Ensemble wave products

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Ocean waves:

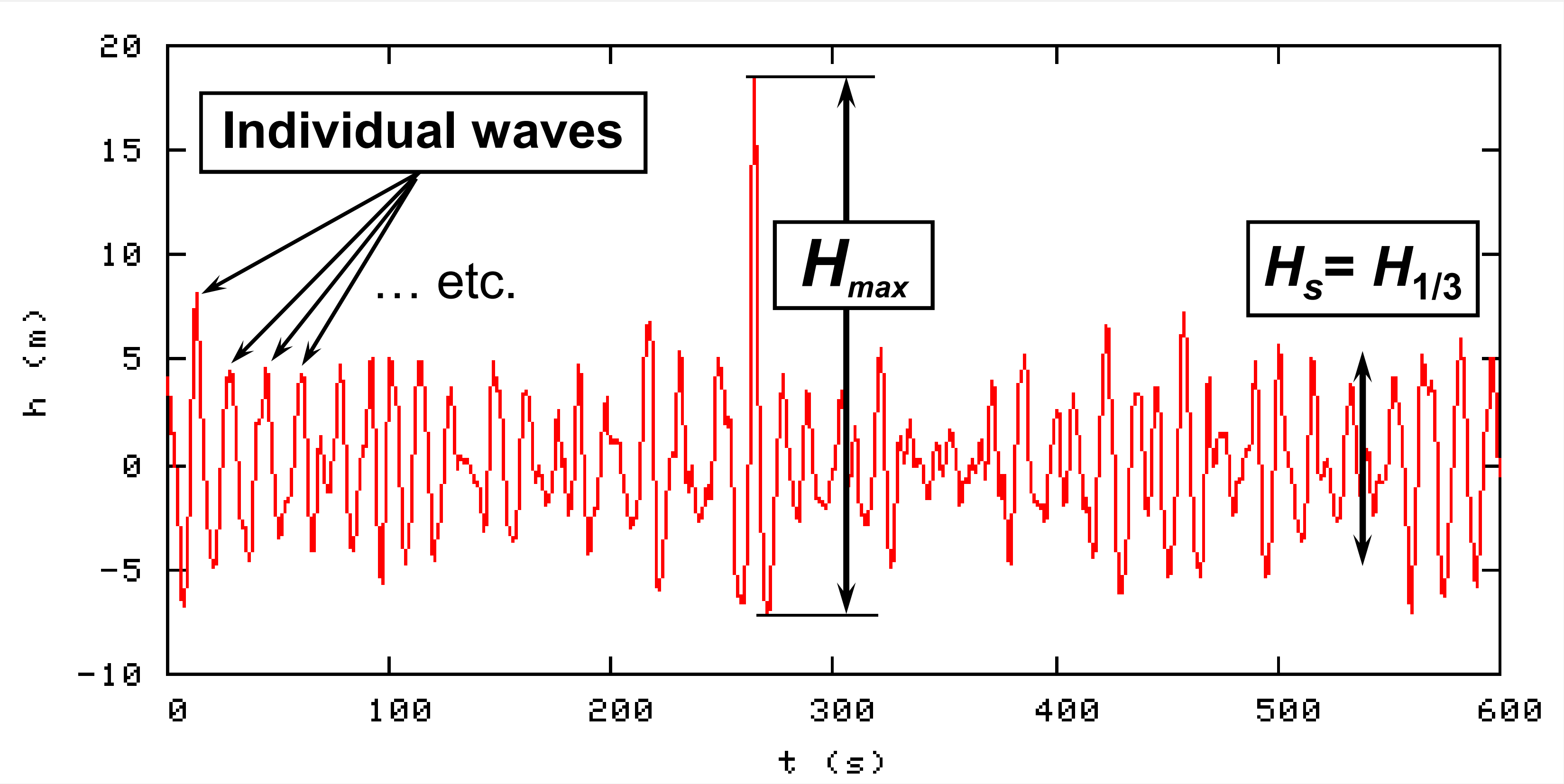
We are dealing with wind generated waves at the surface of the oceans, from gentle to rough …

Porthleven Clock Tower, Cornwall, UK

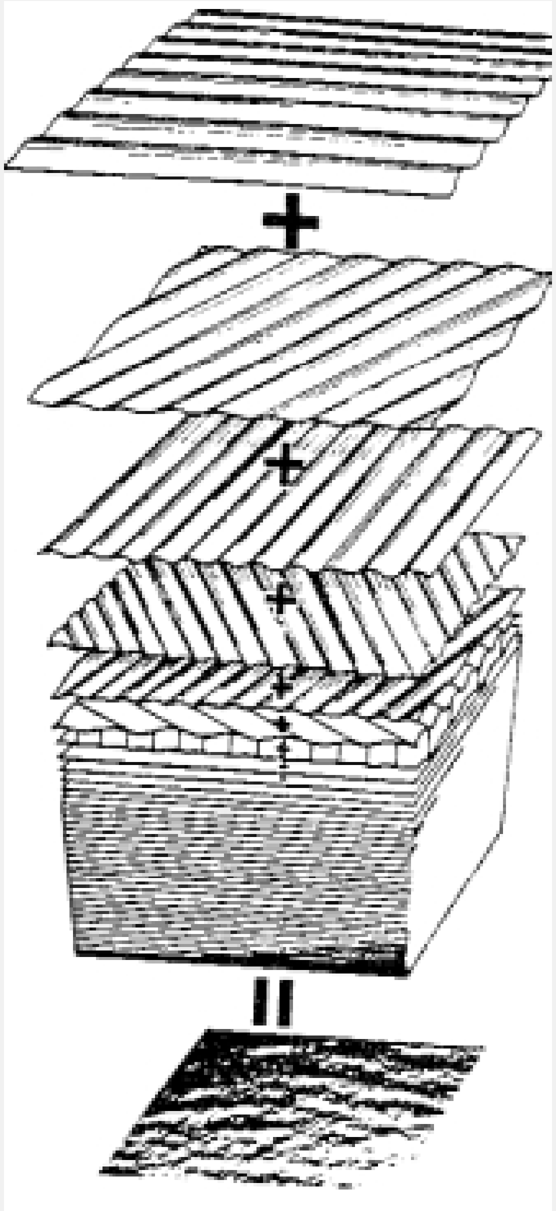
May 1, 2013

February 5, 2014

A Wave Record
Individual Waves,
Significant Wave Height, H_s,
Maximum Individual Wave Height, H_{max}



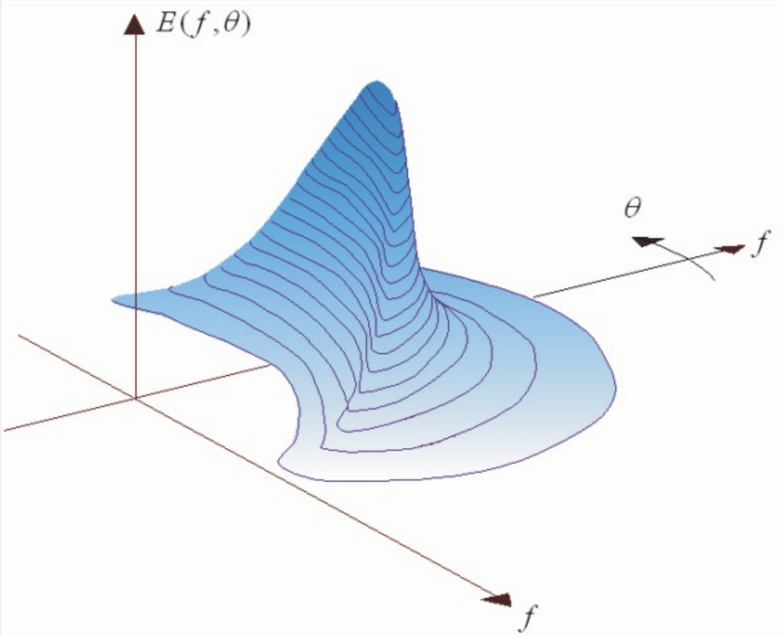
Surface elevation time series from platform Draupner in the North Sea



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, θ).

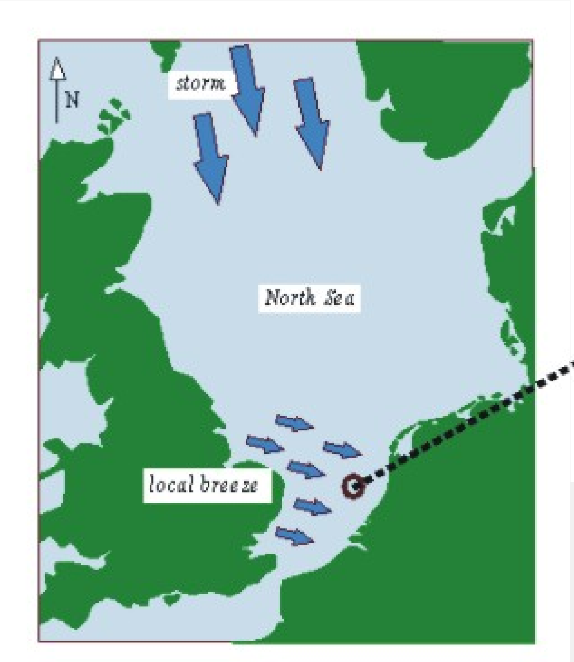


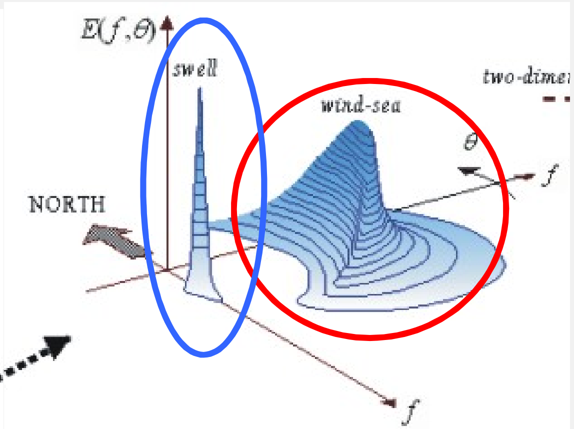
Modern ocean wave prediction systems are based on statistical description of oceans waves (i.e. ensemble average of individual waves).

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.

Ocean Wave Modelling

- The 2-D spectrum follows from the energy balance equation (in its simplest form: deep water case):

$$\frac{\partial F}{\partial t} + \vec{V}_g \cdot \nabla F = S_{in} + S_{nl} + S_{diss}$$

Where the group velocity V_g is derived from the dispersion relationship which relates frequency and wave number.

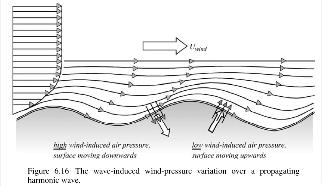


Figure 6.16 The wave-induced wind-pressure variation over a propagating harmonic wave.

the wave grows by this mechanism, the mechanism become the wave can therefore grow faster, which in turn makes the m effective, etc.

S_{in}: wind input source term (generation).

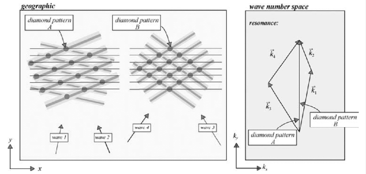


Figure 6.20 *Quadruplet* wave–wave interactions (realisable in deep water). Two pairs of wave components can create two diamond patterns with identical wave lengths and directions and therefore identical wave numbers. When the four waves are superimposed (not shown here), they can thus resonate. The wave-number vectors of the four wave components are shown in the right-hand panel in wave-number space with $\vec{k}_1 + \vec{k}_2 = \vec{k}_3 + \vec{k}_4$.

S_{nl}: non-linear 4-wave interaction (redistribution).

S_{diss}: dissipation term due to whitecapping (dissipation).

Ocean Wave Modelling

- Once you know the wave spectrum F, any other sea state parameters can be estimated. For example, the mean variance of the sea surface elevation η due to waves is given by:

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

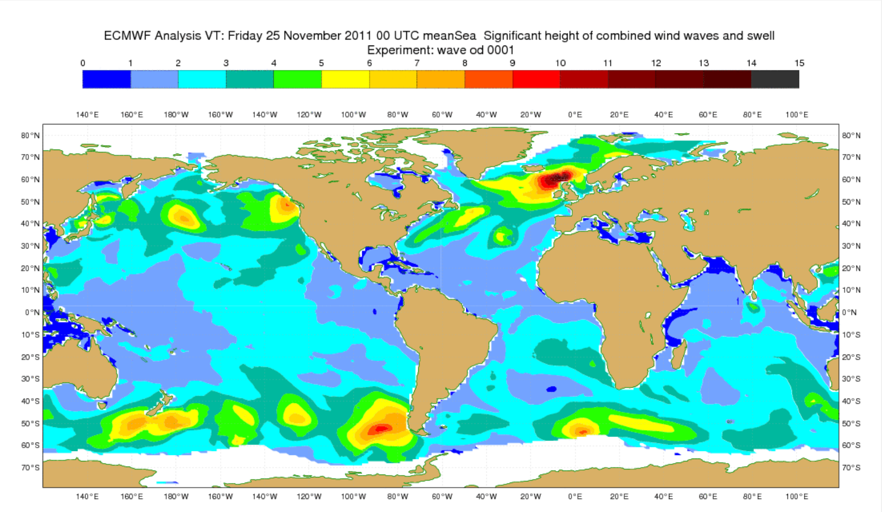
- The statistical measure for wave height, called the significant wave height (H_s):

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

The term significant wave height is historical as this value appeared to be well correlated with visual estimates of wave height from experienced observers.

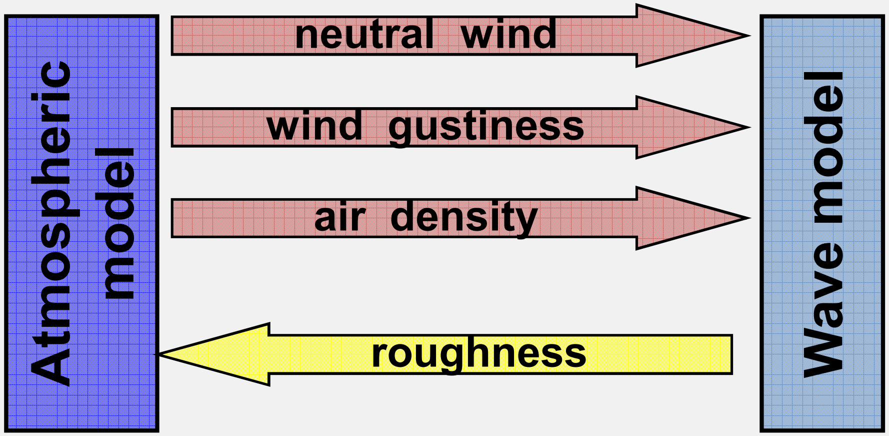
It can be shown to correspond to the average 1/3rd highest waves ($H_{1/3}$).

ECMWF Wave Model Configurations



Global from 81°S to 90°N

Coupled to the atmospheric model with feedback of the sea **surface roughness** change due to waves.



The interface between WAM and the IFS has been generalised to include air density and gustiness effects on wave growth.

ECMWF Wave Model Configurations

High resolution

- 28 km grid spacing.
- 36 frequencies.
- 36 directions.
- Coupled to the TL1279 model.

- Analysis every 6 hrs and 10 day forecasts from 0 and 12 UTC.

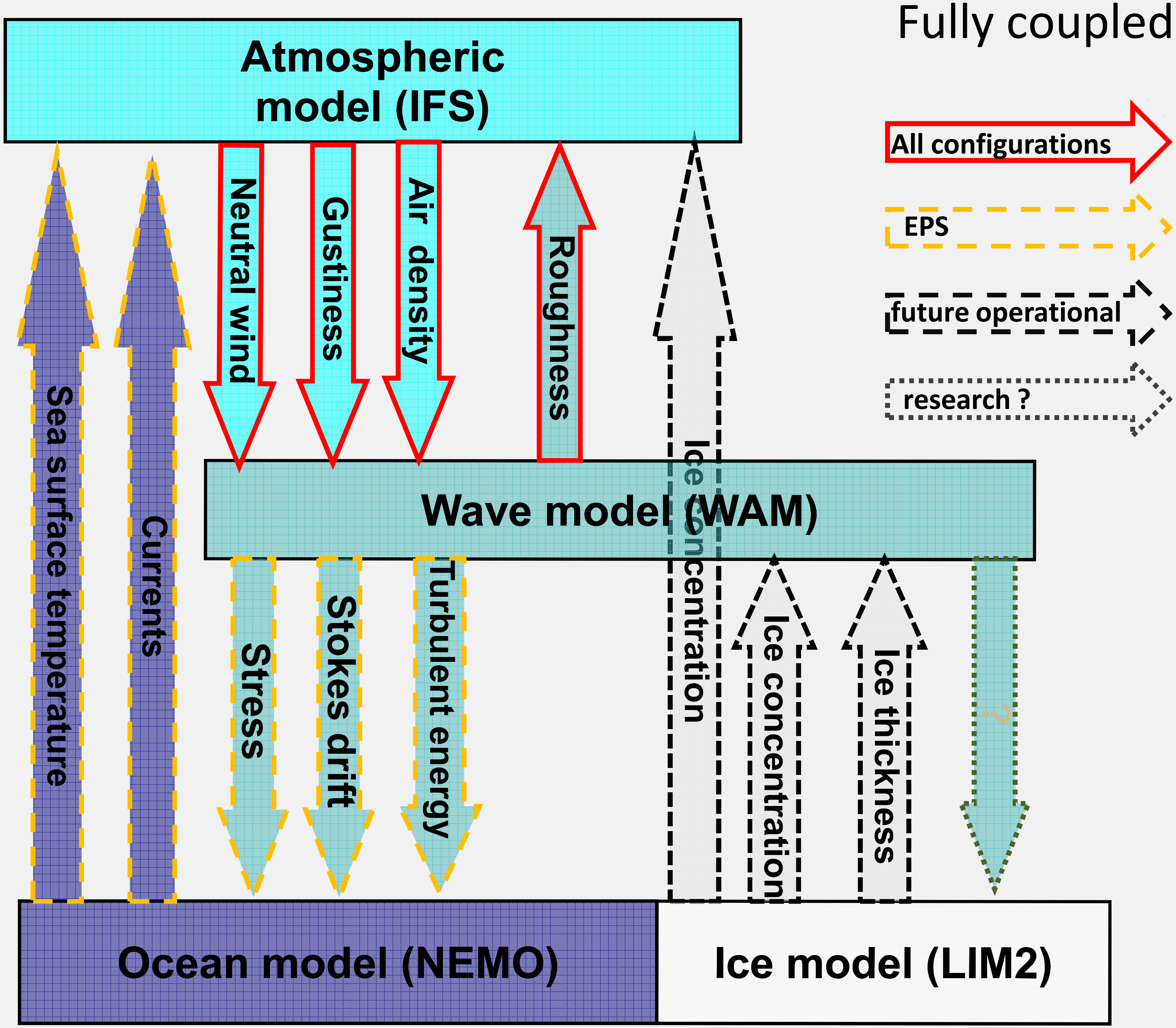
Ensemble forecasts (EPS)

- 55 km grid spacing.
- 30→ 25 frequencies *.
- 24 → 12 directions *.
- Coupled to TL639 → TL319 model *.
- (50+1) (10+5) day forecasts from 0 and 12Z (monthly twice a week).
- **Coupled to ocean model**.

* Change in resolutions after 10 days

NB: also in seasonal forecast at lower resolutions

Fully coupled system?

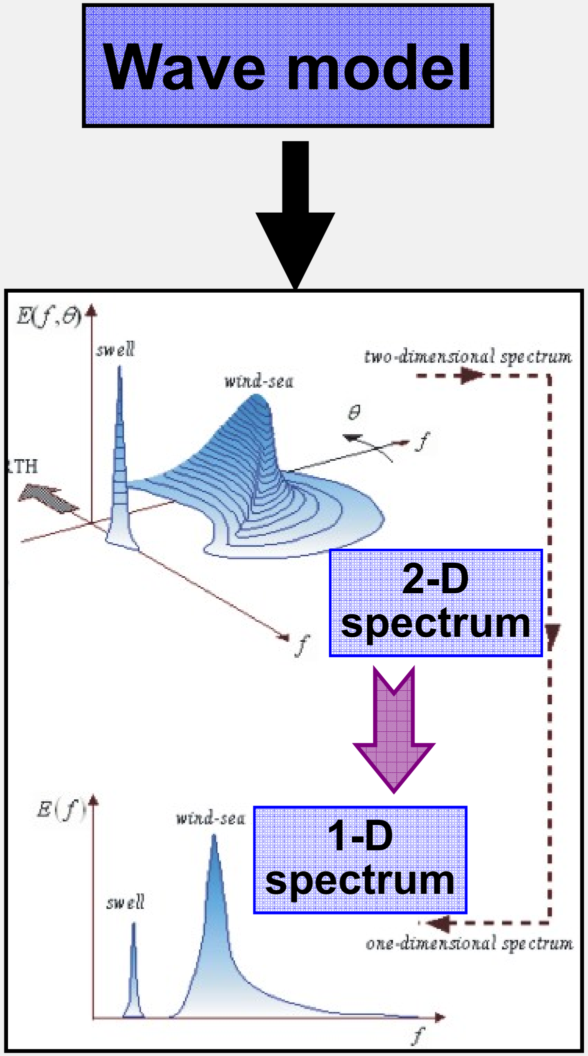


Wave Model Products

The complete description of the sea state is given by the 2-D spectrum, however, it is a fairly large amount of data *(e.g. 1296 values at each grid point in the global model (36x36)*.

It is therefore reduced to integrated quantities:

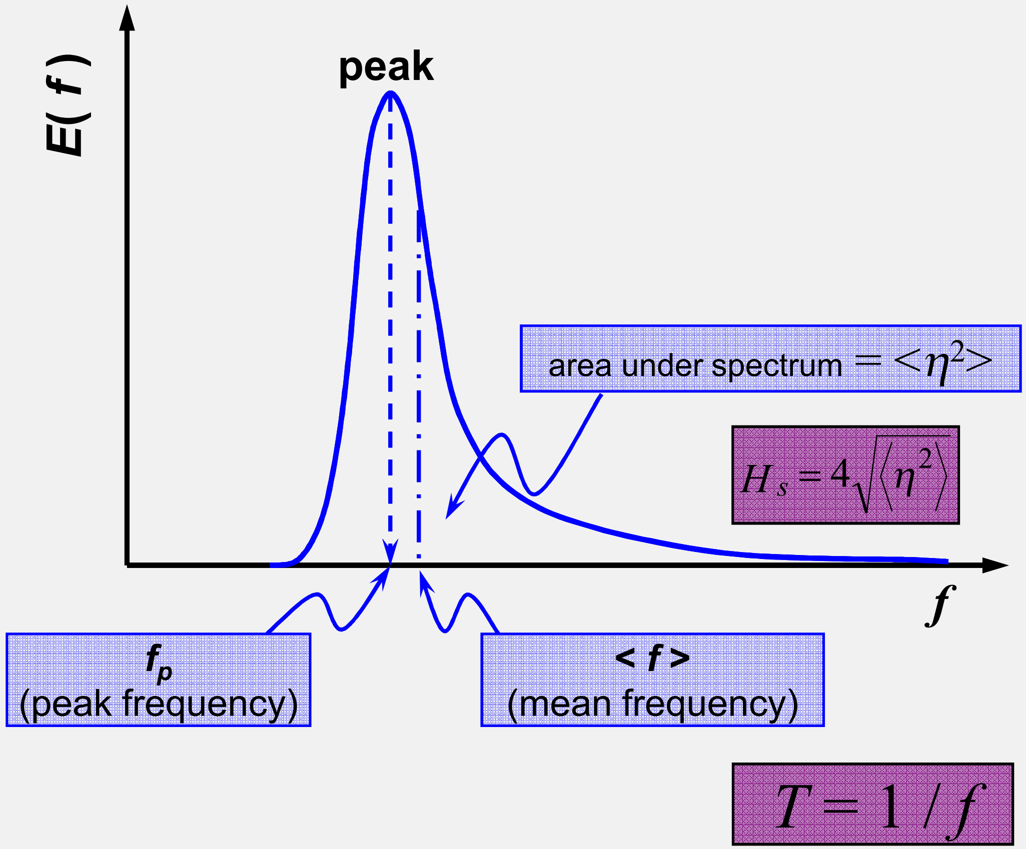
- 1-D spectrum obtained by integrating the 2-D spectrum over all directions and/or over a frequency range.



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.
- *Few others.*

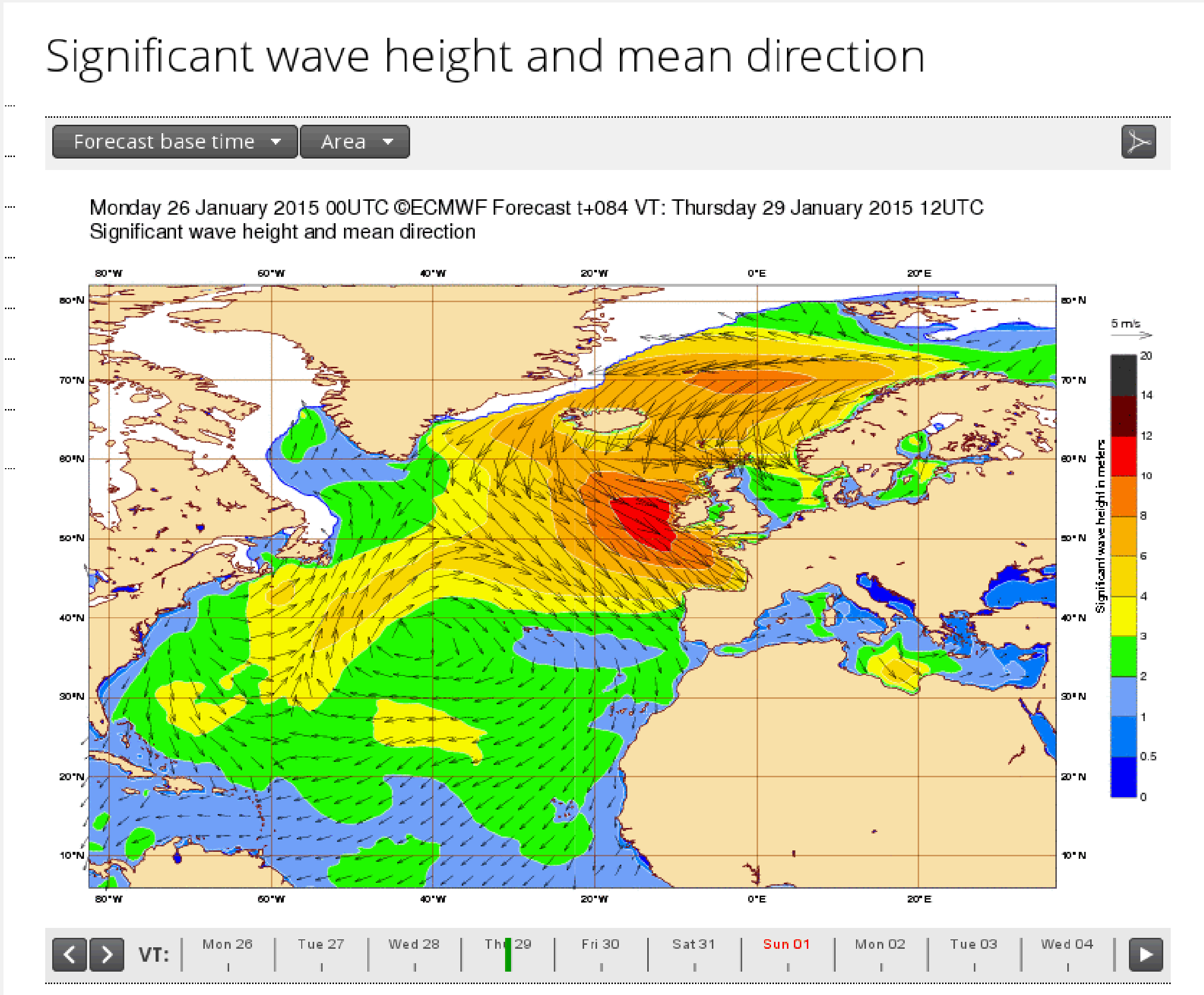


Complete list at: http://www.ecmwf.int/services/archive/d/parameters/order=/table=140/

Wave model deterministic products on the web

Wave products available <u>by default</u> on the centre's web pages: (Home -> Forecasts -> Charts -> Ocean Waves :

http://www.ecmwf.int/en/forecasts/charts/catalogue?f[0]=im_field_chart_type%3A481&f[1]=im_field_parameters%3A539



Ocean wave forecasts

At the end of December 2013 and beginning of January 2014, the UK and western Europe were battered by large waves:

Ocean wave forecasts

Then again in February and early March:

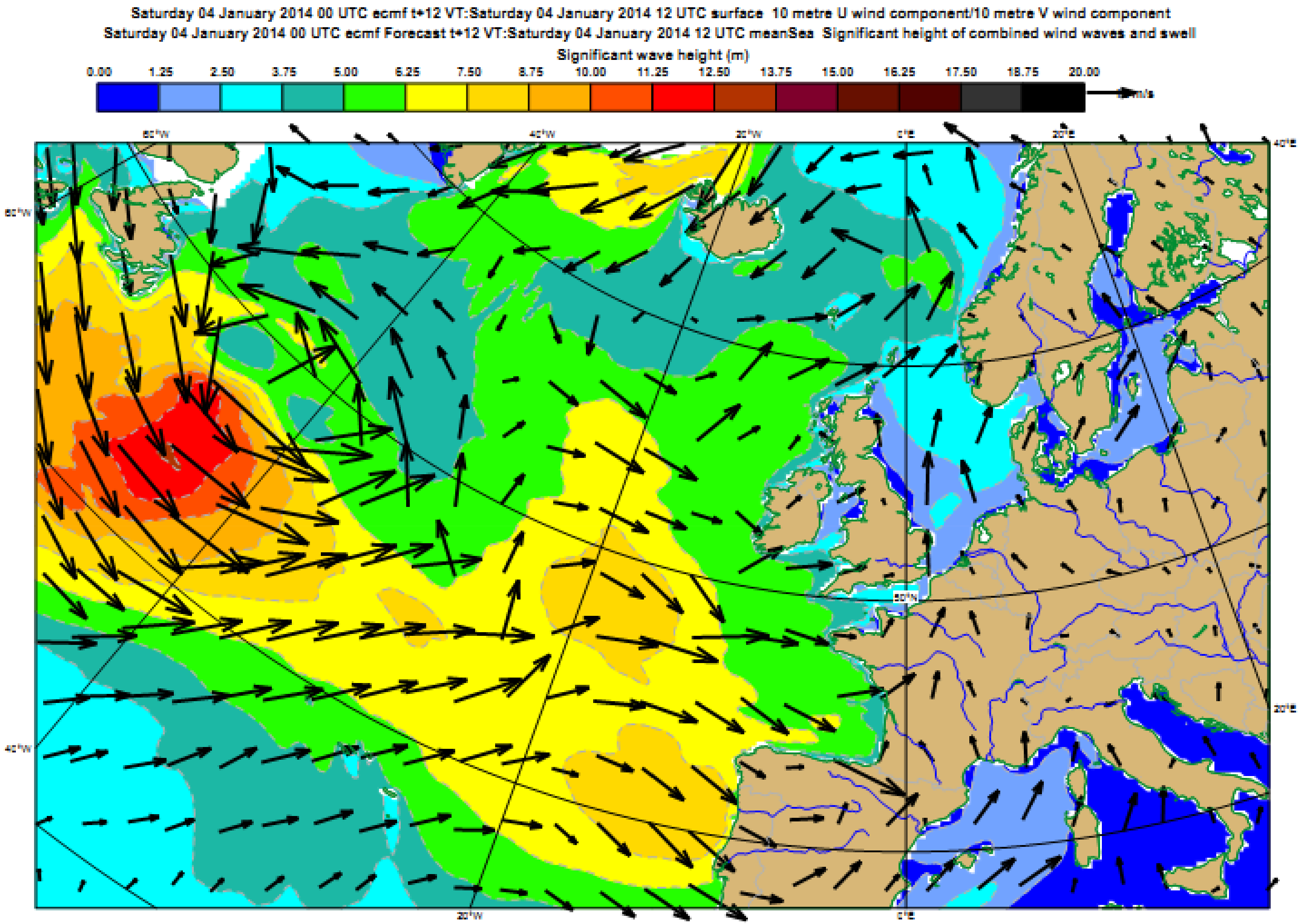
Porthleven Clock Tower, Cornwall

May 1, 2013

February 5, 2014

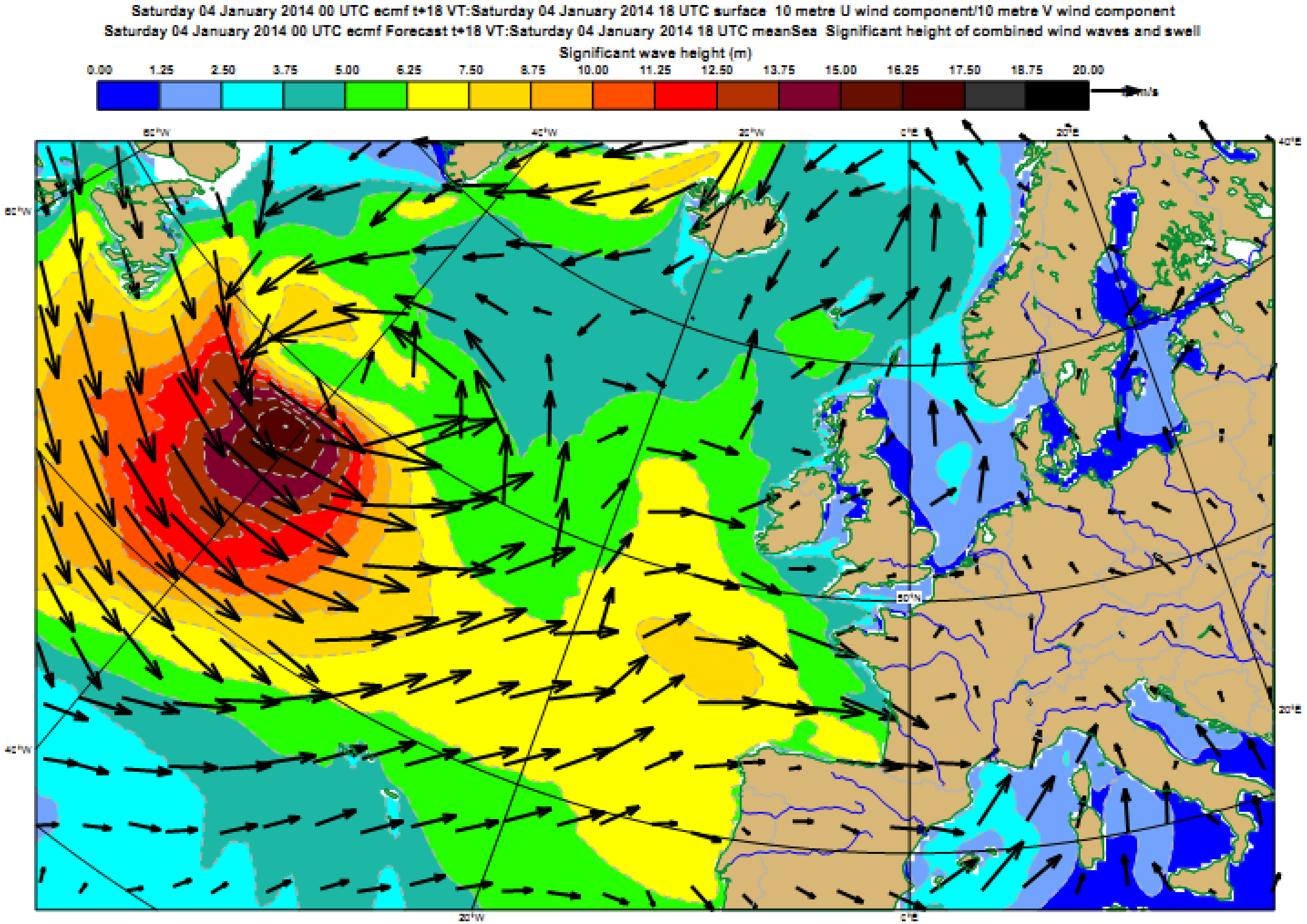
Ocean wave forecasts

Wave height forecast and wind from 4 January 2014, step 12 hours



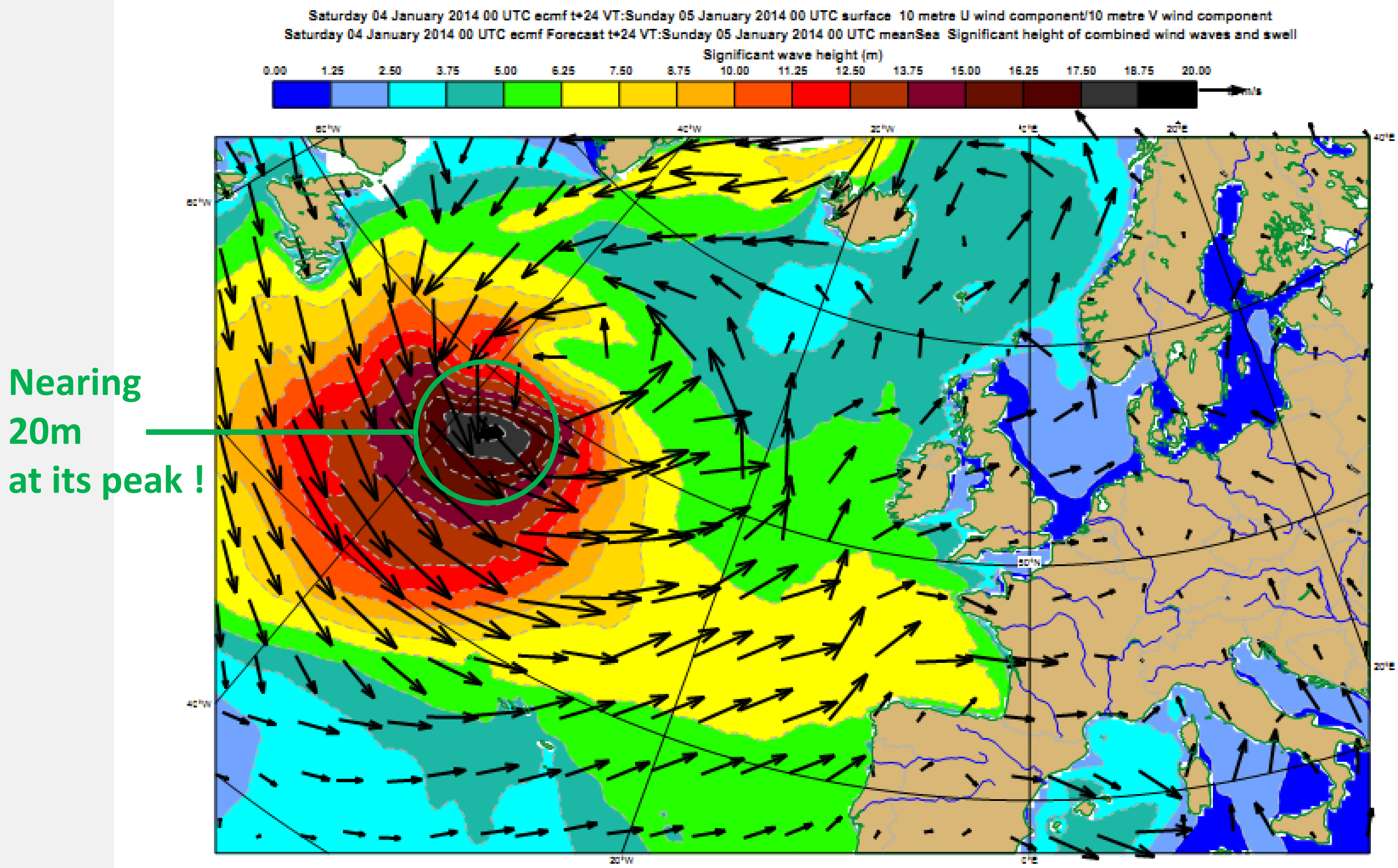
Ocean wave forecasts

Wave height forecast and wind from 4 January 2014, step 18 hours



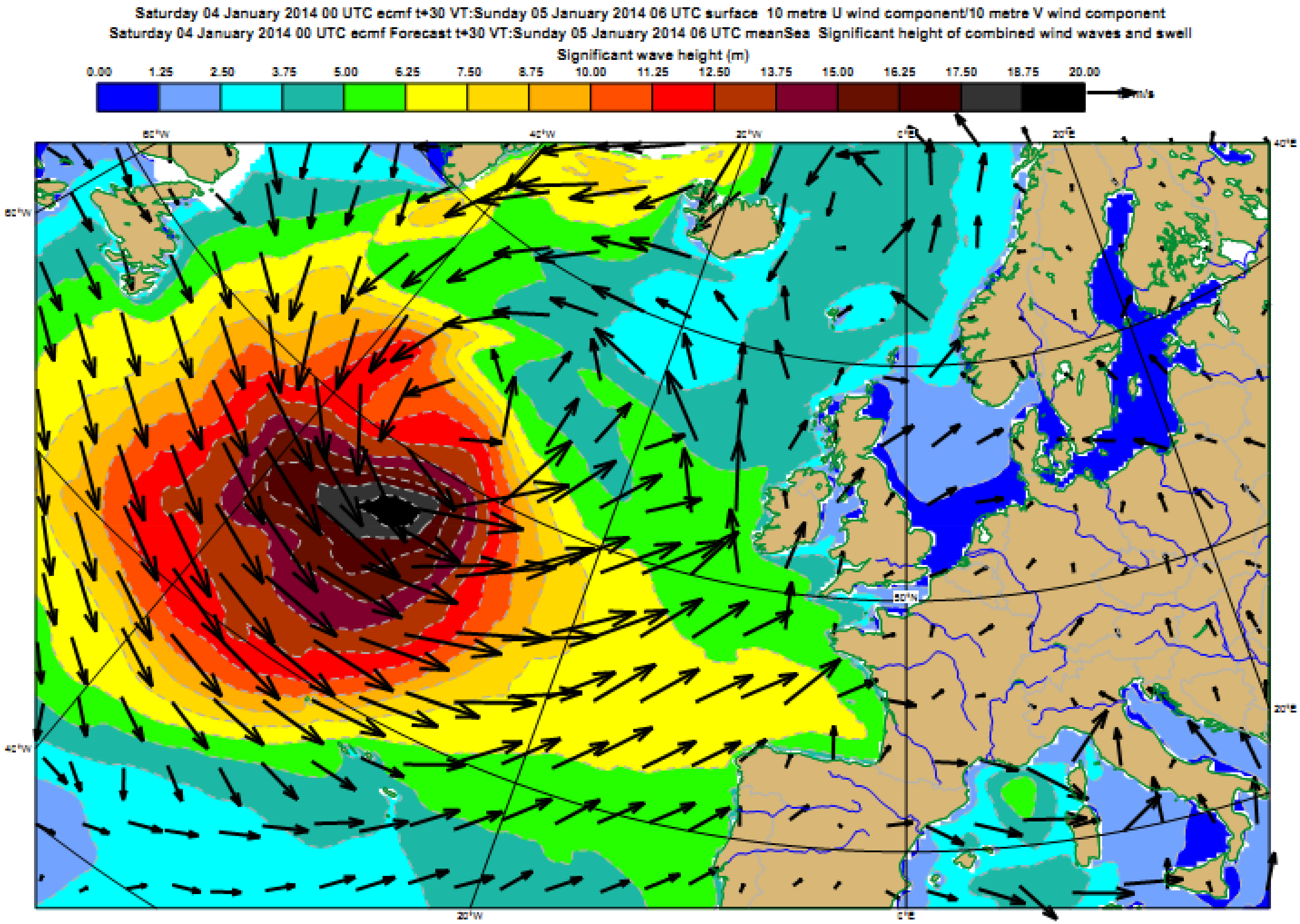
Ocean wave forecasts

Wave height forecast and wind from 4 January 2014, step 24 hours



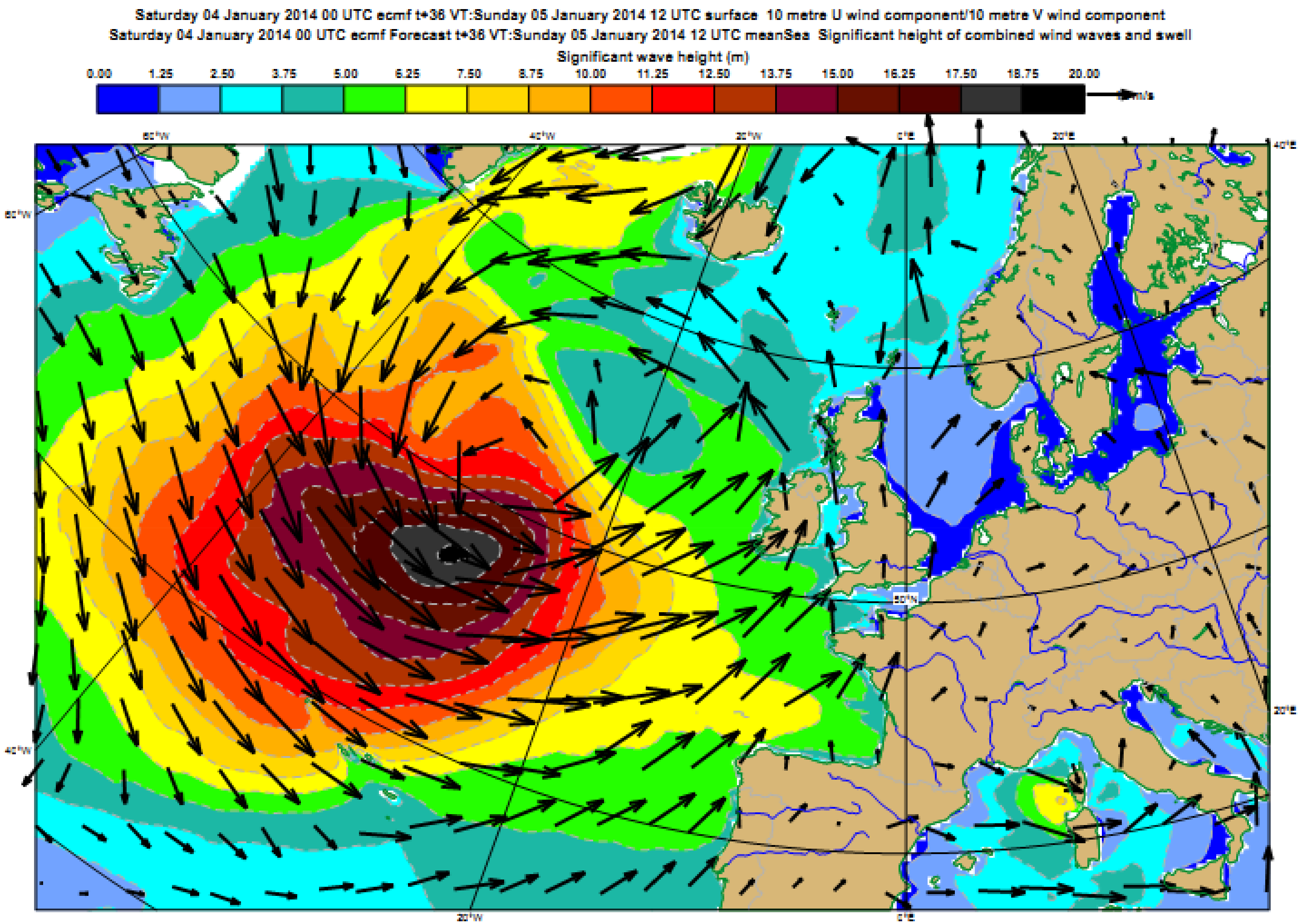
Ocean wave forecasts

Wave height forecast and wind from 4 January 2014, step 30 hours



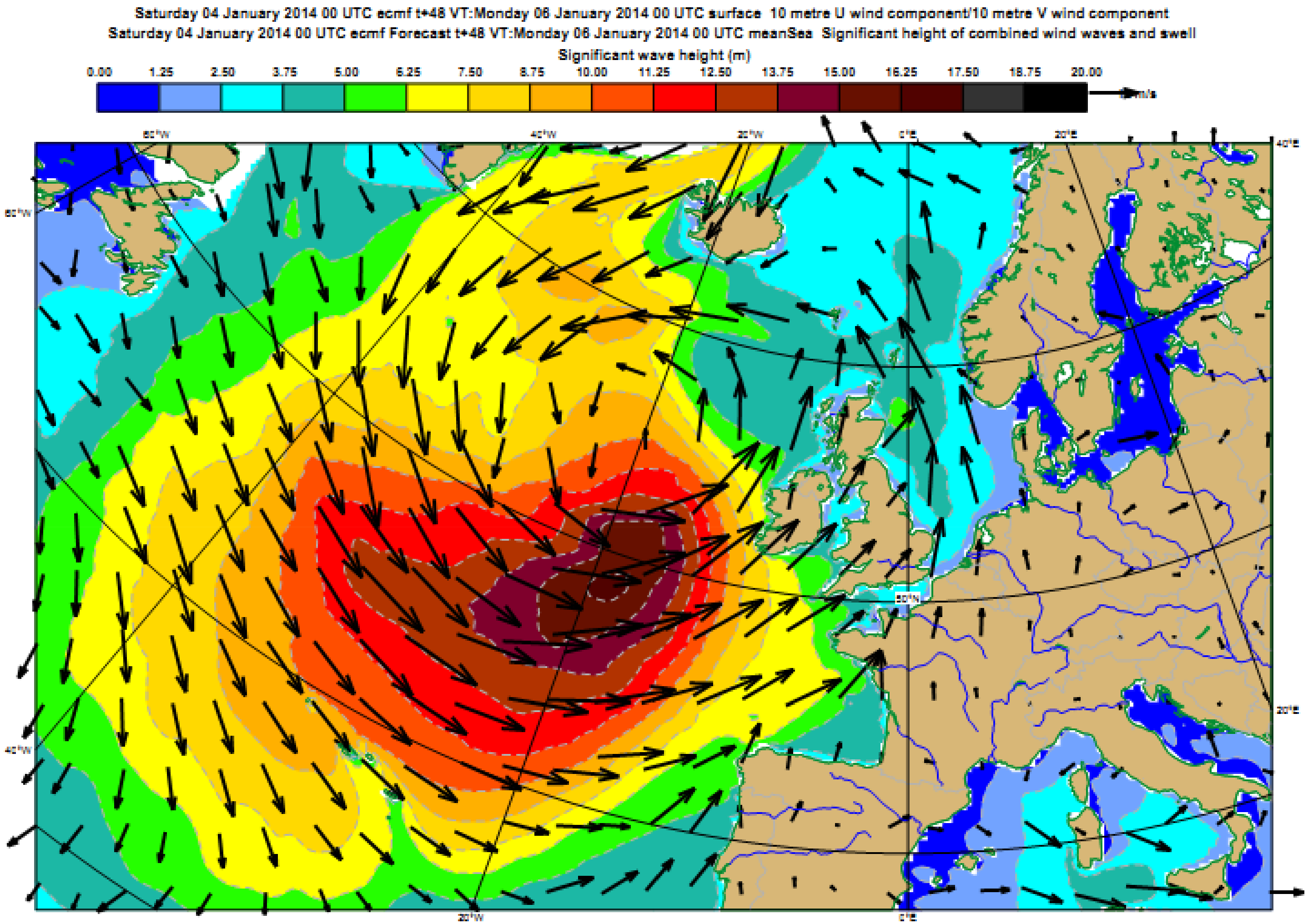
Ocean wave forecasts

Wave height forecast and wind from 4 January 2014, step 36 hours



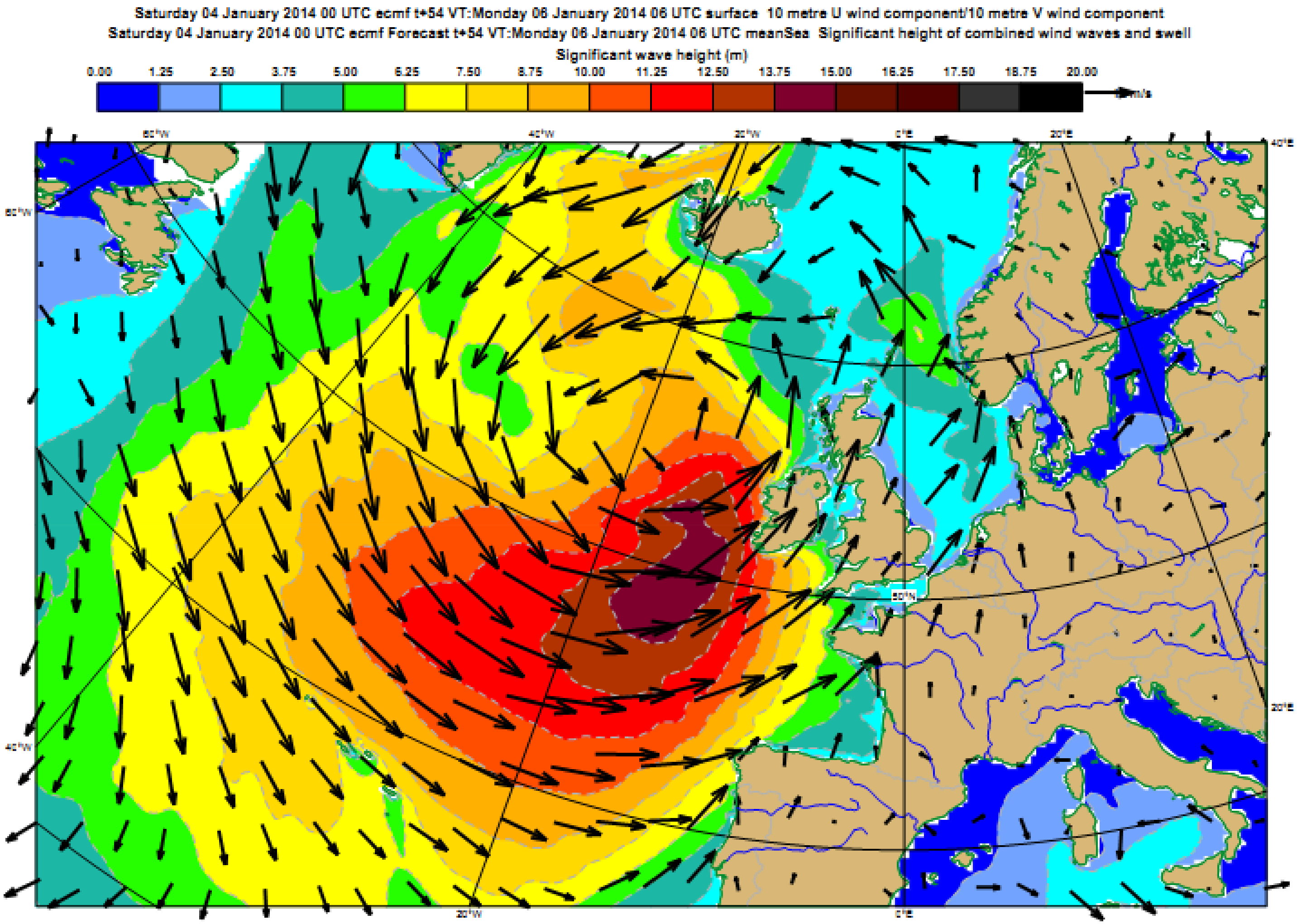
Ocean wave forecasts

Wave height forecast and wind from 4 January 2014, step 48 hours



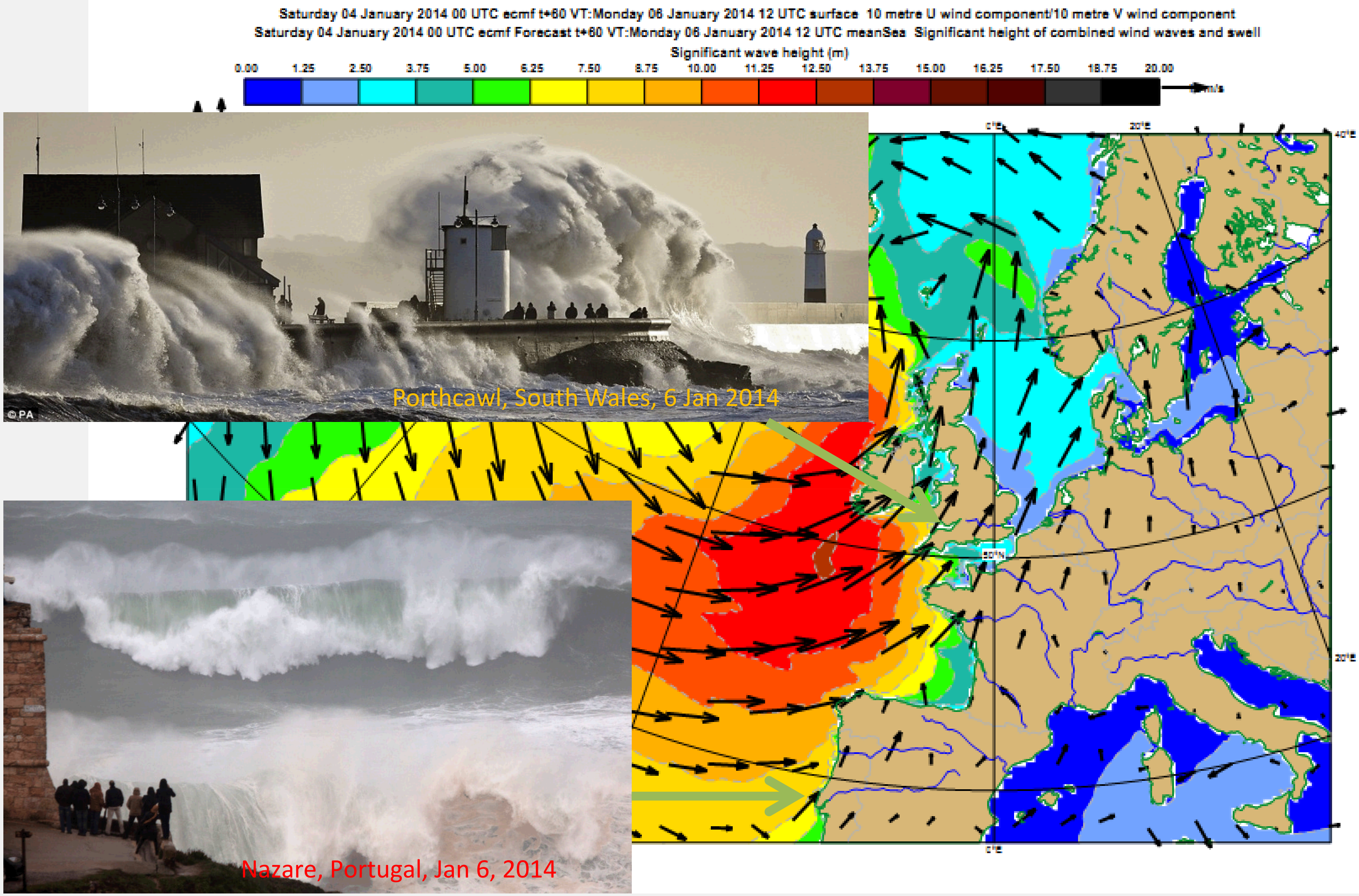
Ocean wave forecasts

Wave height forecast and wind from 4 January 2014, step 54 hours



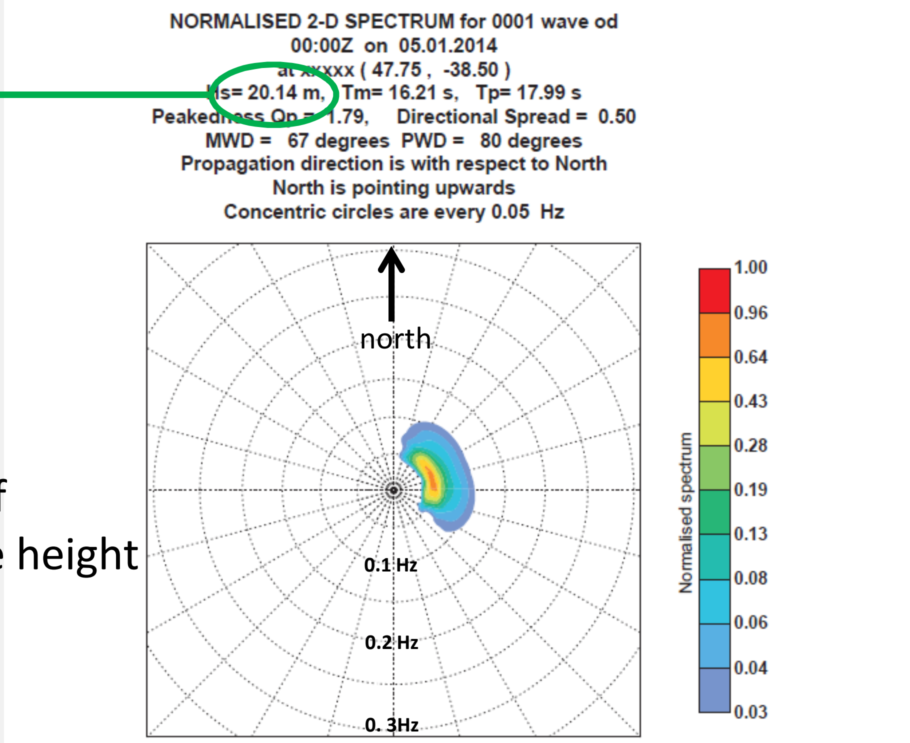
Ocean wave forecasts

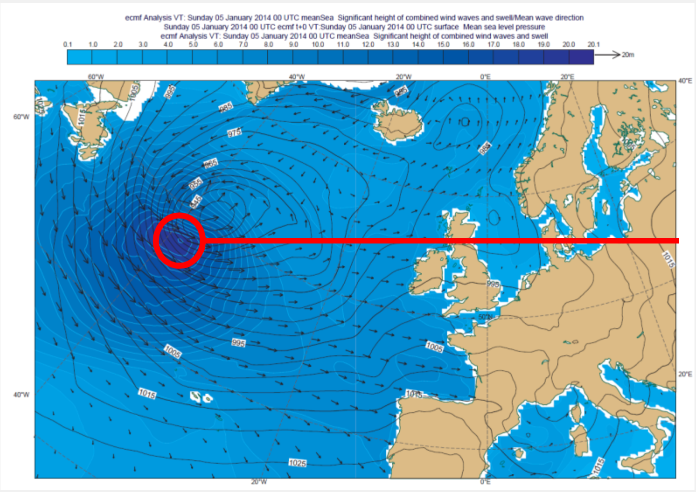
Wave height forecast and wind from 4 January 2014, step 60 hours



Spectral shape: OK

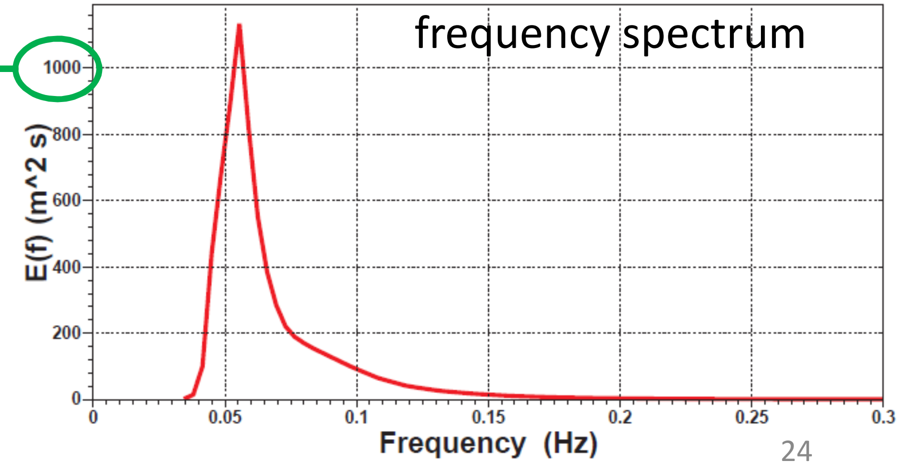
In excess of 20m





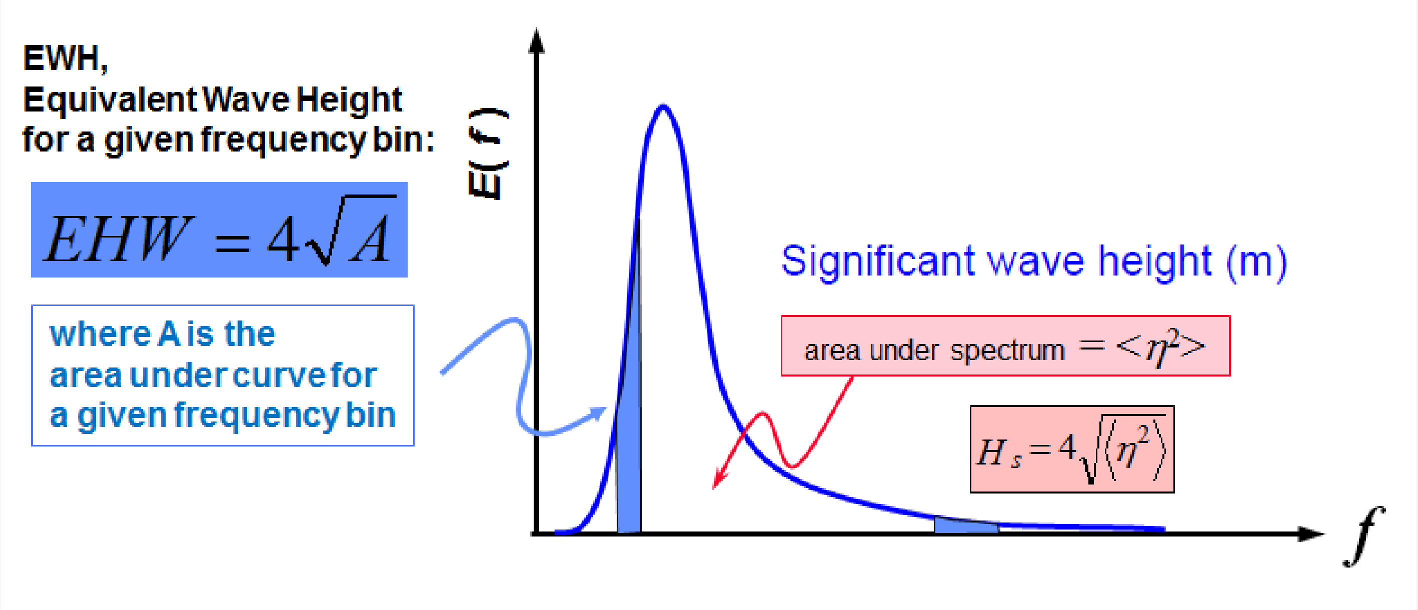
Analysis
at location of
highest wave height

In excess of
$1000\ m^2\ s$



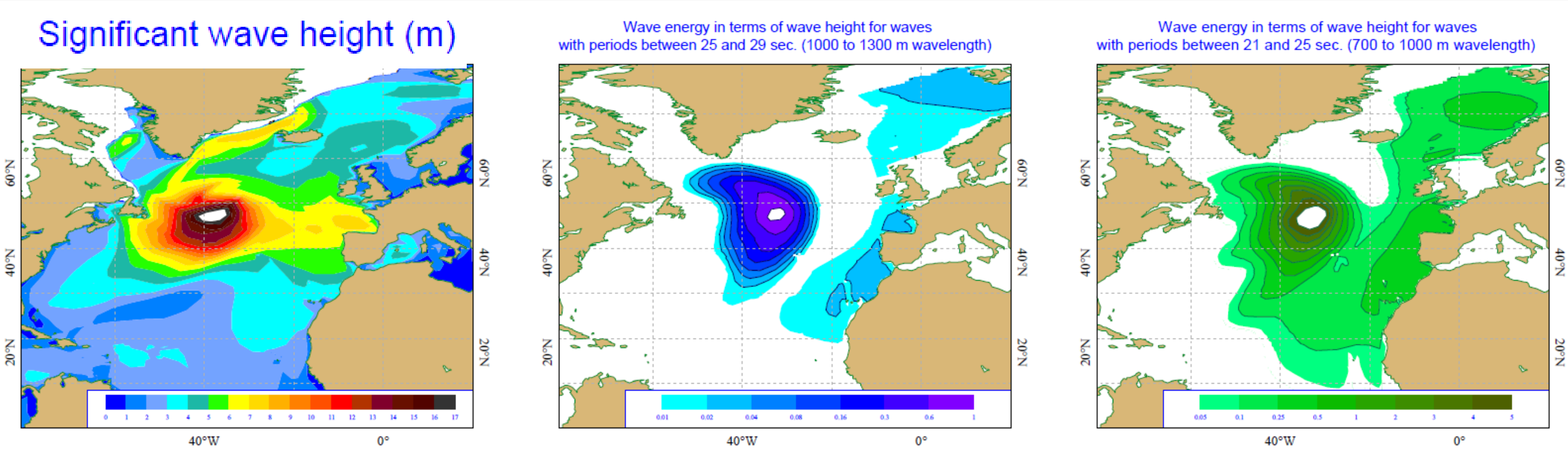
Long swell forecasts

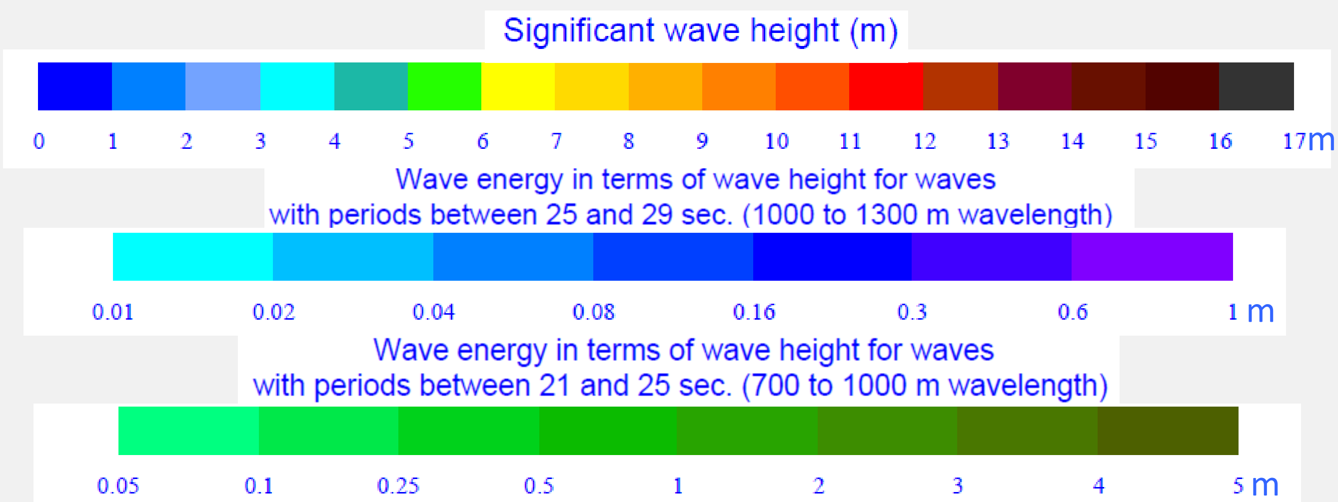
Swell are long waves propagating away from storms.
The wave model predicts the full 2d wave spectrum.
It is possible to follow the evolution of the swell:



Long swell forecasts

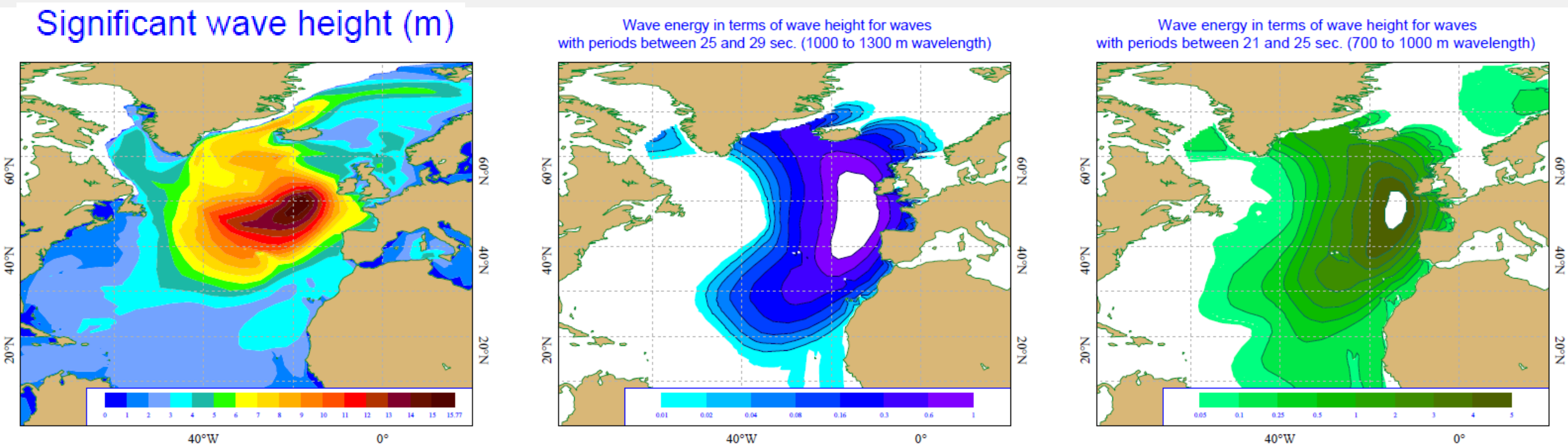
Wave height and long swell forecast from 4 January 2014, step 24

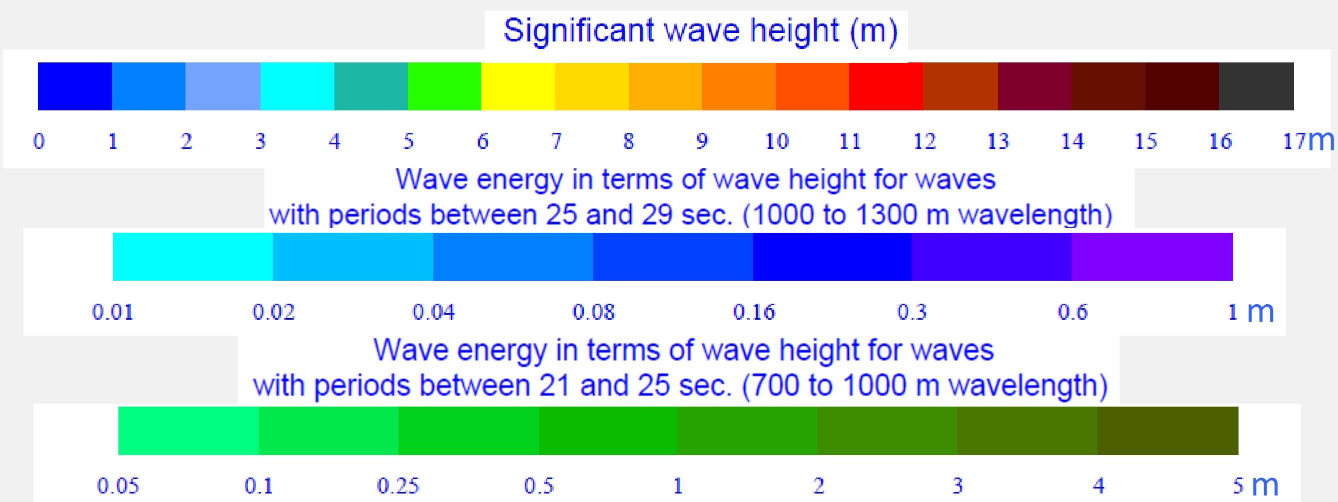




Long swell forecasts

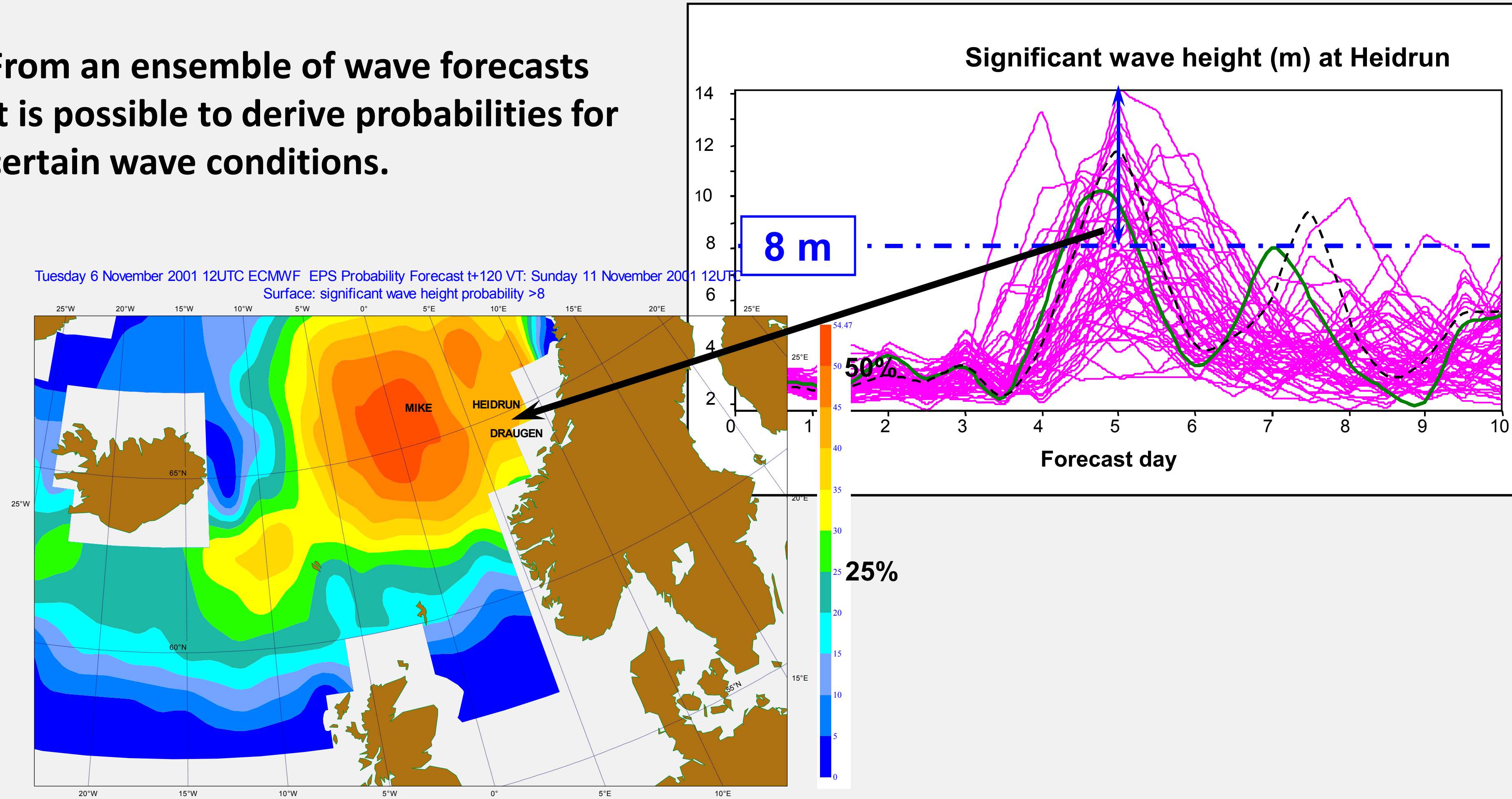
Wave height and long swell forecast from 4 January 2014, step 48





So far, everything has been presented as output from the deterministic forecast system. BUT, forecast should actually be more probabilistic. Nowadays, weather centres rely on ensemble techniques :

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



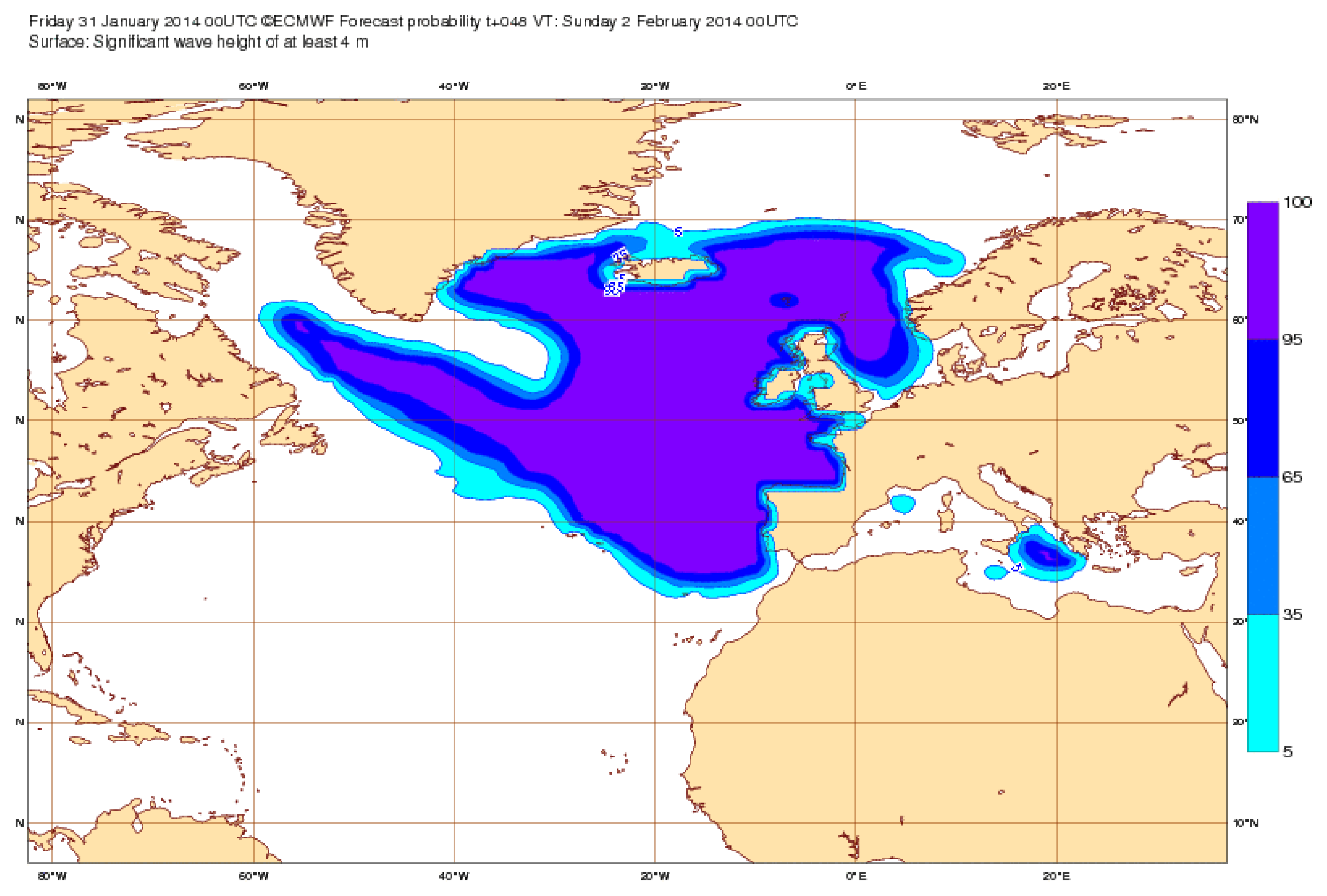
06 Nov. 2001 12 UTC ECMWF EPS probability forecast t+120

Significant wave height above 8 m

ECMWF Newsletter 95 – Autumn 2002

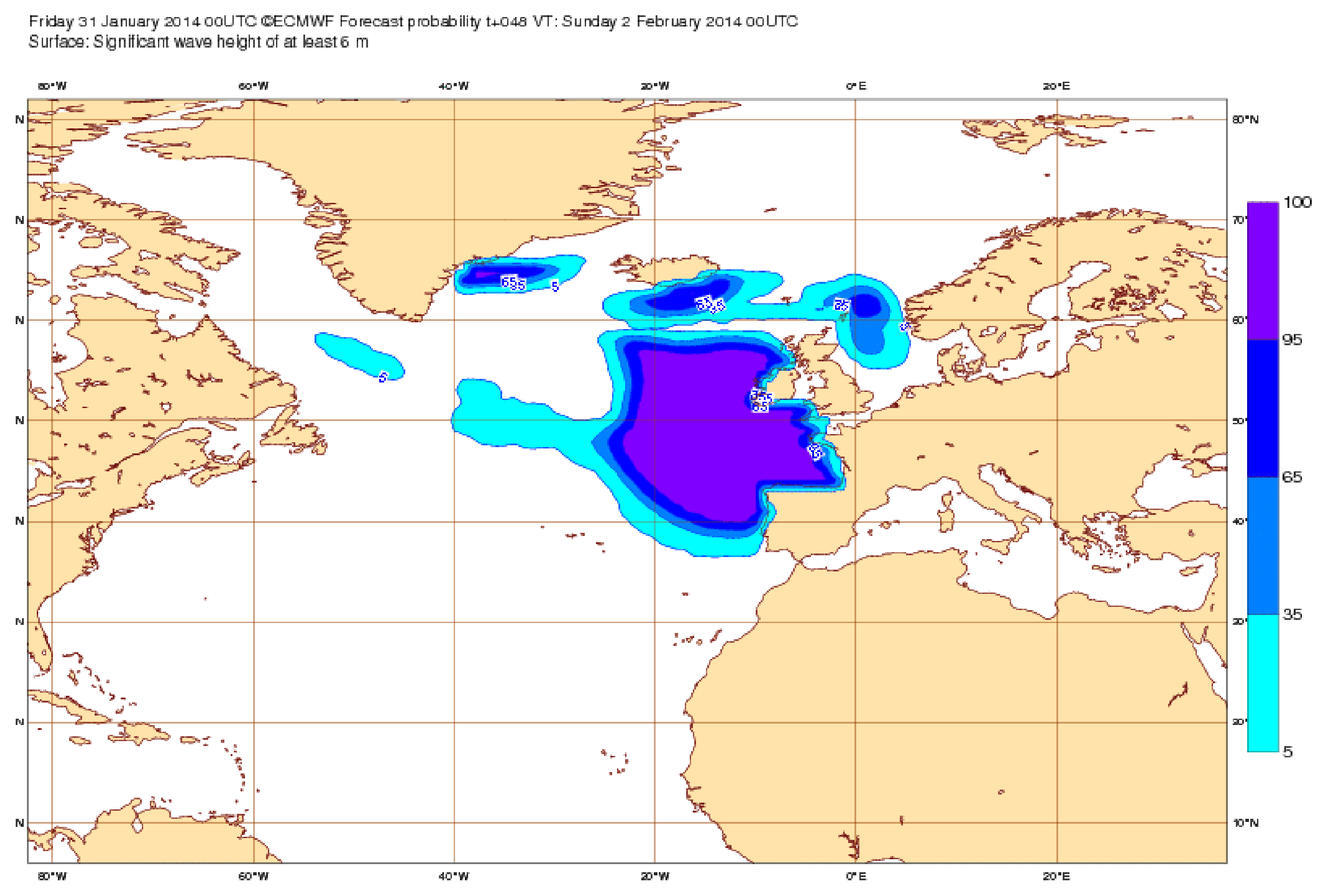
Basic EPS Wave Model Products

probability for set thresholds (4m)



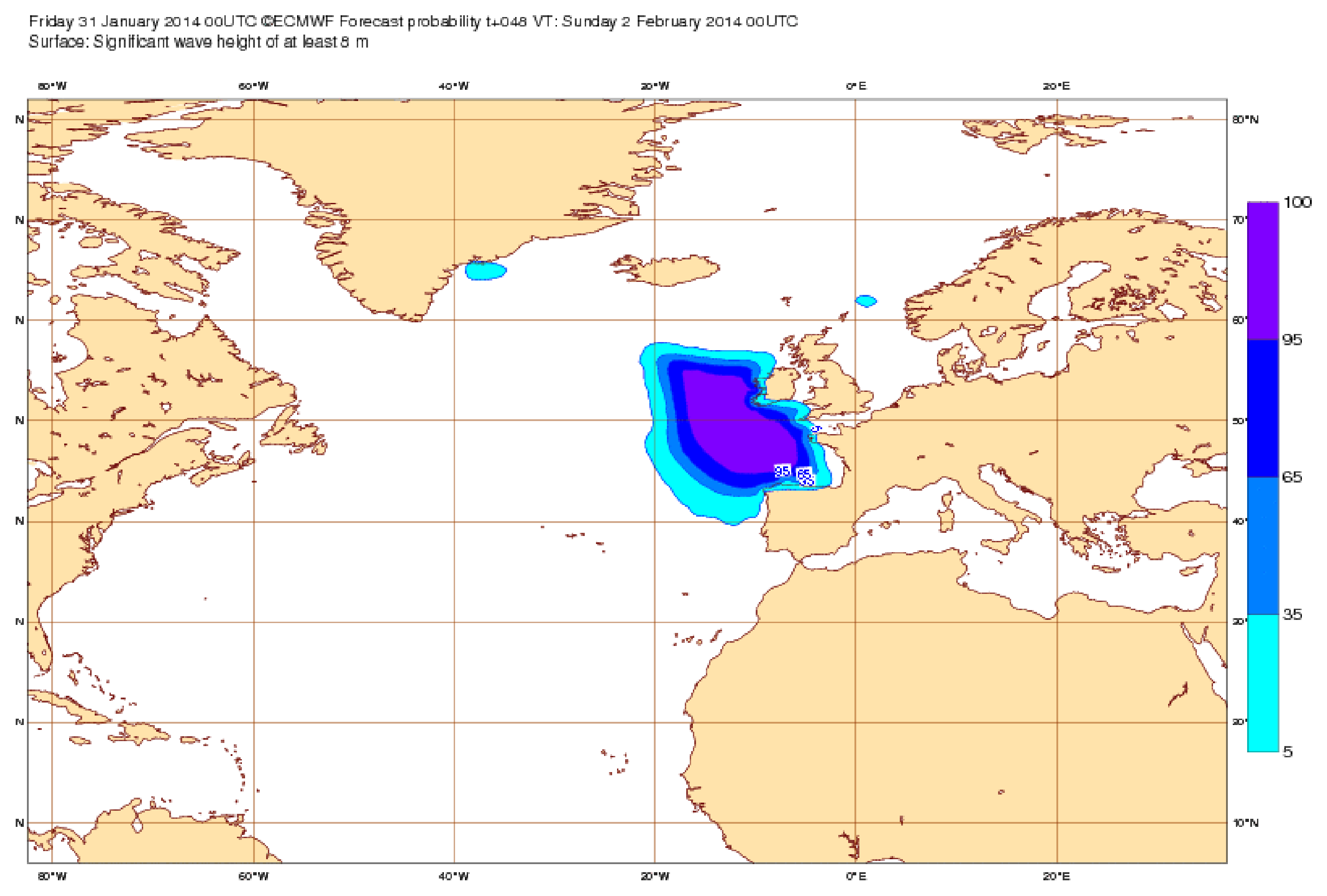
Basic EPS Wave Model Products

probability for set thresholds (6m)



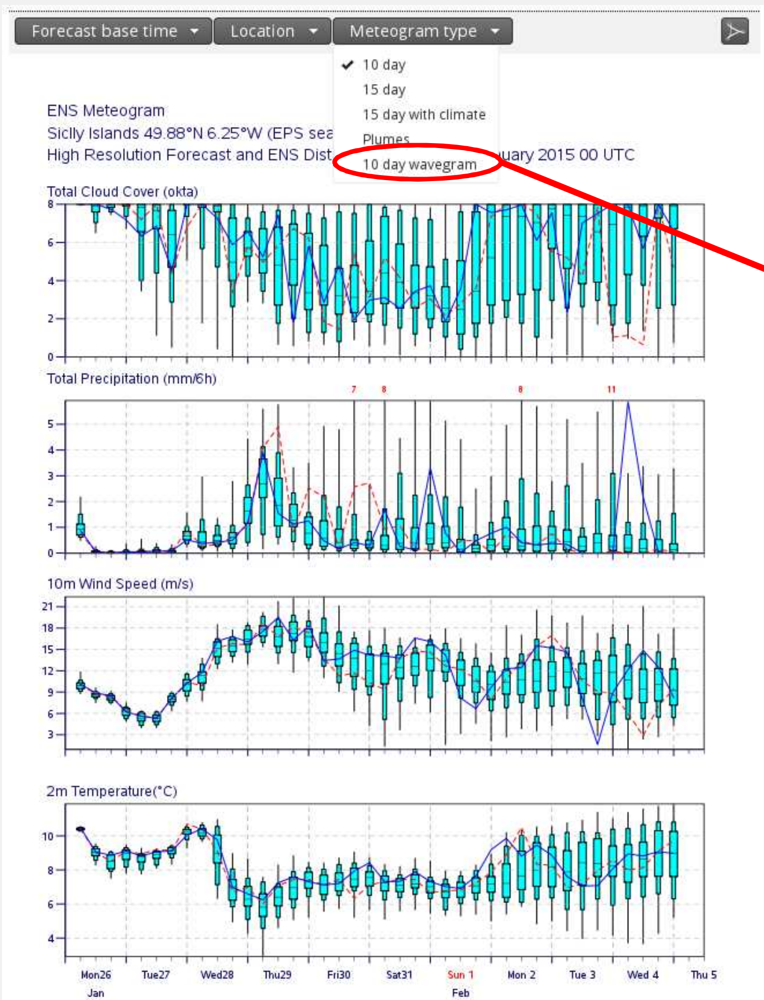
Basic EPS Wave Model Products

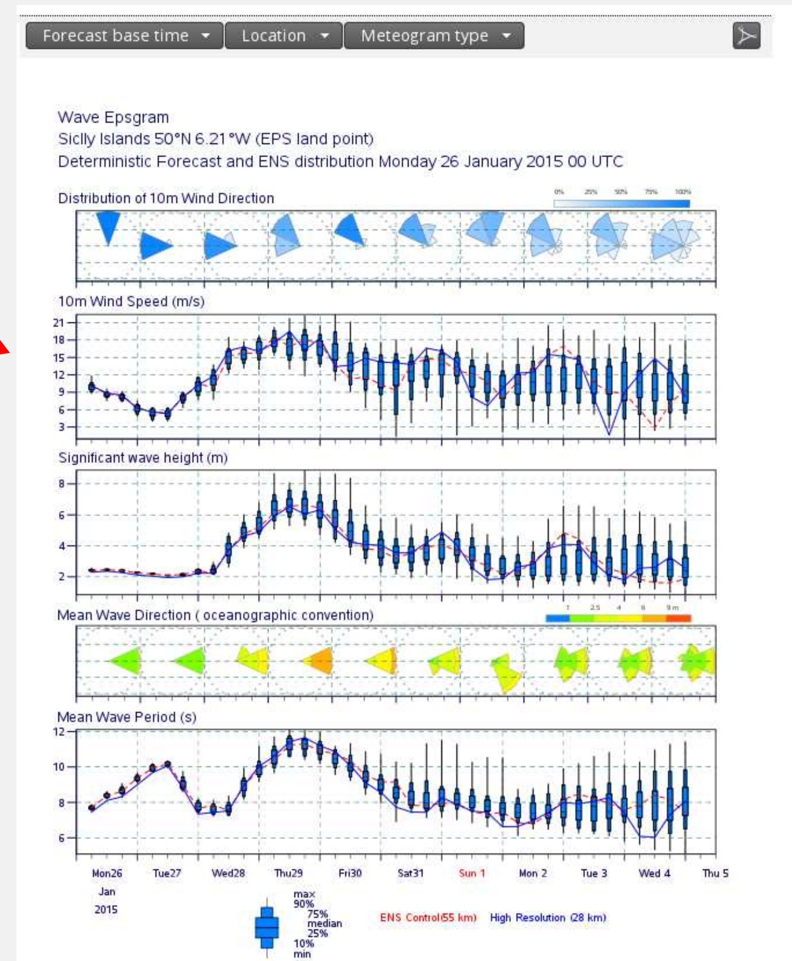
probability for set thresholds (8m)



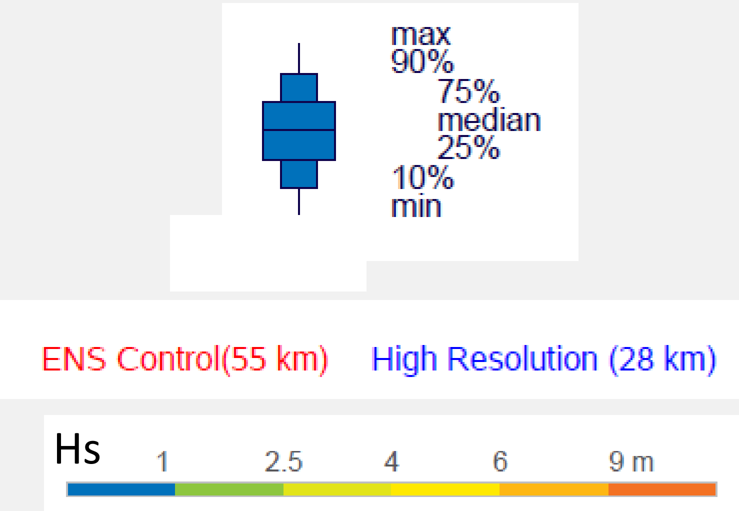
A bit more compact: Wave EPSgram:

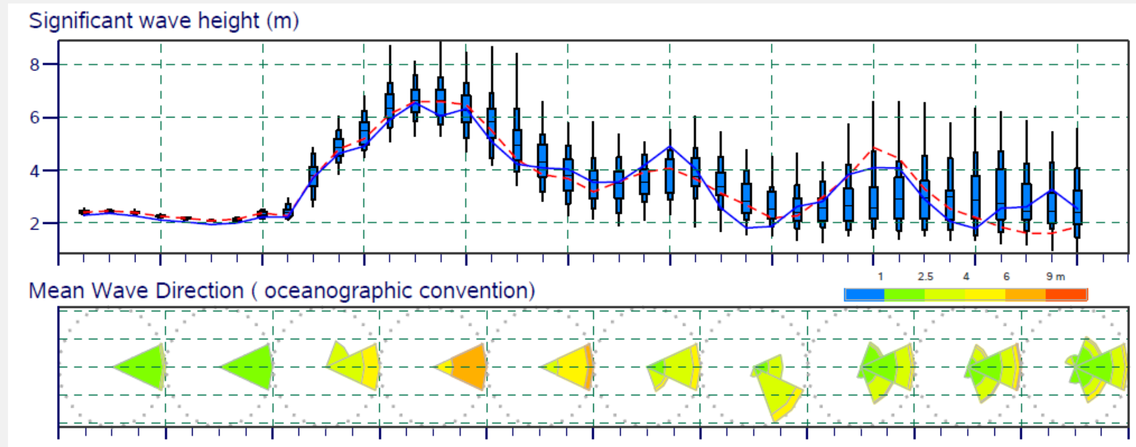
Like normal EPSgram but for
wind direction, wind speed,
significant wave height,
mean wave direction and mean period.

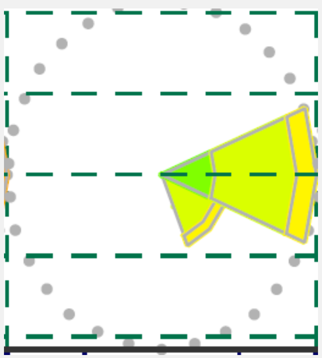




A bit more compact: Wave EPSgram:





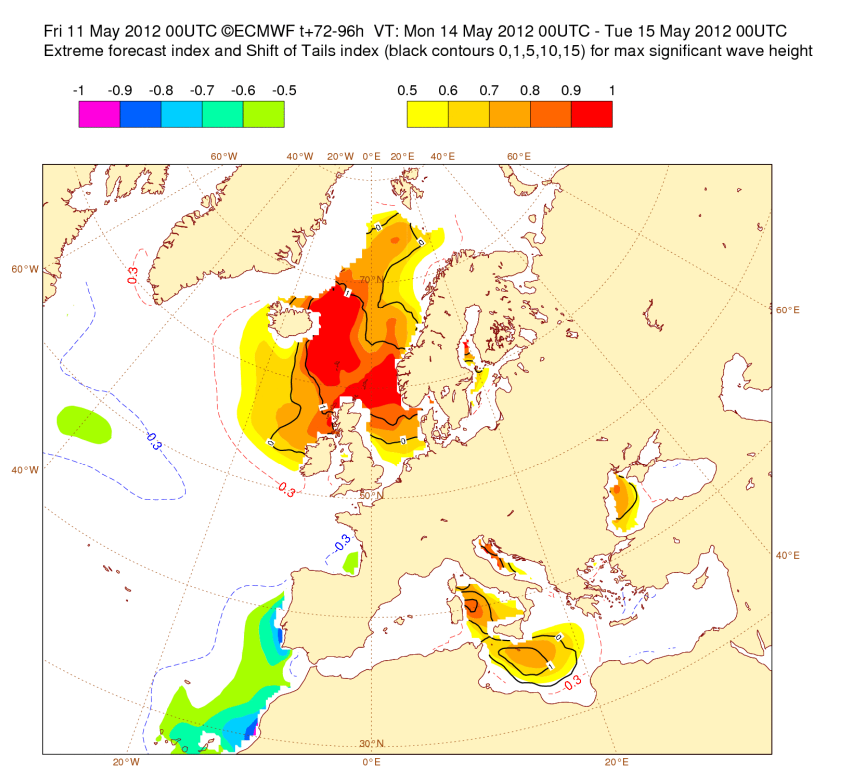


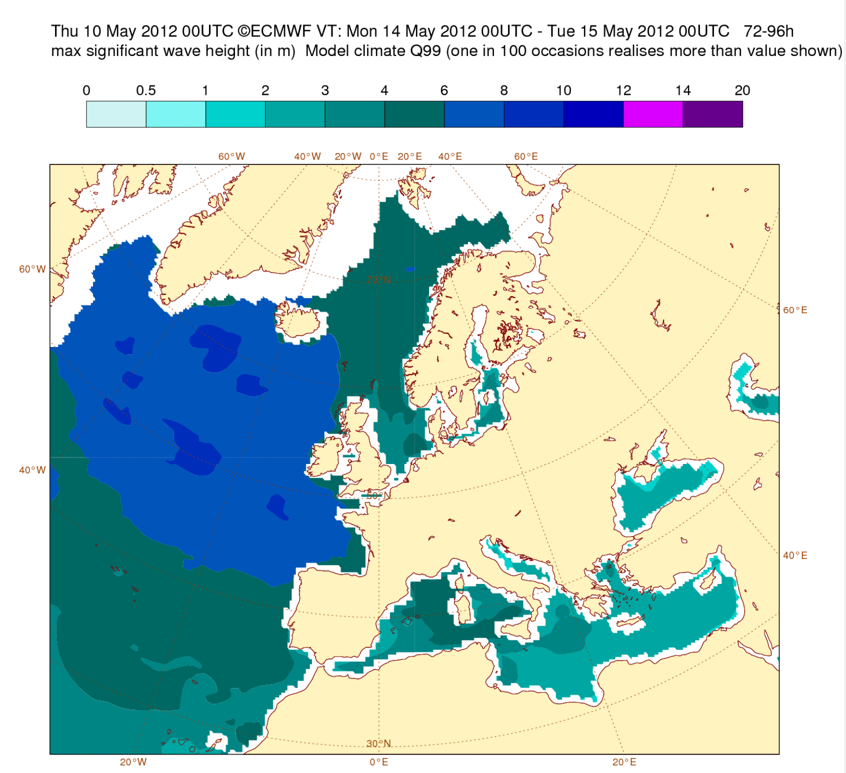
Each octant is coloured based on the distribution of the significant wave height associated with each mean direction. The coloured areas correspond to the fractional number of ensemble members with wave height in the range specified by the coloured ruler.

EFI plots

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 above climate.

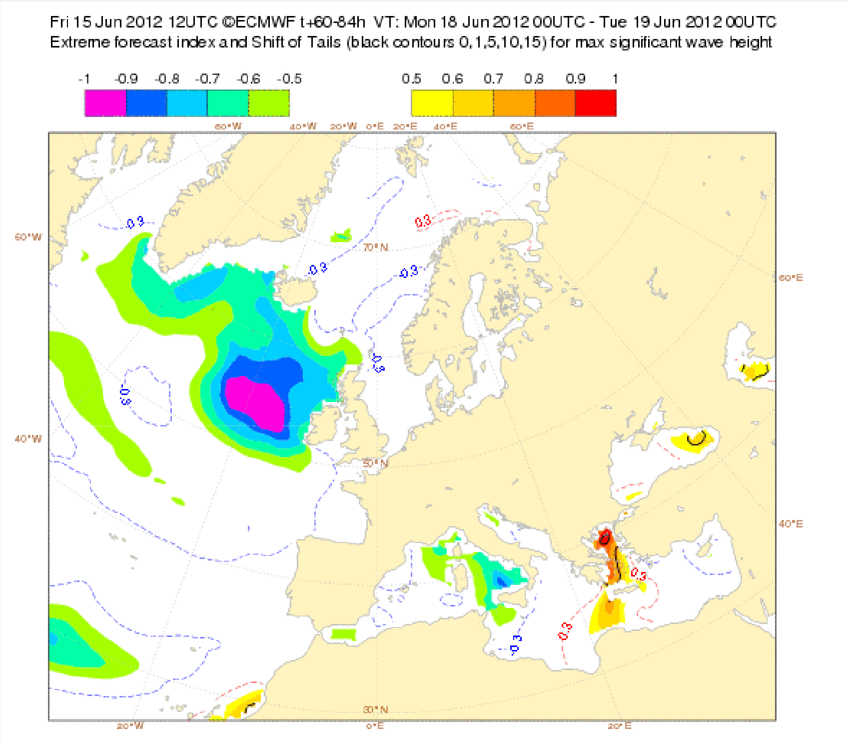


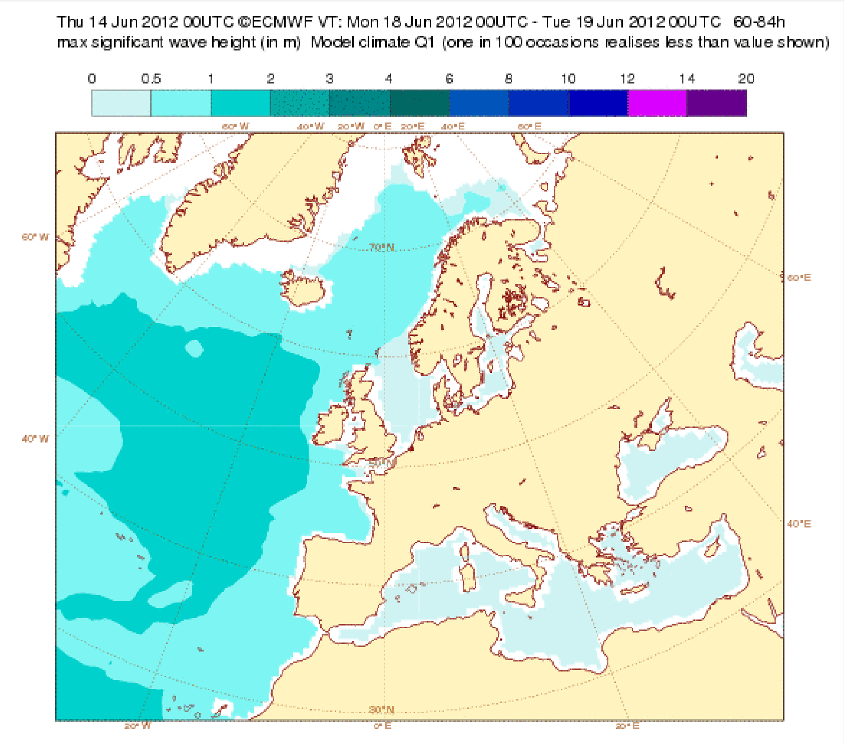


EFI plots

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

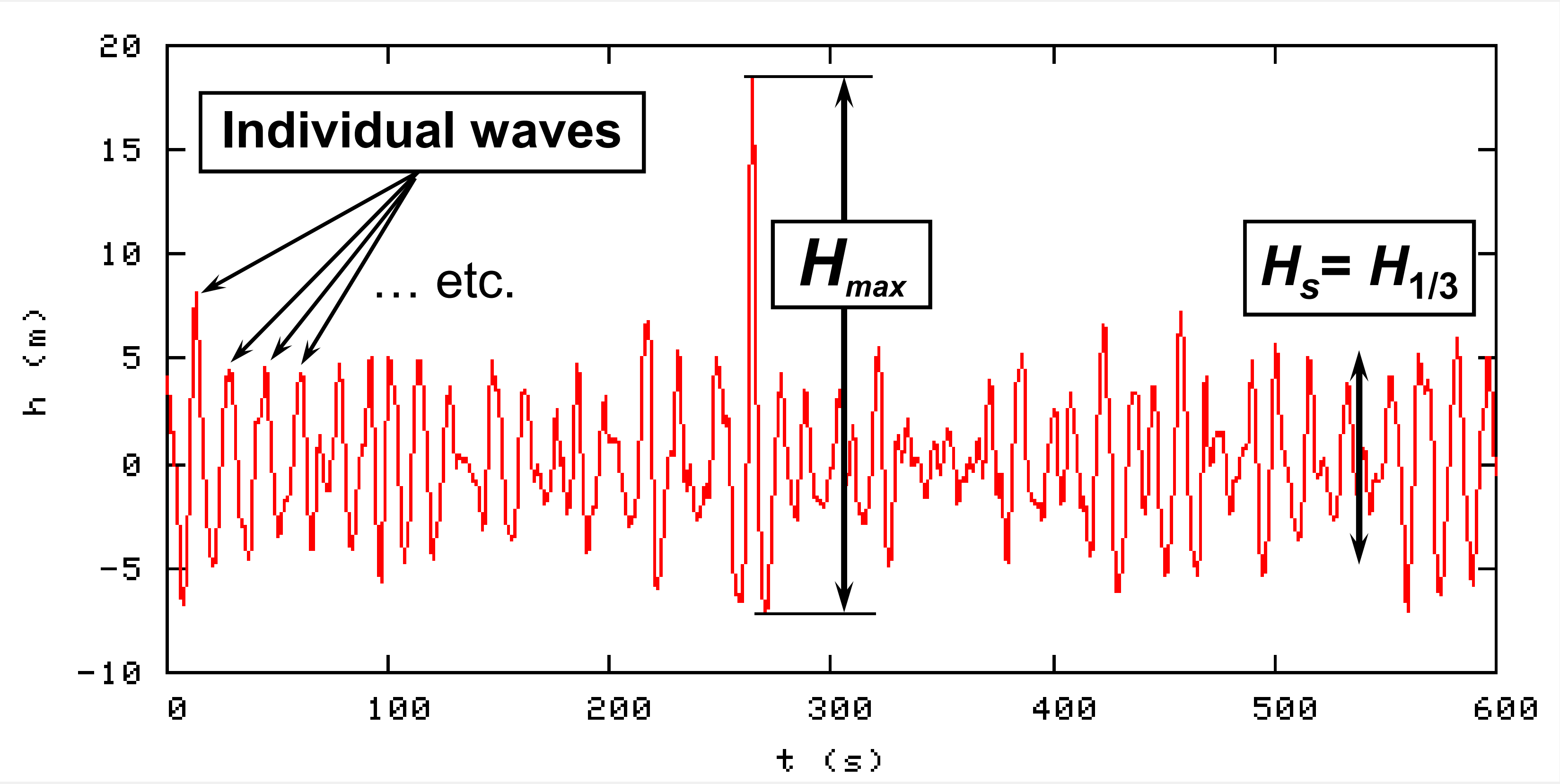
Extreme Forecast Index (EFI): -1 means that all EPS are below climate.





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

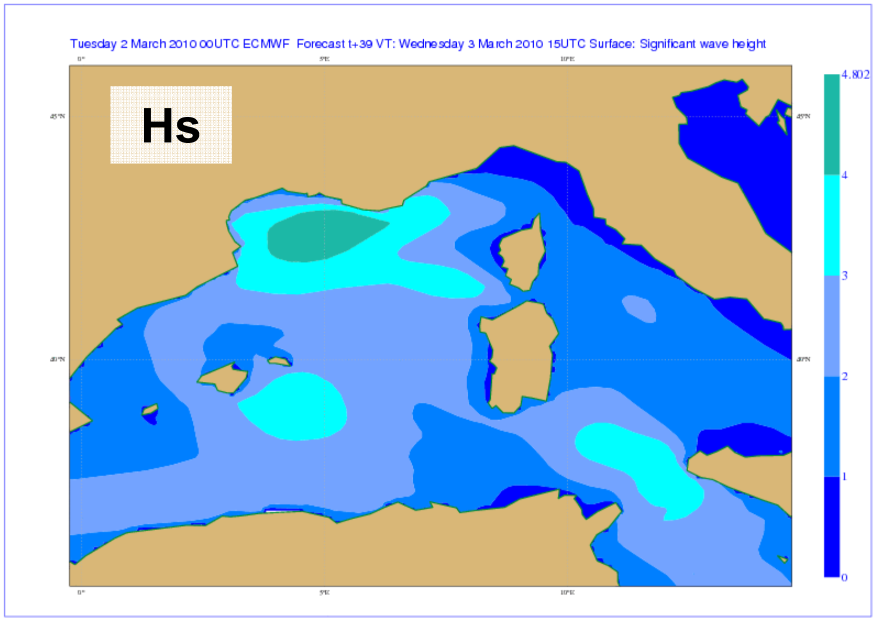
Individual Waves, Significant Wave Height, H_s, Maximum Individual Wave Height, H_{max}, and Freak Wave

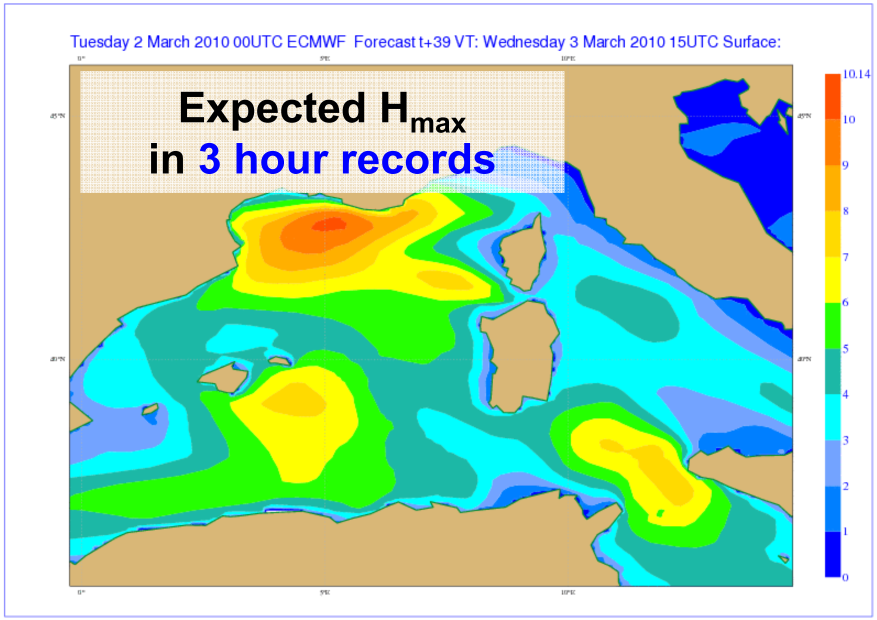


If $H_{max} > 2.2\ H_s$ → freak wave event

Wave Model Products: Extreme Waves

We have recently introduced a new 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

See ECMWF Tech Memo 288 for derivation and discussion
http://www.ecmwf.int/publications/library/do/references/list/14

Questions/comments ?

Ocean Wave Modelling: references

- The ocean wave modelling at ECMWF is based on the wave mode WAM cycle 4 (Komen et al. 1994), albeit with frequent improvements (Janssen 2007: ECMWF Tech. Memo 529, Bidlot 2012, proceeding of the ECMWF Workshop on Ocean Waves, 25-27 June 2012).
- Products from different configurations of WAM are currently available at ECMWF.

http://www.ecmwf.int/publications/manuals/d/gribapi/param/filter=grib1/order=paramId/order_type=asc/p=1/table=140/

- Wave model page on the Centre's web site:

  http://www.ecmwf.int/products/forecasts/wavecharts/index.html#forecasts

- General documentation:

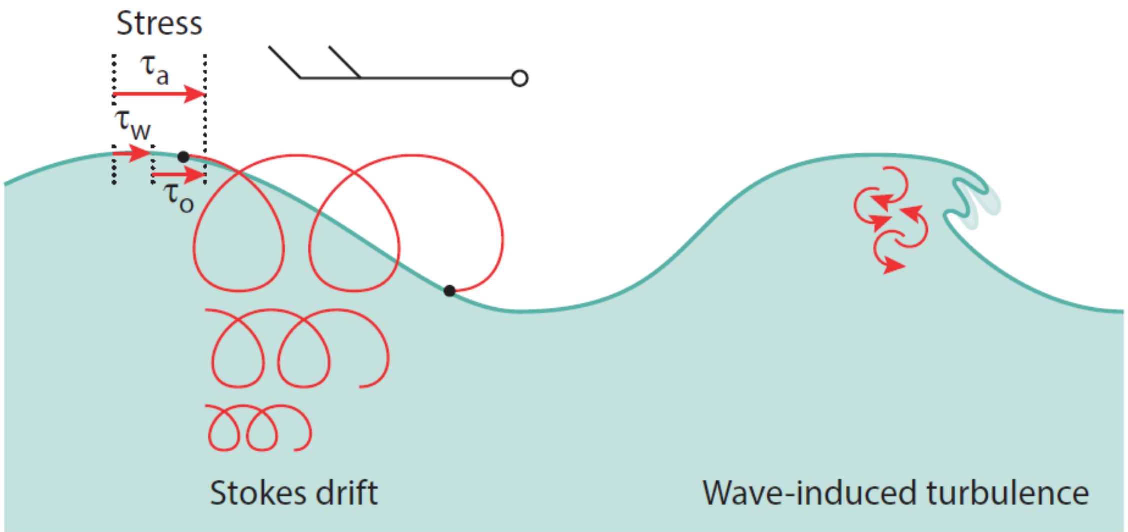
  http://www.ecmwf.int/research/ifsdocs/CY40r1/index.html

IFS-WAM-NEMO coupled system.

Wave-ocean interaction

Three wave effects have recently been implemented in NEMO:

- Stokes-Coriolis forcing: The Stokes drift sets up a current in the along-wave direction. Near the surface it may become substantial ($\sim 1\,\mathrm{m/s}$). The Coriolis effect works on the Stokes drift and adds a new term to the momentum equations known as the Coriolis-Stokes force
- Stress: As waves grow under the influence of the wind, the waves absorb momentum (τ_{w}) which otherwise would have gone into the ocean directly (τ_{o})
- Mixing: As waves break (right), turbulent kinetic energy is injected into the ocean mixed layer, significantly enhancing the mixing.



IFS-WAM-NEMO coupled system. atmosphere – waves - oceans