Factors Effecting UK Coastal Wave Climate Change

David Cotton 02/11/99 Jericho Technical Report -32

Introduction

This report summarises results and conclusions from a number of climate change studies relevant to JERICHO. In particular I have drawn on information from the UK Climate Impact Programme's (UKCIP) Report "Climate Change Scenarios for the UK" (Hulme and Jenkins, 1998), and papers from the WASA programme.

Climate Scenarios

IPCC / UKCIP

Hulme and Jenkins (1998) consider predictions from Global Coupled Model (GCM) output based on four of the six emission scenarios identified by the IPCC. Thus we have:

Low IS92d emissions scenario with "low climate sensitivity", 1% per annum CO_2 increase.
Medium Low The Hadley Centre's HadCM2 Ggd, 0.5% per annum CO_2 increase
Medium High The Hadley Centre's HadCM2 Gga, 1.0% per annum CO_2 increase
(pre industrial CO_2 doubles by 2050, 1961-90 levels double by 2080).
High IS92a emissions scenario with "high climate sensitivity", 1% per annum CO_2 increase.

Note: After Hulme and Jenkins (1998) was compiled, a further Hadley Centre model, HadCM3, has been developed. This model has a better representation of some processes and increased resolution in the ocean. Also referred to is the HadCM2 Sa model. This model includes the effect of sulphate aerosols as well as greenhouse gases.
Although it is clear that each of the GCM runs will have provided sea level pressure and wind fields over the ocean, most of the UKCIP interpretation of the GCM ensemble runs is directed at the consequences over land, which from our point of view is unfortunate. Perhaps a recommendation from JERICHO should be to encourage UKCIP to broaden their remit to include coastal seas.

WASA (*Waves and Storms in the Atlantic*)

The European WASA programme assessed historical changes in wind and wave climate and also modelled a future (double CO_2) scenario. References are WASA (1998), Günther et al. (1999) and Rider et al. (1996).
In the CO_2 experiment, the control run (no change CO_2) generates wind and wave fields that underestimate when compared to other analyses. In fact there is more difference between the wave analyses from the control run and the WASA 40 year hindcast than there is between the no change and doubled CO_2 scenarios. This was interpreted as a possible indication that variability due to "natural" causes may outweigh any consequences of a doubling of CO_2.
It is difficult to reconcile the results from the WASA CO_2 experiment and the GCM experiments reported by Hulme and Jenkins (1998), as least partly because the UKCIP concentrates on the terrestrial consequences of climate change and WASA is focused on the ocean. From the above definitions it seems that the WASA double CO_2 scenario should be most similar to the UKCIP "medium high" scenario, by the year 2080.

The North Atlantic Oscillation (NAO)

The connection between the NAO (the anomaly in sea level pressure gradient between the Azores and Iceland) and the climate of the north east Atlantic and north-western Europe is now widely acknowledged (Hurrell, 1995, and most recently, Rodwell et al, 1999 and Kushnir, 1999). Work by Bacon and Carter (1993), Kushnir et al. (1997), and more recently by Cotton and Challenor (1999) have demonstrated the strong link between the offshore wave climate of the North-East Atlantic and the NAO. Given this strong link it thus seems sensible to see if an empirical expression could be derived to quantify this connection. A Jericho Technical Report by David Woolf presents his work to define such a relationship for the wave climate at the JERICHO coastal sites. To "propagate" this relationship into the future and so provide an estimate of that part of the wave climate affected by the NAO, it is then necessary to use NAO predictions from one of the climate models. A necessary first step is to investigate how well the various large scale coupled climate

models can predict the NAO. Unfortunately, the conclusion for the HadCM2 model (Osborn et al., 1999) is that whilst the HadCM2 model generates the spatial patterns in sea level pressure, temperature, precipitation etc., that are associated with the NAO, it does not represent well the recent observed trend in the NAO. They suggest that this either indicates a deficiency in the model or that "external" (i.e. anthropogenic) forcing is responsible for the recent NAO trends. Whatever the cause, this must mean that we should treat any GCM NAO "forecasts" with healthy scepticism. In fact the HadCM2 climate model predicts a decrease in NAO by 2050. For instance Table 1 compares the behaviour of the DJFM Jones et al. (1997) NAO index, and the simulated DJFM from three HadCM2 model runs:
All models differ significantly from the historical behaviour of the NAO. All models exhibit non-stationary behaviour. Both GGa1 and GSa1 show large decreasing trend in NAO, and GSa1 also shows a large increase in variance. Thus, though NAO is generally decreasing, the maximum value in the period 2030-2070 (3.48) actually exceeds the maximum value in the period 1862-1999 (3.25).
Note: Folland (pers. com.) advises that although the Hadley centre models showed a decrease in the NAO, models run at Hamburg showed an increase.

year begin/ year end	**NAO statistic**	**Jones et al.**	**Control**	**Gga1**	**GSa1**
1862: 1999	mean	0.4191	-0.0212	-0.0950	-0.5635
	variance	1.1935	2.8429	2.5171	2.6296
2000: 2099	mean		0.0919	0.7239	1.1515
	variance		3.6911	2.5732	4.6545
2030: 2070	mean		-0.4312	-0.4724	-1.1566
	variance		3.8598	2.6730	5.6555

Table 1. NAO statistics: Observed: Jones et al (1997) and HADCM2 model (Control, Gga1, GSa1)

Confidence in Predictions

Hulme and Jenkins (1998) provide a table in which they rate the "confidence" , from high to low, with which different climate variables may be predicted. This table is recreated below (Table 2):

Climate Variable	**Confidence**
Atmospheric CO_2 concentration	High
Global mean sea level	
Global mean temperature	
Regional seasonal temperature	
Regional temperature extremes	
Regional seasonal precipitation	
Regional cloud cover	
Regional potential evapotranspiration	
Changes in climatic variability (e.g. daily precipitation regimes)	Low
Climate surprises (e.g. Thermohaline Circulation collapse)	Very Low or unknown

Table 2: Confidence levels (of UKCIP authors) in ability of GCMs to predict various climate variables.

For JERICHO we are most interested in the future distribution of ocean wave fields, hence we are most interested in future wind fields and pressure gradients. From this table the most relevant parameter appears to be climatic variability, the parameter lying at the bottom of the confidence table. This gives a useful indicator of the level of confidence that should be placed in predictions of future wind and wave climate. However, future sea level is also highly relevant to JERICHO, and predictions of sea level are made with more confidence.

Sea Level

Region	**low**	**medium-low**	**medium-high**	**high**
West Scotland	2	9	17	63
East Scotland	8	15	23	69
Wales	18	25	33	79
English Channel	19	26	34	80
East Anglia	22	29	37	83

Table 3. Net predicted sea level rise (in cm) by 2050.

Hulme and Jenkins (1998) report that predicted changes in mean sea level around the UK coast will be similar to the global mean rise (within 2-3 cm). There will be local differences due to regional changes in ocean currents and atmospheric pressure, but an important factor that must be taken into account is vertical land movements. Thus by 2050 East Anglia is predicted to sink by 9 cm, whilst Western Scotland is predicted to rise by 11 cm. Table 3 lists the predicted *net* sea level rise (including land motion) by 2050 for five regions around the UK coast

Storm Surge

WASA modelled the change in storm surges for the doubled CO_2 scenario (Flather and Smith, 1998). WASA(1998) provides a map of change in 5 year return values of water level heights derived from simulations of a storm surge model forced by wind and air pressure from the WASA control and double CO_2 scenario. The predicted increases (in 5 year return water levels) at the 3 JERICHO sites are:

a) ~ 10 cm at St Gowan
b) ~ 20 cm at Lyme Bay
c) ~ 20 cm at Holderness

Note, however, that these changes all lie within the bounds of natural variability

Winds

Hulme and Jenkins (1998) suggest that in 2050 the annual mean wind speed over the UK will be roughly as it is now, but that Autumn (SON) will have a higher mean wind speed (particularly in the North), with winter (DJF) and spring (MAM) having slightly lower mean winds. When they look in more detail at the "medium-high" scenario they find that the HadCM2 model predicts a decrease in the number of winter gales by about 10% in 2050, with a subsequent recovery (particularly in the number of summer gales) by 2080. Table 4 gives more details

	1961-90 gales/year	**2020s % change**	**2050s % change**	**2080s % change**
winter gales	10.9	-1	-9	-5
winter severe gales	8.5	-1	-10	-5
winter very severe gales	1.4	+8	-10	+11
summer gales	1.8	+3	0	+14
summer severe gales	1.1	0	-2	+15
summer very severe gales	0.1	+25	-16	+9

Table 4. Changes in seasonal gale frequencies over the UK for the medium high scenario, as a % change from the 1961-90 mean. The 1961-90 frequencies are calculated from the climate model outputs and not observations. Data are pooled from the four HadCM2 ensemble experiments.

We can also consider the findings from the WASA experiment, which are presented in a different way (and are not differentiated by season). One should note that the general WASA conclusion is that any projected changes (summarised below) lie within the natural range of variability. The WASA group also points out that its findings are critically dependant on the validity of the driving GCMs, and we have noted above that Hulme and Jenkins (1998) place least confidence in the ability of the GCM ensemble experiments to predict climate variability.
With all these caveats in mind, the general findings in terms of projected change in wind fields from a doubling of CO_2 are:

a) the 90% quantile of wind speed shows a slight decrease (-0.6 -1.0 ms^{-1}) over much of the central North Atlantic.
b) the 90% quantile of wind speed shows a slight increase in the North Sea (0.0 -0.6 ms^{-1}) and a larger increase over the Bay of Biscay (0.6 - 1.2 ms^{-1}).
c) the 90% quantile of wind speed also increases slightly in the North West Atlantic Atlantic, a more confused picture is seen in the extreme North East Atlantic.

Waves

We first consider findings from the WASA experiment (the caveats applied to wind data all continue to apply). Two techniques were used. First, a large scale version of WAM, with nested grids of different resolution over the North Atlantic and (European) Continental shelf, as forced by winds from a GCM output. The consequences of a doubling of CO_2 on wave climate from this experiment were:

a) the 90% quantile of total significant wave height shows a slight decrease (0.0 - 0.5 m) over the central N Atlantic, and to the west of Ireland.

b) the 90% quantile of total SWH shows a slight increase in the North Sea (0.0 - 0.25 m) and a larger increase in the Bay of Biscay (0.25 - 0.5 ms).

c) the 90% quantile of total SWH also increases slightly off the Eastern US seaboard, but decreases in the extreme North East.

WASA used the second technique to consider two North Sea sites, Brent and Ekofisk. They derived an empirical connection between the significant wave heights at these two sites and sea level pressure patterns over the North Atlantic. They then used the control and double CO_2 projected sea level pressure patterns to derive the change in certain SWH quantiles, Table 5. This technique suggests a small shift towards higher waves (10-20 cm) at both North Sea sites, apparently consistent with the findings of the larger scale dynamically derived estimates.

	Change (cm)		
Quantile	**50%**	**80%**	**90%**
Brent	13	18	20
Ekofisk	14	19	22

Table 5. Change in SWH percentile values from WASA control to double CO_2.

David Woolf has used a similar approach to the second WASA technique, deriving an empirical relationship between the NAO and monthly mean significant wave heights at the three JERICHO sites. His results are presented separately, but a brief summary of his initial findings is given below:

a) Holderness

No evidence that wave climate variability at Holderness is strongly connected to the NAO.

b) St Gowan and Lyme Bay.

Empirical relationships have been derived between monthly mean wave heights at both sites and the NAO. Both are linearly and positively related. Thus if the NAO is set to decrease, as is predicted by HadCM2, so is the mean wave climate at Lyme Bay and St Gowan.

Precipitation

Possible climate changes in precipitation are relevant to the EA in terms of the potential danger of flooding in river mouths or estuaries. In the UKCIP "medium-high" scenario, variability in precipitation was predicted to increase everywhere in the UK and in all seasons. In particular, large increases in autumn and winter precipitation, over most of the UK, were indicated (+10-13% in DJF precipitation by 2050). Spring and summer show less overall change, though there is a suggestion of drier summers in the south of England (-13- -16% in JJA precipitation).
Early HadCM3 results suggest a larger decrease in summer precipitation than HadCM2 indicated.

Scenarios to model

So far as climate models are able to predict future climate patterns and wind/wave fields, we have the following general predictions:

1) The mean value of the NAO is set to decrease by 2050, though its variability is predicted to increase
2) There is no indication that the (NAO related) recent increasing trend in mean winter waves off the western approaches and west coasts of the British Isles will continue. If anything the general indication is for a slight decrease.
3) There is a suggestion (from WASA) that mean and extreme waves in the North Sea may increase slightly (10-20% - not beyond the observed range of natural variability).
4) There is a projected decrease in the number of winter gales over the UK by 2050
5) Sea levels are confidently predicted to rise, in the range 18-80 cm by 2050.
6) Extremes of storm surge water levels are predicted to increase in the North Sea, though within the range of climate variability

Given that present climate variability, in terms of winds and the NAO, seems poorly represented by climate models, and that the UKCIP places least confidence in representations of future variability, it does not seem sensible to place too much faith in any individual model climate outlook. The suggestion therefore is that instead of tying our modelling to any individual model projection we model a selection of test scenarios based on a combination of (some of) the following options:

Sea Level

a) Present situation (no rise)

b) Predicted "low" scenario (from IPCC climate model ensemble):

+18 cm in Wales (St Gowan)
+19 cm in English Channel (Lyme Bay)
+22 cm in East Anglia (Holderness)

c) Predicted "medium high" scenario:

+33 cm in Wales (St Gowan)
+34 cm in English Channel (Lyme Bay)
+37 cm in East Anglia (Holderness)

d) Predicted "high" scenario

+ 79 cm in Wales (St Gowan)
+ 80 cm in English Channel (Lyme Bay)
+ 83 cm in East Anglia (Holderness)

Storm Surge

a) present extreme value (1 yr, 5 yr, 20 yr, 100 yr?)

b) WASA double $C0_2$ value

Extreme Values of Significant Wave Height at Model Boundaries

a) present extreme value (1 yr, 5 yr, 20 yr, 100 yr?)

b) present value + 20% (say)

Thus it would then be possible to assess which might be the more important affect, an increase in sea level, or a 20% increase in SWH return value at model boundary. Although there is no reason to expect a 20% increase (in fact if anything a decrease is expected) this approach could provide a useful illustration.

References

Bacon S., and Carter D. J. T. (1993) A connection between mean wave height and atmospheric pressure gradient in the North Atlantic, *Int. J. Climatol.*, 11, 545-558.

Cotton P. D. and Challenor P. G. (1999) North Atlantic wave climate variability and the North Atlantic oscillation index, Proceedings of the ninth ISOPE conference, Brest, June 1999. Vol. 3, pp13-157

Flather, R. A. and Smith, J. A. (1998) First estimates of changes in extreme storm surge elevation due to doubling CO2. *Global Atmos. Ocean Sys.*, in press

Günther, H., W. Rosenthal, M. Stawarz, J. C. Carretero, M. Gomez, I., Lozano, O. Serrano, M. Reistad. (1999) The wave climate of the North East Atlantic over the period 1955-94: the WASA hindcast, *Global Atmos. Ocean Sys.*, in press.

Hulme, M. and Jenkins, G. J. (1998) Climate Change Scenarios for the UK: scientific report, UKCIP Technical Report No. 1. Climatic Research Unit, Norwich 80pp.

Hurrell . J. W. (1995) Decadal trends in the North Atlantic Oscillation: regional temperatures and precipitation, *Science*, 269, 676-679.

Jones, P.D., Jonsson, T., and Wheeler, D. (1997) Extension using early instrumental pressure observations from Gibraltar and SW Iceland to the North Atlantic Oscillation. *Int. J. Climatol.* 17: 1433-1450.

.Kushnir Y., (1999) Europe’s winter prospects, *Nature*, 398, 289-291.

Kushnir Y., Cardone, V. J., Greenwood, J. G. , and M. A. Cane (1997) The recent increase in North Atlantic wave heights, *J. Clim.*, 10, 2107-2113.

Rider, K. M., Komen G. J., Beersma, J. J. (1996) Simulations of the response of the ocean waves in the North Atlantic and North Sea to CO_2 doubling in the atmosphere. KNMI scientific report WR 96-05.

Rodwell, M. J. Rowell, and Folland C. K. (1999) Oceanic forcing of the wintertime North Atlantic Oscillation and European climate, *Nature*, 398, 320-323.

The WASA group (1998) Changing waves and storms in the Northeast Atlantic*?*, *Bull. Am. Meteor. Soc.* **79**, No.5, pp741-760.