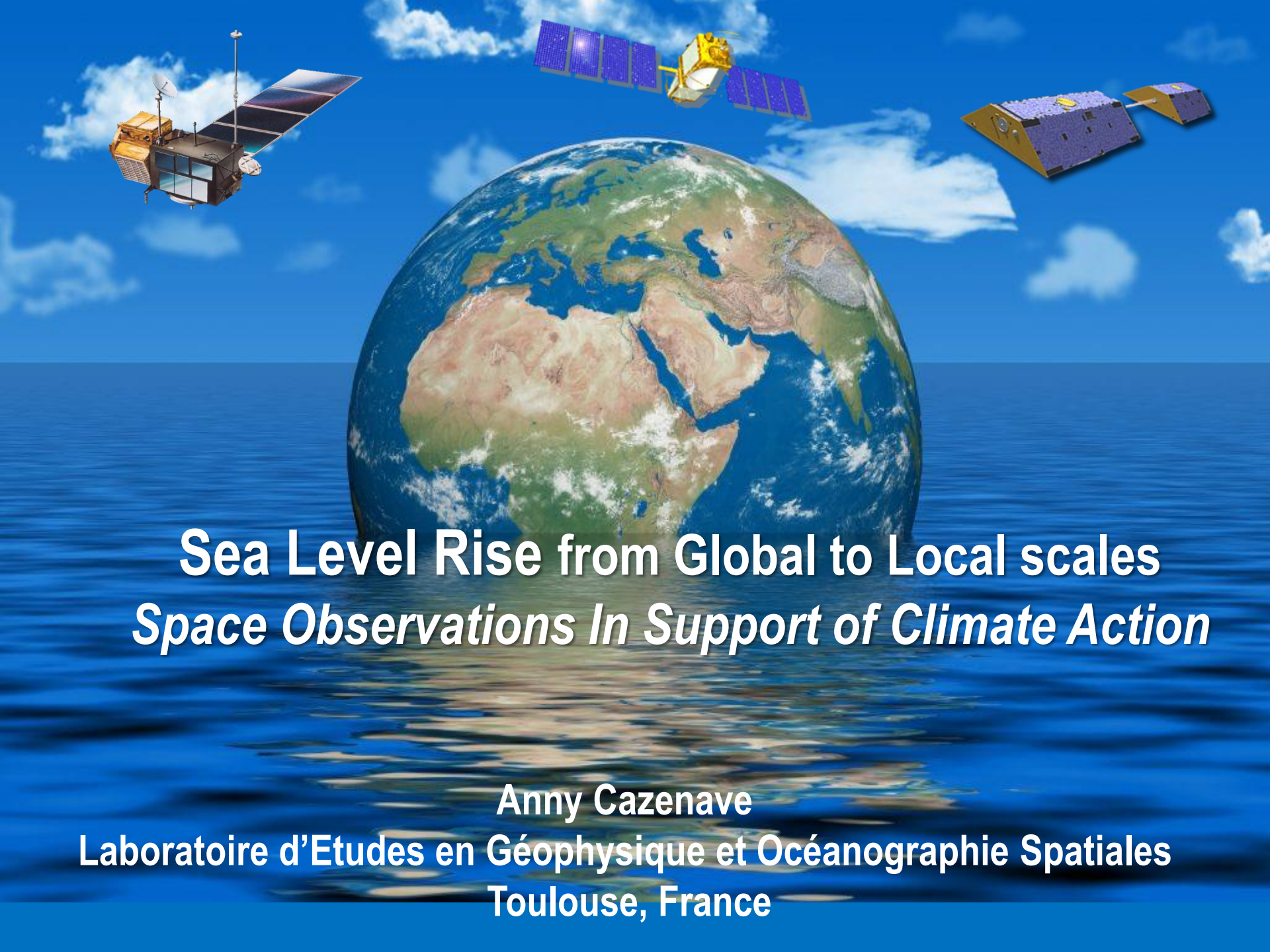


Sea Level Rise from Global to Local scales

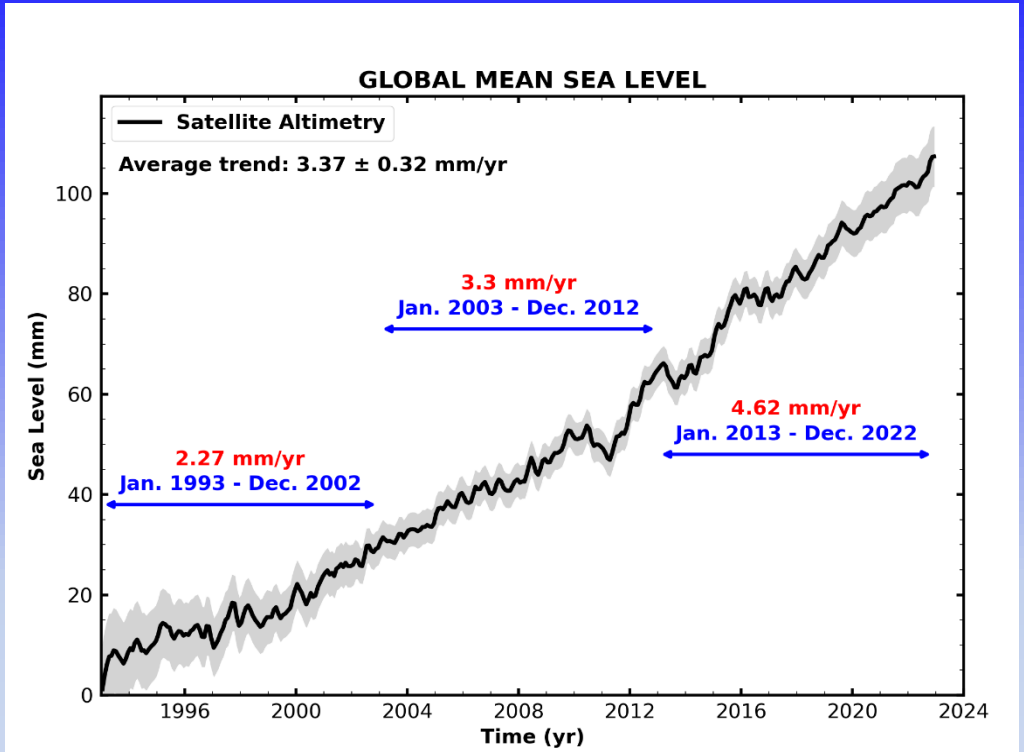
Space Observations In Support of Climate Action

Anny Cazenave

Laboratoire d'Etudes en Géophysique et Océanographie Spatiales

Toulouse, France

Global Mean Sea Level Rise

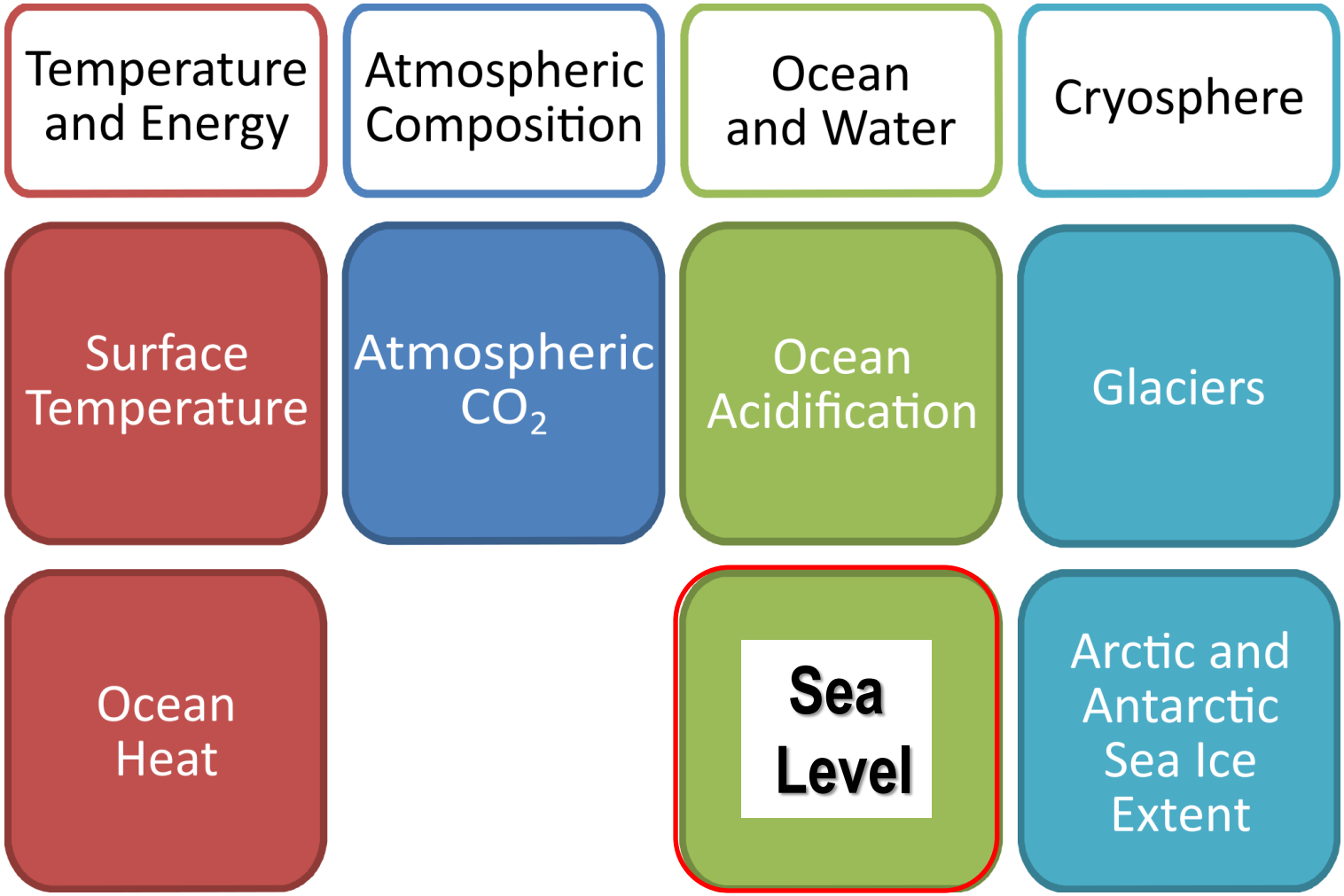


… A leading indicator of global climate changes

→integrated response to changes in ocean heat content, in land ice & land water storage to external forcings and internal variability

With extreme events, future sea level rise will be a major threat for many low-lying and highly- populated coastal regions of the world

The 7 global indicators of present-day climate change



defined by GCOS (Global Climate Observing System) and WMO (World Meteorological Organization)

GCOS GLOBAL CLIMATE OBSERVING SYSTEM

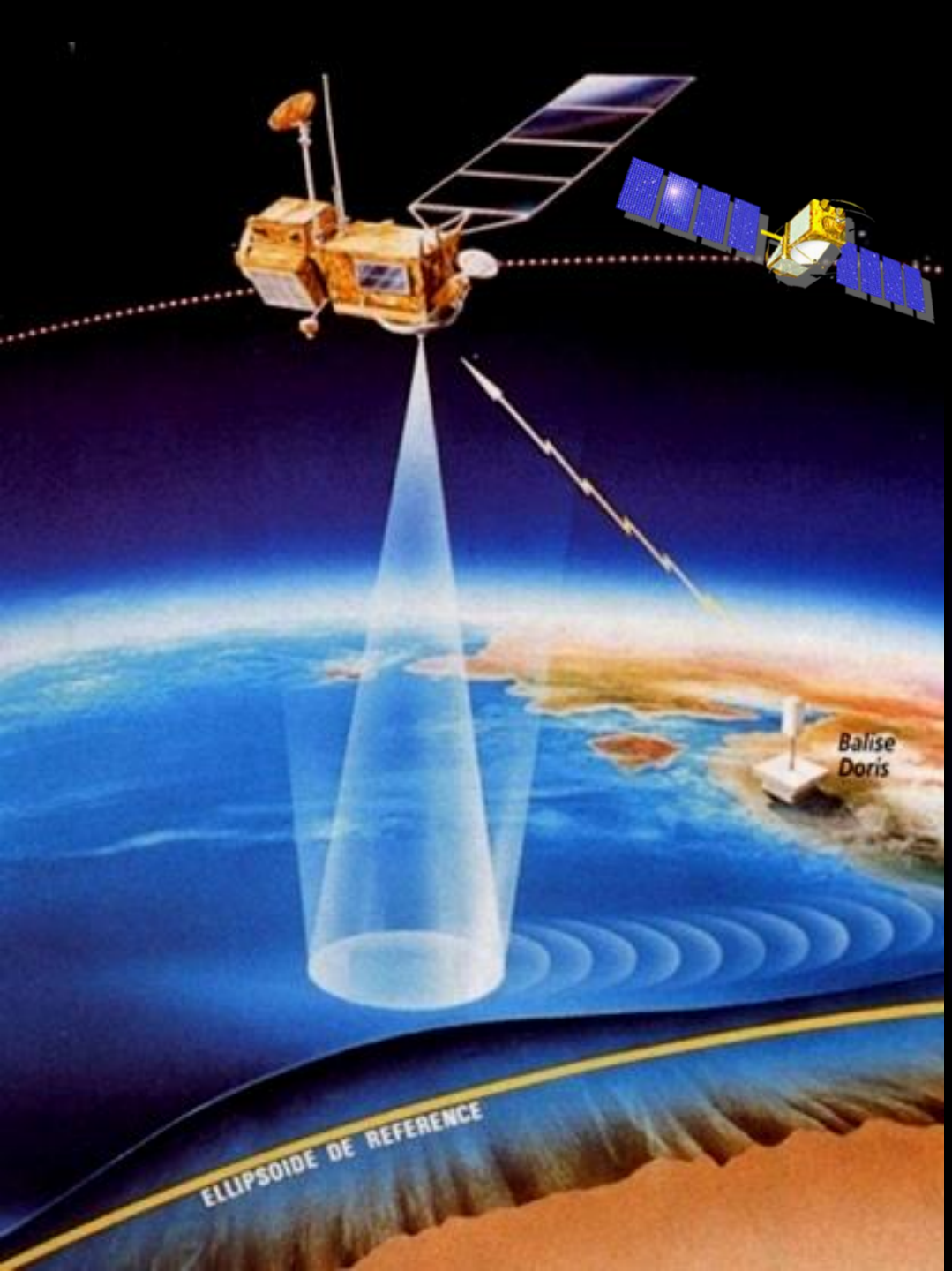
WORLD METEOROLOGICAL ORGANIZATION

Key Questions Related to Current Sea Level Research

- How much will sea level rise, globally and regionally, over the next decades and beyond, in response to ice sheet mass loss and ocean warming?

- How will sea level change along the world coastlines?

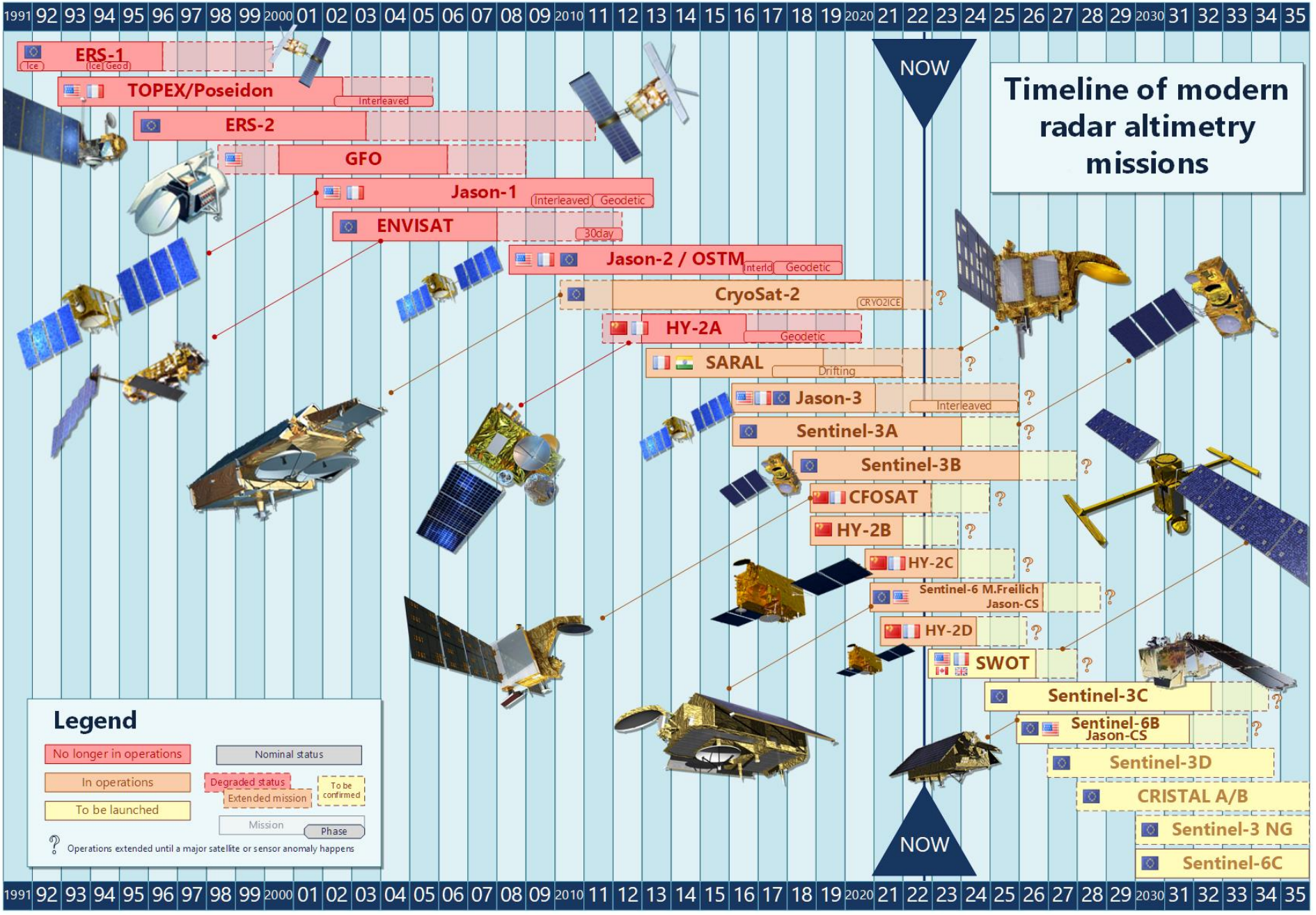
Space observations are now unavoidable for answering these questions

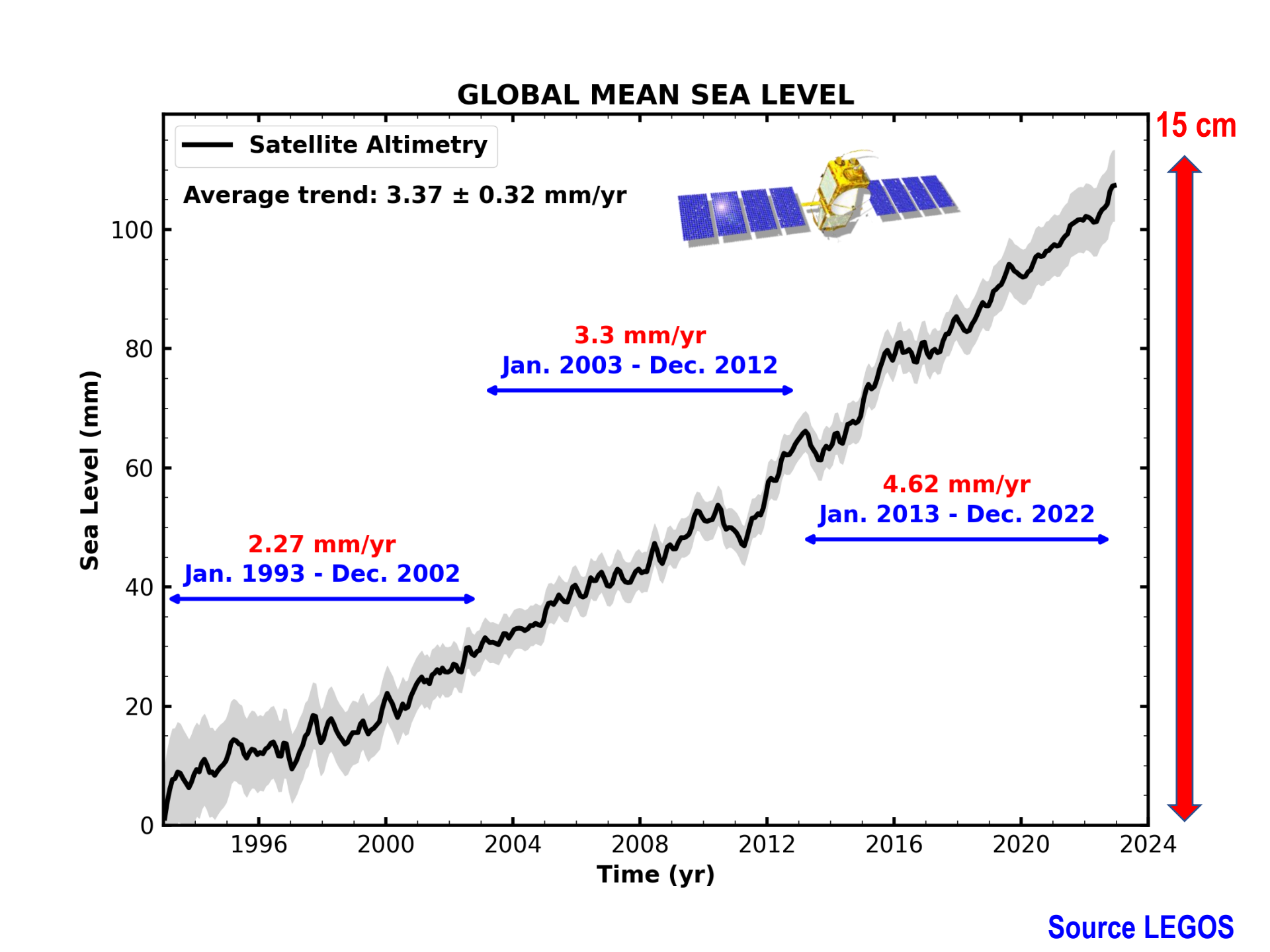


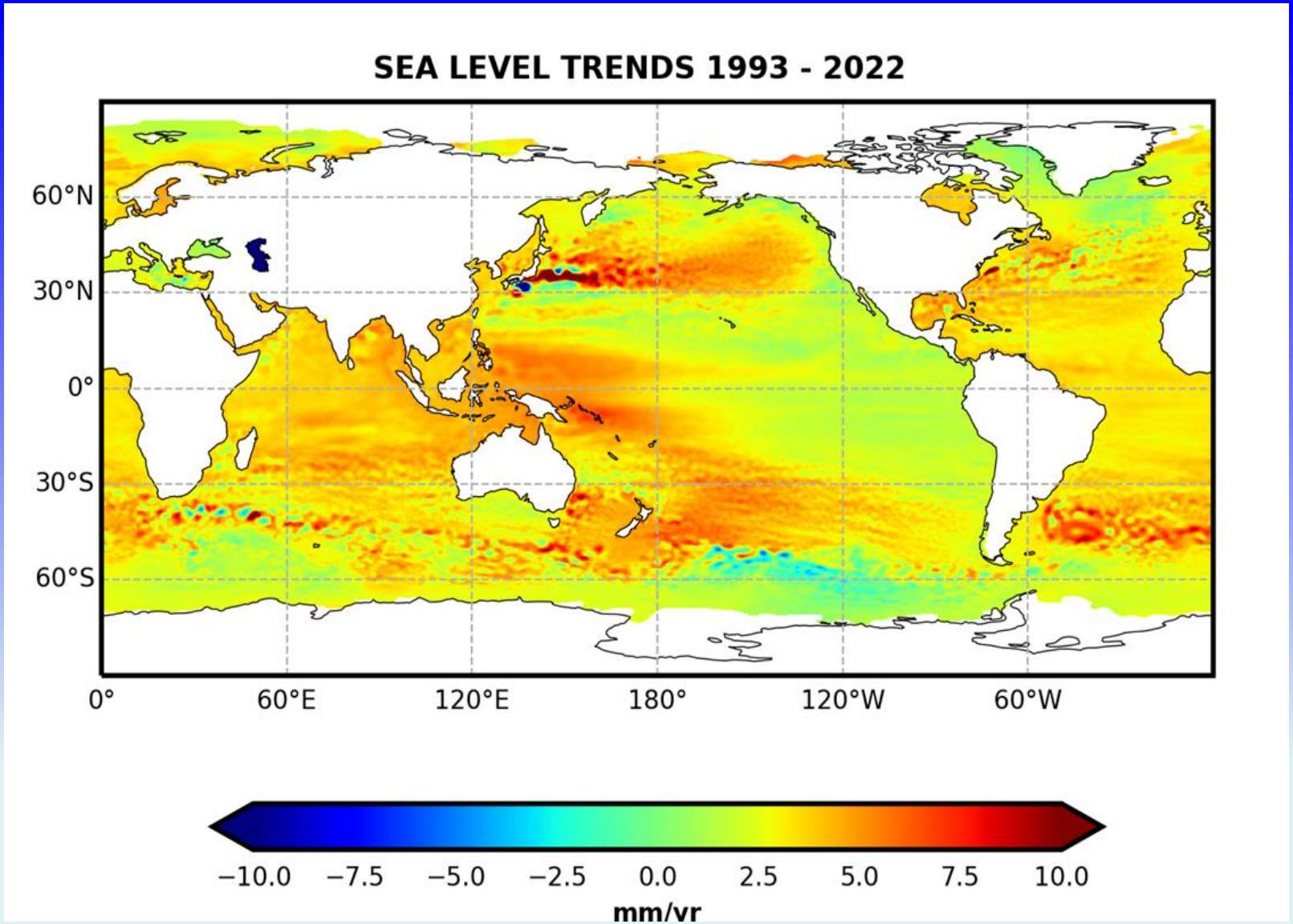
Since the early 1990s satellite altimetry routinely measures sea surface topography from which sea level rise is deduced

Global coverage of the oceans in ~10 days

Constellation of high-precision altimeter satellites since the early 1990s




GLOBAL MEAN SEA LEVEL
Satellite Altimetry
Average trend: 3.37 ± 0.32 mm/yr
3.3 mm/yr
Jan. 2003 - Dec. 2012
4.62 mm/yr
Jan. 2013 - Dec. 2022
2.27 mm/yr
Jan. 1993 - Dec. 2002
15 cm
Sea Level (mm)
Time (yr)
0
20
40
60
80
100
1996
2000
2004
2008
2012
2016
2020
2024
Source LEGOS



Spatial trend patterns amplify the global mean rise

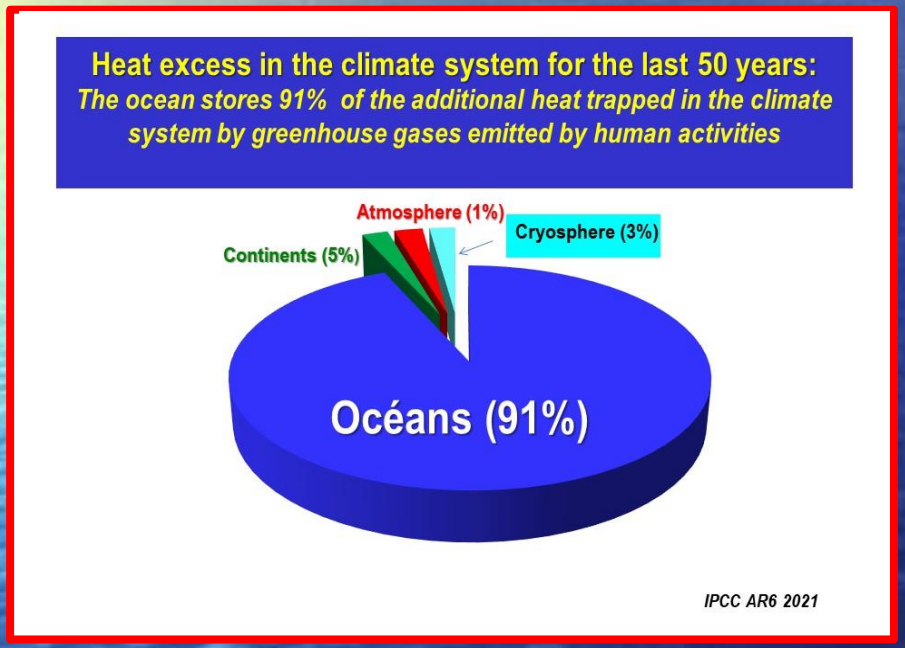
→ **Regional rates can be up to 2-3 times larger than the global mean sea level rise**

Sea Level is not only rising but it is accelerating

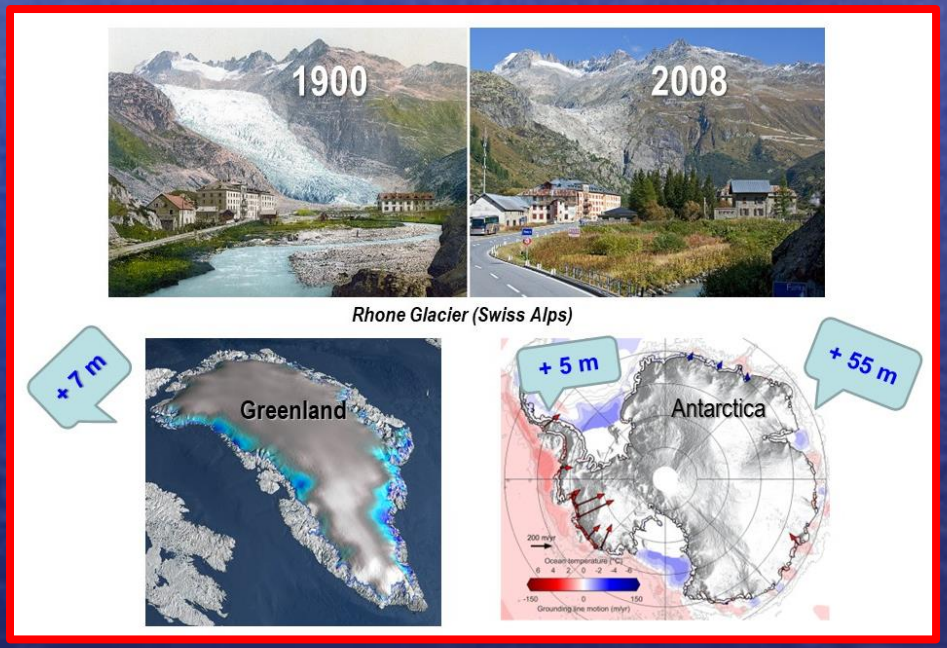
- Rate of rise 1993 - 2002: **2.3 mm/yr**
- Rate of rise 2013 - 2022: **4.6 mm/yr**
- Acceleration mostly due to accelerated ice mass loss from Greenland and Antarctica

Present-day sea level rise: a direct consequence of global warming

Ocean warming and land ice loss are the two main causes of present-day global mean sea level rise

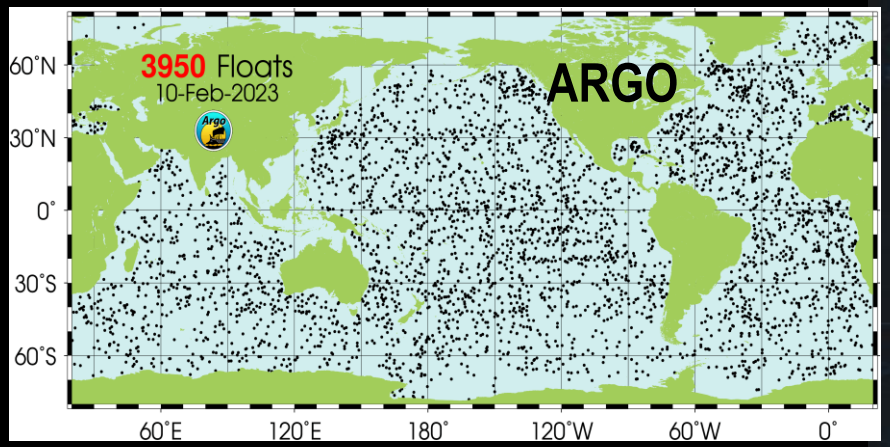


Ocean warming



Land ice melting

Different Observing Systems



SPACE GRAVIMETRY→ GRACE Mission (2002-2017) + GRACE Follow-on (since May 2018)

→ Measurements of spatio-temporal variations of the Earth's gravity field

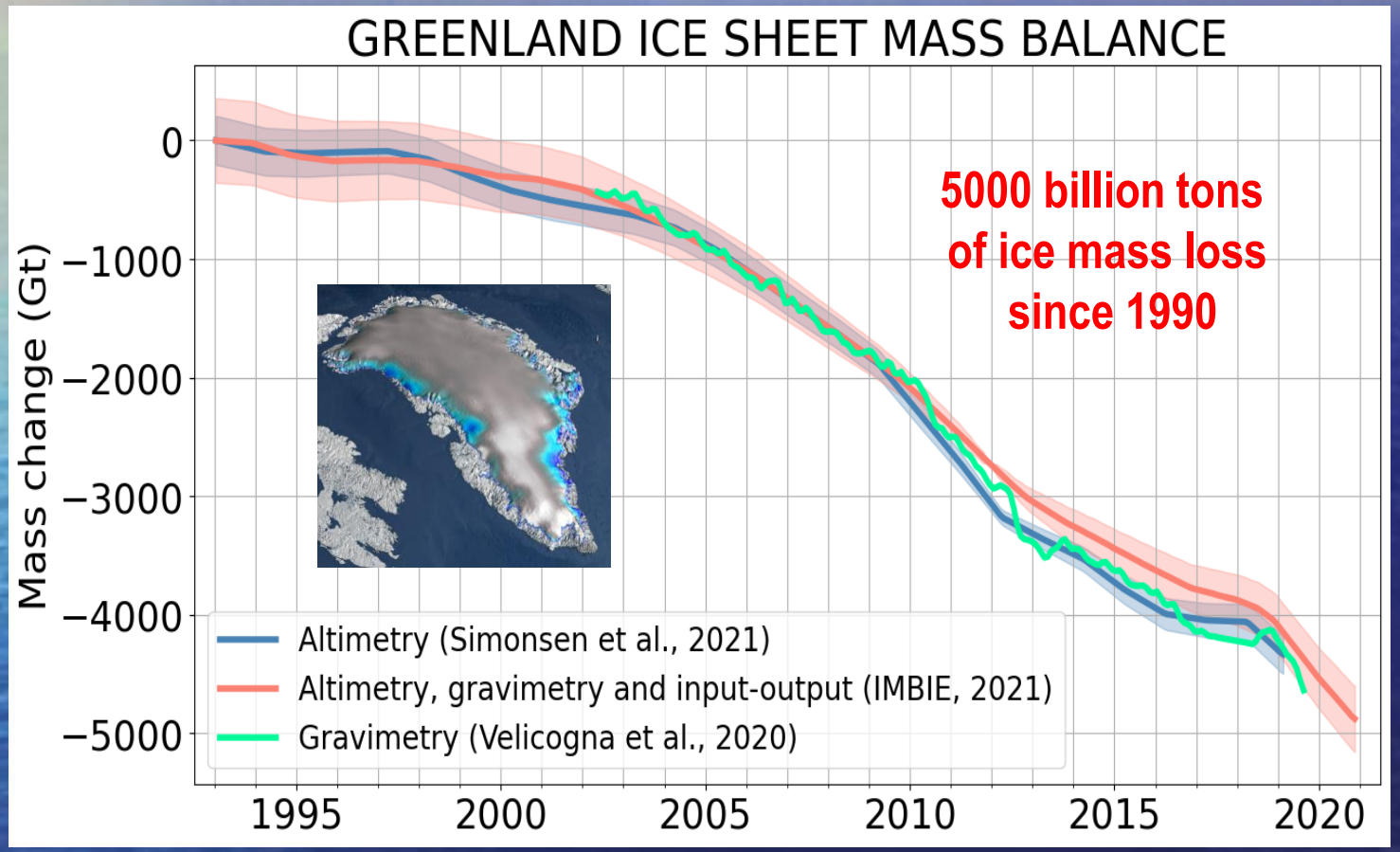
→ Mass redistributions at the surface of the Earth and within its interior

→ Temporal resolution : 1 month

→ Spatial resolution : ~300 km

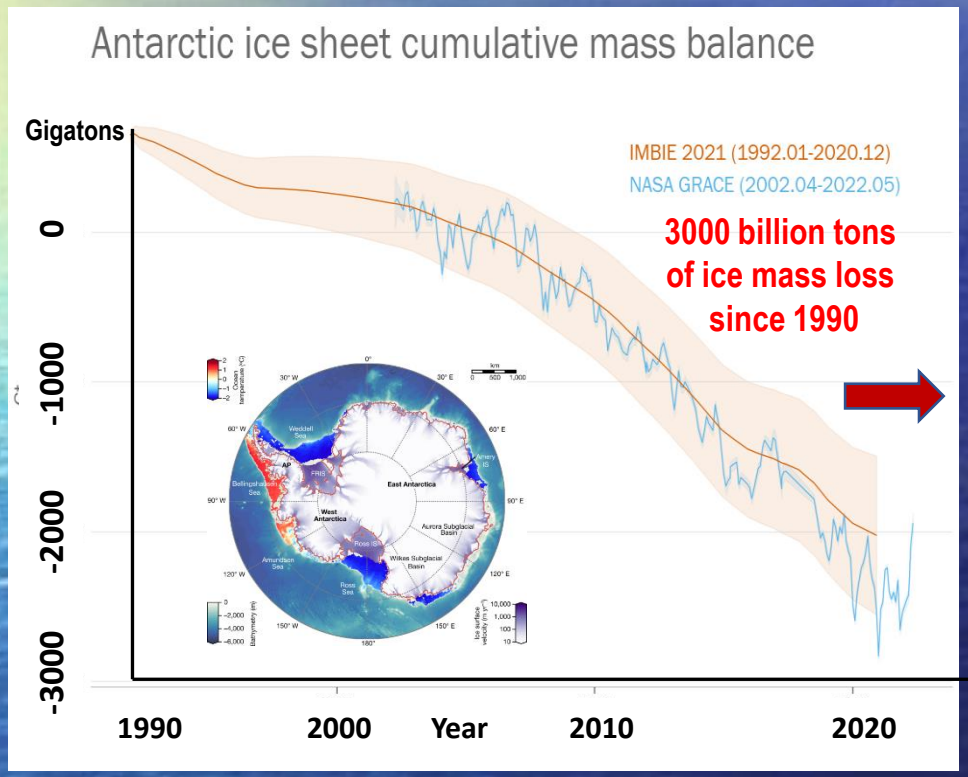
→ MASS COMPONENTS

Ice Mass Loss in Greenland

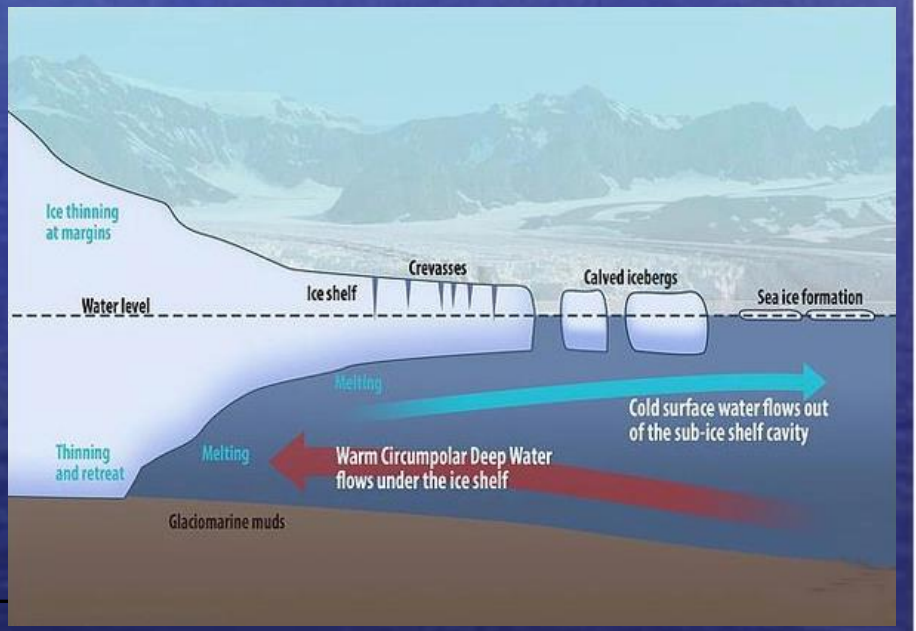


Barnoud et al., 2022

Ice Mass Loss in Antarctica

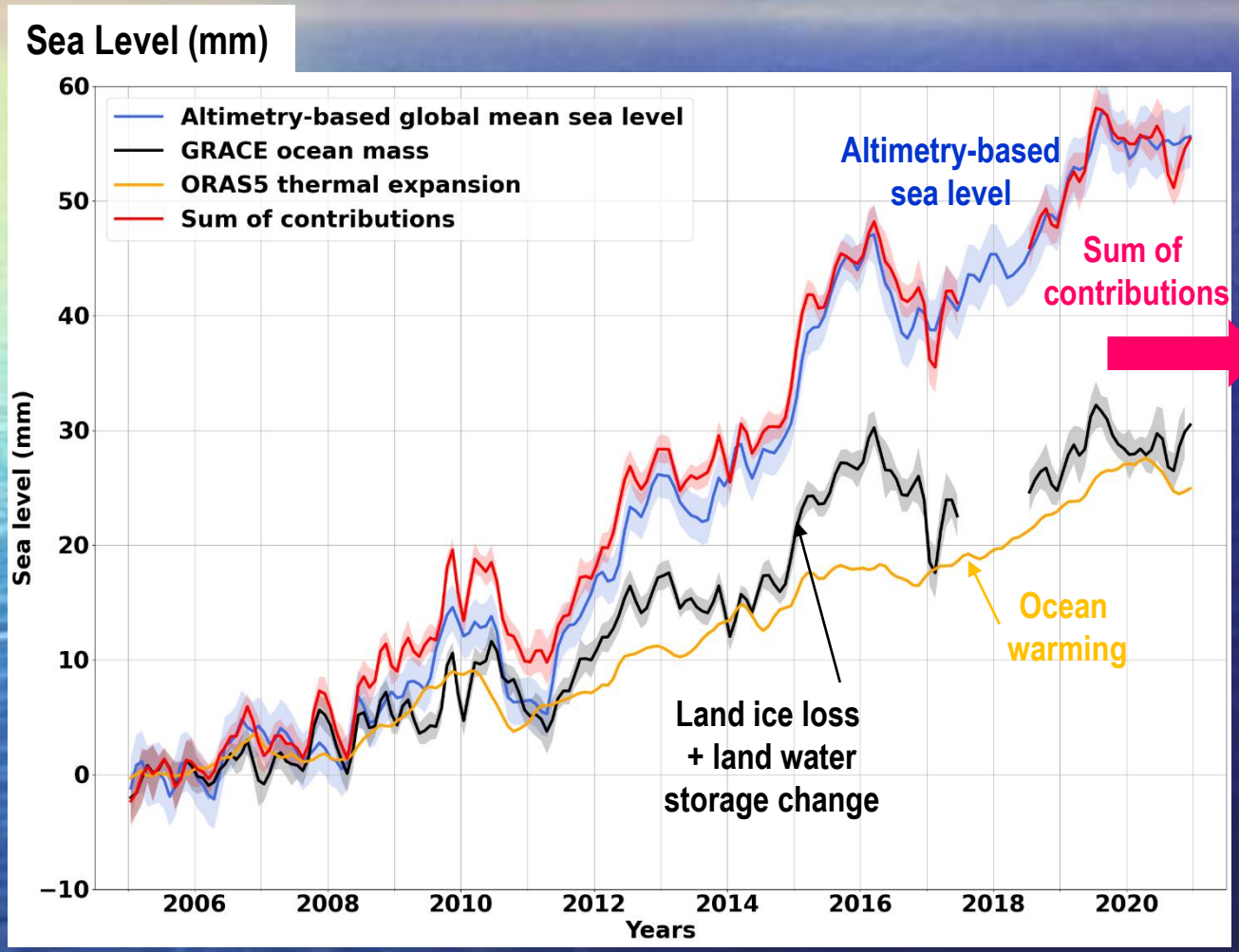


State of the global climate 2022, World Meteorological Organization



Warm coastal ocean waters cause dynamical instabilities at the ice sheet margin
→ accelerated ice mass flow into the ocean

Global Mean Sea Level Budget



CONTRIBUTIONS (last 15 years)

- Ocean thermal expansion: **~40%**
- Total land ice melt (Glaciers+Greenland +Antarctica) + land waters **~60%**

Barnoud et al., 2023

Why is it important to accurately measure sea level rise and understand its causes?

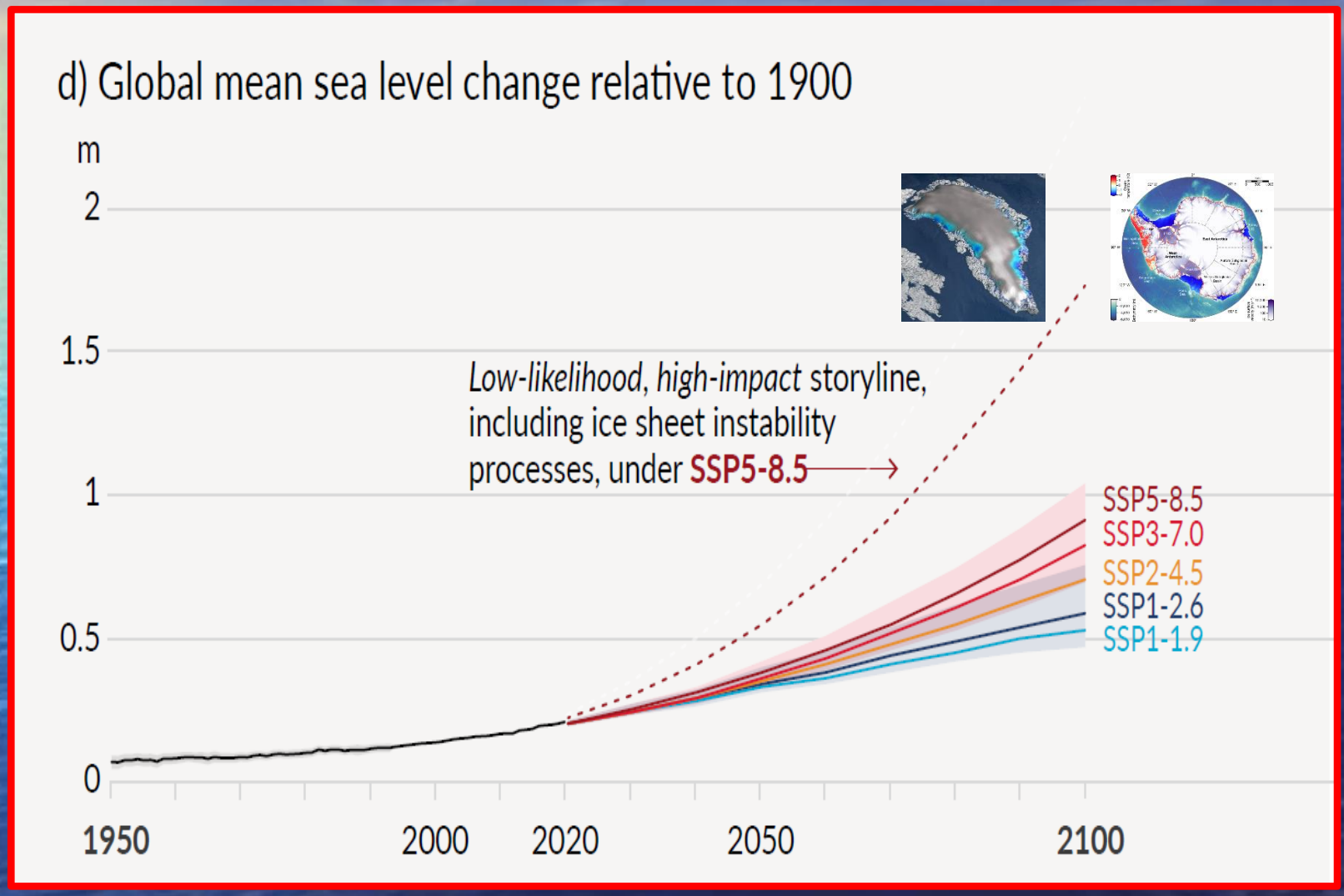
Global Mean Sea Level → An important metric of global climate change

Global Mean Sea Level Budget → important to…

- **Better understand processes at work and follow temporal changes (acceleration?, irreversible change?) of individual components**
- **Place bounds on missing or poorly known contributions *(e.g., deep >2000m ocean warming not sampled by Argo)***
- **Constrain current Earth's Energy Imbalance**

- **Validate climate models used for projections**

Sea level rise projections by 2100 for different warming scenarios



IPCC AR6, 2021

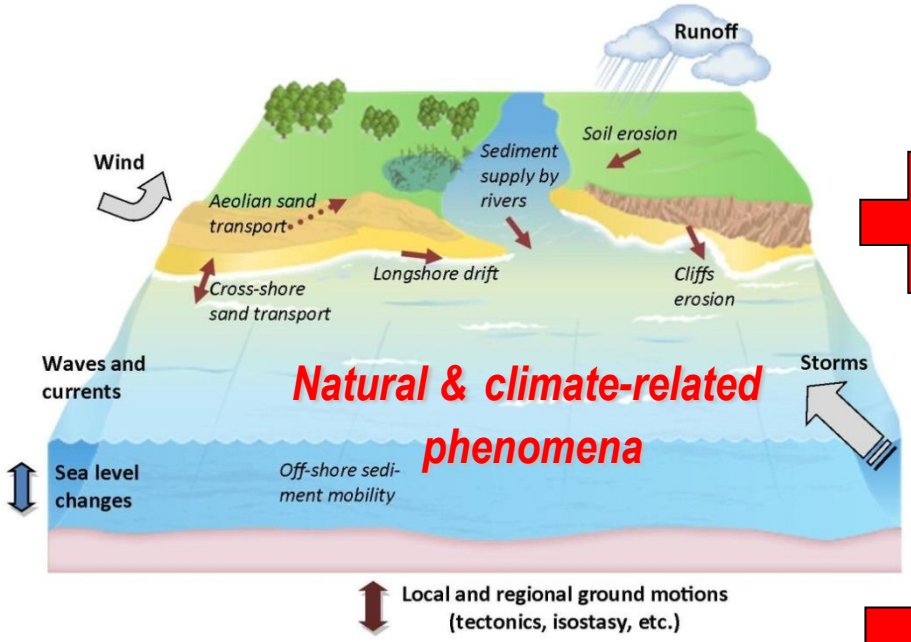
New challenge:
Measure sea level rise at the coast

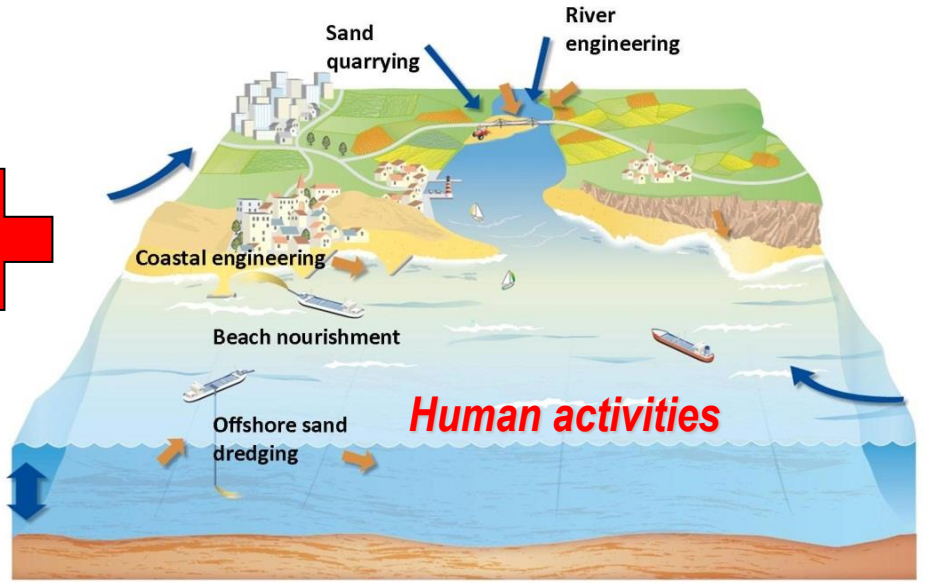
Coastal sea level rise =
global mean rise
+ regional trends
+ small-scale coastal processes

- Shelf currents
- Small-scale eddies
- Atmospheric forcing & wind stress
- Wind-waves
- Density changes in river estuaries & deltas
- Changing tides
- Climate modes
- ....

unknowns

Coastal Zones : 10% of the world population





Complex processes and impacts

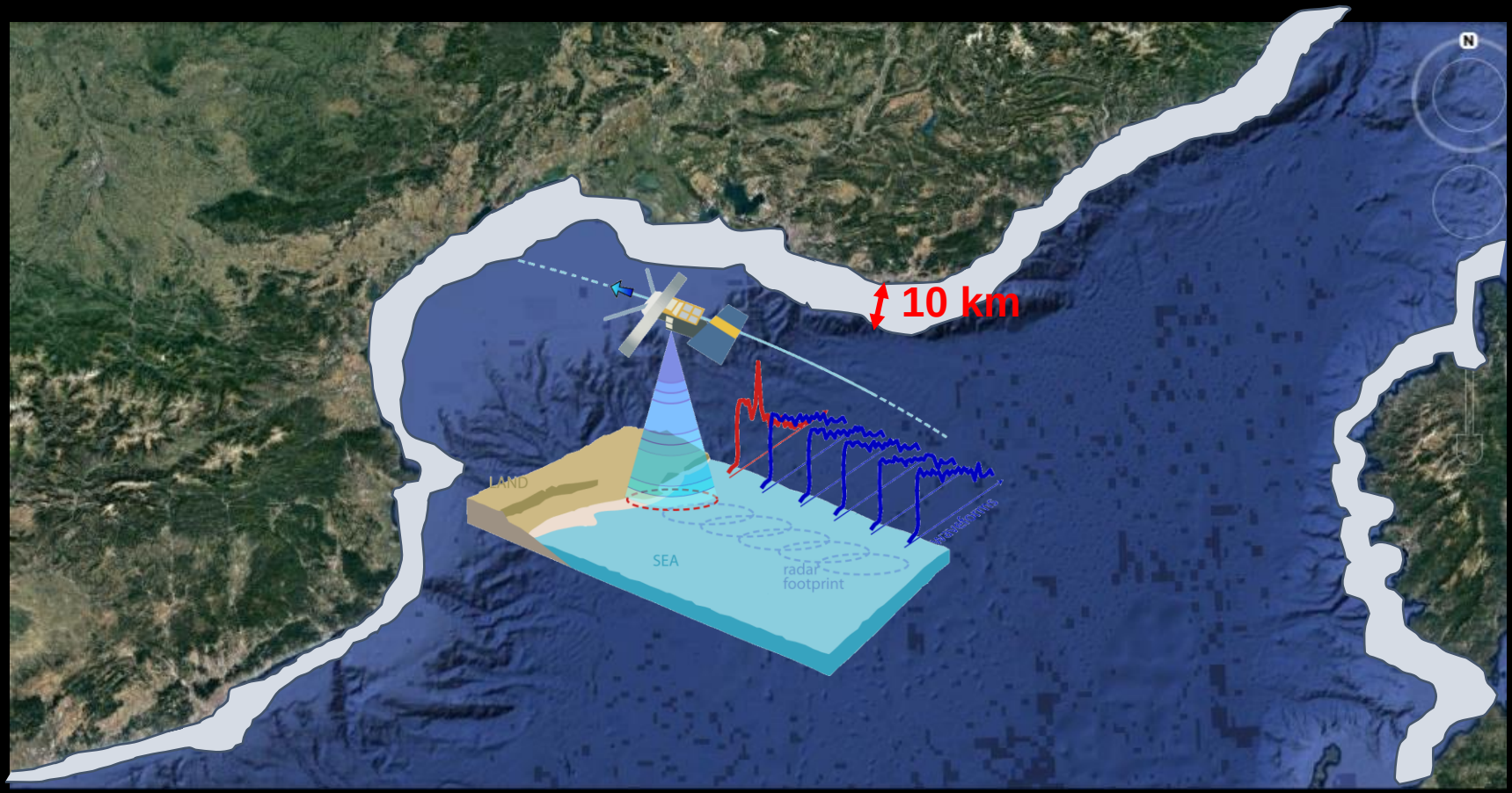
Climate & Other Drivers

- Sea level rise
- Hurricanes, Storm surges
- Extreme waves and winds
- Changes in sea state, coastal currents & eddies, nutrient supply
- River floods
- Ground subsidence
- Coastal engineering
- etc……

Coastal Impacts

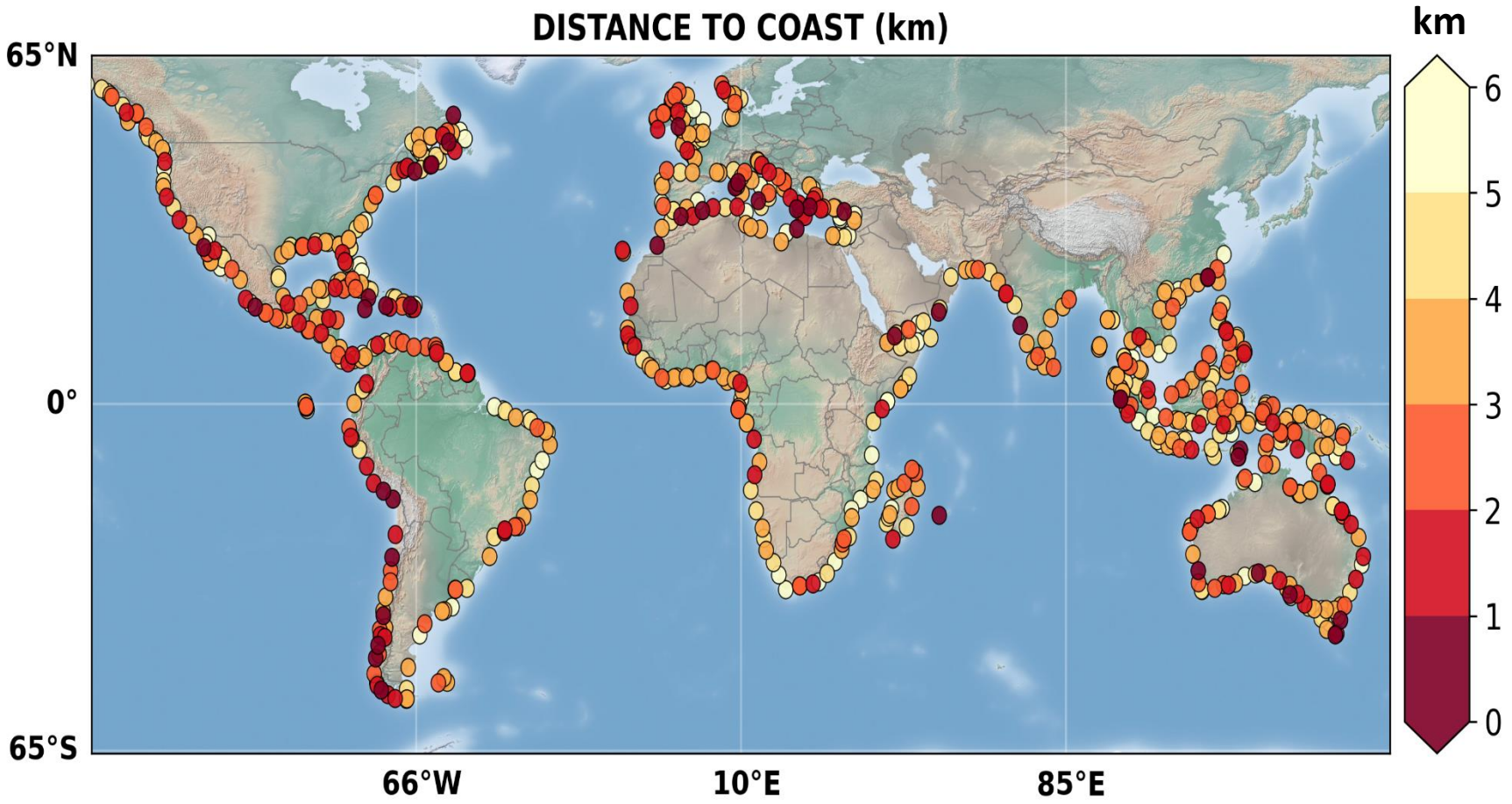
- Shoreline erosion and retreat
- Temporary and permanent flooding
- Changes in sediment stores and seafloor topography
- Changes in estuaries morphology
- Changes in coastal ecosystems
- Salinization of coastal aquifers
- etc……..

Satellite altimetry: optimized to study the open ocean



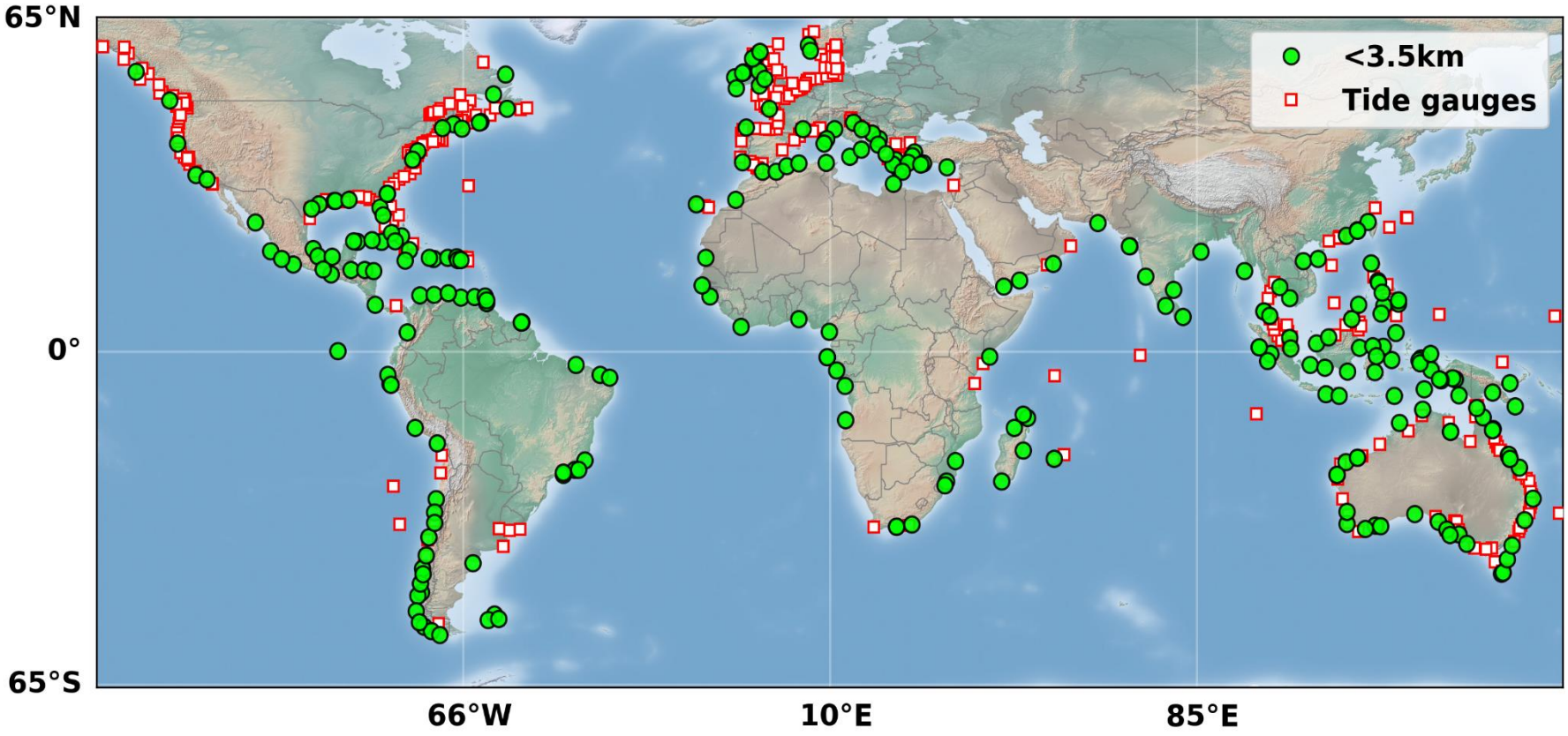
However, new dedicated reprocessing of past altimetry missions now allow constructing long term sea level time series along the world coastlines

‘Virtual’ coastal altimetry stations where long-term sea level time series and associated sea level trends are now avalable



Cazenave et al., 2022

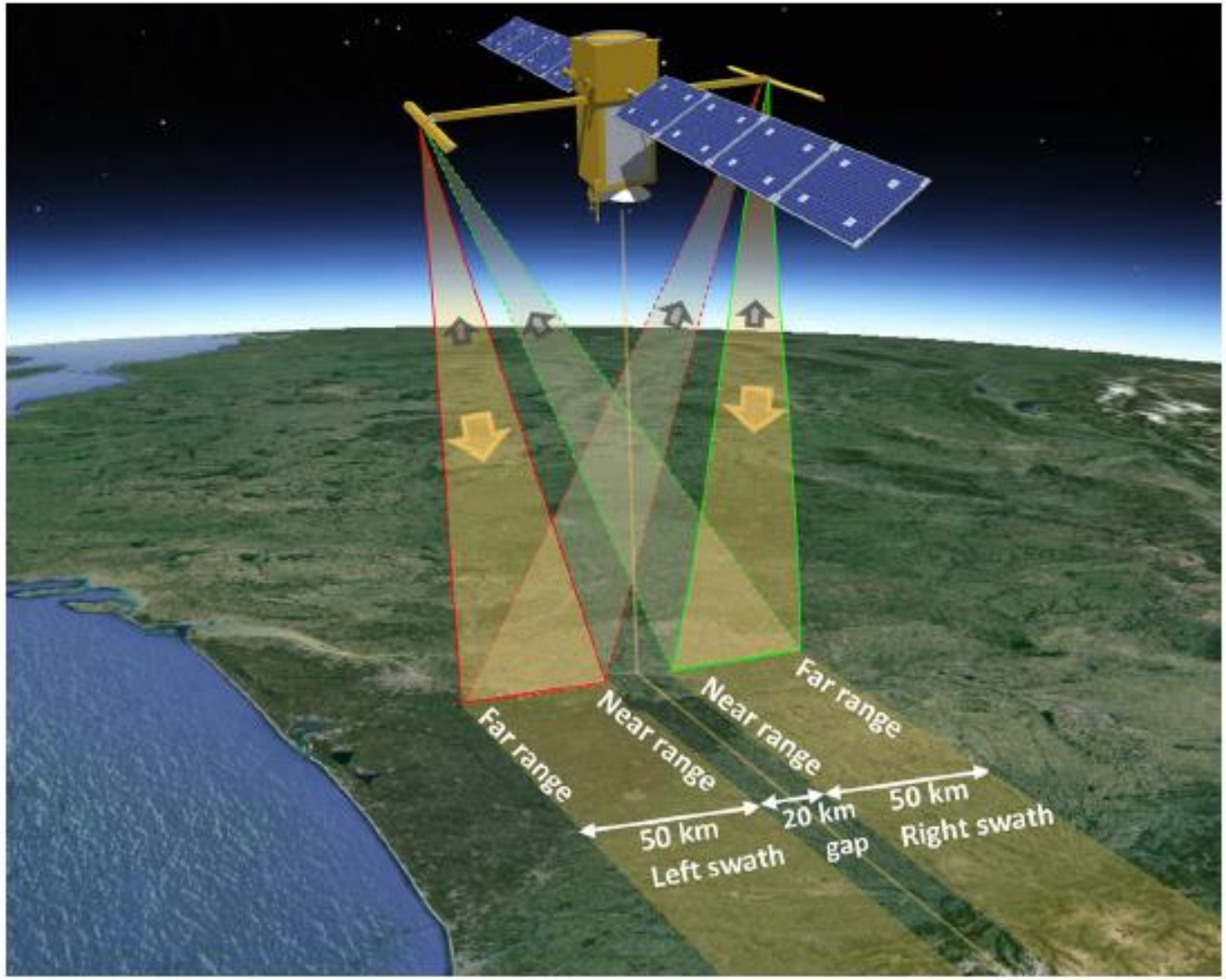
Virtual coastal altimetry stations located at less than 3.5 km from the coast (green dots) and tide gauge sites with available data since 2002 (red squares)

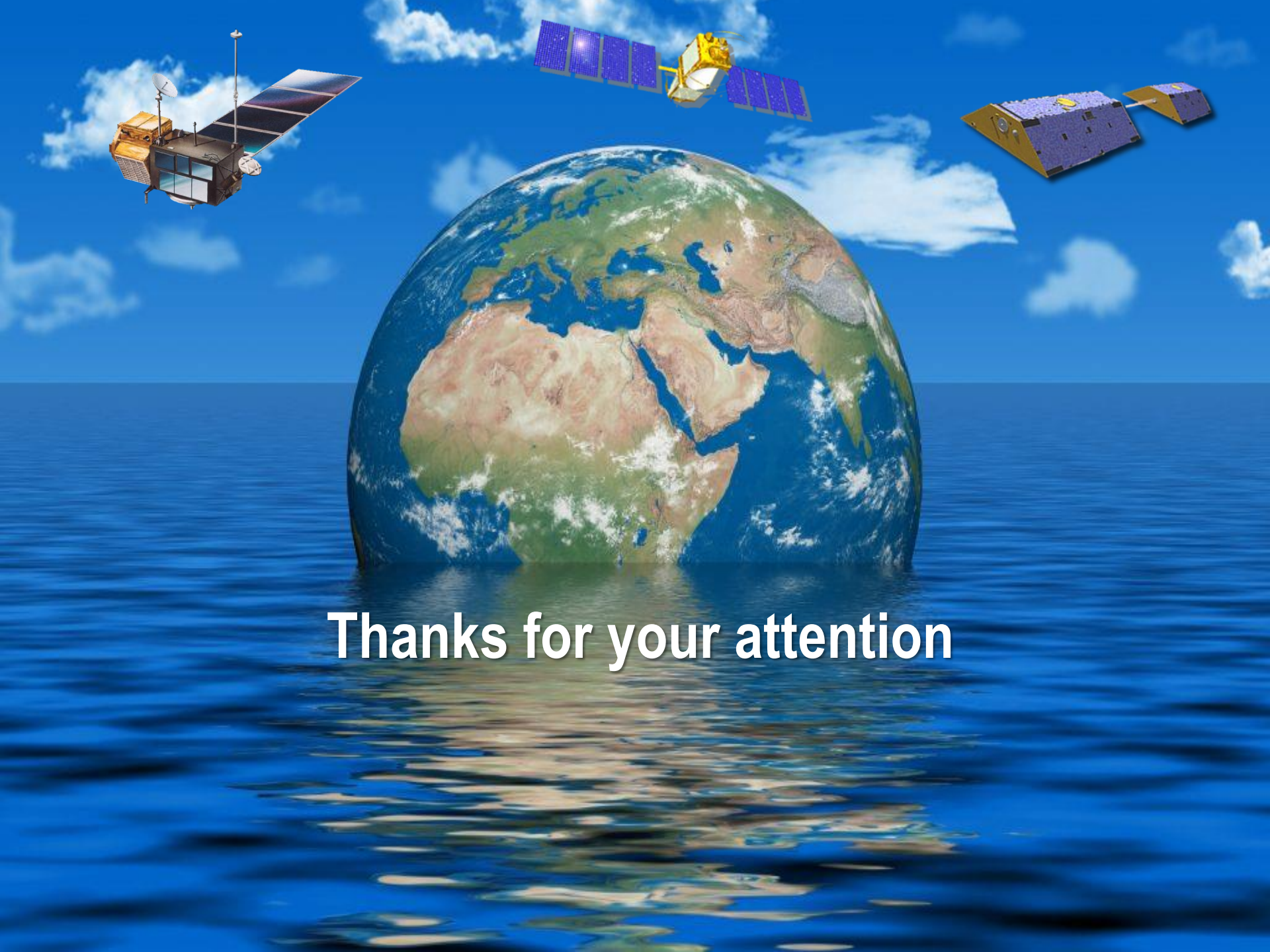


Cazenave et al., 2022

SWOT « Surface Waters-Ocean Topography »

(launched 16 December 2022)




Thanks for your attention