EuroROSE
European Radar Ocean Sensing

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Final Scientific and Technical Report

Annex A3
The EuroROSE Field Experiments

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1. EuroROSE – Introduction

Human activities and their environmental consequences to the coastal zones require a better understanding of the physical processes in the coastal waters as well as in the atmosphere. Wind, wave and current systems are known to be highly complex and transient in many coastal areas, and even course resolution information on these phenomena is difficult and expensive to obtain.

In the perspective of the Global Ocean Observing System (GOOS), the Services and the Coastal modules, an important goal is to develop operational tools for those actors which are in charge of safety and regulation for coastal marine operations and constructions, as well as for the protection of the marine environment. In fact, the ongoing planning of the GOOS Coastal Module already recognises the need to consider such actors as 'strategic partners' for the development of GOOS. The World Meteorological Organisation (WMO) has a global subgroup on ground based radars in ocean sensing (ROSE), bringing together different relevant activities both in Europe and in Australia, USA and Japan. Together with the Intergovernmental Oceanographic Commission (IOC), WMO conducts several global programs for monitoring and predicting the ocean environment.

Among such actors we find Vessel Traffic Services (VTS) operators, harbour management, coastal and waterways management and marine environmental protection organisations. These actors, in the following we use VTS as an example, are in a rapid development process due to general increase in traffic density and the new loads of environmental protection duties, and they feel the urge for more efficient tools. VTS, like other management tools, is an integrated concept embracing vessel and cargo data, seafloor, safety and rescue undertakings, and, in the context of the present proposal, the governing met-ocean conditions (winds, waves, water level and currents) which affect the safety and manoeuvrability of ships, operational performances etc. Further, the requirement for such information is not limited to the actual location of interest, but needed for a fairly extensive area surrounding the focus points. This is due to the existence of strong spatial variability within the area, as well as to the propagating nature of ocean phenomena (such as eddies).

The European Radar Ocean Sensing (EuroROSE) project aims to develop such a tool to be used by VTS operators, harbour and coastal managers, to monitor and predict significant met-ocean conditions with high time/spatial resolution in limited sea areas surrounding locations of dense and sensitive marine operations. This tool consists of four basic elements, each one well matured and proven:

- The high frequency radar systems which provide gridded coverage of wave spectra and currents within a distance from 2 - 40 km off shore and a resolution of 0.5 - 2 km.
- Navigational X-band radar systems which provide near field wave spectra and surface current averages for significant sub-areas (about 1 km²) within a range of 0.5 - 10 km.
- High resolution numerical models (less then 500 m) simulating and predicting all four classes of parameters in an area of about 40x40 km². Such models already exist and there is need to assimilate spatial radar sensed data into the model parameter fields in order to improve their initial fields for the prediction of the next two days.
- An interface, which presents the nowcast and forecast sea state information to the operators in a user friendly way within real time.
Nowadays the sea state variability are monitored by different in situ sensors (e.g. buoys) providing point measurements. To support the decision-making authorities additional model forecast information is normally provided on a coarse grid (about 5 km) and updated every 3-6 hours. A finer temporal and spatial resolution is demanded for harbours with a shallow or narrow approach channel.

The primary objective of EuroROSE was the combination of fine mesh numerical models updated every hour and initialised with the actual radar measurements. These data have been connected to the VTS centres using the existing infra structures.

The methodology was a combination of area covering remote sensed data and high resolution numerical forecast models including data assimilation, co-ordinated with the Vessel Traffic Services at ports and coastal monitoring centres. The system developed has been tested in field experiments, and have also been validated from the scientific point of view.

The project emphasises actived user interaction by involving potential users and system manufacturers as either partners or as members of an expert board engaged to oversee the project.

The work was organised in 4 phases:

- Set-up and preparation of the four basic EuroROSE elements.
- Installation of real time data transfer utilities between the elements.
- Application of the full system in operational mode co-ordinated with the Vessel Traffic Services in field experiments in Norway and Spain.
- Validation of the data obtained during the field experiments and assessment of the added value in terms of forecast skill obtained by combining different data sources.

Further information on the experiments can be found on the EuroROSE web site (http://ifmaxp1.ifm.uni-hamburg.de/ EuroROSE/index.html).
2. Field experiments

After the creation of the pre-operational system, it became imperative to demonstrate that it is suitable for its purposes. Therefore, a full scale field experiment was carried out to prove the capability of such devices to serve as automatic long term monitoring tools. In addition there was a particular need to carry out a scientific validation for such a field experiment. The most convincing approach was to prove the performance in the end users environment.

A few of harbour authorities in Europe expressed their interest in embedding such a pre-operational system at their premises. The final selection of demonstration areas has been made according to the existing infrastructure, and the hydrographic environment. Two field experiments covering different coastal conditions were planning to demonstrate the benefit of a combination of ground-based radar and numerical models in operational mode with VTS’s.

As test areas within the EuroROSE have been chosen:

- coastal waters around the Fedje Island on the western coast of Norway
- coastal waters around City of Gijón on the northern coast of Spain.

For each experiment two HF radars and two marine radar sites were installed. The operational forecast for the boundary values has been organised for each particular area. The hardware set-up and the communication lines have been customised. Both experiments were carried out during the winter season.

2.1 The EuroROSE Fedje Experiment

The EuroROSE Fedje Experiment was successfully carried out from February 15th to March 31st 2000. Instruments deployed have been:

- Two WERA HF Radars at Fedje and Lyngøy operated by University of Hamburg.
- Two WaMoS X-Band Radars at Hellisøy Fyr and Nordøy operated by OceanWaves.
- A directional waverider and a bottom-mounted ADCP operated by GKSS.

The radar data were assimilated in high-resolution current- and wave-models which were operated at DNMI in Oslo. The Data Assimilation Scheme has been developed by the Nansen Center (NERSC) in Bergen.

All the measured radar data and the model results including a 6-hour forecast were on-line presented to the traffic officers and pilots at Fedje VTS by a User Interface developed by Puertos del Estado, Clima Maritimo in Spain.

2.2 Description of experiment area in Fedje

Fedje island is the most westerly part of Norway, some 50 km north of Bergen. Two important oil ports are located nearby at Mongstad (upper right end of the shipping lanes) and at Stura (lower end of the shipping lanes). Information on the Mongstad crude oil terminal can be found at the STATOIL pages. Oil tankers have to pass north and south of Fedje. Ships are guided by Fedje Vessel Traffic Service (Fedje VTS).
The area in front of the passage south of Fedje will be observed by two WERA HF Radars sited at Fedje (blue) and Lyngøy (green), and by two WaMoS Radars (red) sited at Hellisøy and Nordøy. A bottom mounted ADCP (black) and a directional waverider (yellow) are also marked. This map gives an overview on the area and shows the ship ways (light blue) and the estimated coverage of the WERA radars.

![Map of area with instruments](image)

**Fig. 1**

Table 1: Coordinates of the instruments presented in Fig. 1.

<table>
<thead>
<tr>
<th>Instrument</th>
<th>latitude</th>
<th>longitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>WERA at Lyngøy</td>
<td>60° 44.13’ N</td>
<td>4° 43.75’ E</td>
</tr>
<tr>
<td>WERA on Fedje</td>
<td>60° 46.57’ N</td>
<td>4° 41.58’ E</td>
</tr>
<tr>
<td>WaMoS at Nordøy</td>
<td>60° 42.95’ N</td>
<td>4° 43.85’ E</td>
</tr>
<tr>
<td>WaMoS at Hellisøy</td>
<td>60° 45.18’ N</td>
<td>4° 42.65’ E</td>
</tr>
<tr>
<td>ADCP</td>
<td>60° 43.53’ N</td>
<td>4° 39.22’ E</td>
</tr>
<tr>
<td>Waverider buoy</td>
<td>60° 43.16’ N</td>
<td>4° 36.16’ E</td>
</tr>
</tbody>
</table>

There were two important reasons for selecting this passage for the measurements:

- This passage is more dangerous for the tankers, because it is only about 1 km wide and some shallow areas due to rocks (-14 m) are nearby.
- Oceanographic features like eddies travel along the coast from the south to the north. The integrated model/measuring (EuroROSE VTS) system can be adjusted to the features when they arrive at the system area.

The Fedje Traffic Control pilots observed current speeds up to 4 kn (2 m/s) 5 to 6 miles off Fedje. As the tankers have to reduce speed when they approach the passages, they are sometimes drifted off track. The EuroROSE VTS system can in advance give the necessary information to safely guide the ships.
2.3 The EuroROSE Gijón Experiment

The EuroROSE Gijón Experiment has been running from 11-Oct-2000 to 30-Nov-2000. Instruments deployed were the same as in Fedje field experiment, except the directional waverider buoy:

- Two WERA HF Radars at Cabo de Torres and Cabo de Peñas operated by University of Hamburg.
- Two WaMoS X-Band Radars operated by OceanWaves (same locations as WERA)
- A bottom-mounted ADCP operated by GKSS.

Similar to the field experiment in Fedje, the radar data were assimilated in high-resolution current- and wave-models running at DNMI. All the measured radar data and the model results including a 6-hour forecast were on-line presented to the traffic officers and pilots at Gijón VTS by a User Interface.

2.4 Description of experiment area in Gijón

The city of Gijón is located in the central part of the northern coast of Spain (see Fig. 2). The area is swell dominated. Such as long waves are specially dangerous for the small fishing harbours in the area, because under these long wave conditions (waves longer than 20 s) some resonance phenomena appear between the wave field and the harbour structures (i.e. breakwaters).

![Fig. 2: Geographical location of Gijón City.](image)

A detailed map of the area can be seen in Fig. 3.

The mean reason to chose the area close to the city of Gijón for the second EuroROSE field experiment was the logistic of the area and the amount of sensors deployed close by. The sensors, which operated in the area, were:

- Two heave WaveRider buoy moored in shallow waters in the vicinity of Gijón harbour. These buoys are traditional models based on an accelerometer.
- One directional SMART-800 buoy moored close to one of the above buoys. This buoy uses GPS technology to measure the vertical wave elevations, as well as the horizontal displacement of the sea surface.
- One directional WaveWatch buoy moored in deep water to know the incoming wave fields to the coast. This buoy measures other meteorological and oceanographical parameters, such as wind velocity, air and water temperatures, salinity, currents, etc.
- A tidal gauge to provide sea level data.
- A meteorological station.
- An X-band nautical radar station installed in near to measure the incoming wave fields in intermediate waters.
- A bottom-mounted ADCP operated by GKSS.

Unfortunately, the directional wave buoy in the western part of the area was lost before the beginning of the Gijón Experiment. Also the SMART-800 waverider buoy failed during the set-up phase of the experiment. We lost also, due to strong storms on the northern coast of Spain during the experiment, the ADCP.

![Map of the vicinity of Gijón City](image)

**Fig. 3**
Map of the vicinity of Gijón City. The position of the X-band radar, as well as the locations of the two HF radar antennas is shown in this figure. A bottom mounted ADCP (red) is also marked (the position of the wave buoy is similar).

**Table 2: Coordinates of the instruments presented in Fig. 3.**

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Latitude</th>
<th>Longitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>WERA at Cabo de Peñas</td>
<td>43° 39.4’ N</td>
<td>5° 50.5’ W</td>
</tr>
<tr>
<td>WERA at Cabo de Torres</td>
<td>43° 34.3’ N</td>
<td>5° 42.0’ W</td>
</tr>
<tr>
<td>WaMoS at Cabo de Peñas</td>
<td>43° 39.5’ N</td>
<td>5° 51.0’ W</td>
</tr>
<tr>
<td>WaMoS at Cabo de Torres</td>
<td>43° 45.2’ N</td>
<td>5° 42.7’ W</td>
</tr>
<tr>
<td>Wave buoy</td>
<td>43° 36.7’ N</td>
<td>5° 40.0’ W</td>
</tr>
<tr>
<td>ADCP</td>
<td>43° 36.5’ N</td>
<td>5° 40.1’ W</td>
</tr>
</tbody>
</table>
Other reason to choose this area is the geographical position of this harbour, in the middle part of the Bay of Biscay, because the acquired experience can be used for the other commercial, sport and small-fishing harbours in the northern coast of Spain. Gijón has one of the main harbours in the area. The city shore and its harbour are affected by the typical sea states and meteorological conditions, which are present in the Bay of Biscay:

- Long swell coming from Northwest due to the local storms originated in Northern Atlantic Ocean.
- Local wind sea storms coming from North and East.
- Expected significant wave heights from 0 to 8 meters. Higher sea states can be measured in strong storm cases.
- Maximum tide range of 4.6 m.
- Typical current speeds about 0.5 m/s.
- Winds: SW (prevailant), NW (dominant).

3. **High resolution forecasting system for waves and currents**

An automatic system for operational fine scale forecast of waves and currents has been developed at The Norwegian Meteorological Institute (DNMI). This forecasting system was tested during the two field experiments. Fine scale numerical models for waves and currents produced a new analysis and six hours forecast every hour. Wave and current measurements from the HF radar were assimilated into the models. The fine scale models were on a horizontal grid resolution of 1 km, and covered a model domain of approximately 50x50 km. Both models were nested into the larger scale models for waves and currents, which DNMI runs operationally as a part of the national weather prediction service. The forecasted current and wave data for the lateral boundaries and wind forcing from the larger scale weather prediction models are updated two times daily. In the Fedje area the fine scale wave and current models were forced by atmospheric data from a high resolution limited area model (HIRLAM) with 10 km horizontal resolution. In the Gijón area the atmospheric forcing were taken from a model with 50 km horizontal resolution. Observations from the HF radar in the area to be forecasted were transferred to the numerical models via an ftp-server every 20 minutes. Every hour the models ran the previous hour to produce an analysis based on the latest radar data available. Each model cycle consists of assimilation at times -00:40, -00:20, and 00:00 relative to the analysis time. After this, the model generates a six-hour forecast (see below). This cycle is repeated every hour, resulting in several overlapping forecasts. Because we assimilate every 20 minutes, the initial field that starts the next assimilation cycle is a 20 minutes forecast based on the assimilation in the previous cycle.

- -01:00: Model is initialised from previous assimilation cycle
- -00:40: First dataset in, assimilation
- -00:20: Second dataset in, assimilation
- 00:00: Third dataset in, final assimilation, forecast begins
- 06:00: Forecast ends

Finally, the resulting nowcast and six-hour forecast were transferred to the VTS-centre via the ftp-server. The same scheduler that is responsible for controlling the automatic weather forecasting system at DNMI controlled the whole procedure. To secure the stability of the forecast, the computer department at DNMI monitors the forecasting system 24 hours daily.
3.1 The wave model

For wave forecasting, the WAM model was used. The WAM model is a state of the art numerical wave prediction model developed by an international group of scientists (WAMDI Group, 1988). WAM is a third generation wave model, which solves the full energy density equation for waves, including the non-linear transfer terms. In the forecasting system for the Fedje area, a three step nesting system was used. The largest model domain covers most of the North Atlantic. This version has a horizontal grid resolution of 45 km. The next step is a model version on 8 km grid resolution, nested into the former. Finally, this 8 km version provides boundary data for the fine scale model, which has a resolution of 1 km. The 8 km and 1 km areas are shown in Fig. 4. The bottom topography for the fine scale model has been taken from the Earth Topography Five Minutes Grid (ETOPO5) database at a resolution of 5 minutes of latitude and longitude. The bathymetry in ETOPO5 was compiled by U.S. Naval Oceanographic Office (Row et al., 1995). To improve the bathymetry and to introduce small-scale structures, the bottom topography was been manually corrected comparing with navigational maps for the actual area.

Significant wave heights measured by the HF radar were assimilated into the WAM model by an assimilation method described in Breivik and Reistad (1994). The first step in the assimilation procedure is to use the measured significant wave heights to update the significant wave height in the model grid points. This is done by a successive correction method. The second step is to use the updated wave height to modify the wave model spectrum in the grid points. The wave model spectrum is divided into a wind sea part and a swell part and the following assumptions are made:

- The duration and the direction of the wind used in the wave model are correct.
- The relation between the wind sea energy and the swell energy is correctly modelled.

The wind sea part and the swell part of the wave spectrum are updated separately. A new wind sea spectrum is calculated by use of a parametric wave spectrum. If the wave energy is increased, the swell energy is increased and shifted towards lower frequencies, and opposite if the wave energy is decreased.

Since wave energy from the ocean, propagating through the assimilation area, in this case will reach shore shortly after the assimilation time, the impact of assimilation on the wave forecasts has been very limited. This can be seen from Table 3: Comparison of Hs from WAM and wave buoy, which shows some statistics from a comparison between the significant wave height from the model at analysis time and 1, 2, 3, 4, 5 and 6 hours prognosis respectively, and the wave buoy. The significant wave heights from the model and the buoy are well correlated with a correlation coefficient between 0.932 and 0.937. The RMS difference is between 0.55m and 0.58, and the bias is almost zero for the prognosis. The mean significant wave height from the model analysis is however 0.20 m higher than the mean of the significant wave height measured by the buoy. This indicates that the assimilation of the HF radar data increases the significant wave height in the wave model. But the effect of the assimilation almost disappears in the model already one hour after the analysis time. To get larger impact of data assimilation on the wave prognosis it is necessary to have wave measurements over a wider area.
### Table 3: Comparison of Hs from WAM and wave buoy

<table>
<thead>
<tr>
<th>Prog. Time</th>
<th>N</th>
<th>Mean Hs$_{obs}$</th>
<th>Mean HsWAM</th>
<th>St.dev diff</th>
<th>RMS</th>
<th>r</th>
<th>St.dev Hs$_{obs}$</th>
<th>St.dev HsWAM</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 hour</td>
<td>1074</td>
<td>2.85</td>
<td>3.05</td>
<td>0.55</td>
<td>0.58</td>
<td>0.937</td>
<td>1.56</td>
<td>1.42</td>
</tr>
<tr>
<td>1 hour</td>
<td>1075</td>
<td>2.85</td>
<td>2.87</td>
<td>0.55</td>
<td>0.55</td>
<td>0.937</td>
<td>1.56</td>
<td>1.41</td>
</tr>
<tr>
<td>2 hours</td>
<td>1076</td>
<td>2.85</td>
<td>2.86</td>
<td>0.55</td>
<td>0.55</td>
<td>0.937</td>
<td>1.56</td>
<td>1.41</td>
</tr>
<tr>
<td>3 hours</td>
<td>1077</td>
<td>2.85</td>
<td>2.86</td>
<td>0.55</td>
<td>0.55</td>
<td>0.937</td>
<td>1.56</td>
<td>1.41</td>
</tr>
<tr>
<td>4 hours</td>
<td>1078</td>
<td>2.85</td>
<td>2.86</td>
<td>0.55</td>
<td>0.55</td>
<td>0.935</td>
<td>1.56</td>
<td>1.43</td>
</tr>
<tr>
<td>5 hours</td>
<td>1079</td>
<td>2.85</td>
<td>2.86</td>
<td>0.56</td>
<td>0.56</td>
<td>0.934</td>
<td>1.56</td>
<td>1.43</td>
</tr>
<tr>
<td>6 hours</td>
<td>1080</td>
<td>2.85</td>
<td>2.86</td>
<td>0.56</td>
<td>0.56</td>
<td>0.932</td>
<td>1.56</td>
<td>1.44</td>
</tr>
</tbody>
</table>

N: Number of entries
Mean Hs$_{obs}$: Mean observed significant wave height
Mean HsWAM: Mean significant wave height from WAM
St.dev diff: Standard deviation of the difference in Hs between observation and WAM
RMS: Root mean square difference
r: correlation coefficient
St.dev Hs$_{obs}$: Standard deviation of observed Hs
St.dev HsWAM: Standard deviation of Hs from WAM

Fig. 4
Distribution of wave heights (m) in the North Sea with a nesting sequence towards progressively finer meshes around Fedje (31st Jan 00, 6:00 UTC): from 8 km resolution to 1 km. The 8 km model again nested into a 45 km resolution model for the whole North Atlantic.

### 3.2 The ocean model

We used the Princeton Ocean Model (POM) as implemented and modified by The Norwegian Meteorological Institute (DNMI). The lateral hydrodynamic equations are solved on an Arakawa C-grid. Terrain following sigma-coordinates resolve the vertical, which means that the vertical resolution is high in shallow areas and coarse in deeper areas.
The model version developed at DNMI has a Flow Relaxation Scheme (FRS) implemented at the lateral open boundaries (Martinsen and Engedahl, 1987), where forcing from eight tidal constituents is also included (Engedahl, 1995). A thorough description of the basic model set-up can be found in Blumberg and Mellor (1987). For further information on the modifications made to the DNMI version of the model please refer to Engedahl (1995).

Three models are 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 water of southern Norway with a resolution of 4 km (see Fig. 5), and the inner, high resolution model has a resolution of 1 km and covers a 60 by 60 km area (see Fig. 6).

As for the wave model, the bottom topography is taken from the ETOPO-5 database. Also here the data has been manually corrected by comparing with navigational maps. A more detailed description of the model set-up for the Fedje experiment and the assimilation procedure can be found in Breivik and Sætra (2000).

Fig. 5
The 1 km high resolution model domain is shown as a small square superposed on the bathymetry of the 4 km intermediate model covering parts of the North Sea, Skagerrak, Kattegat, and the coastal waters around southern Norway. The projection is polar stereographic, north is toward the upper right hand corner of the map.
To avoid extreme updates in the model due to bad data, a comparison between the modelled and observed currents is made for each observation prior to analysis. If the observed speed differs by more than 0.5 m/s, or the observed direction deviates by more than 45 deg from the modelled current vector, the observation is discarded. These thresholds have been chosen rather arbitrarily, but have stood the test and proved to weed out the strong, erroneous current vectors that are often found along the rim of the radar maps (due to backscatter from the strong antenna pattern side lobes found on the edges of the radar coverage). This quality check is also a way to compensate for the lack of time-varying observation error variances. On the average, only a small percentage of the observations were discarded through this procedure (less than 5%). However, in situations where the radar performed poorly, larger amounts of data were discarded. Further, the assimilation sometimes adds too much fine structure to the model fields. To remove this but retain the longer wavelengths we chose to run a Shapiro second order nine-point filter after each analysis.

Throughout the experiment, an identical model twin was run without assimilation (hereafter referred to as the free run). This free running model allows us to assess the impact of the assimilation scheme on analysis and forecasts. In the following, we have compared the two model runs with the radar data in wond of other sources of ground truth. It is important to keep in mind that the radar data themselves have errors.

For an example of the difference between the free run and the analysis, compare the left and right panels of Fig. 7. The free run is clearly less energetic, and the coastal current appears wider and more diffuse than the assimilated current field.

More important than the quality of the analysis itself is the temporal impact of the analysis. I.e., for how long does the added information keep the model forecast on track? To assess this, we computed the spatially averaged kinetic energy in the radar covered area for both model and observations. This method has the advantage of appreciating a corrected current...
field (typically the coastal current) even when the current maximum is slightly dislocated by the model yet still improved over the free run.

![Fig. 7](image)

Left panel: analysed surface current field (assimilation) Right panel: surface current field of the free running model (no assimilation).

Fig. 8 shows the ratio of the model fields to the observed fields. As can be seen, the free run underestimates the energy level of the coastal current (roughly by 50%). The analysis is a significant improvement over the free run (same figure), with an energy level on a par with what is observed. After analysis, the forecasts spread out quickly, but retain an average energy level well above that for the free running model even after a six-hour forecast.

![Fig. 8](image)

The assimilation skill measured in level of kinetic energy. The ratio of modelled kinetic energy to observed kinetic energy is plotted for the free run model (leftmost boxplot), the analysis, and the forecasts, numbered in forecast lead time (+01:00 to +06:00 h). The box plots consist of a box covering the middle 50% of the data (quartile to quartile), the median line dividing the box, and whiskers indicating the extent of the remaining data. Outliers are plotted as individual crosses.
We have demonstrated that it is possible to make real time analyses and forecasts of coastal currents using a suite of nested ocean models and continuous radar coverage. Both analysis and forecasts clearly outperform the free run, indicating that the assimilation has added information to the model, but the +6 hour forecast is only marginally better (if better at all) than the free run. The assimilation scheme also improves the spectral characteristics of the ocean model, especially for frequencies corresponding to periods longer than five hours. Given the relatively limited coverage of the HF radar, the analyses provide valuable added information through the extrapolation from radar observations to the surrounding waters covered by the model grid. In general, the assimilation scheme is sufficiently sophisticated to allow for long-ranging corrections outside the actual radar coverage (extrapolation), yet fast enough to fit in the tight schedule of a real time framework. The total time from acquisition of data until the presentation of analysis and forecast was ready at the Vessel Traffic Service in Fedje was 45 min. The system was found to be quite robust to bad observations and was able to operate during periods of high and low radar coverage.

4. Instruments used within the EuroROSE field experiments

To achieve the goals of the operational forecasting system, several existing and newly developed components have been integrated. On the measurements side, these were instruments for remote sensing of currents and waves: WERA (Wellen RAdar) HF radar operated by University of Hamburg and WaMoS II microwave radar operated by OceanWaveS. Both radar systems were operated from the coast. Additional information about waves and currents supplied waverider buoys and bottom mounted acoustic current meters. Other data source was the synthetic aperture radar (SAR) carried by the ERS-2 satellite. The following section describe the components in more details.

4.1 WaMoS

The Wave Monitoring System WaMoS II, based on a commercially available nautical X-Band radar, was developed for real time measurements of directional ocean wave spectra. All other sea state parameters such as significant wave height, wave periods and directions can be derived. The system is especially designed for the operation from fixed and moving platforms, and on board all types of ocean going vessels. The overall advantage of WaMoS II is, the continuos availability of wave data in very rough sea conditions even with limited visibility (e.g. by night, fog).

WaMoS II wave information is directly available on site and can be transferred via satellite to support weather and ship routing services. The WaMoS II hardware is designed and tested to fit all major electromagnetic environment regulations (EN/CE/GL). The wave data is validated for various onshore, offshore and ship installations. The validations include ships travelling from 10 to 40 knots. Those data comparisons proved that WaMoS II reaches about the same accuracy as a conventional waverider buoy.
Table 4: Standard WaMoS II outputs and accuracy

<table>
<thead>
<tr>
<th>Wave Spectra</th>
<th>Resolution</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-dimensional frequency-direction (f,θ) spectrum</td>
<td>64 x Δf, 90 x Δf</td>
<td>Δf = 0.003 Hz, Δθ x 4°</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Wave and Current parameters</th>
<th>Accuracy</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Significant Wave height:</td>
<td>+/- 10%</td>
<td>1 – 20m</td>
</tr>
<tr>
<td>Peak direction:</td>
<td>+/- 2°</td>
<td>1st. and 2nd. peak 0 - 360°</td>
</tr>
<tr>
<td>Peak period:</td>
<td>+/- 0.5s</td>
<td>1st. and 2nd. peak 3.5 – 55s</td>
</tr>
<tr>
<td>Peak wave length:</td>
<td>+/- 10%</td>
<td>1st. and 2nd. peak 19 – 600m</td>
</tr>
<tr>
<td>Current speed:</td>
<td>+/- 0.2m/s</td>
<td>0 - 40m/s</td>
</tr>
<tr>
<td>Current direction:</td>
<td>+/- 2°</td>
<td>0 - 360°</td>
</tr>
</tbody>
</table>

1) There is no limit in estimating the wave heights, but up to now a Hs of 20 m was the highest value measured with WaMoS II.
2) These values indicate the typical range. They depend on the radar hardware and therefore can vary for each individual installation.

WaMoS II can be connected to almost any kind of navigational X-band radar. The device and the required PC are easily mounted in a 19” rack. The system is capable of automatic unattended operation. The system has been developed by the GKSS research Centre and is now commercially available from OceanWaveS.

During the Fedje field experiment two WaMoS II stations were set-up for close to shore sea state measurements. Fig. 1 shows both positions at Hellisøy and Nordøy. The radar antennas were installed about 40 m above sea level. The related hardware could be set-up in the nearby Fedje VTS station. Both stations sampled continuously and the data was send automatically, every 20 minutes, to the EuroROSE data communication network. Therefrom all data were displayed in the VTS center and distributed to the Norwegian Met Office (DNMI).

Similar installation was used during the second field experiment carried out in the Gijón area. Fig. 3 shows the experiment site, with the positions of the WaMoS installations at Cabo Peñas and Cabo de Torres. At Cabo Peñas the WaMoS II antenna was mounted about 60 m and at
Cabo de Torres about 50 m above sea level. The continuously sampled data was send to the EuroROSE data communication network, located in the VTS centre of the port of Gijón. All data were displayed in the VTS center and distributed to a central server in Madrid.

4.2 WERA

The University of Hamburg HF radar is based on CODAR and has recently been extended to allow simultaneous measurement of surface current fields using the University of Hamburg current algorithm and ocean wave parameters using the University of Sheffield [UK] algorithms. The extended version is called WERA (WEllen RAdar) (Gurgel et al., 1999a, 1999b). The main modifications to CODAR include:

- Simultaneous measurement of currents and waves.
- Different receiving antenna designs (4 to 16 antennas) in combination with direction finding and beam forming techniques for azimuthal resolution. Here is a picture of the 16-element linear array, which is needed for ocean surface current and wave measurement and this picture shows the 4-element square array, which can be used for ocean surface current measurement only.
- Frequency chirp continuous wave modulation (FMCW)
  - to avoid a blind range in front of the radar,
  - to simply modify the radar's range resolution down to 300 m,
  - to reduce the impact of radio interference.
- The radar is linked to a Unix workstation for data management and processing.
- 90% of the signal processing steps are implemented in software and thus can be modified or updated in a simple way.
- WERA is a very modular design, which can be easily adopted to different applications.

For remotely sensing the ocean, HF radars are mostly operated from the 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 x 40 km or more with a resolution down tp 300 m. One main advantage of the WERA 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 spectral bands. A further advantage is the flexibility in range resolution between 0.3 km and 3.0 km instead of a fixed resolution. This is achieved by transmitting frequency-modulated continuous wave (FMCW) chirps instead of continuous wave (CW) pulses. In addition, this technique avoids the blind range in front of the. Fig. X shows a typical installation of an HF radar at the coast.

During the Fedje field experiment two HF radars WERA were deployed. The measuring period was 9 min. In order to avoid interference, the two sites were operated successively, and repeated every 20 min. The both WERA systems were configured to use 16-element linear receive-antenna array. The radial resolution chosen was 1.2 km. Azimuthal resolution was achieved by beamforming techniques and was some 6°. Mean radial current velocities were computed on a regular grid of 1 km spacing. The radial components measured by the two WERA stations were used to compose the two-dimensional vector of current velocity.
The installation used during the Gijón experiment was similar. Two WERA systems operated successively and connected with a 16-element linear receive-antenna array were used. The radial resolution was 1.2 km and the azimuthal resolution about 6°.

4.3 Waverider buoy

During the EuroROSE Fedje experiments a directional waverider buoy has been used for wave height and wave direction measurements. The direction measurement is based on the translational principle which means that horizontal motions instead of wave slopes are measured. The acceleration of the buoy is measured in x and y directions (two fixed accelerometers) and in vertical direction (accelerometer mounted on stabilised platform). From the measurements in the x and y directions of the moving “buoy reference frame” the acceleration along the fixed, horizontal, north and west axis are calculated.

All analog outputs of the sensors are filtered with a low-pass filter using a cut-off frequency of 1.5 Hz. At this frequency, the buoy’s motions are already strongly attenuated due to short waves compared to the buoy dimensions (geometric attenuation).

From the time series of the translational data a complete wave spectrum is calculated every 30 minutes. In this time the directional waverider processes 8 blocks of 200 seconds data (256 samples) to get all spectral and directional parameters. The estimation of the directional parameters relies on the assumption that the angular distribution is narrow.

Both the measured translation data and the computed spectral data are sent over the radio link to a shore station. The translation data are transferred in real time, while the spectral data are cyclically transmitted.
4.4 ADCP

The Acoustic Doppler Current Profiler (ADCP) measures horizontal current velocities as a function of depth, by averaging over vertical range bins of a selected extension. During the Fedje EuroROSE experiment, a conventional bottom mounted 300-kHz upward-looking ADCP was operated from 16th Feb, 19:24 UTC until 13th Apr, 14:32 UTC at the position marked in Fig. 1. We used the Workhouse Sentinel model (RD Instruments), which was designed for self-contained current profile measurements in the upper ocean or in shallow water at depths less than 200 m. The ADCP was installed on the sea floor at a water depth of 65 m. The bin length chosen results in a vertical resolution of 4 m. The number of bins was 15, the centre of the first one 5.7 m above the sea floor. The sampling interval was 10 minutes. The same instrument was installed during the field experiment in Gijón at a water depth of 50 m at the position marked in Fig. 3. As mentioned before, the ADCP got lost after strong storms in the winter 2000/2001, therefore only ADCP data from The Fedje experiment are available.

In addition, a ship-borne ADCP of the research vessel "Håkon Mossby" was used during the Fedje experiment. The "Håkon Mossby" operated in the measuring area off the Norwegian coast between February 15th and February 23rd 2000. The vertical resolution of this ADCP was 3 m and the uppermost bin centered at a water depth of 13 m.

4.5 Airborne interferometric SAR

The synthetic aperture radar (SAR) carried by the second European remote sensing satellite (ERS-2) was used as other data source in the EuroROSE project. Additional, DLR and GKSS jointly carried out an airborne interferometric SAR (InSAR) campaign during the field experiment in Gijón.

In the InSAR part of the experiment, the airborne InSAR system (AeS-1 developed by Aero-Sensing Radarsysteme GmbH) is using 3-antennas. Two antennas are placed along the aeroplane flight direction and one antenna is placed across the flight direction. This kind of system is a combination of along-track InSAR and across-track InSAR, which is used for oceanic application for the first time. The coordinates of antennas are given in Table 5 (the coordinate refers the GPS point at the centre of aeroplane).

<table>
<thead>
<tr>
<th>Table 5: The coordinates of InSAR antennas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Master antenna</td>
</tr>
<tr>
<td>------------------</td>
</tr>
<tr>
<td>X (flight direction)</td>
</tr>
<tr>
<td>Y (across-flight direction)</td>
</tr>
<tr>
<td>Z (Vertical direction)</td>
</tr>
</tbody>
</table>

The radar parameters are given in Table 6.
### Table 6: Radar parameters.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating frequency</td>
<td>9.6 GHz</td>
</tr>
<tr>
<td>System bandwidth</td>
<td>200 MHz</td>
</tr>
<tr>
<td>Polarisation</td>
<td>HH</td>
</tr>
<tr>
<td>Pulse peak power</td>
<td>2.5 kW</td>
</tr>
<tr>
<td>Antenna look direction</td>
<td>Right look</td>
</tr>
<tr>
<td>Incidence angle</td>
<td>20°-50°</td>
</tr>
<tr>
<td>Flight velocity</td>
<td>70 m/s - 100 m/s</td>
</tr>
<tr>
<td>Azimuth resolution</td>
<td>10 m</td>
</tr>
<tr>
<td>Range resolution</td>
<td>10 m</td>
</tr>
<tr>
<td>Height resolution</td>
<td>0.26 m-0.50 m (depending on signal to noise ratio and flight altitude)</td>
</tr>
<tr>
<td>Swath width</td>
<td>2483 m (flight height 3000 m)</td>
</tr>
<tr>
<td></td>
<td>1242 m (flight height 1500 m)</td>
</tr>
</tbody>
</table>

The radar was operated at the following modes simultaneously:

- one antenna in along-track direction emitted radar pulses and three antennas received the signals
- two antennas in along-track direction emitted radar pulses and three antennas received the signals.

The backscattered signals from the ocean surface received by the 3 antennas are processed separately to 3 complex images. Two complex images obtained from two antennas in flight direction are combined into a complex InSAR image. Its phase is approximately proportional to the radial velocity of ocean surface. Furthermore, two complex images obtained from two antennas across the flight direction are combined into a complex InSAR image too. Its phase is proportional to the ocean surface elevation. Thus, from InSAR phase images, we can derive a 2-dimensional ocean surface elevation field and a 2-dimensional ocean surface velocity field simultaneously with high spatial resolution (about 10m x 10m). The ocean wave spectrum can be estimated from the surface elevation field.
## 5. Measurements during the EuroROSE field experiments

The following section presents the experimental results obtained during both Fedje and Gijón field experiment. Additional the results of the InSAR campaign carried out during the Gijón experiment are shown.

### 5.1 Wind measurements

The wind measurements from the lighthouse on Hellisøy within the Fedje experiment are shown in Fig. 11. Unfortunately, there are several gaps in the data, e.g. the period from 23rd to 24th February or the period from 3rd to 7th March is missing. Wind speeds measured at Fedje were generally high, with speeds over 10 ms\(^{-1}\) on many occasions. Wind directions are rather variable associated with the passage of a series of lows and frontal systems across the region.

Fig. 11
Time series of wind speed (m/s, averaged over 10 min) measured on Hellisøy from 14th Feb to 5th Apr 2000.

The frequency distribution of the measured wind directions is shown in Fig. 12.

Fig. 12
Distribution of wind directions measured on Hellisøy during Fedje field experiment; left: all wind data, right: wind speed > 12m/s.
During the experiment winds from southern directions dominated. Even though winds from north (wind sector from NNW to NNE) preponderate with 24.25%, the three southern sectors (SW, S and SE) amount to 45.41% of the observed wind directions. Quite clear is also domination of the strong winds (>12m/s) from the south: 61.33% of these winds came from the abovementioned southerly sectors, against it 34.35% from northwest and north. The smallest wind probability can be observed in northeast, east and west sector.

Fig. 13 displays time series of the wind speed during the Gijón experiment. The wind was collected by the meteorological station of the port of Gijón. The wind speed varied strongly and there were several storm events with wind speed exceeding 10 ms\(^{-1}\). On the other hand, wind speeds were significantly lower and directions much more stable as measured in Fedje.

![Time series of wind speed](image)

**Fig. 13**
Time series of wind speed (m/s, averaged over 10 min) measured in Gijón from 9\(^{th}\) Oct to 6\(^{th}\) Dec 2000.

During the experiment in Gijón winds from west and southwest directions clear dominated (Fig. 14). Both sectors amount to 74.95% of the observed wind directions. There is also explicit domination of the strong winds (>12m/s): 81.33% of these winds came from the abovementioned westerly sectors. Against it winds from North, East or South are scarce.

![Distribution of wind directions](image)

**Fig. 14**
Distribution of wind directions measured in Gijón; left: all wind data, right: wind speed > 12m/s.
5.2 WERA

The maximum working ranges of the two WERA sites varied considerably, from only 15 km 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. For most of the period from 24\textsuperscript{th} February until 4\textsuperscript{th} April (the Fedje experiment) and from the significant wave height (SWH) was higher than 2 m and exceeded 6 m several times. Also during the Gijón experiment the SWH was higher than 2 m for most of the time. Another reason for a reduced range was the high interference with remote radio stations due to ionospheric reflections.

5.2.1 WERA HF radar current measurements

WERA measures surface currents within the uppermost ~0.5 m of the ocean. These currents are strongly affected by wind.

Fig. 15 displays the two components of the wind vector and the surface current as measured by WERA at the position of the ADCP-mooring (see Fig. 1) during the Fedje experiment. There is about no correlation between the east components while the correlation between the north component is high. The most likely reason for this discrepancy is the influence of the coast which blocks the eastward flowing current. Strong westerly winds (positive east component) do not affect the respective current component. The correlation between wind and current vector is $r = 0.57$, and the current veers by 20° to the right from the wind (this veering is in accordance with the Ekman’s theory). Because of the low correlation of the east component, the modulus of the vector correlation is smaller than the correlation of the north component.

Current maps as shown in following figures have been sent to the data assimilation system. From approximately 3500 current maps two examples from the Fedje experiment are shown in Fig. 16 und Fig. 17.
Fig. 16
A surface current field (arrows) measured by the HF radars at Fedje (blue) and Lyngø (green) with colour-coded velocities on March 17th 2000; left: 02:40 UTC; right: 03:00 UTC. The main shipping routes are indicated by the light blue color.

Fig. 17
A surface current field (arrows) measured by the HF radars at Fedje (blue) and Lyngø (green) with colour-coded velocities on March 26th 2000; left: 00:00 UTC; right: 00:20 UTC. The main shipping routes are indicated by the light blue color.

Fig. 16 shows an eddy which is superimposed by a mean northward flow. The center is 25 km off the coast and the diameter about 20 km. A narrow jet propagates along the coast. The width is about 8 km and the speed 2 kn (~ 1 ms⁻¹). The jet is present for about 24 h, while the eddy structure disappears after 6 h. Jets like in Fig. 16 occurred several times during the experiment and seem to be related to the presence or decay of strong winds.
Fig. 17 represents a current field of relatively low spatial variability. The measurements was carried out under moderate wind and wave conditions. Maximum amplitudes of the current velocity are 1 kn (~0.5 ms\(^{-1}\)). Meanders like in Fig. 17 are visible in most of the maps. In general, they exist for several hours and may change shape or develop into eddies.

During the field experiment in Gijón two WERA sites were selected to cover the entrance to Gijón harbour (Fig. 3). Both sites were on top of high cliffs, 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 x 40 km) has been - quite often - completely covered by the radars. An example of current maps measured in the area of Gijón at 16\(^{th}\) November 2000 is shown in Fig. 18. More details about current measurements during the EuroROSE experiments can be found in Essen et al. (2001).

5.2.2 WERA HF radar wave measurements

In addition to surface currents, HF radars are capable of measuring ocean surface waves. The retrieval of surface currents is based on the offset of the two Doppler lines from the theoretical Bragg positions, i.e. on first-order Bragg scattering. Ocean surface waves with wavelengths longer than the Bragg wave (~5 m for WERA) contribute to the Doppler spectra by second- and higher order effects.

Shown here are measurements of wave parameters that are being made using wave inversion algorithm developed at University of Sheffield. The parameters are obtained from the full directional spectrum, which is itself obtained by an inversion of Doppler spectra provided by the WERA radar system. This technique based on second-order Bragg theory. The white dots on the maps indicate where the inversion has been successful. The wave parameters have also been sent to the data assimilation system. Fig. 19 shows an example of the significant wave

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**Fig. 18**
A surface current field (arrows) measured by the HF radars off Gijón with colour-coded velocities on 16\(^{th}\) November 2000; left: 01:00 UTC; right: 01:20 UTC.
height distribution obtained from the full directional spectrum during the Fedje experiment. Fig. 20 shows an example of the spatial distribution of SWH and -direction obtained during the experiment in Gijón. A more detailed description of the wave measurements during the EuroROSE experiments can be found in Wyatt et al. (2001).

Very large changes in the parameters seen over rather small regions are probably due to noise in the radar signals rather than freak wave events. Research into methods to deal with such noisy signals is in progress at Sheffield University.

The maps were updated every 20 minutes during the field experiments (Fedje and Gijón).

Fig. 19
An example of the spatial distribution of wave parameters during the Fedje experiment on 15th March 2000. Left: spatial distribution of significant wave height and wave direction; right: spatial distribution of wave period and -direction.

Fig. 20
An example of the spatial distribution of wave parameters during the Gijón experiment on 17th October 2000. Left: spatial distribution of significant wave height and wave direction; right: spatial distribution of wave period and -direction.
5.3 WaMoS

During the EuroROSE field experiments two WaMoS II stations were set-up for close to shore sea state measurements. Both stations sampled continuously and the data was send automatically, every 20 minutes, to the EuroROSE data communication network. Therefrom all data were displayed in the VTS center (Fedje or Gijón) and distributed to the Norwegian Met Office (DNMI) and to a server in Madrid.

5.3.1 Installation during the Fedje experiment

The WaMoS II measurements at Hellisøy were taken from February 23rd to March 31st 2000, at Nordøy from February 26th to March 31st 2000. Fig. 1 shows both WaMoS II positions. The radar antennas were mounted about 40 m above sea level. Due to breaking waves in front of Nordøy the analyses array there was moved further from the coast. The system sampled continuously every 2.6 (Hellisøy) and 2.8 (Nordøy) minutes. The single wave measurements were averaged over 20 minutes shows the frequency direction spectrum as provided by WaMoS II on March 6th 2000, 13:34 UTC at Hellisøy. The corresponding spectrum obtained at the same time at Nordøy are shown in Fig. 24. During this time a swell system with a peak wave length of about 180 m and a peak period of approximately 11 seconds approached the coast from the west. At that time the significant wave height at Hellisøy was determined to be about 7 m.

Fig. 21

Frequency direction spectrum \( F(\theta) \) obtained by WaMoS II on March 6, 2000, 13:34 UTC at the EuroROSE experiment site Hellisøy. The colour coding indicates the spectral wave energy. The rings indicate the wave periods.

Fig. 22 shows the time series of the single wave parameters as obtained with WaMoS II at Hellisøy (red dots) and the corresponding parameters obtained by the wave buoy 5 nm west of Fedje (blue dots). The upper panel gives the comparison of the significant wave height, the middle panel shows the peak wave periods and the lower panel the peak wave directions. All parameters are derived directly from the WaMoS II data.
Fig. 22
Comparison of main wave parameter as obtained by WaMoS II at Hellisøy (red) and the buoy at Fedje (blue) during Feb. 15, - March, 31, 2000. Note that each WaMoS II value represents a spectral mean.

WaMoS II delivers no wave height higher than 9 m, while the buoy delivered wave heights up to about 12 m, e.g. at March 6th (Fig. 22). For lower wave heights the agreement between WaMoS II and buoy measurement is good. For higher and longer waves it seems that the spatial distance between the WaMoS II analysis array and the position of the buoy becomes relevant. The buoy is measuring the undisturbed waves under deep water conditions, whereas WaMoS II records waves already transformed by coastal effects. On the way towards the coast, the wave interact with the local bathymetry. Wave breaking and damping yield to a decreasing wave height near the shore. Also wave period and wave direction are influenced by the local bathymetry (wave refraction). Compared to the buoy WaMoS II measured shorter wave periods, especially for high sea states (see Fig. 22). After March 24th, (Julian day 84) the peak wave direction obtained by WaMoS II shows a significant scatter. This is caused by the installation height of more than 20 m. Under such conditions the lower limit for wave measurements with WaMoS is about 1 m.

Fig. 23 shows the directional distribution of the sea state observed by WaMoS II at Hellisøy during the EuroROSE experiment. The waves are mainly approaching from the West. Against it the directional distribution observed at Nordøy (not shown here) shows that the dominant direction is coming from NNW.
Fig. 23
Left: Directional wave distribution measured at Hellisøy. The rings give the percentage of the observed peak wave directions. Right: Directional distribution of the wave height and corresponding peak wave periods. The rings give the significant wave height, the colour coding corresponds to the peak wave directions.

Fig. 24 shows a frequency direction spectrum provided by WaMoS II on March 6th, 2000, 13:34 UTC at Nordøy. At that time the significant wave height increased to 8.2 m. The spectrum shows a distinguished peak at 312° with a peak period of 11.47 s and a wave length of about 204 m. In contrast to the WaMoS II measurement at the same time at Hellisøy (see Fig. 21), the waves at Nordøy are approaching the coast more from the North. Further some energy is also visible in the direction N-NE. This energy is might be due to reflection at the coast.

Fig. 24
Frequency direction spectrum ($F^2(\phi, \Theta)$) obtained by WaMoS II for March 6, 2000, 13:34 UTC at the EuroROSE station Nordøy. The colour coding indicates the spectral wave energy. The rings indicate the wave periods.
### 5.3.2 Installation during the Gijón experiment

During the second EuroROSE experiment carried out in the Gijón area in northern Spain, WaMoS II measurements were taken from October 11\(^{th}\) to December 12\(^{th}\), 2000. Fig. 3 shows the experiment site, with the positions of the WaMoS installations at Cabo Peñas and Cabo de Torres. At Cabo Peñas the antenna was mounted about 60 m above sea level and the wave analysis area was located 1530 m north of the antenna. The radar antenna at Cabo de Torres was mounted about 50 m above sea level and the wave analysis area was located 1370 m northwest of the antenna. Both systems sampled continuously every 2.6 minutes. The single wave measurements were averaged over 20 minutes.

Fig. 25 shows the frequency direction spectrum as provided by WaMoS II on November 8\(^{th}\), 2000, 1:14 UTC at Cabo Peñas. At that time WaMoS II observed a significant wave height of 4.5 m, a peak period of 12.2 s, a peak wave direction of 339° and a peak wave length of 200m. The surface current determined by WaMoS II is 0.8 m/s in NW direction. The direction distribution obtained for Cabo de Torres at about the same time (not shown here), shows a wave system approaching from a more northern direction. This difference in the wave propagation direction indicates a clockwise veering of the waves as they approach the coast.

![Frequency direction spectrum (F^2(\theta)) obtained by WaMoS II at Nov 8, 2000, 1:14 UTC during the EuroROSE experiment at site Cabo Peñas. The color coding indicates the spectral wave energy. The rings indicate the wave periods.](image)

Fig. 26 shows the time series of the 20 minutes mean wave parameters as obtained with WaMoS II at Cabo Peñas (red/yellow dots) and the corresponding parameter obtained by the wave buoy (blue dots). The color coding of the WaMoS II data represents the quality index, where red dots indicate measurements which passed the internal quality control, and yellow dots indicate measurements which did not pass the control. The quality control checks whether the obtain radarbackscatter is sufficient for wave measurements. In the case that the backscatter and/or the modulation due the waves is to low, no reliable wave parameter can be

![Time series of 20 minutes mean wave parameters obtained with WaMoS II at Cabo Peñas.](image)
The measurements which did not pass the quality control are therefore characterised by an unnatural strong scattering in the wave direction.

In general the measurements which pass the quality control show a good agreement for all wave parameter between the two sensors. During the whole experiment about 13 storm events with relatively high wave heights can be identified.

Again WaMoS II measured longer periods than the buoy. Though the WaMoS data is corrected from the influence of the surface current on the wave propagation. This correction can not be made for the buoy data. Also slight deviation have to be presumed as WaMoS II delivered spectral mean values over a time and a space domain, while the buoy give a temporal mean. In addition it has been taken into account that the WaMoS II analysis window and the buoy are located about 7 nm apart. Due to the local topography, the waves change their behaviour such as height, period, length and direction as they approach the coast.

The dominant wave direction at Cabo Torres during the whole experiment was N - NNW. This strengthens the general clockwise veering of the waves as they are approaching the coast.
5.4 Waverider buoy

This section presents the wave buoy measurements obtained during the Fedje experiment. The directional waverider buoy was deployed at a water depth of 280 m about 7 km off the chain of islands in front of the Norwegian coast (see Fig. 1). The distance between buoy location and the WERA stations are 8.9 and 8.0 km, respectively. The directional waverider buoy measures time series of the vertical, as well as the horizontal acceleration. These data allow to determine, in terms of frequency, the spectral density of the wave height, the mean direction and the spreading of the azimuthal distribution. The estimation of the directional parameters relies on the assumption that the angular distribution is narrow. Fig. 28 displays the time series of the significant wave height measured by the waverider during the Fedje field experiment. Fig. 29 displays the time series of the SWH and mean period during a storm in March 2000.
An example of wave data measured by waverider buoy from 5th to 17th March 00; left: significant wave height (cm); right: mean period time (s).

The maximum SHW measured during the Fedje experiment was 11.5 m on 6th March, 22:00 UTC. In general, peak frequencies vary between 0.06 and 0.15 Hz. Higher peak frequencies coincide with low sea states and may be caused by noise. The wave direction varies between 180° and 330°, mostly with a component directed towards the coast. The directional spreading varies between 30° and 50°.

5.5 ADCP

During the Fedje EuroROSE experiment, a conventional bottom mounted upward-looking ADCP was operated from 16th Feb, 19:24 UTC until 13th Apr, 14:32 UTC at the position marked in Fig. 1. The ADCP was installed on the sea floor at a water depth of 65 m. The same instrument was installed during the field experiment in Gijón at a water depth of 50 m at the position marked in Fig. 3. The ADCP deployed in Gijón got lost, therefore only ADCP measurements from the Fedje experiment are presented here.

The chosen ADCP configuration results in a vertical resolution of 4 m. The number of bins was 15 - the centre of the first one was 5.7 m above sea bottom. Due to side-lobe reflections at the sea surface, bins just below the surface may be contaminated. For the configuration used (20° beam angle), the critical depth is 4 m. Thus, only the uppermost bin is affected. However, the estimation of the critical depth relies on a flat surface. Because of the high waves during the experiment, side-lobe reflections may contaminated also deeper bins. In addition, the orbital motion of long waves may perturb the current measurements.
Fig. 30 displays the time series of the horizontal current velocity at three selected depths. The signal of bin 14 at 7.3 m water depth looks very noisy, the same holds for the adjacent bins 15 (3.3 m) and 13 (11.3 m). The north component of bin 12 (15.3 m) shows a clear tidal signal, while noise dominates the east component. Bin 11 (19.3 m) contains less noise similar to the bin 10 (23.3 m) displayed in Fig. 30.

![Fig. 30](image)

Time series of the horizontal current velocity as measured by the ADCP at three different depths: 7.3 m (above), 15.3 m (centre) and 23.3 m (below). The sampling interval is 10 min.

Fig. 31 displays the differences of successive samples of the current velocity. It should be expected that the current is stationary during the short time of 10 min. Thus, the data displayed mainly represents the noise of the measurements. The noise dominates the bins 15 – 13 and partly also bin 12 (east component). There is a period of strong noise from 6th to 7th March which is even visible in the data at the lowermost bin at 59.3 m, i.e. close to the sea floor. In this time the sea state reached its maximum with a significant wave height of 11.5 m. It may be concluded that the contaminations are induced by ocean surface waves. These can also explain the behaviour of bin 12. In general, high ocean waves propagate towards the coast, i.e. the east component of the orbital motion exceeds the north component and causes higher contamination.
Fig. 31
Time series of the difference of successive 10-min samples of the horizontal current velocity as measured by the ADCP at three different depths (from above): 7.3 m, 15.3 m, 23.3 m.

The four beams of the ADCP measure four radial components of the current vector. These are used to compute the three components of the current vector: east, north and vertical, and in addition, a speed error which estimates the reliability of the current vector. By settings a threshold to the error speed of 10 cms\(^{-1}\), less than 1% of the data exceed the bound of the ADCP bins 1, 10.5% of the bin 11, more than 75% of the bins 12 – 14, and 67% of the uppermost bin 15. Thus, in agreement with earlier results, the bins 15 – 12 have to be considered as strongly contaminated. Table 7 summarises some parameters of the ADCP time series. The standard deviations of the two velocity components as function of depth behave differently. While the north component decreases nearly continuously with depth, there is a sudden decrease of the east component between bin 12 and 11. The standard deviations of the velocity differences and the rms values of the speed error confirm the conclusion about the reduced reliability of the upper four bins 15 through 12.

Table 7: Standard deviation of the current velocity components ($\sigma_\text{u}_N$, $\sigma_\text{u}_E$), the difference of successive 10-min samples ($d_N$, $d_E$) and the rms of the error speed (err) of the ADCP time series.

<table>
<thead>
<tr>
<th>bin</th>
<th>depth</th>
<th>$\sigma_\text{u}_N$</th>
<th>$\sigma_\text{u}_E$</th>
<th>$d_N$</th>
<th>$d_E$</th>
<th>err</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>3.3</td>
<td>0.21</td>
<td>0.23</td>
<td>0.18</td>
<td>0.17</td>
<td>0.16</td>
</tr>
<tr>
<td>14</td>
<td>7.3</td>
<td>0.20</td>
<td>0.16</td>
<td>0.14</td>
<td>0.15</td>
<td>0.19</td>
</tr>
<tr>
<td>13</td>
<td>11.3</td>
<td>0.19</td>
<td>0.23</td>
<td>0.13</td>
<td>0.13</td>
<td>0.18</td>
</tr>
<tr>
<td>12</td>
<td>15.3</td>
<td>0.19</td>
<td>0.23</td>
<td>0.09</td>
<td>0.14</td>
<td>0.18</td>
</tr>
<tr>
<td>11</td>
<td>19.3</td>
<td>0.19</td>
<td>0.11</td>
<td>0.07</td>
<td>0.07</td>
<td>0.04</td>
</tr>
<tr>
<td>10</td>
<td>23.3</td>
<td>0.18</td>
<td>0.11</td>
<td>0.06</td>
<td>0.07</td>
<td>0.02</td>
</tr>
<tr>
<td>8</td>
<td>31.3</td>
<td>0.17</td>
<td>0.11</td>
<td>0.05</td>
<td>0.05</td>
<td>0.02</td>
</tr>
<tr>
<td>5</td>
<td>43.3</td>
<td>0.13</td>
<td>0.10</td>
<td>0.04</td>
<td>0.04</td>
<td>0.02</td>
</tr>
<tr>
<td>1</td>
<td>59.3</td>
<td>0.09</td>
<td>0.06</td>
<td>0.04</td>
<td>0.04</td>
<td>0.01</td>
</tr>
</tbody>
</table>
Fig. 32 shows ADCP measurements for five selected bins.

![Fig. 32](image_url)

ADCP measurements from 16th Feb 19:24 UTC to 13th Apr 2000 14:32 UTC. Time marks (+) are given every 240 hours. Data not filtered; black: bin 1, 59.3 m; red: bin 4, 47.3 m; blue: bin 8, 31.3 m; green: bin 11, 19.3 m; yellow: bin 14, 7.3 m.

Table 8: Statistic of ADCP measurements.

<table>
<thead>
<tr>
<th>bin</th>
<th>depth (m)</th>
<th>u-mean (cm/s)</th>
<th>v-mean (cm/s)</th>
<th>w-mean (cm/s)</th>
<th>error (cm/s)</th>
<th>mag (cm/s)</th>
<th>speed (cm/s)</th>
<th>dir (deg)</th>
<th>good (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>3.3</td>
<td>-8.9</td>
<td>6.3</td>
<td>-3.9</td>
<td>4.2</td>
<td>27.5</td>
<td>10.9</td>
<td>305.3</td>
<td>76.1</td>
</tr>
<tr>
<td>14</td>
<td>7.3</td>
<td>0.6</td>
<td>7.6</td>
<td>-1.3</td>
<td>0.8</td>
<td>22.8</td>
<td>7.6</td>
<td>4.2</td>
<td>80.9</td>
</tr>
<tr>
<td>13</td>
<td>11.3</td>
<td>-1.1</td>
<td>13.0</td>
<td>-0.4</td>
<td>-3.8</td>
<td>27.9</td>
<td>13.1</td>
<td>355.1</td>
<td>77.8</td>
</tr>
<tr>
<td>12</td>
<td>15.3</td>
<td>3.4</td>
<td>15.9</td>
<td>0.7</td>
<td>-2.2</td>
<td>31.0</td>
<td>16.3</td>
<td>12.0</td>
<td>93.3</td>
</tr>
<tr>
<td>11</td>
<td>19.3</td>
<td>0.7</td>
<td>16.0</td>
<td>0.1</td>
<td>-0.1</td>
<td>22.5</td>
<td>16.0</td>
<td>2.4</td>
<td>98.7</td>
</tr>
<tr>
<td>10</td>
<td>23.3</td>
<td>0.6</td>
<td>15.0</td>
<td>0.2</td>
<td>0.1</td>
<td>21.9</td>
<td>15.0</td>
<td>2.2</td>
<td>99.5</td>
</tr>
<tr>
<td>9</td>
<td>27.3</td>
<td>0.2</td>
<td>14.3</td>
<td>-0.2</td>
<td>0.1</td>
<td>21.1</td>
<td>14.3</td>
<td>1.0</td>
<td>99.8</td>
</tr>
<tr>
<td>8</td>
<td>31.3</td>
<td>-0.5</td>
<td>13.3</td>
<td>-0.3</td>
<td>0.0</td>
<td>20.0</td>
<td>13.4</td>
<td>357.9</td>
<td>99.9</td>
</tr>
<tr>
<td>7</td>
<td>35.3</td>
<td>-0.7</td>
<td>12.7</td>
<td>-0.3</td>
<td>0.1</td>
<td>19.3</td>
<td>12.7</td>
<td>356.8</td>
<td>99.9</td>
</tr>
<tr>
<td>6</td>
<td>39.3</td>
<td>-1.1</td>
<td>11.9</td>
<td>-0.3</td>
<td>0.0</td>
<td>18.3</td>
<td>11.9</td>
<td>355.0</td>
<td>100.0</td>
</tr>
<tr>
<td>5</td>
<td>43.3</td>
<td>-1.7</td>
<td>10.7</td>
<td>-0.4</td>
<td>0.0</td>
<td>17.0</td>
<td>11.9</td>
<td>350.8</td>
<td>100.0</td>
</tr>
<tr>
<td>4</td>
<td>47.3</td>
<td>-1.9</td>
<td>9.8</td>
<td>-0.4</td>
<td>0.1</td>
<td>15.9</td>
<td>9.9</td>
<td>349.0</td>
<td>100.0</td>
</tr>
<tr>
<td>3</td>
<td>51.3</td>
<td>-2.4</td>
<td>7.5</td>
<td>-0.4</td>
<td>-0.5</td>
<td>13.9</td>
<td>7.9</td>
<td>342.8</td>
<td>100.0</td>
</tr>
<tr>
<td>2</td>
<td>55.3</td>
<td>-3.0</td>
<td>5.9</td>
<td>-0.5</td>
<td>-0.2</td>
<td>11.7</td>
<td>6.6</td>
<td>333.4</td>
<td>100.0</td>
</tr>
<tr>
<td>1</td>
<td>59.3</td>
<td>-3.3</td>
<td>4.2</td>
<td>-0.7</td>
<td>-0.1</td>
<td>9.4</td>
<td>5.4</td>
<td>321.9</td>
<td>100.0</td>
</tr>
</tbody>
</table>

During six days in February 2000, research vessel "Håkon Mossby" operated in the experimental area and performed current measurements with the ship-borne ADCP. The center of the uppermost depth level was at 13 m below the sea surface. This depth is within
the mixed layer. Hence the current change towards the surface due to stratification is negligible. In the area of Fig. 33 19,534 current measurements are available, 214 of them could be collocated with WERA-measurements. The WERA data have been taken from the closest time and grid point. The maximum time difference is 20 min and the location of the ship measurement is always within the averaging area of the WERA grid point.

The standard deviations of the ship ADCP current velocities are 21 cms$^{-1}$ ($u$) and 31 cms$^{-1}$ ($v$), and those of the WERA current velocities: 22 cms$^{-1}$ ($u$) and 41 cms$^{-1}$ ($v$). As expected, the north component $v$ undergoes stronger variations than the east component $u$, and the surface current stronger variations than the subsurface current at the depth of 13 m. The rms-differences between ADCP and WERA current velocities are: 13 cms$^{-1}$ ($u$) and 19 cms$^{-1}$ ($v$). These results agree well with the comparison of the WERA measurements with those of the bottom-mounted ADCP. The vector correlation yields a coefficient of 0.7 and a slight veering of 8° of the surface current relative to the subsurface current.

![Fig. 33](image-url)

Current velocities measured by the ship-borne ADCP mounted on the research vessel "Håkon Mossby" (University of Bergen). The depth level is 13 m. The measurements date from the period between February 16th and February 23rd 2000.
5.6 Airborne InSAR experiment

The airborne InSAR experiment was carried out in the Gijón area on November 9th, 2000, from 10:00 to 14:00 and from 15:00 to 17:00 separately. The areas mapped by InSAR are shown in Fig. 34. They are denoted by A, B, ..., E (black rectangles). Area A is performed for InSAR calibration. Area B is located at the position of a directional buoy deployed at 43°36.89'N, 5°40.44'W. Area C is located in the centre of the EuroROSE measurement area to allow optimal comparisons with the Model and HF data. Areas D and E are inside of the WaMoS measurement areas.

1. At location A, the airborne InSAR was flown at one track
2. At locations B and E, the airborne InSAR was flown along four tracks. The azimuth angle between two neighbouring tracks was 45 degree.
3. At location C, the airborne InSAR was flown along five tracks.
4. At location D, the airborne InSAR was flown along two perpendicular tracks

The total length of tracks is 90 km, which is allocated as following:

Table 9: The length of tracks

<table>
<thead>
<tr>
<th>Location</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>H:3000m</td>
<td>2km</td>
<td>3km*4</td>
<td>8km<em>2+6km</em>3</td>
<td>3km*2</td>
<td>3km*4</td>
</tr>
<tr>
<td>H:1500m</td>
<td></td>
<td>3km*4</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Fig. 34
Airborne interferometric SAR mapping areas and flight directions. A, B, ...E denote the location of InSAR mapping areas. The rectangular boxes represent the areas covered by InSAR images, and arrows denote the airplane flight direction. HF radar at location E and D measurement covers two fan shaped areas. At locations B there is a directional buoy. Moreover, at location B and E, airplane flies at height of 1500m and 3000m, respectively.
Table 10: The location of the centre of A, B, C, D, and E

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lat</td>
<td>43°33.65 N</td>
<td>43°36.89 N</td>
<td>43°40.0N</td>
<td>43°35.16N</td>
<td>43°40.31N</td>
</tr>
<tr>
<td>Long</td>
<td>5°44.52W</td>
<td>5°40.44W</td>
<td>5°40.0W</td>
<td>5°42.03W</td>
<td>5°50.60W</td>
</tr>
</tbody>
</table>

At locations A, C, and D the airborne InSAR was flown at 3000 m. At locations B and E, it was flown at both 1500m and 3000m height. The flight patterns are shown in Fig. 34.

Fig. 35 shows the mapped areas (2 tracks) by airborne InSAR. Those two tracks are perpendicular. The heading angles of track 1 and track 2 are 164.85 degree and 253.49 degree with respect to north, respectively. Fig. 36 shows the SAR amplitude image and the InSAR phase image generated by two complex images obtained from two antennas along the flight direction. The calculated image spectra for amplitude image and for InSAR phase image are shown in Fig. 37. It can be seen that the dominant spectral peak in the SAR image spectrum is located at the same position (at azimuth direction) as in the InSAR phase image spectrum. The dominant ocean wave propagates nearly along the flight direction. This means that the dominant ocean wave propagates from NW to SE. There is a weak spectral peak near range direction. The peak wave length is about 30 m and propagation direction is about 92 degree with respect to the north. This short waves are probably wind waves. It needs to be checked further by using wind field data. However, we estimate the wind direction from wind streaks in ERS-2 SAR image (Fig. 35), and find that the wind direction is about 75 degree with respect to the north. The SAR amplitude image and InSAR phase image for track 2 (not presented here) shown that the dominant ocean wave propagates across the flight direction. When the azimuth wave number increases, SAR image spectrum decreases more quickly than InSAR phase image spectrum. This phenomena is observed in both tracks (see Fig. 37). This is due to the fact that the InSAR phase image has higher signal to noise ratio than SAR image, thus, the weak spectral intensities above the noise level in azimuth direction can be seen in InSAR phase image spectrum.

In track 2 the dominant ocean wave propagates in near range direction, thus, we can estimate the ocean wave spectrum from the InSAR phase image spectrum by using quasi-linear ocean wave - InSAR spectral transform. The result is shown in Fig. 38. Comparing with the ocean wave spectrum measured by WaMOS at Gijón coast (Cabo Peñas), we find that the dominant ocean wave length and propagation direction calculated from InSAR phase image spectrum are in agreement on those measured by WaMoS. But the significant wave height is over estimated in the InSAR phase image spectrum. The reason is under studying.

Table 11: Parameters of the dominant ocean wave

<table>
<thead>
<tr>
<th></th>
<th>Hs</th>
<th>λ</th>
<th>φ</th>
</tr>
</thead>
<tbody>
<tr>
<td>InSAR</td>
<td>3.32 m</td>
<td>151.8 m</td>
<td>155</td>
</tr>
<tr>
<td>WaMoS</td>
<td>2.38 m</td>
<td>144.0 m</td>
<td>162</td>
</tr>
</tbody>
</table>

Hs: Significant wave height (m); λ: Peak wave length (m); φ: Peak propagation direction with respect to north (degree)

The InSAR measured ocean wave and current field have been made available to the EuroROSE databank.
Fig. 35
ERS-2 SAR image acquired on Nov. 9th 2000 at 11:08 (UTC) over Gijón coast. The SAR image shows an overview of experiment area. The location of two tracks are plotted here. The red arrow denotes the flight direction.
Fig. 36
The SAR amplitude image and InSAR phase image for track 1 where the dominate ocean wave propagates near the flight direction.
For track 1 (a) SAR amplitude image (512 * 512 pixels); (b) InSAR phase image (512 * 512 pixels); (c) SAR amplitude image spectrum; (d) InSAR phase image spectrum.
6. User Interface

All the measured data and the model results including a 6-hour forecast were on-line presented to the traffic officers and pilots at both Fedje and Gijón VTS Centre by a User Interface. This part was developed by the port authority Puertos del Estado, Clima Maritimo in Spain. 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 forecast. 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-user, e.g. traffic officers and pilots at VTS.

Following figures show some Screen Shots of the graphics shown by the User Interface at Fedje and Gijón VTS.
Fig. 39
Left: a current map measured by WERA (note the jet near to the island and an Eddie further out; right: a map produced by the current model (note the extended range compared to the WERA measurements).

Fig. 40
Left: a map of significant wave height and wave direction calculated from WERA data by the University of Sheffield; right: a map of significant wave height produced by the wave model WAM (note the extended range compared to the WERA measurements).

Fig. 41
Left: the time series of the significant wave height in front of Cabo Peñas during a period from Oct 15th, 3:54 UTC to Oct 17th, 15:14 UTC 2000; right: directional wave spectrum measured by WaMoS II at Cabo Peñas on Nov 3rd 2000, 15:14 UTC.
7. Data communication scheme

The data communication scheme between the components of the EuroROSE system is shown in Fig. 42. The structure is nearly identical for the two experiments. The Fedje and Gijón VTS stations have a local area network installed to handle the data transfer from the WERA and WaMoS II 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 VTS office. For long-distance data transfers, i.e. from Spain to Norway or Germany, the Internet is used. To protect the radar data and software, and the VTS from unauthorized access and data manipulation, a scheme of firewalls and IP-Masquerading has been applied.

Fig. 42
The data communication set-up used during the EuroROSE Gijón experiment. Firewalls protect sensitive system components from 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 and data assimilation system,
- from the Super Computer in Trondheim providing operational forecasts to the high-resolution model and data assimilation system,
- from the high-resolution model and data assimilation system to the User Interface in the VTS
- from the VTS to the EuroROSE Web Server at the University of Hamburg for public access to the on-line data

Although the system is 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 arrange the data paths. Tha data formats used for the communications 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.
8. The EuroROSE Database

The main objective of the EuroROSE database was to collect available radar-based data for ocean currents and wave spectra from past and ongoing surveys and to compile the data into a common database, which can easily be accessed by all project partners through a WWW server. The WWW access was restricted to the project partners by a username/password mechanism. Data sets put to a FTP server by the EuroROSE partners have been processed by IfM and thereafter put into the database.

A key component for communication between the EuroROSE partners was the Internet. Internet access is available nearly everywhere world-wide and could also be established at the EuroROSE experiment sites. The most important protocols used in this context were HTTP together with SSL for data protection and encryption used by the World Wide Web and FTP used for file transfer.

Two ways to put data sets into the database have been used. The data have been transferred to the FTP server or they have been read from tape or CD-ROM at IfM locally. To ensure the data were not corrupted during the transfer on the Internet, the files have been packed by a utility "ZIP". In this way checksums were added and the file size was decreased. In case of data corruption, unpacking the compressed file shows an error and the data transfer could be repeated.

The data sets were then converted to an ASCII data format, which has been agreed between EuroROSE partners for data exchange, e.g. between the measurement instruments (HF-Radar, WaMoS) and the data assimilation system of the models. The data sets could be accessed via a WWW server. To simplify data transfer of large data sets, the HF-Radar data have been "Zipped" on a per-day basis. To help navigating through the database, a HTML-based menu for the file selection has been set up. Selected data sets were used to calculated the error statistics of the HF-Radar surface current measurements.

9. Conclusions

The both EuroROSE field experiments have proven that the EuroROSE concept is feasible and very helpfull for potential users such as VTS operators, harbour and coastal managment or marine environmental protection organisations.

HF and X-band radar have demonstrated their potential in operational coastal oceanographic monitoring. The combination with numerical models generates detailed information about the sea-state, which never can be achieved by a conventional oceanographic data collection system. The model and data assimilation system have been proven to be run in real-time and supply now- and forecasts. Displaying the sea-state information in maps has proven to be very helpful to the VTS operators and the ship pilots, e.g. to ensure save passage to the narrow entrance channel supervised by the Fedje VTS.

The choice of the shown sea-state parameter and the layout of the display (User Interface) were discussed in detail with the end-users before and during the experiment. This guaranteed that they accepted the operational products from the first day on.
Acknowledgement

This work was partly founded by the European Commission within the EuroROSE project, contract number MAS3-CT98-0168. We are grateful to all the organisations and people involved in the field work in Fedje and Gijón. We wish to thank the crew of "Håkon Mossby" for the preparation and great involvement during the ship campaign in the Fedje area.

References


List of figures

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