Director's Report

Yehuda Bock

Scripps Institution of Oceanography (SIO)

University of San Diego (UCSD)

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

CSRC Coordinating Fall Meeting

Fresno State

November 2, 2023

Contributions by:

SIO: Peng Fang, Katherine Guns, David Sandwell, Roland Hohensinn, Anne Sullivan, Songnian Jiang, Alistair Knox

JPL/Caltech: Angelyn Moore, Zhen Liu

CSRC AT UCSD, SCRIPPS OCEANOGRAPHY

- **CSRC is a Support Group of the UC and UCSD, a non-profit, public research university**
  - Regents of the University of California
  - University of California San Diego (UCSD)
  - Scripps Institution of Oceanography (SIO)
  - Institute of Geophysics and Planetary Physics (IGPP Department)
- **UCSD** was founded in 1960 and is recognized as one of the top 15 research universities worldwide
- **Scripps Institution of Oceanography** has been one of the most reputable institutions for global earth science, oceanographic research, and education since 1903
- **Scripps Orbit and Permanent Array Center (SOPAC)** research group operates CSRC/CRTN and provides staff, facilities and infrastructure
- **CSRC Governance** Executive Committee representing academia, federal, state and local agencies and the private sector (mostly volunteers).

http://sopac-csrc.ucsd.edu/index.php/executive-committee/

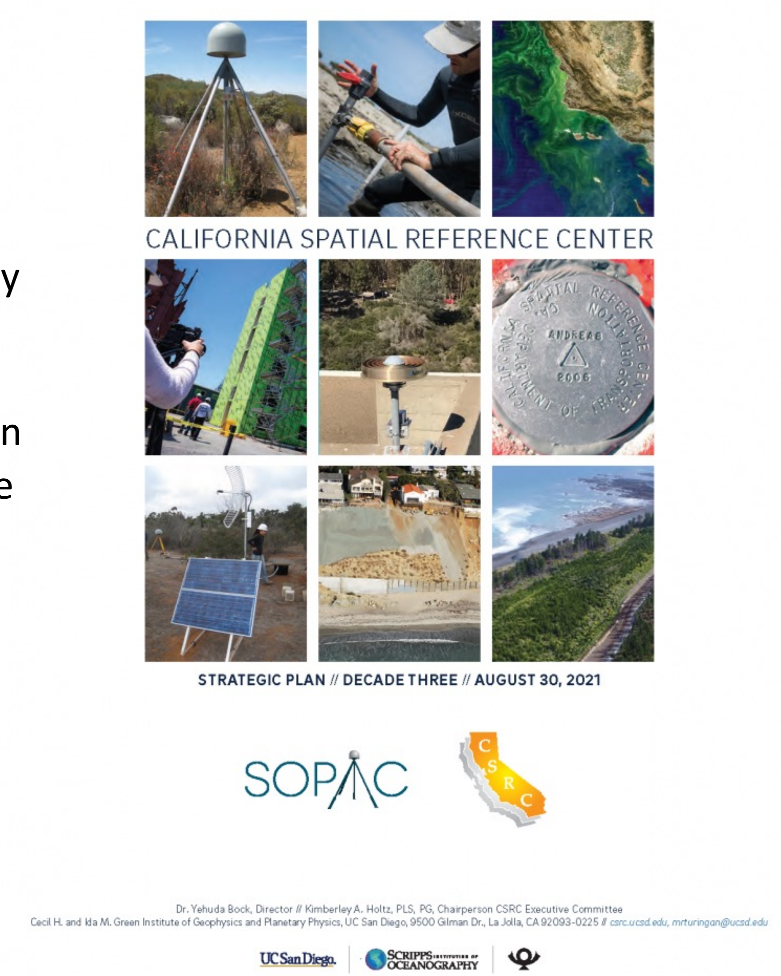
UC San Diego

SOPAC

CRTN

CSRC Mission

The CSRC is responsible for defining, maintaining the **California Spatial Reference System (CSRS)** for our many stakeholders, including local and state organizations, academia, and the public and private sectors. In our Strategic Plan published in 2021, we presented our "plan for modernizing and expanding the CSRC as we continue to meet the ever-evolving needs of the people of California to access accurate, timely, robust, and consistent geospatial information in the presence of significant crustal motions."



http://sopac-csrc.ucsd.edu/wp-content/uploads/2021/09/FrontPage.png

California Spatial Reference System
@ CSRS Epoch 2017.50

- Under contract to Caltrans, **CSRC estimated geodetic coordinates and geoidal heights** for the California Spatial Reference Network of ~900 stations, currently at the "Epoch Date" of 2017.50; A new Epoch Date processed in ITRF2020 will be published in 2024.

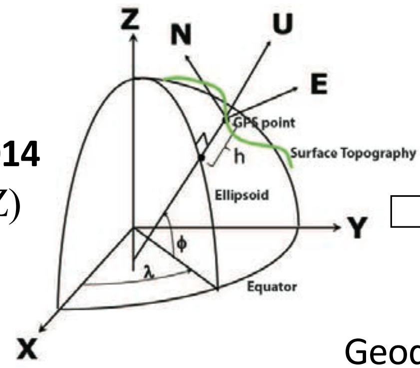
- The **coordinates & heights represent California's Spatial Reference System,** according to the Public Resources Code.

- The **CSRS is aligned with the National Spatial Reference System (NSRS),** published by the National Geodetic Survey.

- CSRC **Epoch 2017.5 (NAD83)** coordinates are transmitted in RTCM3 messages to **California Real Time Network (CRTN)** users

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

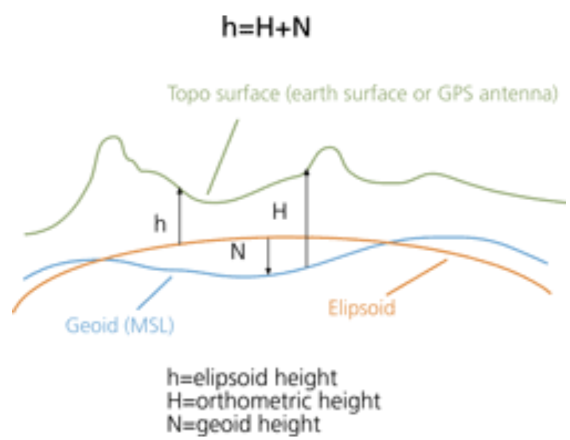
ITRF 2014
(X,Y,Z)



NAD83

(ϕ, λ, h)

Geodetic Coordinates



GEOID12B

Maintaining a Reference Frame in the Presence of Transient Motions

Earthquakes

Tsunamis

Drought

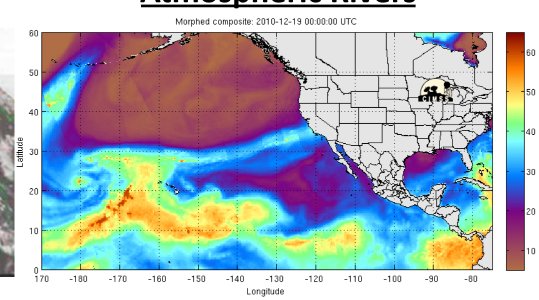
Subsidence

Landslides

Sea Level Rise

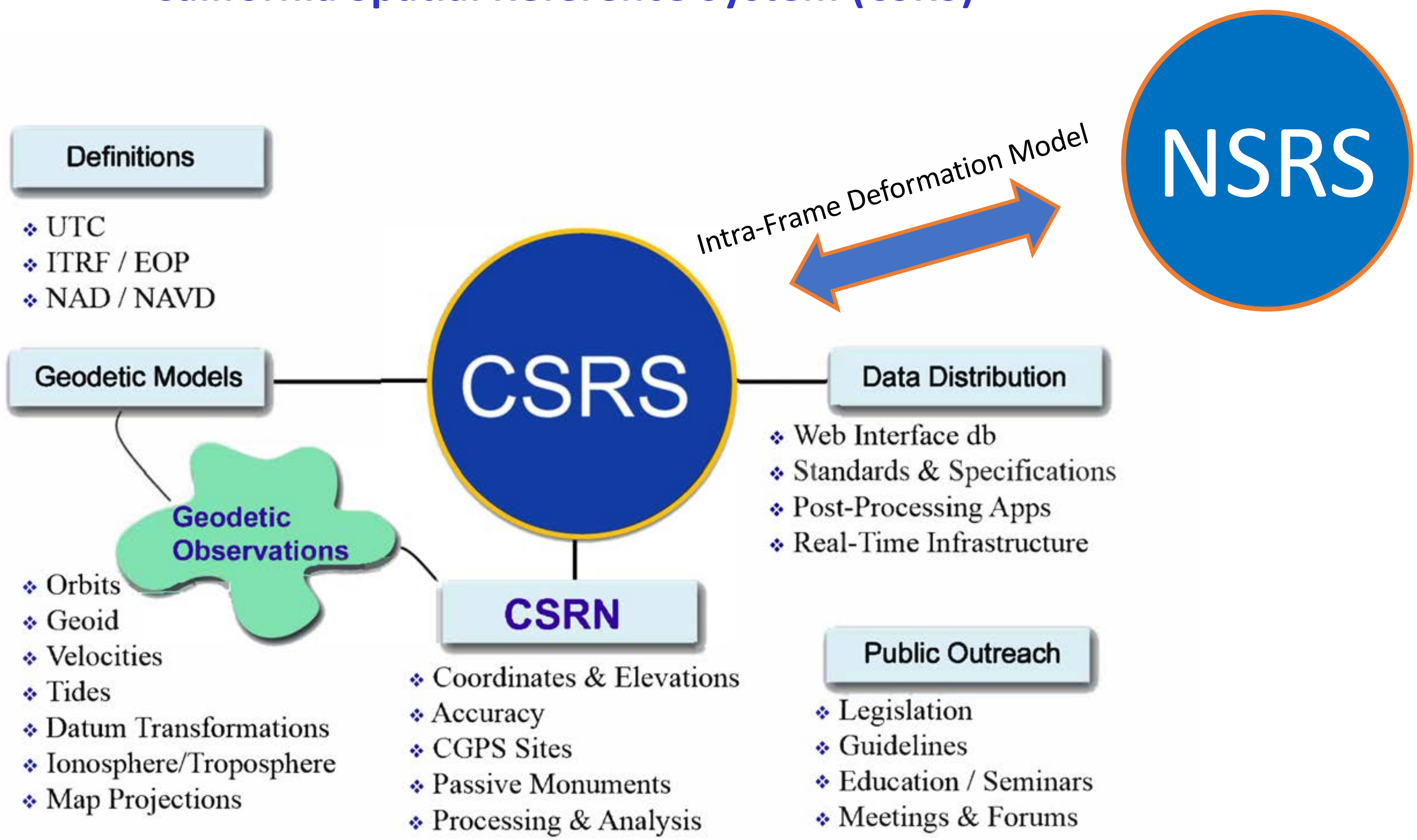
Flooding

Atmospheric Rivers



Volcanoes

California Spatial Reference System (CSRS)



Greg Helmer

SIO NOAA/NGS FY 23 Geospatial Modeling Competition Award

Our collaboration with NGS includes three activities:

1) Create a formal **Geodesy Program at SIO** in support of 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 NSRS for users in regions of significant ground motions, using GNSS and InSAR/GNSS displacement fields (funded by NASA projects) and underlying geophysical models. CSRC will exercise the IFDM through its community of public, private and academic users of precise spatial referencing in our challenging region of secular and transient crustal movements.
3) [Investigate a **unified vertical reference frame**, including a marine geoid optimized to be consistent with the full spectrum of observations from modern gravimetric geoids (e.g., GRAV-D, ICGEM), remotely-sensed observations (e.g., SWOT, ICESat-2), in situ ocean observations and assimilating ocean models, and the TRF.]

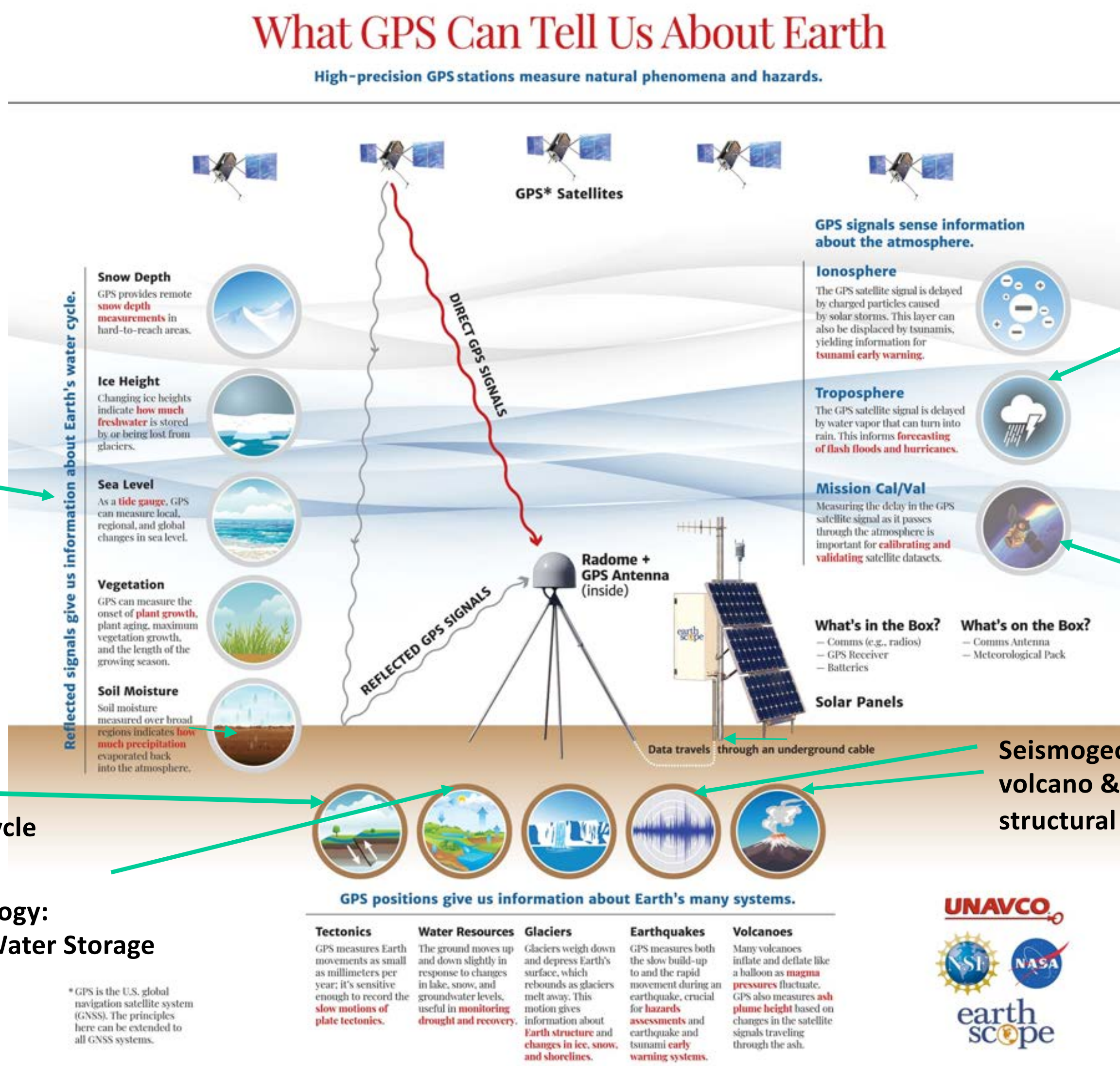
Geodesy Curriculum at SIO

SIO course number	Title	Instructor(s)
229	*Reference Frames and Global Gravity*	Borsa/Bock
239	*GNSS Geodesy (new in 2023)*	Haase
236	*Satellite Remote Sensing*	Fricker/Sandwell
237	*Space Geodesy Seminar*	Fialko/Haase/Sandwell
(new)	*Radar Interferometry*	Sandwell/Mellors
(new)	*Geodetic Field Work and Aircraft Gravity*	Greenbaum
239	*Seafloor Geodesy*	Zumberge/Sandwell
223 A/B	*Geophysical Data Analysis*	Agnew
210	*Introduction to Physical Oceanography*	Talley

Curriculum will include 9 graduate courses including seven that are already offered in the Geophysics Curricular group and two more in development; includes support for five graduate students to enhance the nation's pool of geodetic scientists.

SIO Faculty: David Sandwell, Jennifer Haase, Yehuda Bock, Adrian Borsa, Yuri Fialko, Jamin Greenbaum, Matthew Mazloff, Mark Merrifield, Mark Zumberge, Helen Fricker, Robert Mellors
Collaborators: Humberto Gallegos, East Los Angeles City College, Caltrans, DWR

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



Sea Level/Geoid

Meteorology: Atmospheric Water Vapor

Data Science Calibration/Validation

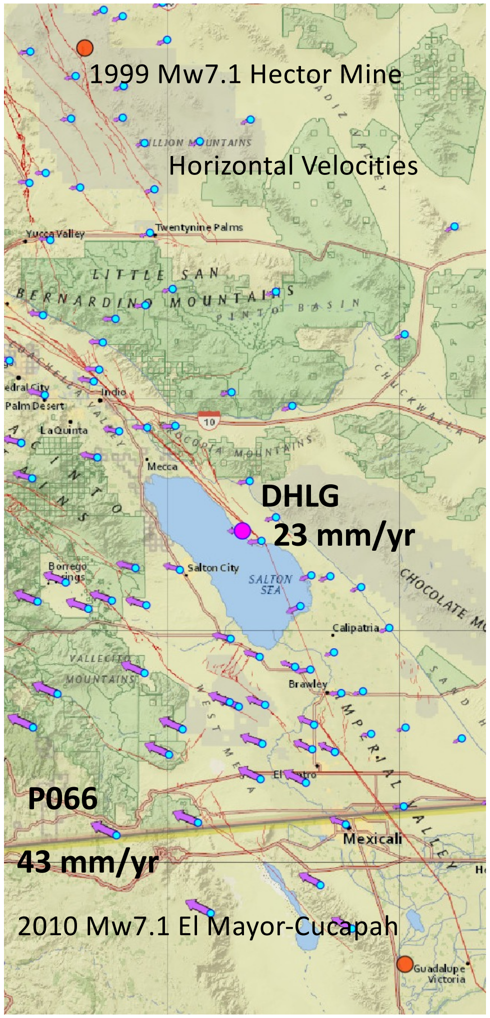
Tectonics: Crustal Deformation/Earthquake Cycle

Hydrology: Total Water Storage

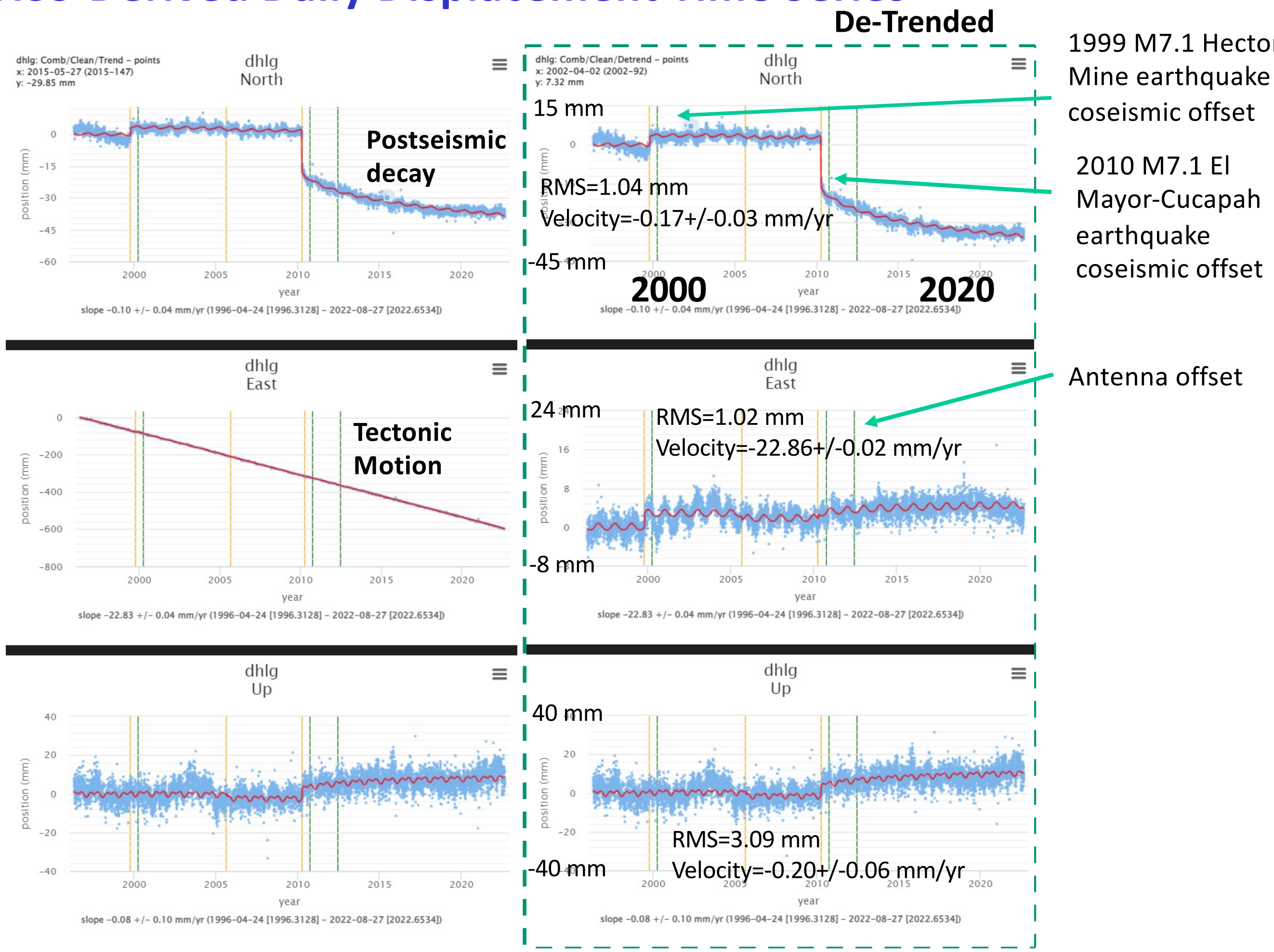
Seismogeodesy: earthquake, volcano & tsunami warning structural monitoring

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

GNSS-Derived Daily Displacement Time Series



1mm = 0.0033 ft

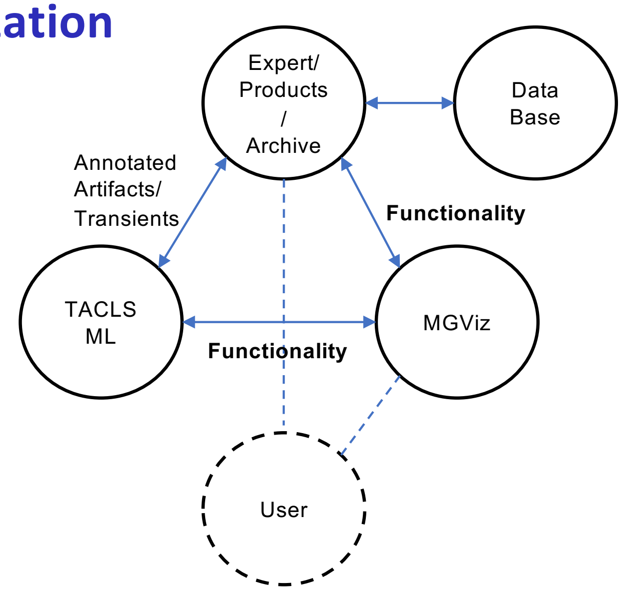


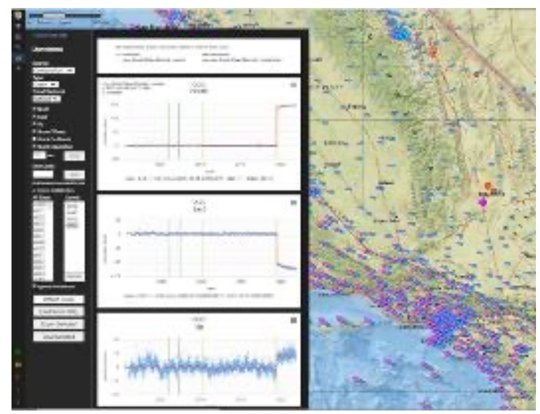
mgviz.ucsd.edu

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

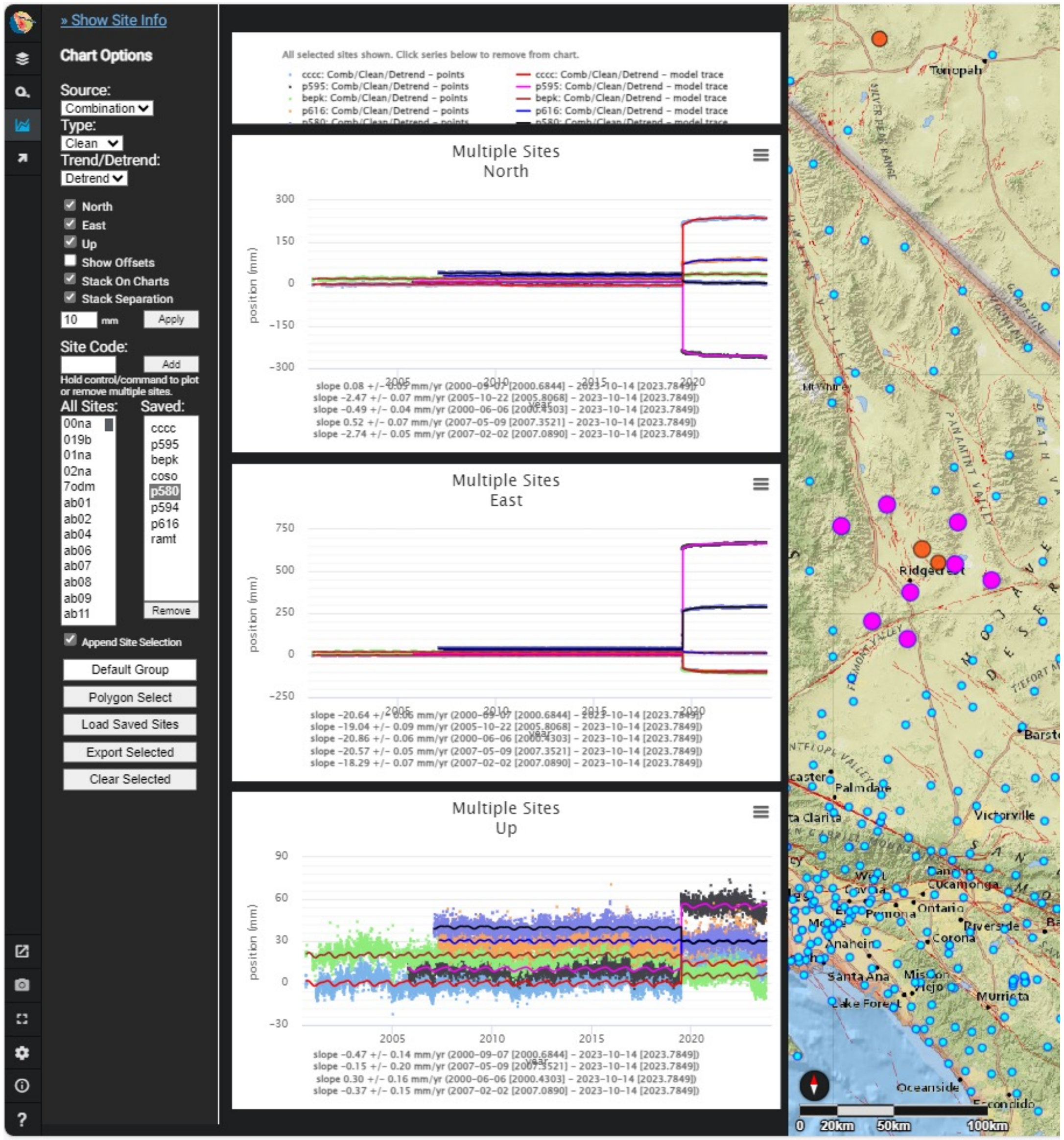
Machine Learning (ML) & Visualization

- Analyzing GNSS displacement time series spanning 30+ years from several thousand stations has required extensive QC to remove outliers and artifacts in order to detect physical transients that need to be considered in maintaining the CSRS. **To achieve optimal results often requires manual intervention.**
- We are embarked on a NASA project to apply machine learning models to automate the process as much as possible by using the **labeled artifacts and transients to train the model** (TACLS - Transient & Artifact Continuous Learning System).
- Expand the open-source visualization software, MGViz to serve as **an interactive environment for exploring transients** aided by ML methods.





http://mgviz.ucsd.edu



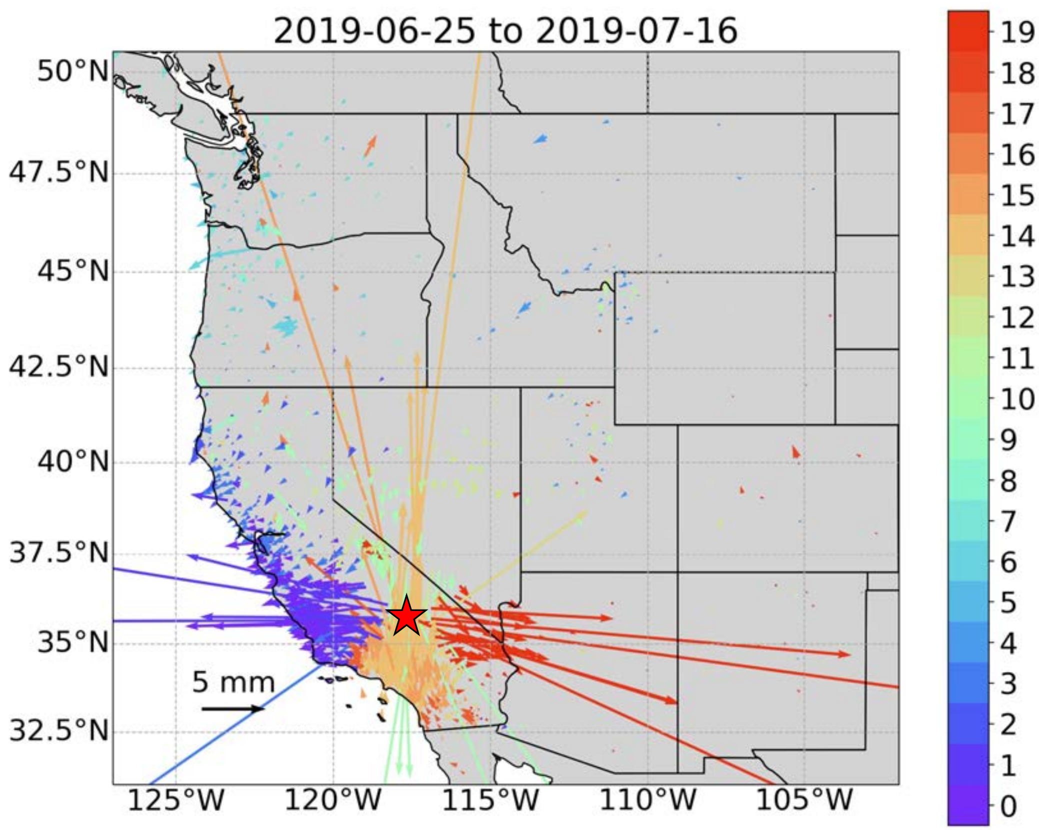
Near-Fault GNSS Displacements– Mw7.1 Ridgecrest Earthquake July 6, 2019

- Stacked daily North, East, Up displacement time series (detrended) for stations nearest the Ridgecrest earthquake's epicenter. showing coseismic offsets up to ~2.3 ft in the horizontal and ~.2 ft in the vertical

- The magnitude of displacements roughly decreases with the distance from the epicenter while the direction varies according to fault geometry and slip, effecting about 300 stations

- Visualization using our MGViz portal http://mgviz.ucsd.edu

Unsupervised Cluster Analysis of GNSS Time Series – Ridgecrest Earthquake July 6, 2019



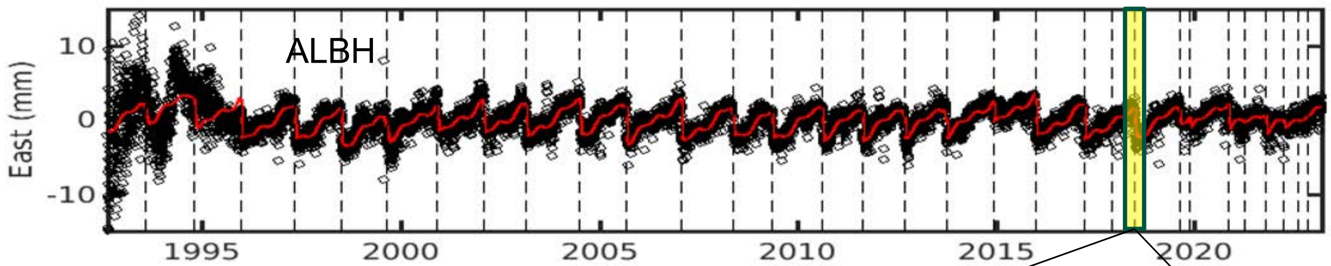
Clustering helps to group time series that are correlated, and isolate geophysical effects

Transform north&east station displacements into magnitude and direction and perform cluster analysis

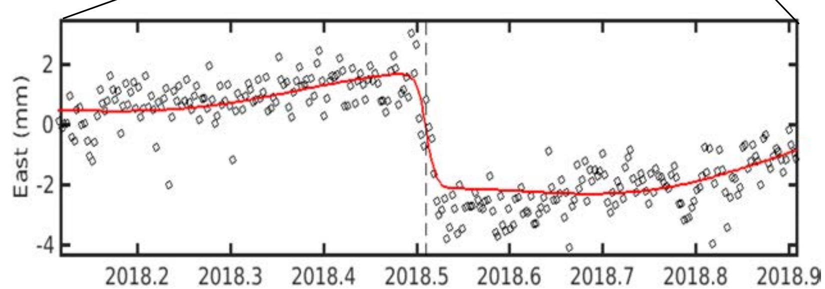
Roland Hohensinn

Detecting Slow Slip Events in Cascadia
24 Episodic Tremor and Slip (ETS) Events since 1994

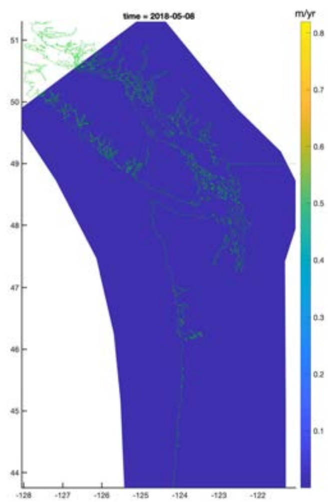
ETS events occur about every 14 months with a duration of several weeks



Daily East displacements



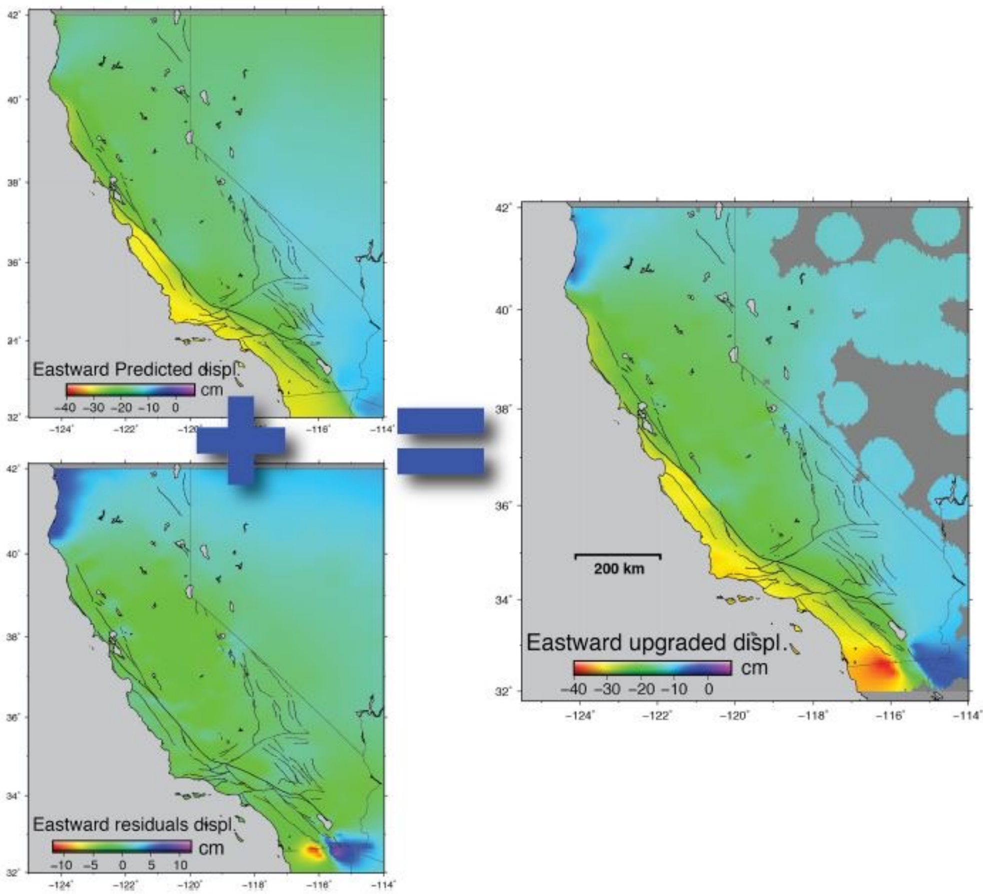
Cascadia subduction zone



ETS affects hundreds of GNSS stations allowing us to model the events in space & time

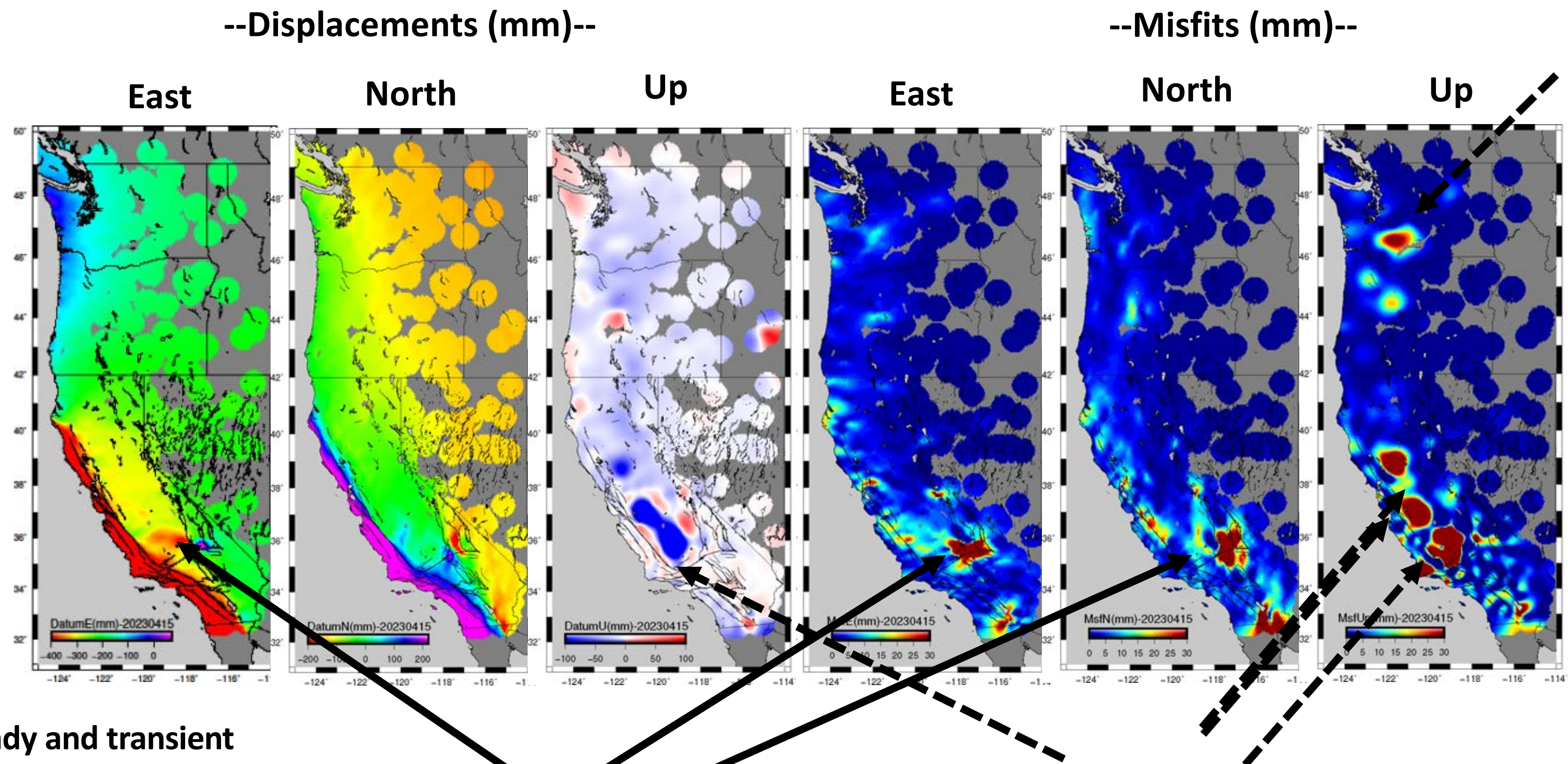
Video of surface motion model

Intra-frame Deformation Model (IFDM) – Dynamic Datum

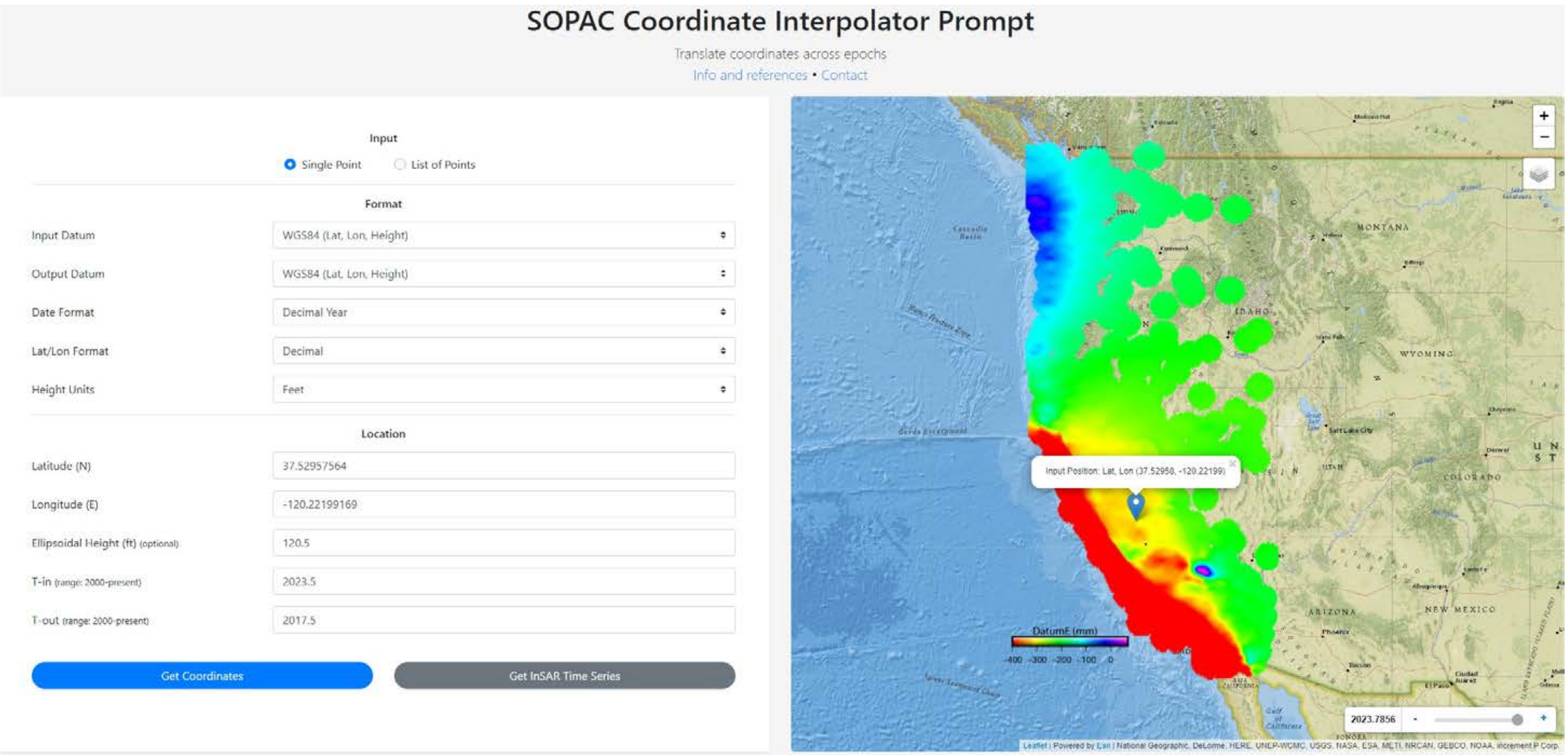


Estimate a position at any location and point in time with respect to a reference epoch, based on the interpolation of weekly displacement grids. The final upgraded weekly model (right) here shown for the **east component** is the sum of the **interseismic displacement field** modeled by Zeng and Shen (2017; upper left) and the **surface interpolation of residuals** (lower left). **The resulting time-dependent grid on the right contains both linear and non-linear corrections.** Source: Klein et al. (2019).

Weekly Displacement Grids (Secular Motions + Transients)

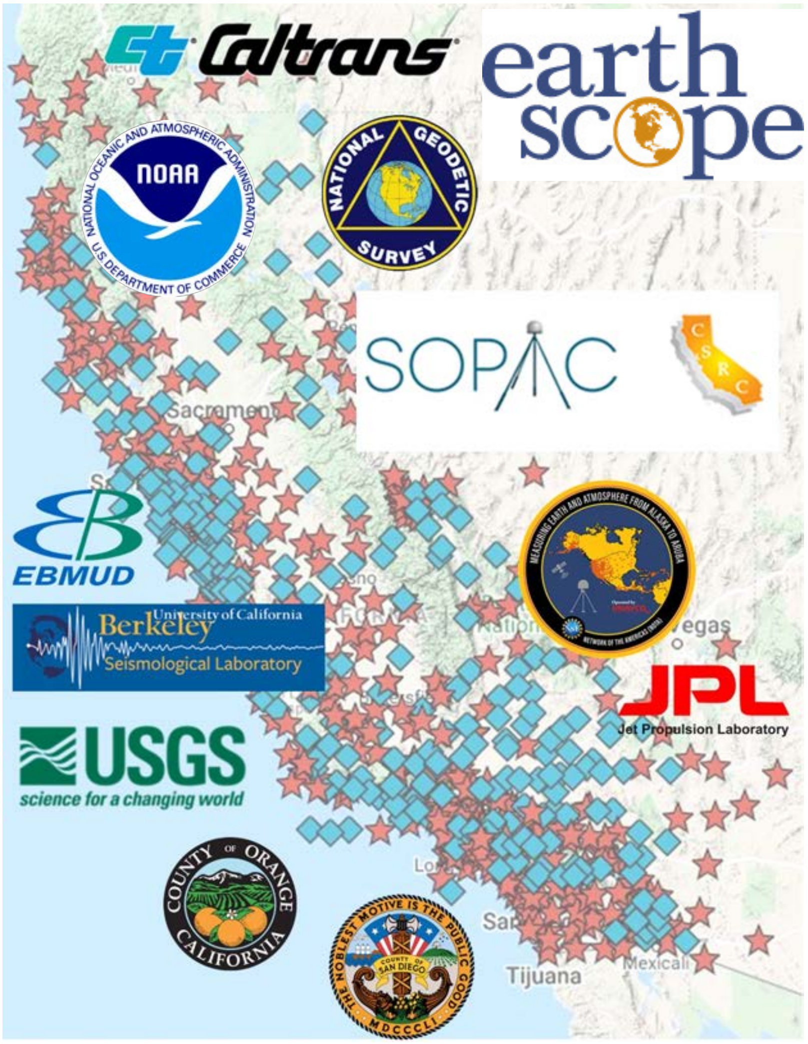


SCIP Dynamic Datum Utility



http://geoapp21.ucsd.edu/

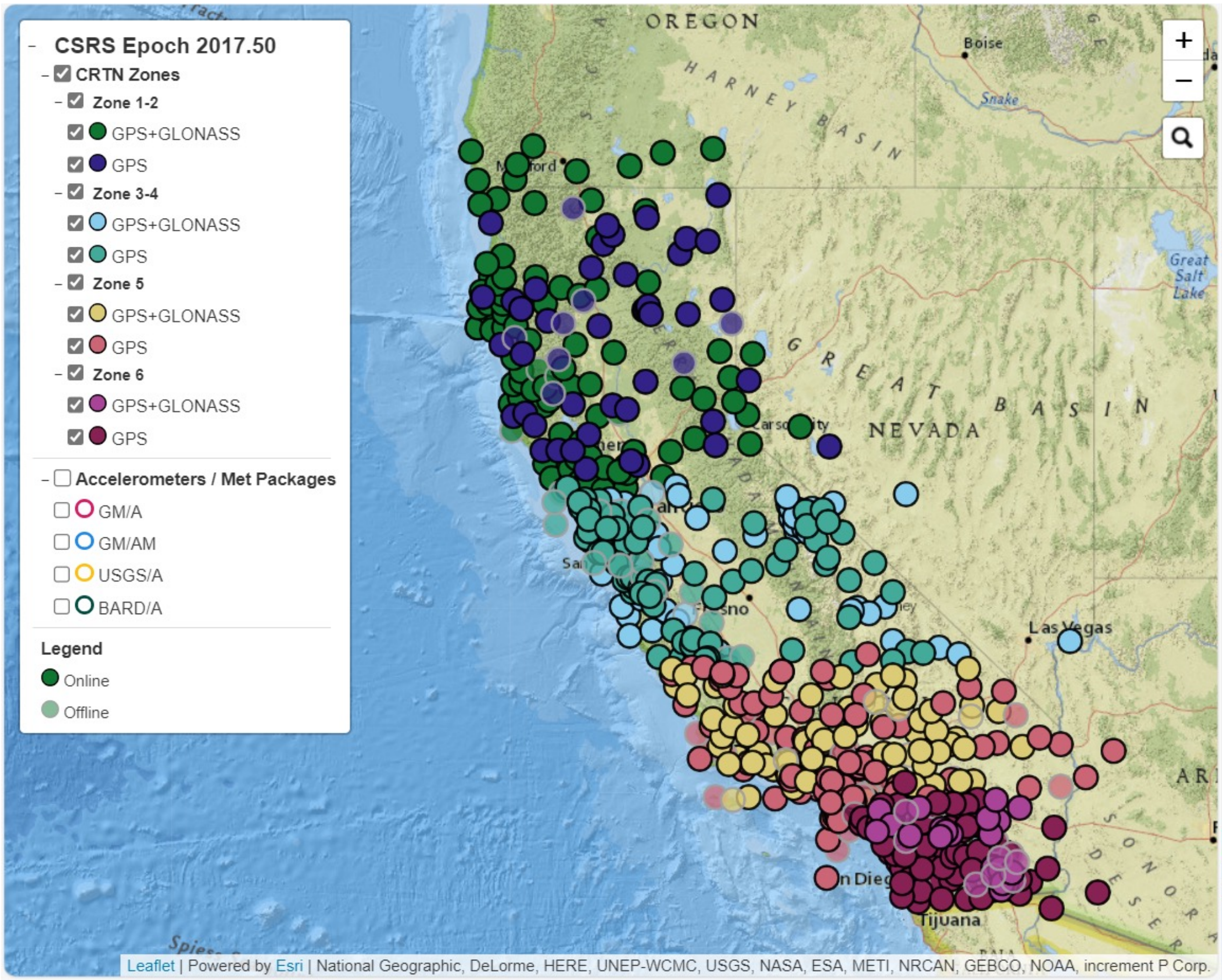
CRTN Status October 2023



- 710 stations from 4 CRTN servers: CCS83 1-2; 3-4, 5, 6
- > 400 GPS+GLONASS
- 55 GNSS stations – Caltrans CTSRN
- SOPAC collects 48 stations – remainder from other agencies shown on map, the majority from EarthScope (formally UNAVCO) NOTA
- CSRS Epoch 2017.50 (NAD83) coordinates transmitted according to Ntrip protocol in RTCM 3.0 format for single-base RTK surveys
- User accounts: ~3000
- Supported annually by CRTN Consortium Members and Contributing Members (hold multiple accounts)

http://sopac-csrc.ucsd.edu/index.php/crtn/

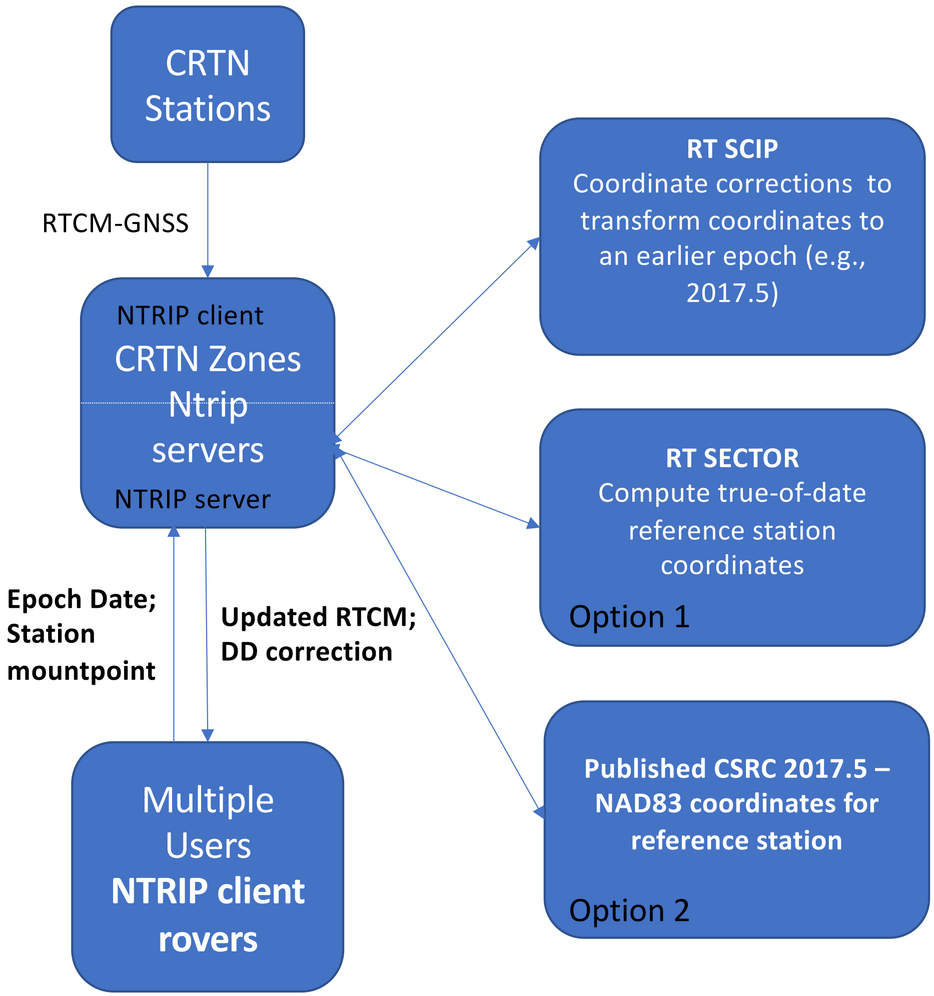
CRTN Issues October 2023



- Station demobilization, reconstruction
- Station maintenance – several SOPAC stations down (loss of full-time field engineer)
- Transition of EarthScope/NOTA to the Cloud (also includes USGS stations)
- User support

CRTN status map: http://sopac-adj.ucsd.edu/crtn-map/

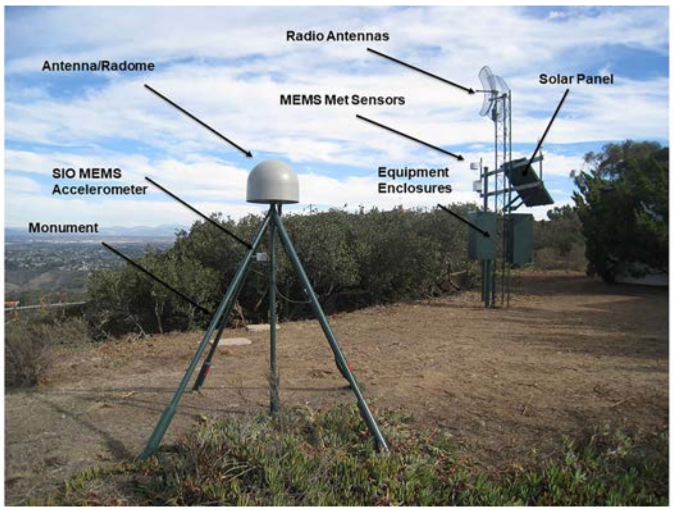
New CRTN Servers & Dynamic Datum (in Beta)



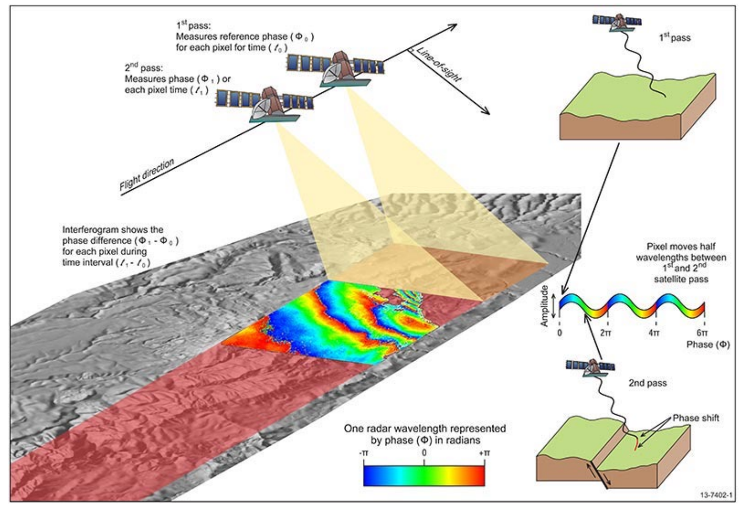
- Fully GNSS capable
- Normal operations transparent to users
- Two options for RTCM3 transmission of base station coordinates (1) real-time SECTOR utility true-of-date; (2) real-time SCIP utility epoch date corrections
- For option (2), need to establish protocol, either through an RTCM message or NTRIP protocol (working with KDM Meridian)

InSAR/GNSS Integration for Higher Spatial Resolution

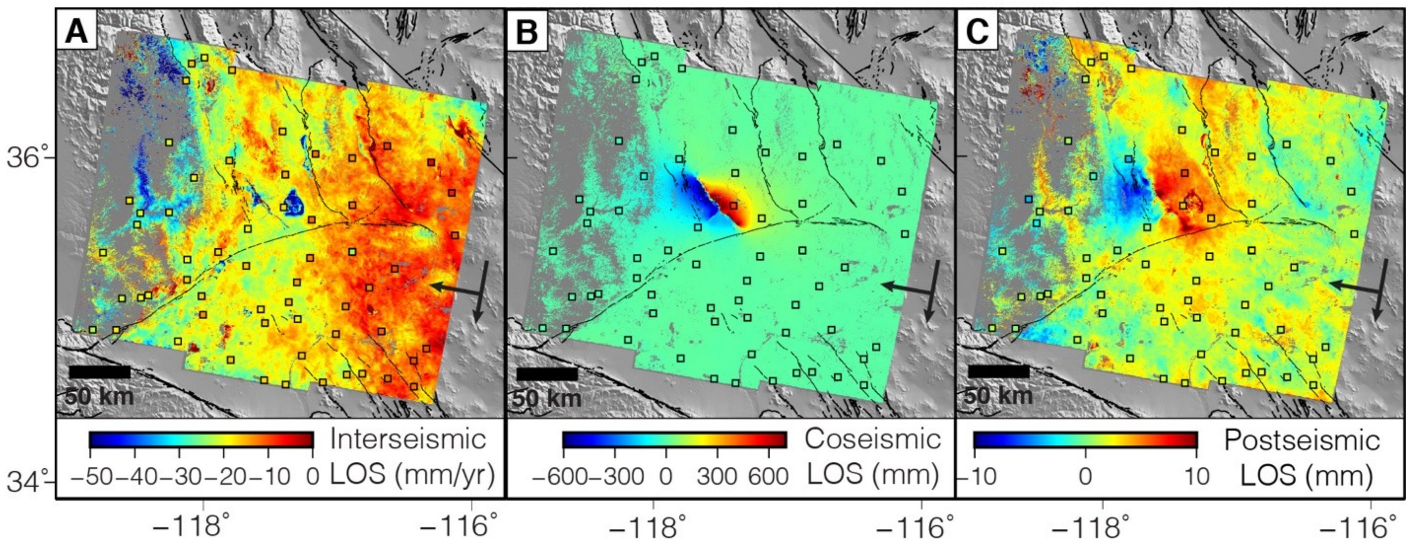
Typical continuous GNSS station (SIO5)



Conceptual diagram for integrated synthetic aperture radar (InSAR)

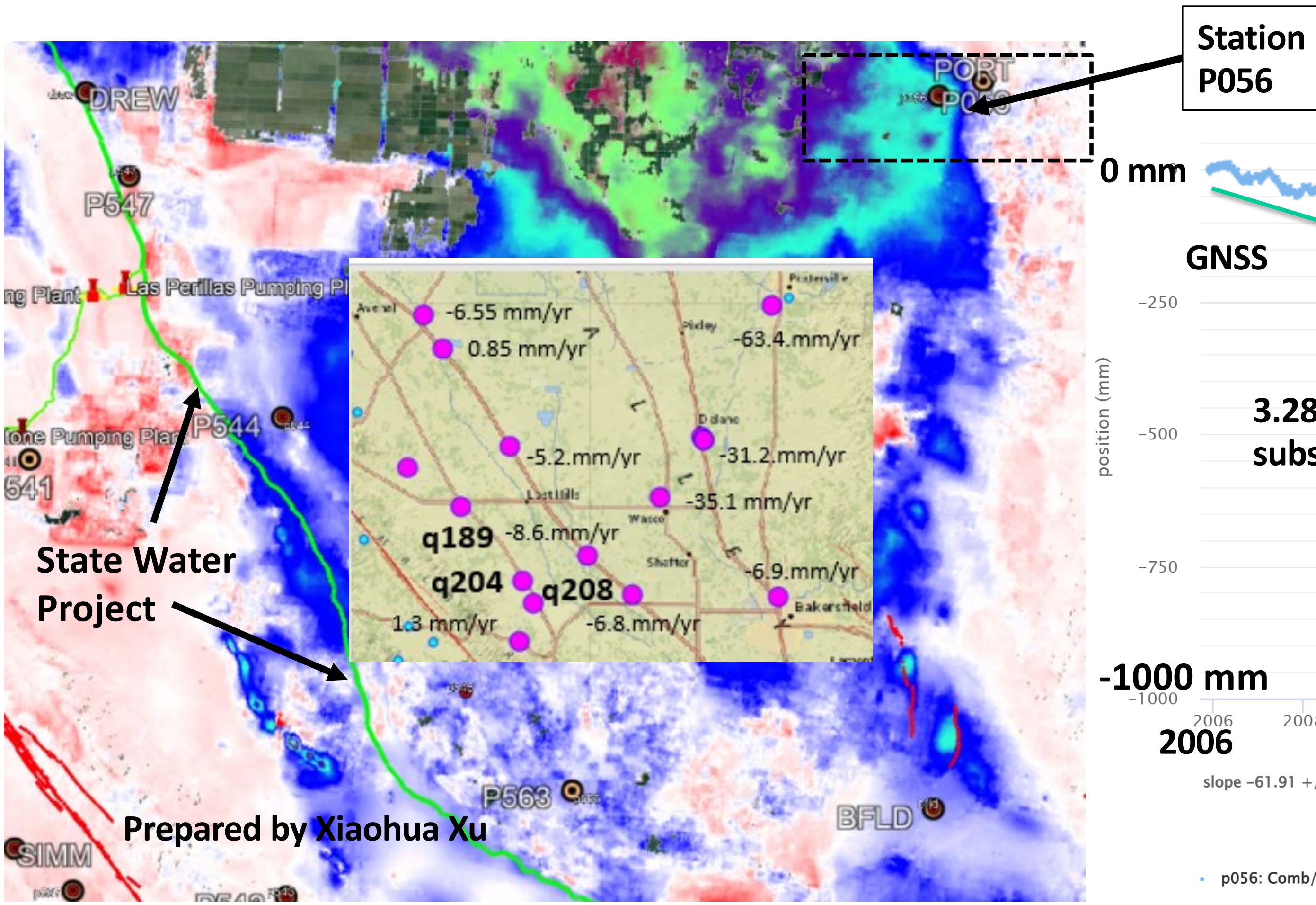


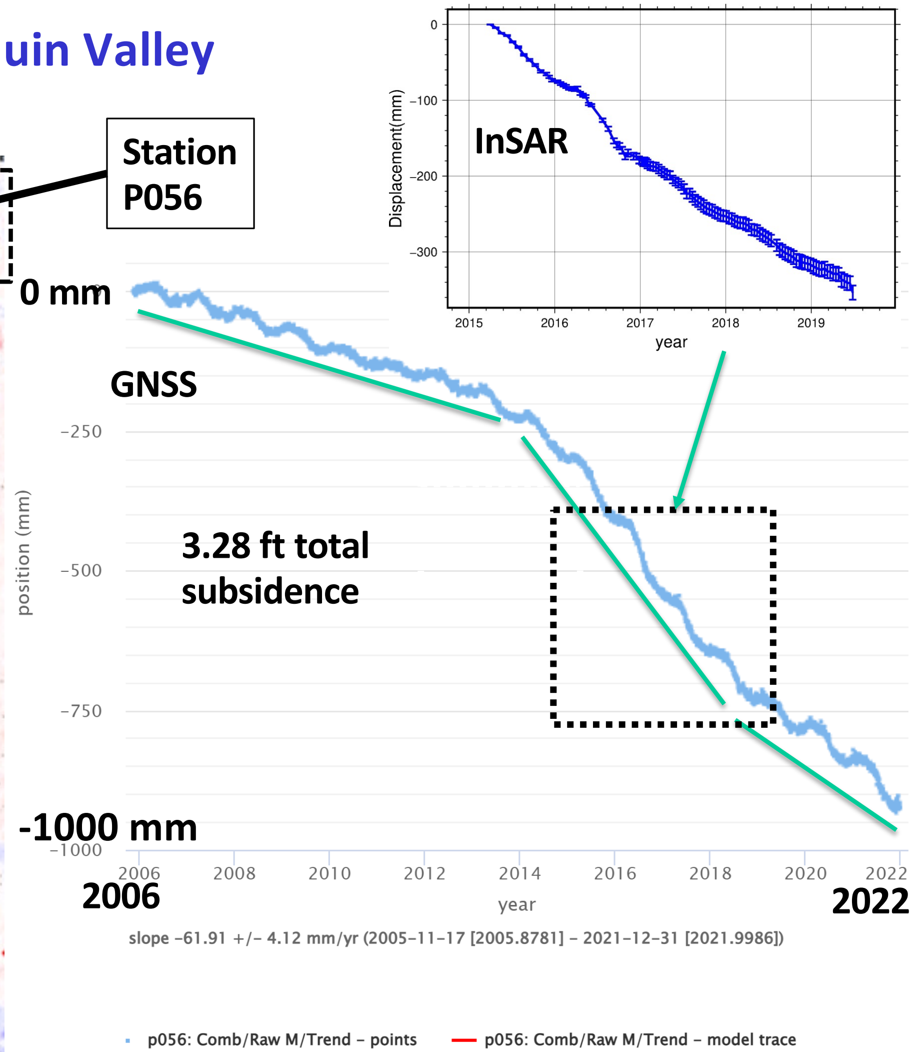
InSAR/GNSS Integration: Crustal Deformation Cycle



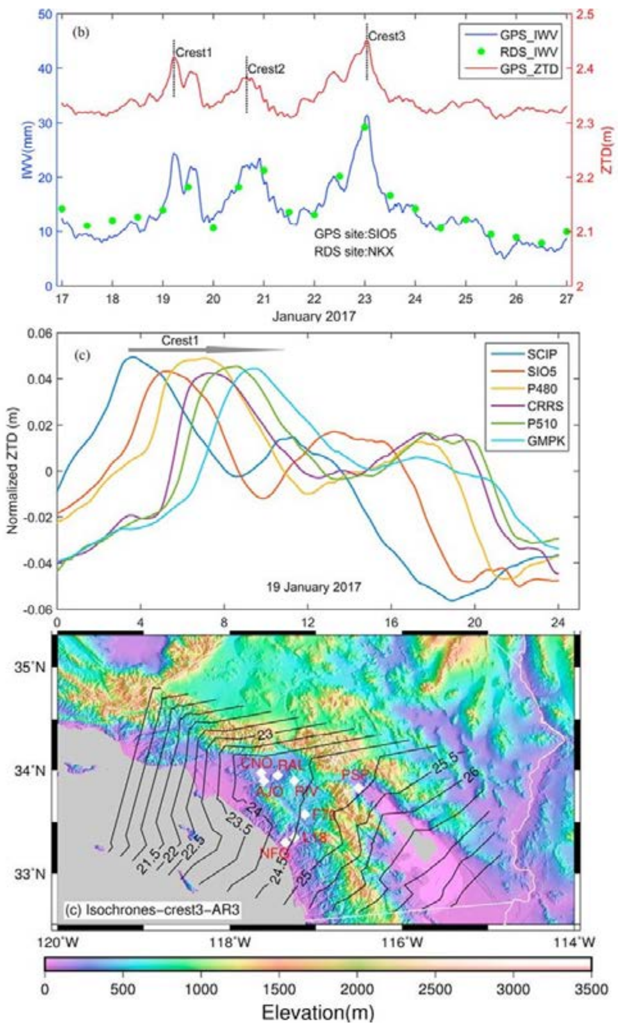
(A) Estimated **interseismic velocity field**, **(B)** Estimated **coseismic displacement field** and **(C)** Cumulative estimated **postseismic displacements** for a 48-day period following the event. Squares are locations of GNSS stations. Note changes in scale between panels. (Guns et al. 2022).

InSAR/GNSS Integration – Subsidence, San Joaquin Valley





https://topex.ucsd.edu/gmtsar/insargen/

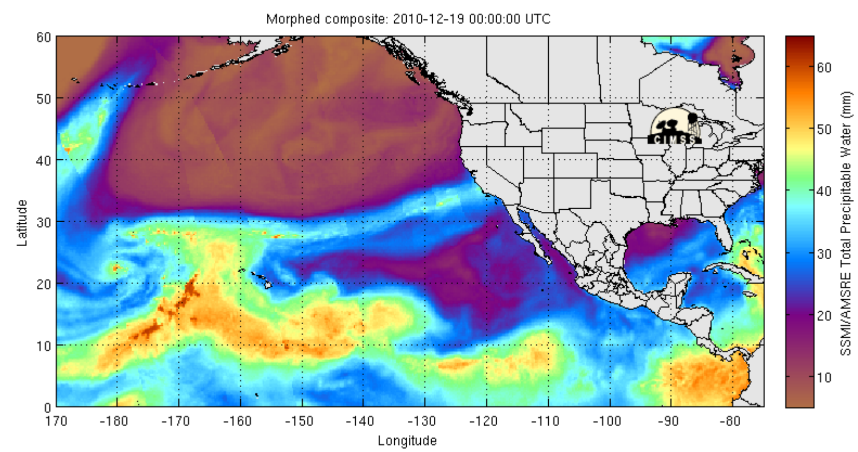


Tracking Extreme Weather Events with ML & Calibrating InSAR/GNSS for Tropospheric Delays

(1) Use the historical record of extreme weather events and 5-minute troposphere delay estimates from GNSS analysis as training data for ML models to track and understand transients such as atmospheric rivers (ARs) as the basis for forecasting extreme weather events and flash flooding.

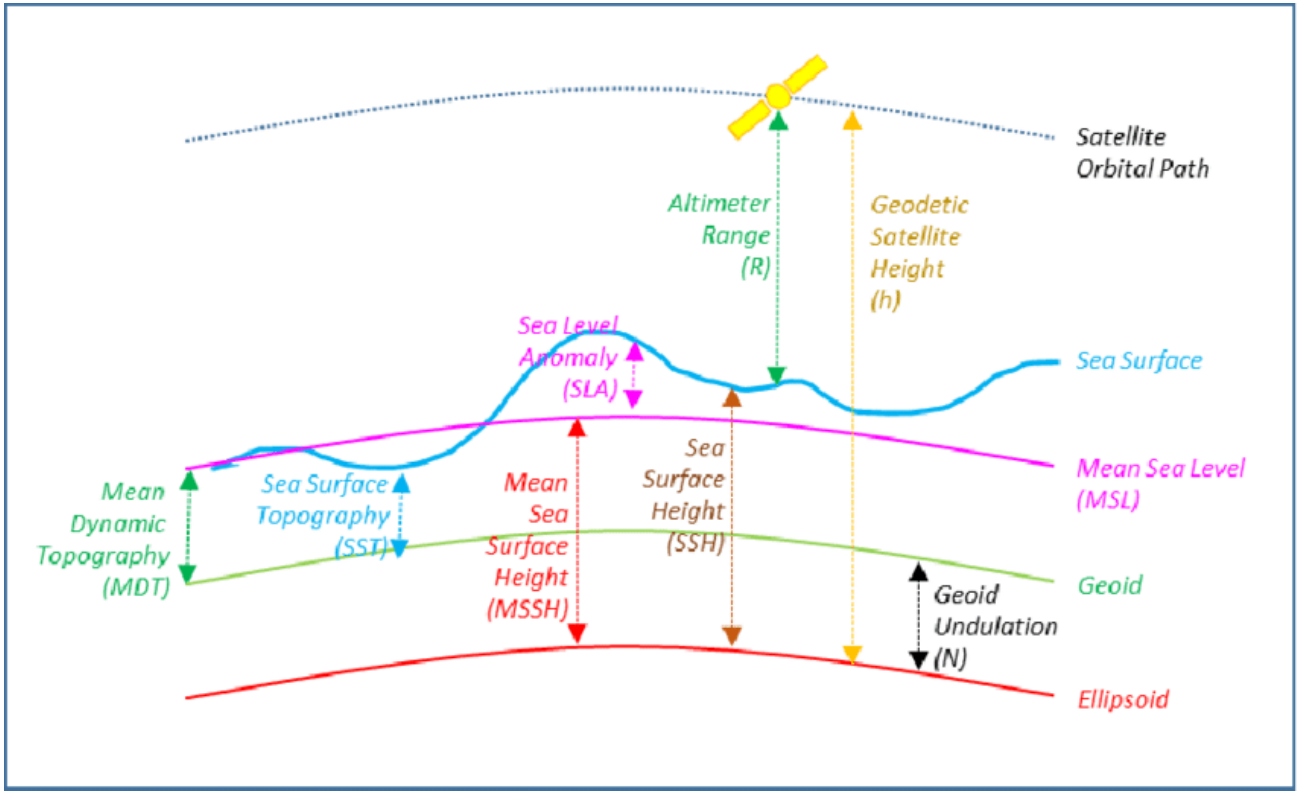
(2) Use the 5-minute troposphere delay time series to correct the InSAR imagery for atmospheric effects.

(Top Left) GPS Zenith Troposphere Delay (ZTD) and Integrated Precipitable Water (IPW) over 10 days with 3 AR events over GNSS station in San Diego. **(Middle)** ZTD for 6 GNSS stations on one day. **(Bottom)** AR arriving time isochrones indicating movement over southern California. (Wang et al., 2019).



Reference Surfaces for Unified Reference Frame

(3) Investigate a **unified vertical reference frame**, including a marine geoid optimized to be consistent with the full spectrum of observations from modern gravimetric geoids (e.g., GRAV-D, ICGEM), remotely-sensed observations (e.g., Surface Water and Ocean Topography (SWOT) mission, ICESat-2), in situ ocean observations and assimilating ocean models, and the TRF.]



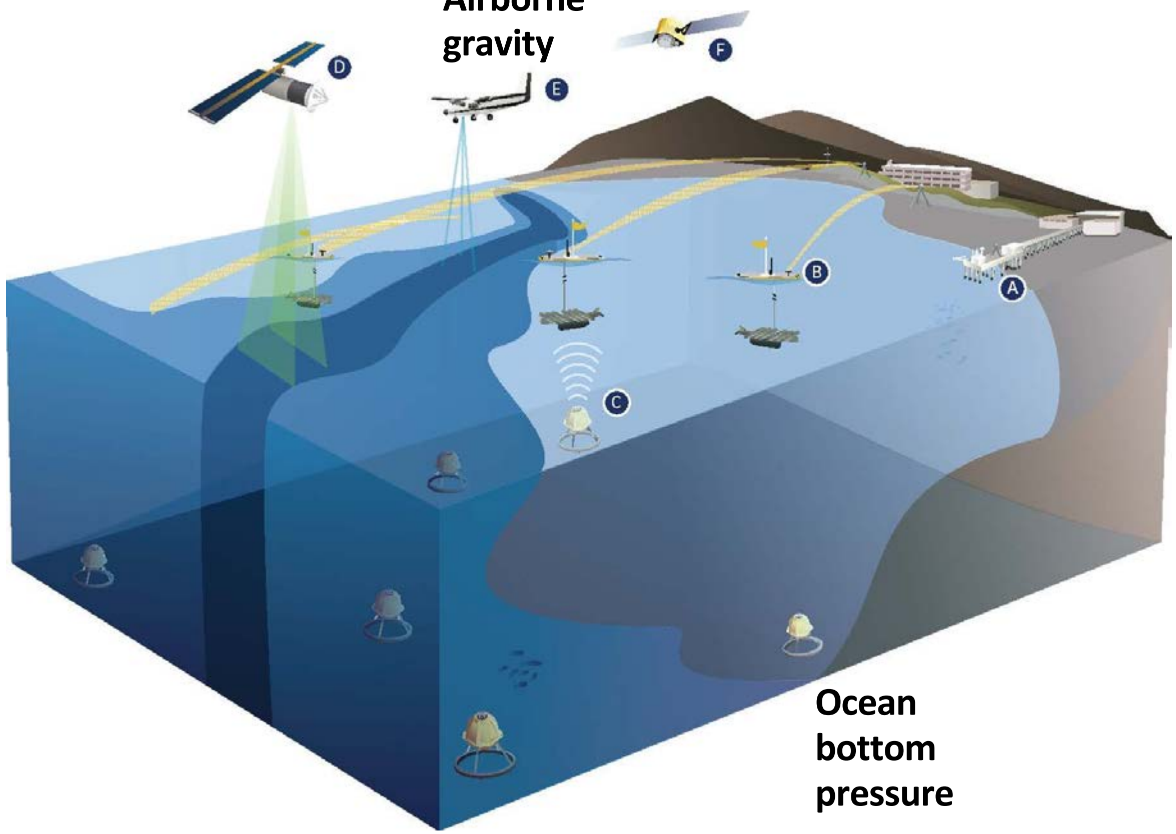
dynamic ocean topography = sea surface topography

Observation Systems: Terrestrial & Marine Geoids

Altimeter

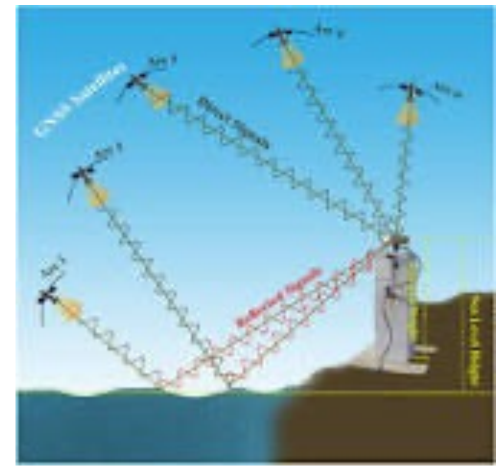
Airborne gravity

GNSS



Ocean bottom pressure sensor

GNSS-IR

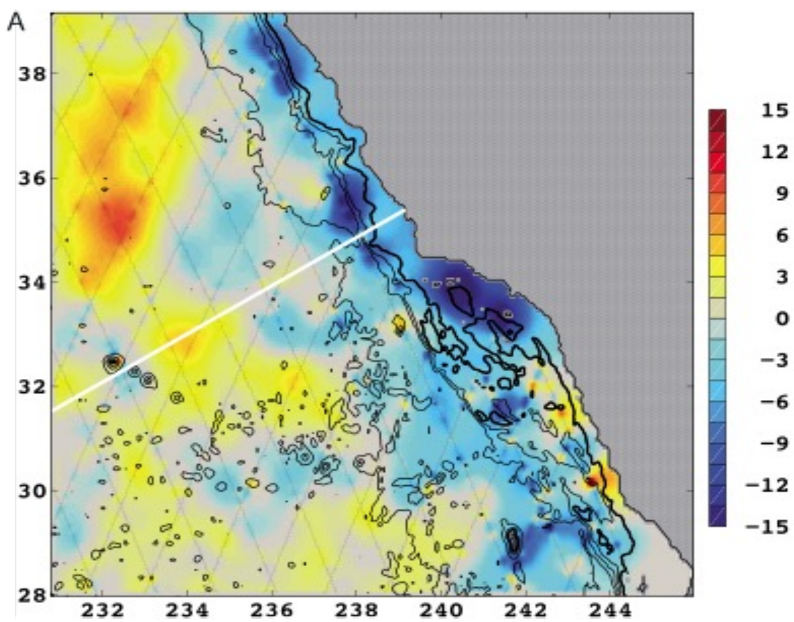


Wave Gliders

Prepared by Jennifer Mathews

Unified Vertical Reference Frame
Marine Geoid

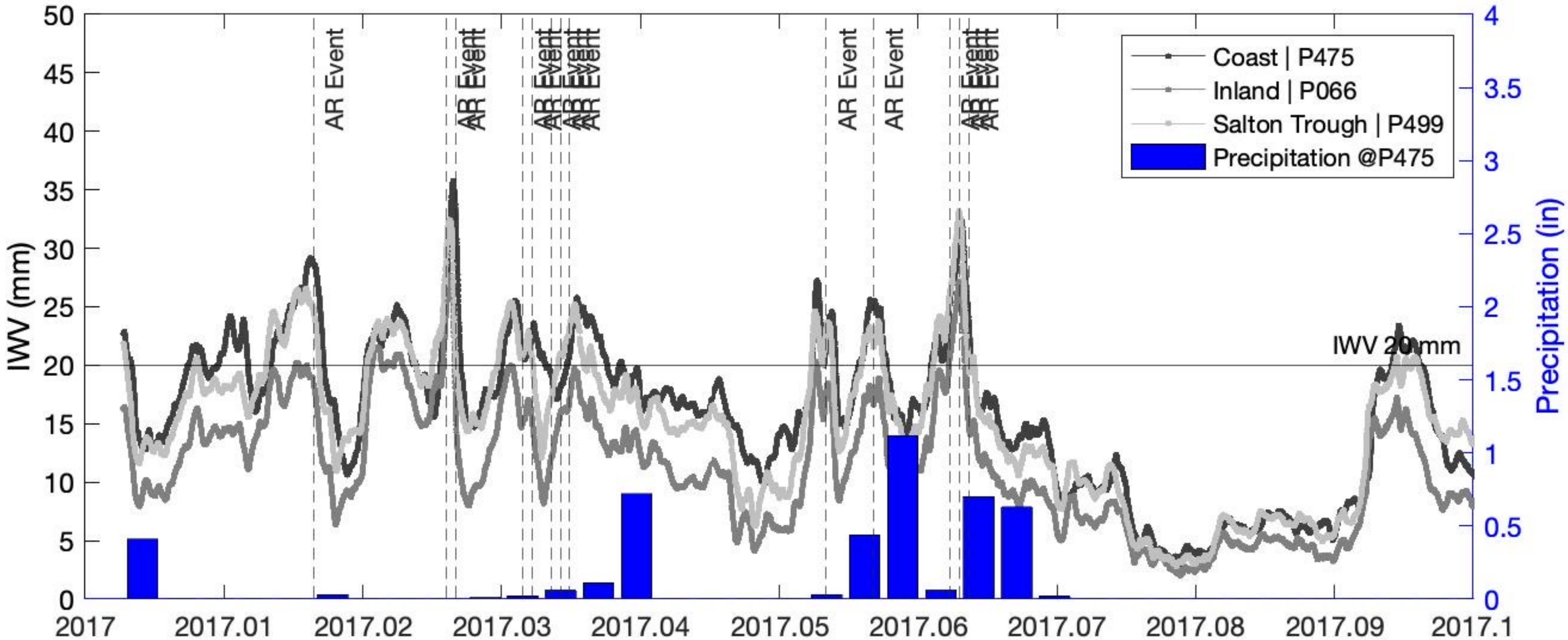
Solve for the marine geoid subject to an ocean model using the available suite of observations and constrain the continuity with the terrestrial geoid. The procedure is to add to our ocean assimilation optimization a geoid correction field that is given a prescribed spatially-varying uncertainty and is smoothed to a prescribed scale. This correction can then be applied to determine the new spatial reference frame effectively unifying the geometric and physical reference frames.



Mean dynamic ocean topography. A correction field to the EGM2008 geoid in centimeters via assimilation of ocean data. Bathymetry is contoured in black with a 1000 m contour interval (Mazloff et al., 2014).


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

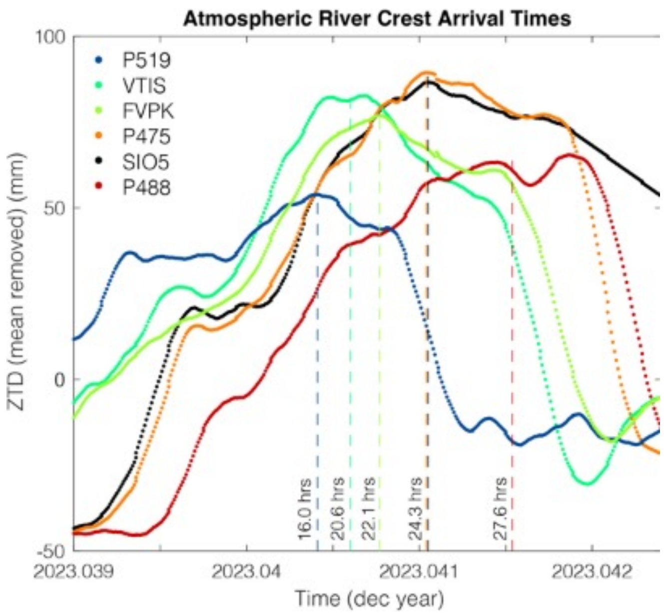
Tracking Extreme Weather Events with GNSS Meteorology



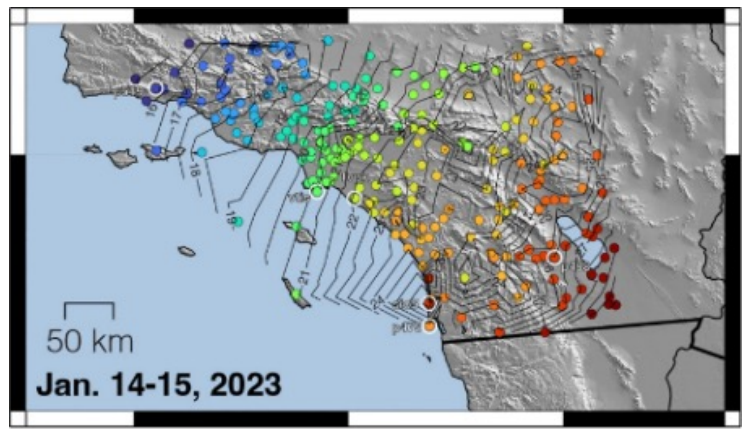
Prepared by Katherine Guns

Detecting Movement of Land-Falling Atmospheric River (AR)
High-Rate Troposphere Delays from GNSS Observations

Extreme weather observed by a network of GNSS stations cause significant delays in GNSS travel time allowing us to measure total water vapor content in the troposphere. NOAA/NWS uses these data to issue flash flood warnings.



Velocity Isochrones



Following the manual analysis in Wang et al. (20xx), we automate detection of peak ZTD values as the AR moves across the terrain. The important parameters for meteorology are the velocity of travel and spatial extent.

NOAA/NGS FY 23 Geospatial Modeling Competition Awards

1. **Oregon State University** is receiving $1,304,056 annually for a potential total of $6,520,280 over a 5-year period for a project titled "NSRS Modernization and Geodetic Workforce Development." The primary objectives of this project are to modernize geodetic tools for the NSRS, create new operating procedures for working with the NSRS, and develop a geodetic workforce for the future.

2. **Scripps Institution of Oceanography (SIO)** is receiving $1,300,000 annually for a potential total of $6,500,000 over a 5-year period for a project titled "NSRS Intra-Frame Deformation Model and New SIO Geodesy Program." The primary objectives of this project are to create a formal geodesy program in support of the nationwide deficiency of geodesists and to modernize geodetic models for the NSRS.

3. **Michigan State University** is receiving $800,000 annually for a potential total of $4,000,000 over a 5-year period for a project titled "Software Tools and Education for Enhancing Geodetic Infrastructure." The primary objectives of this project are to create a formal geodesy program in support of the nationwide deficiency of geodesists and to modernize geodetic tools for the NSRS.

4. The **Ohio State University** is receiving $536,000 annually for a potential total of $2,680,000 over a 5-year period for a project titled "Developing a Fully Kinematic, Backwards-Compatible Reference Frame for the Continental United States of America and Canada." The primary objectives of this project are to modernize geodetic tools and models and to develop a geodetic workforce for the future.

Link