The Perfect Storm:

Exploring wave climate projections and the upper limit of coastal flooding for the UK

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Challenger Waves SIG

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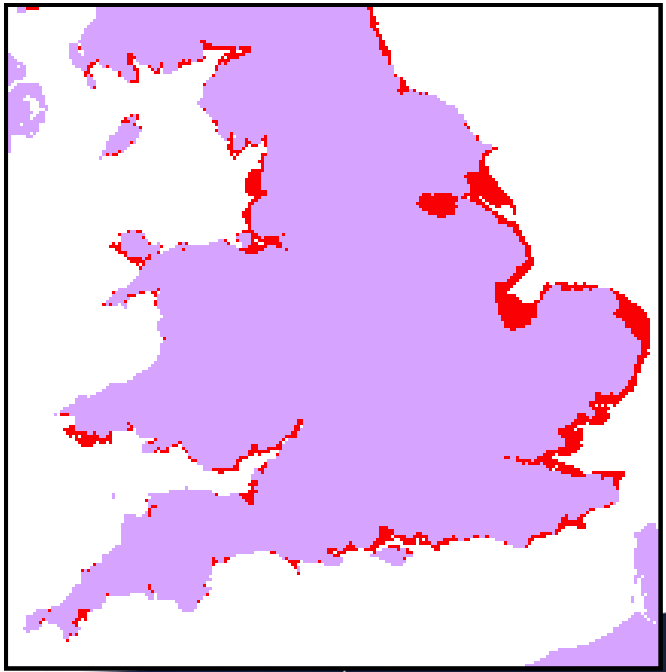
OUTLINE

- Coastal flooding in UK
- North Atlantic storms
- Climate and Wave Model downscaling
- How can we predict the worst case scenarios?
- What are the implications of climate change?

Waves overtopping Blackpool promenade, NW England

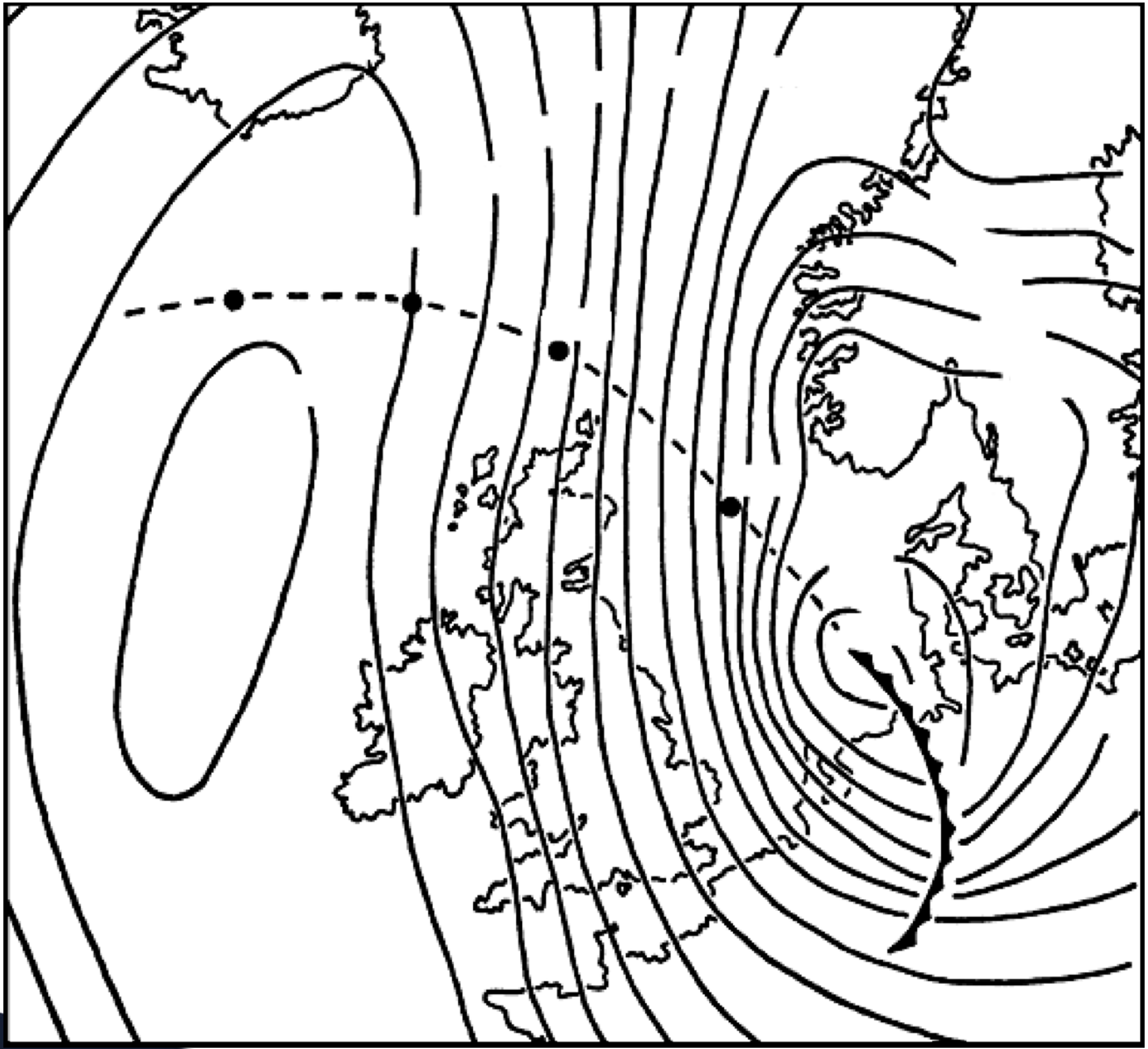
Coastal Defence

- 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



1953 storm surge – Sea Palling, north Norfolk

Over 2000 lives were lost (300 in UK)



Strong and persistent northerly winds

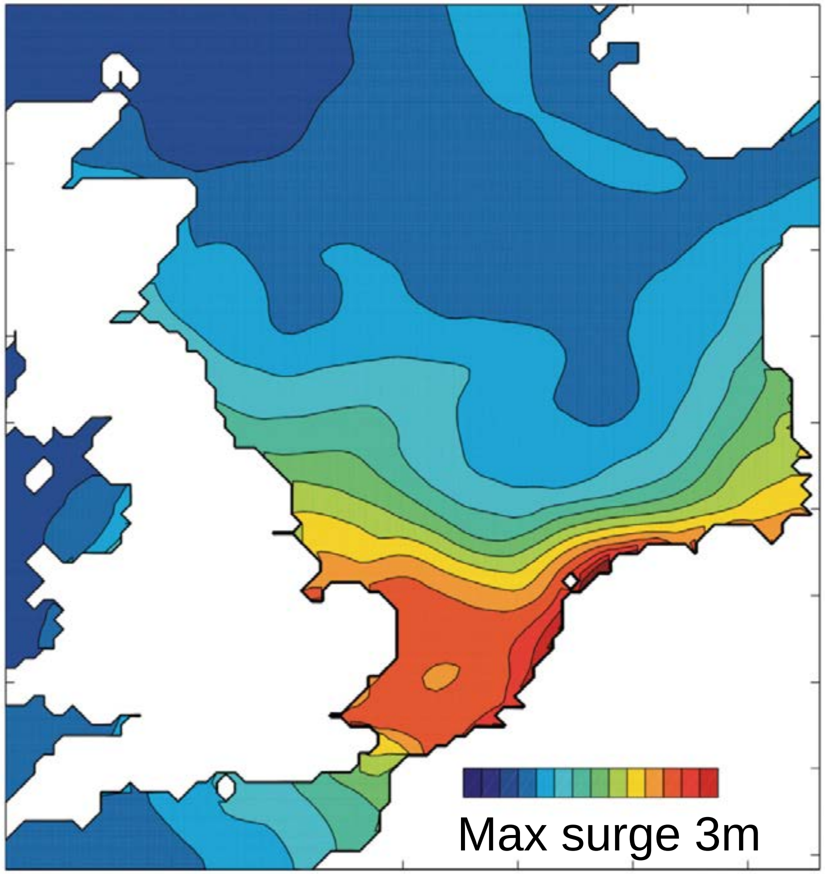
High spring tide

Surge exceeded 2.25m over most of southern North Sea and over 3m on Dutch coast

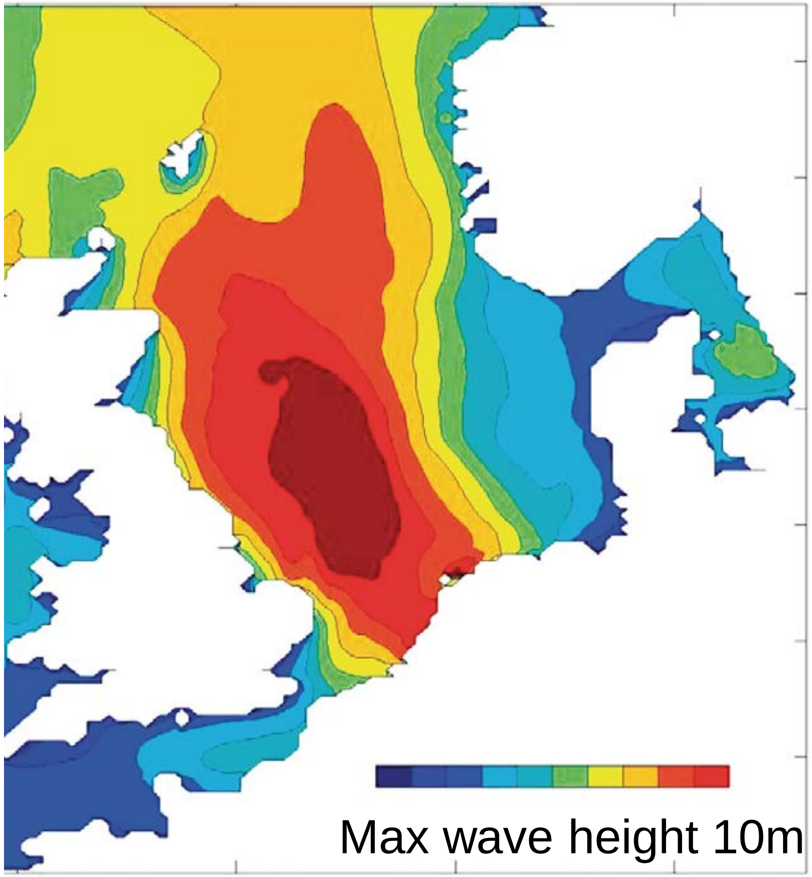
Waves over 8m in southern North Sea

Wolf and Flather (PTRSA, 2005)

Surge



Waves



North Atlantic storms

- Tropical and extra-tropical storms
- Hurricane season June-November
- In March 2004 Catarina was the first hurricane-intensity tropical storm ever recorded in the South Atlantic
- Global warming is leading to more hurricanes
- Mid-latitude depressions are caused by different processes

What factors cause large coastal impacts for UK?

Surges

Inverse barometer effect

Strong winds especially in shallow water

Coastal boundary

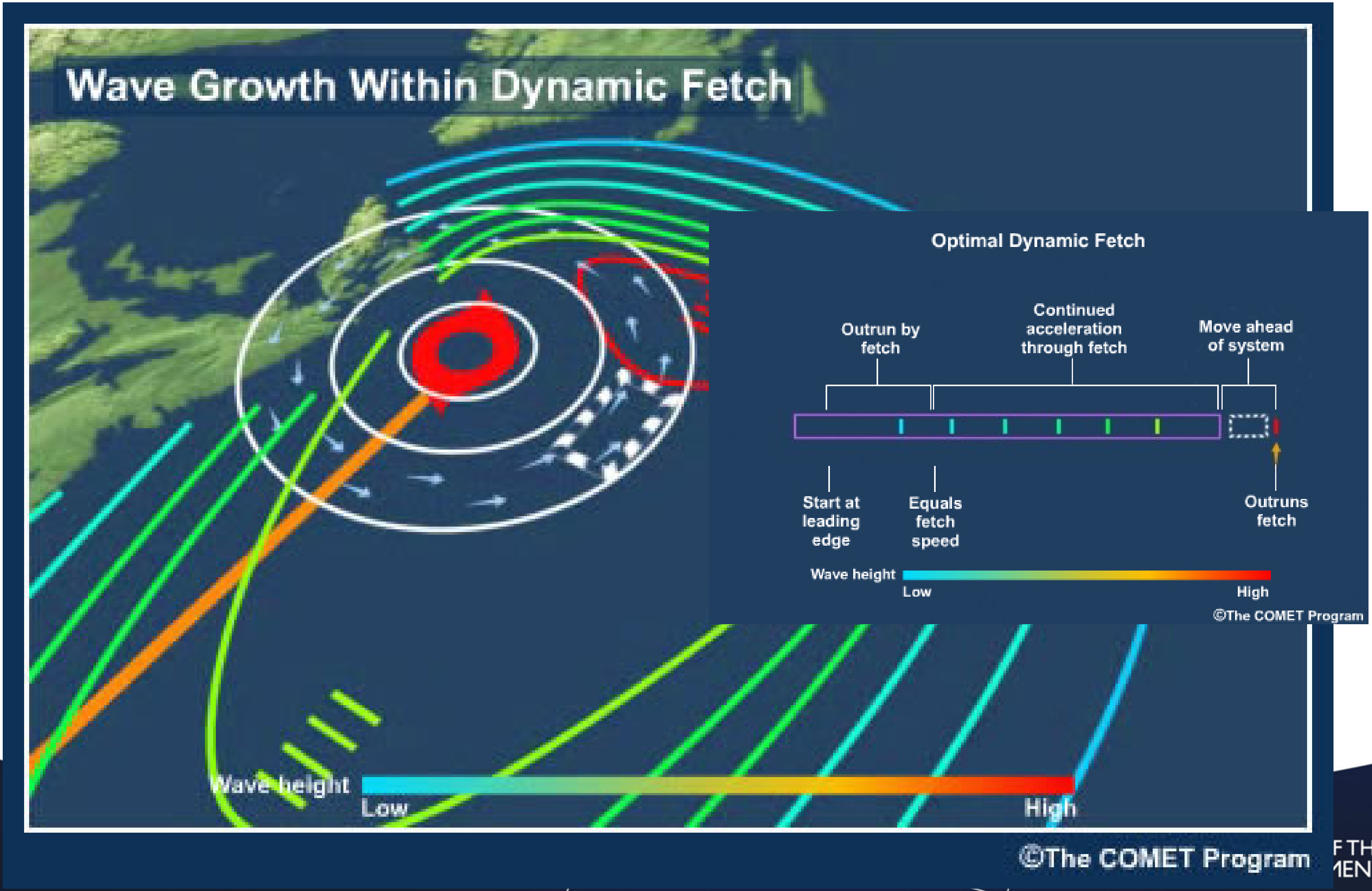
Waves

Strong winds

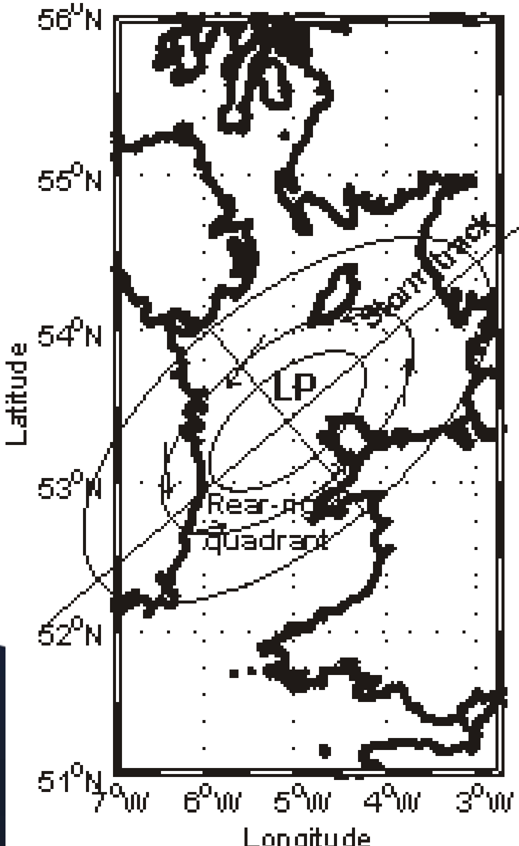
Maximum Fetch

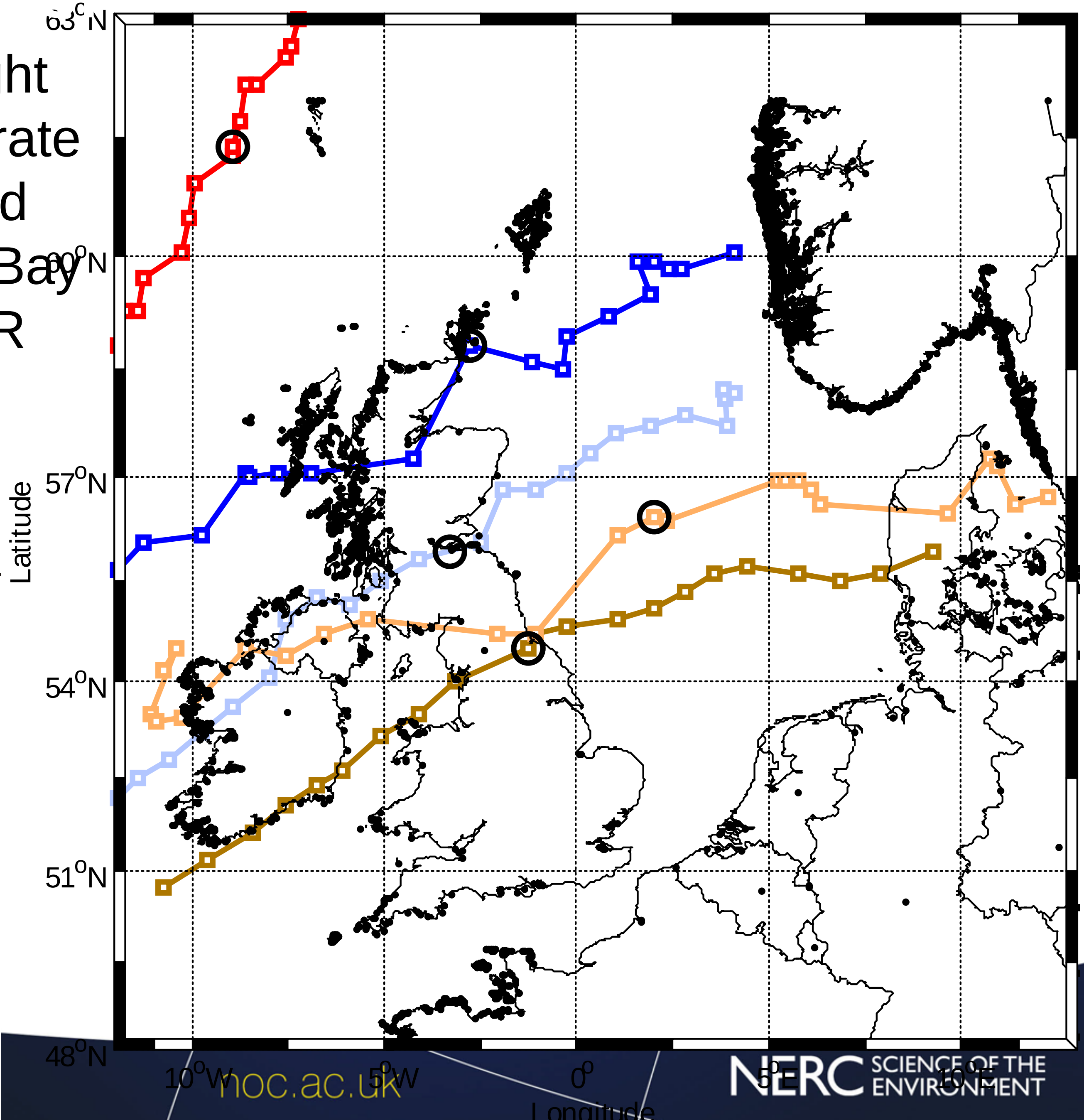
Maximum duration

Dynamic Fetch – a moving storm can increase the effective fetch of revolving winds in a certain quadrant when the storm moves in the same direction as those winds



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





11-12 January 2005, South Uist

In January 2005 a severe storm hit the Outer Hebrides and there was flooding on the islands of South Uist and Barra, caused by storm surge and waves.

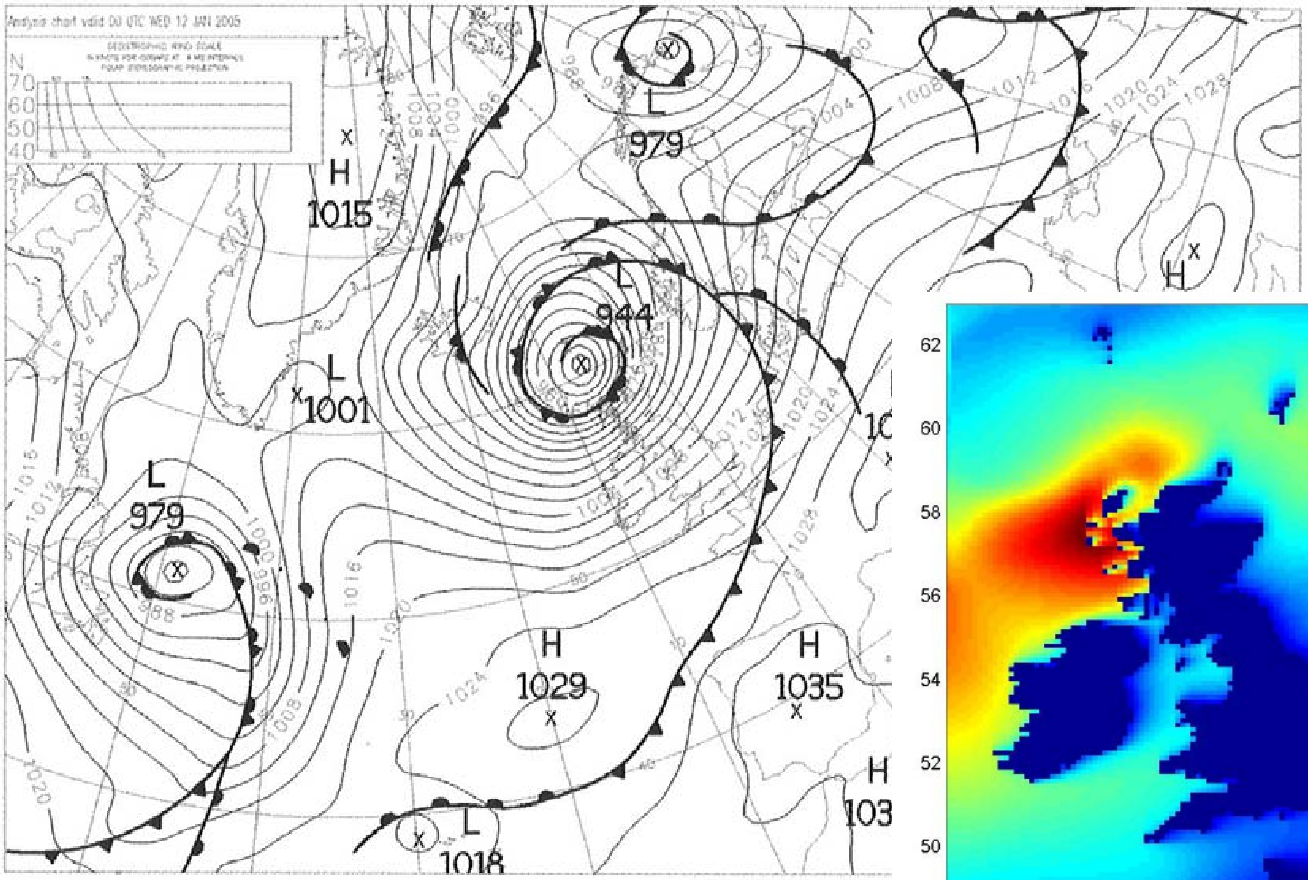
Five lives were lost in one family as they attempted to cross a causeway near Balgarva on South Uist in two cars.

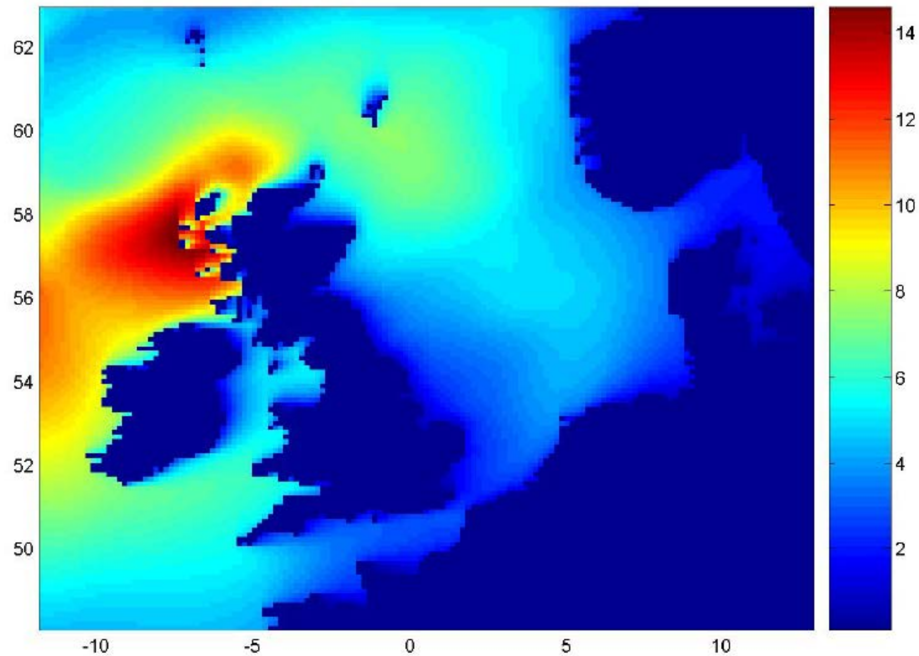
Wave data from buoys and altimeter are used to validate a SWAN model.

The wave set-up was found to be nearly 0.5m due to the proximity of exceptionally high waves reaching over 14m less than 50km offshore.

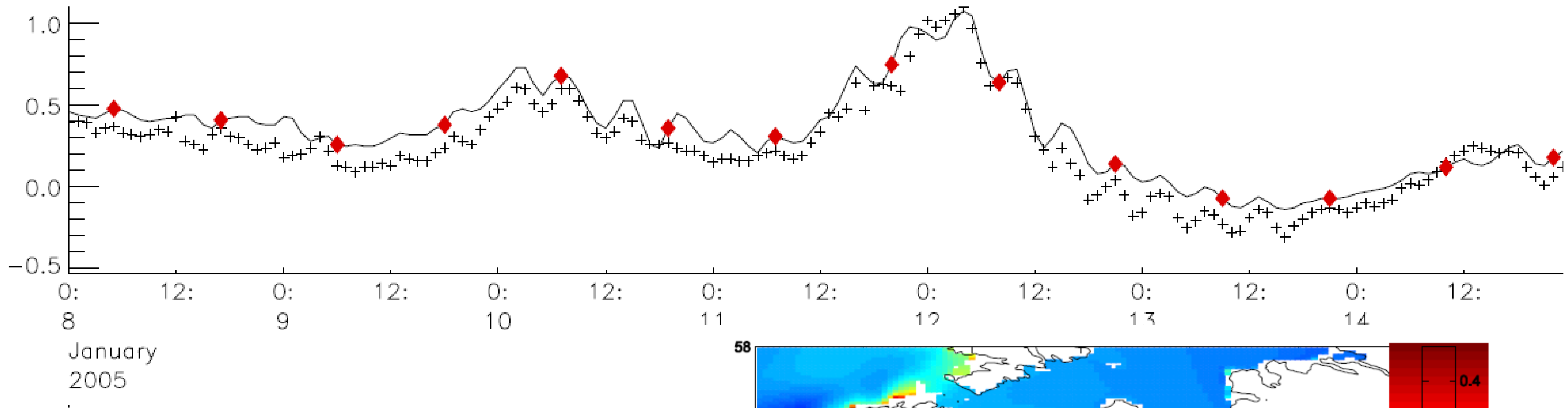
The associated storm surge exceeded 1m at Stornoway

Synoptic chart for 00:00 12 January 2005

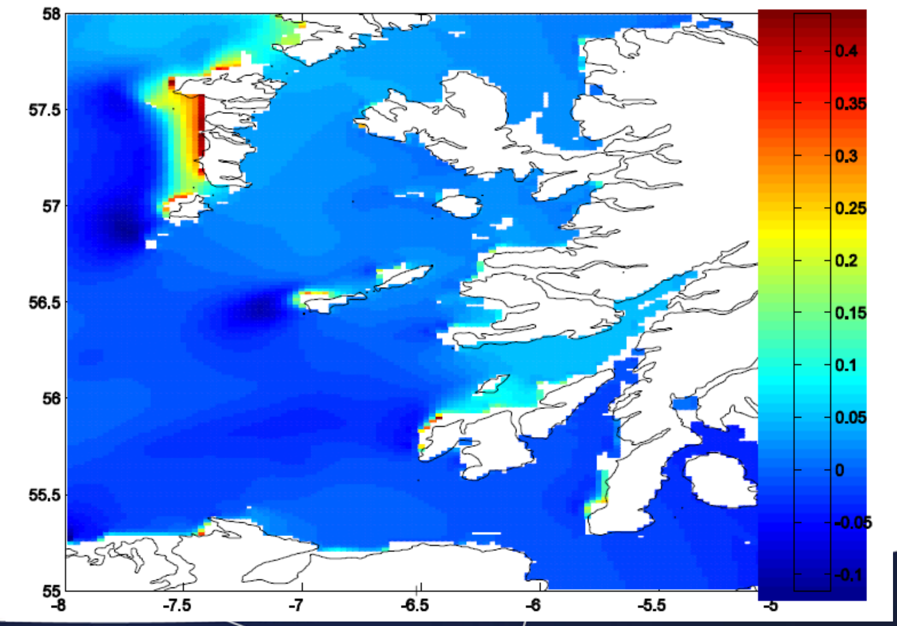




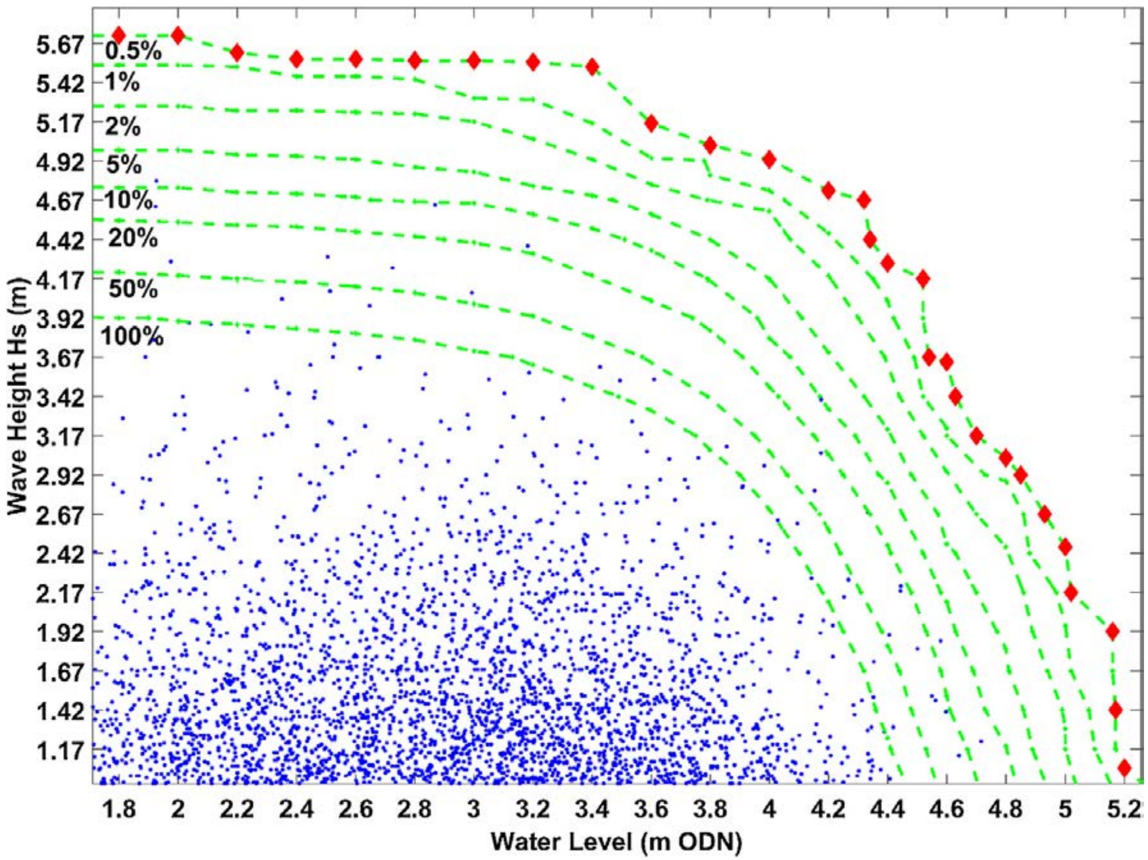
Water level from storm surge plus wave setup



Wave setup at peak of storm 23:00 11 January 2005



Joint probability of waves and water level at Dungeness (from Prime et al. (2016)



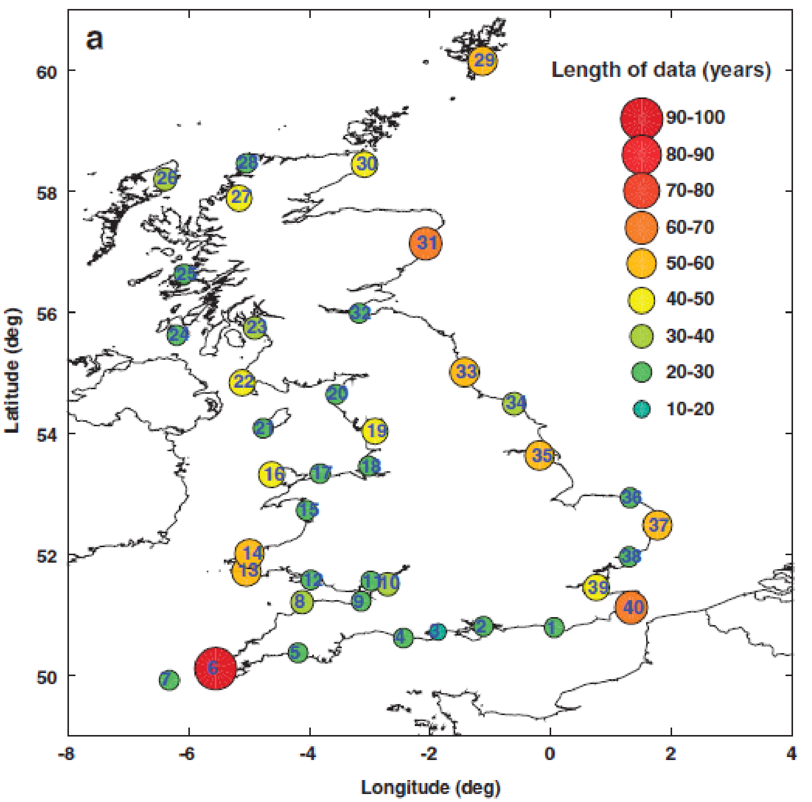
Xbeach-G used to estimate change in beach morphology and overtopping, LISFLOOD-FP used for inundation modelling

Greatest flood hazard is low swell waves with the longest periods during extreme water levels, rather than large, shorter period wind waves occurring at lower water levels.

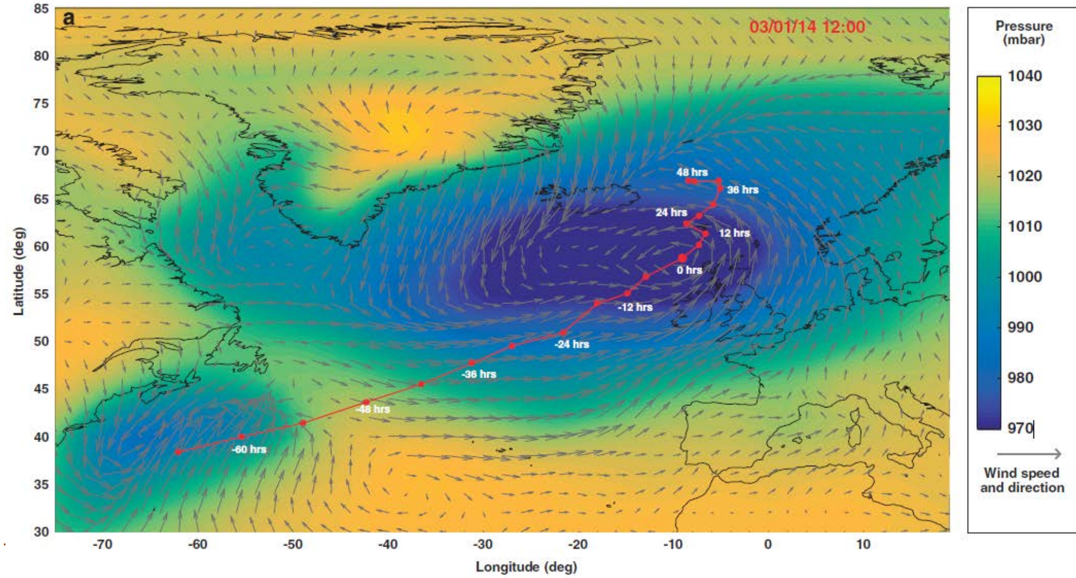
Joint Hs and WL probability curves (green lines) of the observed conditions at Dungeness. The blue dots are wave height and water observations. Red dots = 30 selected water level and wave scenarios

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



RISES-AM- project

- What are projected changes in storms under a warming climate?
- Can these be modelled accurately in climate models?
- Are there significant changes between CMIP3 (2007) and CMPI5 (2013)?
- Will these be converted to significant changes in projected waves and surges on the Atlantic coast of Europe?
- Can we distinguish between natural variability and the climate signal for storms and waves?
- What are the differences between medium (RCP4.5) and high (RCP8.5) emissions scenarios
- What novel coastal adaptation/mitigation methodologies can be deployed?

EcoWatt2050 project

Aim is to assess the effects of climate change and large-scale energy extraction on marine ecosystems by 2050

Method – (i) derive plausible climate scenarios based on RCP4.5 and RCP8.5 using 3D baroclinic hydrodynamic and wave models for time horizon of 2050 (ii) implement tidal turbines and wave devices in the models

Examine effects of climate change on ecosystems especially mobile marine species

Examine effects of large arrays of wave and tidal energy devices on the same ecosystems

Do climate change or energy extraction have the largest impacts and are they additive or compensatory?

COWCliP (Coordinated Ocean Wave Climate Project)

- Part of WMO/JCOMM
- Aim: Raise profile of role of waves in climate modelling
- Good uptake of COWCLIP outcomes into the IPCC WG1 AR5 (Chapter 13: Sea-Level Change)

Future goals::

To develop an ocean current-wave-atmosphere coupled system, eventually to have ocean surface waves modeled in climate and/or earth system models

To develop higher resolution regional projections/simulations for impact studies

Hemer et al. (2013) Projected changes in wave climate from a multi-model ensemble. **Nature Climate Change*, 3, 471-476***

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.

Storm Tracks in Climate Models

- **Models are able to capture the general characteristics of storm tracks and extra-tropical cyclones,** and there is **some evidence of improvement since the AR4**

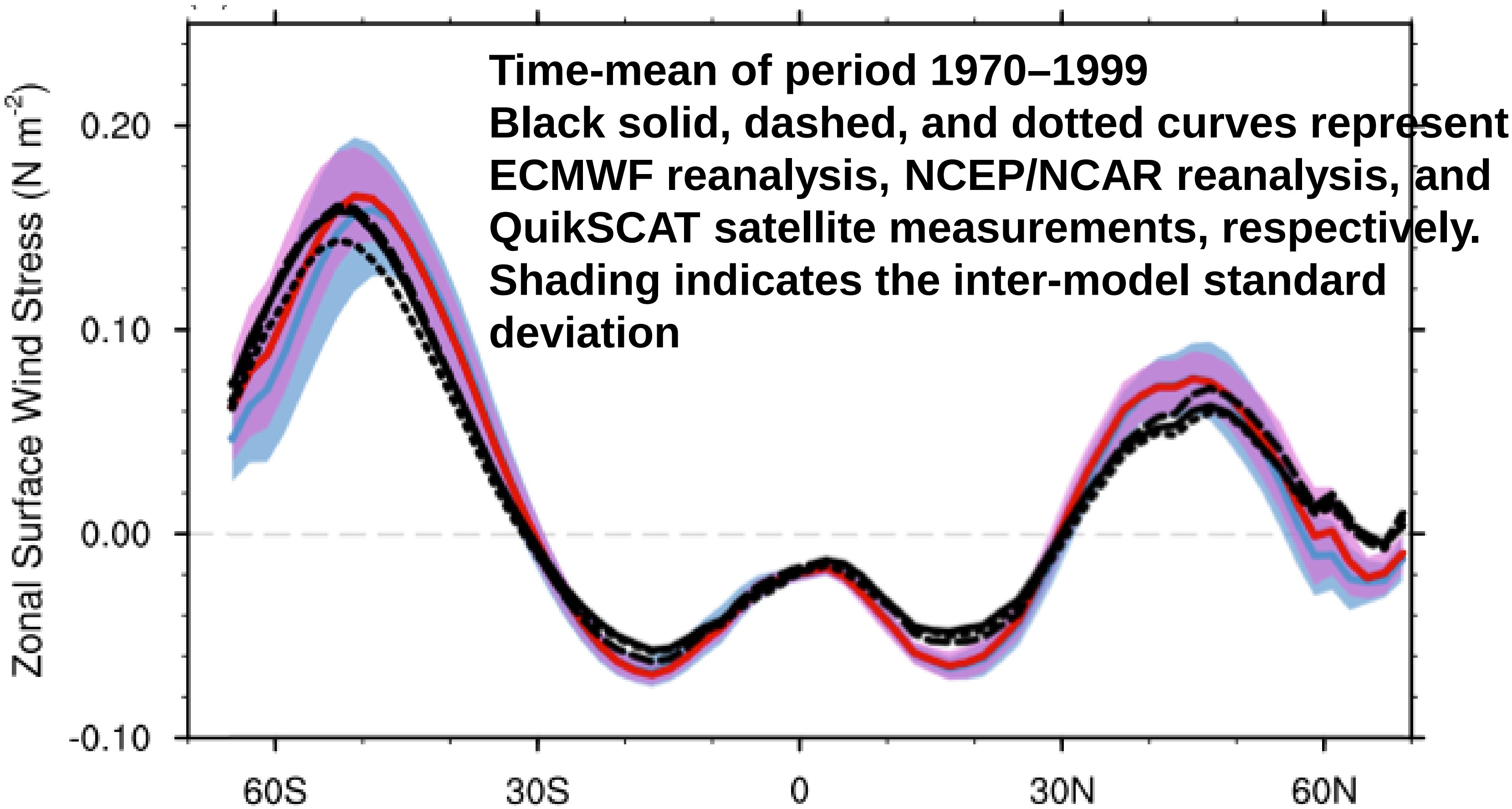
- Storm track biases in the North Atlantic have improved slightly, but models still produce a storm track that is **too zonal and underestimate cyclone intensity**

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

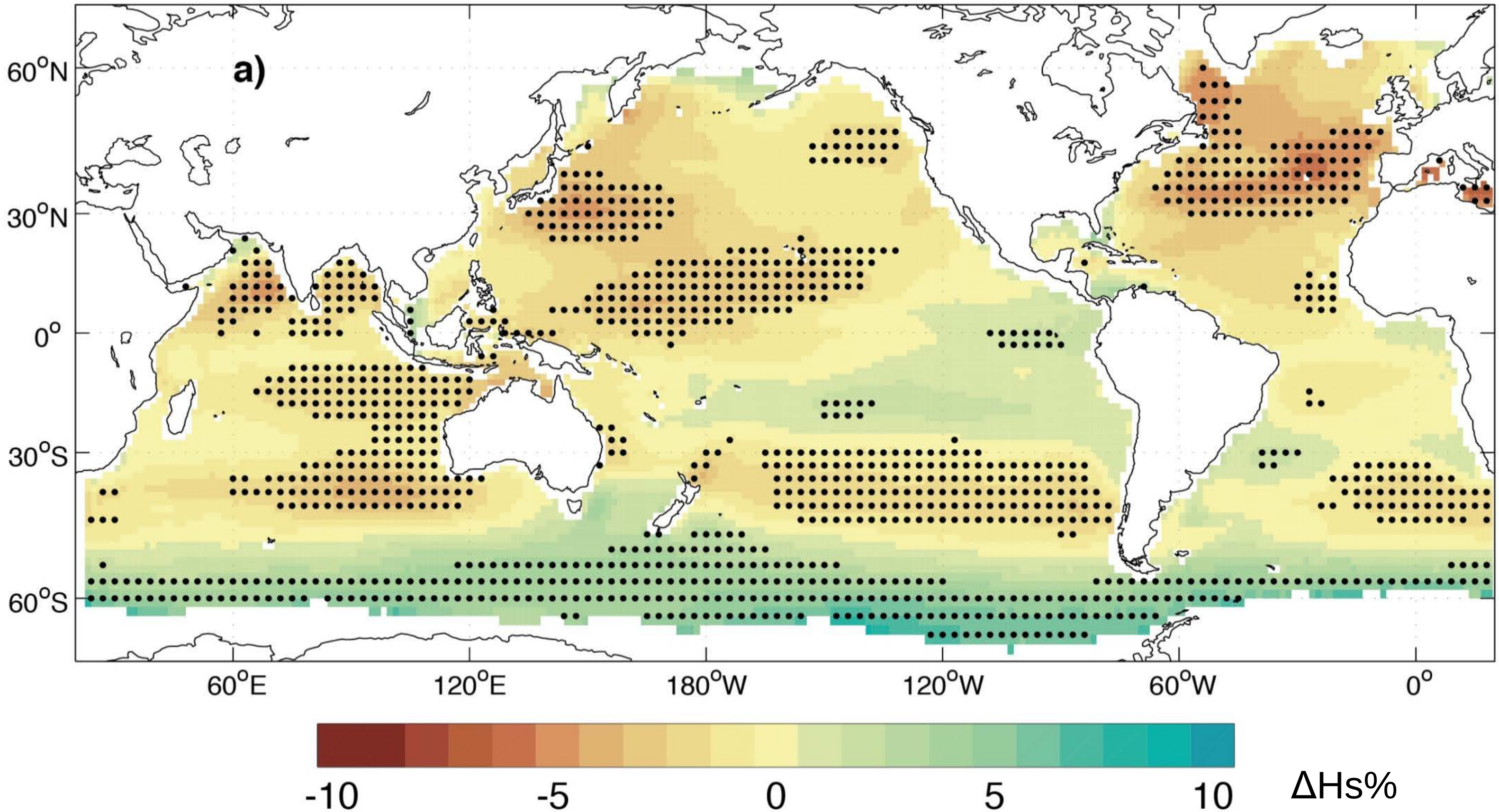
Models generally perform better in summer!

Zonal-mean zonal wind stress over the oceans in a multi-model mean from CMIP3 (blue) and CMIP5 (red) models simulations.

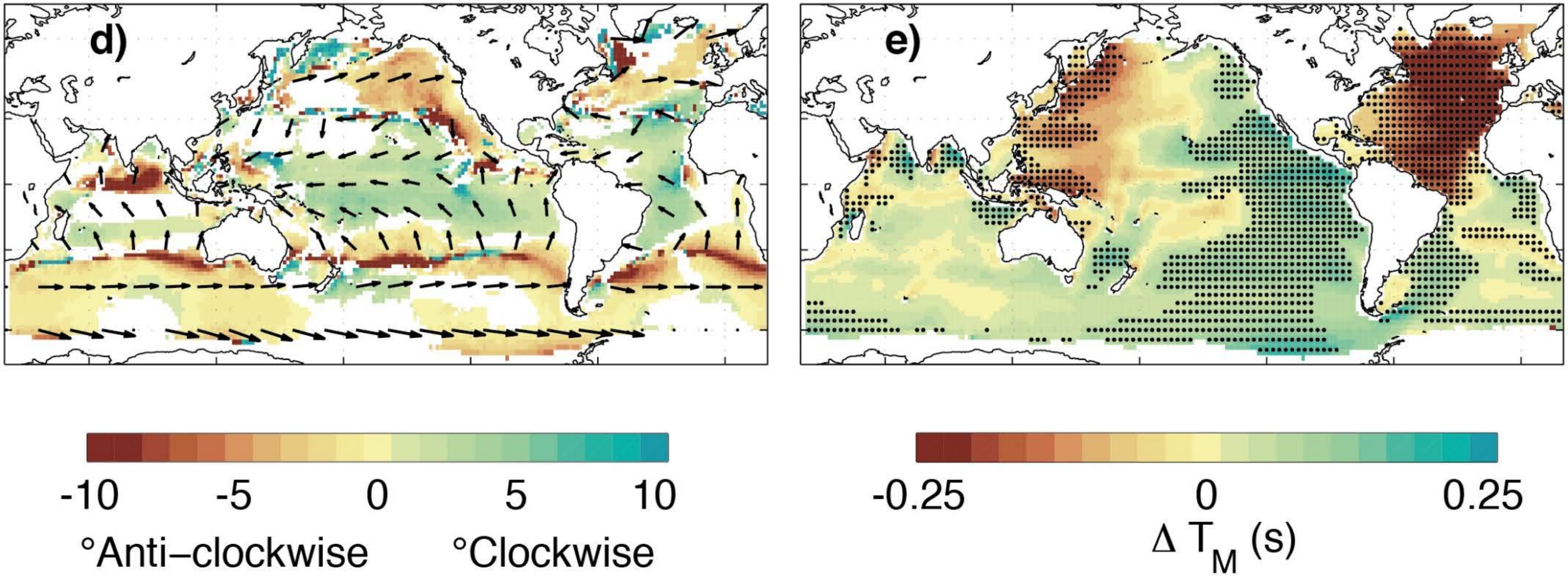


(figure reproduced from Fig. 9.19b in IPCC AR5)

Changes in waves, CMIP3: IPCC AR5 Figure 13:26



Projected changes in wind-wave conditions (~2075-2100 compared with 1980-2009) derived from the COWCLIP project (Hemer et al., 2013) (a) percentage difference in annual mean significant wave height. Hashed regions indicate the difference is greater than the 5-member ensemble standard deviation

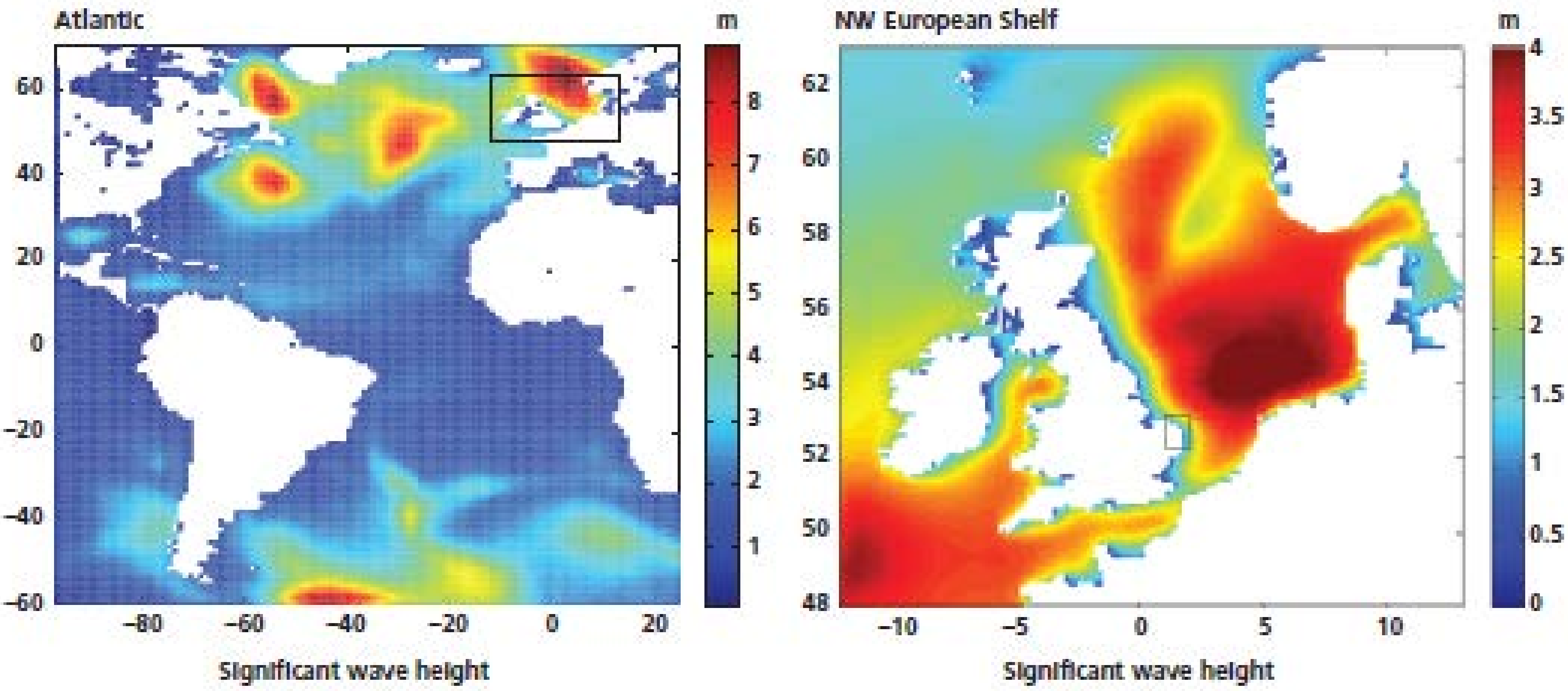


(d) as (a) but displaying absolute changes in mean wave direction, with positive values representing projected clockwise rotation relative to displayed vectors, and colours shown only where ensemble members agree on sign of change (e) as for (a), but displaying absolute change in mean wave period.

Downscaling global to regional winds and waves

- Climate change assessments are almost always based on the outputs of general circulation models (GCMs)
- This typically includes an additional step of downscaling using higher resolution regional climate models or some form of statistical model (Wolf et al., 2015)
- Ways of assessing climate change
  - Use GCM output directly – but **there may be bias** between statistics for ‘control runs’ of historic climate and actual climate
  - Adjust for historic climate using ‘change factors’
  - Use ‘climate analogues’ - using past periods to represent future
  - **Accept bias and use difference between present and future GCM outputs**

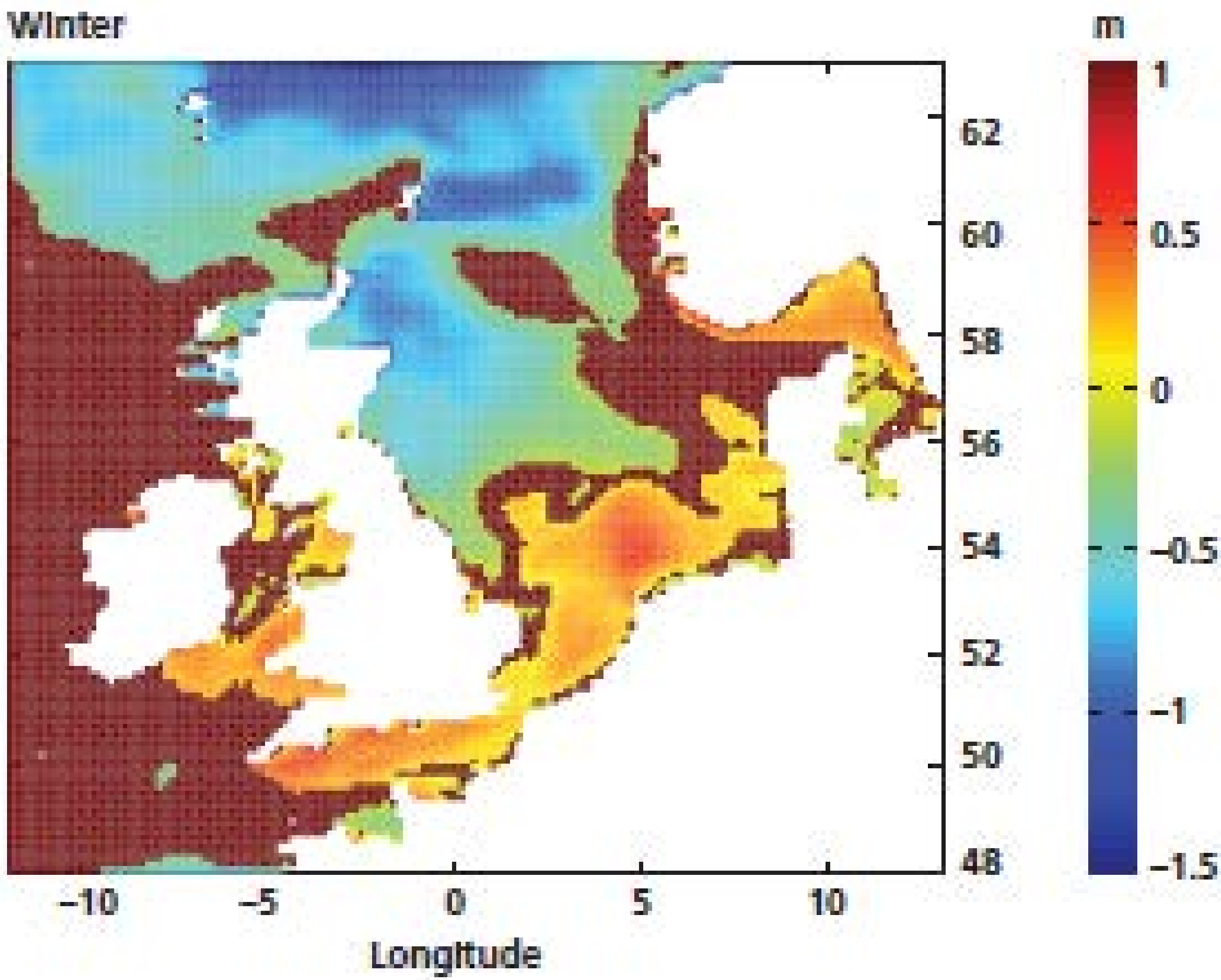
Downscaled wave projections for UKCP09 WAM model forced by CMIP3 SRES HadCM3



Wolf et al. (2015)

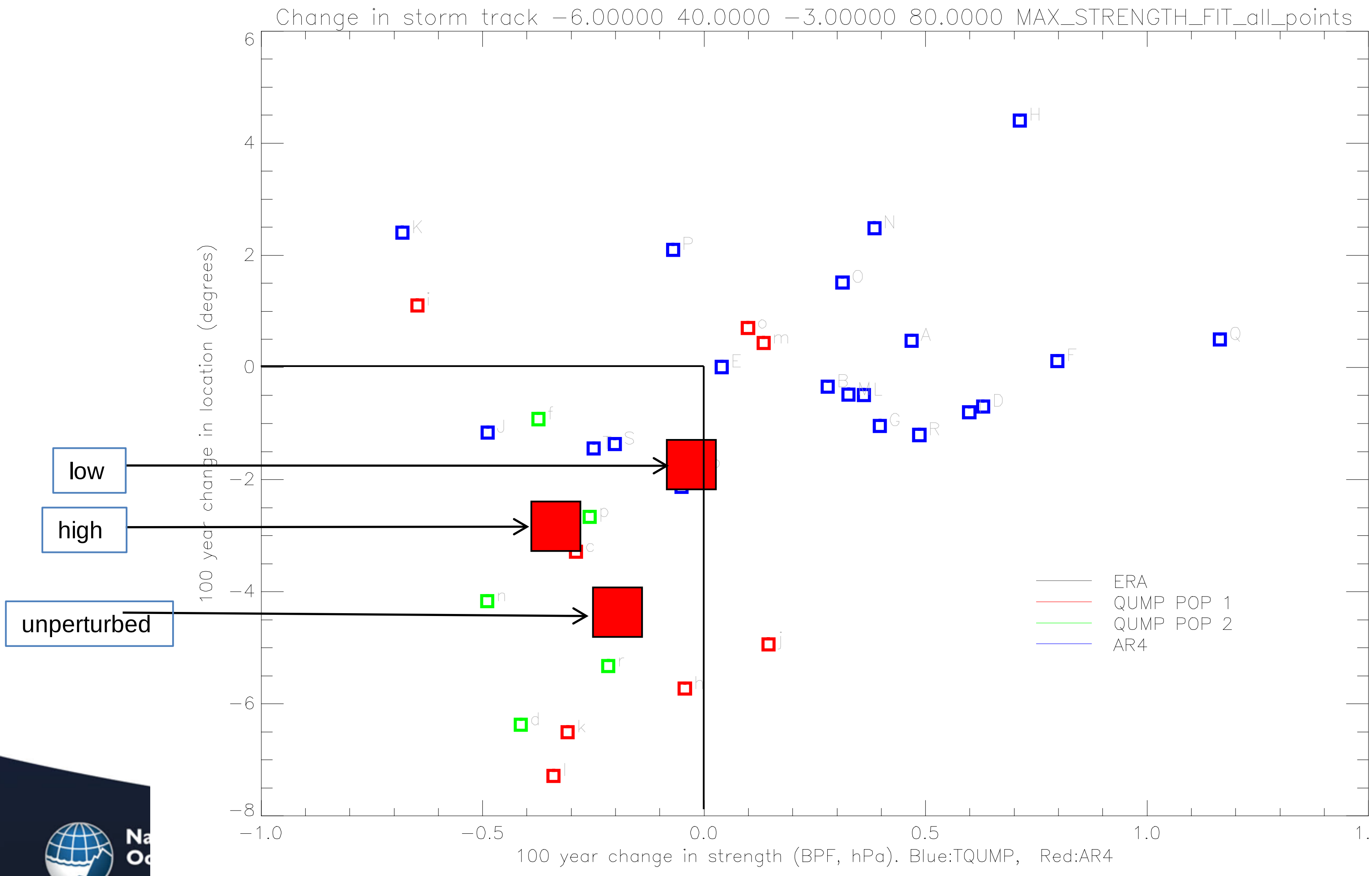
Projected changes in mean winter wave height UKCP09

Brown shading = not statistically significant

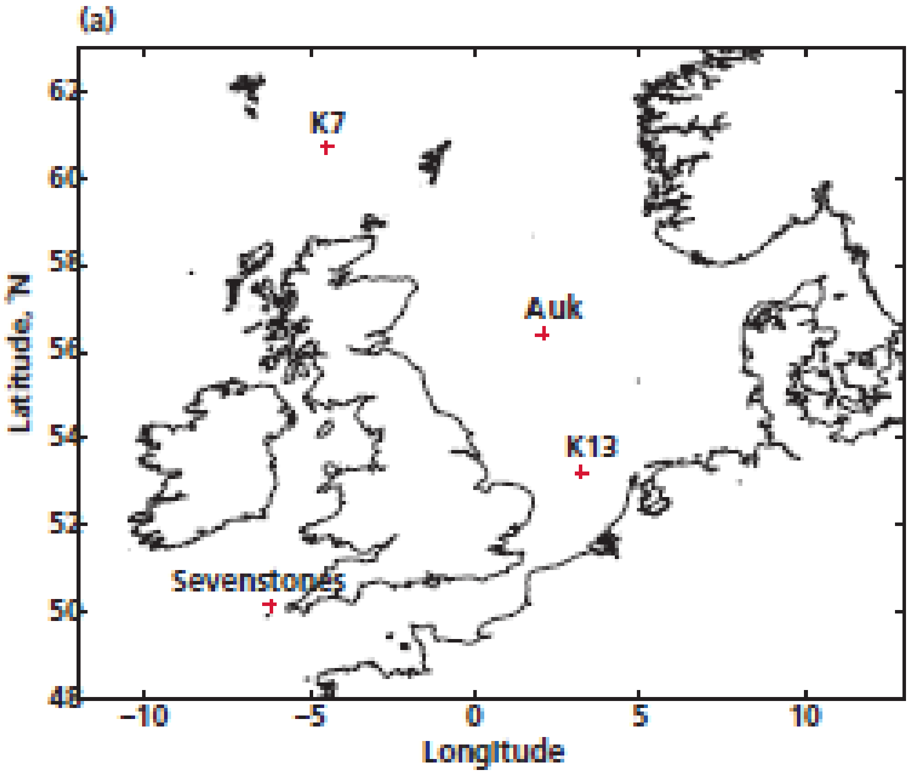


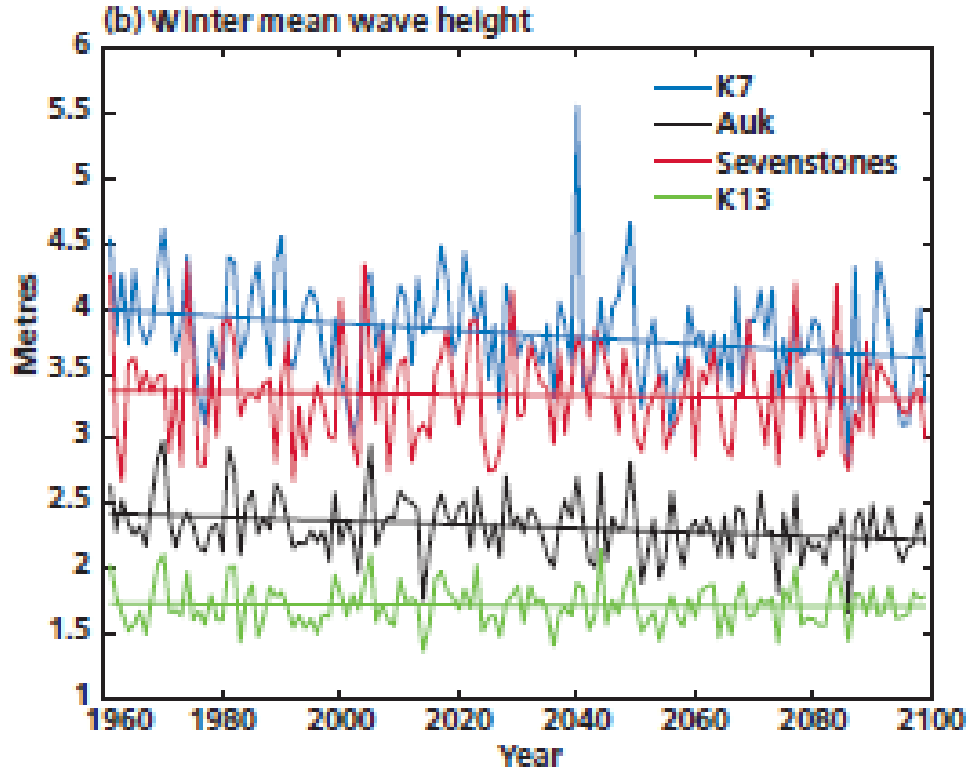
Reduced wave height north of Scotland, increase in wave height to south – consistent with southerly shift of storm tracks

Changes in storm tracks

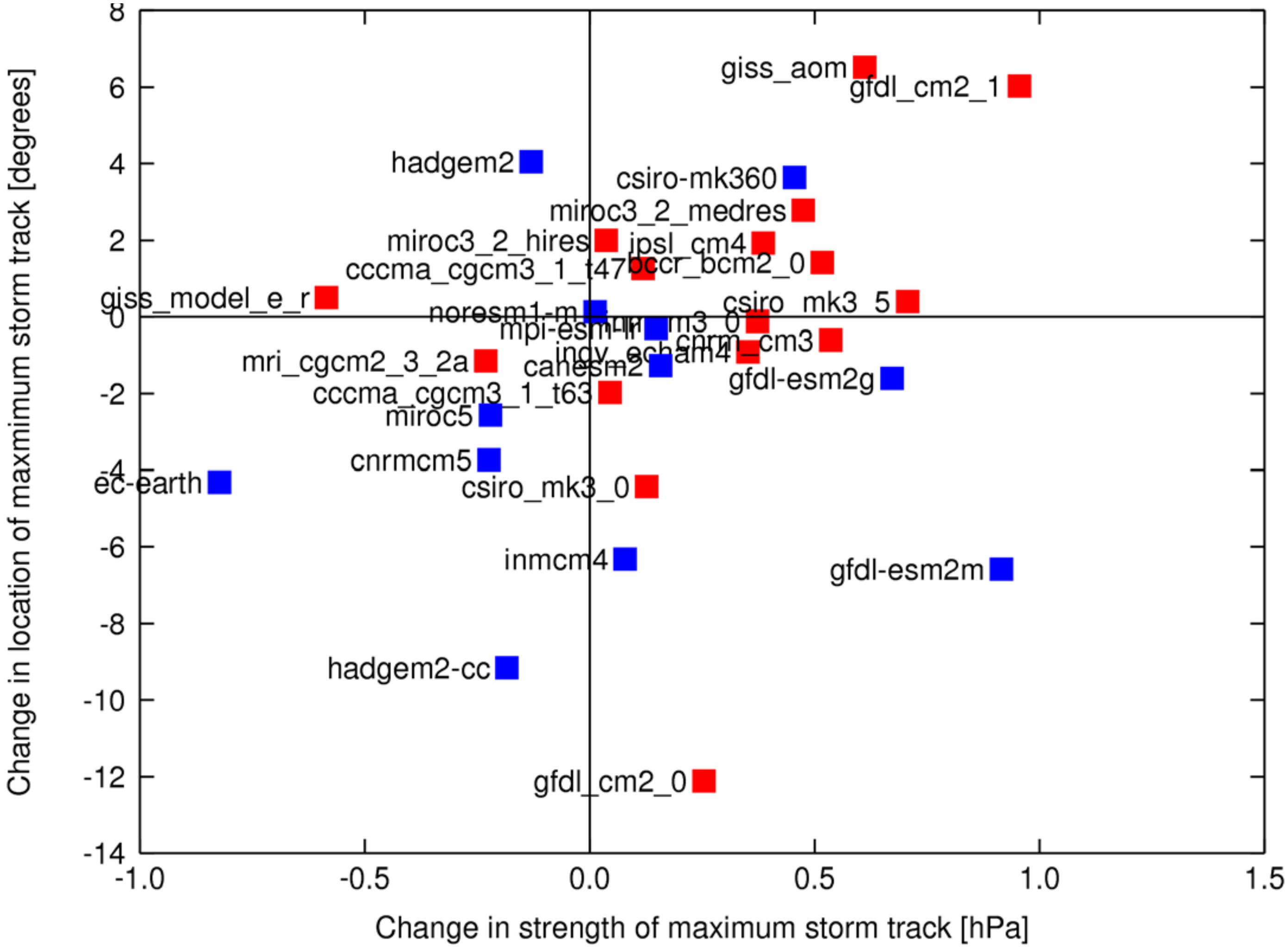


Natural variability





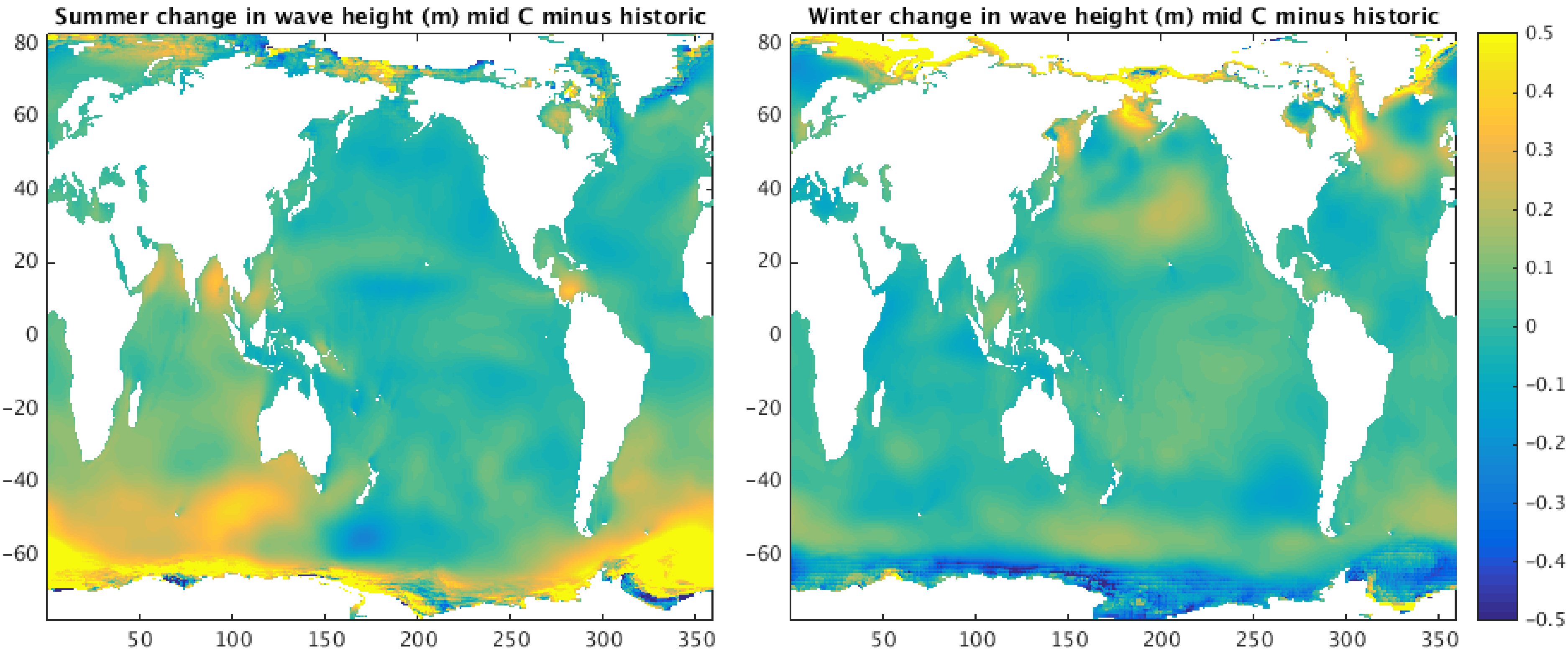
Projected changes in storms: CMIP3 vs CMIP5



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

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

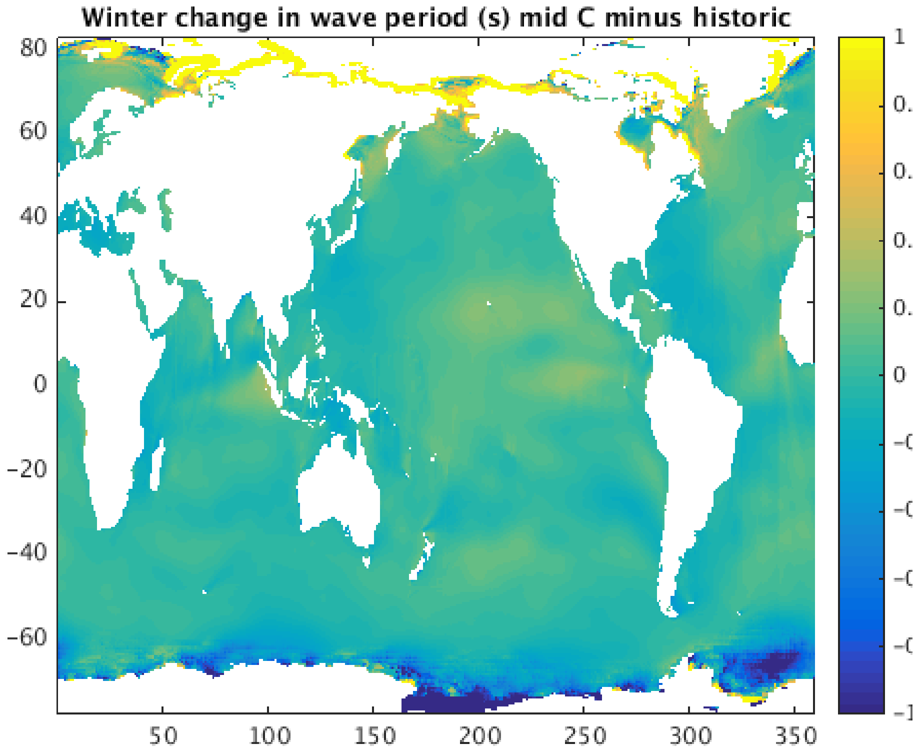
RISES-AM-: Changes in Global wave climate WWIII model forced by CMIP5 RCP scenarios using EC-Earth

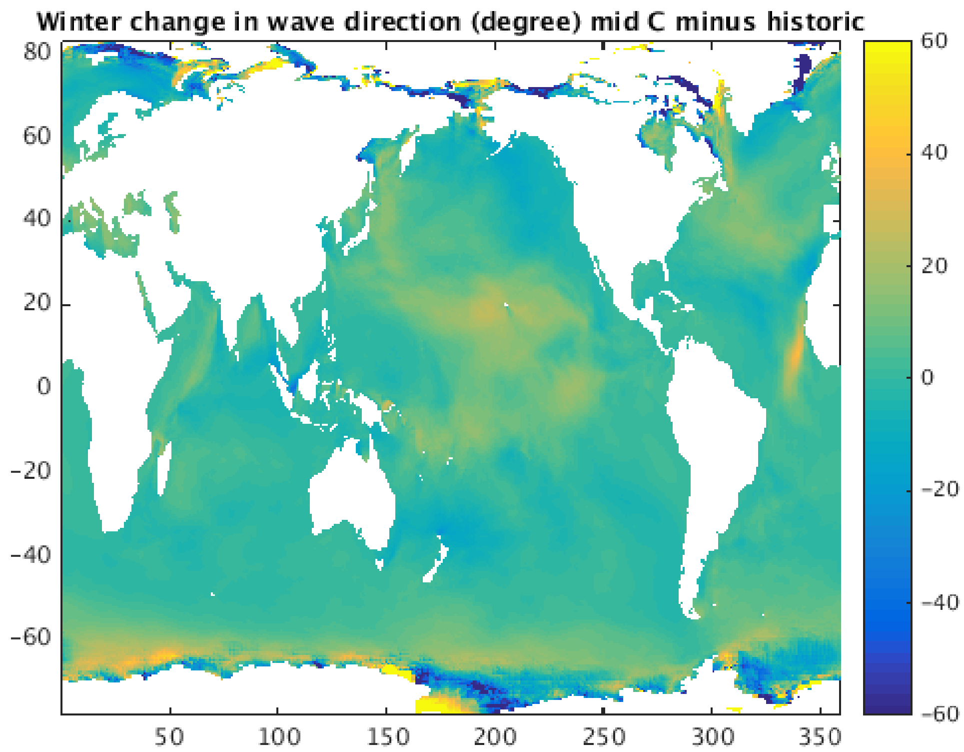


Seasonal change **in significant wave height** between historic (1970-1999) and RCP 8.5 mid century (2030-2059). JJA left, and DJF right.

Yellows indicate higher wave height in the future, and blues a reduced wave height.

Changes in Global wave climate





Winter changes in wave climate between historic (1970-1999) and mid century (2030-2059). Future minus historic.

Wave period in seconds (left) and **wave direction** (right)

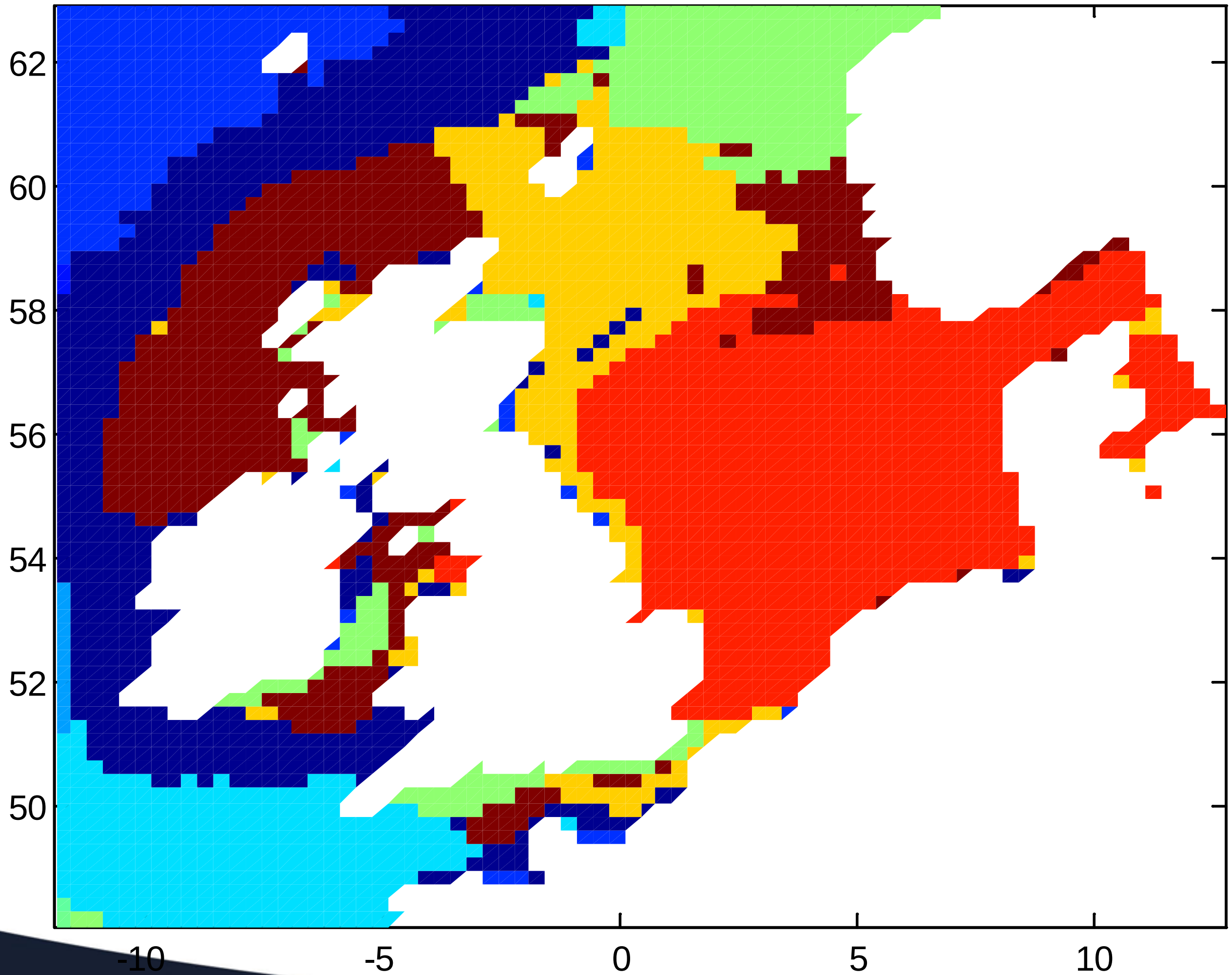
Exploring limits to Coastal Flooding for UK - Environmental Risks to Infrastructure Programme

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.

Storm Wave characteristics – cluster analysis



7 clusters from 4 correlation arrays:

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

Conclusion

- Extreme events (storm surge and waves) at the UK coast are caused by North Atlantic storms bringing low pressure and strong winds
- Despite some limitations in the accuracy of surge and wave models, the main cause of errors in forecasts is errors in the wind fields
- Understanding the behaviour and projected changes in Atlantic storms is thus the most important requirement for assessing future risk of coastal flooding for the UK
- We can examine the past history of storms (e.g. SurgeWatch database) and also analyse projected future storms from climate models (however these still have some limitations)
- Using synthetic 'worst case' storms based on realistic dynamics together with analysis of their probability will allow us to extend the database beyond previously observed storms

The “Perfect Storm”

In 2009, Sir John Beddington, then UK Chief Scientific Advisor, warned environmental groups and politicians about some worrying trends:

It is predicted that by 2030 the world will need to produce around 50 per cent more food and energy, together with 30 per cent more fresh water, whilst mitigating and adapting to climate change. This threatens to create a ‘perfect storm’ of global events…There's not going to be a complete collapse, but things will start getting really worrying if we don't tackle these problems.

This is not a worst case scenario, just assuming that we don’t tackle climate change, food, energy and water shortages aggressively enough


Questions?

References

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