Current status and future of the Community Geodetic Model

Michael Floyd (MIT)
and the Community Geodetic Model Working Group
[CGM (InSAR) Coordinator: Katia Tymofyeyeva (JPL)]

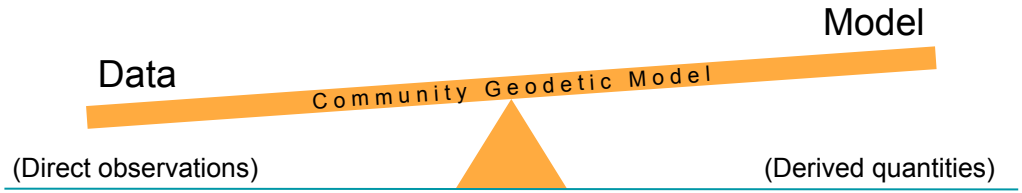
What is the Community Geodetic Model?

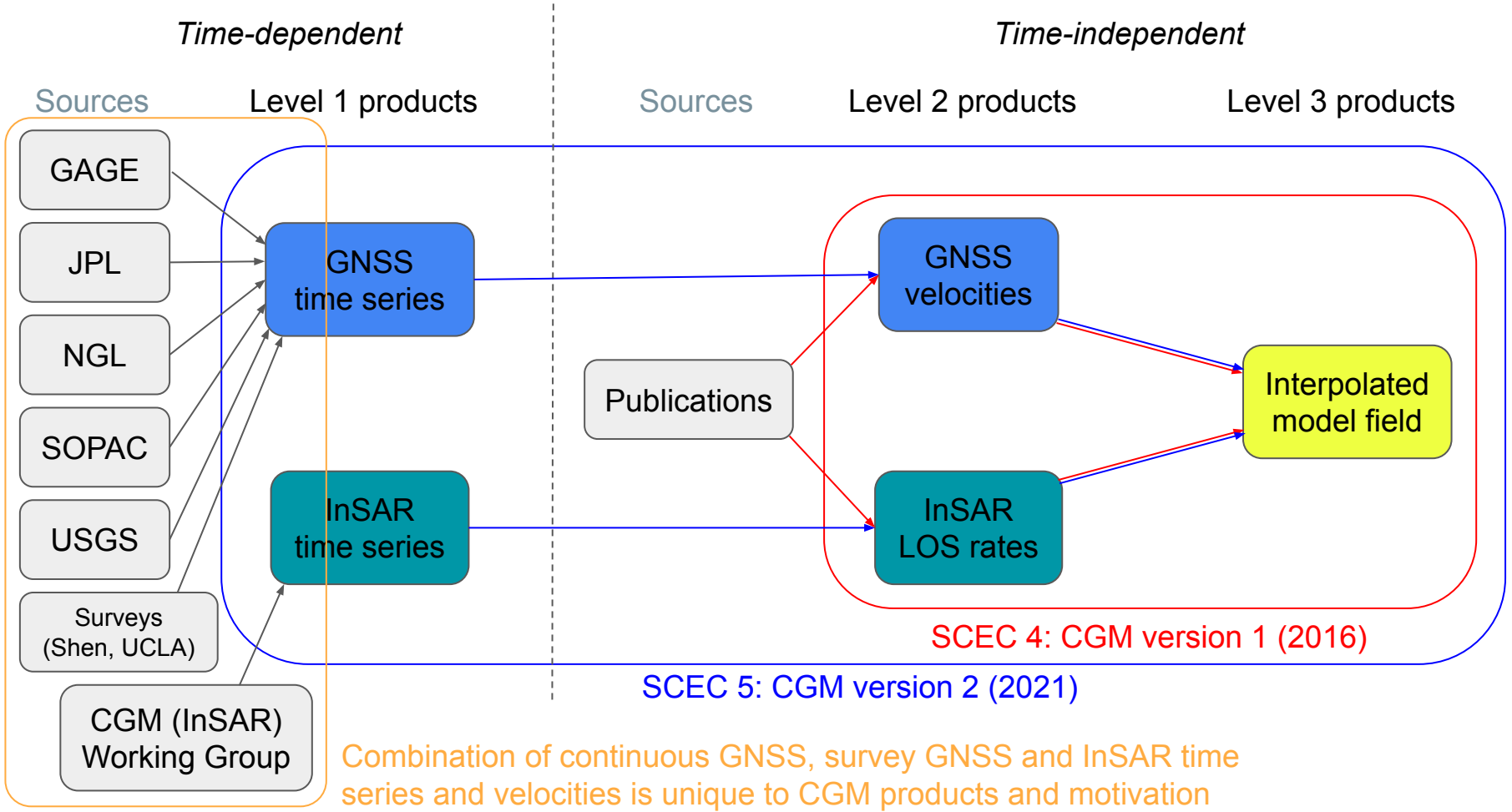
The CGM provides direct measurements of the displacement, and displacement rates, of the surface of the Earth, including derived products such as strain rate and continuous fields

Quantified by combination of data from discrete geodetic sites (survey and continuous GNSS) and spatially dense coverage (InSAR)

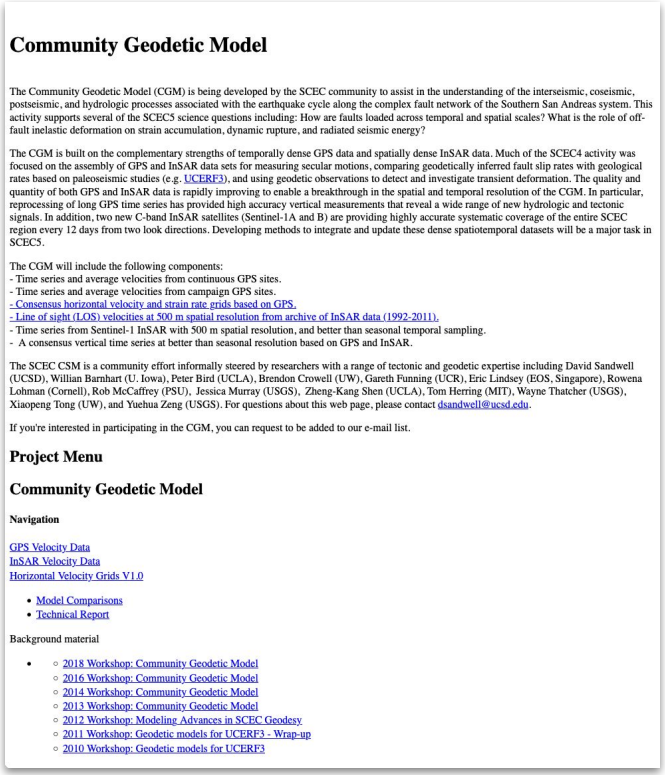
CGM1 (SCEC 4) is time-independent and provides interpolated velocity and strain rate grids in netCDF format

CGM2 (SCEC 5) expands CGM1 to provide time series for both GNSS and InSAR, from which derived quantities such as surface velocity are estimated again




Time-dependent
Time-independent
Sources
Level 1 products
Sources
Level 2 products
Level 3 products
GAGE
JPL
NGL
SOPAC
USGS
Surveys
(Shen, UCLA)
CGM (InSAR)
Working Group
GNSS
time series
InSAR
time series
Publications
GNSS
velocities
InSAR
LOS rates
Interpolated
model field
SCEC 4: CGM version 1 (2016)
SCEC 5: CGM version 2 (2021)
Combination of continuous GNSS, survey GNSS and InSAR time series and velocities is unique to CGM products and motivation

Access to the CGM: Web page



Community Geodetic Model

The Community Geodetic Model (CGM) is being developed by the SCEC community to assist in the understanding of the interseismic, coseismic, postseismic, and hydrologic processes associated with the earthquake cycle along the complex fault network of the Southern San Andreas system. This activity supports several of the SCEC5 science questions including: How are faults loaded across temporal and spatial scales? What is the role of off-fault inelastic deformation on strain accumulation, dynamic rupture, and radiated seismic energy?

The CGM is built on the complementary strengths of temporally dense GPS data and spatially dense InSAR data. Much of the SCEC4 activity was focused on the assembly of GPS and InSAR data sets for measuring secular motions, comparing geodetically inferred fault slip rates with geological rates based on paleoseismic studies (e.g. UCERF3), and using geodetic observations to detect and investigate transient deformation. The quality and quantity of both GPS and InSAR data is rapidly improving to enable a breakthrough in the spatial and temporal resolution of the CGM. In particular, reprocessing of long GPS time series has provided high accuracy vertical measurements that reveal a wide range of new hydrologic and tectonic signals. In addition, two new C-band InSAR satellites (Sentinel-1A and B) are providing highly accurate systematic coverage of the entire SCEC region every 12 days from two look directions. Developing methods to integrate and update these dense spatiotemporal datasets will be a major task in SCEC5.

The CGM will include the following components:
- Time series and average velocities from continuous GPS sites.
- Time series and average velocities from campaign GPS sites.
- Consensus horizontal velocity and strain rate grids based on GPS.
- Line of sight (LOS) velocities at 500 m spatial resolution from archive of InSAR data (1992-2011).
- Time series from Sentinel-1 InSAR with 500 m spatial resolution, and better than seasonal temporal sampling.
- A consensus vertical time series at better than seasonal resolution based on GPS and InSAR.

The SCEC CSM is a community effort informally steered by researchers with a range of tectonic and geodetic expertise including David Sandwell (UCSD), Willian Barnhart (U. Iowa), Peter Bird (UCLA), Brendon Crowell (UW), Gareth Funning (UCR), Eric Lindsey (EOS, Singapore), Rowena Lohman (Cornell), Rob McCaffrey (PSU), Jessica Murray (USGS), Zheng-Kang Shen (UCLA), Tom Herring (MIT), Wayne Thatcher (USGS), Xiaopeng Tong (UW), and Yuehua Zeng (USGS). For questions about this web page, please contact dsandwell@ucsd.edu.

If you're interested in participating in the CGM, you can request to be added to our e-mail list.

Project Menu

Community Geodetic Model

Navigation

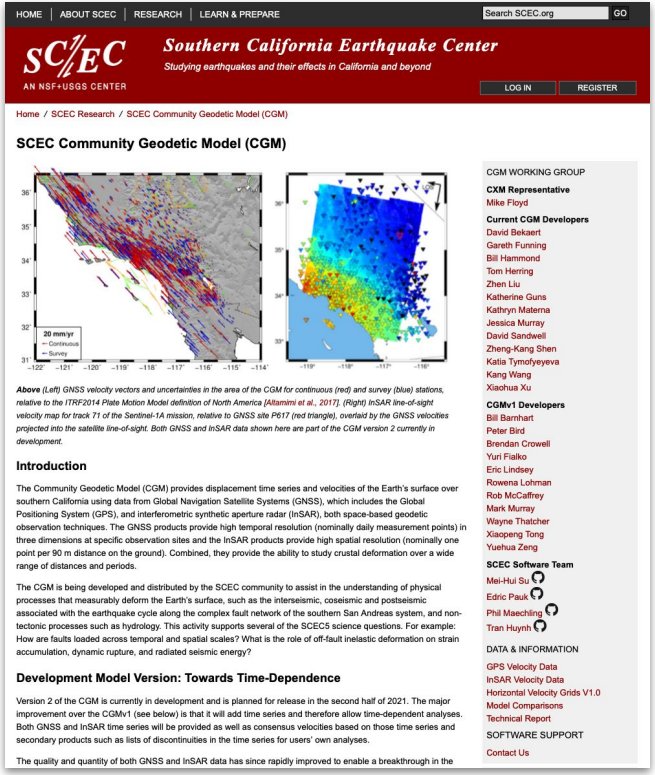
GPS Velocity Data
InSAR Velocity Data
Horizontal Velocity Grids V1.0

- Model Comparisons
- Technical Report

Background material

- 2018 Workshop: Community Geodetic Model
- 2016 Workshop: Community Geodetic Model
- 2014 Workshop: Community Geodetic Model
- 2013 Workshop: Community Geodetic Model
- 2012 Workshop: Modeling Advances in SCEC Geodesy
- 2011 Workshop: Geodetic models for UCERF3 - Wrap-up
- 2010 Workshop: Geodetic models for UCERF3

~~https://topex.ucsd.edu/CGM/CGM_html/~~



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SCEC Community Geodetic Model (CGM)

***Above** (Left) GNSS velocity vectors and uncertainties in the area of the CGM for continuous (red) and survey (blue) stations, relative to the ITRF2014 Plate Motion Model definition of North America [Altamimi et al., 2017]. (Right) InSAR line-of-sight velocity map for track 71 of the Sentinel-1A mission, relative to GNSS site P617 (red triangle), overlaid by the GNSS velocities projected into the satellite line-of-sight. Both GNSS and InSAR data shown here are part of the CGM version 2 currently in development.*

Introduction

The Community Geodetic Model (CGM) provides displacement time series and velocities of the Earth's surface over southern California using data from Global Navigation Satellite Systems (GNSS), which includes the Global Positioning System (GPS), and interferometric synthetic aperture radar (InSAR), both space-based geodetic observation techniques. The GNSS products provide high temporal resolution (nominally daily measurement points) in three dimensions at specific observation sites and the InSAR products provide high spatial resolution (nominally one point per 90 m distance on the ground). Combined, they provide the ability to study crustal deformation over a wide range of distances and periods.

The CGM is being developed and distributed by the SCEC community to assist in the understanding of physical processes that measurably deform the Earth's surface, such as the interseismic, coseismic and postseismic associated with the earthquake cycle along the complex fault network of the southern San Andreas system, and non-tectonic processes such as hydrology. This activity supports several of the SCEC5 science questions. For example: How are faults loaded across temporal and spatial scales? What is the role of off-fault inelastic deformation on strain accumulation, dynamic rupture, and radiated seismic energy?

Development Model Version: Towards Time-Dependence

Version 2 of the CGM is currently in development and is planned for release in the second half of 2021. The major improvement over the CGMv1 (see below) is that it will add time series and therefore allow time-dependent analyses. Both GNSS and InSAR time series will be provided as well as consensus velocities based on those time series and secondary products such as lists of discontinuities in the time series for users' own analyses.

The quality and quantity of both GNSS and InSAR data has since rapidly improved to enable a breakthrough in the

CGM WORKING GROUP

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DATA & INFORMATION
GPS Velocity Data
InSAR Velocity Data
Horizontal Velocity Grids V1.0
Model Comparisons
Technical Report

SOFTWARE SUPPORT
Contact Us

https://www.scec.org/research/cgm/

Access to the CGM: Products

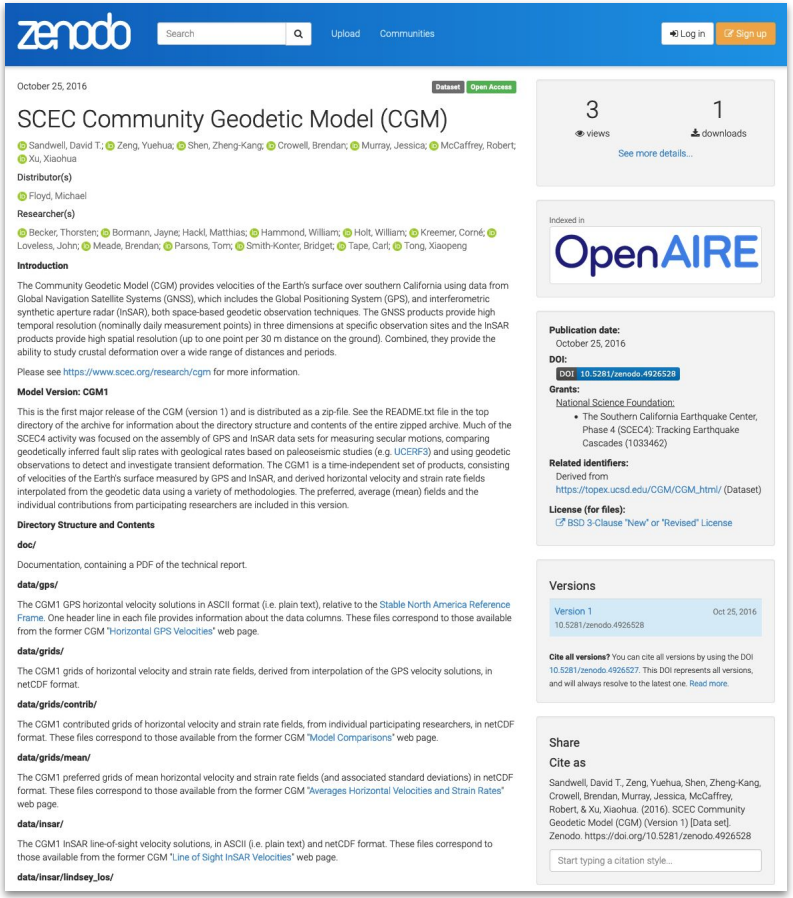
CGM version 1 uploaded to and available on Zenodo with DOI

10.5281/zenodo.4926528

One zip-file (1.9 GB) with all input data tables and netCDF files, and interpolated velocity and strain rate fields also in netCDF format

“Concept DOI”, which is a generic DOI for the CGM as a whole and will direct to the latest version available on Zenodo, is

10.5281/zenodo.4926527



Version 2 of the CGM

Survey GNSS:

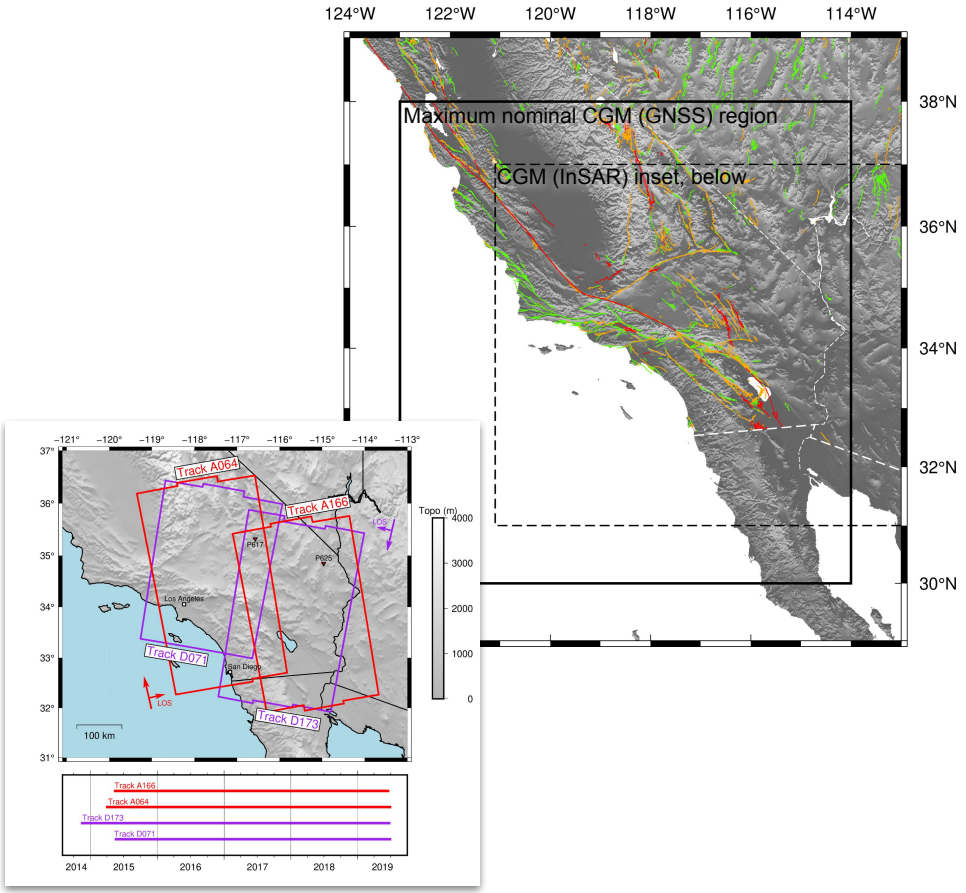
- Processed by Zheng-Kang Shen (UCLA)
- 1124 time series from mid-1991 to present

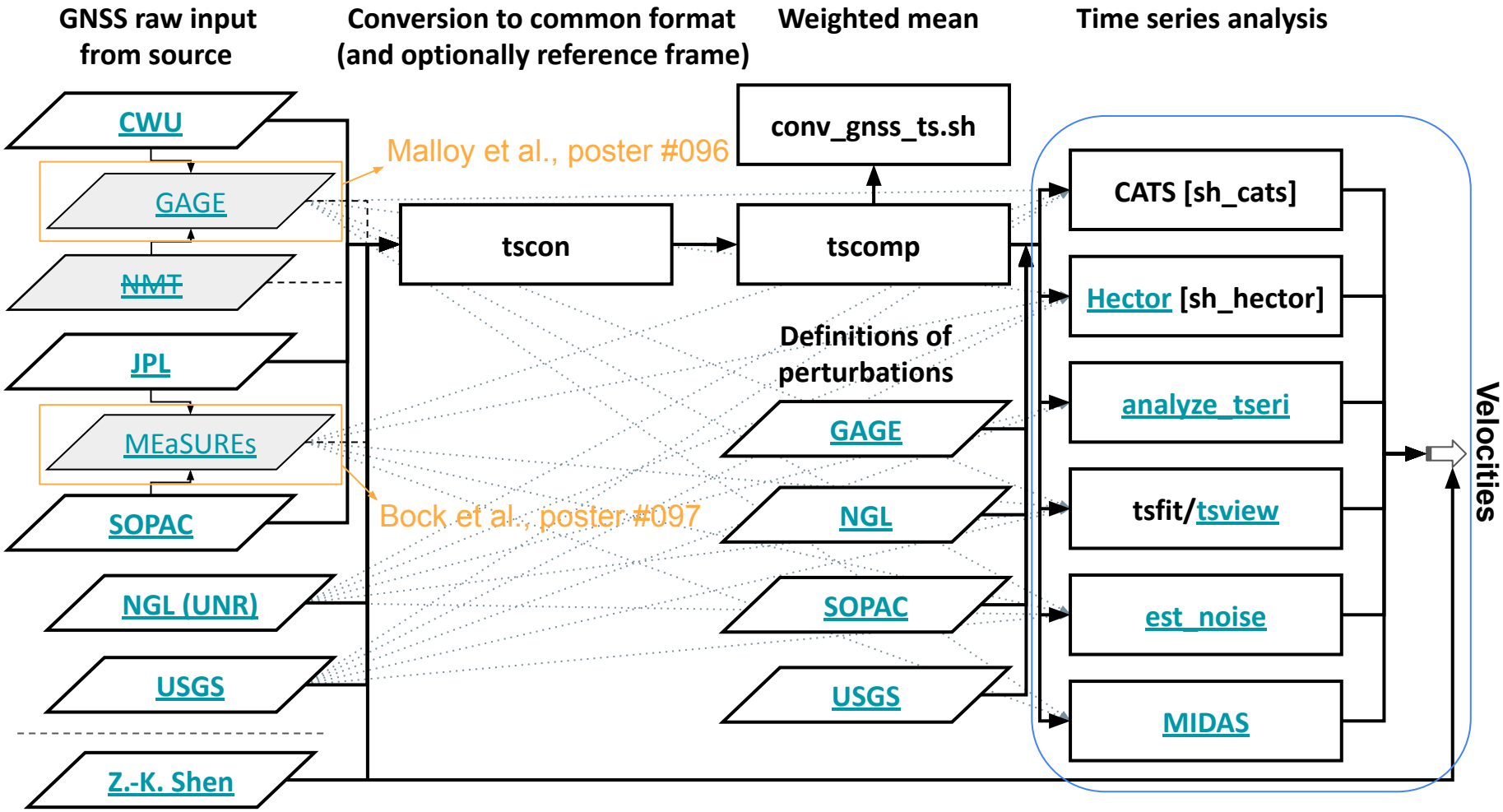
Continuous GNSS:

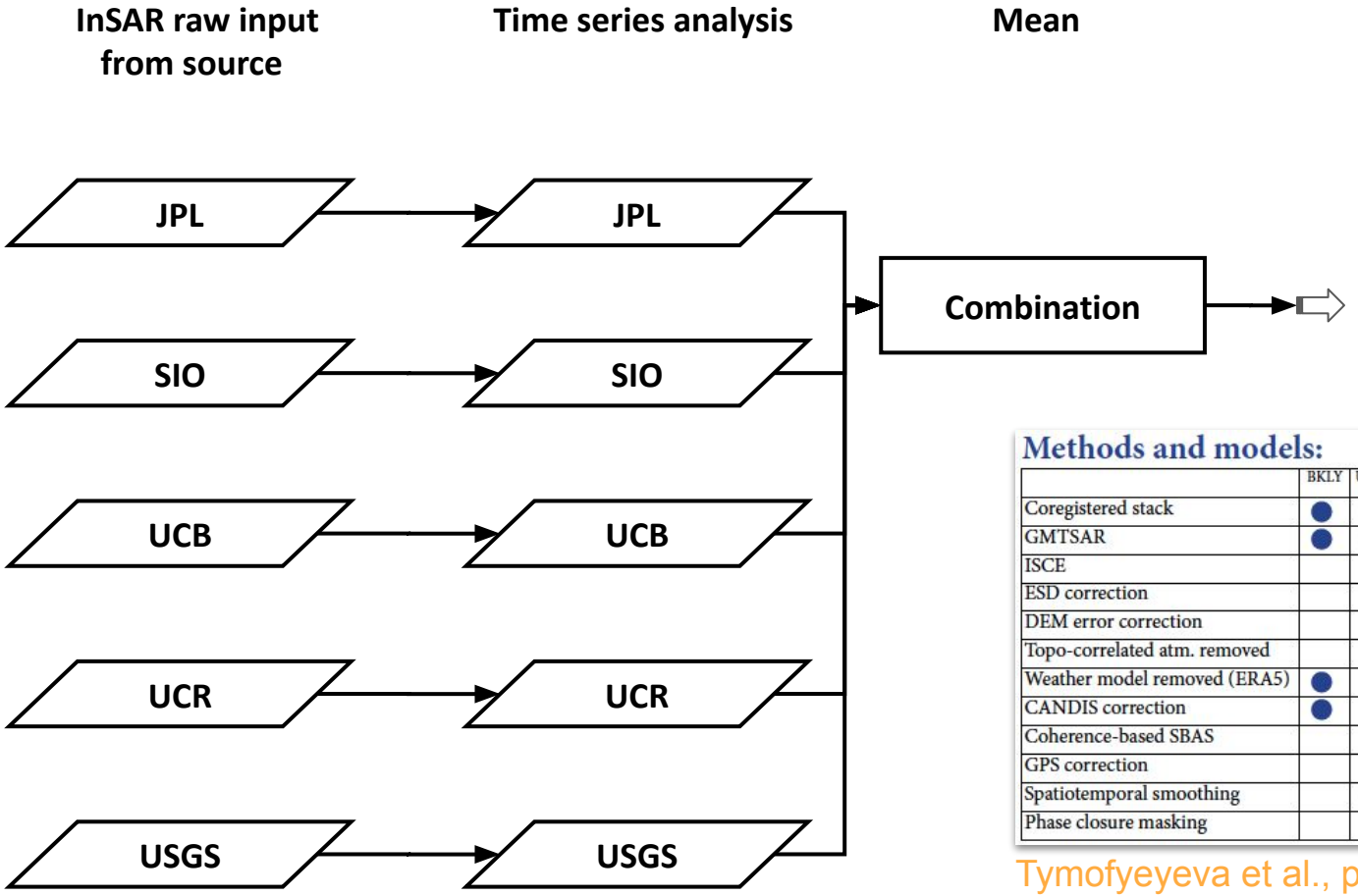
- Ingests five analysis centers, producing publicly available products operationally, to generate “union” or “superset” product
- 1202 time series from 1994 to the present
    - 304 from one source AC, 61 combined from two, 73 from three, 180 from four and 584 from all five

InSAR:

- Averages five solutions from SCEC institutions
- Sentinel-1 from mid-2014 to mid-2019 (stopping at 2019 Ridgecrest earthquake)
- 4 tracks over southern California at a nominal spatial resolution of ~ 200 m (~ 6 million pixels)




GNSS raw input from source
Conversion to common format (and optionally reference frame)
Weighted mean
Time series analysis
CWU
GAGE
NMT
JPL
MEaSUREs
SOPAC
NGL (UNR)
USGS
Z.-K. Shen
Malloy et al., poster #096
Bock et al., poster #097
tscon
conv_gnss_ts.sh
tscomp
Definitions of perturbations
GAGE
NGL
SOPAC
USGS
CATS [sh_cats]
Hector [sh_hector]
analyze_tseri
tsfit/tsview
est_noise
MIDAS
Velocities

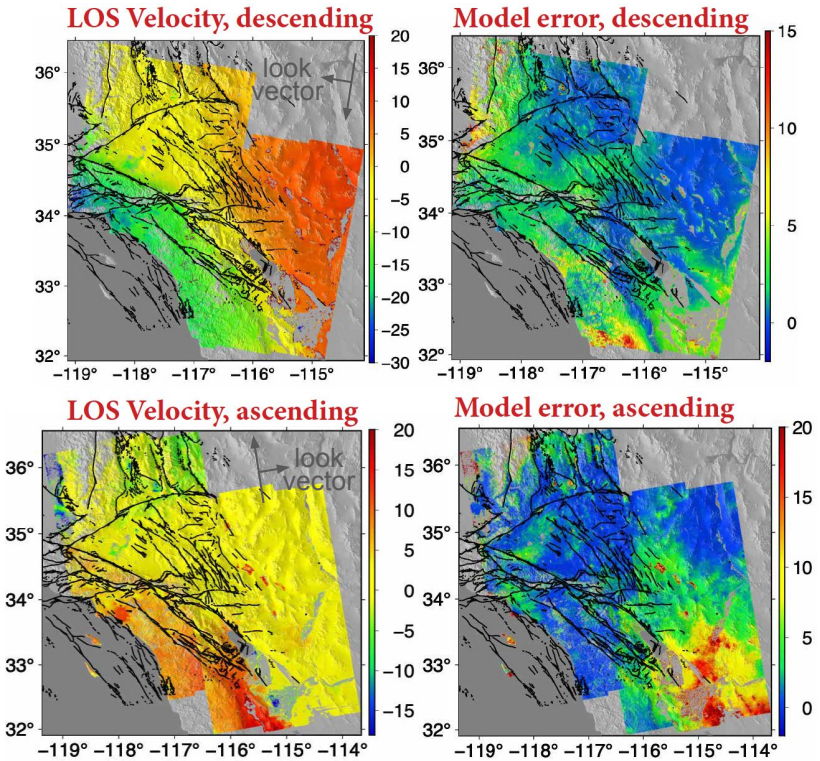


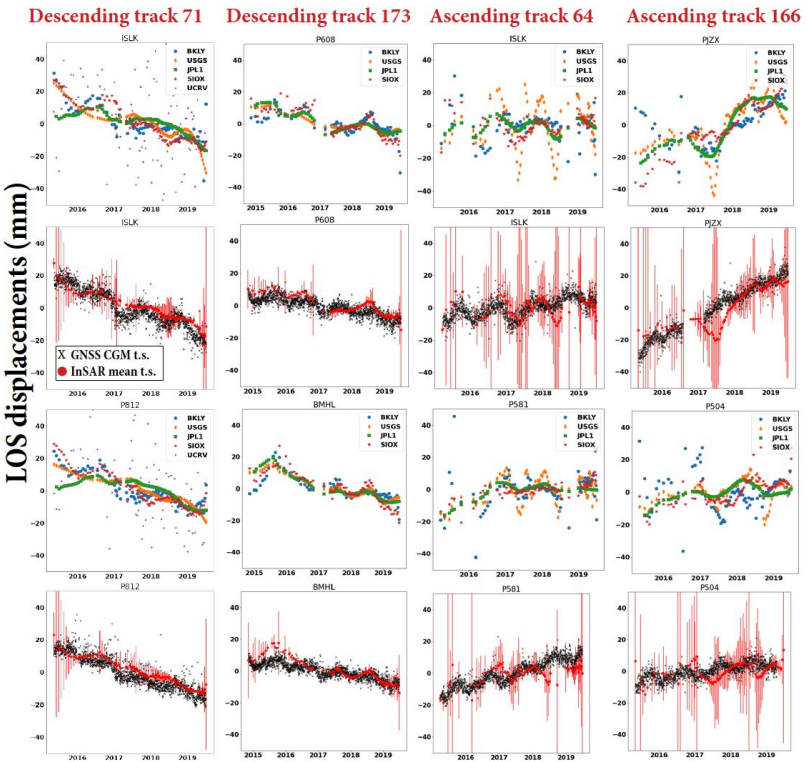
Methods and models:

	BKLY	USGS	JPL1	SIOX	UCRV
Coregistered stack	●	●	●	●	●
GMTSAR	●	●		●	●
ISCE			●		
ESD correction			●		
DEM error correction			●	●	
Topo-correlated atm. removed			●	●	
Weather model removed (ERA5)	●				
CANDIS correction	●			●	
Coherence-based SBAS				●	
GPS correction				●	
Spatiotemporal smoothing		●	●	●	
Phase closure masking			●	●	●

Tymofyeyeva et al., poster #019

InSAR line-of-sight time series and velocity products





Tymofyeyeva et al., poster #019

CGM2 product access and web viewer development

- Product files are available, preliminarily at http://geoweb.mit.edu/~floyd/scec/cgm/ (GNSS) and on Google Drive (InSAR), and will eventually be packaged and uploaded to Zenodo, under the CGM concept DOI and alongside CGM1 products
  - Update schedule is an open question, considering daily acquisition of new geodetic data compared to other more temporally static CXMs

- GNSS time series are provided in GAGE's ".pos" file format, with one shell script (conv_gnss_ts.sh; no dependencies required) for conversion to other common formats (e.g. NGL's ".txyz2" and ".tenv3" formats, and a free-format GeoCSV file)

- Kathryn Materna (USGS) is the lead architect of an HDF5 file format and reader codes to distribute to users the InSAR products, whose time series are written out in a similar free-format GeoCSV file
  - https://github.com/kmaterna/InSAR_CGM_readers_writers

- Each of these is being incorporated into a web viewer being developed by SCEC IT and the CGM Working Group
  - See Su et al., poster #020, at this meeting!

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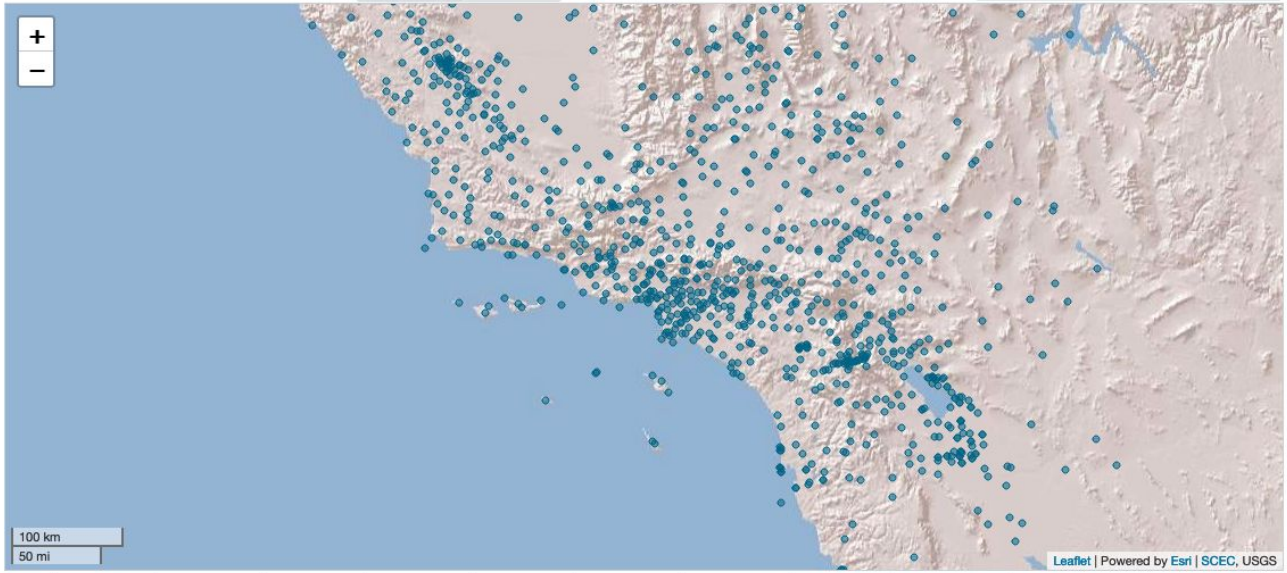
Search the GNSS ... RESET

Select Dataset GNSS ☑ GNSS ☐ GNSS vectors ☐ InSAR ☐ CFM faults Select Map Type Shaded Relief



☐	Station Name	Lat	Lon	Type	East Vel	North Vel	Horizontal Vel (mm/yr)	Azimuth	Vertical Vel (mm/yr)	DOWNLOAD
Metadata for selected points will appear here.										

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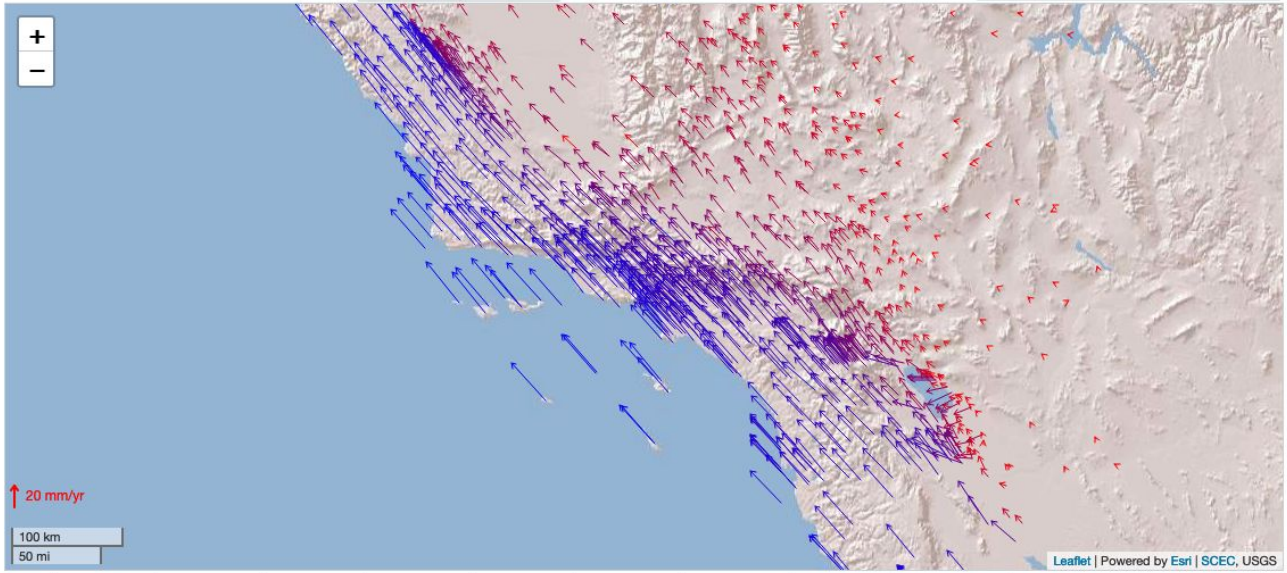
Search the GNSS ... | RESET

Select Dataset: GNSS | ☐ GNSS | ☑ GNSS vectors | ☐ InSAR | ☐ CFM faults | Select Map Type: Shaded Relief



☐	Station Name	Lat	Lon	Type	East Vel	North Vel	Horizontal Vel (mm/yr)	Azimuth	Vertical Vel (mm/yr)	DOWNLOAD
Metadata for selected points will appear here.										

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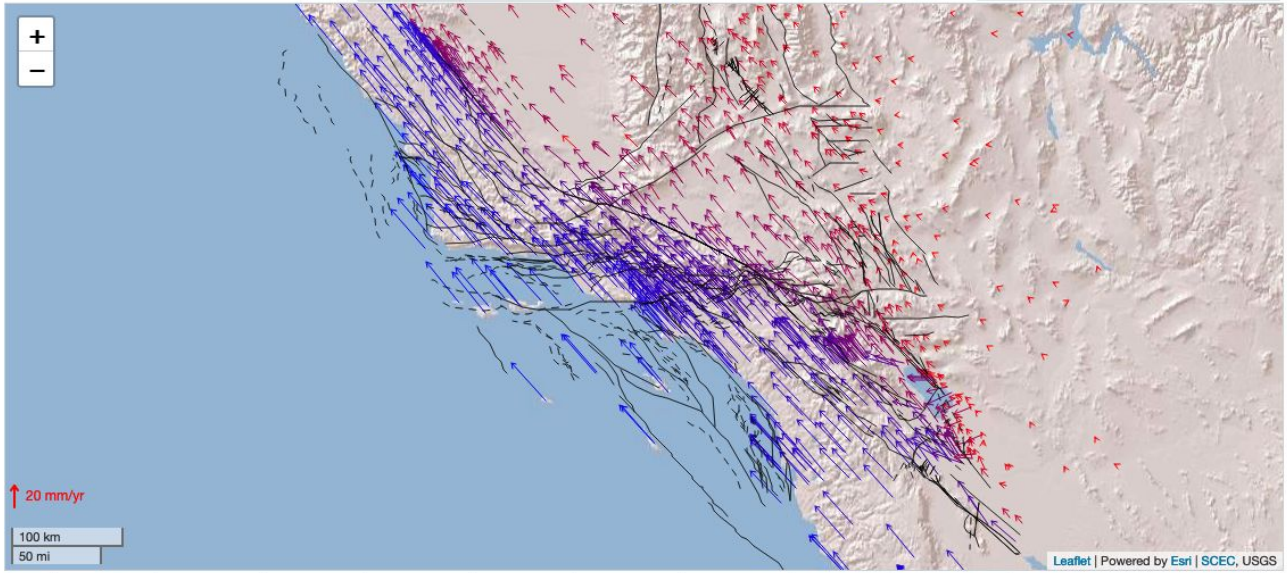
Search the GNSS ... | RESET

Select Dataset: GNSS | ☐ GNSS ☑ GNSS vectors ☐ InSAR ☑ CFM faults | Select Map Type: Shaded Relief



☐	Station Name	Lat	Lon	Type	East Vel	North Vel	Horizontal Vel (mm/yr)	Azimuth	Vertical Vel (mm/yr)	DOWNLOAD
Metadata for selected points will appear here.										

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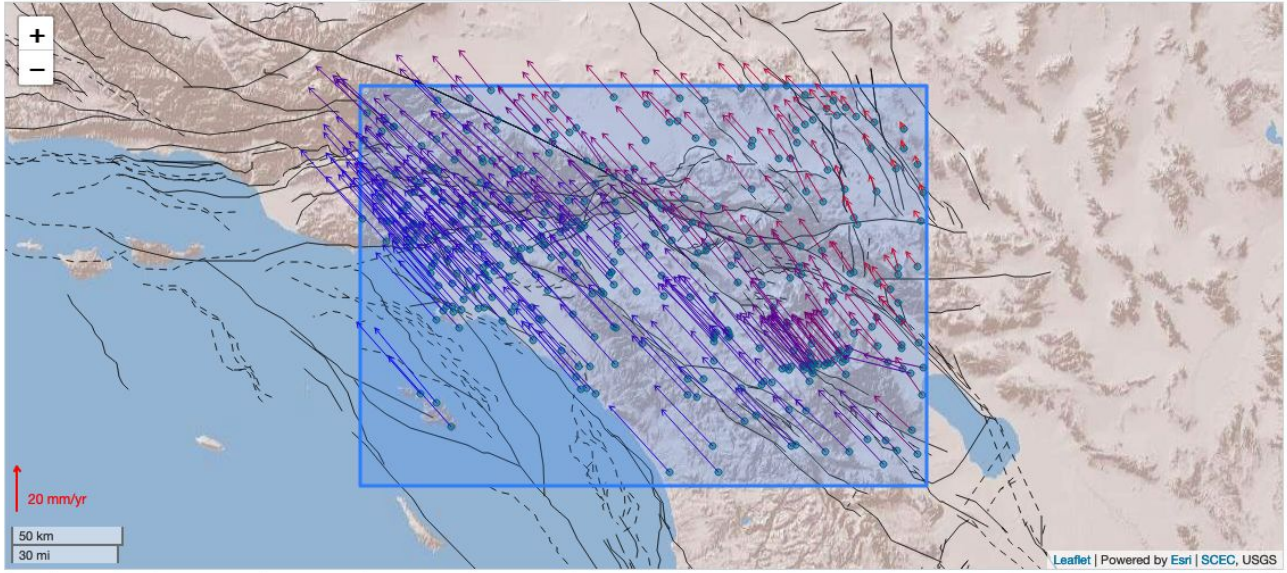
Latitude & Longitude | RESET

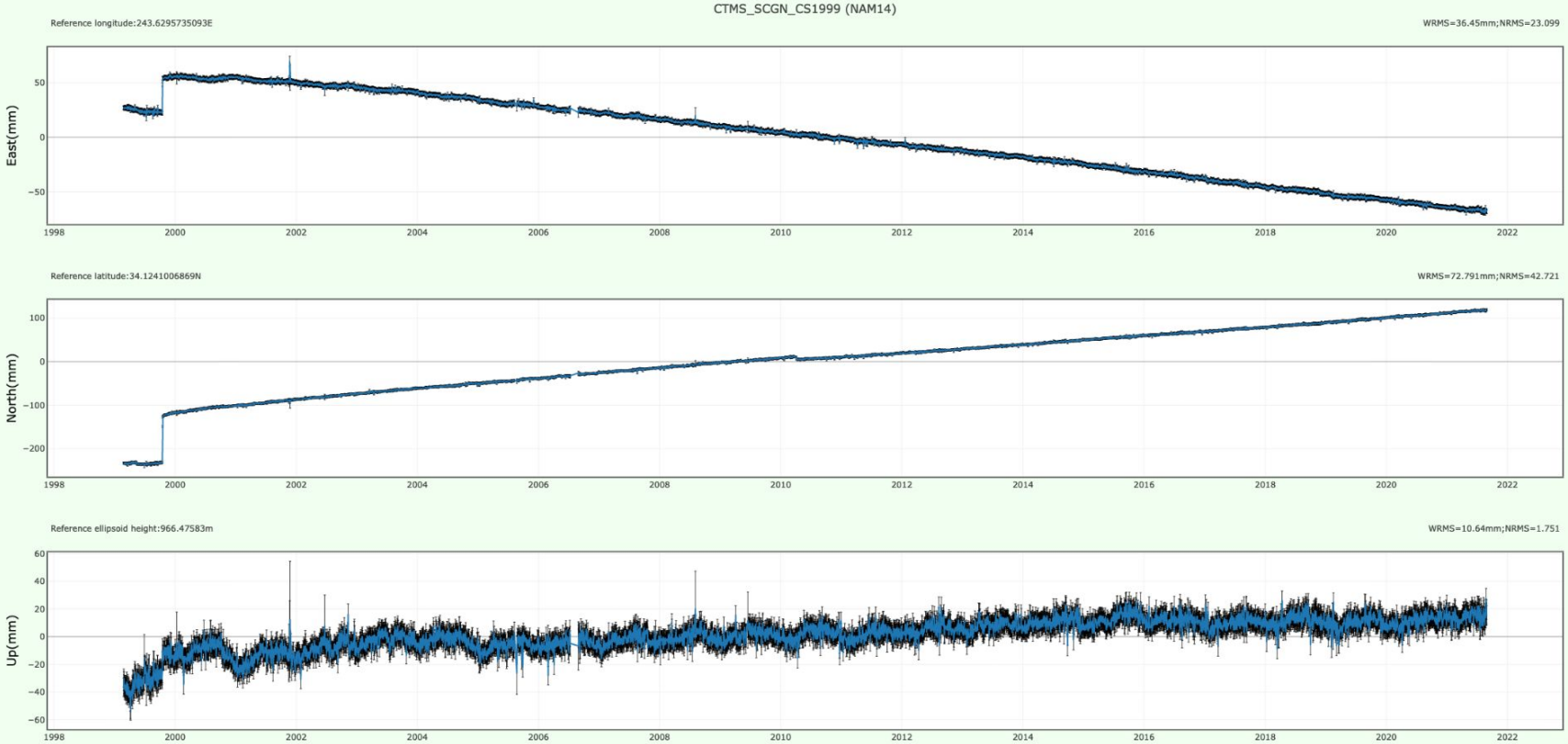
Draw a rectangle on the map or enter latitudes and longitudes

33.074665355 | -118.77319335 | 34.679899556 | -116.03759765

Select Dataset: GNSS | GNSS | GNSS vectors | InSAR | CFM faults | Select Map Type: Shaded Relief



	Station Name	Lat	Lon	Type	East Vel	North Vel	Horizontal Vel (mm/yr)	Azimuth	Vertical Vel (mm/yr)	DOWNLOAD
☐	0048	34.50	-118.26	continuous	-23.513	21.994	32.196	-46.912	0.000	plotTS
☐	0094	34.15	-118.76	continuous	-27.259	30.459	40.875	-41.827	0.000	plotTS
☐	0141	34.47	-118.41	continuous	-22.990	19.687	30.267	-49.426	0.000	plotTS
☐	0701	34.00	-118.40	continuous	-27.430	29.882	40.563	-42.550	0.000	plotTS



Time series file: http://geoweb.mit.edu/~floyd/scec/cgm/ts/*SITE*.cgm.wmrss_*frame*.pos

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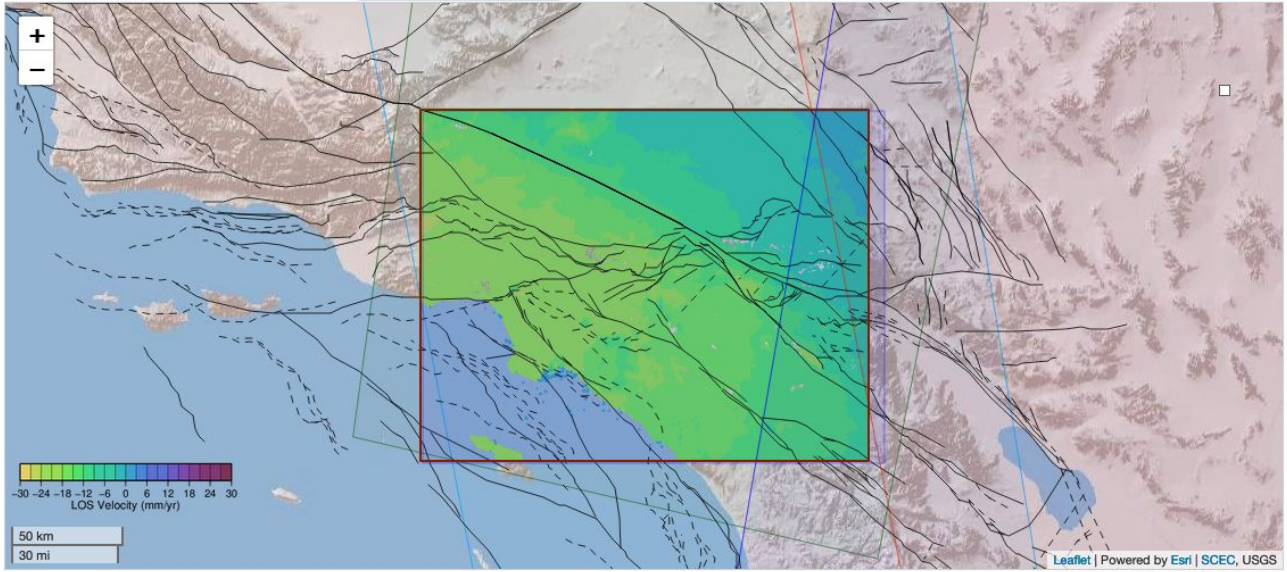
Latitude & Longitude | RESET

Draw a rectangle on the map or enter latitudes and longitudes

33.387 | -118.851 | 34.789 | -116.685

Select Dataset: InSAR | GNSS | GNSS vectors | InSAR | CFM faults | Select Map Type: Shaded Relief



	Track	Lat	Lon	Velocity (mm/yr)	DOWNLOAD
☐	D071	sw:33.387 ne:34.789	sw:-118.851 ne:-116.685	max:0 min:-30.038889 count:605021	showVS plotVS

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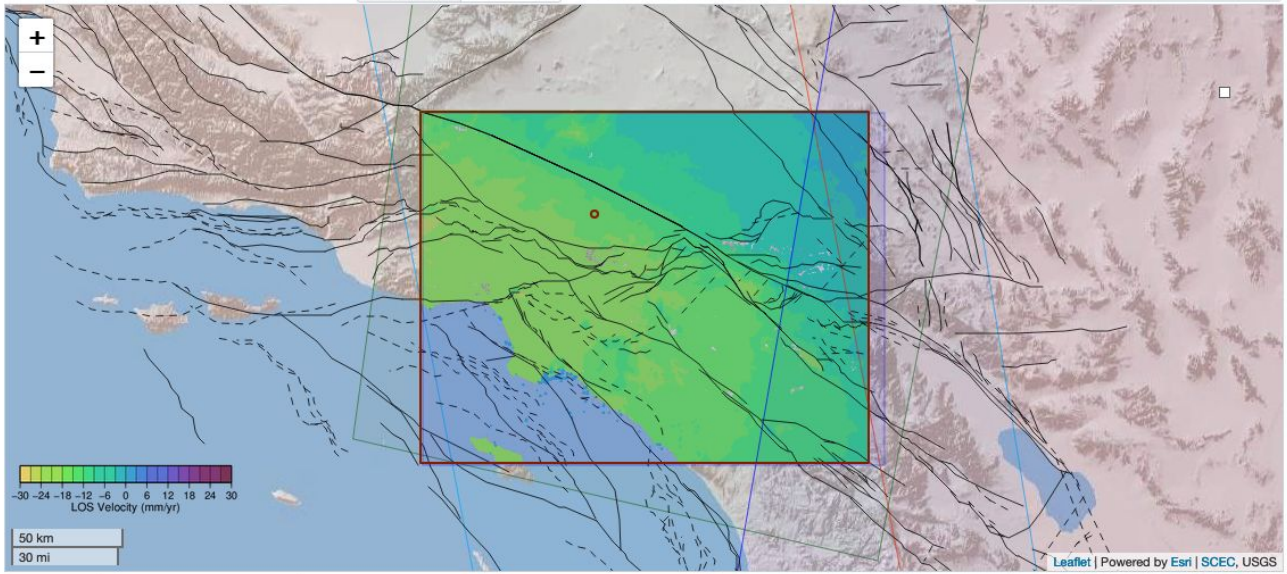
Point Location | RESET

Select a location on the map or enter latitude and longitude: 34.385, -118.009

Select Dataset: InSAR | GNSS | GNSS vectors | InSAR | CFM faults | Select Map Type: Shaded Relief



	Track	Lat	Lon	Velocity (mm/yr)	DOWNLOAD
☐	D071	34.385	-118.009	-16.19177	plotTS
☐	D071	sw:33.387 ne:34.789	sw:-118.851 ne:-116.685	max:0 min:-30.038889 count:605021	showVS plotVS


insar_613e56c45c759_D071(-118.009,34.385)
LOS(mm)
0
−10
−20
−30
−40
−50
−60
May 2015
Sep 2015
Jan 2016
May 2016
Sep 2016
Jan 2017
May 2017
Sep 2017
Jan 2018
May 2018
Sep 2018
Jan 2019
May 2019
Sep 2019

Upcoming events

- Further updates to CGM web page, including new Zenodo link to CGM1
- Initial release of CGM2 union product files and reader codes
  - Please consider acting as a beta-tester!
- CGM web viewer will be advertised
  - Please consider acting as a beta-tester!
- CGM workshop is planned, most likely for early November
  - Please consider joining us for more details on the status and future plans of the CGM!

Future updates and challenges

- Unification of multiple InSAR tracks with GNSS for 3-D displacements/velocities in terrestrial reference frame or plate frame, including application of standard GNSS corrections such as tidal loading and atmospheric delays
    - Existing methodologies include Tong et al. (2013), based on Wei et al. (2010), and Shen and Liu (2020)
    - See Xu et al., poster #098, and Shen and Liu, poster #100, at this meeting!
- Other types of derived products such as differences between source analysis center and CGM time series
    - Will these be useful to researchers who want to assess epistemic uncertainty by comparing product sources?
- InSAR time series across discrete discontinuities, such as earthquakes, and transient perturbations, such as afterslip and visco- and poro-elastic deformation, remains a topic of active research
    - CGMv2 InSAR time series currently end before the Ridgecrest earthquakes
    - See Guns et al., poster #099, and Abolfathian et al., poster #108, at this meeting!
- Smoothed strain rate fields interpolated from geodetic velocities, like CGM version 1 from GPS, or do InSAR displacements provide enough spatial resolution and coverage if rigorously combined?
    - How many types of products should the CGM include (displacement time series, velocities, strain rate, event displacements, etc.) without succumbing to “mission creep”?
- Each additional derived product often requires thousands of new files to be created, so how to keep things accessible to users?