Climate change effects on waves in UK waters

Judith Wolf
Overview

• Definition of wave climate
• What can and can’t be learned from models
• What is storminess?
• Some results
• Effect of climate change via SLR and storminess on coastal wave climate and impacts (over to you Terry!)
• Conclusions
What is wave climate?

- Wave climate is usually described by the probability of occurrence of a range of wave parameters especially height, period and direction, but also others e.g. frequency bandwidth.

- The wave climate can be considered as consisting of three parts: the long term mean climate, the annual or seasonal cycle and non-seasonal variability on both intra-annual and inter-annual time-scales.

- In UK waters, wave climate is strongly seasonal with mean wave heights peaking around January, but with a high risk of both high monthly mean wave heights and extreme wave heights throughout autumn and winter (October to March). There is also high inter-annual variability in monthly mean wave heights.
Summary of changes and trends in wave height in UK waters (IACMST 2004)

- Wave data from ships and buoys indicate that the mean winter wave height in the northeast Atlantic increased significantly between the 1960s and 1980s. Satellite data confirm that this increase continued into the early 1990s.
- In the northern North Sea, there was an upward trend of about 5-10% (0.2-0.3m) in mean significant wave height (Hs) for January–March for the period 1973-1995, but a decrease thereafter.
- In the central North Sea, the trend for January–March was upwards until 1993/94, with a decrease thereafter. The October–December Hs peaked around 1982/83 and 1983/84, with a similar high value in 1999/2000.
- In the southern North Sea, there is no discernible trend in Hs for January–March and only a slight indication of a downward trend in Hs for October–December from 1980/81.
- At Sevenstones LV, off Land’s End, the acceptable value is an increase of 0.02 m/yr in mean wave height over a period of about 25 years. This trend seems to have persisted into the early 1990s at least, although recent winters have suggested a levelling off.
Decadal variability and the NAO

NAO (DJFM) Index 1964-2007

Yearly data
10-year running mean
8-year running mean
POSITIVE PHASE OF NAO AND NAM (from IPCC AR4)

NAO = North Atlantic Oscillation

NAM = Northern Annular Mode

Both modes are associated with strengthening of westerly winds.
What can we learn from models (and what can’t we)?

- When models can be validated against observed data we can use them to help understand the relative importance of different processes
- Model reanalyses e.g. ERA40, going back over decades, are very useful to give a consistent long-term reconstruction
- Climate models reproduce some aspects of decadal variability quite well but the recent positive phase of the NAO was larger than the variability of the model system (Tim Osborn)

BUT

- Model resolution is limited e.g. global models cannot resolve storms properly
- Models omit processes we don’t know about
- Remember GIGO
- We may learn more when models don’t work!
CS3 (12km) model wave climate 2000-2004 – Met Office mesoscale model forcing
Validation – northern North Sea, Jan 2003
Extreme waves

1-Year Return Period (2000-2004)

5-Year Return Period (2000-2004)


Seasonal variation of wave height, period and bottom stress
Storminess

- Storminess may be defined as the number of wind events exceeding a certain threshold e.g. gale force
- Proxies need to be used to derive long time series e.g. pressure and sea level
- Models of future climate suggest there may be fewer but more intense storms, with storm tracks moving poleward – is this increased storminess?
- What is the role of decadal cycles – just a red herring?
- Recent positive phase of NAO happened to coincide with most intensive observations ever (including satellite data), also increasing concern about global warming
- We really need to better understand the natural variability of the ocean-atmosphere system
Future changes in the frequency of winter mid-latitude storms (from Macdonald)

<table>
<thead>
<tr>
<th>Reference</th>
<th>Model</th>
<th>Experiments</th>
<th>NH Change</th>
<th>SH Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carnell and Senior 1998</td>
<td>HadCM2 N48</td>
<td>IS95a 3x30y</td>
<td>Fewer</td>
<td></td>
</tr>
<tr>
<td>Geng and Sugi 2003</td>
<td>JMA T106</td>
<td>20y OBS 2050s</td>
<td>Fewer Poleward and eastward</td>
<td>Fewer</td>
</tr>
<tr>
<td>Fyfe 2003</td>
<td>CCCma</td>
<td>3xIS92a 500y Ctrl</td>
<td>Sub-Antarctic 30% fewer</td>
<td></td>
</tr>
<tr>
<td>Lambert and Fyfe 2006</td>
<td>IPCC 4AR GCMs</td>
<td>20y</td>
<td>Fewer</td>
<td>Fewer</td>
</tr>
<tr>
<td>Watterson 2006</td>
<td>CSIRO Mk2 R21,</td>
<td>30y A2</td>
<td>Fewer</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mk3 T63</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bengtsson et al. 2006</td>
<td>ECHAM5 OM T63</td>
<td>3x30y A1B</td>
<td>No change Poleward shift</td>
<td>No change Poleward shift</td>
</tr>
</tbody>
</table>

Summary: There are fewer mid-latitude storms in winter in both hemispheres in the future simulations.
Future changes in the frequency of intense Northern Hemisphere winter mid-latitude storms (from Macdonald)

<table>
<thead>
<tr>
<th>Reference</th>
<th>Model</th>
<th>Experiment</th>
<th>Intensity measure</th>
<th>Change in frequency of intense cyclones</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carnell and Senior 1998</td>
<td>HadCM2 N48</td>
<td>IS95a 3x30y</td>
<td>Central MSL pressure</td>
<td>More intense</td>
</tr>
<tr>
<td>Geng and Sugi 2003</td>
<td>JMA T106</td>
<td>20y OBS, 2050s</td>
<td>Central MSL pressure gradient</td>
<td>More intense</td>
</tr>
<tr>
<td>Lambert 2004</td>
<td>CGCM1 CGCM2</td>
<td>1% 1850-2100</td>
<td>Central MSL pressure</td>
<td>More intense</td>
</tr>
<tr>
<td>Watterson 2006</td>
<td>Mk2 R21, Mk3 T63</td>
<td>A2</td>
<td>Measures &amp; precipitation</td>
<td>Dynamical intensity, more precipitation</td>
</tr>
<tr>
<td>Lambert and Fyfe 2006</td>
<td>IPCC 4AR GCMs</td>
<td>20y</td>
<td>Central MSL pressure</td>
<td>More intense</td>
</tr>
<tr>
<td>Bengtsson et al. 2006</td>
<td>ECHAM 5 OM T63</td>
<td>3x30y A1B</td>
<td>Central Relative vorticity</td>
<td>Fewer weak</td>
</tr>
</tbody>
</table>

Summary: There is some evidence of an increase in the frequency of the deepest storms in the future simulations.
Results – ongoing projects

• Tyndall wave climate modelling for Coastal Simulator
  – 30y time slices, 1960-1990, 2070-2100
  – Nested wave models (Atlantic to CS3), downscaling from OGCM to RCM
  – 3 scenarios from UKCIP02 (A2 and B2) and UKCIP08 (ensemble extremes)

• COFEE (NERC FREE programme)
  – Surge and wave modelling of Liverpool Bay
  – Application to coastal evolution of the Sefton coast
Integrated Modelling For Coastal Impacts: The Tyndall Coastal Simulator
CoFEE - Coastal Flooding by Extreme Events

- **Aim** – to assess present and future flood risk in a range of environments
- **Study area** – eastern Irish Sea/Liverpool Bay – cell 11a – Great Orme’s Head to Ribble Estuary, with particular focus on Sefton coast
- **Extensive field data** to calibrate, validate and verify predictions from numerical models (POLCOMS/WAM/SWAN)
- **Personnel**: PI Jon Williams (U Plym), Andy Plater (UoL), Alex Souza, Judith Wolf, Roger Proctor, Jenny Brown (POL), Graham Lymbery Sefton BC), Annie Worsley (Edge Hill)
Overview of processes

- **Natural forcing**
  - Wind
  - Waves
  - Mean sea level
  - Tides
  - Runoff

- **Rate and extent of coastal flooding**
  - Offshore wave climate
  - Nearshore wave climate
  - Water level
  - Tidal prism

- **Bathymetry/Topography**

- **Sediment transport**

- **Controls**
  - Geology/geomorphology
  - Offshore sediment availability
  - Fluvial sediment availability

The diagram illustrates the influence of natural forcing factors on the rate and extent of coastal flooding. Each factor is connected to the others, showing how they interact and contribute to the overall process.
Flood risk and preliminary wave model results – 20m/s NW wind

EA flood risk map

Wave setup

Bottom dissipation
Waves in Liverpool Bay

PDF of Liverpool Bay wave height 2003-6

Weibull pdf for Liverpool Bay wave data
Conclusions

• Wave models are quite accurate in general, main limitation is accuracy of the wind forcing

• There is a lack of long-term wave observations, need to understand storm climate, interannual variability

• Impacts of waves include coastal flooding and erosion – present-day ‘extreme’ events may become more commonplace, just due to sea level rise

• Future climate – still more questions than answers?
1953 storm waves
1953 storm surge – Sea Palling
Coastal erosion at Happisburgh