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no. 9 / 2006
Remote sensing

Use of RA-2 wave heights in operational wave analysis and forecasting

Report from the EnviWave project

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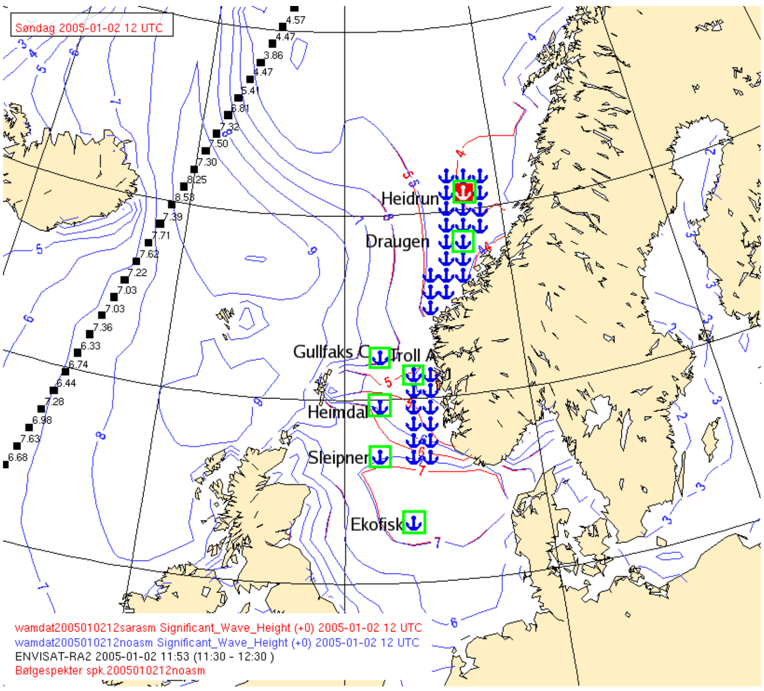

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Title
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Section
Remote sensing
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Client(s)
EU

Date
24 October, 2006
Report no.
9 / 2006
Classification
☒ Free ☐ Restricted
ISSN 1503-8025
e-ISSN 1503-8025
Client's reference
EVG1-CT-2001-00051

Abstract
The ENVISAT satellite is serving the user community with geophysical ocean wave products. The EnviWave project had focus on optimal use of the ASAR and RA-2 data provided by the ENVISAT satellite for operational wave monitoring and forecasting. The RA-2 data has been made available for the forecasters and included in the operational nowcasting software at the marine forecasting centre. Assimilation of the ENVISAT RA-2 data is implemented in the HIRLAM-WAM system, and has been tested for January 2005 with positive impact.

Keywords
wave spectra, wave heights, altimeter, wave model, assimilation, nowcasting, forecasting

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Introduction

At met.no, the radar altimeter (RA) data from ERS-1 and -2 have been in use for operational wave and wind monitoring and forecasting since 1991. The ERS-1 and -2 RA wave height observations proved to be very reliable and useful information. ERS-2 RA data are still (2006) received at met.no in near real time via the international meteorological network GTS. The data are used in monitoring the wave state and evaluating the performance of the operational wave model at the forecast centre. A method for assimilating the data in the wave model was developed and implemented and has been in operational use since 1993 (Breivik and Reistad 1994).

The RA-2 altimeter at ENVISAT represents a continuation of the availability of altimeter information from polar orbiting satellites. RA-2 wind and wave data are received in near real time via ftp from ESRIN. At met.no in the context of the EnviWave project, the aim has been to continue the utilization of altimeter data by using RA-2 data. We will in the following shortly describe the results of the evaluation of RA-2 data, the assimilation scheme and the results of the impact study.

Evaluation of the RA-2 data

The first step toward operational use is a thorough evaluation of the quality of the new wave and wind information. The evaluation of RA-2 at met.no was organized as a part of the EnviWave project. The work was also a contribution to ESA's geophysical evaluation and calibration activities for ENVISAT and therefore partly sponsored by ESA.

The evaluation project utilized the operational wave forecast system at met.no consisting of the HIRLAM atmospheric and the regionally adapted WAM Cycle 4 wave model. This is a third generation wave model developed by the international WAMDI group (WAMDI Group 1988). Surface winds were available from the HIRLAM model with 20 km horizontal grid resolution in an area covering the North-Atlantic.

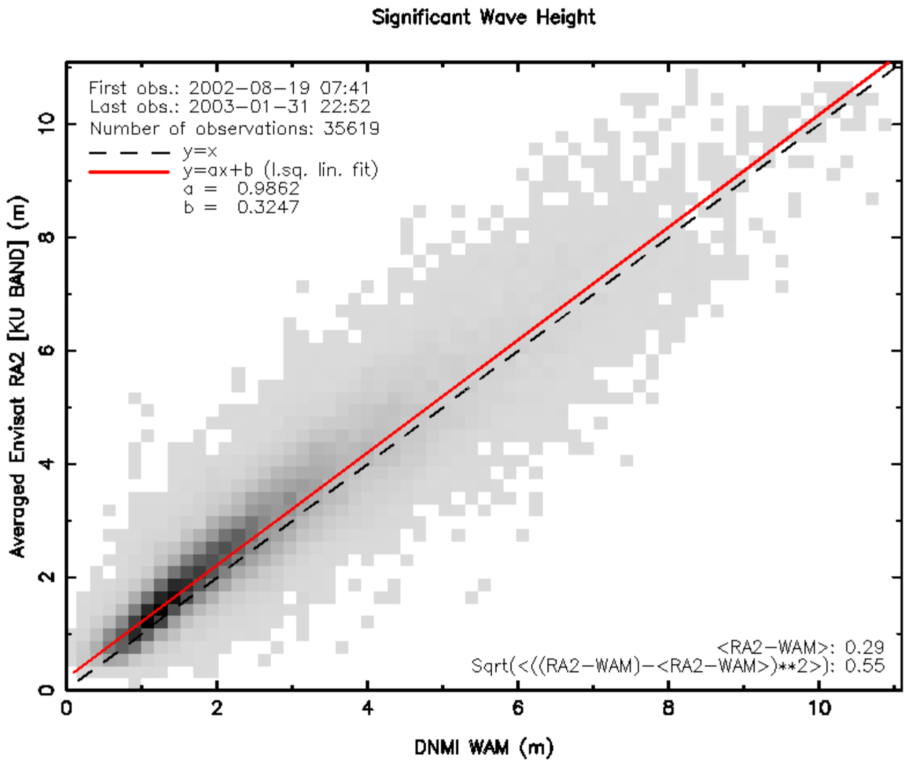


Figure 1: Density plots of WAM vs. RA-2 significant wave height (KU-band); Aug. 2002 – Jan. 2003. The grayscale indicates the number of observations in each bin. (from Brattli and Breivik, 2003)

The results from the evaluation project are given in Brattli and Breivik (2003). A scatter plot comparing RA-2 significant wave height (SWH) with wave model analysis (met.no WAM) collocated between August

2002 and January 2003 is given in Figure 1. As seen there is a very good agreement between the model reference wave heights and the RA-2 measurements. This was confirmed by other studies performed in the EnviWave projet.

The overall conclusion is that the RA-2 data are of very high and stable quality and suitable for operational use both in wave model assimilation and in nowcasting.

Assimilation of RA-2 wave height observations

The analysis and the correction of the wave spectrum

The analysis scheme used for assimilation of the RA-2 data in the wave model WAM is based on the analysis scheme developed at met.no for assimilation of ERS-1 and -2 altimeter data (Breivik and Reistad 1994). The analysis scheme is a version of the Modified Successive Correction scheme (Bratseth 1986), and the functioning is similar to the Optimal Interpolation which is commonly used for data assimilation at several centers. Starting from a first guess field of significant wave height SWH^F from the WAM model, the field is corrected by use of the significant wave height observations from RA-2, SWH^o. A simple version of the analysis equation reads:

$$SWH_X^A = SWH_X^F + \sum_{j=1}^{N} p_j (SWH_j^O - SWH_j^F)$$

where X denotes model grid points and j denotes observation points. p_j are the analysis weights. A thorough description of the iterative analysis equations and the weights are given in Breivik and Reistad (1994). This also describes how the model wave spectra are updated on basis of the analyzed SWH^A.

Results, impact study

An experiment has been set up to test the impact of assimilation of RA-2 altimeter wave heights in the wave model WAM. A model run with full assimilation of all available RA-2 wave height observations was set up for a period of one month in January 2005. This model run has been compared to a reference model run for the same period without assimilation of RA-2 data. ERS altimeter data which are in operational use for assimilation in WAM at met.no has been excluded in this RA-2 assimilation experiment.

The impact experiment has been run in a full operational analysis and forecast cycle. Four 36 hour forecasts are produced daily from 00, 06, 12, 18 UTC. RA-2 data has been assimilated continuously 6 hours prior to the forecast starting hour.

The experiment period is mid winter. In this season there are normally large gradients at the Polarfront with low pressure systems and storms moving eastward into the north-east Atlantic. This gives rise to strong winds and high waves in the Norwegian Sea and in the North Sea. January 2005 was no exception from this. The period was characterized by strong storms with wave heights occasionally above 10 meter in these areas.

The impact of the assimilation on the forecast can be evaluated by comparing results from the model run with assimilation of RA-2, hereby called *RA-2-exp*, with results from the reference run, hereby called *Ref*. This has been done by comparing the model results in terms of SWH with independent measurements on four offshore stations. The four stations are three in the North Sea: Ekofisk (56.5N, 3.2E), Sleipner (58.4N, 1.9E) and Gullfaks (61.2N, 2.3E) and one further north in the Norwegian Sea, Heidrun (65.3N, 7.3E). At Ekofisk the wave measurements are from a wave rider buoy. At the three other stations the waves are measured by MIROS radars. Model output of +0, +6, +12, +24 and +36 hours forecast have been compared to the platform observations. The results are given in Table 1 and 2. All values are in meter.

Table 1: Comparison of SWH (in m) between model results and independent measurements on four offshore stations. At Ekofisk the wave measurements are from a wave rider buoy. At the other stations waves are measured by MIROS radars.

Ekofisk	*Bias Ref*	*Bias RA-2-exp*	*Std Ref*	*Std RA-2-exp*	*Rms Ref*	*Rms RA-2-exp*
+ 0	0.31	0.29	0.58	0.56	0.65	0.63
+ 6	0.35	0.33	0.62	0.61	0.71	0.69
+12	0.38	0.37	0.60	0.60	0.71	0.70
+24	0.49	0.49	0.72	0.72	0.87	0.87
+36	0.59	0.59	0.96	0.96	1.13	1.13

Sleipner	*Bias Ref*	*Bias RA-2-exp*	*Std Ref*	*Std RA-2-exp*	*Rms Ref*	*Rms RA-2-exp*
+ 0	1.13	1.06	0.83	0.77	1.41	1.31
+ 6	1.14	1.10	0.84	0.79	1.42	1.36
+12	1.17	1.13	0.87	0.83	1.45	1.40
+24	1.28	1.26	1.05	1.04	1.66	1.63
+36	1.42	1.41	1.44	1.44	2.02	2.01

Gullfaks	*Bias Ref*	*Bias RA-2-exp*	*Std Ref*	*Std RA-2-exp*	*Rms Ref*	*Rms RA-2-exp*
+ 0	1.01	0.90	0.77	0.67	1.27	1.13
+ 6	1.05	0.98	0.80	0.72	1.32	1.22
+12	1.11	1.04	0.88	0.82	1.41	1.33
+24	1.20	1.18	1.06	1.05	1.60	1.58
+36	1.18	1.18	1.25	1.24	1.72	1.71

Heidrun	*Bias Ref*	*Bias RA-2-exp*	*Std Ref*	*Std RA-2-exp*	*Rms Ref*	*Rms RA-2-exp*
+ 0	0.41	0.39	0.75	0.66	0.86	0.77
+ 6	0.41	0.40	0.76	0.70	0.86	0.81
+12	0.41	0.39	0.78	0.76	0.89	0.86
+24	0.49	0.48	0.92	0.90	1.04	1.02
+36	0.63	0.63	1.05	1.05	1.23	1.23

Table 2: Observed mean SWH (in m) at the four offshore stations.

	Ekofisk	***Sleipner***	***Gullfaks***	***Heidrun***
Mean SWH-exp	4.16	3.69	4.59	4.20

From the tables we see that the SWH from the model runs on average are higher than the observations from the four platforms. By assimilating the RA-2 altimeter data we are generally bringing the wave model results closer to the observations.

The positive impact is gradually decreased. This is illustrated in the four plots in Figure 2 and 3.

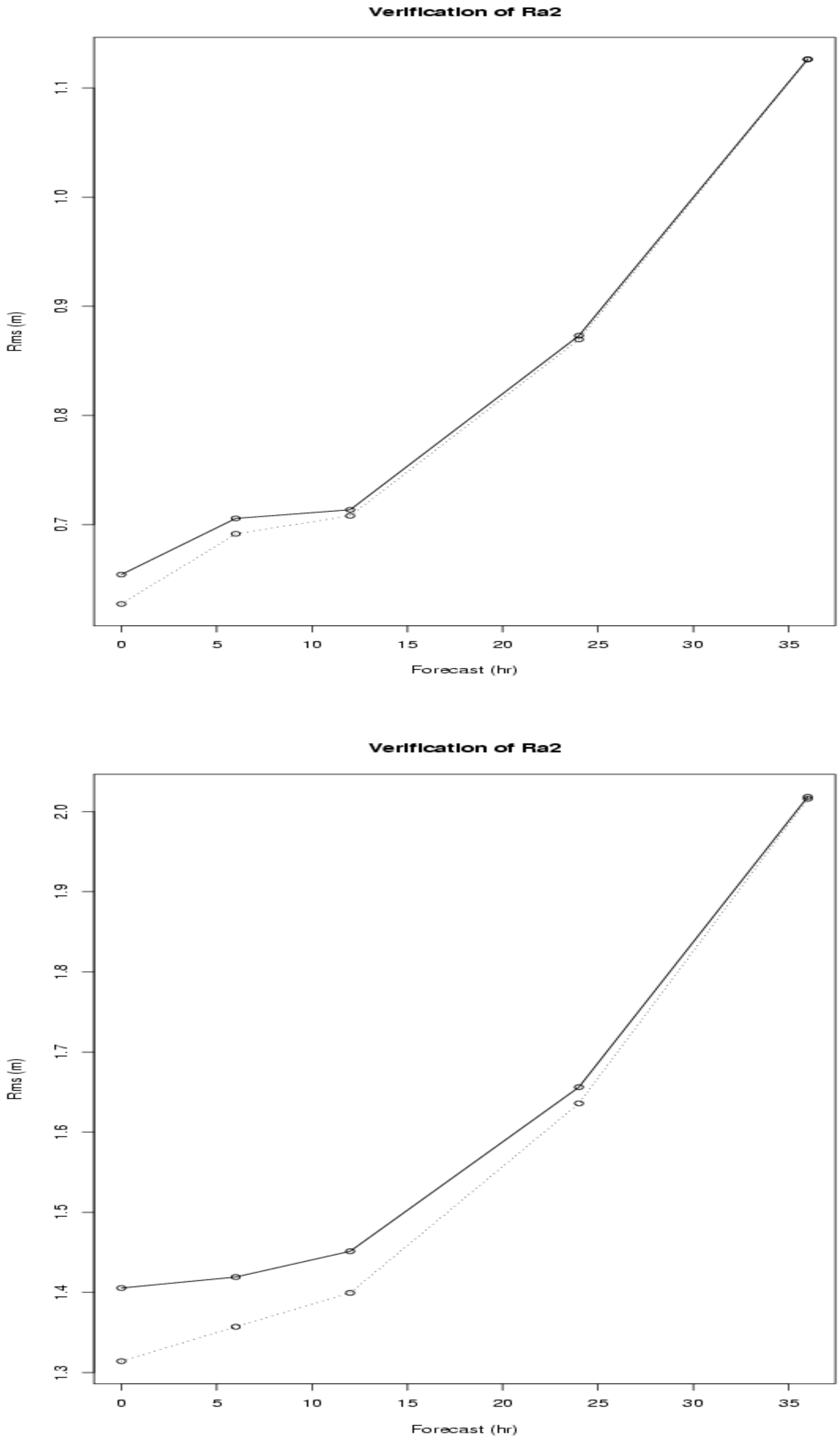
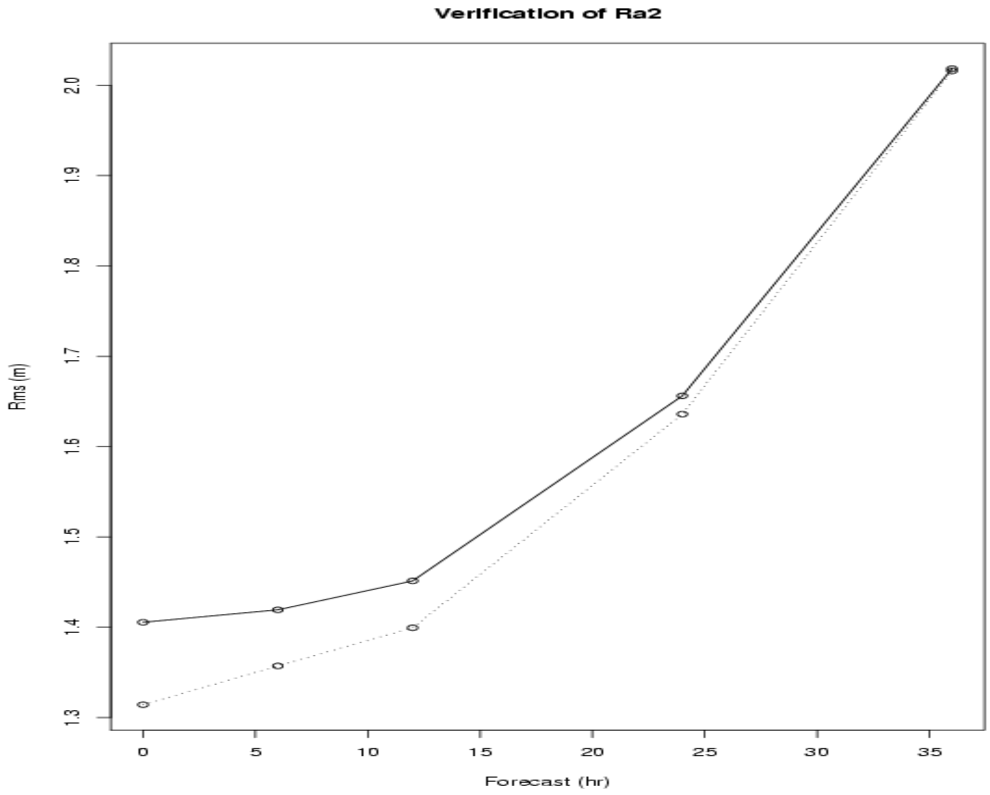


Figure 2: Rms-values as a function of forecast hour (0-36) for Ekofisk (upper panel) and Sleipner (lower panel). Dotted and solid lines represent with and without SWH assimilation, respectively.



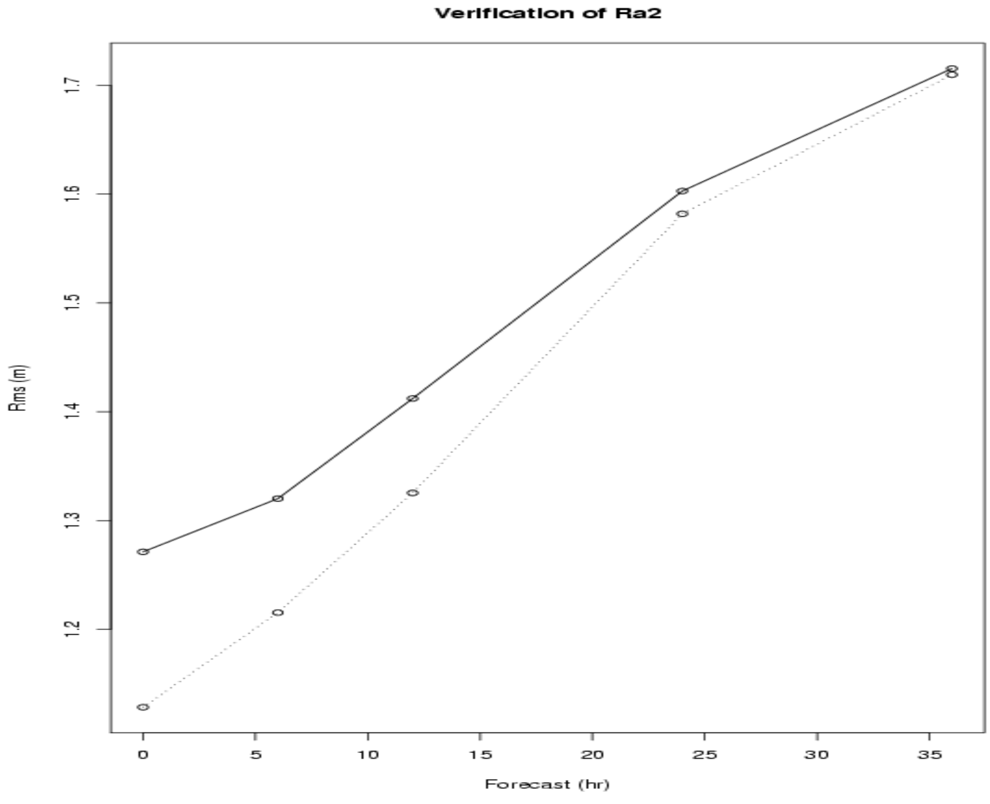


Figure 3: Rms-values as a function of forecast hour (0-36) for Gullfaks (upper panel) and Heidrun (lower panel). Dotted and solid lines represent with and without SWH assimilation, respectively.

Conclusion

From Figures 2 and 3 we see the positive impact is largest for the northernmost stations Gullfaks in the Northern North Sea and Heidrun in the Norwegian Sea. The positive impact is smallest for the southernmost station Ekofisk in the Central North Sea. The wave state in the Northern North Sea and the Norwegian Sea is more dominated by swell systems from the Atlantic, and the model results will be affected by assimilation of RA-2 data over a large area. Further south the North Sea is more closed and the wave development is thereby more controlled by the local wind systems in the area. In areas more exposed to swell the influence of assimilation will be seen for a longer time in the prognoses than in more sheltered areas, where the local wind soon will force the assimilation run and the reference run towards the same sea state.

ENVISAT RA-2 wave data in operational monitoring and nowcasting

With the high quality of the RA-2 data it is clear that the data are well suited for operational use. This is of course dependent on stable availability of the data in near real time. The RA-2 is available by ftp from ESRIN with 2-3 hours delay from actual measurement time. For maximum benefit in nowcasting the delay should be reduced to less than half an hour.

As a part of the EnviWave project the RA-2 data is integrated in the monitoring and analysis system DIANA at met.no (Bergholt et al. 2005). Operationally in near real time the RA-2 wave and wind data can be displayed at the forecaster's workstation. Using the visualization tools in DIANA the forecaster can combine output from various weather and ocean forecast models with satellite data and images and conventional observations. The various images, fields and observations can be overlaid, and the forecaster can zoom in on a particular area of interest. In this system the RA-2 data gives an important contribution to the capability of monitoring in particular the wave state, but also the wind situation. The figures below gives three examples. Figure 4 shows RA-2 SWH plotted together with SWH analysis output from the WAM model valid June 12, 2005. The model analysis and altimeter observations are fairly consistent with wave heights from 1 m in the North Sea increasing to 4 m in the Norwegian Sea. For the same situation on Figure 5, RA-2 wind speeds are plotted together with a wind speed forecast from the HIRLAM model and wind speed observations from QuikScat scatterometer. Also here there are fairly good consistence between the output results.

Concerning wind the scatterometers onboard the American QuikScat satellite and the ERS-2 satellite currently give a very good coverage of offshore wind observation, not only wind speed, but complete wind vectors. This situation will continue in the future with the scatterometer ASCAT onboard METOP from 2006, and the role of altimeter wind speed observations is not critical for operational monitoring. Concerning wave observations however, the situation is very different. Altimeter data plays a key role in the observing system. Today ERS-2 and ENVISAT altimeter data give a relatively good coverage. In the near future Jason 2 data will be operationally available, however with an upper latitude limit on approximately 60 degrees due to the satellite orbit. There are no plans for polar orbiting altimeter data giving operational wave measurements at high latitudes after ENVISAT.

This is critical as we see that the RA-2 data are particularly important in northern ocean areas with few in situ observations, for example in the Barents Sea. An example of use of altimeter data in DIANA for the Barents Sea is given in Figure 6. In this example from May 11 2005, altimeter data are plotted together with QuikScat wind vectors and sea ice concentration derived from SSM/I data. Together with scatterometer wind data, the RA-2 data has significantly increased the possibility to monitor the sea state conditions in the Barents Sea. This ocean area had almost no wind and wave observations before data from satellites became available. Improved weather and wave monitoring and forecasting in the Barents Sea is important both for the large fishing activity and the growing oil and gas exploration and production in the area.

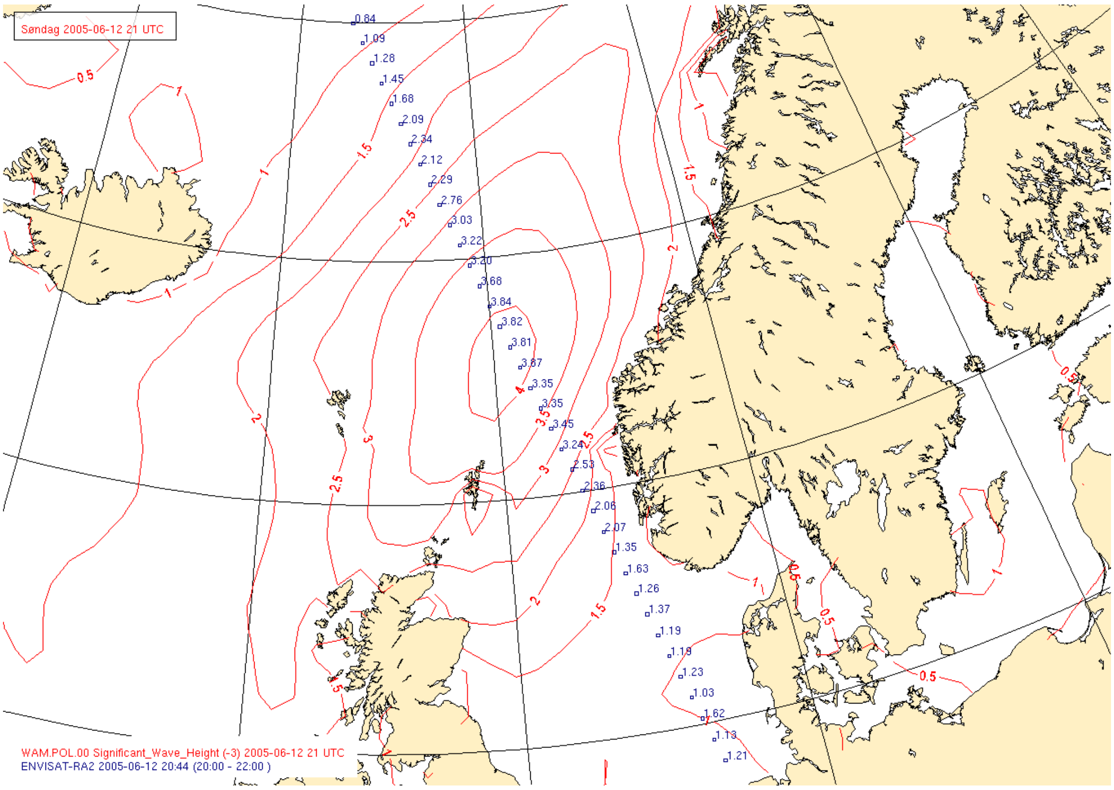


Figure 4: Envisat RA-2 SWH observations in the Norwegian Sea and North Sea June 12 2005 displayed on the meteorological work station DIANA. Together with the wave heights are SWH analysis output from the wave model WAM.

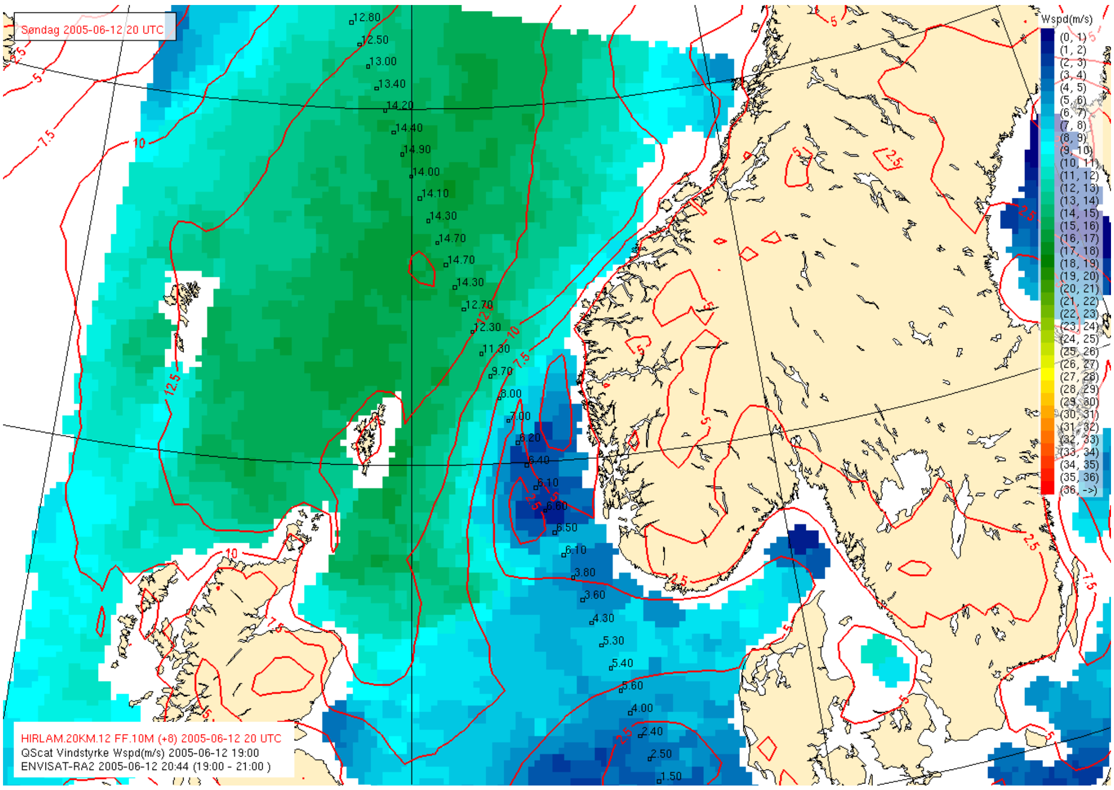


Figure 5: Envisat RA-2 wind speed observations in the Norwegian Sea and North Sea June 12 2005 displayed on the meteorological work station DIANA. Together with the RA-2 wind speeds are wind speed forecast from HIRLAM (red isolines, and wind speed derived from scatterometer data (QuikScat).

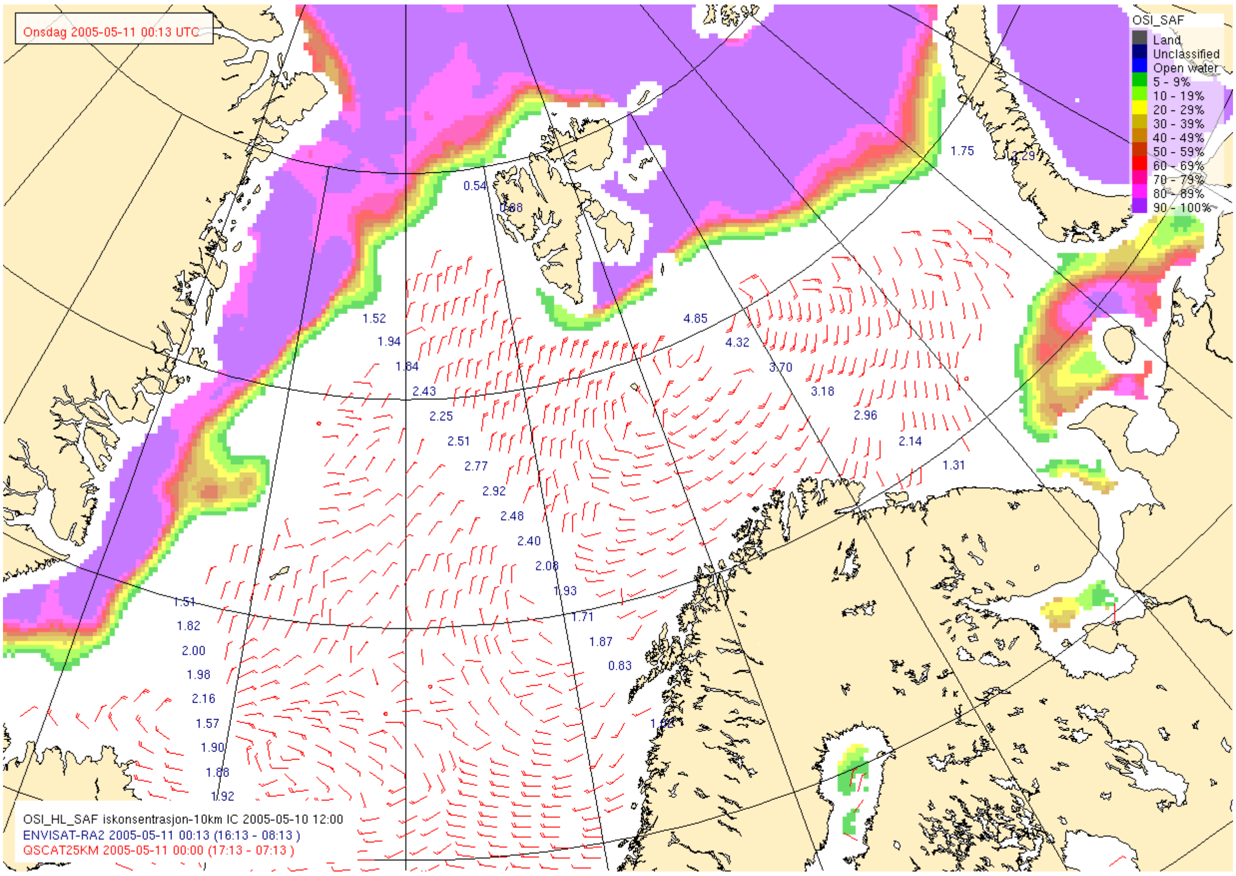


Figure 6: Envisat RA-2 SWH observations in the Norwegian Sea and Barents Sea from May 11 2005 displayed on the meteorological work station DIANA. Together with the wave heights are wind vectors from QuikScat (SeaWind scatterometer) and sea ice concentration from SSM/I.

Aspects on future RA-2 assimilation

RA-2 altimeter data is clearly of good value for both operational wave monitoring and assimilation in wave models. Currently ERS-2 and ENVISAT altimeter data give good coverage. In the near future Jason 2 data will be operationally available, however with an upper latitude limit on approximately 60 degrees due to the satellite orbit. For met.no it is important to argue for the value of operational altimeter data for wave purposes at high latitudes after ENVISAT.

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