RADAR SURVEY OF NEAR SHORE BATHYMETRY WITHIN THE OROMA PROJECT

Friedwart Ziemer[1], Carsten Brockmann[2], Robin A. Vaughan[3], Jörg Seemann[4] and Christian M. Senet[4]

1. GKSS Research Centre Geesthacht, Institute for Coastal Research, D-21502 Geesthacht, Germany; ziemer(at)gkss.de
2. Brockmann-Consult, D-21502 Geesthacht, Germany; brockmann(at)brockmann-consult.de
3. University of Dundee, Dundee, DD1 4HN, UK; r.a.vaughan(at)dundee.ac.uk
4. V2T VISION TO TECHNOLOGY GmbH, D-21502 Geesthacht, Germany; seemann(at)v2t.de

ABSTRACT

Preliminary results from the OROMA project (Operational Radar and Optical Mapping in monitoring hydrodynamic, morphodynamic, and environmental parameters for coastal management) are presented in this paper. The aim of the project is to conduct experimental monitoring to increase the effectiveness of technologies in coastal regions to meet with end-user requirements. The project integrates data from mobile ground/ship radar systems, SAR and optical satellite data and ground truth and uses inverse modelling to assess the coastal status. Thematic maps will be produced, which will be presented in near-real-time on a geo-coded grid to be distributed via electronic networks for quick access by managers.

The paper gives an overview on the flow of information within the project and gives an example on one of the methods used, which is the inverse modelling of radar observations, to measure bathymetry.

Keywords: Morphodynamics, monitoring, bathymetric radar survey

INTRODUCTION

Four test sites, the Western Schelt, the Maars Deep (both NL), the Gulf of Gdanks (PL), and the Lister Tief (G) are being studied. Optical remote sensing and in situ measurements in the Western Schelt and Wadden Zee in the Netherlands are intended to monitor the health of the deep water shipping lanes. Ongoing channel and port developments increase the necessity for a continuous monitoring of suspended sediment, chlorophyll-a and pollution hazards. These techniques are also being used in the southern Baltic to study the erosion and deposition of sediment along the coast at Gdansk, and the erosion of the Hel peninsula. For the Gulf of Gdansk test site, interest is specifically targeted on the operational monitoring of the changing nature of the Vistula outlet. Changing positions and depths of a shoaling sand produce unpredictable backup flooding due to winter ice congestion.

The project involves scientists from Germany, UK, The Netherlands and Poland as well as end-users from these countries. To meet the objective to deliver information to the coastal management, the data are transformed from the raw product to the visualised information. Different monitoring techniques, instruments and algorithms are combined, to adapt the flow of information for the specific parameter of interest. Data fusion, data assimilation and inverse modelling techniques will provide "raw information" mapped into one grid. The maps produced to study the interacting processes will be interpreted by experts and will be provided using GIS.

Airborne optical data (1), MERIS, SeaWiFS and AVHRR satellite data are all being used with the aim of meeting end-user requirements for the thematic mapping of suspended sediment and algae. Particular problems to be examined here include modelling the impact of non-water pixels and shallow water as well as uncertainties in atmospheric correction.

Ship and ground-based radar measurements are being conducted in the Lister Tief (Germany) to map the normalised radar cross-section (NRCS) and its modulation by waves and currents (2). From these maps, the actual bathymetry of the sandy sea floor will be derived by inverse modelling (3,4). During the three years of the project, repeated mapping of the NRCS will produce a time series of bathymetric maps which will help to estimate the eroding forces. This work will be supplemented by SAR from ERS and ENVISAT (3), and airborne optical measurements from the Variable Interference Filter Imaging Spectrometer (VIFIS). The problem being studied is the transport of sand around the northern coast of the island of Sylt. The inverse modelling technique will be further developed to produce the bathymetry from data acquired by airborne and satellite radars. The example shows a land-based system to acquire maps under the special condition of low grazing angles (5,6).

FLOW OF INFORMATION

Near coastal morphodynamics, being of high natural variability, requires to be monitored by coastal managers in order to preserve the environment. For this, the authority has to manage permanent human intervention such as dredging, beach nourishment, jetty construction or other coastal protection measures. To optimise these actions actual thematic information is needed in order to assess the status and possible risks within the environment of the coastal zone. This is necessary for the security in shipping to minimise the risk of accidents. Biological factors need to be surveyed as oil pollution does, which has a negative impact on the natural and recreational value of the area and which endangers the use of coastal waters as a food supply area.

Therefore, the objective of OROMA is to present the necessary information on the actual status of the coastal bathymetry, on hydrology, and on some important biological factors such as chlorophyll *a*. OROMA is developing innovative tools for mapping and presenting the processes of interest over large areas in near-real time. The OROMA team, consisting of 6 developers and 4 end users (from coastal management), is pursuing the problem of converting scientific knowledge into actual thematic information to be distributed via electronic network.

Cost effectiveness is achieved by a structure within the flow of information, which opens the possibility to make observations on different temporal and spatial scales, and which are well adapted to the process. This may include episodic observations, which may be triggered by the management or released by natural events such as storms or accidents due to human activities.

The backbone of the OROMA project is the flow of information. The chart in Figure 1 illustrates how data from different sources will be linked to produce information. The integration of experts' work will result in thematic interpretation presented to the responsible coastal management. Focussing to the level of problems the instruments at level of tools are combined to achieve an effective monitoring. Raw data by radar-, optical- and *in situ* instruments are acquired and quality checked. OROMA will adapt the instruments and algorithms to the specific parameter of interest. Within the level of interface raw data from different tools will be combined by data fusion, assimilation, and inverse modelling techniques. Here data from different sources, including most recent scientific innovations together with well-approved techniques, will be mapped into one grid and forwarded to the level of interpretation. Within this level, thematic information will be exchanged among experts and the interacting processes will be studied.

The level of presentation is more than presenting paper reports giving an overview on the discussed problem on a statistical basis or giving a status report. This project includes the presentation of an operational continuous quality checked updating of all monitored parameters. Using GIS methods the results will be "mapped" into a geo-coded grid and distributed using information technologies to make actual updates accessible to the management as fast as possible.

AN EXAMPLE OF INVERSE MODELLING

The radar can be used to image the surface gravity wave field. It is assumed that the modulation of radar signals by waves follows roughly the same physical behaviour as the wave field itself. Thus we discuss the wave physics to explain the set up of the inverse model. The dispersion for long gravity waves approaching the coast is completely described by:

$$\omega = \sqrt{gk \tanh(kh)} + (\vec{u} \cdot \vec{k}). \qquad (1)$$

In this equation $\omega = 2\pi/\tau$ is the frequency of the wave with the period τ and $k = 2\pi/\lambda$ is the wavenumber of the wave with length λ. The earth acceleration *g* defines the balancing force of the disturbed sea surface. The factor tanh*(kh)* is the correction term for shallow water condition, where *h* is the local water depth (see Figure 2). The term under the square root is isotropic, that means the frequency is independent of the wave propagation direction, which is defined by the wave-number-vector $\vec{k} = (k_x, k_y)$ with the modulus $k = \sqrt{k_x^2 + k_y^2}$.

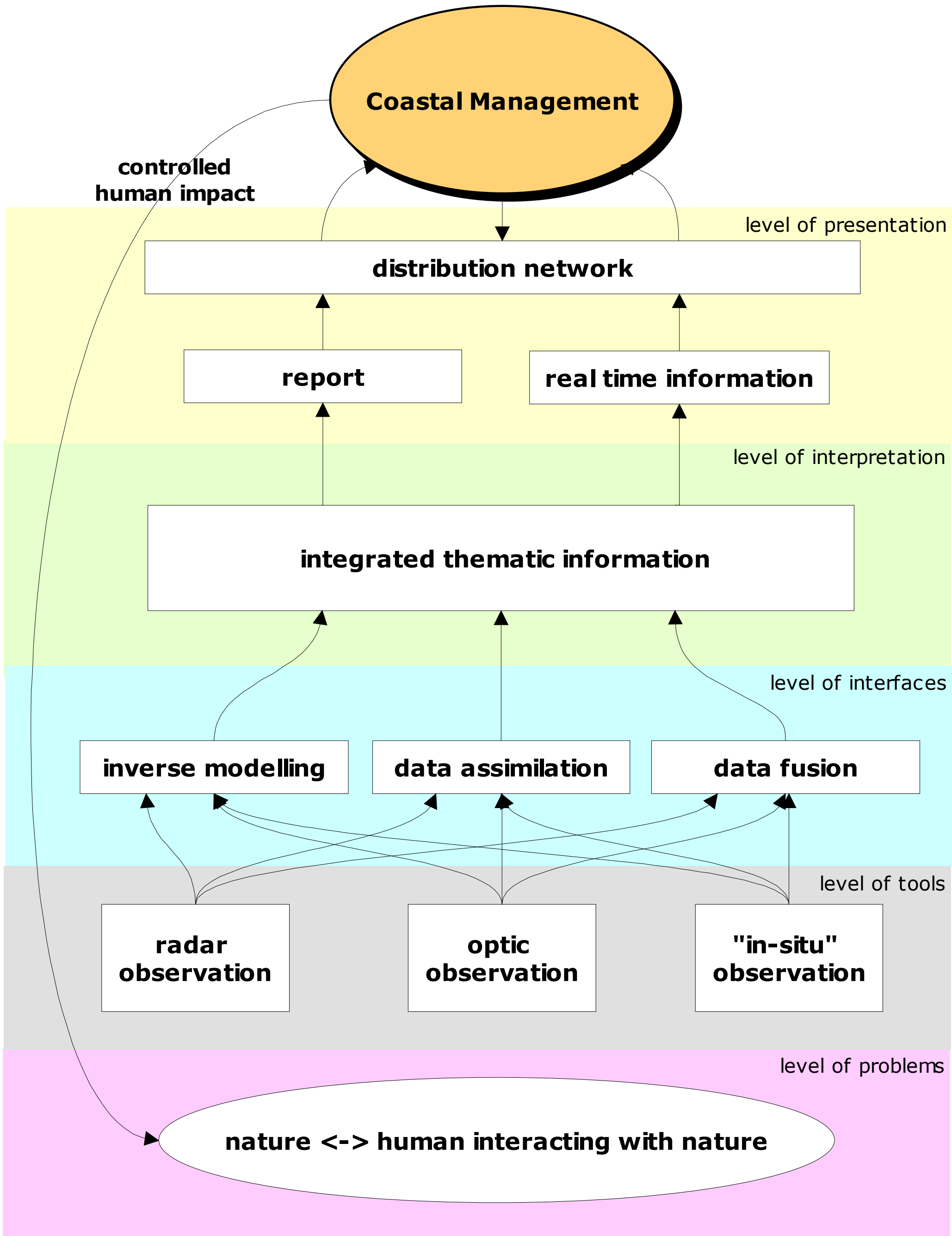

Figure 1: OROMA flow chart. The coastal management controls the human impact on the base of the information provided from the presentation level of OROMA.

The situation is different under the influence of an underlying current, which has a directionality itself: $\vec{u} = (u_x, u_y)$. The dot product on the right side of (1) contains the directional dependency on the angle of encounter *φ* between the two vectors $\vec{k}$ and $\vec{u}$. The frequency shift is biggest by opposing or with-going current and wave-number, while there is no shifting effect if the vectors point perpendicular to each other. For intermediate angles of encounter *φ* the frequency shift depends on cos (*φ*).

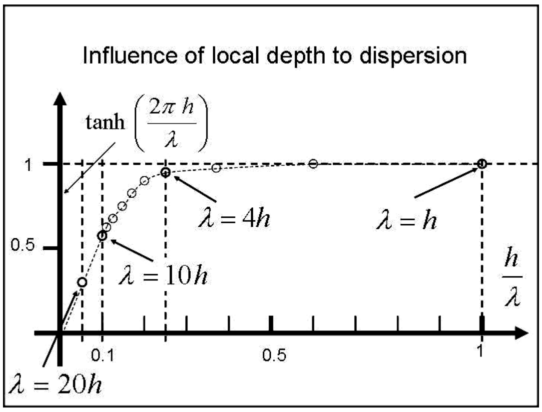

Figure 2: The graph gives the value of the depth-dependent correction parameter tanh(kh) under the root of Eq. (1). Within the "deep water range" (the wave length is shorter than $\lambda = 4h$) this term only deviates little from "1". The "transient depth range" lies within [$\lambda = 4h, \lambda = 20h$]. Here the most noticeable change is to be seen. Waves with lengths longer than $\lambda \approx 20\,h$ are "shallow water waves"; with $\omega = \sqrt{gh}\,k$.

The sea surface gravity wave field is imaged by a radar instrument mounted onshore close to the coast (see Figure 3). During each rotation of the radar antenna the sea clutter, which is the radar return induced by the rough sea surface, is acquired. Within this radar return the long wave field modulates the backscatter conditions. Thus, the radar return images the sea surface gravity wave field. It is assumed that the impact on wave dispersion by the local current and the local water depth is transferred to each radar image. For the study discussed in this section, observations are acquired during 256 antenna rotations representing the surface gravity wave field approaching the coast. The observation covers a time period of approximately 10 minutes and a spatial area of 4 km x 4 km (see Figure 2.2 on the right). The wave propagation within this box varies locally due to the variations of the bathymetry.

The algorithm DiSC (Dispersive Surface Classifier) is based on the relation (1). The algorithm inverts the information inherent in the three-dimensional spectrum of the gravity wave field on the basis of the time – spatial radar observation (7,8). The gravity wave dispersion steered by the local water depth and the local current vector can be used to calculate the local information on the steering parameter. The algorithm detects the shifts of frequencies and wave numbers of each gravity wave component to compose a spatial matrix of these steering parameters.

The site "Lister Tief", where the DiSC algorithm is applied, is shown on the left of Figure 3. In addition, one clutter image out of a series of 256 images is shown. This clutter demonstrates the refraction impacting on the propagation of waves over the bathymetry. The local change of the wave travel direction and the wave length can be seen within this image. Comparing the wave lengths in the right image with the water depths in the nautical chart shows long waves over deep water and shorter over the shallow water.

A result produced by DiSC applied to a ten-minute radar observation at the test site "Lister Tief" is shown in Figure 4. For each grid cell the results for the water depth are given in a colour code. As this article is written at the beginning of the project, this is the first result within a row of planned observations. Thus, we cannot show a change in the bathymetry as yet. This will be provided later on in the course of the project.

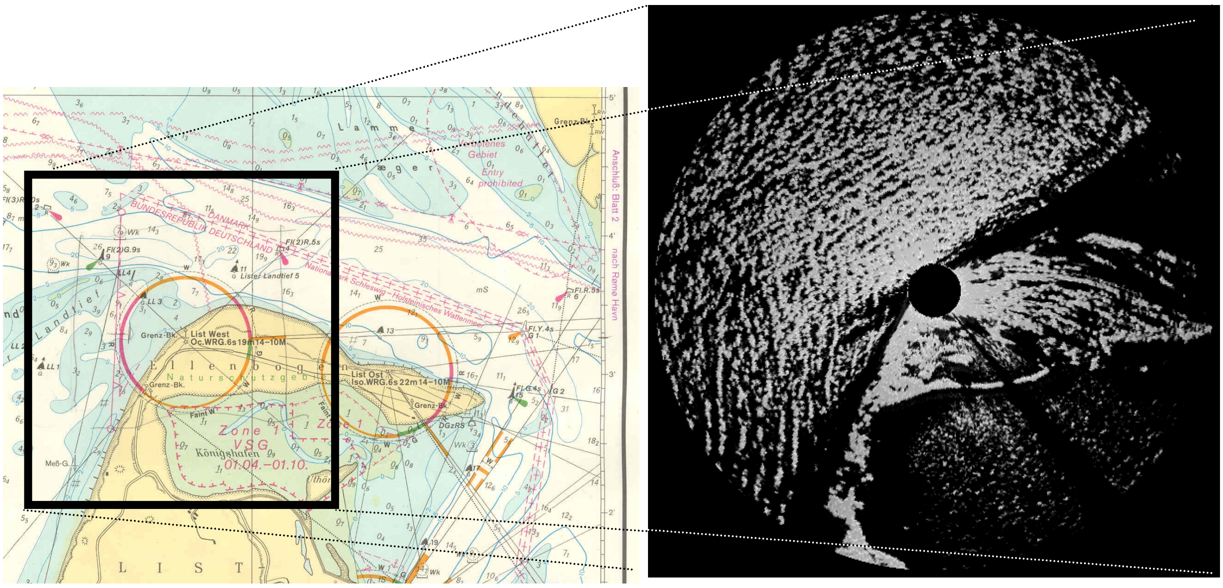

Figure 3: Left: Nautical map (source: BSH) of the "Lister Tief" area. The frame on the chart marks the area surveyed by the method DiSC. The radar is mounted close to the light house „List West", which lies in the centre of the square. Right: A single sea clutter image of a series of 256 radar images. The acquisition time of this image corresponds to one rotation period of the antenna, which is 2 s. The total acquisition time is 8.5 minutes. The black circle in the centre marks the position of the radar.

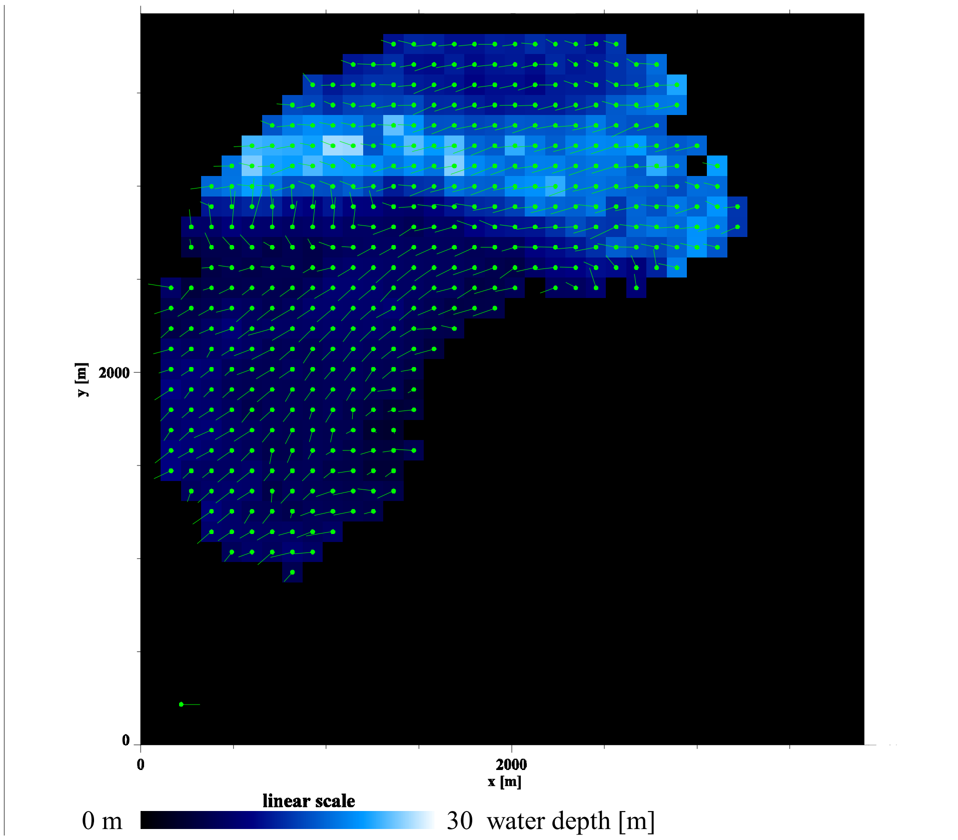

Figure 4: Results produced by DiSC applied to a ten-minute radar observation of the test site "List". The grid point distance is 100 m. The colour code gives the average water depth within the grid cell and the vectors correspond to the mean local current vector. The data acquisition time was 3 hours after high tide. During this phase the tidal basin east of the observation area was emptying. The local variations within the current field are due to the guidance by the bathymetry. Grid cells which show no results have been left blank when the algorithm did not find satisfactory significance.

The current vectors are valid at the position marked by the dots, which is the central position of the grid cells; the pointer gives the direction. At the time of data acquisition, 3 hours after high tide, the tidal basin east of the observation area is emptying with full tidal current. The local variations within the current field are due to the guidance by the bathymetry (compare Figure 2). Grid cells which show no results have been left blank when the algorithm did not find satisfactory significance.

The scatter diagram (Figure 5) shows the comparison between radar-deduced water depths and echo sounding depths. The number of wave components locally usable for the analysis varies from grid point to grid point. A high number means a high significance of the deduced parameter; a low number means a low significance. To indicate this significance, the number of partial wave components used for the estimation is indicated by the colours of the dots. For a water depth of less than 10 m the results show a small scatter indicating that the inversion was working properly. This example shows that on deeper water the spectrum of the observed wave field contains fewer components with lengths shorter than $\lambda \le h/4$.

The right part of the graph in Figure 2 shows that for shorter wave lengths the shallow water dispersion reaches the value 1 asymptotically. Here the inverse model finds less information and the deviation between radar and echo depth increases as seen in Figure 5. This demonstrates that the threshold of usability of this method depends on the imaged wave components. Conversely, the longer the wave components within the observed wave field are the better are the results for deeper cells.

The next step, which is not discussed in this paper, is to transfer the results into a geo-coded map and to visualise it for an end user. The map will allow to overlap this information with other data and to make changes between succeeding observations visible. As the radar delivers the raw data within 10 minutes and the analysis time is approximately one hour, the results may be delivered to the user within a couple of hours.

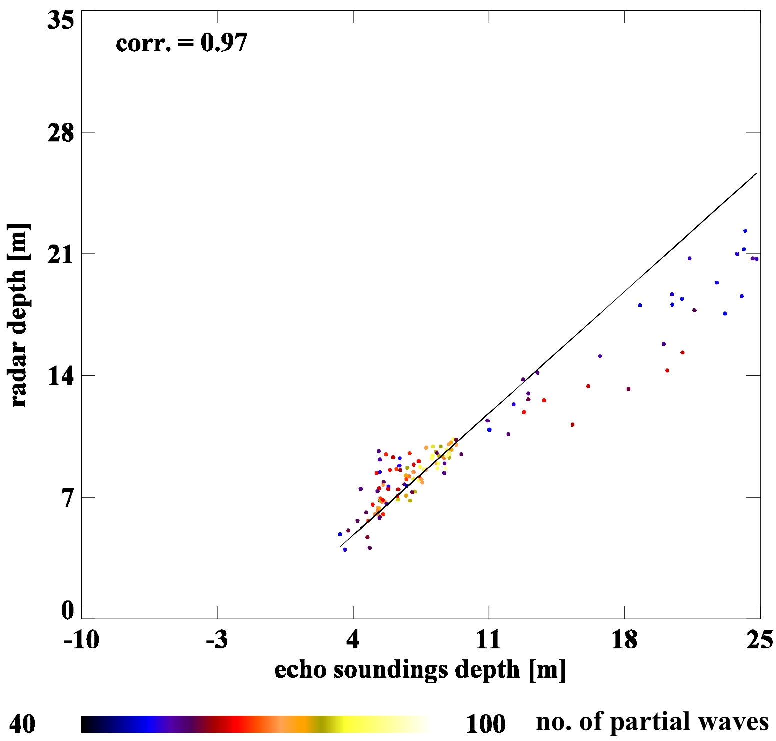

Figure 5: Scatter diagram produced by the comparison between radar-deduced water depths with echo sounding depths. The dot's colours qualify the radar depth by representing the number of partial wave components used for the estimate. The deviation for deeper water cases is due to the asymptotic character of the dispersion for increasing values of λ/h (see Figure 2).

CONCLUSIONS

The example discussed in the paper represents the observation of one single time step, which is the first of a series of planned observations. The next observation will provide the possibility to deduce the change within the bathymetry. This method has the potential to visualize the result in near real time allowing to overlap the information with other data and to make changes between succeeding observations visible. In general radar instruments as well as optical devices deliver observations on a large and medium spatial scale within a relatively short data acquisition time. Thus the information provided to the end users via an electronic network will be the most up-to-date. On the basis of actual data the momentary status of the process of interest can be assessed much more effectively than by means of any method used so far.

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