National Aeronautics and Space Administration

# Large-scale Vertical Land Motion from Time-series InSAR Displacements


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## 1. Introduction

**Vertical land motion (VLM)** is one of the key datasets for groundwater management and local sea-level rise studies in the NASA 2017 Decadal Survey. As part of the OPERA[1] project, NASA tasked JPL to produce high-resolution land-surface displacement products over North America[1] from NISAR and Sentinel-1 InSAR time-series. Due to the InSAR relative observations in satellite line-of-sight (LOS), additional processing is required to derive VLM from the upcoming OPERA displacement products.

**Objective:**

- Develop a robust and reliable approach for the operational generation of large-scale high-resolution **VLM** from InSAR displacement rates, with **associated uncertainties,** in a geodetic reference frame (case study: California)

**Challenges:**

- Large areas are usually covered by multiple tracks of relative InSAR LOS observations acquired under different imaging geometries and noise levels, and with respect to a different local reference point

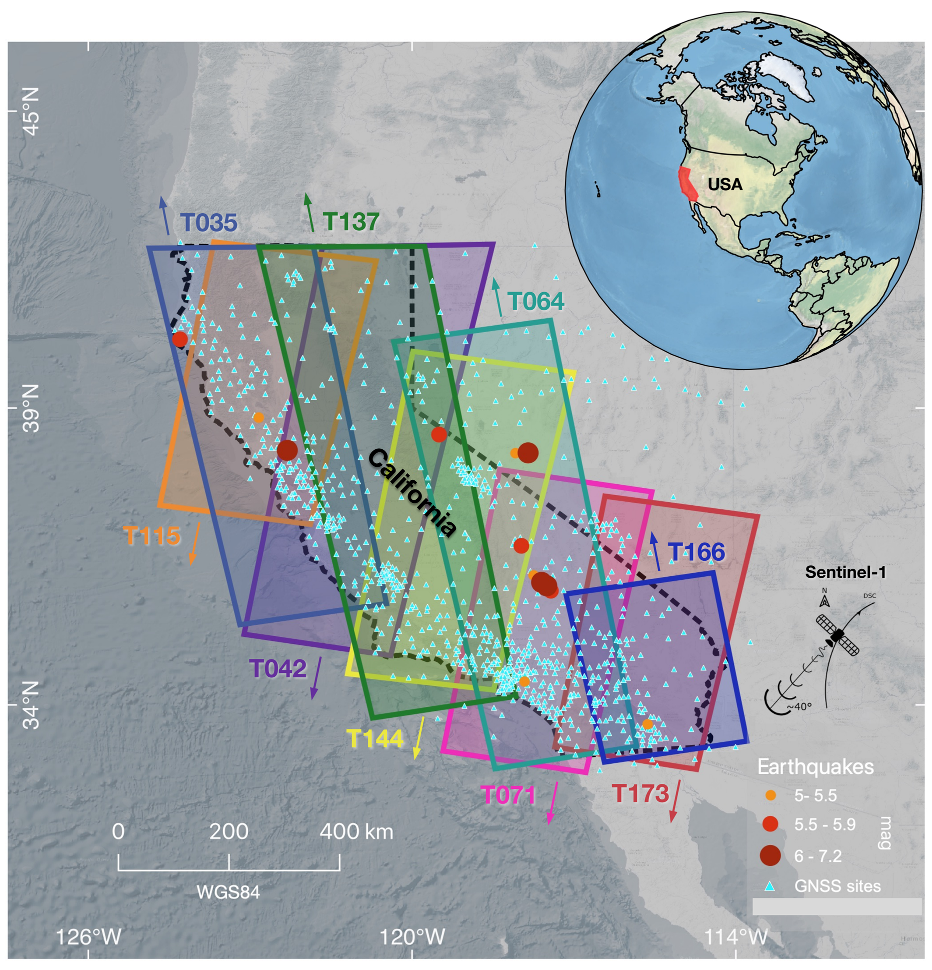


**Figure 1.** Sentinel-1 ground tracks coverage over California, with GNSS sites and strong earthquakes in 2014-2022

[1]OPERA; Observational Products for End-Users from Remote Sensing Analysis, https://www.jpl.nasa.gov/go/opera
[2]ARIA; Advanced Rapid Imaging and Analysis Project, https://aria.jpl.nasa.gov/)

## 2. Data & Methodology

**Data:**

- ESA's Sentinel-1 images acquired from 9 tracks of ascending and descending satellite orbit (2014-2022)
- JPL's GNSS 3D displacement rates (GeoGateway, 2022 )

**Methodology:**

1. Geocoded unwrapped interferograms generated with the automated JPL's ARIA[2] system
2. InSAR time-series analysis in Mintpy (Yunjun et al., 2019) with GACOS tropospheric correction (Yu et al 2018), and coseismic steps (earthquakes in Figure 1).
3. Removal of Horizontal Motion from InSAR LOS using GNSS data, and projection to vertical direction
4. Transformation of relative InSAR-VLM rates into a geodetic reference frame using planar corrections (Bekaert et al 2019). InSAR and GNSS uncertainties are used as weights in the least squares inversion:

$$\min\left[v_{GNSS} - \left(V_{INSAR_i} + P_i\right)\right]$$

$$\min\left[\left(V_{INSAR_i} + P_i\right) - \left(V_{INSAR_j} + P_j\right)\right]$$

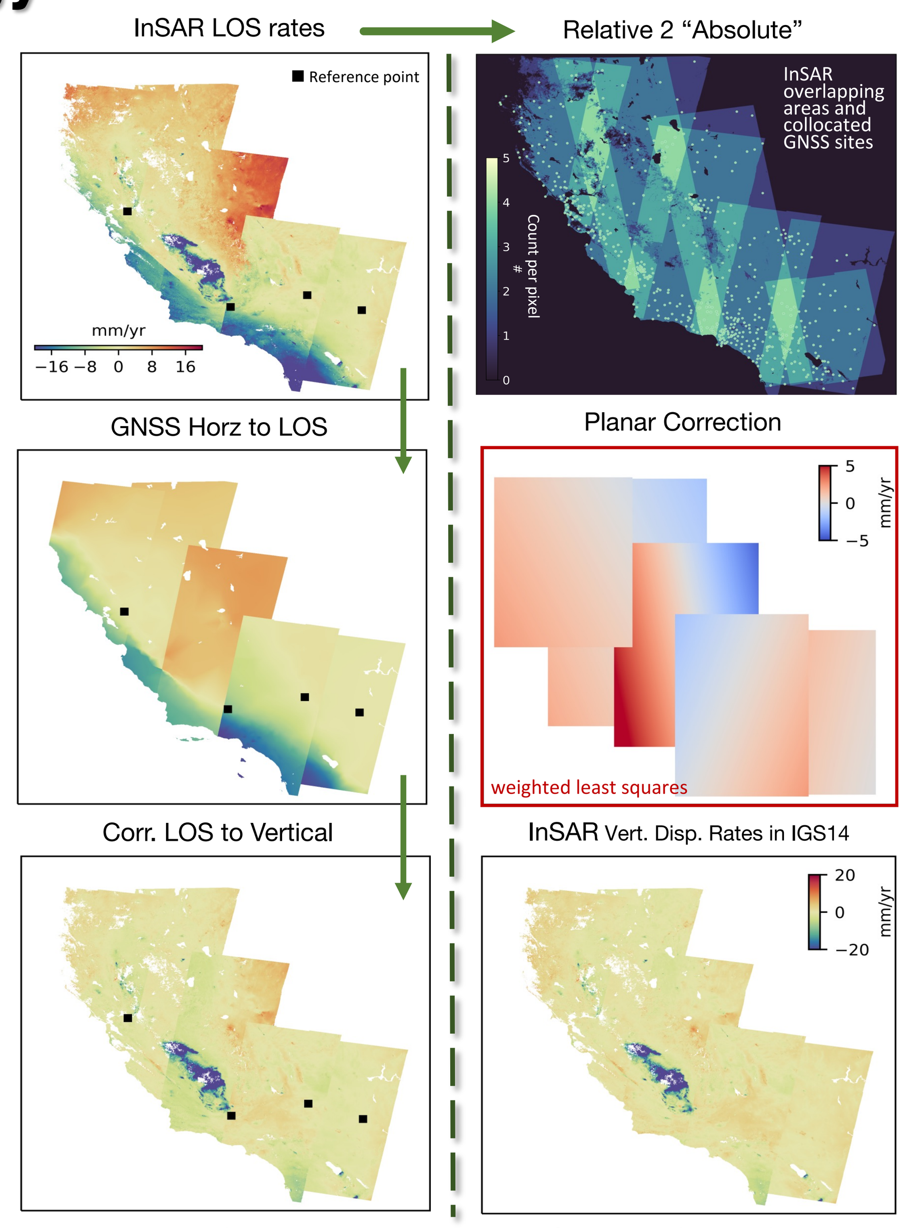


**Figure 2.** Pipeline to generate VLM from multi-track relative InSAR LOS displacements

## 3. Results

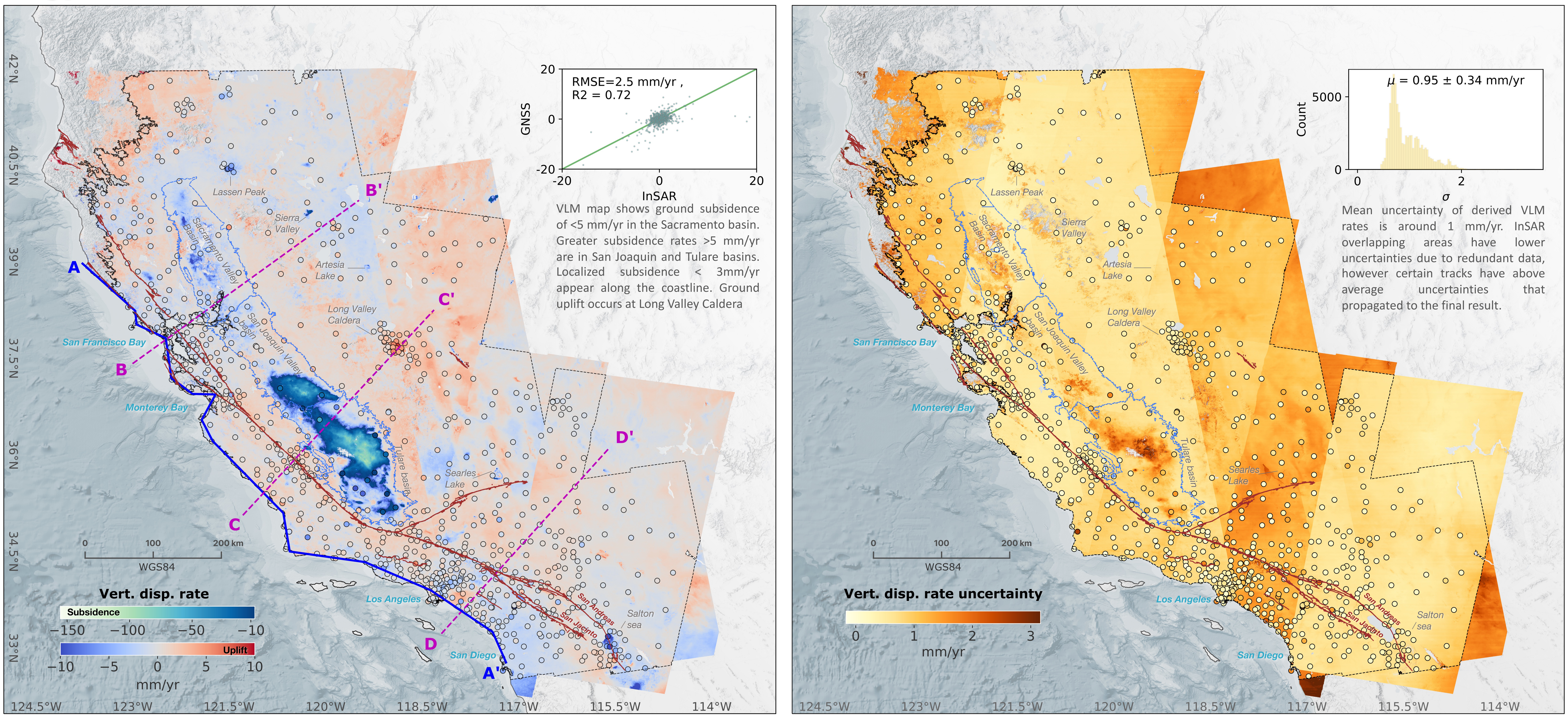


**Figure 3.** Long-term InSAR VLM rates with associated uncertainties in IGS14, circles mark GNSS sites. Blue and magenta lines are transects shown in Figure 4. Right inset image is InSAR vs GNSS scatterplot, and left inset image shows VLM uncertainty distribution. Black dashed lines encircle reliable data, and the burgundy-red lines are faults with slip > 5 mm/yr (USGS 2022)

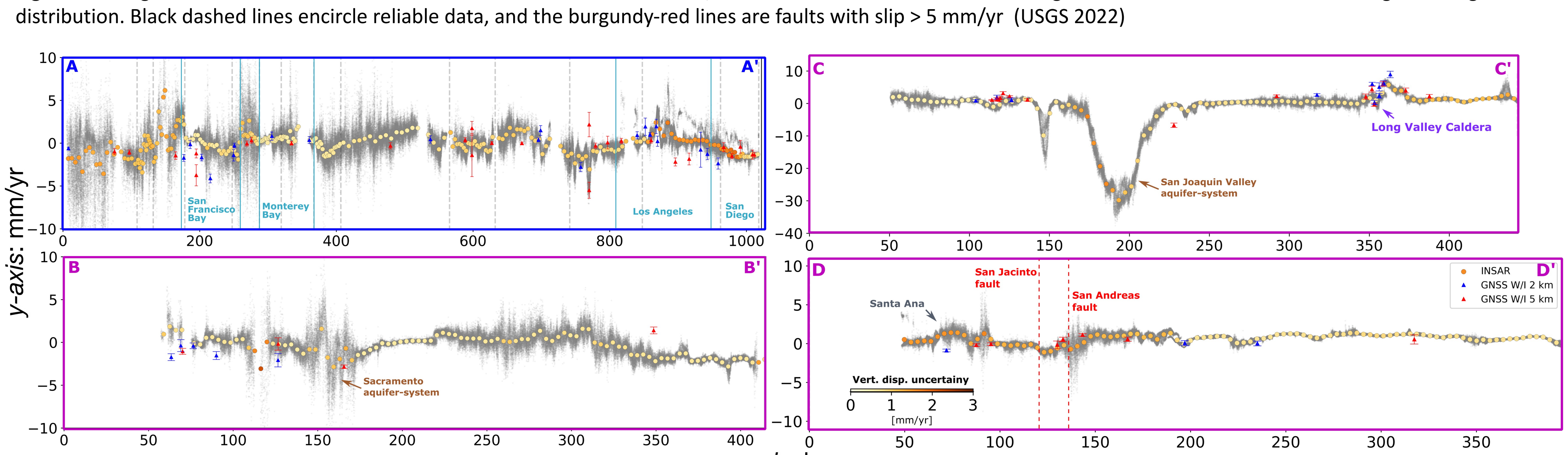


**Figure 4.** Transects shown in Fig. 3. with GNSS and InSAR vertical displacement rates, circles are binned mean displacement rates and their uncertainties (color-scale), grey dots show a dispersion of displacement rates within 2 km around the transect

## 4. Conclusions

- **Validation**: GNSS and InSAR-derived VLM rates agree well (R = 0.72 and RMSE of 2.5 mm/yr)
- Our VLM map captures **detailed** localized and regional patterns of **subsidence and ground uplift rates** in California, **with associated uncertainties,** in the IGS14 reference frame
- Large-scale InSAR-derived VLM offers **wide-range of applications** for relative sea level rise (Fig 4., A-A'), groundwater management (Fig 4., B-B', C-C'), faulting (Fig 4., D-D'), and other natural and anthropogenic processes.

**Next Steps:**

- Explore InSAR corrections for bulk plate motion, solid Earth, and ocean tidal motion
- InSAR-derived horizontal and vertical motion maps with associated uncertainties


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Poster Number: **PRD-EB#008**



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