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Outstanding Student & PhD candidate Presentation contest

Sea-level rise along the North Atlantic coasts since 1900

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1/ Context

- Local sea-level rise can deviate considerably from the global mean sea-level rise (e.g. Cazenave and Moreira, 2022)
- Accurate projections are needed as coastal areas are densely populated
- Future sea-level is estimated using coupled climate models and come along with large uncertainties notably due to:
  - model differences
  - model sensitivity to the radiative forcing
  - **internal variability**

→ spontaneous fluctuations of the system - Fig. 1, example for the SST

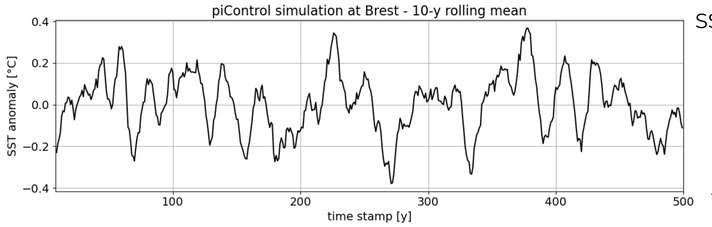

Figure 1: sea surface temperature anomaly evolution for the ACCESS-ESM1-5 pre-industrial control simulation

Scientific objective

Understand the **internal variability contribution to sea-level trends** during the historical period (1900-2014) by comparing in-situ observations to simulated sea level

2/ Significance

- When comparing simulated trends to observed trends the **internal variability must be accounted for** (e.g. Simpson et al., 2025 ; Jain et al., 2023)
- Before the advent of single model ensembles, “ensemble of opportunities” were used (i.e. ensemble created from several climate models with 1 historical simulation / climate model)
- The underlying assumption was that the internal variability would be sampled with the ensemble of opportunities
- Here we show that this assumption may not hold because **climate models do not have the same internal variability**

3/ Data & methods

Observed relative sea level

56 tide gauge stations in the North Atlantic (Fig. 2)
> Data from the PSMSL database [Holgate et al., 2013; PSMSL, 2025]

Simulated relative sea level

<u>*GIA-induced relative sea-level:*</u>
due to the Glacial Isostatic Adjustment
> Data from Caron et al., 2018

<u>*Sterodynamic sea-level:*</u>
due to the change in circulation and density, with the inverse barometer correction
> Data from 7 climate models
- 30 historical simulations / model
- within a single model ensemble, the historical simulations:
  - have **different initial conditions** taken from the pre-industrial control simulation
  - **share** the same external forcing (solar radiation, greenhouses gases, aerosols)

→ for a given model, differences between historical simulations are attributed to the internal variability

$$\eta = \eta_{\mathrm{GIA}} + \eta_{\mathrm{bGRD}} + \eta_{\mathrm{SD}}$$

<u>*Barystatic-GRD induced relative sea-level:*</u>
due to the ongoing melting of ice sheets, glaciers and changes in land water storage
> Data from Frederikse et al., 2020

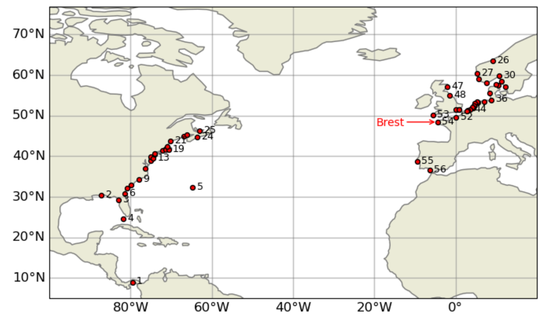

Figure 2: tide gauge stations used in this study

4/ Brest case study

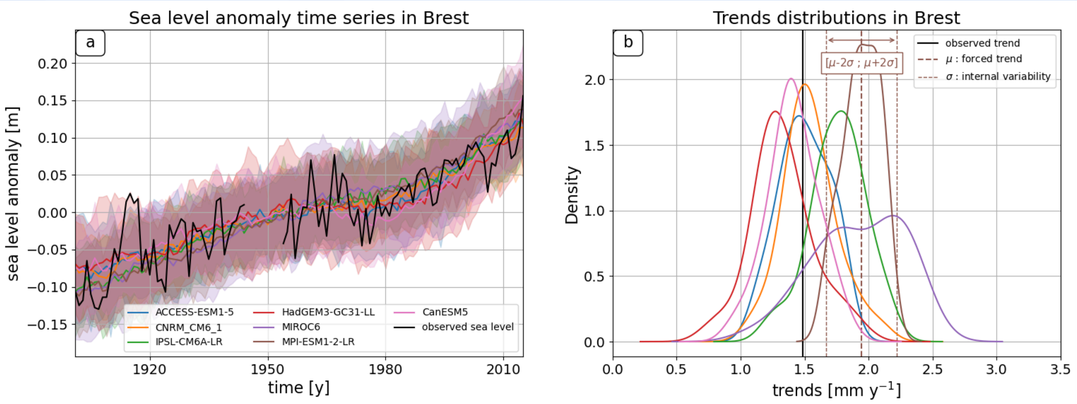

Figure 3: Observed (black curve) and simulated (colored curves) sea level anomaly in Brest (a). Each simulated sea level is based on a separate climate model, the plain lines are the ensemble means (30 members per model) and the spread corresponds to two standard deviations. Associated distributions of the simulated trends (b) for each climate model (colored kernel density estimates), and observed trend (black vertical line).

- The simulated sea-level time series represent the observed time series within the 2σ range (Fig. 3a)
- Yet, the distribution approach show that the models have **different forced trends** (mean (μ) of the distributions) and **sterodynamic internal variability** (shape and width of the distributions) (Fig. 3b)

5/ Extension to all the locations

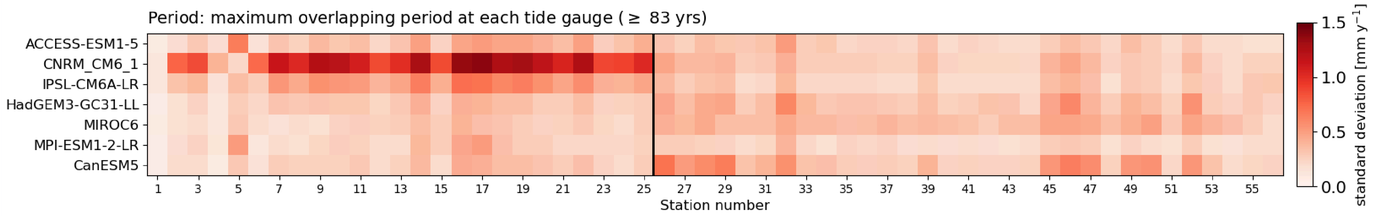

Figure 4: Standard deviation of the simulated sea level trends at each tide gauge station (x-axis) and for each simulated sea level based on separate climate models (y-axis). The vertical line between stations 25 and 26 indicates the separation between the west side and the east side of the North Atlantic basin (see Fig. 1)

- Sterodynamic internal variability on the west side of the basin is large according to the CNRM-CM6-1 model
- **Internal variability** is **model** and **location-dependent**

References: **Cazenave and Moreira, 2022** Contemporary sea-level changes from global to local scales: a review. Proc R Soc A. 478(2261):20220049. ; **Frederikse et al., 2020**, The causes of sea-level rise since 1900. Nature. 584(7821):393–7. ; 1.; **Caron et al., 2018**, GIA Model Statistics for GRACE Hydrology, Cryosphere, and Ocean Science. Geophysical Research Letters. 45(5):2203–12 ; **Permanent Service for Mean Sea Level (PSMSL), 2025**, "Tide Gauge Data", Retrieved 03 Mar 2025 from http://www.psmsl.org/data/obtaining/. **Holgate et al., 2013,** New Data Systems and Products at the Permanent Service for Mean Sea Level. Journal of Coastal Research. 29(3):493.; **Simpson et al., 2025** Confronting Earth System Model trends with observations. Sci Adv. 14;11(11):eadt8035. ; **Jain et al., 2023** Importance of internal variability for climate model assessment. npj Clim Atmos Sci. 17;6(1):68.