Statistical Reconstruction and Projection of Ocean Waves

Xiaolan L. Wang, Val R. Swail, and Y. Feng

Climate Research Division, Science and Technology Branch, Environment Canada

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Outline

- Methodologies and Datasets
- Some characteristics of the observed SWH-SLP relationships
- Preliminary results on North Atlantic wave height trends over 1871-2008 (138 yr)
- Preliminary results on changes as projected in CMIP5 simulations
- Ongoing/future work
Methodologies

Statistical “downscaling” \( \leftrightarrow \) use an observed predictor-predictand relationship

- Conventional linear and quantile regressions \( \rightarrow \) means, extremes
  
  (both need high resolution data for extremes)

- Extreme value (EV) model with covariates (predictors) \( \rightarrow \) extremes

  Both the location and scale parameters vary with the predictors?

In order to diminish climate model biases:

- Use normalized predictor quantities in statistical downscaling

  \( P_t \) – normalized anomalies of seasonal mean SLP

  \( G_t \) – normalized anomalies of seasonal mean squared SLP gradient

  (geo-wind energy index)

- Use a quantile-matching algorithm to adjust (CMIP5) model simulated predictor values, so that the adjusted simulations for a baseline period share the same distribution as the corresponding observations (reanalysis data).
Datasets

1. ERA40 SLP – predictors
2. ERA40 waves (SWH) - predictand
   - different statistical downscaling methods
     e.g., linear regression versus Quantile regression
   - different temporal resolutions, e.g., seasonal versus 6-hourly

Important - find good predictors that are also well simulated by climate models!

3. Predictors from 6-hourly SLP of 20CRv2, The 20th Century Reanalysis (56 runs)
   → the relationships → to reconstruct the past (1871-2008) wave climate
   - temporal homogeneity issues, homogenization - ongoing
   - basically homogeneous for the North Atlantic – focus of this presentation

4. Predictors from CMIP5 model simulations
   → the relationships → to project future wave climates
For extremes, scale is also varying with the covariates in a large portion of the oceans

Compare **EV1**: only location par. varies with the predictors, but scale & shape are constant
with **EV2**: both location & scale par’s vary with the predictors, but shape is constant

**EV0**: parameters are not significantly related to the predictors (EV1 is used)

Potential technical problem: very difficult to estimate an EV model with varying scale!
Alternative: use high resolution data (e.g., 3 or 6 hourly data) to project extremes

Also, need to find better predictors for the tropics (the grey areas).
New: use **6-hourly** data to calibrate predictand-predictors relationships

Using **ERA40**

- 6-hourly SLP on 2°x2° lat-lon grid
- 6-hourly Hs on 1.5°x1.5° lat-lon grid

for 1981-2000 (baseline period)

Will also use **ERA-Interim**

- 6-hourly SLP on 2°x2° lat-lon grid
- 6-hourly Hs on 0.7°x0.7° lat-lon grid

for 1981-2000

Calibrate a linear regression $H_t \sim (P_t, G_t)$ relationship for each season separately.

Evaluate the models that are calibrated from data in a calibration period with data in an evaluation period that does not overlap with the calibration period, e.g.,

- calibration: ERA40 for 1981-2000
- evaluation: ERA40 for 1958-1977

allows us to check statistical models’ time-transferability
Anomaly correlation skill scores

Lower skill in the lower latitudes, especially in the cold seasons (JFM, OND)
The statistical model overestimates the wave height climate, especially in high latitudes in winter. It overestimates mainly the low quantiles of wave heights, for example.
It systematically over-predicts wave heights that are below 2 m, but under-predicts the extremes.

To improve model skill:

Will explore new models, such as quantile regression

– different predictor-predictand relationships for different quantiles (e.g, one for the lowest 10%, one for 10-20%, ..., and one for 90-100%, respectively.)

Will add a few predictors that can represent swell components.
Reconstructed 1871-2008 trends in wave heights

For now, just show trends in the North Atlantic, in which 20CR is homogeneous; it suffers from inhomogeneity in other basins.
The 1871-2008 trends in seasonal **mean** SWH in the North Atlantic (↔ 6-hourly relationships)

- **JFM – H_mean**
- **AMJ – H_mean**
- **JAS – H_mean**
- **OND – H_mean**

**Yellow:**
**Cyan:**
**Contours:** linear trends

**Crosses:** location of significant (at least 5%) linear trends  
**grid-hatching:** locations of significant quadratic trends
Trends from 6-hourly relationships

JFM – $H_{\text{mean}}$

Yellow:

Cyan:

Contours: linear trends

Crosses: location of significant (at least 5%) linear trends

Trends from seasonal relationships

JFM – $H_{\text{mean}}$

Yellow:

Cyan:

Contours: linear trends

grid-hatching: locations of significant quadratic trends

JAS – $H_{\text{mean}}$

JAS – $H_{\text{mean}}$
The 1871-2008 trends in seasonal max SWH in the North Atlantic (6-hourly relationships)

- JFM – H_max
- AMJ – H_max
- JAS – H_max
- OND – H_max

Yellow: Crosses: location of significant (at least 5%) linear trends
Cyan: grid-hatching: locations of significant quadratic trends

Contours: linear trends
Examples of changes in the distribution of JFM seasonal maximal significant wave heights (from seasonal GEV relationships)

A 20-yr event has become a 14-yr event during the past century. The increase is mainly in the last 30 years.
Examples of changes in the distribution of JFM seasonal maximal significant wave heights
(from seasonal GEV relationships)

A 20-yr event has become a 17-yr event during the past century. The increase is mainly in the last 30 years.
Examples of changes in the **distribution** of JFM seasonal maximal significant wave heights (from seasonal GEV relationships)

There seems to be a significant decrease in the early decades but no trend since early 20C.
Trends in wave heights as downscaled from the CanESM2 simulations

- historical simulations for 1941-2005 (5 ensemble members)
- RCP 2.6 simulations for 2006-2100 (95 yrs)
- RCP 4.5 simulations for 2006-2100 (95 yrs)
- RCP 8.5 simulations for 2006-2100 (95 yrs)
CanESM2 simulated trends in JFM mean wave heights

Crosses: location of significant (at least 5%) linear trends
grid-hatching: locations of significant quadratic trends

20CR (1941-2005)

RCP 4.5 (1941-2100) 160 yrs

Opposite trends

historical (1941-2005)

RCP 8.5 (1941-2100) 160 yrs

Crosses: location of significant (at least 5%) linear trends
grid-hatching: locations of significant quadratic trends
CanESM2 simulated trends in JAS mean wave heights

Opposite trends

Crosses: location of significant (at least 5%) linear trends
grid-hatching: locations of significant quadratic trends

Single model projections can be unreliable, need multi-model projections:
multiple climate models + multiple “downscaling” methods for waves
→ COWCLIP

Histori

20CR (1941-2005)

RCP 4.5 (1941-2100)
160 yrs

RCP 8.5 (1941-2100)
160 yrs
Ongoing/future work

- Develop, apply, and evaluate different statistical downscaling methods - ongoing

- Reconstruct the 1871-2008 global wave climate using the 20CRv2 SLP - ongoing

- Characterize global wave climate trends over the 138-year period since 1871, with temporal homogeneity assessment

- Conduct statistical projections of global wave climate using CMIP5 simulations

- Analyze the COWCliP wave projections to characterize climate change signal and various uncertainty associated with wave climate change projections

Thank you very much!