3RD INTERNATIONAL WORKSHOP ON WAVES, STORM SURGES, AND COASTAL HAZARDS

Wave modeling uncertainty in global wave climate projections: assessment and quantification

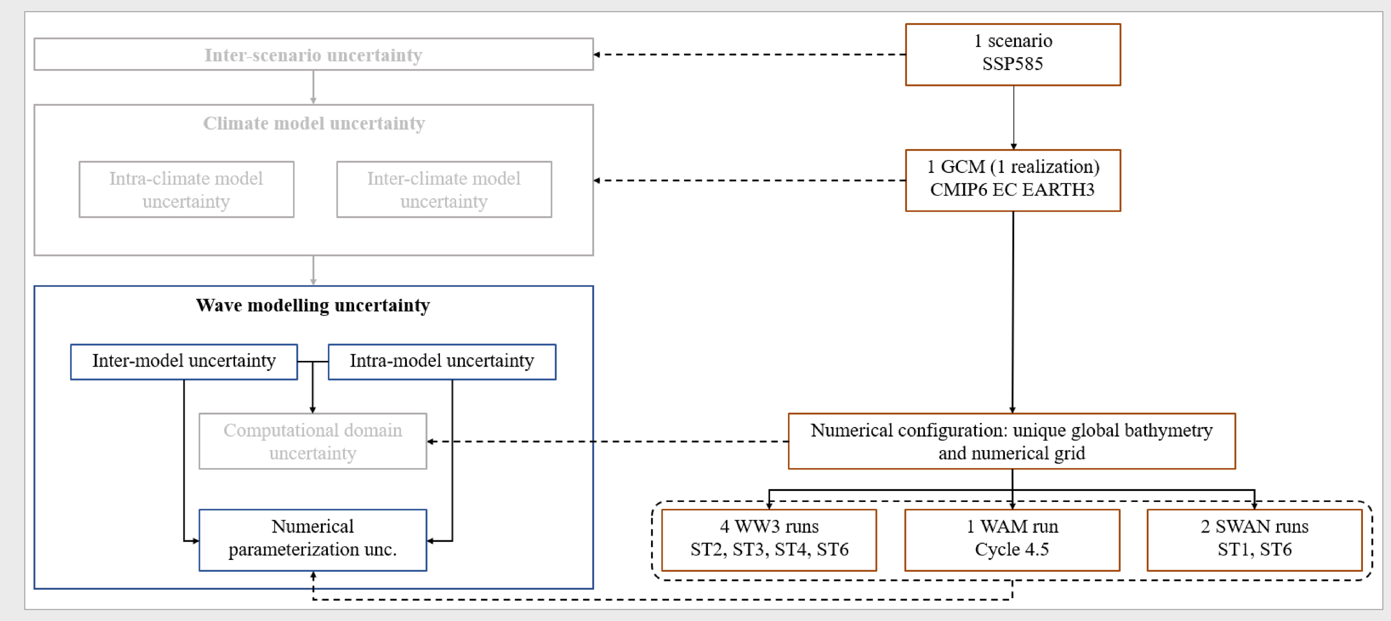
Hector Lobeto (lobetoh@unican.es), Alvaro Semedo, Melisa Menendez, Gil Lemos, Rajesh Kumar, Adem Akpinar, Mikhail Dobrynin and Bahareh Kamranzad

Introduction

- ❑ Ocean **wind waves** are **projected** to **change** over the twenty-first century under a warming climate.
- ❑ The standard approach to conduct these studies is based on **wave climate projections.**
- ❑ These products represent future wave climates, for different scenarios, developed using forcing drivers from global climate models (**GCMs**) or regional climate models (**RCMs**).
- ❑ Projected changes in wave climate are affected by **multiple sources of uncertainty** (see **Figure**): aleatoric uncertainty, socio-economic scenario uncertainty, uncertainty related to GCMs and the epistemic uncertainty associated with the wave modeling.

Main goal

To isolate the epistemic uncertainty in wave climate projected changes associated with the wave modeling, examining the relative importance of its main sources, and quantifying its magnitude.

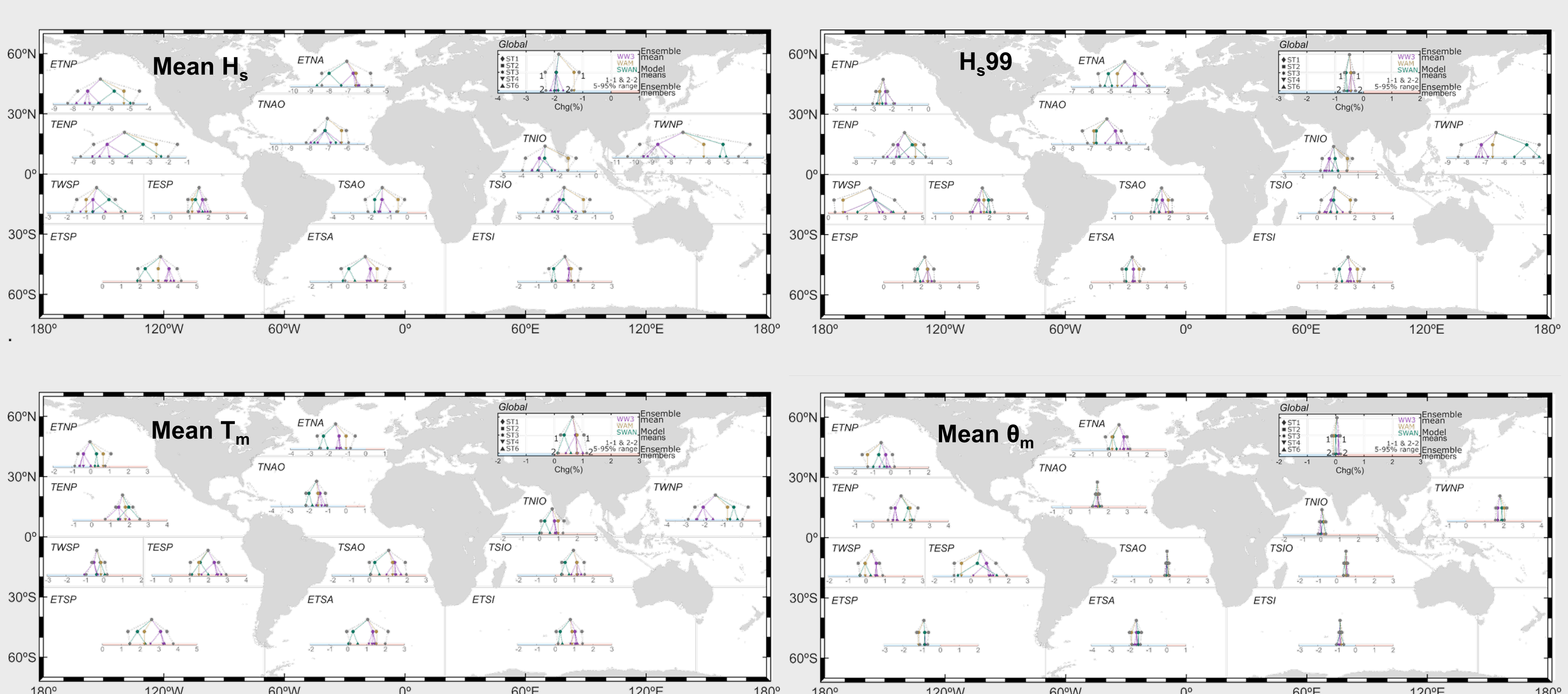


Outline of the uncertainty cascade related to the assessment of wave modeling uncertainty in wave climate projected changes.

Wave climate data

- ❑ This study uses a **wave climate projection ensemble** forced by a single run (r1i1p1f1) of the **CMIP6** GCM **EC-EARTH3**.
- ❑ The time slices **1995-2014** and **2081-2100** are used as **baseline** and **future periods**, respectively.
- ❑ Each ensemble member is developed using a **wave model with a different numerical parameterization**.
- ❑ The ensemble comprises **seven members**, integrating **four WW3 runs** developed with the source term packages **ST2**, **ST3**, **ST4** and **ST6**, **two SWAN runs** with the source term packages **ST1** and **ST6** and **one WAM run** with the **Cycle 4.5** source term package.

Uncertainty assessment



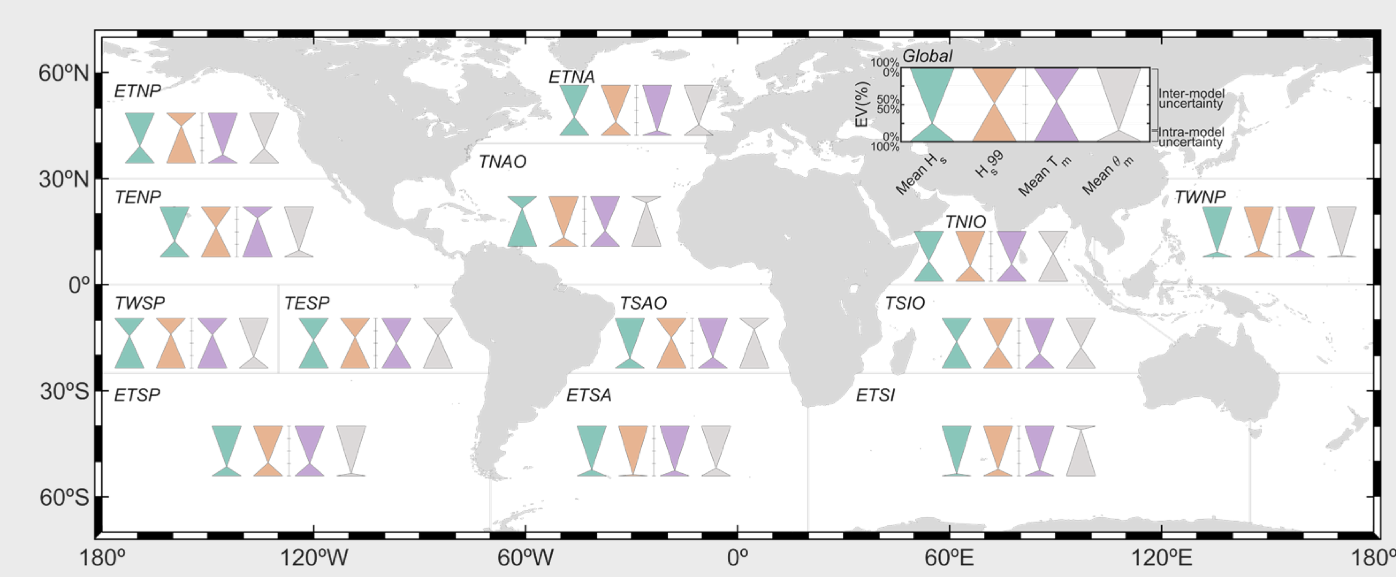
Uncertainty cascades for mean H_s, H_{s99}, mean T_m and mean θ_m. projected changes, per region and globally. Lower levels of the cascades represent more disaggregated changes: Top level – ensemble mean relative change, intermediate level – wave model mean relative changes, and lower level – ensemble member relative changes. Outside gray dashed lines represent the 5-95% range. WAM – Cycle 4.5 is displayed as ST4 for the sake of simplicity.

Contribution between inter- and intra-model uncertainties

- ❑ The **relative contribution** between the **inter-model** and **intra-model** uncertainty is assessed through a one-way **ANOVA**:

$$EV_{inter}\ (\%) = \frac{SS_{inter}}{SS_{total}} x100 \qquad EV_{intra}\ (\%) = 100 - EV_{inter}$$

where SS_{total} is the total sum of squares and SS_{inter} is the sum of squares between wave models



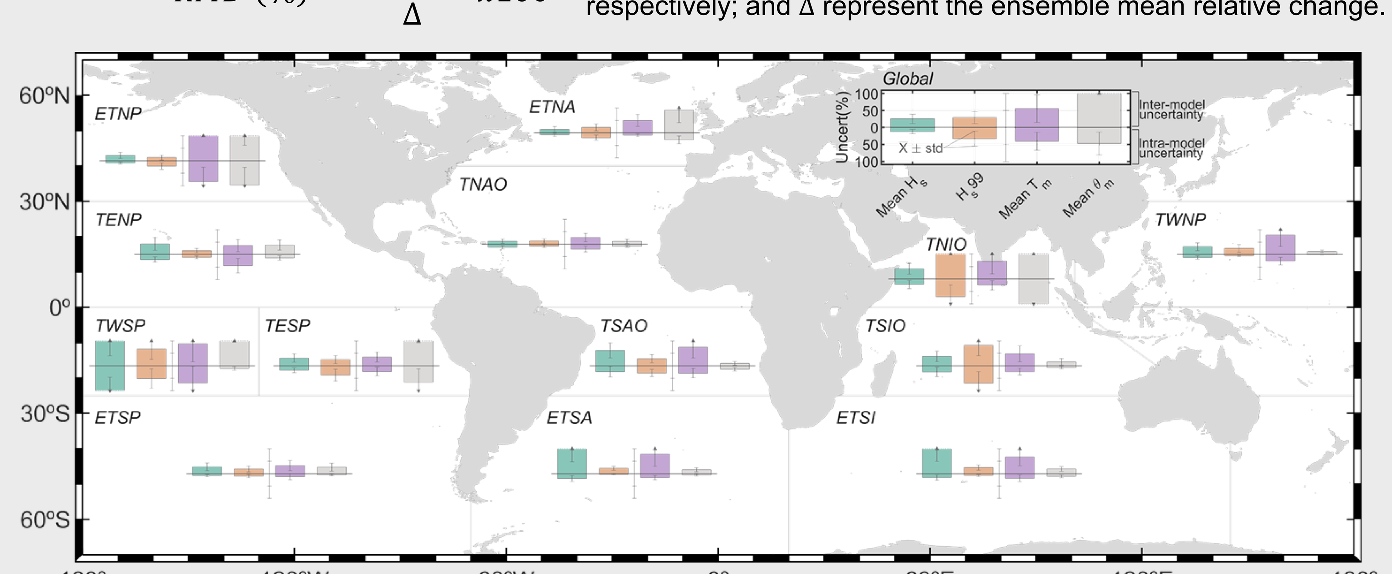
Relative contribution to the total wave modeling epistemic uncertainty, expressed as the explained variance (in %), for projected changes in mean H_s, H_s99, mean T_m and mean θ_m, per region and globally, between the inter-model and intra-model uncertainties.

Quantification of uncertainty

- ❑ **Inter-model** and **intra-model** uncertainties are quantified by assessing the differences between the projected changes from different wave models and model parameterizations, respectively. Discrepancies are measured through the relative mean difference (**RMD**) metric:

$$RMD\ (\%) = \frac{\Delta_n - \Delta_m}{\bar{\Delta}} x100$$

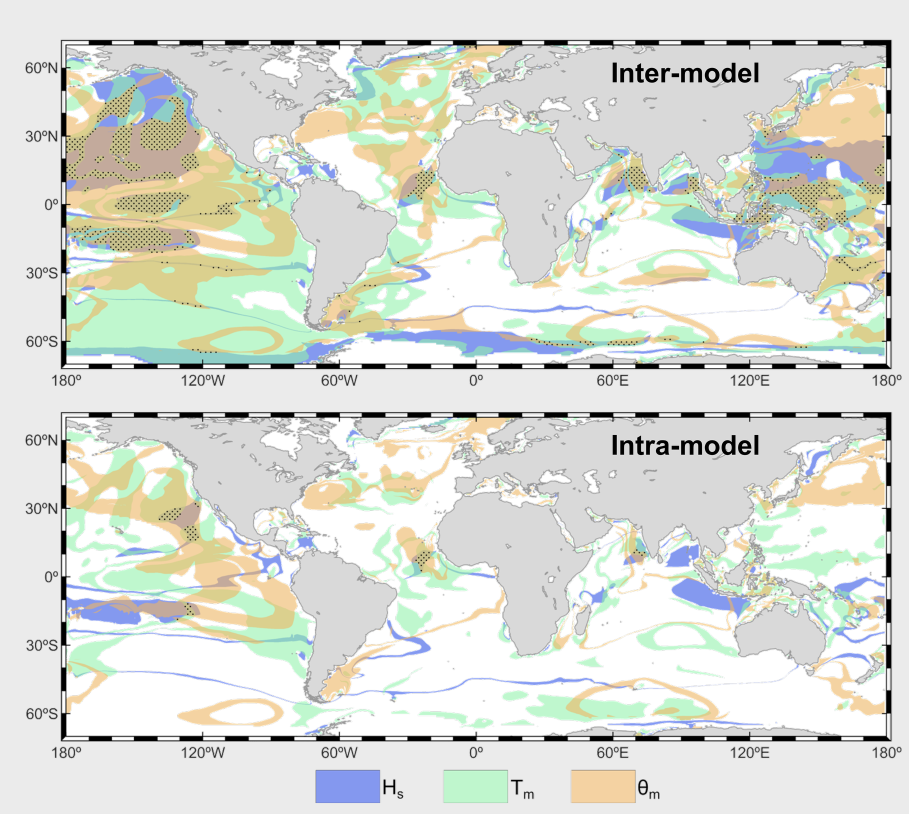
where Δ_n and Δ_m represent the relative change in runs n and m, respectively; and $\bar{\Delta}$ represent the ensemble mean relative change.



Quantification of the inter-model and intra-model wave modeling epistemic uncertainty for projected changes in mean H_s, H_s99, mean T_m and mean θ_m, per region and globally. Black arrows indicate values higher than 100%.

Significance of uncertainty

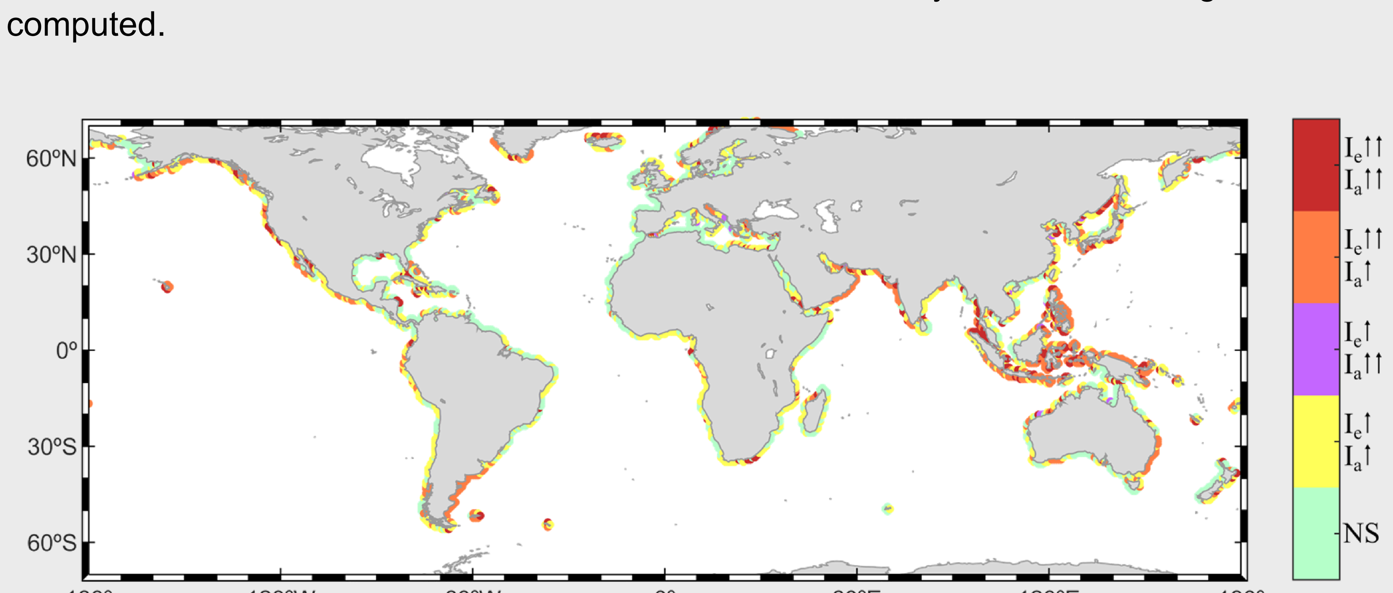
- ❑ The relevance of uncertainty is assessed to identify **areas** where it may have a **greater impact**.
- ❑ A specific ocean location (i.e., ocean grid point) is considered to have significant uncertainty if:
  - The mean uncertainty value is **greater than 25%**.
  - The absolute **ensemble mean projected changes exceed** the absolute **global median** projected change **and/or** if **the standard deviation** of individual member projected changes is **greater than twice the ensemble mean projected change**.



Ocean areas showing significant wave modeling uncertainty for mean H_s (blue), mean T_m (green) and mean θ_m (orange) projected changes. Stippling indicates significant uncertainties for the three metrics analyzed.

Coastal relevance

- ❑ Significant uncertainties may have **severe implications** in the **coastal zone**.
- ❑ The number of wave climate variables in which the uncertainty is found to be significant is computed.



Two upward arrows indicate that at least two out of the three wave climate metrics analyzed show significant uncertainty in projected changes. One upward arrow indicates that one or less of the three wave climate metrics analyzed show significant uncertainty in projected changes. The green color highlights the case where both sources of uncertainty show no significance (NS) in wave climate projected changes. The wave climate metrics analyzed are mean H_s, mean T_m and mean θ_m.

Conclusions

- ❑ This study addresses the **wave modeling** epistemic **uncertainty** in **wave climate projected changes**, isolating it from other uncertainties such as GCM and scenario-related uncertainties.
- ❑ Our wave climate projection ensemble utilizes the **three main wave propagation models—WW3, WAM, and SWAN**—with different **parameterizations** to capture **inter-model** and **intra-model** uncertainties.
- ❑ Our results reveal that **inter-model uncertainty has a greater impact** on wave climate projections than intra-model uncertainty, especially in extra-tropical regions.
- ❑ **Inter-model uncertainties** showed mean values exceeding **50%** in various **ocean regions** for metrics such as mean significant wave height (H_s), period (T_m), and direction (θ_m), while intra-model uncertainties were generally lower.
- ❑ **Wave period** emerged as the variable with the **greatest uncertainty** across ocean surfaces, followed by wave direction and wave height, with the Pacific Ocean showing particularly high levels of uncertainty.
- ❑ **Significant** wave modeling **uncertainties** affect **80% of global coastlines**.
- ❑ **Further research** is needed to elucidate the distinct **contribution** of the **processes** involved in the **uncertainties** found.

References

This study is under review in Environmental Research Letters:
- Lobeto, H., Semedo, A., Menendez, M., Lemos, G., Kumar, R., Akpinar, A., Dobrynin, M., & Kamranzad, B. (2023). On the Assessment of the Wave Modeling Uncertainty in Wave Climate Projections. Environmental Research Letters. *Under Review.*

More information about the wave climate projection ensemble used can be found in:
- Lemos, G., Semedo, A., Kumar, R., Dobrynin, M., Akpinar, A., Kamranzad, B., ... & Lobeto, H. (2023). Performance evaluation of a global CMIP6 single forcing, multi wave model ensemble of wave climate simulations. Ocean Modelling, 184, 102237.