

Application of the InSAR method for determining coseismic displacement after the earthquake on January 7, 2025, in the South Tibet region

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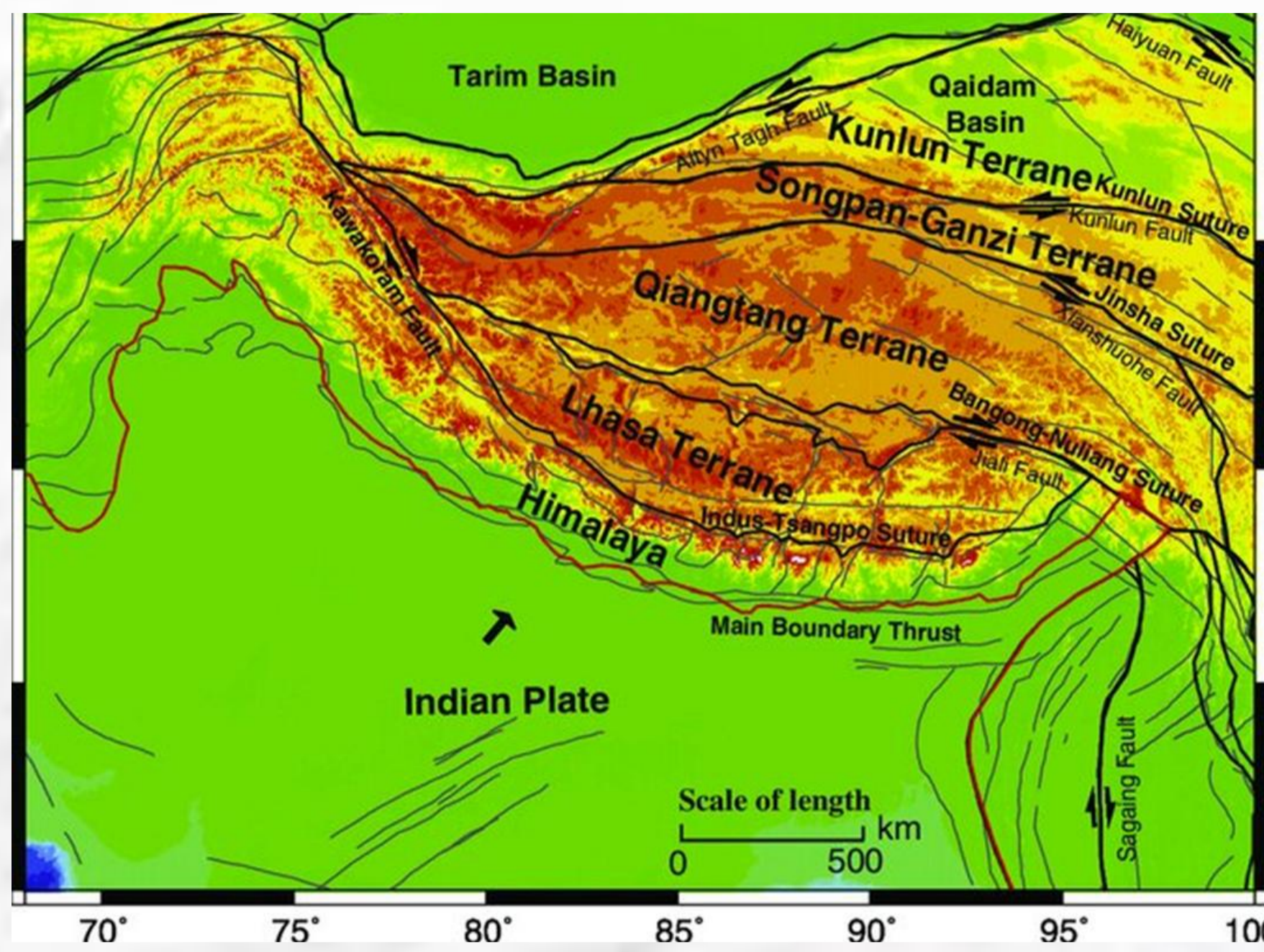


Figure 1. Tectonic map of the Himalayan-Tibetan region. Red and black lines are plate and terrane boundaries, respectively [1].

Sentinel-1 is an important mission for monitoring seismic activity on Earth with its InSAR capabilities. It is the first satellite component of the Copernicus program. The satellites perform interferometric SAR scans of the Earth's surface to create paired or multiple interferograms—images that reveal changes in the landscape over large areas with high detail. Interferograms are visualized as optical interference patterns, where light waves interact to form colorful and comprehensive maps. The colored stripes represent changes in the topography or surface of the Earth due to seismic activity, each corresponding to a 28 mm displacement. To determine the Earth's displacements, we need data from two radar images: the first taken before the event and the second after the earthquake.

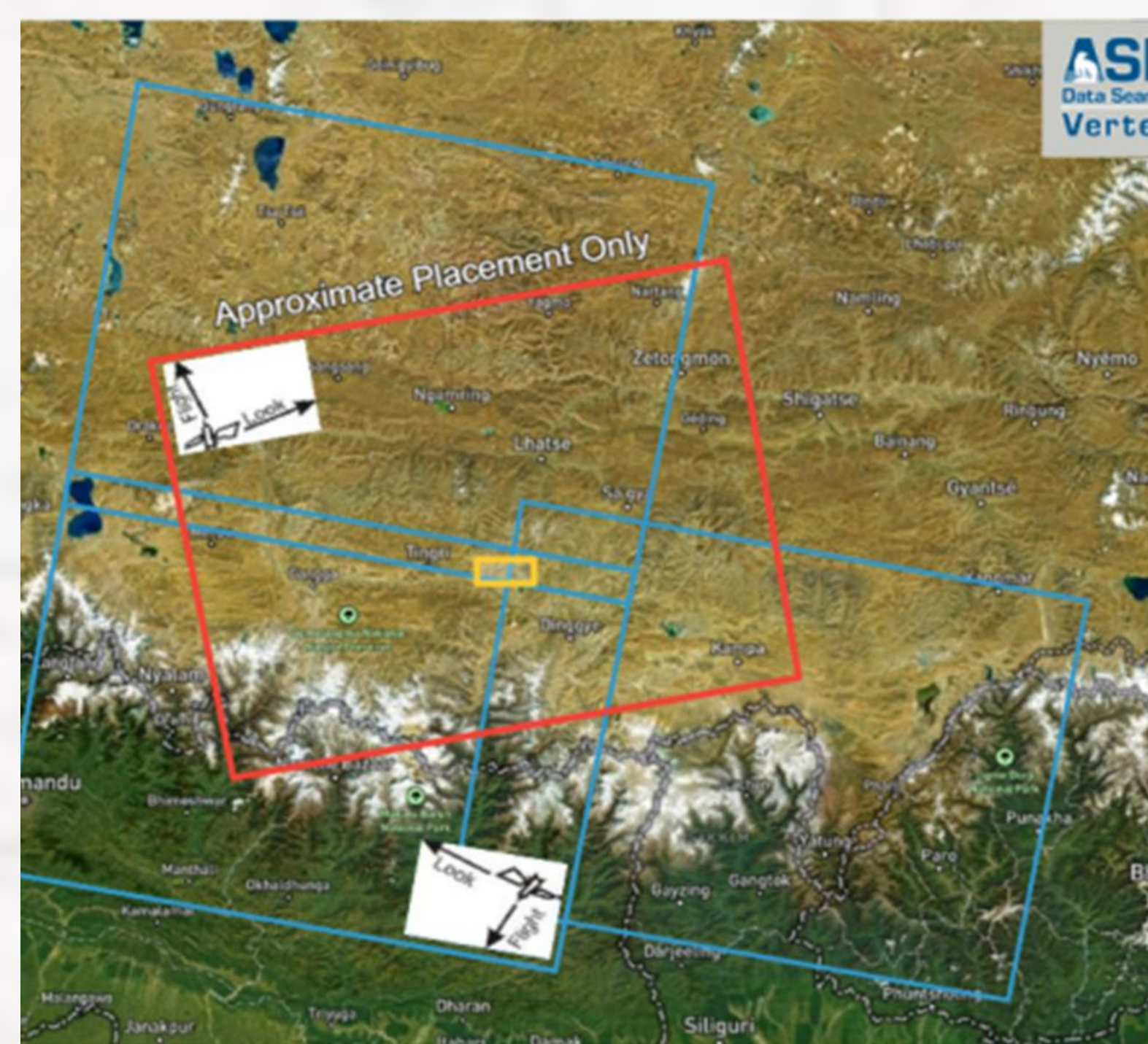


Figure 2. Satellite tracks used for earthquake analysis: ascending (red): track 12; descending (blue): tracks 48 and 121. The earthquake epicenter is marked by a yellow rectangle

To determine the displacements that occurred after the earthquake on January 7, 2025, we processed Sentinel-1 TOPS (Terrain Observation with Progressive Scans) SAR images (C-band with a radar wavelength of 5.6 cm) from two different viewing geometries. We used a total of 8 radar images, from 3 overlapping ascending and descending tracks (ascending: tracks 12; descending: tracks 48, 121) of the Sentinel-1 A satellites operated by the European Space Agency (ESA), as shown in Figure 2 and Table 1.

Table 1. Basic information of the SAR data used in this study

Sensor	Orbit Direction	Master-Slave Date	Track	Spatial Perpendicular Baseline [m]	Wavelength [cm]	Pixel Resolution [m] (Range × Azimuth)	Imaging Mode
Sentinel-1A	Descending	01.01.2025 13.01.2025	T121	15.0	5.6	2.3 × 14.0	TOPS
Sentinel-1A	Ascending	05.01.2025 17.01.2025	T12	57.0	5.6	2.3 × 14.0	TOPS

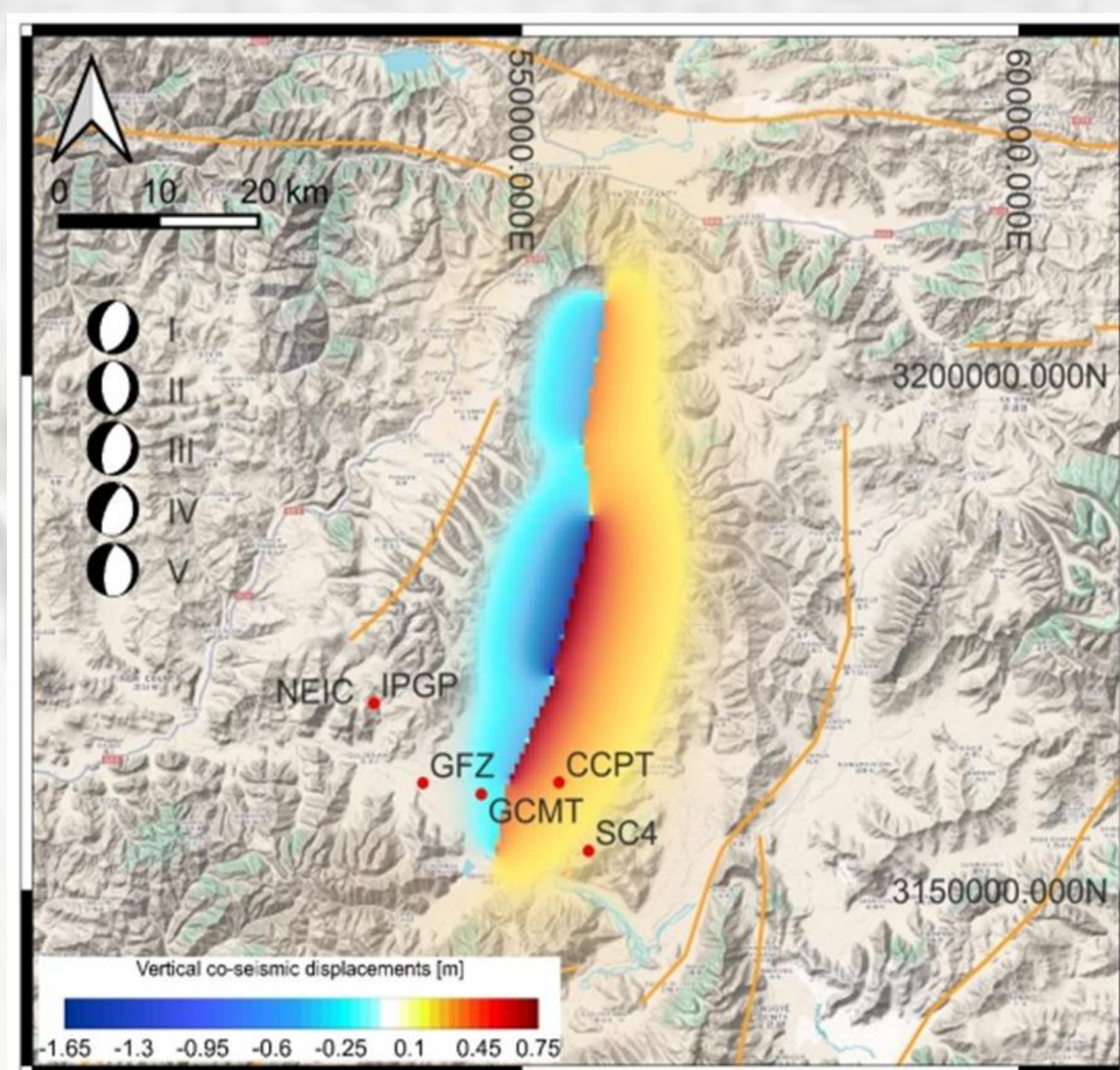


Figure 4. Coseismic displacements calculated by means of Okada model according to earthquake.

In this study, we compared and analyzed co-seismic displacements obtained from InSAR with those obtained using the Okada model. The comparison reveals valuable insights into the seismic behavior of the Tibetan Plateau, particularly in relation to the Mw 7.1 earthquake on January 7, 2025. The results indicate that the maximum uplift and maximum subsidence deformations from these two methods are comparable. Okada's model allows for precise characterization of the source geometry, enabling researchers to accurately model a wide range of seismic events and fault configurations. Additionally, the location (e.g., latitude, longitude, and depth) and geometry (length and width for rectangular source) of the seismic source significantly influence surface deformation. The Okada model interprets ground displacement data, estimates fault slip, and assesses other source parameters of the earthquake. This model has proven effective in simulating deformations caused by dip-slip earthquakes, providing a reliable tool for comparing modeled results with real geodetic observations, such as InSAR and GNSS data.

The earthquake on January 7, 2025, with a magnitude of 7.1, occurred in the southern Tibetan Plateau, north of the boundary between the Eurasian and Indian plates. The rupture occurred on a roughly north-south striking fault, dipping moderately to the east or west. The continental collision between the Indian and Eurasian plates drives the uplift of the Himalayan Mountains. The region near the India-Eurasia plate boundary has a history of large earthquakes. In the past century, there have been numerous earthquakes of magnitude 6 or greater in the region studied in relation to the January 7, 2025 earthquake.

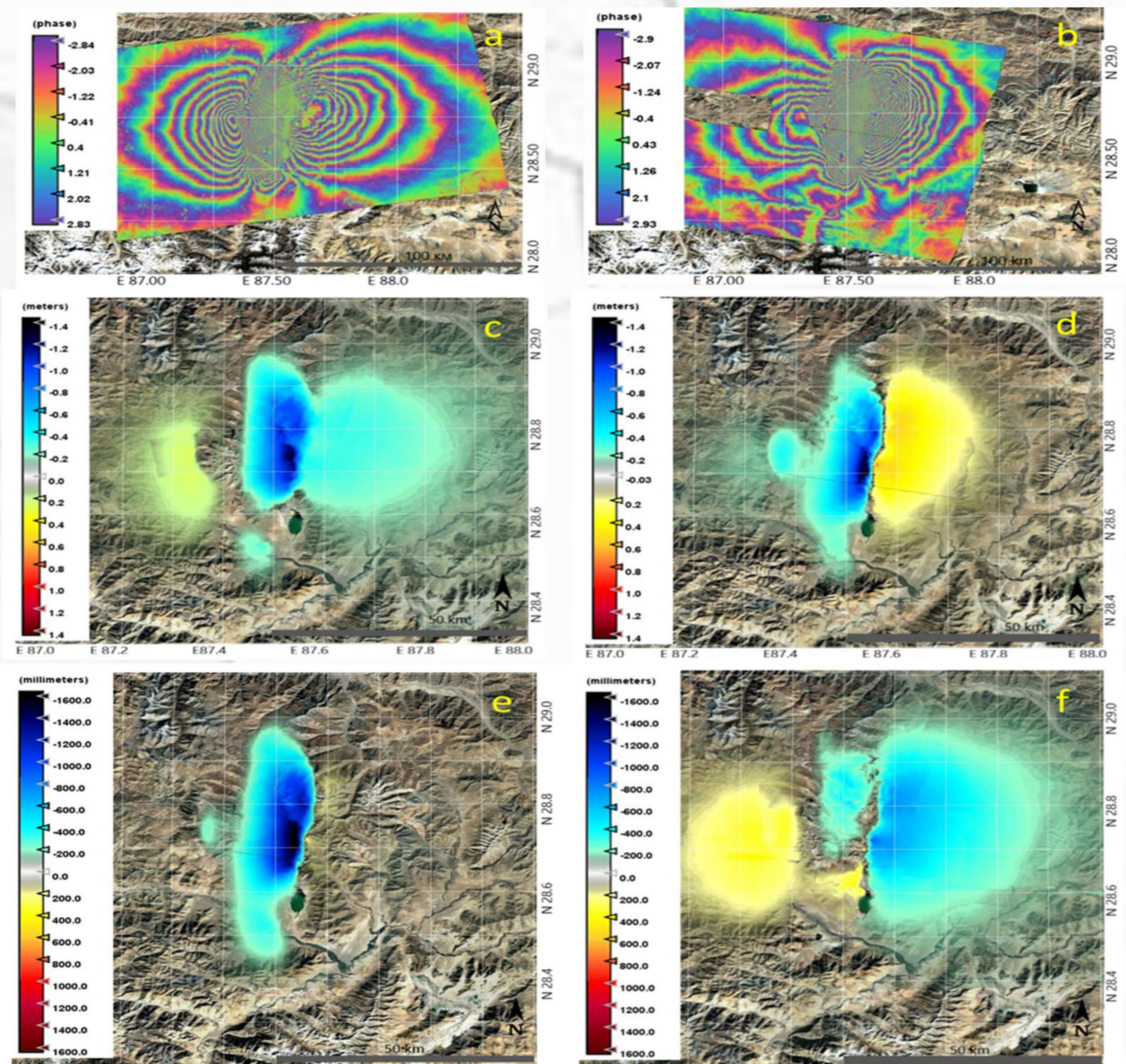
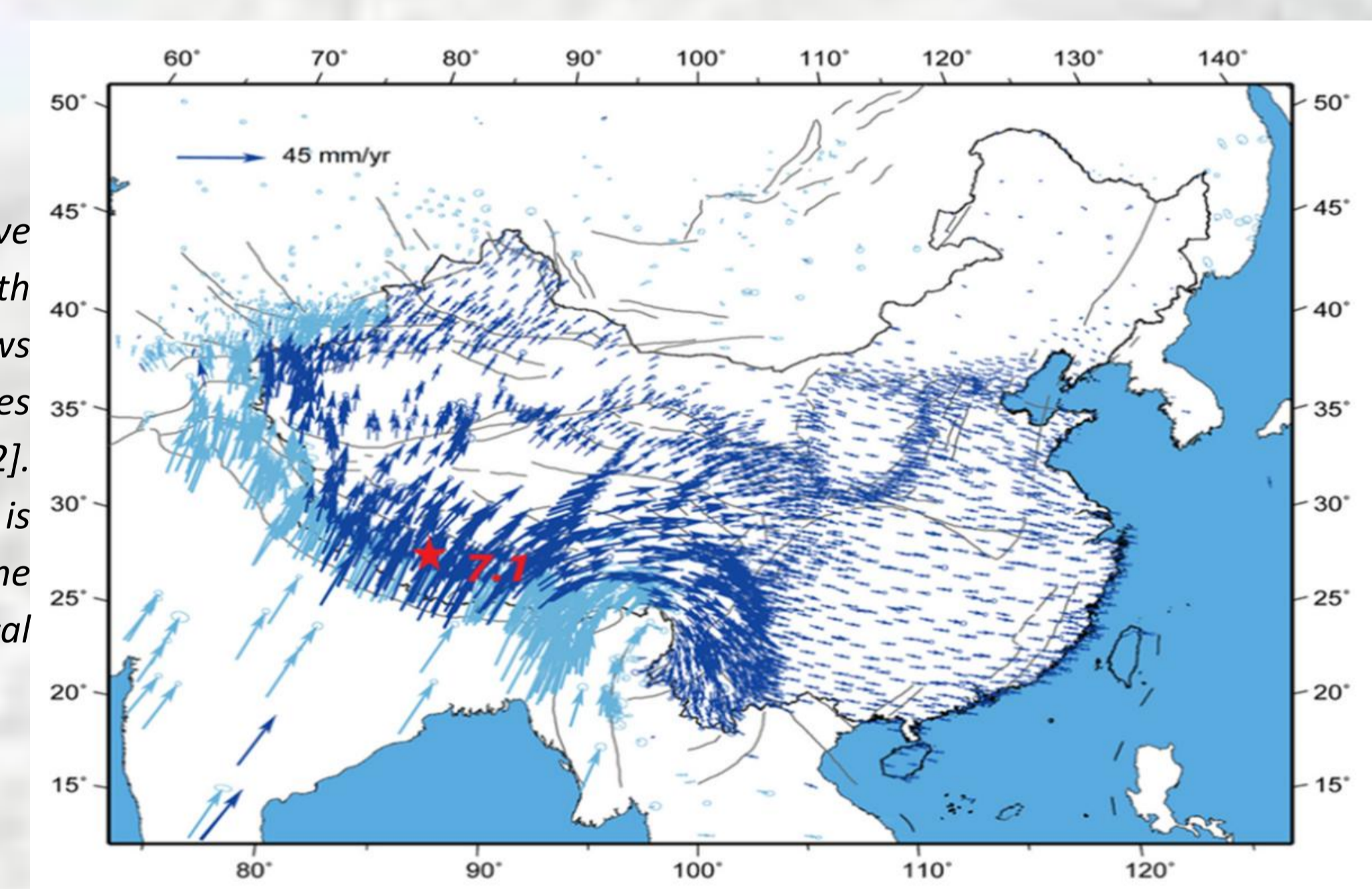


Figure 3. InSAR observations and displacement from Sentinel-1 data. (a, b) Interferogram observations from Sentinel-1 data: ascending track 12 and descending track 121. (c) SAR displacement along the LoS from ascending track 12. (d) SAR displacement along the LoS from descending track 121. (e) Vertical displacement (Up-Down) from ascending track 12 and descending track 121. (f) Horizontal displacement (W-E) from ascending track 12 and descending track 121.

The fault, including its main central segment and several faults in the S-N direction, is entirely covered by the InSAR data. We used two different models to mitigate topographic contributions to the interferometric phase DEM: Shuttle Radar Topography Mission (SRTM) 1 arc sec (~30 m resolution) digital elevation model (DEM) and Copernicus DEM (30 m resolution) digital elevation model (DEM). Following interferogram formation, we applied the Goldstein phase filter to reduce the phase noise contribution to the signal, which is well-suited for measuring tectonic deformation around active faults. The displacements along the line of sight (LOS) are then decomposed into vertical displacement and the east-west component of deformation. The earthquake and the fault are located at the boundary, exactly where eastward rotation occurs. We determined the displacement in the eastward direction, but due to the almost polar orientation of the satellite's orbit configuration, we cannot calculate the displacements in the S-N direction.

Figure 5.

GPS velocity field relative to the Eurasian plate, with deep and light blue arrows representing GPS velocities from previous studies [2]. The epicenter location is indicated according to the United States Geological Survey [3].



Conclusions

In this study, we used Sentinel-1 data and processed interferograms to visualize how the landscape was reshaped by the event. Satellite data help us understand the impact of major seismic events and also serve as a powerful reminder of how dynamic and ever-changing our planet is.

In conclusion, we recommend using the Copernicus 30-meter Global DEM for seismic studies in the region, as it proved effective in mitigating topographic contributions to the interferometric phase and improving the quality of displacement measurements.

Acknowledgments

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- [1] Bai L., Zhang T., Complex deformation pattern of the Pamir–Hindu Kush region inferred from multi-scale double-difference earthquake relocations, *Tectonophysics* Volume 638, 7 January 2015, Pages 177–184, <https://doi.org/10.1016/j.tecto.2014.11.006>
- [2] Wang M., Shen Z., Present-Day Crustal Deformation of Continental China Derived From GPS and Its Tectonic Implications. *JGR Solid Earth* 2020, 125, e2019JB018774, doi:10.1029/2019JB018774.
- [3] U.S. Geological Survey, 2025 <https://www.usgs.gov/programs/earthquake-hazards/earthquakes>.

Abstract: Our research interest is focused on detecting ground displacements after an exceptionally large number of earthquakes occurred in the Cyclades region. These were recorded as a seismic swarm of earthquakes clustered in one place, most of which had a magnitude between 3 and 5, with the strongest occurring on February 5, with a magnitude of 5.2. In active seismic regions, the analysis of InSAR ground deformation data provides a valuable tool for seismic risk assessment. In addition, InSAR data can be used to assess the consequences of the earthquake and its associated events, such as landslides, collapses, and the area of destruction. Earth displacement in the Santorini region is determined based on InSAR time-series data from the S1A satellite of the European Space Agency. SAR data from ascending orbit 29 and descending orbit 129 were used. The results of the InSAR analysis in the line-of-sight (LOS) direction of the satellite demonstrate displacement rates between master and slave. SAR images span the period January–March 2025. Tectonic structures in the region where the Santorini earthquakes occurred (Aegean plate), along with the location of the Kolumbo submarine volcano, are significant features in the area. The seismic activity that developed northeast of the island of Santorini was analyzed, and its implications were evaluated based on the available SAR data (January–March 2025).

A unique seismic sequence has been ongoing near the Cyclades Islands since January 24, 2025. The activated area is located northeast of Santorini (Fig. 1), according to the European-Mediterranean Seismological Centre (EMSC).

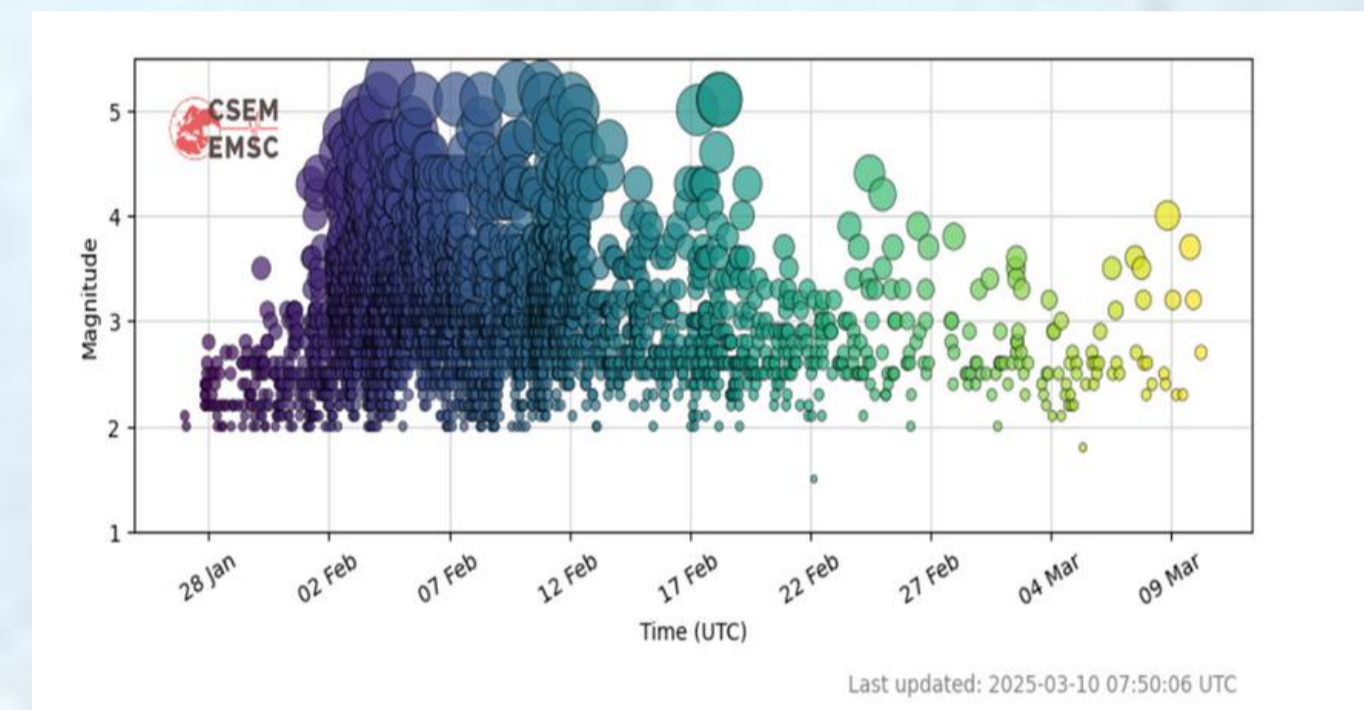
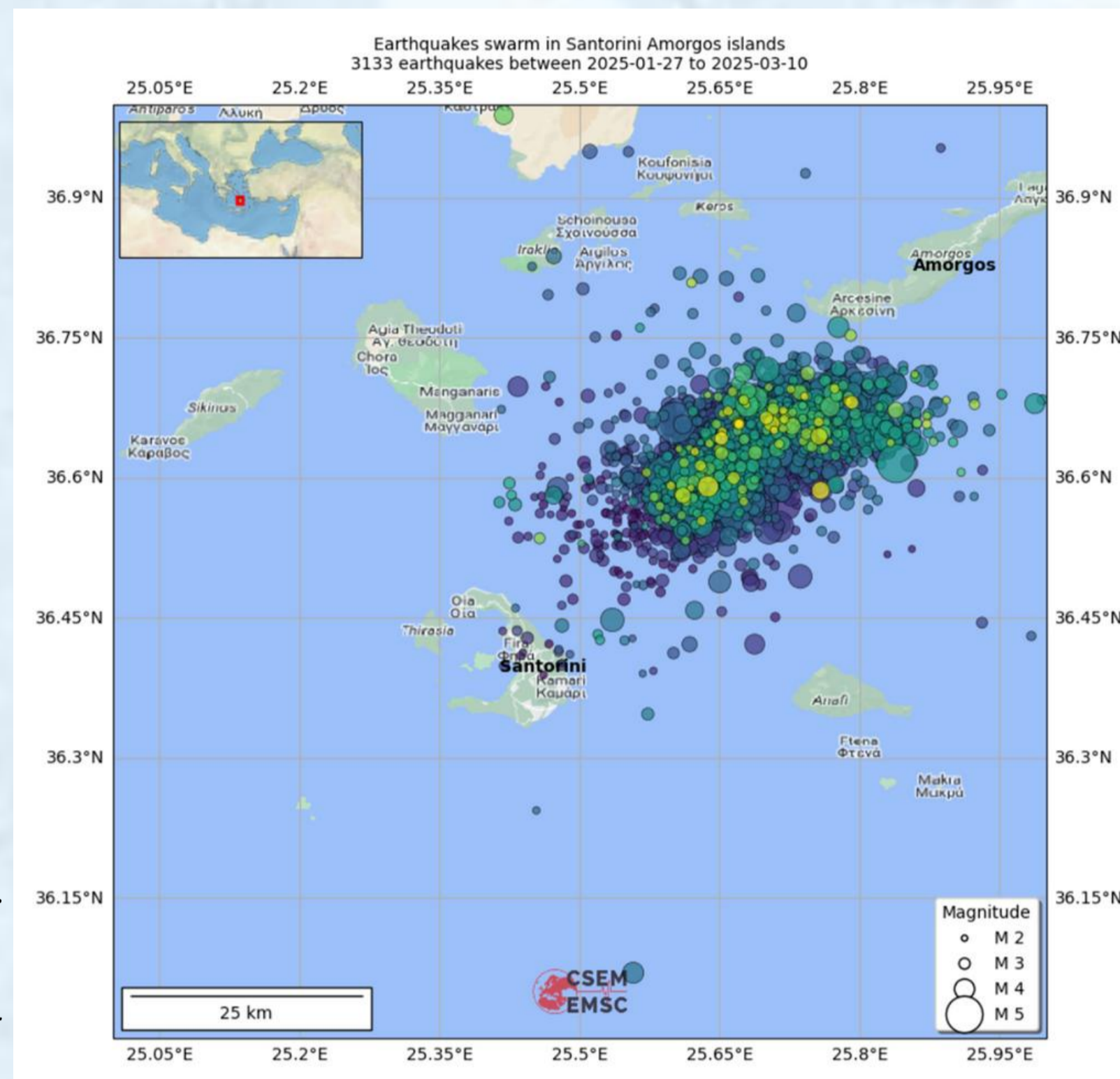


Figure 1. Spatial and temporal distribution of the seismic activity. Purple dots represent the oldest earthquakes in the series, while yellow dots represent the most recent earthquakes. The size of each dot is related to the magnitude of the earthquake. [European-Mediterranean Seismological Centre] [1].



Sentinel-1 is an important mission for monitoring seismic activity on Earth due to its InSAR capabilities. It is the first space component of the Copernicus program. The satellites perform interferometric SAR scans of the Earth's surface to create paired or multiple interferograms—images that reveal changes in the landscape over large areas with high detail. Interferograms are visualized through optical interference patterns of light that combine to form a colorful and comprehensive map. The colored stripes represent changes in the topography/surface of the Earth due to seismic activity, with each stripe corresponding to a 28 mm displacement. To determine the Earth displacements that have occurred, data from two radar images are required: one taken before the event and the other after the earthquake.

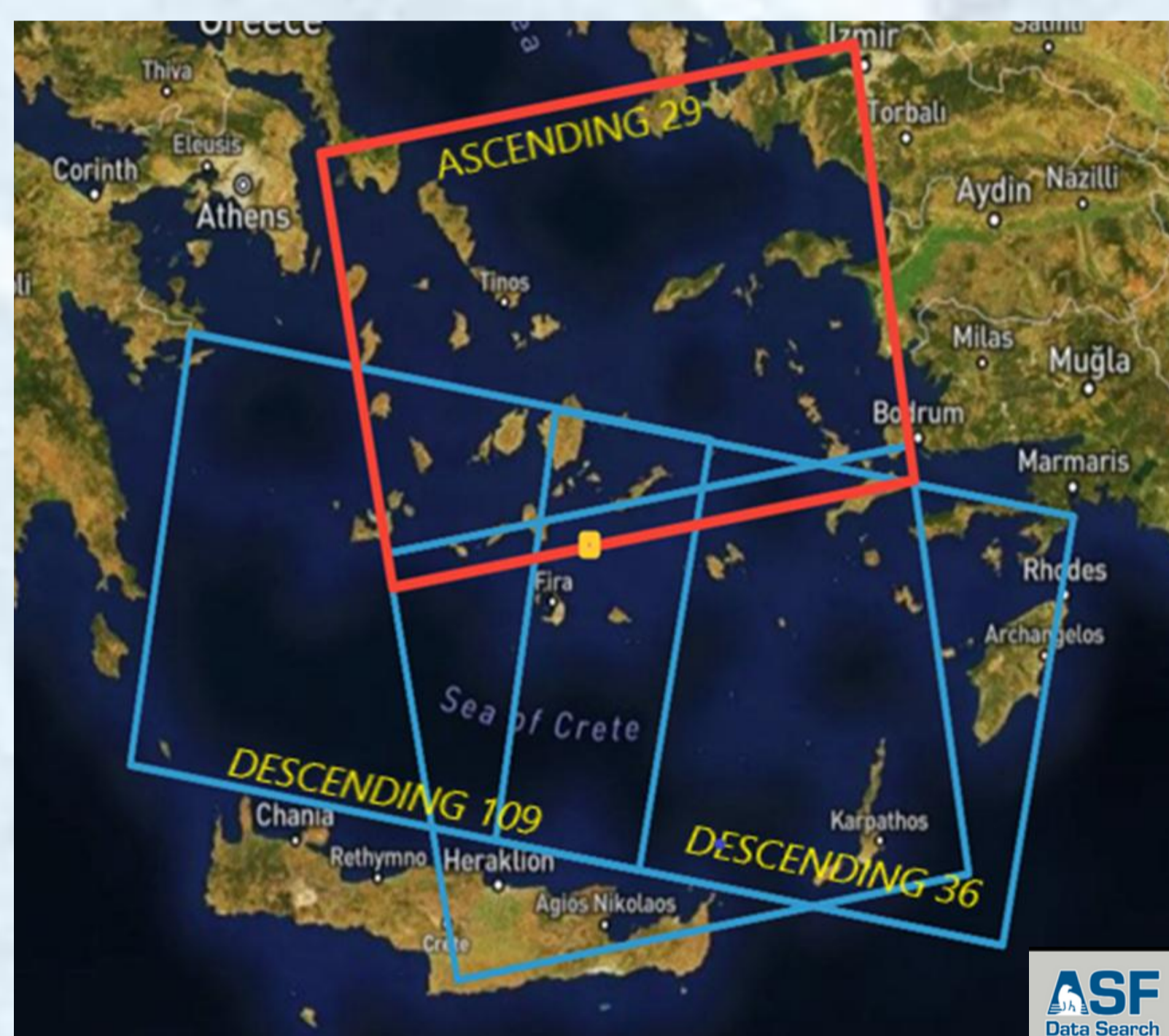


Figure 2. Satellite tracks used for earthquake analysis: ascending (red): track 29; descending (blue): tracks 109 and 36. The earthquake epicenters is marked by a yellow rectangle [2]

To detect the displacements that occurred after the earthquakes in the Cyclades region during the period from January 24 to March 7, 2025, we processed Sentinel-1 TOPS (Terrain Observation with Progressive Scans) SAR images (C-band with a radar wavelength of 5.6 cm) from two different viewing geometries. We used a total of 12 radar images from two overlapping ascending and descending tracks (ascending: track 29; descending: track 109) of the Sentinel-1A satellites operated by the European Space Agency (ESA). See Figure 2 and Table 1.

Table 1. Basic information of the SAR data used in this study

Sensor	Orbit Direction	Master-Date	Slave Date	Track	Spatial Perpend. Baseline [m]	Wavelength [cm]	Imaging Mode
Sentinel-1A	Descending	24.01.2025	05.02.2025	109	-1	5.6	TOPS
		05.02.2025	17.02.2025	109	1	5.6	TOPS
		17.02.2025	01.03.2025	109	1	5.6	TOPS
Sentinel-1A	Ascending	30.01.2025	11.02.2025	29	-49	5.6	TOPS
		11.02.2025	23.02.2025	29	-27	5.6	TOPS
		23.02.2025	07.03.2025	29	-74	5.6	TOPS

We used the DEM-Shuttle Radar Topography Mission (SRTM) 1 arc sec (~30 m resolution) digital elevation model (DEM) to mitigate topographic contributions to the interferometric phase. After interferogram formation, we applied the Goldstein phase filter to reduce phase noise contributions to the signal.

We were able to compare the interferograms we obtained with the results from VERTEX [2].

On the ASF Alaska site, there are freely available time series of interferograms processed using the GAMA software for the volcanic Nisyros area. Nisyros is a volcanic Greek island located in the Aegean Sea.

Interferograms were provided over 12 days (with a 6-day period from Sentinel-1B) starting on 01.01.2021. The area of the island of Santorini falls within the scope of the images provided to the ASF. Figures 5 and 6 present examples of interferograms from VERTEX for the same time interval for ascending orbit 29 and a very close period to our study for descending orbit 36. We took this opportunity to check our results before unwrapping the phase and obtaining the final displacements.

The SAR data provided by the Sentinel-1 ESA satellite are useful for determining the coseismic displacements in the Cyclades region. Our InSAR analysis covers the period from January 24, 2025, to March 7, 2025, and uses the InSAR time series analysis method with the SNAP software. The results of the InSAR analysis (Fig. 3 for ascending orbit; Fig. 4 for descending orbit) demonstrate displacements of up to 50 mm in the line-of-sight (LOS) direction of the satellite over a 12-day period.

Despite the large number of registered earthquakes (hundreds) over the two-month period, no major ruptures were detected, and the determined ground deformations/displacements were in the order of 2-3 cm over the 12-day period.

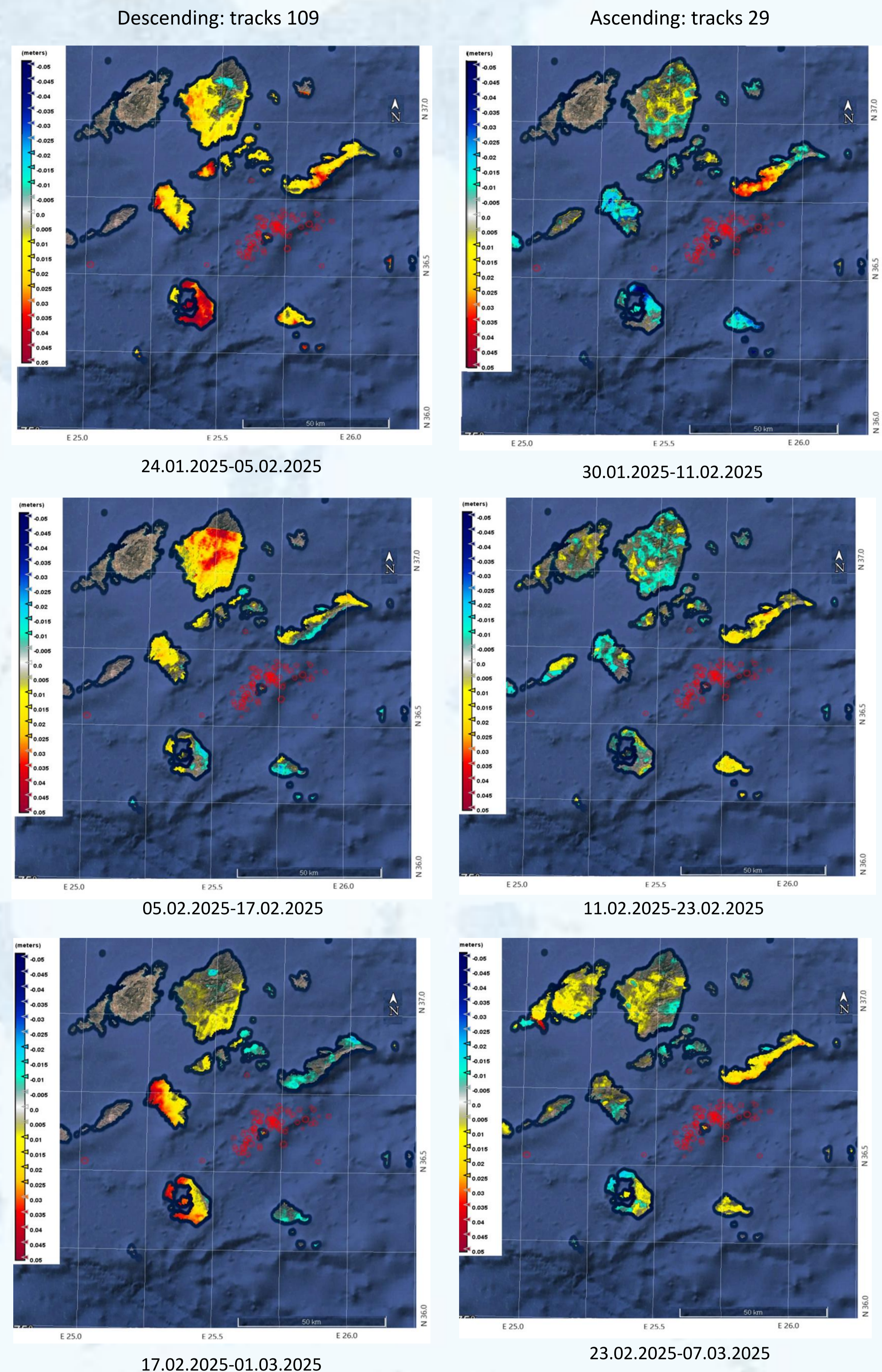


Figure 3. SAR displacement along the LoS from descending 109 track

Figure 4. SAR displacement along the LoS from ascending track 29

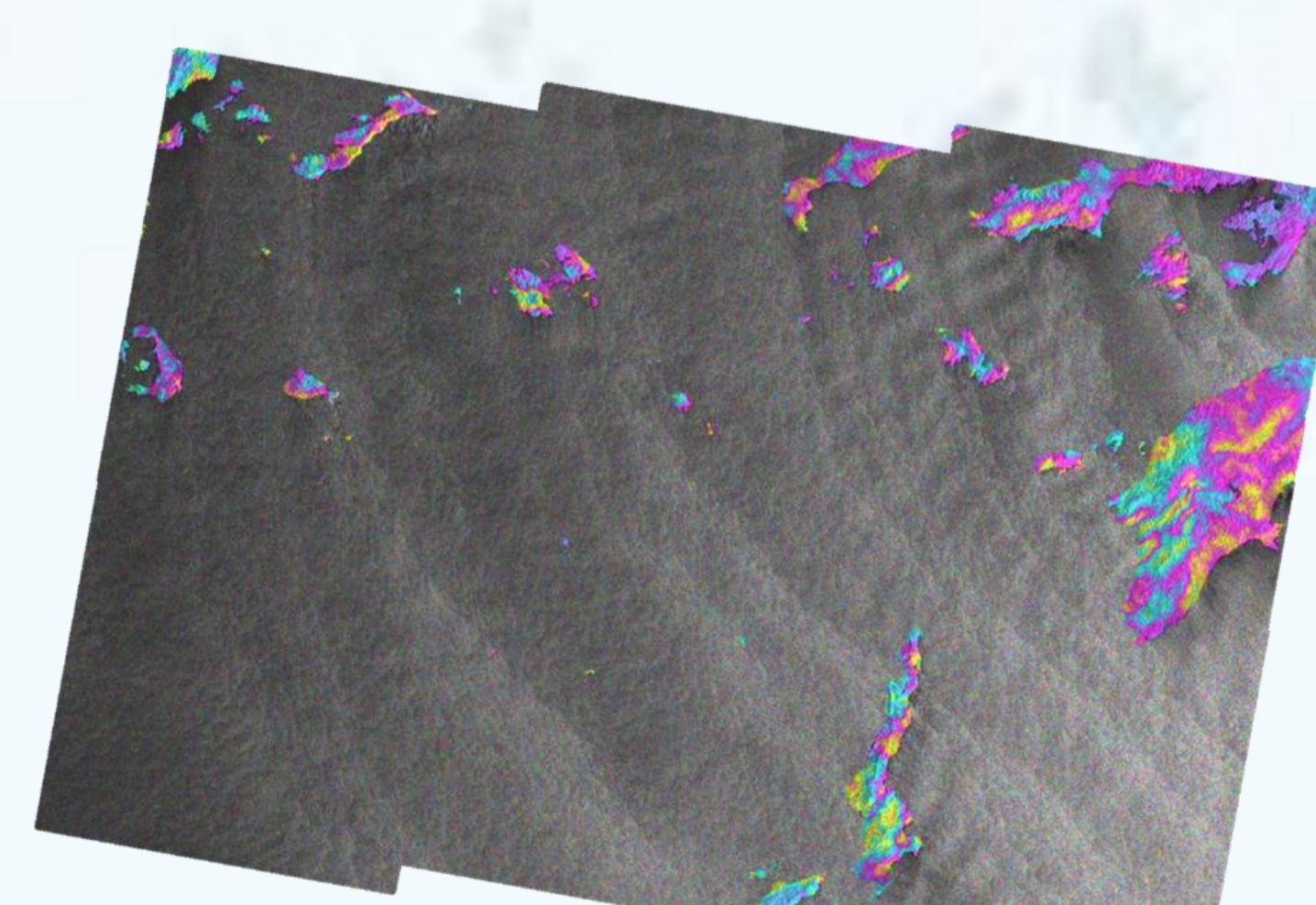


Figure 5. Interferogram 12.02-24.02.2025 Descending Path 36 Frame 472 [2]

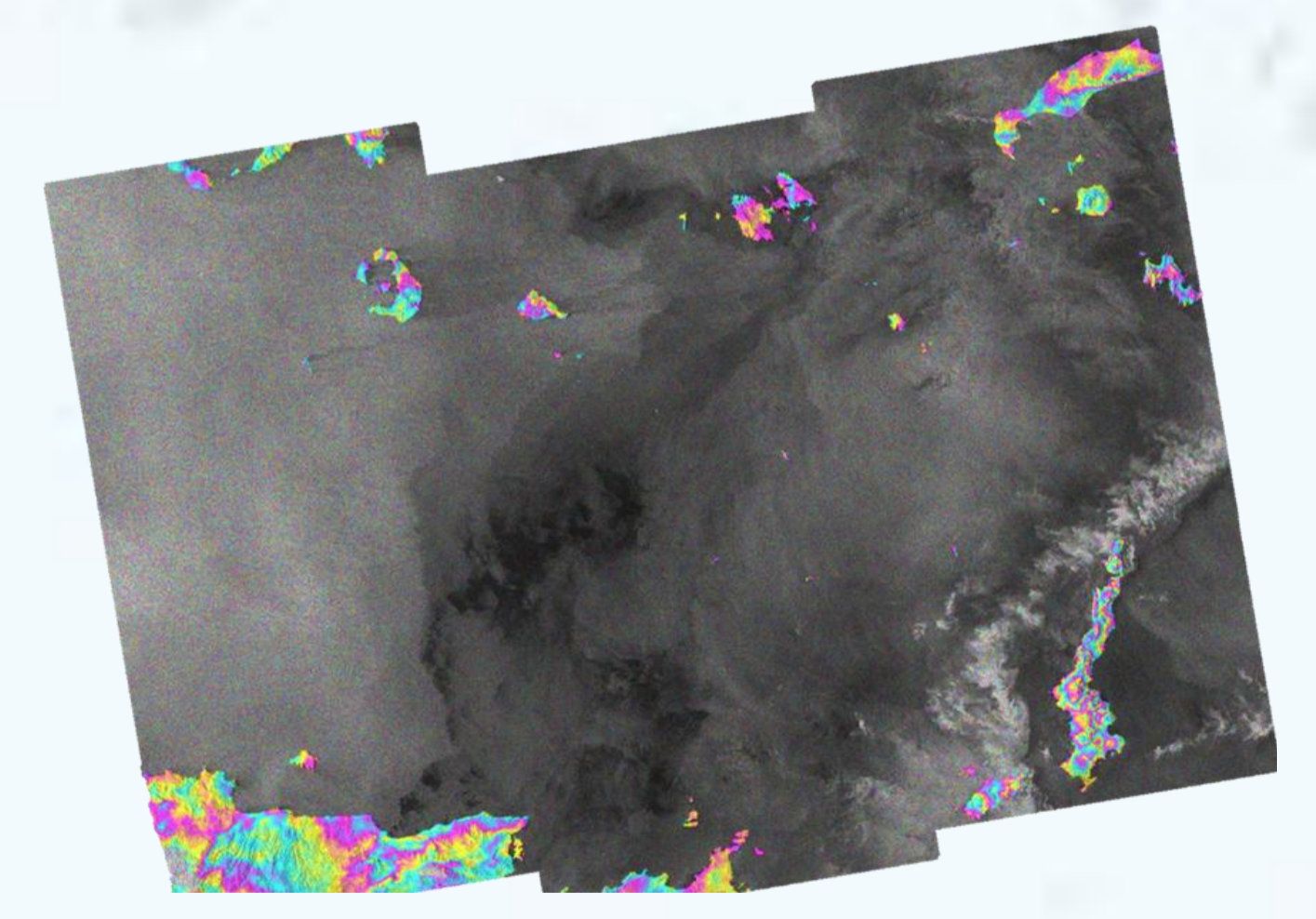


Figure 6. Interferogram 30.01-17.02.2025 Ascending Path 29 Frame 113[2]

Conclusions

The latest satellite-based radar measurements of the surface of the Cyclades island group show that deformations in the Earth's crust have not severely affected the island complex since the start of the seismic crisis about two months ago. InSAR methods demonstrate displacements between -30 to -40 mm in the line-of-sight (LOS) direction of the satellites. The findings are not yet very conclusive, and the observed deformation is still relatively weak.

Acknowledgments

The scientific results are part of the work on the project: "Study of Coseismic Deformations of the Earth's Crust for the Territory of the Balkan Peninsula Based on Satellite Data," financed by the "Competition for Financial Support of Basic Research Projects – 2023" of Bulgaria, Contract No. KP-06-N74/2 from 14.12.2023.

[1] Euro-Mediterranean Seismological Centre <https://www.emsc-csem.org/>

[2] Alaska Satellite Facility (ASF) operates the NASA archive of SAR data <https://search.asf.alaska.edu/#/>