National Aeronautics and Space Administration

OPERA

Observational Products for End-Users from Remote Sensing Analysis

Fifth OPERA Workshop

September 11, 2025

Introduction to New Products: Vertical Land Motion

This workshop is open to US and non-US participants. The material presented has been cleared for unlimited release. No ITAR information is to be presented.

CL#25-3133

Introduction to New Products:
Vertical Land Motion (VLM)
VLM-S1, VLM-NISAR

Marin Govorcin
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California Institute of Technology

National Aeronautics and Space Administration

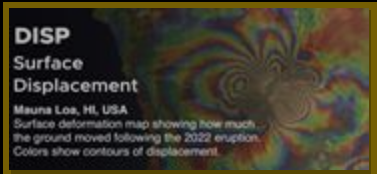
- Product Overview
- Product workflow
- Product algorithm
- Product applications
- Product validation
- Looking forward

Algorithm Development Team for VLM:
- Marin Govorcin
- Scott Staniewicz
- Sara Mirzaee

VLM Product Overview

National Aeronautics and Space Administration

Level-3 products



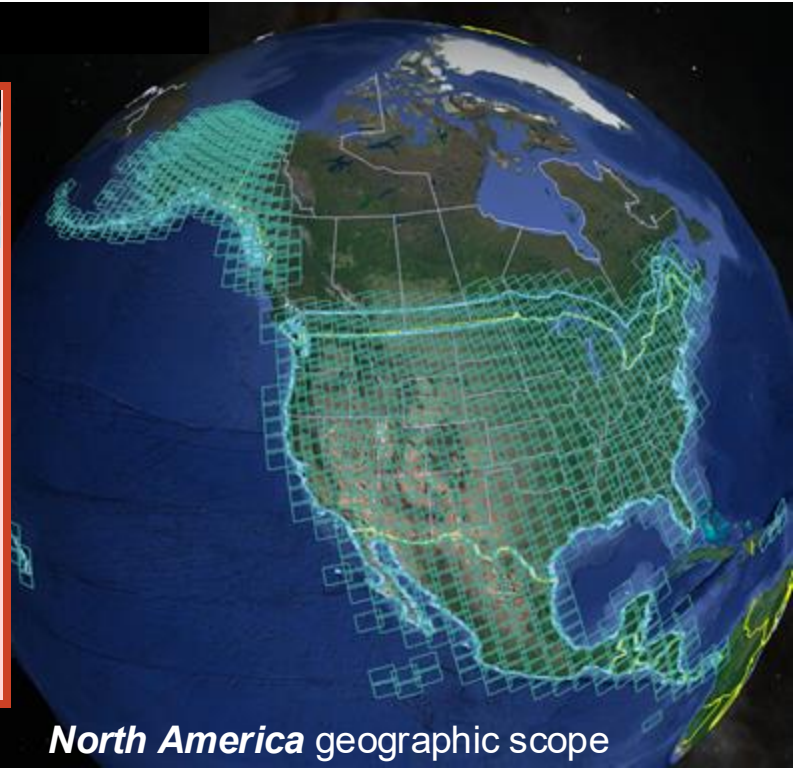
- **Description:** Maps surface displacements in LOS (S1 and NISAR)
- **Coverage:** North America*
- **Temporal resolution:** 6, 12, or 24 days
- **Spatial Resolution:** ≤ 30 m
- **Product Record Begins:** May 2016 (S1), NISAR validated record.
- **Production Begins:** May 2025 (S1) Sep. 2026 (NISAR)

DISP-S1 Available now!

Level-4 products

- **Description:** Maps surface displacements in vertical + horiz. (S1 and NISAR)
- **Coverage:** North America*
- **Temporal resolution:** 15, or 30 days (TBD)
- **Spatial Resolution:** ≤ 120 m
- **Product Record Begins:** Jan. 2019 (S1), Q1 2026 (NISAR, TBC)
- **Production Begins:** Feb. 2029 (S1 + NISAR)
- **Latency**: once a month (TBD)

Available in 2029 !



VLM Workflow: 2 stages

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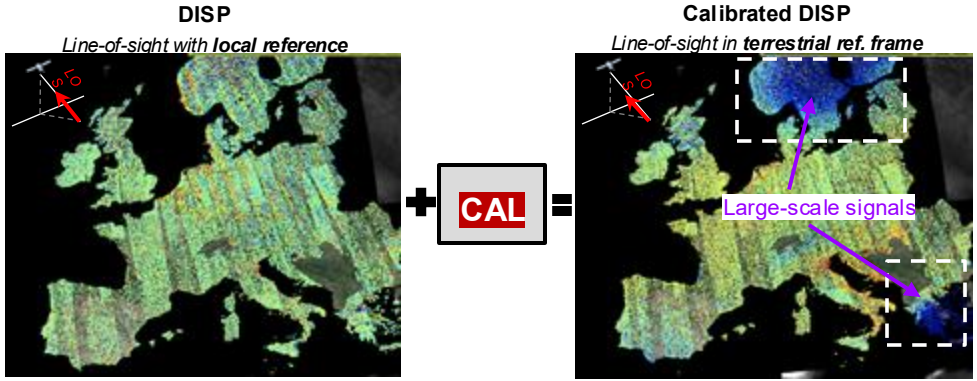
1. Calibration for Displacement [CAL] (*intermediate product*)

Re-referencing OPERA DISP to a geodetic reference frame using long-wavelength corrections (e.g., GNSS, plate motion, GIA).

- Frame-based (30 × 30 m posting)
- In collaboration with University of Reno / Nevada Geodetic Laboratory
- **Planned release:** Feb 2028

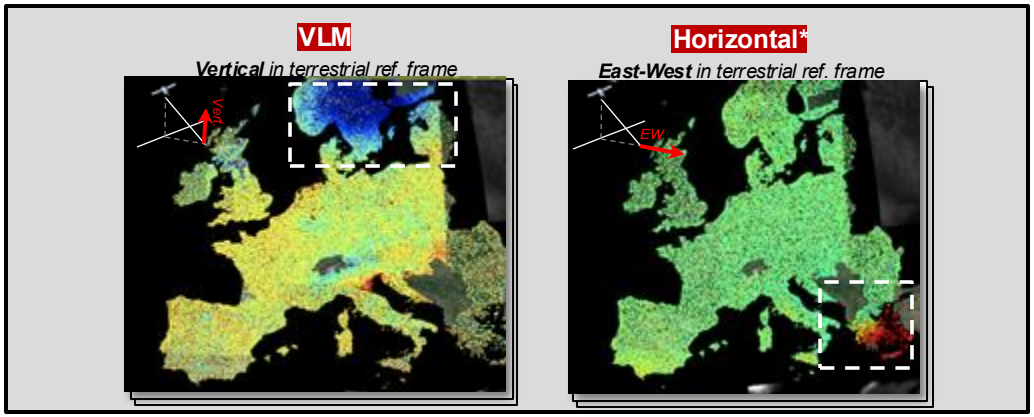


2. Vertical Land Motion time-series

Calibrated OPERA DISP decomposed into vertical and horizontal (where applicable) time series.

- MGRS tile-based [TBD], 120 × 120 m posting [TBD]
- Combines ascending and descending tracks (*where available)
- **Planned release:** Feb 2029

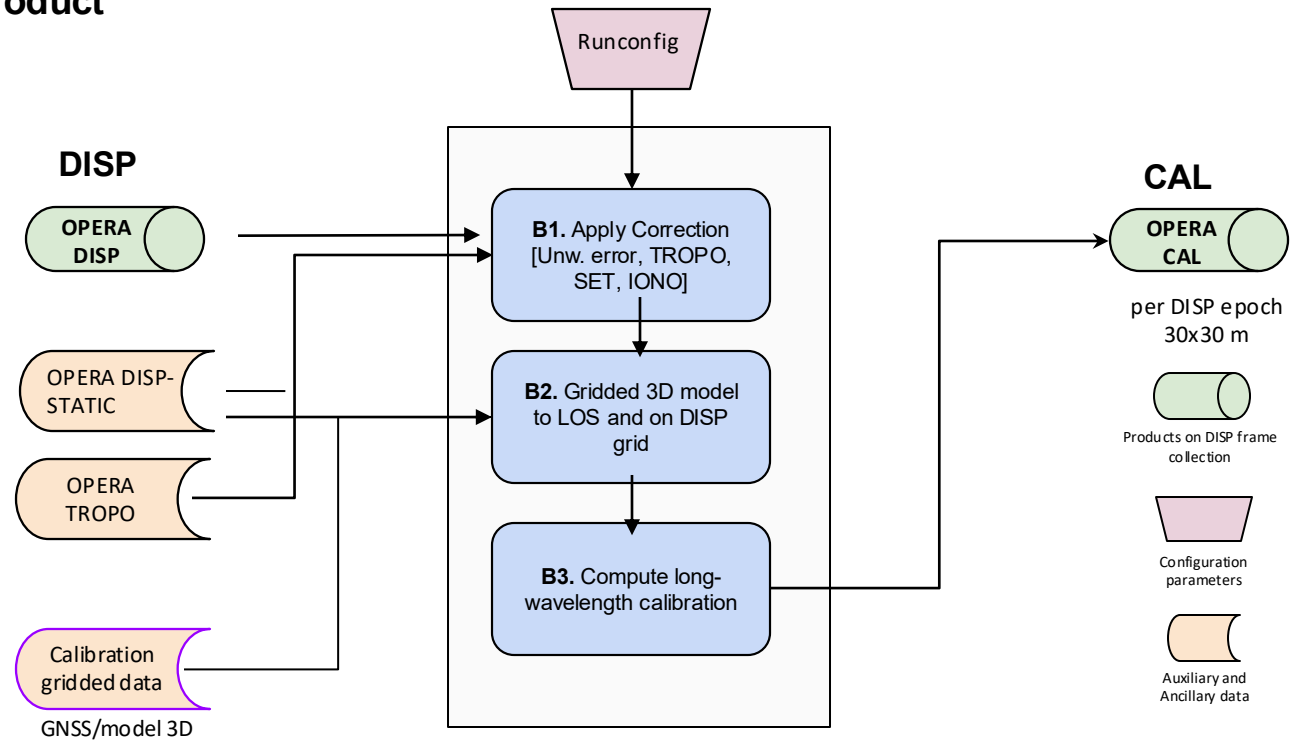
NOTE: linear rates are not included



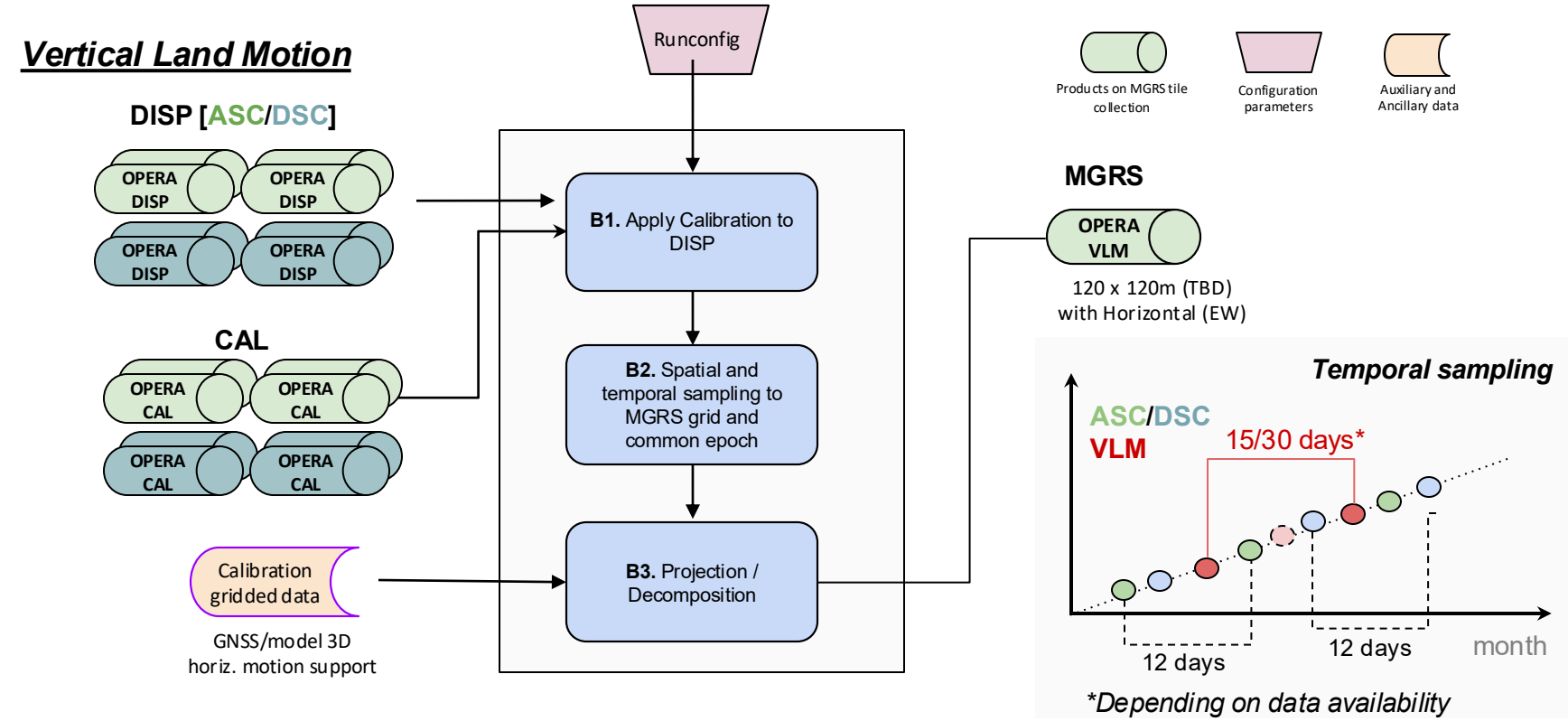
Figures: European Ground Motion Service

Algorithm Workflow - same for S1 and NISAR

Calibration product



Algorithm Workflow - same for S1 and NISAR



VLM prototypes

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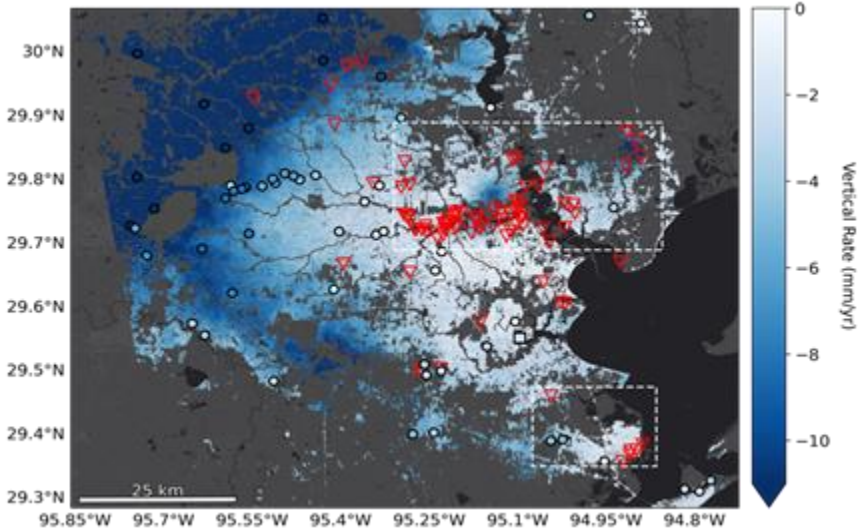
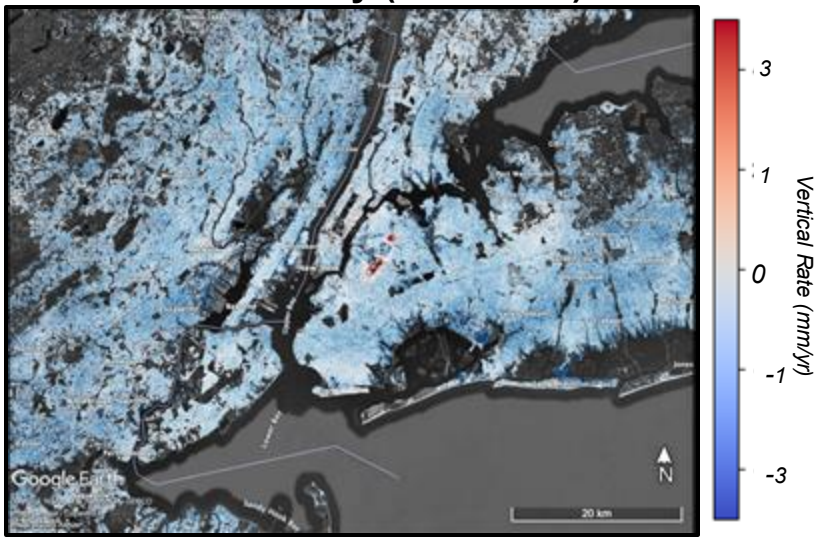
Houston (2016-2024)



VLM S1 prototype to assess critical infrastructure, e.g. above ground storage tanks, for exposure to subsidence and flooding hazards.

(Buzzanga, B., et al 2025; Scientific Reports, https://doi.org/10.1038/s41598-025-01970-8)

New York City (2016-2024)



VLM S1 prototype to access coastal subsidence and exposure to relative sea level rise.

Product Applications

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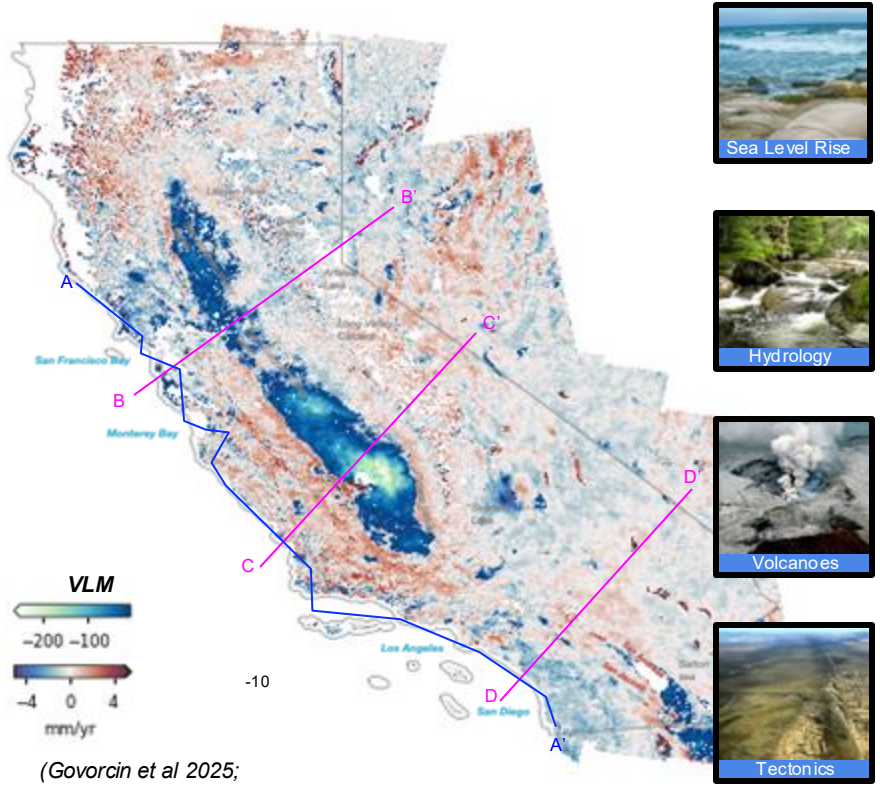

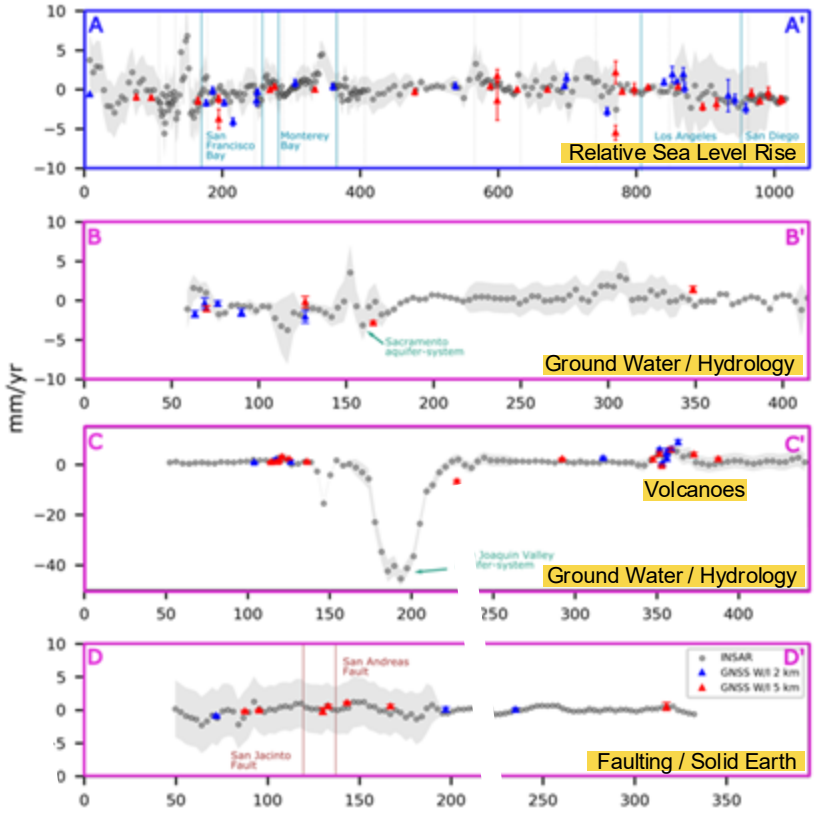

(Govorcin et al 2025;
Science Advances, DOI: 10.1126/sciadv.ads8163)

VLM Validation

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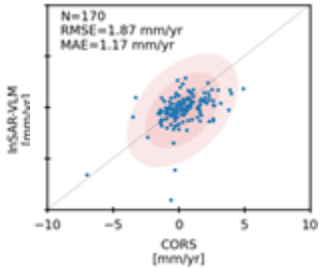
- Validation will be assessed by comparing VLM times-series and long-term linear rates with **GNSS solutions from different providers**

- Public GNSS solutions from:
  - ***NOAA-Continuously Operating Reference Stations*** (CORS) - vertical datum
  - NASA MEaSUREs: Extended Solid Earth Science ESDR System
  - Nevada Geodetic Laboratory

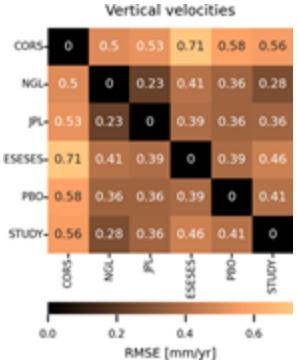
- Validation sites will be selected to match those used for OPERA DISP (TBD).

California InSAR-VLM Validation with GNSS.



Top: assessment against NOAA CORS.

Bottom: comparison against 5 different GNSS providers



(Govorcin et al 2025; Science Advances, DOI: 10.1126/sciadv.ads8163)

Looking Forward

Operational OPERA VLM products are expected starting in Feb 2028 [CAL] and Feb 2029 [VLM]

Summary

- The OPERA project will generate VLM products from Sentinel-1/NISAR on a North America geographical scope
- The OPERA VLM delivery consists of 2 stages: Calibration and Vertical Land Motion
- The OPERA team will use GNSS/model gridded data (UNR) as input to Calibration
- The OPERA team will use Calibrated DISP as input to Vertical Land Motion time series
    - Sentinel-1: 10 yr of data, (2019-2029), NISAR: ~4/5 yr of data (2026-2030)
- We expect OPERA VLM products suitable for a wide range of applications

Next Steps

- OPERA team is currently developing all software required for CAL and VLM S1/NISAR

BACKUP

What is Vertical Land Motion (VLM): Subsidence/Uplift

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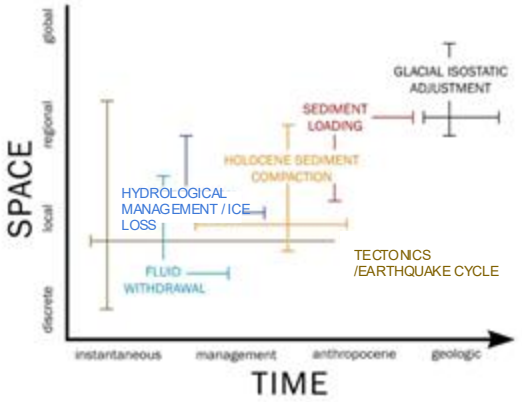
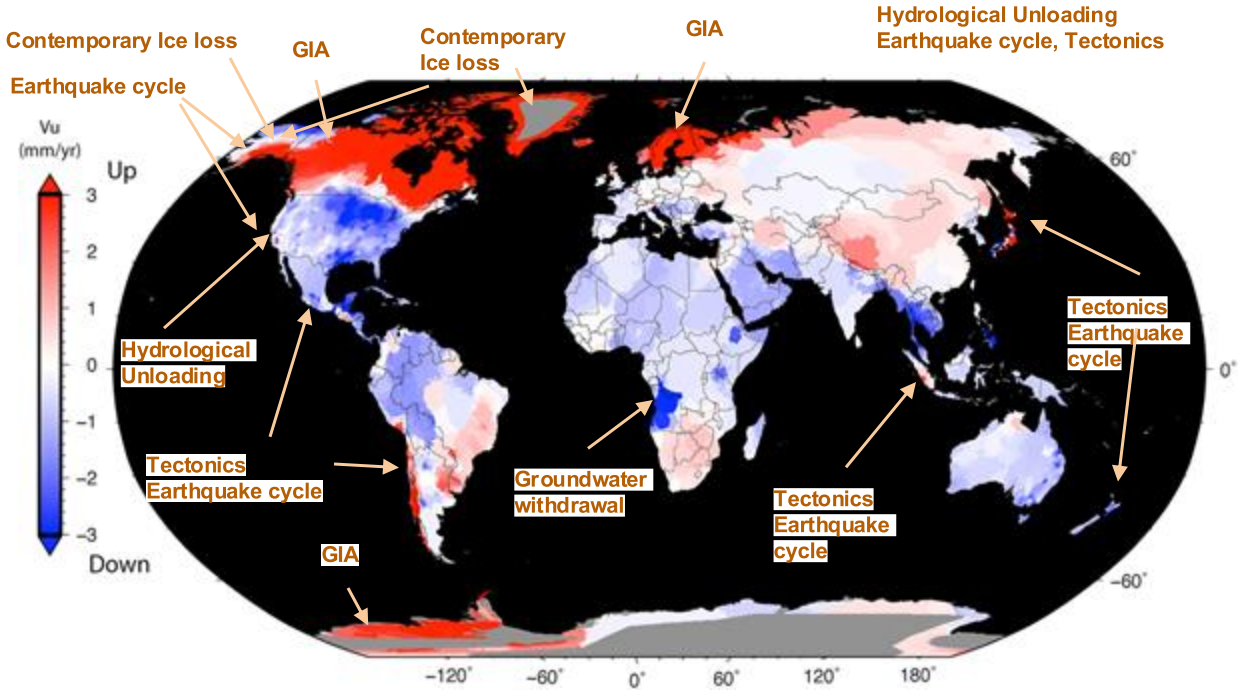
VLM is driven by multiple processes acting at different spatial-temporal scales





Fitzpatrick, C., Jankowski, K.L., & Reed, D. (2020). 2023 Coastal Master Plan: Determining Subsidence Rates for Use in Predictive Modeling. Version I. (p. 70). Baton Rouge, Louisiana: Coastal Protection and Restoration Authority.

Hammond et al (2021): GPS Imaging of Global Vertical Land Motion for Studies of Sea Level Rise, https://doi.org/10.1029/2021JB022355

Observing VLM Using Remote Sensing

GNSS:

+ Very accurate in time
+ Measurement with respect to a geodetic reference
- Not dense in space

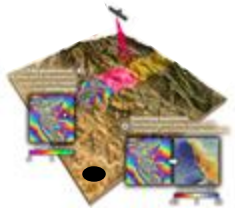
Very good to capture the long spatial processes.

Credit: Earthscope Consortium

Interferometric Synthetic Aperture Radar (InSAR):

+ Accurate in time when densely sampled
+ Dense in space when signal is maintained
- Measurement with respect to a relative location and time

Very good at capturing the short spatial scales



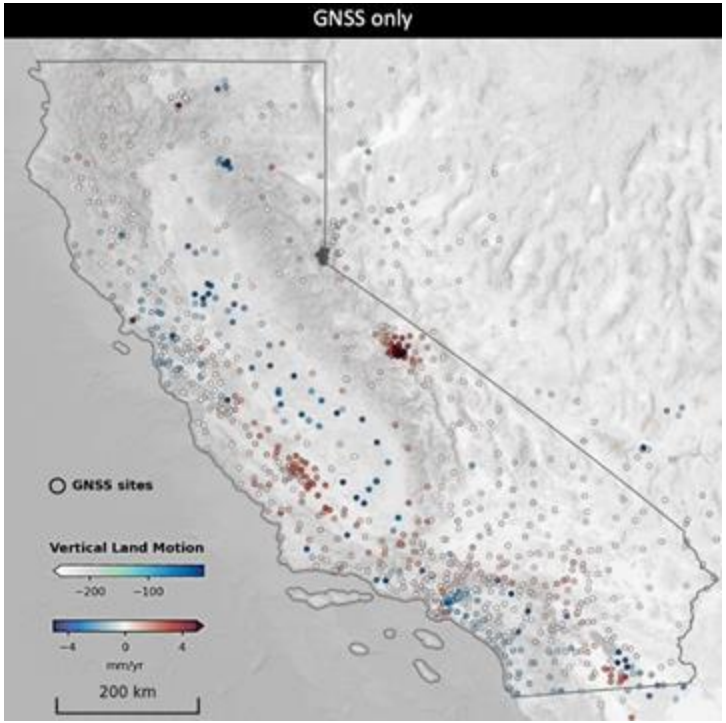
Credit: NASA Earth Observatory

This product:

VLM combining GNSS+INSAR

+ Leverages strengths of GNSS and InSAR.
+ Measurement with respect to a geodetic reference frame

Very good at capturing the short and long spatial scales



OPERA VLM prototype (GNSS +InSAR)

(Govorcin et al 2025; Science Advances, DOI: 10.1126/sciadv.ads8163)

OPERA VLM Prototype Integrated in CA State SLR Report

National Aeronautics and Space Administration

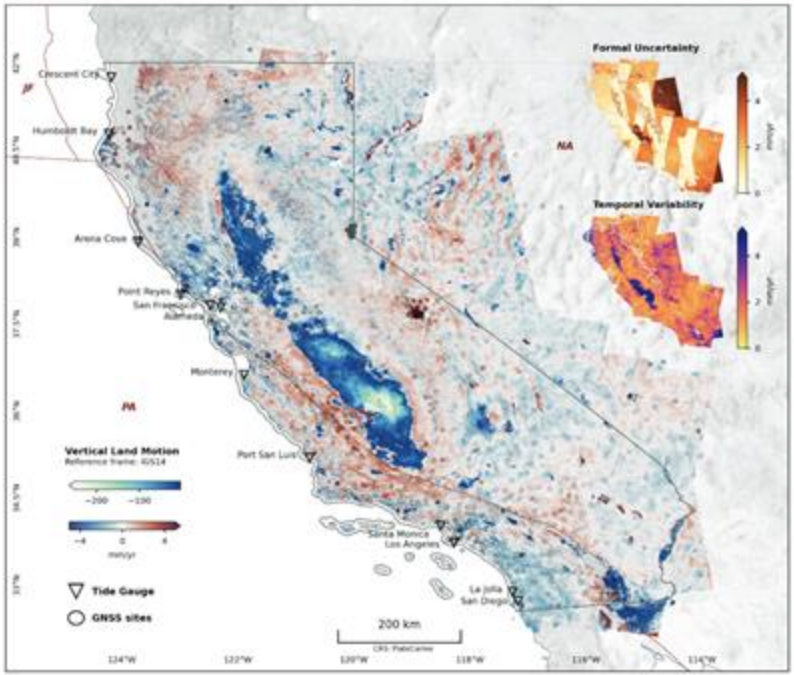
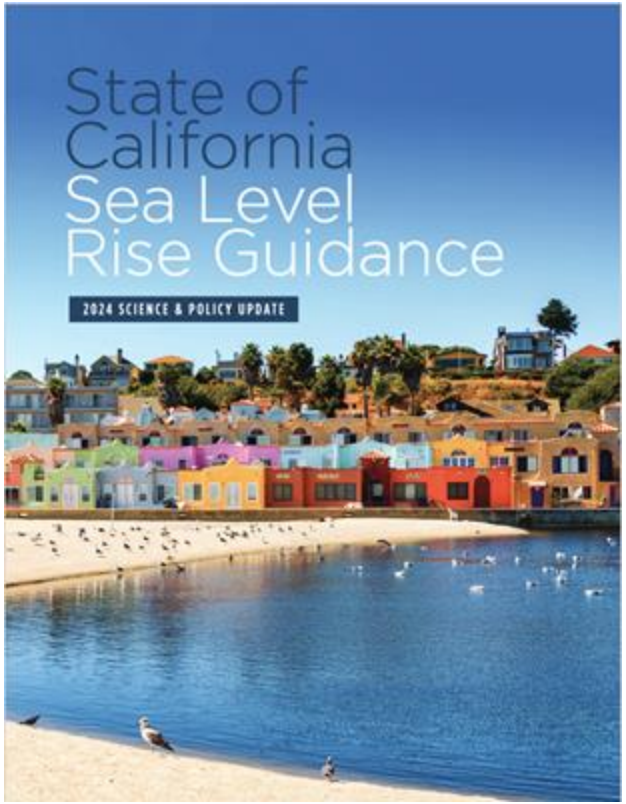


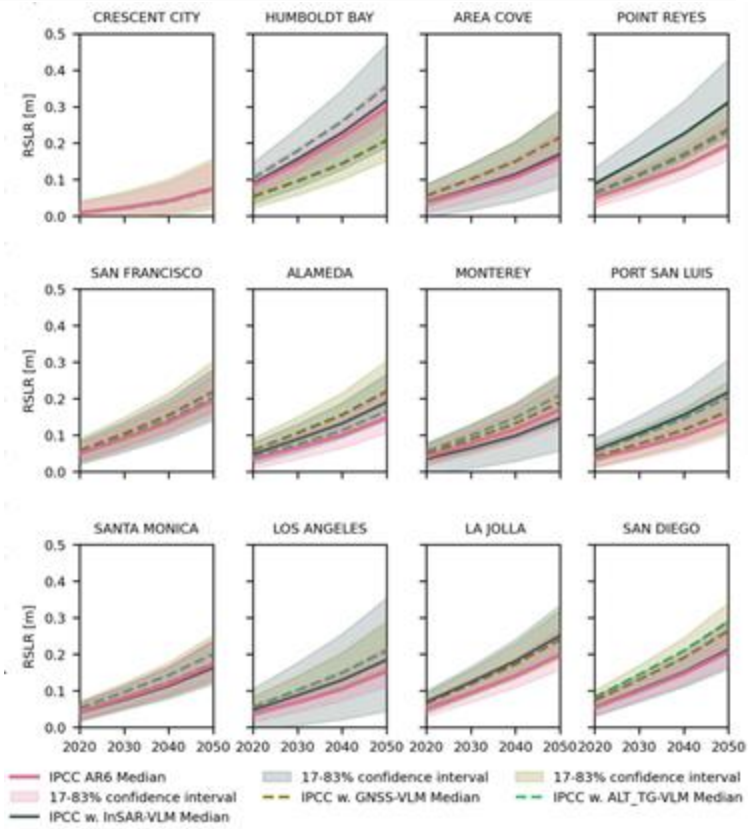
FIGURE A3.1. *Map of vertical land motion rates (mm/year) from Sentinel-1 over the period from 2016-2023 using InSAR analysis for California. Blue indicates subsidence while red indicates areas of uplift. Uncertainty on the rates and variability in the trends over the record are shown in the insets.*

Govorcin M., Bekaert, D., Hamlington B., Sangha, S. Sweet, W. (2024.) Variable Vertical Land Motion for Sea Level Rise Projections (submitted)



OPERA VLM for sea level projections, example CA

- Direct **VLM** observations at tide-gauges (TG) that don't have collocated GNSS
- **OPERA VLM** can be used for sea level projections, both regional (at TG) and local
- **OPERA-VLM** will capture local VLM variations, missing in current projection frameworks (e.g. IPCC), yet important for effective coastal adaptation strategies



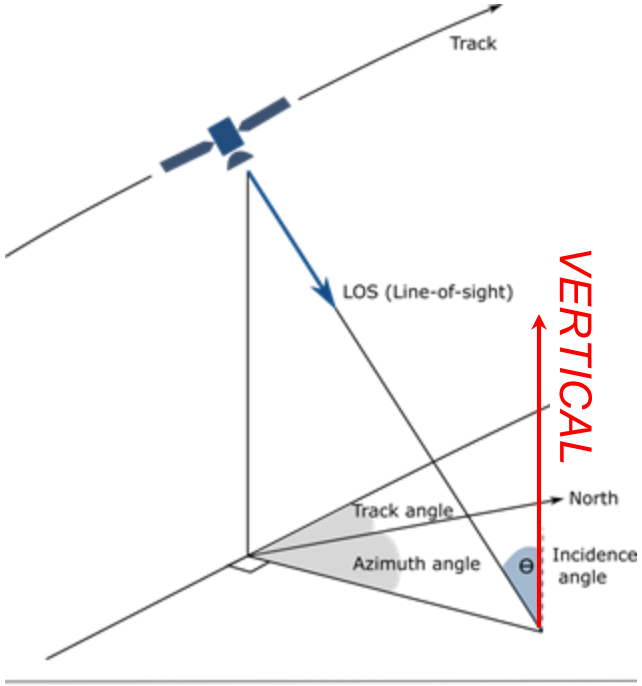
Govorcin *et al.*, 2024 [under review]

VLM Product Overview

The VLM product with ***North America*** geographic scope includes the following:

- **<u>Calibration product for Displacement</u>**
  - Sentinel-1 Calibration product for Displacement
  - NISAR Calibration product for Displacement

- ***<u>Vertical Land Motion time-series</u>***
  - Sentinel-1 Vertical Land Motion time-series
  - NISAR Vertical Land Motion time-series



VLM Product Overview

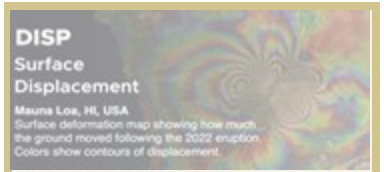
National Aeronautics and Space Administration

The VLM product with ***North America*** geographic scope will consists of 2 stages and include:

- **Calibration product for Displacement**
  - Sentinel-1 Calibration product for Displacement
  - NISAR Calibration product for Displacement

- ***Vertical Land Motion time-series***
  - Sentinel-1 Vertical Land Motion time-series
  - NISAR Vertical Land Motion time-series

Level-3 products



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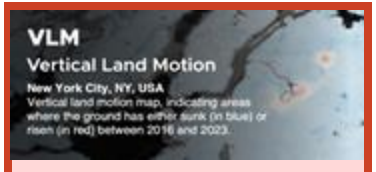
- **Coverage:** North America*
- **Temporal resolution:** 6, 12, or 24 days
- **Spatial Resolution:** ≤ 30 m
- **Product Record Begins:** Apr. 2014 (S1), NISAR validated record.
- **Production Begins:** Dec. 2024 (S1) Sep. 2026 (NISAR)

Available now!

Level-4 products



- **Description:** Maps surface displacements in vertical + horiz. (S1 and NISAR)
- **Coverage:** North America*
- **Temporal resolution:** 15, or 30 days (TBD)
- **Spatial Resolution:** ≤ 120 m
- **Product Record Begins:** Jan. 2019 (S1), NISAR (2026)
- **Production Begins:** Apr. 2028 (S1 + NISAR)
- **Dynamic update**: once a month (TBD)

Available in 2028 !

VLM Product Overview

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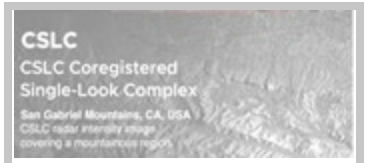
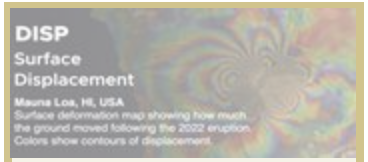
Level-2 products



- **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



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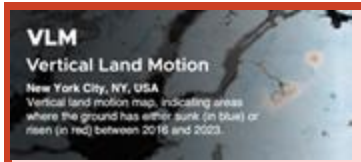
Available now!

Level-4 products



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