Identifying the most extreme storms for wave impact at the UK coast

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SUCCESS K/O Feb 2017

SUMMARY

- Recently interest has increased in the contribution of waves to coastal flooding events
- The evidence suggests wave models do a good job of turning winds into waves for mid-latitude storms, the largest errors still being the errors in the wind-field
- The UK coasts can be partitioned into sea areas with a similar response to wind fields. We have selected a subset of storms in the recent past from a global and regional hindcast for NW Europe to increase the robustness of this analysis
- For each area a worst case storm will be designed and its probability identified with reference to the historical record
- These wind and wave fields are being used to explore storm events impacting the UK as part of the SUCCESS project led by Kevin Horsburgh

Outline

- Background and motivation
- NE Atlantic storms, wave climate & coastal impacts, future climate
- The Perfect Storm
- The SUCCESS project (Synthesising Unprecedented Coastal Conditions: Extreme Storm Surges)

What factors cause large coastal impacts for UK?

1. Tides 2. Storms 3. Long term sea level

Surges

Inverse barometer effect

Strong winds especially in shallow water

Coastal boundary, geometry and bathymetry

Waves

Strong winds

Maximum Fetch

Maximum duration

Storm track and moving fetch effect

Sea level changes on longer time periods

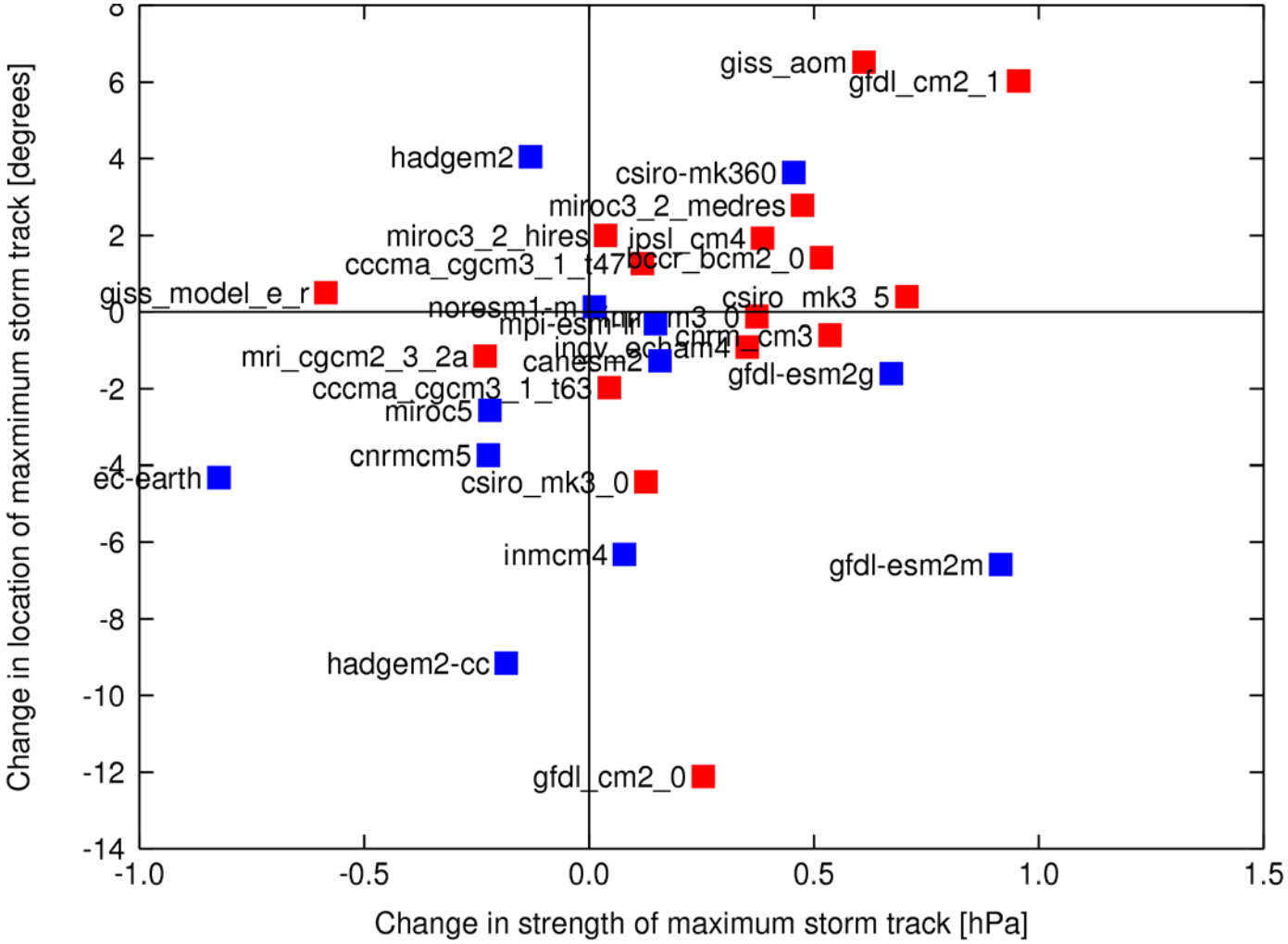
Motivation

- Understanding wave impacts at the UK coast
- Water levels
- Offshore wave conditions
- Wave transformation, setup, run-up, over-topping
- Impact and adaptation
- Different approaches to exploring extremes
- Problem of inter-annual variability and limited number of realisations of extreme events in determining wave climate
- How to extend the observed storm record?
- Statistical e.g. weather typing and extreme value analysis
- Modelling very large ensembles
- Consider dynamics and the dynamical limits of storm events

Storms and Waves (IPCC AR5)

- **Tropical cyclone frequency** will **likely decrease** or remain roughly constant - **more likely than not** that the **frequency of the most intense storms will increase in some ocean basins**
- Changes in **extra-tropical storms** – less clear
- Change **from CMIP3 to CMIP5 – still some biases in storm tracks**
- Wave generation in the Southern Ocean is projected to undergo pronounced increase in the wind speed and significant wave height in the near future under a future scenario of climate change
- **Ocean waves projected to increase in the ice-free future Arctic Ocean**
- In the main part of **North Atlantic**, a **decrease of wind speed and significant wave height** is projected
- **Low confidence in region-specific projections** due to the **low confidence in tropical and extratropical storm projections**, and to the **challenge of downscaling** future wind fields from coarse-resolution climate models.

Projected changes in storms: CMIP3 vs CMIP5



In future will storm tracks move north or south in NE Atlantic?

Credit: Ben Harvey, NCAS. Section at longitude=zero.

Blue: CMIP5 (RCP8.5) Red: CMIP3 (SRESA1B)

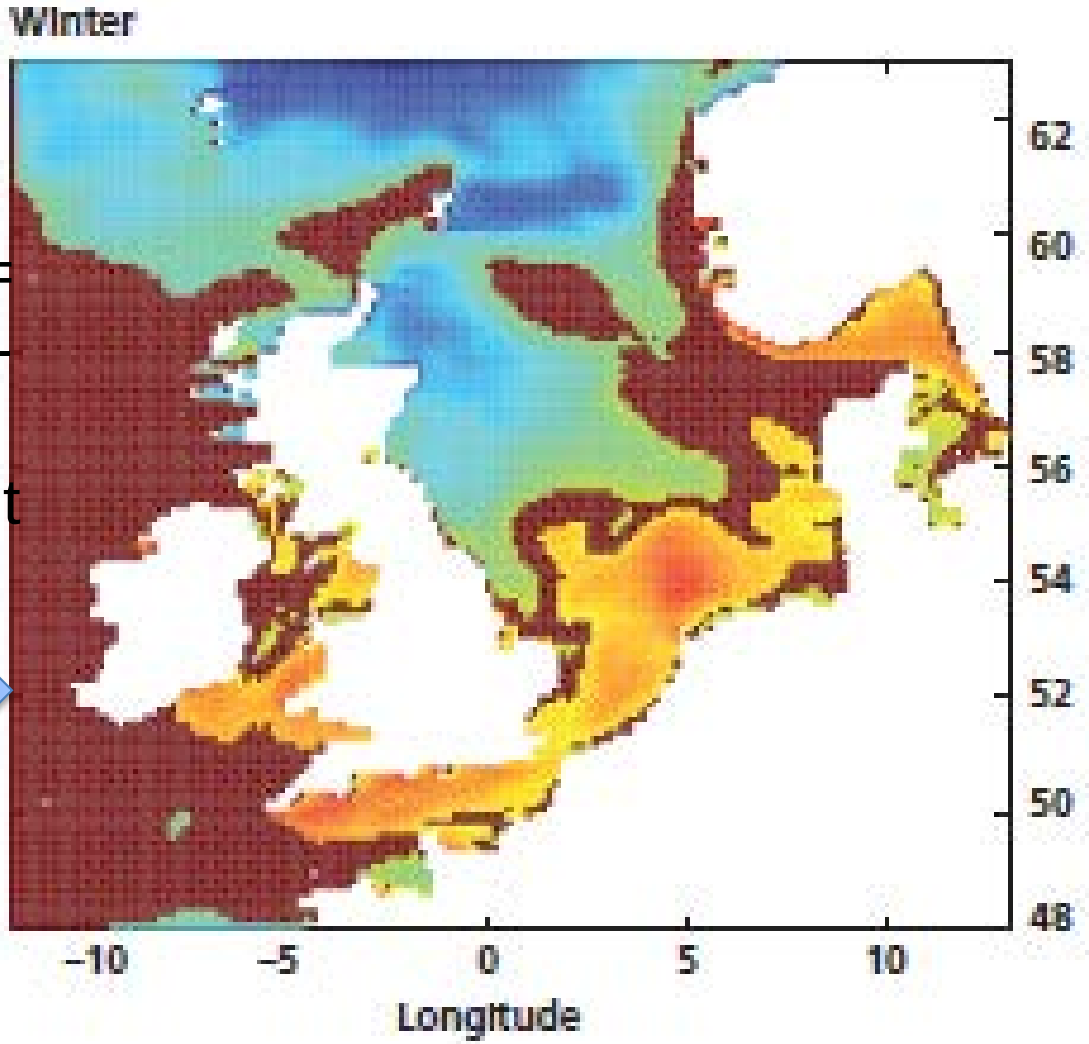
North Atlantic storms in CMIP5 models (Zappa et al., 2013)

- winter-time North Atlantic storm tracks (compared to CMIP3) are still either **too zonal or displaced southwards**
- there are improvements both in number and intensity of North Atlantic cyclones, in the higher resolution CMIP5 models. 3 groups of models:
  - small biases in winter-time position, median latitude consistent with reanalysis data: **EC-Earth**, GFDL-CM3, HadGEM2 and MRI-CGCM3
  - southern displacement of the winter-time storm track: BCC-CSM, CMCC-CM, CNRM-CM5, CSIRO, FGOALS-g2, IPSL-LR, and MIROC-ESM
  - Remainder of CMIP5 models too zonal
- winter-time southward displacement of the North Atlantic storm track leads to too few and weaker cyclones over the Norwegian Sea and too many cyclones in central Europe

Models generally perform better in summer!

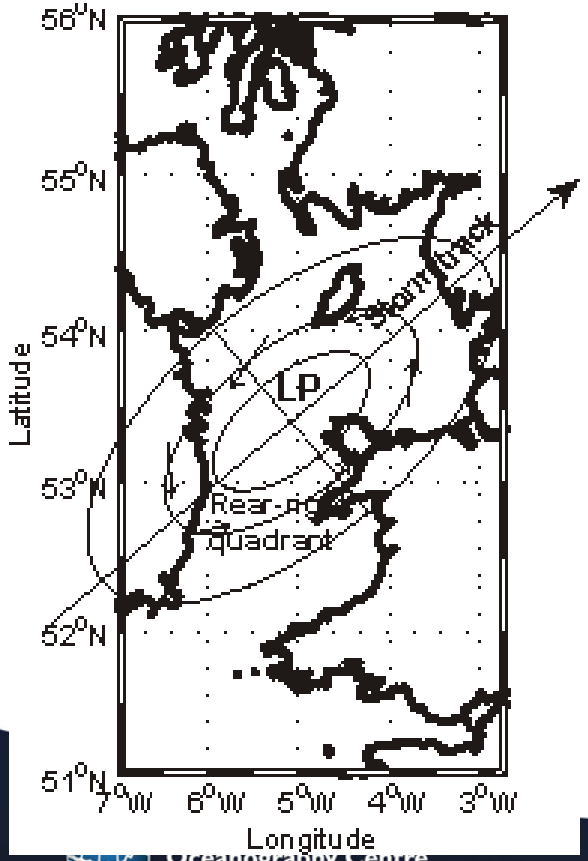
Projected changes in mean winter wave height in UKCP09 (CMIP3), Wolf et al (2015)

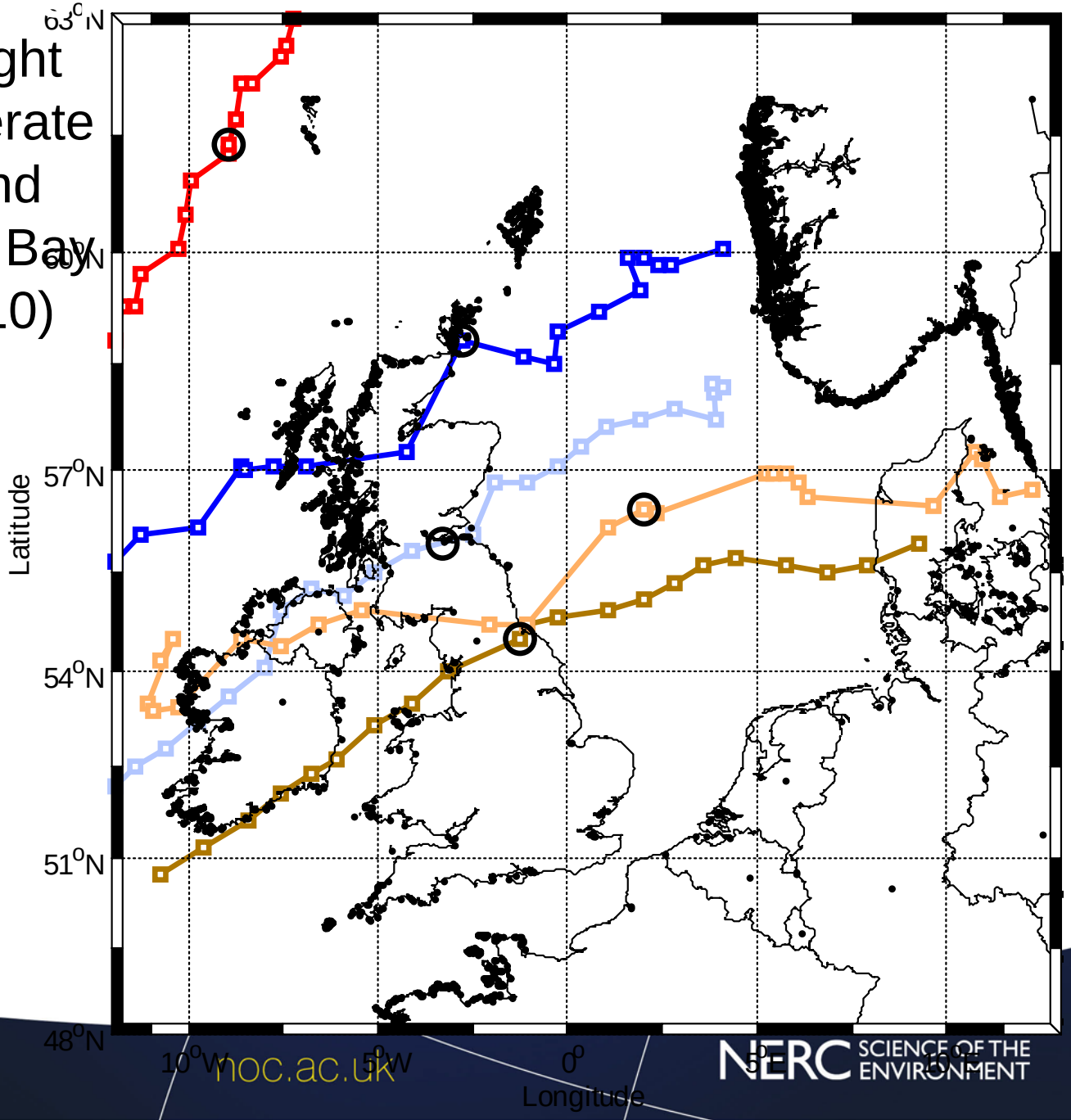
Brown shading = not statistically significant



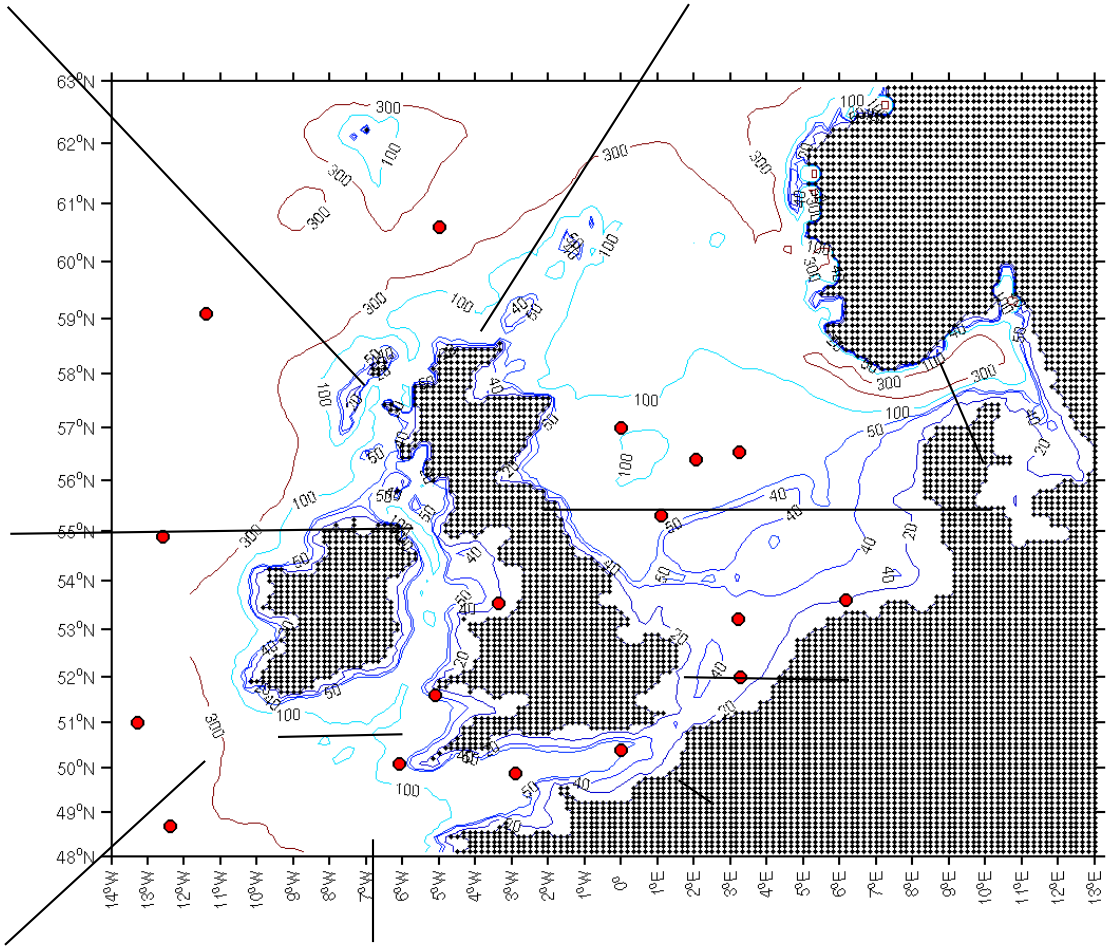
Reduced wave height north of Scotland, increase in wave height to south – consistent with southerly shift of storm tracks

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

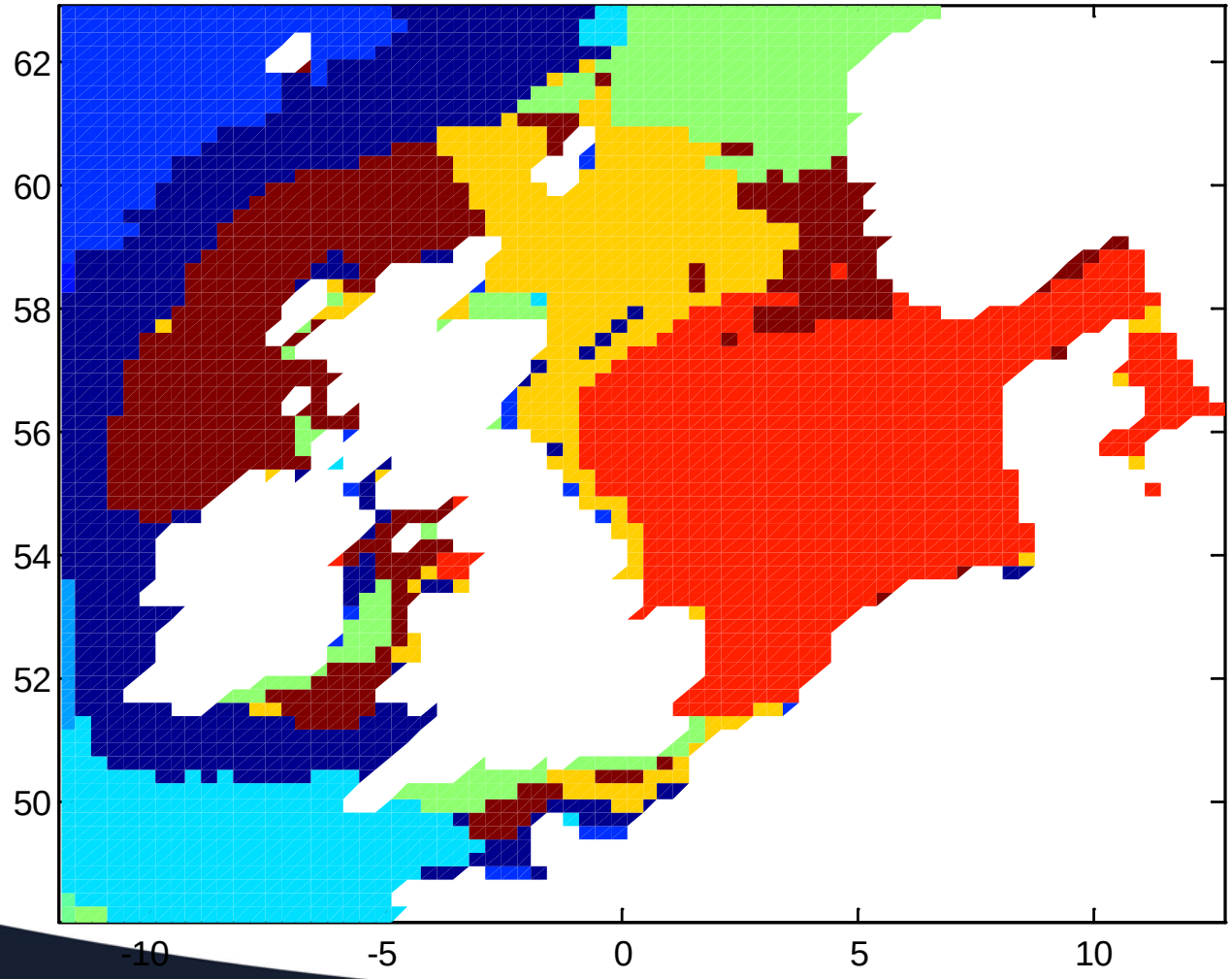




UK Wave Climate: different types of coastal exposure



Storm Wave characteristics – cluster analysis



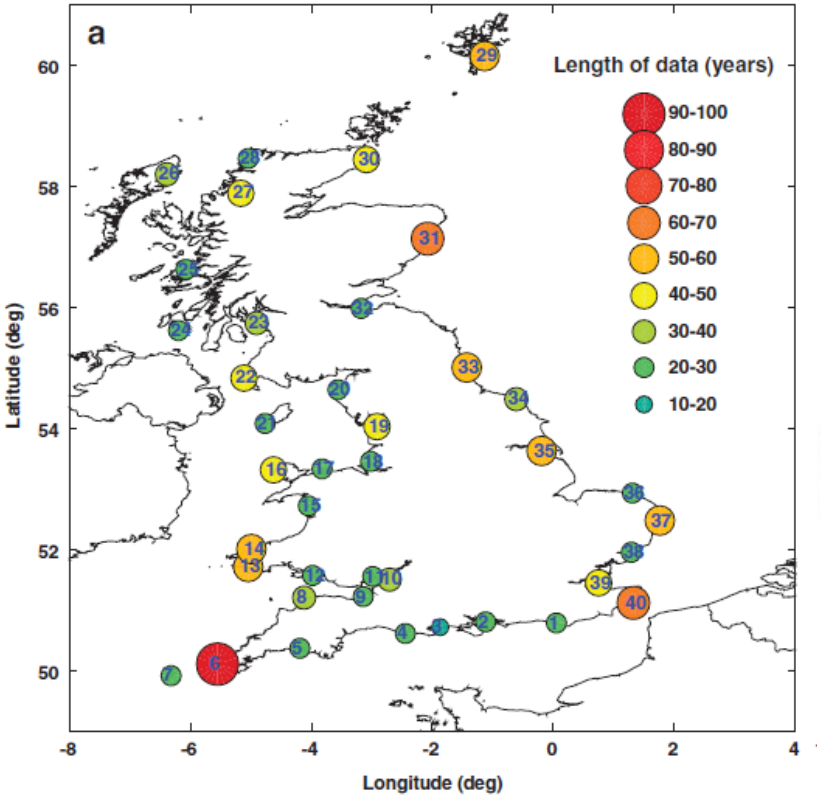
7 clusters from 4 correlation arrays:

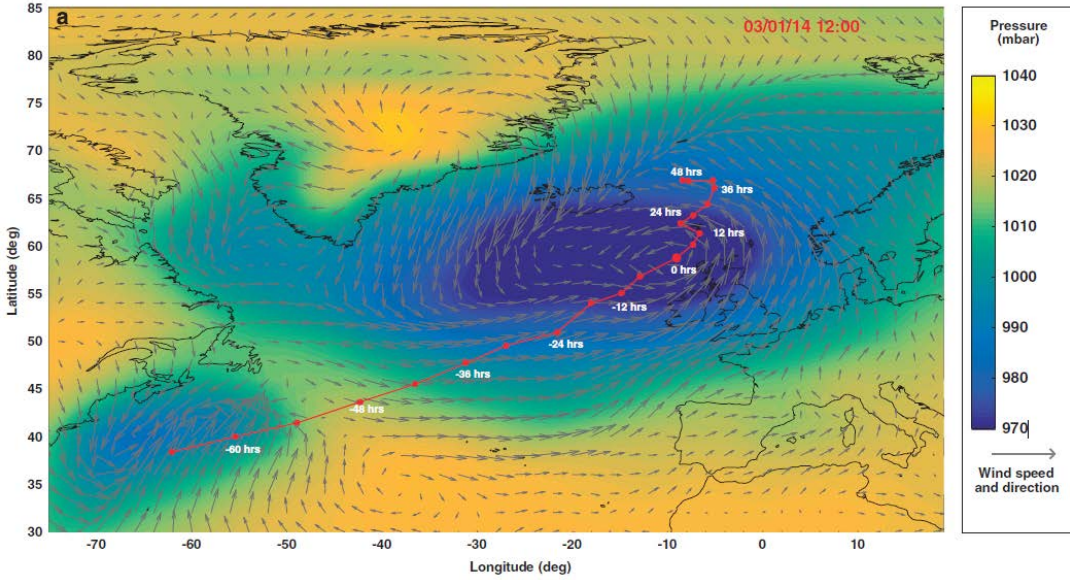
Hs:abs(U10);
Hs:Tz;
Hs:Tp;
Hs:Dm;

SurgeWatch database

Haigh et al. (Nature Scientific Data 2016)
DOI: 10.1038/sdata.2015.21

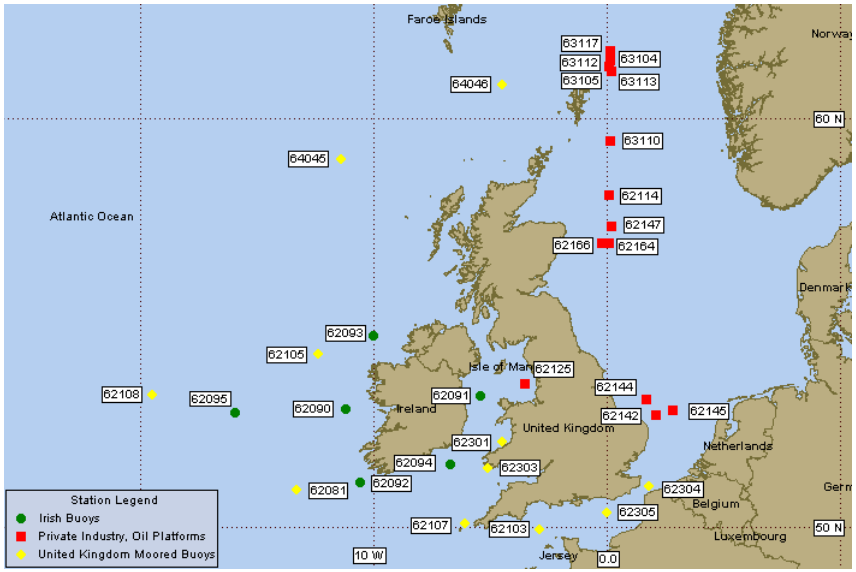
96 storms identified 1915-2014 where surge level exceeded 1:5 y return period





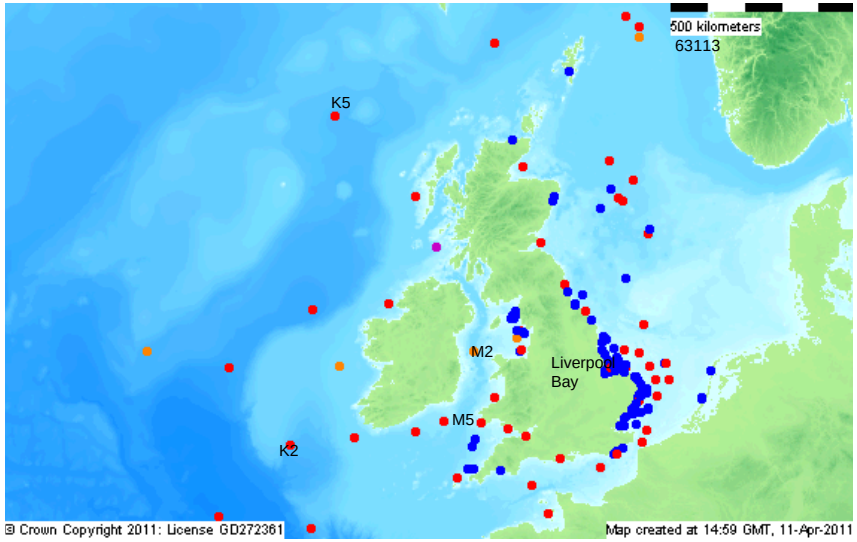
Wave buoy network around UK

NDBC wave buoys

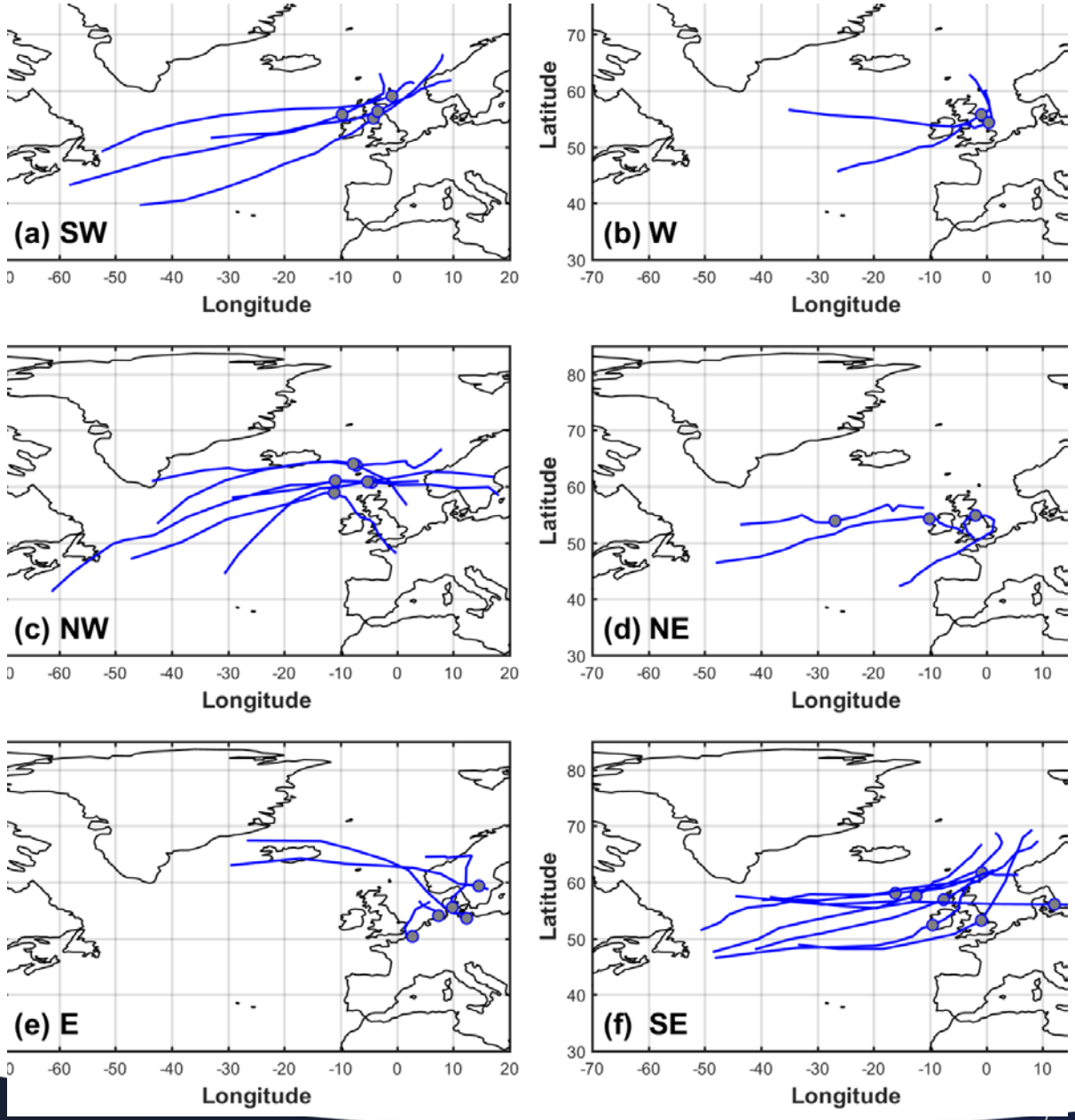


http://www.ndbc.noaa.gov/maps/United_Kingdom.shtml

UK CEFAS WaveNet buoys



http://www.cefas.defra.gov.uk/our-science/observing-and-modelling/monitoring-programmes/wavenet.aspx



Santos et al. (2017) identified 6 sea areas for waves

Synthesising Unprecedented Coastal Conditions: Extreme Storm Surges
PI: Horsburgh, Co-I: Haigh and Wolf

We will synthesise a number of “black swan” storm surge and wave events that impact on different parts of the UK coastline. We define a black swan as a storm that we have not observed but that is physically plausible on the basis of meteorological history and dynamically controlled adjustment to the observed weather systems.

This will be done by deriving synthetic storms to find the worst possible dynamically consistent forcing for each sea area and combining surge and wave components

These events will provide a new level of understanding of extreme coastal sea levels that will provide coastal planners and engineers with the information they need to effectively protect people and infrastructure.

SUCCESS project: perturbation of a storm

Modify storm of 6 Dec 2013 (Xaver)

Run UK surge model forced by original and perturbed storm

Use global and regional WW3 model output

Set up CS3 grid (same as surge model extent

Run same events as surge model

We want to (objectively) design a perfect (worst case) storm for each sea area.

Then determine its probability in present and future climate.

Winter of 2013/2014

- Slingo et al. (2014) noted that ‘recent studies suggest an increase in the intensity of Atlantic storms that take a more southerly track, typical of this winter’s extreme weather’. The pattern for winter 2013-2014 was for a more intense North Atlantic jet stream which moved further south over the UK.
- Special circumstances:
- Record low temperatures on the North American continent
- Contrast between the warm tropical Atlantic and cold air advecting south across the United States partly responsible for the persistence and unusual strength of the North Atlantic jet stream, which created the ideal conditions for generation of storms.
- Could have been related to the filling of the Aleutian Low in the northeast Pacific, which itself could be linked to high sea surface temperatures and a westward displacement of precipitation in the tropical Pacific.
- Possible influence of the tropical stratosphere and the potential for Arctic sea ice extent and solar activity to affect the climate of the UK.
- Need for further research to better understand the drivers of extreme UK winters and, due to their rare nature and high impact, how they may be affected by climate change. Is this going to recur? Is there a relationship with NAO etc?

Storm ‘Xaver’ 5-6 Dec 2013

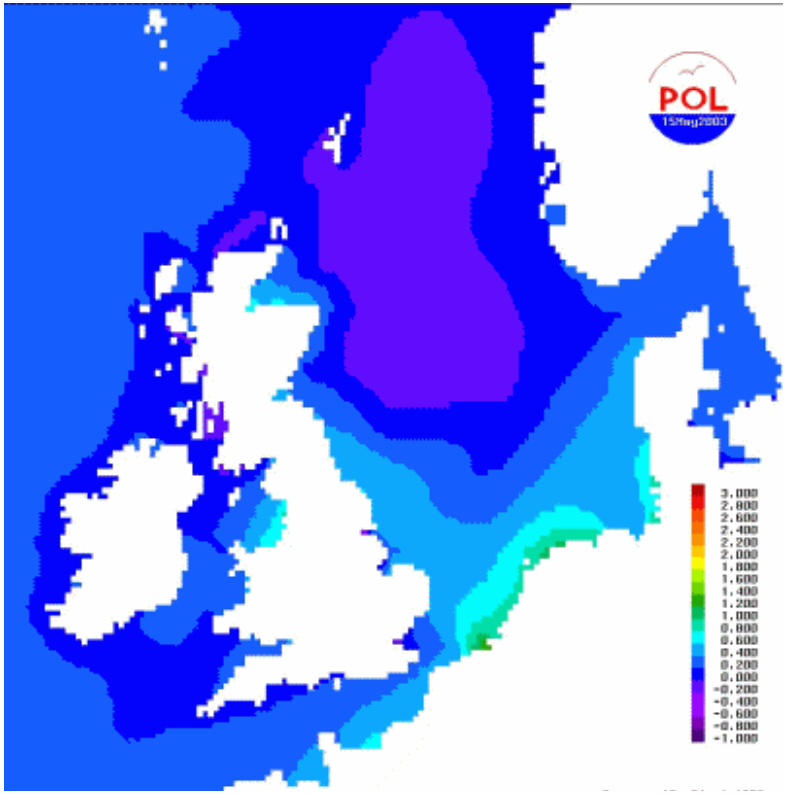
Biggest event to impact the UK east coast for more than half a century. Much flooding and damage, particularly in the northeast, but a repeat of the 1953 damage levels was prevented. (SurgeWatch Database)

Thousands of residents living in the UK's eastern coastal areas were evacuated following flood warnings by the UK Environment AgencyAuthorities closed the Thames Barrier to protect London from rising waters.

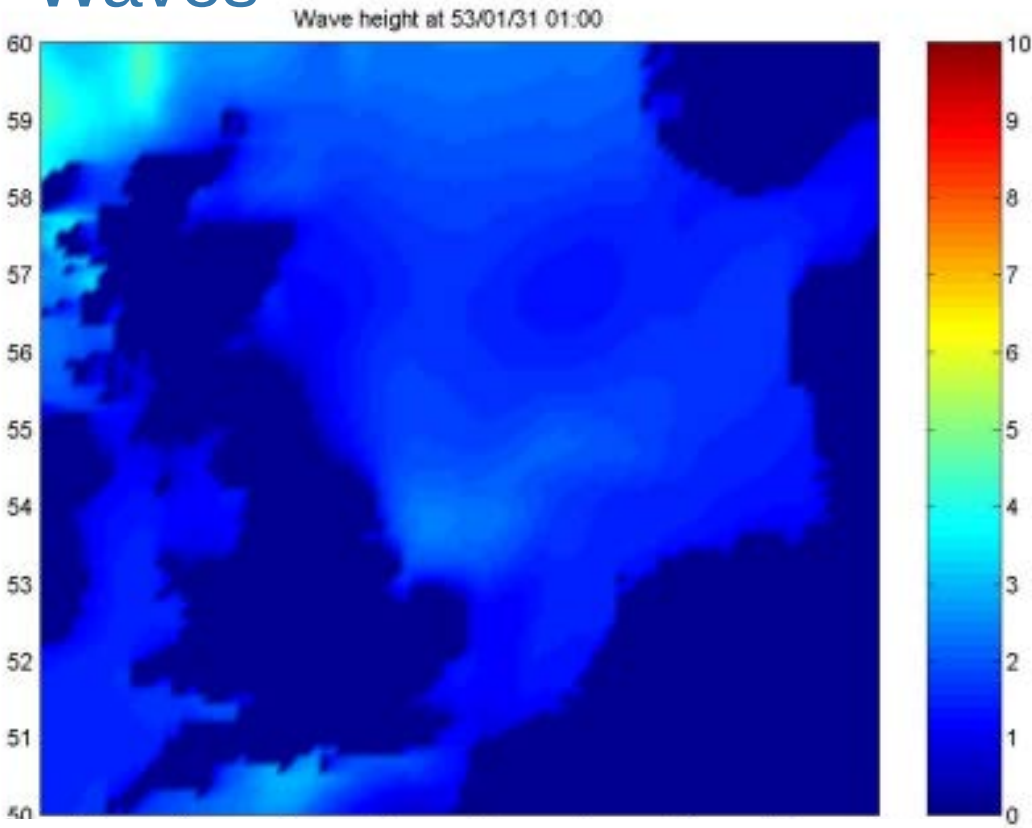
German port city of Hamburg saw worst flooding in decades. Water levels were reportedly some 6 meters (20 feet) above sea level, a level last reached just twice in the early 1990s.

The North Sea surge – Jan-Feb 1953 storm: Wolf and Flather (2005)

Surge

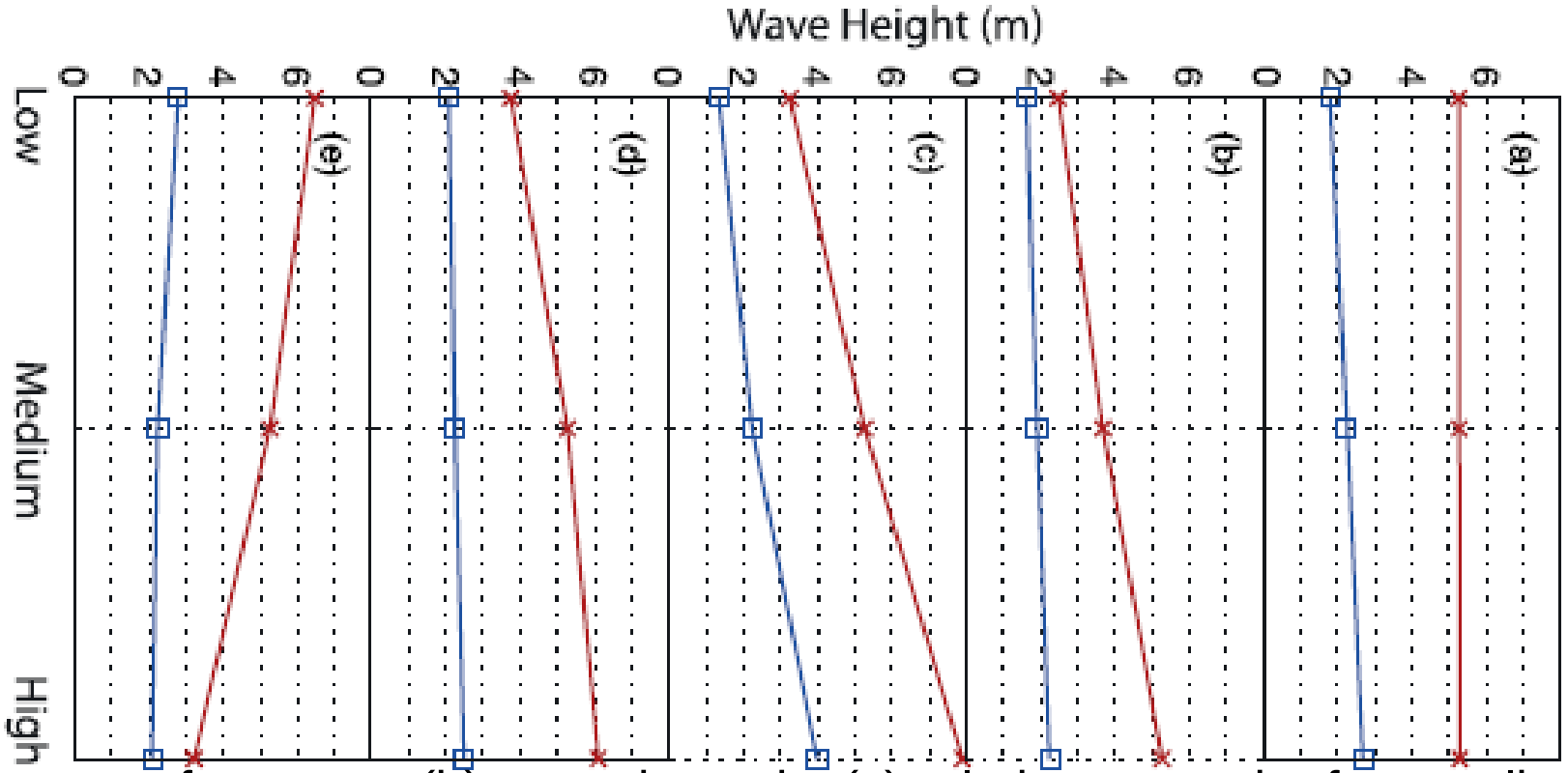


Waves



The track of the storm brought exceptionally strong northerly winds over shallow areas of the western and southern North Sea where the main surge effect was generated. The elongation of the storm to the north also produced a long fetch and generated large wind waves. This storm is still regarded as producing the highest water levels (equivalent to 5-6 Dec 2013)

What makes a perfect storm?
Wolf and Woolf (2006)



(a) storm frequency (b) storm intensity (c) relative strength of westerlies (d) storm track and (e) storm translation speed on wave height.
Red crosses = monthly maximum, blue squares = monthly mean.

References

Brown, J. M., Souza, A. J., & Wolf, J. (2010) **An investigation of recent decadal-scale storm events in the eastern Irish Sea.** *Journal of Geophysical Research (Oceans)*. doi:10.1029/2009JC005662

Haigh, I.D., Wadey, M.P., Wahl, T., Ozsoy, O., Nicholls, R.J., Brown, J.M., Horsburgh, K., Goulby, B. (2016) **Spatial Footprint and Temporal Clustering of Extreme Sea Level and Storm Surge Evens around the Coastline of the UK.** Scientific Data, 3, 160107.

Santos, V.M., Haigh, I.D. and Wahl, T. (2017) **CoastlineSpatial and Temporal Clustering Analysis of Extreme Wave Events around the UK Coastline.** Journal of Marine Science and Engineering, 5, 28; doi:10.3390/jmse5030028

Spencer, T. et al., (2015). **Southern North Sea storm surge event of 5 December 2013: Water levels, waves and coastal impacts.** Earth-Science Reviews, 146, pp.120–145.

Wadey, M.P., Haigh, I.D. & Brown, J.M., (2014). **A century of sea level data and the UK' s 2013/14 storm surges: an assessment of extremes and clustering using the Newlyn tide gauge record**. Ocean Science, 10(6), pp.1031–1045.

Wadey, M.P. et al., (2015). **A comparison of the 31 January–1 February 1953 and 5–6 December 2013 coastal flood events around the UK.** Frontiers in Marine Science, 2.

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

Wolf, J. 2009 **Coastal Flooding – Impacts of coupled wave-surge-tide models.** Natural Hazards, 9 (2), 241-260.

Wolf, J., Lowe, J. and Howard, T. (2015) **Climate Downscaling: Local Mean Sea-Level, Surge and Wave Modelling**, Chapter 2 in 'Broad Scale Coastal Simulation: New Techniques to Understand and Manage Shorelines in the Third Millennium' (eds R. J. Nicholls, R. J. Dawson and S. A. Day); Springer.

Woolf, D. and Wolf, J. (2013) **Impacts of climate change on storms and waves,** MCCIP Science Review 2013, 20-26, doi:10.14465/2013.arc03.020-026

Zappa, G., et al.(2013) A multimodel assessment of future projections of the North Atlantic and European extratropical cyclones in the CMIP5 climate models. J. Clim. 26, 5846–5862


Questions?

SUMMARY

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