SAFER NAVIGATION IN COASTAL AREAS WITH THE AID OF RADAR-MEASURED SURFACE CURRENTS

Heinz-Hermann Essen, Klaus-Werner Gurgel and Thomas Schlick

Universität Hamburg, Institut für Meereskunde, Bundesstraße 53, 20146 Hamburg, Germany; {essen/gurgel/schlick}(at)ifm.uni-hamburg.de

ABSTRACT

In 2000, coastal currents off the coast of Norway were measured and modelled during an experiment of the European Radar Ocean Sensing (EuroROSE) project (funded by EU). The objective of EuroROSE was to develop a radar based ocean monitoring system in support of safe navigation in port approach areas and otherwise densely operated sea areas. Radar measured data were assimilated into a fine gridded numerical model with the aim of predicting, for a few hours, currents and waves. Maps and time series of current velocity measured by the HF radar WERA (Wellen-Radar) are compared with results of the numerical model. The model is capable of reproducing the spatial and temporal variability of the measured currents for nowcasting. The correlation between the measured current velocities and those predicted by the model decreases from about 0.9 of the nowcast to 0.8 of the 2-h forecast and to 0.6 of the 6-h forecast.

Keywords: HF radar, high-frequency radar, coastal currents, coastal navigation

INTRODUCTION

In 2000, coastal currents off the coast of Norway were measured and modelled during an experiment of the European Radar Ocean Sensing (EuroROSE) project. The main idea behind EuroROSE is to combine high-resolution numerical current models with remotely sensed data covering the area by data assimilation to provide operational forecasting in limited areas, such as port approach areas. This paper summarizes results concerning currents (1), wave data are presented by (2). The methodology should be transportable for application in different areas. The data should be provided on-line to monitoring centres or ships.

To achieve the goals of the operational forecasting system, several existing and newly developed components have to be integrated. On the measuring side high-frequency (HF) radars were used. These radars are able to map surface currents off shore by means of land-based stations. HF radars provide surface currents in real time on a regular grid. Depending on the transmit frequency, ranges of up to 100 km can be achieved with a resolution of about 1 km. These data can be assimilated by a numerical model with the aim of extrapolating the measured currents to larger areas and into the future.

The numerical models within EuroROSE were operated by the Norwegian Metoffice (met.no), the data assimilation technique was developed by the Norwegian Nansen Environmental and Remote Sensing Center (NERSC). To provide the results to the end-users, i.e. to the pilots on tankers, a User Interface was developed by the Spanish port authority Puertos del Estado.

METHODS

High-frequency (HF) radars have been used for measuring surface current fields and ocean-wave spectra for more than 20 years. In 1977, Barrick et al. (3) introduced the Coastal Radar (CODAR) which was designed for current mapping only. The physics behind HF radar is based on backscattering from a moving rough sea surface. The Doppler shift of the backscattered signal is used for measuring the radial current speed relative to the radar site. Guided propagation along the conductive sea surface (ground wave) allows measurements beyond the horizon. The radar systems are deployed along the coast. Two sites are necessary for computing a two-dimensional current vector.

The surface current measured is a horizontal mean over several km in both range and azimuth, over about the upper 0.5 - 1.0 m of the ocean (penetration depth of scattering ocean waves), and over some 10 minutes (measuring time). Sample rates of 10 minutes can be achieved.

Progress in electronics and computer techniques allowed the design of a new high-frequency (HF) radar system, called WERA (Wellen Radar) at the University of Hamburg, Germany. WERA (4) is a frequency-modulated continuous-wave (FMCW) radar which, when linked to a linear array of receive antennas, simultaneously measures surface currents and ocean waves. Operating at 27 MHz, the highest spatial resolution is 0.3 km. The area covered in this mode is about 40x40 km. The total length of the 16-antenna array used is 80 m. Recently, two 16 MHz WERAs have been installed on the Hawaii islands. Ranges of 100 km could be achieved with a resolution of 1.2 km.

Within EuroROSE coastal currents were computed by a suite of nested ocean models which assimilate surface currents measured by the HF-radar WERA (5). The Princeton Ocean Model (POM) was used as implemented and modified by met.no. Terrain following sigma-coordinates resolve the vertical. Three models were nested inside each other. The outer model covers the North Atlantic and the Norwegian Sea with a resolution of approximately 20 km. The intermediate model covers the coastal waters of southern Norway with a resolution of 4 km, and the inner, high resolution model has a resolution of 1 km and covers a 60 x 60 km area, see Figure 1. The inner model has 17 sigma-levels. The main part of the area covered by the HF radar has a water depth of about 300 m. At this depth, the height of the uppermost grid cell is about 0.6 m. Hence, the radar currents are comparable to the currents in the uppermost model layer. The outer and the intermediate model are forced with 50 km resolution winds, the inner model with 10 km resolution winds.

The data assimilation scheme used was implemented by NERSC. Optimal interpolation (OI) was applied, which is a sequential data assimilation method using predefined (time invariant) error statistics. Because a traditional OI scheme cannot take spatial inhomogeneities into account, it was necessary to extend the method to incorporate modelled covariances between the different hydrodynamic variables. A hindcast study was set up for the geographic area of interest. Thus, instead of covariances that vary only with direction and distance, geographically dependent cross-covariances were used in the assimilation update. The OI scheme applied is a simplified Ensemble Kalman filter method. Instead of deriving the error covariance matrix from a number of simultaneously operated models, the matrix was taken from the hindcast study and does not change with time.

RESULTS

The two WERA sites on the Norwegian coast were located only 13 km apart (Figure 1). This configuration is not optimal for current measurements up to 40 km off shore. Narrow angles between the two radial components, used for composing the surface-current vector, considerably reduce its accuracy. However, the emphasis of EuroROSE was on the near-shore region. In addition, this configuration allowed the measurement of waves, which requires a higher signal-to-noise ratio than the current measurement.

Several strong storms occurred during the 6-week experiment in February-March 2000 with significant wave heights exceeding 11 m. High waves affected the WERA (reduced ranges). Figure 2 compares measured and modelled surface currents. The error propagation from the radial components to the vector components depends on the angle between the two radar beams, i.e. causes an amplification of the error of at least one vector component if the intersection deviates from perpendicular. For this reason, we confine our analysis to grid points at which the two WERA beams intersect with angles between 25 and 155 degrees. Modelled data displayed are confined to this area, too.

Figure 2 shows a reduced WERA coverage area at the significant wave height of 6 m as compared to the wave height of 3 m. In addition, this example demonstrates the capabilty of the model to extrapolate the current field. During the experiment, the maximum ranges of the two WERA sites varied considerably, from only 15 up to 45 km. Low ranges were observed during periods of extreme wave height. Thus, one reason for short ranges is the presence of high swell.

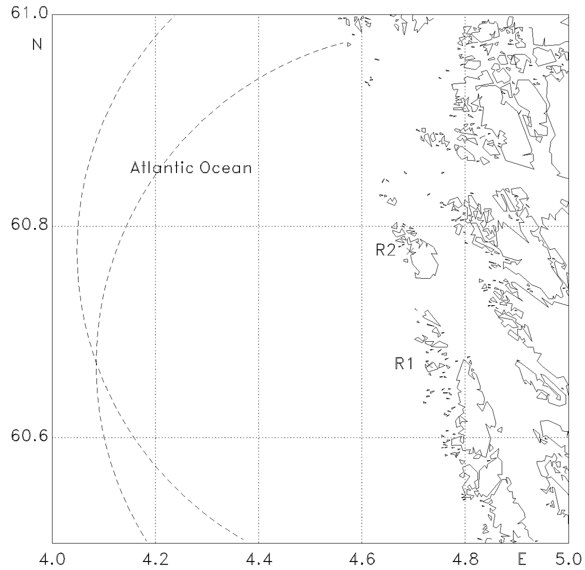

Figure 1: EuroROSE experimental area off the Norwegian coast. The positions (R1 and R2) of the two WERAs are indicated. The dashed lines represent the average range of 35 km. The area shown coincides with the 1 km resolution domain of the numerical model.

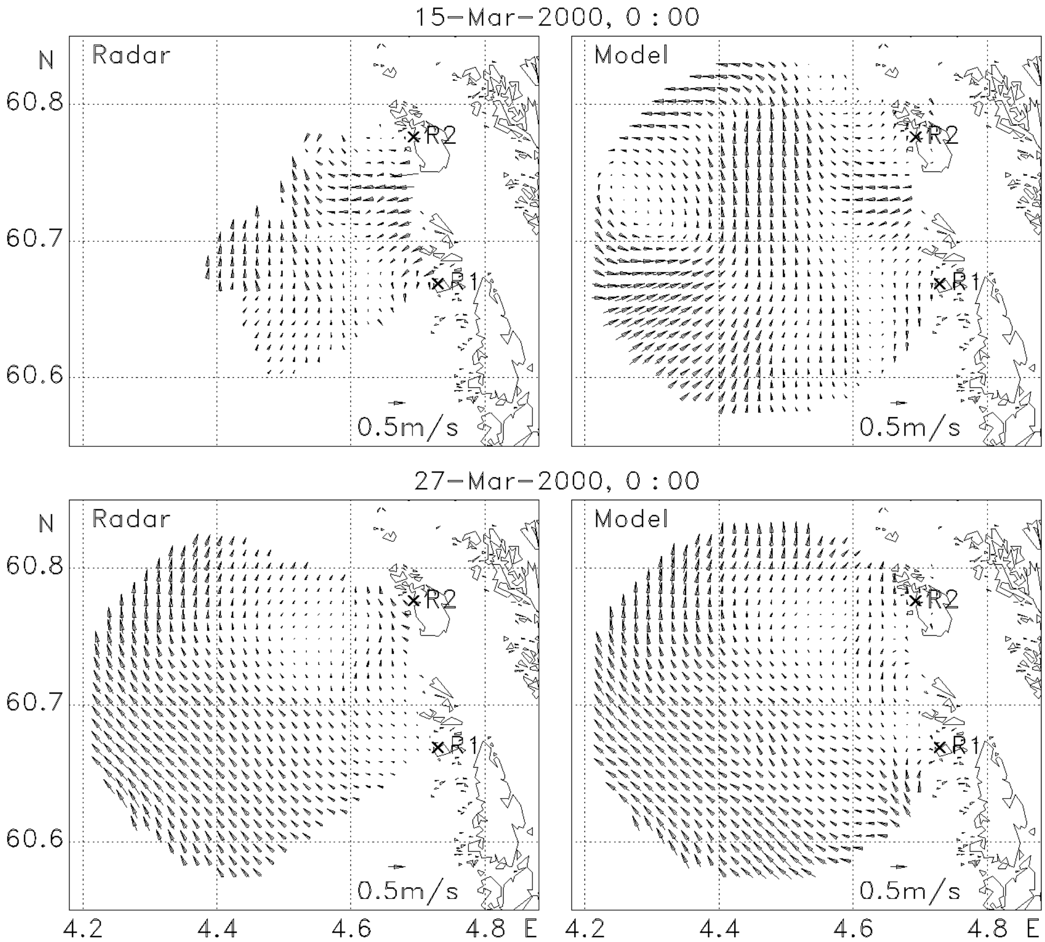

Figure 2: Maps of surface currents as measured by WERA (left panels), and determined by the model which assimilates the WERA data (right panels). The arrows represent speed and direction of surface currents. The grid spacing is 1 km. The measurements presented were taken during periods of different sea state, 6 m and 3 m significant wave height (upper and lower left panel, respectively).

The model data presented in Figure 2 are interpolated on to the WERA grid by computing weighted means from adjacent model grid points. The weights depend on the distance of the grid points. The model reproduces well the measured current field and extrapolates it to greater distances. In general, the comparisons of measured and modelled current fields reveal a good agreement.

Currents within the measuring area are dominated by the Norwegian coastal current which, on average, flows northward. The current is conducted by a narrow trench (width of about 100 km) in front of the Norwegian coast. There is a very distinct frontal structure between the cold coastal water of low salinity and the warmer Atlantic water of higher salinity. The front shows a strong temporal and spatial variablity with scales from 10 up to 100 km.

Figure 3 presents scatter plots which compare the east- and north-component of the measured surface current with model results of the nowcast, 2-h and 6-h forecast. The experiment lasted about 6 weeks, and the sampling rate was 1 h. Because of power failure (due to lightning) some measurements are lacking. Also the model data are not complete. In total, 17 % of the possible data are missing. Following the coast, the north component of the current vector reveals higher amplitudes than the east-component. Tidal variations mainly affect the north component. Surface currents are strongly influenced by wind and also by the wave-induced Stokes drift. The nowcast in Figure 3 reveals high correlation coefficients, especially for the stonger north component. The forecasts refer to model times 2 and 6 h before the measurement was taken. The correlations decrease depending on the forecast period.

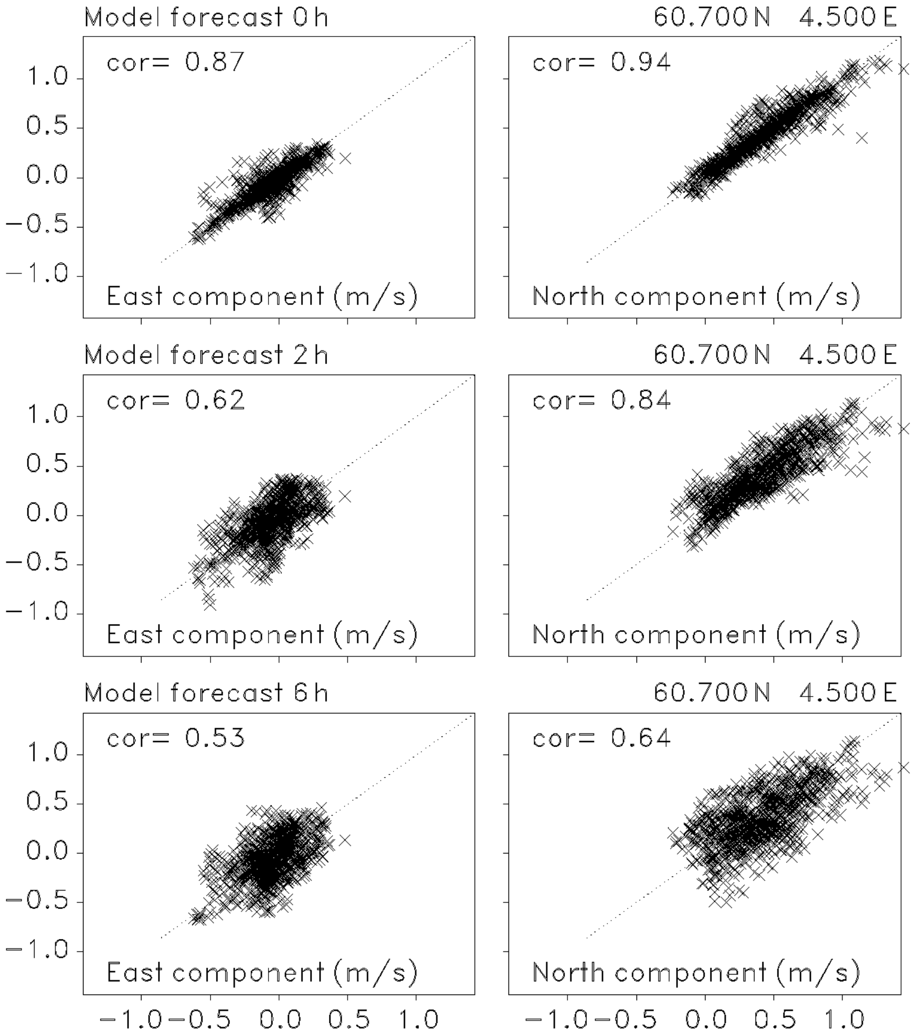

Figure 3: Comparison of measured and modeled surface currents at a selected grid point. The modeled data represent the nowcast, 2-h and 6-h forecast (from above). Correlation coefficients are indicated for both the east and north component of current velocity.

CONCLUSIONS

The EuroROSE project aimed to develop a tool to be used by Vessel Traffic Service operators, harbour and coastal managers, to monitor and predict the significant met-ocean conditions with high time/spatial resolution in limited areas surrounding locations of dense operations. This paper demonstrates the importance of radar-measured current fields which describe the nowcast and are needed as initial values for the forecast of numerical models. The comparison of predicted and measured current velocities reveals a decrease of the correlation coefficient from higher than 0.9 (nowcast) to about 0.65 (6 h prediction). The 6-h forecast is not yet satisfactory. A larger survey area may be helpful in order to cover events which move from outside into the forecast area. This is even more important for forecasting waves which move much faster than currents.

The main objective of the new WINGS-FOR-SHIPS project (funded by EU) is to improve the decision making process of ship masters on board of high speed vessels related to environmental information by designing an intelligent maritime workplace. As part of this project, two WERAs will be deployed on Corsica in fall 2003. The transmit frequency will be 16 MHz, and we hope to achieve ranges of up to 100 km.

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