

SCEC Project #25141: Leveraging operational OPERA DISP-S1 product archive to expand and refine time-series InSAR analysis in support of the Community Geodetic Model

Final Report

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Abstract

Over the course of our proposed efforts under SCEC the past several years, we have worked to bridge the gap between research-grade InSAR archives and operational geodetic monitoring for the California plate boundary. While the project initiates the transition to NASA's Observational Products for End-Users from Remote Sensing Analysis (OPERA) Surface Displacement from Sentinel-1 (DISP-S1) product operational product archive, the primary scientific focus of the past year has been the completion of a statewide surface velocity map derived from the 2014–2023 standardized Advanced Rapid Imaging and Analysis Sentinel-1 Geocoded Unwrapped Phase products (ARIA-S1-GUNW) archive. This work, detailed in a soon-to-be-submitted publication (Sangha et al., 2026), provides a high-resolution (90-meter) geodetic baseline that captures interseismic strain, shallow fault creep, and anthropogenic subsidence. We present results across nine Sentinel-1 tracks, validated against GNSS observations, and highlight localized deformation dynamics in the Los Angeles Basin and Central California. These findings provide the essential benchmark for ongoing efforts to integrate operational OPERA products into the SCEC Community Geodetic Model (CGM).

Project Objectives

We work to facilitate the expansion and refinement of time-series InSAR analysis in support of the CGM by leveraging new operational data streams. Specifically, the project aims to:

1. **Baseline Establishment:** Finalize the statewide velocity field using the comprehensive 2014–2023 ARIA-S1-GUNW archive to provide a consensus geodetic reference.
2. **Operational Transition:** Ingest and validate provisional and operational Level-3 Surface Displacement products (DISP-S1) from the NASA OPERA project.
3. **Community Integration:** Align relative InSAR line-of-sight (LOS) observations to the terrestrial reference frame defined by the GNSS Network of the Americas (NOTA) to support CGM updates.

Previous Year Findings

As a continuation of a multi-year effort, this project focused on the initial ingestion of provisional OPERA DISP-S1 products. Key findings included:

- **Workflow Refinement:** We successfully adapted existing ARIA-tools (<https://github.com/aria-tools/ARIA-tools>) and MintPy (<https://github.com/insarlab/MintPy>) workflows to handle the 30-meter spatial resolution and HDF5 format of the DISP-S1 products.
- **Central California Validation:** Preliminary time-series analyses in Central California confirmed that DISP-S1 velocity estimates are consistent with tectonic expectations, resolving horizontal motions of the San Andreas Fault (SAF) and rapid subsidence in the San Joaquin Valley.
- **Stakeholder Engagement:** Developments were shared with academic and federal stakeholders through OPERA Stakeholder Engagement Program (SEP) meetings, establishing a collaborative framework for the March 2025 official product release. In addition, our efforts and developments were highlighted at the annual OPERA SEP workshop in September 2025.

Methodology

Our approach utilizes standardized InSAR products to ensure scalability and reproducibility. For the 2014–2023 statewide analysis, we processed the full archive of ARIA-S1-GUNW products across nine tracks.

- **Time-Series Analysis:** We employed the Miami INsar Time-series software in Python (MintPy) to estimate LOS velocities. The modeling includes long-term linear trends, annual/semiannual seasonal fits, and Heaviside step functions to account for coseismic offsets from major events (e.g., 2019 Ridgecrest, 2020 Monte Cristo Range, and 2021 Antelope Valley).
- **Corrections:** Tropospheric noise was mitigated using weather-model-based corrections derived from the ERA5 model via PyAPS.
- **Validation:** InSAR velocities were validated using a "double-difference" method against NOTA GNSS observations, ensuring the results meet the accuracy requirements for CGM integration.

Ongoing work is currently applying these validated methods to the operational OPERA DISP-S1 archive, which utilizes a hybrid Persistent Scatterer and Distributed Scatterer (PS/DS) approach to maintain higher coherence in challenging terrains (Staniewicz et al., 2026).

Results and Significance

Statewide Surface Velocity

The 2014–2023 ARIA analysis resulted in a seamless statewide LOS velocity mosaic (**Figure 1**). This map reveals the broad right-lateral shear gradient associated with the Pacific-North American plate boundary. Validation against GNSS shows millimeter-per-year agreement after tropospheric correction,

with typical uncertainties of ≤ 1 mm/yr in coherent regions. The significance of this result lies in its ability to fill the spatial gaps of the GNSS network, providing a continuous view of strain accumulation across the entire San Andreas Fault System (SAFS).

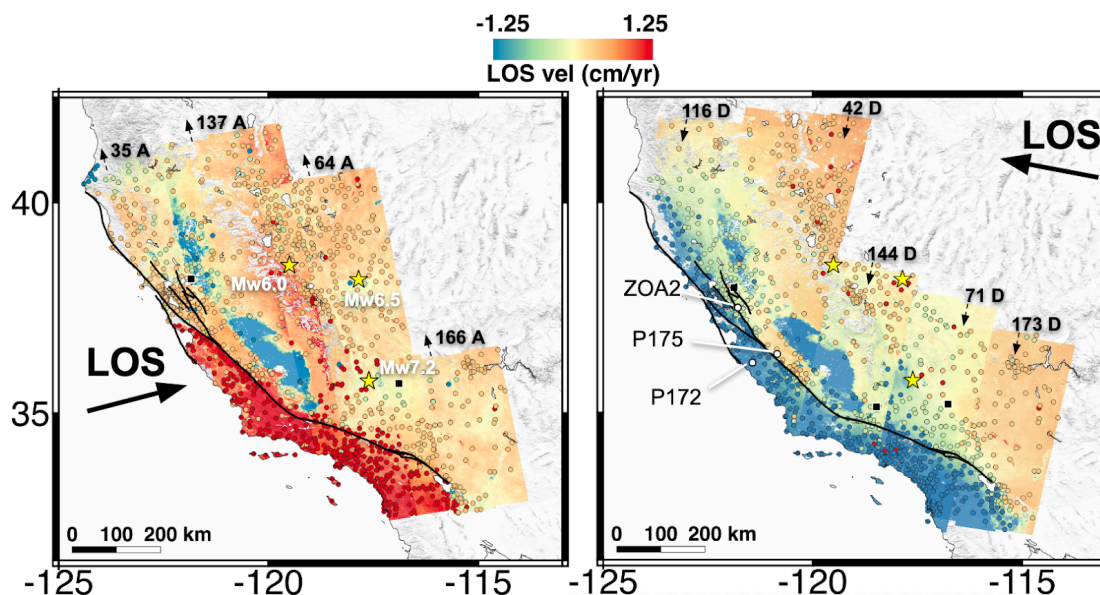


Figure 1. Mosaic of line-of-sight (LOS) surface velocities from ARIA-S1-GUNW InSAR products spanning 2015–2023. Velocities are estimated assuming a linear rate for each Sentinel-1 track (dashed arrows), corrected for tropospheric noise using weather-model-based corrections, and referenced to a local GNSS station (black squares). Additional GNSS sites used for comparison are shown as colored markers, with rates estimated over the same time span as the InSAR data. Positive values denote motion of the ground toward the satellite. Coseismic events (yellow stars) are included in the time-series modeling, with the long-term interseismic velocity assumed to remain consistent before and after each event. Traces of major faults (black lines) are from the U.S. Geological Survey (2025a). Background hillshade is from the USGS Shaded Relief Only basemap (U.S. Geological Survey, 2025b), and coastlines and waterbody boundaries are from the National Oceanic and Atmospheric Administration (NOAA) shoreline/coastline database (2025b). General agreement is observed between ascending and descending tracks, with LOS rates consistent with GNSS estimates. Minor discontinuities in overlap regions are primarily attributed to differences in viewing geometry between near- and far-range acquisitions.

Regional Dynamics in the Los Angeles Basin

High-resolution analysis in the LA Basin (**Figure 2**) distinguishes between complex overlapping signals.

- **Anthropogenic Activity:** We identify clear subsidence signals collocated with the Wilmington and Long Beach oil fields, as well as seasonal groundwater-related fluctuations in the Santa Ana coastal basins.
- **Landslide Monitoring:** Reversals in signal sign between ascending and descending geometries identify the horizontal creeping motions of the Portuguese Bend landslide. These results demonstrate InSAR's utility for urban infrastructure monitoring and hazard assessment, providing critical data for local stakeholder response.

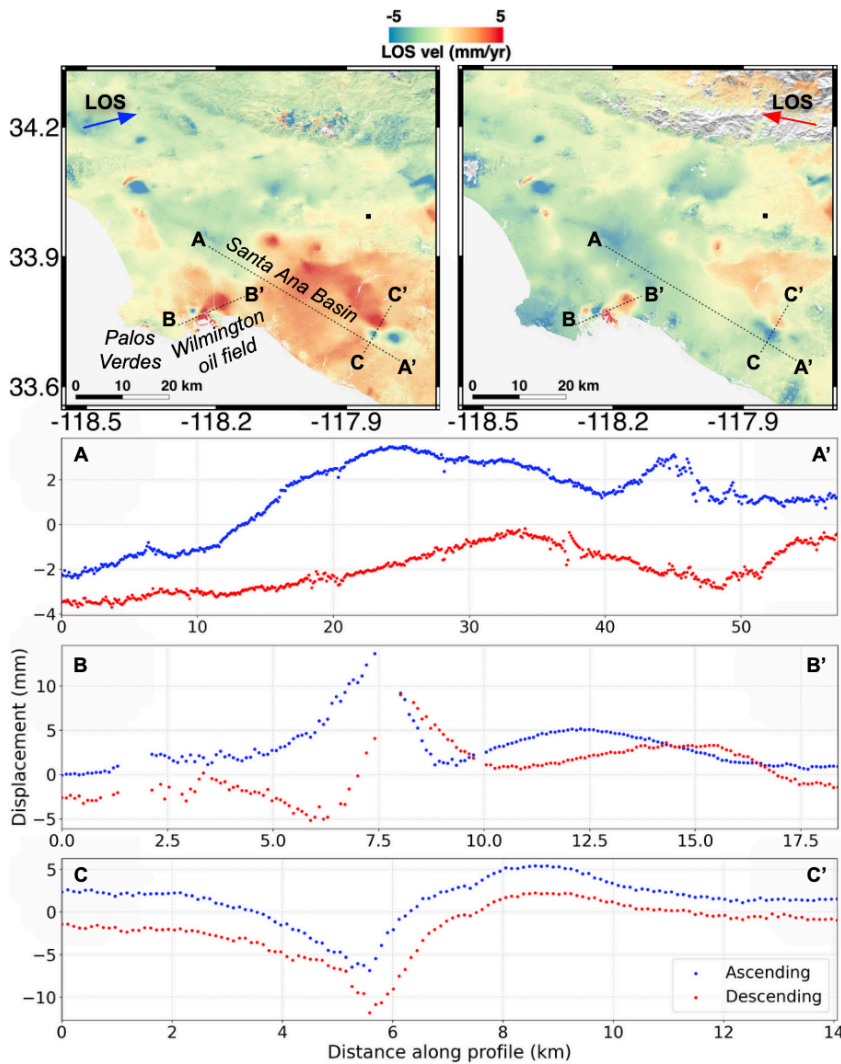


Figure 2: (Top) LOS surface velocities across the greater Los Angeles Basin derived from Sentinel-1 ascending track 64 and descending track 71. (Bottom) Cross-sectional velocity profiles extracted along the transects denoted on the maps. Profile A–A' spans the Santa Ana Basin, B–B' crosses the Wilmington oil field near Long Beach, and C–C' traverses the southern Santa Ana Basin near groundwater wells examined by Bawden et al. (2001). Opposite-sign velocities between ascending and descending geometries across the Santa Ana Basin indicate deformation dominated by vertical motion, while localized signals near Wilmington highlight anthropogenic deformation associated with hydrocarbon extraction. These observations are broadly consistent with earlier InSAR studies of deformation in the Los Angeles Basin (e.g., Bawden et al., 2001).

Tectonic Kinematics in Central California

Central California analysis (**Figure 3**) highlights the diverse behavior of the SAF.

- **Creep vs. Locked Segments:** Velocity profiles across the central SAF reveal a sharp discontinuity at the surface trace, indicative of shallow creep. In contrast, southern segments exhibit the broad arctangent gradient characteristic of elastic strain accumulation on a locked fault.
- **Extreme Subsidence:** The San Joaquin Valley continues to exhibit the highest deformation rates in the state, with subsidence exceeding 10 cm/yr due to groundwater extraction. Capturing these varying fault behaviors within a single geodetic framework is essential for refining seismic hazard models and understanding the long-term evolution of the plate boundary.

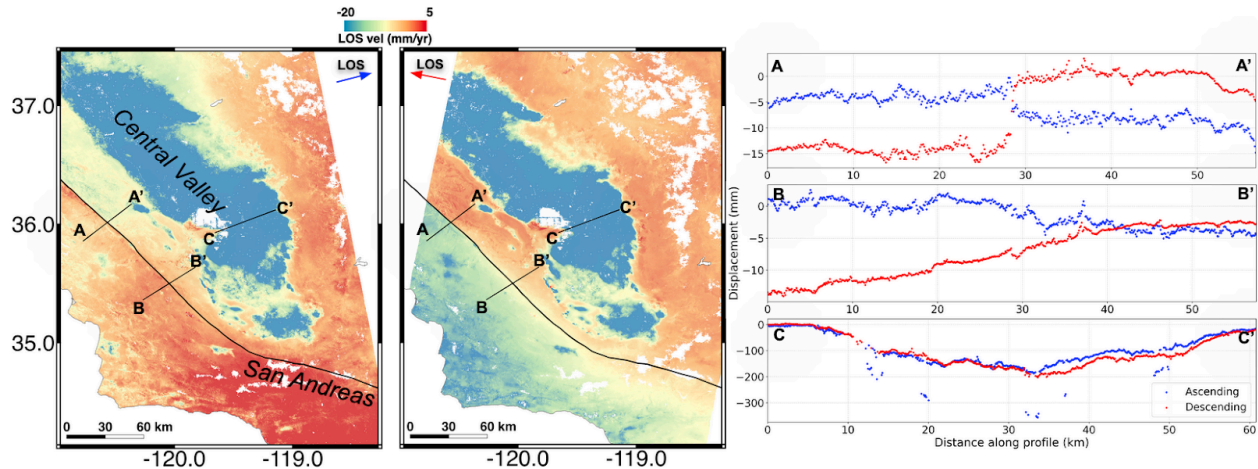


Figure 3: (Left) Line-of-sight (LOS) surface velocities across Central California derived from ascending and descending Sentinel-1 tracks 137 and 144, respectively. Velocities are referenced to a single GNSS station (black square) for each track. (Right) Cross-sectional velocity profiles along the transects denoted on the maps. Profile A–A′, located along the creeping segment of the San Andreas Fault, exhibits a sharp velocity discontinuity coincident with the fault trace. Profile B–B′, positioned on a locked segment of the San Andreas, displays the characteristic arctangent-shaped velocity gradient associated with elastic strain accumulation. The reversal in velocity offset between the ascending and descending geometries reflects predominantly horizontal fault-parallel motion. Profile C–C′ crosses a region of maximum subsidence within the Central Valley, highlighting deformation dominated by vertical motion (note the change in the displacement scale).

Conclusion and Future Work

The transition to the operational OPERA DISP-S1 product archive is currently ongoing. This project has established the ARIA-derived 2014–2023 velocity map as a high-fidelity benchmark against which these new operational products are being compared. Future efforts will focus on the routine ingestion of the DISP-S1 archive to provide low-latency updates to the CGM.

The approaches demonstrated in Sangha et al. 2026 will also be extended for future NISAR data analysis. Over the past year, the ARIA-tools software has been updated by members of this team to support downloading and time-series analysis preparation of NISAR GUNW products. Just as with ARIA-S1-GUNWs, ARIA-tools provides command-line utilities to access NISAR interferograms, mosaic and crop scenes, extract auxiliary layers, and prepare the data for ingestion into community time-series processing workflows such as MintPy. Because the interface remains agnostic between Sentinel-1 and NISAR inputs, existing time-series processing pipelines and training materials translate directly to NISAR analysis efforts, enabling rapid community adoption and facilitating future statewide deformation analyses using the methods presented in this study.

References (**contributions from proposal contributors highlighted*)

Sangha, S. S., Funning, G. J., Govorcin, M., & Bekaert, D. P. (2026). A statewide InSAR velocity map for California produced by a comprehensive large scale analysis of ARIA standard products. *AGU Advances*. **SCEC Contribution 15010** [in prep]

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