Hybrid Approach for the Assessment of Changes of Extreme Waves at the German Baltic Sea Coast on the Basis of Regional Climate Model Data

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I. Effects of climate change → wave climate, sediment transport
II. Effectiveness and safety of structures
III. Strategies, methods and local adaptation measures
Constructional/Functional Design of Coastal and Flood Protection

Fig.: Water depth (top) and significant wave heights (bottom), Warnemünde Germany (University of Rostock)

<table>
<thead>
<tr>
<th>Actual condit.</th>
<th>Future condit.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$H_{s,200}$</td>
<td>3.66m</td>
</tr>
<tr>
<td>$T_{m02}$</td>
<td>6.23s</td>
</tr>
<tr>
<td>$\Theta_m$</td>
<td>0°</td>
</tr>
</tbody>
</table>

Combination with scenarios of future storm surge levels $HW_{200} + \Delta W(SLR)$
Wind-wave-correlations = statistical correlations from measurements of waves and wind [Fröhle & Fittschen 1999; Fröhle 2000]

Numerical simulations: stationary runs of SWAN wave model [Booij et al., 1999]

4 Long-term time series of hourly near-surface wind velocity and direction (1960-2100) C20 + SRES scenarios A1B, B1 (2x)

Statistical analyses: changes of average wave conditions & extreme events

RCM: Cosmo-CLM*

4 Long-term time series of hourly significant wave heights, mean wave periods and mean wave directions (1960-2100)

Note: all calculations at MSL (deep water conditions)

* [Rockel et al., 2008], [Lautenschlager et al., 2009] [Nakićenović et al., 2000]
Short-Term Measurements of Wind and Wave Conditions

depth=10m, ca. 1km off the coast at quasi deep water conditions
Comparison of Calculated and Observed Wave Parameters (WWC)

<table>
<thead>
<tr>
<th>∆H m0</th>
<th>∆T m02</th>
<th>∆Θ m</th>
</tr>
</thead>
<tbody>
<tr>
<td>[m]</td>
<td>[s]</td>
<td>[°]</td>
</tr>
<tr>
<td>Warnemünde</td>
<td>0.10473</td>
<td>0.44819</td>
</tr>
<tr>
<td>Travemünde</td>
<td>0.08785</td>
<td>0.45050</td>
</tr>
<tr>
<td>Westermarkelsdorf</td>
<td>0.07481</td>
<td>0.21654</td>
</tr>
</tbody>
</table>

**Mean absolute deviations**

![Graphs showing comparison of calculated and observed wave parameters](image-url)
Limitation of Wind-Wave-Correlations

<table>
<thead>
<tr>
<th>Area</th>
<th>Deviation 10%</th>
<th>7.5%</th>
<th>5%</th>
<th>2.5%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Schönhagen</td>
<td>0.75 $U_{\text{max}}$</td>
<td>0.81 $U_{\text{max}}$</td>
<td>0.86 $U_{\text{max}}$</td>
<td>0.93 $U_{\text{max}}$</td>
</tr>
<tr>
<td>Heiligenhafen</td>
<td>0.76 $U_{\text{max}}$</td>
<td>0.81 $U_{\text{max}}$</td>
<td>0.86 $U_{\text{max}}$</td>
<td>0.95 $U_{\text{max}}$</td>
</tr>
<tr>
<td>Brodten</td>
<td>0.76 $U_{\text{max}}$</td>
<td>0.81 $U_{\text{max}}$</td>
<td>0.91 $U_{\text{max}}$</td>
<td>0.97 $U_{\text{max}}$</td>
</tr>
</tbody>
</table>

$U_{\text{cut,0.05}} \leq 1/(0.86 \times U_{\text{max}}) = 1.16 \times U_{\text{max}}$

[Fröhle & Fittschen, 1999]
Numerical Simulations

Maximum wind speed for CLM run A1B_2 (2001-2100) and cut off wind speed for 5% error margin and measurement period (1996, 1998-1999), location Warnemünde

Cut off wind speed

stationary mode and constant wind field over the area
resolution of wind boundary: $\Delta U_{10}=1\text{m/s}$, $\Delta \Theta_{w}=10^\circ$
Comparison of Calculated Long-Term Time Series of Wave Heights

Wind-Wave-Correlation

Hybrid Approach
Statistical Analyses of Changes of Extreme Wave Heights

(1) Sample Selection: annual maximum values, time periods of 40 years, 4 long-term time series of wave heights

(2) Fitting: Extreme Value Distributions (EVDs) Gumbel, Weibull, Log-Normal and GEV using MLE (Maximum Likelihood Estimate)

(3) Goodness of fit-tests (comparison of empirical & theoretical CDF) → Log-Normal = best

(4) Relative change of significant wave heights (return-level 200 years)

C20: control period (C20_1, C20_2)  S1: scenario 2040 (A1B_1, A1B_2, B1_1, B1_2)  S61: scenario 2100 (A1B_1, A1B_2, B1_1, B1_2)
Results: Change of Significant Wave Height (40yr, Log-Normal, RL=200)

3 different signals of change depending on the location and scenario run!
Comparison With Results from Other Studies

Changes of the wave climate for the whole Baltic Sea from Groll, Hünicke and Weisse (HZG, 2013)

→ WAM* (5.5km, 1hr) 1960-2100, Cosmo-CLM: C20, A1B, B1 (2x) [Hasselmann et al., 1988]

Fig. Changes of annual maxima of significant wave height 2071-2100 vs. 1961-1990 for 1st realisation of A1B and B1 [Groll, Hünicke and Weisse, 2013]
Comparison With Results from Other Studies

Fig. Changes of annual maxima of significant wave height 2071-2100 vs. 1961-1990 for 2\textsuperscript{nd} realisation of A1B and B1 [Groll, Hühnicke and Weisse, 2013]

No comparison of trend possible: different parameter of the wave climate (Hmax), reference period (1961-1990) and offshore wave conditions!
Constructional/Functional Design of Coastal and Flood Protection

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Water Levels</th>
<th>Wave Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>„Moderate“</td>
<td>+ 30 cm</td>
<td>No Significant Changes</td>
</tr>
<tr>
<td>„Average“</td>
<td>+ 60 cm</td>
<td>Hs,200 + 3 % = 3.77m; Tm02 = 6.32s; Dir=0°</td>
</tr>
<tr>
<td>„High“</td>
<td>+ 90 cm</td>
<td>Hs,200 + 7 % = 3.92m; Tm02 = 6.44s; Dir=0°</td>
</tr>
</tbody>
</table>

2009:
Hs,200 = 3.66m
Tm02 = 6.23s
Dir=0°
Summary and Outlook

Results:
• Four long-term time series (1960-2100) of wave parameters for different locations and climate change scenarios A1Bx2, B1x2 (RCM Cosmo-CLM) at the German Baltic Sea Coast
• Different signal of change/trend depending on location and scenario run
• Changes of sign. wave height up to +14% → different loads on coastal structures

Pros and Cons:
+ Fast in comparison with instationary numerical simulations 1960-2100
+ Timeseries are applicable for EVA
  - Wind and wave measurements
  - Uncertainty of stationary numerical simulation

Next Steps:
EVA of time series from instationary numerical simulations for the Western Baltic Sea → SWAN* (1km, 1hr) 1960-2100, Cosmo-CLM: C20, A1B, B1 (2x)

*[Booij et al., 1999]
Questions/Remarks?
References


Fröhle, P., Fittschen T. 1999. Assessment of short-term directional wave measurements with respect to long-term statistical evaluations. Proc. 5th Int. Conf. on Coastal and Port Engineering in Developing Countries (COPEDEC V), (Cape Town, South Africa), 1005-1016.


Lautenschlager, Michael; Keuler, Klaus; Wunram, Claudia; Keup-Thiel, Elke; Schubert, Martina; Will, Andreas; Rockel, Burkhardt; Boehm, Uwe 2009; Climate Simulation with CLM, Climate of the 20th Century run no.1-3, Scenario A1B run no.1-2, Scenario B1 run no.1-2 , Data Stream 3: European region MPI-M/MaD. World Data Center for Climate
