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Remote sensing big data characterization of tectonic and hydrological sources of ground deformation in California

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Although scientific advances have been achieved in every individual geoscience discipline, enabled by more extensive and accurate observations and more robust models, our knowledge of the Earth's complexity remains limited. California represents an ideal natural laboratory that hosts active tectonics processes associated with the San Andreas fault system and hydrological processes dominated by the Central Valley, which contribute to dynamic surface deformation across the state. The spatiotemporal characteristics and three-dimensional patterns of the tectonic and hydrological sources of ground motions differ systematically. Spatially, interseismic creep is distributed along several strands of the San Andreas Fault (SAF) system. The elastic deformation off the locked faults usually spreads out over tens of kilometers in a long-wavelength pattern. Hydrologically driven displacements are distinct between water-bearing sedimentary basins and the bounding fault structures. Temporarily, both displacement sources involve long-term trends such as from interseismic creep and prolonged climate change. In addition, episodic signals are due to seismic and aseismic fault slip events, seasonal elastic surface and groundwater loading, and poroelastic groundwater volume strain. The orientation of tectonic strain accumulation in California mainly represents a northwest trending shear zone associated with the right-lateral strike-slip SAF system. Hydrological processes mainly deform the Earth vertically while horizontal motions concentrate along the aquifer margins.

We used the time-series ground displacements during 2015-2019 relying on four ascending tracks and five descending tracks of the ESA's Sentinel-1 Interferometric Synthetic Aperture Radar (InSAR) observations. We considered the secular horizontal surface velocities and strain rates, constrained from GNSS measurements and tectonic models, as proxies for tectonic processes. InSAR time series and GNSS velocity maps benefit from the Southern California Earthquake Center (SCEC) Community Geodetic Model (CGM) developments. We further extracted the seasonal displacement amplitudes from InSAR-derived time-series displacements as proxies for hydrological processes. We synergized multidisciplinary remote sensing and auxiliary big data including ground deformation, sedimentary basins, precipitation, soil moisture, topography, and hydrocarbon production fields, using an ensemble, random forest machine learning algorithm. We succeeded in predicting 86%-95% of the representative data sets.

Interestingly, high strain rates along the SAF system mainly occur in areas with a low-to-moderate vegetation fraction, suggesting a correlation of rough/high-relief coastal range morphology and topography with the active faulting, seasonal and orographic rainfall, and vegetation growth. Linear discontinuities in the long-term, seasonal amplitude and phase of the surface displacement fields coincide with some fault strands, the boundary zone between the sediment-fill Central Valley and bedrock-dominated Sierra Nevada, and the margins of the inelastically deforming aquifer in the Central Valley, suggesting groundwater flow interruptions, contrasting elastic properties, and heterogeneous hydrological units.