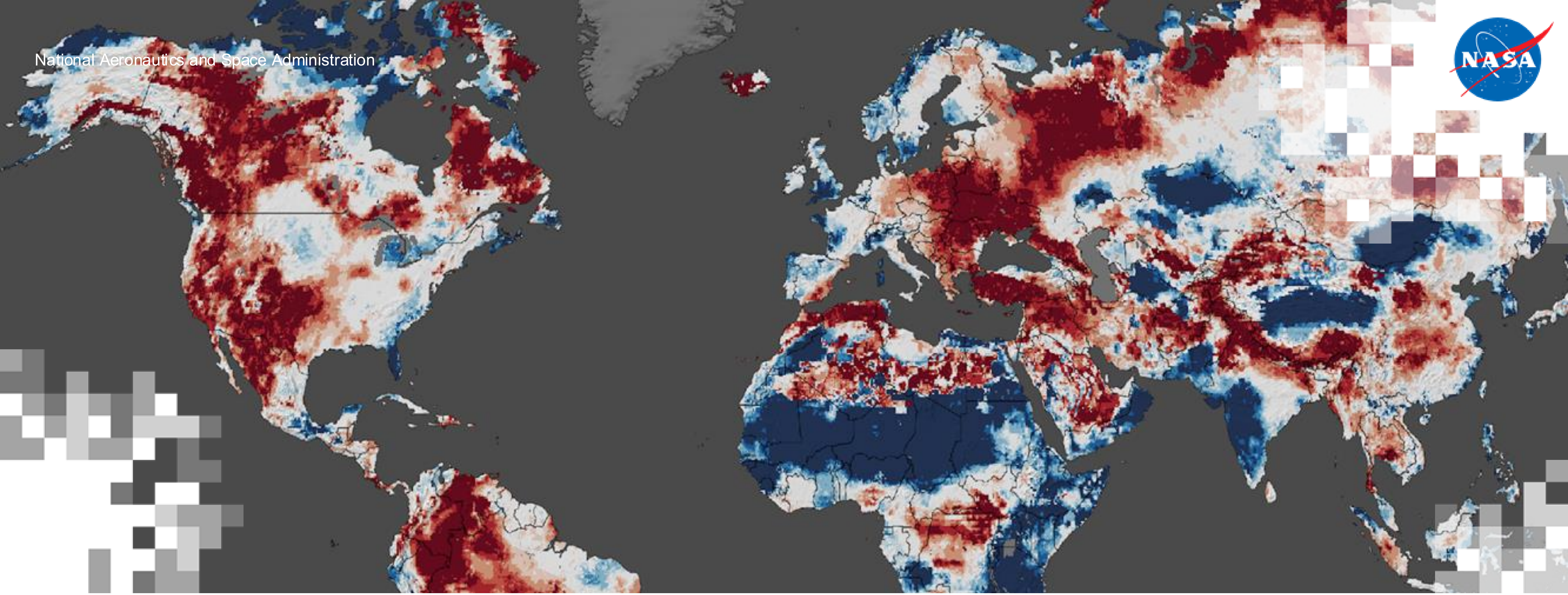
National Aeronautics and Space Administration



Monitoring Groundwater Changes for Water Resources Management

Part 3: Overview and Applications of OPERA-DISP to Monitor Groundwater Changes

ARSET Host: Amita Mehta (612, GESTAR II)
Guest Insturctor: Eric Fielding (NASA JPL)

April 30, 2026

Training Outline

Part 1

Overview and Analysis of NASA Terrestrial Water Storage data from GRACE/GRACE-FO

April 23, 2026

Part 2

Overview and Applications of GLDAS Groundwater data products at Regional Scale

April 28, 2026

Part 3

Overview and Applications of OPERA-DISP to Monitor Groundwater Changes

April 30, 2026

Homework

Opens April 30 – Due May 15 – Posted on Training Webpage

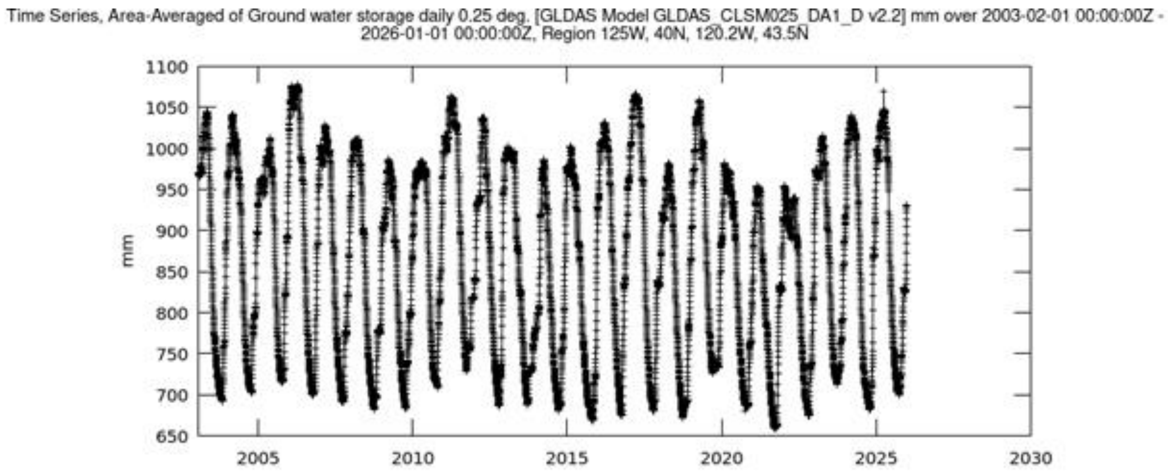
A certificate of completion will be awarded to those who attend all live sessions and complete the homework assignment(s) before the given due date.

Review of Part 2: GLDAS 2.2

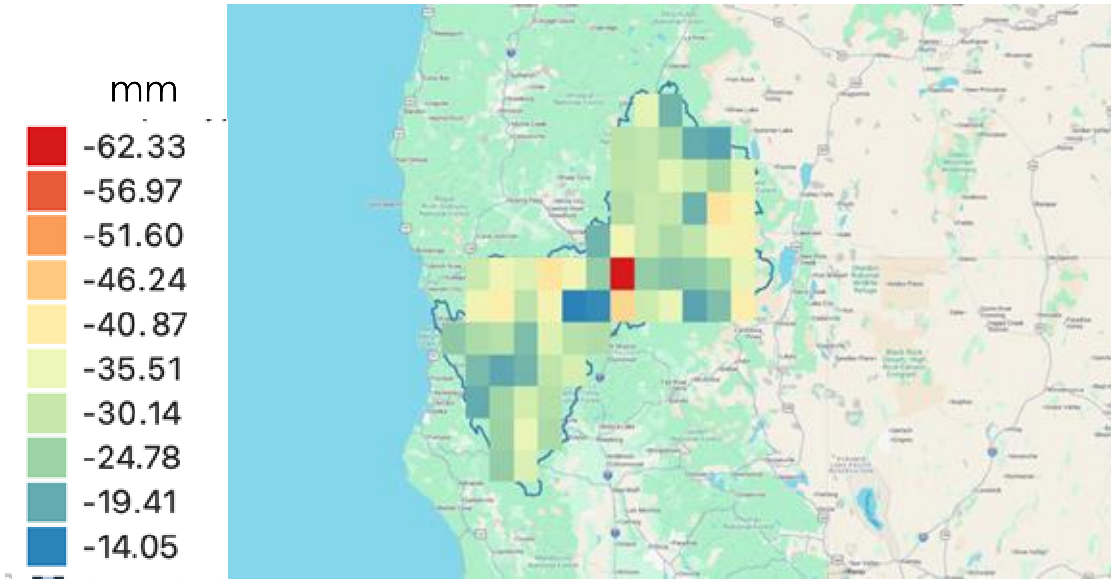
- **Land data assimilation systems (LDAS)** integrate data from various sources, using algorithms that represent our knowledge of physical processes to fill spatial and temporal gaps
- **GLDAS 2.2 integrates GRACE/FO observations** of terrestrial water storage with other information using data assimilation, enabling spatial and temporal downscaling and vertical disaggregation
- GLDAS 2.2 soil moisture and groundwater output has been evaluated extensively using ground-based observations
- Key Limitations
  - **The model does not simulate water management** (e.g., groundwater pumping), so it cannot effectively downscale GRACE/FO observations where direct human impacts are significant
  - **The model does not simulate confined aquifer storage changes**, which may be an important component of TWS changes observed by GRACE/FO in certain regions
- **GLDAS 2.2 output are updated monthly on GES DISC**
  - associated wetness/drought indicator maps and monthly forecasts are updated weekly on the National Drought Mitigation Center website

Review of Part 2: Groundwater Storage Data Access, Analysis, and Visualization for Klamath River Basin

In Giovanni, we created maps and timeseries of GLDAS 2.2 groundwater storage data.



In QGIS, we examined Interdecadal groundwater storage changes between 2003-2013 and 2004-2025.



Part 3 Objectives

- Identify characteristics of OPERA surface displacement product
- Access and visualize OPERA-DISP data to infer groundwater changes at regional scale for applications

How to Ask Questions

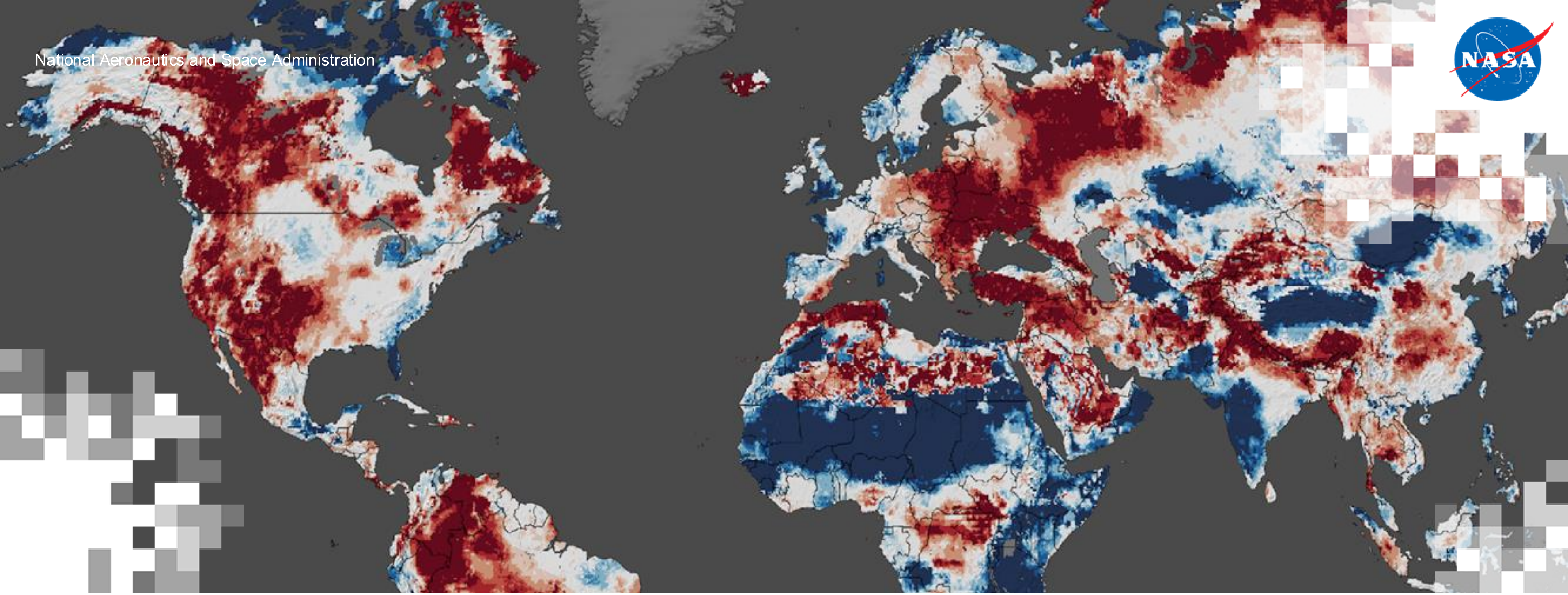
- Please put your questions in the Questions box and we will address them at the end of the webinar.
- Feel free to enter your questions as we go. We will try to get to all of the questions during the Q&A session after the webinar.
- The remainder of the questions will be answered in the Q&A document, which will be posted to the training website about a week after the training.

Part 3 – Trainer

Dr. Eric Fielding

Senior Research Scientist

Caltech/JPL



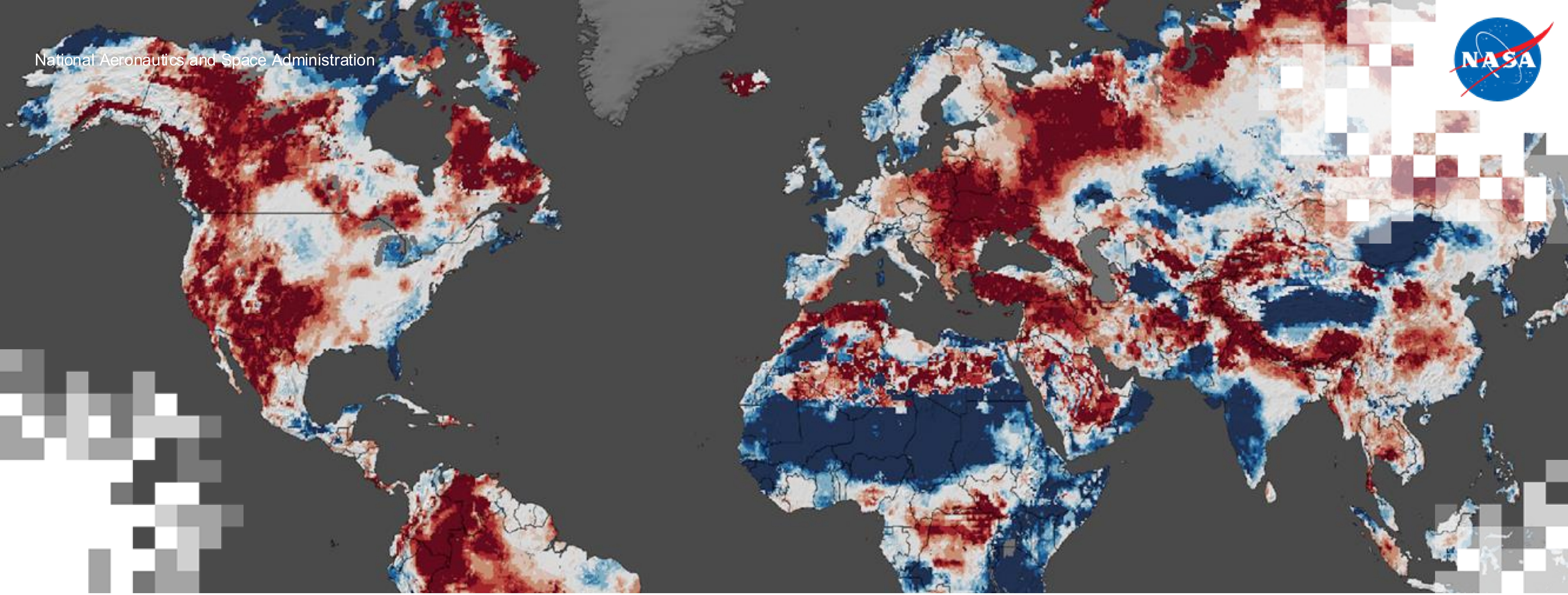
Monitoring Groundwater Changes for Water Resources Management

Session 3: Overview and Applications of OPERA-DISP to Monitor Groundwater Changes

Eric Jameson Fielding & M. Grace Bato (Jet Propulsion Laboratory, CA Institute of Technology)

April 30, 2026

National Aeronautics and Space Administration



Session 3: Overview and Applications of OPERA-DISP to Monitor Groundwater Changes

Session 3 Objectives

By the end of Part 3, participants will be able to:

- Understand the basic physics of SAR interferometry
- Describe what SAR interferometric phase tells us about the land surface and subsidence
- Understand the Observational Products for End-Users from Remote Sensing Analysis (OPERA) Displacement (OPERA DISP) product measurements
- Understand what OPERA DISP time series reveal about land subsidence due to groundwater extraction

Prior Knowledge

- ARSET Basics of Synthetic Aperture Radar
- Measuring Surface Subsidence due to Groundwater Extraction with InSAR (Part-2)

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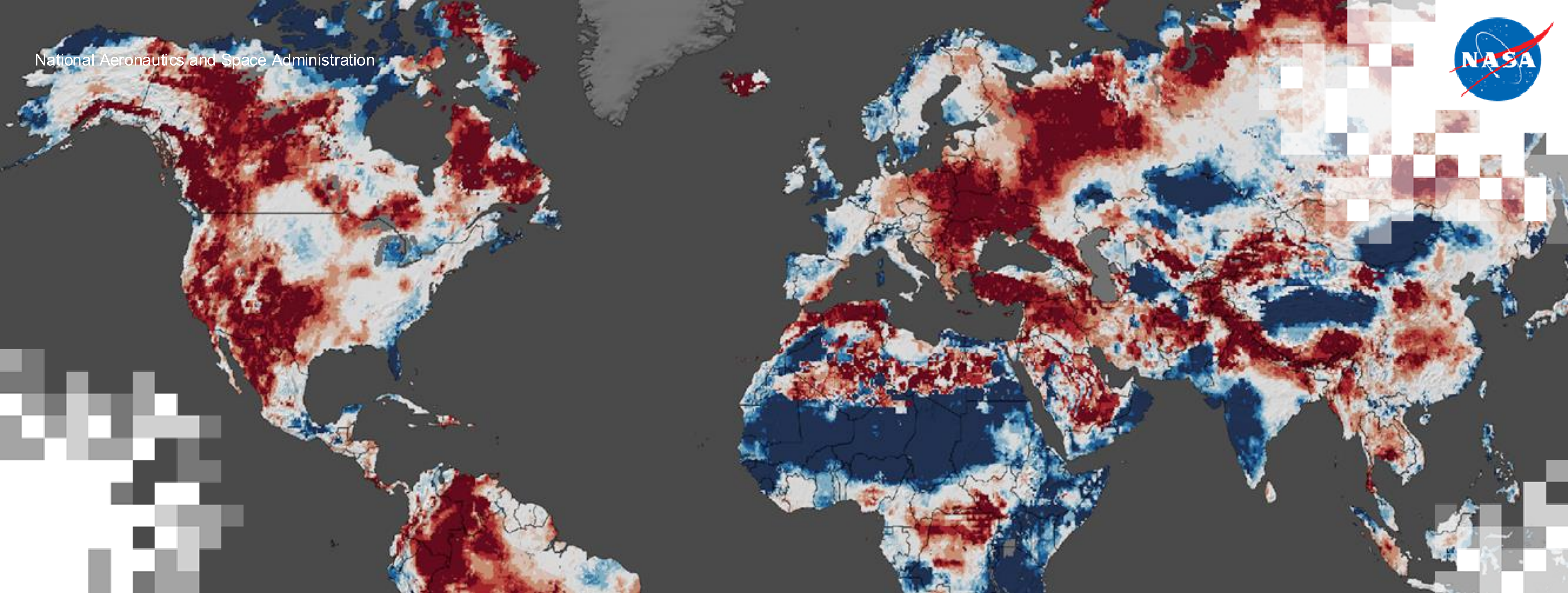


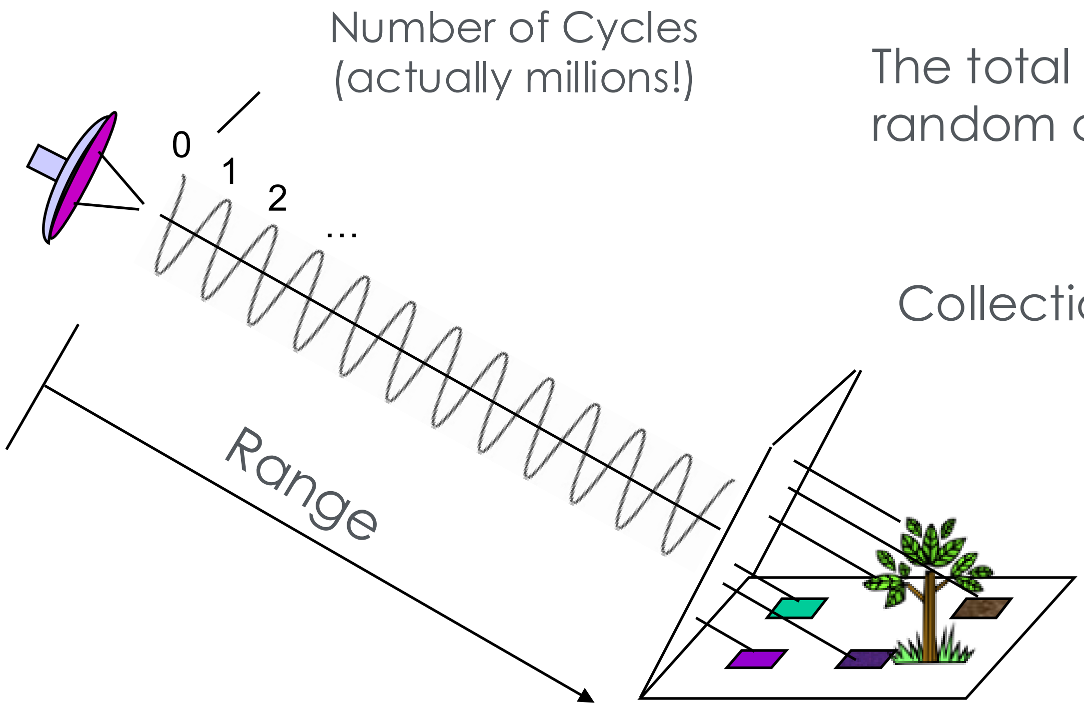
SAR Interferometry Theory (Review)

SAR Interferometry Theory

- Quick review of synthetic aperture radar interferometry theory
- See the 2017 ARSET training Introduction to SAR Interferometry and 2019 ARSET training Interferometric SAR for Landslide Observations for more details
- In SAR interferometry, it is all about the phase of the SAR signal

SAR Phase – A Measure of Range and Surface Complexity

The phase of the radar signal is the number of **cycles of oscillation** that the wave executes between the radar and the surface and back again.



The total phase is a two-way range measured in wave cycles + random components from the surface.

Collection of random path lengths jumbles the phase of the echo.

Only **interferometry** can sort it out!

Slide modified from Paul Rosen (JPL)

A Simplistic View of SAR Phases

Phase of Image 1

$$\phi_1 = \frac{4\pi}{\lambda} \cdot \rho_1 + other\ constants + \ n_1$$

Phase of Image 2

$$\phi_2 = \frac{4\pi}{\lambda} \cdot \rho_2 + other\ constants + \ n_2$$

1. The "other constants" cannot be directly determined.

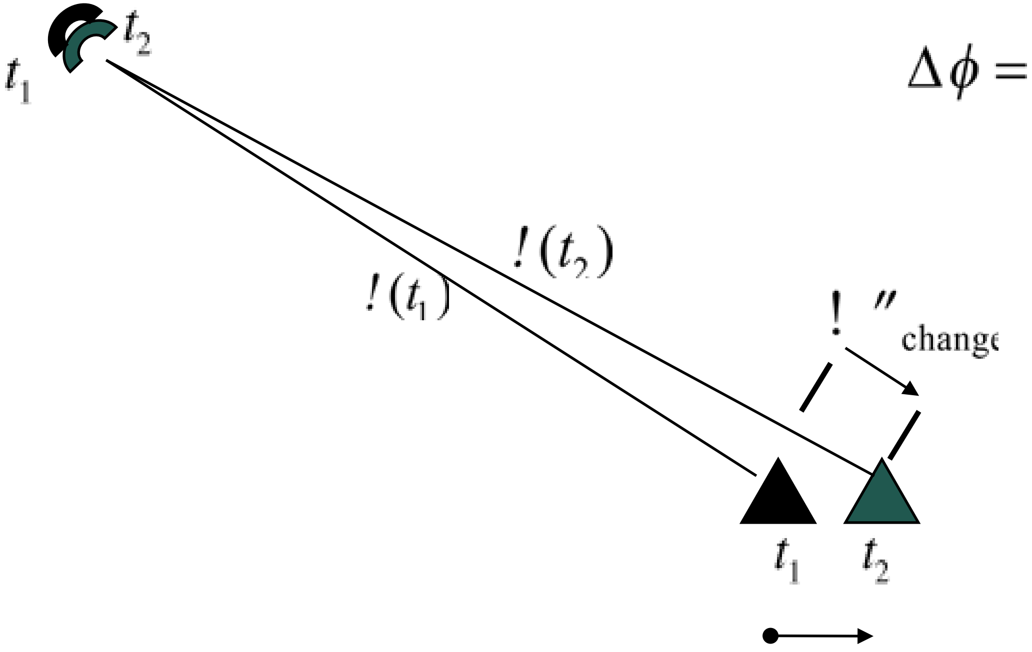
2. "Other constants" depends on scatterer distribution in the resolution cell, which is unknown and varies from cell to cell.

3. The only way of observing the range change is through interferometry (cancellation of "other constants").

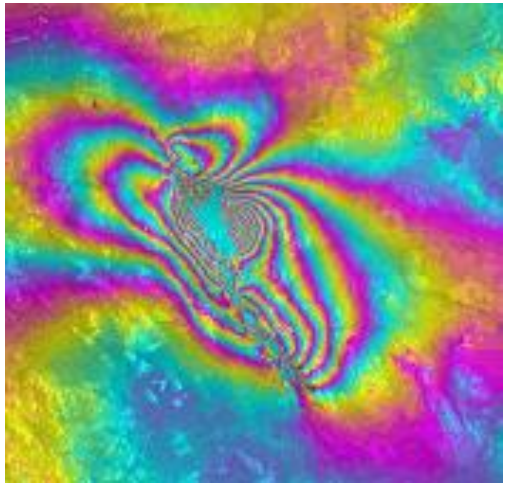
Slide modified from Paul Rosen (JPL)

Differential Interferometry

- When two observations are made from the same location in space but at different times, the interferometric phase is proportional to any change in the range or distance of a surface feature directly.



$$\Delta\phi = \frac{4\pi}{\lambda}(\rho(t_1) - \rho(t_2)) = \frac{4\pi}{\lambda}\Delta\rho_{\text{change}}$$



Slide modified from Paul Rosen (JPL)

Differential Interferometry Sensitivities

- The reason differential interferometry can detect millimeter-level surface deformation is that the differential phase is much more sensitive to displacements than to topography.

$$\frac{\partial \phi}{\partial h} = \frac{2\pi p b \cos(\theta - \alpha)}{\lambda \rho \sin \theta} = \frac{2\pi p b_{\perp}}{\lambda \rho \sin \theta}$$ Topographic Sensitivity

(*f* ⇔ *Df*) $$\frac{\partial \phi}{\partial \Delta \rho} = \frac{4\pi}{\lambda}$$ Displacement Sensitivity

$$\sigma_{\phi_{topo}} = \frac{\partial \phi}{\partial h} \sigma_h = \frac{4\pi}{\lambda} \frac{b_{\perp}}{\rho \sin \theta} \sigma_h$$ Topographic Sensitivity Term

$$\sigma_{\phi_{disp}} = \frac{\partial \phi}{\partial \Delta \rho} \sigma_{\Delta \rho} = \frac{4\pi}{\lambda} \sigma_{\Delta \rho}$$ Displacement Sensitivity Term

Since $\frac{b}{\rho} << 1$ ==> $\frac{\sigma_{\phi_{disp}}}{\sigma_{\Delta \rho}} >> \frac{\sigma_{\phi_{topo}}}{\sigma_h}$

Meter Scale Topography Measurement - Millimeter Scale Topographic Change

Slide modified from Paul Rosen (JPL)

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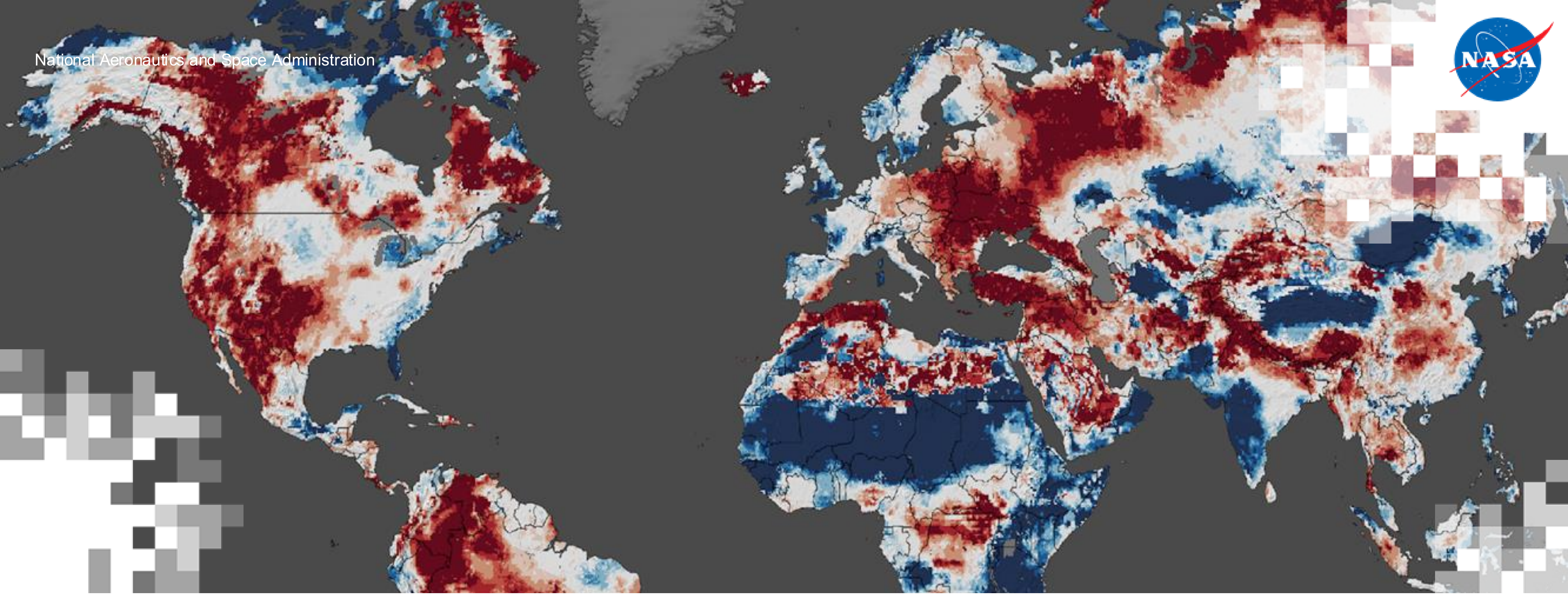


Observational Products for End-Users from Remote Sensing Analysis (OPERA) Displacements

OPERA Enabling End-Users to Take Action

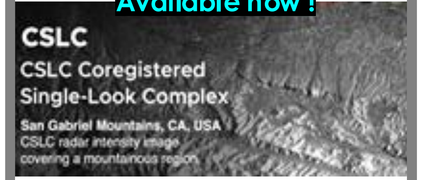
- **Observational Products for End-users from Remote sensing Analysis** is a NASA Satellite Needs Working Group (SNWG) project
- **Free and open** analysis-ready data products designed for science and application for federal stakeholders and beyond
- OPERA goes beyond a single mission (Landsat 8/9, Sentinel-1/2, NISAR) to produce **Ready-To-Use, Cloud-optimized, GIS Friendly data products**

OPERA Products

Level-2 products

- **Description:** S1 radar backscatter corrected for topography
- **Coverage:** Near-global

Available now !



- **Description:** Geocoded and coreg. SLC (S1)
- **Coverage:** North America*

Available now !

Level-3 products

- **Description:** Maps surface water using optical (HLS) and SAR imagery (S1, NISAR)
- **Coverage:** Near-global

Available now !

- **Description:** Maps disturbance using optical (HLS) and SAR imagery (S1)
- **Coverage:** Near-global

Available now !

- **Description:** Maps surface displacements in LOS (S1 and NISAR)
- **Coverage:** North America*

Available now !

Level-4 products

- **Description:** Maps surface disp. in vertical + horiz. (S1 and NISAR)
- **Coverage:** North America*

Available in 2028

- **Description:** provides global estimates of atmospheric delay that can help correct atmospheric signal errors from any SAR mission.
- **Coverage:** global

Available now !

Posting: 30 m for all products except VLM (120 m) and Tropo (8 km)
Temporal sampling: sub-weekly to weekly

All OPERA data products are free and available through the SNWG Data Portal on NASA Earthdata Search

S1 = Sentinel-1
NISAR = NASA-ISRO SAR mission
HLS = Harmonized Landsat Sentinel-2

OPERA Surface Displacement (DISP)

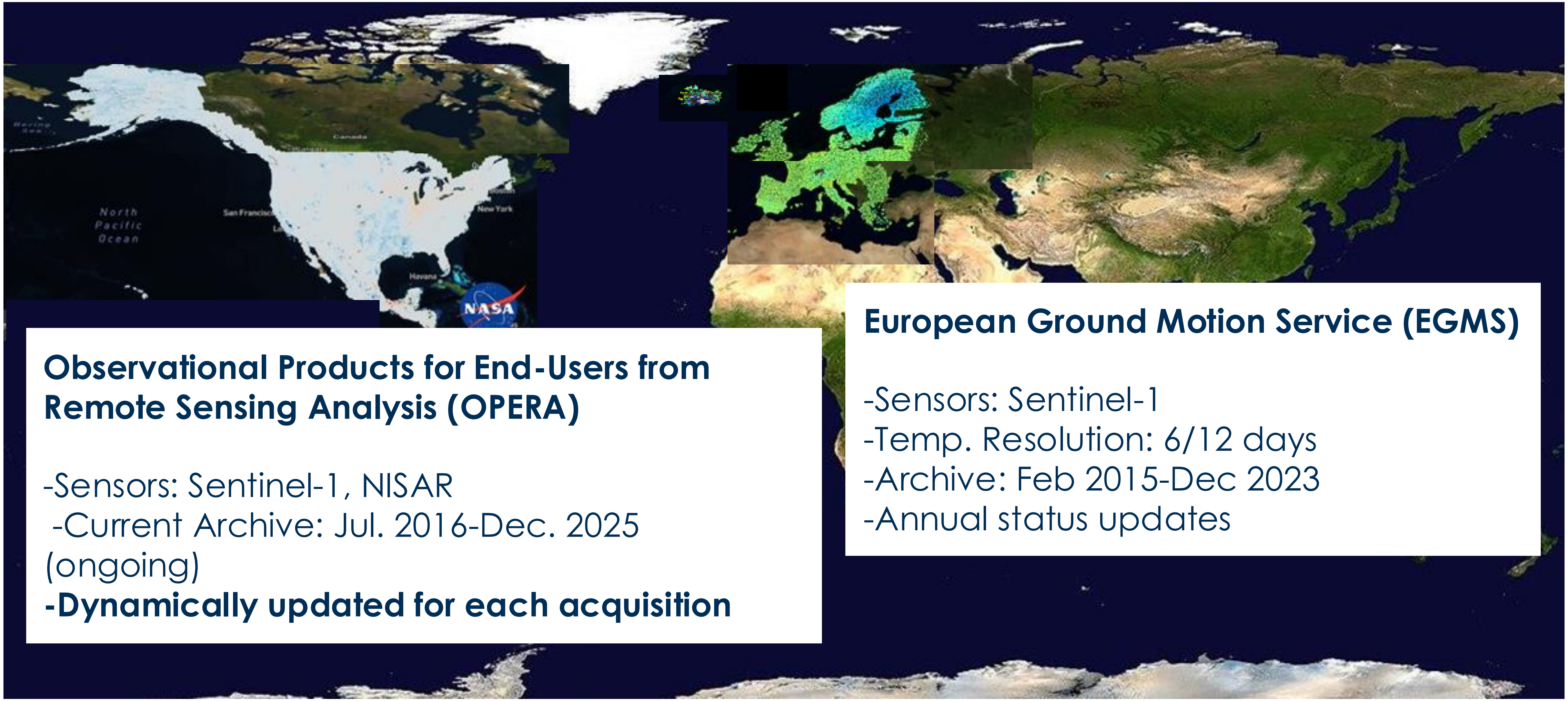
- **Description:** Surface displacements time series in LOS (S1 and NISAR)
- **Coverage:** North America*
- **Temporal resolution:** 6, 12, or 24 days
- **Spatial Resolution:** 30 m
- **Product Record Begins:** Jul. 2016 (S1), TBD (NISAR)
- **File format:** netCDF
- **Access:** ASF DAAC and NASA EarthData

DISP-S1 Available now !

***First ever operational surface displacement time series product for North America!**

First ever InSAR product certified as CEOS-ARD (Application Ready Data)

Surface Displacement products available globally



Observational Products for End-Users from Remote Sensing Analysis (OPERA)

-Sensors: Sentinel-1, NISAR
-Current Archive: Jul. 2016-Dec. 2025 (ongoing)
-Dynamically updated for each acquisition

European Ground Motion Service (EGMS)

-Sensors: Sentinel-1
-Temp. Resolution: 6/12 days
-Archive: Feb 2015-Dec 2023
-Annual status updates

OPERA Surface Displacement (DISP) Product Layers

Nominal product layer:

- Displacement (meters)

Visualization product layer:

- Short wavelength (meters)
  - **Local displacement derived from the Displacement layer and is used in ASF DAAC Displacement Portal**

Correction layers:

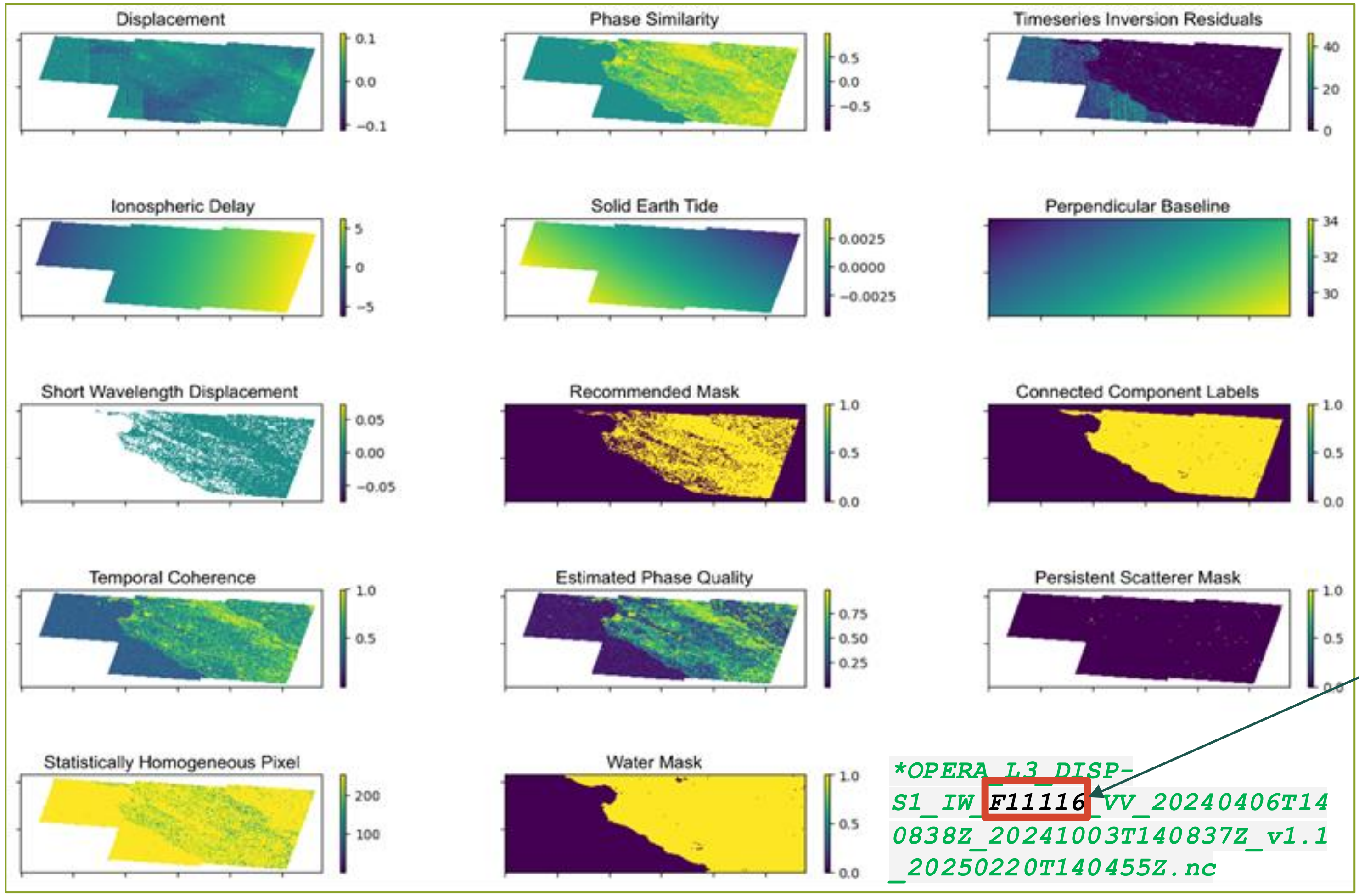
- Ionospheric delay
- Solid Earth tide
- Perpendicular baseline - correction for phase from errors in the DEM

Quality metric layers:

- Recommended quality mask
- Connected components labels
- Phase similarity
- Estimated phase quality
- PS mask
- Temporal coherence
- Timeseries inversion residuals
- SHP (statistically homogeneous pixels) count

Other

- Water mask



Frame number

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Other
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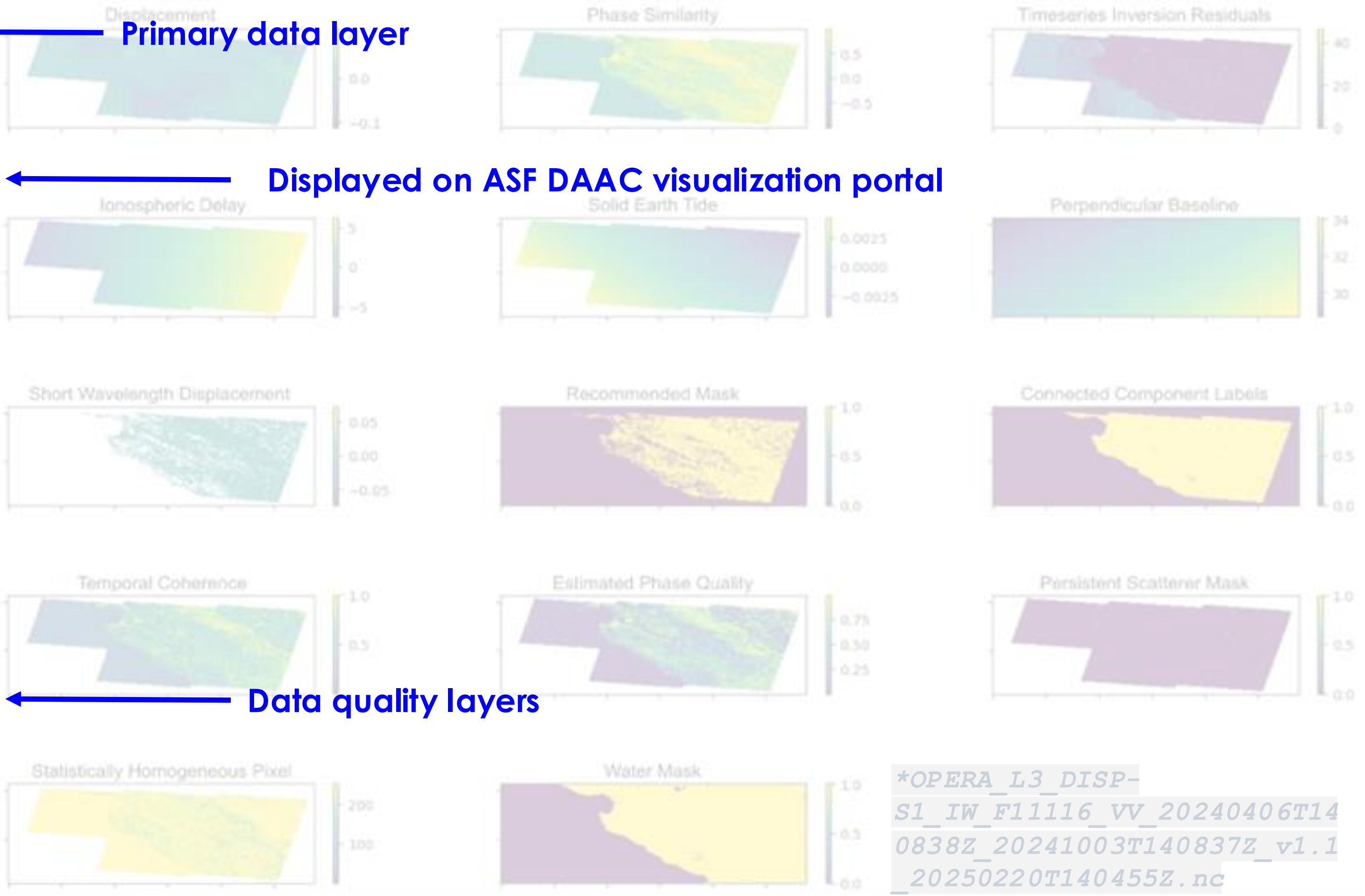
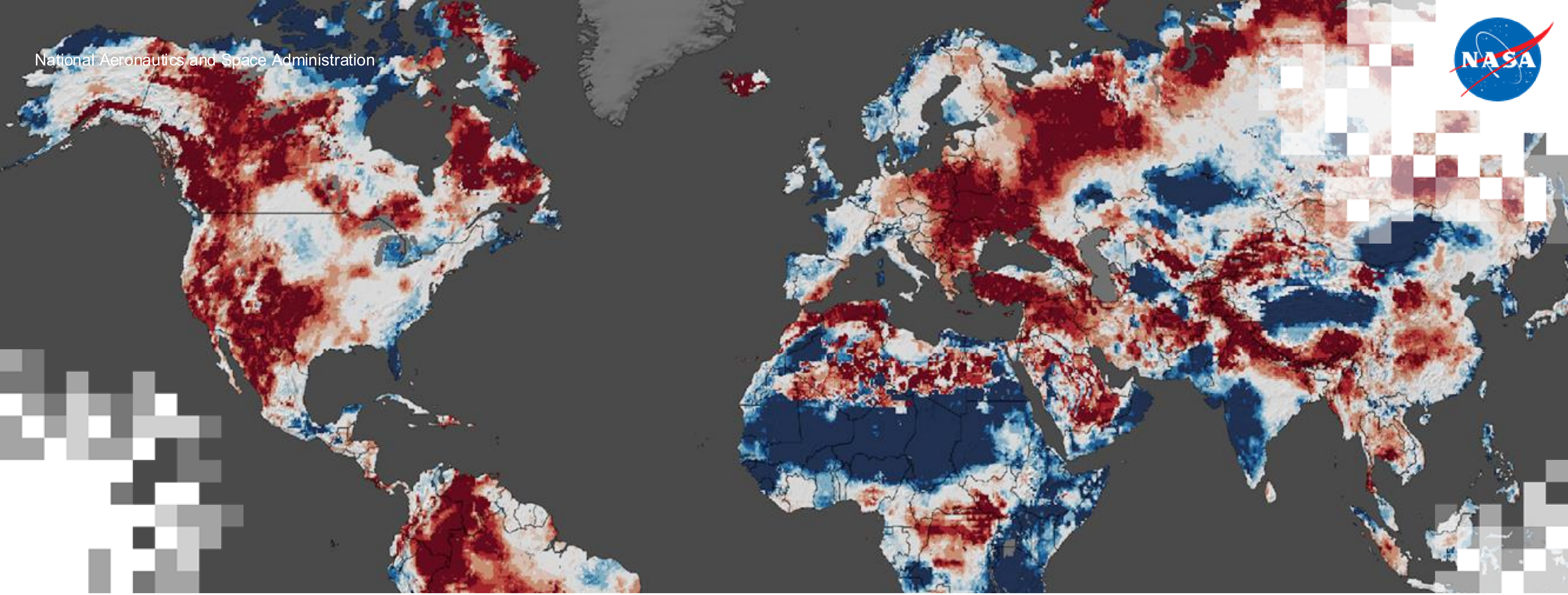
Primary data layer

Displayed on ASF DAAC visualization portal

Data quality layers



*OPERA_L3_DISP-S1_IW_F11116_VV_20240406T140838Z_20241003T140837Z_v1.1_20250220T140455Z.nc



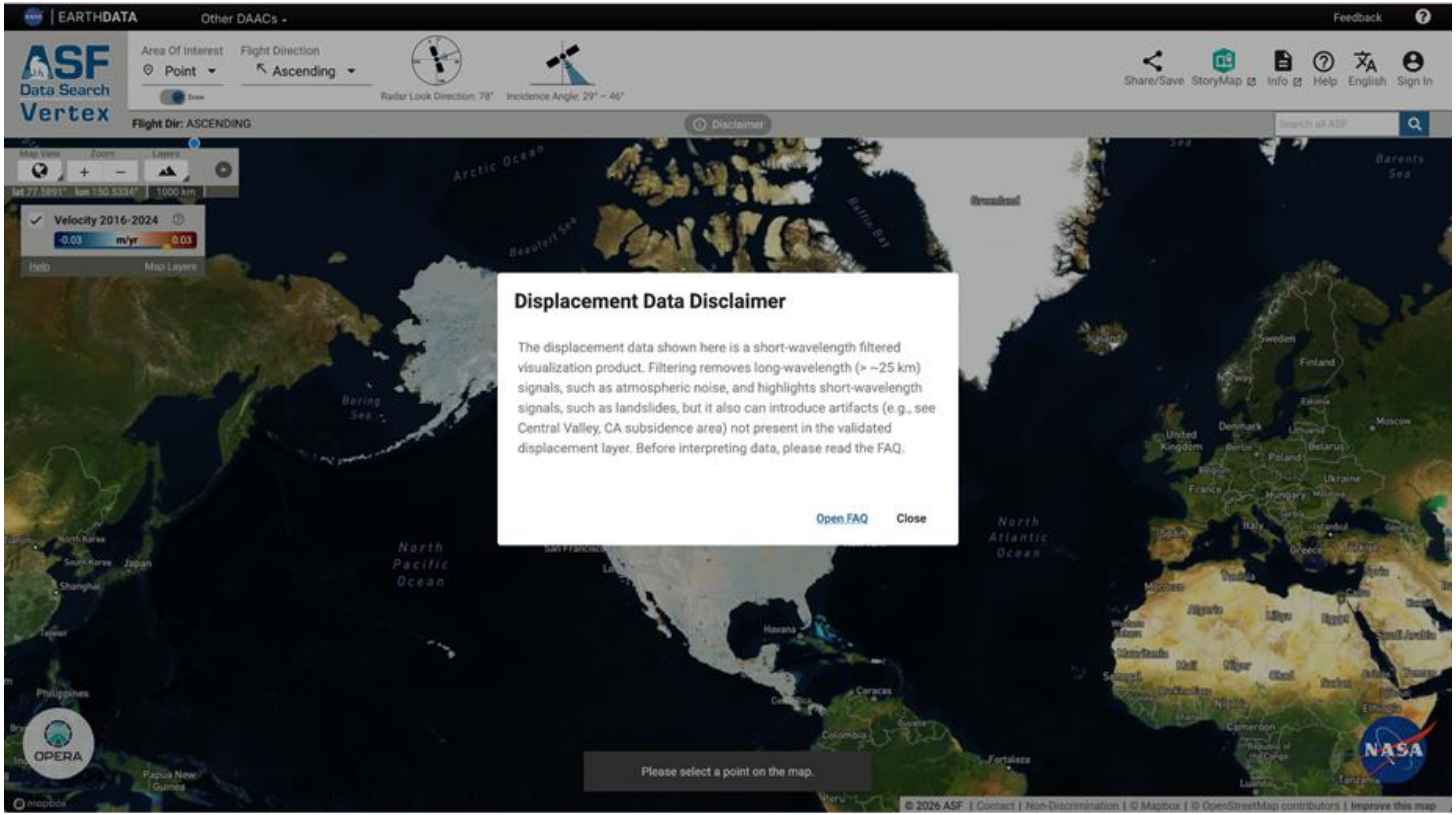
Demonstration of OPERA DISP access and analysis

Demo Overview

- Learn about the ASF OPERA Displacements visualization portal and about ways to analyze the full dataset
- Jupyter notebook for in-depth analysis of OPERA DISP products

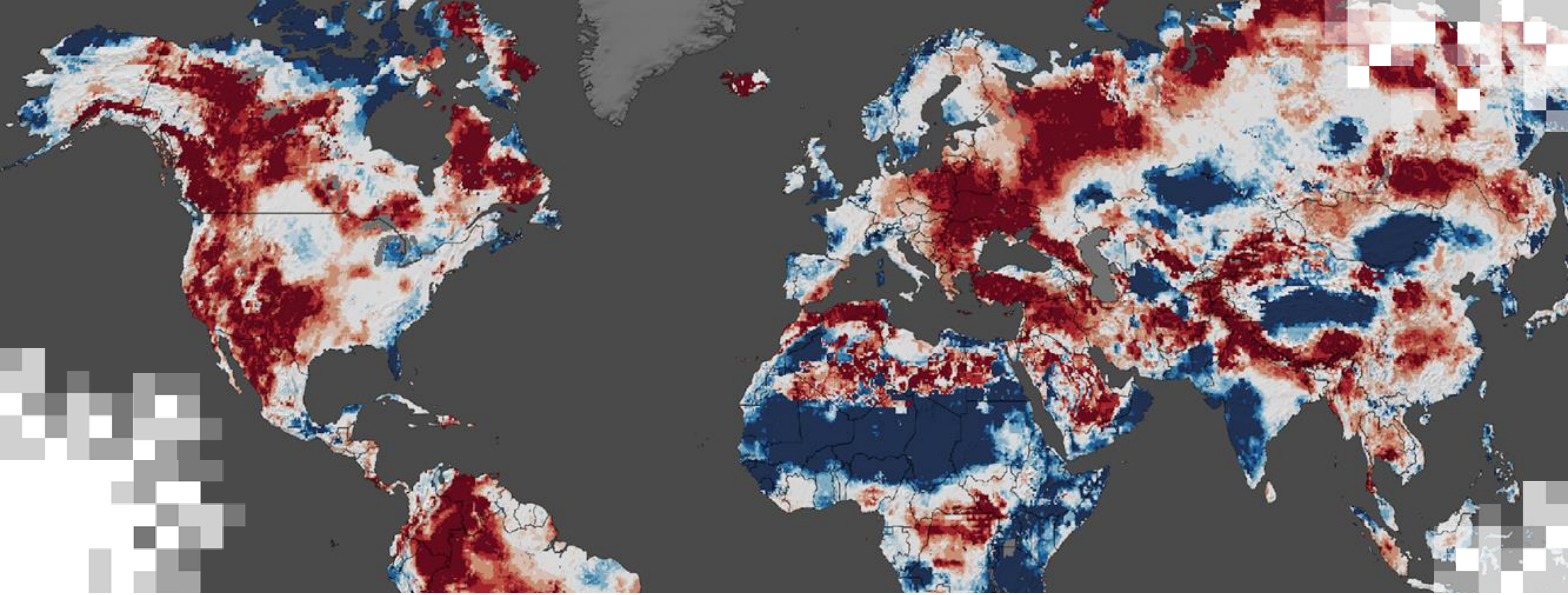
ASF Displacements Portal for OPERA DISP

[ASF Data Search Vertex]



Resources

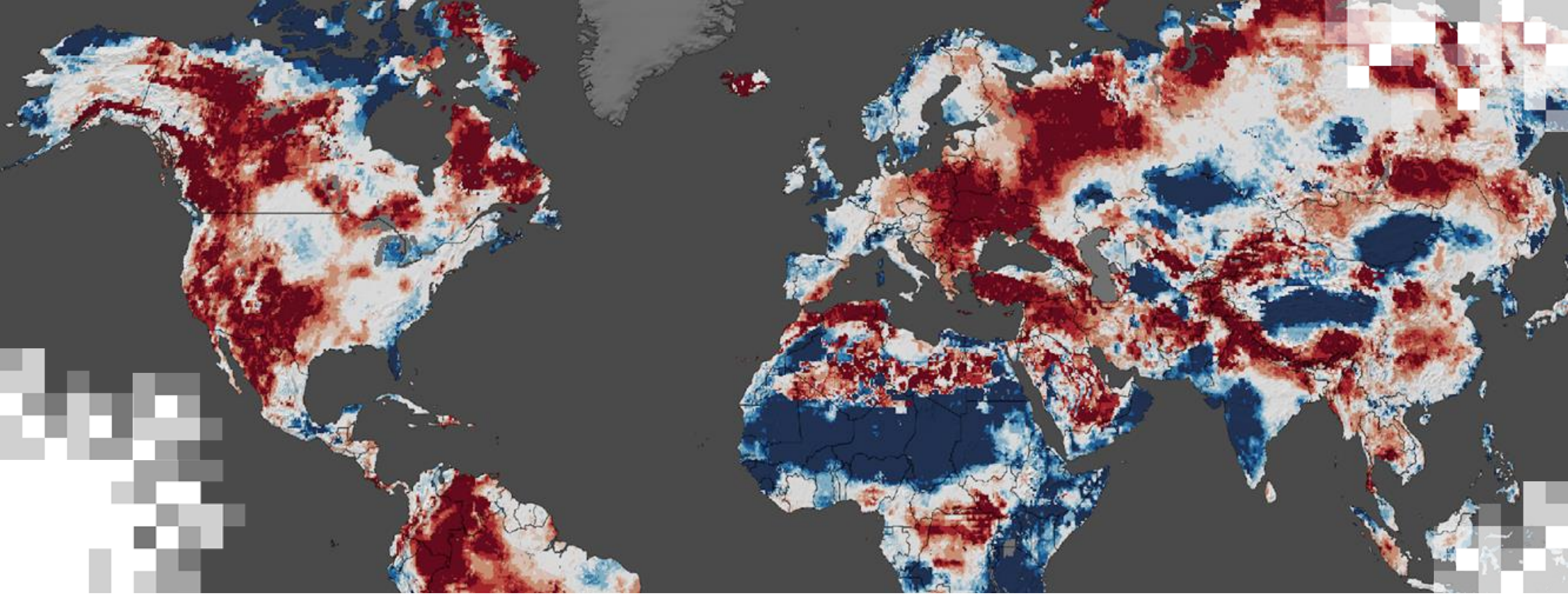
- NASA Earthdata
- Satellite Needs Working Group
- ASF Displacement Portal
- OPERA Product Information
- OPERA Jupyter Notebooks
- NASA Worldview



Part 3:
Summary

Summary

- Review of SAR Interferometry: Phase of SAR signal is important.
- When two observations are made from the same location in space but at different times, the interferometric phase is proportional to any change in the range or distance of a surface feature.
- Overview of Observational Products for End-Users from Remote Sensing Analysis (OPERA) Displacement Product (DISP) is derived from Sentinel-1 SAR imagery.
- OPERA DISP products provide information on movements of the Earth's surface, such as subsidence due to groundwater or oil and gas extraction, uplift due to water injection, and ground motion from tectonic faults, landslides, volcanoes.
- OPERA Displacements visualization portal available from the Alaska SAR Facility.
- Demonstration: Jupyter notebook for in-depth analysis of OPERA DISP products.
  - Change in subsidence in Central Valley, CA, indicating groundwater changes.



Monitoring Groundwater Changes for Water Resources Management
Training Summary

GRACE/FO, GLDAS, OPERA Data Access, Analysis, Visualization

Demonstrations: Search and select data, create maps and time series

GRACE/FO Terrestrial Water Storage Changes

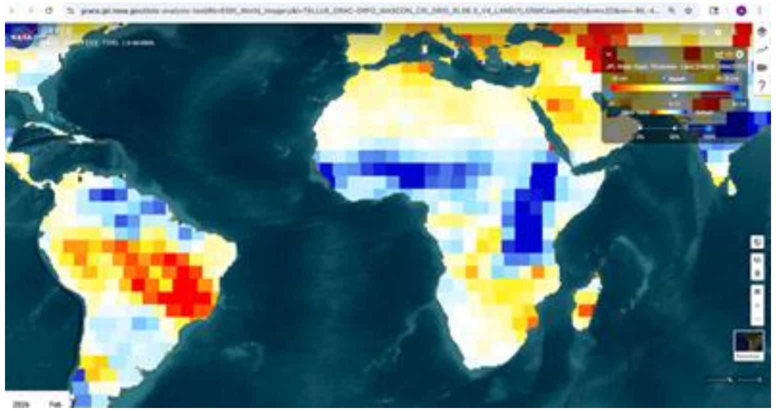
GRACE Data Analysis Tool

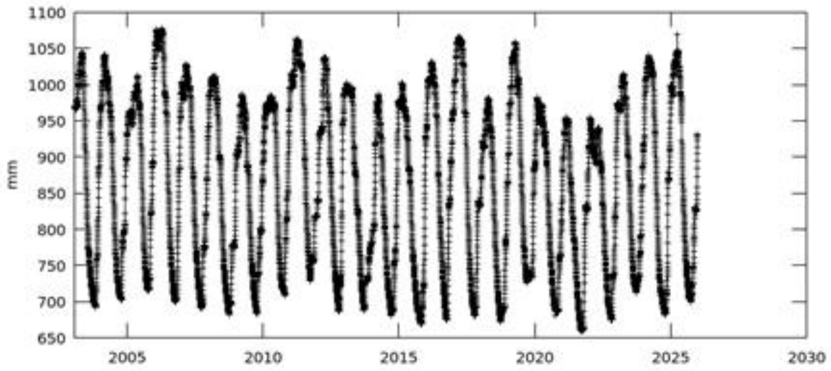
GLDAS groundwater Storage

Giovanni

OPERA DISP

ASF Displacement Portal





Homework and Certificates

- **Homework:**
  - One homework assignment
  - Opens on 30/04/2026
  - Access from the training webpage
  - Answers must be submitted via Google Forms
  - **Due by 5/15/2026**

- **Certificate of Completion:**
  - Attend all three live webinars (attendance is recorded automatically)
  - Complete the homework assignment by the deadline
  - You will receive a certificate via email approximately two months after completion of the course.

Acknowledgements

Dr. Matthew Rodell

Deputy Director of Earth Sciences for Hydrosphere, Biosphere, and Geophysics (NASA/GSFC Affiliation)

Dr. Eric Fielding

Senior Research Scientist

Caltech/JPL

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- ARSET Website
- ARSET YouTube

For questions, comments, or to share how you have applied our trainings to your work or studies, email nasa.arset@gmail.com.

Join our quarterly newsletter to stay up-to-date on our latest trainings:

1. Send an email with no subject line to arset-join@lists.nasa.gov.
2. Follow the instructions sent in response.

Share Your Thoughts!

Within a day or two, we will send you an invitation to complete a short online survey.* **Your feedback helps us improve the ARSET program.**

- Participation is optional, and all responses are confidential.
- **Survey data are crucial to helping us understand how to better meet your needs. We want to help you use Earth observation data more effectively.**
- We read every survey comment – so please share your thoughts!

*The survey will come from noreply@alchemer.com. This is not spam.

Resources

- GSFC Mascon Product
- JPL data portal
- GFZ data portal
- GRACE website at University of Texas at Austin Center for Space Research (CSR)
- GLDAS 2.2
- GRACE Data Analysis Tool
- Giovanni
- NASA Earthdata
- ASF Displacement Portal
- OPERA Product Information
- OPERA Jupyter Notebooks

Thank You!