L'interferometria radar satellitare per il monitoraggio delle dighe

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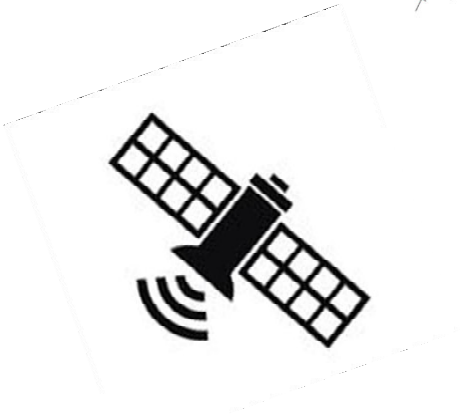
Aim

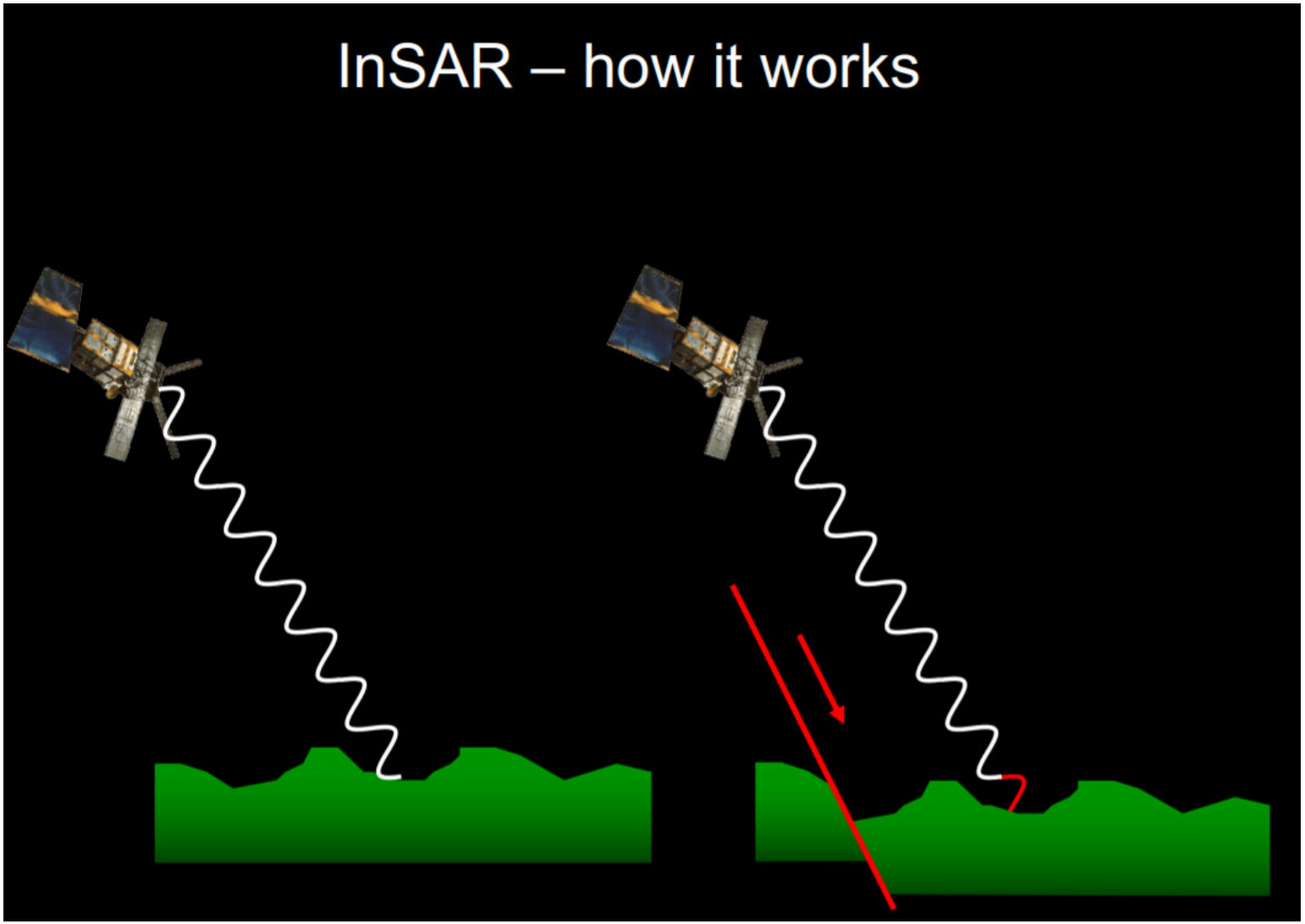


STEADY project

SaTEllite synthetic Aperture radar interferometry to model Dam stability

This work is aimed on highlighting the potential of SAR data and Multi-temporal Interferometric techniques on dam monitoring, and how to support traditional techniques, focusing on the infrastructures and eventually on the surrounding basin.

Methods



Methods

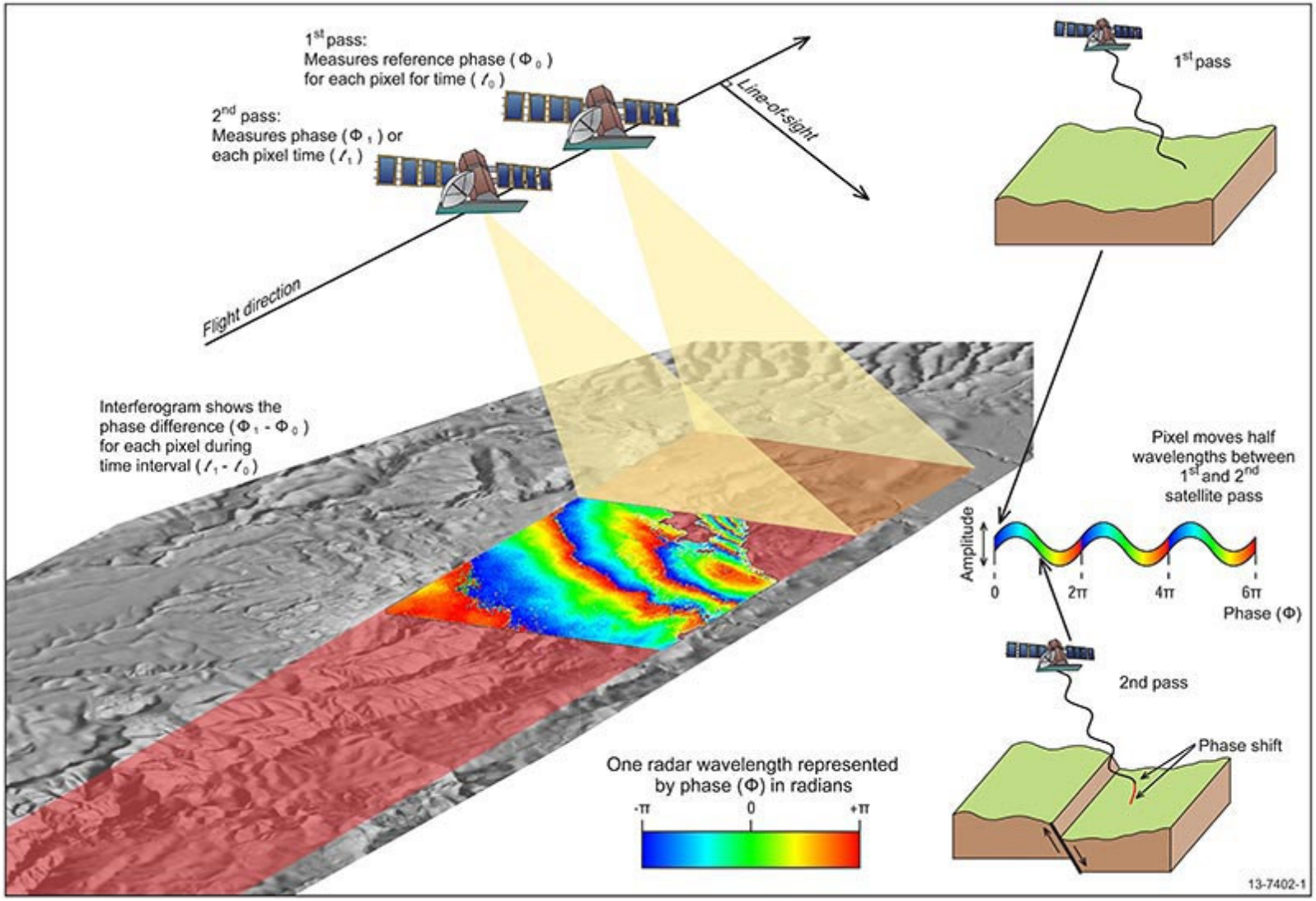
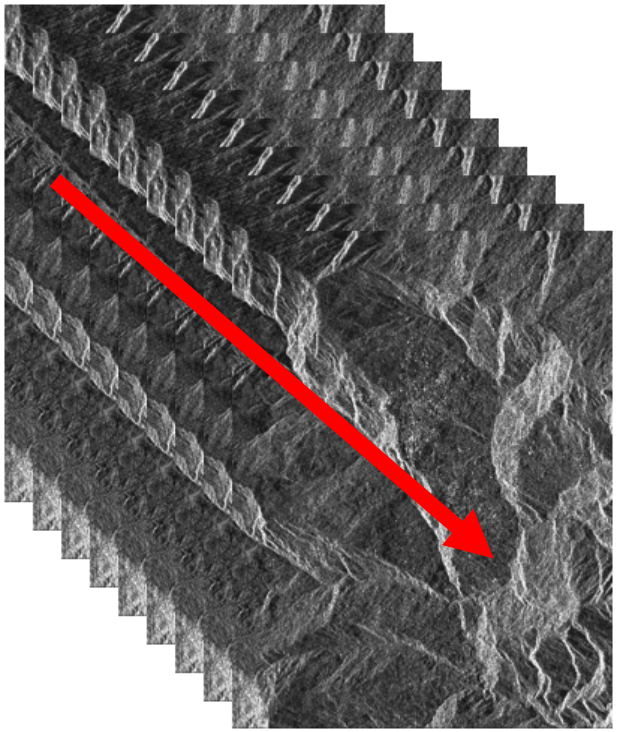


Image: Geoscience Australia

Methods - Multi-temporal Interferometric techniques

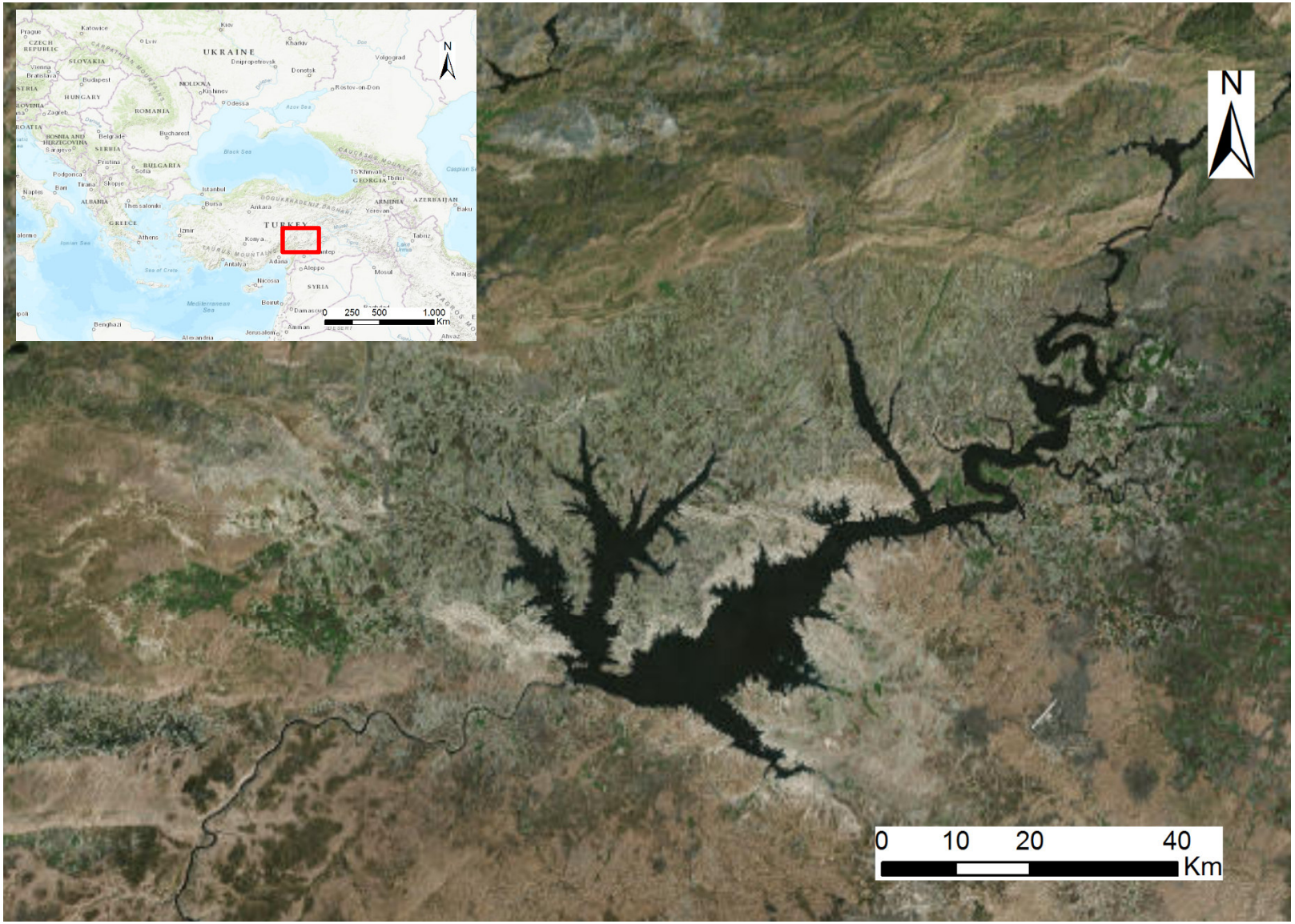
$$\phi_{Int} = \phi_{Topography} + \phi_{Change} + \phi_{Movement} + \phi_{Atmosphere}$$



- Persistent Scatterers (PS)
- Small Baseline Subset (SBAS)

PS	SBAS
Independent, incorrelated motions	At best spatially correlated motions
Pixelwise continuous time series	Possibility of handling time seriers with temporal holes
Time interval between two acquisitions limited by displacement rate	Time interval between two acquisitions limited by temporal decorrelation
Very accurate on PS	Slightly less accurate
Linear displacements favoured	Larger variety of parametric models possible. Non-parametric modeling possible

Ataturk dam

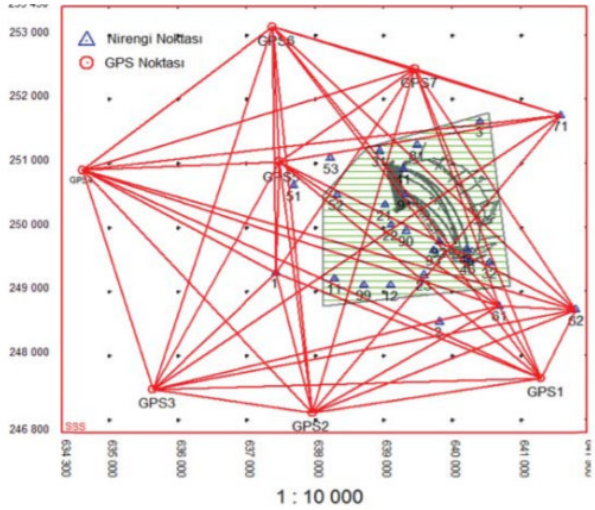

N
0 10 20 40
Km
UKRAINE
SLOVAKIA
HUNGARY
ROMANIA
BULGARIA
SERBIA
GREECE
TURKEY
SYRIA
0 250 500 1.000
Km

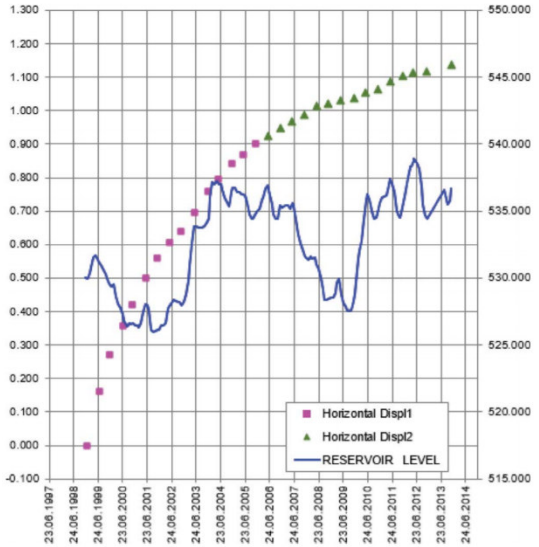
Ataturk dam

Ataturk Dam is a zoned rocked-fill dam with a central clay core. It was built between the 1983 and 1990, primarily for water storage and hydropower generation. The dam embankment is 169 m high and 1,820 m long. Its total storage capacity of 48.7 million m^3.

The rock-fill dam undergoes deformations that are regularly and systematically monitored since 1990 with different types of sensors. It is estimated that the central portion of the dam crest has settled by several meters since the end of the construction. The maximum horizontal (radial) deformation measured is about 2.9 m.

Terrestrial measurements



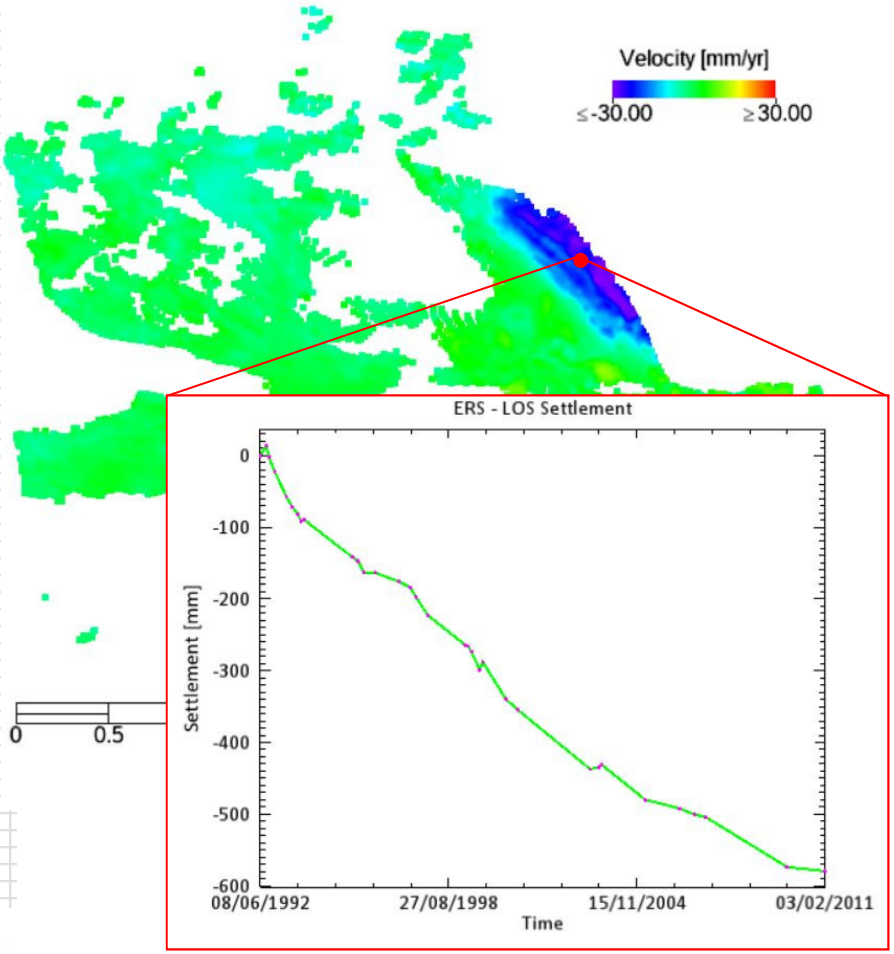


H. H. Yavaşoğlu, et al., 2018. Monitoring the deformation and strain analysis on the Ataturk Dam, Turkey. Geomatics, Natural Hazards and Risk

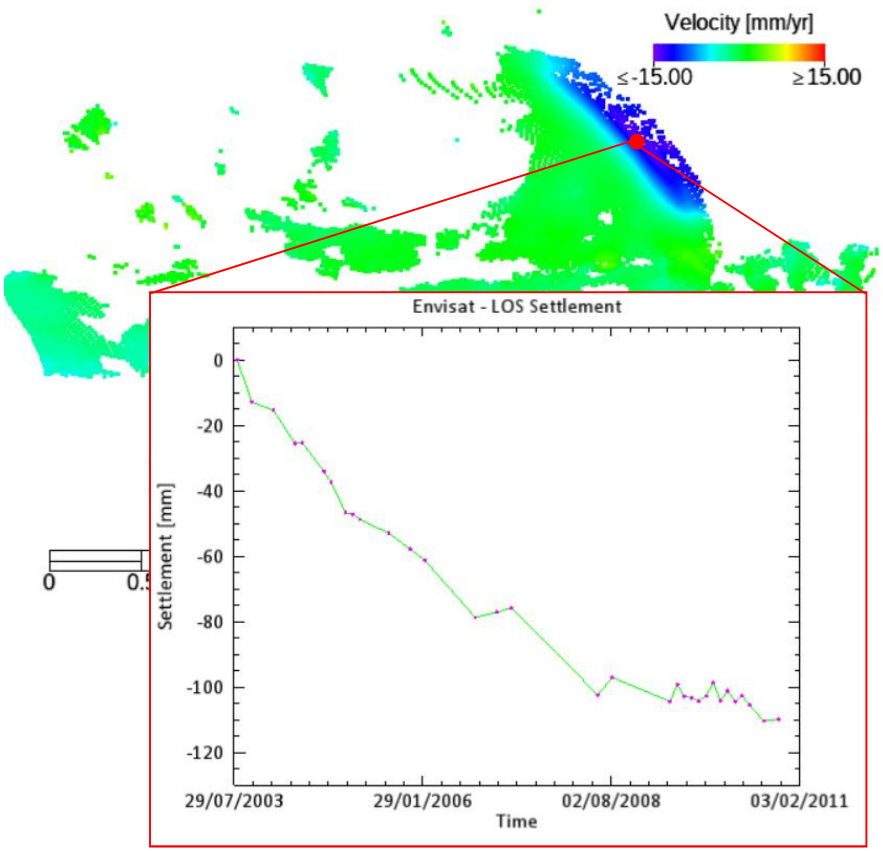
SAR Datasets

Mission	Track	Time interval	N. scenes
ERS	35 D	June 1992 – February 2011	45
Envisat	35 D	August 2003 – October 2010	34
Sentinel 1	123 D	October 2014 – March 2018	140
	116 A	October 2014 – April 2018	132

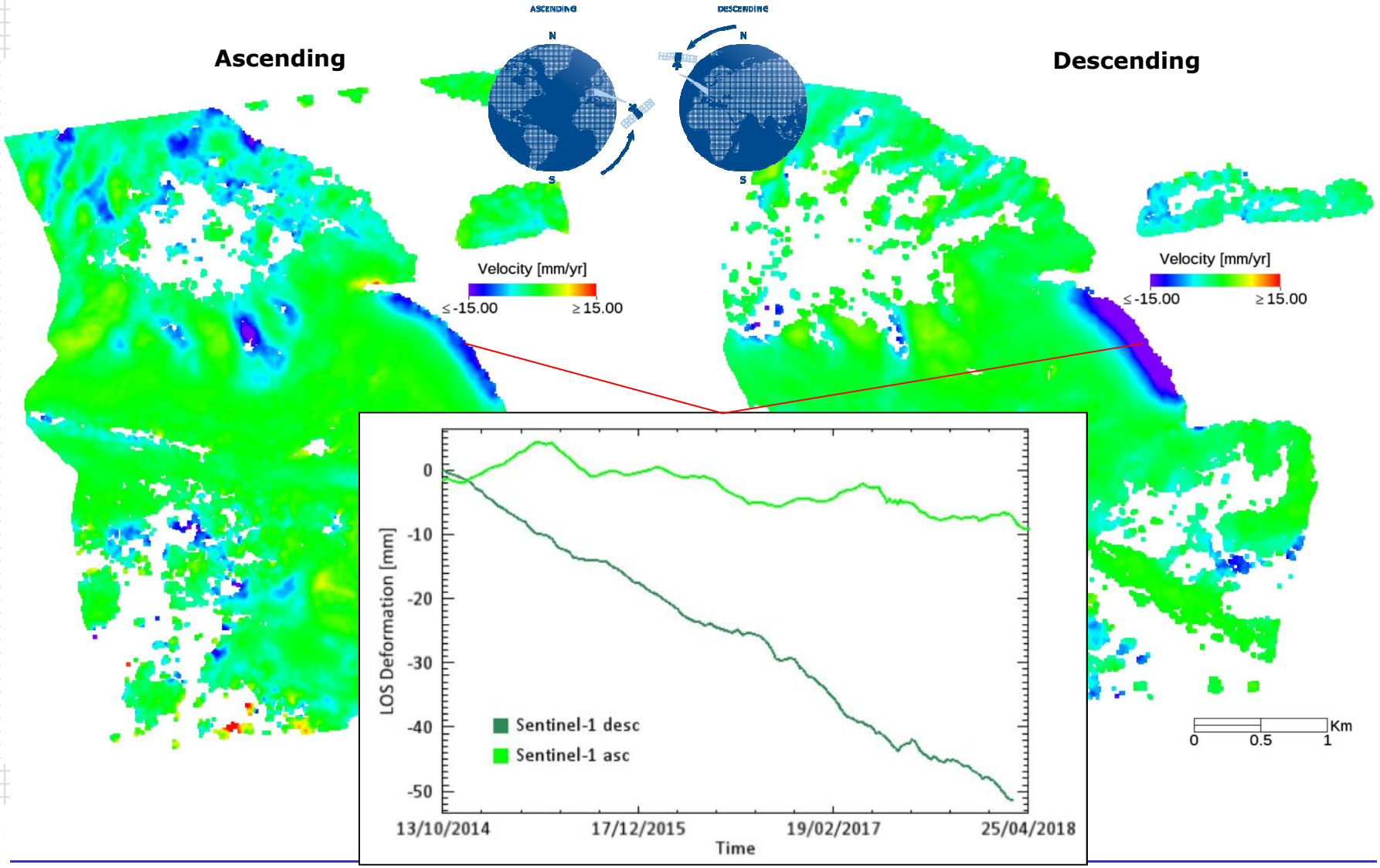
ERS
June 1992 to February 2011 average displacement rate [mm/year]

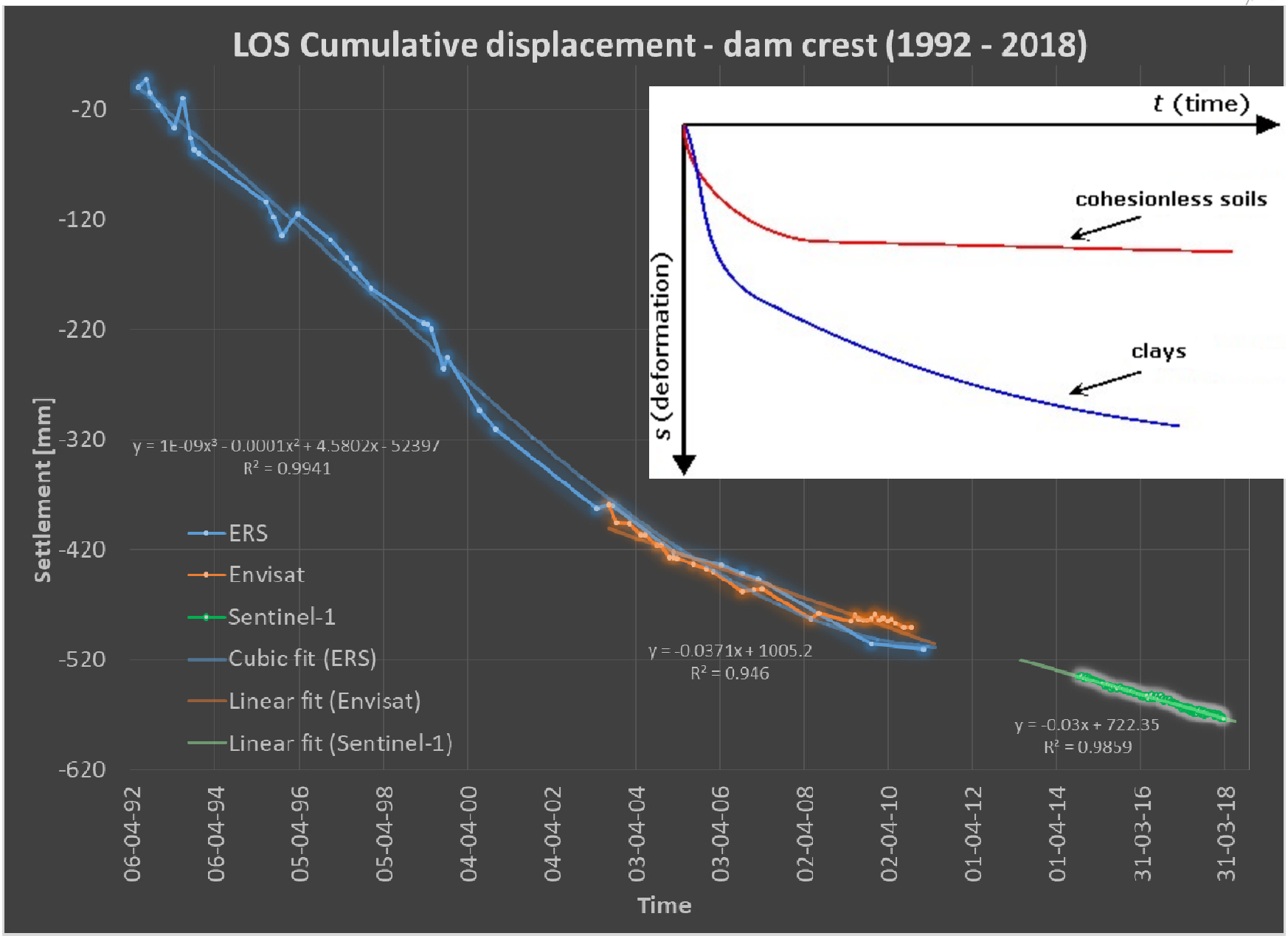


Envisat
August 2003 to October 2011 average displacement rate [mm/year]

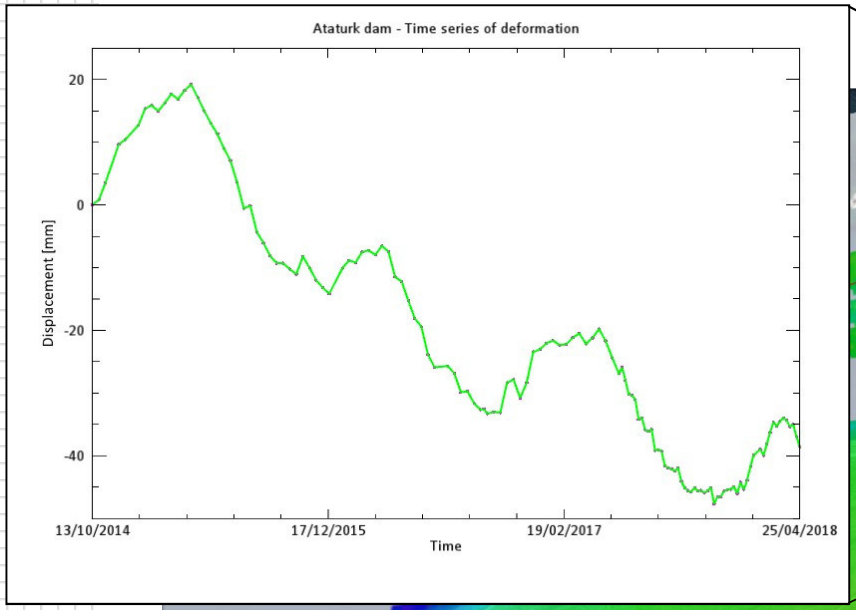


Sentinel -1
October 2014 to March 2018 average displacement rate [mm/year]




LOS Cumulative displacement - dam crest (1992 - 2018)
Settlement [mm]
-20
-120
-220
-320
-420
-520
-620
06-04-92
06-04-94
05-04-96
05-04-98
04-04-00
04-04-02
03-04-04
03-04-06
02-04-08
02-04-10
01-04-12
01-04-14
31-03-16
31-03-18
Time
y = 1E-09x³ - 0.0001x² + 4.5802x - 52397
R² = 0.9941
y = -0.0371x + 1005.2
R² = 0.946
y = -0.03x + 722.35
R² = 0.9859
ERS
Envisat
Sentinel-1
Cubic fit (ERS)
Linear fit (Envisat)
Linear fit (Sentinel-1)
t (time)
s (deformation)
cohesionless soils
clays

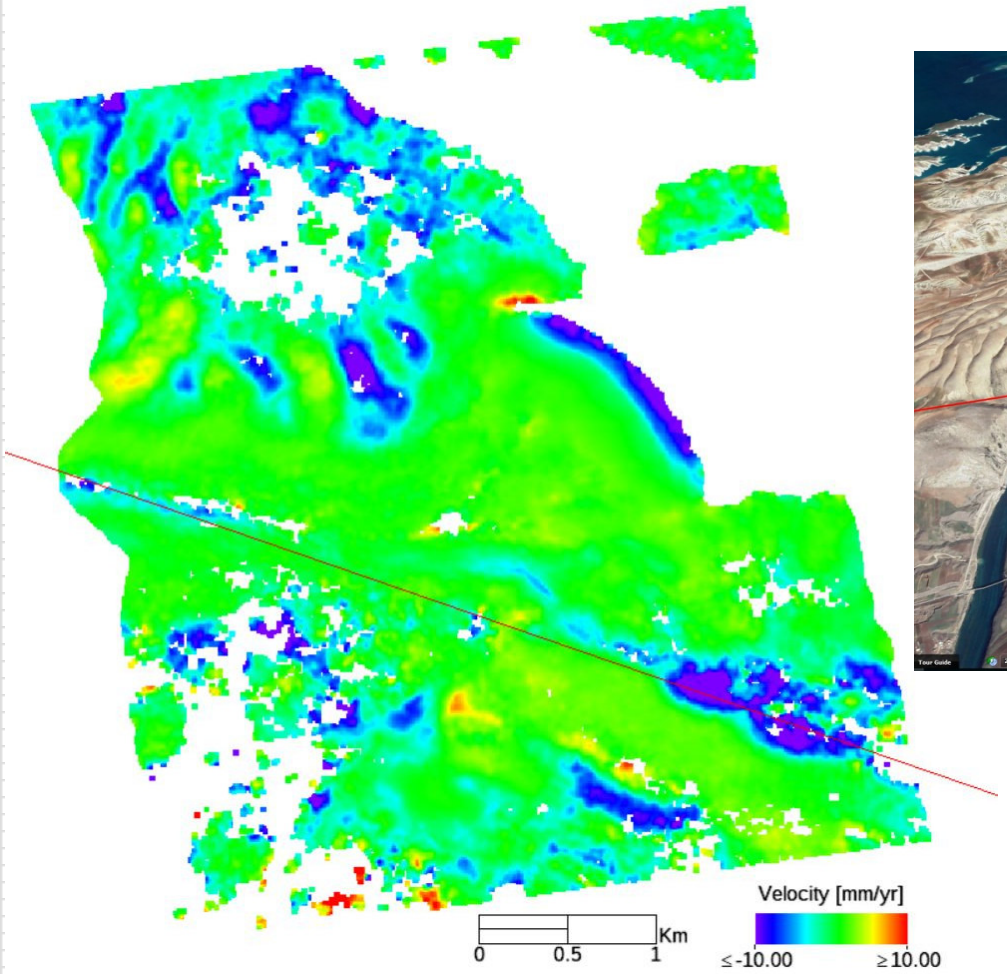
October 2014 to March 2018 average displacement rate [mm/year]



Ascending

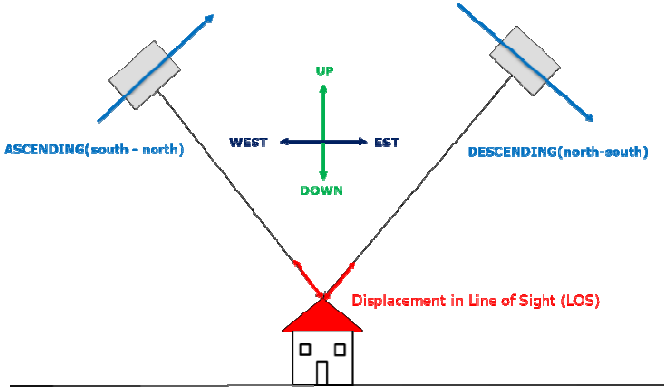
October 2014 to March 2018 average displacement rate [mm/year]

Ascending

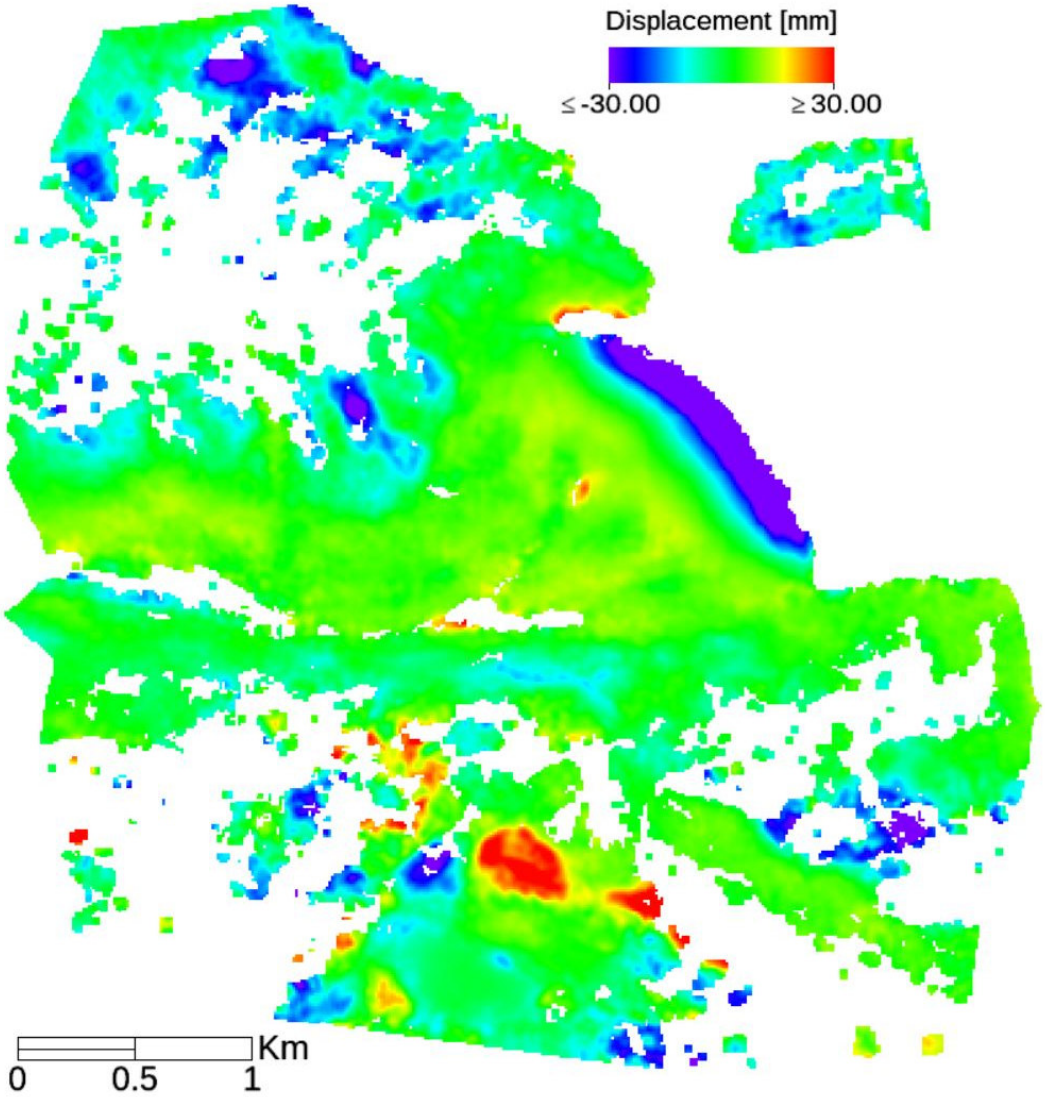


Bozova Fault which runs right underneath the dam.

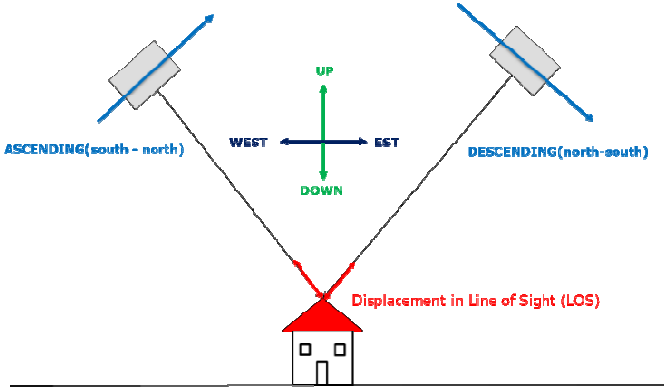
October 2014 to March 2018 average displacement rate [mm/year]



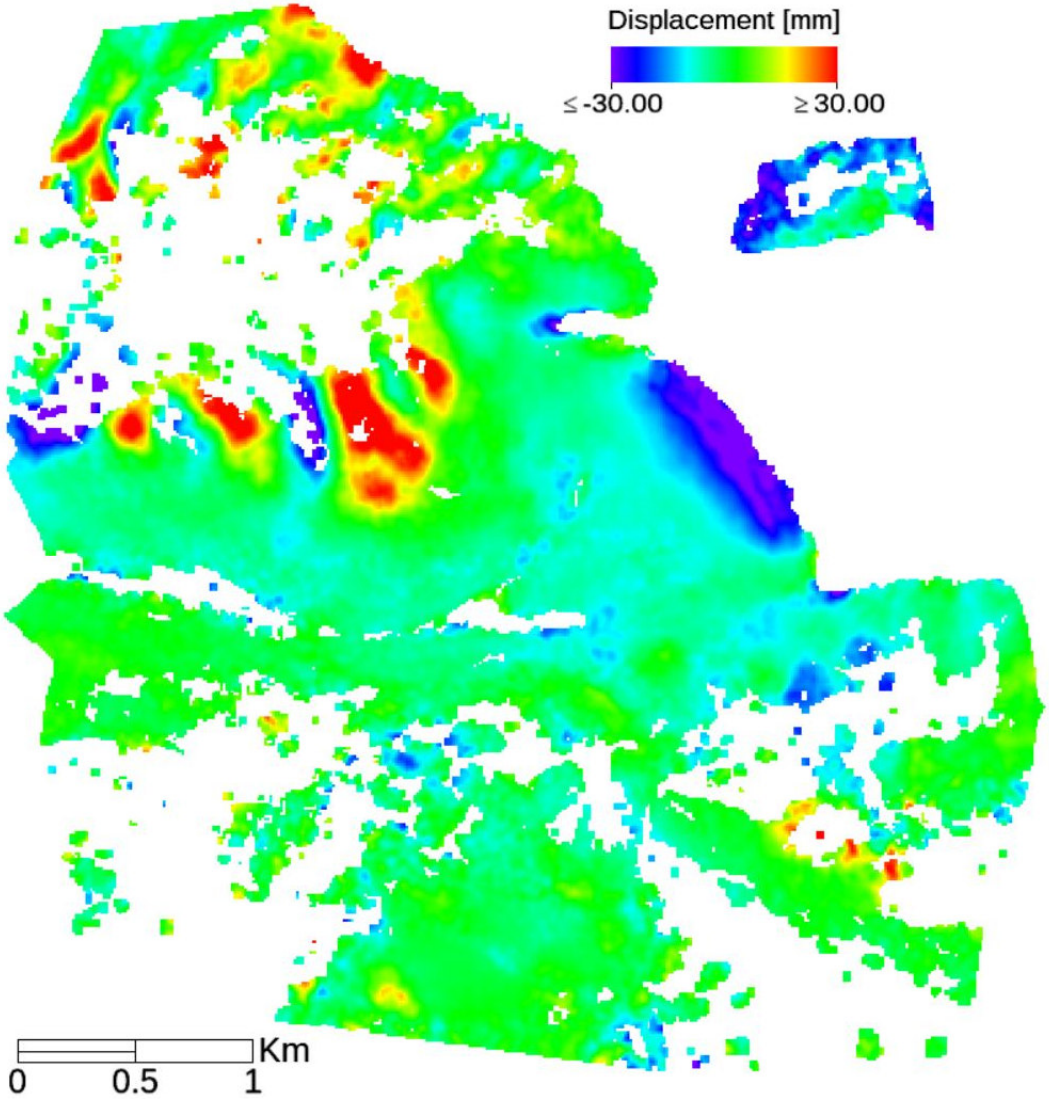
Vertical component

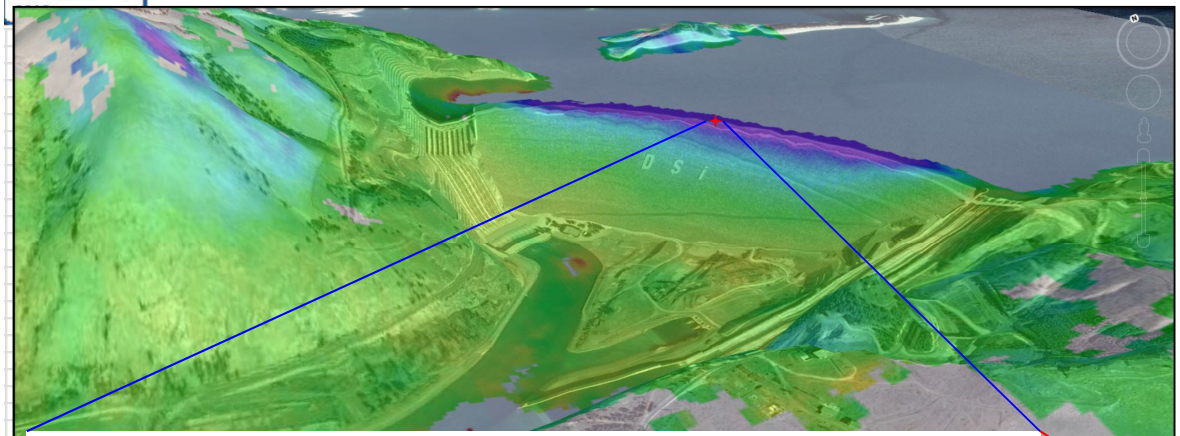


October 2014 to March 2018 average displacement rate [mm/year]

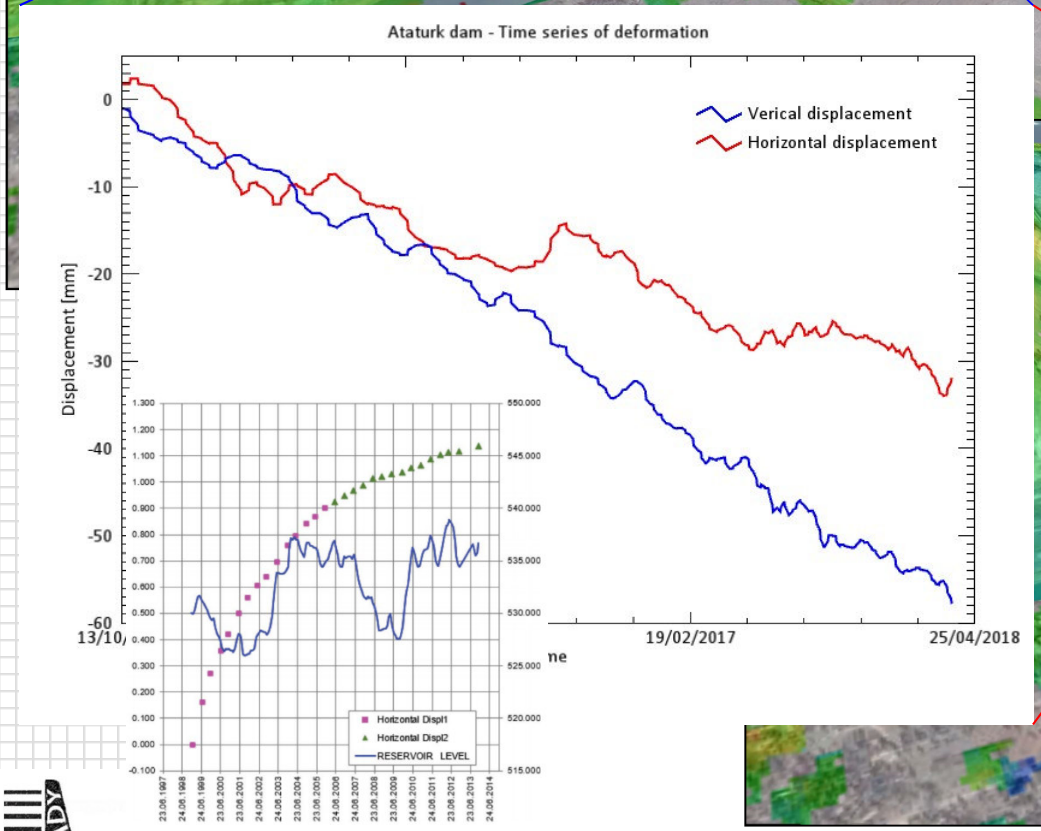


Horizontal component

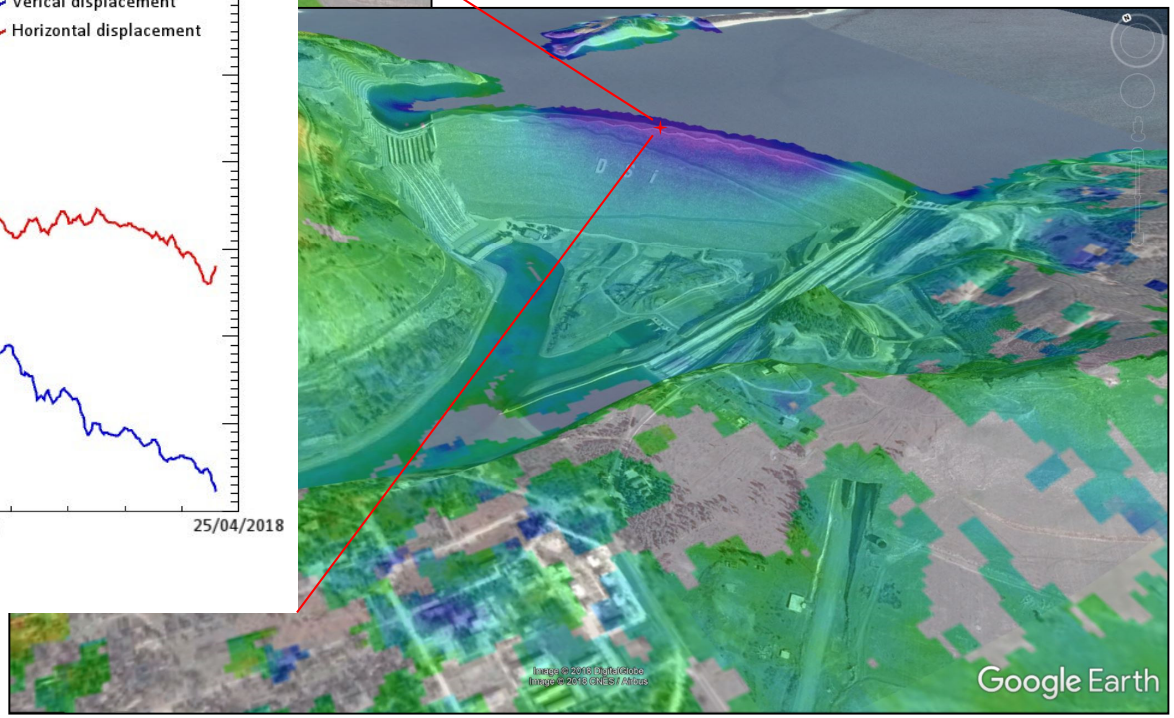




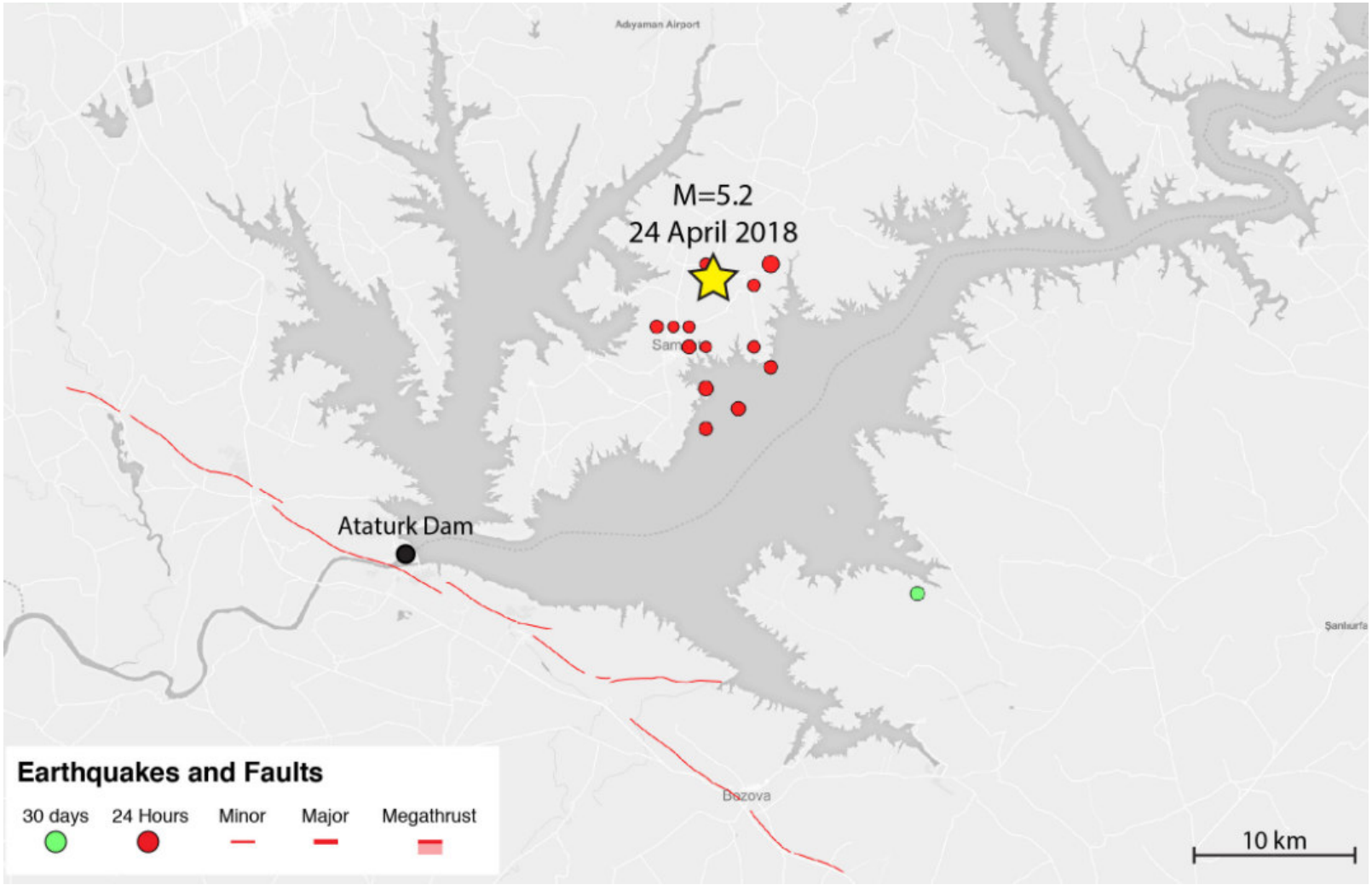
Vertical component



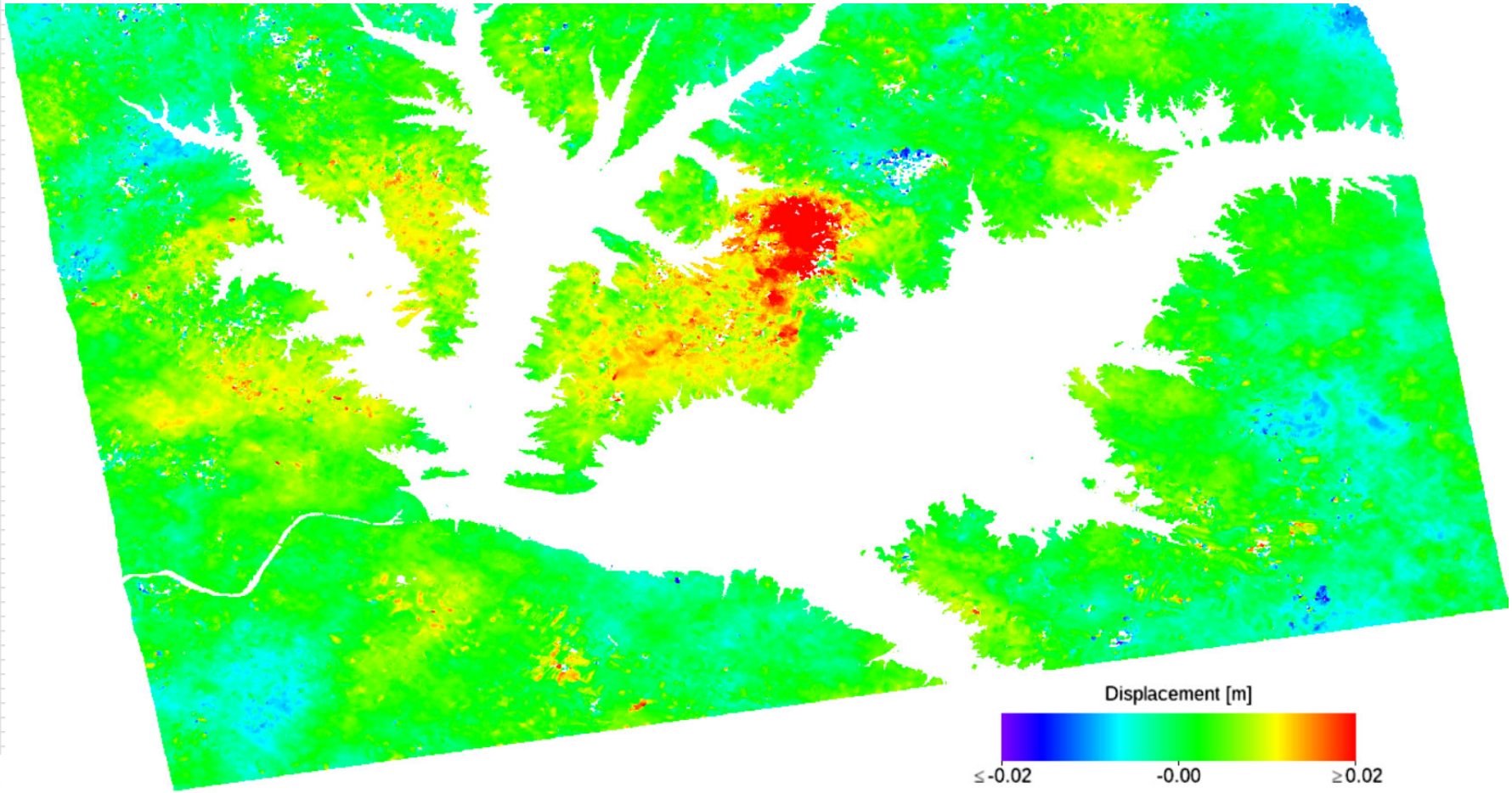
Horizontal component



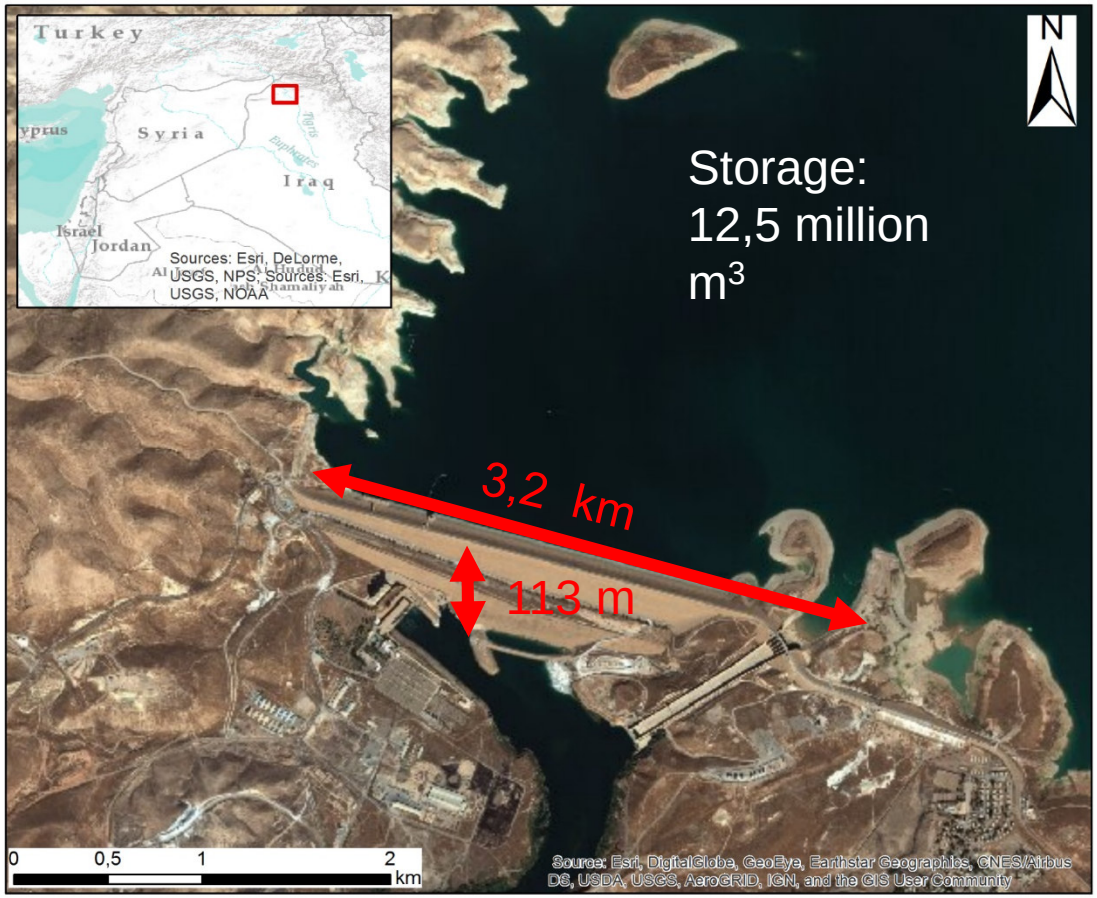
This map shows the location of today's M=5.2 earthquake in southeastern Turkey. It also highlights the location of the Ataturk Dam, which is believed to be partially responsible for induced earthquakes in the region.



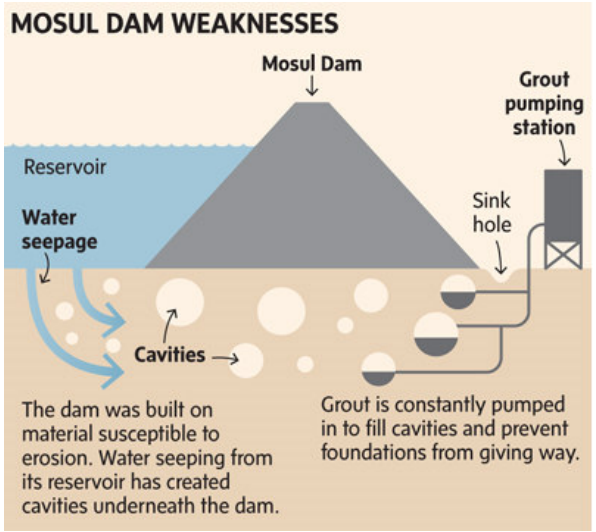
Earthquake: 24/04/2018
Sentinel-1 co-seismic couple: master 19/04/2018, slave 26/04/2018



Mosul dam



The Mosul dam is the biggest dam in Iraq. It is located along the river Tigris, 35 km north from the city of Mosul. It is an earthen dam with a clay core, 113 mt high, 3.2 km long and it was inaugurated in 1986.



Soon after its inauguration, the dam has suffered some structural problems caused by the soft gypsum subsoil, on which it was built. The water penetrates from underneath the basement causing erosion. Therefore, to slow down this process, some concrete has been injected throughout the years.

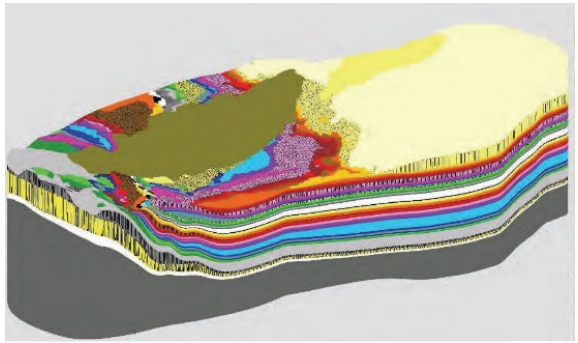
Geological Setting

The dam foundation lies on alternating units of gypsum, anhydrite, marl and limestone strongly sensitive to dissolution under the environmental and hydrological condition of the dam.

Dissolution caused formation of karst features, superficially manifesting as sinkholes.

Abutments and foundation of Mosul dam:

- West abutment lies on geological units dipping northern, towards the reservoir on the north flank and away from the dam on the southern flank with no geological connection from upstream to downstream
- The east abutment dip to a shallow angle to the South-East promoting a preferential groundwater flow and hydraulic connectivity



US Army corps of Engineers- J. R. Kelley et al., 2007. Geological Setting of Mosul Dam and its Engineering Implications

Data

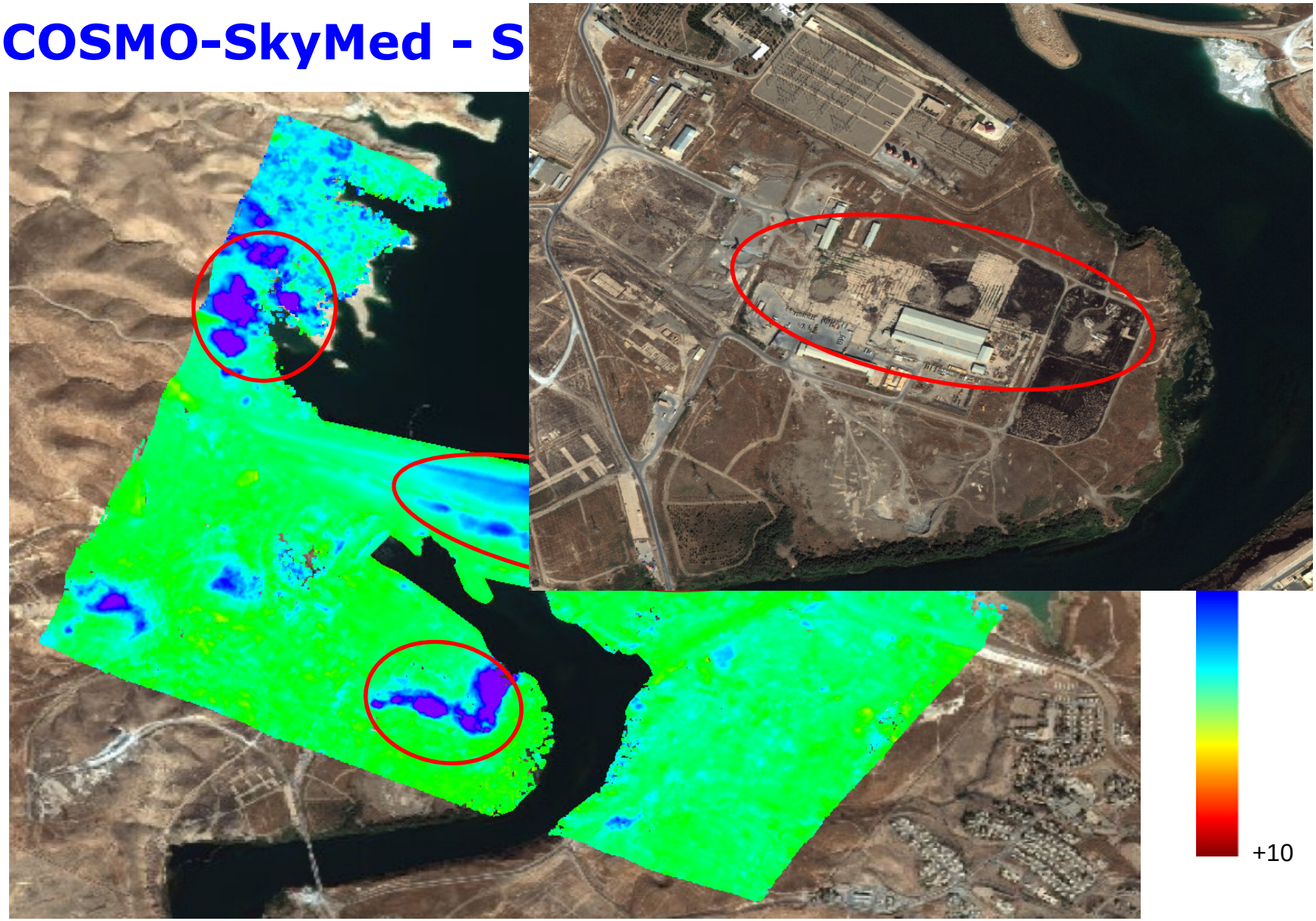
✓ COSMO-SkyMed data:

- 61 stripmap ascending data from Dicember 2012 to July 2015

✓ Sentinel-1 data:

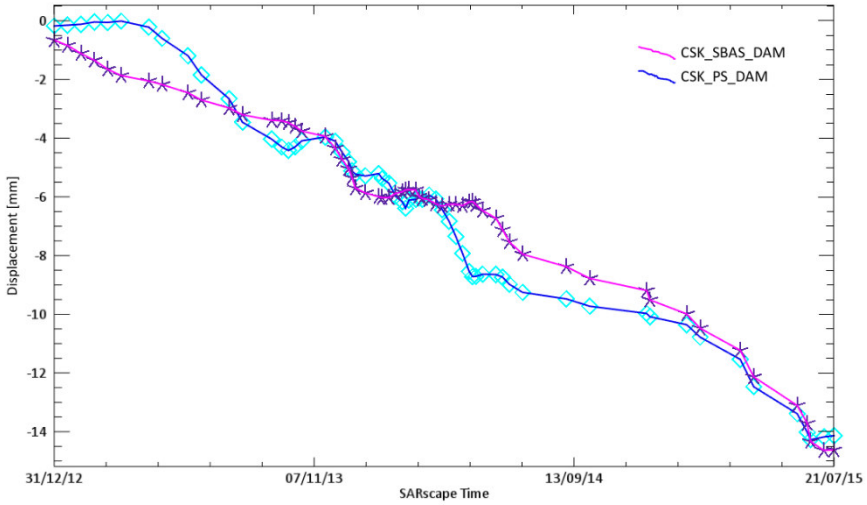
- 59 ascending data from October 2014 to February2017
- 74 descendig data from October 2014 to February 2017

COSMO-SkyMed - S

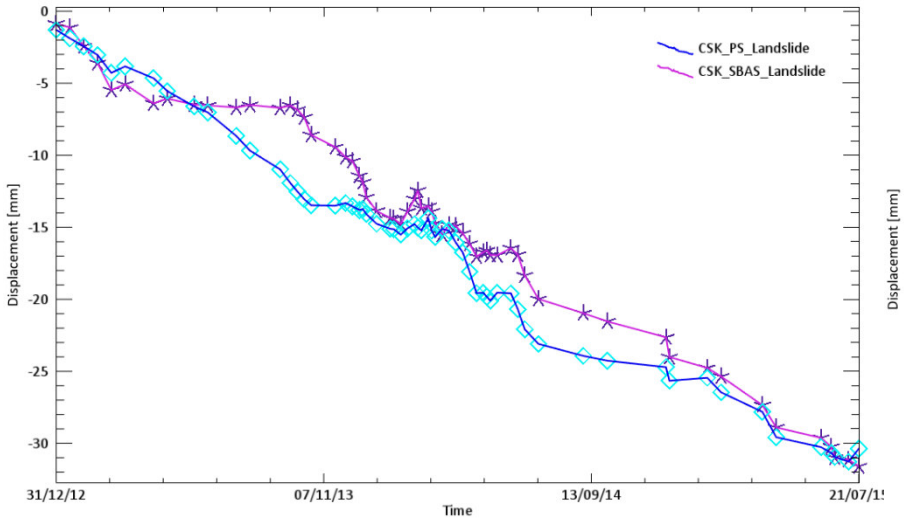


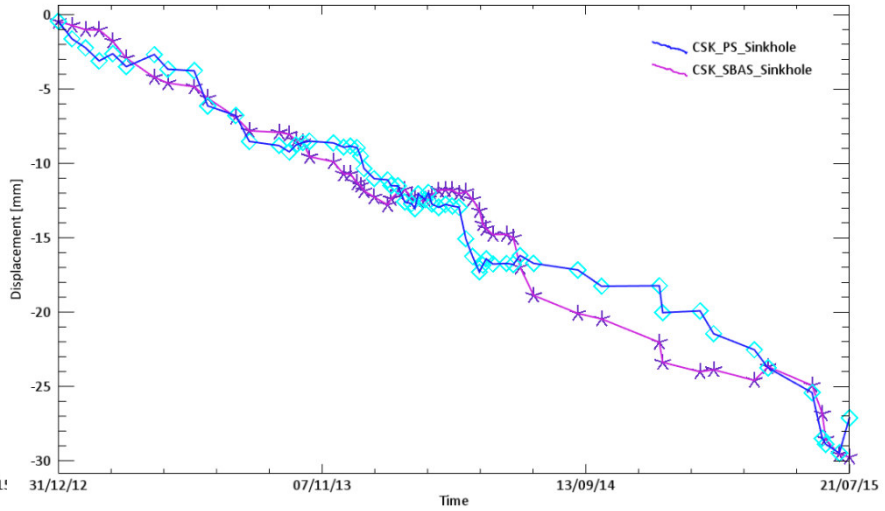
COSMO-SkyMed - PS

61 ascending Stripmap data from December 2012 to July 2015

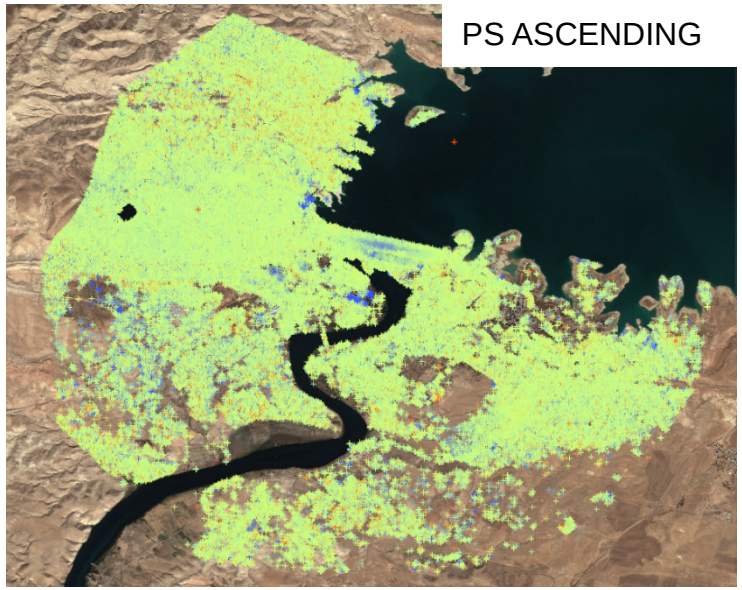

CSK_SBAS_DAM
CSK_PS_DAM
Displacement [mm]
0
-2
-4
-6
-8
-10
-12
-14
31/12/12
07/11/13
13/09/14
21/07/15
SARscape Time

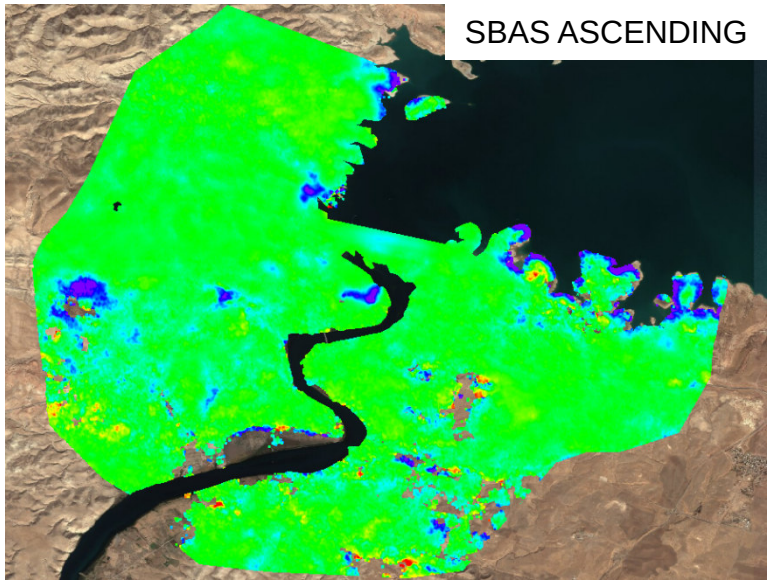

LANDSLIDE
DAM
SINKHOLE

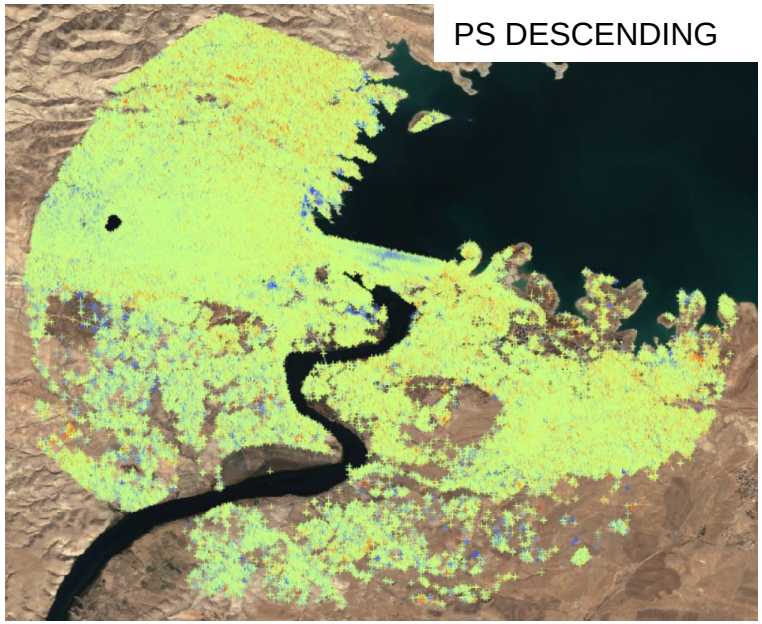

CSK_PS_Landslide
CSK_SBAS_Landslide
Displacement [mm]
0
-5
-10
-15
-20
-25
-30
31/12/12
07/11/13
13/09/14
21/07/15
Time

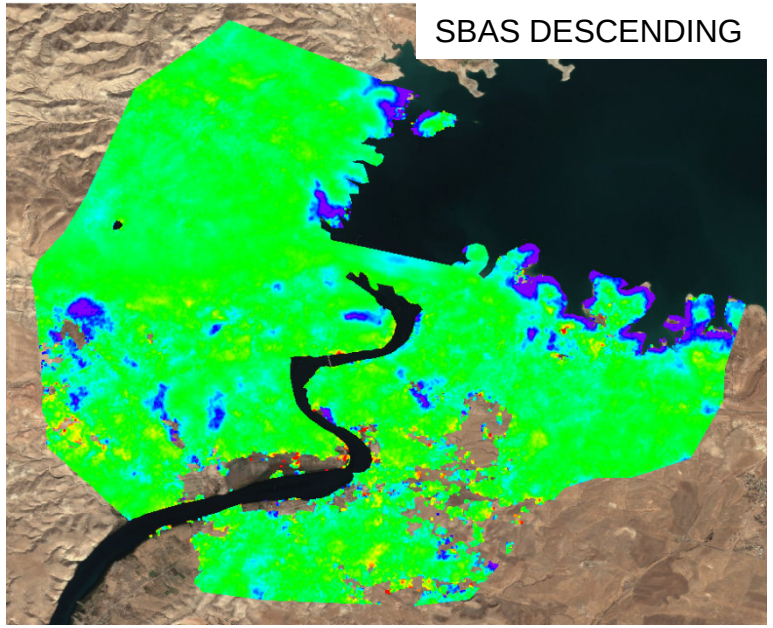

CSK_PS_Sinkhole
CSK_SBAS_Sinkhole
Displacement [mm]
0
-5
-10
-15
-20
-25
-30
31/12/12
07/11/13
13/09/14
21/07/15
Time

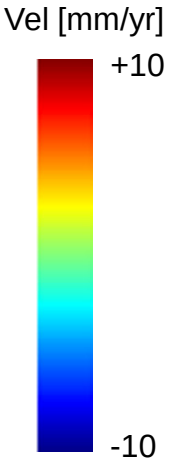
Sentinel-1 stacking: PS and SBAS (2014-2017)



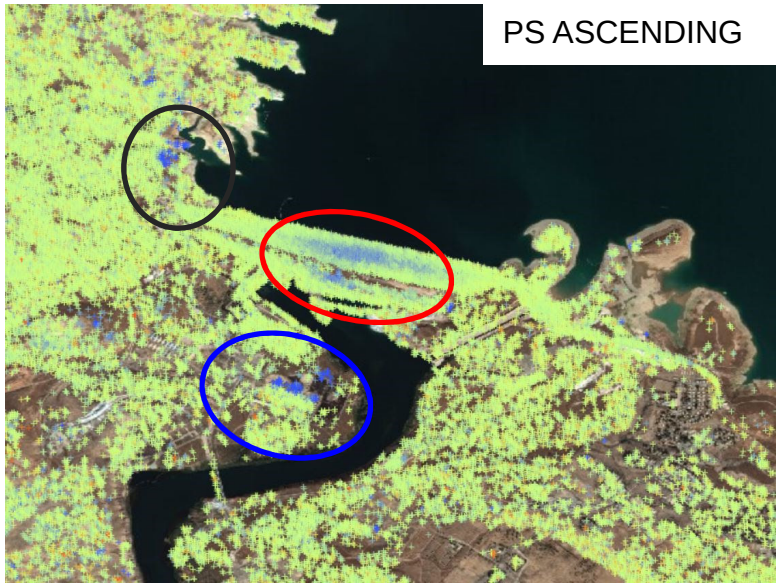


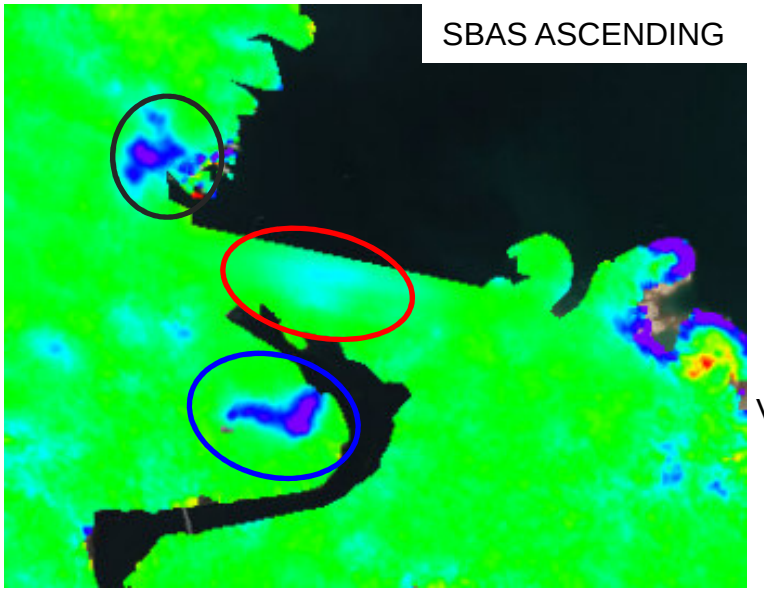


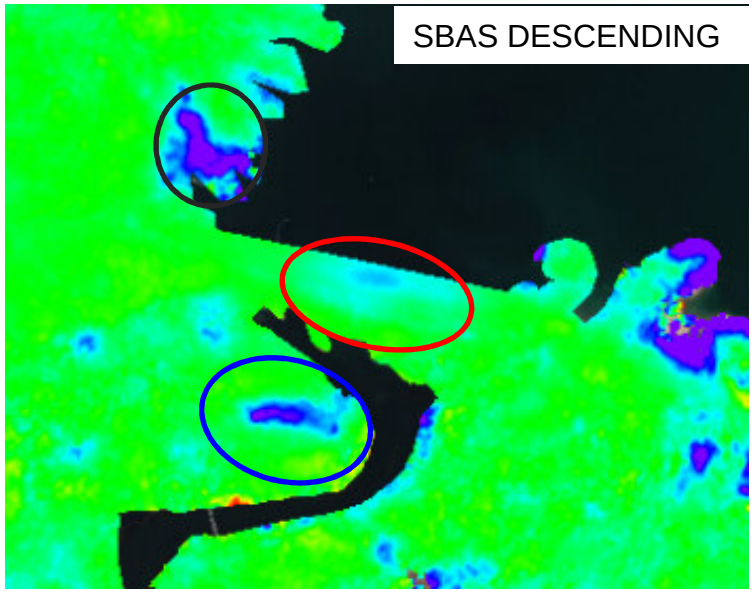




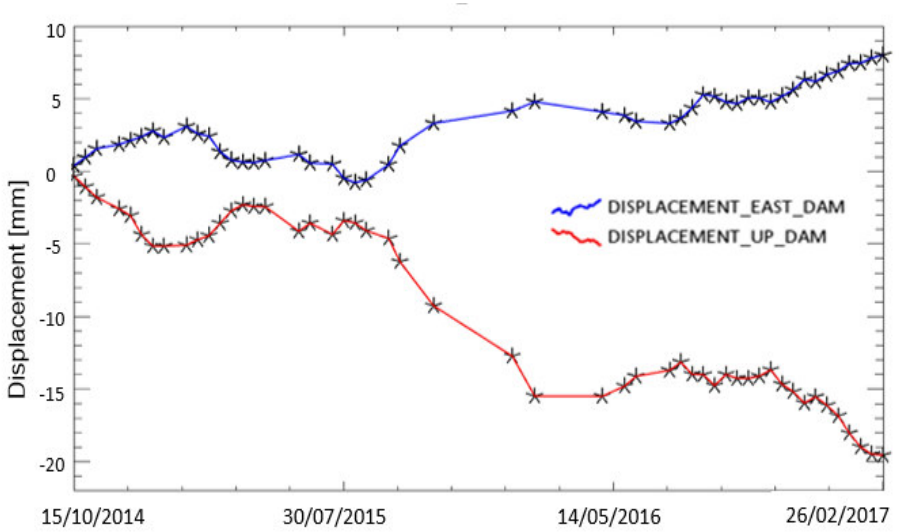
Sentinel-1 stacking: PS and SBAS (2014-2017)

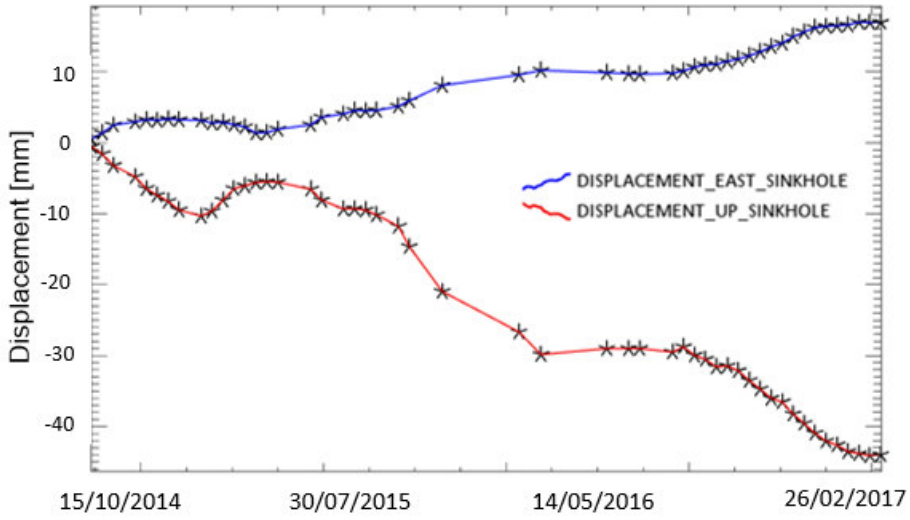


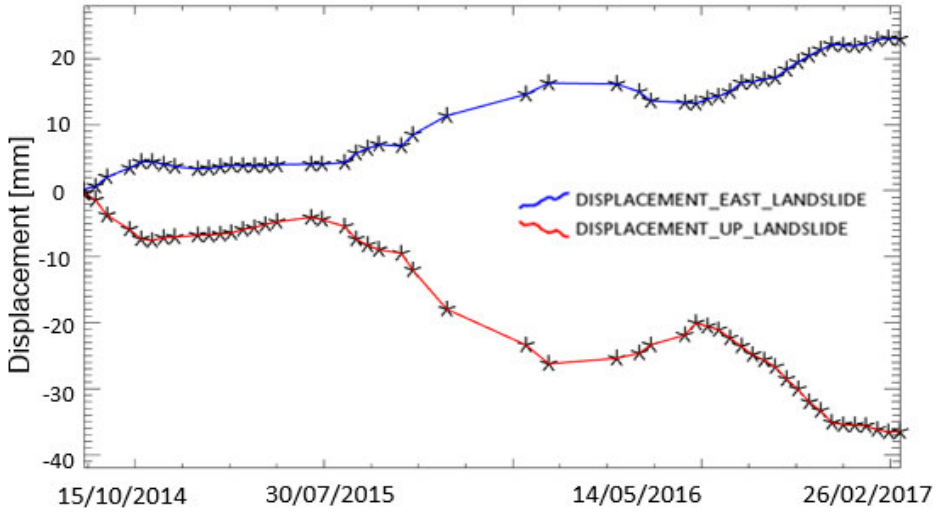





LANDSLIDE
DAM
SINKHOLE


Displacement [mm]
10
5
0
-5
-10
-15
-20
15/10/2014
30/07/2015
14/05/2016
26/02/2017
DISPLACEMENT_EAST_DAM
DISPLACEMENT_UP_DAM


Displacement [mm]
10
0
-10
-20
-30
-40
15/10/2014
30/07/2015
14/05/2016
26/02/2017
DISPLACEMENT_EAST_SINKHOLE
DISPLACEMENT_UP_SINKHOLE


Displacement [mm]
20
10
0
-10
-20
-30
-40
15/10/2014
30/07/2015
14/05/2016
26/02/2017
DISPLACEMENT_EAST_LANDSLIDE
DISPLACEMENT_UP_LANDSLIDE

Sentinel – time series behavior

$$y = k_0 + k_1 t + k_2 \sin\left(k_3 + \frac{2\pi}{T} t\right)$$

$$var = \sqrt{\sum_{i=1}^{n} \frac{(y_i - d_i)^2}{n}}$$

$\boldsymbol{k_0}$: *constant*

$\boldsymbol{k_1}$: *velocity coefficient*

$\boldsymbol{k_2}$: *amplitude of the oscillation*

$\boldsymbol{k_3}$: *intial phase*

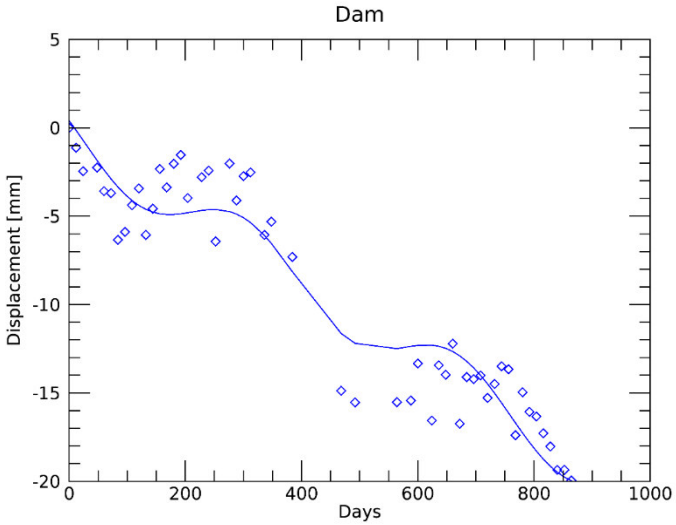
$\boldsymbol{t}$: *acquisition time*

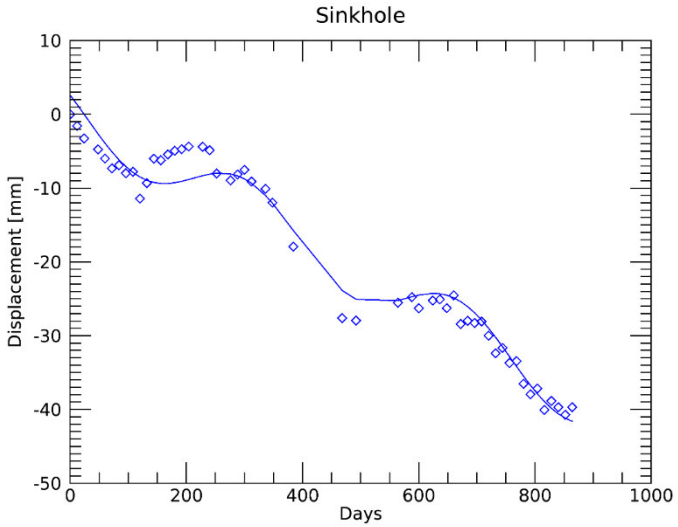
y_i: *estimated displacement*

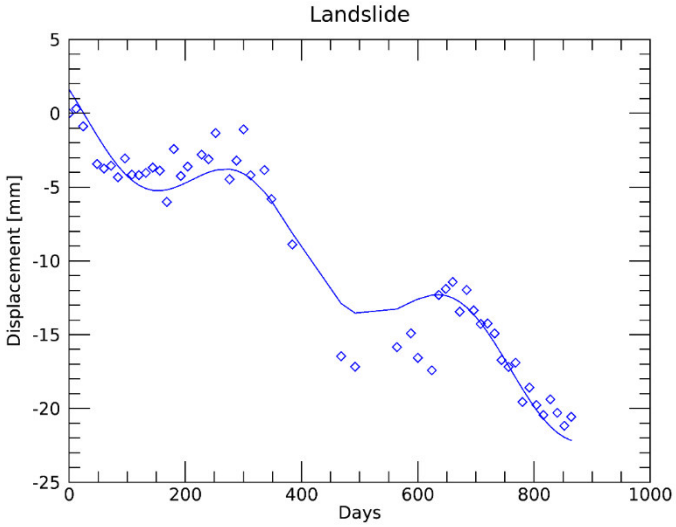
d_i: *observed displacement*

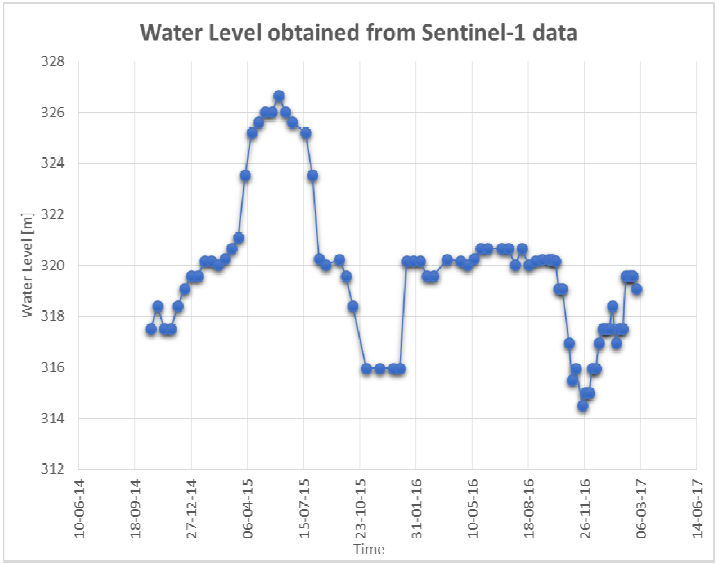
var: *variance*

Sentinel – time series behavior





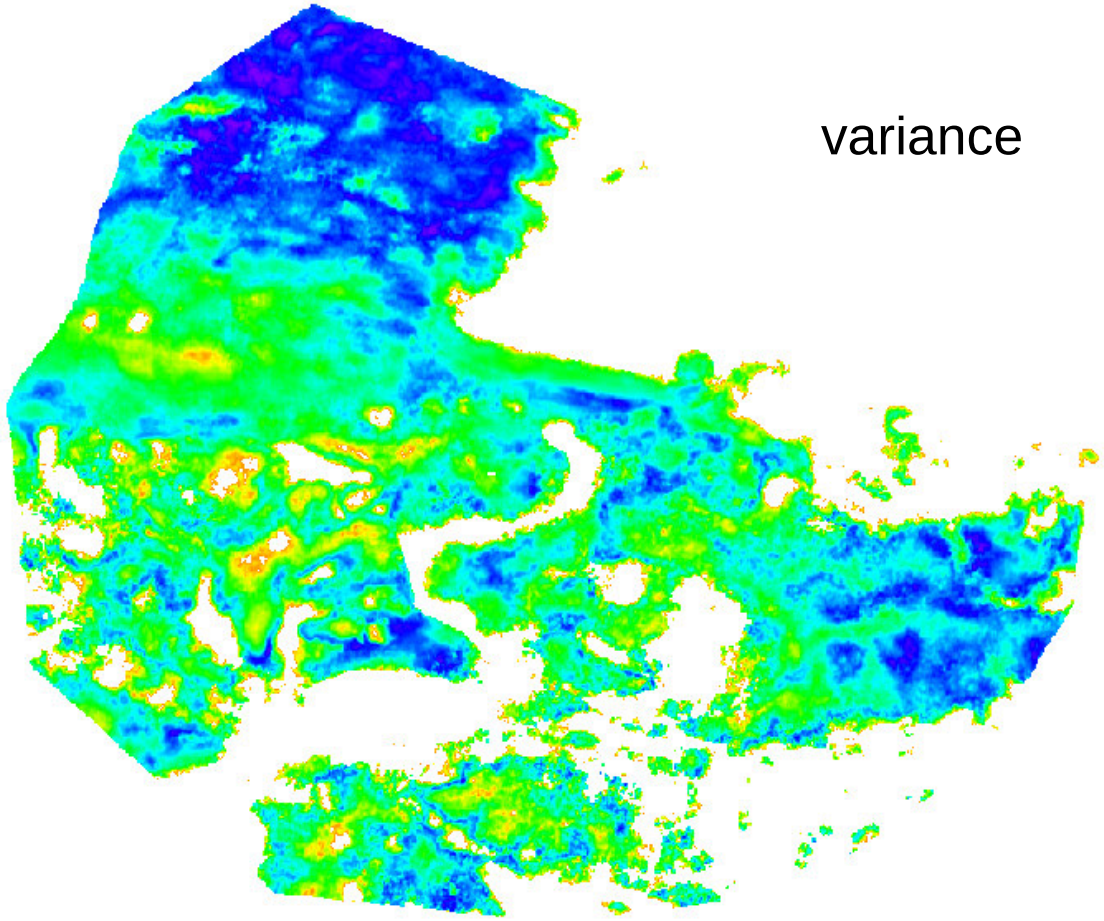


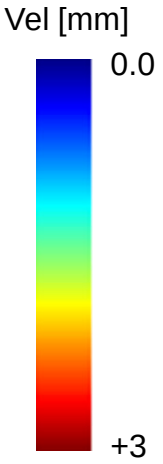


Sentinel – time series behavior

Vertical projection

variance

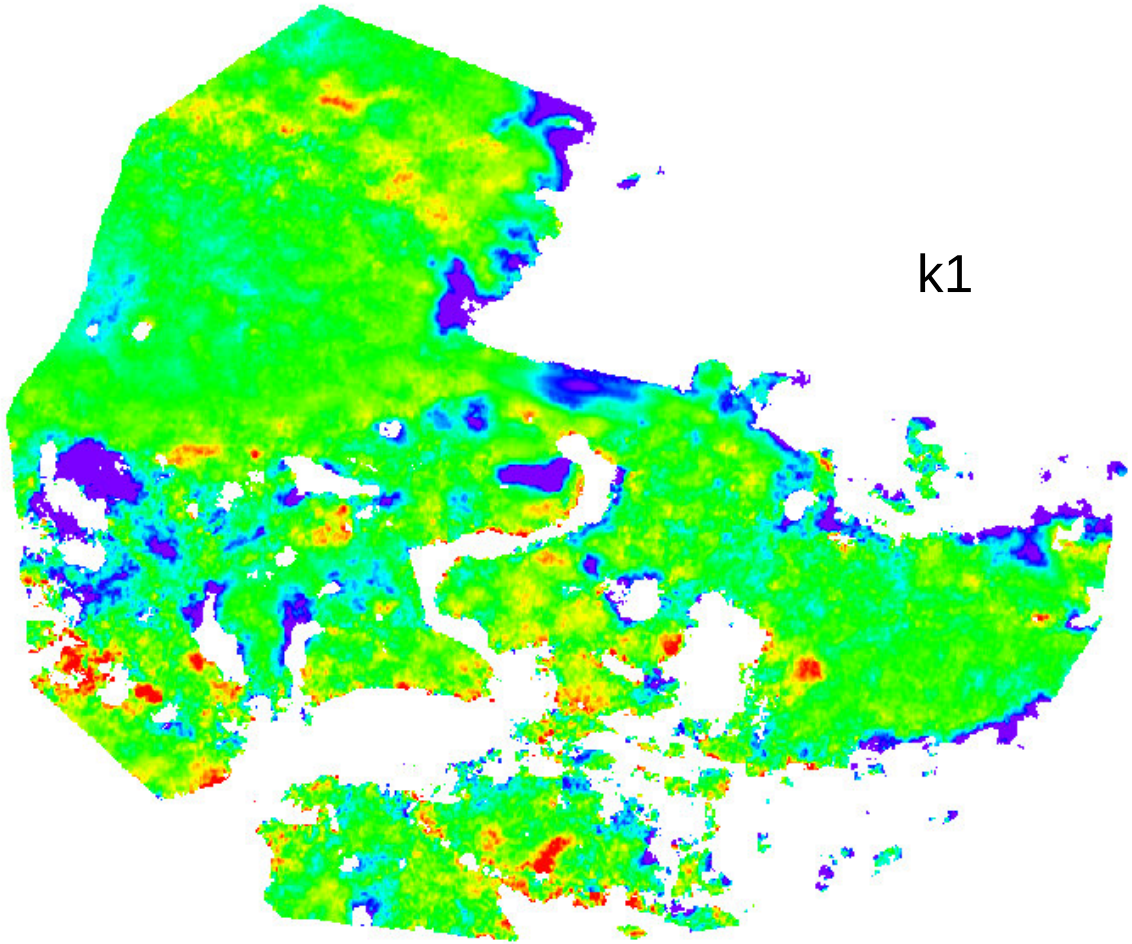




$$y = k_0 + k_1 t + k_2 \sin\left(k_3 + \frac{2\pi}{T} t\right)$$

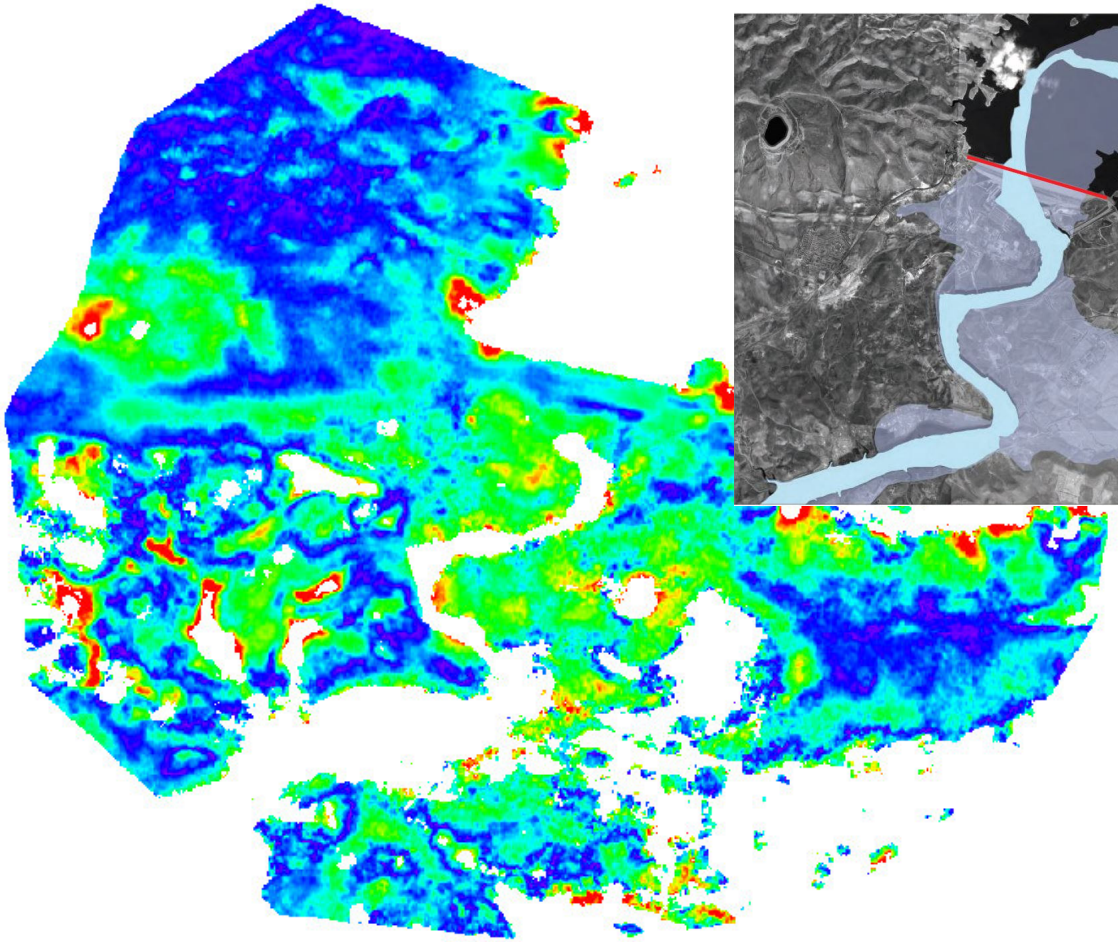
Sentinel – time series behaviour

Vertical projection



$$y = k_0 + k_1 t + k_2 \sin\left(k_3 + \frac{2\pi}{T} t\right)$$

Sentinel – time series behaviour



River Tigris and its floodplain (Pearson et al.)

Vel [mm]

0.0

+5

Vertical projection

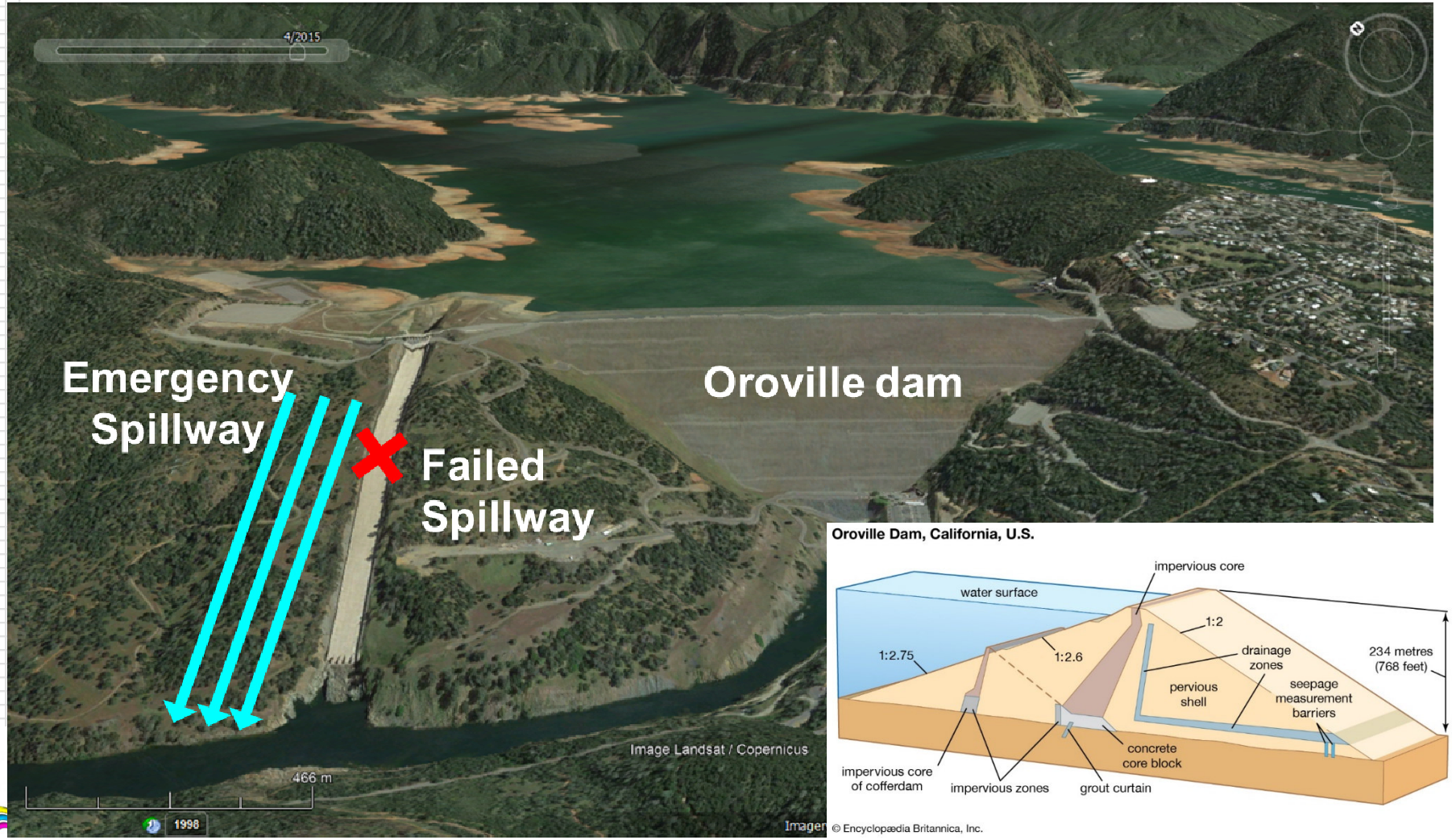
$$y = k_0 + k_1 t + k_2 \sin\left(k_3 + \frac{2\pi}{T} t\right)$$

Oroville dam

Oroville Dam is an earthen embankment dam located on the Feather River, east of the city of Oroville in Northern California. The dam was completed in 1968.

Oroville dam

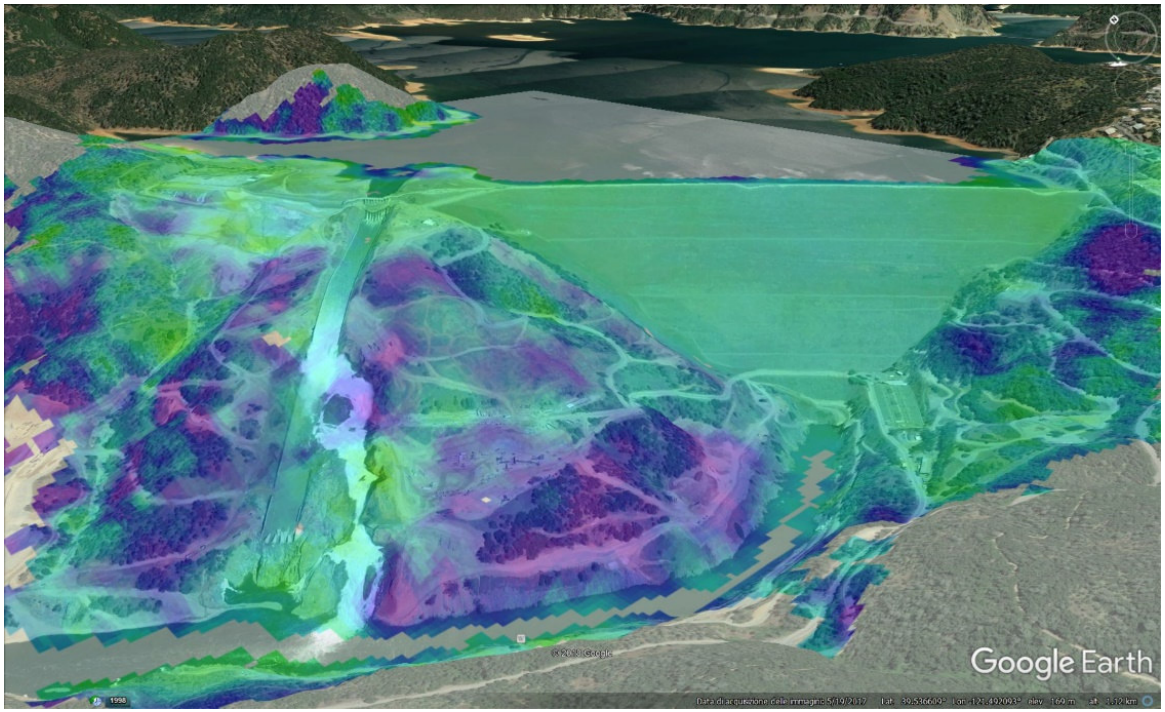
It is the tallest earthen dam in the United States, at 768 feet (234 m) and 6,920 feet (2,109 m) long at its crest; it has a volume of about 59,635,000 cubic m and forms a reservoir of some 4,300,000,000 cubic m capacity.



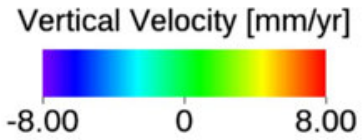
Oroville Dam, California, U.S.

Oroville dam collapse

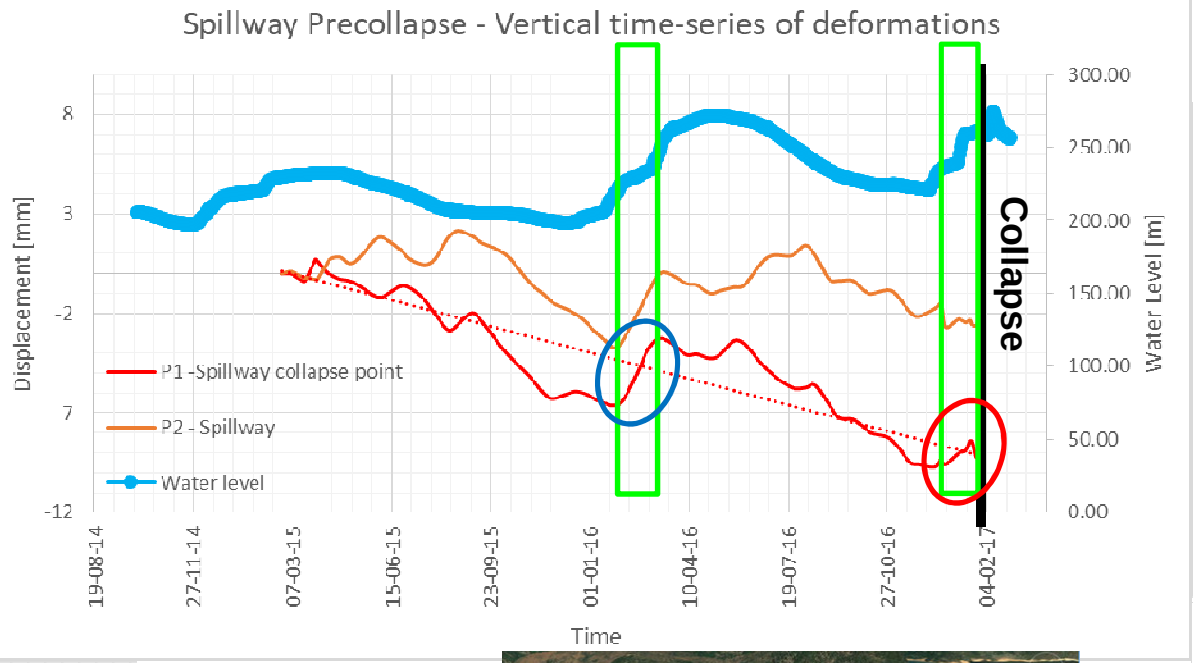
Oroville dam collapse

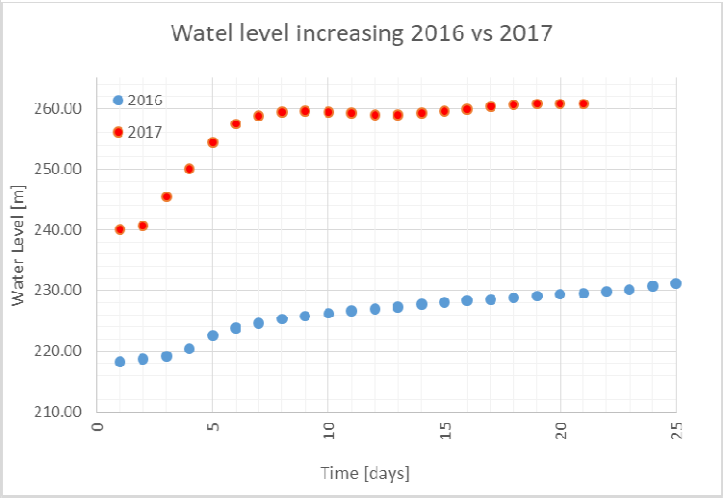


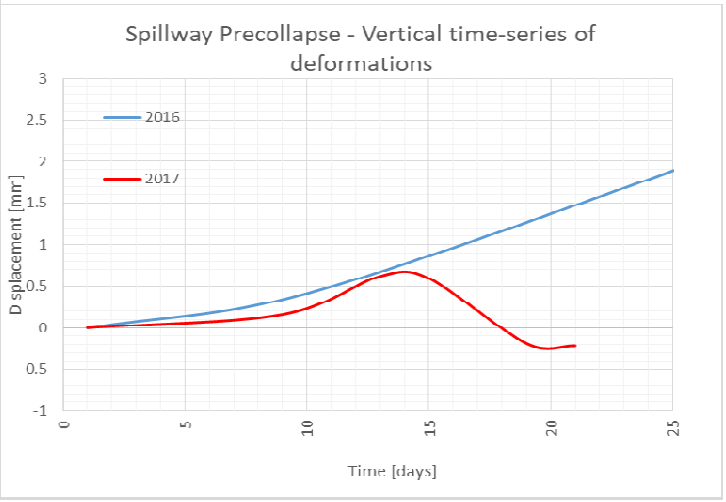
Vertical deformation on the spillway collapse



Oroville dam collapse



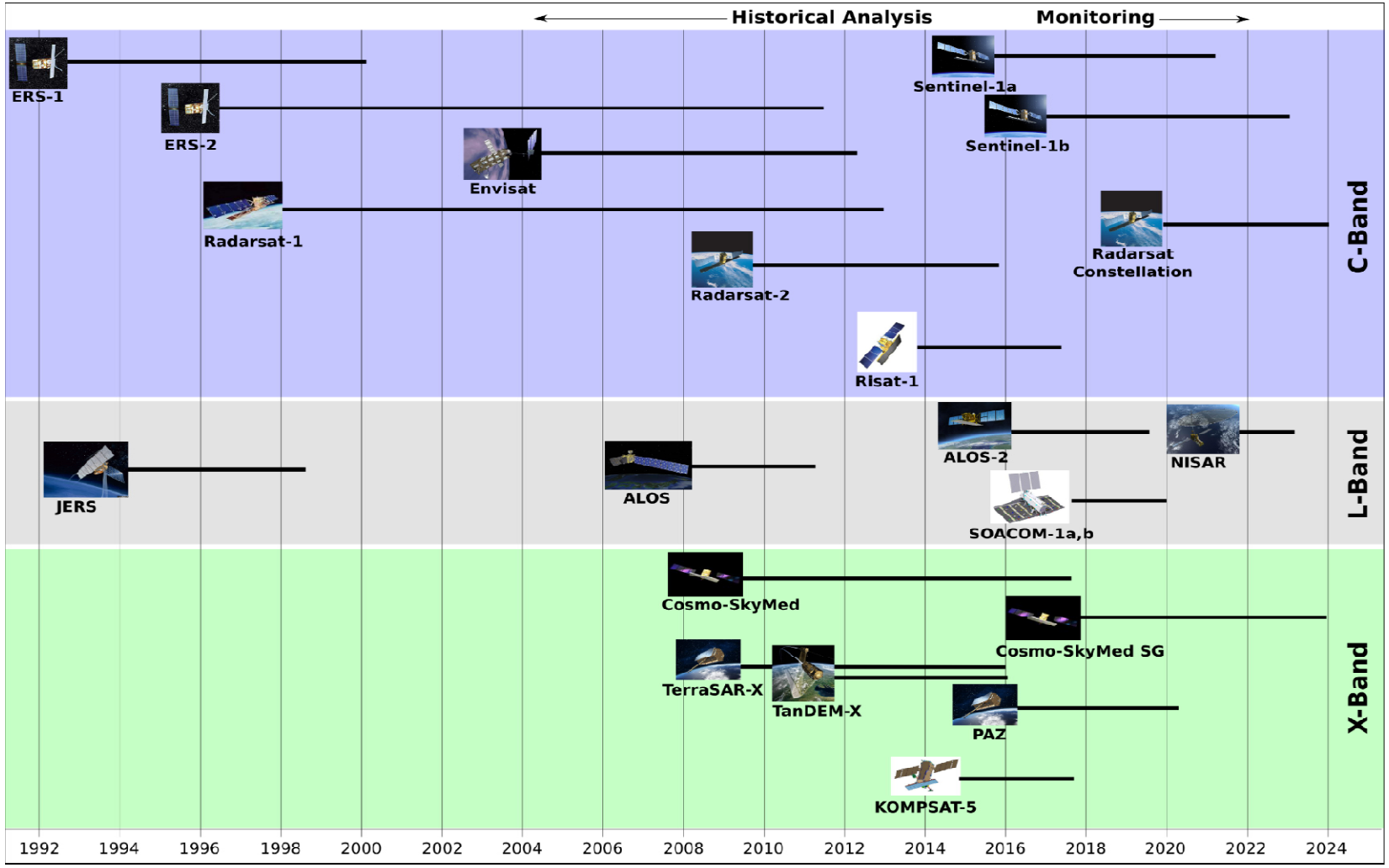




Vertical deformation on the spillway collapse point (P1)

Why should I use SAR data?

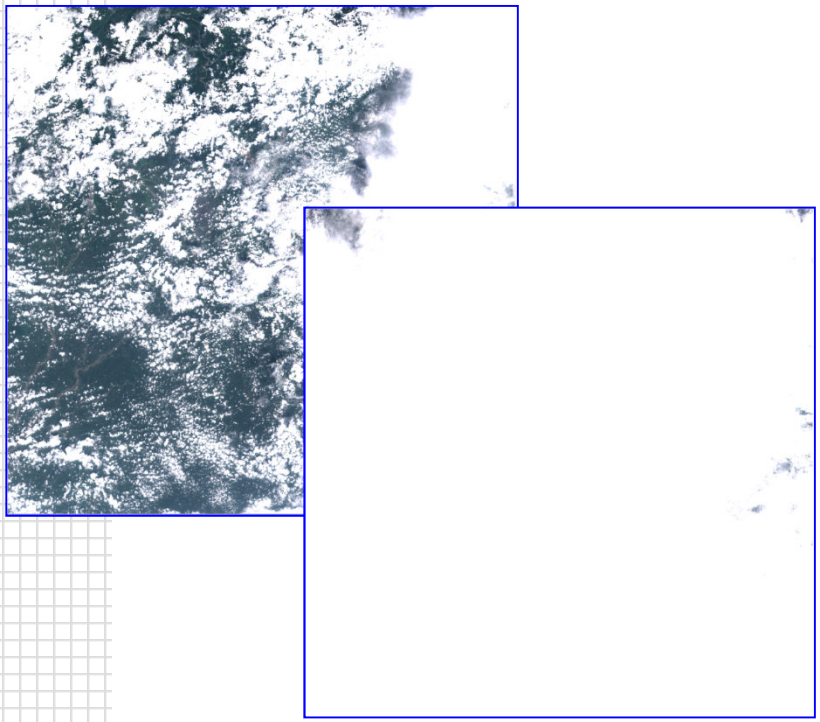
SAR Satellite missions

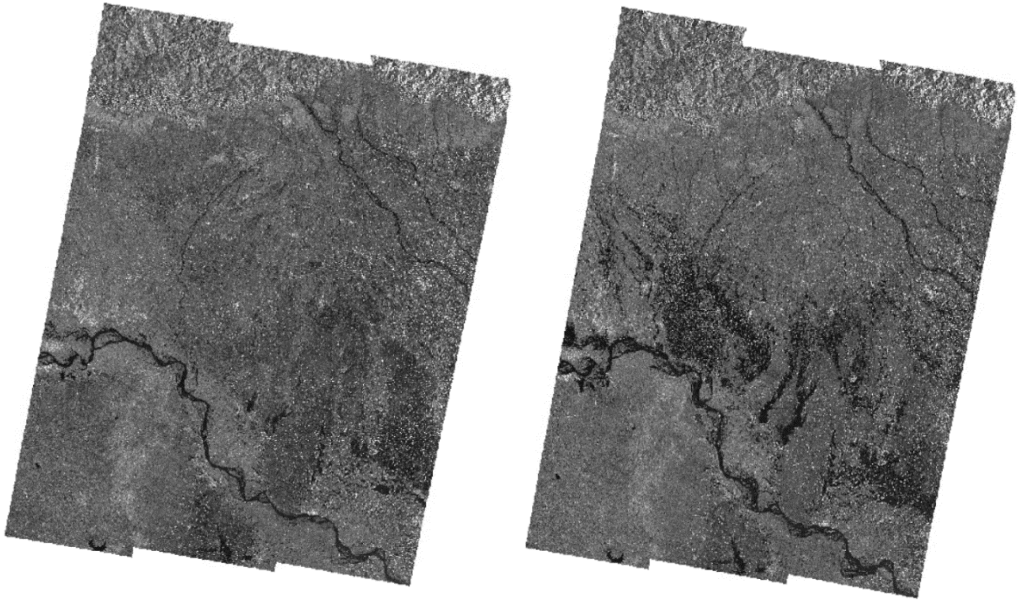


Why should I use SAR data?

Optical versus Synthetic Aperture Radar (SAR)

Bihar Flood (2017)



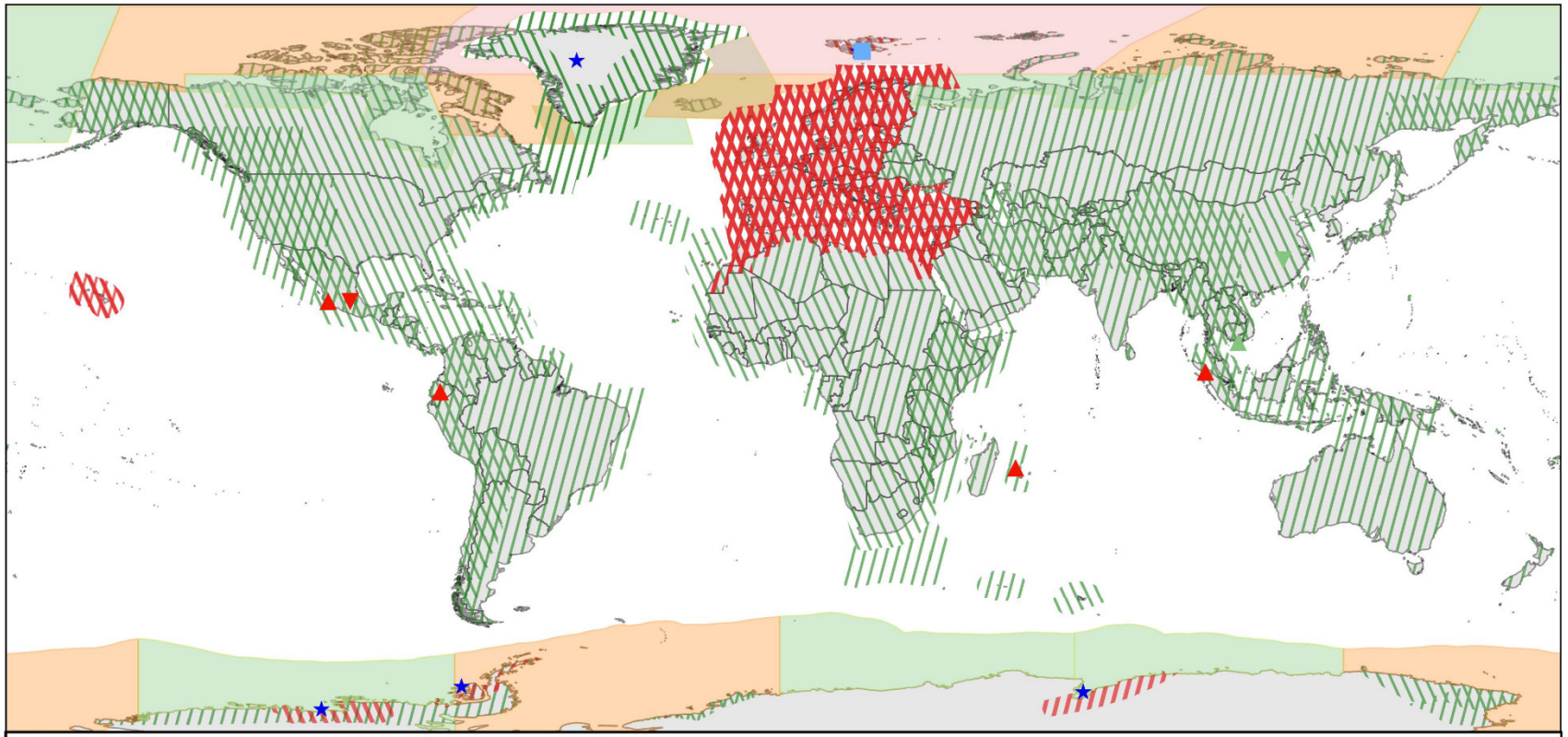


Why should I use SAR data?

Sentinel-1 Constellation Observation Scenario: Revisit & Coverage Frequency

sentinel-1

validity start: 05/2017



Why should I use SAR data?

Optical versus Synthetic Aperture Radar (SAR)

TerraSAR-X -Indianapolis

07/01/ 2007

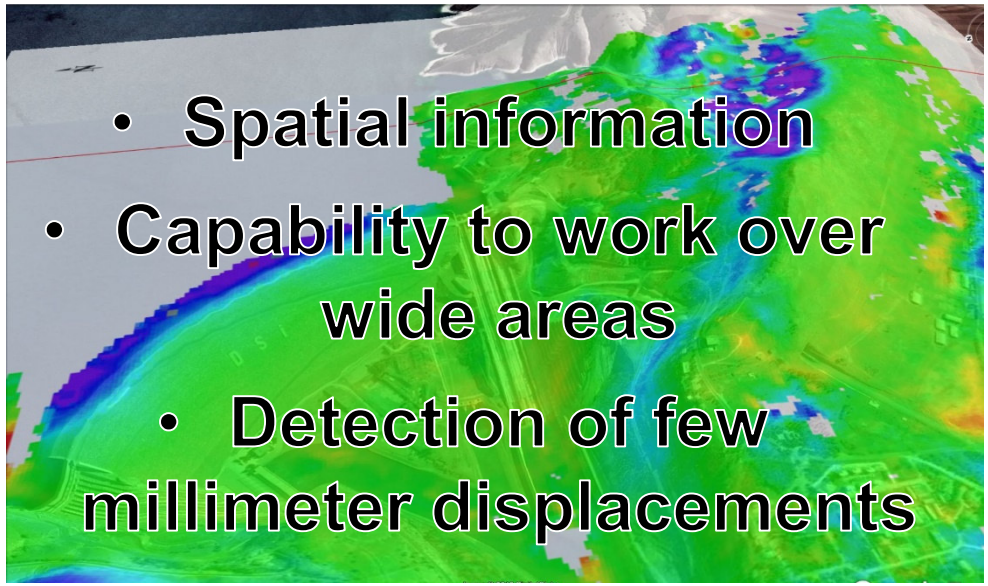
QuickBird - Indianapolis

07/01/ 2007

Why should I use SAR data?

Levelling and GPS versus Synthetic Aperture Radar (SAR)

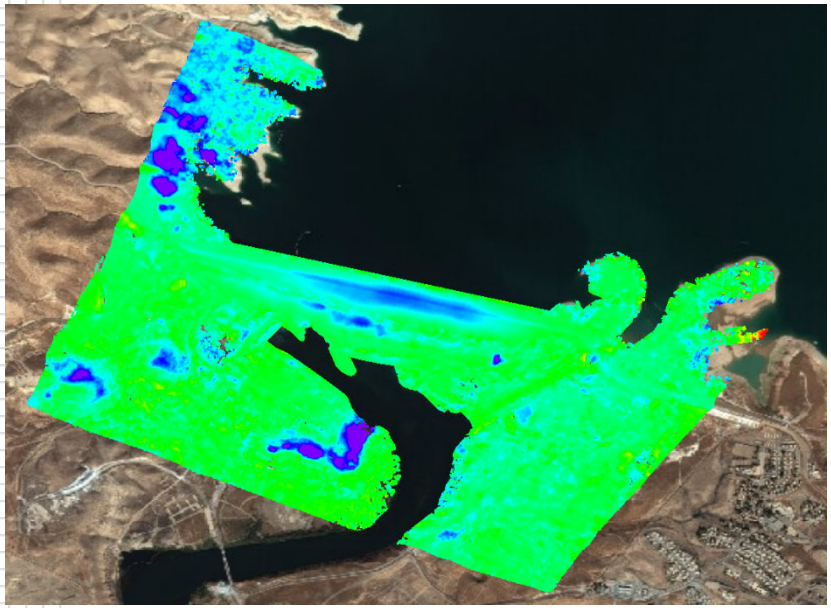
Monitoring of deformations

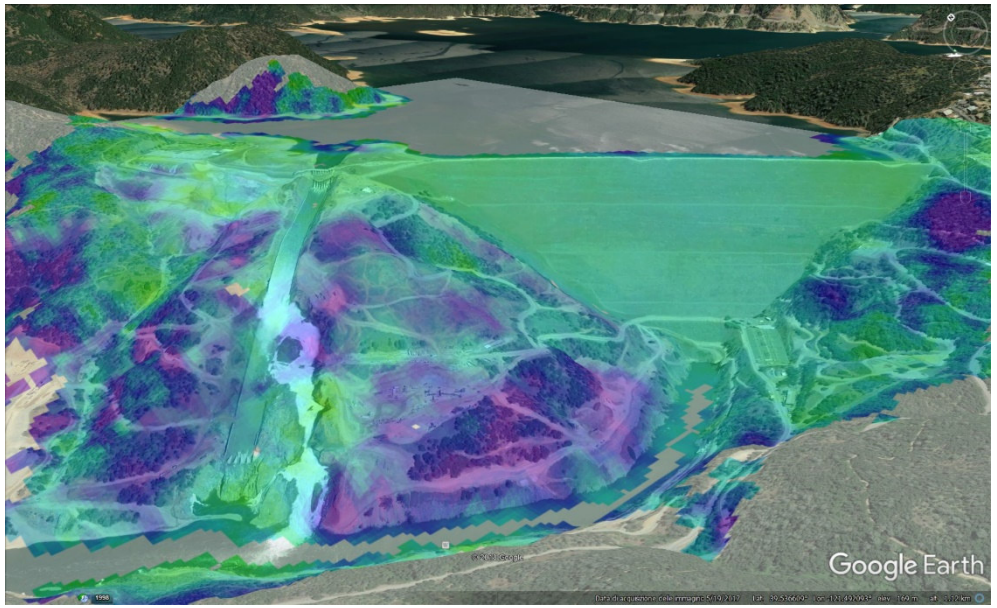


Why should I use SAR data?

Safety issues – Detection of precursor deformations

Monitoring of deformations





Thank you for your attention

giulia.tessari@sarmap.ch

Acknowledgment:

STEADY project

- SaTEllite synthetic Aperture radar interferometry to model Dam stability -

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