Modelling of Storm Impacts on the Shandong Peninsula Coast

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ABSTRACT

This paper presents results of the investigation of the effect of storms on the morphodynamics of the Yantai coastal areas in the Shandong Peninsula, China. A two-dimensional depth integrated morphodynamic model for prediction of the morphological changes during extreme events was developed and applied. The model covers the entire Bohai Sea with increasing grid resolution towards the coastal areas near Yantai. Calibration and validation using tidal constituents and measured water levels and current velocities showed that the model is capable of predicting the hydrodynamics in good agreement with observations. Emphasis was given to the proper description of the spatial distribution of the seabed sediments and bed stratigraphy. The 20 most severe storms observed in the region from 2000 to 2013 were identified and reconstructed. Storm surges with increases in mean sea level of up to 1.7 m and significant wave heights up to 4.1 m were considered. The results showed that during the storms the levels of energy are mainly due to waves and tidal currents are only relevant at the capes and some channels and straits along the Shandong Peninsula. The resulting morphological changes indicated that although there is an overall loss of seabed material, particularly during the peak of the storms, the beaches near Yantai recover quite quickly just a few days after the extreme events.

ADDITIONAL INDEX WORDS: Bohai Sea, morphodynamics, sediment transport.

INTRODUCTION

China is annually harmed by a large number of storm surges. The majority of the storms are induced by tropical cyclones, which usually strike, at the southern coasts in summer, while during winter periods storm surges as a result of cold-air outbreak can hit the northern coastal regions. Like other Chinese Seas, the Bohai Sea is susceptible to storm surges induced by both tropical and extra-tropical cyclones. However, only a few tropical cyclones manage to move to such high latitudes. Despite the fact that in the Bohai Sea the increases in water levels during such events are not significant, in general they take place every season causing serious damage. On the other hand, winter storm surges generated by cold-air outbreaks usually lead to major increases in sea level in the southern part of the Bohai Sea coast. As more than 90% of the strong winds over the Bohai Sea are induced by cold-air outbreaks, they are more likely to occur at the time of the high tide than tropical cyclones and to bring damage along the coast (Zhao and Jiang, 2011).

The Bohai Sea is a semi-enclosed shallow water body situated in the northern part of China. The sea and its surrounding provinces are rich in natural resources such as oil, coal and fish thus playing an important economic role. Hence it is subject to the strongest marine environment preservation requirements currently in place in China. The sea covers an area of approximately 79 000 km² with average depths of about 18 m. It is rather shallow except for the submerged valley near the north connecting the Bohai Sea with the Yellow Sea. Figure 1 shows the bathymetry of the Bohai/Yellow Sea. The seas are bounded in the west by Hebei Province; in the south by Shandong Peninsula, and in the east partly by the Liaodong Peninsula. The Bohai Strait in the east, also known as Huanghai Sea (Yellow Sea), is the only connection to the open ocean. According to Huatong and Wang (1985) the flow circulation in the area is mainly due to the combined effect of tidal forcing and winds. Jiang et al. (2004) states that wind generated waves play an important role on the temporal and spatial distribution of the suspended particulate matter concentration. Northerly winds prevail in winter. In the flood seasons of summer and fall river discharges affect tidal currents to a certain extent.

Storm surges in the Bohai Sea were investigated using dimensional analysis by Chin and Feng (1975). With the development of computational capabilities numerical models have been developed and applied to study storm surges in the region. Shi et al. (1997) introduced an effective numerical model for real-time forecasting of storm surge flooding using a wet-dry grid point method with generalized curvilinear computational grids. Li et al. (2003) coupled a wave model (WAVEWATCH III)
with a three-dimensional ocean model (POM) to simulate storm surges. A strong impact on the elevation and current was found by considering the wave effect.

Despite of the large number of investigations, little is known about the impacts of storms on the sediment dynamics and morphodynamics in the near coastal areas of the Bohai Sea. Except for the mouth of the Yellow River, there is no much information about the dynamics of storms and its relevance on the resulting sediment transport in other coastal regions. In the framework of a sino-german cooperation, the relevance of storms on the coast of the Shandong Peninsula in the southeast of the Bohai Sea is addressed. Emphasis has been given to the hydrodynamics of the coastal regions off Yantai using a numerical model implementing modules of flow, waves, sediment transport and morphodynamics.

**METHODS**

A description of the numerical model for prediction of the tide and wave induced currents, the resulting sediment transport and morphological changes (morphodynamics) along the coastal areas of the Shandong Peninsula is provided initially. This is followed by the selection of the storm events and a description of the simulated periods.

**Model description**

The model employed in this study was set-up on the basis of the Delft3D suite, developed by Deltares. A coupled modeling system implementing modules of flow, waves, sediment transport and morphodynamics was set-up. The flow module (FLOW) solves the continuity, motion and transport equations under the shallow water assumption. In relatively shallow areas, wave action becomes important because of whitecapping, wave breaking on the surface and energy dissipation near the bottom. In the surf zone long-shore and cross-shore currents are generated, and the bed shear stress is enhanced. The wave module solves the discrete spectral action balance equation accounting for such processes. In this study wave simulations are performed using the 3rd generation spectral wave model SWAN (SWAN is an acronym for Simulating WAVes Nearshore.) (Holtuusen et al., 1993). The interaction between the flow and wave modules takes into account the effect of waves on current (via forcing, enhanced turbulence and bed shear stress) and the effect of currents on waves (via set-up, current refraction and enhanced bottom friction). The sediment transport module (SED) uses the tide and wave induced currents to determine bed suspended loads and transports, while a morphodynamic module (MOR) continuously updates the model bathymetry based on the calculated sediment fluxes.

A nesting sequence was set-up to study the effects of storms at the northern coast of the Shandong Peninsula (Figure 2). The model bathymetry is based on nautical charts and data from the General Bathymetric Chart of the Oceans (GEBCO) (OC, IHO, and BODC, 2003) with a resolution of about 1.5 km. The larger scale rectangular model (BYS) covers the Bohai/Yellow Seas above the parallel of 34.5° with ca. 5 km grid resolution. The smaller circular model (SNS), centered close to the Yantai urban area, covers the northern part of the Shandong Peninsula, with horizontal grid resolution varying from 0.2 km onshore up to 1 km offshore (Figure 2). The BYS model has an open boundary in the south. Tidal forcing based on the Global Model of Ocean Tides (TPXO) (Egbert and Bennett, 1994) is imposed at this boundary. Water levels and wave spectrum information from the larger scale model are imposed at the open sea boundaries of the small-scale model as time series. The model is forced with tides at the open sea boundary and wind and pressure fields from the global model of the German Weather Service (DWD) (Majewski, Frank, and Liermann, 2014) with spatial and temporal resolution of ca. 30 km and 3 hours respectively. Figure 3 shows comparisons of the measured and modeled air pressure, wind magnitude and direction. Measurements at the airport meteorological stations (UW) (University of Wyoming, Department of Atmospheric Sci-

![Figure 1. Topography of the Bohai/Yellow Sea region. (Source: GEBCO (OC, IHO, and BODC, 2003))](https://bioone.org/journals/Journal-of-Coastal-Research)
ence) and the Ocean Data and Information Network for the Western Pacific Region (ODIN-WESTPAC) (Ocean Data and Information Network for the Western Pacific Region) database are compared to results of the DWD model at the locations; Dalian, Qingdao and Yantai. The location of the stations is indicated in Figure 1. Comparisons are shown for three of the storms (storms 15, 17 and 18) considered in this study. Details of the storms are given in Table 1. It can be seen that the meteorological model is able to predict wind velocities and directions in good agreement with observations.

Hydrodynamic models

Results of sensitivity studies showed that a two-dimensional depth-integrated approximation (2DH) is capable of describing flow and transport processes in the region reasonably well. Only in summer, during periods in which density currents are stronger, the monthly averaged currents cannot be well approximated by the 2DH model. The large-scale flow model was calibrated on the basis of tidal components at the stations Dalian and Lianyungang. The location of the stations is shown in Figure 1. Figure 4 shows comparisons of the tidal components obtained on the basis of measured and modeled results. There is good agreement at the two stations. At Dalian, in the north, the correlation coefficient between measured and modeled values is 0.99 whereas at Lianyungang, close to the open boundary, the correlation is 0.93. The lower correlation is attributed to the fact that in the global tidal model the amphidromic point near Lianyungang is not in the exact same location as given by the Chinese co-tidal and co-range charts, although the maps generated from model results agrees reasonably well with the ones based on observations. Figure 5 shows comparisons of measured and simulated water levels, wave heights and current velocities. Measured values from a stationary ADCP deployed in the Yantai Bay in September 2013 at a water depth of about 17 m were used (see Figure 2). There is good agreement between measured and computed values. The wave heights are slightly underestimated due to the low temporal resolution of the meteorological forcing, which is unable to capture the peaks of wind velocities values adequately.

![Model grids: BYS Model (down) and SNS Model (up)](image_url)
Figure 3. Comparison of measured and predicted air pressure, wind magnitude and direction at the (+) airport meteorological station, (●) ODIN-WEST-PAC and (◇) DWD model data. Values are shown at the stations: (a) Yantai for storm 15, (b) Qingdao for storm 17, and (c) Dalian for storm 18.
Sediment transport and morphodynamic models

The transport of the cohesive and non-cohesive sediment fractions is modeled following Partheniades (1965) and van Rijn et al. (2000), respectively. The main rivers discharging into the Bohai Sea are modeled as river mouth discharge points. Monthly averaged river discharges and suspended sediment concentrations are imposed. For the Yellow River values based on the Yellow River Sediment Bulletin (Yellow River Conservancy Commission of the Ministry of Water Resources) were used. The bed stratigraphy is represented in the sediment transport model through several sub-layers. The 5m-bed layer under the seabed was subdivided into 0.2 m thick sub-layers. Below this layer another 5m-sand layer composed of a mixture of fine and medium sand is considered. The spatial distribution of the sediment fractions is based on Liu et al. (2010). They presented an update of the original distribution of surface sediments in the Yellow Sea and its surrounding seas after Li et al. (2005) (see Figure 6). It can be seen that the surface seabed sediment is mainly composed of cohesive material comprising of different mixtures of clay and silt. However in some regions there are large deposits of coarser material (from fine to coarse sand). Based on this distribution, three sediment fractions were defined in the model; the first frac-
tion consists of cohesive material (D₉₀ < 63 μm); the second of fine sand (D₉₀ = 200 μm); and the third of medium sand (D₉₀ = 500 μm).

The sediment transport model was warmed up for a year period considering a simplified spatial distribution of the three sediment fractions. To speed up the mixing of the bed composition, the sediment transport was multiplied by a factor of 100, without enabling morphological update as proposed by van der Wegen et al. (2010). The evolution of each sediment fraction during the warming-up simulation is shown in Figure 7 for six different locations (see Figure 8j). It can be seen that at the locations (a) and (b) the changes of the volume fractions are very small. At locations (c) and (f) the volume of mud in the sediment decreases as the fine sand volume increases. At location (e) a significant transformation is visible between the sand fractions. Later, only small variations around a mean value settle. Although at the location (d) a “stable” composition has not been fully reached within the warming-up period, it can be observed that towards the end of the simulation period both mud and fine sand volume fractions tend back to their initial values. The final sediment distribution obtained from the warming-up simulation is presented in Figure 8. This result was used as initial sediment distribution for the storm simulations and also for a “long-term” simulation covering a five years period, from 2009 to 2013. Finally the morphodynamic model was used to update the model bathymetry at each computational time-step. The changes in mass of bed material due to the sediment sink and source terms and transport gradients is calculated and then translated into bed level changes based on the dry bed densities of the various sediment fractions. The total bed elevation change due to the sediment transport at each grid cell is calculated as follows:

\[
\Delta h = \Delta h_{\text{bed}} + \Delta h_{\text{bu}} + \Delta h_{\text{s}}
\]

where \( \Delta h_{\text{bed}} \) is the bed elevation change due to bedload, \( \Delta h_{\text{bu}} \) is the bed elevation change due to suspended load, \( S_{\text{bu}} \) and \( S_{\text{bu}} \) are the bedload transport vector components, \( \Delta t \) is the computational time-step, \( A \) is the grid cell area, and \( \text{Sink} \) and \( \text{Source} \) are the suspended-sediment sink and source terms.

**Storm events**

The territory of China covers zones of temperate, subtropical and tropical climate. The coastline is affected mainly by tropical or mid-latitude storm surges. While in the East and South China Seas most of the storm surges are of tropical nature, both types can occur in the Yellow and Bohai Seas. However, the frequency of mid-latitude storm surges is greater. In the Bohai/Yellow Sea region the annual climate is distinguished mainly in two seasons; summer and winter. During the summer (April to September) mid-latitude storms coming mainly from south strike the region, while in the winter, storm surges produced by cold-air outbreak coming from north hit the region.

The selection of the most severe storms was done according to the wind magnitude near Yantai and the annual Chinese reports from SOA (China State Ocean Administration Staff, 2000–2013). Air pressure and wind data were taken from the results of the simulations with the German Weather Service’s meteorological model from 2000 to 2013. Periods with maximum wind speed exceeding 12 m/s (Beaufort 6) where identified, as this value represents the order of magnitude for storms in the region (Zhao and Jiang, 2011). Table 1 lists the mean wind speeds and direction of the selected storms in chronological order. Storms with significant wave heights up to about 4 m were identified. Figure 9 shows wind roses for normal and storm weather conditions. As it can be seen in Figure 9a, the threshold of 12 m/s seems to be a reasonable limit for storms in the area. The predominant wind direction during storms oscillates between NNE and NNW (see Figure 9b).

**RESULTS**

The results of the model simulations are analyzed hereafter. First an evaluation of the energy levels along the coast of the Shandong Peninsula is presented. After that the resulting sediment transport patterns are analyzed.

**Energy levels on the coast**

The total energy from currents and waves is estimated at each grid cell as follows:

\[
E = \frac{1}{2} \rho d^2 + \frac{1}{8} \rho g H^2
\]

where \( E \) is the energy given in J/m², \( \rho \) is the water density in kg/m³, \( d \) is the water depth in m, \( v \) is the current velocity in m/s, \( g \) is the gravity acceleration in m/s² and \( H \) is the significant wave height in m. The first term on the right-hand side of Equation 4 refers to currents and the second one to the waves.
Figure 7. Evolution of the sediment fraction during the warming-up simulation
Figure 8. Final sediment distribution for cohesive material (g), fine sand (h) and medium sand (i).

Table 1. Most severe storms in Yantai from 2000 to 2013

<table>
<thead>
<tr>
<th>Storm id</th>
<th>Start date</th>
<th>End date</th>
<th>Mean storm wind speed (m/s)</th>
<th>Mean storm wind direction (°N)</th>
<th>Max. water level at ADCP station (m)</th>
<th>Max. sig. wave height at ADCP station (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>02.04.2000</td>
<td>12.04.2000</td>
<td>14.3</td>
<td>322°</td>
<td>1.38</td>
<td>2.66</td>
</tr>
<tr>
<td>2</td>
<td>07.10.2003</td>
<td>17.10.2003</td>
<td>13.2</td>
<td>14°</td>
<td>1.15</td>
<td>2.44</td>
</tr>
<tr>
<td>3</td>
<td>21.11.2004</td>
<td>01.12.2004</td>
<td>14.2</td>
<td>304°</td>
<td>0.93</td>
<td>2.25</td>
</tr>
<tr>
<td>4</td>
<td>04.08.2005</td>
<td>14.08.2005</td>
<td>15.0</td>
<td>76°</td>
<td>1.34</td>
<td>2.80</td>
</tr>
<tr>
<td>6</td>
<td>18.10.2006</td>
<td>28.10.2006</td>
<td>14.9</td>
<td>348°</td>
<td>0.99</td>
<td>2.88</td>
</tr>
<tr>
<td>7</td>
<td>01.03.2007</td>
<td>11.03.2007</td>
<td>16.2</td>
<td>344°</td>
<td>1.25</td>
<td>4.08</td>
</tr>
<tr>
<td>8</td>
<td>18.12.2008</td>
<td>28.12.2008</td>
<td>13.6</td>
<td>342°</td>
<td>0.77</td>
<td>2.20</td>
</tr>
<tr>
<td>9</td>
<td>19.01.2009</td>
<td>29.01.2009</td>
<td>13.4</td>
<td>303°</td>
<td>0.86</td>
<td>2.45</td>
</tr>
<tr>
<td>10</td>
<td>09.03.2009</td>
<td>19.03.2009</td>
<td>12.4</td>
<td>329°</td>
<td>1.08</td>
<td>2.01</td>
</tr>
<tr>
<td>11</td>
<td>08.04.2009</td>
<td>18.04.2009</td>
<td>14.6</td>
<td>23°</td>
<td>1.17</td>
<td>2.42</td>
</tr>
<tr>
<td>12</td>
<td>09.04.2010</td>
<td>19.04.2010</td>
<td>13.8</td>
<td>319°</td>
<td>1.20</td>
<td>2.01</td>
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<tr>
<td>13</td>
<td>21.10.2010</td>
<td>31.10.2010</td>
<td>13.5</td>
<td>7°</td>
<td>0.95</td>
<td>2.33</td>
</tr>
<tr>
<td>14</td>
<td>07.11.2010</td>
<td>17.11.2010</td>
<td>13.6</td>
<td>280°</td>
<td>1.06</td>
<td>1.76</td>
</tr>
<tr>
<td>15</td>
<td>04.08.2011</td>
<td>14.08.2011</td>
<td>16.2</td>
<td>350°</td>
<td>1.33</td>
<td>3.90</td>
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<tr>
<td>16</td>
<td>27.03.2012</td>
<td>06.04.2012</td>
<td>13.5</td>
<td>343°</td>
<td>0.96</td>
<td>2.05</td>
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<tr>
<td>17</td>
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<td>03.09.2012</td>
<td>14.6</td>
<td>345°</td>
<td>1.24</td>
<td>2.61</td>
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<td>17.11.2012</td>
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<td>283°</td>
<td>1.09</td>
<td>1.82</td>
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<tr>
<td>19</td>
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<td>12.03.2013</td>
<td>15.1</td>
<td>342°</td>
<td>1.07</td>
<td>3.29</td>
</tr>
<tr>
<td>20</td>
<td>22.05.2013</td>
<td>01.06.2013</td>
<td>14.0</td>
<td>89°</td>
<td>1.66</td>
<td>2.44</td>
</tr>
</tbody>
</table>
The resulting maximum levels of energy in the area were estimated by averaging all the maximum values obtained in the simulations with the 20 storms. Maps of mean energy due to currents only, waves only and currents and waves are shown in Figure 10a, 10b and 10c, respectively. It should be pointed out that there is a “natural” energy level along the coast. In order to estimate the long-term energy level, simulations covering a five-year period (2009–2013) were carried out. Figure 10d, 10e and 10f show mean values of the whole period, again from currents only, waves only and total energy, respectively. The energy magnitudes both figures are scaled to each case, to some and 5 kJ/m² respectively. It was found that along most stretches of the coast the maximum energy during storms is mainly due to waves (Figure 10h). Along the coastline of the Shandong Peninsula the contribution due to waves is up to three times higher than the energy due to currents (Figure 10a). Apart from the capes and near channels/straits, where tidal currents predominate, the long-term energy due to currents (Figure 10d) and waves (Figure 10e) is quite low. During storms the hydrodynamics due to currents and waves increases significantly. At the Shandong Peninsula the wind-generated waves play a more important role.

Near coastal area sediment transport

To identify the regions in the area where sediment transport might take place, maps of the resulting energy levels along the coast were constructed (see Figure 10). To cross-check this information with the actual modeled sediment transport, the mean sediment transport vectors from all the simulated storms are indicated in Figure 11 (left). In general an eastward sediment transport is observed. However, close to land, an opposite pattern is observed and the local circulation and wave effects become more important. Similarly to the patterns of sediment transport observed in the offshore regions, the strongest transport takes place at capes, channels and straits and it is oriented towards the east. However by analyzing the east-west component of the transport vectors (Figure 11 (center)), a weak but opposing transport westwards can be observed in some areas of the coast of the Shandong Peninsula. In Figure 11 (right) the normalized vectors of flow and wave currents averaged during the storm periods are presented. By comparing the center and right columns, it can be observed that the westward transport along the coast is usually found where wave currents match its direction (center and east coast).

Having identified the main directions and magnitudes of sediment transport, the resulting morphological changes due to the storms are investigated. Figure 12 shows (a) maximum bathymetrical changes and (b) final bathymetrical changes averaged from all simulated storm events. It can be seen that in most parts of the model area the bed level changes reach a maximum/minimum state during the storm events and afterwards they retreat towards the initial conditions. This is not the case for the near coastal areas. Close to the shore, several zones of deposition can be identified (yellow). Besides, along the whole Shandong Peninsula, there are very narrow erosion zones between the areas of deposition and the coastline (light blue).

DISCUSSION

The quantification of the effect of storms on coastal areas is rather difficult. Depending on the characteristics of the coastal area different aspects, such as the regional climate, main driving forces, sediment characteristics and geological composition should be account for. Even though several additional studies of storm surges and typhoons were carried out in the Bohai Sea, most of them consider air pressure and wind fields generated empirically. Li et al. (2010) summarized results of investigations of the 2003 storm surge in the Bohai Sea. They concluded that storm generated waves strongly affect the tidal system and that the resulting flow field influences the transport of sediments. Ding and Ding (2014) showed that during the same extreme event the storm surge current velocities were greater than the tidal currents. They pointed out that the current patterns get complicated under the influence of wind direction, which might affect the sediment movement close to the coast.
Figure 10. Mean available energy: currents (a), waves (b) and total (c) from storms, and currents (d), waves (e) and total (f) from long term.
Figure 11. Mean sediment transport (left), mean east-west transport component (center) and mean flow/wave current vectors (right) during storms.
The results obtained in this study have shown that the investigation of the effects of storms on the coast of the Shandong Peninsula requires a distinguished interpretation. Therefore results of a global meteorological model were used instead. Despite of the limited spatial and temporal resolutions of the meteorological model used here, it shall provide a better description of the conditions in terms of currents and waves during normal and storm conditions.

It was found that as a result of the northern wind direction during the storms, the water masses are pushed towards the southern coast of the Bohai Sea causing it to flow out through the northern coast of the Shandong Peninsula. This explains the strong, in general eastward transport of sediments along the northern deeper waters (see Figure 11). When approaching the coast, two different situations can be observed: (1) in most areas the east-west transport gets weaker and very often changes direction; (2) at straits, capes and along the deeper channels the strong eastward transport pattern predominates. The first one might be due to the local circulation and the direction of wave breaking during northerly storms, whereas the second one seems to be related to the local water depth.

Based on the resulting bathymetric changes during the simulated storms, it can be inferred that the movement of sediment close to the shore is initiated by wave action and then transported by tidal currents. Waves can transport coarser and heavier sediment particles in the breaking zone, but afterwards tidal currents redistribute the finer and lighter fractions of the eroded material, in suspension.

Care should be taken in the interpretation of the results. As already mentioned, a 2DH model approximation was adopted. Although the model results show a tendency of recovery of the seabed after storms (after about five days), it is well known that the density gradients could be quite significant in summer and thus play an important role in the long-term sediment transport. That means the actual energy contribution from currents could become important and therefore change the dynamics of suspended sediment and the annual sediment budget. Besides, the main rivers discharging into the Bohai Sea have been modeled in a simplified way. In this study the monthly river discharges and sediment transport averaged over recent years were considered. In other words the annual variation in terms of fresh water and sediment supply was not taken into consideration. In this study the actual variations in river discharges throughout the past decade, particularly the decreasing river discharges and sediment, were not accounted for.

CONCLUSIONS

Results of an extensive assessment of the effect of storms on the morphodynamics of the coastal areas of Yantai in the Shandong Peninsula were analyzed. The most severe storms observed from 2000 to 2013 were identified and reconstructed with the help of a high-resolution morphodynamic model forced with wind and pressure fields from a global meteorological model. A nesting sequence covering the entire Bohai Sea with increasing resolution towards the coast of Yantai was adopted. Altogether 20 severe storms were simulated. The resulting water levels, current veloci-

Figure 12. Maximum (a) and final (b) bathymetric changes due to storm events
ties, wave heights, sediment transport and bed elevation changes were analyzed.

During the storms water levels reached up to 1.7 m and maximum wave heights of more than 4 m resulted near Yantai. The results showed that the main contribution to the available energy during storm events comes from waves. Tidal currents are more relevant only at capes and channels/straits. Besides, storms tend to produce a stronger eastward transport of sediment on offshore areas of the northern Shandong Peninsula and a weaker westward transport of sediment on shallower areas closer to the shore. The westward transport due to storms is mainly the result of wave-induced currents. Although an overall loss of seabed material during the peak of the storm events is observed, there is a clear tendency for the seabed to recover. In other words, after a given storm event the sediment eroded in the deeper waters will probably be replaced by the dynamics of normal conditions. However nearer to the shore, usually a wide accretion area right in front of a narrower erosion zone is observed. This fact emphasizes the importance of natural sediment deposits along the coast (coastal sand dunes), which can contribute to the coastal stability. To advance the understanding in this field, future research on long-term sediment transport processes should focus on the investigation of the relevance of the density currents using a 3D model approximation. Attention should also be paid to the influence of the Yellow River discharge on the dynamics of suspended sediment in the Shandong Peninsula coast.

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LITERATURE CITED


