Director's Report

Yehuda Bock

Institute of Geophysics and Planetary Physics (IGPP)

Scripps Institution of Oceanography (SIO)

University of San Diego (UCSD)

http://sopac-csrc.ucsd.edu/

CSRC Coordinating Council Fall Meeting

Scripps Institution of Oceanography

La Jolla, CA

May 14, 2025

Contributions by:

SIO: Peng Fang, Anne Sullivan, Songnian Jiang, Sean King, Rohith Rachala, Bhavik Chandna, Aubrey Bennett, Lavoisiane Souza, David Sandwell, Molly Zebker, Roland Hohensinn, Greg Helmer (CSRC)

JPL/Caltech: Angelyn Moore, Zhen Liu, Umaa Rebbapragada, Joe Roberts

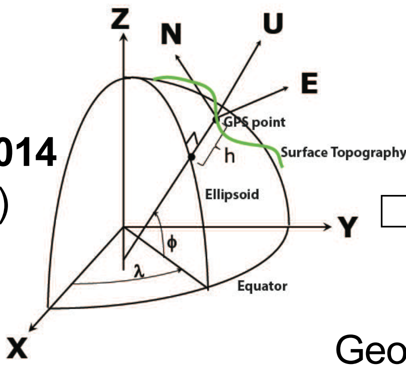
Outline

- CSRS Epoch 2025.00 NAD83(2011)
- Dynamic Reference Frame
- GNSS/InSAR integration
- Geodesy track at SIO/IGPP
- CRTN Update
- Flash Flood Warnings with Machine Learning

California Spatial Reference System @ CSRS Epoch 2017.50 NAD83(2011)

- Under contract to Caltrans, CSRC estimated geodetic coordinates and geoidal heights for the California Spatial Reference Network of ~900 stations at Epoch Date 2017.50
- The coordinates & heights represent California's Spatial Reference System, according to the Public Resources Code
- The CSRS is aligned with the National Spatial Reference System (NAD83 2011), published by the National Geodetic Survey
- CSRC Epoch 2017.5 (NAD83) coordinates are transmitted in RTCM3 messages to California Real Time Network (CRTN) users

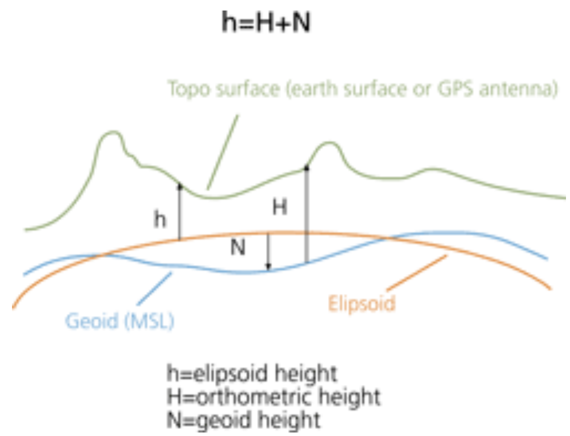
ITRF 2014
(X,Y,Z)



NAD83

(ϕ, λ, h)

Geodetic Coordinates



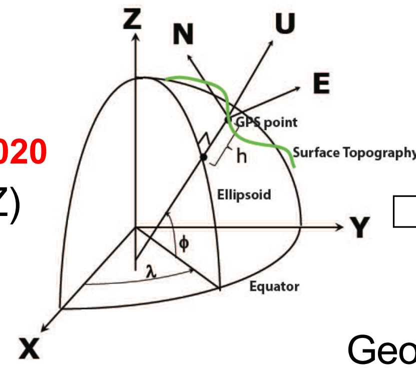
GEOID12B

https://sopac-csrc.ucsd.edu/index.php/epoch2017/

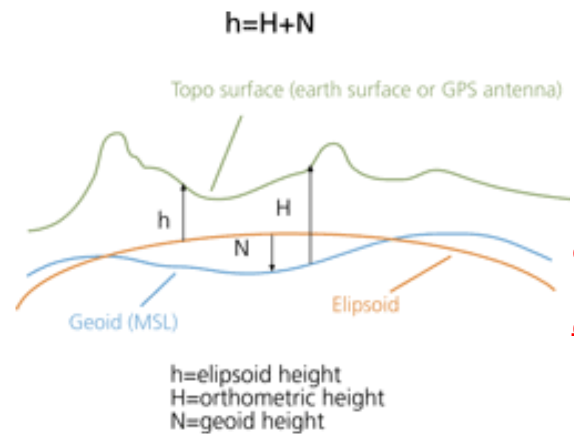
California Spatial Reference System
@ CSRS Epoch 2025.00 NAD83(2011)

- Under contract to Caltrans, CSRC is publishing geodetic coordinates and geoidal heights for the California Spatial Reference Network with 1059 CSRN stations at Epoch 2025.00, replacing Epoch 2017.50
- Daily positions estimated in ITRF2020 to account for plate boundary deformation, 2019 Mw7.1 Ridgecrest earthquake – coseismic and postseismic motion (affected about 300 stations) and 2024 Mw 7.0 Mendocino earthquake; uplift and subsidence; additional quality control; new Caltrans CTSRN & DWR stations
- Transformed to NAD83 (2011) rather than the National Spatial Reference System (NSRS 2022), not published yet by the National Geodetic Survey
- Epoch 2025.00 NAD83(2011) coordinates will be transmitted in RTCM3 messages to California Real Time Network (CRTN) users

ITRF 2020
(X,Y,Z)

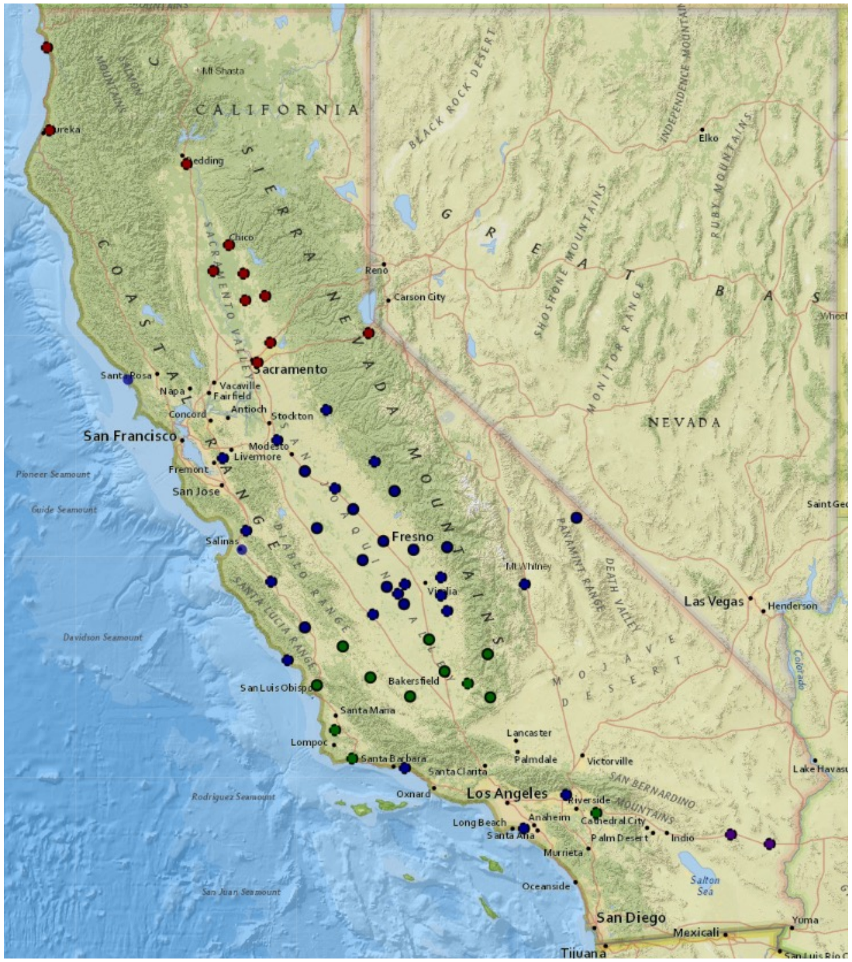


NAD83(2011)
~~NSRS 2022~~
(ϕ, λ, h)
Geodetic Coordinates



GEOID18b
~~GEOID2022~~

CTSRN Stations



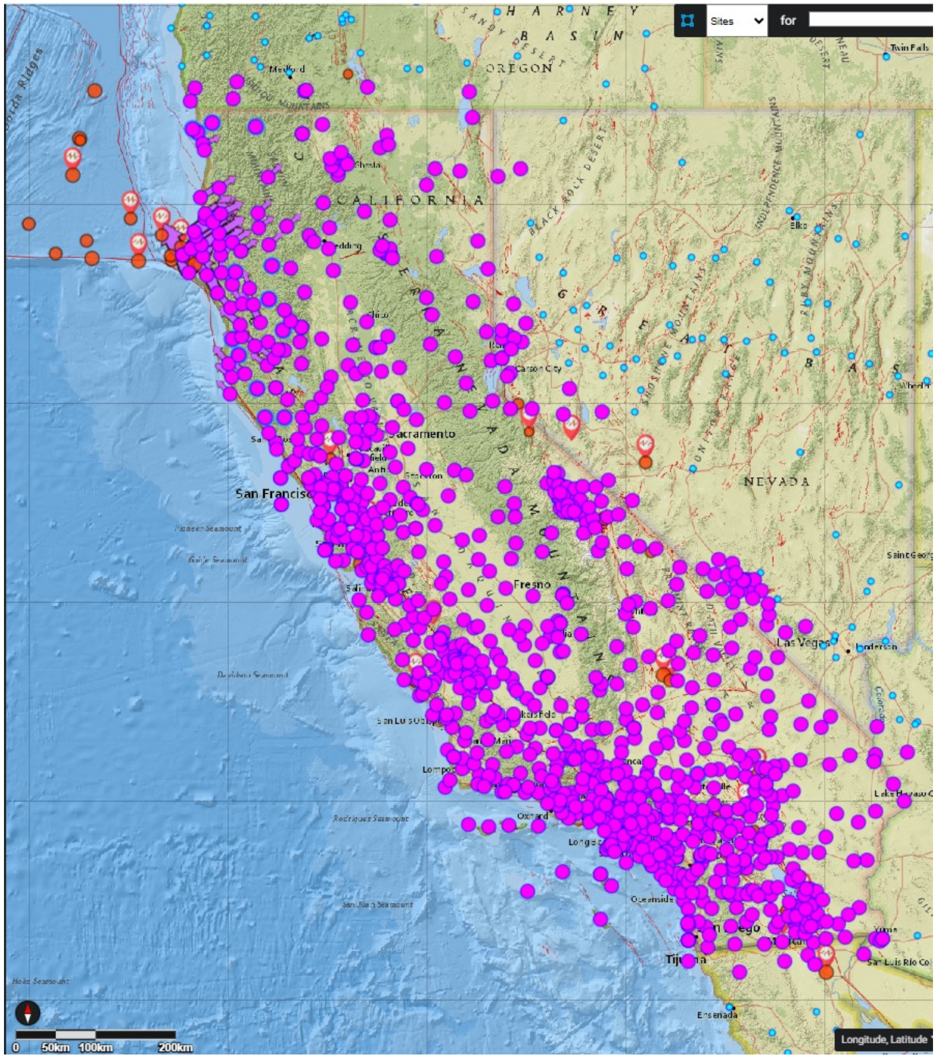
DWR Stations

California Spatial Reference System @ CSRS Epoch 2025.00

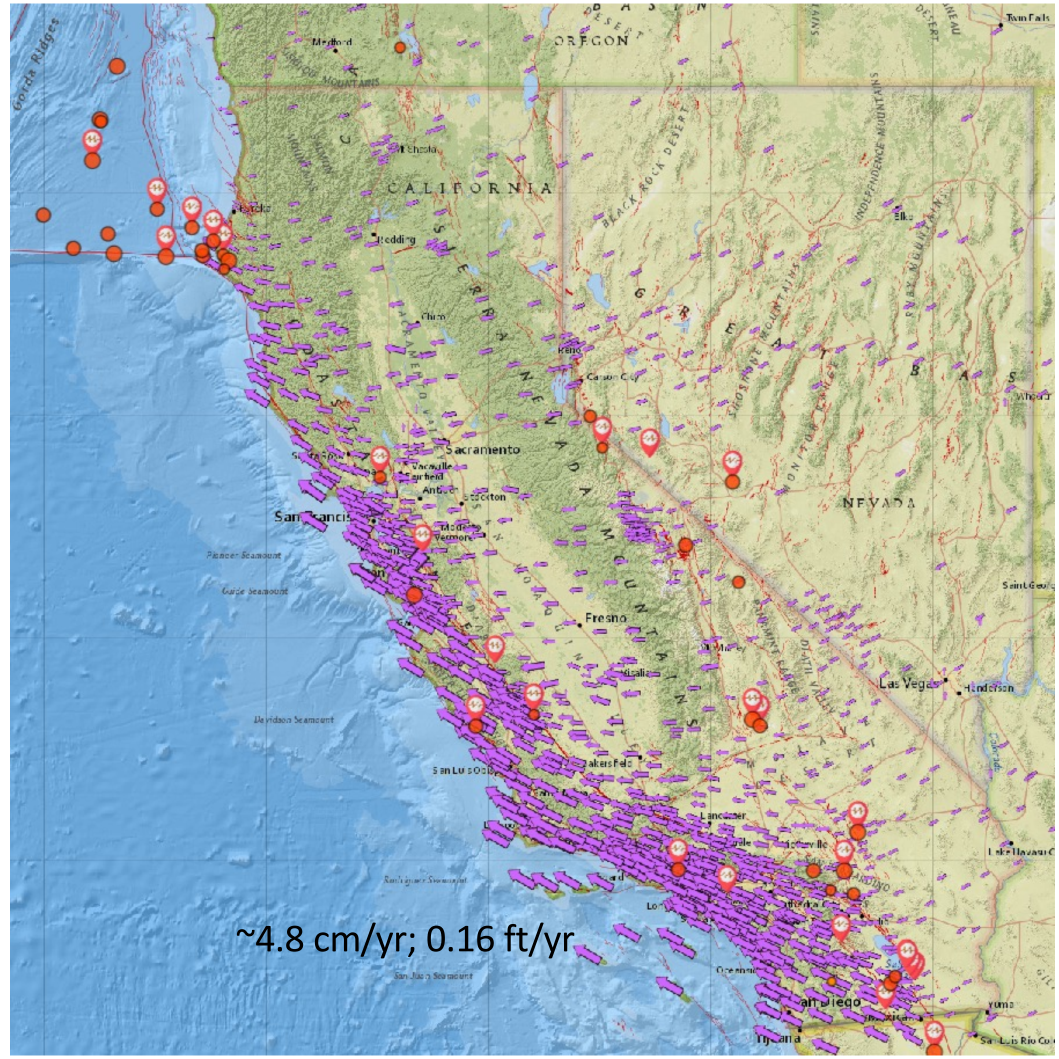
- ITRF2020 and NAD83 (2011) epoch 2025.00 coordinates, velocities, and uncertainties for 1059 CGPS stations in California and border regions
- California Spatial Reference System Epoch date is 2025.00 (2025-01-01; 2025, day of year 1; GPS week 2347, GPS day 1)
- Computed by SOPAC/CSRC SECTOR utility on 04/16/2025 Basis: SOPAC filtered position time series up to epoch 2025.2589 (04/5/2025; GPS week 2360, GPS day 6; 2025 day 095)
- Transformed to ITRF2020/IGS20 to NAD83(2011): used HTDP 3.5 ITRF2020 to NAD_83(2011) North America Plate Fixed (https://www.ngs.noaa.gov/TOOLS/Htdp/Htdp_transform.shtml)
- Coordinates refer to the geodetic reference mark (monument)
- Sigmas are at the 95% confidence level

- Station 4-character code
- Station long name
- ITRF2020 (XYZ) coordinates
- ITRF2020 (XYZ) uncertainties
- ITRF2020 geodetic (latitude, longitude, height) coordinates WGS84 ellipsoid
- ITRF2020 geodetic (latitude, longitude, height) uncertainties
- WRMS (N,E,U)
- ITRF2000 velocities (N,E,U)
- ITRF2000 velocity uncertainties (N,E,U)
- NAD83(2011) coordinates (X,Y.Z)
- NAD83(2011) geodetic coordinates WGS84 ellipsoid
- 3-D coordinate changes from Epoch 2017.5
- Start and End Dates
- Geoid 18 heights
- Geoid 18 height uncertainties
- QC comments (subsidence, transients, unstable, decommissioned)

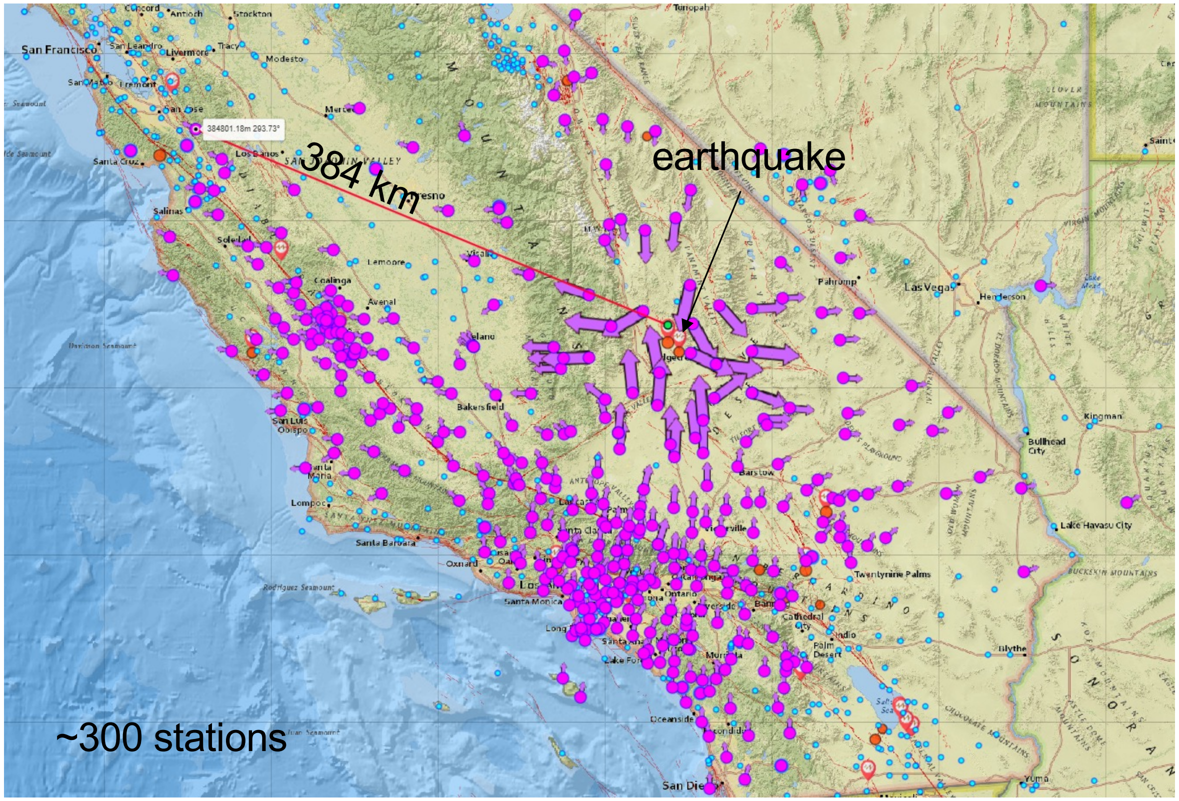
CSRS Epoch 2025.00 1058 Stations

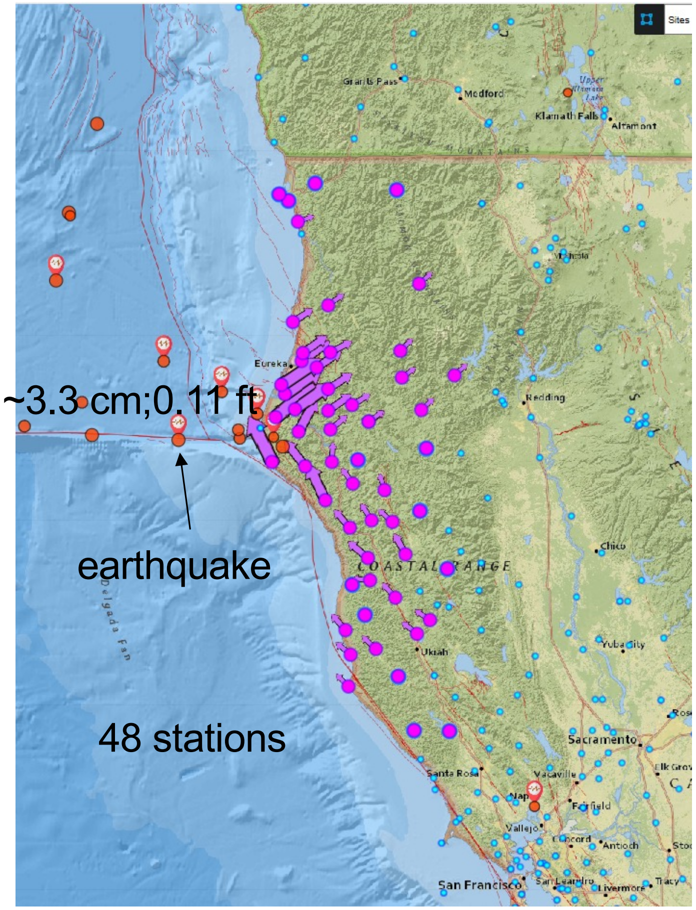


CSRS Epoch 2025.00 Velocities (ITRF2020)



Coseismic Events since Epoch 2017.5

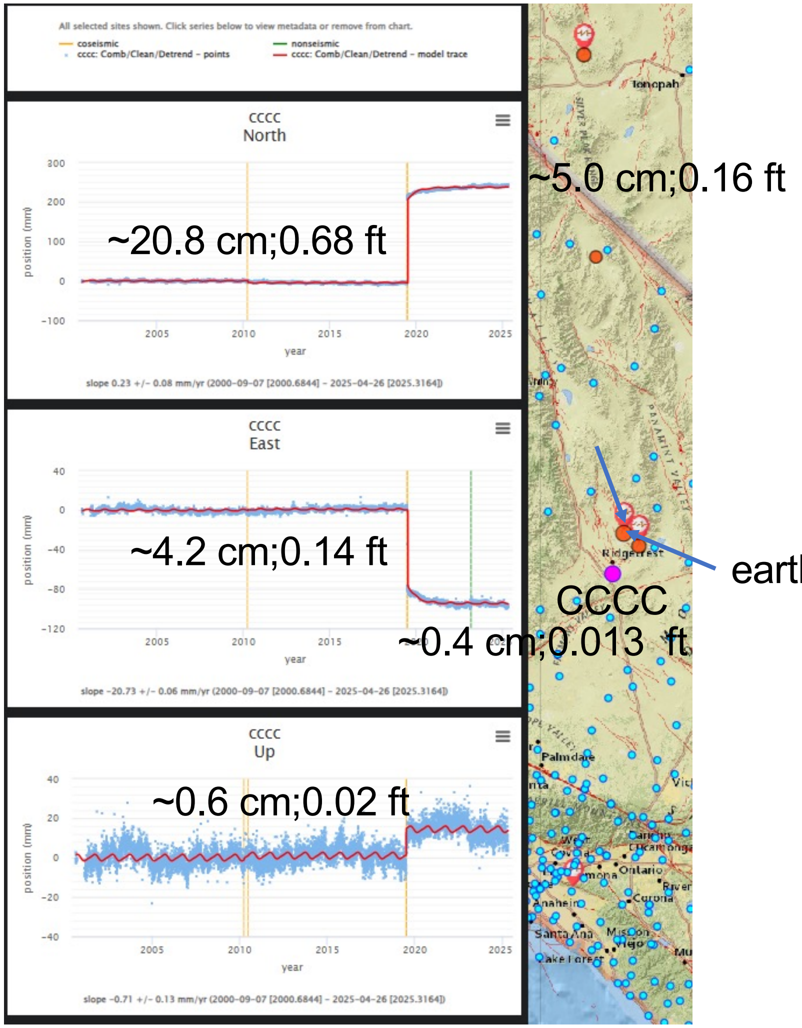




July 6, 2019
Mw7.1 Ridgecrest Earthquake

December 6, 2024
Mw7.0 Mendocino Earthquake

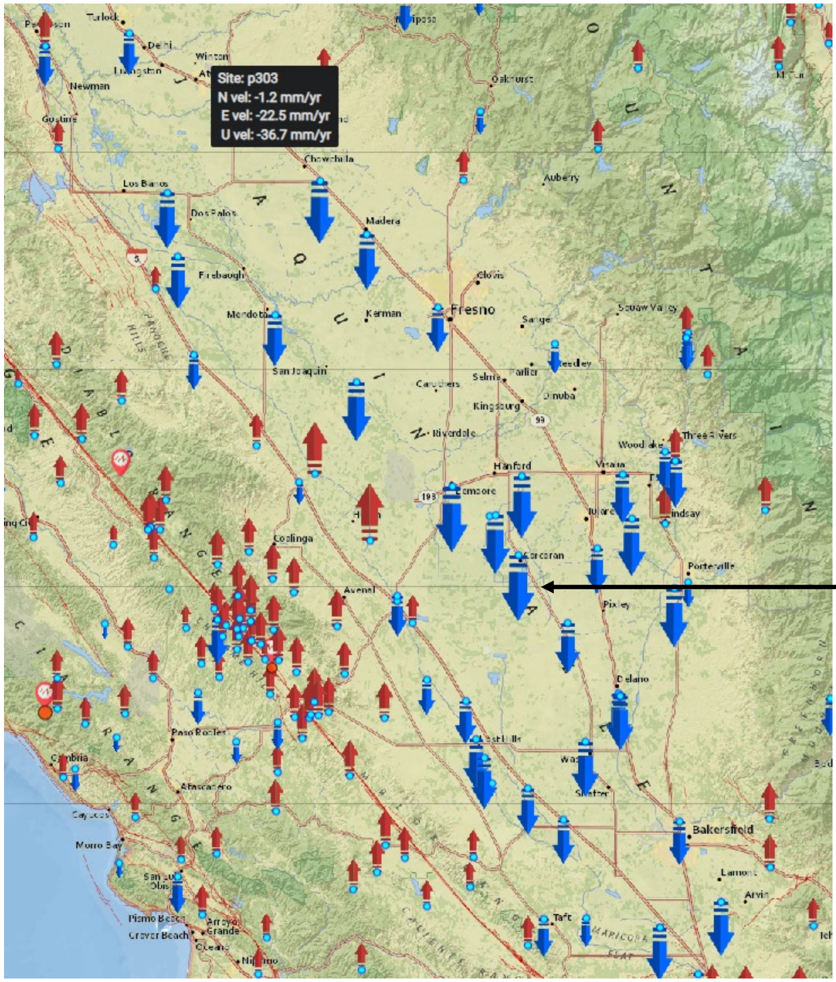
Postseismic Deformation
July 6, 2019 Mw7.1 Ridgecrest Earthquake



mgviz.ucsd.edu

Daily North, East, Up displacement time series (detrended) for station CCCC nearest the Ridgecrest earthquake's epicenter showing coseismic offsets and cumulative postseismic offsets since the earthquake

Subsidence
San Joaquin Valley



CTSRN station Corcoran RW Highway 43 (CRCN)
-18.5 cm/yr; -0.6 ft/yr

SIO NOAA/NGS FY 23 Geospatial Modeling Competition Award

Our collaboration with NGS includes three activities:

1) Create a formal **Geodesy Program at SIO** to address the nationwide deficiency of geodesists. Expand current geophysics curriculum – funding for 5 graduate students

2) Develop an **Intra-Frame Deformation Model (IFDM)** to supplement the upcoming National Spatial Reference System for users in regions of significant ground motions, using GNSS and InSAR/GNSS displacement fields and underlying geophysical models

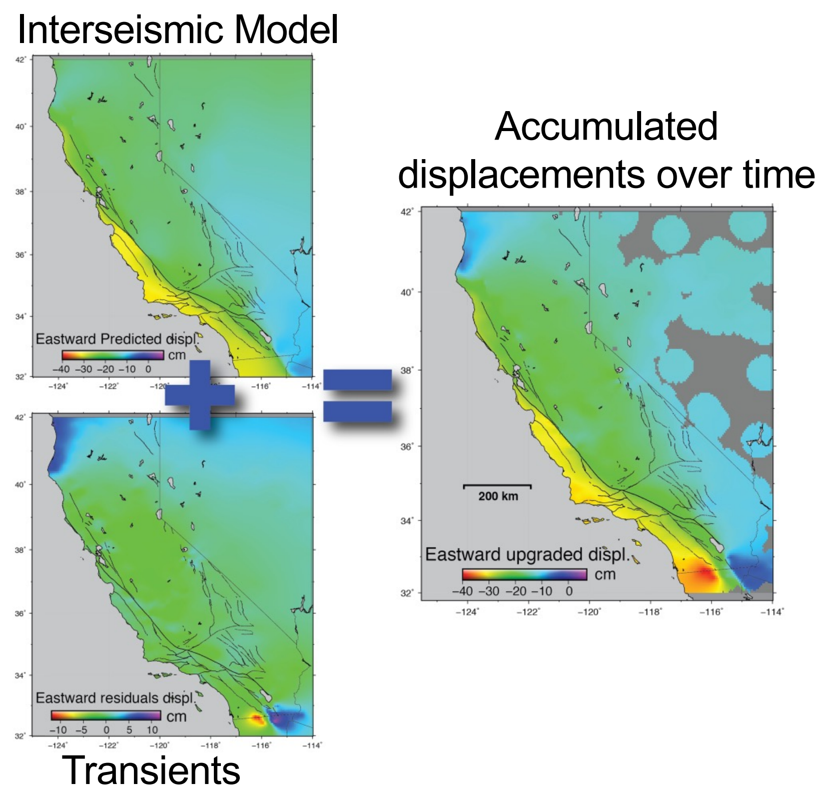
3) Investigate a **unified (marine/terrestrial) vertical reference frame**, through measurements of sea surface topography from remotely-sensed observations (e.g., SWOT, ICESat-2)

Intra-Frame Deformation Model

- Our main objective is to contribute to the development of the Intra-Frame Deformation Model-IFDM suitable for the significantly deforming regions of the U.S. (West Coast, Alaska, Hawaii, Caribbean) based on combined GNSS and InSAR data and methods.
- We are expanding on the dynamic datum approach (Klein et al., 2019), which provides a time-dependent three-dimensional reference frame to allow users in deforming regions to tie into the National Spatial Reference System (NSRS).
- The project is funded by the NOAA National Geodetic Survey's Geospatial Modeling Program as a complement to the new National Spatial Reference System.
- We are integrating GNSS and InSAR (where available) displacement fields to achieve higher spatial resolution (< 1km) than available from GNSS alone (~20-40km), and to improve precision in areas of significant vertical land motion.

Dynamic Datum Concept

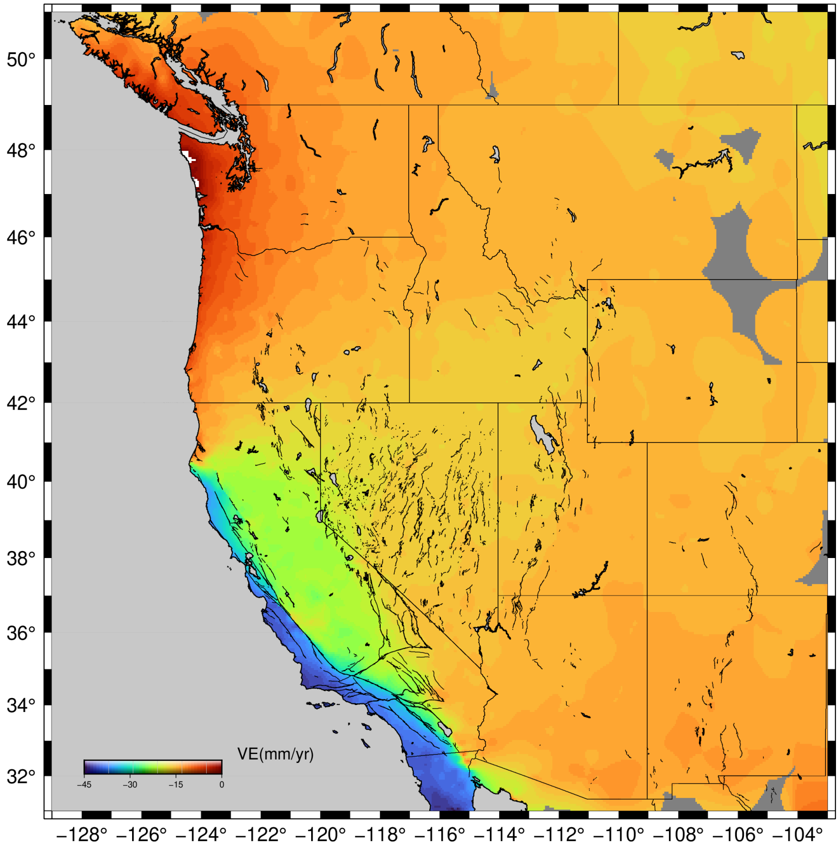
- Dynamic three-dimensional reference frame
- Interseismic model and observed surface displacements provide changes in coordinates between different epochs of time for precise surveying applications (Bock and Klein, 2018)
- Interseismic model represents the secular motion, and it is used to predict the linear displacement at any point inside the region covered by the reference network
- Observed surface displacements by GNSS stations are used to parametrically model their transient motion, defined as a station's non-secular physical motions
- Parametric model includes coseismic and postseismic displacements
- Transients include vertical motions with natural causes, such as hydrological surface loading, water aquifer recharge, and magmatic processes or anthropogenic, such as water and mineral extraction, and hydrothermal power plant generation (Bock and Klein, 2018)



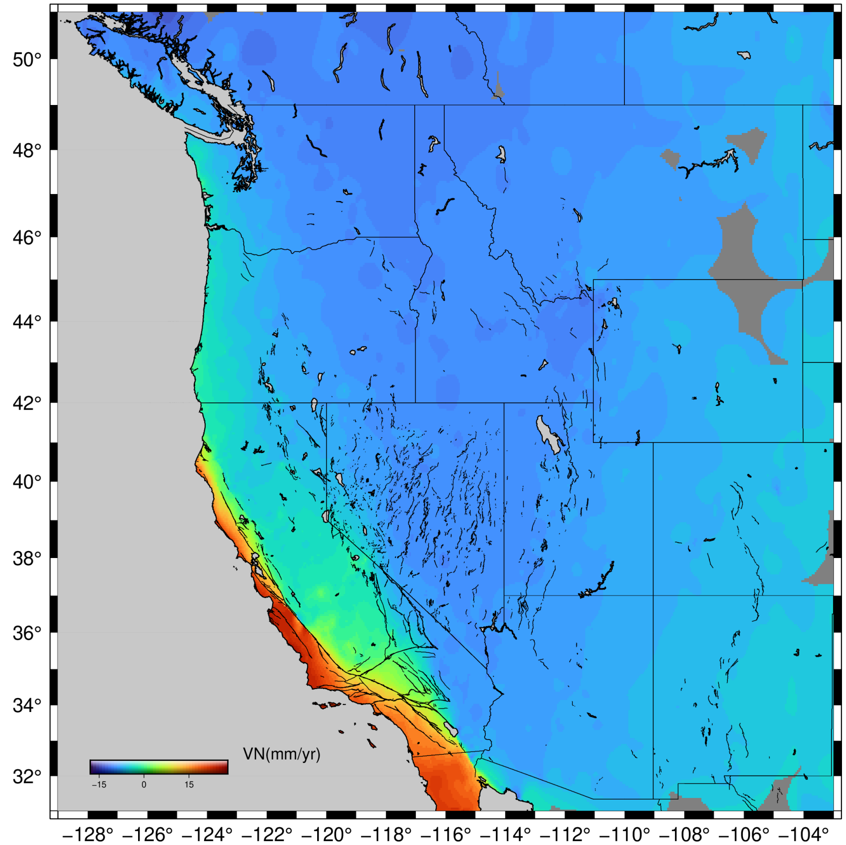
Source: Klein et al., 2019

Steady-State Velocity Field (Interseismic): Horizontal

East Component



North Component

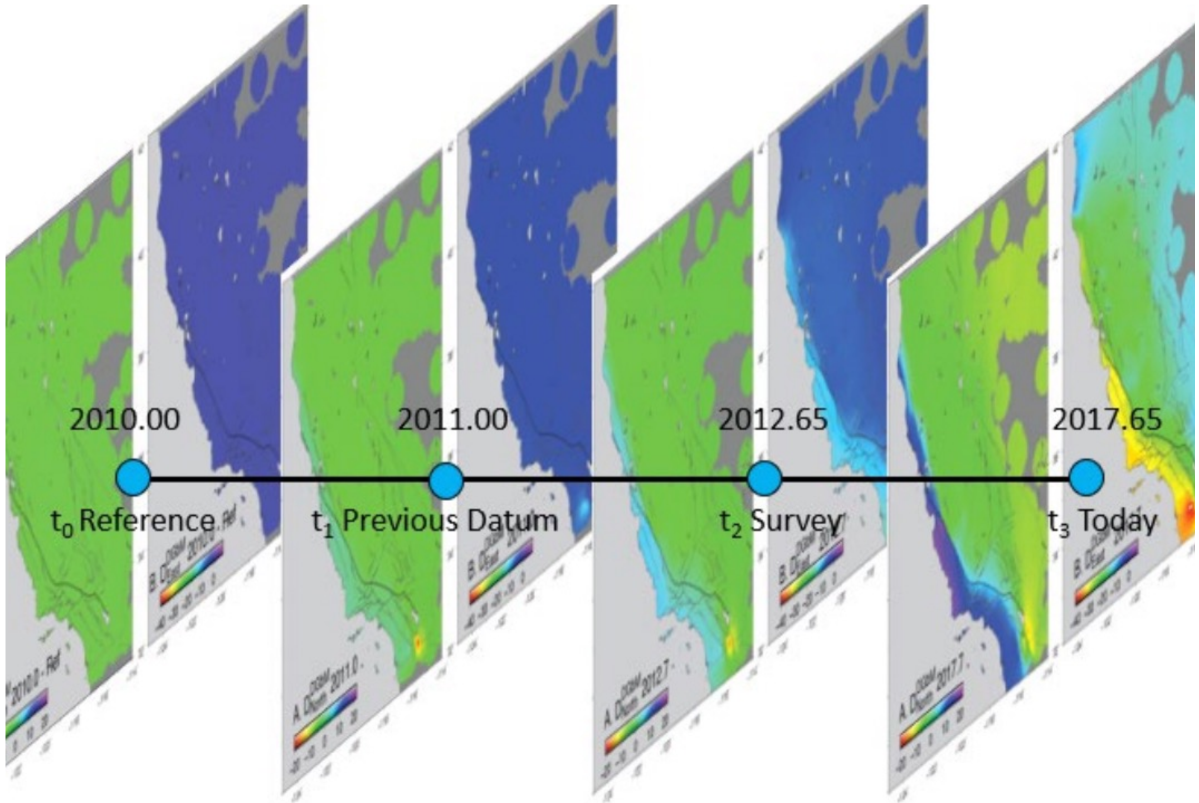


Prepared by Lane Souza

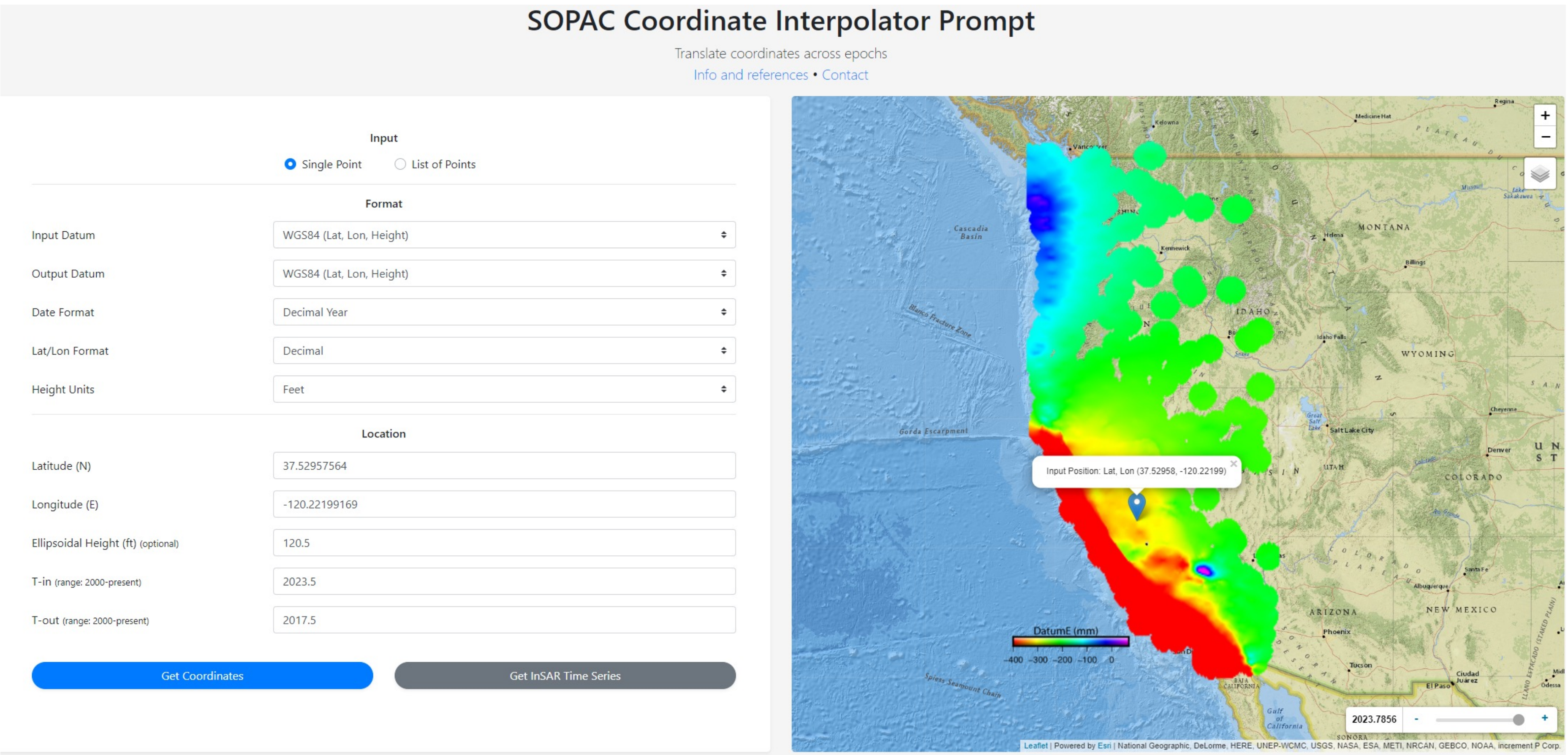
Zeng, 2023, USGS

Weekly Displacement Grids

The SCIP web application for the Western U.S. (http://sopac-adj.ucsd.edu/scip/). Provides the expected 3-D displacements between any two epochs with respect to several reference frames (e.g., NAD83(2011) and ITRF2020)



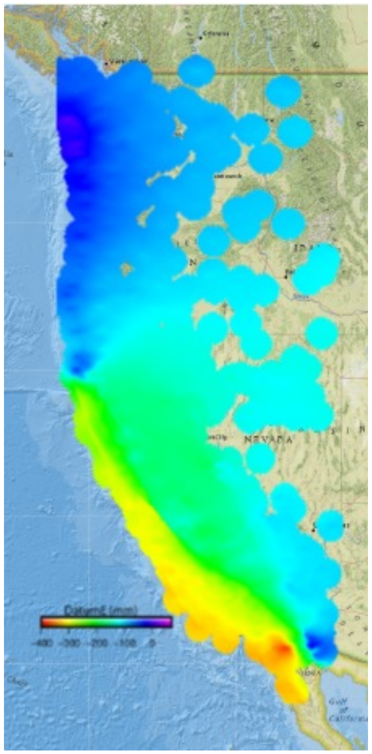
SCIP Utility



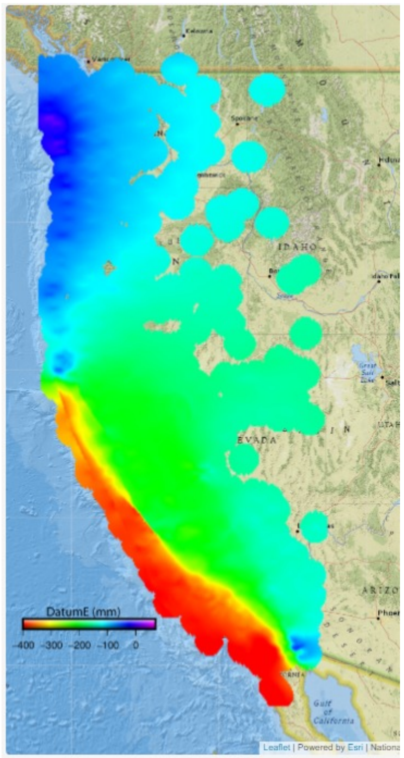
http://sopac-adj.ucsd.edu/scip/

Intra-Frame Deformation Model: Horizontal

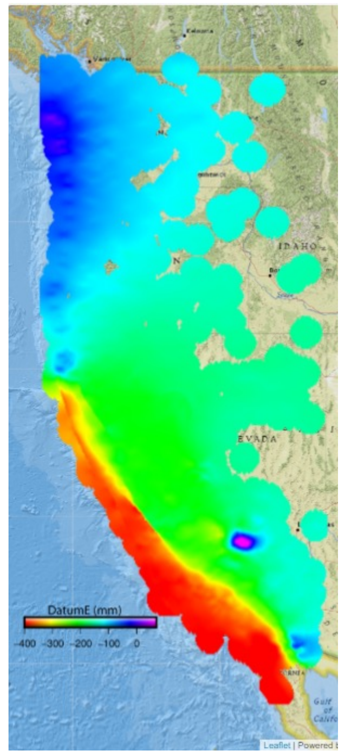
Weekly Displacement Grids – East Component



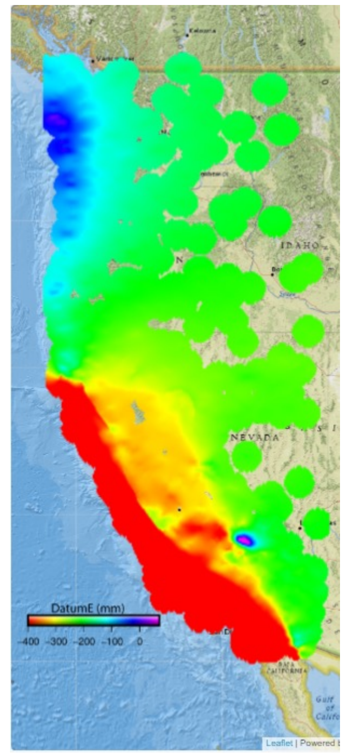
2017-05-27



2019-06-05

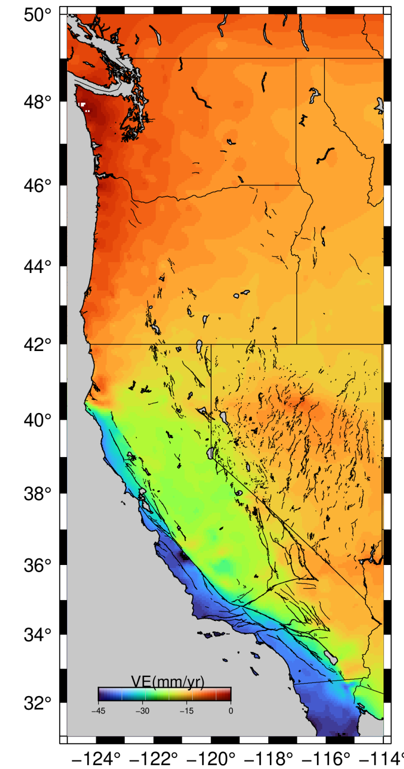


2019-07-10



2024-04-21

East Velocity Model (wrt North America Plate)



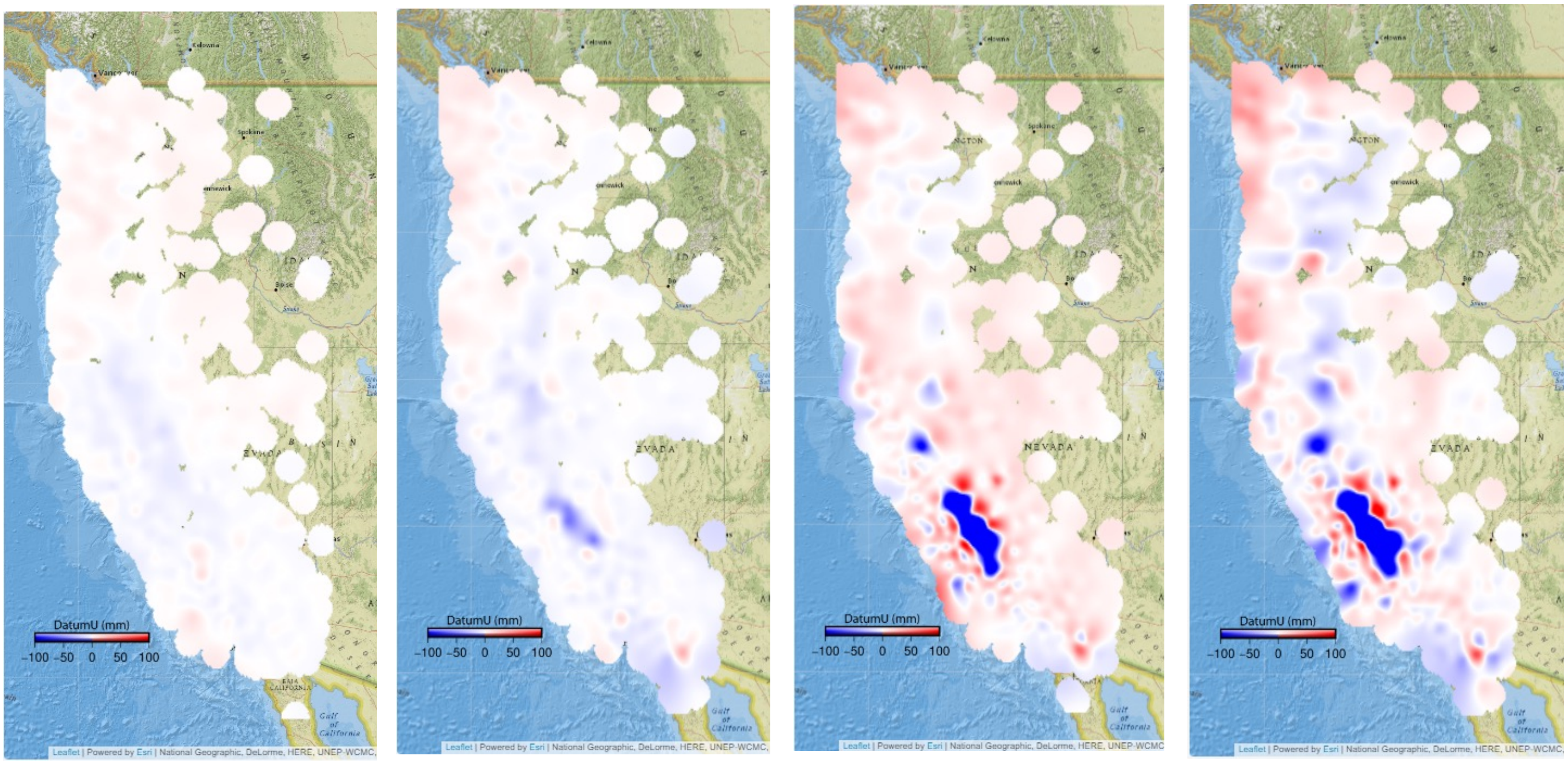
Zeng, 2023

SCIP Utility http://sopac-adj.ucsd.edu/scip/

Intra-Frame Deformation Model: Vertical

Weekly Displacement Grids – Up Component

Up Velocity Model



2010 2012 2016 2020

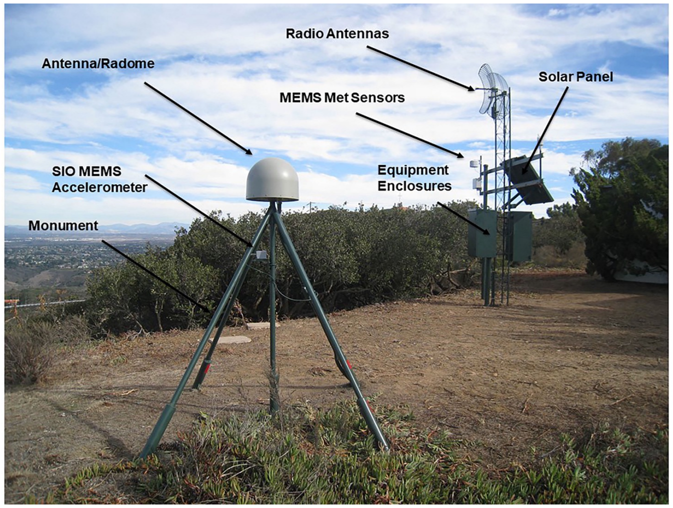
X

Increase spatial resolution using integration with Interferometric synthetic aperture radar (InSAR)

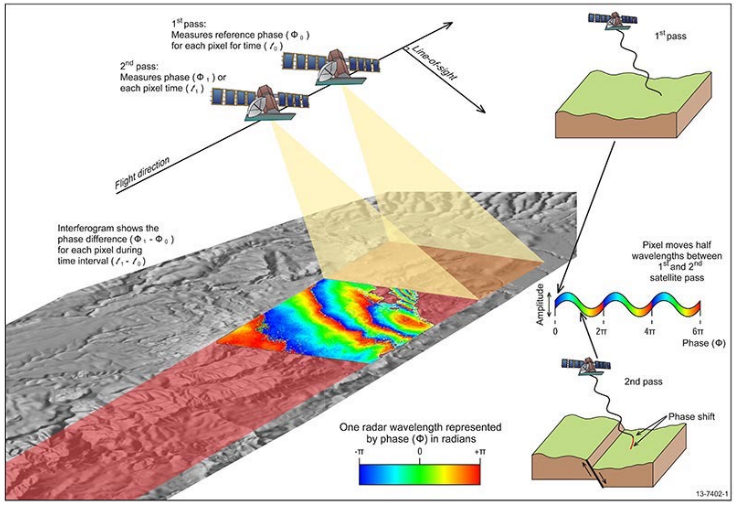
SCIP IFDM Utility http://sopac-adj.ucsd.edu/scip/

Observation Systems: Instrumentation

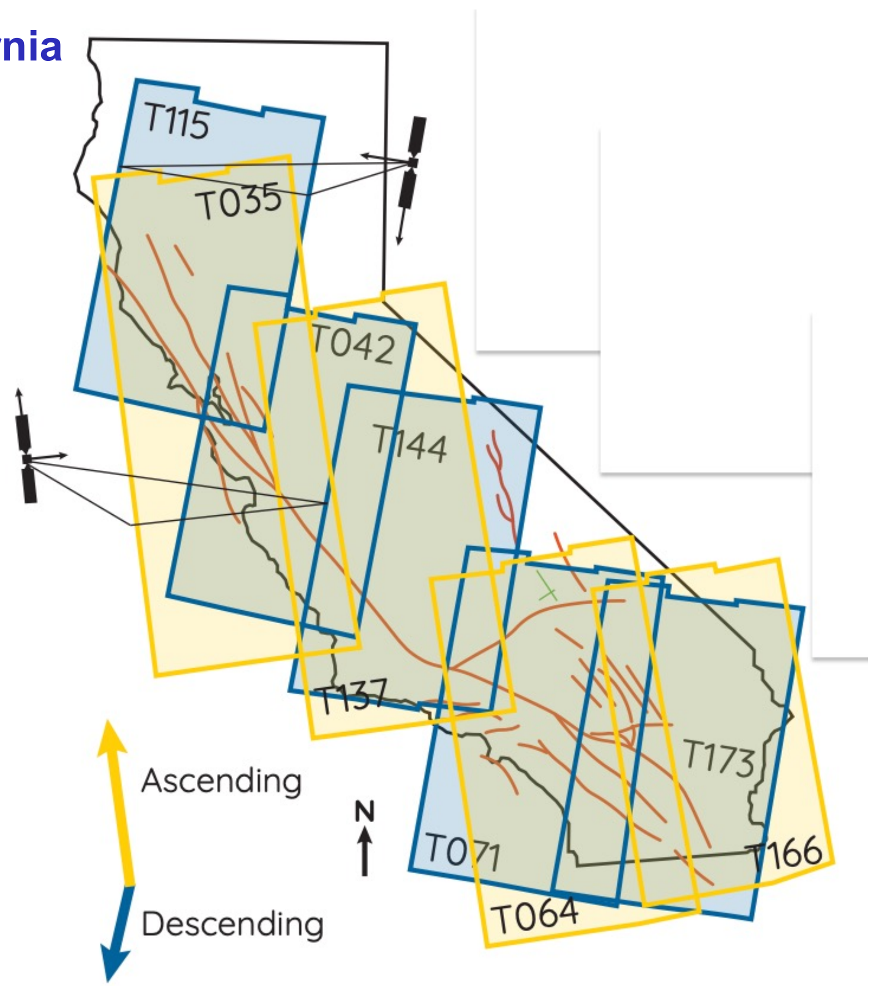
Typical continuous GNSS station



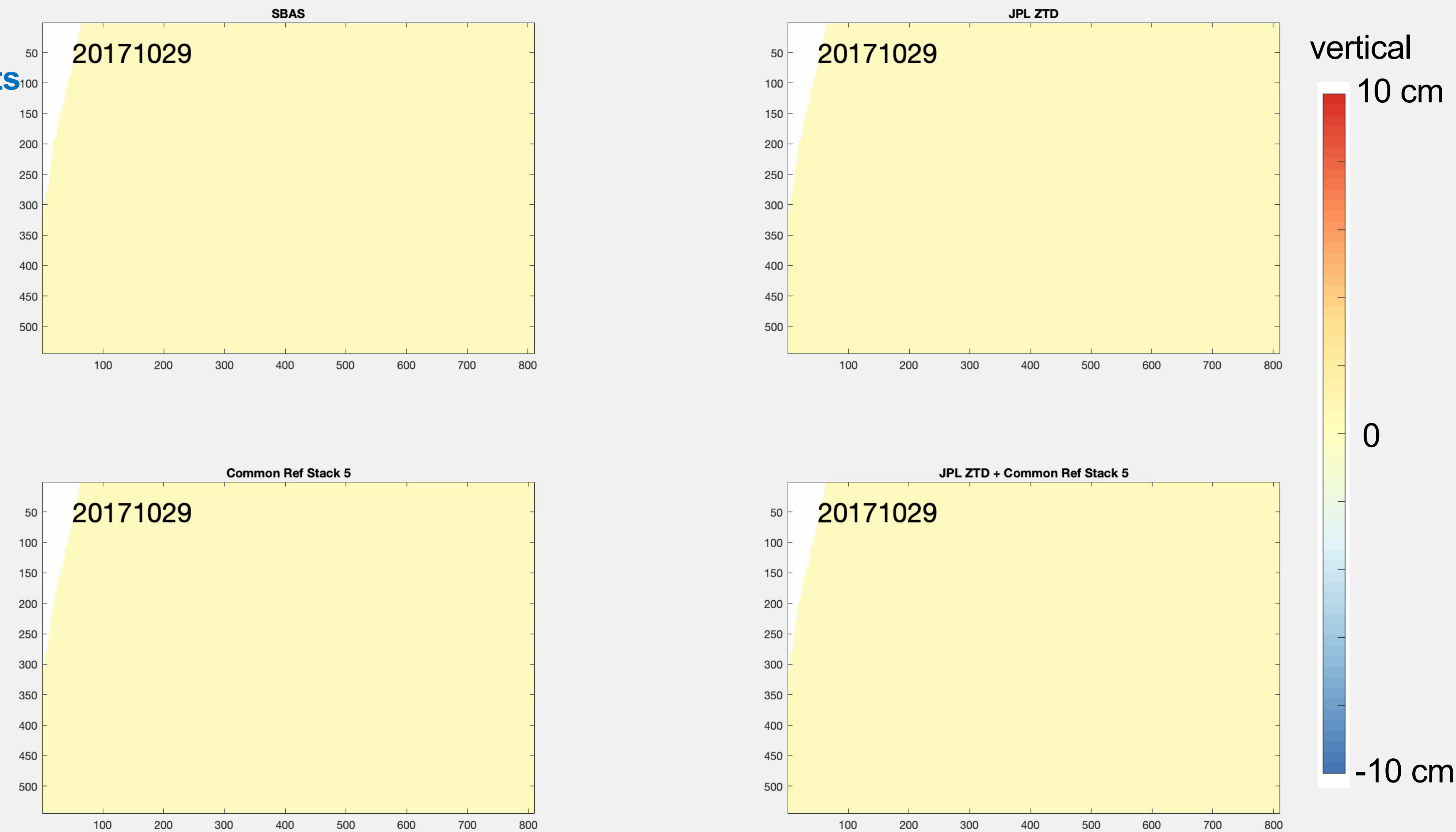
Conceptual diagram for integrated synthetic aperture radar InSAR



InSAR Tracks Over California



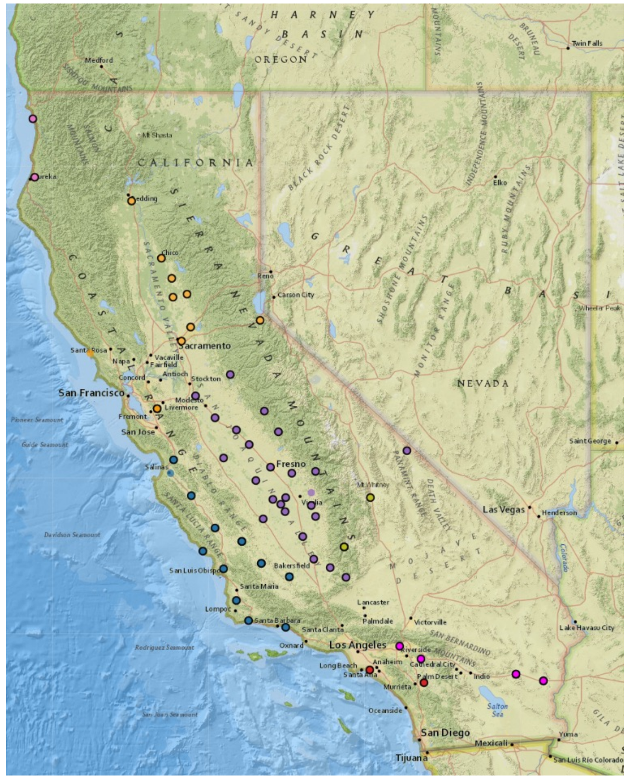
InSAR/GNSS Vertical Displacements



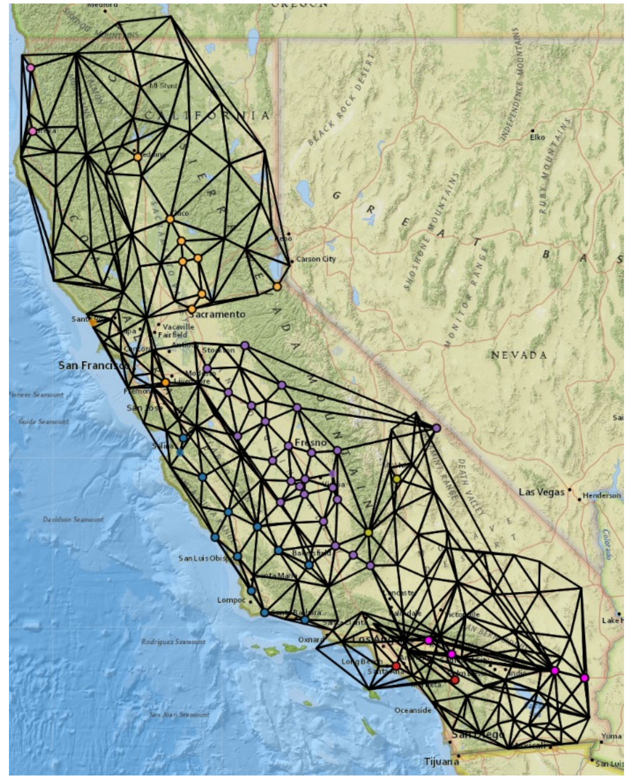
Prepared by Molly Zebker

Caltrans Spatial Reference Network (CTSRN)

CTSRN – Including Affiliates



CTSRN – Caltrans Stations

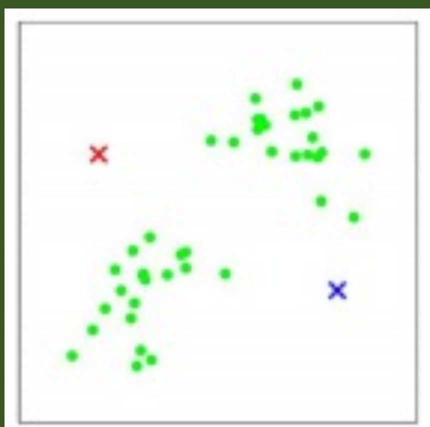


CTSRN – Subnetworks

Identify regions to reduce the amount of work needed to maintain the CTSRN by reducing the need for frequent Epoch dates in stable areas, increase adjustment intervals in volatile areas, and define the boundaries between areas

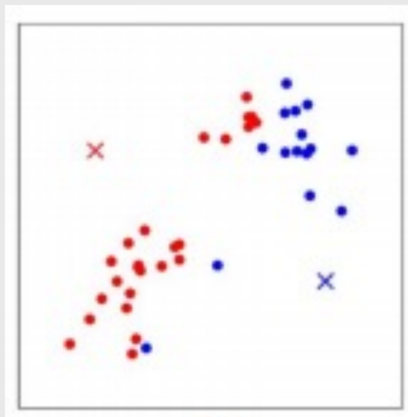
Machine Learning Approach: K-Means Clustering

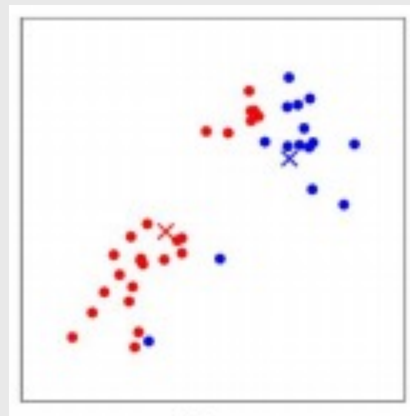
Starts:



Unlabeled dataset with a specified number of cluster centers placed randomly.

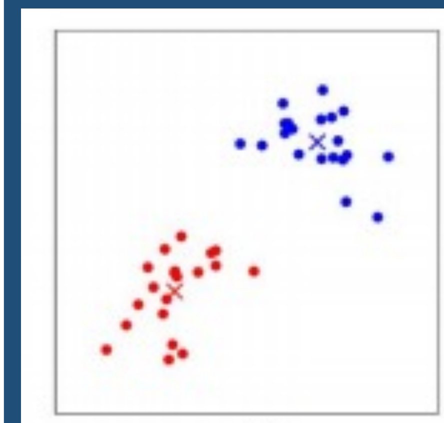
Iterates:





The data points are assigned to the closest center. Then, the cluster centers are moved according to the data.

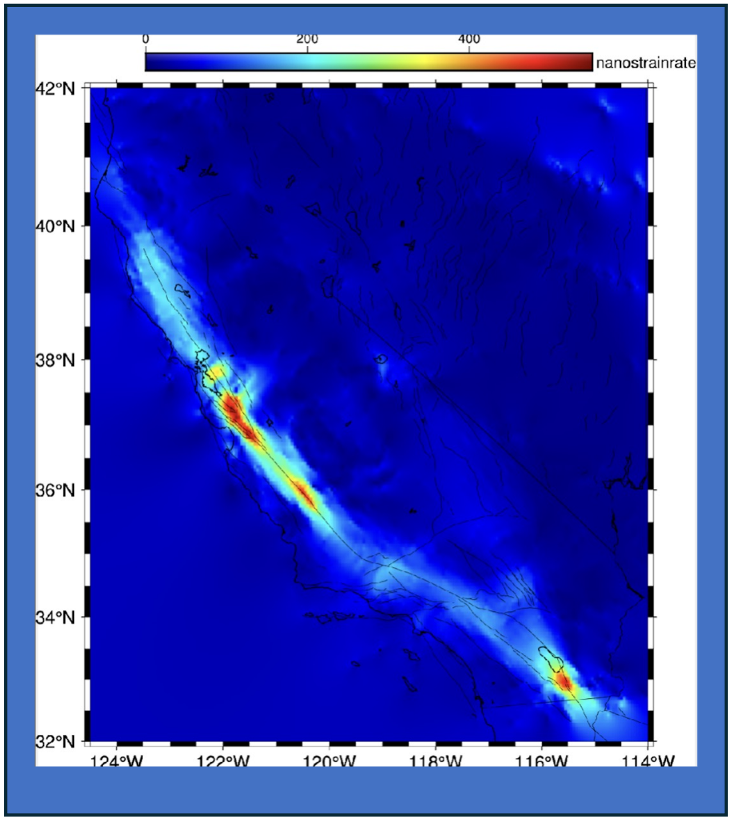
Ends:



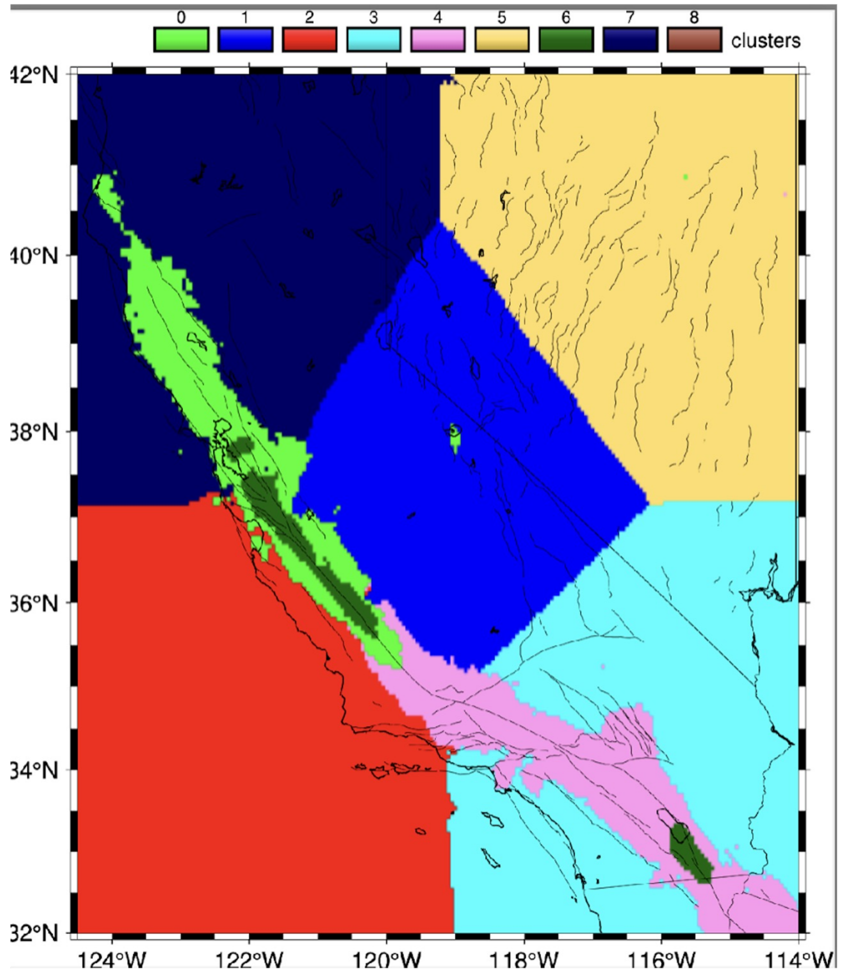
When fit tolerance or maximum number of iterations are hit, K-Means stops

Prepared by Aubrey Bennett

K-means Clustering
Input: Maximum Shear Stain Rates Derived from Horizontal Velocities



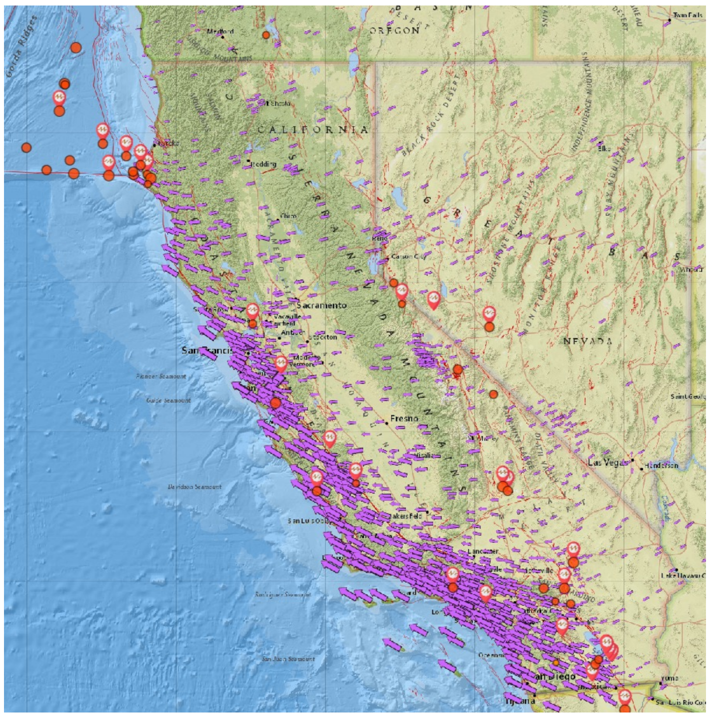
8 clusters



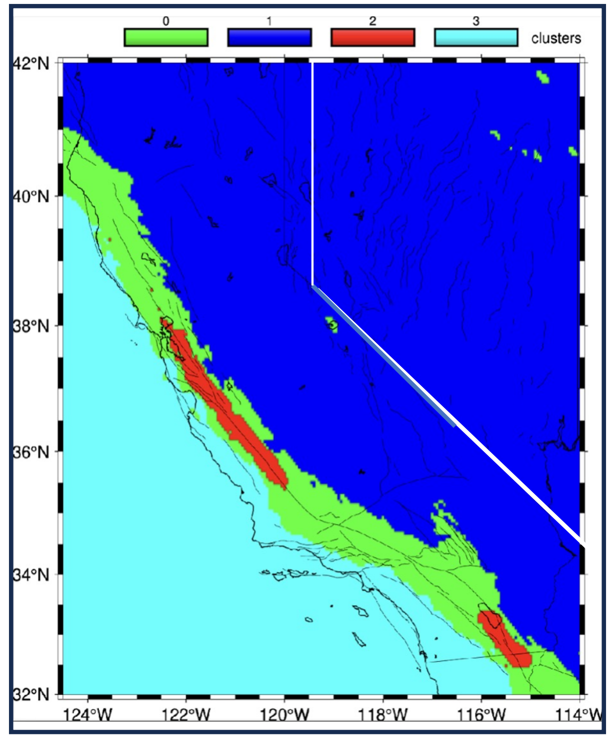
Maximum shear strain rate refers to the highest rate at which the Earth's crust is being sheared. Used to identify fault z9ones over time. In geophysics and tectonic studies, it's typically derived from GNSS velocity fields and is important for identifying deformation zones such as faults or shear zones.

Prepared by Aubrey Bennett

K-means Clustering
Input: Horizontal Velocities & their Derivatives



4 clusters



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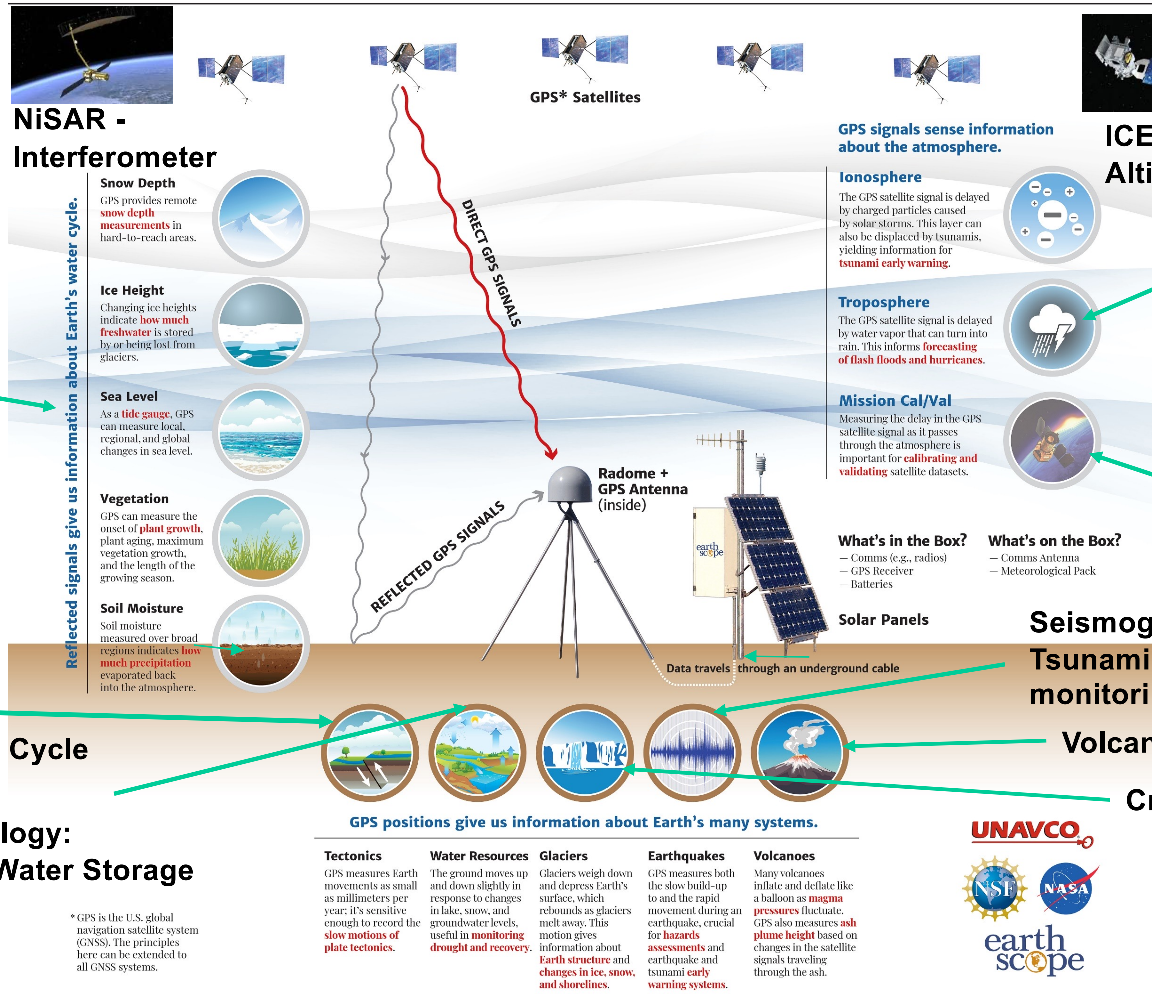
3) Investigate a **unified (marine/terrestrial) vertical reference frame**, through measurements of sea surface topography from remotely-sensed observations (e.g., SWOT, ICESat-2)

Focus: Acquire Geodetic Principles to Support a Range of Science Applications & Expand the Pool of Geodesists in the U.S.

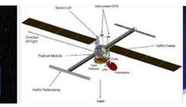
Geodesy
What ~~GPS~~ Can Tell Us About Earth

High-precision GPS stations measure natural phenomena and hazards.



NiSAR - Interferometer

ICESAT-2 Altimeter



SWOT - Altimeter

GRACE - Gravimeter

Meteorology: Atmospheric Water Vapor

Sea Level/Geoid

Gravity; Data Science Calibration/Validation

Seismogeodesy: Earthquake & Tsunami Warning ; Structural monitoring

Tectonics: Crustal Deformation/Earthquake Cycle

Volcanology

Cryosphere/Glaciology

Hydrology: Total Water Storage

https://www.unavco.org/wordpress/wp-content/uploads/2021/06/UNAVCO-infographic-GPSforEarthScience.jpg

Geodesy Track at SIO

- Project includes five years of funding for five graduate students (NGS Grant) and two graduate students (National Geospatial-Intelligence Agency - NGA)

- The students follow the new Geodesy track with the existing Geophysics Program and have a geodesy-related thesis. [One or more of the students will focus on developing an intra-frame deformation model (IFDM) to supplement the NSRS in areas of significant crustal motions.]

- Five students are currently in program

- Three students admitted for Fall Quarter 2025

- For five graduate student researchers:
  Salary + benefits $202,809; tuition remission - $116,145 (Year 2 or project)
  Overhead (58%): $117,629: **Total: $436,583; $87,316.6/student**

Geodesy Track Classes (2024-2026)			
Number	**Title**	**Instructor(s)**	**Schedule**
SIO 229	Fundamental of Gravity and Geodesy	Borsa/Bock	Winter 2025
SIO 239	Geophysical Applications of GPS/GNSS Geodesy	Haase	Fall 2024
SIO 135	Satellite Remote Sensing	Fricker/Sandwell	Spring 2025
SIOG 237 (some field work)	Space Geodesy Seminar	Fialko/Haase/Sandwell	Winter 2025
SIO 230	Radar Interferometry	Sandwell/Mellors	Fall 2025
SIO 223a/b (foundational)	Geophysical Data Analysis I, II	Morzfeld/Agnew/Fan	Fall 2024/Winter 2025
SIOC 210	Introduction to Physical Oceanography	????	????
SIO 239 (new)	Sea Floor Geodesy	Zumberge/Sandwell	
New	Geodetic Field Work & Aircraft Gravity	Greenbaum	2026

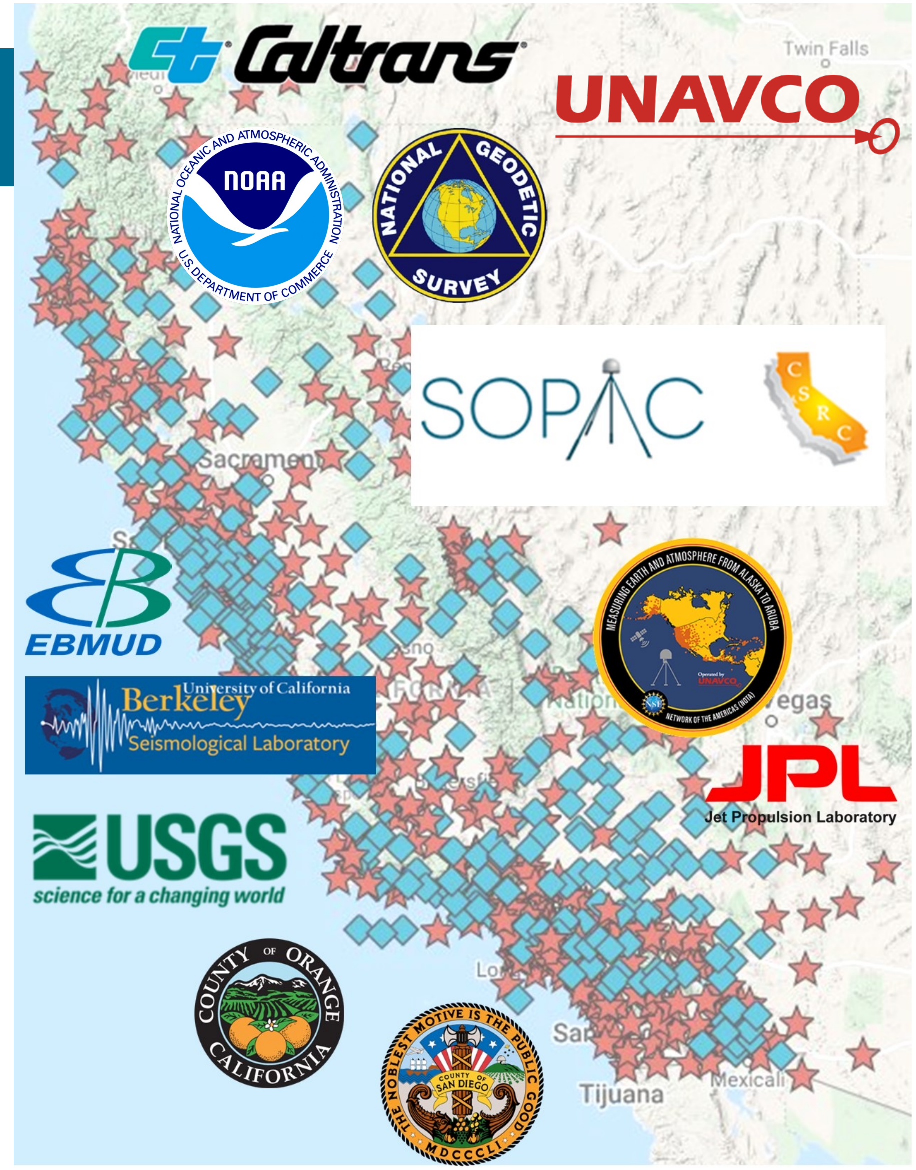
SIO Faculty: David Sandwell, Jennifer Haase, Yehuda Bock, Adrian Borsa, Yuri Fialko, Jamin Greenbaum, Matthew Mazloff, Mark Zumberge, Helen Fricker, Robert Mellors

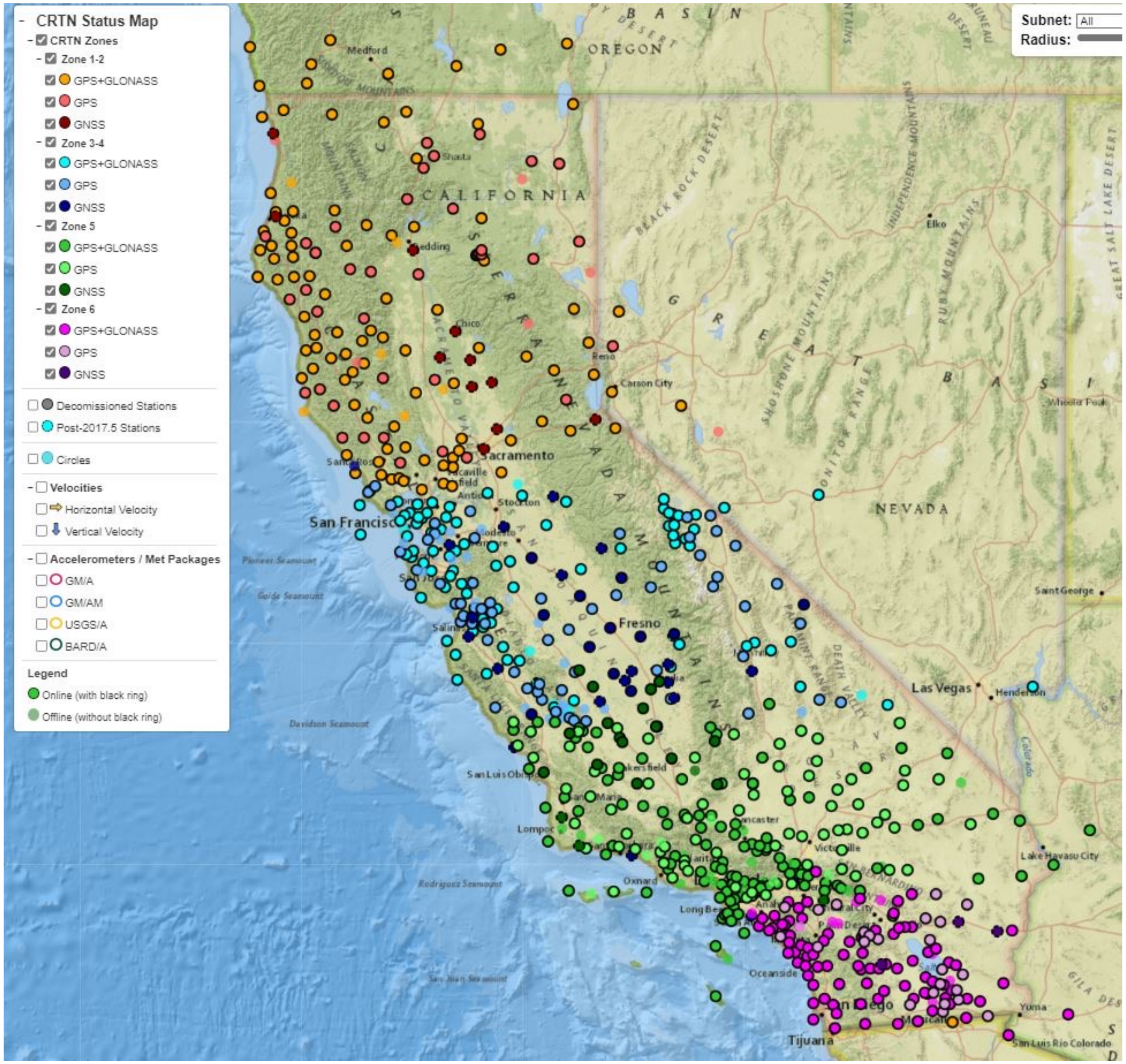
Collaborators: Humberto Gallegos, California Baptist University

NGS: Jacob Heck (Subject Matter Expert); Dana Caccamise, Pacific Southwest Regional Advisor (CA, NV)

California Real Time Network @ CSRS Epoch 2025.00

- Migrated to Dynamic Datum software – Zones 3-4 & 5
  Plan to add Zones 1-2 and 6
- New CTSRN & DWR stations
- CSRC **Epoch 2025.00 (NAD83)** coordinates will be transmitted in RTCM3 messages to **CRTN** users
- Access to EarthScope's new NOTA server with full GNSS messages





CRTN Status Map

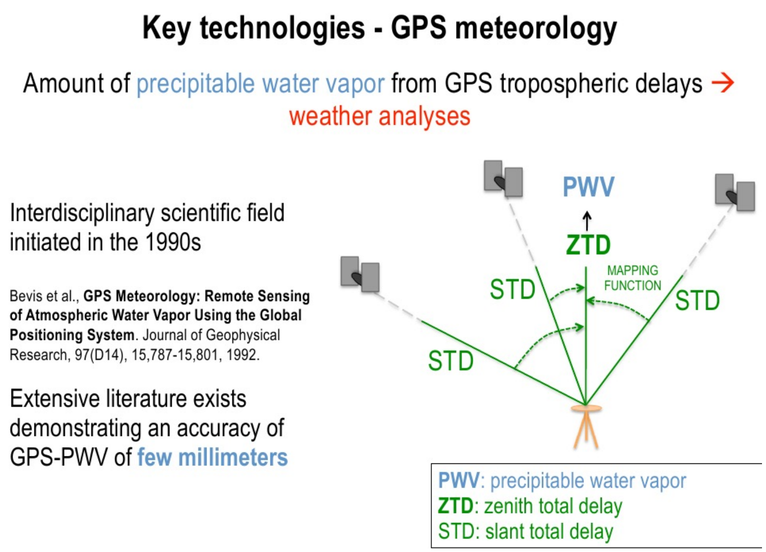
All stations

Updated continuously

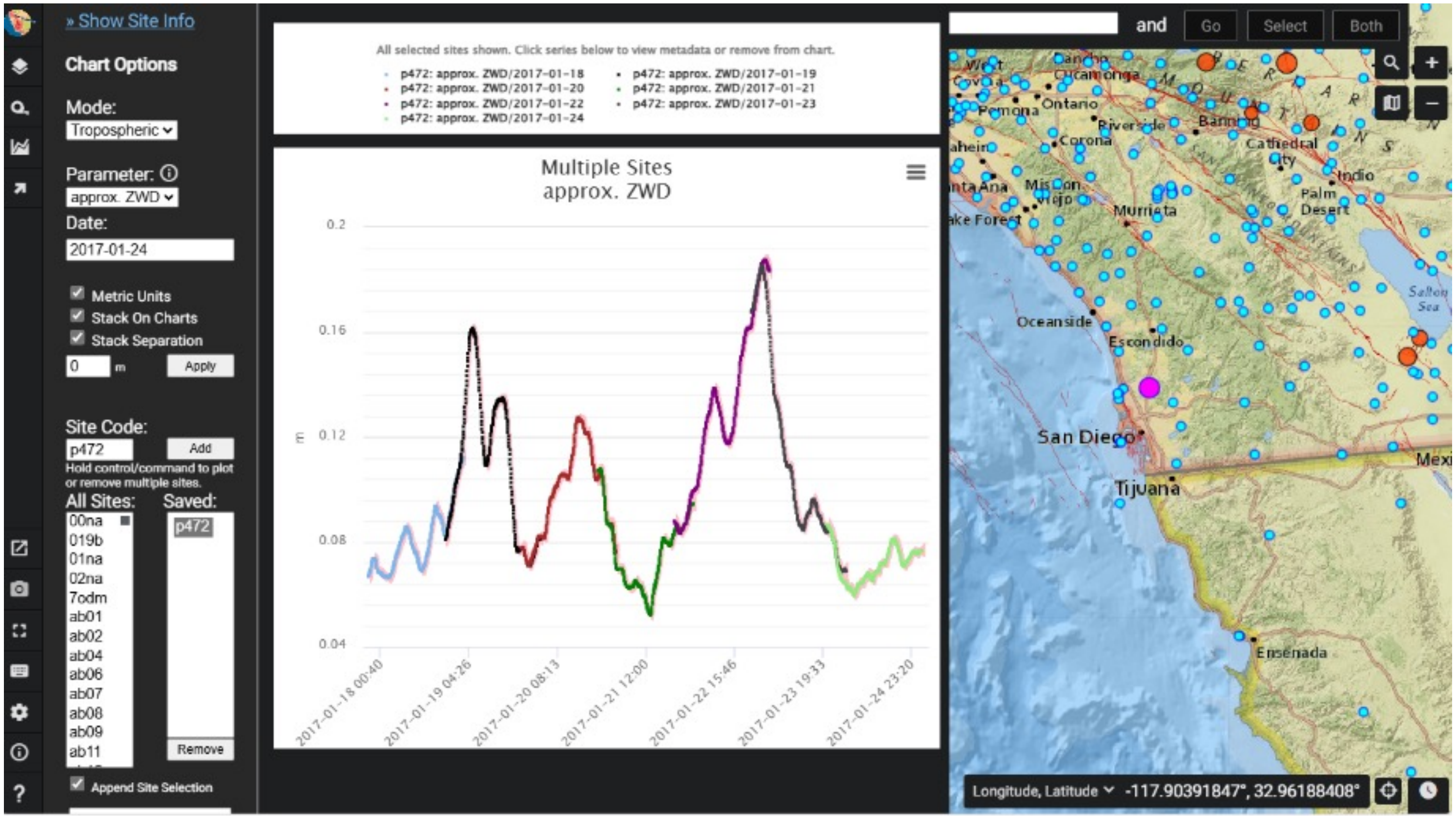
https://sopac-adj.ucsd.edu/crtn-map/

Flash Flood Warning Decision using "GNSS Meteorology"

- The travel time of the radio signals from a GNSS satellite to a ground station is delayed as they traverse the troposphere. This delay must be considered in the analysis of GNSS data for position, by estimating total zenith tropospheric delays (ZTD) over each station in a GNSS network
- ZTD has two components, zenith hydrostatic delay (ZHD) and zenith wet delay (ZWD); ZHD can be computed empirically while ZWD can be estimated with in situ pressure and temperature readings and is related to "precipitable water" (PW), the primary factor driving extreme weather events. "GNSS Meteorology" (Bevis et al., 1992,1994) is used to estimate PW above the region spanned by a GNSS network
- Not all of the 1000+ GNSS stations on the U.S. West Coast have met sensors so we calculate an approximate ZWD observation by subtracting ZHD from ZTD and using it as a surrogate for PW.
- Using the approximate ZWD observations, the union of the Guan and Waliser's & Rutz's atmospheric river catalogs, precipitation records and historical flash flood warnings to label events, we construct a Long Short-Term Memory (LSTM) machine learning method to rapidly predict the spatio-temporal path of landfalling ARs and whether or not to issue a flash flood warning.

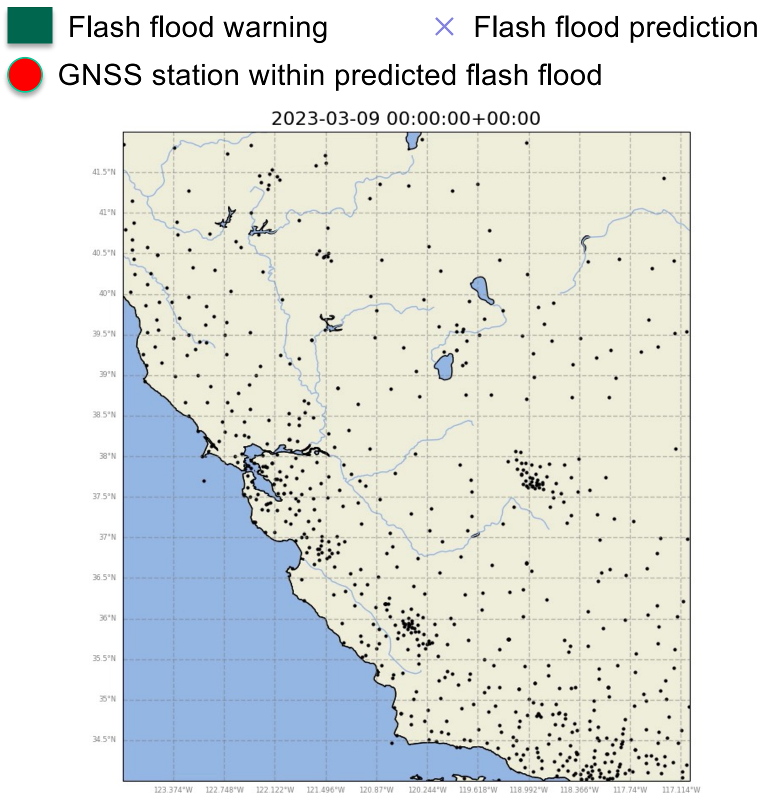


MGViz
Viewing Troposphere Parameters



Zenith wet delay before and after sequence of AR events: 2017-01-18 to 2017-01-24

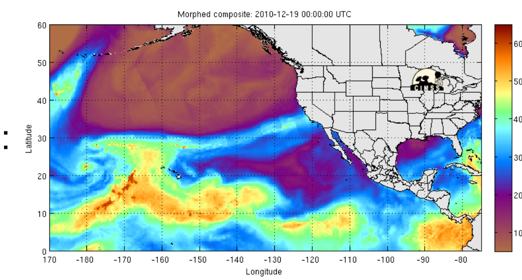
Flash Flood Predictions with LSTM



Training Set (2004–2014): Used for model training.
Validation Set (2015–2016): Used for hyperparameter tuning and intermediate evaluations.
Testing Sets/Predictions (2017, 2021, 2023): Used for final performance evaluation.

Input: ZWD and gradients
Labels:
Union of 2 AR catalogs
Precipitation records
Historical Flash Flood Warnings
Output:
Movement of weather events
Issue flash flood warning

Atmospheric Rivers

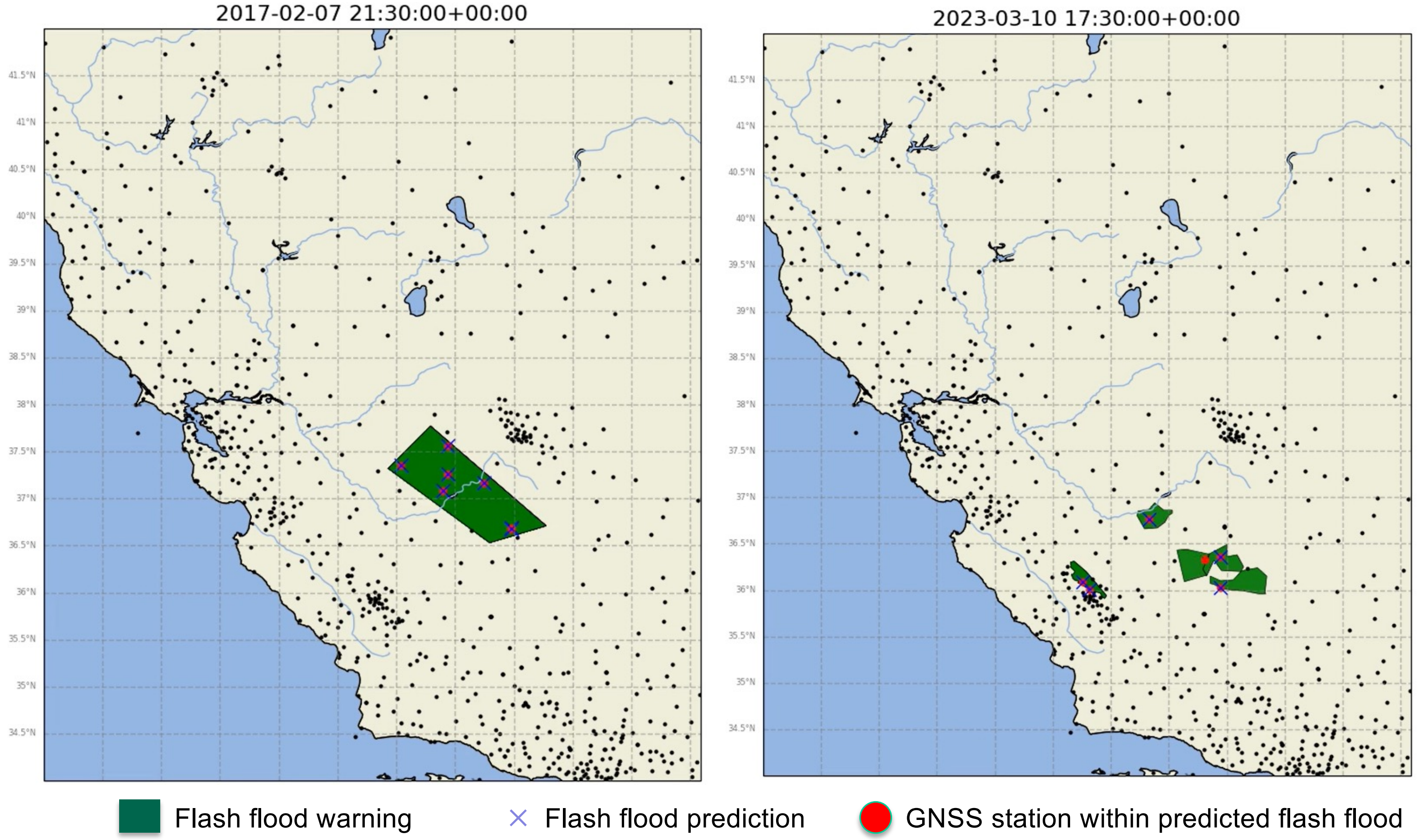


Flash Flooding

An atmospheric river (AR) is a long, narrow, and transient corridor of strong horizontal water vapor transport originating in the Pacific delivering large concentrations of water vapor causing an increasing number of damaging and sometimes deadly flash floods, debris flows, high elevation blizzards, and high winds

Prepared by Bhavik Chandna

Flash Flood?



Prepared by Bhavik Chandna


Thank you!
Questions?
Photo by Catherine Johnson, November 2005