New Intra-Frame Deformation Model for the Western U.S.
G43C - 0336

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Abstract

We report on a new dynamic intra-frame deformation model (IFDM) for the Western U.S. that provides three-dimensional weekly displacement grids of the cumulative effects of secular (interseismic) motions and transients (e.g., coseismic, postseismic, slow slip, subsidence). The grids are based on daily GNSS-derived displacement time series starting in 1999 in ITRF2020, updated weekly, and supplemented, when and where available, through InSAR/GNSS integration (from mid 2015) to increase spatial resolution. Besides its intrinsic scientific value, the IFDM provides user access to the National Terrestrial Reference Frame 2022 through the pole of rotation published by the National Geodetic Survey (NGS). That is, a user can determine the change in position between any two epochs of time and at any point within the region spanned by the GNSS network with respect to "stable" North America.

Here we analyze horizontal transients and strain rates due to postseismic deformation and from the several large strike-slip earthquakes in the region: the 1999 Mw 7.1 Hector Mine, 2010 Mw 7.2 El Mayor-Cucapah, Mw 6.4 & Mw 7.1 2019 Ridgecrest sequence, and the 2024 Mw 7.0 Cape Mendocino (with possible preseismic event). We also visualize: volcanism at Long Valley, Mount Shasta and Lassen Peak, and several earthquake swarms in the Salton trough. In addition, we present vertical transients including time-variant subsidence most apparent in hydrological cycles in the Central Valley but also visible in other locations, and uplift due to postseismic deformation and volcanism. We also present a K-Means clustering analysis that differentiates between deformation regimes such as the locked and creeping section of the San Andreas fault. We describe two interactive web-based applications, SCIP and MGViz, for reference frame analysis and visualization.

Intra-Frame Deformation Model

SOPAC has maintained an Intra-Frame Deformation Model (Klein et al, 2019), which allows the user to find their position and change in position between two epochs in time for the Western United States. The SCIP utility allows the user to change between datums ITRF2020, ITRF2014, NAD83, and NATRF2022. The application also shows horizontal velocities (in both ITRF2020 and NATRF2022) and the IFDM model grids in NEU components (Figure 1).

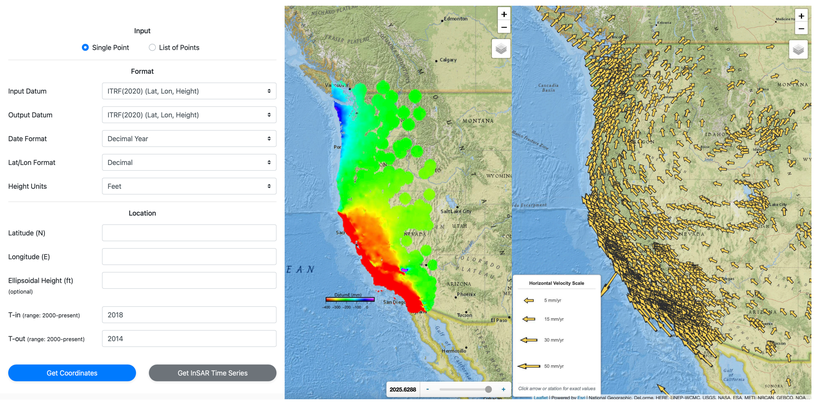
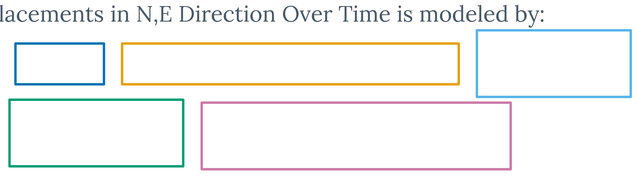


Figure 1: View of the total East Datum(left) for the Intra-Frame Deformation Model and the NATRF2022 velocities (right) as viewed on the SCIP Utility.

The IFDM is split into secular and transient displacements for both the North and East components (the basis of which is the GNSS timeseries shown with the equations below). Meanwhile, the Up component's displacements are visualized together (with aid from InSAR, **see poster 0335**). Because the Western U.S. is subject to secular plate velocities and a variety of transients (including volcanism, large magnitude earthquakes, earthquake swarms, and subsidence), the user can visualize these transients on SCIP and obtain displacements due to these motions.

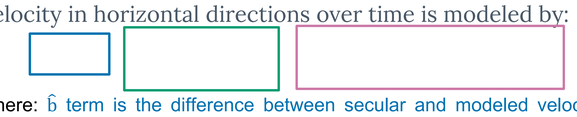
Important Formulas/ Time Series Background:

Displacements in N,E Direction Over Time is modeled by:



Where: a and b terms represent initial position and secular velocity, A terms are the annual/semi-annual signals, g are offsets in the time-series, h are slope changes, and k is post-seismic motion

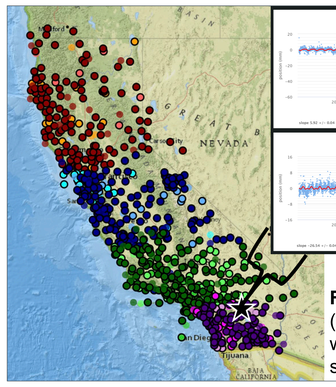
Velocity in horizontal directions over time is modeled by:



Where: $\hat{b}$ term is the difference between secular and modeled velocity with a fault slip model (Zeng et al., 2022) , h are slope changes, and k is post-seismic motion

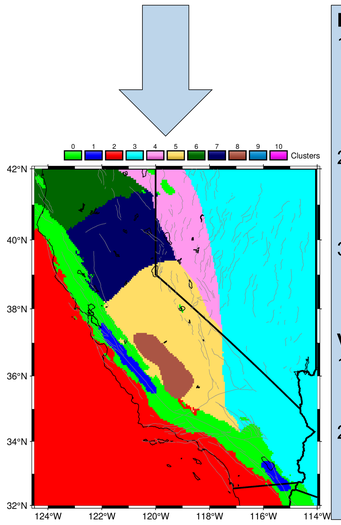
Epoch-Date K-Means Analysis

SOPAC has also been tasked with updating the California Caltrans Spatial Reference Network (CTSRN) subnetwork reference system to minimize the periodic reprocessing needed to maintain horizontal and vertical accuracy within the state.



Started with Epoch 2025.00 coordinates (Bock et al., 2025), ITRF2020 validated GNSS stations in California and the periphery of neighboring states and modeled displacement and velocity timeseries.

Figure 2: California Real Time Network Zones (Kevin Maxwell, Caltrans, personal communication) with example SOPAC/JPL detrended GNSS time series as viewed on MGViz (Bock et al., 2023).



Horizontal Method:

1. Computed dilatation, max shear strain rate, and horizontal gradients from SOPAC secular/ interseismic velocity grids (Bock et al., 2023) (created with gmt gpsgridder (Sandwell & Wessel, 2016).
2. Inputted grids into K-means algorithm, where ideal number of clusters was determined by silhouette score (how far apart the clusters are) (e.g. Savage & Simpson, 2012).
3. Re-clustered Eastern side of the San Andreas with secular velocities until data spread in each cluster was minimized.

Vertical Method:

1. Used vertical up displacements that are cumulative since Epoch 2010.0 (Klein et al., 2019).
2. For year 2018 (no large magnitude earthquakes in California), clustering was performed on monthly basis to ensure that seasonal signals were not excluded.

Figure 3: Total clustering results with the horizontal and vertical methods. For Caltrans subnetworking purposes, cluster #1, which differentiates the creeping versus locked sections of the San Andreas fault, is absorbed into cluster #0. Cluster #8, which is in Central Valley, is the only subnetwork boundary from the vertical method.

Evaluating Horizontal Reprocessing Times

To maintain 1cm horizontal accuracy, reprocessing times were evaluated for CTSRN GNSS stations within each subcluster given secular displacements (Zeng et al., 2022).

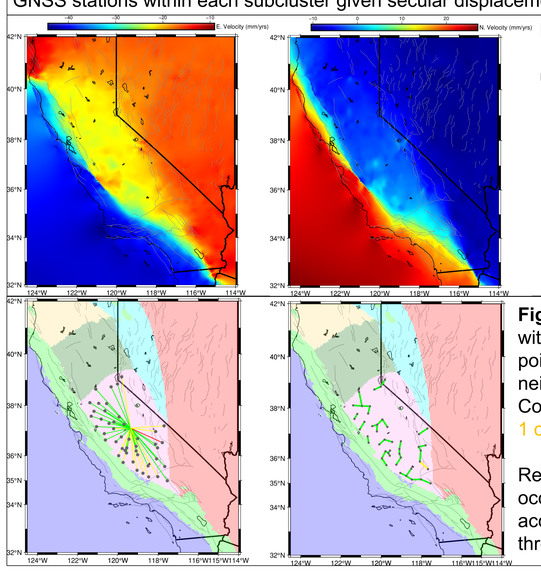


Figure 4: East (left) and North (right) secular grids used

Figure 5: Stations evaluated with respect to a central point (left) and nearest neighboring station (right). Colors indicate: 0–.5 cm, .5–1 cm, & +1 cm displacement.

Reset of the subnetwork occurs when 2+ stations' accuracy degrades past threshold

Epoch-Date Horizontal Reprocessing

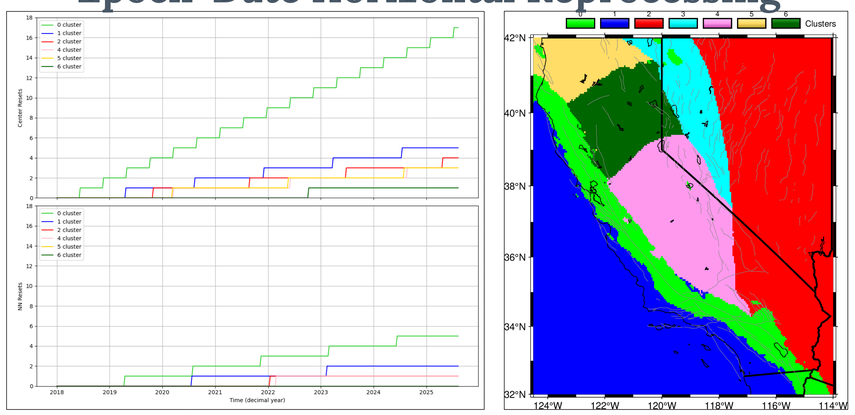


Figure 7: Number of resets needed from 2018 – 2025.6 with respect to a center point (top) or nearest neighbor station (bottom).

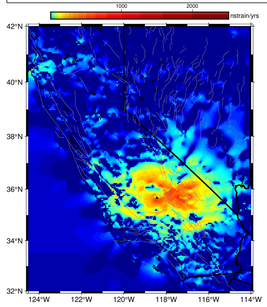
To maintain internal horizontal accuracy, clusters must be reprocessed:

- Cluster #0: 0.4 – 1.25 yrs
- Cluster #1: 1.25 - 2.5 yrs
- Cluster #2: 1.8 – 4 yrs
- Cluster #4: 2.2 - 4.2 yrs
- Cluster #5: 2.2 - over 7.6 yrs
- Cluster #6: 4.75 - over 7.6 yrs

The range in times highlight that the location and scope of the project matters. The subnetwork contrasts with the IFDM, where displacements and positions are modeled/accumulated over time

Horizontal Transient Effect

To test the effect of horizontal transients on the timeseries, for the years 2018.0 – 2025.6, offsets and postseismic displacements are added to the North and East components. Over this time, the largest effect is from the 2019 Ridgecrest event.



Placeholder for plot like 7 I am fixing

Figure 8 (left): Maximum shear strain rate change one week after – one week before the Ridgecrest earthquake
Figure 8 (middle): Maximum shear strain rate change ten weeks after – one week before the Ridgecrest earthquake
Figure 8 (right): Difference between the number of resets needed for the horizontal transient displacements + secular displacements versus for the secular displacements only.

The Ridgecrest event causes substantial changes in the number of resets needed for multiple clusters during a broad duration of the timeseries

Key Takeaways:

1. SOPAC offers interactive web applications to visualize GNSS timeseries (MGViz) and to perform reference frame analysis (SCIP)
2. K-Means clustering was utilized to create a new subnetwork reference system for California
3. The subnetwork reference system's horizontal velocities were used to assess reprocessing times and the effect of horizontal transients on the network.

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