



# Improving present-day estimates of extreme sea levels with the Global Tide and Surge Model

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and many more colleagues



Need for return  
periods to  
estimate flood  
risk and  
adaptation





## **Global Tide and Surge Model**

**Depth-averaged hydrodynamic model**

**Delft3D Flexible Mesh**

**2.5/1.25 km resolution at the coast**

## **Applications**

**Operational forecasting**

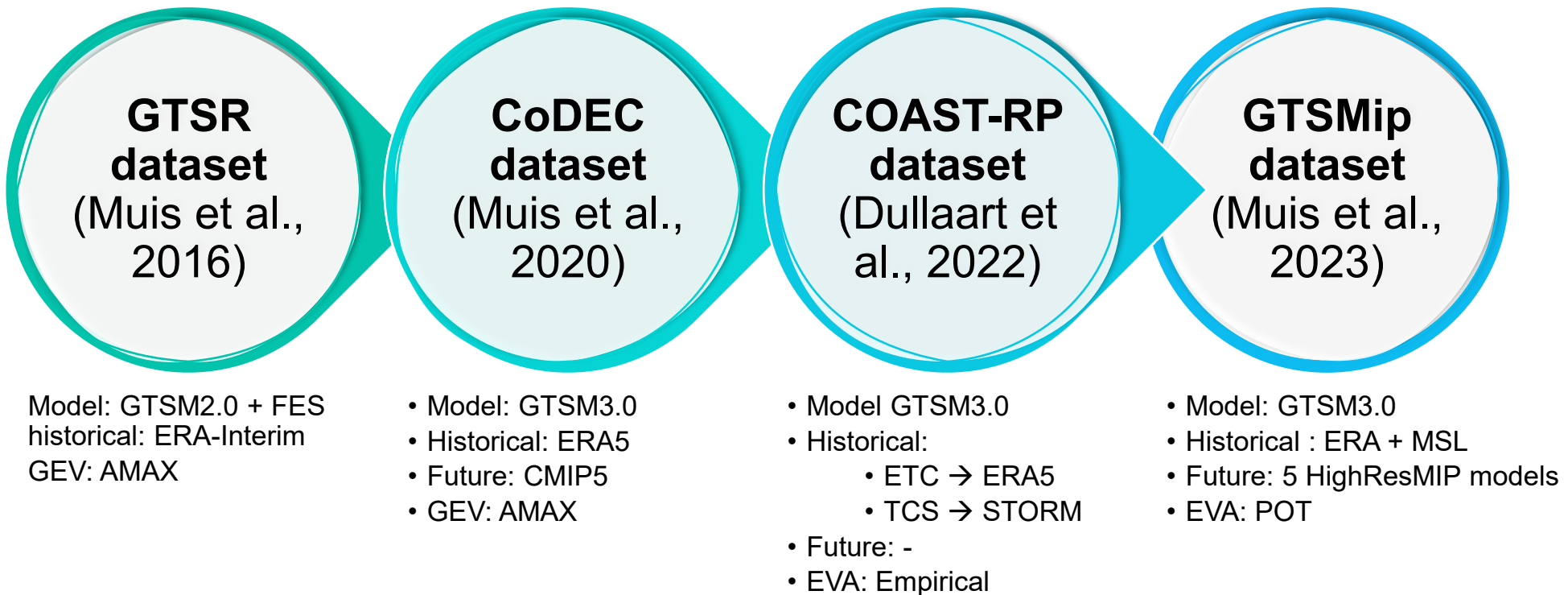
**Reanalysis of historical extremes**

**Future climate projections**

**Providing input data to coastal flood risk  
assessments**

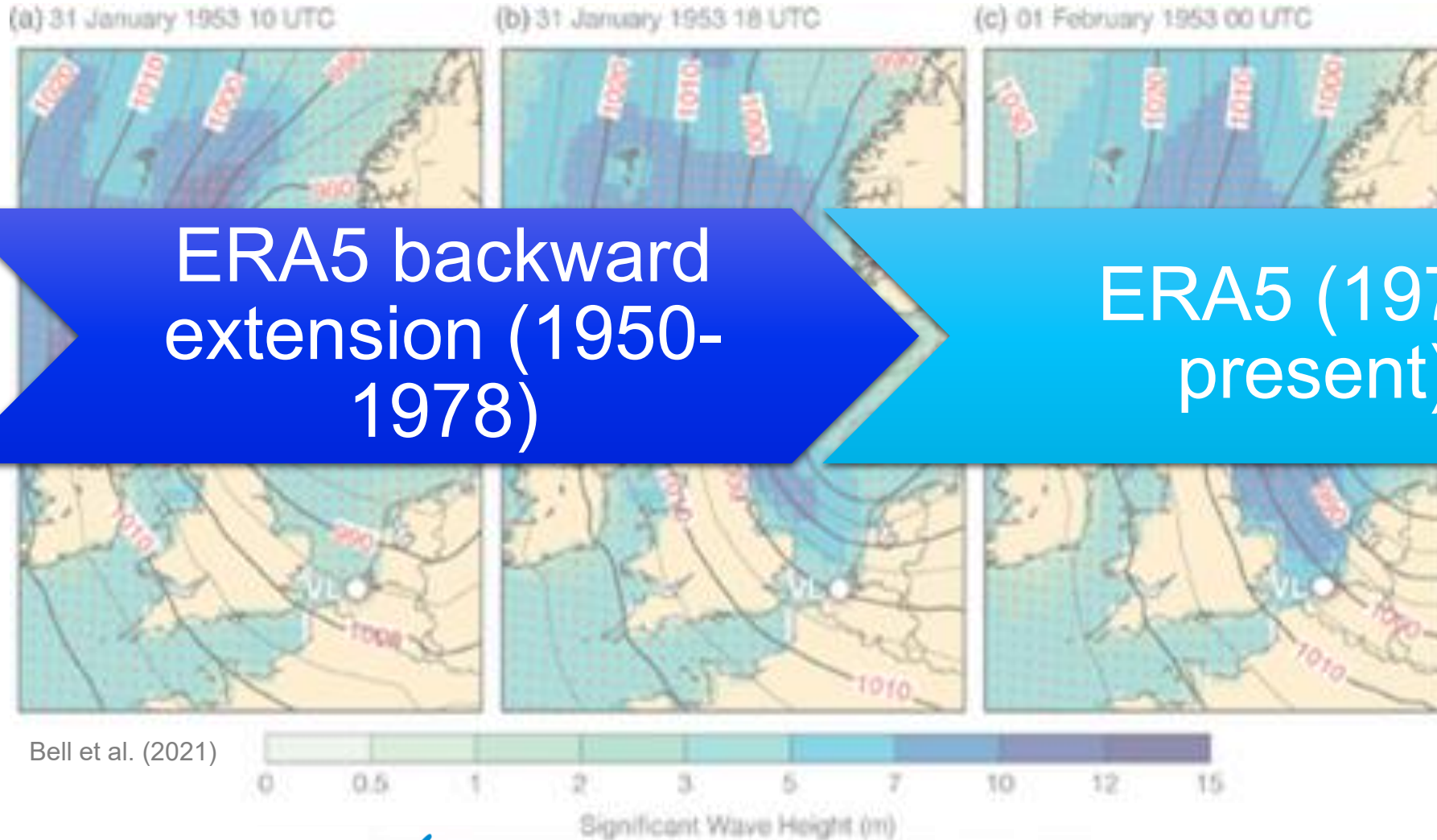
# Present-day return periods derived from GTSM

## An overview

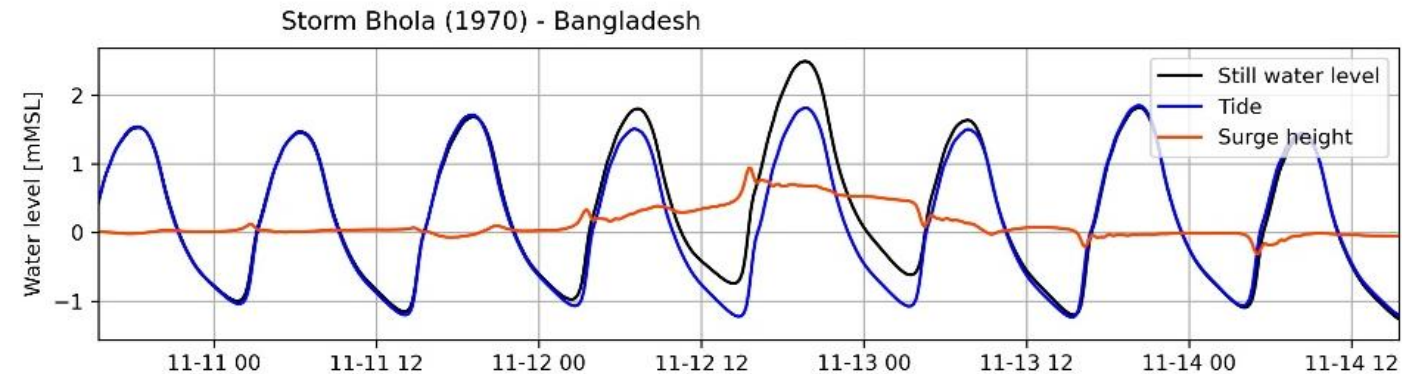
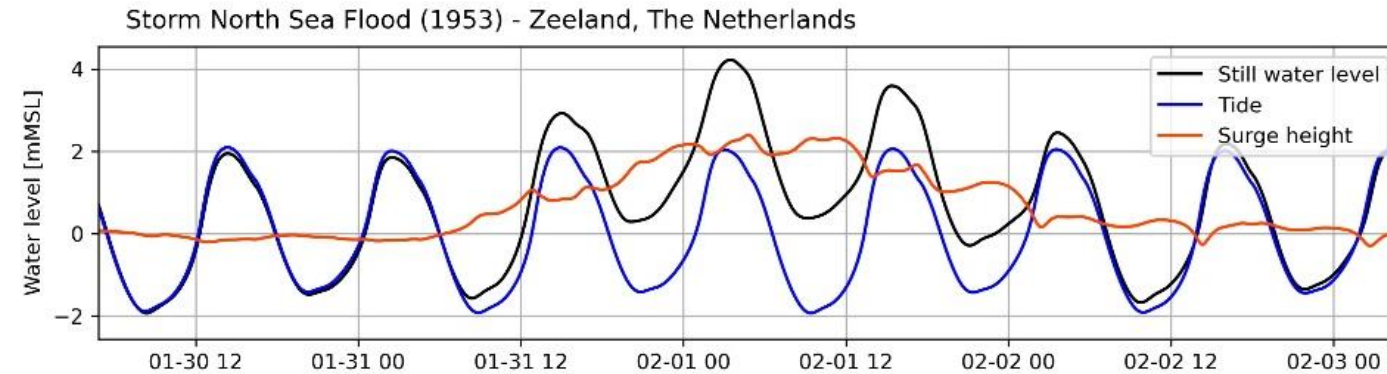




# GTSM-ERA5 extension from 42 to 74 years of data



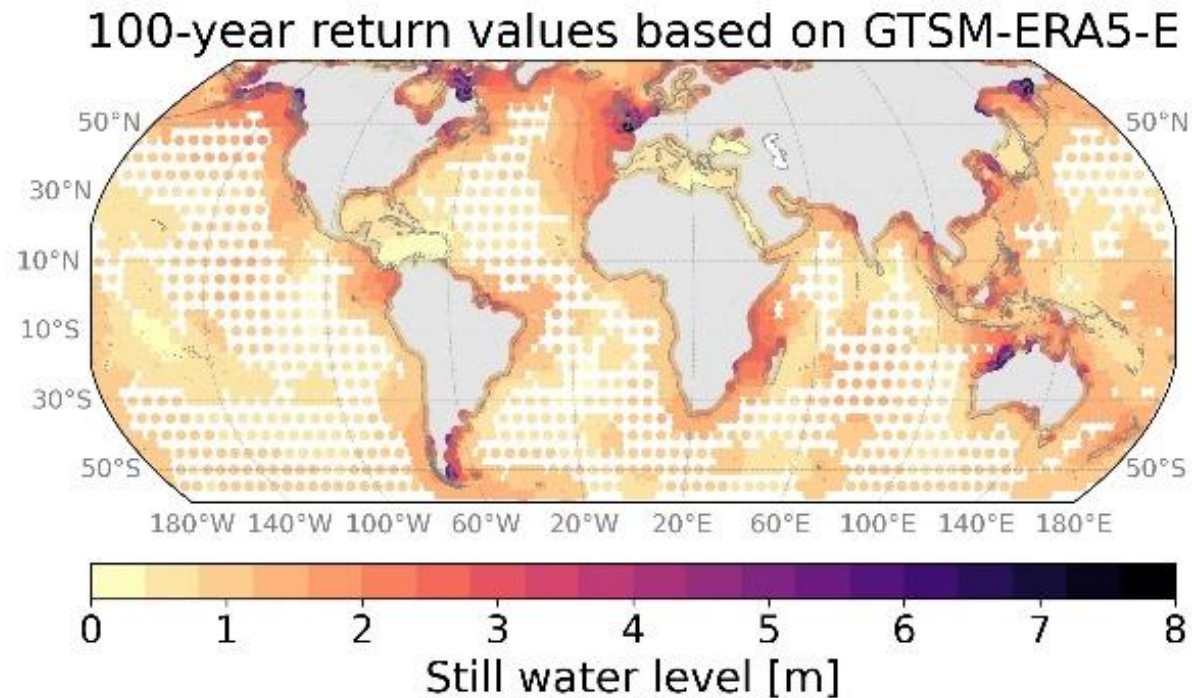
# Historical extremes that were previously not recorded



Aleksandrova et al. (in review)

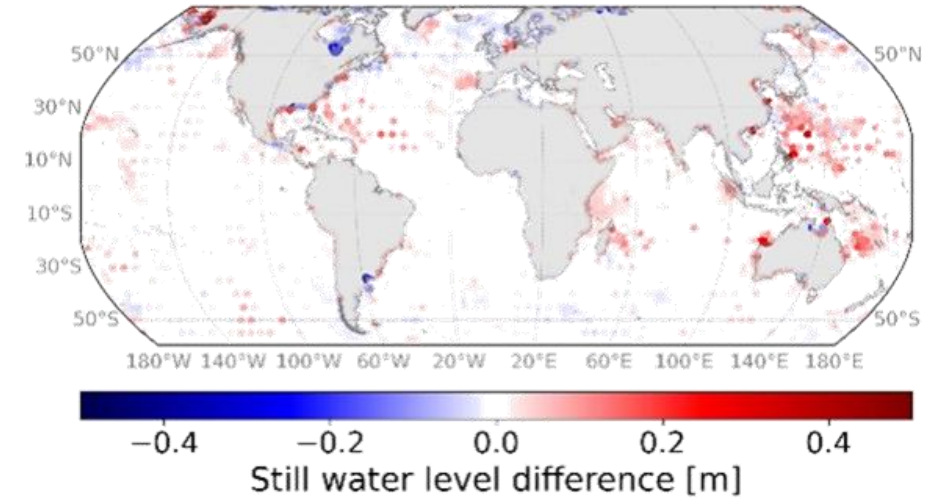


# Longer records allow for updated estimates of return levels

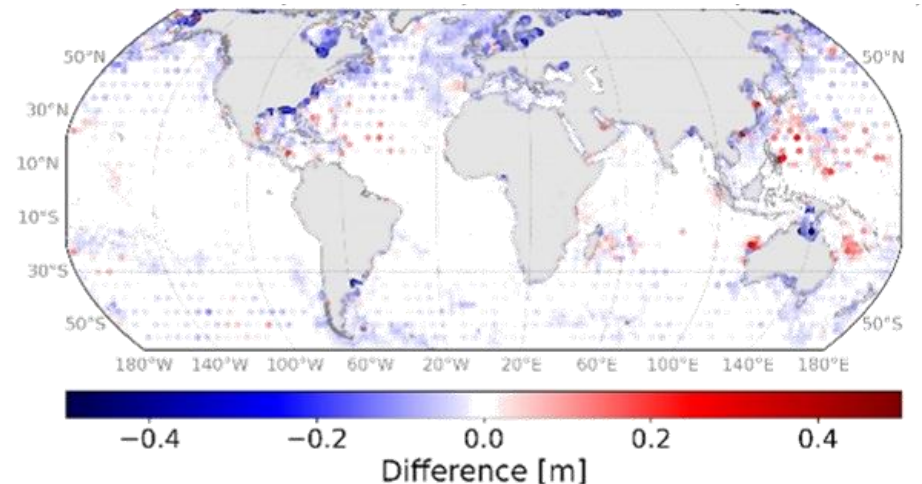


Aleksandrova et al. (in review)

In most places: higher return levels

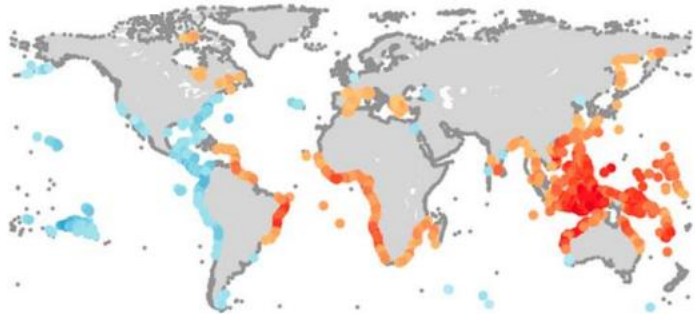


In most places: smaller confidence bounds



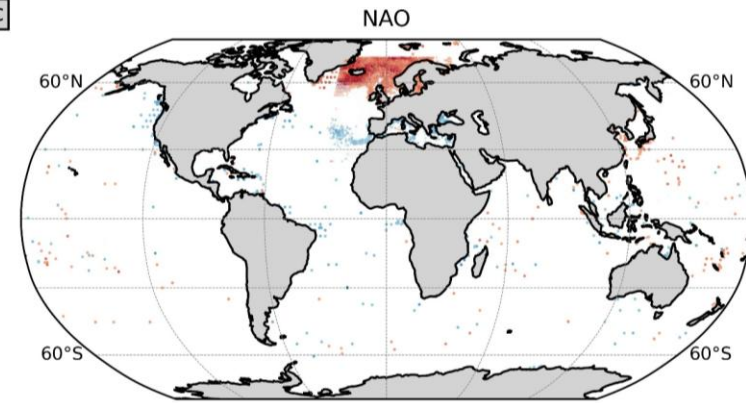
# Longer records allow for better evaluation of climate variability

ENSO

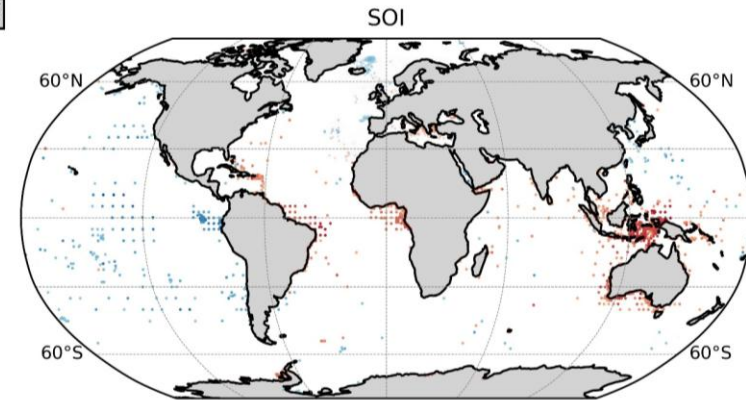


Muis et al. (2018)

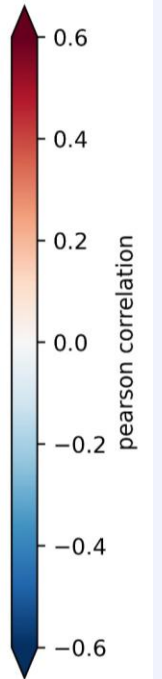
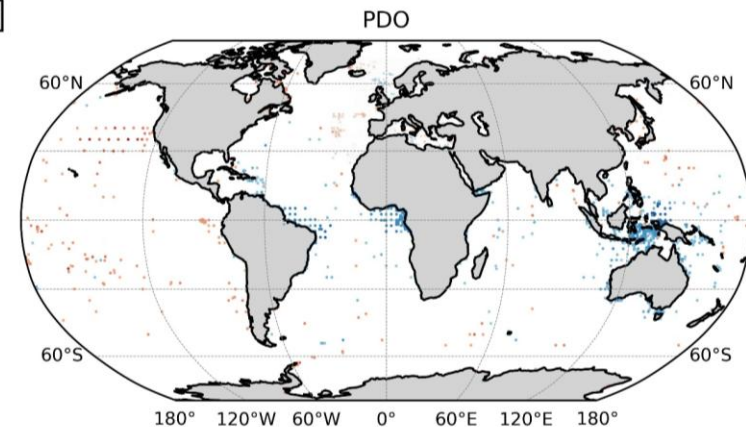
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# Openly available at the C3S Climate Data Store

- **Timeseries** from 1950-2023
  - Mean sea level
  - Tides
  - Storm surges
  - Total water level

<https://doi.org/10.24381/cds.6edf04e0>

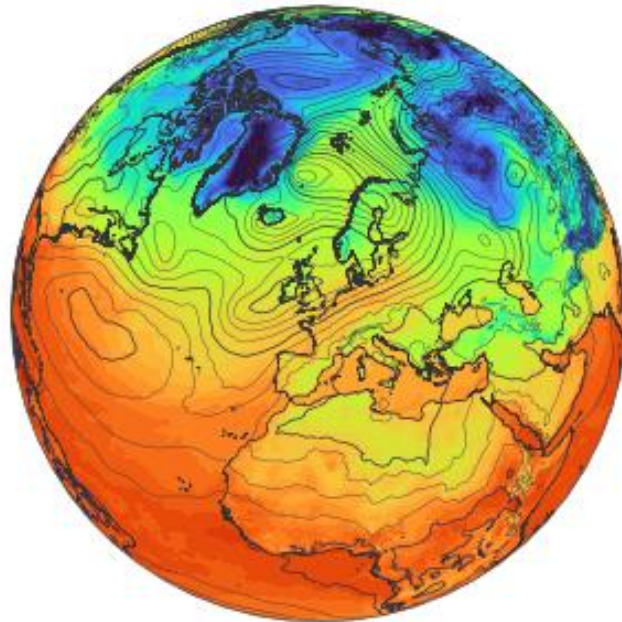


The screenshot displays the CDS Climate Data Store interface. At the top, there are logos for the European Union, Copernicus, ECMWF, and Climate Change Service, along with a 'Login/register' button. The main title is 'Water level change indicators for the European coast from 1977 to 2100 derived from climate projections'. A warning message states: 'CDS is currently having some technical issues. For more updated information please visit our User Forum. Sorry about any inconvenience caused.' Below this, a notice says: 'WARNING: The layout of this catalogue entry was updated 19-02-2021, please update any cdsapi scripts and/or CDS toolbox workflow to reflect the new download form'. The interface includes tabs for 'Overview', 'Download data', and 'Documentation'. The 'Download data' tab is active, showing a form with the following sections:

- Variable:** At least one selection must be made. Options include: Annual highest high water level, Annual mean highest high water level, Epoch mean highest high water level, Highest astronomical tide, Mean sea level, Tidal range, Annual lowest low water level, Annual mean lowest low water level, Epoch mean lowest low water level, Lowest astronomical tide, Surge level, and Total water level.
- Experiment:** At least one selection must be made. Options include: Historical, ERA5 reanalysis, RCP4.5, and RCP8.5.
- Statistic:** At least one selection must be made. It includes a 'Return period' section with options for 2 years, 5 years, 10 years, 25 years, and 50 years, and a 'Percentiles' section with options for 10th, 25th, 50th, and 75th.
- Format:** Options include 'Zip file (.zip)' and 'Compressed tar file (.tar.gz)'.

Buttons for 'Show API request', 'Show Toolbox request', and 'Please check mandatory fields' are at the bottom of the form. On the right side, there is a 'Contact' section with links to 'ECMWF Support Portal', 'Licence', 'Licence to use Copernicus Products', 'Publication date' (2020-06-07), and 'References' (DOI: 10.24381/cds.6edf04e0). A small chat bubble on the right says: 'Hello, I am the Knowledge Duck. I'm here to help you to understand the CDS. What would you like to know today?'.

# Limitations of ERA5 for extreme value analysis



Unprecedented events

Small sample

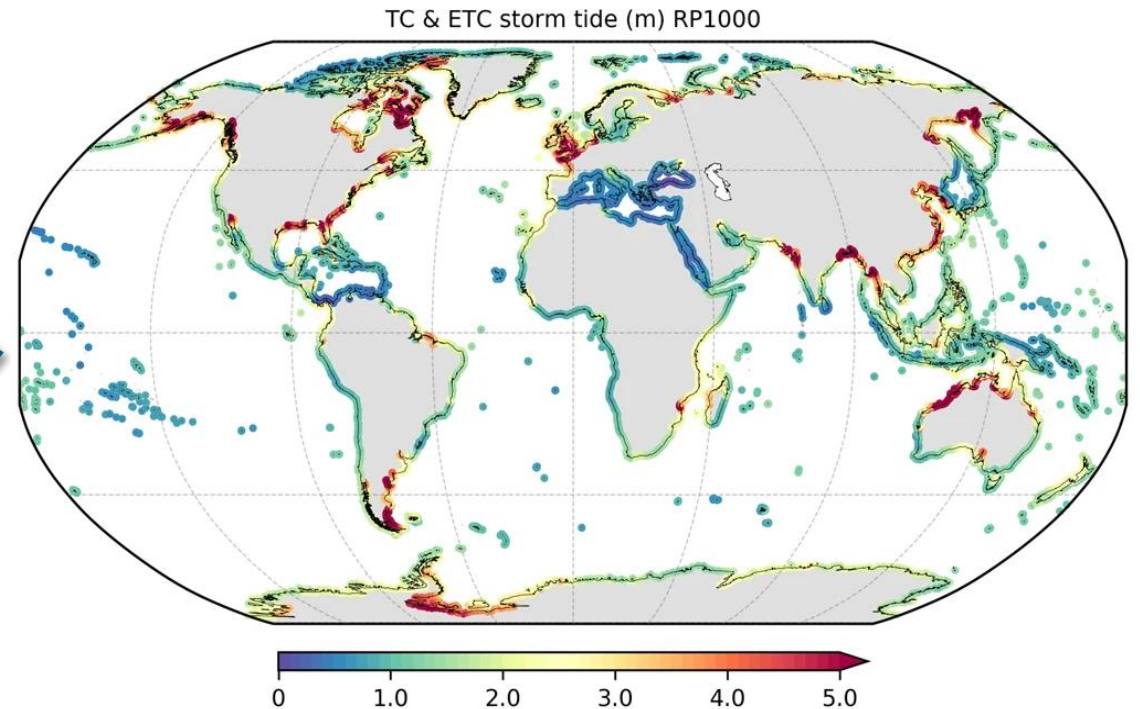
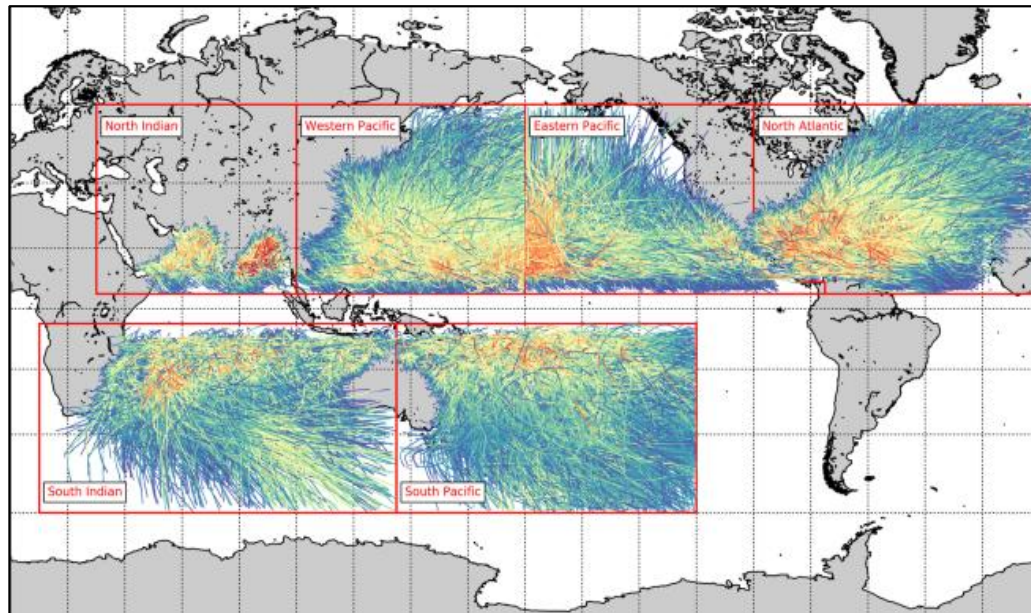
EVA assumes stationarity

Large interannual variability



# For tropical cyclones, we can use synthetic tracks

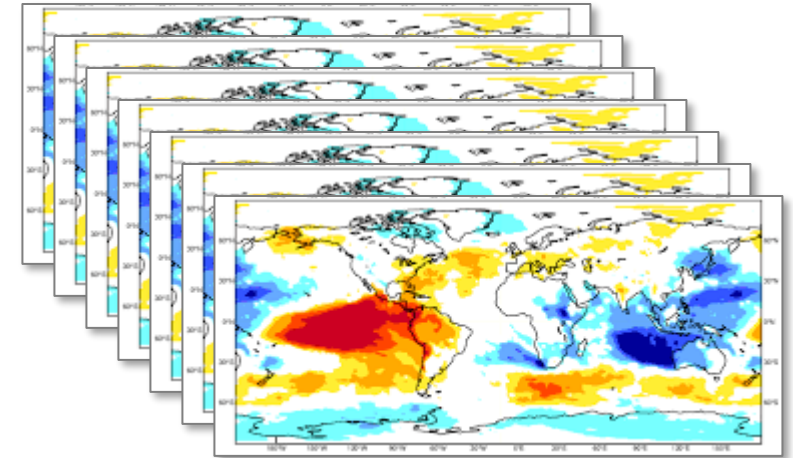
STORM 10.000 years of data



Bloemendaal et al. (2021) **STORM**

# Extra-tropical regions require different approach

- Pooling from SEAS5 seasonal forecast ensemble
- SEAS5 archive provides ~7,000 years of data
  - Re-forecasts :1981–2016, 25 ensemble members.
  - Forecast: 2017 to present, 51 ensemble members
  - Initialized monthly, have a 7-month length,
  - 6-hourly temporal resolution with a 36 km horizontal resolution

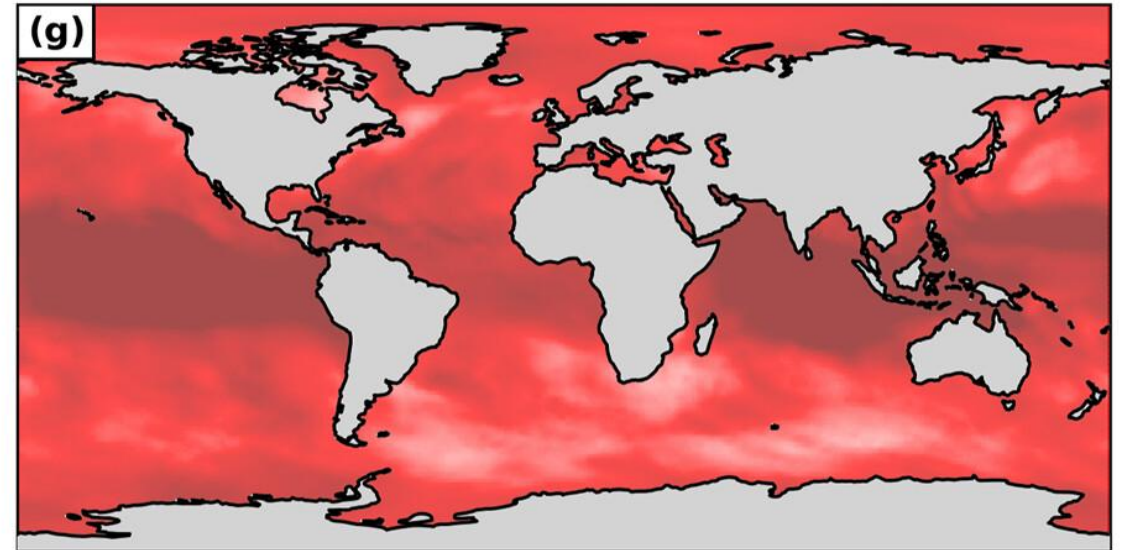




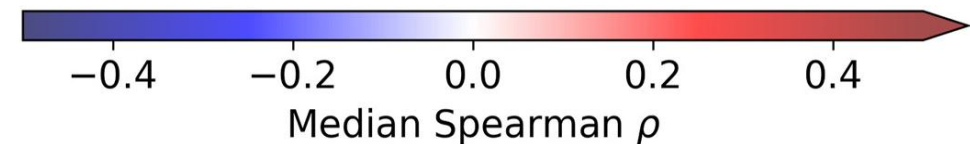
# Independent

- Poor skill beyond lead time of 1 month in mid-latitude regions

Forecast (2017 - 2023)



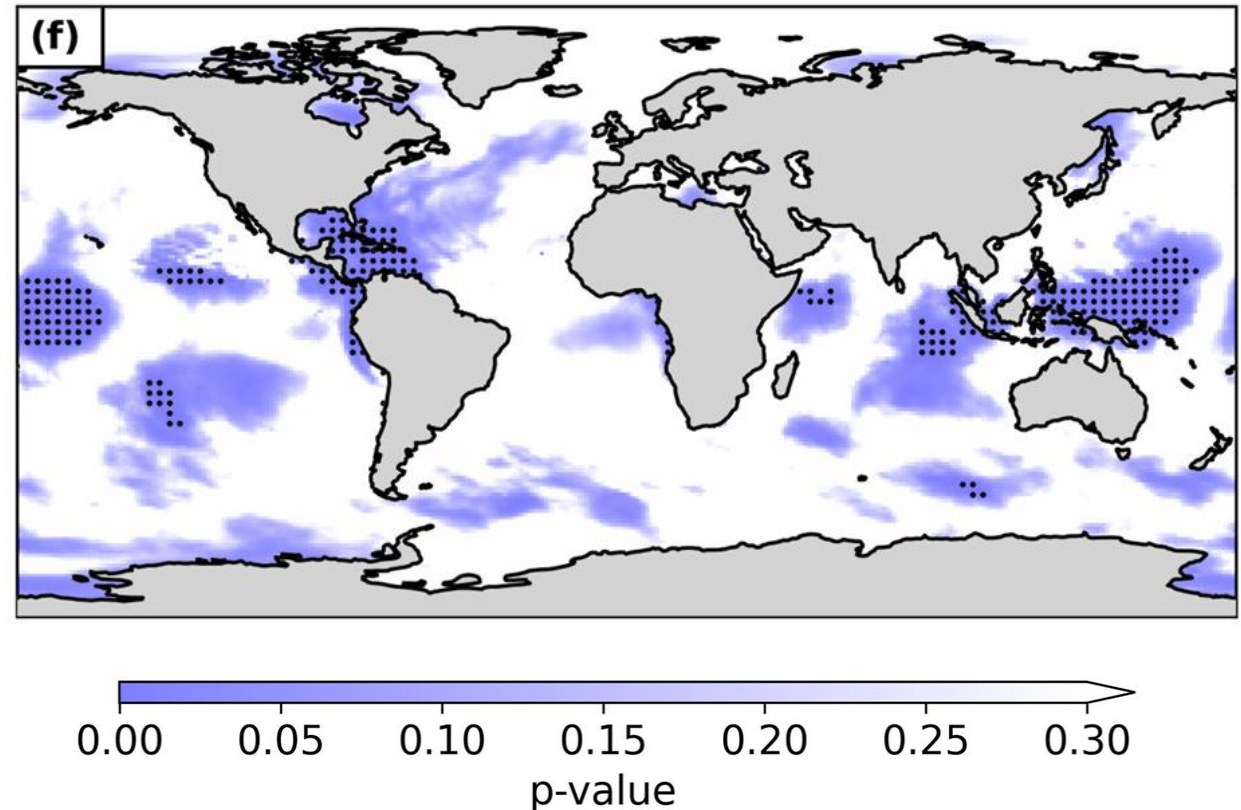
Benito et al. (2025)



# Unbiased

Bootstrapping to test if the mean of the monthly minimum sea level pressure is significantly different

Forecast (2017 - 2023)

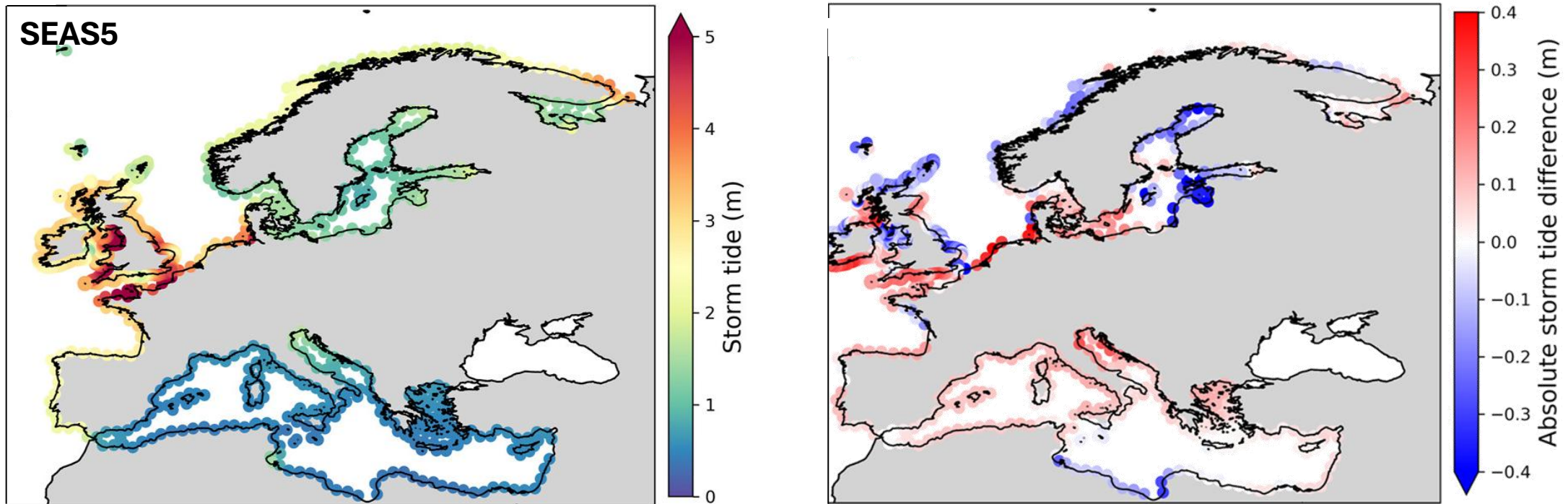


Benito et al. (2025)



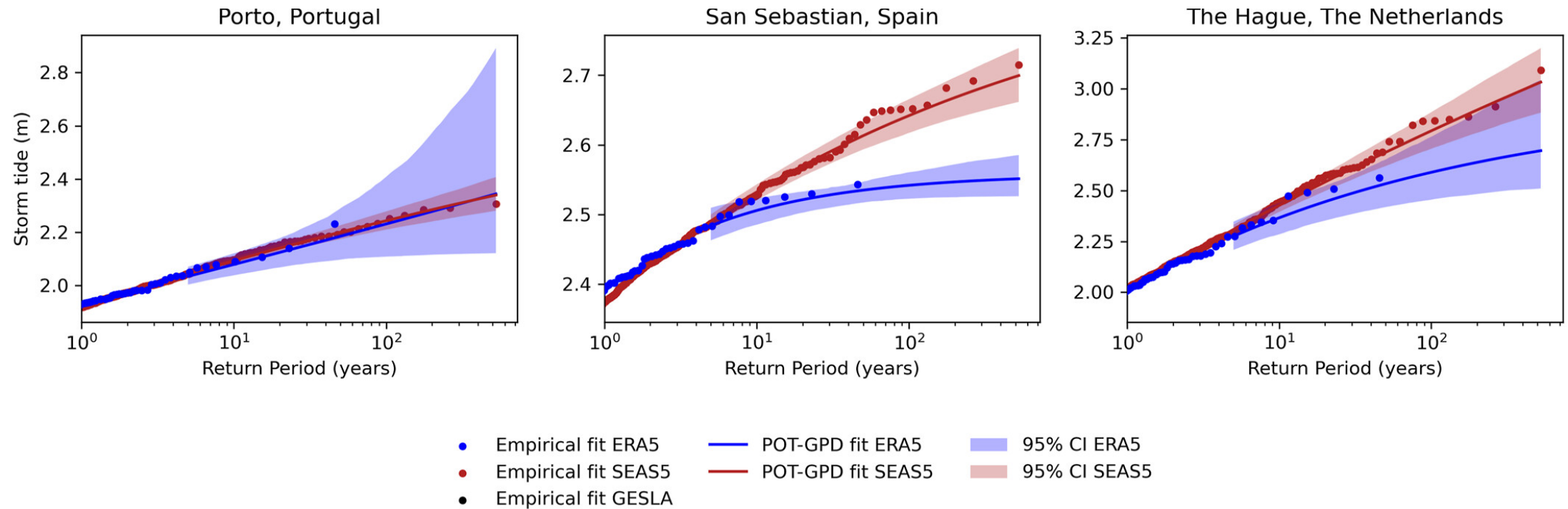
# 525-year GTSM simulations forced with SEAS5

1 in 500-year return level



Benito et al. (2025)

# Example for selected cities



Benito et al. (2025)



# Conclusions

GTSM-ERA5 dataset is extended backwards and updated to 2023, longer records open up new possibilities to analyze historical events and variability

GTSM-SEAS5 dataset is based on pooling of seasonal forecast ensemble, allows for analysis of low-probability return levels and unprecedented events

