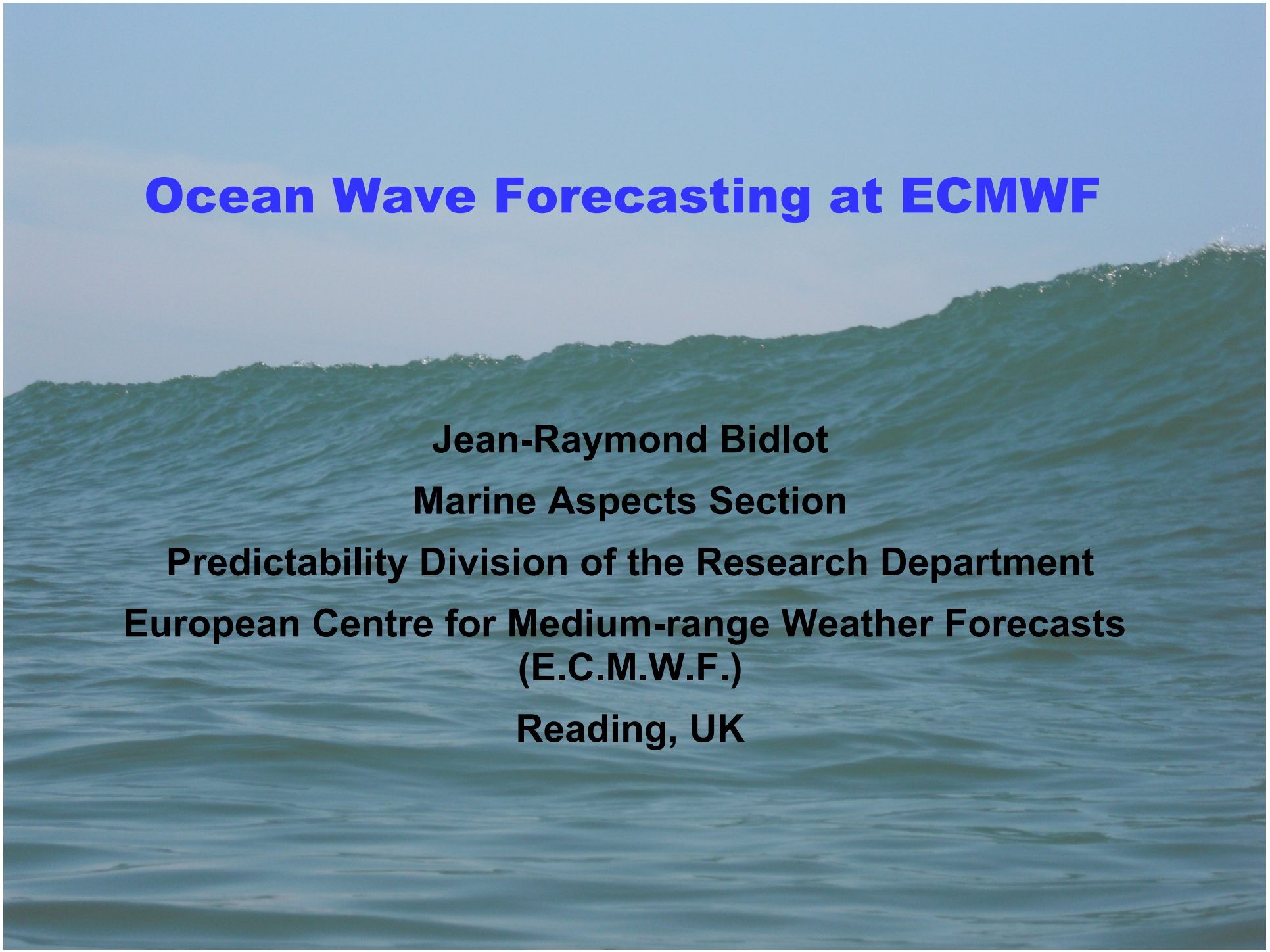


Ocean Wave Forecasting at ECMWF

Jean-Raymond Bidlot

Marine Aspects Section

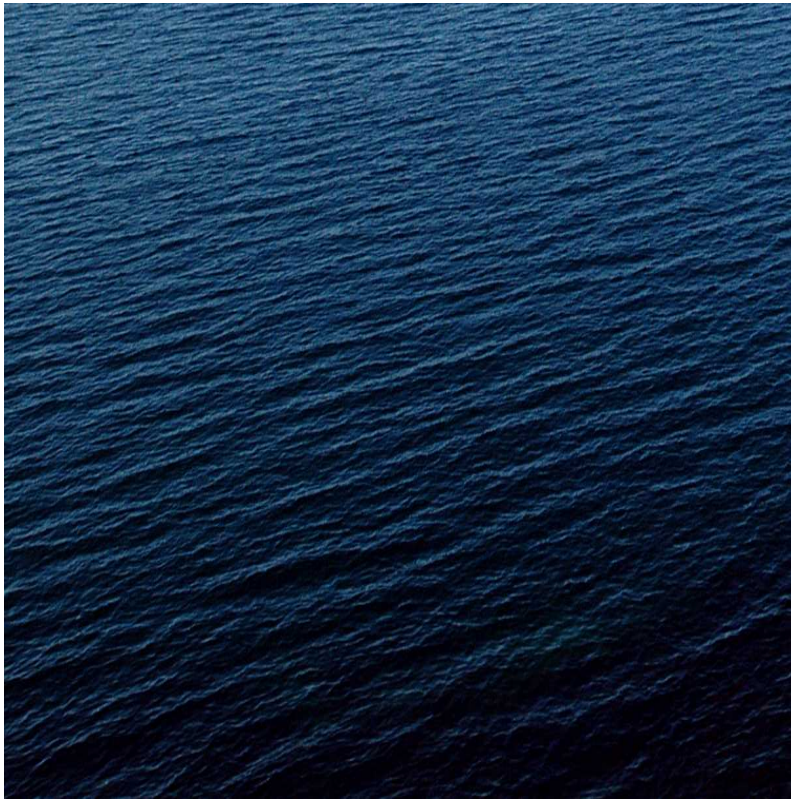
Predictability Division of the Research Department

European Centre for Medium-range Weather Forecasts (E.C.M.W.F.)

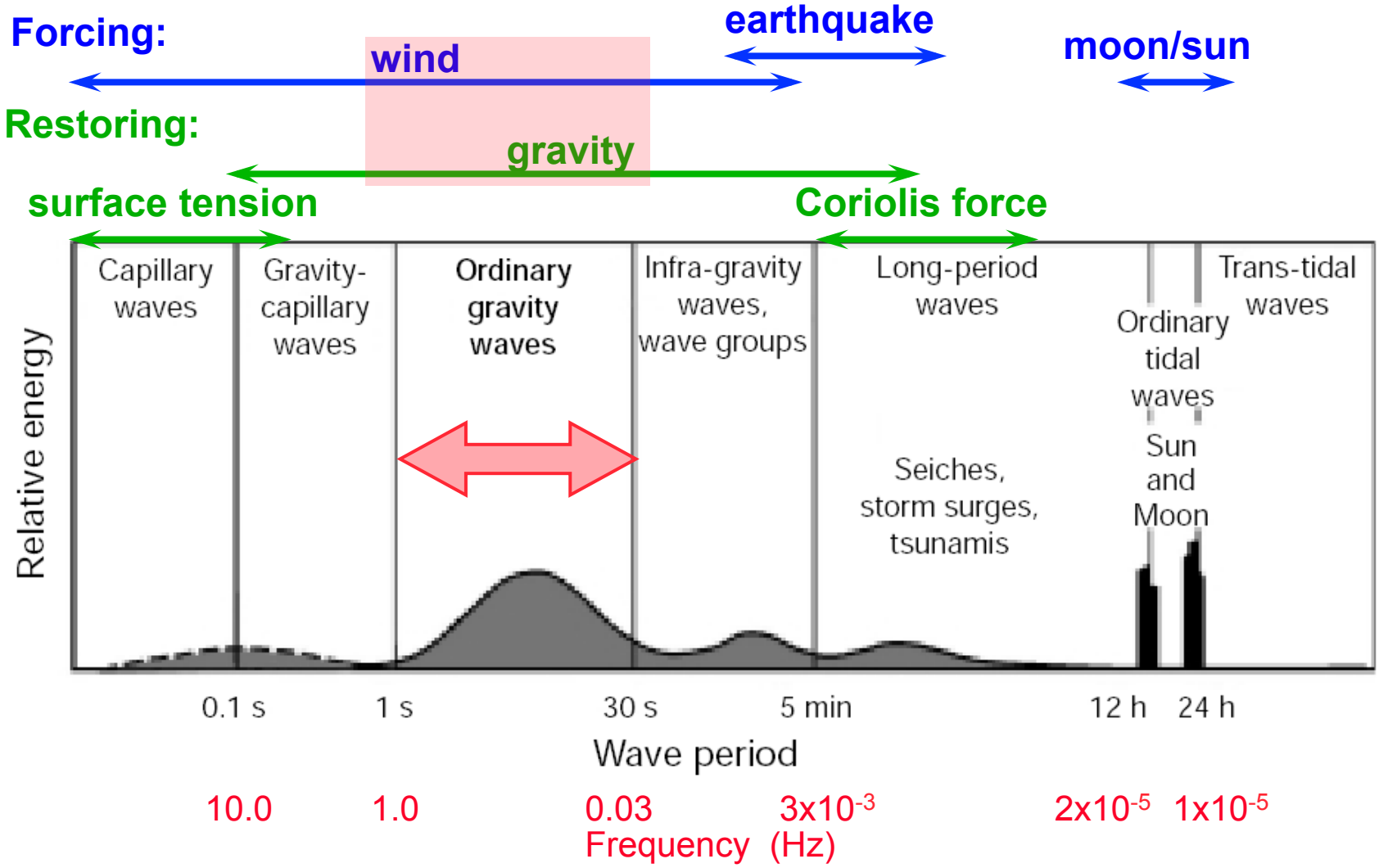
Reading, UK

Ocean waves:

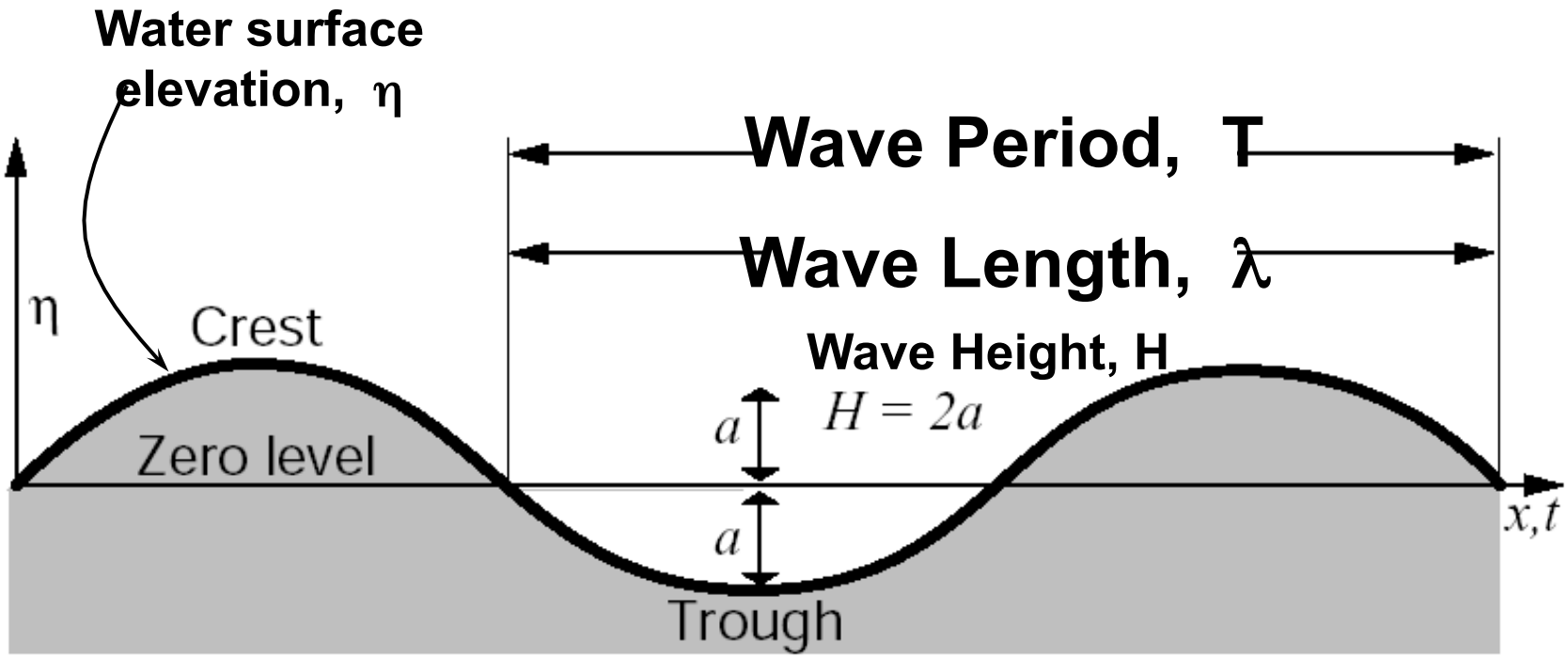
We are dealing with wind generated waves at the surface of the oceans, from gentle to rough …



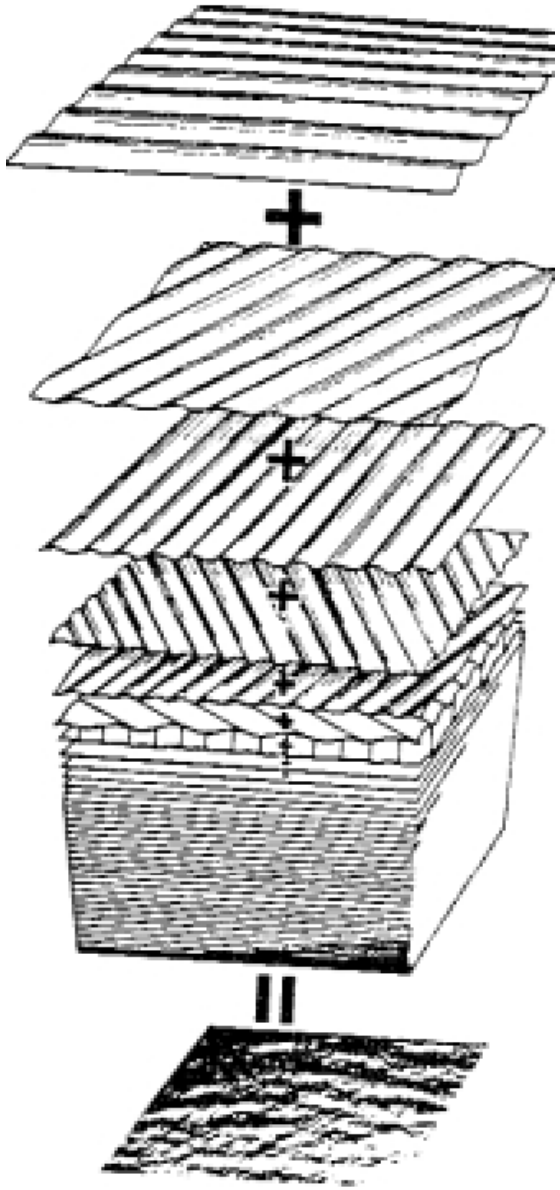
Ocean Waves


Forcing:
wind
earthquake
moon/sun
Restoring:
gravity
surface tension
Coriolis force
Capillary waves
Gravity-capillary waves
Ordinary gravity waves
Infra-gravity waves, wave groups
Long-period waves
Ordinary tidal waves
Trans-tidal waves
Seiches, storm surges, tsunamis
Sun and Moon
Relative energy
0.1 s
1 s
30 s
5 min
12 h
24 h
Wave period
10.0
1.0
0.03
3x10-3
2x10-5
1x10-5
Frequency (Hz)

What we are dealing with?

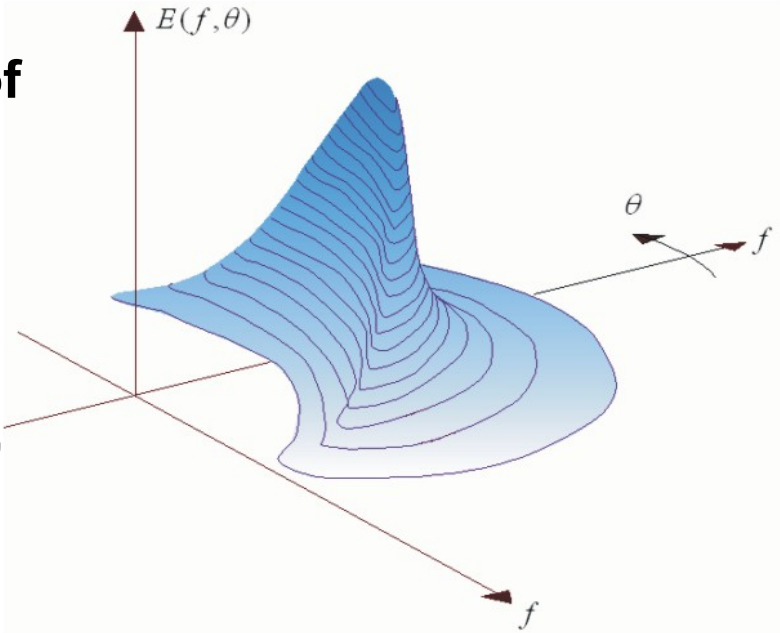


Wave Spectrum



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

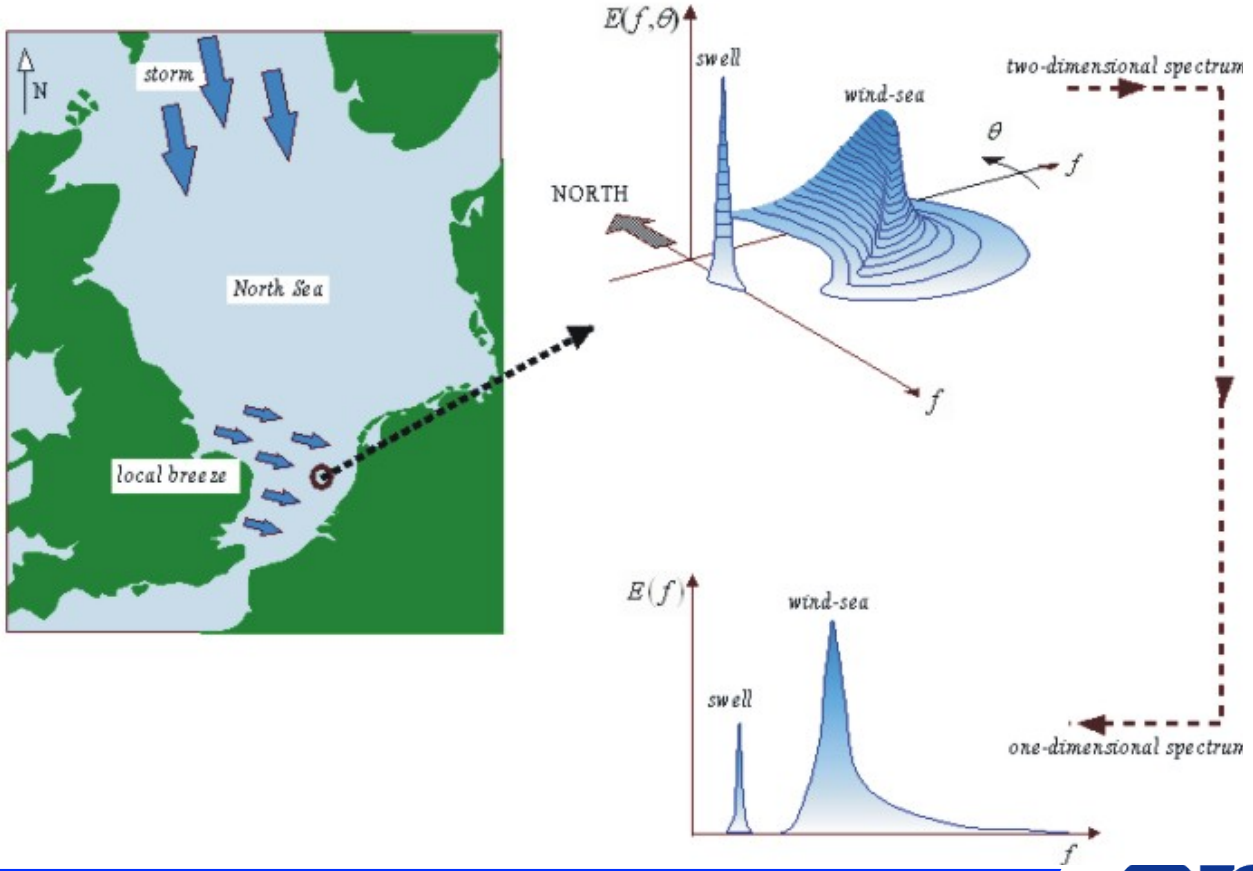
- The distribution of wave energy among those components is called: "**wave spectrum**", F(f,θ).



Ocean Wave Modelling

- **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 $F(f,\theta)$.**



Ocean Wave Modelling

- **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 mean energy associated with those waves is:**

$$\langle energy \rangle = \rho_w g \langle \eta^2 \rangle$$

- **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 ($H_{1/3}$).

Ocean Wave Modelling

- **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.).**
- **Products from different configurations of WAM are currently available at ECMWF.**
- **Wave model wave page:**

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

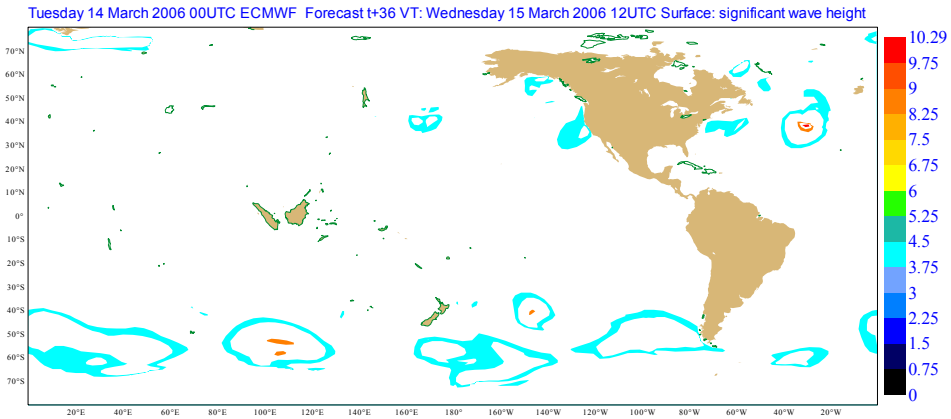
- **General documentation:**

  http://www.ecmwf.int/research/ifsdocs/CY36r1/index.html

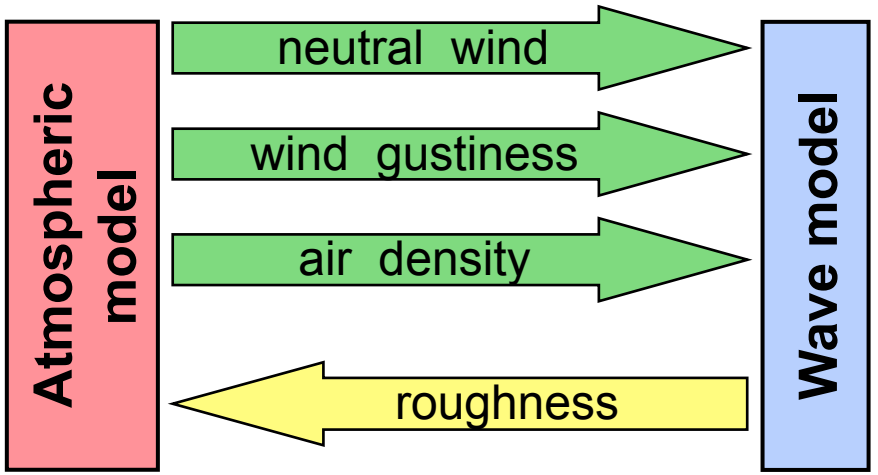
ECMWF Wave Model Configurations

Global models

- Global from 81°S to 90°N, including all inland seas.
- Coupled to the atmospheric model (IFS) 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 and more recently neutral winds.
- Data assimilation Jason-2 altimeter wave heights.



Forecast wave height on 15/03/2006 12UTC.



ECMWF Wave Model Configurations

Deterministic model

- 28 km grid spacing.
- 36 frequencies.
- 36 directions.
- Coupled to the TL1279 model.
- Analysis every 6 hrs and 10 day forecasts from 0 and 12Z.

Probabilistic 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 once a week).

* Change in resolutions after 10 days

NB: also in seasonal forecast at lower resolutions

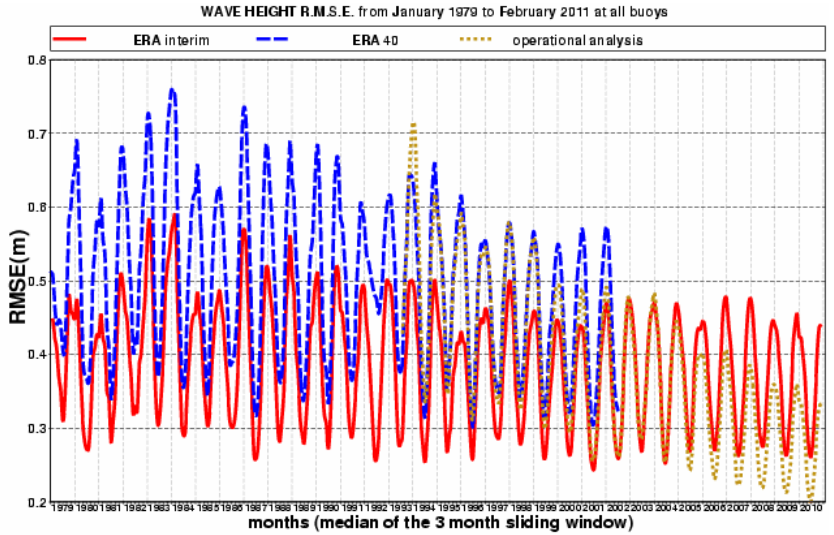
ECMWF Wave Model Configurations

Interim reanalysis (1979 to present)

(as a follow-up to ERA40 (45 year reanalysis)

- **1.0°x1.0°.**
- **30 frequencies.**
- **24 directions.**
- **Coupled to TL255 model**
- **Production is ongoing.**
- **Very satisfactory performance:**

Comparison with buoys:



Operations
ERA-40
ERA Interim

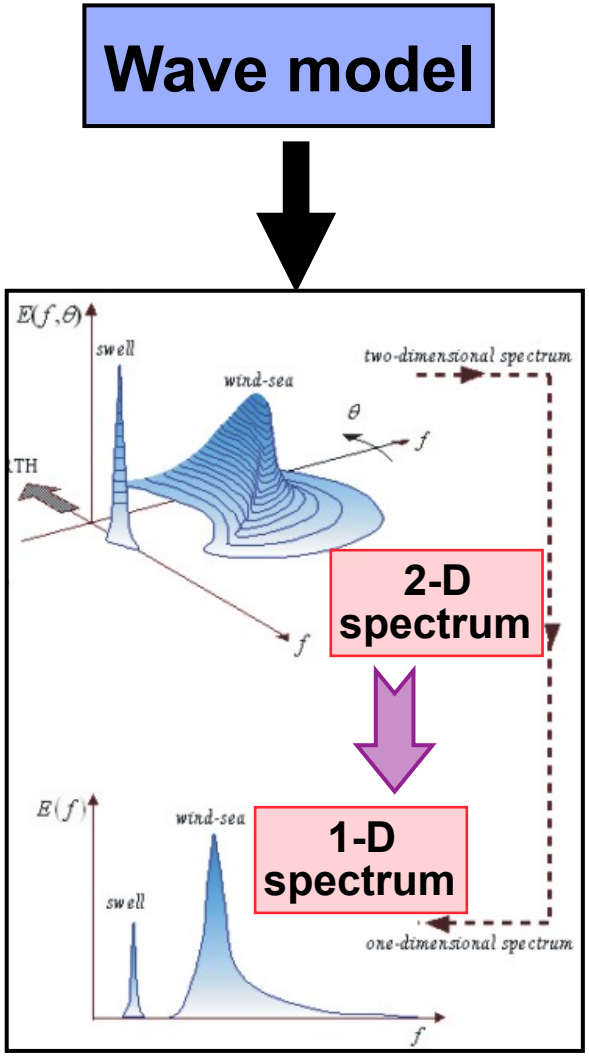
- http://www.ecmwf.int/research/era/do/get/era-interim
- ECMWF Newsletters No. 110 (Winter 2006/07) & 111 (Spring 2007) http://www.ecmwf/publications/newsletters

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. 24x30 values at each grid point in the global model)*.

It is therefore reduced to integrated quantities:

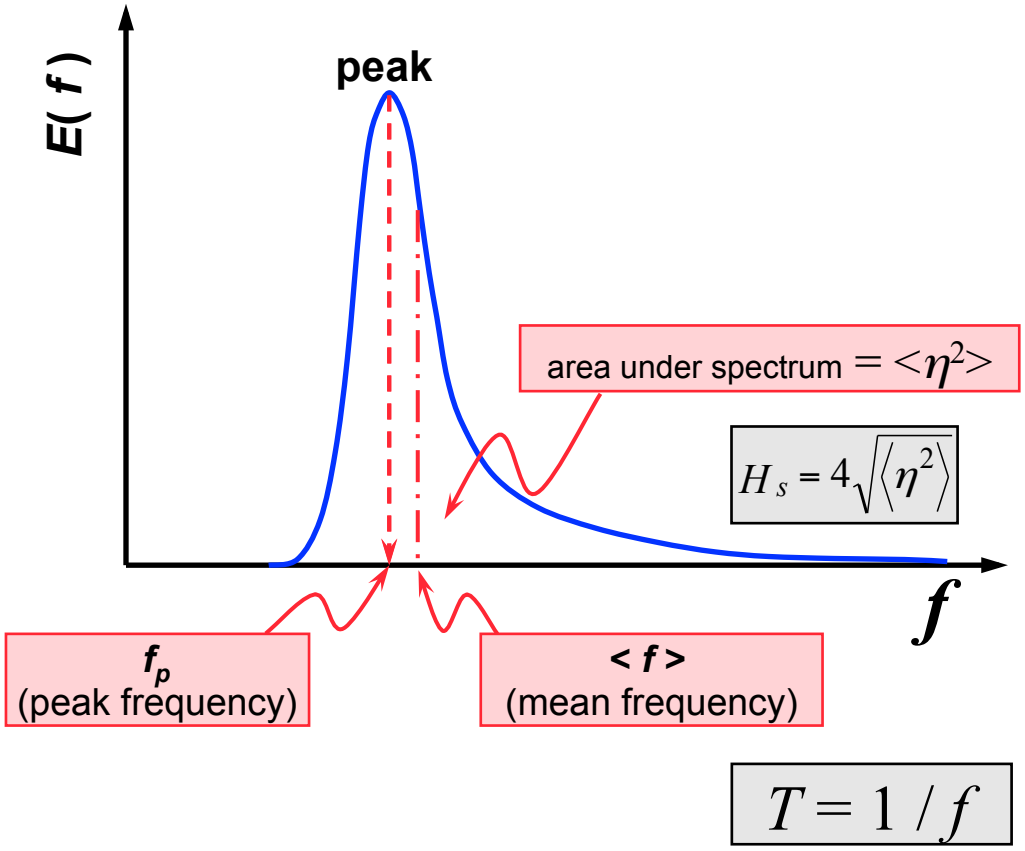
- **1-D spectrum obtained by integrating the 2-D spectrum over all directions and/or over a frequency range.**



Wave Model Products

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

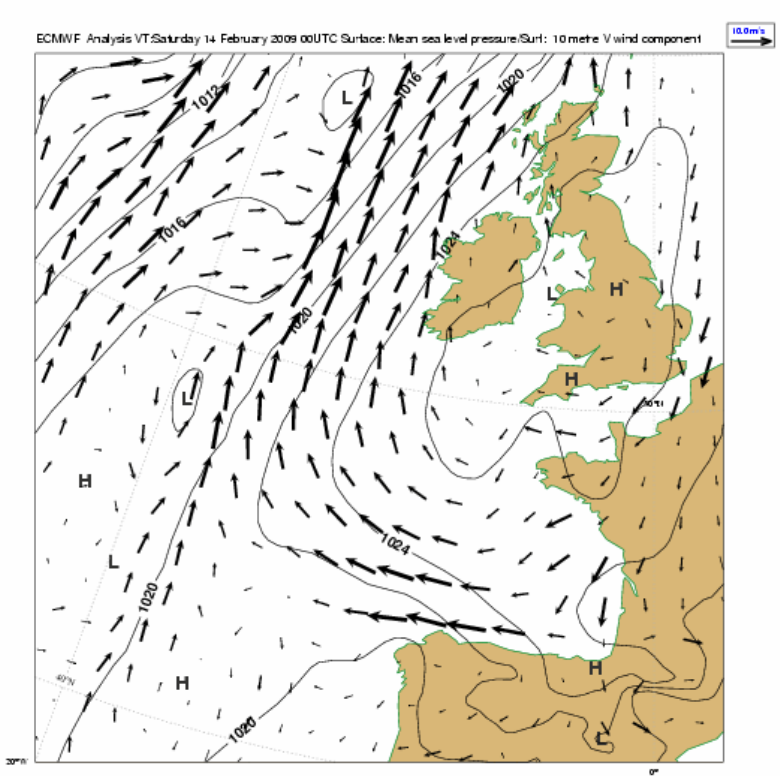
- **The significant wave height (H_s).**
- **The peak period (period of the peak of the 1-D spectrum).**
- **Mean period(s) obtained from weighted integration of the 2-D spectrum.**
- **Integrated mean direction.**
- ***Few others.***



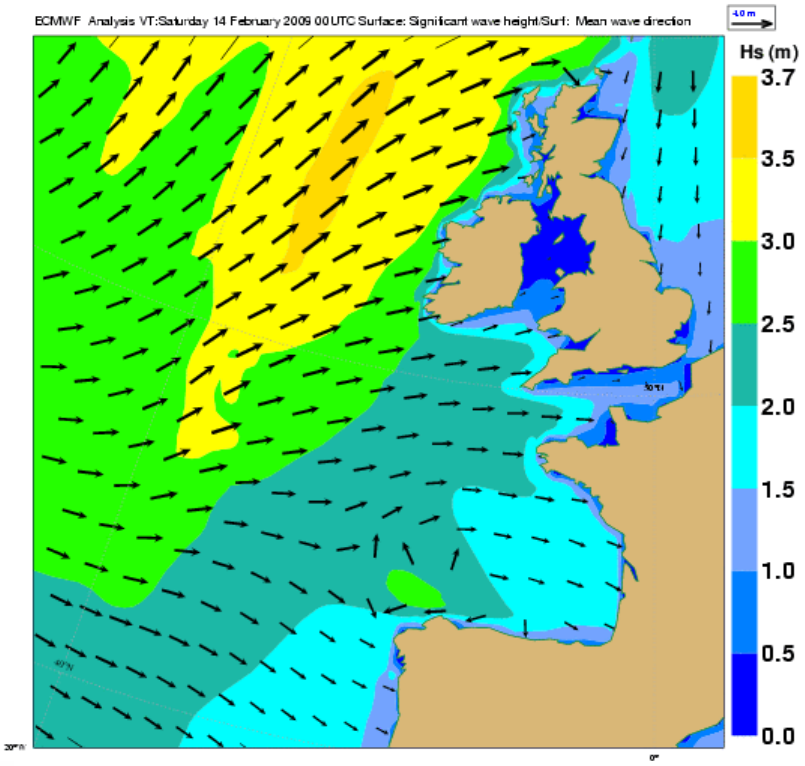
Complete list at: http://www.ecmwf.int/services/archive/d/parameters/order=/table=140/

Wave Model Products

Use simple parameters:
total wave height and mean propagation direction



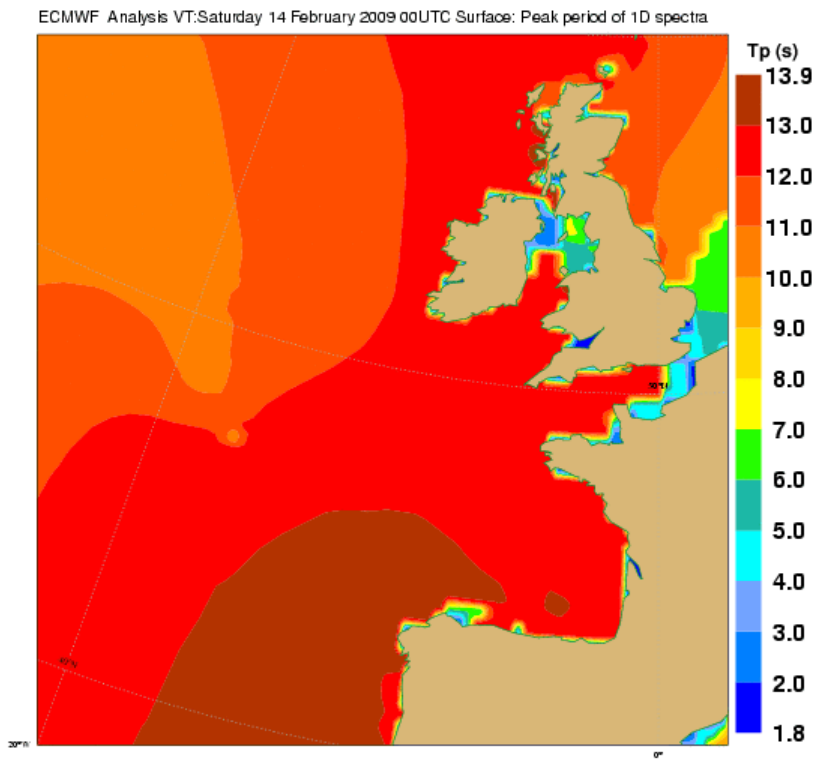
10m winds and mean sea level pressure:
Analysis : 14 February 2009, 00 UTC



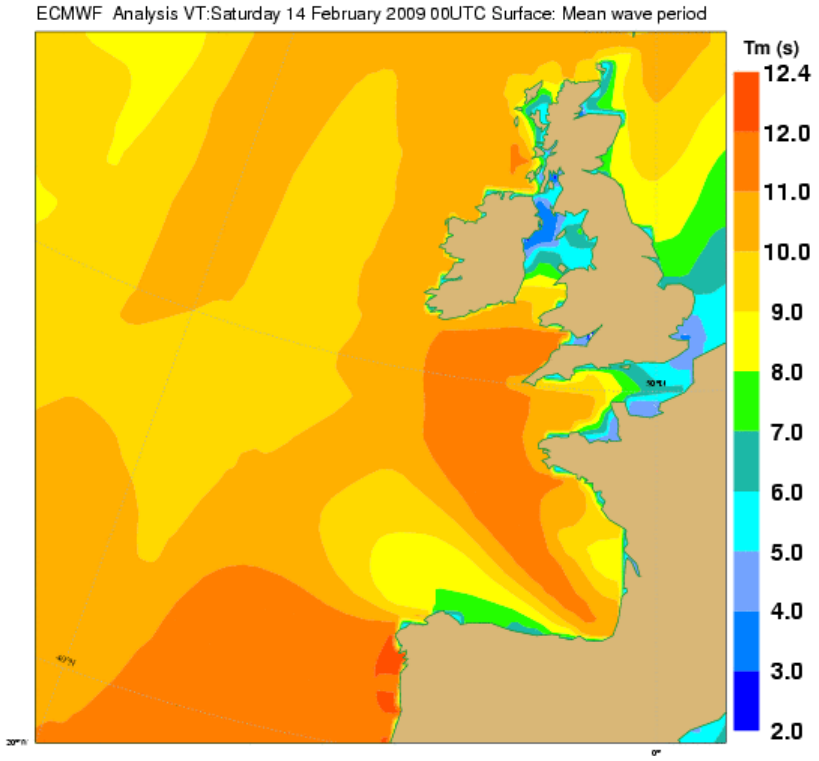
Wave height and mean direction:
Analysis : 14 February 2009, 00 UTC

Wave Model Products

Wave periods: at the peak of the spectrum or in the mean

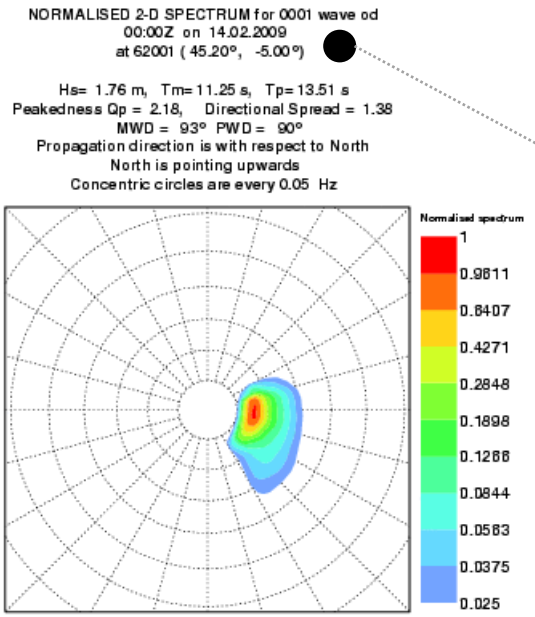


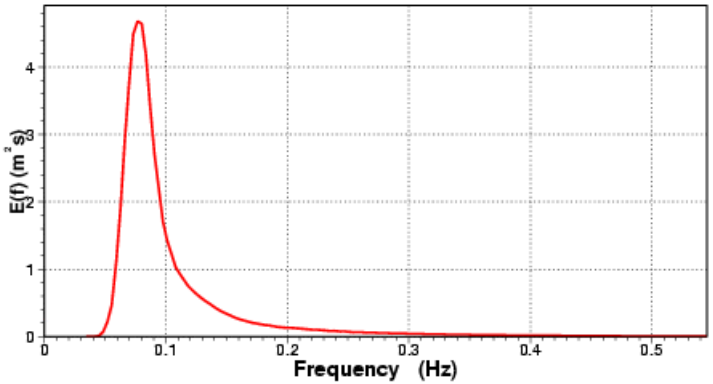
PEAK PERIOD:
Analysis : 14 February 2009, 00 UTC

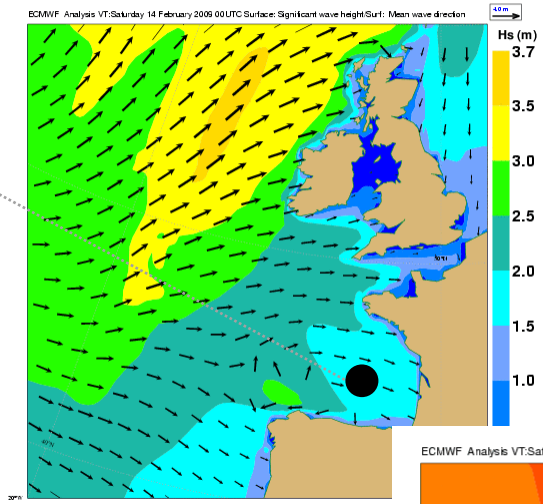


MEAN WAVE PERIOD:
Analysis : 14 February 2009, 00 UTC

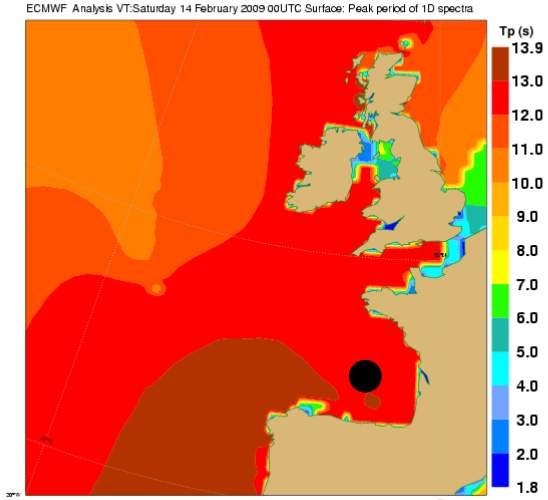
Wave Model Products







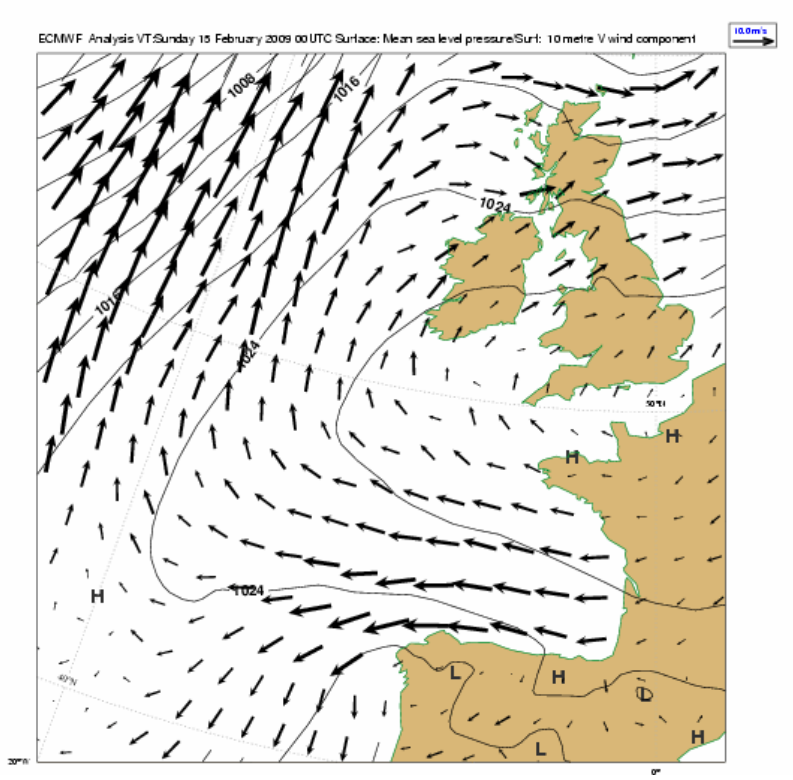
Wave height and me
Analysis : 14 February



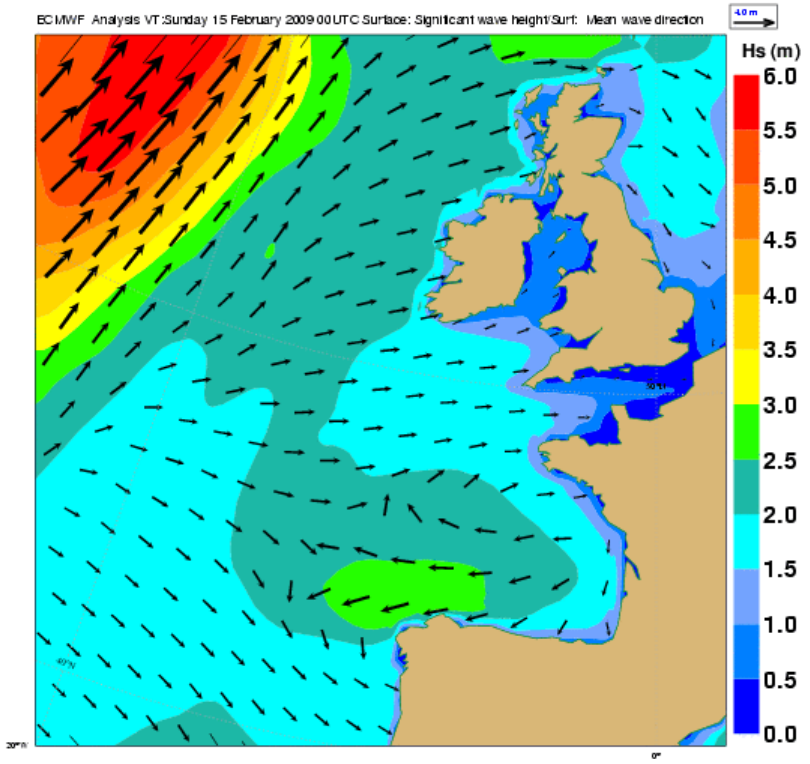
PEAK PERIOD:
Analysis : 14 February 2009, 00 UTC

Wave Model Products

Situation might be more complicated !



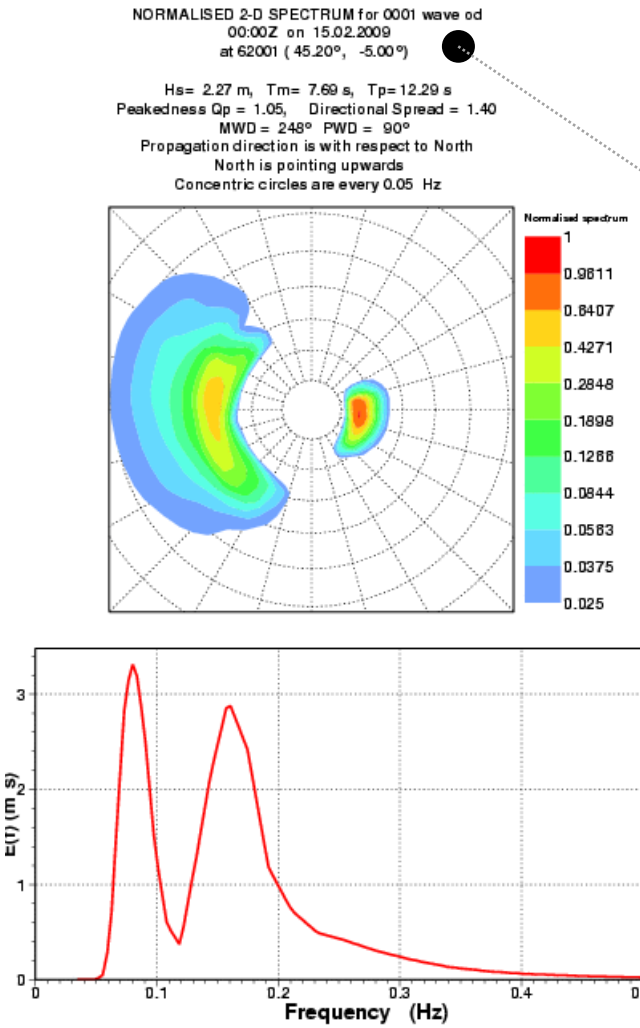
10m winds and mean sea level pressure:
Analysis : 15 February 2009, 00 UTC

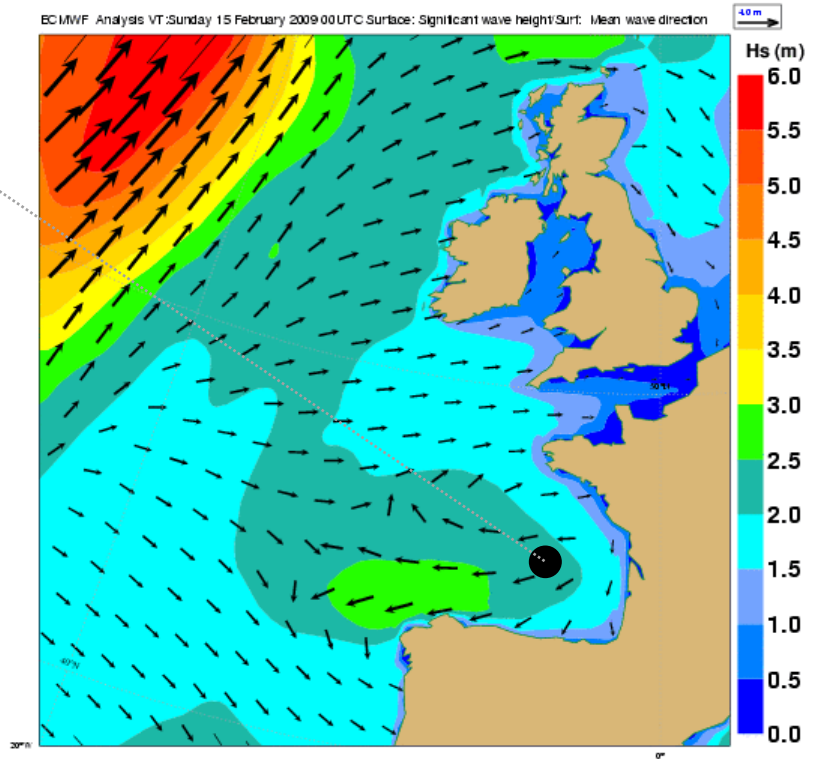


Wave height and mean direction:
Analysis : 15 February 2009, 00 UTC

Wave Model Products

Situation might be more complicated:

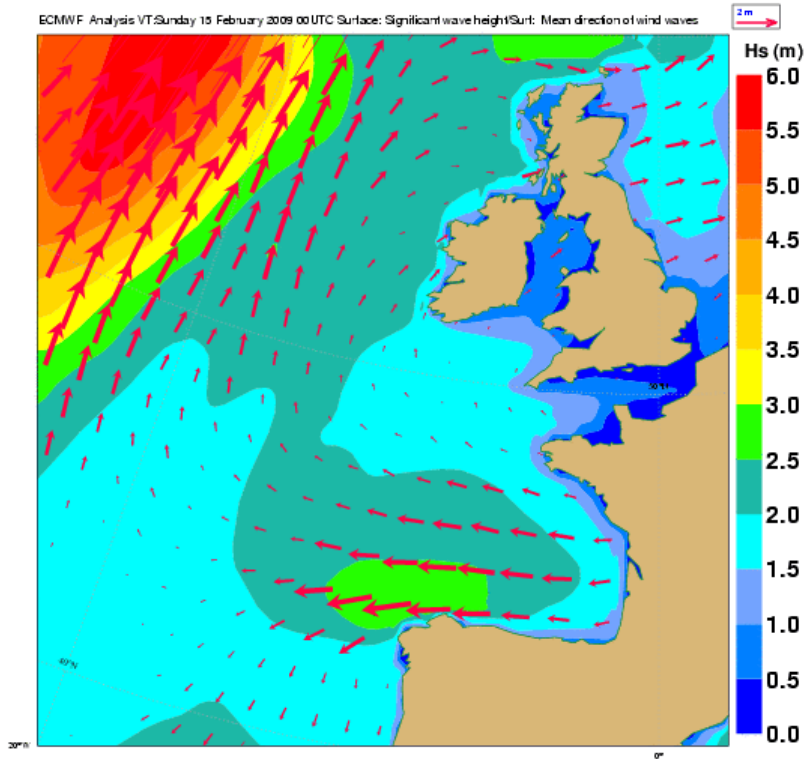




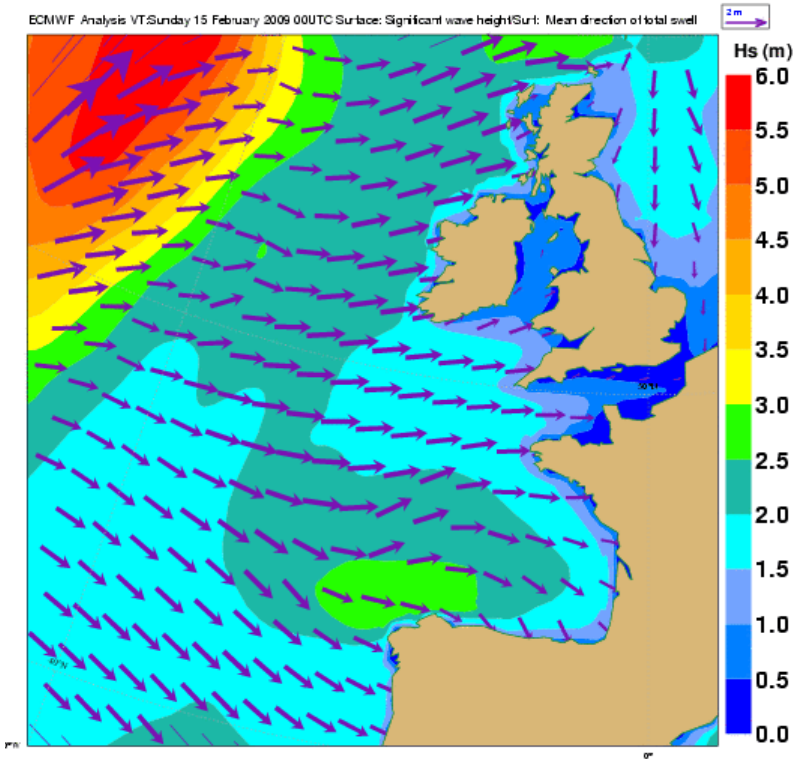
Wave height and mean direction:
Analysis : 15 February 2009, 00 UTC

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.



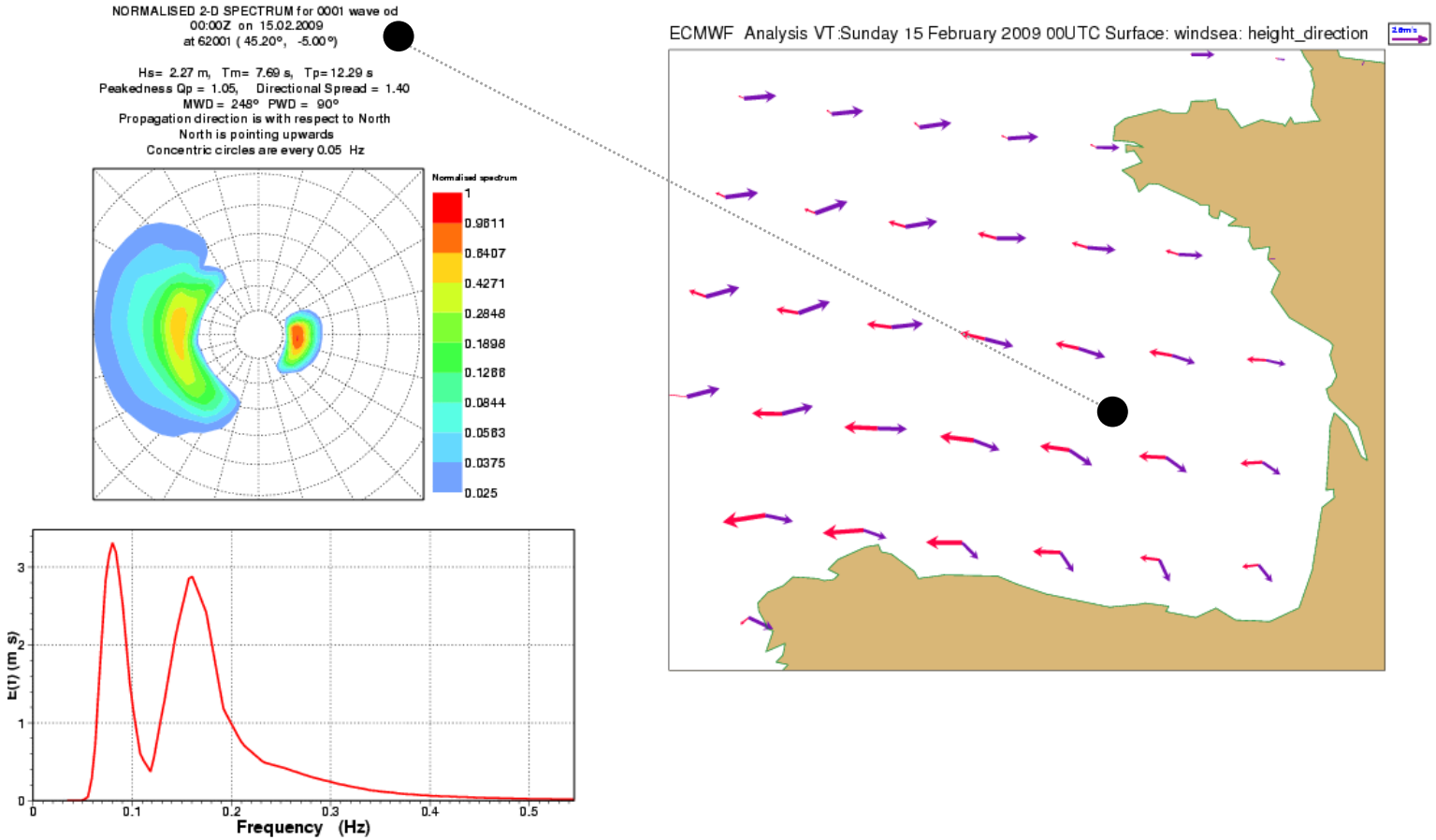
Wave height and windsea mean direction:
Analysis : 15 February 2009, 00 UTC



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

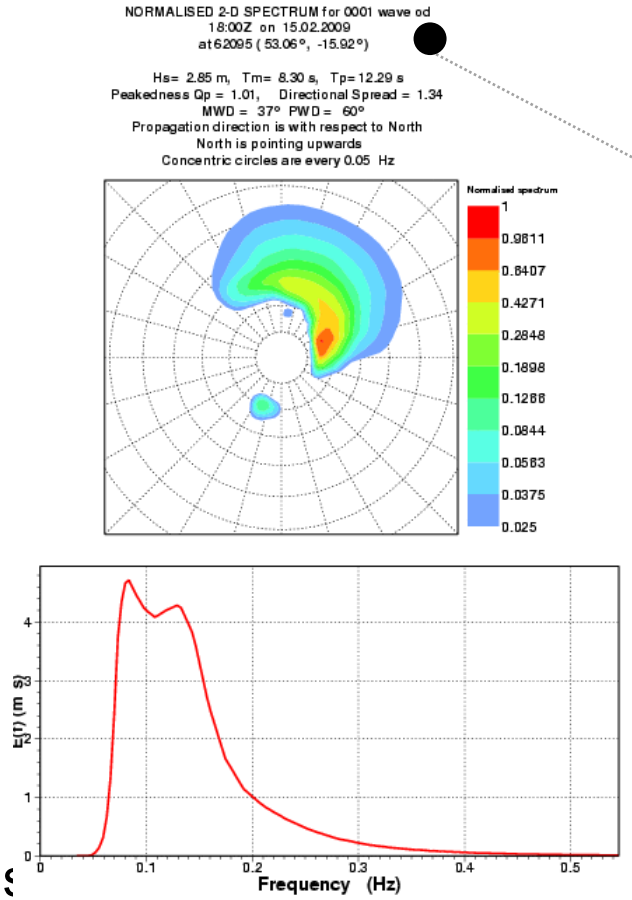
Wave Model Products

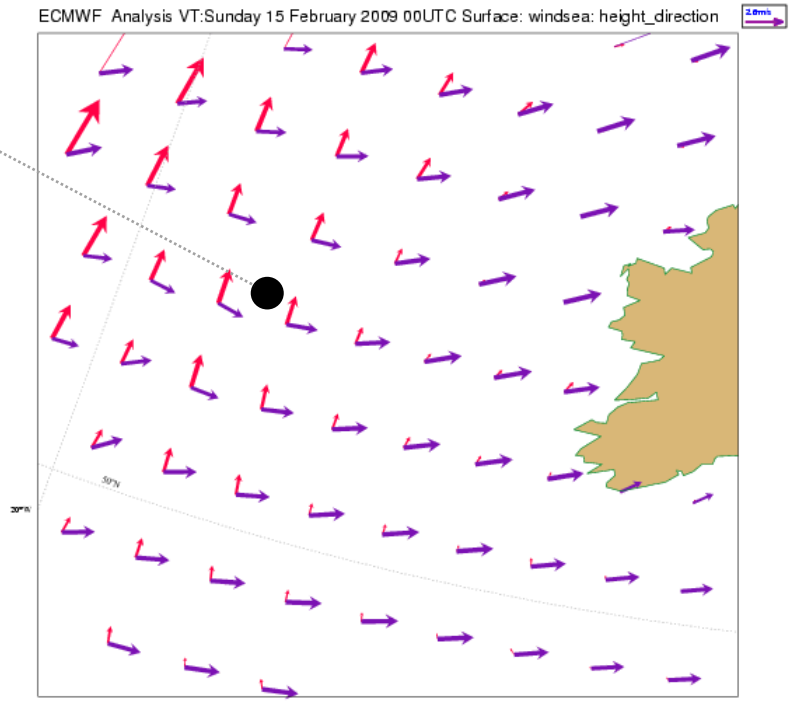
Windsea and swell: opposing sea



Wave Model Products

Windsea and swell: cross sea

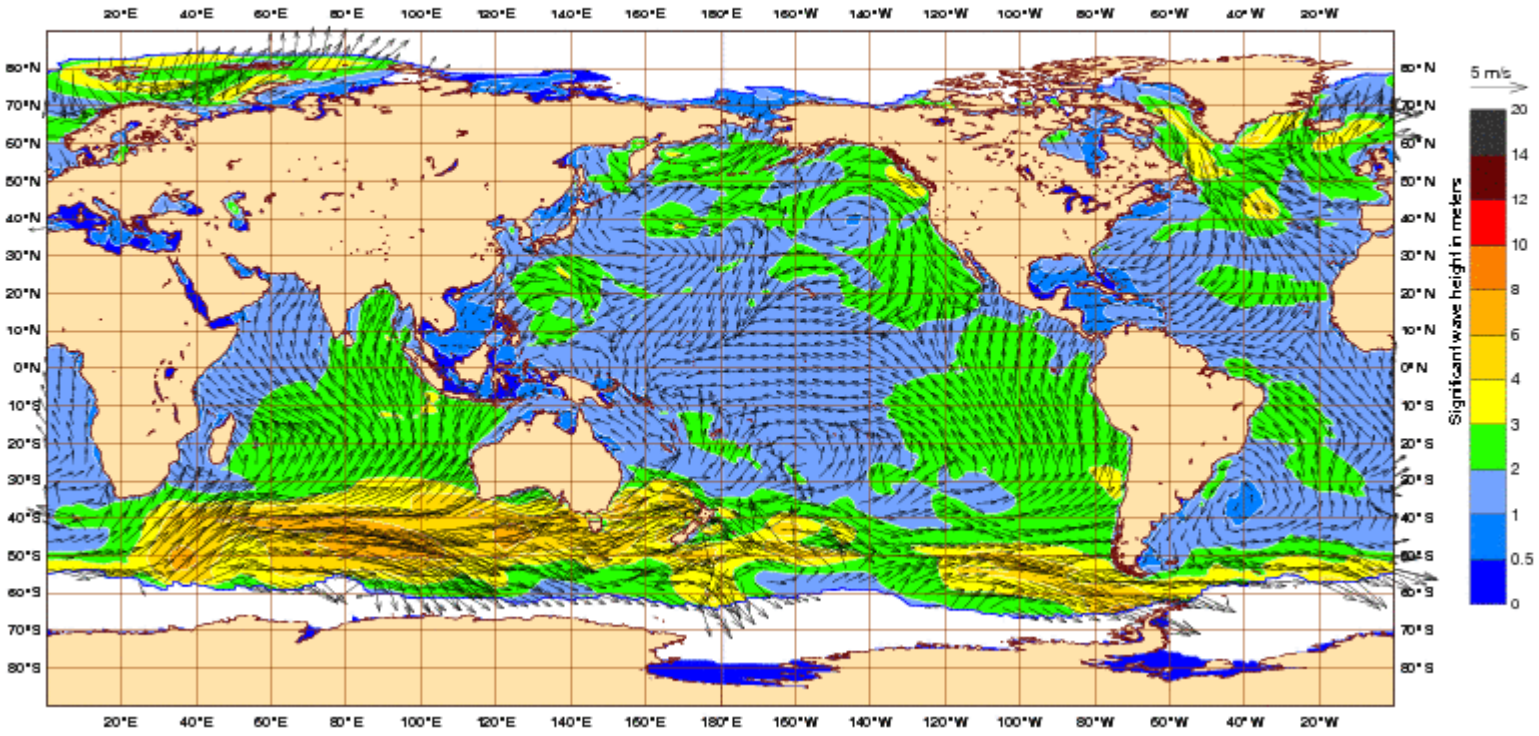




Wave Model Products on the web:

Currently on our web: significant wave height and mean direction

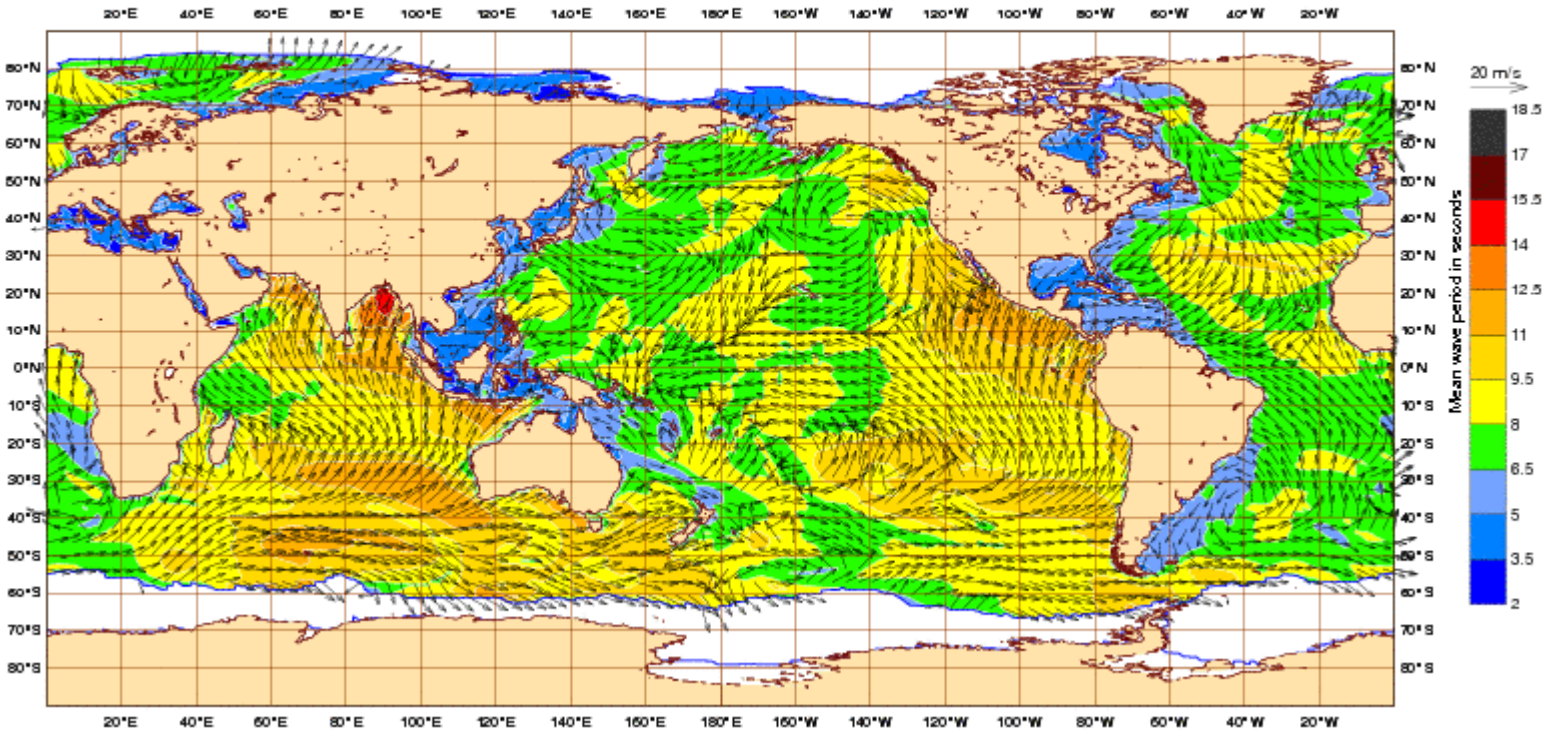
Friday 4 October 2013 00UTC ©ECMWF Forecast t+180 VT: Friday 11 October 2013 12UTC
Significant wave height and mean direction



Wave Model Products on the web

Currently on our web: mean wave period and direction

Friday 4 October 2013 00UTC ©ECMWF Forecast t+180 VT: Friday 11 October 2013 12UTC
Mean wave period and direction

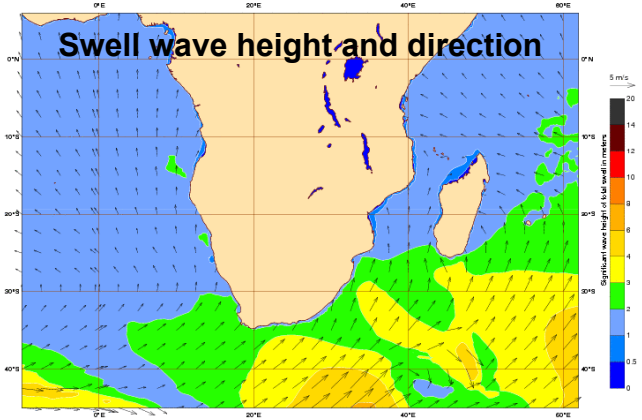


Wave Model Products on the web:

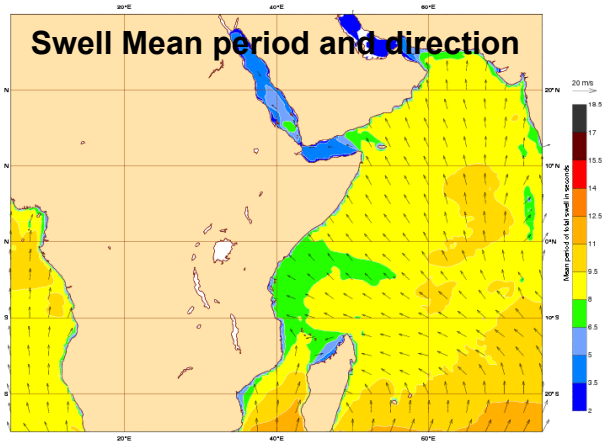
For the Severe Weather Forecast Demonstration Projects (SWFDP) for South Africa, East Africa and the Pacific windsea and swell plots are <u>also</u> available:

e.g.:

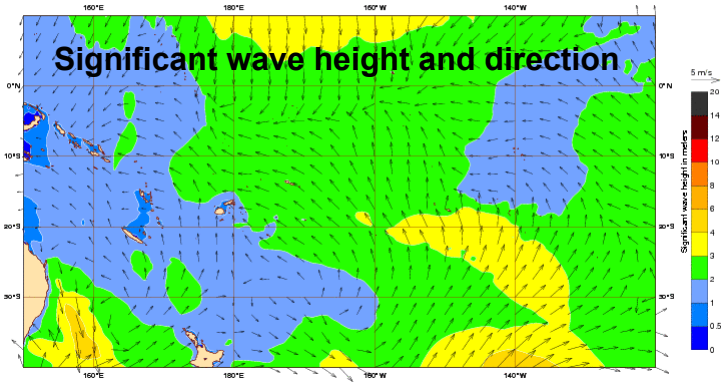
Thursday 11 October 2012 00UTC ©ECMWF Forecast t+006 VT: Thursday 11 October 2012 06UTC
Significant wave height of total swell and mean direction



Thursday 11 October 2012 00UTC ©ECMWF Forecast t+006 VT: Thursday 11 October 2012 06UTC
Mean period of total swell and direction



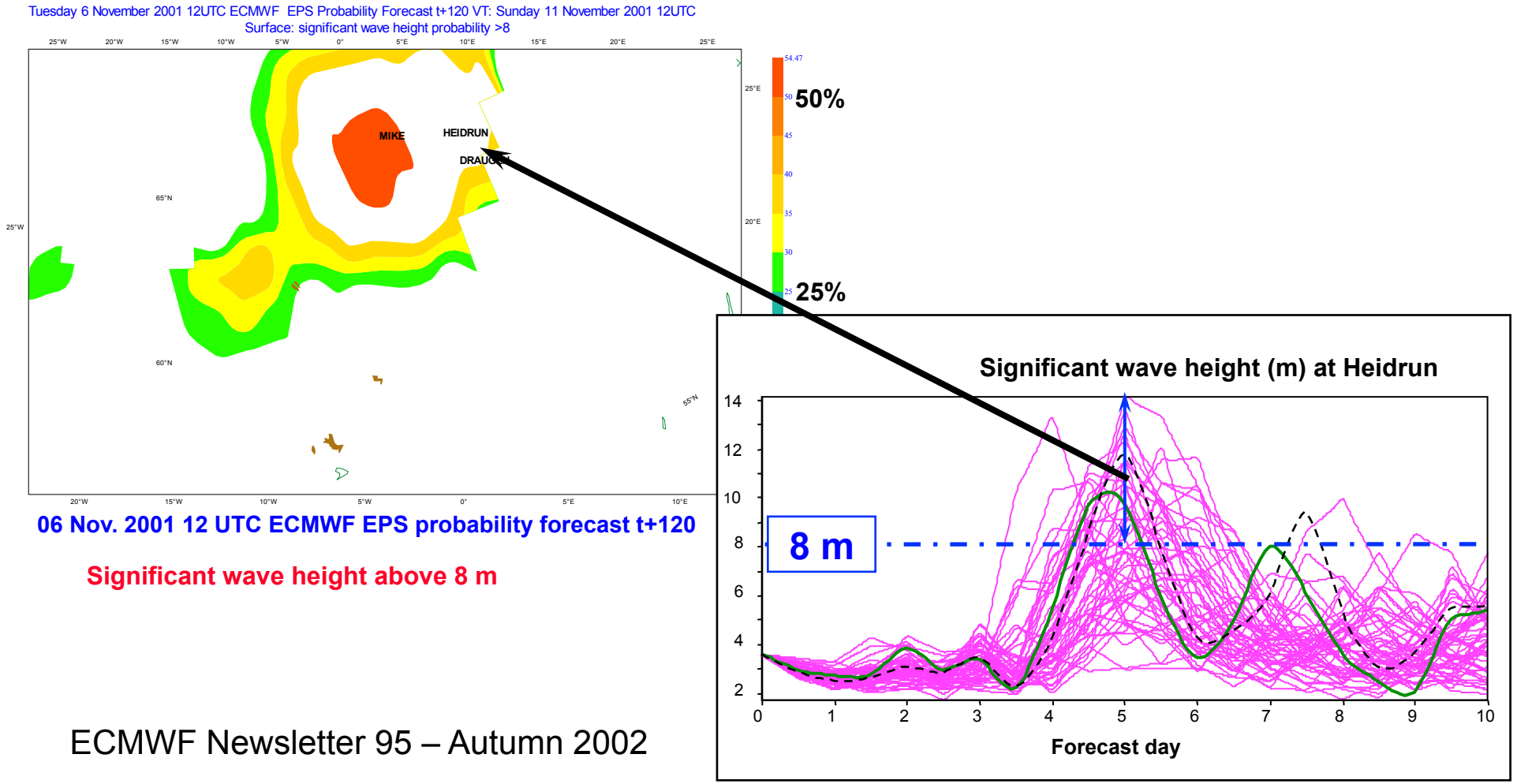
Thursday 11 October 2012 00UTC ©ECMWF Forecast t+006 VT: Thursday 11 October 2012 06UTC
Significant wave height and mean direction



http://www.ecmwf.int/products/forecasts/d/charts/medium/special

Wave Model Products: EPS

From the EPS wave forecasts it is possible to derive probabilities for certain wave conditions.



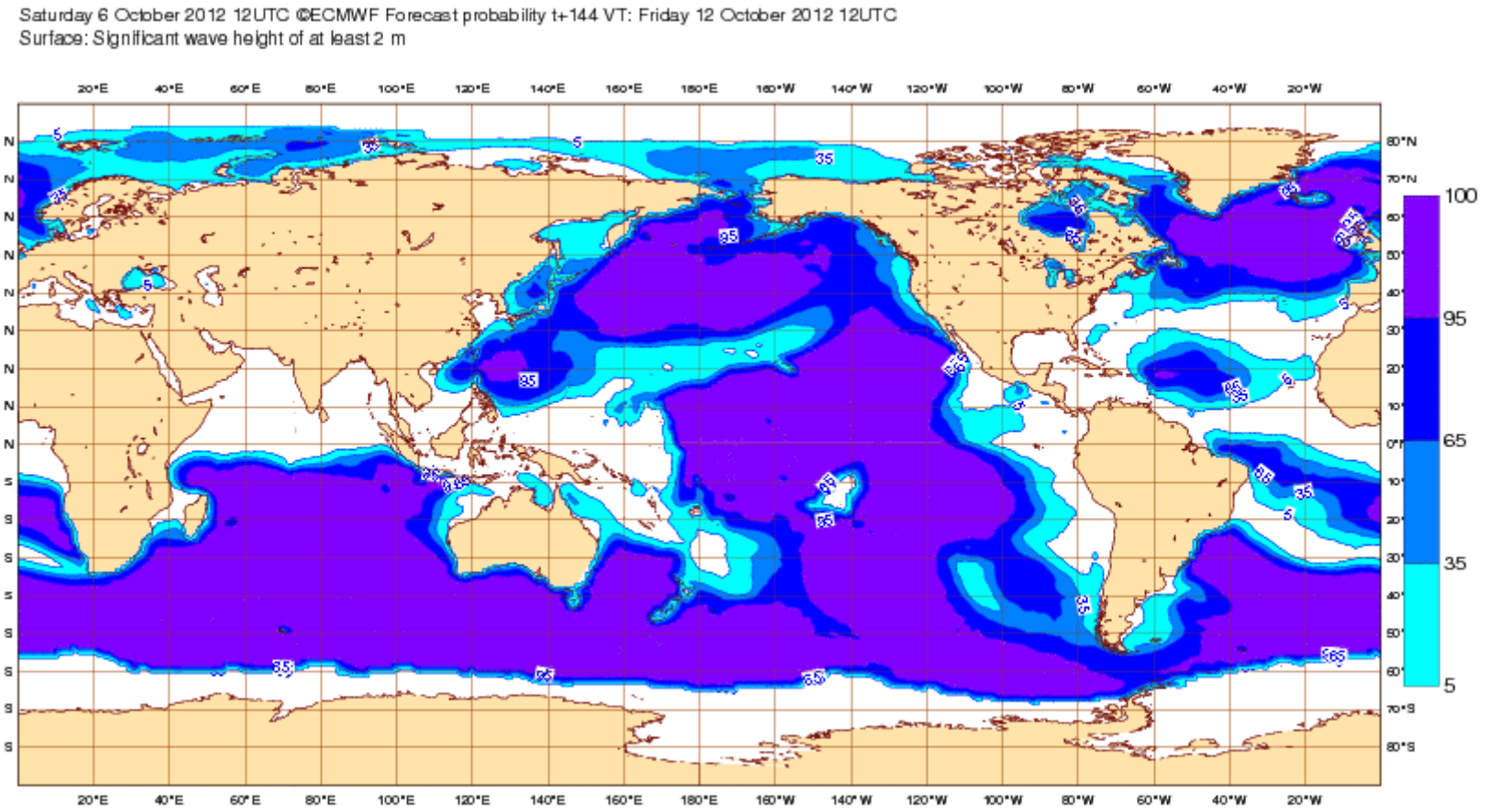
06 Nov. 2001 12 UTC ECMWF EPS probability forecast t+120

Significant wave height above 8 m

ECMWF Newsletter 95 – Autumn 2002

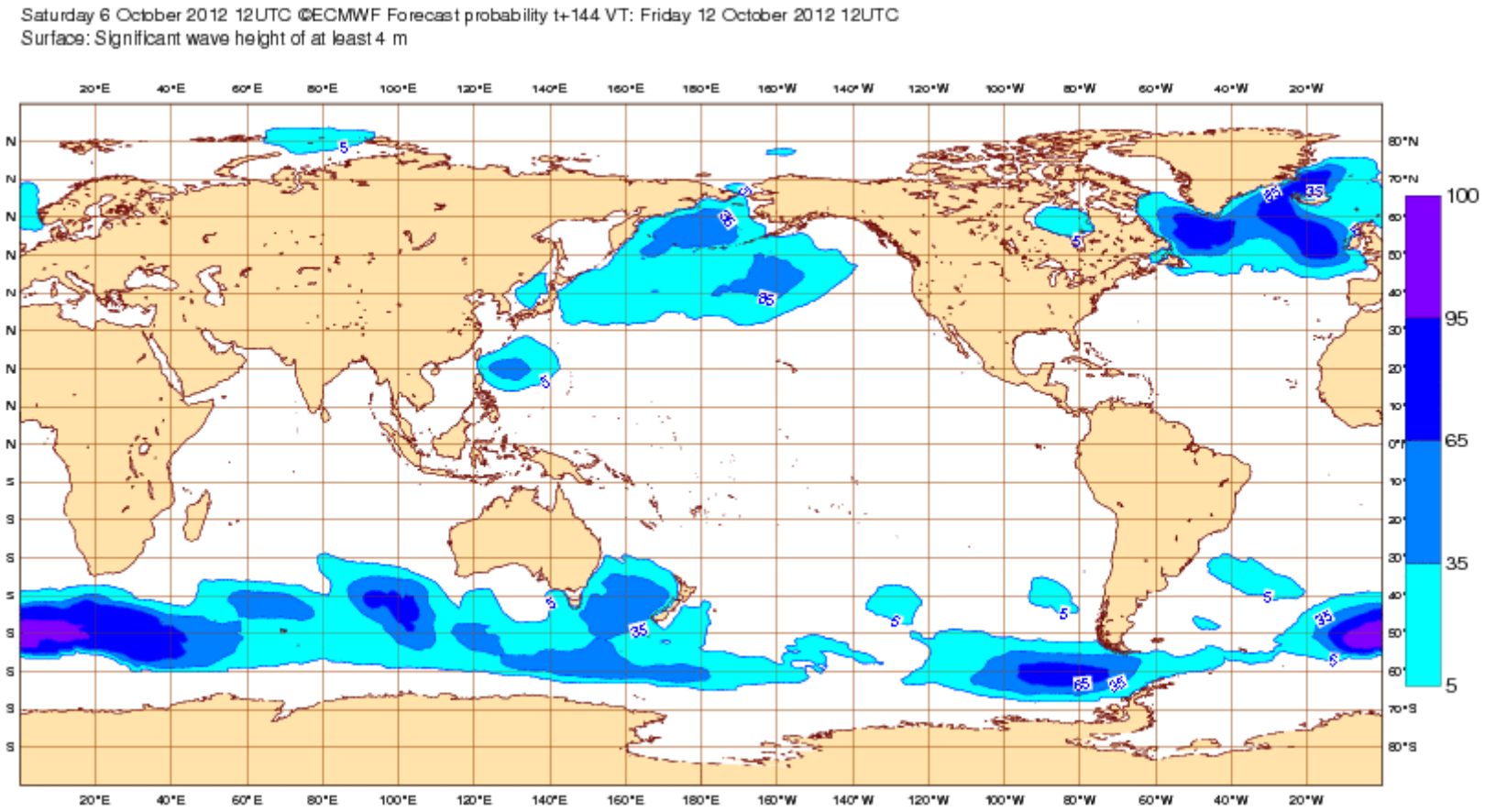
Wave Model Products on the web

Currently on our web: probability for set thresholds (2m)



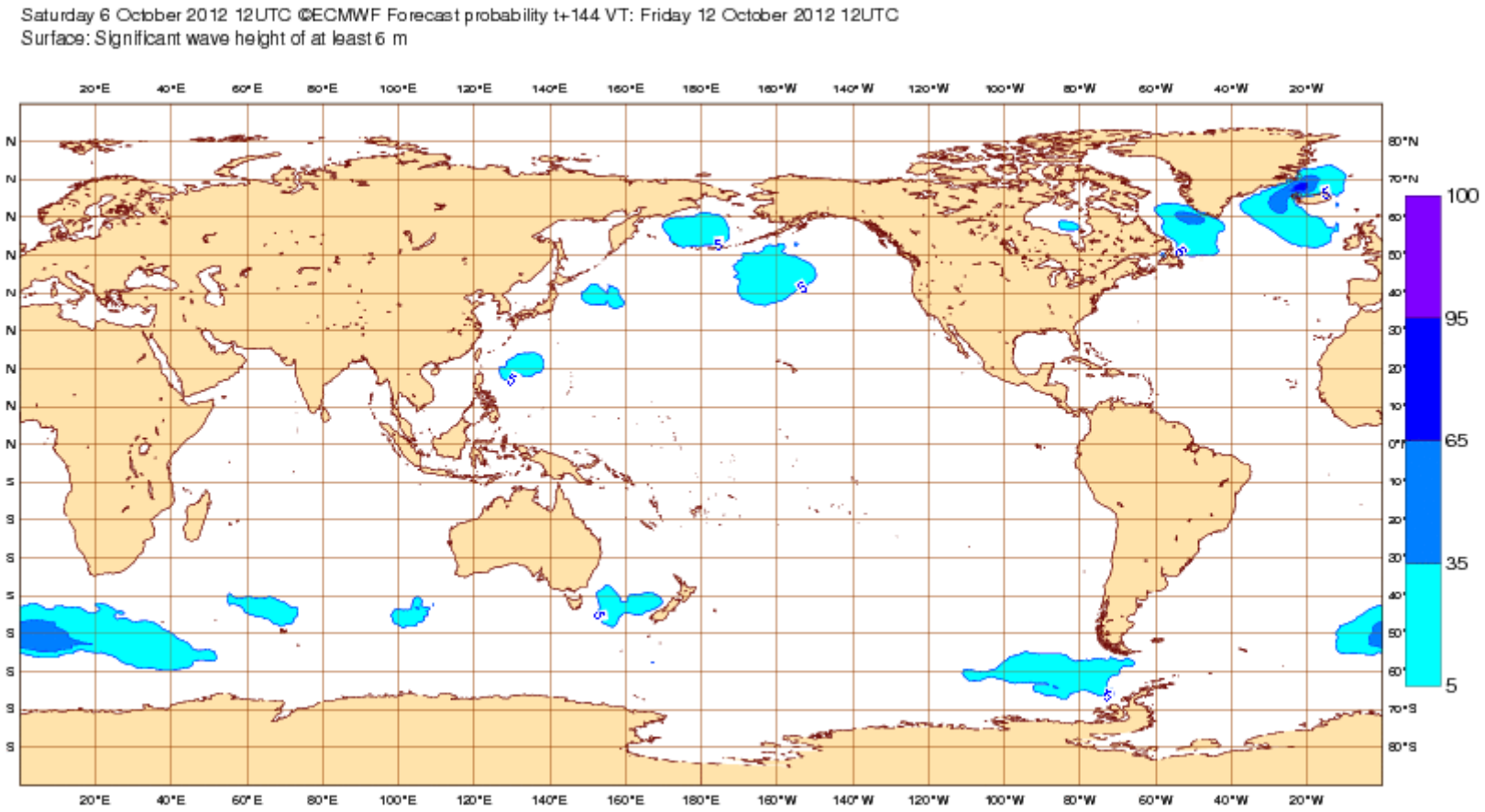
Wave Model Products on the web

Currently on our web: probability for set thresholds (4m)

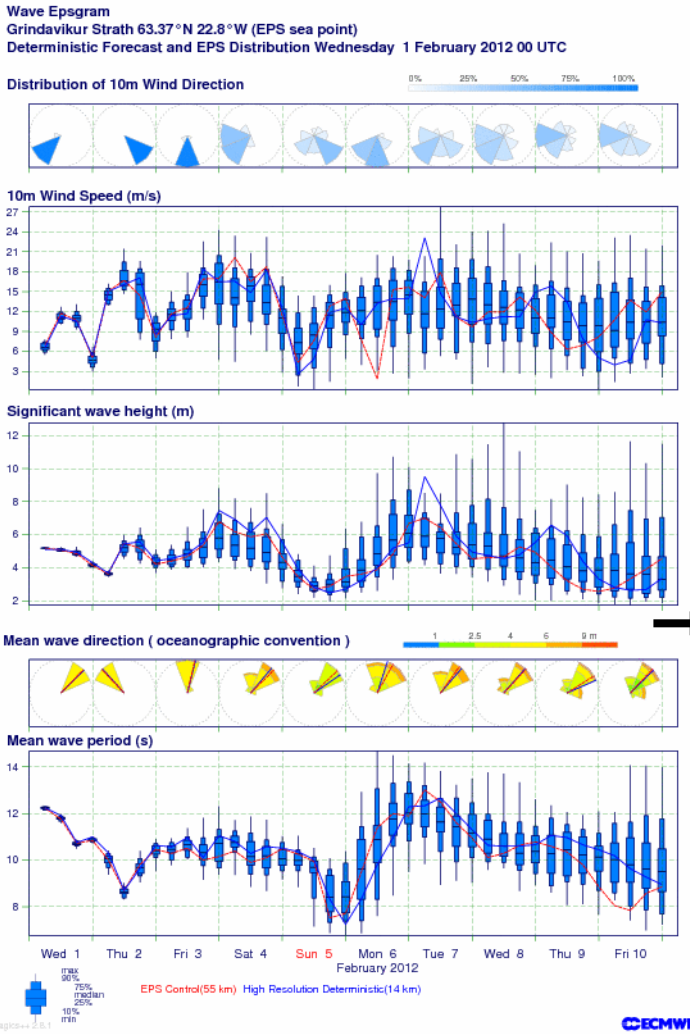


Wave Model Products on the web

Currently on our web: probability for set thresholds (6m)

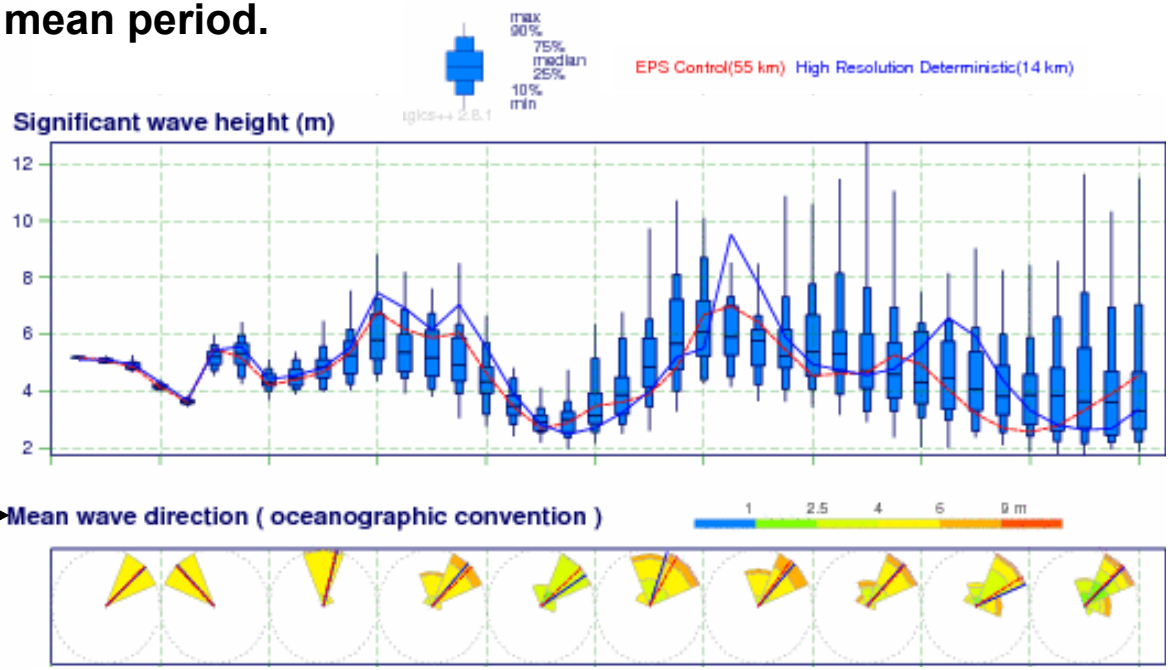


A bit more compact: Wave EPSgram:



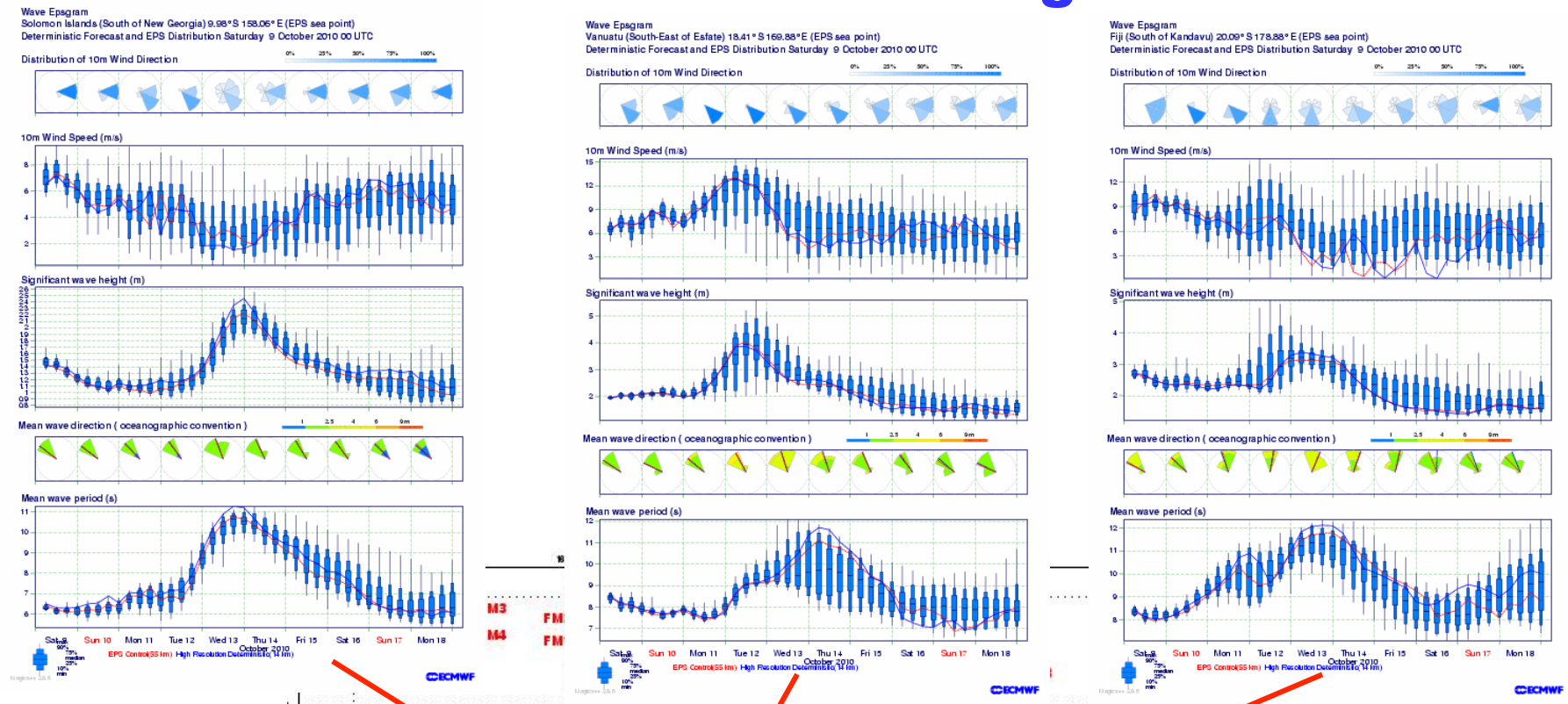
South of Grindavik, Iceland

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

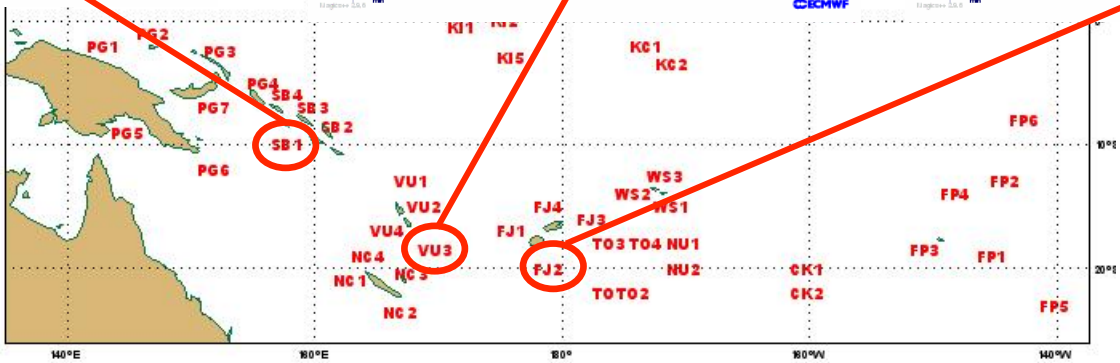


Each octant is coloured based on the distribution of the significant wave height associated with each mean direction. The coloured areas correspond to the fractional number of ensemble members with wave height in the range specified by the coloured ruler.

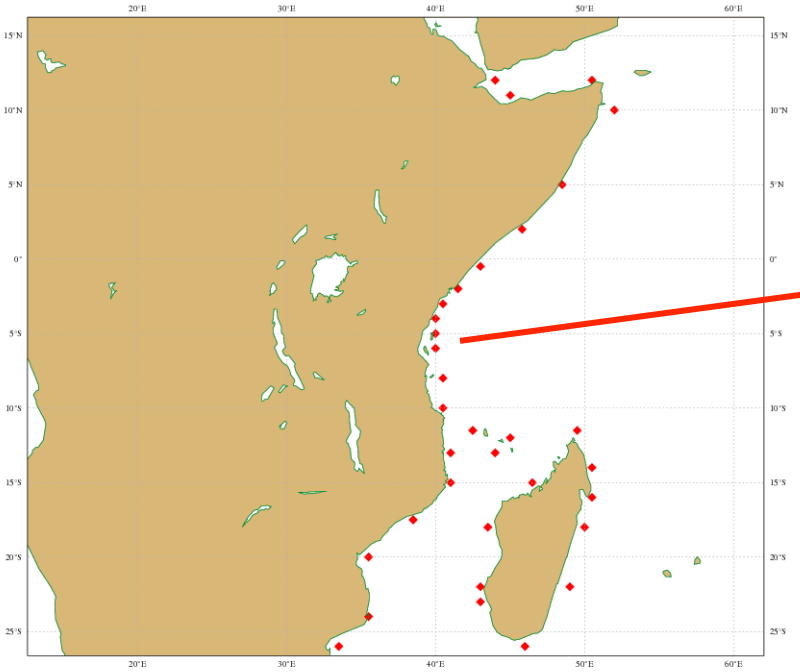
EPS Wave Model Products on the web: SWFDP Pacific wave EPSgrams:

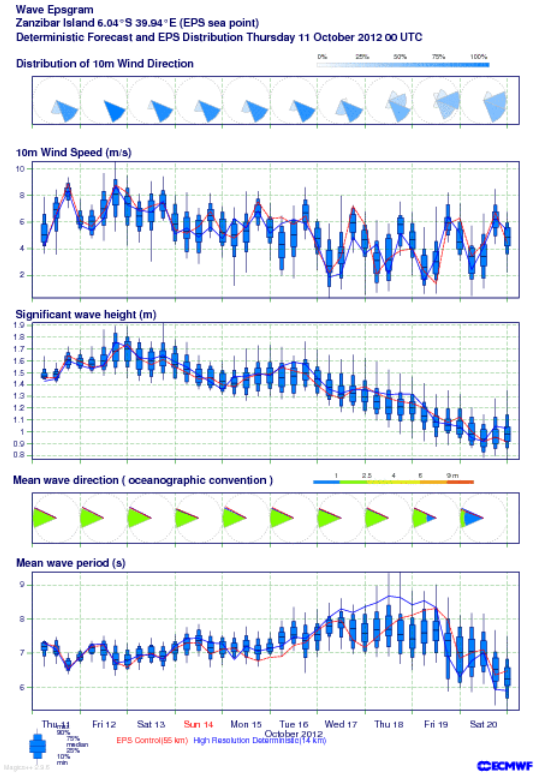


Set of locations where wave EPSgram are available



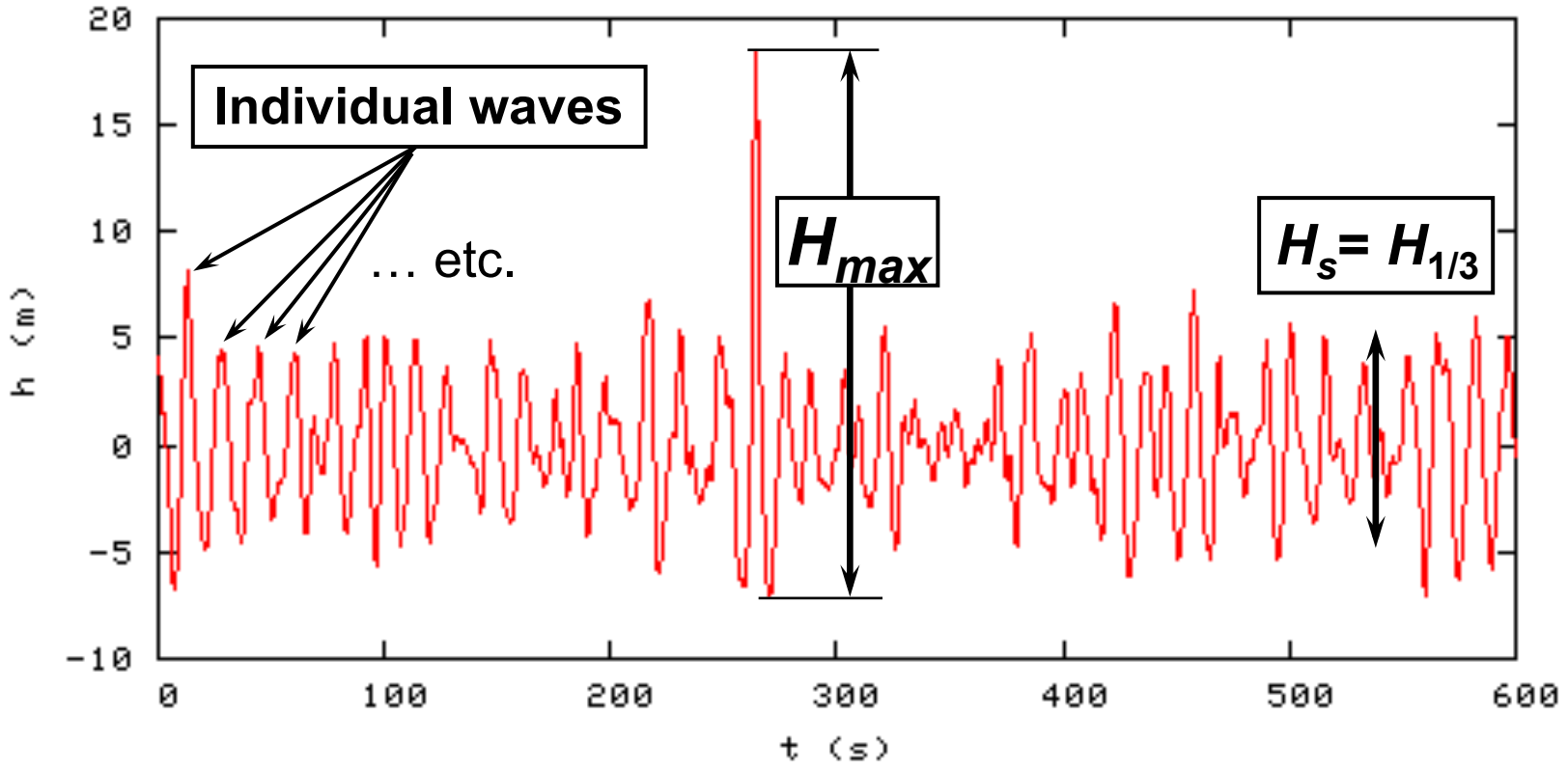
EPS Wave Model Products on the web: SWFDP East Africa wave EPSgrams:





Set of locations where wave EPSgram are available

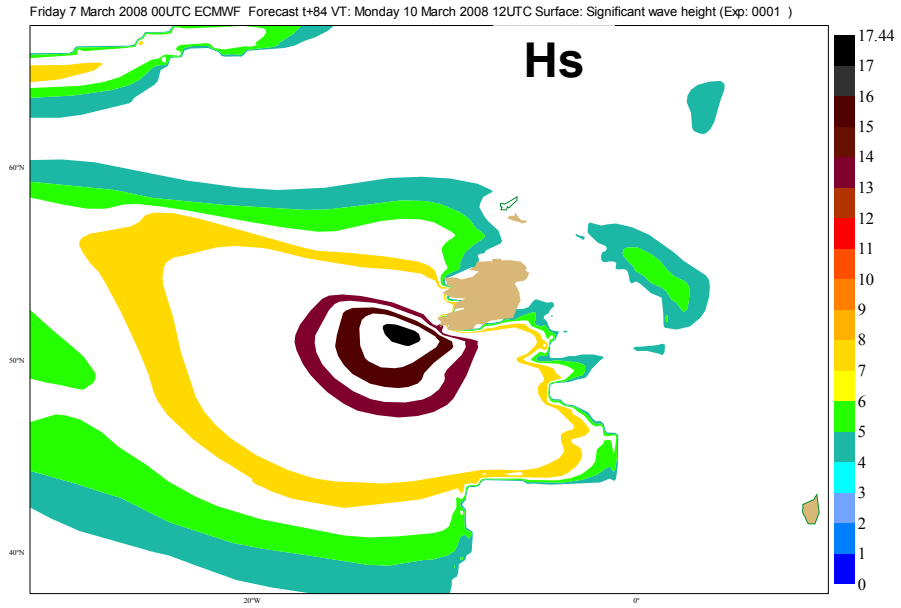
Individual Waves, Significant Wave Height, H_s, Maximum Individual Wave Height, H_{max}, and Freak Wave

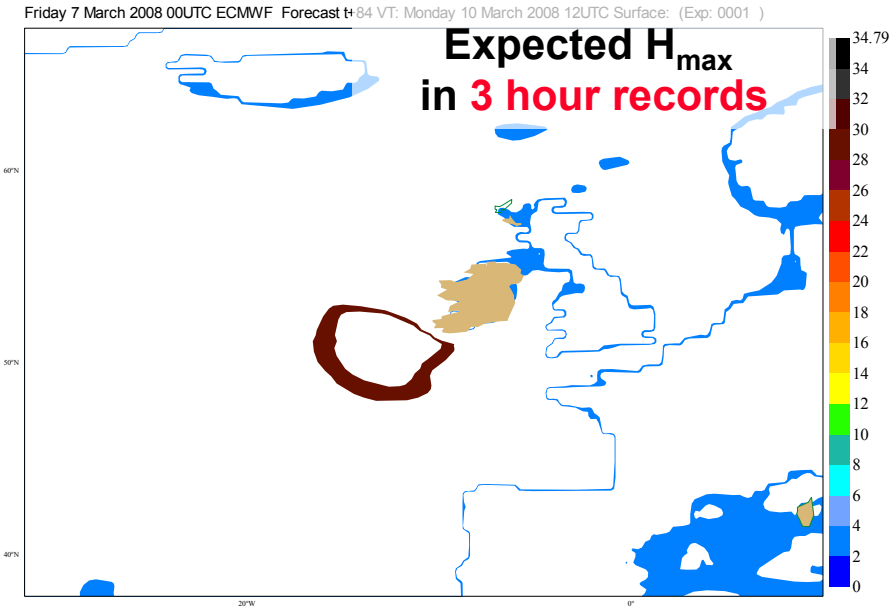


If $H_{max} > 2\,H_s$ ➔ freak wave event

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:





March 10th, 2008, 12UTC
Forecasts fields from
Friday 7th March, 2008, 0 UTC

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

ECMWF

Large swell reaching la Réunion, May 2007: the aftermath

Lagon de Trou d'Eau

Coastal flooding

Fisherman who was swept out to sea rescued by helicopter.

Saint-Leu. Photo Ludovic Lai-Yu

Hotel hit hard

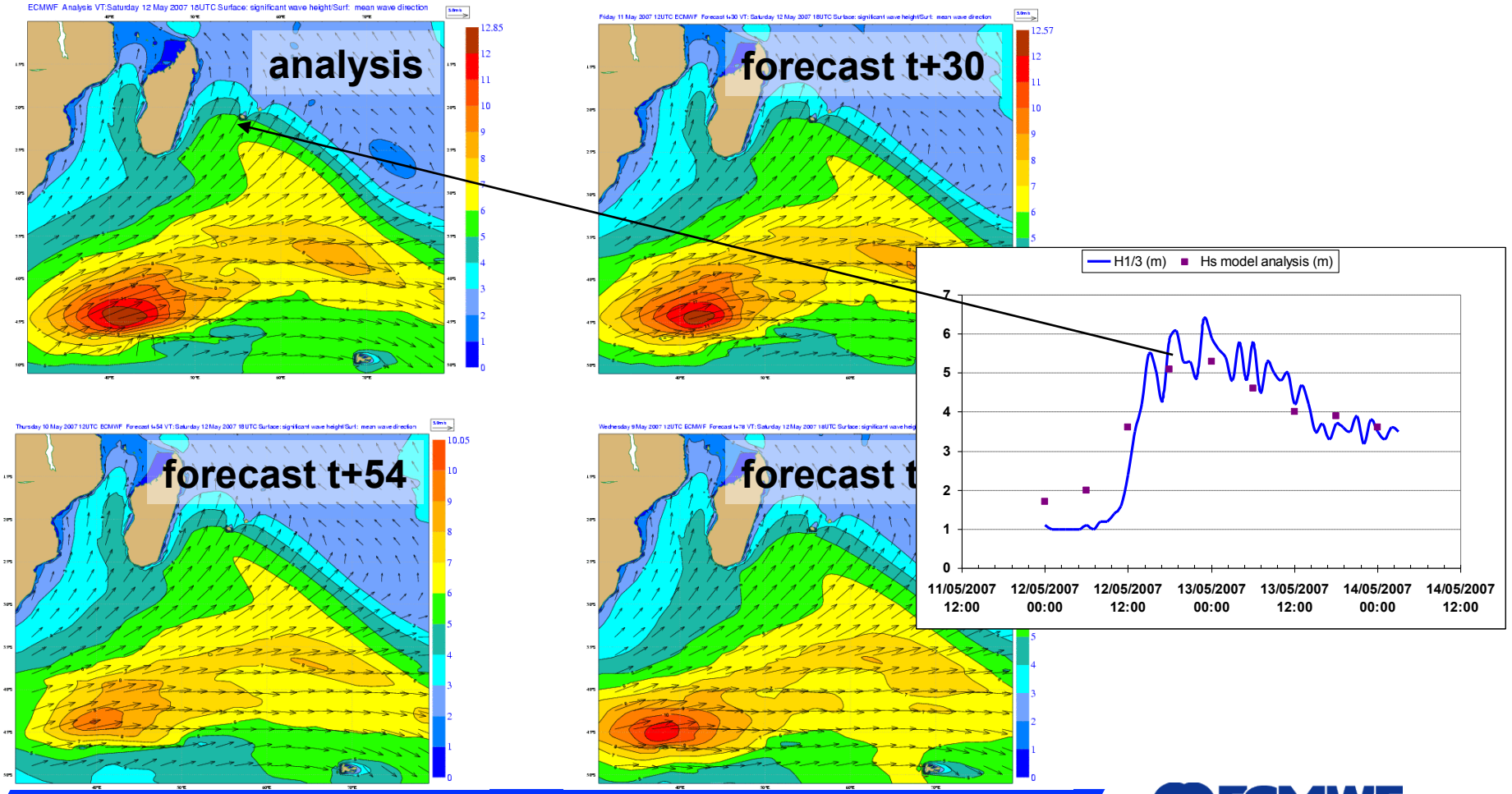
Sea front destroyed

All pictures courtesy of CLICANOO (www.clicanoo.com)

Large Swell Reaching la Réunion: The Model

Sig. wave height and mean propagation direction valid on May 12, 2007, 18UTC.

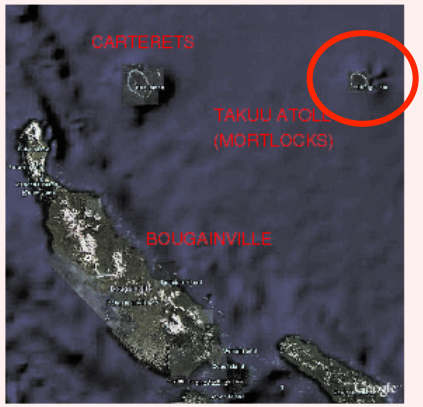
The model has nicely predicted significant wave height in excess of 5m in the evening of the 12th.



Case study: long swell affecting the western Pacific in December 2008

Coastal flooding linked to high tide, barometric surge and long swell, e.g. Nukutoa on Takuu Atoll:

Takuu Atoll (the Mortlock Islands)



Flooding Damage

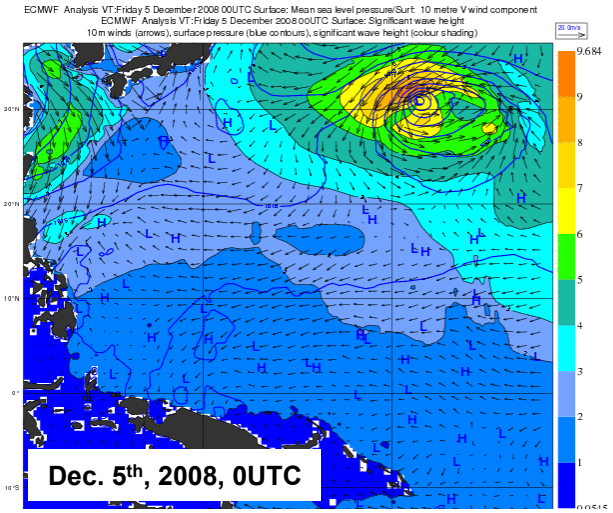
A Hydraulic Jump

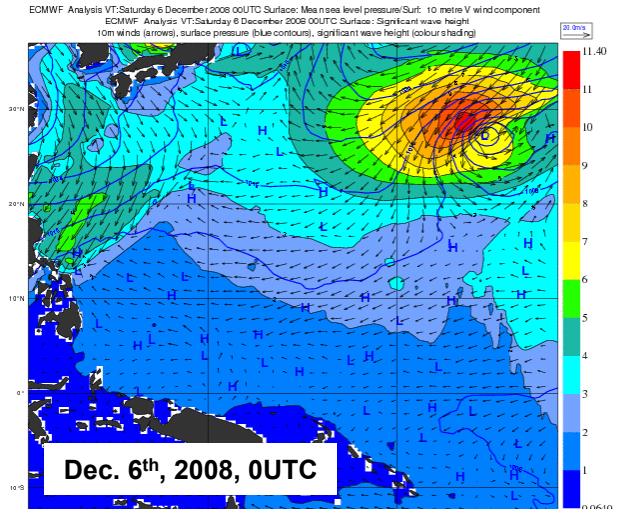
Pictures courtesy of
John Hunter
Antarctic Climate & Ecosystems
Hobart, Tasmania, Australia

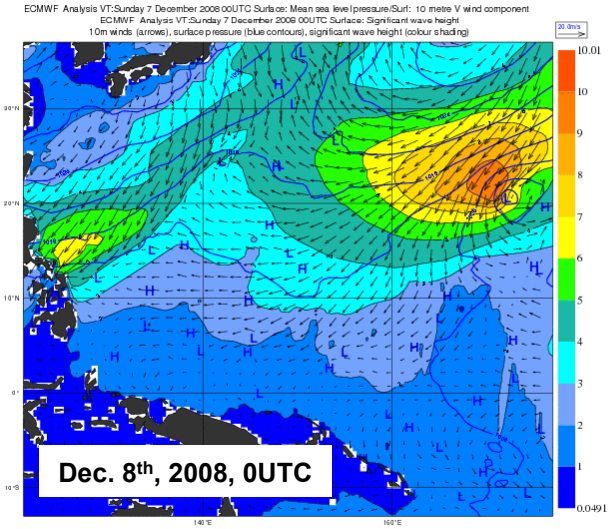
Damaged Schoolbooks

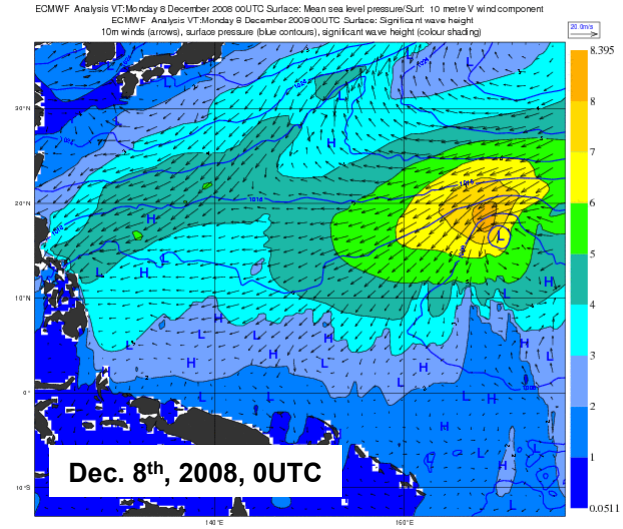
Case study: long swell affecting the western Pacific in December 2008

10m winds (arrows)
Sfc pressure (contours)
Sig. wave height (shading)





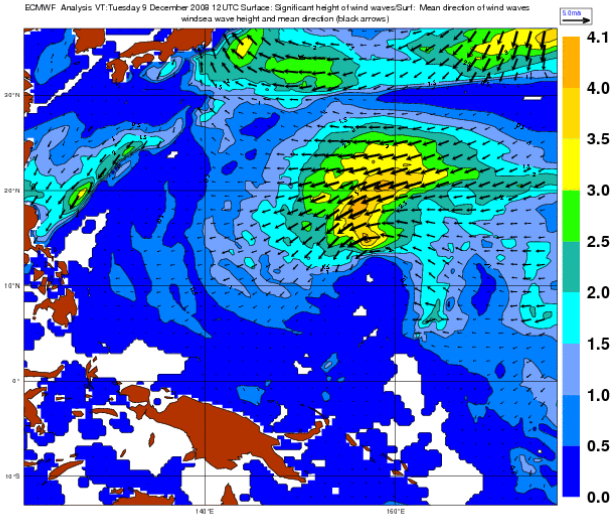


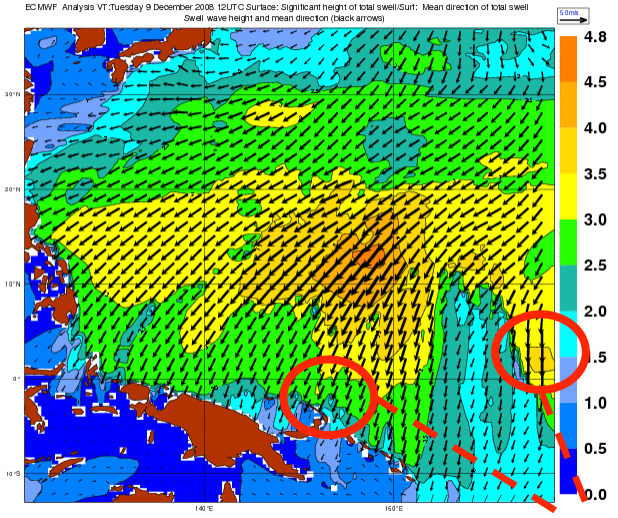


Case study: long swell affecting the western Pacific in December 2008

Dec. 9th, 2008, 12 UTC

Windsea wave height and direction

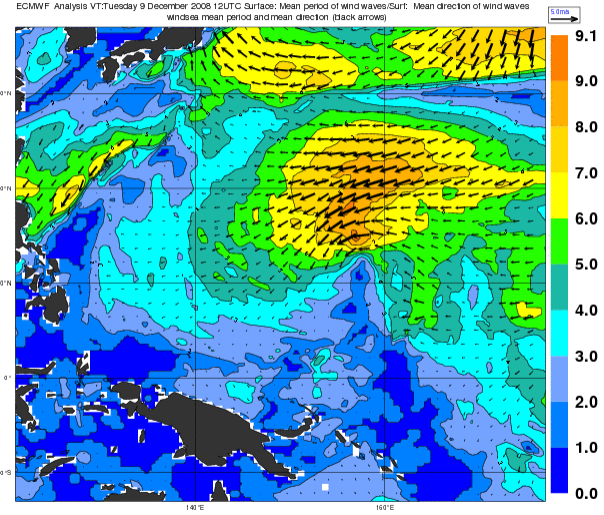


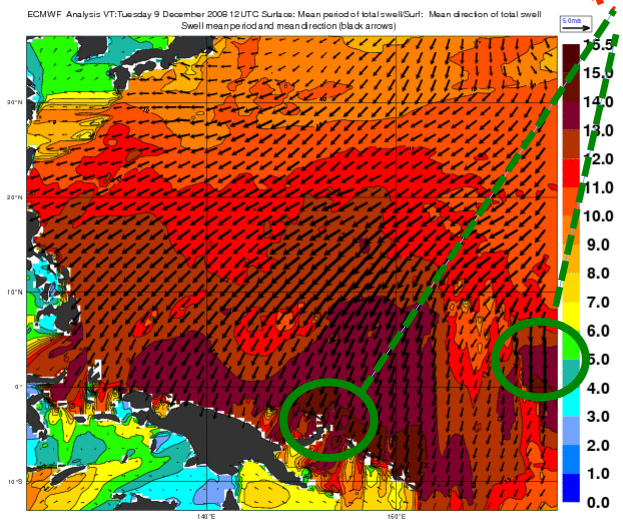


Swell wave height and direction

Long swell reaching South !

Windsea Mean period and direction



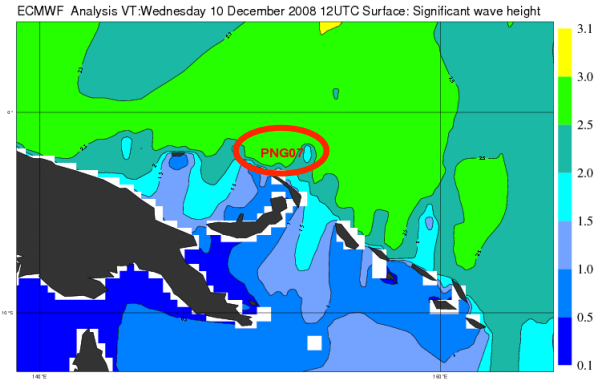


Swell Mean period and direction

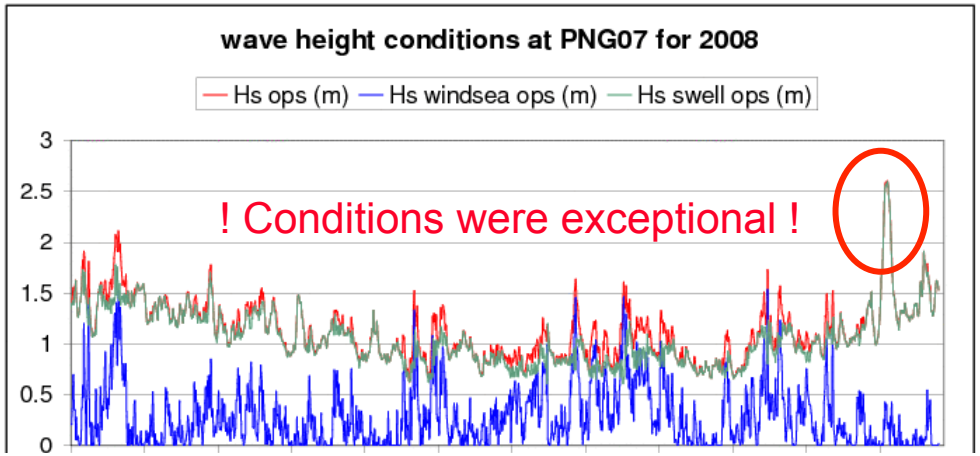
ECMWF

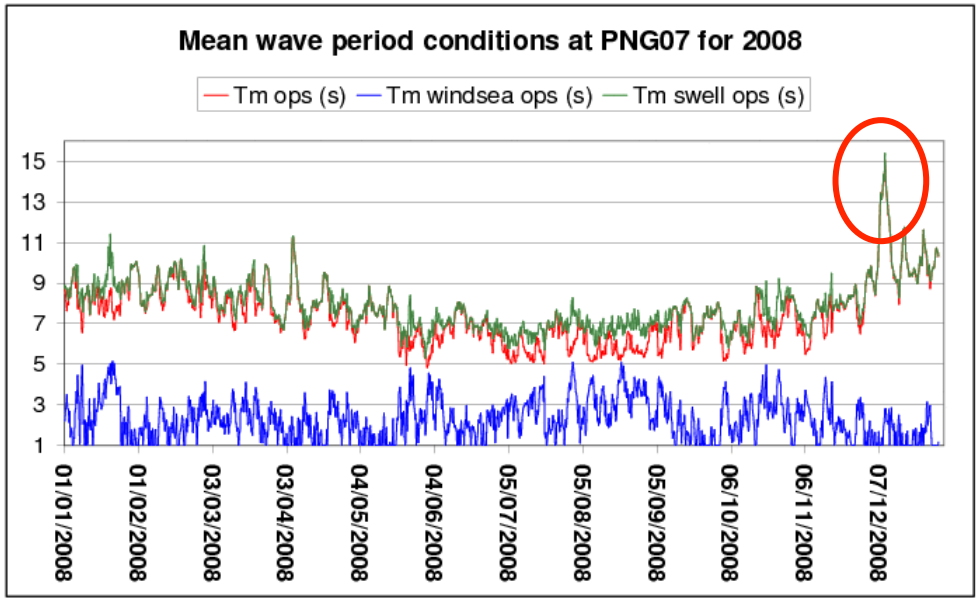
Case study: long swell affecting the western Pacific in December 2008

Wave condition north of New Ireland (PNG07) for 2008, based on ECMWF analysis



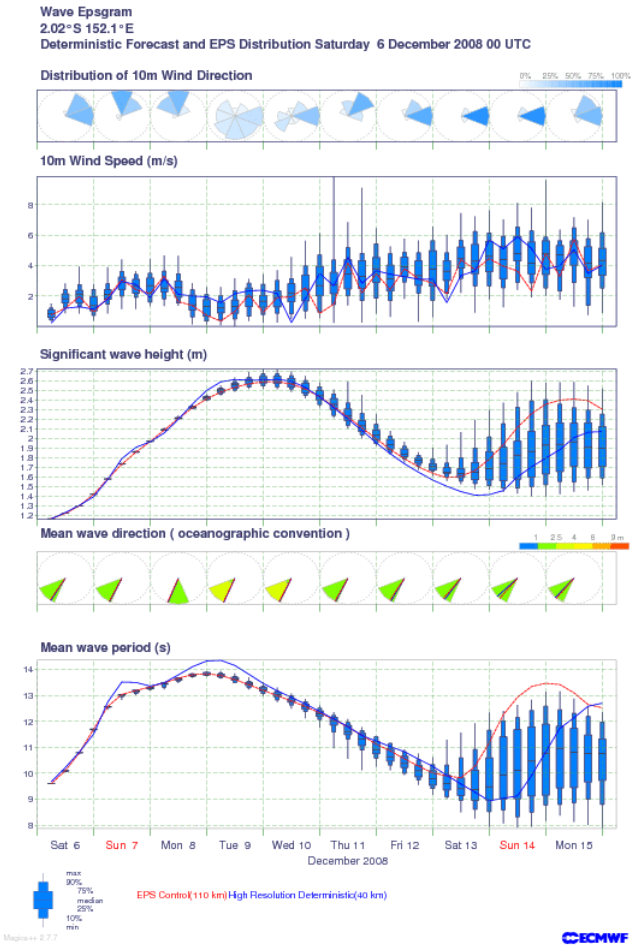
Sig. wave height Dec. 10th, 2008, 0 UTC



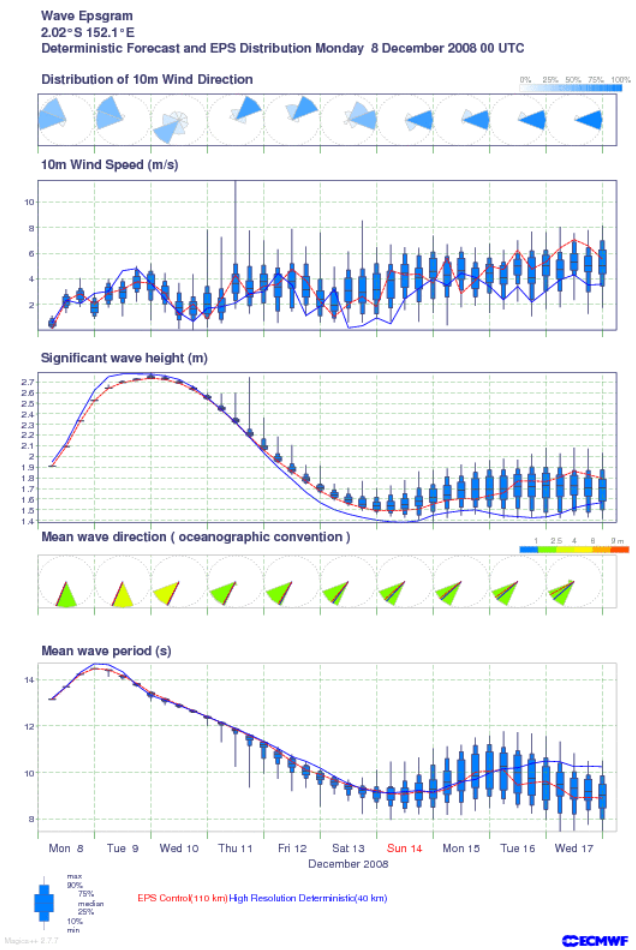


Case study: long swell affecting the western Pacific in December 2008: EPS

Wave Epsgram from Dec. 6th, 2008 at PNG07



Wave Epsgram from Dec. 8th, 2008 at PNG07



Duck, North Carolina