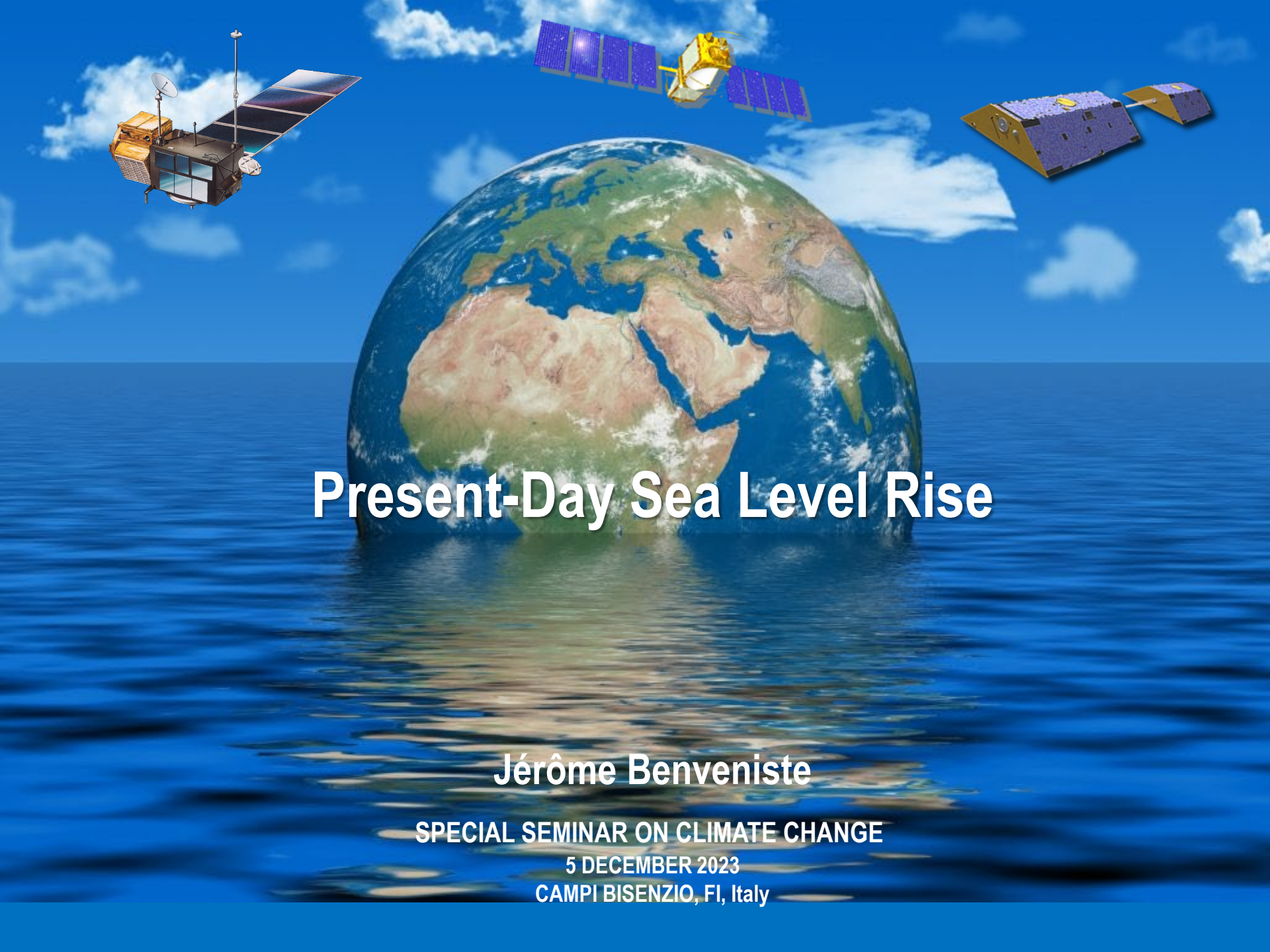


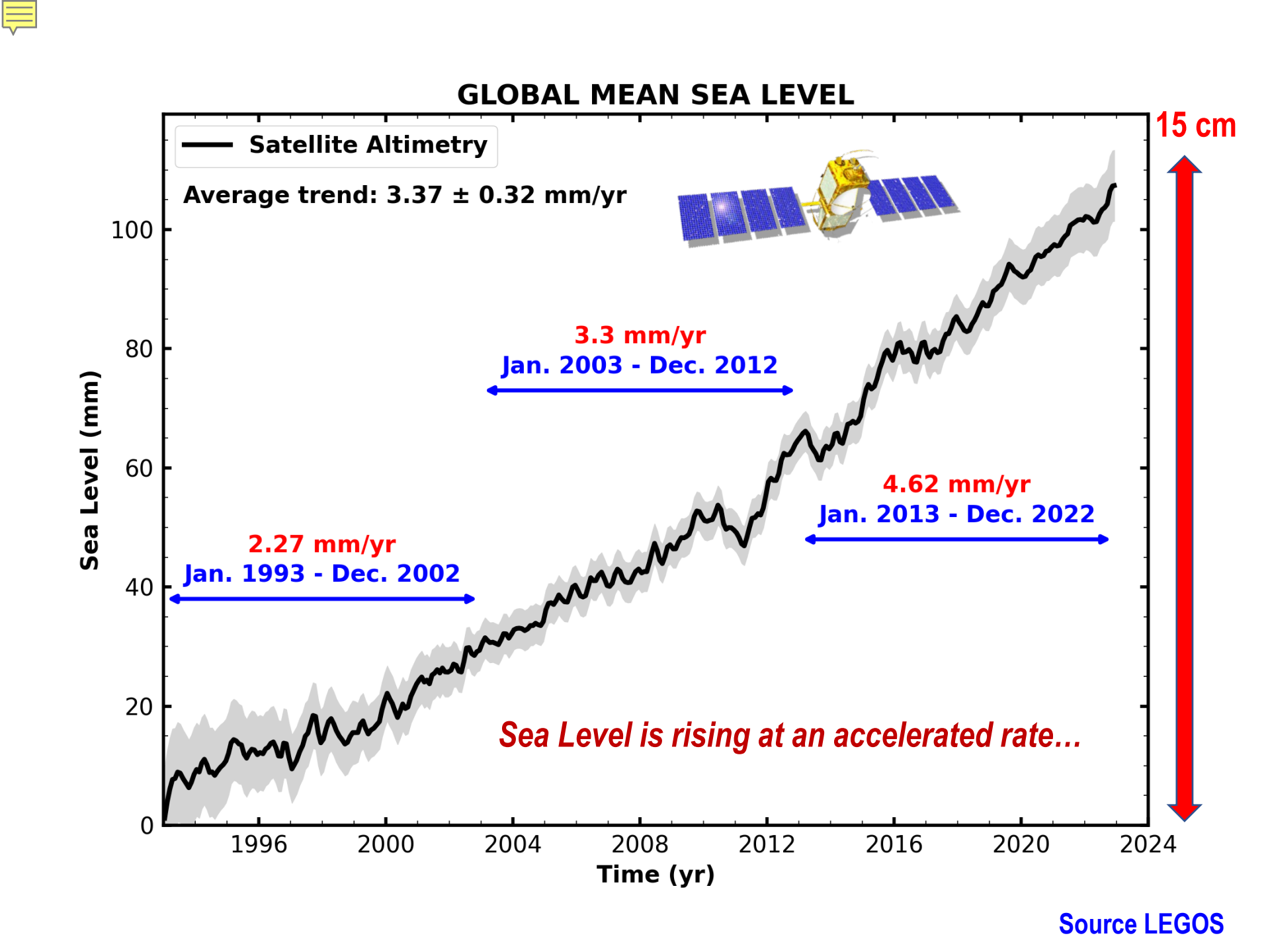
Present-Day Sea Level Rise

Jérôme Benveniste

SPECIAL SEMINAR ON CLIMATE CHANGE

5 DECEMBER 2023

CAMPI BISENZIO, FI, Italy

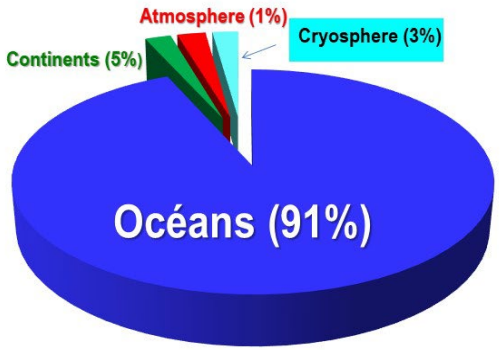

GLOBAL MEAN SEA LEVEL
Satellite Altimetry
Average trend: 3.37 ± 0.32 mm/yr
15 cm
3.3 mm/yr
Jan. 2003 - Dec. 2012
4.62 mm/yr
Jan. 2013 - Dec. 2022
2.27 mm/yr
Jan. 1993 - Dec. 2002
Sea Level is rising at an accelerated rate...
Sea Level (mm)
Time (yr)
0
20
40
60
80
100
1996
2000
2004
2008
2012
2016
2020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

Sea Level rise 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

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

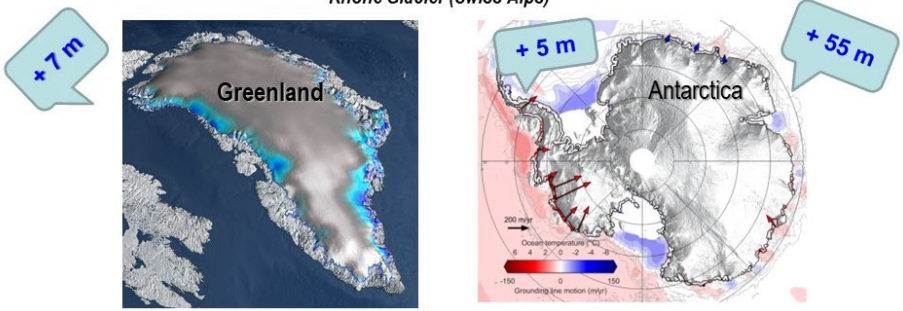
Heat excess in the climate system for the last 50 years:
The ocean stores 91% of the additional heat trapped in the climate system by greenhouse gases emitted by human activities



IPCC AR6 2021

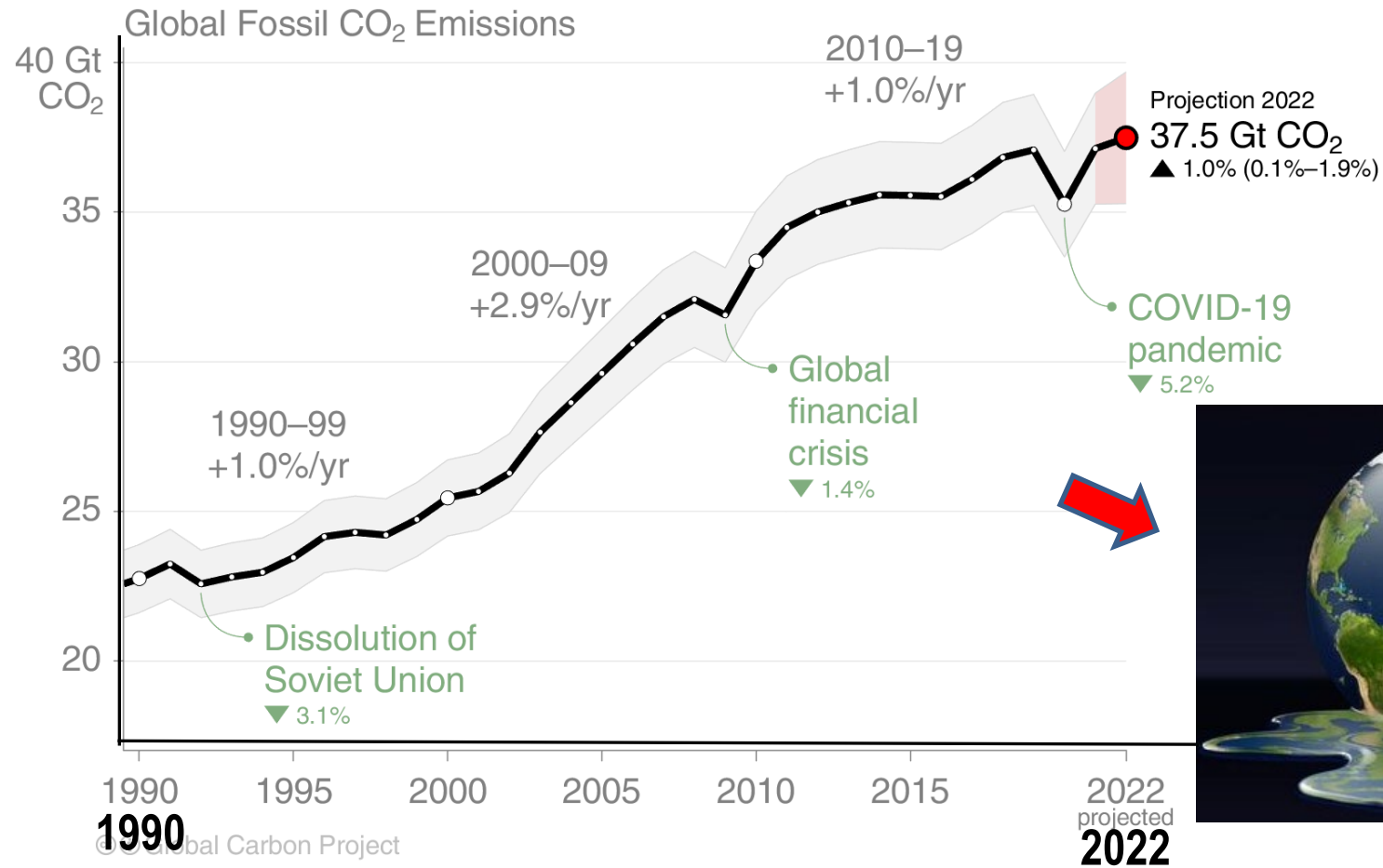
Ocean warming

Rhone Glacier (Swiss Alps)



Land ice melting

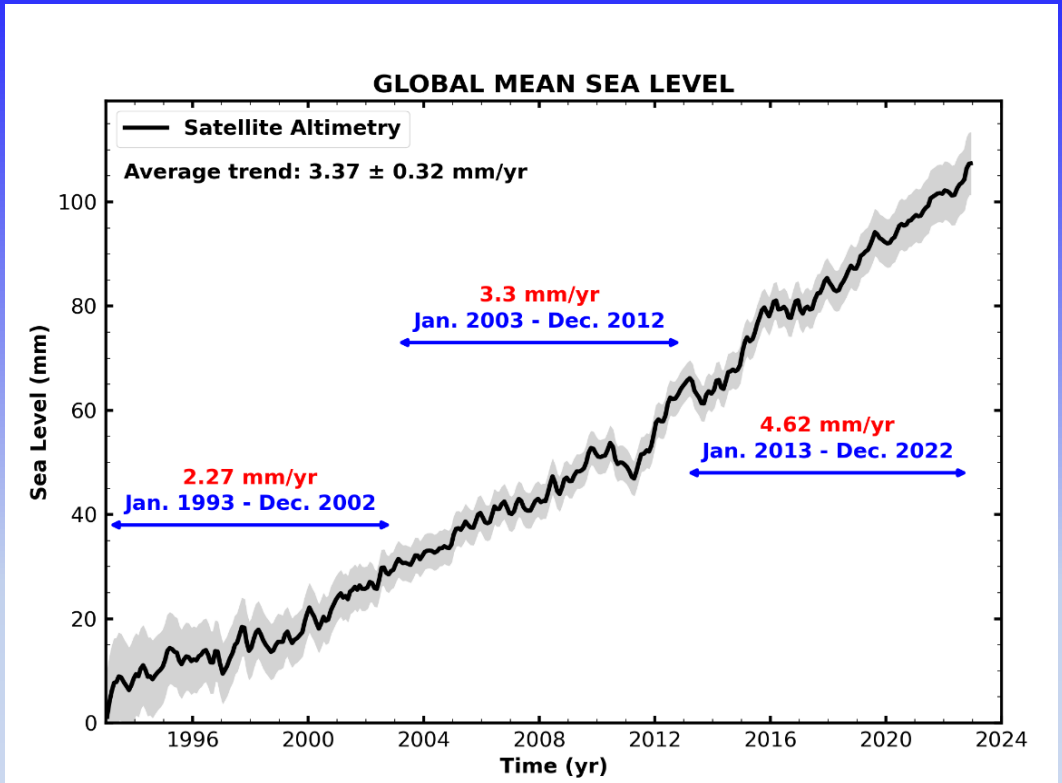
Greenhouse gas (CO_2) anthropogenic emissions since 1990



Global emissions in 2021 : 37.1 +/- 2 $GtCO_2$
(+63% wrt 1990)
Global emissions in 2022: 37.5 +/- 2 $GtCO_2$
(+1% wrt 2021)

Source: Global Carbon Project 2022

The Global Mean Sea Level Rise…

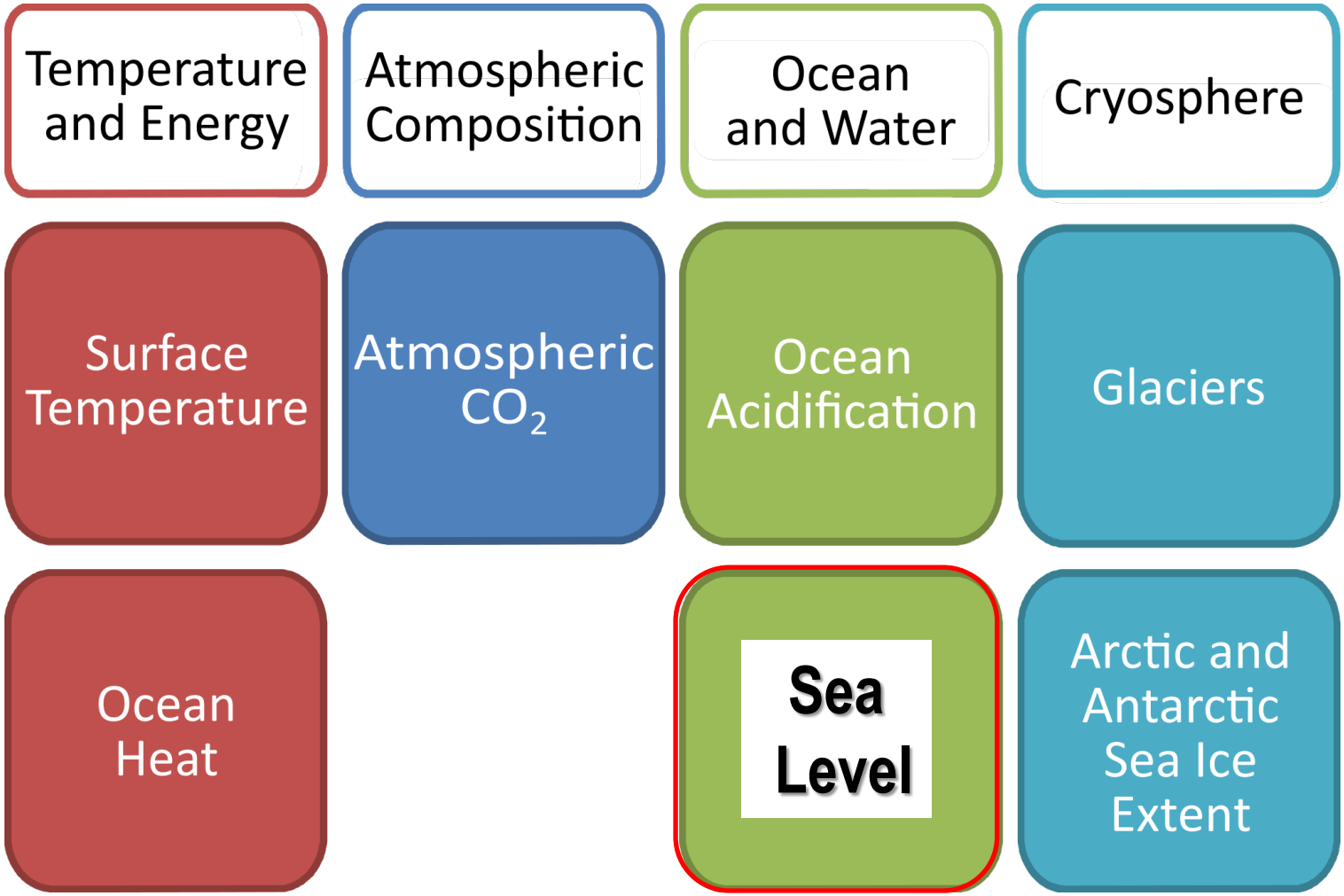


… is a leading indicator of global climate change

→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



GCOS GLOBAL CLIMATE OBSERVING SYSTEM

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

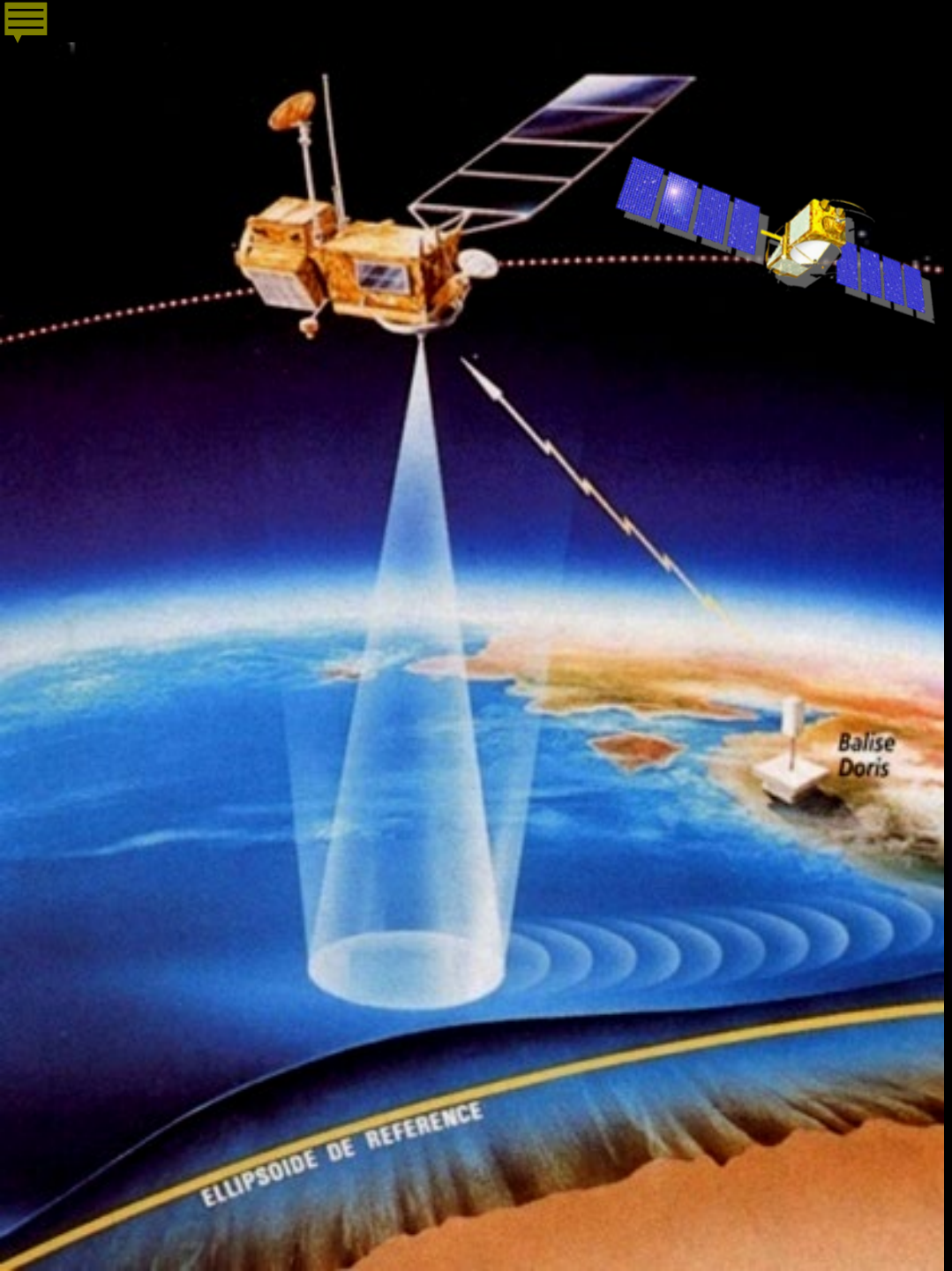
WORLD METEOROLOGICAL ORGANIZATION

Key Questions Related to Current Sea Level Research

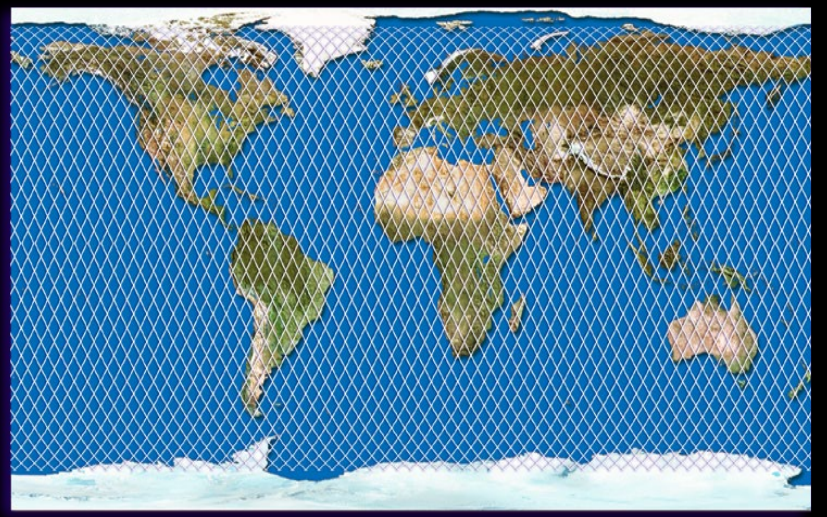
- How much will sea level rise, globally and regionally, over the next decades and beyond, in response to ice sheet mass loss and ocean warming?

- How will sea level change along the world coastlines?

Space observations are now unavoidable for answering these questions

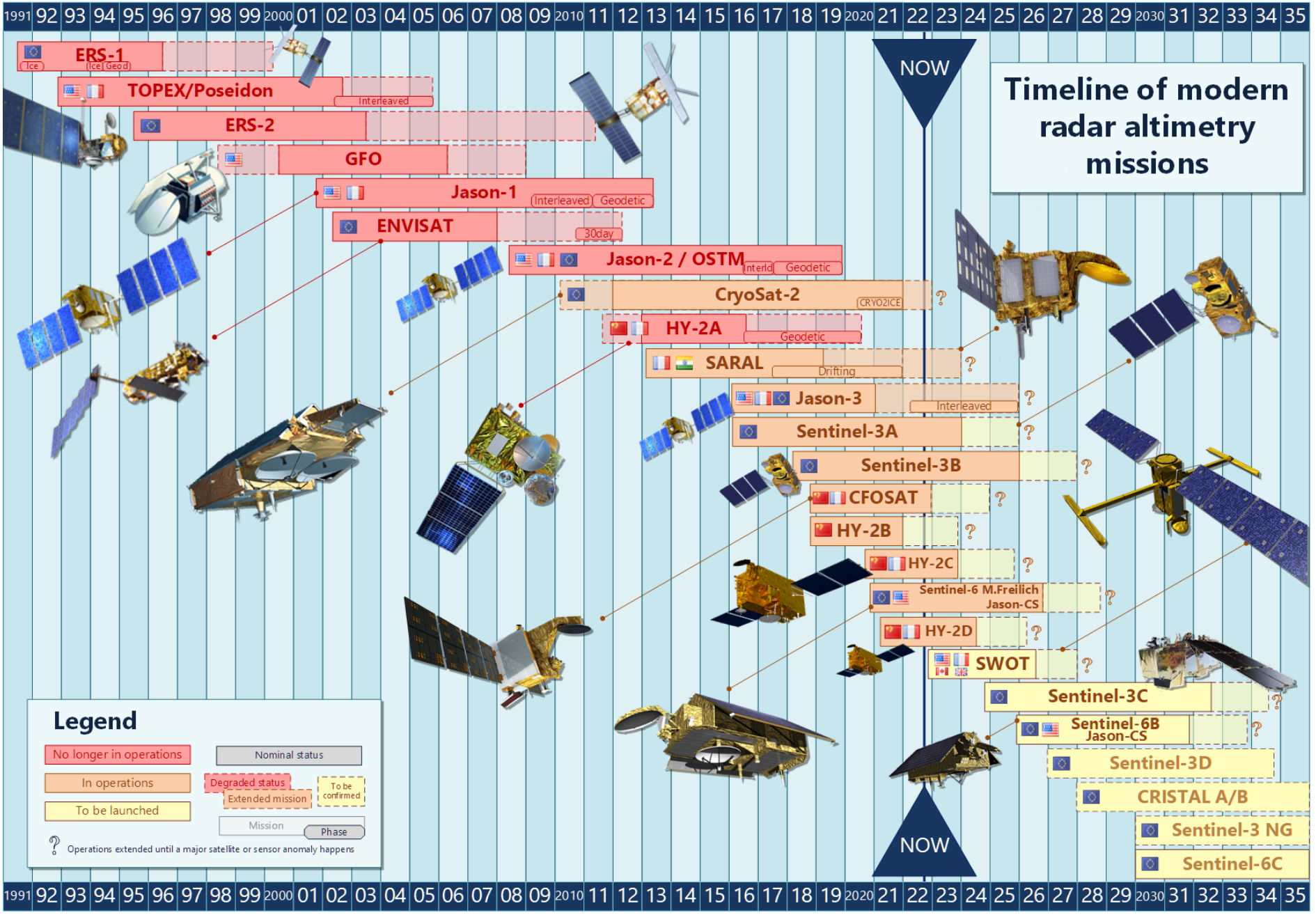


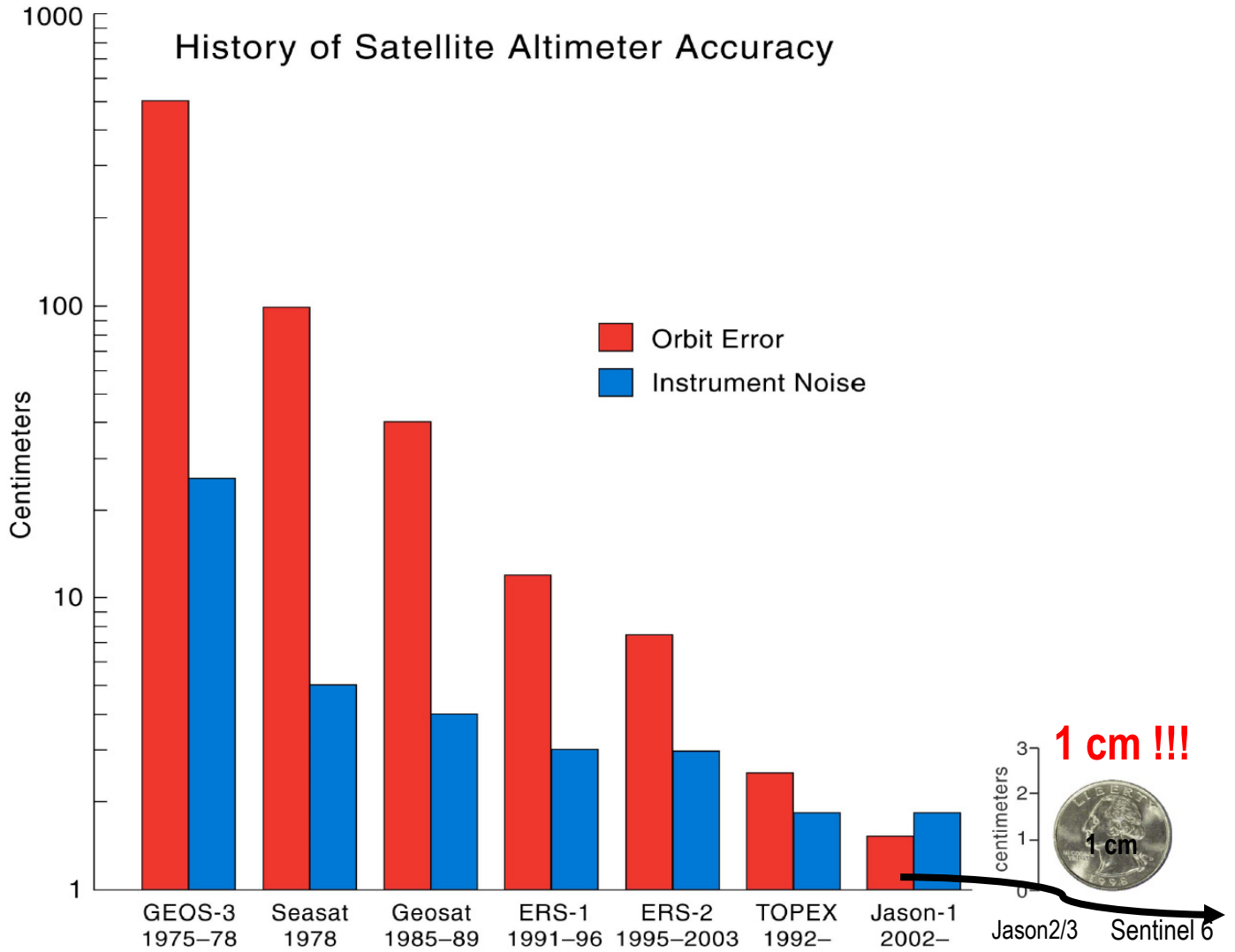
Since the early 1990s satellite altimetry routinely measures sea surface topography from which sea level rise is deduced



Global coverage of the oceans in a few days

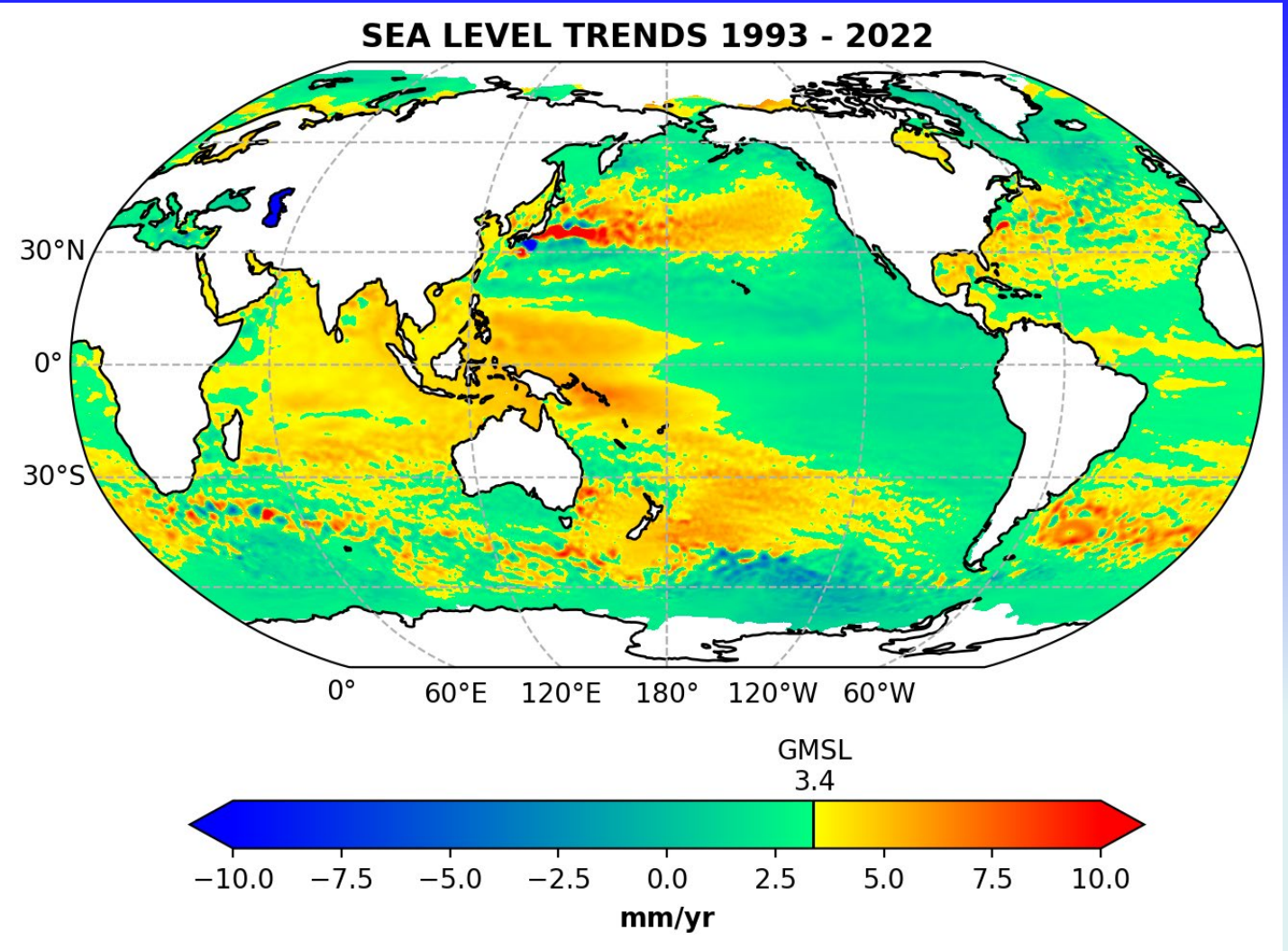
Constellation of high-precision altimeter satellites since the early 1990s





From L.L.Fu & A. Cazenave, IAC, 2022

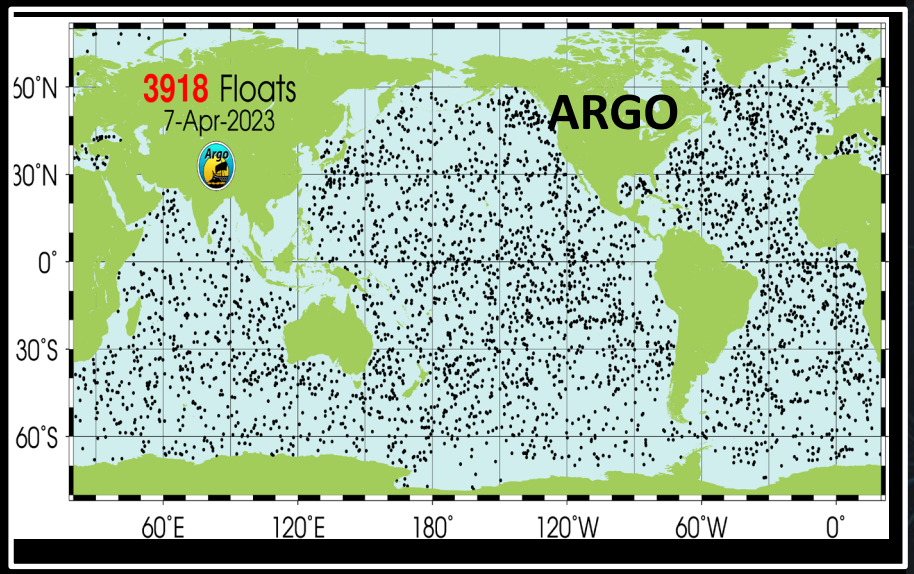
Regional rates of sea level change (1993-2022) (mm/yr)



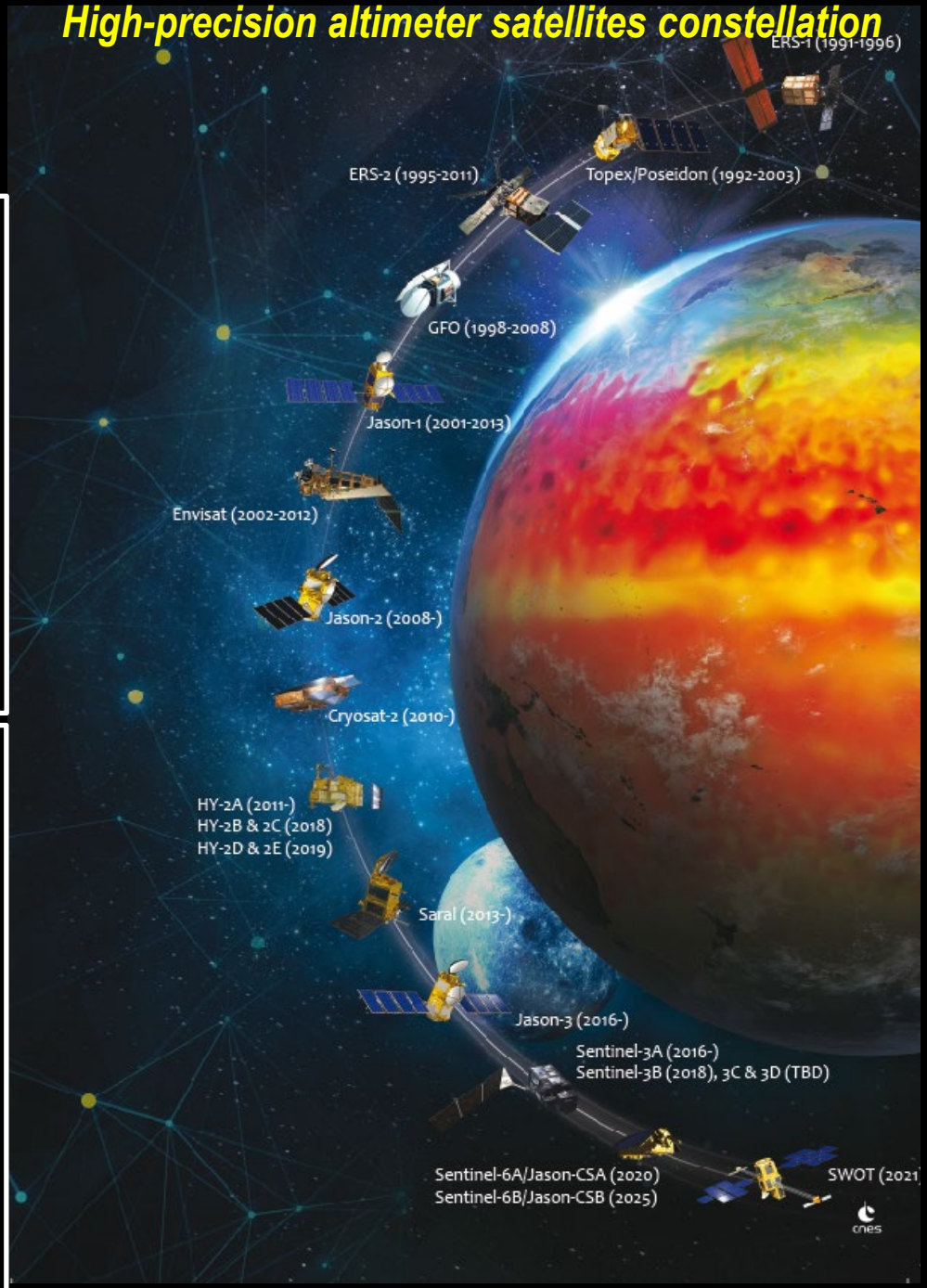
Spatial trend patterns amplify the global mean rise

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

Different observing systems to estimate the causes of sea level rise…



High-precision altimeter satellites constellation



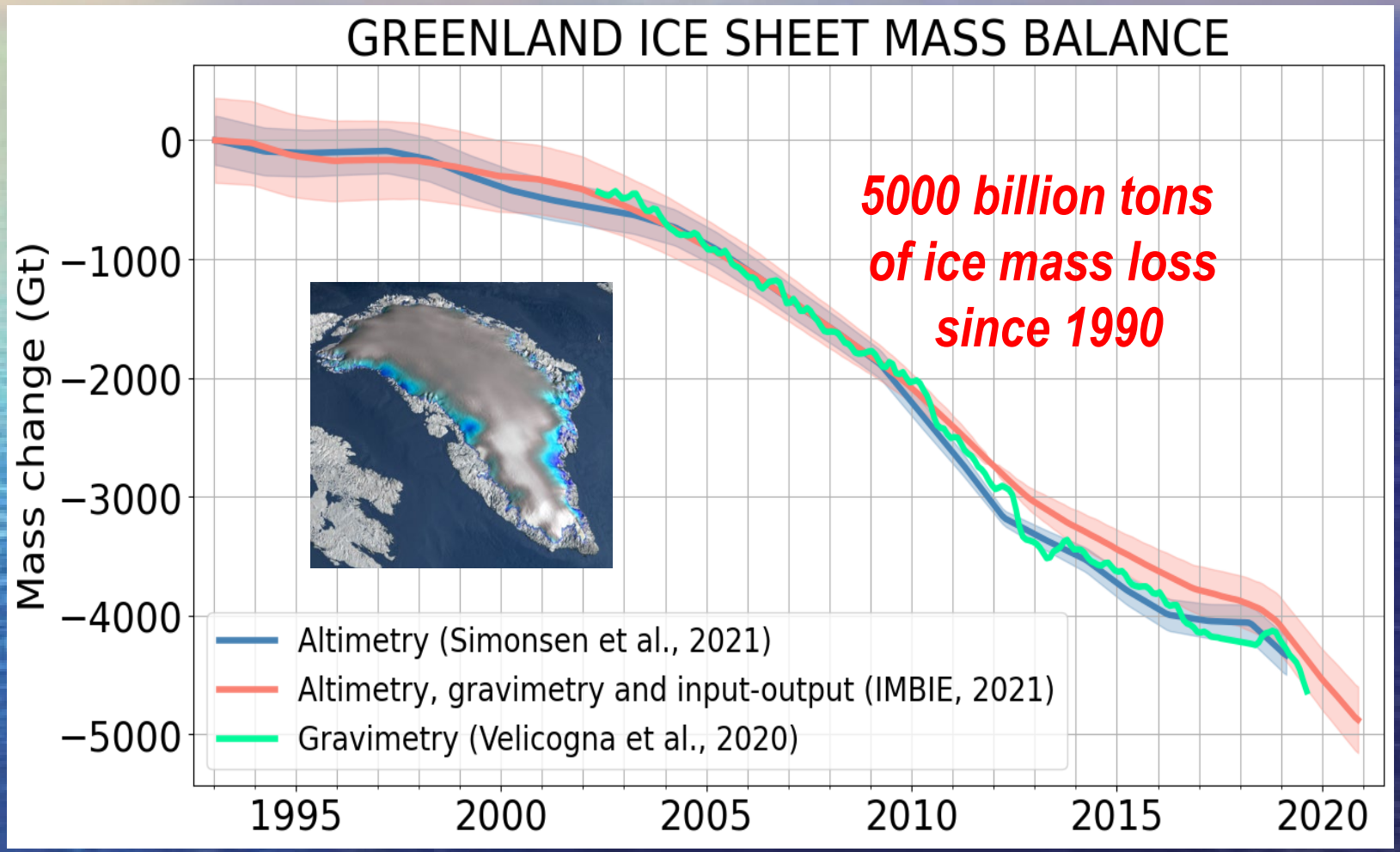
GRACE/GRACE Follow-On SPACE GRAVIMETRY MISSIONS (2002-present)

Applications:

- ✓ *Mass balance of the ice sheets and glaciers;*
- ✓ *Land water storage change;*
- ✓ *Change in the mass of the oceans*
- ✓ *Post Glacial Rebound (GIA)*
- ✓ *Earthquakes*

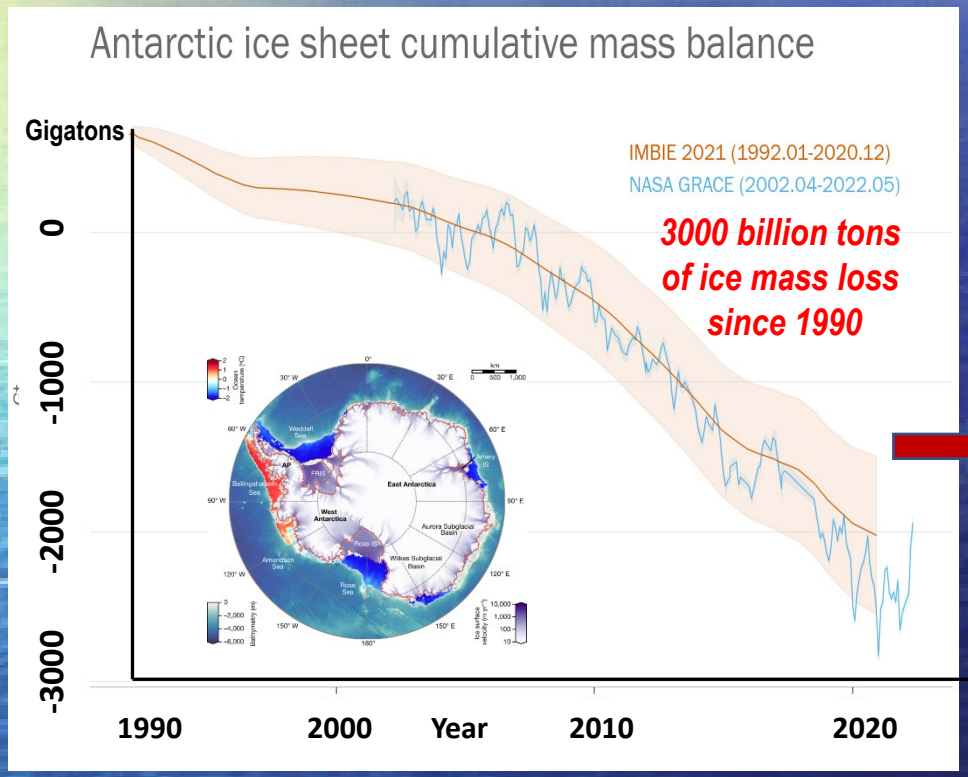
GRACE measures all types of mass redistributions within the Earth and at its surface

Ice Mass Loss from Greenland

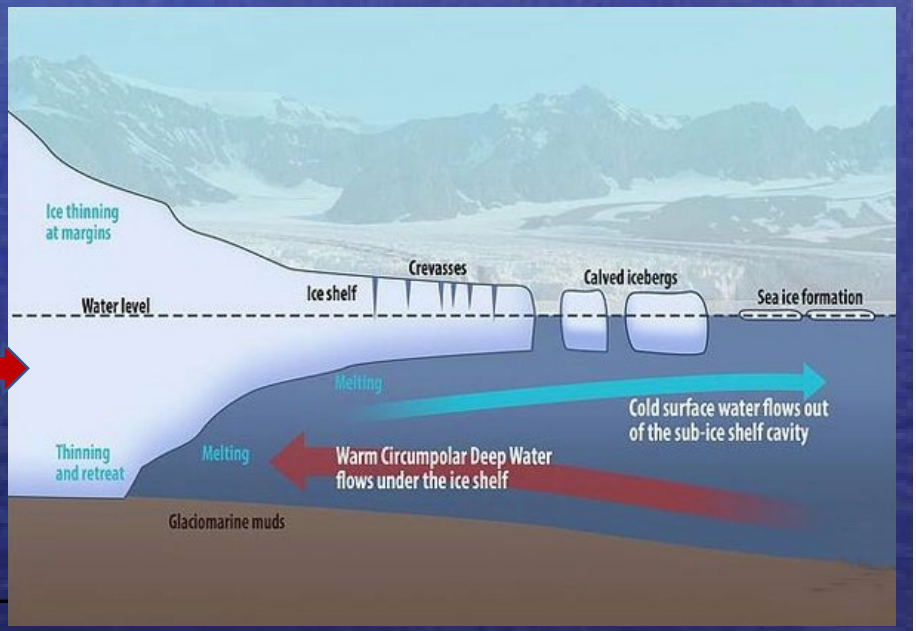


Barnoud et al., 2022

Ice Mass Loss from Antarctica

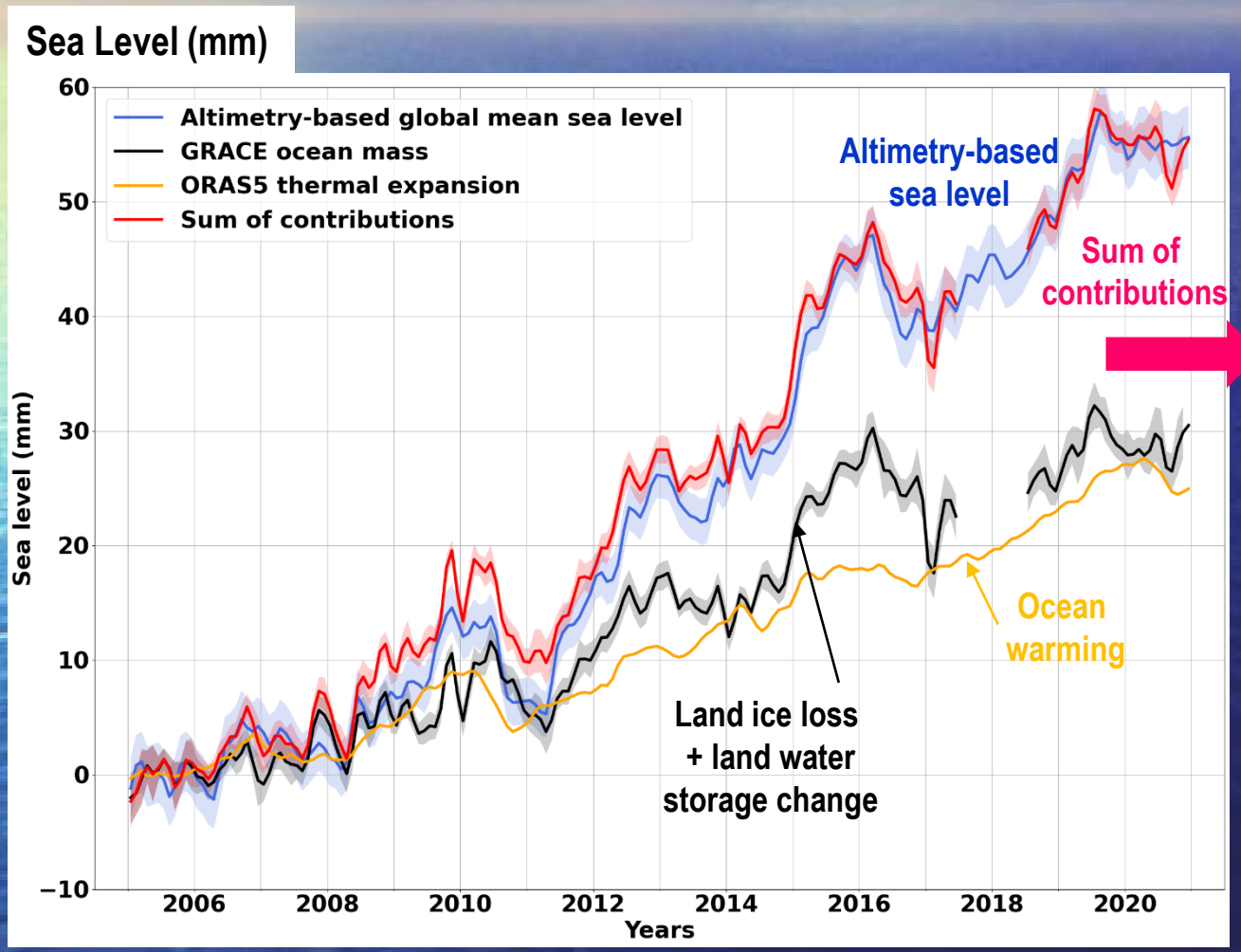


State of the global climate 2022
World Meteorological Organization



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?

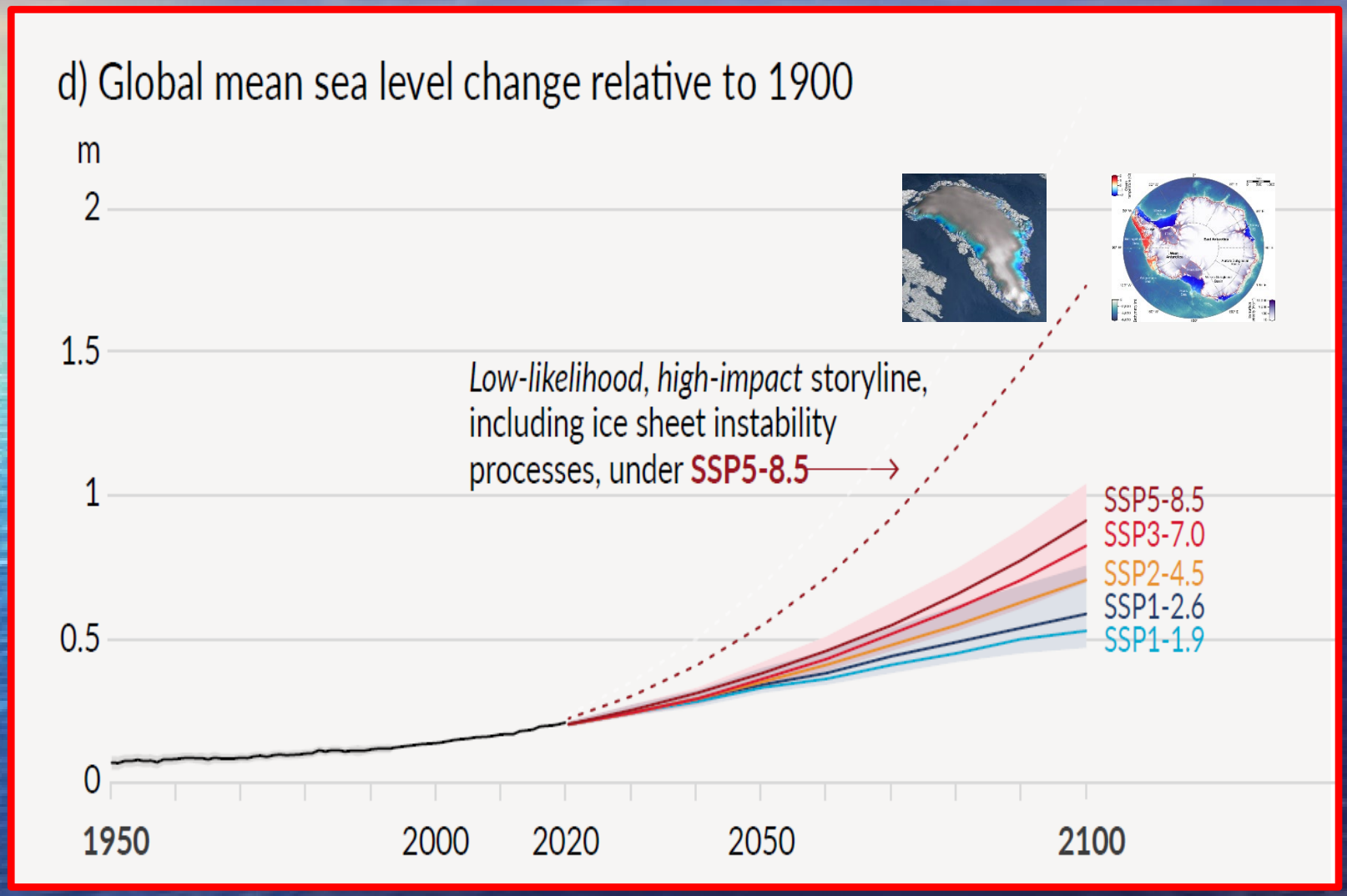
Global Mean Sea Level → An important metric of global climate change

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**

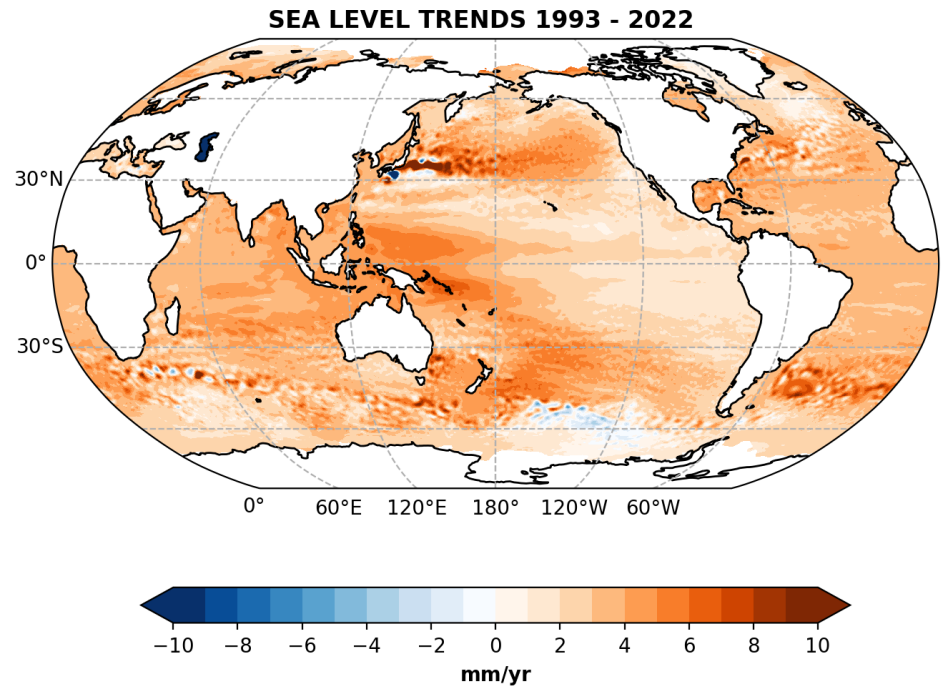
- **Validate climate models used for projections**

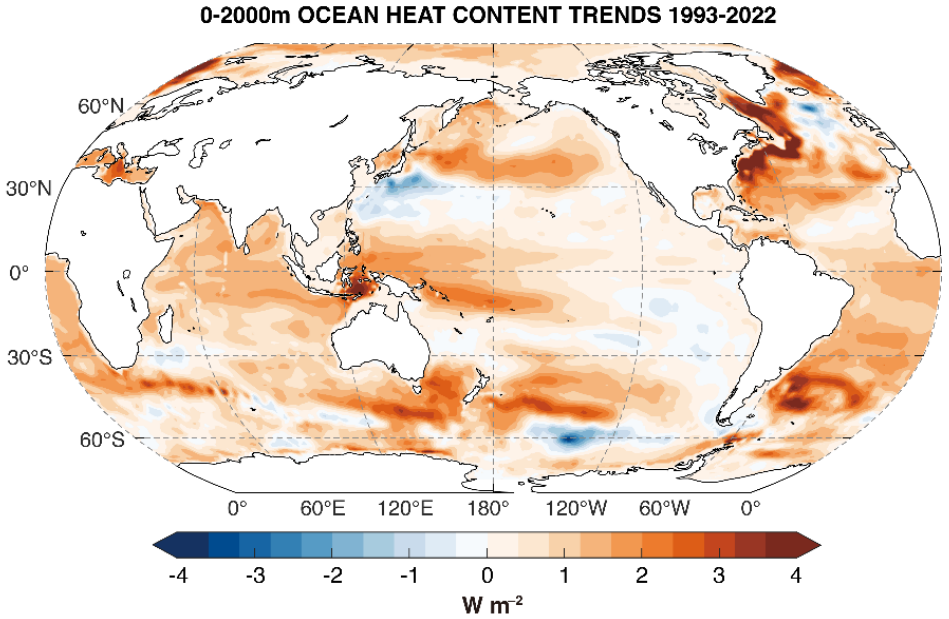
Sea level rise projections by 2100 for different warming scenarios



IPCC AR6, 2021

Regional trends (1993-2022)
in sea level (left) and ocean heat content (right)

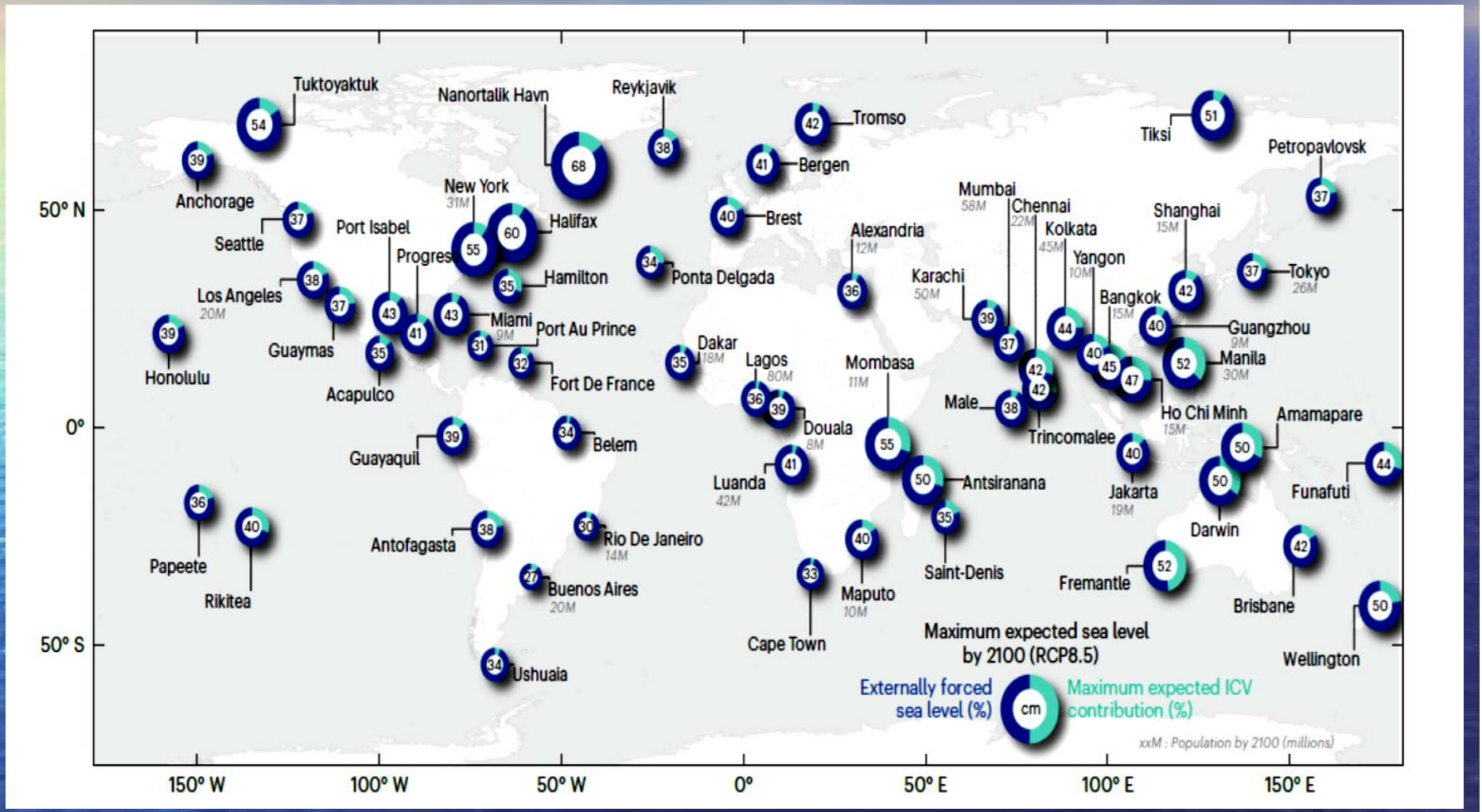




Present-day regional trends in sea level mostly due to non uniform ocean heat storage…

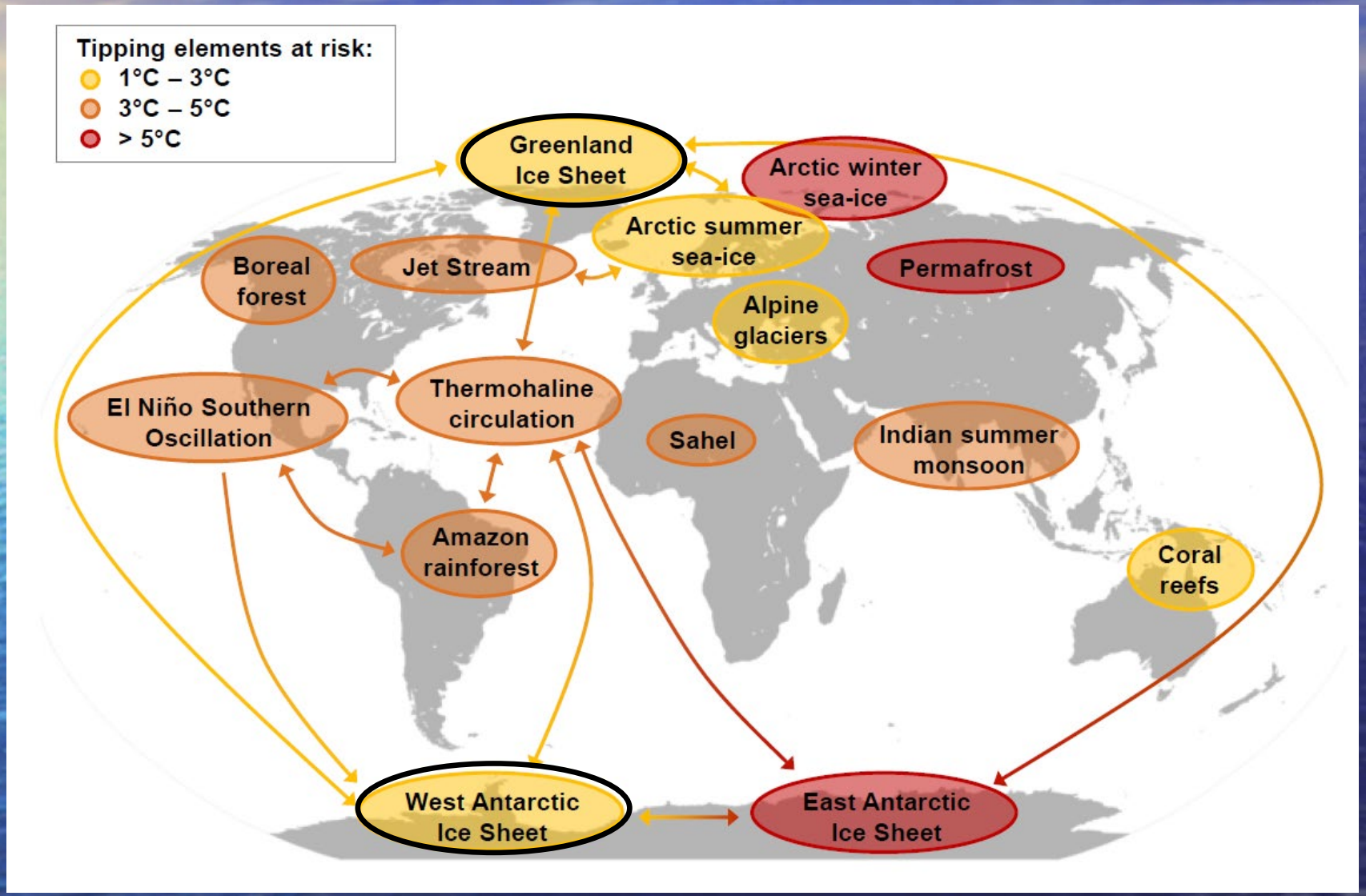
Source LEGOS & WMO

Expected contribution of the ocean warming to sea level rise by 2100 (elevation –in cm- above 2006; land ice melt not included here)



Source: Becker et al., 2023

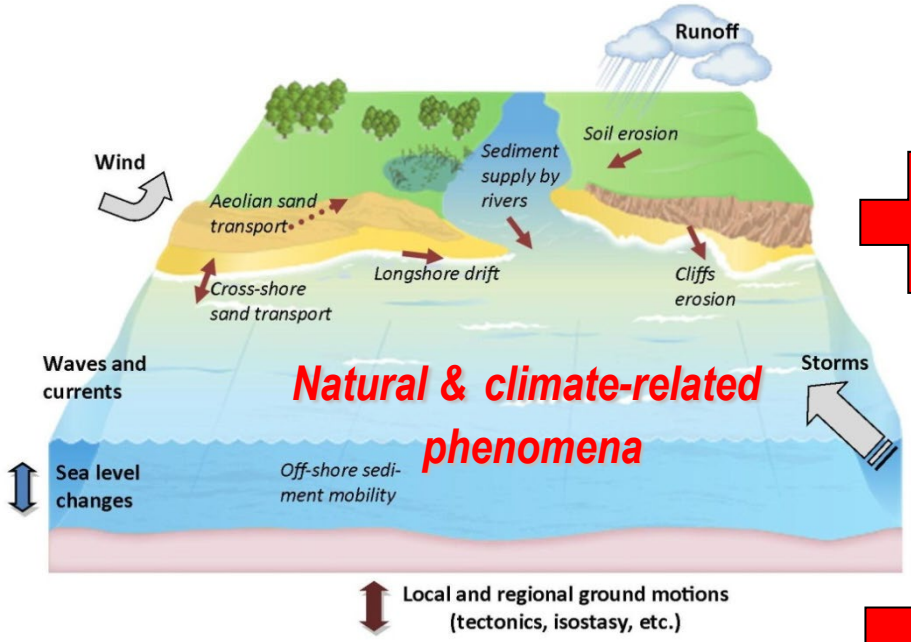
Tipping elements of the climate system: Expected irreversible changes according to the Earth's mean temperature increase

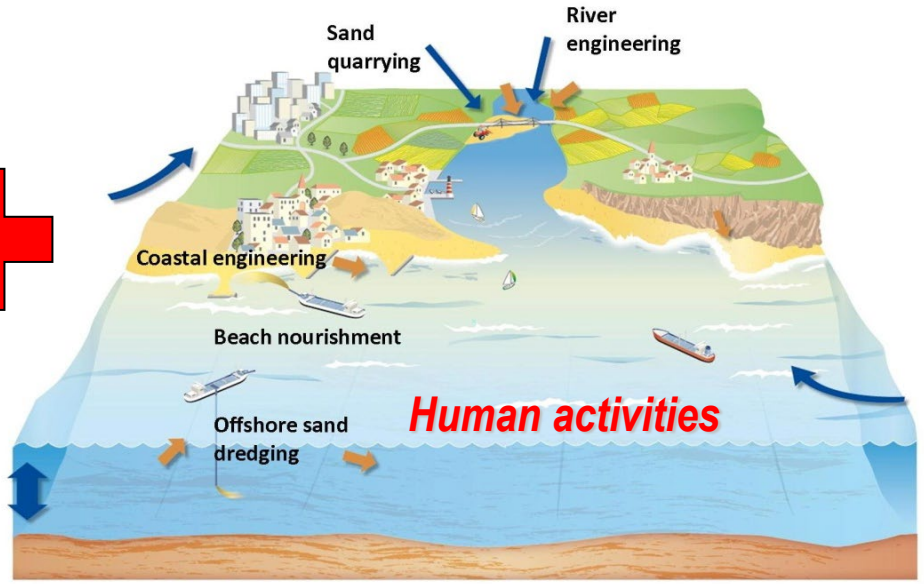


Source: Steffen et al., 2018


Thanks for your attention!

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……

Sea level rise at the coast

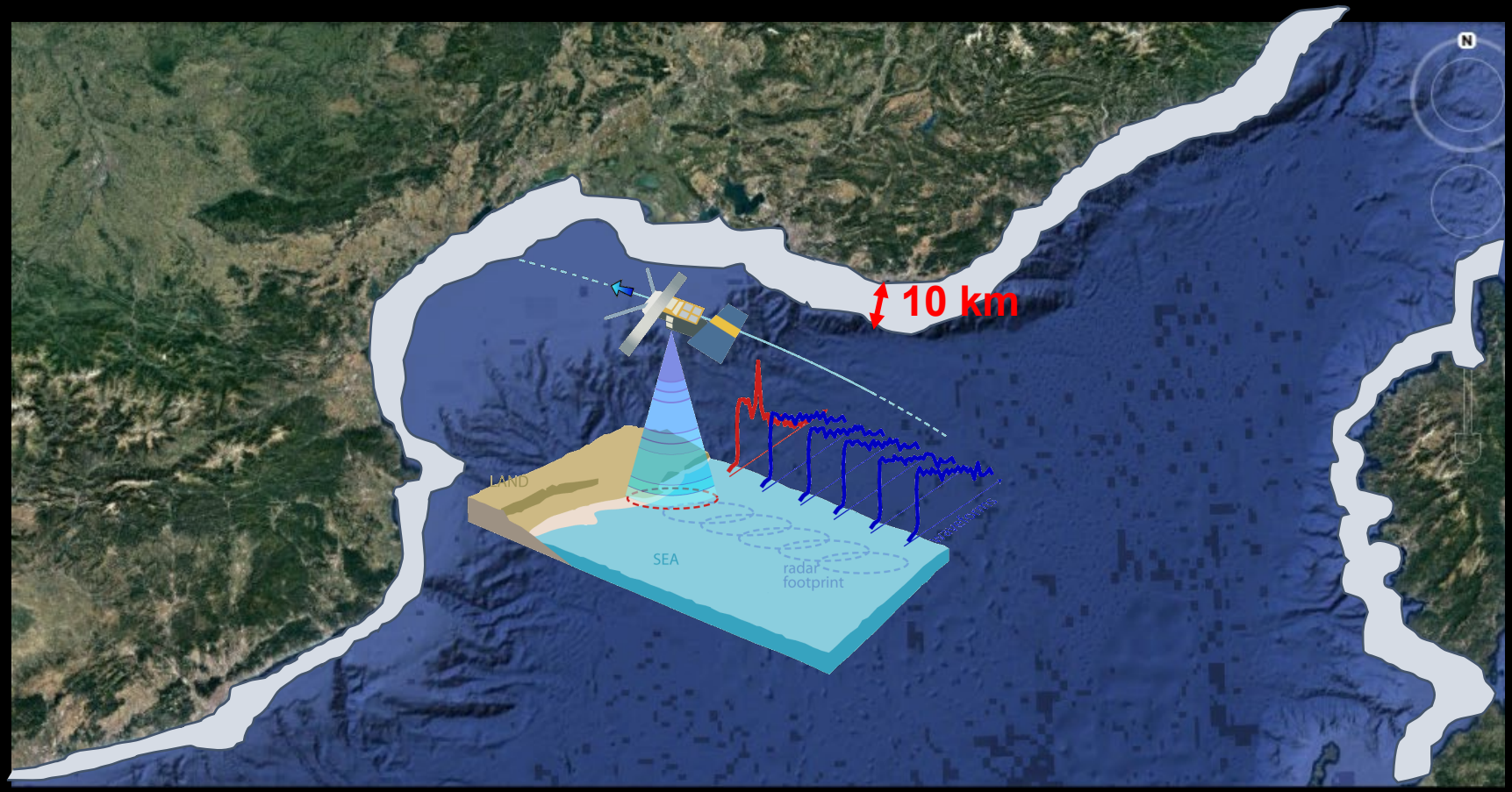
Coastal sea level rise =
global mean rise
+ regional trends
+ small-scale coastal processes

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

unknowns

+ vertical crustal motions (ground subsidence)

Satellite altimetry: optimized to study the open ocean

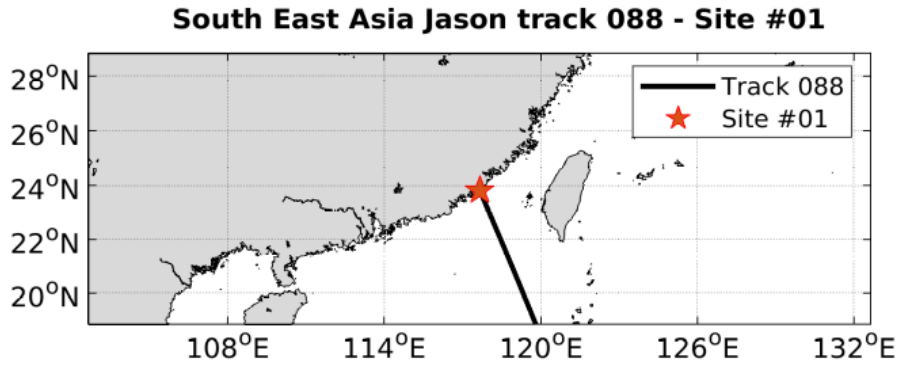


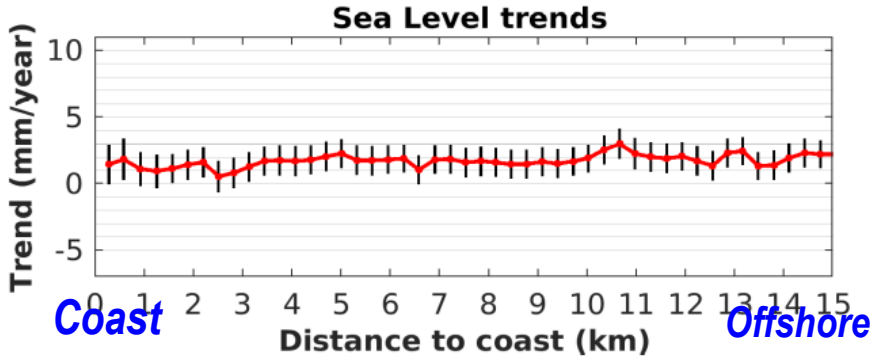
However, new dedicated reprocessing of past altimetry missions now allow constructing long term sea level time series along the world coastlines

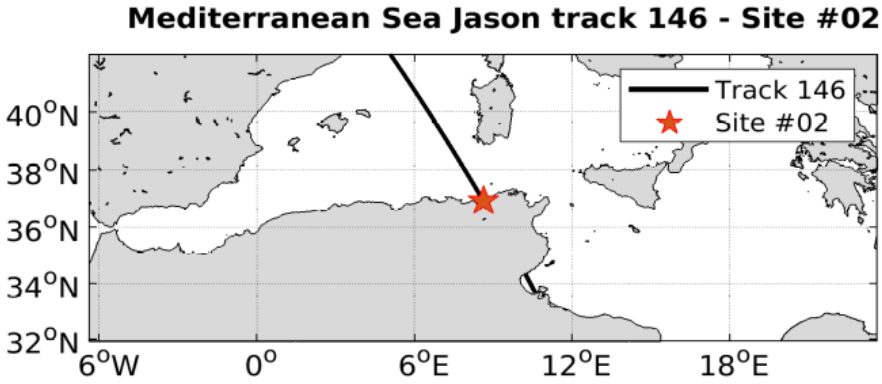
→ ESA Climate Change Initiative Coastal Sea Level Project

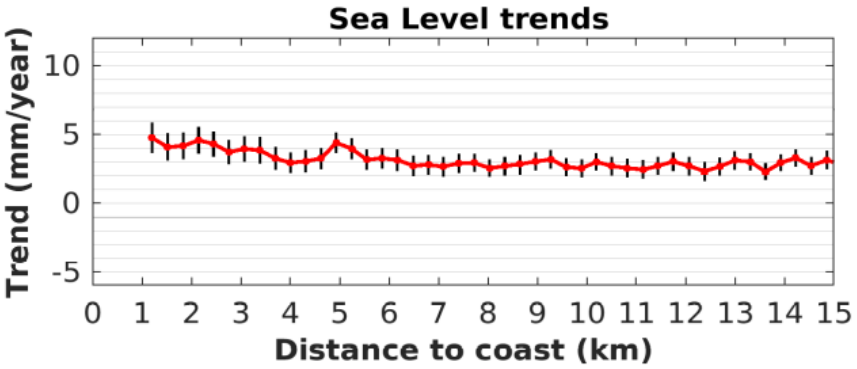
Examples of results obtained with this new reprocessing:

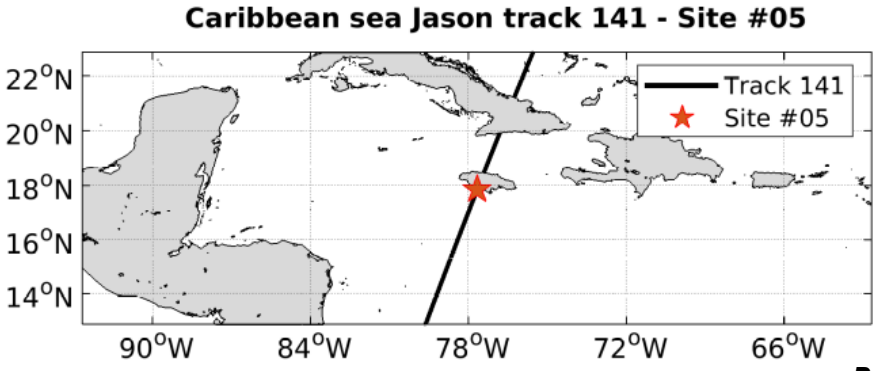
Sea level trends (2002-present) against distance to the coast

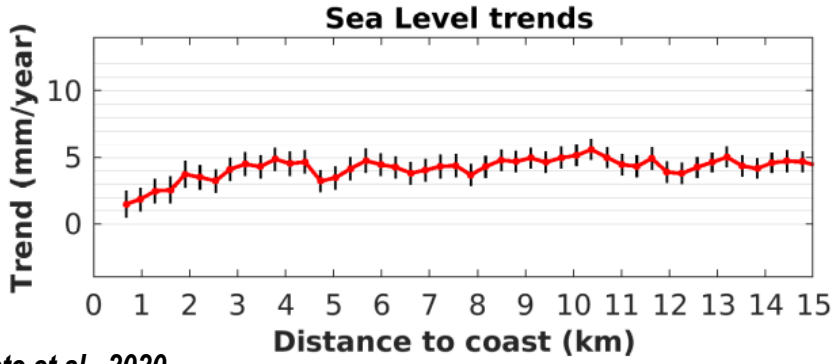






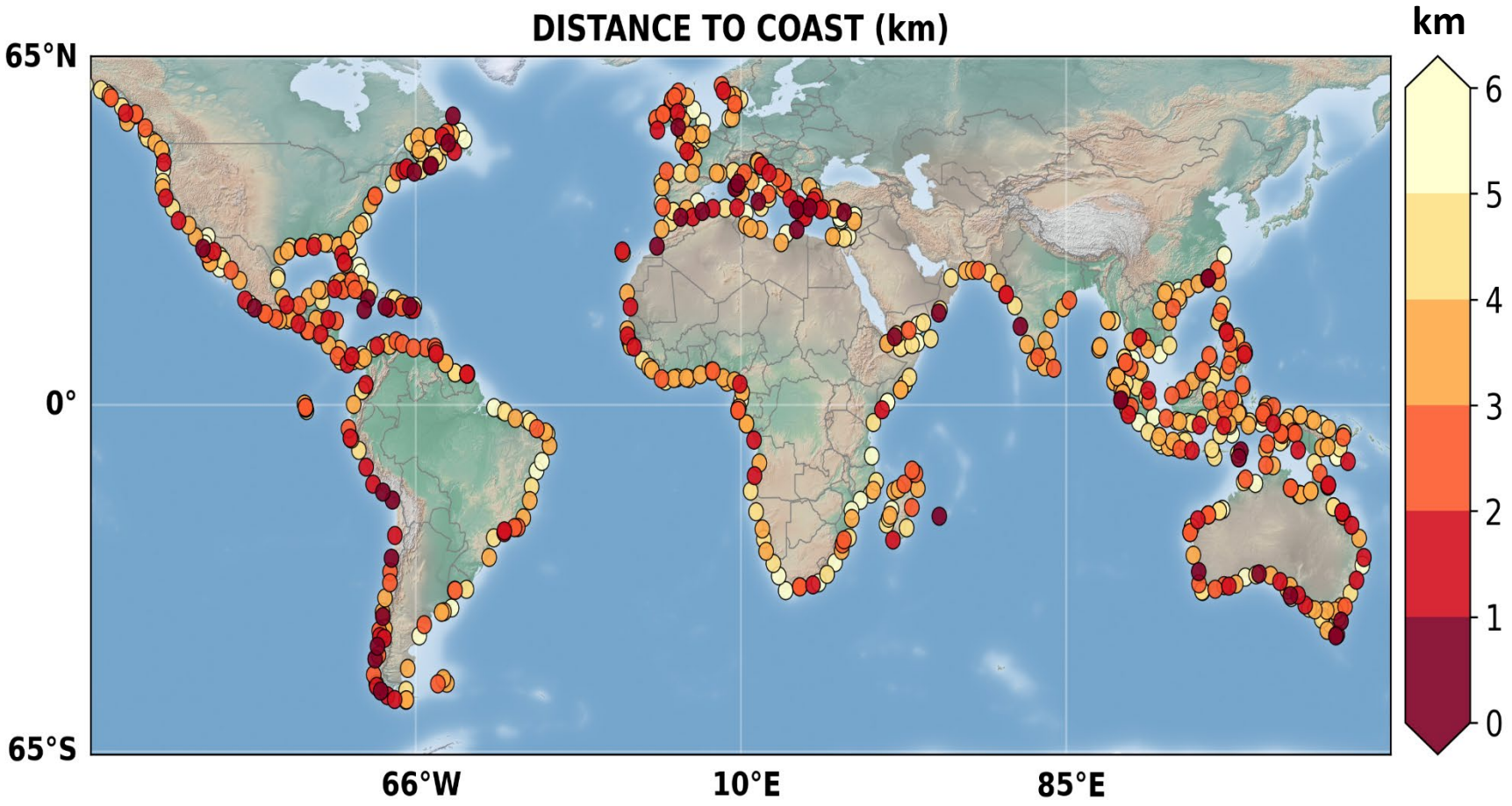






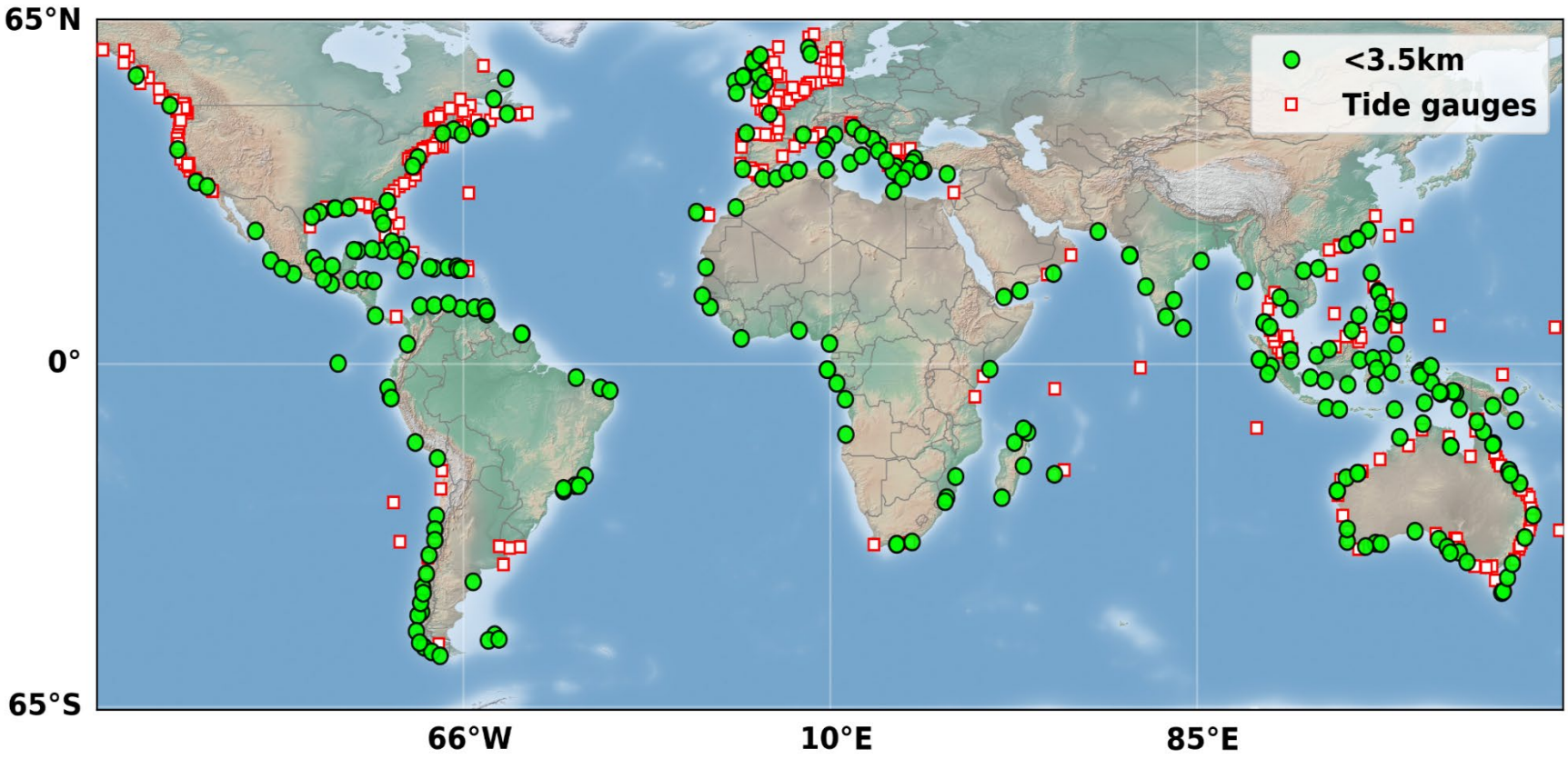
Benveniste et al., 2020
Cazenave et al., 2022

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



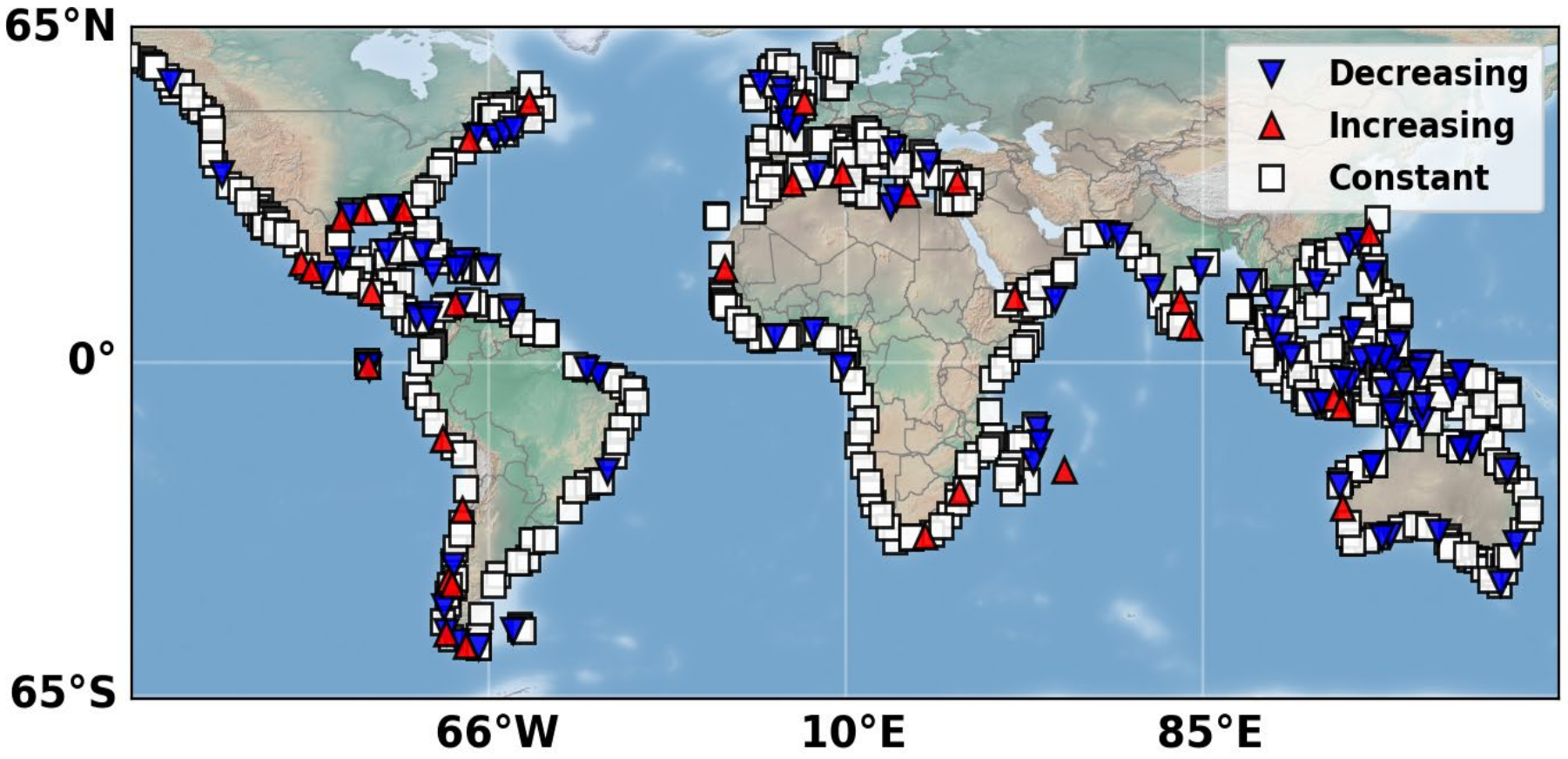
Benveniste et al., 2020
Cazenave et al., 2022

Virtual coastal altimetry stations located at less than 3.5 km from the coast, where long-term sea level trends can be estimated (green dots) and tide gauge sites with available data since 2002 (red squares)



Benveniste et al., 2020
Cazenave et al., 2022

Trend in coastal sea level compared to offshore (past 2 decades)



At some coastal sites, the rate of sea level rise is either faster or slower than offshore

LEGOS

New challenge: quantify small-scale coastal processes able to explain long-term sea level changes at the coast

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

In situ coastal networks almost inexistent everywhere…

The role of Small Satellite (SmallSat) constellations for monitoring sea level rise related-coastal processes and more generally coastal impacts of climate change…

SmallSat

A small satellite spacecraft with a mass less than 600 kg

- CubeSat: a spacecraft with multiple size where a single unit has a physical dimension of 10cmx10cmx10cm in size
- Minisatellite: A small satellite spacecraft with a mass in the range of 100-600 kg
- Microsatellite: A small satellite spacecraft with a mass in the range of 10-100 kg
- Nanosatellite: A small satellite spacecraft with a mass in the range of 1-10 kg

NRC report 'Leveraging commercial space for Earth (The National Academy Press, https://doi.org/10.17226/26380).


Thanks for your attention!