Earth Surf. Dynam. Discuss.,
doi:10.5194/esurf-2016-24-AC1, 2016

Earth Surface Dynamics Discussions

Interactive comment on "Long-term coastal openness variation and its impact on sediment grain-size distribution: a case study from the Baltic Sea" *by* Wenxin Ning et al.

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Received and published: 1 July 2016

The authors would like to thank reviewer Evan Goldstein for giving the constructive comments, which will definitely improve the manuscript. Below we firstly addressed each comment and also indicate changes that have been made in the manuscript.

Comment #1: I believe this manuscript could benefit with more description as to the mechanics of sediment transport in this specific system to justify the results (Section 3.2). For instance, what drives sand transport in the modern system? Does sand come from the Baltic into the inlet? Or is the sand coming from the terrestrial setting? i.e., as a reader it would be helpful to understand in more detail how this physical system works?

Authors' reply on comment #1: Thanks for the good points. As the catchment of the inlet is characterized with thin soil and the inlet only has a few small rivers draining into it. On one hand, we speculated that sand transportation into the inlet from the catchment could be limited. On the other hand, the sand input into the inlet from the offshore regions could be very small, as a result of the narrow and shallow sill between the inlet and the open sea water. Overall, sand and/or sediment can be transported into the inlet through both terrestrial input and offshore region with limited amount (supported by relatively low sedimentation rate, <1.5 mm yr-1, during the last 1 ka). We speculated that sediment accumulated in the inlet mostly originates from the terrestrial setting, compared with the sandy offshore region.

Changes made in the manuscript based on comment #1: Page 3, line 9: "which hinders sediment transportation between the inlet and the open water." is added after the sentence "It has a restricted water exchange with the open Baltic Sea through a narrow and shallow strait (500 m wide, <20 m deep) in the east".

Page 3, line 15: "Therefore, there is a lack of erodible soil and subsequent sediment transportation into the inlet. Even so, sediment accumulated in the inlet is expected to originate mostly from the terrestrial setting, compared with sediment transportation from the sandy offshore region. Sediment accumulation rate over the last 1 ka is generally less than 1.5 mm per year (Ning et al., 2016)." is added after the sentence "The RSL has decreased by 17 m in. . .1.5 mm yr-1".

Comment #2: Can the authors connect openness index with a near bottom water velocity and sediment transport in some way - i.e., fetch, wind speed, and water depth to calculate wave orbital motions at the bed using the relations presented in Young and Verhagen (1996)? Or perhaps the authors could relate the (spatial) change in openness index to the wind field (modern or ancient) and the fetch?

Author's Reply on comment #2: Thanks for the great point. It would be really interesting to relate the estimated openness index with other environmental variables to potentially

explain sediment transport mechanism. However, there is a lack of reliable data on historic wind speed and direction in the Baltic Sea region. Thus, calculating wave orbital motions at the bed for the long-term scale is not possible at this moment.

As the reviewer correctly pointed out, it could be interesting to link the spatial change in the openness to the changes of wind field in the inlet, which may improve the ability of our current method in explaining sediment variation. However, since the main focus of this study is to explain the temporal dynamics of grain size changes at long-term scale, it may bring additional uncertainties to our estimations if we only use the available modern wind data for the past 5.4 ka. With availability of reliable wind data at long-term scale in future, it will definitely be interesting to explore potential impacts of wind on the grain size changes at the core site.

Changes made in the manuscript based on comment #2: No changes have been made.

Comment #3: The authors focus on developing an 'openness index' which is the average length of line from the core site to land at a given time/sea level. Why are landward vs. seaward openness indices differentiated? And a related comment, the shifting angle is discussed only briefly. Can the authors give us some guidance on picking a starting position? Do any radial lines, at any time, make it to the open Baltic sea (i.e., do any openness measurements exceed the 8 km line segments used)? Are these lines important? (I would presume so, because these directions would permit larger waves into the system and exert more work on the bed.)

Author's reply on comment #3: Both the seaward and landward openness indices can be linked with fetch and wave energy in the inlet, where high indices values potentially indicate relatively large bottom velocity. Thus higher openness indices in the open system lead to larger grain size in the sedimentation area. In comparison with the landward openness, the seaward openness index better reflects the morphological changes of the inlet, which is the main cause for hydrodynamic energy changes in the inlet over the last 5.4 ka. The landward index is used to describe the changes in

offshore distances and it can be important if prevailing wind direction is from the land to the sea. Thanks for the suggestions on adding comments on the shifting angle. The shifting angles of 0° to 4° have been used to test whether different starting angles influence the openness indices. The results presented in Fig. 7 showed that using 5° interval and different shifting angles, the changes in openness indices were substantial. If the interval is set as 1°, changing the shifting angle from 0° to 4° would be lead to little changes in the openness indices. Therefore using low degree interval such as 1° for calculating the openness indices is preferred. The optimal interval for estimating openness index could vary from different coastal settings and we suggest to test it before apply the index with other proxy data. In our study, using 1° interval would give the most robust results when calculating openness indices, although the computing time would be longer than larger degree intervals.

We have sediment data from the core site and this is also the site we are interested to investigate factors impacting sedimentation process. So it is straightforward for us to use the core site as the starting point of radial lines and the estimated changes of openness index can further link the index with other measured sediment variables.

The maximum length of 8 km line was used because it reached open water region for scenarios at the 5.4 ka ago and is recognized as a reasonable limit. For most time slices, the radial lines have already intersected with islands at less than 8 km distance from the coring site (see Fig. 4). As Fig. 4 illustrates, some lines will reach further before intersecting with land. With increasing length of radial lines, one or a few these far-reaching lines could contribute more to the openness index since it averages lengths for all radical lines, which may increase the relative changes of the estimated openness index through the time. We will do a sensitivity testing to quantify potential effects of the maximum length on the estimated openness index. In general, the changes caused by different lengths of radial lines will most probably not alter the trend which was detected with the current estimation.

Changes in the manuscript based on comment #3:

Page 4, line 13: The text of "The radiating lines of 8 km were used as they can reach open water region when the inlet was relatively open" is added after the sentence "The length of the radiating lines. . .was set as 1-5, 10 and 15°".

Page 5, line 10: "The shifting angles of 0° to 4° have been used to test whether different starting angles influence the openness indices. The results presented in Fig. 7 shows when using different shifting angles, the openness indices show substantial differences. However, if interval is set as 1°, changing the shifting angle from 0° to 4° would result in little differences in openness indices. Therefore using low degree interval such as 1° for calculating the openness indices is preferred and should be recommended for other similar studies, although the computing would be longer than higher degree intervals. The landward and seaward openness indices were differentiated although they both reflect morphological changes of the inlet over the last 5.4 ka. The seaward openness index better reflect the embayment process in comparison with the landward openness, as the most distinct changes of the inlet is from the sill in the east. Even so, the landward openness index, reflecting offshore distances, is calculated, though with lacking of information for the past prevailing." is added after the sentence "Therefore, the associated uncertainties. . .openness variability." The impacts of different shifting degrees on the calculated openness index will be quantified by statistics. A sensitivity test of different maximum radial lengths (10 km and 15 km) effects on the openness index will be conducted

Comment #4 The authors present Figure 6 and 7 to show there is variation in the openness index for a given degree interval (or shifting angle) at a given time. Is there a way to make this analysis more quantitative? (i.e., p5, line 9; how much 'larger'?) One suggestion to illustrate this in the figures is to plot openness variance as opposed to the raw openness index. On a related note, the authors state that they endeavor to find an optimal degree interval (p. 5 line 3). I assume 'optimal' in this context refers to a negligible variance in openness index relative to decrease computation time (associated with increasing the degree interval)? Perhaps quantifying the variation in

openness index for a given degree interval will aid them in searching for an 'optimal' interval?

Author's reply on comment #4: Different shifting angles and intervals are used to test if there is large difference among them. The results in Fig. 6 demonstrate that there are large variances among different shifting angles and intervals. We agree that it would be good to quantify the differences among different scenarios and which has now been quantified in the revised manuscript (see the changes below as well). The 1° interval is recognized as an 'optimal' interval in our study. Still, this is based on the fact that in our study, the computing time for using 1° interval is still acceptable. If further study has large data set (i.e. processing openness index focusing on many sites), the computing time may need to take into consideration and may end up with larger intervals, e.g., 2° or 3°.

Changes made in the manuscript based on comment #4: Page 5, line 5: "For example, the calculated landward and seaward indices using 15° interval are at the maximum 7% and 20% larger than the 1° interval scenario." is added after the sentence "Both the seaward. . .the smaller degree intervals (Fig. 6)." Page 5, line 6: "(maximum 5%)" is added after "only minor difference".

Comment #5: The authors present openness index data and grain size in figure 8. I believe more quantitative analysis could be performed with this data to convince the readers. For instance, what values of shifting angle and degree interval was used? Why? What is the correlation between opening index vs sand %? or openness index vs silt/clay?

Authors' reply on comment #5: Shifting angle of 0° and interval of 1° are used in the Fig. 8 scenarios. When the interval of 1° is used, the shifting angle will only have little impact on the openness indices (see the replies on comment #3). The size of the interval indicates empties spaces without radial lines. With a reduced interval size, there is high chance to capture more detailed morphological changes and also there is

less impact from the shifting angle on the estimated index.

Changes made in the manuscript based on comment #5: To quantify the relationship between openness index with sand fraction, the R2 with significance level was calculated to better inform the readers and has now been added in the Table 1 in the revised manuscript.

Comment #6

Has there been erosion of the islands since 5 ka? (i.e., is the present subaerial expression of the islands identical to the coastlines of the island in the past?) how could this impact your study?

Author's reply on comment #6: Erosion from the islands since 5.4 ka most likely occurred but has been weak as these islands are mostly rocky. It may have caused a delivery of relatively large grains into the coring site during the land-uplift process. As the uplift process has been generally linear, we might observe a linear change in the grain size data if land uplift has played the dominant role in governing the grain size. However, the sand contents and silt/clay ratios exhibit non-linear changes, which indicate the long-term openness change of the inlet is more important.

Changes made in the manuscript based on comment #6: Page 6, line 4: "Erosion from the islands since 5.4 ka most likely occurred but has been weak as these islands are mostly rocky. It may have caused a delivery of relatively large grains into the coring site during the land-uplift process. As the uplift process has been generally linear, we might observe a linear change in the grain size data if land uplift has played the dominant role in governing the grain size. However, the sand contents and silt/clay ratios exhibit a stepwise change, which indicates the long-term openness change of the inlet is more important. Coarse grains such as sand can also be transported to the coring site through storm events, winter sea ice or drifting sea weed, although their impacts are difficult to estimate." is added after "Together with sheltered condition. . .in the sediments".

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