IMPACTS OF CLIMATE CHANGE ON STORMS AND WAVES

David Woolf [1,2] & John Coll [1]

[1] Environmental Research Institute, North Highland College, Thurso

[2] National Oceanography Centre, Southampton

Executive Summary

There is strong evidence for increased wave heights in western and northern UK territorial waters and for increased occurrence of strong winds over the UK from the 1960s to the present. It is unclear whether recent behaviour is driven by "global climate change" or is simply natural variation and whether substantial changes in storminess are likely in the 21st century. Bacon and Carter (1991) inferred an increase in mean wave height of about 2% per year "over the whole of the North Atlantic in recent years, possibly since 1950" from observational data notably from Seven Stones Light Vessel (1962-1986). Recent analyses of a more extensive data set confirm a significant upward trend in wave heights in the North Atlantic, but only for the last 50 years and embedded within a pattern of multi-decadal variability over more than a century (Gulev and Hasse, 1999; Gulev and Grigorieva, 2004). There have also been significantly more severe storms over the UK since the 1950s (Alexander *et al.*, 2005). However, trends in winds around the UK are much weaker than for wave heights, and therefore most of the increase in wave heights is attributed to "swell" rather than "wind sea".

Changes in winds and waves can be better understood by considering their relationship to atmospheric pressure gradients (Bacon and Carter, 1993) and particularly to large-scale atmospheric variability such as the North Atlantic Oscillation (NAO). Wave heights in the North-East Atlantic and northern North Sea are known (from analysis of *in situ* data, satellite data and model reconstructions) to respond strongly and systematically to the NAO (e.g. Woolf *et al.*, 2002 and 2003). Other parameters - such as cyclone activity (Gulev *et al.*, 2001) and the number of "gale days" at coastal sites in Scotland - show a weaker, but still significant response to NAO. Thus, many of the changes over the last 50 years can be understood in terms of the behaviour of the NAO. The recent strong trend in the NAO (towards stormier conditions) is apparently unique in its history, but it is controversial whether this is a response to greenhouse gas forcing (Osborn, 2004). Many Global Climate Models suggest a general trend towards the stormier tendency of NAO in the 21st century (e.g. Terray *et al.*, 2004). If so, worsening wind and wave conditions in the wintertime in western and northern UK waters are inevitable (Tsimplis *et al.*, 2005; Wolf and Woolf, 2006). However, alternative analyses primarily based on Regional Climate Models suggest different and mostly weaker changes in winds and storminess (e.g. Hulme *et al.*, 2002; Barnett *et al.*, 2006).

Level of Confidence

High (changes have occurred over the last 50 years).

There is a lot of data, and the agreement between data sources is high (noting that some parameters are more sensitive than others to change)

Low (changes will occur in the future).

There is a moderate amount of model output, but the agreement is low

Key sources of Information

See supporting evidence

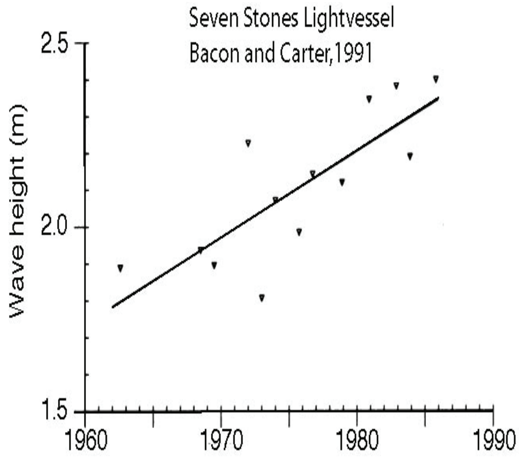
Supporting Evidence

DATA SOURCES

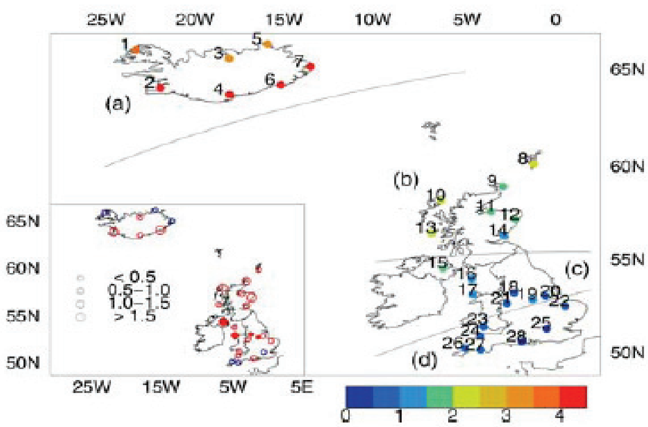
In the context of marine climate, storminess can be measured in terms of statistics of wind speeds and wave heights at, near and offshore of the coast. Adequate information on offshore marine winds and waves exist for the last twenty years, primarily through data from satellite-borne instruments (especially radar altimeters and scatterometers). Data are also available over a similar history from a few offshore sites (notably associated with the North Sea oil industry), near shore sites and wind and other meteorological measurements from coastal UK Met Office stations. Gale day frequency at coastal sites is a useful proxy for more stormy conditions and some long (~ 100 year) time series are available. UK Met Office (and also MetEireann in Ireland) have also established meteorological data buoys (that include wave height and period as standard observations) at a number of sites, mainly to the west of the UK in the last decade. Recently, near shore wave data provision has improved rapidly through national (WAVENET) and local (e.g. Channel Coastal Observatory) initiatives. For previous decades, up to sixty years from present, observational data are available through the Ocean Weather Station network (though this was partly dismantled in the 1970s and 1980s) and a few other sources. These scattered data are supplemented by comprehensive output from “reanalysis projects” of Numerical Weather Service products covering a similar time period. For the first half of the century, only voluntary observing ships provide a substantial source of data (Gulev and Grigorieva, 2004).

OBSERVATIONS

Bacon and Carter (1991) inferred an increase in mean wave height of about 2% per year "over the whole of the North Atlantic in recent years, possibly since 1950" from observational data notably from Seven Stones Light Vessel (1962-1986).



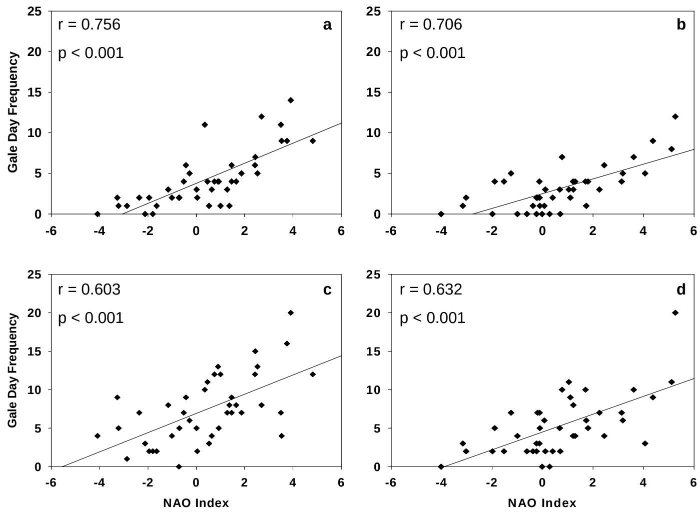
Recent analyses of a more extensive data set confirm a significant upward trend in wave heights in the North Atlantic, but only for the last 50 years and embedded within a pattern of multi-decadal variability over more than a century (Gulev and Hasse, 1999; Gulev and Grigorieva, 2004). Gale day frequency shows a complex history with no clear trend but much decadal variability through the twentieth century. There also have been significantly more severe storms over the UK since the 1950s (Alexander *et al.,* 2005).



From Alexander *et al*. (2005). The annual average number of severe storms at stations used in the analysis. The inset shows the linear trends (red positive; blue negative) in the number of severe storms over the period of record and filled circles indicate where trends are significant.

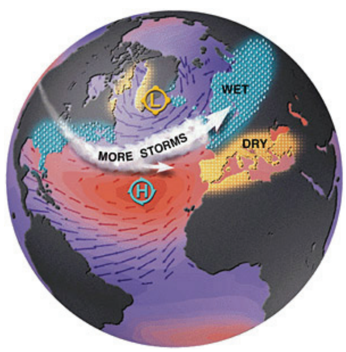
Trends in winds around the UK are much weaker than for wave heights, and therefore most of the increase in wave heights is attributed to "swell" rather than "wind sea".

Changes in winds and waves can be better understood by considering their relationship to atmospheric pressure gradients (Bacon and Carter, 1993) and particularly to large-scale atmospheric variability such as the North Atlantic Oscillation (NAO). Wave heights in the North East Atlantic and northern North Sea are known (from analysis of *in situ* data, satellite data and model reconstructions) to respond strongly and systematically to the NAO (e.g. Woolf *et al.*, 2002 and 2003). Other parameters - such as cyclone activity (Gulev *et al.*, 2001) and the number of "gale days" at coastal sites in Scotland - show a weaker, but still significant response to NAO. Gale day frequency over the last few decades at west Scotland sites is significantly correlated to NAO, with greater frequency in NAO + winters associated with an increased frequency of easterly tracking depressions across the region.

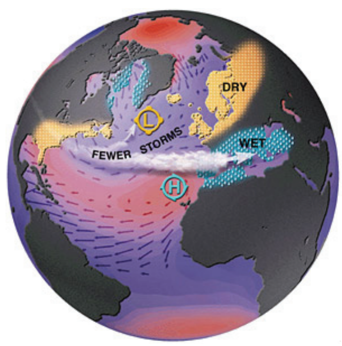


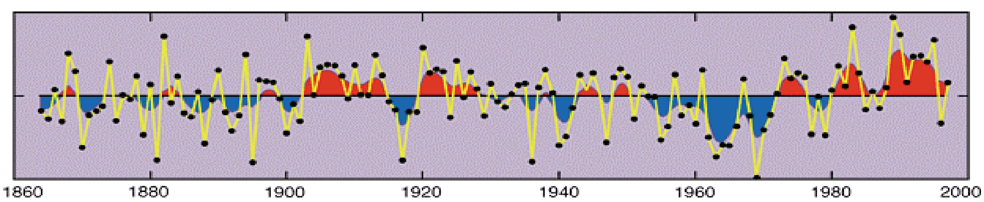
Gale day frequencies versus monthly NAO Index (1960-2000). More positive values for the NAO are significantly associated with a greater frequency of gale days. Datasets are from (a) Stornoway, Isle of Lewis, Outer Hebrides (January); (b) Stornoway, February; (c) Tiree, Coll, Inner Hebrides, January; (d) Tiree, February.

High Index:



Low Index:





High Index NAO (More storms) and Low Index (Fewer storms) from:
http://www.jason.oceanobs.com/html/applications/climat/nao_explication_uk.html

Thus, many of the changes over the last 50 years can be understood in terms of the behaviour of the NAO. The recent strong trend in the NAO (towards stormier conditions) is apparently unique in its history, but it is controversial whether this is a response to greenhouse gas forcing (Osborn, 2004).

PREDICTIONS

Many Global Climate Models suggest a general trend towards the stormier tendency of NAO in the 21st century (e.g. Terray *et al.*, 2004; Kuzmina *et al*., 2005). If so, worsening wind and wave conditions in the wintertime in western and northern UK waters are inevitable (Wang et al., 2004; Tsimplis et al., 2005; Wolf and Woolf, 2006). However, alternative analyses primarily based on Regional Climate Models (RCMs) suggest different and mostly weaker changes in winds and storminess (e.g. Hulme *et al*., 2002; Hanson *et al*., 2004; Lozano *et al.*, 2004; Barnett *et al*., 2006; Leckebusch *et al.*, 2006).

Factors related to the wind such as storminess and roughness of the sea are recognised to be very difficult to predict within climate change scenarios, with present confidence in GCM and RCM modelled windfield changes remaining low (Hulme *et al*., 2002). Downscaling *via* general structural changes in the atmosphere (such as shifts in NAO) may be more suitable for “storminess” than analysing winds in RCMs. Given that preference, the shift to stormy conditions suggested by Terray *et al*. (2004) and others should carry more weight than the contrary results from RCMs, but it is debatable.

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References

Alexander, L.V., Tett, S.F.B. and Jonsson, T. 2005. Recent observed changes in severe storms over the United Kingdom and Iceland. *Geophysical Research Letters*, 32, L13704, doi:10.1029/2005GL022371.

Bacon, S. and Carter, D.J.T. , 1991. Wave climate changes in the North Atlantic and North Sea. *International Journal of Climatology*, 11, 545-558.

Bacon, S. and D.J.T. Carter. 1993. A connection between mean wave height and atmospheric pressure gradient in the North Atlantic. *International Journal of Climatology*, 13, 423-436.

Barnett, C., J. Hossell, M. and Perry, C. Procter and G. Hughes. 2006. *Patterns of climate change across Scotland: Technical Report*. SNIFFER Project CC03, Scotland & Northern Island Forum for Environmental Research, 102pp.

Hulme, M., G.J. Jenkins, X. Lu, J.R. Turnpenny, T.D. Mitchell, R.G. Jones, J. Lowe, J.M. Murphy, D. Hassell, P. Boorman, R. McDonald and S. Hill. 2002. *Climate Change Scenarios for the United Kingdom: The UKCIP02 Scientific Report*. Tyndall Centre, UEA, Norwich, April 2002.

Gulev, S.K. and V. Grigorieva. 2004. Last century changes in ocean wind wave height from global visual wave data. *Geophysical Research Letters*, 31, L24302, doi:10.1029/2004GL021040.

Gulev, S.K. and L. Hasse. 1999. Changes of wind waves in the North Atlantic over the last 30 years. International Journal of Climatology. 19, 1091-1117. doi:10.1002/(SICI)1097-0088(199908)19:10<1091::AID-JOC403>3.0.CO;2-U

Gulev, S.K., O. Zolina and S. Grigoriev. 2001. Extratropical cyclone variability in the Northern Hemisphere winter from the NCEP/NCAR reanalysis data. *Climate Dynamics*, 17, 795-809.

Hanson, C. E., Holt, T., and Palutikof, J.P. 2004. An Integrated Assessment of the Potential for Change in Storm Activity over Europe: Implications for Insurance and Forestry in the UK. Norwich, Tyndall Centre for Climate Change Research, Final Technical Report IT1.4, 101pp.

Kuzmina, S. I., Bengtsson, L., Johannessen, O.M., Drange, H., Bobylev, L.P., and Miles, M.W. 2005.The North Atlantic Oscillation and greenhouse gas forcing. *Geophysical Research Letters,* 32, L04073.

Leckebusch, G. C., Koffi, B., Ulbrich, U., Pinto, J.G., Spangehl, T., Zacharias, S. 2006. Analysis of frequency and intensity of European winter storm events from a multi-model perspective, at synoptic and regional scales. *Climate Research*, 31, 59-74.

Lozano, I., Devoy, R.J.N., May, W., Andersen, U. 2004. Storminess and vulnerability along the Atlantic coastlines of Europe: analysis of storm records and of a greenhouse gases induced climate scenario. *Marine Geology* 210, 205-225.

Osborn, T. J.. 2004. Simulating the winter North Atlantic Oscillation: the roles of internal variability and greenhouse gas forcing. *Climate Dynamics,* 22, 605-623. doi:10.1007/s00382-004-0405-1

Terray, L. M.-E. Demory, M. Déqué, G. de Coetlogon and E. Maisonnave. 2004. Simulation of late-21st-century changes in wintertime atmospheric circulation over Europe due to anthropogenic causes. *Journal of Climate,* 17, 4630-4635.

Tsimplis, M.N., D.K. Woolf, T. Osborn, S. Wakelin, P. Woodworth, J. Wolf, R. Flather, D. Blackman, A.G.P. Shaw, F. Pert, P. Challenor and Z. Yan. 2005. Towards a vulnerability assessment of the UK and northern European coasts: the role of regional climate variability. *Philosophical Transactions: Mathematical, Physical & Engineering Sciences.* doi:10.1098/rsta.2005.1571.

Wang, X. L., Zwiers, F.W., and Swail, V.R. 2004. North Atlantic Ocean Wave Climate Change Scenarios for the 21st Century. *Journal of Climate* 17, 2368-2383.

Wolf, J. and D.K.Woolf. 2006. Waves and climate change in the north-east Atlantic. *Geophysical Research Letters*, 33, L06604, doi:10.1029/2005GL025113.

Woolf, D.K., P.G. Challenor and P.D. Cotton. 2002. The variability and predictability of North Atlantic wave climate. *Journal of Geophysical Research*, 107(C10), 3145, doi: 10.1029/2001JC001124.

Woolf, D.K., P.D. Cotton and P.G. Challenor. 2003. Measurements of the offshore wave climate around the British Isles by satellite altimeter. *Philosophical Transactions: Mathematical, Physical & Engineering Sciences*, 361(1802), 27-31, doi: 10.1098/rsta.2002.1103