Session 1: Workshop Overview and State of the SCEC CGM

Tuesday 9 November 2021, 09:00–10:00 PST (UTC−8)
Moderators: Mike Floyd (MIT) and Katia Tymofyeyeva (JPL)
Reporters: Mike Floyd (MIT) and Katia Tymofyeyeva (JPL)
State of the Community Geodetic Model

Michael Floyd (MIT)
Welcome!

Who is the Community Geodetic Model?

The CGM, and all SCEC Community Models, are the collective fruit of the contributing community’s labor.

The CGM is of the community, by the community and for the community.

The CGM is all of us combined.

We welcome you all to contribute your expertise, product lines, algorithms, etc. to the CGM!
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
CGM activities

“Friends of InSAR” discussion at AGU Fall Meeting initiates regular InSAR Working Group activity

Consensus GNSS velocity solution; combination of GNSS and InSAR products; derived products, e.g. strain rate maps, etc.

Initial web site live

CGM version 2 InSAR consensus time series and LOS rates developed

CGM version 2 GNSS consensus time series developed

First attempts at reconciling GNSS velocity solutions, and discussions of InSAR time series

CGM version 2 GNSS time series operational

CGM Workshop (virtual)

CGM Workshop at SCEC AM

CGM Workshop at SIO

SCEC 4

2016

SCEC 5

2018

2019

2020

2021

CGM version 1
released; includes GNSS velocities and InSAR line-of-sight rate maps, and derived strain rate grids

2017

2016

2017

2017

2017

2017

2017
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 intraplate, coseismic, and postseismic processes associated with the earthquake cycle along the complex fault network of the Southern California region. This activity supports several of the SCEC science questions including: How are faults loaded across transient and propagating seismic waves? What is the role of off-fault elastic 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 SCEC activity was focused on the assembly of GPS and InSAR data sets for measuring secular motions, computing geodetically inferred fault slip rates, and computing results based on paleoseismic studies (e.g., [1]), 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 spatiotemporal 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, the future CGM InSAR satellites (Sentinel-5A and B) are providing highly accurate systematic coverage of the Southern California region every 12 days from two look directions. Developing methods to integrate and update these dense spatiotemporal data sets will be a major task in SCEC.

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.
- Continuous horizontal velocity and vertical uplift rates calculated from GPS.
- Land of study (LOS) velocities at 39 points from first velocity of InSAR data (1992-2011).
- Time series from Sentinel-5A 30 m InSAR with 608 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 CGM is a community effort informally steered by representatives with a range of tectonic and geodetic expertise including David Sandwell (UCSD), William Harbert (UC), Kevin Blaser (UCI), Bruce Yardley (GSFC), Matthew Shipp (USGS), and Sherwood Luh (UCB). If you are interested in participating in the CGM, you can be added to our email list.

Project Menu

Community Geodetic Model

Navigation

GPP Velocity Data
InSAR Velocity Data
Historical Vehicle CGM V.1.0
- Model Comparisons
- Technical Report

Background material
- 2010 Workshop: Community Geodetic Model
- 2010 Workshop: Community Geodetic Model
- 2012 Workshop: Community Geodetic Model
- 2012 Workshop: Community Geodetic Model
- 2012 Workshop: Modeling Advances in SCEC Geodetic
- 2013 Workshop: Geodetic models for UCRSF
- 2016 Workshop: Geodetic models for UCRSF

https://topex.ucsd.edu/CGM/CGM_html/
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
Mailing lists

Three mailing lists have been created:

http://mailman.mit.edu/mailman/listinfo/scec_cgm_gnss (for the GNSS Working Group)
http://mailman.mit.edu/mailman/listinfo/scec_cgm_insar (for the InSAR Working Group)
https://forms.gle/knjBDtgXumAjo7J6 (for CGM users; please sign up by first completing this short questionnaire)

Please feel free to sign up but only if you wish to hear about announcements regarding CGM activities.

These mailing lists are not intended as general forums; for example, I do not intend to constantly monitor the “users” mailing list for ideas, feedback or questions, only to have the list available to send messages to those interested in hearing about the CGM.
Why are we here?

Overarching goals

- Update of work, products and direction since the last workshop
- Hearing about new and novel data techniques, and uses and applications of the resulting products and derived quantities
- Prioritization of future research and products

Motivating questions

- What does the community need from the CGM?
- What can you contribute to the CGM?
- How do we use and validate the CGM?
- What are the most critical next steps to help advance earthquake and general geophysical research in southern California (and beyond)?
Summary of GNSS products

Michael Floyd (MIT)
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
Definitions of perturbations

- GAGE
- NGL
- SOPAC
- USGS
- Z.-K. Shen
- MEaSUREs
- NMT
- JPL
- CWU
- USGS
- SOPAC
- NGL (UNR)

Time series analysis

- CATS [sh_cats]
- Hector [sh_hector]
- analyze_tseri
- tsfit/tsvview
- est_noise
- MIDAS

Conversion to common format (and optionally reference frame)

- tscon
- tscomp
- conv_gnss_ts.sh
GNSS time series corrections and combinations
Weighted average of realigned source time series

Coordinates: \( x_i(t) = \frac{\sum x_i(t) / \sigma_i^2(t)}{\sum 1 / \sigma_i^2(t)} \)

Associated uncertainties: \( \sigma_i(t) = \sqrt{n} / \sqrt{\sum 1 / \sigma_i^2(t)} \)

<table>
<thead>
<tr>
<th>Analysis Center</th>
<th>JPL</th>
<th>NGL (UNR)</th>
<th>USGS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sigma scaling factor</td>
<td>2.3</td>
<td>2.2</td>
<td>2.1</td>
</tr>
</tbody>
</table>
CGM2 time series available operationally

Via the prototype web viewer (Session 3, later today)

Via direct download from http://geoweb.mit.edu/~floyd/scce/cgm/ts/

File names are of the form <SITE>.cgm.<wmrss|final>_<frame>.pos, where

- <SITE> is the four-character site ID
- "wmrss" is "weighted mean with re-scaled sigma" for continuous time series, "srvey" is for Zheng-Kang Shen's survey time series
- "frame" is one of "igb14", "nam14" or "pcf14" (Altamimi et al., 2017), or "nam17" (Kreemer et al., 2018)

A script to convert between the “.pos” format and other common formats, e.g. the Nevada Geodetic Laboratory's (NGL’s) .txyz2 and .tenv3 formats, a free-format GeoCSV (e.g. http://geows.ds.iris.edu/documents/GeoCSV.pdf) and GMT’s “psxy” format, is available at http://geoweb.mit.edu/~floyd/scce/cgm/conv_gnss_ts.sh
Velocities

Preliminary velocity solution has been provided to a few beta testers directly but is still under development.

Discontinuities list is critical before estimation of velocity and other parameters (being finalized by Mike Floyd, MIT).

Several common algorithms will be used (previous slide), the results compared for pros, cons, consistency, and a consensus reached, like the time series.

Eventually the velocity solution will also be operational through the prototype web viewer and, likely, directly updated on the server at MIT.
Summary of InSAR products

Katia Tymofyeyeva (JPL)
InSAR Consensus Velocity Model
InSAR Consensus Velocity Model

Ekaterina Tymofyeyeva¹, Kathryn Materna², Xiaohua Xu³, Zhen Liu¹, Kang Wang⁴, Gareth Funning⁵, Katherine Guns⁶, David Bekaert¹, Niloufar Abolfathian¹, Eric Fielding¹, Michael Floyd⁷, David Sandwell⁶

¹. NASA Jet Propulsion Laboratory, Pasadena, CA
². Earthquake Science Center, US Geological Survey, Moffett Field, CA
³. University of Texas Austin, Austin, TX
⁴. Berkeley Seismology Laboratory, Berkeley, CA
⁵. University of California Riverside, Riverside, CA
⁶. Scripps Institute of Oceanography, University of California San Diego, San Diego, CA
⁷. Massachusetts Institute of Technology, Cambridge, MA
Why?

- Provide a set of self-consistent and well-documented products (time series and velocities) over southern California.
- Compare state-of-the art methods to understand differences in outcomes due to distinct processing strategies.
- Develop a set of best-practices for InSAR time series estimation.
- Collation, correction and averaging of InSAR solutions processed by the SCEC CGM (InSAR) Working Group help to reduce systematic biases, missing data or other inaccuracies due to any single strategy.
### Methods and models:

<table>
<thead>
<tr>
<th>Method</th>
<th>BKLY</th>
<th>USGS</th>
<th>JPL1</th>
<th>SIOX</th>
<th>UCRV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coregistered stack</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>GMTSAR</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>ISCE</td>
<td></td>
<td>●</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ESD correction</td>
<td></td>
<td>●</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DEM error correction</td>
<td></td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Topo-correlated atm. removed</td>
<td></td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Weather model removed (ERA5)</td>
<td>●</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CANDIS correction</td>
<td>●</td>
<td>●</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coherence-based SBAS</td>
<td></td>
<td></td>
<td>●</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GPS correction</td>
<td></td>
<td></td>
<td>●</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spatiotemporal smoothing</td>
<td></td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Phase closure masking</td>
<td></td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
</tbody>
</table>

- **Topo-correlated atmosphere removal**  
  pros: can remove time-correlated atmosphere  
  cons: can sometimes remove deformation signals

- **Weather model corrections**  
  pros: corrects for seasonal tropospheric contribution using auxiliary data  
  cons: models may lack coverage or resolution

- **CANDIS correction**  
  pros: reduces turbulent tropospheric contribution  
  cons: may smooth some time-dependent signals.

- **GPS correction**  
  pros: helps correct InSAR errors at long spatial wavelengths  
  cons: solution is poorly constrained in areas of poor GNSS coverage and at image edges

- **Spatiotemporal filtering**  
  pros: removes turbulent atmospheric noise  
  cons: requires prior knowledge of noise characteristics
We present the consensus InSAR Community Geodetic Model LOS velocity solutions for descending tracks 71 and 173, ascending tracks 64 and 166, and the corresponding model errors. The models use InSAR data collected between 2014 and 2019, before the Ridgecrest earthquakes. We obtained the InSAR CGM consensus model by averaging the individual solutions provided by the five participating groups. The error was computed by taking the variance among the different velocity models provided by each processing group.
InSAR Time Series Comparisons
Next steps

- Working toward better estimation of **InSAR uncertainties**.
- Identifying and isolating **coseismic and postseismic deformation** related to the Ridgecrest earthquakes.
- Finding the best strategy for **integration between InSAR and GNSS Community Geodetic Model velocities and time series** in a common reference frame.
- Combining InSAR and GNSS measurements to estimate **deformation in 3 dimensions**.
- Expanding the study time period with additional Sentinel-1 data acquired after the Ridgecrest earthquakes and up to the present day.
- Adding data from legacy satellite missions, such as **ERS1-2, ALOS-1, and Envisat**, as well as more recent InSAR acquisitions from **ALOS-2**.
- Making the data available to the public via the **SCEC web interface**.
Considerations to keep in mind through the workshop

● **We need your feedback**
  ○ Have you tried using the product? Are we providing all the layers you need at a resolution that you need? Is there enough metadata?

● **What’s next?**
  ○ Let us know what steps in our future development are most important to you. 3D deformation? Strain? Extending the time series in space and time?

● **How can you contribute?**
  ○ We would love to incorporate your expertise, data, and methods into this community model!
SCEC milestones for CXM (specifically CGM)

<table>
<thead>
<tr>
<th>Science Milestone</th>
<th>Y1</th>
<th>Y2</th>
<th>Y3</th>
<th>Y4</th>
<th>Y5</th>
</tr>
</thead>
<tbody>
<tr>
<td>r Produce a consensus combined campaign/continuous GPS time series product.</td>
<td></td>
<td></td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>s Develop grids of horizontal velocity and strain rate derived from consensus GPS time series. Upload to CGM v. 1.0 website.</td>
<td></td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>t Develop consensus vertical time series from continuous GPS sites.</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>u Identify and develop best practices for producing and updating LOS time series from the new data streams provided by Sentinel-1A and 1B, and ALOS-2.</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>v Produce a consensus secular velocity InSAR product using the full archive of SAR data (ERS, Envisat, ALOS-1, Sentinel) for the S Cec region.</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>w Conduct peer review of initial CGM products through a virtual workshop.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>x Develop methods for integrating full vector GPS time series with LOS InSAR time series from multiple platforms to construct 1 km spatial resolution grids of horizontal and vertical time series.</td>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>bb Deliver a deformation model based on the Community Geodetic Model (CGM) to the CSM.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
</tr>
</tbody>
</table>