Forecasting Ocean Waves:
What type of information is available from models.

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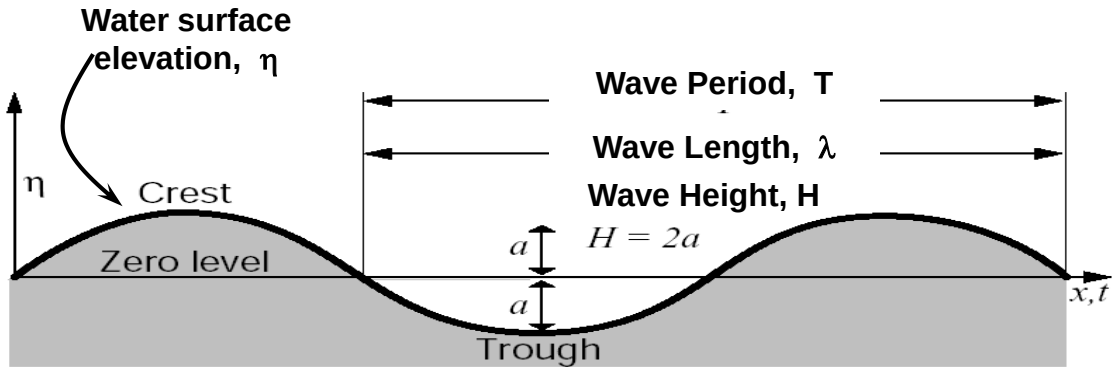
Waves breaking on the sea front in Ardrossan, Western Scotland, as Storm Gertrude hits the UK **on January 29, 2016**.

IMAGE: DANNY LAWSON/PA WIRE/ASSOCIATED PRESS

What did you know about ocean waves before the course?



nothing

expert

We are dealing with wind generated waves from gentle to rough …

May 1, 2013

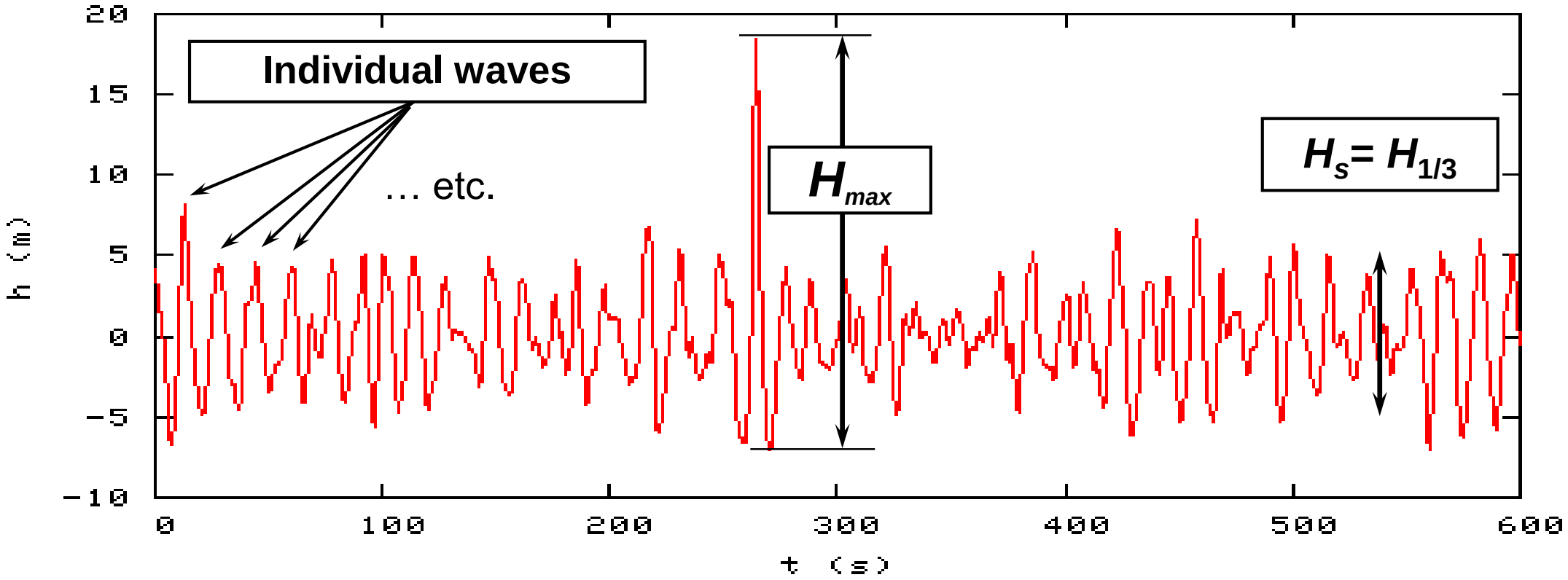
Porthleven Clock Tower, Cornwall, UK

February 5, 2014

Observe individual waves,

After a while, you can estimate a characteristic height the waves:
the Significant Wave Height, H_s,

You might also notice that some waves are larger than the rest,
characterised by the Maximum Individual Wave Height, H_{max}



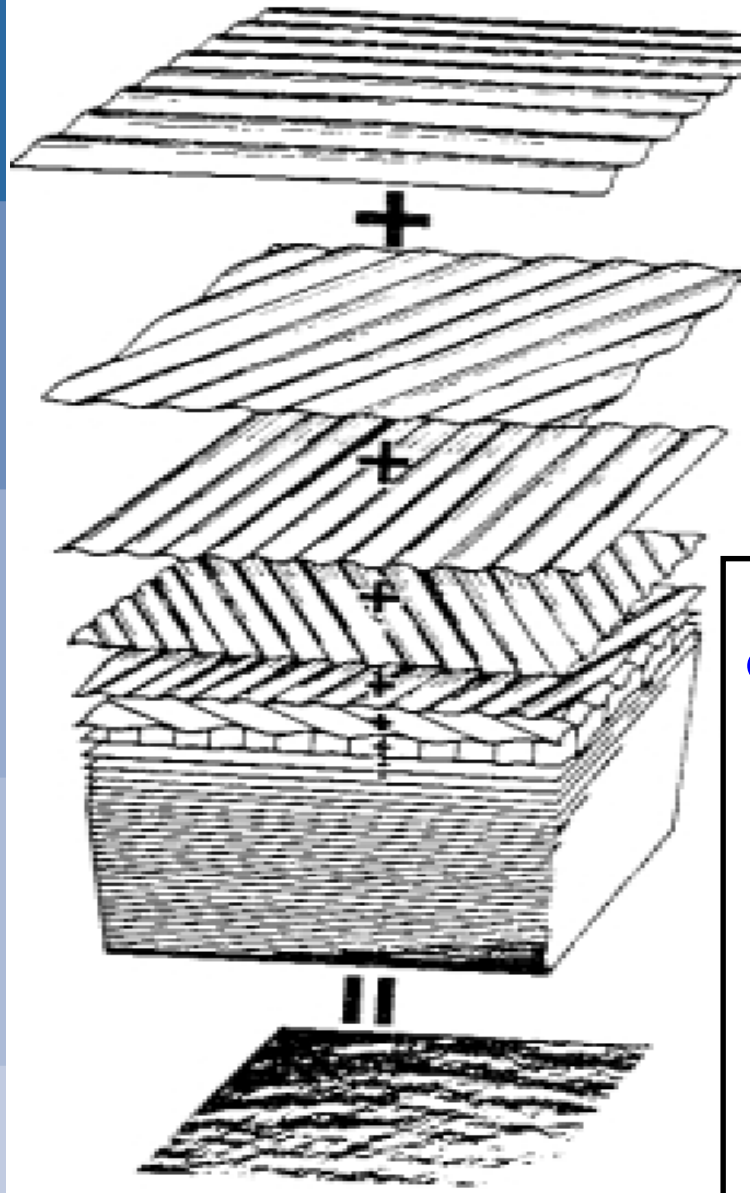
Surface elevation time series from platform Draupner in the North Sea

How do we go about making predictions on the sea state?

We are dealing with wind generated waves from gentle to rough …

Has anybody ever sailed in sea like this ?

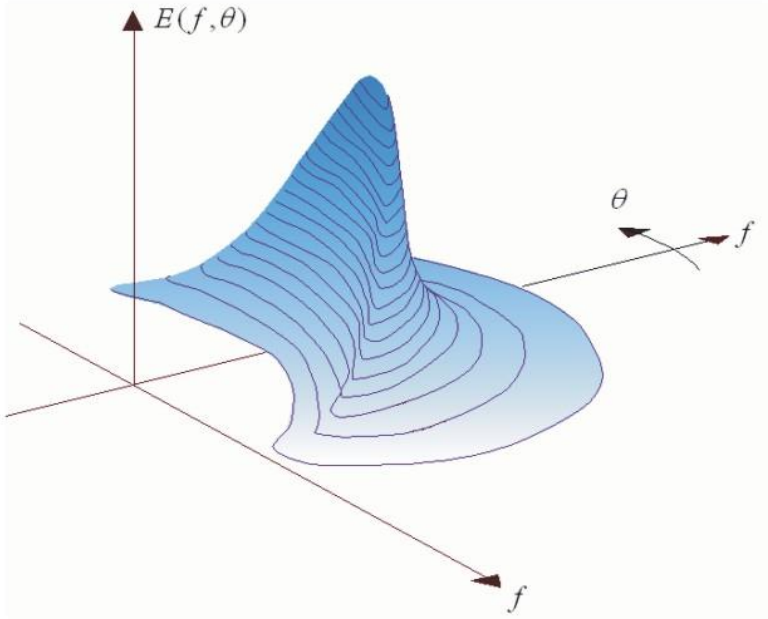
or rather like this ?



Wave spectrum

The irregular water surface can be decomposed into (*infinite*) number of simple sinusoidal components with different frequencies (f) and propagation directions (θ).

- The distribution of wave energy among those components is called: "wave spectrum", $F(f,\theta)$.



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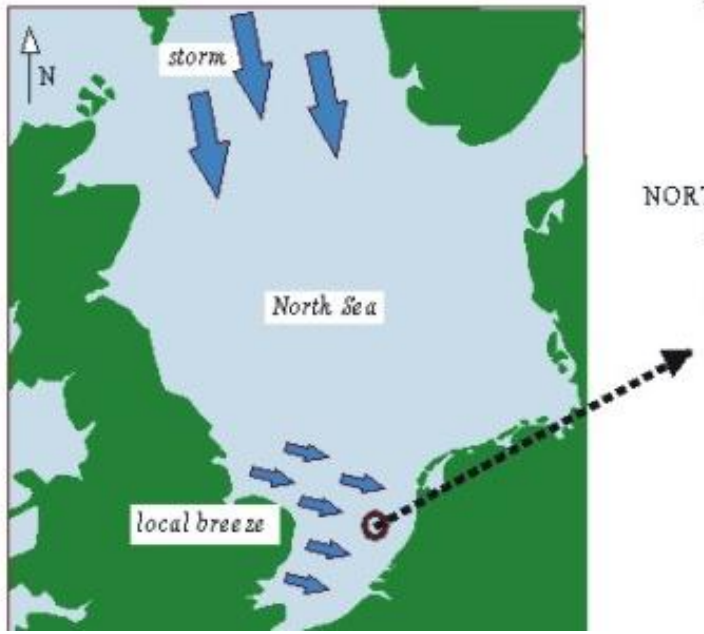
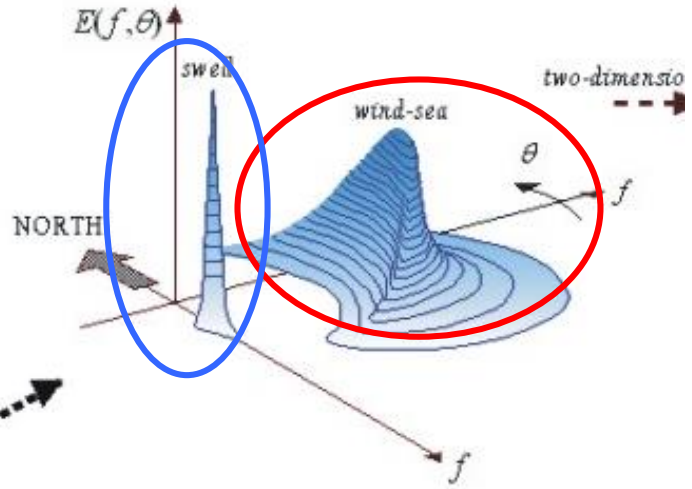
Modern ocean wave prediction systems are based on statistical description of oceans waves (i.e. ensemble average of individual waves).

The sea state is described by the two-dimensional wave spectrum F(f, θ).

For instance, the sea state off the coast of Holland might the results of a local sea breeze. These waves are generally known as windsea

Waves might have also propagated from their generation area as swell





Windsea: broad distribution of the waves around a peak

swell: well defined peak in direction and frequency.

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Significant wave height

Once the spectrum is known, information about the sea state can be derived.

For example, the mean variance of the sea surface elevation η due to waves is given by:

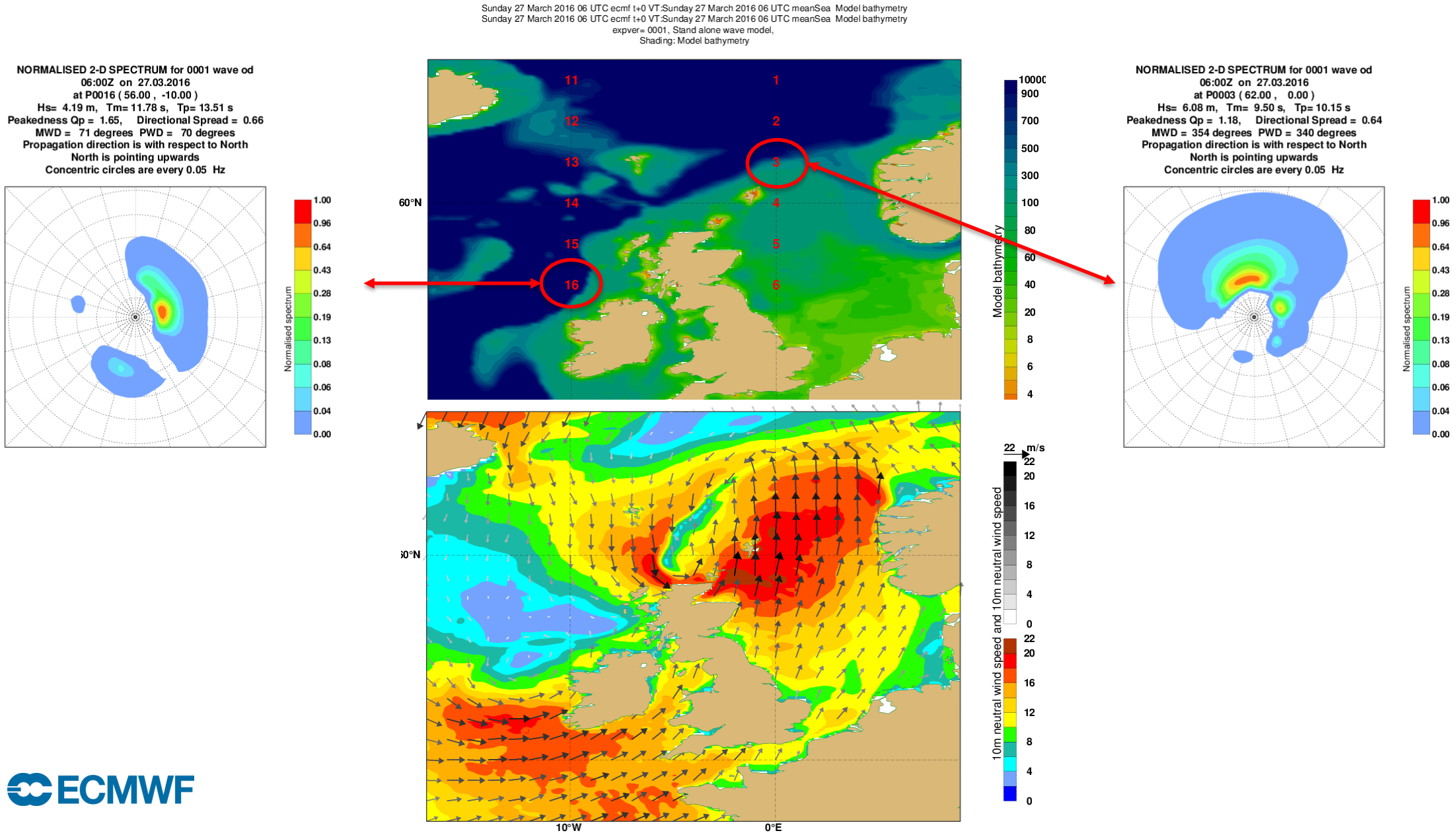
$$\langle \eta^2 \rangle = \iint F(f,\theta) df d\theta$$

The statistical measure for wave height, called the significant wave height (H_s):

$$H_s = 4\sqrt{\langle \eta^2 \rangle}$$

The term significant wave height is historical as this value appeared to be well correlated with visual estimates of wave height from experienced observers. It can be shown to correspond to the average 1/3rd highest waves ($H_{1/3}$).

2D wave spectra are now routinely output

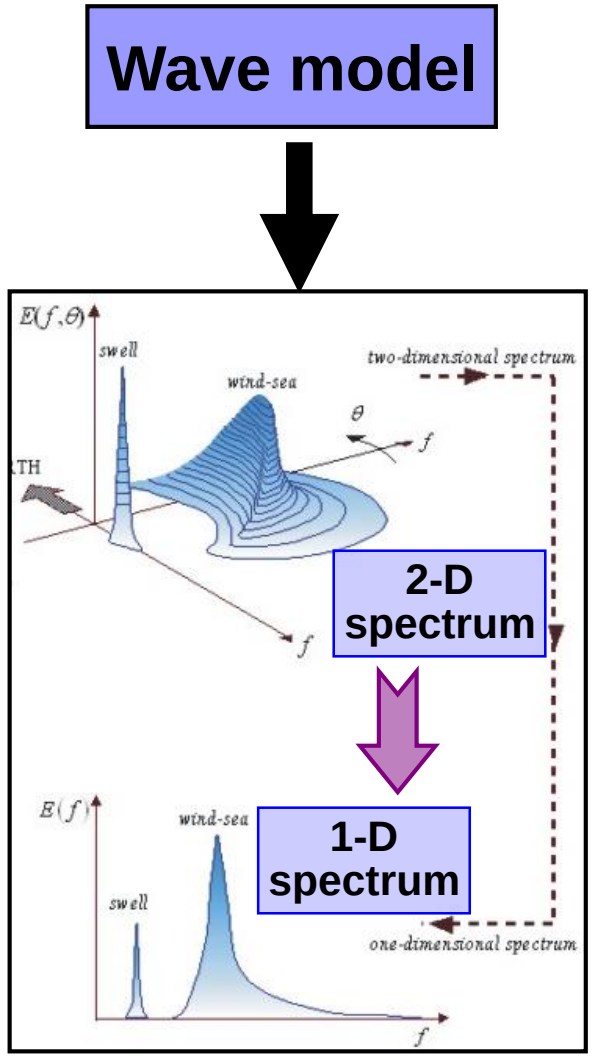


Wave model products:

The complete description of the sea state is given by the 2-D spectrum, however, it is a fairly large amount of data.

It is therefore reduced to integrated quantities:

1-D spectrum obtained by integrating the 2-D spectrum over all directions and/or over a frequency range.



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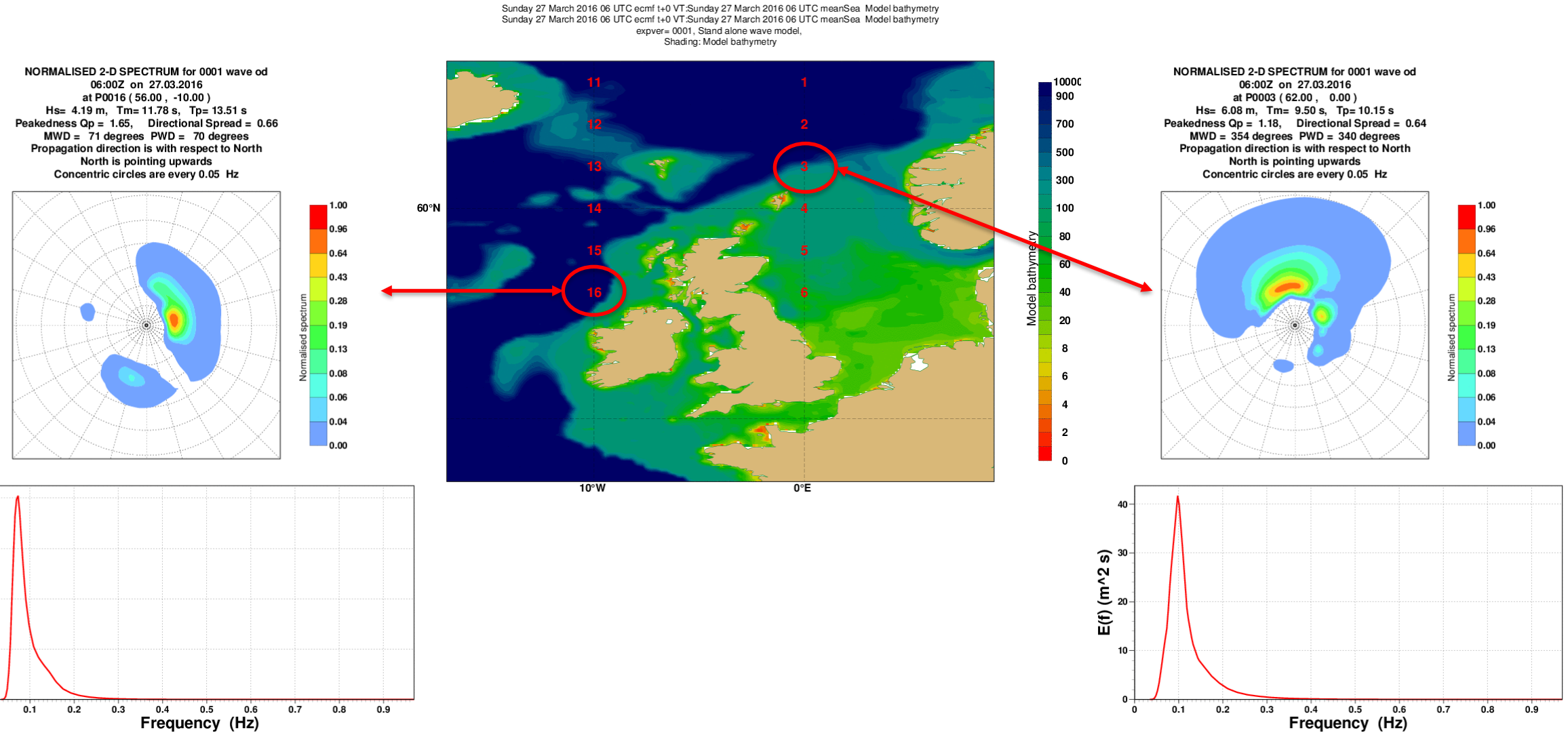

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Wave model products:

When simple numbers are required, the following parameters are available:

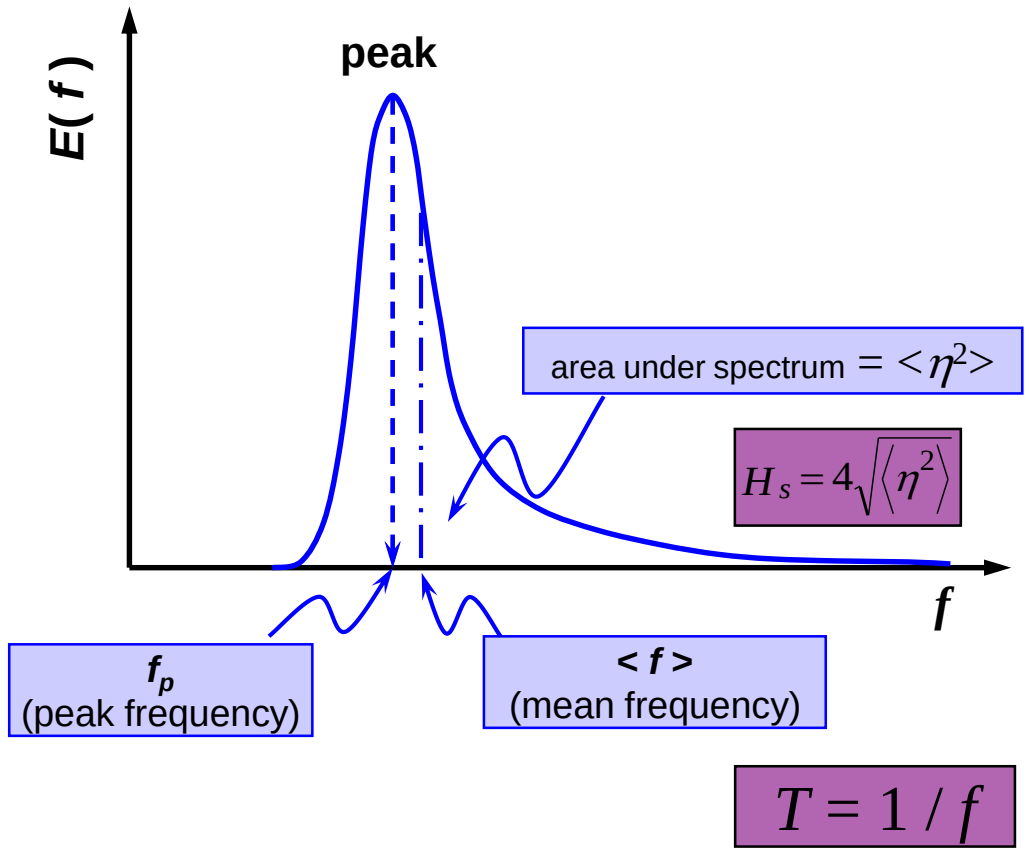
The significant wave height (H_s).

The peak period (period of the peak of the 1-D spectrum).

Mean period(s) obtained from weighted integration of the 2-D spectrum.

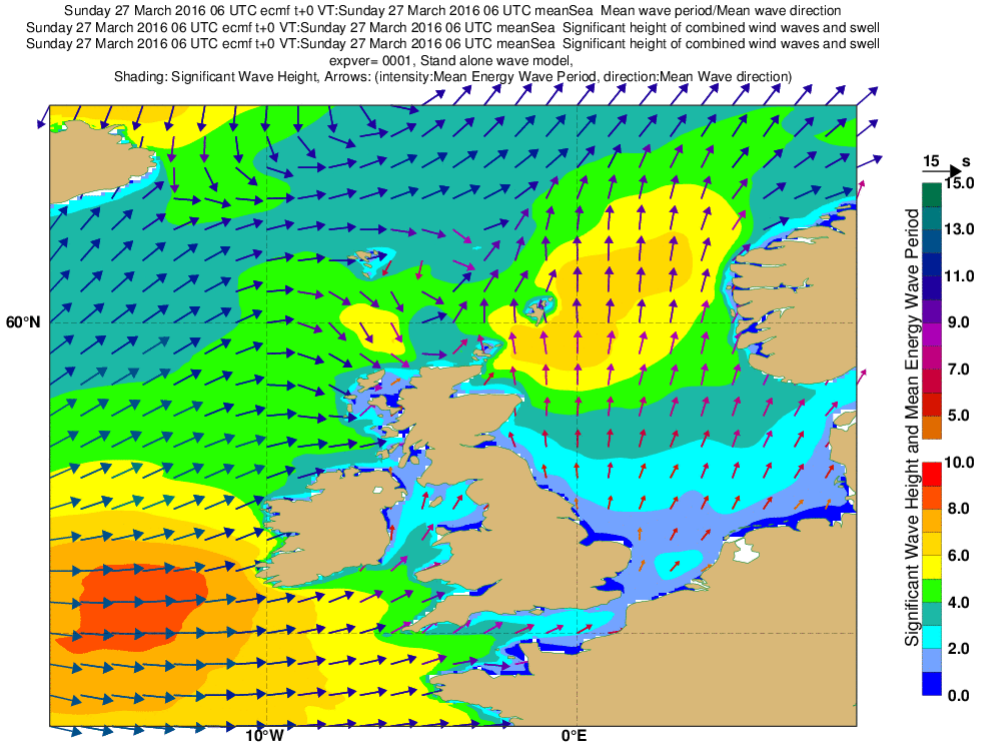
Integrated mean direction.

and many others.



Reference to chapter 10 of part VII of IFS documentation

Model output: ‘historically’



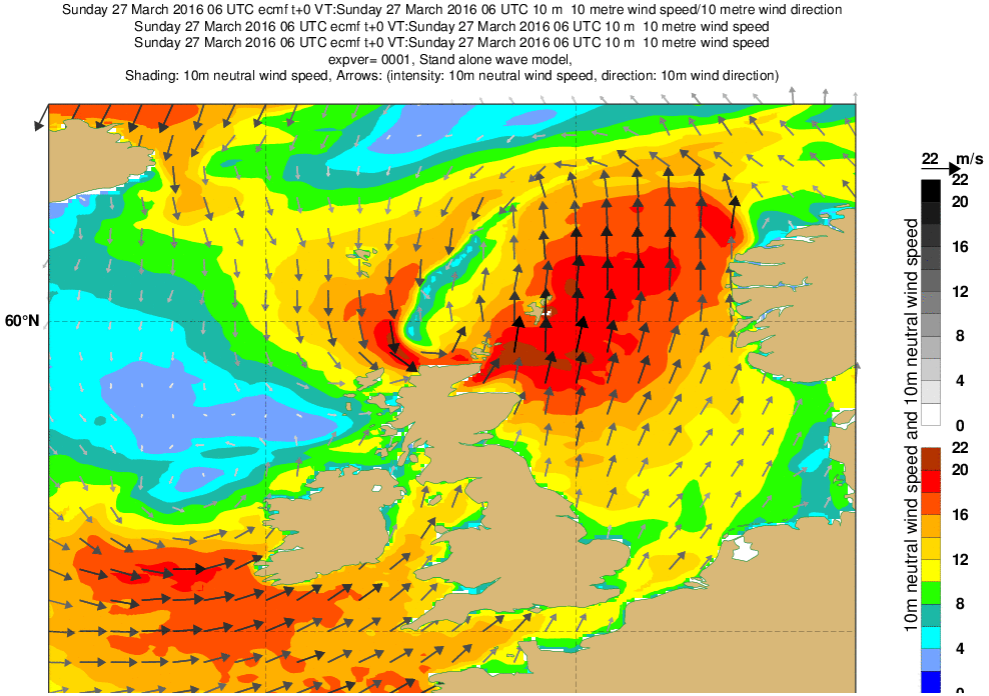


Figure 10.5 *10m neutral Wind Speed (colour shading, arrow length and grey scale), direction) on 23 March 2016, 6 UTC.*

Figure 10.4 *Significant wave height (H_s) (colour shading), Mean Wave Direction (arrow direction) and Mean Wave Period (T_{m-1}) (arrow length and colour) on 23 March 2016, 6 UTC.*

H_s and mean wave period (T_m) in mean wave direction

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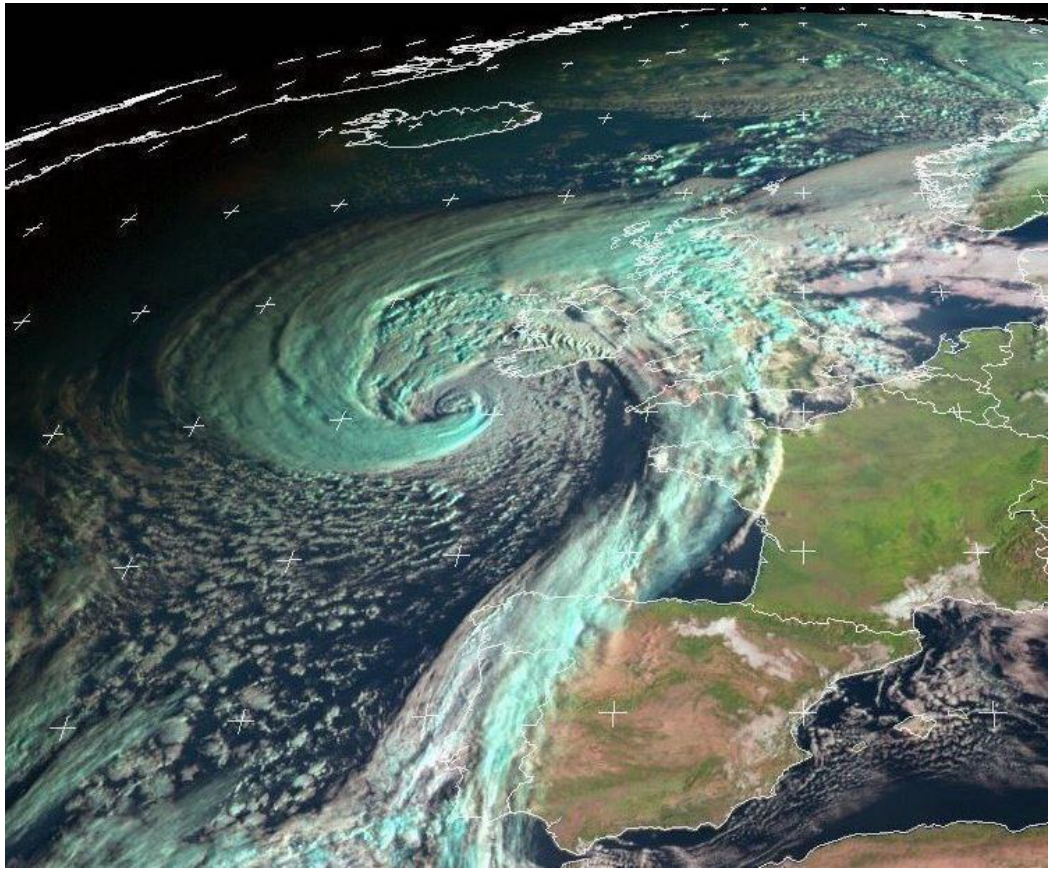
Are you ready for the first “animation”?



Ex-hurricane Ophelia

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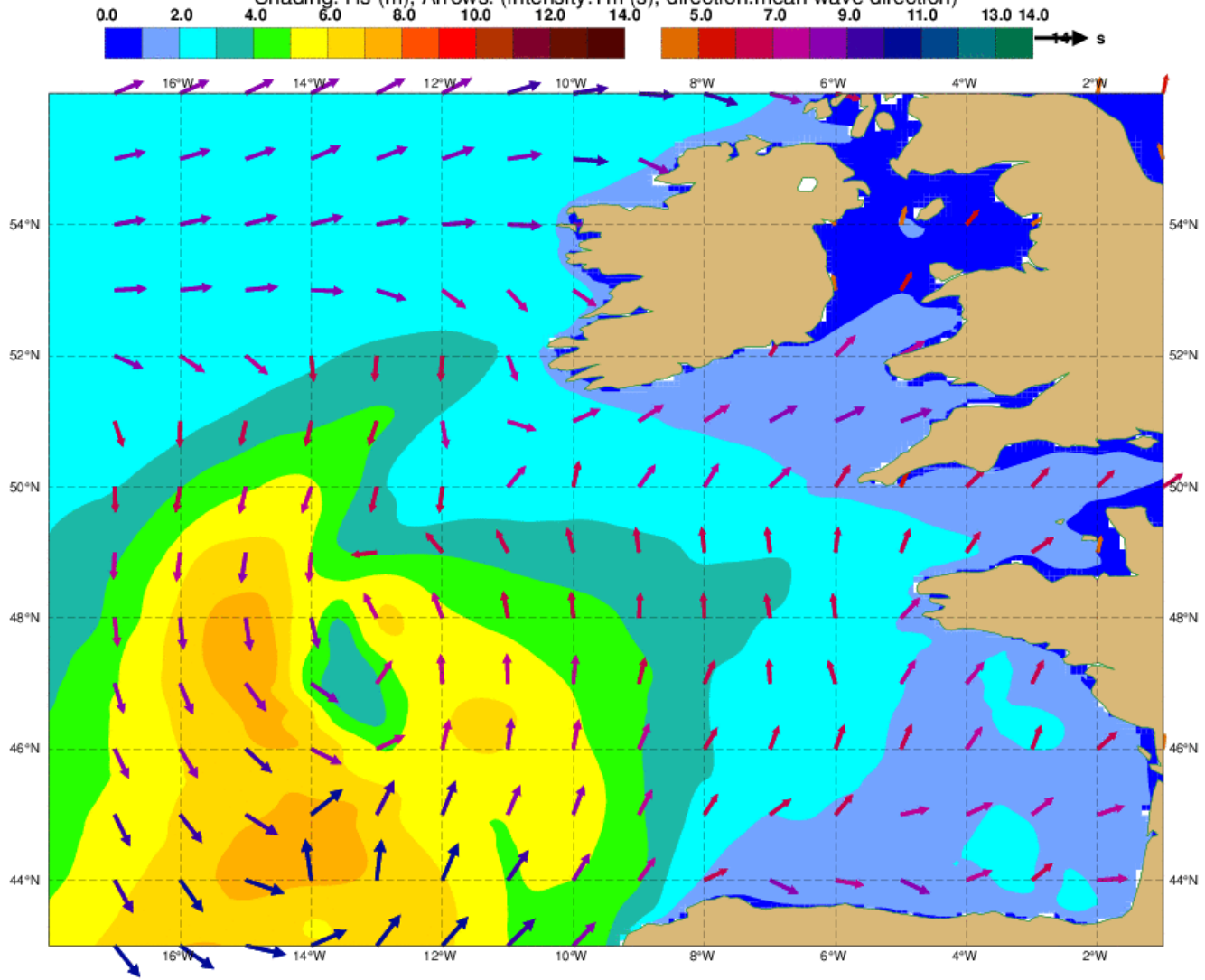
ECMWF operational forecast from HRES SAW system
Shading: Hs (m), Arrows: (intensity:Tm (s), direction:mean wave direction)



ECMWF

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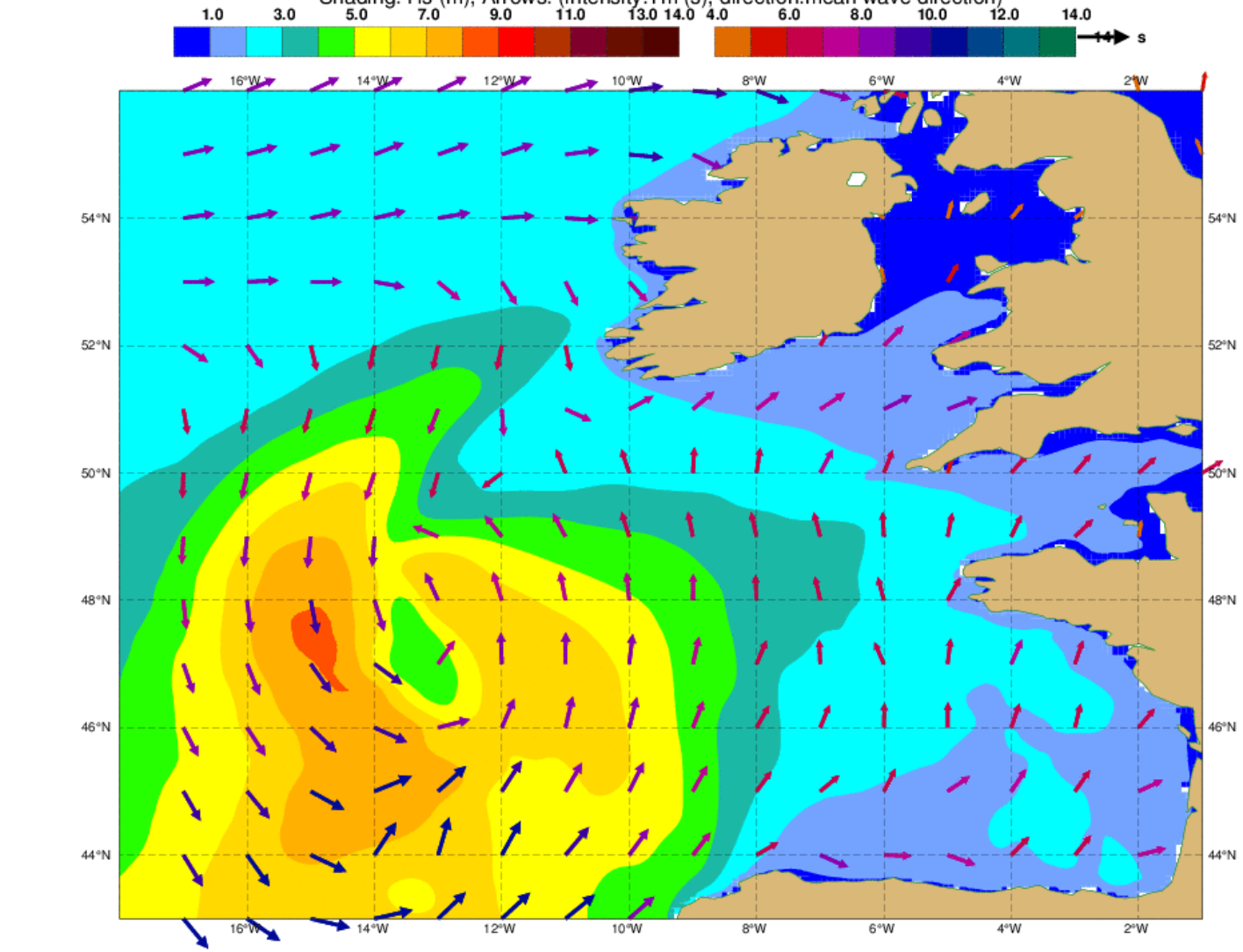

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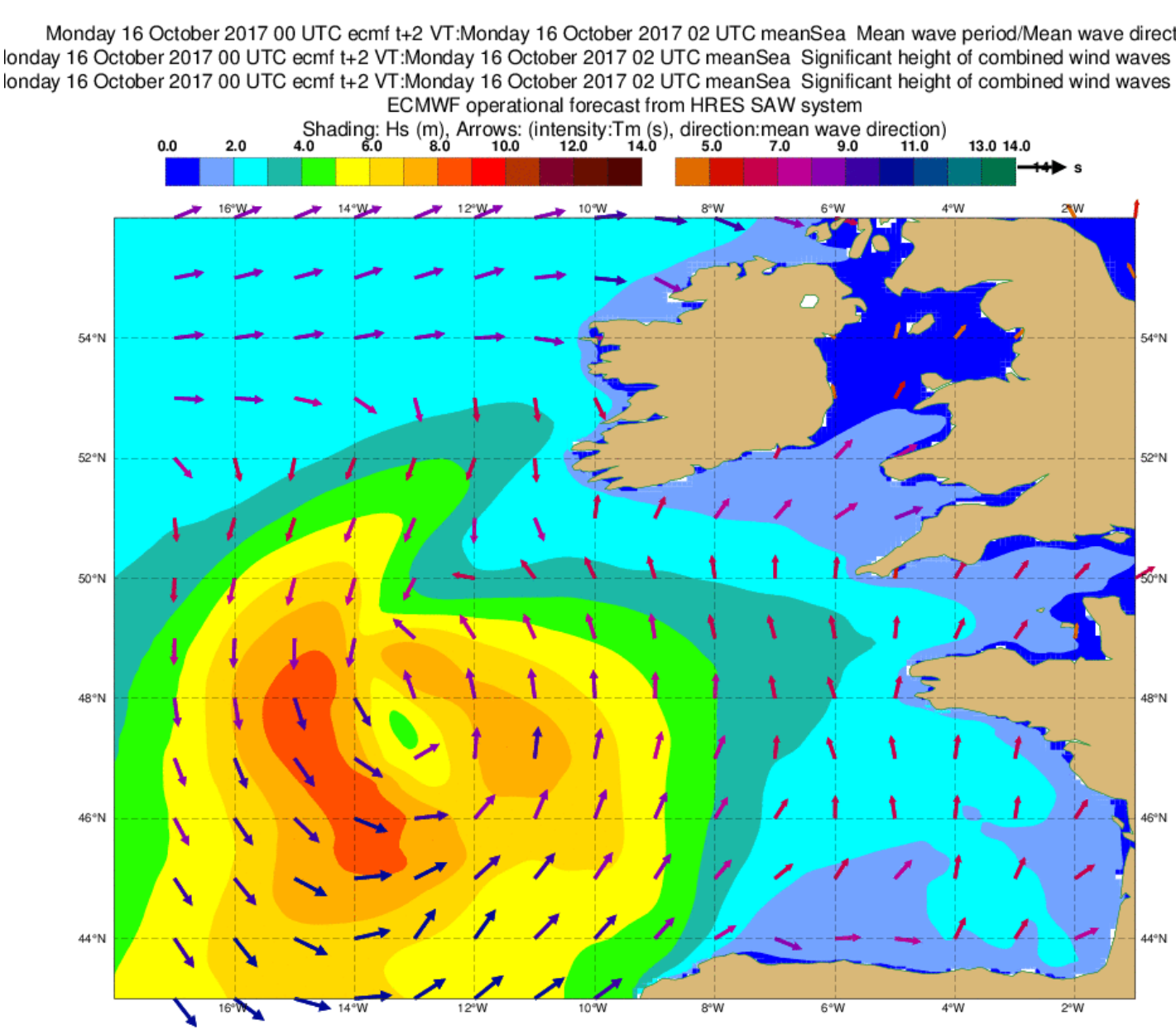
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ECMWF operational forecast from HRES SAW system
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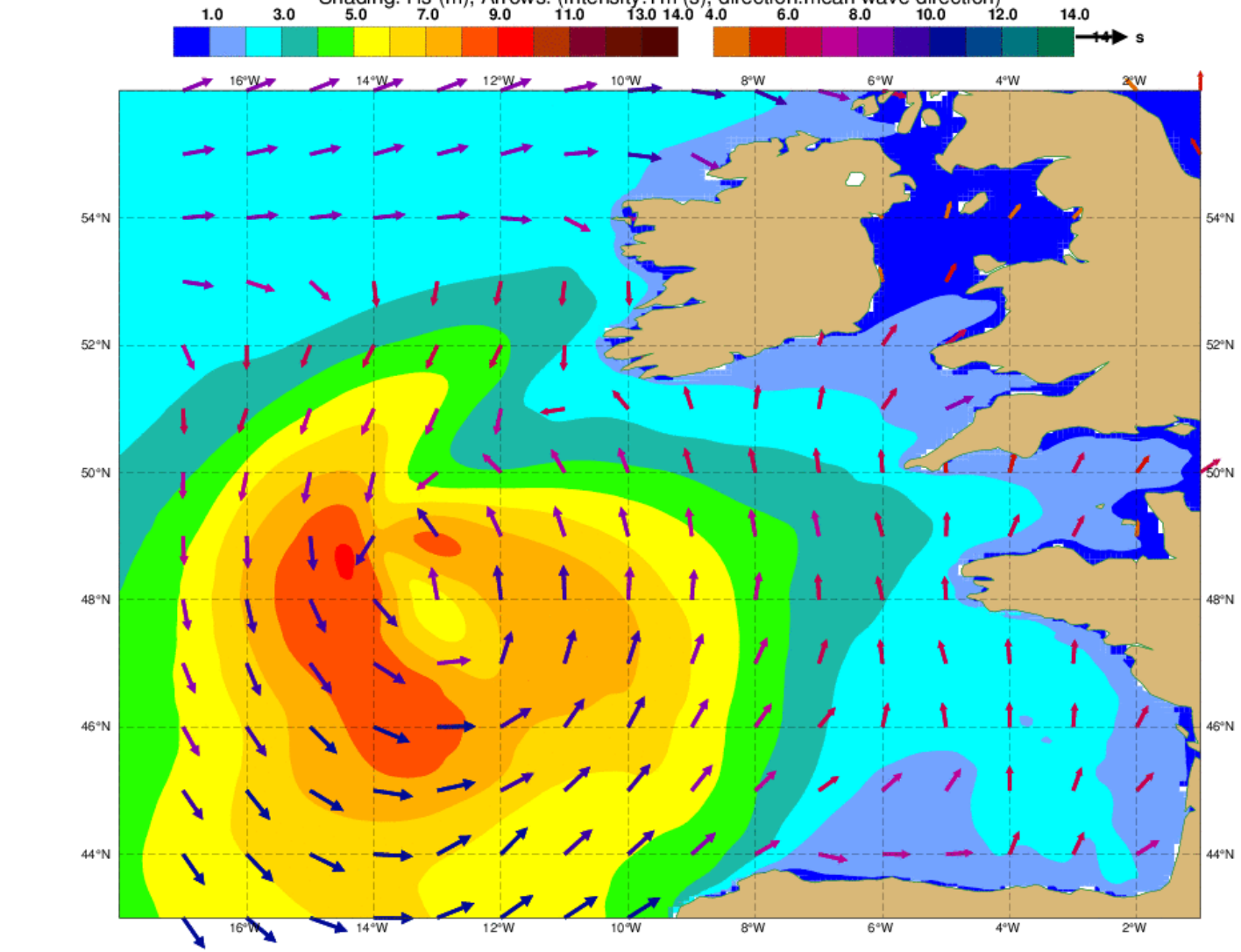

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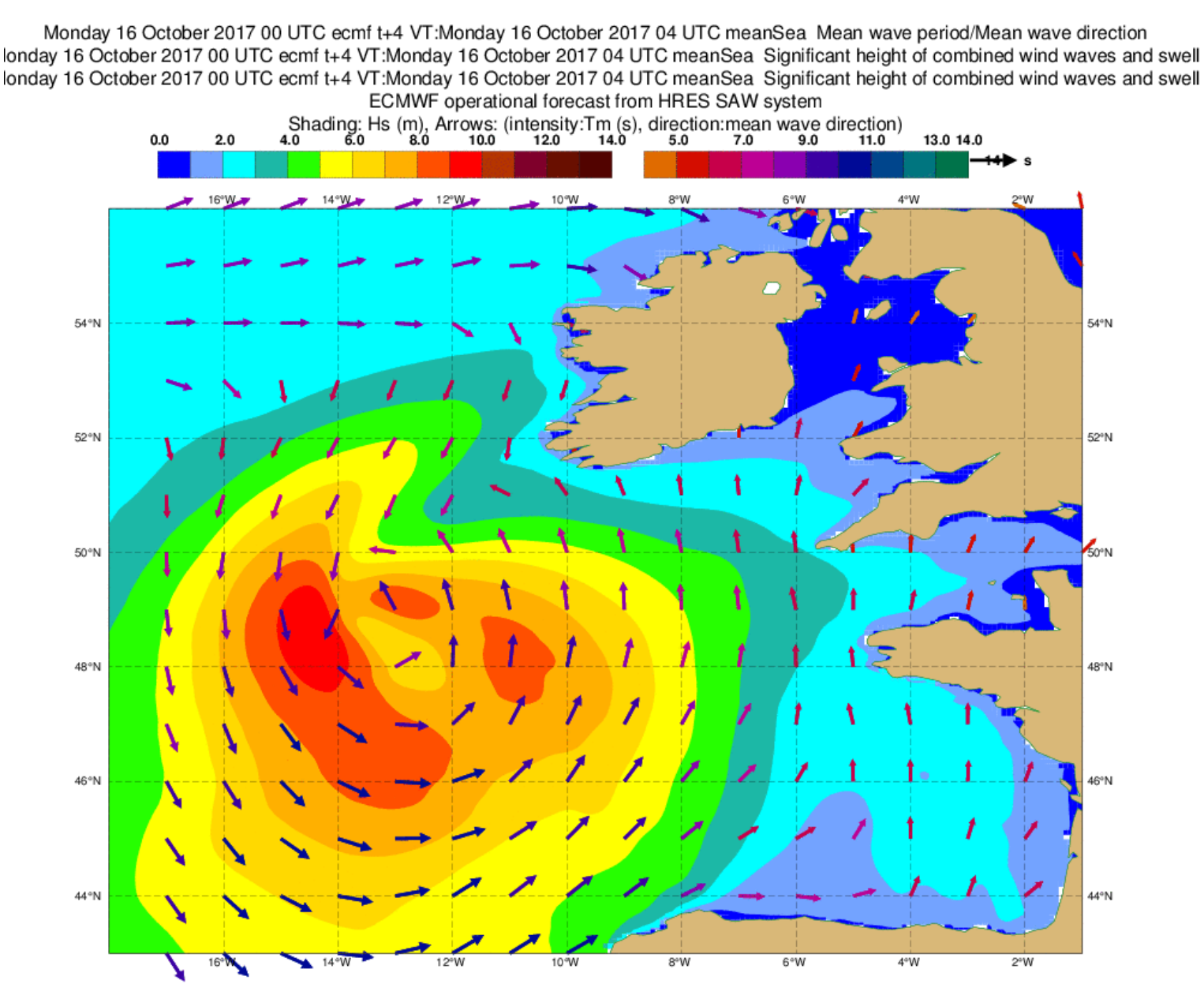
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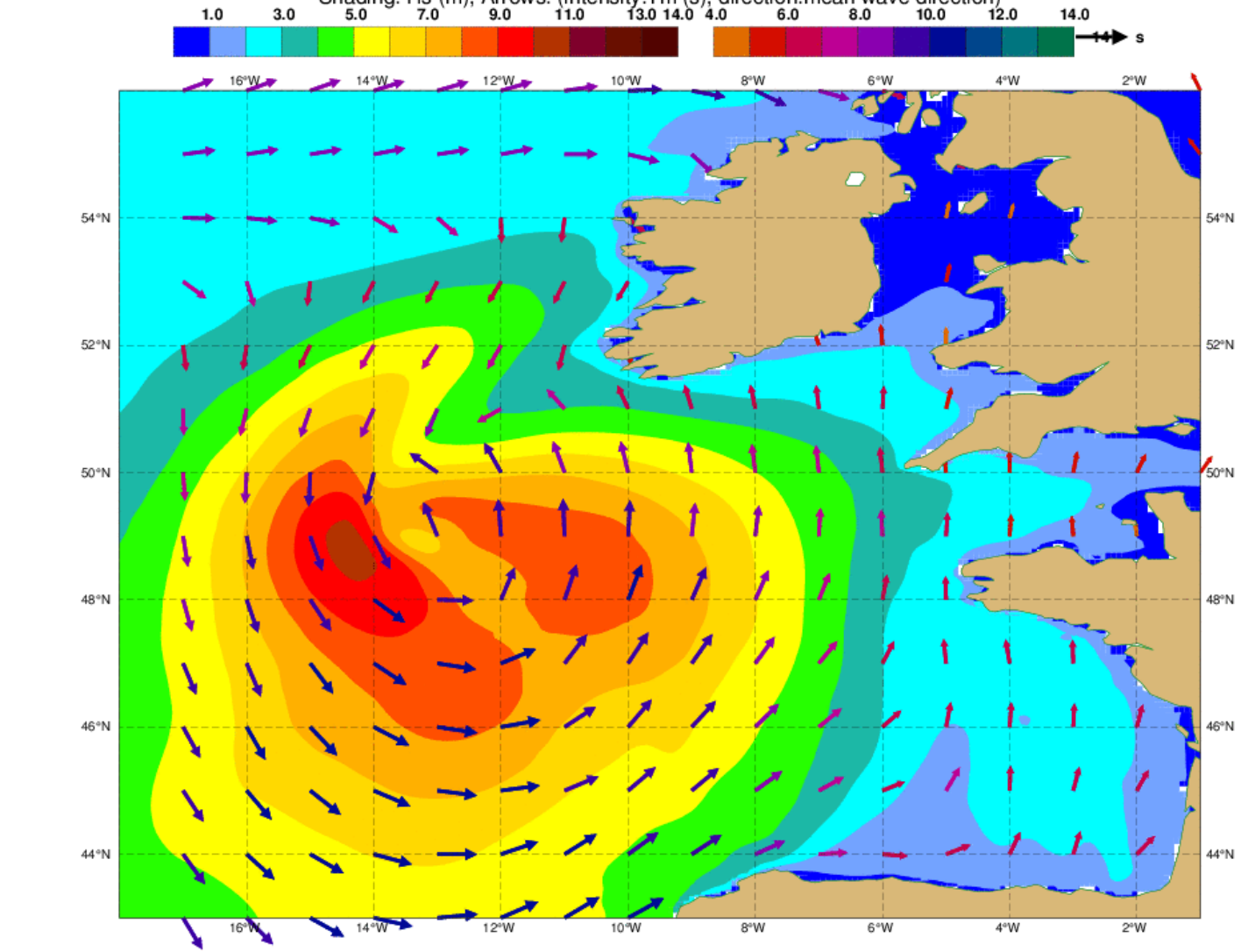

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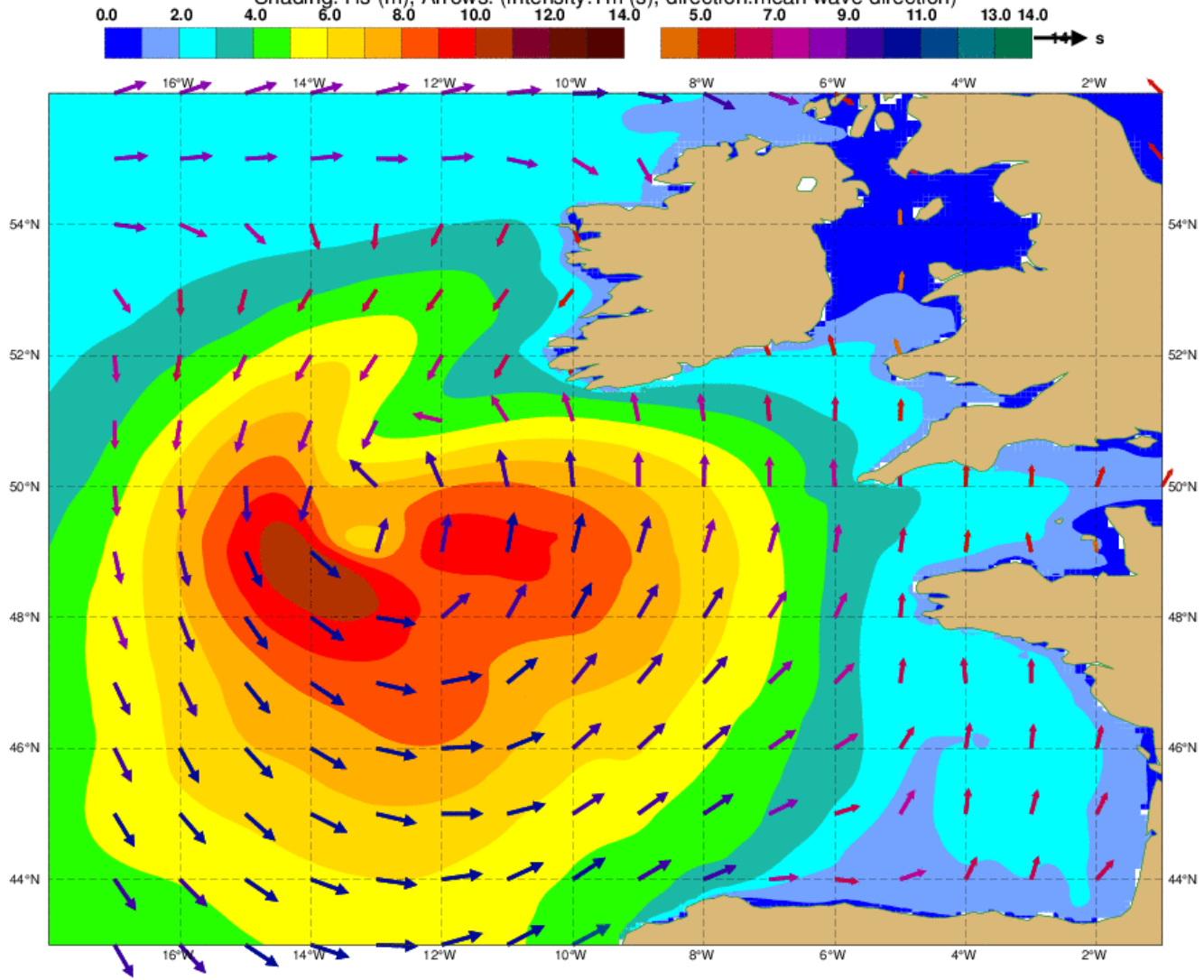
ECMWF operational forecast from HRES SAW system
Shading: Hs (m), Arrows: (intensity:Tm (s), direction:mean wave direction)



ECMWF

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ECMWF operational forecast from HRES SAW system
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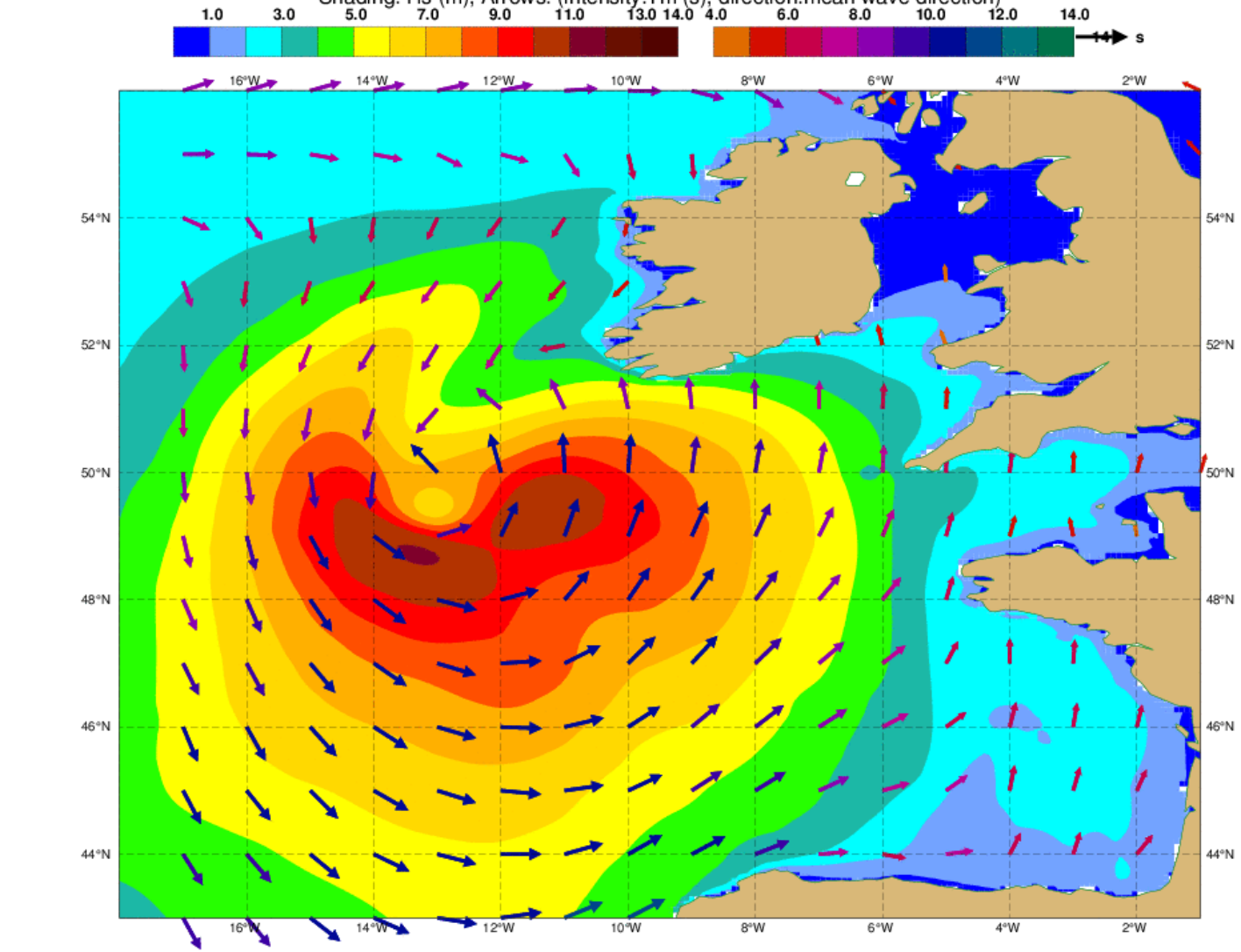

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ECMWF operational forecast from HRES SAW system
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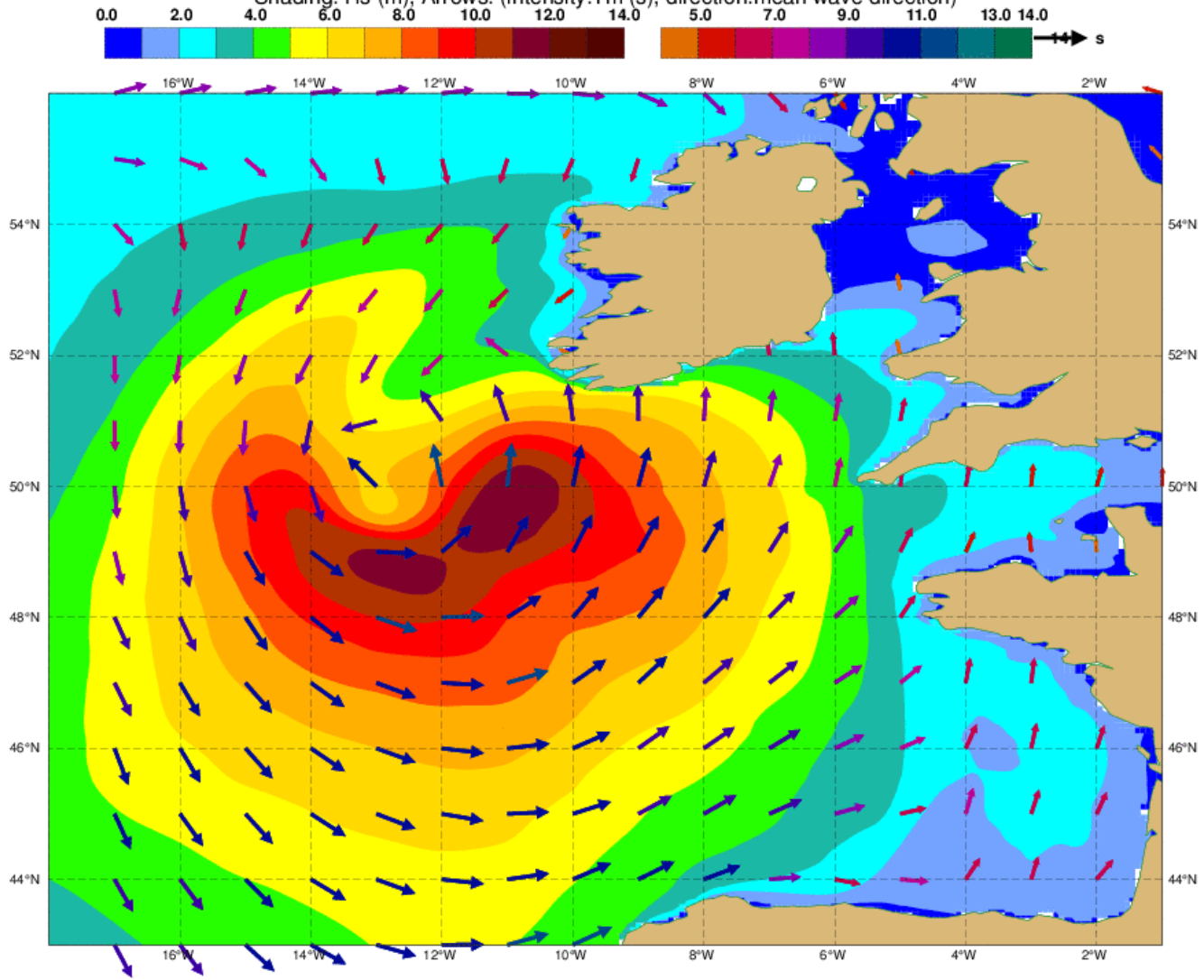

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ECMWF operational forecast from HRES SAW system
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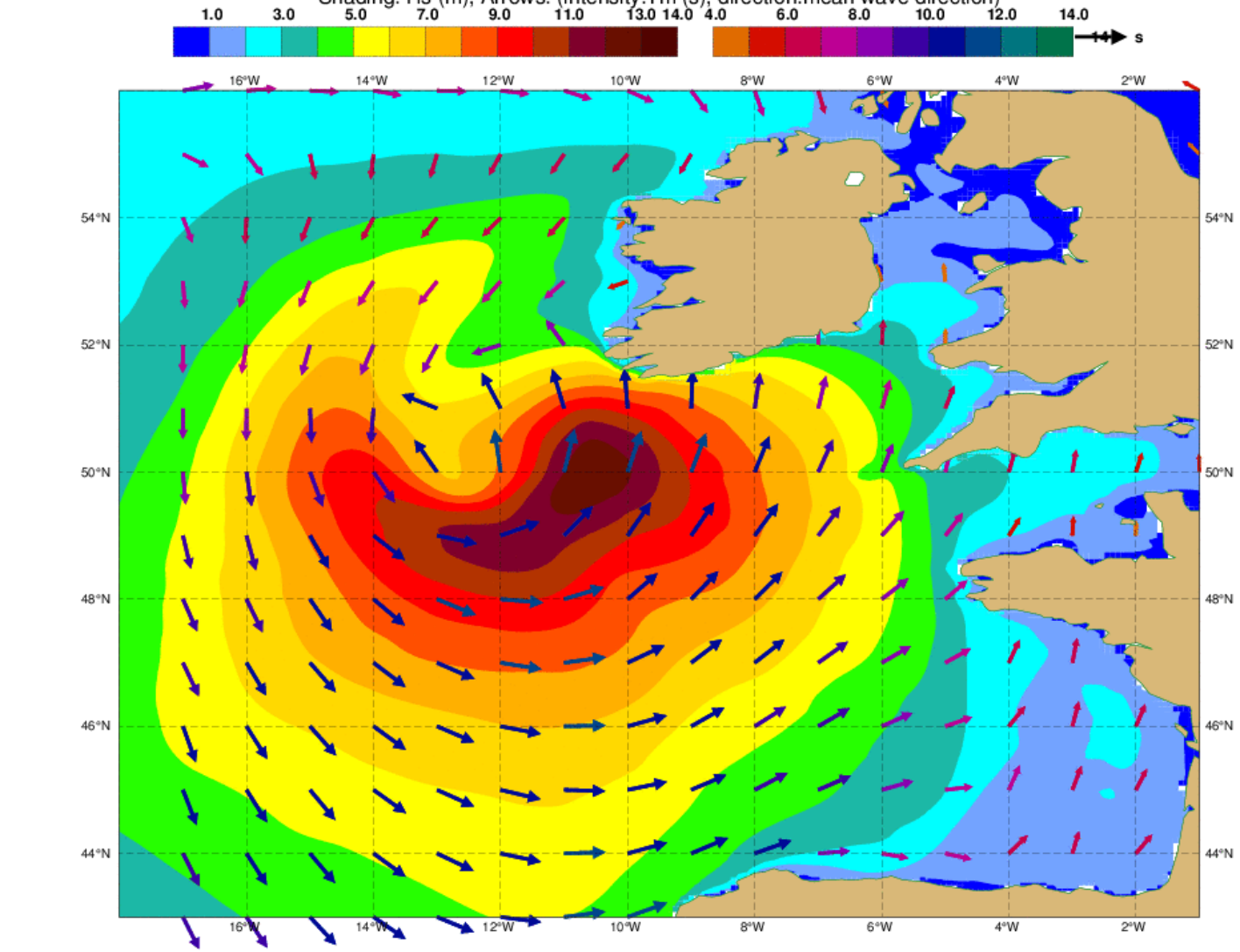

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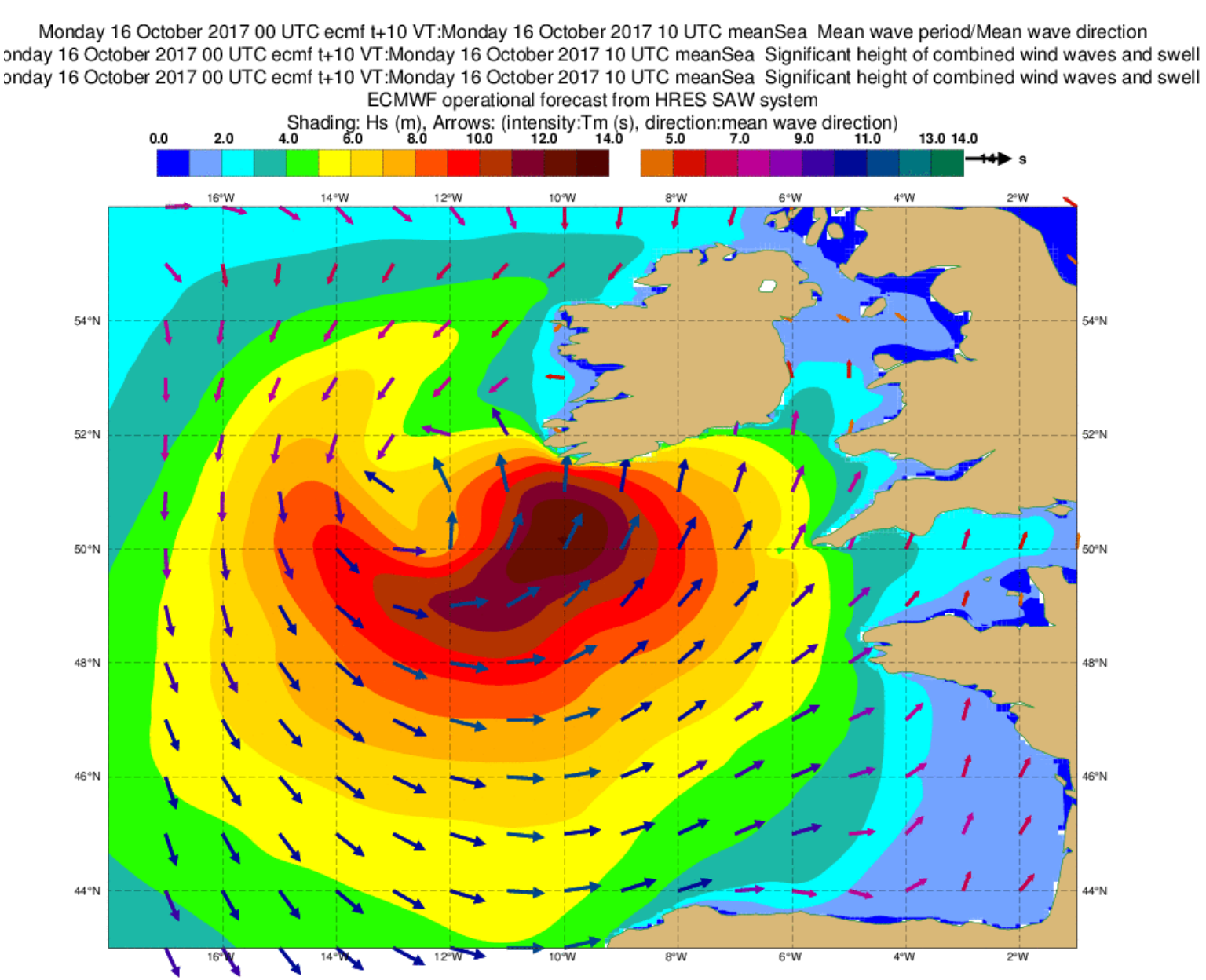
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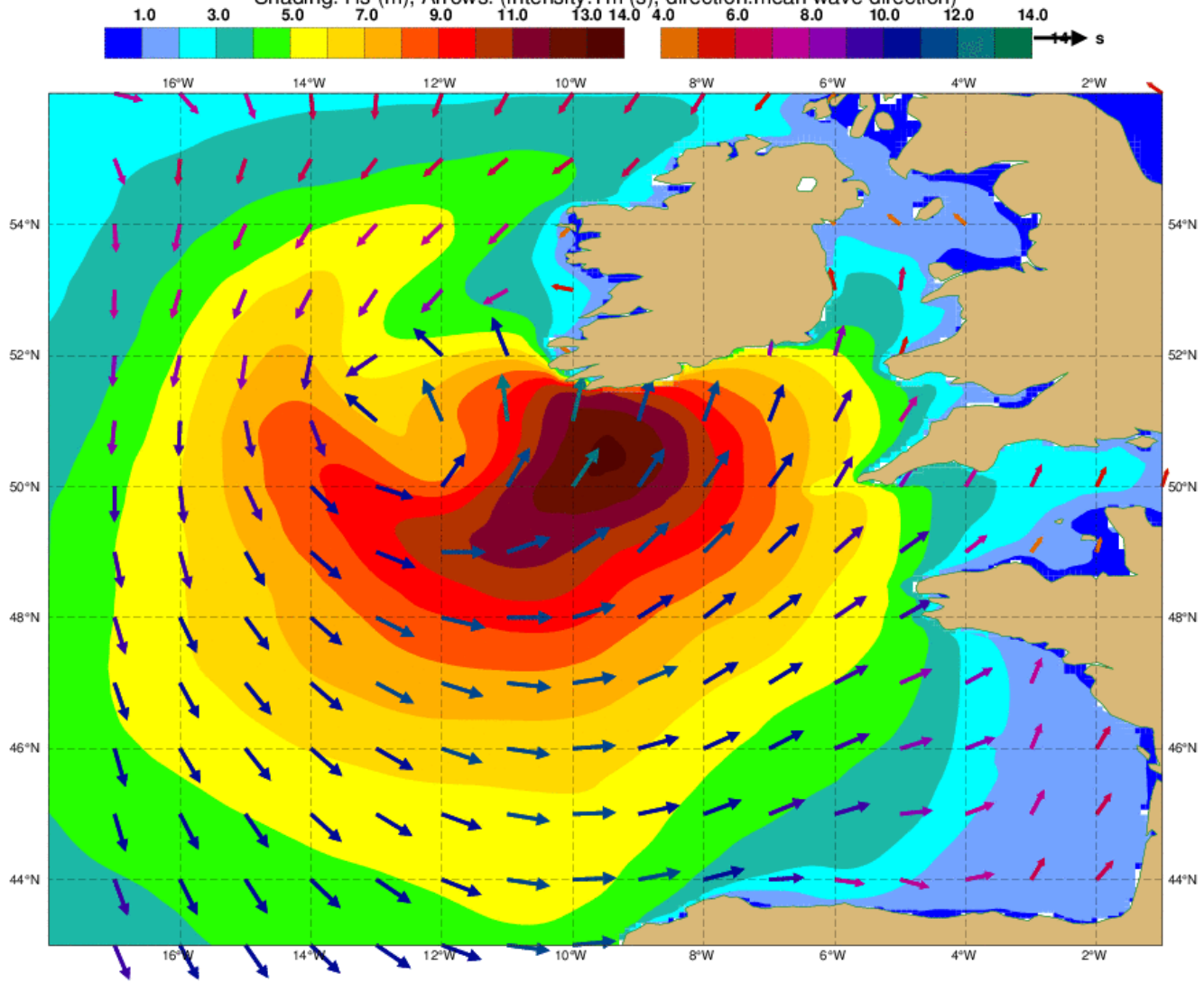

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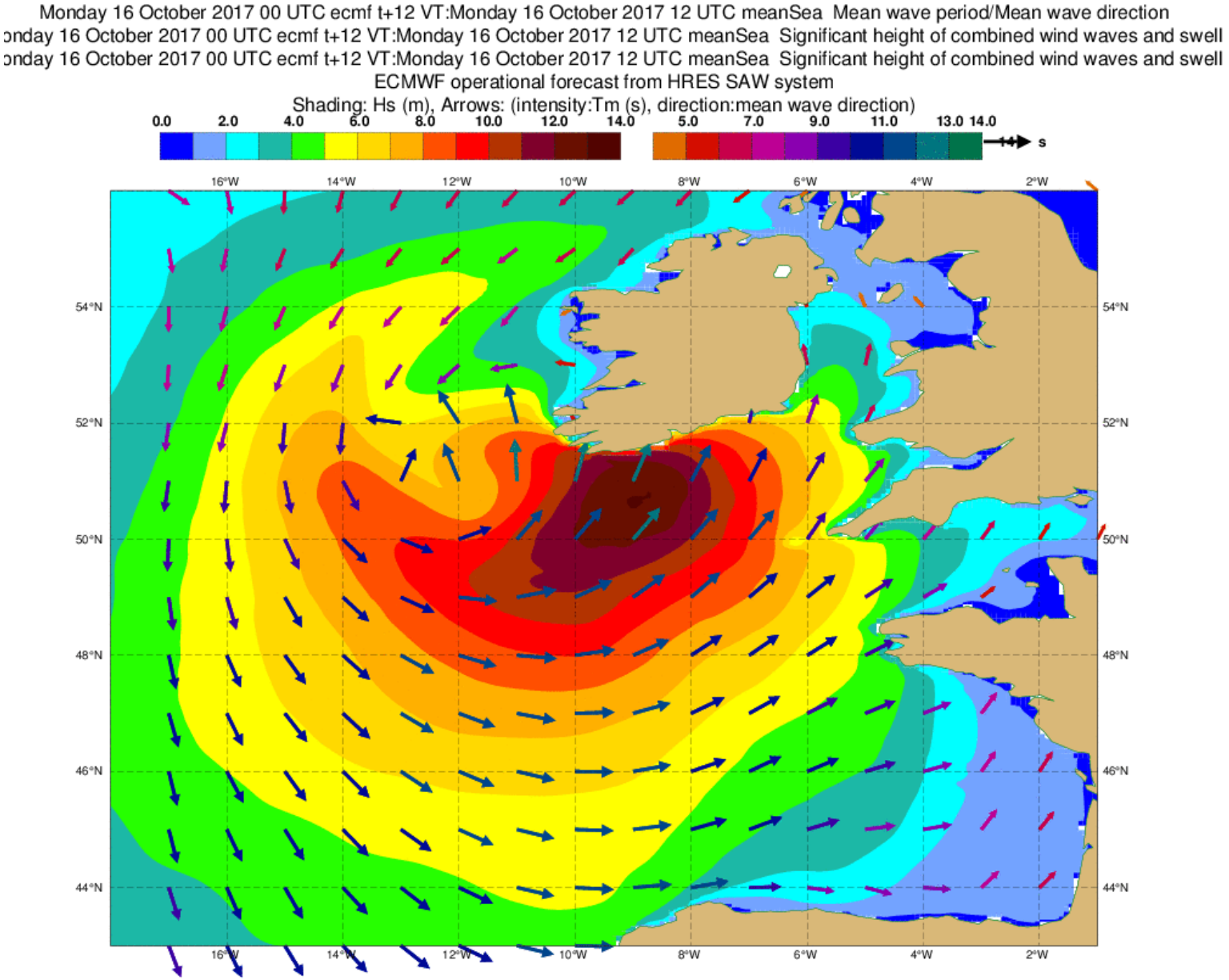
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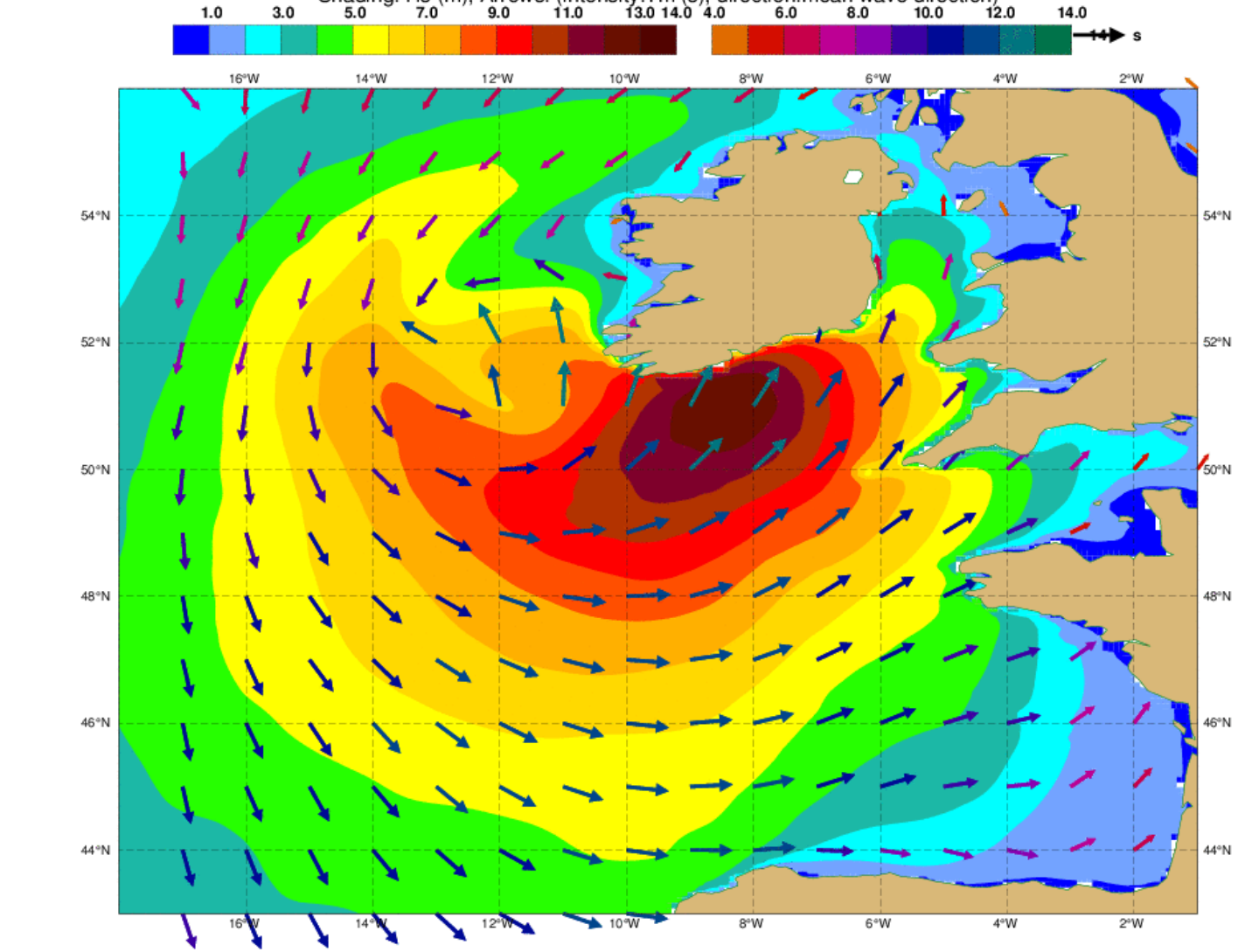

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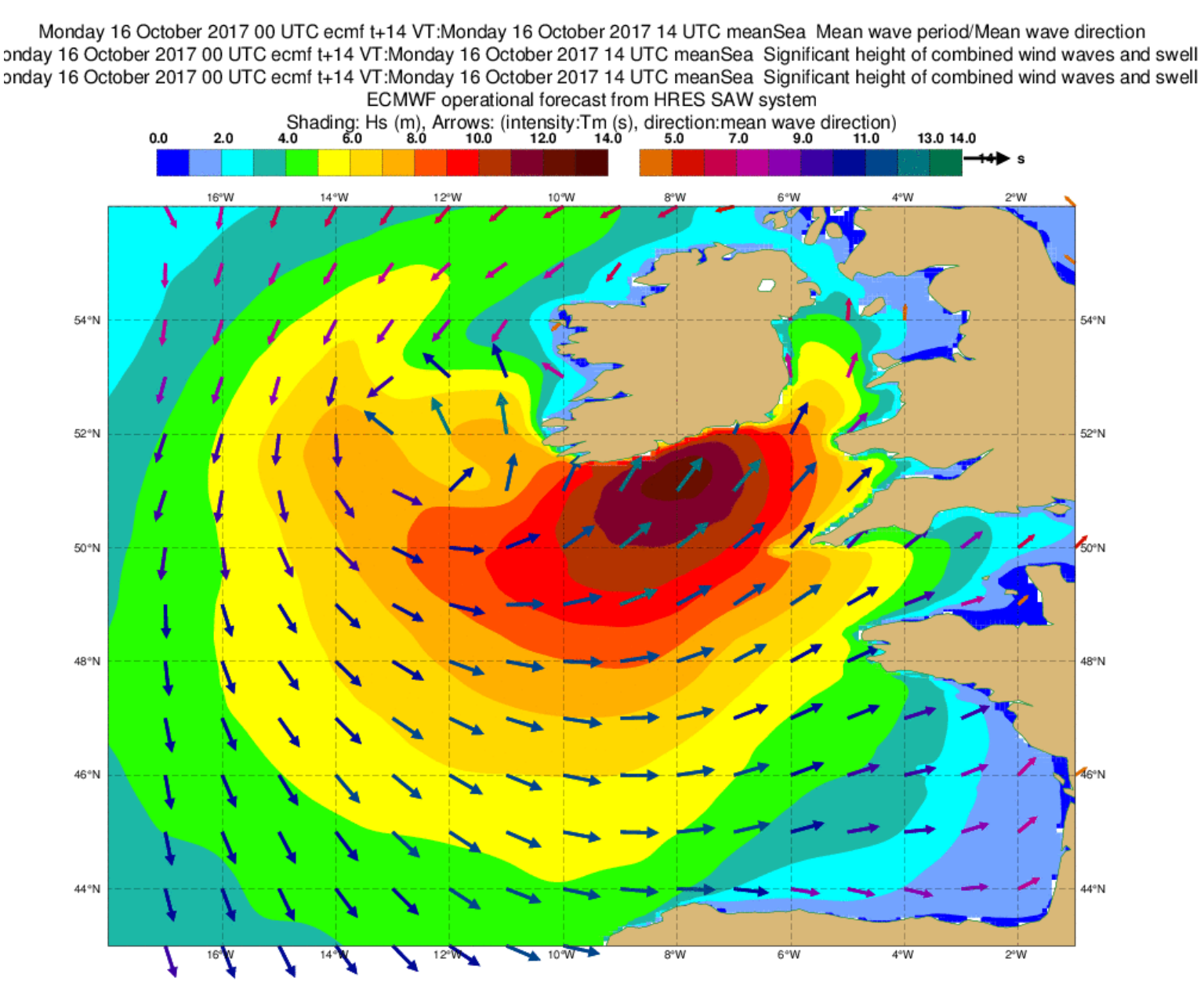
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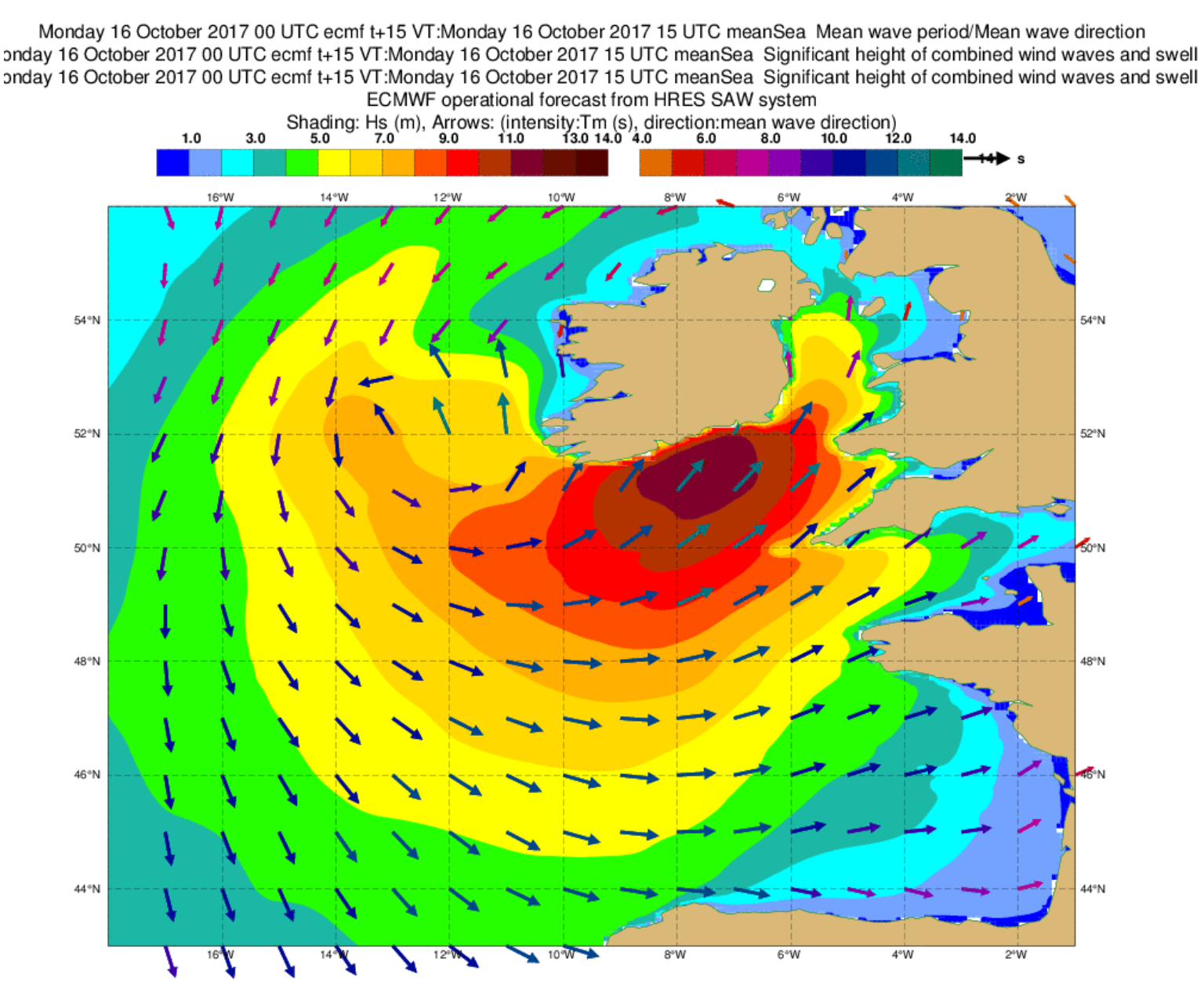
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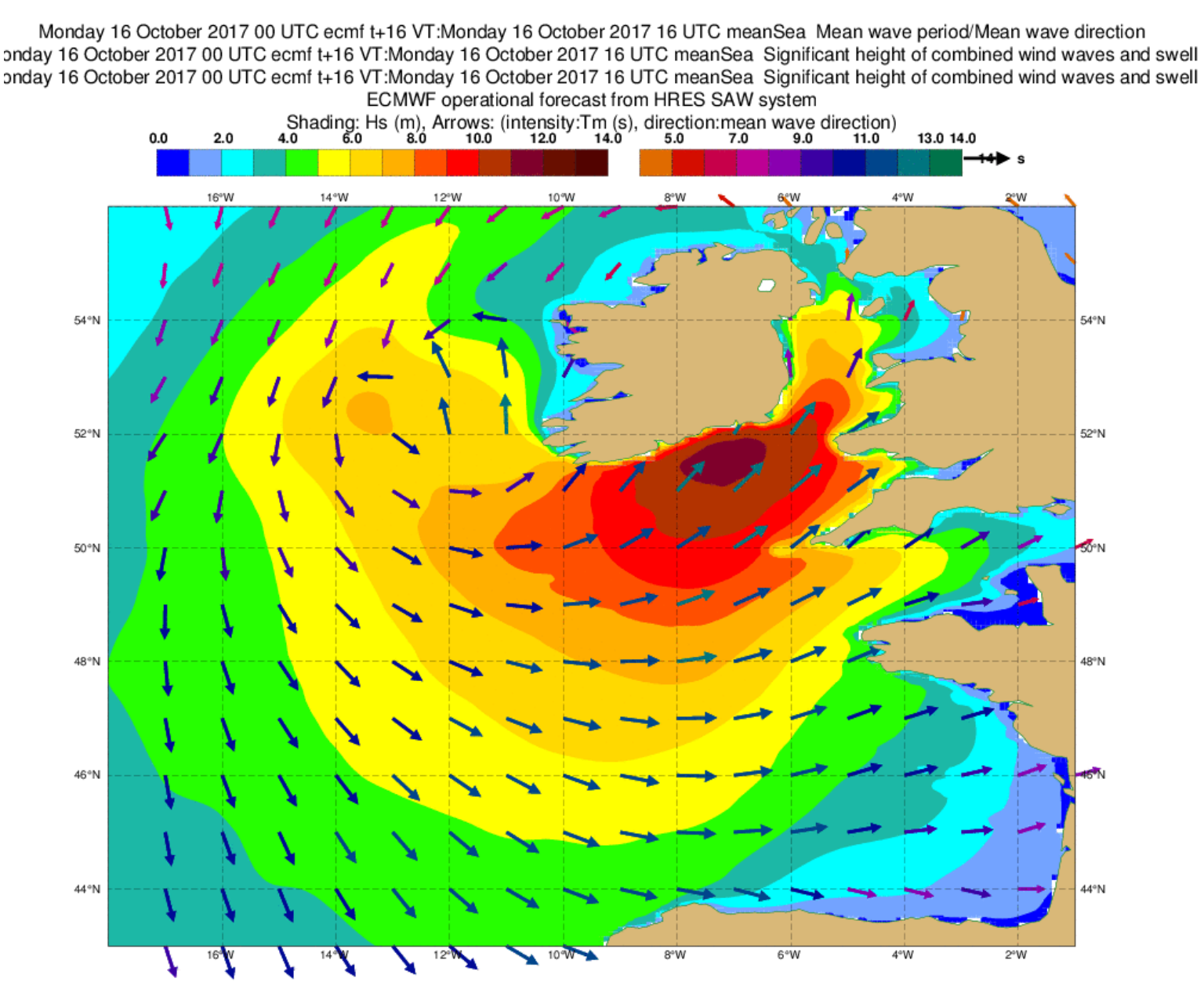
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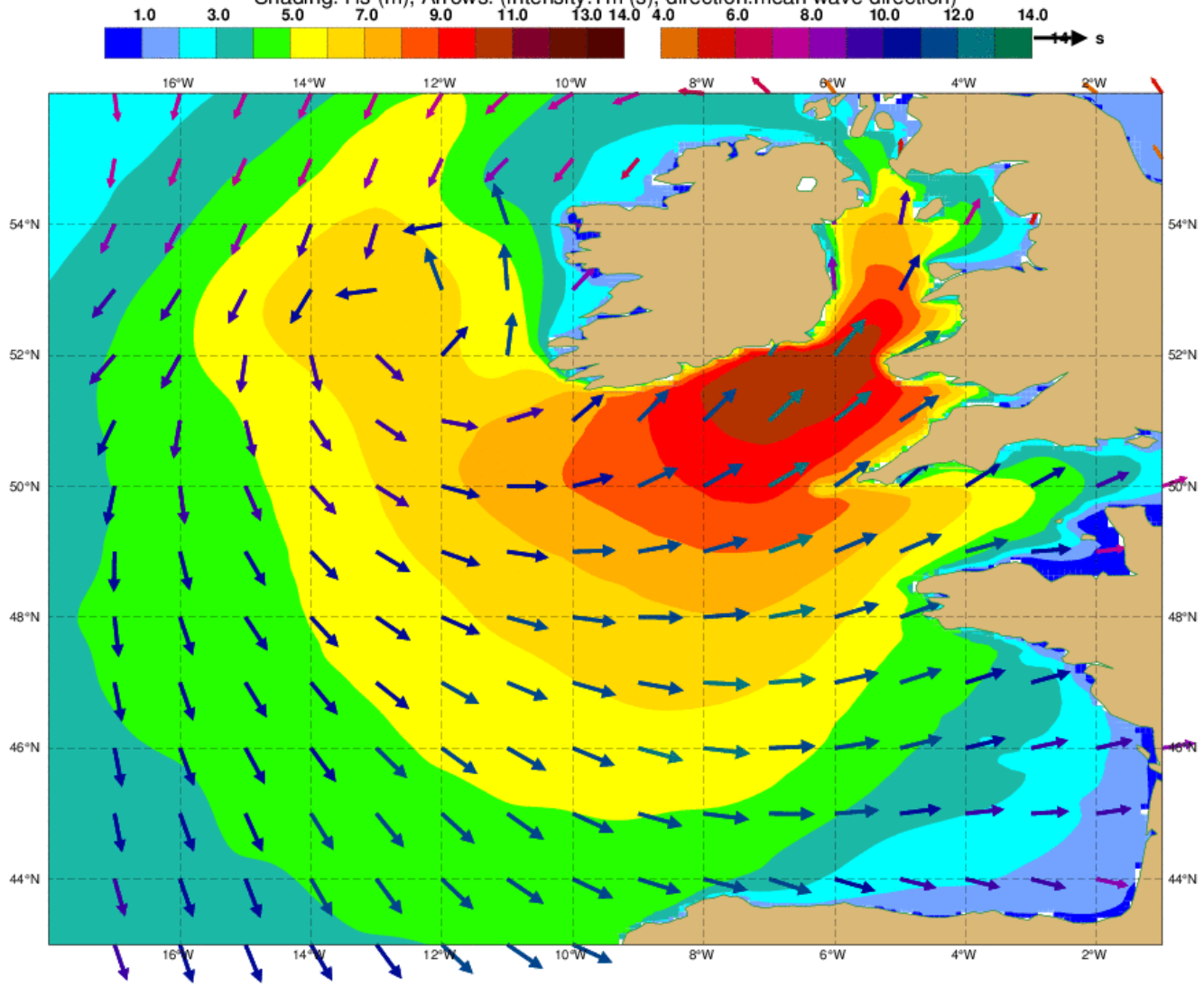

ECMWF

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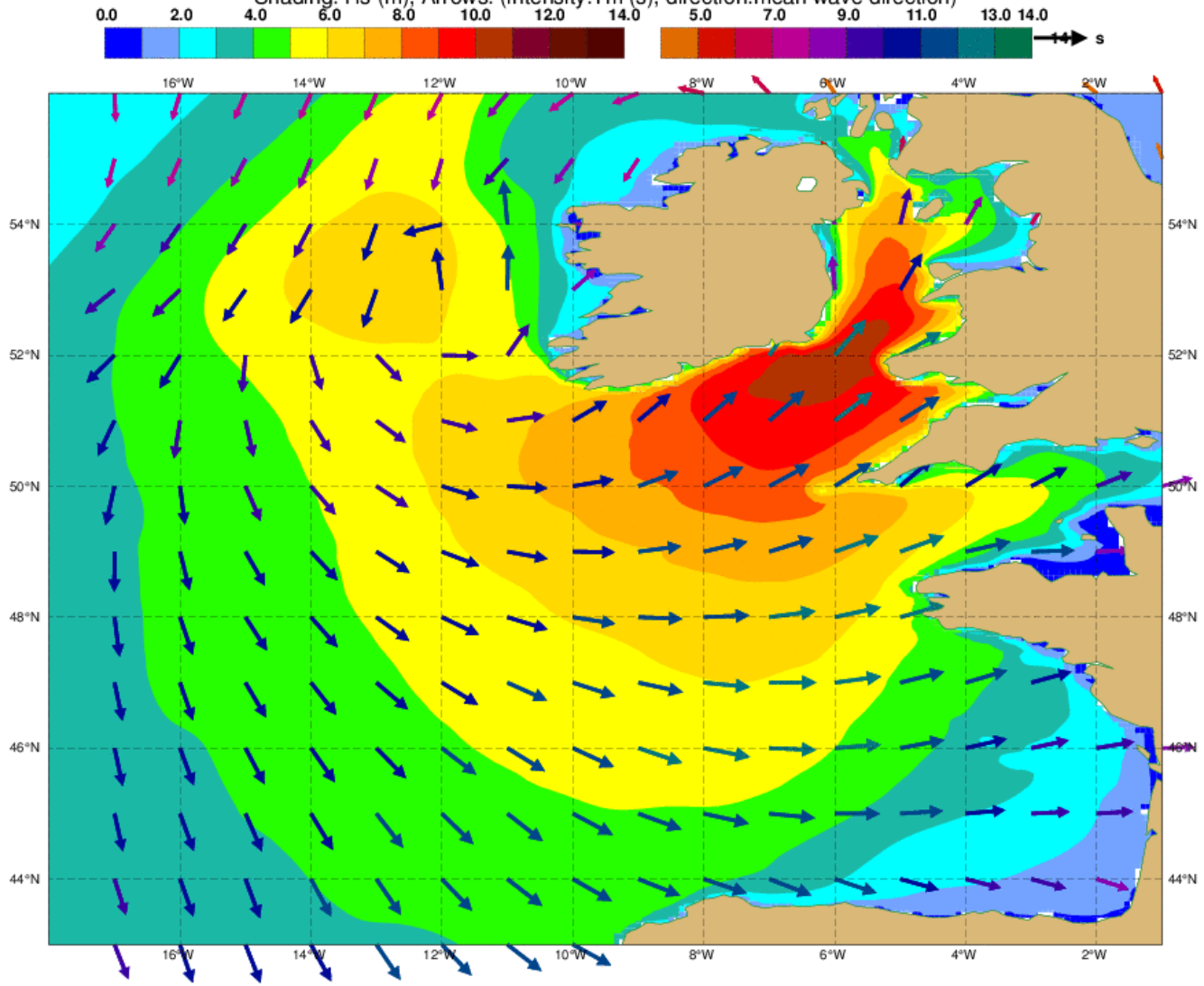
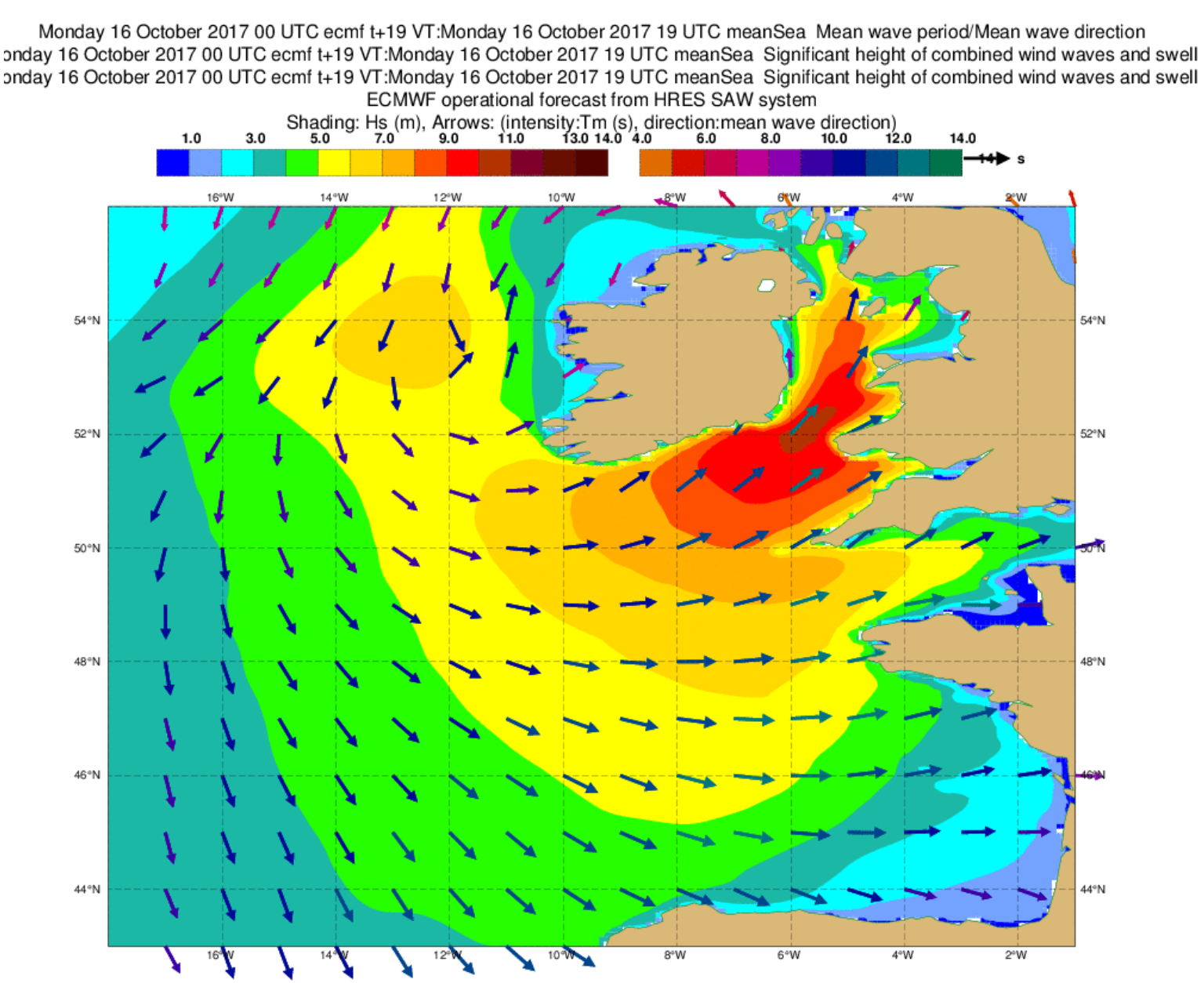
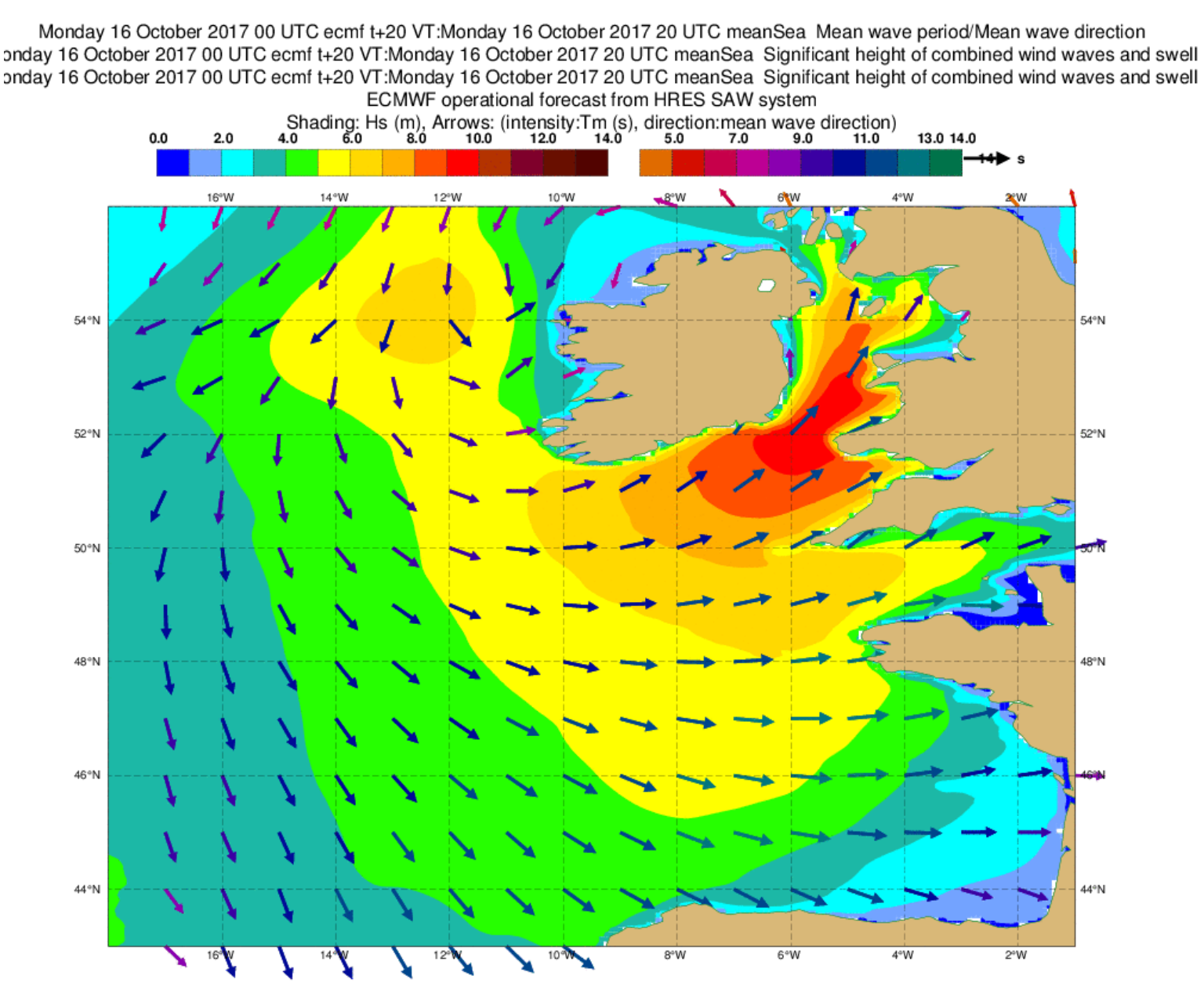
onday 16 October 2017 00 UTC ecmf t+18 VT:Monday 16 October 2017 18 UTC meanSea Significant height of combined wind waves and swell
ECMWF operational forecast from HRES SAW system
Shading: Hs (m), Arrows: (intensity:Tm (s), direction:mean wave direction)



ECMWF


Monday 16 October 2017 00 UTC ecmf t+19 VT:Monday 16 October 2017 19 UTC meanSea Mean wave period/Mean wave direction
onday 16 October 2017 00 UTC ecmf t+19 VT:Monday 16 October 2017 19 UTC meanSea Significant height of combined wind waves and swell
onday 16 October 2017 00 UTC ecmf t+19 VT:Monday 16 October 2017 19 UTC meanSea Significant height of combined wind waves and swell
ECMWF operational forecast from HRES SAW system
Shading: Hs (m), Arrows: (intensity:Tm (s), direction:mean wave direction)
1.0 3.0 5.0 7.0 9.0 11.0 13.0 14.0 4.0 6.0 8.0 10.0 12.0 14.0
s
16°W 14°W 12°W 10°W 8°W 6°W 4°W 2°W
54°N 52°N 50°N 48°N 46°N 44°N

ECMWF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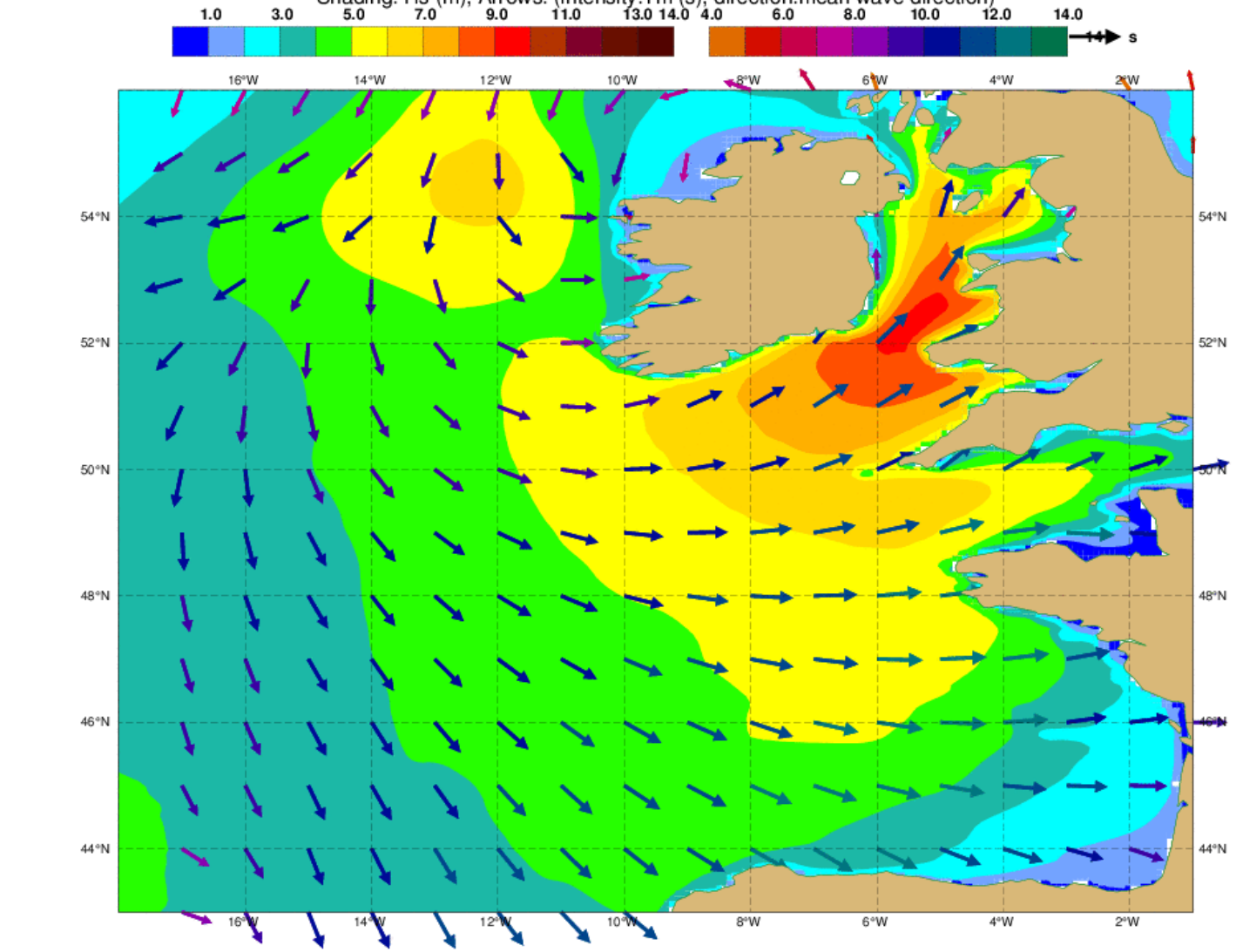
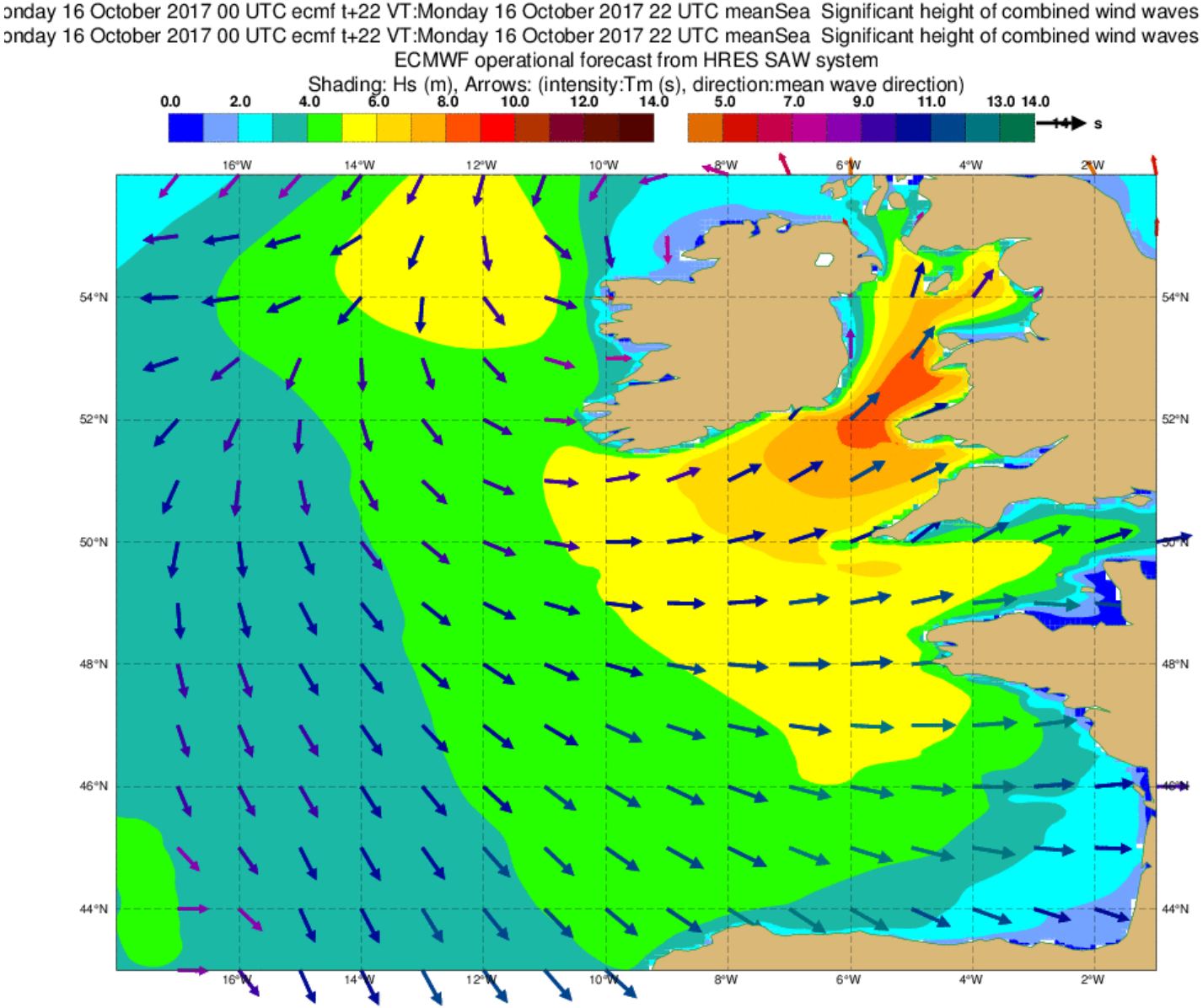
onday 16 October 2017 00 UTC ecmf t+20 VT:Monday 16 October 2017 20 UTC meanSea Significant height of combined wind waves and swell
onday 16 October 2017 00 UTC ecmf t+20 VT:Monday 16 October 2017 20 UTC meanSea Significant height of combined wind waves and swell
ECMWF operational forecast from HRES SAW system
Shading: Hs (m), Arrows: (intensity:Tm (s), direction:mean wave direction)
0.0 2.0 4.0 6.0 8.0 10.0 12.0 14.0
5.0 7.0 9.0 11.0 13.0 14.0
s
16°W 14°W 12°W 10°W 8°W 6°W 4°W 2°W
54°N 52°N 50°N 48°N 46°N 44°N

ECMWF

Monday 16 October 2017 00 UTC ecmf t+21 VT:Monday 16 October 2017 21 UTC meanSea Mean wave period/Mean wave direction
onday 16 October 2017 00 UTC ecmf t+21 VT:Monday 16 October 2017 21 UTC meanSea Significant height of combined wind waves and swell
onday 16 October 2017 00 UTC ecmf t+21 VT:Monday 16 October 2017 21 UTC meanSea Significant height of combined wind waves and swell
ECMWF operational forecast from HRES SAW system
Shading: Hs (m), Arrows: (intensity:Tm (s), direction:mean wave direction)



ECMWF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onday 16 October 2017 00 UTC ecmf t+22 VT:Monday 16 October 2017 22 UTC meanSea Significant height of combined wind waves and swell
onday 16 October 2017 00 UTC ecmf t+22 VT:Monday 16 October 2017 22 UTC meanSea Significant height of combined wind waves and swell
ECMWF operational forecast from HRES SAW system
Shading: Hs (m), Arrows: (intensity:Tm (s), direction:mean wave direction)
0.0 2.0 4.0 6.0 8.0 10.0 12.0 14.0
5.0 7.0 9.0 11.0 13.0 14.0
s
16°W 14°W 12°W 10°W 8°W 6°W 4°W 2°W
54°N 52°N 50°N 48°N 46°N 44°N

ECMWF

Monday 16 October 2017 00 UTC ecmf t+23 VT:Monday 16 October 2017 23 UTC meanSea Mean wave period/Mean wave direction
onday 16 October 2017 00 UTC ecmf t+23 VT:Monday 16 October 2017 23 UTC meanSea Significant height of combined wind waves and swell
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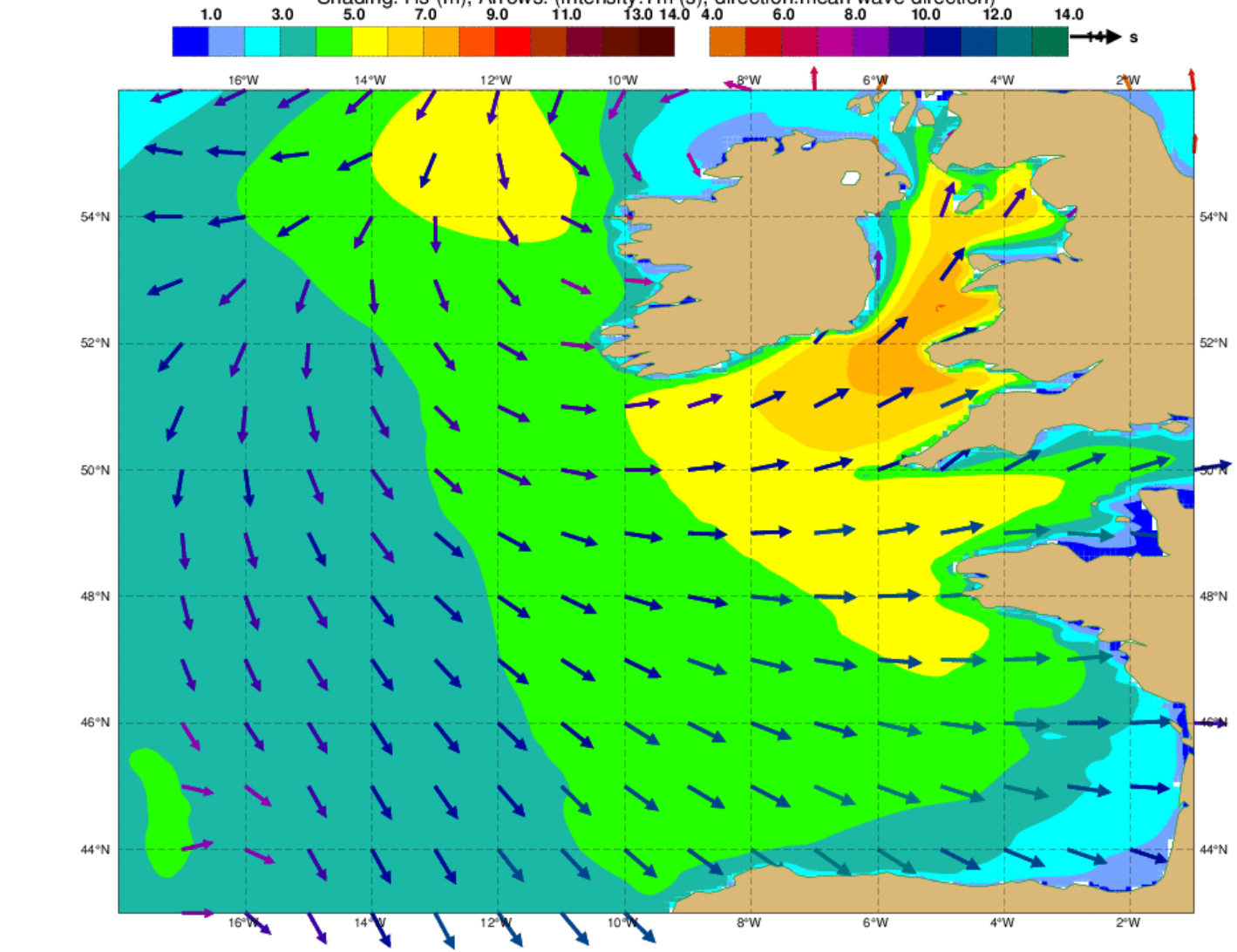
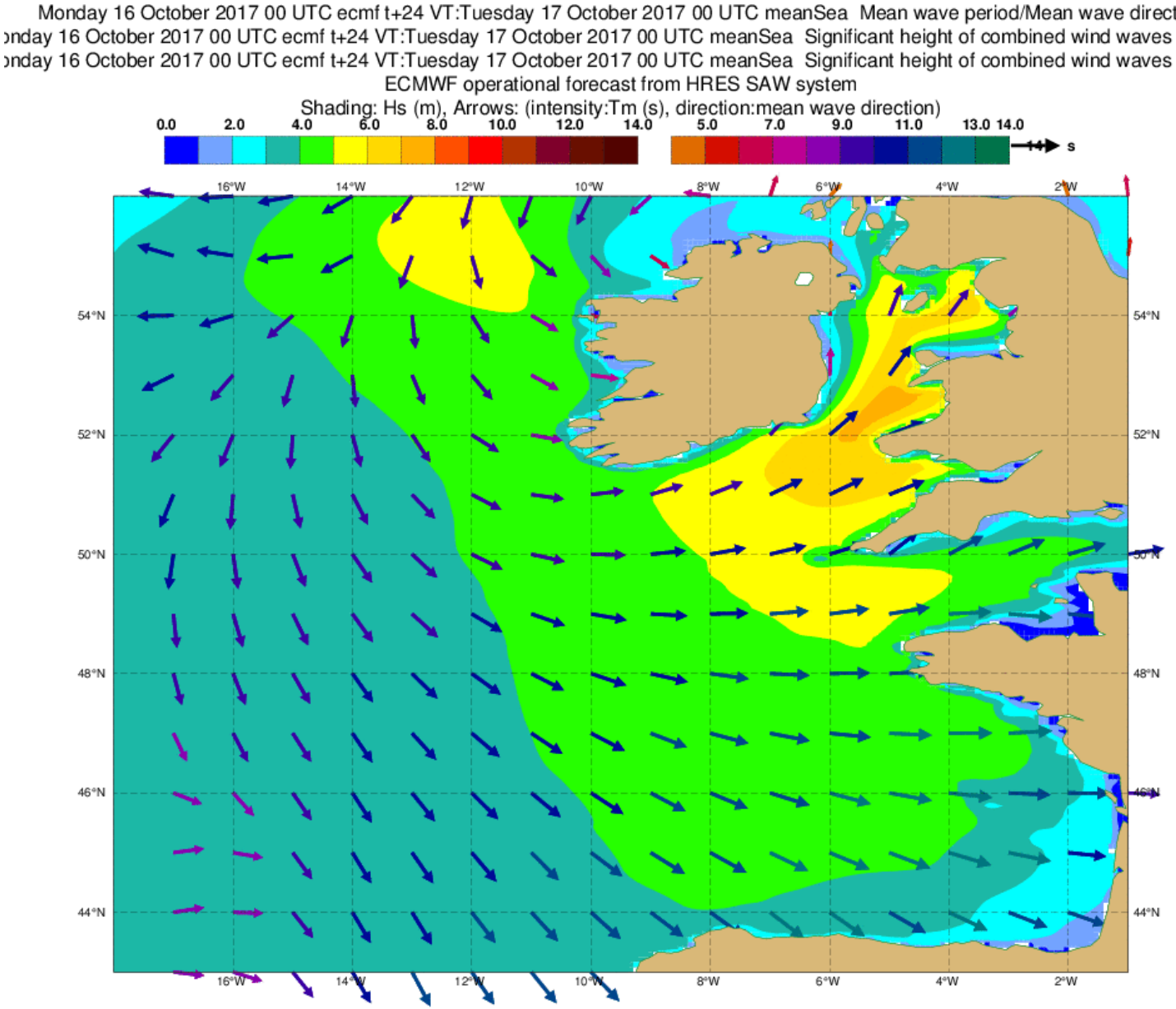
ECMWF operational forecast from HRES SAW system
Shading: Hs (m), Arrows: (intensity:Tm (s), direction:mean wave direction)



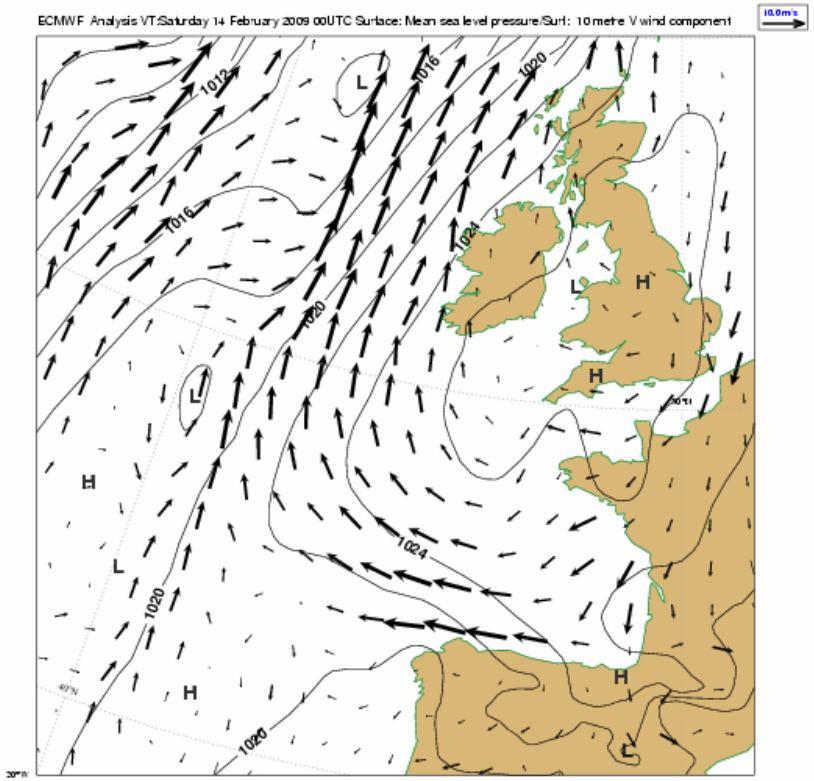
ECMWF


Monday 16 October 2017 00 UTC ecmf t+24 VT:Tuesday 17 October 2017 00 UTC meanSea Mean wave period/Mean wave direction
onday 16 October 2017 00 UTC ecmf t+24 VT:Tuesday 17 October 2017 00 UTC meanSea Significant height of combined wind waves and swell
onday 16 October 2017 00 UTC ecmf t+24 VT:Tuesday 17 October 2017 00 UTC meanSea Significant height of combined wind waves and swell
ECMWF operational forecast from HRES SAW system
Shading: Hs (m), Arrows: (intensity:Tm (s), direction:mean wave direction)
0.0 2.0 4.0 6.0 8.0 10.0 12.0 14.0
5.0 7.0 9.0 11.0 13.0 14.0
s
16°W 14°W 12°W 10°W 8°W 6°W 4°W 2°W
54°N 52°N 50°N 48°N 46°N 44°N

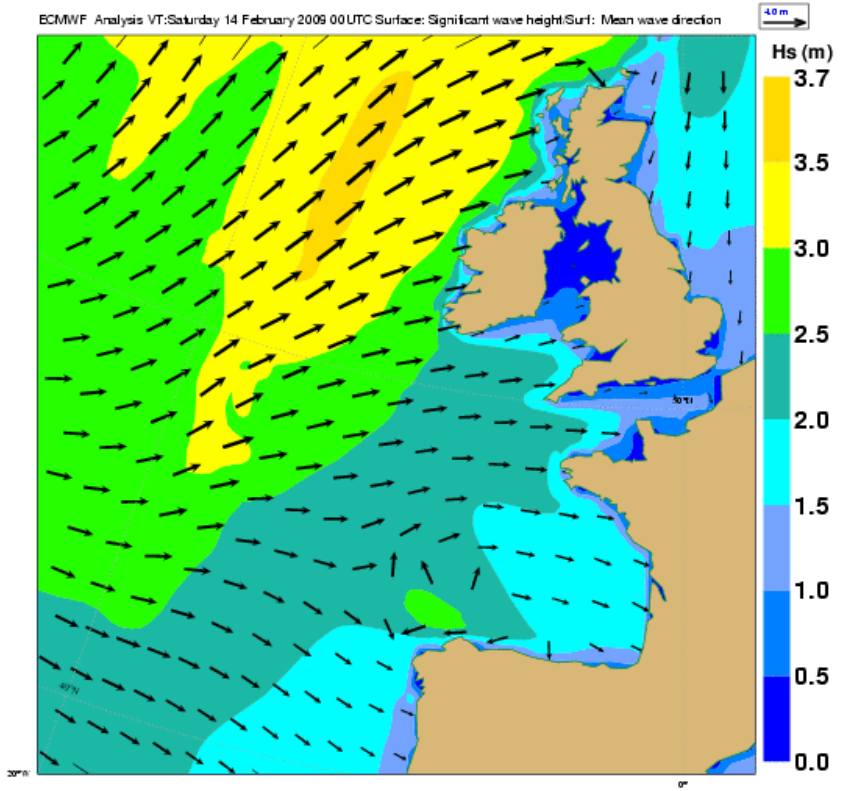
ECMWF

A bit more on Wave Model Products

Use simple parameters:
total wave height and mean propagation direction



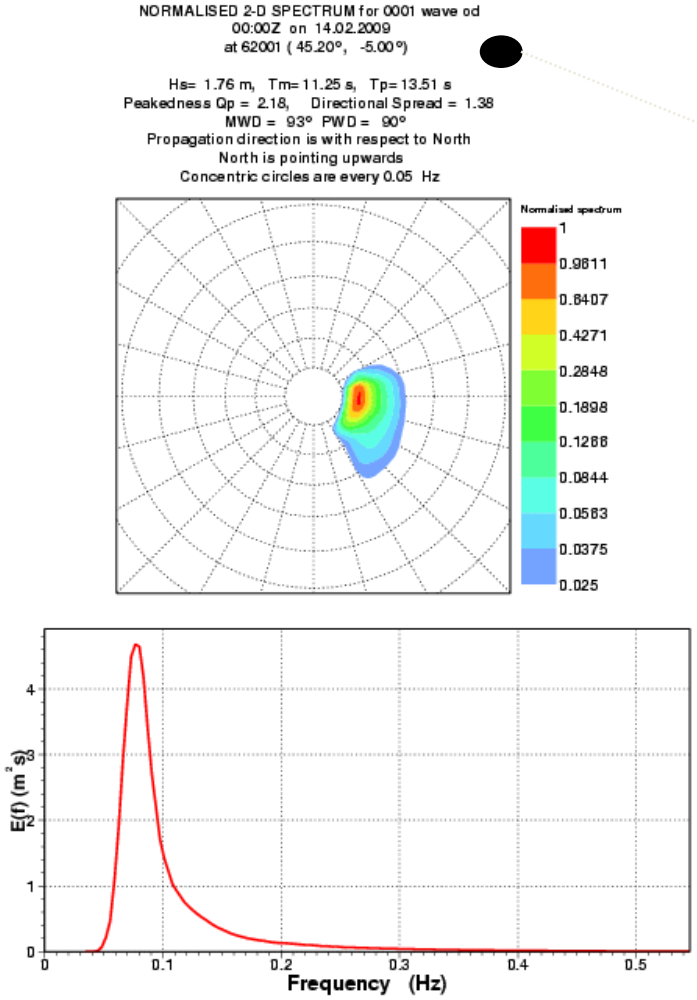
10m winds and mean sea level pressure:
Analysis : 14 February 2009, 00 UTC

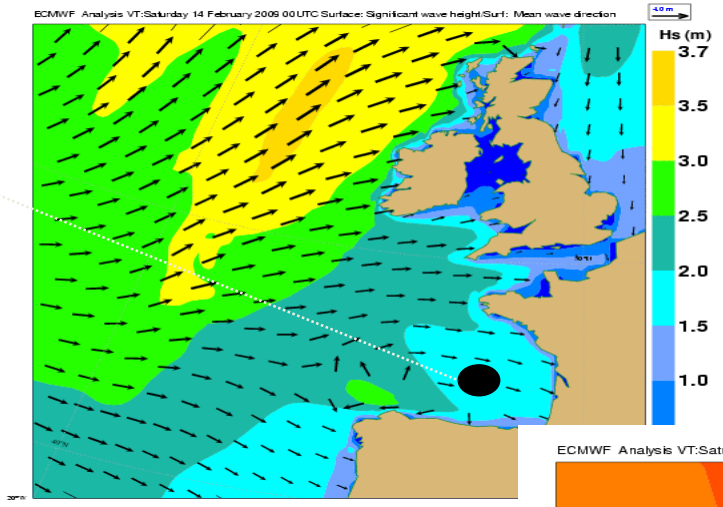


Wave height and mean direction:
Analysis : 14 February 2009, 00 UTC

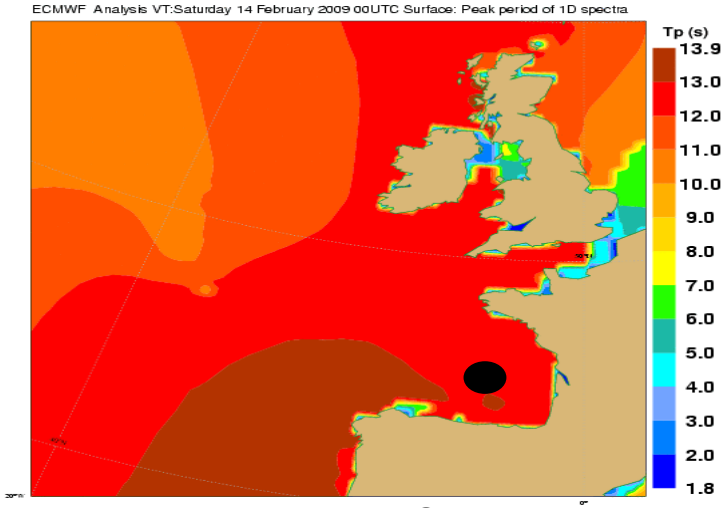
ECMWF

Wave Model Products





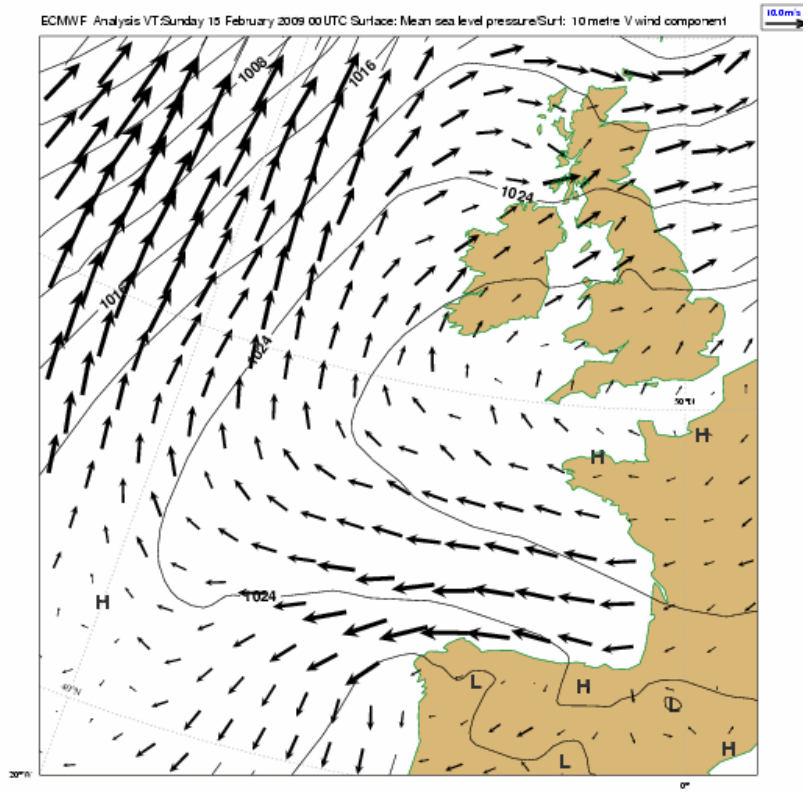
Wave height and mea
Analysis : 14 February



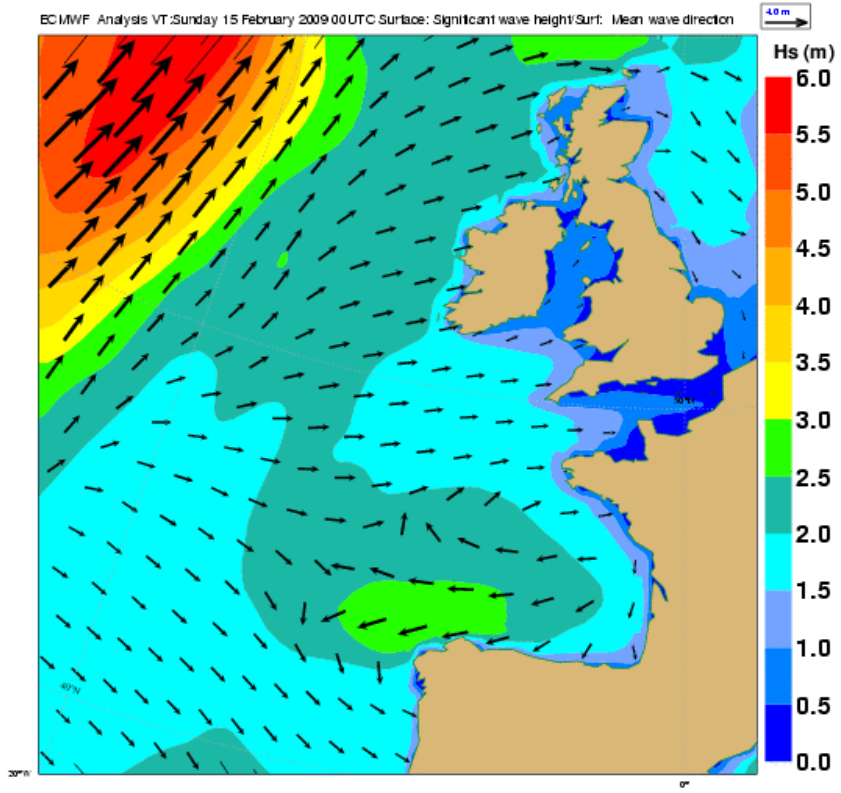
PEAK PERIOD:
Analysis : 14 February 2009, 00 UTC

Wave Model Products

Situation might be more complicated !



10m winds and mean sea level pressure:
Analysis : 15 February 2009, 00 UTC

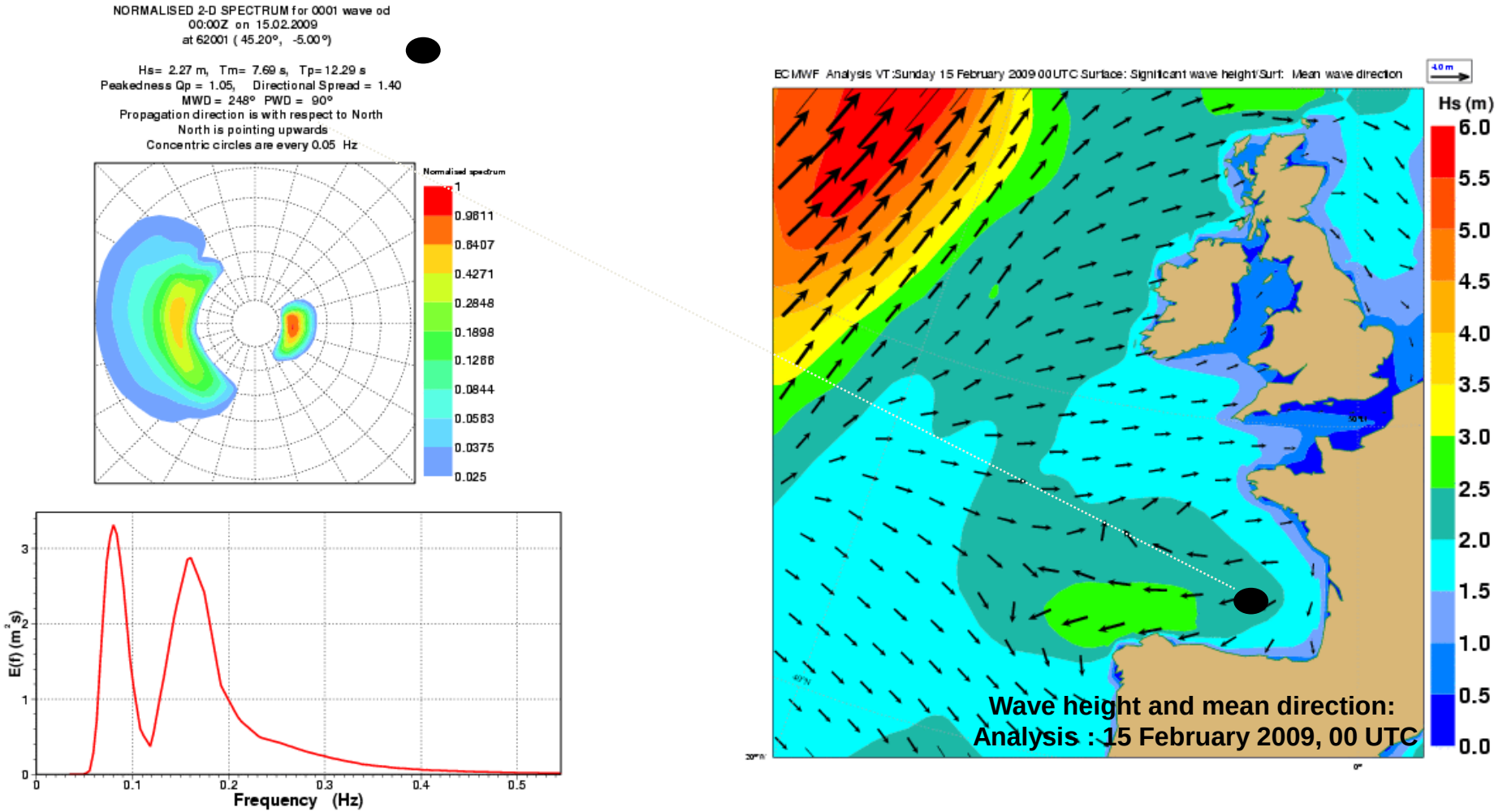


Wave height and mean direction:
Analysis : 15 February 2009, 00 UTC

ECMWF

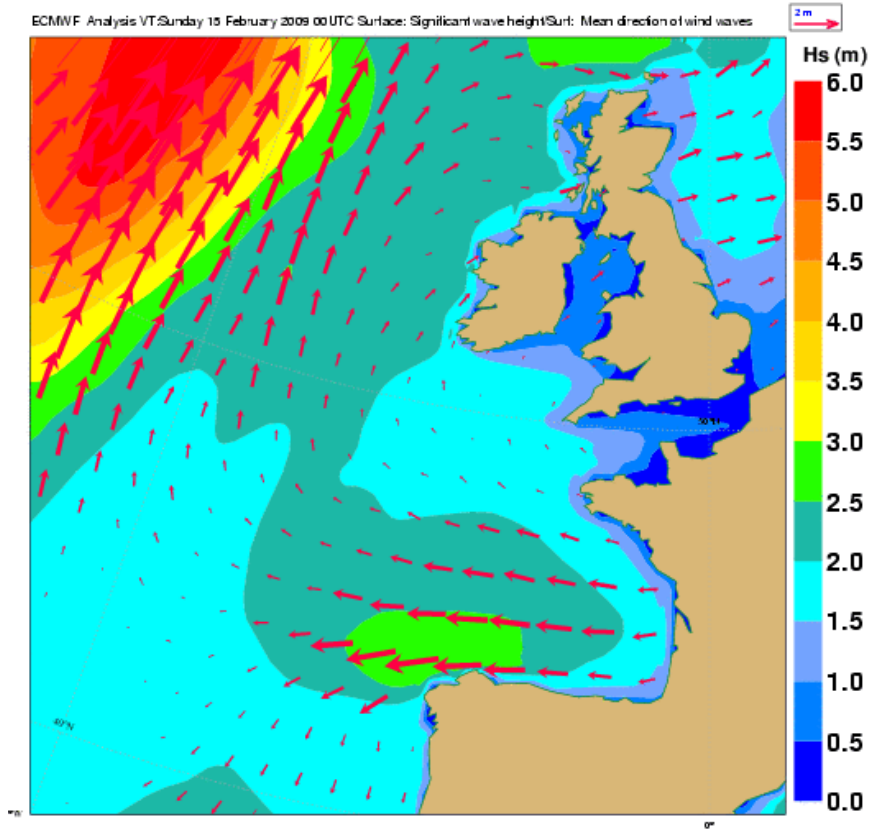
Wave Model Products

Situation might be more complicated:

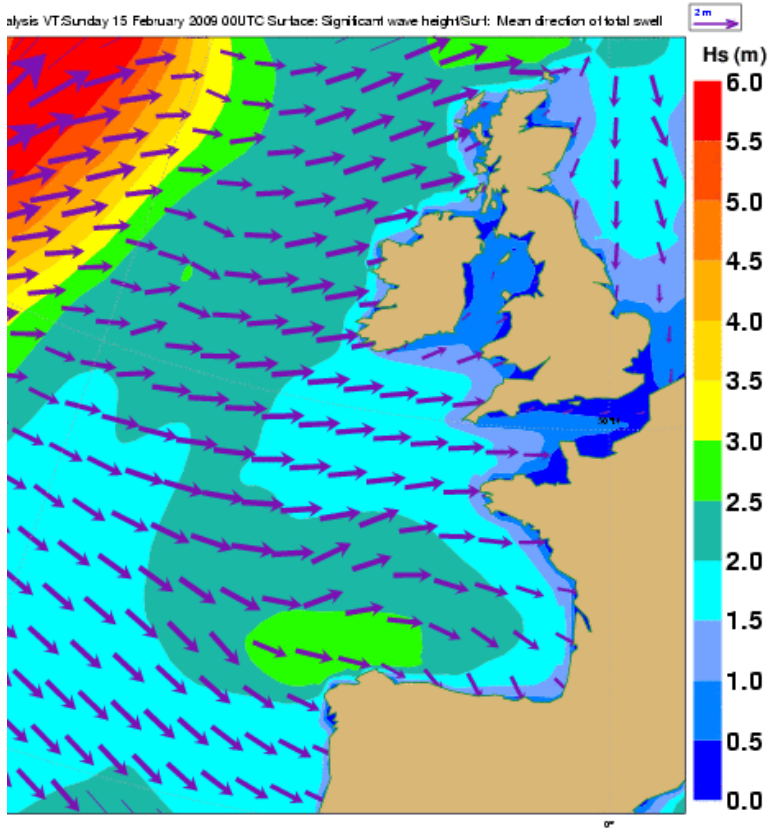


Wave Model Products

A scheme is used to split the global wave fields into waves which are under the direct influence of the forcing wind, the so-called windsea or wind waves, and those waves that are no longer bound to the forcing wind, generally referred to as swell. Period and mean direction are also determined for these split fields.



Wave height and windsea mean direction:
Analysis : 15 February 2009, 00 UTC

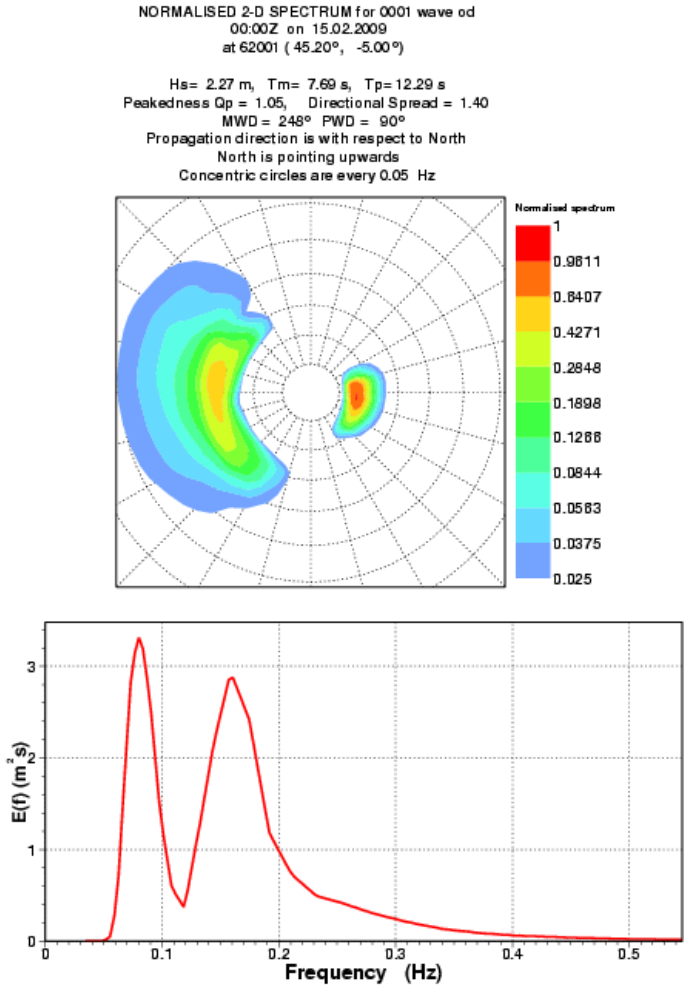


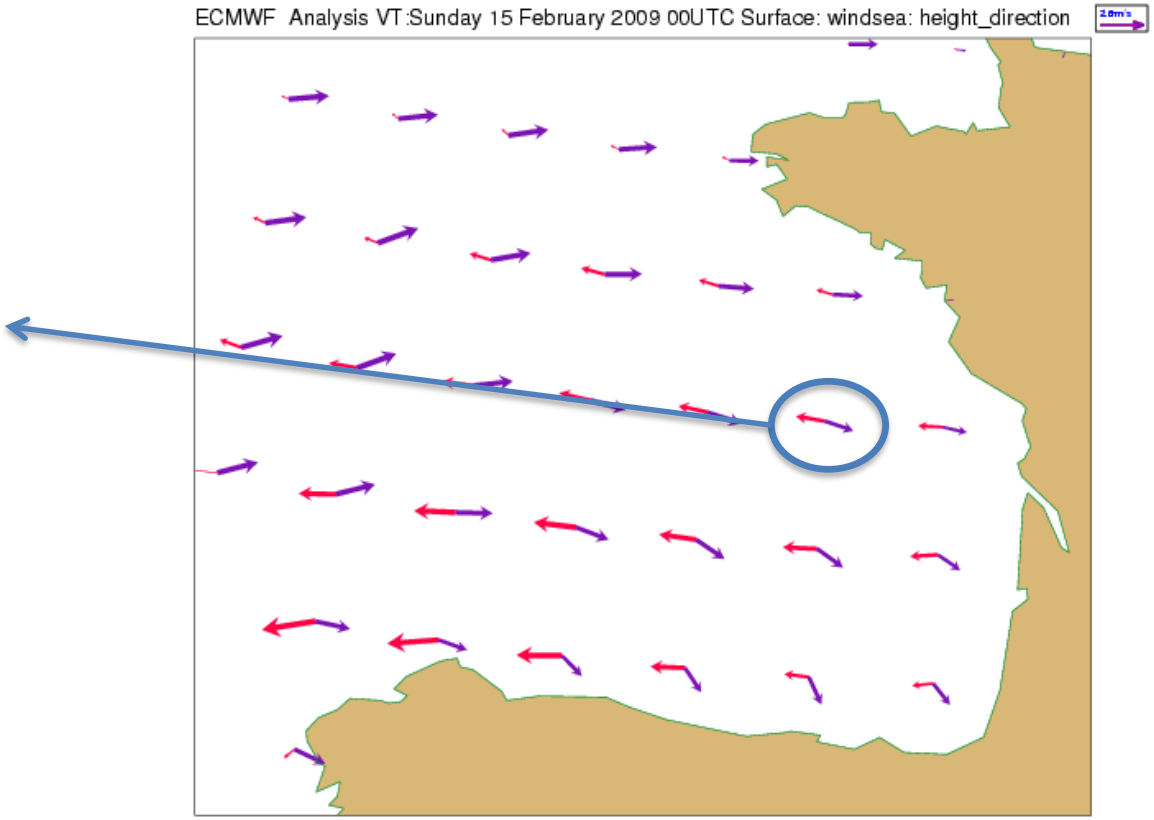
Wave height and swell mean direction:
Analysis : 15 February 2009, 00 UTC

ECMWF

Wave Model Products

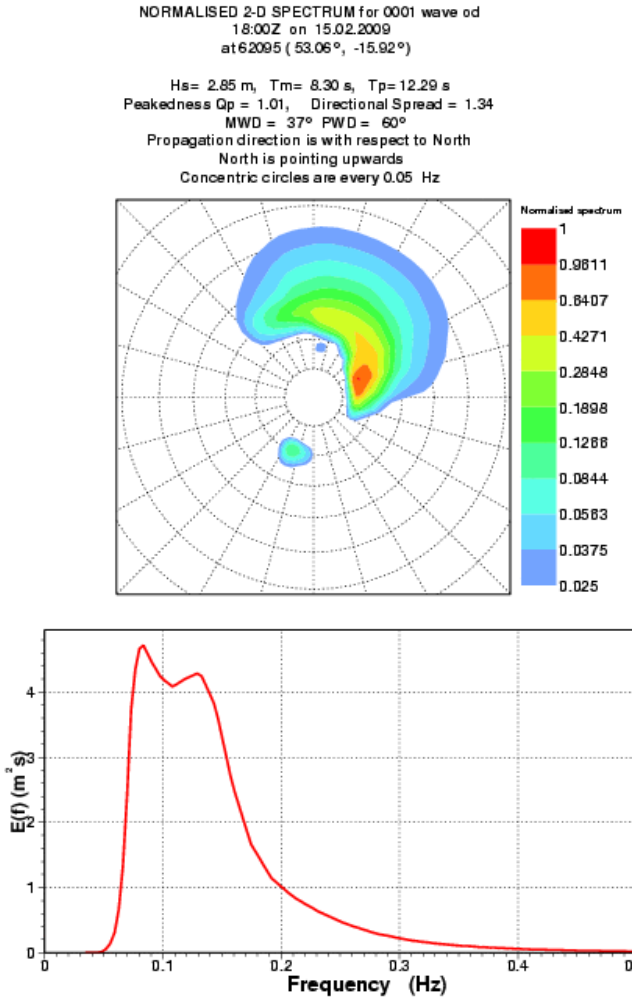
Windsea and swell: opposing sea

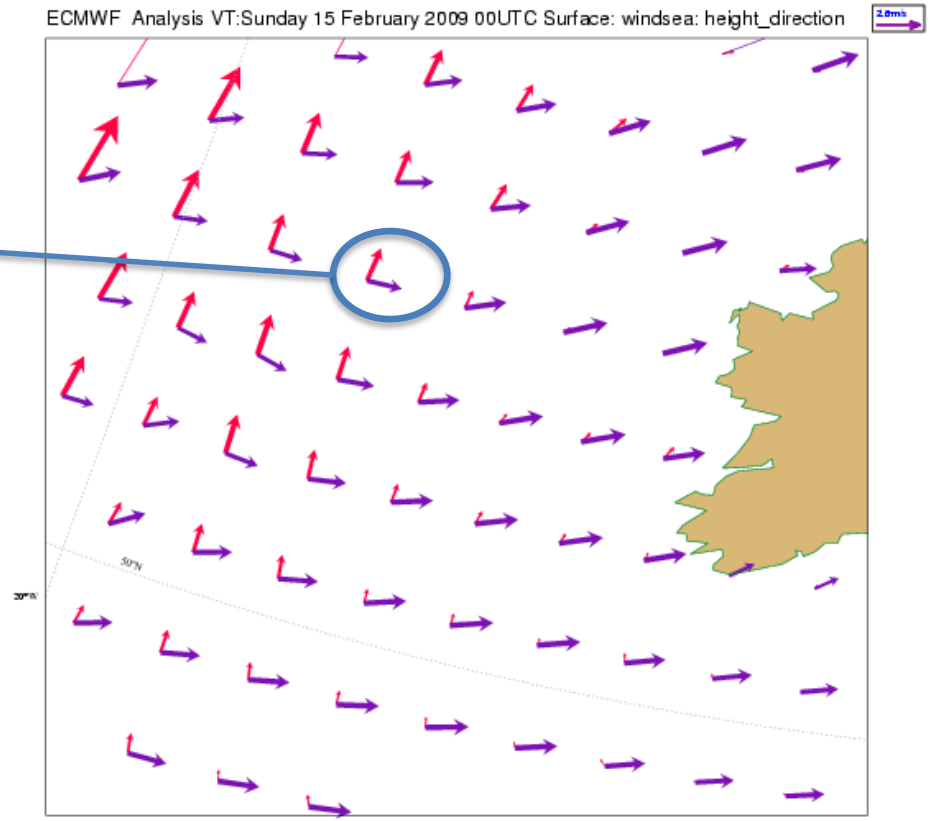




Wave Model Products

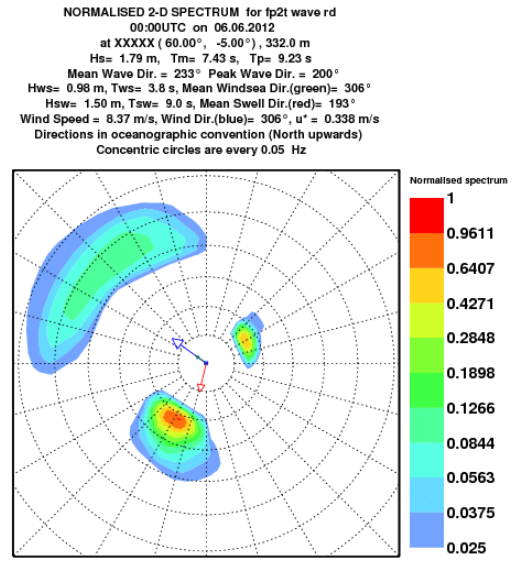
Windsea and swell: cross sea

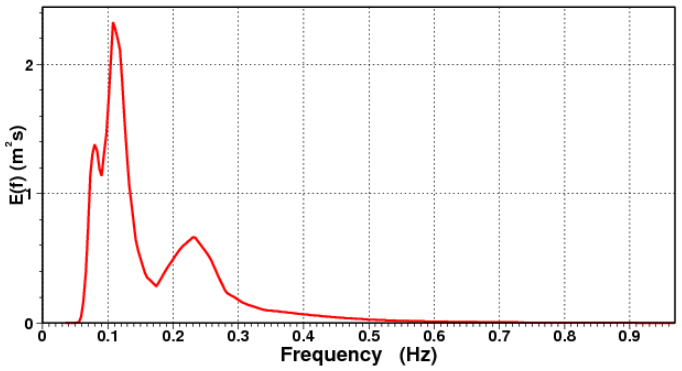




Model output: wave systems

Swell systems identified using spectral partitioning of the total swell:

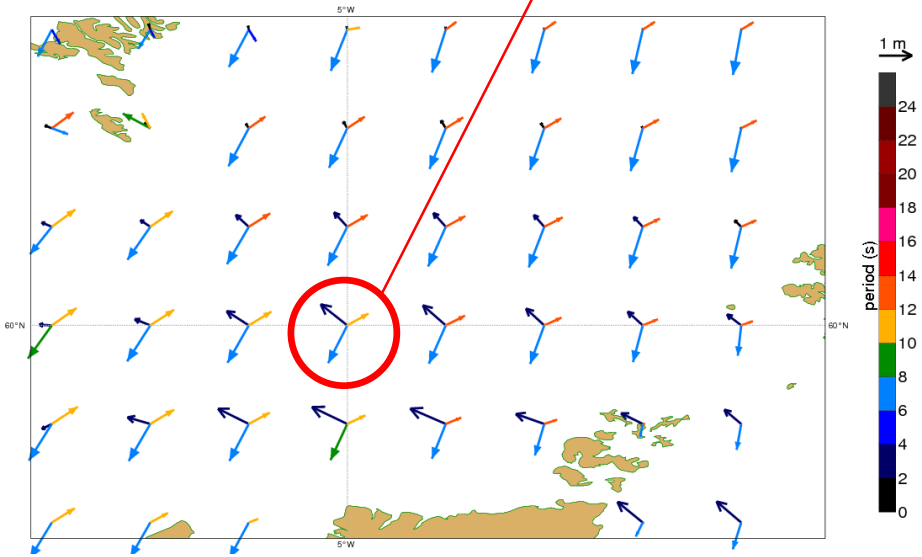




Swell3 if it exists

arrow length: wave height,
arrow colour: mean wave period

New decomposition (set of vectors):



ECMWF

Model output: long swell forecast

Has anyone ever surf ?

http://surfingforeveryone.weebly.com/famous-surfers.html

ECMWF

Model output: long swell forecast

Swell are long waves propagating away from storms.

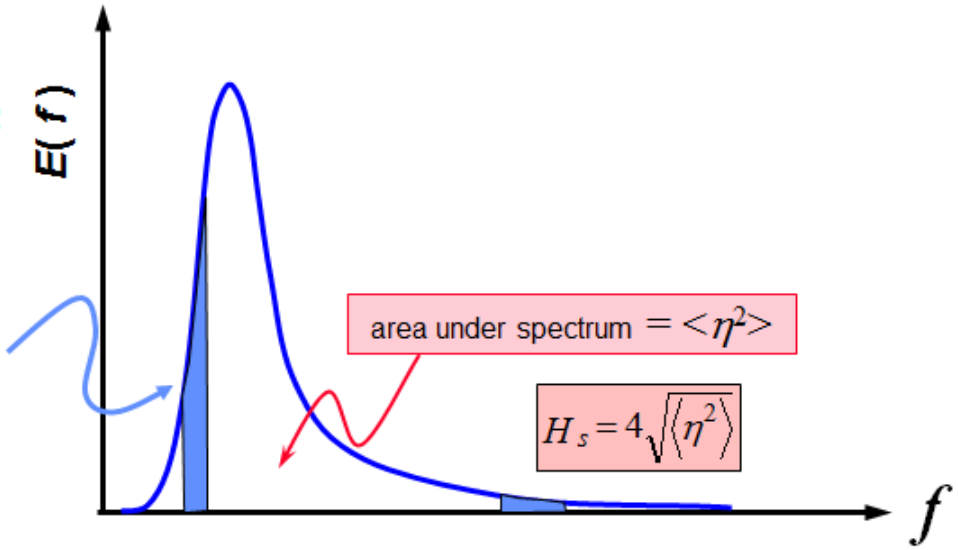
It is possible to follow the evolution of the swell.

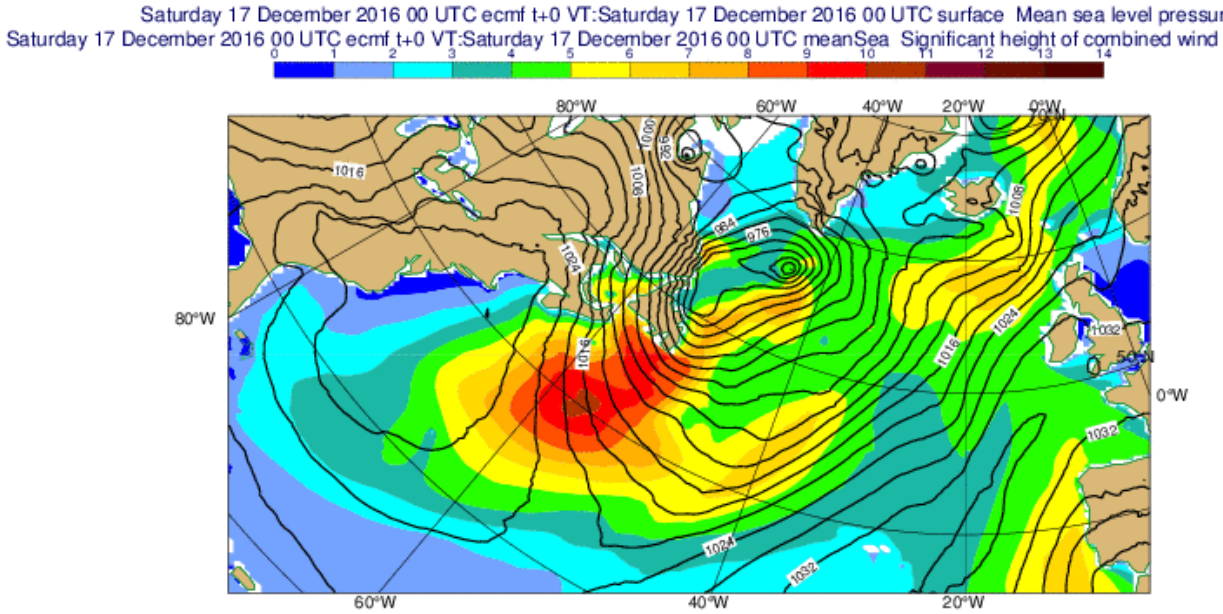
Define the Equivalent Wave Height:

EWH,
Equivalent Wave Height
for a given frequency bin:

$$EHW = 4\sqrt{A}$$

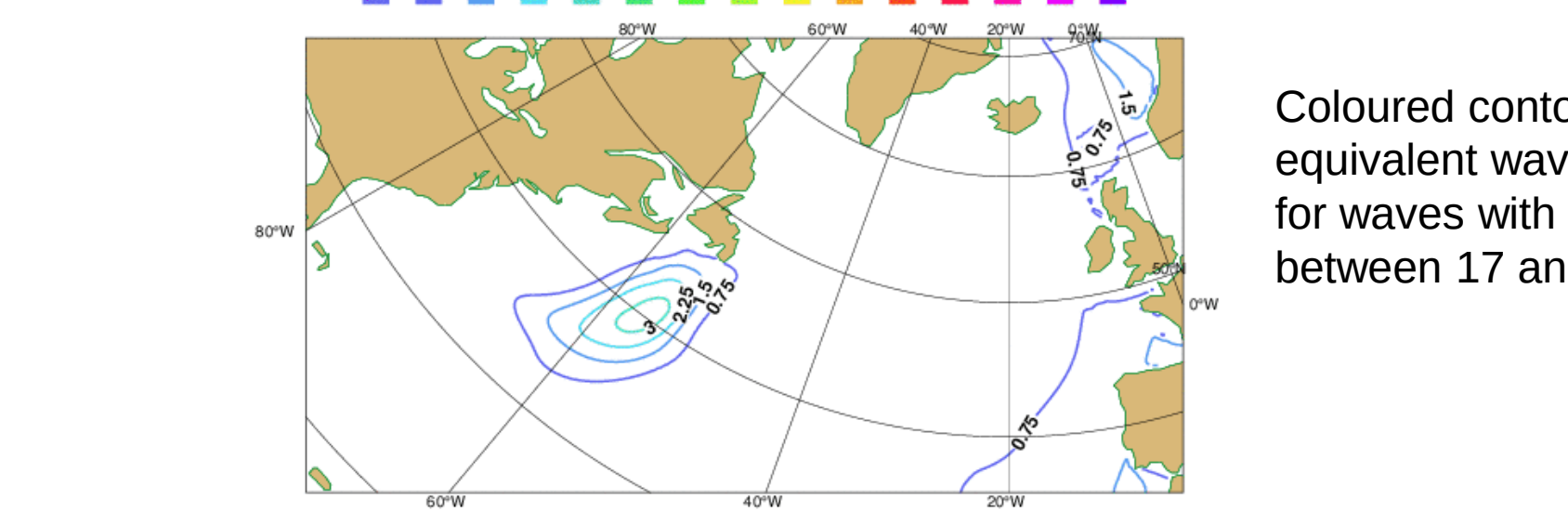
where A is the area under curve for a given frequency bin





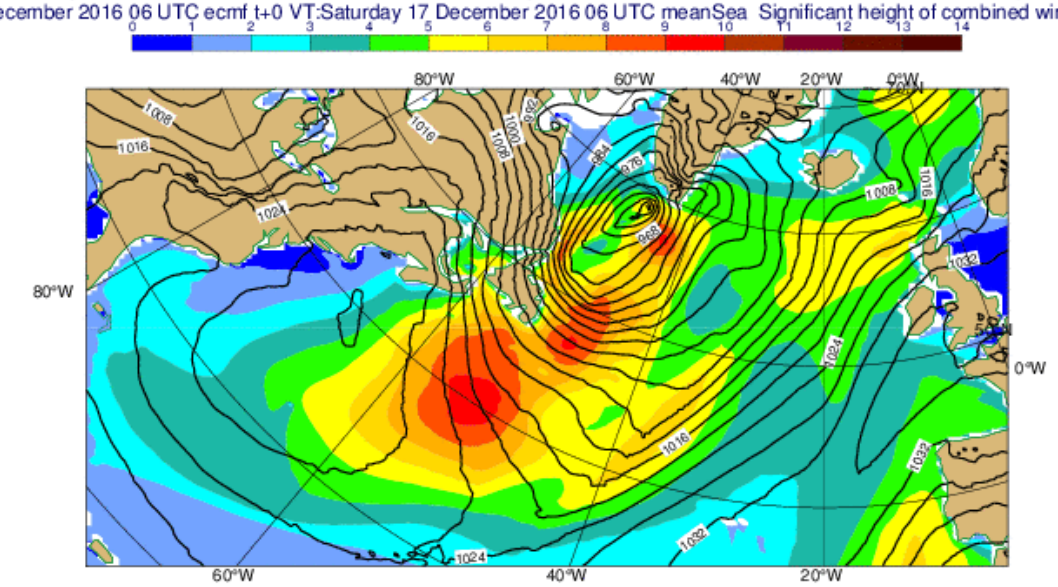
Black contours:
mean sea level pressure (hPa).

Coloured shading:
significant wave heights (m).

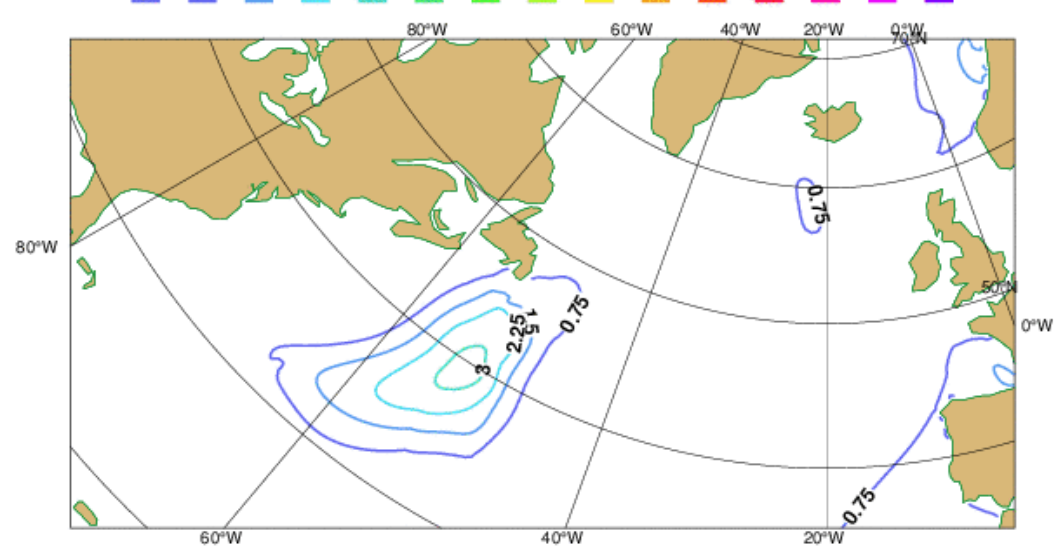


Coloured contours:
equivalent wave heights (m)
for waves with periods
between 17 and 21 seconds

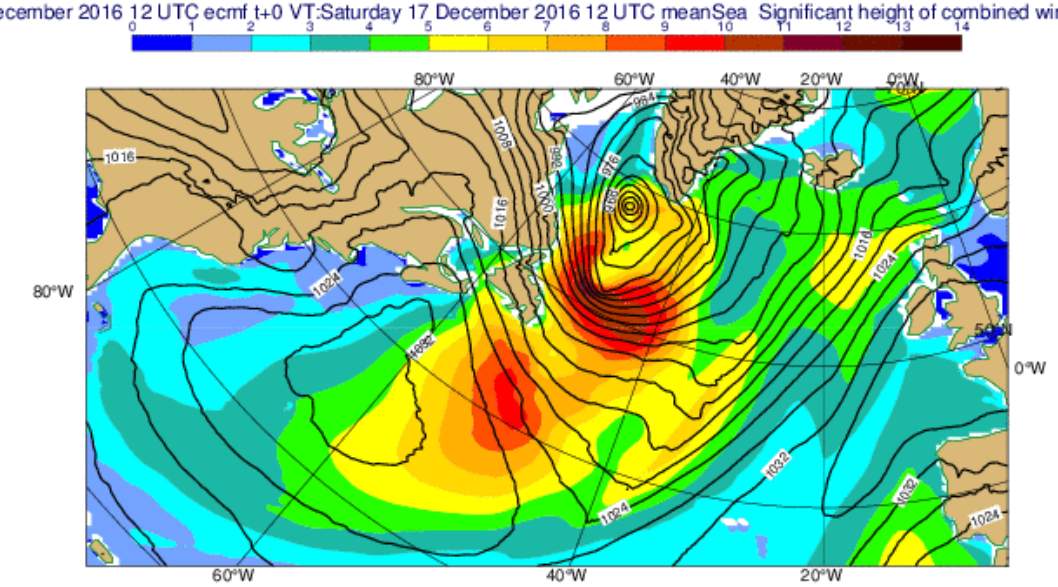
Saturday 17 December 2016 06 UTC ecmf t+0 VT:Saturday 17 December 2016 06 UTC surface Mean sea level pressure
Saturday 17 December 2016 06 UTC ecmf t+0 VT:Saturday 17 December 2016 06 UTC meanSea Significant height of combined wind waves and swell



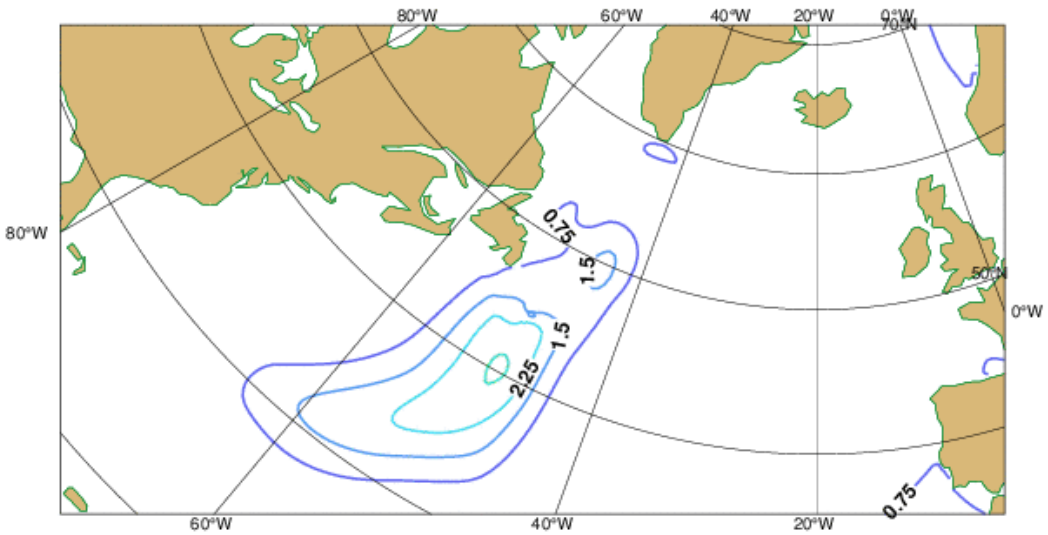
17 December 2016 06 UTC ecmf t+0 VT:Saturday 17 December 2016 06 UTC meanSea Significant wave height of all waves with periods within the inclusive range from 17 to 21 seconds



Saturday 17 December 2016 12 UTC ecmf t+0 VT:Saturday 17 December 2016 12 UTC surface Mean sea level pressure
Saturday 17 December 2016 12 UTC ecmf t+0 VT:Saturday 17 December 2016 12 UTC meanSea Significant height of combined wind waves and swell



17 December 2016 12 UTC ecmf t+0 VT:Saturday 17 December 2016 12 UTC meanSea Significant wave height of all waves with periods within the inclusive range from 17 to 21 seconds



Saturday 17 December 2016 18 UTC ecmf t+0 VT:Saturday 17 December 2016 18 UTC surface Mean sea level pressure
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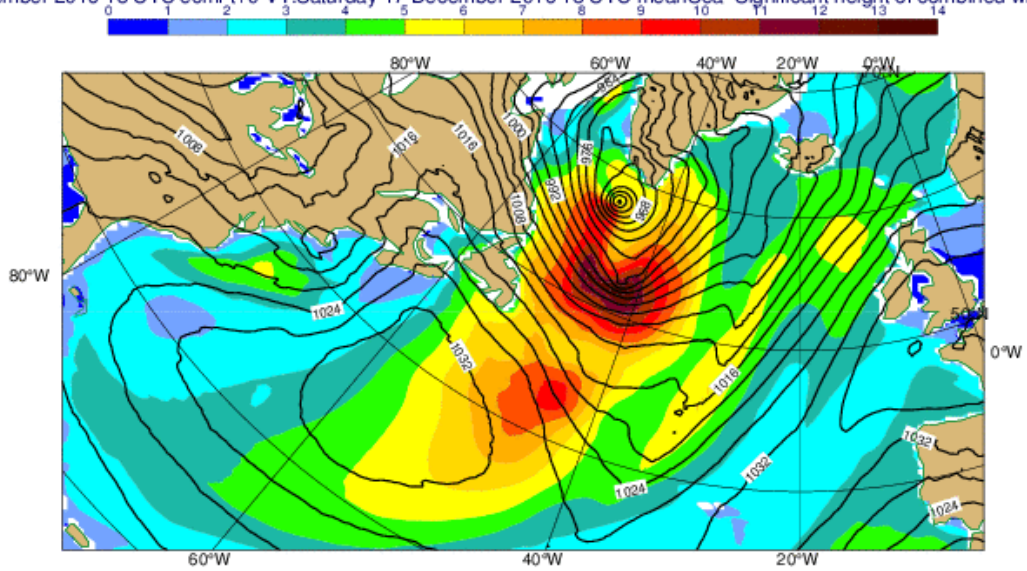
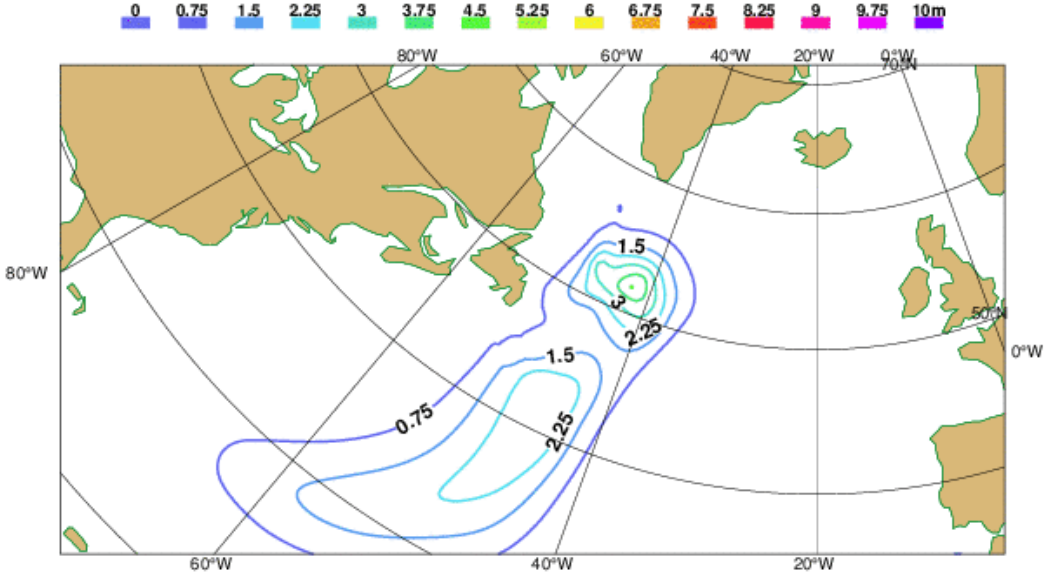
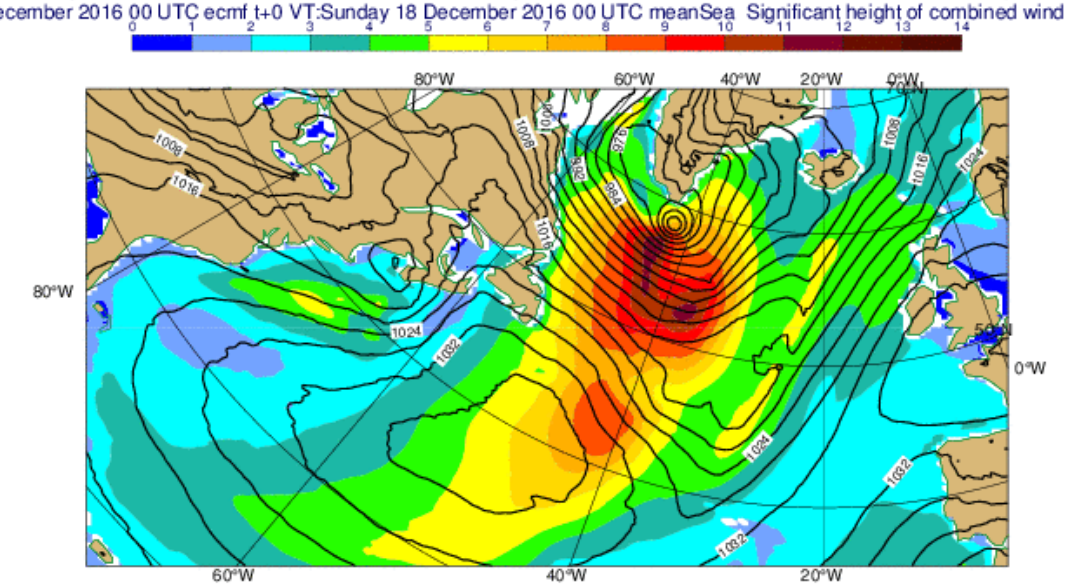


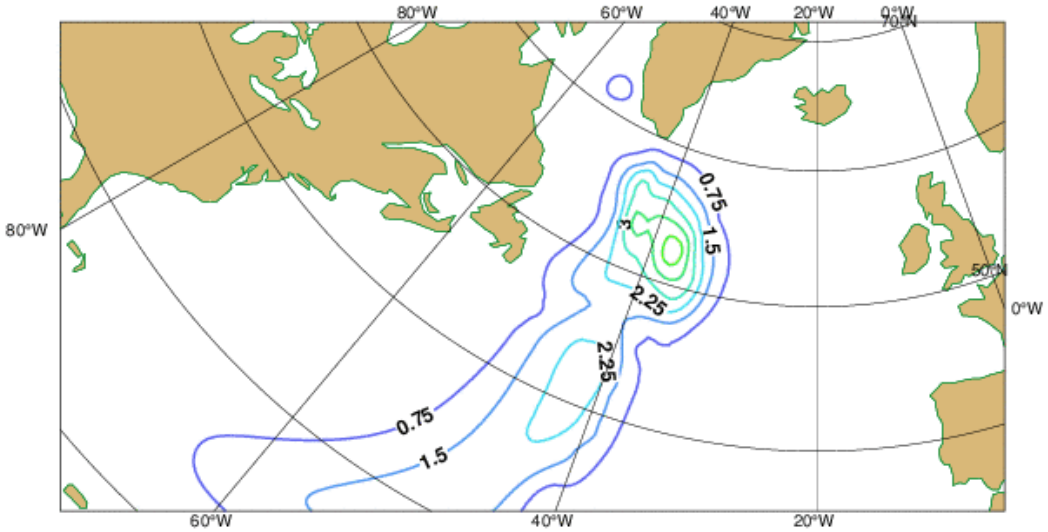
17 December 2016 18 UTC ecmf t+0 VT:Saturday 17 December 2016 18 UTC meanSea Significant wave height of all waves with periods within the inclusive range from 17 to 21 seconds



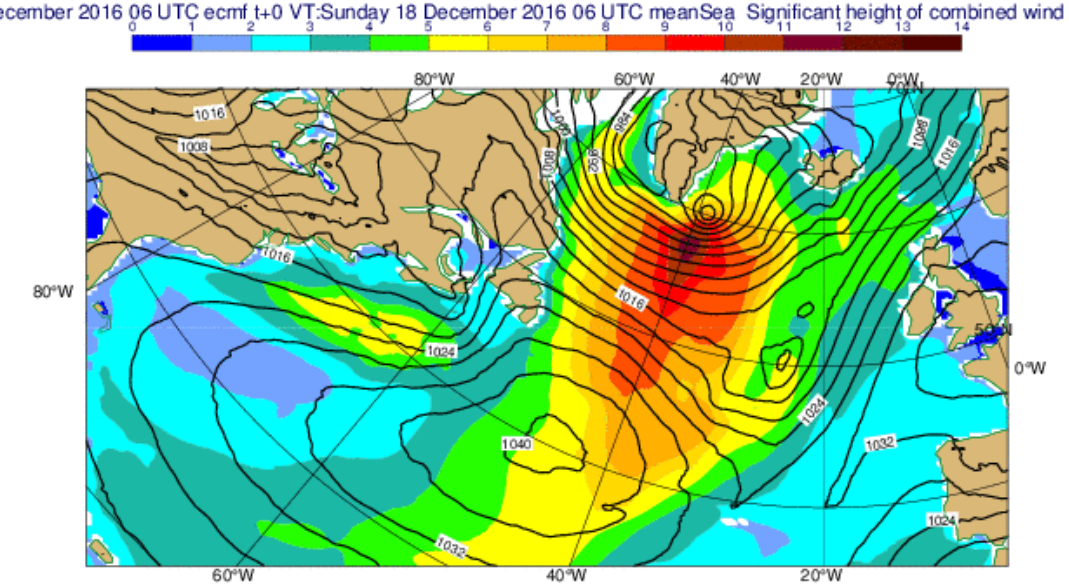
Sunday 18 December 2016 00 UTC ecmf t+0 VT:Sunday 18 December 2016 00 UTC surface Mean sea level pressure
Sunday 18 December 2016 00 UTC ecmf t+0 VT:Sunday 18 December 2016 00 UTC meanSea Significant height of combined wind waves and swell



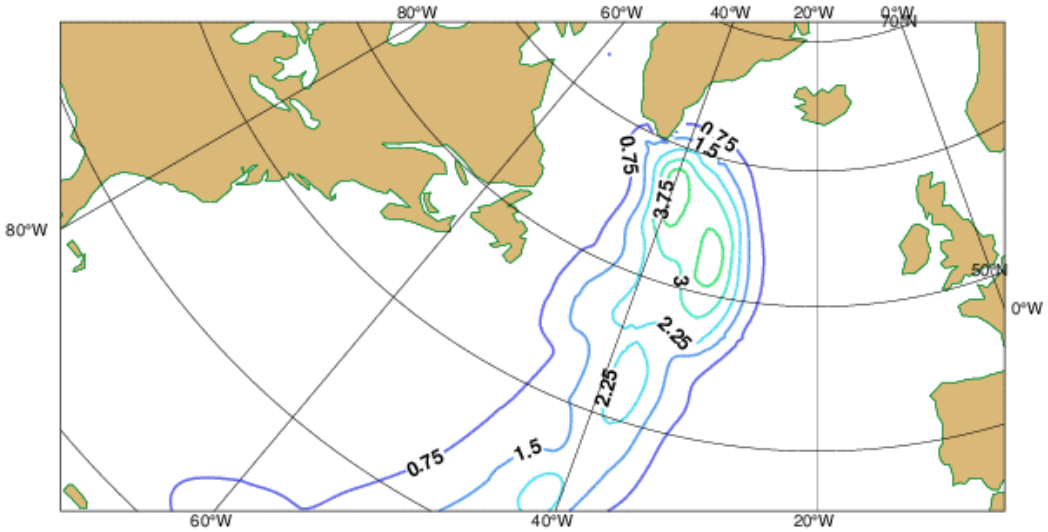
18 December 2016 00 UTC ecmf t+0 VT:Sunday 18 December 2016 00 UTC meanSea Significant wave height of all waves with periods within the inclusive range from 17 to 21 seconds



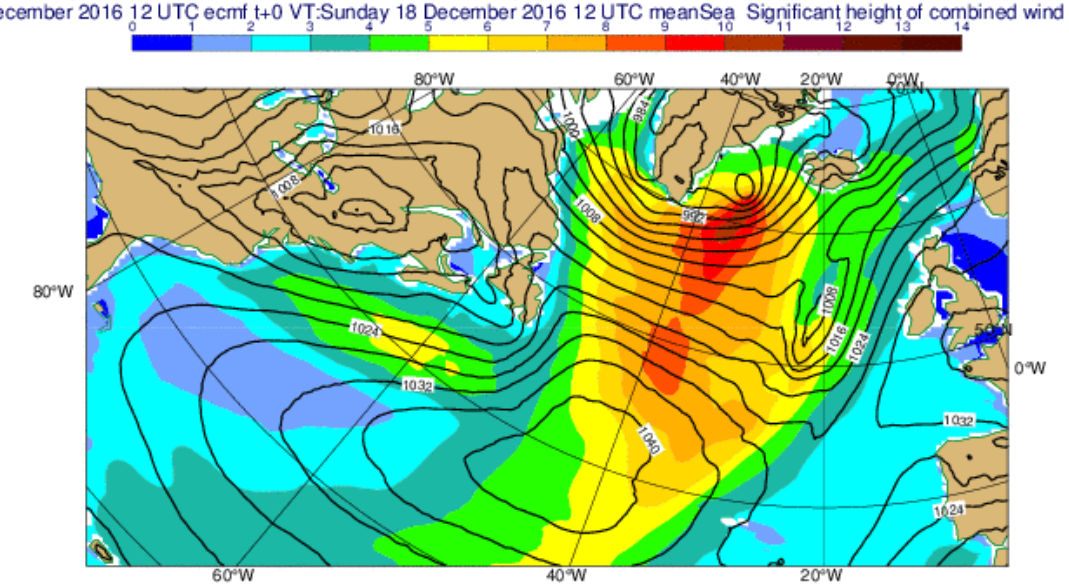
Sunday 18 December 2016 06 UTC ecmf t+0 VT:Sunday 18 December 2016 06 UTC surface Mean sea level pressure
Sunday 18 December 2016 06 UTC ecmf t+0 VT:Sunday 18 December 2016 06 UTC meanSea Significant height of combined wind waves and swell



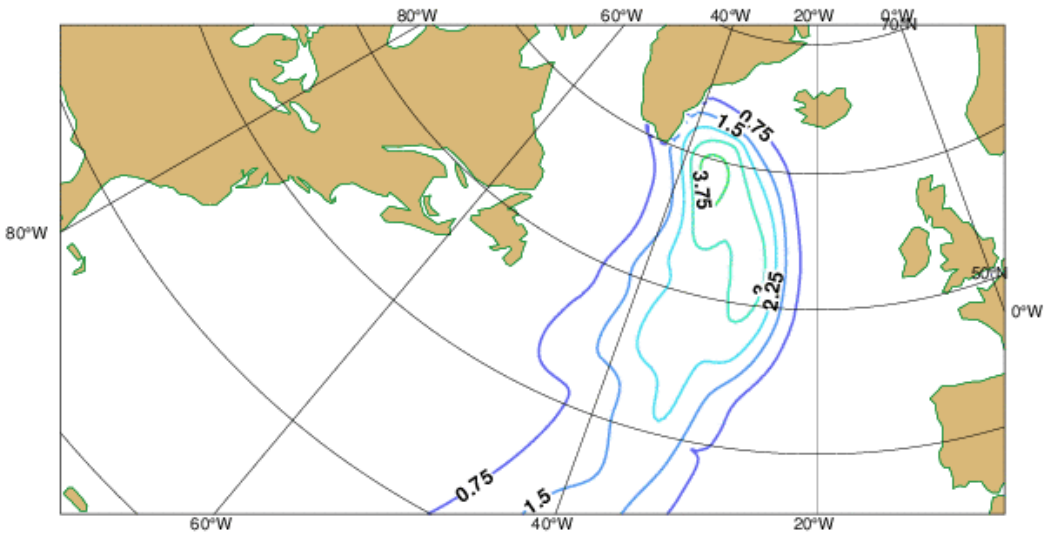
18 December 2016 06 UTC ecmf t+0 VT:Sunday 18 December 2016 06 UTC meanSea Significant wave height of all waves with periods within the inclusive range from 17 to 21 seconds



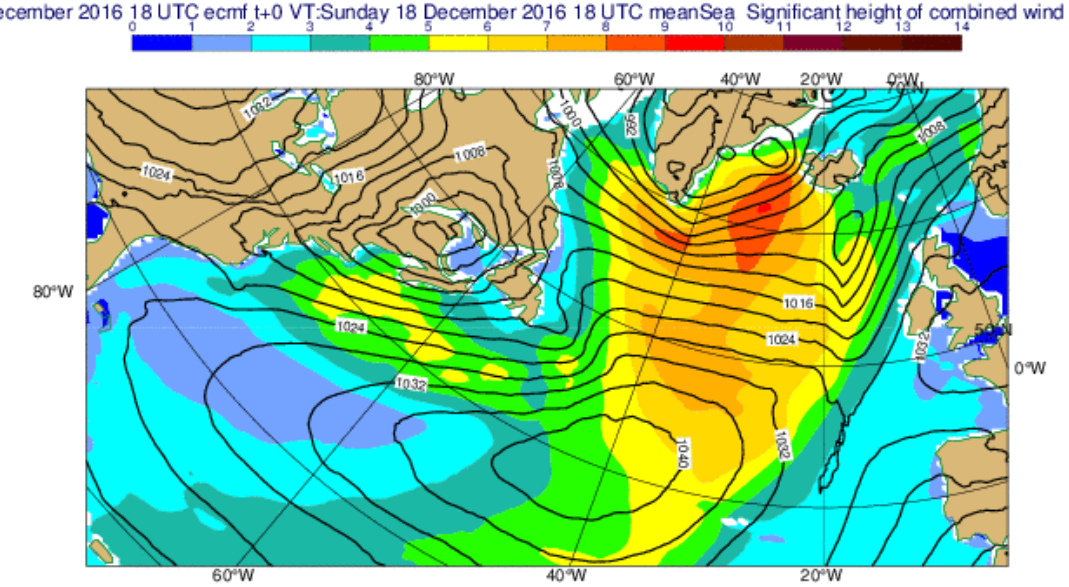
Sunday 18 December 2016 12 UTC ecmf t+0 VT:Sunday 18 December 2016 12 UTC surface Mean sea level pressure
Sunday 18 December 2016 12 UTC ecmf t+0 VT:Sunday 18 December 2016 12 UTC meanSea Significant height of combined wind waves and swell



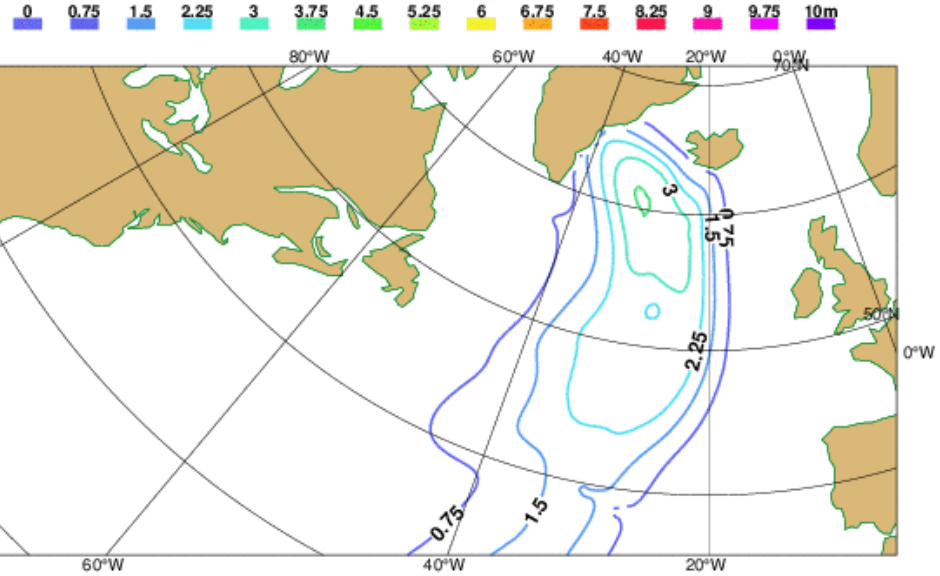
18 December 2016 12 UTC ecmf t+0 VT:Sunday 18 December 2016 12 UTC meanSea Significant wave height of all waves with periods within the inclusive range from 17 to 21 seconds



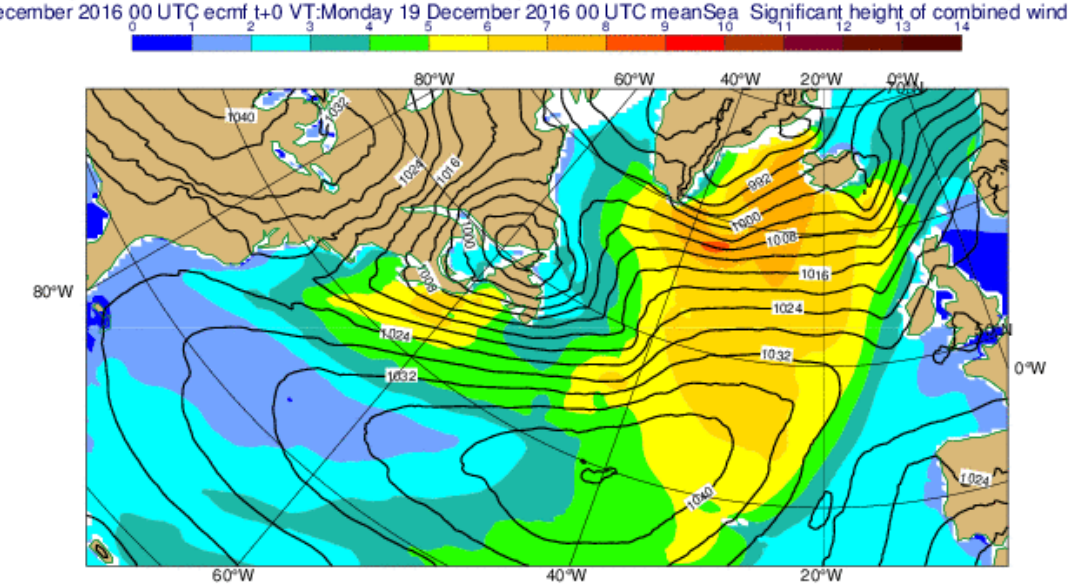
Sunday 18 December 2016 18 UTC ecmf t+0 VT:Sunday 18 December 2016 18 UTC surface Mean sea level pressure
Sunday 18 December 2016 18 UTC ecmf t+0 VT:Sunday 18 December 2016 18 UTC meanSea Significant height of combined wind waves and swell



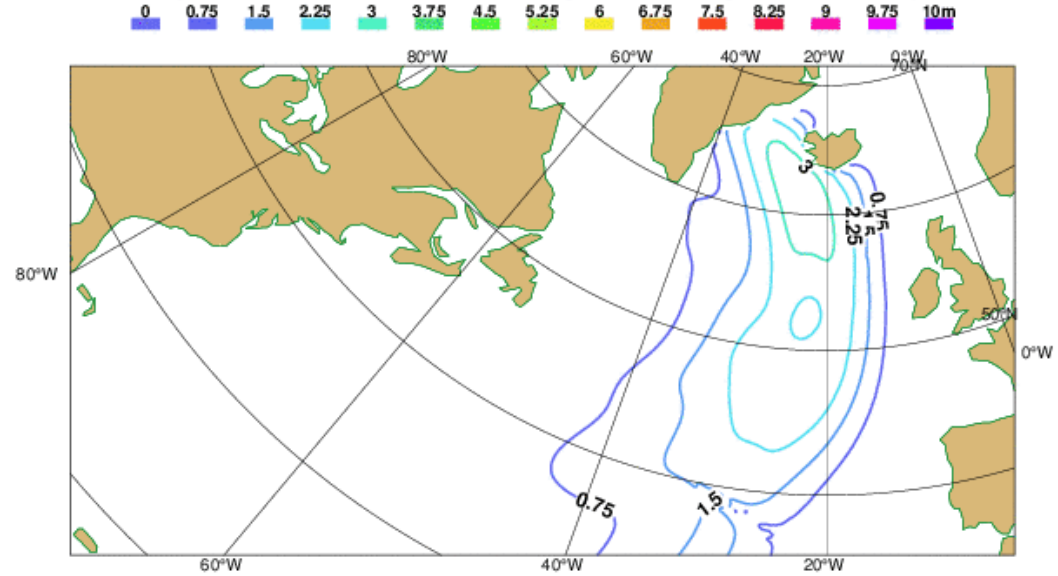
18 December 2016 18 UTC ecmf t+0 VT:Sunday 18 December 2016 18 UTC meanSea Significant wave height of all waves with periods within the inclusive range from 17 to 21 seconds



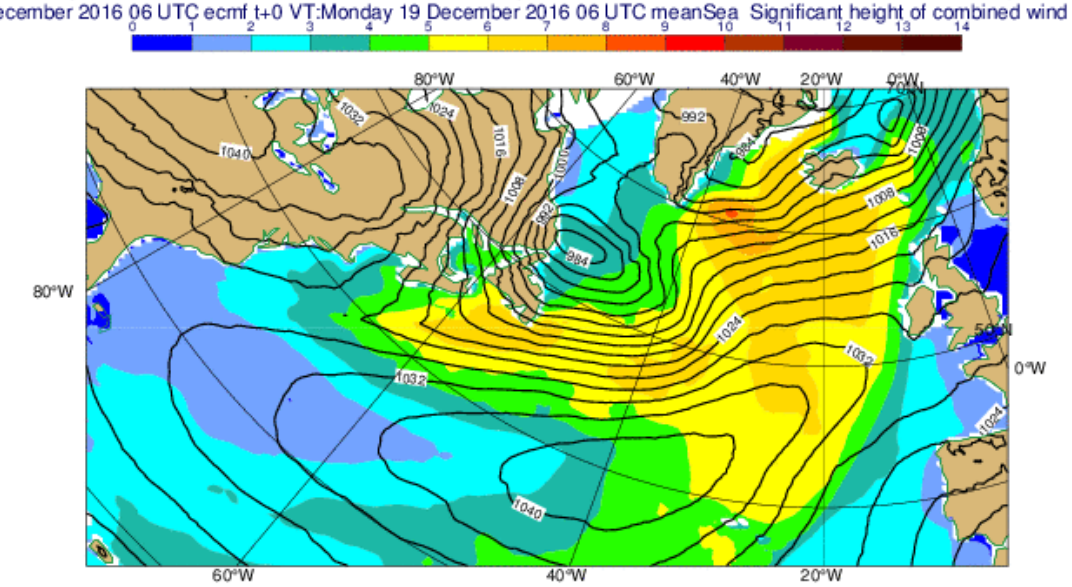
Monday 19 December 2016 00 UTC ecmf t+0 VT:Monday 19 December 2016 00 UTC surface Mean sea level pressure
Monday 19 December 2016 00 UTC ecmf t+0 VT:Monday 19 December 2016 00 UTC meanSea Significant height of combined wind waves and swell



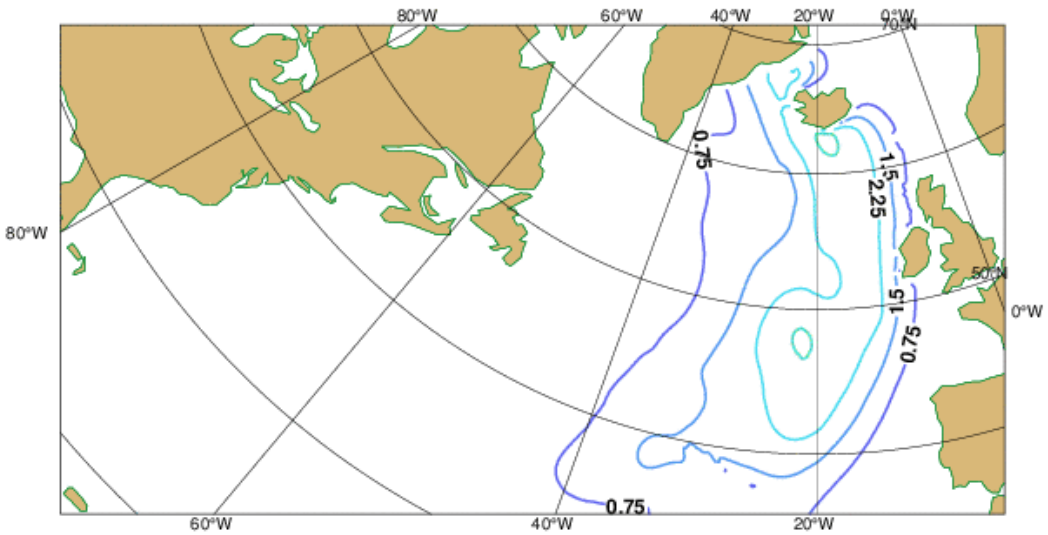
19 December 2016 00 UTC ecmf t+0 VT:Monday 19 December 2016 00 UTC meanSea Significant wave height of all waves with periods within the inclusive range from 17 to 21 seconds



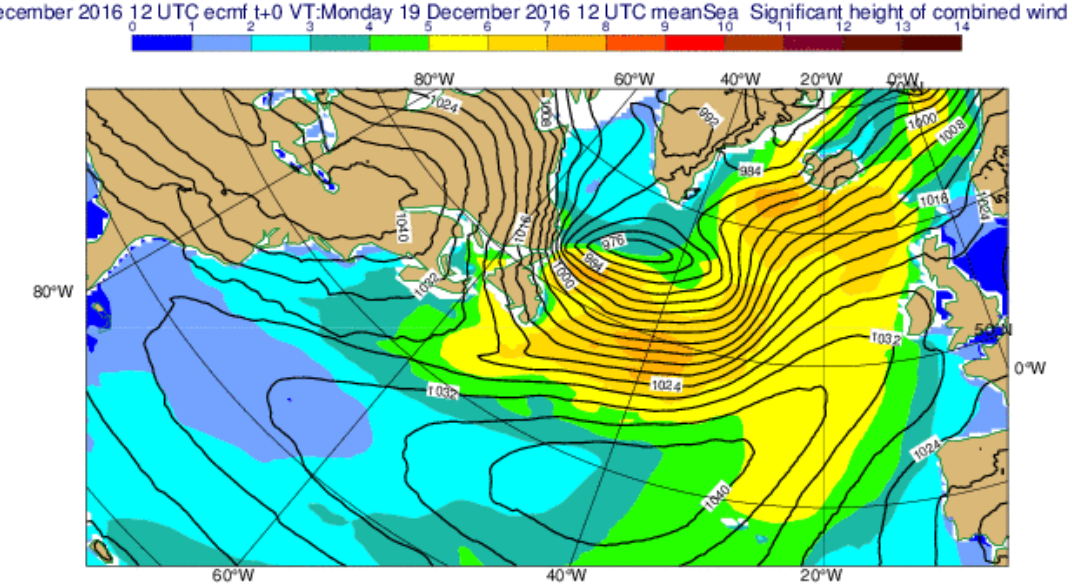
Monday 19 December 2016 06 UTC ecmf t+0 VT:Monday 19 December 2016 06 UTC surface Mean sea level pressure
Monday 19 December 2016 06 UTC ecmf t+0 VT:Monday 19 December 2016 06 UTC meanSea Significant height of combined wind waves and swell



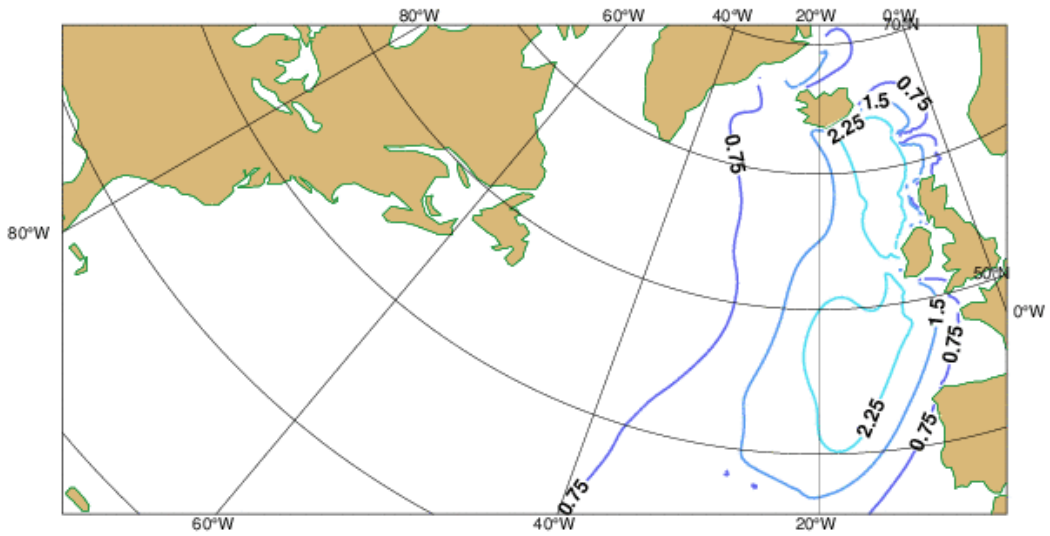
19 December 2016 06 UTC ecmf t+0 VT:Monday 19 December 2016 06 UTC meanSea Significant wave height of all waves with periods within the inclusive range from 17 to 21 seconds



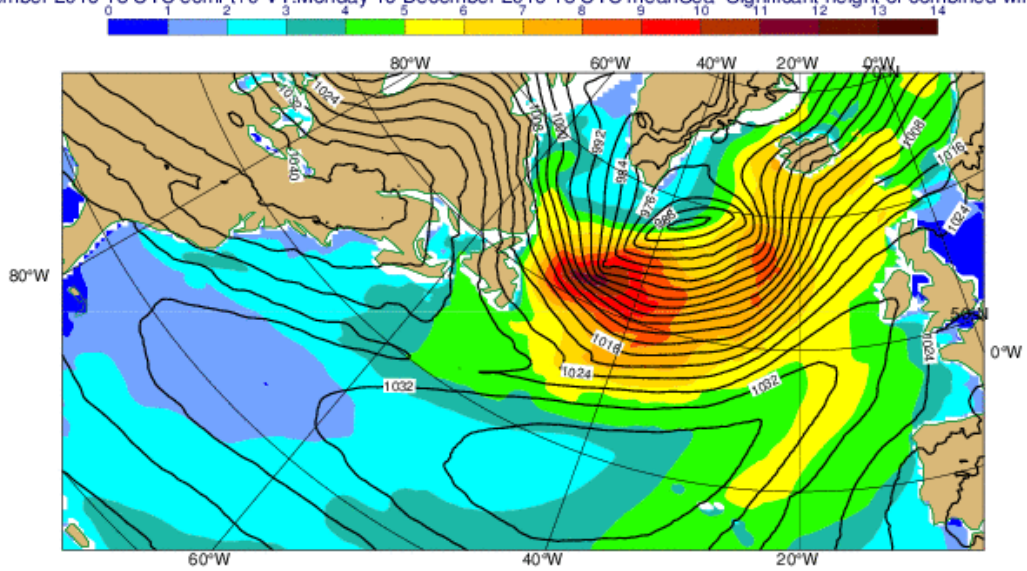
Monday 19 December 2016 12 UTC ecmf t+0 VT:Monday 19 December 2016 12 UTC surface Mean sea level pressure
Monday 19 December 2016 12 UTC ecmf t+0 VT:Monday 19 December 2016 12 UTC meanSea Significant height of combined wind waves and swell



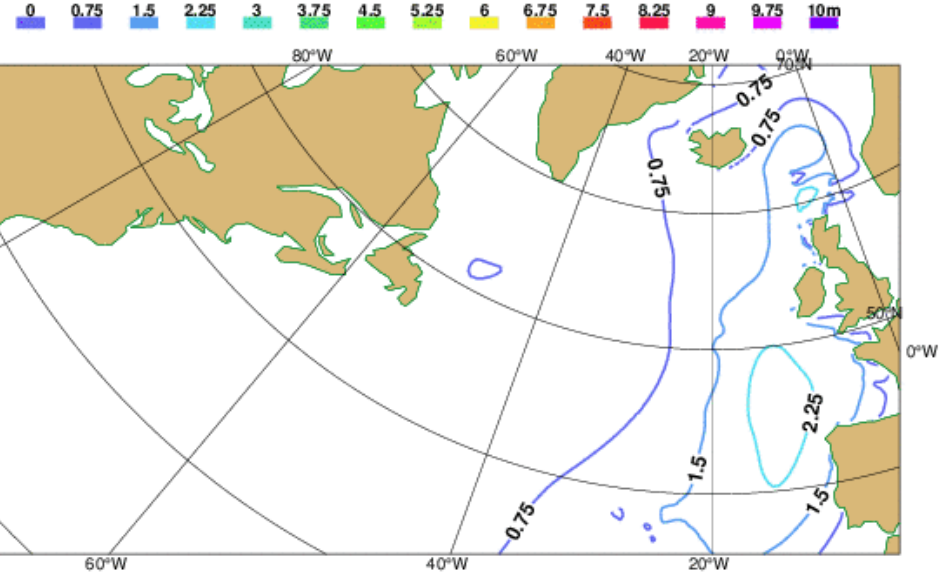
19 December 2016 12 UTC ecmf t+0 VT:Monday 19 December 2016 12 UTC meanSea Significant wave height of all waves with periods within the inclusive range from 17 to 21 seconds



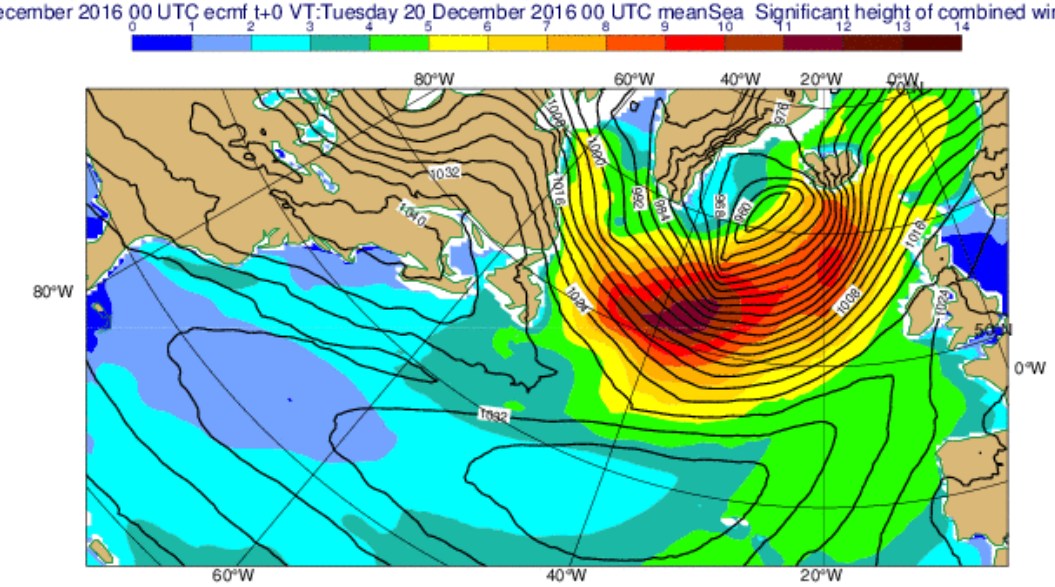
Monday 19 December 2016 18 UTC ecmf t+0 VT:Monday 19 December 2016 18 UTC surface Mean sea level pressure
Monday 19 December 2016 18 UTC ecmf t+0 VT:Monday 19 December 2016 18 UTC meanSea Significant height of combined wind waves and swell



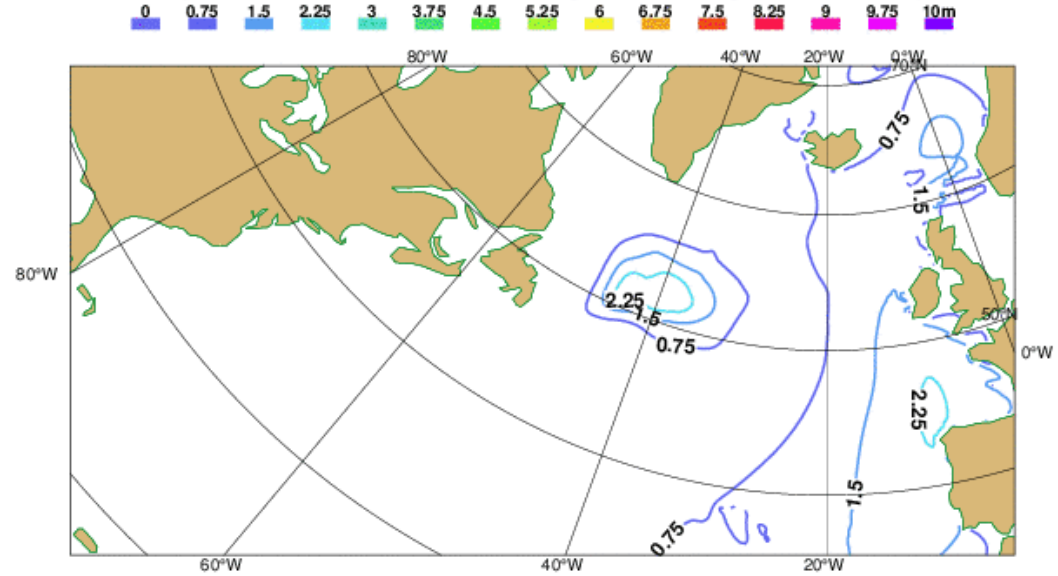
19 December 2016 18 UTC ecmf t+0 VT:Monday 19 December 2016 18 UTC meanSea Significant wave height of all waves with periods within the inclusive range from 17 to 21 seconds



Tuesday 20 December 2016 00 UTC ecmf t+0 VT:Tuesday 20 December 2016 00 UTC surface Mean sea level pressure
Tuesday 20 December 2016 00 UTC ecmf t+0 VT:Tuesday 20 December 2016 00 UTC meanSea Significant height of combined wind waves and swell



20 December 2016 00 UTC ecmf t+0 VT:Tuesday 20 December 2016 00 UTC meanSea Significant wave height of all waves with periods within the inclusive range from 17 to 21 seconds



Tuesday 20 December 2016 06 UTC ecmf t+0 VT:Tuesday 20 December 2016 06 UTC surface Mean sea level pressure
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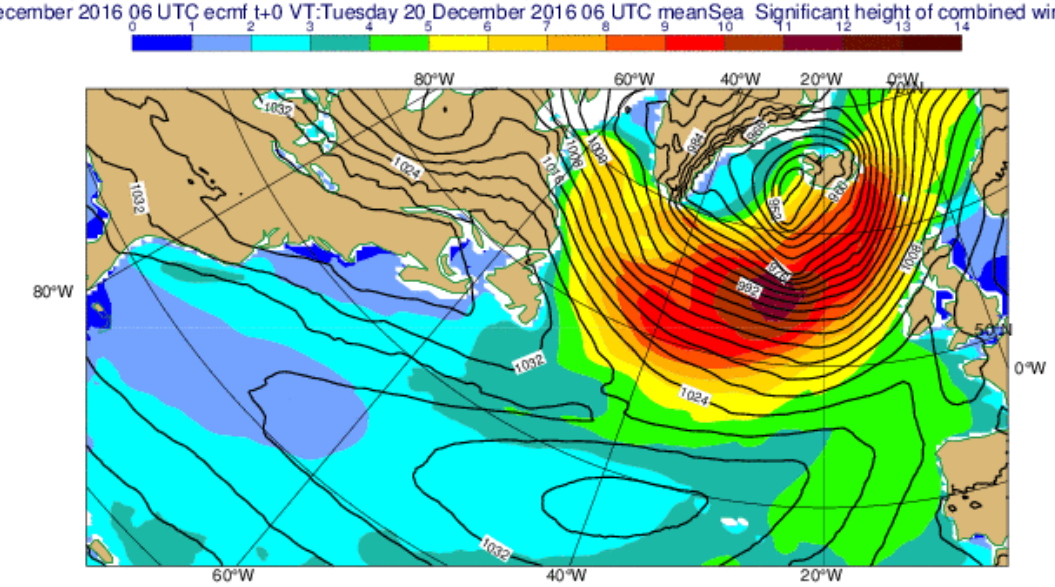
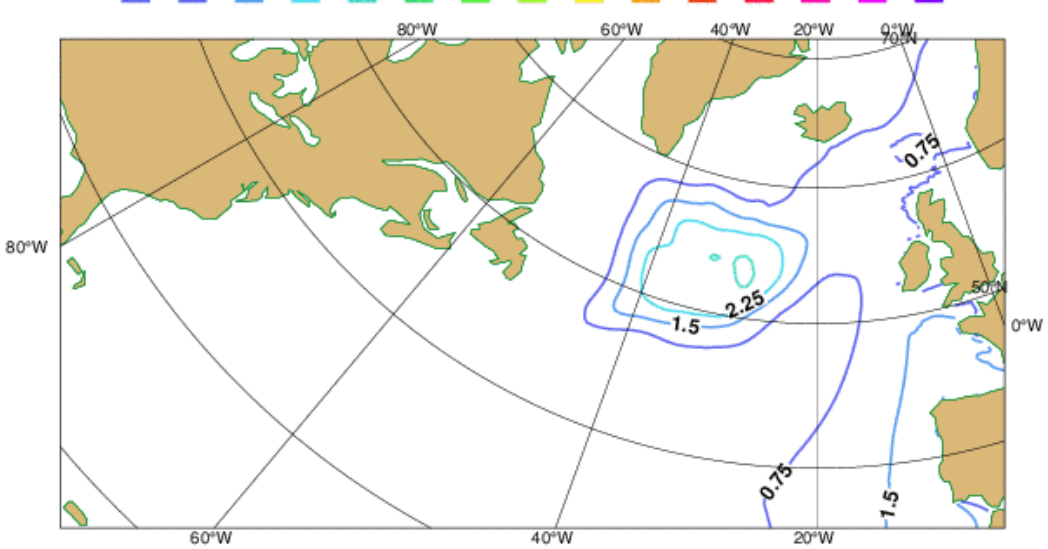


20 December 2016 06 UTC ecmf t+0 VT:Tuesday 20 December 2016 06 UTC meanSea Significant wave height of all waves with periods within the inclusive range from 17 to 21 seconds



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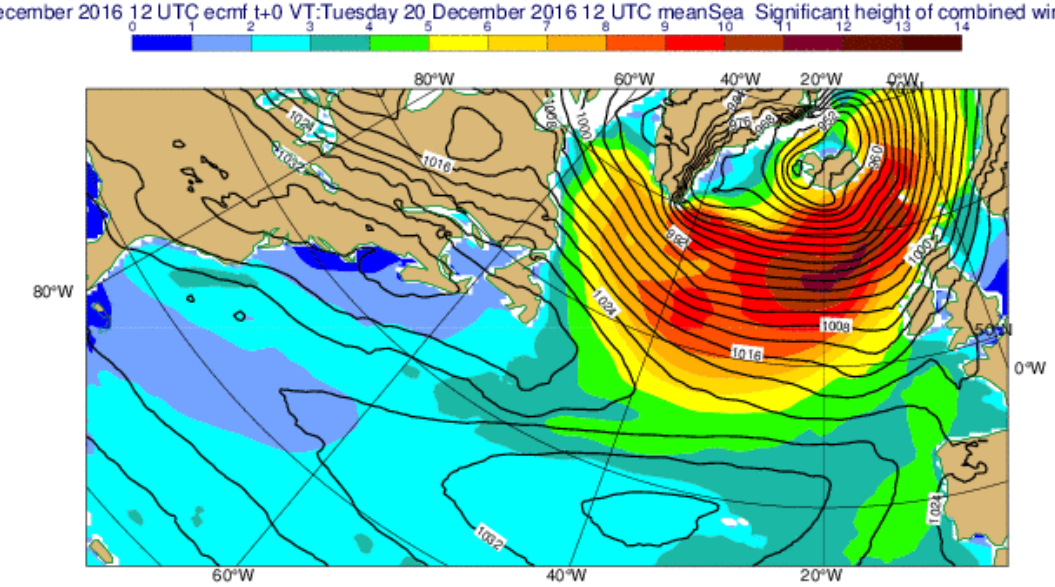
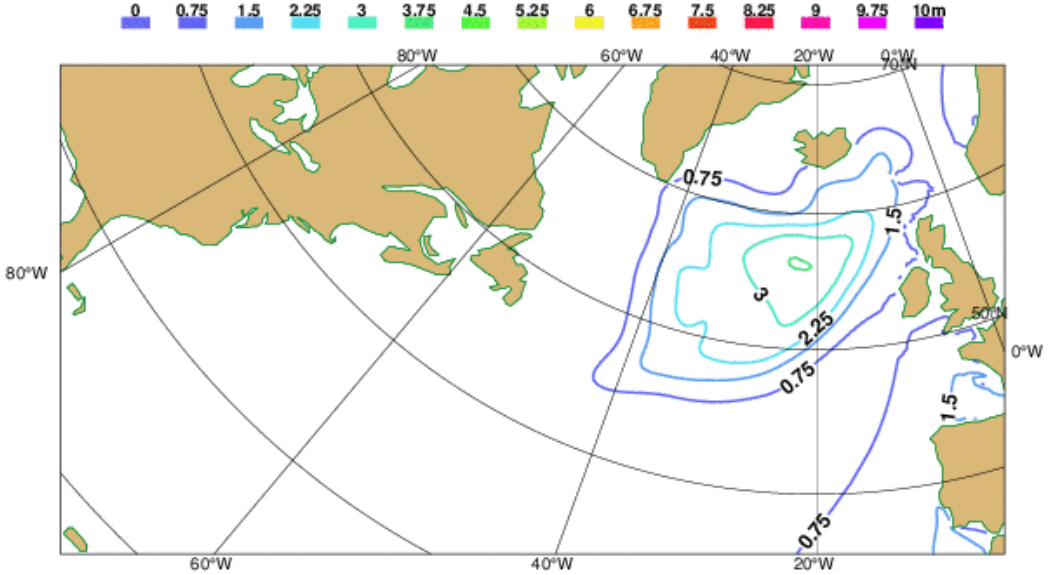


20 December 2016 12 UTC ecmf t+0 VT:Tuesday 20 December 2016 12 UTC meanSea Significant wave height of all waves with periods within the inclusive range from 17 to 21 seconds



Tuesday 20 December 2016 18 UTC ecmf t+0 VT:Tuesday 20 December 2016 18 UTC surface Mean sea level pressure
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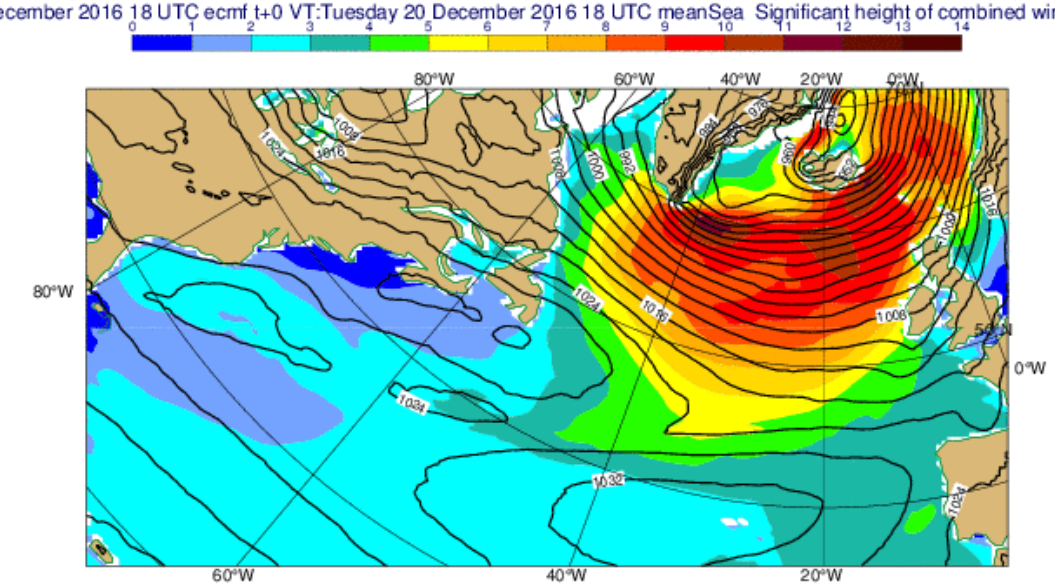
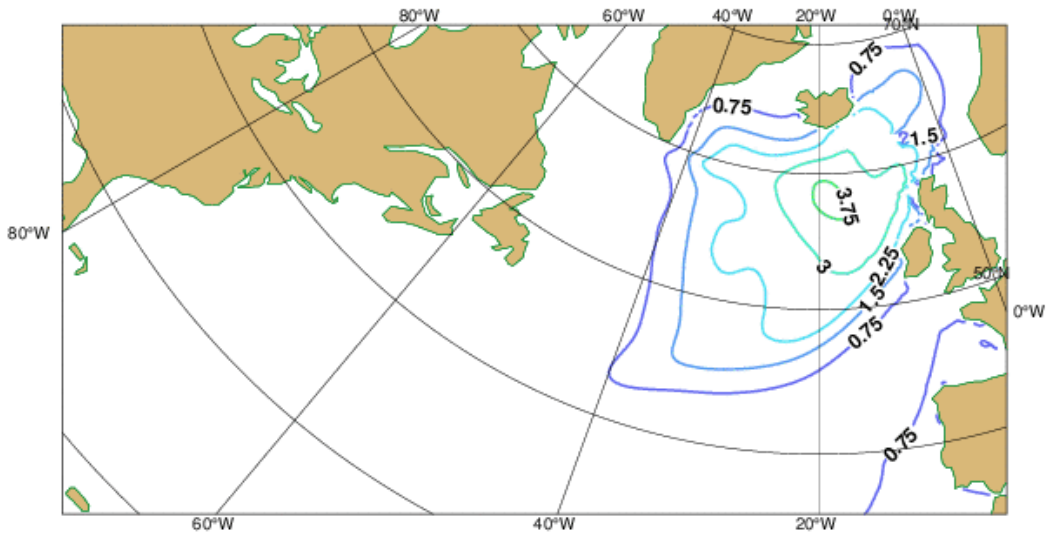
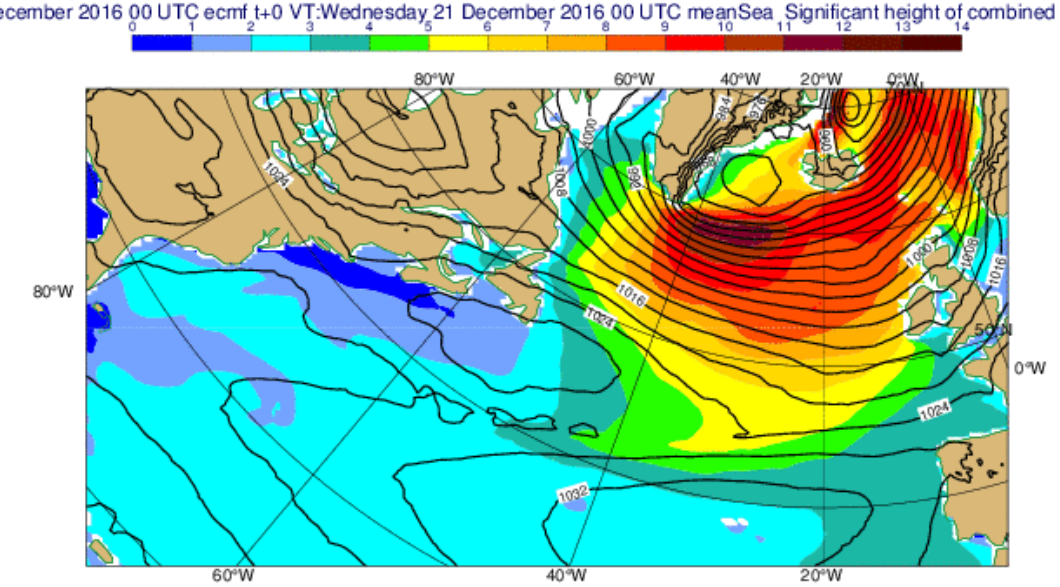


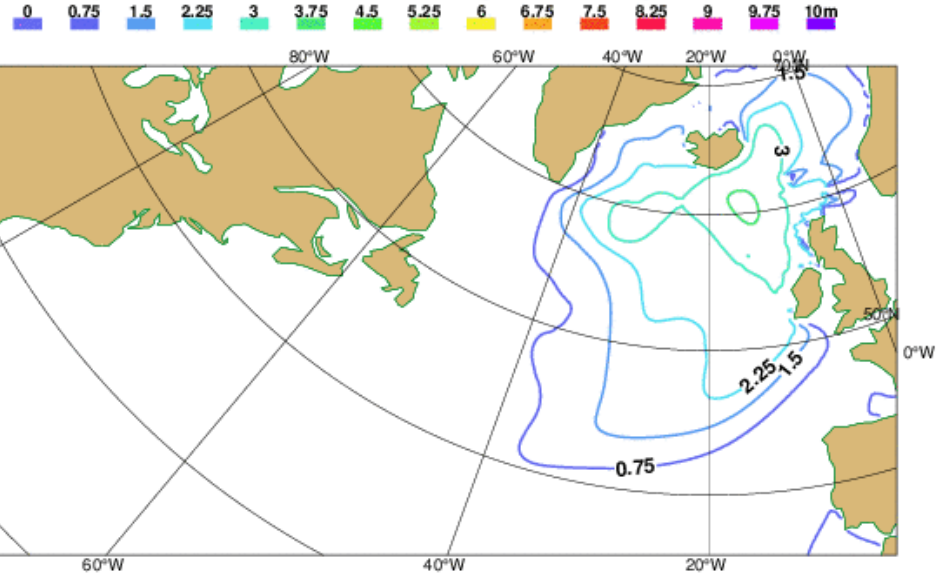
20 December 2016 18 UTC ecmf t+0 VT:Tuesday 20 December 2016 18 UTC meanSea Significant wave height of all waves with periods within the inclusive range from 17 to 21 seconds



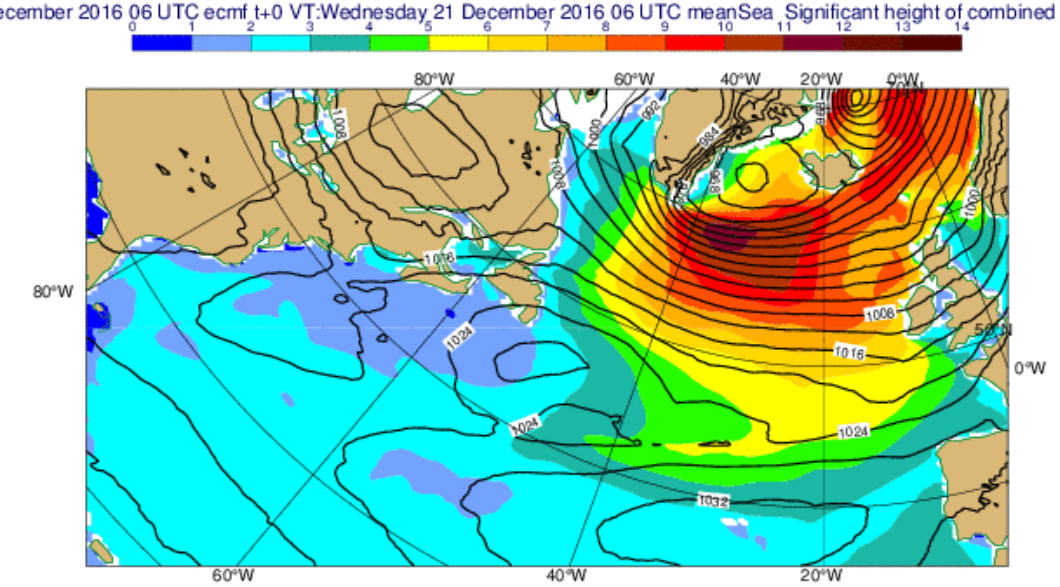
Wednesday 21 December 2016 00 UTC ecmf t+0 VT:Wednesday 21 December 2016 00 UTC surface Mean sea level pressure
Wednesday 21 December 2016 00 UTC ecmf t+0 VT:Wednesday 21 December 2016 00 UTC meanSea Significant height of combined wind waves and swell



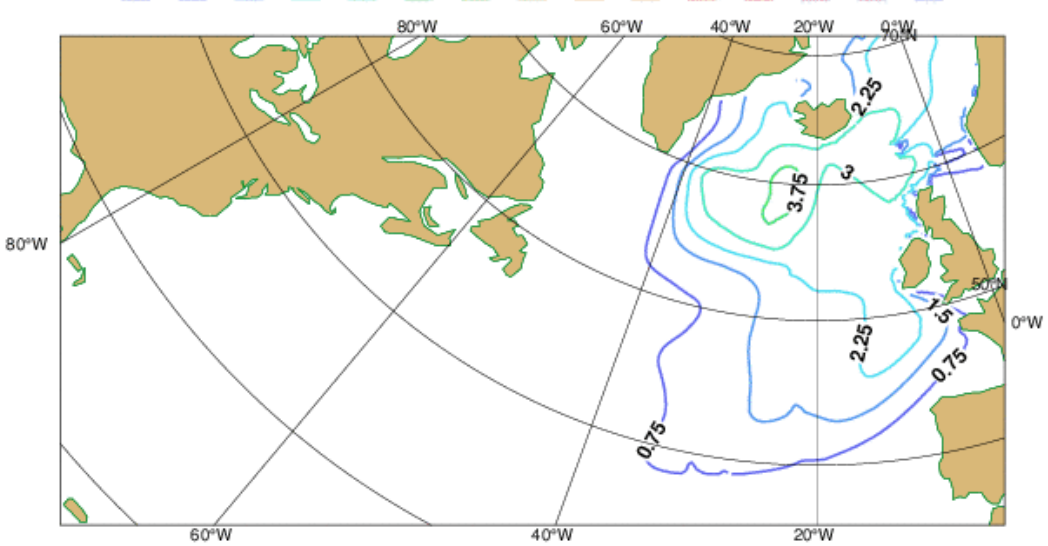
21 December 2016 00 UTC ecmf t+0 VT:Wednesday 21 December 2016 00 UTC meanSea Significant wave height of all waves with periods within the inclusive range from 17 to 21 seconds



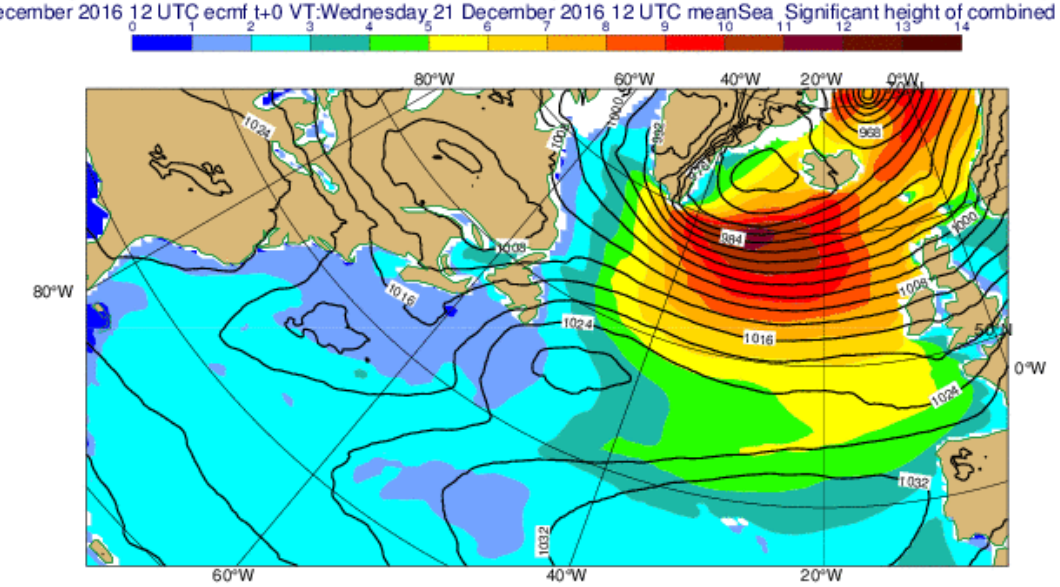
Wednesday 21 December 2016 06 UTC ecmf t+0 VT:Wednesday 21 December 2016 06 UTC surface Mean sea level pressure
Wednesday 21 December 2016 06 UTC ecmf t+0 VT:Wednesday 21 December 2016 06 UTC meanSea Significant height of combined wind waves and swell



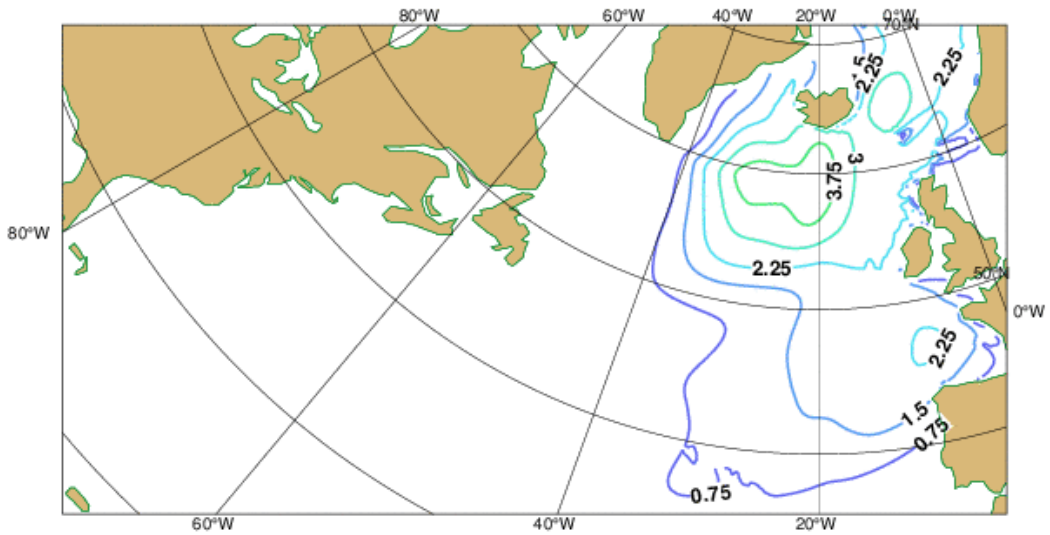
21 December 2016 06 UTC ecmf t+0 VT:Wednesday 21 December 2016 06 UTC meanSea Significant wave height of all waves with periods within the inclusive range from 17 to 21 seconds



Wednesday 21 December 2016 12 UTC ecmf t+0 VT:Wednesday 21 December 2016 12 UTC surface Mean sea level pressure
Wednesday 21 December 2016 12 UTC ecmf t+0 VT:Wednesday 21 December 2016 12 UTC meanSea Significant height of combined wind waves and swell



21 December 2016 12 UTC ecmf t+0 VT:Wednesday 21 December 2016 12 UTC meanSea Significant wave height of all waves with periods within the inclusive range from 17 to 21 seconds



Wednesday 21 December 2016 18 UTC ecmf t+0 VT:Wednesday 21 December 2016 18 UTC surface Mean sea level pressure
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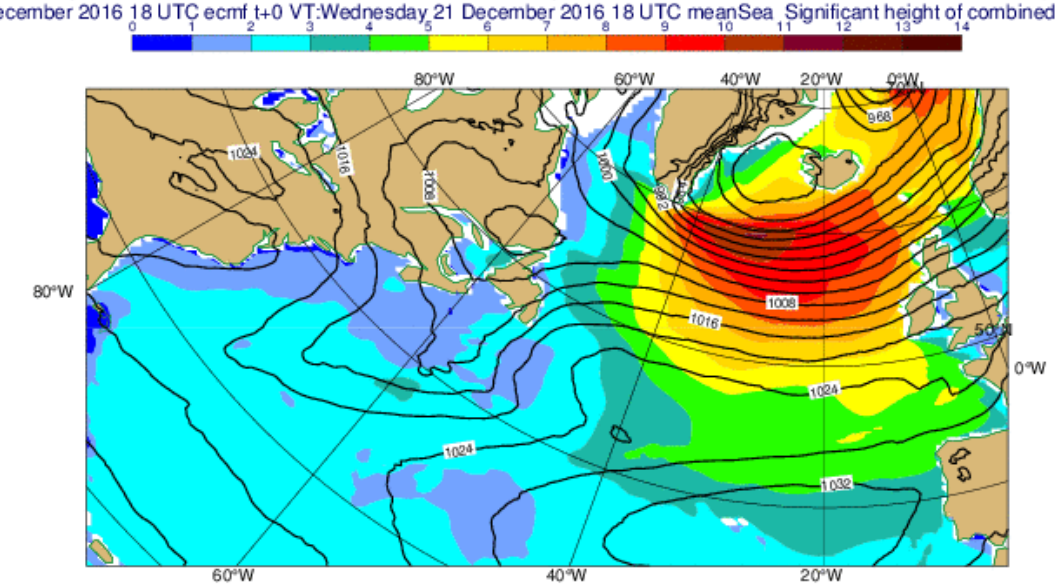
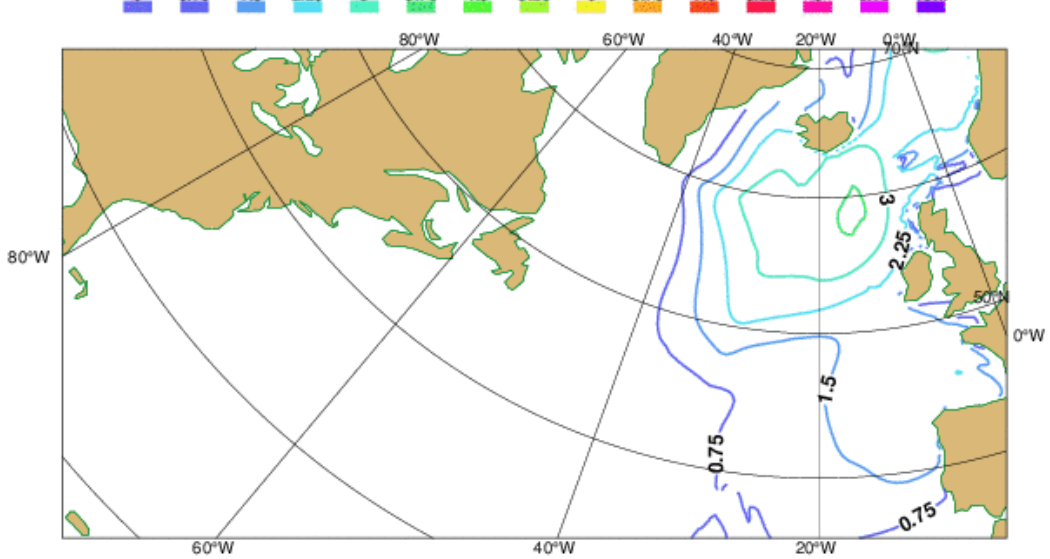
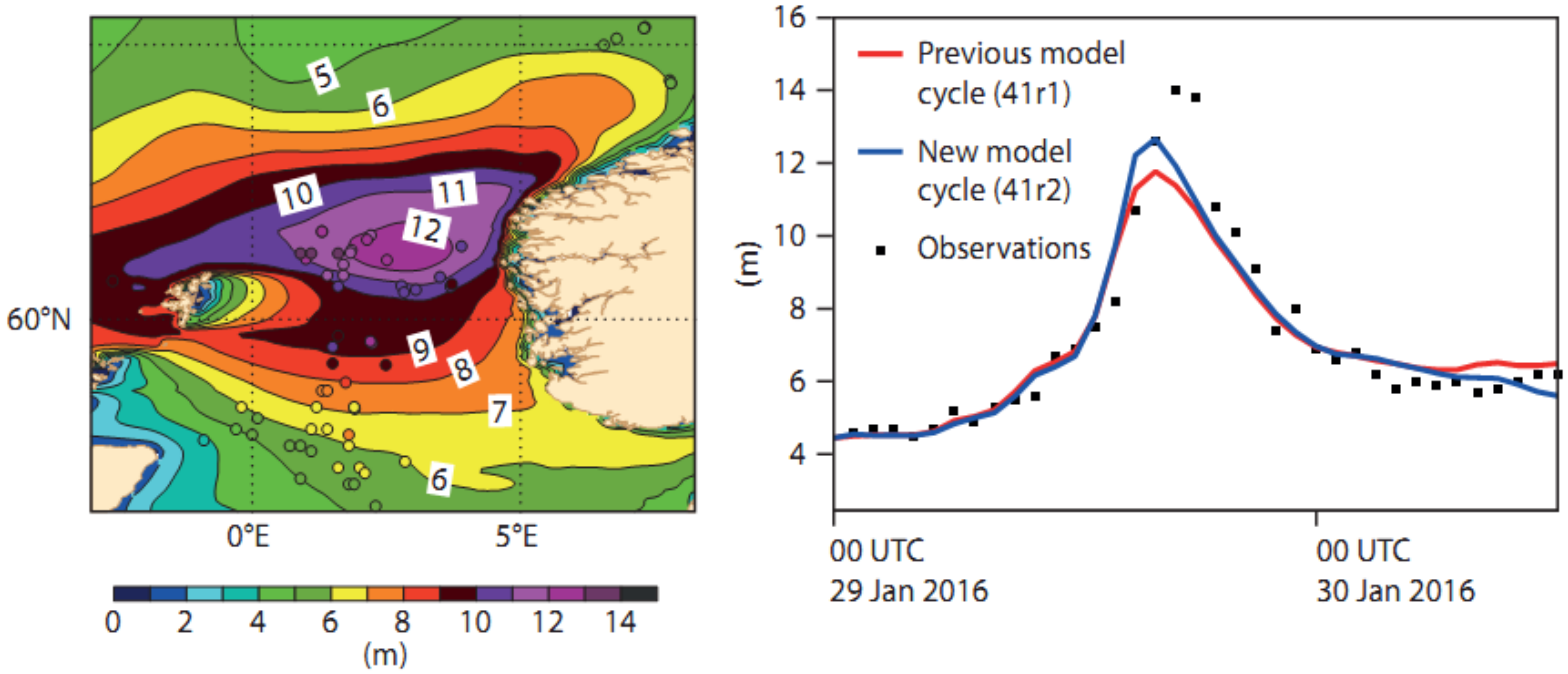


21 December 2016 18 UTC ecmf t+0 VT:Wednesday 21 December 2016 18 UTC meanSea Significant wave height of all waves with periods within the inclusive range from 17 to 21 seconds



Extremes can be captured **but** resolution matters



North Cormorant

High-resolution wave forecasts and observations. The left-hand panel shows ECMWF's 18-hour high-resolution significant wave height forecast from 00 UTC on 29 January (shading) produced using the new model cycle 41r2, and raw observations (circles). The right-hand panel shows observations from an oil platform located at 61.2°N, 1.1°E, and high-resolution forecasts (HRES) for the nearest grid point from 00 UTC on 29 January produced using the previous model cycle 41r1 and the new model cycle 41r2.

Magnusson,, L and Bidlot J. 2016. Wind and wave forecasts during storm Gertrude/Tor Newsletter 147 ECMWF.

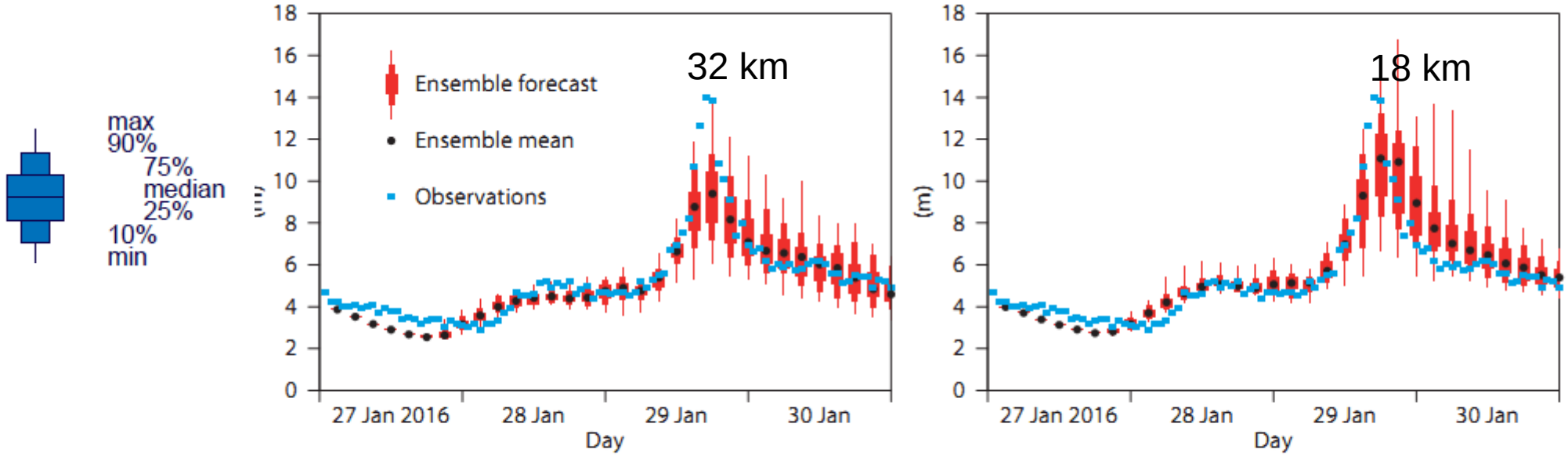
Cycle 41r2 in operations since March 2016:
High resolution:16 km -> 9 km

ECMWF

Forecasting extremes: Ensemble approach

Cycle 41r2 in operations since March 2016:
Ensemble: 32 km -> 18 km

North Cormorant



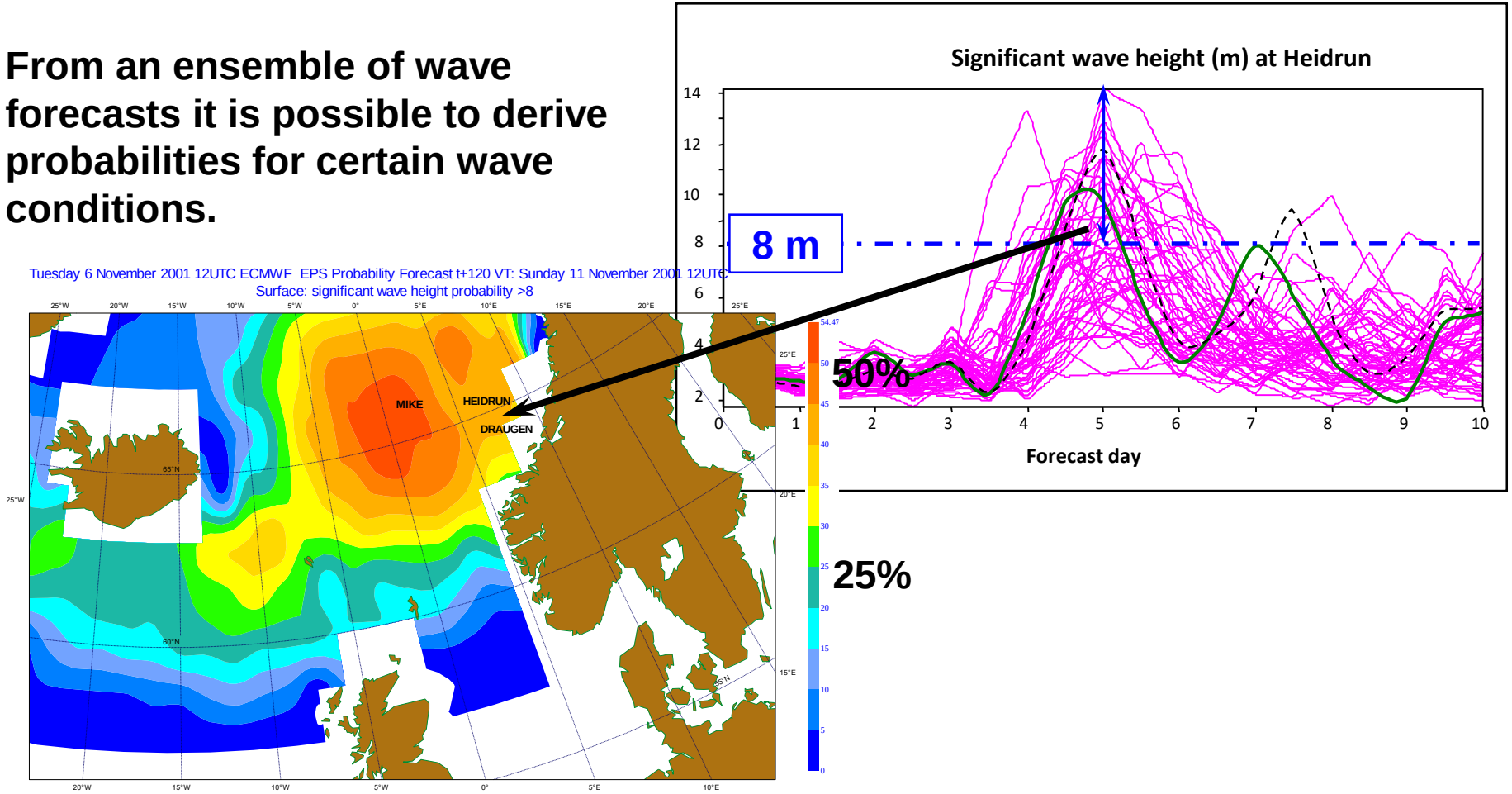
Ensemble wave forecasts and observations. Ensemble forecasts of significant wave height from 00 UTC on 27 January 2016 for 61.2°N, 1.1°E, from the previous model cycle 41r1 (left) and the new model cycle 41r2 (right), and observations.

Magnusson,, L and Bidlot J. 2016. Wind and wave forecasts during storm Gertrude/Tor Newsletter 147 ECMWF.

ECMWF

Forecasting extremes: Ensemble approach

From an ensemble of wave forecasts it is possible to derive probabilities for certain wave conditions.

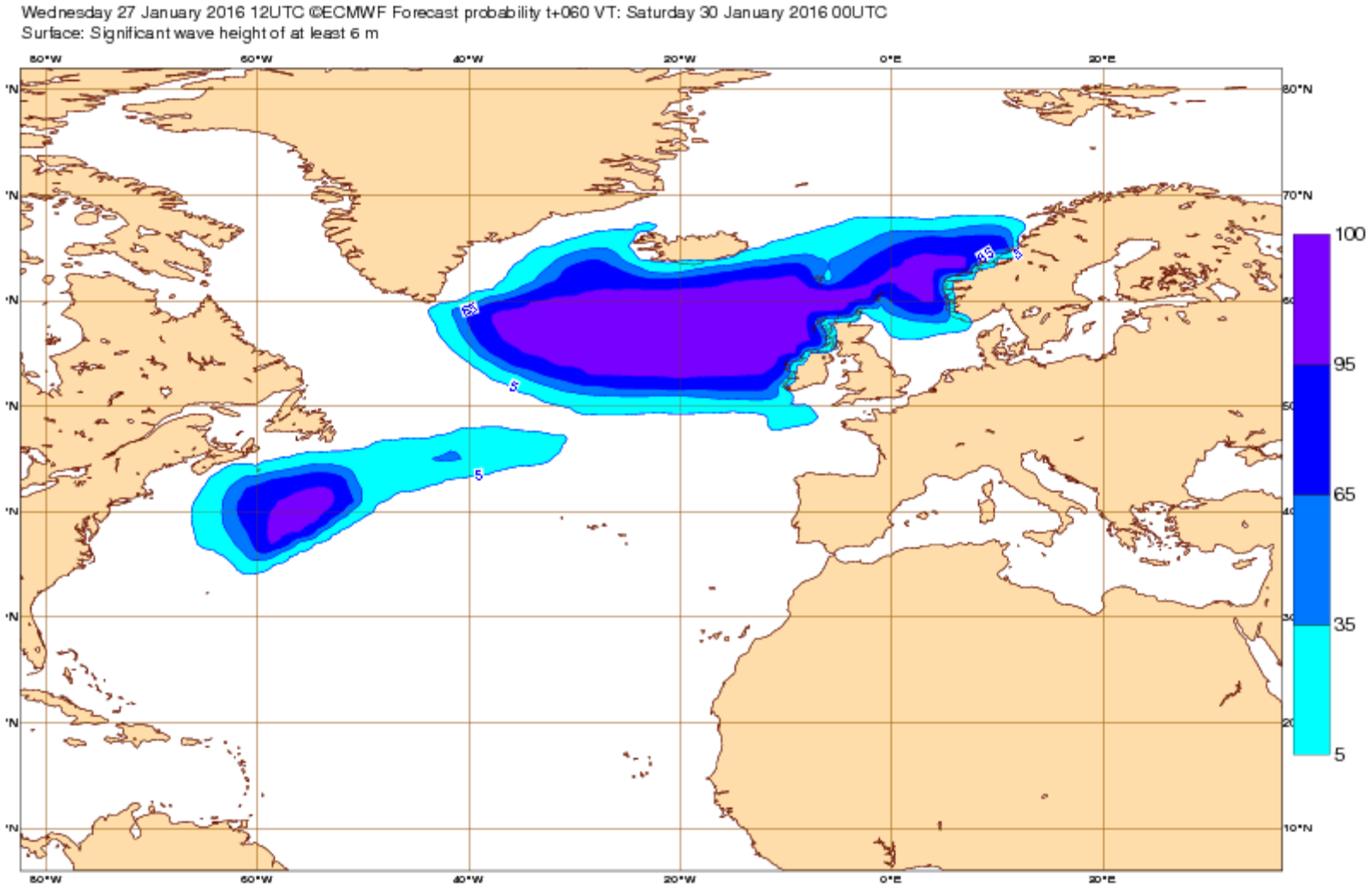


06 Nov. 2001 12 UTC ECMWF EPS probability forecast t+120

Significant wave height above 8 m

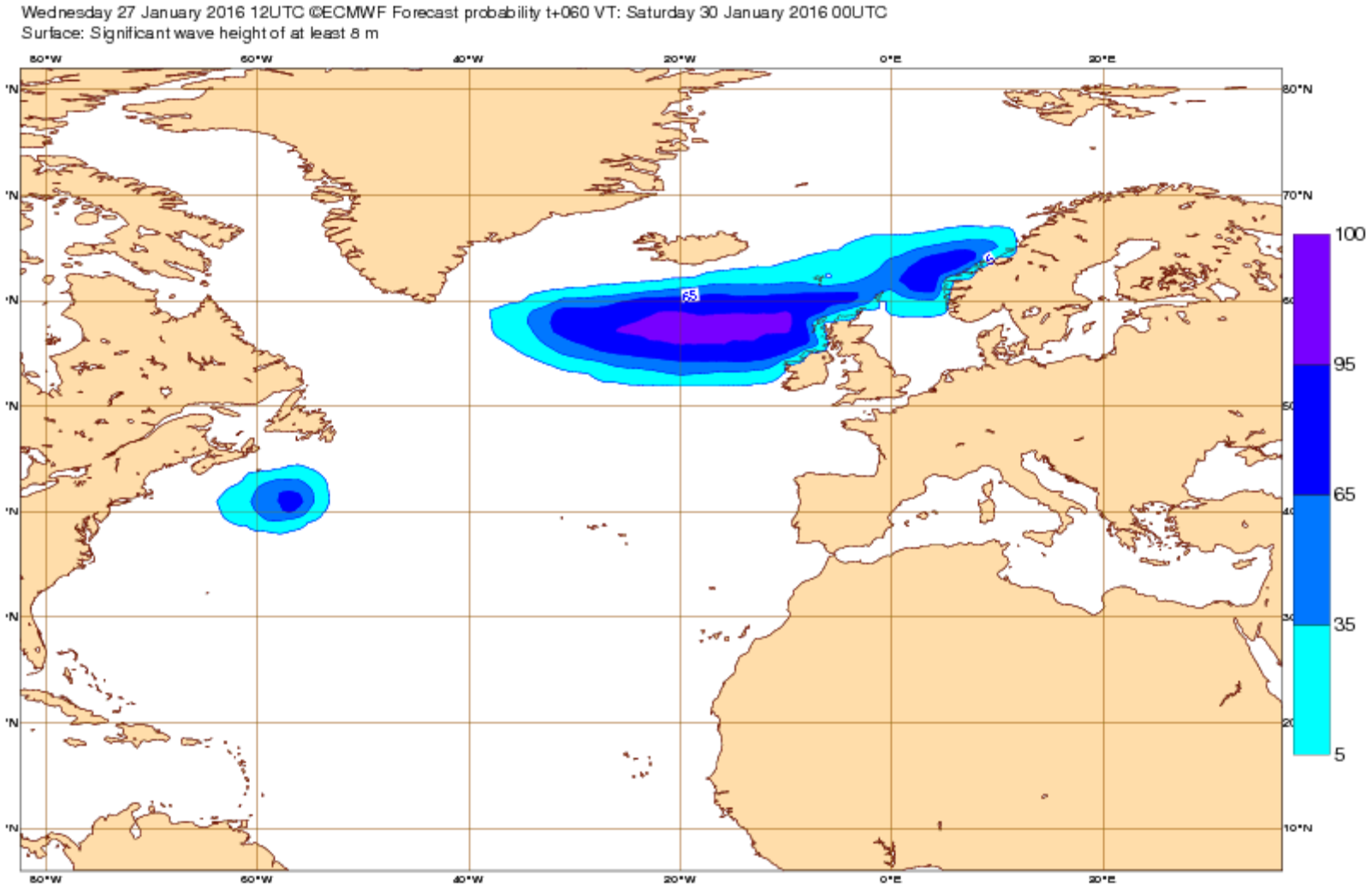
ECMWF

Basic EPS Wave Model Products



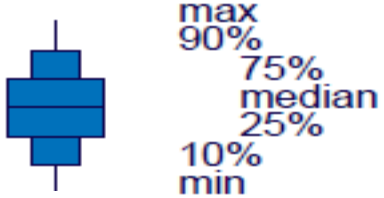
Probability that SWH > 6m

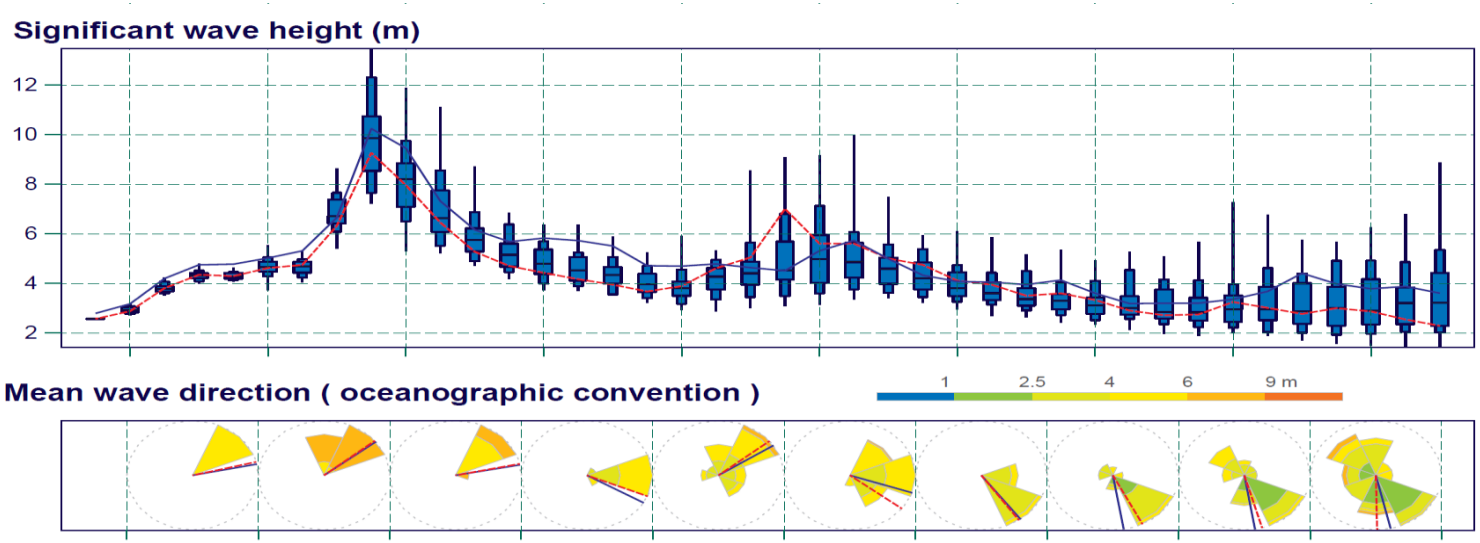
Basic EPS Wave Model Products



Probability that SWH > 8m

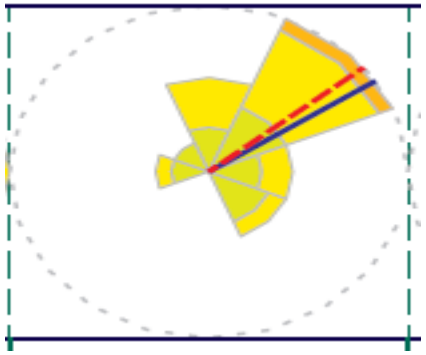
A bit more compact: Wave EPSgram:





ENS Control(55 km) High Resolution (28 km)

Hs 1 2.5 4 6 9 m



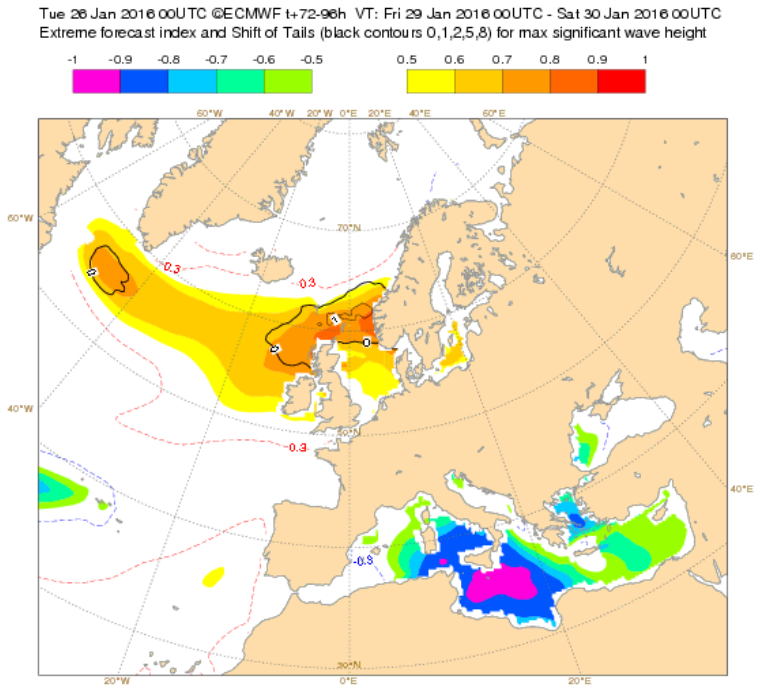
Each octant is coloured based on the distribution of the significant wave height associated with each mean direction. The coloured areas correspond to the fractional number of ensemble members with wave height in the range specified by the coloured ruler.

ECMWF

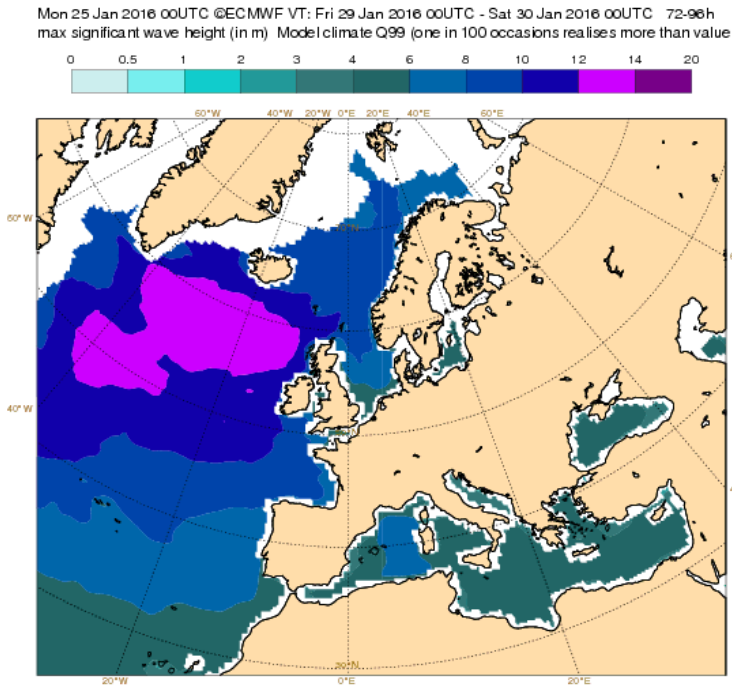
Forecasting extremes: Ensemble approach

From the model climate, it is possible to derive indices that indicate deviations in probabilistic terms from what is ‘expected’.

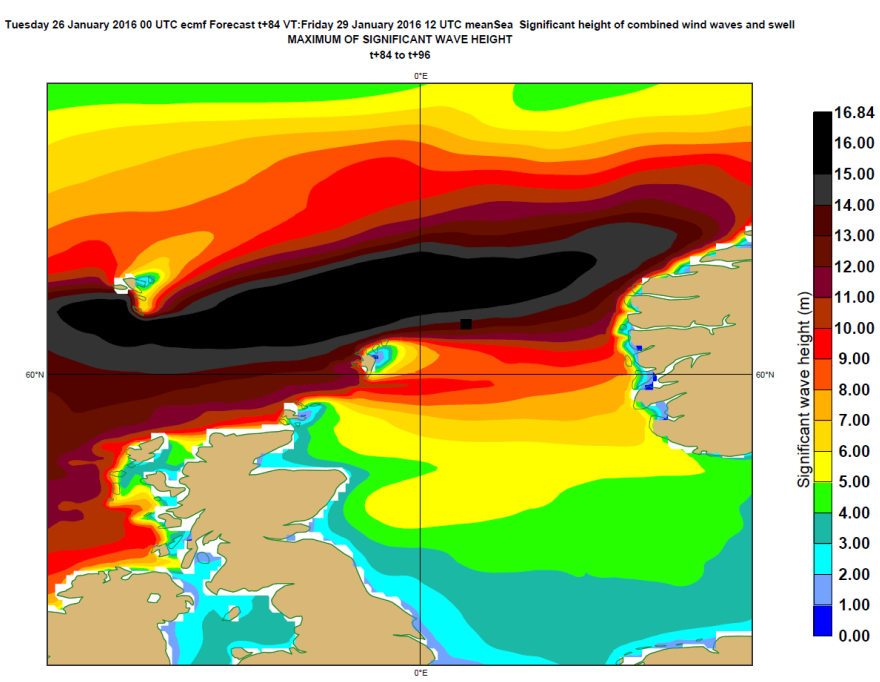
Extreme Forecast Index (EFI): 1 means that all EPS are above climate.



EFI and shift of tail for significant wave height



99 percentile of the distribution for significant wave height



Max of Significant Wave Height forecast from 2016-01-27 t=60-72

Tue **27** Jan 2016, 00 UTC, t=72-96

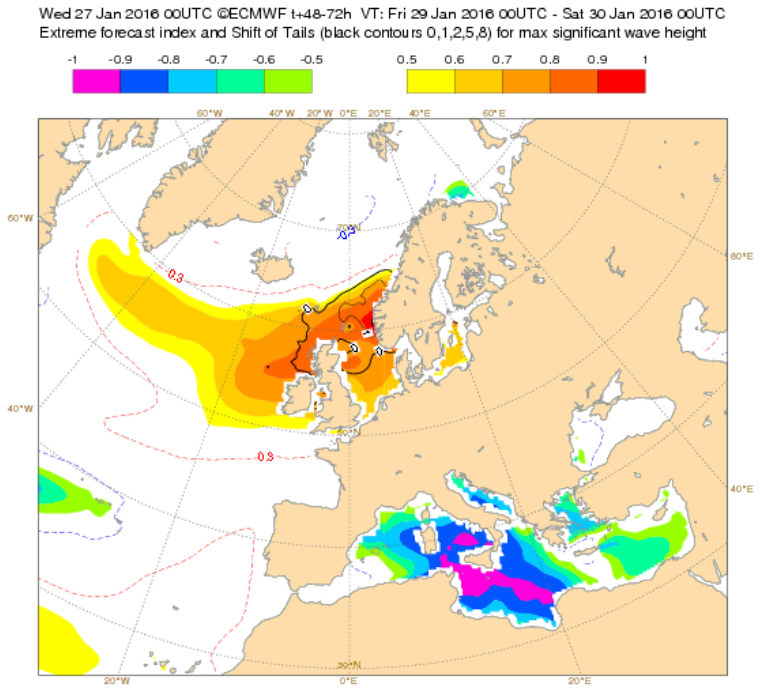
Gertrude (UK), Tor (Norway)

ECMWF

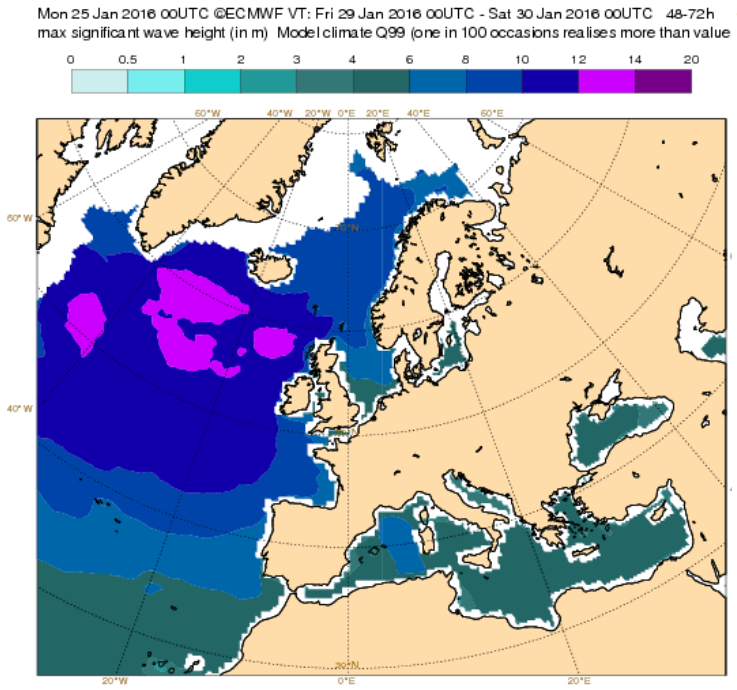
Forecasting extremes: Ensemble approach

From the model climate, it is possible to derive indices that indicate deviations in probabilistic terms from what is ‘expected’.

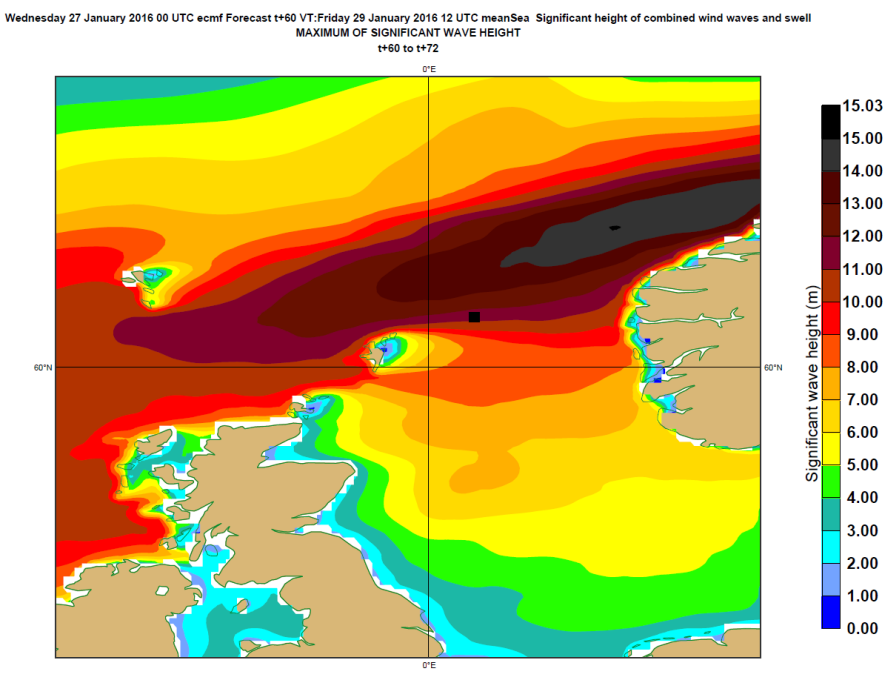
Extreme Forecast Index (EFI): 1 means that all EPS are above climate.



EFI and shift of tail for significant wave height



99 percentile of the distribution for significant wave height



Max of Significant Wave Height forecast from 2016-01-26 t=84-96

Tue **26** Jan 2016, 00 UTC, t=48-72

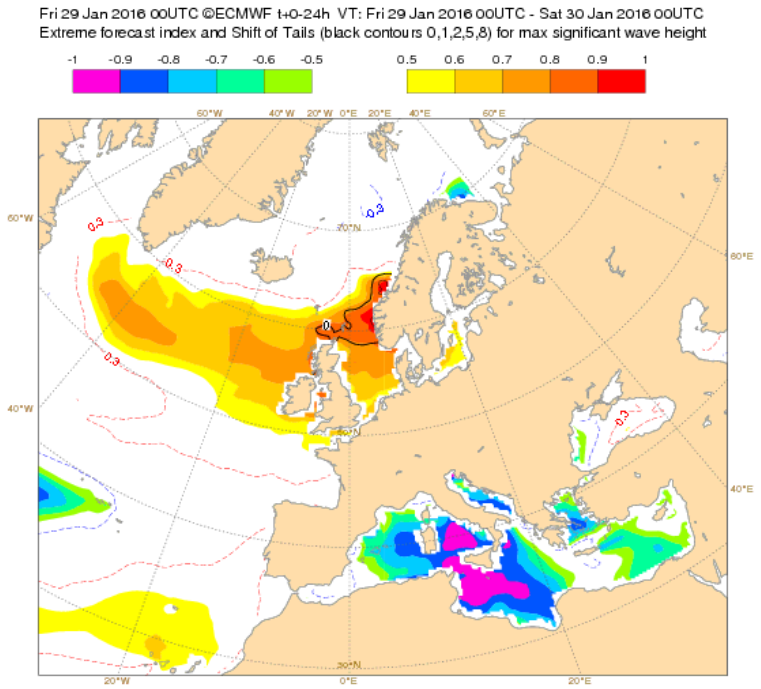
Gertrude (UK), Tor (Norway)

ECMWF

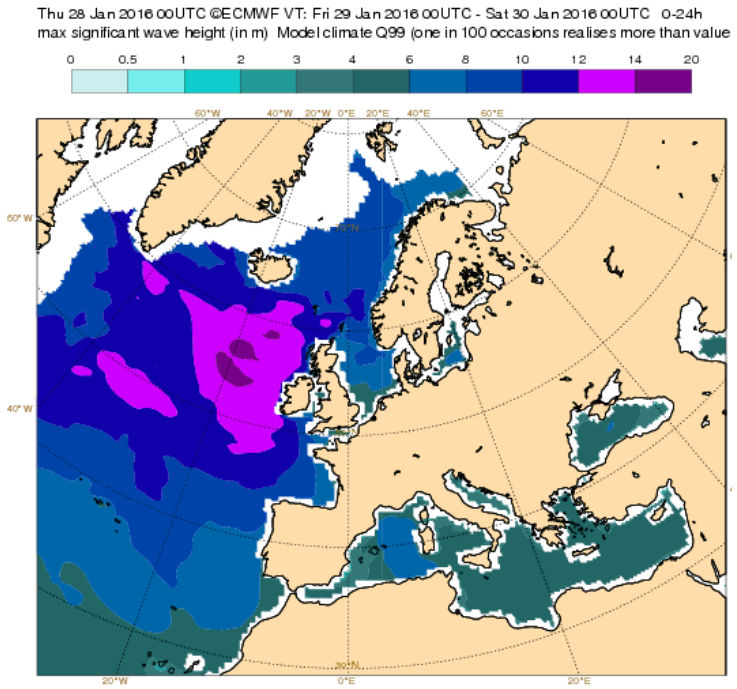
Forecasting extremes: Ensemble approach

From the model climate, it is possible to derive indices that indicate deviations in probabilistic terms from what is ‘expected’.

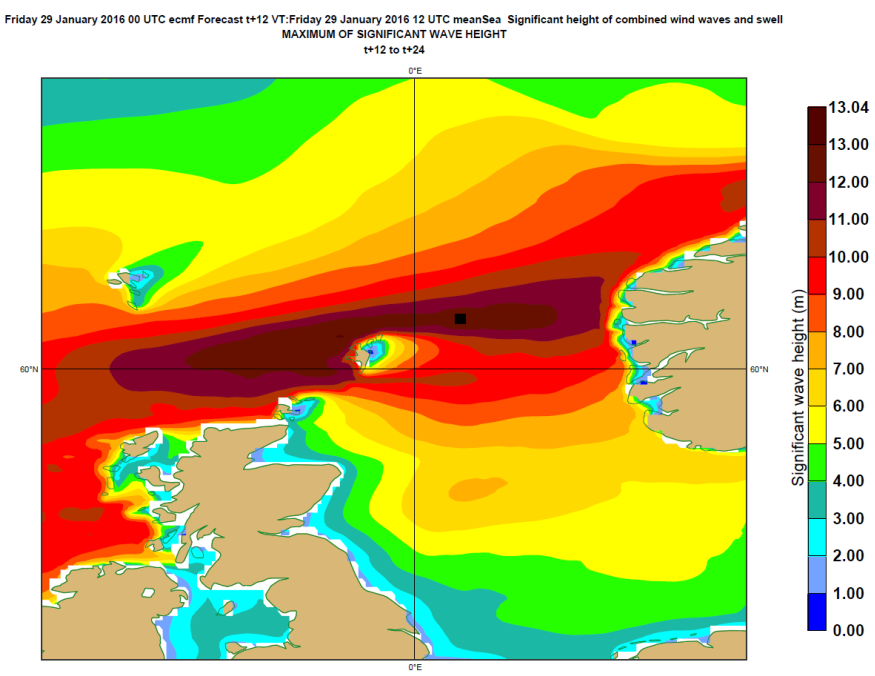
Extreme Forecast Index (EFI): 1 means that all EPS are above climate.



EFI and shift of tail for significant wave height



99 percentile of the distribution for significant wave height



Max of Significant Wave Height forecast from 2016-01-29 t=12-24

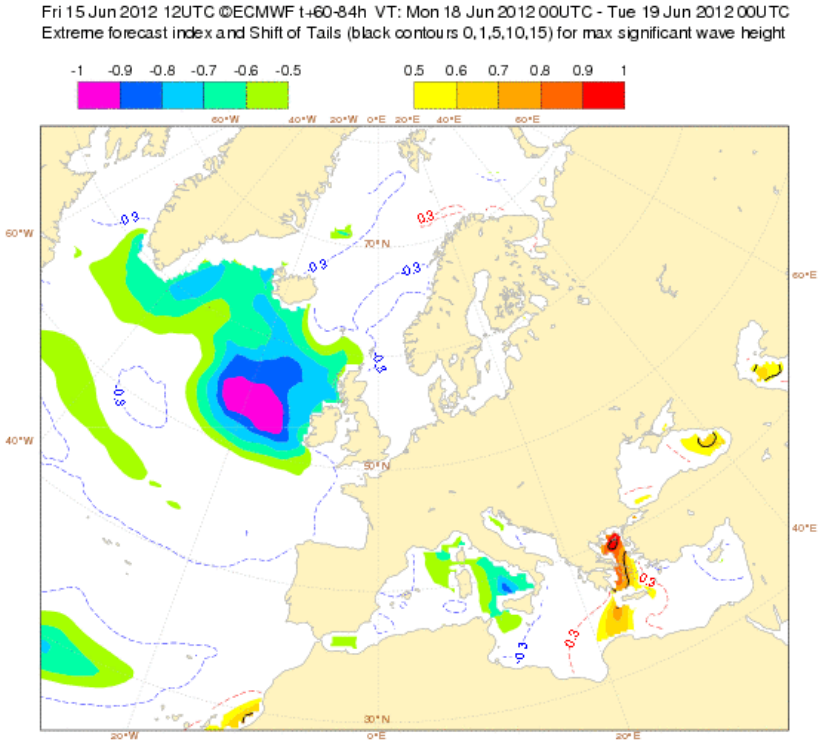
Tue **29** Jan 2016, 00 UTC, t=12-24

Gertrude (UK), Tor (Norway)

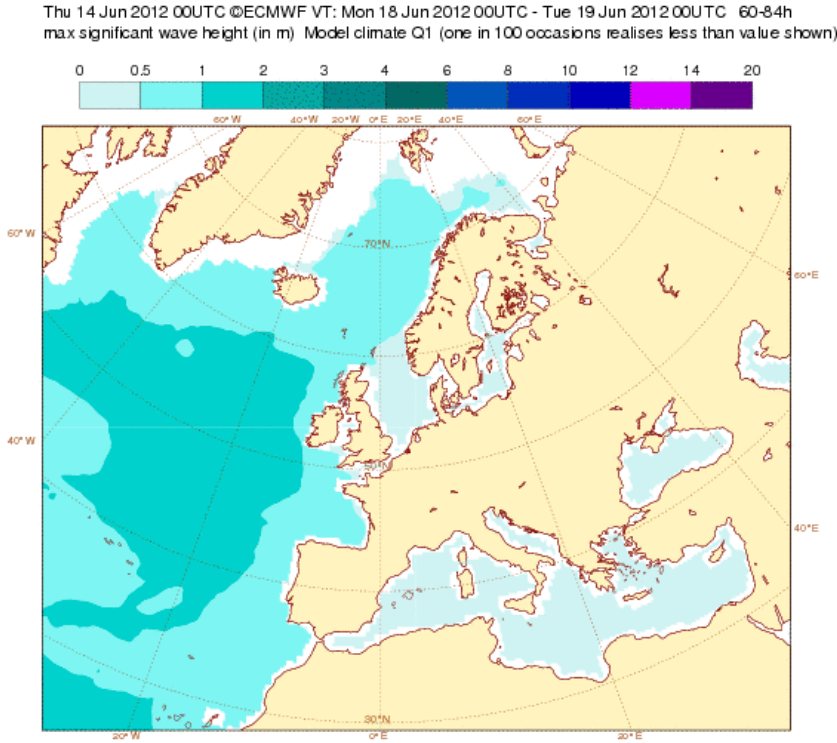
ECMWF

From the new model climate, it is possible to derive indices that indicate deviations in probabilistic terms from what is 'expected'.

Extreme Forecast Index (EFI): -1 means that all EPS are <u>below</u> climate.



EFI for significant wave height

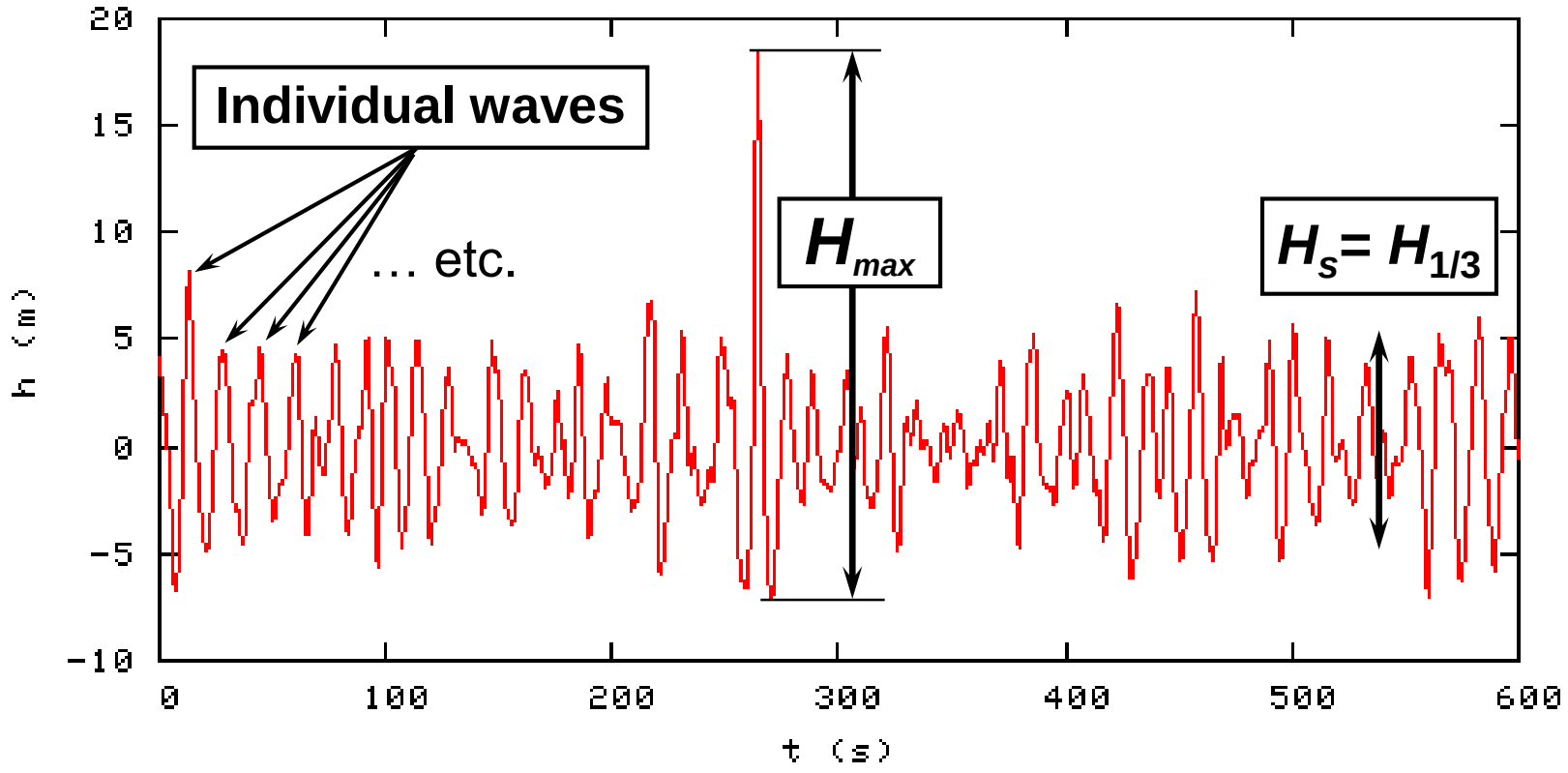


01 percentile of the distribution for significant wave height

Freak waves: We are not always dealing with nice ‘predictable’ waves:

ECMWF

Freak waves: Draupner freak wave



Individual Waves,
Significant Wave Height, H_s,
Maximum Individual Wave Height, H_{max}, and
Freak Wave

If $H_{max} > 2.2\ H_s$ ➔ freak wave event

ECMWF

Freak waves: “we can do the meteorology”

Conditions during Draupner freak wave

Atmospheric conditions

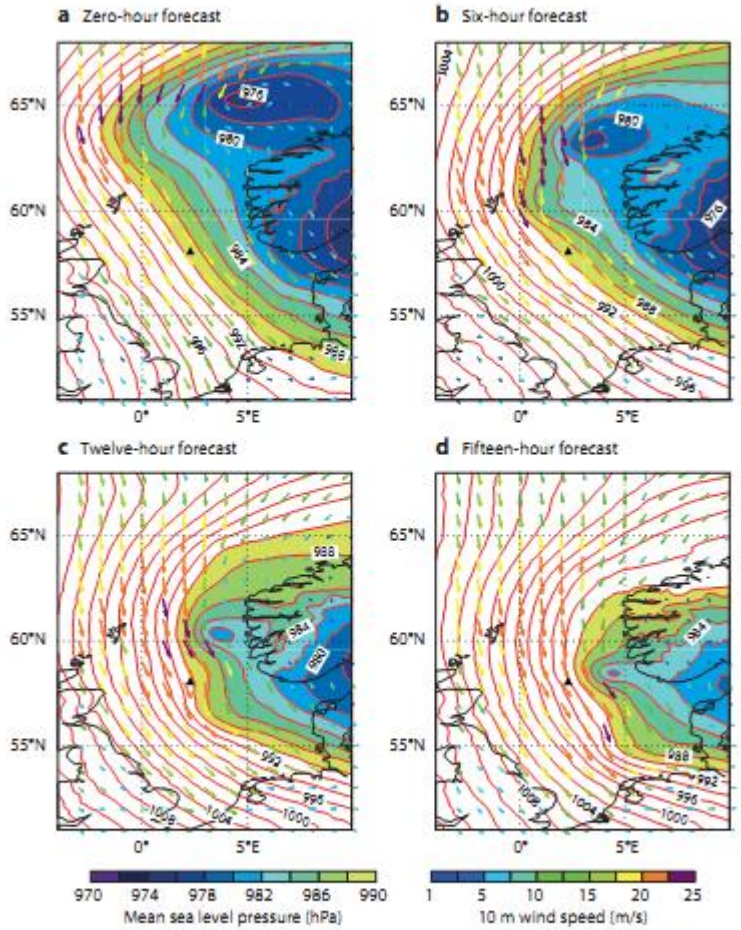


Figure 1 High-resolution forecasts of 10-metre wind (arrows) and mean sea level pressure (contours, shading) in the North and Nor Seas on 1 January 1995, showing (a) a 0-hour forecast, (b) a 6-hour forecast, (c) a 12-hour forecast, and (d) a 15-hour forecast, all starti 00 UTC. The black triangle shows the position of the Draupner platform.

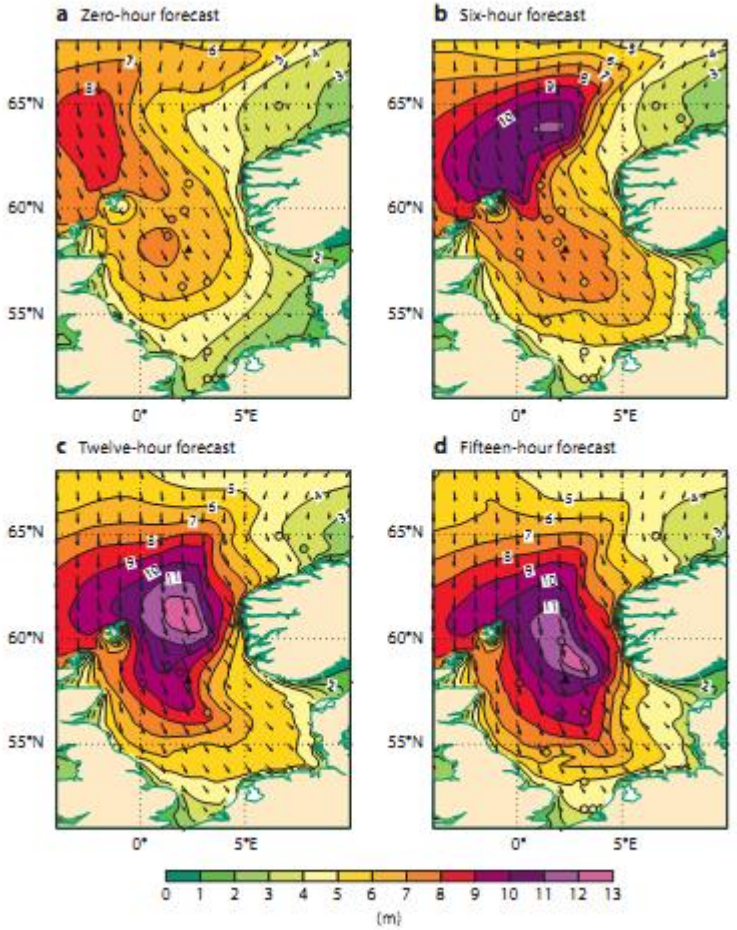


Figure 2 High-resolution forecasts of significant wave height distribution (shading) and mean wave direction (arrows) in the North and Norwegian Seas on 1 January 1995, showing (a) a 0-hour forecast (b) a 6-hour forecast, (c) a 12-hour forecast and (d) a 15-hour forecast, all starting from 00 UTC. The black triangle shows the position of the Draupner platform. Coloured circles denote corresponding wave height observations (same colour scale as for the forecasts) as archived at ECMWF.

Waves conditions

Bidlot J. et al. 2016. **What conditions led to the Draupner freak wave?** Newsletter 148 ECMWF.

Cavaleri et al, 2016. The Draupner wave: a fresh look and the emerging view. JGR ocean

ECMWF

Freak waves: “we can do the science”

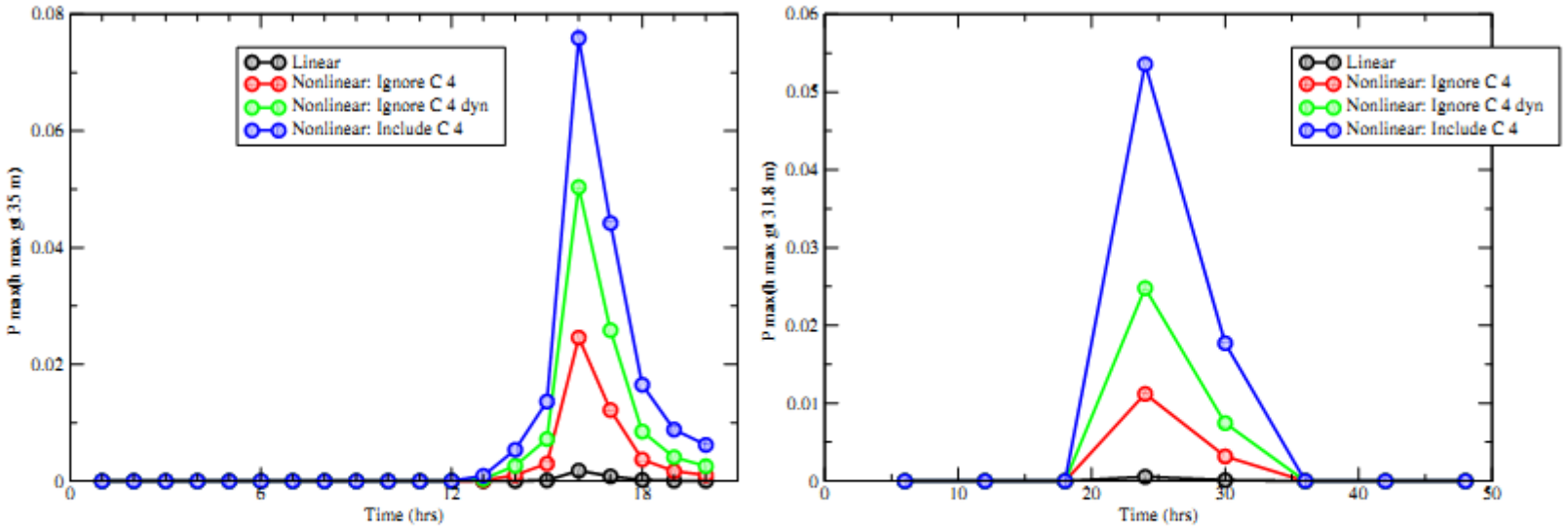
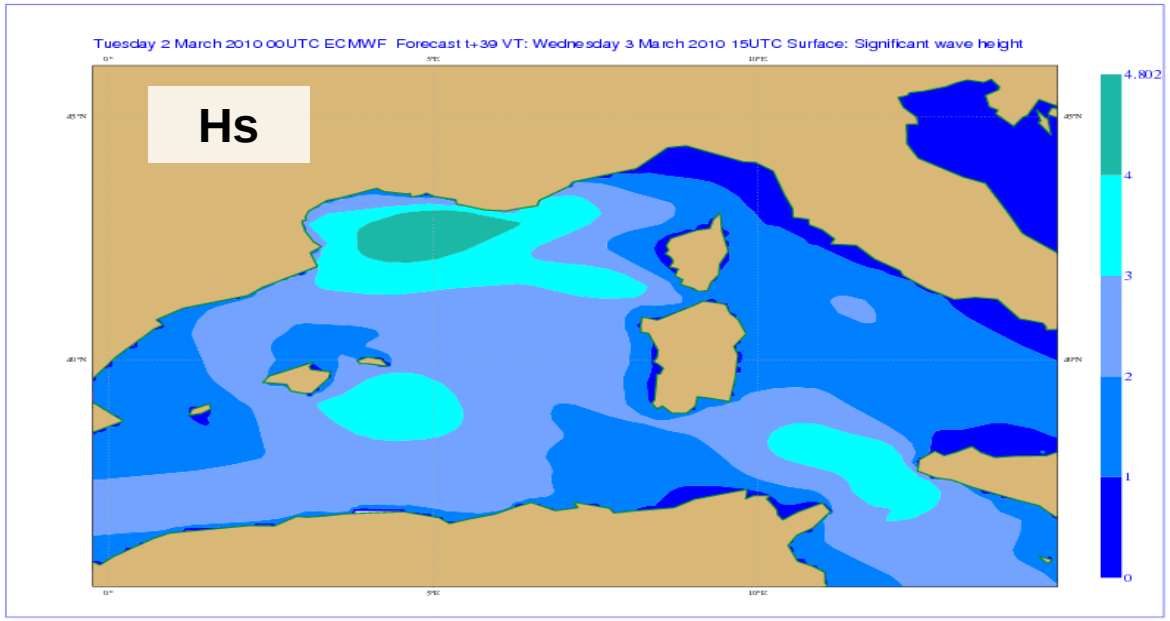


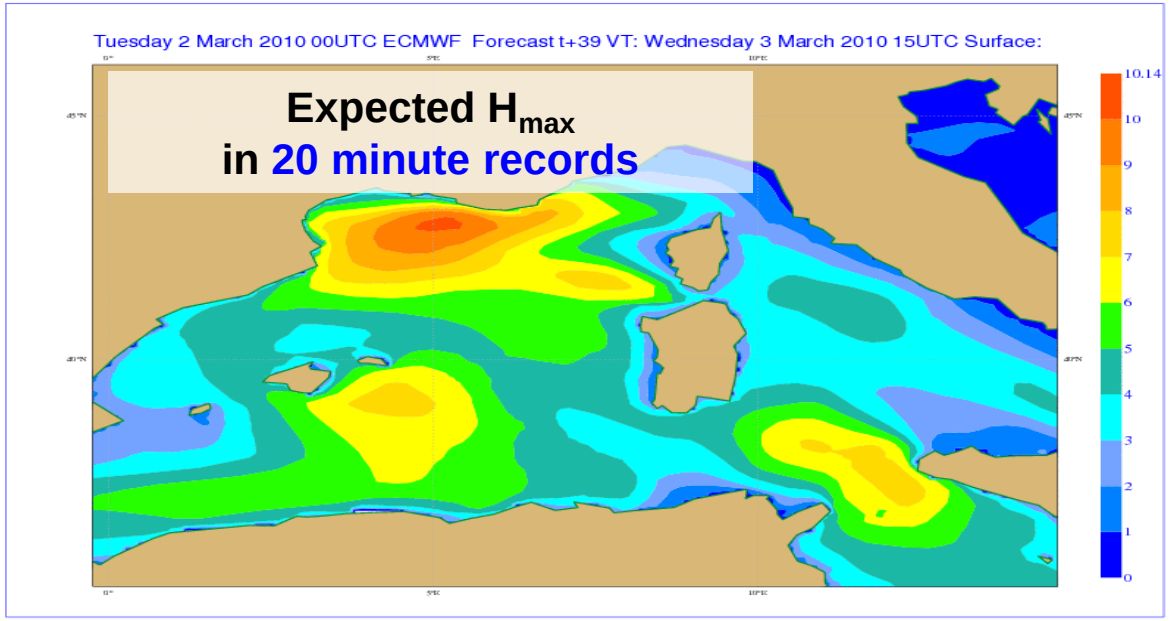
Figure 8: Evolution in time of simulated exceedance probability $P_{max}(h_{max}^{obs})$ for $h_{max}^{obs} = 35$ m (Draupner, left panel) and for $h_{max}^{obs} = 31.8$ (Andrea storm, right panel). For comparison the corresponding results from linear theory are shown, whereas also the impact of dynamic kurtosis and total kurtosis is depicted.

Shallow-water version of the Freak Wave Warning System,
Peter A.E.M. Janssen, 2017, ECMWF Tech Memo

Wave Model Products: Extreme Waves

We have a parameter to estimate the height of the highest individual wave (H_{max}) one can expect. Its value can be derived from the 2d wave spectrum:





March 3, 2010, 15UTC
Forecasts fields from Friday 2 March, 2010, 0 UTC

ECMWF


Questions ?
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