Modeled effects of the planned Jade-Weser Port Project on sediment distributions and flows in Jade Bay, Germany

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Abstract

The following case study is part of a project initiated and conducted by students of the Carolo-Wilhelmina zu Braunschweig Technical University, Germany. The main scope of the study as a whole, is to learn more about ecosystem relationships and the behavior of climatic, botanic and morphologic processes on different spatial scales.

The most westerly salt marsh of the Jade Bay (North Sea), South of Wilhelmshaven, Germany was chosen to conduct the experiment and to obtain the needed data via digital data collection of various environmental parameters. The scope of this essay is to contribute a sediment simulation to the project, which is conducted by applying the 3DD Computational Marine and Freshwater Laboratory model. The assessment of possible environmental problems and impacts on the Jade Bay connected with the construction of the planned JadeWeser deep sea terminal is the aim of the simulation. Overall, the undertaken model runs identified no fundamental environmental influences caused by the newly constructed port.

However, it is indicated that the deep sea port might have an influence on the tide-driven mass transport into the bay. The velocity in the entrance to the bay decreases due to the construction. Therefore, the model illustrates higher integrated counts of particle visits to each grid cell, which implies a sediment accumulation in the Jade Bay. For reasons of environmental protection of the e.g. national park Niedersächsisches Wattenmeer more detailed calculations and model runs are considered to be essential to further reinforce the construction and the feasibility of the deep sea JadeWeserPort.
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1 Introduction

The Carolo-Wilhelmina Technical University of Braunschweig (TU BS), Germany offers a degree program fairly new and unfamiliar to many people called Geoecology. Students are required to have a basic prior understanding of math, earth sciences and biology. Throughout the course of the study it is possible to focus on a large variety of research fields such as hydrology, soil sciences, ecology, environmental chemistry and water management. However, present-day environmental developments, mostly driven by anthropogenic influences call for a more detailed and broader understanding of global ecosystem cycles and responses. The studies of Geoecology equip students with the ability to identify causes, origins and relations of environmental changes, which helps to deal with the mitigation of natural hazards and altered ecosystem behavior.

Since the TU BS does not offer lectures specifically dedicated to climate sciences on master’s level, students initiated a project mainly dealing with climatology but also including issues of micro-morphology, sedimentation and soil sciences, as well as vegetation and ecology. This idea was strongly supported by Prof. Herrmann, who agreed to offer supply and the required technical equipment, finances and knowledge.

The project was agreed on to be placed at the coastline of the North Sea in Wilhelmshaven and Cáccoliengroden, Germany. The studies are conducted in collaboration and with the support of the following departments:

- Centre for Research on Shallow Seas, Coastal Zones and the Marine Environment (ICBM), Wilhelmshaven, Germany
- University of Oldenburg, Germany
- Central Agricultural Research Center (FAL) of the German weather service (DWD), Braunschweig, Germany
- National park ”Niedersächsisches Wattenmeer”, Germany
- Lower Saxony Institute for Historical Coastal Research (NIHK), Wilhelmshaven (Niedersächsisches Institut für historische Küstenforschung, Wilhelmshaven), Germany.

The ICBM works closely with one of the main weather forecasting institutes in Europe (meteomedia founded by Jörg Kachelmann) and focuses amongst others on ecological research in the mud plains of Germany’s North Sea coasts, oceanographic biology and chemistry, as well as marine earth science and offshore technology. However, the ICBM offered the opportunity to undertake research studies in the national park ”Niedersächsisches Wattenmeer” (Wadden National Park Lower Saxony) and generously supported the project with long-time climate data sets. Further data sets were obtained from the FAL Braunschweig. More detailed information concerning the various institutions may be obtained from the following home pages:
Following 6 months of preparation, technical devices to collect data were installed. The experimental set-up included two meteorological stations that recorded and digitally saved climatic data every 15 minutes from the beginning of June until the end of October. In addition to the constantly recorded data one-day field trips, a major and two smaller field campaigns ranging between two days and one week duration were undertaken. The two meteorological stations were situated in downtown Wilhelmshaven and on a salt marsh westward of the community Cäcilliengroden (Figure 1.1).

Figure 1.1: Location of the experiment sites Wilhelmshaven and Cäcilliengroden, North Sea, north-west Germany. Circles in the map, which was obtained from Google Earth, indicate the positions of the experimental set ups.

Further information concerning the location and the site will be provided in Section 2.2. However, the stations gathered the same data applying identical techniques: precipitation (Hellmann), temperature, wind speed, and humidity. Additionally, radiation-balance-measurement tools were installed in the salt marsh, and wind direction was also registered (Figure 1.2). Data collection concerning smaller local scales was undertaken during the field trips. Soil and water samples were taken, vegetation was identified in special transects and the micro-relief as well as temperature variations in different types
of vegetation were measured. Obtained results and evaluations will be assessed in six essays, each addressing different themes. Further information concerning this project including the studies are published online and may be obtained from the following home page: www.tu-braunschweig.de/geokologie/abteilungen/hydrolo/studprojekte/salzwiesen.

![Installed equipment continuously collecting climatological data at the Jade Bay, Germany between June and October 2007 (left: salt marsh, right: downtown Wilhelmshaven). Devices were set up by students of the TU BS, Germany.](image)

Unfortunately, none of the departments, which are supporting this research is able to feasibly offer the possibility to evaluate the sediment distribution and flow into and out of the Jade Bay. Therefore this paper contributes the missing sediment simulation to the project.

The scope of this study is to identify whether the sediment flow and particularly the sediment transport of the Jade-Bay will be significantly influenced by the construction of the JadeWeserPort. Furthermore, observations made by inhabitants concerning the filling of the Jade Bay with sediment and the supposedly increasing extent of the salt marsh during the last years is discussed and evaluated.
The Site

2.1 Jade Bay and its hinterland

The north-westerly border of Germany is defined by the coastal shoreline to the North Sea. The North Sea is a shallow sea with depths generally less than 45 m and seldom occurring maximum depths of 70 m (Smetacek et al., 2002). There are two tidal zones, which can be identified along the coast of the North Sea. Low mesotides, which show an amplitude of 1 m - 2 m, occur between the island of Sylt and Blåvands-Huk (Netherlands), and low macrotides with amplitudes of more than 3 m occurring between the tidal inlet of the Jade Bay (Germany) and the peninsula of Eiderstedt (Schleswig-Holstein, Germany) (Smetacek et al., 2002).

The Jade Bay is a tidal dominated system with no significant freshwater inflow (Plüß and Schüttrumpf, 2004) and characterized by branched quite complex drainage systems with depths up to 30 m. The channels are filled with Holocene sediments.

Pre-Holocene sediments make up the Geest. The Geest are presten-day features inland (Behre, 2004) and composed of boulder clay, which was formed during the Saale glacial period. Spatially occurring Lauenburger Clay and the pre-Holocene sediments are covered by blanket sheet sand accreted during the last glacial period, the Weichsel glaciation. The Geest surface is gently sloped and decreases in its height above sea level in north-easterly landward direction (Behre, 2004). The following inter-glacial period, the Holocene, is represented by transgression and regression periods of the ocean. This can be reproduced by soil profiles sequences in the Geest area. Soil profiles show progressive transition of low-bog peat over clayey brackish water sediments, changing into marine wadden sand and clay, back to brackish accretions and peat development. This is illustrated in the following figure (Figure 2.3).

In the early 16th century, the Jade Bay reached its largest extension (Figure 2.4). However, large parts have been regained by construction of dikes which still protect the
shoreline from high tides and storm surges. The first dikes were composed of wood. Since this time, the techniques of dike building have significantly improved. The first low dikes created have been recovered in the area of Wilhelmshaven and are dated to be from the 12th century. They protected farmland, etc. from being flooded during summer floods but offered no protection against winter storm tides. In the 13th century, the single dikes were connected, the first coherent dike system was established (Behre, 2004).

However, as time has passed increasing amounts of land were regained, resulting in polders of different age following one another. Due to increased accretion on the foreland and polders, and due to rising rates of compaction of the hinterland because of e.g. framing, the polder landscape subsided and show a decrease in height below sea level of -2 m – -3 m (Behre, 2004). Figure 2.5 briefly illustrates this process, which was mainly anthropogenically induced by means of dewatering of peat in order to create agricultural sites.

Figure 2.4: Development of the Jade Bay till the beginning of the 16th century. Dotted area corresponds to the Geest extent, black parts illustrate the salt marsh and Holocene bog, and the dotted line shows the current coastline. Illustration A pictures the situation until 1164 AC. Image B until D show impacts of major floods in 1164 AC, 1362 AC, and 1511 AC (figure obtained from Behre (2004).
2.2 The deep sea JadeWeserPort, Wilhelmshaven, Germany

On the 30th of March 2001, the Lower Saxony’s Prime Minister and the Mayor Round of Hamburg as well as of Bremen declared the construction of the first deep sea container port at the German Bight (location see Figure 1.1 and 4.8). It is the largest infrastructure project in Germany in the last 50 years. However, the planned JadeWeserPort in Wilhelmshaven (Figure 2.6), with its ideal geographical location, will be the only German port, that is able to deal with modern jumbo container ships of lengths up to 430 m, widths of about 58 m and draughts up to 16.5 m. It will therefore be one of the most important lynchpins in the European North Range, easing the transport on land and sea between the world, Europe, Scandinavia, Finland, Russia and the Baltic States as well as Great Britain (JadeWeserPort et al., 2006).

Figure 2.6 offers an overview of the planned area. The planning for the project began in 2001, construction started in 2008 and is supposed to last until 2011. The first jumbo container ships are expected to be served within the same year. The whole port development is estimated to cost 950 mio Euros (JadeWeserPort et al., 2006). The quay is going to be 1,725 m long with a width of 650 m. This enables the port to handle 4 container and feeder ships at once. A 170 ha large area for industrial utilization and commercial enterprises is provided with almost unlimited room in the hinterland to expand to (Kleinsteuber, 2002).
The location

- short sea approach of only 23 miles,
- already existing fairway of 18 m depth,
- furthest East located deep water port,
- direct motorway excess,
- large hinterland area for commercial and industrial expansion,
- and an excellent rail network

make Wilhelmshaven a feasible location for Europe’s largest deep water terminal beside Rotterdam. Positive side effects such as lowering the high unemployment rate, drawing new industry into the region, and infrastructure improvement are also likely results. Furthermore, the timing of the construction is very well planned. Currently the international trade is growing rapidly with booming container traffic and growing volumes of ship loads (Kleinsteuber, 2002). The handling volume is modeled to double in the German seaports within the next 10 years, which calls for a deep sea port being able to handle capacities in excess of 12,000 TEU regardless of tidal constraints (JadeWeserPort et al., 2006).

However, even though major advantages may result from the construction of the terminal, arguments against the port need to be considered as well. Improvements concerning the east-west land connection need to be made by means of new road construction, inhabitants of the whole regions fear major noise disturbance and environmental influences and negative air quality quickly impacts. Furthermore, large areas of the environment will be constantly disturbed and destroyed. The greatest damage will be found on the maritime side. However, reduction of recreational space on the continent should also not be underestimated (road construction, industrial real estate, etc.). A loss of 20,000 tourists is expected on a daily basis, which might have major influences on the tourism industry of Wilhelmshaven and the region. In addition, the National Nature Park ”Niedersächsisches Watttenmeer” embodies a variety of habitats for many different species. Direct intervention into the park is not expected (Kleinsteuber, 2002), however, our ability to forecast ecological impacts on a permanent scale are quite limited. In summary, despite all disadvantages connected with the terminal construction, the feasibility of the project is not at all questioned according to Kleinsteuber (2002).

3 3DD Computational Marine and Freshwater Laboratory

The 3DD Computational Marine and Freshwater Laboratory is a numerical program by Dr. Kerry Black and was initially programmed in the early 1980’s. So far, it has been undergoing constant renewal and adaptation regarding present knowledge and therefore
The hydrodynamic model 3DD

**3 3DD Computational Marine and Freshwater Laboratory**

embodies the current state of the art concerning computer models. The 3DD suit has become the primary tool for predicting, managing, and understanding the hydrological environment with special focus on oceanographic modeling. The program itself is backed up by studies of the Australian Research Council such as "Wave and Sediment Research" and shows off 25 years of applications on marine and freshwater environment modeling (Black, 2006c).

Due to the development of more employable and faster computers with more memory capacity it is recently possible to couple physical models with ecological models, which offers a better insight into the whole ecosystem response and behavior. The main advantage of physical models is the supply of a better understanding of turbulence and sub-grid-scale processes as well as increased resolution by means of simulations. However, several sub-grid processes cannot be resolved yet and need to be parameterized such as the eddy viscosity (describes the effect of turbulence as if it behaved the same way as an increased molecular viscosity (James, 2002)). Models are still dependent on high resolved and accurate meteorological and tide data sets. However, the lack of oceanographic data is the number one problem that limits the trustworthiness and correctness of model outcomes in present days. The simulation of e.g. turbulence, currents, tides, salinity, temperature etc. by physical models, which are based on relatively simple and almost linear relationships, has been replaced by more up to date high resolution empirical, numerical and coupled models, which are based on statistical relationships (James, 2002). The 3DD model is a coupled model being essentially composed of six different numerical models that simulate biological and physical processes in marine and freshwater environments. It embodies the following models (Black, 2006c):

- A 3-dimensional flow, dispersal, short-wave and ocean/atmosphere heat transfer model (3DD),
- a 3-dimensional dispersal model called Pol3DD,
- an estuary wave climate model (WGEN),
- a refraction of monochromatic and spectral waves simulation referred to as WBEND,
- a beach circulation and sediment transport model (2DBEACH)
- and a model simulating sedimentation around coastal structures (GENIUS).

The 3DD model is controlled through the Front End Manager, which directs the user to the individual simulation options (Figure 3.7). Overall, there are five steps, that always have to be followed in order to obtain a high quality simulation result: One of the most important data sets employed in the 3DD program is the bathymetry file (.md-file). The more accurate and the more this file corresponds to the natural environment, the more the results mirror the actual environmental and ecological processes. Having produced the bathymetry, boundary files (.bnd-files) need to be created. These files basically characterize the forcings on the model and are mostly composed of time-series such as tidal ranges (sea-level). In order to run the model properly various non-compulsory
files and the operational file (.dat or .in-file) have to be generated. The additional non-compulsory files (e.g. wind (.wnd)-files) alter the models default settings and adjust the simulation to match the environment of interest more realistically (Black, 2006a). The operational file controls the model in terms of boundary files, grid inputs, time series, input/output files and data parameters such as the eddy viscosity (Black, 2006c). However, the fourth step is the model run, which is followed by the examination and interpretation of the simulation through Matlab Graphics (Black, 2006a). The output data set of the simulation is stored in the output files. For all but the 3-dimensional dispersion model the output is a .out-file, for the Pol3DD simulation the modeled data is saved in a .pol-file (Black, 2006a).

The following subsections provide a basic overview of the applied models in this case study, which are the 3DD and the Pol3DD model. Governing equations and model set-up options will be emphasized. However, for reasons of completeness the following itemization deals with the four models not utilized in this study and briefly explains their nature and field application (Black, 2006d):
The hydrodynamic model 3DD

3.1 The hydrodynamic model - 3DD

- WGEN
  WGEN is a wave generation model coupled with 3DD and was introduced in 1992. It was developed for fetch-limited water bodies and treats plan shapes, which change during the tidal cycle with the submergence and emergence of intertidal sand banks (Black, 2006d). The original version has been constantly extended and at present the program includes depth-limited breaking, shoaling and bed friction. It incorporates the Joint North Sea Wave Project (JONSWAP) equation and the Bretschneider formulae. Linked to 3DD its nonlinear wave-current interaction in the bed friction term can be realized. Coupled with the sediment dynamics models, it offers the possibility to estimate sediment transport in wave and current environments.

- WBEND
  The 2-dimensional numerical wave refraction model WBEND is applied to simulate monochromatic waves or a wave spectrum over variable topography for refraction and shoreline sediment transport. Wave height, wave period, breakpoint location, longshore sediment transport, bottom orbital currents and near-bed reference concentration of suspended material is estimated via applying iterative, finite-difference approaches of wave action equations (Black, 2006d).

- GENIUS
  GENIUS is applied to obtain estimates concerning refraction, breakpoint wave conditions and longshore sediment transport on beaches. Due to including extra features such as frictional attenuation of wave height and a more physically-based treatment of wave transmission factors it is slightly different and probably wider applicable than the GENESIS model by Hanson and Kraus (1989) (Black, 2006d). GENIUS applies the Snell’s Law and therefore assumes that the bathymetry variability is only minor. However, highly differentiated bathymetry files should be modeled using a more complex simulation such as WBEND (Black, 2006d). Snell’s law, also known as the law of reflection, is a formula used to describe the relationships between the angles of incidence and refraction of waves impinging on an interface between two media with different indices of refraction. Further information concerning the individual models may be obtained from the corresponding 3DD Manuals.

3.1 The hydrodynamic model - 3DD

The 3DD model is a 3-dimensional circulation and mass transport numerical hydrodynamic simulation tool and is the primary component of the ASR hydrodynamic modeling system. Based on highly accurate Eulerian/Lagrangian mathematical techniques it provides the scientific world with trustworthy simulations of environmental marine and freshwater processes on times scales varying from seconds to weeks (Black, 2006d). It is essentially five different models couples and combined into one – the 3DD is composed of the following “sub-models” (Black, 2006d):
• a side-view, 2-dimensional, 3-dimensional homogeneous and 3-dimensional stratified hydrodynamic model,

• a Lagrangian and Eulerian mass transport model including buoyant plumes (for e.g. temperature and salinity calculations),

• ocean/atmosphere heat transfer simulations to estimate air/sea heat transfers and thermocline generation/dissipation,

• a “Boussinesq” shallow water short waves model,

• and a radiation-stress wave-driven circulation model.

Furthermore, it is fully coupled with dispersal, sediment transport, oil spill, wave refraction and generation models enabling the 3DD Computational Model and Freshwater Laboratory to produce most accurate and reliable insights of complex environments (Black, 2006b). The output of the model gives estimations of flow speed and directions, sea levels and temperature, salinity as well as density structure of the water (Black, 2006b).

The governing equations for of the hydrodynamic model are the following and describe the horizontal motion for an incompressible fluid on a rotating earth in Cartesian coordinates with the z-axes positive upward:

\[
\frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} + w \frac{\partial u}{\partial z} - f v = -g \frac{\partial \xi}{\partial x} - \frac{1}{\rho} \frac{\partial P}{\partial y} + A_H \left( \frac{\partial^2 u}{\partial x^2} \right) + \left( \frac{\partial^2 u}{\partial y^2} \right) + \frac{\partial}{\partial z} \left( N_z \frac{\partial u}{\partial z} \right) \tag{1}
\]

\[
\frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} + w \frac{\partial u}{\partial z} - f u = -g \frac{\partial \xi}{\partial y} - \frac{1}{\rho} \frac{\partial P}{\partial y} + A_H \left( \frac{\partial^2 v}{\partial x^2} \right) + \left( \frac{\partial^2 v}{\partial y^2} \right) + \frac{\partial}{\partial z} \left( N_z \frac{\partial v}{\partial z} \right) \tag{2}
\]

\[
w = -\frac{\partial}{\partial x} \int_{-h}^{z} u dz - \frac{\partial}{\partial y} \int_{-h}^{z} v dz \tag{3}
\]

Where \( t \) is the time, \( u, v \) are horizontal velocities in the \( x, y \) directions, \( w \) the vertical velocity (positive upward), \( h \) the depth, \( g \) the gravitational acceleration, \( \xi \) the sea level above a horizontal datum, \( f \) the Coriolis parameter, \( P \) the pressure, \( A_H \) the horizontal eddy viscosity coefficient, and \( N_z \) the vertical eddy viscosity coefficient and \( \rho \) is the density, which varies with the depth (Black, 2006b).

The simulation of the salt concentration and temperature are coupled with the hydrodynamic model through a baroclinic pressure gradient, which is associated with the horizontal temperature and/or salinity density field. The equations (advection/diffusion) are solved on the same grid as the hydrodynamic model applying a second-order-accurate, explicit, finite difference solution. Various boundary conditions regarding the temperature and salinity conditions as well as wind stress can also be included (Black, 2006b).

Since these applications are not utilized in this study (e.g. Boussinesq Terms, heat balance of the ocean, body force, etc.), no further details will be provided at this point but may be obtained from the 3DD Computational Marine and Freshwater Laboratory Manuals.
3.2 The dispersion model - Pol3DD

The model Pol3DD is applied to simulate the transport of dissolved, passive and active material such as larvae, bacteria, and e.g. sediment by solving a Lagrangian 3-dimensional numerical dispersal model (Black, 2006c). This study will apply the Pol3DD to track particles in the homogeneous, shallow North Sea. However, in a homogeneous and stratified ocean and in continental shelf and shallow water environments the particles are tracked by the model through solving transport and dispersion equations employing the novel Lagrangian particle tracking technique. The model determines, in cooperation with the hydrodynamic model 3DD, dispersal paths, concentrations, particle numbers, integrated particle visits, particle settlements and erosion, mean grain sizes, and particle positions. Therefore, it has a wide range of application including the investigation of the influence of ports (which will be determined in this study) sediment dynamics, larval dispersal, effluent transport/dispersal and e.g. eutrophication in sheltered waters. In order to obtain this data Pol3DD has three main capabilities combined in one program: Pol3DD simulates the transport of passive tracers, dispersal and dilution of buoyant plumes or stratified water bodies and the transport of sediment applying the Lagrangian modeling (Black, 2006c).

The Lagrangian technique has certain advantages compared to other solving techniques, which makes this approach the most favorable. It is useful at sharp concentration gradients and shows only minimal numerical diffusion and dispersion, which could alter the results and lead to different conclusions. Pol3DD displays the exact particle position directly by means of x,y,z-coordinates with no interpolation/averaging process covering the grid. The only averaging deals with the interpolation of the velocity from the Eulerian model grid, which has to be averaged over the entire grid to produce a girded output of e.g. concentration, particle numbers, etc (Black, 2006c).

The Pol3DD model works in four steps following the Lagrangian technique: stage one represents the fulfilling of the boundary conditions, such as the release of particles specifying volume inputs, for example. Stage two refers to advection and diffusion processes. Advection is modeled by means of currents, which are derived from a hydrodynamic model. Diffusion is simulated as random positions and increments proportional to the vertical and horizontal eddy diffusivity/viscosity (Black, 2006c). Stage three determines the accumulation of particles by means of particle volume, masses and mean residence time in each cell of the grid. The decay of particles represents the last process, referring to the removal of material from the active simulation through deposition, for example. Applying these four stages is preferred by Pol3DD in comparison to utilizing the older Eulerian finite difference advection-diffusion scheme (Black, 2006c). Each of the four stages, which are employed by Pol3DD, are all characterized by certain numerical processes. The exact definitions and processes of the Lagrangian technique are closely described in (Black, 2006c) and may be obtained from this source.
4 Model Setup

In order to guarantee high quality model results certain procedures need to be followed (see Section 3). The following section will illustrate these steps according to the current case study on the Jade Bay, which involves simulating the sediment flow by means of the particle-tracking technique of the model Pol3DD. However, before the coupled model can be applied, the bathymetry and boundary conditions for the hydrodynamic model need to be prepared. The 3DD model run will supply the dispersion model with the required input data (tidal forcing) ensuring that results correspond closely to reality.

4.1 3DD

4.1.1 The bathymetry

The bathymetry data set was obtained from the publication of Plüß and Schüttrumpf (2004). Figure 4.8 shows the original map from Plüß and Schüttrumpf (2004) and the digitized data set. The program SURFER was used to obtain the grid. Only minor differences might be recognized when comparing both data sets, especially in the northeastern part of the bathymetry. These variations do not influence the model run, since the simulation was undertaken with special regards to the Jade Bay and the possible interaction between the harbor and the sediment flow. Close attention was paid to this special area of interest (Figure 4.9), which can be seen by means of highly matching depths distributions and in comparison to the rest of the digitized map, detailed depths agreements.

![Figure 4.8: Comparison between the original data set of the SE North Sea on the left hand side and the digitized map, which was applied to 3DD in the modeling process.](image_url)
However, one major adaptation was made concerning the island Alte Mellum (North of the Jade Bay). The island was left out in the original grid. During the following simulation it might show, whether the additionally added land surface has altering effects on the sediment flow. The exact position of Alte Mellum is derived from Google Earth.

In comparison with the Lagrangian technique, 3DD depends on the grid. The hydrodynamic model interpolates the velocities and sea-level alterations according to the grid. However, this data set is applied to the Pol3DD later on in order to model the particle tracking and to be able to relate the outcome of the model to the same spatial coordinates (Prasetya et al., 2003). The file displayed in Figure 4.8 has a cell size of $922 \times 997$ cells, each grid being $60 \times 60$ m large. The grid-cell size remained the same throughout the model runs. However, due to the relatively large cell size and therefore the long time required to model, the bathymetry file was cropped down to a cell size of $364 \times 596$ in the region of interest for the second simulation without the harbor (Figure 4.9).

![Figure 4.9: Comparison between the original data set of the SE North Sea on the left hand side and the digitized map of the Jade Bay (r.h.s.), which was applied to 3DD in the modeling process.](image)

**4.1.2 Initial and boundary conditions**

A stationary homogeneous water profile with two open boundaries in the North and West of the grid were generated. On the Eastern side of the grid and on parts of the Western border (South of the barrier islands) sponges had to be applied. Sponges are boundaries, which absorb outgoing oscillations and eliminate reflection of boundaries that would alter the currents unrealistically throughout the simulation. Figure 4.10 illustrates the applied time series, which were utilized as boundary conditions in the North and West,
which simultaneously function as a driving force on the model. The data was obtained from MUMM (2008) and is itself a modeled/forecasted data set. Since the tides do not change because of their dependence on the circulation of the moon around the Earth, the modeled boundary conditions have no impact on the accuracy of the simulation they are applied to. Since the moon takes 14.8 days to circle the Earth, a calibration period of 15 days is recommended to cover all tidal induced conditions. However, Figure 4.10 shows randomly picked 15 days (27.07., 6 pm – 27.07., 6 pm) of a semi-diodal cycle (two low and tow high tides within one moon period), which typically occurs at the North Sea.

Due to the lack of data, no wind file was included into the model leaving the settings as default. Parameters like the eddy viscosity (EV) and the roughness length (RL) were also left unchanged (EV = 1, RL = 0.001).

Figure 4.10: Typical semi-diodal tide time series obtained from MUMM (2008) for the Wilhelmshaven area of the North Sea, Germany.

### 4.2 Pol3DD

Two model runs were conducted using the dispersal model Pol3DD. Eighty hours of simulation were undertaken that applied the large bathemetry file with the harbor and the smaller grid without the harbor influence to the dispersion model. Both simulations were set up exactly the same way in order to ensure comparability.

#### 4.2.1 Initial and boundary conditions

A homogeneous constant vertical structure was assumed to account for vertical and horizontal advection. However, again due to lack of data, no wind file was employed. The prior modeled current file was utilized as a boundary condition, wave action was also not taken into account. Not only time-series may function as boundary condition, e.g. as driving forces, but also constant parameters and processes. In this case a release boundary file was created. This file determined the number of particles and the time span for the release of the material at a certain point. During this case study, 15,000 particles were released over a time span of 4 hours, commencing after the first 60 minutes.
of the simulations had passed. The location of the sediment input was centered in the Jade Bay. The horizontal diffusion was assumed to be constant, whereas the vertical one was determined to be linear in the z-direction with parameters corresponding to the default settings. Decay of sediment such as the loss from the active simulation due to sedimentation or occultation was not taken into account.

5 Results and Discussion

Running the hydrodynamic model 3DD yields e.g. the sea-level elevation and the velocity, which are illustrated in Figure 5.11. The velocity is displayed in the images 5.11.A and 5.11.B, whereas the seal-level elevation is shown in Figure 5.11.C and 5.11.D. The left side of this image corresponds to the model with the harbor (5.11.A is just zoomed in), the right side without. Comparing both images of the velocity distribution, it seems that the harbor has some influence on the speed of the water movement (both figures (5.11.A and 5.11.B) show conditions after 100 hours). The right image implies higher channel-like velocities leading into the Jade Bay, whereas the 5.11.A shows some disturbances and "slowing-down" of the velocity in the channel. The velocity reduction in the bay’s bottle neck area is likely to be caused by the harbor, which seems to dilute and therefore widen the main channel of water flow. However, images 5.11.C and 5.11.D illustrate sea level elevations at the same time but randomly picked out of the tidal cycles. The nicely corresponding values (different scales!) indicate as expected that the tidal range is not influenced by the planned JadeWeserPort.

The primary emphasis of this study was to simulate the particle distribution within the bay and the influence of the harbor on the particle movement. This study is not only important concerning the impacts of the harbor’s construction, but it also gives valuable insight into possible movement of pollutants, which might be caused by the harbor or by natural contamination like certain algae blooms. Particle tracking and sediment in general is of major interest because pollutants may occur in a dissolved, but also in a particulate or absorbed state (e.g. to sediments) etc. (James, 2002).
5 Results and Discussion

Figure 5.11: Figure illustrates velocity in the Jade Bay after 100 hours (A,B) and the sea-level elevation (C,D) at an equal but randomly picked time of the tidal cycle. The left column corresponds to the model run with the harbor, the right one without.

However, Figure 5.12 illustrates the distribution of 15,000 particles at different time steps. The image displays the different model results by means of two arrays: the left column corresponding to the simulation including the harbor, the right column modeling the present situation without the construction site. Each horizontal array of figures represents a similar time period. Since the models were started during different situations in the tidal cycle a time lag of approximately 4 hours between both simulation is present. Therefore, Figure 5.12 shows the images during the same tidal situation at slightly differing time steps: A.1 ~ 27.5 hrs, A.2 ~ 31.5 hrs, B.1 ~ 36 hrs, B.2 ~ 40 hrs, C.1 ~ 53 hrs, C.2 ~ 57 hrs, D.1 ~ 76 hrs, D.2 ~ 80 hrs. These time steps are chosen,
since they convincingly illustrate the particle movement through the system:
Figure 5.12: Particle tracking (black shading) results of the model Pol3DD after various time steps. A.1 \sim 27.5 \text{ hrs}, A.2 \sim 31.5 \text{ hrs}, B.1 \sim 36 \text{ hrs}, B.2 \sim 40 \text{ hrs}, C.1 \sim 53 \text{ hrs}, C.2 \sim 57 \text{ hrs}, D.1 \sim 76 \text{ hrs}, D.2 \sim 80 \text{ hrs}. 
5 Results and Discussion

- A
  The first row of the image (5.12.A1 and 5.12.A2) illustrates the initial particle movement a little more than one day after the release. It is emphasized that the sediment was released at the same location in both model runs. The slight differences of particle movement might be due to the time offset between both simulations of about 4 hours. However, the time lag is considered in all following images of Figure 5.12. Here, in Figure 5.12.A Particles were released during flood time resulting in channel-following initial particle movement towards the Jade coast.

- B
  These two images display ebb conditions after almost all 15,000 particles were released. It shows that the sediment is transported towards the open sea in Figure B.2., whereas Figure B.1 still illustrates more sediment in the bay. This observation corresponds well with the finding that flow velocities slow down due to the construction site, resulting in slower sediment transport out of and into the Jade bay as a whole. As a result the sediment plume is stretched (Figure B.1) in comparison to the more compact plume in the model run with higher flow velocities (Figure B.2).

- C
  However, the figures corresponding to the third time step (C) show a significant difference concerning the particle movement. While in the harbor-influenced model-run the sediment partly remains in the channel and the rest distributes over the whole bay, the situation in C.2 shows a concentration of material in the bay and no sediment outside of the bay. This implies that due to the harbor and resulting reduced velocities, possible eddies as well as flow disablements do not move the same amount of sediment in comparable time periods. The particles in Figure C.2 are concentrated in the bay spreading over the East water body, particles in C.1 mainly distribute over the central part of the Jade Bay area but also remain in the channel in front of the harbor and further North.

- D
  The last group of figures illustrates the particle position after the entire simulation of 80 hours. While Figure D.2 already shows a wider distribution of particles across the model area (in and outside the bay), the other model run’s particle distribution covers larger parts with higher densities inside the Jade Bay (D.1). The harbor seems to shift the particle movement from shallower parts (D.2) into the channel area and therefore deeper parts of the tidal flats. It is indicated that more particles remain inside the bay and in the harbor area in Figure 5.12.D.1. In comparison to D.2 where the particle distribution seems to be balanced.

As introduced earlier, the bathymetry file was optimized with respects to an additional island. Over all the particle tracking does not seem to show significant interferences with the additional island. However, in order to assess this question in ways of quantity
and in order to be able to state volume differences in particle movement a new model without the island has to be simulated for comparison reasons. Since this is not the scope of this study and since there was only a limited time frame assessable, a third model run was not conducted.

As it is shown in Figure 5.12 and 5.13 the overall sediment distribution, budget and behavior seems to be slightly altered. Figure 5.13 (and 5.12.D) shows the sediment distribution at the approximately same time period during an upcoming ebb cycle towards the end of the model. It is indicated that more particles seem to gather around the harbor which can be assigned to the lower velocity. However, the amount does not reach alarming dimensions and should eventually be spread evenly across the tidal flats. Nevertheless, it needs to be evaluated if the varying particle distribution and the higher density of the particle transport inside the bay is going to have an impact on the ecology or the proper functioning of the harbor. Still, it can be assumed that there is no major environmental influence to be expected due to local water movements and currents into and out of the Jade that will probably distribute the sediment evenly across the shore in the long run. This finding correlates well with James’s results from 2002, who did not find that any major differences would result in the sediment flow regarding the influence of the deep sea port construction project. Kleinsteuber (2002) came to similar results concerning the feasibility of the harbor. However, it needs to be emphasized that a detailed sediment budget is still outstanding but absolutely essential in order to estimate the full environmental consequences of the harbor construction. Unfortunately, an exact budget would have gone beyond the intended dimension of this study.

To underline these conclusions, Figure 5.14 emphasizes the integrated counts of particle-visits to each cell. The image illustrates that there are no major sites around the harbor, where particles tend to occur more often compared to the situation without a harbor.

Figure 5.13: Particle distribution (black shading) close to the construction site in comparison with the same site and no environmental influence.
However, the figure does show, that without the influence of the harbor the released sediment tends to be spread more evenly and in higher concentrations across the grid in front of the bay’s entrance. This results in reduced particle visits per cell in the bay. Even though no exact quantitative conclusion can be drawn concerning the flow of sediment into and out of the Jade Bay, the latter figure indicates that there has not been a major accumulation of sediment into the bay thus far. This model result counteracts with the reported observations of inhabitants that observed an increasing sediment accumulation on the tidelands. The outcome of the simulation implies a natural redistribution of material within the bay, which might have lead to the impression of accumulating wadden sediment. However, these last statement remains an assumption, since no direct flux and balance evaluation was undertaken, and since no actual particle-volume comparison inside the bay, with and without the harbor was conducted.

Besides the fairly even sediment distribution before the harbor construction Figure fig:inincel obviously shows more particle visits per grid cell inside the bay indicating that increasing sediment fluxes might be expected in the future after the construction of the port project. This goes well with the conclusions drawn from Figure 5.12. However, these findings are only qualitative (missing budgets) and further research needs to be undertaken in order to estimate the actual sediment transport. This is of great interest not only for the sediment budget and possible correlated miss-functions of the harbor but also for reasons of environmental protection. In order to estimate and even mitigate the possibility of a contamination of the National Park "Niedersächsisches Wattenmeer" through higher imports of potential sediment absorbed pollutants by means of shifted sediment budgets additional, more detailed analysis are required.
6 Conclusion

Over all, the 3DD Computational Marina and Freshwater Laboratory has once again proven to be a valuable tool having the capability to supply the scientific society with important insights into most complex environmental processes. This case study is part of a joint cooperation between students and professors of different departments, universities, and even countries. The scope of this study was to find out about whether the planned deep sea port JadeWeserPort in Wilhelmsaven, Germany significantly alters the sediment flow and the hydrodynamic environment in general. Furthermore, an answer to the recently posed question, whether the Jade Bay is filling up with sediment, wanted to be found. In summary, the modeled results generally coincide with James (2002) and Kleinsteuber (2002) findings, stating that the construction of this project will probably not have major unexpected effects on the environment but that further research is still required.

Even though changes concerning the sediment transport and the velocity were found, no resulting significant impact on the Jade Bay or adjacent environments are expected. However, it has to be mentioned that the integrated number of visits of sediment particles inside the bay increased after the construction of the port according to the results of the dispersal model Pol3DD (Figure 5.14). If this relates to possible increasing accretion in the Jade Bay future pollutants, which might be caused by the harbor and absorbed or just transported as particles, might be a major threat to the valuable environment of the National Park "Niedersächsisches Wattenmeer".

Furthermore, the widening of the wadden area due to sediment accretion which was observed by inhabitants could not be detected and is ascribed to natural redistribution of sediment due to local currents and eddies in the bay.

The model is a valuable tool and it might even be underestimated by some users due to its apparent straightforwardness. Despite all advantages, there might be some possibilities to improve the model’s application in general and concerning this special case study. Within this study many possibilities to apply 3DD could not be taken into account, due to lack of data and a small time frame. That is why wave and wind interaction with the environment was neglected, as well as possible sediment coagulation processes and sediment budget estimations. Including more environmental processes, which closely interact with the ecosystem such as wind speed, sediment erosion, accretion, dispersion, or e.g. sediment loss might alter the simulated results leading to varying conclusions.

Therefore further research is suggested especially concerning the sediment budget of the Jade Bay and the correlated threat of the increasing pollution potential due to the construction and future emissions of the JadeWeserPort.

Compared to some other simulation tools, 3DD is a very straightforward model with a seemingly easy-to-understand interface. However, once applied to more complex processes, it becomes obvious that the beginning simplicity is deceiving. Often complex processes require complex approaches in order to be understood, which can be offered and handled by the model 3DD. Unfortunately, ASR does not offer an easy accessible, sufficient online help and unfortunately the published manual only covers basic applications of the model. Therefore, it is highly recommended to generate an easy to obtain
e.g. online help in order to be able to play out the whole simulation potential of the program. Furthermore, it constantly needs to be remembered that a model is only as good, as it is altered, improved and adapted to the present state of the art regarding the program’s scope.
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