Assessing the Impact of Burst Overlap Interferogram of Sentinel-1 TOPS on Near-Fault 3D Displacement Modelling: A Case Study of the 6th February 2023 Mw7.8 and Mw7.5 Kahramanmaraş Earthquakes, Türkiye

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1.Background

- Türkiye experienced the two biggest devastating doublet earthquakes in its modern history, with *Mw*7.8 and *Mw*7.6, on February 6, 2023.
- The earthquakes created surface ruptures over 300 km along the East Anatolian Fault (EAF) and around 150 km along the Çardak-Sürgü Fault (ÇSF) segment, respectively.
- Such ruptures leading to big phase gradients pose challenges for standard interferograms in detecting the total displacement and tracking surface ruptures in near fields.
- Second, InSAR measurements are not sensitive to the along-track (~North-South) component of the total displacement.
- We utilized Double Difference Interferometry to overcome these obstacles, exploiting burst and subswath overlaps to extract along-track displacement more accurately and enhance the 3D displacement fields for the earthquakes that struck Kahramanmaraş on February 6th.

2.Subswath and Burst Overlap Interferometry (SBOI)

- Double Difference Interferometry leverages the spectral diversities within the burst overlap regions of Sentinel-1 TOPS acquisition mode [1].
- The method is commonly used in coregisteration step of TOPS mode for stationary scenes, also known as Enhanced Spectral Diversity [2].
- For nonstarionary scenarios, the method is sensitive to displacements in the along-track (azimuth) direction since range direction is cancelled out by double differencing [3].
- Subswath overlaps can be also exploited for double differencing to observe along-track displacement, with different sensitivity levels, which we call as SBOI.

	BOI	SBOI_Backward	SBOI_Forward
ΔfDC (Hz)	~4500	2695	~1435
Scale Factor (m/π)	0.244	0.385	0.735
Phase Ambiguity (m)	0.766	1.210	2.310

Table: Comparison spectral seperation and ambiguity band of overlap regions of S-1 TOPS mode.

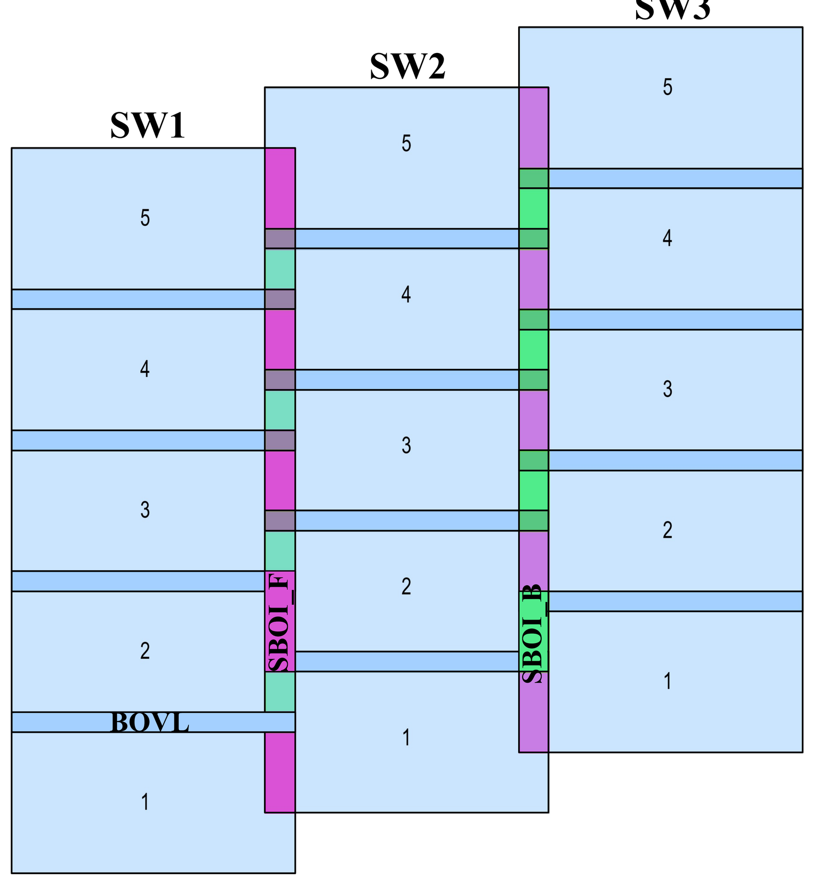


Figure: Overlap regions of burst windows. Dark blues show burst-overlap regions, pink areas are forward-subswath overlap regions and green's are backward-subswath overlap regions.

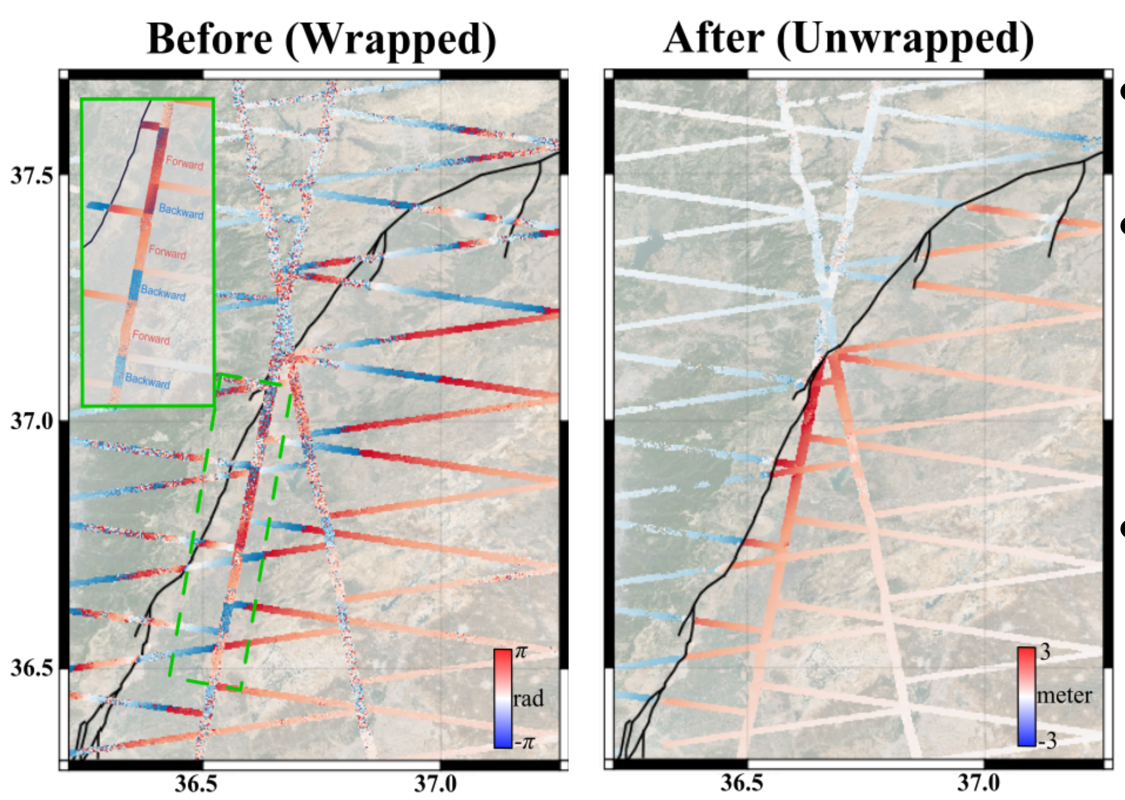


Figure: SBOI dataset before and after unwrapping.

- SBOI are generated through GAMMA Sofware.
- The scaling of phase to displacement changes significantly in azimuth direction, therefore scaling factor is calculated on a pixel-by-pixel basis.
- The wrapped SBOIs unwrapped through Azimuth Offset Tracking (AOT) [4].

3. Coherence Investigation

- After the earthquakes, snowfall occurred around the earthquake region (mostly northern part), leading to decrease in coherence.
- The coherence matrix of the ascending (014A) and descending (021D) frames helps us to observe the effect of snowfall on different Area of Interest (AOI).
- This analysis facilitates the selection of the optimal SBOI pairs by optimizing coseismic coherence.

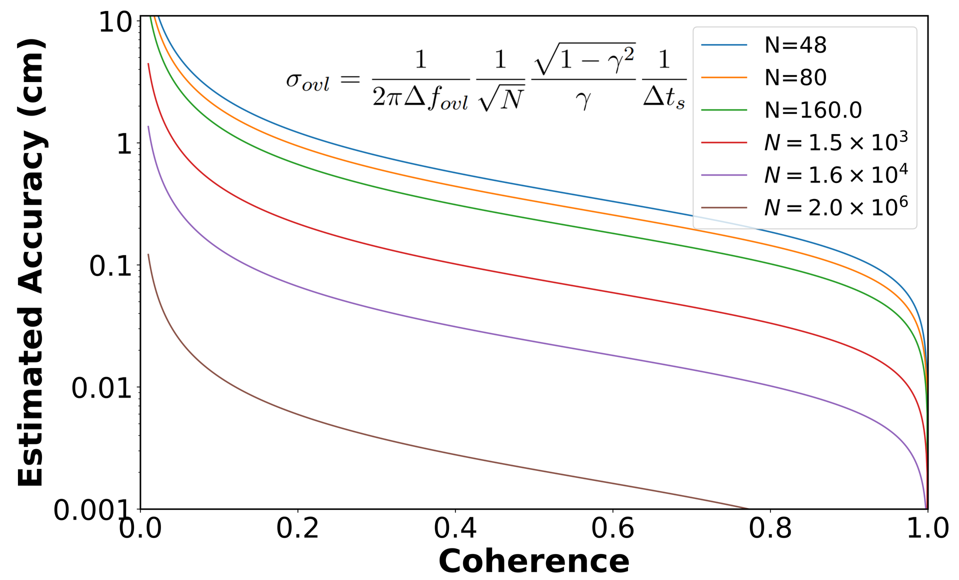


Figure: Estimated accuracy of ESD. The accuracy depends on coherence and number of looks.

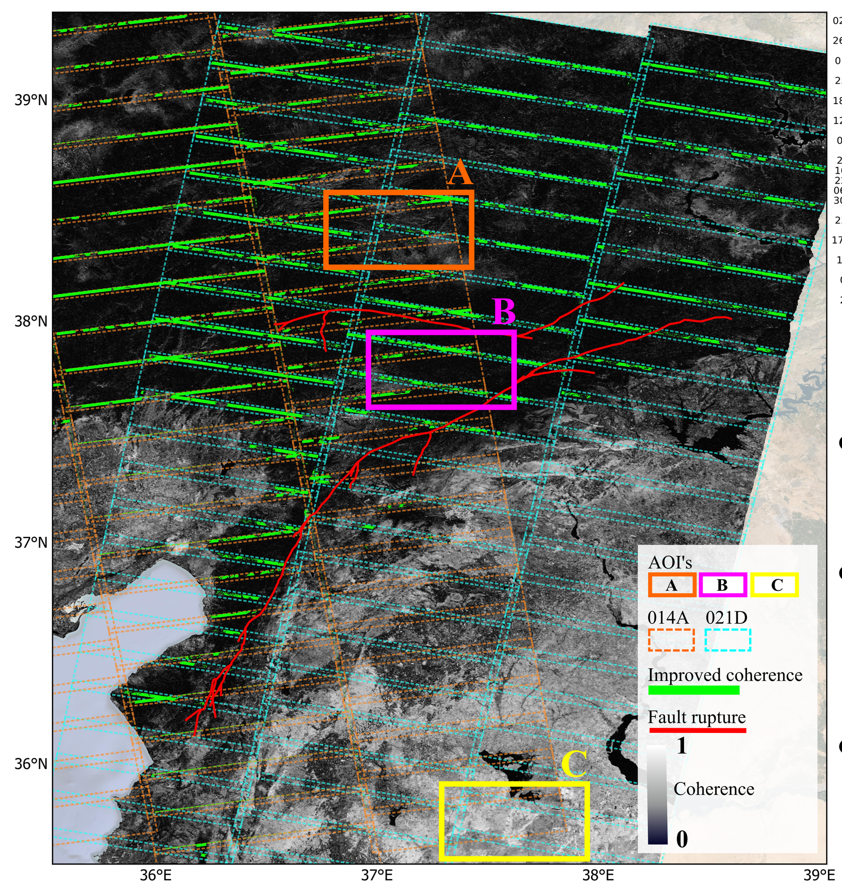


Figure: Coherence map of 021D and 014A frames: Solid rectangles represent AOIs, dashed rectangles denote the frame traces, and the red lines indicate the fault ruptures.

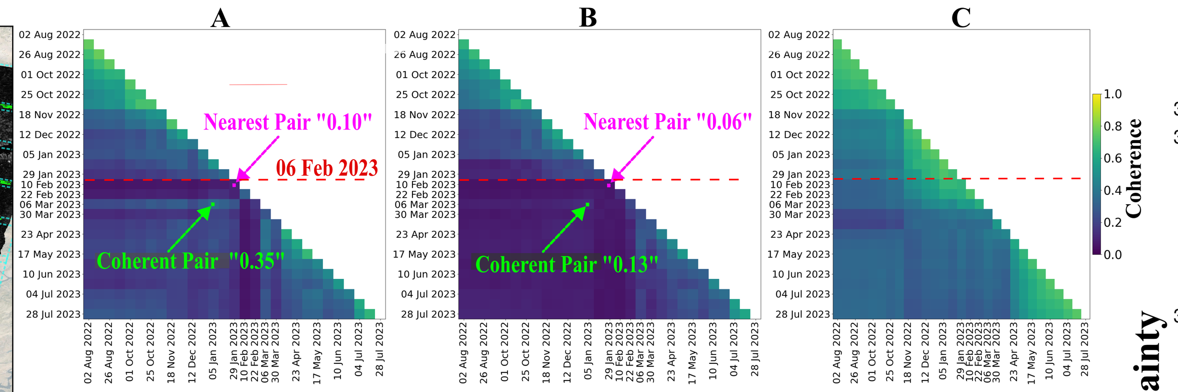
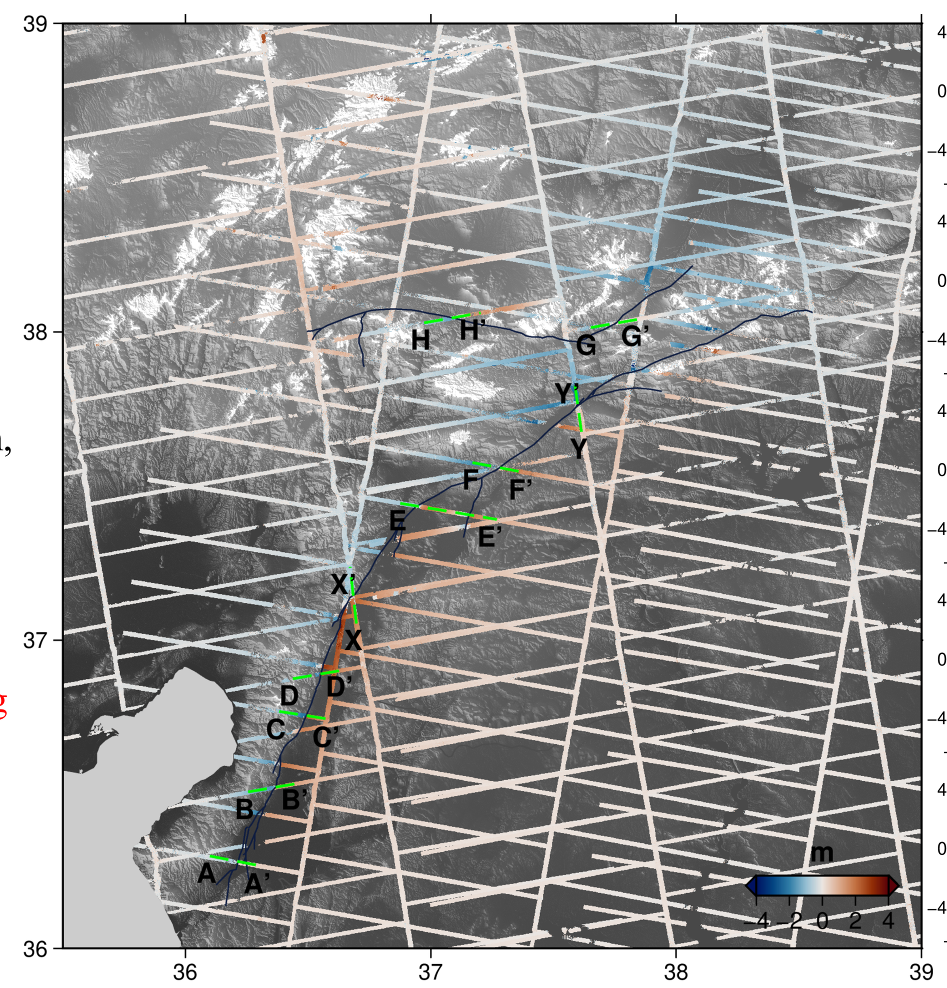
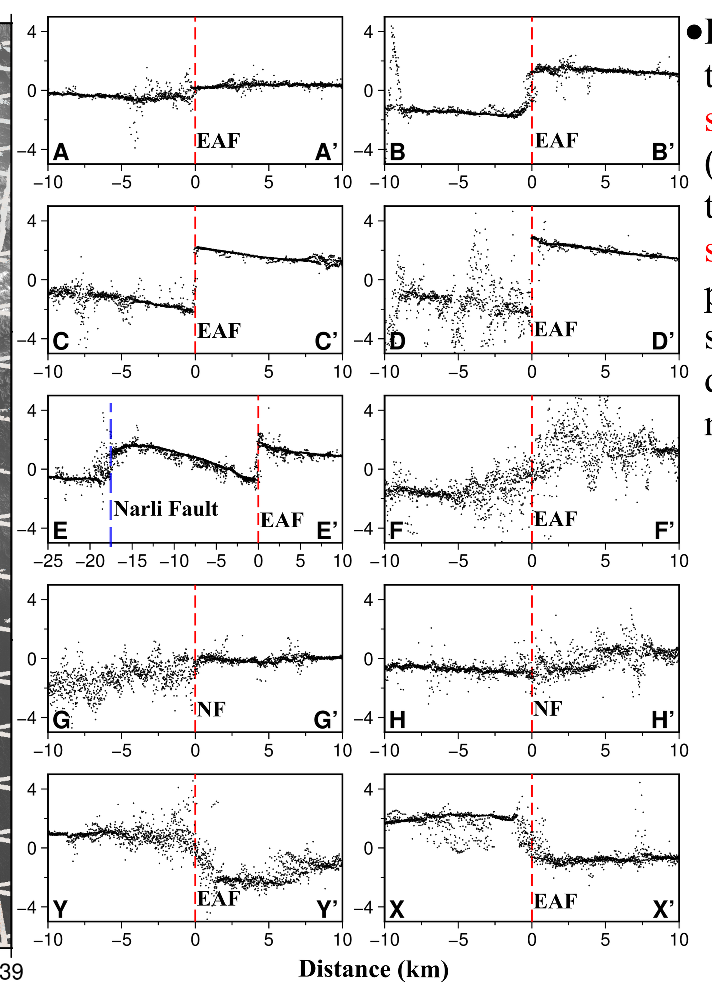


Figure: Coherence matrix of AoI's of 021D frame.

- Snowfall significantly impacted coherence in the northern part and near fault zones, with the far southern part remaining unaffected.
- After snowmelt, coherence in the northern region returned to normal, while the near fault zone continued to exhibit low coherence due to the earthquakes damage.
- For the 021D (dashed turquoise), the pair of 2023-01-05/2023-03-06 exhibits higher coherence, while the optimal coherence is at pair of 2023-01-28/2023-03-05 for the 014A (dashed orange).
- Refined coherent SBOI illustrated as green color in the left figure, which indicate ~35% refinement compared to the nearest epochs.

4. Profiles Along the Near Fault





- Profile samples near the fault indicate that sharp cut-off profiles (C and D) imply that the slip reaches the surface, while smoother profiles (A and B) suggest a zone of more distributed deformation near the surface.

Figure: (Left) N-S displacement from SBOIs after 3D decomposition: Red color indicates the northward motion, while blue shows southward motion. Green dash lines represent profile examples, while white-black background is the DEM. (Rigth) Profile examples within the SBOIs along the EAF and ÇSF.

5. 3-D Displacement Field, Strain and Slip

- We utilized SBOI's with Range Offset Tracking (ROT) from two ascending frames (014A, 116A) and two descending (021D, 123D) frames to generate 100 m resolution 3D displacements, with associted uncertainties.

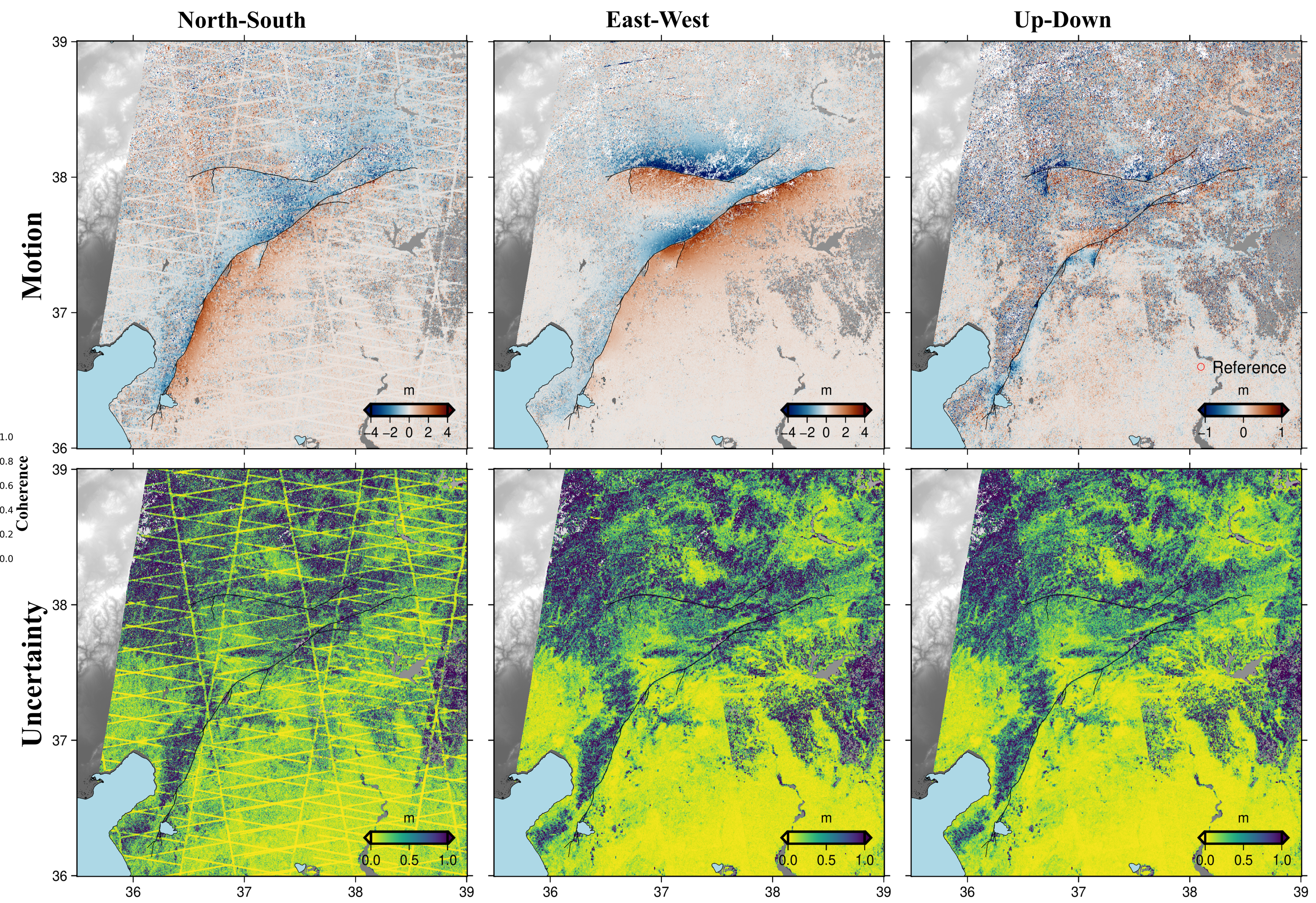


Figure: 3-D deformation map and its uncertainties from ROT, SBOI within overlap regions and AOT outside of the overlaps.

- Uncertainties of the 3D show that the uncertainty of northward component is improved where SBOIs are available. Within the overlaps, the mean uncertainty is ~ 0.11, while it reaches ~ 0.26 outside of the overlaps.

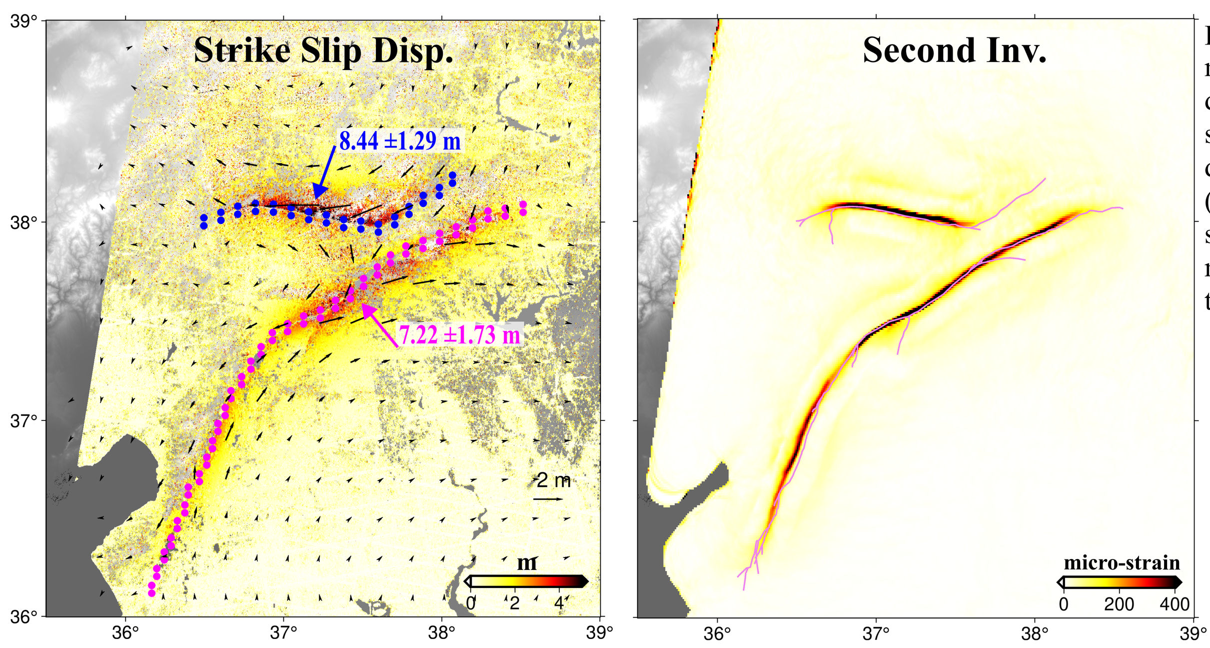


Figure: (Left) Strike-slip displacement map: Arrows indicate horizontal displacement, while colors represent strike slip displacement. Blue and red dot pairs illustrate slip profile samples. (Right) Second invariant derived from slip displacement: A magenta line marks the fault rupture as identified by the USGS.

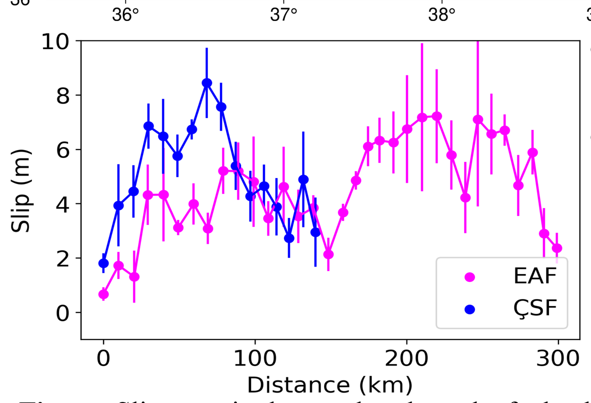


Figure: Slip magnitude samples along the faults: blues indicate the samples on ÇSF, while reds show the samples along the EAF.

- Strike-slip calculated from east and north displacements.
- The second invariant of the slip was calculated from a 30km median-filtered displacement map to highlight the fault rupture, by utilizing the SBOI dataset for this study.
- The samples along the faults show that the slip reach the 8.44±1.29m on ÇSF, while the peak slip is 7.22±1.73m on EAF.

6. Outlook and Conclusions

- SBOI provides precise along-track displacement, effectively addressing a current major drawback of InSAR.
- It also facilitates the use of subswath overlaps, expanding the coverage area beyond that of burst overlaps.
- The coherence matrix of different AOIs can help observe non-tectonic effects, such as snowfall, on the coseismic coherence, thereby enabling the extraction of more robust phase information in both the near and far field.
- Furthermore, SBOI contributes to enhancements in 3-D displacement maps and slip magnitude, alongside improvements in N-S displacement profiles in the near fault zone.

References

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