New Geodesy Track at UCSD/SIO Geophysics: Contributions to the NSRS

Yehuda Bock

Institute of Geophysics and Planetary Physics (IGPP)

Scripps Institution of Oceanography (SIO)

University of San Diego (UCSD)

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

NOAA Hydrographic Services Review Panel (NSRP) Meeting

March 7, 2024

SOPAC/CSRC AT UCSD, SCRIPPS OCEANOGRAPHY

IGPP Department, April 2023

CSRC/SOPAC Group + Sandwell at CRTN Station SIO5, Nov. 2023

- **Scripps Orbit and Permanent Array Center (SOPAC)** research group. Maintains operations of California Spatial Reference Center (CSRC) with staff, facilities and infrastructure
- **CSRC is a Support Group of UCSD, a non-profit, public research university promoting outreach to non-academic users**
- **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/

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.

SIO NOAA/NGS FY 23 Geospatial Modeling Competition Award

FY 2023 Geospatial Modeling Program

Geospatial Modeling Grant Number: NOAA-NOS-NGS-2023-2007815

NSRS Intra-Frame Deformation Model and New SIO Geodesy Program

Proposed project start and end dates: October 1, 2023 to September 30, 2028

Cooperative Agreement

Recipient Name: The Regents of the University of California, San Diego

Recipient Unique Entity Identifier number: Scripps Institution of Oceanography: QJ8HMDK7MRM3

Principal Investigator:
Yehuda Bock
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Institute of Geophysics and Planetary Physics (IGPP)
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Co-Investigators (UCSD/SIO):
David Sandwell, Adrian Borsa, Yuri Fialko. Jamin Greenbaum, Jennifer Haase, Matthew Mazloff, Mark Merrifield, Mark Zumberge, Helen Fricker, Robert Mellors

Financial representative (names, organization, and contact information):
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rmadson@ucsd.edu; (858) 534-4552

Authorized Representative (name, organization, and contact information:
Mr. William Park III, Contract and Grant Officer
Scripps Institution of Oceanography
9500 Gilman Drive #0210, La Jolla, CA 92093-0210
wparkiii@ucsd.edu; (858) 822-1350

Funding Request:
Year 1 $1,300,000
Year 2 $1,300,000
Year 3 $1,300,000
Year 4 $1,300,000
Year 5 $1,300,000
Total $6,500,000

Collaborators:
Caltrans
California DWR
East Los Angeles City College

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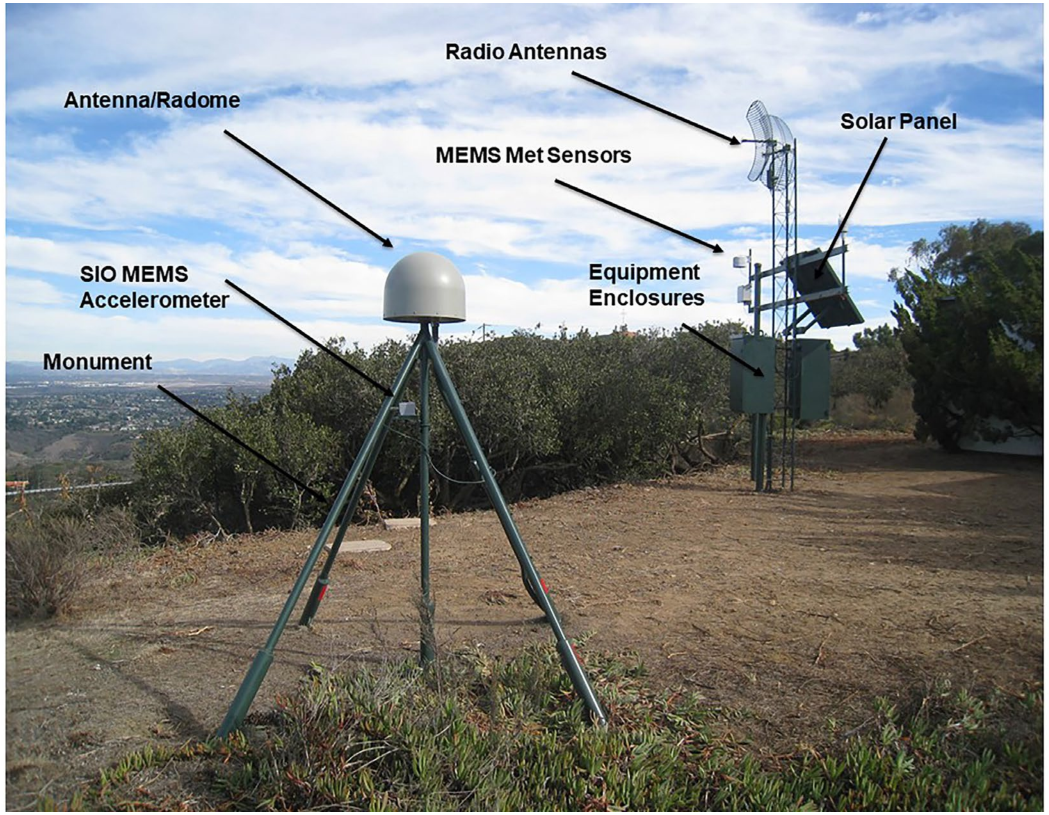
2) Develop an **Intra-Frame Deformation Model (IFDM)** to supplement the upcoming National Spatial Reference System for users in regions of significant ground motions, using GNSS and InSAR/GNSS displacement fields (funded by NASA projects) and underlying geophysical models. CSRC will exercise the IFDM 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 (marine/terrestrial) vertical reference frame**, through measurements of sea surface topography from remotely-sensed observations (e.g., SWOT, ICESat-2,

Geodesy Track at SIO Geophysics

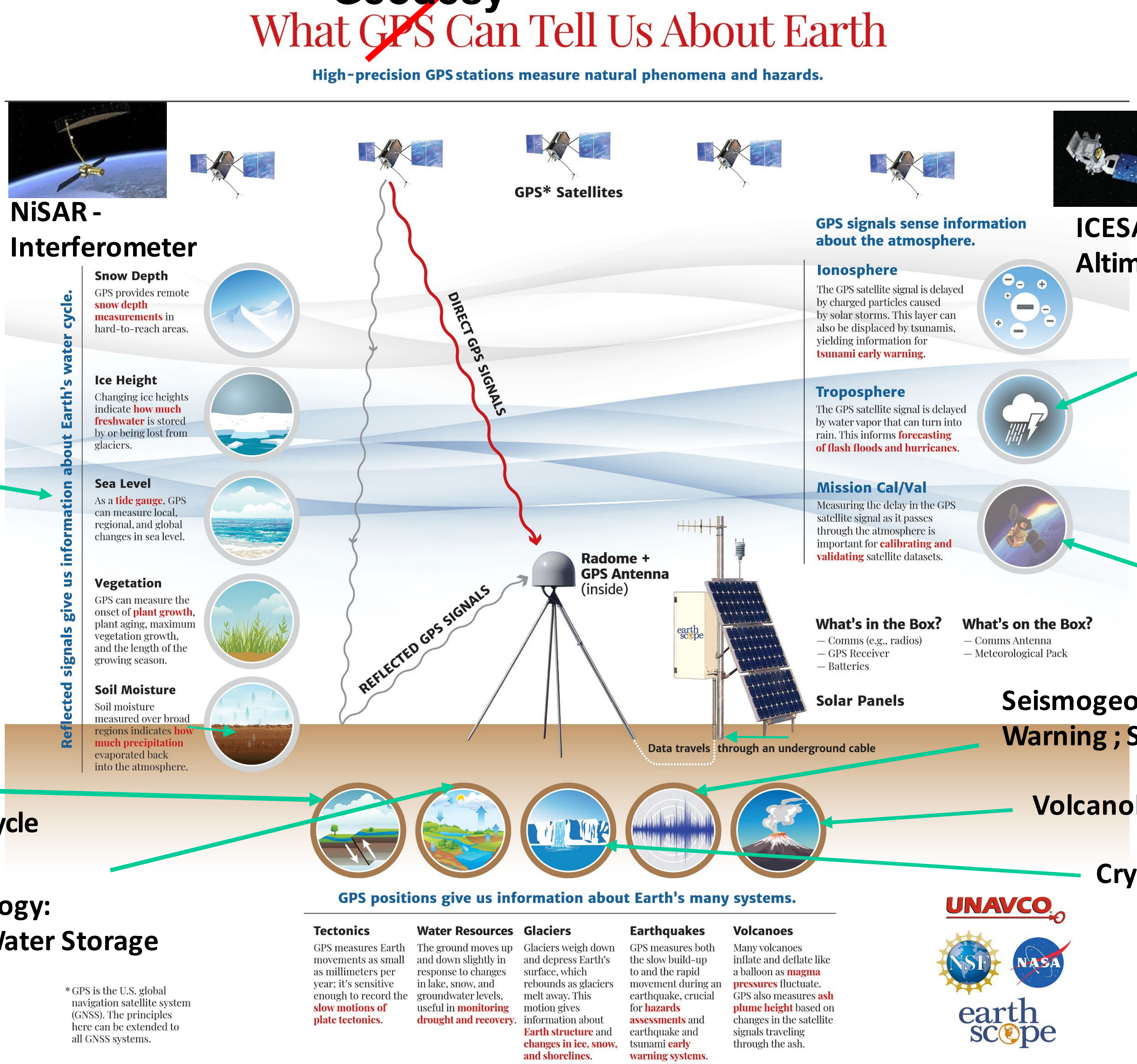


GNSS Continuous GNSS/Seismic Station on Mt. Soledad. Near SIO

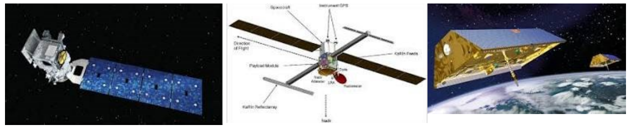
- Five years of funding for five graduate students, preferably U.S. Citizens
- Students expected to follow the new Geodesy track with the existing Geophysics Curriculum Group and have a geodesy-related thesis. [One or more of the students will focus on time dependent geodetic reference system for western North America based on combined GPS/GNSS and InSAR – will interact with NGS employees].
- Have already taken on two students (one first year, one second year)
- Identified three new 2024-2025 PhD applicants
- Forming internal and external education committees
- For five graduate student researchers: Salary + benefits $202,809; tuition remission - $116,145 (Year 2 or project)

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

Geodesy



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

Focus of Natural Hazards Mitigation: U.S. West Coast

Earthquakes

Tsunamis

Drought

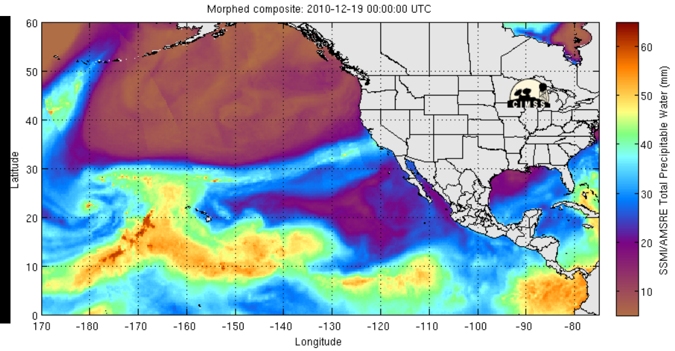
Subsidence

Landslides

Sea Level Rise

Flooding

Atmospheric Rivers



Volcanoes

Geodesy Curriculum at SIO (PhD, MSc)

SIO course number	Title	Instructor(s)
229	*Reference Frames and Global Gravity*	Borsa/Bock
(new)	*GNSS Geodesy (new in 2024)*	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 six that are already offered in the Geophysics Curricular group (upgraded with additional material) and three 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

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

Geodesy Courses - 1

Geodesy Program Curriculum

Reference Frames and Global Gravity – (SIO 229) Borsa/Bock

- Reference systems and reference frames
- Earth's moments of inertia and J_2
- Definition and derivation of the geoid
- Laplace's equation and spherical harmonics
- Global Gravity Models
- Geometric measurements: VLBI, SLR, GNSS
- Satellite gravimetric measurements: LAGEOS, GRACE, other satellites
- Time-variable reference frames
- Time-variable gravity

GNSS Geodesy – (SIO 239) – Haase

- Introduction to geophysical interpretation of geodetic time series
- Elements of geodesy: coordinates, the ellipsoid, the geoid, reference frames
- Satellite orbits: Keplerian orbits and GNSS satellites
- GNSS signal propagation and parameter estimation
- GNSS precise point positioning applications to seismotectonics
- GNSS signal propagation applications to atmospheric remove sensing.
- GNSS reflection: soil moisture and sea level and the vertical datum

Satellite Remote Sensing – (SIO 236) - Fricker and Sandwell

- Overview of remote sensing
- Platforms and orbits
- Electromagnetic radiation, polarization
- Fourier transform introduction
- Spectra, Fourier transforms, and diffraction
- Thermal radiation
- Propagation, dispersion, and scattering
- Image processing and classification
- Optics, stereo, and electro-optical systems
- Passive microwave systems
- Radar and laser altimetry
- Scattering and Synthetic Aperture Radar (SAR)

Space Geodesy Seminar (SIO 237) – Fialko, Haase, and Sandwell

- Introduction to SAR
- Introduction to InSAR
- Basic InSAR Processing
- GNSS Field Surveys
- Basic GNSS Processing
- InSAR Time Series and current topics in geodetic time series

Geodesy Courses - 2

Radar Interferometry – (expanded from UNAVCO short course and new textbook) – Sandwell, Mellors, Fialko

- Essentials of satellite remote sensing
- Principles of synthetic aperture radar
- Satellite orbits
- SAR image formation
- Interferometric SAR
- Coherence, filtering, gradient, and geocoding
- Phase unwrapping
- SAR modes
- Troposphere, ionosphere, and tide corrections
- Time series and corrections

Geodetic Field Work and Aircraft Gravity – (new) Greenbaum

- Theoretical methods of geoid estimation from regional gravity surveys
- Acquisition and processing of geodetic data at Pinon Flat Observatory
- Processing of aircraft gravity, GNSS, INS and lidar data
- Processing of aircraft photogrammetry data
- UAV operations, safety, and logistics
- Final data processing, interpretation, and presentation of results

Introduction to Physical Oceanography – (SIO 210) – Talley

- Physical properties of sea water
- Observational tools and data analysis methods
- Dynamics including geostrophy
- Gyres, boundary currents, circulation and dynamic ocean topography
- Waves and tides
- Climate and the oceans

Seafloor Geodesy – (SIO 239) Zumberge and Sandwell

- Seafloor geodesy overview
- Ocean environment sound propagation
- GNSS – Acoustics
- Wave gliders and tour of SIO Marine Facility labs
- Bottom pressure and gravity
- Tilt, fiber optic strain, and DAS
- Processing of seafloor geodesy data

Geophysical Data Analysis - (SIO 223) – Agnew

- Orthogonality for functions
- Multidimensional Fourier transform and Hankel transform
- Discrete-time sequences and operations, including convolution
- Data collection and the sampling of continuous functions
- Digital filters, especially Finite Impulse Response filters
- Simulating lumped-parameter systems with digital filters
- Sequences of random variables and stationary processes
- The power spectral density of a stationary random function
- The simplest estimator for the power spectrum, the periodogram
- Multitaper estimations of the power spectrum
- Prewhitening of series using prediction-error filters to reduce bias
- Statistical descriptions for pairs of random data
- Stationary processes in the plane and the power spectrum for these

Proposed Undergraduate Course Title: Geodesy and Geospatial Information

Course justification and content objectives: Geodesy is the study of Earth's size (geometry), shape (gravity field) and deformations (e.g., plate tectonic motions, subsidence). It provides access to a well-defined spatial reference system for precise geospatial information (latitude, longitude, height, elevation with respect to sea level) used for positioning, navigation, surveying and mapping. Geodesy is also an important discipline within the earth, atmospheric and oceanographic sciences, using observations of GPS and other satellite navigation constellations, remote sensing platforms (satellite and drone), and various terrestrial sensors. It is a data- and analysis-intensive discipline increasingly requiring modern data science methods. This introductory course will provide students with a solid background in geospatial systems for eventual employment in the public and private sectors. The course will also serve as a pipeline to the geodesy track at SIO/Earth Sciences and to other academic institutions and to alleviate the nationwide deficiency of geodesists. The objective is to provide basic knowledge of geodetic concepts for Earth and data scientists and the underlying geodetic framework for precise spatial information.

Learning objectives:

(1) Acquire basis concepts of geodetic science
(2) Provide overview of geodetic instrumentation and observations
(3) Develop elementary skills in geodetic data analysis
(4) Explore existing geodetic infrastructure and data repositories
(5) Experience hands on visualization and manipulation of geospatial information
(6) Understand the underlying geodetic framework for precise spatial information systems
(7) Provide example of data science applications in solving geodetic problems

Preferred background: statistics, linear algebra, Matlab/Python

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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 (CSRN) of ~900 stations, currently at the “Epoch Date” of 2017.50; A new Epoch Date processed in ITRF2020 will be published in 2024.

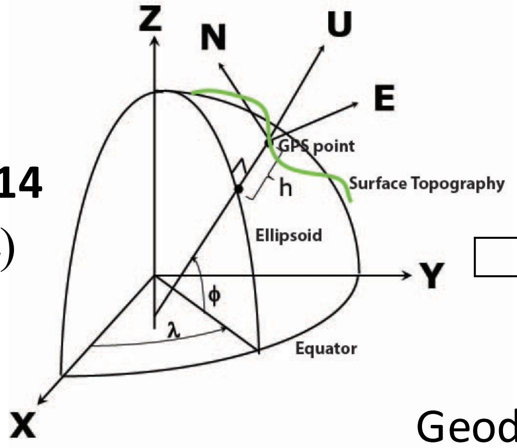
- The **coordinates & heights represent California’s Spatial Reference System,** according to the Public Resources Code.

- 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

ITRF 2014

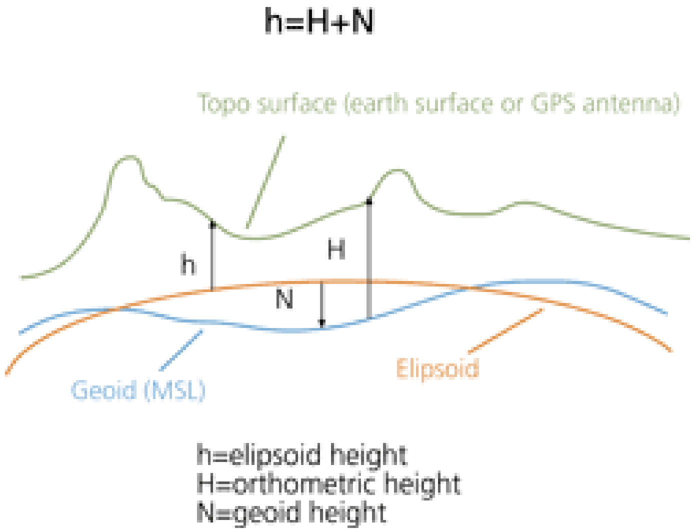
(X,Y,Z)



NAD83

(ϕ, λ, h)

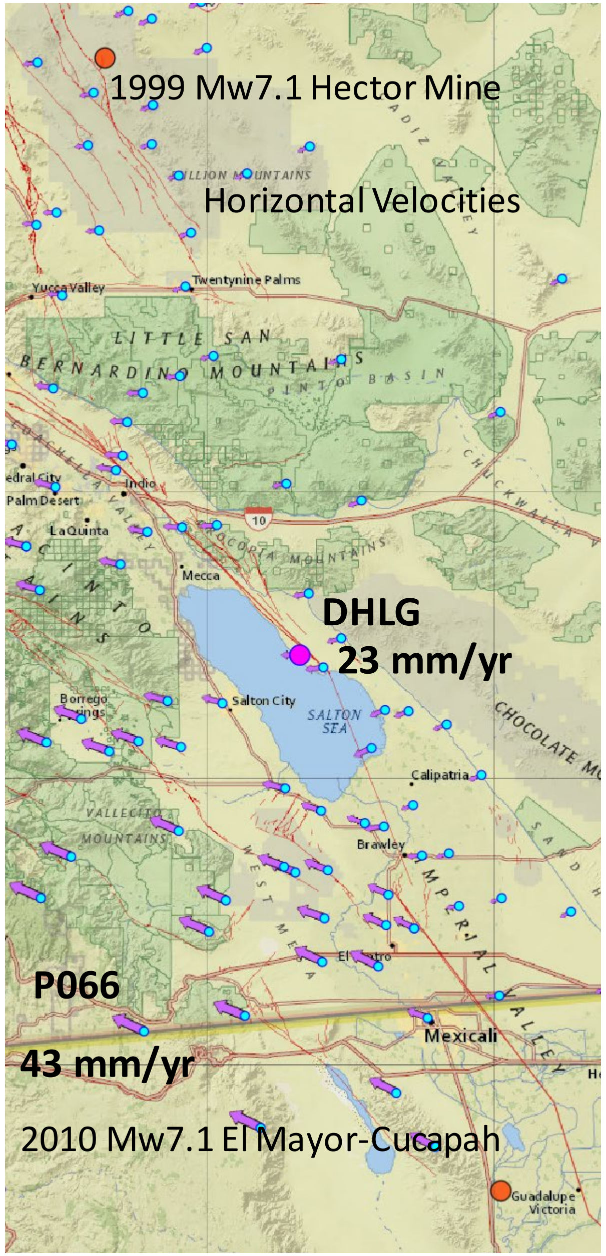
Geodetic Coordinates



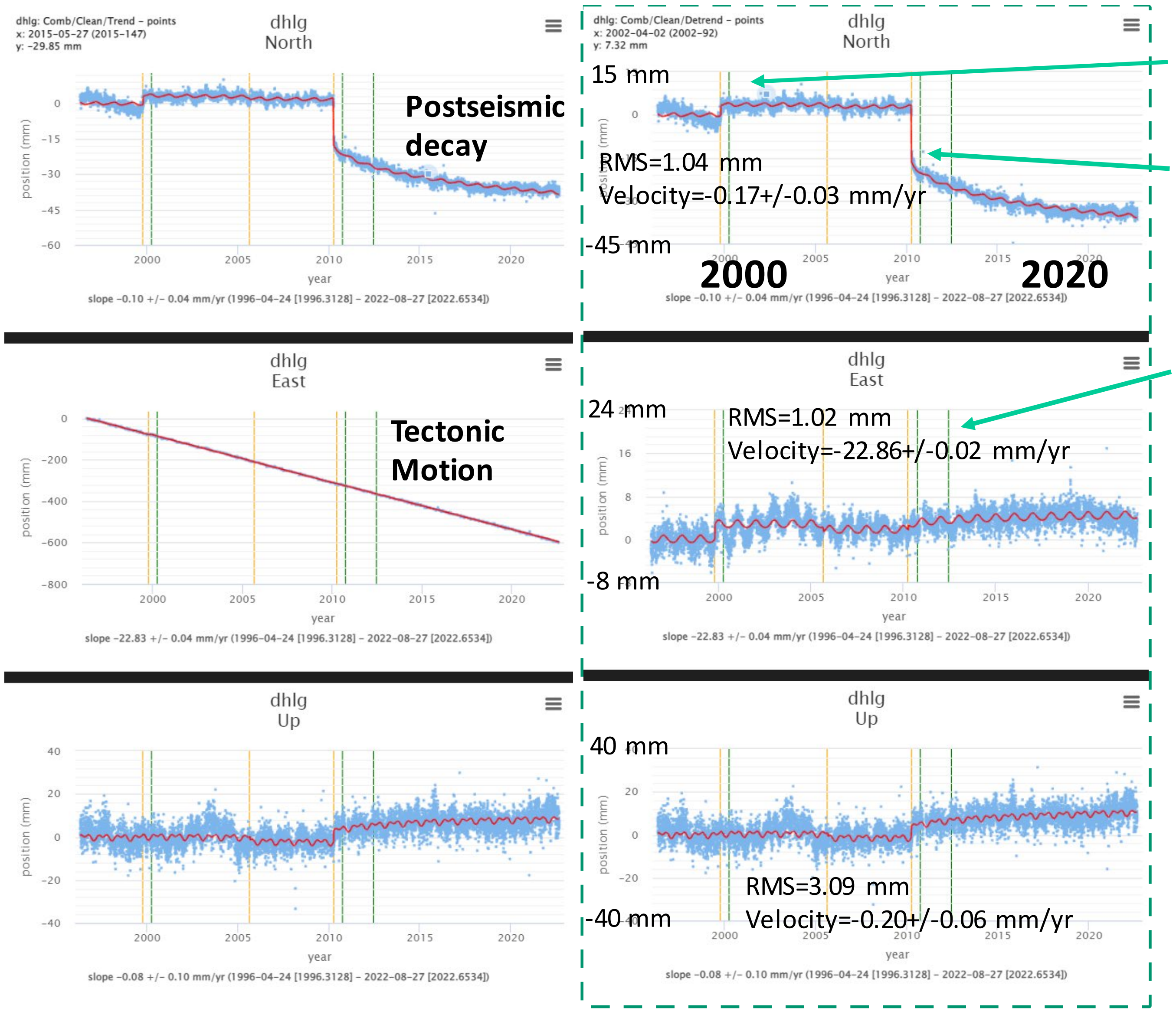
GEOID12B

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

GNSS-Derived Daily Displacement Time Series



De-Trended



1999 M7.1 Hector Mine earthquake coseismic offset

2010 M7.1 El Mayor-Cucapah earthquake coseismic offset

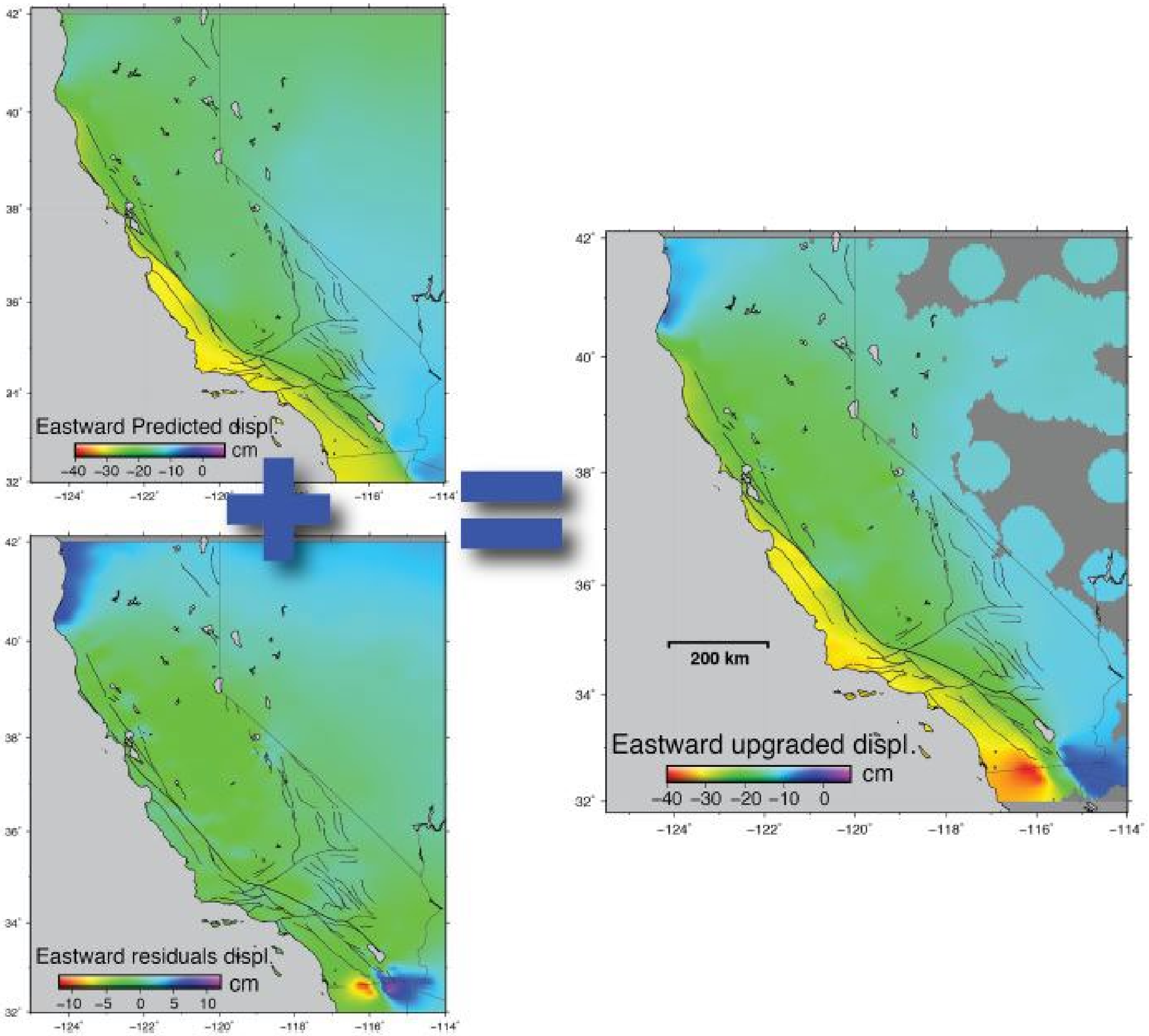
Antenna offset

mgviz.ucsd.edu

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

1mm = 0.0033 ft

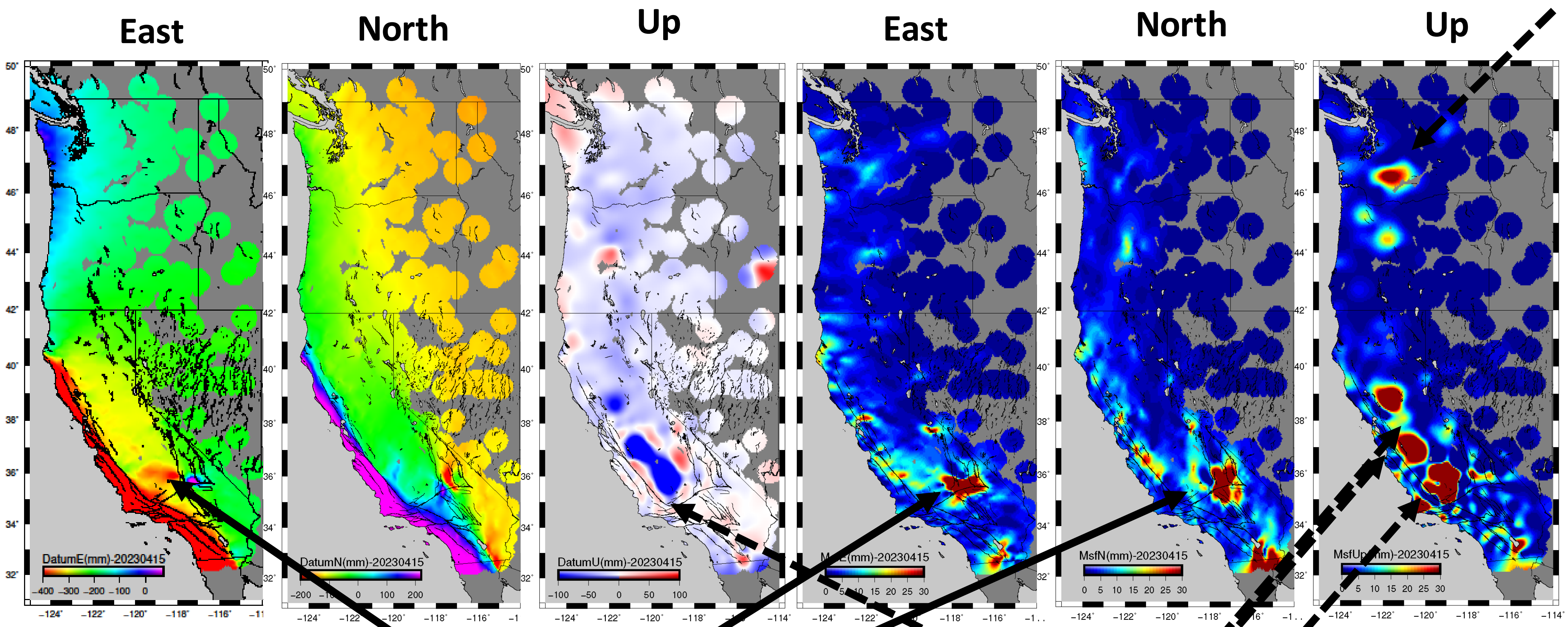
Intra-frame Deformation Model (IFDM) – Dynamic Datum



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)

--Displacements (mm)--   --Misfits (mm)--



Steady and transient displacements: 2023-04-15 with respect to 2010-01-01

July 2019 Ridgecrest earthquakes

San Joaquin & Sacramento Valleys Subsidence

SCIP Dynamic Datum Utility

SOPAC Coordinate Interpolator Prompt

Translate coordinates across epochs

Info and references • Contact

Input

- (•) Single Point
- ( ) List of Points

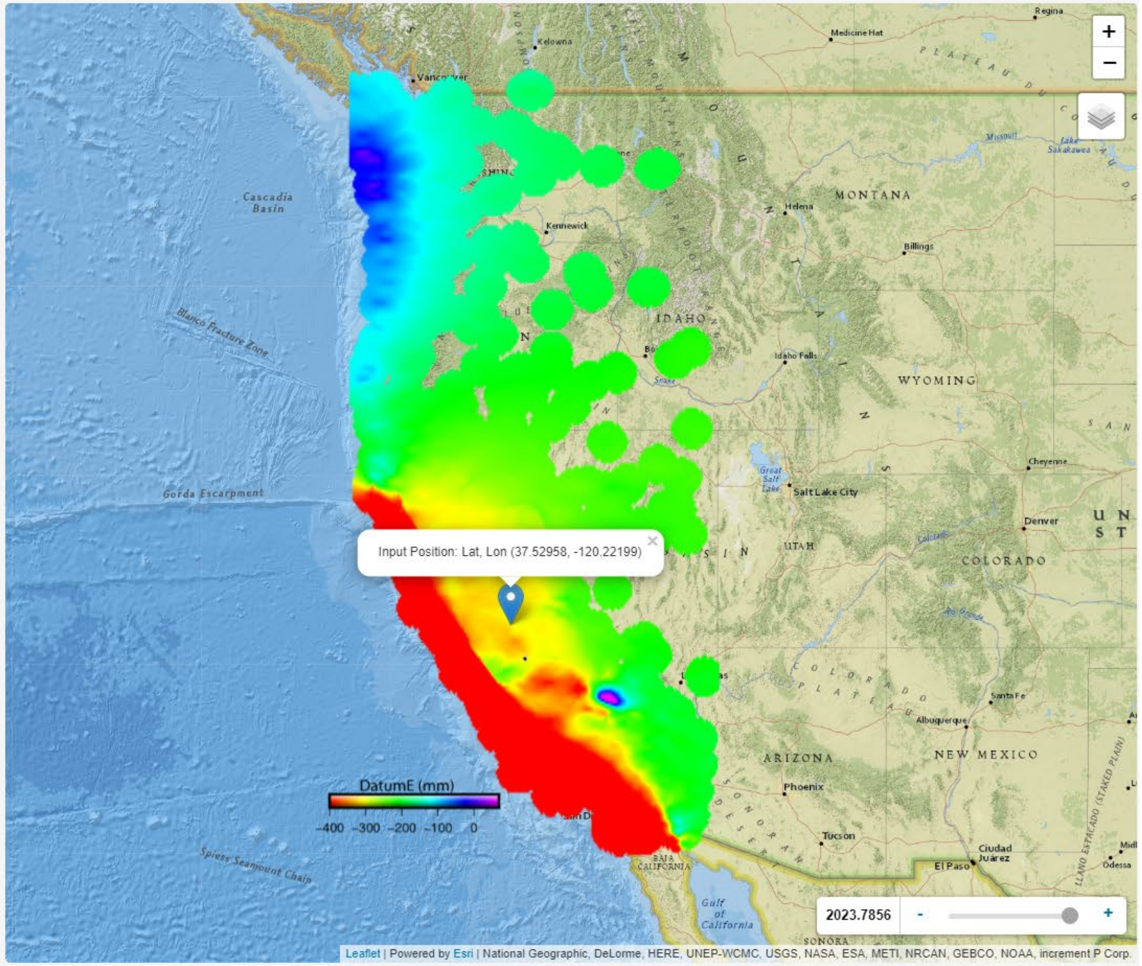
Format

Input Datum	WGS84 (Lat, Lon, Height)
Output Datum	WGS84 (Lat, Lon, Height)
Date Format	Decimal Year
Lat/Lon Format	Decimal
Height Units	Feet

Location

Latitude (N)	37.52957564
Longitude (E)	-120.22199169
Ellipsoidal Height (ft) (optional)	120.5
T-in (range: 2000-present)	2023.5
T-out (range: 2000-present)	2017.5

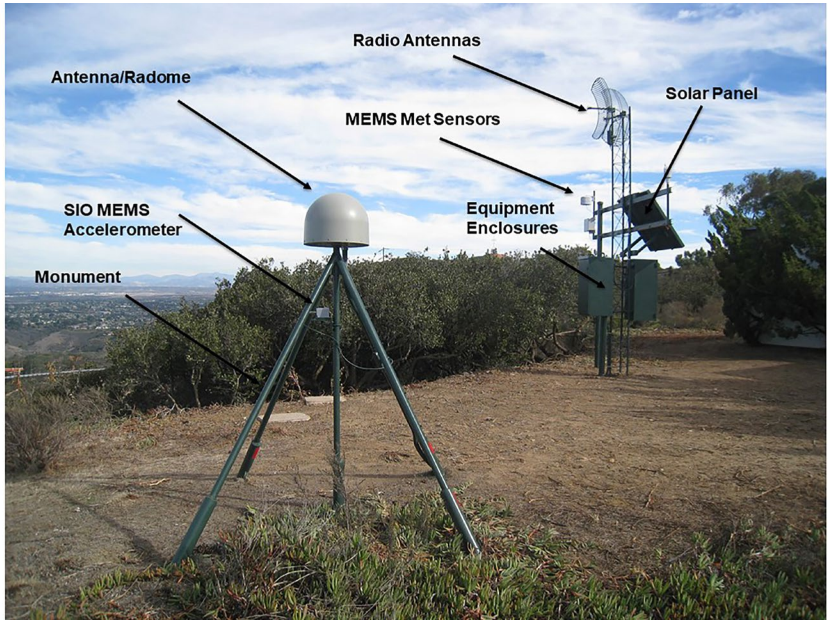
Get Coordinates | Get InSAR Time Series



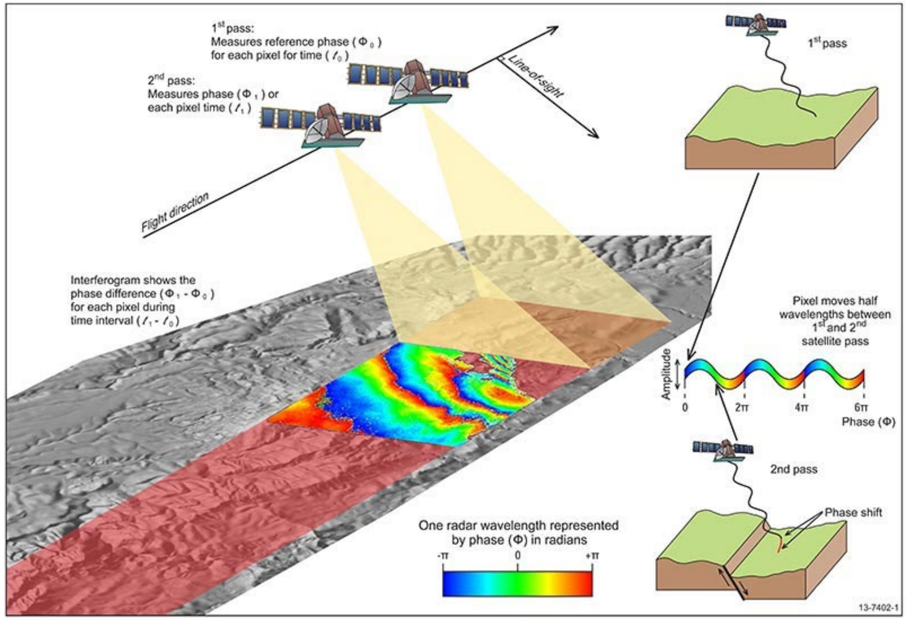
http://sopac-adj.ucsd.edu/scip/

InSAR/GNSS Integration for Higher Spatial Resolution

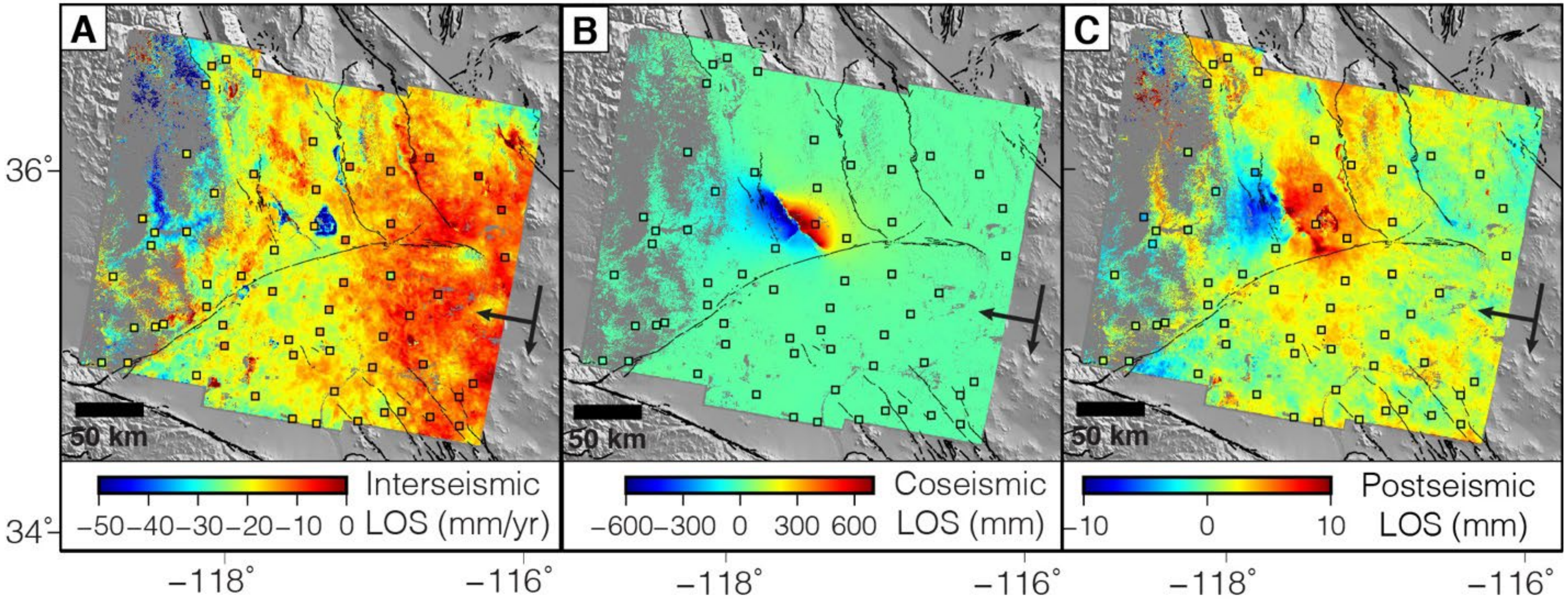
Typical continuous GNSS station (SIO5)



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).

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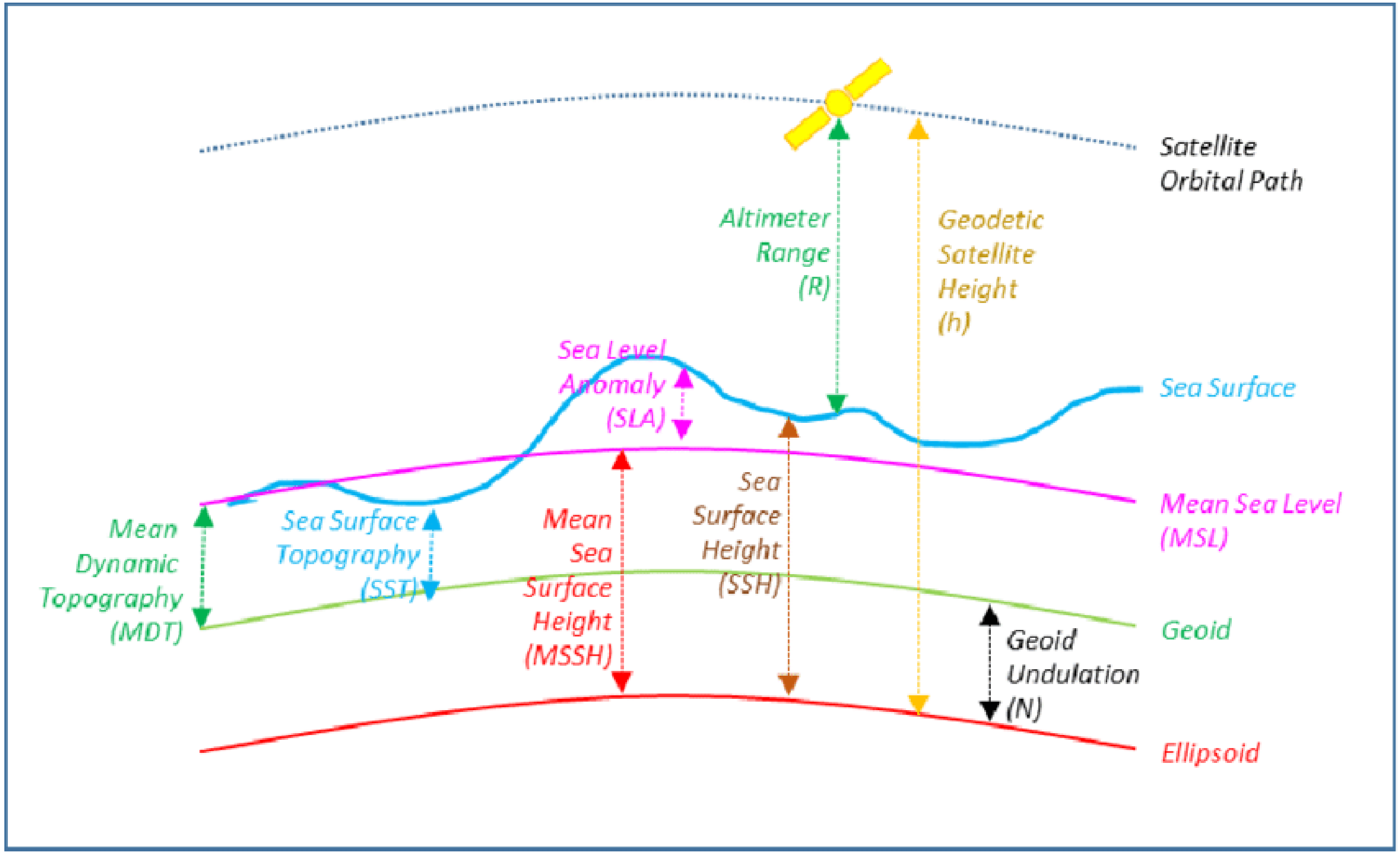
Reference Surfaces for Unified Vertical Reference Frame

Unified (marine/terrestrial) vertical reference frame through measurements of sea surface topography – funded by 5-year NGS grant. Led by Matt Mazloff and graduate student Tommy Stone (one of the NGS fellows for geodesy track)



dynamic ocean topography = sea surface topography

Thank you!
Questions?