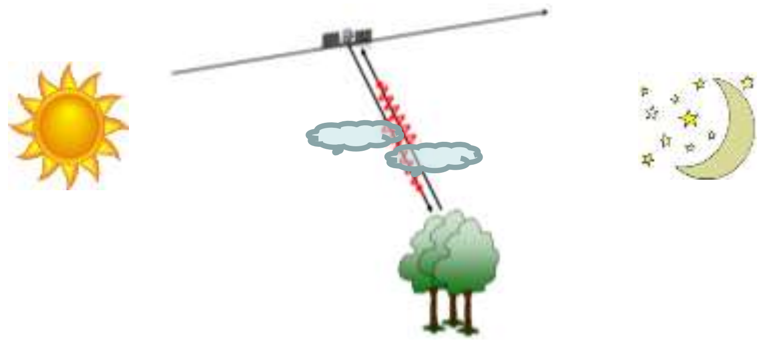
Microwave Remote Sensing



Antonios Mouratidis
amourati@geo.auth.gr
ARISTOTLE UNIVERSITY OF THESSALONIKI
EO.Lab Earth Observation & Geospatial Applications Lab

Overview (of 2 days)

- Introduction
- (Light) Microwave (SAR) Remote Sensing theory
- SAR missions/Sentinel-1
- Microwave vs optical
- Applications
- Workshop – joint TAT 2023 project & publication

Short CV – Engineering/Scientific background

1. PhD in GPS & GIS-assisted Spaceborne Remote Sensing applications in Geomorphology
2. MSc. in Rural and Surveying Engineering (5 years), focus on Remote Sensing, Photogrammetry, GIS/Cartography, Geodesy/GNSS
3. BSc. Geology (4 years), MSc. Geography & Environment (2 years), focus on Remote Sensing & GIS

Short CV – Highlights of professional experience

1. PhD student at Ecole Normale Supérieure (ENS), Paris, France, Satellite data processing/InSAR techniques & GNSS (2007-2008)
2. Post-Doctoral Research Fellow, ESA/ESRIN Italy (2010-2013), heavily involved in Education, Training, Capacity Building & Outreach
3. ESA consultant (2013-2014)
4. Today: Assist. Prof., School of Geology, Aristotle University of Thessaloniki, Greece

Short CV – Expertise & Interests

1. Earth Observation, GNSS, GIS applications

- DEMs (production, validation, applications)

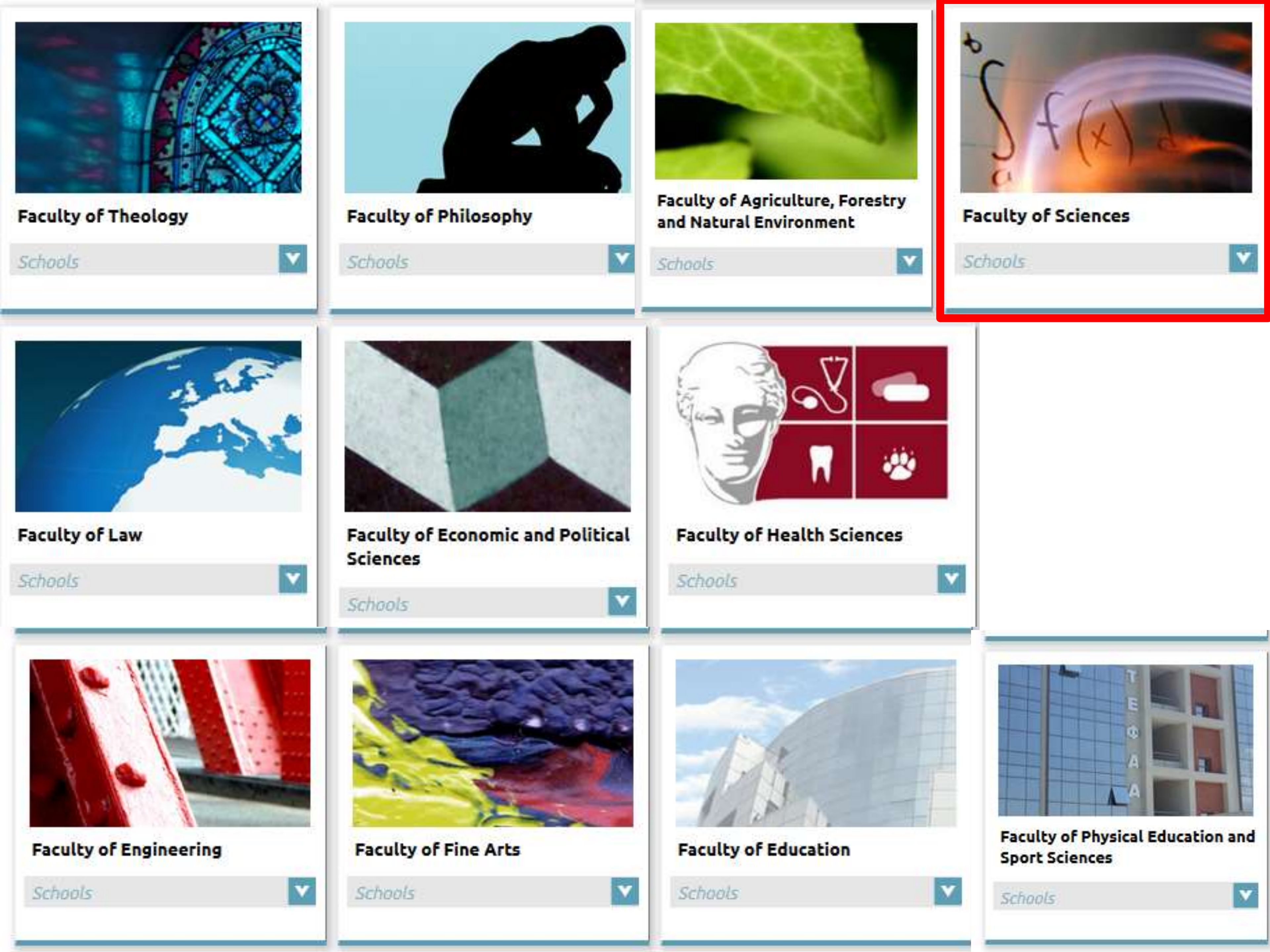
- Natural Disasters (mitigation & mapping/monitoring)

2. InSAR/SAR land applications expert

3. Geospatial technology in Education, Training, Capacity Building and Outreach

Aristotle University of Thessaloniki (AUTh)

1. Thessaloniki:
   - 2nd largest city of Greece
   - Population: ca. 1,100,000 (Metr.)
2. AUTh:
   - Largest Univ. in Greece & in the Balkans
   - ≈ 33.4 ha + vast off-campus facilities
   - ≈ 70,000 students
   - ≈ 2,500 Acad. Staff
   - ≈ 900 Admin. Staff


Faculty of Theology
Schools
Faculty of Philosophy
Schools
Faculty of Agriculture, Forestry and Natural Environment
Schools
Faculty of Sciences
Schools
Faculty of Law
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Faculty of Economic and Political Sciences
Schools
Faculty of Health Sciences
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Faculty of Engineering
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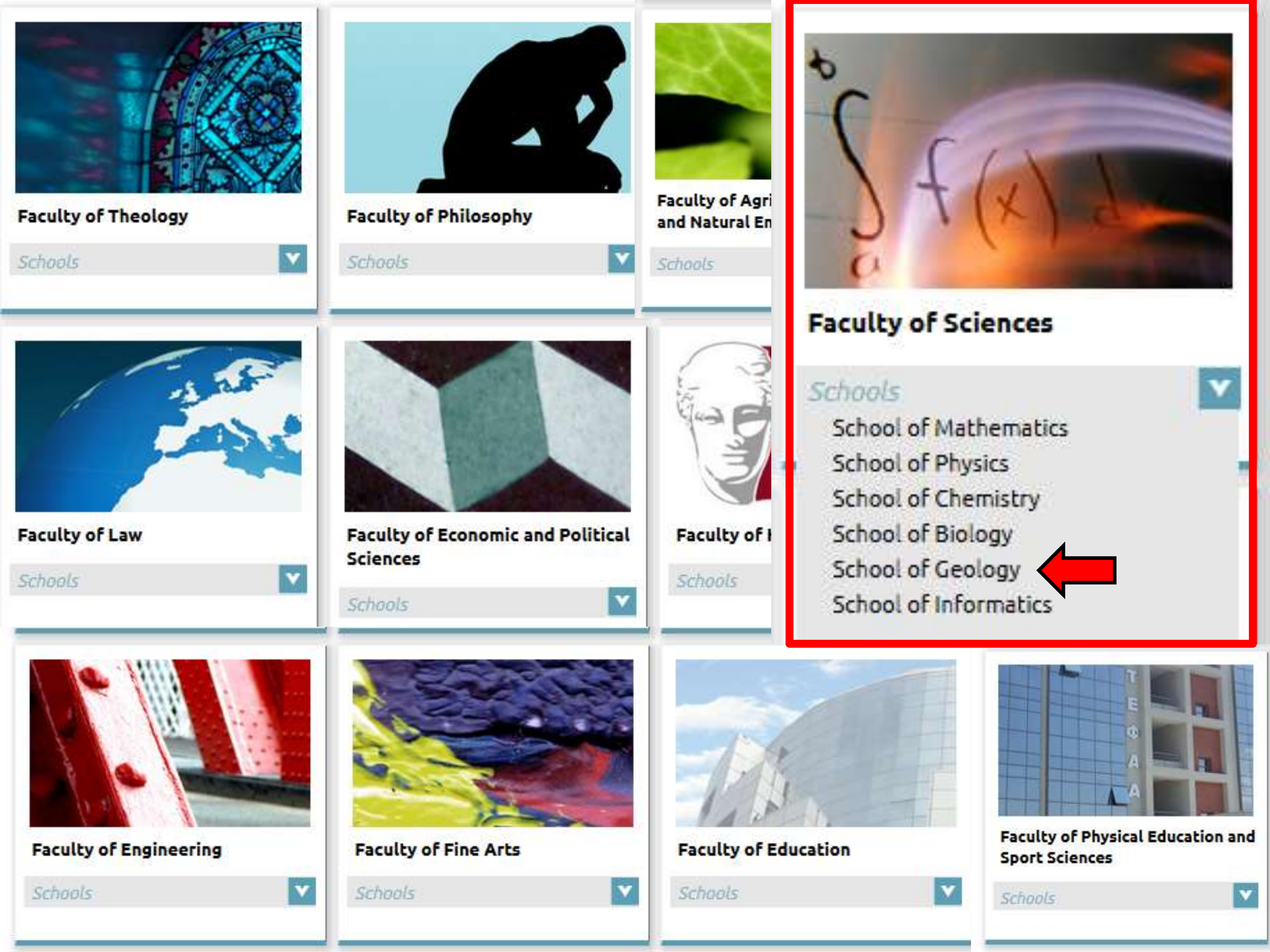
Faculty of Fine Arts
Schools
Faculty of Education
Schools
Faculty of Physical Education and Sport Sciences
Schools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School of Geology
School of Informatics
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Schools
Faculty of Engineering
Schools
Faculty of Fine Arts
Schools
Faculty of Education
Schools
Faculty of Physical Education and Sport Sciences
Schools

School of Geology

Departments:

1. Geology
2. Mineralogy-Petrology-Economic Geology
3. Geophysics
4. Meteorology and Climatology
5. Physical and Environmental Geography

Department of Physical and Environmental Geography (f. 2001)

- 4 Academic Staff + 2 Emeritus Profs
- Teaching (1, Dr.) and technical (3) staff
- ≈ 140 undergrad students/year
- > 80 post-grads/year (4 MSc. Programmes + PhD students)

Laboratories:

1. Laboratory of Physical Geography (f. 1965)
2. Earth Observation & Geospatial Applications Lab (f. 2003)

EO.Lab
Earth Observation
& Geospatial Applications Lab

https://eolab.geo.auth.gr/

Department of Physical and Environmental Geography (f. 2001)

Courses:

1. Geography
2. Earth Observation / Remote Sensing
3. GIS – Digital Cartography
4. Natural and Anthropogenic Environment
5. Physical Geography
6. Sedimentology
7. Oceanography
8. ICT in Education

Department of Physical and Environmental Geography (f. 2001)

Master Programms:

1. Applied and Environmental Geology
2. Ecological Quality and Water Management (Biology-Geology-Civil Engineering Depts)
3. Hydrocarbon Exploration and Exploitation (Coll.)
4. Meteorology, Climatology and Atmospheric Environment

Erasmus Agreements with Charles Univ. (graduate and post-graduate level)

Erasmus+ Traineeship

EO.Lab
Earth Observation
& Geospatial Applications Lab

From Academic Research to Operational Services

Center of Interdisciplinary Research and Innovation (CIRI-AUTh)

EO.Lab
Earth Observation
& Geospatial Applications Lab

- Integration of the interdisciplinary CEO^2 (Center of Earth and Ocean Observation) team in CIRI

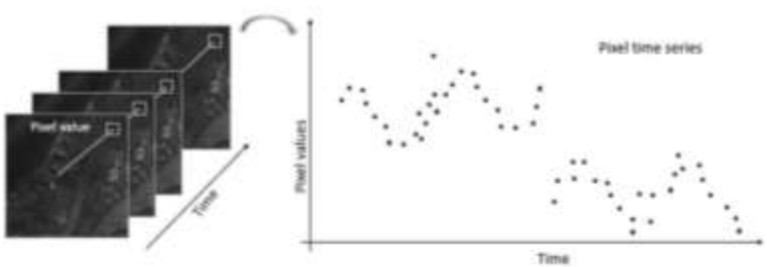
CIRI-AUTH
CENTER FOR INTERDISCIPLINARY RESEARCH AND INNOVATION
Aristotle University of Thessaloniki

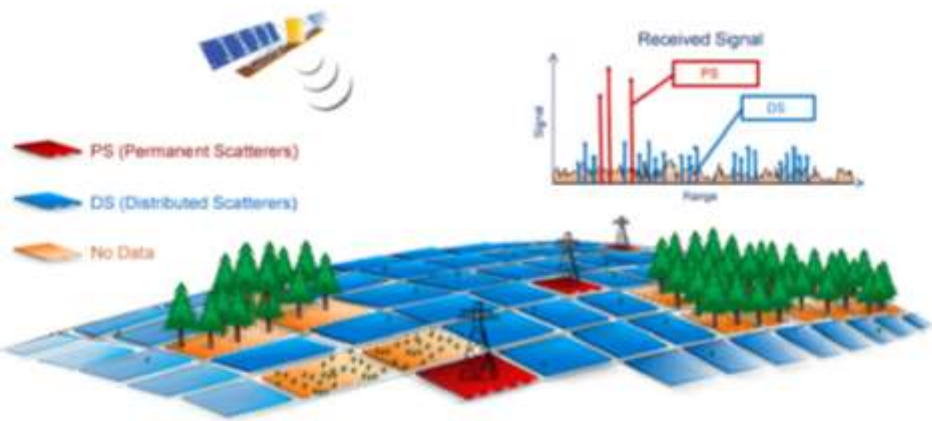
https://kedek.auth.gr

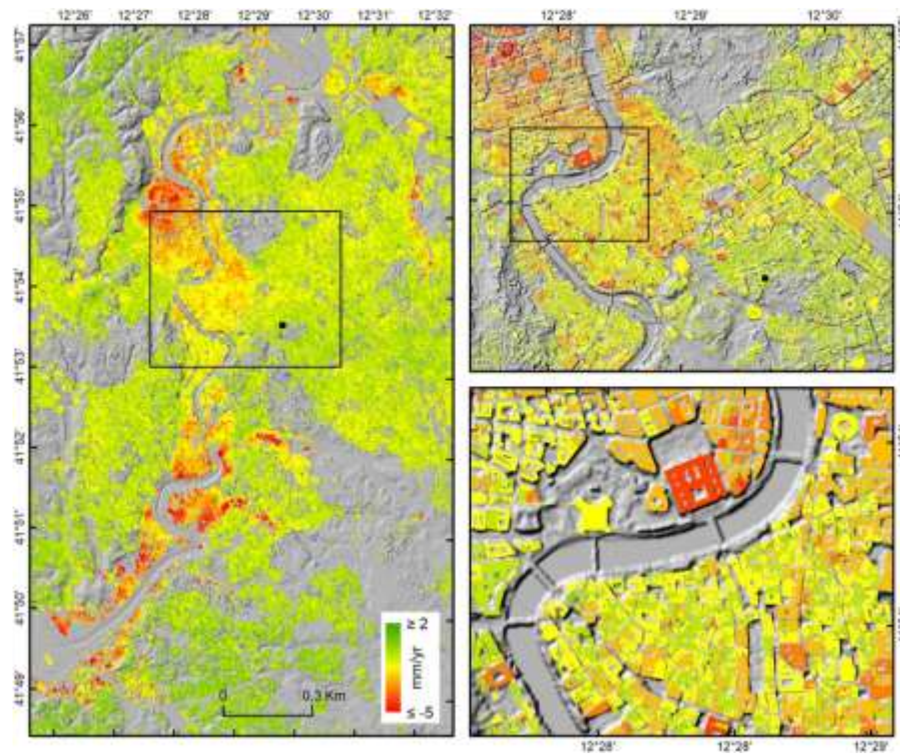
The main mission of **CIRI** is the promotion and development of interdisciplinarity in an open and collaborative environment of excellence, which utilizes the research infrastructures of AUTH at the local, national and European level, expands the University's synergy with society and contributes to the economic and social development of the country.

Multi-Temporal SAR Interferometry

Exploit temporal and spatial characteristics of interferometric signatures from point targets remaining 'stable' over time



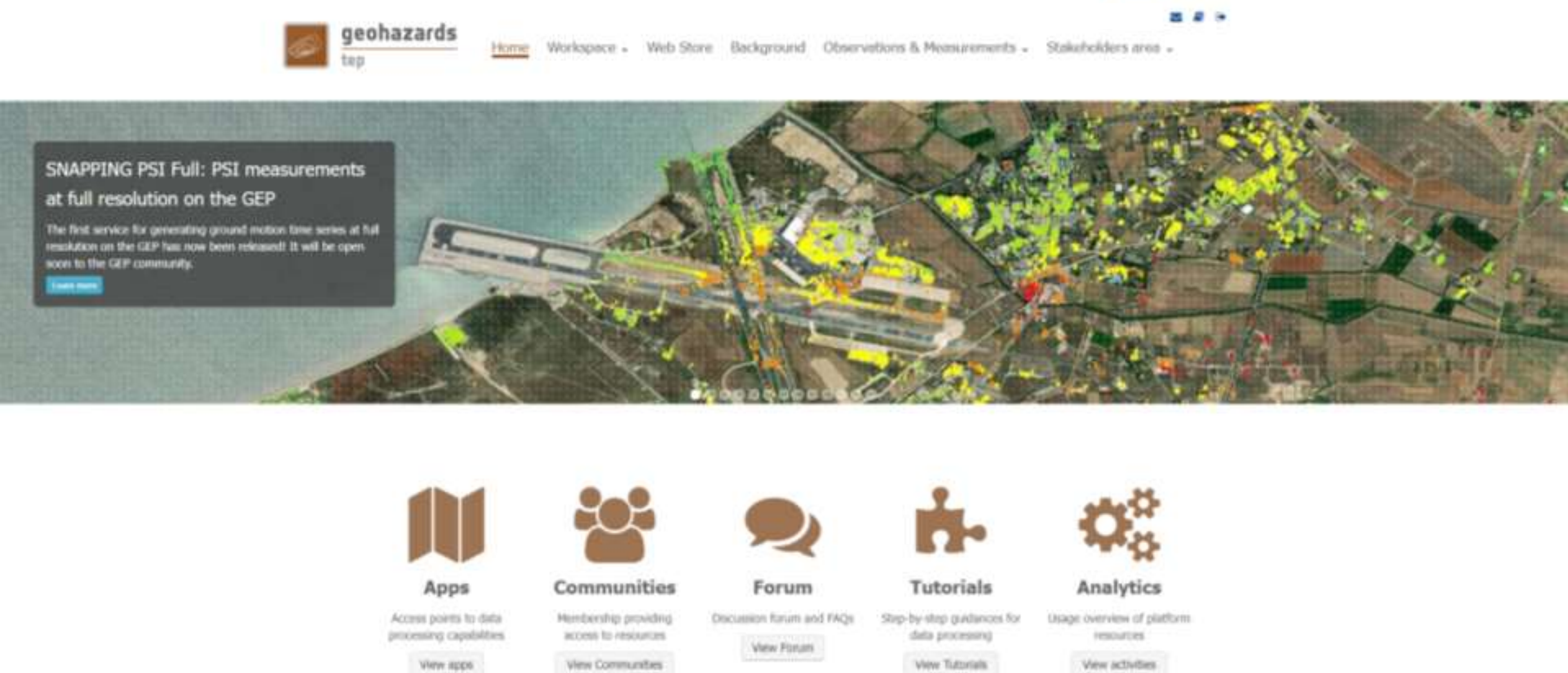




Delgado Blasco, J.M.; Foumelis, M.; Stewart, C.; Hooper, A. Measuring Urban Subsidence in the Rome Metropolitan Area (Italy) with Sentinel-1 SNAP-StaMPS Persistent Scatterer Interferometry. *Remote Sens.* **2019**, *11*, 129. https://doi.org/10.3390/rs11020129

Geohazards Exploitation Platform | GEP

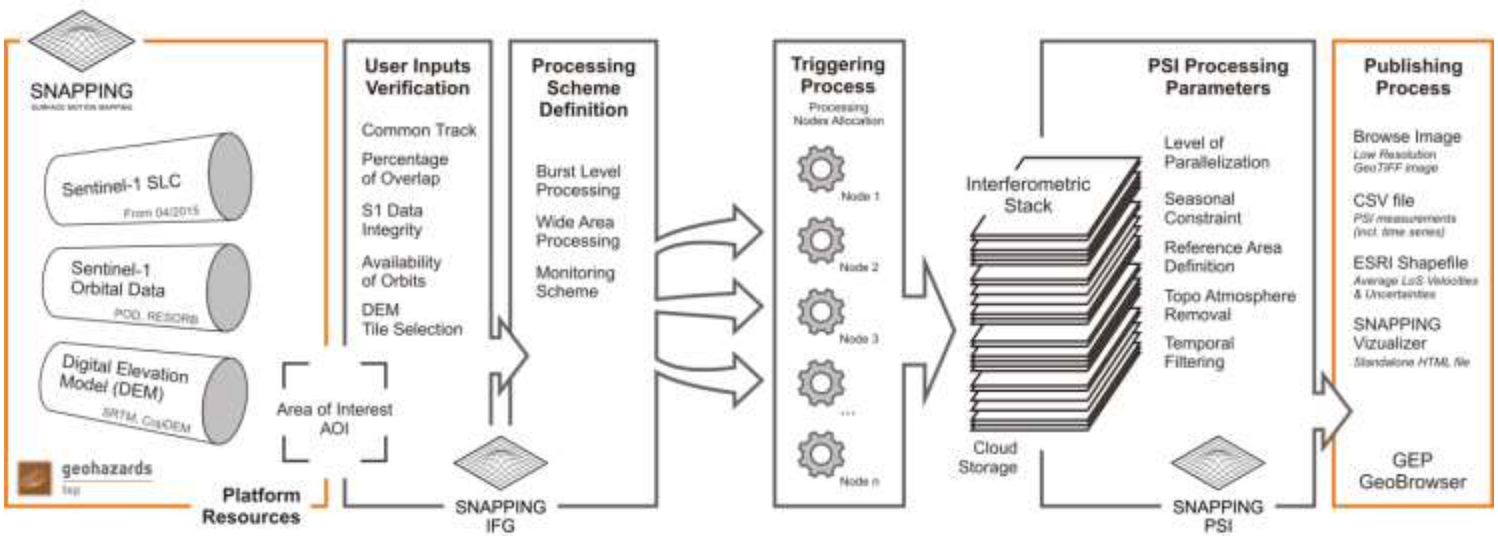
https://geohazards-tep.eu



SURFACE MOTION MAPPING | SNAPPING SERVICE ON GEP

SNAPPING
IFG

SNAPPING
PSI



SNAPPING
SURFACE MOTION MAPPING

geohazards
tep

Family of SNAPPING Services

SNAPPING
SURFACE MOTION MAPPING

SNAPPING
PSI

SNAPPING PSI Med

A service focusing on the delivery of PSI measurements at reduced spatial resolution (spatial averaging of point targets within a 100x100 meters radius to allow wide-area coverage in a relatively short time. The SNAPPING PSI Med service is proposed for inspection of areas of large extent to identify sites where more dedicated analysis is required.

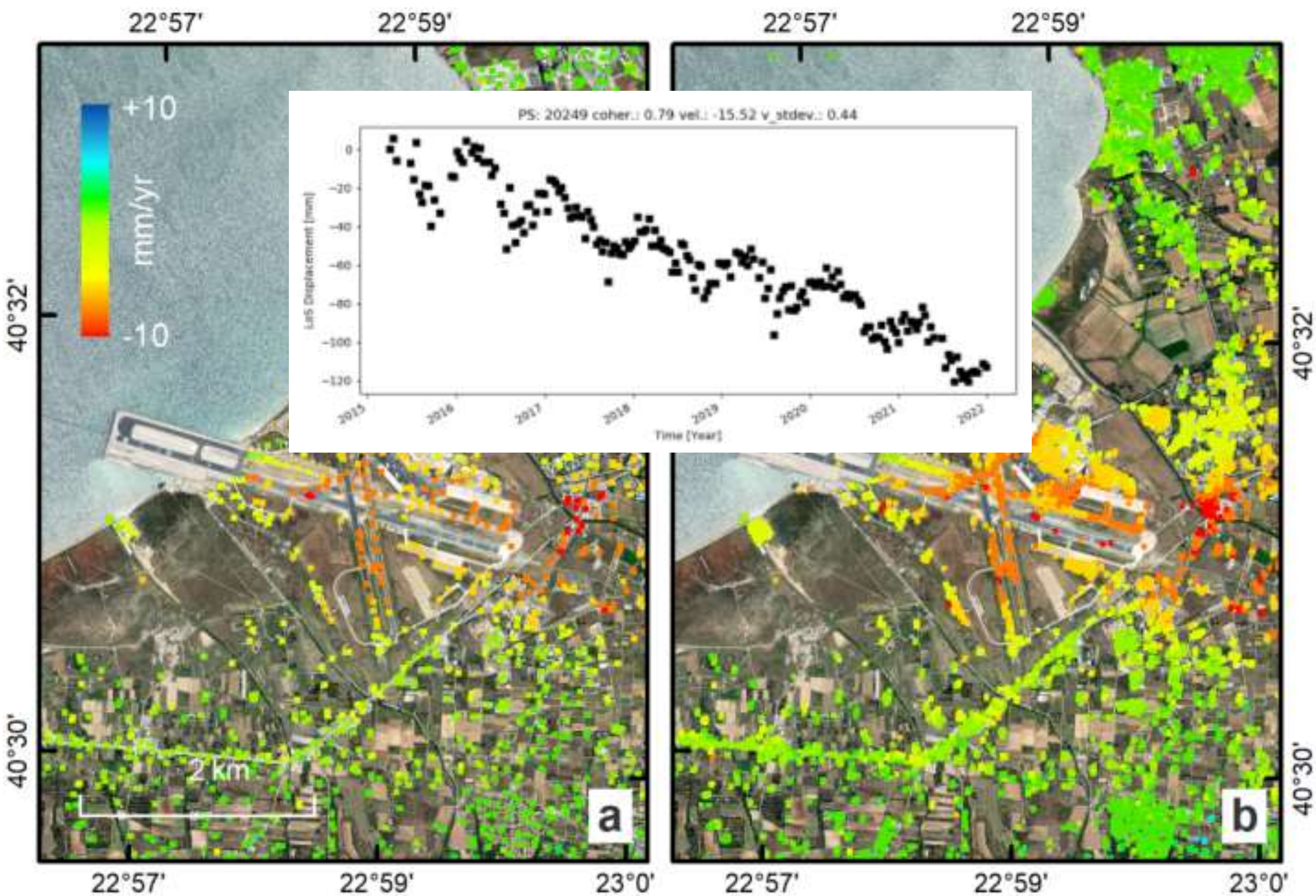
SNAPPING PSI Full

Full sensor resolution PSI service applicable for a detailed regional investigation of surface motion, as well as for building-level and infrastructure monitoring. Persistent Scatterers (PS) targets represent surface features stable over the observation period, mainly man-made objects and non-vegetated natural terrain.

SNAPPING PSI+ (PS/DS)

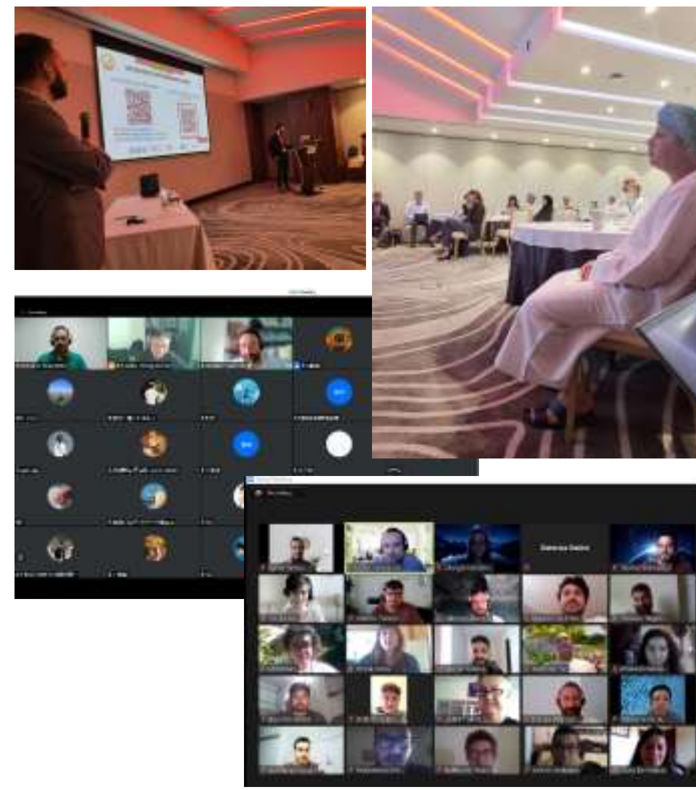
Tailored interferometric processing on both PS and Distributed Scatterers (DS), providing optimum measurement densities. DS are typically identified over homogeneous ground, non-cultivated lands and deserted areas.

SNAPPING PSI | Medium vs Full Resolution



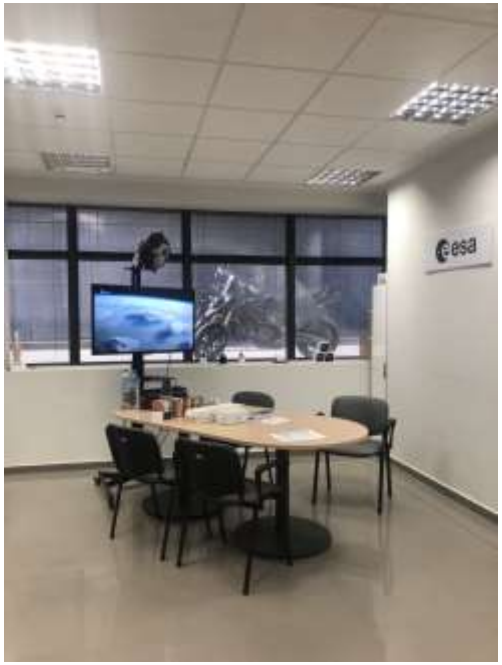
Training Services

- Education, Training, Capacity Building and Outreach
- Physical presence & online
- Permanent educational activities
- Ad-hoc educational services at National, European and International level
- Collaborations with ESA & NASA
- Collaboration with other educational Institutions in Greece, Europe and worldwide



European Space Education Resource Office (ESERO) Greece:

Space in the Classroom
(https://esero.gr/)

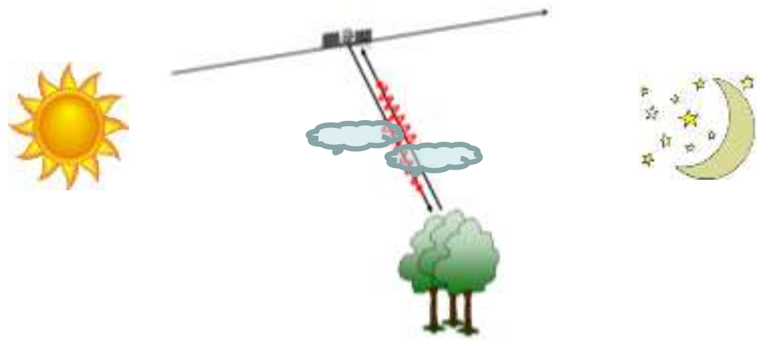


esa

Greece esero

CIRI-AUTH
Aristotle University of Thessaloniki

Microwave Remote Sensing



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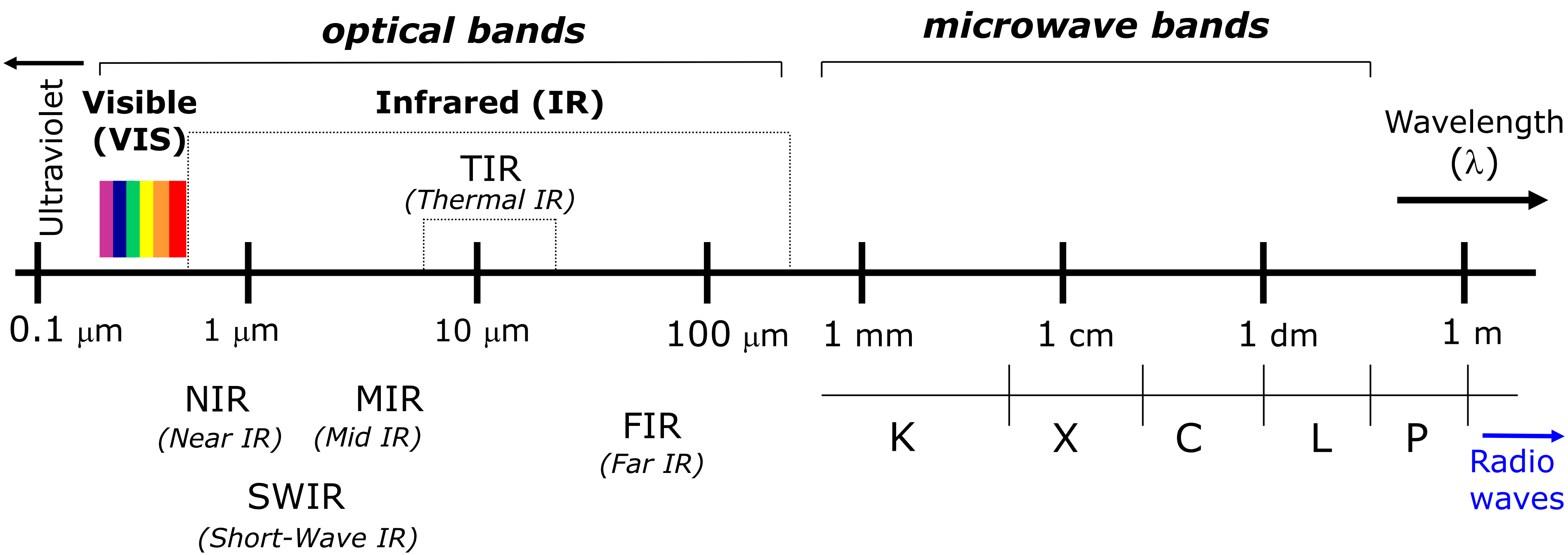
esa

NASA

Remote Sensing and the Electromagnetic Spectrum



Potentialities of radar

- **'All-weather'** observation system (active system)



- Sensitivity to **dielectric** properties of medium (**water content**), and to its **roughness**

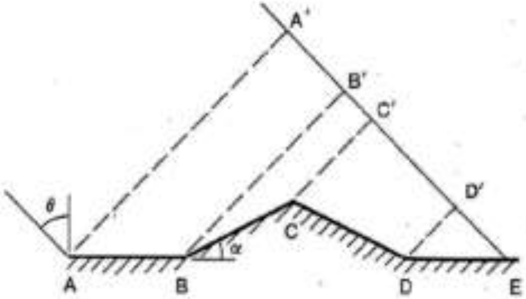
the radar response ↗ *when the* ***moisture*** ↗ *and/or when* ***roughness*** ↗

- **Penetration** capabilities ➡ estimation of **plant biomass,**

observation of buried structures, cartography of subsoils, etc.

penetration ↗ *when the frequency* ↘

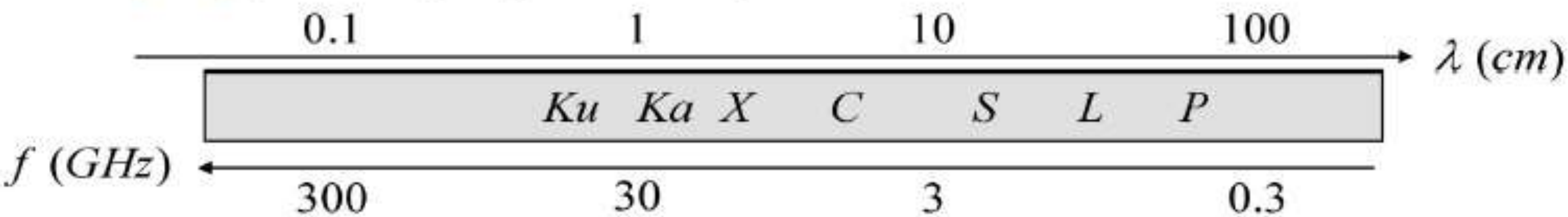
- Sensititivity to **topography** (*related to the acquisition geometry*)



- Sensitivity to geometrical structures with a scale of the same order as **the wavelength**

Radar transmission features

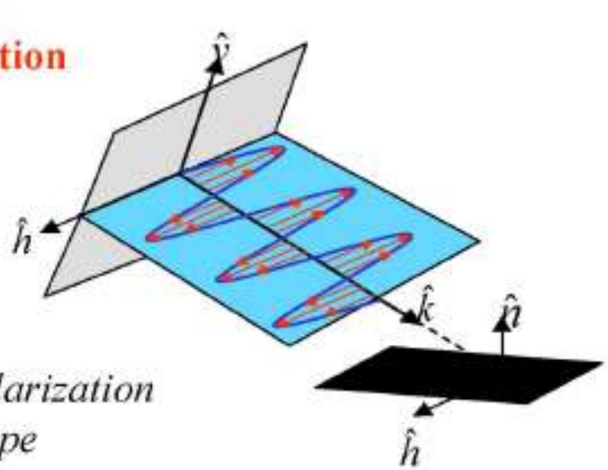
- The **frequency** (carrier frequency + bandwidth)



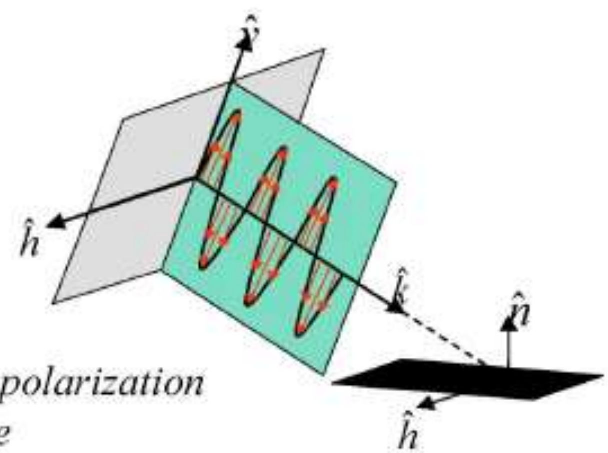
- The **propagation direction** (Ex: ERS: **23**°)

- The **transmitted power** (Ex: ERS: ~ **5 kW** pic) ← *impact on image quality*

- The **polarization**



Horizontal polarization
RADARSAT type



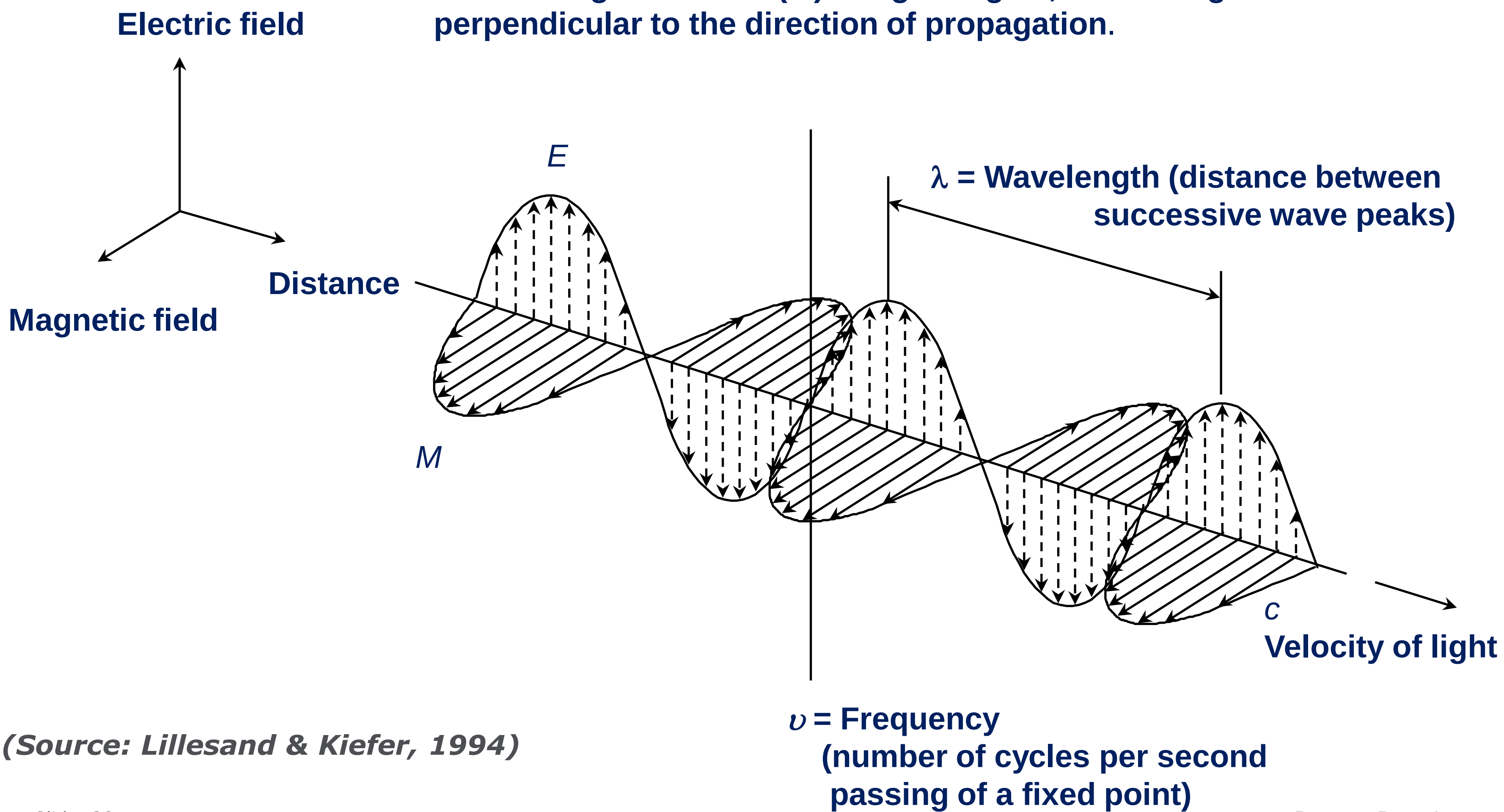
Vertical polarization
ERS type

Information Derived from the Radar Signal

1. Amplitude
2. Phase
3. Time interval
4. Polarization

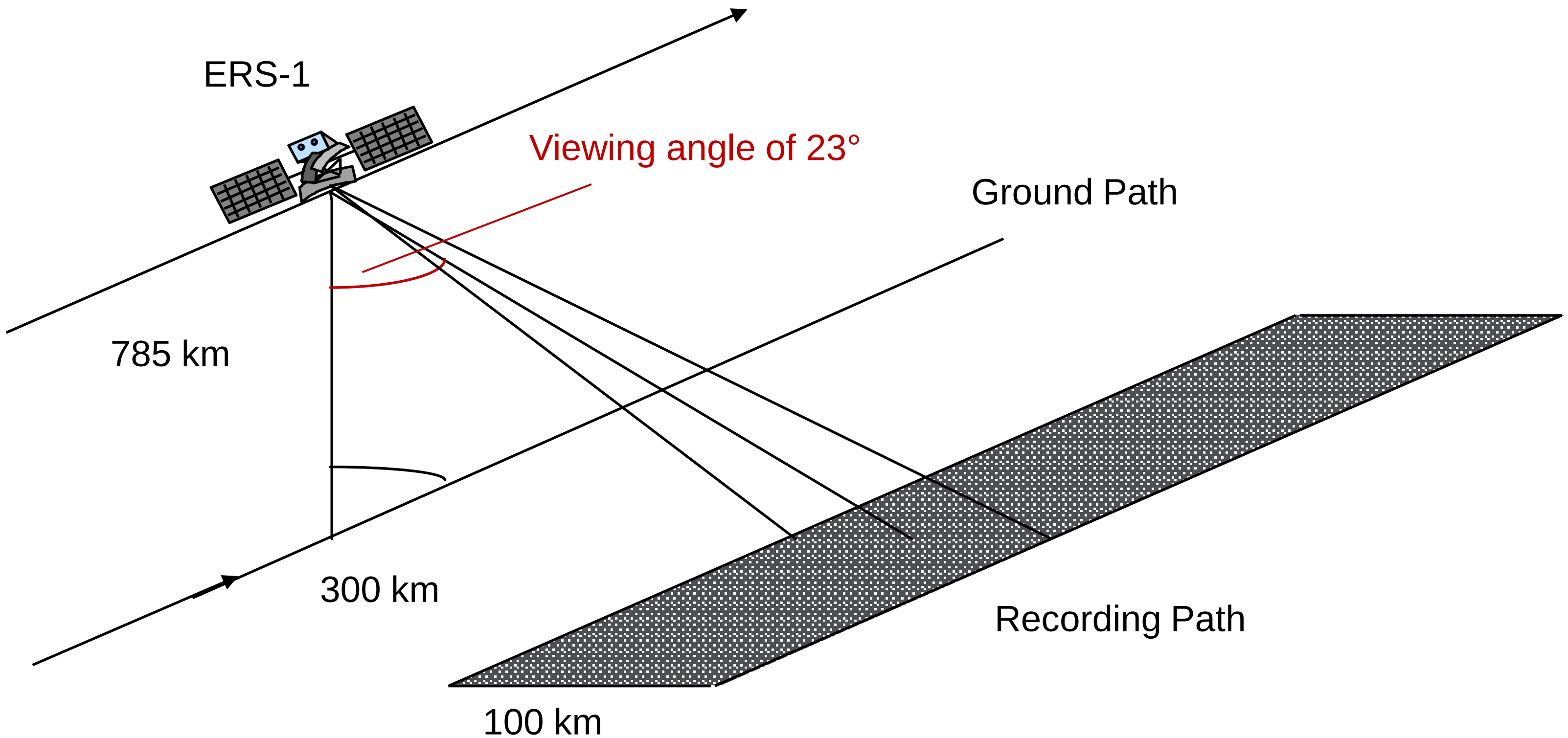
Electromagnetic Wave

Components include a sinusoidal electric wave (*E*) and a similar magnetic wave (*M*) at right angles, both being perpendicular to the direction of propagation.



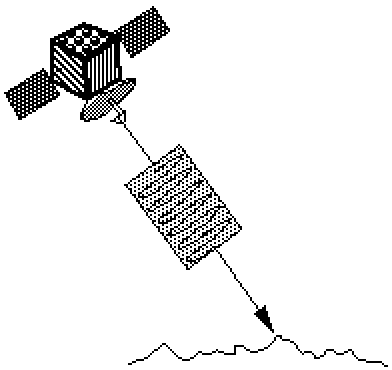
(Source: Lillesand & Kiefer, 1994)

Synthetic Aperture Radar (SAR): Observing principle (I)

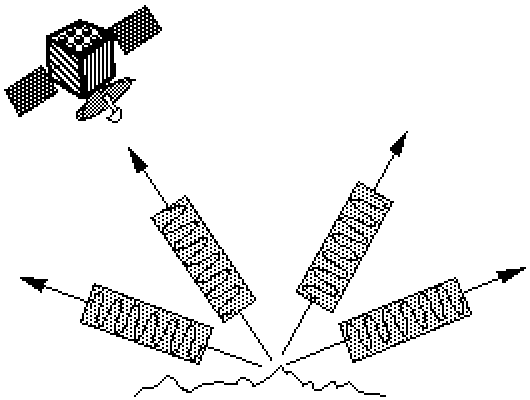


Radar scattering

Transmit

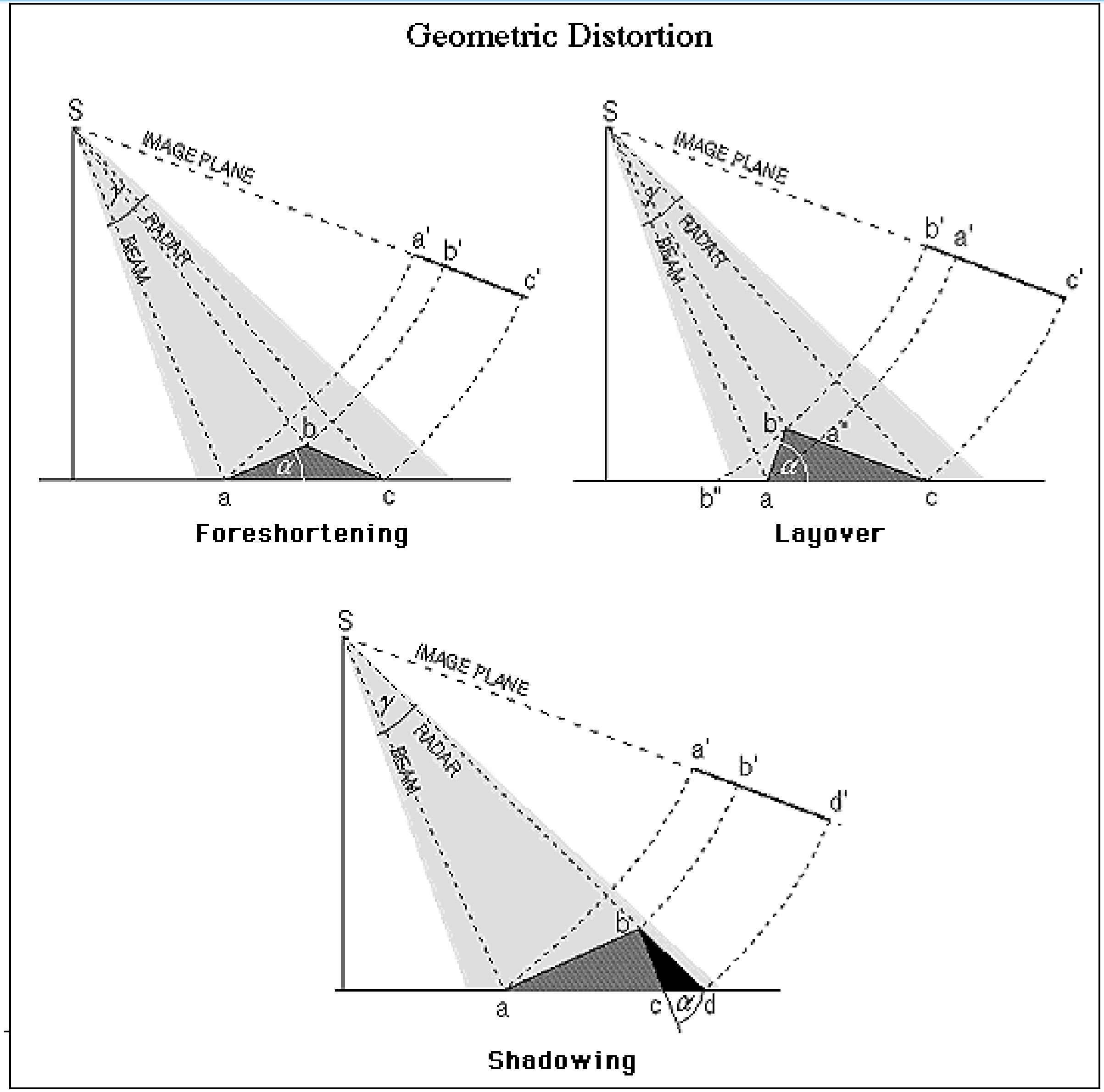


Scattered echoes

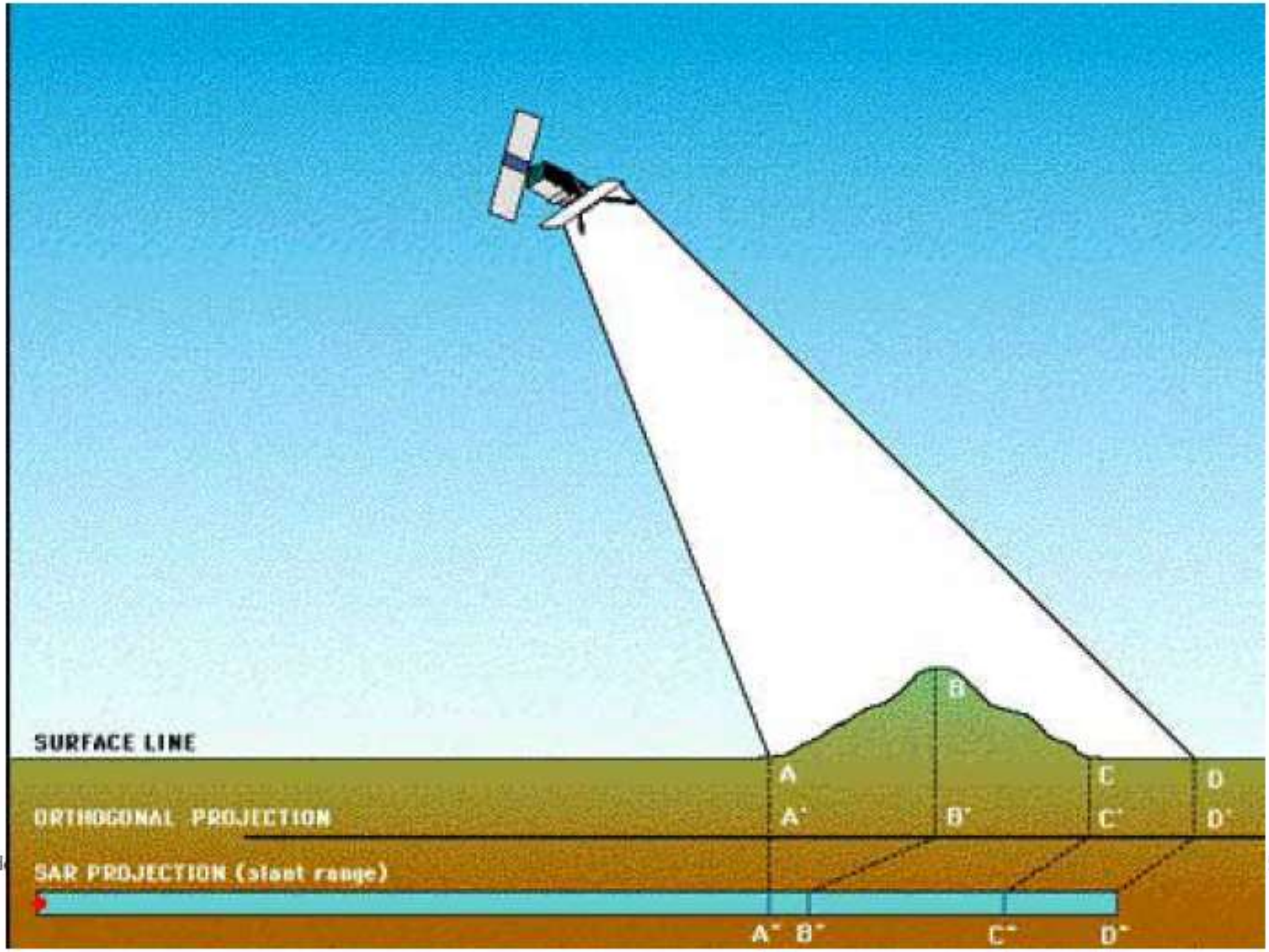


1. The radar transmits pulses which are scattered in all directions by the surface observed.
2. Some of the scattered echoes are measured back by the radar -> **backscattering**

Radar geometric distortions

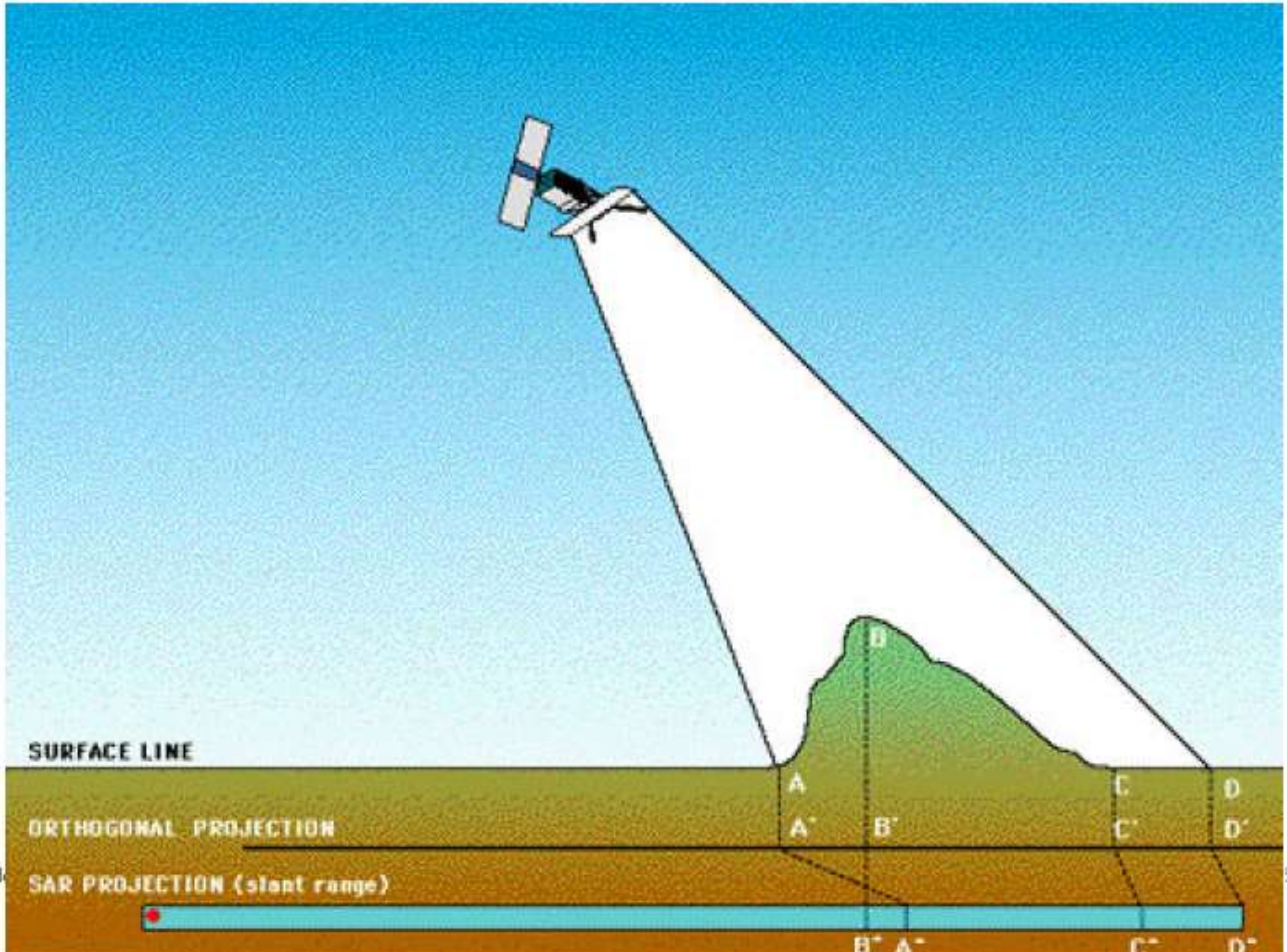


SAR image geometry – Foreshortening

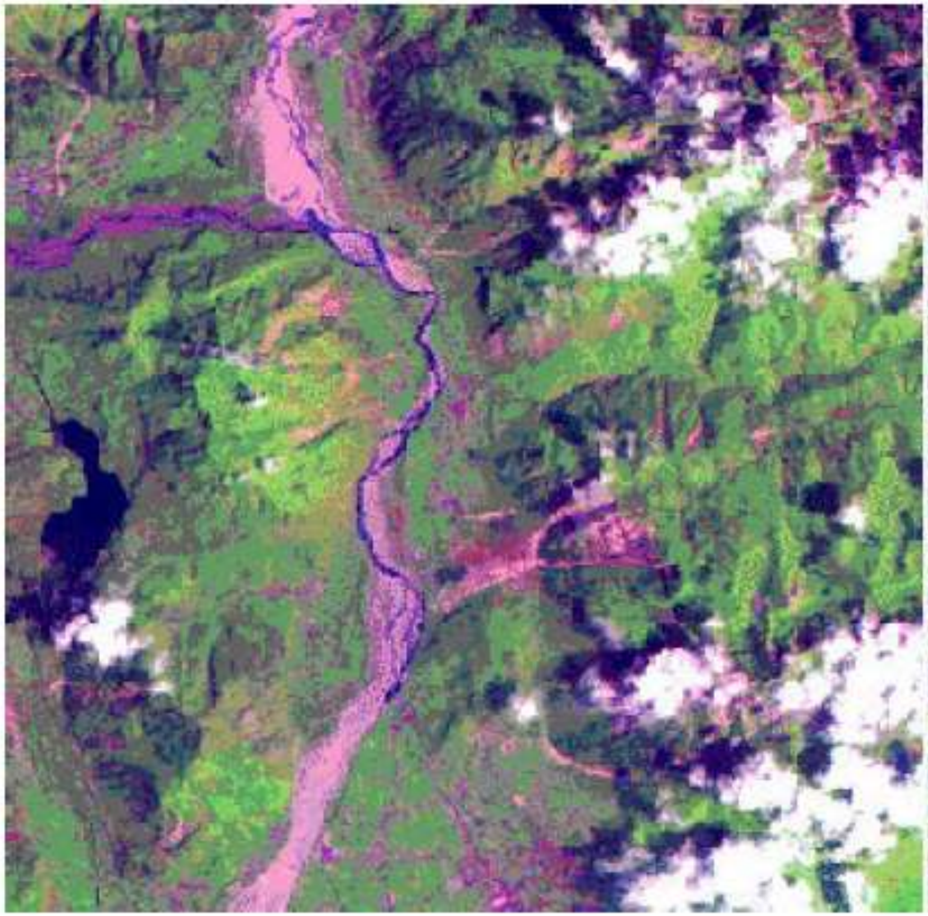


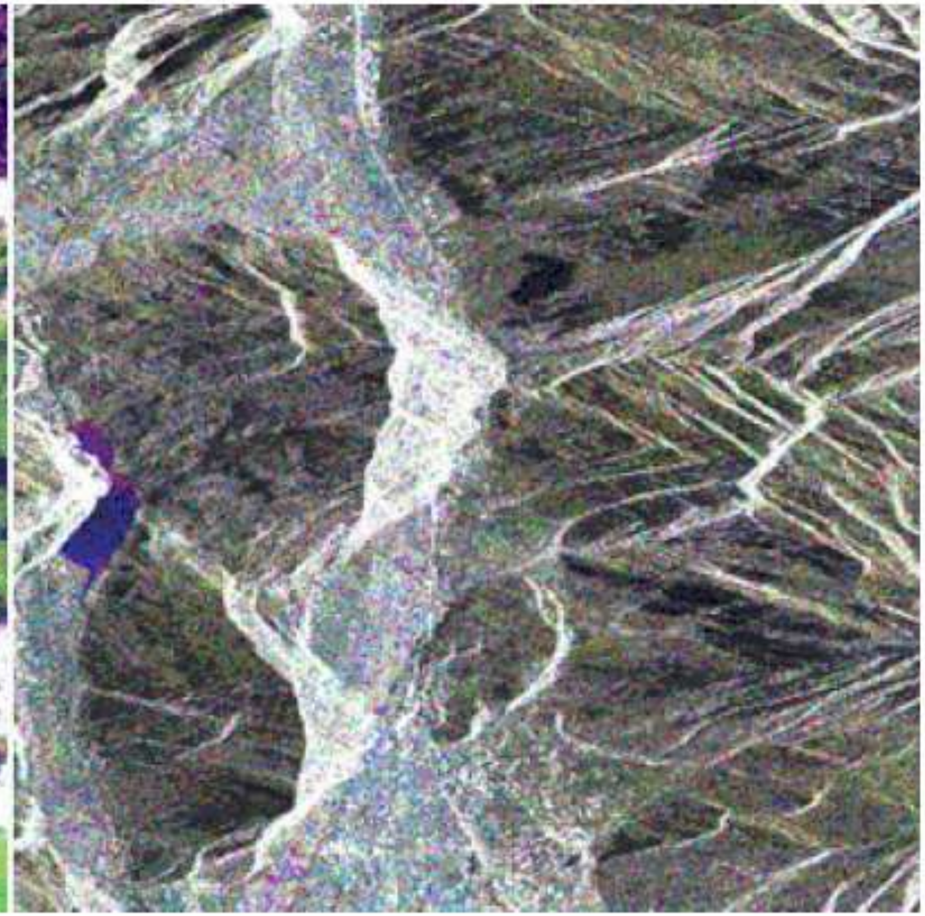
SAR image geometry - Foreshortening

SAR image geometry – layover

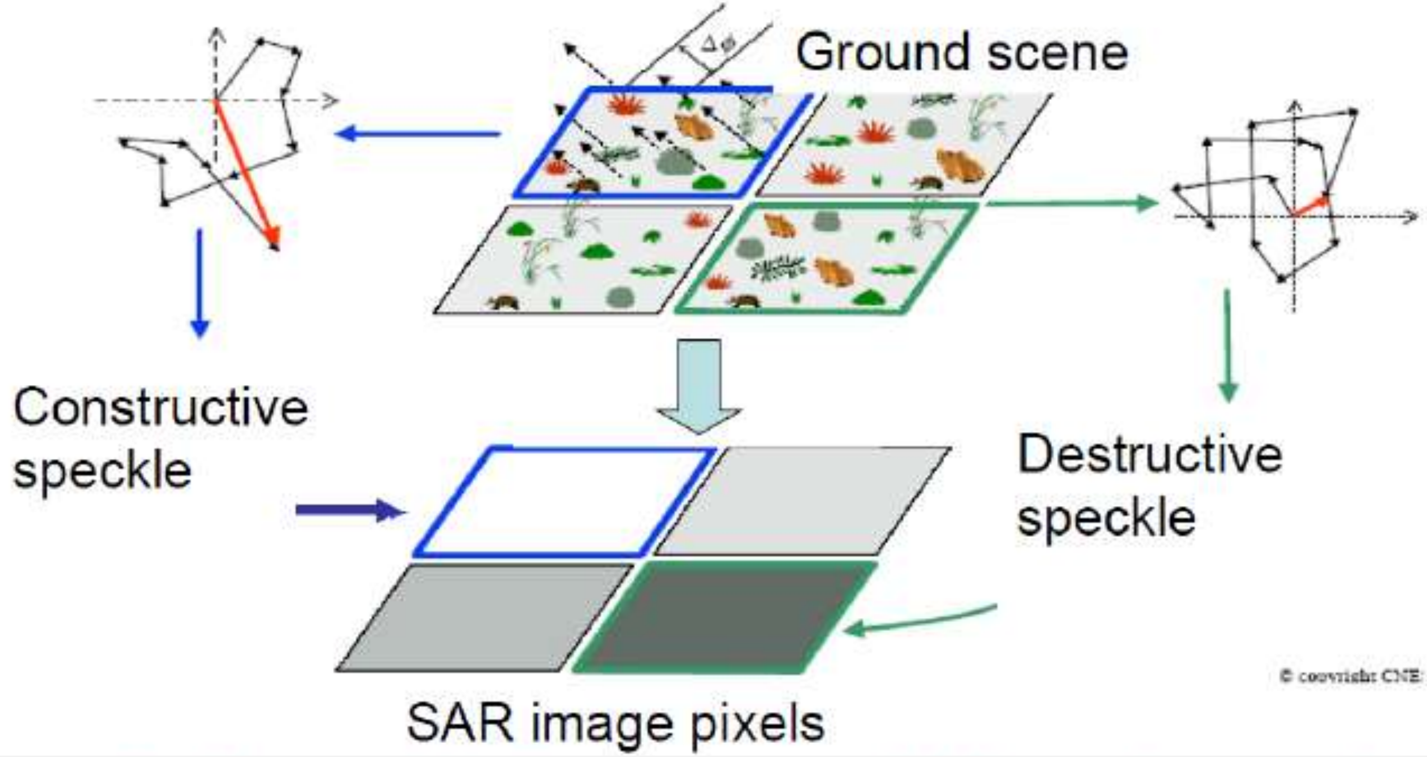


SAR image geometry - layover

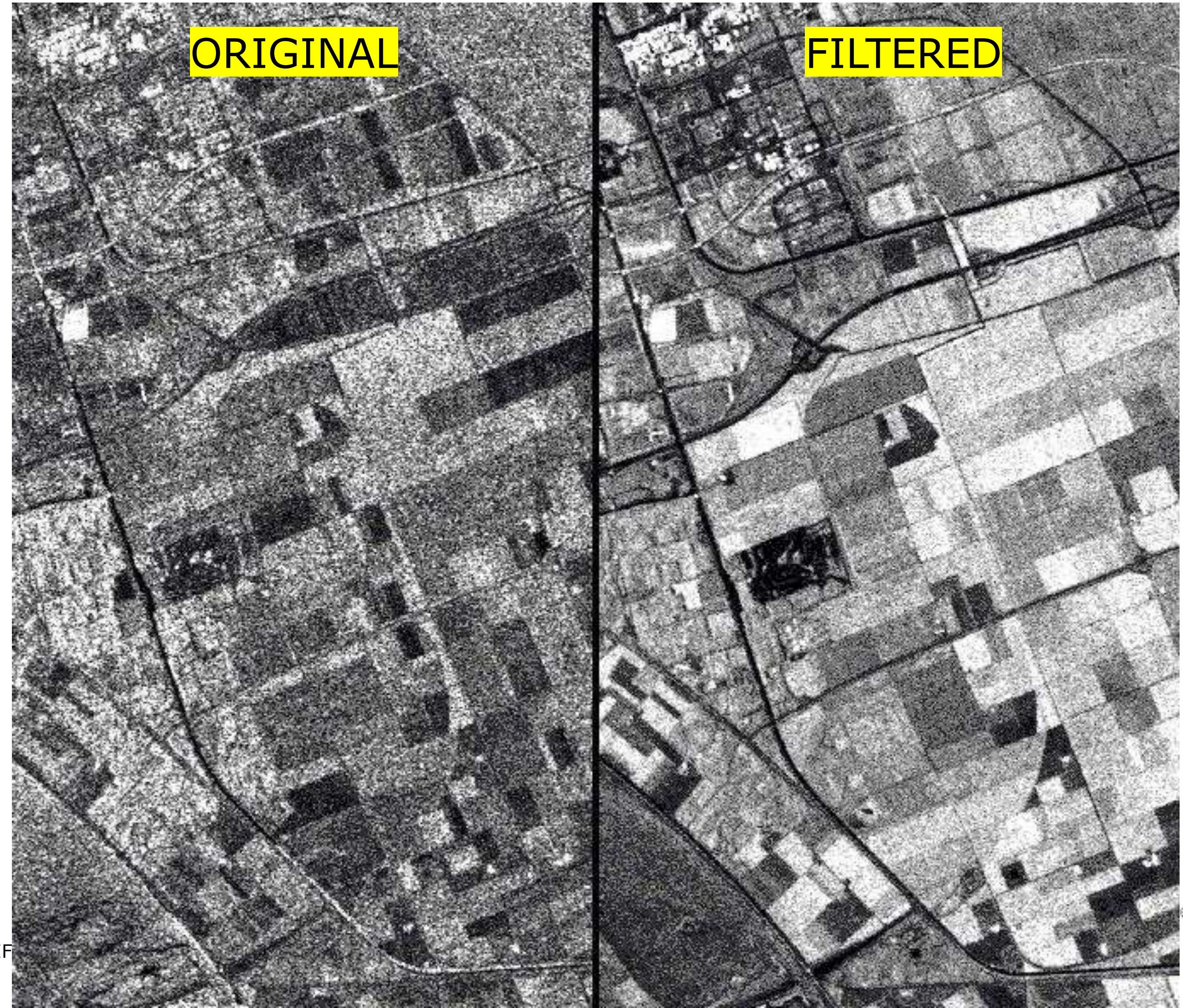




The physical origine of speckle



Resolution cells are made up of many scatterers with different phases, leading to interference and the noise-like effect known as ***speckle****.*


ORIGINAL
FILTERED

Typical SAR data products

A. Level-0 (unfocused, raw data)

B. Level-1 (popular for most users)

- Single Look Complex (SLC)
- Ground Range Detected (GRD)

C. Level-2 (higher level products)

Single Look Complex (SLC)

- Focused
- Georeferenced
- In slant-range geometry
- Single look in each dimension
- Preserving both the phase and amplitude information

SLC IS THE MOST INFORMATIVE PRODUCT

Ground Range Detected (GRD)

- Focused, detected and multi-looked
- Projected to ground range using an Earth ellipsoid model

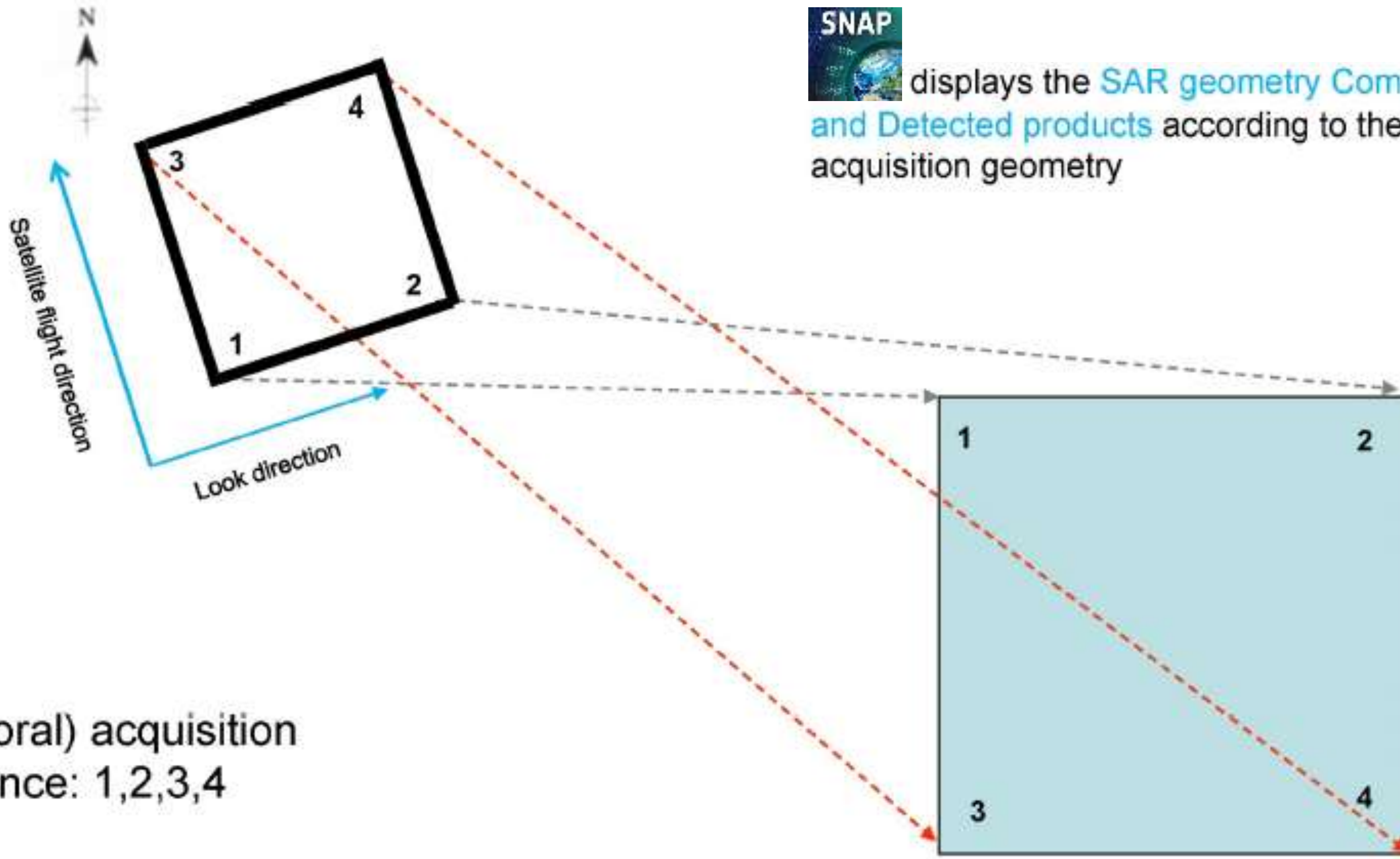
- Phase information is lost

- Approximately square resolution pixels and square pixel spacing
- Reduced speckle at the cost of reduced geometric resolution

Ascending passage – Right looking SAR

Right-looking SAR acquiring data from near to far along cross track direction

SNAP displays the SAR geometry Complex and Detected products according to the acquisition geometry

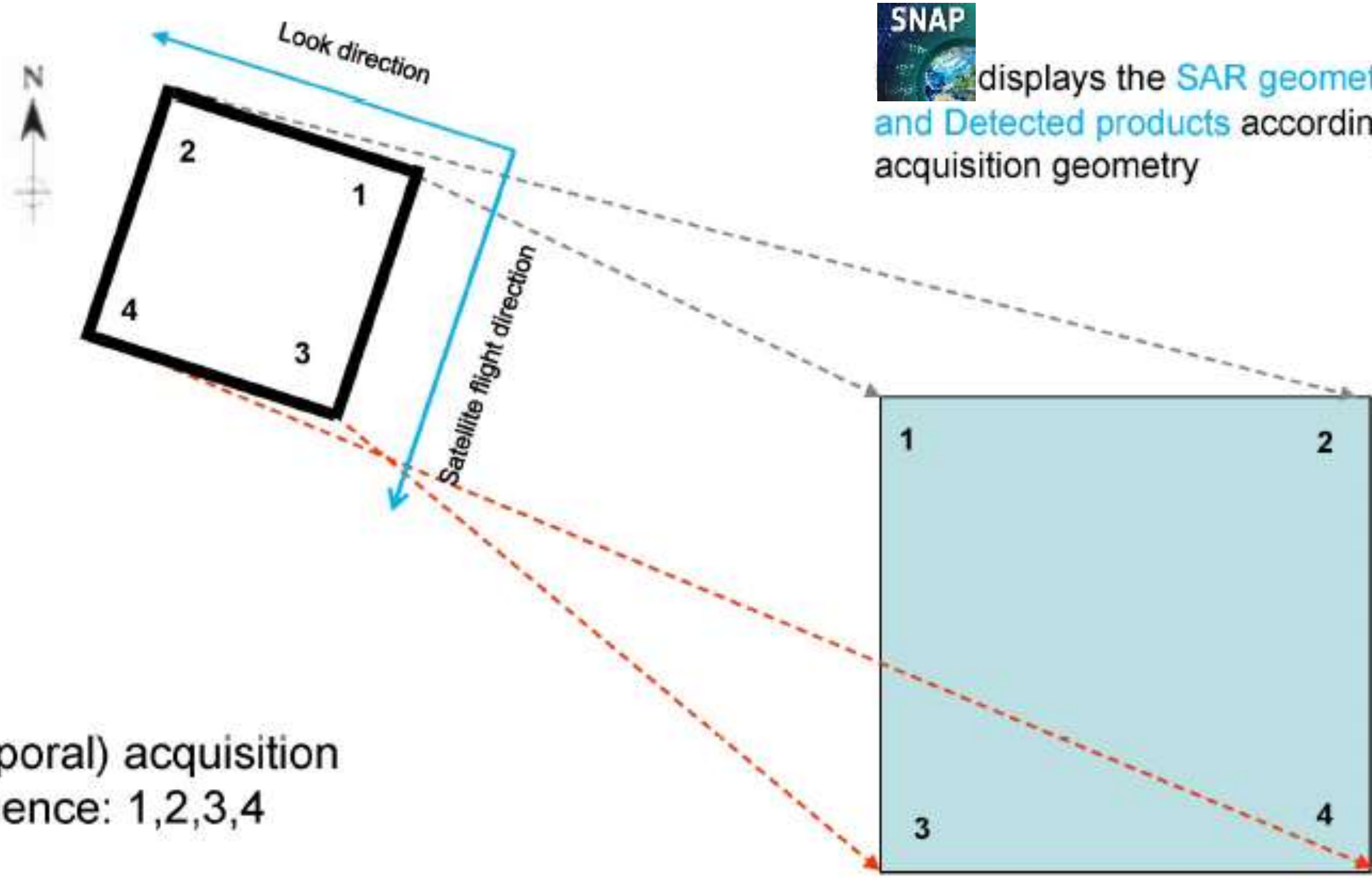


(temporal) acquisition sequence: 1,2,3,4

To get a North orientation like the image has to be flipped vertically (1-3)

Descending passage – Right looking SAR

Right-looking SAR acquiring data from near to far along cross track direction

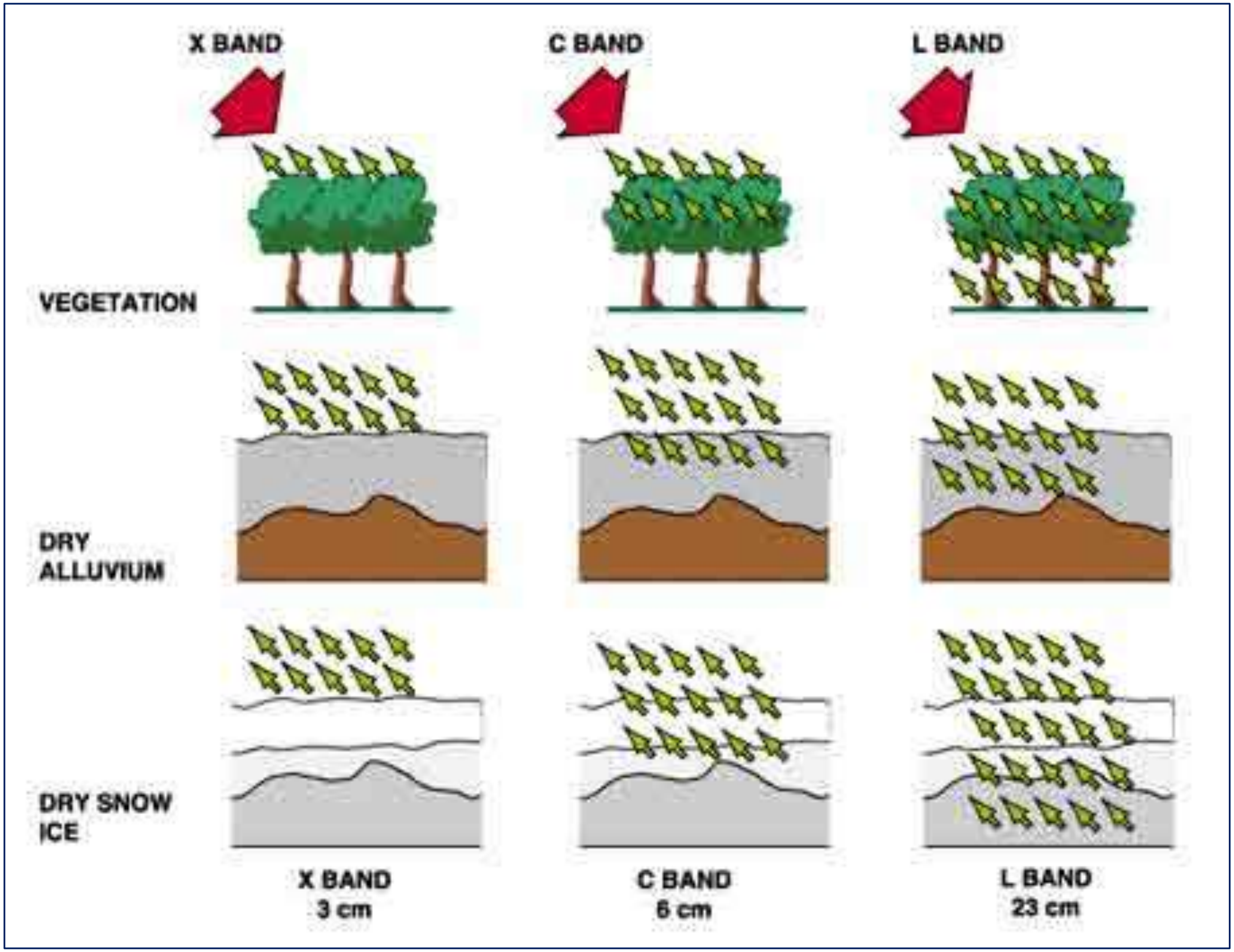


SNAP displays the SAR geometry Complex and Detected products according to the acquisition geometry

(temporal) acquisition sequence: 1,2,3,4

To get a North orientation like the image has to be flipped horizontally (1-2)

Scattering as a function of frequency



How the trees are seen by radars?

Austrian pine

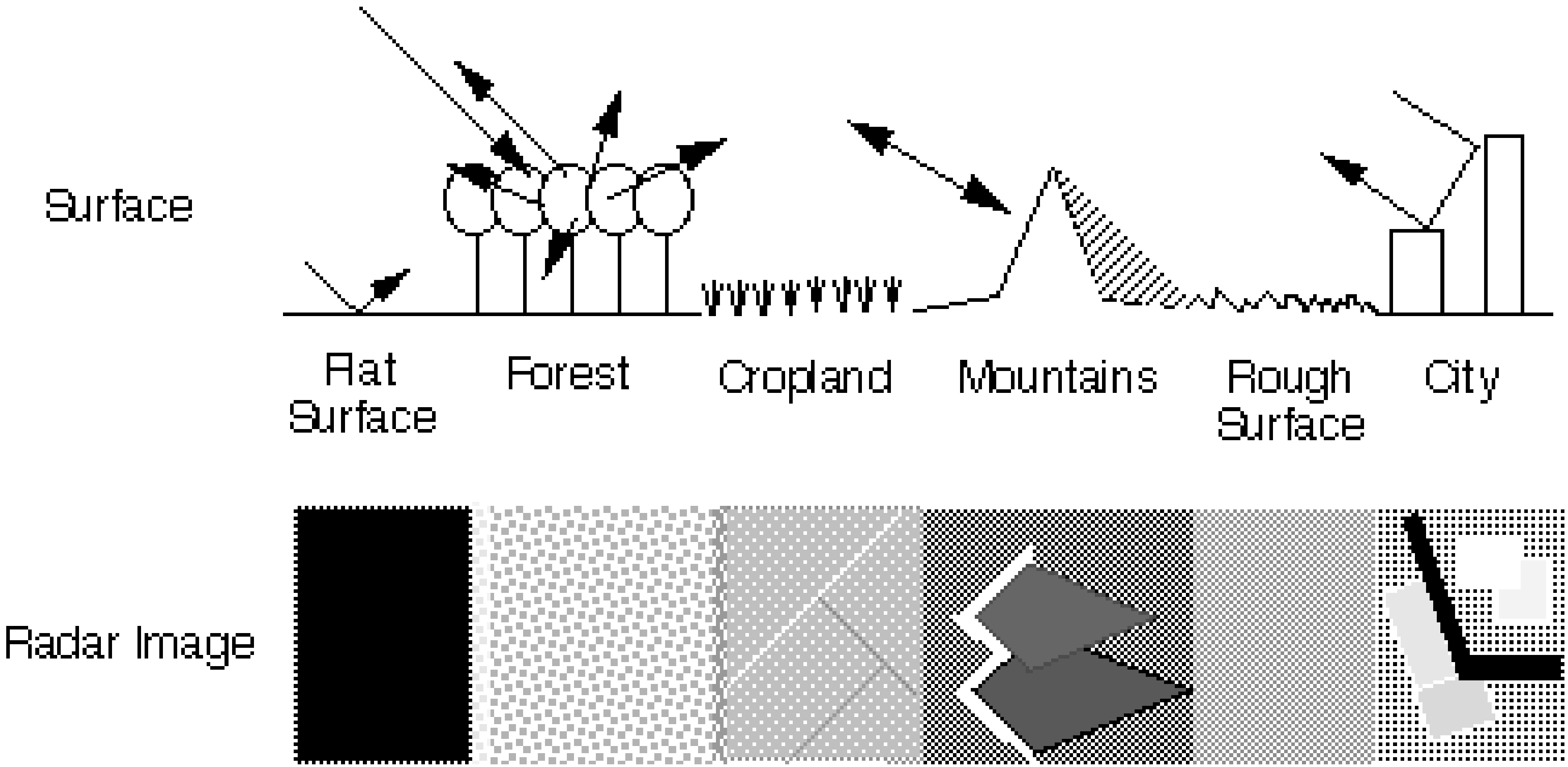
X band
λ= 3 cm

L band
λ= 27 cm

P band
λ= 70 cm

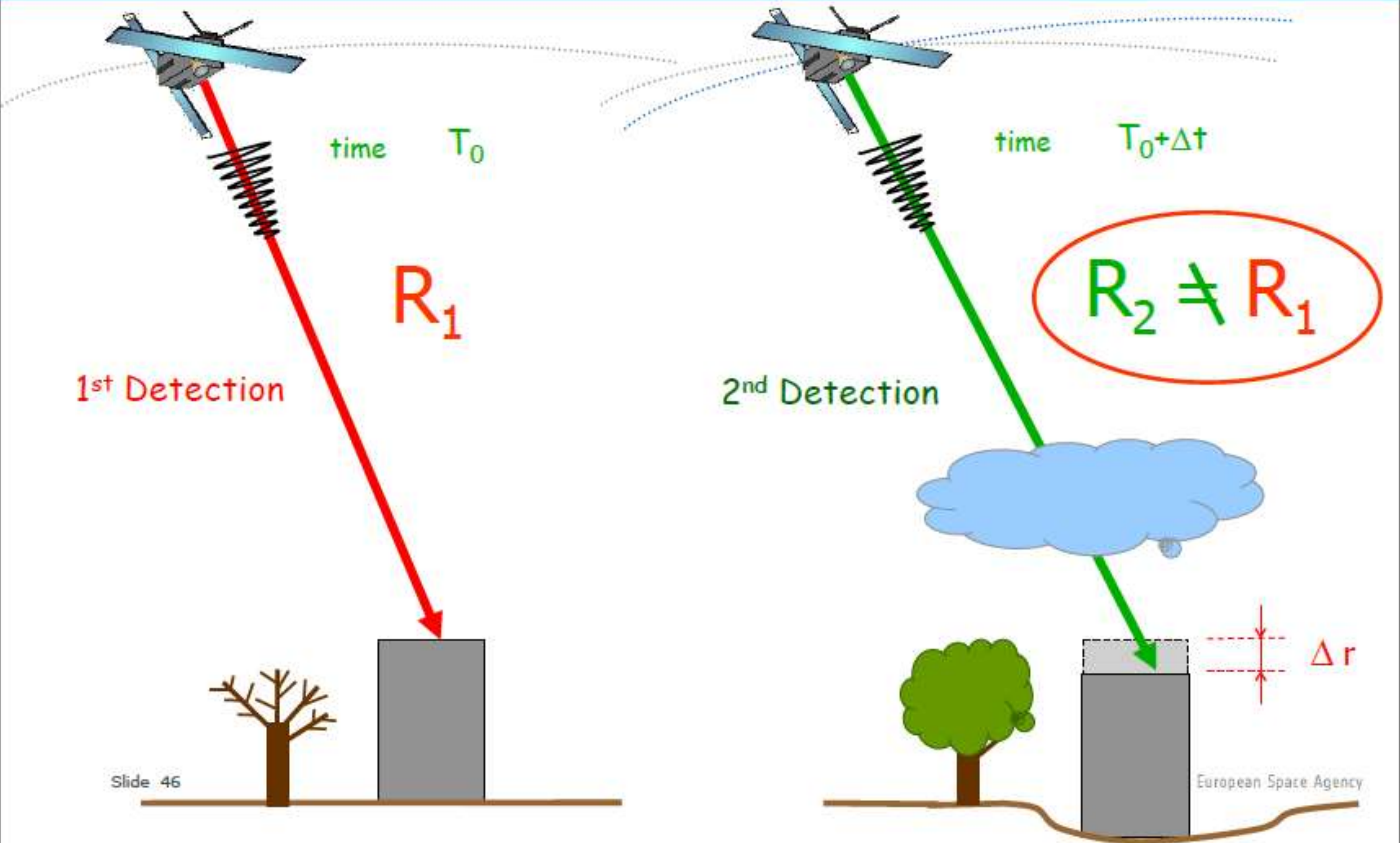
VHF
λ > 3 m

SAR images of different types of surfaces



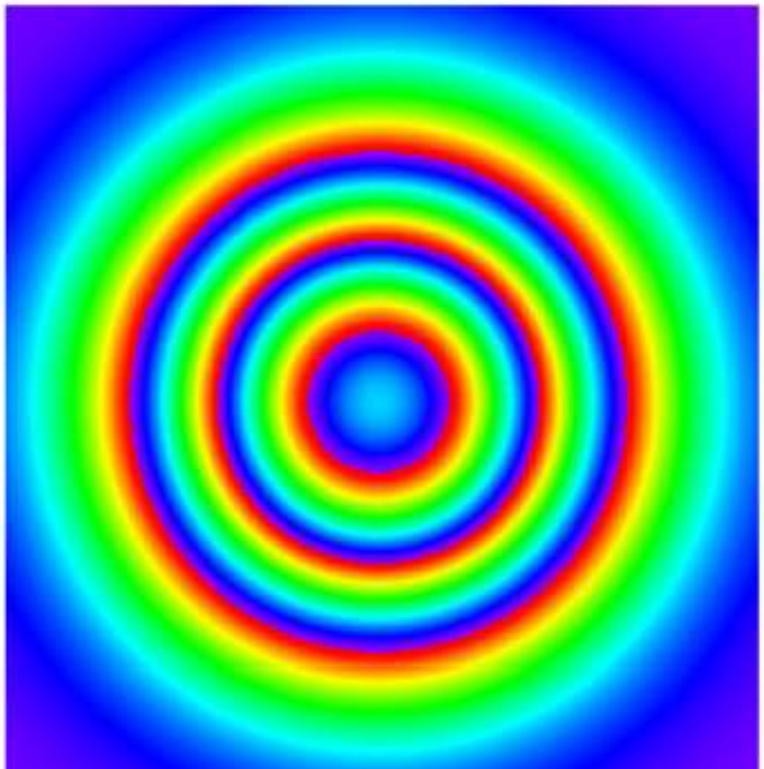
(Source: NASA)

Radar Interferometry to measure small movements of the terrain



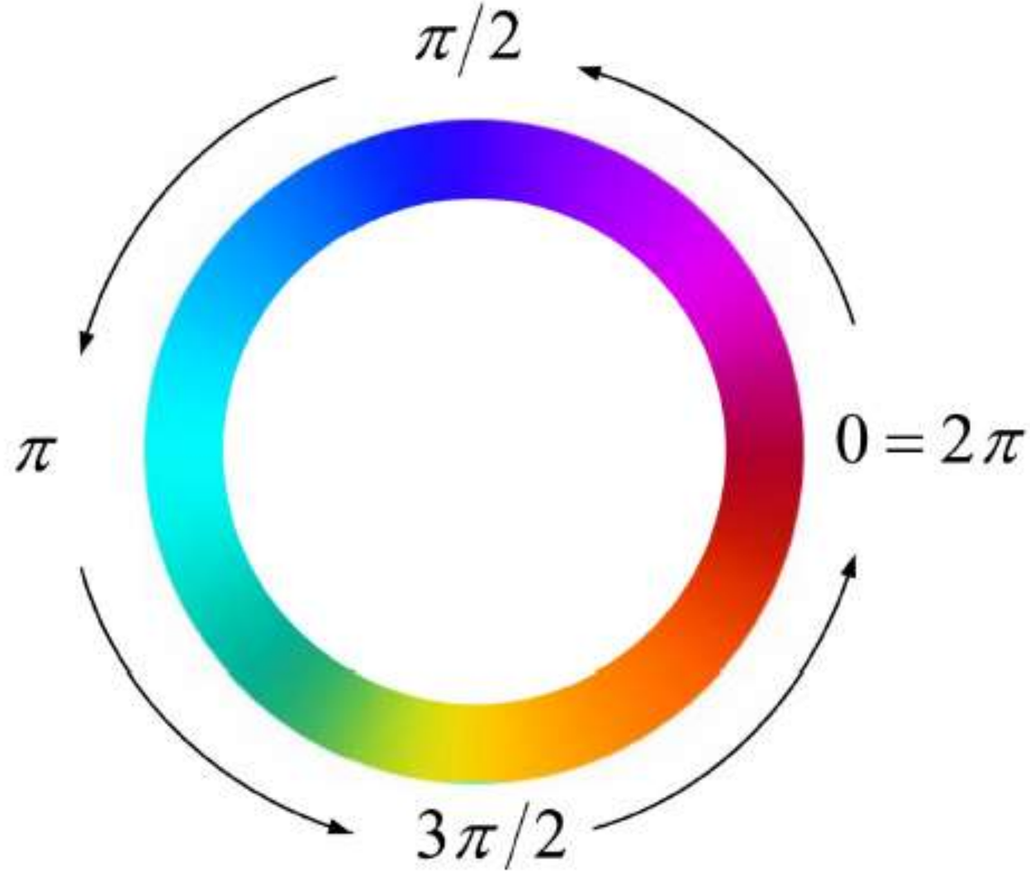
SAR Interferometry

Model of an Interferogram



Each color cycle = one "fringe"

Representation of 2π phase



Phase components

$$\phi = 2k\pi + \phi_{topo} + \phi_{defo} + \phi_{orb} + \phi_{atm} + \phi_{scat} + \phi_{noise} =$$

$$= 2k\pi + \frac{4\pi B_{\perp}}{\lambda R \sin(\theta)} + \frac{4\pi}{\lambda} D + \phi_{orb} + \phi_{atm} + \phi_{scat} + \phi_{noise}$$

The role of the wavelength

($\lambda \approx 3$ cm)

$\boldsymbol{\Delta\Phi_d = 2\pi \leftrightarrow 1{,}5}$ **cm**

$$\Delta\phi_d = \frac{4\pi}{\lambda} d$$

($\lambda \approx 5{,}6$ cm)

$\boldsymbol{\Delta\Phi_d = 2\pi \leftrightarrow 2{,}8}$ **cm**

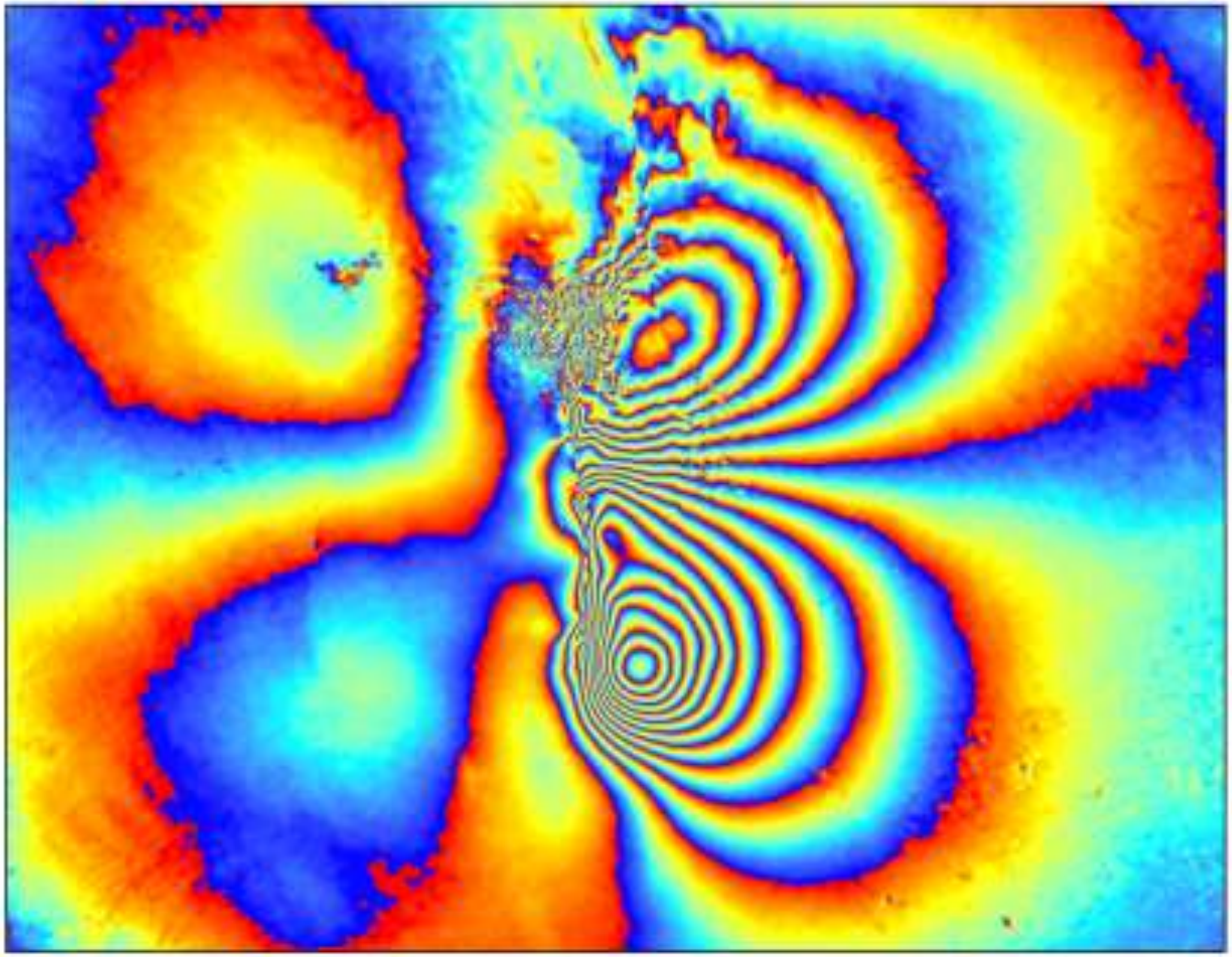
If $\Delta\Phi_d = 2\pi$

$$d = \frac{\lambda}{2}$$

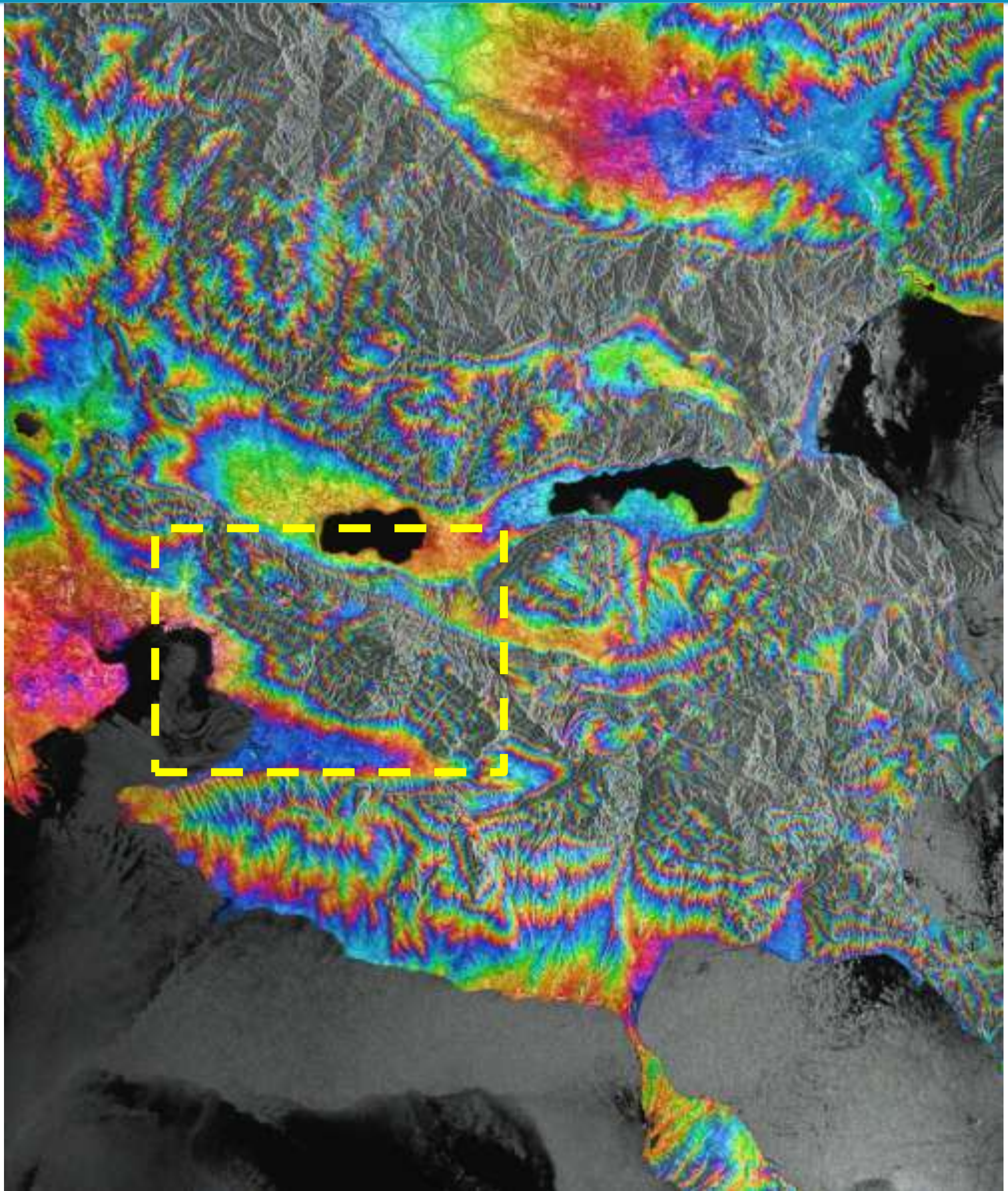
($\lambda \approx 24$ cm)

$\boldsymbol{\Delta\Phi_d = 2\pi \leftrightarrow 12}$ **cm**

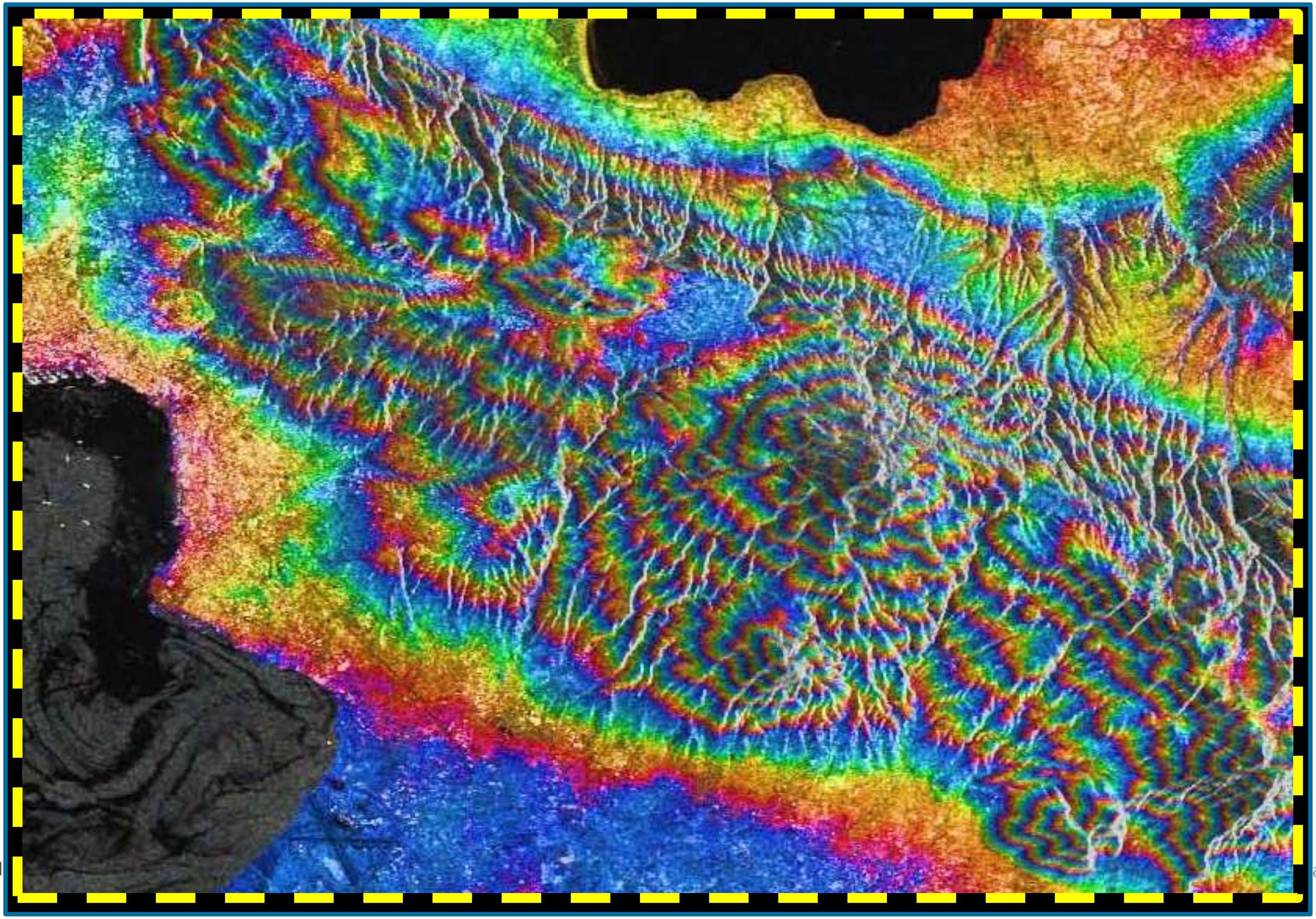
Radar Interferometry/InSAR for deformation monitoring

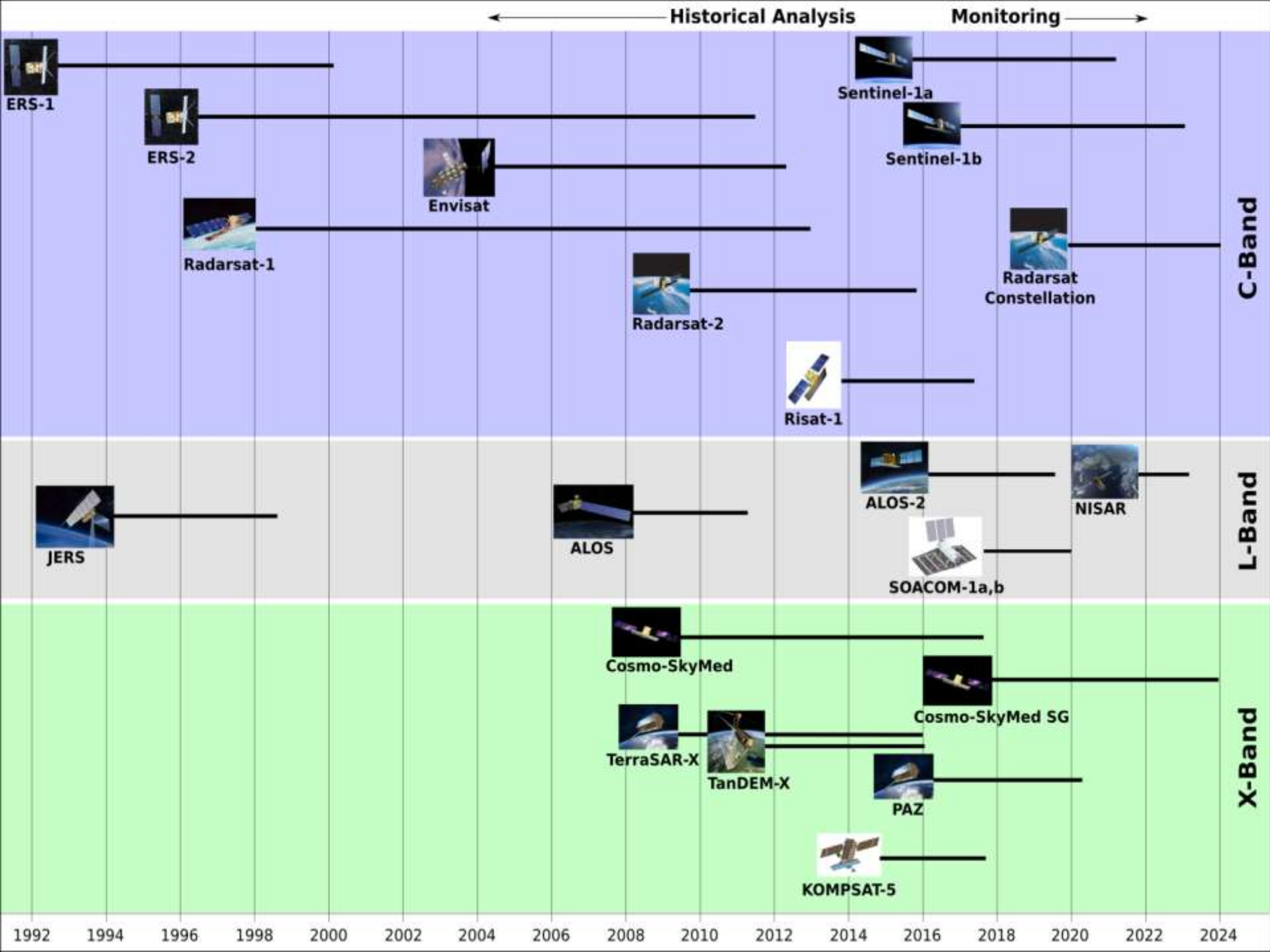


Radar Interferometry/InSAR for DEM Production



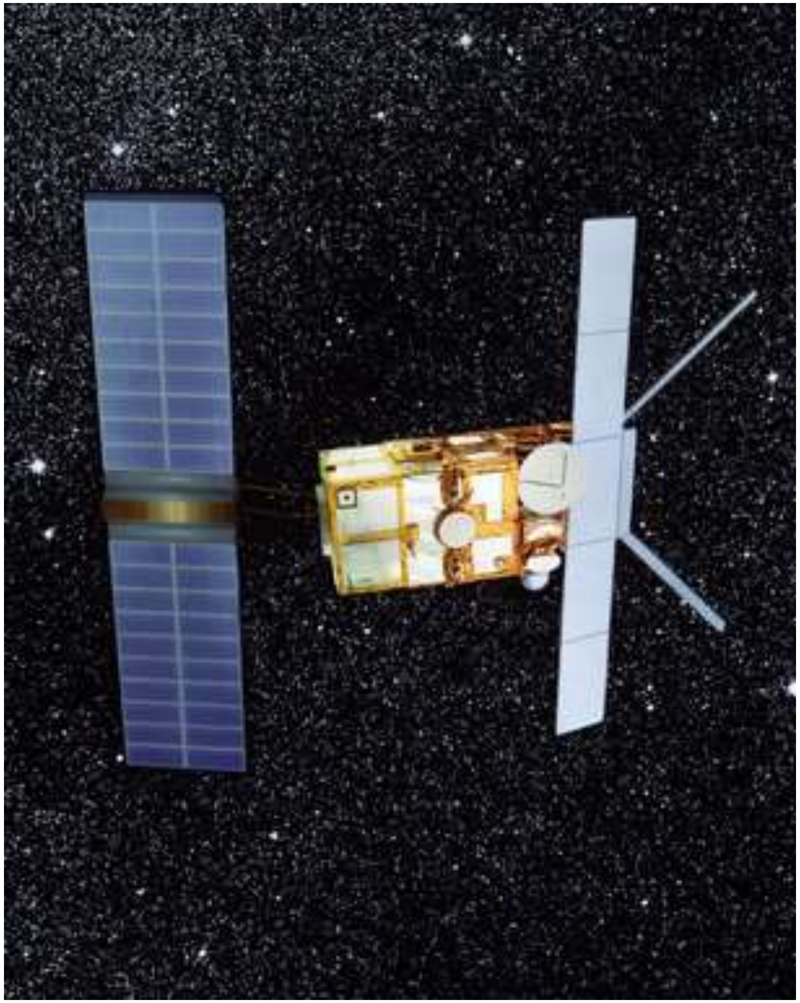
Radar Interferometry/InSAR for DEM Production



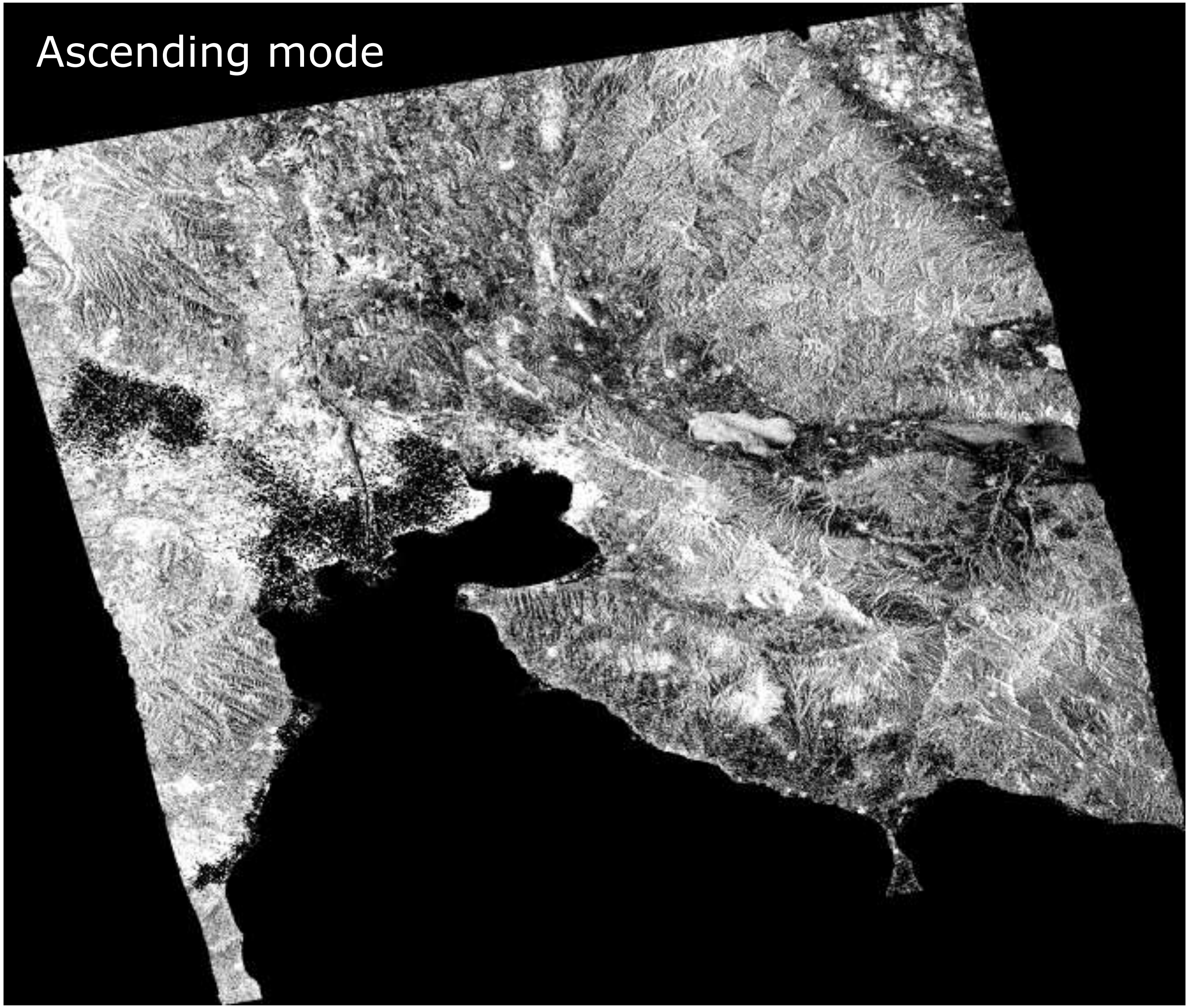


Historical Analysis
Monitoring
ERS-1
ERS-2
Envisat
Radarsat-1
Radarsat-2
Sentinel-1a
Sentinel-1b
Radarsat Constellation
Risat-1
C-Band
JERS
ALOS
ALOS-2
NISAR
SOACOM-1a,b
L-Band
Cosmo-SkyMed
Cosmo-SkyMed SG
TerraSAR-X
TanDEM-X
PAZ
KOMPSAT-5
X-Band
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024

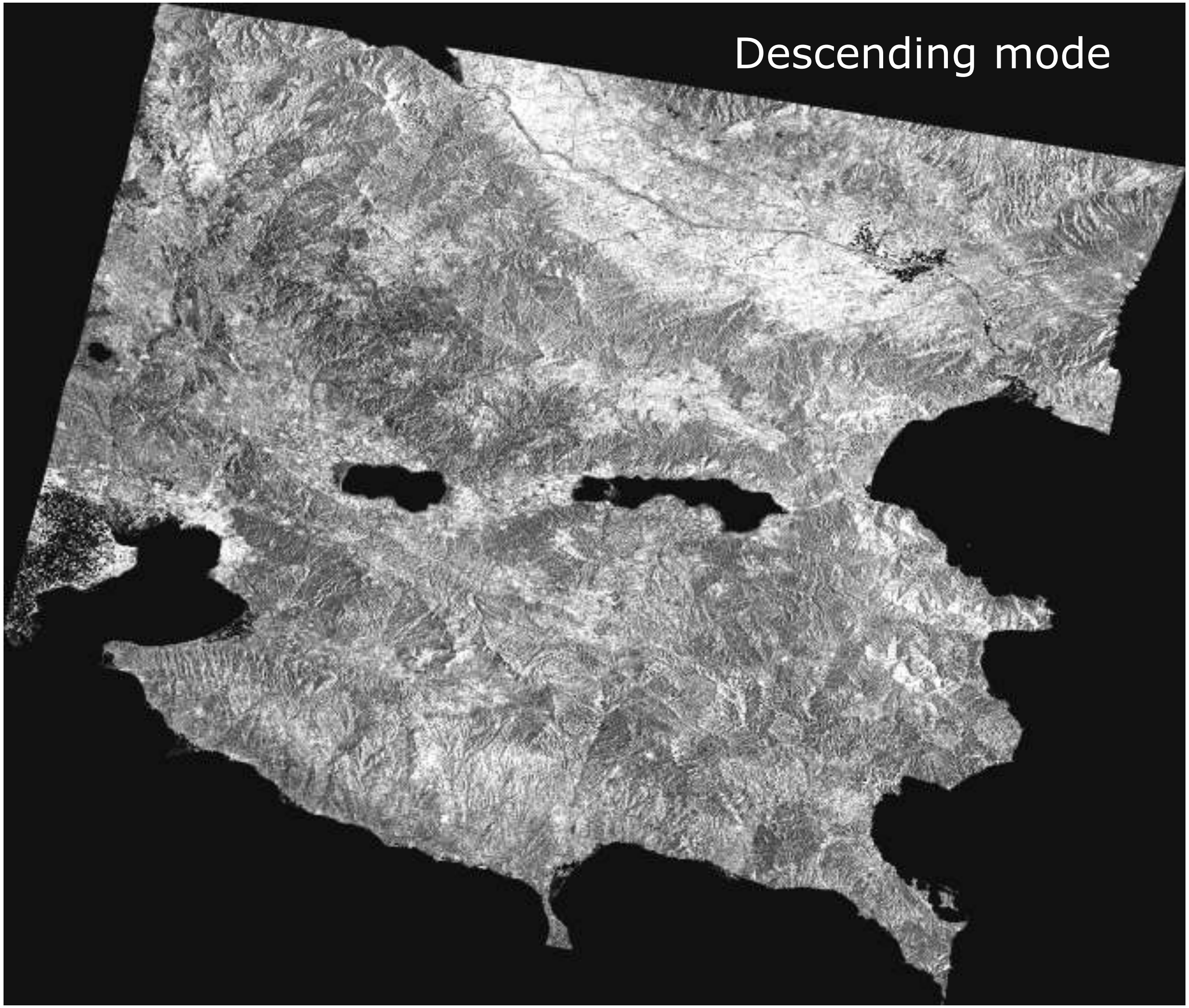
ERS-1 & ERS-2



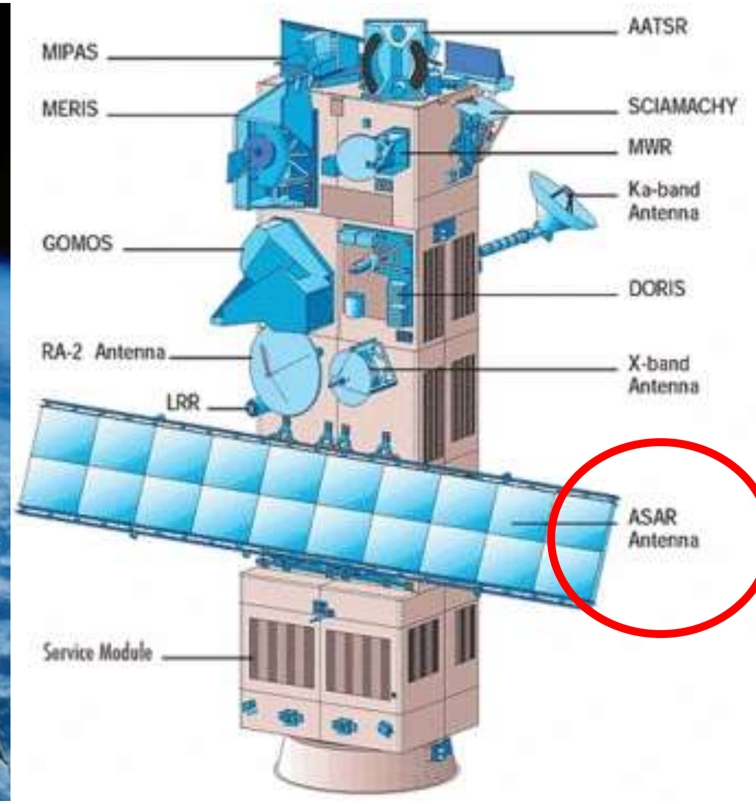
ERS-1 & ERS-2



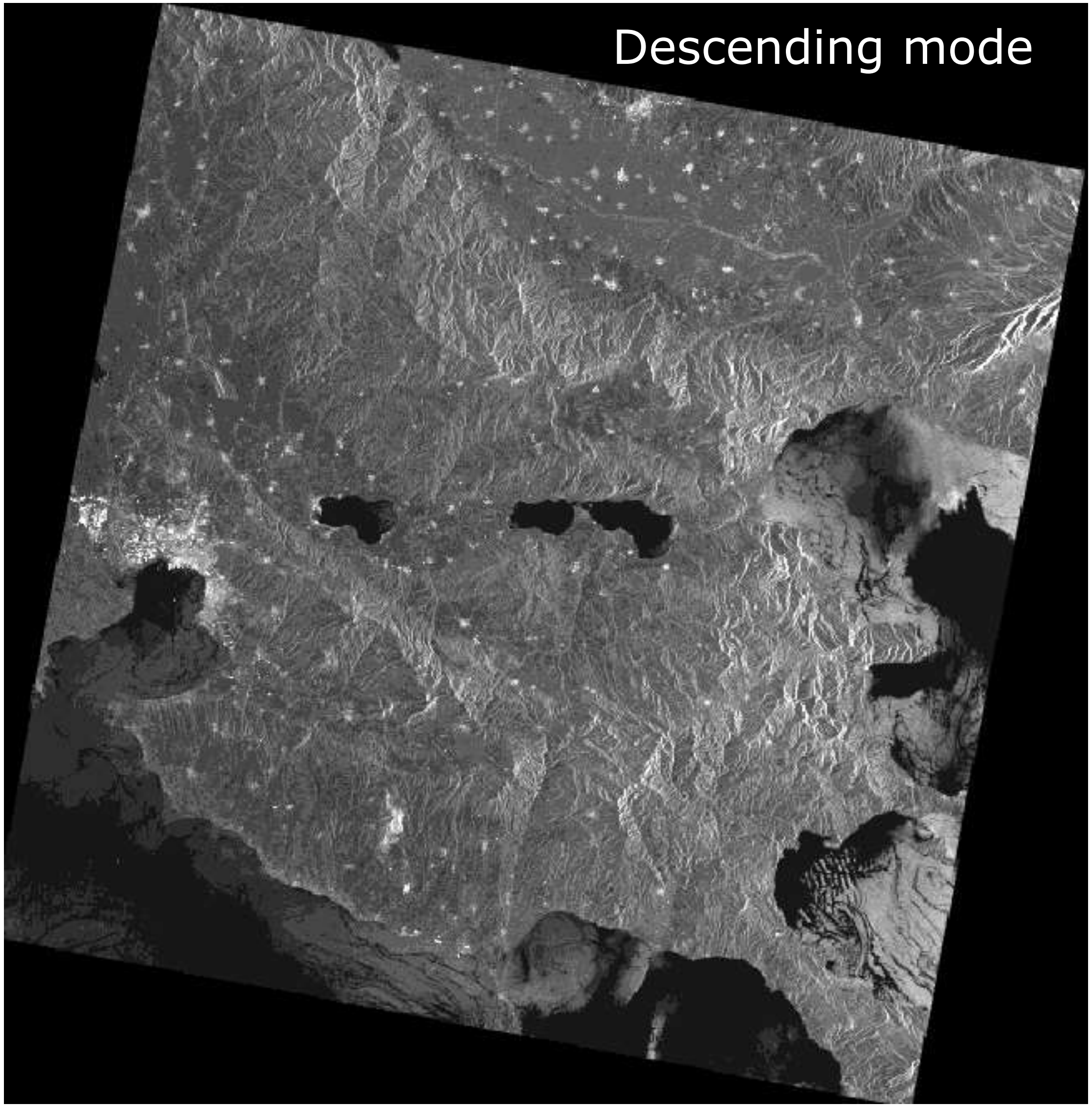
ERS-1 & ERS-2



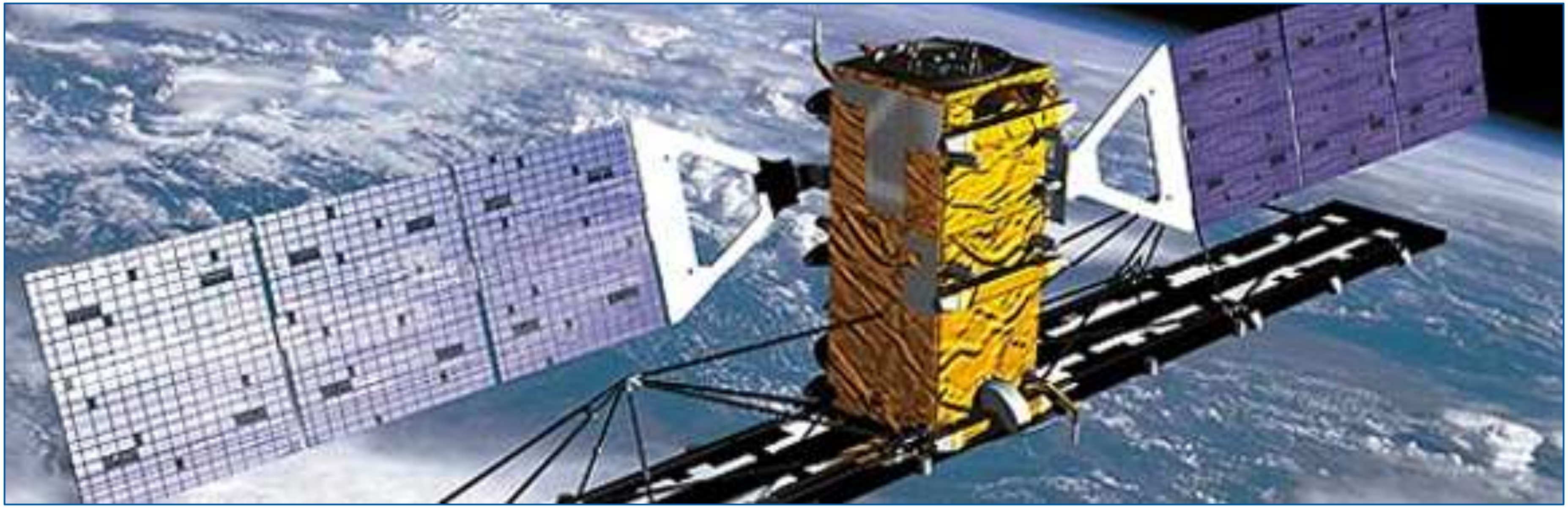
ENVISAT/ASAR



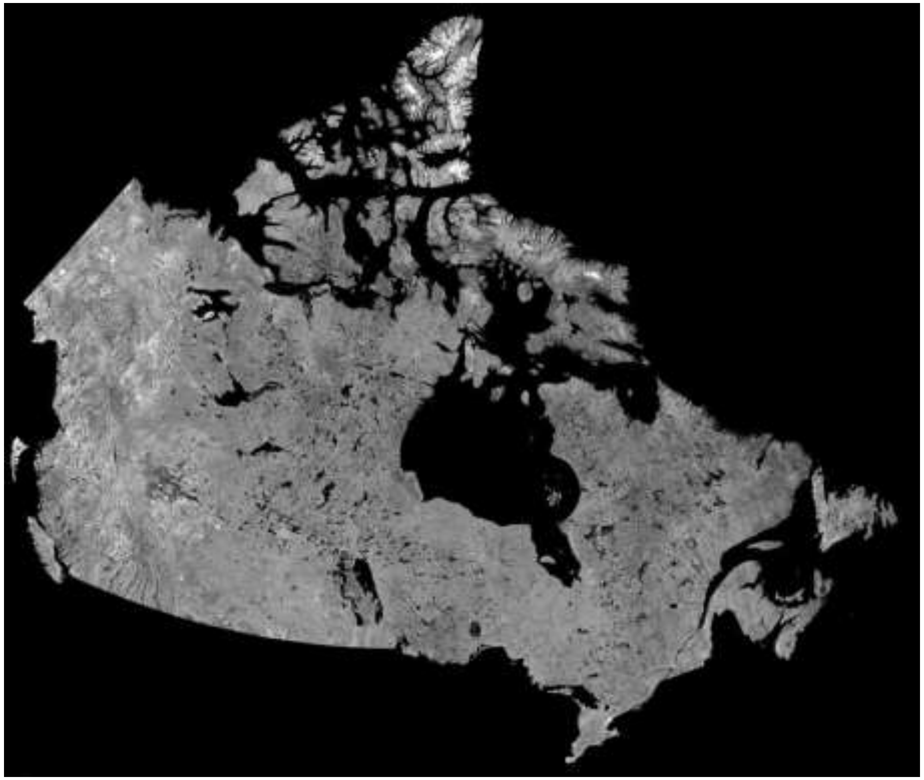
ENVISAT/ASAR

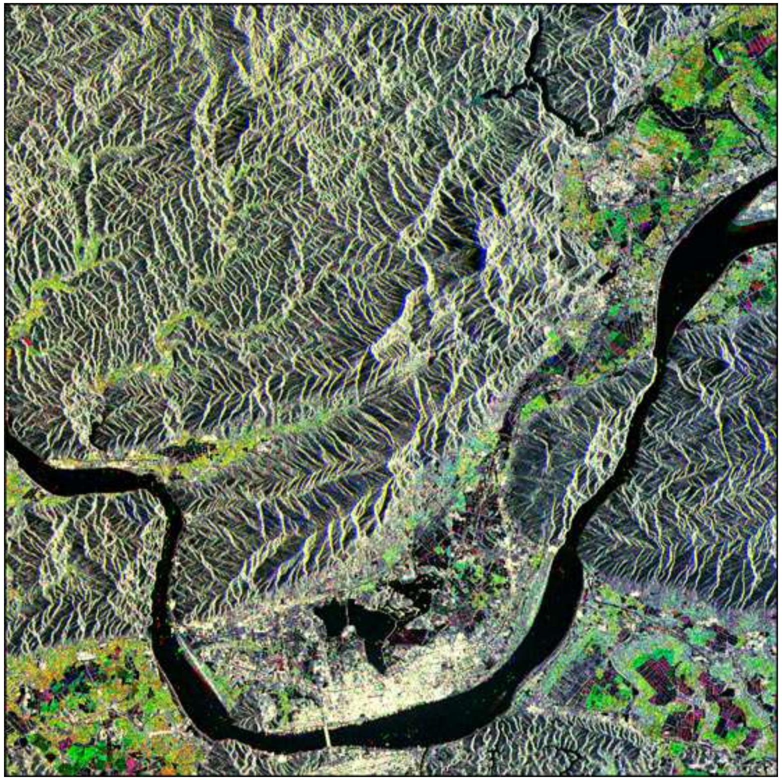


Radarsat



Radarsat

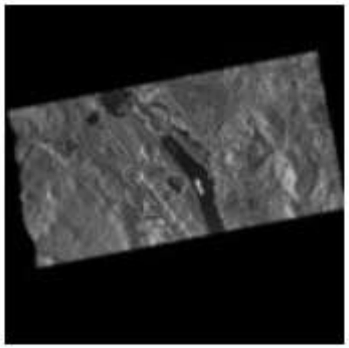




TerraSAR-X, Tandem-X

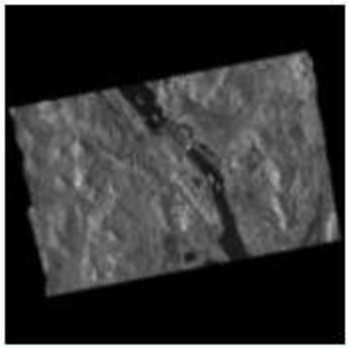
TerraSAR-X, Tandem-X

Staring SpotLight



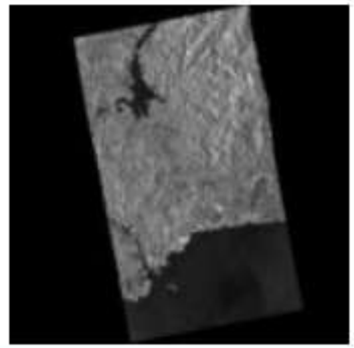
- Up to 25cm resolution
- Scene size depending on incidence angle, for example ~ 4km (width) x 3.7km (length) at 60°

High Resolution SpotLight



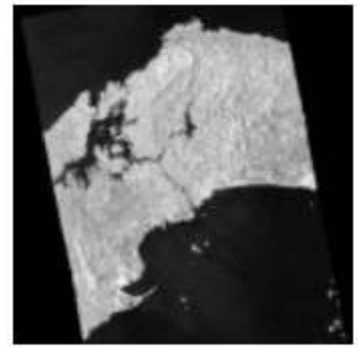
- Up to 1m resolution
- Scene size 5 to 10km (width) x 5km (length)

StripMap



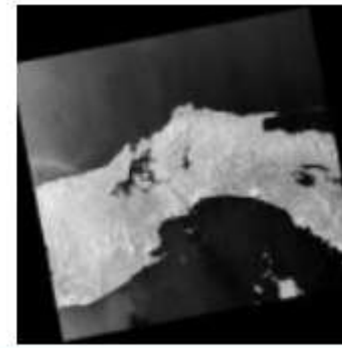
- Up to 3m resolution
- Scene size 30km (width) x 50km (length*)

ScanSAR



- Up to 18.5m resolution
- Scene size 100km (width) x 150km (length*)

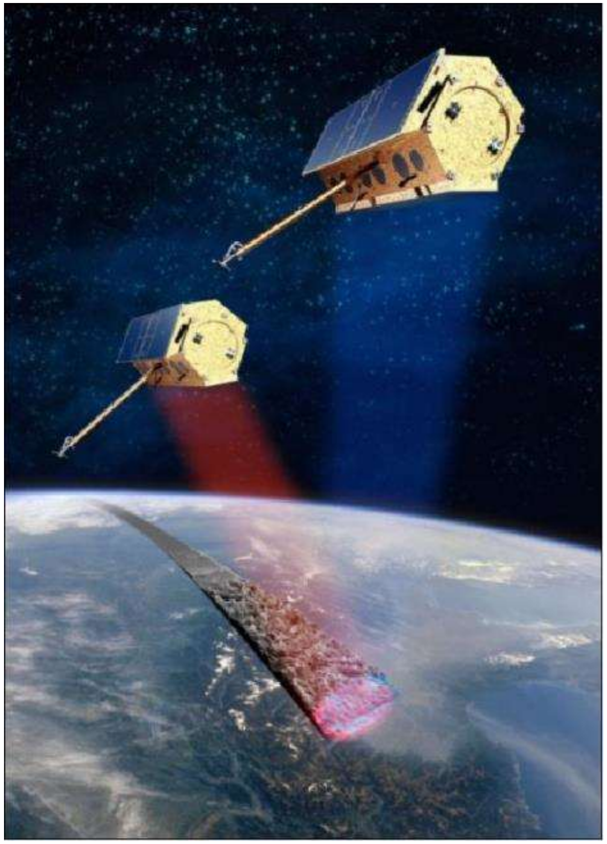
Wide ScanSAR

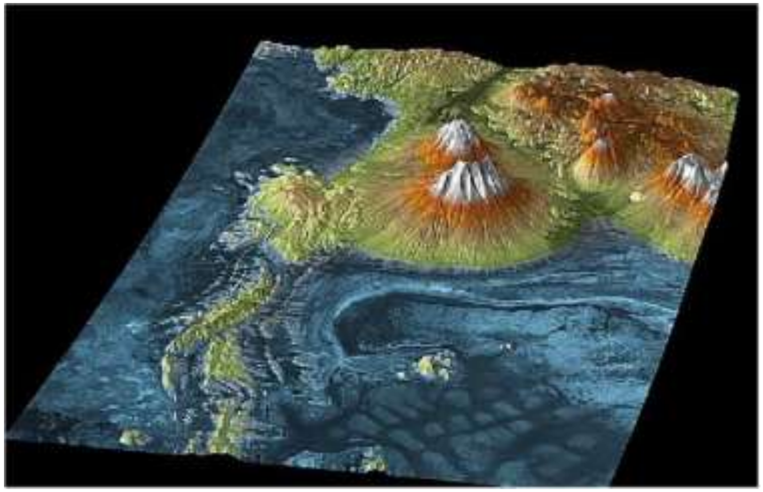


- Up to 40m resolution
- Scene size up to 270km (width) x 200km (length**)

TerraSAR-X, Tandem-X

Tandem-X

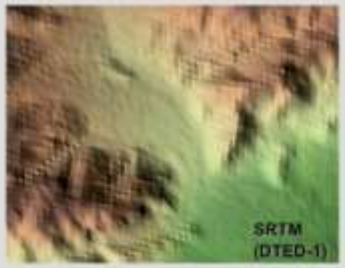




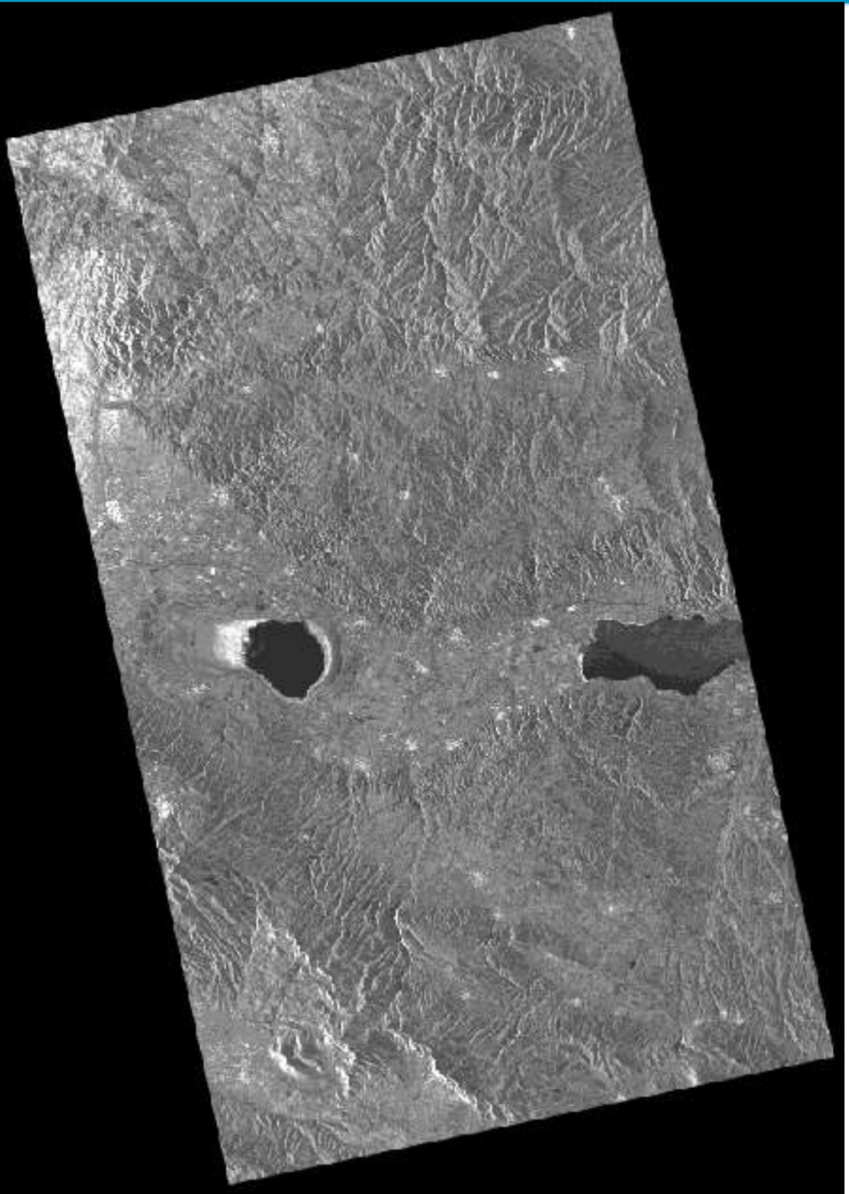
Primary Mission Objectives

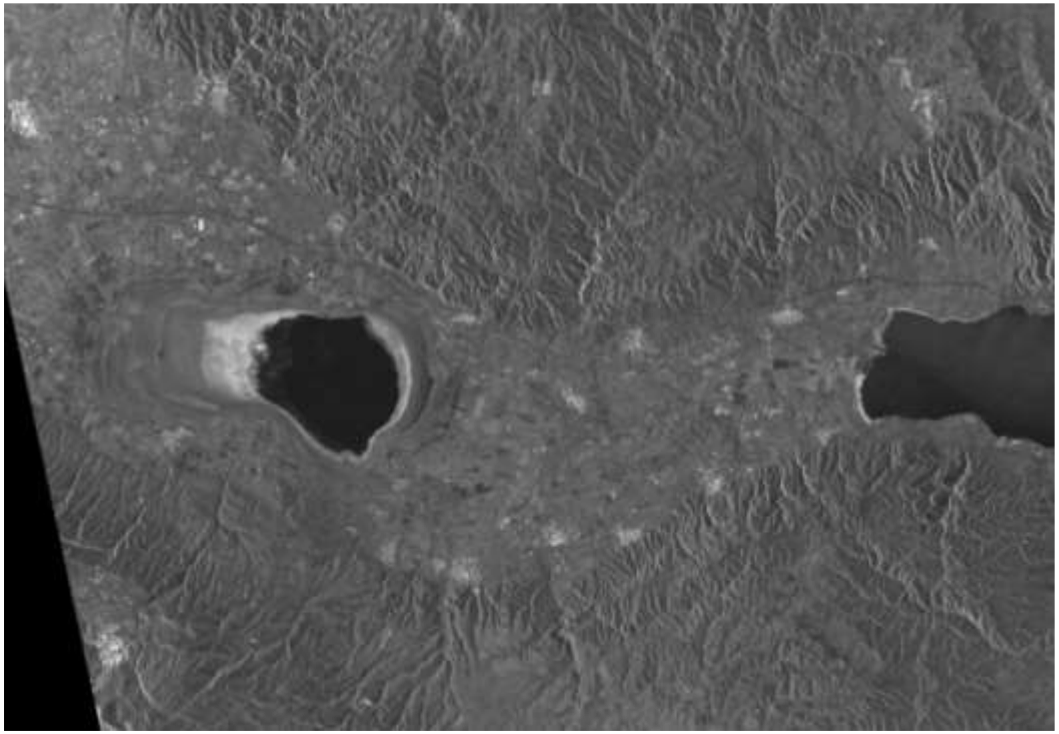
Standards for Digital Elevation Models (DEM)

DEMs	Spatial Resolution	Absolute Vertical Accuracy (90%)	Relative Vertical Accuracy (point-to-point in 1° cell, 90%)
DTED-1	90 m x 90 m	< 30 m	< 20 m
DTED-2	30 m x 30 m	< 18 m	< 12 m
TanDEM-X DEM	12 m x 12 m	< 10 m	< 2 m
HDEM	6 m x 6 m	< 5 m	< 0.8 m



TerraSAR-X, Tandem-X





Operational & Near-future EO missions:
The Sentinels (Copernicus)

1. **Sentinel-1: SAR mission for land and ocean services**

2. **Sentinel-2:** Optical high resolution land mission

3. Sentinel-3: Medium resolution land and ocean mission

4. Sentinel-4: Geostationary atmosphere mission

5. Sentinel-5: Low Earth orbit atmosphere mission

ESA Sentinel 1 Mission

C-band SAR Mission

Sentinel-1A (3/4/2014)
Sentinel-1B (25/4/2016)

Applications:

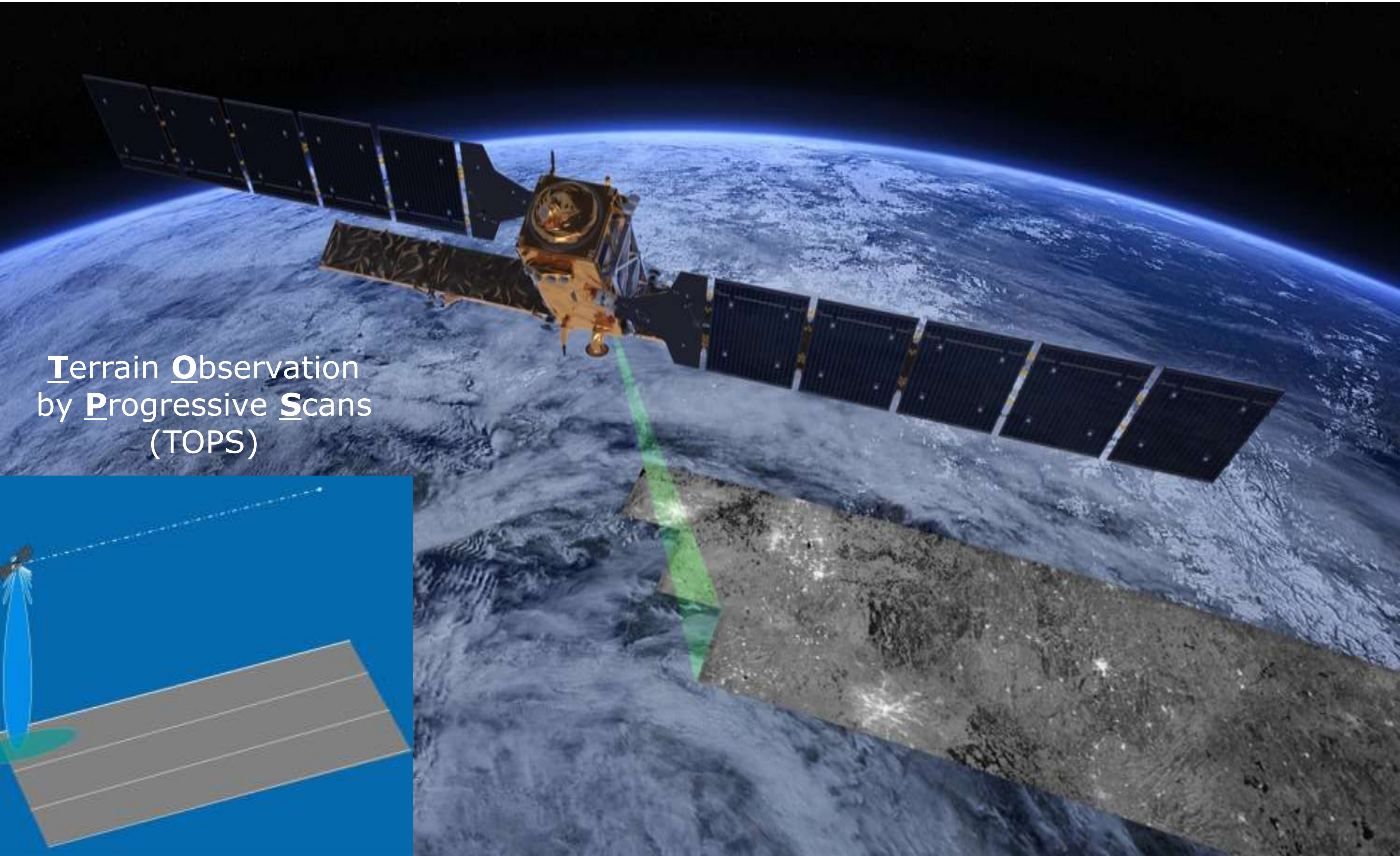
- Ice and marine/land monitoring;
- Mapping in support of humanitarian aid in crisis situations.

Main features:

- C-band (5.4 GHz) SAR
- Daily coverage of high priority areas;
- Bi-weekly global coverage;
- 12 days repeat cycle (6 days with both Sentinels 1A and 1B operational);
- 7 years design life-time (consumables for 12 years).

Modes	Resolution	Swath Width	Polarization
Stripmap (SM)	5 x 5 m²	> 80 km	HH+HV or VV+VH
Interf. Wideswath (IW)	**5 x 20 m²**	**> 250 km**	**HH+HV or VV+VH**
Extra Wideswath (EW)	25 x 100 m²	> 400 km	HH+HV or VV+VH
Wave (W)	5 x 20 m²	20 x 20 km² @ 100 km spacing	HH or VV

Image Acquisition in Interferometric Wide Swath mode (IW)



Terrain **O**bservation by **P**rogressive **S**cans (TOPS)

C-band SAR comparison

PARAMETERS	ERS 1/2	ENVISAT	Radarsat 1/2	Sentinel 1A/B
Centre frequency (GHz)	5,300	5,331	5,3 / 5,405	5,405
Polarization	VV	HH/VV, HH/VH, VV/HH	HH / HH, HV, VV, VH	HH+HV, VV+VH
Incidence angles (°)	23	15 - 45	20 - 49	20 - 45
Orbit (km)	800	800 → 783 (2010+mission)	793-821 / 798	693
Inclination (°)	98,5	98,5	98,6	98,18
Repeat cycle (day)	35	35	24	12 (6)
Launch date	17 Jul. 1991 / 21 Apr. 1995	1 March 2002	4 Nov. 1995 / 14 Dec. 2007	3 April 2014 / 2016
Spatial resolution (m)	25	25	30	20
Swath width (m)	100	100	100	250

ESA Sentinel 1 Mission

C-band SAR Mission

Sentinel-1A (2014)
Sentinel-1B (2016)

Advantages with respect to previous ESA SAR missions :

- Radar data will be delivered within an hour of acquisition;
- Shorter time necessary to create a stack exploitable;
- Capability to observe faster phenomena due to the shorter repeat time;
- Reduced orbital tube (i.e., maximum allowed orbital deviation with respect to the nominal orbit) ➜ smaller baselines ➜ all possible interferometric pairs satisfy the conditions of the Small Baseline approach (SBAS).

Active microwave remote sensing properties

1. **Pros**
   a. Day and night observation capability
   b. Insensitive to cloud coverage
   c. High “operationability”
2. **Cons**
   a. Human eyes not “trained” for microwaves
   b. Technology is more demanding than for optical remote sensing
   c. More expensive than optical RS
   d. Needs high power

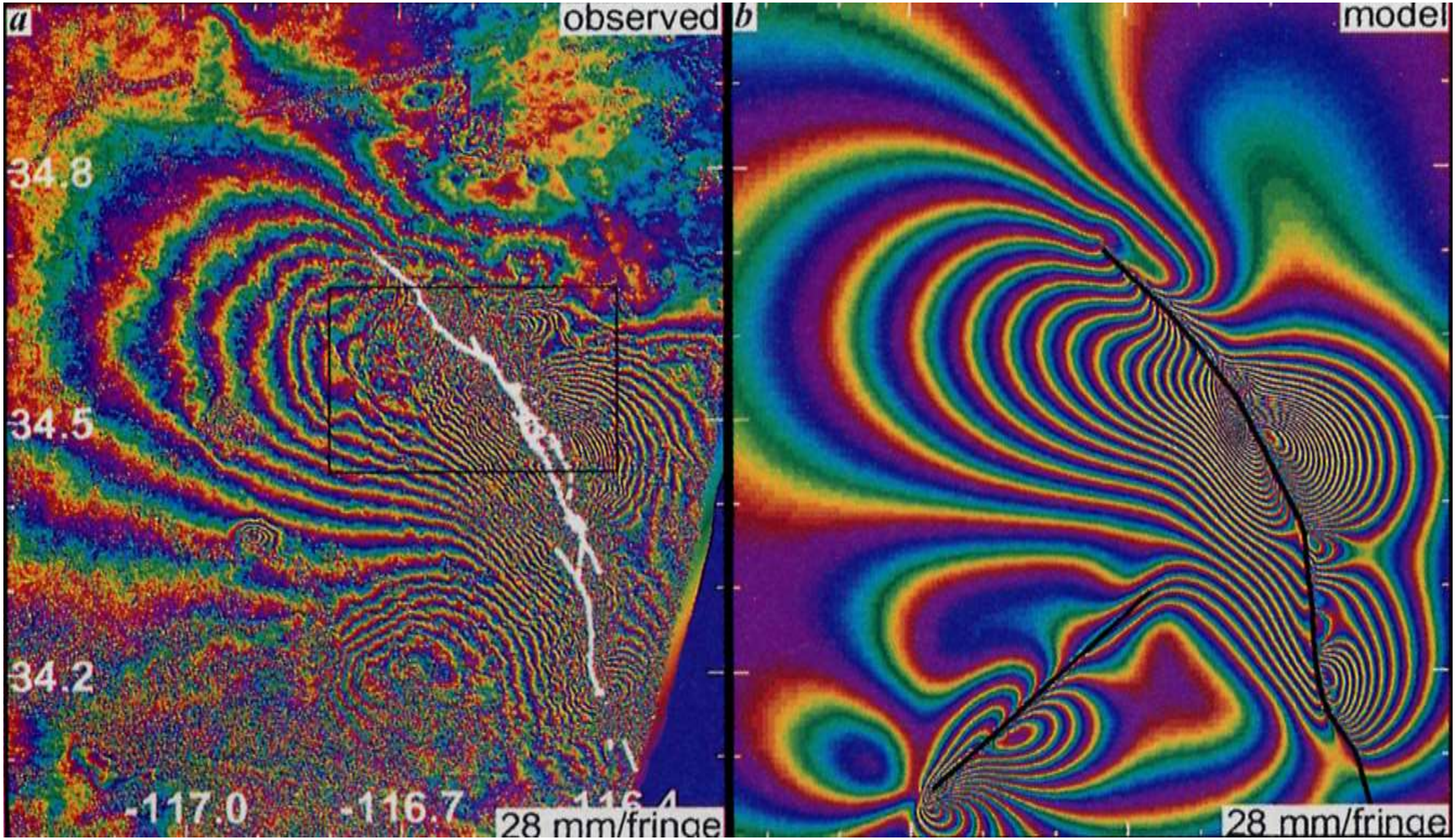
Optical vs. Microwave Remote Sensing

Parameter	Optical RS	Active microwave RS
Wavelength	λ << object	λ ~ object
Frequency	Several bands	A few bands (frequencies)
Polarisation	None	Up to fully polarimetric
Illumination	Passive (sun)	Active (antenna)
Observation times	Day only	Day and night
Cloud coverage	Very sensitive	Independent
Data calibration	Difficult	Difficult
Ground resolution	~ decameters	~ deca-hectometers
Image quality	No speckle	Speckle
Incidence angle	~ Nadir	$20\text{-}60^{o}$
Measurements	Chemical & physical processes	Roughness, geometry, water content, dielectric constant

Indicative

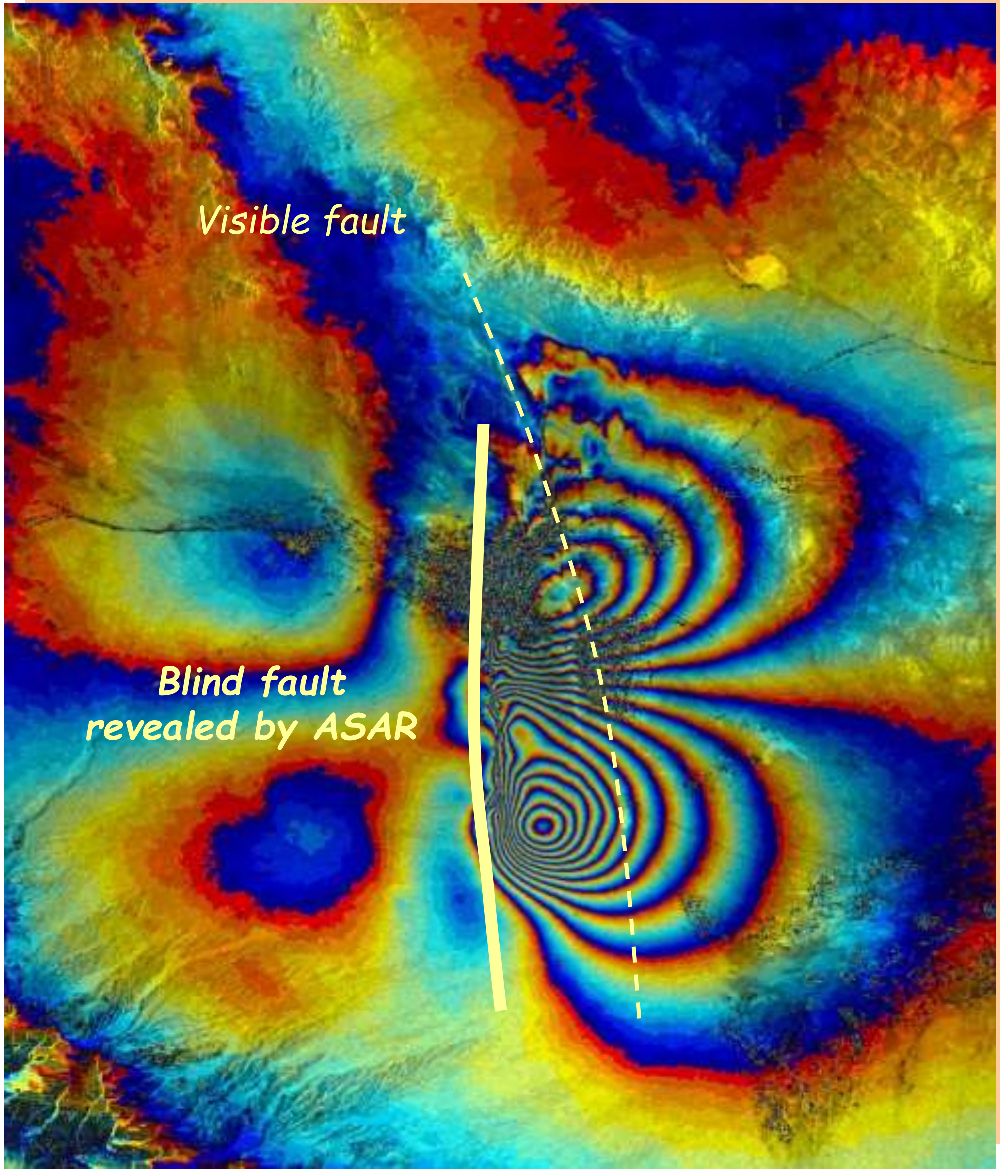
Applications

Deformation detection & monitoring

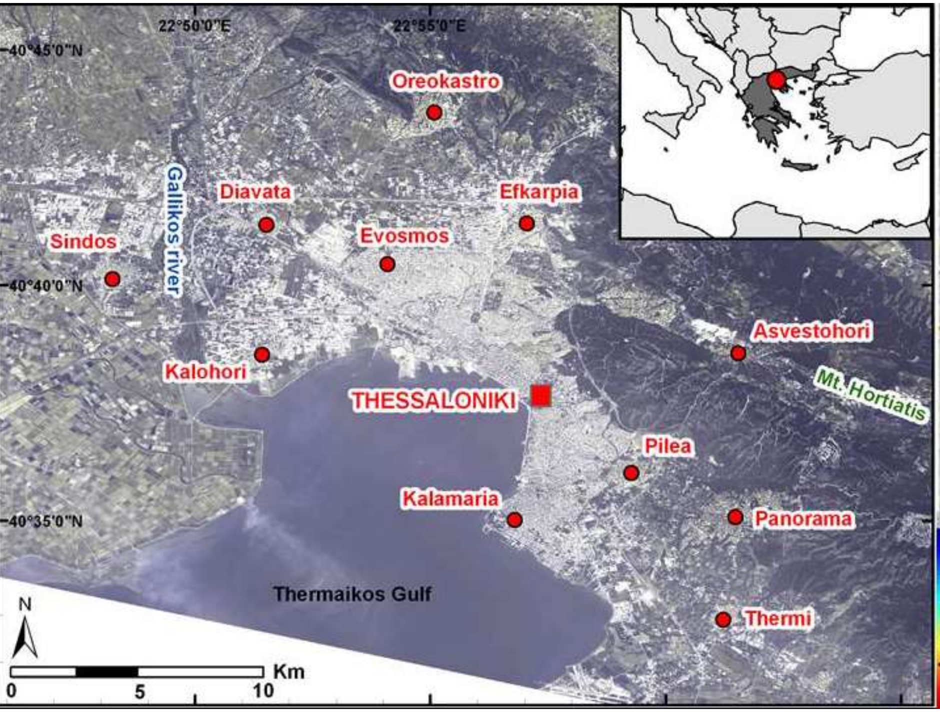


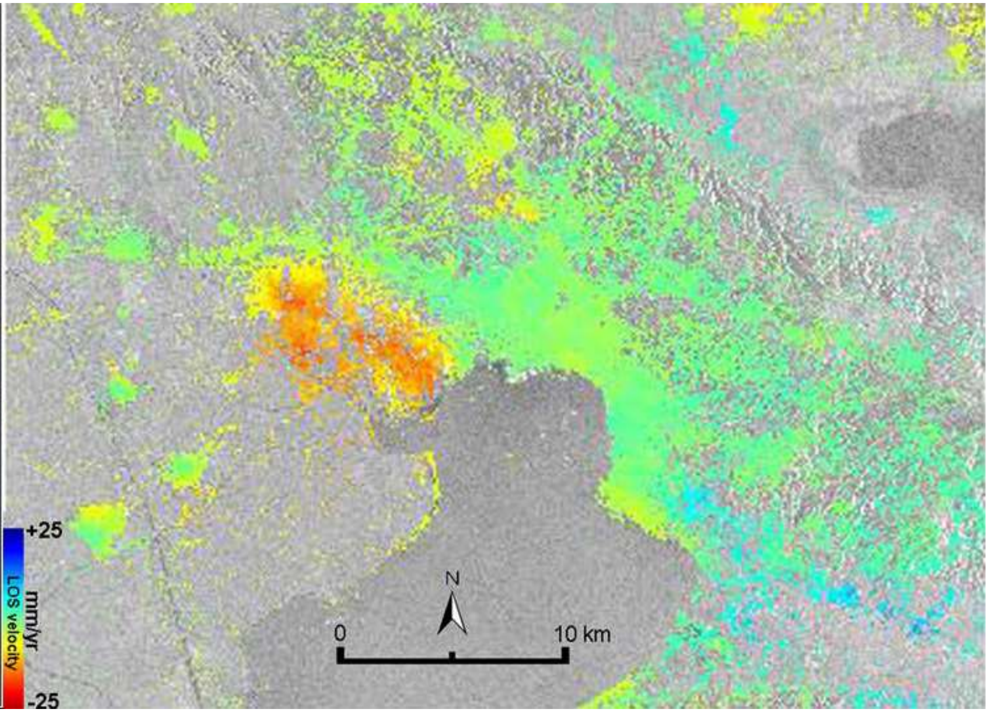
The displacement field of the Landers earthquake mapped by ERS radar interferometry (Massonnet et al., 1993)

Coseismic Deformation of Bam Earthquake 26/12/03



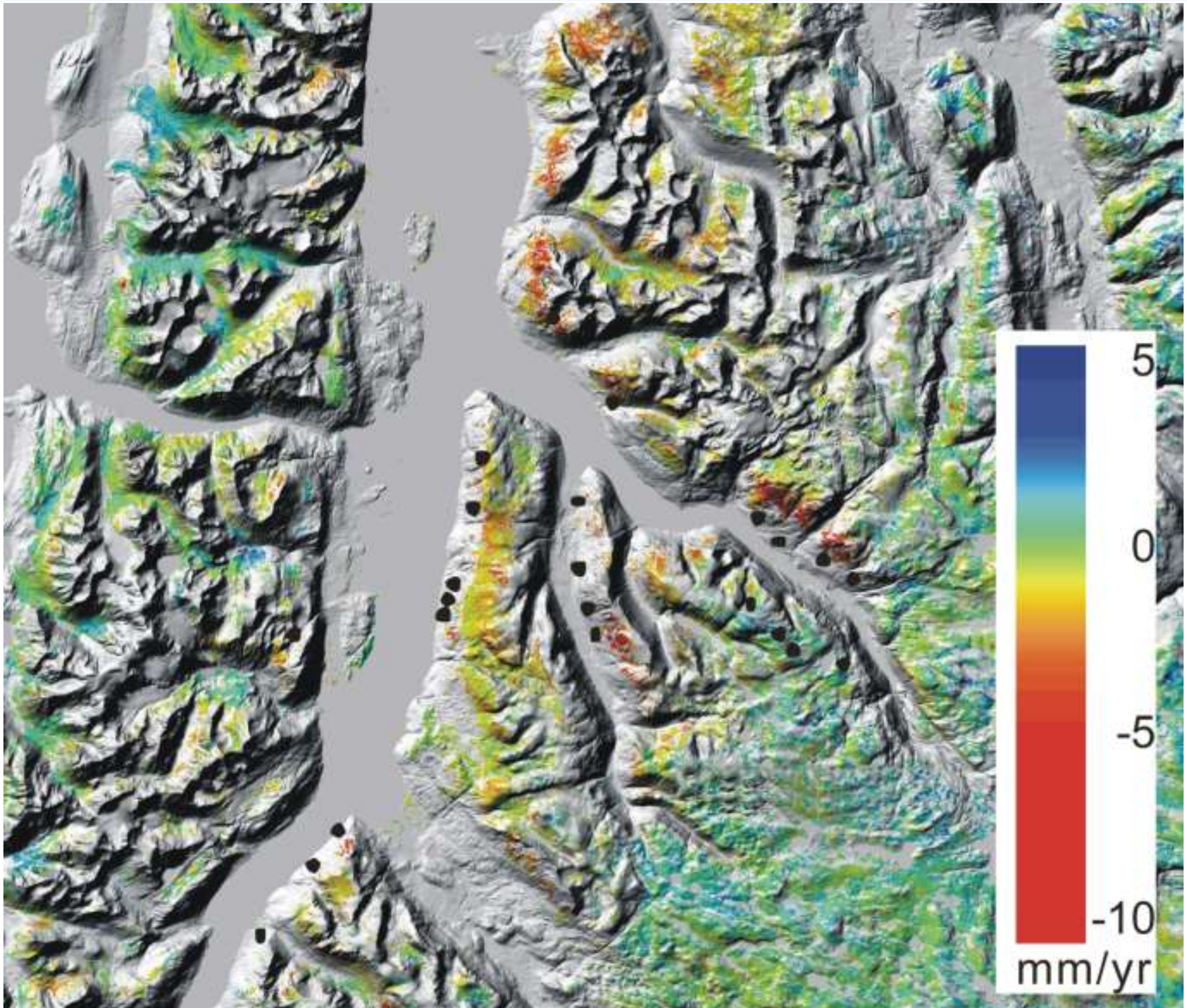
Deformation monitoring





2004-2010 subsidence monitored by PS InSAR, using Envisat/ASAR data (Mouratidis and Costantini, 2012)

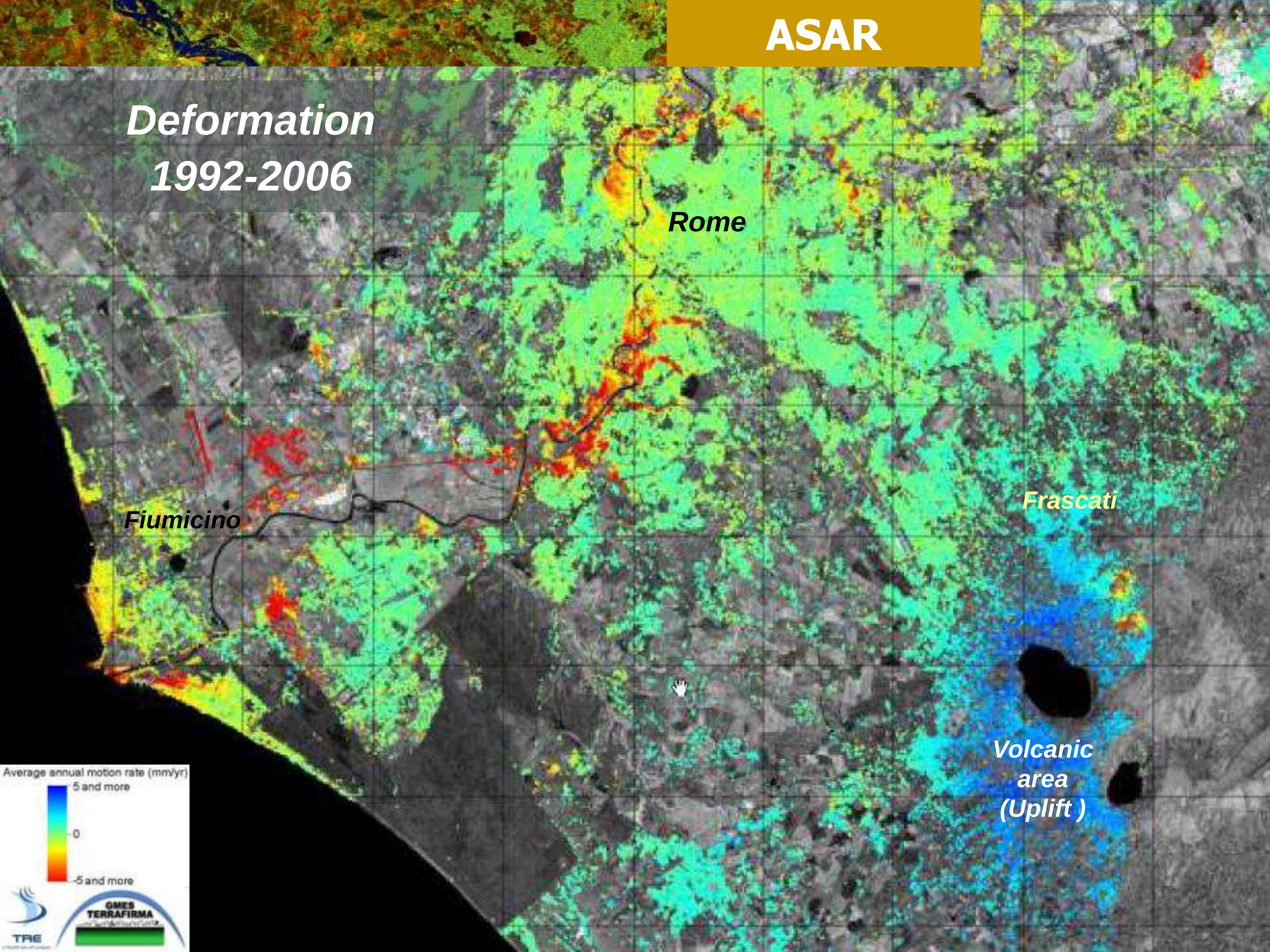
SAR Interferometry



European Space Agency

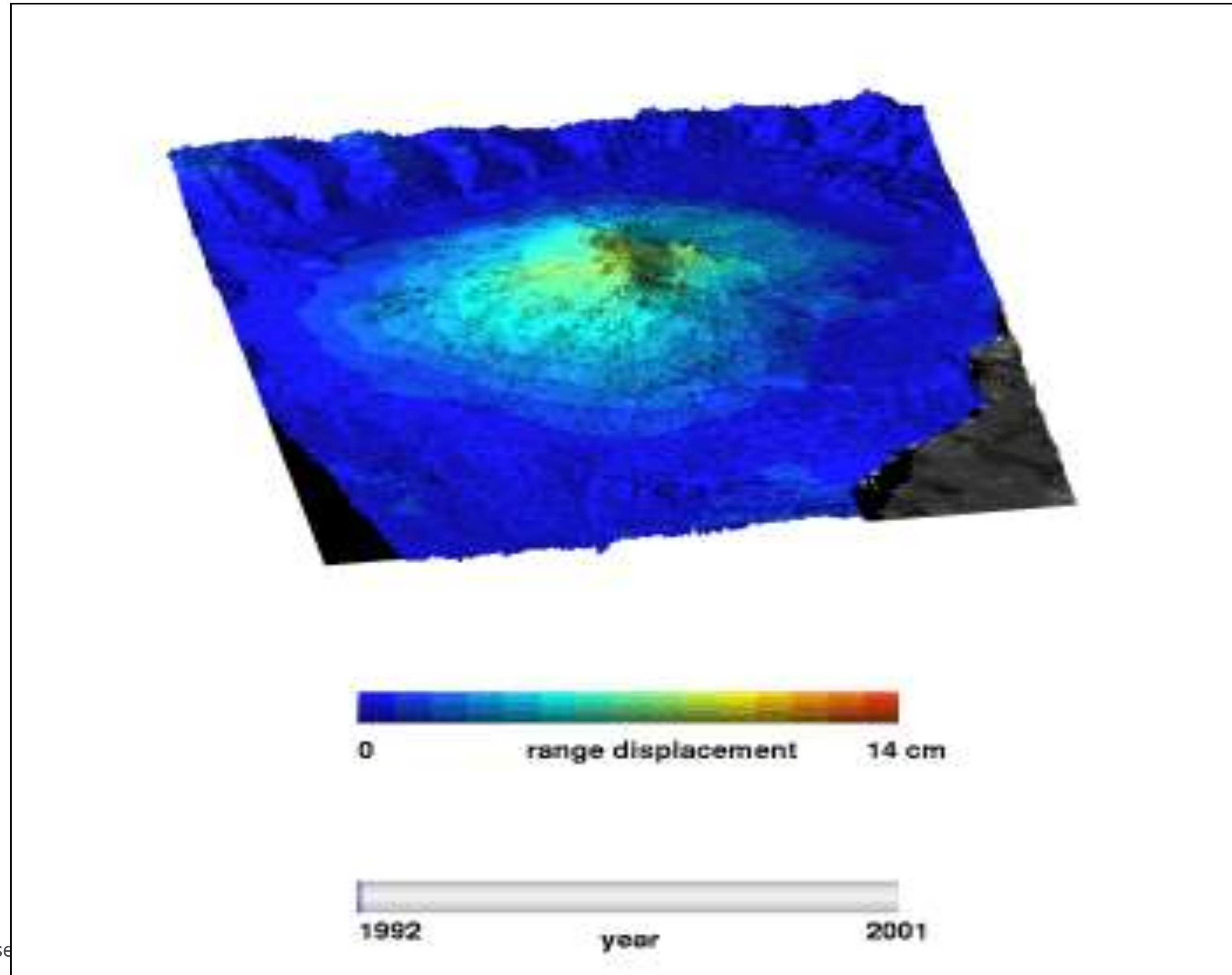
(Credits: Lauknes, T.R.)

ASAR



Deformation
1992-2006
Rome
Fiumicino
Frascati
Volcanic
area
(Uplift)
Average annual motion rate (mm/yr)
5 and more
0
-5 and more
TRE
GMES
TERRAFIRMA

Deformation of Etna (1992 - 2001)



Credits: ESA

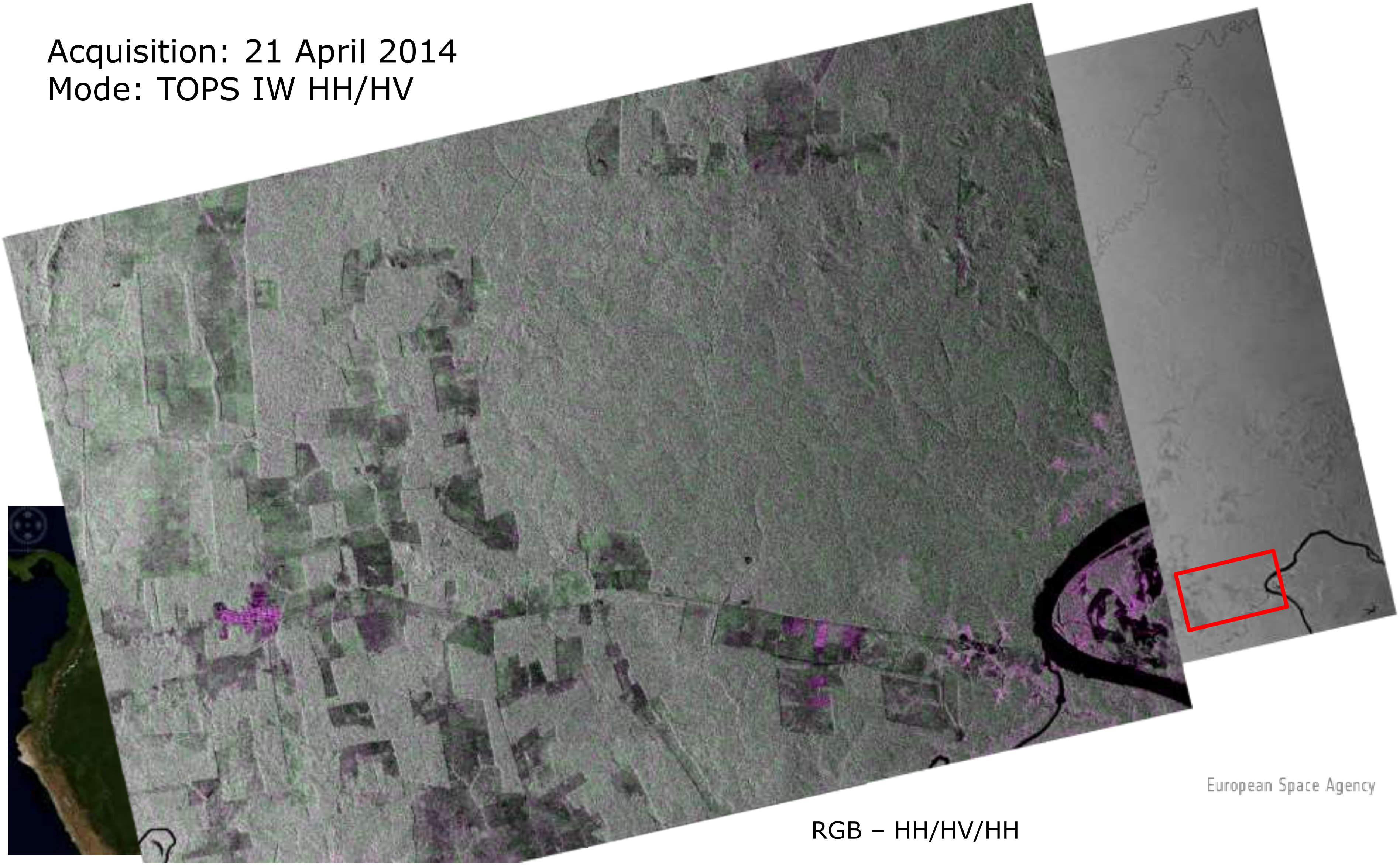
Classification/Land cover

Drawbacks & solutions

1. SAR typically consist of 1-2 bands
2. Maximum of 4 bands (fully polarimetric modes, e.g. Radarsat-2)
3. Use Coherence (also as additional band for FCCs)

Sentinel-1A Deforestation over Brazil

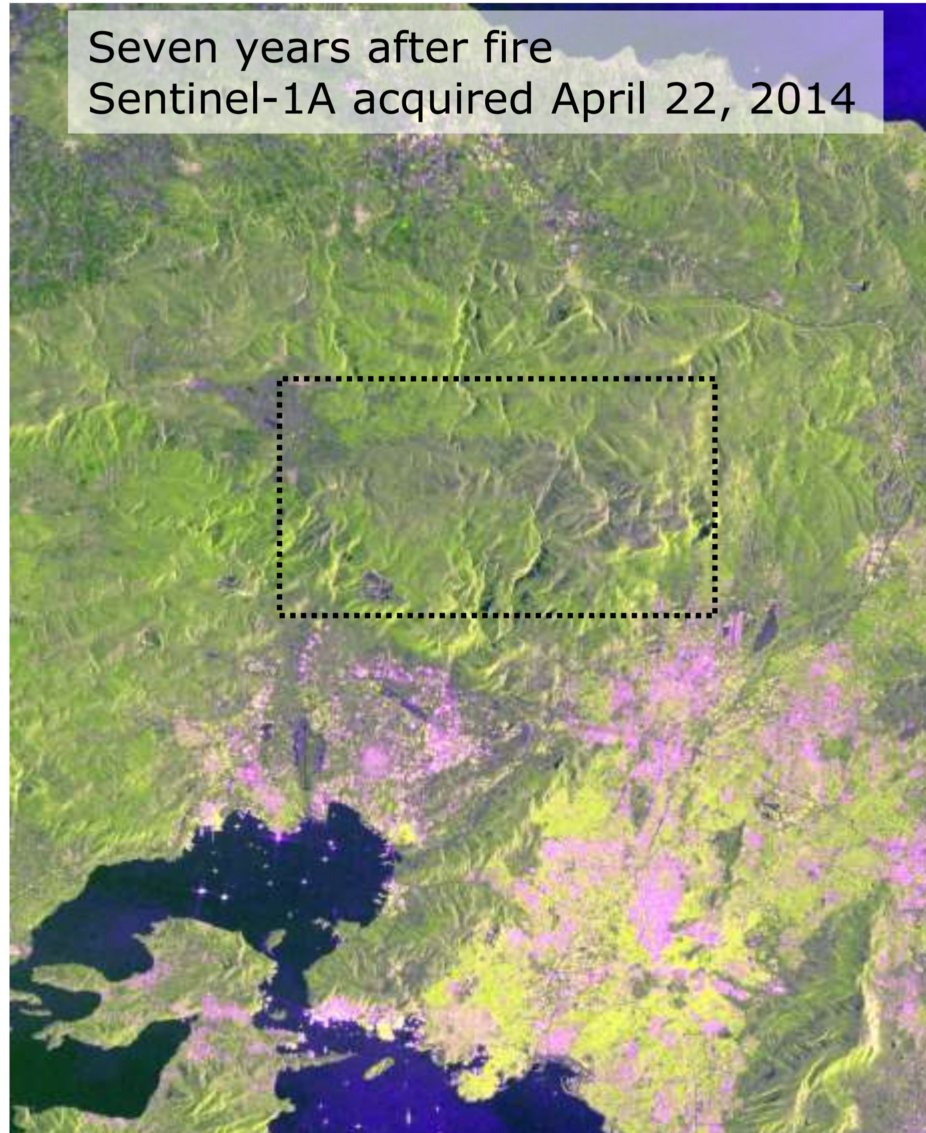
Acquisition: 21 April 2014
Mode: TOPS IW HH/HV



RGB – HH/HV/HH

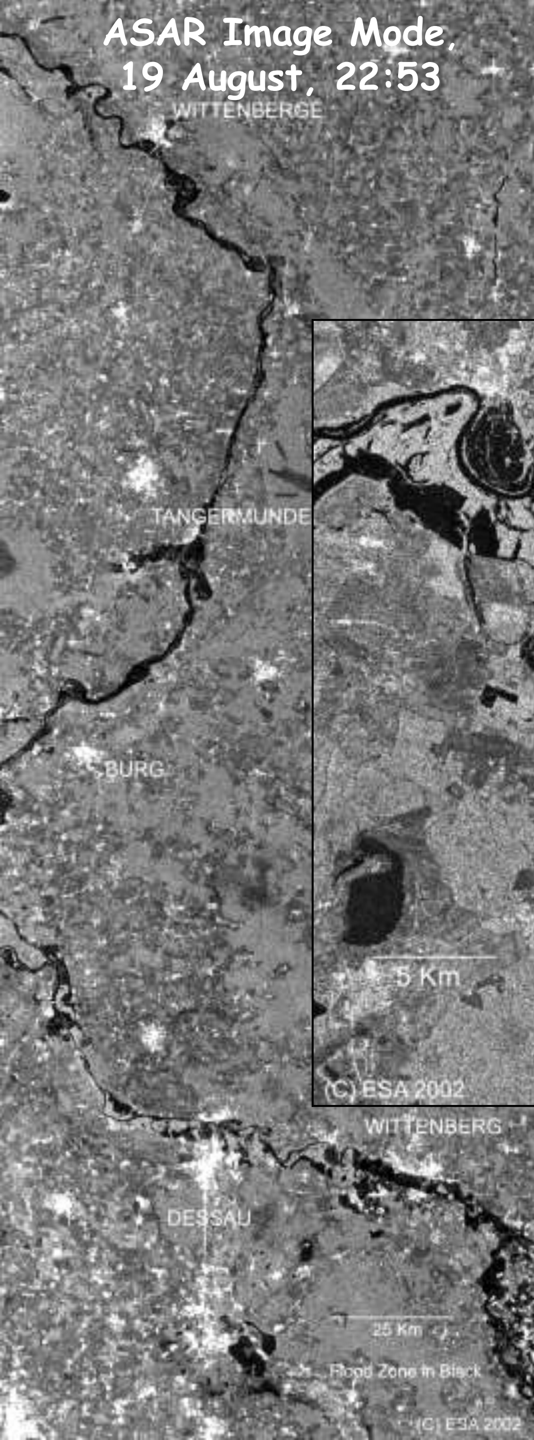
Vegetation Regeneration

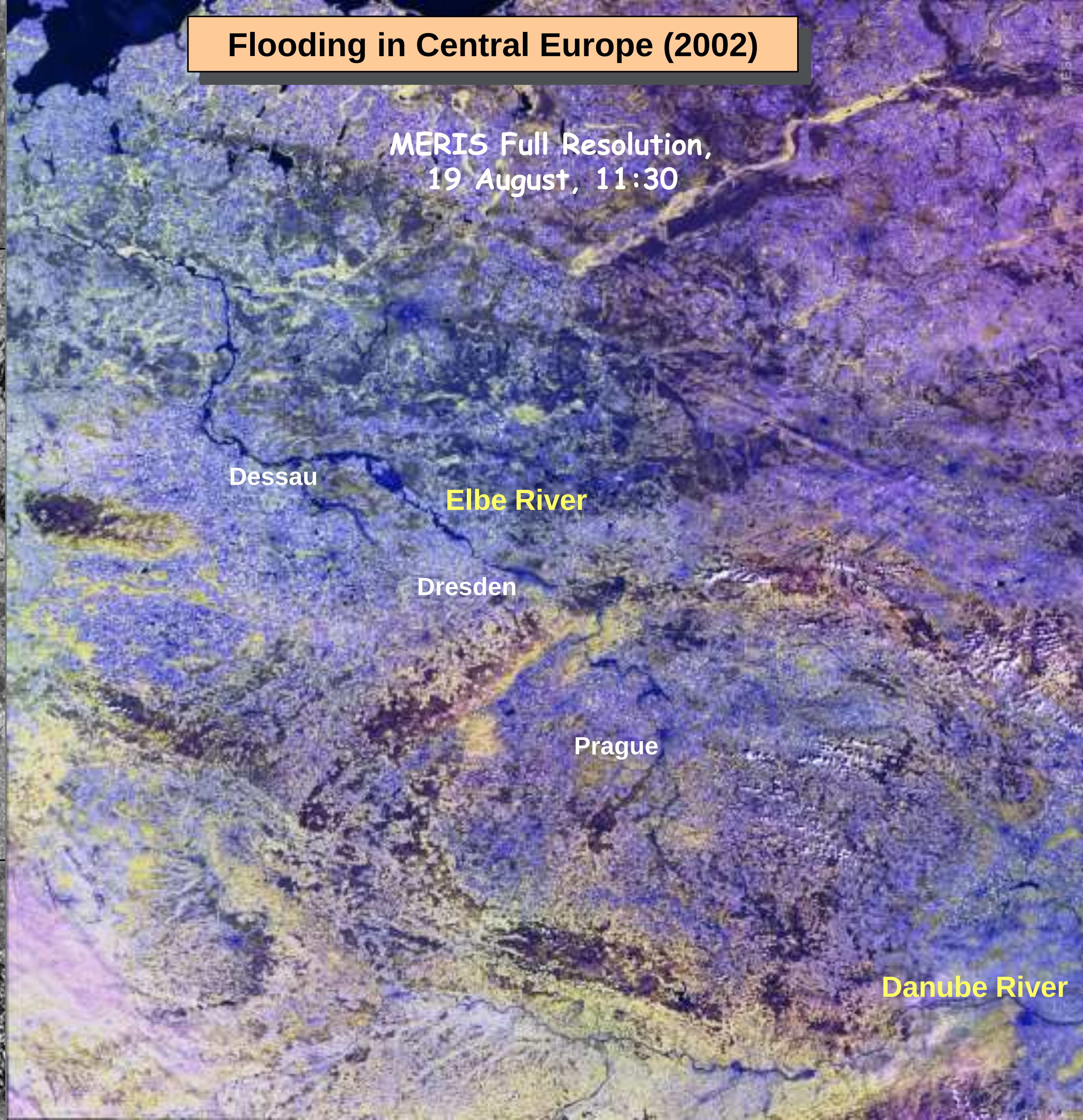
Burn Scar over Parnitha Mt. (Greece)



Flood mapping

Flooding in Central Europe (2002)





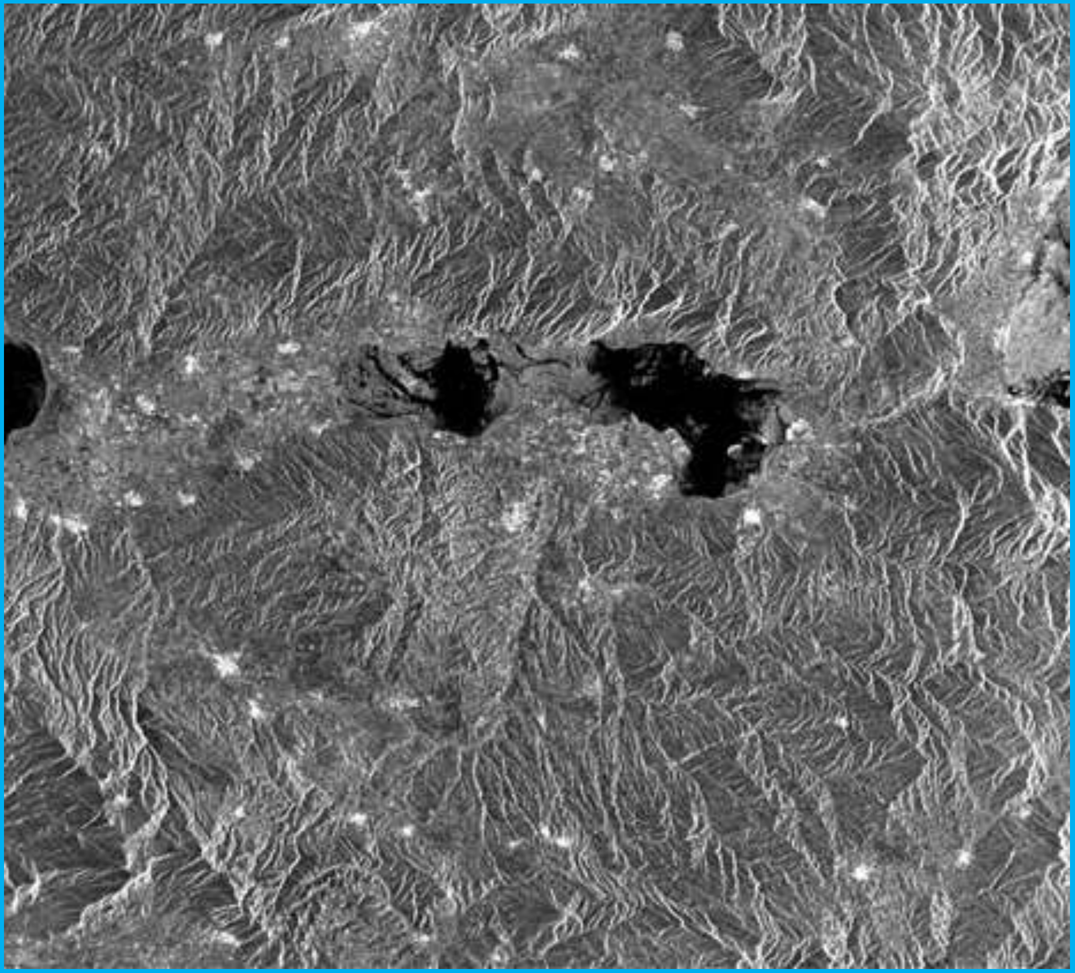
SAR

Surface roughness

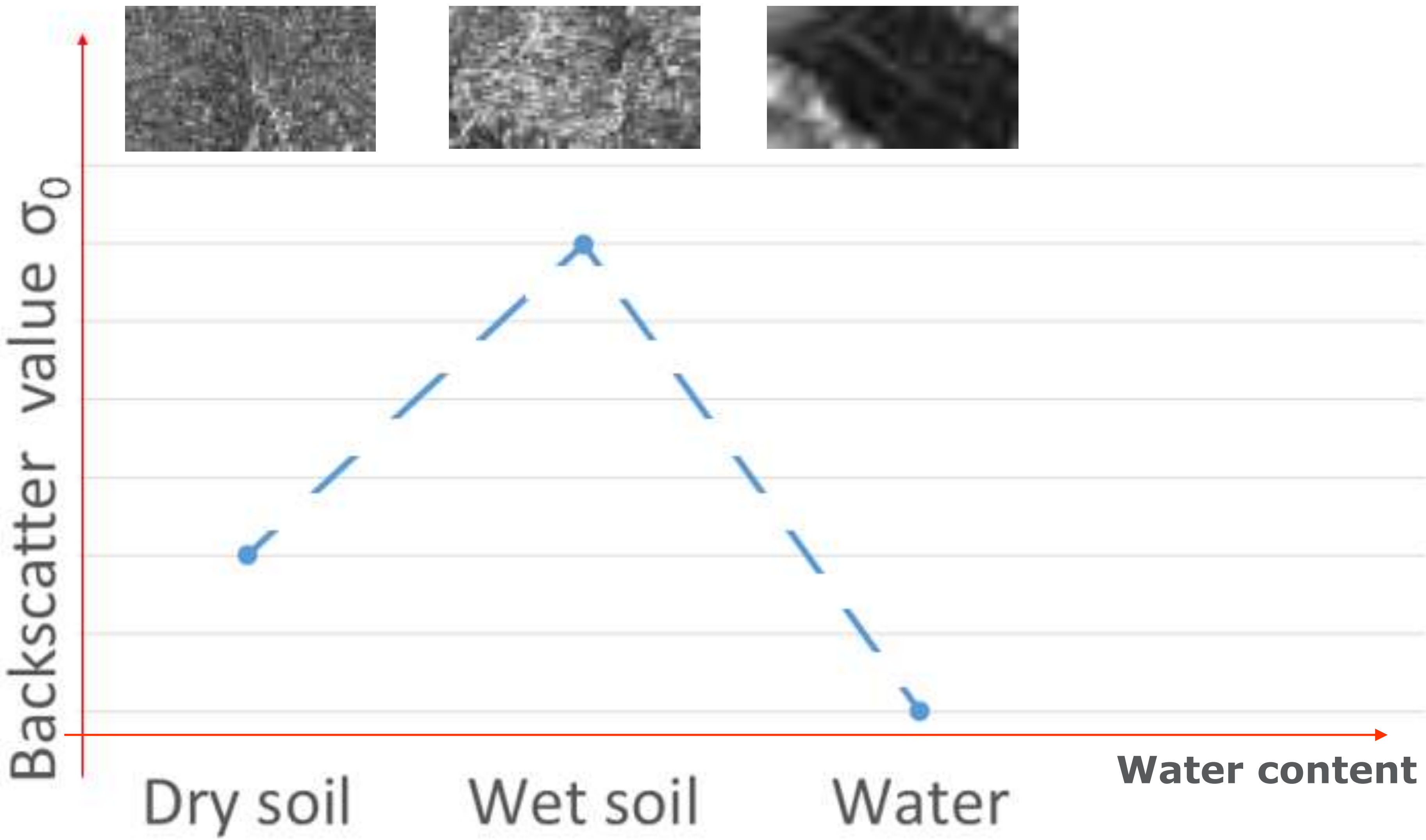
backscattering

Surface roughness

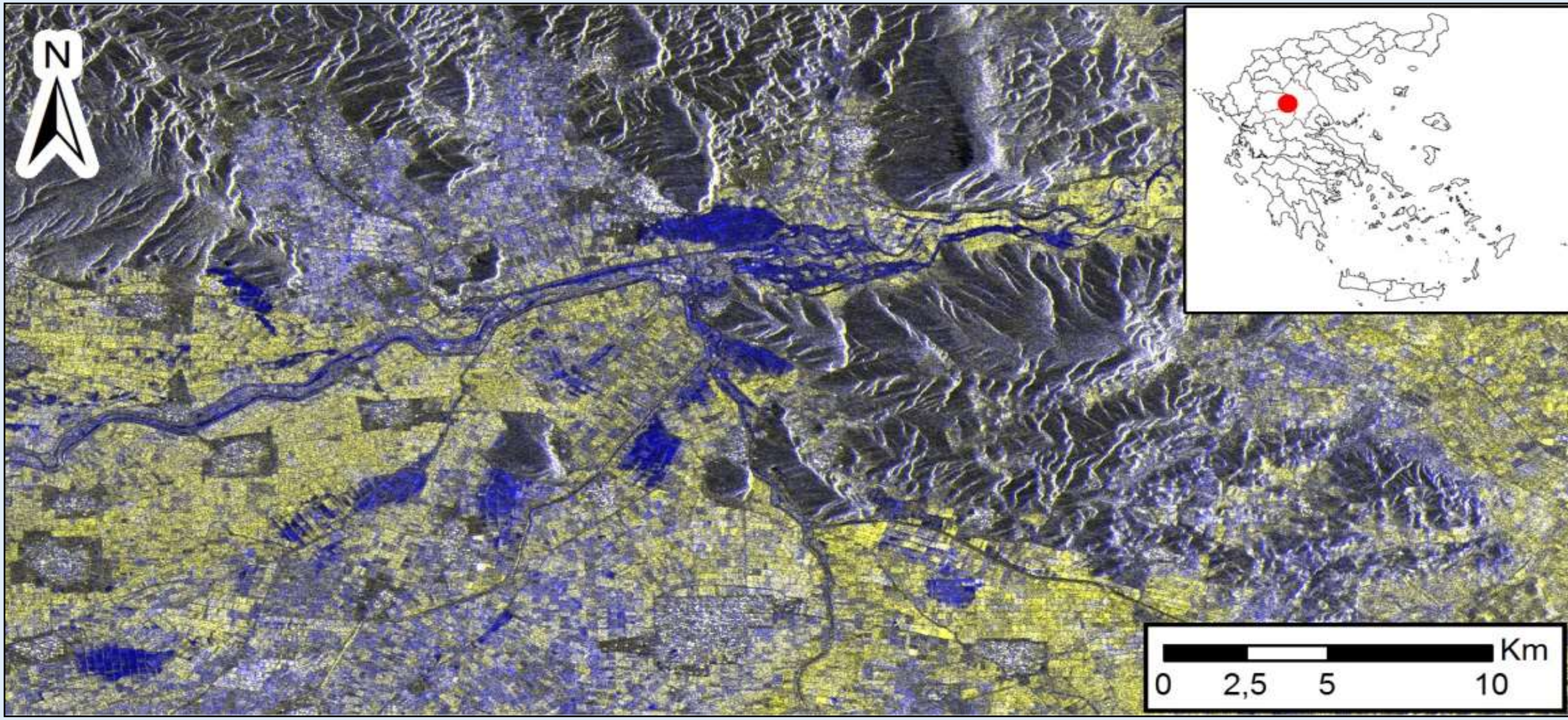
backscattering



The…strange σ_0 - water relationship



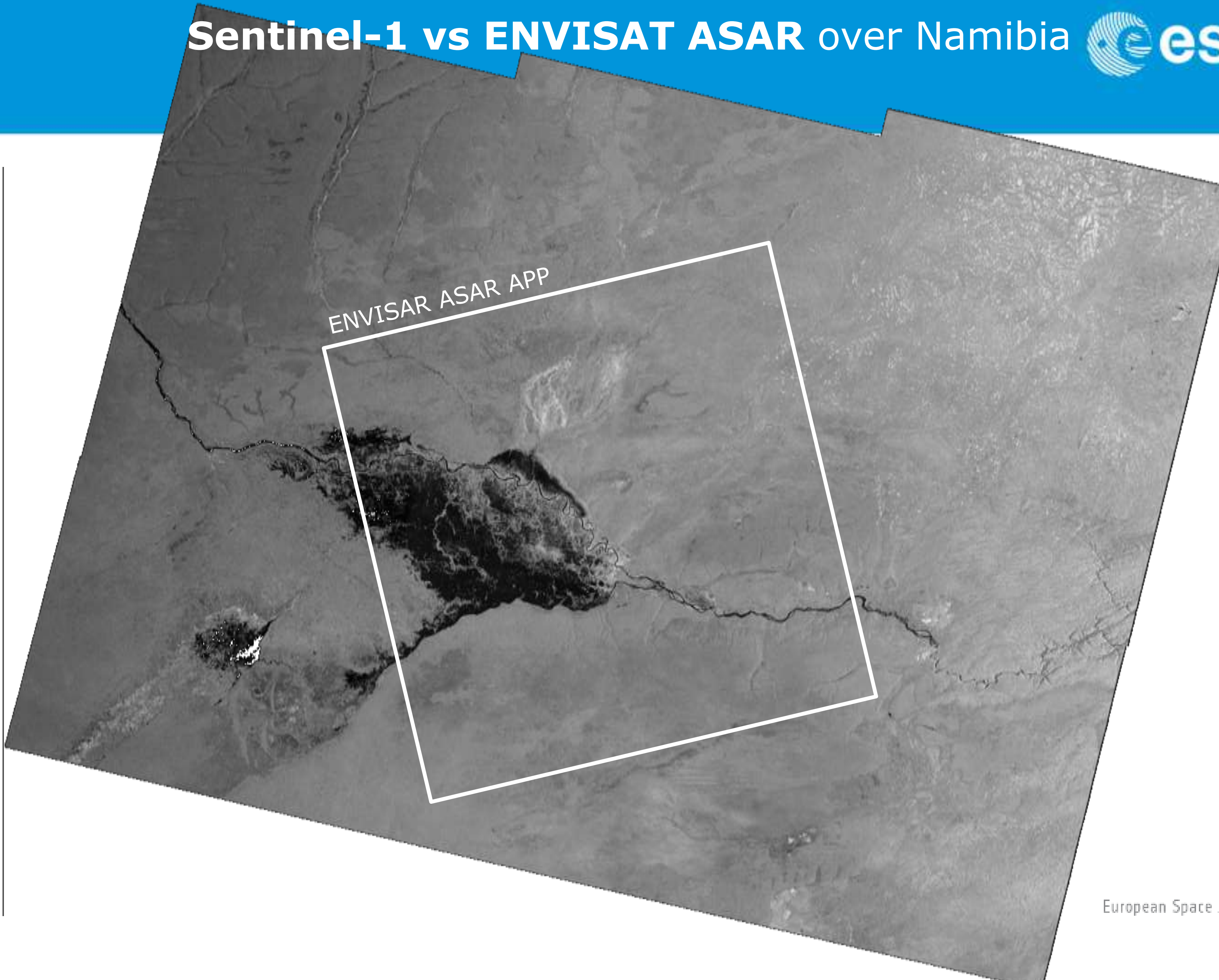
SAR image analysis



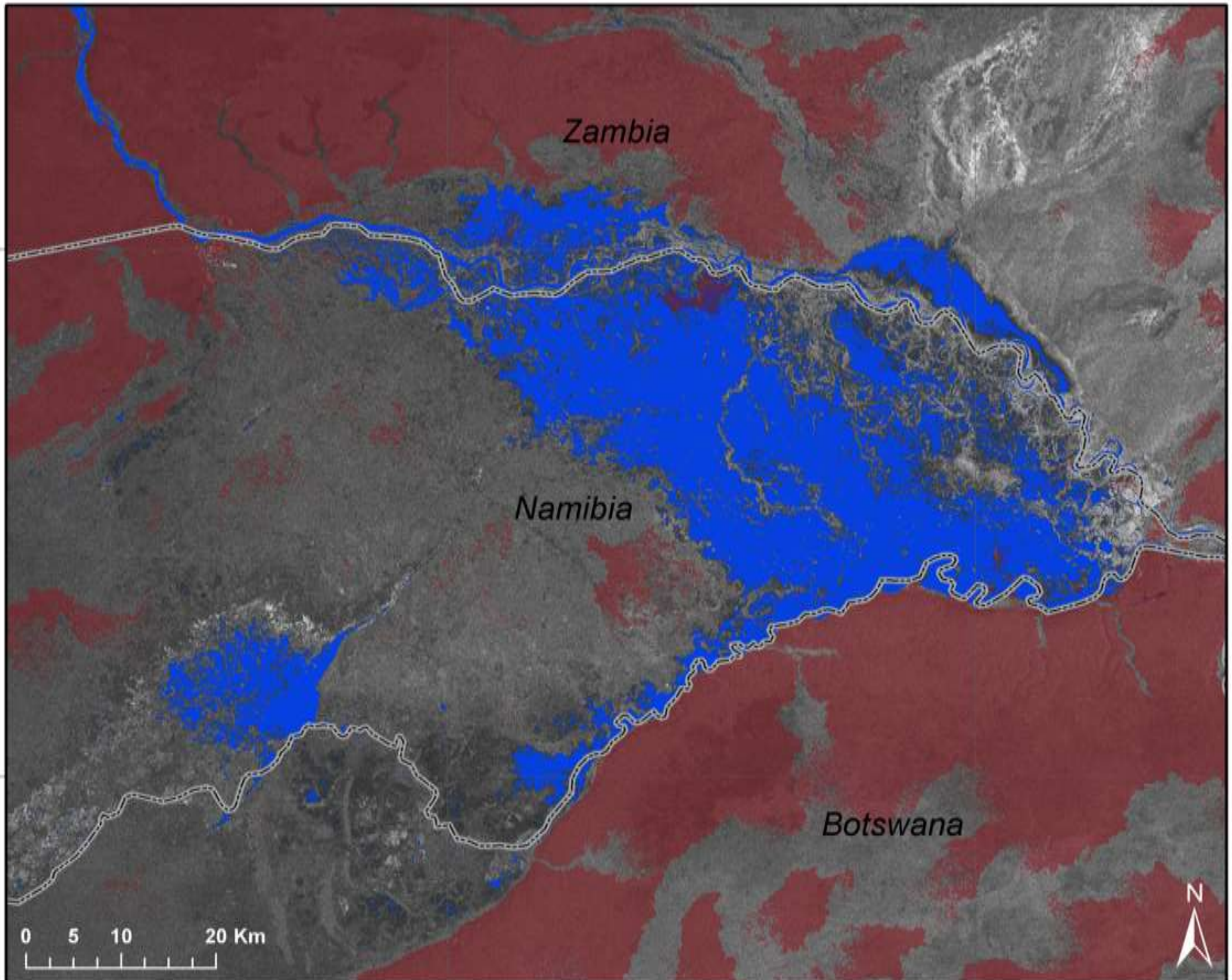
Case study: Thessaly

Floods along Pinios river, near Piniada, Farkadona and surrounding areas captured by ERS-2 during the crisis phase. SAR RGB false colour composite: R=G=02/02/2003 (flood image), B= 06/02/2005 (dry conditions). Blue = flooded regions, Yellow = wet soil.

Sentinel-1 vs ENVISAT ASAR over Namibia



Sentinel-1 Flood Monitoring of Caprivi Flood Plain, Namibia



Legend

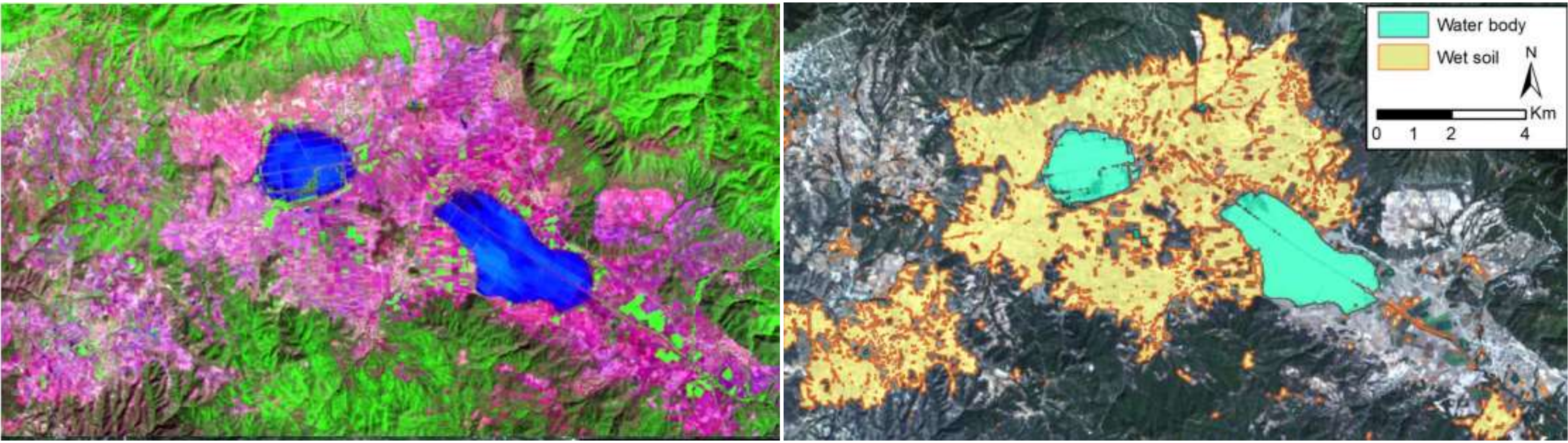
- Country border
- Derived HAND Index > 10 m
- Flooded areas

Description:
This map shows the flooding situation in the Caprivi flood plain of Zambezi River on 13th of April, 2014. The flood was delineated with the Water Observation and Information System (WOIS) based on SENTINEL-1A satellite data.

Source data:
SENTINEL-1A IW mode, 20 m resolution, acquired on 13th of April, 2014 at 03:50 GMT.
SENTINEL-1 image was provided by the European Space Agency.

Cartographic Reference
Projection: EPSG:4326
Datum: WGS 84

Optical imagery

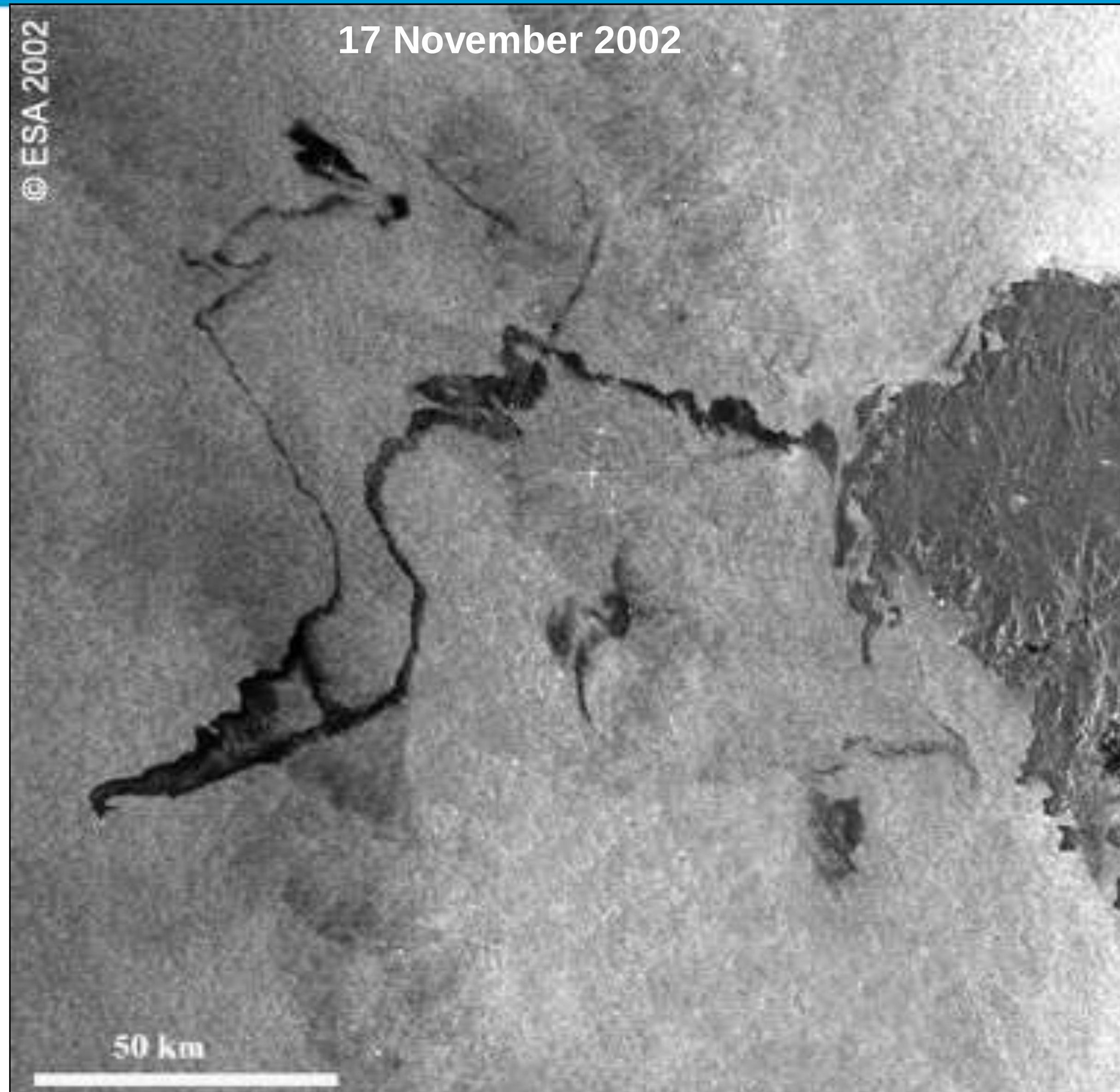


Case study: Thessaloniki

Results from the 2011 floods near Thessaloniki; Left: Landsat- 5/TM image, R/G/B: 7/4/3, depicting the flooded areas in blue colours. Right: Classified Landsat-5/TM image depicting water and wet soil classes.

Other SAR Applications

Oil slick from “Prestige” tanker
(Galicia, Spain)

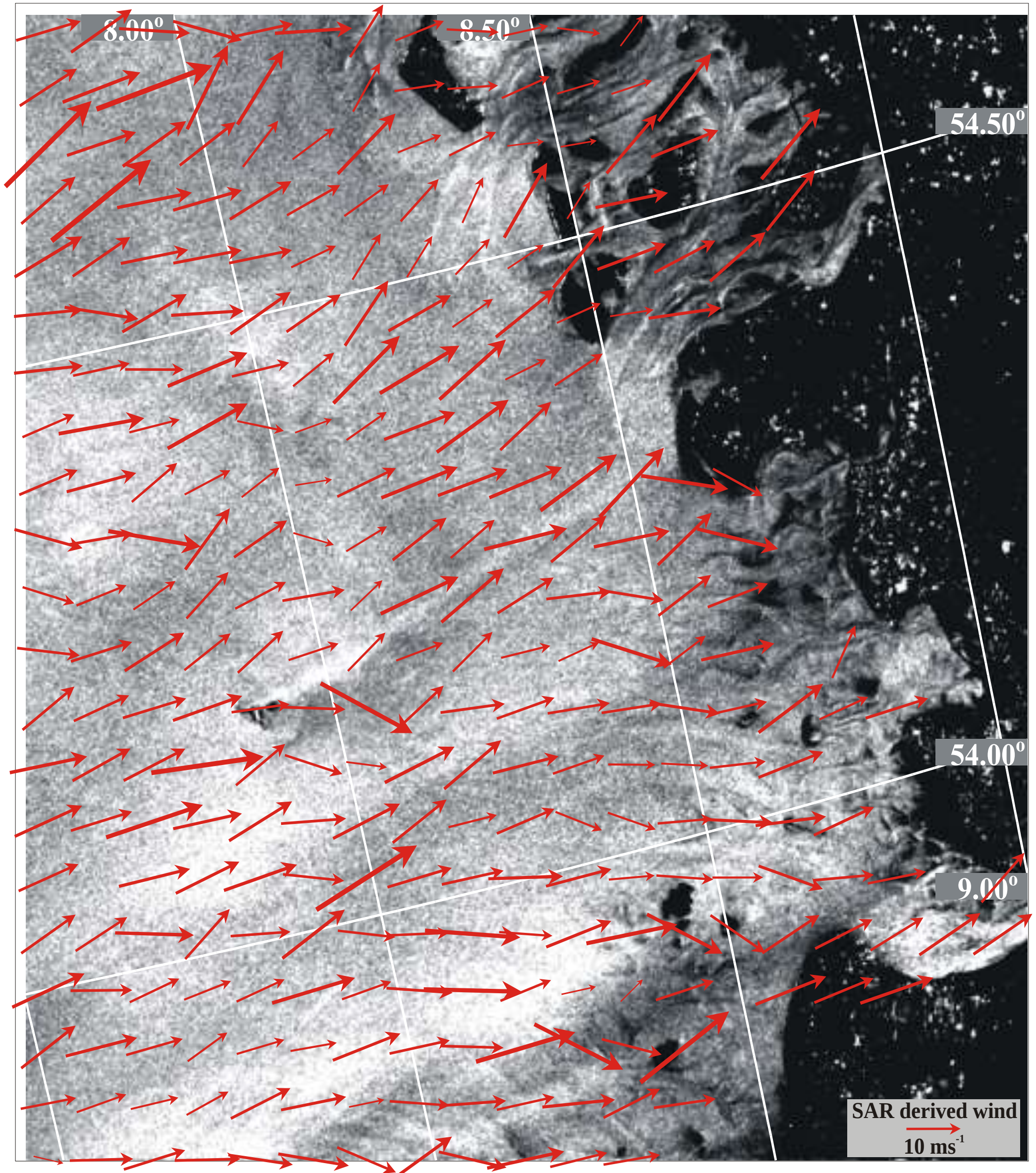


Wind field estimation

German Bight

ERS-2\SAR

Planning and impact assessment of wind parks



References & Resources

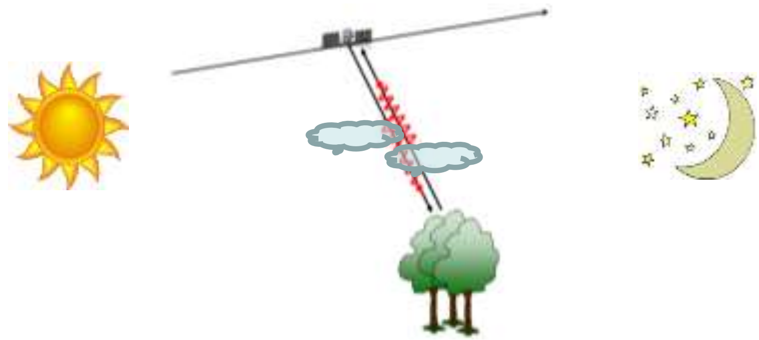
References

1. Lillesand, T. M. and Kiefer, R. W. (1994). Remote Sensing and image interpretation, 3rd edition, John Wiley & Sons Inc., New York, 750 p.

Hyperlinks to online Resources

- ESA Radar Courses
- What is Imaging Radar? (NASA)

Microwave Remote Sensing



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EO.Lab Earth Observation & Geospatial Applications Lab