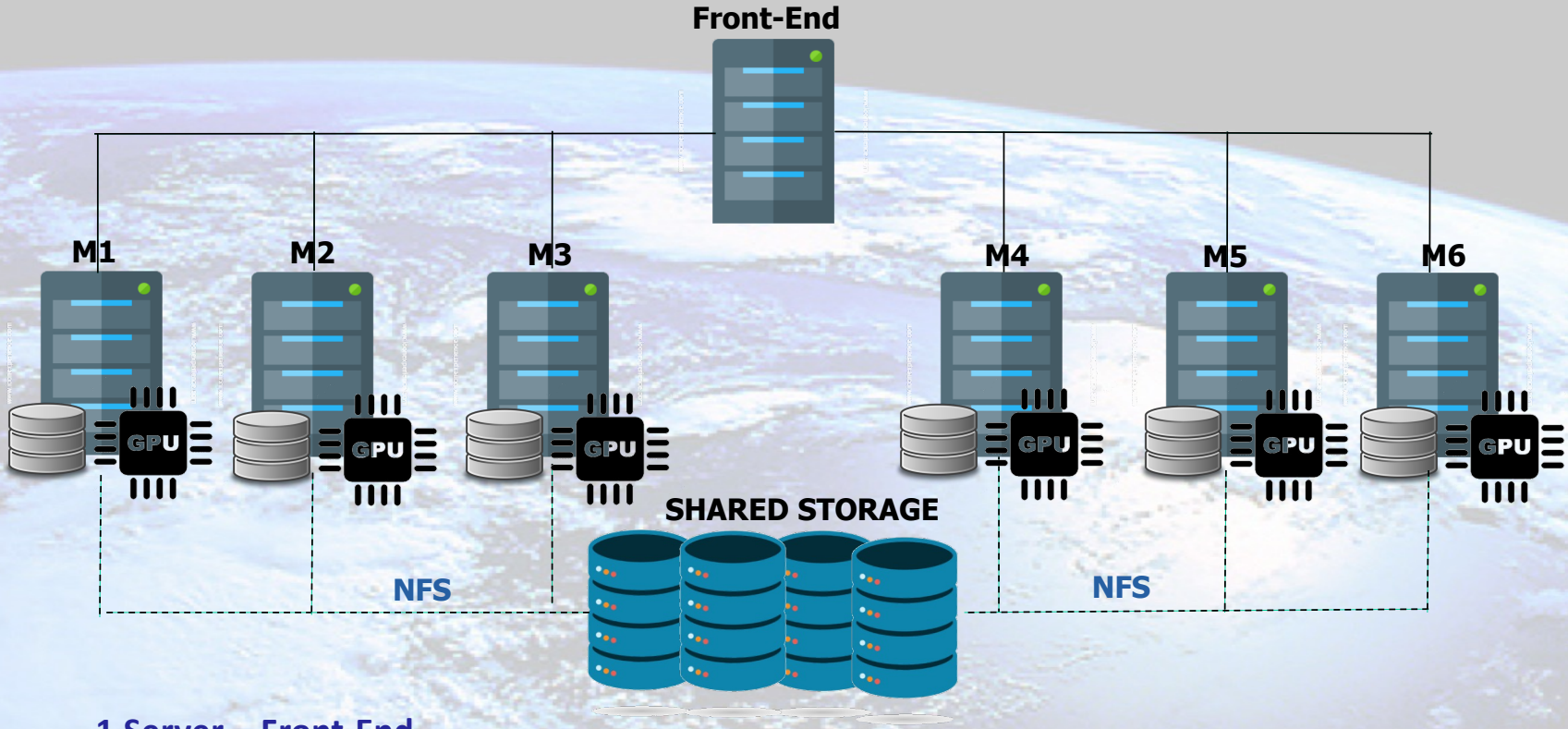
Methods and algorithms for the massive processing of Synthetic Aperture Radar interferometric satellite data for the analysis of deformation phenomena of the soil and the built environment

M. Bonano[1], S. Buonanno[1], F. Casamento[1], F. Casu[1], C. De Luca[1], G. Donvito[2], R. Lanari[1], M. Manunta[1], G. Onorato[1], M. Perniola[2], G. Vino[2], I. Zinno[1]

(1) IREA-CNR, Napoli e Milano
(2) ReCaS-INFN, Bari

The computing infrastructure implemented within the I.Bi.S.Co ReCaS data-center

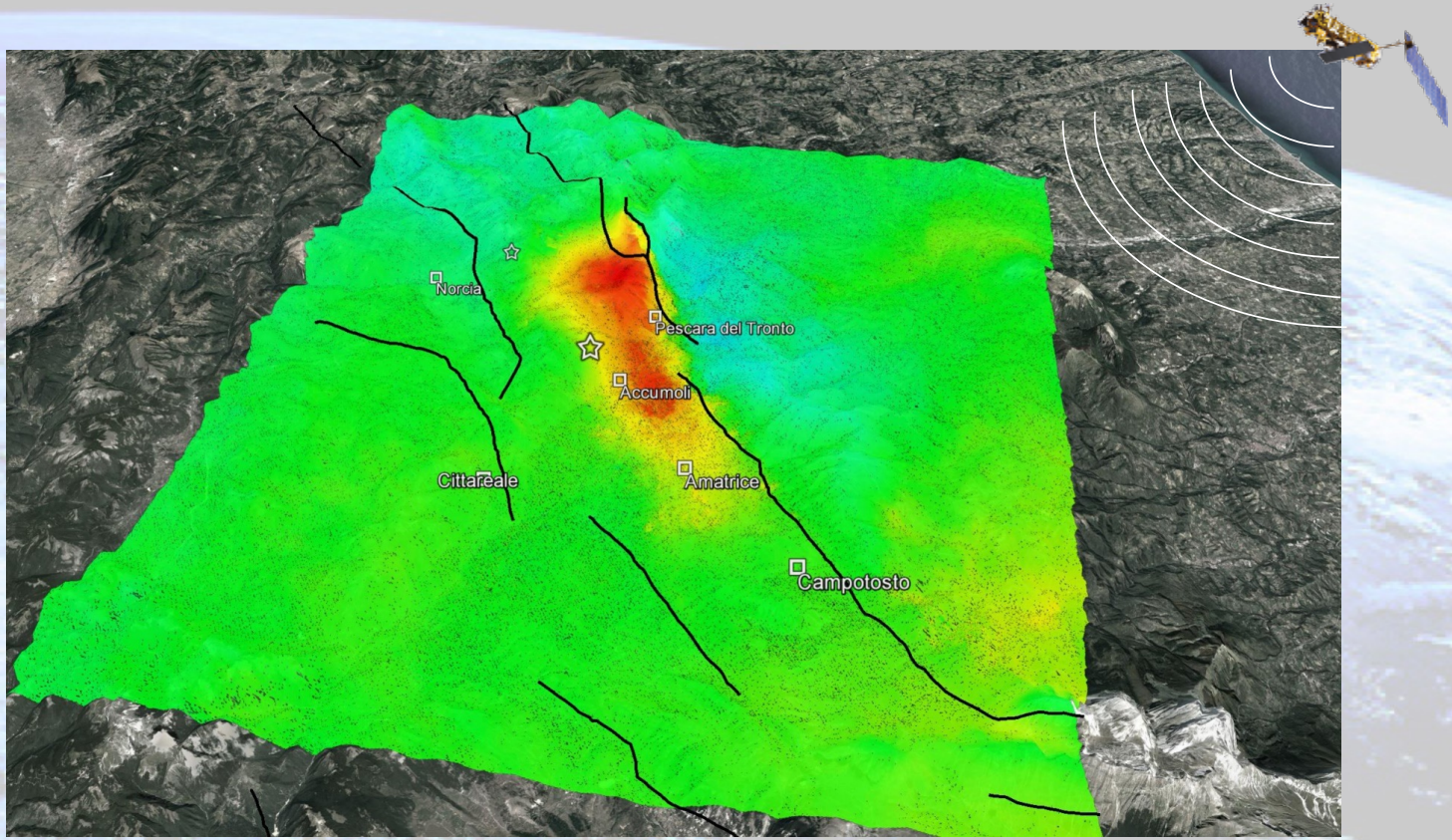


1 Server – Front-End

6 Bare Metal nodes (M1….M6) , each with:
- 2 AMD EPYC 7H12 64 CPU
- 3 NVIDIA A100-PCIE-40GB GPU
- 2 TB RAM and 21 TB local storage

280 TB Shared Storage (NFS mounted)

Surface deformations DInSAR map relevant to the Amatrice earthquake (24/08/16)

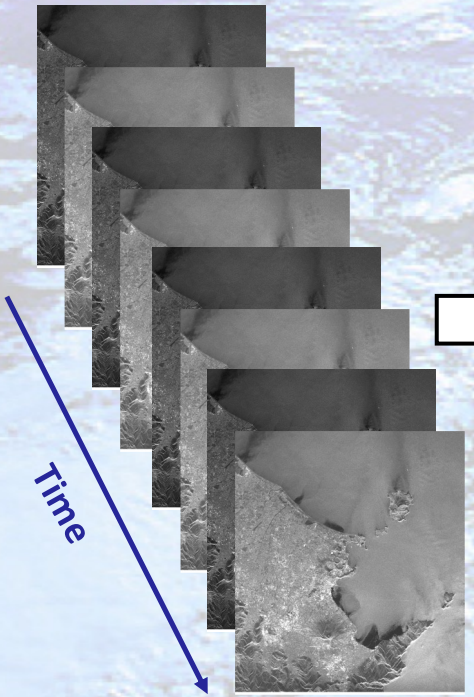


<-20 **LOS Deformation [cm]** >20

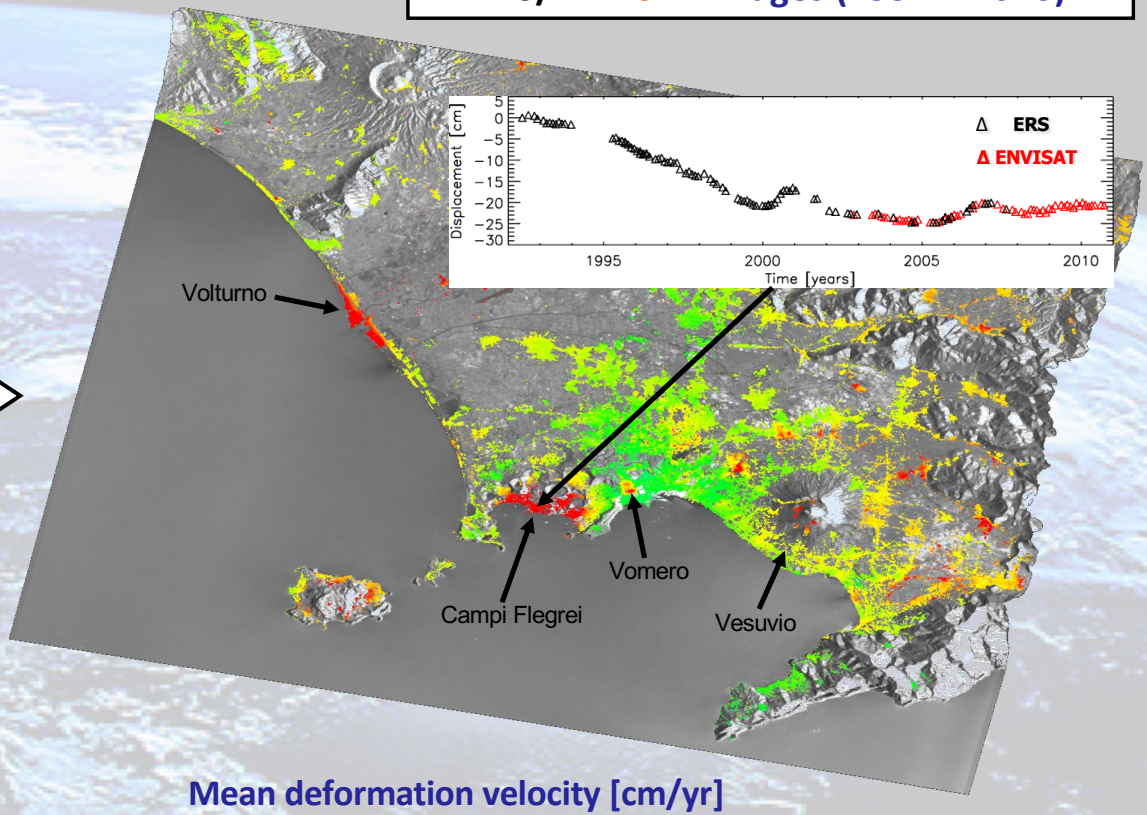
Lavecchia et al., 2016, GRL

DInSAR analysis of the ground deformations temporal evolution

Small BAseline Subset (SBAS) technique



ERS/ENVISAT images (1992 – 2010)



Mean deformation velocity [cm/yr]

<- 5 **> 5**

Berardino et al., 2002, IEEE Trans. Geosci. Remote Sens. *4466 citations (Google Scholar source)*

Sentinel-1 (S-1) constellation

December 2021 | 2024?

Sentinel-1A | Sentinel-1 | Sentinel-1C | Sentinel-1A

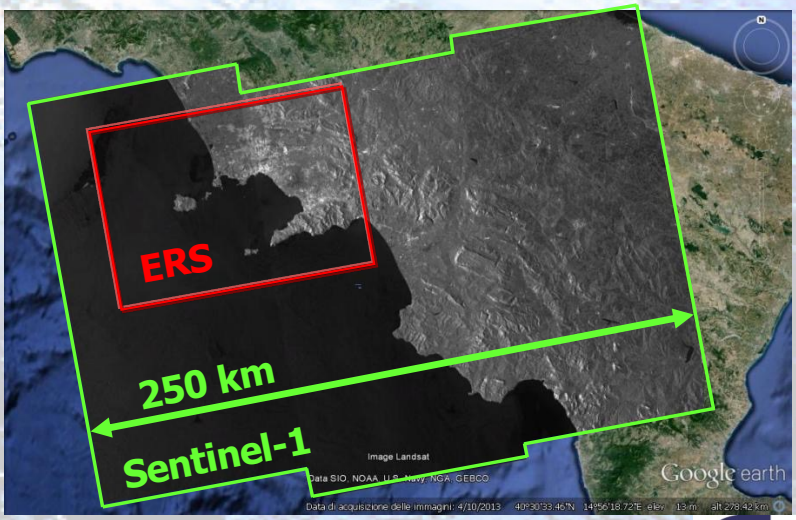



Time

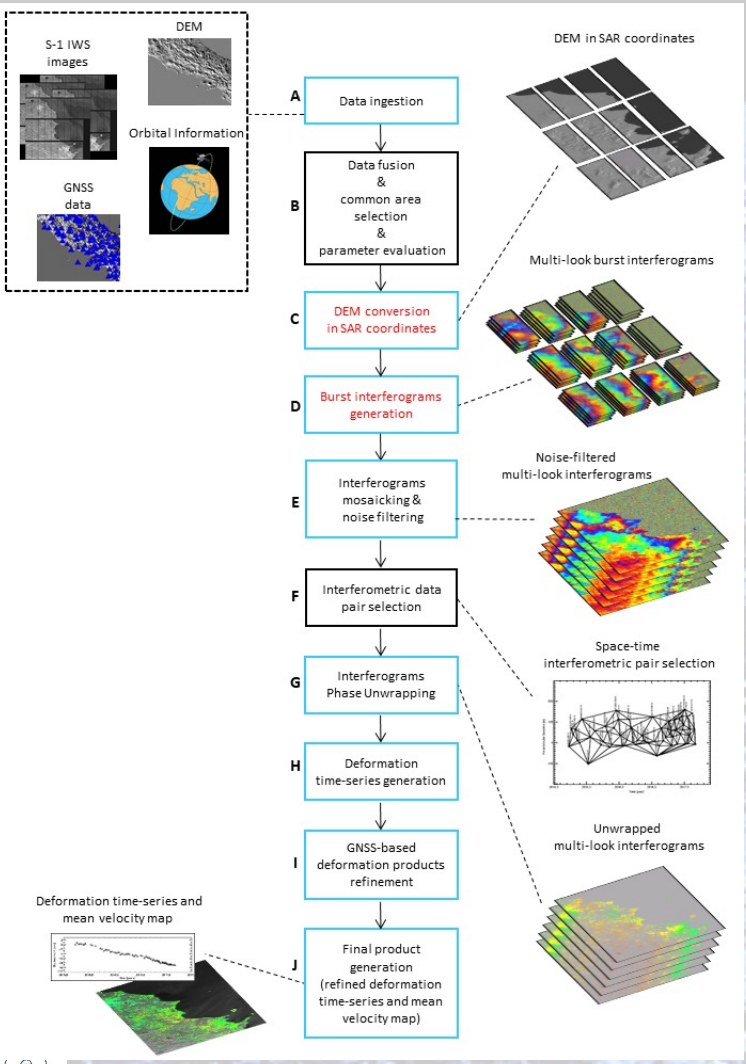
6 days

12 days

- Spatial resolution (TOPS): **20 m x 4 m**
- Coverage (TOPS): **250 km**
- **C-Band** (λ ~ **5.6 cm**)
- **Global coverage**
- S-1 data access: **"free and open"**
- Satellites launch**: 4/2014- 4/2016**



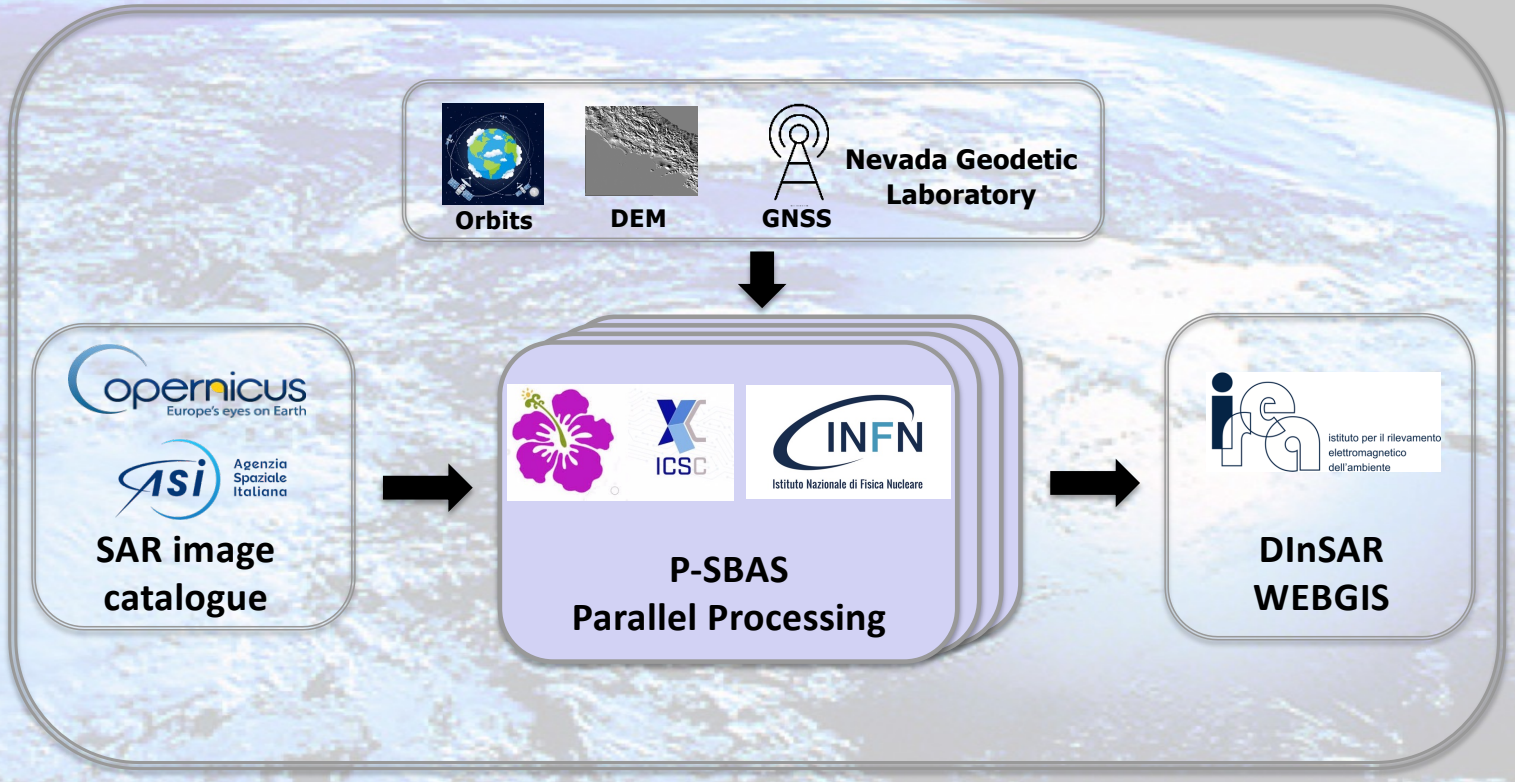
Sentinel-1 Parallel SBAS (P-SBAS) workflow



- **Capability to process huge amount of SAR data**
- **Parallelization strategies based on both Multi-Node and Multi-Core architectures**
- **GPUs exploitation for full resolution analyses**
- **Exploitation of cluster, grid and Cloud-Computing environments**
- **Scalability**

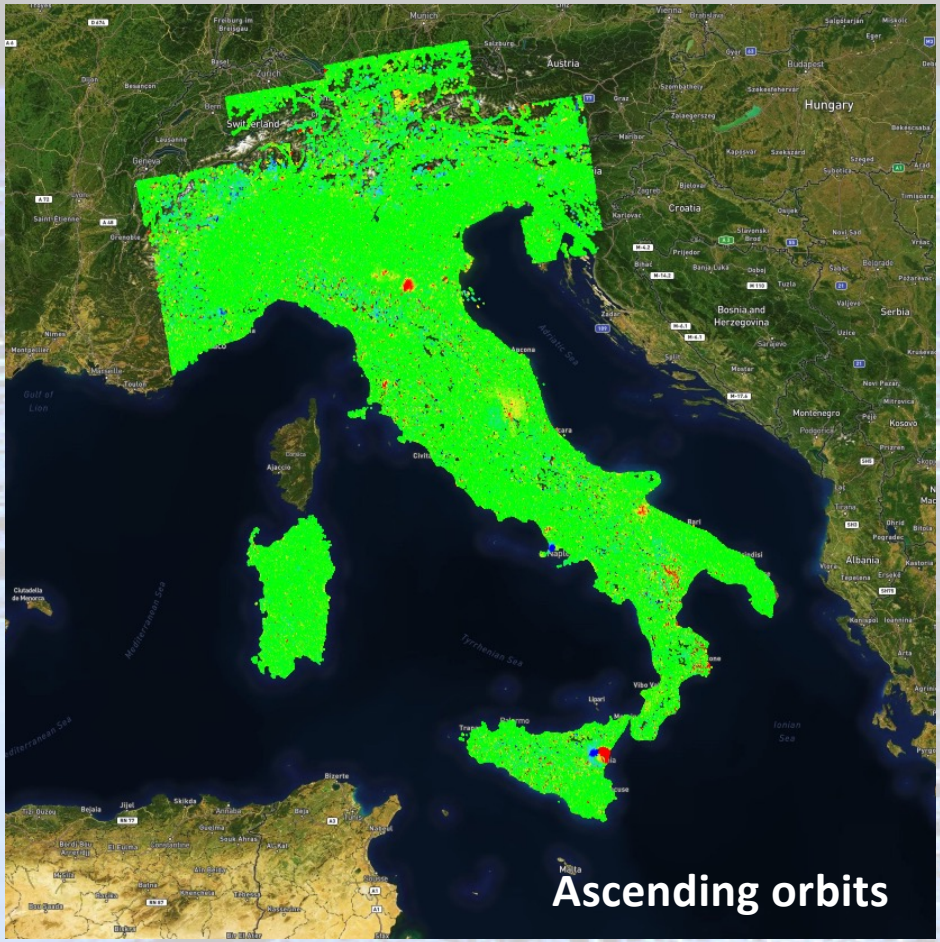
Casu et al., 2014, IEEE JSTARS
Zinno et al., 2015, IEEE Trans. Cloud Computing
Zinno et al., 2018, IEEE Trans. Big Data
Manunta et al., 2019, IEEE TGRS
Lanari et al., 2020, RS

Parallel SBAS (P-SBAS) pipeline for massive DInSAR processing



P-SBAS pipeline for Sentinel-1 and CSK/CSG processing

P-SBAS DInSAR analysis at the national scale with Sentinel-1 data (2016-2023)

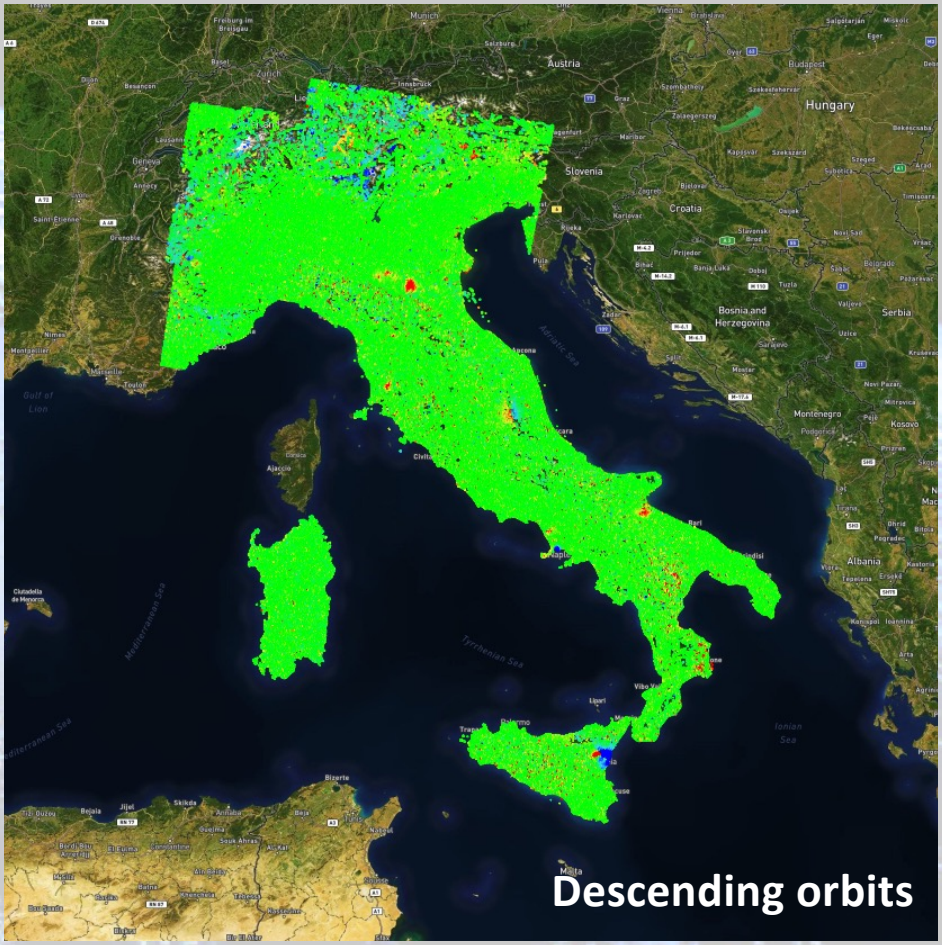


>1

Mean deformation velocity

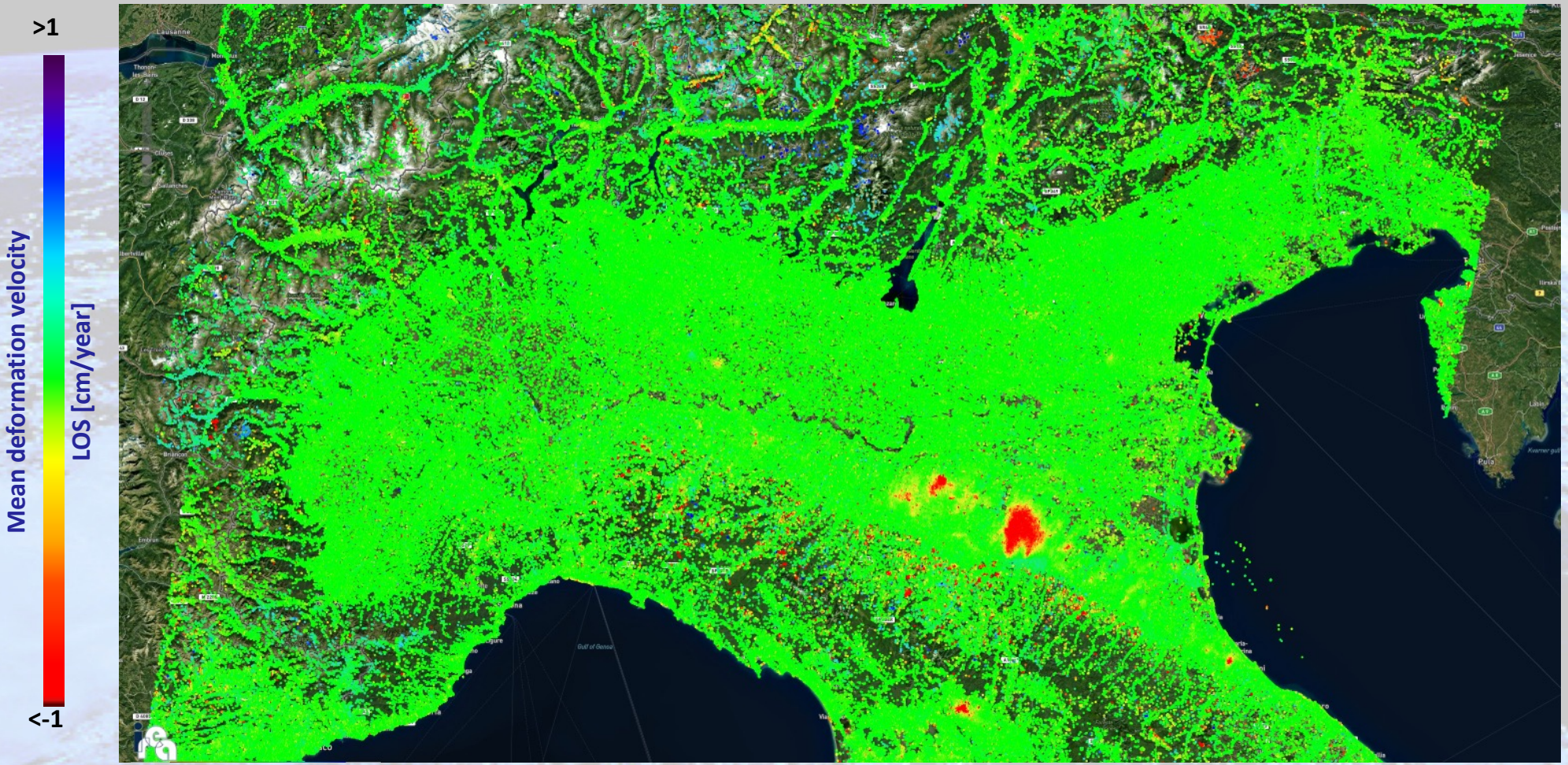
LOS [cm/year]

<-1

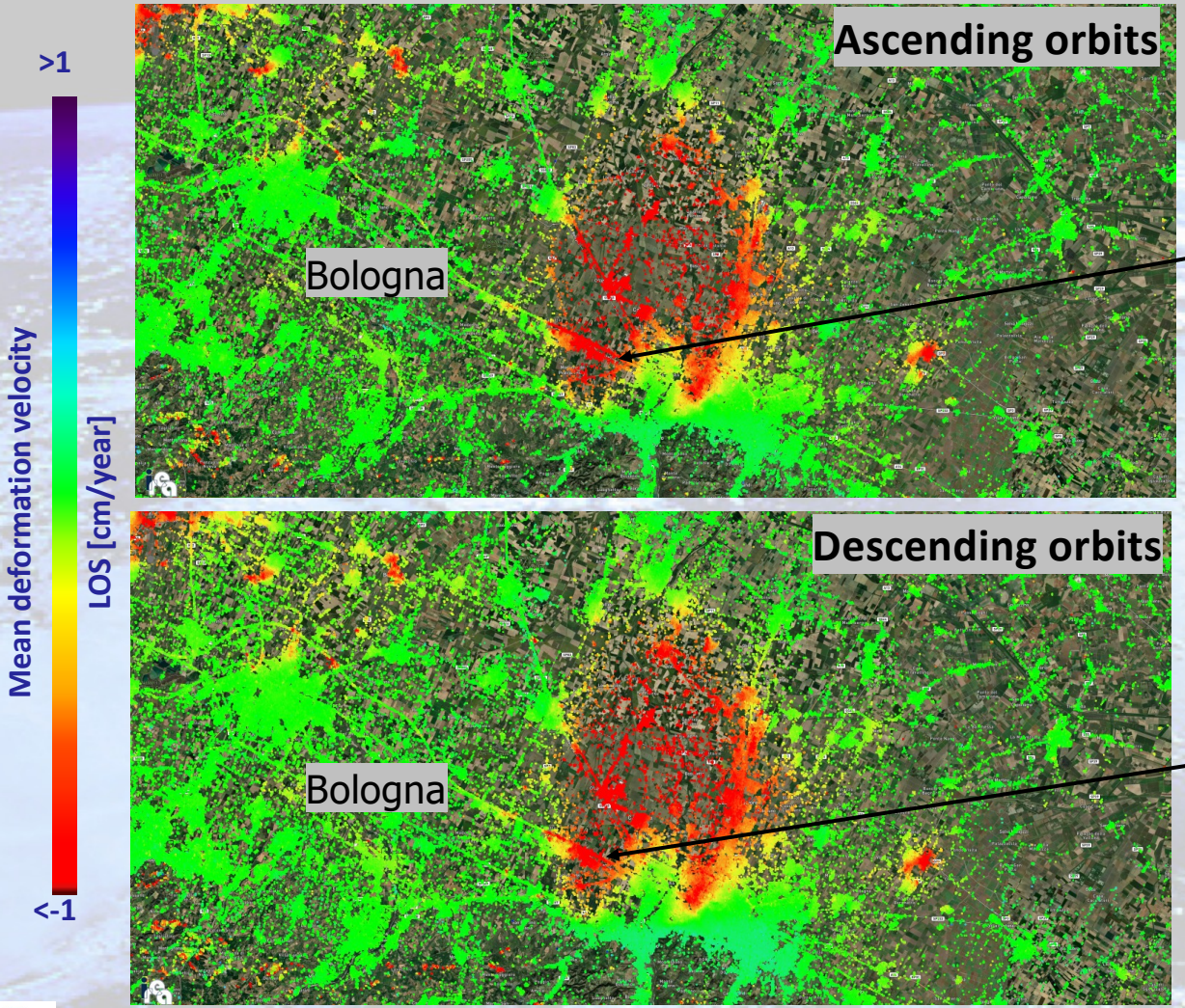


Analysis performed at medium resolution (≃ 80 m x 80 m) and with 6-month updates

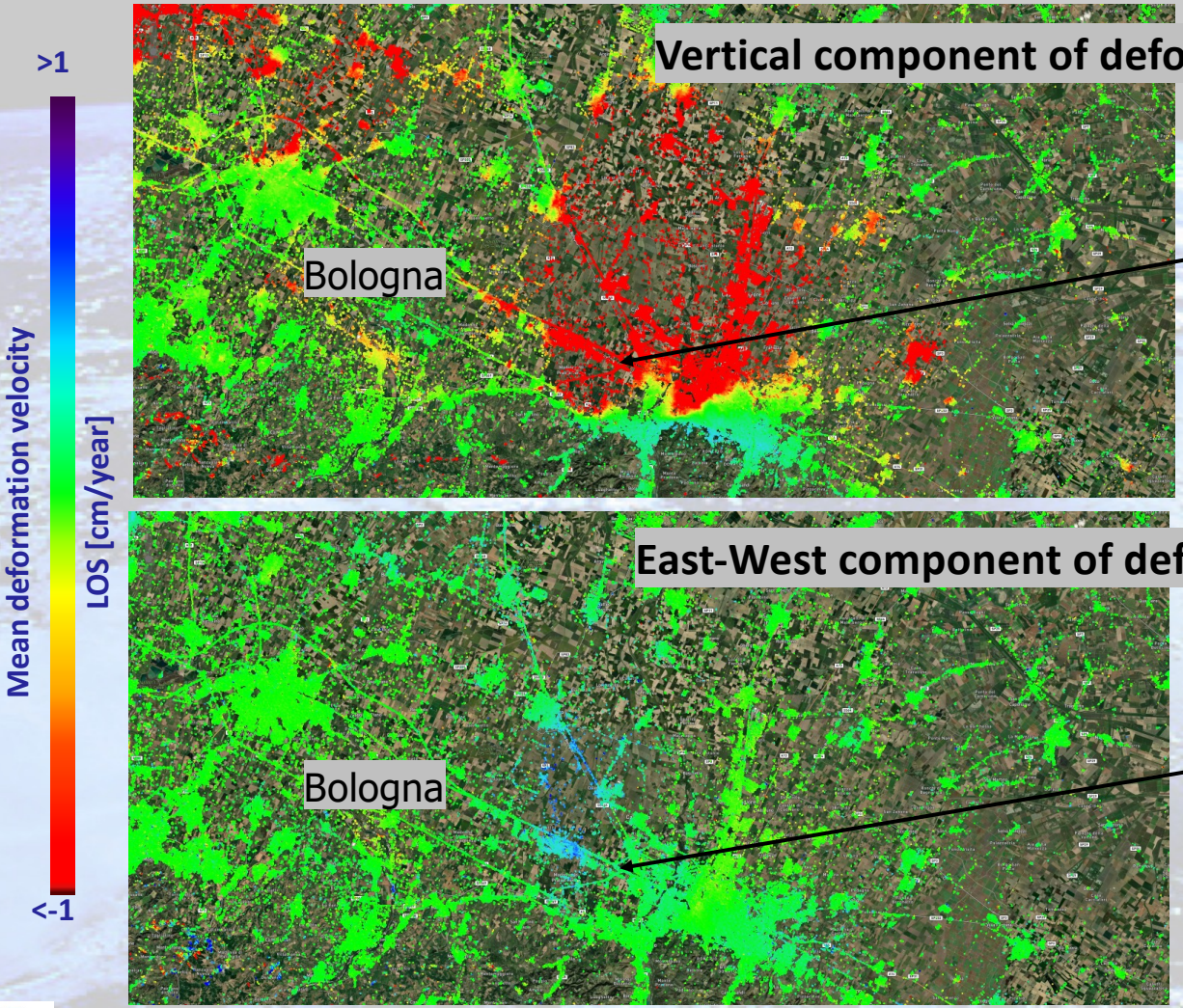
P-SBAS DInSAR analysis at the national scale with Sentinel-1 data (2016-2023)

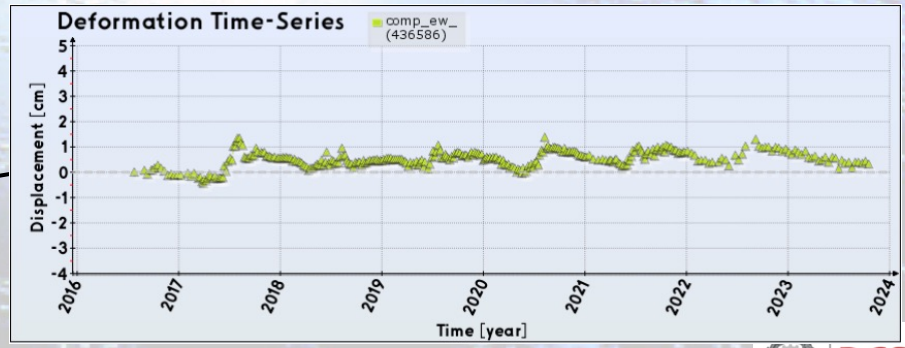


P-SBAS analysis at the national scale: deformation map over the area of Bologna

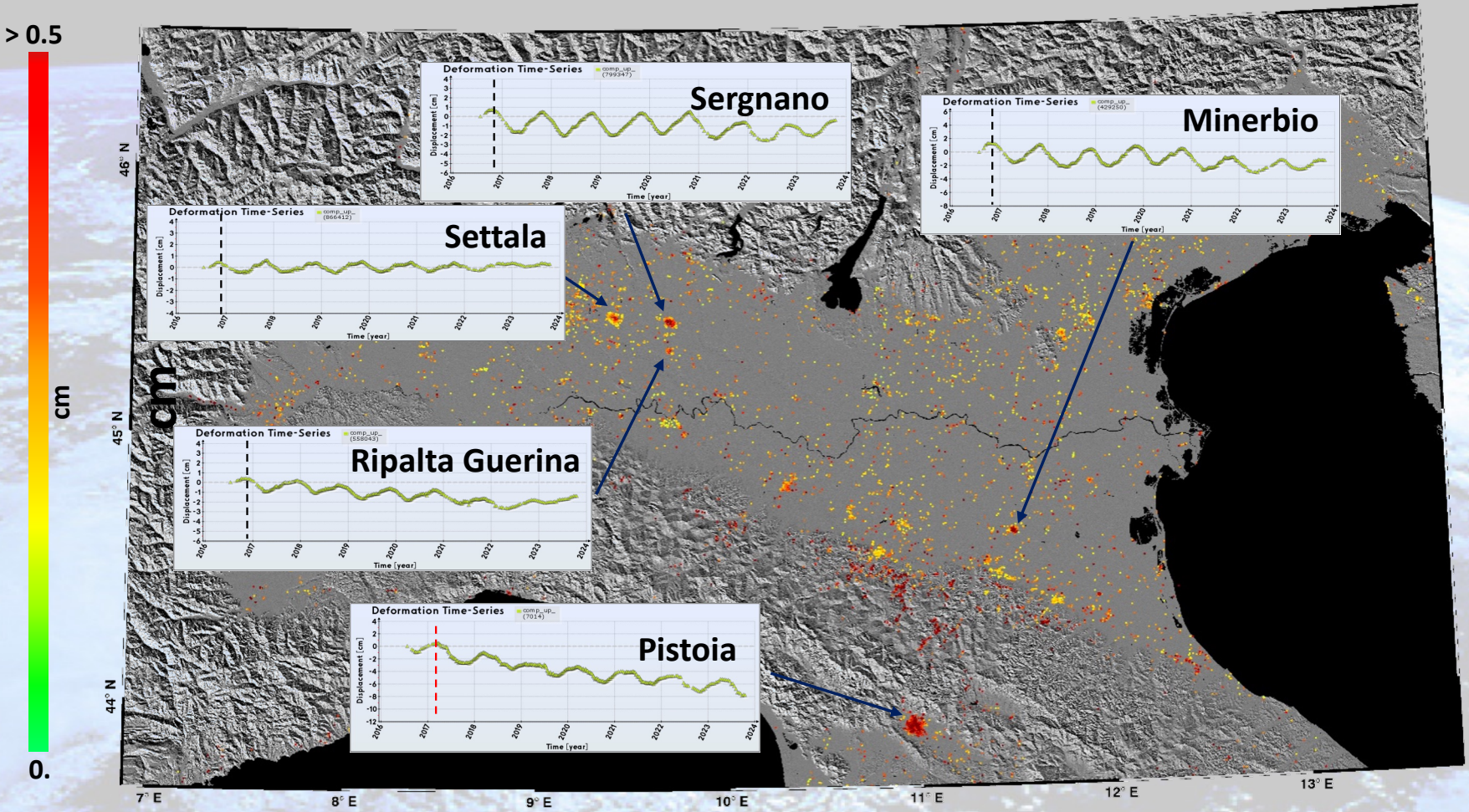


P-SBAS analysis at the national scale: deformation map over the area of Bologna

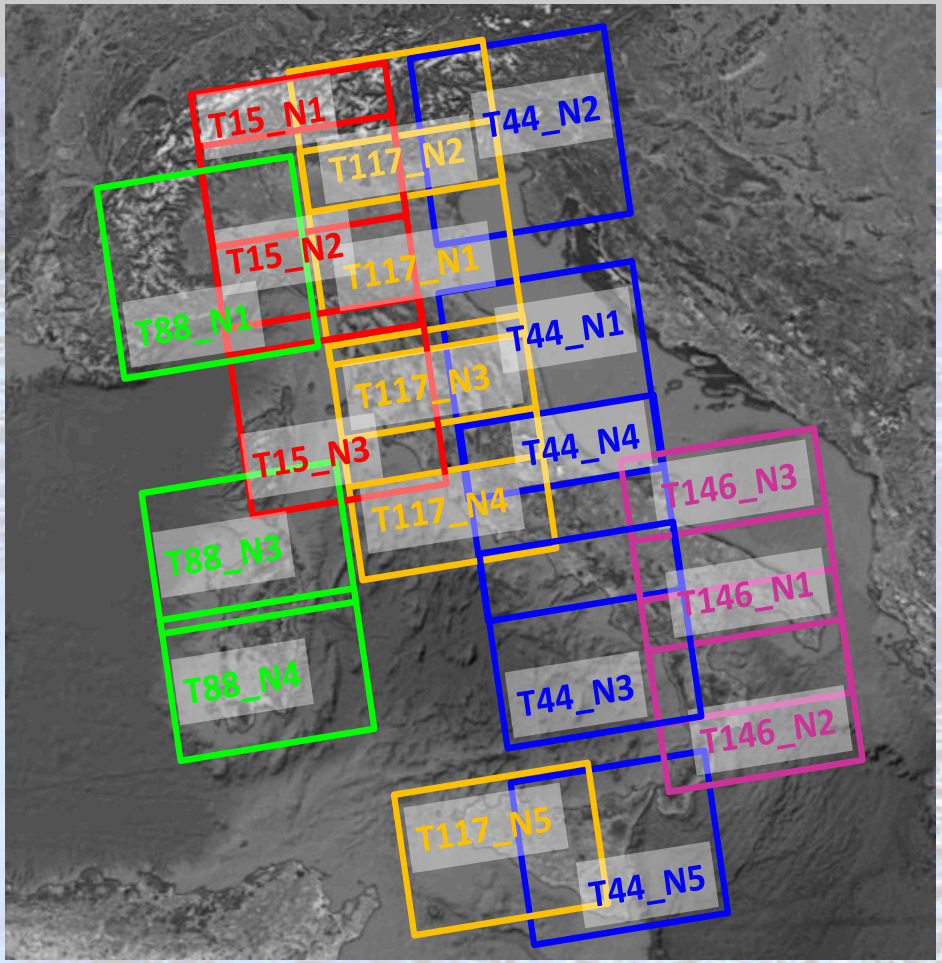




P-SBAS analysis at the national scale: oscillation amplitude map (Jun 16 – Nov 23)



P-SBAS DInSAR analysis at the national scale with Sentinel-1 data



Ascending orbits

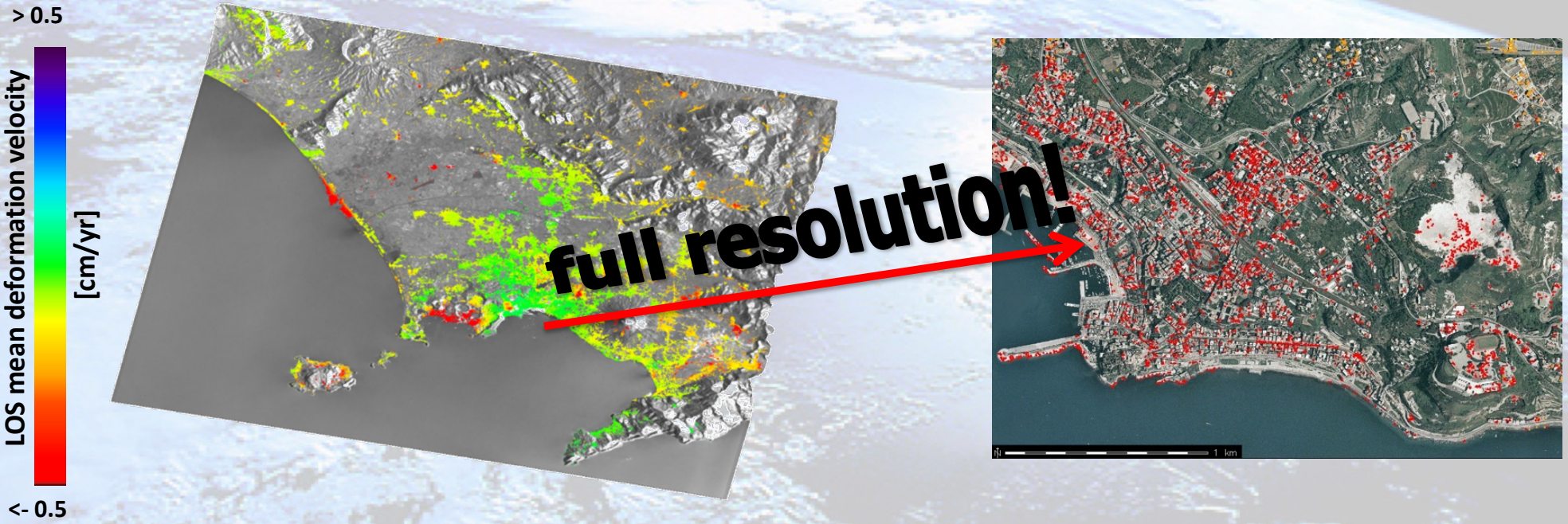
General info about the processing of a Sentinel-1 frame

Sentinel-1 dataset	
Time span	7+ years (Jun 2016 – Nov 2023)
Extent of the observed area	~ 250 x 250 Km^2
S-1 single data (frame) size	~ 4.3 GByte
Total data size	~ 4.7 Tbyte (~1100 data files)
Processing	
Total download time	~ 3.5 hours
Processing time	~ 8 days
Highest temporary disk occupancy	~ 12TByte
Clear elaboration occupancy	~ 4.5 TByte
Storage	
Saved data and results occupancy	~ 1TByte

SBAS-DInSAR analysis at different spatial resolution scales

Medium spatial resolution analysis (pixel size of about 30-100 m)

Full spatial resolution analysis (pixel size of about 3-10 m)



Lanari et al., 2004, IEEE Trans. Geosci. Remote Sens.
Bonano et al., 2012, Int. Jour. Remote Sens.

COSMO-SkyMed I and II Generation (CSK/CSG) → *Focus: built-up environment deformations*

COSMO-SkyMed Second Generation (2019-today)

CSG1

CSG2

COSMO-SkyMed (2007-today)

CSK4

October 2022

CSK1

CSK

CSK2

CSK1

6 days

8 days

2 days

Time

4 days

3 days

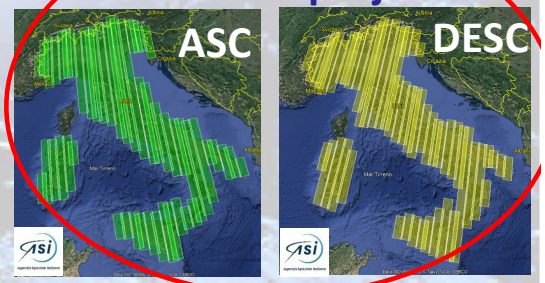
1

8 days

16 days

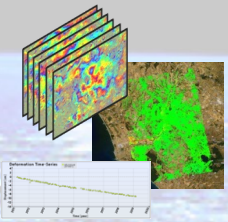
- Spatial resolution (StripMap): **3 m x 3 m**
- Coverage (StripMap): **40 km**
- **X-Band (λ ~ 3.1 cm)**
- **Dual mission (civil - military)**

MAP ITALY project



The full resolution SBAS-DInSAR technique: block diagram

Medium Resolution Processing Results

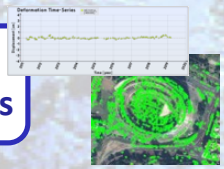


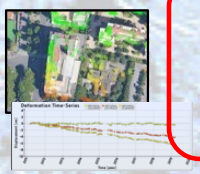
High Pass Filtering

Linear Phase Components Estimation and Removal

Non-linear phase component retrieval (SVD method)

Full Resolution Deformation Time Series



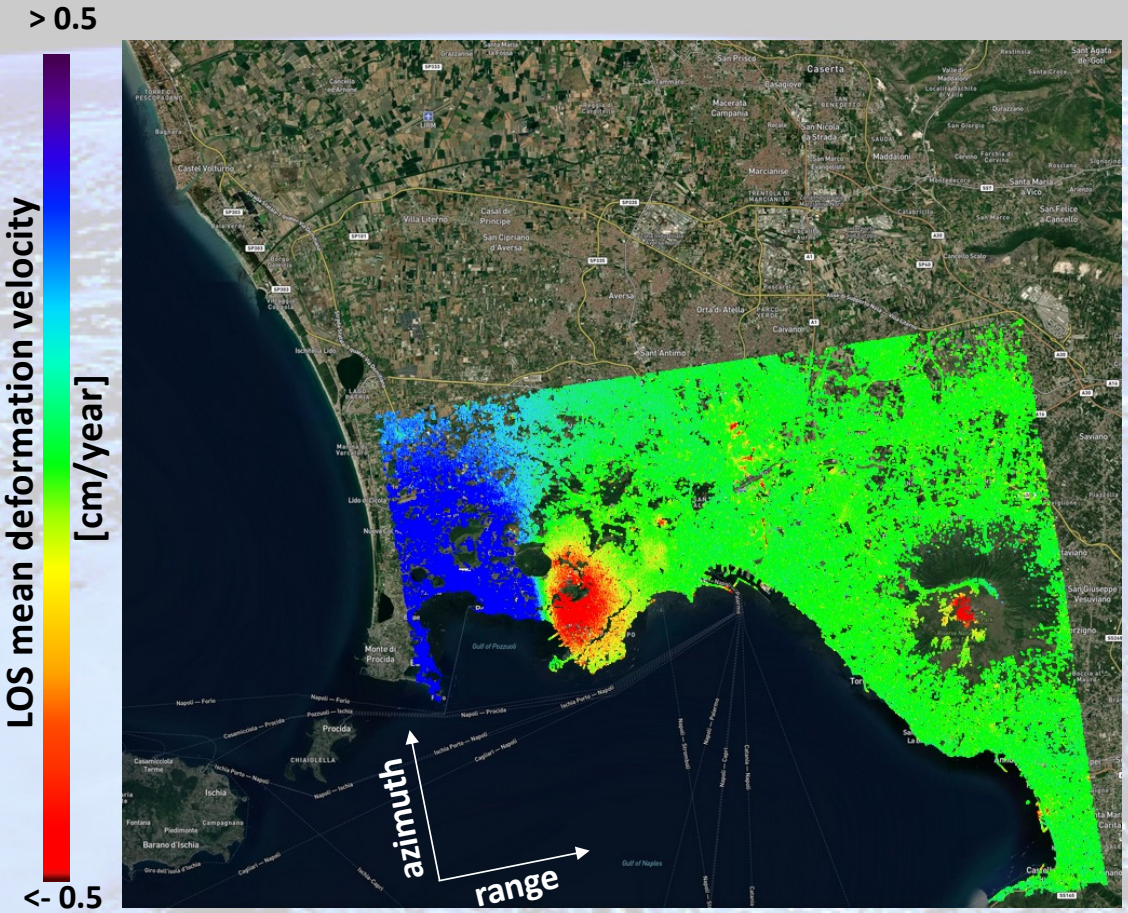


- Drastic increase in number and size of SAR images
- Drastic increase of data processing load and complexity
- Adoption of GPU-based parallel solutions to speed-up the overall processing time and achieve high scalability and computing performance

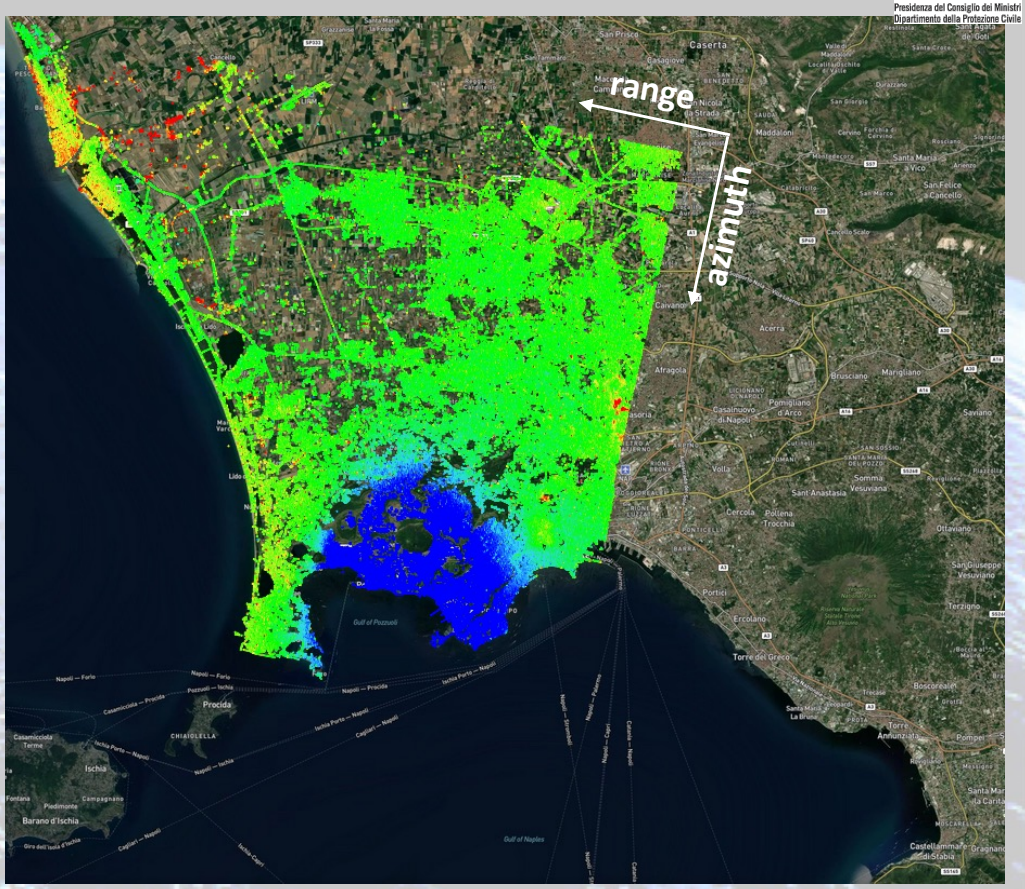
Parallel hardware architectures based on GPU and multi-core processing

FR P-SBAS analysis with CSK/CSG SAR data: the Napoli (southern Italy) case study

PROTEZIONE CIVILE
Presidenza del Consiglio dei Ministri
Dipartimento della Protezione Civile

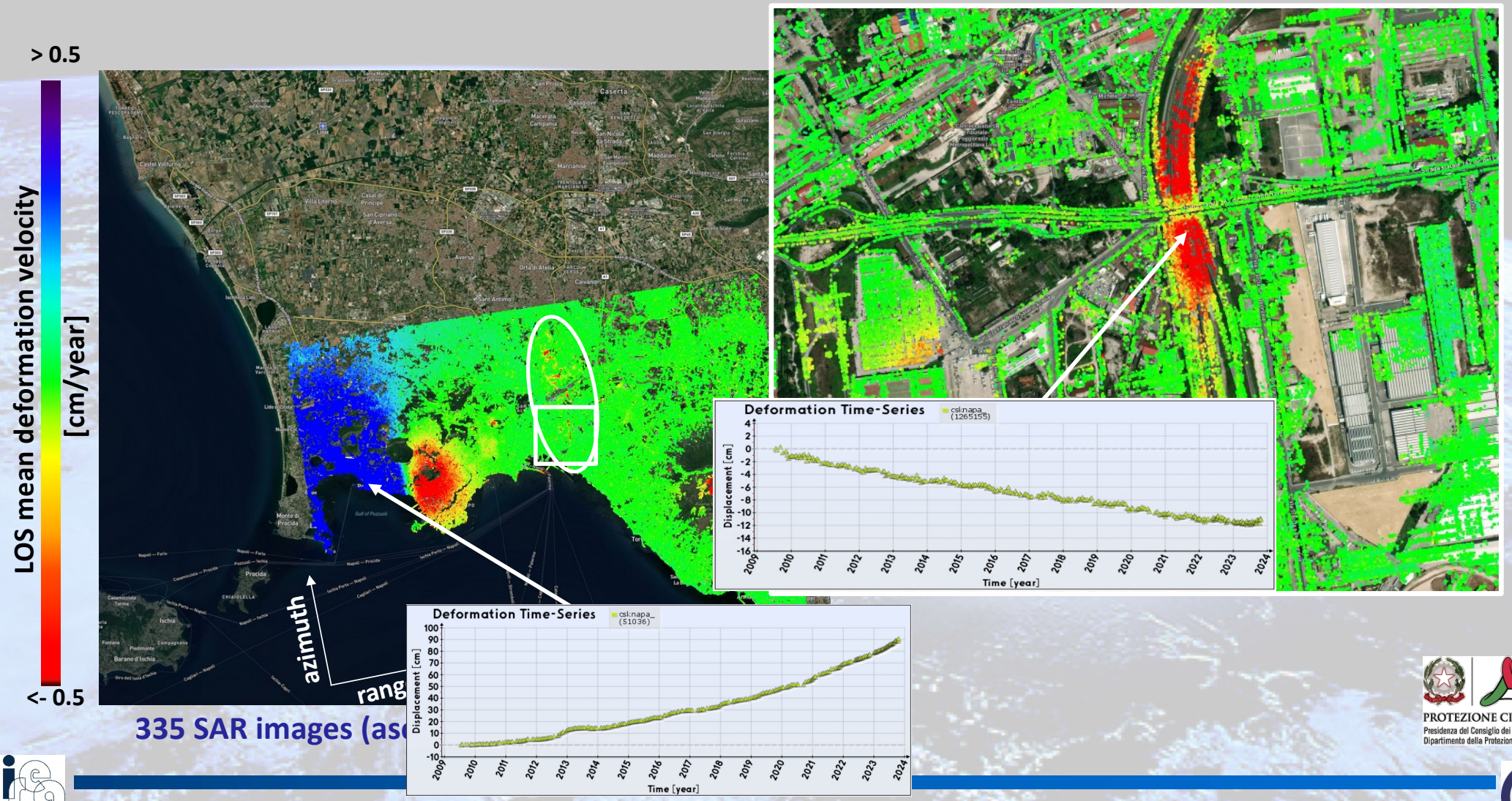


335 SAR images (ascending orbits, 2009-2023)



186 SAR images (descending orbits, 2011-2023)

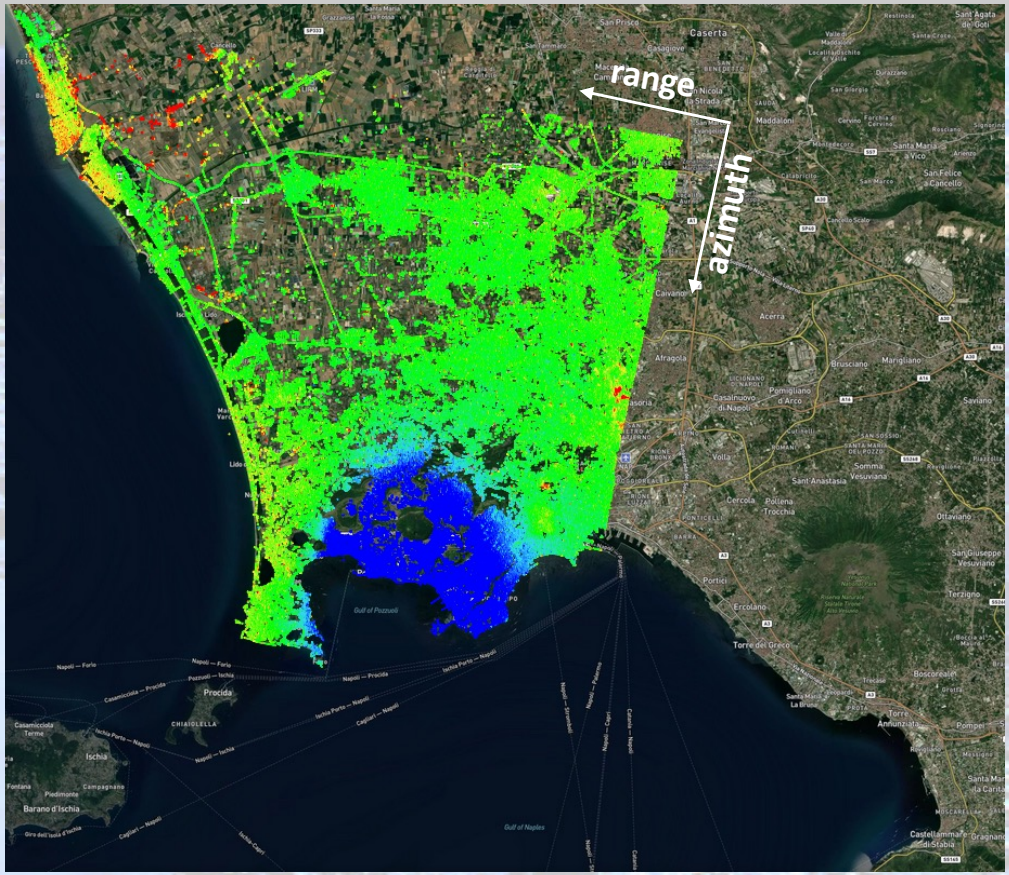
FR P-SBAS analysis with CSK/CSG SAR data: the Napoli (southern Italy) case study



335 SAR images (as

PROTEZIONE CIVILE
Presidenza del Consiglio dei Ministri
Dipartimento della Protezione Civile

Computing times for a Parallel FR-SBAS processing with CSK/CSG data



186 SAR images (descending orbits, 2011-2023)

Napoli area (Descending orbits)	
# SAR images	186
#DInSAR interferograms	1035
Time span	07/2011 – 12/2023
Ground Coverage	32x37 km2
#Pixels	17000x18000
Storage Data INPUT	590 GB
Overall Storage	~ 17 TB
Computing resources exploited within the processing	
# CPU totali	128
# GPU	3 (A100)
Overall computing time	3 days

Thank you for the attention !