Extreme waves in the ECMWF operational wave forecasting system

Jean-Raymond Bidlot
Peter Janssen
Saleh Abdalla

European Centre for Medium range Weather Forecasts

Shinfield Park, RG2 9AX, Reading,

United Kingdom

+44-118-9499-708

jean.bidlot@ecmwf.int

Outline

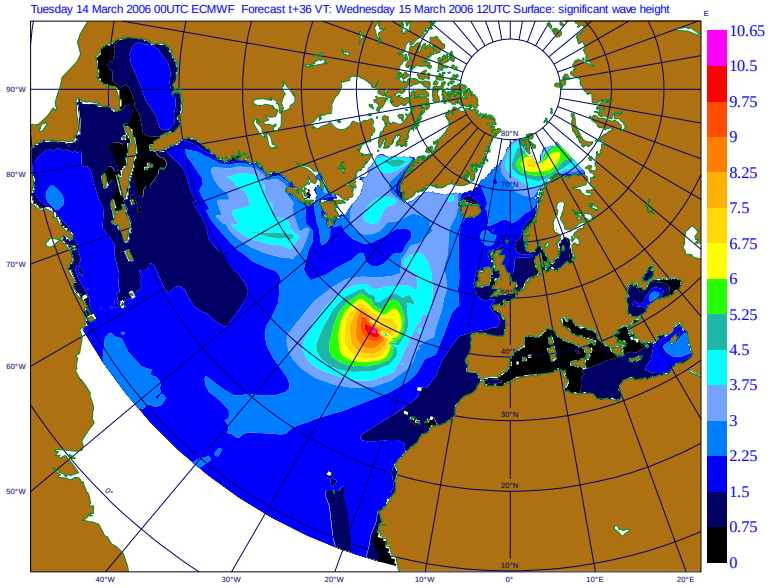
- **ECMWF wave forecasting system.**
- **Impact of recent improvements.**
- **Extreme wave forecasting:**
  - **Ensemble prediction system (EPS)**
  - **Freak wave**

Operational wave forecasting at ECMWF

- **A version of WAM cycle 4 (ECWAM) is used at ECMWF.**
- **It is an integral part of the Centre's forecasting systems.**
- **The wave model benefits from improvements in the atmospheric model via the forcing winds. Work on improving the wave model physics, dynamics and data assimilation is continuing.**
- **Several operational configurations exist.**

1) Limited area model (LAW)

- From 9°N to 81 °N and 98°W to 42°E
- 28 km grid spacing (→ 15km soon).
- 30 frequencies and 24 directions
- Forced by 10m wind fields from the global atmospheric model.
- Data assimilation of altimeter wave heights (ENVISAT and Jason) and ASAR spectra (ENVISAT).
- 2 daily forecasts (from 0 & 12 Z) extending to day 5.

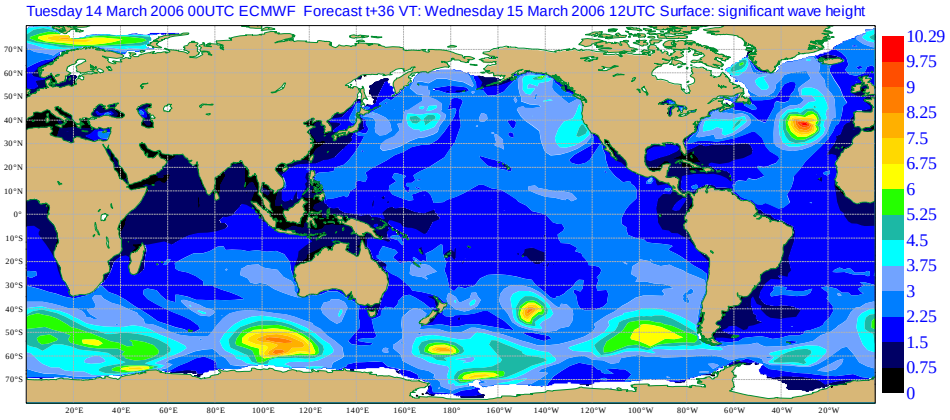


Forecast wave height on 15/03/2006 12UTC.

ECMWF wave model configurations

2) Global models

- **Global from 81°S to 81 °N**
- **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 of ENVISAT and Jason altimeter wave heights and ENVISAT ASAR spectra.**



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

ECMWF wave model configurations

Deterministic model

- 40 km grid spacing.
- 30 frequencies and 24 directions.
- Coupled to the TL799 model (~25km resolution).
- Analysis every 6 hrs and 10 day forecasts from 0 and 12UTC and 4 day forecasts from 6 and 18 UTC.

Probabilistic forecasts

- 110 km grid spacing.
- 30 frequencies and 24 directions.
- Coupled to the TL399 model (~50km resolution).
- (50+1) 10 day forecasts from 0 and 12Z.

ECMWF wave model configurations

Monthly forecasts

- 1.5°x1.5° grid.
- 25 frequencies and 12 directions.
- Coupled to the TL159 model.
- Deep water physics only.

Seasonal forecasts

- 3.0°x3.0° .
- 25 frequencies and 12 directions.
- Coupled to the T95 model.
- Deep water physics only.

ECMWF wave model configurations

ERA40 reanalysis (1957-2002)

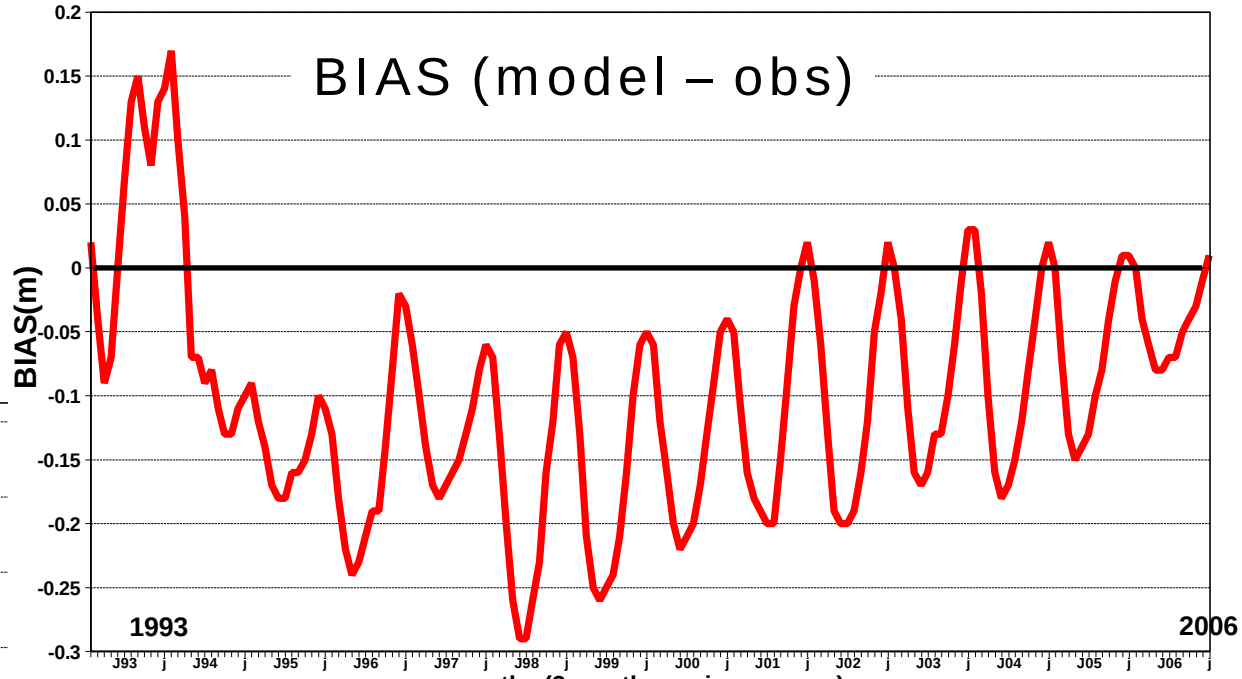
- 1.5°x1.5° grid.
- 25 frequencies and 12 directions.
- Coupled to the TL159 model.
- Deep water physics only.
- 45 years of wave analysis
- The data were analysed at knmi.

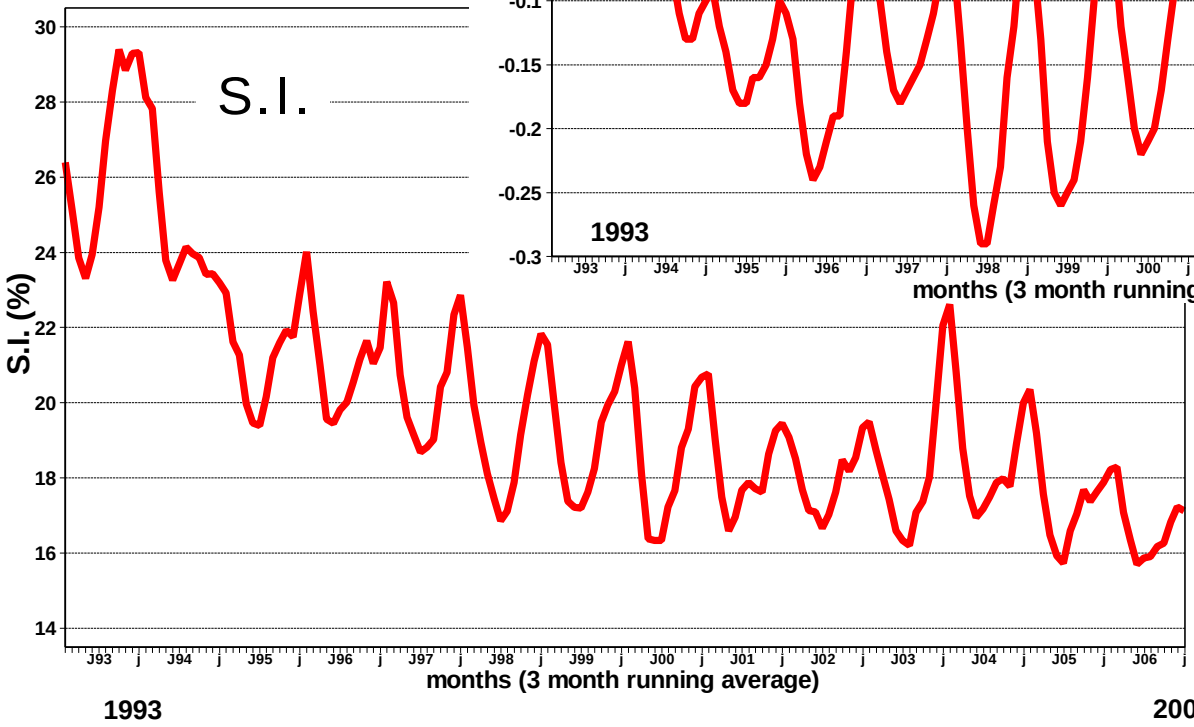
http://www.knmi.nl/waveatlas

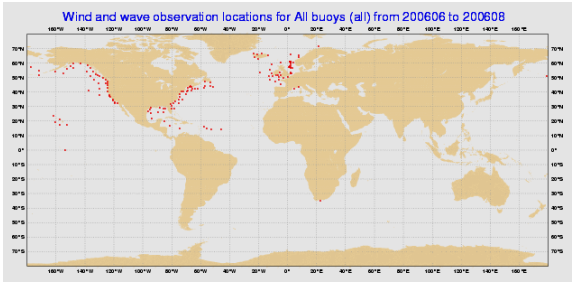
Interim reanalysis (1989 to present)

- 1.0°x1.0° grid.
- 30 frequencies and 24 directions.
- Coupled to the latest TL255 model.
- Shallow physics only.
- Production has started.
- Early assessment indicates a much improved data set.

Monitoring: ECMWF analysis against GTS in-situ data





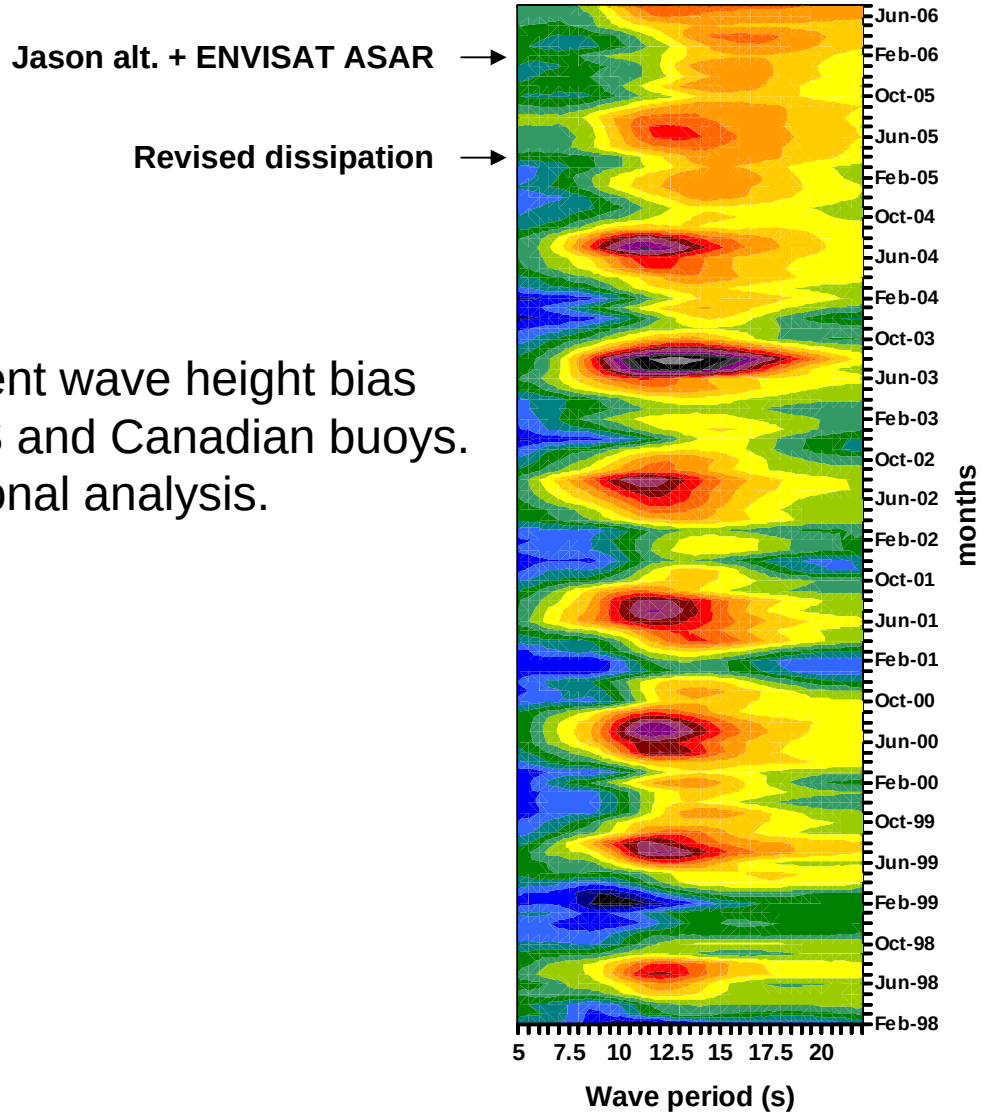


GTS in-situ wave data locations

S.I.: standard deviation of error normalised by the mean of the observations

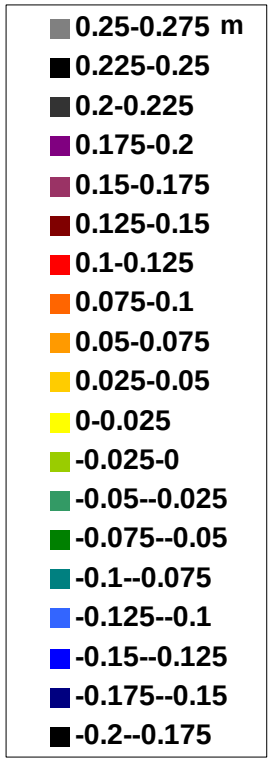
ECMWF

ECMWF analysis *versus* buoy spectral data



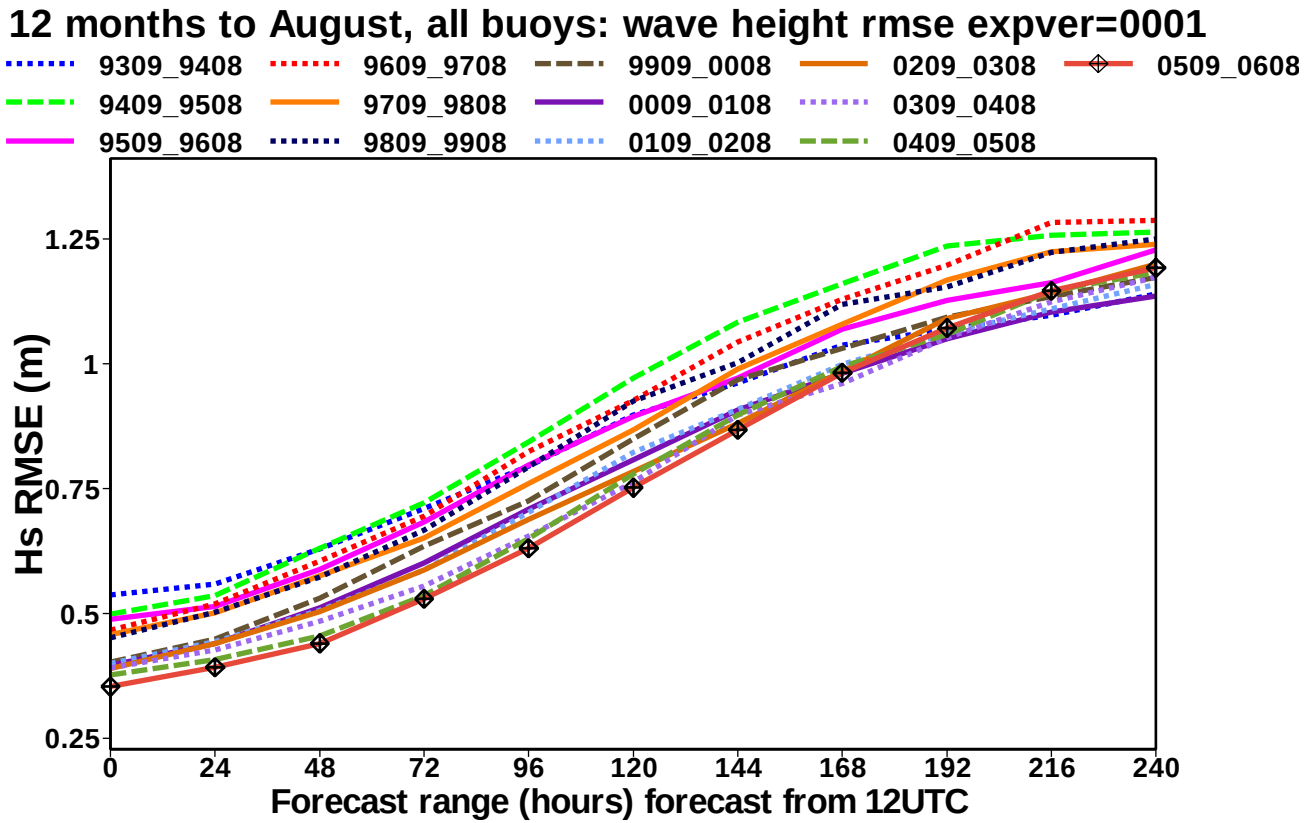
Equivalent wave height bias at all US and Canadian buoys. Operational analysis.

Bias (m) : model - buoy



ECMWF forecasts *versus* GTS in-situ data

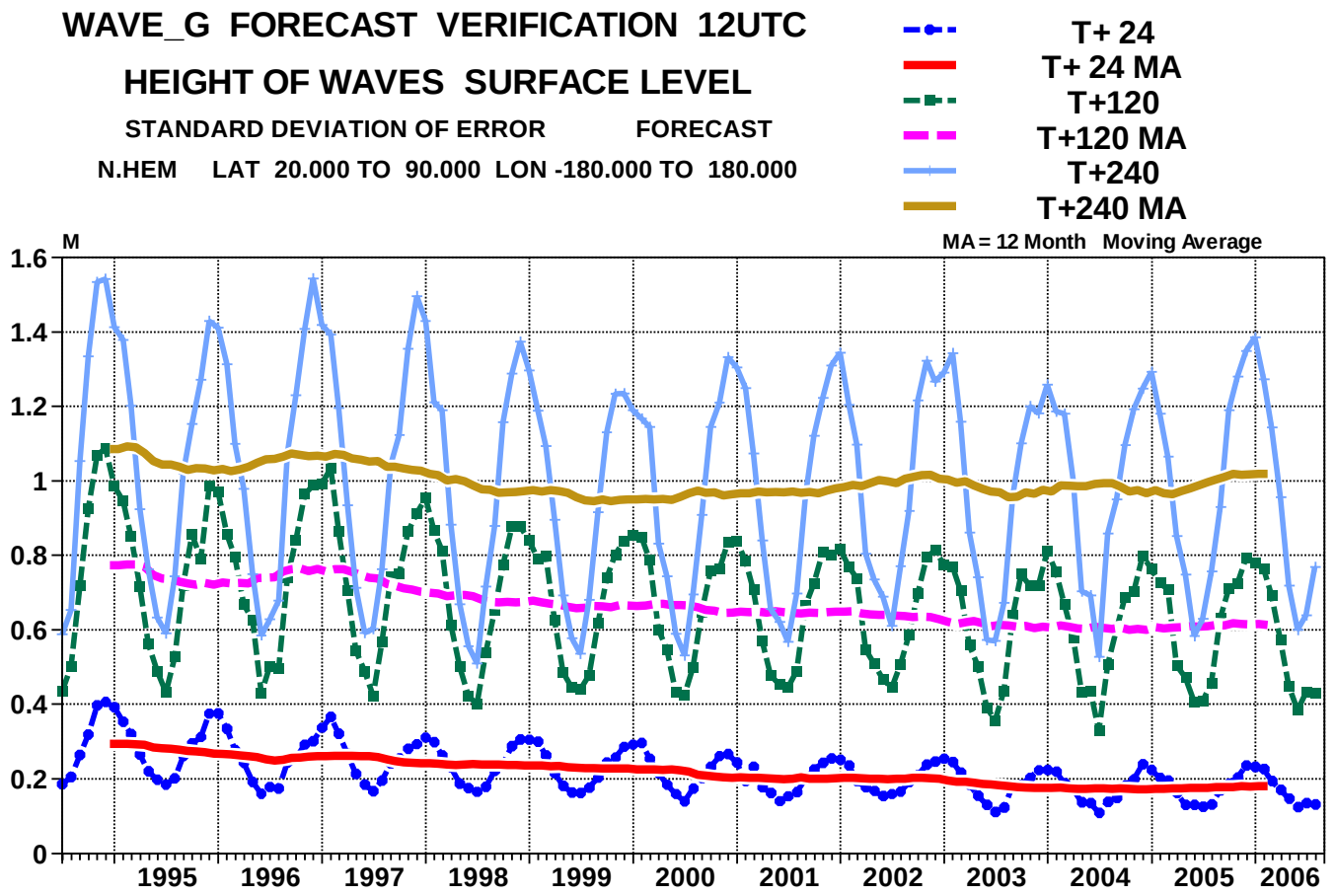
Operational forecasts



ECMWF forecasts *versus* own analysis

Forecast scores are also obtained by verifying against own analyses as it is done with atmospheric fields.

Standard deviation of error for N.Hem.

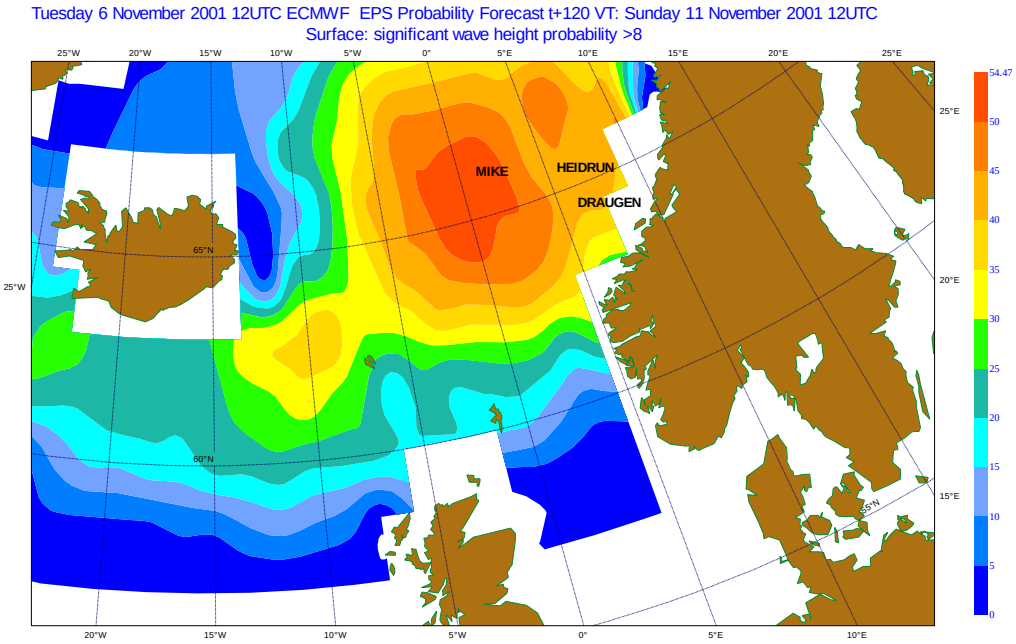


Ensemble forecasting for waves

- **Beside its deterministic model, ECMWF also runs an ensemble of 50 forecasts twice daily.**
- **These 50 forecasts are initialised from a set of perturbed analyses, designed to represent the inherent uncertainty in the operational analysis. Similarly, the uncertainty in the model physical parametrisation is accounted for by stochastic perturbations. Because of limited computer resources and lack of predictability of small scales, these forecasts are run with a coarser resolution.**
- **A control forecast is also run at that reduced resolution.**
- **These (50+1) forecasts are used to derive forecast error estimate and forecast probabilities.**
- **Waves are in the EPS since June 1998.**

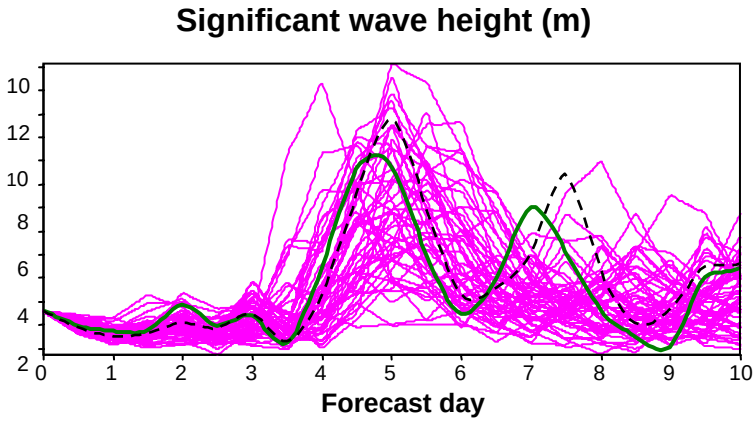
Old example: 10-11 November storm in the Norwegian Sea

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



06 November 2001 12 UTC ECMWF EPS probability forecast t+120

SIGNIFICANT WAVE HEIGHT GREATER than 8 m



Forecasts from 6 Nov 2001, 12 UTC
at platform Heidrun

Perturbed forecasts

Control forecast

Deterministic forecast

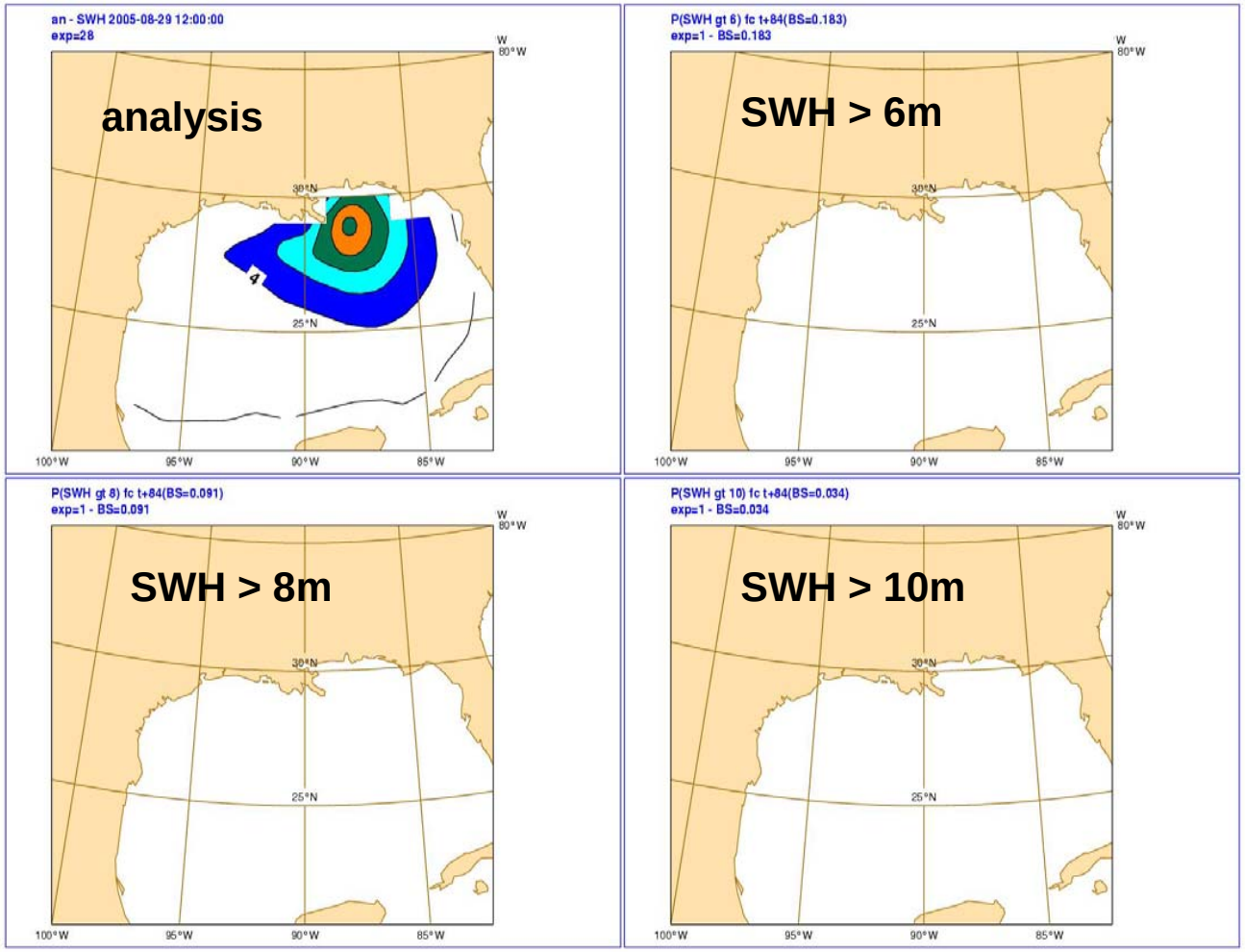
Katrina: SWH probability in the then operational system T255 (~80km) from opereational analysis in +84h fcs

The top-left panel shows the significant wave height (SWH) in the T799 analysis (cont interval is 2m).

The other panels show the probabilities that:

- SWH>6m (t-right)
- SWH>8m (b-left)
- SWH>10m (b-right)

Prob cont iso are 2/5/10/20/40/60%.



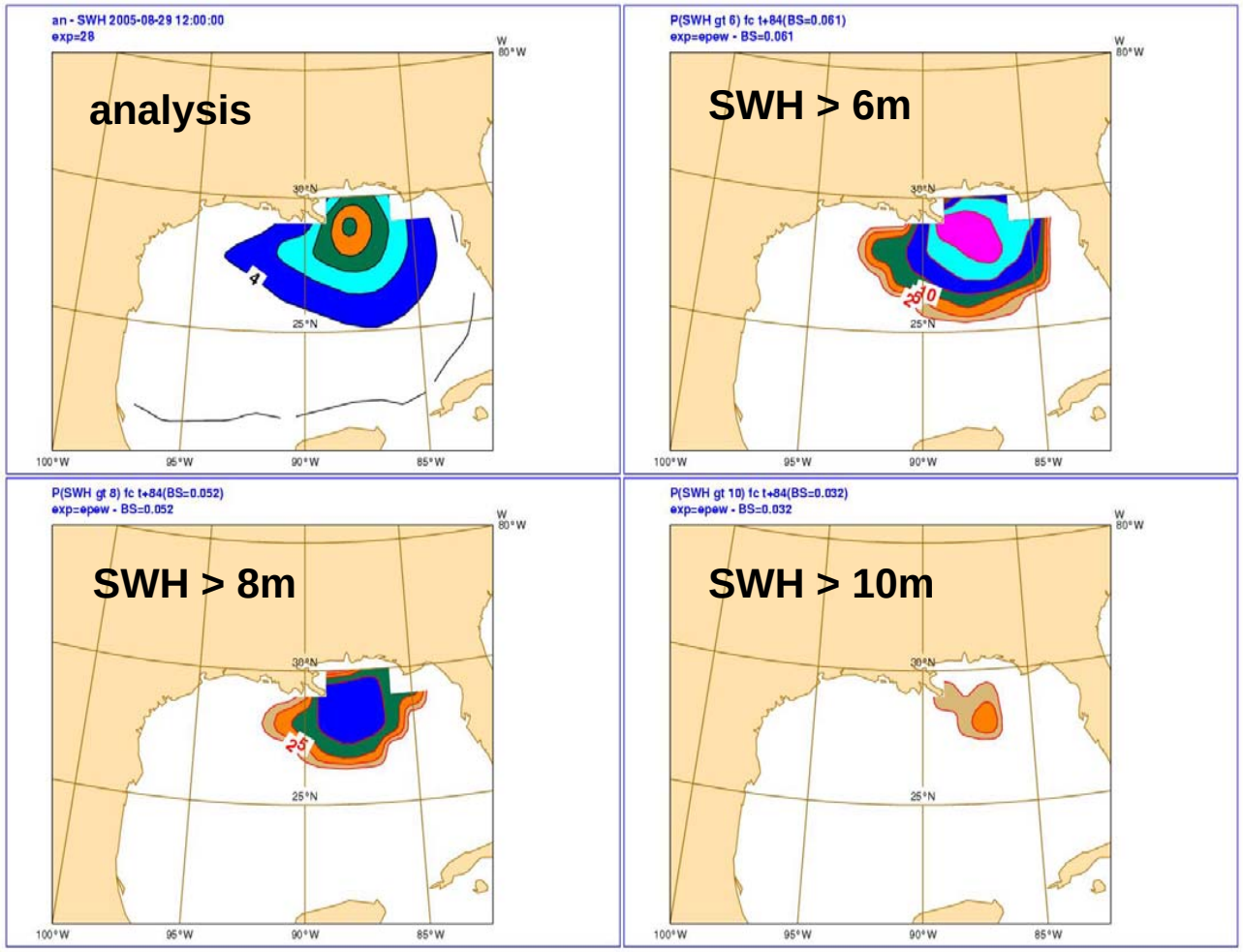
Katrina: SWH probabilities in the new operational_system T399 (50 km) from operational analysis in +84h fcs

The top-left panel shows the significant wave height (SWH) in the T799 analysis (cont interval is 2m).

The other panels show the probabilities that:

- SWH>6m (t-right)
- SWH>8m (b-left)
- SWH>10m (b-right)

Prob cont iso are 2/5/10/20/40/60%.

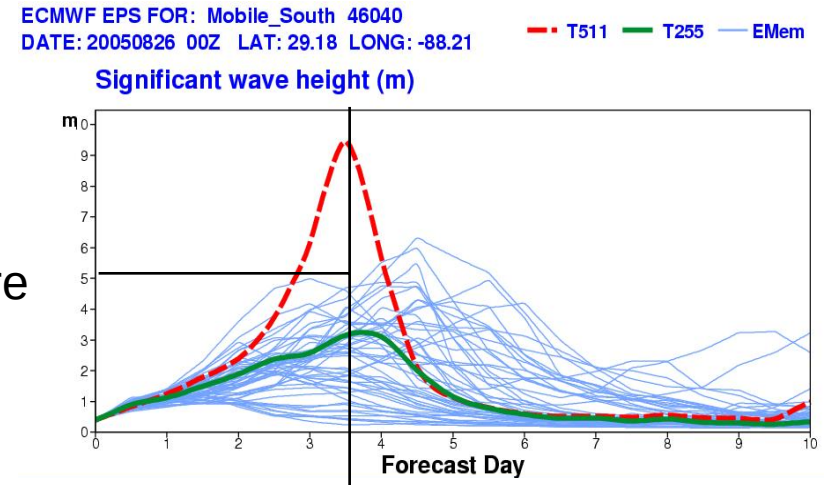


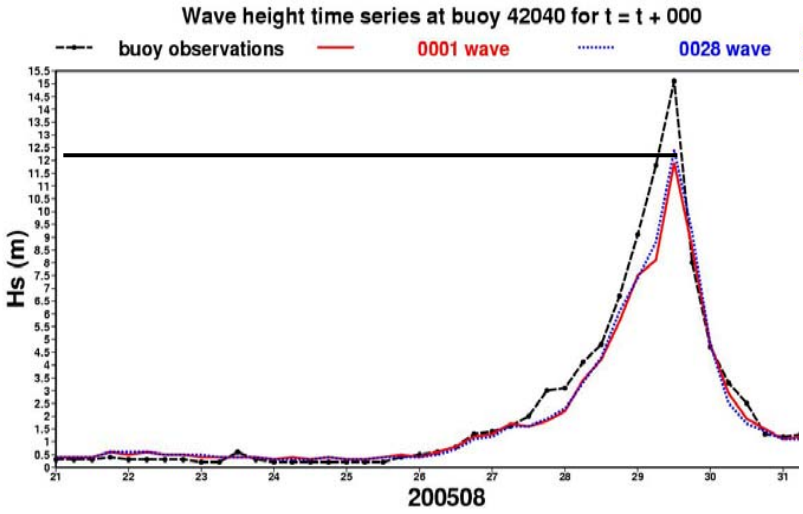
ECMWF

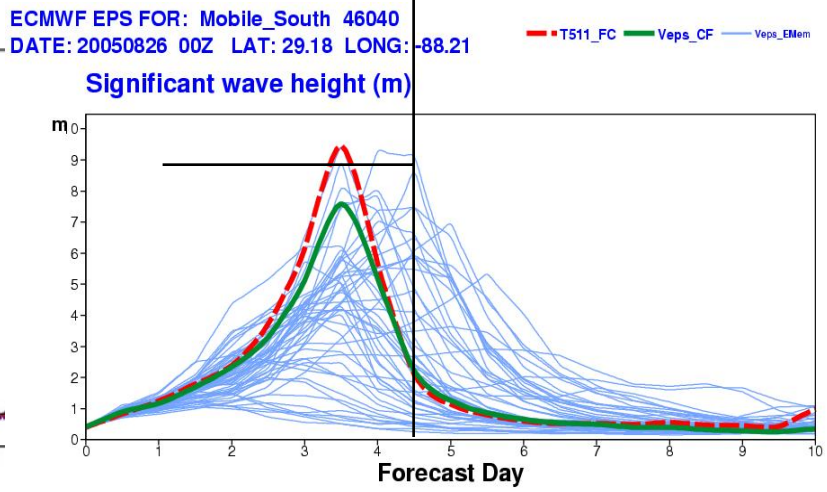
Katrina: SWH t+84h fcs at buoy, T399 and T255: resolution matters

Buoy 42040 obs for 12UTC of 29 Aug and t+84h forecasts from 26 Aug 00UTC.

Bottom-left panel: buoy measured SWH of 15m. ECMWF analysis at T511 and T799 produced SWH of 12m. EPS forecasts were up to ~5m (top-right), while VAREPS forecasts reached 9m (bottom-right).

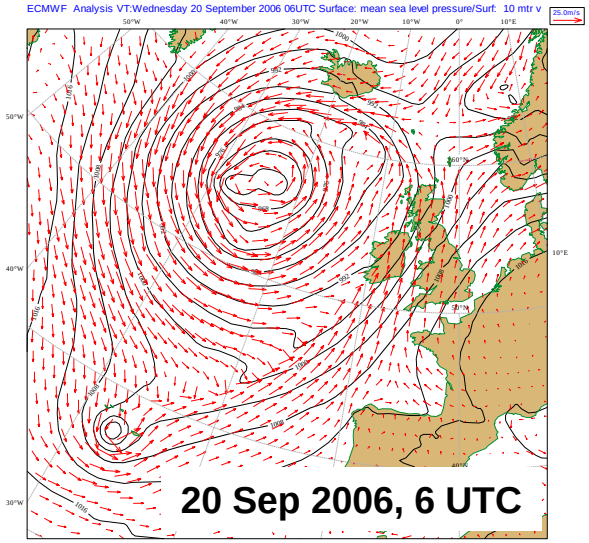


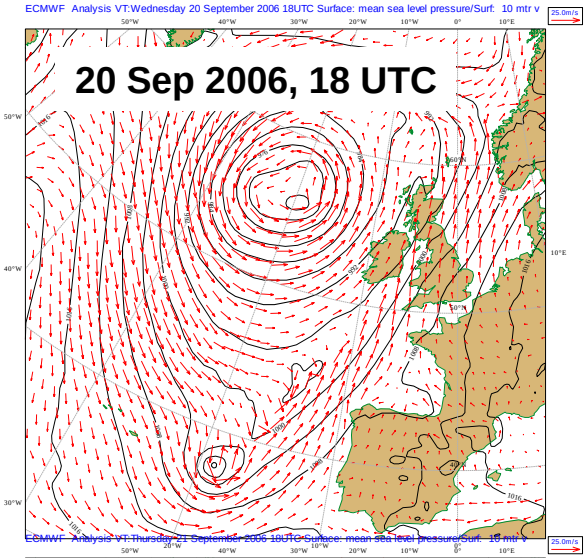


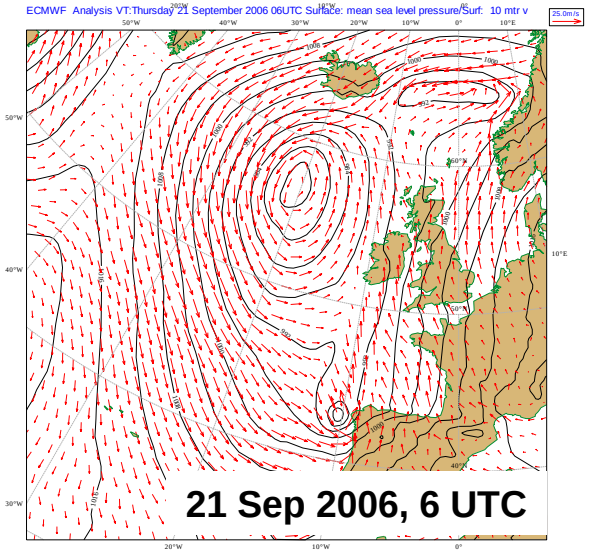


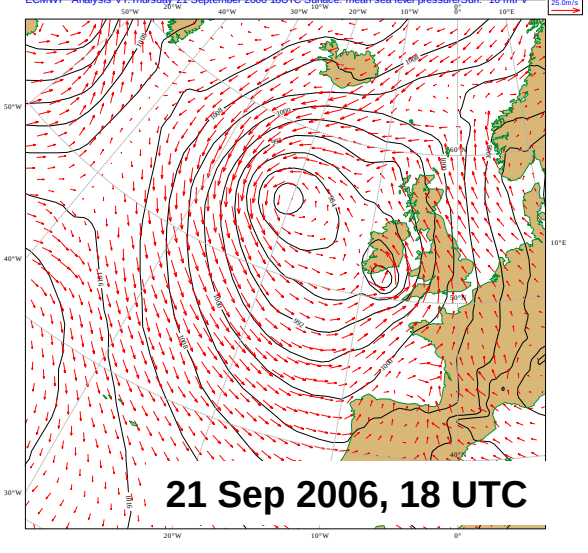
Recent example: extra-tropical Gordon landfall in Ireland

Analysed
mean Sea Level
pressure
and
10m winds

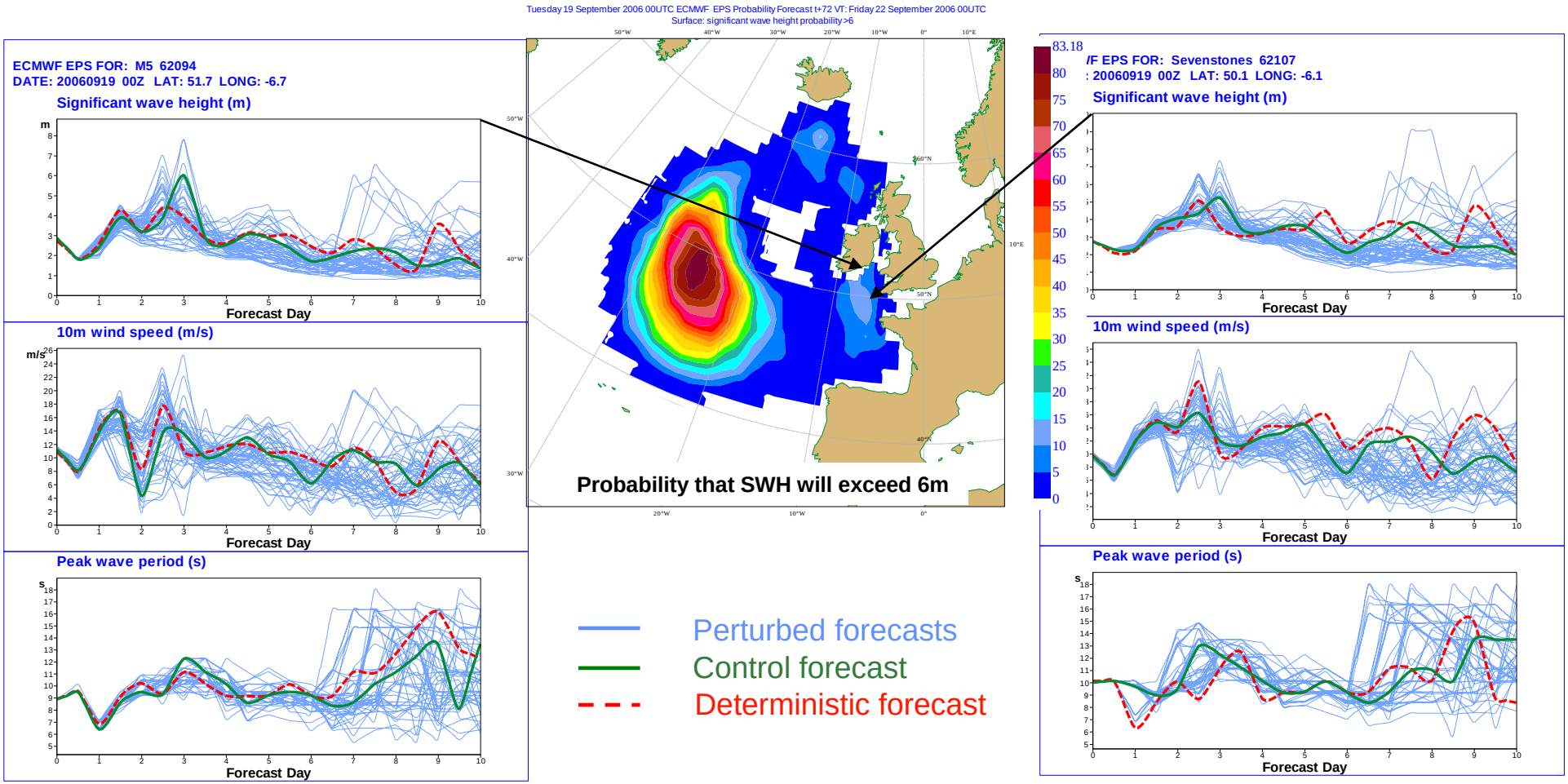




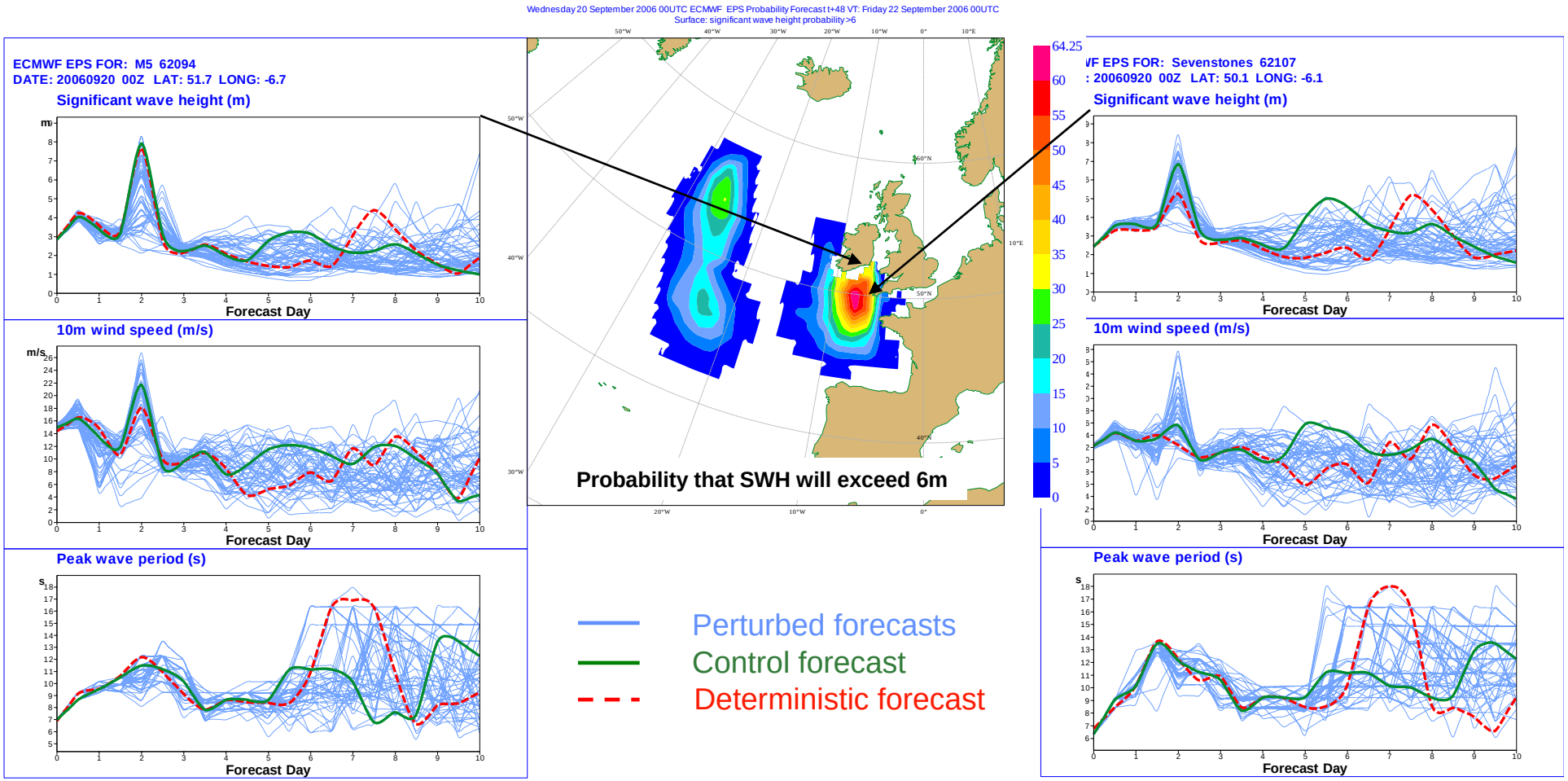




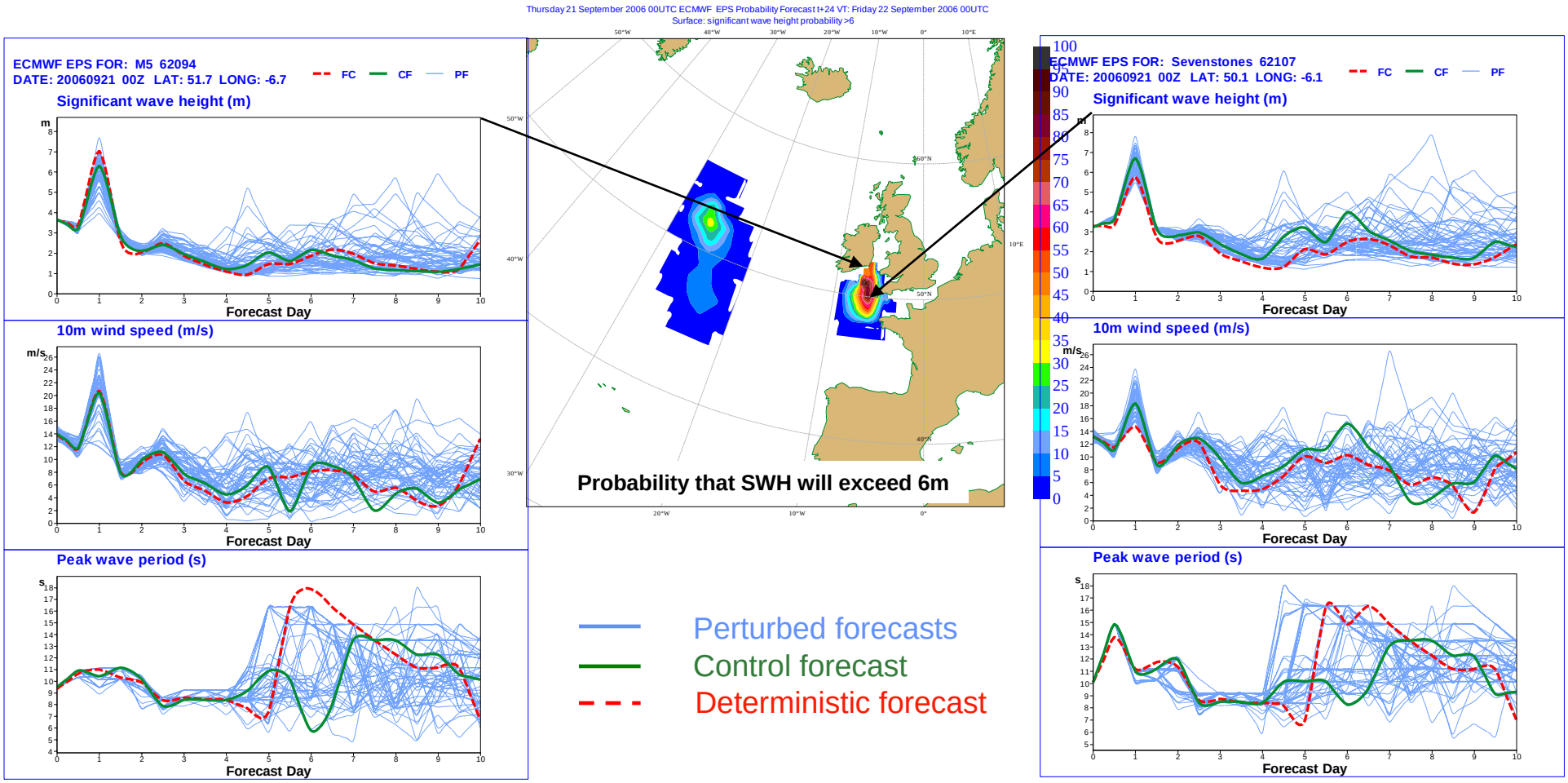
Extra-tropical Gordon landfall: 3-day forecasts



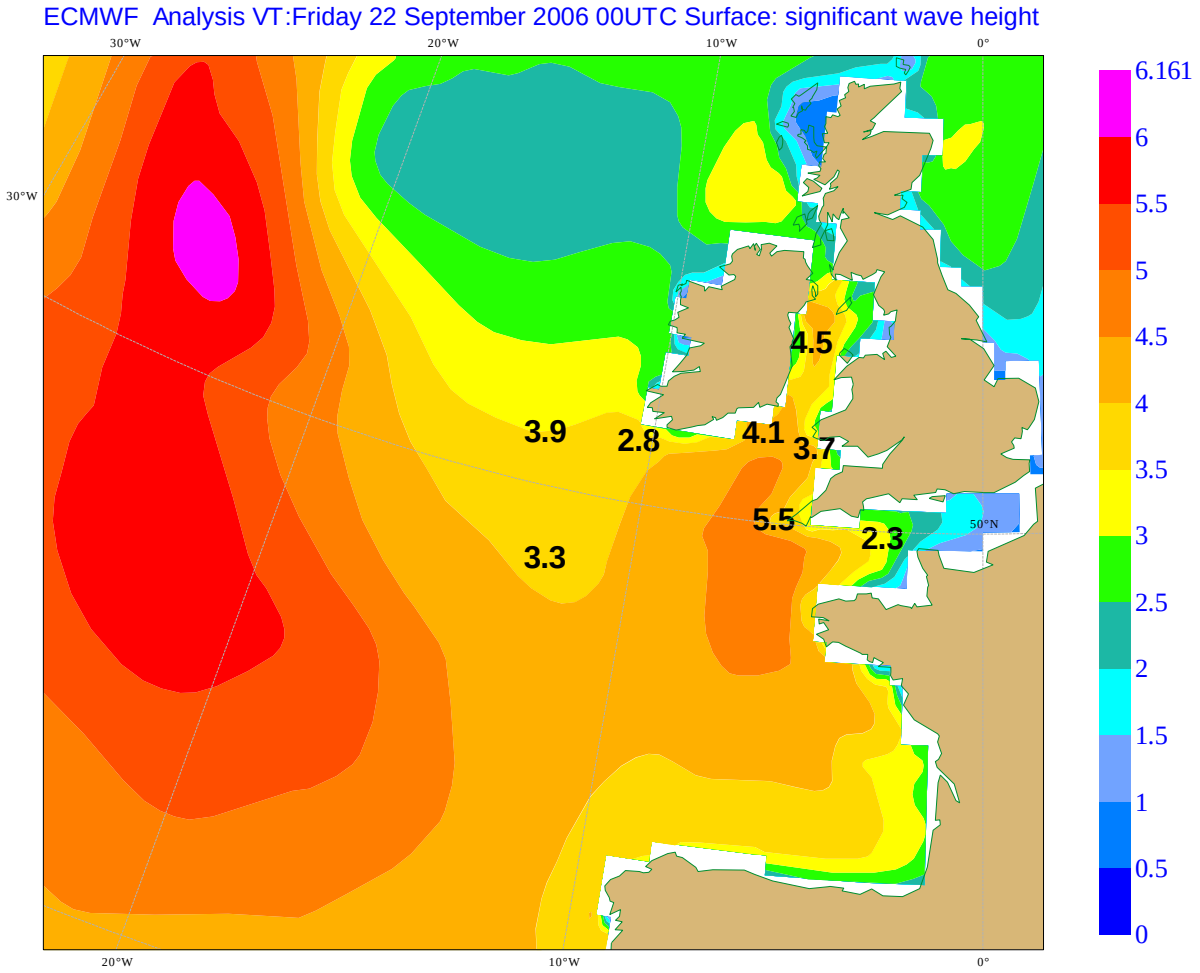
Extra-tropical Gordon landfall: 2-day forecasts



Extra-tropical Gordon landfall: 1-day forecasts



Extra-tropical Gordon landfall: analysis



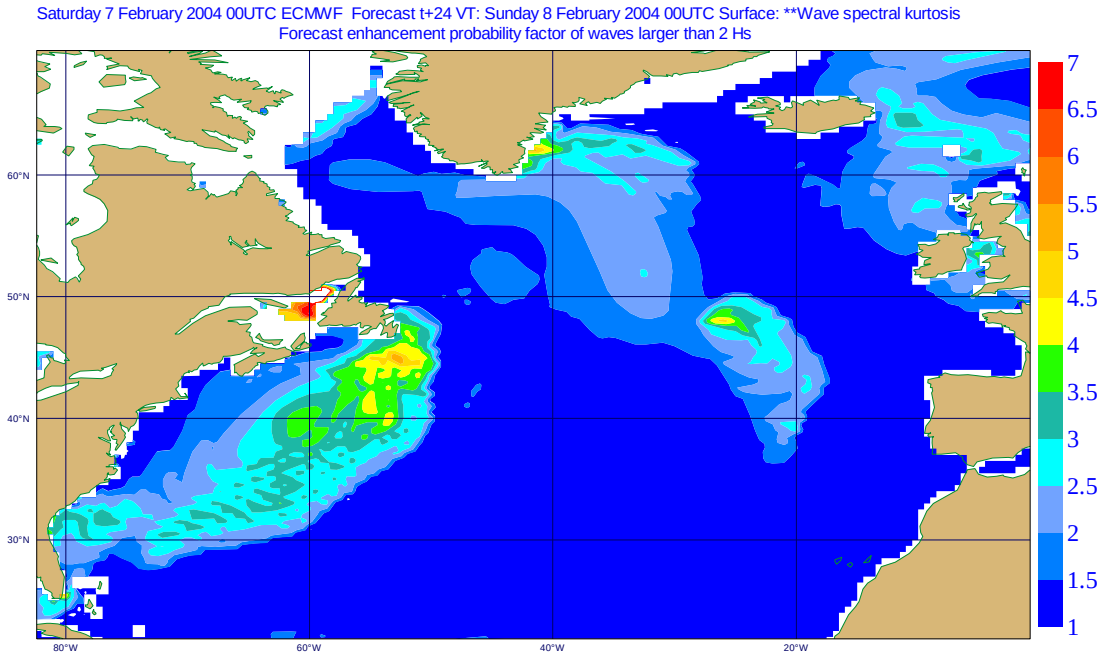
Freak waves

- **Extreme conditions can arise on much smaller time scale as modelled by current spectral wave model: i.e. as freak waves.**
- **From Janssen (2003), it appears that nonlinear wave-wave interaction is one of the possible mechanisms that will lead wave energy focussing.**
- **Waves needs to be sufficiently coherent and steep as quantified by the Benjamin-Feir Index (BFI), namely the ratio of the steepness of the waves and the width of the spectrum. A large BFI corresponds to favourable condition for freak waves.**
- **For freak waves prediction, probabilistic approach is feasible, following Janssen (2003), there is a link between BFI and the kurtosis of the sea surface elevation.**

Wave model products: Freak waves

Since October 2003, 3 new wave parameters have been produced that characterize extreme sea state:

For example,
The kurtosis of the sea surface elevation can be used to derive the enhanced probability that waves are larger than twice the significant wave height:



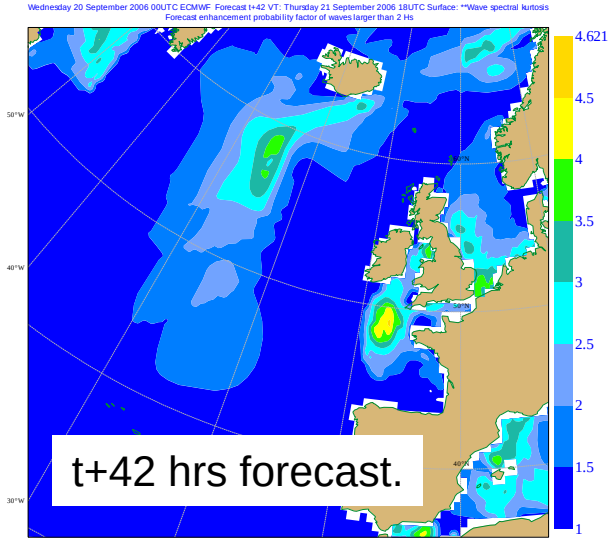
One day forecast of enhanced probability of extreme events (twice Hs) for 8th February 2004.

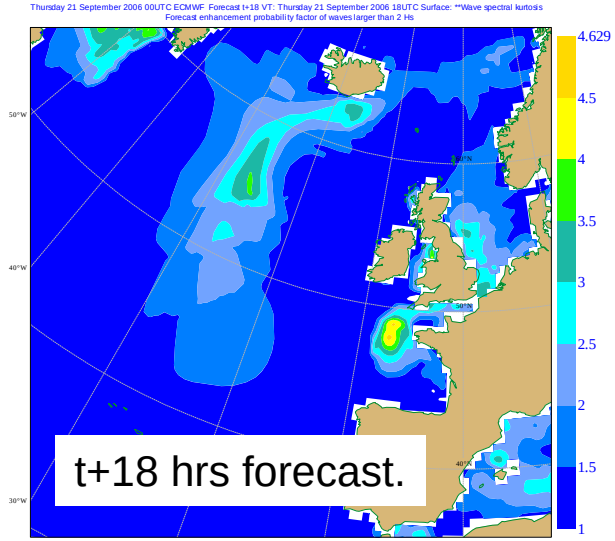
Wave model products: Freak waves

Enhanced probability of extreme events for

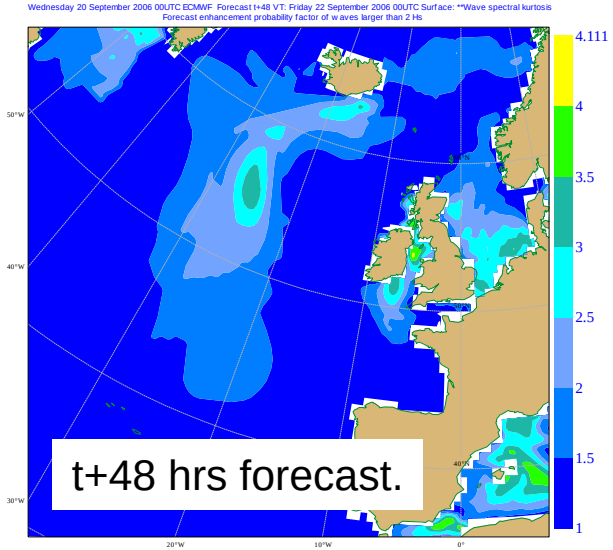
.

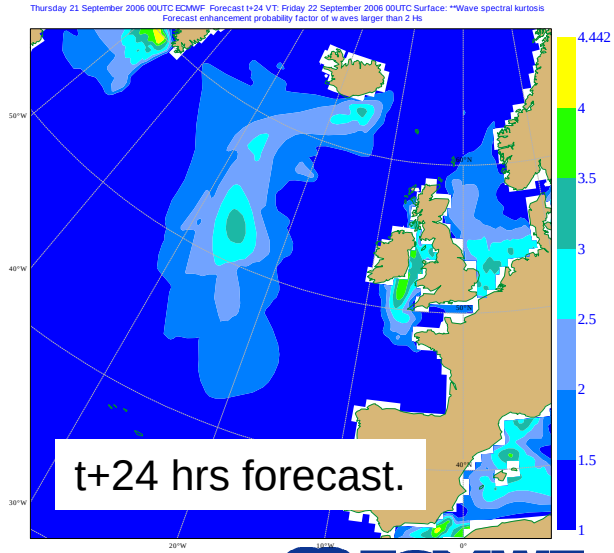
21 Sep 2006, 18 UTC





22 Sep 2006, 00 UTC





Final words :

- **Improved wave model and atmospheric model yields better forecasts.**
- **Probabilistic forecast can be useful in assessing likelihood of severe waves.**
- **Freak waves: ongoing validation of new parameters.**