Orbite a media inclinazione per costellazioni di sistemi SAR compatti e loro utilizzo per analisi DInSAR: il caso della costellazione NIMBUS-IRIDE

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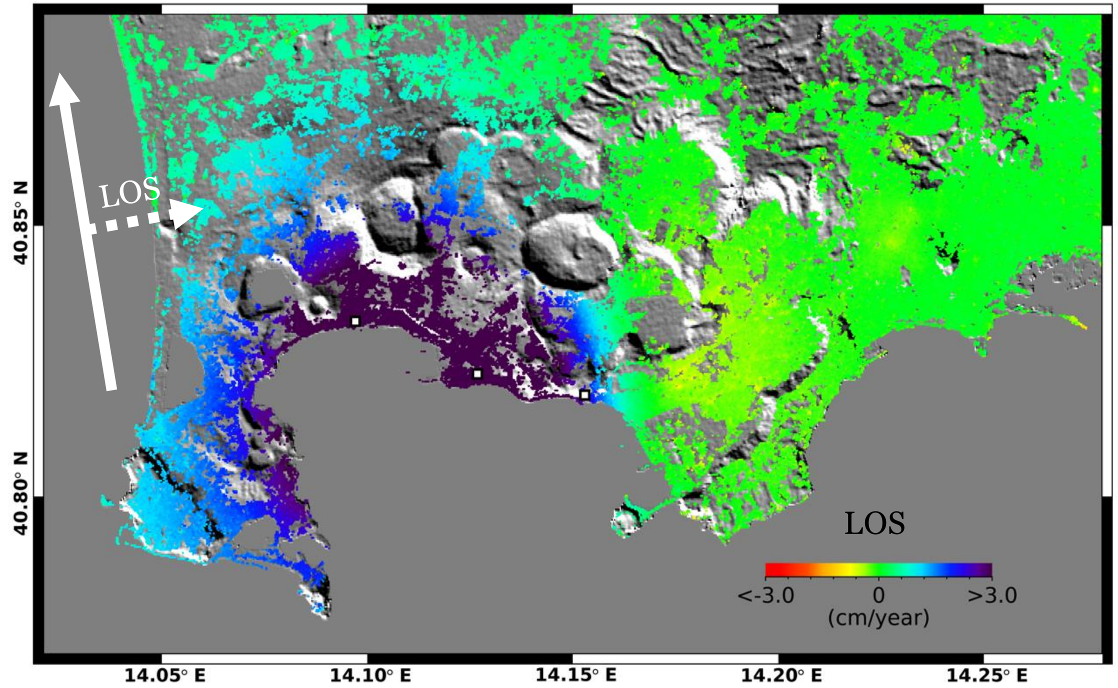
(3) ESA-ESRIN, Frascati (Roma), Italy
(4) Università degli Studi di Napoli "Federico II", Napoli, Italy

From Line of Sight (LOS)….

Ascending



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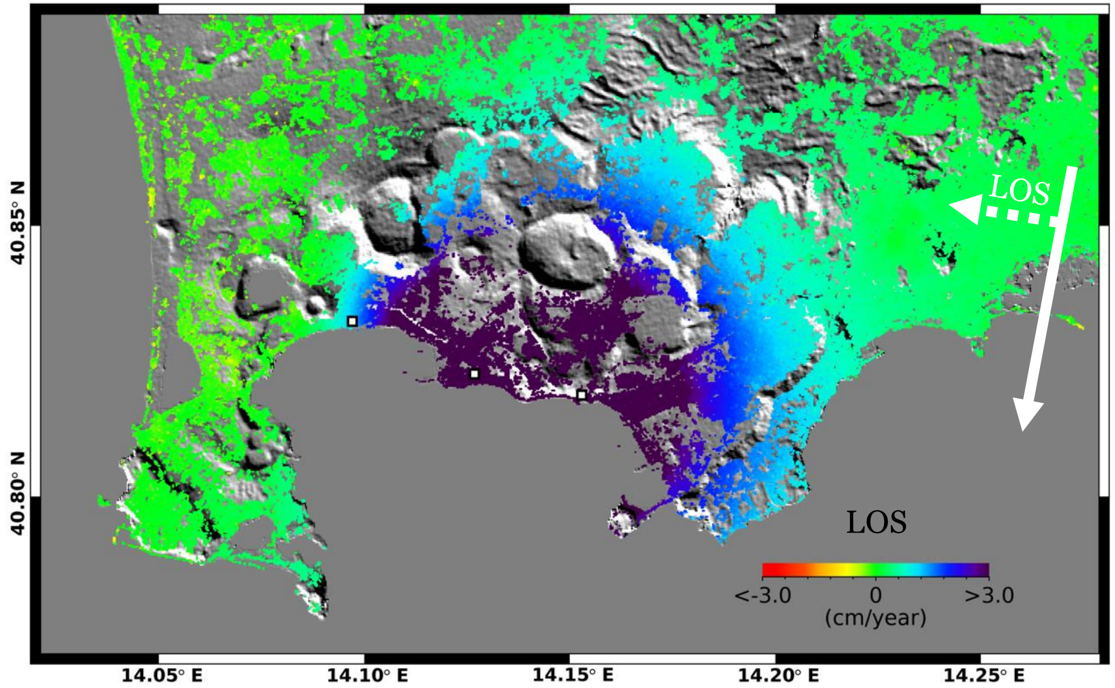

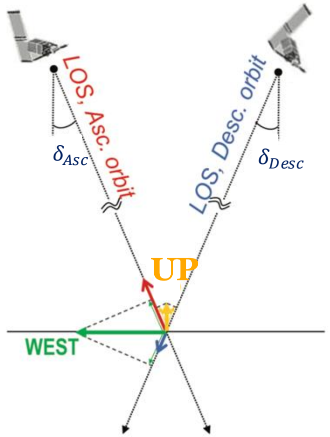

$$d_{losAsc} = d_{up} cos\delta_{Asc} - d_{East} sin\delta_{Asc}$$

$$d_{losDesc} = d_{up} cos\delta_{Desc} + d_{East} sin\delta_{Desc}$$

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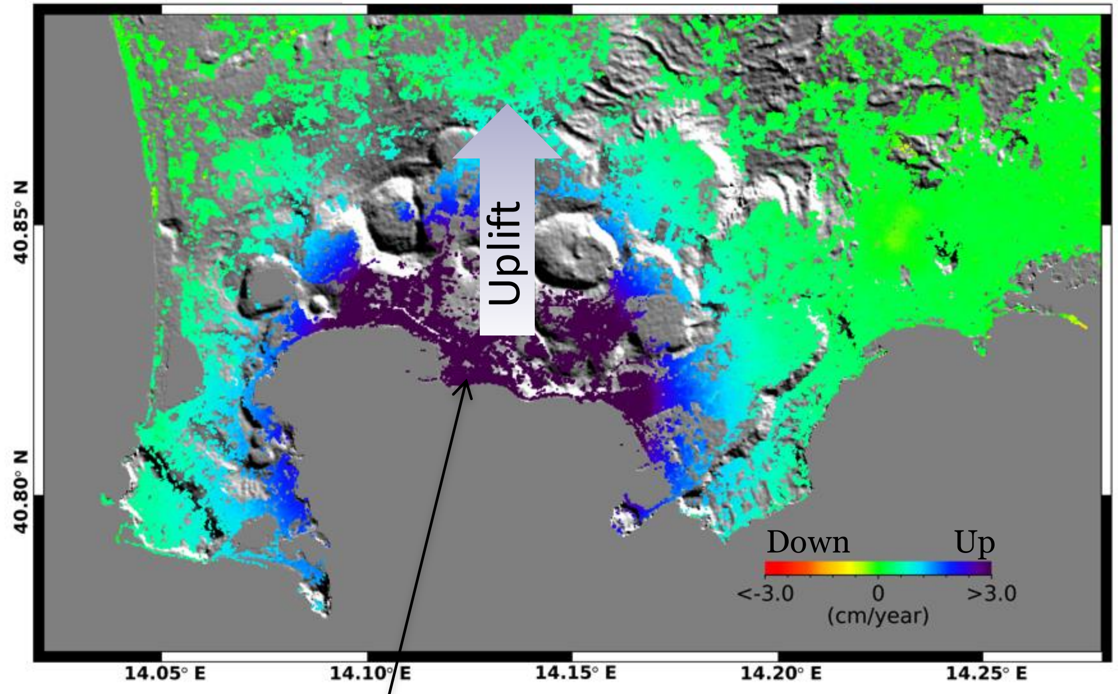
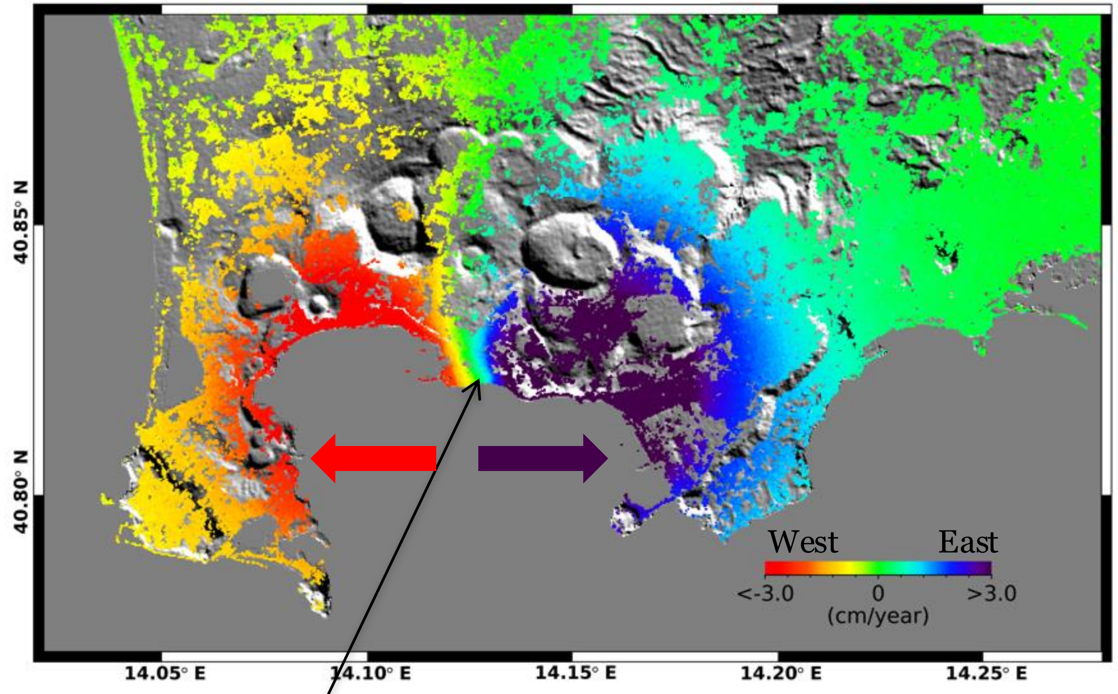
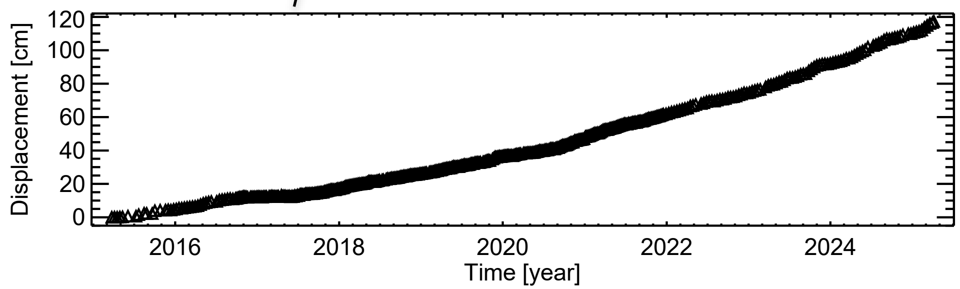
…. to Vertical and East-West deformation measurements

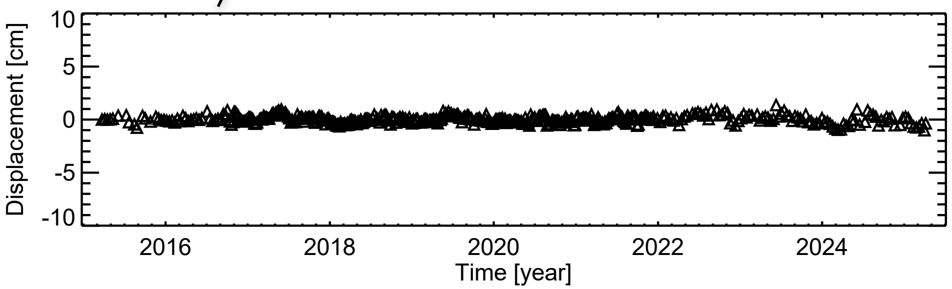
Vertical



East-West







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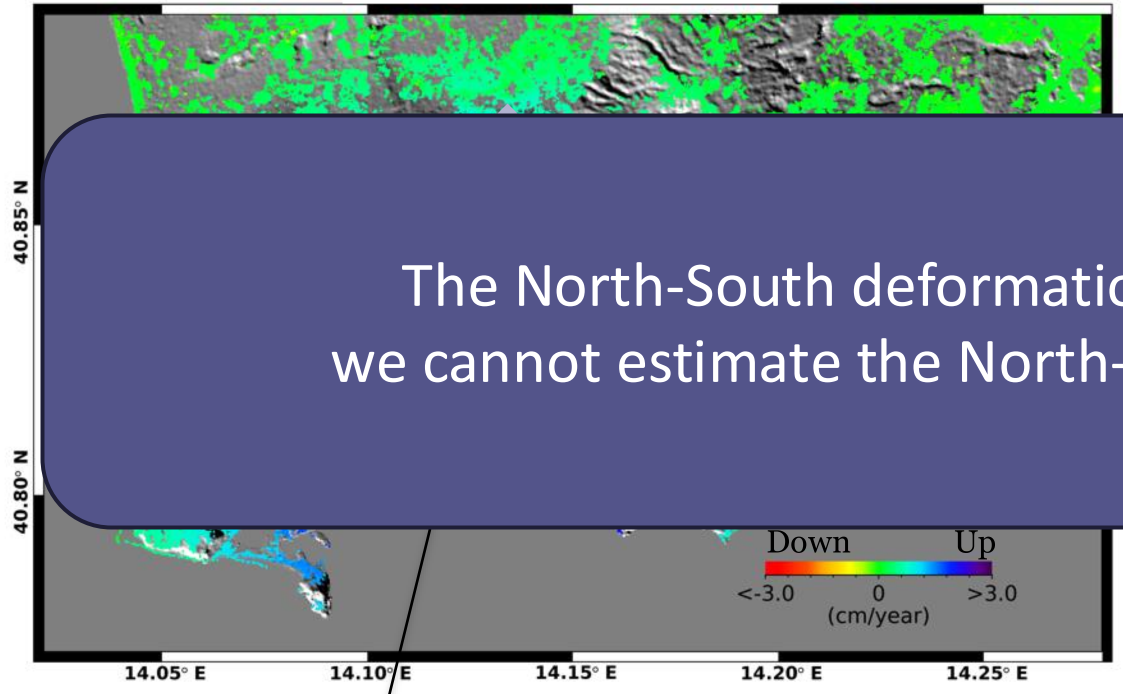
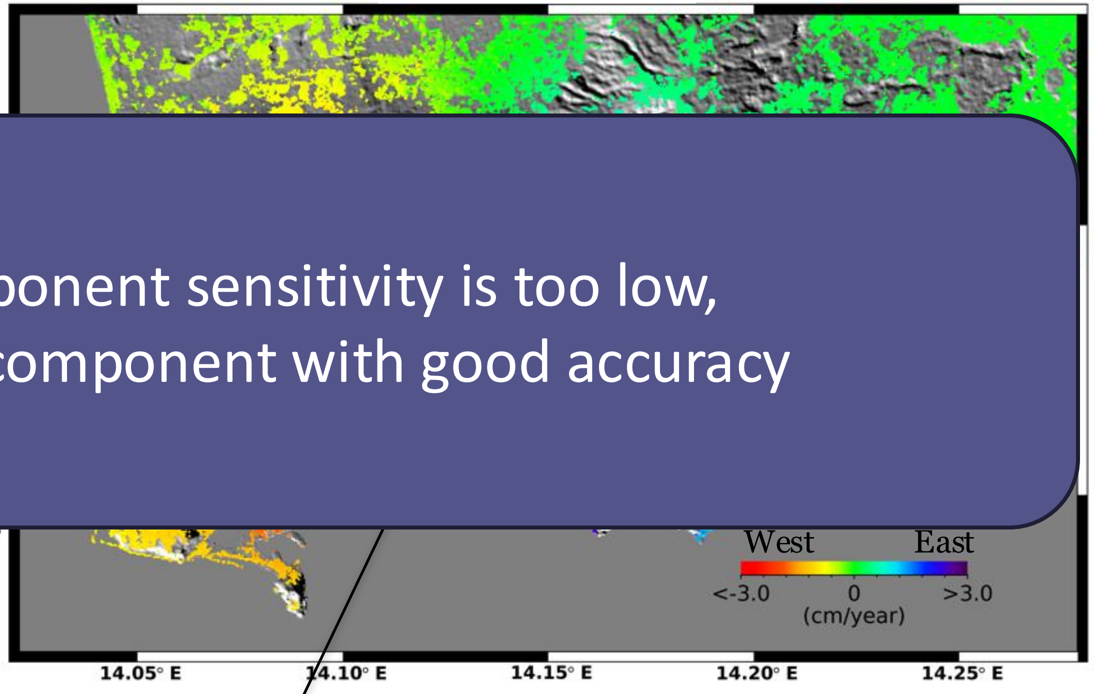
…. to Vertical and East-West deformation measurements

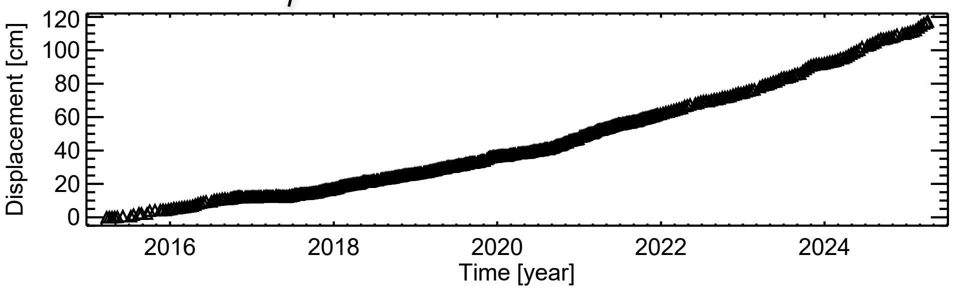
Vertical

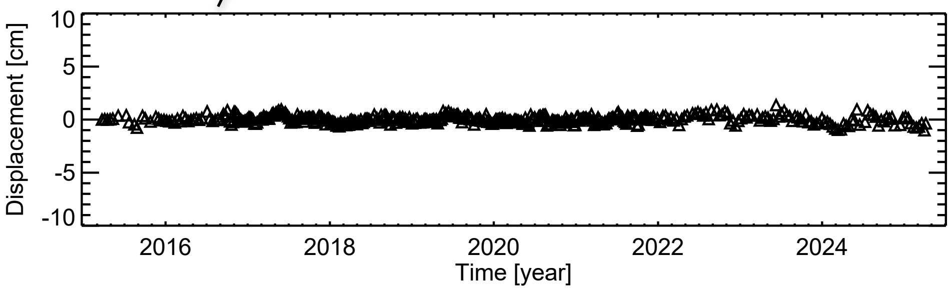


East-West



The North-South deformation component sensitivity is too low,
we cannot estimate the North-South component with good accuracy





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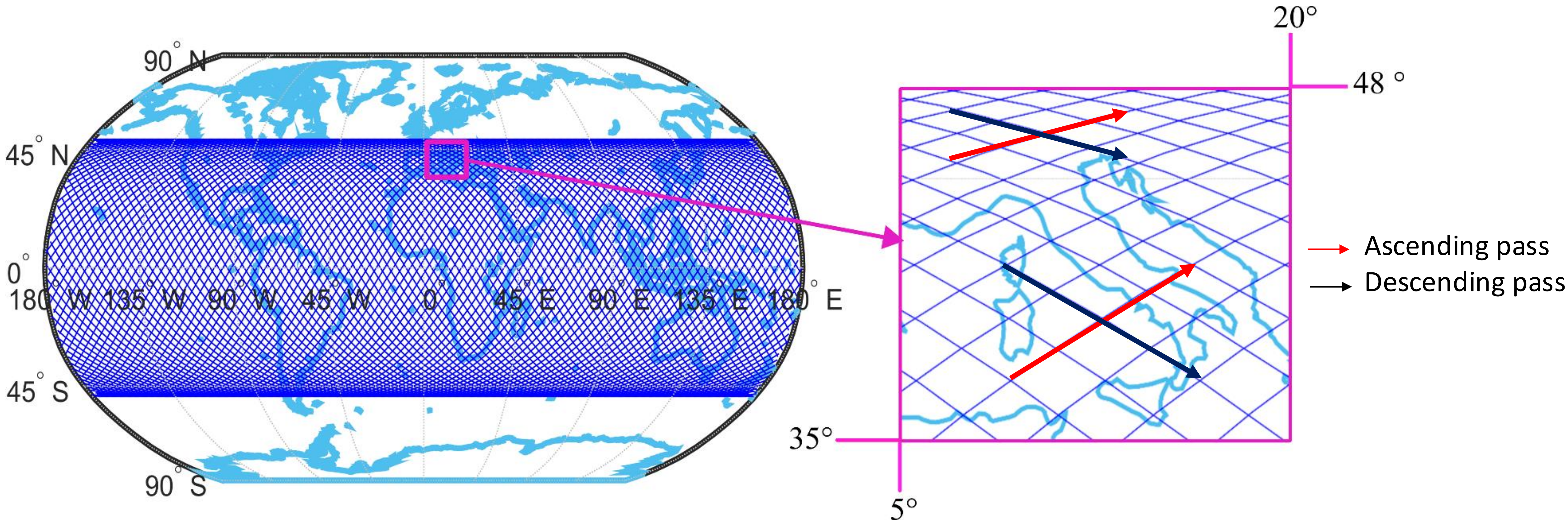
Mid Inclination Orbits (Orbital Characteristics)



- MIO ground track tends to exhibit a near-horizontal orientation at latitudes close to the orbital inclination.
- The inter-track distance tends to reduce as we move to the North of the AoI. This implies that, with the above-discussed strategy, it is much easier to fill the inter-track distance in the north of the AoI than in the south.

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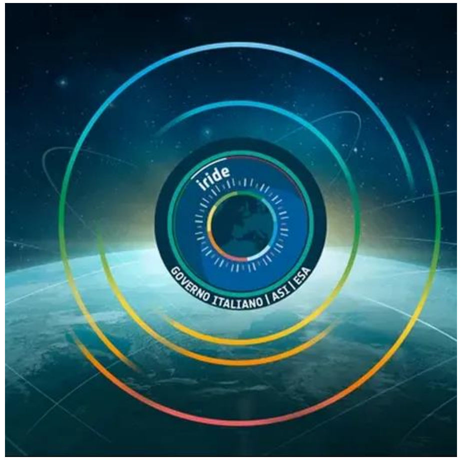
Brief Introduction to the IRIDE Constellation

The Italian constellation **IRIDE** will be completed by 2026 under the management of ESA with the support of ASI for the Italian government.



It is conceptualized as a constellation of constellations, comprising multiple small satellites in LEO equipped with different sensing technologies (SAR, optical sensors) with **medium and high resolution capabilities.**

IRIDE will provide 8 key services to assist institutional entities, such as the DPC, in **systematically** monitoring Italian territory.

Coastal Monitoring | Air Quality | Ground Motion | Soil Moisture | Meteorology | Hydro Resources | Emergency | Security

In addition to the primary goal, IRIDE can be used for **on-demand** acquisitions outside the AoI (i.e., specific defense purposes, commercial users)

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The NIMBUS-SAR platform

- *Focus*: investigating the optimal orbital configuration for the **NIMBUS/IRIDE** SAR sub-constellation (first batch).
- *Objective*: Italian territory coverage (AoI) with **high spatial resolution (2-3 m)** and **short interferometric revisit time.**

Parameter of the NIMBUS/IRIDE sub-constellation	Present Value
Number of satellites	6
Orbital altitude range	490-550 km
Orbital inclination range	44° up to SSO
Swath width extension range **Stripmap mode**	25-28 km
Spatial resolutions (az – ground rg) **Stripmap mode**	2.7 m – 2.7 m
Radar Wavelength	X-Band (λ ~ 3.1 cm)
Orbital control Tube 3σ	500 m
Looking mode	Right/Left

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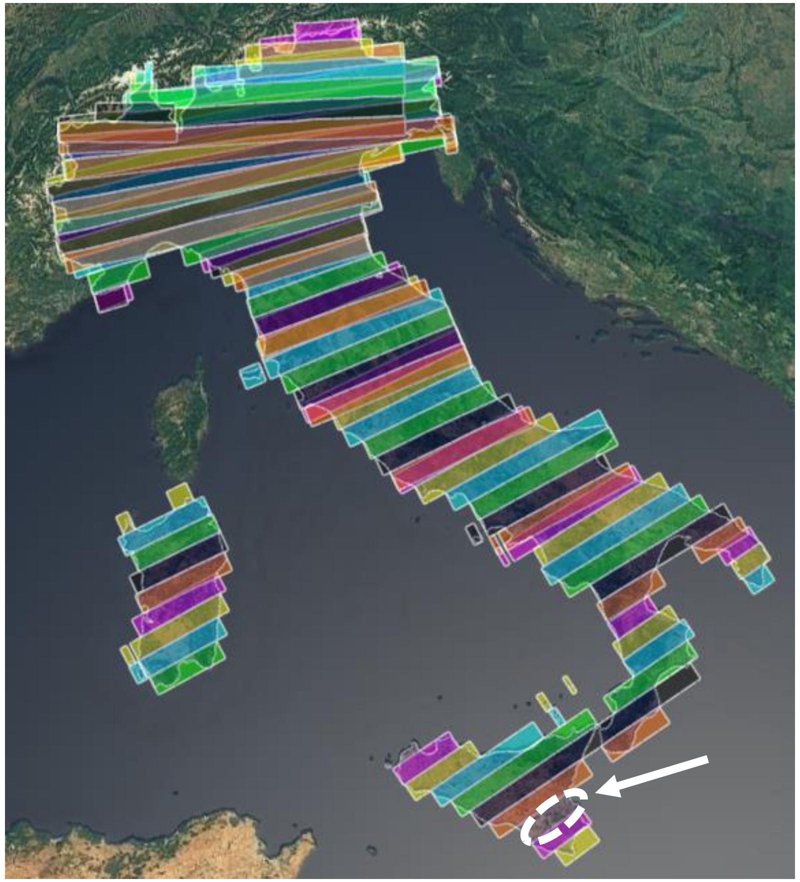
Coverage Analysis over the AoI

Swath width = 27.5 km

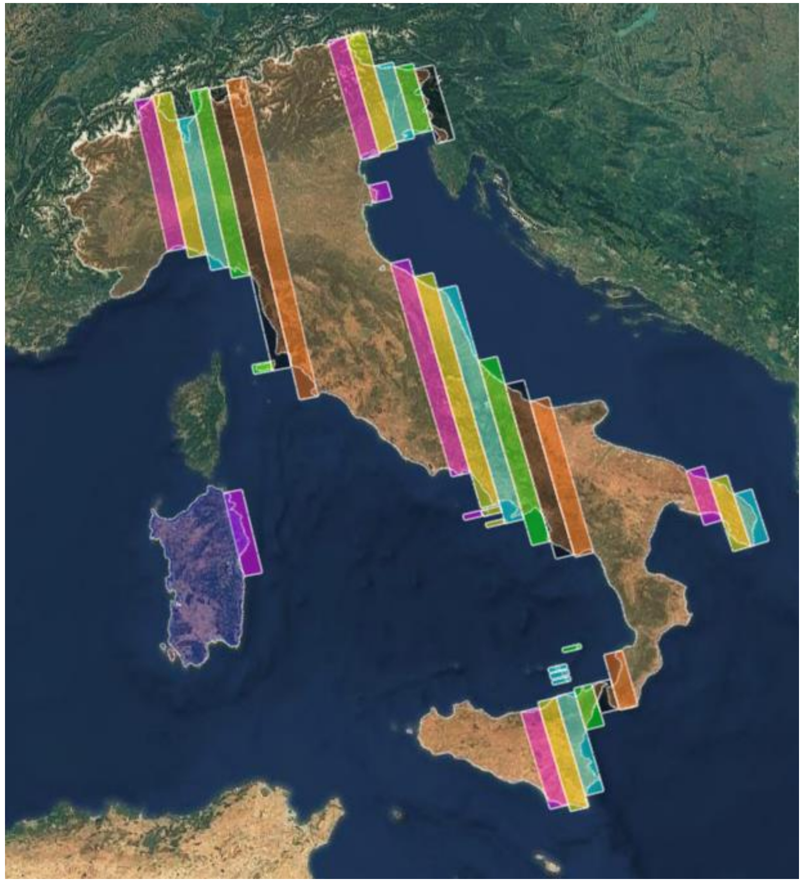
Interferometric revisit time = 6 days

Right-looking acquisition mode

MIO case (49°) – Ascending Passes



SSO case – Ascending Passes



Satellite 1 Satellite 2 Satellite 3
Satellite 4 Satellite 5 Satellite 6

- The MIO scenario allows a very effective 6-day coverage of nearly all the Italian territory
- A further (even small) increase of the swath would be beneficial

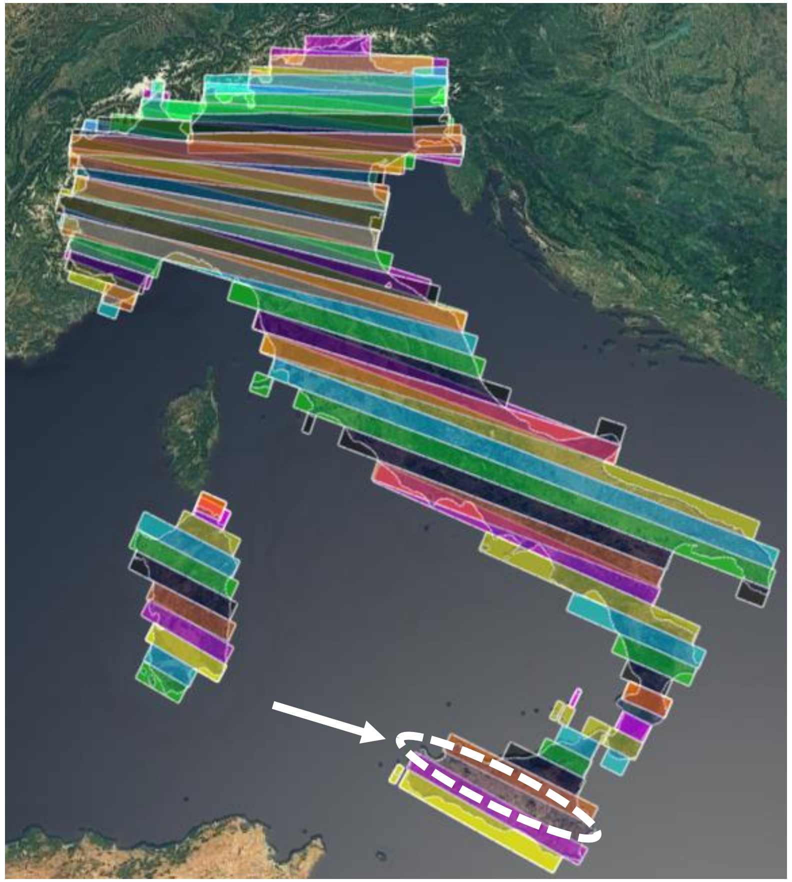
Coverage Analysis over the AoI

Swath width = 27.5 km

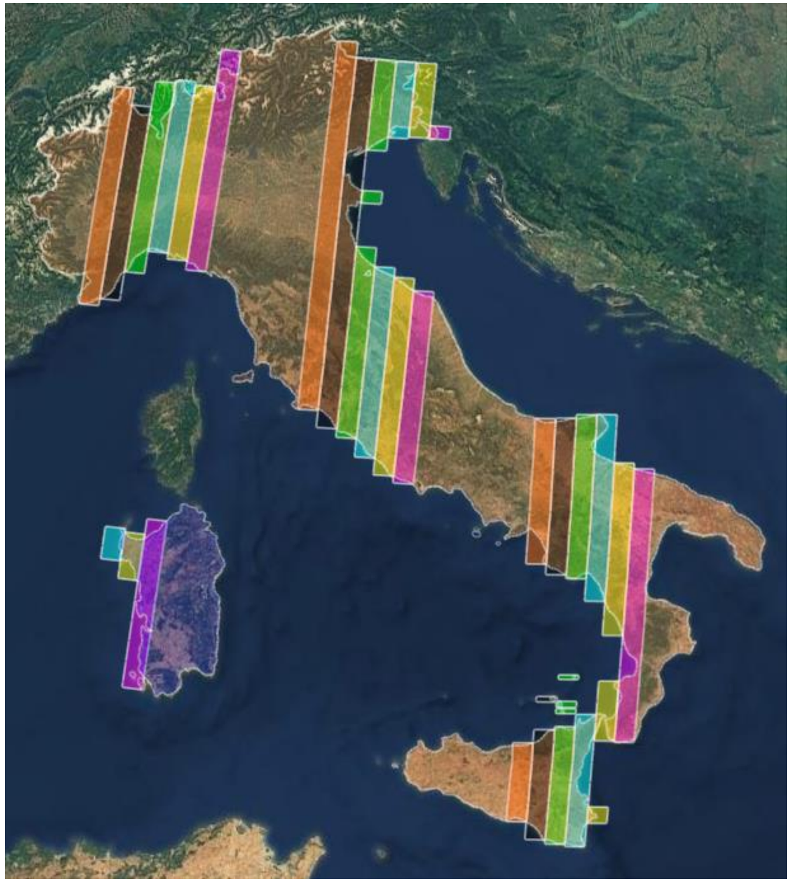
Interferometric revisit time = 6 days

Right-looking acquisition mode

MIO case (49°) – Descending Passes



SSO case – Descending Passes



Satellite 1 Satellite 2 Satellite 3
Satellite 4 Satellite 5 Satellite 6

- The MIO scenario allows a very effective 6-day coverage of nearly all the Italian territory

- A further (even small) increase of the swath would be beneficial

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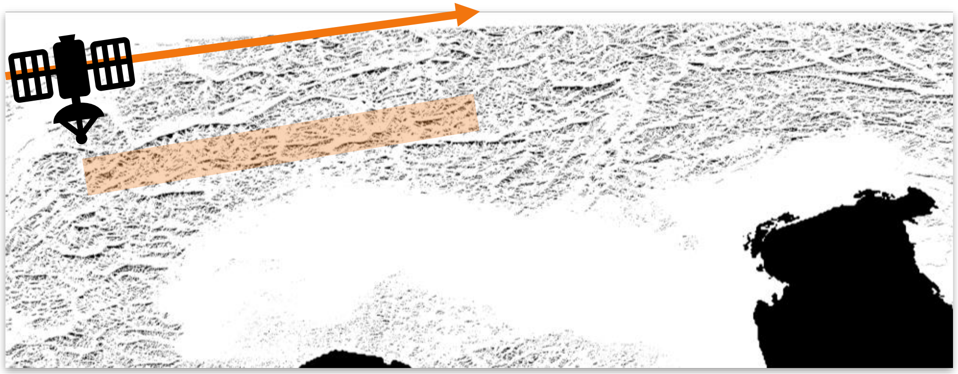
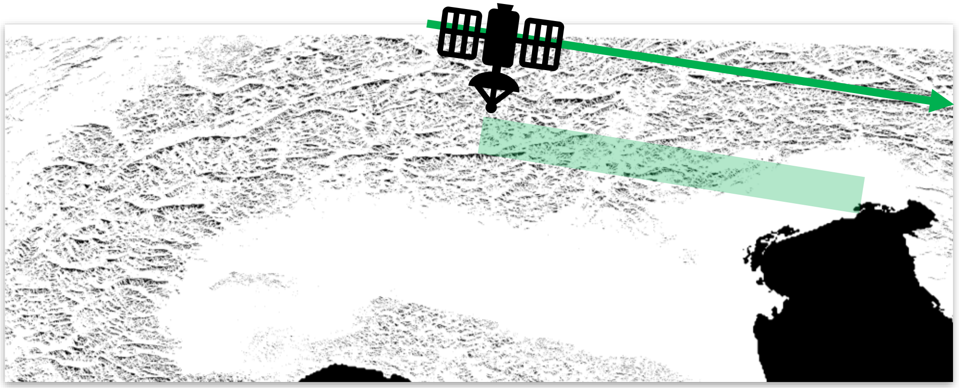
Mid Inclination Orbits (DInSAR scenario)



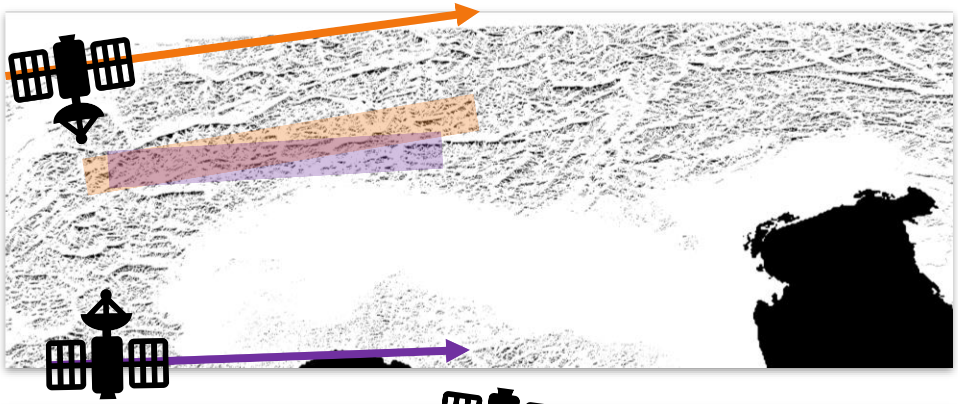
Foreshortening/Layover
Ascending Case 49° Right Looking



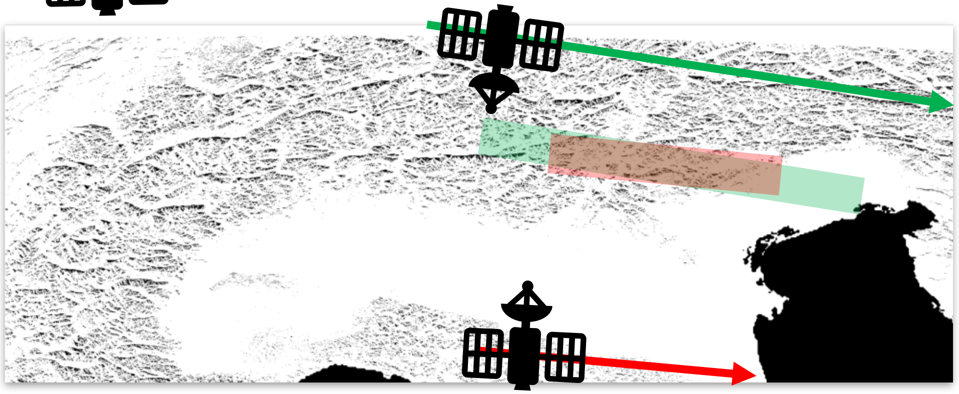
Foreshortening/Layover
Descending Case 49° Right Looking

- **70 % of Foreshortening/Layover points are common** to both the ascending and descending cases in the North of the AoI.

Mid Inclination Orbits (DInSAR scenario)



Foreshortening/Layover
Ascending Case 49° Right Looking
Ascending Case 44° Left Looking



Foreshortening/Layover
Descending Case 49° Right Looking
Descending Case 44° Left Looking

- **70 % of Foreshortening/Layover points are common** to both the ascending and descending cases in the North of the AoI.
- A **Second NIMBUS batch, in a left-looking acquisition mode (43° or 44°),** would guarantee a complementary view and it would further enhance the 3D deformation mapping capability.

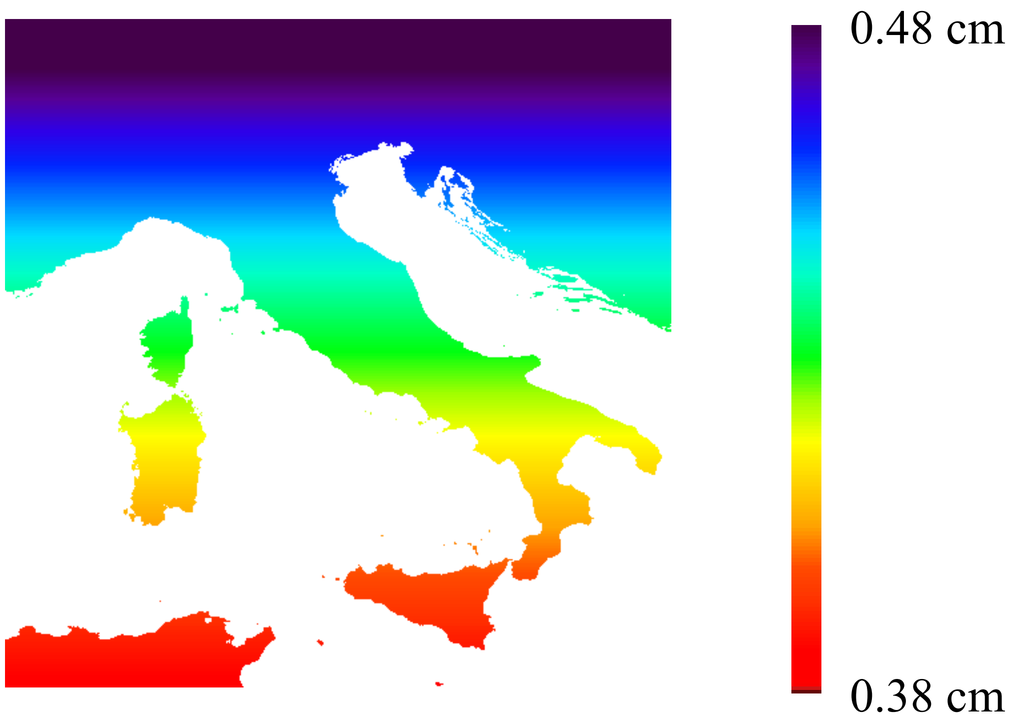
Mid Inclination Orbits (DInSAR scenario)

- An advantage of MIO is the capability of overcoming the issue relevant to the limited accuracy toward the north-south deformation component, as it is evident from the decomposition equations.

$$d_{losAsc} = d_{up} cos\delta_{Asc} - d_{East} sin\delta_{Asc} cos\alpha_{Asc} - d_{North} sin\delta_{Asc} sin\alpha_{Asc}$$

$$d_{losDesc} = d_{up} cos\delta_{Desc} + d_{East} sin\delta_{Desc} cos\alpha_{Desc} - d_{North} sin\delta_{Desc} sin\alpha_{Desc}$$

- Indeed, unlike the SSO case, in a 49 °MIO more than 40% of the North-South component contributes to the SAR Line of sight.



Accordingly, the joint exploitation of the NIMBUS-IRIDE (MIO) and CSK-CSG (SSO) DInSAR measurements will allow a 3D displacement retrieval at high spatial resolution.

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MIO Capella Space Acquisitions over Campi Flegrei Caldera (Italy)

Capella Space at an orbit inclination of 45°, experimentally acquired a repeat ground track (RGT) orbit with a repeat cycle of approximately 3 days.

During July-August 2024, Capella-14 acquired three Stripmap SAR datasets in ascending and descending orbits and right- and left-looking directions, using complementary satellite heading angles over the Campi Flegrei caldera.

Parameter	Value
Orbital altitude	590 km
Orbital inclination	45°
Revisit time (solar days)	~ 2.95 days
Radar frequency	X band
Acquisition mode	Stripmap
Looking direction	Right-Left
Swath width (range)	10 km
Radar frequency	X band
Slant range resolution	0.60 m
Azimuth resolution	1.20 m

MIO Capella Space Acquisitions over Campi Flegrei Caldera (Italy)

PASS: **ASCENDING LEFT-LOOKING**

ORBIT: **45° MIO**

LOCAL HEADING ANGLE: **~60°**

OFF-NADIR ANGLE: **~31°**

DATASET SIZE: **17 ACQ.**

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MIO Capella Space Acquisitions over Campi Flegrei Caldera (Italy)

PASS: **ASCENDING RIGHT-LOOKING**

ORBIT: **45° MIO**

LOCAL HEADING ANGLE: **~71°**

OFF-NADIR ANGLE: **~19°**

DATASET SIZE: **17 ACQ.**

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MIO Capella Space Acquisitions over Campi Flegrei Caldera (Italy)

PASS: **DESCENDING LEFT-LOOKING**

ORBIT: **45° MIO**

LOCAL HEADING ANGLE: **~121°**

OFF-NADIR ANGLE: **~33°**

DATASET SIZE: **16 ACQ.**

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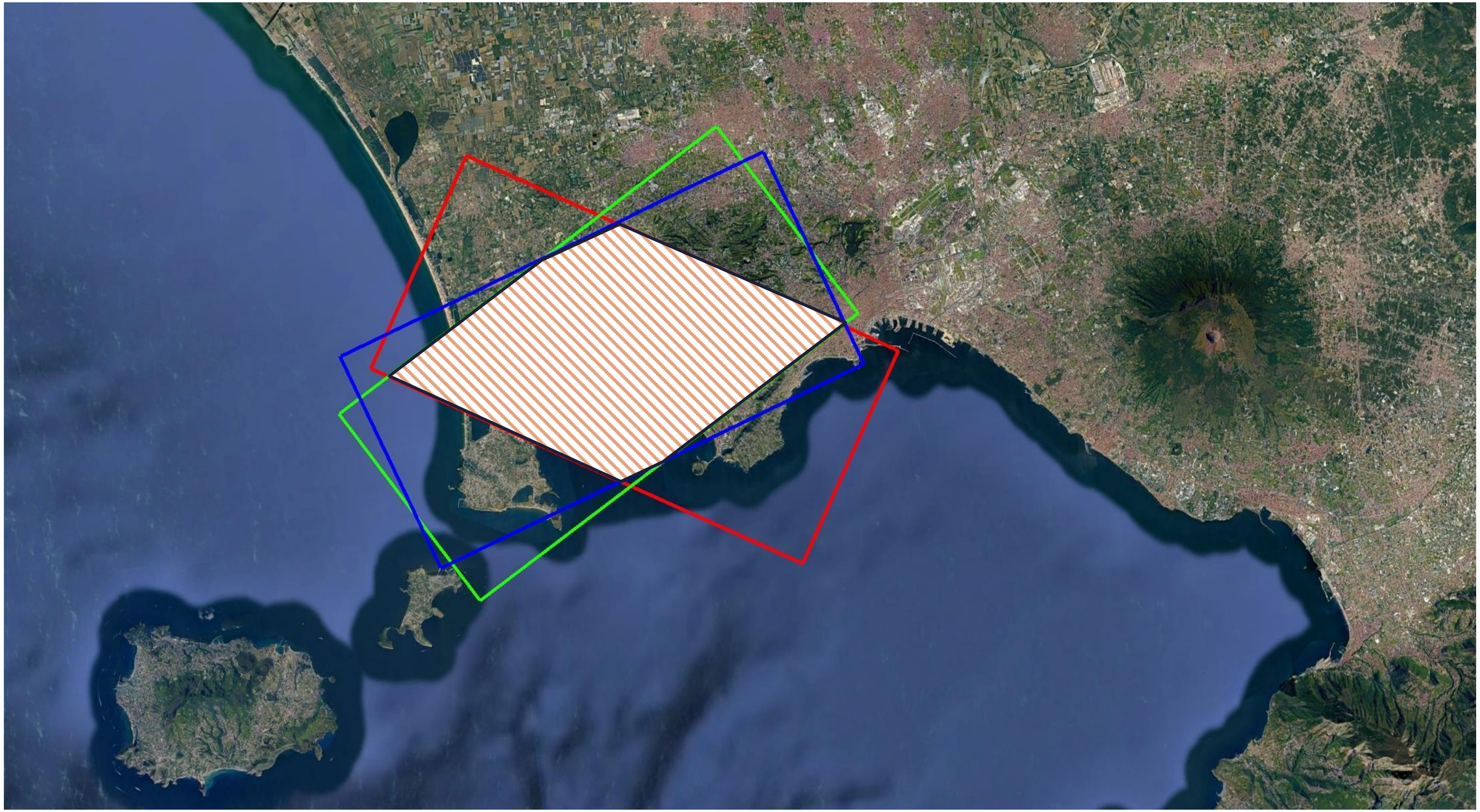
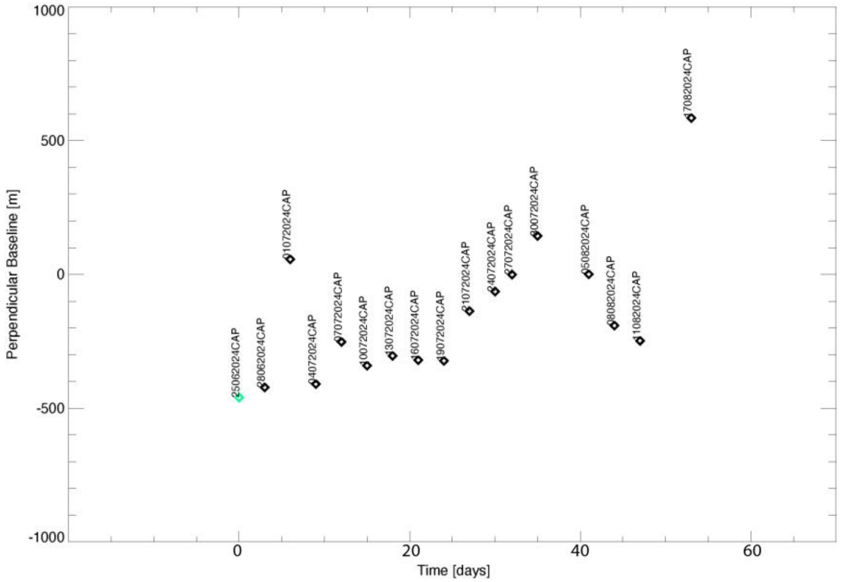
MIO Capella Space Acquisitions over Campi Flegrei Caldera (Italy)



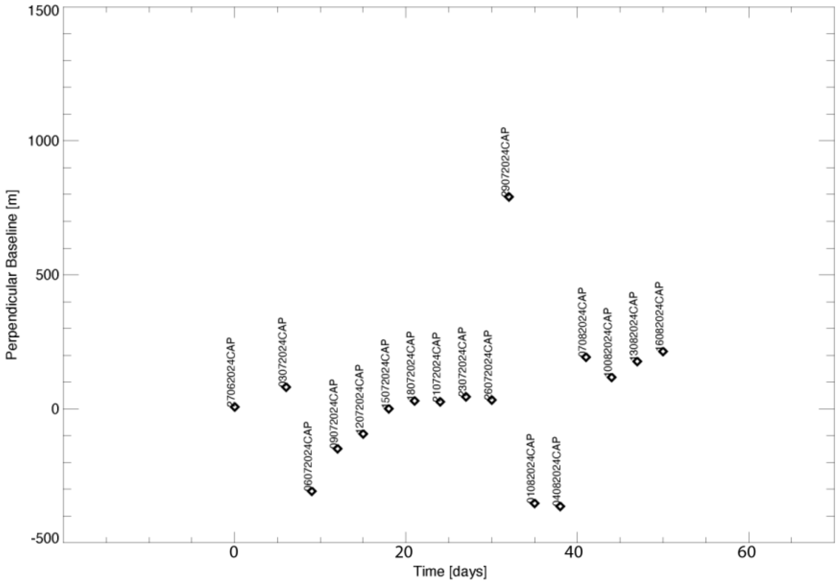
MIO Capella Space Acquisitions over Campi Flegrei Caldera (Italy)

Ascending Left



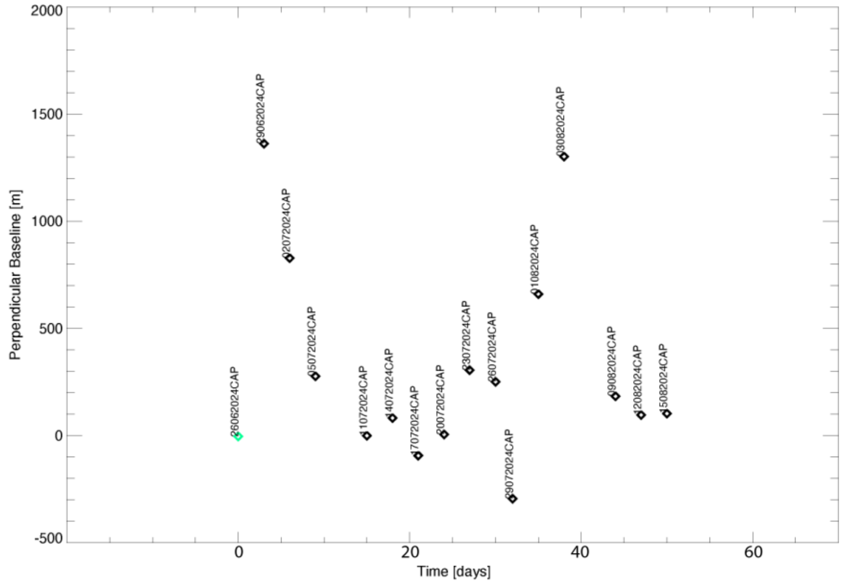
17 Acquisitions
25 06 2024-17 08 2024
(54 days)

Ascending Right



17 Acquisitions
27 06 2024-16 08 2024
(51 days)

Descending Left



16 Acquisitions
26 06 2024-15 08 2024
(51 days)

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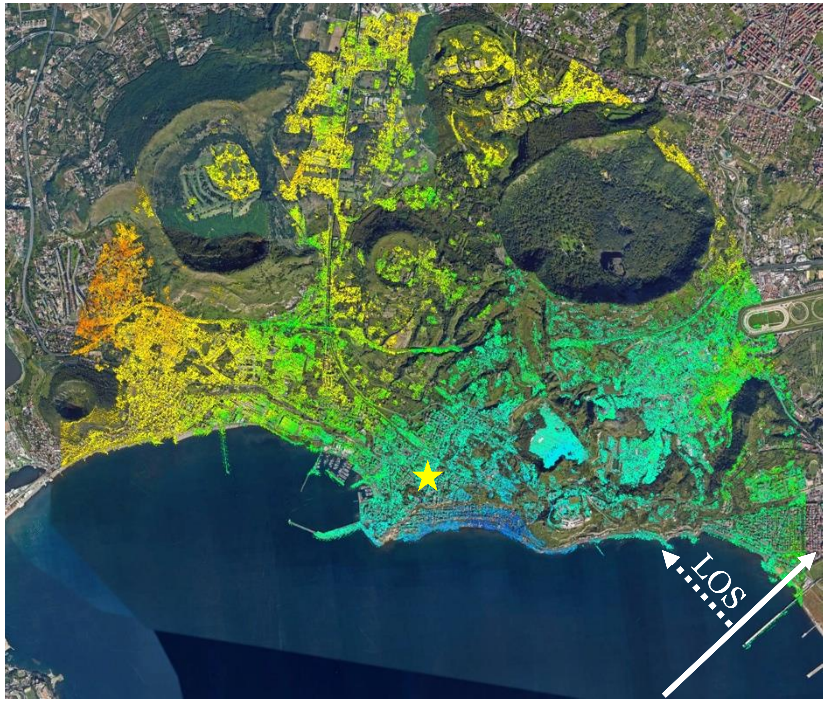
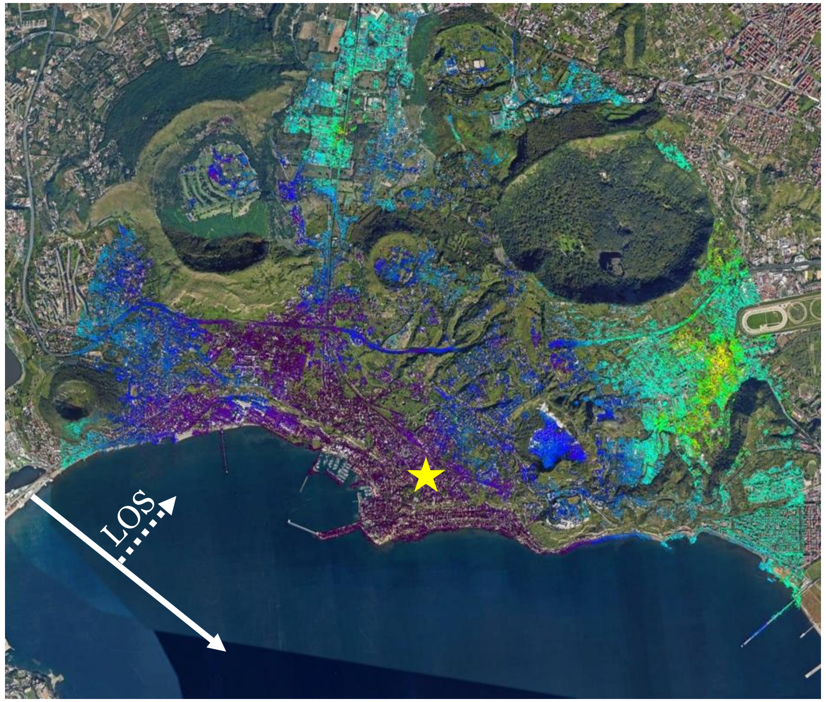
MIO Capella Space LOS Results over Campi Flegrei Caldera (Italy)

Ascending Left

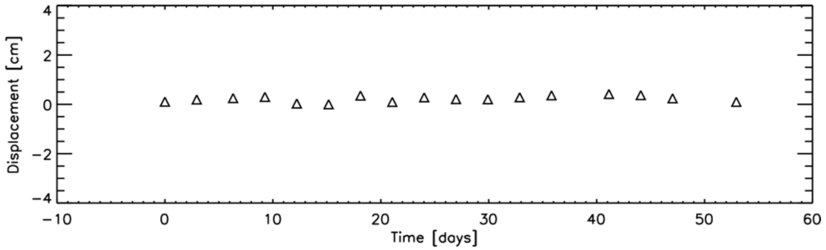


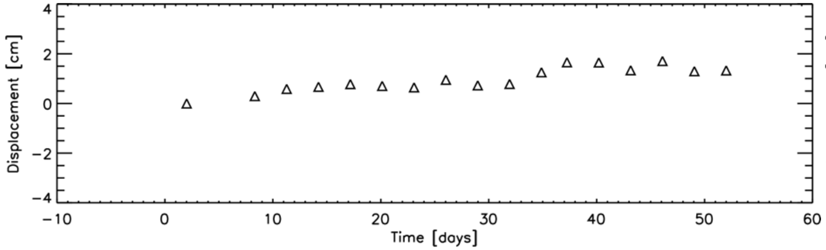
Ascending Right

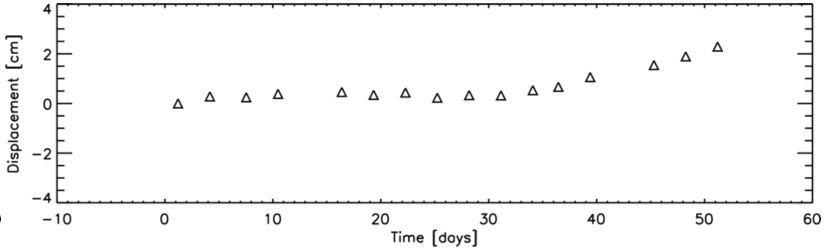
Descending Left



LOS deformation velocity [cm/month]







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GNSS Network (OV-INGV) in the Campi Flegrei Caldera

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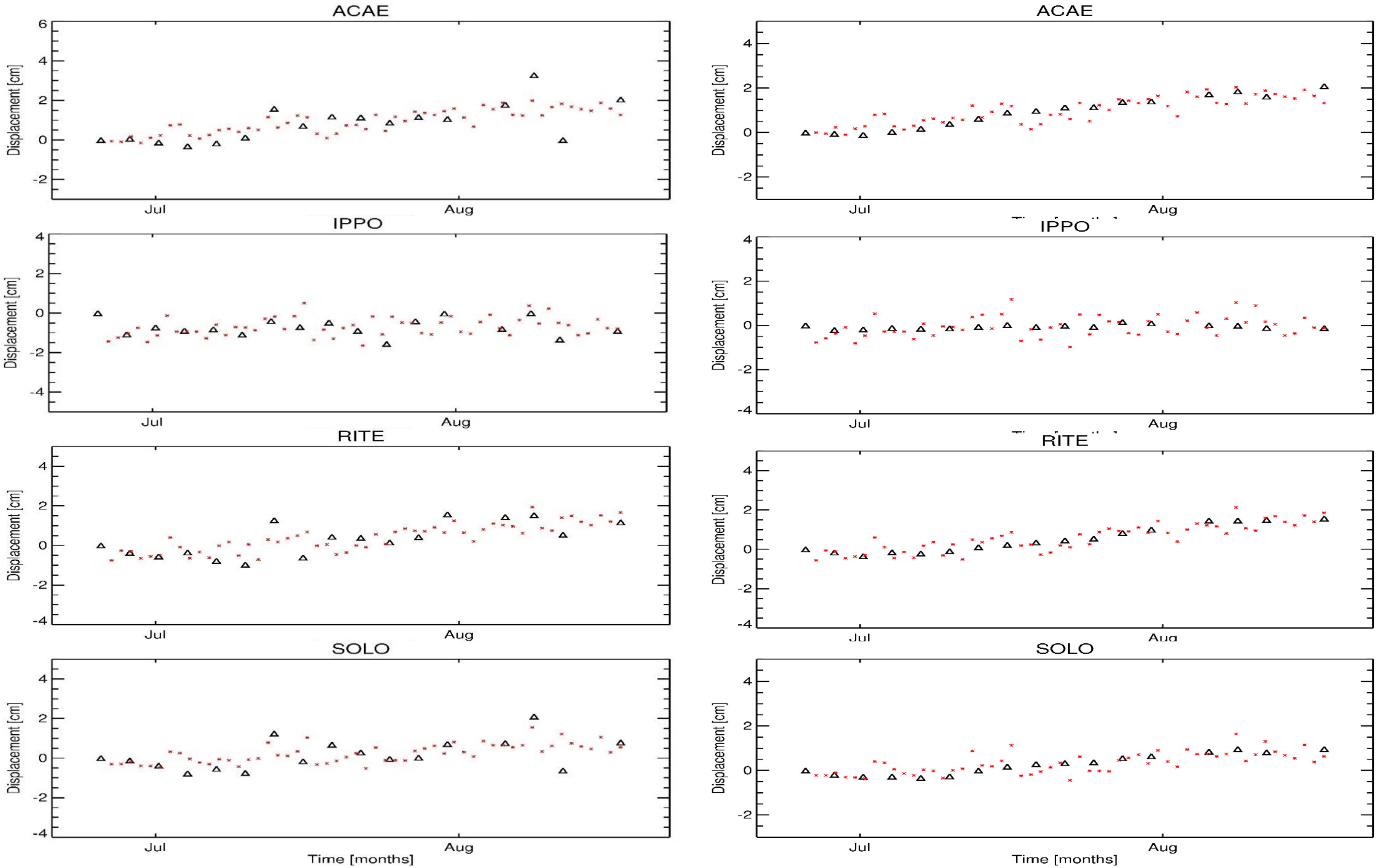
GNSS vs. MIO Capella Space Measurement Comparisons

ASCENDING LEFT

UNFILTERED

FILTERED



GNSS vs. MIO Capella Space Measurement Comparisons

ASCENDING LEFT

GPS station	ST. DEV. [cm]
ACAE	0.29
ARFE	0.37
ASTR	0.17
BAIA	0.28
CMIS	0.62
CUMA	1.06
IPPO	0.11
ISMO	0.13
ISPT	0.26
MITT	0.23
MORU	0.59
MPRO	0.16
MSTA	0.21
PIS1	0.19
QUAR	0.69
RITE	0.22
SOLO	0.22
STRZ	0.28
TOIA	0.61
VICA	0.27
VNAP	0.25
Mean Standard Deviation	**0.34**

ASCENDING RIGHT

GPS station	ST. DEV. [cm]
ACAE	0.24
ARFE	0.35
ASTR	0.12
BAIA	0.35
CUMA	0.40
IPPO	0.21
ISMO	0.10
ISPT	0.40
MITT	0.37
MORU	0.23
MPRO	0.61
MSTA	0.32
PIS1	0.25
QUAR	0.33
RITE	0.40
SOLO	0.31
STRZ	0.31
TOIA	0.22
VICA	0.25
VNAP	0.41
Mean Standard Deviation	**0.31**

DESCENDING LEFT

GPS station	ST. DEV. [cm]
ACAE	0.51
ARFE	0.49
ASTR	0.25
BAAC	0.19
BAGN	0.20
CUMA	0.57
IPPO	0.22
ISMO	0.13
ISPT	0.34
LICO	0.55
MITT	0.44
MORU	0.66
MSTA	0.15
NISI	0.20
PIS1	0.30
QUAR	0.35
RITE	0.40
SOLO	0.36
STRZ	0.60
TOIA	0.61
VICA	0.62
VNAP	0.40
Mean Standard Deviation	**0.39**

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North-South Deformation Component Retrieval: Preliminary Results

Conclusions

- Mid Inclination Orbit (MIO) represents the optimal choice to retrieve the **North-South deformation component** that, conversely, cannot be measured in Sun Synchronous Orbits (SSO).

- The **NIMBUS-SAR platform** of the IRIDE programme will permit the **systematic coverage of the Italian territory** with short interferometric revisit time (6 days) and high-resolution capabilities (2-3 m). Accordingly, MIO and SSO (CSK/CSG) DInSAR products can be combined to retrieve value-added information on the 3D deformation field.

- **Capella Space** demonstrated the capability to exploit Mid Inclination Orbit configurations to estimate the multi-angle (3D) displacement through advanced DInSAR analyses.

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