FORECASTING A 100-YEAR WAVE EVENT

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ABSTRACT

On 11th of January 2006 the forecasts sent from the Marine Forecasting centre in Bergen (Market Division of the Norwegian Meteorological Institute) gave indications of significant wave heights up to a 100 year return value (16m). This study of reanalysed numerical fields and observations available from different sites along the storm track lead us to the conclusion that maximum wave height must have culminated close to 15.5m in northern parts of the Haltenbanken area.

1. INTRODUCTION

On the 11th of January 2006 a storm, with winds up to 30 m/s from the southwest, entered the southern Norwegian Sea producing sea states with significant wave heights (Hs) up to 14-15m. The operational wave forecasting model run at the Norwegian Meteorological Institute (met.no) indicated a maximum Hs above 17m on the 9th and 10th of January (60 hours in advance, see Figure 1). The 100-year return value of Hs for the area is 16m. The storm was therefore likely to expose many offshore installations in the area to wave heights close to operational shutdown criteria.

The personnel in charge of operations had close contact with the forecasters of at least two forecasting services. Focus was on expected maximum values and preparations were done in case of a shut down action to be taken. Several activities were stopped, floating rigs and some of the boats in the area were sent to harbour.

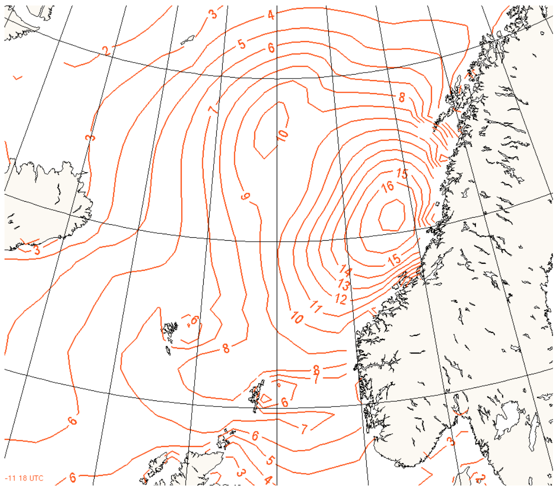

Figure 1 Significant wave height (Hs) at 11th January 2006 at 18 UTC, +18 hrs prognosis. Hs = 17 m at maximum.

Atmospheric and wave model prognoses are started every six hours as part of the met.no forecast system The prognoses were compared with all available measurements. There are several wave recorders on installations in the area, and some of the measurements are available in real time to the monitoring and forecasting services. A large spread was seen in the measured values, and some of the sensors were clearly failing.

In this paper we present a description of the weather using fields from the numerical forecasting models of the atmosphere and of the surface waves used at met.no, together with observations from different sources and areas. The variability in the forecasts produced in the days prior to the event on the 10th and 11th is also described.

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2. HISTORICAL RECORDS

The severity of a storm of 16-17m can be understood when comparing with historical data. Wave measurements from the southern Norwegian Sea are available since 1981 except for some years from the mid-1980s to the mid-1990s. Analysis of measured and hindcast data (from the Norwegian hindcast database) from the Draugen platform (64.3ºN, 7.8ºE, operated by Shell) counts 6 storms with Hs larger than 13 m (2001, 1993, 1991, 1990, 1989, 1989). Only two of the storms are considered to be at a level 14 – 14.5m in the area where there are production platforms (2^{nd} – 3^{rd} February 1993 and 11^{th} November 2001).

In the 2001 case, Ocean Weather Ship MIKE (Polarfront, 66°N, 2°E) measured 15.5m with a ship borne wave recorder. The recording system is based on analysis of data from 2 accelerometers combined with pressure sensors and compensation for ship response data (Holliday et al, 2006, Tucker and Pitt, 2001). Measurements from the offshore installations were, as in the 11^{th} January 2006 storm, varying from sensor to sensor, and some measurements have been rejected as erroneous. The analysis of the full dataset is still ongoing, but it is believed (by these authors) that the storm maximum is larger then 14 m (se below), with a strong gradient southward, so that platforms around 65ºN and south (i.e. Heidrun, Draugen, Åsgård, Njord) are subject to lower wave heights (see sections below) than at the maximum in the storm.

The storm in November 2001 is remembered by offshore personnel as an extreme storm also because of the effect on some of the installations: Heidrun (65.3ºN, 7.3ºE) experienced an unpleasant “minor” ringing phenomenon (high frequency resonance in the structure), and the FPSO Norne (66.0ºN, 8.1ºE) experienced very high heave for a 15 minute period. So, it is no surprise that the wave forecasts indicating a Hs in excess of 16m issued two days before culmination of the storm were followed closely.

3. WEATHER DESCRIPTION

On the days previous to the January 11^{th} storm, a high pressure (MSLP > 1035 hPa) was dominating over the European continent, while a series of lows were developing and propagating east and north-eastwards over the North Atlantic, moving northeast into the Norwegian Sea and further into the Barents Sea. On the 10^{th} of January (Figure 2 and 3) a new depression developed west of the British Isles, intensifying in the afternoon near the Faeroes with drops in atmospheric pressure larger than 12 hPa in 3 hours. Together with large pressure rises on the back side, these were indications of a rapidly moving and intensifying storm centre. The atmospheric prognoses evaluated the storm to reach a maximum over the Norwegian Sea late afternoon on the 11^{th} on northern Norway, close to Lofoten (~68ºN).

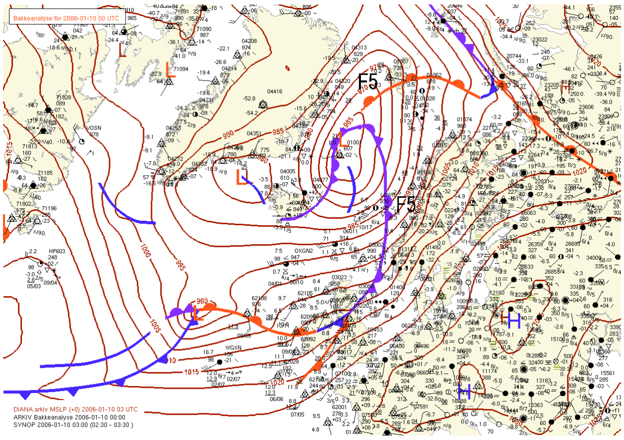

Figure 2 Analysed weather maps, 10th January 2006 at 00 UTC

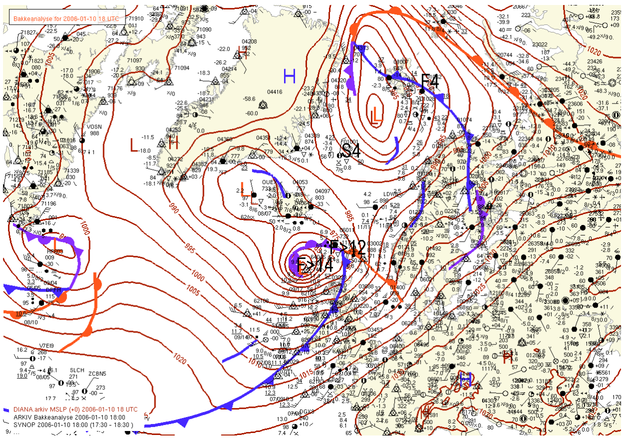

Figure 3 Analysed weather maps, 10th January 2006 at 18 UTC.

4. MODEL FORECASTS

The limited area model HIRLAM (see i.e. Bjørge et al, 2003, Unden et al, 2002) is used at met.no for weather forecasting at several resolutions for different purposes. As cpu capacity increases, improvements can be made in different ways, like special resolution (horizontally and vertically), or in the physics. In

January 2006 the resolution of the operational model was 20km (and 10km since April 2006). The surface winds are used as forcing in the operational wave model WAM (cycle 4), run at 45 km resolution in January 2006 (and 10km since May). Details about the WAM model are found in WAMDI Group (1988) and Komen et.al. (1994). The WAM model has been the operational wave prediction model at met.no since 1998.

The wind speed

The highest wind speed associated with this low pressure was reaching (in HIRLAM20km) about 60 knots on the 11th at 00 and 03 UTC.

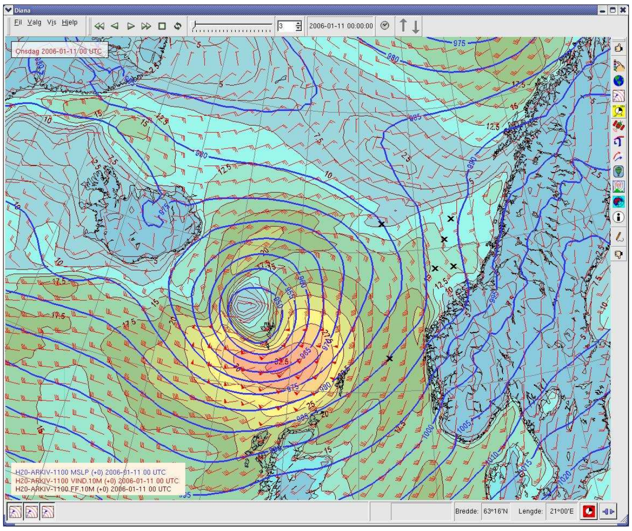

Figure 4 Isobars and winds speeds in HIRLAM20km at 11th January 2006 at 00 UTC (analysed field). Isolines for wind speeds are every 2.5 m/s, with highest wind speeds above 32.5 m/s at 00 UTC.

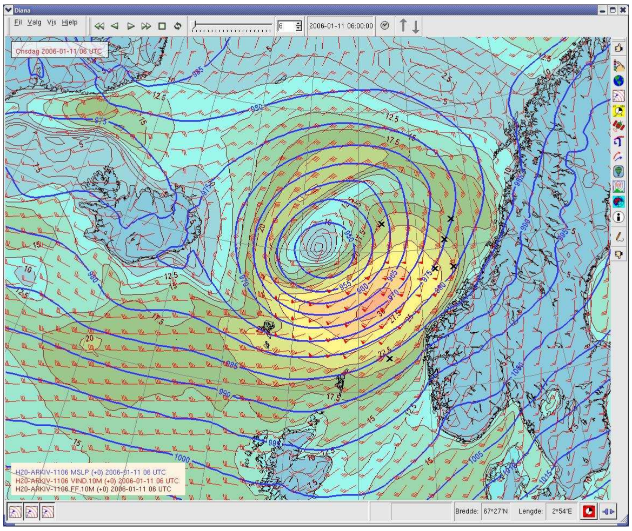

Figure 5 As above, for 11th January 2006 at 03UTC (+3 hour prognosis). Highest wind speeds about 30 m/s.

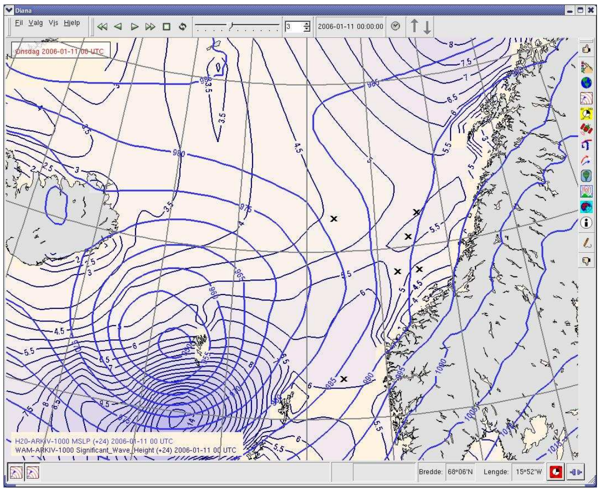

Figure 6. Isobars and Significant Wave Height at 11th January 2006 at 00 UTC (24hrs forecast). Maximum Hs is about 14.5m.

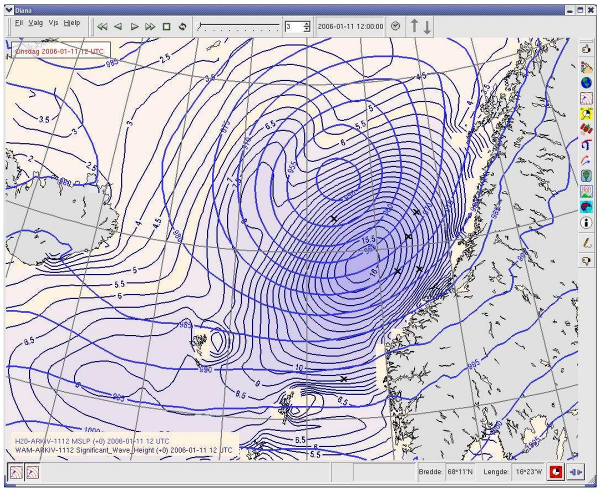

Figure 7. As above, for 11th January 2006 at 12 UTC (analysed field, +0 hrs). Maximum Hs is about 16m

Wave heights

The operational wave forecasting model gave maximum values of significant wave height up to about 16 m when approaching the Haltenbanken area, and from some runs (9th at 12UTC and 11th at 00 UTC) the maximum wave height was even forecasted up to 17 m (see Figure 6 and 6).

At the same time, prognoses available from ECMWF indicated maximum values of 12m at the maximum. Wind fields from ECMWF were less intense than in the Norwegian limited area model HIRLAM20km, a difference often observed. Met.no's operational models for the atmosphere and surface waves are started 4 times daily. As time went on and new model results were available, the severity of the storm was confirmed by quite steady tracks and strength.

Forecasts were sent with warnings of wave heights up to 14-16 m by met.no for the customer installations off mid-Norway. Contact was made with companies responsible for delivering wave measuring devices on the platforms in the area to ensure quality control and running systems.

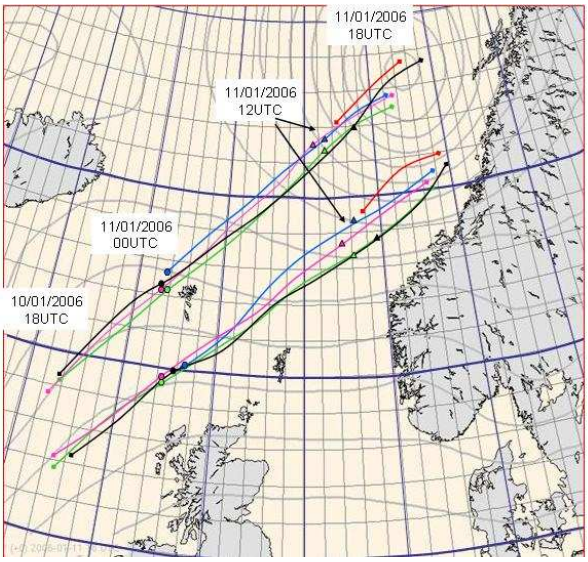

Figure 8 Tracks of Low pressure centres (upper lines) and peak significant wave height (Hs, southernmost tracks) in prognoses started at 09/1-12UTC (black), 10/1- 00UTC (pink), 10/1-12UTC (green), 11/1-00UTC (blue) and 11/1-12UTC (red). All tracks start at 10/1-18UTC.

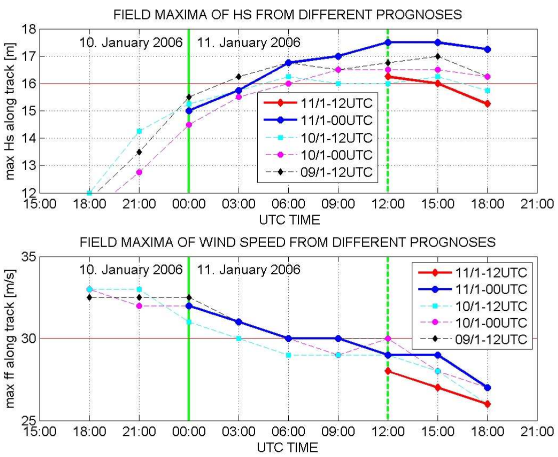

Figure 9 Values of maximum significant wave height (top) and wind speed (bottom) versus time along the tracks shown in Figure 8.

Variability in the model forecasts

Figure 8 shows the track of the low pressure centres in the different prognoses starting at 10th January 2006 at 18UTC southwest of the Faeroes. The tracks end west of Lofoten 24 hours later. Atmospheric pressure is at its lowest at 03 UTC close to the Faeroes, later the pressure, in the centre of the low, stays near 950hPa until 15UTC. At 18UTC the low pressure centre is around 955hPa. The pressure field is quite similar in all runs. The tracks of the area with maximum wave height (Hs) are also drawn. Markers are put for 11th at 00 and 11th at 12UTC. The last prognosis that started on the 11th at 12 is seen to have the centres of minimum pressure and maximum Hs a bit further and north of the previous prognoses, indicating a slightly faster movement of the low. Values of Hs and wind speed along the tracks are shown in Figure 9. We see that the last WAM run with analyzed wind fields at 12UTC evaluate the wave maximum to 16.2m at the position 64.6ºN, 3.90ºE. The track thereafter is a bit north of Heidrun, close to Norne. At that time our models evaluate the waves to be between 15.2 and 16m at the maximum.

Some of the questions posed when presenting the observations in the next section are:

a) Were the surface winds in HIRLAM20km too strong?
b) Were the modelled waves too high already when arriving in the proximity of the Faeroes? (with reference to Figure 6, showing a maximum of 14.5 m).
c) Is the resolution of 45 km in the WAM model, and the consequent numerical treatment of the advection of waves through the Faeroe Shetland Channel, making an erroneous impact on the wave field?

5. OBSERVATIONS

Measurements of waves in very high sea states are difficult to make, and this storm is no exception to this rule. Several radars and buoys were recording during the storm passage. They showed a wide spread, and some measurements showed clearly they were erroneous. There is still ongoing work on the post analysis of the data. All reports given here are not fully quality controlled at this stage, but are given nonetheless to try to give a picture of how rough the storm was.

We focus on observation sites south of the Faeroes, measurements from buoys and offshore platforms off mid-Norway, and 2 satellite tracks at mid-day on the 11th.

Wind observations

Wind observations close to the Faeroes as well as in the Haltenbanken area are important for the validation of the wind field in the models.

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On 11th 00UTC we find that the UK Met Office buoy number 64046 (at 60.7ºN 4.5ºW) measured a 10min mean wind speed of 26.8 m/s and has a Hs of 10.6m (personnel communication with Dr. Mike McCulloch at UK MetOffice). Atmospheric pressure is still decreasing, but 3 hours later it is increasing by 8.9 hPa in 3hrs. The wave height decreases after 00 UTC (10m and 8.5m at 03 and 06 respectively). In Figure 10 we see from the observations that the gusts have been up to 76 knots (39m/s) during the last 6 hours. Note that the position on the map of this station is about half a degree to the west of the coordinates given on the web site. This indicates that the mean wind (not available) may have been up to 60 knots (~30m/s) in the hours before the observation at 00UTC (probably in the previous hour). The southernmost observation at the Faeroes indicates a strong mean wind (65 knots) at 03UTC, see Figure 11 (55 knots at 00), but it may be influenced by topography. The maximum gust value of 102 kts and 104 kts at both times indicate rough weather nonetheless, and this indicates that the wind speed as modelled in HIRLAM20km may not be too far from the truth.

At Heidrun the wind speed was between 55 and 60 kts between roughly 9:30 and 13 UTC. At Draugen, south of the maximum area, the wind speed was over 50kts from 06 UTC to 17UTC, a bit higher (50-55kts) between 12 and 16 UTC.

The Faeroes, on 11th January 2006 around midnight: Observations from both manned and automatic stations are transmitted to national meteorological services through WMO's Global Telecommunication System (GTS). Automatic stations send reports usually at hourly intervals. One automatic station from south of the Faeroes reported in real time an increase of Hs to 11m at 02UTC on the 11th January, then no data at 03 UTC, and then close to 10m at 04UTC. At the time of preparation of this paper, only observations every 3 hours are available (and not all of them). Only UK-buoy nr 64046 is seen in Figure 11 (02 not available).

When the 00UTC forecast run was ready, the wave field calculated from analysed wind fields showed a maximum Hs close to 15m in a small area south of the Faeroes. The forecasted (+24hrs) Hs-field is shown in **Figure 6**, top, with a maximum of 14.5m in the centre (the position is approximately the same in the analysed field).

The peak wave height must be passing close to 00UTC through the Faeroe-Shetland straight. The wave field is seen to have a strong gradient, so it is plausible that the maximum height area passed in between observing sites. That the automatic buoy station reporting in real time south of the Faeroes failed at 03UTC may also be an indication of very high sea states. Having buoy failure at some time during the peak of a storm is not unusual. It has been seen before that buoys are torn away by rough seas due to mooring failure, but since the data came back again, it is probable that transmission in real time failed.

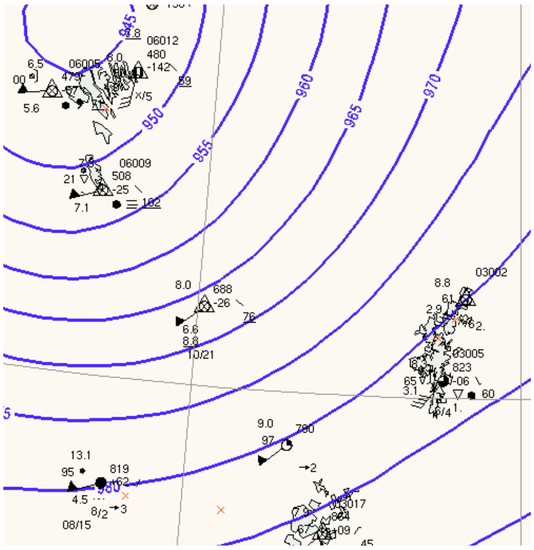

Figure 10 Observations stored at met.no from 11th January 2006 at 00UTC. Isobars from analysed field is also included at 00UTC. Red crosses show all other observations that are available but not showed here due to lack of space.

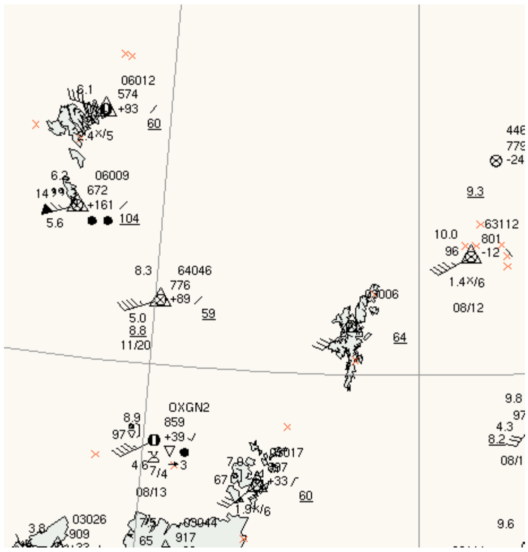

Figure 11 Observations at 11th January 2006 at 03UTC.

Wave observations around the Faeroes are made by the "Office of Public Works" and are available in real time on their web site www.landsverk.fo at hourly intervals. Values retrieved after the storm from the buoy located on the southernmost part of the Faeroe Islands (a Datawell directional buoy, south of Suðuroy) have kindly been made available through personnel communication, with notice that a full analysis of the data is ongoing work. Some of the values are given in Table 1. We see the highest value is Hs=13m at 02 UTC. Peak period at 01 and 02 UTC are 15.4 and 16.7 sec.

Table 1 Observations from south part of Faeroes

10^{th}-11^{th} Jan. 2006 UTC	Real time Hs (m) Aut. St.	BUOY Hs (m)	BUOY Tp(sec)
23		10.07	14.3
00		11.83	14.3
01		12.33	15.4
02	11.0	12.98	16.7
03	Nil	11.46	14.3
04	10.5	10.02	12.5

Observations from the Haltenbanken area:
The WAMOS radar (Hessner et al, 2001) on the FPSO Norne (66ºN, 8.1ºE) reported up to 12 m, while a neighbouring buoy reported 15-17m. The MIROS system (Brodtkorb et al, 1986) on Heidrun reported 13.7m at the maximum, but was believed to underestimate the waves due to its position on the platform. It is placed looking Northward, so that it analyses the return signal given from the leeside of the waves, and this has been shown to underestimate the waves slightly (5-10%, but the exact number is not known).

There are several wave recorders on the installations in the area. There was large divergence in the maximum Hs values reported, but it was clear some of the sensors were failing. Extremely high values (close to 19m) were reported, obviously wrong. These data, coming from MIROS Doppler radars mounted on floating installations (i.e. Åsgård, 65ºN, 7ºE), were later post processed with improved compensation of the rig movement. Maximum values were then reduced to around 13.5m. The WAMOS at Norne gave a maximum value of 13.3m at 14:20, after which the values fell slowly, while a buoy in the same position still showed increasing Hs values (Figure 12). Figure 13 shows a good correlation between the buoy and the WAMOS data for Hs values up to 11m. The large discrepancies for higher wave heights occurred during this storm, at the arrival of the largest waves at Norne. The buoy maximum is 17m at 16:20. We see the buoy reports Hs values above 15m from 15 to 18UTC. The value of 17m may be erroneous, but the buoy is obviously in a very high sea state. It is above 14 meters for 5 hours, and is 15 or above for 2-3 hours. Raw data from the buoy are unfortunately not available for a further analysis.

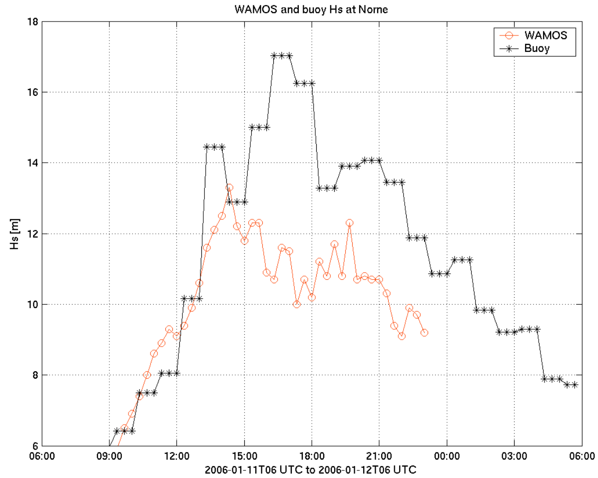

Figure 12 Time series of significant wave height from the WAMOS and the buoy at Norne (66ºN, 8.1ºE) on the 11^{th} January 2006 (from 11^{th} 06UTC to 12^{th} 06UTC).

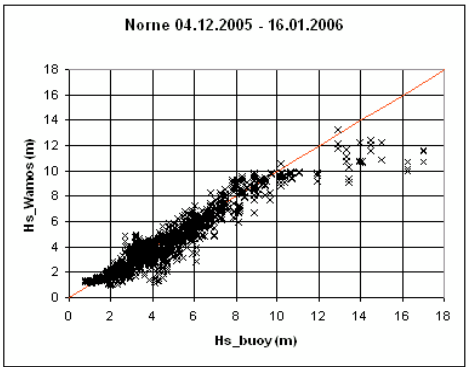

Figure 13. Wave observations from the WAMOS and the wave buoy at Norne (66ºN, 8.1ºE). Figure by Sverre Haver, Statoil.

The hourly records from Ocean Weather Ship Polarfront (66ºN, 2ºE) report significant wave height 11.7m at the maximum at 13UTC. The wave height is around 10-11 m between 09 and 18UTC. When looking at the distribution of wave height (for example Figure 7, 11^{th} January at 12 UTC) we see the gradient in Hs is very large in the area were Polarfront is situated. That the values are about 11 m for many hours can be explained by the propagation direction of the area with maximum wave height.

A directional waverider deployed by NIVA for Norsk Hydro is located at 63ºN, 6.2ºE (Aukra-buoy), see Figure 14. It measured Hs above 8m between 11 and 16 UTC. The maximum value was 9.4m at 13:40 UTC. Peak Period Tp was in the range 15-17sec. Wave direction was about 250-260 degrees in that period.

Satellite data

Surface wind speed and significant wave height measured by satellite altimeters are available in these parts of the oceans a few times per day. The satellites giving wave heights and wind speed along tracks under the satellite are ENVISAT, JASON, and ERS-2. Wind speed and direction is also available from QuickScat, covering a wide track with a spatial resolution of 25 km. In the morning of 11th January 2006 all QuickScat paths were unfortunately much further north, outside the interesting area of this storm. Two interesting altimeter passes came around noon on the 11th. First, ERS-2 passed about 11.30 UTC, then ENVISAT half an hour later, crossing the Norwegian Sea in a north south-path, close to the probable centre of the maximum wave area. The ERS-2 altimeter produces estimates of wave height along the satellite ground track every second (6.7 km spacing). These are available to the marine forecasting centre in Bergen as close as possible (with 30-40 minutes delay) to real time through the ESA funded project, CAMMEO.

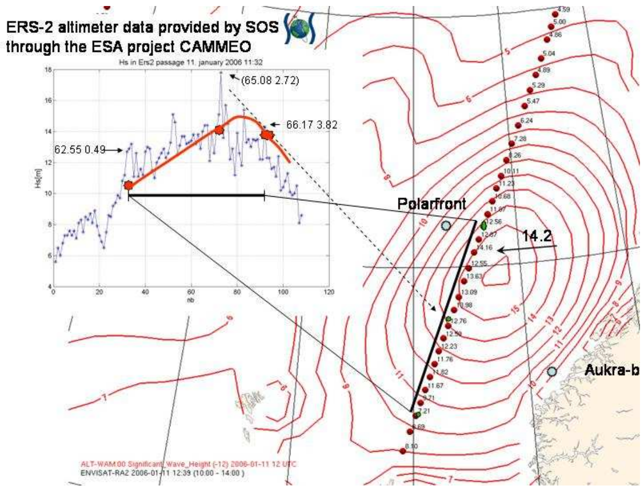

Figure 14. ERS-2 and ENVISAT altimeter wave height (Hs) at 11:30 and 12:00 UTC. WAM-model at 12 UTC (reanalysed field) shows Hs field with 1m interval, peaking at 16m.

The ENVISAT data are measured half an hour after the wave field, and ERS-2 path should be crossing or tangent to the Hs-peak area. We see that ERS-2 values are spiky, but can deduce from the figure a maximum value about 14m, perhaps 14.5m. The value of near 18m is disregarded. The ENVISAT data vary as well, about a 13m value, with a spiky value at 14.2m (indicated by black arrow). The paths were available approximately around 13UTC. It is probable that the ERS2 passage was very close to the maximum area at 11:30, while the ENVISAT passage is to the west of the peak area at the time of its passage at 12:00.

6. ANALYSED WAVE MODEL FIELDS

Every 6 hours, met.no's operational atmospheric model is restarted, assimilating observations available in the previous 6 hourly period from air planes, satellites and at the surface. The wave model is then restarted with these "analysed" wind fields, also assimilating available altimeter wave height values. The resulting analysed wave fields for 15UTC, 18UTC and 21UTC, that were available at the run start on 12th January 2006 at 00UTC, are shown in Figures 15 to 17. The analysed field at 12UTC is shown in Figure 13. The maximum wave heights are seen to be approximately 16m, 15.5m, 15m and 14m at respectively 12UTC, 15UTC, 18UTC and 21UTC.

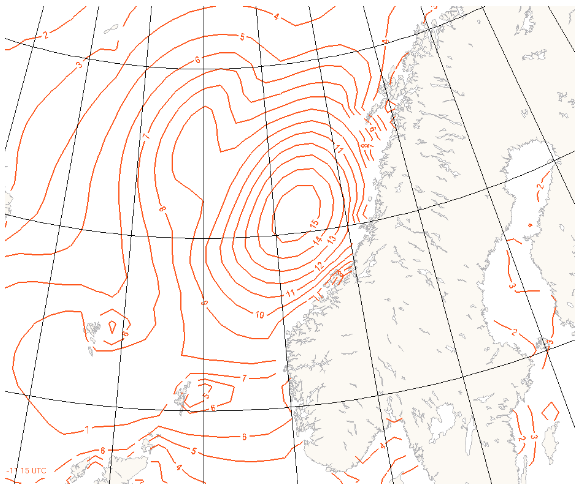

Figure 15 Hs at 11th January 2006, 15UTC, from model run with analysed wind fields available at 12th January 00UTC.

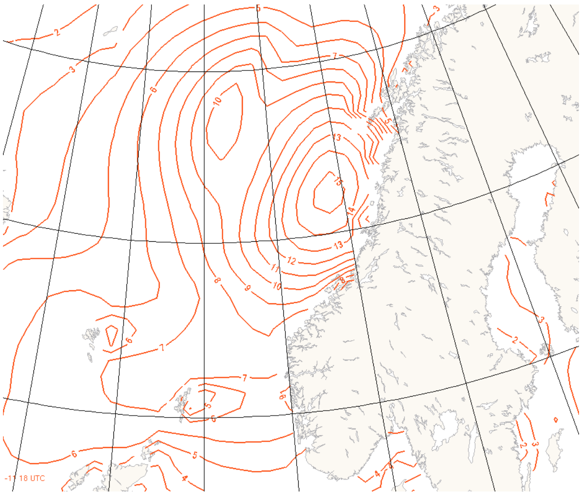

Figure 16 As in figure 15, valid 11th January 2006, 18UTC.

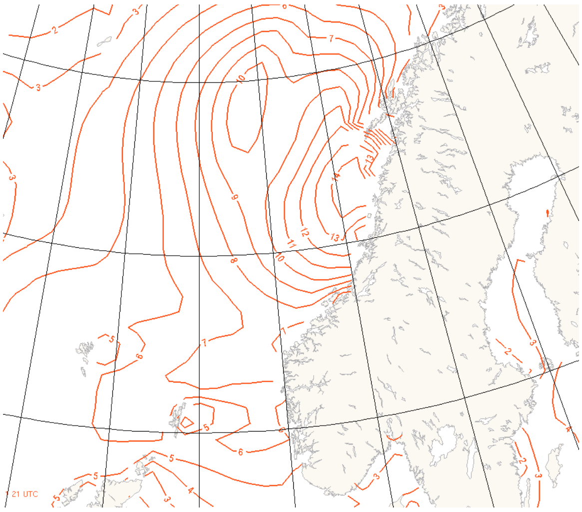

Figure 17 As in figure 15, valid 11th January 2006, 21UTC.

7. DISCUSSION AND CONCLUDING REMARKS

The analysed wave fields, shown in Figures 15 to 17, show that the highest wave observations at the southern offshore sites in the area (Draugen and Njord), that were about 13 m, are more or less conform with the wave distribution on the south of the peak of the storm. The MIROS at Heidrun (13.7m) is measuring waves looking northward, meaning the radar received return signals from the mostly lee parts of the waves in this situation. This is known to make the waves underestimated by about 5-10%, but this cannot be confirmed. Maybe the value of 13.7m should be upgraded to 14.5m? Norne is, according to the tracks and the analysed wave fields, the closest site to the peak of the storm. That the buoy at Norne has spiky values up to 17m is not a surprise in rough weather. But given the time series of the buoy (Figure 12), a maximum value of 15.5m is hereby suggested in the vicinity of Norne.

Studies on buoy behaviour and consequence on wave data have shown that crest values and skewness of waves are largely underestimated by buoys. But this should not affect the significant wave height (personnel communication with Tom Marthinsen, Norsk Hydro).

It seems (referring to the questions posed at end of section 4) that the model winds were not too strong, if so not more than 5 knots in error. The wave observations south of the Faeroes do not prove that modelled wave field is too high. The observed peak period, being around 15-17s, is important for the forecasting: the area with maximum wind speed is moving with a speed around 25-30 knots, which is the group velocity of waves with peak periods 16-19 s. This indicates that the running fetch observed can produce the waves as modelled if the winds are as strong as in the reanalysed HIRLAM20km model.

The satellite data available around 12UTC are obviously crossing close to the maximum wave height area. They may indicate that the wave field is a bit (0.5-1m) too high, but validity of the data is also questionable at these high wave heights.

The impact of the propagation speed of a low on wave growth was studied by Reistad et al (2005), in a work performed for Statoil in 2003. Tests on changing the propagation speed of the low in the case of 11th November 2001 showed that increasing the propagation speed of the low reduces the maximum Hs at Draugen from 14m to 12m. A slight change in the amount of wave energy that passes through the Faeroe Shetland channel, and a smaller surface wind speed, may change the highest wave heights produced in the reanalysis at 12UTC. If this is the case, it would reduce the maximum Hs close to the Norne site between 15 and 18UTC.

Values of significant values from any measuring device will always be questionable, but the authors believe this study shows that the storm was close to a 100 year event at Haltenbanken.

Recommendations will be to closely reanalyse atmospheric data and rerun the atmosphere and wave models with finer resolution.

8. ACKNOWLEDGEMENTS

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