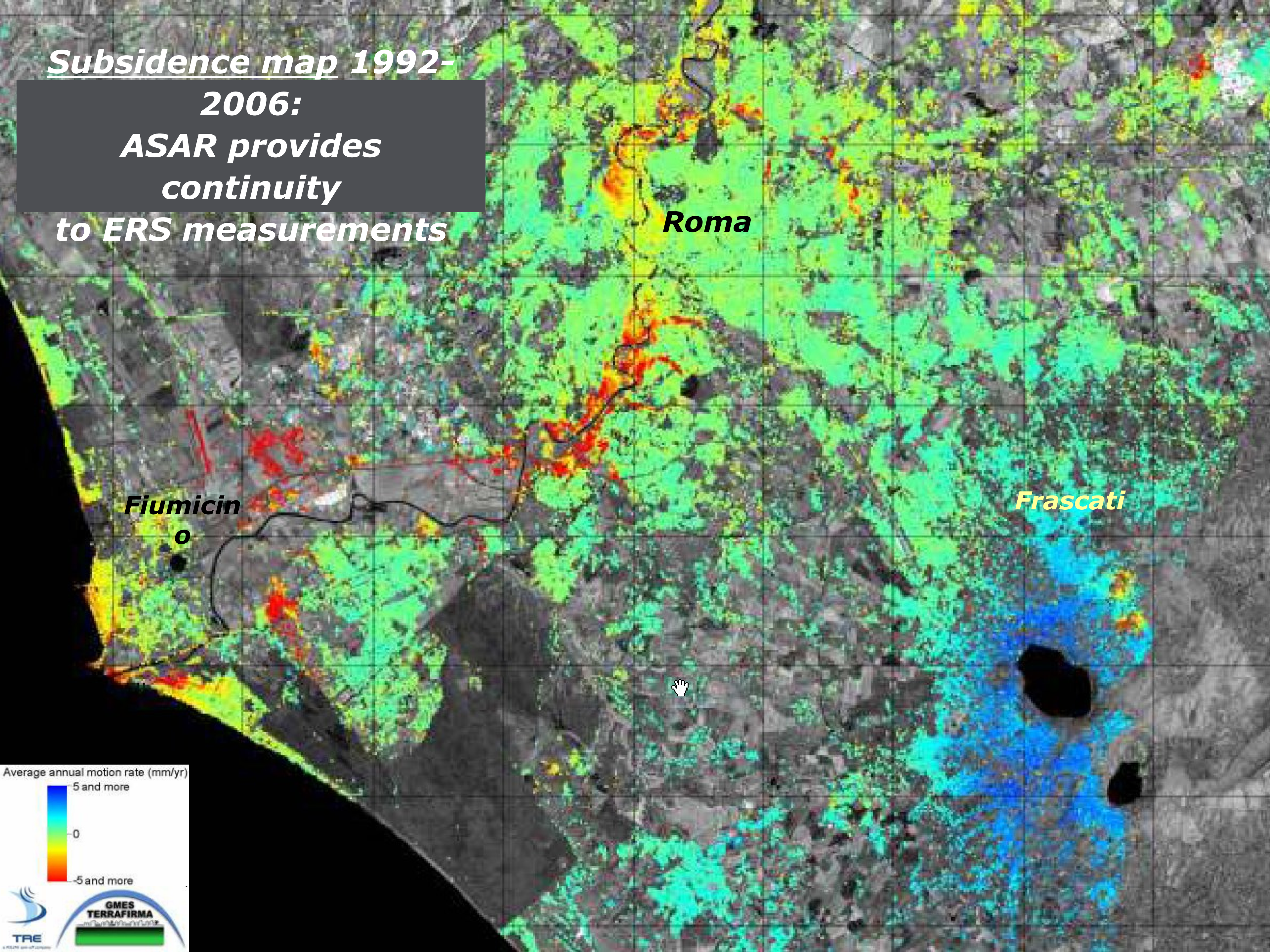


Subsidence measurement



(F. Amelung, Stanford)

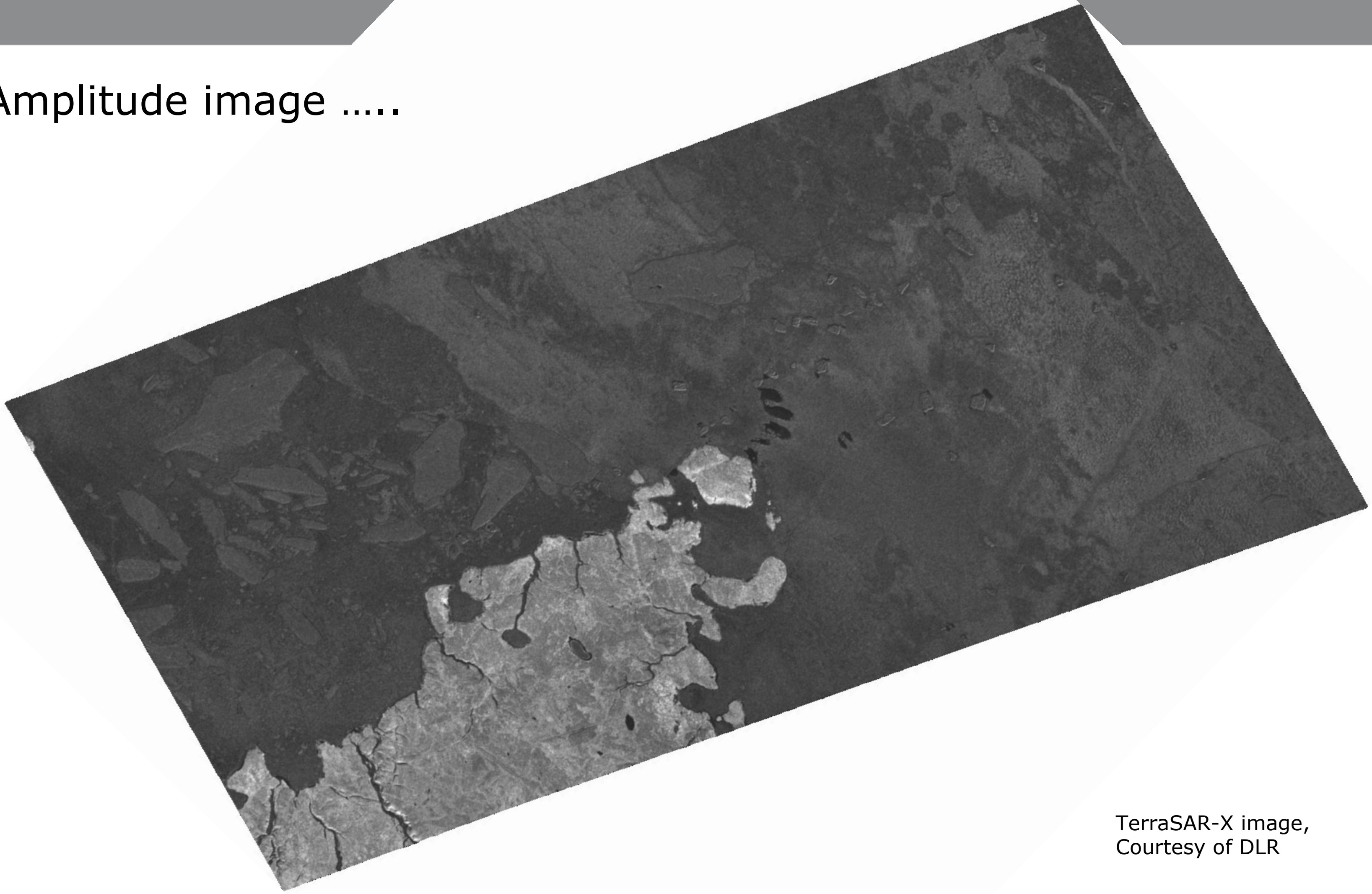
Subsidence map 1992-2006: ASAR provides continuity to ERS measurements



Topography Applications

Topography

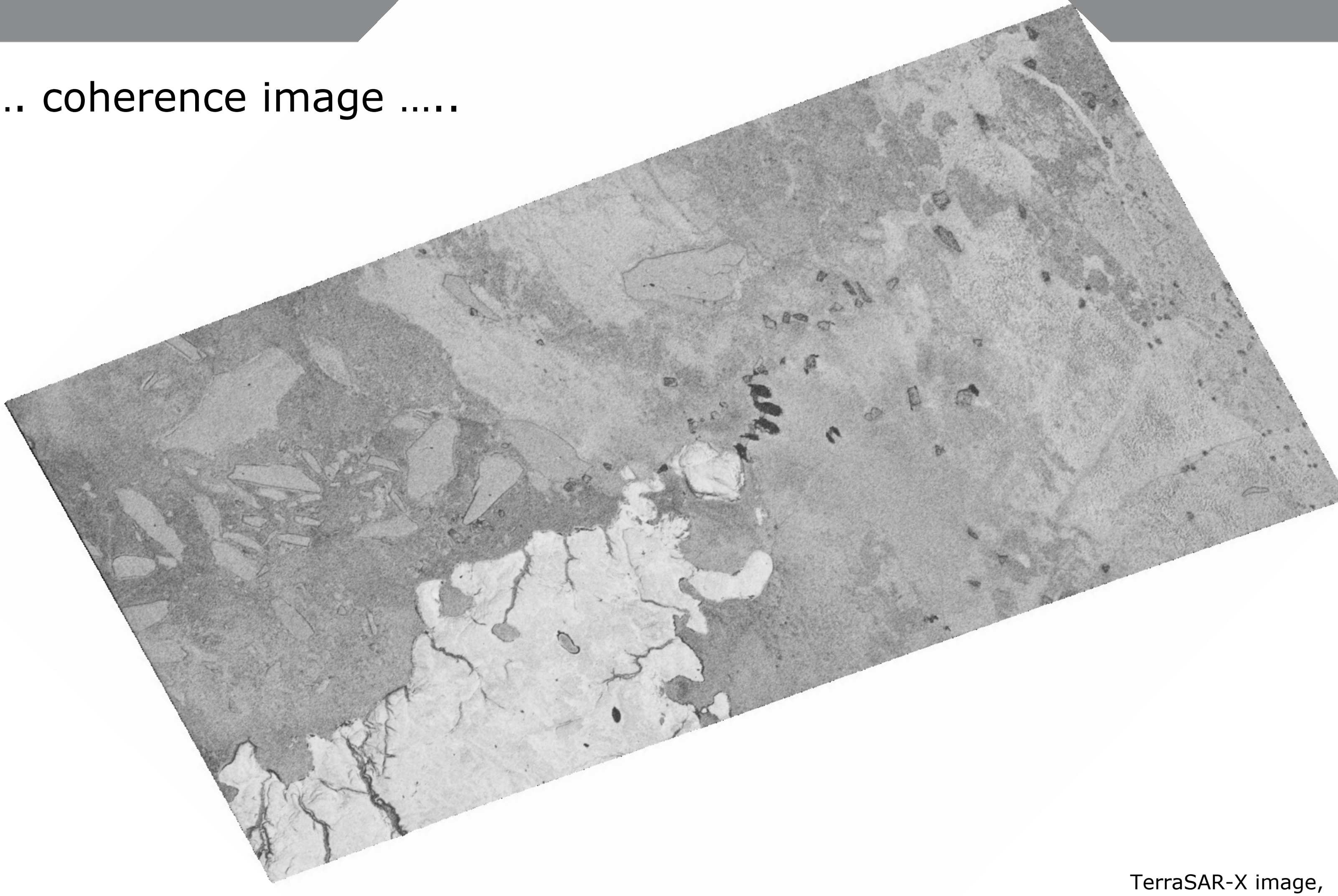
Amplitude image …..



TerraSAR-X image,
Courtesy of DLR

Topography

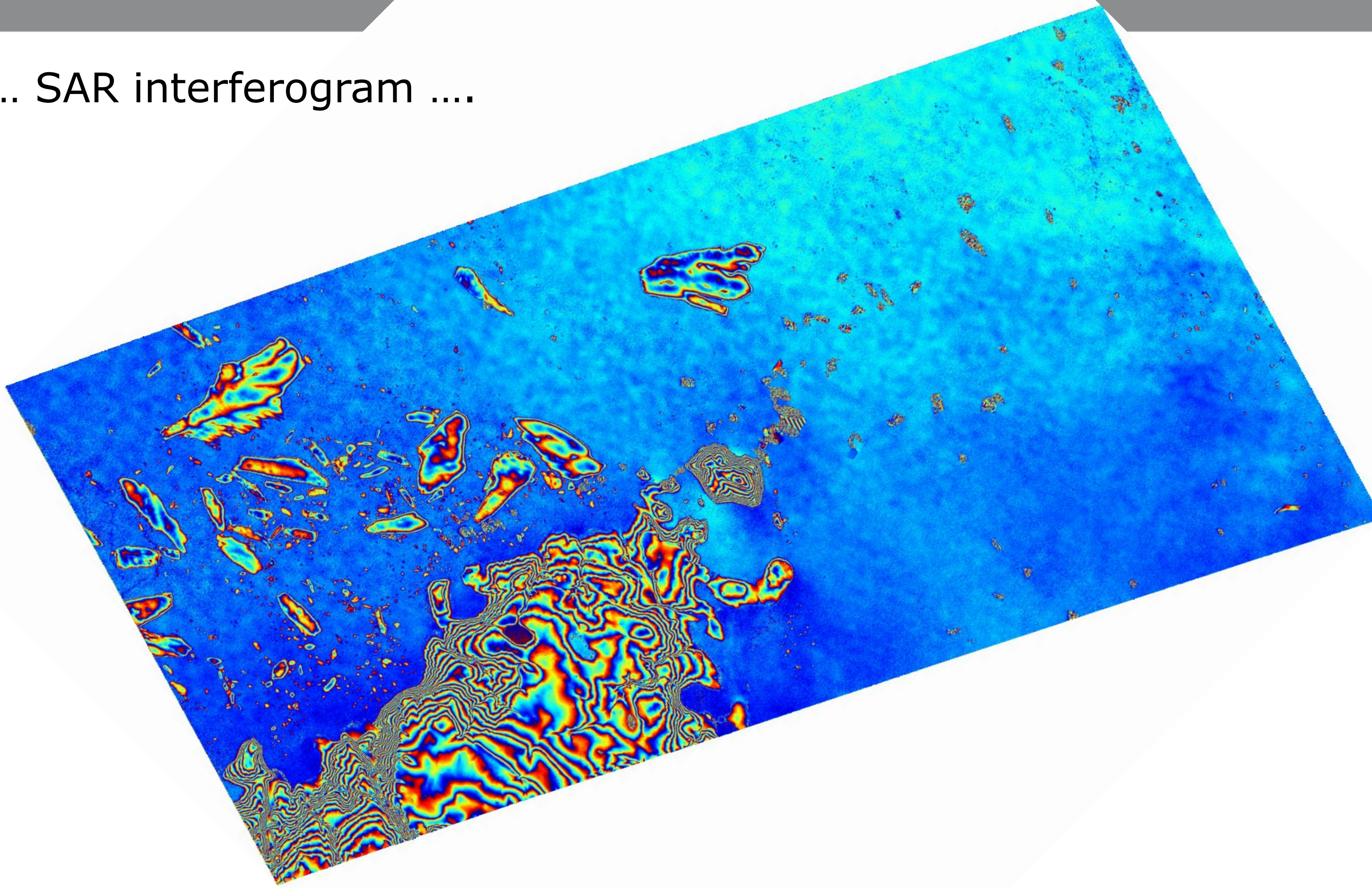
…. coherence image …..



TerraSAR-X image,
Courtesy of DLR

Topography

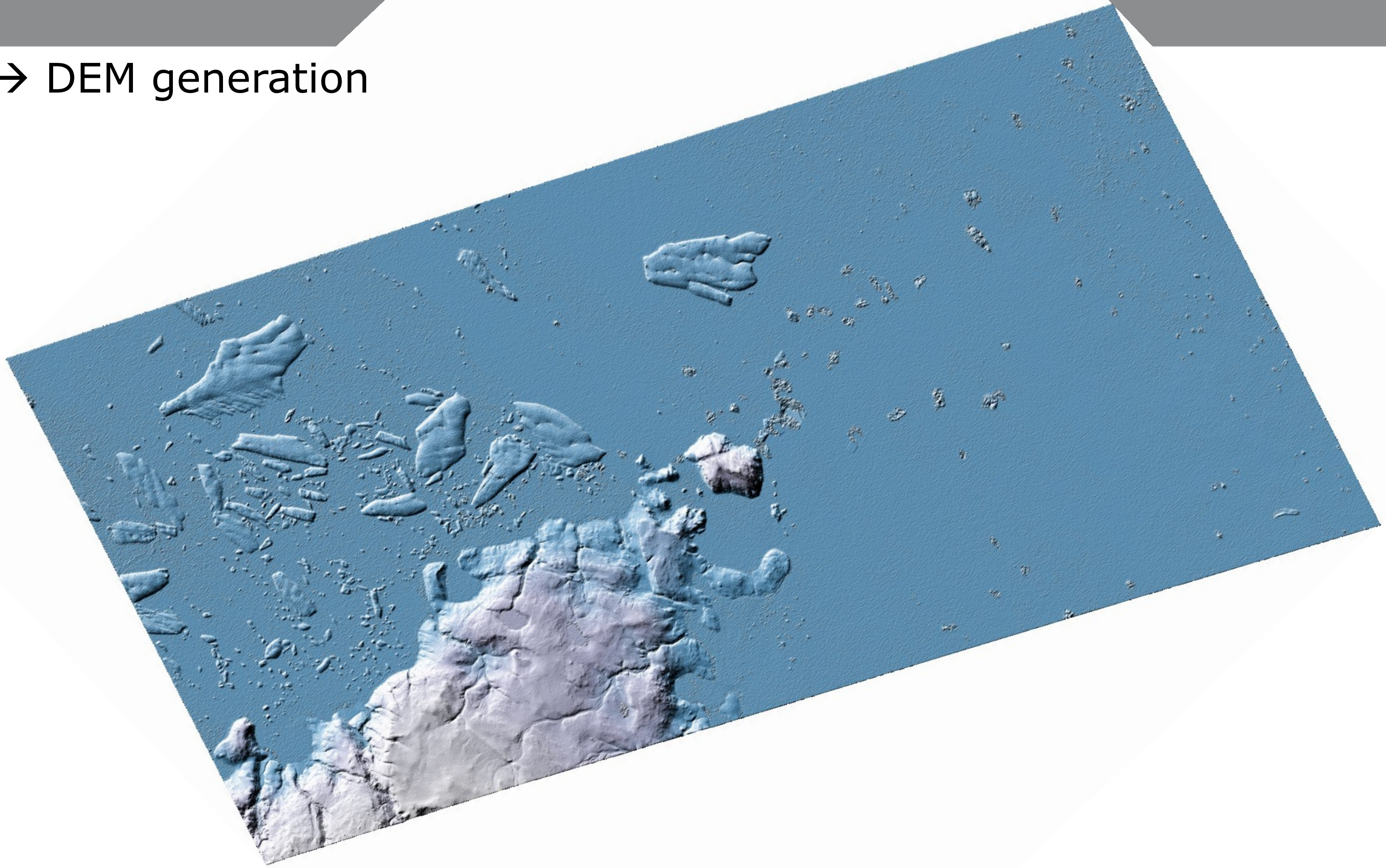
… SAR interferogram ….



TerraSAR-X image,
Courtesy of DLR

Topography

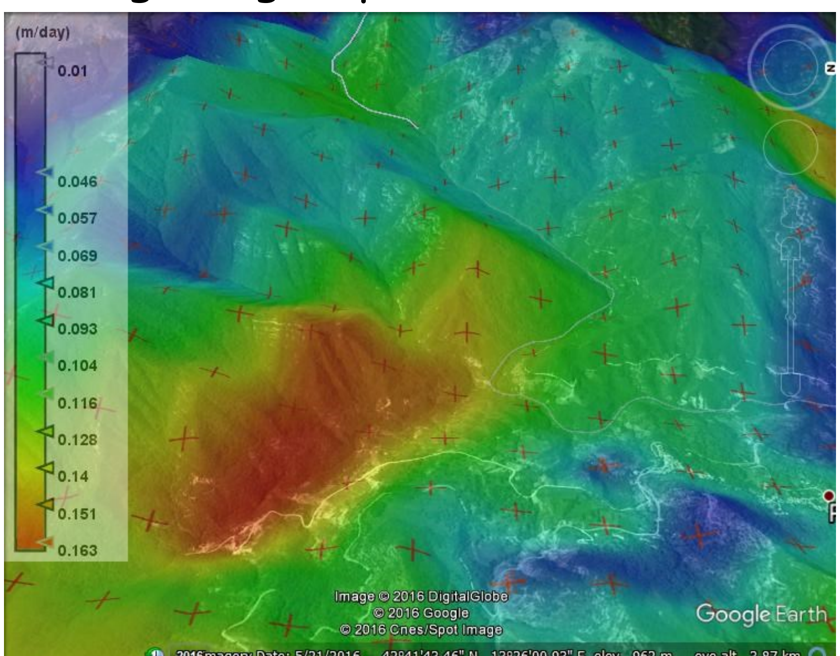
→ DEM generation

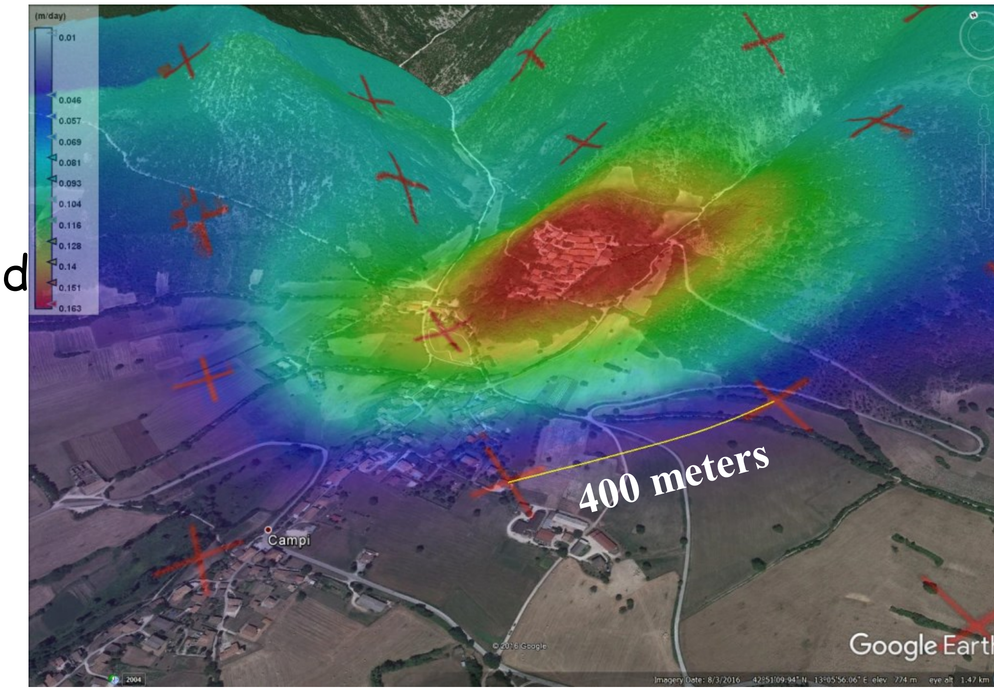


TerraSAR-X image,
Courtesy of DLR

Mass movement-landslides

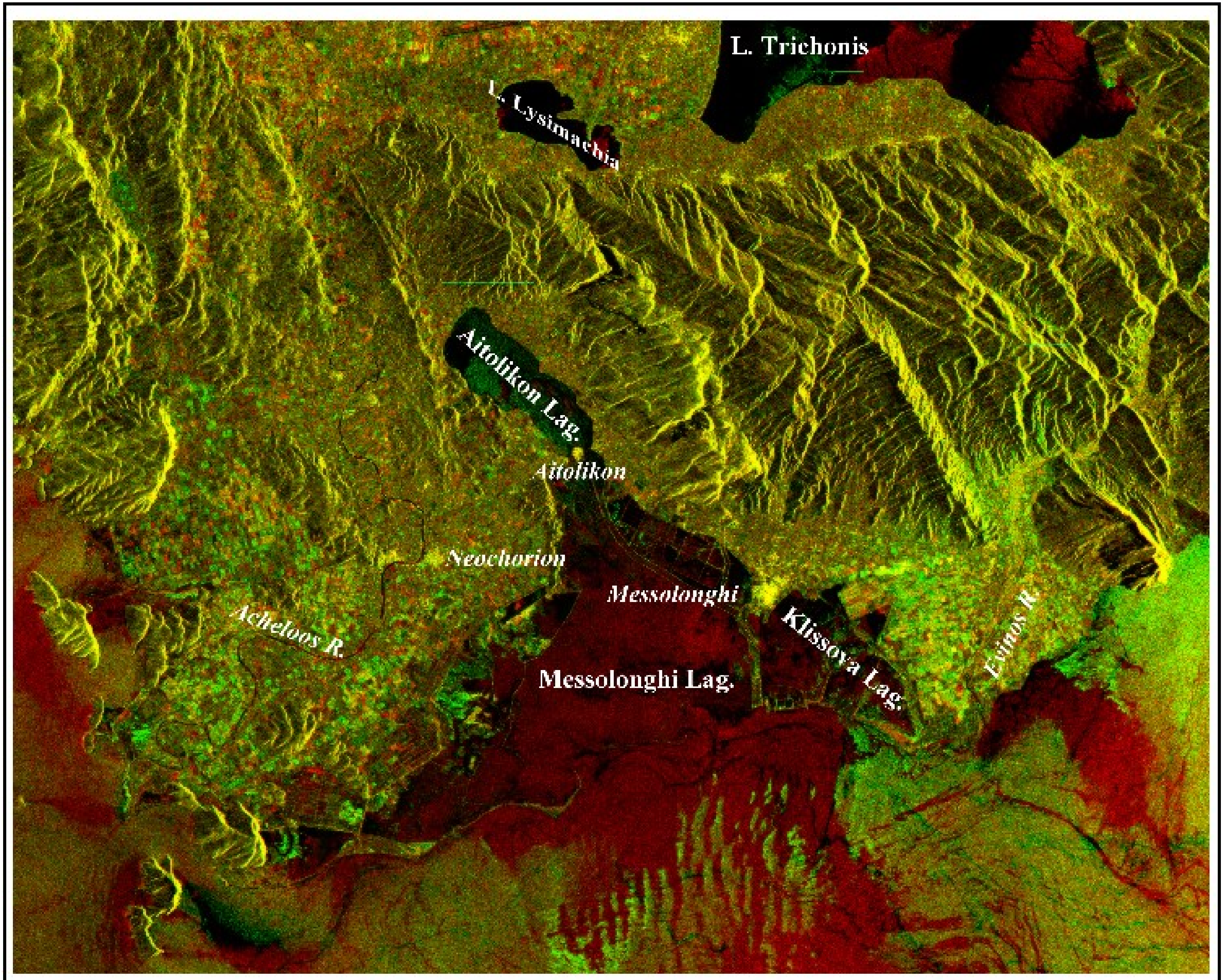
Two main tools based on earth observation data are used to estimate ground surface movements both using SAR products the first one concerns SAR Interferometry based on phase and amplitude and the second one is offset tracking using amplitude-based method.





Offset tracking to map mass movements of earthquake-triggered landslides (Umbria EQ). The method is based on cross-correlation on a preselected high number of GCPs (Ground Control Points) in the two scenes after their coregistration.

Multitemporal SAR image combinations of two SAR scenes (RG)



Hieronymus van Aken (Bosch), (1450 - 1516)