First studies with the high-resolution coupled wave current model CWAM and other aspects of the project Sea State Monitor

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1. Introduction

The high resolution Coastal Wave Model (CWAM) for the German Bight and the western Baltic Sea has been developed by the German Meteorological Service (Deutscher Wetterdienst, DWD) and the German Maritime and Hydrographic Agency (Bundesamt für Seeschifffahrt und Hydrographie, BSH) in cooperation with the Helmholtz-Zentrum Geesthacht (HZG). CWAM is based on the Wave Model (WAM) (Hasselmann et al. 1988) and it will complement the series of wave models consisting of the Global Wave Model (GWAM) and the European Wave Model (EWAM) which are operated by the DWD. The intention of the development of CWAM is not primarily a scientific purpose, but rather an improvement of the operational daily forecasts of sea state, currents, and water level for the German coastal waters. In these sea areas a variety of human activities are carried out which have need of precise sea state and current prediction. Naturally it is important to have a reliable prediction of extreme events like storm surges and extraordinary sea state caused by storms. However, several human activities at sea, e.g. the construction and maintenance of offshore wind power plants, are subjected to relative low limits of sea state. Thus they need very exact forecasts in the low and moderate range of wave heights and an incorrect forecast can result in financial loss, material and human damages. The improvement of sea state prediction by CWAM relative to conventional models is owed to a higher resolution, consideration of variable, time-dependent water depth, and currents.

The development of CWAM is part of the project “Sea State Monitor” which itself is embedded in the project DeMarine2 (see www.demarine.de) and the European program Copernicus (see www.copernicus.eu). Although the paper is focused on CWAM also further aspects of the project are considered. The structure of the paper is as follows. The Coastal Wave Model is briefly described in section 2. A comparison of model results with observational data is presented in section 3. The influence of changing sea level and sea currents is considered in section 4. Finally, summary, conclusion and an outlook are given in sections 5 and 6.

2. The Coastal Wave Model for the German Bight and the Western Baltic Sea

The Coastal Wave Model is based on WAM (Hasselmann et al. 1988). With a horizontal resolution of about 900 m CWAM extends from 6.173611^oE to 14.909722^oE and from 53.229167^oN to 56.445835^oN. CWAM is nested within EWAM the wave model that is used by the DWD for sea state prediction in European sea areas. Figure 1 shows the model area of CWAM. An interactive coupling between CWAM and the HIROMB-BOOS ocean circulation model (HBM) is intented. HBM provides informations about currents and water depth influenced by tides and wind effects. It has been developed by BSH and Danish Meteorological Institute (DMI) (see e.g. Berg and Poulsen (2012); Poulsen and Berg (2012)). However, the present version of CWAM is working with sea current data from HBM in a kind of a one way coupling. HBM uses the same spatial resolution as CWAM. Naturally CWAM is also driven by wind fields which are taken from the atmospheric regional model COSMO-EU that is operated by the DWD.

For test purposes currently three configurations of CWAM run twice a day with a forecast time of 12 hours. The model configurations are listed in table 1. The full version CWAMC takes sea currents and variable, time-dependent water depth into acount. CWAMD considers only variable depth, while CWAMN runs with fixed water depth and without current.

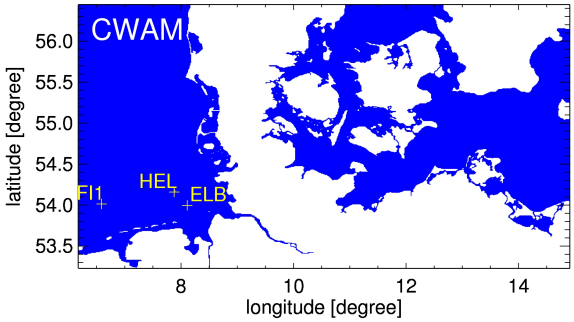

Fig. 1. CWAM area covering the German Bight and the western Baltic Sea. The position of the Elbe Buoy (ELB), buoy south of Helgoland (HEL), and the platform FINO1 (FI1) are marked.

Table 1. List of model simulations.

configuration	taking into account
CWAMN	fixed depth, no current
CWAMD	variable depth, no current
CWAMC	variable depth and current

3. Comparison of model results with observational data

In the project Sea State Monitor it is planned to compare the model results with high resolution satellite observations in near real-time. It offers an excellent possibility to assess model data extensively in near shore areas where buoy measurements are rare and sea state exhibits a spatially complex structure. It will give the user of forecasts the possibility to assess the quality of model predictions. The German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt, DLR) has developed methods in order to derive meteorological and marine parameters from high resolution TerraSAR-X observations. An example of wave and wind fields obtained from TerraSAR-X data and a comparison with CWAM results is presented in section a. In section b CWAM results are compared with buoy measurements.

a. Comparison with satellite data

As mentioned above besides the development of CWAM a further aim of the project Sea State Monitor is a near real-time validation of the operational daily model forecasts using satellite data. Methods for the purpose of deriving wind and sea state parameters measured by synthetic aperature radar (SAR) have been developed and applied by the DLR. Figure 2 depict the sea surface as seen by TerraSAR-X on 20. March 2013, 05:51 UTC northwest of the estuary of the river Elbe. Figure 3 shows the sea surface wind field derived from the scene in figure 2 using the XMOD2 algorithm (Li and Lehner 2013). The wave height that is obtained from the TerraSAR-X scene and the XWAVE algorithm (Bruck and Lehner 2012) is presented in figure 4.

Although it is shown that the algorithms provide reasonable results in many cases (see e.g. Lehner et al. (2011)), recent examinations have revealed that there is a need of refining and adjusting the existing methods in order to obtain exact wave height for diverse underlying conditions occurring in the model area. However, figure 5 compares the SWH derived from the TerraSAR-X scene mentioned above and computed by CWAMC. It can be seen that TerraSAR-X data show a more complex structure than CWAM data. Differences between TerraSAR-X and CWAM of 0-30 cm occur in the present case.

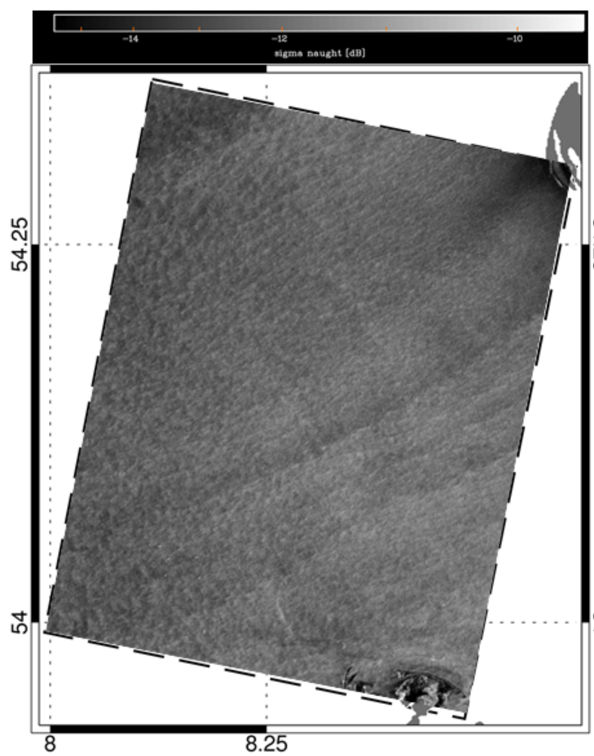

Fig. 2. TerraSAR-X scene viewing the sea surface northwest of the estuary of the river Elbe on 20. March 2013, 05:51 UTC.

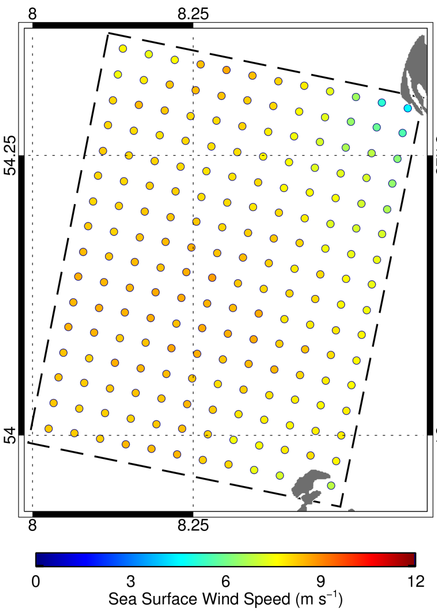

FIG. 3. Wind field derived from TerraSAR-X scene that is shown in figure 2.

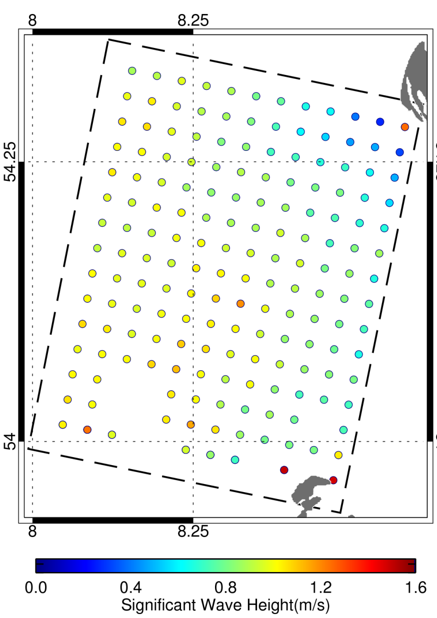

FIG. 4. Wave height derived from TerraSAR-X scene that is shown in figure 2.

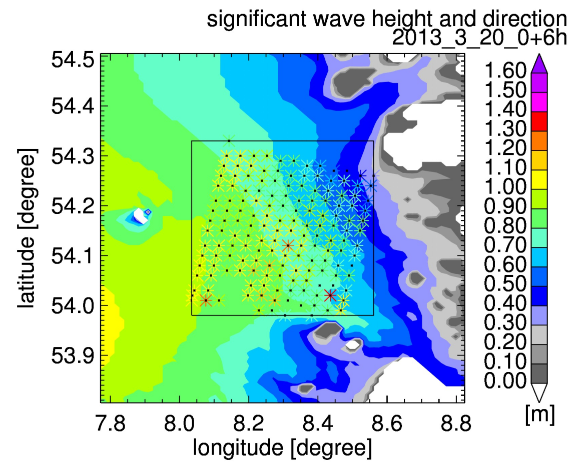

FIG. 5. Comparison of SWH calculated by CWAMC (color contours) and derived from TerraSAR-X data (asterisks) for the 20. March 2013, 05:51 UTC. The black square encloses the area of the TerraSAR-X scene and small black dots within this square indicate observation points.

b. Comparison with buoy measurements

In contrast to polar orbiting satellites in situ measurements by buoys supply oceanographic parameters more continuously but only for a few given positions. Unfortunately, buoy measurements are particularly rare in those coastal areas where the strongest improvements of sea state prediction are expected. However, comparisons of modeled SWH with buoy measurements are presented in the following.

Figure 6 shows modeled and measured SWH for the positions of the Elbe buoy west of the estuary of the river Elbe, a buoy close south of Helgoland, and FINO1 [1]. A time period from 1. January 2013 to 31. July 2013 is considered. The positions can be seen in figure 1. Besides the results of CWAMC also SWH calculated by EWAM is shown. All figures indicate a quite similar behaviour of CWAMC and EWAM. Also a close resemblance of models and observations is evident.

For a more detailed insight figures 7, 8, and 9 show scatter plots comparing modeled and observed SWH for the same positions as considered above. In order to obtain informations about the sea state forecast and to minimize uncertainties caused by the wind forecast, only the one hour forecast time steps are taken into account for CWAMC, CWAMN, and EWAM here. As can be derived from the correlation coefficients and scatter indizes distinctions between CWAMC and CWAMN are rather marginal at the three positions. This is not surprising since at all postions

[1] Buoy and FINO data are provided by BSH. FINO is promoted by the German Federal Ministry for the Environment, Nature Conservation, and Nuclear Safety and by the Projektträger Jülich.

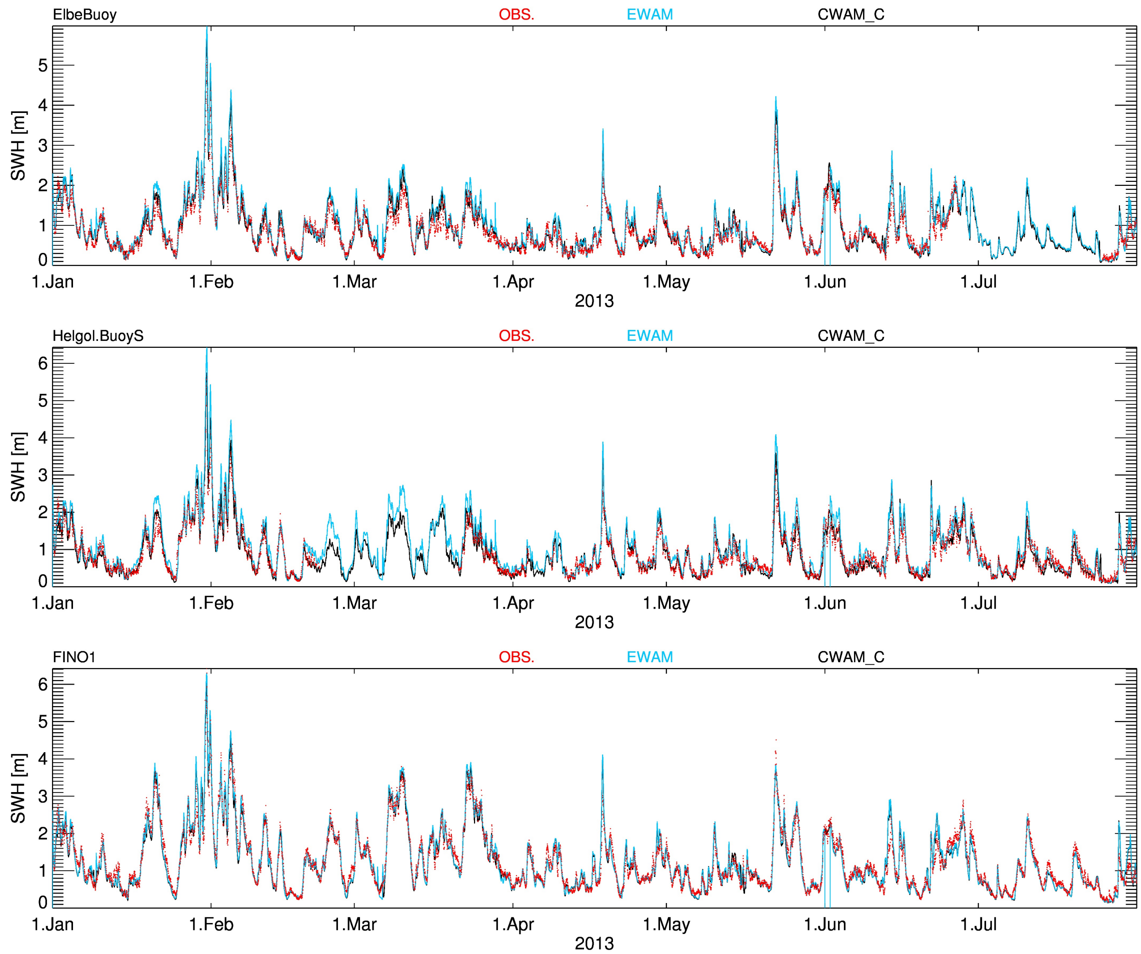

FIG. 6. Time series of modeled and observed significant wave heights for the positions of the Elbe buoy (top), a buoy south of Helgoland (center), and FINO1 (bottom). The black curve shows values from CWAMC, cyan from EWAM, and red dots are associated with buoy measurements. A time range from 1. January to 31. July 2013 is considered. Positions can be seen in figure 1.

currents are rather weak and changes of water depth are small compared with the absolute depth. As emphasized in section 4 currents and water depth affect the sea state significantly in nearshore areas. In all cases the scatter index is greater for EWAM than for CWAM indicating an improvement of SWH prediction when using CWAM. Since differences between CWAMC and CWAMN are rather small it can be assumed that improvements of CWAM relative to EWAM, in particular at the positions of the Elbe buoy and buoy south of Helgoland, result from the high resolution of CWAM. FINO1 is located in deep water far away from any topographic feature whose resolution would significantly affect the quality of the foreacast. Thus the differences between CWAM and EWAM are rather marginal for FINO1.

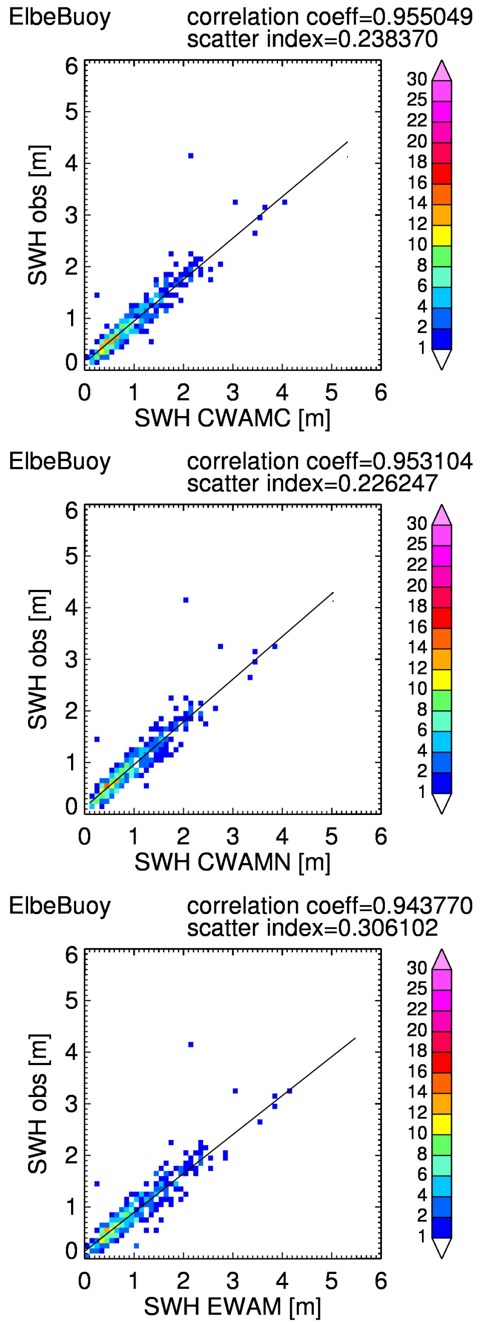

Fig. 7. Scatter plots show the comparison between SWH calculated by CWAMC (top), CWAMN (center), and EWAM (bottom) with observational data. Only the one hour forecast time steps are considered for a time period from 1. January 2013 to 31. July 2013. Colors indicate the number of pairs of values within a 10×10 cm interval. Here the comparison for the position of the Elbe Buoy is presented. Correlation coefficient and scatter index are also shown for each case. The averaged depth at the position is 25 m.

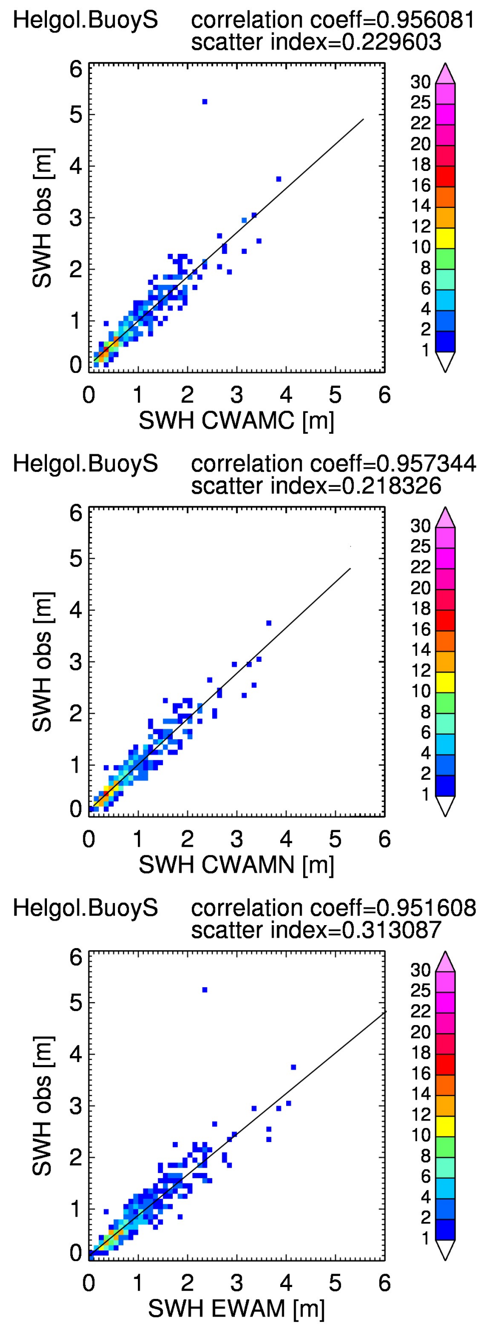

Fig. 8. As figure 7 but for position south of Helgoland. The averaged depth at the position is 25 m.

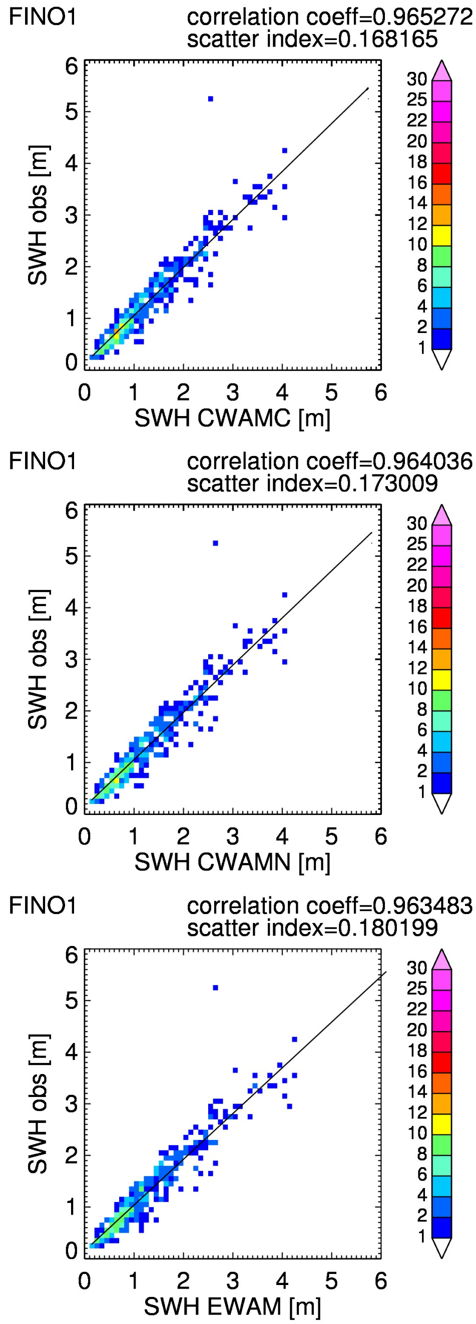

FIG. 9. As figure 7 but for position of FINO1. The averaged depth at the position is 30 m.

4. The influence of sea currents and changing water depth

Presently CWAM is operated with three different configurations. They are listed in table 1. Considering differences between the model simulations effects of water depth and currents on sea state can be studied. The difference of CWAMC and CWAMN provides information about the collective influence of water depth and current, while the difference CWAMC-CWAMD indicates the separated influence of current. Combining these informations also the effects of variable water level can be derived. Figure 13 shows the combined effects of variable water level and current on SWH within the German Bight on 1. June 2013, 18 UTC. Figure 14 shows the separated influence of current on SWH. In order to assess the results figures 10 and 11 show wind and current fields used by the model. The SWH calculated by CWAMC is displayed in figure 12. As can be seen in figure 13 the combined influence of changing water depth, current, and wind causes a significant increase of SWH in the near coastal regions.

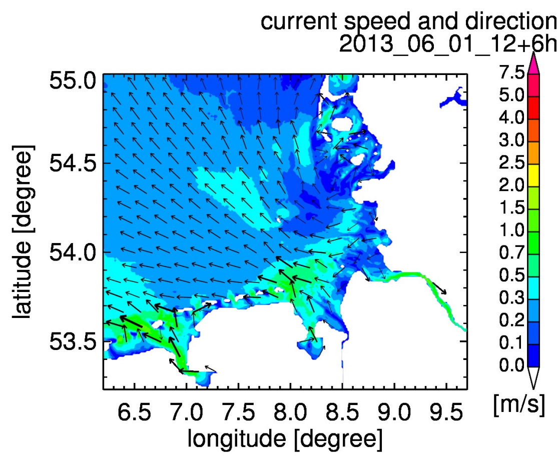

FIG. 10. Current speed and direction in the German Bight on 1. June 2013, 18 UTC calculated by HBM and used by CWAMC.

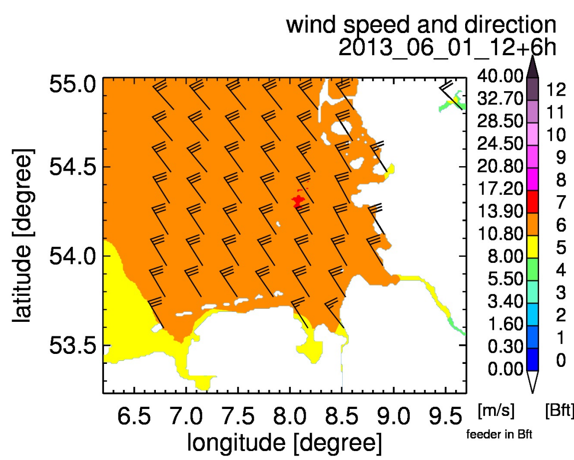

FIG. 11. Wind field on 1. June 2013, 18 UTC provided by COSMO-EU and used by CWAM.

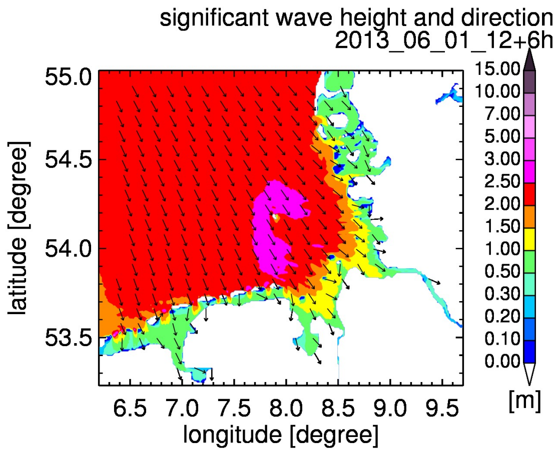

FIG. 12. Significant wave height and mean wave direction on 1. June 2013, 18 UTC calculated by CWAMC.

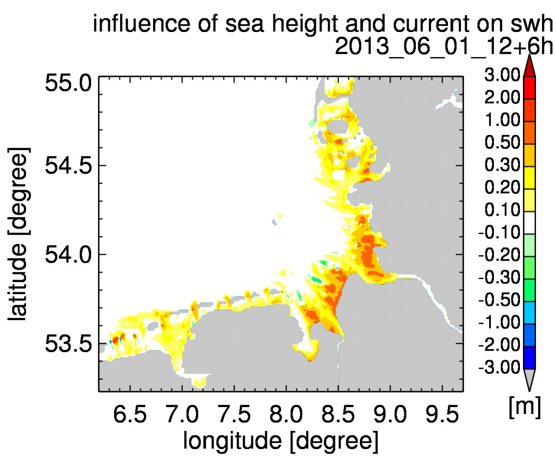

FIG. 13. Difference of SWH between CWAMC and CWAMN showing the influence of changing water depth and current on 1. June 2013, 18 UTC.

Figure 14 indicates that the influence of currents is primarily confined to narrow areas between the Frisian Islands. Here a strong current and a high wind sea act in opposite directions. It can be assumed that in the present case the remarkable SWH increase within the inner German Bight is caused by a larger local water depth which is taken into account when the time varying sea surface elevation is considered.

5. Summary and Conculsions

The high resolution wave model CWAM for the German Bight and the western Baltic Sea has been developed within the project Sea State Monitor. CWAM is coupled with a model that provides information about currents and water depth. SWH computed by CWAM and by the conventional wave model EWAM are compared with buoy measurements. The comparison indicates that a higher model resolution and a more detailed representation of the topography lead to a general improvement of the wave height prediction. Moreover, the present study indicates a further potential improvement in near shore areas when time varying sea surface elevation is taken into account. Sea current has a significant influence, even though it is highly localized. However, the affected areas are frequently passed by ships, potential users of wave forecasts. Therefore an exact wave forecast which takes variable water depth and current into account is required.
Furthermore, within the project also algorithms have been developed in order to derive meteo-marine parameters from high-resolution satellite measurements. Although the algorithm has to be refined, for the future it offers an excellent possibility to validate model results.

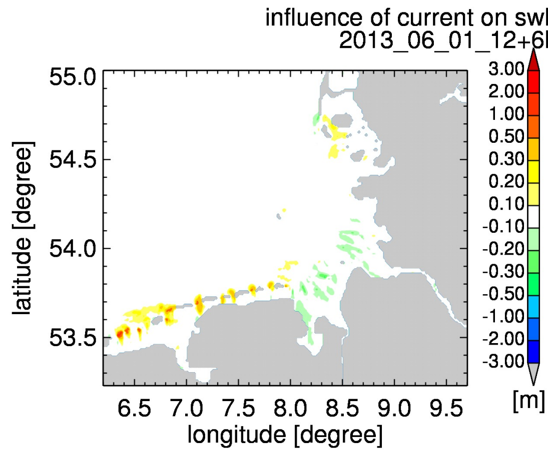

FIG. 14. Difference of SWH between CWAMC and CWAMD showing the influence of current on 1. June 2013, 18 UTC.

6. Outlook

It is intended to couple the wave model CWAM with the ocean circulation model HBM interactively. CWAM will run in a pre-operational state for an extended forcast time range of 48 or 72 hours. A product will be created that combines forecasts and a near real-time assessment with high-resolution satellite data.

REFERENCES

Berg, P. and J. W. Poulsen, 2012: Implementation details for HBM. Tech. rep. no.12-11, DMI.

Bruck, M. and S. Lehner, 2012: Sea state measurements using TerraSAR-X data. *SPIE Remote Sensing*, International Society for Optics and Photonics, 85 360O–85 360O.

Hasselmann, S., et al., 1988: The WAM model - a third generation ocean wave prediction model. *J. Phys. Oceanogr.*, **18**.

Lehner, S., A. Pleskachevsky, and M. Bruck, 2011: High resolution satellite measurements of coastal wind field and sea state. *Int. J. Remote Sensing*, **33**, doi:10.1080/01431161.2012.685975.

Li, X.-M. and S. Lehner, 2013: Algorithm for sea surface wind retrieval from TerraSAR-X and TanDEM-X data. *IEEE Transaction on Geoscience and Remote Sensing*, **51**, doi:10.1109/TGRS.2013.2267780, in press.

Poulsen, J. W. and P. Berg, 2012: HBM general modelling theory and survey of recent studies. Tech. rep. no.12-16, DMI.