Severe Sea-States: Present and Future Wave Climate

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1. Introduction to extreme sea states
2. Present Extreme wave climate
3. Future changes in Extreme Wave climate
CLIMATE EXTREME PHENOMENA (*definition*)

Event associated with certain conditions of the atmosphere-ocean system at its greatest or highest degree (very intense; of the greatest severity).

The highest value of a climatic element observed during a given period.

SEVERE EXTREME SEA STATE

- **Hazard**

STRONG IMPACT / DISASTER

- **Exposition**
- **Vulnerability**
Extreme Analysis on Waves

EXTREME VALUE THEORY

Statistical discipline that develops a set of techniques and methods to quantify and model the stochastic behavior of extreme events, either in magnitude or frequency

[...unique as a statistical discipline for describing the unusual rather than usual...]

percentile time series

• Sample of sea state parameter
  • High value

Extreme sample:
  a) Maxima within a block time (GEV)
  b) Exceedances/peaks over a threshold (Pareto, Poisson)

Adding complexity to the Extreme analysis:
  a) Non-stationary models
  b) Multivariate models (Sea state parameters, RFA, ...)

UC
Extreme Analysis on Waves

Return Period:

a) an average time interval, usually expressed in years, after which an event of a certain magnitude will be exceeded.
b) the expected waiting time until an exceedance occurs.

That is, if the return period or interval of occurrence of an event of a certain magnitude is 100 years, then there is a 1% probability of the event occurring in a year.

\[ \text{Prob} = 1 - \frac{1}{R} \]
Why analyzing Extreme waves?

Design of Maritime works

Damages in infrastructures

Flooding

Erosion

Are related to Extreme Wave Climate

Changes in extreme waves in the future??

On the need of Wave Climate Projections [COWCLIP]
1. Introduction to extreme sea states
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Present Climate of Extreme Waves

**GOW2 wave hindcast** (1979-present, 38yrs in the map below)

~25km spatial resolution on ‘coastal areas’

Present Climate of Extreme Waves

Spatial variability of the shape parameter of extreme wave height distribution around the world.

TOPEX, Jason-1, Jason-2, Envisat, GFO and ERS-2
Only statistically significant values at the 90% confidence interval are dotted.


Data source: GOW2 wave hindcast (1979–2018)
Only statistically significant values at the 0.05 level are dotted.
Present Climate of Extreme Waves

Seasonal and interannual variability of extreme wave height distribution worldwide.

TOPEX, Jason-1, Jason-2, Envisat, GFO and ERS-2

Present Climate of Extreme Waves

Data source: **GOW2 wave hindcast**
(1985-2005)
SWH threshold: 99.5%

Figure 7. Spatial distribution of (a) Poisson parameter $\lambda$; b) mean duration of the time windows of the significant wave height over the threshold 99.4th percentile; c) Scale parameter $\psi$; d) Shape parameter $\xi$ of the GDP-P model using historical GOW2 database (1985-2005).
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Preliminary concept

Cascade of Uncertainties!

- Emission Scenarios
  - GHG concentration emissions (Representative Concentration Pathways, RCPs)
  - Atmospheric-Ocean Global Climate Models
    - Inter-model / Intra-model uncertainty
  - Regional Climate Models
    - Inter-model / Intra-model uncertainty
- Wave modelling
  - Downscaling approaches
    - Dynamical Statistical
- Bias correction

Ocean Wave Climate
## Future Extreme Wave Climate

### Climate Forcings database

<table>
<thead>
<tr>
<th>GCM</th>
<th>Institution</th>
<th>Country</th>
<th>Atmospheric resolution (lat x lon)</th>
<th>Time periods</th>
</tr>
</thead>
<tbody>
<tr>
<td>MIROC5</td>
<td>MIROC</td>
<td>Japan</td>
<td>1,40° x 1,40°</td>
<td>1985-2005; 2026-2045; 2081-2100</td>
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<tr>
<td>IPSL-CM5A-MR</td>
<td>Institut Pierre-Simon Laplace</td>
<td>France</td>
<td>1,25° x 1,25°</td>
<td>1985-2005; 2026-2045; 2081-2100</td>
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<td>GFDL-ESM2G</td>
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<td>USA</td>
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<td>1985-2005; 2026-2045; 2081-2100</td>
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<tr>
<td>CNRM-CM5</td>
<td>Centre National de Recherches Météorologiques</td>
<td>France</td>
<td>1,40° x 1,40°</td>
<td>1985-2005; 2006-2100;</td>
</tr>
<tr>
<td>CMCC-CM</td>
<td>Centro Euro-Mediterraneo per I Cambiamenti Climatici</td>
<td>Italy</td>
<td>0,75° x 0,75°</td>
<td>1985-2005; 2026-2045; 2081-2100</td>
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<tr>
<td>ACCESS1</td>
<td>CSIRO-BOM</td>
<td>Australia</td>
<td>1,25° x 1,90°</td>
<td>1985-2005; 2006-2100;</td>
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<tr>
<td>HadGEM2-ES</td>
<td>Met Office Hadley Centre</td>
<td>UK</td>
<td>1,25° x 1,90°</td>
<td>1985-2005; 2026-2045; 2081-2100</td>
</tr>
</tbody>
</table>

Wind (3h) and Ice marine coverage (daily)

RCP4.5 & RCP8.5
Future Extreme Wave Climate

On the need of bias correction.

Bias (GCM – GOW) in the 99th percentile of the significant wave height (m) in the historical period (1985-2005): CMCC-CM; ACCESS1; CNRM-CM5; GFDL-ESM2G; HagGEM2-ES; IPSL-CM5A-MR; MIROC5.

PDF-Score Metric:

\[ PDF_{score} = \frac{1}{n} \sum_{i=1}^{n} \min(PDF_{obs}, PDF_{mod}) \]
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On the need of bias correction..

Bias Correction technique: 
**EMPIRICAL QUANTILE MAPPING**

- Linearly spaced $q_i = 1, 5, 10, ..., 90$:
- Gumbel scale for a better representation of the upper tail of the distribution. Quantiles over the 90th are selected using a standard Gumbel distribution: $q_i = \exp \left[ - \exp \left( -x_{q_i} \right) \right]$. $q_{lo} = 90$ and $q_{up} = 99.999$. 
Empirical distributions of the time windows over the threshold 99th percentile of the significant wave height obtained from historical data GOW2 and the dynamical wave projections of the 7 GCMs at 3 selected locations without the bias corrected (upper panels) and with the bias corrected (lower panels).
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For the Reference (historical) period (PC)
1985-2005

GOW2 wave hindcast

Mean Ensemble
(after bias correction)
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Changes in GEV parameters
2081-2100, RCP8.5
From the 7-members ensemble
(Dot if 6/7 Clim. Sim. Agreed)
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CMCC

IPSL

MIROC5

Ensemble 20yr Hs (m)
Multimodel mean (upper panels) and standard deviation (lower panels) of the projected changes in the return periods of 2, 20 and 50 years of the significant wave height for future period 2081–2100 relative to present climate (1985–2005) for RCP8.5 scenario.

Stippling represents agreement on the sign of change of more than 80% of the models.
Thanks for your attention!