Global Wave Climate Projections – The COWCLIP Project

Alvaro Semedo
IHE Delft, The Netherlands
a.semedo@un-ihe.org

Acknowledgements:
COWCLIP team

London, September 26, 2018
Global Wave Climate Projections – The COWCLIP Project

Alvaro Semedo
IHE Delft, The Netherlands
a.semedo@un-ihe.org

Acknowledgements:
COWCLIP team

- Why worry about changes in wave climate?
- How are wave climate projections done (at the moment)
- COWCLIP project
- Global and regional wave climate projections (what have we done so far)
- COWCLIP-2 large Ensemble
- Summary
Climate:
… (in a narrow sense) is the ‘average weather’, defined by surface variables such as temperature, precipitation, and wind (IPCC 2013).

Wave climate:
… is the distribution of sea state characteristics (defined by wave ‘parameters’), averaged over a period of time and for a particular location
Why are waves important and why should we care about them?

- Waves are part of the climate system
- Strong impact in coastal areas (major coastal hazard: inundation, coastal erosion/deposition, etc.)
- Impact on coastal and offshore infrastructures
- Define ship and coastal/offshore structures design
- Impact operability, and safety factors (offshore platforms)
Why are waves important and why should we care about them?

**The devil is in the extremes! …**

**ULS** (Ultimate Limit State) - For a specific location, a structure has to sustain the 100 year load level without damage.

**ALS** (Accidental Damage Limit State) - Norwegian Standard NORSOK (2017) requires that there must be enough room for the wave crest to pass beneath the deck to ensure that a 10 000-year wave load does not endanger the structure integrity.
‘Wave climate’ is the distribution of wave characteristics averaged over a period of time and for a particular location.

Present wave climate

- Monitoring of present wave conditions (Hs, Tm, MWD)
- Observations (in situ and remote sensing, etc.)
- Modelling (reanalysis or hindcasts)
- Ship and structure design
- Coastal zone management

Future wave climate

- Projected wave climate (modeling)
- How changes in climate affect future wave climate, compared to present conditions
- Projected, i.e., based on greenhouse gasses emission/concentration scenarios
• Waves are generated by the local wind, but they propagate away as swell
• Need to study wind and wave climates separately (keeping wind at sight!)
• Main wave generation areas (extratropical latitudes)
• Extreme waves (extratropical storms and tropical cyclones)
Wave climate

ERA-Interim 1979-2016
Mean annual $H_s$

Max $H_s$

Warning, ERA-Interim underestimates extremes!
IACS* tankers common structural rules (CSR) are based on North Atlantic wave climate (based on VOS data**; areas 8, 9, 15, and 16)

(*) International Association of Classification Societies (IACS): standards for the construction and operation of ships and offshore structures.

(**) Idea to have it replaced in near future by new generation of wave reanalysis/hindcast data (ERA5?).

Global Wave Statistics zone designation (VOS)
http://www.globalwavestatisticsonline.com/
Wave climate projections

• If the present wave climate is the ‘mean of observed or modeled wave parameters’, how can we assess the future wave climate?

Dynamical or statistical simulations

20th century


1980 1960 2000 2090 2050 2060 2070 2080 2090 2100

21st century

Present Climate

Historic Period

1950 1970 1990 2005


Future Climate

Statistics

Present vs. Future Climate

Reanalyses/hindcasts
In situ observations
Remote sensing observations

H_s, T_m and θ_m
Means, extremes, seasonality

Performance/skill Evaluation
(skills in reproducing present climate)

GCM runs (present radiative conditions)
U10 winds (MSLP) and sea ice force physical (statistical) wave model

GCM 1
GCM 2
GCM 3
GCM n

Of-line runs

Wave model 1
Wave model 2
Wave model 3
Wave model n

Ensemble approach

GCM runs with future radiative conditions (from forcing scenarios)
U10 winds (MSLP) and sea ice force physical (statistical) wave model

GCM 1
GCM 2
GCM 3
GCM n
The future time slice is based on a specific scenario (set in the GCM/RCM).

- GCM runs with future radiative conditions (from forcing scenarios)
- U10 winds (MSLP) and sea ice force physical (statistical) wave model
Wave climate projections

**AR4 - CMIP3** forced wave climate simulations
SRES (Special Report on Emission Scenarios)

**AR5 - CMIP5** forced wave climate simulations
RCP (Representative concentration pathways)

![Graphs showing global surface warming from 1900 to 2100 for CMIP3 and CMIP5 models, with scenarios such as Historical, SRES B1, SRES A1B, and SRES A2 for CMIP3, and Historical, RCP 2.6, RCP 4.5, RCP 6.0, and RCP 8.5 for CMIP5.]

→ A1B and A2

→ RCP4.5 and RCP8.5
... If the present wave climate is the ‘mean of observed or modeled wave parameters’, how can we assess the future wave climate?

- Single studies are not capable of fully quantifying the uncertainty of projected changes.
- Ensembles of wave climate projections allow the quantification of the uncertainty (to a certain degree).

Dynamical or statistical simulations:
- GCM runs (present radiative conditions) and sea ice force physical (statistical) wave model.
- U10 winds (MSLP) and sea ice force physical (statistical) wave model.
- GCM runs with future radiative conditions (from forcing scenarios) and sea ice force physical (statistical) wave model.

Of-line runs:
- Single studies are not capable of fully quantifying the uncertainty of projected changes.
- Ensembles of wave climate projections allow the quantification of the uncertainty (to a certain degree).

Performance/skill evaluation (skills in reproducing present climate):
- Reanalyses/hindcasts.
- In situ observations.
- Remote sensing observations.
- Means, extremes, seasonality.

Statistics:
- Present vs. Future Climate.

Present Climate
Historic Period

Future Climate
Wave climate projections

Large uncertainties!
Wave climate projections

Morim et al. (2018)
• Wave climate projections are still performed off-line (prior GCM runs needed)
• Studies are based on the models’ (GCM and wave model) ability to reproduce the “observed” historical wave climate.
• (Need to have confidence in how the simulated wave fields reproduce the present, to be able to assess the climate change impact for the future!)
COWCLIP – Coordinated ocean wave climate projections

**COWCLIP - Goals**

- Community working group focused on coordinated ocean-wave climate projections.
- Collaborative working group with interest in global wave climate historical and future changes.
- Resolve priority questions to aid climate impacts community.
- Document wave climate projections methods being applied, and summarize existing wave climate projection studies.
- Define a working protocol for wave climate projections.
- Develop a technical framework to support the working group.
COWCLIP-1:

CMIP3 ensemble of “opportunity”
Dynamical and statistical projections
Several scenarios
4 dynamical; 9 statistical

(Courtesy of Mark Hemer)
Wave climate projections

Projections of $H_s$, $T_m$ and $\theta_m$ ~2070-2100

Annual projection of $H_s$

Seasonal projection of $H_s$

Annual projection of $\theta_m$ and $T_m$

Hemer et al. (2013) Nature Climate Change
and Church et al. (2013), IPCC AR5
Projections of $H_s$, $T_m$ and $\theta_m$ ~2070-2100

- Increase $H_s$ Southern Ocean
- Decrease $H_s$ North Atlantic/Pacific
- Increase $T_m$ East Pacific
- Changes in mean wave direction

Hemer et al. (2013) Nature Climate Change
and Church et al. (2013), IPCC AR5
• COWCLIP-1 ensemble of “opportunity” had little overlap in the sample space, which resulted in high (unquantifiable) uncertainty in the projected wave conditions.

• COWCLIP-2 (CMIP5) experiment has been designed to overcome the COWCLIP-1 shortcomings.

Hemer et al. (2013) Nature Climate Change and Church et al. (2013), IPCC AR5
COWCLIP-1 ensemble of “opportunity” had little overlap in the sample space, which resulted in high (unquantifiable) uncertainty in the projected wave conditions.

COWCLIP-2 (CMIP5) experiment has been designed to overcome the COWCLIP-1 shortcomings.
Summary of wave climate projections - before COWCLIP-2

Morim et al. (2018a)
• Several coastal regions at high risk still overlooked...

Regional studies

Morim et al. (2018a)
Studies (regional and global) 2004-2017

Some level of qualitative consensus in signal (in some areas)

Morim et al. (2018a)
• No standard evaluation method
• Some studies were not validated (?), raising questions regarding model uncertainty and unrealistic models
• COWCLIP-1: 13 simulations (4 dynamical and 9 statistical)  
  [Ensemble of opportunity – several CMIP3 scenarios]

• COWCLIP-2: 145 simulations (76 dynamical and 69 statistical)  
  [“Coherent” ensemble: RCP8.5 and RCP4.5]
• Extensive evaluation

Bias in annual mean $H_s$ (ERA-Interim)

Morim et al. unpublished to be submitted to NCC
Extensive evaluation
Projected change in annual mean $H_s$ – RCP8.5

Morim et al. unpublished – to be submitted to NCC
Projected change in annual mean $H_s$ – RCP4.5

Morim et al. unpublished – to be submitted to NCC
Ensemble projected change in annual and seasonal annual mean $H_s$, $H_s$ 99%, $T_m$ and $\theta_m$ – RCP4.5 and RCP8.5

White areas: Projected change not statistically significant (Wilcoxon rank sum test)

Hashed areas: Magnitude of climate change signal exceeds magnitude of variance within ensemble

Ensemble: Weighted by frequency of forcing (GCMs)

Morim et al. 2018 unpublished to be submitted to NCC
• Comparison (rough) to other cross ensemble studies

Courtesy of Mark Hemer
Summary

- Waves will respond to variability and change in the global climate system
- Changing storm tracks/intensity will drive changes in global wave field
- Changing sea-level morphology will drive changes in coastal wave fields
- Potential implications:
  - Coastal (in)stability
  - Off-shore platform design/installation/operability/maintenance (oil and gas and offshore renewables)
  - Ship design and route planning
  - Feedback processes via altered air-sea fluxes (heat/mass/radiation/salt)
• Considerable increase of future wave climate studies (global and regional) in last 8-10 years
• Most studies (particularly global) under COWCLIP auspices.
• COWCLIP-2 global projections ensemble is much larger than COWCLIP-1:
  • Increased robustness
  • Can now resolve differences between scenarios and GCMs
Considerable increase of future wave climate studies (global and regional) in last 8-10 years

Most studies (particularly global) under COWCLIP auspices.

COWCLIP-2 global projections ensemble is much larger than COWCLIP-1:
  - Increased robustness
  - Can now resolve differences between scenarios and GCMs

Challenges ahead:
  - Mid 21st century dynamical projections
  - Regional coverage (global south vulnerable areas)
  - Coupled ocean-waves-atmosphere climate models
  - Integrated sea-level, surge, wave climate assessments
  - Bias correction
Existing mid 21st century wave climate projections are regional or statistical.

Morim et al. 2018a
Different rates of change in 21st century

Lemos & Semedo et al. (2018)
In press in GLOPLACHA