COSYNA: Improving regional forecasting capabilities for the German Bight

J. Schulz-Stellenfleth, S. Grayek, J. Staneva, H. Günther, W. Petersen, E. Stanev
Institute for Coastal Research, GKSS Research Centre, Max-Planck-Str. 1, 21502 Geesthacht, Germany
Contact: emil.stanev@gkss.de, Tel: +49 (0)4152 87 1597

Introduction

The presented study is part of the COSYNA (Coastal Observation System for Northern and Arctic Seas) project. The objective of COSYNA is to enable a long-term observational network for the southern North Sea and Arctic coastal waters, which will be linked to pre-operational models for scientific and management purposes.
An overview is given of COSYNA related activities at the GKSS Research Centre with a focus on data analysis and numerical modeling. The following components play a major role in the improvement of the forecasting capabilities for the North Sea:

- Downscaling
- Use of new COSYNA observations, e.g., FerryBox
- Inclusion of additional parameters and components in the forecast models (e.g., ocean wave current coupling)
- Assimilation

First results were obtained concerning each of these issues. For example numerical circulation models and ocean wave models were used in combination with optical satellite data to estimate suspended particulate matter (SPM) concentrations in the North Sea (Dobrynin et al., 2008). A detailed study on the impact of currents and waves on sediment transport processes was carried out for the East-Frisian Wadden Sea using a nested model approach (Staneva et al., 2008).
As a preparation for the assimilation of FerryBox data a new method to re-construct SST and SSS fields from measurements acquired by ferry ships was developed (Grayek et al., 2009). Furthermore first steps towards the assimilation of water level data into the circulation model GETM using a Singular Evolutive Interpolated Kalman filter (SEIK) were taken.
Finally a study on the assessment of observational networks in the German Bight was carried out (Schulz-Stellenfleth and Stanev, 2009). This method allows to compare different instrumentation scenarios and can be used as a basis for the optimisation of network configurations.

Model Setup

The focus of the present work is on the German Bight. The German Bight is part of the North Sea, which is dominated by tides with a typical tidal range of 2-4 m and a dominant period of 12.4 hrs. The largest non-tidal variations are caused by atmospheric low pressure systems, either as external surges from the North Atlantic or internally generated surges. The German Bight is furthermore characterised by very shallow water with Wadden Sea areas falling dry during low tide. The 3-D numerical model GETM (Burchard and Bolding, 2002) was used to simulate the hydrodynamical processes in the German Bight. GETM is a primitive equation model, in which the equations for the three velocity components and sea surface height, as well as the equations for turbulent kinetic energy and the eddy dissipation rate are solved. The application of the model to the area of our study is described in (Staneva et al., 2008). The model is run on a spherical grid with 1 km resolution. Terrain following equidistant coordinates (sigma-coordinates) are used for the vertical dimension. The water column is discretised into 21 nonintersecting layers. The model was coupled with a sediment transport model, which is based on a standard diffusion-advection equation for suspended sediment concentrations. The nested-grid model consists of three model configurations: a coarse-resolution North Sea-Baltic Sea (about 5 km) outer model, a fine-resolution (about 0.8 km) inner model covering the German Bight, and a very fine-resolution (about 200 m) model for the Wadden Sea region resolving the barrier

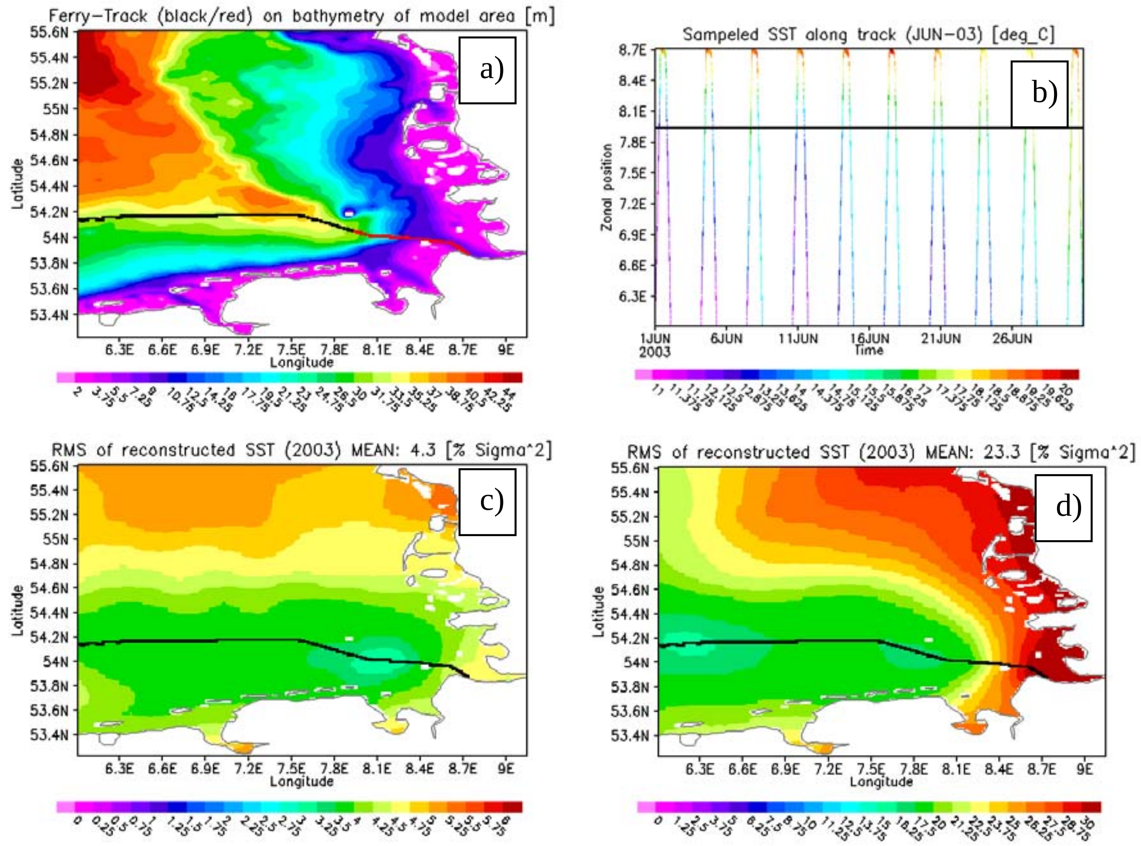

Fig 1: a) Track of the ferry „TorDania“ operating between Cuxhaven and Immingham. b) Along track SST ship measurements for June 2003. c),d): Relative re-construction errors using simulated measurements c) and real FerryBox data d).

islands and the tidal flats. The model is forced by 1) atmospheric fluxes estimated by the bulk formula using 6-hourly ECMWF re-analysis data (wind, atmospheric temperature, relative humidity and cloud cover) and simulated by the model SST, 2) hourly river run-off data provided by the Bundesamt für Seeschiffahrt und Hydrographie (BSH), and time varying lateral boundary conditions of sea surface elevations and salinity. The sea surface elevations of the open boundary are generated using simulated data from a larger-scale model for the North Sea and Baltic Sea with coarser resolution (about 5 km). This model uses the same computational code (GETM). The sea surface elevation at the open boundary for the North Sea-Baltic Sea model is generated using tidal constituents. Temperature and salinity at the open boundary are interpolated from monthly mean climatological data.

A new method to estimate SST and SSS fields from FerryBox data

Within the GOOS (Global Ocean Observing System) and EuroGOOS Framework GKSS has started initiatives to develop automatic measuring systems for biological-chemical parameters including measurements from ships of opportunity. One major activity in the last years has been in the framework of the European project "FerryBox", in which several ferry routes were investigated in comparison. An important aspect of COSYNA is the efficient use of FerryBox data for the improvement of forecasts. The irregular and one-dimensional (1-D) sampling of parameters like SST or SSS provided by ships of opportunity requires dedicated techniques to re-construct two-dimensional (2-D) spatial information. As an example Fig 1 a) shows the (“mean”) track of the Roll-on/roll-off vessel (“TorDania”) operating between Cuxhaven and Immingham. In Fig 1 b) the respective SST measurements along the track are given for June 2003.

A new approach to derive complete 2-D SST or SSS was developed, which is based on EOF decompositions of both the 1-D ship measurements and the corresponding 2-D parameter fields. Basically the FerryBox provides data of the form

$$FB(t) = \beta(t, s(t))$$

where β is the measured parameter and s(t) denotes the ship track. The analysis of these data includes the following steps:

- Interpolation of vessel data in time yielding a continuous time series of parameter estimates along the track, i.e. FB(s,t) for all times and points along the track.
- EOF decomposition of the ship track data FB(s,t) and the 2-D background fields $\beta(x,t)$ using data from numerical models.
- Setup of an empirical relationship between the principal components (PCs) of the track data and the 2-D background fields using numerical model data.

Applying the latter empirical relationship to real FerryBox data enables the re-construction of 2-D SST and SSS fields. As an example Fig 1 c) and Fig 1 d) show the SST re-construction errors for December 2003. Fig 1 c) is based on simulated measurements whereas d) corresponds to real FerryBox data. One can see that even with real data the errors are very reasonable with the best performance observed close to the ship track as expected.

Sediment transport

Modern satellite observations have a resolution comparable with high-resolution numerical models allowing to describe and validate new and so far unknown patterns of sediment distribution The GKSS-BSH three-dimensional suspended particulate matter (SPM) transport module was combined with the hydrodynamic circulation model HAMSON to simulate 2 years of SPM distributions in the North Sea with high spatial resolution (Dobrynin et al., 2008). The metereological forcing is based on hourly data from the Regional Model of the Atmosphere (REMO) and ocean wave information is provided by the spectral ocean wave model WAM with wind input taken from REMO. Optical data acquired by the MERIS instrument onboard the ENVISAT satellite were assimilated into the model using a sequential optimum interpolation method. Seasonal means of SPM surface concentrations for the calm period (Apr 15-Oct 15) and for the storm period (Oct 15-Apr 15) with and without assimilation of MERIS data were derived. Especially for the calm period and for SPM concentrations < 10 mg/l the effect of assimilation is pronounced. The entire horizontal SPM distribution from the English cliffs up to the German Bight and the SPM front in the German Bight changed due to assimilation (Dobrynin et al., 2008).

Furthermore a local study of sediment transport processes in the East Frisian Wadden Sea was carried out using a combination of a nested numerical model and optical MERIS satellite data (Staneva, 2008). It was demonstrated that simulated SPM concentration patterns are in good agreement with MERIS data. A quantitative comparison showed deviations in the order of 10 %.

Assimilation of surface elevations

As a first step towards the improvement of water level forecasts in the North Sea assimilation experiments were carried out based on simulated measurements. The General Estuarine Transport Model (GETM) was used for the numerical prediction of water levels. A model setup with 1 km resolution was implemented for the study. A tidal forcing was used for the western and northern boundaries of the model regime. The temperatures and salinities at the boundaries are taken from climatological data. A singular evolutive interpolated Kalman filter (SEIK) was implemented to carry out the assimilation. SEIK is based on an ensemble of model trajectories which are updated in each analysis step using the available observations. Eight ensemble members were used for the investigation. The required start ensemble was generated running the model over a period of one day with disturbed wind forcings.

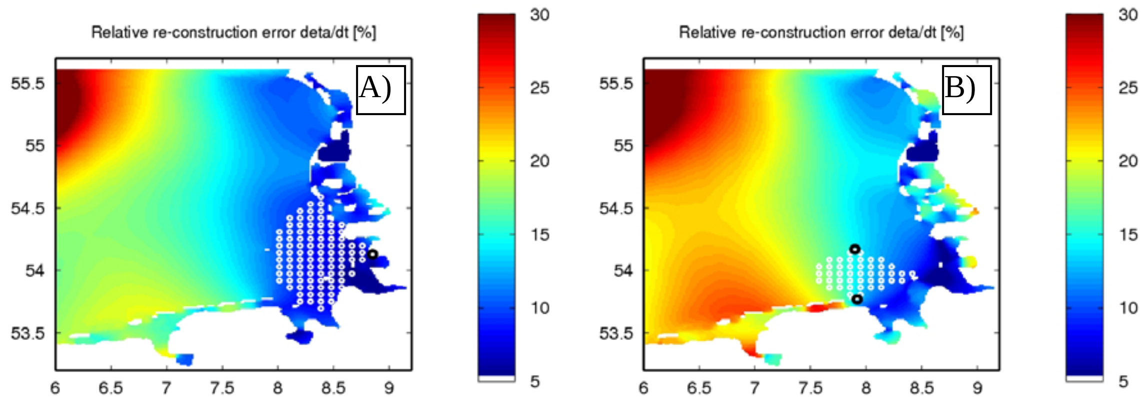

Figure 2: Relative REs obtained for Jul 2007 using different Hf radar configurations (A) Re-construction of the elevation change rate with on station at Büsum. (B) Re-construction of the elevation change rate with two stations at Wangerooge and Helgoland.

To test the assimilation a twin experiment was set up. A run without disturbance was used as a "true" reference. Observations were then simulated by applying the respective measurement operator and adding measurement noise. Different observation scenarios were investigated. It was demonstrated that the assimilation scheme is able to "pull" the forecast in the direction of the observations. Some work is still needed to ensure consistency with boundary conditions and to optimise the models for forecast errors and measurement errors.

Assessment of observational networks

A set of tools to assess ocean observing networks was applied for the analysis of different instrumentation scenarios in the German Bight (Schulz-Stellenfleth and Stanev, 2009). The techniques are based on the optimal linear estimation of physical parameters from observations. A priori information about the covariance structure of the ocean state vector, as well as models for measurement errors were used for the re-construction of quantities, which are not observed directly. The performance of the observing network is quantified in terms of the re-construction quality. Re-construction error maps were analysed to study the spread of information gathered by the network. The estimation of ocean state vectors as well as the re-construction of scalar parameters like mean values or principal components was considered. Apart from the capability of the network to provide estimates of state parameters at the time of the observations, the potential of the measurements for forecasts was investigated as well. Furthermore a simple method to compare single measurements with continuous observations is developed. Finally the relative importance of different components of an observational network was analyzed.

The methods were applied to water level measurements in the German Bight. The General Estuarine Transport Model (GETM) was used to estimate the second order background statistics. Synthetic measurements provided by tide gauges, satellite altimeters, and Hf radar were considered in the analysis. The estimation of the complete water level field in the German Bight was compared for altimeter and tide gauge measurements. It was shown that the orientation of the satellite track with respect to the coastline is of high importance in this context. The estimation of mean water levels was compared in terms of signal to noise ratios. The ability of both sensors to detect water level EOFs was analysed as well. The benefit of the tide gauge array to provide continuous measurements was quantified. It is furthermore shown how the information provided by a tide gauge propagates with the Kelvin wave.

The potential of Hf radar to provide information on water levels and the respective change rates was analysed. Different radar locations and systems with one and two radar stations were investigated. Fig. 2 shows the re-construction errors for the elevation change rate $d\eta/dt$ for a system with one antenna station at Büsum and a system with two stations at Wangerooge and Helgoland.

Summary
First results concerning modeling activities in the framework of the COSYNA project were presented. The objective is to improve the forecasting capabilities for the southern North Sea and Arctic coastal waters.
First steps were taken towards the assimilation of sediment concentration measurements obtained from satellite data. Sediment concentrations were simulated in the East Frisian Wadden Sea with a resolution of 200 m. Comparison to satellite data showed good agreement.
A new approach was presented to derive 2D salinity and temperature fields from FerryBox data. It was demonstrated that the method is able to extract a lot of interesting information about the spatial structure of the respective fields.
An ensemble Kalmann filter technique was used to assimilate synthetic tide gauge data. Twin experiments demonstrated that the method is able to improve the agreement of the model with the observations. Some work is still required to ensure consistency of the analysis with the boundary forcing.
Finally a study was performed to assess observational networks. With this technique different instrumentation scenarios can be compared. The method was applied to tide gauge and Hf radar measurements as well as, satellite altimeter obervations.

References

Dobrynin, M., Günther, H., Gayer, G., *Assimilation of satellite data in a Suspended Particulate Matter transport model*, US/EU-Baltic International Symposium, IEEE/OES, Tallinn, Estonia, May 27-29, 2008

Burchard, H., and Bolding, K., GETM-a general estuarine transport model. Technical Report, European Commission, 2002, No EUR 20253 EN, printed in Italy

Grayek, S., Staneva, J., Schulz-Stellenfleth, J., Petersen, W., Stanev, E., FerryBox Data in the German Bight: Their contribution to the improvement of state estimates and numerical predictions, in preparation for J. of Marine Systems, 2009

Staneva, J. , Stanev, E., Wolff, J.-O., Badewien, T. H., Reuter, R., Flemming, B., Bartholomä, A., Bolding, K., *Hydrodynamics and sediment dynamics in the German Bight. A focus on observations and numerical modelling in the East Frisian Wadden Sea.* Continental Shelf Research, 29:302-319, 2008

Schulz-Stellenfleth, J., Stanev, E., Assessment of ocean observing networks – A study of warter level measurements in the German Bight, submitted to Ocean Modelling, 2009