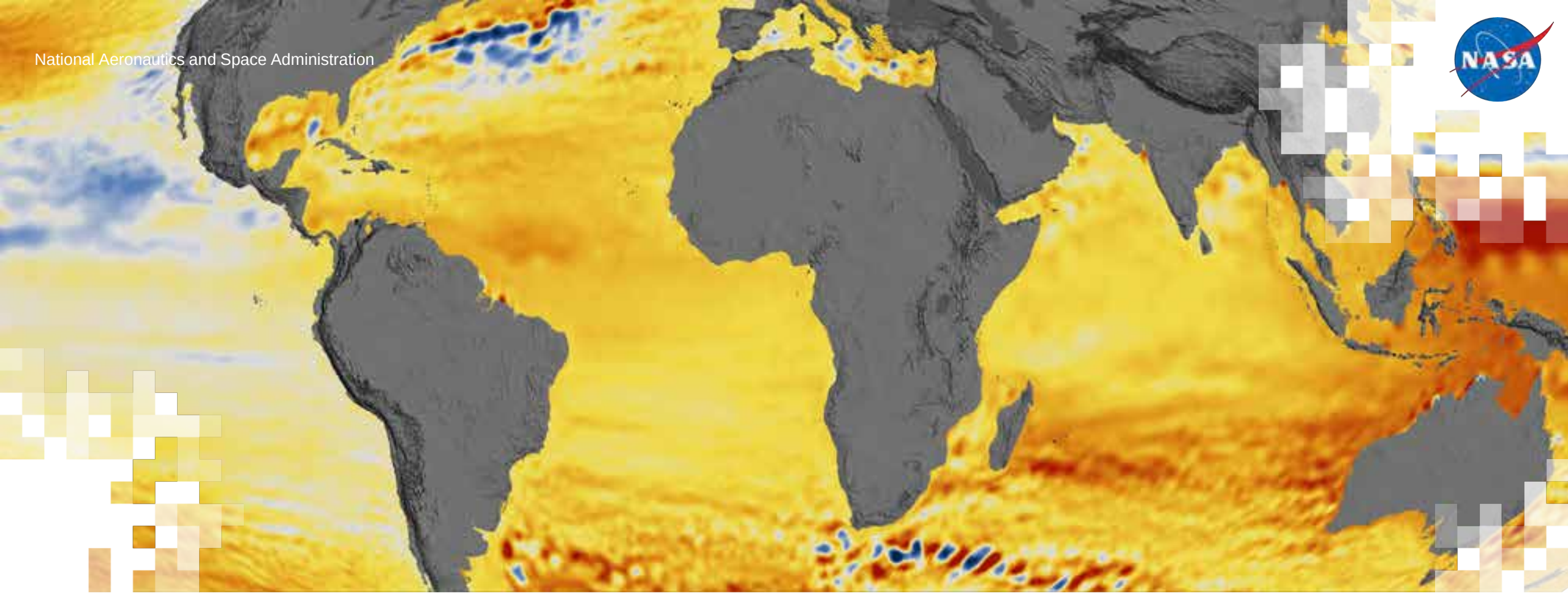
National Aeronautics and Space Administration

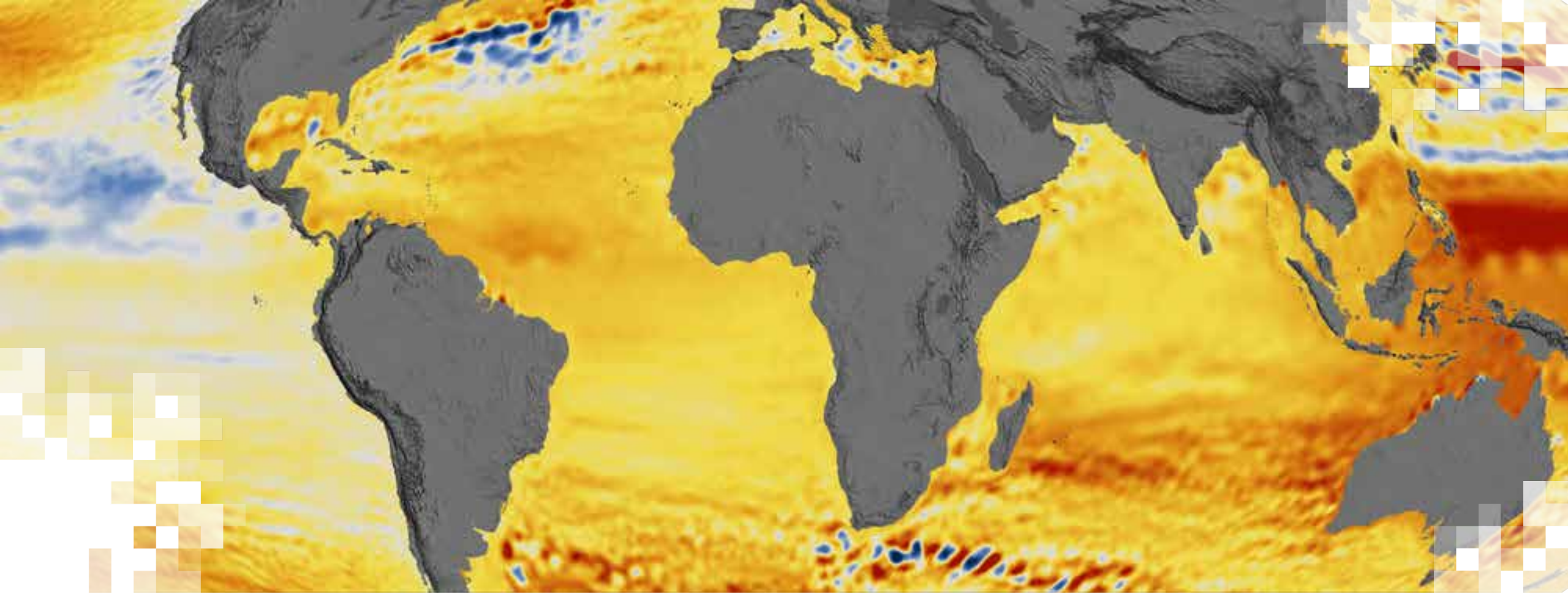


Sea-Level Change Tools for Planning and Decision Support

Part 1: Overview of Sea Level Change – Regional to Global

Angelica Rodriguez (NASA JPL/Caltech), Denis Felikson (NASA GSFC), & Sean McCartney (NASA GSFC/SSAI)

June 10, 2025



About ARSET

About ARSET

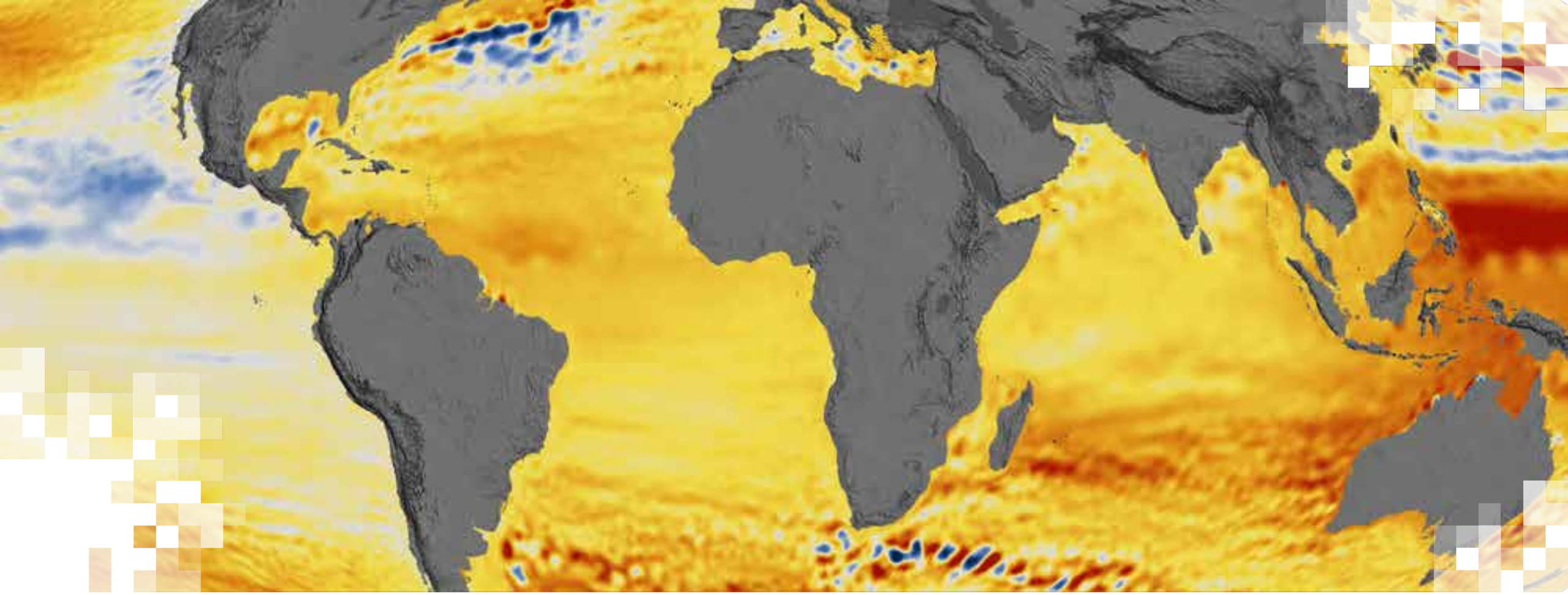
- **ARSET provides accessible, relevant, and cost-free training on remote sensing satellites, sensors, methods, and tools.**

- Trainings include a variety of applications of satellite data and are tailored to audiences with a variety of experience levels.

About ARSET Trainings

- Online or in-person
- Live and instructor-led or asynchronous and self-paced
- Cost-free
- Bilingual and multilingual options
- Only use open-source software and data
- Accommodate differing levels of expertise

- Visit the ARSET website to learn more.



Sea-Level Change Tools for Planning and Decision Support
Overview

Overview

- Earth's seas are rising because of a changing climate, and this rate is projected to increase over the next century.
- Due to the warming atmosphere and ocean, ice sheets and mountain glaciers are melting, resulting in the addition of fresh water into the ocean.
- Ocean water expands as it absorbs trapped heat, causing sea levels to rise.
- Data on this increase in the rate of global sea level rise is critical to planners understanding the trajectory of future sea level rise.

Credit: Chris Larsen, NASA's Operation IceBridge mission

Training Learning Objectives

By the end of this training, participants will be able to:

- Identify underlying Earth processes contributing to relative sea-level change at global and regional scales.
- Recognize remote sensing and modeled data used for assessing sea level change on a regional to global scale.
- Describe how coastal communities and infrastructure can be impacted by flooding caused by sea level change.
- Demonstrate how to assess the processes contributing to past and future sea-level change with the Sea Level Explorer tool–at global and regional scales.
- Demonstrate how to access future projections of relative sea-level change under different emissions scenarios with the IPCC AR6 Projection Tool.
- Visualize oceanic and groundwater flooding maps with the Pacific Islands Flooding Tool.

Training Outline

Part 1

Overview of Sea Level Change – Regional to Global

June 10, 2025

Part 2

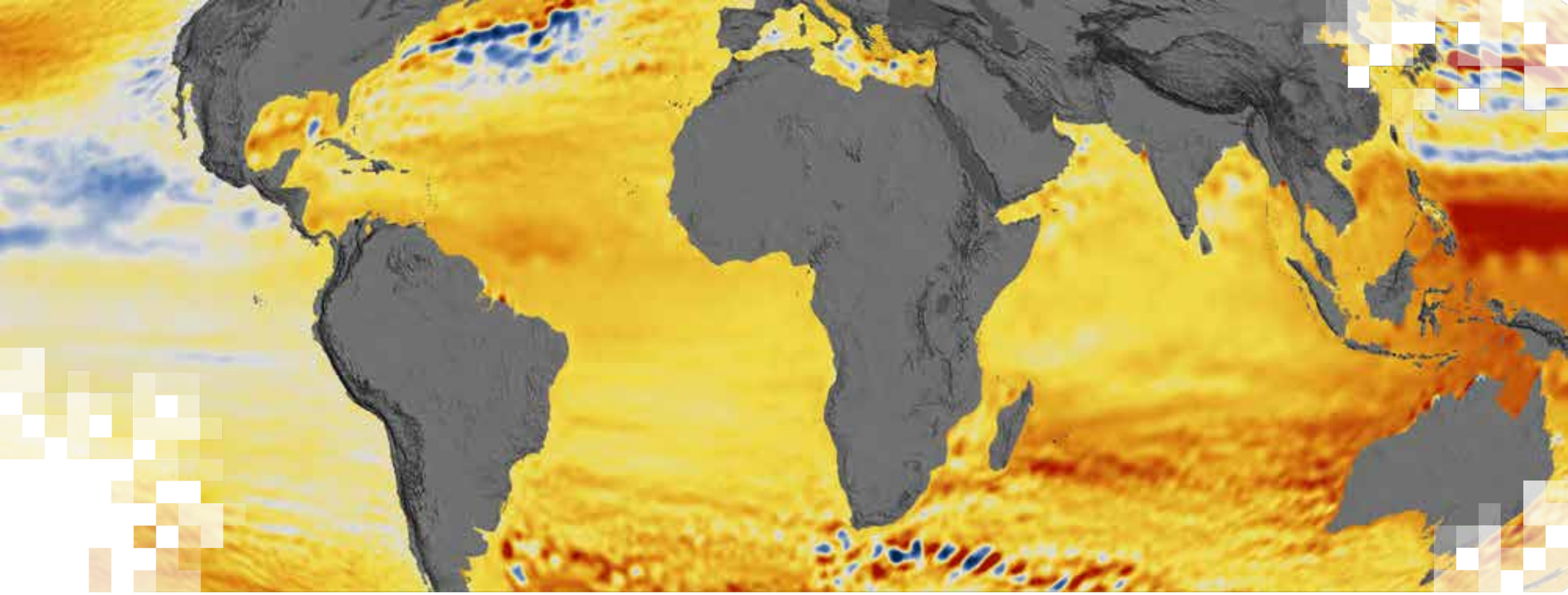
Assessment Tools for Sea Level Change

June 17, 2025

Homework

Opens June 17 – **Due July 1** – posted on training webpage

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



Sea-Level Change Tools for Planning and Decision Support

Part 1: Overview of Sea Level Change – Regional to Global

Part 1 Objectives

By the end of Part 1, participants will be able to:

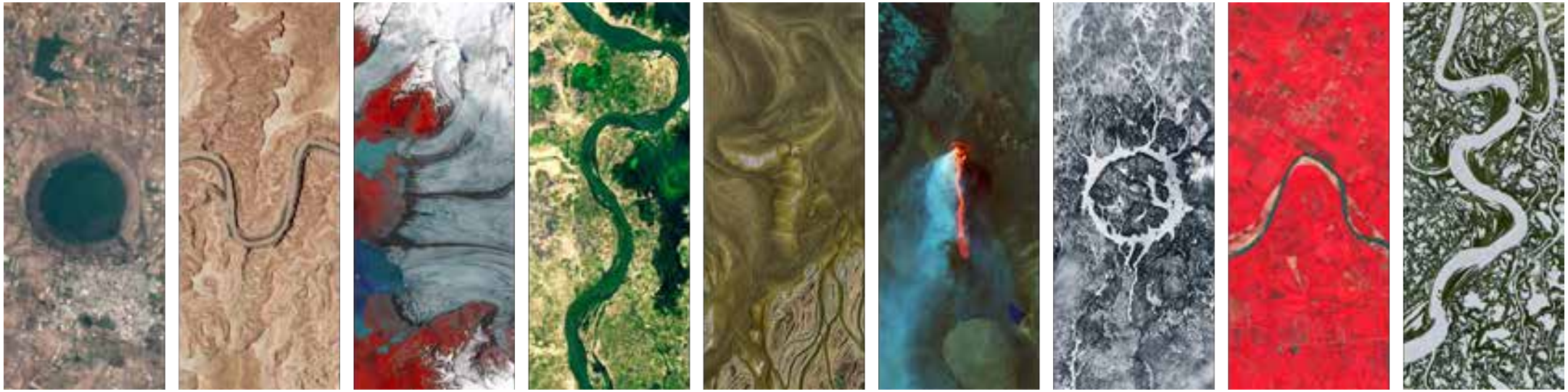
- Identify underlying Earth processes contributing to relative sea-level change at global and regional scales.
- Recognize remote sensing and modeled data used for assessing sea level change on a regional to global scale.
- Describe how coastal communities and infrastructure can be impacted by flooding caused by sea level change.
- Demonstrate how to assess the processes contributing to past and future sea-level change with the Sea Level Explorer tool–at global and regional scales.

Review of Prior Knowledge

- Satellite **radar altimetry** is a form of active remote sensing that measures the altitude of a surface from orbit by emitting **radar pulses** and measuring the time it takes for those pulses to return after reflecting off the surface.
- Satellite **laser altimetry** is a form of active remote sensing that measures the altitude of a surface from orbit by emitting **laser pulses** and measuring the time it takes for the reflected pulses to return.
- Subtle shifts in Earth's gravity occur, primarily dominated by water movements from one place to another on and under land, in the ocean, and in the atmosphere.
- Satellite **gravimetry** is a form of active remote sensing which uses a **microwave ranging system**, where satellites that follow each other closely in orbit send microwave signals to each other to measure the distance between them. From distance measurements between the two satellites, data can be used to estimate Earth's gravity field to monitor changes in underground and surface water storage, soil moisture, **ice sheets and glaciers**, and **sea level** caused by the addition of water to the ocean.

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 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.

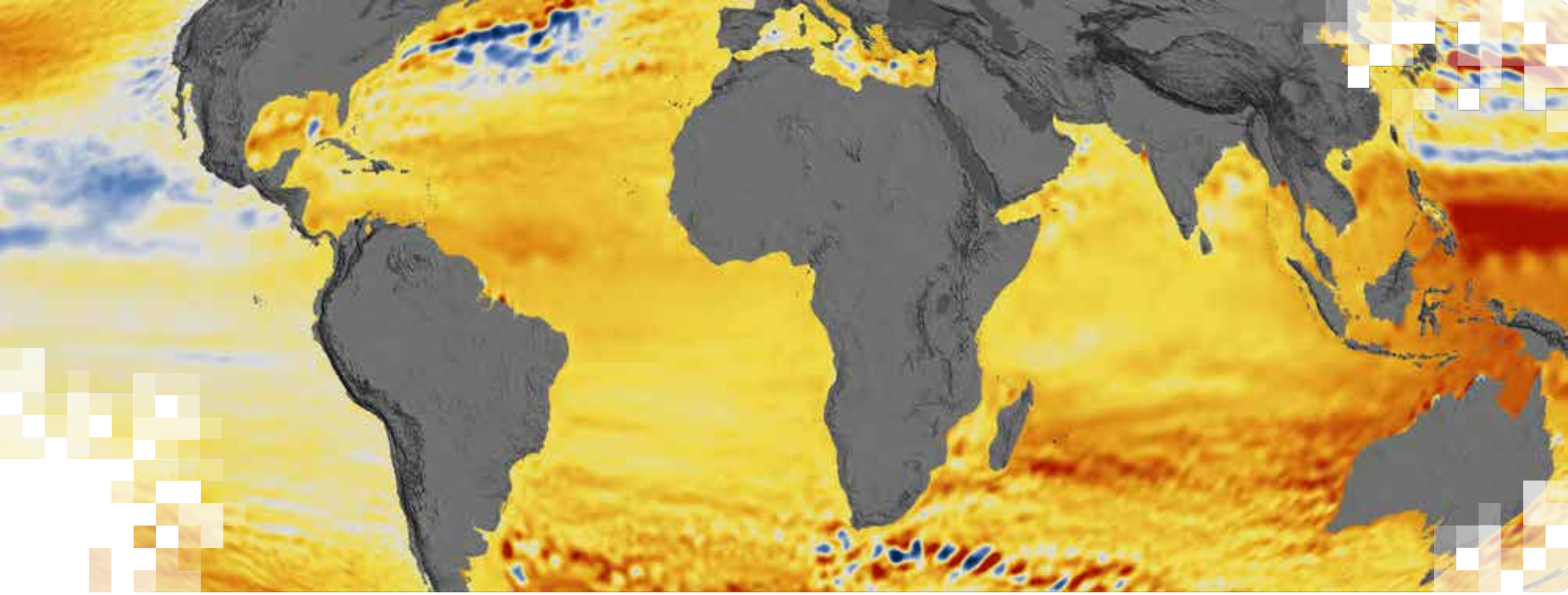


Credit: Your Name In Landsat

Part 1 – Trainers

Dr. Angelica Rodriguez
Research Scientist
NASA JPL/Caltech

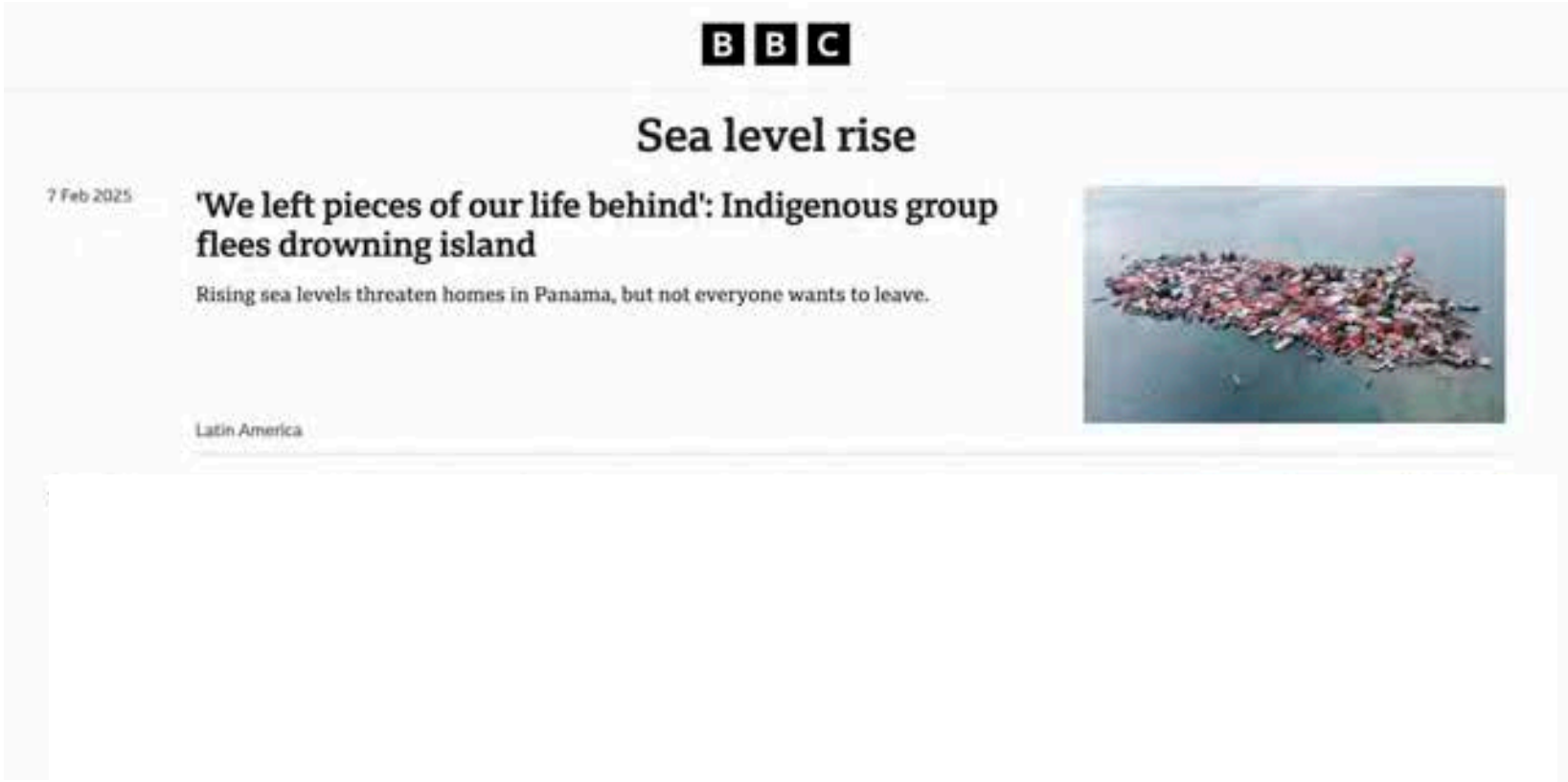
Dr. Denis Felikson
Research Scientist
NASA GSFC



Sea-Level Change Overview

Angelica Rodriguez, PhD
NASA Jet Propulsion Laboratory

Sea Level Change – A Global Phenomenon



BBC

Sea level rise

7 Feb 2025

'We left pieces of our life behind': Indigenous group flees drowning island

Rising sea levels threaten homes in Panama, but not everyone wants to leave.

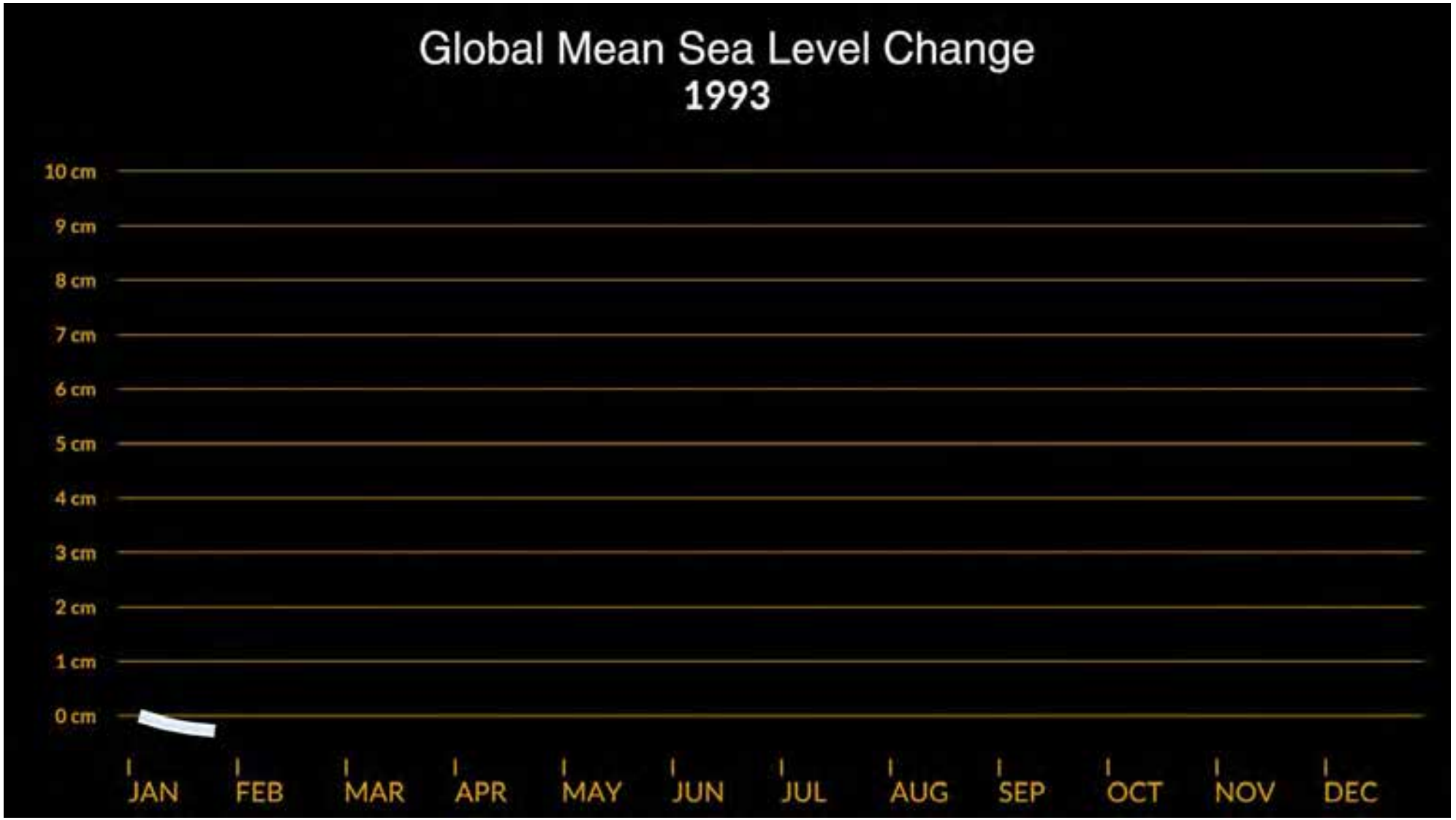
Latin America

- Coastal communities world-wide are grappling with changes occurring along the interface between the ocean and society.
- Media coverage on the topic is vast, as leaders from smallest of seaside towns to the global stage are faced with decisions on how best to respond.

BBC News – Sea Level

What exactly is happening?

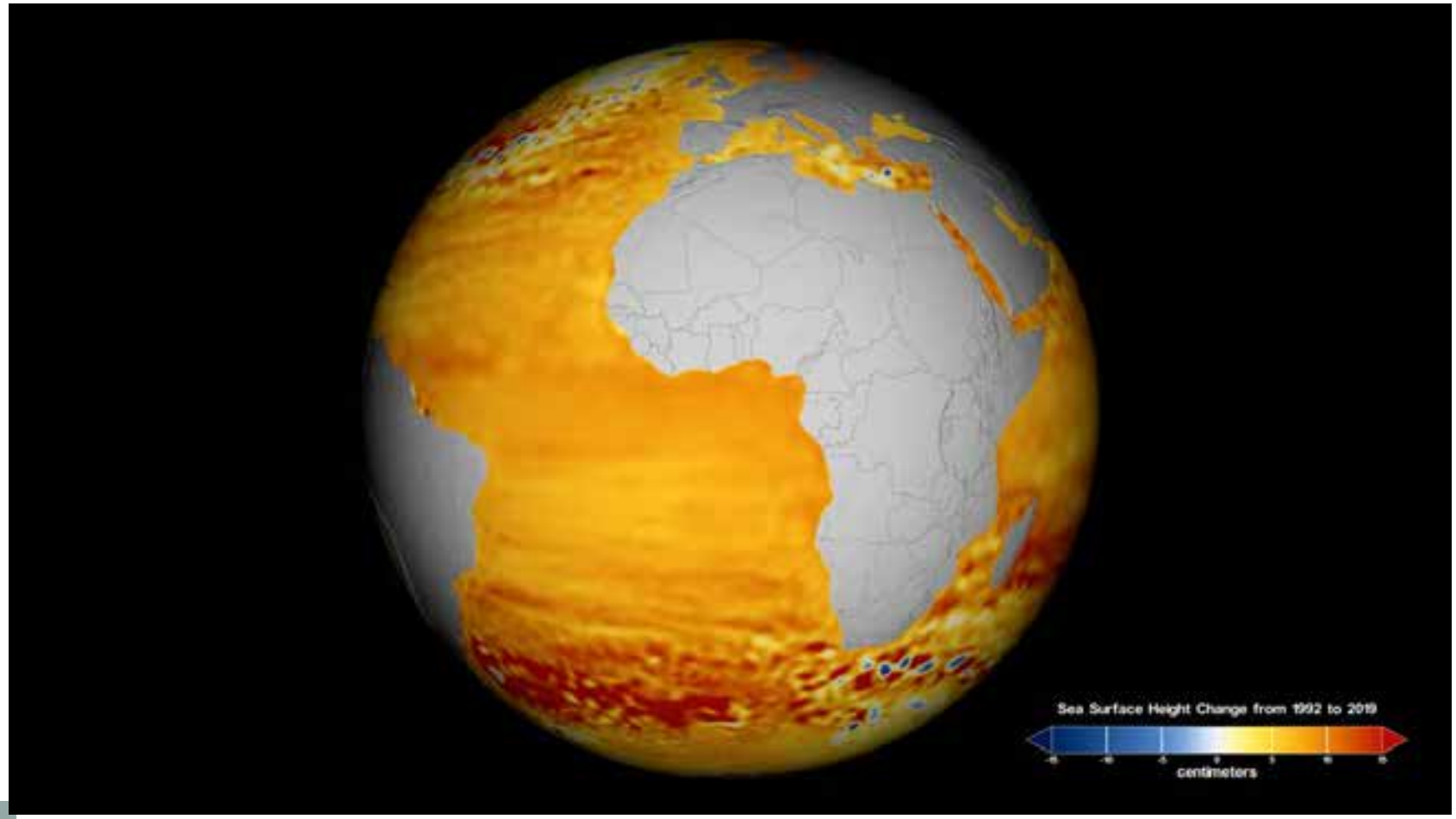
The Average Height of Global Ocean is Increasing Year Over Year



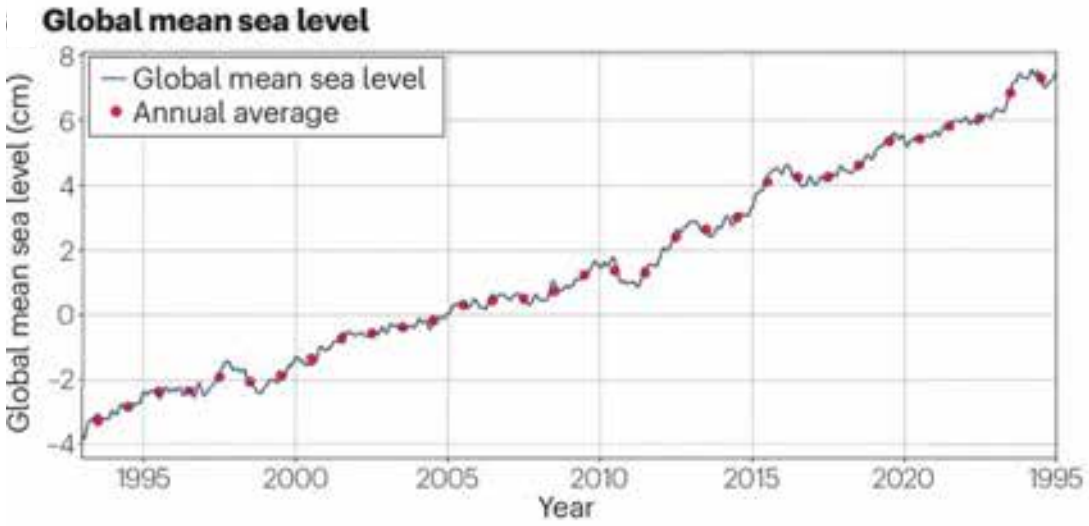
NASA Satellites Observe the Ocean's Surface Topography, or Sea Level

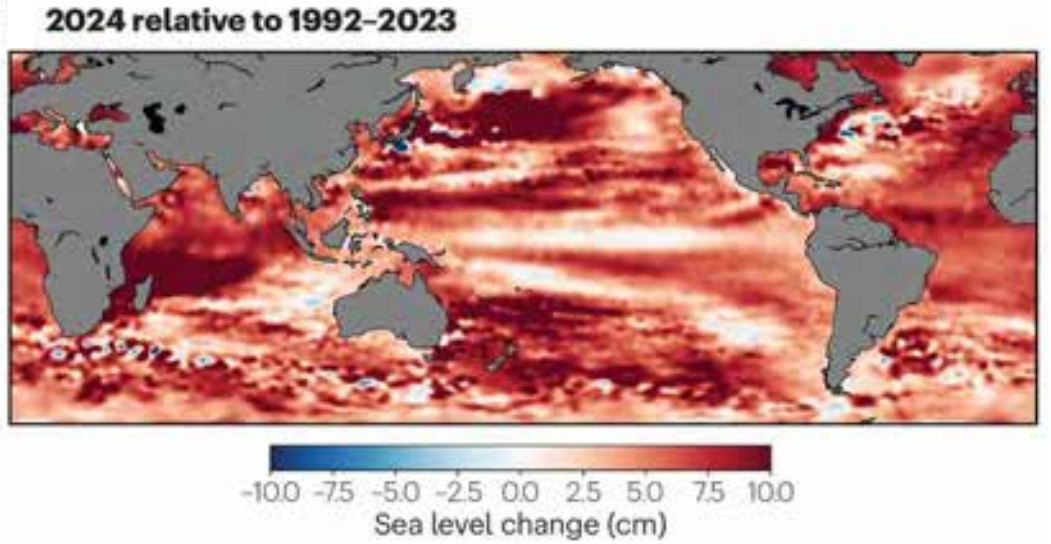
- Ocean topography satellites transmit radar pulses directly downwards (at nadir) and measures the time it takes for the pulse to reflect off the surface and return to the satellite, essentially measuring the range to the closest point on the surface within a relatively large footprint.
- Data is collected along a narrow strip directly beneath the satellite.
- Radar altimetry provides a measurement of absolute, or geocentric, sea level.

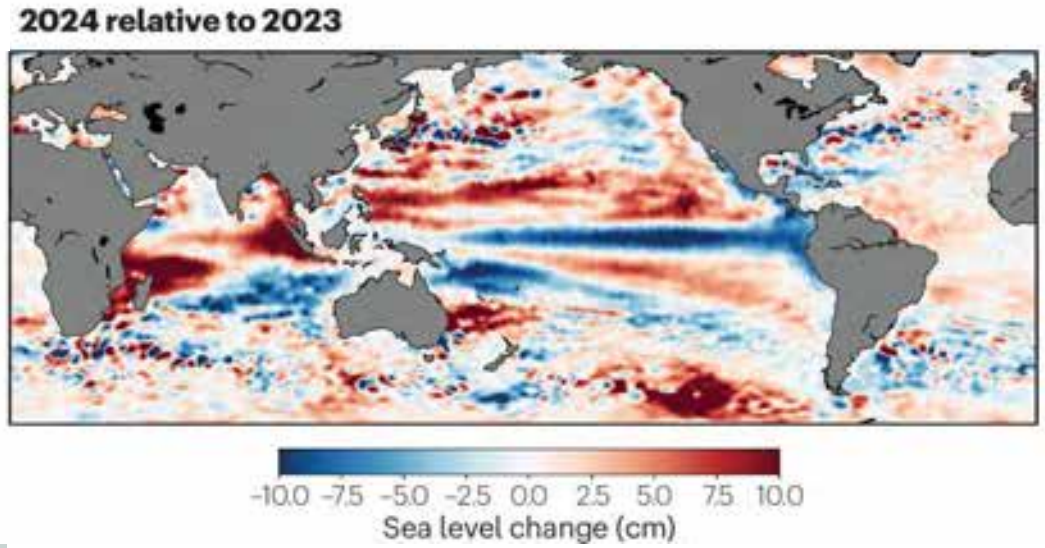
Sea Level is Increasing Globally and Regionally

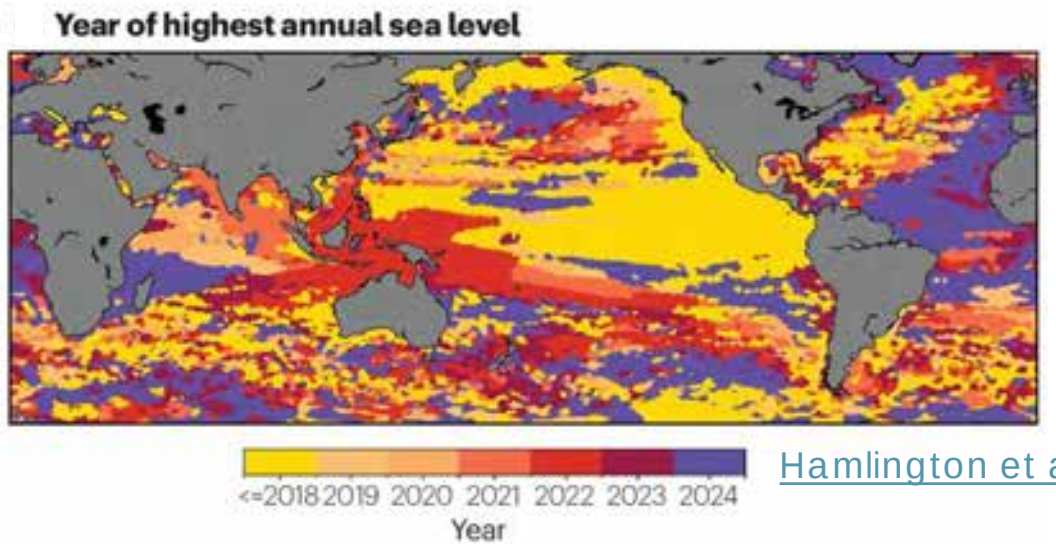


Global Sea Level Rose 0.59cm in 2024 Relative to 2023, Reaching a Total Increase of 10.5 cm Over the 31-Year Satellite Record





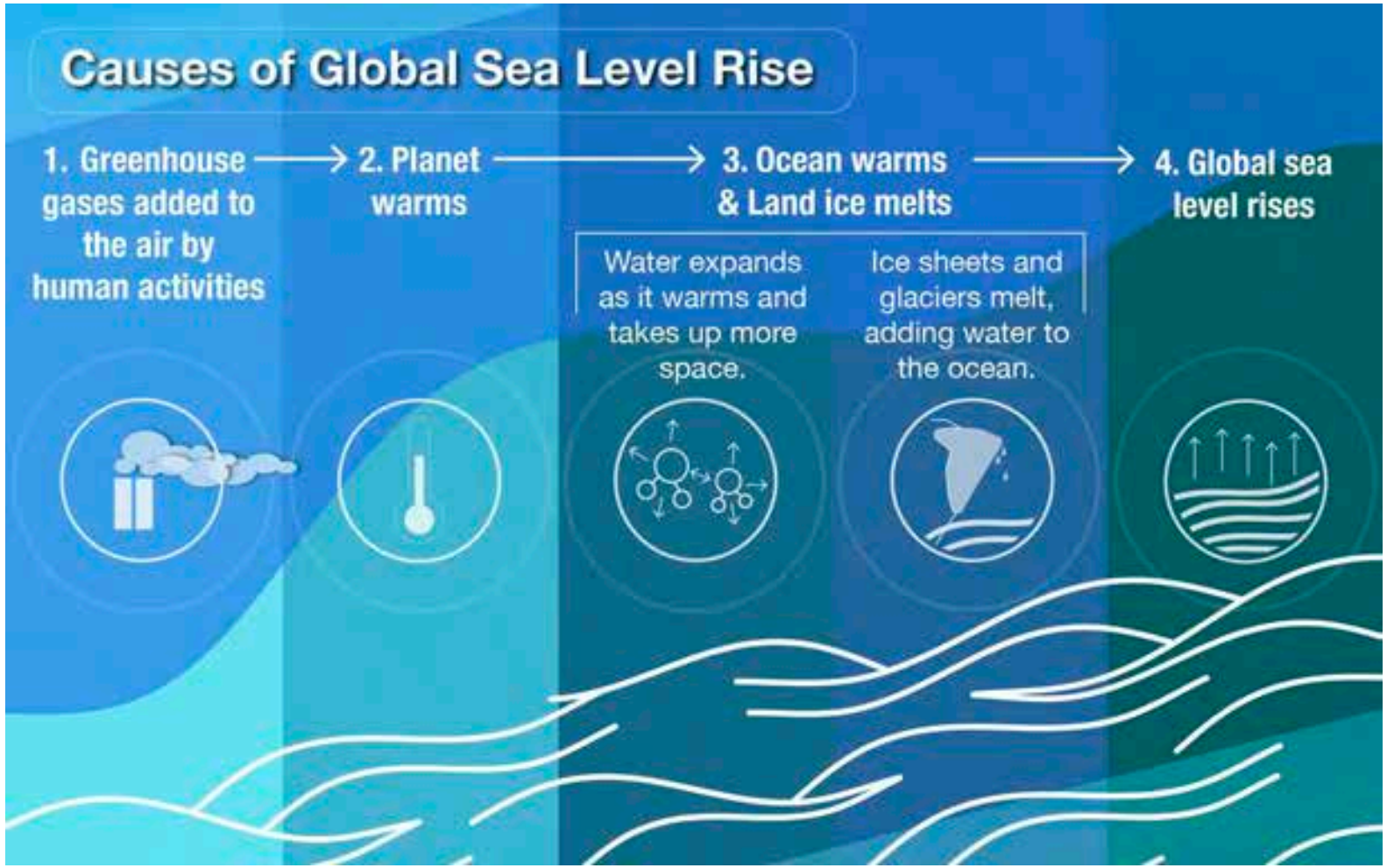




Hamlington et al. (2025)

Will this continue? To answer that, we need to know what is causing the observed acceleration in sea level rise.

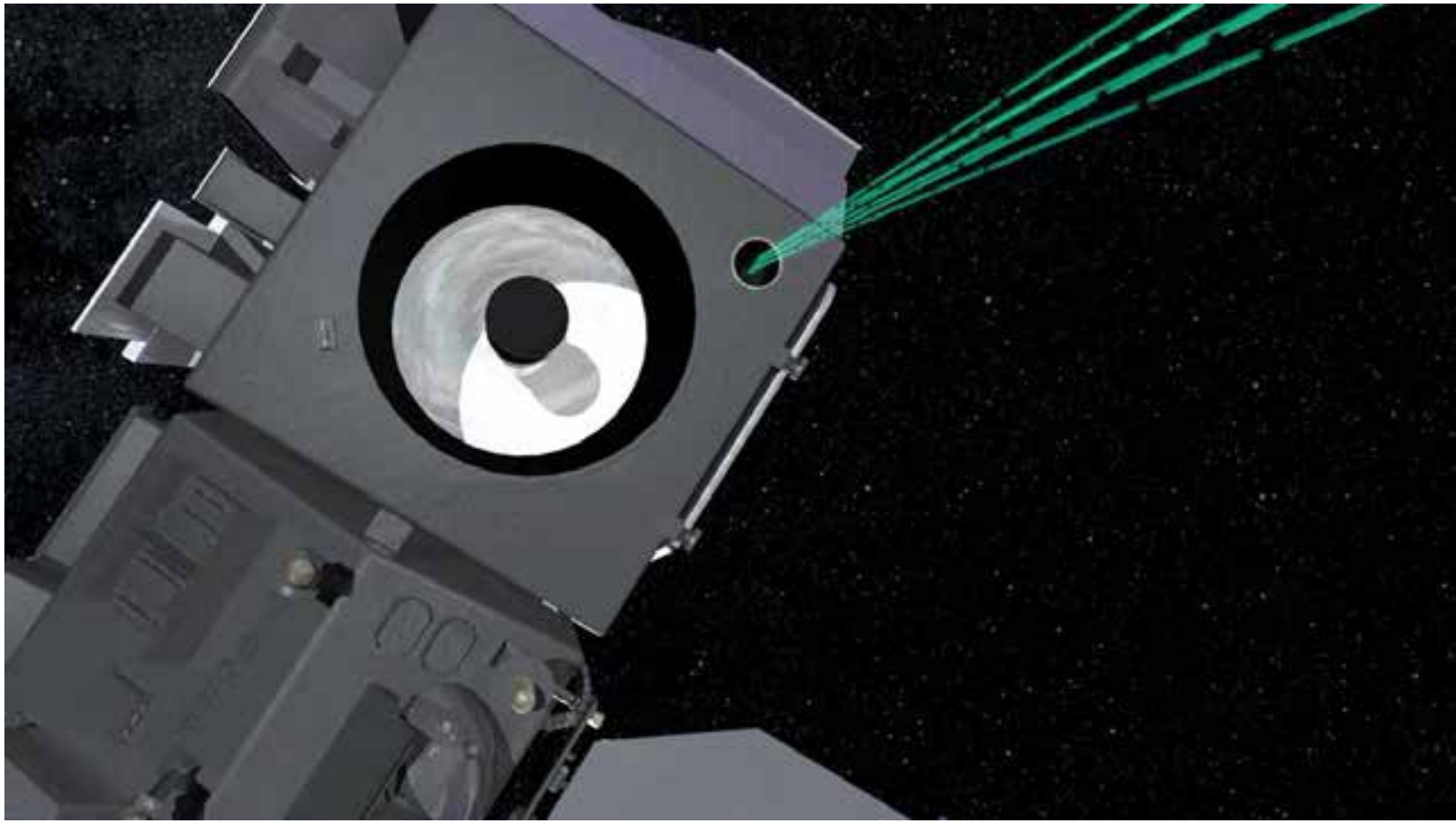
In the Global Average, there are Two Main Processes that are Causing Sea Level to Rise



Changes in terrestrial water storage, or how much freshwater is transferred from land to the ocean, also influence global sea level change but in a smaller percentage.

NASA Measures Ice Sheet Change Using Satellite Laser Altimetry

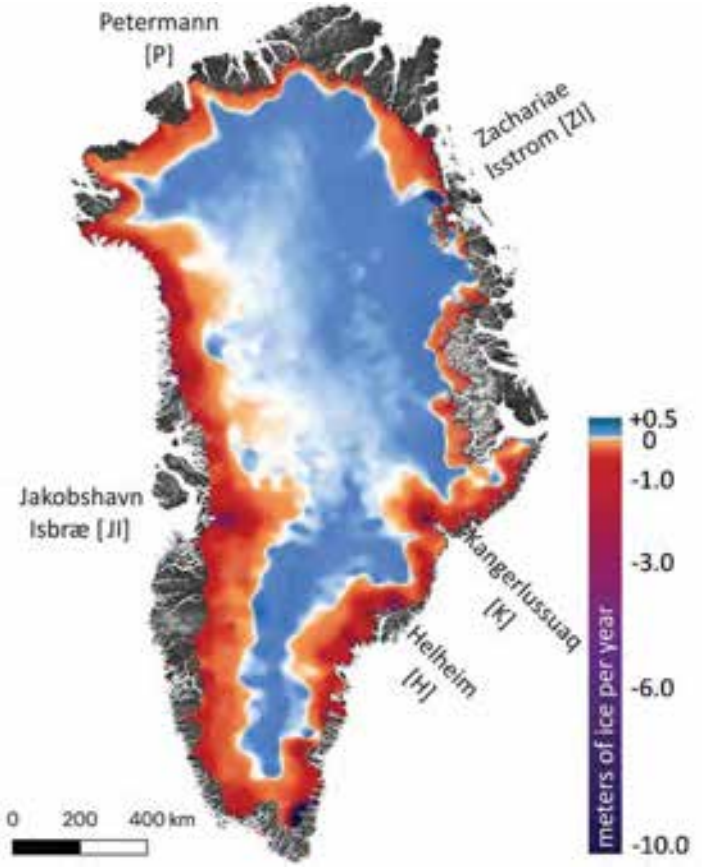
- NASA's ICESat-2 mission continues key elevation observations begun by the original ICESat satellite (2003 to 2009) and Operation IceBridge (2009 through present).
- A multiple-beam laser sends 10,000 pulses of light to the ground each second. A small fraction of the light photons bounce off Earth's surface and return to the instrument, where a photon-counting detector times their flight.

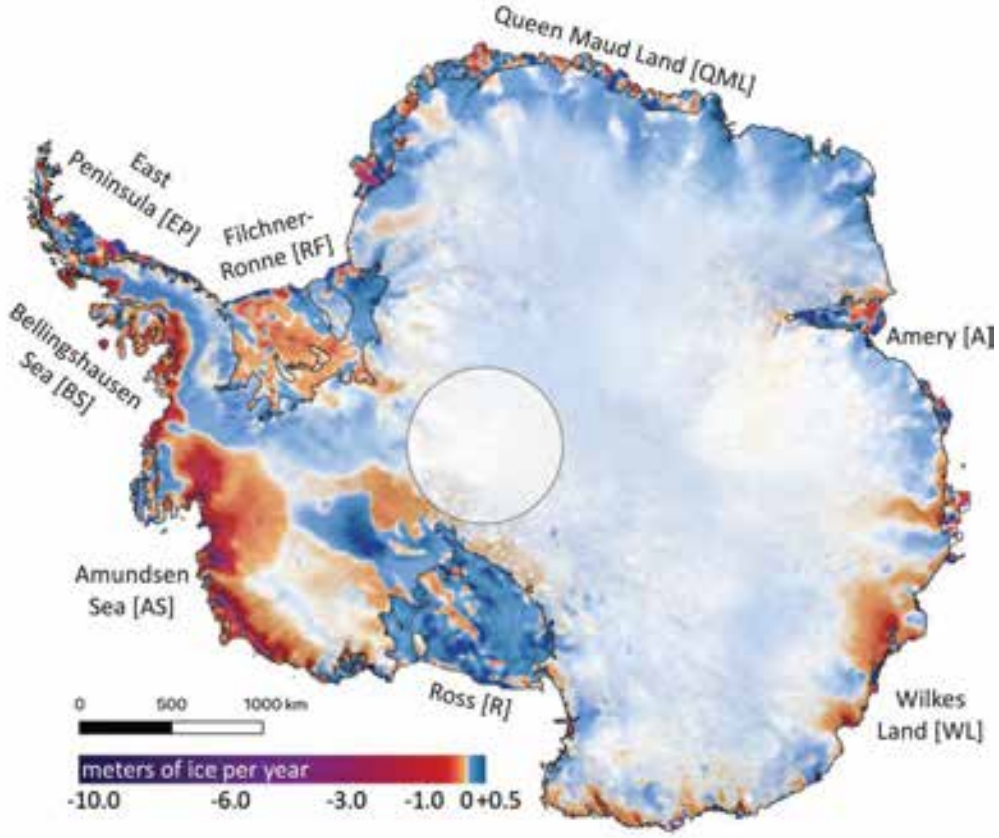


- Similar to radar altimetry, ICESat-2 provides a measurement of the Earth surface elevation below.

NASA Scientific Visualization Studio

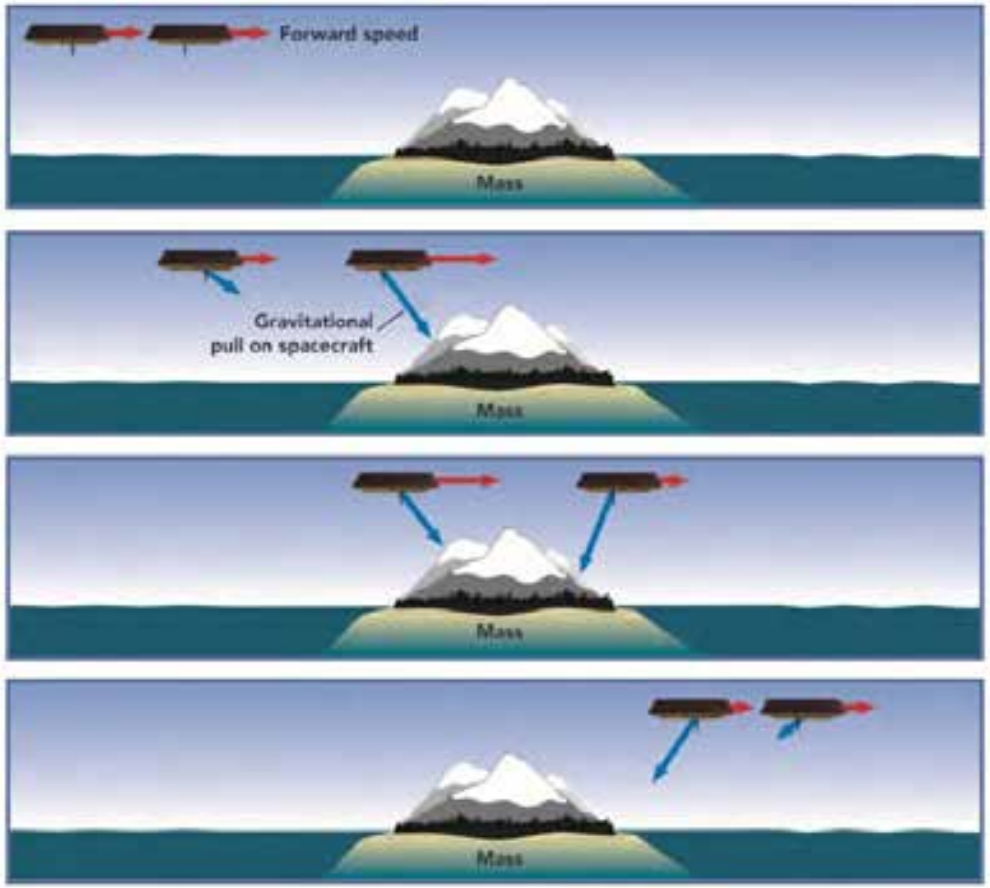
NASA Measures Ice Sheet Change Using Satellite Laser Altimetry

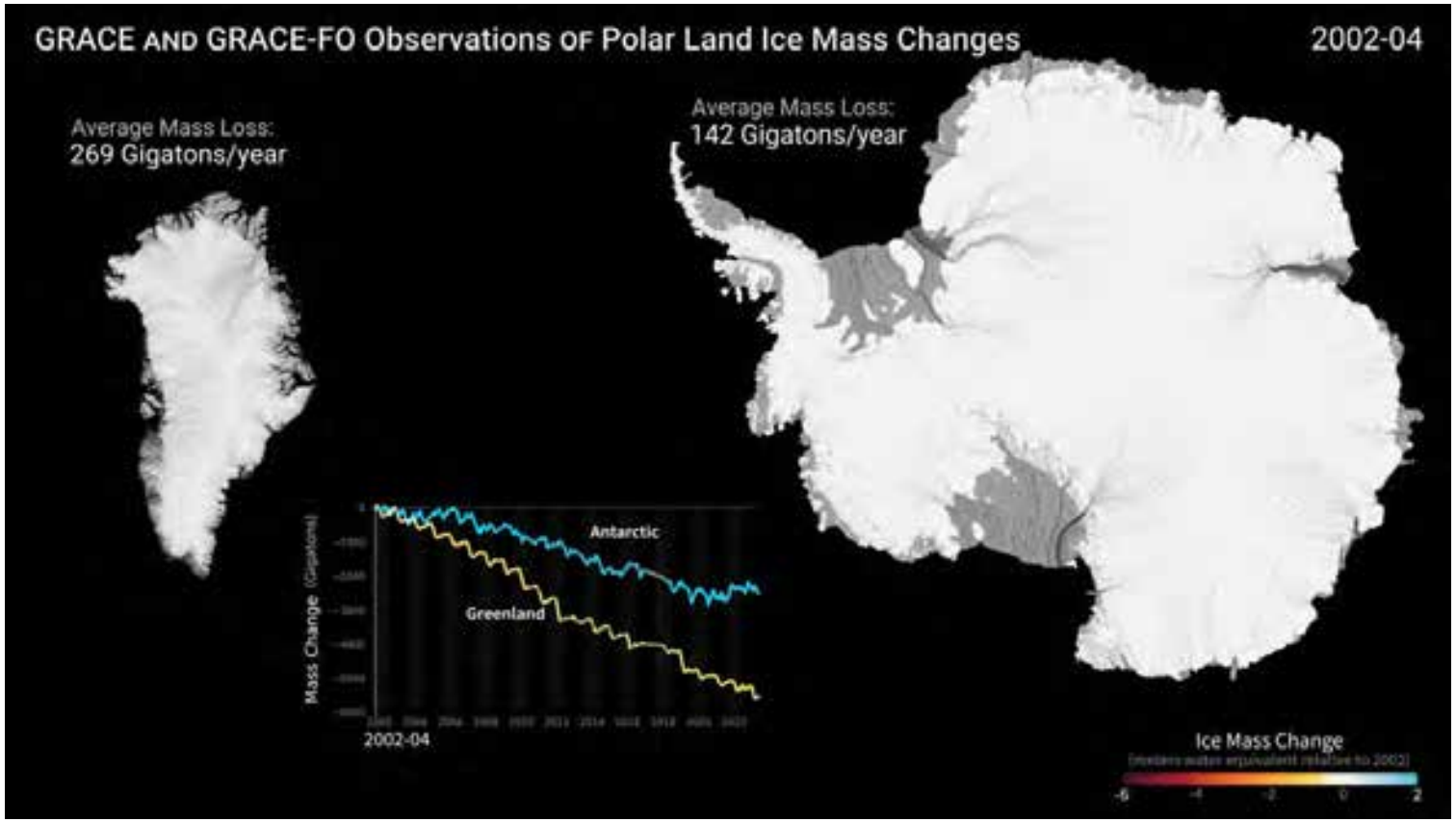




Smith et al. (2020)

NASA Measures Ice Mass Loss Using Satellite Observations of Earth's Gravity

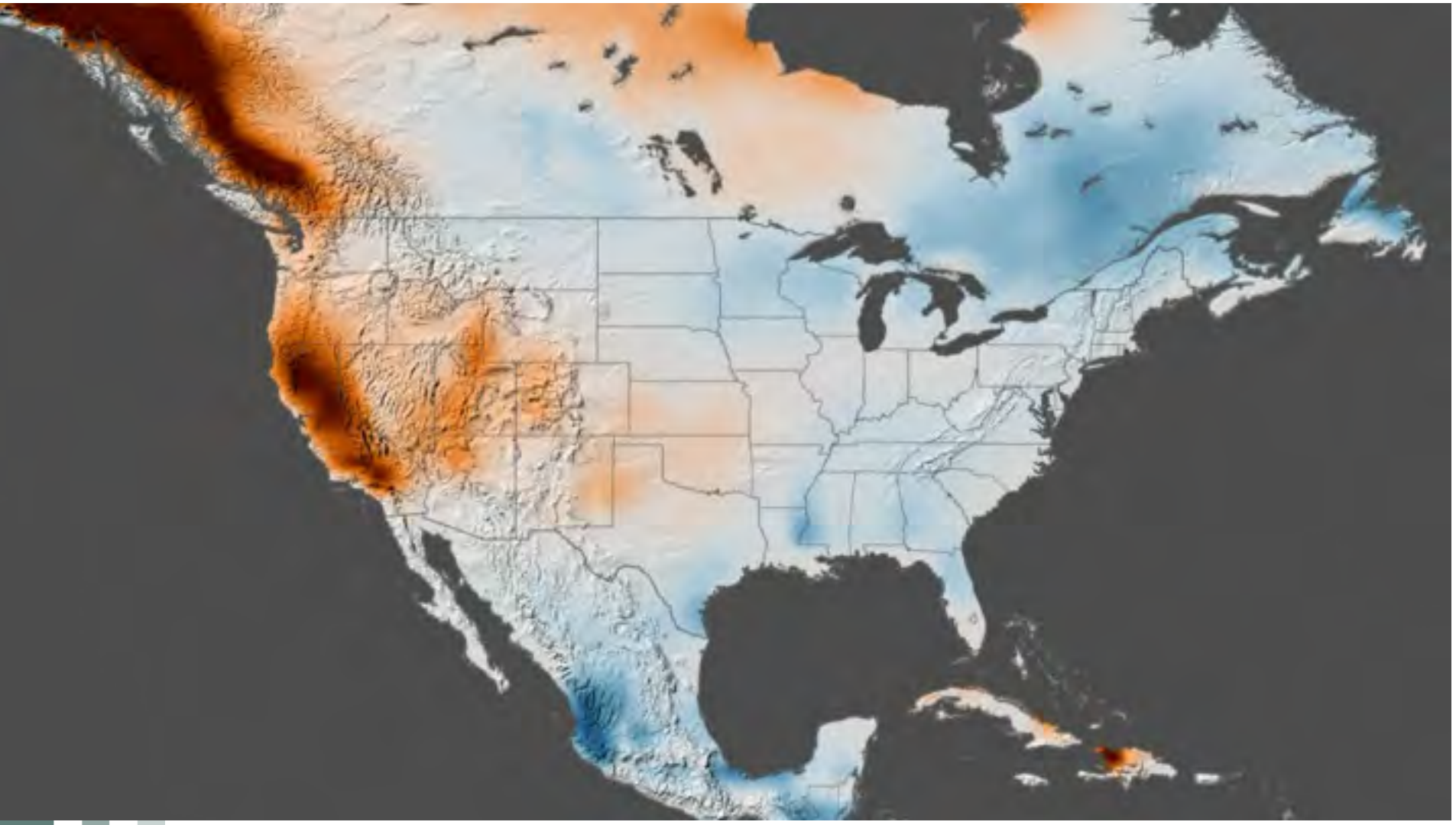




The GRACE-FO mission is a successor to the original GRACE mission (2002–2017). A microwave ranging system detects minuscule changes in the distance between the satellites, which responds to spatial changes in Earth's gravity field. Mapping the gravity field over time provides details on the redistribution of mass across the globe.

NASA Scientific Visualization Studio

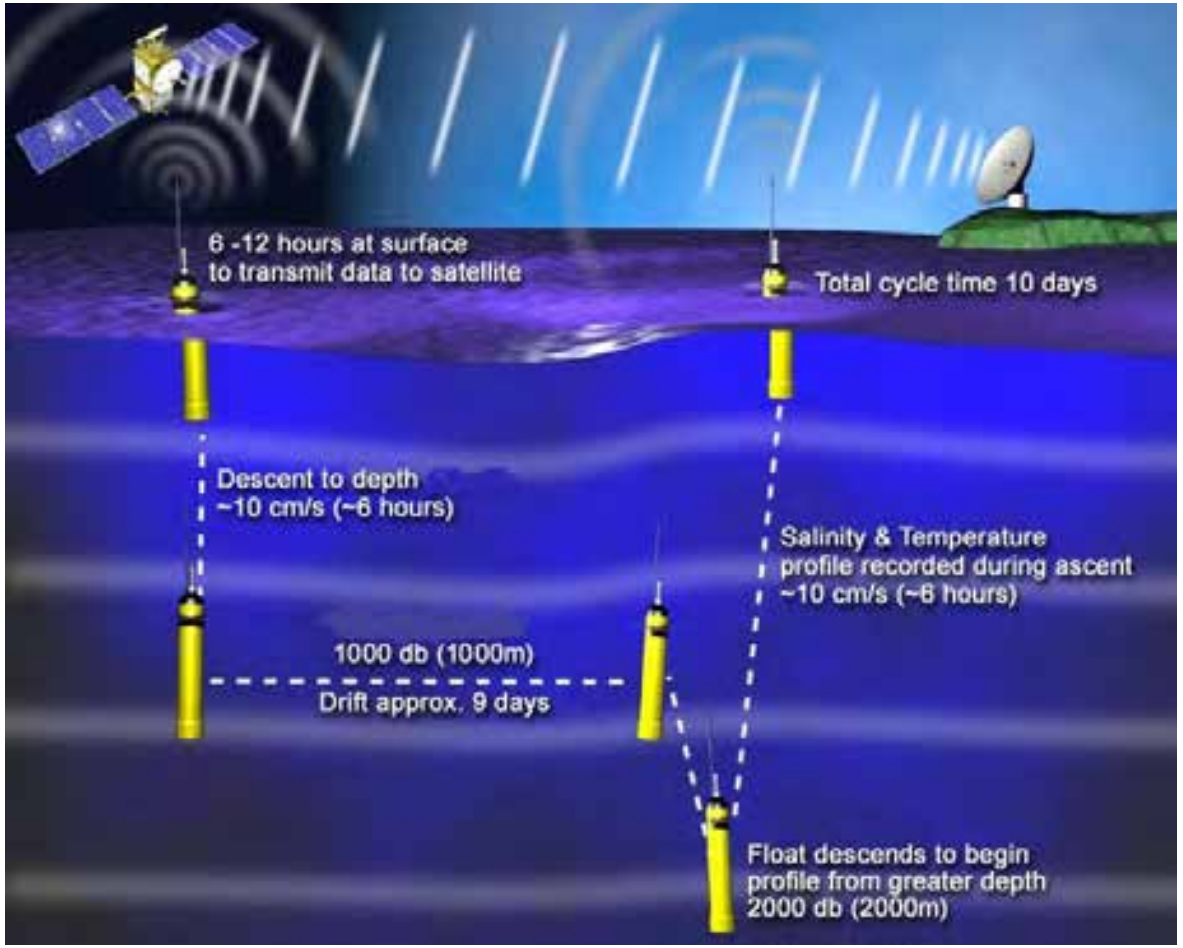
GRACE-FO also Provides Estimates of Land Water Storage

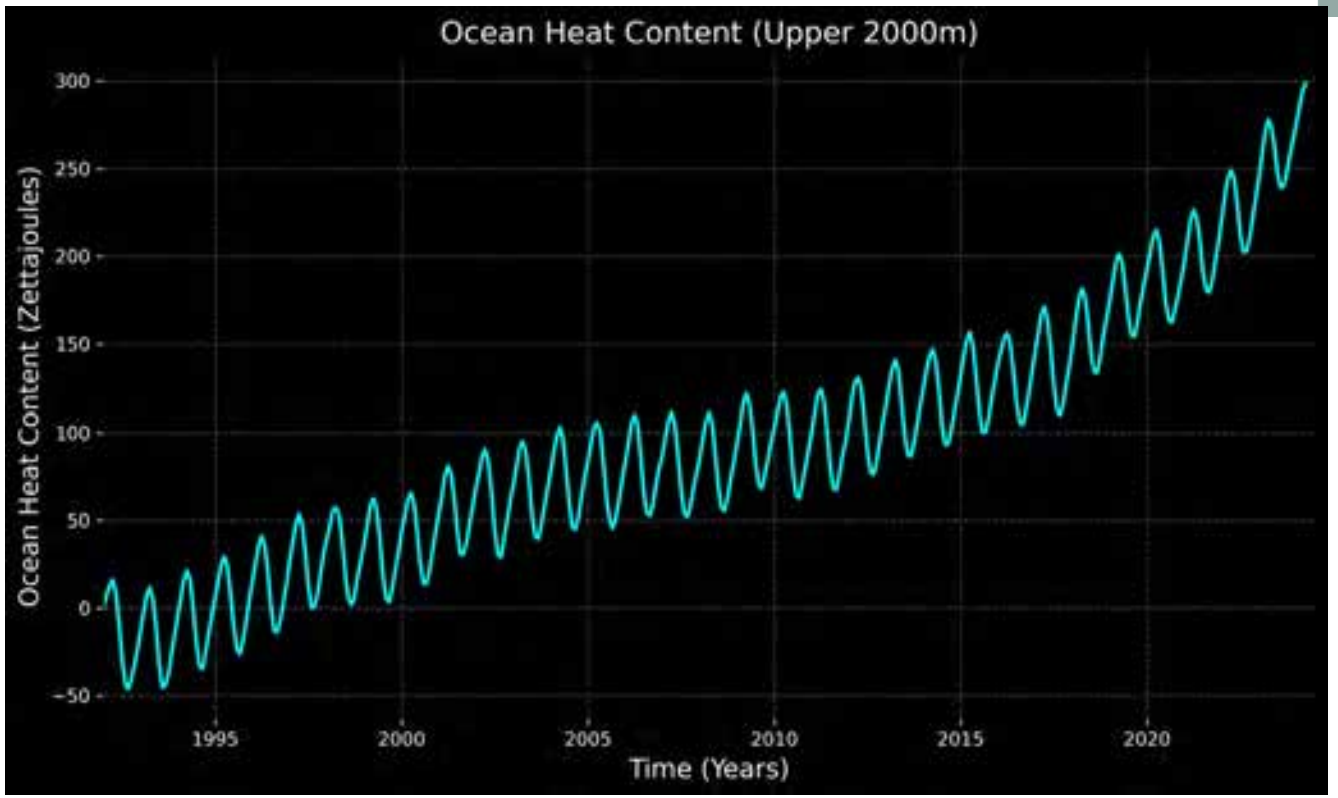


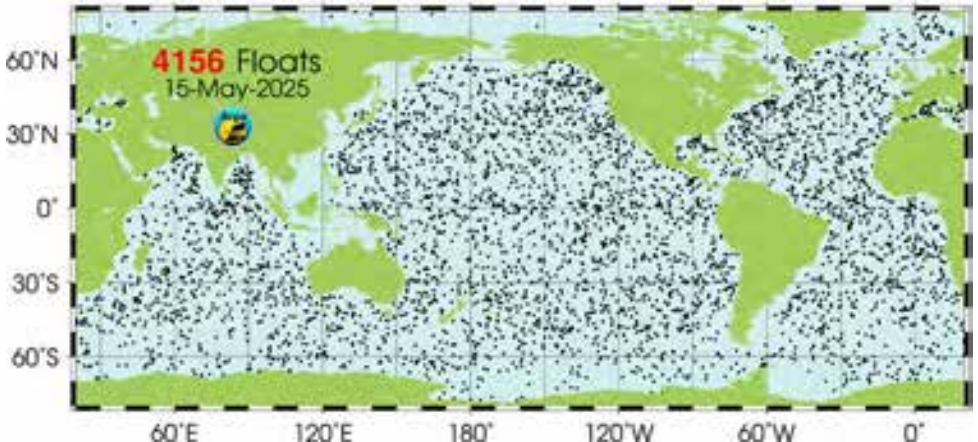
- While terrestrial land water storage changes are generally a secondary contributor, in terms of magnitude, to the long-term sea level trend budget, the proper accounting of both human activity and water cycle variability is necessary for accurate sea-level budget closer on various time and space scales.

NASA Scientific Visualization Studio

Ocean Heat Content between the Surface and 2000m Depth is Observed by a Global Network of Profiling Floats

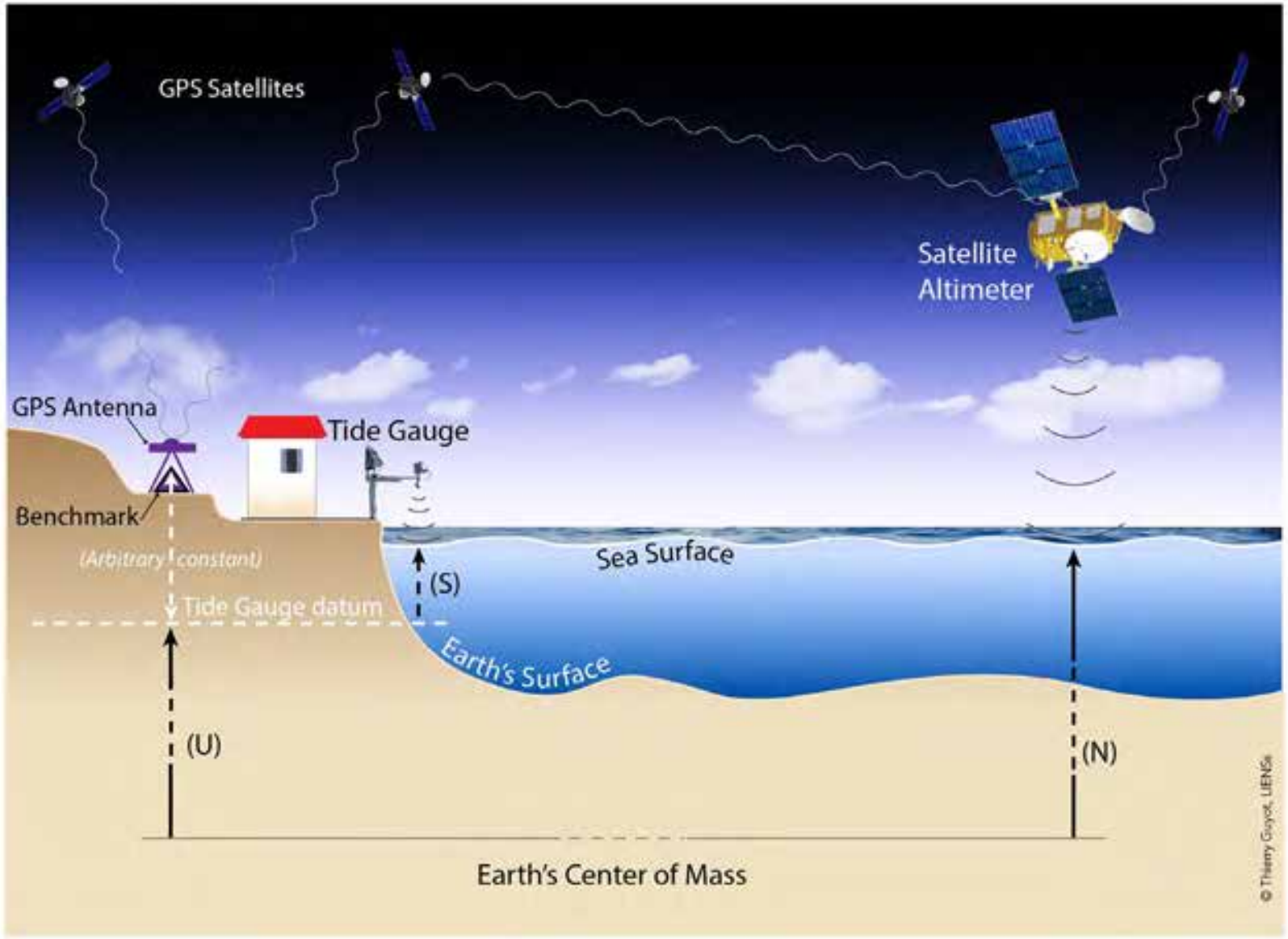




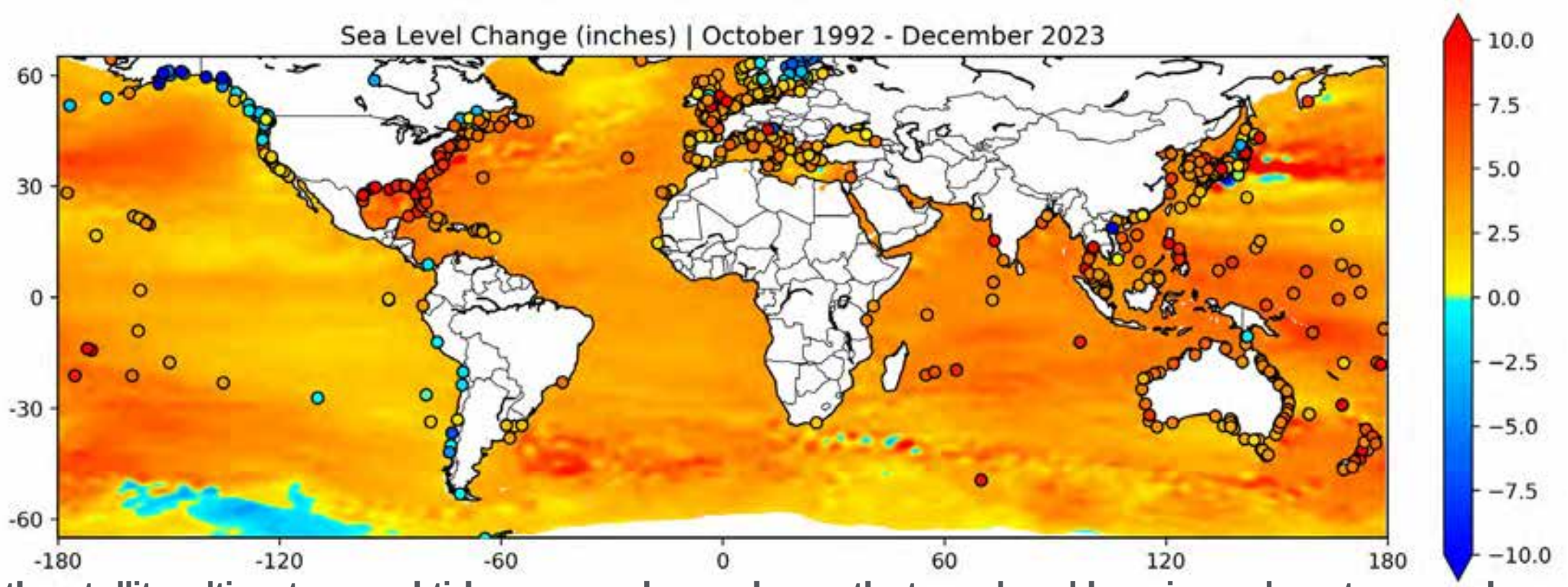


[Argo Program]

Tide Gauges also Measure Relative Sea Level



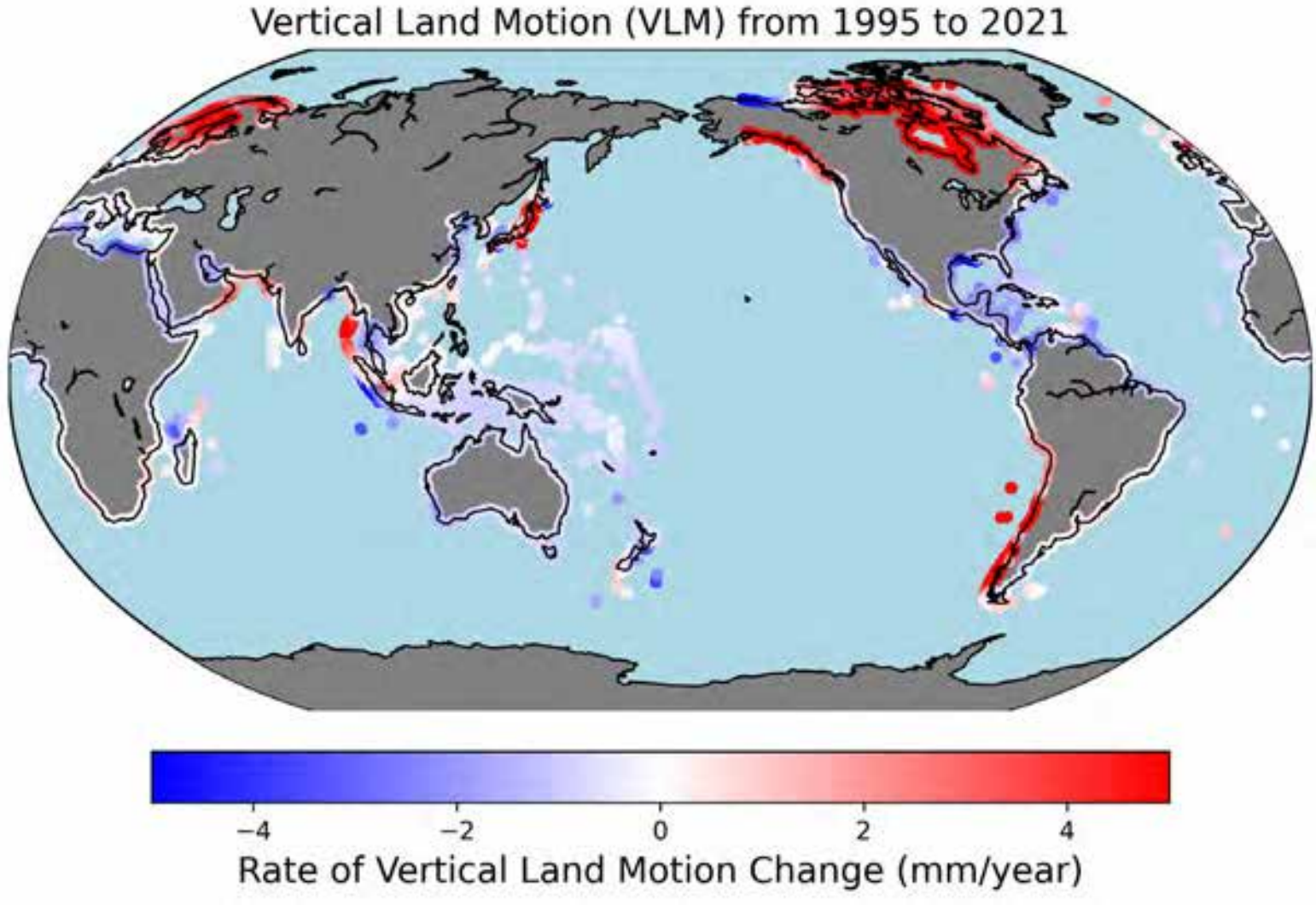
Different Measurement Systems, Same Conclusion (Mostly)



- **Both satellite altimeters and tide gauges have shown that sea level has risen almost everywhere over the last 30 years.**
- Satellite altimeters measure only the height of the ocean, while tide gauges measure the sea surface height relative to land. Where the land is moving, we can see big differences in the measurements from satellite altimeters and tide gauges.

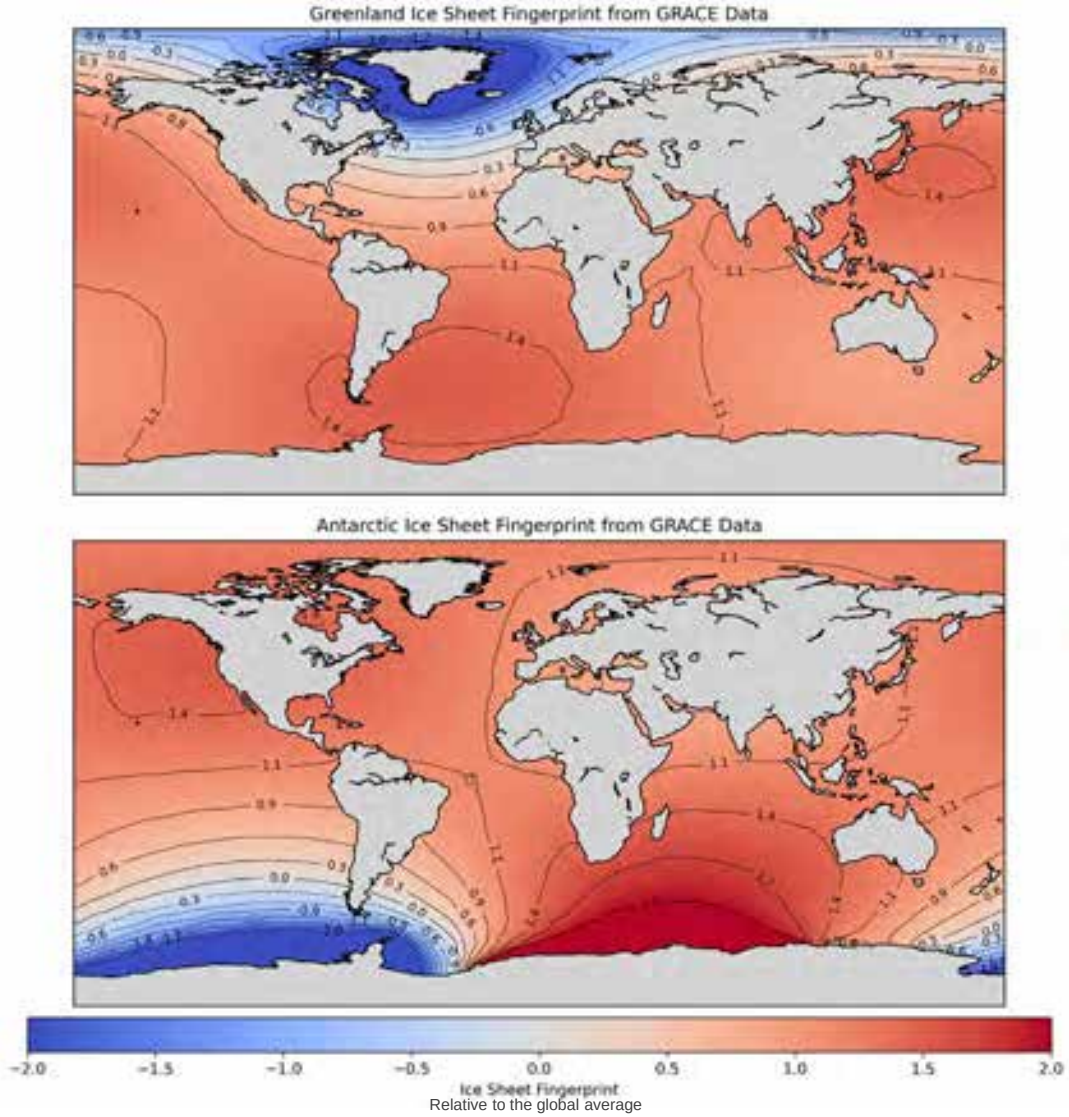
Vertical Land Motion (VLM)

- **VLM** is caused by a combination of several things:
  - Glacial isostatic adjustment (GIA)
  - Tectonic activity
  - Surface mass loading changes
  - Other localized effects on the compaction or uplift of the land surface (natural or anthropogenic)



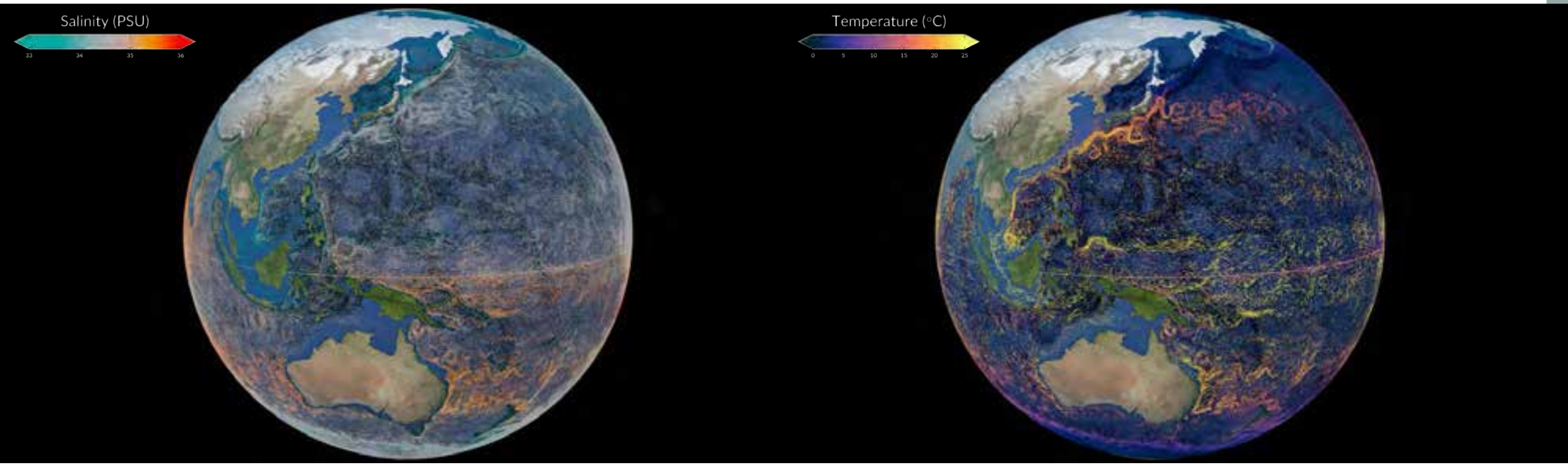
Oelsmann et al. (2024)

Other Factors Affect Local Sea Level As Well – Ice Sheet Fingerprints



- When ice sheets melt, the redistribution of melted water induces changes to the gravity, rotation, and shape of the Earth.
- These patterns are known as **ice sheet fingerprints.**
- The further away from where ice is melting, the more sea level rise that location will get. Areas that are far away from the Greenland and Antarctic Ice Sheets are most impacted by sea level rise from ice melting.
- The net effect is the combination of the individual ice sheet fingerprints superimposed on the effects of other melting sources.

Other Factors Affect Local Sea Level As Well – Sterodynamics

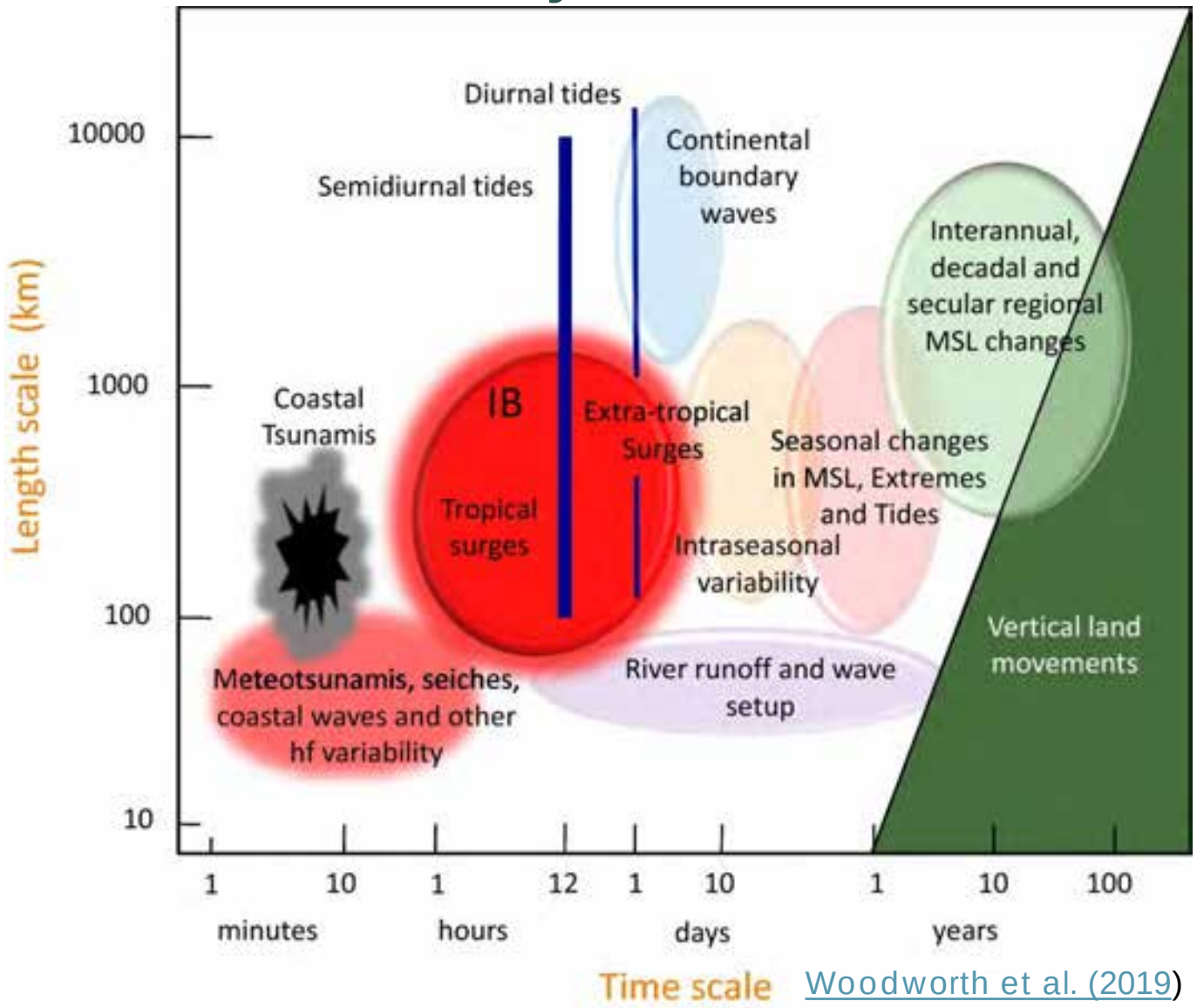


- **Steric changes** refer to variations in sea level due to changes in the density of seawater, which can be affected by temperature and salinity. These steric changes can lead to regional variations in sea level, as different parts of the ocean experience varying rates of warming and changes in salinity.
- **Ocean currents** play a crucial role in transporting heat and distributing seawater across the globe.

NASA Scientific Visualization Studio

Other Factors Affect Local Sea Level As Well – Sterodynamics

- **Dynamic changes** involve the redistribution of water masses due to ocean currents, wind patterns, and atmospheric pressure systems.

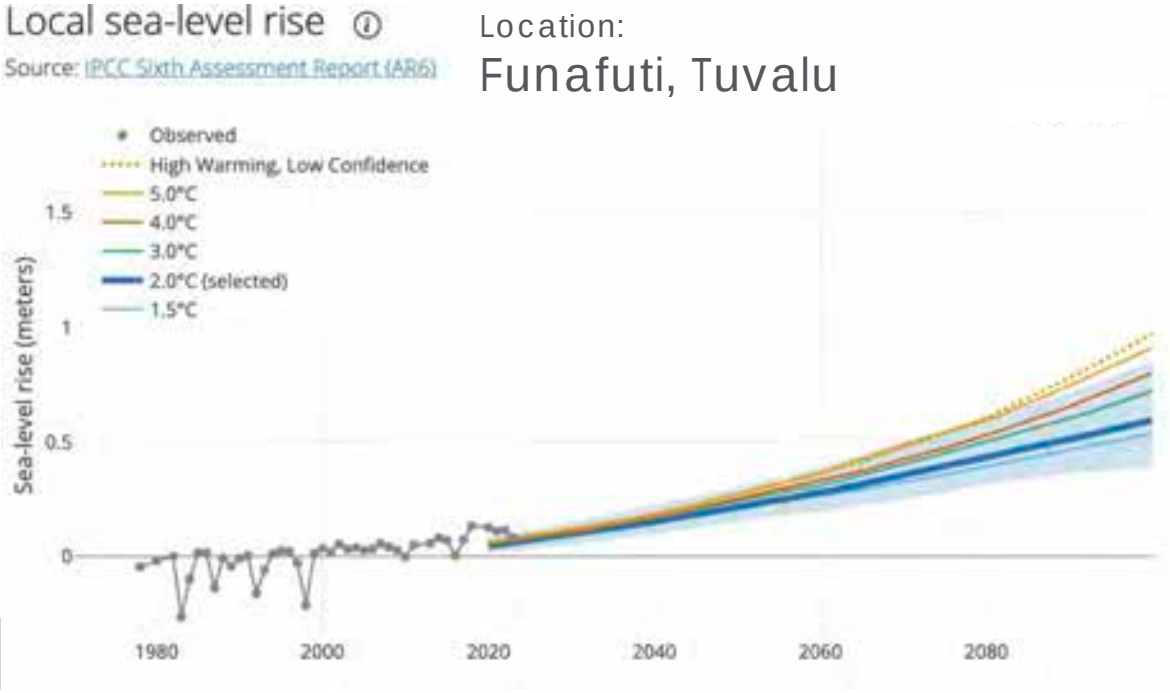


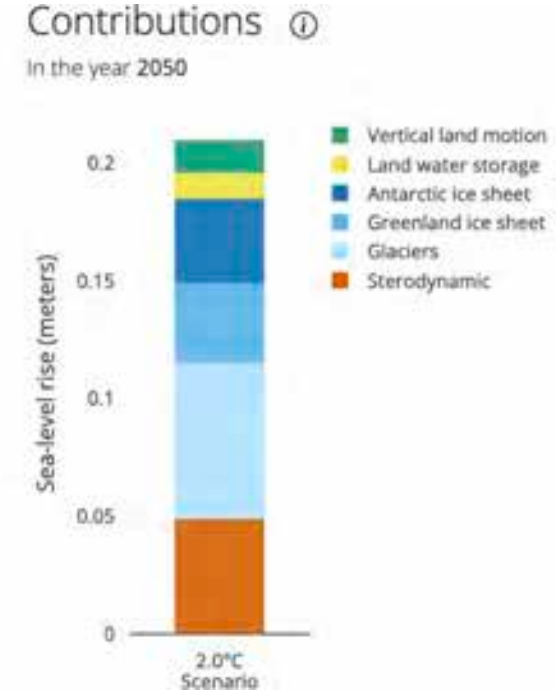
Woodworth et al. (2019)

So how will the average (mean) sea level change in the future?

Using Consensus Knowledge of Modeled Physical Processes and Statistics Informed by Data Records, Future Sea Level can be Projected

- The Intergovernmental Panel on Climate Change Sixth Assessment Report (AR6) sea level projections are built using comprehensive assessments of a wide range of physical processes contributing to future sea level changes. The report integrates results from global climate models and specialized research on individual components affecting sea level, such as ice sheet dynamics, ocean thermal expansion, glacier melt, and land water storage changes**.**
- **AR6 provides a probabilistic framework that accounts for both well-understood mechanisms and more uncertain aspects of future sea level rise.**

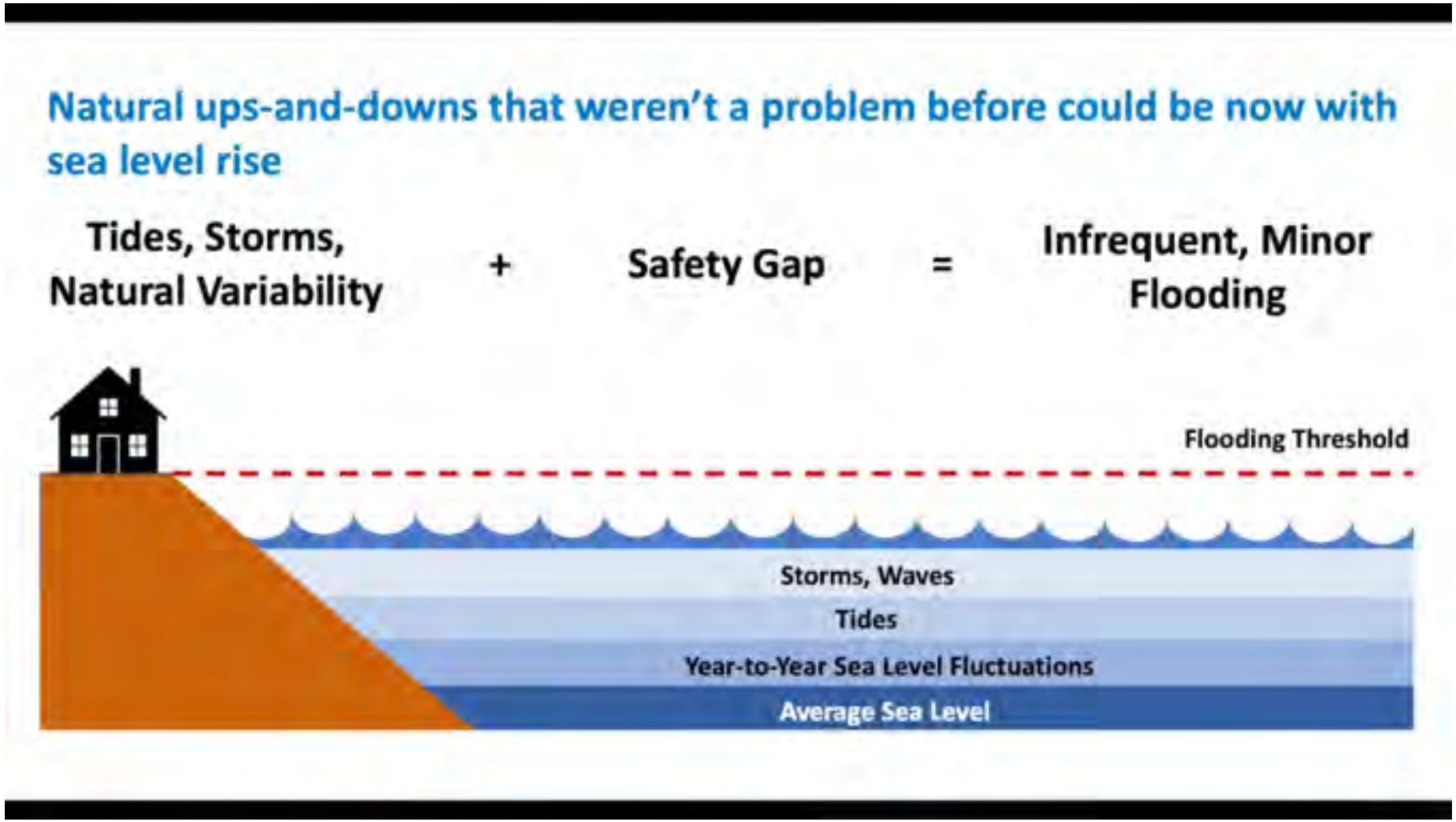




Warming levels indicate changes in 2080–2100 global mean surface temperatures relative to 1850–1900.
More on this in part 2!

How will this affect our coasts in the future?

Dynamic Variations in the Local Sea Level Combine, Resulting in Fluctuations of the Waterline Along a Stretch of Coast



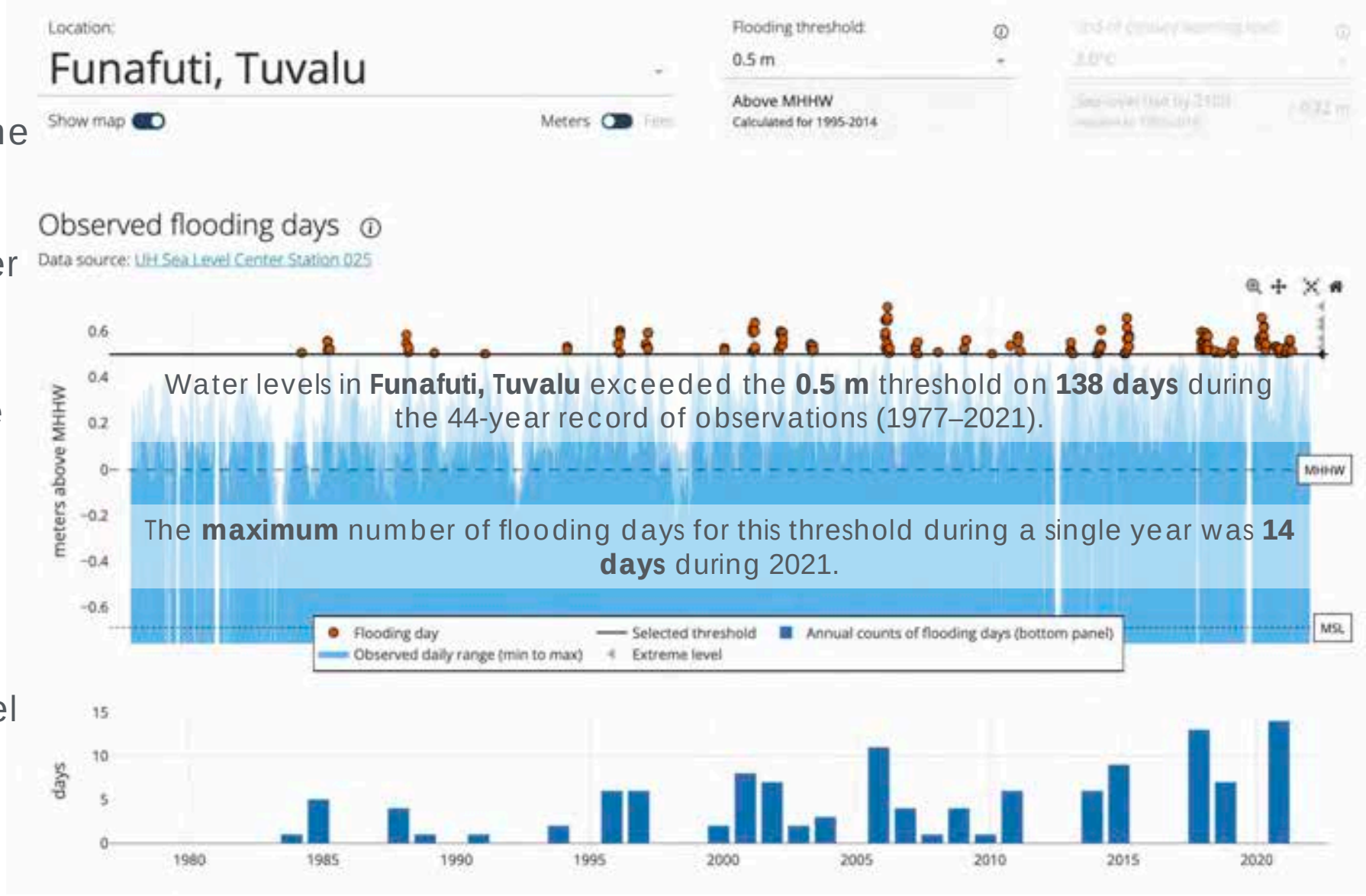
High-Tide Flooding

- **High tide flooding**, sometimes referred to as nuisance flooding, sunny-day flooding, or king tide flooding, refers to inundation occurring at water elevations above the normal high tide level.
- This can be caused by both overflow of oceanic water, as well as upward percolation of the subsurface water table.

George McLeod for the NASA Sea Level Portal News

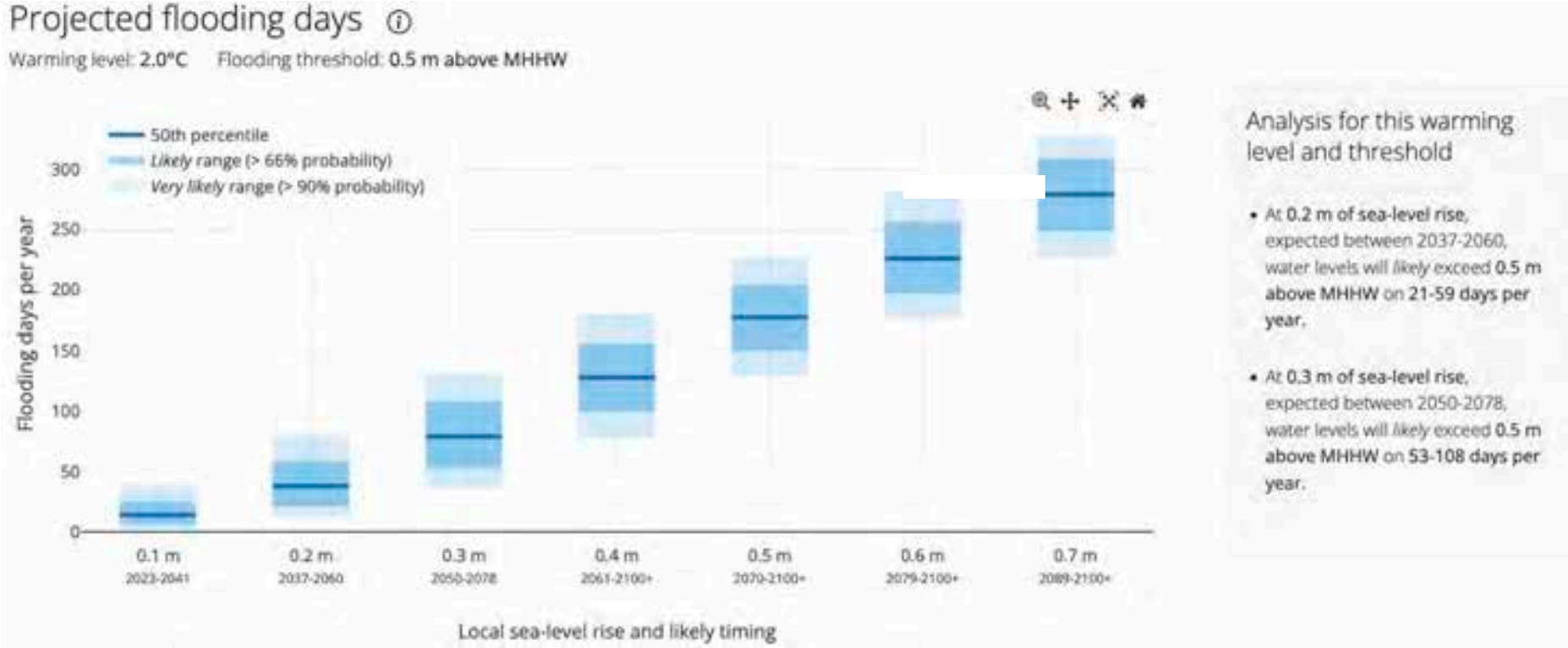
High-Tide Flooding

- Tide gauges can give an indication of how severe the flooding may be by providing observations of how much higher the water level was than previously recorded high values.
- In many places around the world, high-tide flooding is occurring more frequently every year.
- Take, for example, the tide gauge at Funafuti, Tuvalu.
- We can use mean sea level projections to project the number of flooding days in the future.



Using Consensus Knowledge of Modeled Physical Processes and Statistics Informed by Available Data Records, Future Sea Level can be Projected

- Part 2 of this training will go into further details on:
  - AR6 projections of mean sea level
  - How local sea level projections are combined with historical tidal data to determine plausible ranges for the number of high tide flood days per year out to 2100

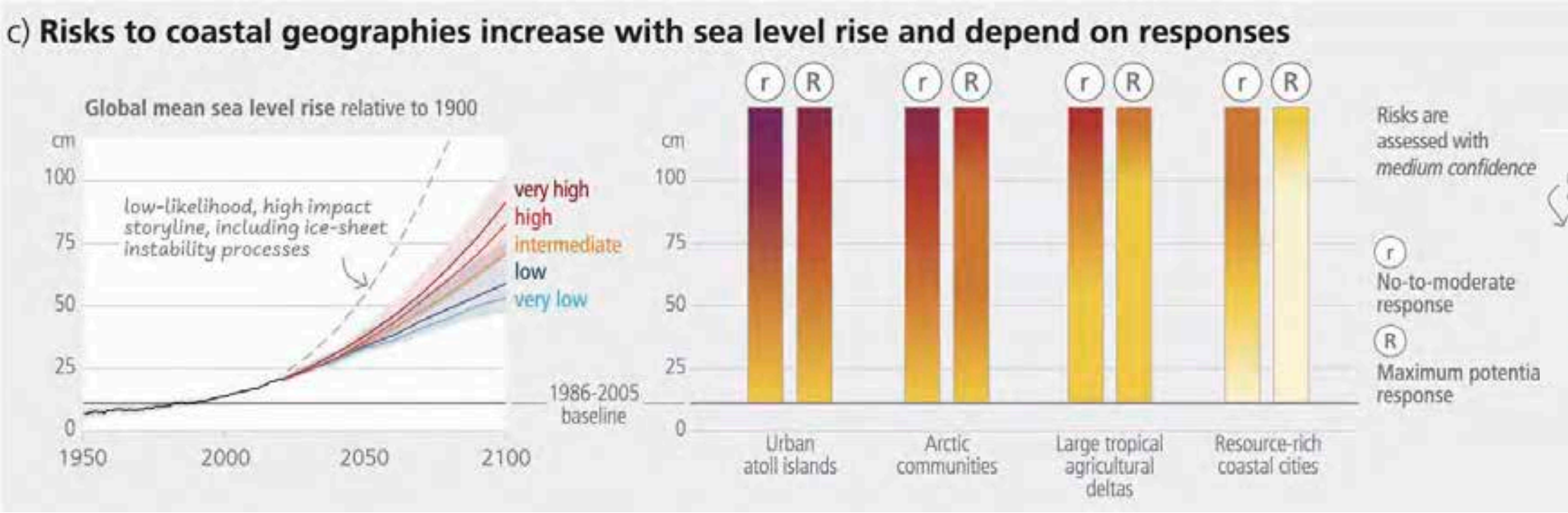


Warming levels indicate changes in 2080–2100 global mean surface temperatures relative to 1850–1900.
More on this in part 2!

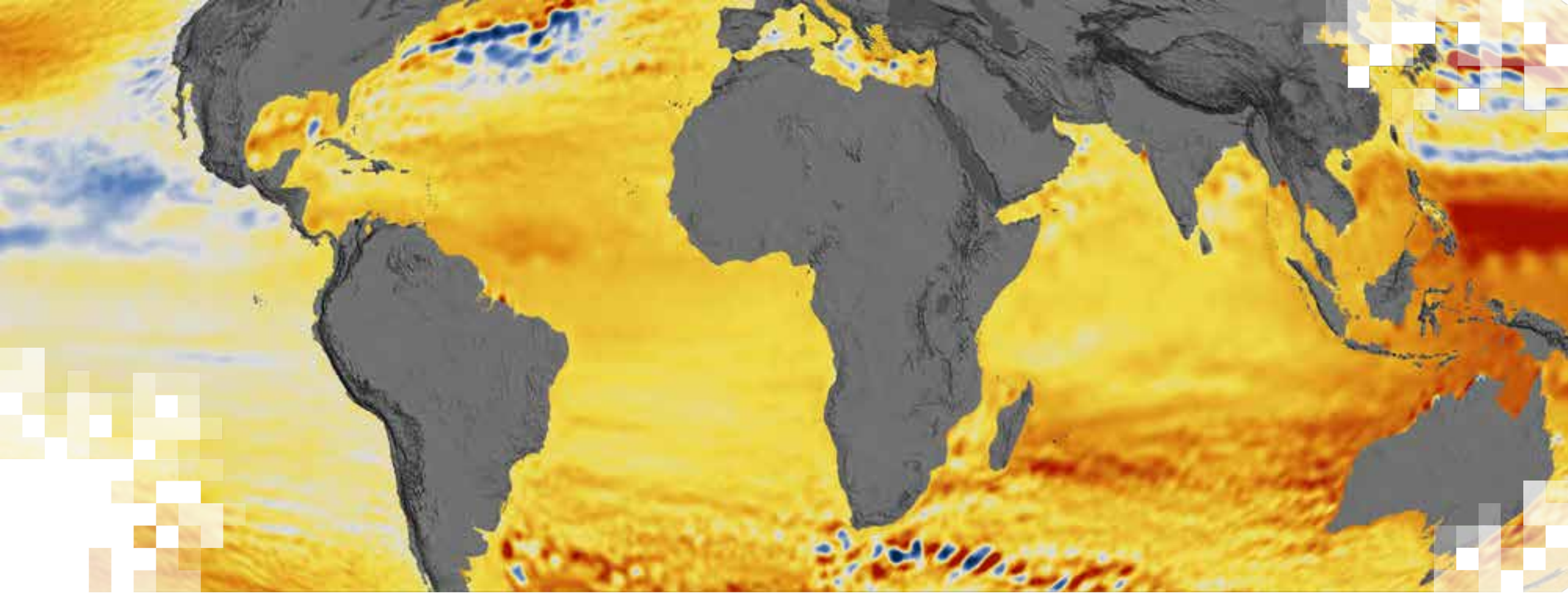
Increasing Mean Sea Level can have Far-Reaching Consequences

- **Direct impacts** from sea level rise include increases in flooding, coastal erosion, saltwater intrusion, elevated groundwater, and landscape changes.
- **Cascading impacts** result from the direct impacts and include infrastructure and property damage, health risks, economic challenges, and habitat loss.

Projections can be Used to Assess Vulnerability to Future Impacts and Inform Adaptation Planning



- Variations in coastal landscapes and environments, social and economic factors, and coastal development all play a role in determining how sea level rise impacts are felt in different locations and by different communities.



Sea Level Explorer Tool

Denis Felikson, PhD
NASA Goddard Space Flight Center

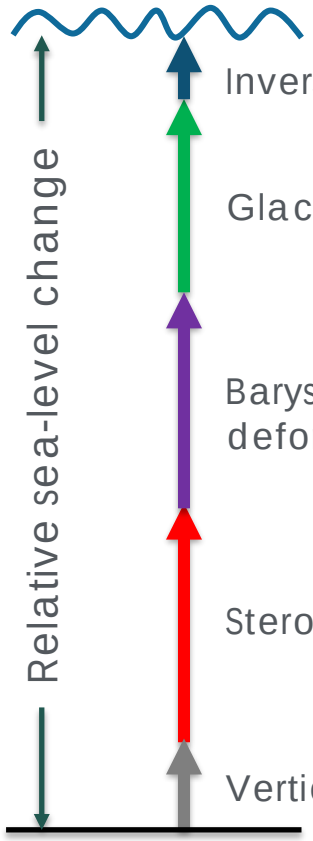
Overview of Tools

- In this training, we focus on three tools for accessing sea-level change information:
  - Sea Level Explorer: **provides high-level synthesis of past, present, and future sea-level rise and impacts for coastal locations around the world**
  - IPCC AR6 Projections Tool: provides easy access and visualization of the sea-level projection data from the IPCC 6th Assessment Report (AR6)
  - Pacific Islands Flooding Analysis Tool: decision-relevant assessments of how sea-level rise and other factors will affect the frequency and extent of high-tide flooding for Pacific Islands
    - This is currently being expanded to global scale.

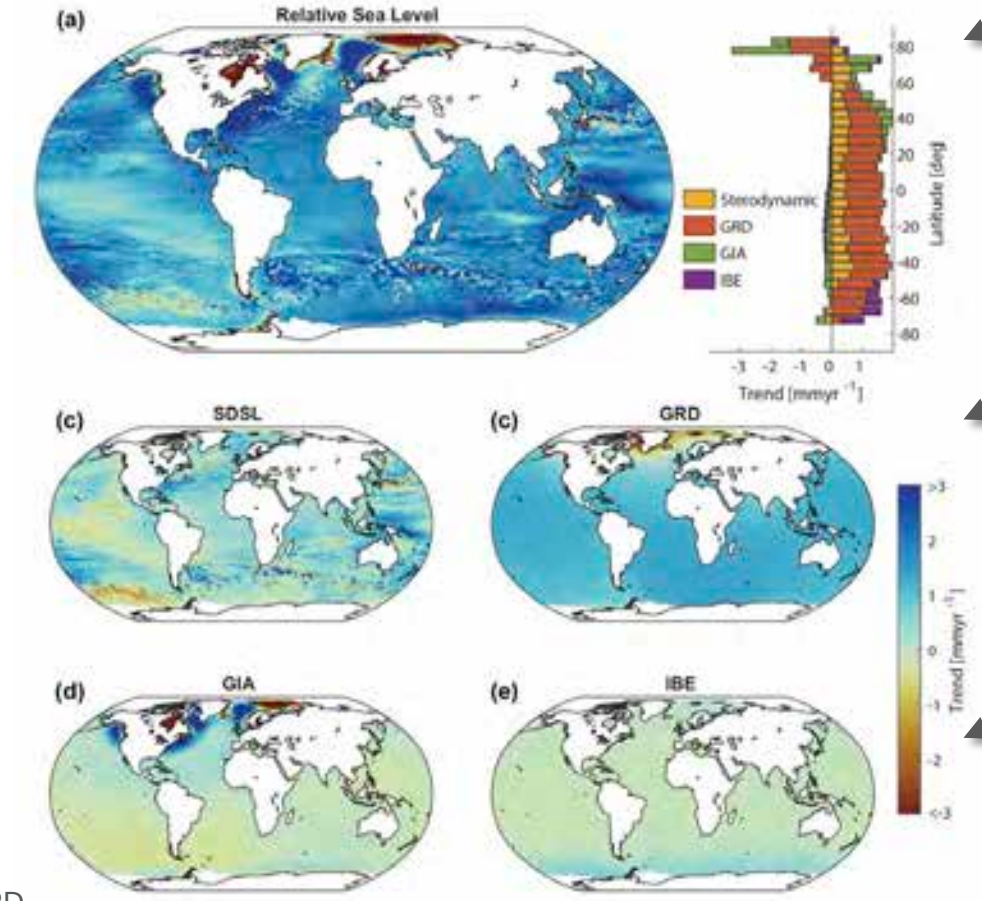
- There is consistency in the underlying datasets and methodology across these three tools.
- Information comes from peer-reviewed papers and assessment reports.

Sea-Level Reconstructions Within the Sea Level Explorer

- Historical sea-level and contributions from individual components can be reconstructed by combining tide gauge records with satellite observations.

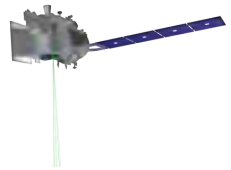


*Note that sometimes, VLM can include GIA and GRD



NASA radar altimetry

NASA laser altimetry



NASA gravimetry

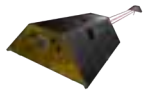
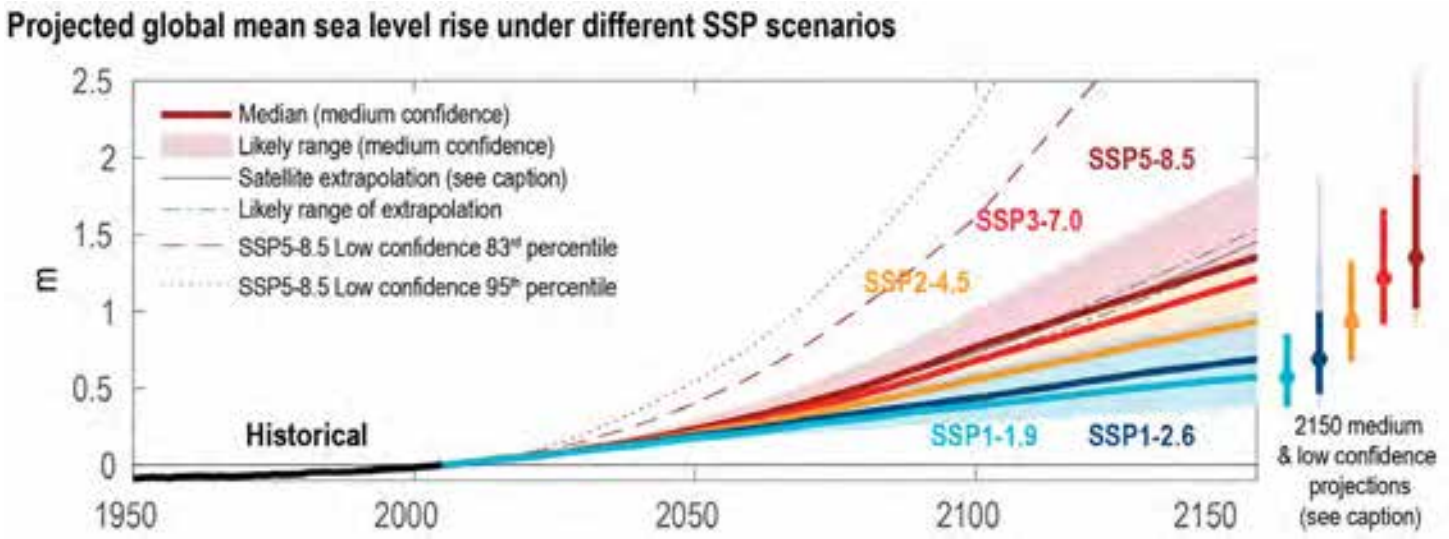


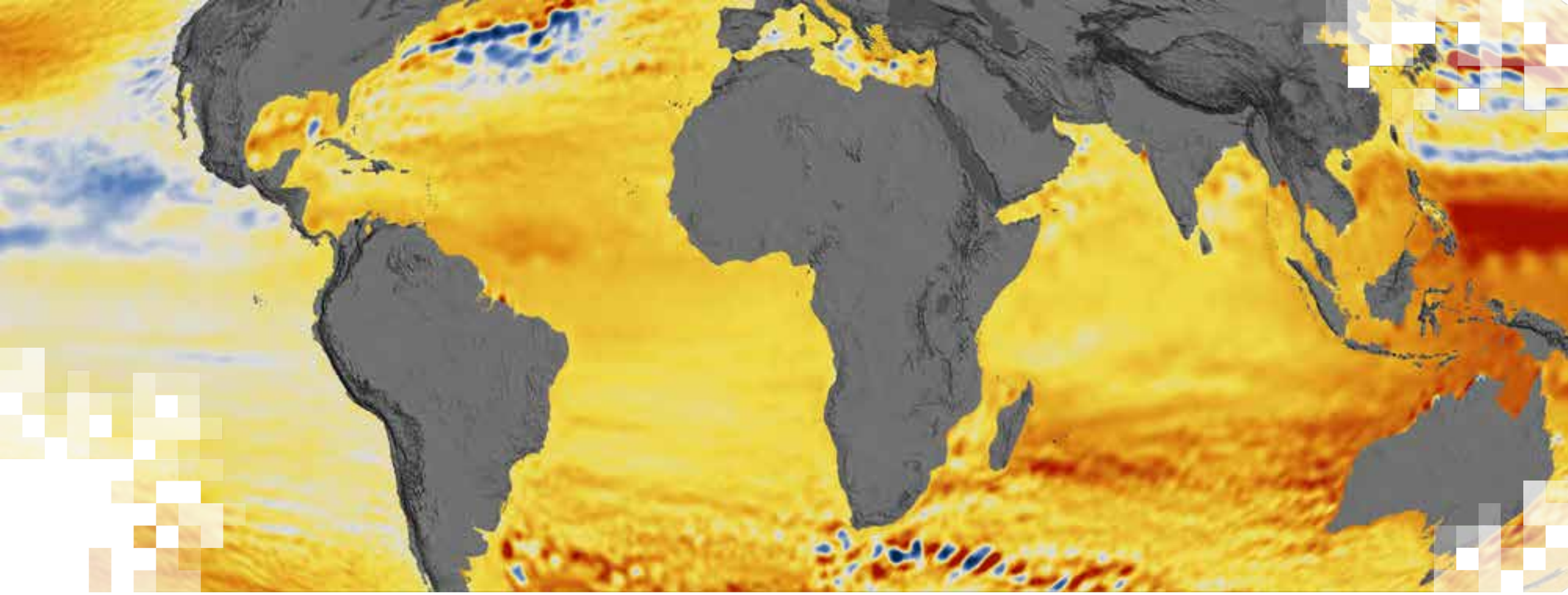
Figure 12 from Dangendorf et al. (2024)

Sea-Level Projections Within the Sea Level Explorer

- Future projections of sea-level change are from the Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report (AR6), published in 2021 (IPCC AR6).
  - The IPCC is the United Nations body for assessing the science related to climate change.
- The IPCC AR6 surveys and distills the scientific literature and provides consensus projections on future sea levels across the globe under a range of possible future scenarios called Shared Socioeconomic Pathways (SSPs).
- The AR6 incorporates advances in modeling and understanding of ice sheet dynamics, ocean thermal expansion, and regional variations.
- Part 2 of this ARSET training will provide more details on IPCC AR6 sea-level projections.



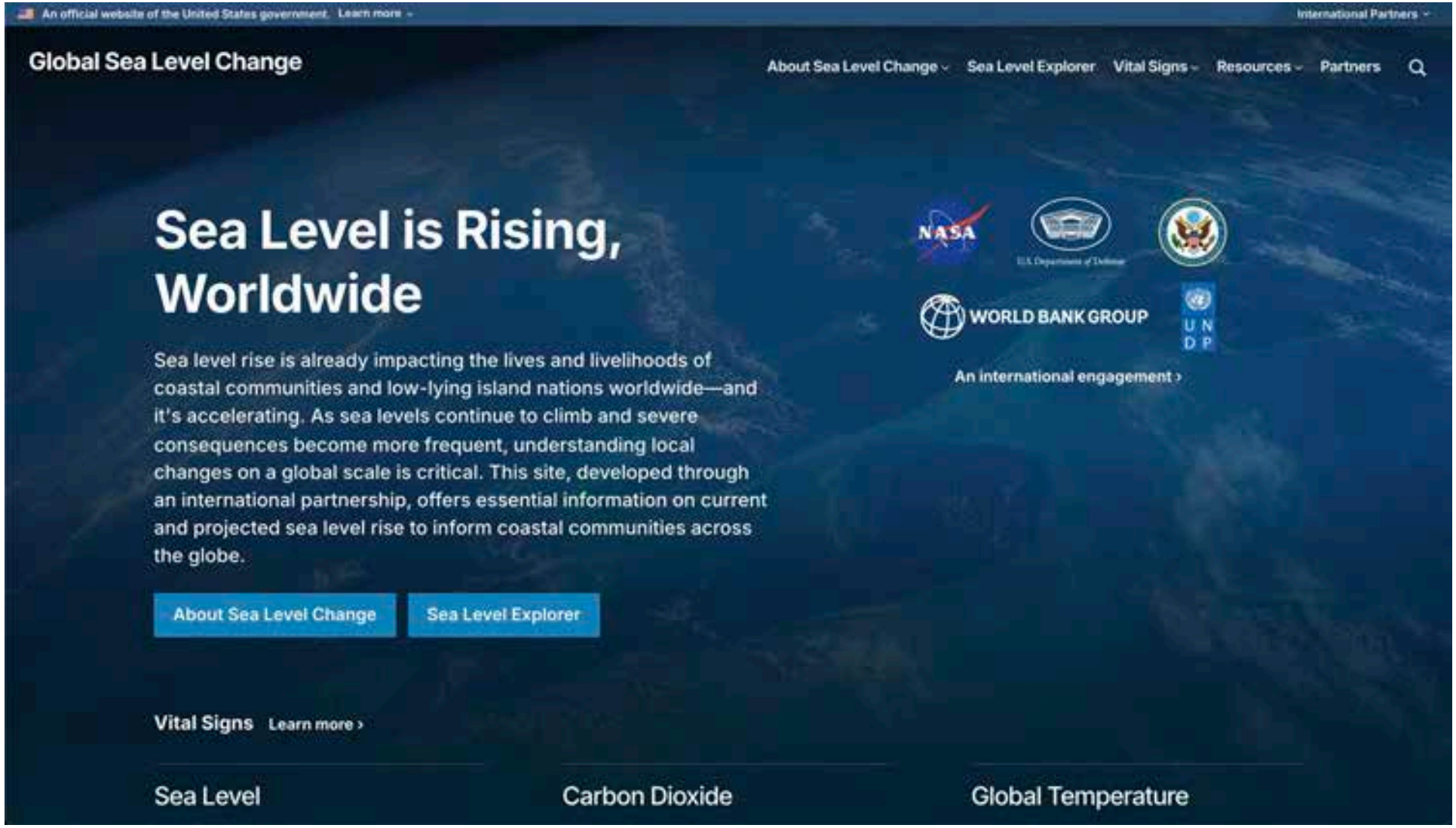
IPCC AR6 – Figure 9.27



Demonstration

Sea Level Explorer

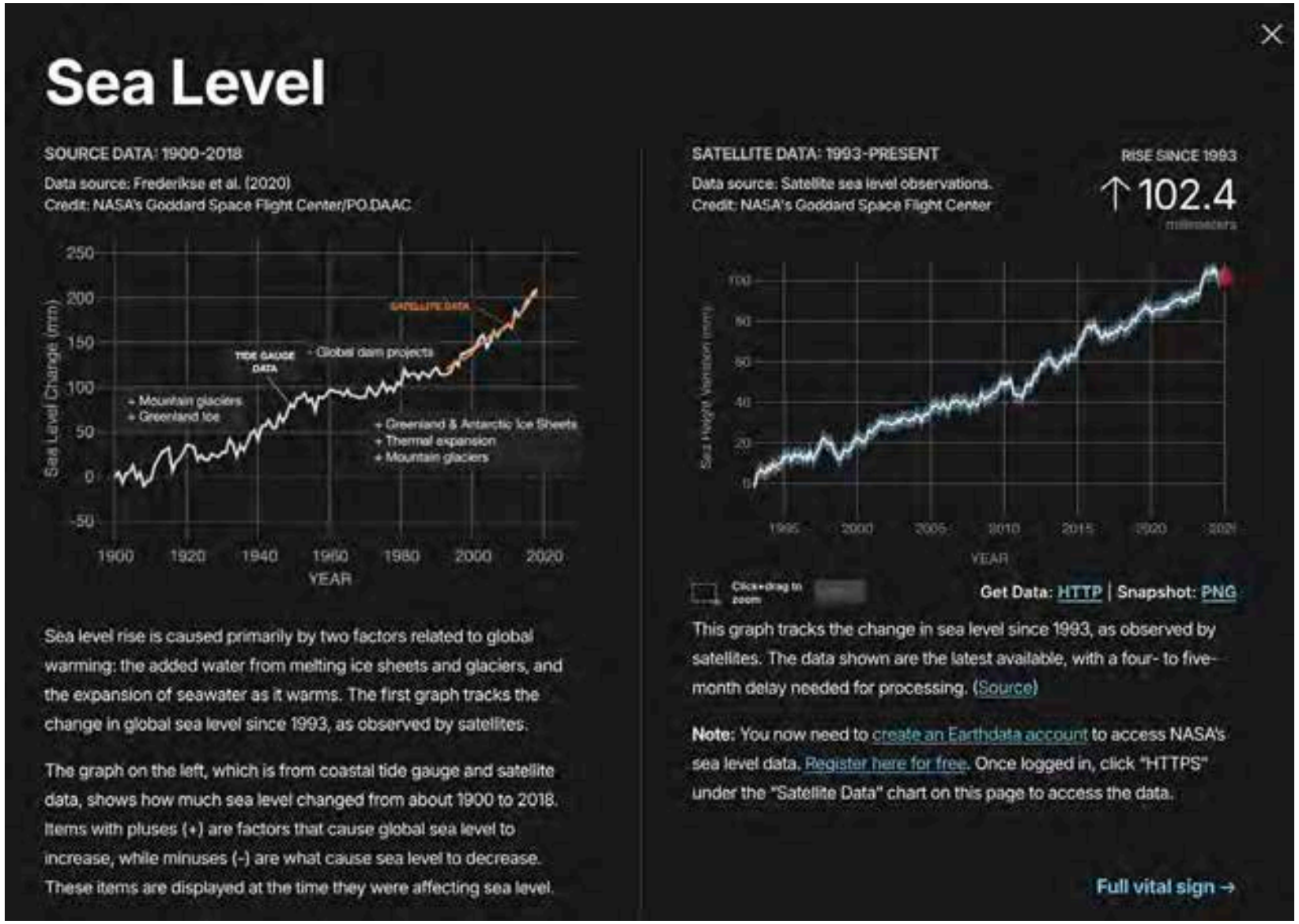
Introduction to earth.gov/sealevel



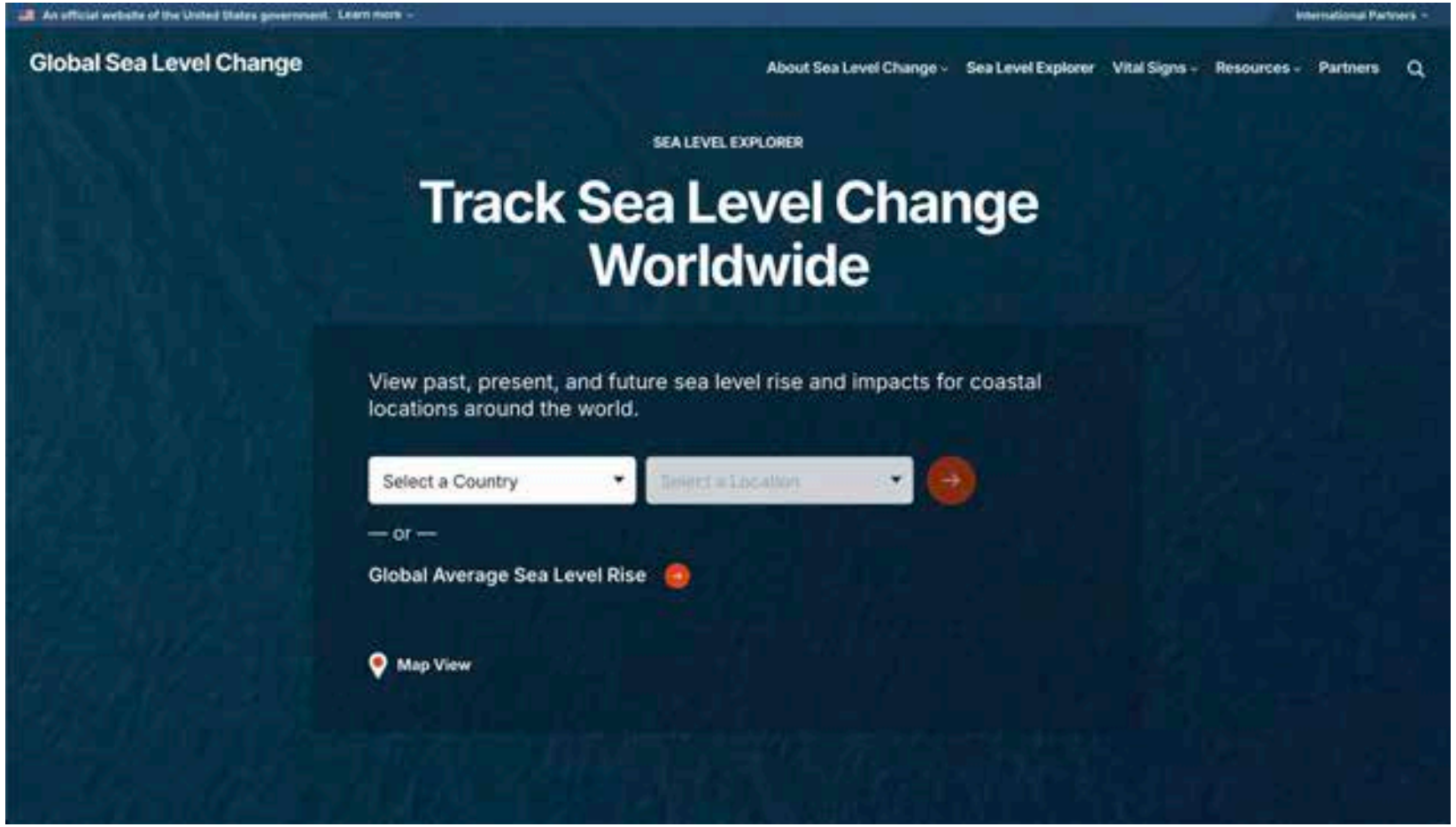
Vital Signs


Vital Signs Learn more ›
Sea Level
↑ 10 centimeters since January 1993
Carbon Dioxide
↑ 430 parts per million
Global Temperature
↑ 1.5 °C since preindustrial
Ocean Warming
↑ 372 zettajoules since 1955
Antarctica Ice Sheet
↓ 136 billion metric tons per year since 2002
Greenland Ice Sheet
↓ 267 billion metric tons per year since 2002

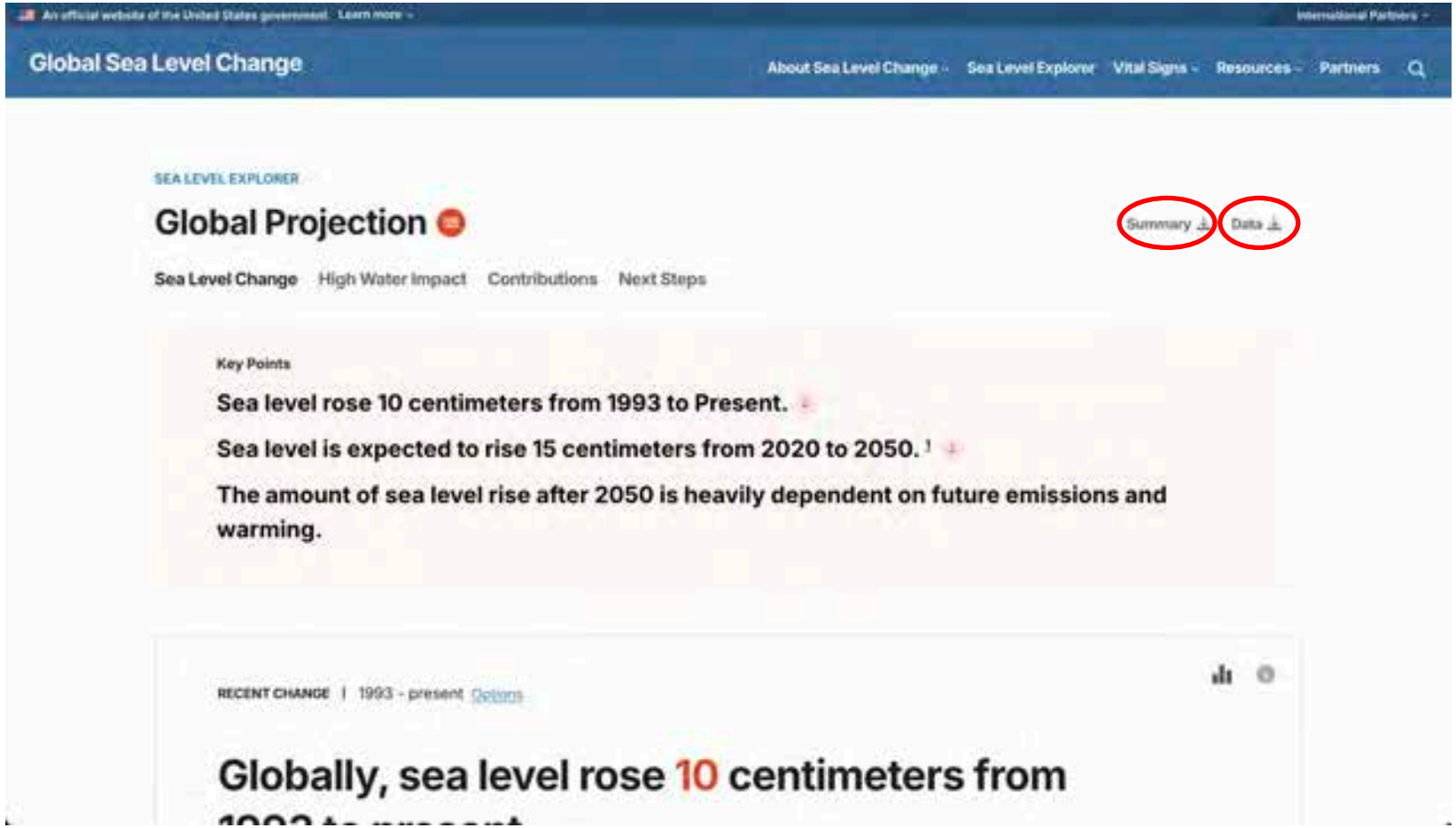
Vital Signs: Sea Level



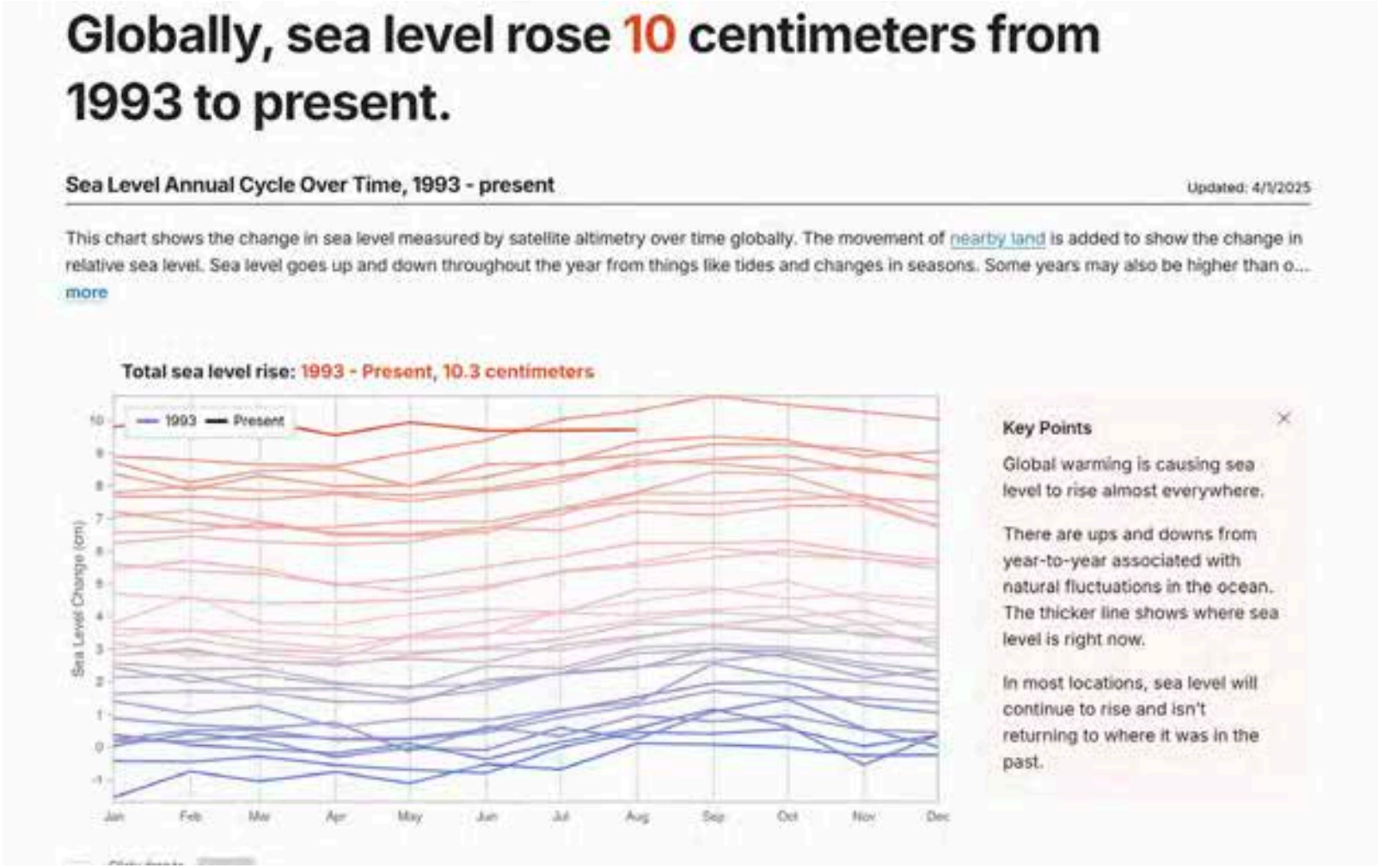
Sea Level Explorer



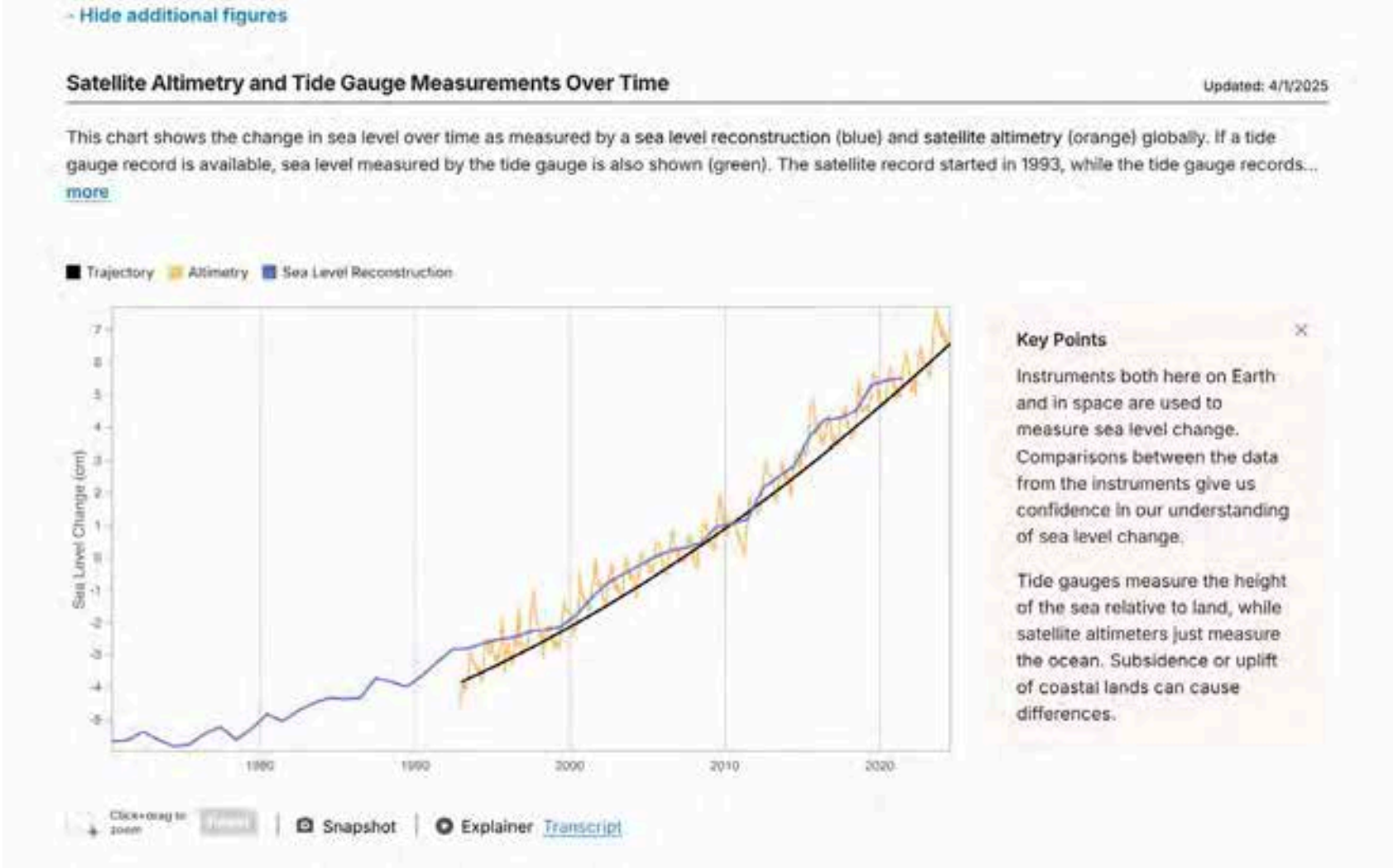
Sea Level Explorer: Global Average (Overview)



Sea Level Explorer: Global Average (Historical)



Sea Level Explorer: Global Average (Historical)



Sea Level Explorer: Global Average (Historical)

Summary of Tide Gauge Measurement Data, 1970-Present

The table below shows how fast the sea level is changing each decade and the total change across selected years based on tide gauge measurements. The first column shows the decade. The second column is the rate of change over that decade. This tells us how fast sea levels are changing. The large...
more

Time Frame	RATE (cm/yr)	VALUE (cm)
1990s	0.24	1.7
2000s	0.30	3.0
2010s	0.37	3.7
2020s	0.39	2.0
1970 - Present	0.33	10.4

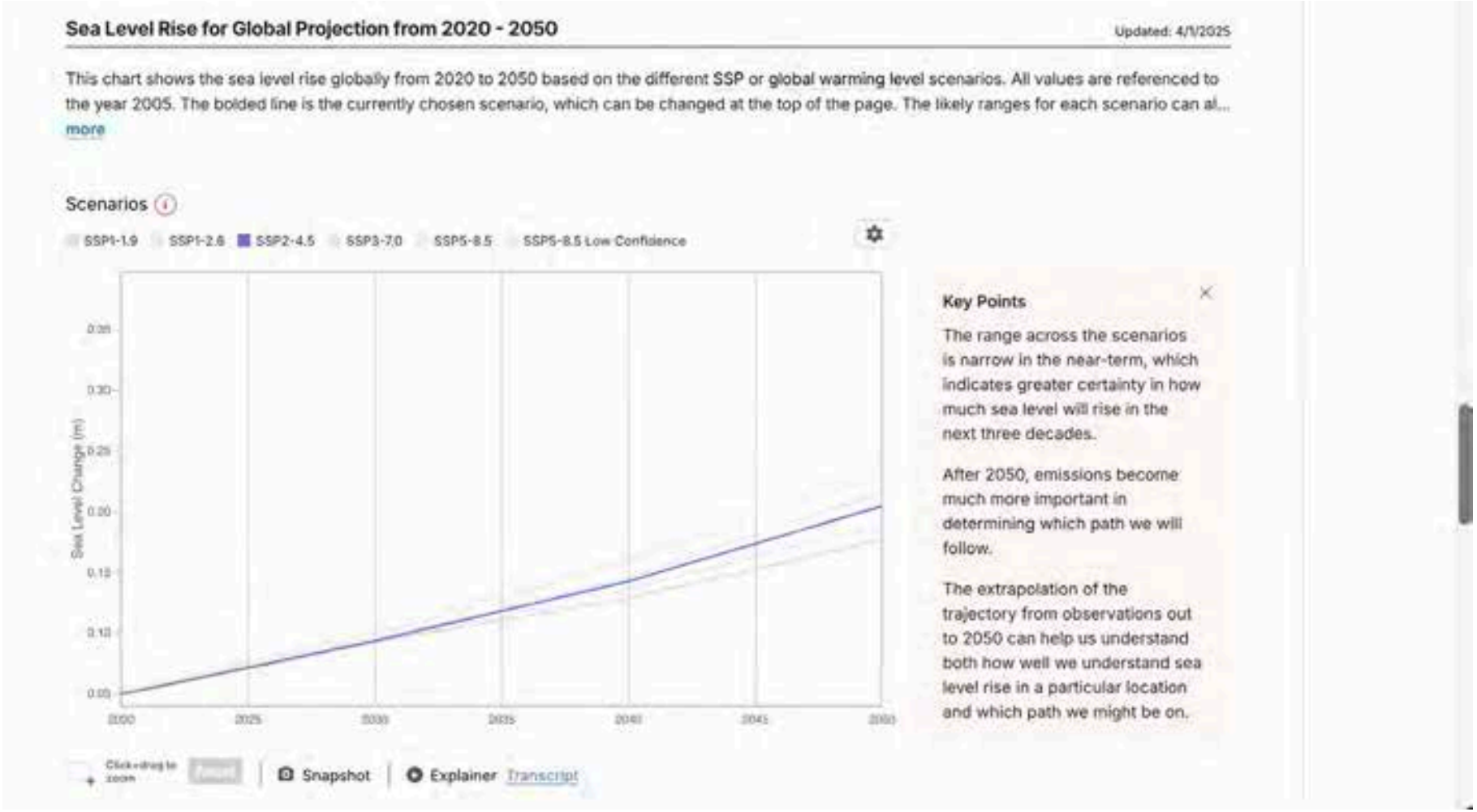
Key Points

Using the trajectory of the past data, we can see that the rate at which sea level is rising is changing over time.

In many locations - but not all - sea level is rising faster than it used to, just like putting our foot on the gas pedal.

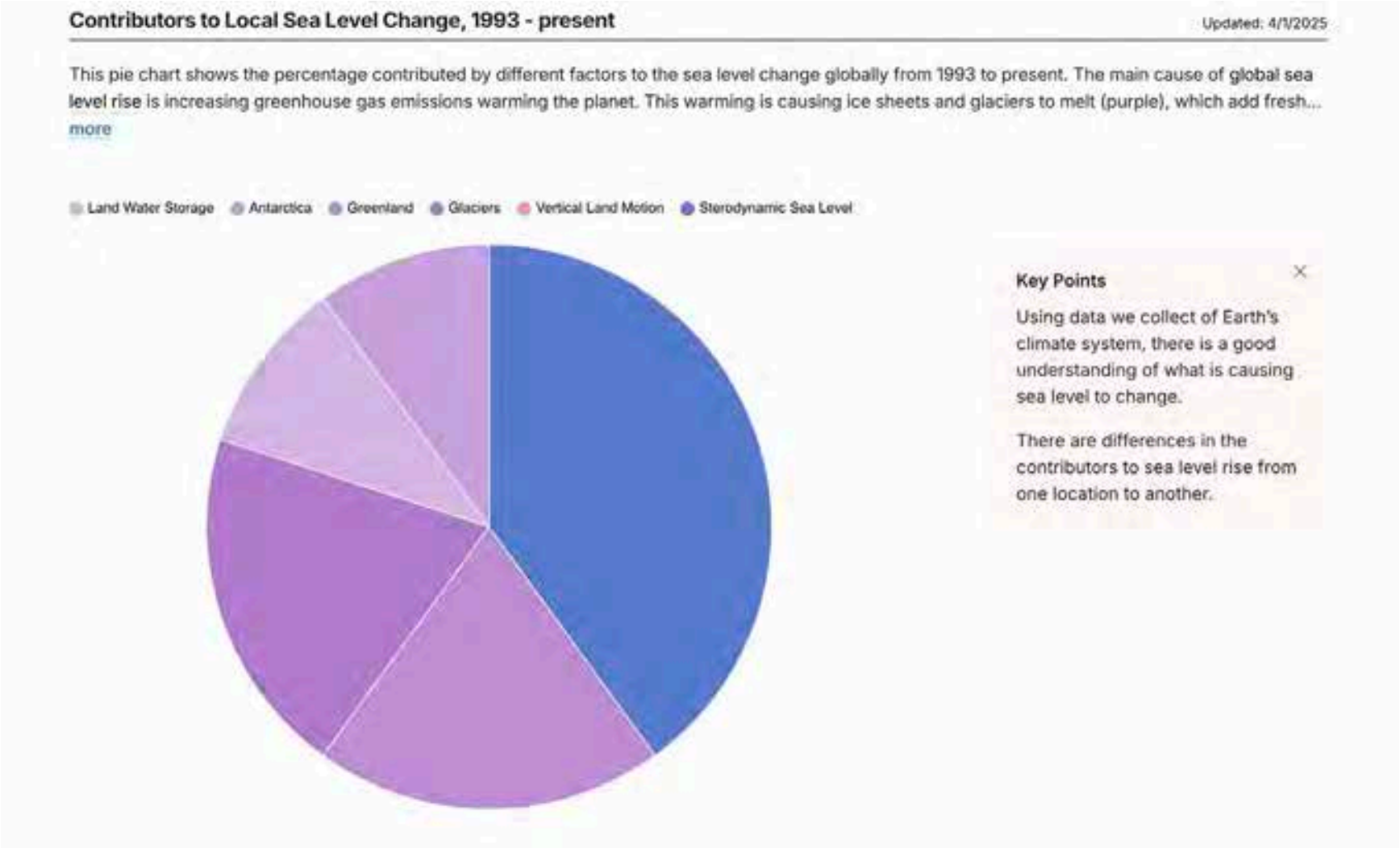
Sea Level Explorer: Global Average (Future)

Sea Level Explorer: Global Average (Future)

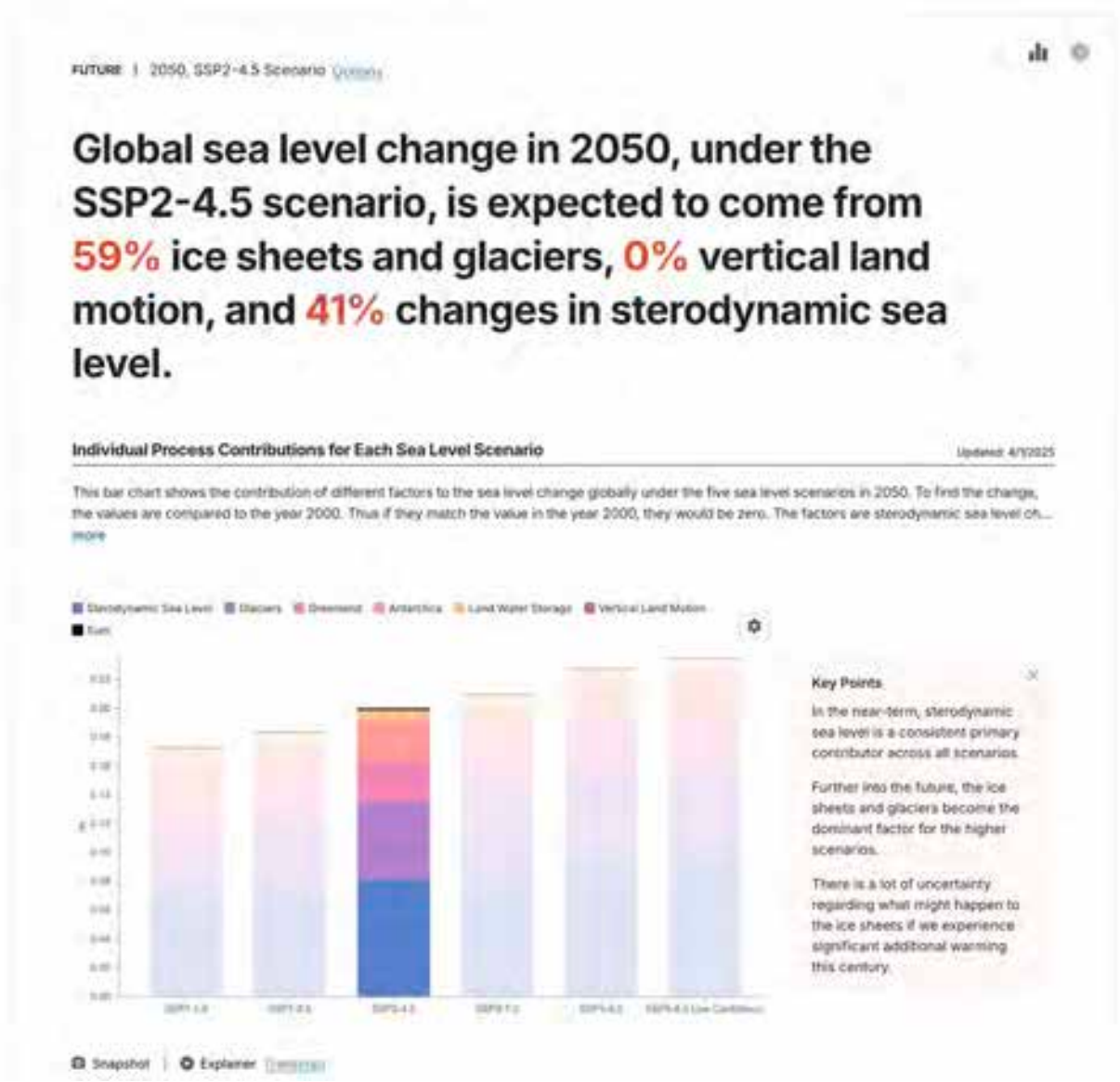


Sea Level Explorer: Global Average (Contributions)

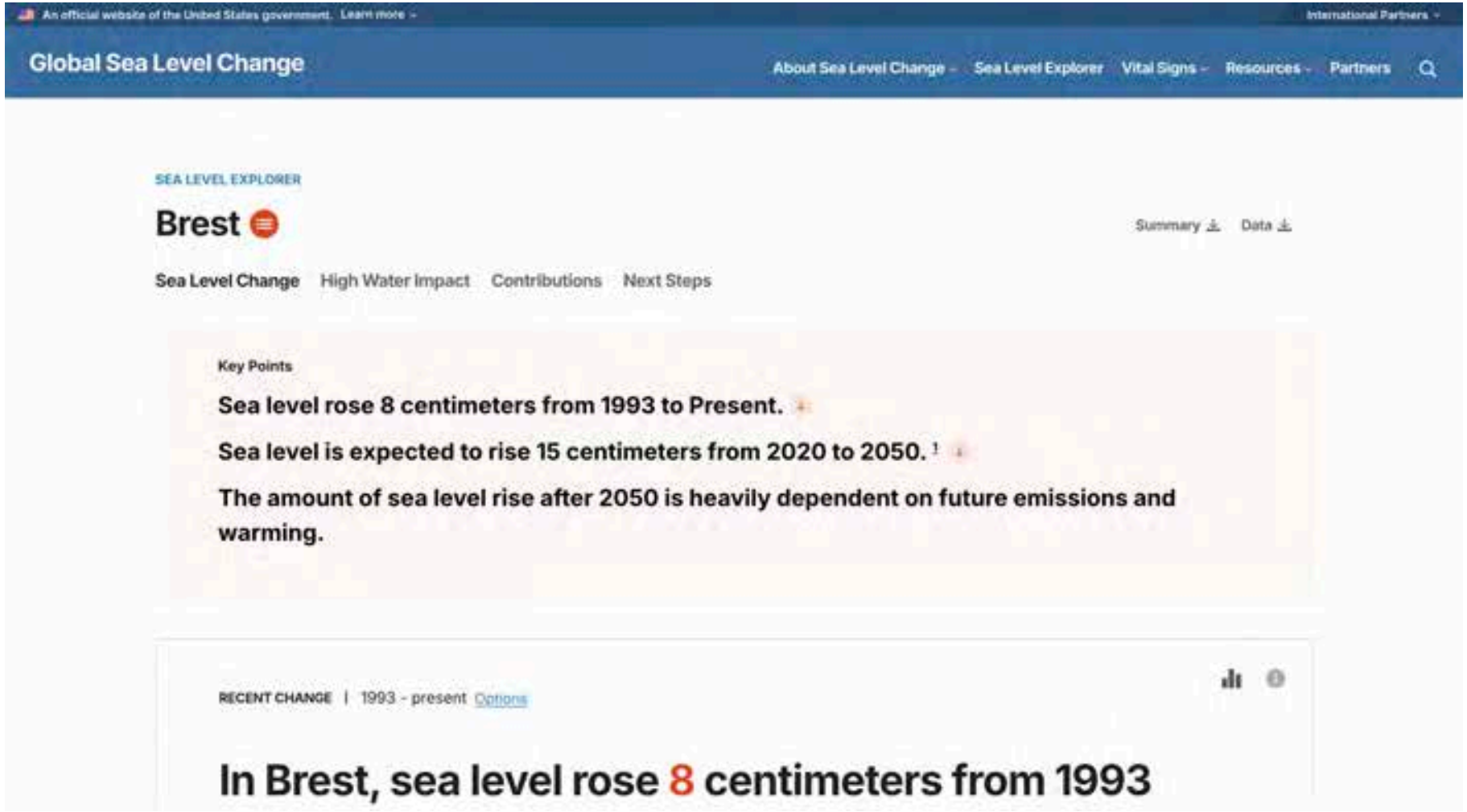
Sea Level Explorer: Global Average (Historical Contributions)



Sea Level Explorer: Global Average (Future Contributions)



Sea Level Explorer: Brest, France (Overview)



Sea Level Explorer: Brest, France (Historical)

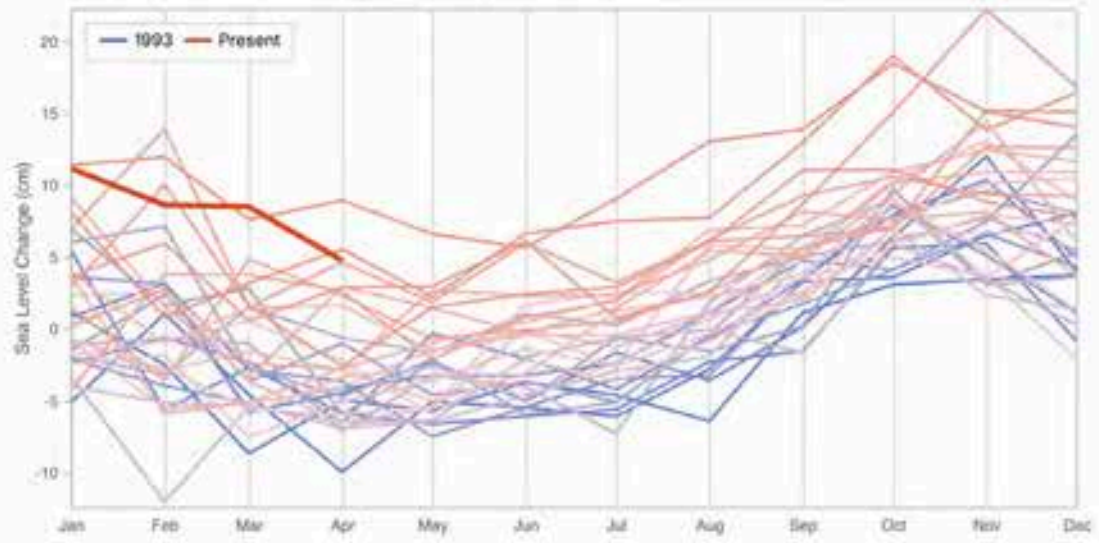
In Brest, sea level rose 8 centimeters from 1993 to present.

Sea Level Annual Cycle Over Time, 1993 - present

Updated: 4/1/2025

This chart shows the change in sea level measured by satellite altimetry over time in Brest. The movement of nearby land is added to show the change in relative sea level. Sea level goes up and down throughout the year from things like tides and changes in seasons. Some years may also be higher than o...
more

Total sea level rise: 1993 - Present, 8.4 centimeters



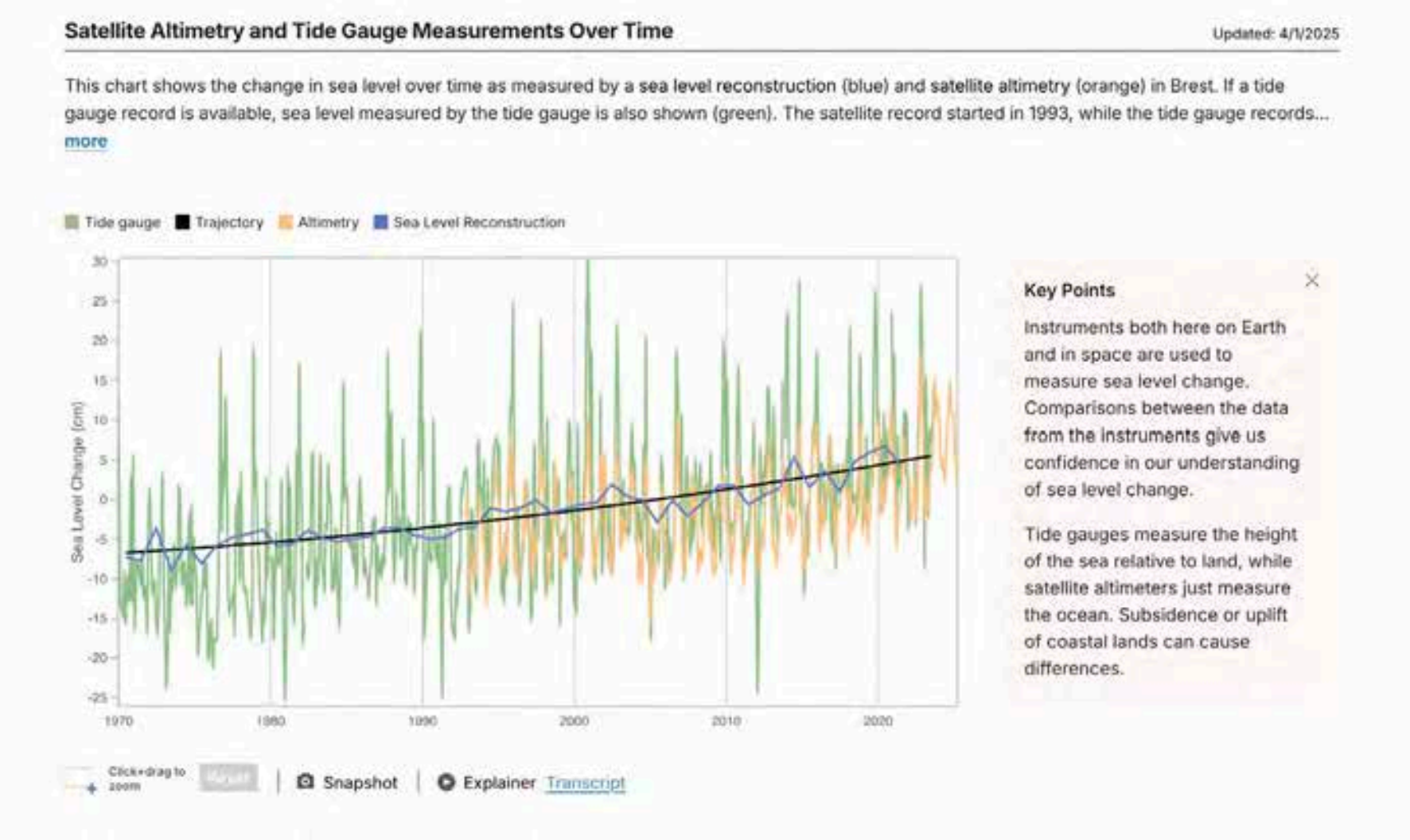
Key Points

Global warming is causing sea level to rise almost everywhere.

There are ups and downs from year-to-year associated with natural fluctuations in the ocean. The thicker line shows where sea level is right now.

In most locations, sea level will continue to rise and isn't returning to where it was in the past.

Sea Level Explorer: Brest, France (Historical)



Sea Level Explorer: Brest, France (Historical)

Summary of Tide Gauge Measurement Data, 1970-Present

The table below shows how fast the sea level is changing each decade and the total change across selected years based on tide gauge measurements. The first column shows the decade. The second column is the rate of change over that decade. This tells us how fast sea levels are changing. The large...
more

Time Frame	RATE (cm/yr)	VALUE (cm)
1970s	0.12	1.2
1980s	0.16	1.6
1990s	0.20	2.0
2000s	0.24	2.4
2010s	0.28	2.8
2020s	0.34	1.0
1970 - Present	0.23	12.3

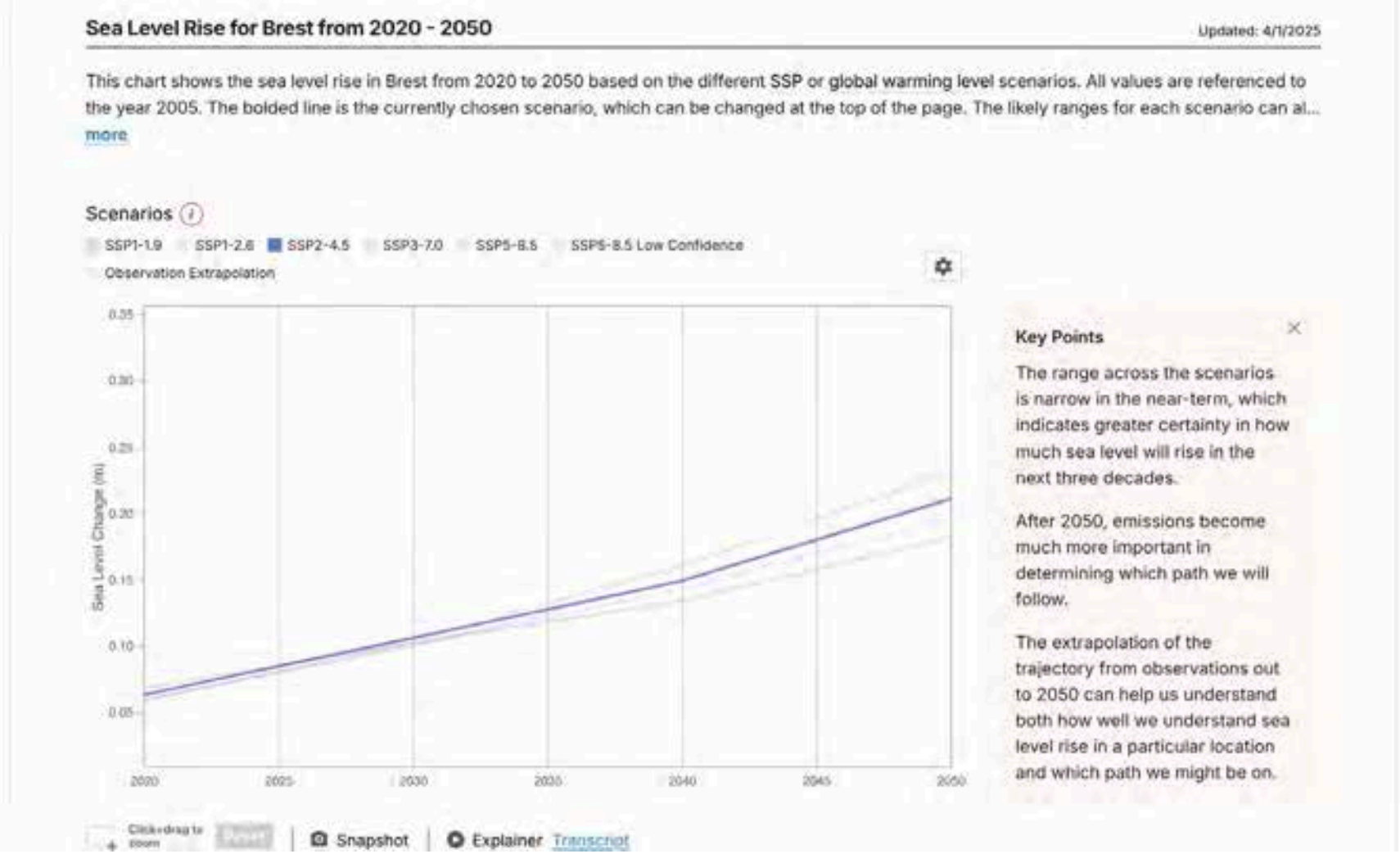
Key Points

Using the trajectory of the past data, we can see that the rate at which sea level is rising is changing over time.

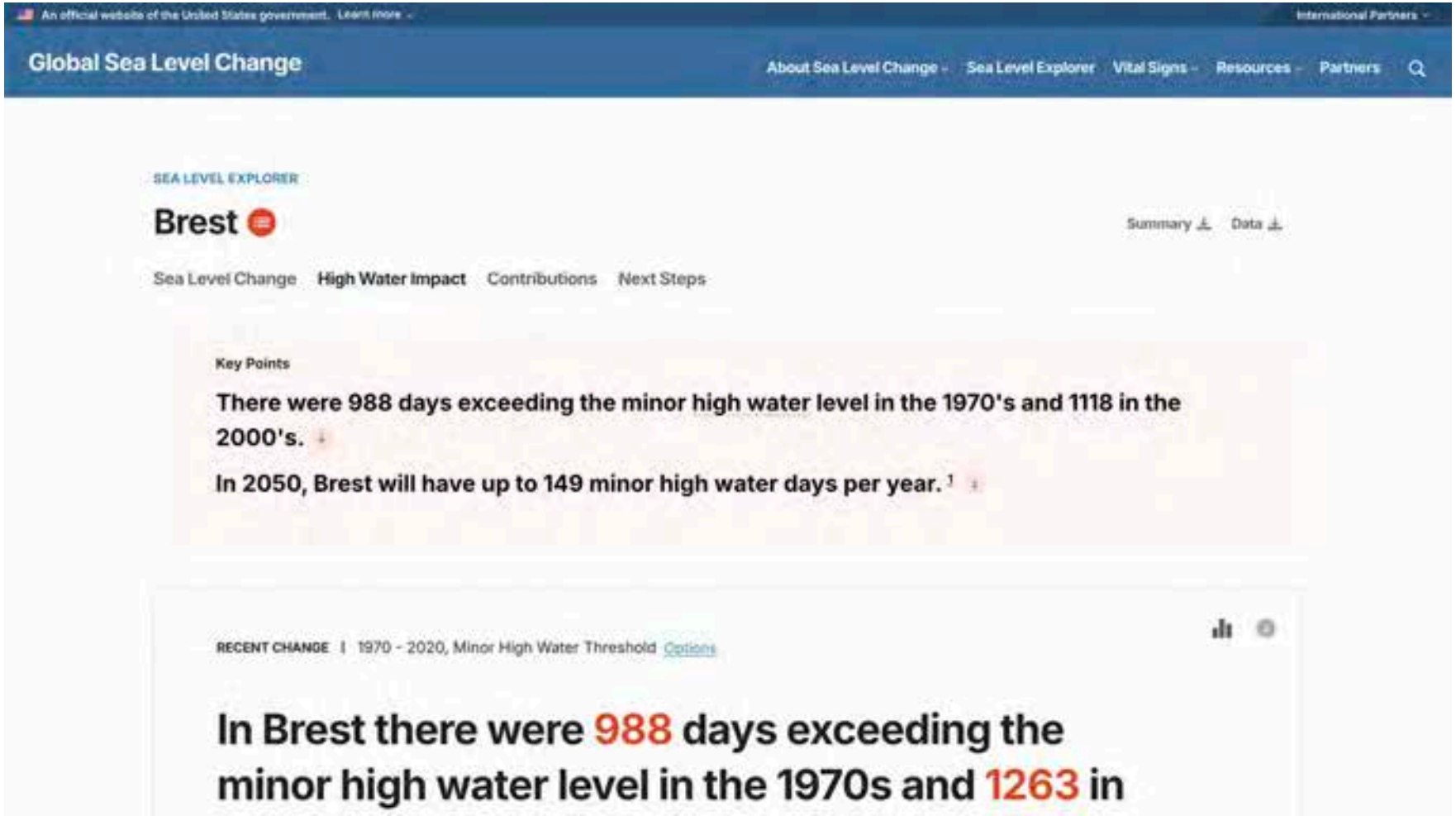
In many locations - but not all - sea level is rising faster than it used to, just like putting our foot on the gas pedal.

Sea Level Explorer: Brest, France (Future)

Sea Level Explorer: Brest, France (Future)

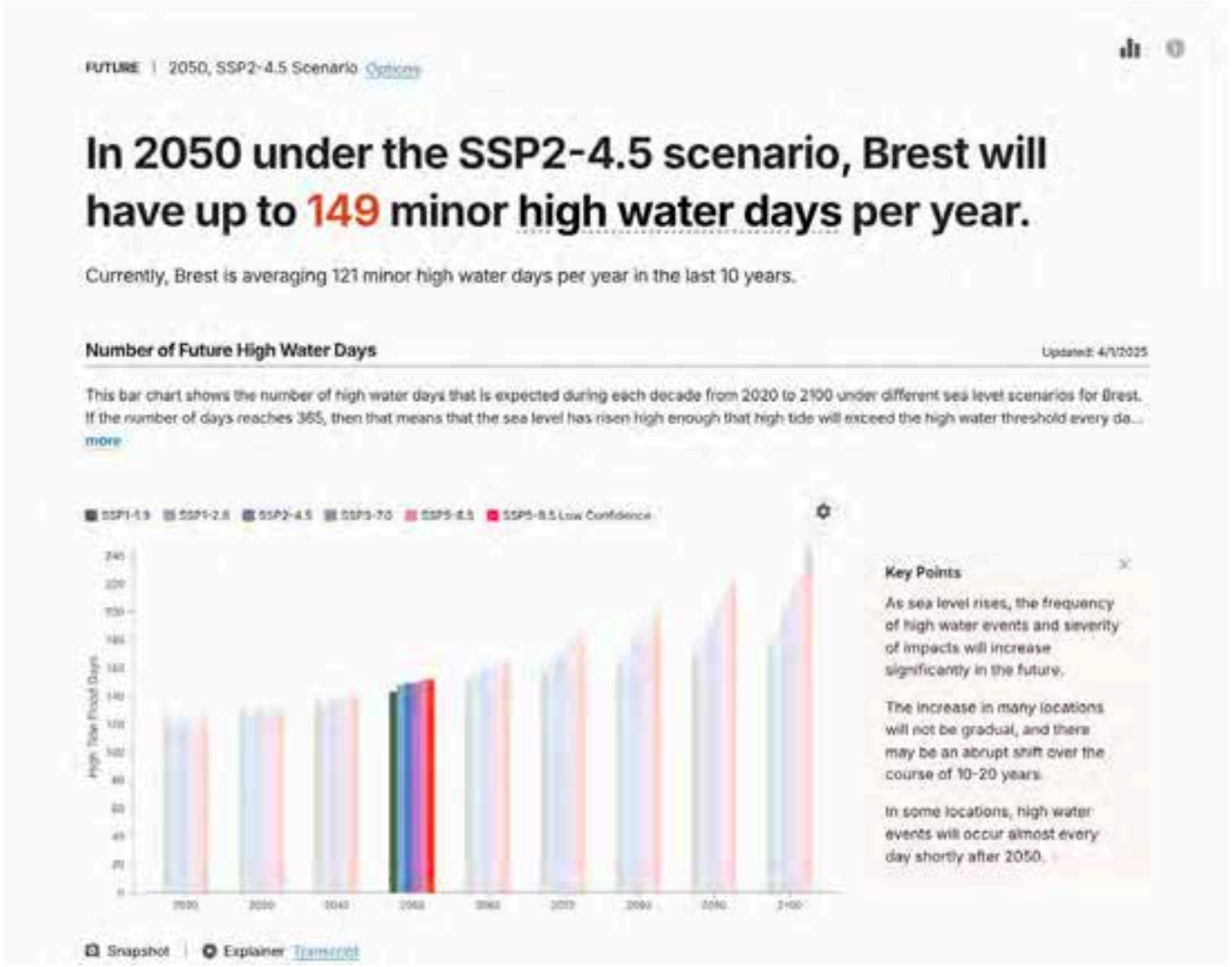


Sea Level Explorer: Brest, France (High Water Impact)

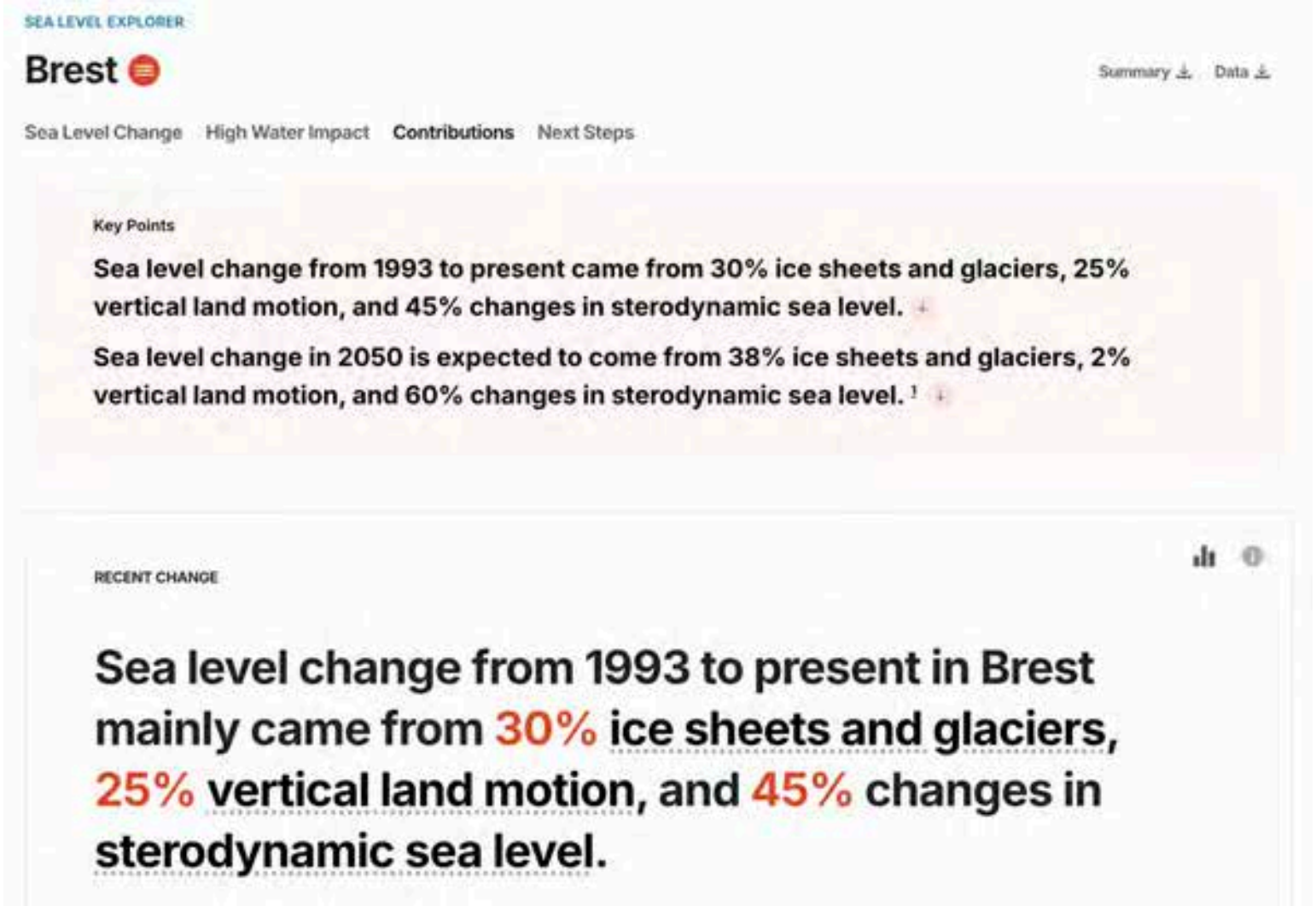


Sea Level Explorer: Brest, France (High Water Impact)

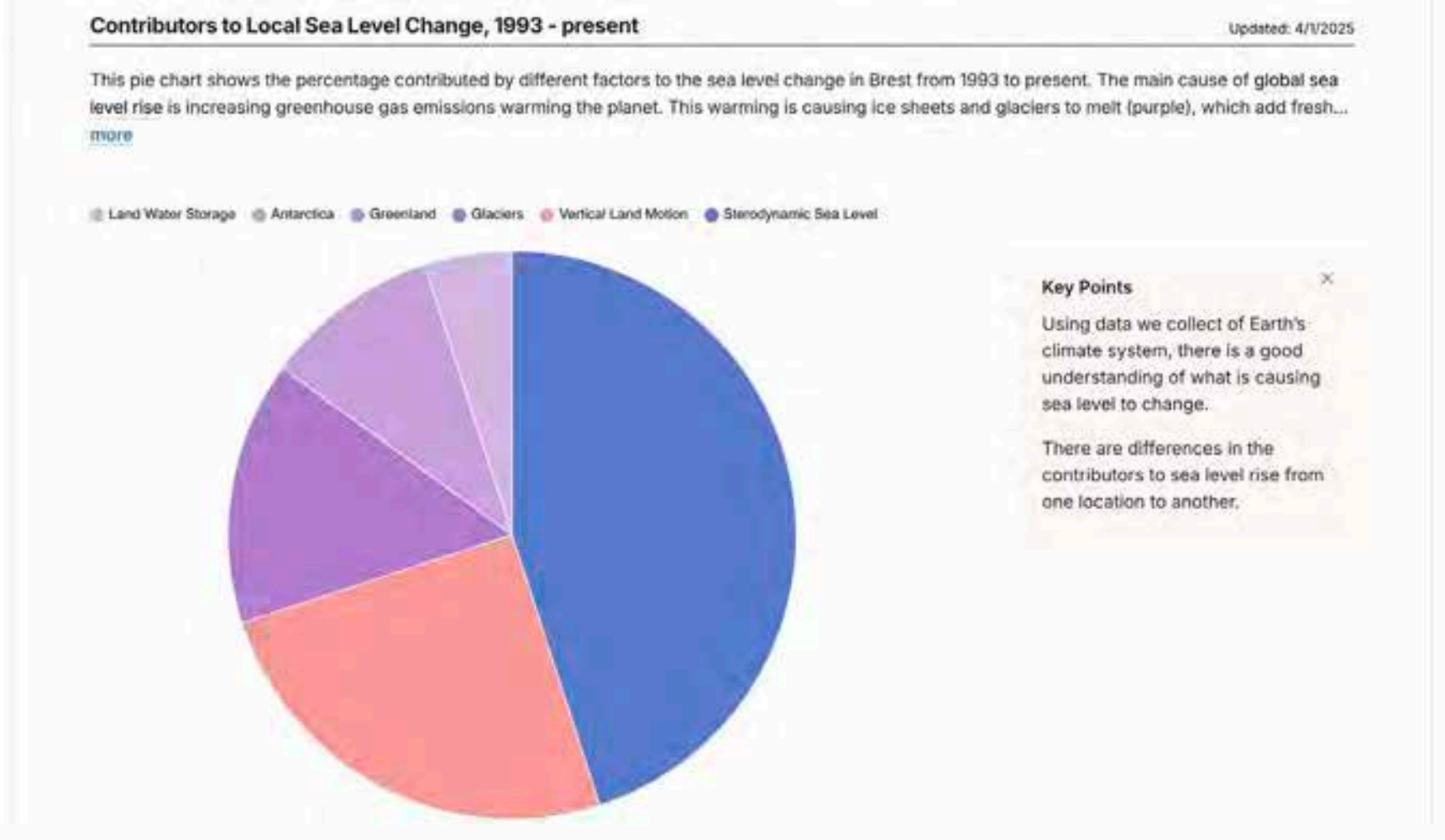
Sea Level Explorer: Brest, France (High Water Impact)



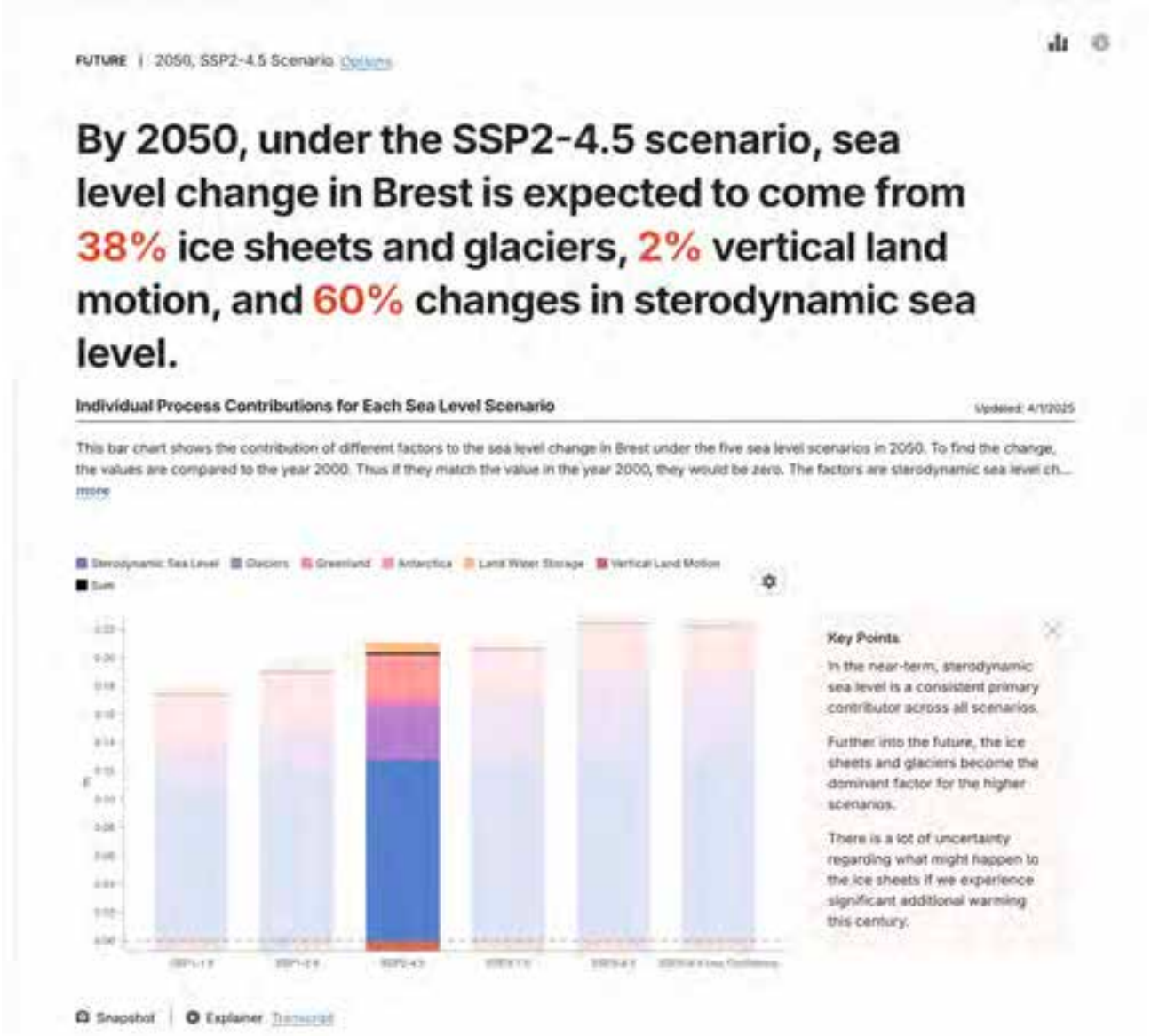
Sea Level Explorer: Brest, France (Contributions)

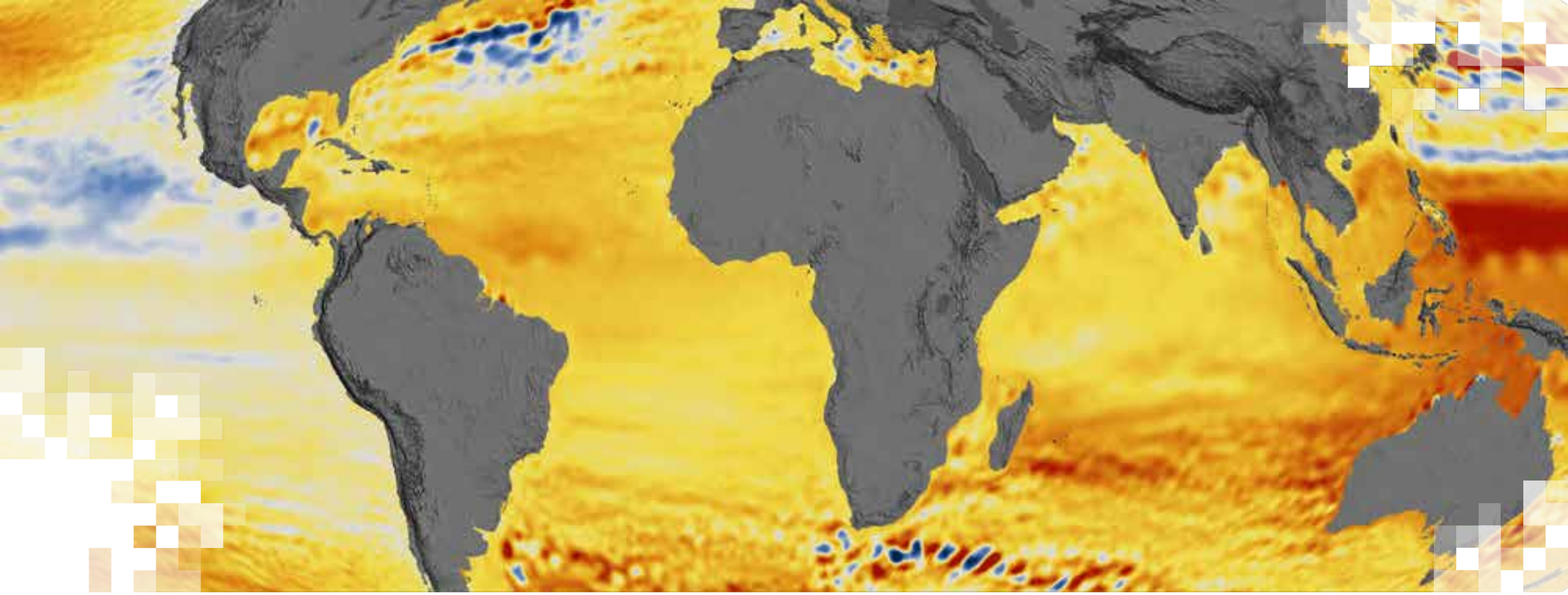


Sea Level Explorer: Global Average (Historical Contributions)



Sea Level Explorer: Global Average (Future Contributions)





Part 1: Summary

Summary

- Processes contributing to sea-level change
  - Greenhouse gases added to air by human activities
  - Planet warms
  - Ocean expands as it warms
  - Ice sheets and glaciers melt, adding water to oceans
  - Global sea level rises
- Impacts of sea-level change
  - High tide flooding (a.k.a., sunny-day flooding)
  - Variations in coastal environments, social and economic factors, and coastal development all play a role in determining how impacts are felt in different locations by different communities.
- NASA's unique capabilities in both remote sensing and modeling
  - Radar altimetry (Sentinel-6 Michael Freilich), Laser altimetry (ICESat-2), Gravimetry (GRACE-FO)
- Overview and demonstration of Sea-Level Explorer
  - Provides high-level synthesis of past, present, and future sea-level rise and impacts for coastal locations around the world.

Looking Ahead to Part 2

- Projecting Future Sea-Level Change
- Framework for Assessing Changes To Sea-level (FACTS)
- Overview and Demonstration of the Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report (AR6) Projections Tool
- Overview and Demonstration of the Pacific Islands Flooding Analysis Tool
  - Oceanic flooding
  - Groundwater flooding

Homework and Certificates

- **Homework:**
  - One homework assignment
  - Opens on June 17, 2025
  - Access from the training webpage
  - Answers must be submitted via Google Forms
  - **Due by July 1, 2025**

- **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. Angelica Rodriguez
Research Scientist
NASA JPL/Caltech

Dr. Denis Felikson
Research Scientist
NASA GSFC

Contact Information

Trainers:

- Angelica Rodriguez, PhD
  - angelica.rodriguez@jpl.nasa.gov
- Denis Felikson, PhD
  - denis.felikson@nasa.gov
- Sean McCartney
  - sean.mccartney@nasa.gov

- ARSET Website
- Follow us on Twitter!
  - @NASAARSET
- ARSET YouTube

Visit our Sister Program:

- DEVELOP

Resources

Websites

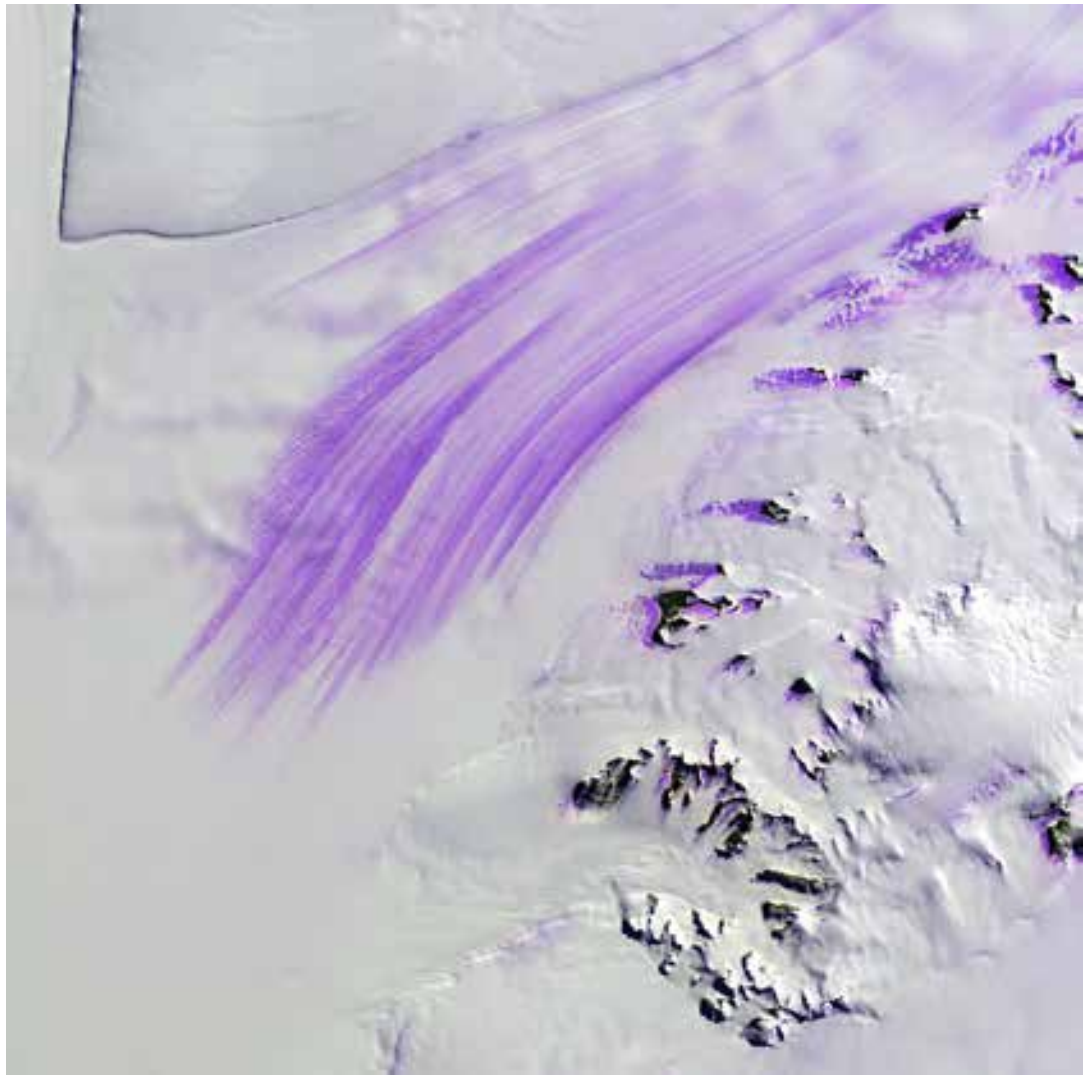
- Global Sea Level Change - About Sea Level Change
- Ocean Surface Topography
- ICESat-2
- GRACE-FO
- Information on current NASA Earth Science satellite fleet
- ECCO
- Argo Program
- NASA Sea Level Change Portal
- IPCC AR6
- Sea-level projection data from IPCC AR6
- Sea Level Explorer Tool

References

- Hamlington, B.D., Fournier, S., Thompson, P.R. *et al.* Sea level rise in 2024. *Nat Rev Earth Environ* **6**, 246–248 (2025). https://doi.org/10.1038/s43017-025-00667-w
- Dangendorf, S., Sun, Q., Wahl, T., Thompson, P., Mitrovica, J. X., and Hamlington, B.: Probabilistic reconstruction of sea-level changes and their causes since 1900, Earth Syst. Sci. Data, 16, 3471–3494 (2024), https://doi.org/10.5194/essd-16-3471-2024
- Oelsmann, J., Marcos, M., Passaro, M. *et al.* Regional variations in relative sea-level changes influenced by nonlinear vertical land motion. *Nat. Geosci.* **17**, 137–144 (2024). https://doi.org/10.1038/s41561-023-01357-2
- Smith, B., Fricker, A., Gardner, A. *et al.* Pervasive ice sheet mass loss reflects competing ocean and atmosphere processes. *Science* **368**,1239–1242 (2020). DOI: 10.1126/science.aaz5845
- Woodworth, P.L., Melet, A., Marcos, M. *et al.* Forcing Factors Affecting Sea Level Changes at the Coast. *Surv Geophys* **40**, 1351–1397 (2019). https://doi.org/10.1007/s10712-019-09531-1

Questions?

- Please enter your questions in the Q&A box. We will answer them in the order they were received.
- We will post the Q&A to the training website following the conclusion of the webinar.



Credit: USGS, Landsat 8


APPLIED REMOTE SENSING TRAINING PROGRAM
TRAIN - EMPOWER - ADVANCE

Thank You!