Intra-Frame Deformation Model for the Western U.S.
P2 23 Fang

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Abstract

We have developed an intra-frame deformation model (IFDM) for the Western U.S. as a complement to the new National Spatial Reference System, NATRF2022, defined and maintained by the U.S. National Geodetic Survey (NGS).

The IFDM is a kinematic frame defined by the evolving positions of quality-controlled, thirty-five-year-long daily displacement time series, of about 1300 GNSS Western U.S. stations, produced through a long-lived NASA MEaSUREs collaboration between UCSD's Scripps Institution of Oceanography and Caltech's Jet Propulsion Laboratory.

The time series are estimated with respect to IGb20, the IGS realization of ITRF2020 and converted to local North, East, Up displacements. Weekly medians of the daily displacements are gridded and used to detect transients including coseismic and postseismic deformation, vertical land motion and other non-secular transients such as fault creep and slow slip events.

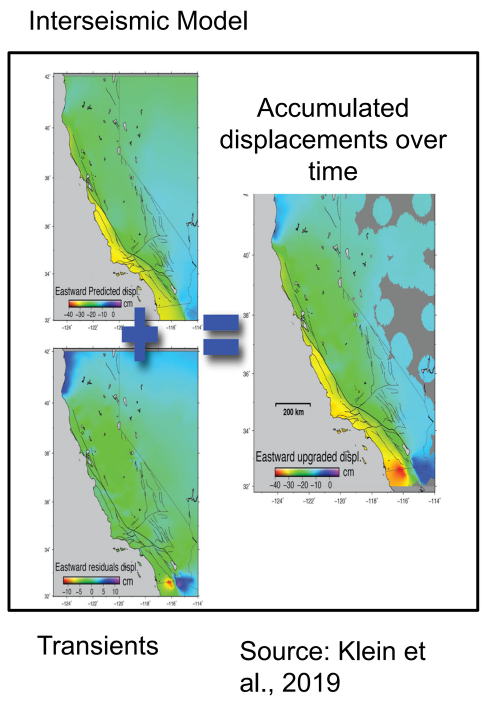
To account for secular horizontal motions, we grid the velocities of an interseismic model for the Western U.S. provided by the U.S. Geological Survey. For the vertical component, we create weekly grids without the use of an underlying model, relying strictly on the weekly observations.

The IFDM is then defined by adding the non-secular and secular grids, describing total station motions since an arbitrary reference epoch (we use 2010.00, which is prior to several major earthquakes in the region). We maintain the IFDM with respect to ITRF2020 and then rotate it into NATRF2022 using the North American pole of rotation provided by NGS.

Access to the IFDM is through a web-based utility SCIP (http://sopac-adj.ucsd.edu/scip/) that allows a user to move between any two epochs at any location within Western North America, and between reference frames (NATRF2022, NAD83 and ITRF2020). To date, we have not found any significant offsets in our displacement time series as new ITR2020 versions are published.

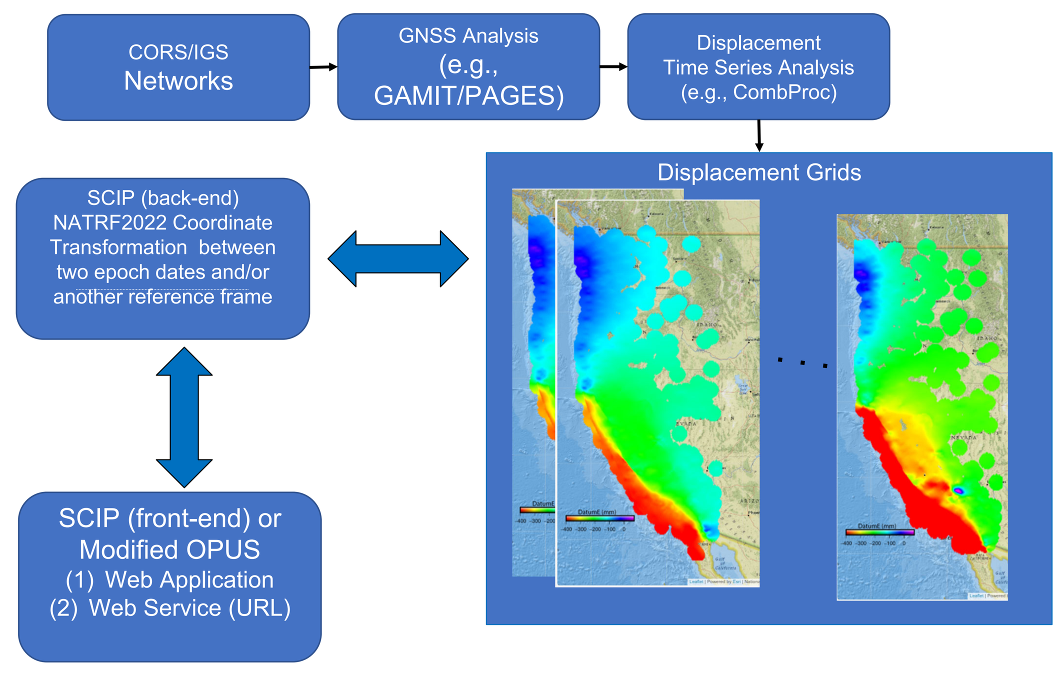
Intra-Frame Deformation Model: Concept

- Interseismic model and observed surface displacements provide changes in coordinates between different epochs of time.
- Interseismic model represents the secular motion, used to predict the linear displacements at any point inside the region covered by the reference network.
- Time series of GNSS weekly displacements are used to parametrically model transient motion, defined as a station's non-secular physical motions.
- Horizontal transients are primarily due to coseismic & postseismic deformation, slow-slip events and creep.
- Vertical transients are due to natural causes, such as hydrological surface loading, water aquifer recharge, and magmatic processes or anthropogenic, such as water and mineral extraction, and hydrothermal power generation.



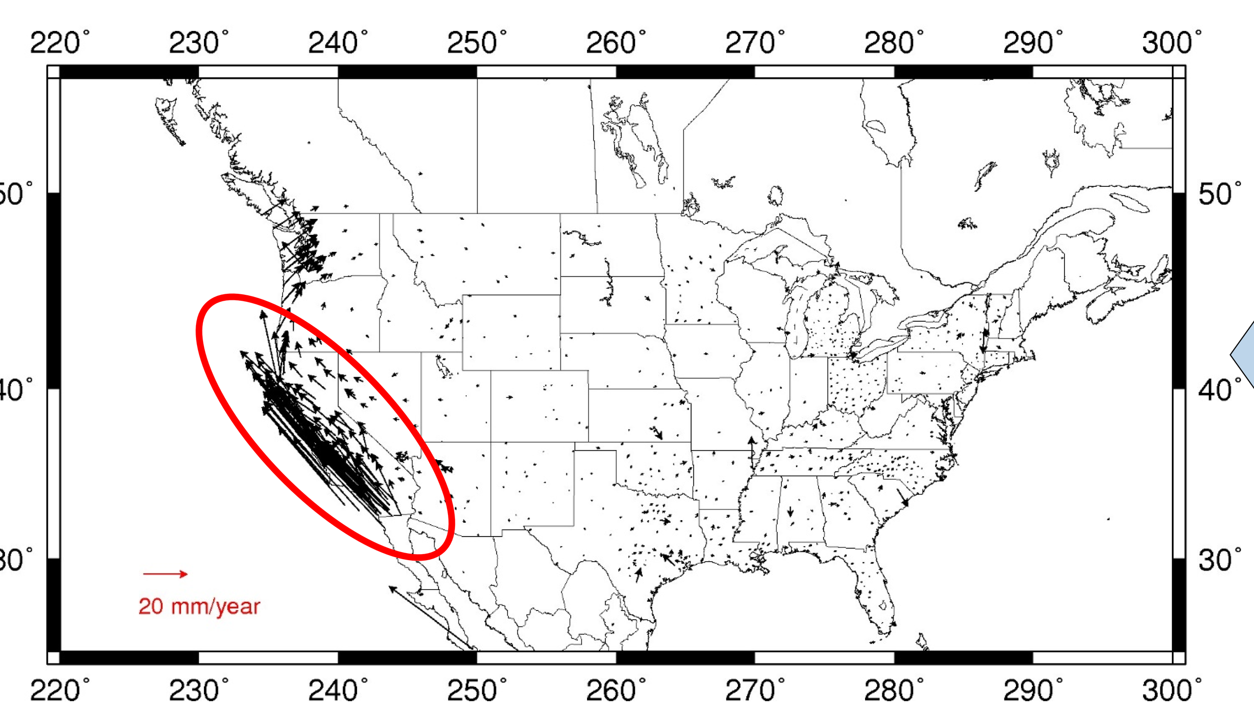
Source: Klein et al., 2019

IFDM (Real-Time or Post-Processing)

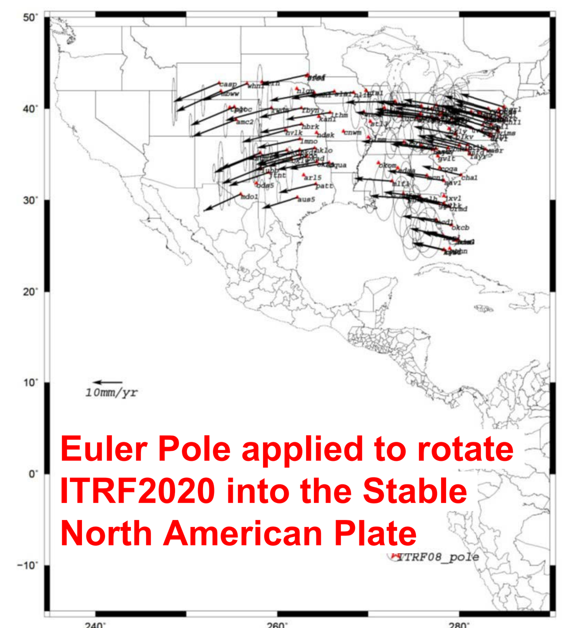


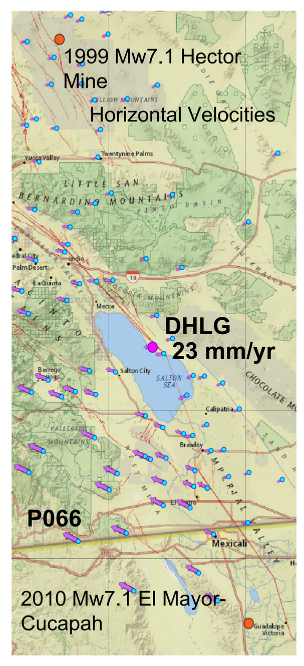
Background

NATRF2022 Velocities over CONUS



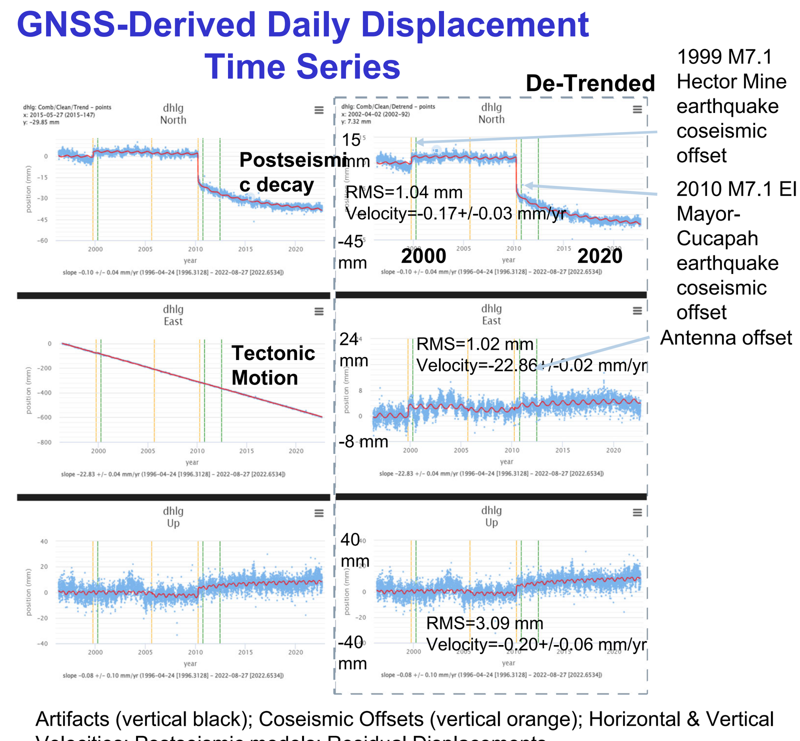
Why we need a dynamic/adaptive frame for highly active deformation region





mgviz.ucsd.edu

GNSS-Derived Daily Displacement Time Series

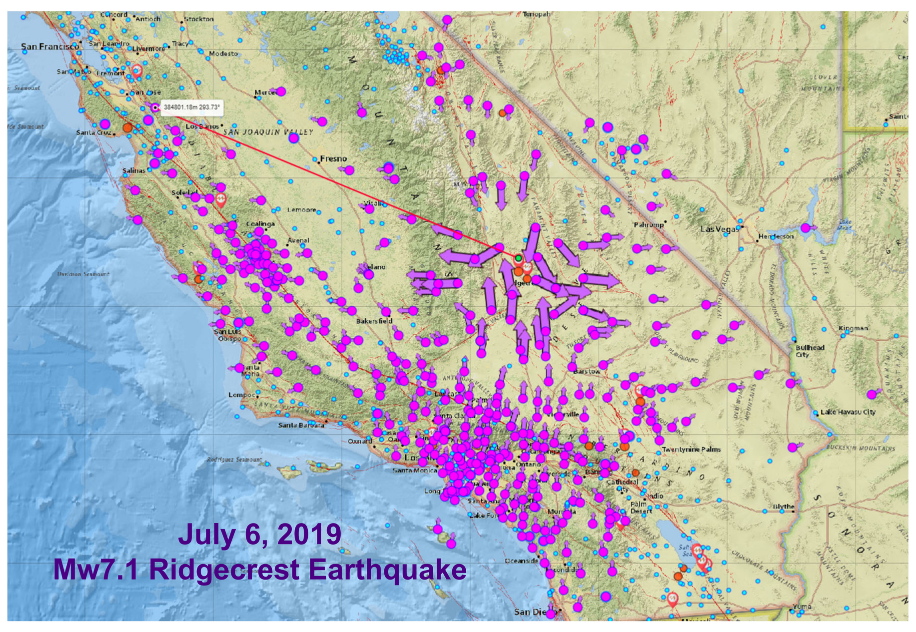


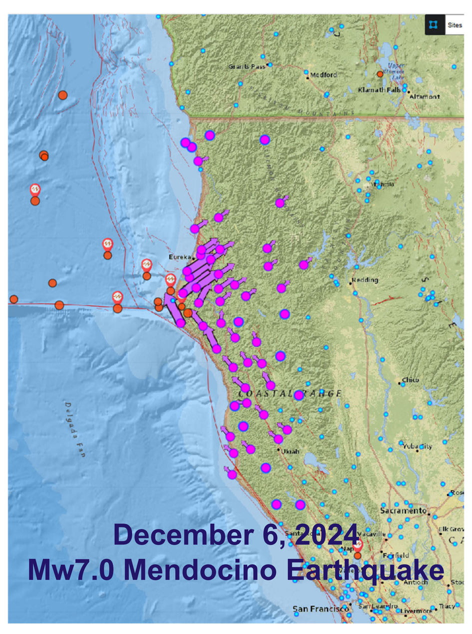
Artifacts (vertical black); Coseismic Offsets (vertical orange); Horizontal & Vertical Velocities; Postseismic models; Residual Displacements

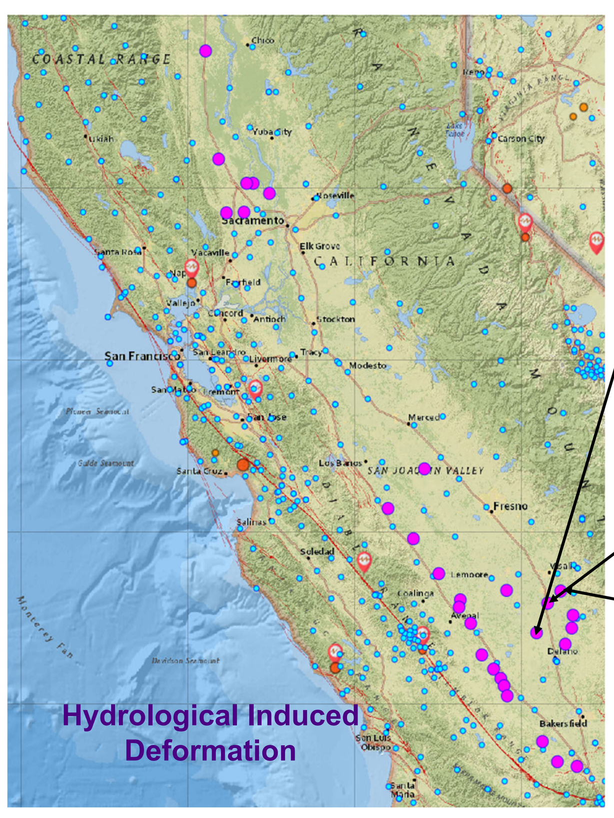
Coseismic Events since Epoch 2017.50

Date	UTC	Name	Mw	Depth (km)	Latitude (N)	Longitude (W)	Sites Affected
2019-07-04	17:33:49	Ridgecrest Foreshock	6.4	10.5	35.705	117.504	16
2019-07-06	3:19:53	Ridgecrest Mainshock	7.1	8.0	35.770	117.599	401[1]
2020-10-01	0:31:27	Westmoreland	4.9	14.2	33.055	115.591	4
2021-06-05	17:55:58	11 km W of Calipatria[2]	5.3	5.8	33.14	115.635	4
2021-12-21	20:10:31	7 km N of Petrolia	6.2	27.04	40.39	124.298	8
2022-12-20	10:34:24	15km WSW of Ferndale	6.4	17.9	40.525	124.423	18
2024-12-05	18:44:21	Offshore Cape Mendocino	7.0	10	40.374	125.022	55

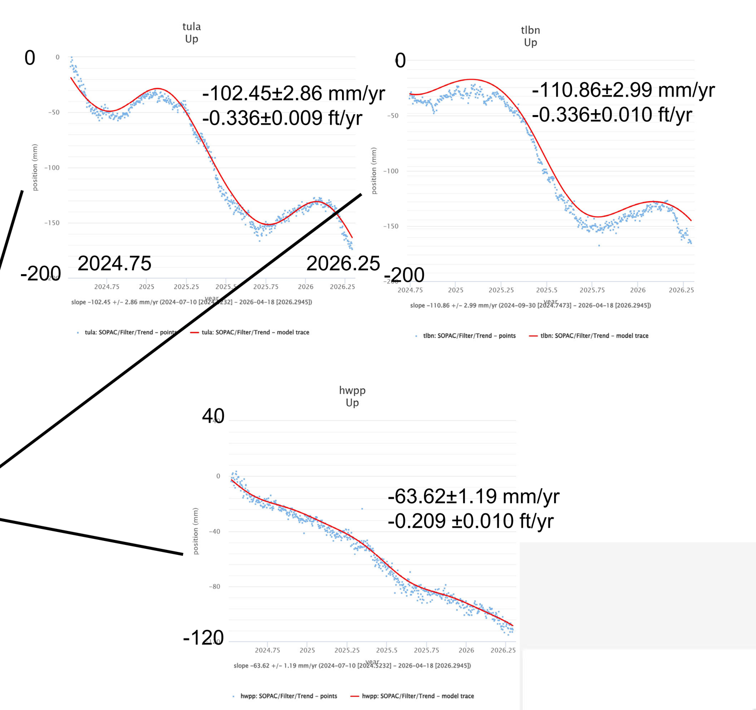
Coseismic Motions



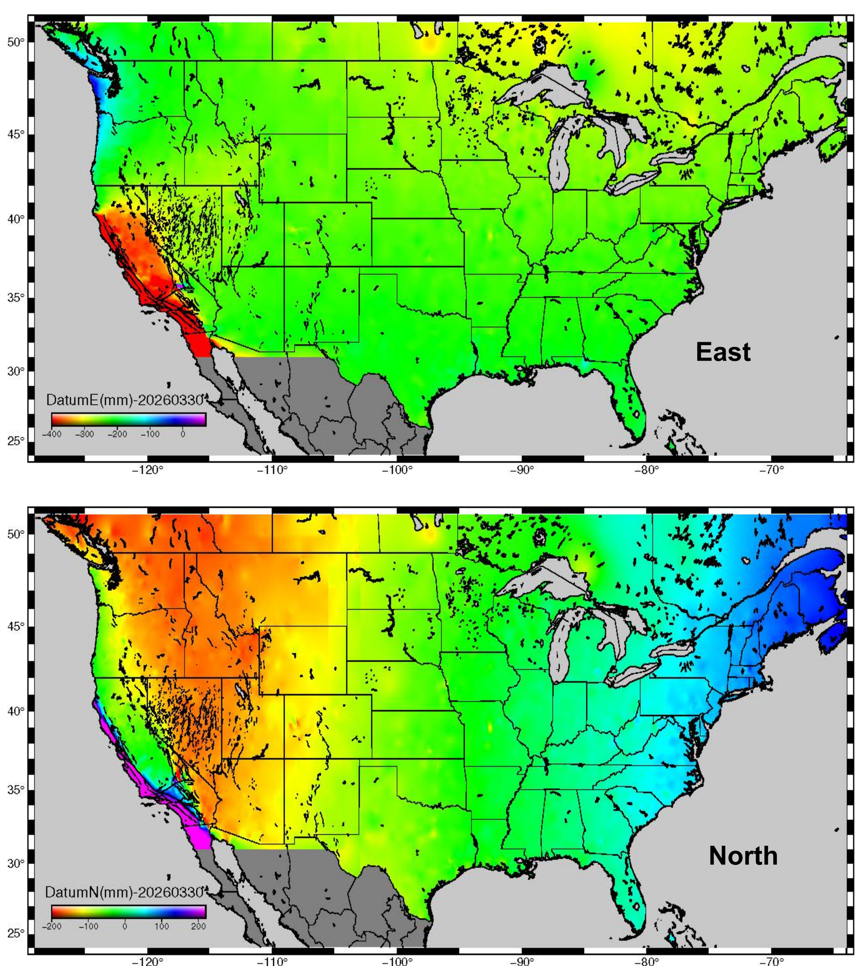




California Department of Water Resources Network

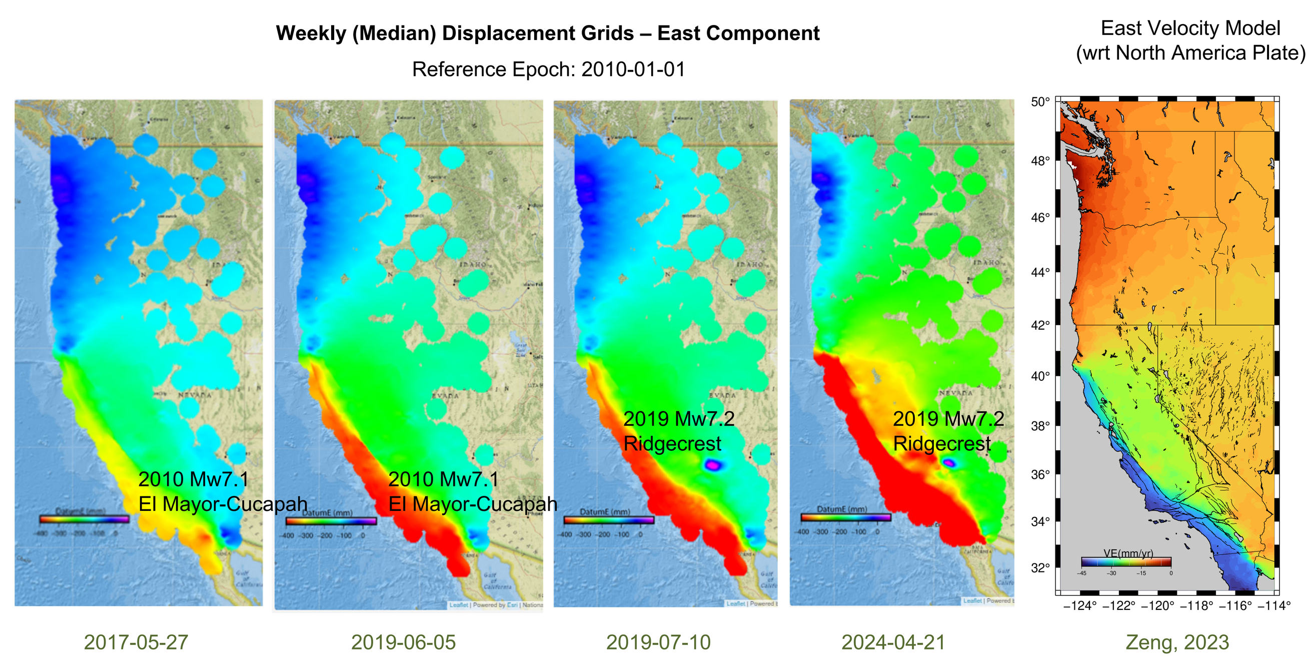


IFDM in action

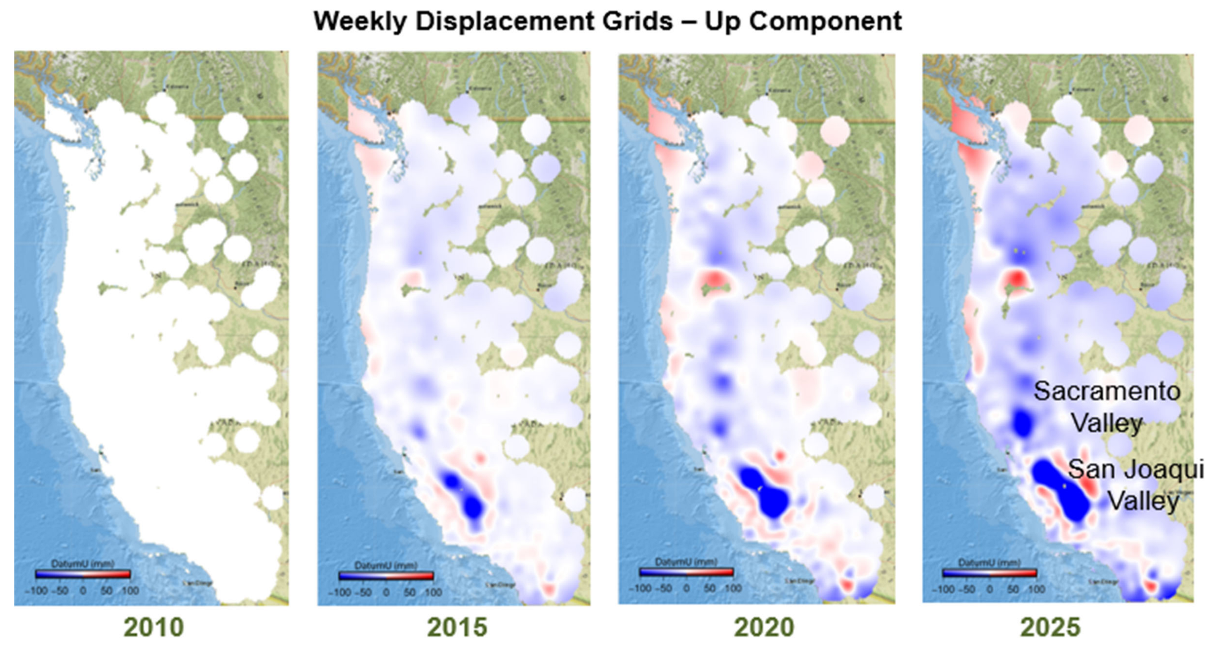


Weekly snapshot (2026-03-30) of IFDM in east (top)and north (bottom) components depicting the combination of interseismic and transient deformation. Clearly seen is total displacements since the 2010 reference epoch (including coseismic and postseismic effects in Western North America. Also seen is the effect of Glacial Isostatic Adjustment (GIA), mostly prominent in the Northeast.

Intra-Frame Deformation Model: Horizontal

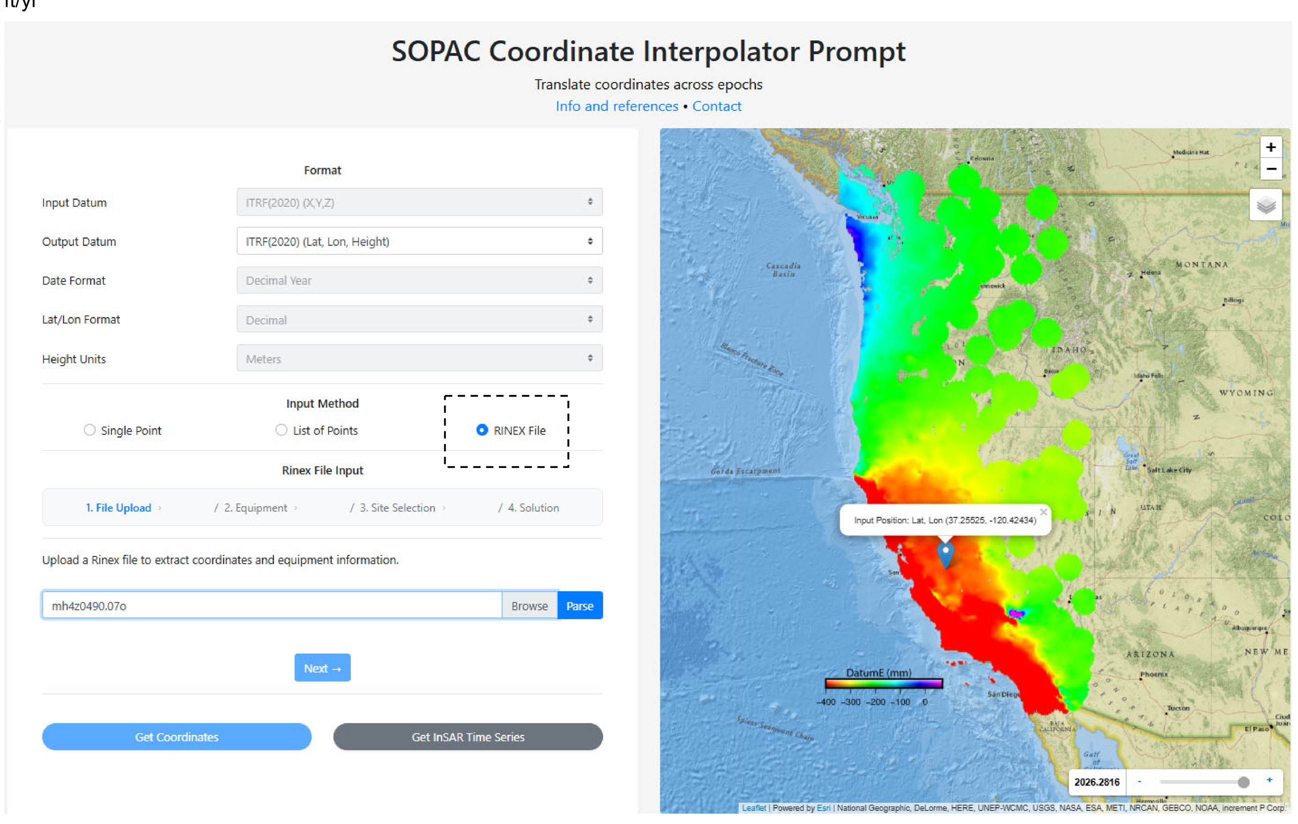


Intra-Frame Deformation Model: Vertical



No underlying physical model – suboptimal spatial resolution. Planning to add InSAR/GNSS derived vertical displacements with high spatial resolution (250 meters).

SCIP utility user interface



Reference Frames

SCIP supports ITRF2020 & ITRF2014 (in X,Y,Z & Lat, Long Height), NAD83(2011) & NATRF2022(2020) -beta/horizontal

- **ITRF2020 (X,Y,Z):** IGb20 realization of ITRF2020 - https://lists.igs.org/pipermail/igsmail/2024/008539.html
- **ITRF2020 (Lat, Long, Height):** Transformation from ITRF2020 XYZ coordinates to geodetic latitude, longitude and height using GRS080 ellipsoid values: a = 6378137 meters; 1/f = 298.257223563.
- **ITRF2014 (X,Y,Z):** IGb14 realization of ITRF2014 - https://lists.igs.org/pipermail/igsmail/2020/007917.html
- **ITRF2014 (Lat, Long, Height):** Transformation from ITRF2014 XYZ coordinates to geodetic latitude, longitude and height using GRS080 ellipsoid values: a = 6378137 meters; 1/f = 298.257223563.
- **NAD83(2011) (Lat, Long, Height):** NAD83 system used for CSRS Epoch 2025.00 - https://sopac-csrc.ucsd.edu/index.php/csrn-epoch-2025-00/
- **NATRF2022 (2020):** New realization of National Terrestrial Reference System (NSRS) at Epoch 2020.0 - https://beta.ngs.noaa.gov/NATRF2022/

Parametric Time Series Analysis

Displacements:

$$y(t_i) = \boxed{a(t_0) + bt_i} + \boxed{A_0 \sin(\omega_0 t_i + \phi_0) + A_1 \sin(2\omega_1 t_i + \phi_1)} + \boxed{\sum_{j=1}^{n_g} g_j H(t_i - T_{gj})}$$
$$+ \boxed{\sum_{j=1}^{n_h} h_j H(t_i - T_{hj}) t_i} + \boxed{\sum_{j=1}^{n_k} k_j \left(1 - e^{\frac{-(t_i - T_{kj})}{\tau_j}}\right) H(t_i - T_{kj}) + \epsilon}$$

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 multiple slope changes, and k is post-seismic motion

Velocity over time is estimated by:

$$\dot{y}(t_i) = \boxed{(\hat{b} - \nu_M)} + \boxed{\sum_{j=1}^{n_h} h_j H(t_i - T_{hj})} + \boxed{\sum_{j=1}^{n_k} \frac{k_j}{\tau_j} \left(e^{-\frac{(t_i - T_{kj})}{\tau_j}}\right) H(t_i - T_{kj}) + \epsilon}$$

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

Functional Utilities:

SOPAC offers interactive web applications to visualize GNSS timeseries (MGViz) and to perform IFDM analysis (SCIP)

References

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