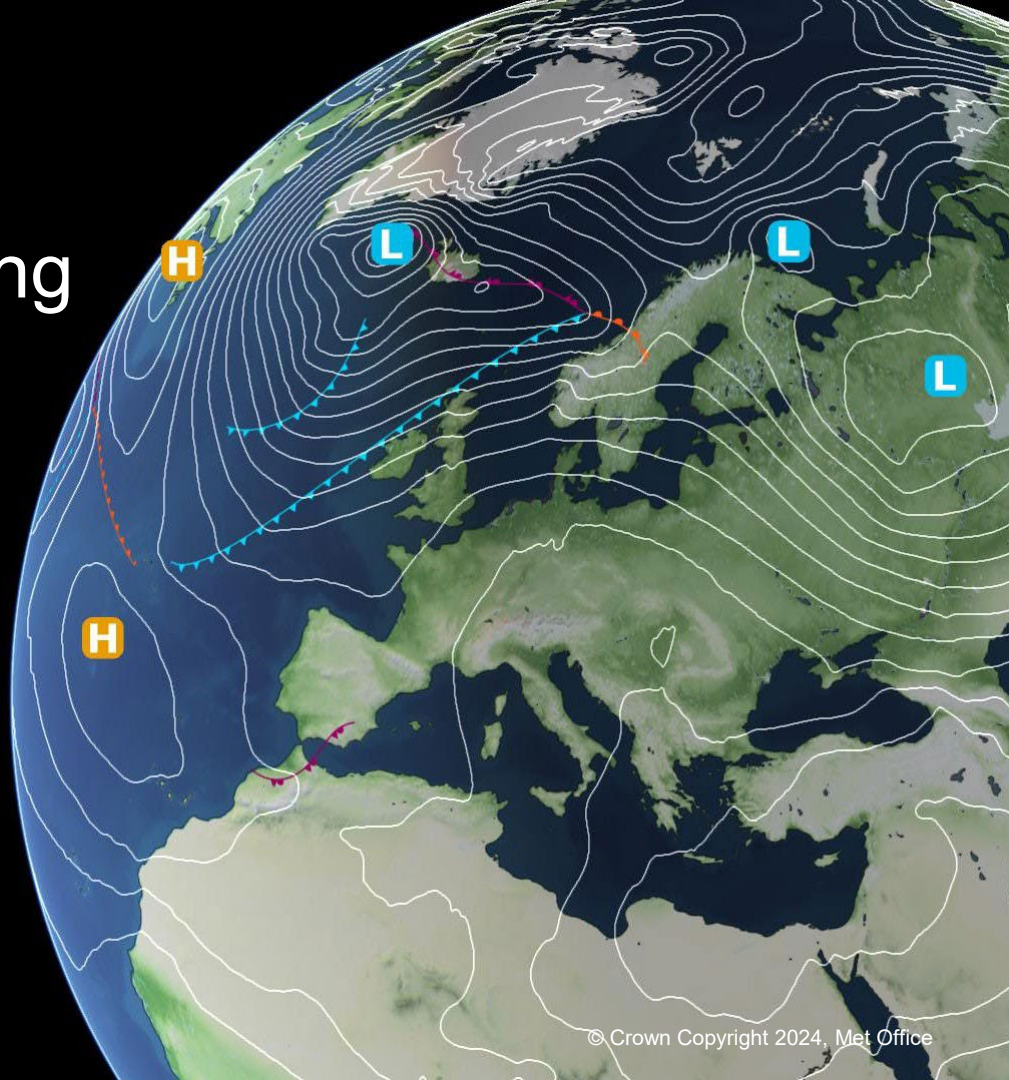
Wave ensemble forecasting with a regional coupled system

Vivian Fraser-Leonhardt, Ségolène Berthou , Juan Castillo , Christopher Bunney, Breogan Gomez



Met Office

Aim

Aim: To have the Fully coupled ensemble to be a candidate for forecasting
Focus: Analysing and improving the accuracy of forecasting Significant wave height(HS) and Wind Speed (U10).

Outline

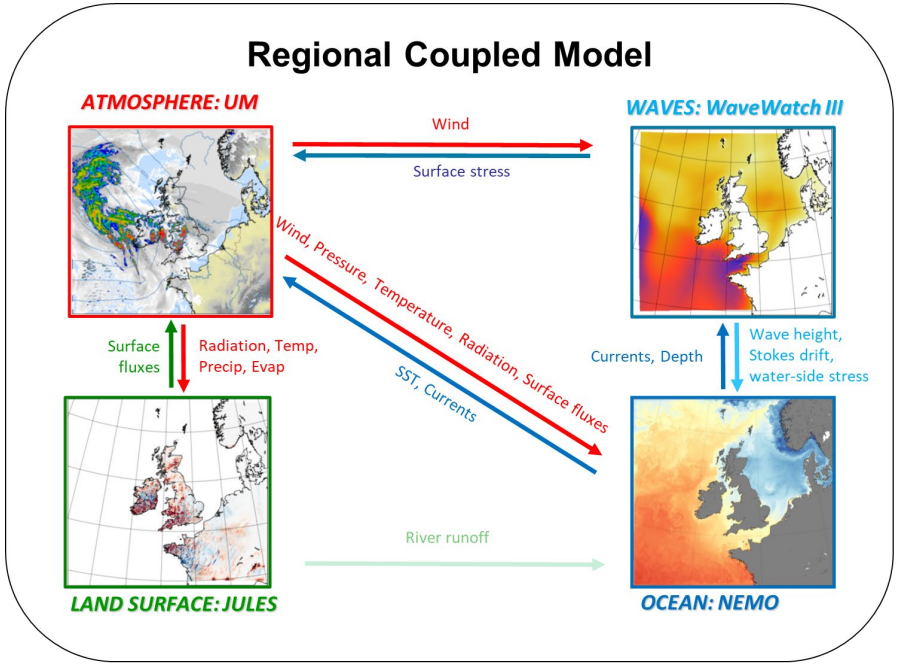
Background:

- Regional coupled suite
- Ensembles
- Some results showing the impact of coupling with waves (Wind speed and SSTs)
- Brief description on the operational forecasting and coupled system

Project: Analysing the accuracy of forecasting HS and U10

- Operation wave models (Atlantic wave ensemble and AMM15) vs Fully coupled ensemble (Background, HS, and WS)
- Sensitivity tests:
  - Increasing coupling frequency (from 1 hour → 10 minutes)
  - Reduction Betamax parameter (1.48 → 1.39)
  - Converting from 10-meter winds to 10-meter neutral wind

Regional Coupled Suite (RCS)



Regional coupled model (for this project): Atmosphere (UM, 13.0), Land (JULES, 7.0), Ocean (NEMO, 4.0.4) and Waves (WWIII, 7.12)

Regional Coupled Team

RCS team (Foundation Science, RMED)

Ségolène Berthou (scientific manager, river dev)

Alex Arnold (ocean & climate)

Juan Ma Castillo (software engineer – architect of Regional Coupled Suite, coupling expertise, LFRic)

Vivian Fraser-Leonhardt (industrial placement, waves & winds)

Huw Lewis (former scientific manager, co-architect of Regional Coupled Suite, river dev)

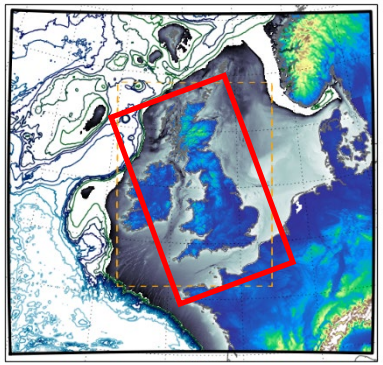
Sana Mahmood (coupled ensembles, links with Bristol University)

Claudio Sanchez (Atmosphere/ocean coupling, cyclones, tropics, K-scale, Chemistry&aerosol)

+ Momentum partners

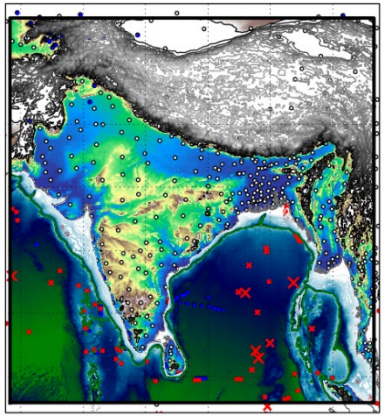
Regional Coupled Suite: Domains

Across UM and UK partners

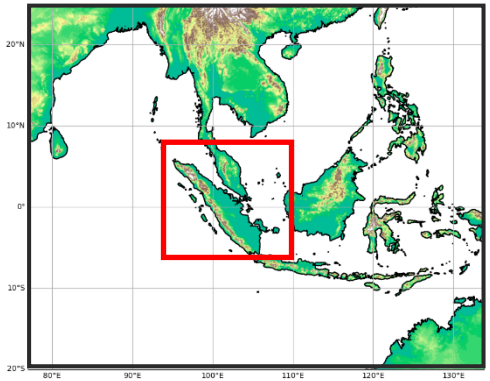


Met Office AOW
MONSooN +Bcg (branch)

NOC – OW on Archer2



Met Office AOW
MONSooN +1D
NCMRWF Ocn(KPP)



Met Office (climate branch)
AO(1/12th)
CCRS – OW
+ AOW over cSINGV domain

Running configuration
Configuration in development (porting required first)

So far: Ensemble forecasting

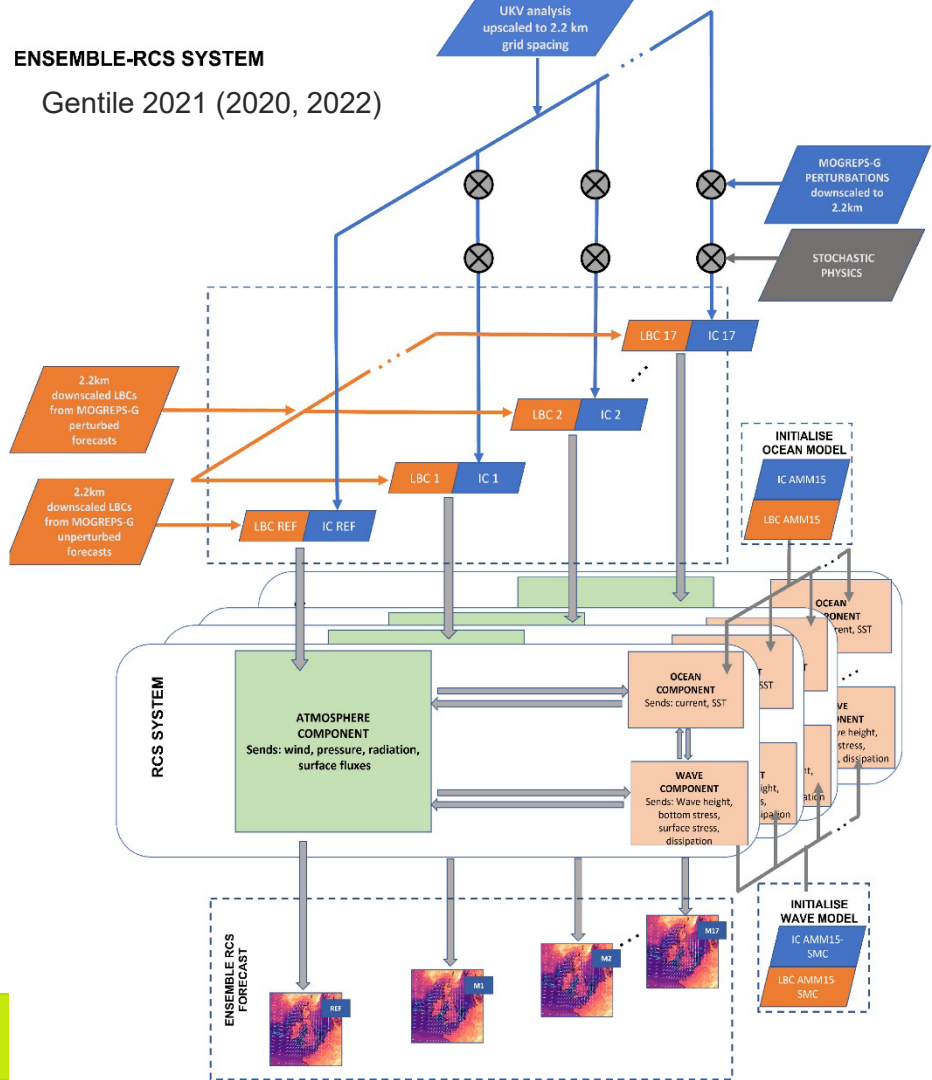
Decrease in forecasting skills are due to:

1. Uncertainties in the initial conditions
2. Approximations used in the forecast models

Coupled ensemble comes from MOGREPS-UK which inherits the perturbations of MOGREPS-G

Spread:

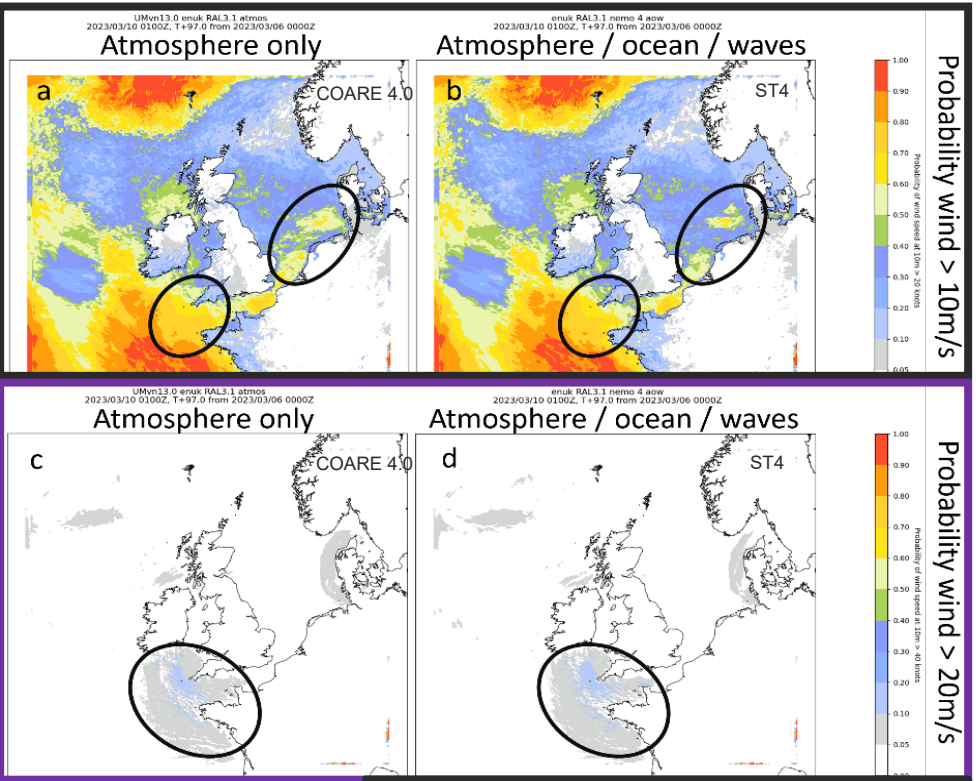
1. Boundary conditions: LBC and IC
2. Stochastic physics
3. Inflated spread in the ST



Background

So far: Impact of wave coupling on …

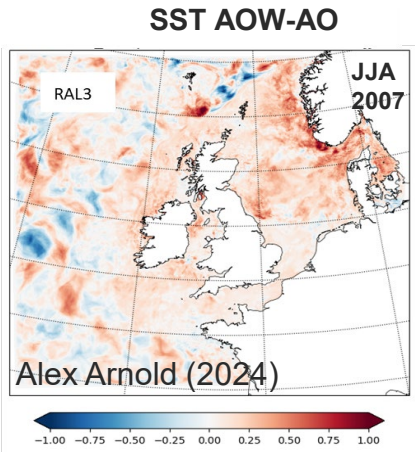
… Wind Speeds

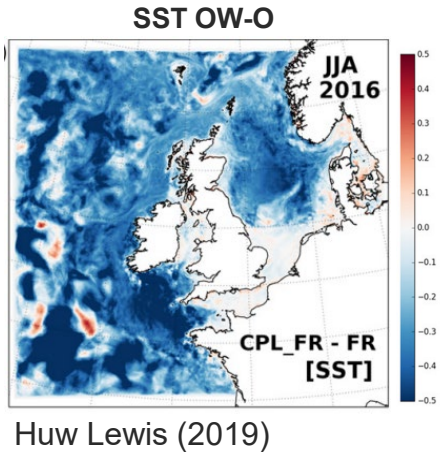


Wind speed > 40 knots: AOW increases probability of strong wind speed.

Moderate wind speeds (10m/s):AOW reduced probability because young growing waves extract momentum from the atmosphere.

… SST





Huw Lewis (2019)

Get warmer SST with AOW during the summer months

Cooler SST with OW during the summer months

The change in windspeed more dominant effect than increase vertical mixing.

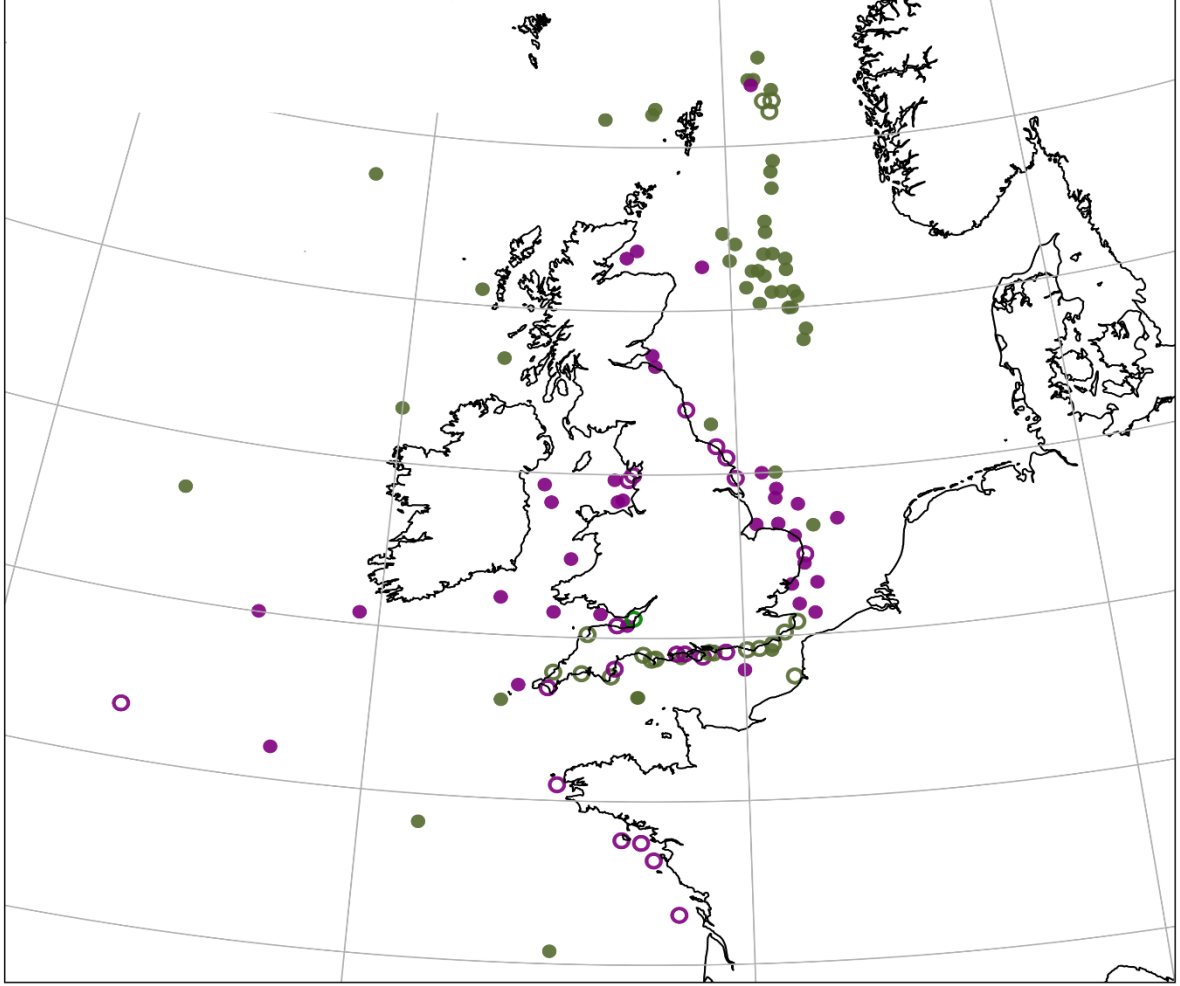
Met Office

Operational and the fully coupled systems

	Atlantic wave ensemble (oper)	AMM15 (oper)	Fully coupled
Members	18	1	18
Resolution	25km, 12km, 6km, 3km	3km, 1.5km	2.2km
Model	Wave only	Ocean-wave	Atmosphere-Land-Ocean-Wave
Domain	North Atlantic	AMM15 (like UKV)	UKV
Driven by	MOGREPS-G	glm (NWP global fc)	MOGREPS-UK

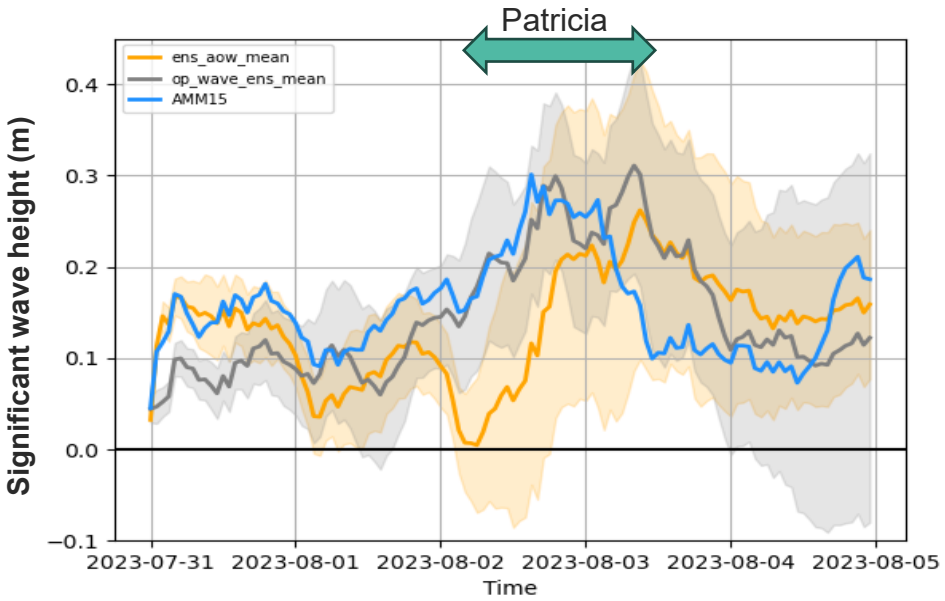
UK Buoy

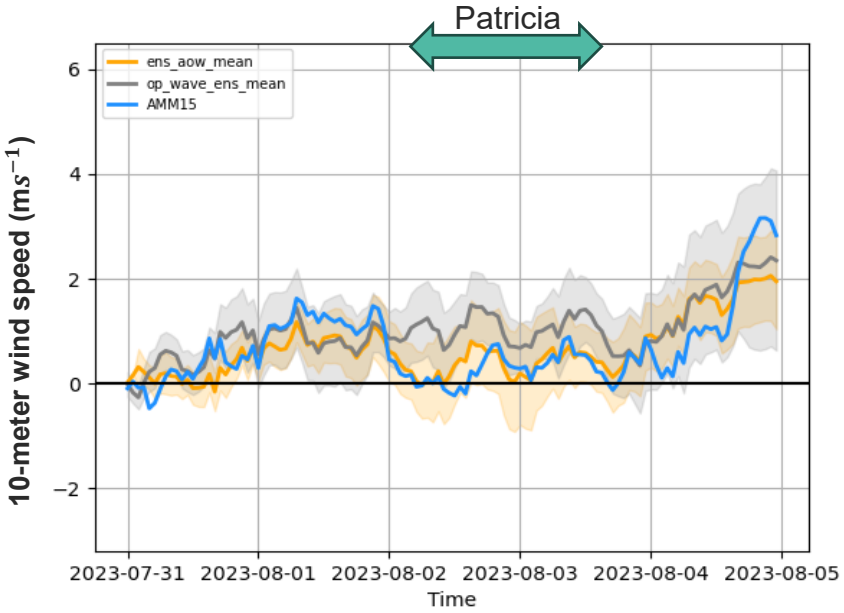
- Buoy bias towards the coast and the Northern North Sea (oil rigs)
- This is the UKV and AMM15 domain



Met Office Operational vs Ensemble HS and WS timeseries

UK Mean bias – 20230731-20230805 (storm Patricia)

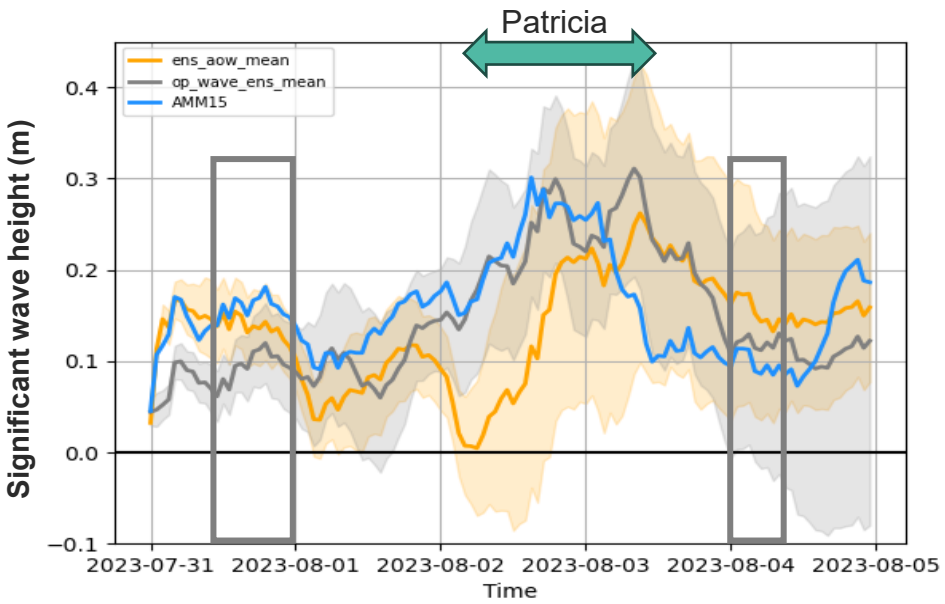


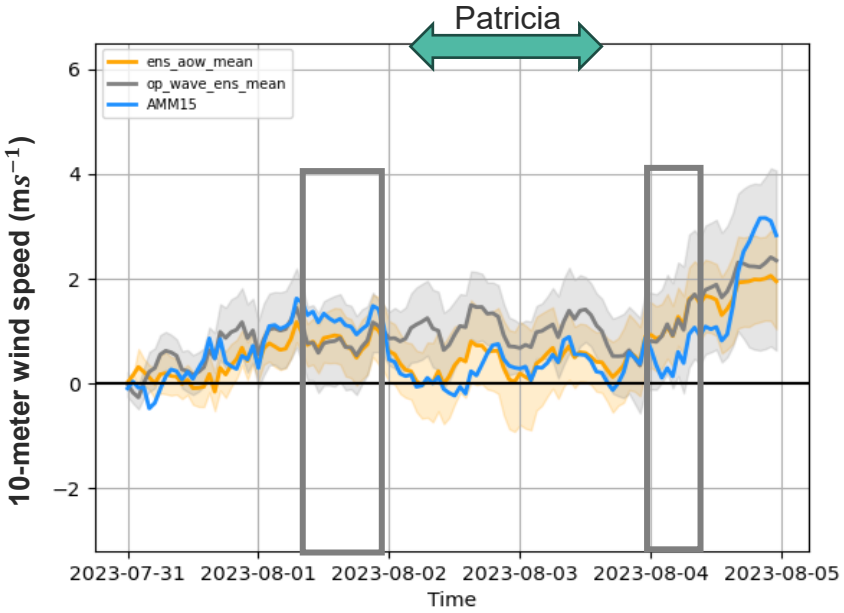


- **Coupled ensemble:**
- **Operational wave ensemble:**
- **AMM15:**

Met Office Operational vs Ensemble HS and WS timeseries

UK Mean bias – 20230731-20230805 (storm Patricia)





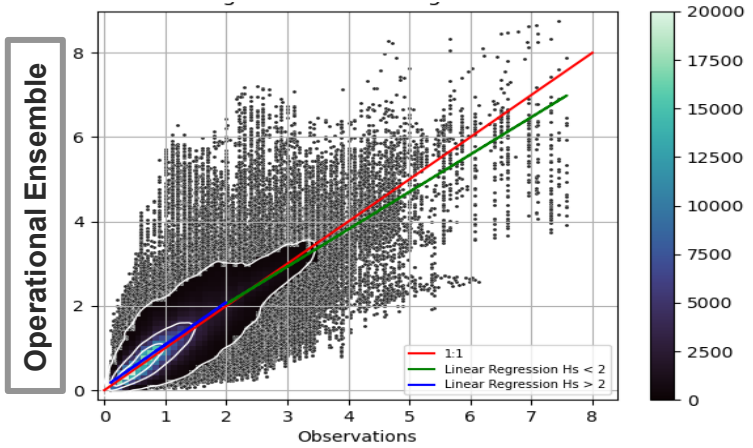
- **Coupled ensemble:**
- **Operational wave ensemble:**
- **AMM15:**

Ensemble models against observations HS and WS scatter (6 cases studies)

Met Office

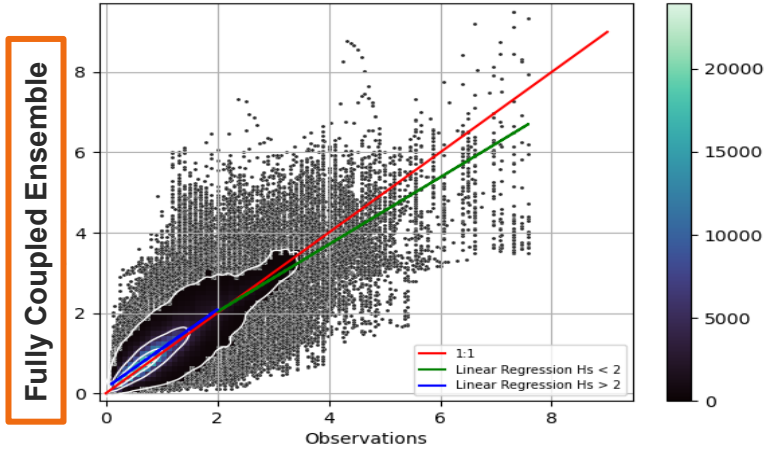
Significant Wave Height (m)

Operational Ensemble



Significant Wave Height (m)

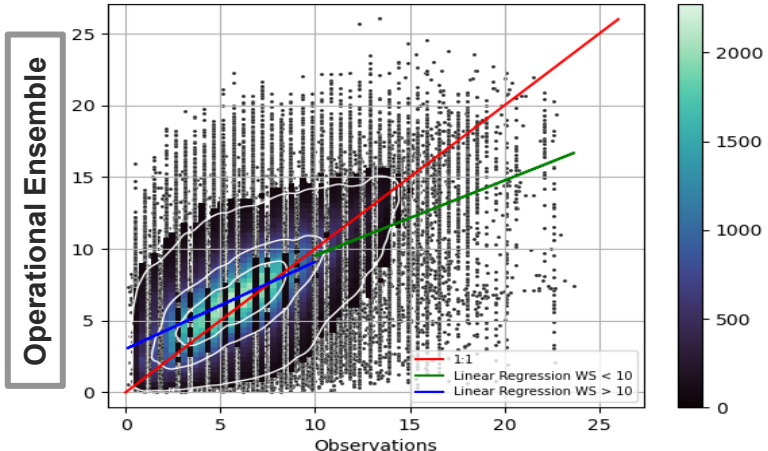
Fully Coupled Ensemble



Regresion: HS<2:
Regression: HS>2:
1:1

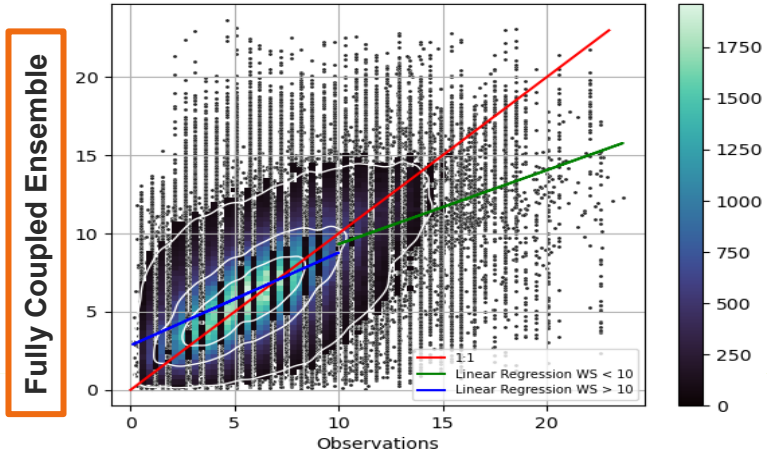
10-meter wind speed (ms^{-1})

Operational Ensemble



10-meter wind speed (ms^{-1})

Fully Coupled Ensemble



Regresion: WS<10:
Regression: WS>10:
1:1

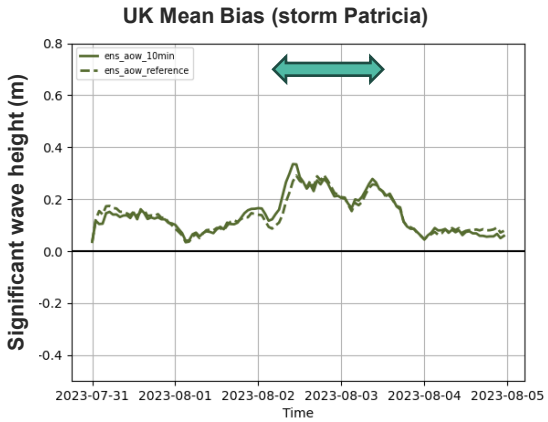
Sensitivity tests

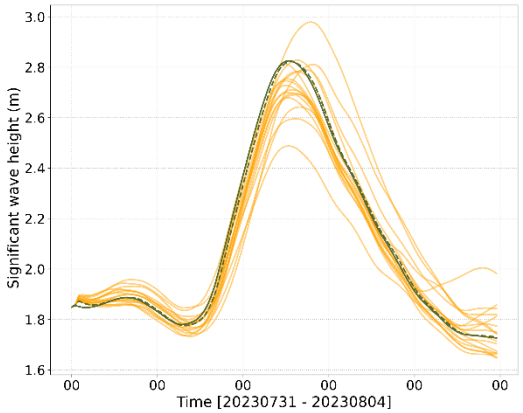
1. Increasing in coupling frequency (from 1 hour → 10 minutes)

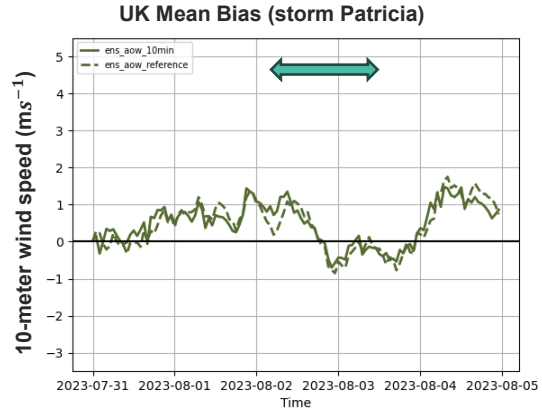
2. Reduction in the Betamax parameter (1.48; IFS → 1.39; Operational Met Office)

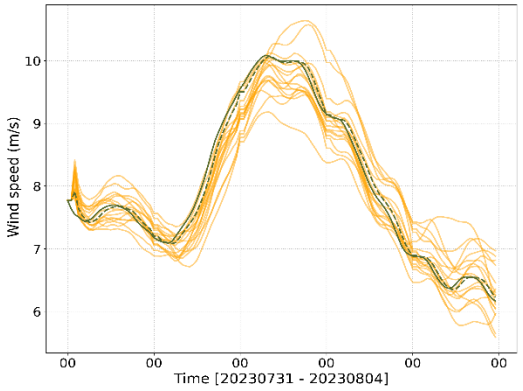
3. Converting from 10-meter winds to 10-meter neutral wind speeds

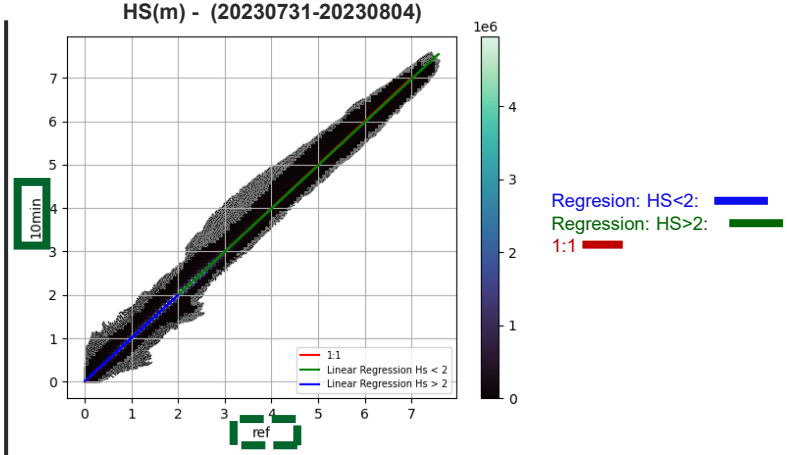
Sensitivity Test 1: Reduction in coupling frequency (from 1 hour → 10 minutes)

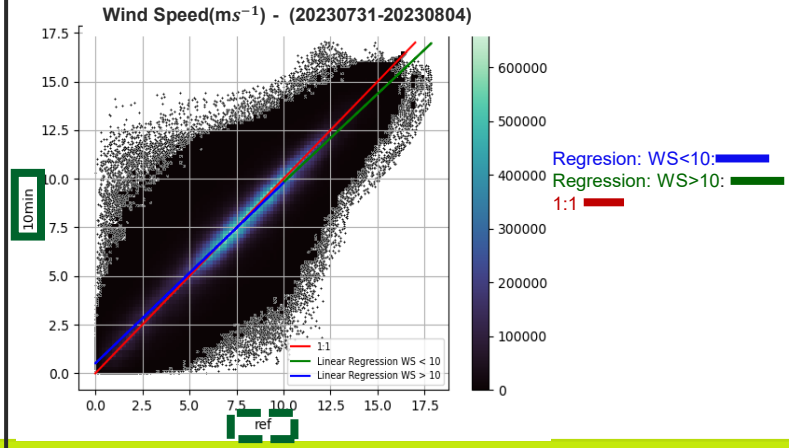






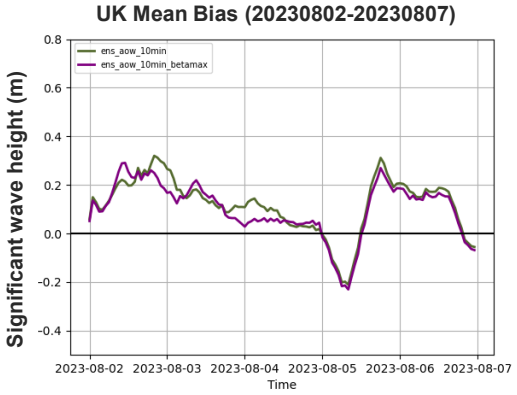


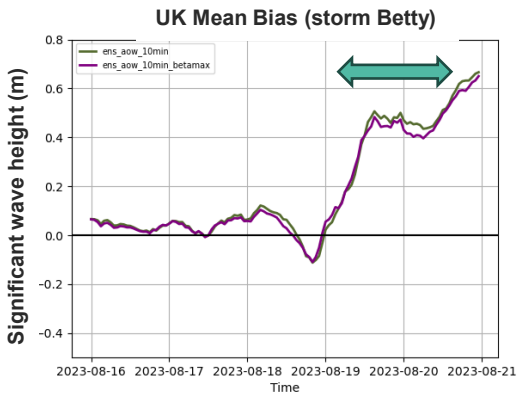


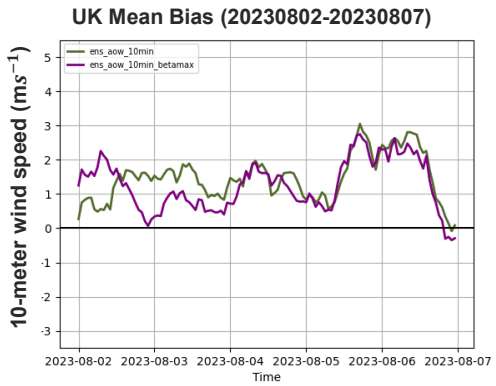


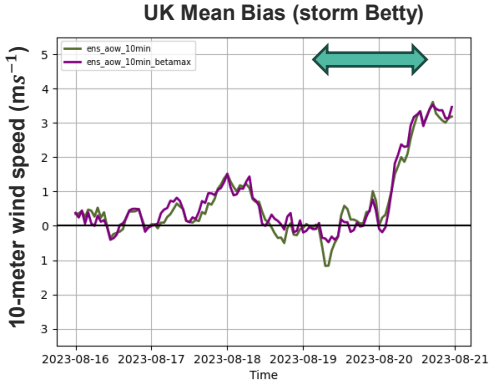
- 1h ensemble member:
- 10min member:
- Individual ensemble members

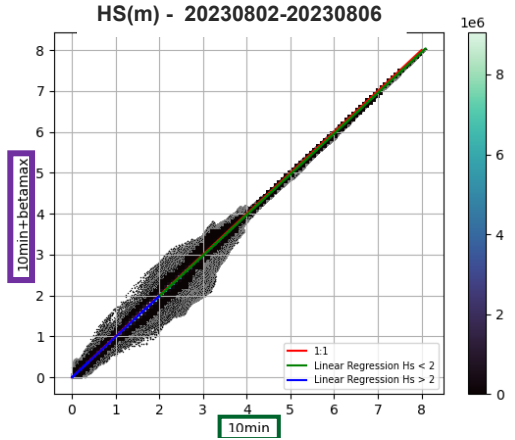
Sensitivity Test 2: Reduction in the Betamax (1.48 → 1.39)



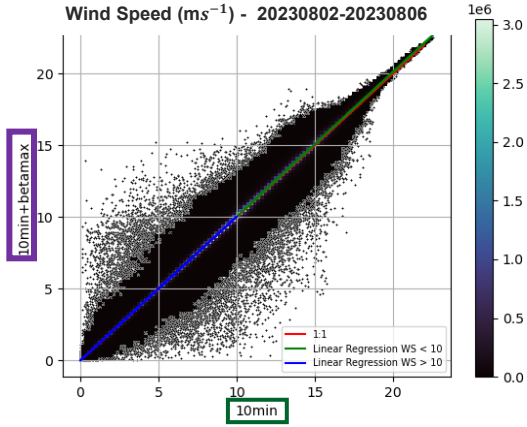








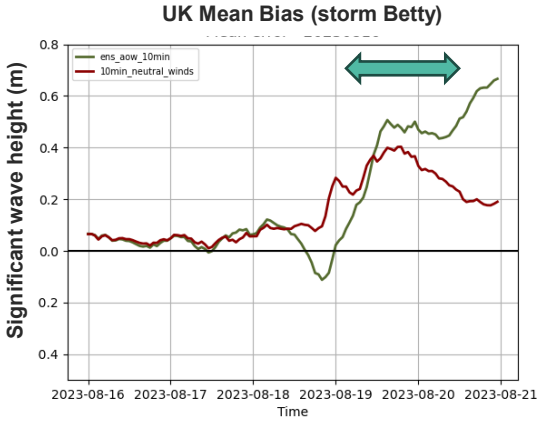
Regresion: HS<2:
Regression: HS>2:
1:1

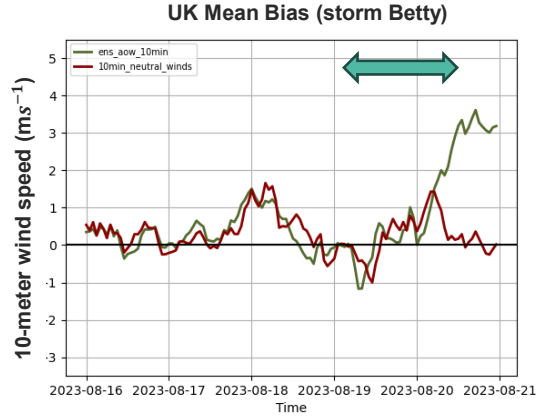


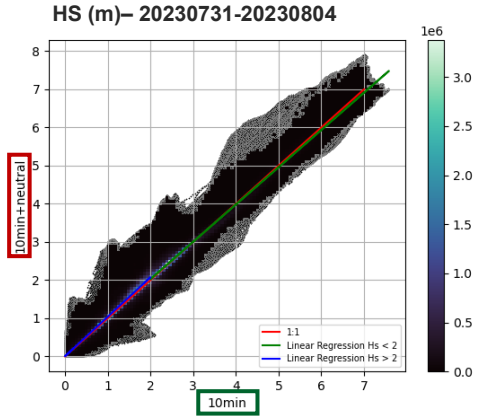
Regresion: WS<10:
Regression: WS>10:
1:1

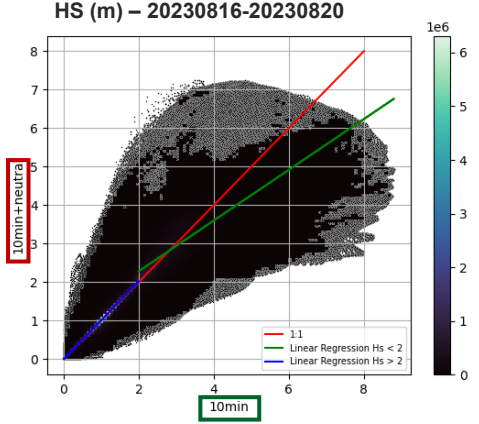
- 10min member:
- 10min + operational Betamax:

Sensitivity Test 3: 10-meter neutral winds

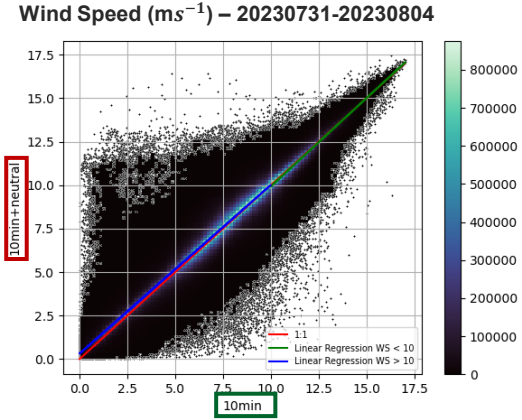


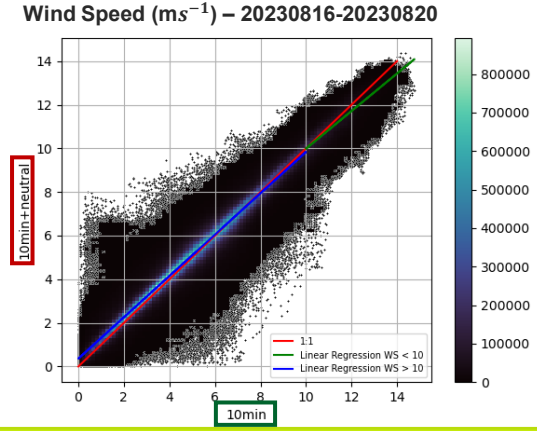






Regresion: HS<2:
Regression: HS>2:
1:1

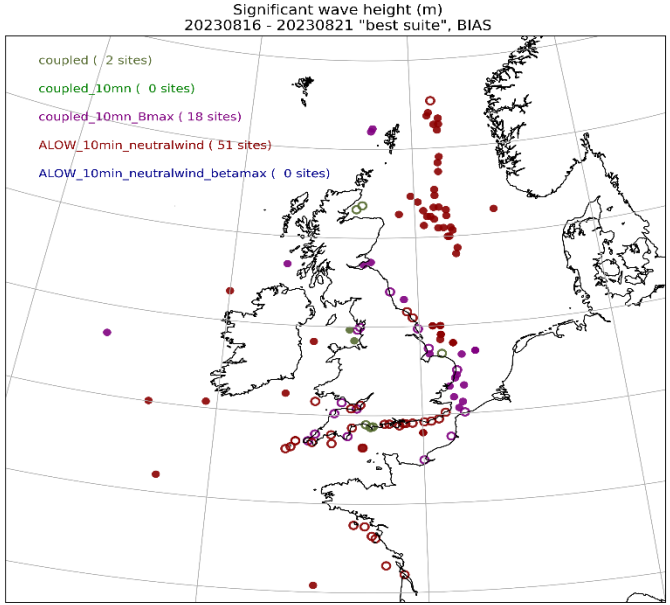


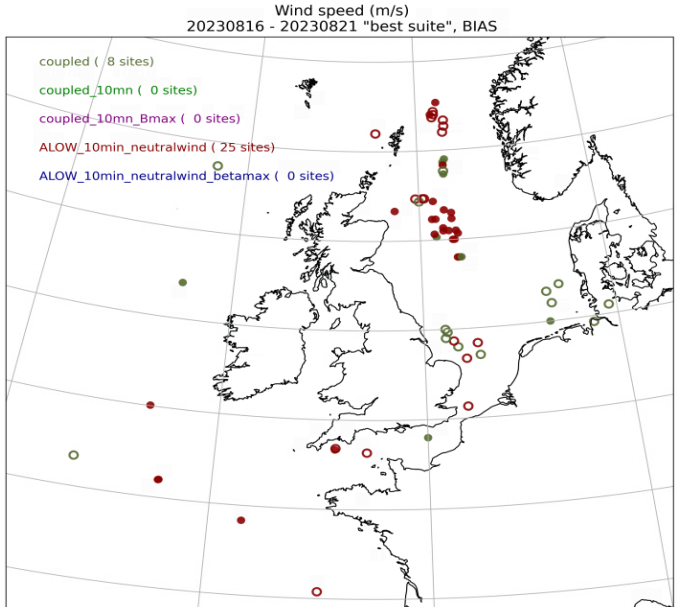


Regresion: WS<10:
Regression: WS>10:
1:1

- 10min member:
- 10min + neutral winds:

What combination is best?





The 'filled' points are plotted when a model provides a significance level of 5%, with a student t-test.

'Best model' (BIAS)	HS (m)	Wind Speed (ms^{-1})
1st	10 minute + neutral winds	10 minute + neutral winds
2nd	10 minute + new betamax	1 hour (original)

Future plans

- Further examination on how the ensemble behaves with different parameters (e.g SST)
- Further analysis on the cases studies: different areas of the western European continental shelf
- Experimenting with the Betamax parameter
- AOW: Running 10 year hindcast climate run and developing a future 2060-2070 run
- Capri project (UEA and Met Office): Looking at the impact of wave and current coupling on meso-eddies and tidal currents, using FAAM-aircraft observations; 15meters above sea level.

Image taken inside FAAM (flying 15 meters above sea level)

Conclusion

The fully coupled system has similar skills in forecasting HS and wind speed.

Sensitivity test results:

	HS	Wind Speed
1hour -> 10 min coupling frequency	Extreme: Small decrease Calm: Negligible	Extreme: Small decrease Calm: Small increase
1.48 → 1.39 Betamax	Extreme: Slight decrease Calm: Negligible	Extreme: Slight increase Calm: Negligible
10m winds → 10m neutral winds	Case dependent	Case dependent

Despite the degradation we will adopt all three-sensitivity test (to help forecast high-frequency events, for consistency in the Met Office, and to better conserve momentum).

The best model configuration for forecasting HS and wind speed is the 10-minute coupling frequency with neutral winds (At least around the coast and Northern North Sea).

Thank you for listening

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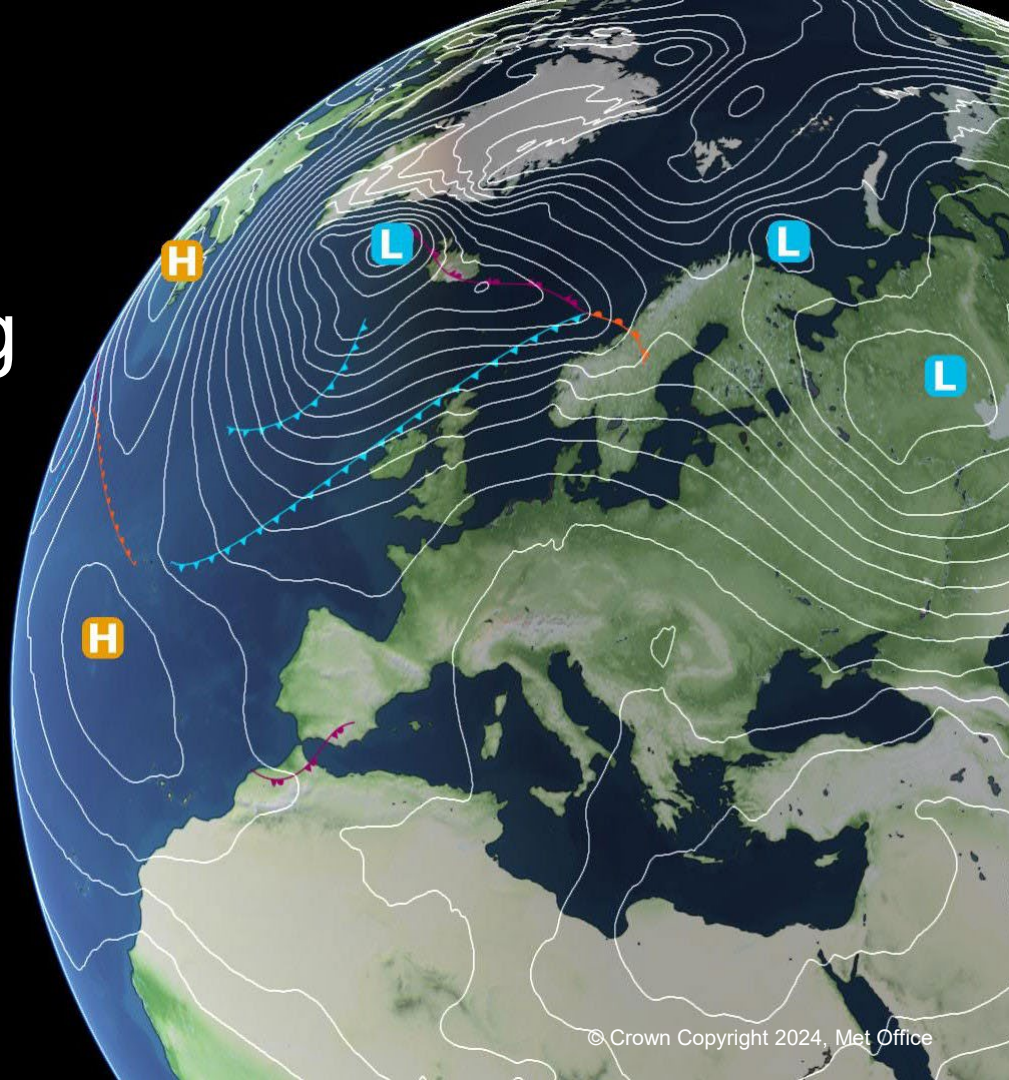
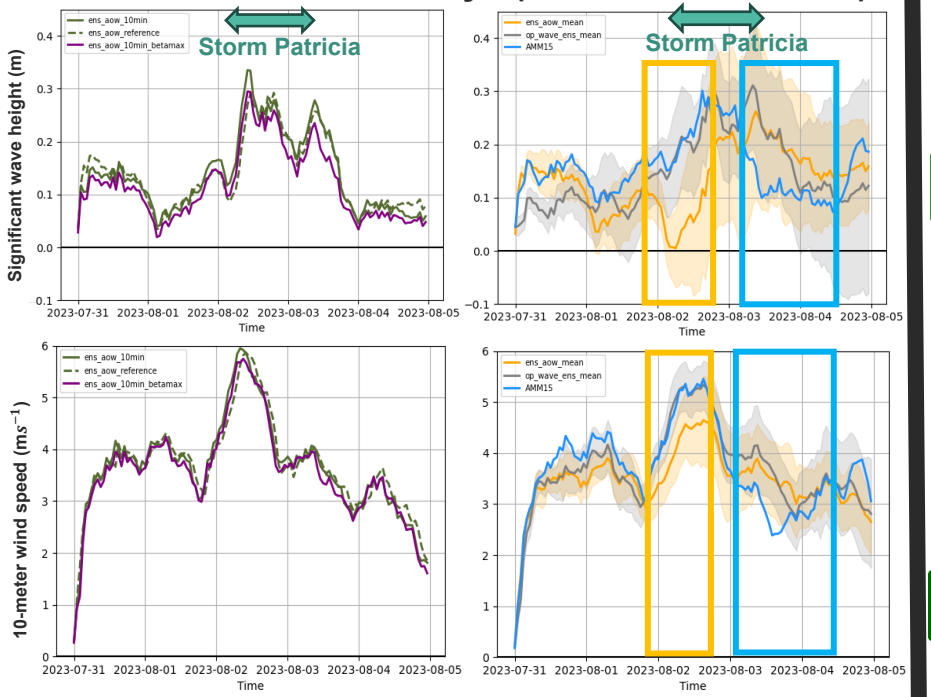


Further slides

Met Office

Case study: Storm Patricia

Mean bias of 77 uk buoys (20230731-20230805)

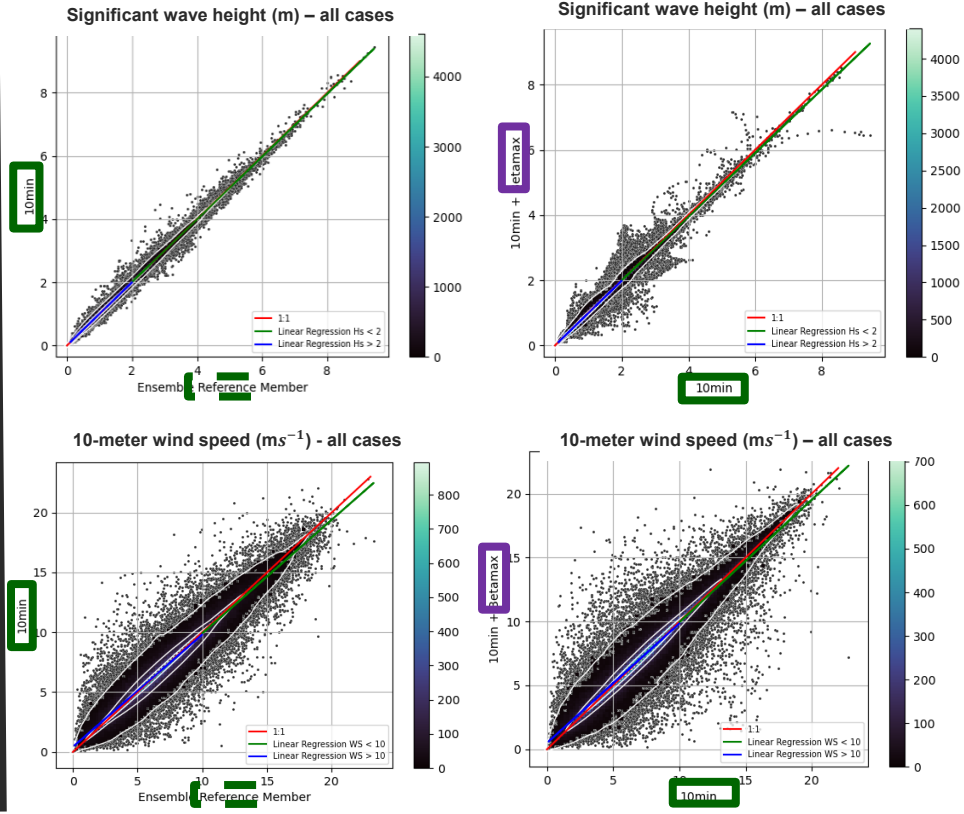


- 1h ensemble member:
- 10min member:
- 10min + operational Betamax:
- Coupled ensemble:
- Operational wave ensemble:
- AMM15:

Sensitivity tests:

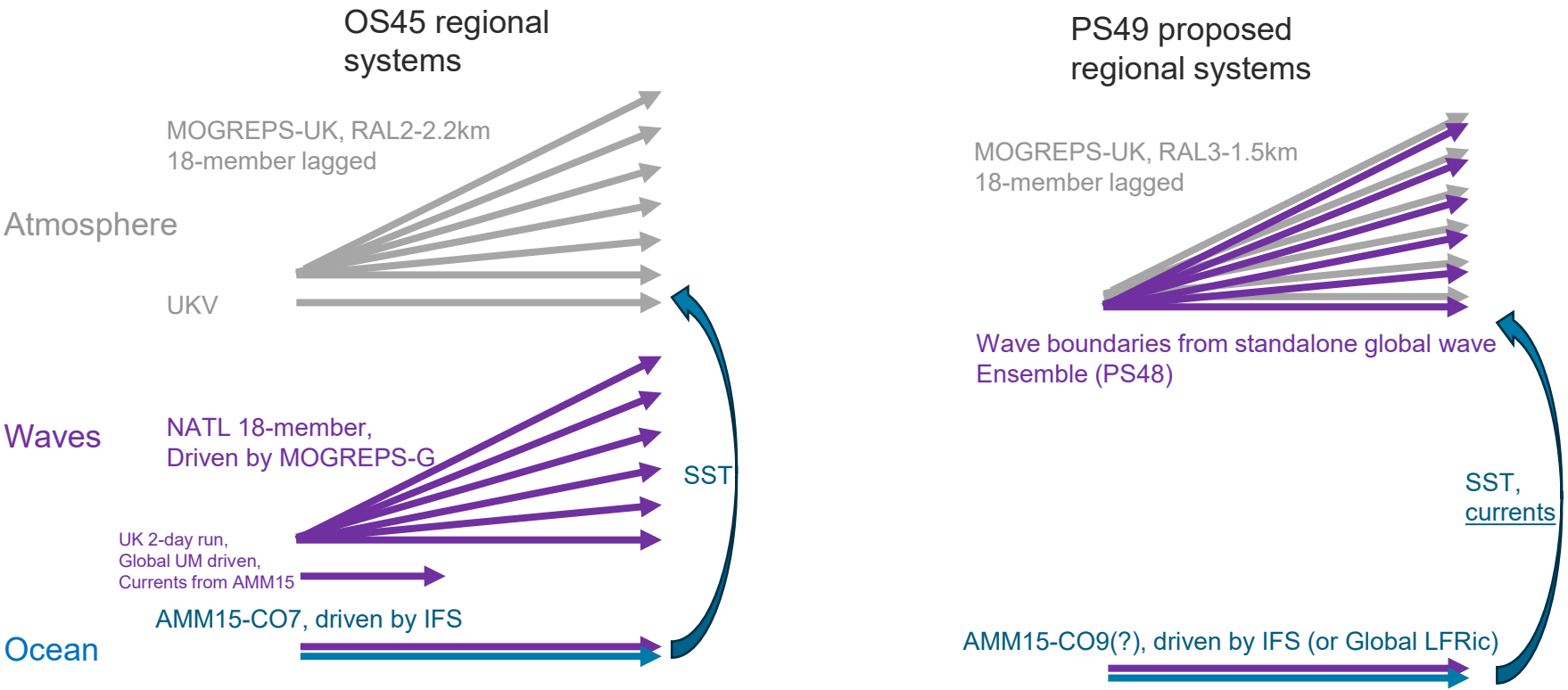
Investigating the influence of coupled frequency (10min against 1h)

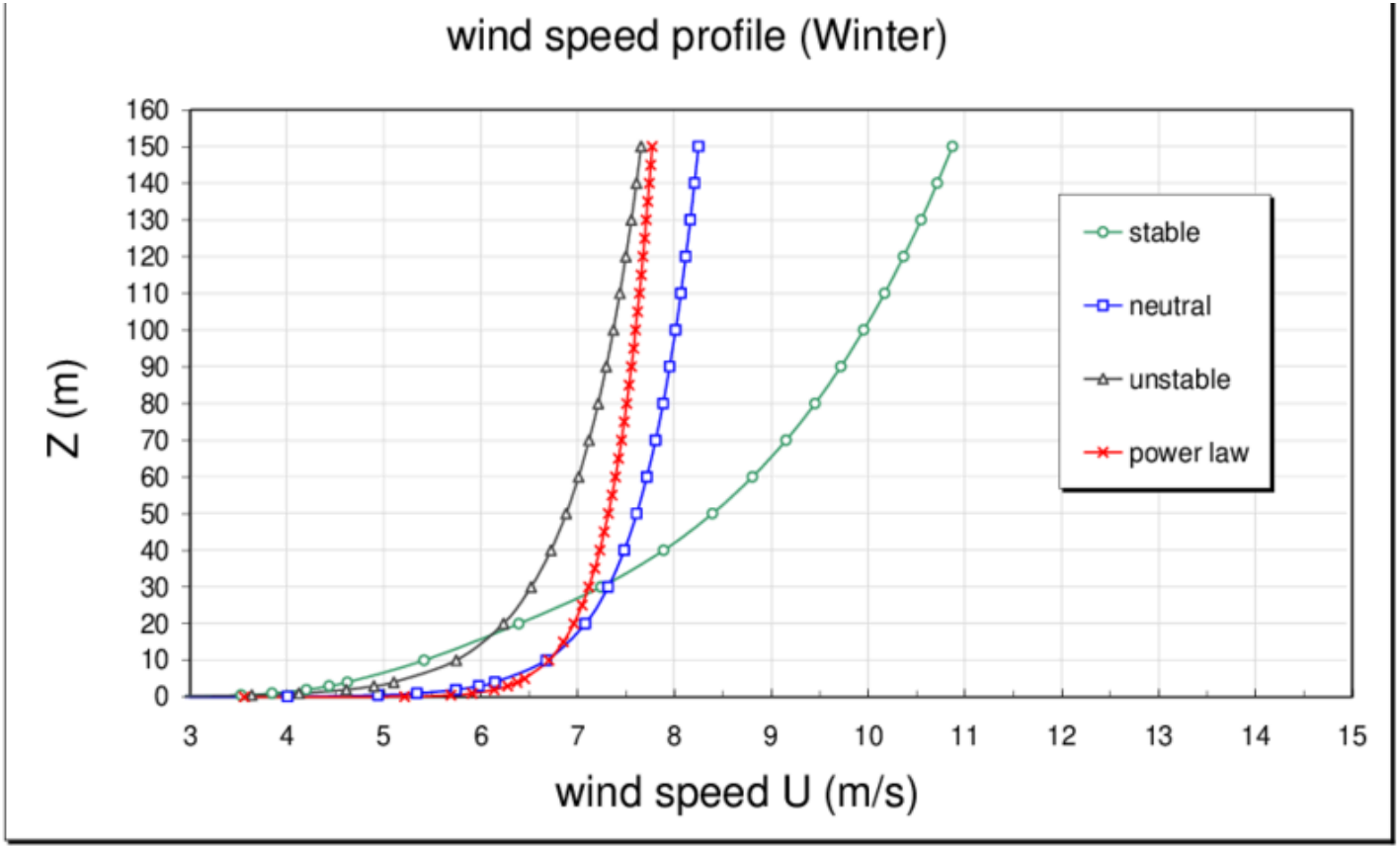
Investigating the effect of reducing the growth parameter (Betamax) value (from 1.48 to 1.39)



Regional coupled model (for this project): Atmosphere (UM), Land (JULES), Ocean (NEMO) and Waves (WWIII)

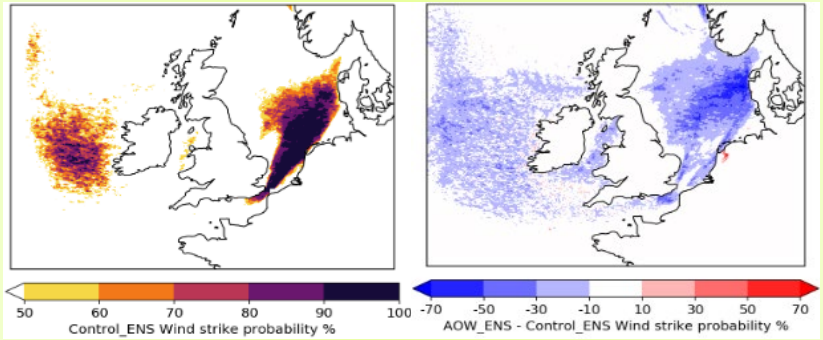
Proposed intermediate operational implementation




wind speed profile (Winter)
Z (m)
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
3
4
5
6
7
8
9
10
11
12
13
14
15
wind speed U (m/s)
stable
neutral
unstable
power law

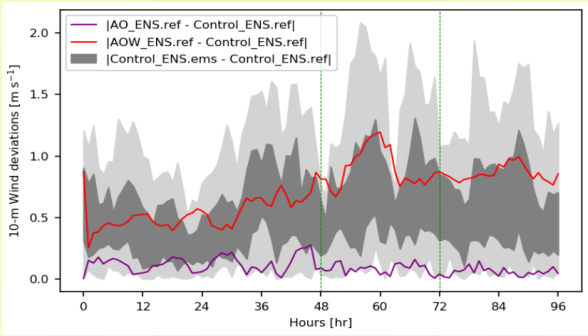
So far: REP: air-wave-ocean interactions

Young, growing wind waves reduce the wind speed by increasing the sea-surface aerodynamic roughness



Gentile et al. (2021)

Impact of wave coupling is as large as inter-member spread in ensemble forecasting

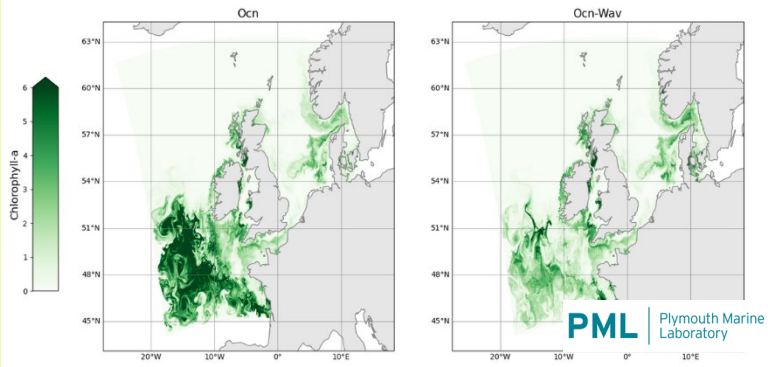


Gentile et al. (2022)

New RAL3 drag scheme (COARE4.0+Donalan cap) more similar to wave parameterization of drag coefficient.

Wave/ocean coupling reduces wave error for extremes – OS43&44

Wave/ocean coupling increases ocean vertical mixing, which delays the spring phytoplankton bloom when coupling to biogeochemistry (ERSEM)



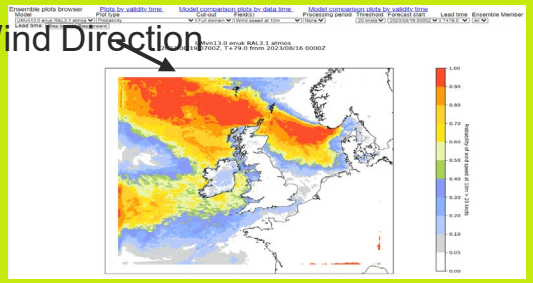
Storm Agnus (25 September)

Error (instability) → allow_1h coupling in the atmosphere (could be initial conditions, boundary conditions or coupling; because it crashes on the first iteration).

Atmospheric time step was reduced and still crashed

The instability error – 10 min coupling

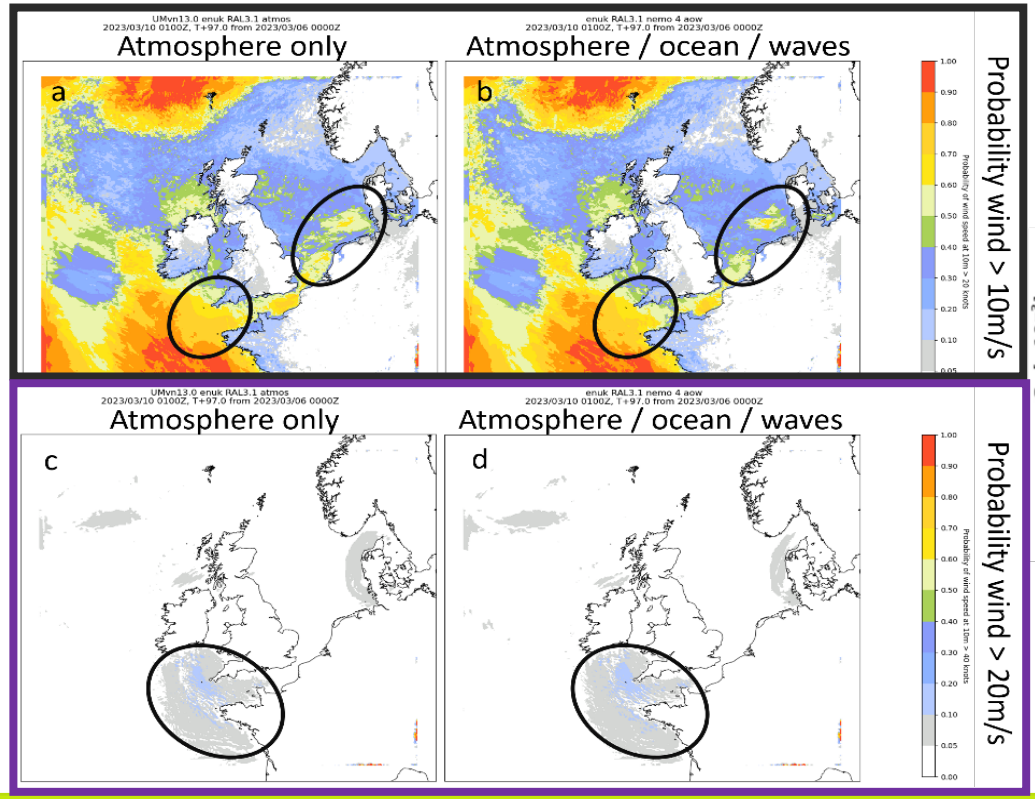
- To run this, the ocean timestep was forced from 100 to 60s.
- I believe that this is subharmonic instability due to time-periodic forcing, classic example being Faraday oscillations.



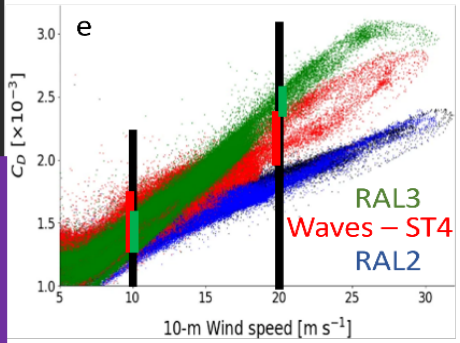

```
 ===>>> : E R R O R
        ===========

STOP
  stp_ctl: |ssh| > 20 m  or  |U| > 10 m/s  or  S <= 0  or  S >= 100  or  NaN encounter in the tests

kt 1031 |ssh| max    3.134      at i j    787  997     MPI rank 209
kt 1031 Vel2  max    142.0      at i j k  784 1002   1 MPI rank 209
kt 1031 Sal   min    32.79      at i j k  768  994   1 MPI rank 209
kt 1031 Sal   max    35.24      at i j k  760 1027 50 MPI rank 209

       ===> output of last computed fields in output.abort* files

huge E-R-R-O-R : immediate stop
```

Note that this is not the case for storm agnus as the wind is coming from SW.

So far: Impact of wave coupling on wind speeds



Moderate wind speeds (10m/s) -> young growing waves extract momentum from the atmosphere and reduce wind speed



John Edwards, Nieves Valiente

Wind speed > 40 knots (20m/s) probability -> Atmosphere-only RAL3.1 has weaker probability of strong wind speed, consistent with higher drag at these wind speeds.

Probability of wind speed > 10m/s (a, b), >20m/s (c, d) for atmosphere only (a, c), atmosphere-ocean-waves (b, d), e) shows the drag coefficient as a function of wind speed (for another case) for RAL3 (=atmosphere-only), Waves – ST4 terms (=AOW) and RAL2 (older model version).