STATISTICAL APPROACHES TO ASSES CLIMATE CHANGE COASTAL IMPACTS

Paula Camus (camusp@unican.es)
C. Izaguirre, A. Tomás, I.J. Losada, M. Menéndez, J. Pérez

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Motivation

Uncertainty

RCP Scenarios

Ensemble
Global Circulation Models

Ensemble
Regional Circulation Models

Coastal forcing models

Impact models

BIAS CORRECTION

Adapted from Ranasinghe et al. (2013)
STATISTICAL DOWNSCALING

Motivation

- RCP Scenarios
  - Ensemble Global Circulation Models
    - Ensemble Regional Circulation Models
      - Coastal forcing models
        - Impact models
More details in Camus et al., 2014; Pérez et al., 2015; Camus et al., 2017
PROJECTED CHANGES in Hs
Scenario RCP8.5 – Multi-model Ensemble
For the period **2070-2099**
Relative to the period 1979-2005
### Methodology

**1. Projected Climate at Certain Time Slice**

- Variables: $P_i$ (WT)

**2. Semi-Guided Classification**

- Linear Regression: $Ŷ = XB$
- K-means: $Z = (1-α)X + αŶ$

**3. Weather Types**

- Types: $p_1, p_2, p_3, p_4$

**4. Global Wave Hindcast**

- Spatial resolution: $1.0^\circ \times 1.0^\circ$

**5. Regional Wave Hindcast**

- Spatial resolution: $0.25^\circ$

**6. Coastal Impact Indicators**

- Total Water Level
- Operability - Overtopping

**7. Statistical Downscaling at Global Scale**

- Inferred Distribution

**8. Regional Statistical Downscaling**

- Inferred Mean Value

**9. Empirical Distributions**

- Variables: $f(Y), f'(Y)$

- Inferred Distribution

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**Atmospheric Data (Predictor)**

- $X$ = SLP, SLPG

**Wave Data (Predictando)**

- $Y$ = Hs, Tm, SS

**Predictor Definition**

- Spatial domain, temporal, gradients...
INTERMODEL CHANGES
Scenario RCP8.5
For the period 2070-2099
Relative to the period 1979-2005
**Climate Change Assessment of Coastal Impacts**

**COASTAL FLOODING**

\[
TWL(t) = SS(t) + AT(t) + Setup(t) + MSL(+SLR)
\]

\[
Setup = 0.043 \cdot \sqrt{H/L_0}
\]

SS: DAC database
AT: reconstruction from an harmonic analysis
SLR: Slangen et al., 2014

**OPERABILITY DUE TO OVERTOPPING**

Owen 1980:

\[
Q = \frac{q}{\sqrt{g \cdot H_s^3}} = 8 \cdot 10^{-5} \cdot \exp\left(-b \frac{R_c}{H_s}\right) \cdot \exp(3.5 \cdot b \cdot \theta_r)
\]

In future scenarios \(R_c = R_c - SLR\)
MULTI-MODEL PROJECTED CHANGES
Scenario RCP8.5
For the period 2070-2099
Relative to the period 1979-2005
Camus et al., 2017
MULTI-MODEL PROJECTED CHANGES
Scenario RCP8.5
For the period 2070-2099
Relative to the period 1979-2005
Probabilistic Assessment of Port Operability

Historical Climate Conditions

Empirical Data $X^0$

Stochastic Simulation

Simulated Data $X^0$
Probabilistic Assessment of Port Operability

Historical Climate Conditions
Waves: Hs, Tm, Dir
Sea Level: SS, AT

STOCHASTIC GENERATOR
Synthetic Climate Conditions
(Hs, Tm, Dir, Sea Level)

SELECTION
(Hs, Tm, Dir, Sea Level)

Harbour Agitation Model
(Hs inside the harbour)

Reconstruction of Hs inside the port
Probabilistic Assessment of Port Agitation
Probabilistic Assessment of Port Operability

Rueda et al., 2016

**STOCHASTIC GENERATOR**
Synthetic Climate Conditions
(Hs, Tm, Dir, Sea Level)

**SELECTION**
(Hs, Tm, Dir, Sea Level)

Harbour Agitation Model
(Hs inside the harbour)

Reconstruction of Hs inside the port
Probabilistic Assessment of Port Agitation

- Historical Climate Conditions
  - Waves: Hs, Tm, Dir
  - Sea Level: SS, AT

- **MARGINAL DISTRIBUTIONS**

- **MULTIVARIATE DISTRIBUTION**
  - **GAUSSIAN COPULAS**

- **SYNTHETIC GENERATION**
  - MULTIVARIATE DATA
Probabilistic Assessment of Port Operability

Historical Climate Conditions
Waves: Hs, Tm, Dir
Sea Level: SS, AT

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Waves: Hs, Tm, Dir
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Probabilistic Assessment of Port Agitation
Probabilistic Assessment of Port Operability

Historical Climate Conditions
Waves: Hs, Tm, Dir
Sea Level: SS, AT

STOCHASTIC GENERATOR
Synthetic Climate Conditions
(Hs, Tm, Dir, Sea Level)

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(Hs, Tm, Dir, Sea Level)

Harbour Agitation Model
(Hs inside the harbour)

Reconstruction of Hs inside the port
Probabilistic Assessment of Port Agitation

Hs = 5.6 m; Tp = 6.9 s; Dir = 54.1°; marea = 3.20 m. 1948/05/16 04:00
Probabilistic Assessment of Port Operability

Historical Climate Conditions
Waves: Hs, Tm, Dir
Sea Level: SS, AT

STOCHASTIC GENERATOR
Synthetic Climate Conditions
(Hs, Tm, Dir, Sea Level)

SELECTION
(Hs, Tm, Dir, Sea Level)

Harbour Agitation Model
(Hs inside the harbour)

Reconstruction of Hs inside the port
Probabilistic Assessment of Port Agitation
Probabilistic Assessment of Port Operability under Climate Change

Historical Climate Conditions
Waves: Hs, Tm, Dir
Sea Level: SS, AT

STOCHASTIC GENERATOR
Synthetic Climate Conditions
(Hs, Tm, Dir, Sea Level)

SELECTION
(Hs, Tm, Dir, Sea Level)

Harbour Agitation Model
(Hs inside the harbour)

GCM Projections
RCP Scenarios
WT probabilities

Regional SLR
RCP Scenarios

Reconstruction of Hs inside the port
Probabilistic Assessment of Port Agitation

Synthetic Climate Conditions
(Hs, Tm, Dir, Sea Level)

GCM Projections
RCP Scenarios
WT probabilities

Regional SLR
RCP Scenarios

Reconstruction of Hs inside the port
Probabilistic Assessment of Port Agitation
Conclusions

• The spatial resolution of wave projections depends on the historical wave database used as reference, not fixed as in dynamical simulations (e.g., global projections at 1.0° or regional projections at 0.25° or higher). Semi-supervised WTs at a 1.0°x 1.0° grid can be used to downscale wave climate at different spatial resolutions.

• Low computational effort is required to quantify uncertainty associated with climate change scenarios and various GCMs, to cover the whole century (not limited to the end of the 21st century as most dynamical simulations) and to update CMIP outputs.

• Multivariate marine projections can be obtained using the same statistical scheme (not limited to wave height as other statistical methodologies)

• Coastal impact can be assessed by means of direct downscaling of impact indicators which integrate climate change variations of various marine hazards and SLR.

• A probabilistic assessment of the impact of climate change on port operability due to wave agitation is introduced based on the semi-supervised WT collection. The results highlights the importance of modelling the non-linear effect of SLR in the wave penetration inside the port using a physical process-based model.

Acknowledgments:

Characterization of wave generation areas

ESTELA Method
(Pérez et al., 2014)
Validation of the statistical model

**Correlation Coefficient Hs**

![Correlation Coefficient Hs Map]

**NRMSE Hs**

![NRMSE Hs Map]

**Correlation Coefficient Tp**

![Correlation Coefficient Tp Map]

**NRMSE Tp**

![NRMSE Tp Map]
Global Statistical Projections

PROJECTED CHANGES in Tp
Scenario RCP8.5 – Multi-model Ensemble
For the period 2070-2099
Relative to the period 1979-2005

Multi-model annual mean Tp (s) (1979-2005)

Multi-model changes annual Tp

Multi-model changes JFM Tp

Multi-model changes JAS Tp
Temporal Series annual mean Hs relative to the period 1979–2005

Global Statistical Projections

ID06 (South Pacific)

ID09 (North Atlantic)
Probabilistic Assessment of Port Operability

Reconstruction of Hs inside the port

Probabilistic Assessment of Port Agitation
Probabilistic Assessment of Port Operability

Historical Climate Conditions
Waves: Hs, Tm, Dir
Sea Level: SS, AT

STOCASTHIC GENERATOR
Synthetic Climate Conditions
(Hs, Tm, Dir, Sea Level)

Selection
(Hs, Tm, Dir, Sea Level)

Harbour Agitation Model
(Hs inside the harbour)

Reconstruction of Hs inside the port
Probabilistic Assessment of Port Agitation