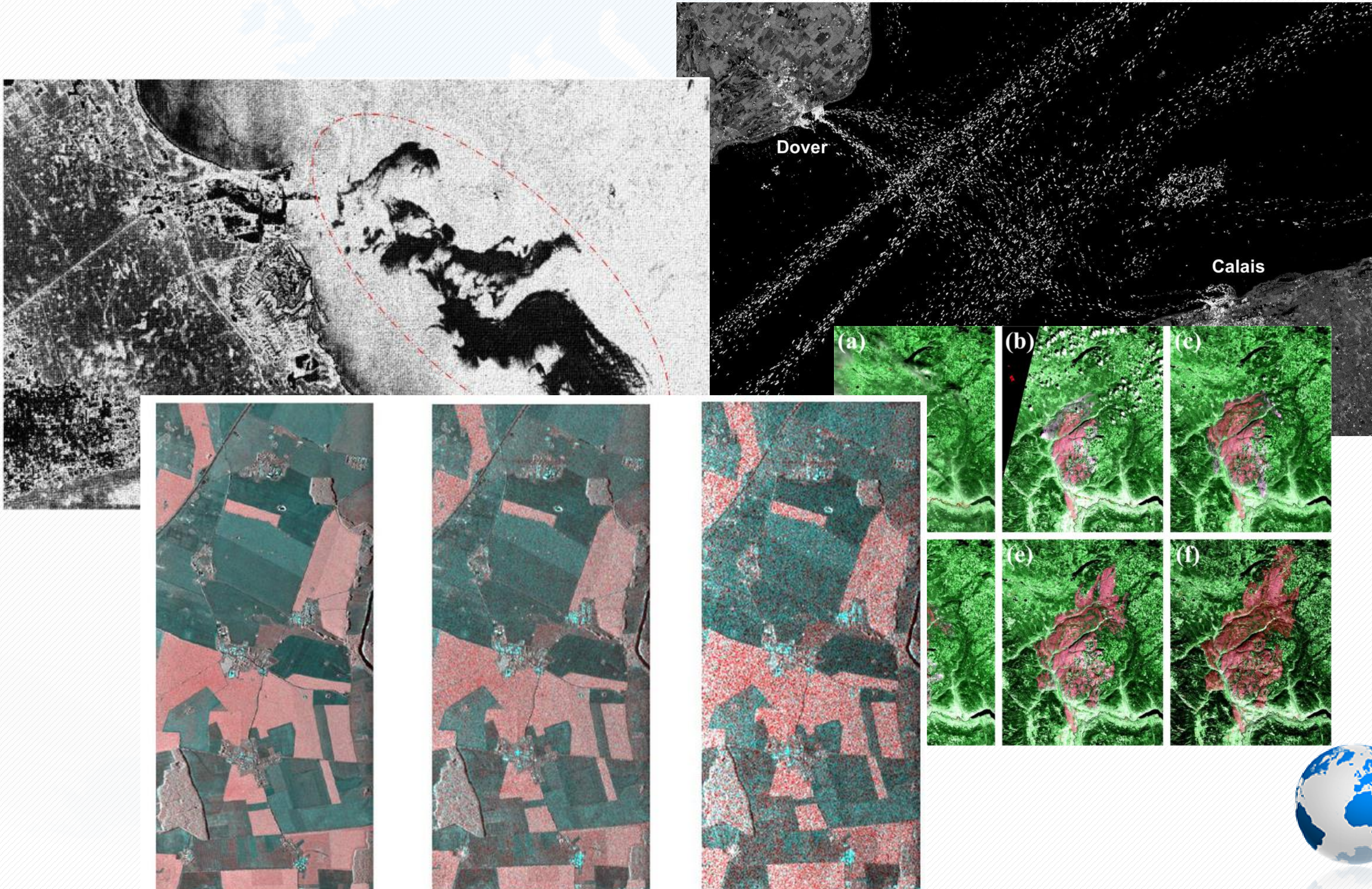
University of Zagreb
Faculty of Geodesy

Marijan Grgić

EO4GEO Fast disaster response – satellite technologies for surface displacement monitoring

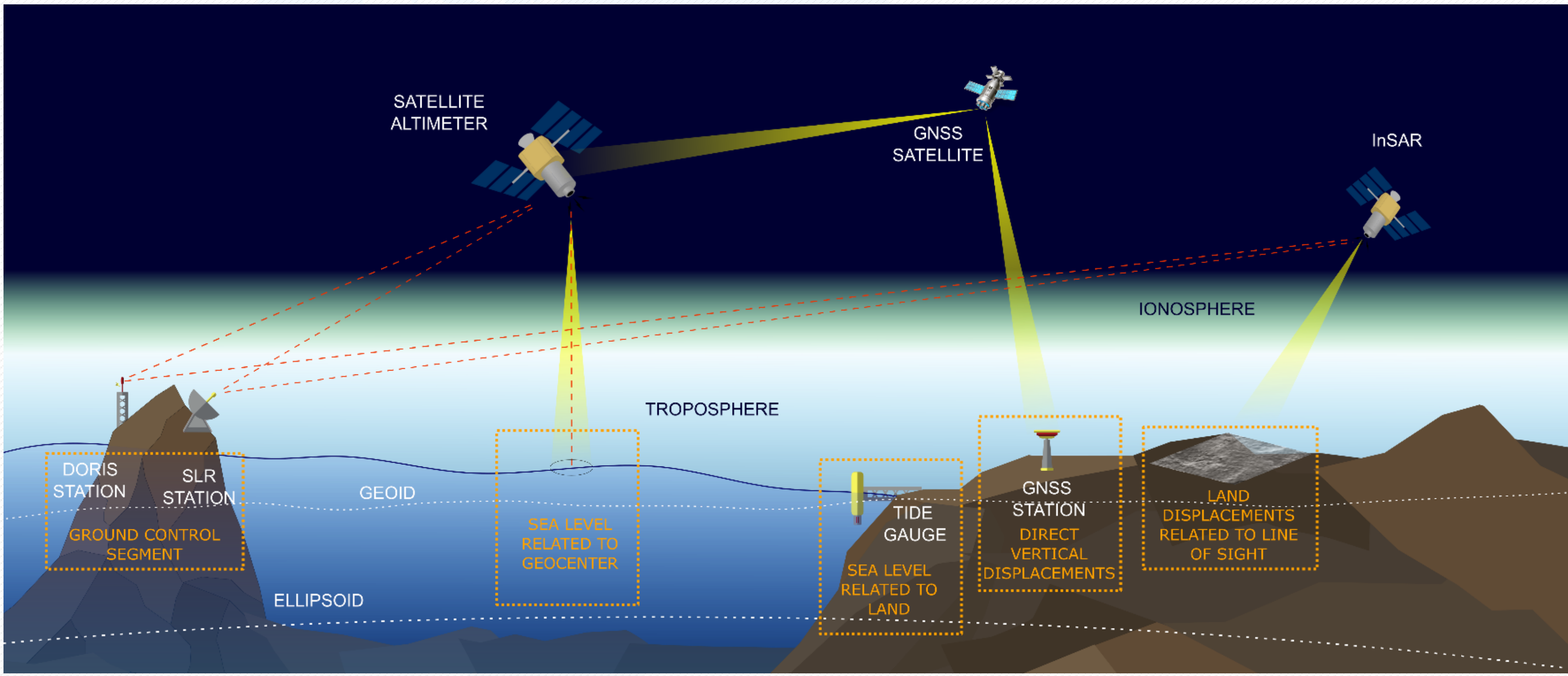
July 12th – 14th, 202

Radar satellite systems
Active sensors for Earth Observations



Radar satellite systems
Active sensors for Earth Observations

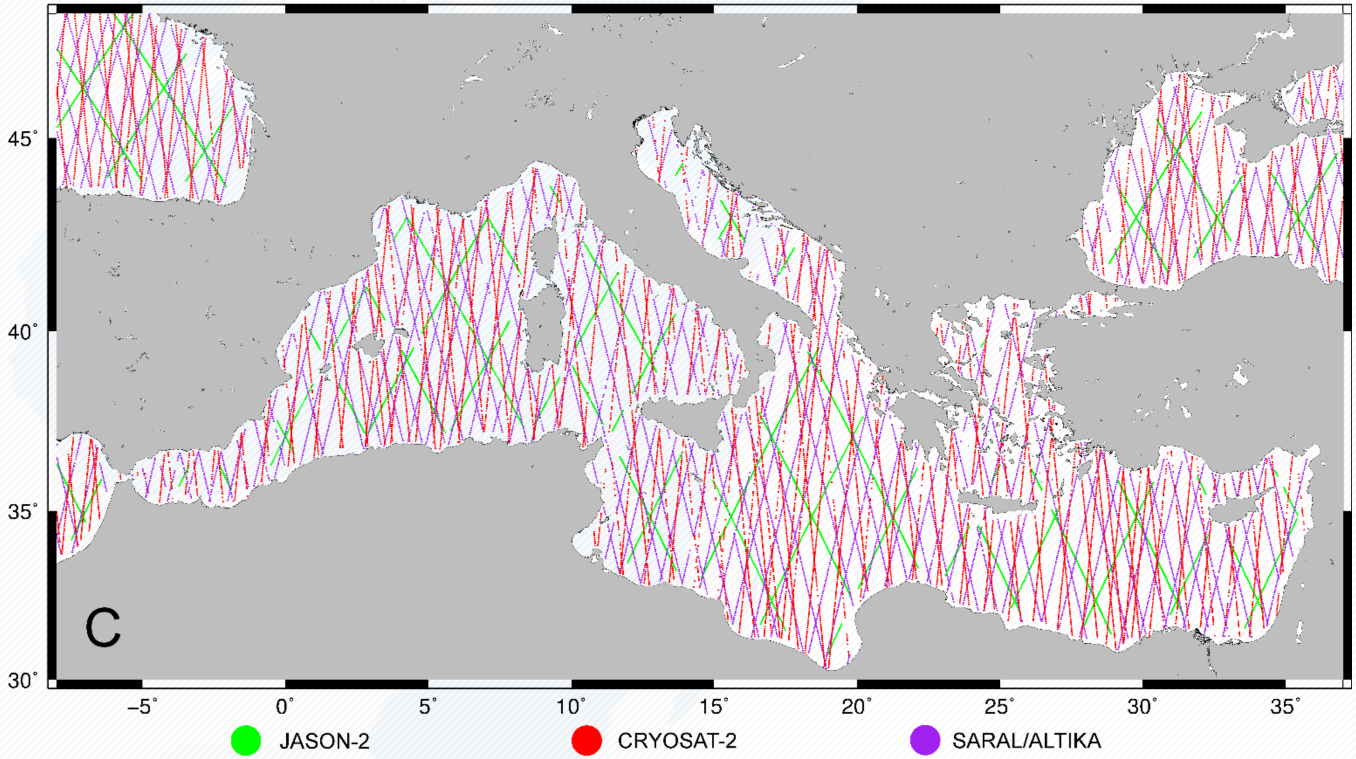
- Acquisition of the measurements of the Earth's surface by analysis of backscattered radar signal.



https://www.mdpi.com/2072-4292/12/21/3543

- (SAR) Radar satellite altimetry (water areas) vs (In)SAR data (inland)

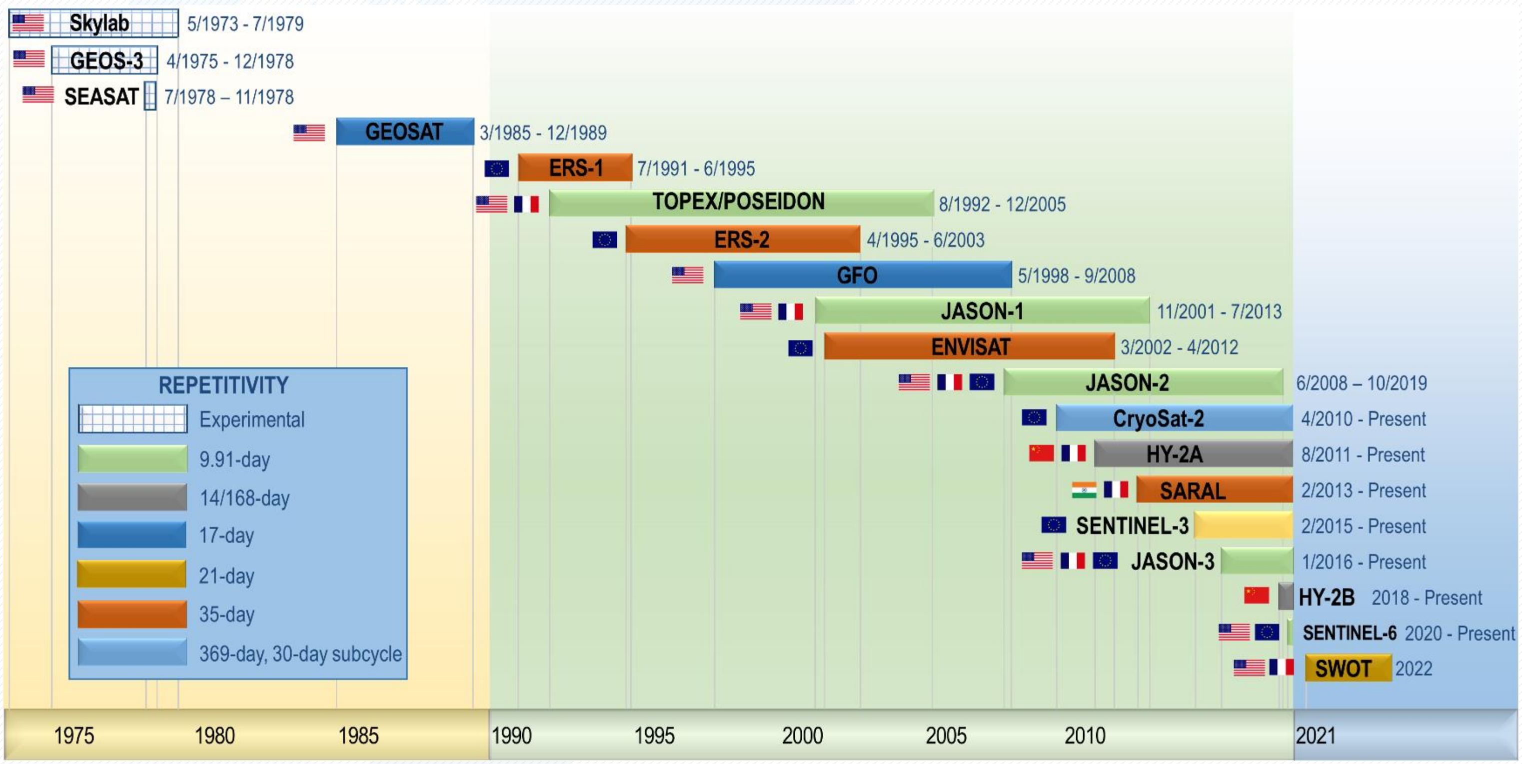
Satellite Altimetry: Monitoring Sea Level Change
Terrestrial vs satellite data



Satellite altimeter data (August 2015) in Mediterranean

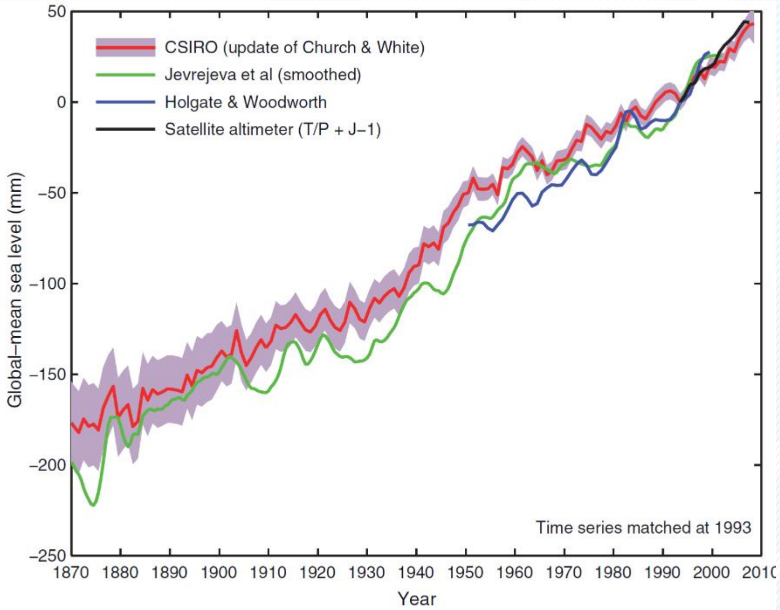
Satellite Altimetry: Monitoring Sea Level Change

Terrestrial vs satellite data

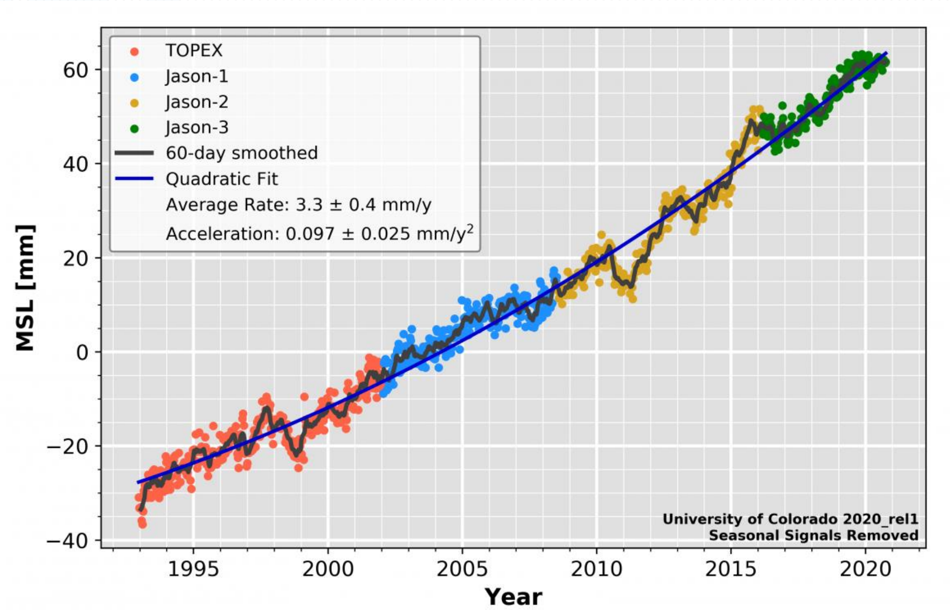


Available satellite altimeter missions (Grgić and Bašić, 2021)

Satellite Altimetry: Monitoring Sea Level Change
Global sea level trends



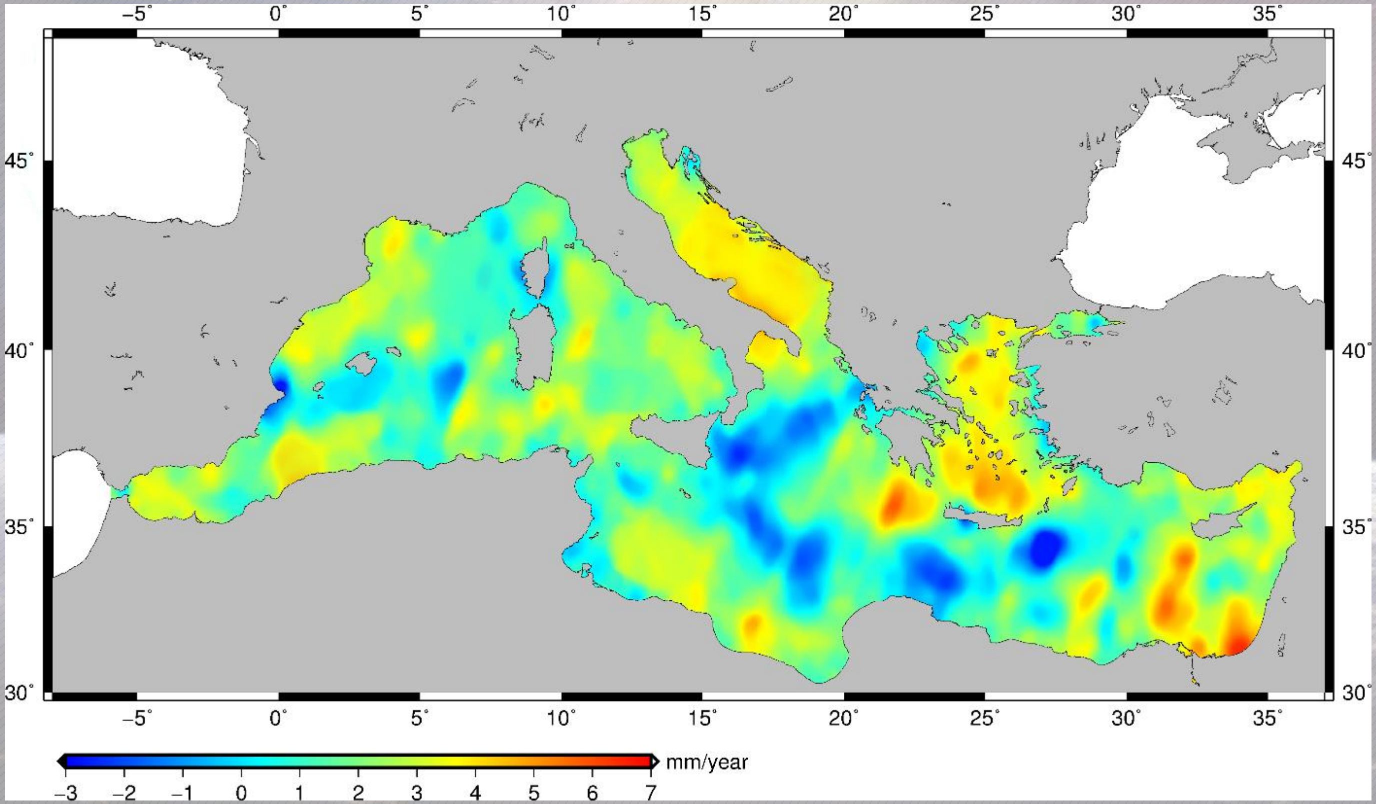
Global sea level change over the last 140 years (Church et al. 2010)



Current estimates on global sea level change and trend (Nerem et al., 2021)

Satellite Altimetry: Monitoring Sea Level Change

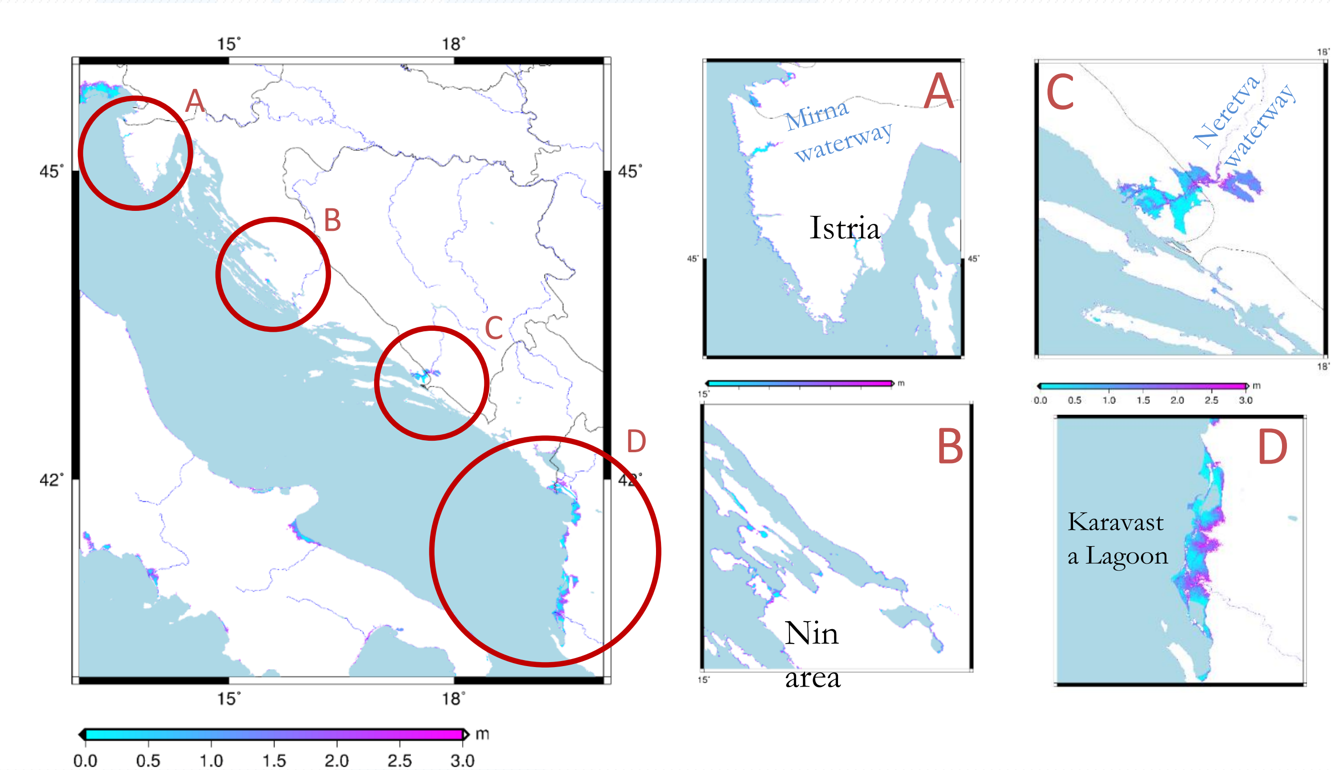
Regional sea level trends



Sea level trends in Mediterranean (Grgić et al., 2017)

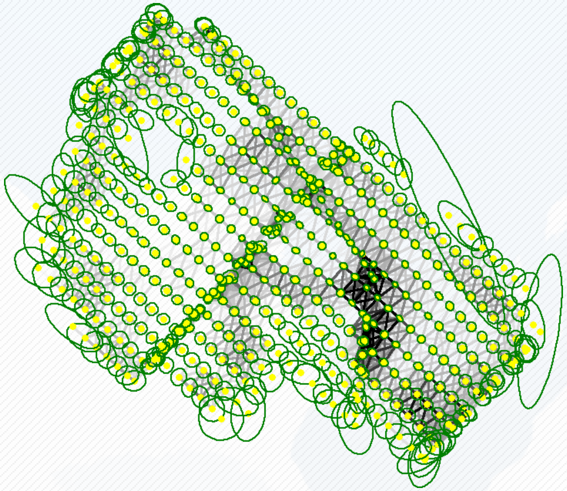
Satellite Altimetry: Monitoring Sea Level Change

Regional sea level trends – impact of sea level rise



Eastern Adriaic Sea Area loss prediction throughout 21st century and vulnerable areas detection; A – Istria, B – Mid-Eastern Adriatic, Neretva valley, and Albanian coast

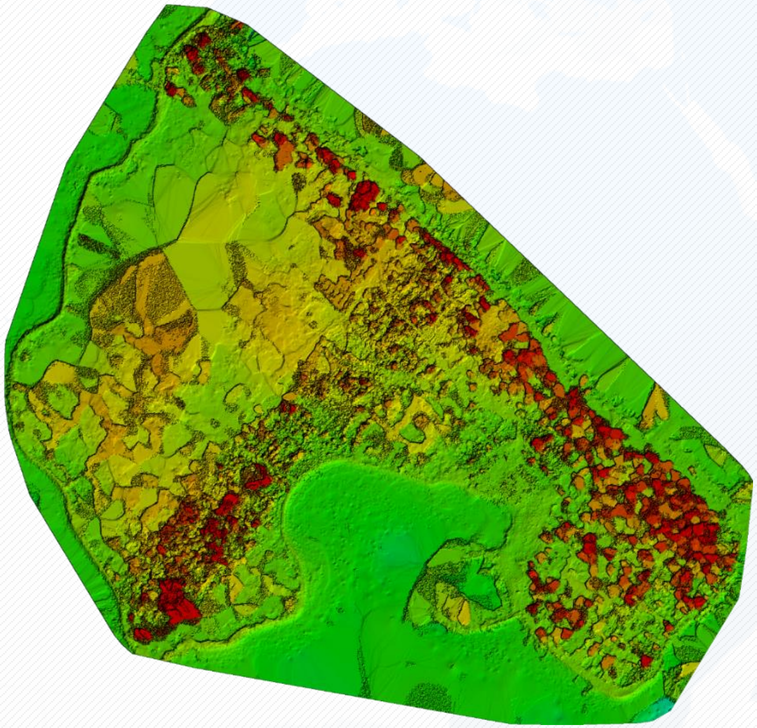
Satellite Altimetry: Monitoring Sea Level Change
Regional sea level trends – impact of sea level rise



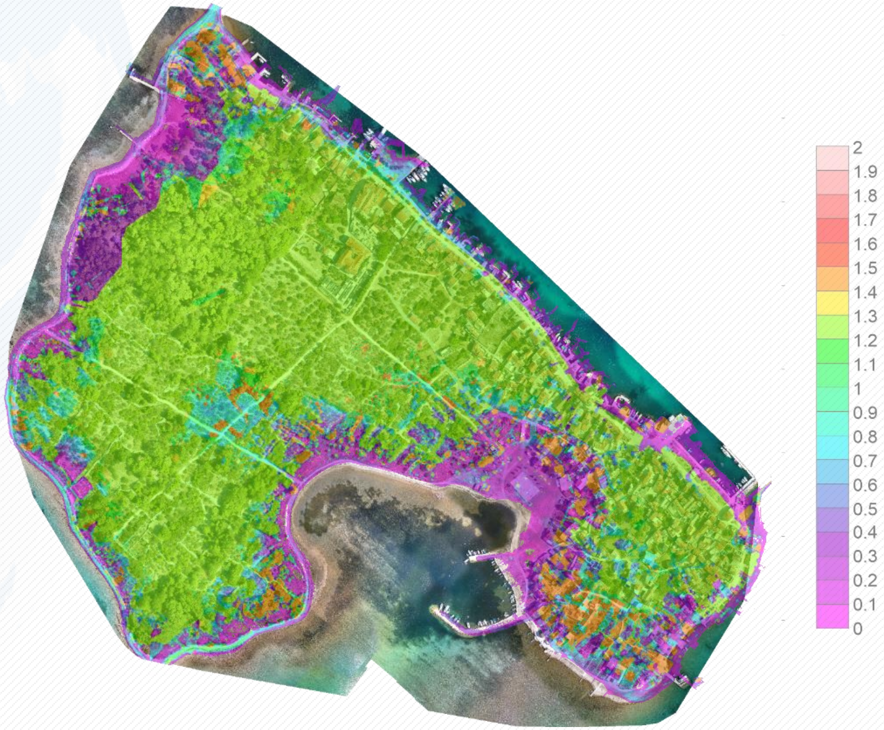
Sea level rise impact – case study: Krapanj (Grgić et al., 2018)

Satellite Altimetry: Monitoring Sea Level Change

Regional sea level trends – impact of sea level rise

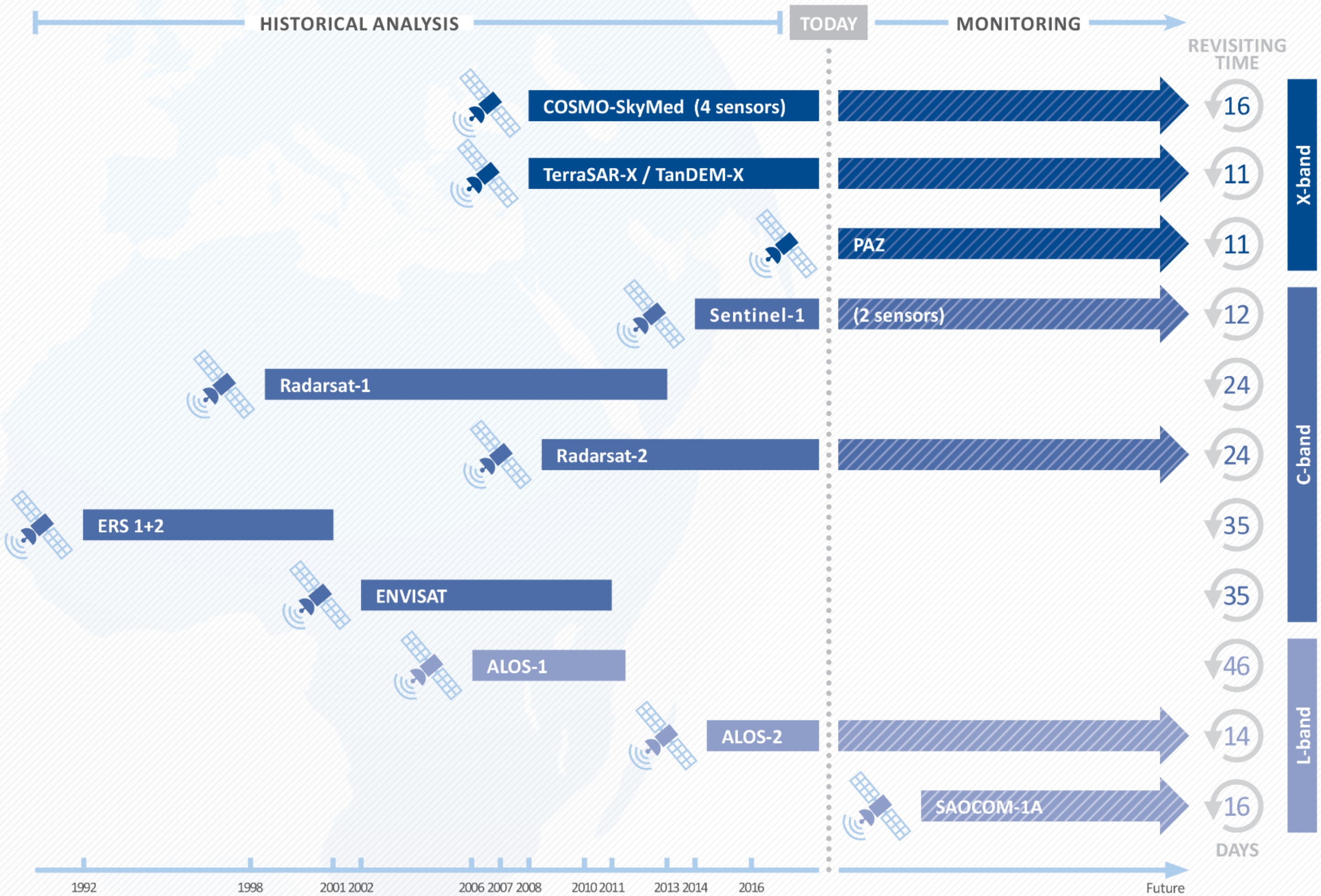


Digital surface model of the island derived from drone mapping



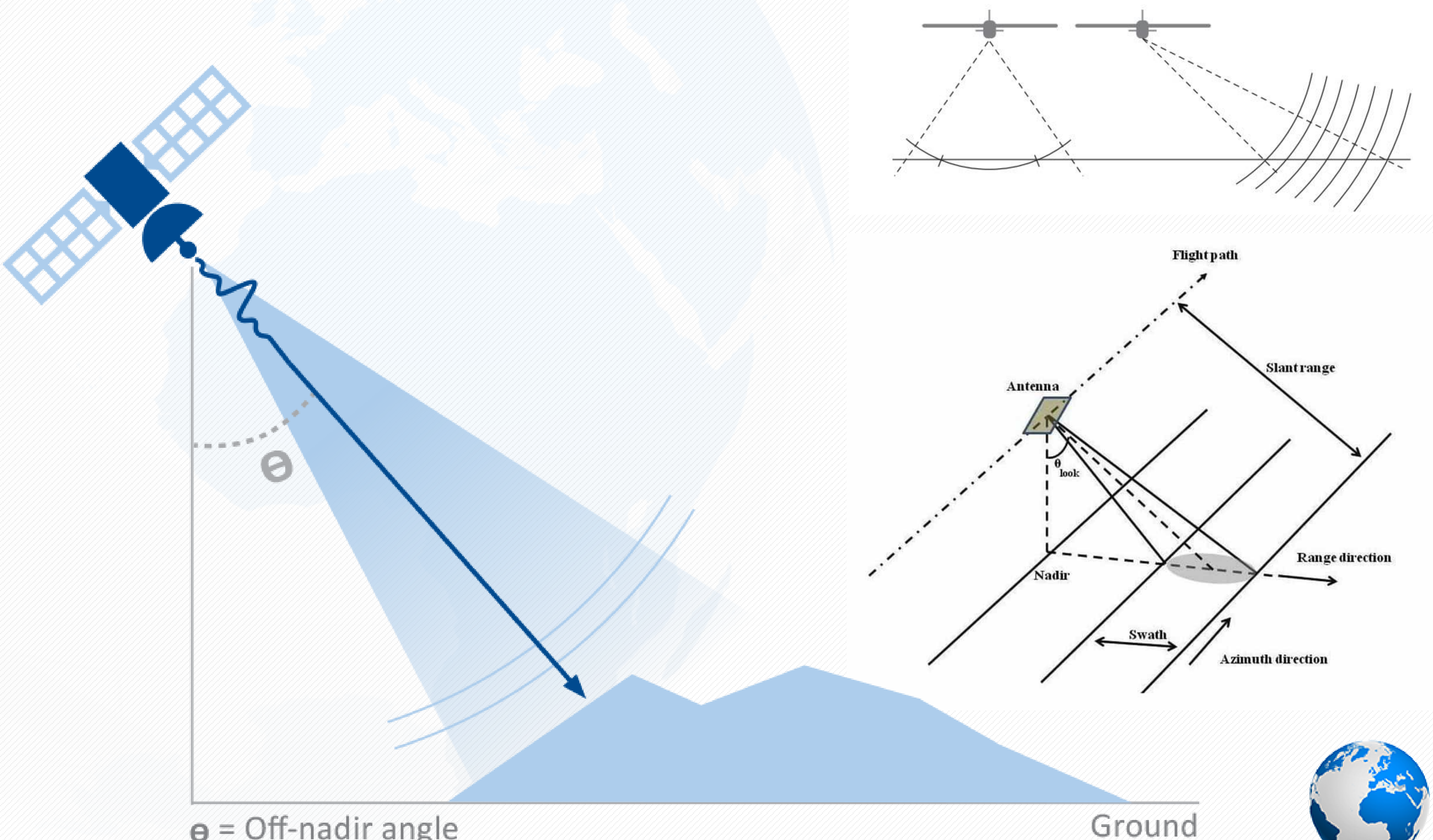
Sea level rise impact – case study: Krapanj (Grgić et al., 2018)

Radar satellite systems – SAR



https://site.tre-altamira.com/insar/

SAR – technology



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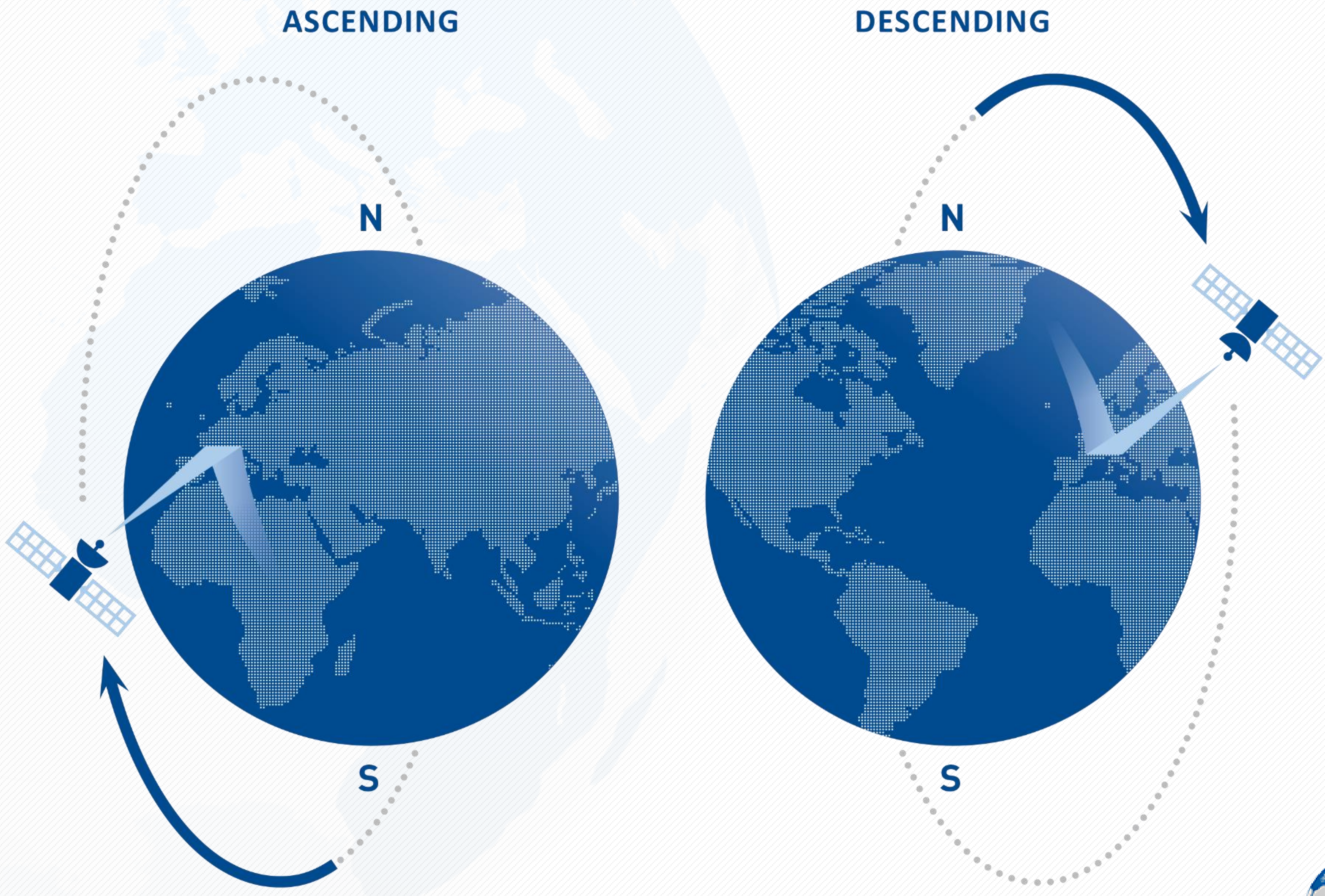
SAR – technology



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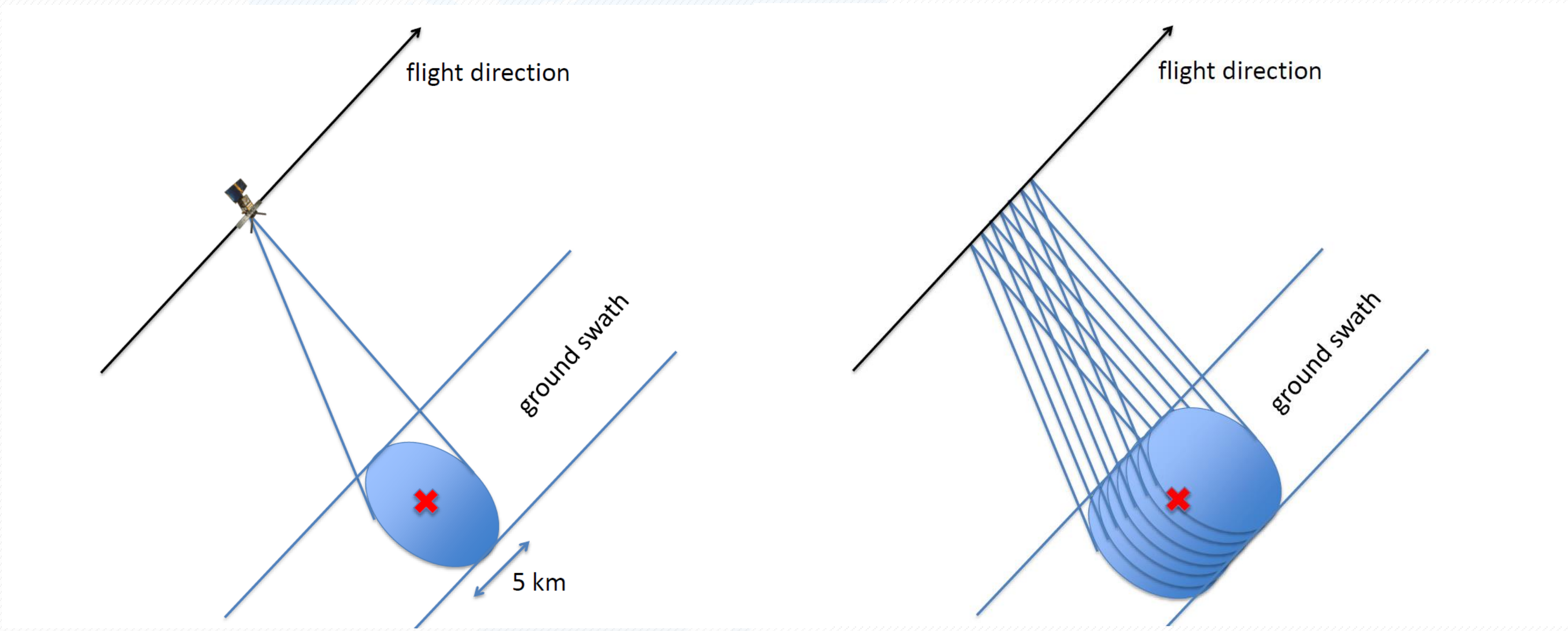
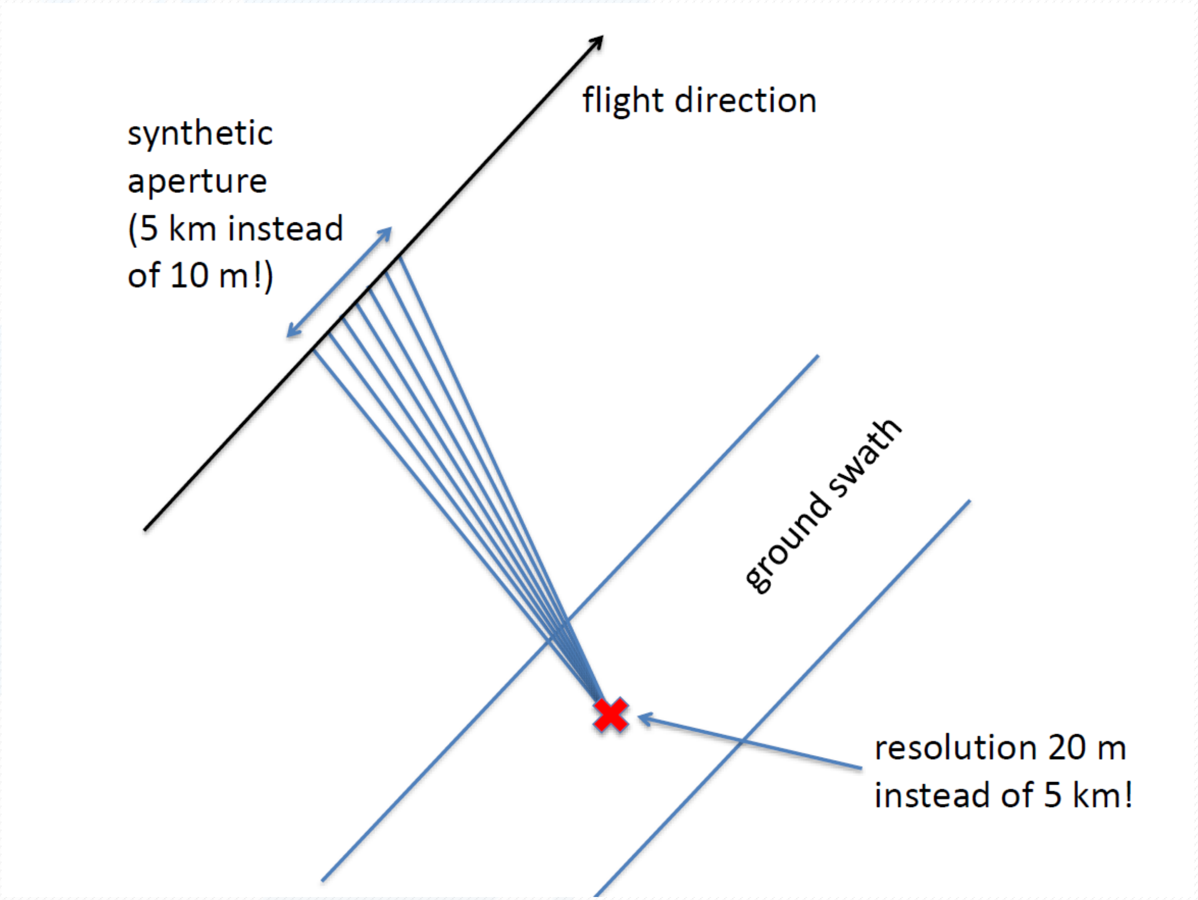
SAR – technology



Pulse-limited radar (PLR) – *footprint size* approximately 5 km (orbit altitude 600 km)

Funning (UNAVCO, How does InSAR work)

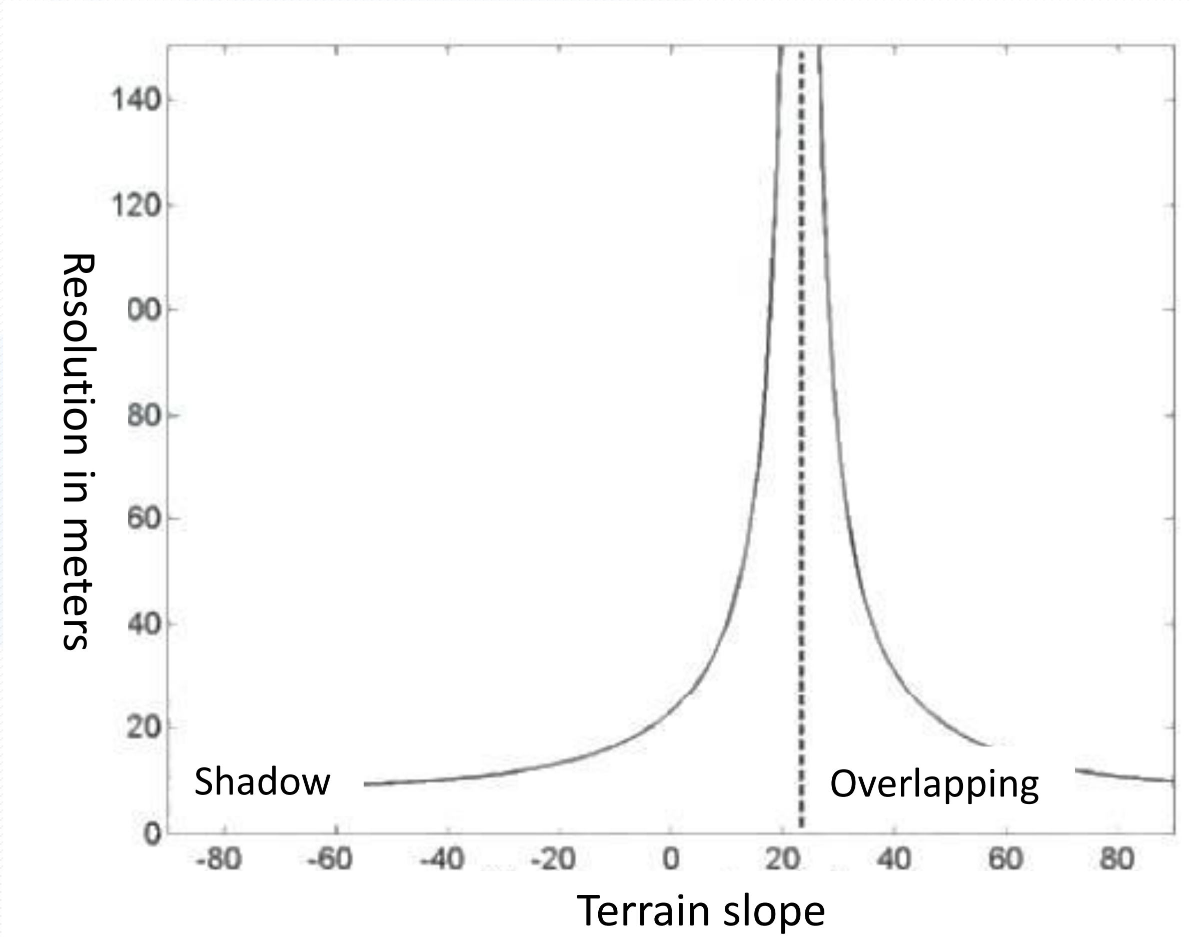
SAR – technology



SAR (Synthetic Aperture Radar) metoda –*footprinta* oko pet m (orbita na otprilike 600 km)

Funning (UNAVCO, How does InSAR work)

SAR – technology



SAR - Impact of terrain slope on the image resolution, θ=23° (Ferretti et al. 2007)

SAR – technology

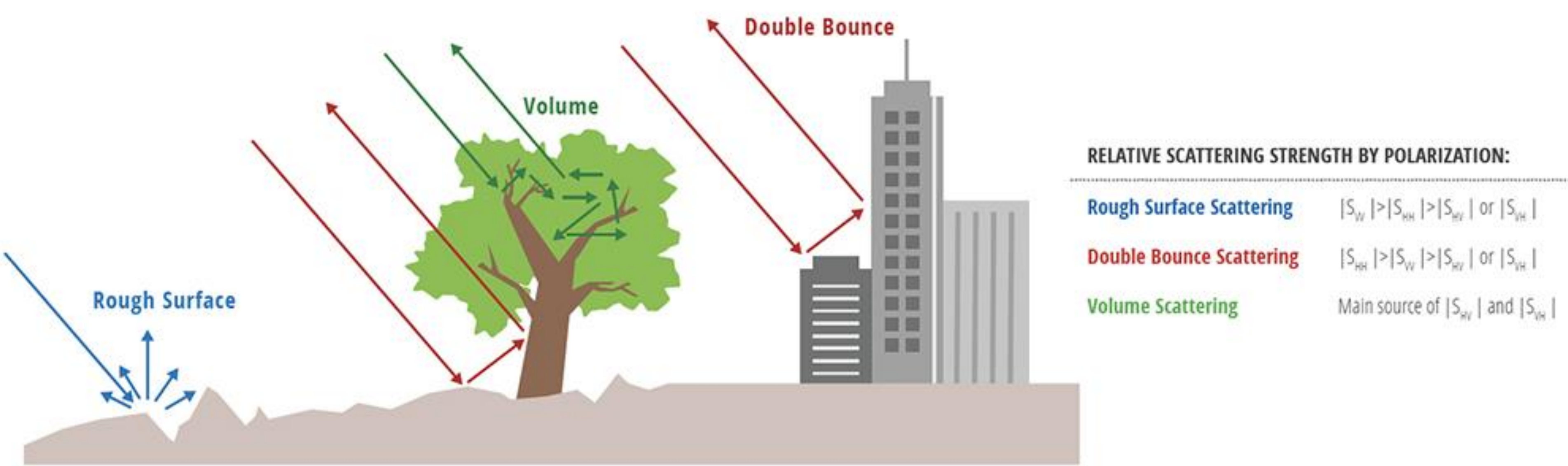
The Role of Frequency and Wavelength

Band	Frequency	Wavelength	Typical Application
Ka	27–40 GHz	1.1–0.8 cm	Rarely used for SAR (airport surveillance)
K	18–27 GHz	1.7–1.1 cm	rarely used (H_2O absorption)
Ku	12–18 GHz	2.4–1.7 cm	rarely used for SAR (satellite altimetry)
X	8–12 GHz	3.8–2.4 cm	High resolution SAR (urban monitoring,; ice and snow, little penetration into vegetation cover; fast coherence decay in vegetated areas)
C	4–8 GHz	7.5–3.8 cm	SAR Workhorse (global mapping; change detection; monitoring of areas with low to moderate penetration; higher coherence); ice, ocean maritime navigation
S	2–4 GHz	15–7.5 cm	Little but increasing use for SAR-based Earth observation; agriculture monitoring (NISAR will carry an S-band channel; expends C-band applications to higher vegetation density)
L	1–2 GHz	30–15 cm	Medium resolution SAR (geophysical monitoring; biomass and vegetation mapping; high penetration, InSAR)
P	0.3–1 GHz	100–30 cm	Biomass. First p-band spaceborne SAR will be launched ~2020; vegetation mapping and assessment. Experimental SAR.

SAR – technology

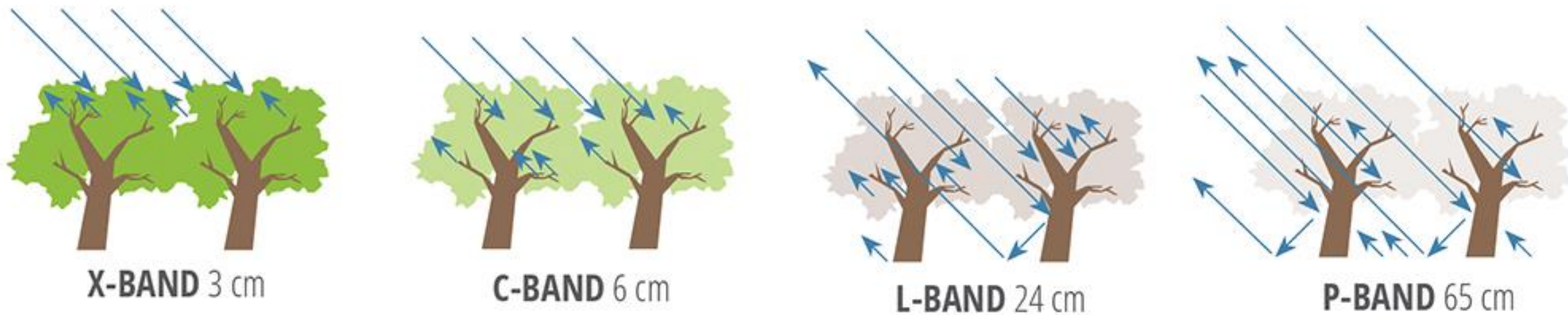
The Role of Polarization

- Polarization refers to the orientation of the plane in which the transmitted electromagnetic wave oscillates
- Signals emitted in vertical (V) and received in horizontal (H) polarization would be indicated by a VH. Alternatively, a signal that was emitted in horizontal (H) and received in horizontal (H) would be indicated by HH, and so on.



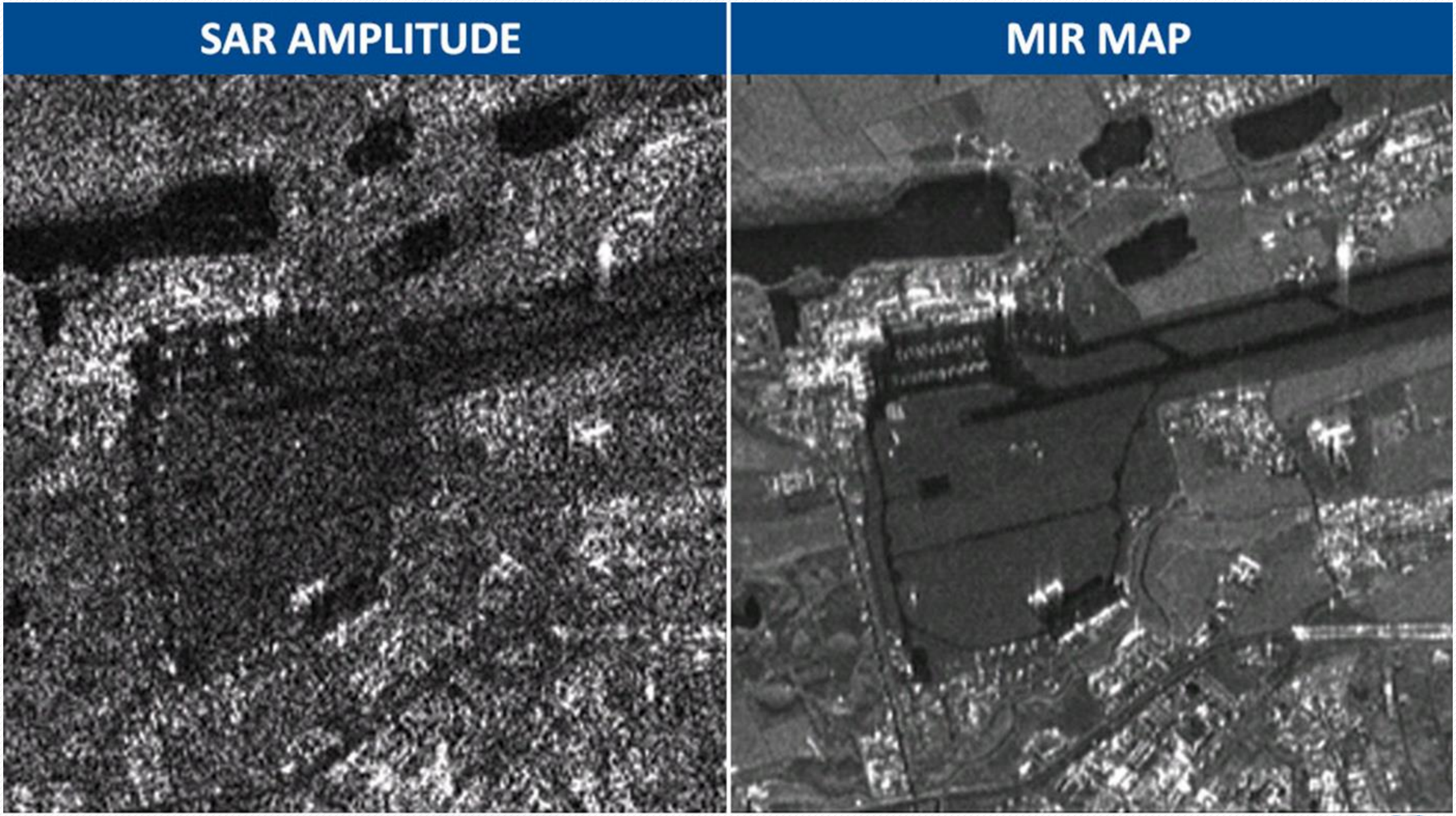
SAR – technology

The Role of Polarization



Sensitivity of SAR measurements to forest structure and penetration into the canopy at different wavelengths used for airborne or spaceborne remote sensing observations of the land surface. Credit: NASA SAR Handbook.

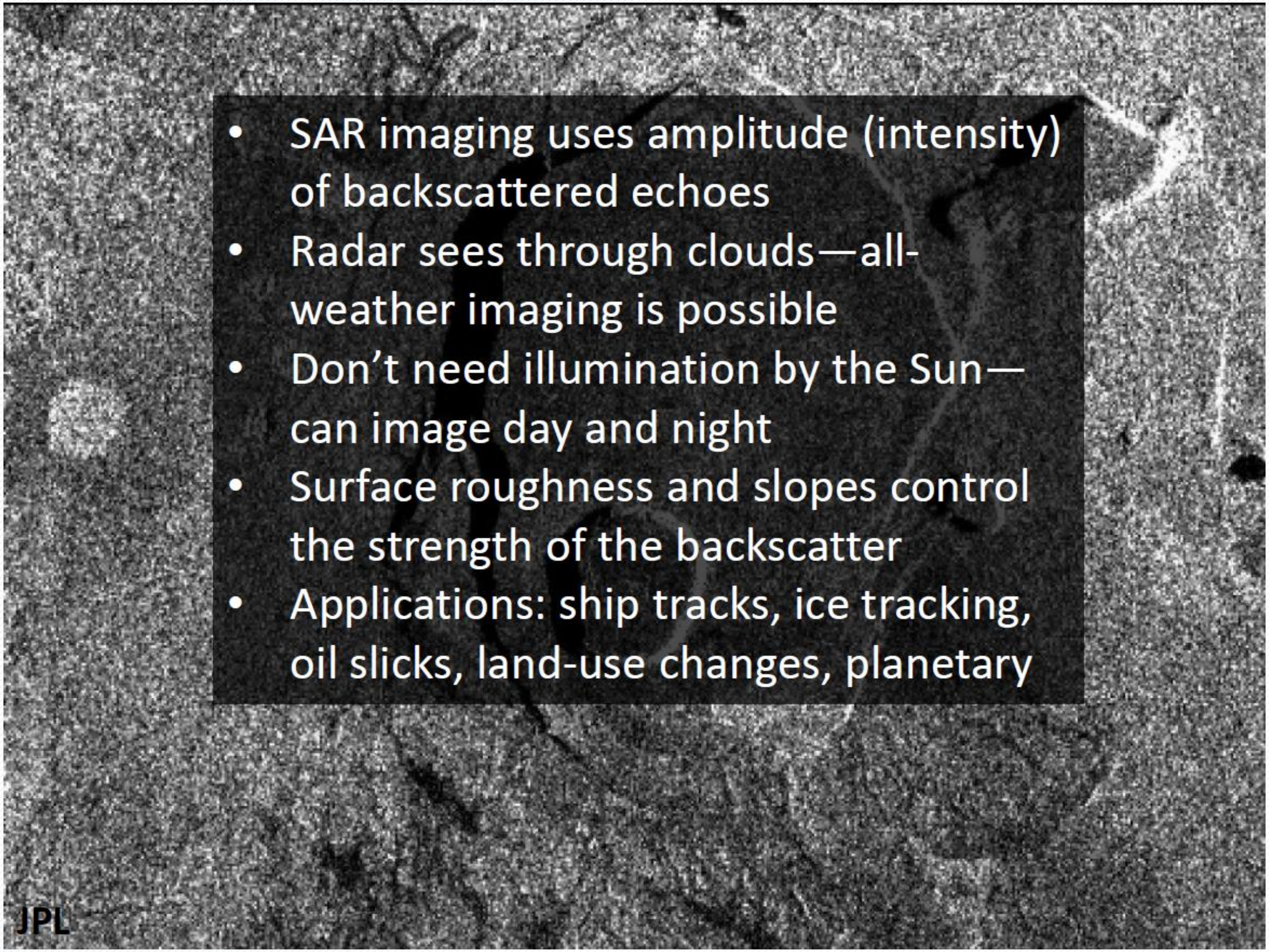
SAR – technology



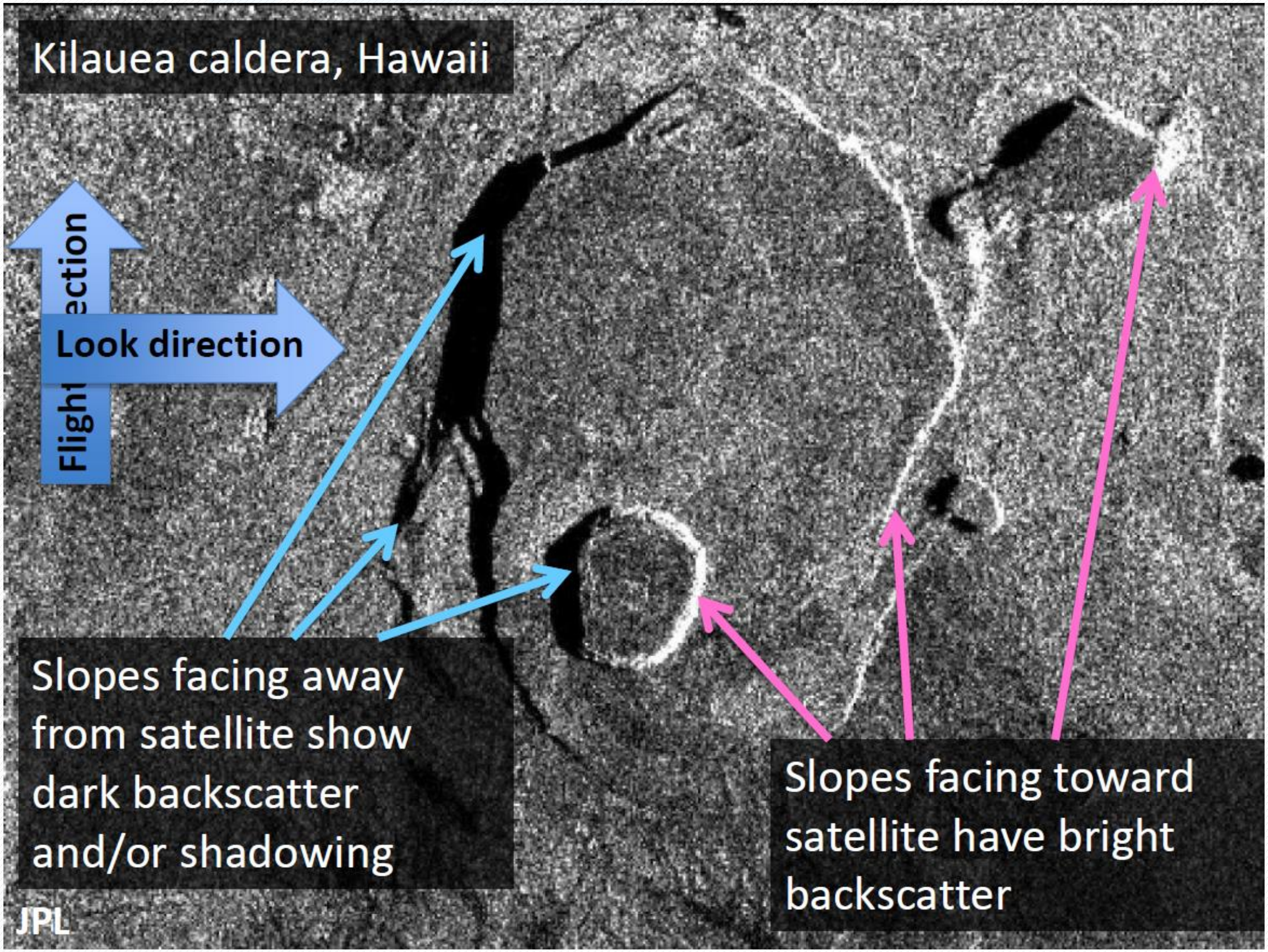
SAR signal amplitude and MIR (Multi Image Reflectivity) map

SAR – technology

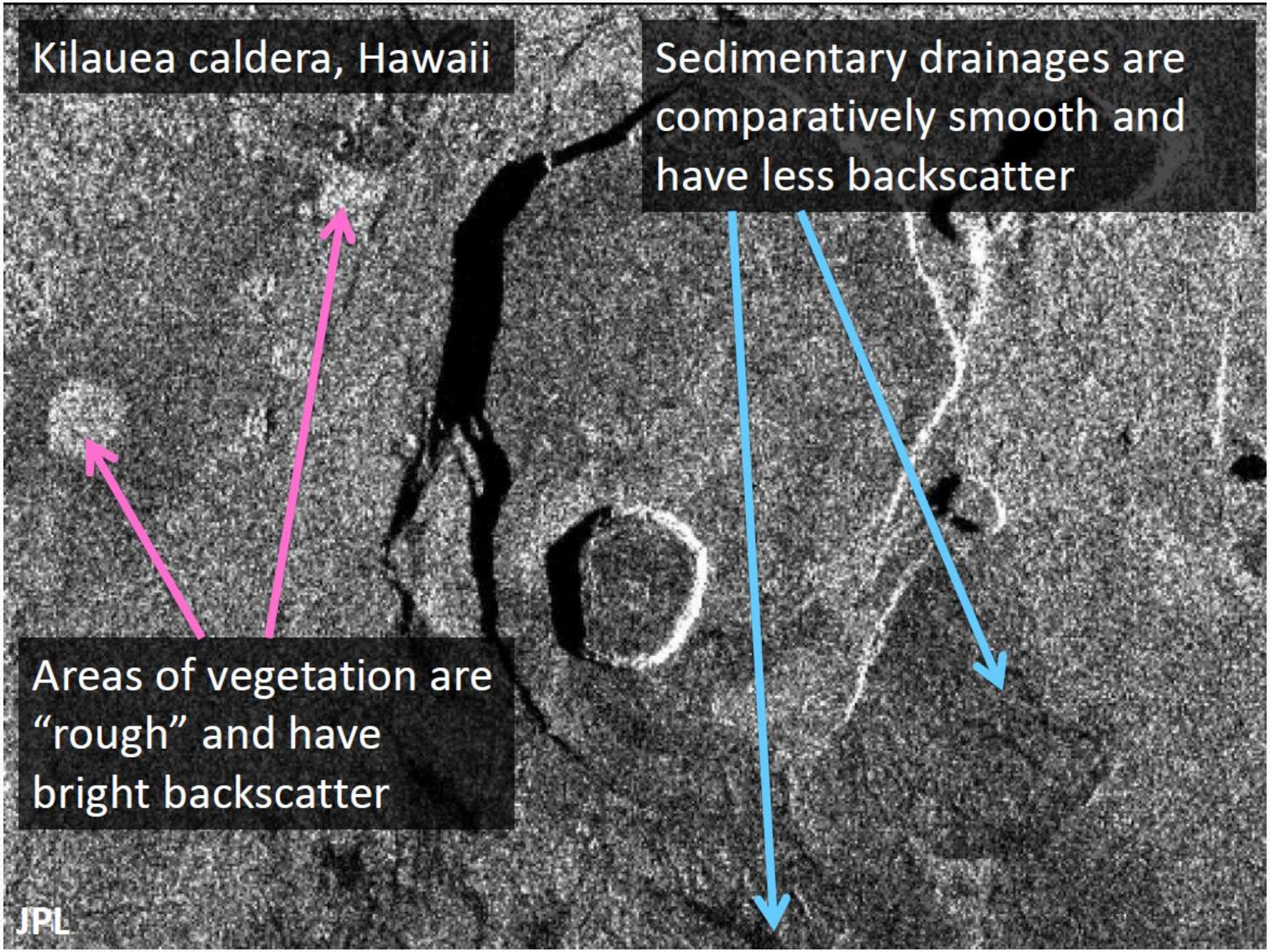
- SAR imaging uses amplitude (intensity) of backscattered echoes
- Radar sees through clouds—all-weather imaging is possible
- Don't need illumination by the Sun—can image day and night
- Surface roughness and slopes control the strength of the backscatter
- Applications: ship tracks, ice tracking, oil slicks, land-use changes, planetary



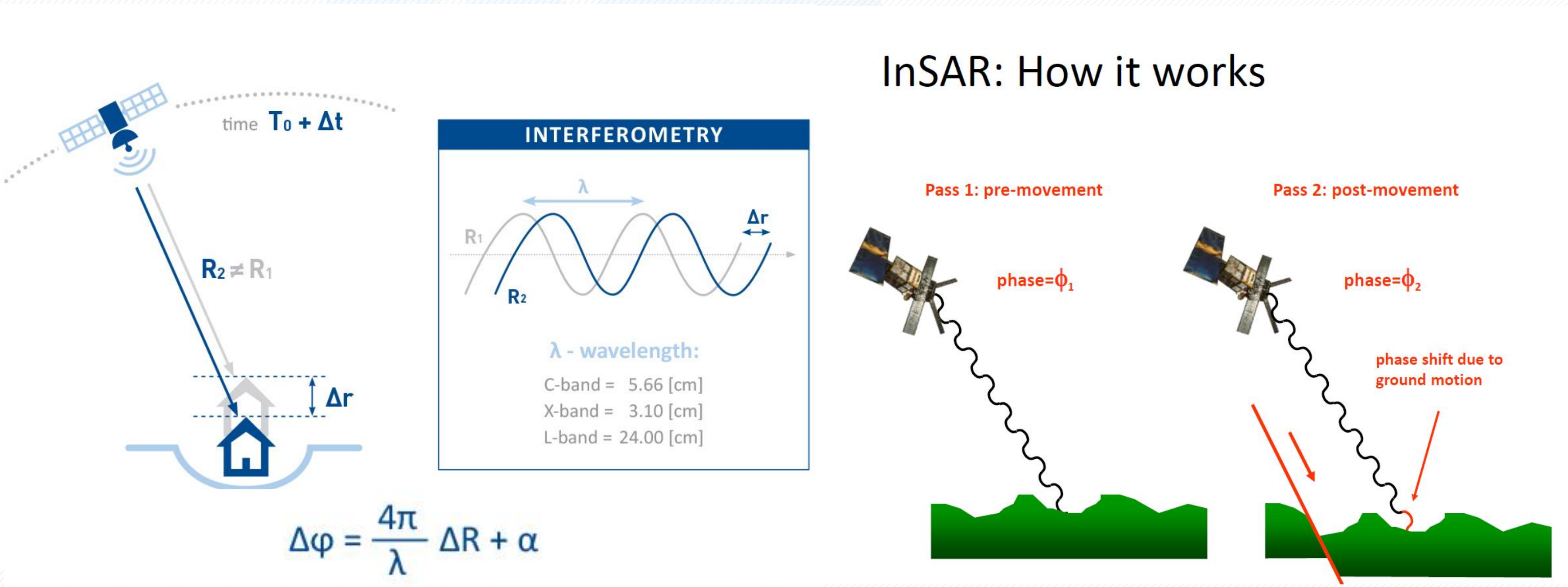
InSAR – technology



InSAR – technology

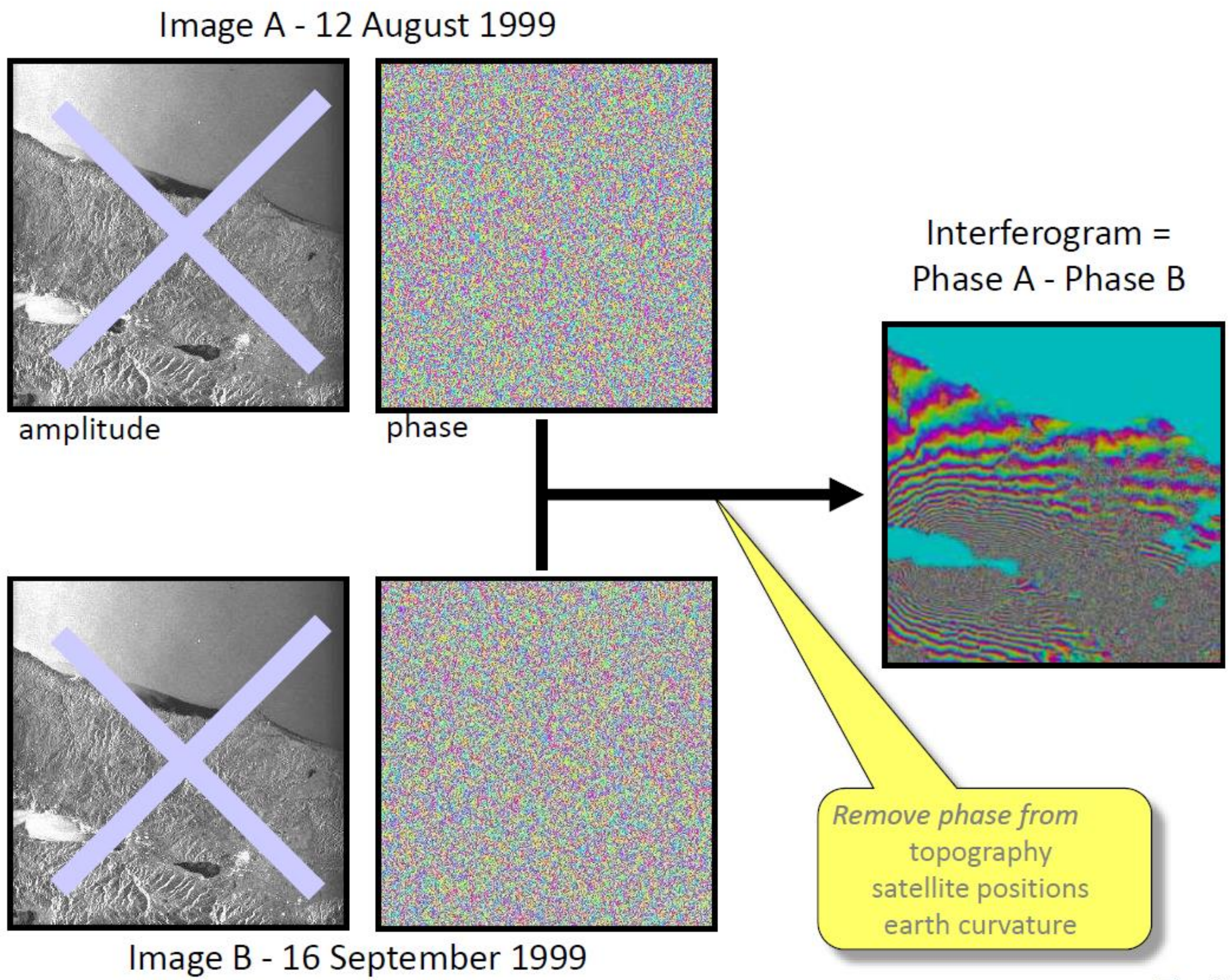


InSAR – technology



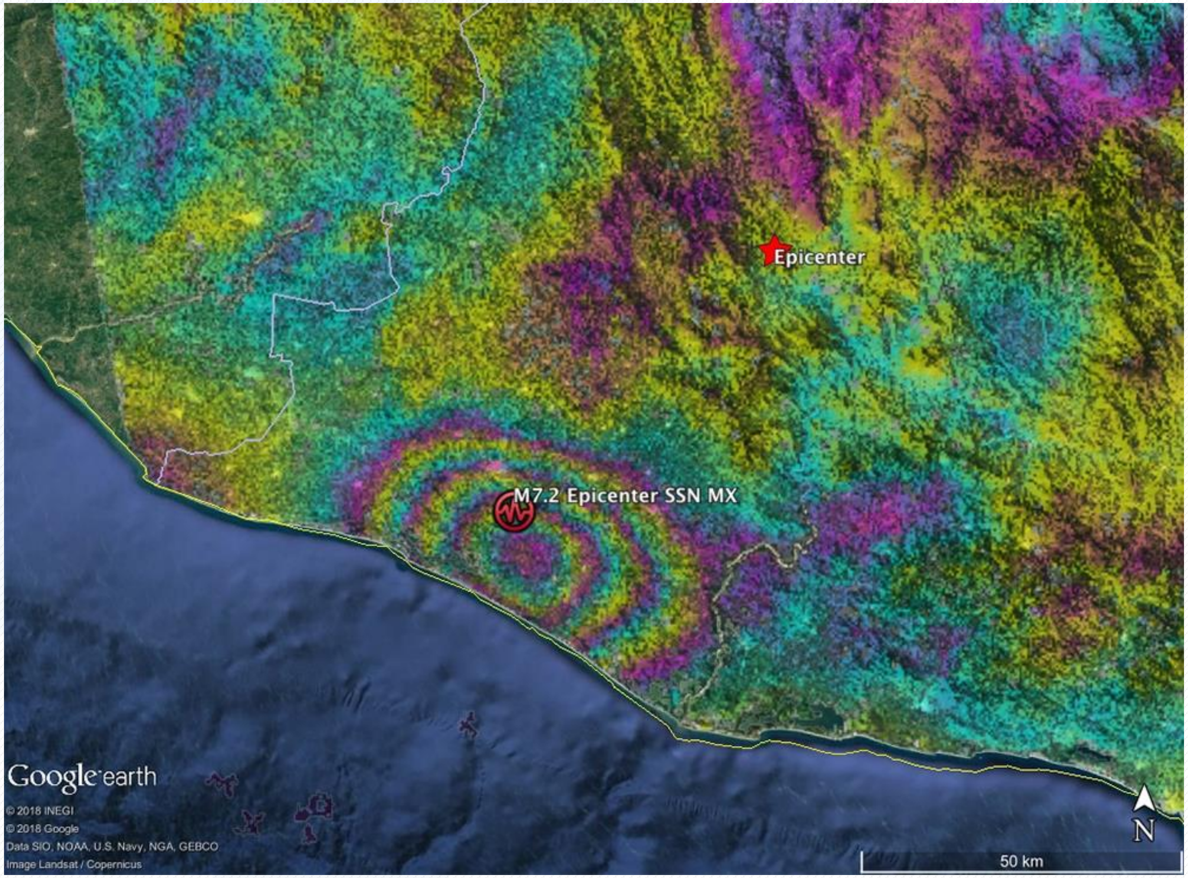
InSAR method – monitoring of the Earth's surface

InSAR – technology



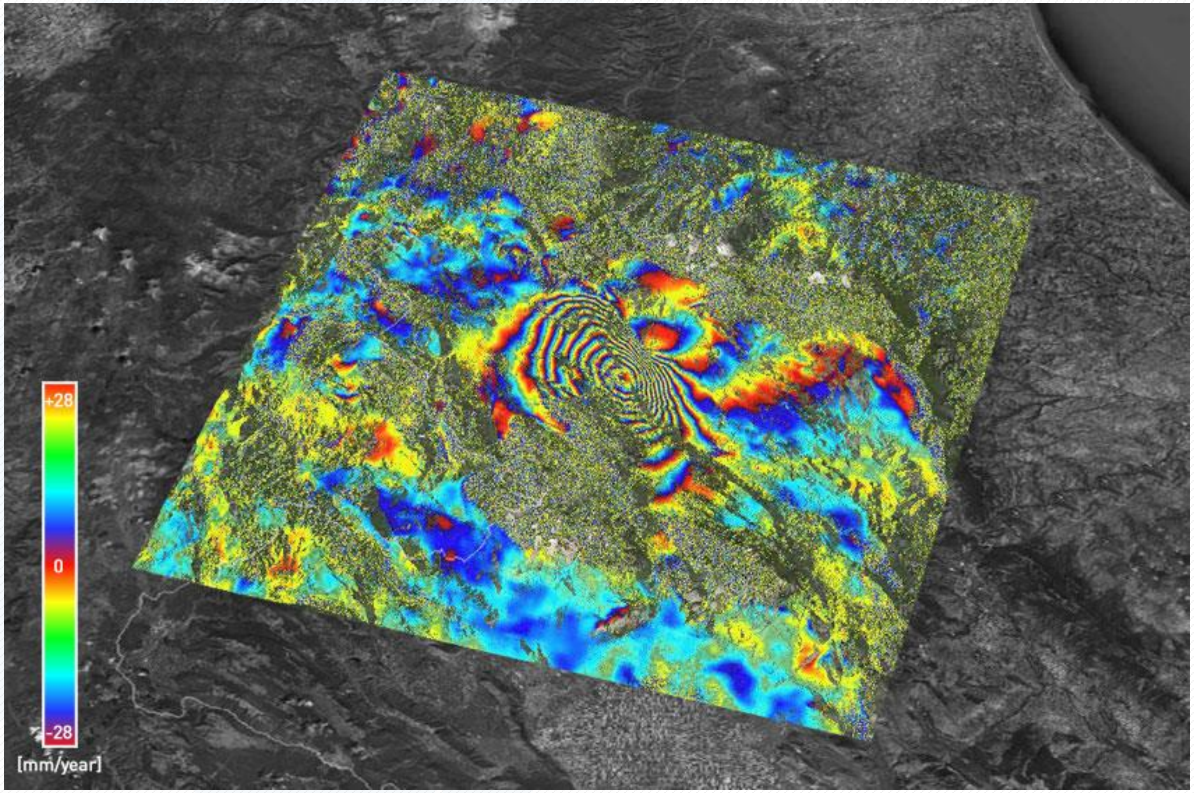
Tim Wright

InSAR – technology



Interferogram from Sentinel-1 SAR data acquired 2018/02/17 and 02/05 shows earthquake fault slip on a subduction thrust fault causing up to 40 cm of uplift of the ground surface. The motion has been contoured with 9 cm color contours, also known as fringes. Credit: NASA Disasters Program.

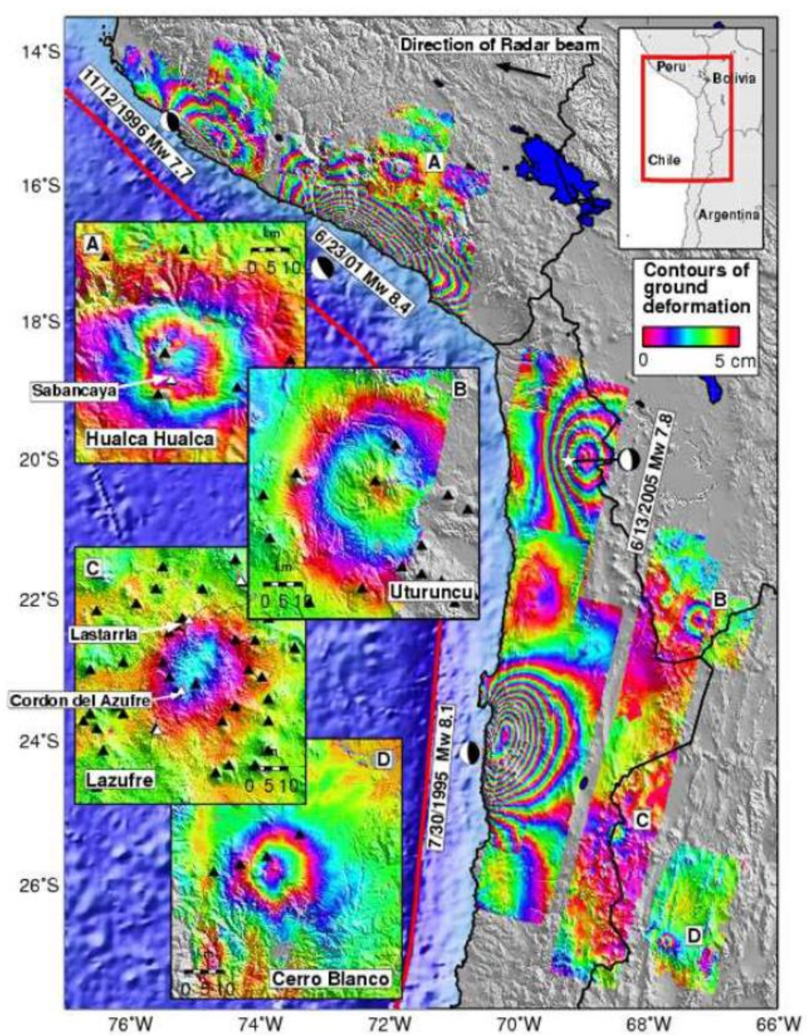
InSAR – technology



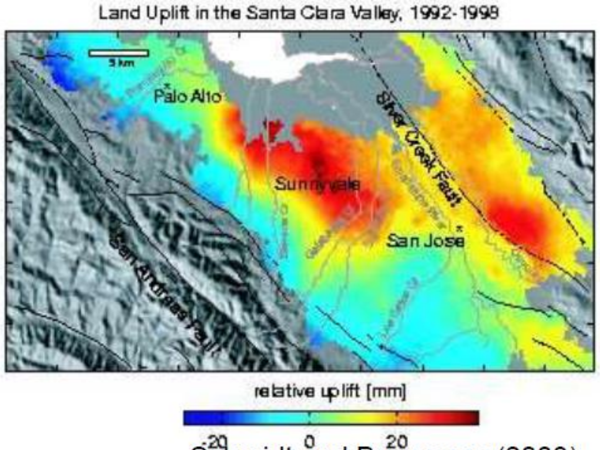
Interferogram integrates:

1) Topographic effects due to different elevation angles of the images
2) Atmospheric effects
3) True (real) displacements
4) Measurement noise

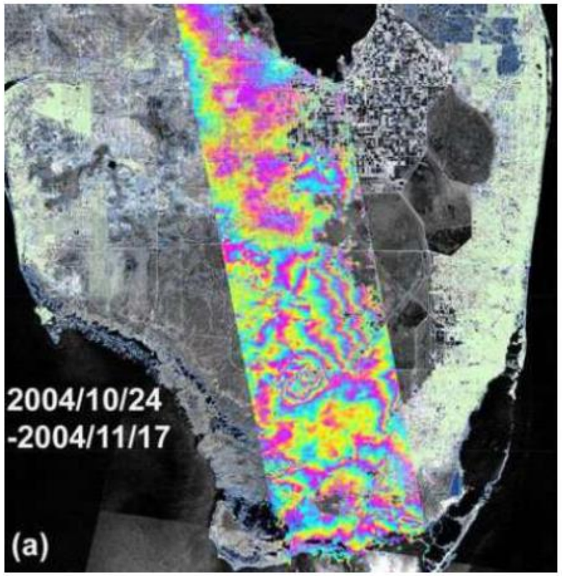
InSAR – technology



Pritchard and Simons (2004)



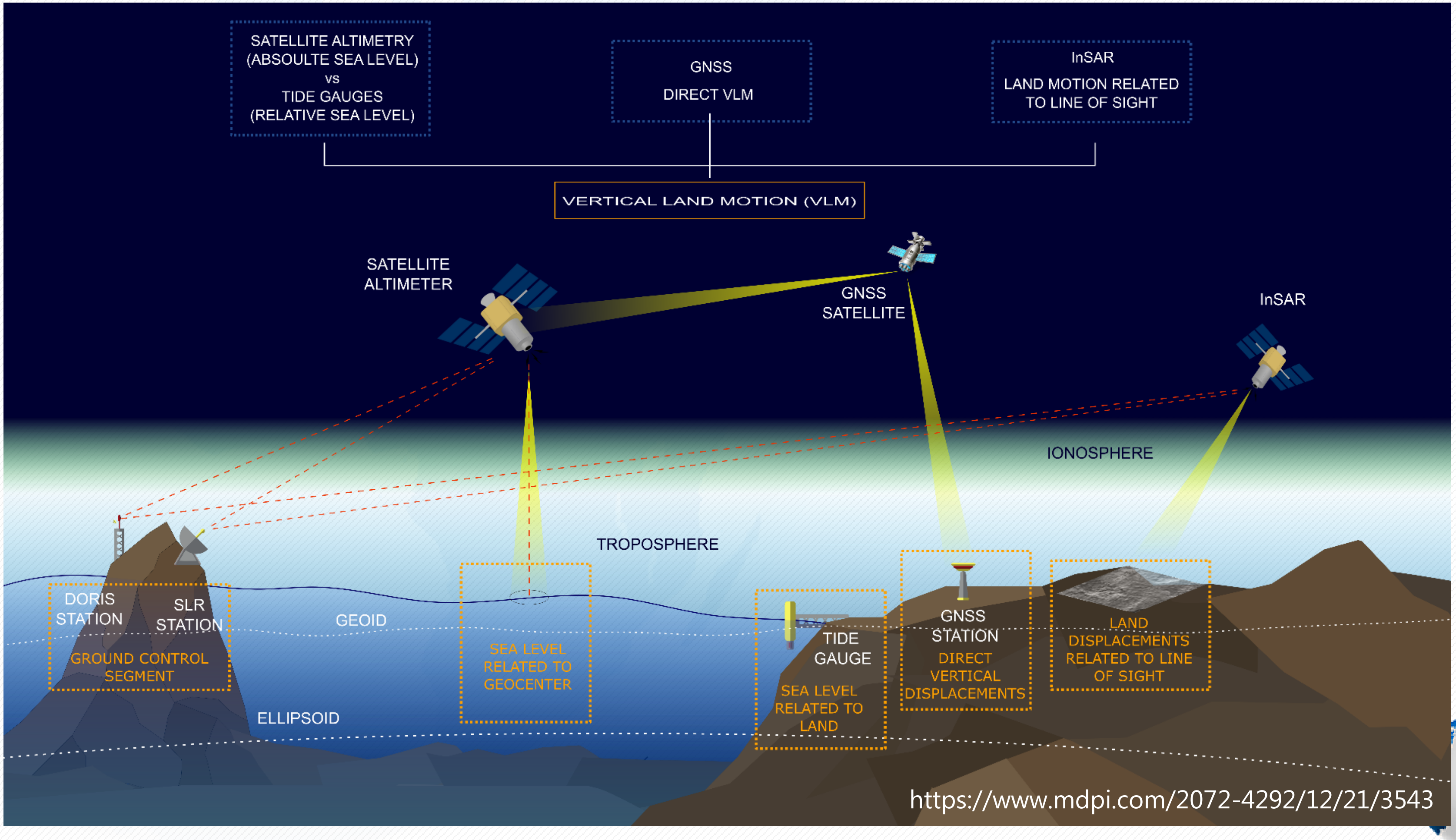
Schmidt and Burgmann (2003)



Wdowinski et al (2006)

Radar satellite systems
Active sensors for Earth Observations

- Study example: **Estimating Vertical Land Motion from Remote Sensing and In-Situ Observations in the Dubrovnik Area (Croatia): A Multi-Method Case Study (Grgić et al. 2020)**



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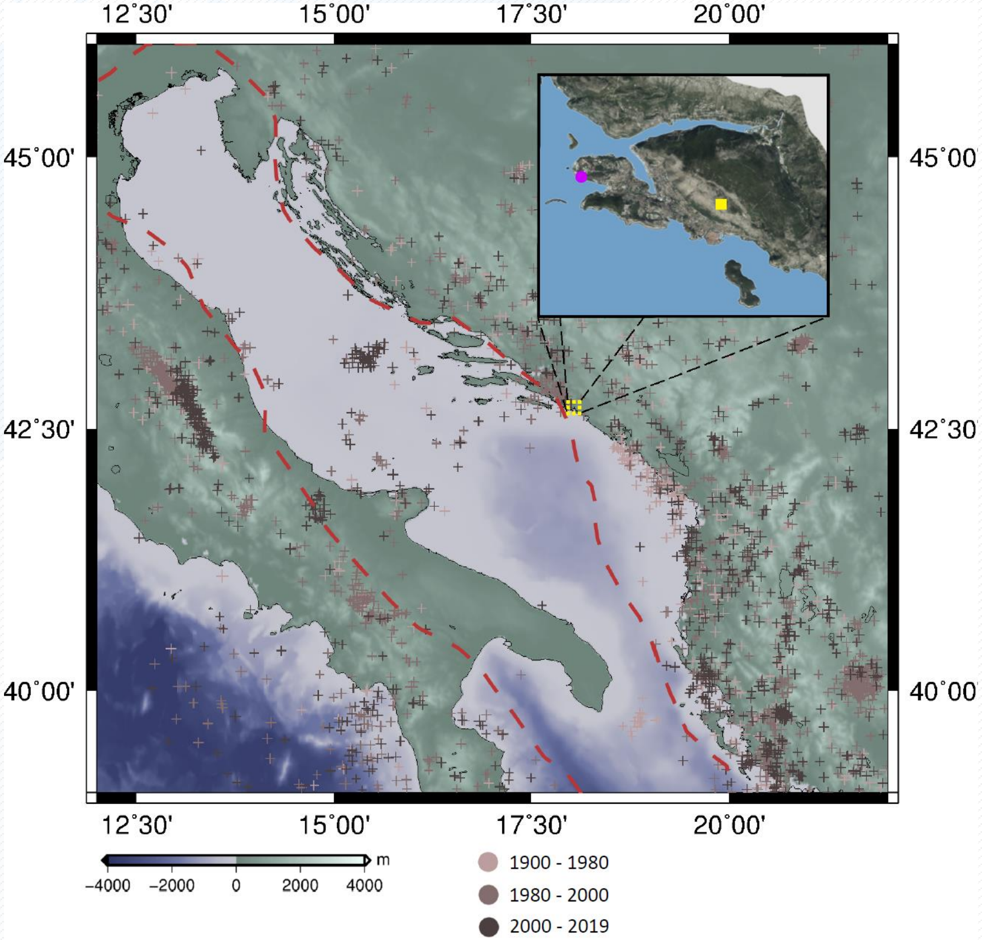

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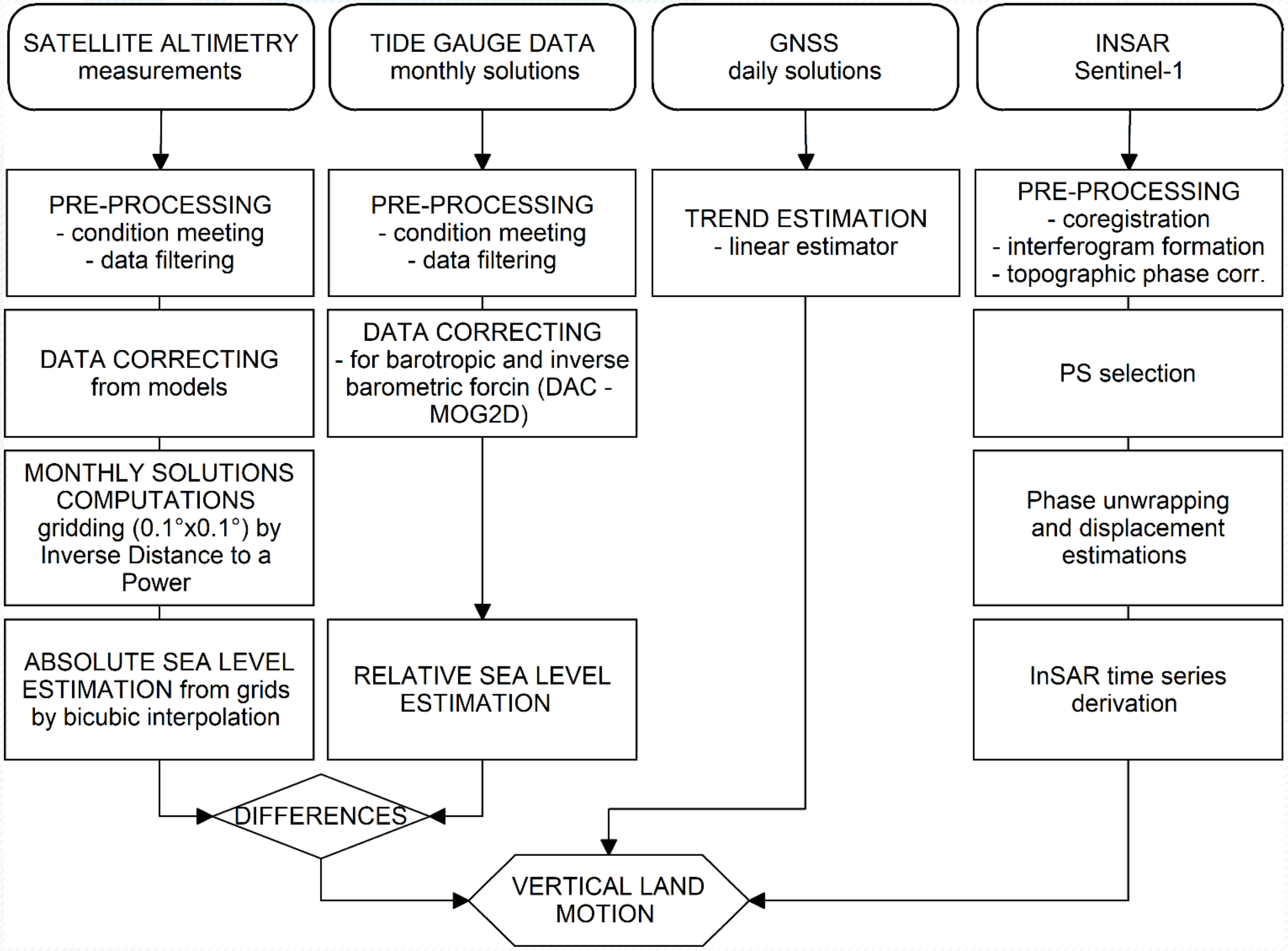

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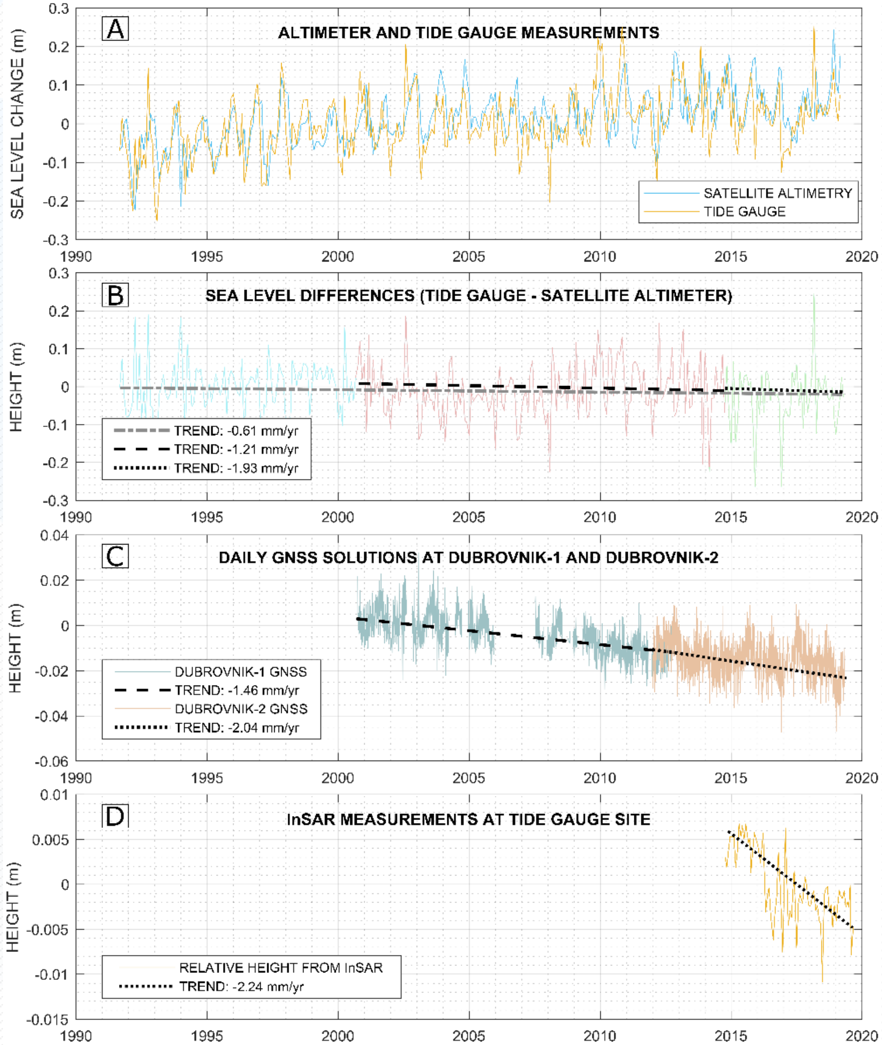

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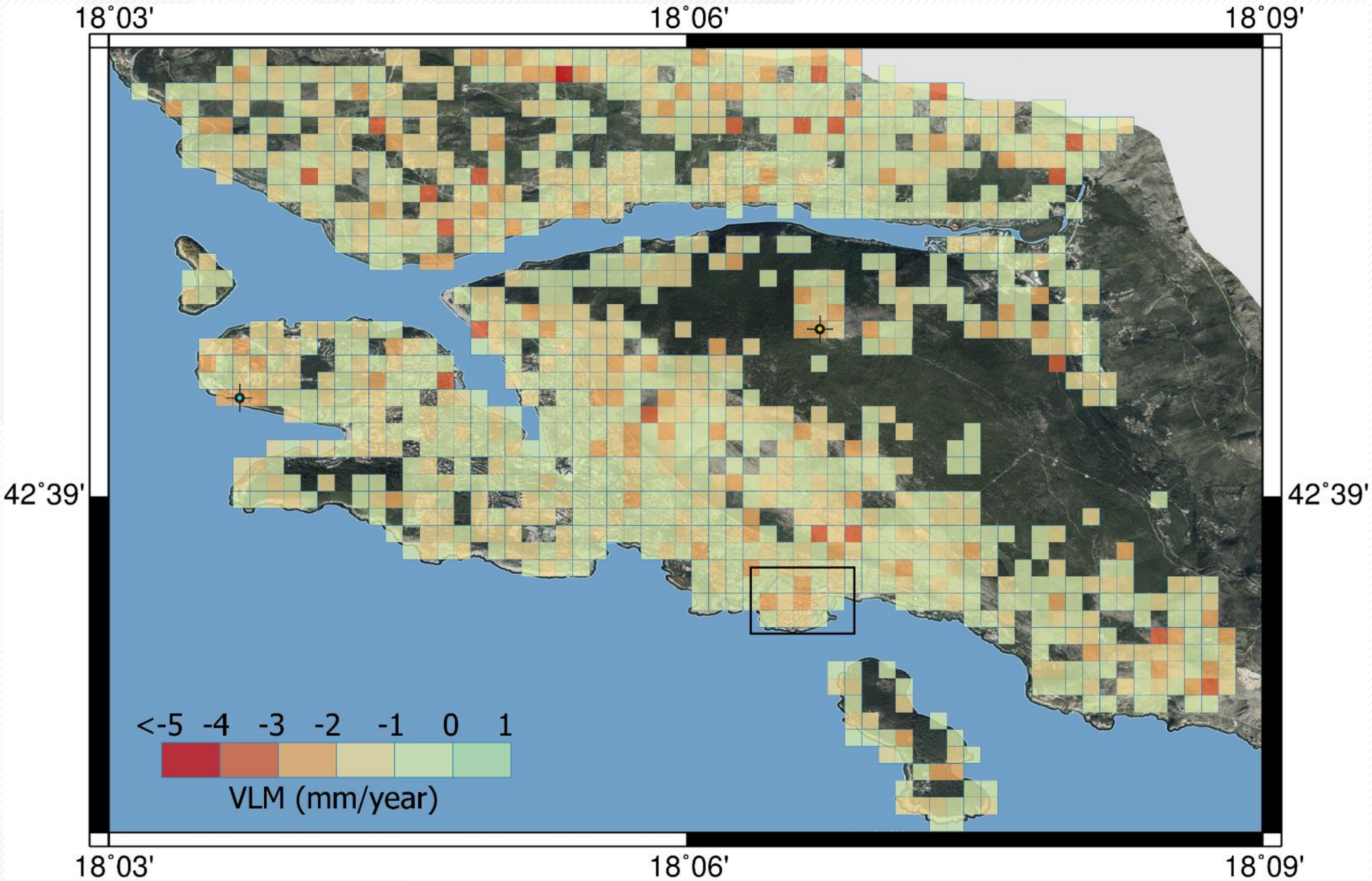
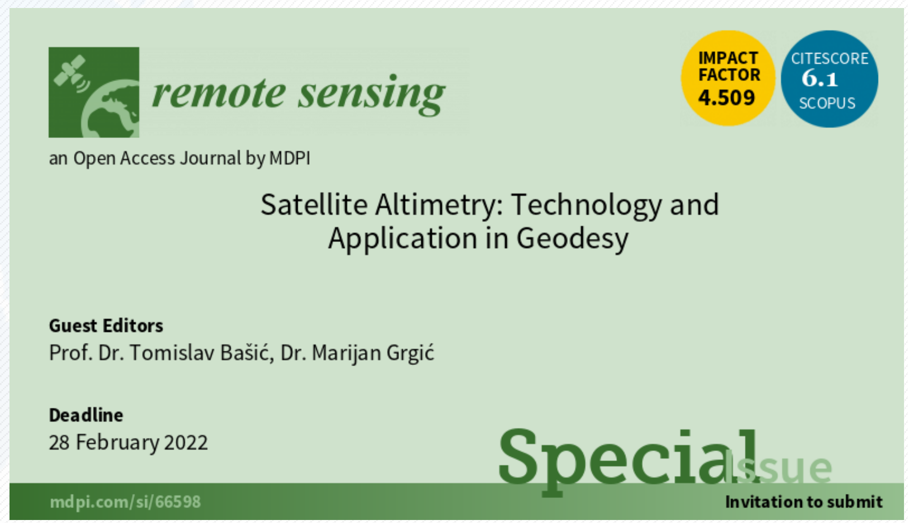


Satellite Altimetry: Monitoring Sea Level Change
More on the topic

E.g., see our publications! ☺

If you are already researcher in the field, consider publishing in our *Special Issue* in *Remote Sensing: https://www.mdpi.com/journal/remotesensing/special_issues/Satellite_Altimetry_Geodesy*



InSAR – hands on Sentinel-1

Sentinel-1

Low orbit (693 km) constellation of two polar-orbiting satellites, operating day and night performing C-band synthetic aperture radar imaging.

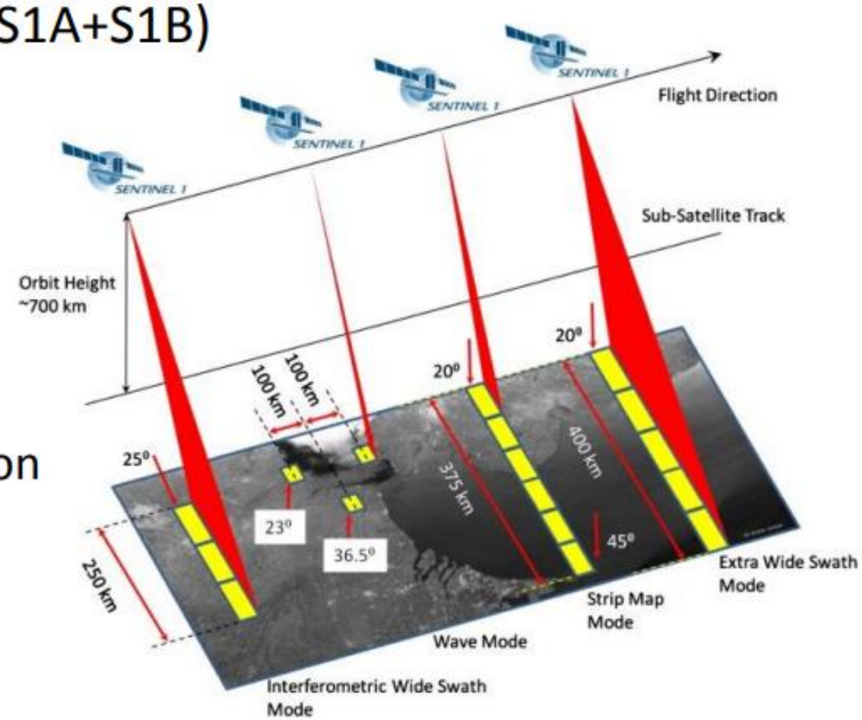
Sentinel-1

Frequency	5.405 GHz
Wavelength	5.546 cm
Polarisation	HH+HV, VV+VH, VV, HH
Elevation angle	20°-46°
Antenna size	12.3x0.821 m
Azimuth beam width	0.23°
Elevation beam width	3.43°
Pulse duration	5-100 μs
Phase error	5°
PRF (Pulse Repetition Frequency)	1000-3000 Hz

InSAR – hands on Sentinel-1

- Sentinel-1A and Sentinel-1B operational
- Orbit Type: Sun-synchronous, near-polar, circular Orbit Height: 693 km
- C-band Synthetic Aperture Radar (SAR)
- 6 Days repeat cycle (S1A+S1B)

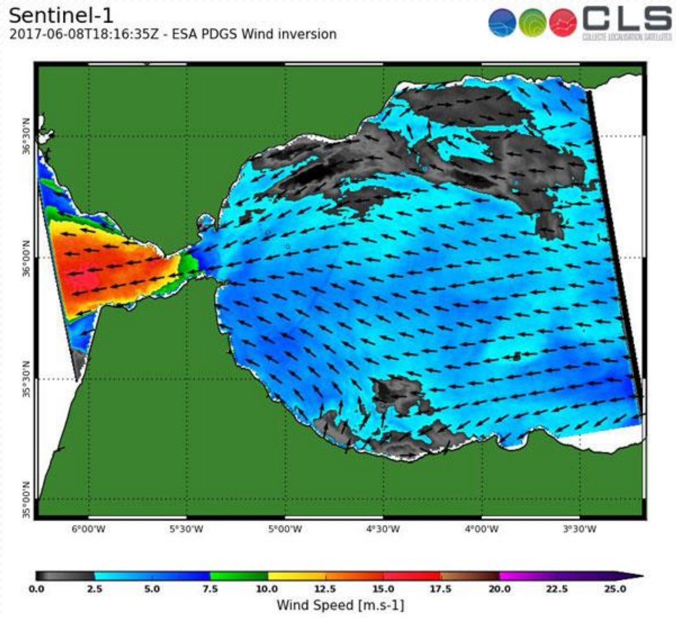
- Strip Map Mode (SM):
  80 km swath width, 5 x 5 m spatial resolution
- Interferometric Wide Swath (IW):
  250 km swath width, 5 x 20 m spatial resolution
- Extra-Wide Swath Mode (EW):
  400 km swath width, 25 x 100 m spatial resolution
- Wave-Mode (WV):
  20 km x 20 km, 5 x 20 m spatial resolution



InSAR – hands on Sentinel-1

Sentinel-1

Sentinel-1 data products acquired in SM, IW and EW mode are distributed at three levels of processing.



Level-0

The SAR Level-0 products consist of compressed and unfocused SAR raw data. Level-0 products are the basis from which all other high level products are produced.

Level-1

Level-1 focused data are the products intended for most data users. The Level-0 product (raw data) is transformed into a Level-1 product by the Instrument Processing Facility (IPF) via the application of various algorithms as indicated below. These Level-1 products form a baseline product from which Level-2 products are derived.

Level-2

Level-2 consists of geolocated geophysical products derived from Level-1. Level-2

Sentinel-1 - resolutions

Level-1 Single Look Complex

Single Look Complex products have spatial resolutions that depend on acquisition mode. In the table below for SLC SM/IW/EW products, the spatial resolutions and pixel spacing are provided at the lowest and highest incidence angles. For SLC WV products, the spatial resolution and pixel spacing are provided for the WV1 and WV2.

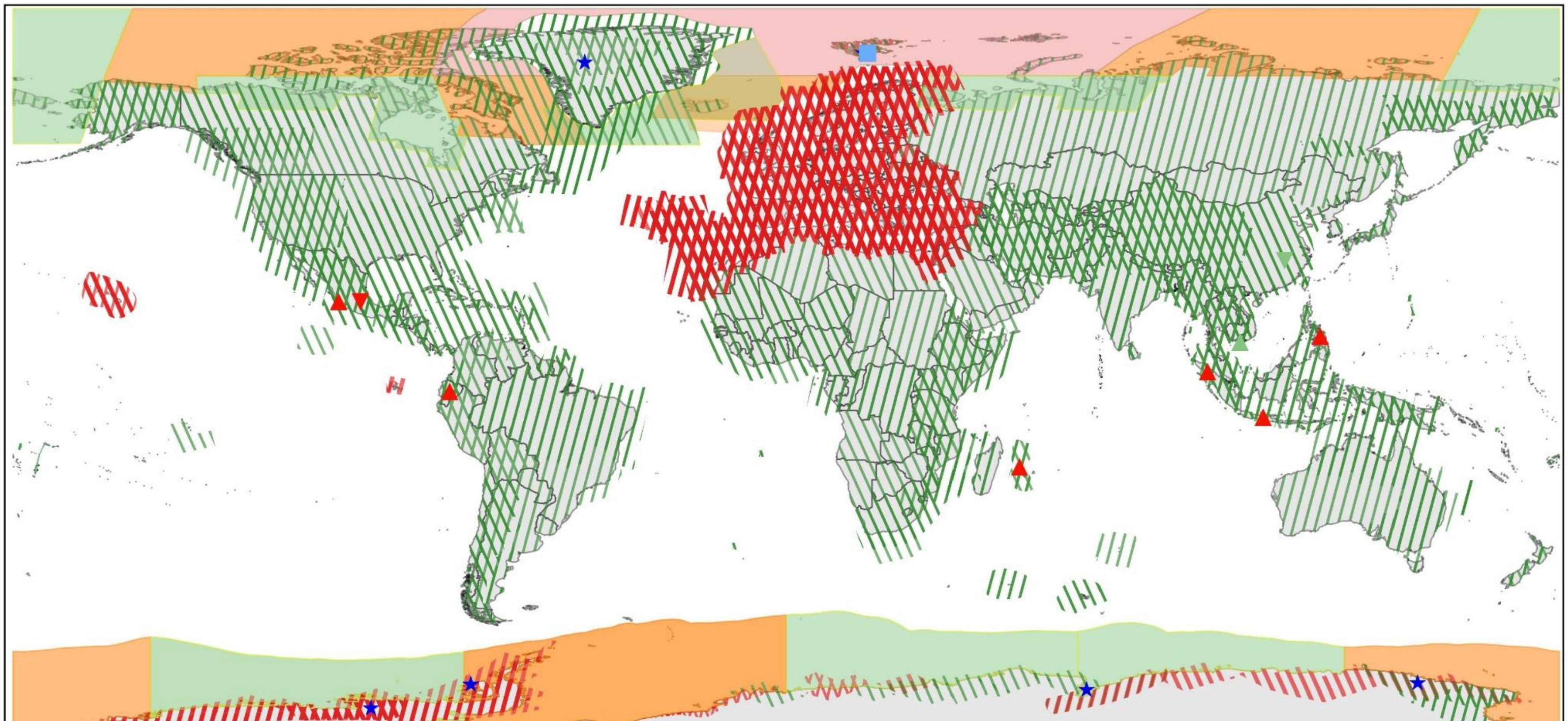
Mode	Resolution rg x az	Pixel spacing rg x az	Number of looks	ENL
SM	1.7x4.3 m to 3.6x4.9 m	1.5x3.6 m to 3.1x4.1 m	1x1	1
IW	2.7x22 m to 3.5x22 m	2.3x14.1 m	1x1	1
EW	7.9x43 m to 15x43 m	5.9x19.9 m	1x1	1
WV	2.0x4.8 m and 3.1x4.8 m	1.7x4.1 m and 2.7x4.1 m	1x1	1

InSAR – hands on Sentinel-1

Sentinel-1 Constellation Observation Scenario: Revisit & Coverage Frequency

sentinel-1

validity start: 05/2019



PASS
- ASCENDING
- DESCENDING

REVISIT FREQUENCY *
- 6 days
- 12 days

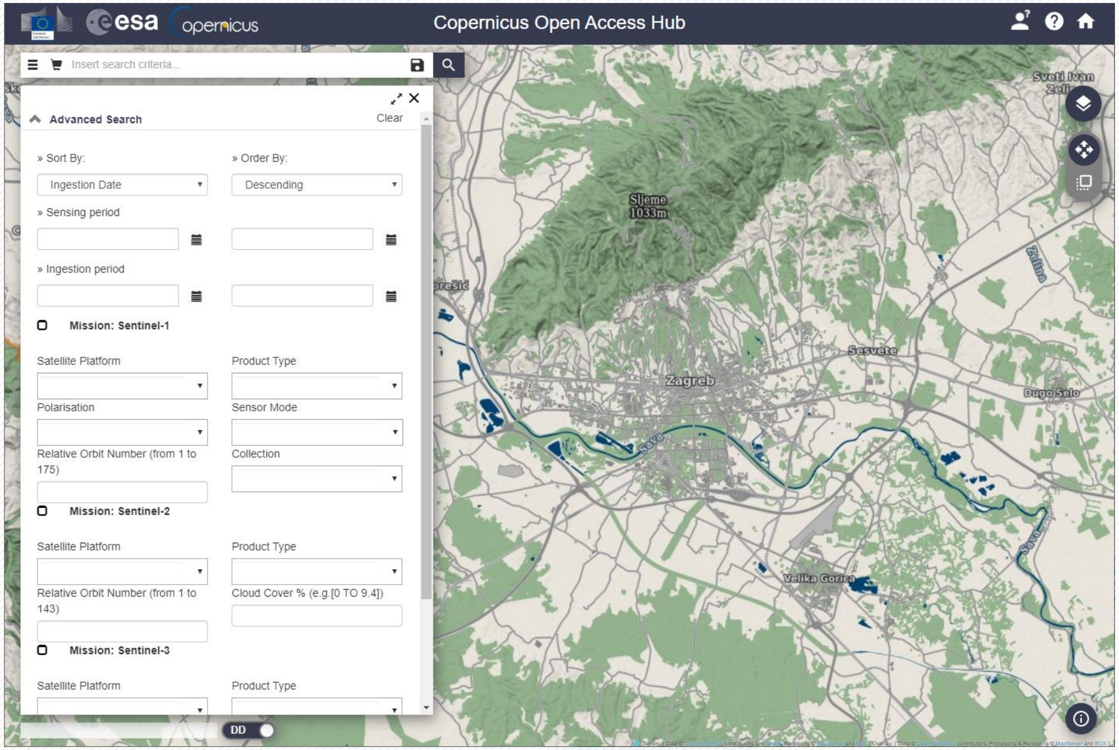
COVERAGE FREQUENCY **
- 1 days
- 1-3 days
- 2-4 days

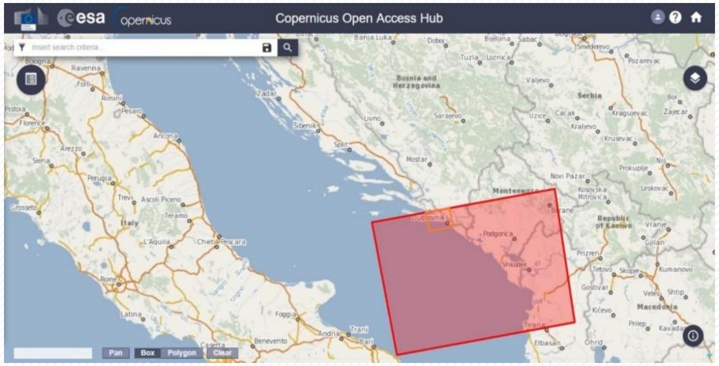
REFERENCE DATA SITES (6d repeat)
- Highly active volcanism
- Fast subsidence
- Short growth cycle, intensive agriculture
- Fast changing wetlands
- Fast moving outlet glaciers
- Permafrost & glaciers

* coverage ensured from same, repetitive relative orbits
** coverage not considering repetitiveness of relative orbits

InSAR – hands on Sentinel-1

Sentinel-1 – dana download **COPERNICUS OPEN ACCESS HUB** https://scihub.copernicus.eu/





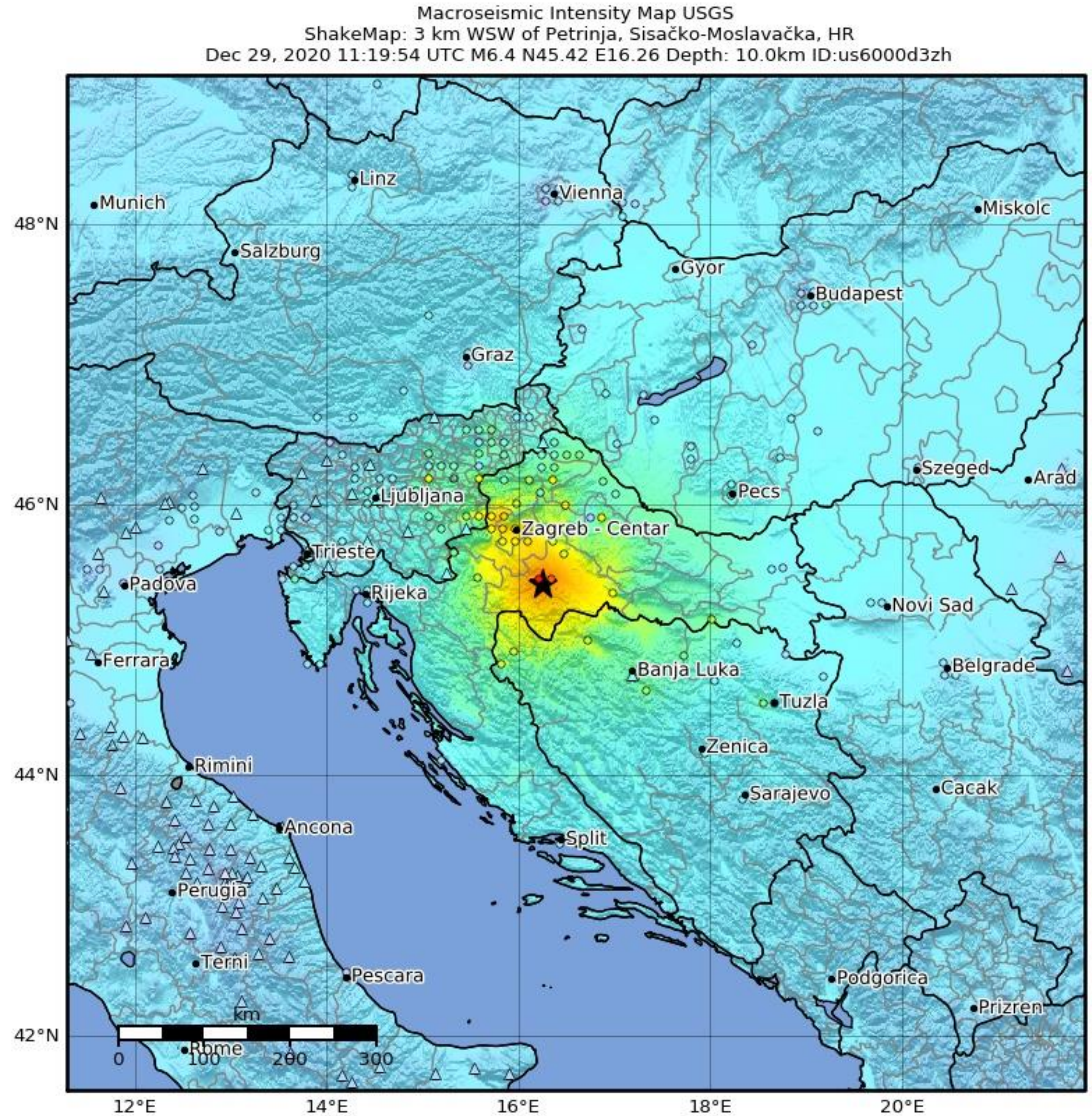
SLC product – enables interferometry because it encompasses both amplitude and phase information.

Free registration.

SAR – hands-on Sentinel-1

Practical assignment – SNAP (Sentinel Application Platform)

Detect and map vertical displacements caused by the earthquake of magnitude 6.4 Mw (6.2 ML) that occured in Petrinja on 29 December 2020

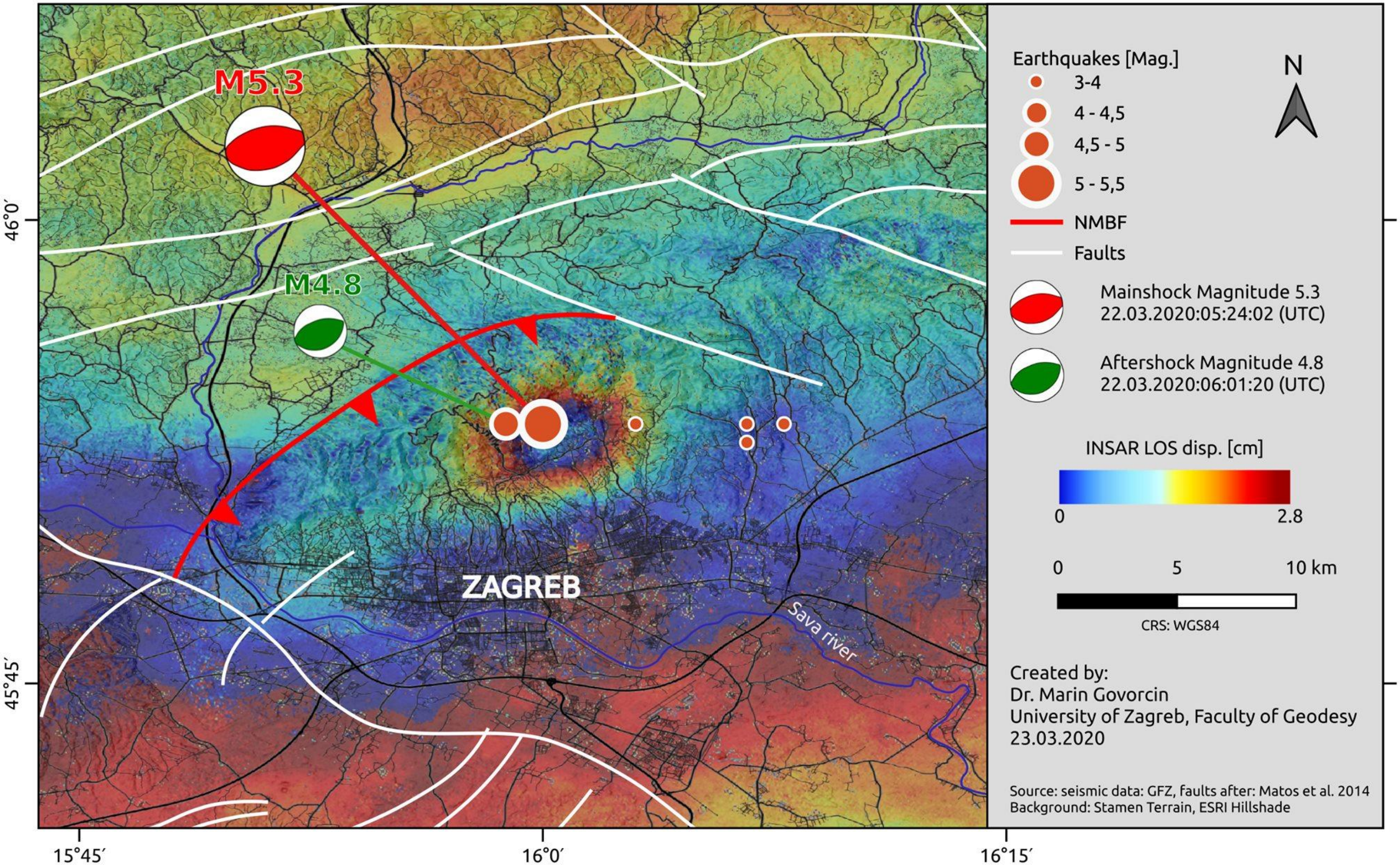


SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
DAMAGE	None	None	None	Very light	Light	Moderate	Moderate/heavy	Heavy	Very heavy
PGA(%g)	<0.0464	0.297	2.76	6.2	11.5	21.5	40.1	74.7	>139
PGV(cm/s)	<0.0215	0.135	1.41	4.65	9.64	20	41.4	85.8	>178
INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

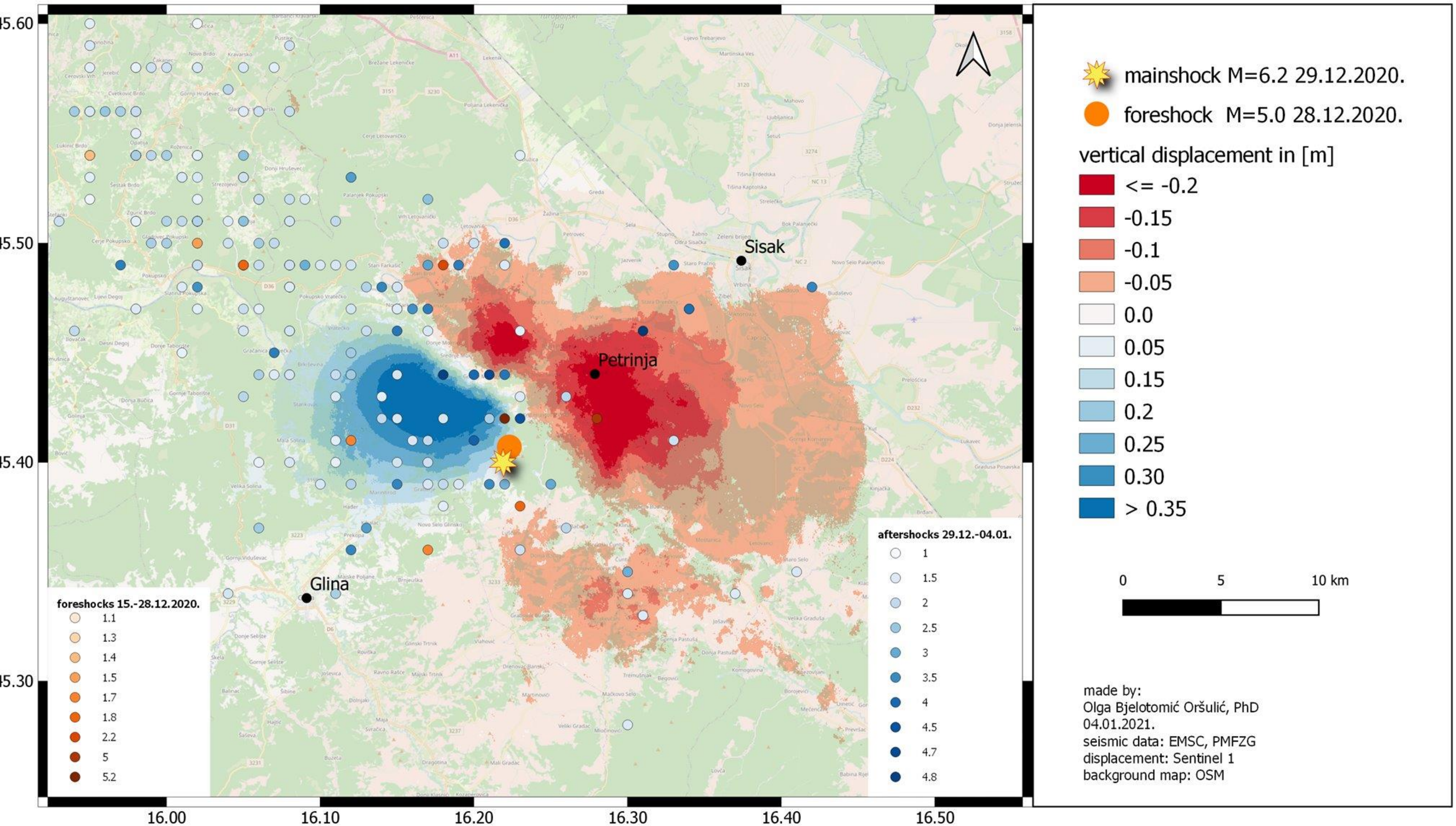
Scale based on Worden et al. (2012) Version 4: Processed 2020-12-30T11:21:46Z

△ Seismic Instrument ○ Reported Intensity ★ Epicenter

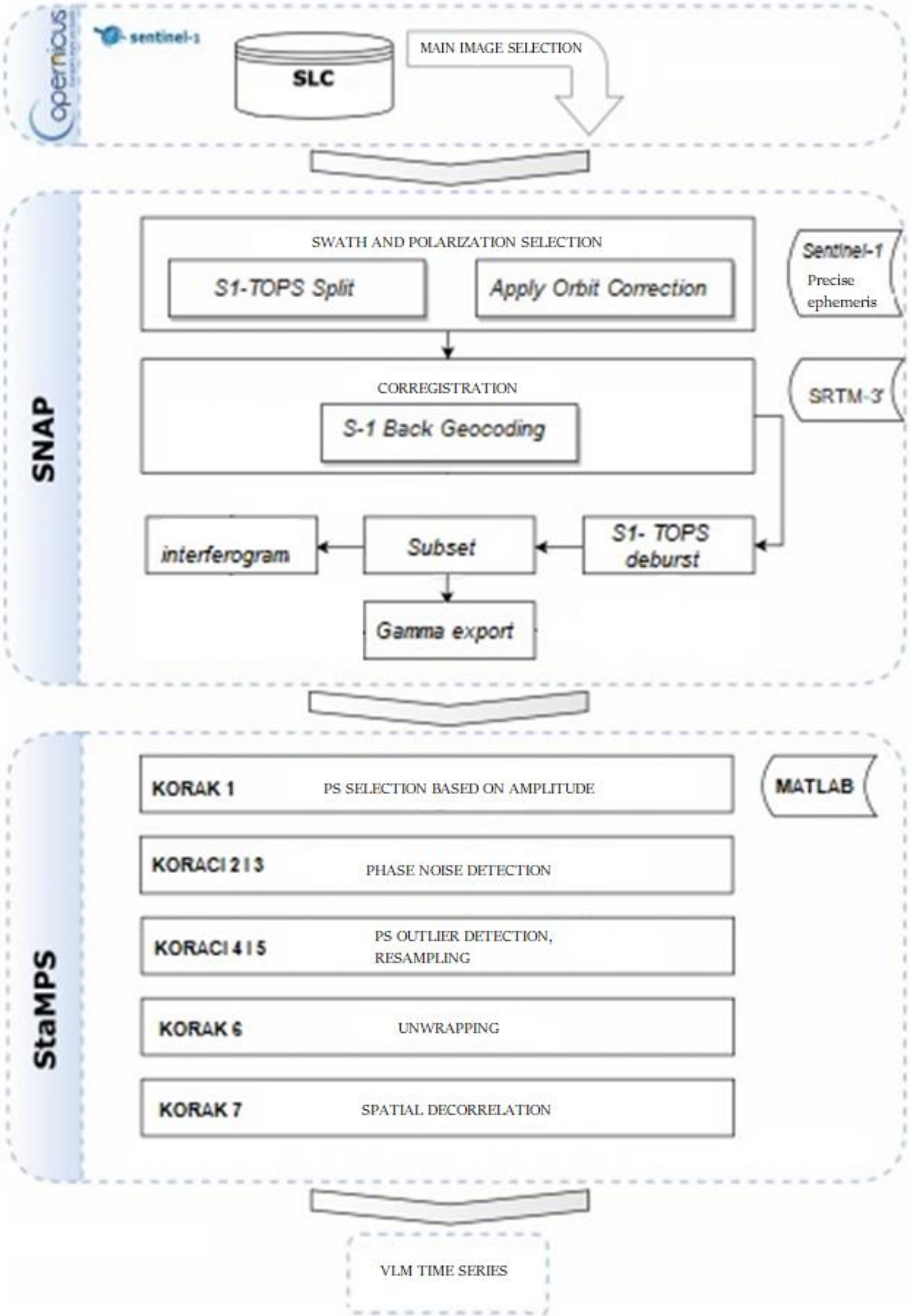
Mar 22, 2020 M5.3 and M4.8 Zagreb earthquake (NW Croatia)
Sentinel-1 (T146) M: 17.03.2020 S: 23.03.2020 T:16:50



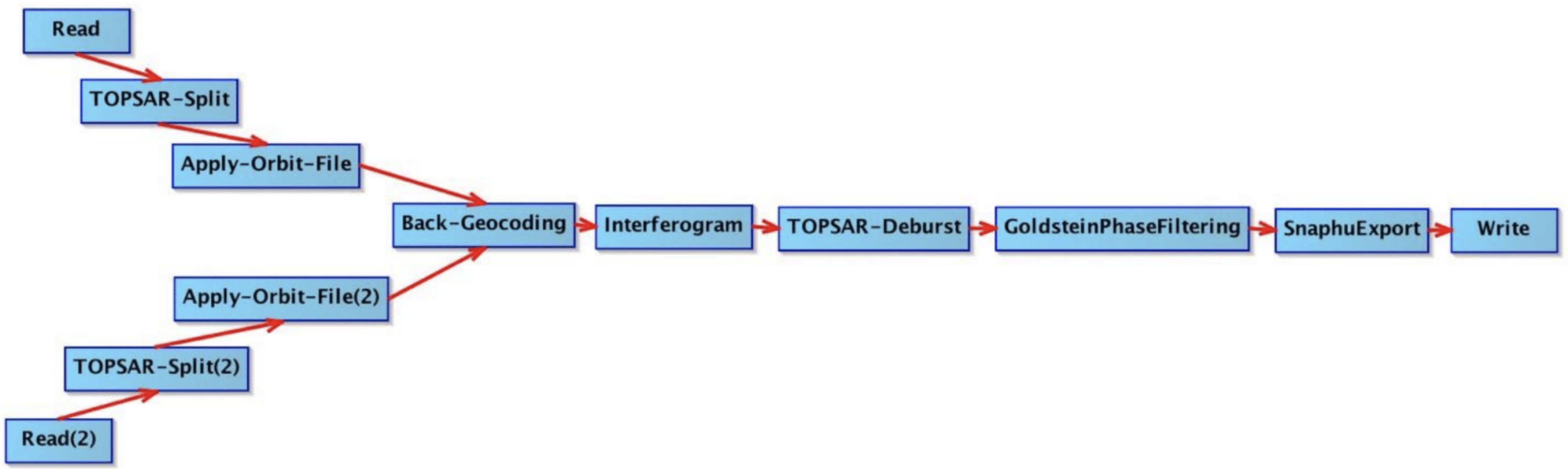
Vertical displacement map for M=6.2 earthquake in NW Croatia on 29.12.2020. 12:19 (UTC) from Sentinel 1 C-SAR data



SAR – hands-on Sentinel-1

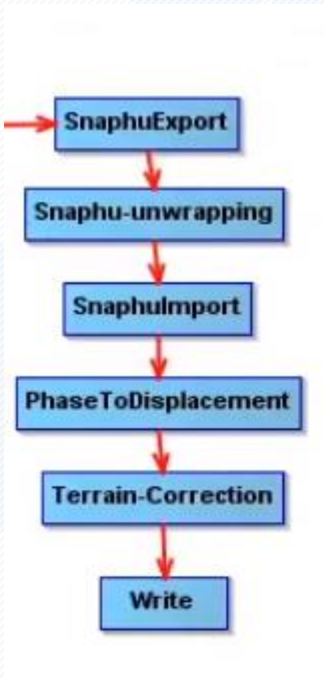


SAR – hands-on Sentinel-1

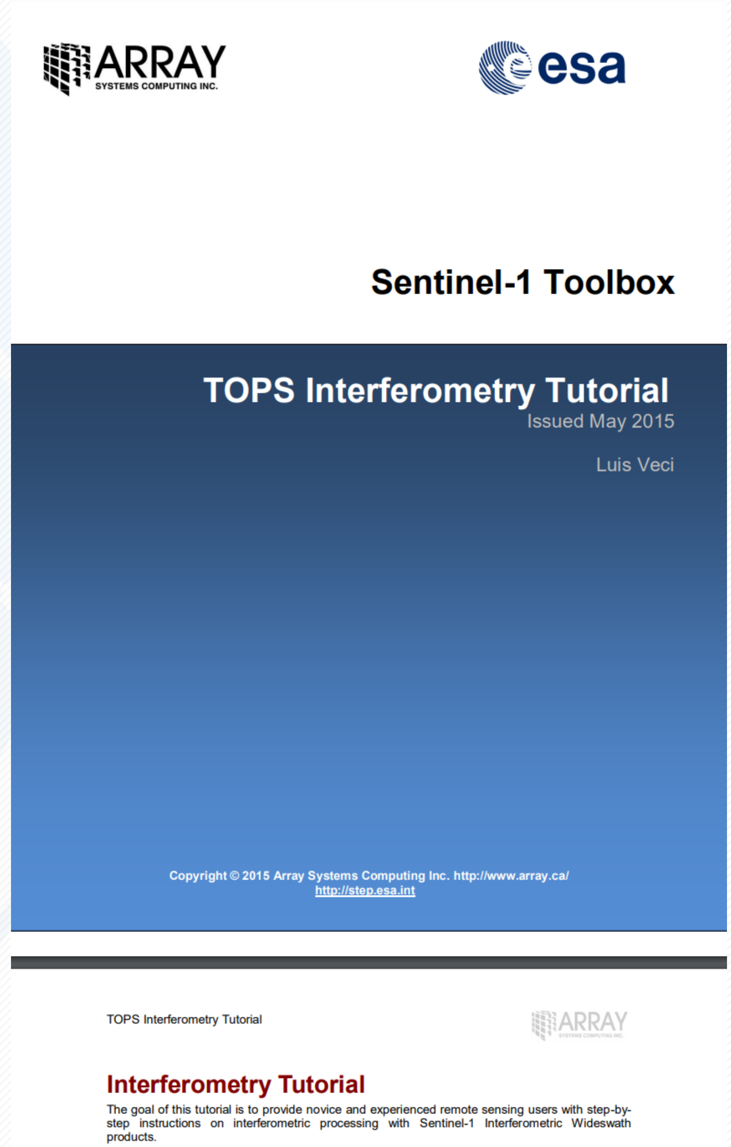


Pre-unwrapping steps in SAR processing

SAR – hands-on Sentinel-1



Post-unwrapping steps in SAR processing



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Sentinel-1 Toolbox

TOPS Interferometry Tutorial

Issued May 2015

Luis Veci

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TOPS Interferometry Tutorial

Interferometry Tutorial

The goal of this tutorial is to provide novice and experienced remote sensing users with step-by-step instructions on interferometric processing with Sentinel-1 Interferometric Wideswath products.

Thank you for the attention!