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Validation of the operational wave model WAM for the years 2012 and 2013

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Abstract

The significant wave height (Hs) from the operational wave model WAM is validated against in-situ buoys observations for the two years period 2012-2013. The wave model WAM is run at 50km, 10km and 4km resolution (WAM50, WAM10 and WAM4) and is forced with 10m winds from the atmospheric model HIRLAM12, HIRLAM8 and UM4 respectively.
The quality of the forecasted wave height for WAM10 has improved after the removal of an artificial enhancement of the wind in November 1, 2011.
When comparing the different WAM models, the behavior of the models are quite similar. They present good fit with observations with a small tendency for overestimation as Hs increases.
We can not see any clear advantage of model WAM4 over WAM10. The winds that force WAM4 come from a non hydrostatic atmospheric model. We expected that this would have a positive impact on Hs in comparison to previous years. This may be due to the fact that the available buoys are located offshore where the advantages cannot be seen.
The Limited area wave model from ECMWF (WAMECMWF) run at 11km resolution, has a better score than WAM10. The WAMECMWF is a coupling system between the atmospheric and wave model and assimilates altimeter data. These two features are absent in our WAM10 system and exclude important dynamics.

Keywords

WAM, Significant wave height, Validation

Disciplinary signature
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Responsible signature
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1 Introduction

The aim of this validation is to estimate the forecast skill of the operational wave model WAM at the Norwegian Meteorological Institute (MET Norway) for the years 2012 and 2013. The analysis is done by using in-situ buoy observations and modeled significant wave height, Hs. At MET Norway there are three wave models WAM that run operationally. The resolutions are 50km, (WAM50), 10km (WAM10) and 4km (WAM4). These models are forced with winds at 10 meters from the atmospheric models HIRLAM and UM4. The WAM domains are shown in Figure (1) together with the location of the buoys.

The significant wave height is the wave parameter measured the most by the buoys instruments. Other wave parameters, like mean wave period and mean wave direction are scarcely measured and a significant validation is not possible. The report is organized as follows. Chapter 2-4 gives an introduction of the wave models, the observations and the methods applied. Results from a long term validation of WAM since 1999 are presented in Chapter 5.1. The forecast skill of the wave models is shown in chapter 5.2, 5.3 and 5.4. Finally in chapter 6 a summary and conclusions are presented.

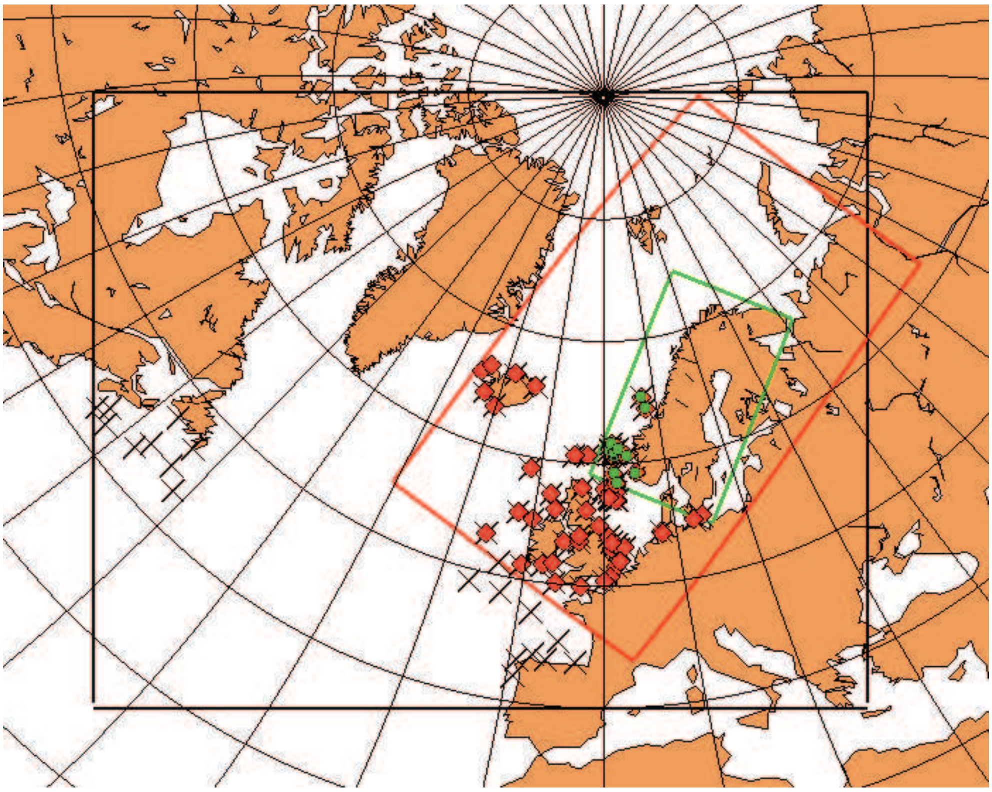


Figure 1: Buoys locations and domains. The large domain corresponds to WAM50 (black) the middle to WAM10 (red) and the smallest to WAM4 (green).

2 Model

2.1 WAM at MET Norway

The operational wave prediction model at MET Norway is the third generation spectral wave model, WAM, initially developed by an international group of scientists [Saetra et al. (2004); Komen et al. (1994)]. In contrast to first and second generation models WAM solves the wave action equation explicitly without any presumptions on the shape of the wave spectrum and represents the physics of the wave evolution for the full set of degrees of freedom of a two-dimensional wave spectrum. WAM50 (50km resolution) is run four times a day and it is forced with winds from HIRLAM12[1]. WAM10 (10km resolution) is run twice a day and it is forced with winds from HIRLAM8[2]. Finally WAM4 (4km resolution) is run twice a day and it is forced with winds from UM4[3]. In September 19th 2013 WAM4 was forced with winds from merged fields HIRLAM8 and AROME-Norway2.5 (Homleid (2013)). The forecast period for each model is 66 hours. WAM runs without data assimilation. The WAM model computes two-dimensional wave spectra, with 25 frequencies and 24 directions.

2.2 WAM at ECMWF

MET Norway has access to the wave forecast from the WAM of ECMWF (WAMECMWF). The WAM model at ECMWF is a different version to the one run at MET Norway but has the same physics. The WAM model at ECMWF is coupled to their atmospheric model TL799L91 through the exchange of the Charnock parameter (Janssen PAEM (1989)). It produces 10 days forecast every 12 hrs. The output data from their Limited Area model (LAW) were used in this report. The LAW, which covers the area from 5^oN to 90^oN and 98^oW to 56^oE, has a 11 km resolution and it is forced with 10 m neutral wind fields from the global system. The wave energy spectra is discretized into 36 frequencies and 36 directions. The model assimilates data from altimeter wave heights (ENVISAT and Jason 2).

3 Buoy observations

3.1 From ECMWF

The buoy observations are processed and quality controlled by the ECMWF. Since Buoys exhibit high-frequency variability not captured by the model results, the hourly observations are averaged in a window of 4 hours centered around the verification time, see Bidlot et al. (2002). The resulting time series have a 4 hour time interval. Not averaging the

[1]HIRLAM12 = Atmospheric model with 12km resolution,[Unden (2002)]

[2]HIRLAM8 = Atmospheric model with 8km resolution,[Unden (2002)]

[3]UM4 = Non Hydrostatic atmospheric Unified Model developed at UK Met Office. http://metcoop.org/memo/2012/01-2012-METCOOP-MEMO.PDF

data can result in a scatter between the models and observations [Janssen et al. (1997)]. For a more detailed description of the data treatment, see Bidlot et al. (2002) and Saetra et al. (2004). A summary of the data used can be seen in Table 1. The locations of the buoys are shown in Fig.(1).

Models	WAM50	WAM10	WAM4	
2012 total obs	47109	38253	8032	
2012 buoys used	79	65	14	
2013 total obs	44512	39040	8723	
2013 buoys used	77	64	16	
Models to compare	WAM50	WAM10		
2012 obs	38832	38832		
2012 buoys	61	61		
2013 obs	35444	35444		
2013 buoys	60	60		
Models to compare		WAM10	WAM4	
2012 obs		7406	7406	
2012 buoys		14	14	
2013 obs		8682	8682	
2013 buoys		16	16	
Models to compare		WAM10		WAMECMWF
2012 obs		36037		36037
2012 buoys		61		61
2013 obs		36266		36266
2013 buoys		60		60

Table 1: Numbers of buoys and observations used to validate the models. Observations refers to the mean number of observations at each forecast time. Also presented is the number of buoys and observations used when comparing several models.

3.2 From MET Norway

Six sites in the Norwegian and North Sea are used to validate WAM from 1999 up to 2013. Their locations are shown in Fig.(2). These in-situ observations are quality controlled at met.no, but have not been averaged in a window of 4 hours as for the observations processed at ECMWF. They have been averaged over each hour, and the resulting time series have a 1 hour time interval. This is the same method used in previous work on validating WAM, see Gusdal (2010). Since the results in Chapter 5.1, are extended time series from former study, we apply the same method in this study.

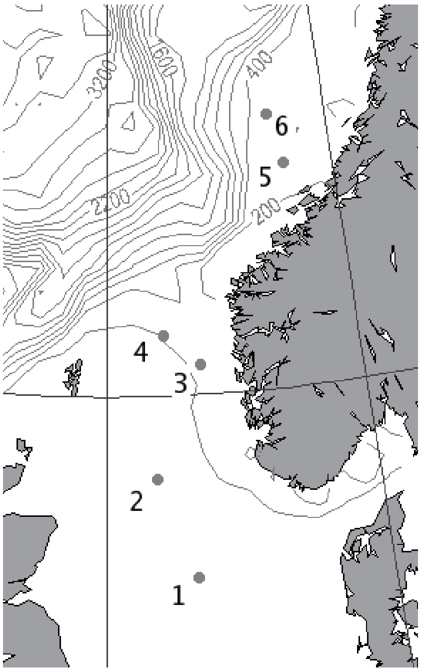


Figure 2: Displayed is the observation sites located in the Norwegian and the North Sea. The sites are 1: Ekofisk, 2: Sleipner, 3: Troll A, 4: Gullfaks C, 5: Draugen and 6: Heidrun.

4 Methods

4.1 Statistics

The skill is measured using standard statistics. The Mean Square Error ($MS\ Error$) and BIAS, is defined as

$$MS\ Error_j = \frac{1}{n}\sum_{i=1}^{n}(H_i^{mod} - H_i^{obs})^2 \tag{1}$$

$$BIAS_j = \frac{1}{n}\sum_{i=1}^{n}(H_i^{mod} - H_i^{obs}) \tag{2}$$

where the subscript j denote the day number in a month, i represent the observation number and H_i^{mod} and H_i^{obs} is the modeled and observed wave height respectively. The monthly Root Mean Square Error (RMSE) and BIAS are then defined as

$$RMSE = \sqrt{\frac{1}{N_T}\sum_{j=1}^{N_d} MS\ Error_j \cdot N_j} \tag{3}$$

$$BIAS = \frac{1}{N_T}\sum_{j=1}^{N_d} BIAS_j \cdot N_j \tag{4}$$

$$N_T = \sum_{j=1}^{N_d} N_j \tag{5}$$

where N_j is the number of existing observations for day j and N_T is the number of observations in a month.

5 Results

5.1 WAM - 1999 to 2013

In this study, observations from six sites in the Norwegian and the North Sea are applied, Ekofisk, Sleipner, Troll A, Gullfaks C, Draugen and Heidrun as shown in Fig.(2).The rmse and bias (model minus observations) for different lead times are displayed in Fig.(3), covering the period February 1999 through 2013. In the first period, the forecast skill of WAM50 (50km resolution) is shown. In March 2007, the higher resolution model WAM10 (10km resolution) was employed at met.no, and the forecast skill of WAM10 is therefore represented in the latest period. In WAM at met.no, an artificial enhancement of the wind has been used since 1998, where the enhancement is 4% for winds between 15m/s and 25m/s. However, there has been many upgrades in the mesh size of HIRLAM from 50km, to 20km and to 12km. The higher resolution wind field leads to stronger winds and the WAM model have never been tuned due to these changes. This may be the reason for the systematically overestimation in Hs as shown by the bias. This artificial intensification of the wind was removed from the model November 1, 2011 and we can see how the systematically overestimation in Hs don't appear any more. By looking at the rmse results, no decreasing trend in the rmse can be seen for the model analysis since 1999. However, the forecast skill has improved, illustrated by the decreasing deviation in rmse between the model analysis and the different lead times. This is due to the continuously improvements implemented in the 10m forcing over this time period and the introduction of a higher resolution model WAM10.

5.2 Each model

From the scatter and quantile-quantile plots at analysis time shown in Figures (4) and (5), we can see that the three models: WAM50, WAM10 and WAM4, behave quite well, with an slightly tendency towards overestimation as the wave heights increase. With the exception of WAM10 in 2012, see Figure (4), where the overestimation starts at $Hs = 8m$, small overestimation can be seen in the lower wave heights, $Hs = 4m$, and it increases rapidly after $Hs = 8m$. From the scatter plots we can see that the three models present a very high correlation coefficient, 0.95, 0.96 and 0.92, with a large number of data. WAM10 in 2012 has the best fit between observations and model data and the worse is WAM4 in 2013. In both years WAM4 does not give a better fit than WAM10.

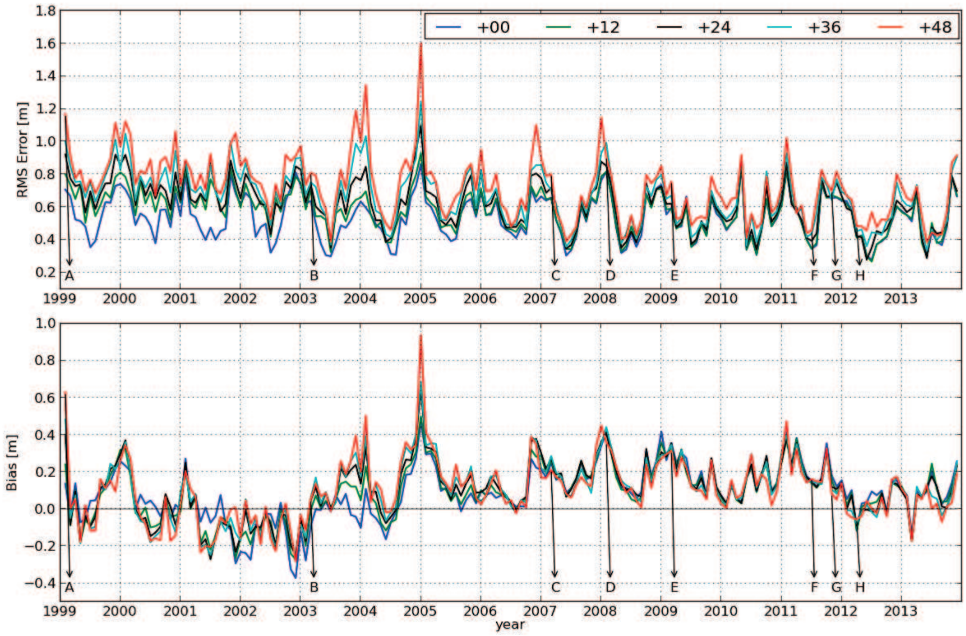


Figure 3: Time series of the rmse and bias for the forecast of Hs for the period 1999 to 2013. Note that model results from WAM50 are included for the period before March 2007, while model results from WAM10 are included for the later period. A:WAM50 introduced at MET, B:HIRLAM20 is introduced instead of HIRLAM50, C:WAM10 introduced at MET, D:HIRLAM12 is introduced instead of HIRLAM20, E:ENVISAT used as observations source in the Assimilation system, F:ERS-2 retired, G:Removed intensification of the highest winds, H:Lost communication with ENVISAT

5.3 WAM50 vs WAM10

In order to compare the statistical performance of WAM50 and WAM10, only buoys covered by both model domains and time are included in this analysis. This reduces the number of data, see Table(1). The bias and rmse are plotted in Figures (6) - (8). The forecast was better during the summer months than the winter months, where storms are more common. WAM10 presents smaller values of rmse than WAM50 and the bias of WAM10 are closer to zero than those of WAM50. In general the difference in rmse and bias is constant. Both models present an increase of rmse and a decrease of bias with lead time.

5.4 WAM10 vs WAM4

Figures (9) - (12) present the rmse and bias of co-located data between WAM10 and WAM4. In general WAM10 scores better than WAM4. As in the previous section the forecast was better during the summer months than the winter months. The bias is also

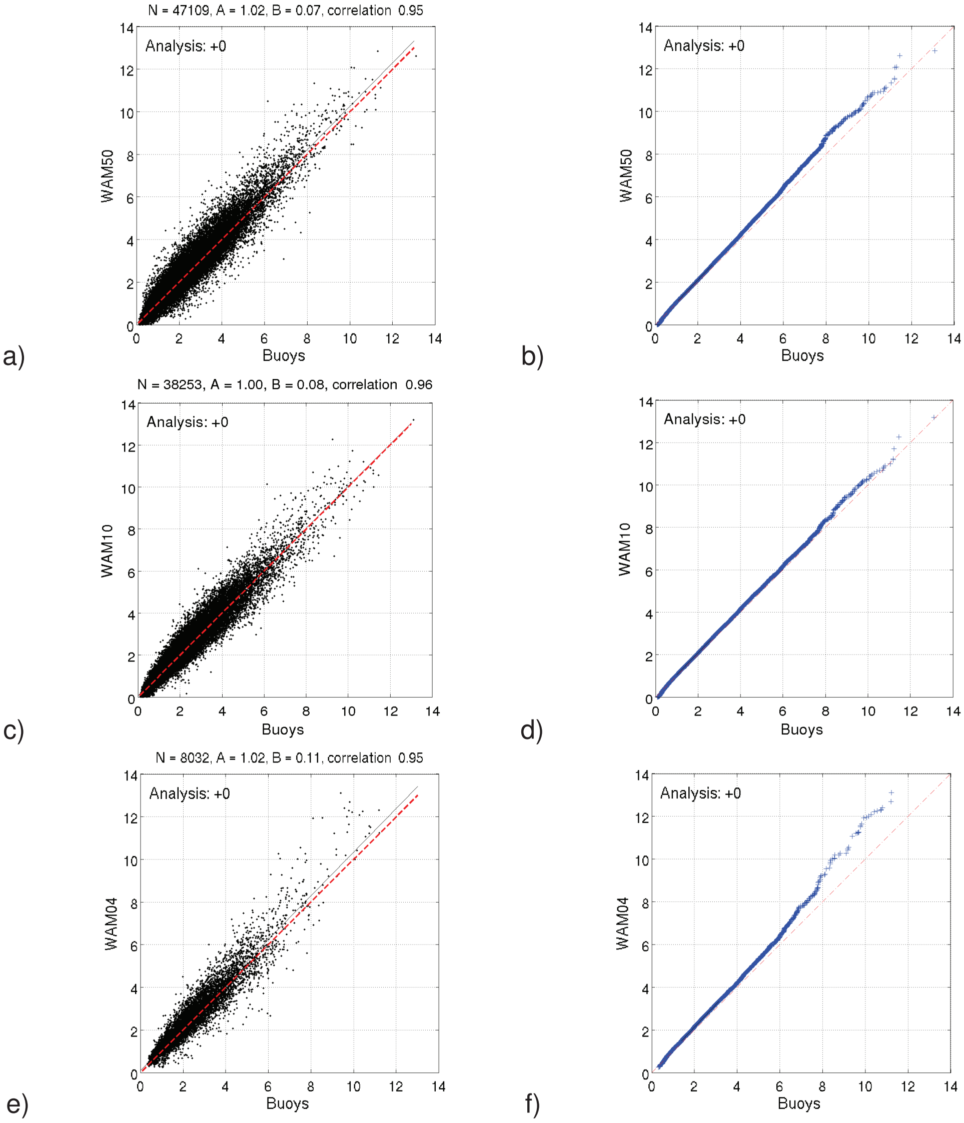


Figure 4: For the year 2012, scatter and quantile-quantile between observed and modeled significant wave height. a and b for WAM50, c and d for WAM10 and e and f for WAM4. The black line is the linear regression while the red dashed line represents the perfect fit between the two data sets. The total number of observations used, N, the slope, A and the correlation coefficient are written in the header of the scatter plots.

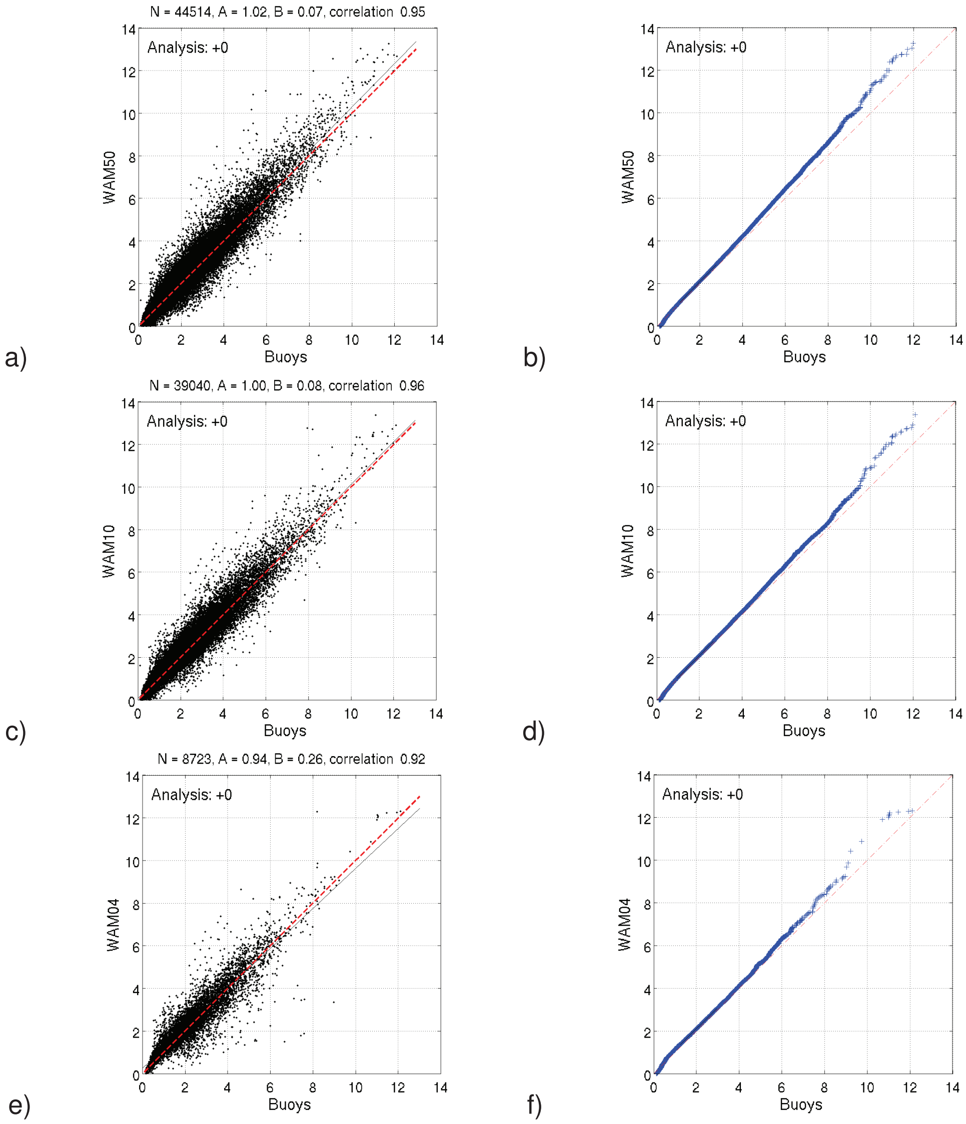


Figure 5: Same as Figure (4) but for 2013.

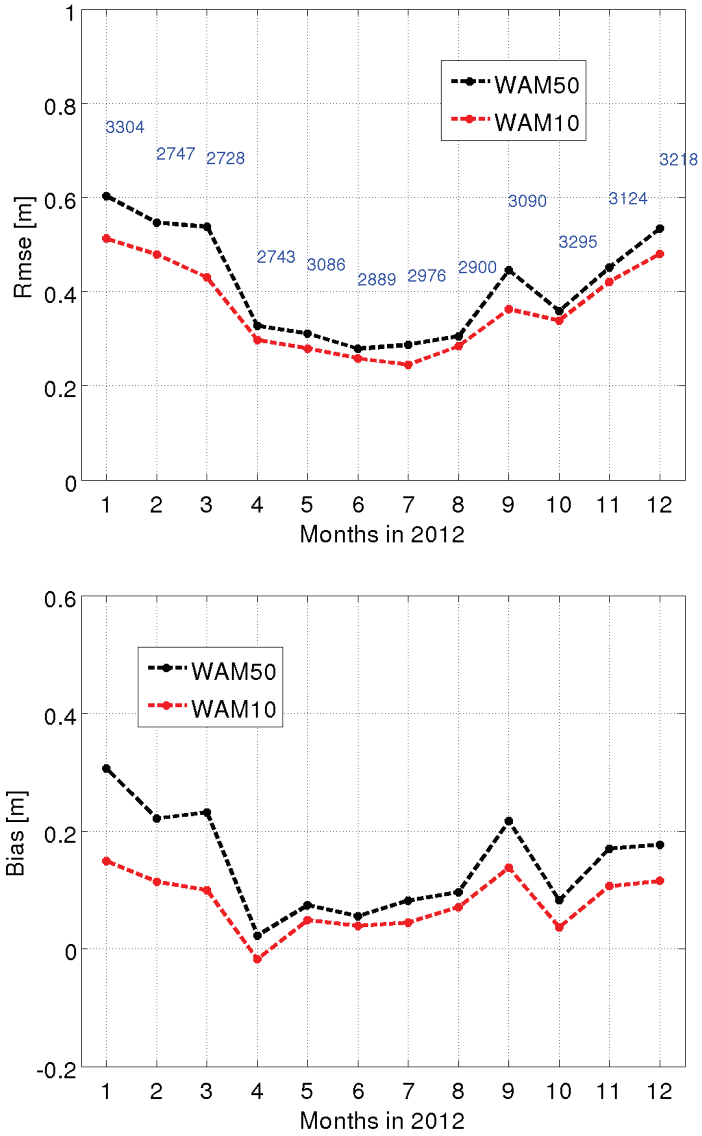


Figure 6: Comparison between WAM10 and WAM50 in 2012. Rmse and bias variations during the year. The numbers in blue indicate the amount of data used at each month.

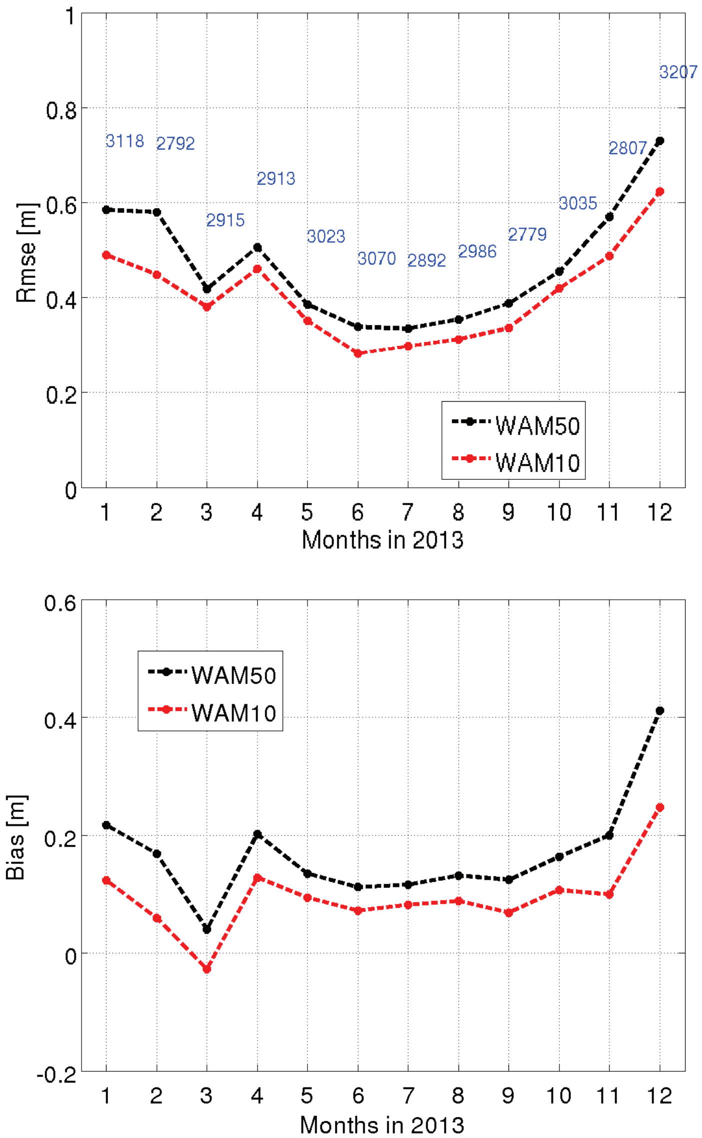
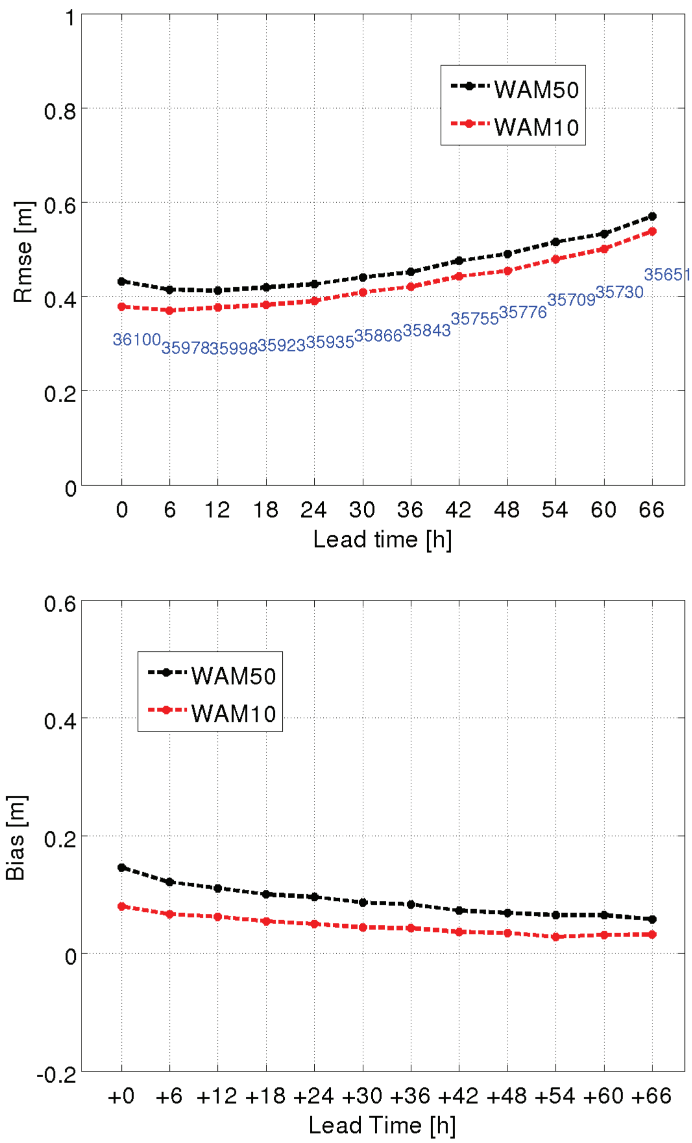


Figure 7: Same as Figure (6) but for 2013.



Comparison between WAM10 and WAM50 in 2012. Rmse and bias variations with lead time. The numbers in blue indicate the amount of data used at each lead time.

bigger during the winter months. WAM4 performs specially bad during February of 2013. The rmse increases with lead time and the bias is relatively constant with lead time.

5.5 WAM10 vs WAMECMWF

A comparison between WAM10 and WAMECMWF is performed by using co-located data, see Figures (13) - (15). The skill scores are very similar between these two model but the

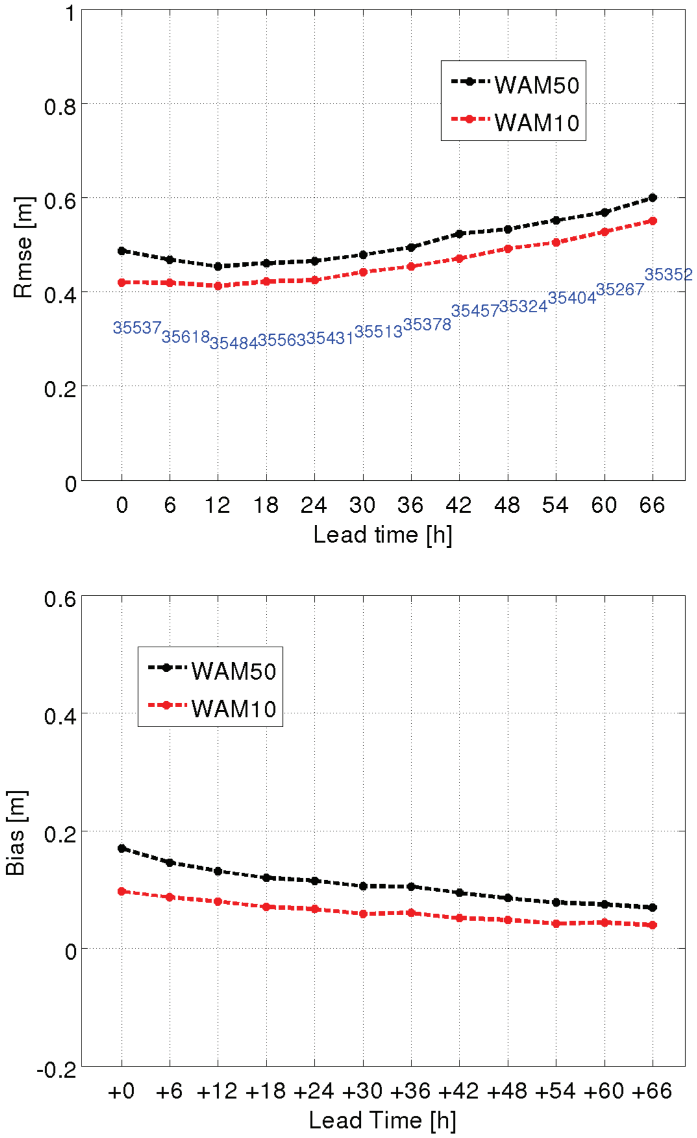


Figure 8: Same as in Figure (5.3) but for 2013.

WAMECMWF scores better. In the winter months the difference in rmse is bigger (0.18 m) than in the summer months (0.08 m). In general WAM10 present a small positive bias during the two years while the bias of WAMECMWF is very close to zero. At analysis

WAM10 presents a positive bias of 0.1 in the summer months while the WAMECMWF has a bias of zero.

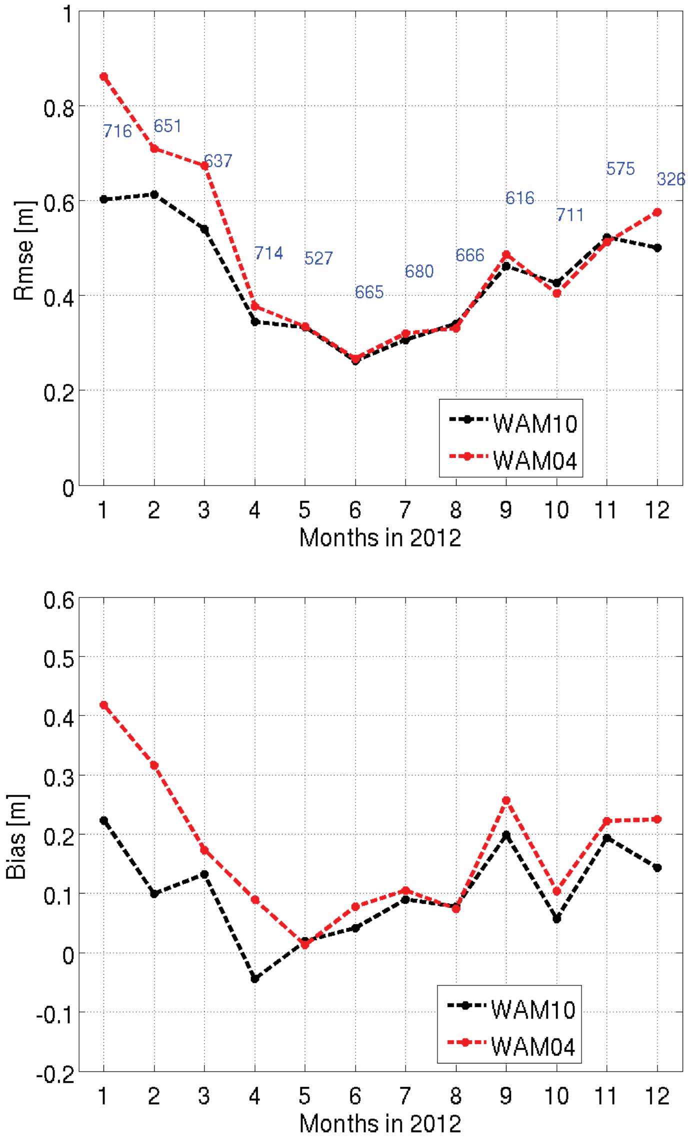


Figure 9: Comparison between WAM4 and WAM10 in 2012. Rmse and bias during the year. The numbers in blue indicate the amount of data used at each month.

5.6 Summary and Conclusions

A validation of the wave height (Hs) forecast at the Norwegian Meteorological Institute has been carried out for the years 2012-2013. Model results from the wave model WAM and observations from in-situ buoy are used for this purpose. The wave model WAM is run at 50km, 10km and 4km resolution (WAM50, WAM10 and WAM4) and is forced with 10m winds from the atmospheric model HIRLAM12, HIRLAM8 and UM4 respectively.

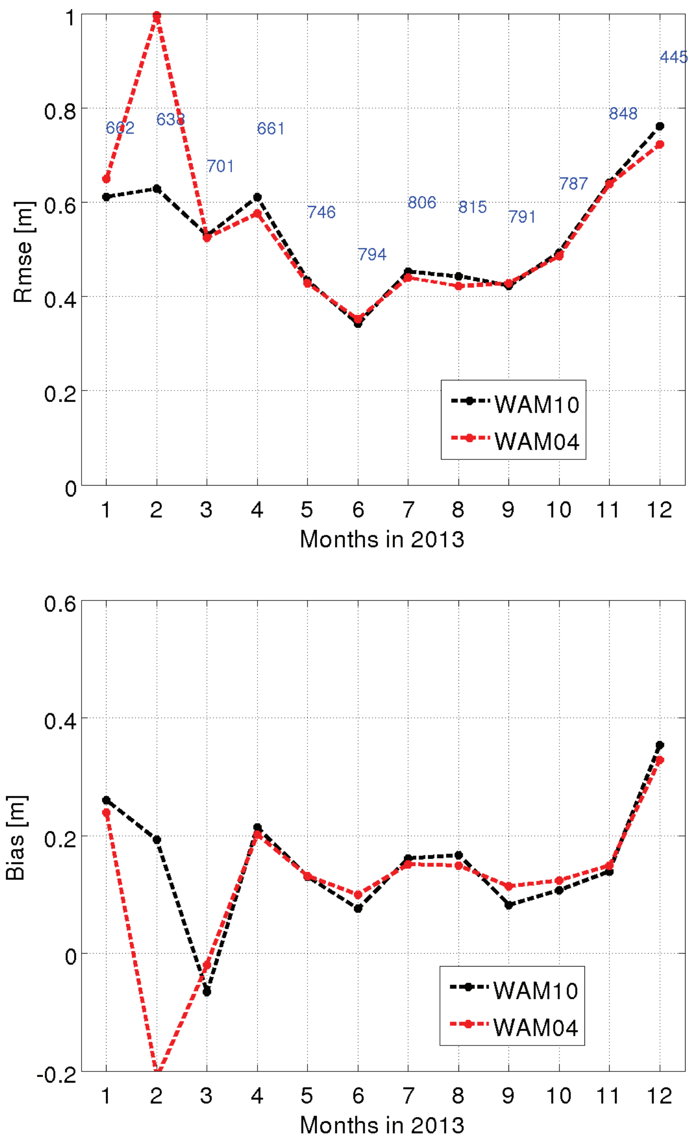


Figure 10: Same as Figure (9) but for 2013.

Since HIRLAM is run operational at met.no, it is frequently upgraded with higher resolutions and improved set-ups/model codes. This has shown to have a positive impact on the wave model leading to improved forecast skills of Hs. The quality of the forecasted wave height for WAM10 has improved after the removal of an artificial enhancement on the wind in November 1, 2011.

The different WAM models present good fit with observations with a small tendency to overestimation as Hs increases. WAM10 scores better than WAM50 and WAM4. Be-

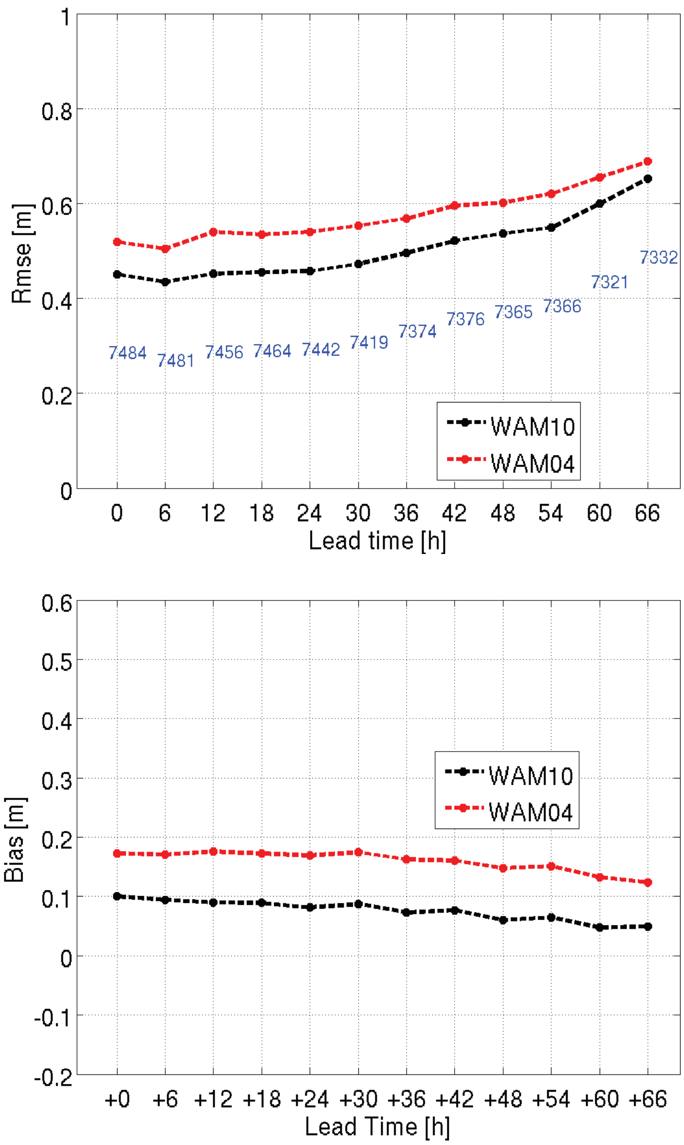


Figure 11: Rmse and Bias variations with lead time of WAM4 and WAM10 for 2012. The numbers in blue indicate the amount of data used at each lead time.

cause of the increase of resolution in wave and atmospheric models, it was expected that WAM10 performs better than WAM50. The increase of resolution from 10km to 4km and the forcing of better winds (from a non hydrostatic model) in WAM4 did not improve its performance with respect to WAM10 as in previous years, see Gusdal (2012). It is possible that the advantages are noticeable in locations near the coast and the buoys used in this report are far from it.

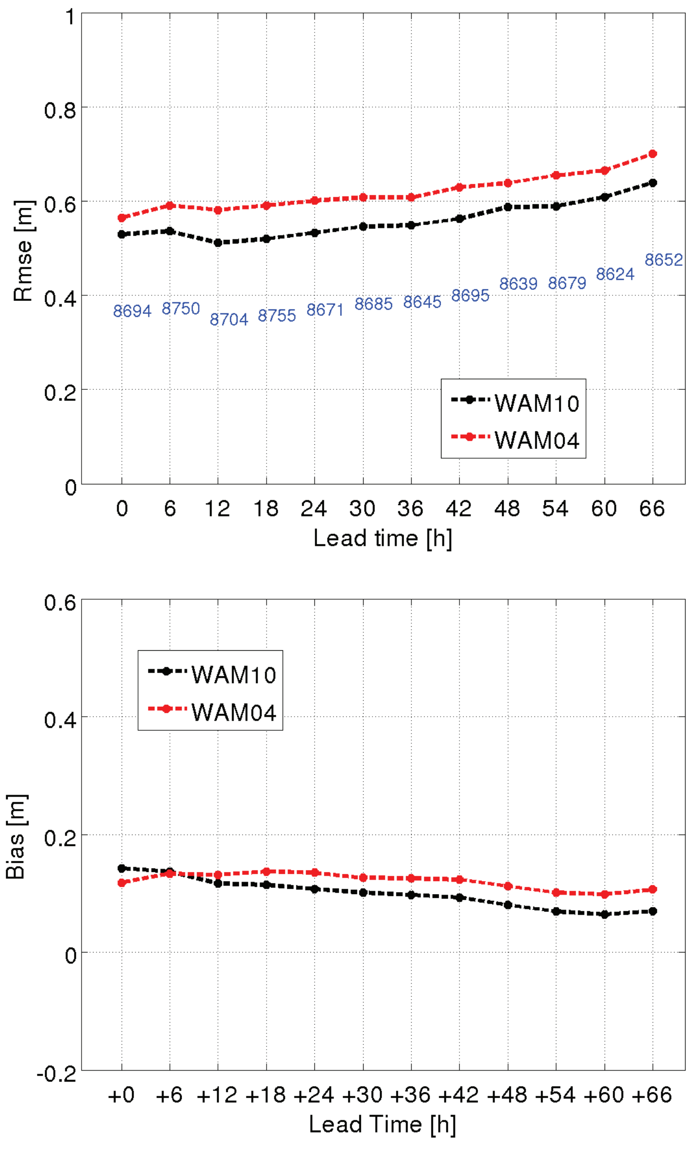


Figure 12: Same as Figure (11) but for 2013.

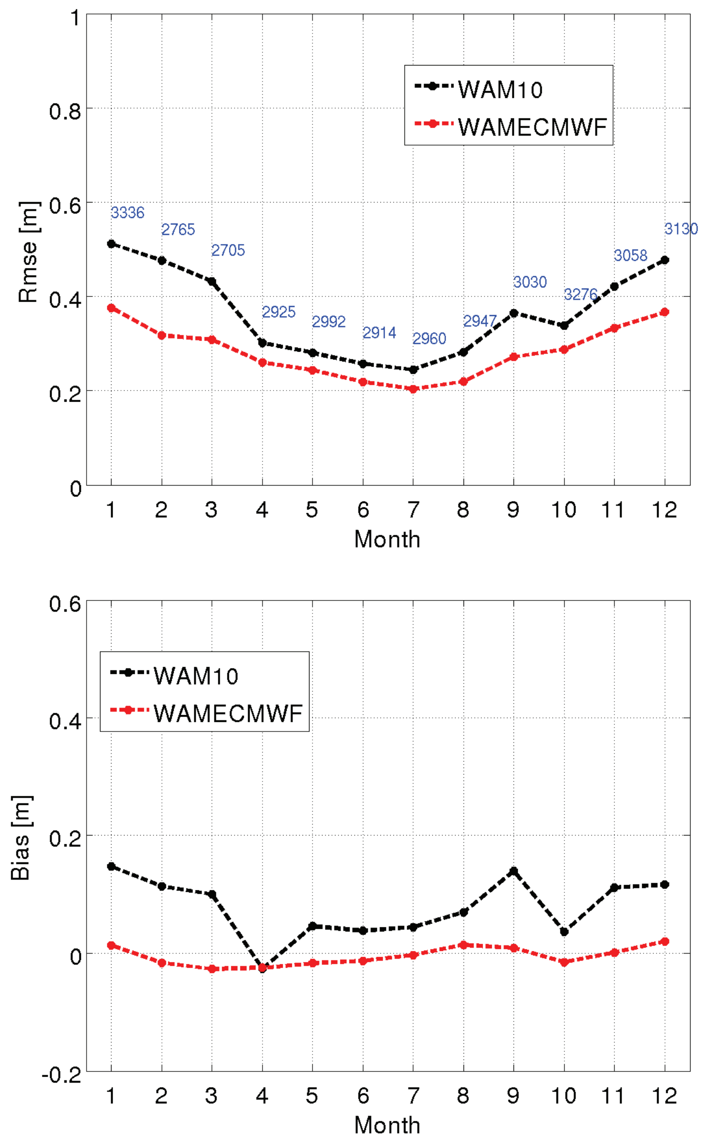


Figure 13: Rmse and bias of WAMECMWF and WAM10 during 2012.

The Limited area wave model from ECMWF run at 11km resolution (WAMECMWF) scores slightly better than our WAM10. The WAMECMWF is a coupling system between the atmospheric and wave model and assimilates altimeter data. These two features are absent in our WAM10 system and exclude important dynamics.

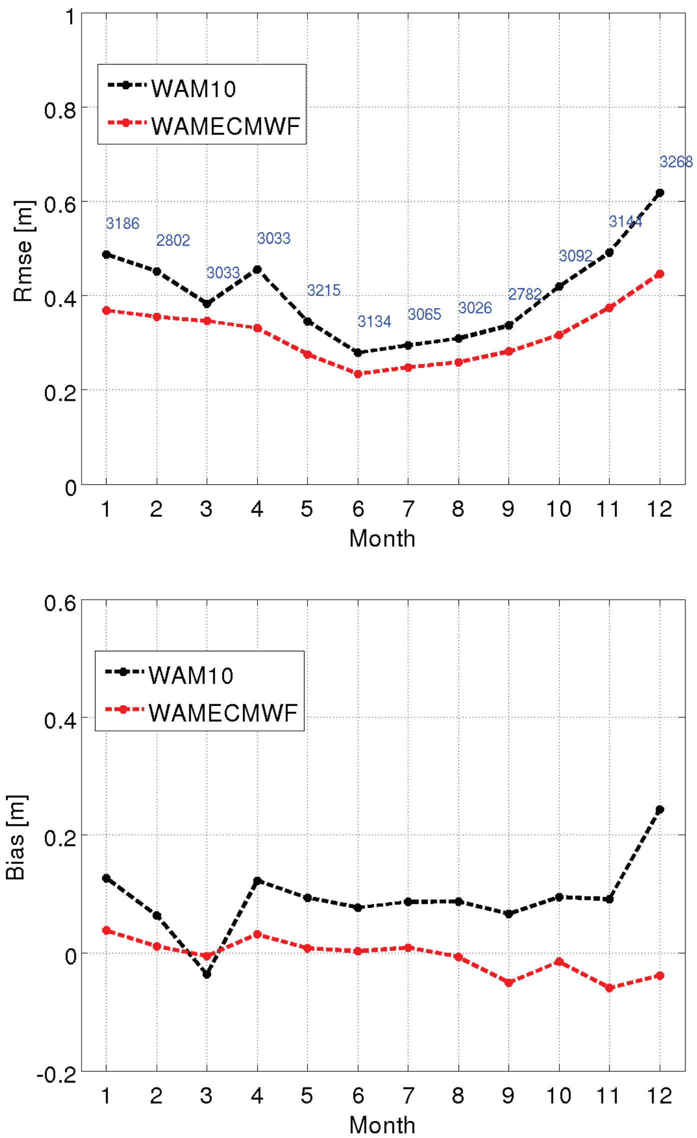


Figure 14: Rmse and bias of WAMECMWF and WAM10 during 2013.

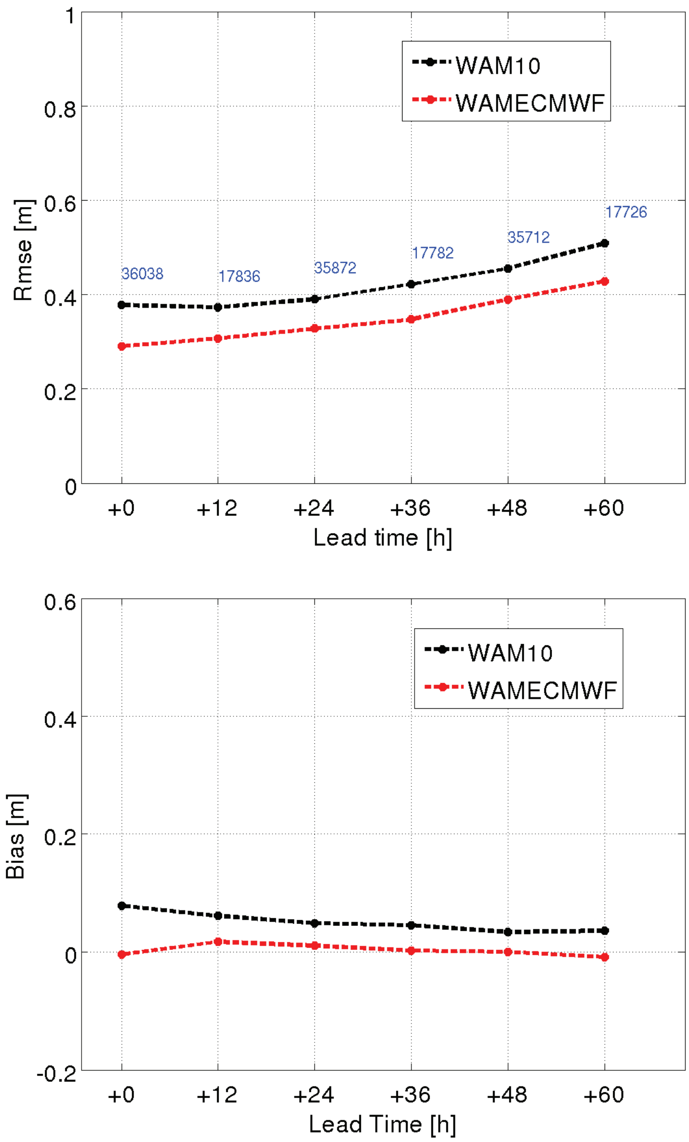


Figure 15: Rmse and bias variations with lead time for WAMECMWF and WAM10 during 2012.

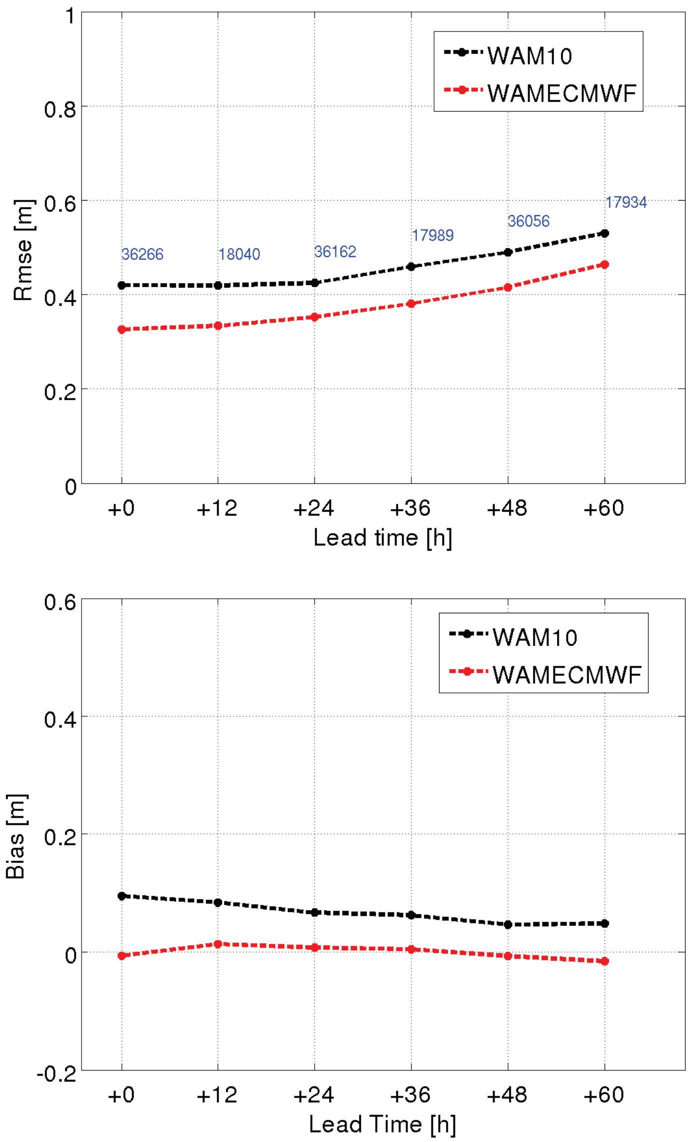


Figure 16: Rmse and bias variations with lead time for WAMECMWF and WAM10 during 2013.

References

Bidlot, J.-R., D. J. Holmes, P. A. Wittmann, R. L. Lalbeharry, & H. S. Chen, (2002) Intercomparison of the performance of operational ocean wave forecasting systems with buoy data, Wea. Forecasting, 17, 287-310. doi: http://dx.doi.org/10.1175/1520-0434(2002)017<0287:IOTPOO>2.0.CO;2

Gusdal, Y.,(2010) Validation of the Operational Wave Model WAM - February 1999 through June 2009, met.no Rep. 3, Norwegian Meteorological Institute. 12 pp.

Gusdal, Y., A. Carrasco (2012) Validation of the Operational Wave Models - Report 2011. met.no Rep. 23/2012, ISSN: 1503-8025. Norwegian Meteorological Institute.

Homleid M., Apelien T. and J.B. Bremnes.(2013) Verification of Experimental HARMONIE Models, March to May 2013. met.no note. Note no. 4/2013, Oslo June 6.

Janssen PAEM (1989) Wave-induced stress and the drag of air flow over sea waves. J Phys Oceanogr, 19(6):745-754. http://dx.doi.org/10.1175/1520-0485(1989)019<0745:WISATD>2.0.CO;2

Janssen, PAEM, B. Hansen, & J.-R. Bidlot (1997) Verification of the ECMWF forecasting system against buoy and altimeter data, Wea. Forecasting, 12, 763-784. doi: http://dx.doi.org/10.1175/1520-0434(1997)012<0763:VOTEWF>2.0.CO;2

Komen, G., J.L. Cavaleri, M. Donelan, K.Hasselmann, S.Hasselmann, and P.A.E.M. Jansen, Dynamics and Modelling of Ocean Waves, 1994, Cambridge University Press, 533 pp.

Saetra, Ø, and J.-R. Bidlot (2004) Potential Benefits of Using Probabilistic Forecast for Waves and Marine Winds Based on the ECMWF Ensemble Prediction System, 2004,American Meteorological Society, 673-689.

Unden, P., Hirlam-5 Scientific Documentation, (ed.) 2002, 1-144, Available at: http://www.hirlam.org