OPERA

Observational Products for End-Users from Remote Sensing Analysis

Deploying Corner Reflectors for Geolocation Accuracy Assessment and Displacement Monitoring: From experiment formulation to product validation and analysis of OPERA CSLC and DISP products

November 2024

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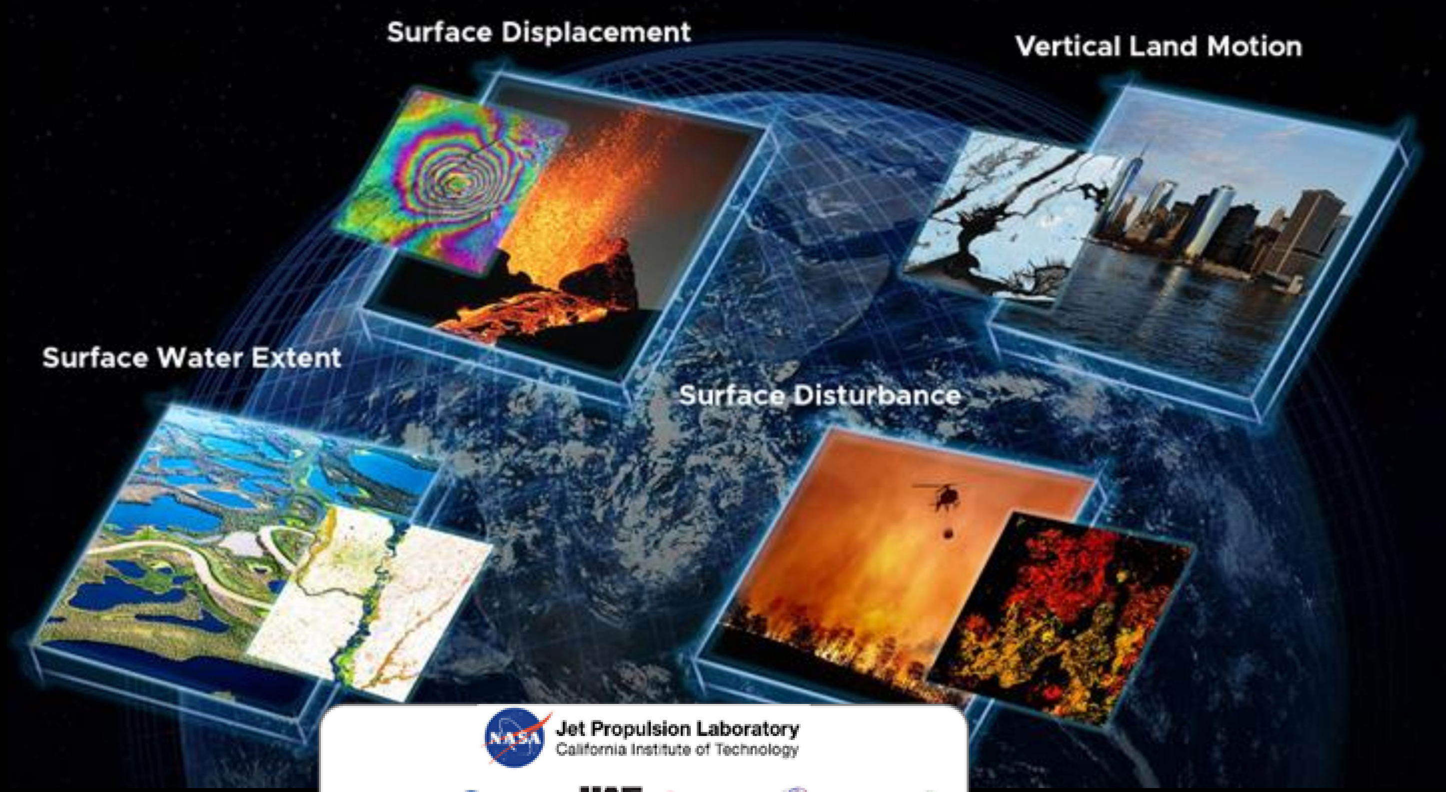
[1]Jet Propulsion Laboratory, California Institute of Technology; [2]Southern Methodist University; [3]Earthscope

OPERA Enabling End-Users to Take Action

Observation **P**roducts for **E**nd-users from **R**emote sensing **A**nalysis



- **Free and open Analysis Ready Data** products designed for science and application stakeholders.
- 5 product lines in production
- ***New*** *since last science highlights:*
  - ***Sentinel-1 (radar) Surface Water product in production.***
  - ***OPERA funded for creation of a Vertical Land Motion Product***
  - ***RTC-S1 product is CEOS ARD approved***

OPERA is spearheading an innovative model within NASA that goes beyond a single mission (Landsat 8/9, Sentinel-1/2, NISAR) to develop multiple product lines

Product Details

Latency: As soon as the input data is available
Posting: 30m or better
Temporal Sampling: sub-weekly to weekly

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Level-2 products

- **Description:** S1 radar backscatter corrected for the topography. Basis for the DSWx-S1 and DIST-S1 products.
- **Coverage:** Near-global
- **Spatial Resolution:** 30 m
- **Product Record Begins:** Oct. 2023

Available now!

- **Description:** Geocoded and coreg. SLC (S1, NISAR). Basis for all the DISP products.
- **Coverage:** North America*
- **Spatial Resolution:** ≤ 10 m
- **Product Record Begins:** Apr. 2014 (S1) and TBD (NISAR)
- **Production Begins:** Oct. 2023 (S1), TBD (NISAR)

Available now!

Level-3 products

- **Description:** Maps surface water using optical (HLS) and SAR imagery (S1, NISAR)
- **Coverage:** Near-global
- **Temporal resolution:** every few days
- **Spatial Resolution:** 30 m
- **Product Record Begins:** Apr. 2023 (HLS), Sep. 2024 (S1), Jun. 2026 (NISAR)

Available now!

- **Description:** Maps vegetation disturbance using optical (HLS) and SAR imagery (S1)
- **Coverage:** Near-global
- **Temporal resolution:** every few days
- **Spatial Resolution:** 30 m
- **Product Record Begins:** Feb. 2023 (HLS), Mar. 2026 (S1)

Available now!

- **Description:** Maps surface displacements in LOS (S1 and NISAR)
- **Coverage:** North America*
- **Temporal resolution:** 6, 12, or 24 days
- **Spatial Resolution:** ≤ 30 m
- **Product Record Begins:** Apr. 2014 (S1), NISAR validated record.
- **Production Begins:** Dec. 2024 (S1) Sep. 2026 (NISAR)

Available End of 2024!

Level-4 products

- **Description:** Maps surface displacements in vertical + horiz. (S1 and NISAR)
- **Coverage:** North America*
- **Temporal resolution:** 6, 12, or 24 days
- **Spatial Resolution:** ≤ 100 m
- **Product Record Begins:** Jan. 2019 (S1), NISAR validated record.
- **Production Begins:** Apr. 2028 (S1 + NISAR)

Available in 2028!

OPERA data is available through SNWG data portal:
https://search.earthdata.nasa.gov/search?portal=snwg

OPERA code in open source domain is built on core ISCE3 modules developed by NISAR.
https://www.jpl.nasa.gov/go/opera/resources/opera-code-repositories-and-resources/

Project Requirements

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CSLC-S1
Absolute Location Error (ALE)

The Sentinel-1-based CSLC product (CSLC-S1) shall have an Absolute Location Error 1.5 meters or better in both the ground range and azimuth directions, excluding the effects of DEM errors and ionospheric scintillation on SAR acquisitions, in at least 80% of all validation products considered.

CSLC-S1
Relative Location Error (RLE)

The Sentinel-1-based CSLC product (CSLC-S1) shall have a Relative Location Error of 0.5 meters and 0.75 meters or better in ground range and azimuth directions respectively, in areas with high cross-correlation accuracy, excluding the effects of DEM errors and ionospheric scintillation on SAR acquisitions, in at least 80% of all validation products considered. The product's Relative Location Error shall be determined relative to a single reference image within the stack.

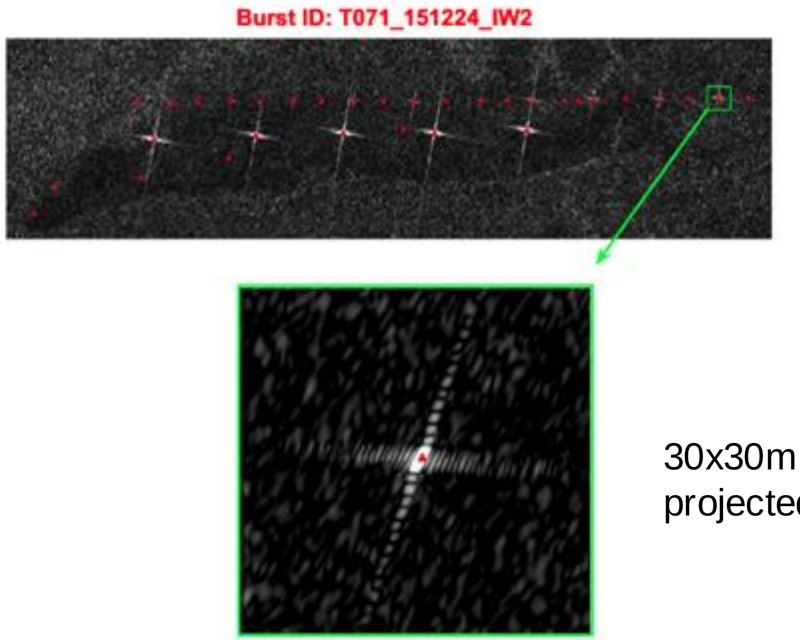
DISP-S1

Sentinel-1 DISP product (DISP-S1) shall measure from a single line-of-sight geometry surface displacement rates with an uncertainty of *5 mm per yr or better over length scales within 0.1 km < L < 50 km from 4 years of regularly sampled* (at least 80% of Sentinel-1 acquisitions at 12 days sampling or better) *Sentinel-1 A/B data* (VV polarization imagery in IW-mode), in regions where the interferometric signal is maintained (i.e., the coherence is above 0.5).

Using corner reflectors to assess product requirement

To validate the **Absolute Location Error (ALE) of OPERA CSLCs**, we mainly use corner reflectors over Rosamond, California, Alaska (Fairbanks), and Oklahoma. ALE is evaluated through point-target analysis.

A 2.4-m Rosamond trihedral corner reflector.
https://uavsar.jpl.nasa.gov/cgi-bin/calibration.pl



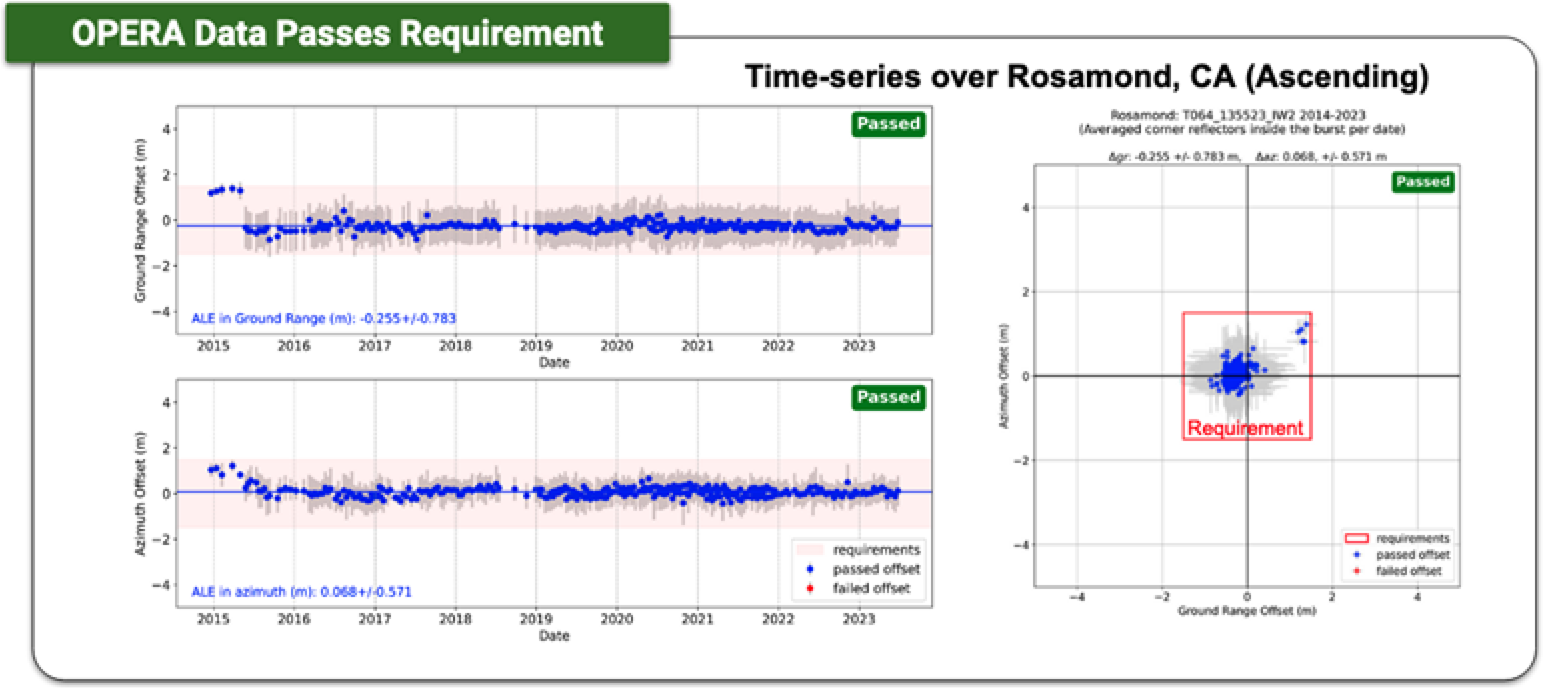
Oversampled 32 x 32 patch centered on a CR

30x30m ground projected SLC

Prior to release: OPERA CSLC-S1 meets all L2 requirements

National Aeronautics and Space Administration

	L2 Accuracy Requirements	CSLC-S1
ALE	**1.5 m** in Ground Range and Azimuth for **80%** of validation data	**100%** of validation data met requirement
RLE	**0.5 m** in Ground Range and **0.75 m** in Azimuth for **80%** of validation data	**88%** of validation data met requirement



← Example evaluation of ALE for an Ascending track CSLC-S1 product over Rosamond, CA

Deploying corner reflectors across San Andreas Fault and in Central Valley:
An experiment to support OPERA's CalVal and Algorithm Development

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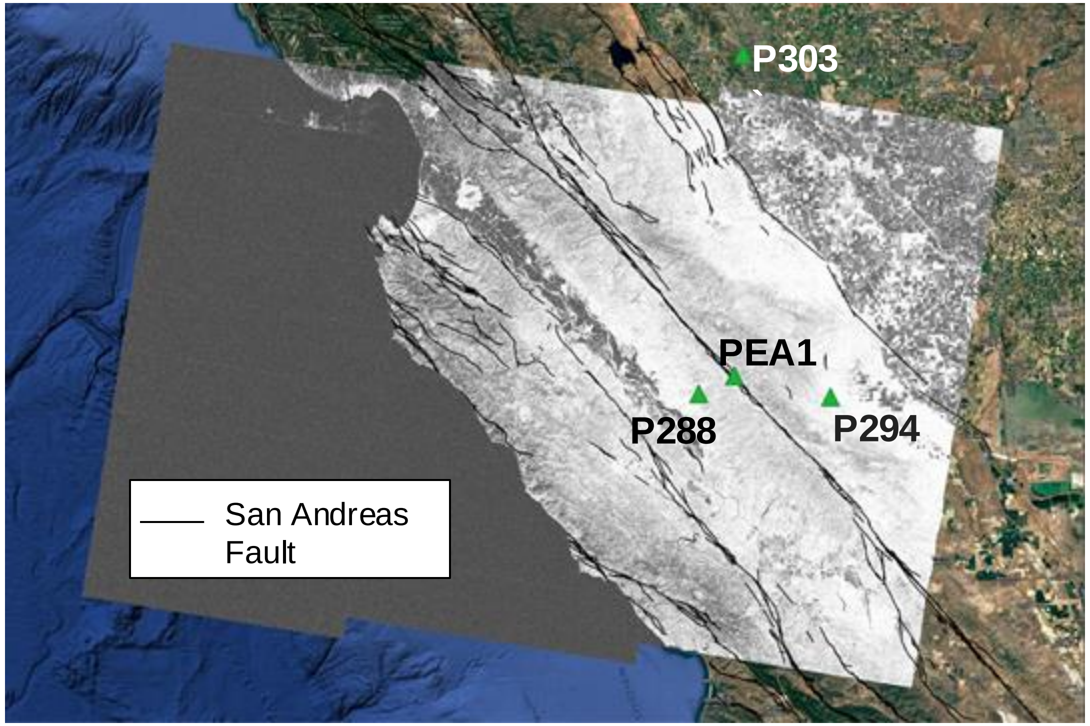

OPERA corner reflectors (deployed), collocated with EarthScope-managed Continuous GNSS stations across the creeping segment of the San Andreas Fault and in Central Valley, CA. Underlying image is the phase correlation layer from OPERA DISP-S1 product.

- San Andreas Fault (SAF) is moving at a rate of ~36 mm/yr (Ludwig et al, 2019) whereas Central Valley in California is subsiding at a rate of > 200 mm/yr (Govorcin et al., in review).
- Displacement product from InSAR can suffer from unwrapping errors.
- Corner reflectors support the OPERA CalVal and algorithm development activities for CSLC and DISP products (Sentinel-1 and NISAR).
  - 6 x 2.4m reflectors across SAF (P288, PEA1, P294)
  - 1 x 2.4m reflector and 1 x 1.2m reflector are deployed in Central Valley (P303)

←Design of the OPERA 2.4-m corner reflectors (perforated aluminum)
Credit: *L. Ortiz*

Rain or shine deployment in partnership with Earthscope

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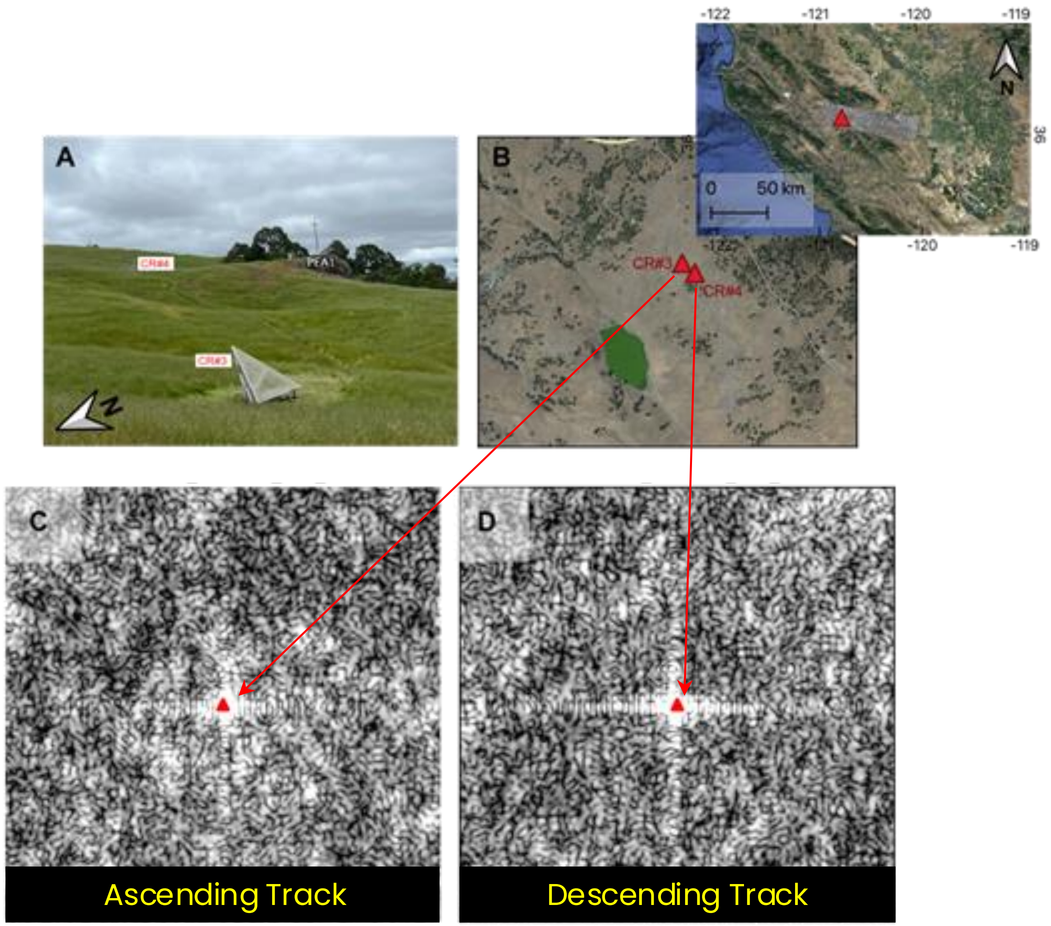

OPERA Corner Reflector Team: M. Grace Bato, Bruce Chapman, Annemarie Peacock, Simran Sangha, and the EarthScope team (Andre Basset, Matt Burgess, James Downing, Karl Feaux, Bill Funderburk, Shawn Lawrence, Doerte Mann, Glenn Mattioli).

On going DISP-S1 product validation activities

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VA1: Direct comparison of GNSS and InSAR over regions with dense GNSS networks.

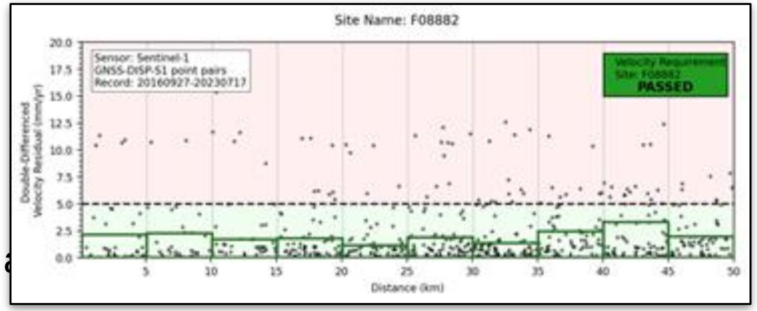
VA2: InSAR residual analysis.

VA3: (*Experimental*): Direct comparison of the OPERA Corner Reflectors installed across the San Andreas Fault and InSAR.

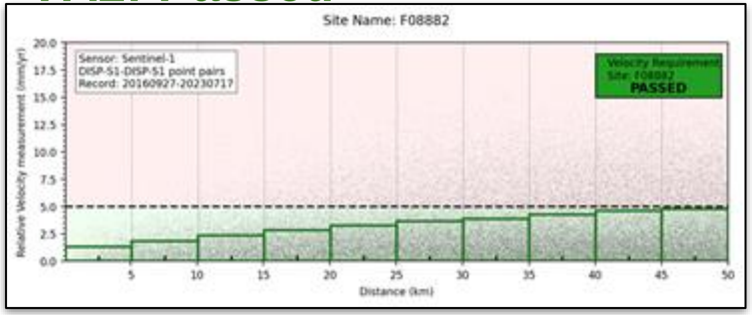
Passes Requirement

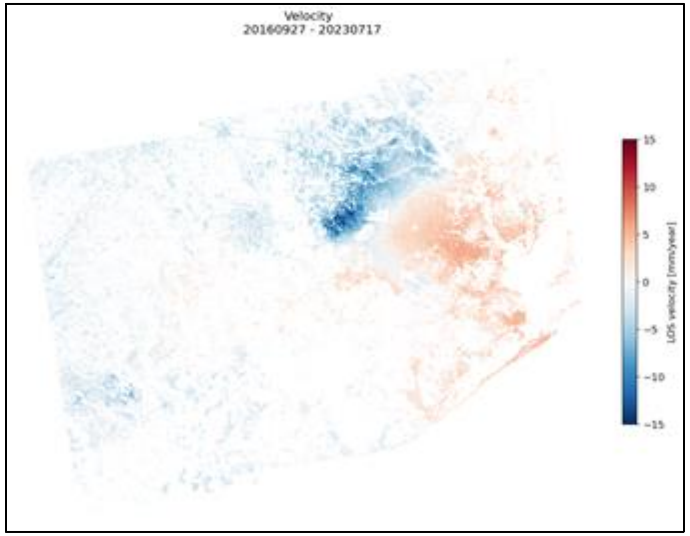
Example: Houston, USA, Frame 08882 (DISP-S1)

VA1: Passed



VA2: Passed





On going DISP-S1 product validation activities

National Aeronautics and Space Administration

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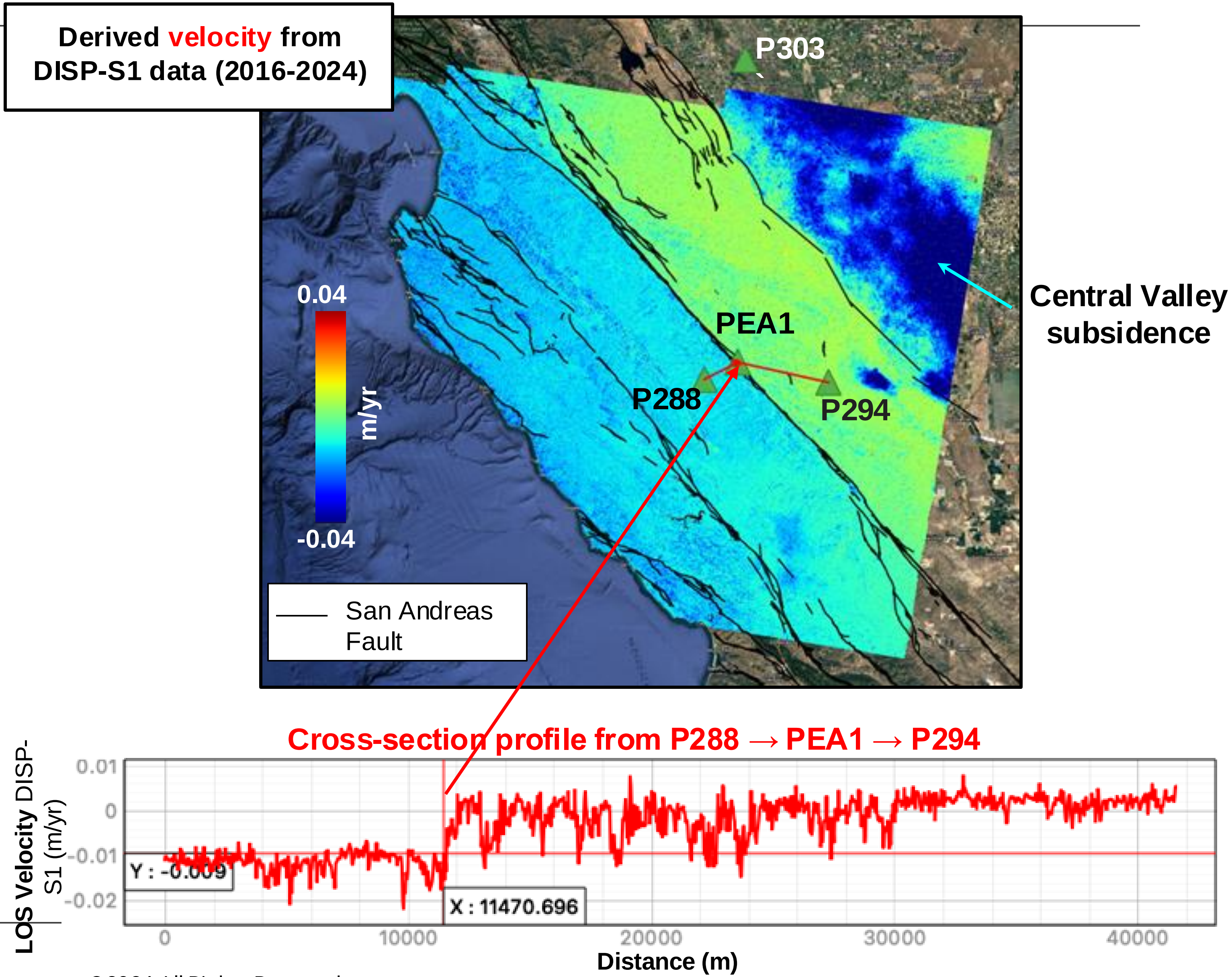
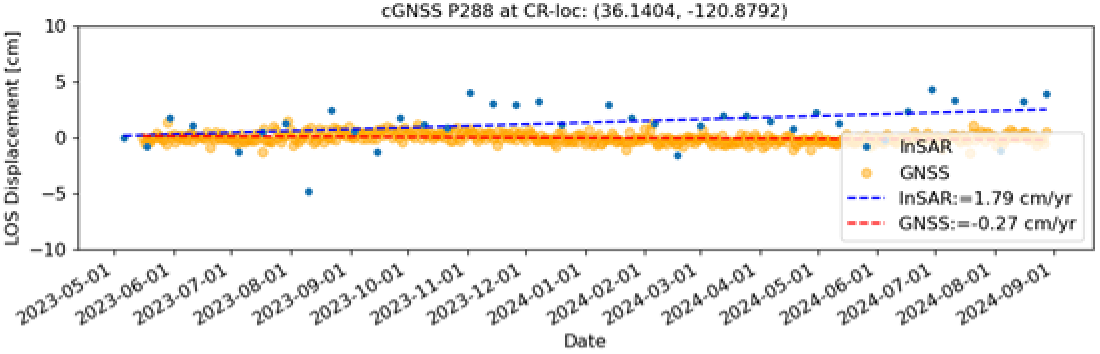
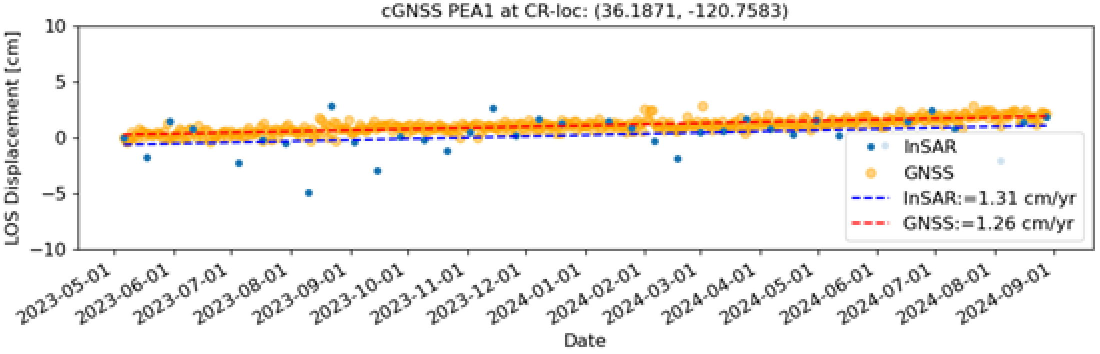
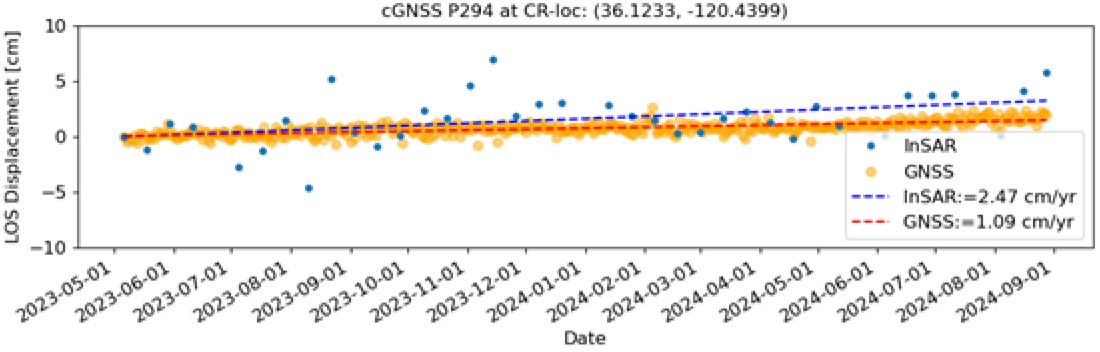


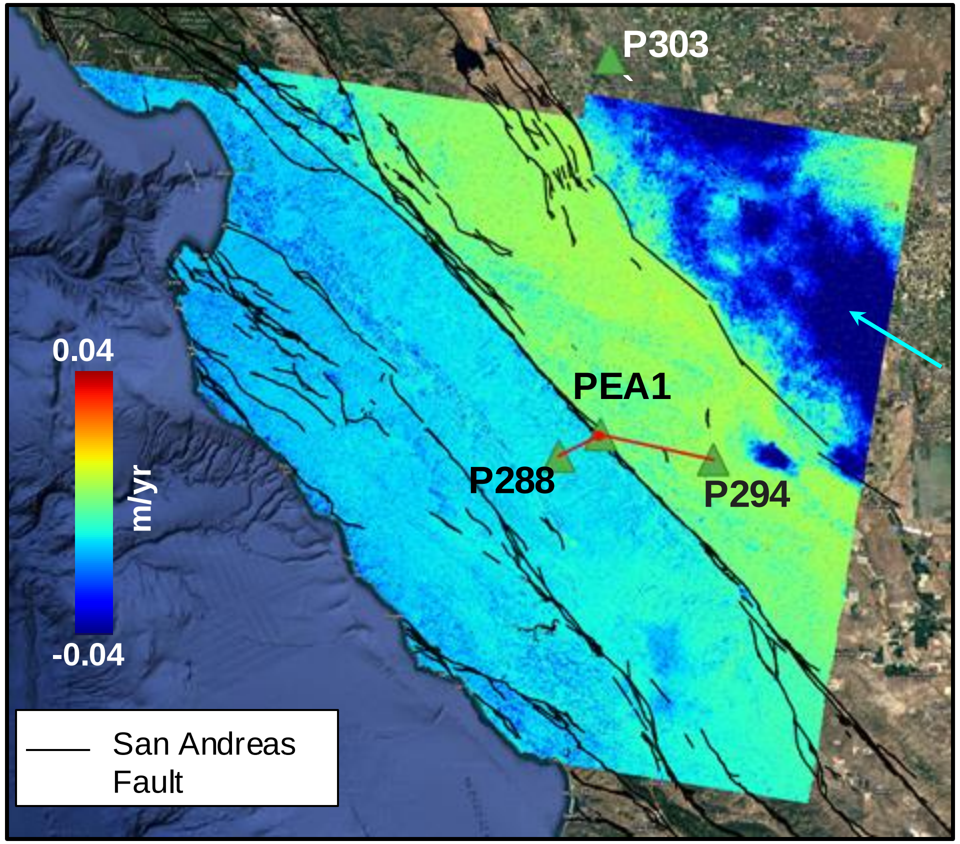
Initial results:

cGNSS vs DISP-S1 Timeseries at the CR-location







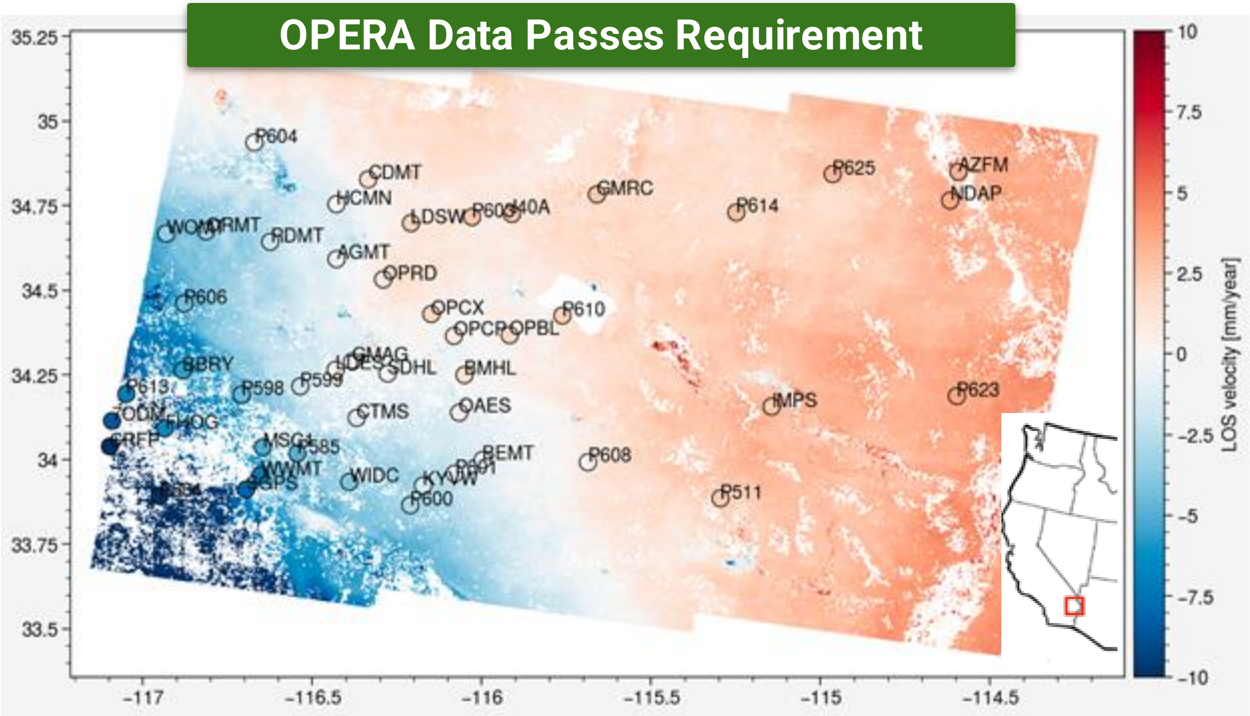


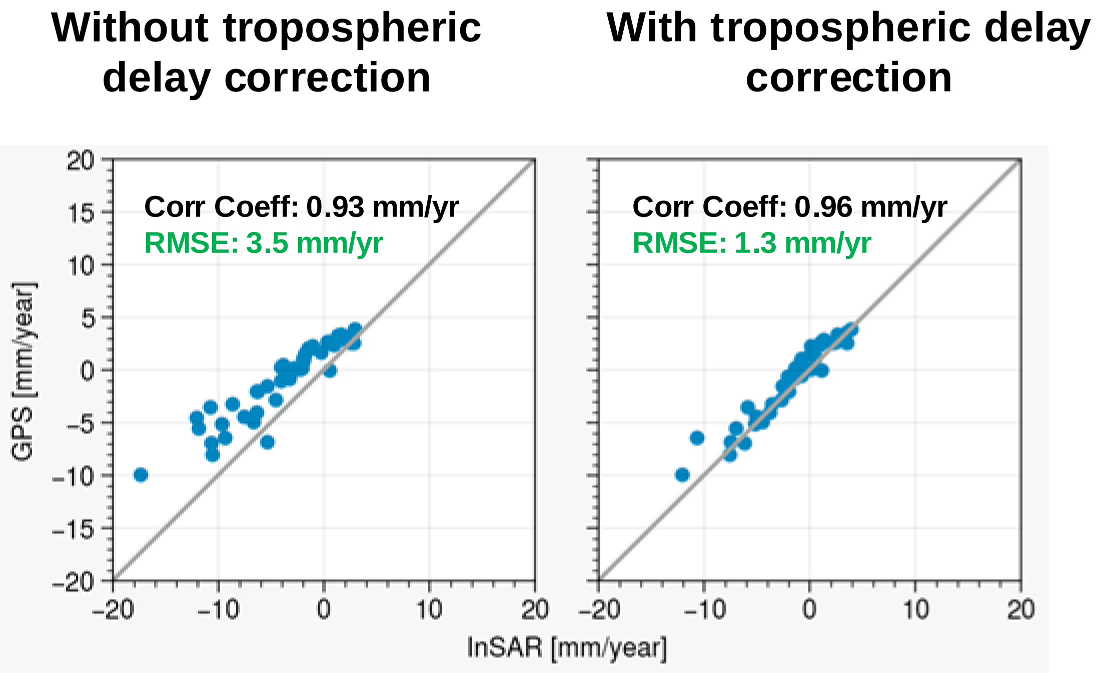
Central Valley subsidence

The larger scatter in the DISP-S1 timeseries can be related to tropospheric delay. We anticipate that this will improve with the addition of a tropospheric correction layer, soon to be provided by OPERA.

Preliminary results:
Mojave Validation site: Impact of Troposphere correction

Velocity: Feb 2017 - Dec 2020





Shows ***improved*** accuracy with application of correction layer for troposphere delay

Global SAR-agnostic tropospheric correction ancillary

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*NEW OPERA PRODUCT**

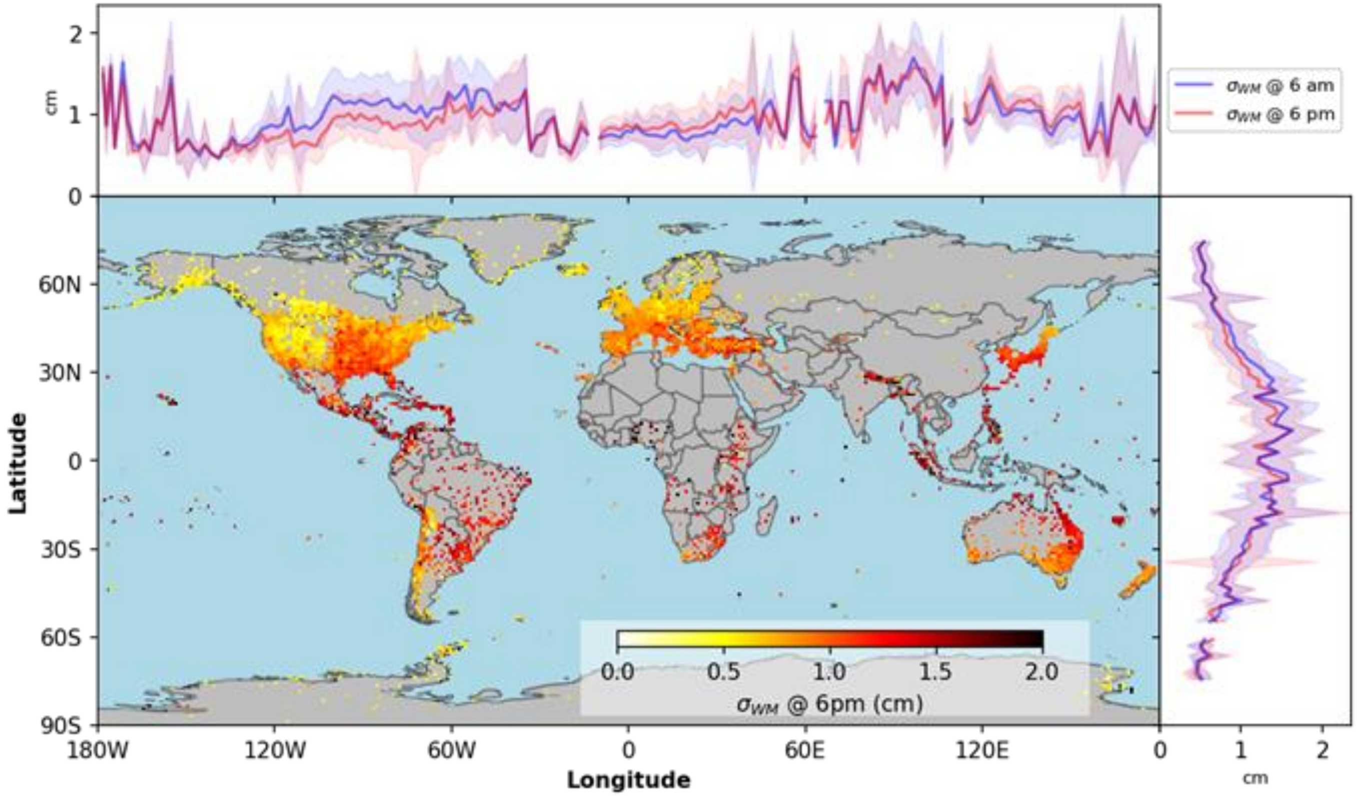
OPERA will create a global tropospheric correction ancillary to the DISP product:

- Derived from ECMWF HRES (~9km @ 00-06-12-18 UTC)
- 3D cube (x,y,z) allows for data compression (adopting NISAR idea)
- Zenith delays for SAR agnostic

Distributed through ASF DAAC

Currently starting from 2016

Release planned for mid 2025



HRES weather model performance against GNSS global Zenith tropospheric delay estimates (Bekaert et al., in prep)

Open Source Validation Tools Available via GitHub

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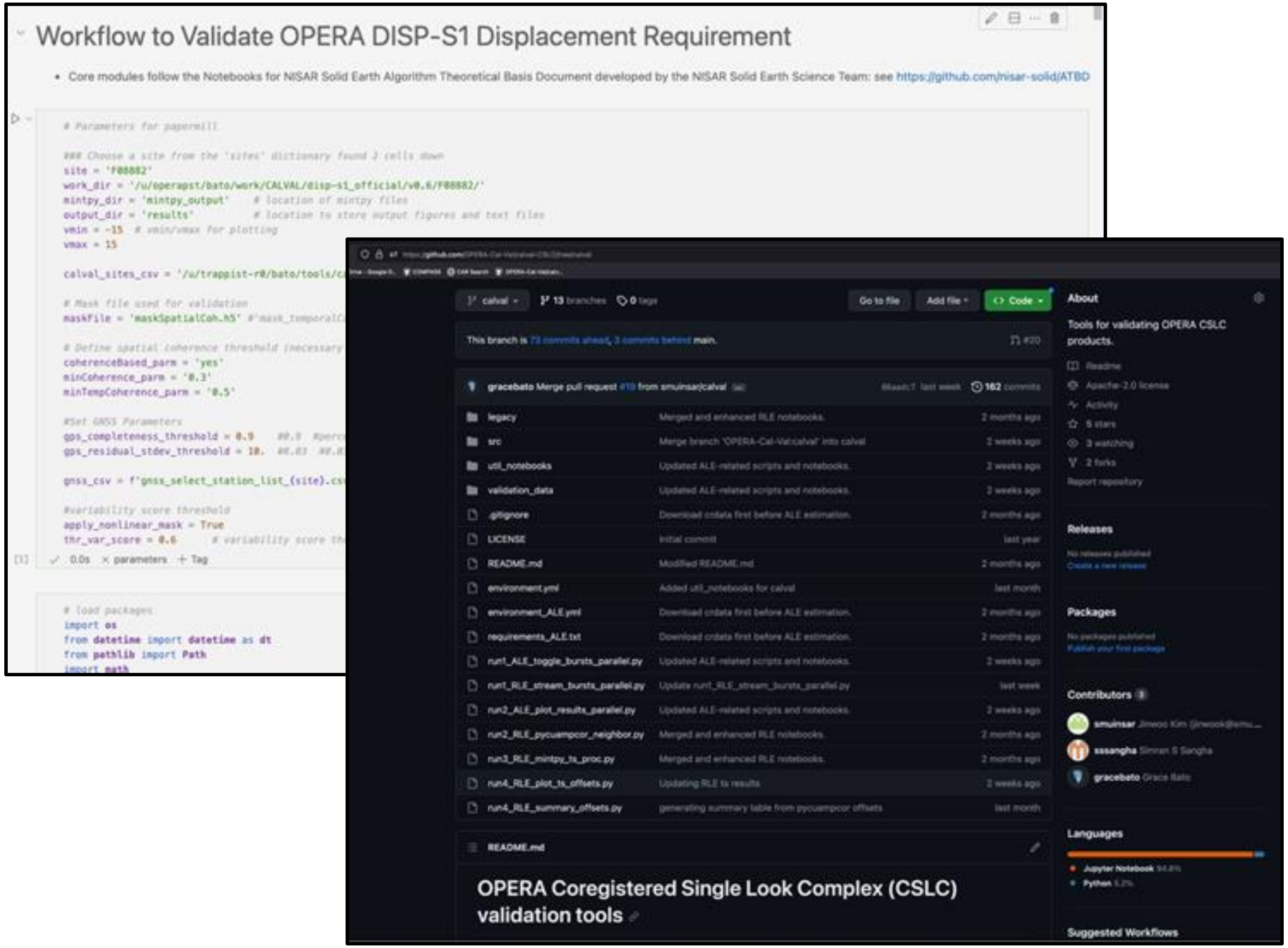

All the validation tools developed for OPERA CSLC-S1 and DISP-S1 (and others) are available on GitHub:

https://github.com/OPERA-Cal-Val

Conclusion

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- OPERA CSLC-S1 **meets all L2 requirements**. Production is ongoing.

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- OPERA is on track to start DISP-S1 production on December 2024.

Backup


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Space Administration
www.jpl.nasa.gov/go/opera
www.nasa.gov

Exciting Applications!

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- Example: OPERA's DISP product will be extremely valuable for monitoring active landslides.
    - The Portuguese Bend landslide which started to accelerate significantly in summer 2023, and continues to move at high rates today. The resulting destruction of homes and infrastructure has prompted Gov. Newsom to declare a State emergency.

Eos

Rancho Palos Verdes Landslides Have Residents Seeking Science

Residents of Rancho Palos Verdes are looking to the scientific community for help in understanding the slow-moving landslides that are destroying their community.

A project [OPERA] led by NASA's Jet Propulsion Laboratory will produce a data set [OPERA DISP] of land surface displacements across North America that will be useful for Rancho Palos Verdes city officials [and residents]

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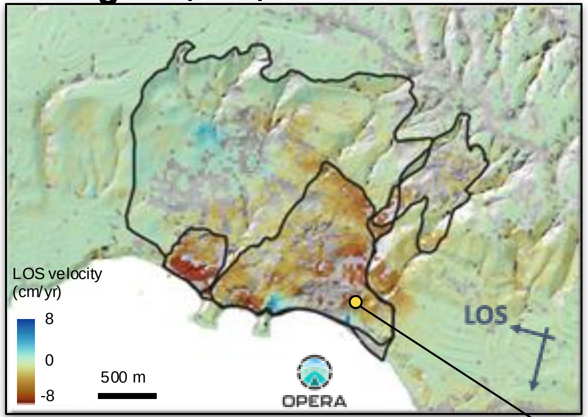
(Jason Armond / Los Angeles Times)

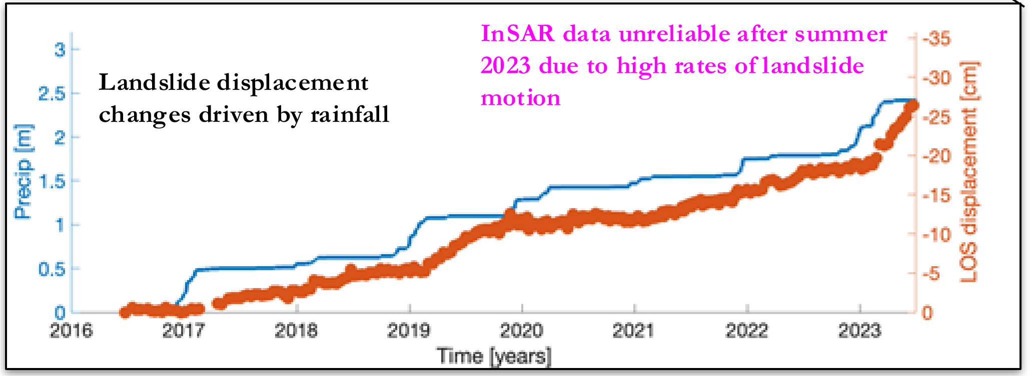
Increased activity at Portuguese Bend landslide since 2023 has led to a State of Emergency

Los Angeles, CA, 2016-2023

OPERA DISP-S1



OPERA DISP-S1 Time series



Prelim. OPERA DISP-S1 data provided by S. Staniewicz (OPERA - JPL). Rainfall data from PRISM

OPERA Coregistered SLC (CSLC-S1): General Information

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The North America-scope CSLC-S1 datasets are *burst-wise*, geocoded to the same geographical grid and result in aligned time-series of SLC images.

The product includes:

- Complex backscatter (HDF5)
  - Co-polarization (VV or HH) for Sentinel-1

`OPERA_L2_CSLC-S1_T064-135523-IW2_20230625T015058Z_20230907T122709Z_S1A_VV_v0.2.h5`

- Geometric data layers
  - Distributed in a separate HDF5 file (STATIC LAYER)

`OPERA_L2_CSLC-S1-STATIC_T064-135523-IW2_20140403_20230903T090947Z_S1A_v0.2.h5`

- CSLC-S1 products are corrected for:

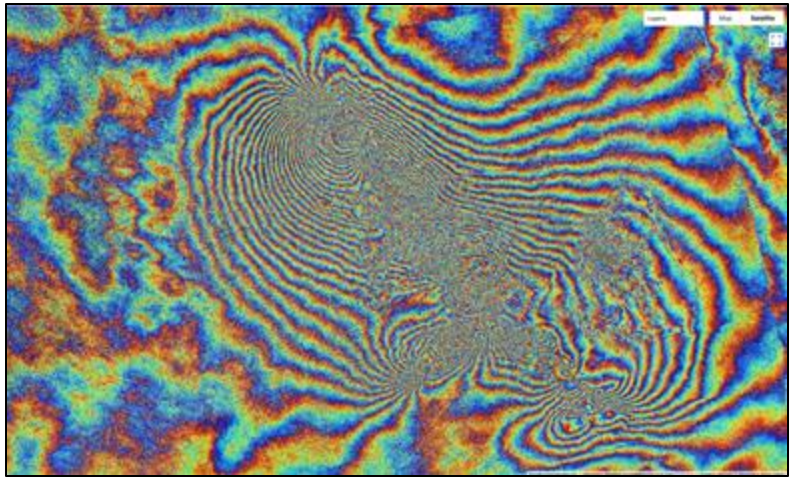
  1) bistatic delay
  2) azimuth FM rate mismatch
  3) Doppler induced range shift

  } SAR processing related

  4) range shift due to Solid Earth tides
  5) range delay due to troposphere (static model)
  6) range delay due to ionosphere

  } Earth environment related

The CSLC products allow for direct interferogram generation.



Wrapped phase (merged bursts). Ridgecrest, CA.