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COWCLIP Ocean Wave Climate

3RD INTERNATIONAL WORKSHOP ON

Waves, Storm Surges, and Coastal Hazards

UNIVERSITY OF NOTRE DAME

CHALLENGES IN ASSESSING WAVE CLIMATE TRENDS & THE ROLE OF THE INTERNAL CLIMATE VARIABILITY

Mercè Casas-Prat, Xiaolan L. Wang, Nobuhito Mori, Tomoya Shimura, Yang Feng, Rodney Chan

& COWCLIP collaborators

October 2023

Canada

(Accepted)

nature reviews earth & environment

Wind wave climate changes and their impacts

Mercè Casas-Prat[1,*], Mark A. Hemer[2], Guillaume Dodet[3], Joao Morim[4], Xiaolan L. Wang[1], Nobuhito Mori[5], Ian Young[6], Li Erikson[7], Bahareh Kamranzad[8], Prashant Kumar[9], Melisa Menéndez[10], and Yang Feng[1]

[1]Environment and Climate Change Canada, Climate Research Division, Science and Technology Branch, Toronto, Canada
[2]Commonwealth Scientific and Industrial Research Organisation Environment, Hobart, Tasmania, Australia
[3]Univ. Brest, CNRS, IFREMER, IRD, Laboratoire d'Océanographie Physique et Spatiale, Brest, France
[4]University of Central Florida, Orlando, FL, USA
[5]Disaster Prevention Research Institute, Kyoto University, Kyoto, Japan
[6]Department of Infrastructure Engineering, University of Melbourne, Parkville, Victoria, Australia
[7]US Geological Survey, Pacific Coastal and Marine Science Center, Santa Cruz, CA, USA
[8]Department of Civil and Environmental Engineering, University of Strathclyde, Glasgow, G11XJ, United Kingdom
[9]National Institute of Technology, Delhi, India
[10]Environmental Hydraulics Institute (IHCantabria), Universidad de Cantabria, Santander, Spain
[*]e-mail: merce.casasprat@ec.gc.ca

COWCLIP Ocean Wave Climate

The COWCLIP community
(Coordinated Ocean Wave Climate Project)

www.nature.com/scientificdata

https://doi.org/10.1038/s41597-023-02058-6

scientific data

Check for updates

OPEN

DATA DESCRIPTOR

A 100-member ensemble simulations of global historical (1951–2010) wave heights

Mercè Casas-Prat[1] ✉, Xiaolan L. Wang[1], Nobuhito Mori[2], Yang Feng[1], Rodney Chan[1] & Tomoya Shimura[2]

frontiers | Frontiers in Marine Science

ORIGINAL RESEARCH
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Check for updates

Effects of Internal Climate Variability on Historical Ocean Wave Height Trend Assessment

Mercè Casas-Prat[1], Xiaolan L. Wang[1], Nobuhito Mori[2], Yang Feng[1], Rodney Chan[1] and Tomoya Shimura[2]*

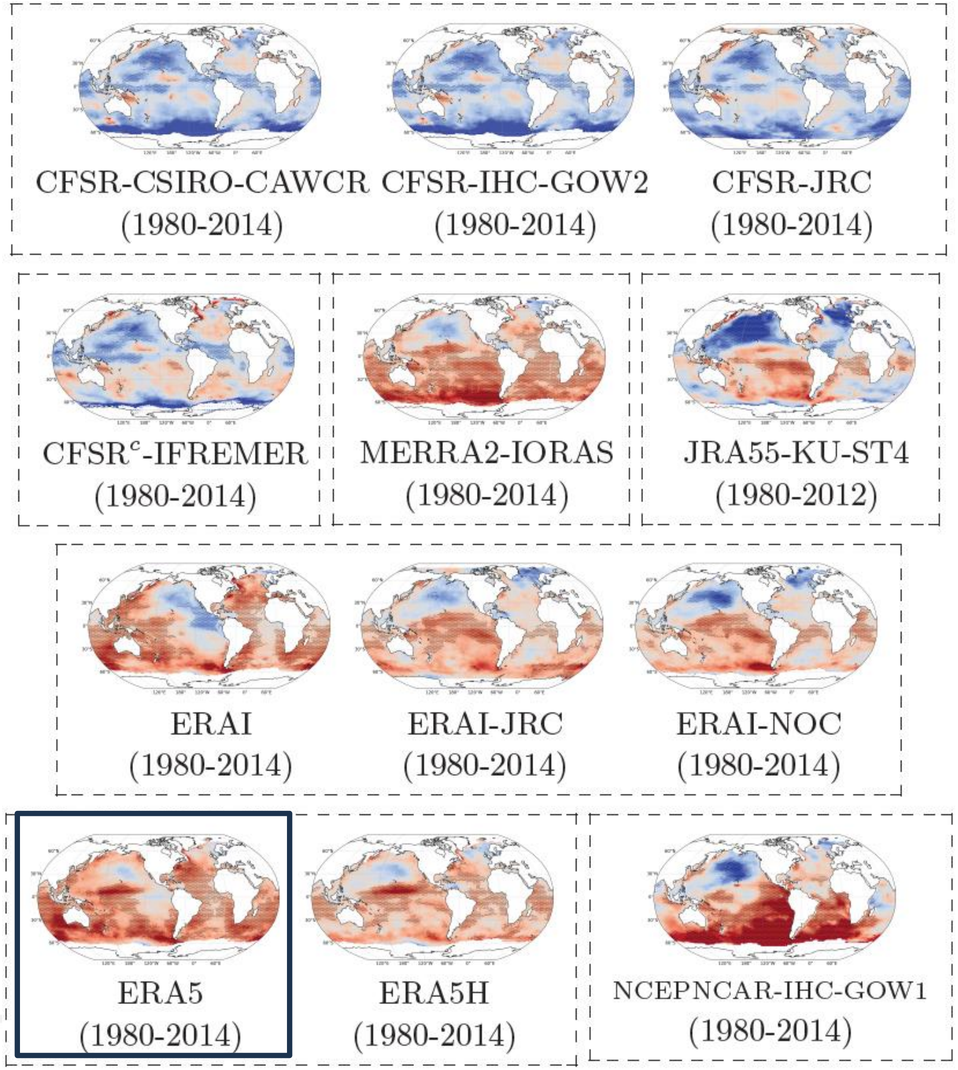
[1]Climate Research Division, Science and Technology Branch, Environment and Climate Change Canada, Toronto, ON, Canada, [2]Disaster Prevention Research Institute, Kyoto University, Kyoto, Japan

CONTENTS

- Challenges in assessing wave climate trends
- d4PDF-WaveHs dataset
- The role of internal climate variability in trend assessment

WAVE REANALYSIS TRENDS

Trend is calculated with Sen's slope estimator in conjunction with a modified Mann-Kendall method that accounts for the effects of lag-1 autocorrelation by iterative pre-whitening (Wang et al, 2015)



Modern reanalysis/hindcasts exhibit non-negligible trend differences.

Agreement increases after removing CFSR-derived products, which have been shown to have a marked discontinuity in 1994.

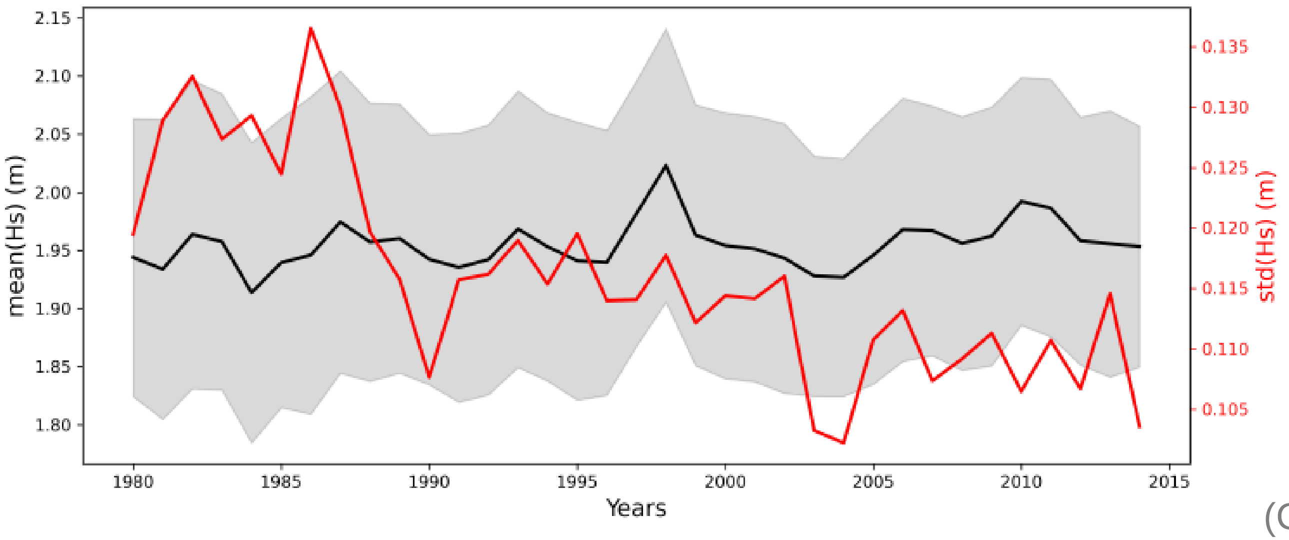
However, regardless of the agreement among reanalysis/hindcasts, there are indications that they are in general temporally inhomogeneous.

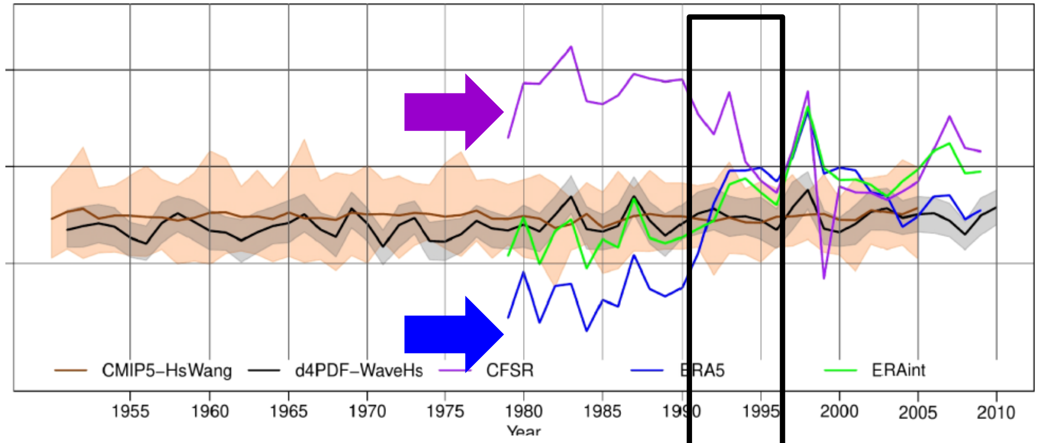
(Casas-Prat et al, accepted) using ensemble of modern reanalysis statistics (Morim et al, 2022)

TEMPORAL INHOMOGENEITY

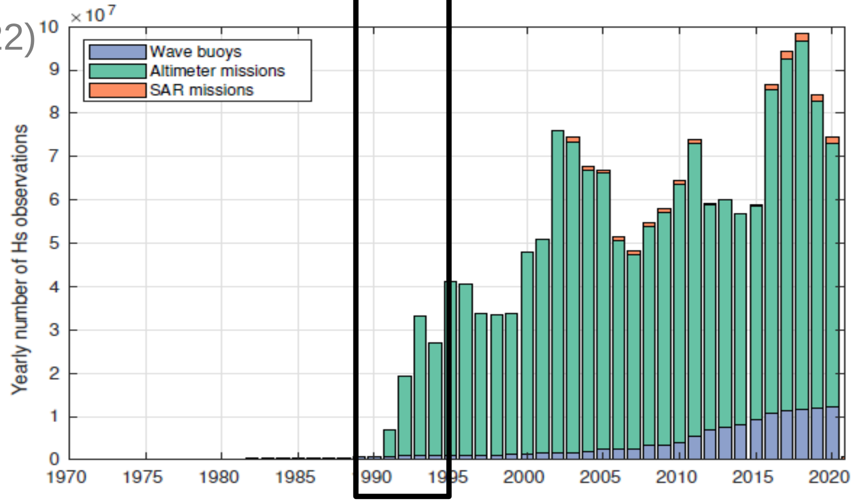
Global annual mean Hs & inter-model variability

(Casas-Prat et al, accepted)





(Casas-Prat et al, 2022)



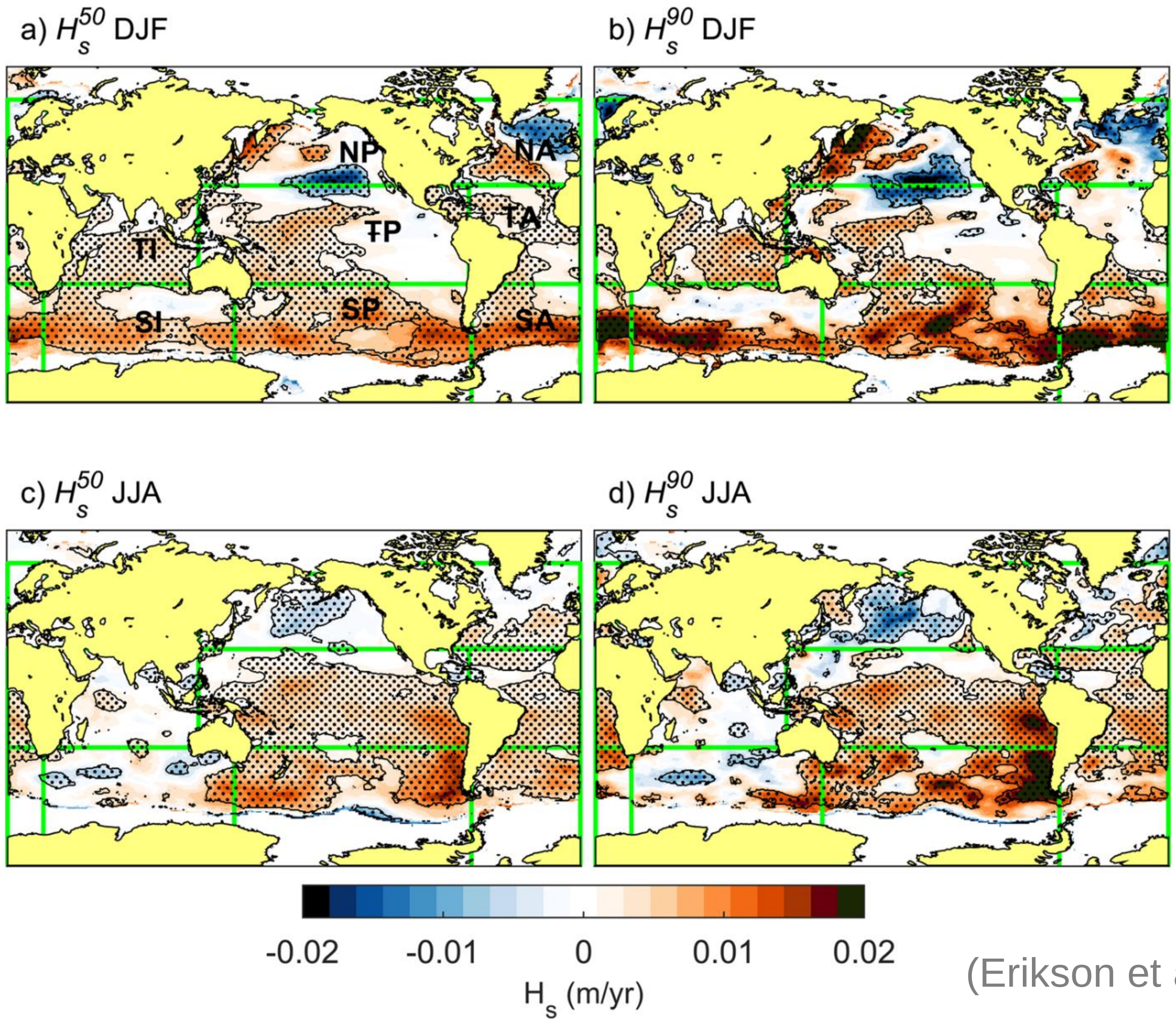
Tendency of wave reanalysis/hindcast to become closer over time

Also, there is a marked increase in atmospheric observations:
ERA5 wave reanalysis increased from approximately 0.75 million obs per day in 1979 to around 24 million per day by the end of 2018 (Hersbach et al, 1986)

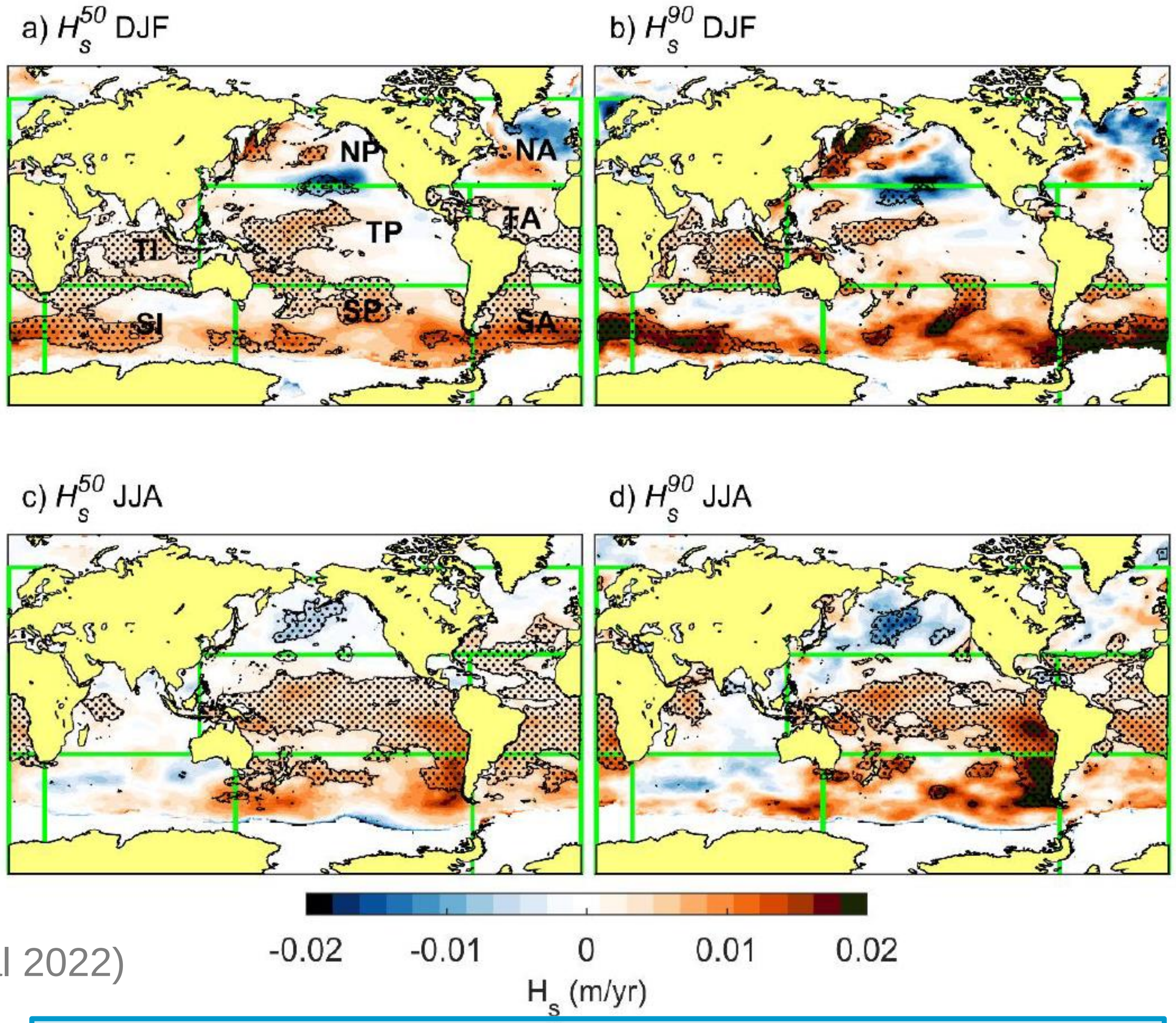
Increase of type/amount of wave observations

(Casas-Prat et al, accepted)

AGREEMENT DEPENDS ON METHOD



(Erikson et al 2022)



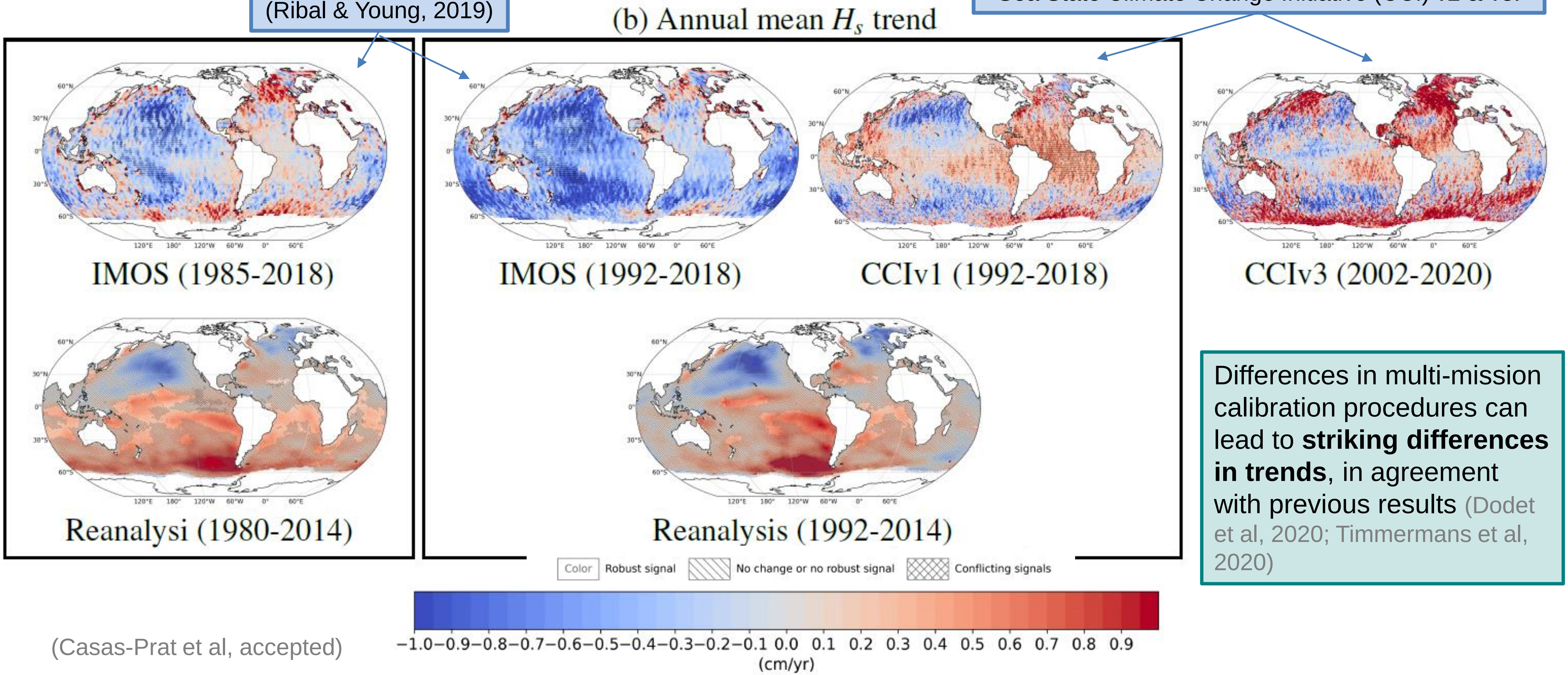
Multi-member ensemble mean > inter-member standard deviation

>50% models exhibit significant trends and 80% of those agree on the sign.

SATELLITE

Integrated Marine Observing System (Ribal & Young, 2019)

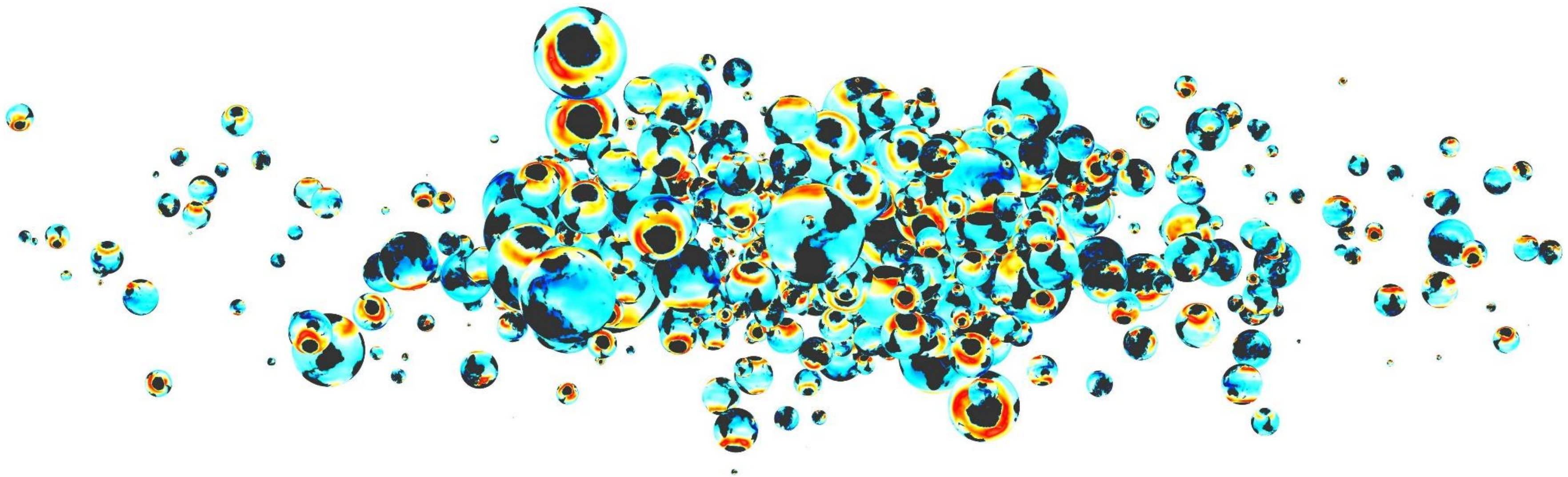
The European Space Agency (ESA) Sea State Climate Change Initiative (CCI) v2 & v3.



Differences in multi-mission calibration procedures can lead to **striking differences in trends**, in agreement with previous results (Dodet et al, 2020; Timmermans et al, 2020)

(Casas-Prat et al, accepted)

INTERNAL CLIMATE VARIABILITY

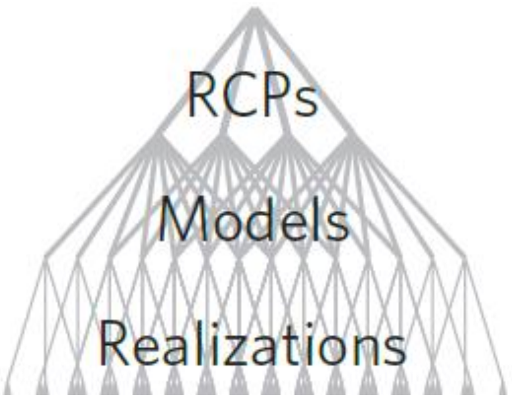


Climate varies naturally over different time scales. Internal (or natural) climate variability refers to the variation in climate parameters due to interactions of the Earth system rather than being caused by changes in external forcing. This variability can mask or enhance human-induced changes.

Climate simulations (and observed climate!) are only one possible realization of the climate.

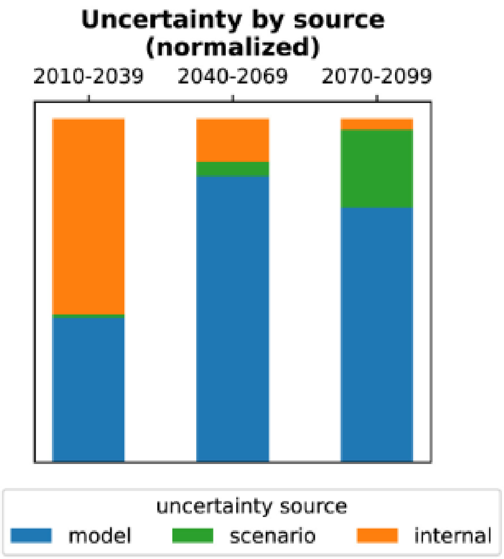
Internal climate variability cannot be properly assessed from single climate realizations, especially if they cover a few decades.

INTERNAL CLIMATE VARIABILITY



The importance of internal climate variability has been demonstrated for many climate variables (e.g. temperature, precipitation, etc), impacts (e.g. mortality, field crops, etc), and type of assessments, such as:

- Detection and attribution
- **Trend assessment**
- Estimation of near-future projected changes
- Extreme value analysis
- Validation of model with observations

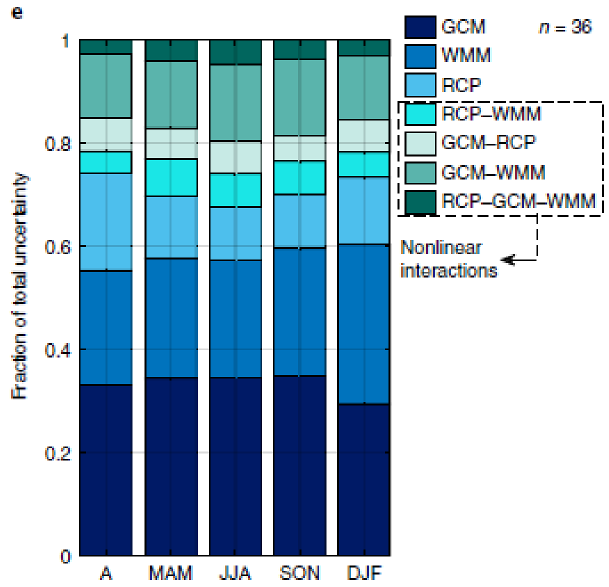


Mortality
(Schwarzwald et al, 2022)

However, there is poor knowledge on the role of internal climate variability on ocean wave climate assessments. The COWCLIP large ensemble of CMIP5-driven wave projections provided insight into contribution of uncertainty derived from scenario, climate model and wave model, but internal climate variability was not well covered.

This is partially due to do the lack of Single Model Initial Condition Large Ensembles (SMILE)-based ensembles.

2081-2100



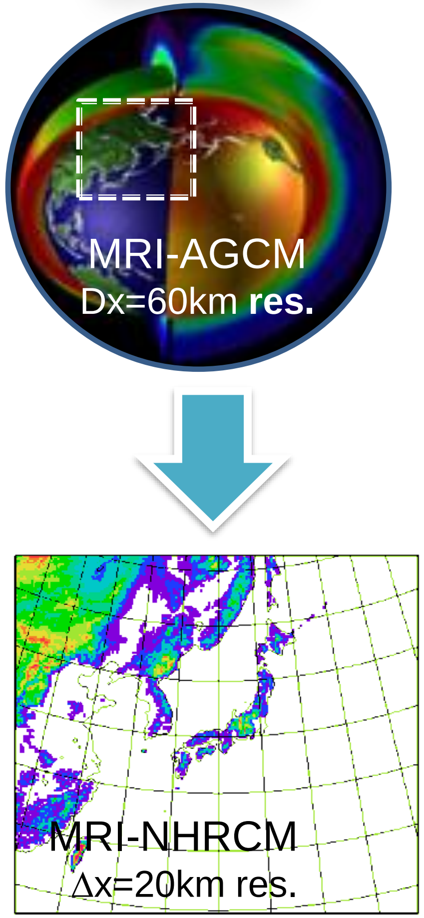
Wave height

(Morim et al, 2019)

d4PDF-WaveHs dataset

- First SMILE-based wave height large ensemble:
  - 100 members of 6-hourly Hs for the period 1951-2010 on 1°x1 ° lat-lon grid.
  - → **6000 years** of data!
- Forcing: d4PDF (Database for policy decision-making for future climate changes) (Mizuta et al, 2017; Ishii & Mori, 2020)
  - 60-km resolution AGCM historical ensemble simulations.
  - Different initial conditions, small perturbations of Sea Surface Temperature, Sea Ice Concentration and Sea Ice Thickness (in relation to observational uncertainty).
  - MRI-AGCM is an atmospheric-only model and therefore these low boundary perturbations account for the role of the ocean in the internal climate variability.

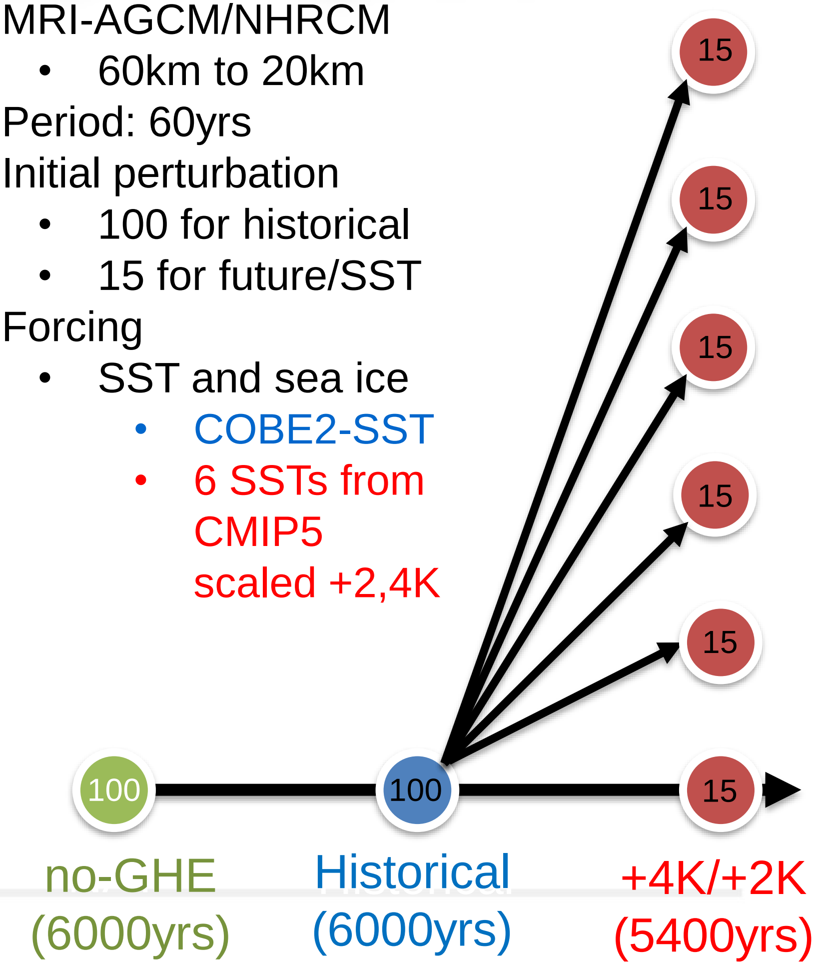
Model



Japan Meteorological Research Institute

Exp. Configuration

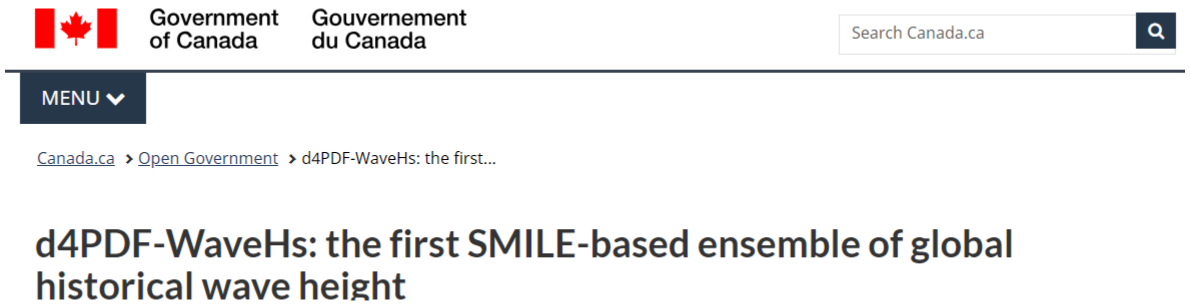
- MRI-AGCM/NHRCM
  - 60km to 20km
- Period: 60yrs
- Initial perturbation
  - 100 for historical
  - 15 for future/SST
- Forcing
  - SST and sea ice
    - COBE2-SST
    - 6 SSTs from CMIP5 scaled +2,4K



DATA AVAILABILITY

d4PDF-WaveHs

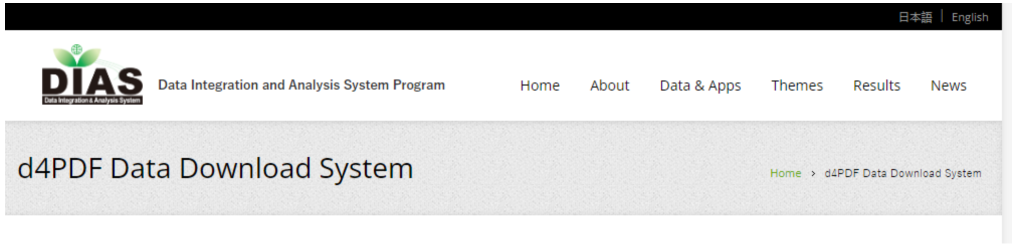
Government of Canada Open Data Portal



https://doi.org/10.18164/d68361d0-8141-48b9-a25e-a9bc98d71438

d4PDF
(3PB)

Data Integration and Analysis System Program



https://diasjp.net/en/service/d4pdf-data-download/

OCEAN WAVE MODELLING APPROACH

Multivariate regression model (Wang et al, 2012, 2014)

$$H_t = a + \sum_{k=1}^{K} b_k X_{k,t} + \sum_{p=1}^{P} c_p H_{t-p} + u_t$$

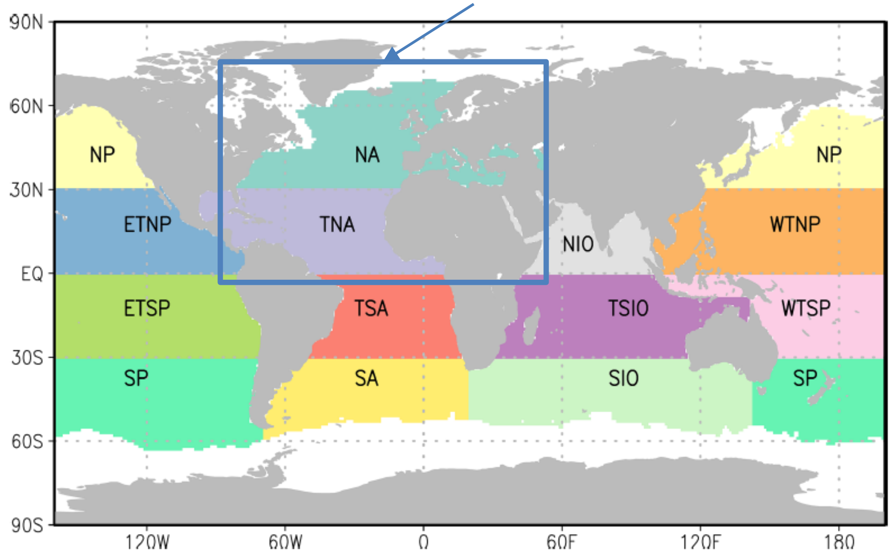
M-order autoregressive process (white noise if M=0)

Lagged-dependent variable

SLP-derived predictors:
- Anomalies of 6-hourly SLP (Sea Level Pressure) (1)
- Anomalies of 6-hourly squared SLP gradient (geostrophic wind proxy) (1)
- Associated Principal Components (PCs) (60)

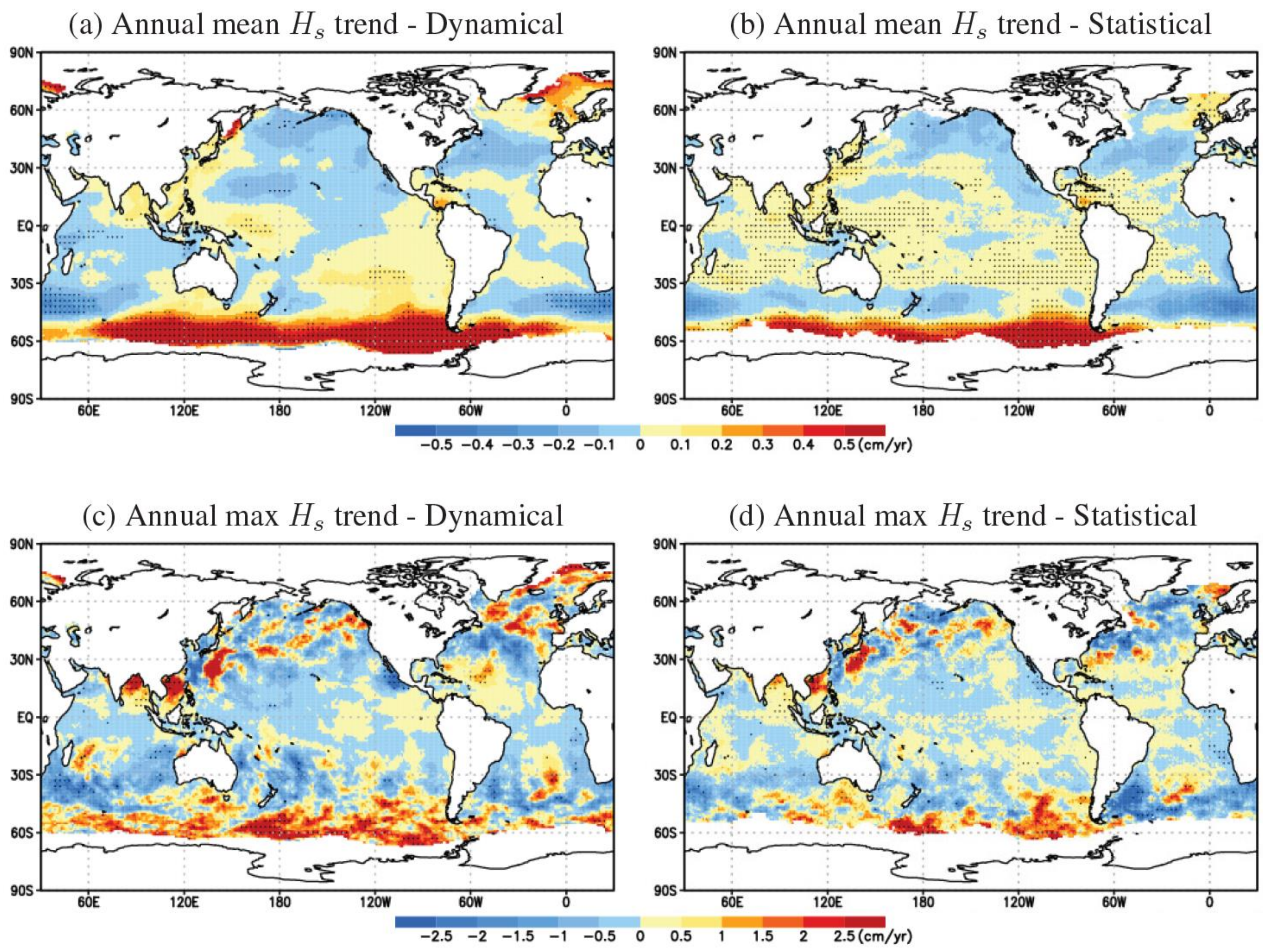
(anomalies are relative to the 1981-2000 mean)

Area to calculate PCs for NA



- SLP gradients and H_t are transformed using **Box-Cox function** to make data closer to Normal distribution. Then this model becomes non-linear.
- ***F* test** with equivalent sample size (von Storch and Zwiers, 1999) is used to select final predictors (from 62-predictor pool), P and M.
- Model calibrated (and predictors bias-corrected) with ERA-interim data. Model validation with WW3 wave simulations (Shimura & Mori, 2019).
- Method already applied to generate CMIP5-based global wave projections, that were integrated in the COWCLIP mega ensemble of wave projections (Morim et al, 2019).

TREND COMPARISON - WAVE MODELLING METHODS



Reasonable agreement

WW3

(0.5°)

Statistical model

(1°)

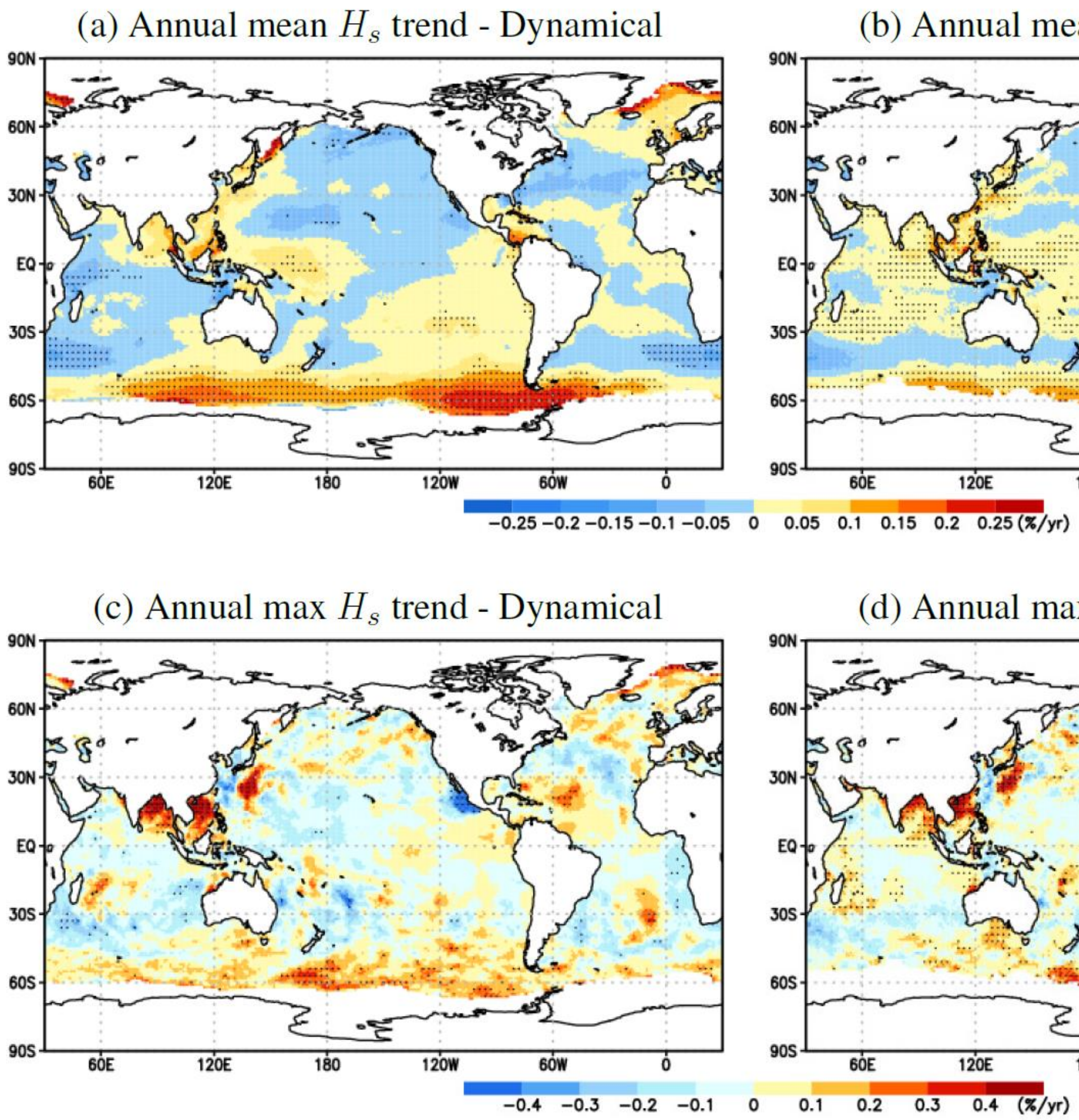
(1 run)

(Casas-Prat et al, 2022)

TREND COMPARISON - WAVE MODELLING METHODS

WW3

(0.5°)



Relative trend (%/yr)

Larger agreement

Statistical model

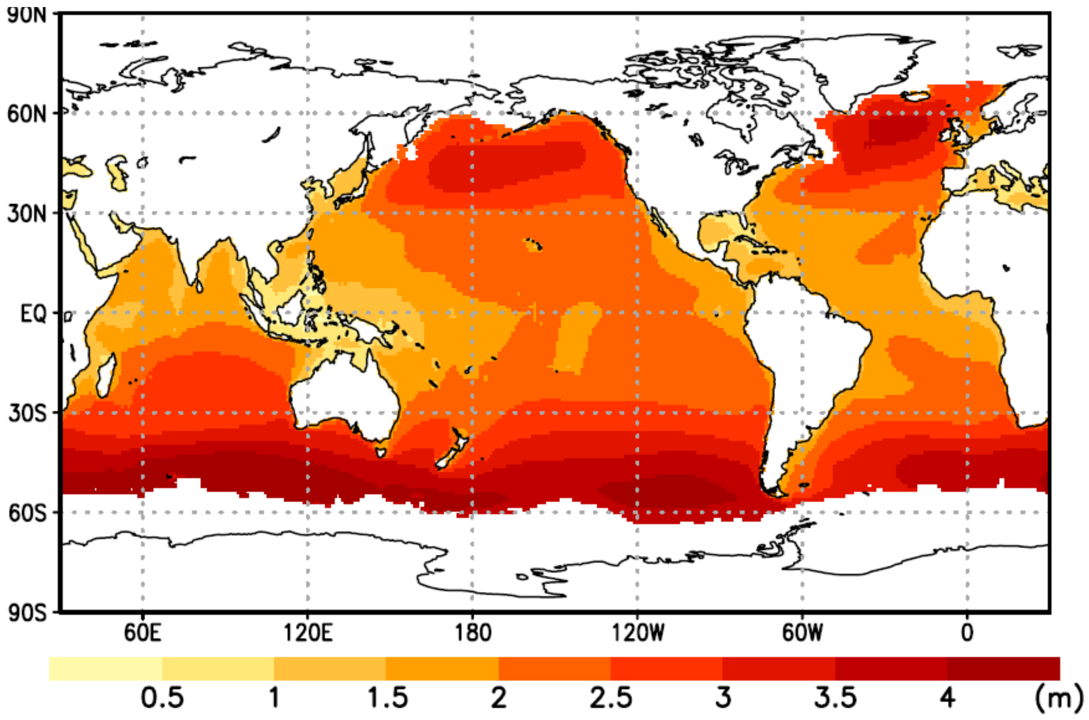
(1°)

(1 run)

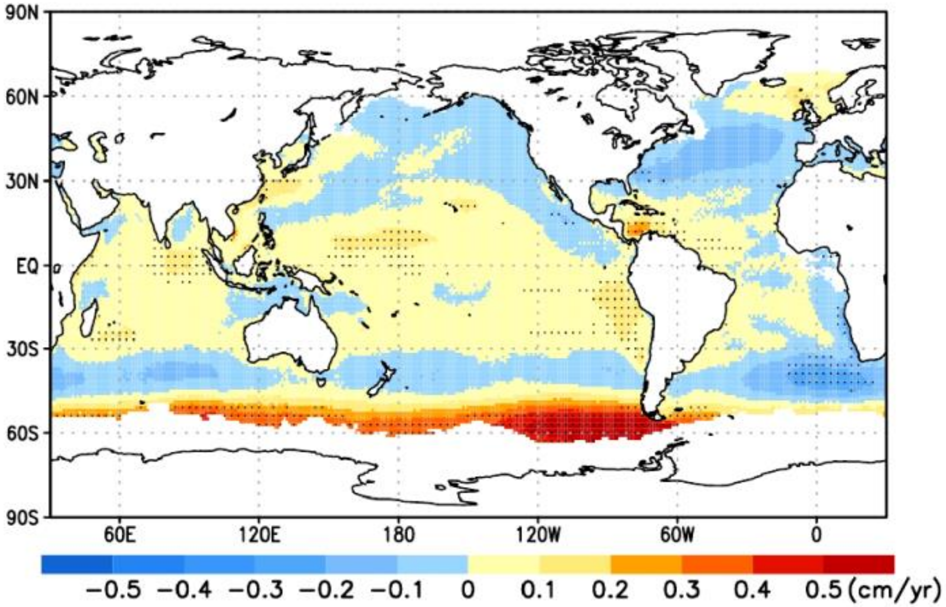
(Casas-Prat et al, 2022)

ANNUAL MEAN HS (1951-2010)

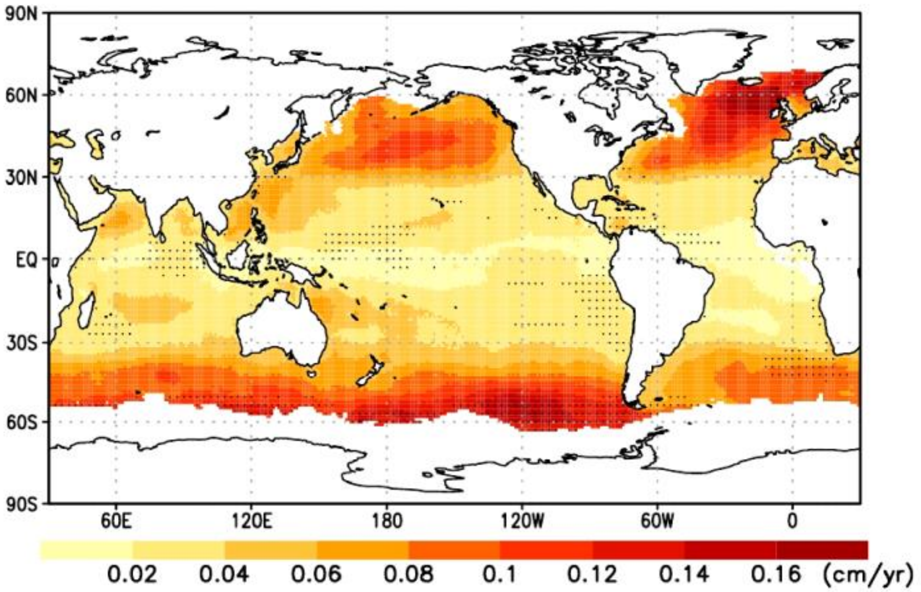
Ensemble average of the annual mean Hs



Trend average



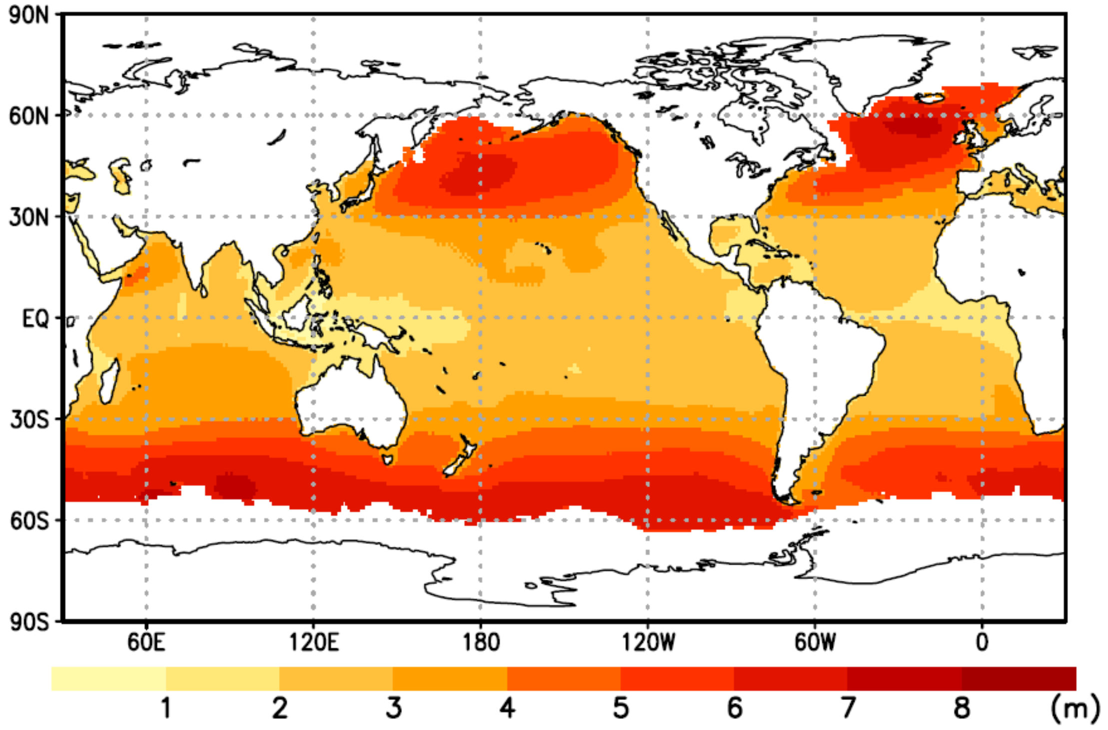
Standard deviation of the trend



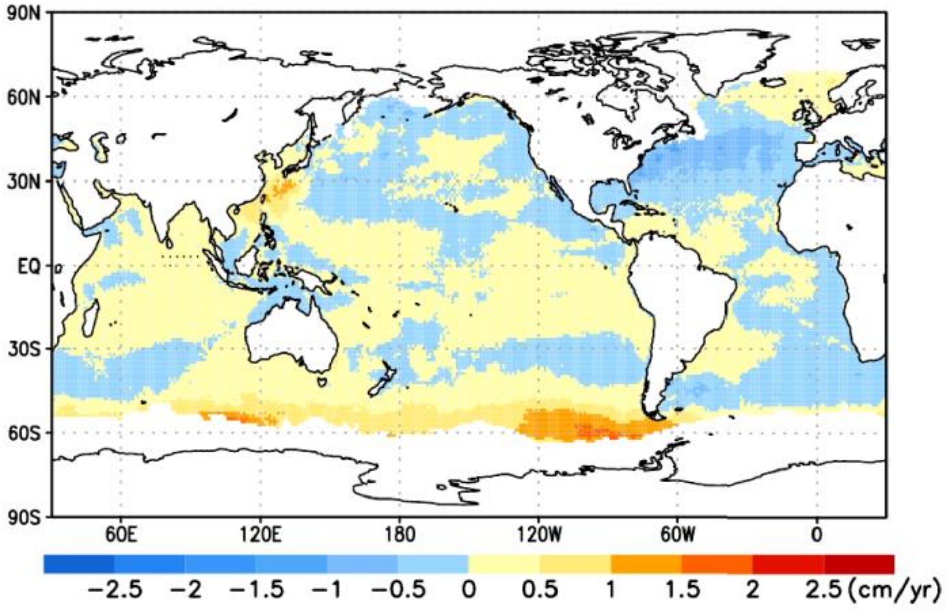
(Casas-Prat et al, 2022; 2023)

ANNUAL MAXIMUM HS (1951-2010)

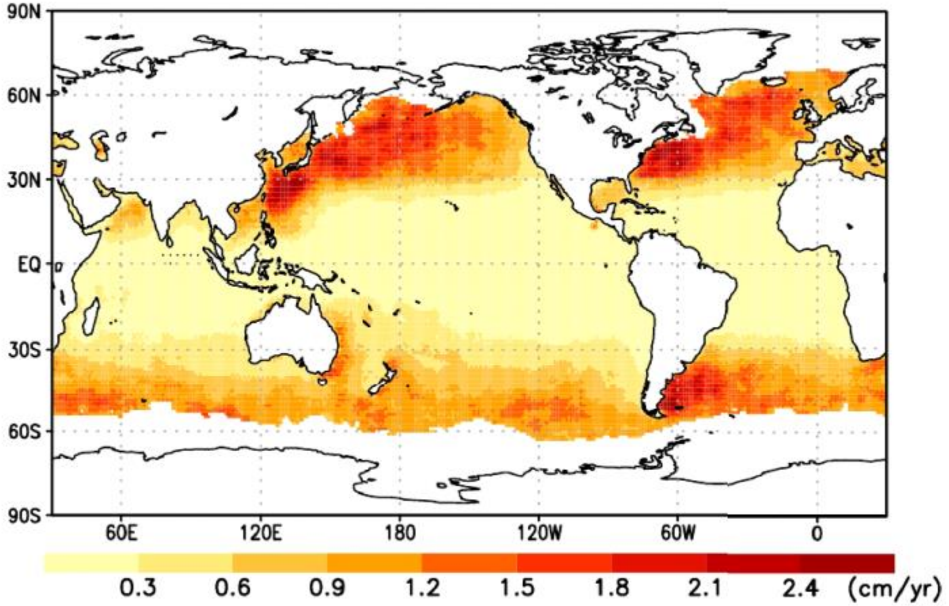
Ensemble average of the annual maxima



Trend average

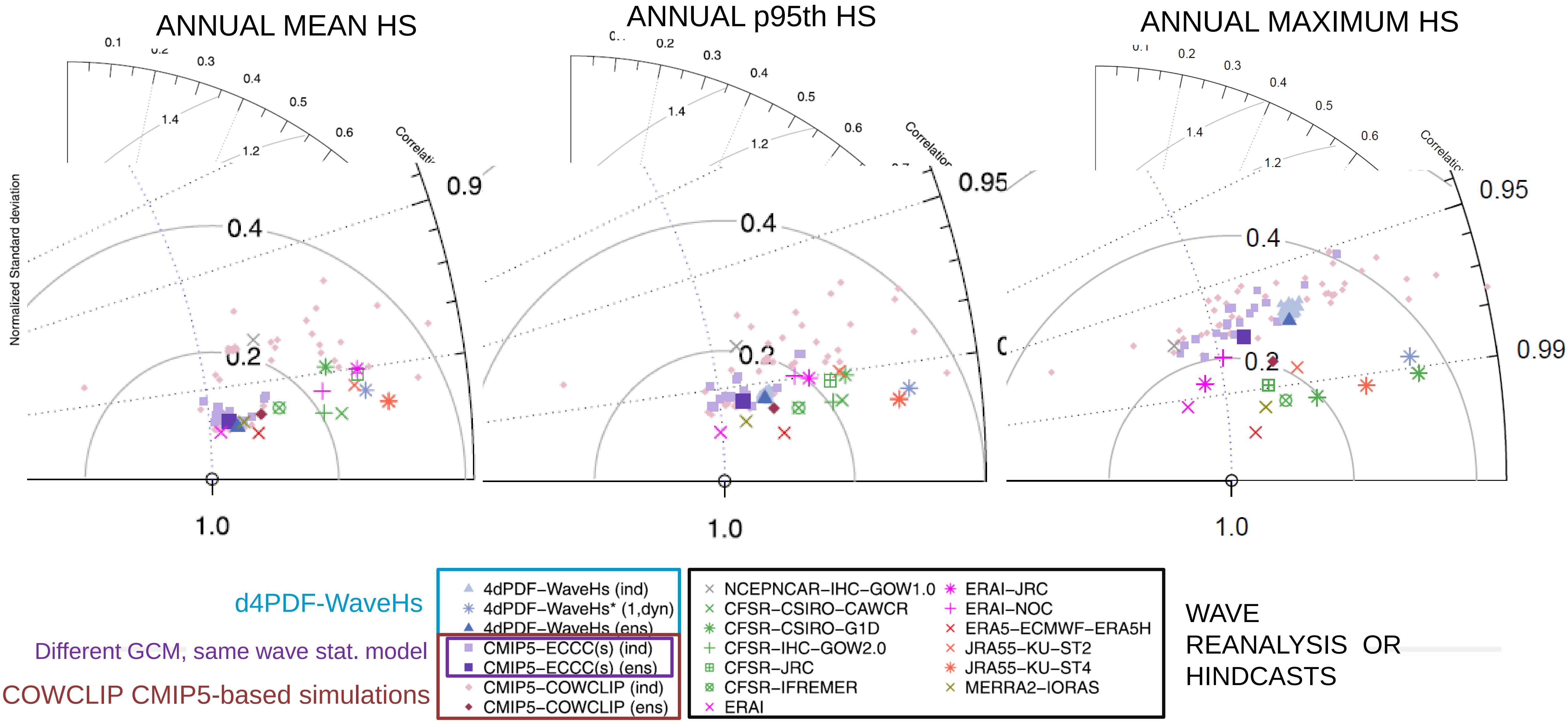


Standard deviation of the trend

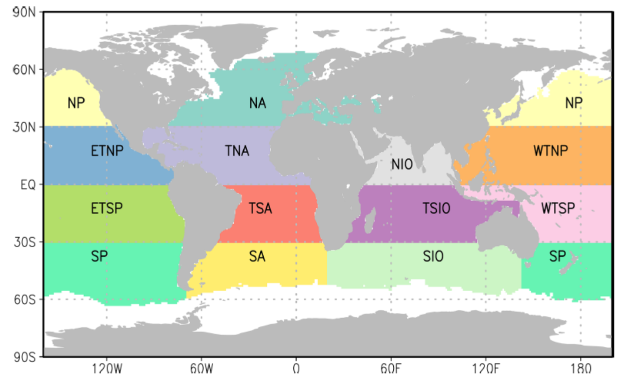


(Casas-Prat et al, 2022; 2023)

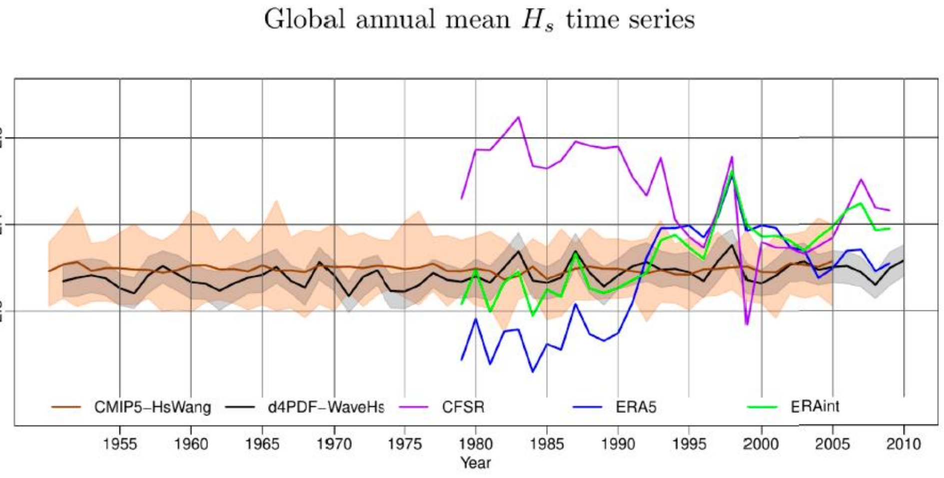
CLIMATOLOGY - COMPARISON AGAINST OTHER PRODUCTS



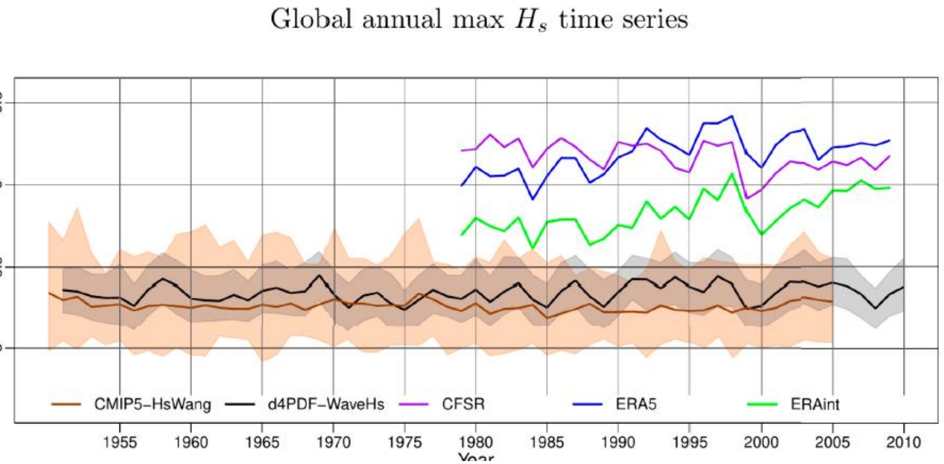
EVOLUTION OF REGIONAL MEAN



A



B



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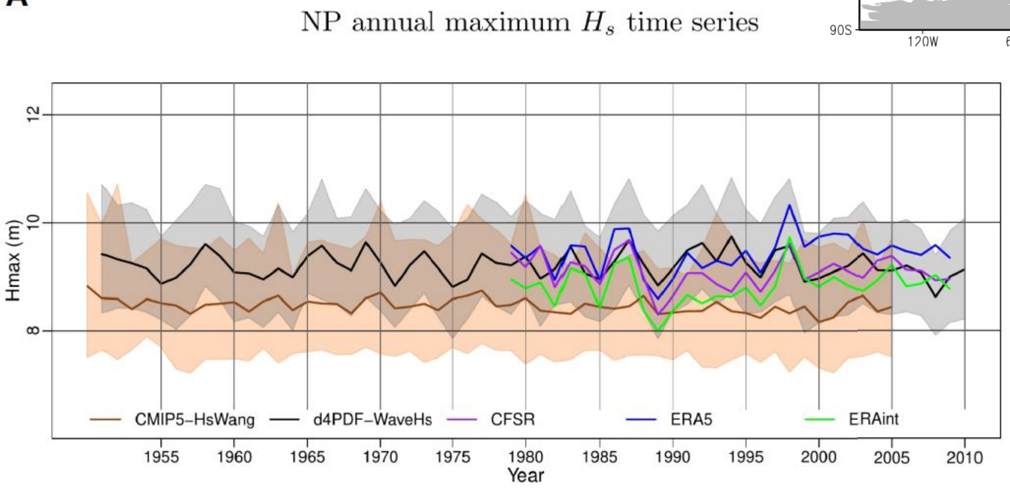
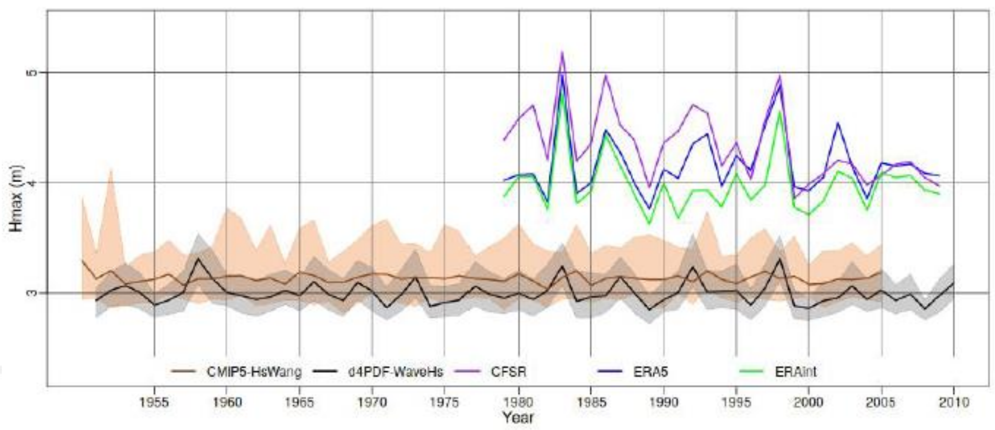


B

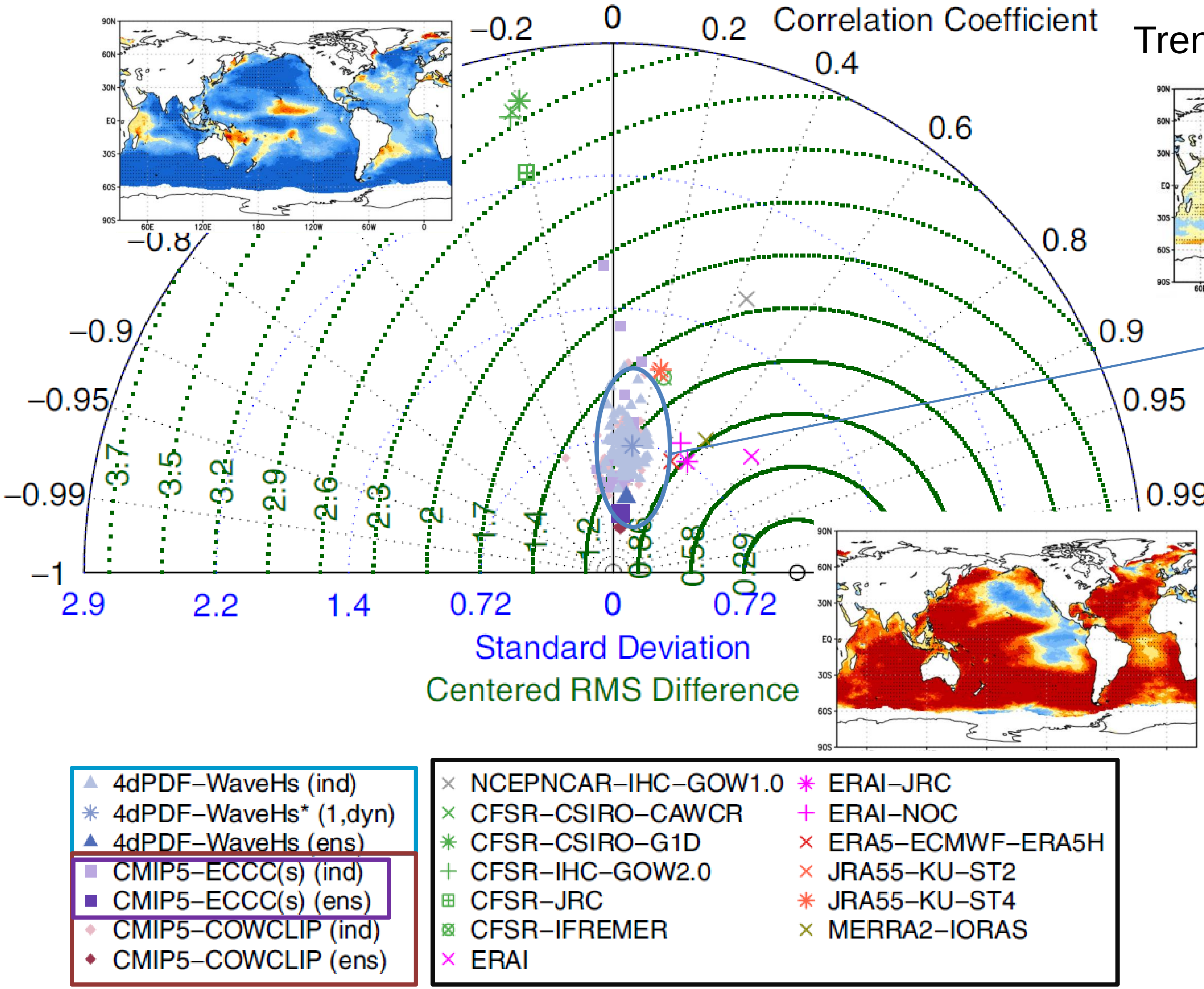
ETNP annual maximum Hs time series



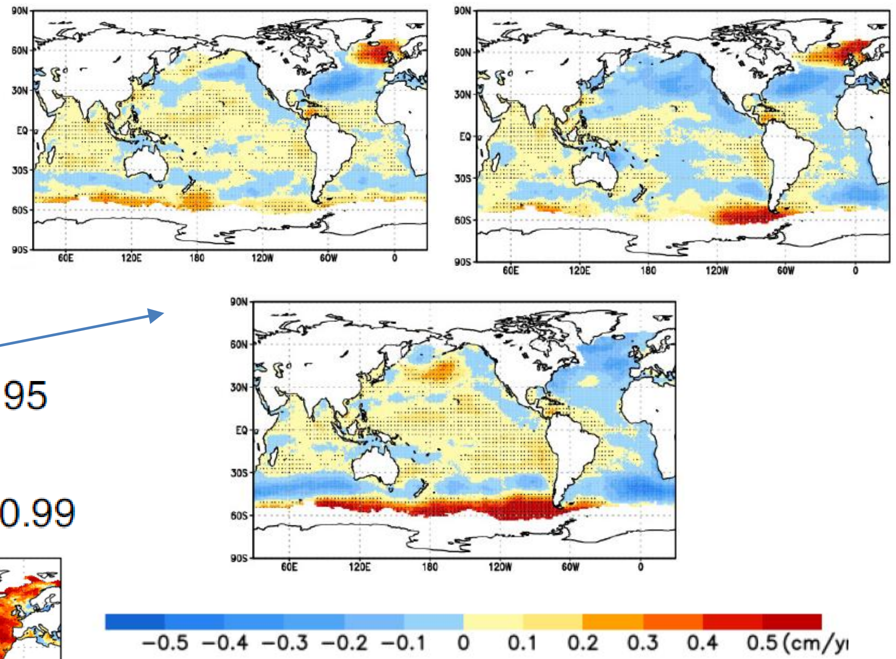
Temporal inhomogeneities tend to affect more annual mean Hs.

Underestimation of extremes occurs in the tropics but performance is good for the extra-tropics.

TREND - COMPARISON AGAINST OTHER PRODUCTS



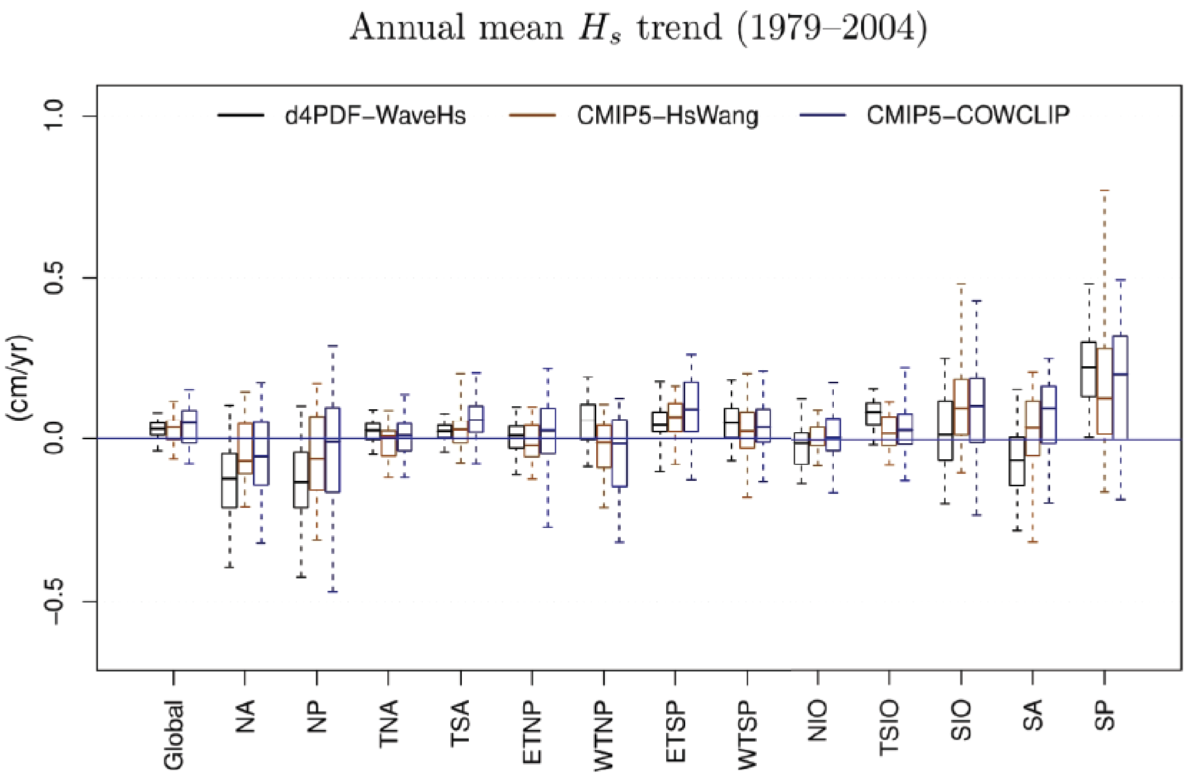
Trends as obtained from individual runs



Besides the expected discrepancies among reanalysis products, this figures shows large trend variability among d4PDF runs, with a similar spread to what is seen for multi-model ensembles

INTER-MODEL VS INTERNAL VARIABILITY

A



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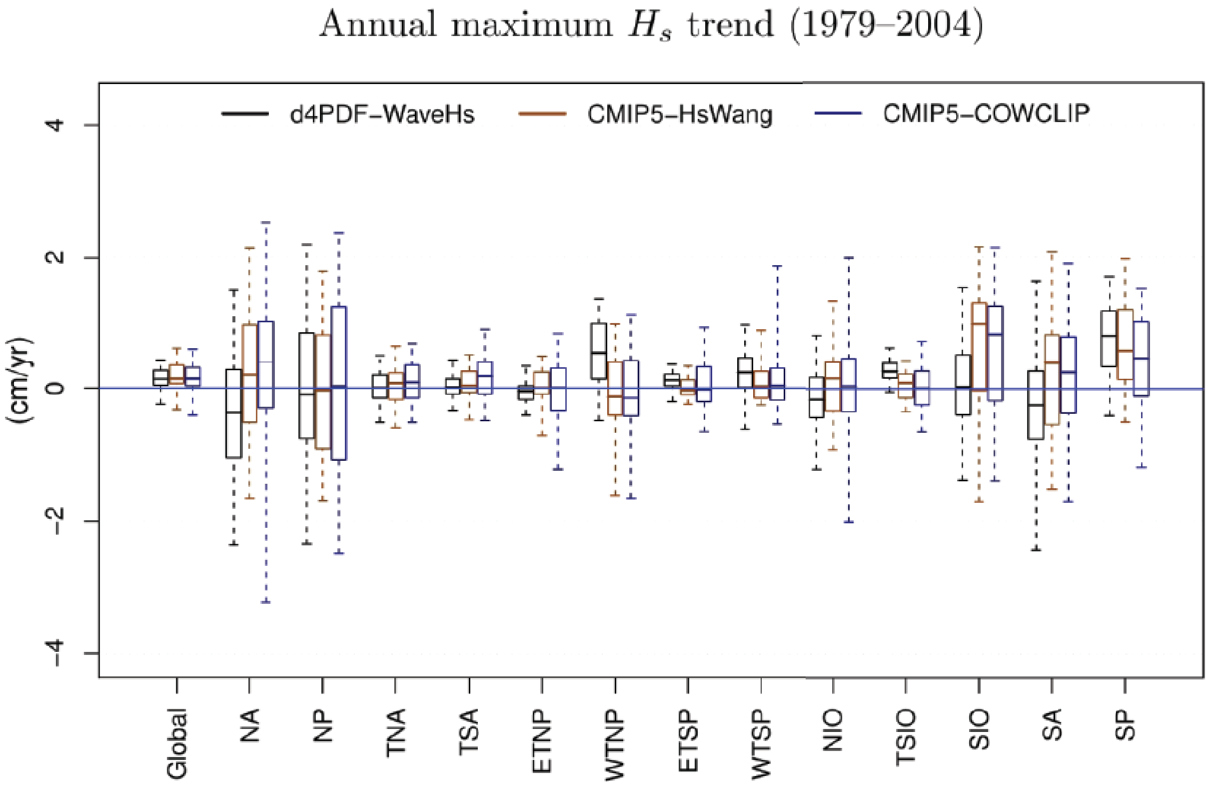
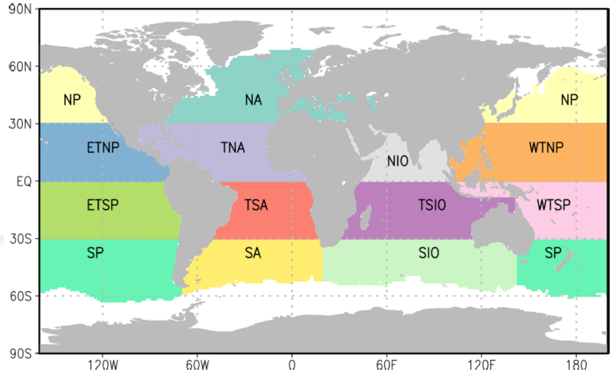




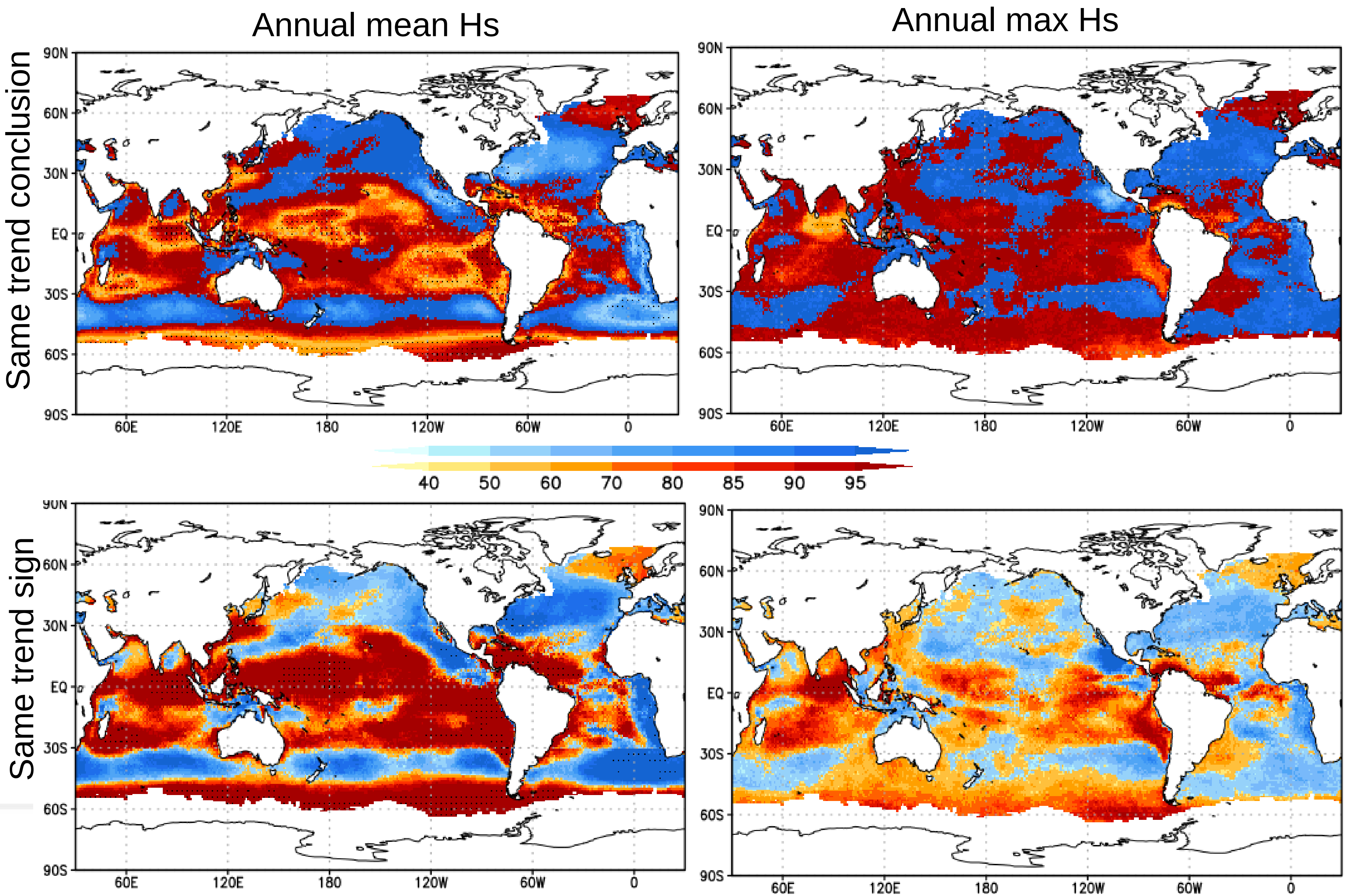
Trend uncertainty due to inter-model variability is comparable to trend uncertainty due to internal climate variability.

WHAT HAPPENS IF WE USE ONLY ONE CLIMATE REALIZATION?

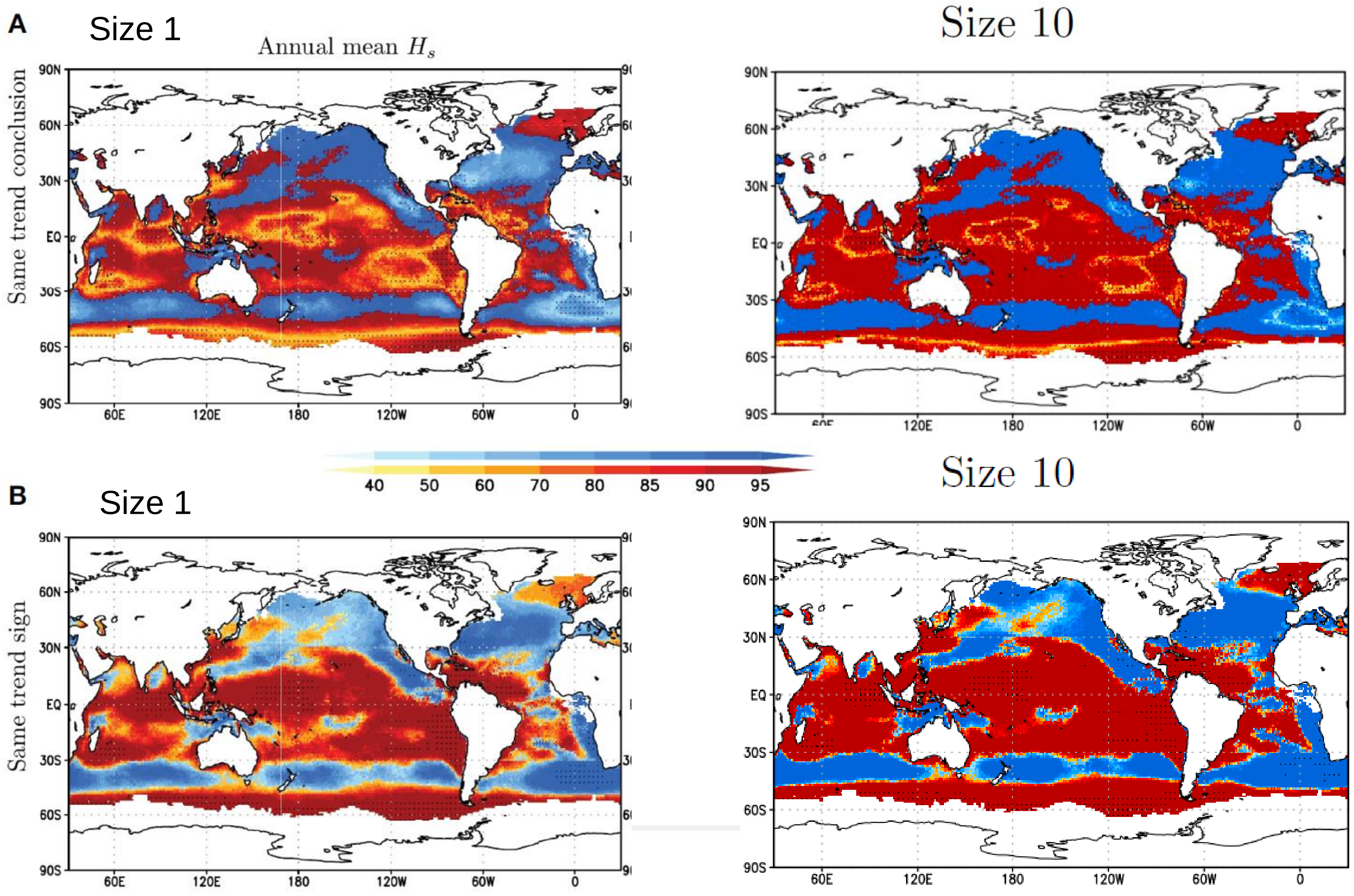
Trend conclusion can be:
Stat significant +
Stat significant –
Not significant

Using only one climate simulation leads to notable probability of trend miss-assessment in some areas.

For extremes, there is more variability in the trend sign but there is more agreement in terms of ‘trend conclusion’ as most runs exhibit no statistically significant trend.



OPTIMAL ENSEMBLE SIZE



CONCLUSIONS

- Reanalysis/hindcast present temporal inhomogeneities and therefore their use for trend assessment is questionable (agreement among reanalysis/hindcasts does not guarantee temporal homogeneity).

- Trend assessment is challenging (temporal inhomogeneities, calibration uncertainty, model uncertainty, etc). Moreover, the internal climate variability complicates the assessment of trends.

- We presented d4PDF-WaveHs dataset, which is a potential tool to assess the internal climate variability in wave climate assessments and their application to trend assessment, extreme value analysis, etc.

- While the internal climate variability has little influence on the annual mean Hs climatological mean, it greatly impacts the associated trends. This variability varies regionally, and it is comparable to the role of climate model uncertainty.

- Using only one climate realization can lead to miss-assess trends in some areas (with probability >50%). The optimal ensemble size depends on the region and target statistics, but a general recommendation would be to at least consider 10 members.

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JOB OPPORTUNITY

POSTDOCTORAL RESEARCHER POSITION (Toronto, Canada)

(with possibility to become INDETERMINATE)

Wave and storm surge modelling to develop Canada-focused coastal water level predictions

We are seeking an enthusiastic postdoctoral researcher with experience in **storm surge modelling** (e.g. NEMO) and development and statistical analysis of large climate datasets. Experience in **ocean wave modelling** (e.g. WW3) and machine learning methods will be considered an asset.

This research will contribute to the creation and analysis of National Climate Scenarios to support climate change adaptation in Canada, in the framework of the Canada's National Adaptation Strategy.

The postdoctoral researcher will work at Environment and Climate Canada with an interdisciplinary team of scientists from the Climate and Meteorological Research Divisions.

If you are interested or know someone who might be interested, please reach out merce.casasprat@ec.gc.ca

Thanks!