Evaluation of the new ECMWF WAM model

George Galanis [1,2], George Kallos [1], Peter C. Chu[3], Yu-Heng Kuo[3]

[1] *University of Athens, School of Physics, Division of Environmental Physics-Meteorology, Atmospheric Modeling and Weather Forecasting Group, University Campus, Bldg. PHYS-V, Athens 15784, Greece*
Email: kallos@mg.uoa.gr
[2] *Hellenic Naval Academy, Section of Mathematics, Xatzikyriakion, Piraeus 18539, Greece*
Email: ggalanis@mg.uoa.gr
[3] *Naval Postgraduate School, Department of Oceanography, Graduate School of Engineering & Applied Science, Monterey, CA 93943, USA*
Email: pcchu@nps.edu

ABSTRACT

During the last years the European Centre for Medium-Range Weather Forecasts (ECMWF) released new editions of the wave model WAM. The latest model version has been evaluated on both wave height and spectrum in close and shallow seas as well as in open oceans. The purpose of this work is twofold: First to discuss some evaluation results concerning the model performance and secondly to study the sea state characteristics in North Atlantic Ocean in a case of extreme wind and wave conditions by means both of satellite measurements and WAM forecasts.

1. INTRODUCTION

The new version of WAM model (cycle 33R1) released from ECMWF has introduced important modifications including the employment of a new advection scheme, in which the corners of the grid are taken into account providing a more uniform propagation of wave spectra, as well as new parametrization of shallow water effects. On the other hand, new techniques of estimating extreme wave parameters have been added.

The Atmospheric Modeling and Weather Forecasting Group (AM&WFG) of the University of Athens, in cooperation with ECMWF, has developed a stand alone version of WAM for linux clusters.

In this work model characteristics under extreme conditions in the area of North Atlantic are discussed.The study was focused on a 10-day period (26 October - 5 November, 2009) and particularly on the last three days during the extreme weather conditions where severe winds of 30 m/sec led to extreme waves with heights exceeding 10 m.

Envisat RA-2 altimeter records were used for correcting initial conditions (Janssen et. al., 1987; Breivik and Reistad 1994; Abdalla et. al., 2005; Emmanouil et. al., 2007) while different observational sources were employed for the evaluation of the results:

- Buoys of the UK Met Office provided wind and wave observations for the entire study period.
- ASAR level-2 spectra records at specific points within the area of interest
- Merged altimetry records from different satellites (ESA, NASA, NOAA, US NAVY).

2. THE WAVE MODEL AND DATA SETS.

In older versions of WAM (WAMDIG, 1988; Komen et al., 1994) the wave energy balance equation

$$\frac{\partial F}{\partial t}+\frac{\partial (u_g F)}{\partial x}+\frac{\partial (v_g F)}{\partial y}=0,$$

was solved using a first order upwind scheme considering contributions from neighboring points only in x and y directions ignoring the corners of the grid (F is the wave variance spectrum and u_g, v_g the group velocity components). In the new version of the model (cycle 33R1) the advection scheme is extended to account also for the corner points by using the Corner Transport Upstream scheme providing a more uniform propagation in all directions. On the other hand, a new parametrization of shallow water effects is introduced that affects both the time evolution of the wave spectrum and the determination of the kurtosis of the wave field, based on a recent work of Janssen and Onorato (2007). Moreover, a number of technical modifications, concerning mainly the minimum time step, can be proved valuable for the use of the model in high resolution grids.

The area under consideration is North Atlantic Ocean (Latitude 0N-80N and Longitude 80W – 30E) as illustrated in Fig. 1. WAM was integrated on 30 frequencies, 24 directions and at horizontal resolution of 0.5x0.5 degrees. The evaluation area was restricted in the northern part of the Atlantic Ocean (40N – 65N, 50W – 0), however the need of adapting adequately swell waves imposed the extension of the domain used.

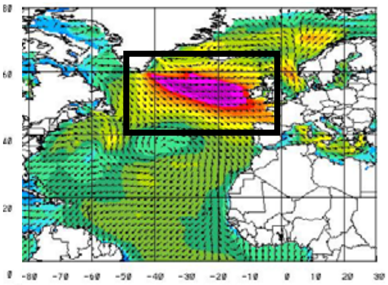


Figure 1. The model domain and the study area (inner rectangle)

The first integration frequency was set to 0.0417 Hz while the propagation time step was defined to 180 seconds and the source term integration time step to 900 sec. WAM was driven with 10 m forecasted wind fields available every 3 hours from NCEP/GFS global model with horizontal grid resolution of 0.5x0.5 degrees.

The model was configured to run on pseudo-operational mode on 36 hour cycles. The first 12 hours the Envisat RA-2 altimeter records were assimilated followed by a 24-hour forecasting period. Ten cycles have been performed.

For the evaluation of the results different observational sources and statistical tools have been utilized. More precisely, significant wave height and direction, wind speed and direction as well as mean wave period values were obtained from the UK Met Office buoys 62613 (47.500N, 8.5W) and 62001 (45.201N, 5W).

Figure 2. The buoys used for evaluation

In addition, ASAR level 2 spectra records at specific points of the study area have been utilized for verification and merged altimeter measurements for the study of the SWH distribution.

The statistical evaluation is based on the following indices:

Bias between observed and forecasted data:

$$Bias = \frac{1}{N} \cdot \sum_{i=1}^{N} \left(obs(i) - for(i) \right)$$

where *obs* denotes the recorded, *for* the corresponding forecasted value and *N* the size of the sample.

Root Mean Square Error:

$$RMSE = \sqrt{\frac{1}{N} \cdot \sum_{i=1}^{N} \left(obs(i) - for(i) \right)^2}$$

Skewness :

$$g_1 = \frac{\frac{1}{N} \cdot \sum_{i=1}^{N} \left(swh(i) - \mu \right)^3}{\sigma^3}$$

where m denotes the mean value of the sample, that measures the asymmetry of the probability distribution, and

Kurtosis:

$$g_2 = \frac{\frac{1}{N} \cdot \sum_{i=1}^{N} \left(swh(i) - \mu \right)^4}{\sigma^4} - 3$$

indicating the dependence of the variance on possible outliers.

3. RESULTS

The prevailing wind characteristics during the material period are summarized as follows: Extreme westerly winds at about 30 m/sec donated the area between the southern edge of Greenland to the West and Irish and British islands to the East as illustrated in Figure 3.

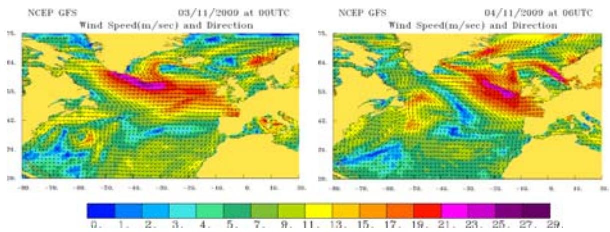


Figure 3. Wind conditions at the area and time of study.

A direct result was the generation of extreme waves with SWH around 12-14 meters at specific locations (Figure 4).

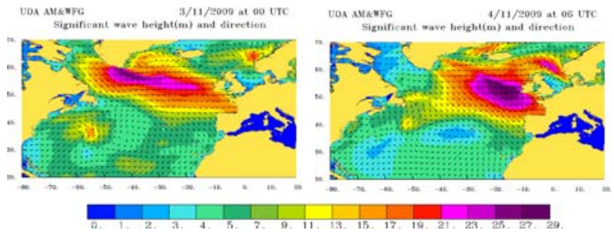


Figure 4. Significant wave height and direction.

The wind and wave distribution over the area implies that wind waves are the main component of the sea state. The swell counterpart is illustrated in Figure 5.

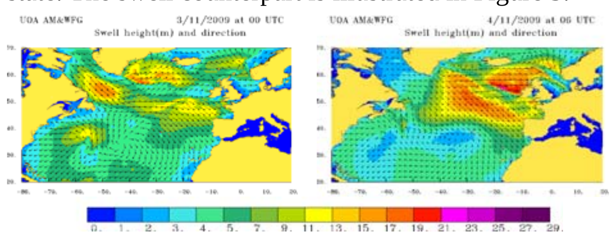


Figure 5. Swell height and direction.

The new feature of the WAM model for the calculation of the Maximum Expected Wave Height based on the wave distribution seems to give high values for extreme wind conditions where wave peaks tend to be flattened (Figure 6).

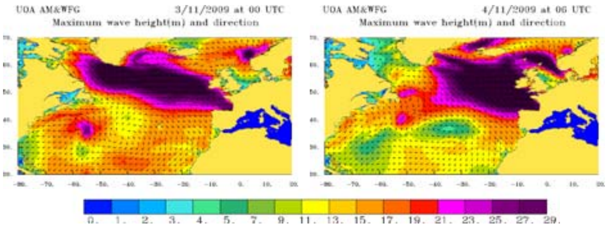
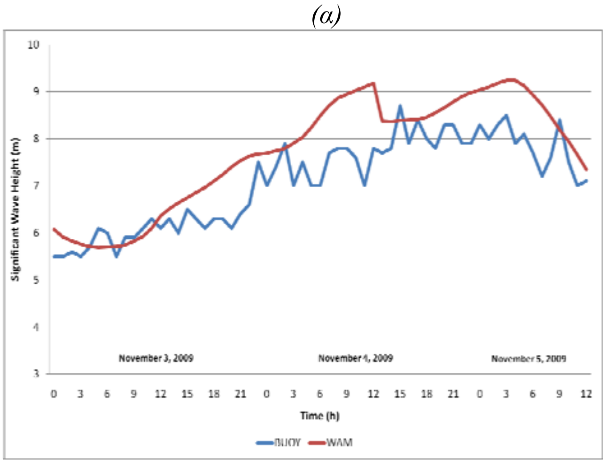


Figure 6. Maximum expected wave height and direction forecasts.

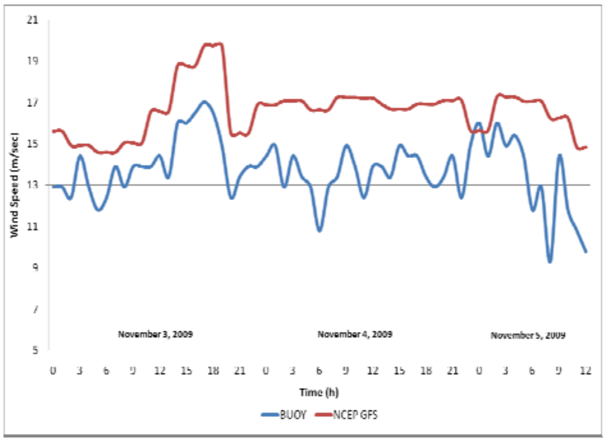
The comparison of modelled SWH with the buoy data indicates a slight but constant overestimation of WAM something that seems related to the overprediction of winds from the atmospheric model. Wave period is also overestimated something that can be, at least partly, attributed to wind overestimation over long fetching. (Figures 7-9).

(a)

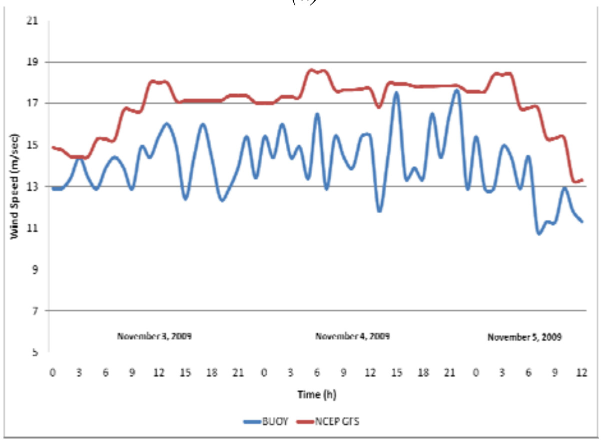


(b)

Figure 7. SWH at the buoy #62001 (a) and #62163 (b) (blue lines) and WAM (red lines).



(a)



(b)

Figure 8. Wind Speed at buoy #62001 (a) and #62163 (b) as forecasted by NCEP/GFS model (red lines) and recorded by buoys (blue lines).

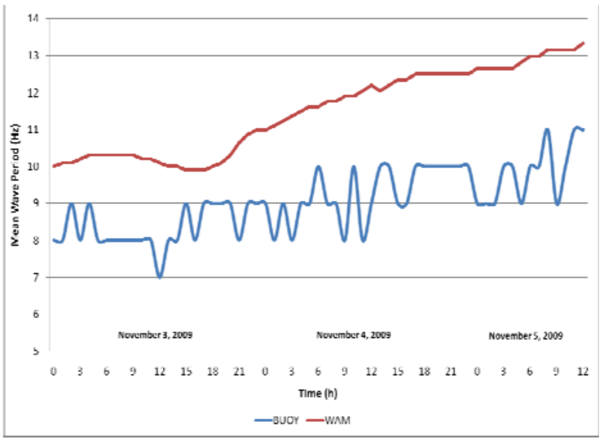


Figure 9. Mean Wave Period at buoy #62001 as forecasted by WAM model (red line) and recorded by the buoy (blue line).

The above mentioned results are further supported by the statistics presented in Tables 1 and 2. The increased RMSE values indicate further variable wave forecasts compared to buoy observations.

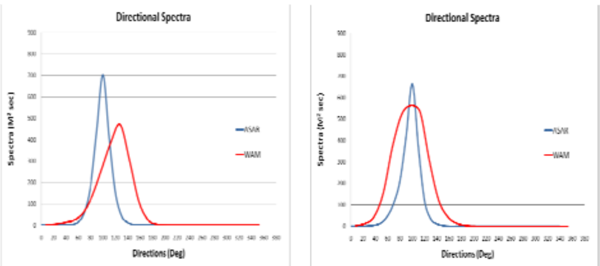
Buoy 62001	Wind_Dir (deg)	Wind_Speed (m/sec)	Wave_Height (m)	Wave_Period (sec)
Bias	11.38	2.88	0.58	2.46
RMSE	14.67	3.20	0.75	2.60

Table 1. Statistics for the buoy 62001

Buoy 62163	Wind_Dir (deg)	Wind_Speed (m/sec)	Wave_Height (m)
Bias	1.30	2.88	0.62
RMSE	7.03	3.23	0.83

Table 2. Statistics for the buoy 62163

Further analysis of the model results related to the evaluation of wave energy distribution is based on ASAR level 2 spectra products at characteristic locations. In the area of high waves the model distributes the energy over a wider directional interval while the spectral distribution from both the model and ASAR seems to be quite similar. In order to illustrate the above general characteristics, the spectra distribution at two representative points I (50.24N, 23.98W) and II (54.63N, 22.34W) are presented in Figures 10-13.



(a) *(b)*

Figure 10. The directional distribution of recorded (blue line) and forecasted (red line) wave energy at point I (a) and II (b)

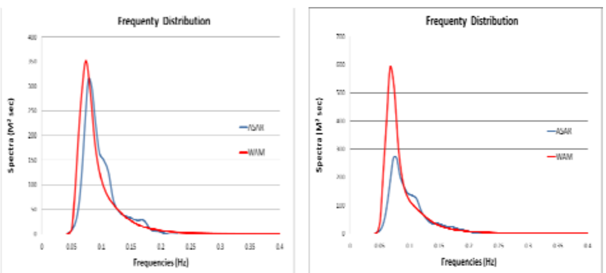
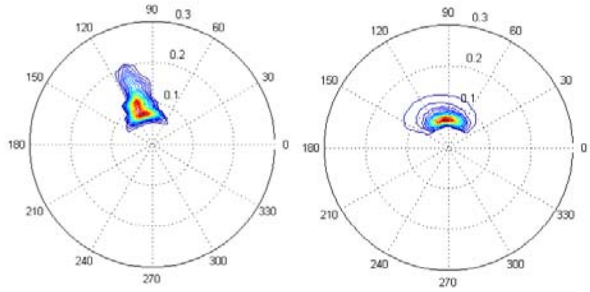
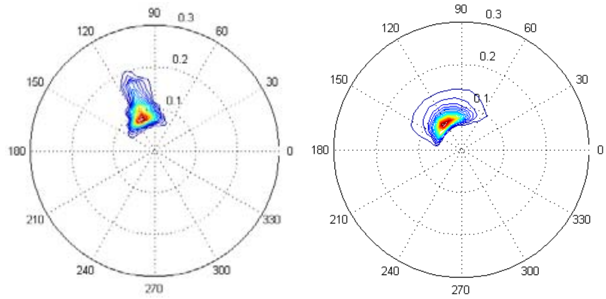


Figure 11. The spectral distribution of recorded (blue line) and forecasted (red line) wave energy at point I (a) and II (b)



ASAR spectra *WAM spectra*

Figure 12. The wave energy distribution as recorded by ASAR and forecasted by WAM in polar plots for point I



ASAR spectra *WAM spectra*

Figure 13. The wave energy distribution as recorded by ASAR and forecasted by WAM in polar plots for point II

A third source of observations used for the evaluation of model results has been based on the Radar Altimetry Toolbox utilized for mining satellite observations of significant wave height. According to (Rosmorduc et. al., 2009), these gridded data result by merging different satellite records (CNES, ESA, NASA, NOAA and US NAVY) and are calibrated based on Jason-1 as reference mission. This intercomparison is made over the entire study area (Figure 1). The main results are summarized in Tables 3 and 4.

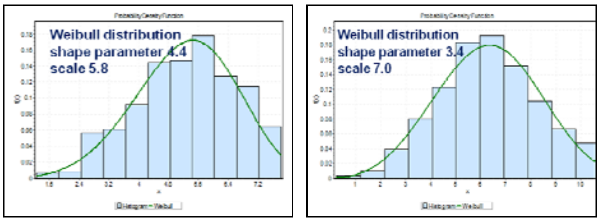
Percentiles	**SAT**	**WAM**
P_{5}	2.81	3.06
P_{10}	3.38	3.72
$P_{25}=Q1$	4.36	4.98
P_{50} *(Median)*	5.38	6.32
$P_{75}=Q3$	6.30	7.63
P_{90}	6.98	9
P_{95}	7.32	9.73

Table 3. Percentiles of satellite records and WAM forecast for the study period

Statistical Parameter	**SAT**	**WAM**
Range	6.55	10.51
Mean	5.28	6.31
Std. Deviation	1.34	1.96
Skewness	-0.31	-0.01
Kurtosis	-0.50	-0.37

Table 4. Main statistical parameters for satellite records and WAM forecasts during the study period

The model overestimation of SWH, concluded by the increased percentiles and mean values, can be attributed to the corresponding wind overestimation be the GFS model to a certain degree. The corresponding deviation is also overpredicted. On the other hand, the low values of skewness and kurtosis reveal rather canonical samples.
The two data sets, namely model and satellite altimeter, have been further analyzed by using Kolmogorov-Smirnov tests for distribution fitting. From this analysis it was found that the best choice is Weibull distribution for both samples (Figure 14). However, the shape and scale parameters deviate. It worth also noticing that both cases diverge from the classical Rayleigh distribution (Weibul with scale parameter 2) that SWH normally follows under non extreme conditions (Longuet-Higgins, 1980; Battjes and Groenendijk, 2000)



(a) *(b)*

Figure 14. Distributions that best fit to satellite (a) and WAM (b) SWH values.

4. CONCLUSIONS

In this work a first attempt was made to evaluate the performance of WAM model (ECMWF version, cycle 33R1). The evaluation was performed over North Atlantic Ocean under extreme wind and wave conditions. The evaluation data set includes buoy measurements, ASAR-level 2 full wave spectra as well as gridded altimeter observations. For this intercomparison, the following remarks can be made:

- In general the model predicts wave direction satisfactory although wave energy is spread over a wider angle.
- Modelled SWH tends to be overestimated but for the present case this can be attributed, to a certain degree, to the wind overestimation. Further analysis is required on this issue.
- Modelled peak wave period tends to be shifted towards higher frequencies. This is a common characteristic usually encountered in such ASAR-model intercomparisons.
- Both forecasts and satellite records follow Weibull distributions with different scale and shape characteristics.
- The probability density function of SWH under extreme conditions deviate from the classical Rayleigh distribution followed in average conditions

5. REFERENCES

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