Applications of WERA within the EuroROSE Project

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Abstract. European Radar Ocean Sensing (EuroROSE) is an EU-funded project, bringing together 6 partners from 4 European countries. The main objective is the development of a transportable methodology for monitoring and forecasting waves and currents in limited areas (typical extent 40 by 40 km), such as coastal and port approach areas, and to on-line distribute this information to end-users, i.e. port authorities and Vessel Traffic Management Services (VTMS) operators. To achieve this aim, EuroROSE makes use of remote sensed current and wave data, as measured by HF and Microwave radar, which is assimilated into high-resolution models to provide on-line now- and forecast information.

The two main purposes for using models in addition to the measurements are to provide forecasts, e.g. to help planing ship routes or rescue operations, and to deliver the information which is actually needed, e.g. the current field effecting large and deep ships when only the surface data are measured.

Especially in areas, where the current structures are highly variable due to generation of eddies and fronts, the models need additional input to accurately reflect the actual situation. By assimilating the remote sensed current and wave fields, as measured by the University of Hamburg WEllen RAdar (WERA), the model results can be kept very close to nature and the quality of the forecast can be significantly increased.

This paper describes the EuroROSE system set-up, which was successfully applied during two demonstration experiments at the Norwegian and Spanish coast. Besides the installation of WERA, other instruments like WaMoS, the model system, the data communication scheme, and the User Interface to display the results to the end-users are presented.

1 Introduction

In some regions of the world, mesoscale processes like eddies of diameters between 10 and 100 km and strong current fronts or coastal jets affect man's activities in shipping, fishing and engineering. The coastal current dynamics, such as generation, propagation and decay of these oceanographic phenomena is not yet completely understood and hard to describe and forecast by oceanographic models. On the instrument side, ship surveys and moored instruments are the classical tool of oceanographers to study these processes. Since some 20 years remote sensing methods are available. Their main advantage is the synoptic view of the ocean, which however, is restricted to the near sea surface. The use of HF radar systems offers a unique method of measuring mesoscale current fields and ocean waves with high spatial and temporal resolution.

The main idea behind EuroROSE is to combine high resolution numerical current and wave models with area covering remote sensed data by data assimilation to provide operational forecasting in limited areas (typical extent 40 km by 40 km), such as coastal and port approach areas. This methology should be transportable for easy adaption in different bassins. The data should be on-line provided to Vessel Traffic Management Services (VTMS) at ports and monitoring centres. The capability of the system has been demonstrated in two field experiments. The experiment areas were Fedje in Norway in February/March 2000 and Gijon in Spain in October/November 2000. This paper presents the EuroROSE system and results of both experiments.

2 The components of the EuroROSE System

To achieve the goals of the operational forecasting system described above, several existing and newly developed components had to be integrated. On the measurement side, these are instruments for remote sensing of currents and waves. The University of Hamburg's WERA (WEllen RAdar) HF radar and OceanWaveS' WaMoS (Wave Monitoring System) microwave radar have been selected. Both radar systems are operated from the coast and provide measurements three times per hour. Using satellites like ERS-1/2 in costal monitoring have the disadvantage of poor temporal coverage, i.e. one image every 35 days. However, these satellites play an important role in the large scale operational forecasts. The numerical models within EuroROSE have been operated by The Norwegian Meteorological Institute (DNMI), the data assimilation technique has been developed by the Norwegian Nansen Environmental and Remote Sensing Center (NERSC). To provide the results to the end-users, i.e. the traffic officers in the VTMS station, a User Interface has been developed by the Spanish port authority Puertos del Estado. A description of the EuroROSE system can be found in [5] and [6]. The following sections describe the components

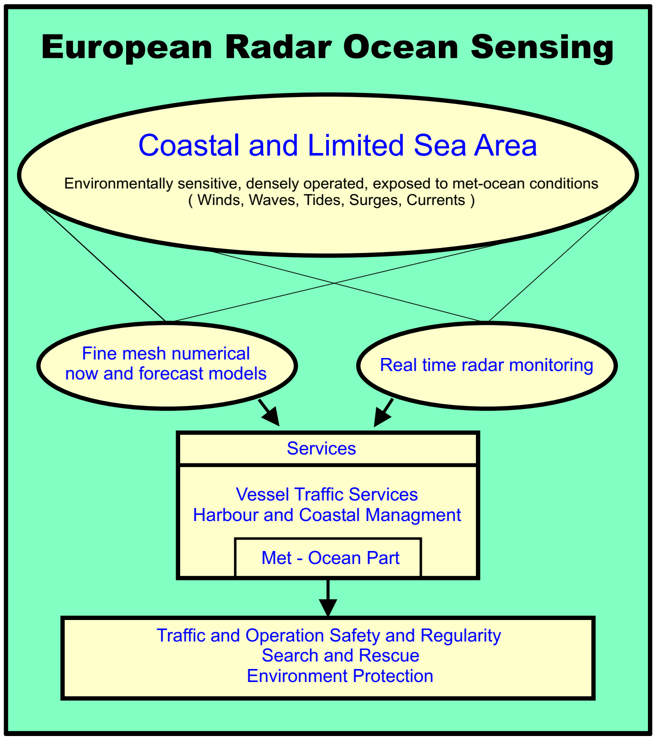

Figure 1. The structure of the EuroROSE system, which provides on-line now- and forecasts of currents and waves for harbour and coastal management.

in more detail. A Web site has been set up for internal communication and to promote the EuroROSE system to the public. This information can be found at http://ifmaxp1.ifm.uni-hamburg.de/EuroROSE/ .

2.1 The WERA HF Radar

In contrast to microwave radars, which are widely used for naviagtion purposes, High-Frequency (HF radars) use frequencies between 3 MHz and 30 MHz with electromagnetic wavelengths of 100 m to 10 m. These systems make use of resonant backscattering of radio waves from the rough sea surface by a process known as Bragg scattering, i.e. 10 m electromagnetic waves couple to 5 m ocean waves.

For remotely sensing the ocean, HF radars are mostly operated from the coast. The advantage of HF radars is the possibility of continuously mapping surface current and ocean waves over large areas, i.e. 40 km $\star$ 40 km or more with a resolution down to 300 m.

The University of Hamburg recently developed a new HF radar for coastal applications called WERA (WEllen RAdar) [7] and [8]. One main advantage of the system is the possibility of using different configurations of receive antennas, e.g. when operated with a linear array, information on the sea state can be obtained via second-order

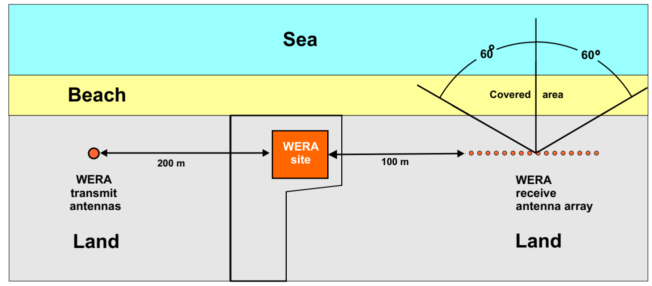

Figure 2. An example of a WERA HF radar installation at the coast using a linear array receive antenna. This configuration enabled simultaneous mesurement of ner-surface currents and ocean wave spectra.

spectral bands. A further advantage is the flexibility in range resolution between 0.3 km and 3.0 km. By using Frequency-Modulated Continuous Wave (FMCW) modulation, this can simply be achieved by reprogramming the bandwidth of the frequency chirp. In addition, this technique avoids the blind range in front of the radar because there is no transmit to receive switching involved. Figure 2 shows a typical installation of an HF radar at the coast.

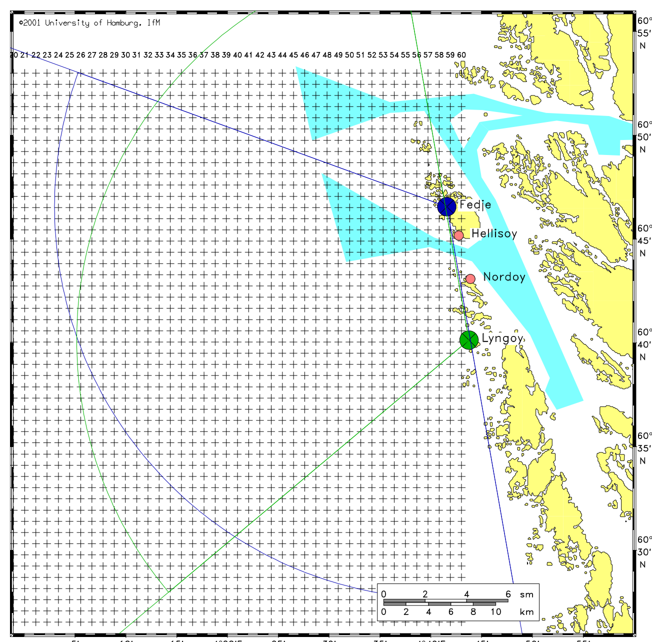

Figure 3. The Norwegian coast off Fedje with the shipping channel, the two WERA HF radar sites at Fedje and Lyngøy, and the two WaMoS sites at Hellisøy and Nordøy. The WERA measurement grid and the area covered by the two WERAs is also shown.

During the EuroROSE experiments, two WERA

HF radars have been installed, as one WERA measures the radial component of the near surface current towards or away from the radar site. The second WERA was deployed some 13 km apart. Figure 3 shows the sites selected for the HF radars during the EuroROSE Fedje experiment, the radar coverage, and the measurement grid defined. The WERA radars have been operated continuously and provided three measurements per hour. Current maps like shown in figure 8 (EuroROSE Fedje experiment) and 9 (EuroROSE Gijon experiment) have been sent to the data assimilation system.

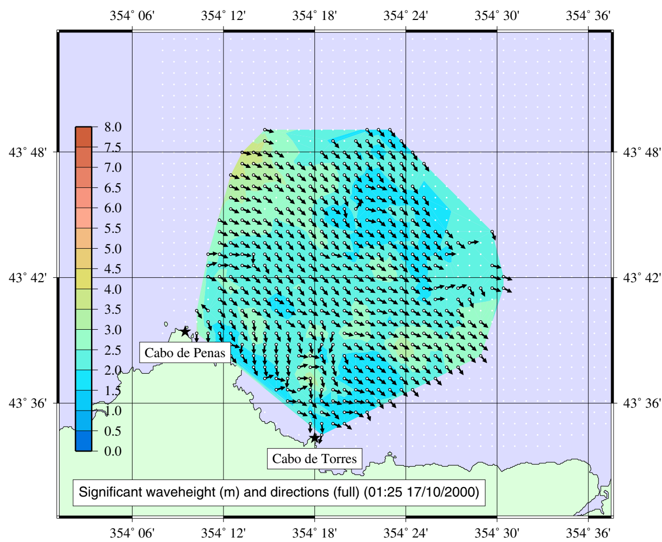

Figure 4. An example of the spatial distribution of significant waveheight and -direction off Gijon as processed by the University of Sheffield from WERA raw data.

Maps of significant waveheight, wavedirection, and peak frequency have also been processed online using the University of Sheffield HF radar wave inversion algorithm [10]. These wave parameters have also been sent to the the data assimilation system. Figure 4 shows an example measured during the EuroROSE Gijon experiment.

2.2 The WaMoS wave measuring system

The WaMoS system is based on a standard nautical radar and quite small and easy to install and operate. It has been developed by the GKSS Research Centre, Germany, and is now commercially available from OceanWaveS.

Besides the target echos from ships, buildings, or the coast line, a nautical radar shows images of the sea surface, known as sea clutter. This sea clutter is generated by backscattering of electromagnetic microwaves from the sea surface ripples at nearly grazing incidence angles. For navigational purposes the sea clutter is suppressed by the radar imaging processor as good as possible. However, by applying special alogrithms based on the spatial and temporal structure analysis of a sequence of radar images, the sea clutter can be used to extract the unambiguous directional wave spectrum and in turn the significant wave height and peak period [9]. The advantage of such a system compared to a wave buoy is the safe and easy accessable installation on land. Also, the system can not be damaged by high breaking waves during storm conditions.

The WaMoS radars have been used within EuroROSE to provide sea state information at the most critical points with respect to the sailing ships, e.g. within the shipping channel south of Fedje (figure 3). The User Interface showing WaMoS significant waveheight can be seen at figure 6.

2.3 The nested model chain

The high-resolution current and wave models, which deliver their results to the User Interface, offer a grid spacing of 1 km $\star$ 1 km. To supply these models with the best available boundary conditions, a nested model approach is used. There is a three step model chain for currents: The outer model covers the North Atlantic and the Norwegian sea with a resolution of about 20 km. This model delivers boundary conditions to an intermediate model of the coastal waters of southern Norway, which is operated at 4 km resolution. The inner model covers an area of 60 km $\star$ 60 km. The models are Princeton Ocean Models as implemented and modified by The Norwegian Meteorological Institute (DNMI). The outer and intermediate models are forced with 50 km resolution winds from an atmospheric model, the inner model is forced with 10 km resolution winds designed to include topographic effects near the coast. Both atmospheric models and the two outer current models are routinely run by DNMI. A description of the model system can be found at [1], an example of the current model result can be seen in figure 5. A similar approach has been used for the EuroROSE wave now- and forecast.

This sofisticated and costly model system currently can only be operated by the national met-offices, like DNMI in Norway, or large companies. The inner high-resolution model with the data assimilation system has been run locally on a powerful workstation and once an hour delivered a nowcast and hourly forecasts up to +6 hours.

2.4 The data assimilation system

The data assimilation scheme used within EuroROSE has been implemented by the Norwegian Nansen Center

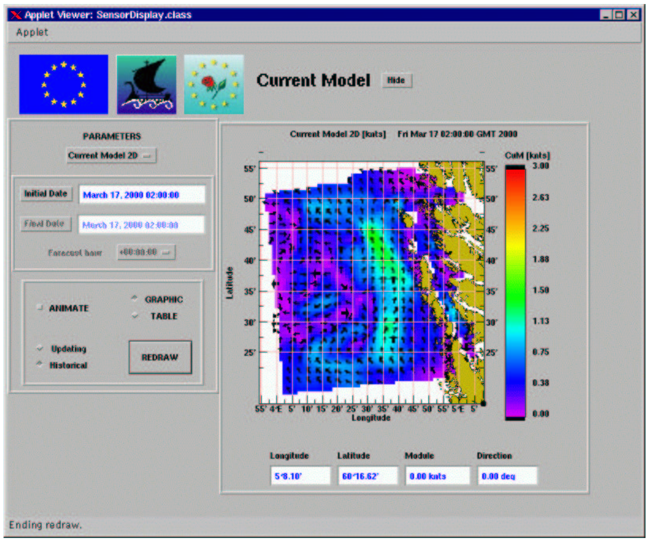

Figure 5. The screen of the User Interface showing the current velocities in front of Fedje.

(NERSC). A sequential method called Ensemble Kalman filter ([4] and [2]) has been used. Instead of deriving the error covariance matrix from a number of simultaneously run models, the matrix is derived from a number of model states stored from a run with a similar climatology. The error statistics of the measurement data to be assimilated into the model are derived from previous measurement campaigns and include the spatial variability due to geometrical effects. A description of the data assimilation system used during EuroROSE can be found at [1].

Updating the hydrography (temperature and salinity) from the measured surface currents by including their cross-correlation to make the density field consistent with the observations led to strong inconsistencies at the bounds of the model and made the model crash several times. This happened, because after a while the boundary conditions delivered from the intermediate model were inconsistent with the density field in the inner model. A solution would be to apply data assimilation to the outer models too. However, in a real-time application this appears to be too costly. To make the inner model stable, the cross-updates to the hydrography were left out.

As expected, the nowcast and the measurement show a strong correlation of 0.9 and a low rms error of 10 cm/s for a position in the center of the measurement area. When comparing the 2-hour forecasts with the measurements taken at that time, the correlation reduces to 0.8 and the rms error increases to 20 cm/s. For the 6-hour forecasts, the values are 0.6 for the correlation and 20 cm/s for the rms error.

2.5 *The User Interface*

Besides all the measurement equipment and numerical models involved in the EuroROSE system, one very important component is the User Interface. The User Interface displays all this complex results in a simple manner to the traffic officers at the VTMS. This part has been developed by the Spanish port authority Puertos del Estado. It is based on open software components like Linux, MySQL and Java. The User Interface is run on a Linux server and can be displayed by a standard web browser like Netscape, which makes it platform independent.

From an entry page, the user can select the area and instrument he is interested in. In a next step he can zoom in and out or step through the time from the actual time to the forecasts. The display is automatically updated, as soon as new on-line data are available. The User Interface has been developed in close cooperation to the end-users.

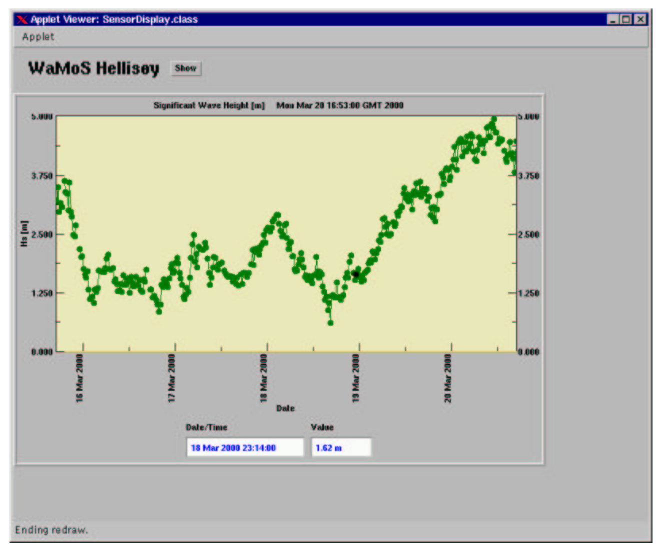

Figure 6. The screen of the User Interface showing the development of the significant waveheight in front of Hellisøy during a periode from 15-Mar-2000 17:00 UTC to 20-Mar-2000 17:00 UTC.

2.6 *The data communication scheme*

The data communication scheme between the components of the EuroROSE system is shown in figure 7. The structure is nearly identical for the two experiments. The Fedje and Gijon VTMS stations have a local area network installed to handle the data transfer from the WERA and WaMoS radars to data server in Oslo. The same LAN is used to deliver the high-resolution model now- and forecasts to the User Interface installed at the VTMS office. For long-distance data transfers, i.e. from Spain to Norway or Germany, the Internet is used. To protect the radar data and contol software, and the VTMS from unauthorized access and data manipulation, a scheme of firewalls and IP-Masquerading has been applied.

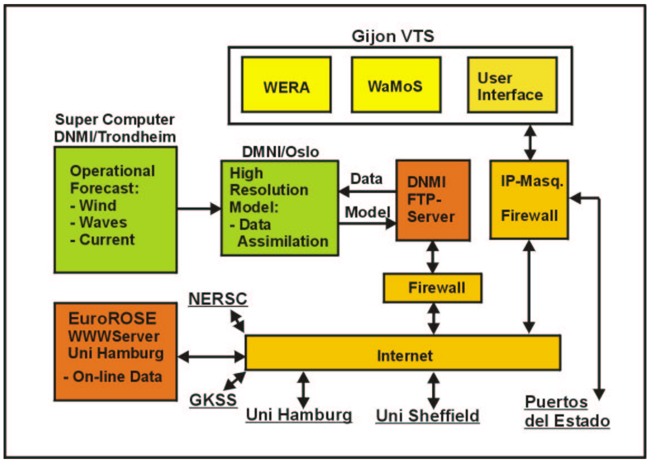

Figure 7. The data communication set-up used during the EuroROSE Gijon experiment. Firewalls protect sensitive system components unauthorized access.

The following data paths have been set-up:

- From the instruments to the Data Server in Oslo,
- from the Data Server in Oslo to the High-resolution Model / Data Assimilation System,
- from the Super Computer in Trondheim providing operational forecasts to the High-resolution Model / Data Assimilation System,
- from the High-resolution Model / Data Assimilation System to the User Interface in the VTMS,
- from the VTMS to the EuroROSE Web Server at the Universit of Hamburg for public access to the on-line data.

Although this seems to be quite complex, the installation and tests of the data communication between all components were finished after a few days. The use of standardized IP protocols like HTTP and FTP helped to make things easy. The data formats used for the communication between the components of the EuroROSE System had been agreed at an early stage of the project, and example data sets have been used to implement and test the inter-component communication.

3 The experiments

To prove the portability of the EuroROSE system, two different areas in Europe have been selected. Both sites have a VTMS operational to control and guide the ship's traffic. One site selected has been the entry to two large oil terminals in Norway, north of Bergen, the other site was located at the north Spanish coast at Gijon harbour.

3.1 The EuroROSE Fedje Experiment

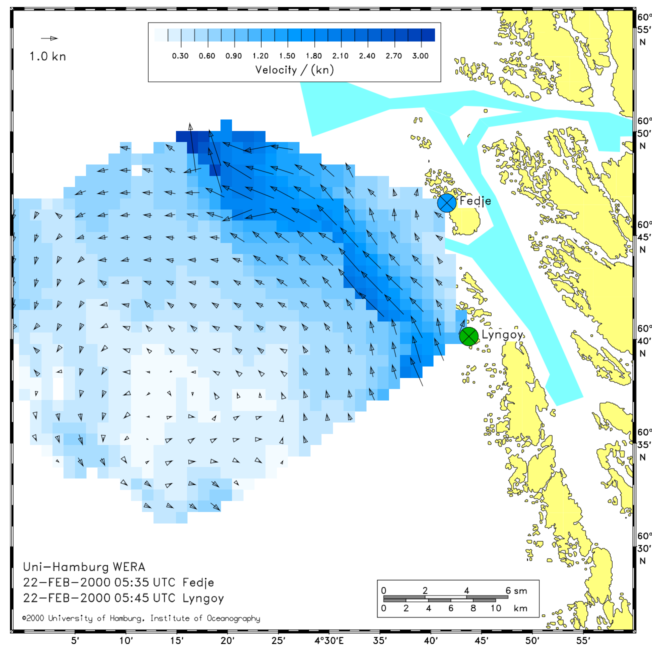

Figure 8. The coastal jet connected with an eddy in front of the shipping channel south of the island Fedje observed at 22th February 2000 05:40 UTC. The current vectors give direction and speed, the grey shading behind the vectors gives the absolute value of the speed. The grey area between the islands indicate the shipping channel.

The area in front of Fedje has been selected, because of the problems large oil tankers have to deal with when they enter the shipping channel between small islands and shallow water. The dynamics of the Norwegian coastal current which, on the average, flows northward, are characterized by a very distinct frontal structure between the cold coastal water of low salinity and the warmer Atlantic water of higher salinity [3]. The front shows a strong temporal and spatial variablity with scales from 10 km up to 100 km. Sometimes a coastal jet is present at speeds up to 2 m/s. This costal jet varies in width and position and has to be crossed perpendicular by the oil tankers. Depending on the actual situation, the tankers may then have to head to a island instead of the path between the islands. It is very helpful for the traffic officers and the pilots on board of the ships to know about the situation in advance.

3.2 The EuroROSE Gijon Experiment

The area around Gijon hosts one of the largest steal industries of Spain. The harbour of Gijon handels large vessels carrying coal and iron ore. The main problem concering ship safety is the high and long-periodic swell coming from the west. As the harbour itself is shaded by the coast, the ships hit these high waves several miles off the harbour. In former times, several ships unexpectedly capsized. In contrast to the Fedje area in Norway, the near-coast currents do not play such an important role and have never been measured in detail.

The two WERA sites were selected to cover the entrance to Gijon harbour. Both sites were on top of high clifs, about 80 m above the sea surface. It turned out, that the working range of the radars was significantly larger compared to the installation at Fedje. The measurement grid defined for this experiment (40 km $\star$ 40 km) has quite often completely been covered by the radars.

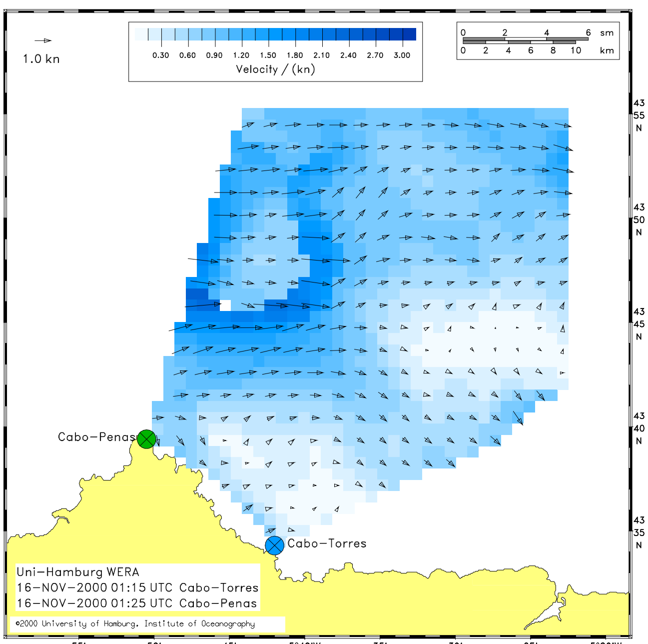

Figure 9. Fronts and eddies off Gijon observed at 16th November 2000 01:20 UTC. The current vectors give direction and speed, the grey shading behind the vectors gives the absolute value of the speed.

4 Conclusions

For the first time, all the components of the EuroROSE system have been coupled together to provide on-line now- and forecasts to traffic control officers at VTMS centers. It has been demonstrated that a system designed like this could be reliabley operated and provides important information. The HF radar is one of the key components, as it continously measures area-covering data of near-surface current and ocean waves. The model and data assimilation system has been proven to be run in real-time and supply now- and forecasts. The User Interface has been developed in close cooperation with the end-users and provides the graphical interface to the results of the EuroROSE system.

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