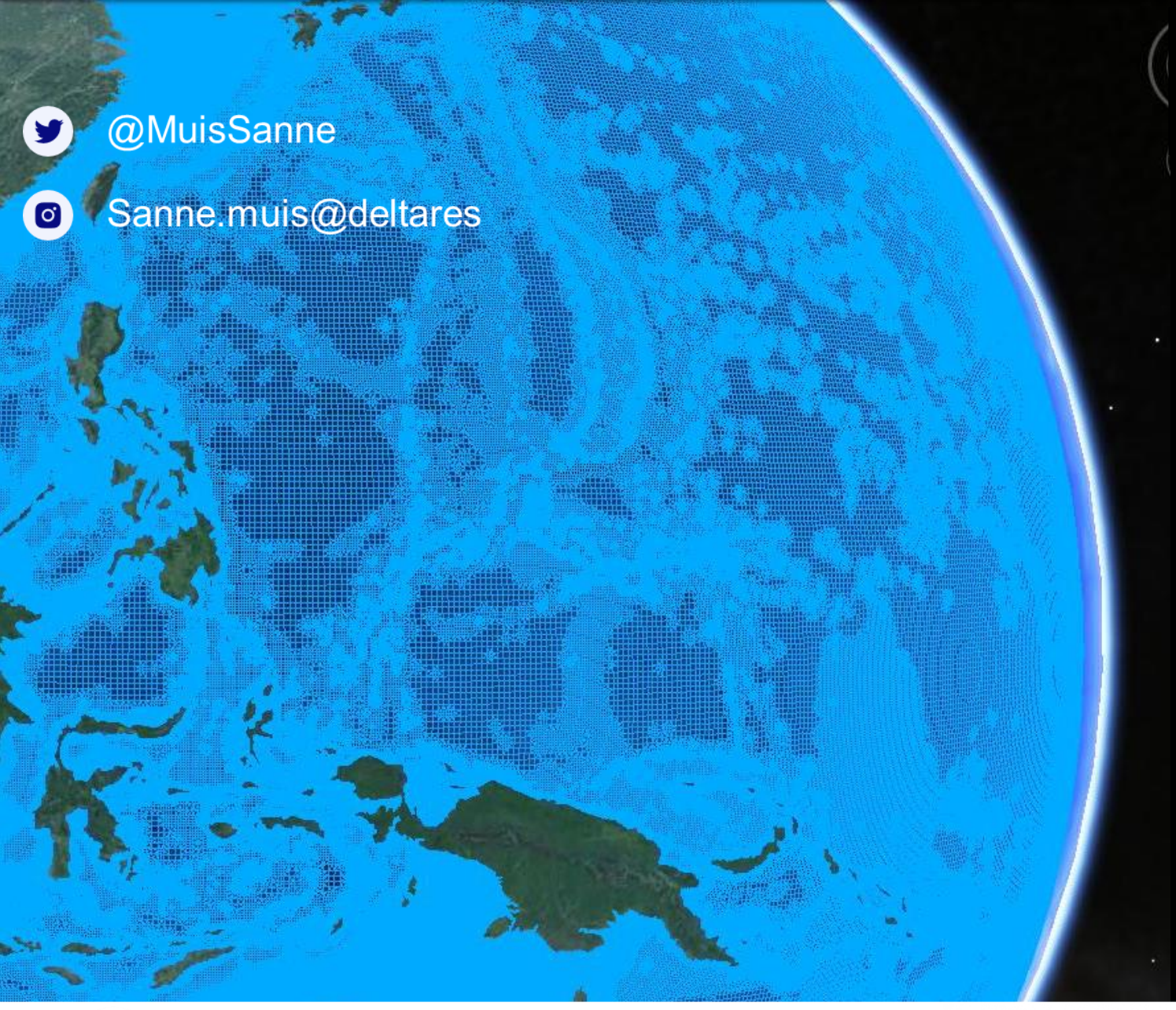


@MuisSanne

Sanne.muis@deltares

Global storm surge projections based on CMIP6 high-resolution climate models

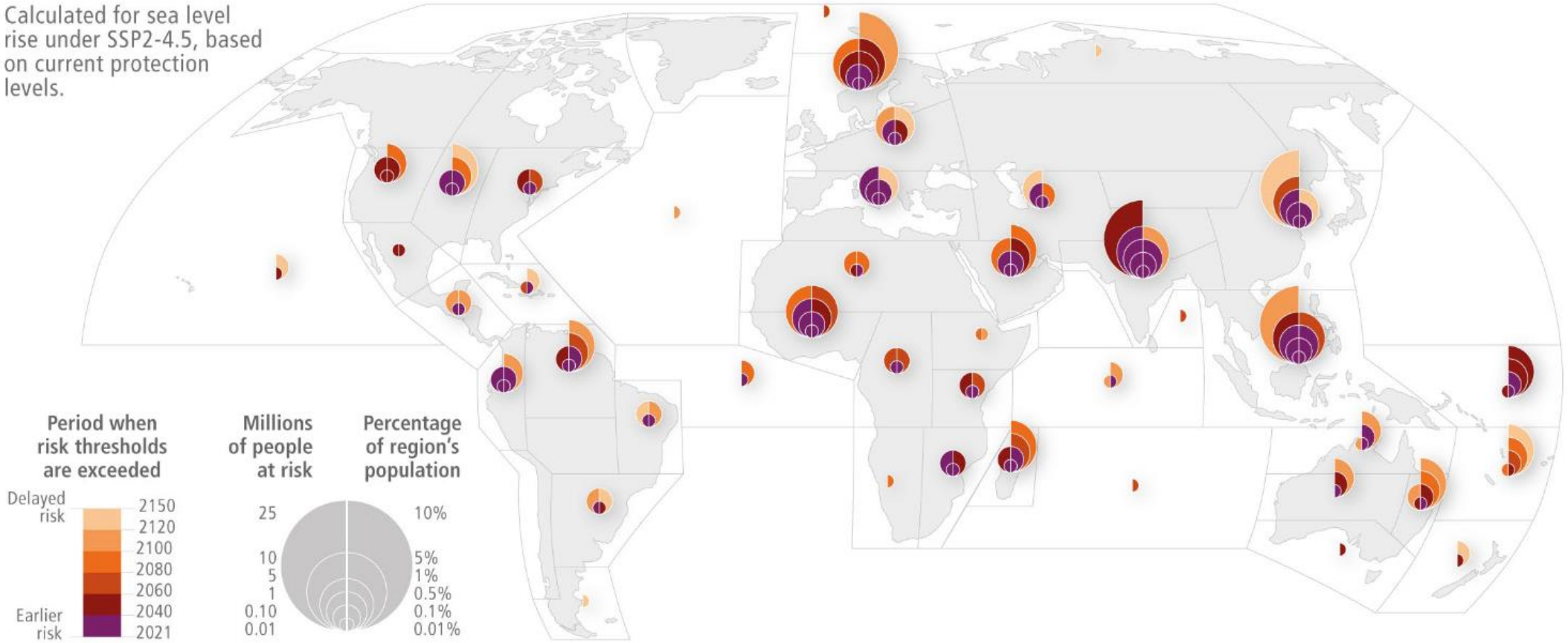
Sanne Muis, Jeroen C.J.H. Aerts, José A. Á. Antolínez, Dewi Le Bars, Job C. Dullaart, Trang Minh Dong, Li Erikson, Rein Haarsma, Maialen Irazoqui Apecechea, Andrea O'Neill, Roshanka Ranasinghe, Malcolm Roberts, Kun Yan, Martin Verlaan, and Philip J. Ward

Deltares VU VRIJE UNIVERSITEIT AMSTERDAM Koninklijk Nederlands Meteorologisch Instituut Ministerie van Infrastructuur en Waterstaat UNESCO IHE DELFT PIK Met Office USGS

Coastal population increasingly at risk of flooding

Jonas Gratzer

Projected number of people at risk of a 100-yr coastal flood



IPCC, 2022, WGII

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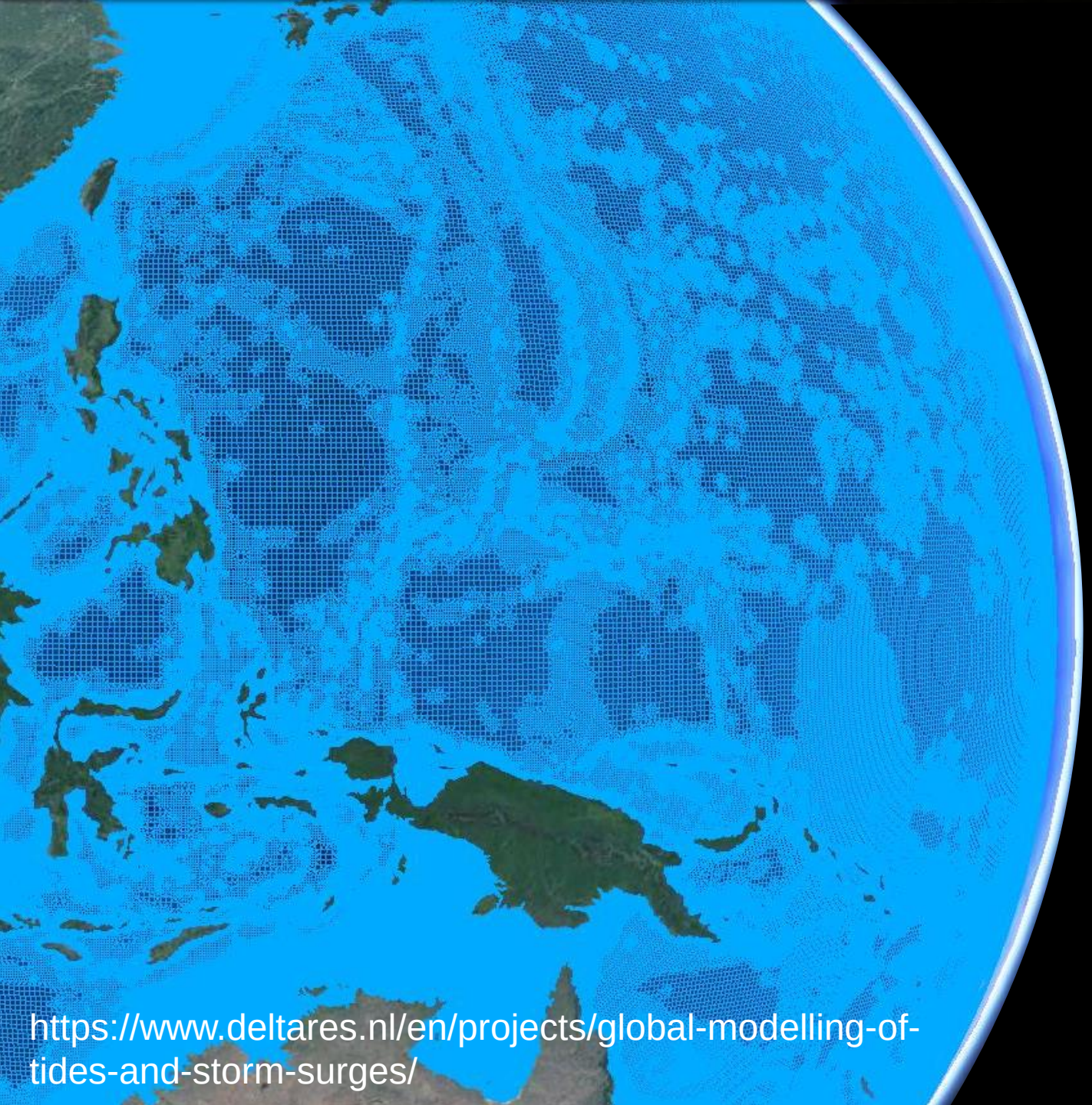

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Global Tide and Surge Model

Depth-averaged hydrodynamic model

Delft3D Flexible Mesh

2.5/1.25 km resolution at the coast

Applications

Operational forecasting

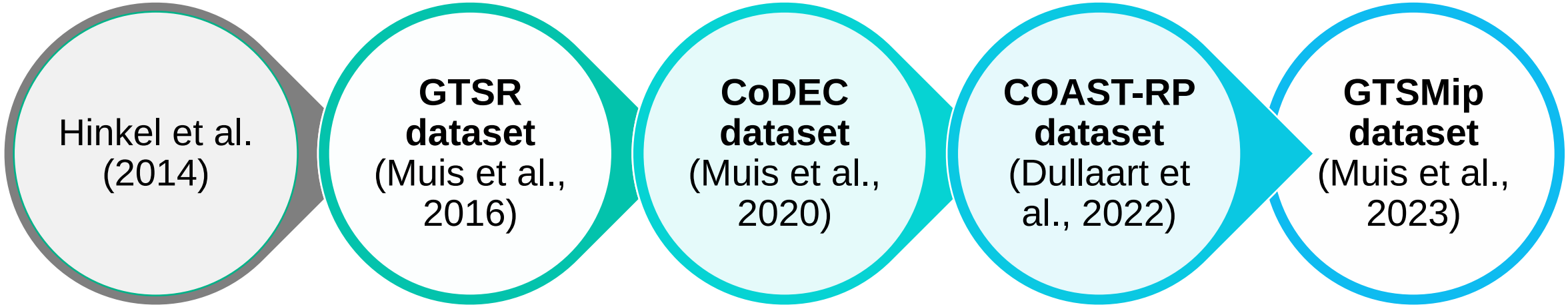
Reanalysis of historical extremes

Future climate projections

Providing input data to coastal flood risk assessments

https://www.deltares.nl/en/projects/global-modelling-of-tides-and-storm-surges/

Significant advances in global modelling of extreme sea levels, and flood risk assesment



- Global flood damages under different SLR scenarios
- Based on empiral formulations for storm surge

Model: GTSM2.0 for storm surge and FES2012 for tides
Historical: ERA-Interim based reanalysis
Future: -

- Model: GTSM3.0 for tides storm
- Historical: ERA5
- Future: 1 CMIP5 model + CORDEX

- Model GTSM3.0
- Historial:
  - ETC → ERA5
  - TCS → STORM
- Future: -

- Model: GTSM3.0
- Historical : ERA + MSL
- Future: 5 HighResMIP models

Global risk studies only consider SLR changes

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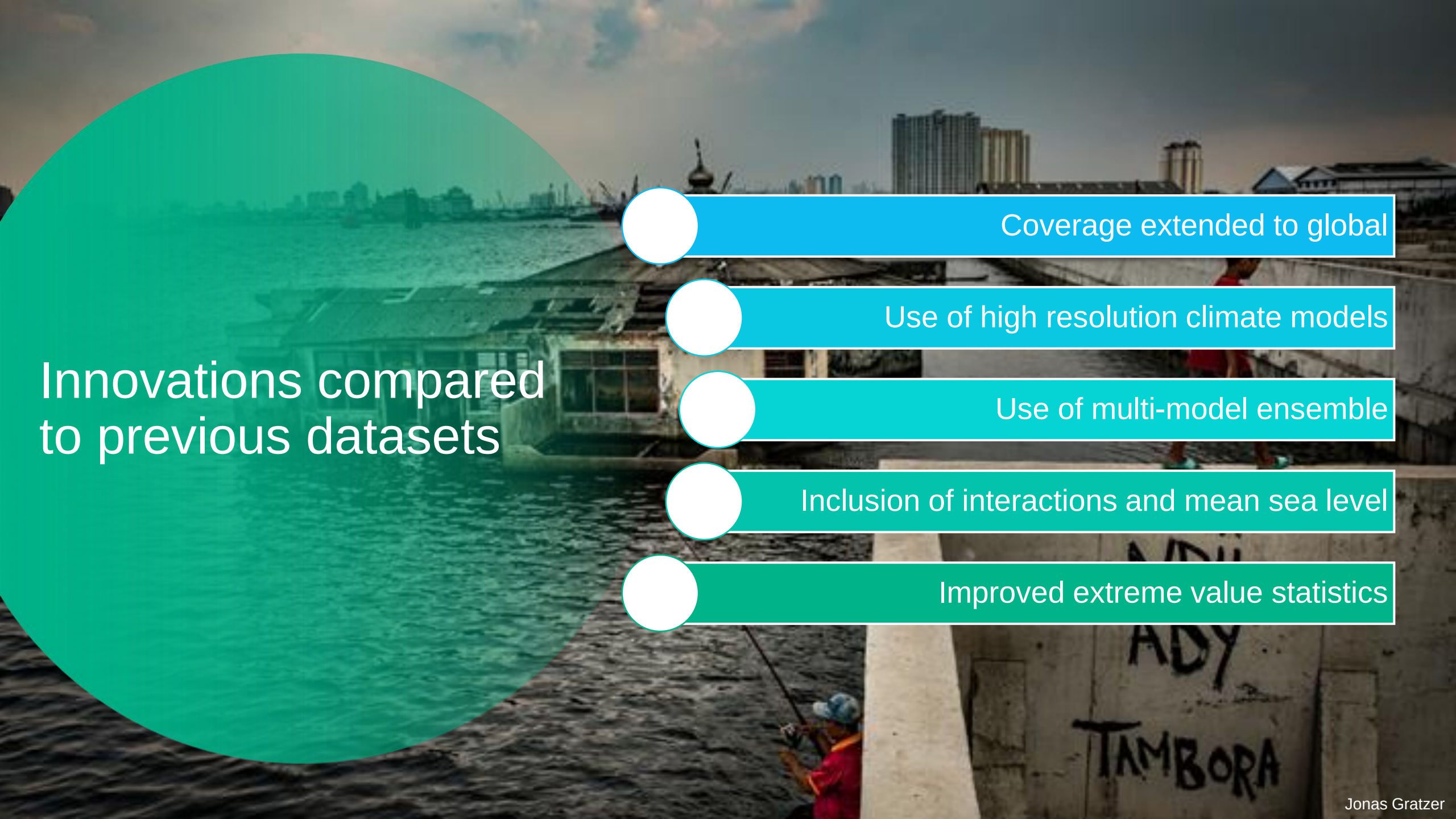
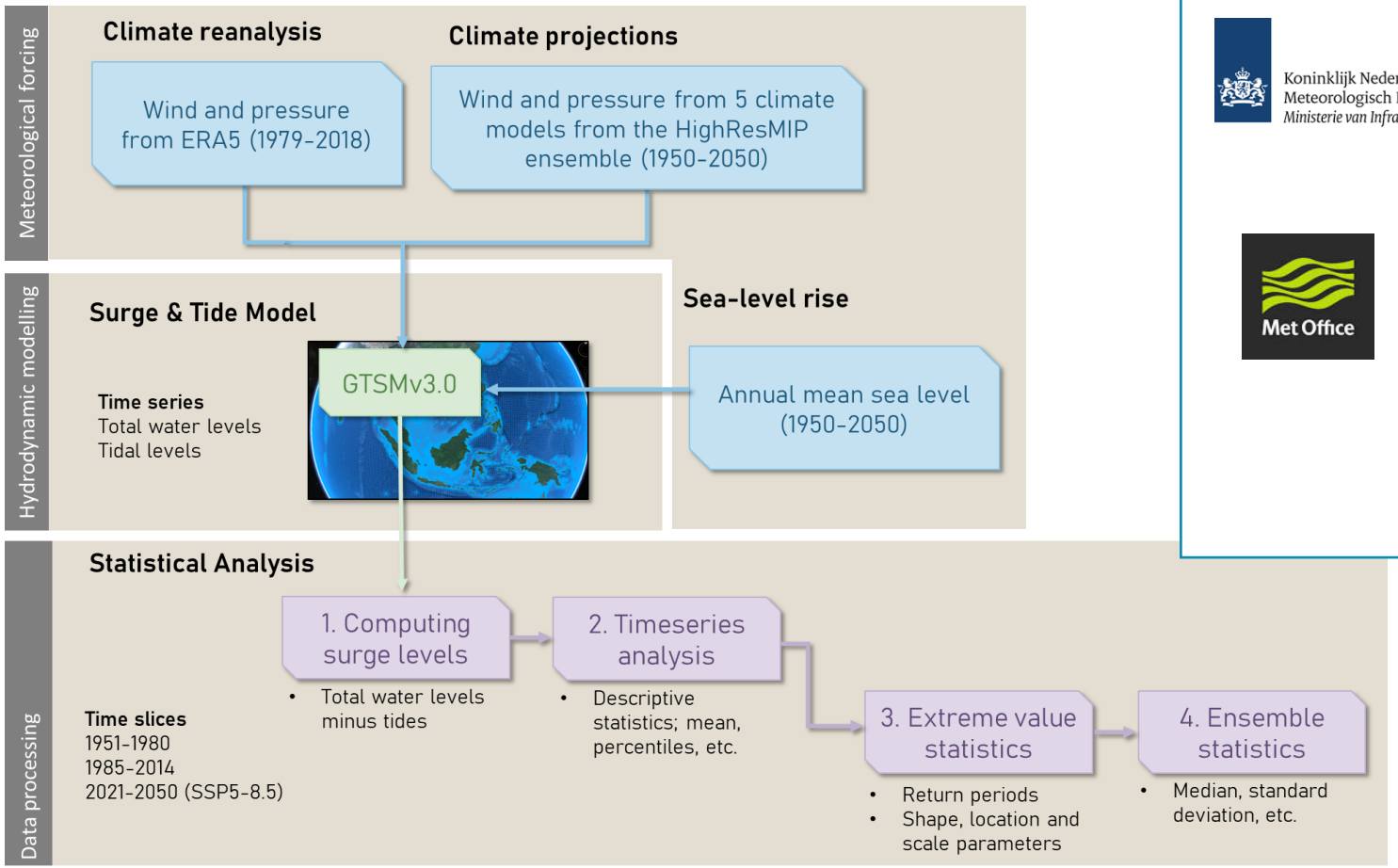
Innovations compared to previous datasets

- Coverage extended to global
- Use of high resolution climate models
- Use of multi-model ensemble
- Inclusion of interactions and mean sea level
- Improved extreme value statistics



Jonas Gratzer

Methodology



Collective effort

Koninklijk Nederlands Meteorologisch Instituut
Ministerie van Infrastructuur en Waterstaat

VU VRIJE UNIVERSITEIT AMSTERDAM

USGS

Met Office

UNESCO IHE DELFT

PIK

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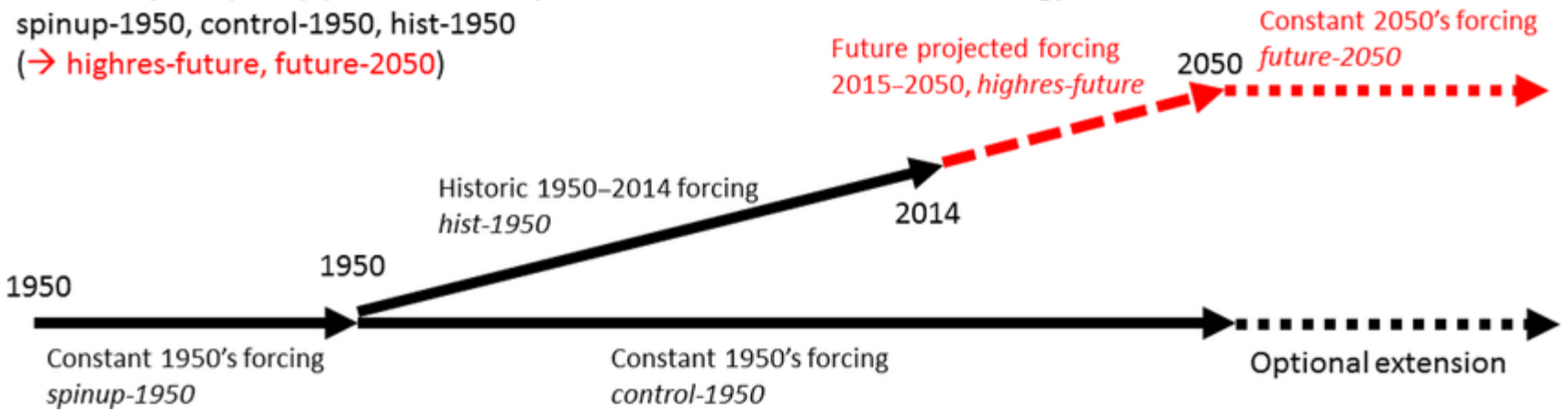
HighResMIP projections

CMIP6 HighResMIP simulations

Physical model only x 2 resolutions, simplified aerosol optical properties (MACv2-SP) recommended

Atmosphere-land-only, 1950–2014 (→ 2050)
Forced by observed SST and sea-ice and historic forcings (→ projected)
highresSST-present (→ highresSST-future)

Coupled climate, 1950–2014 (→ 2050)
Forced by constant 1950 and historic forcings (→ projected)
Initial coupled spin-up period ~ 30–50 years from 1950 EN4 ocean climatology
spinup-1950, control-1950, hist-1950
(→ highres-future, future-2050)



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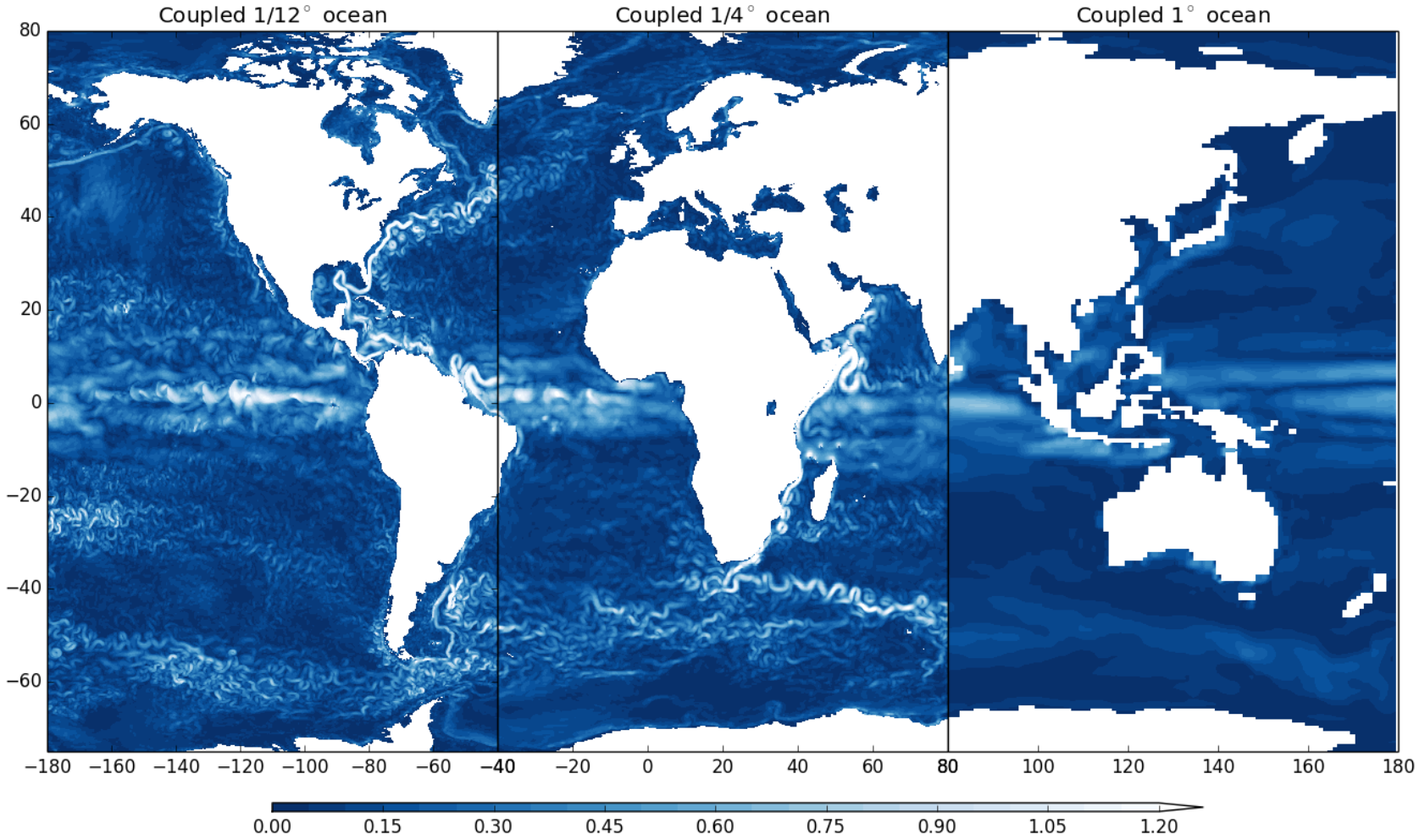
Haarsma et al. (2016)

Why use HighResMIP?



courtesy of Malcolm Roberts

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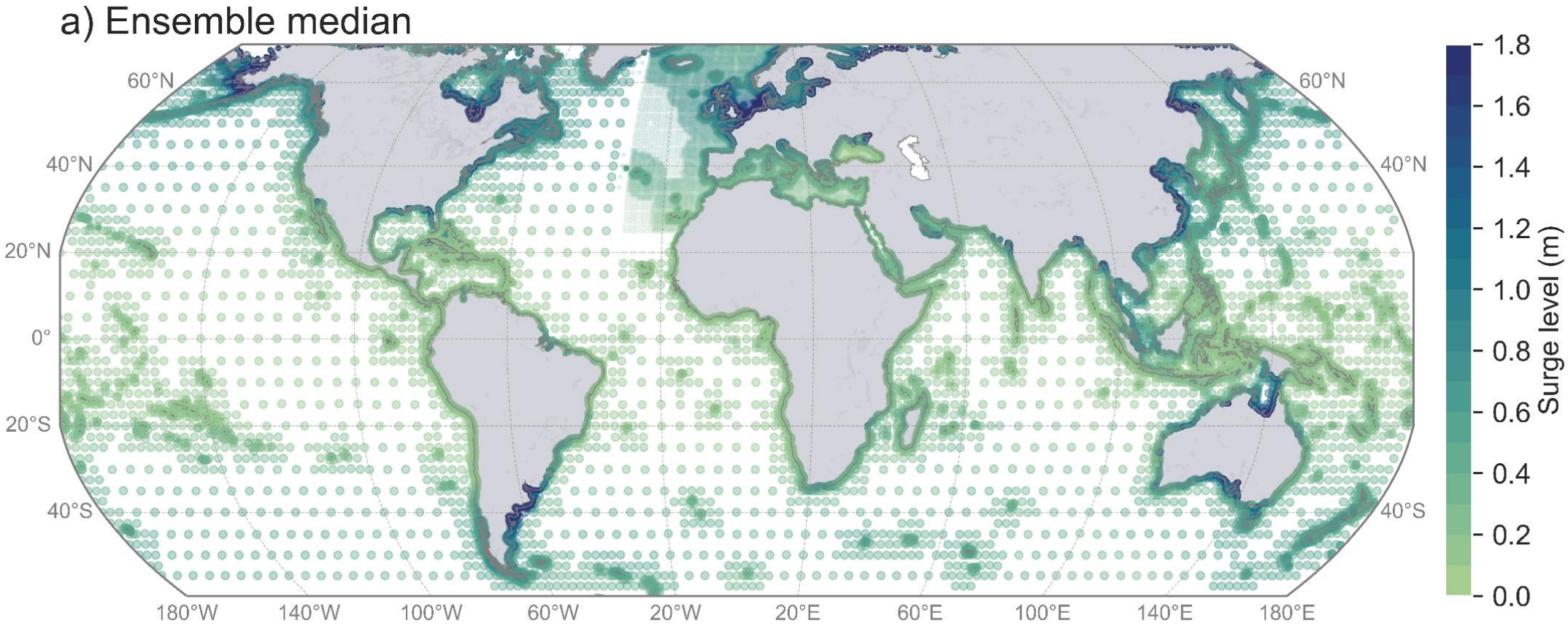
10-yr water level for 1985-2014



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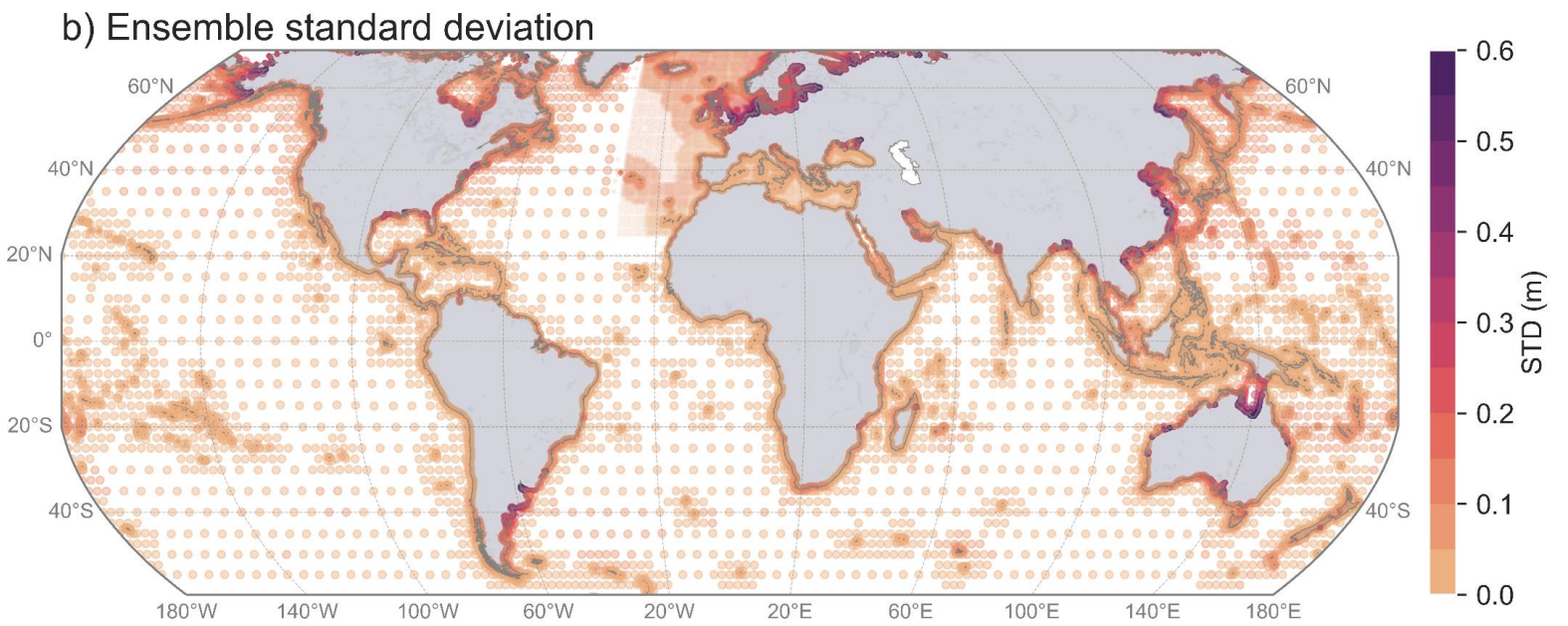
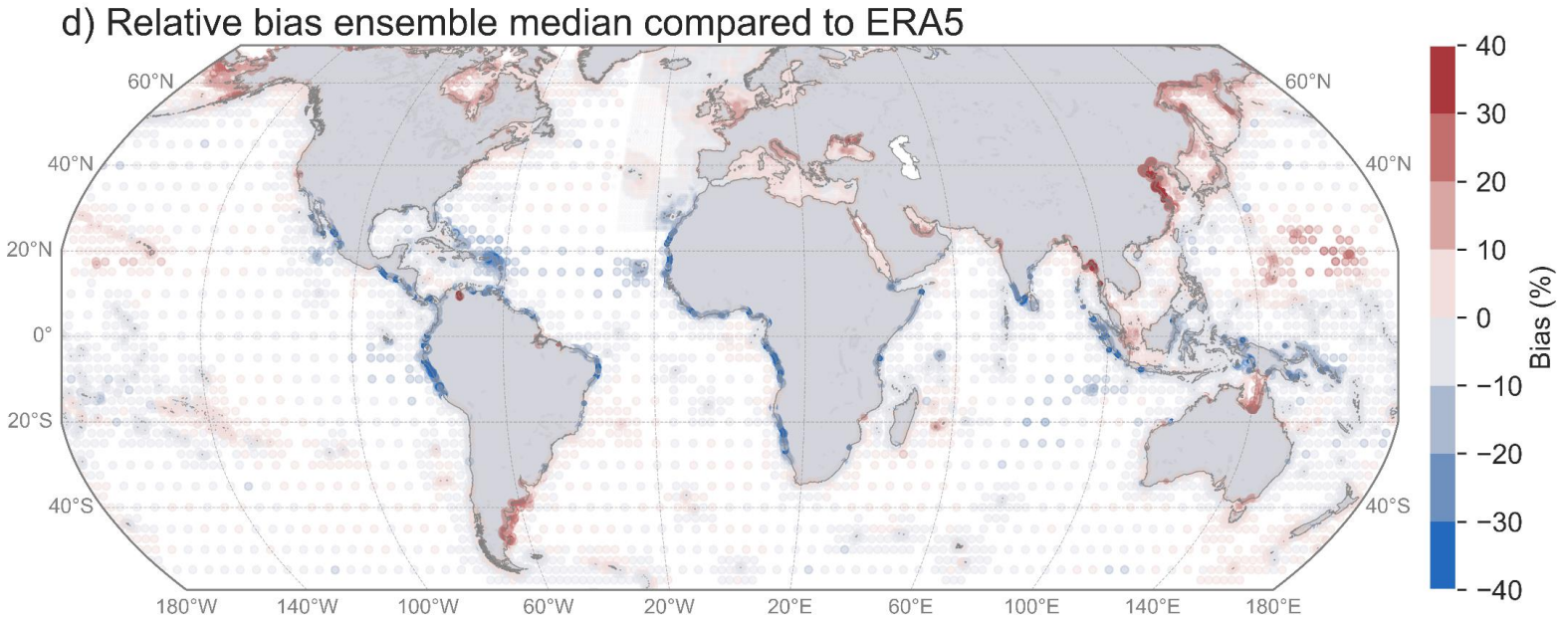
Model performance against ERA5

Global statistics

Pearson corr.	0.986
Mean Bias (m)	0.06 (S.D. 0.13)
Mean Rel. Bias (%)	4.13 (S.D. 13.9)





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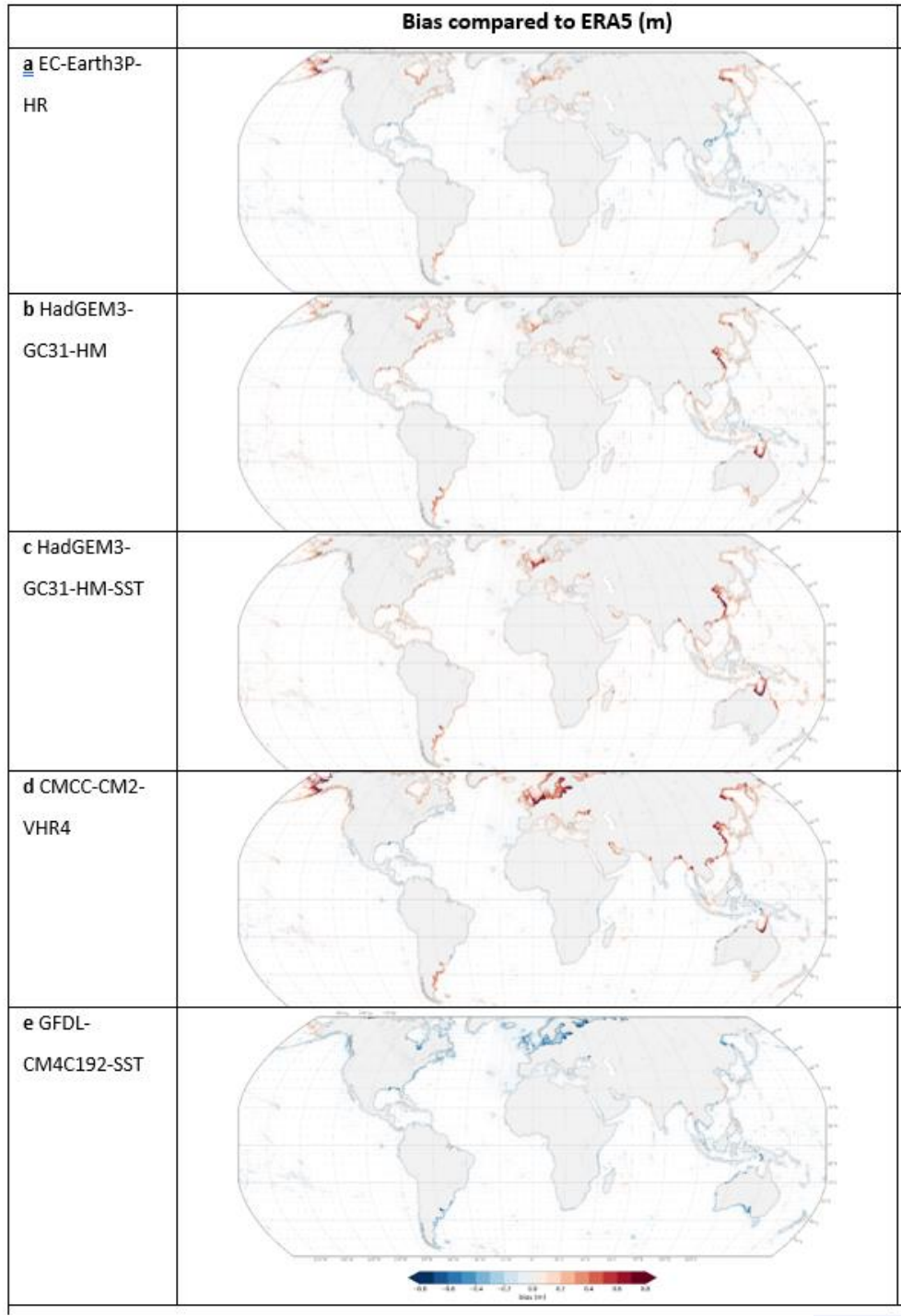
Individual models show even larger spatial biases

- Mostly positive at mid to high-latitudes and negative at low-latitudes
- Most profound near shelf areas
- Percentiles show the same biases



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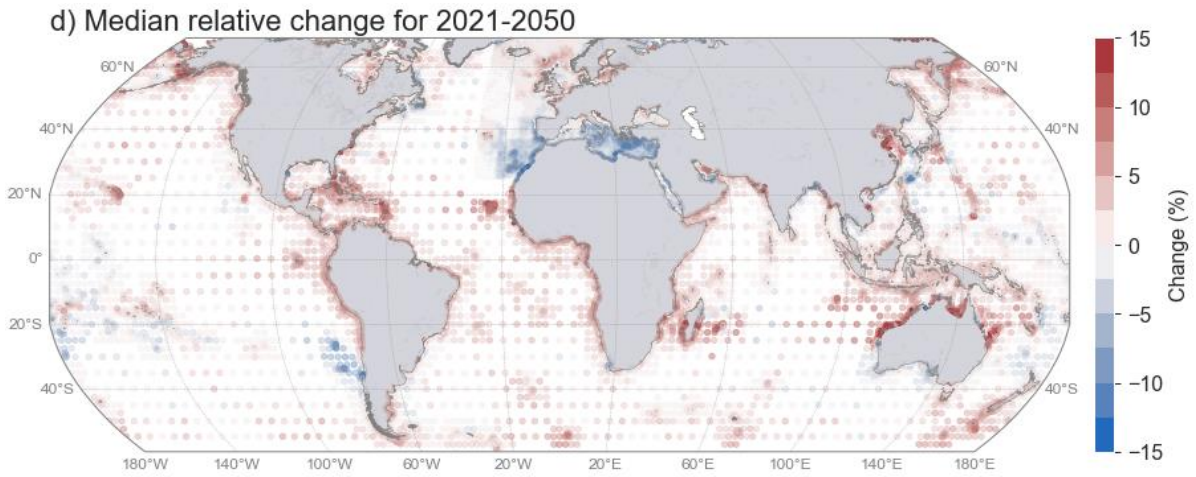
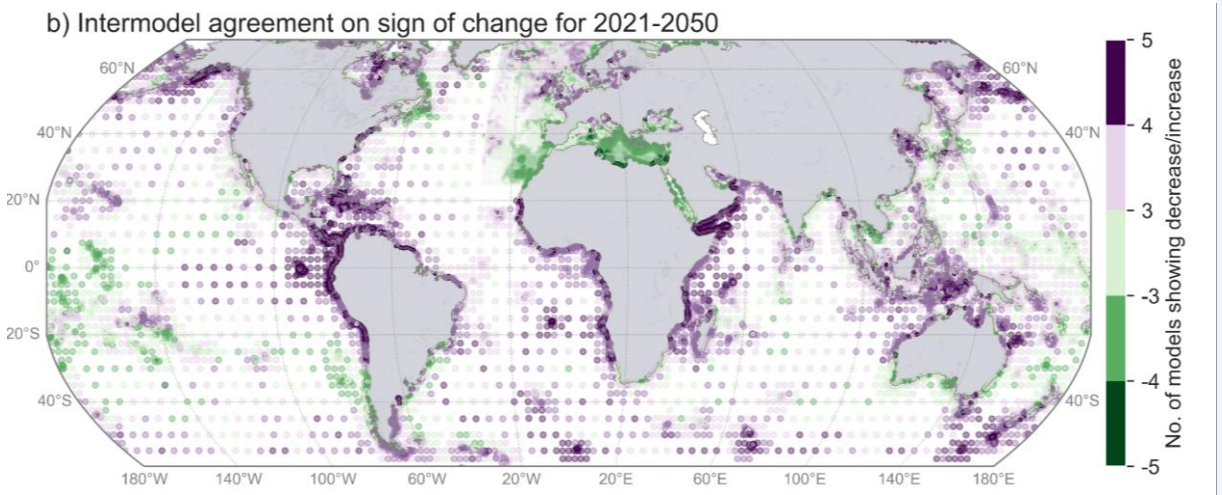
Changes in the 10-year surge level
(2021-2050 against 1951-1980)





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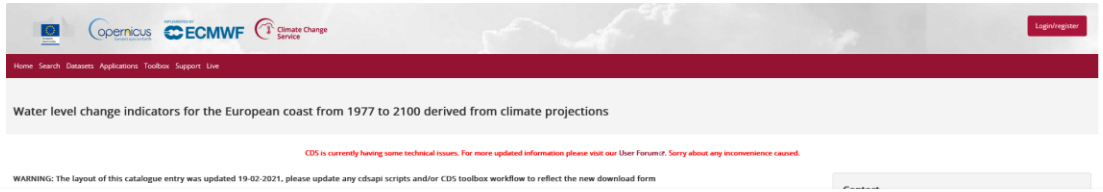
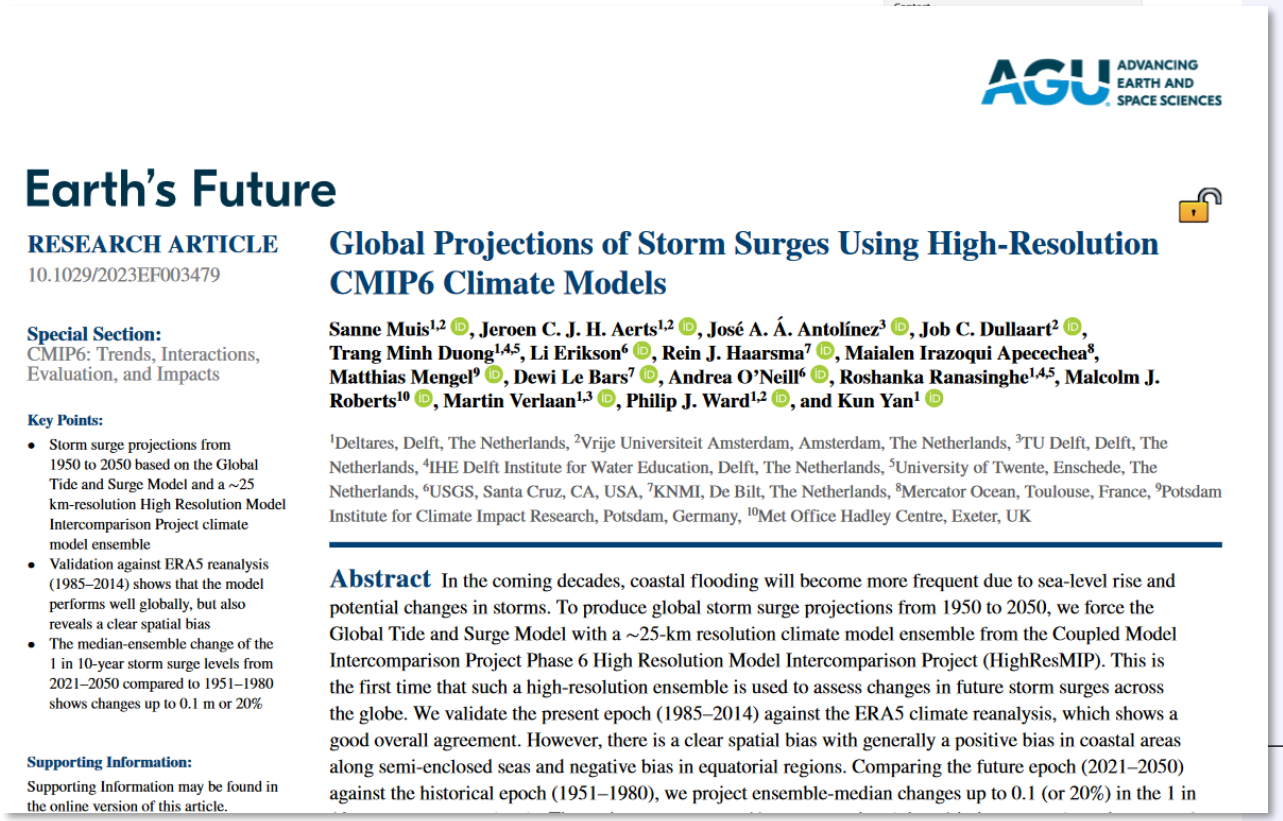
Openly available at the Climate Data Store

- **Timeseries** from 2050-2150
  - Mean sea level
  - Tides
  - Storm surges
  - Total water level

- **Statistical indicators** for 3 time slices
  - Return periods of total water levels and surges
  - Tidal levels
  - Individual models and ensemble statistics





AGU ADVANCING EARTH AND SPACE SCIENCES

Earth's Future

RESEARCH ARTICLE
10.1029/2023EF003479

Special Section:
CMIP6: Trends, Interactions, Evaluation, and Impacts

Key Points:
- Storm surge projections from 1950 to 2050 based on the Global Tide and Surge Model and a ~25 km-resolution High Resolution Model Intercomparison Project climate model ensemble
- Validation against ERA5 reanalysis (1985–2014) shows that the model performs well globally, but also reveals a clear spatial bias
- The median-ensemble change of the 1 in 10-year storm surge levels from 2021–2050 compared to 1951–1980 shows changes up to 0.1 m or 20%

Supporting Information:
Supporting Information may be found in the online version of this article.

Global Projections of Storm Surges Using High-Resolution CMIP6 Climate Models

Sanne Muis[1,2], Jeroen C. J. H. Aerts[1,2], José A. Á. Antolínez[3], Job C. Dullaart[2], Trang Minh Duong[1,4,5], Li Erikson[6], Rein J. Haarsma[7], Maialen Irazoqui Apecechea[8], Matthias Mengel[9], Dewi Le Bars[7], Andrea O'Neill[6], Roshanka Ranasinghe[1,4,5], Malcolm J. Roberts[10], Martin Verlaan[1,3], Philip J. Ward[1,2], and Kun Yan[1]

[1]Deltares, Delft, The Netherlands, [2]Vrije Universiteit Amsterdam, Amsterdam, The Netherlands, [3]TU Delft, Delft, The Netherlands, [4]IHE Delft Institute for Water Education, Delft, The Netherlands, [5]University of Twente, Enschede, The Netherlands, [6]USGS, Santa Cruz, CA, USA, [7]KNMI, De Bilt, The Netherlands, [8]Mercator Ocean, Toulouse, France, [9]Potsdam Institute for Climate Impact Research, Potsdam, Germany, [10]Met Office Hadley Centre, Exeter, UK

Abstract In the coming decades, coastal flooding will become more frequent due to sea-level rise and potential changes in storms. To produce global storm surge projections from 1950 to 2050, we force the Global Tide and Surge Model with a ~25-km resolution climate model ensemble from the Coupled Model Intercomparison Project Phase 6 High Resolution Model Intercomparison Project (HighResMIP). This is the first time that such a high-resolution ensemble is used to assess changes in future storm surges across the globe. We validate the present epoch (1985–2014) against the ERA5 climate reanalysis, which shows a good overall agreement. However, there is a clear spatial bias with generally a positive bias in coastal areas along semi-enclosed seas and negative bias in equatorial regions. Comparing the future epoch (2021–2050) against the historical epoch (1951–1980), we project ensemble-median changes up to 0.1 (or 20%) in the 1 in

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A leap forward compared to previous work, but many challenges

Large uncertainties compared to the projected changes

Large model biases

Large model spread

Large interannual variability

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Ways forward

- Enlarge ensemble
  - Extend ERA5 reanalysis back to 1950
  - Simulate additional HighResMIP models/members)
- Dive deeper
  - Quantify interannual and seasonal variability
  - Improve EVA and calculate trends
- Adress the biases
  - Investigate mechanism driving the biases
  - Develop methods for bias correction
  - Collaborate closer with the climate community

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Next years

CHANCE Climate cHange impActs on extreme sea levels iN Coastal watErs

- Funded by NWO (Dutch Research Council)
- Collaboration between VU Amsterdam and TU Delft
  - 1 PhD project on enhancing global projections of extreme sea levels
  - 1 PhD project on methods for downscaling global projections to the regional scale
  - 1 research assistant that will help with making all data/methods openly availale


Sanne Muis (PI)


José Antolínez (co-PI)


Mia Pupić Vurilj (PhD1)


Ayoola Apolola (PhD2)

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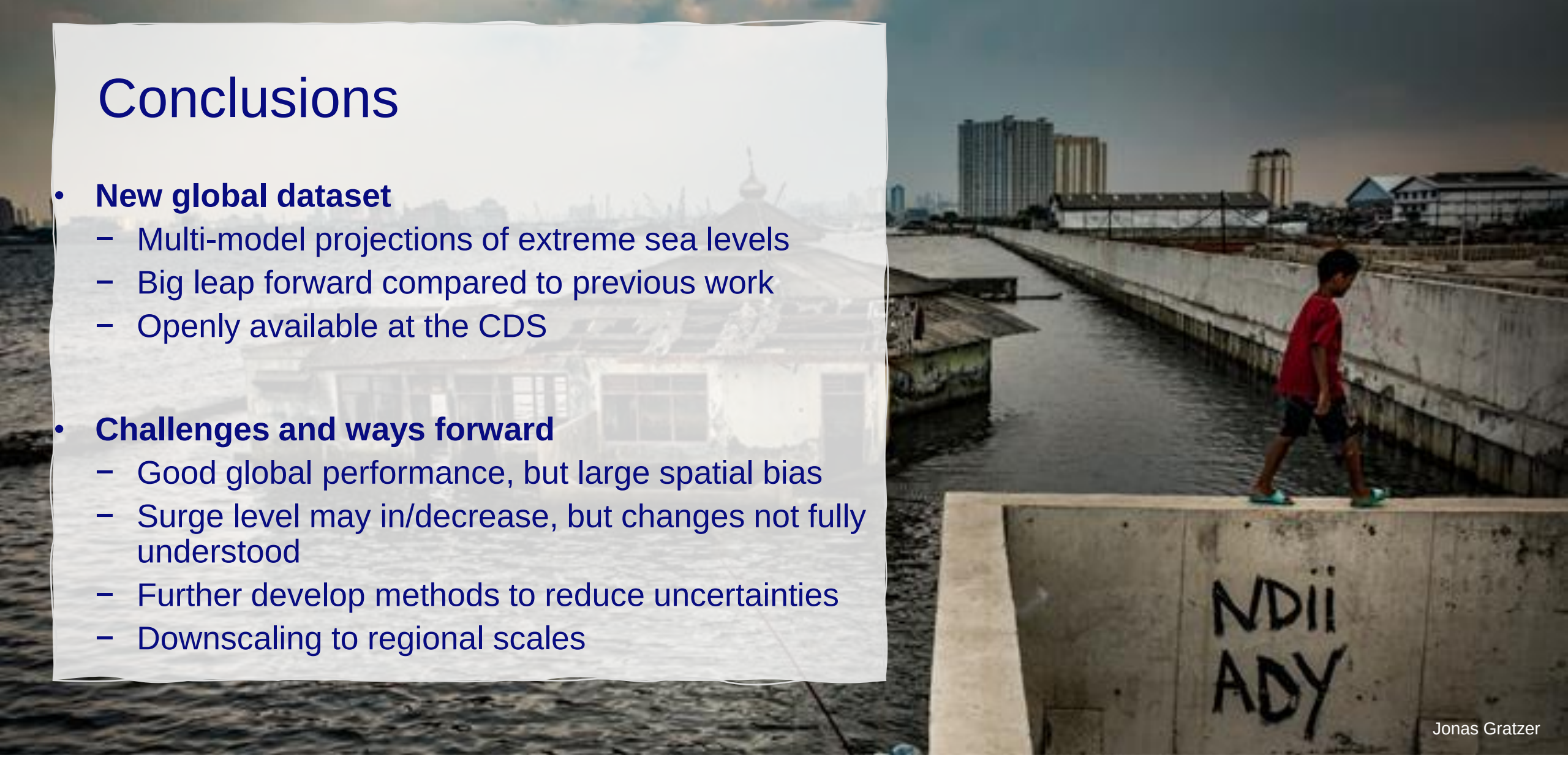
Conclusions

- **New global dataset**
  - Multi-model projections of extreme sea levels
  - Big leap forward compared to previous work
  - Openly available at the CDS

- **Challenges and ways forward**
  - Good global performance, but large spatial bias
  - Surge level may in/decrease, but changes not fully understood
  - Further develop methods to reduce uncertainties
  - Downscaling to regional scales



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More info on:
www.deltares.nl/en/projects/global-modelling-of-tides-and-storm-surges