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The Wave and Surge Climate of the NW European shelf

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Waves13, Oct-Nov 2013

Motivation

- Coastal areas (less than 100m above sea level) are presently the most densely populated on earth with >35% GDP and >40% of population and with present trends this is likely to increase

- Surges and waves, together with changes in MSL and tides cause coastal impacts, including coastal flooding and erosion

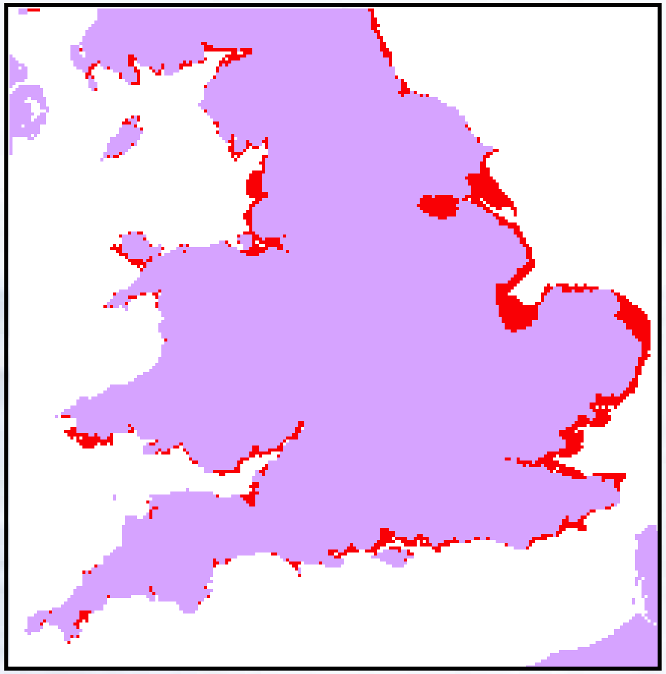
- Global warming, projections of SLR and possible changes in storms require us to understand present surge and wave climate, including natural variability, and probability of future change

- Sea level could reach +1m by 2100 in the RCP8.5 scenario, due to a combination of thermal expansion and the melting of glaciers and ice sheets. Rate of SLR will be positive for the coming centuries, requiring 200-400 years to drop to the 1.8 mm/yr 20th century average

- Adaptation to climate change is essential for coastal zones since the vulnerability to coastal flooding due to all the above factors will increase.

Coastal Defence

- Insured annual losses due to coastal flooding - £1 billion
- Without sea defences this figure would rise to about £3.5 billion
- Defences – costly! New sea wall at Blackpool cost £62m for 3.2 km
- The UK has 12,400km of coastline
- Made worse by rising mean sea level



Methodology

- Review surge and wave climate
- Surge and wave models and their limitations
- Wave and surge model validation
- Results from some hindcast studies (work in progress)
- Wave and surge projections from A1B scenario

Summary of conclusions

- Multi-year hindcasts of waves and surges are very useful for understanding the patterns of response of shelf seas to storms, however there are some issues with validation in the nearshore zone.

- We may have some confidence in future projections of coastal impacts, if we can assume the underlying behaviour of the impact models remain the same, and if we can confidently project changes in storms.

- Studies up till now suggest changes in extreme water levels are related only to changes in sea level, there seems no evidence of an increase in surge heights

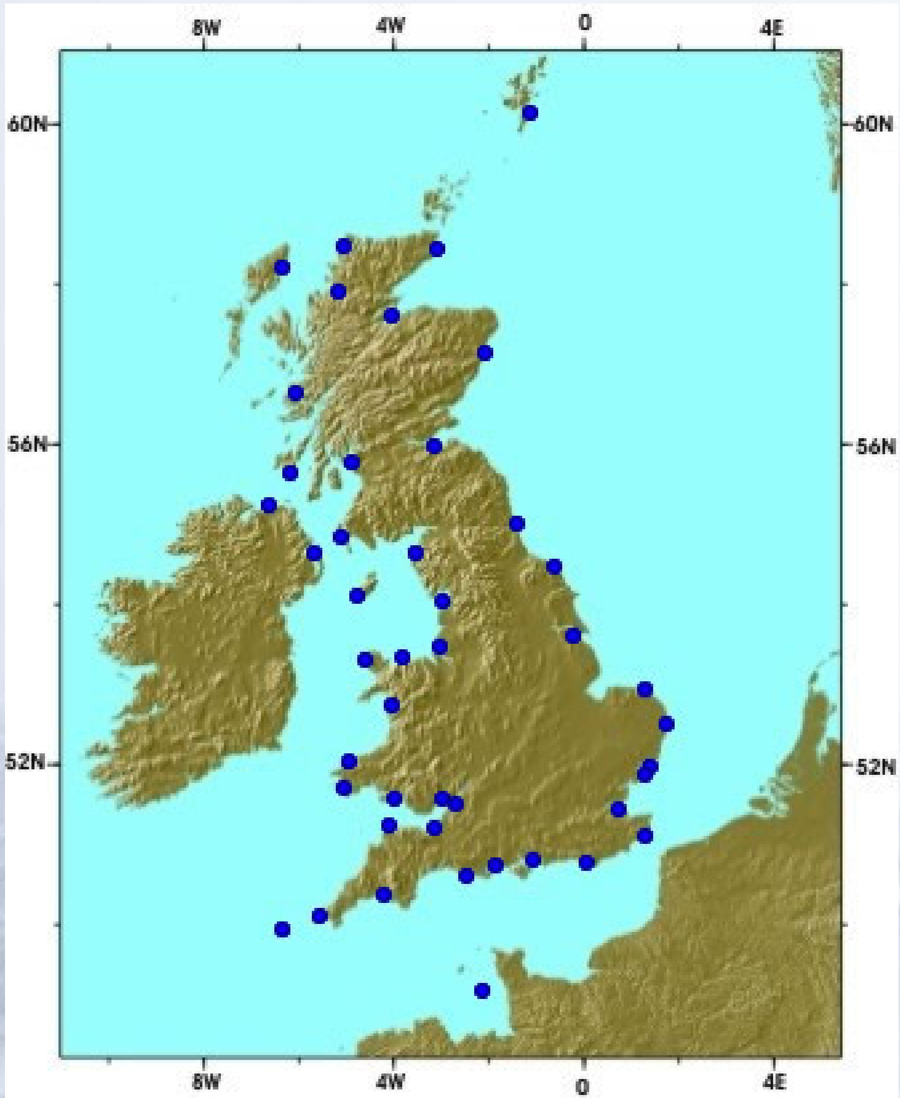
- There may be changes in mean and maximum wave heights due to a shift in storm tracks and coastlines may be sensitive to changes in wave direction

- Future climate model projections have a particularly large spread between models and a low signal to noise ratio over Europe compared to other mid-latitude regions

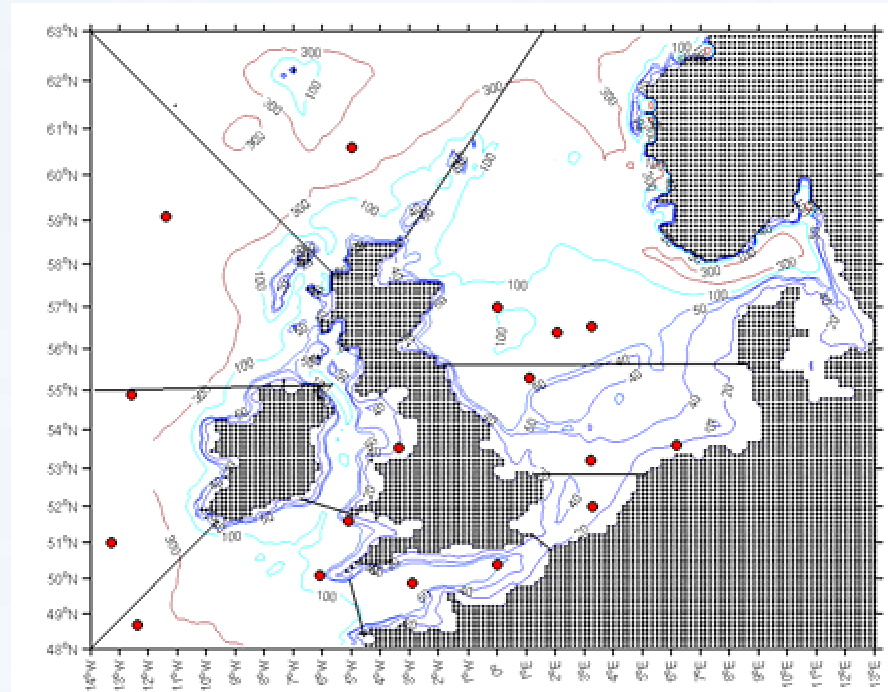
Model limitations

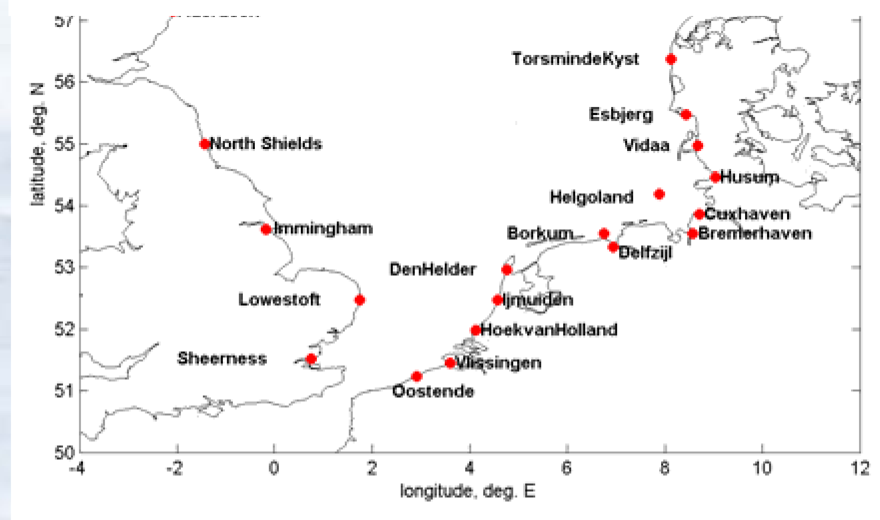
- Up to now surge models have been mainly 2D, 3D models are available (maybe little effect of baroclinicity but this needs to be assessed)
- Wave models are well validated in the deep ocean and the deeper continental shelf, some issues in shallow water
- Getting good quality atmospheric pressure and wind forcing is essential – what resolution is important? (Bricheno et al, JAOT, 2013)
- Getting the right wind-stress is an interesting challenge, is the wave effect important? (Brown and Wolf, 2009)

NW European shelf surge and wave model validation



UK A-class gauges



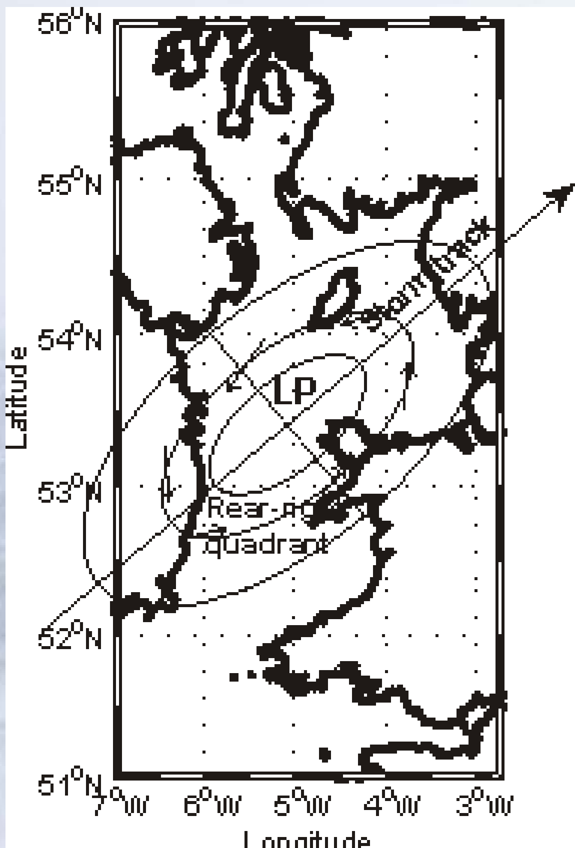


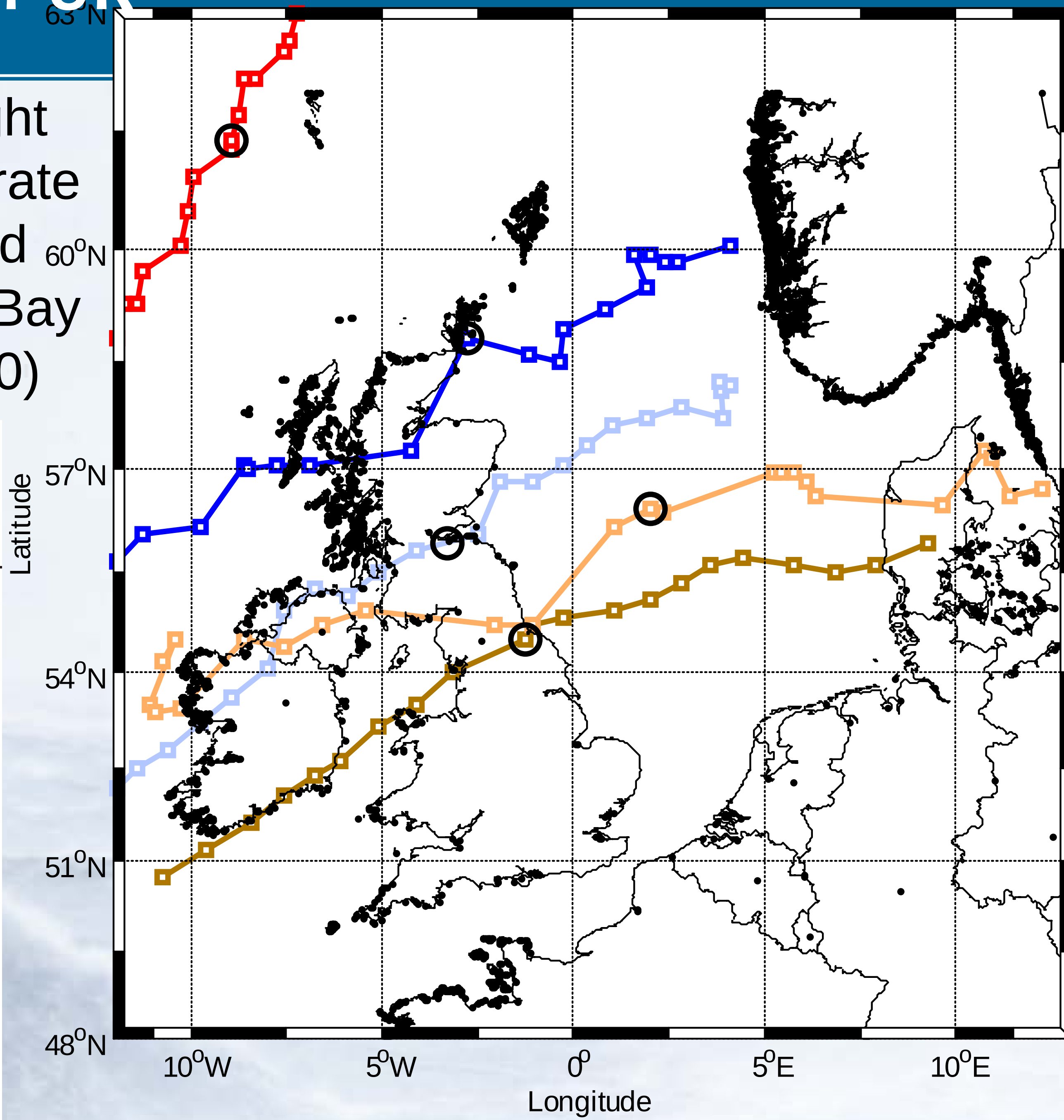
NOC Model Hindcasts

- 12km POLCOMS-WAM continental shelf model: 1999-2008, plus 2D surge model
- 1.8km POLCOMS-WAM IRS model: 1996-2006
- 1.8km POLCOMS-WAM ECNS: 1999-2008
- WaveWatchIII implementation in progress (collaboration with UK Met Office through NCOF – National Centre for Ocean Forecasting
- Surge and wave projections 1960-2100, forced by HadCM3/HadRM3 A1B forcing, with PPE

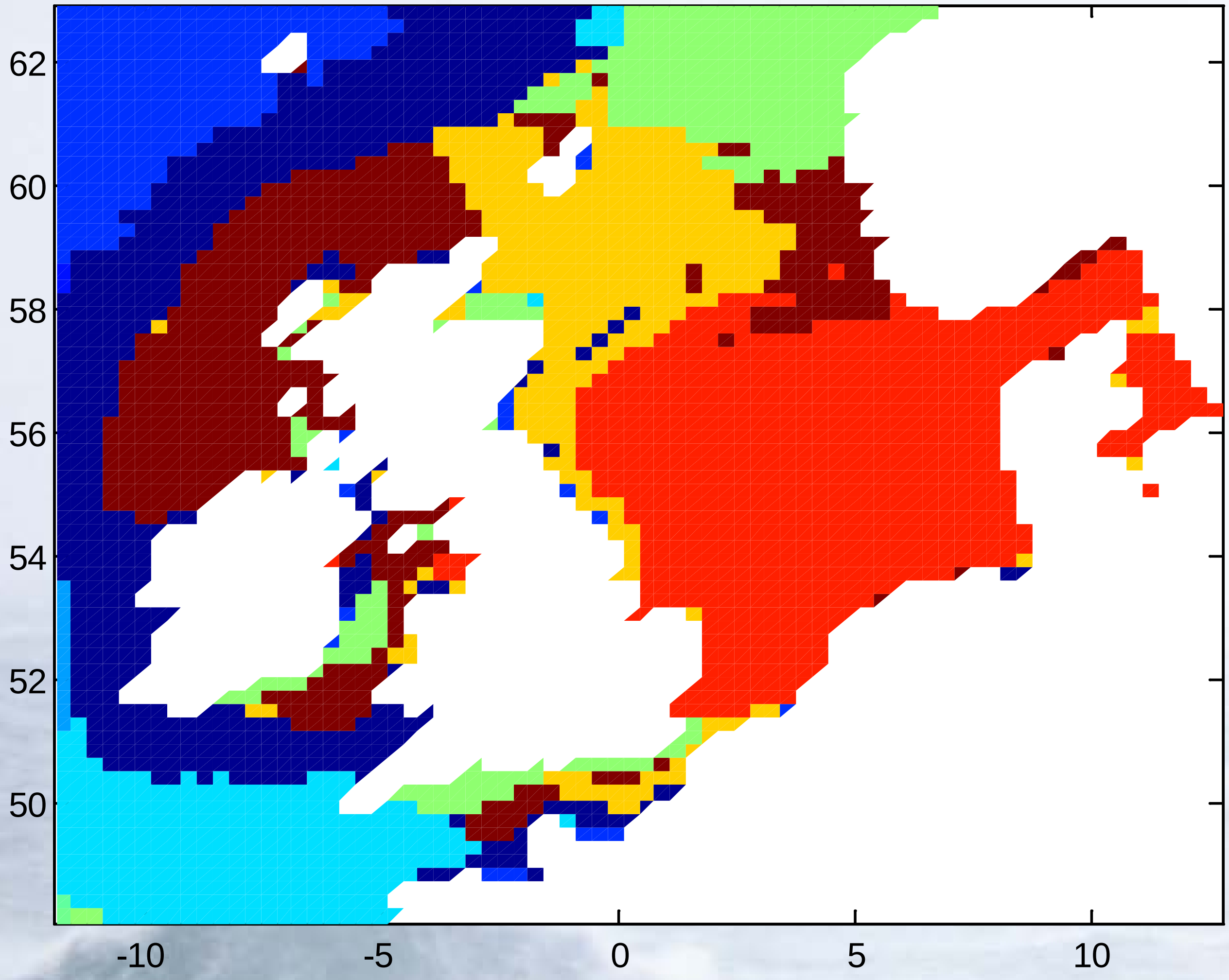
Storm tracks for UK

SW-W winds in right rear quadrant generate largest surges and waves in Liverpool Bay (Brown et al., 2010)





Storm Wave characteristics – cluster analysis



7 clusters from 4 correlation arrays:

Hs:abs(U10);
Hs:Tz;
Hs:Tp;
Hs:Dm;

Wind-stress

UK surge model
Charnock (1955):

$$\frac{1}{C_d} = \left[\frac{1}{\kappa}\log\frac{g\,z}{\beta C_d U^2}\right]^2, \quad (1)$$

which is solved iteratively for the drag coefficient C_d, where

$$\tau = C_d \varrho_a \mathbf{U} U; \quad (2)$$

U is the wind vector at height z above the sea surface; $U = |\mathbf{U}|$ is the wind speed at height z above the sea surface; g is the acceleration due to gravity; κ is von Kármán's constant (taken to be 0.41); ϱ_a is the density of air at mean sea level; and β, chosen by tuning the operational surge model for optimal surge results, is 0.0275; z is always 10 m in this work.

Brown and Wolf (2009)
Janssen (1991):

$$U(z) = \frac{u_*}{\kappa}\ln\left(\frac{z+z_1}{z_0+z_1}\right) \quad (7)$$

where κ is the von Karman's constant. The profile depends on a background roughness, z_0, which accounts for processes such as flow separation that are not considered explicitly. This roughness length is parameterised by a Charnock relation:

$$z_0 = \frac{\hat{\alpha} u_*^2}{g} \quad (8)$$

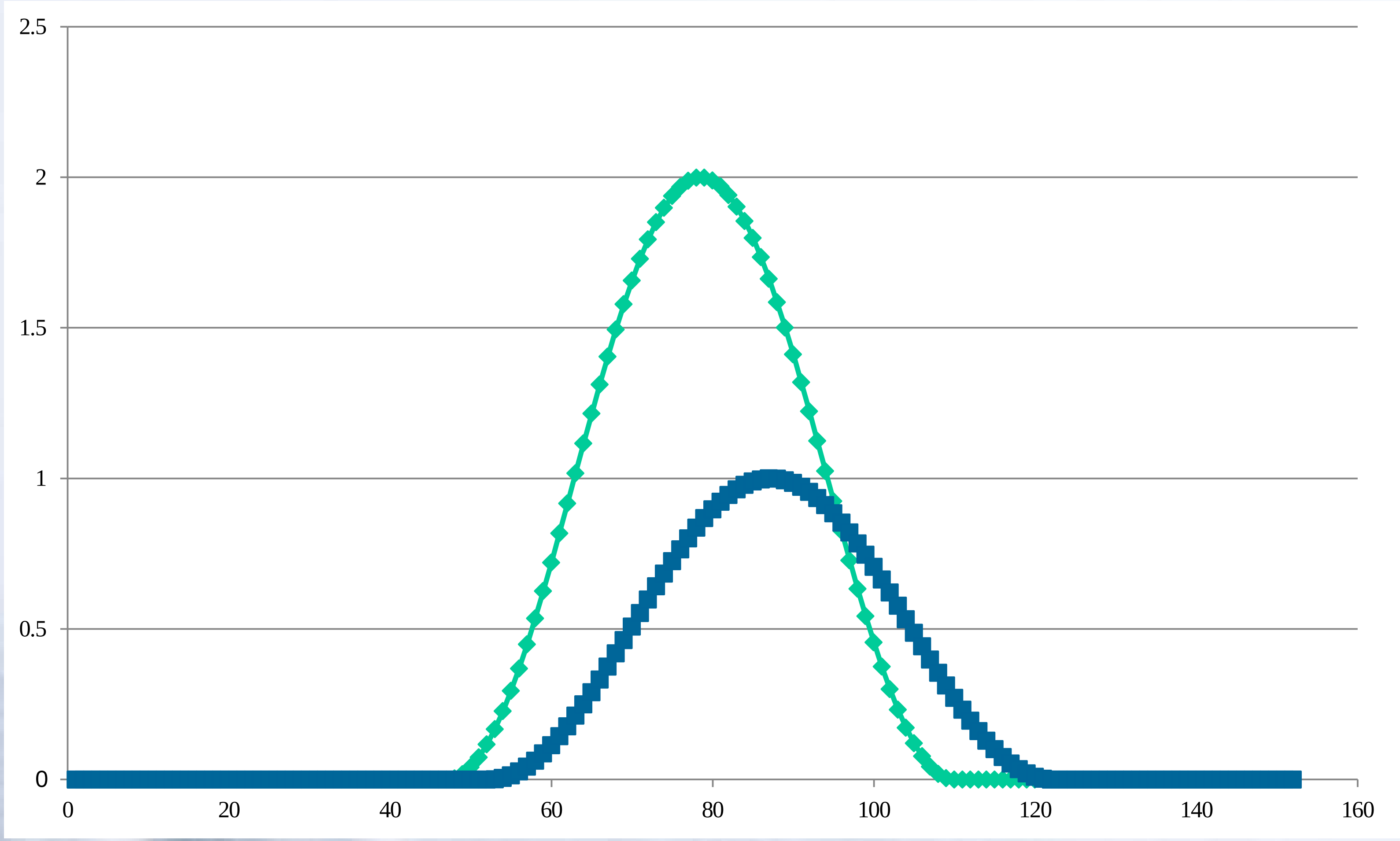
where $\hat{\alpha}$ is constant

This is combined with the roughness length due to (short) gravity waves, z_1, to give the effective roughness, $z_e = z_0 + z_1$. The effective roughness is calculated in the wave model by a Charnock-like relation:

$$z_e = \frac{\alpha u_*^2}{g}, \text{ where } \alpha = \hat{\alpha}\Big/\sqrt{1-\frac{\tau_w}{\tau}} \quad (9)$$

where τ_w is the wave stress and τ the total wind-stress given by Eq. (4). The constant $\hat{\alpha}$ was selected by trial and error as 0.01, so for old wind-seas $\alpha = 0.0185$ in Eq. (9), in agreement with observations collected by Wu (1982). A wave spectrum with relatively high peak frequency is termed 'young' ($c_p/u_* \sim 10$) and refers to a sea state where the waves have just started to be generated by the wind. A fully developed sea state is termed 'old' ($c_p/u_* \sim 30$) and the wave energy hardly changes in time (Janssen,

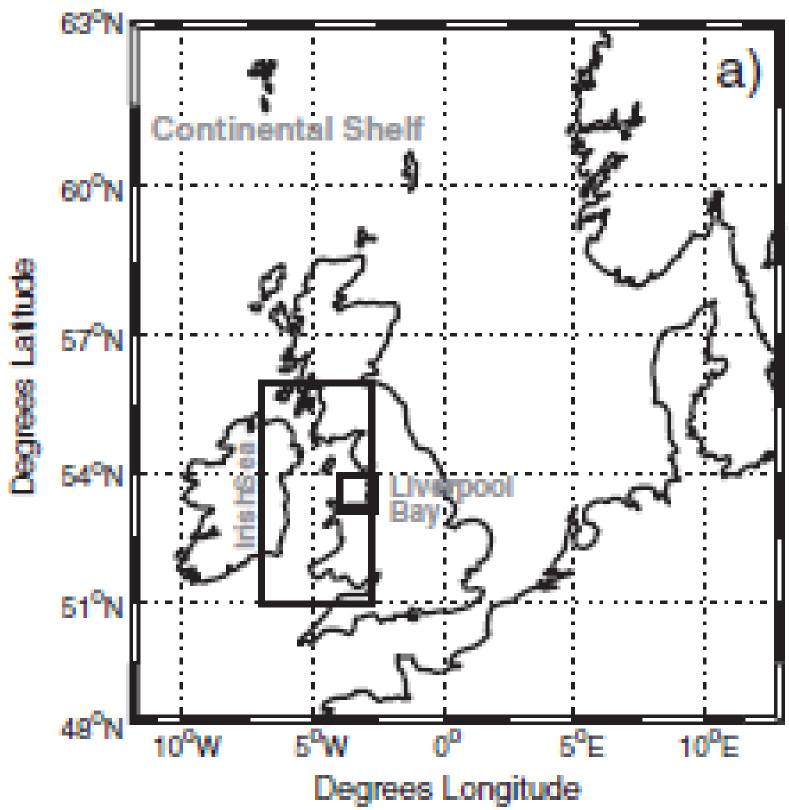
Model validation

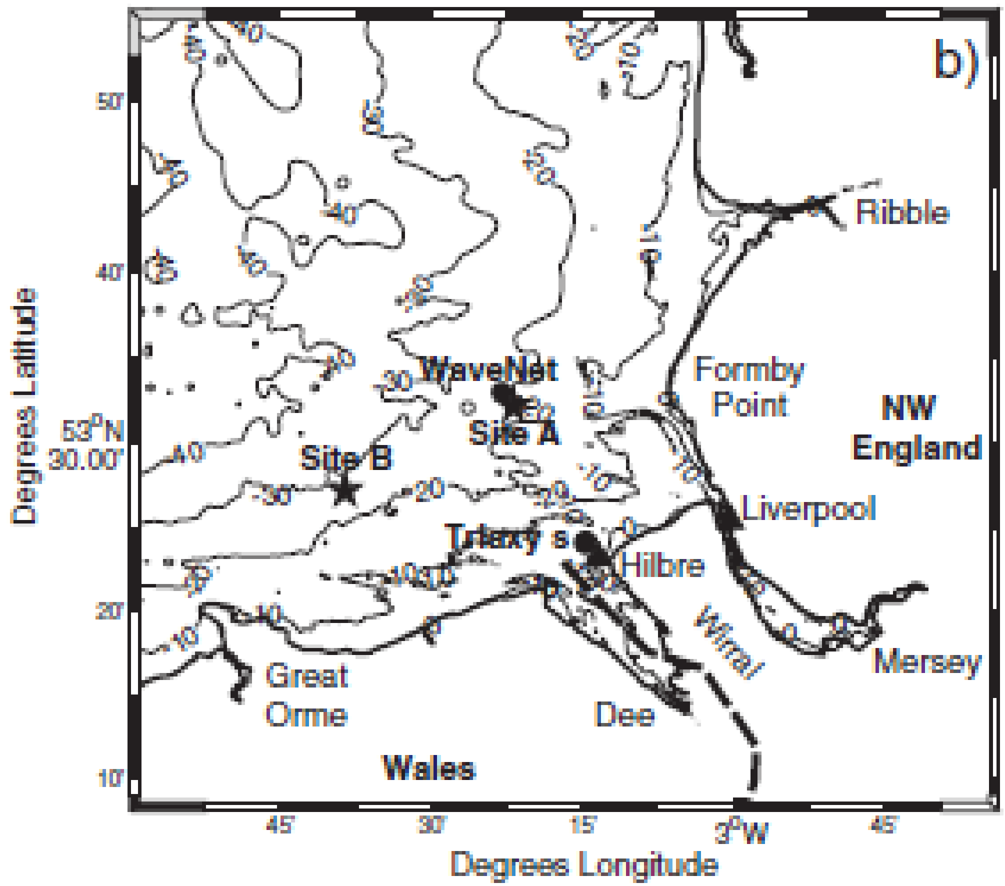


• Usual metrics: rms error, correlation, Taylor diagram are limited

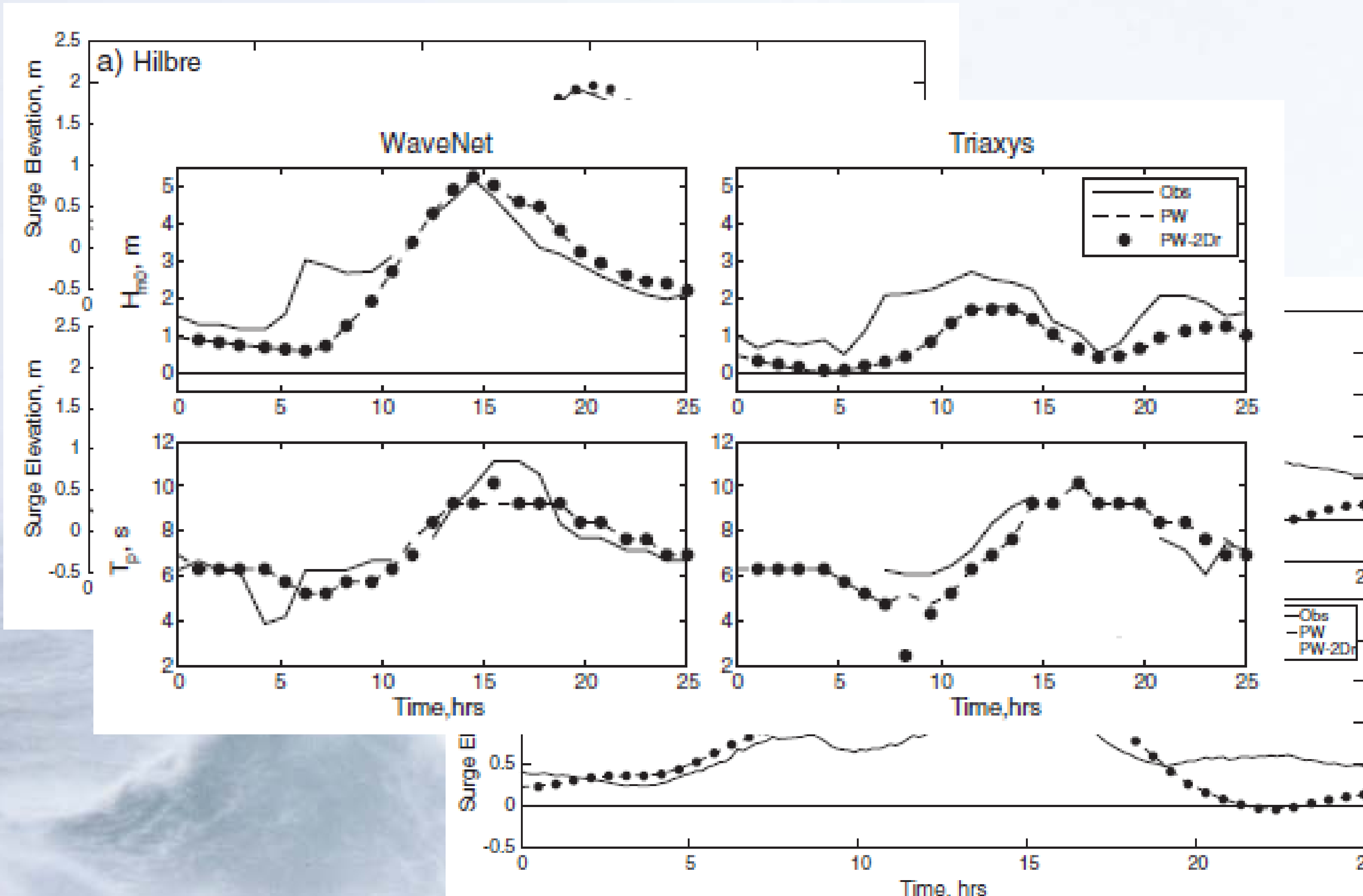
• Actually we want to optimise amplitude, timing and duration of ‘events’, but also get ‘average’ conditions ‘correct’

Brown, Bolanos and Wolf, Coastal Engineering, 2013

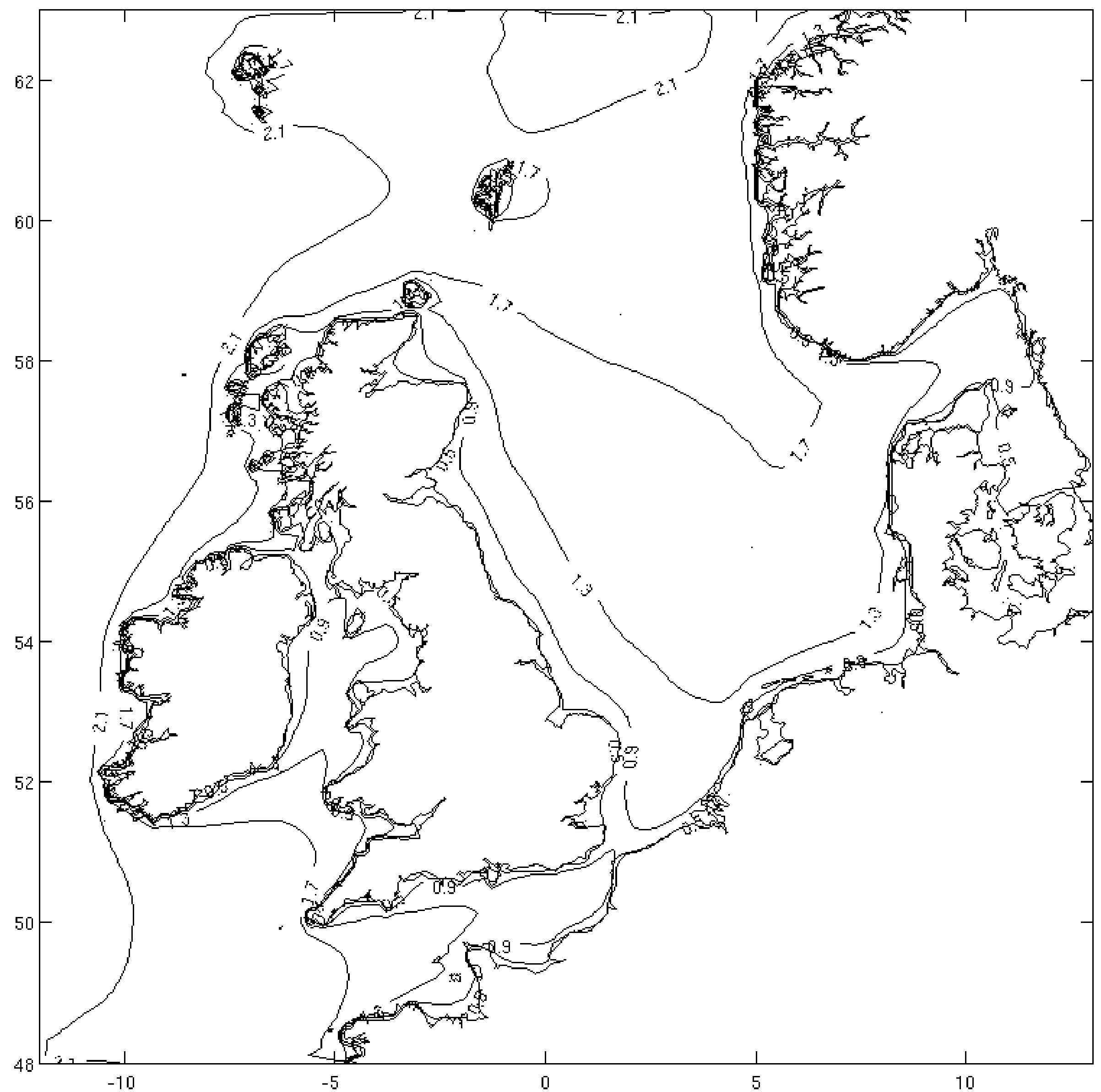




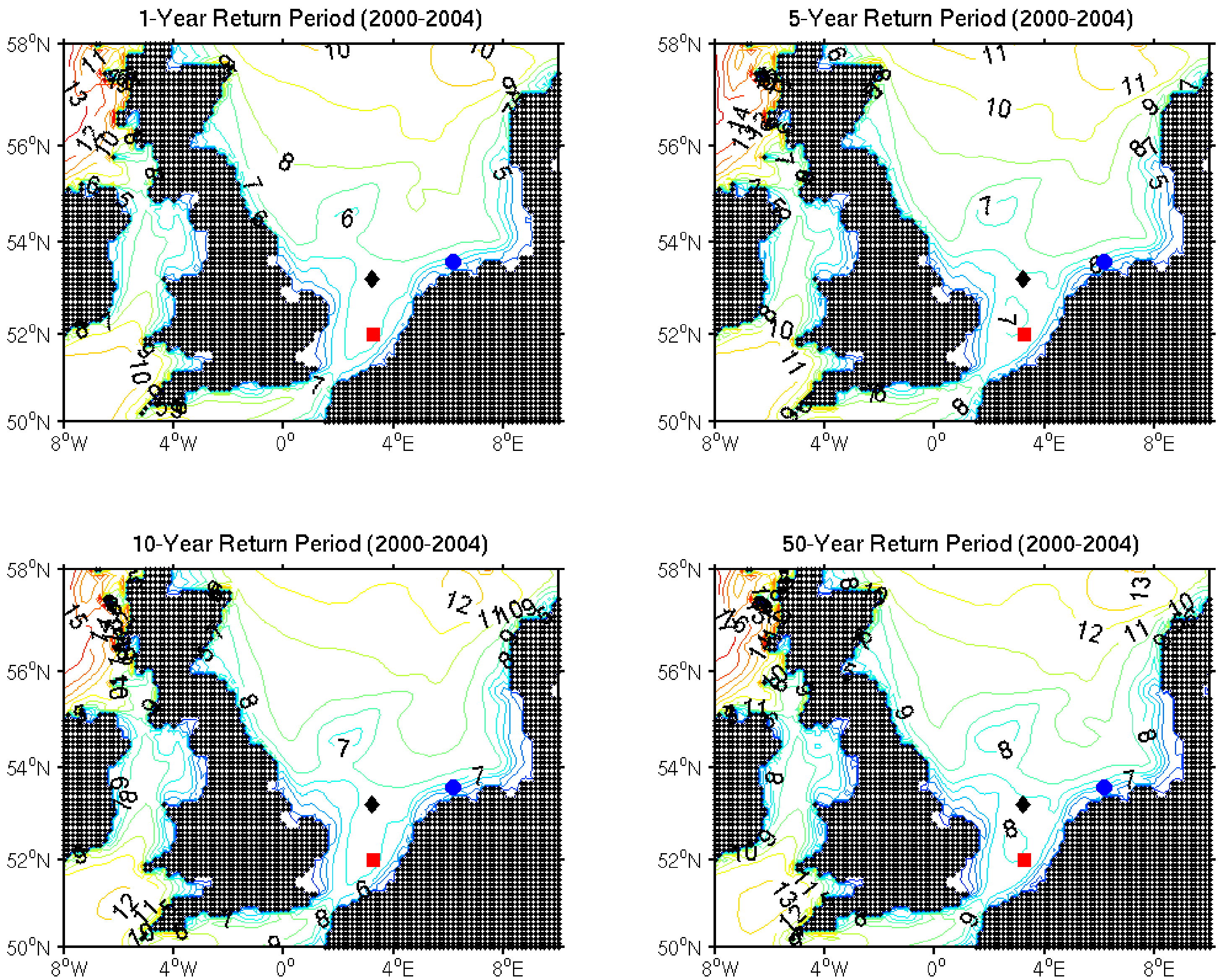
Time series comparison, surge and wave, 18 Jan 2007



Annual mean wave height (m)

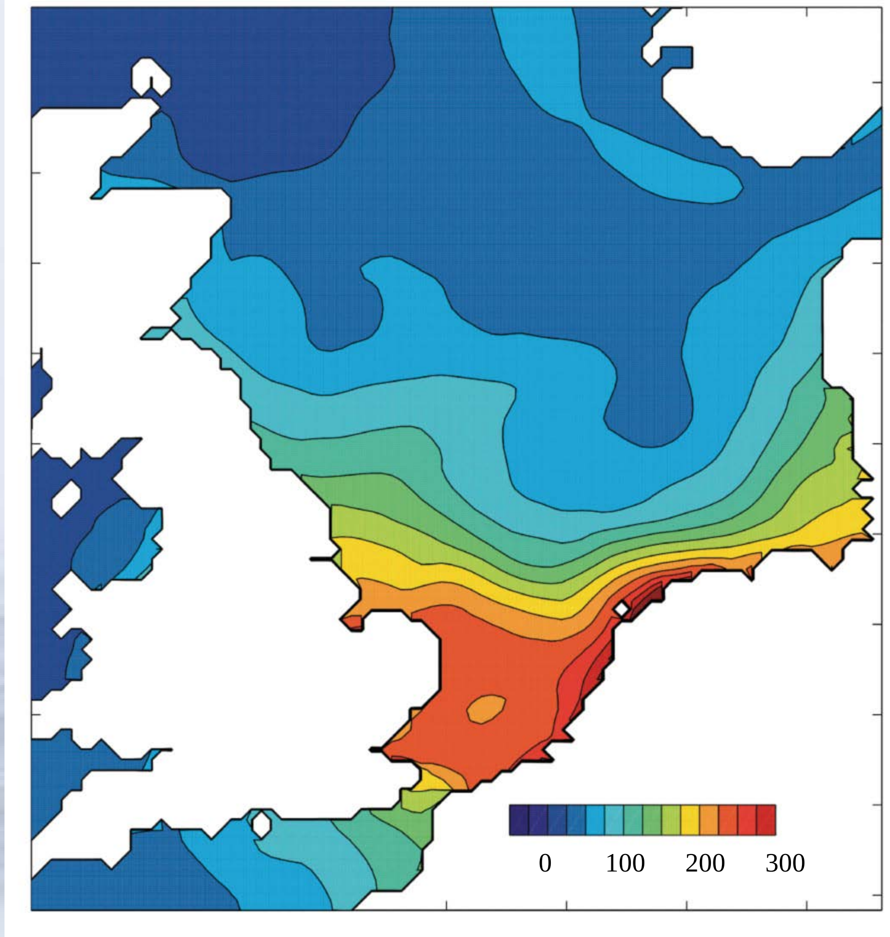


Extreme waves from r-largest GEV (m)

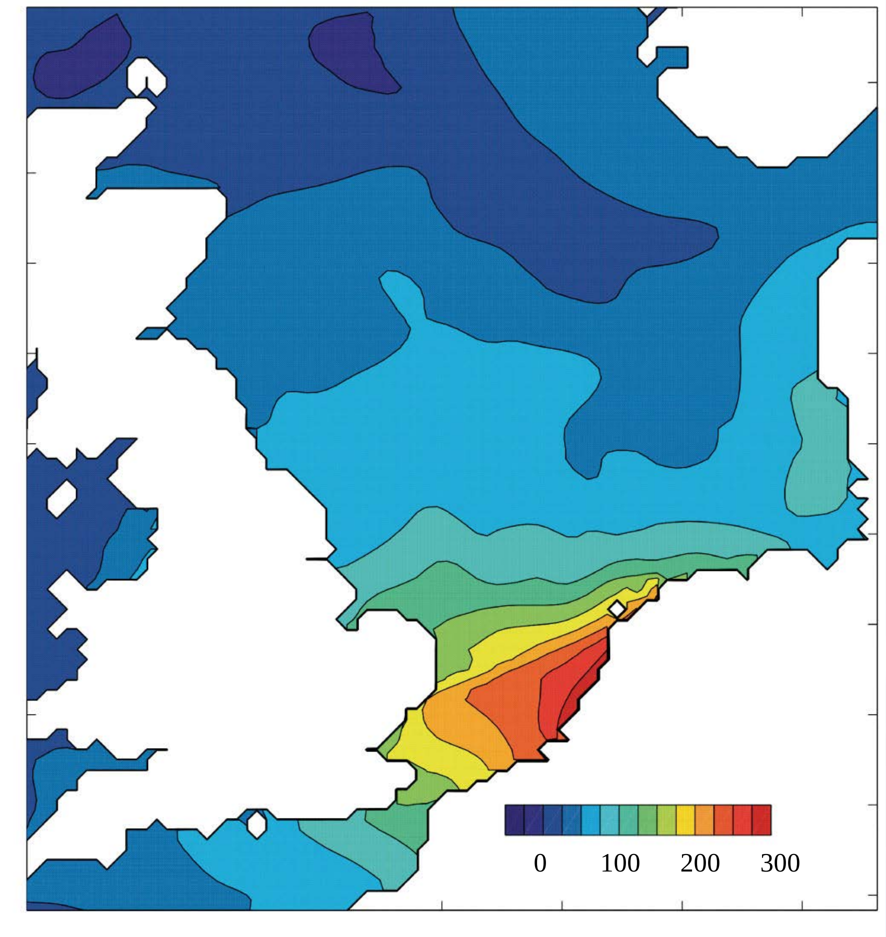


1953 storm surge

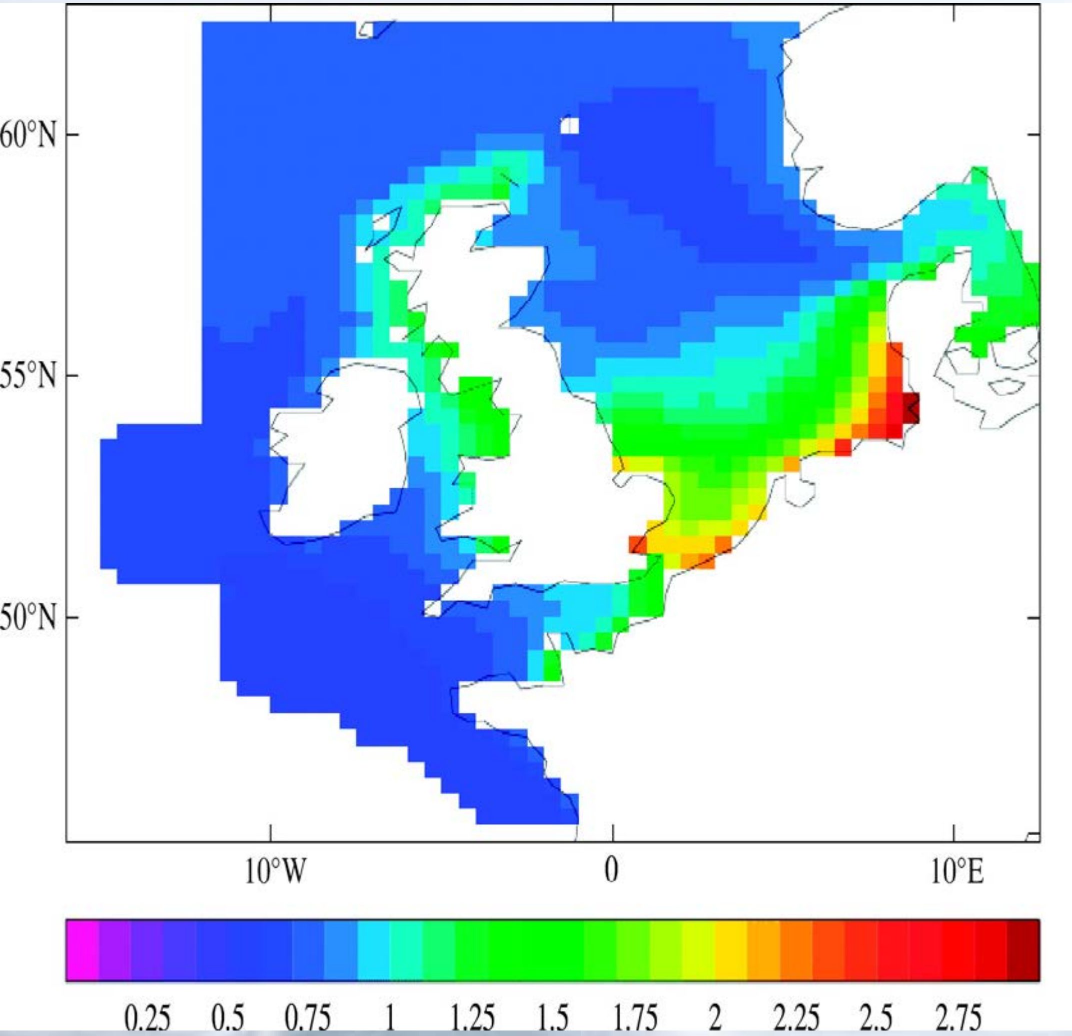
Max surge (cm)

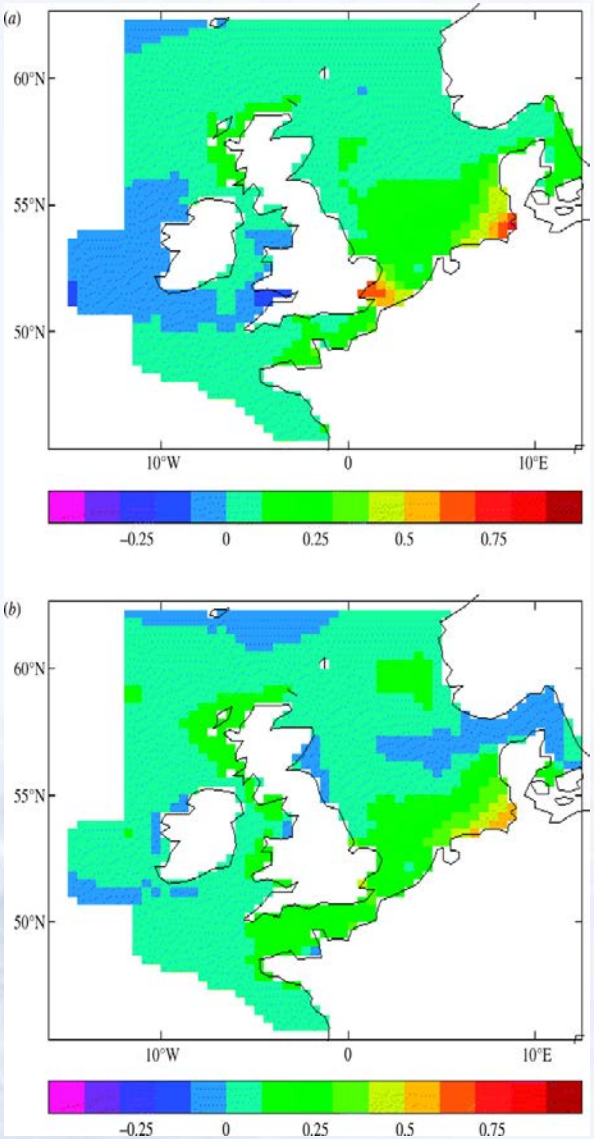


Max skew surge (cm)



Simulated present day 50 year return period storm-surge height (m) and effect of climate change





A2

B2

Lowe J , and Gregory J Phil. Trans. R. Soc. A 2005;363:1313-1328

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A

50-year storm surge (UKCP09)

- Around the UK the size of surge expected to occur on average about once in 50 yr is projected to increase by less than 0.9 mm yr (not including relative mean sea level change) over the 21st century. In most locations this trend cannot be clearly distinguished from natural variability. Thus our assessment suggests that this component of extreme sea level will be much less important than was implied by UKCIP02, where corresponding values exceeded 5 mm yr in places.

- The largest trends are found in the Bristol Channel and Severn Estuary, where the trend is for an increase in the 50-yr skew surge return level of around 0.8 mm yr, not including relative mean sea level change.

UK Storms and Waves Policy Guidance

- **Charting Progress 2:**
  - average number of winter storms in UK has increased significantly over the past 50 years – but this has largely balanced a decline in the first half of the 20th century, so that the storminess at the beginning and end of the 20th century was rather similar
- Natural variability in wave climate is large and the role of anthropogenic influence is unclear
- Increases in monthly mean and maximum wave height in the NE Atlantic occurred between 1960 and 1990 and were coincident with a strongly positive phase of the NAO – this increase in wave height may be part of long-term natural variability
- There has been no clear pattern since 1990

http://ukclimateprojections.defra.gov.uk/

http://www.mccip.org.uk/

Wave model framework

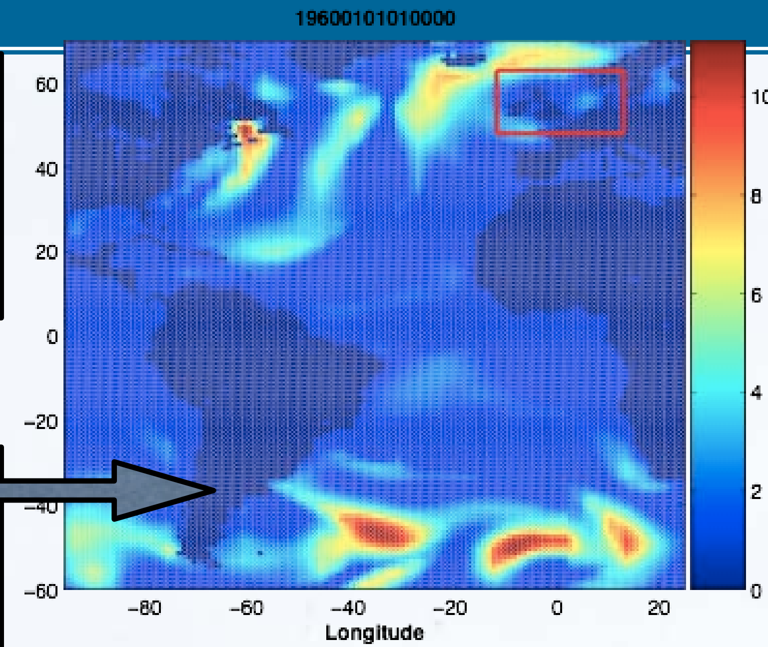
Ocean-Atmosphere Global Climate Model
HADCM3
Atm Res: 2.5 x 3.75
Oc Res: 1.25 x 1.25

Pre-industrial GHG emissions

Future SRES scenarios

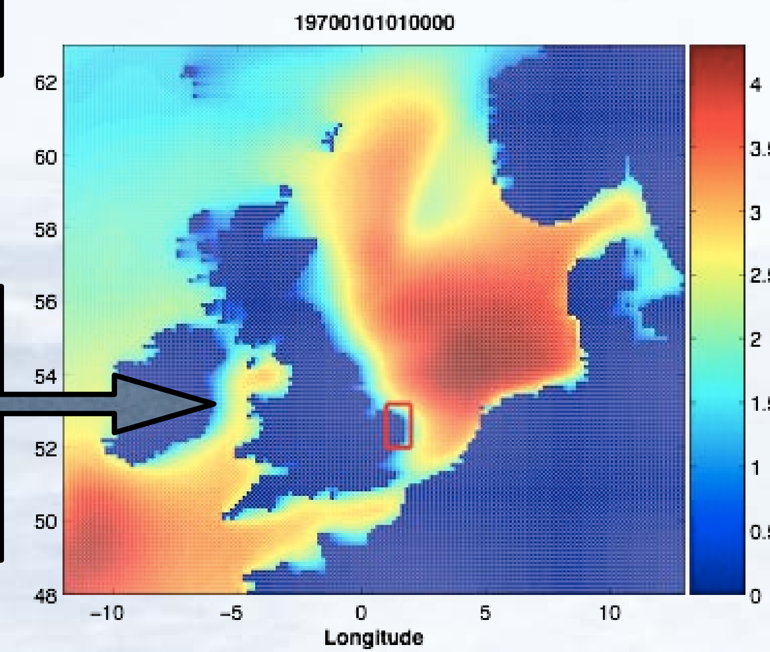
Global Climate Model
HadAM3H
Res: 1.25 x 1.88

Atlantic Wave Model
WAM
Grid: 97W-25E
60S-70N
Res: 1 x 1

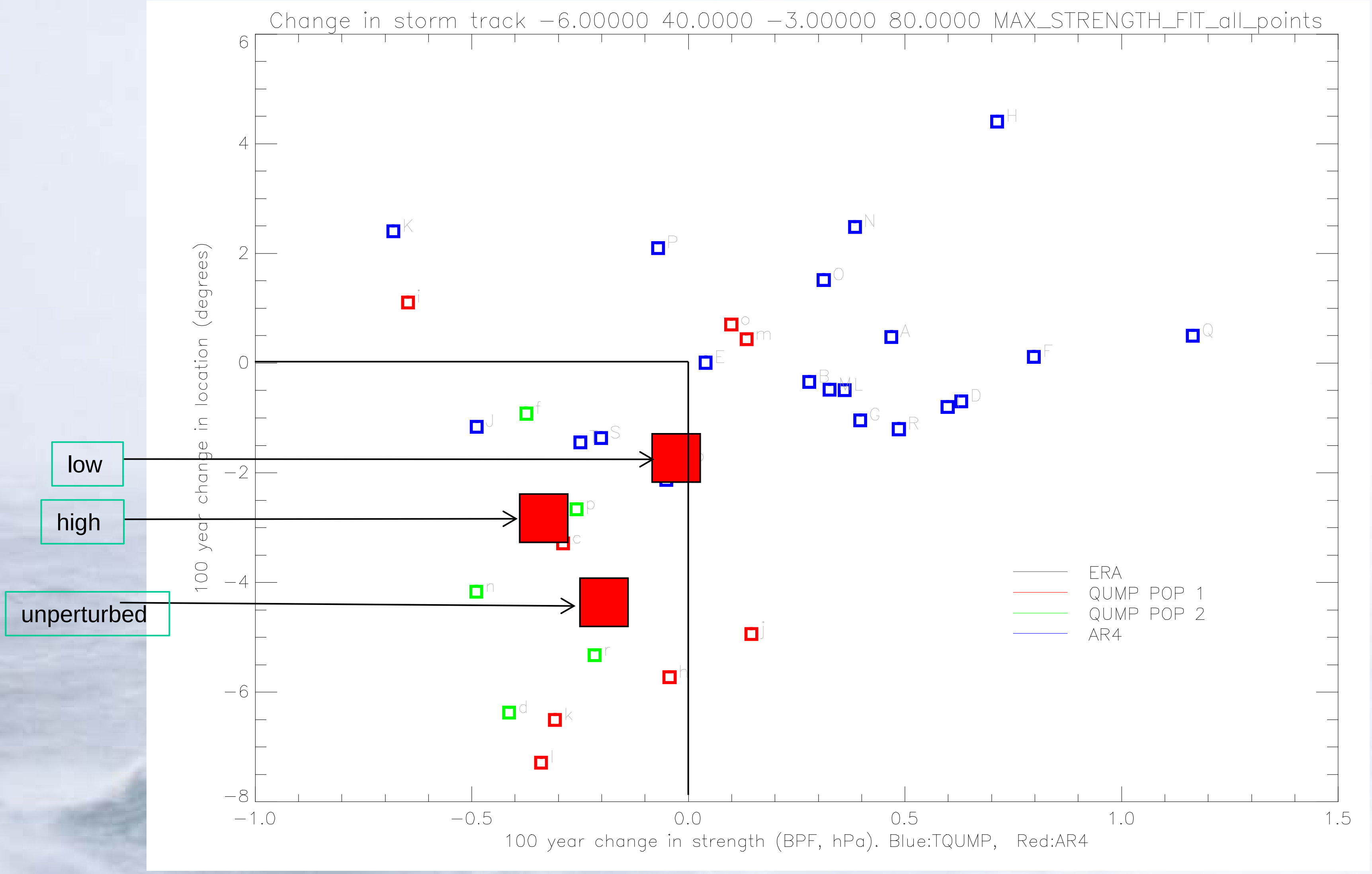


Regional Climate Model
HadRM3H
Grid:
Res: 0.44 x 0.44

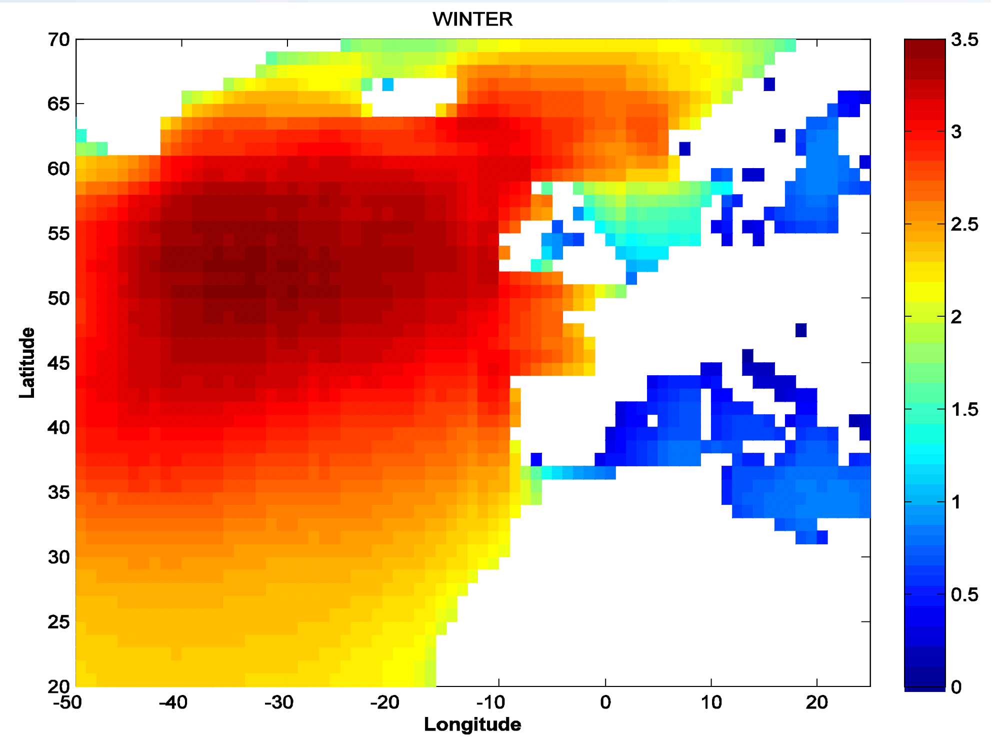
CS3 Wave Model
WAM
Grid:12W-13E
48N-63N
Res: 1/6 x 1/9

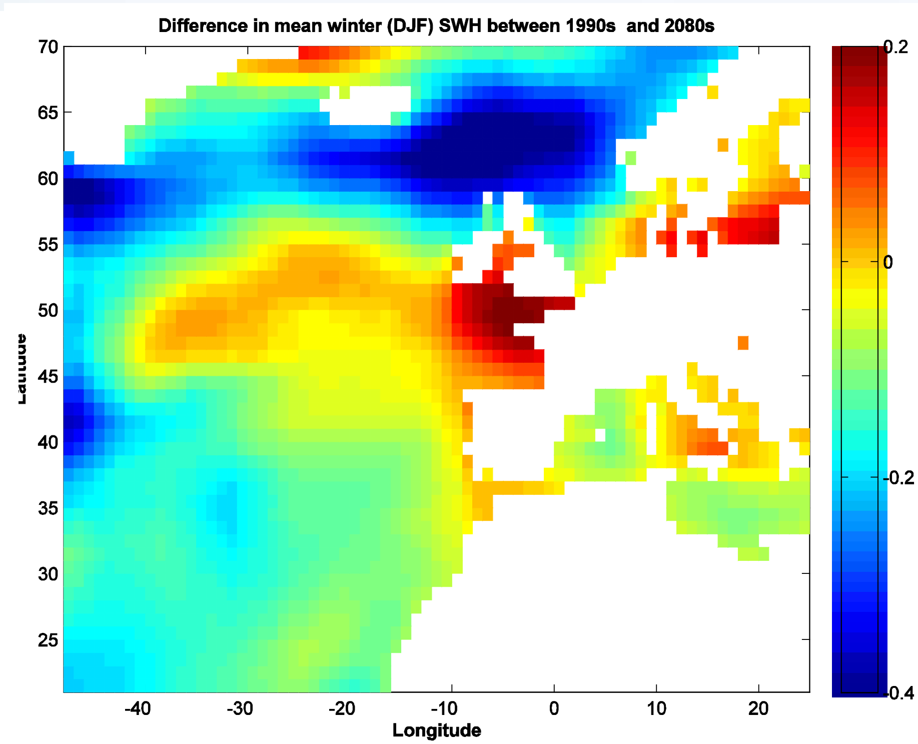


Changes in North Atlantic winter storms in HadCM3



Differences in North Atlantic winter-mean wave height

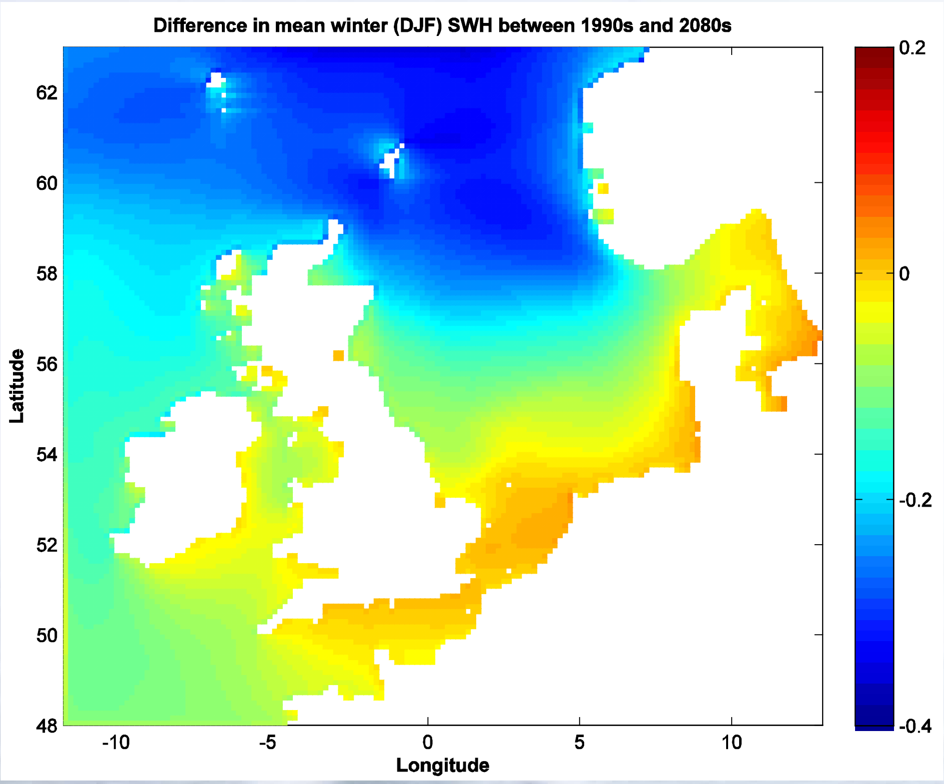




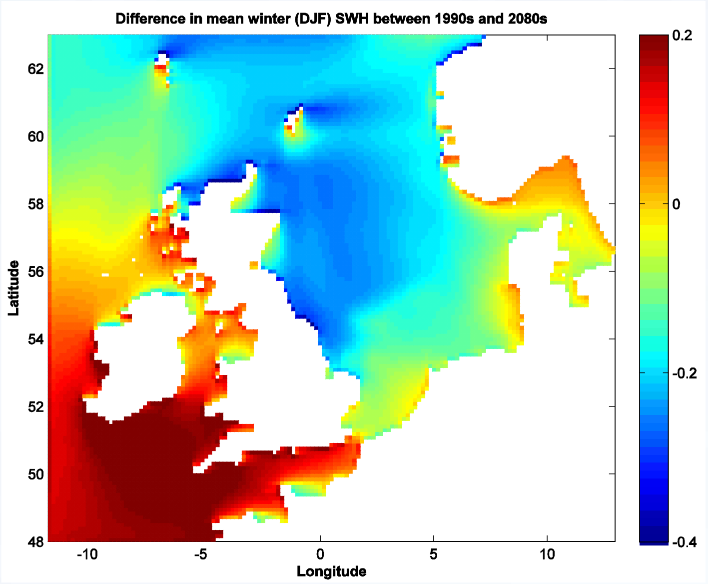
Present day (1960-1990)

Future (2070-2100) - Present day

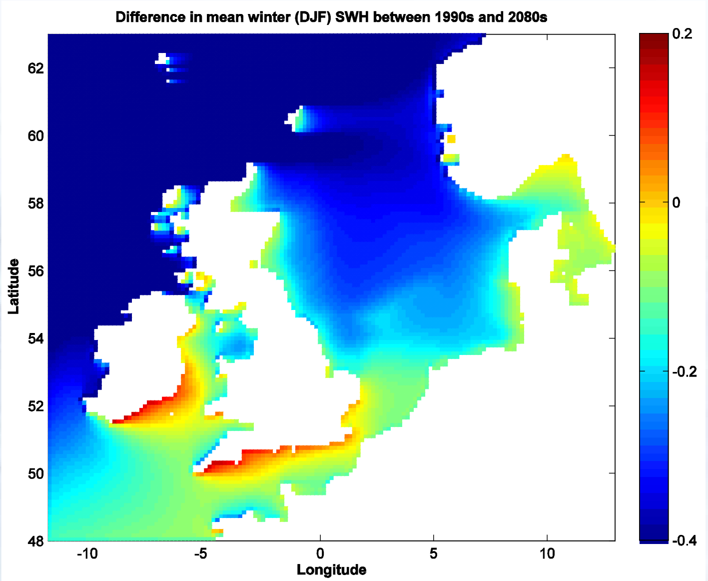
Changes in wave-heights from different PPE (perturbed physics ensemble) members



unperturbed



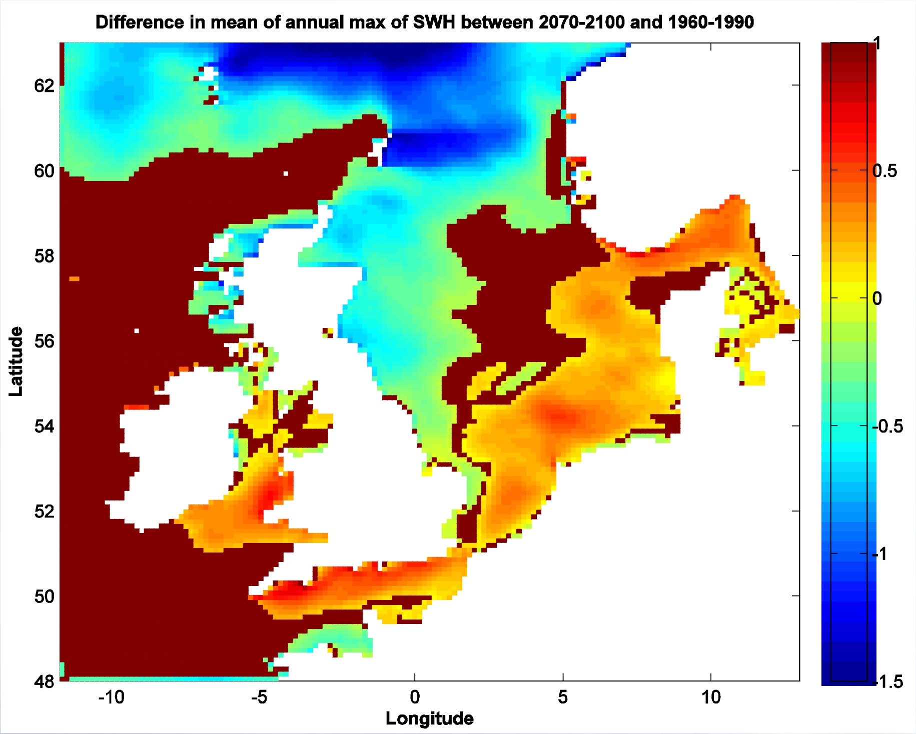
low

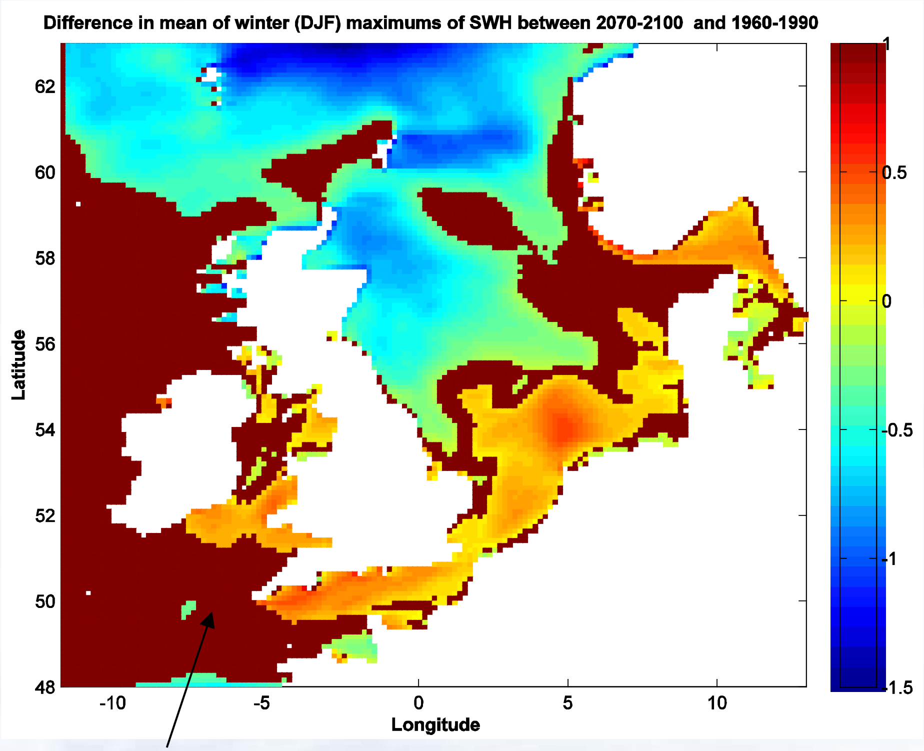


high

Low/high sensitivity to CO_2

Changes in extreme wave-heights





Insignificant changes based
on 30-year variabilty

Changes in mean annual (left) and winter (right) maxima of SWH from 1960-1990 to 2070-2100

Natural Variability important
Need to look at whole 1960-2100 period

Conclusions from wave projections

- Projected waves in 2100 are larger to the south of UK and smaller to the north of Scotland, consistent with a southerly shift of the storm track, in contradiction to some other climate model results.
- The effect of subtle changes in wave direction for alongshore sediment transport on the east coast and potential for coastal realignment will be of interest to coastal managers.

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