Topic

Storms and Waves

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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 & 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 & Hasse, 1999; Gulev & 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. Most of the increase in wave heights is attributed to "**swell**" responding to changes in the persistence of westerly winds over the North Atlantic rather than "wind sea" responding to local winds.

Changes in winds and waves can be better understood by considering their relationship to **atmospheric pressure gradients** (Bacon & Carter, 1993) and particularly to large-scale atmospheric variability such as the **North Atlantic Oscillation (NAO)**. The characteristics of fluctuations in the westerly winds in the temperate northern hemisphere may also be described as an 'annular mode', the **Northern Annular Mode (NAM)** (Solomon *et al.*, 2007). Thus the increased mid-latitude westerlies in the North Atlantic can largely be viewed as reflecting either NAO or NAM changes (Solomon *et al.*, 2007).

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/NAM in the 21st century (e.g. Terray *et al*., 2004; Miller et al., 2006). However, alternative analyses primarily based on RCMs suggest different and mostly weaker changes in winds and storminess (e.g. Hulme *et al*., 2002; Barnett *et al*., 2006). Typically, climate models predict a decrease in the total number of **extra-tropical** cyclones but an increase in the number of intense events (Lambert & Fyfe, 2006). Either a strengthening of the storm track or an increase in intense cyclones will result in a deterioration of wave conditions (Wolf & Woolf, 2006). This is a likely outcome in the wintertime in western and northern UK waters (Tsimplis *et al*., 2005) but there can be only low confidence in this prediction.

Full Review

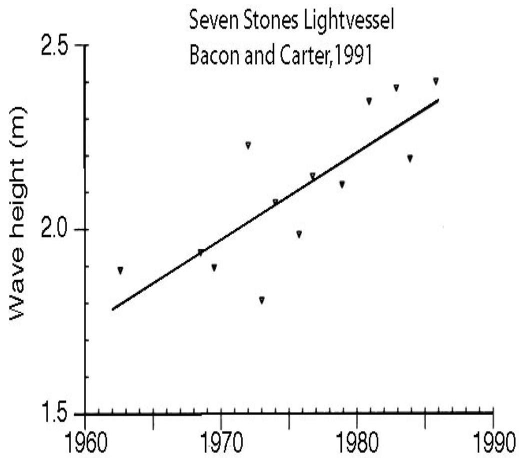
The United Kingdom lies at a **temperate latitude** where storms are associated with the most intense extra-tropical cyclones propagating across the North Atlantic along a storm track that can cross the UK or pass to the north or south. These storms can build very large seas in the North Atlantic that reach UK shores. Storm and wave climate variation is related to the strength and position of the storm track and to the number and intensity of cyclones.

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 & Grigorieva, 2004).

OBSERVATIONS

Bacon & 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 & Hasse, 1999; Gulev & 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).

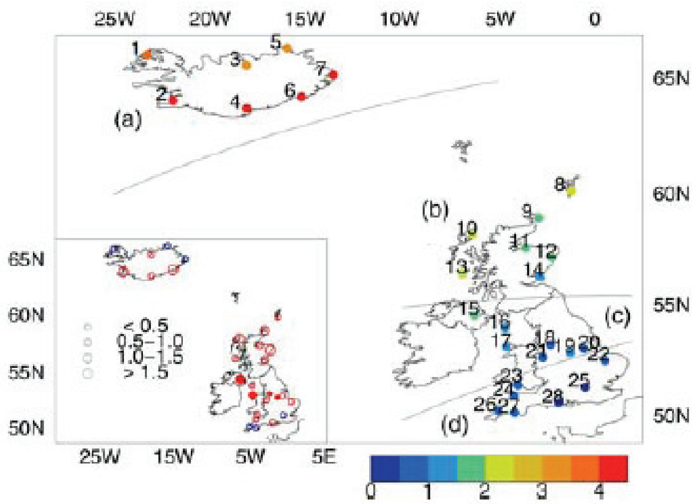


Figure 1. From Alexander *et al*. (2005). The annual average number of severe storms at stations used in the analysis. The inset shows the linear trends (red positive; blue negative) in the number of severe storms over the period of record and filled circles indicate where trends are significant.

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 & 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. Similarly, recent work incorporating an analysis for the directional component of wind indicates that the occurrence and frequency of strong south westerly winds over the extended winter period for sites around the Scottish coast are closely linked to the behaviour of the NAO (Corbel *et al.*, 2007).

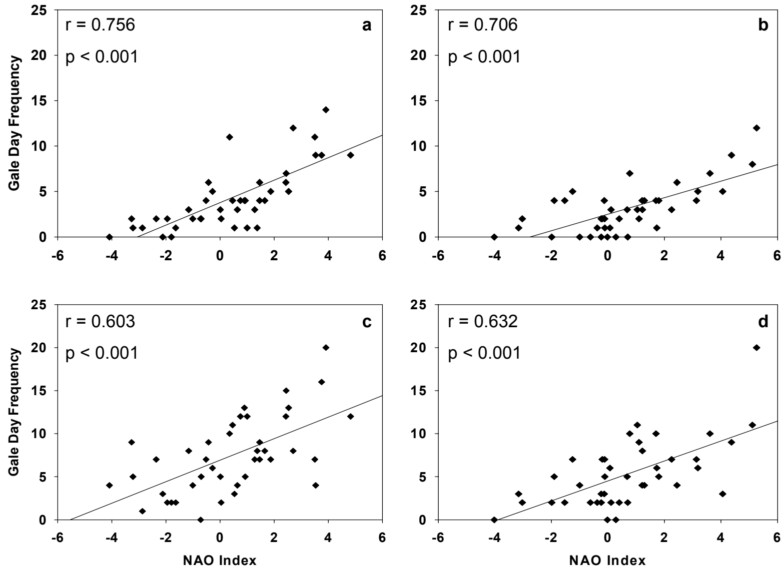


Figure 2. Gale day frequencies versus monthly NAO Index (1960-2000). More positive values for the NAO are significantly associated with a greater frequency of gale days. Datasets are from (a) Stornoway, Isle of Lewis, Outer Hebrides (January); (b) Stornoway, February; (c) Tiree, Coll, Inner Hebrides, January; (d) Tiree, February.

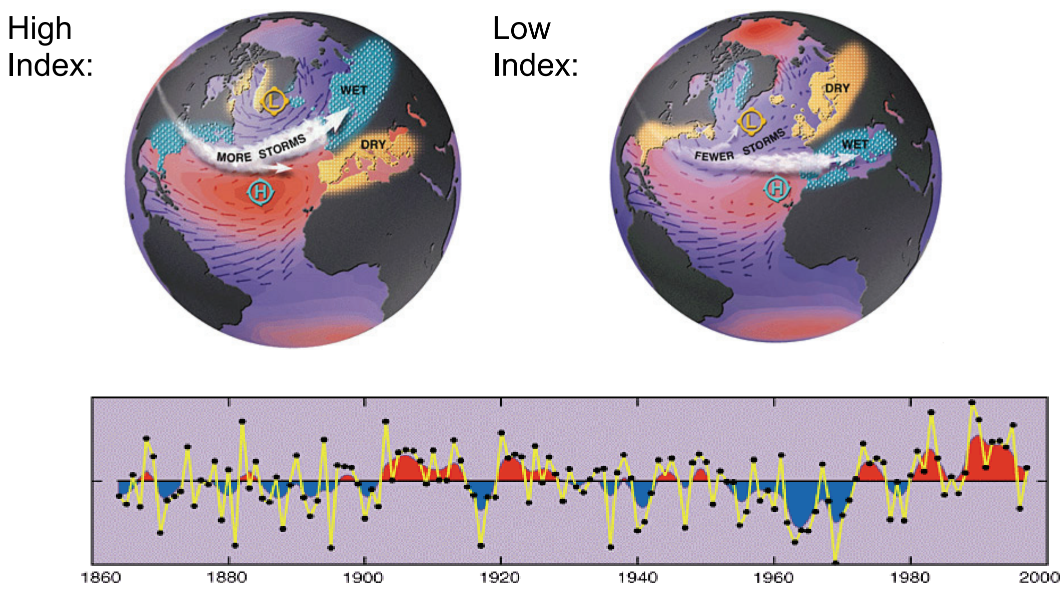


Figure 3. High Index NAO (More storms) and Low Index (Fewer storms) from: http://www.jason.oceanobs.com/html/applications/climat/nao_explication_uk.html

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

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 Global Climate Models (GCMs) and Regional Climate Models (RCMs) modelled wind field changes remaining low (Hulme *et al.*, 2002). However a large number of analyses have now been conducted. Some analyses have focussed on general features of the storm track (strength and position) and related changes in regional indices (NAO/NAM). Wolf & Woolf (2006) have shown the sensitivity of the wave climate to such changes. Other analyses have focussed on the number and intensity of extra-tropical cyclones. It is a feature of the analyses that different approaches suggest significantly different views of future storm climate.

Many GCMs suggest a general trend towards the stormier tendency of NAO/NAM in the 21st century (e.g. Terray *et al.*, 2004; Kuzmina *et al.*, 2005). Both a stronger storm track and a poleward displacement of that track are common features in studies of this kind (e.g., Miller et al., 2006).

Analyses primarily based on 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). An analysis of outputs from fifteen coupled GCMs forced by enhanced greenhouse warming experiments finds that there is a reduction in the total number of extra-tropical cyclones but an increase in the number of intense events (Lambert and Fyfe, 2006). With no apparent change in the geographical positions of the storm tracks, they conclude that there is no obvious shift in storm tracks associated with global warming (Lambert and Fyfe, 2006).

Downscaling *via* general structural changes in the atmosphere (such as shifts in NAO) may be more suitable for "storminess" than analysing winds in RCMs; not least since the resolution of GCM/RCM grid cells is too low to enable the reliable use of the resulting wind fields to directly force wave models and eventually obtain significant wave height (SWH) climate projections offline (Caires *et al*., 2006). 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 this is debatable. If the storm track does intensify, then 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 & Woolf, 2006).

Confidence Assessments

'What is already happening' - High (that 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)

'What could happen in the future' - Low

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

Knowledge Gaps

See full review

Commercial impacts

Not stated

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