

Variabilité interne et tendances du niveau de la mer le long des côtes de l'Atlantique Nord de 1900 à 2014

Blandine JACOB, William LLOVEL, Lucia PINEAU-GUILLOU, Virginie THIERRY

Introduction

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- Global mean sea level is rising (Palmer et al., 2021, Cazenave and Moreira, 2022)

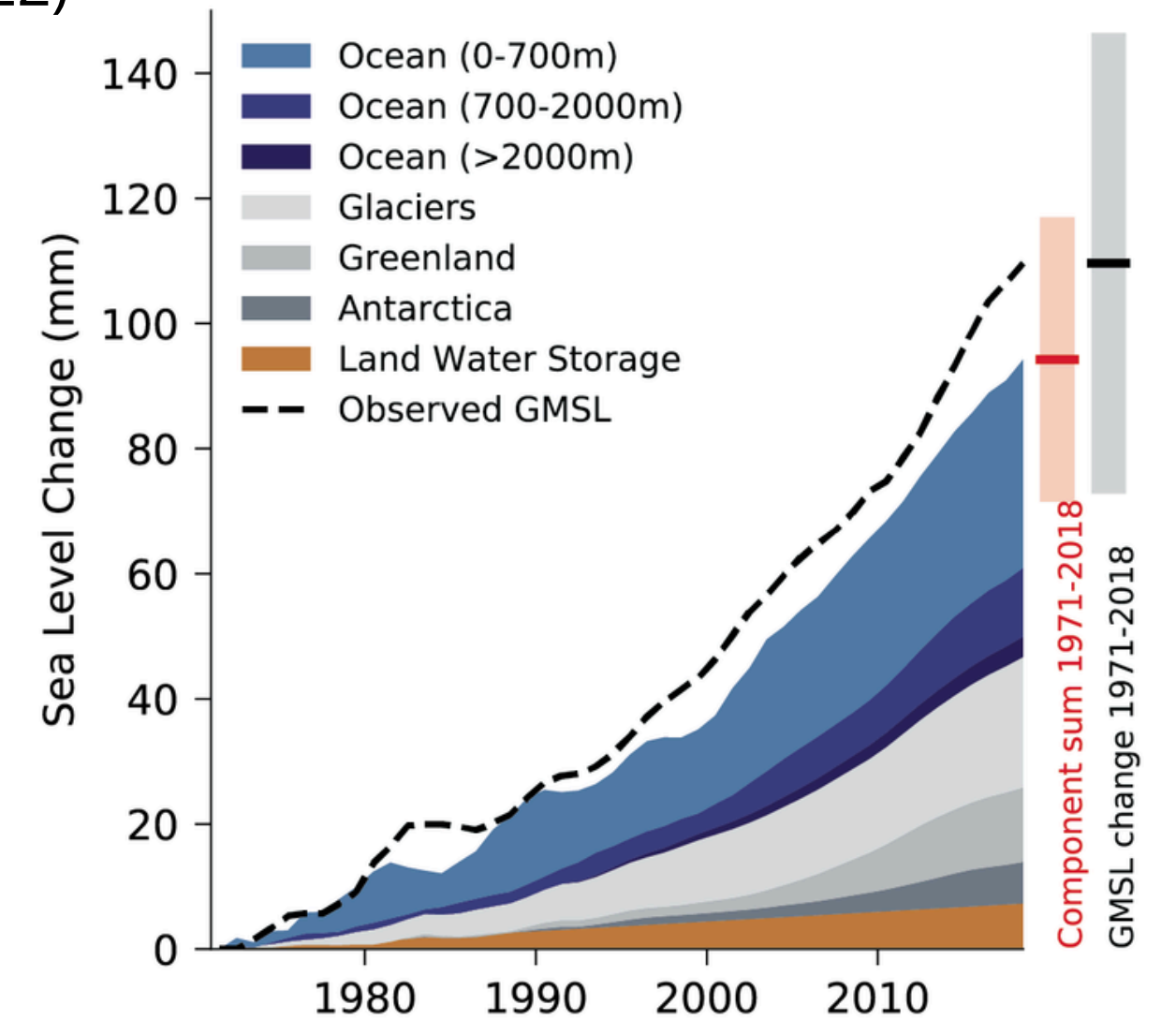


Figure adapted from IPCC
AR6 report, 2021

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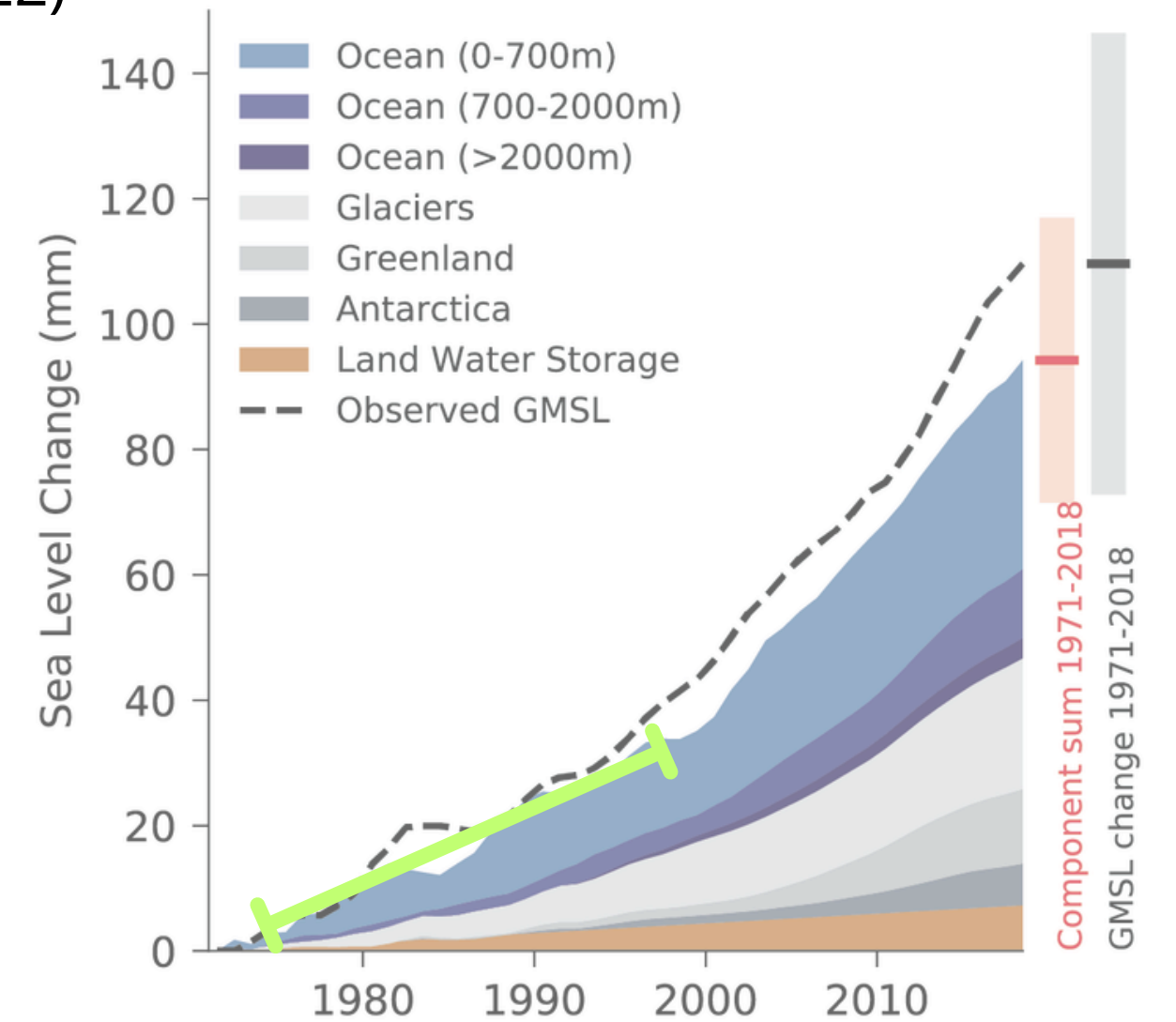


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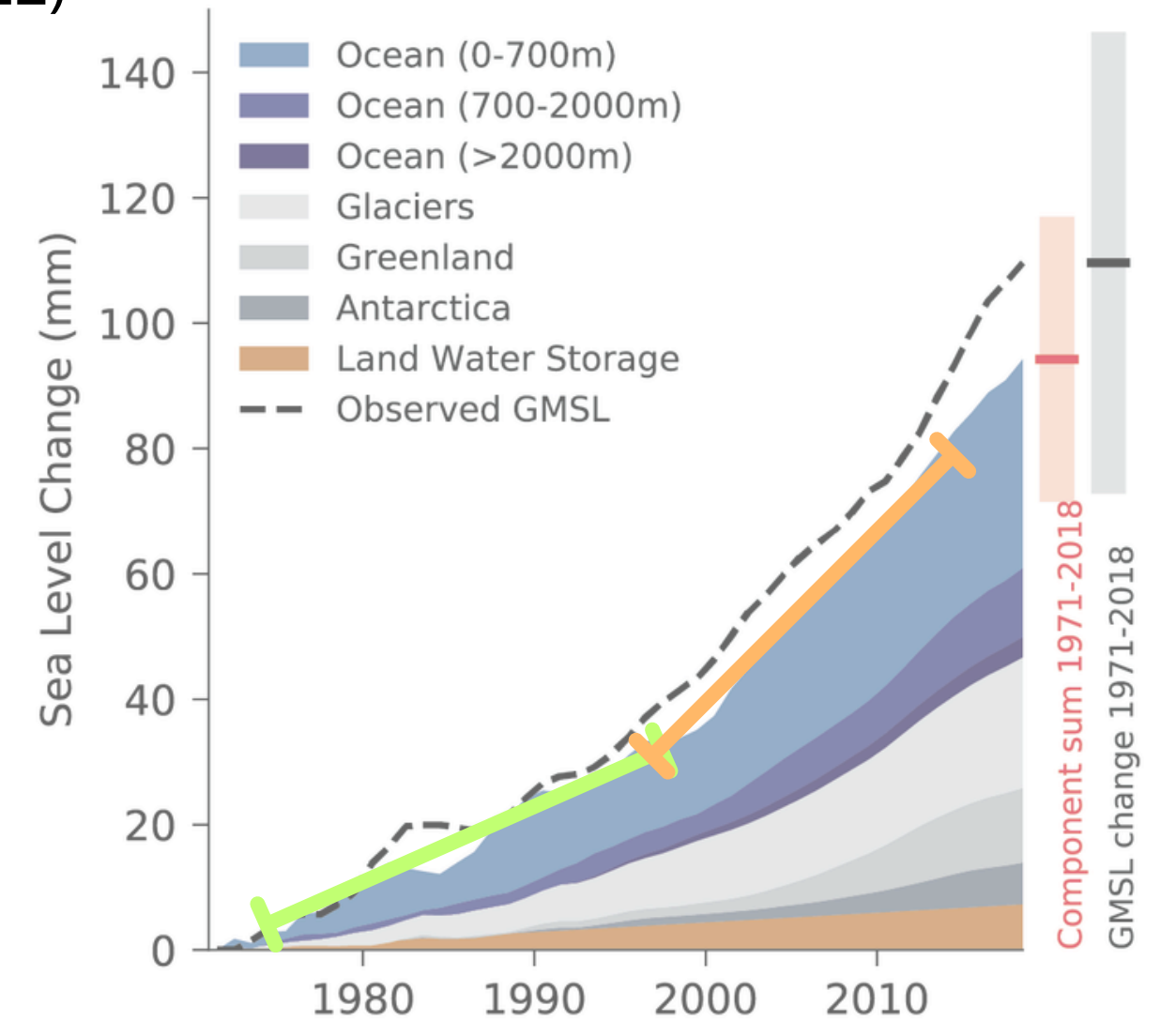


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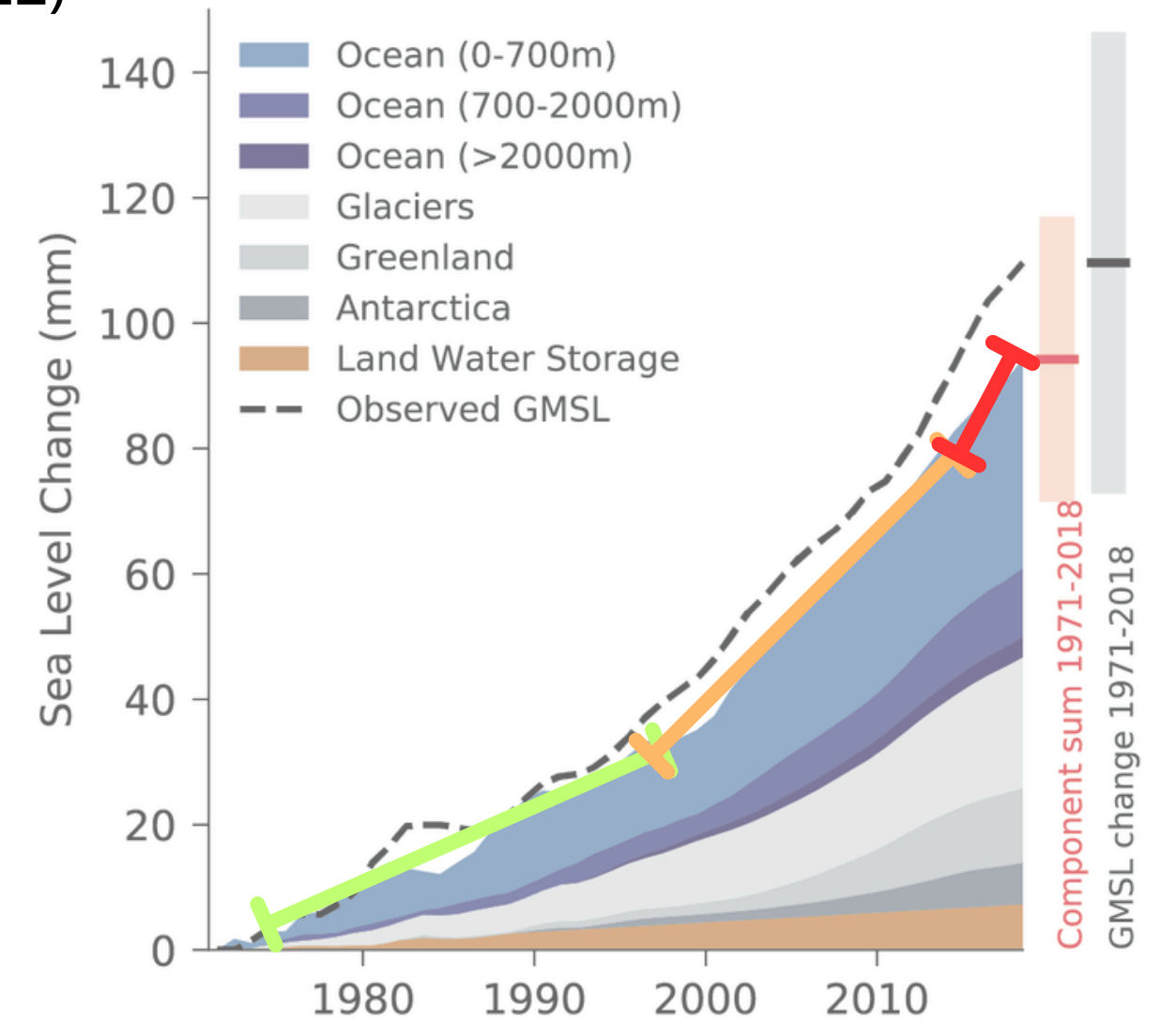
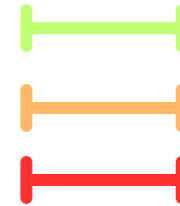


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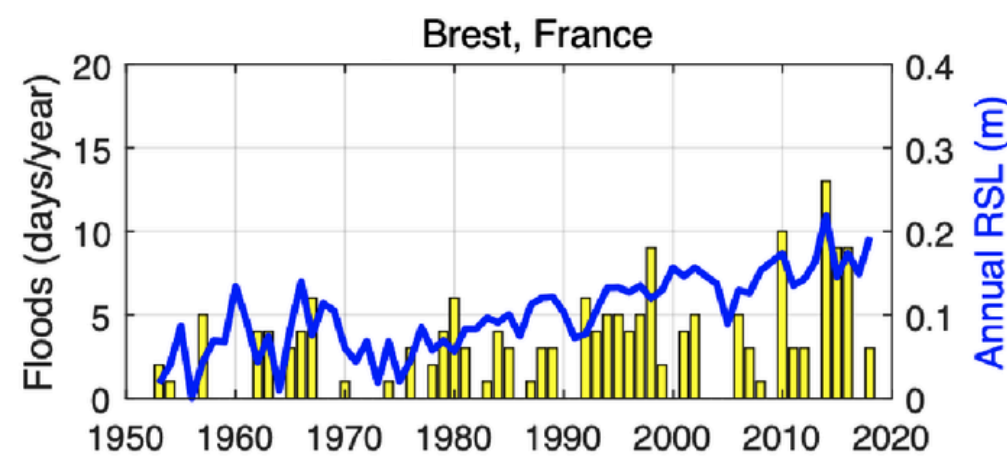
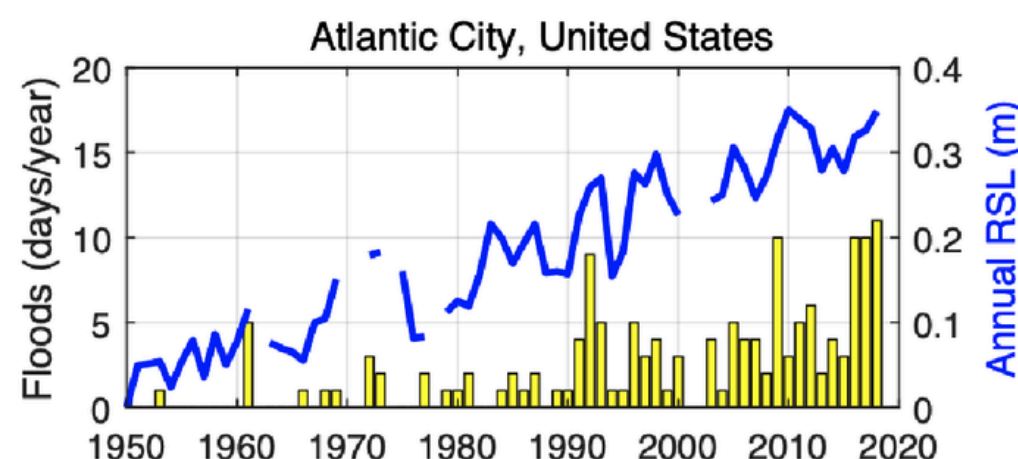


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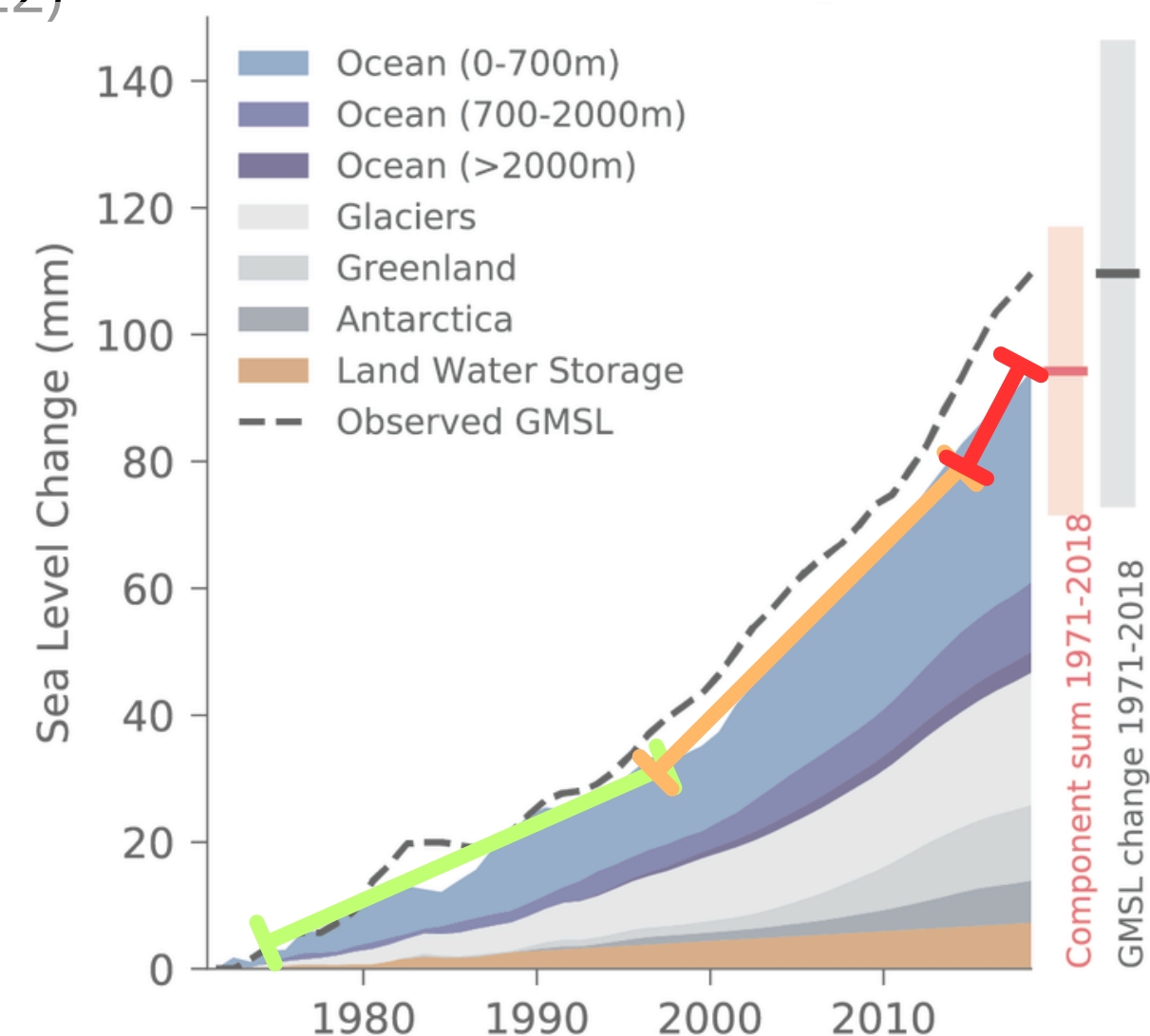


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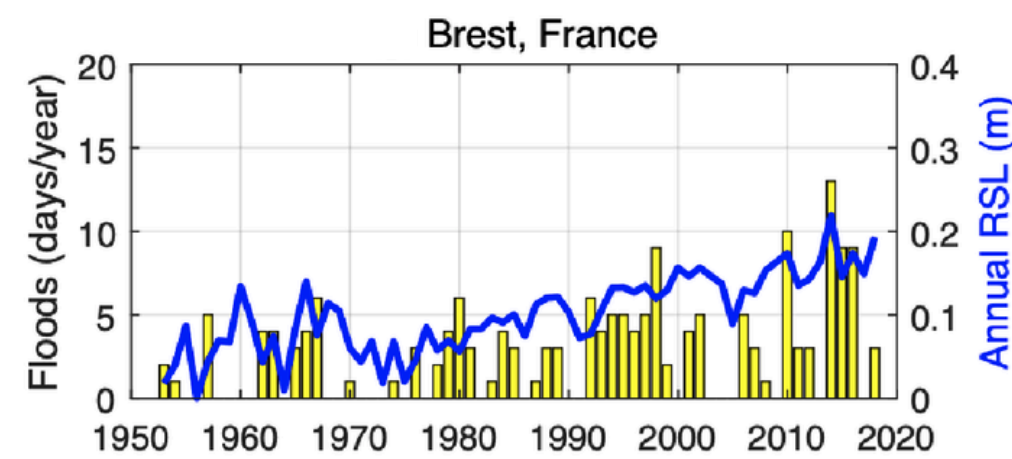
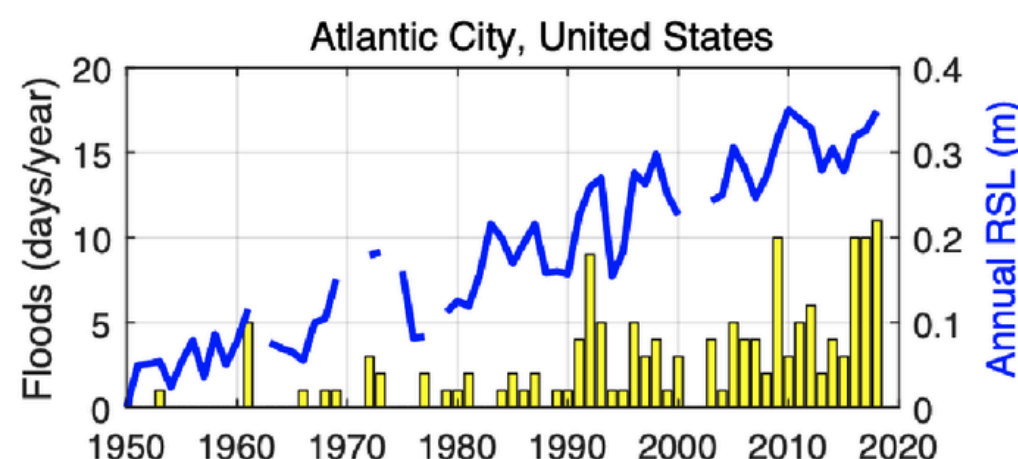


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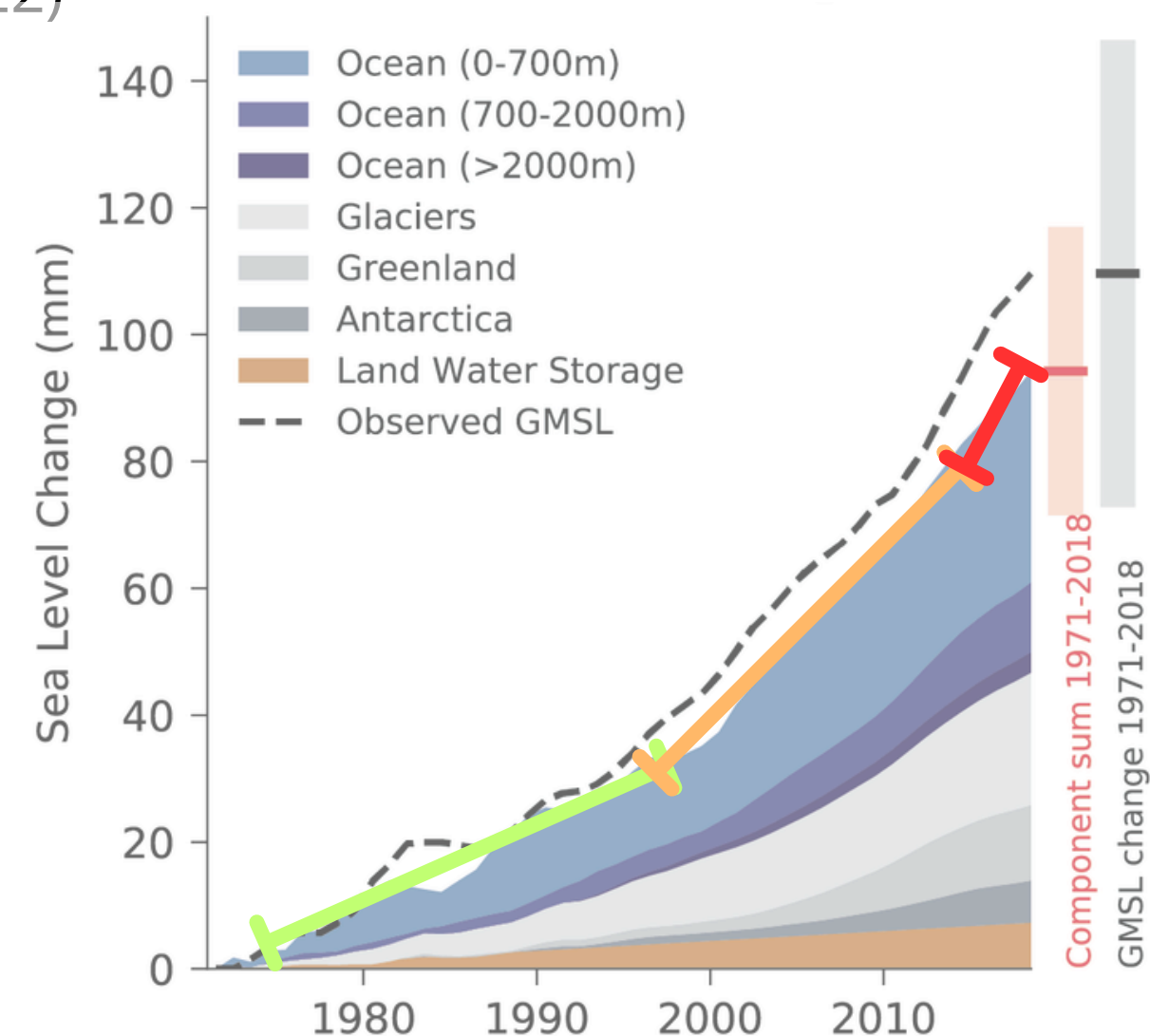


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- Coastal risks associated with mean sea level rise (e.g. Nicholls and Cazenave, 2010):
 - increased flooding, erosion, saltwater intrusion into groundwater, etc

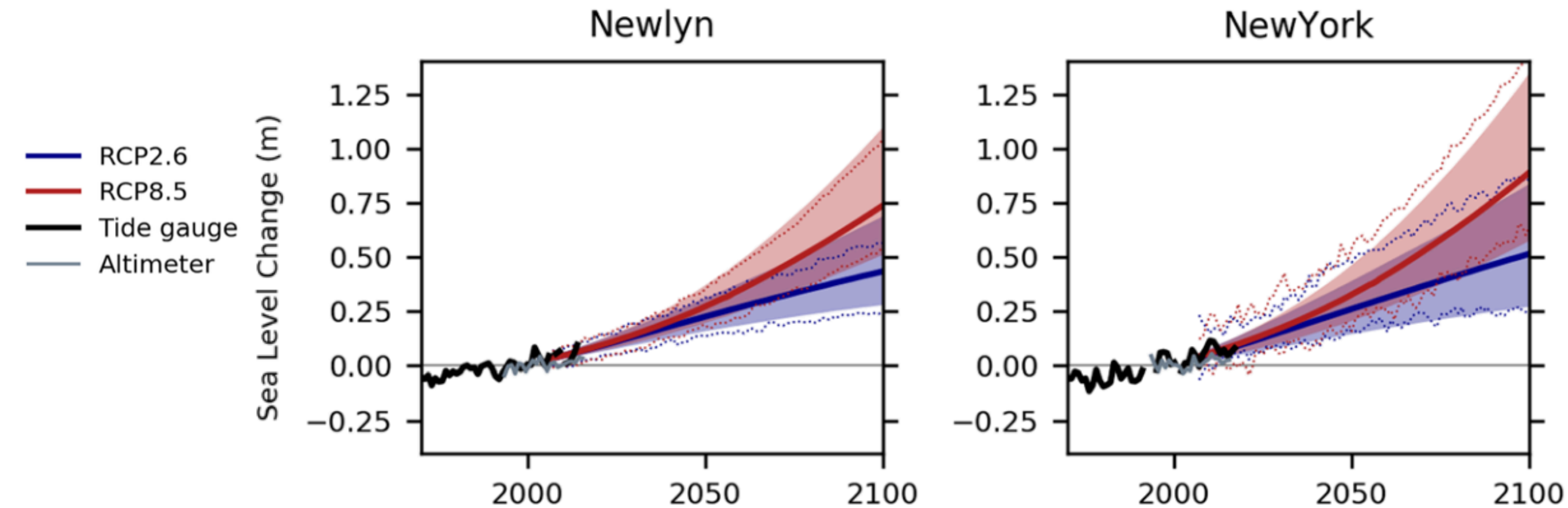
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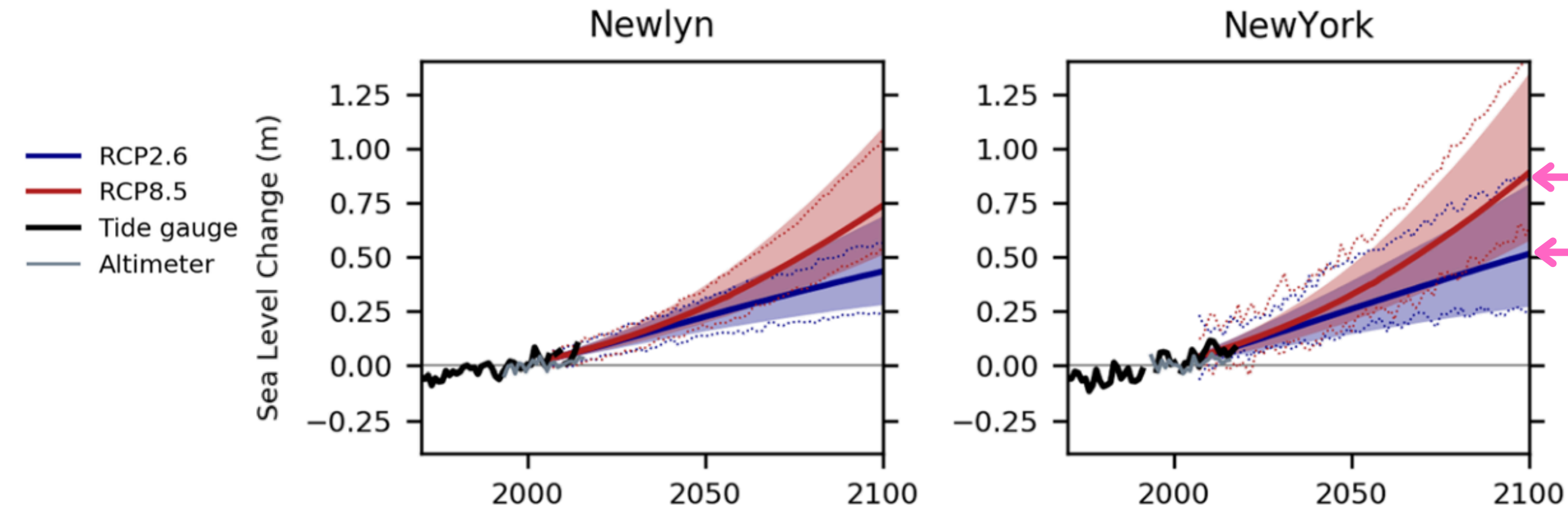
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- **Uncertainties arise from:**

Figure adapted from Palmer et al., 2020

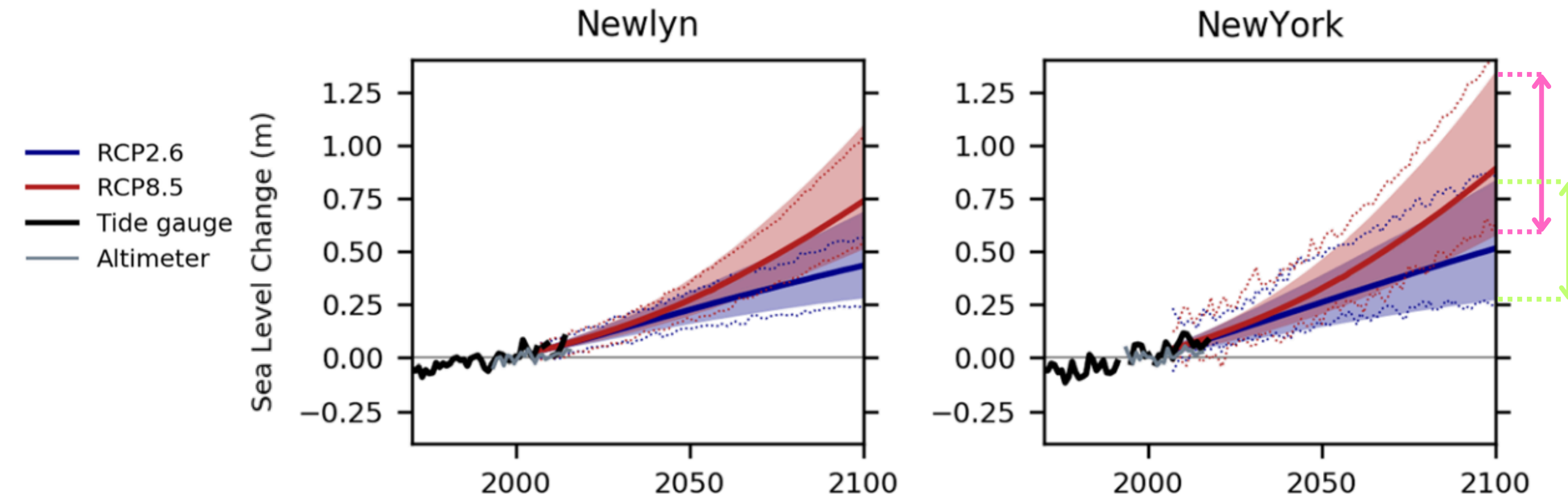
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- Uncertainties arise from:
 - **climate scenarios**

Figure adapted from Palmer et al., 2020

- Policymakers rely on **projections** based on **climate models** to design adaptation measures (IPCC reports, Palmer et al., 2020)
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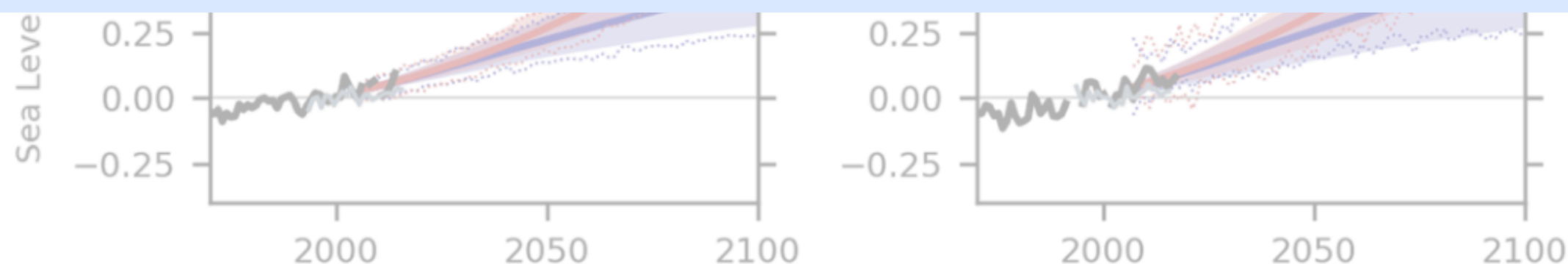
- Uncertainties arise from:
 - climate scenarios
 - **model differences**
 - **internal variability**

Figure adapted from Palmer et al., 2020

- Policymakers rely on **projections** based on **climate models** to design adaptation measures (IPCC reports, Palmer et al., 2020)

1. Do **reconstructed sea level trends** - based on climate model output - **match tide gauge trends**?

2. What are the **uncertainties** of the sea level component from **climate models**?



○ internal variability

Figure adapted from Palmer et al., 2020

Data & Methods

Data & methods

Study area & period

- **Relative** sea level change: $\Delta R(\mathbf{r}) = \Delta \eta(\mathbf{r}) - \Delta F(\mathbf{r})$ (Gregory et al., 2019)

↓
geocentric sea
level change

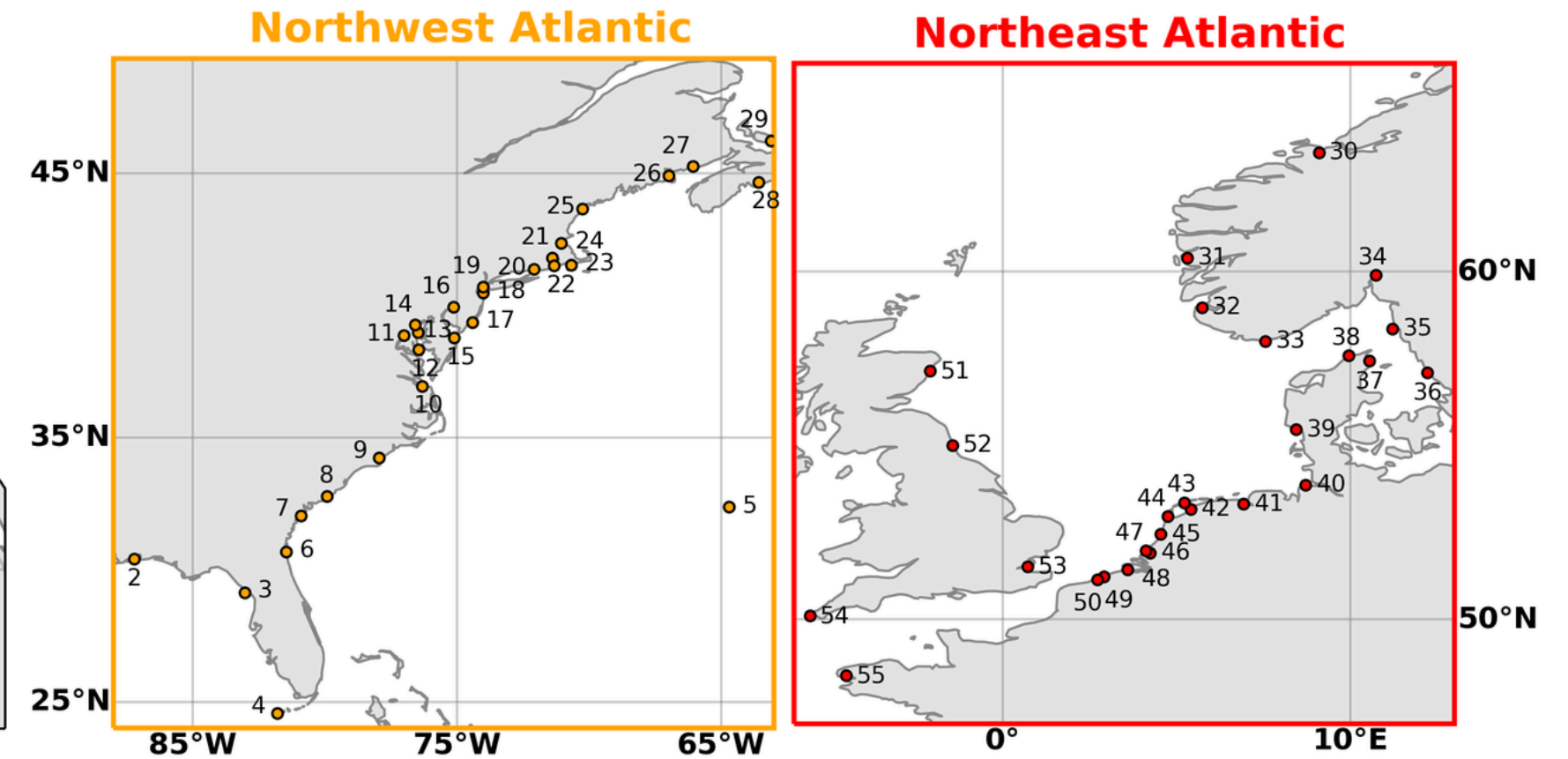
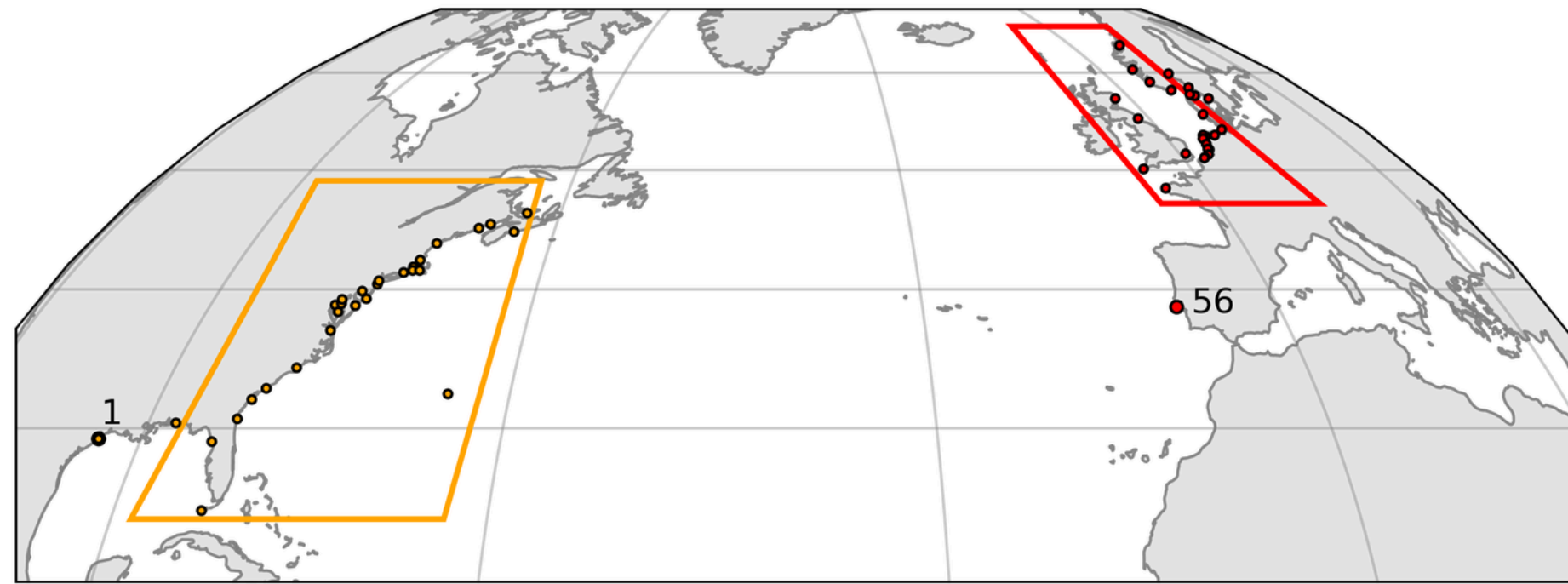
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vertical land
movement

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- **Study area:** North Atlantic
- **Period:** historical:
 - Centennial period (> 72 years)
 - 1993-2014 (21 years)



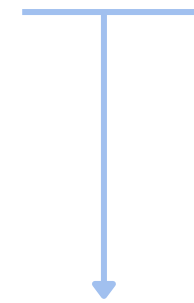
- 56 tide gauge records from the Permanent Service for Mean Sea Level database
- minimum length of 80 years
- minimum completeness of 60%

Data & methods

Reconstructed sea level

SD + IB + bGRD + GIA

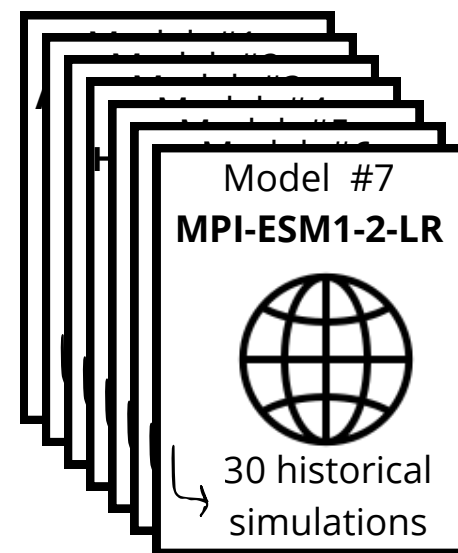
SD + IB + bGRD + GIA



sterodynamic sea level
(ocean circulation & density)

Data & methods

Reconstructed sea level



CMIP6 model output
(zos, zostoga)

- 7 models
- 30 historical simulations / model

SD

+

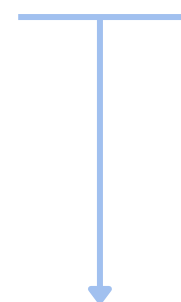
IB

+

bGRD

+

GIA



sterodynamic sea level
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Value: mean of the (7x30) 210 trends

Uncertainty: standard deviation of
the 210 trends

Data & methods

Reconstructed sea level

inverse barometer
(*atmospheric pressure*)

Pressure at mean sea level from
the 20th Century Reanalysis

Uncertainty: **not taken into account**

SD

+

IB

+

bGRD

+

GIA

SD + IB + bGRD + GIA

data from Frederikse et al., 2020

Uncertainty: **not taken into account**

barystatic-GRD induced
relative sea level
(ice sheets, glacier, land water storage)

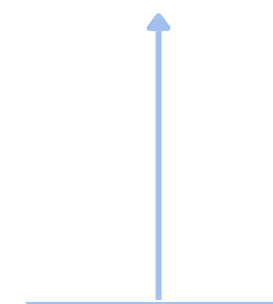
Data & methods

Reconstructed sea level

data from Caron et al., 2018

Uncertainties: **not taken
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GIA-induced
relative sea level



SD + IB + bGRD + GIA

Do reconstructed sea level trends match tide gauge trends?

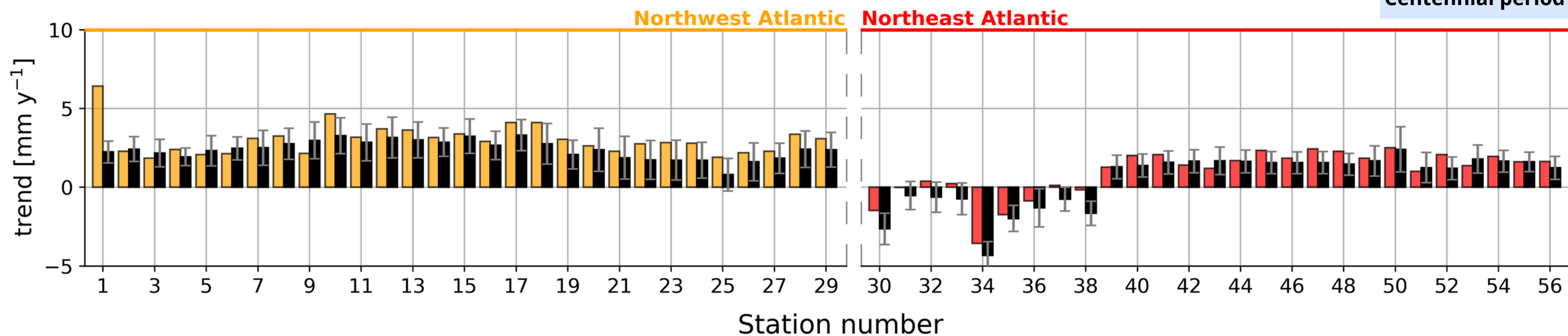


tide gauge trend



mean and 2σ
of the 210 multi-model-based
reconstructed trends

Centennial period



- Reconstructed trends: **not significantly different** (95% C.L.) to multi-decadal coastal trends at **77 %** of the stations

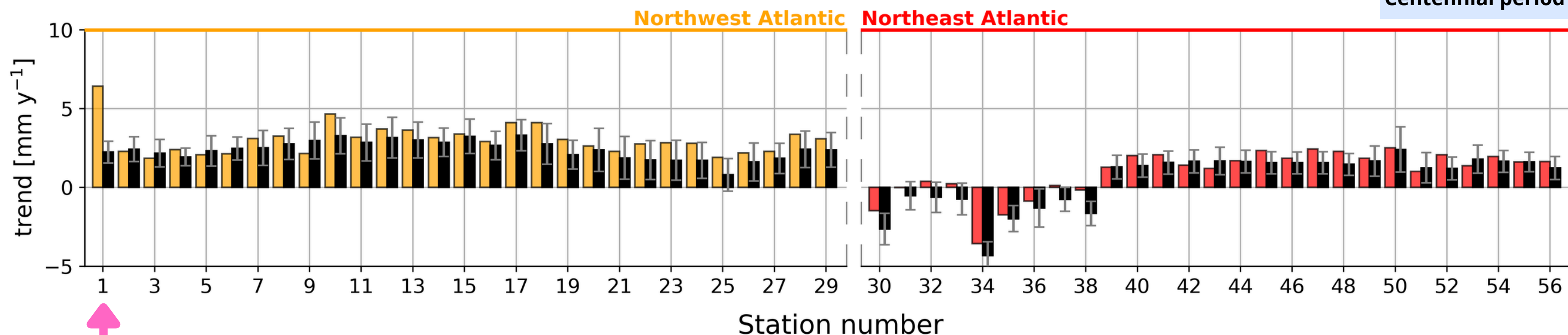


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- Cause of discrepancy:
 - local vertical land movement (**Station 1 - Galveston**, Liu et al., 2020)

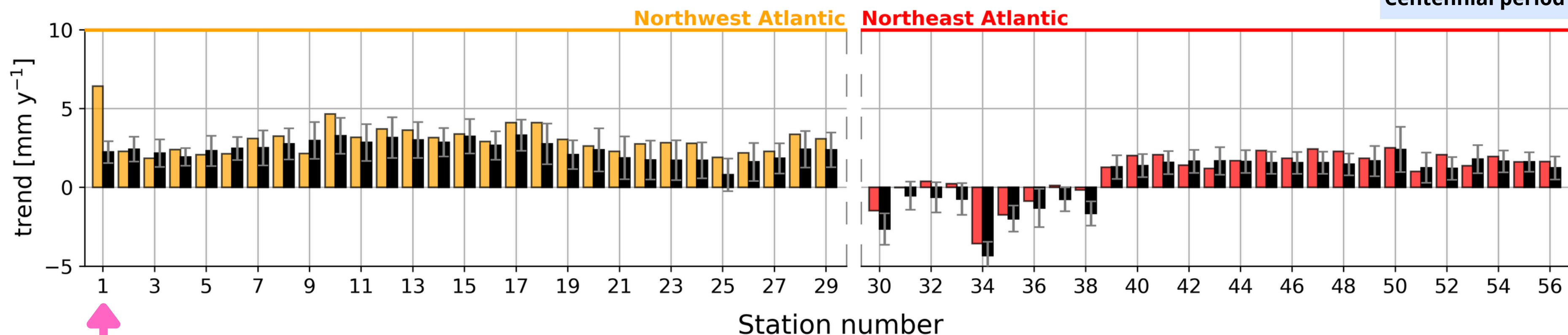


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 - local vertical land movement (**Station 1 - Galveston**, Liu et al., 2020)
 - conservative **uncertainties** as **only those related to climate model output** are considered

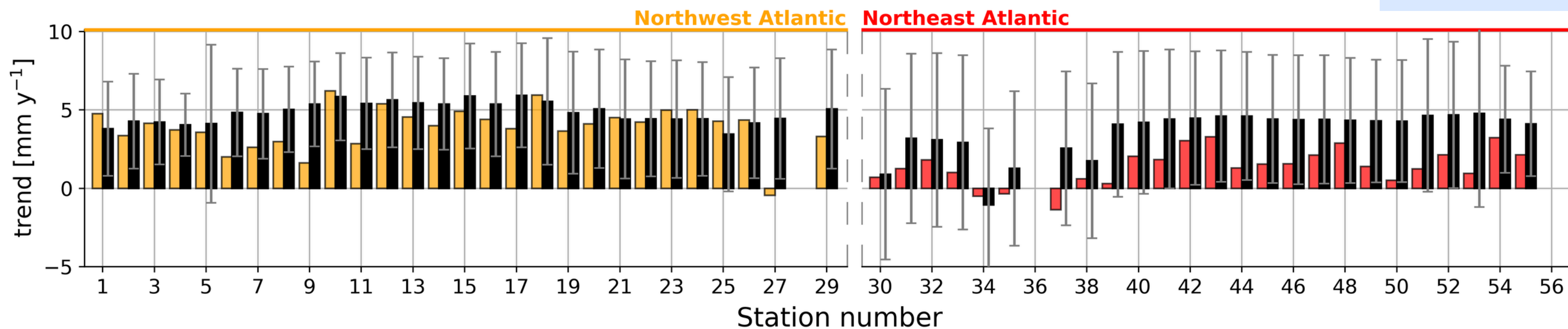


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Period: 1993-2014



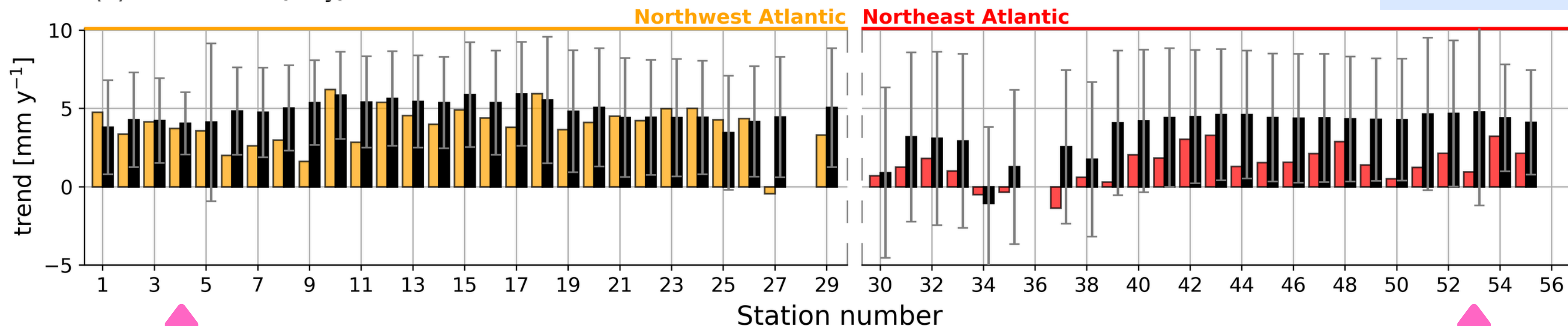
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- Reconstructed trends: **not significantly different** (95% C.L.) to multi-decadal coastal trends at **95 %** of the stations

but **large error bars:**

- 2 σ minimum: 1.99 mm y⁻¹ (Key West - station 4)
- 2 σ maximum: 5.98 mm y⁻¹ (Southend - station 53)

What are the uncertainties of the sea level trend component from climate models?

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Method

Earth's radiative balance:

forced versus ***internal*** variability

response of the Earth
system to the radiative
forcing

{ aerosols
solar activity
greenhouse gases

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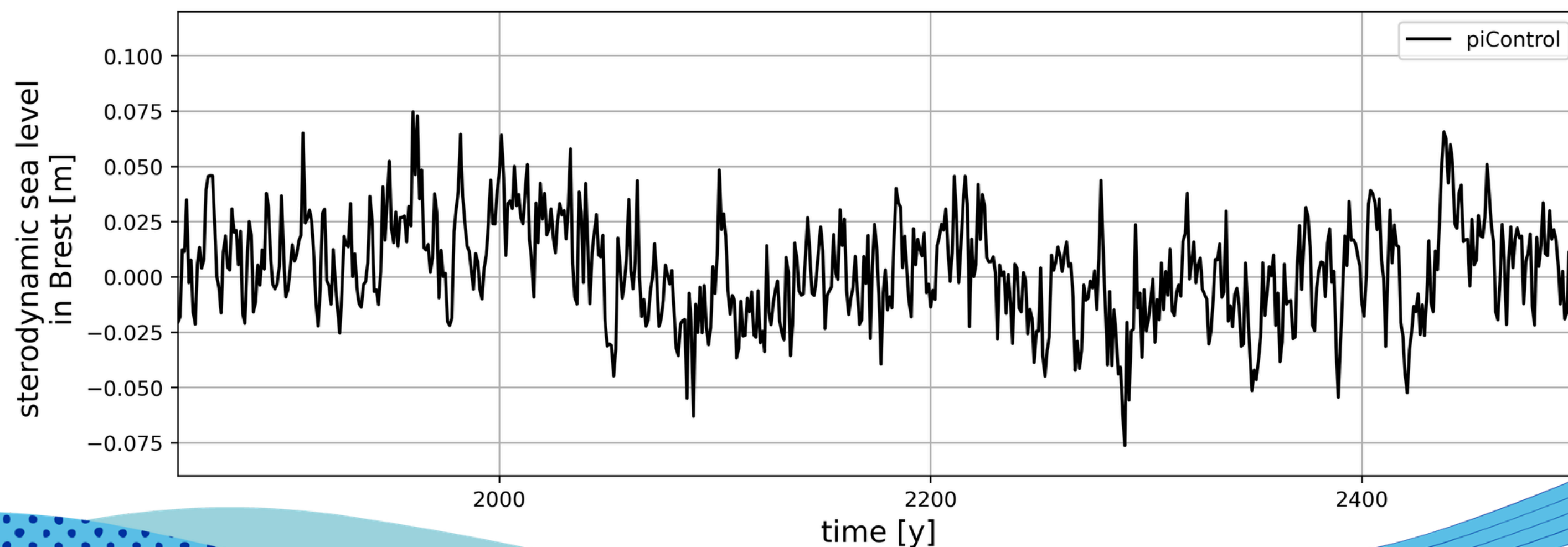
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spontaneous fluctuations of the Earth system

{ variability that would be
 observed if radiative
 forcing was identical over
 time



Method

Model #1



30 historical simulations

For a given model the 30 historical simulations:

- share the same external forcings
- have distinct initial conditions from a pre-industrial control simulation

→ **differences** explained by **internal variability**!

Earth's radiative balance:

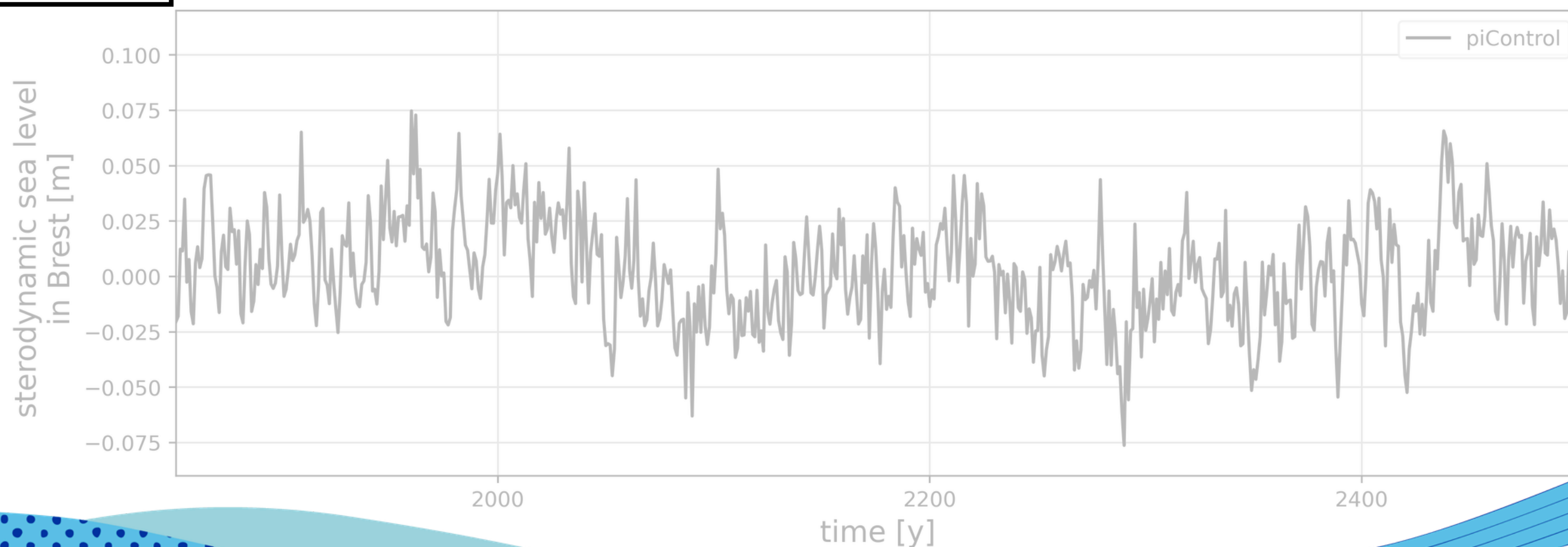
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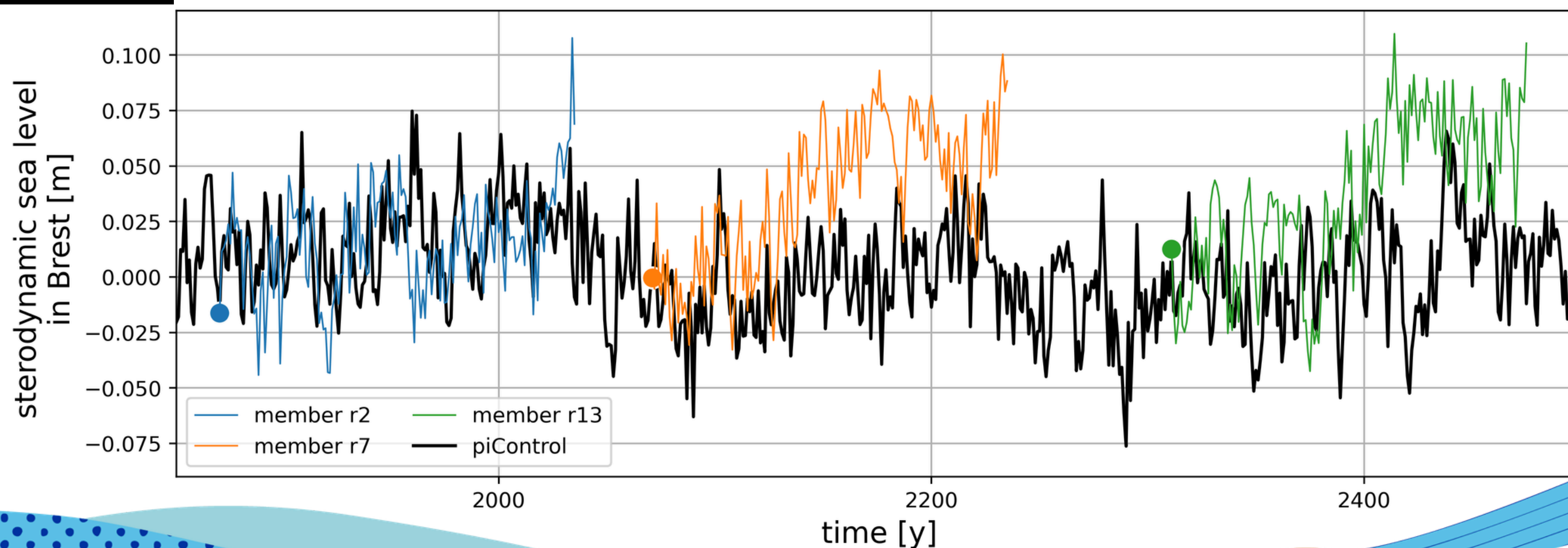
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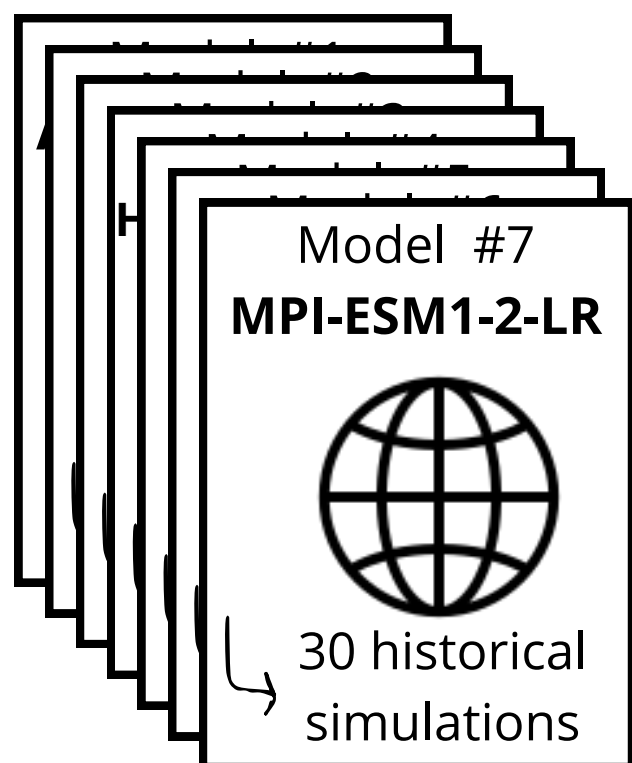
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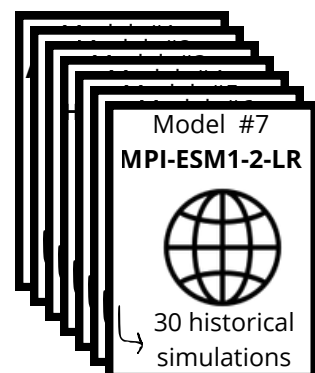


Method

7 models & 30 historical simulations per model

variance of the 210 trends = variance due to models' differences + variance due to internal variability

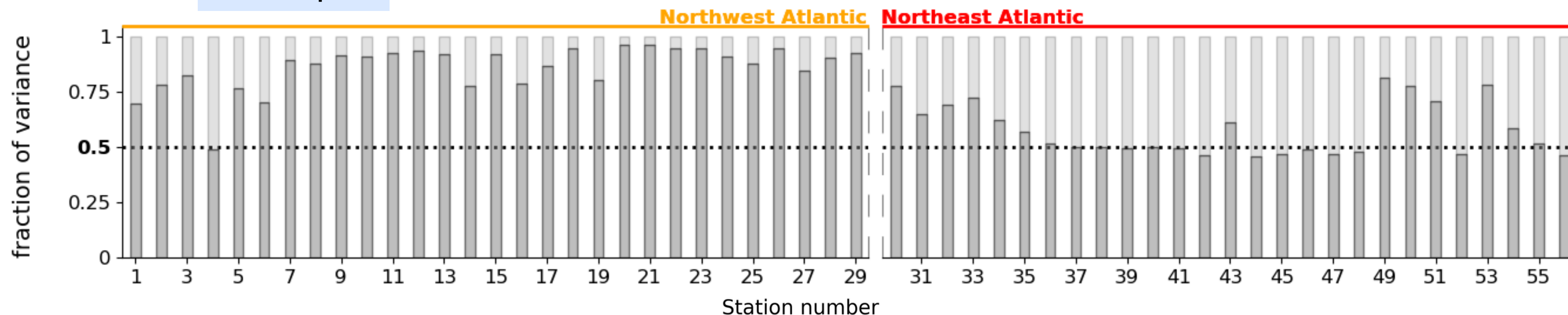




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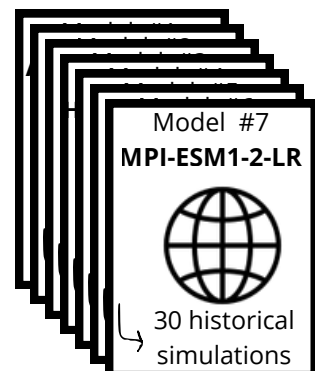


Centennial period



Fraction of variance of the simulated trends from mean internal variability:

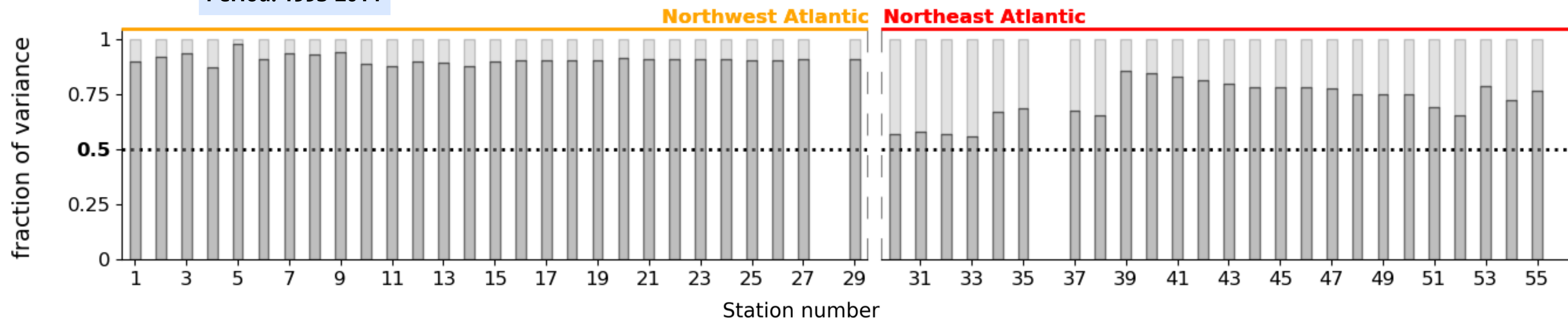
- > 0.5 for 80 % of the locations
- on average = 0.86 in the Northwest Atlantic
- on average = 0.58 in the Northeast Atlantic



variance of the 210 trends = variance due to models' differences + variance due to internal variability

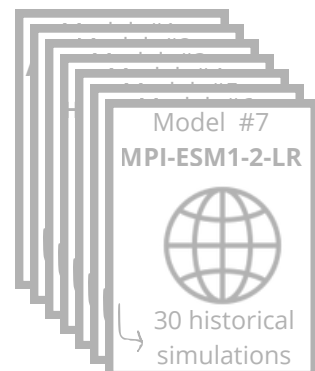


Period: 1993-2014



Fraction of variance of the simulated trends from mean internal variability:

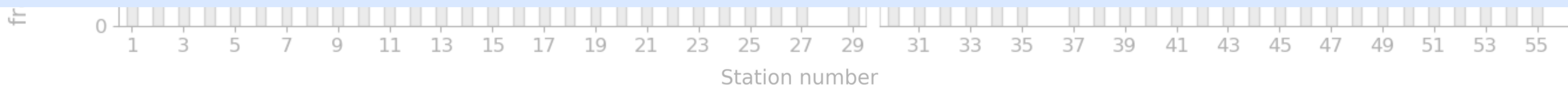
- > 0.5 for 100 % of the locations
- on average = 0.91 in the Northwest Atlantic
- on average = 0.72 in the Northeast Atlantic



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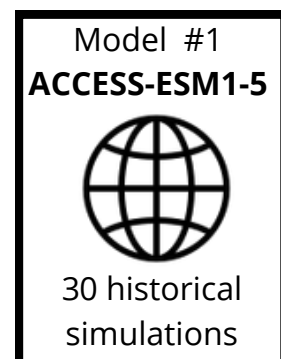


Multi-model mean internal variability dominates: how is internal variability within each model ensemble?



Fraction of variance of the simulated trends from mean internal variability:

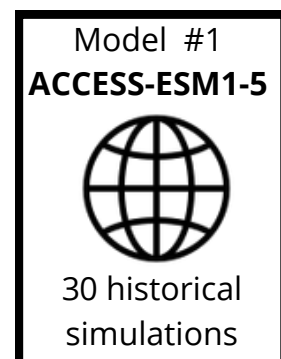
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1 model = 30 historical simulations

internal variability diagnostic = standard deviation of the 30 trends



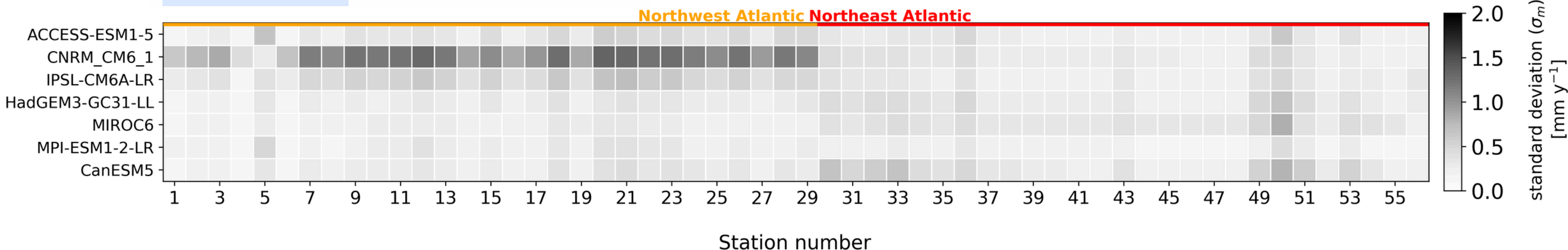


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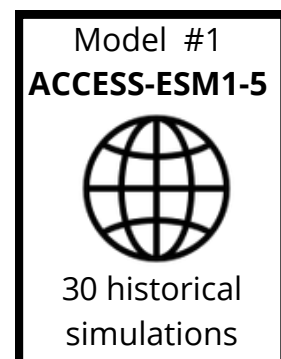


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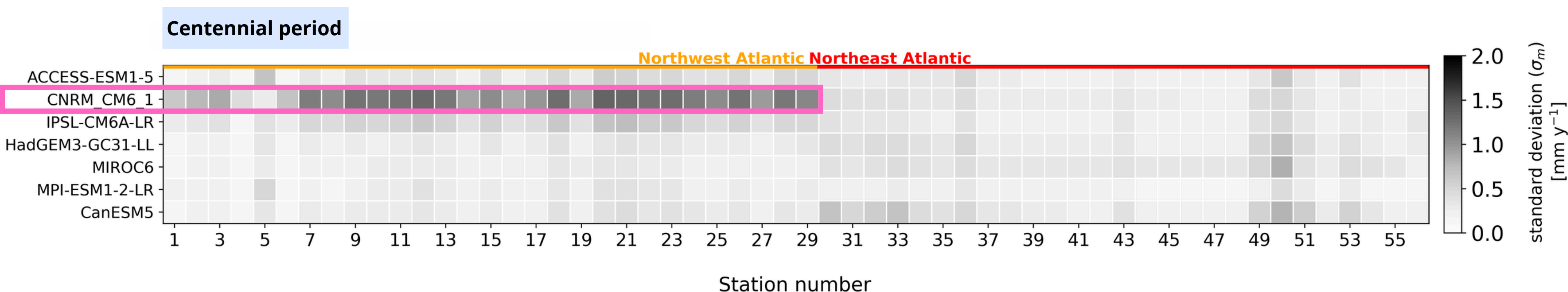
Internal variability is:

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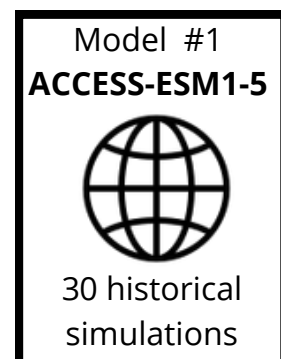
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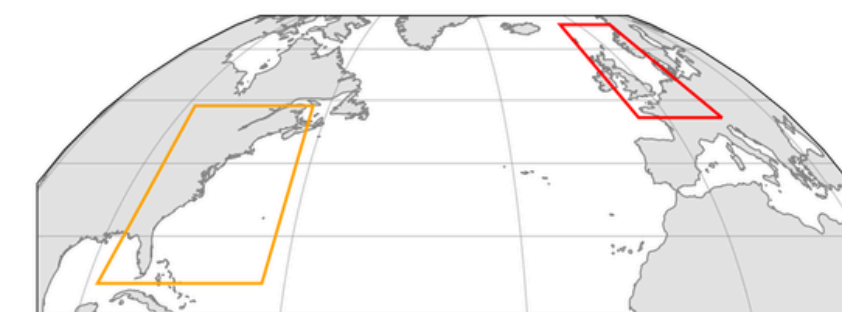
Internal variability is:

- location & model-dependent
- **CNRM-CM6-1** model exhibits a **large internal variability in Northwest Atlantic**

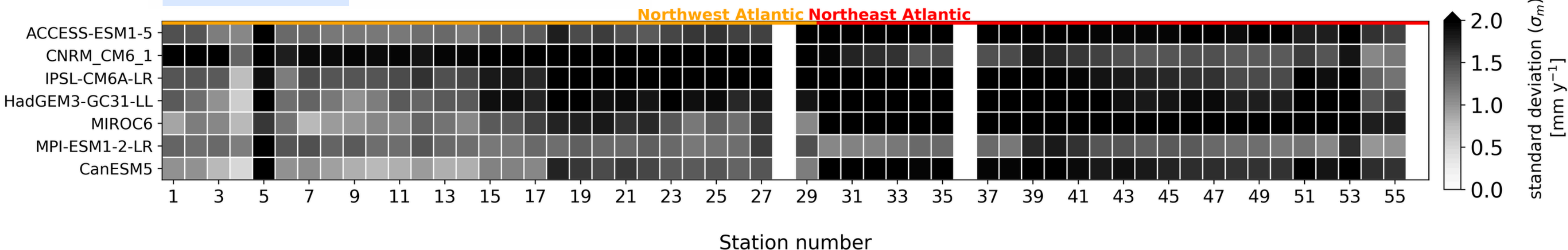


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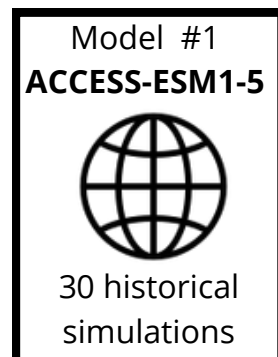


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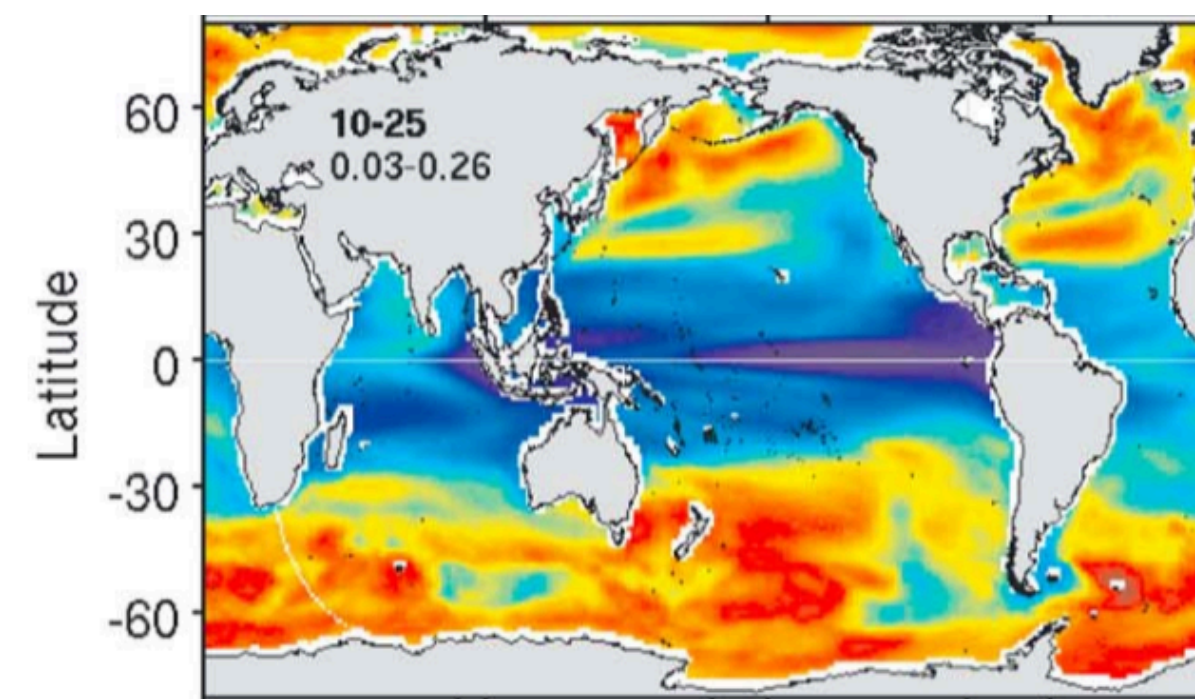
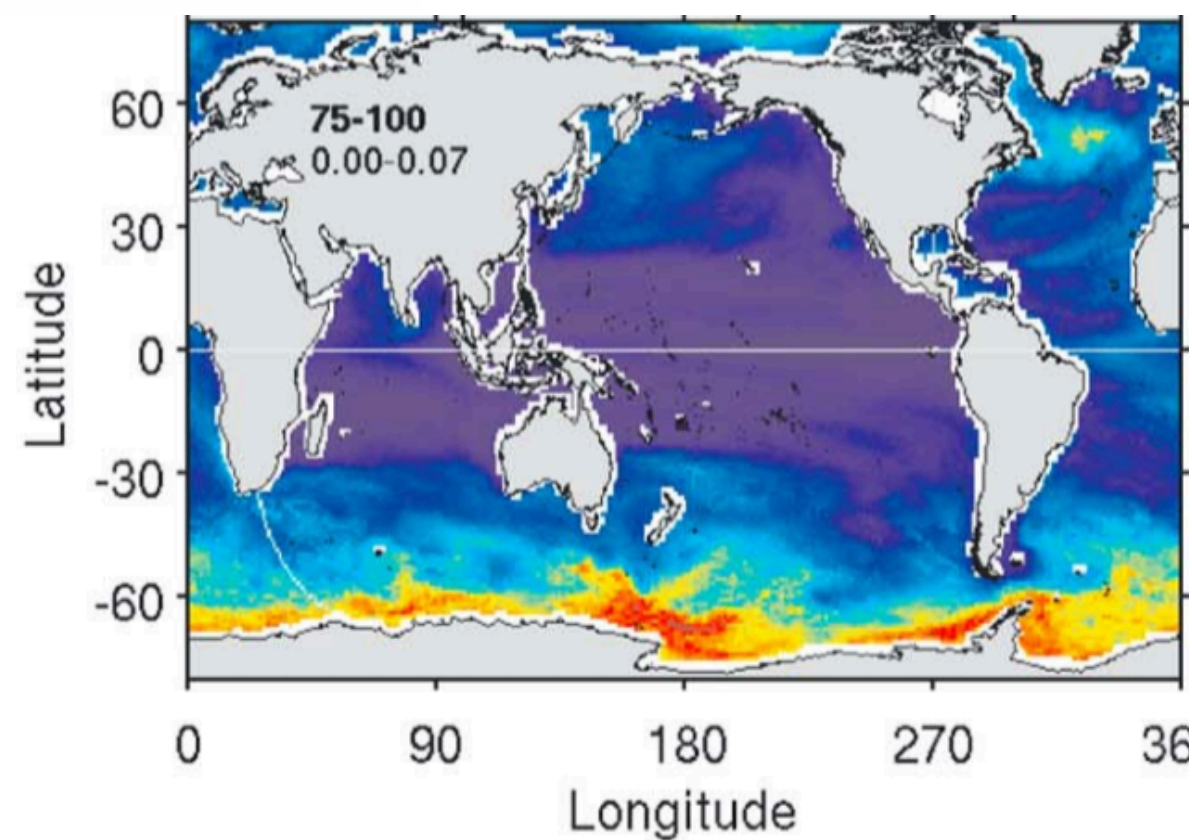
Internal variability is:

- larger than the centennial period



1 model = 30 historical simulations

internal variability diagnostic = standard deviation of the 30 trends



Internal variability is:

- larger than the centennial period
- In agreement with **Monselesan et al., 2015**

Figure adapted from Monselesan et al., 2015

Do reconstructed sea level trends match tide gauge trends?

- When taking into account the uncertainties associated with climate models output, there is an **agreement of the trends** at:
 - **77 %** of the locations over the **centennial period**
 - **95 %** of the locations over **1993-2014**
- Disagreement: local vertical land movement? uncertainties of the other components?
 - Further investigated in a follow-up study

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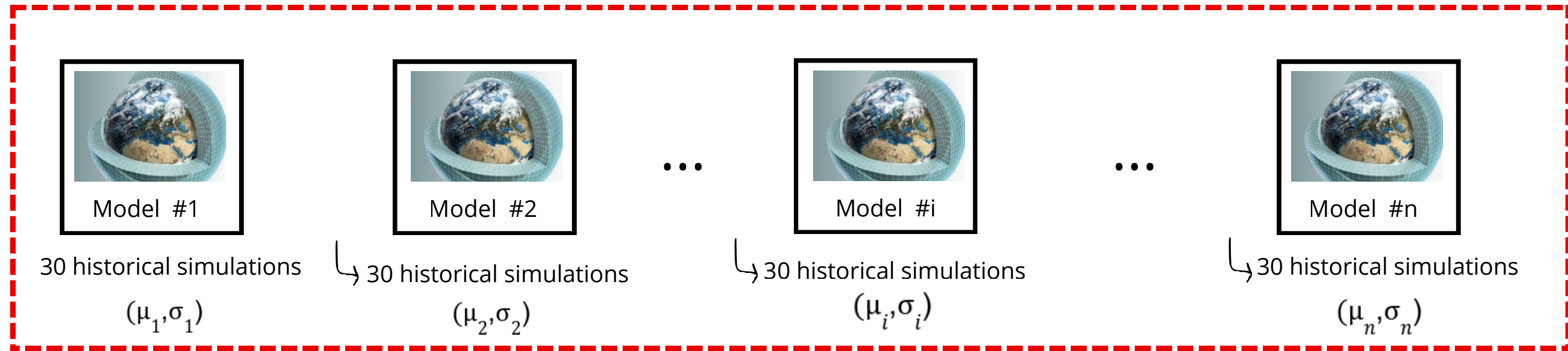
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What are the uncertainties of the sea level component from climate models?

- **Internal variability dominates over model differences** for the two periods considered
- Further analyses are performed to investigate the east/west difference in internal variability

Extra slides

Disentangle internal variability from model uncertainty in historical sea-level trends



Uncertainty partitioning

Total uncertainty = model uncertainty + internal variability

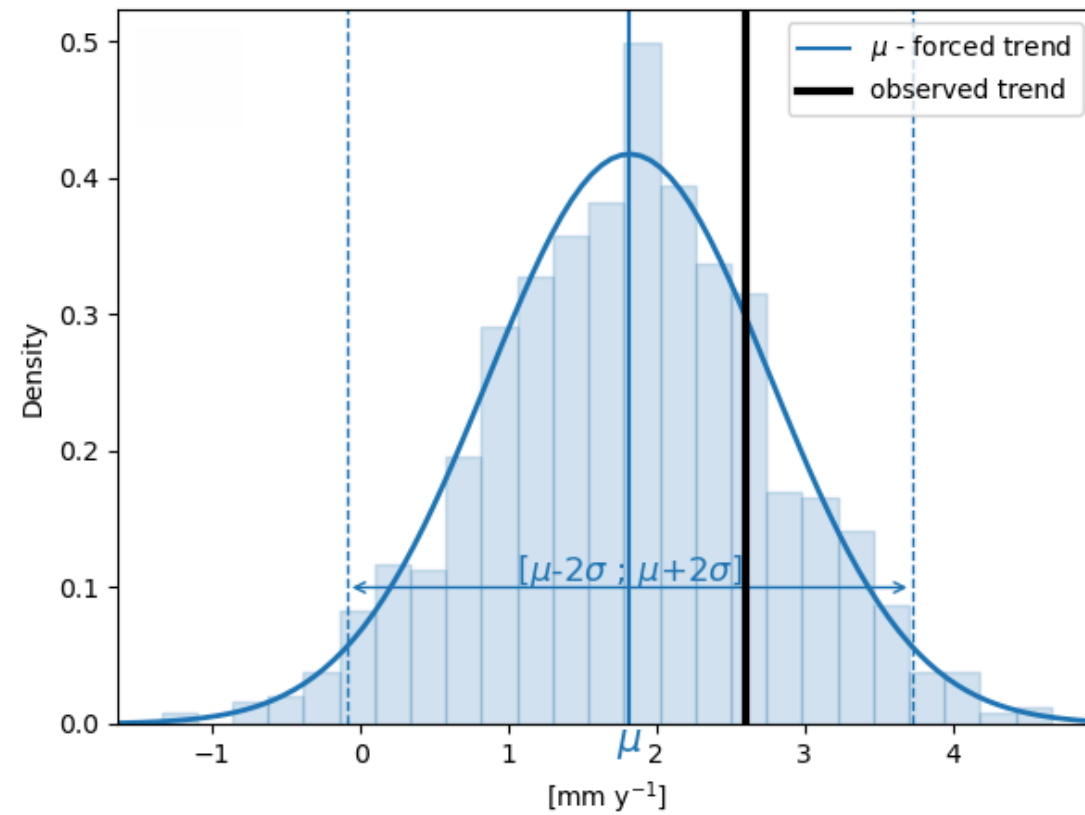


variance across the model ensemble
means

mean of the variance across the model
ensemble members

$$\text{Var}(\mu_i)$$

$$\text{mean}(\sigma_i)$$



Assumption: model independance

VLM_{other}

In a geocentric referenceframe, we write:

$$\text{VLM}_{\text{total}} = \text{VLM}_{\text{GIA}} + \text{VLM}_{\text{bGRD}} + \text{VLM}_{\text{other}}$$

Nevada dataset at
tide gauges
(Hammond et al.,
2021)



from Caron et al.,
2018



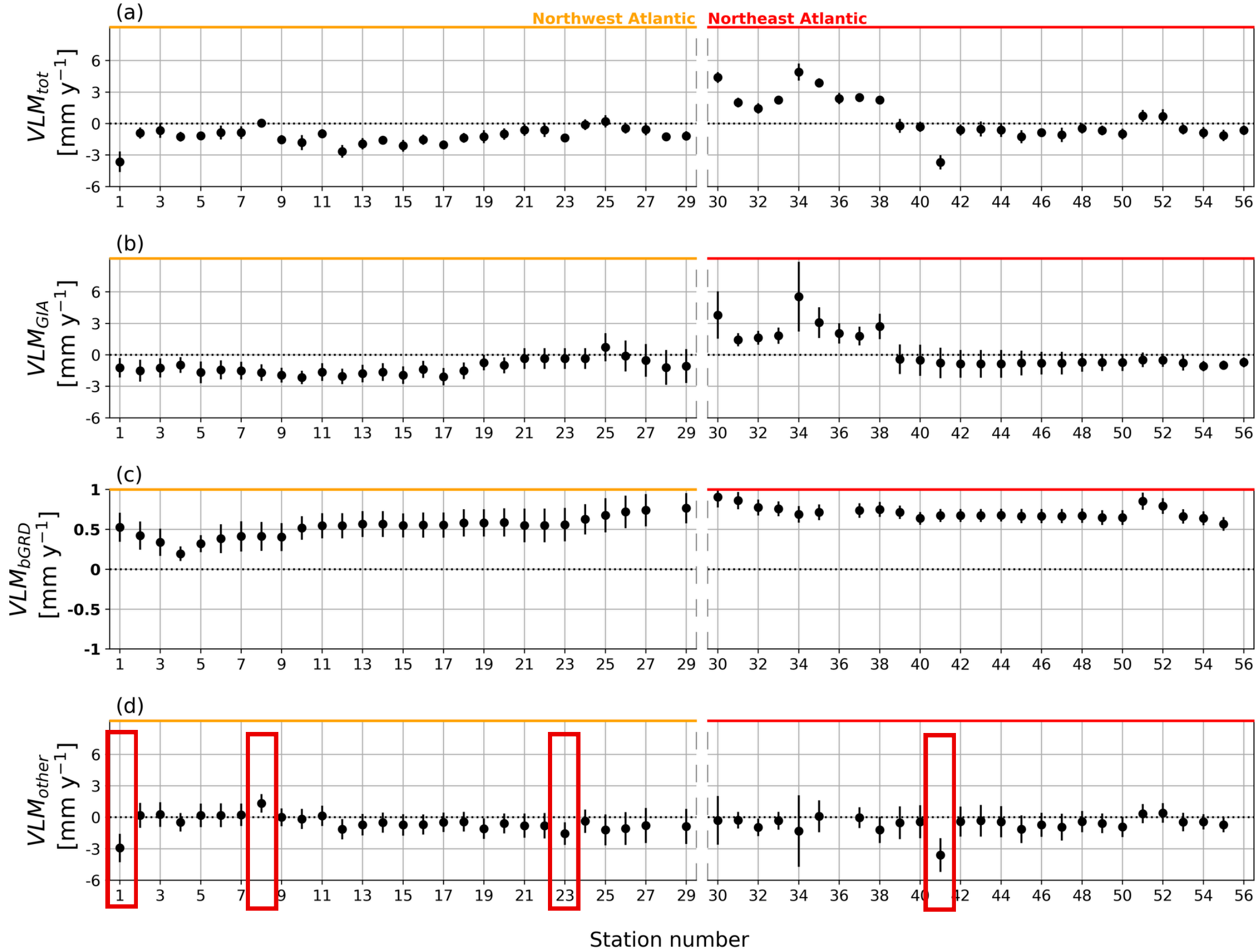
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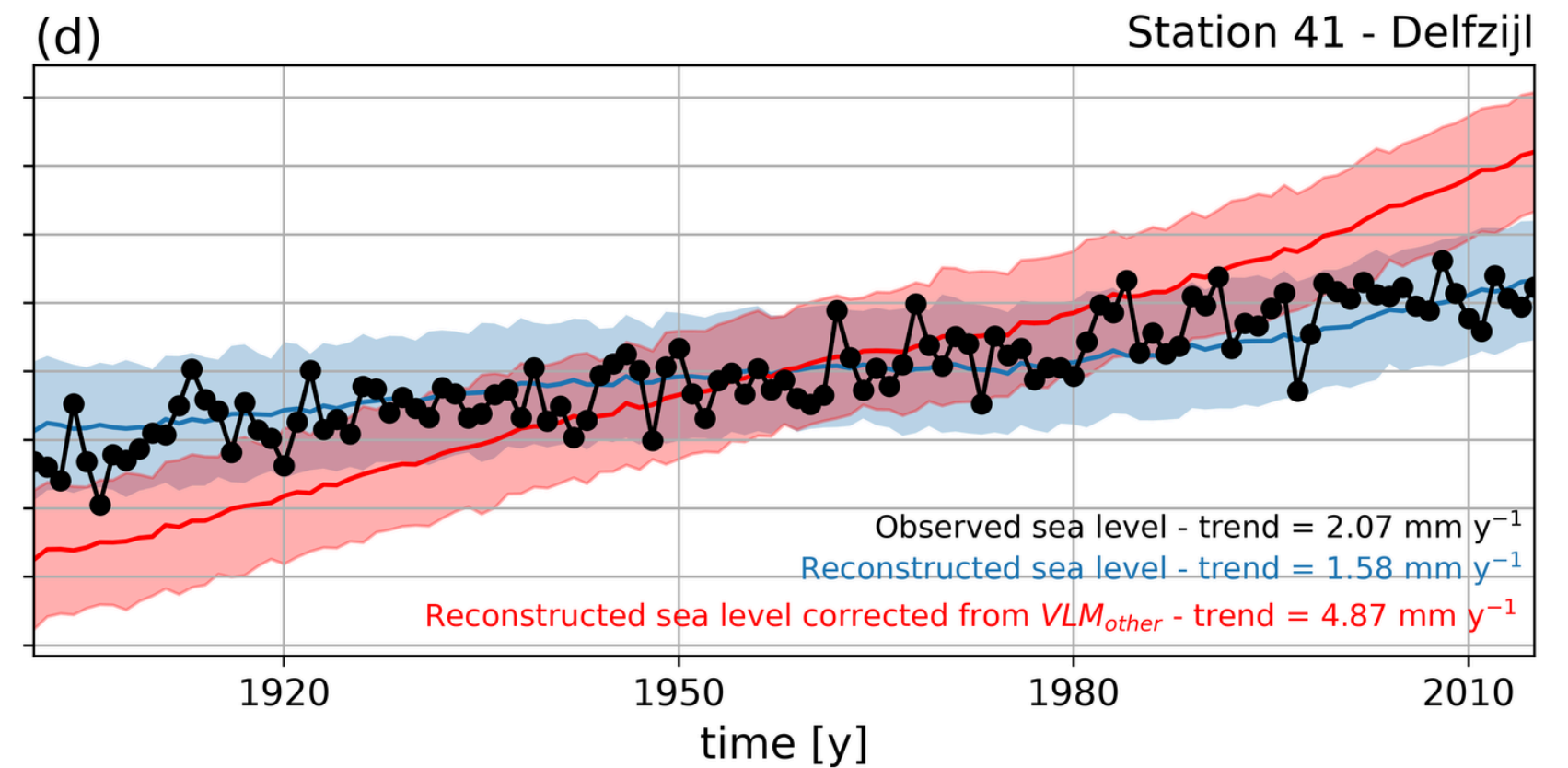
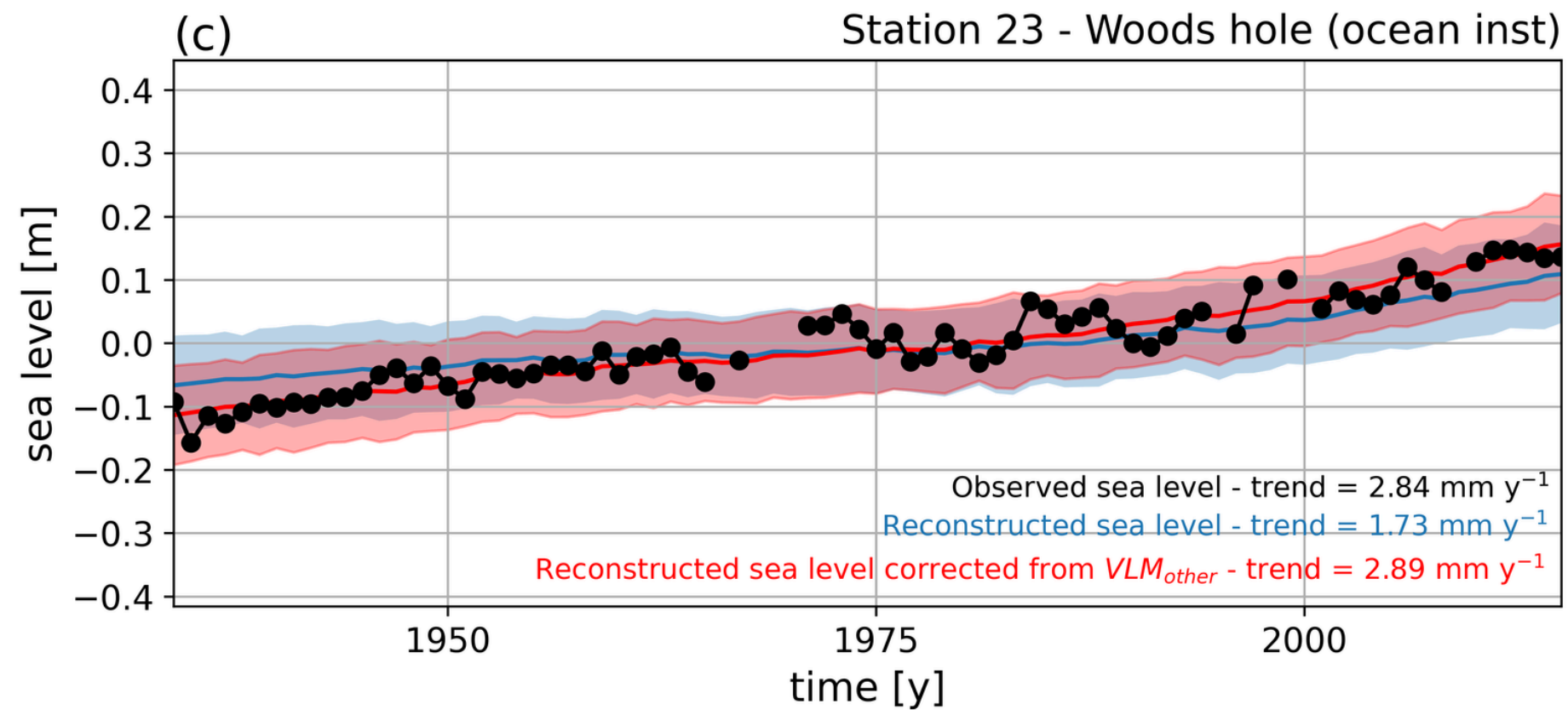
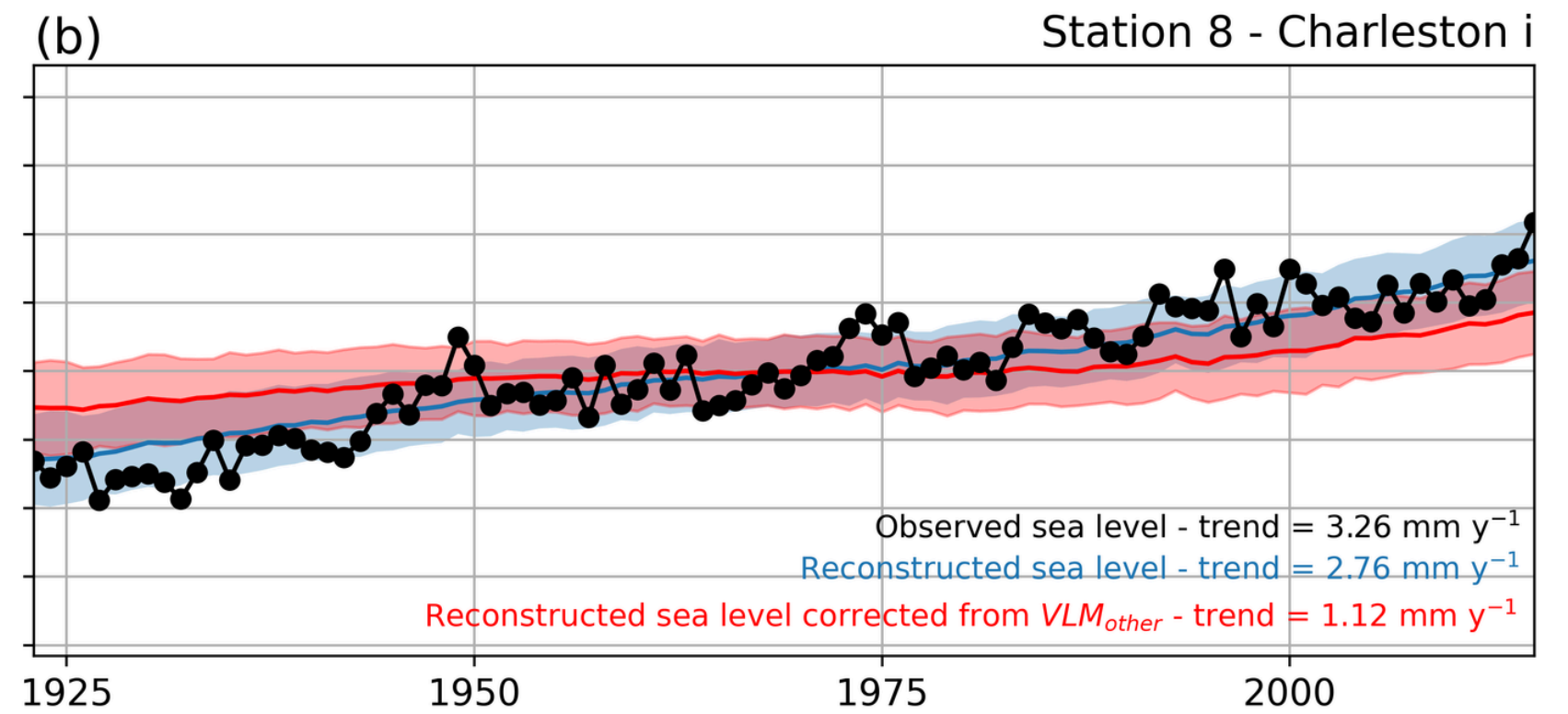
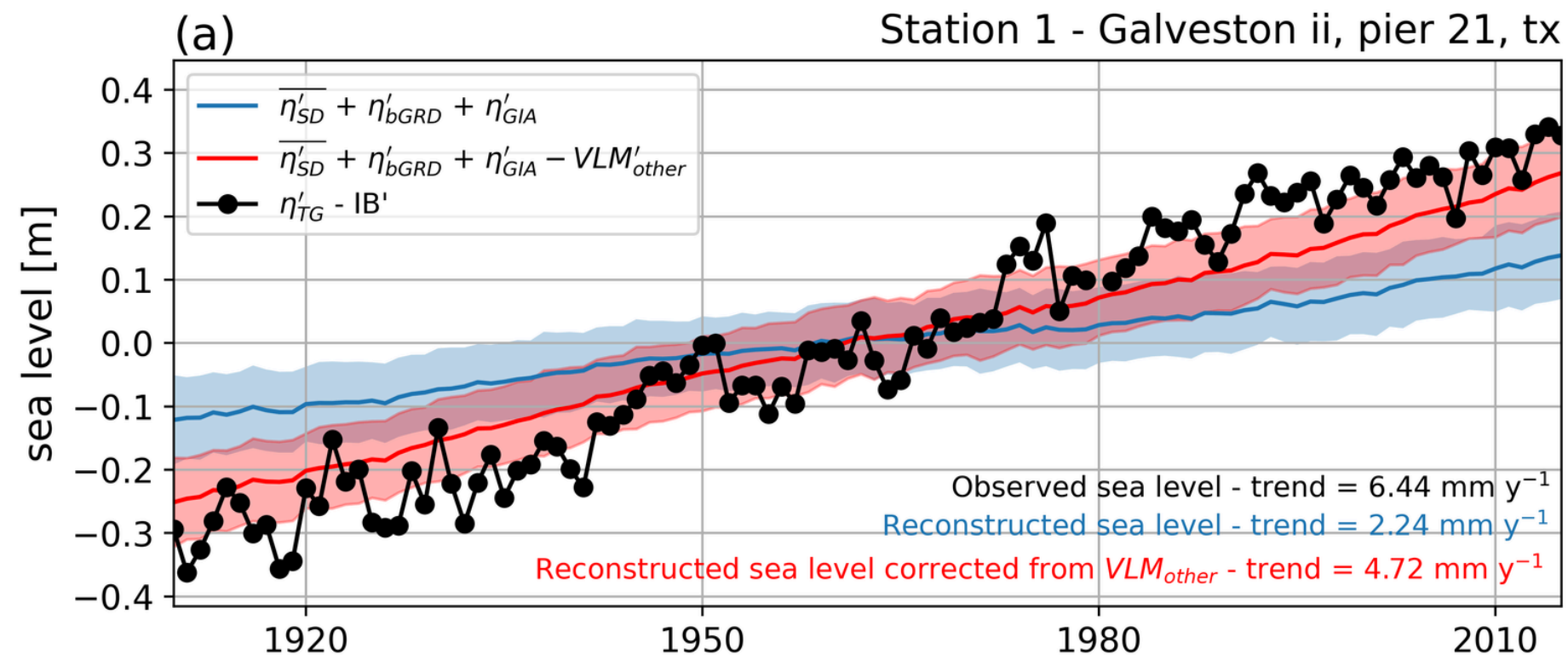


deducted from
the 3 other terms



$$VLM_{\text{total}} = VLM_{\text{GIA}} + VLM_{\text{bGRD}} + VLM_{\text{other}}$$





Tide gauges	Galveston	Charleston	Woods Hole	Delfzijl
$\eta - \eta_{obs}$ trends [mm y ⁻¹]	-4.2	-0.5	-1.11	-0.49
$\eta_{corr} - \eta_{obs}$ trends [mm y ⁻¹]	-1.72	-2.14	0.05	2.8