“Morphological and sedimentological response of a mixed-energy barrier island tidal inlet to storm and fair-weather conditions” [esurf-2013-42]

Authors: Gerald Herrling and Christian Winter

We are grateful to both referees and the editor for their valuable comments on this discussion paper.

Their suggestions led to clarifications that will improve three key elements of the manuscript: (a) detailed descriptions of the model, (b) figures allowing the comparison of model results with observations and (c) further references with respect to the identification of physical processes in the discussion.

Response to reviewer #1, M. van der Wegen (received Dec. 10th 2013)

General comments and questions of reviewer #1:
Dynamics of different sediment fractions is assumed based on combining plots of sediment distribution and plots of residuals of total sediment amounts. Plots of residuals per fraction would clarify even more.

→ During the writing process, we had considered presenting additional plots with respect to distinct sediment fractions as suggested here. Residuals of total sediment loads (suspended and bed load) of small fractions , i.e. 150 or 200 microns, show comparable pathways as the overall residuals of suspended load of all five fractions. The coarser fractions of 350 and 450 microns resemble more the pathways of overall residual bed loads. This is not so surprising.

We believe that presenting additional plots with the individual pathways of different fractions would only give negligible additional information but complicate the reading of the paper and increase the number of figures significantly. Their descriptive comparison would require specifying the relevant hydrodynamic condition, the individual grain-size fraction and the specific sediment transport load under consideration.

****Question: what would happen if you apply a single fraction? maybe you can show the difference in a plot? if your study shows that multiple fractions are needed to explain the dynamics (what I suspect), I would state that more clear in the abstract and conclusions. This would require some extra work, but also a very firm and fundamental statement!***

→ Our preliminary model investigations with single sediment fractions (250 microns) indeed showed morphological patterns of erosion and deposition similar to the here presented multi-fractional model simulations. Fortunately - otherwise the majority of quoted single-fraction morphological studies with Delft3D would be obsolete.

The principle aim of this manuscript, however, is to identify surface sediment grain-size redistributions in response to distinct hydrodynamic forcing conditions. This could not have been achieved by running simulations with a single sediment fraction only. In addition, multi-fractional model simulations with initially distributed sediment fractions yet reveal better resistance to excessive, unrealistic erosion that was observed in the inlet throat during tide-dominant conditions and at the ebb-tidal delta during wave-dominated conditions. Here, obviously, the well sorted, coarse grain-sizes tend to stabilize the bed.

Our study is a qualitative comparison of oppositional scenarios to show the sedimentological and morphological effect of either tide- or wave-dominated conditions. We did not intend a technical model study where sensitivity and verification analyses are in the foreground. Thus we do not see the comparison of a single versus a multi-fractional morphodynamic simulation in this context.

On the other hand, we do agree that this is a fundamental and interesting issue and worth to be investigated in further studies focusing on the methodology of tidal inlet (and other domains) modelling. Here, the number of applied sand fractions, thus the gradation, should be investigated and the influence of preliminary sediment distributions; whether the model simulation needs to be run in 3D or 2DH …. etc. Obviously, in order to determine model skill, reliable morphological observations of tidal inlet morphodynamics need to be available then.

In the following we like to address the inline comments and recommendations of reviewer #1 successively:

P.747, L.9: see also Dastgheib (2012)

→ Hayes (1975, 1979) classified wave-, tidal- and mixed energy tidal inlets. Nahon (2012) applied a process-based model to visualize the resulting tidal inlet morphology by imposing distinct ratios of wave forcing versus tidal forcing. Our intention was to mention that process-based models had been used before to verify these well accepted and known relationships. Unfortunately we have been not able to find a relation of Dastgheib (2012) publications to what we liked to express here.

P.747, L.12: see also Dissanayake et al. 2010 (?)

→ By citing Sha & van den Berg (1993) we intended to stress the importance of the interaction of tidal currents in the inlet and alongshore combined with wave-induced currents alongshore and cross-shore. Dissanayake et al. (2009) (!?) explained the tidal inlet channel orientation and geometry due to tidal forcing only and neglected the contribution of waves. Dissanayake et al. (2009) could undoubtedly show that tidal forcing is the dominant driver determining the channel orientation but here we wanted to stress the interaction of tides and waves. For this reason we believe that the reference to Dissanayake et al. (2009) is not obvious here, but is added in the discussion (see below).

P.747, L.13: asymmetry?

→ We do agree that the term “symmetry” is not meaningful and the suggested term “asymmetry” or even “geometry” would be more appropriate. We suggest replacing it by “geometry” which also appears in the title of the quoted paper.

P.748, L.6: replace “suggested” by “assumed”

→ ok, corrected

P.748, L.21: replace “into the inlet throat” by “between the ebb-tidal delta and the inlet throat”

→ ok, corrected

P.748, L.22: “can you explain a little bit more what you mean with reversed sediment fluxes?“

→ We realized that all three citations are based on the Ameland tidal inlet, why we relativize “at Dutch barrier island tidal inlets” to “at the Dutch Ameland tidal inlet”. We also like to emphasize that this circulation cell is downdrift of the ebb-tidal delta and supports reversed sediment fluxes back to the tidal inlet throat. Additionally, we realized that our mentioned citation (Sha et al. 1990) is of 1989 and not 1990. We thus like to change the sentence to:

“For the Dutch Ameland tidal inlet, authors mention recirculation cells at the downdrift shoals of the ebb-tidal delta supporting reversed net sediment transports towards the inlet throat but claim only minor significance with respect to the overall sediment dynamics (e.g.: Sha et al.,1989; Elias et al., 2006; Cheung et al., 2007).”

P.749, L.4: “include ref to figure 1”

→ ok, corrected

P.749, L.13: “How far off shore is this located from the study site?”

→ changed to: “Mean wind directions are from the westerly sector with mean velocities of about 7ms^{-1} observed at the offshore platform FINO1 about 40 km off the East Frisian Barrier Islands.”

P.752, L.15: replace “large” by “long”

→ ok, corrected

P.753, L.13: What value did you take for the active layer thickness?

→ We like to add supplementary information on the selected settings in the bed layer model:

“The uppermost layer of the bed layer model, the so called active layer, has a constant thickness and records the grain-size composition of the underlayers beneath. The underlayers account for the bed level change, while their thicknesses increase or decrease depending on the prevailing erosion or deposition of a certain grain-size fraction. In the present study, the selected active layer thickness is 0.25 m. At the start of the simulation, the total thickness of the underlayers is 10 m in order to guarantee enough sediment supply in case of locally strong erosion."

P.753, L.14: replace "it is referred to" by "reference is made to"

→ ok, corrected

P.753, L.18: "Are these runs with or without bed level updating or only to generate sediment distribution?"

→ We recognize that this question touches an important methodological issue about the 'sedimentological spin-up' of morphodynamic numerical model simulations. Therefore we have decided to elaborate on the significance of two different model initializations: On the one hand the synthetic case of an initialization with uniform grain-size distribution, on the other hand the more realistic simulations taking into account a distribution of sediment grain-size that was generated by a preceding run.

In section 3.5 we introduce two different concepts and associated model runs:

1) Synthetic simulations: initiated with uniform sediment type distribution
    (a) Generation of two sediment distributions in response to fair-weather and storm conditions, respectively
    (b) Generation of one sediment distribution in response to a series of alternating forcing conditions (fair-weather/ storm/ fair-weather)
2) Analysis simulations: initiated with spatially distributed sediments (1b) and used for analysis of morphodynamics

In section 4.3 we add the comparison of the synthetic simulations (1a; old Fig.8) to highlight the general difference of sediment distributions in response to either tide- or wave-dominant forcing conditions, i.e. tide-induced coarsening of channel sediments and wave- induced coarsening of ebb-tidal delta sediments. Descriptions of mean sediment grain-size distributions associated to old Fig. 8 are thus transferred from section 5 to section 4.3.

In section 4.3, we yet refer to Figure 3 as the comparison between the synthetically generated sediment distribution (1b) and measured surface sediment grain-size distribution available at the outer Otzumer Balje tidal inlet. This has following intentions:

(i) Validation of our modelling approach and settings based on a qualitative comparison of predicted and observed grain-size distributions. (referred to in section 4: model validation)

(ii) Presentation of the generated sediment distribution (Fig. 3a) that is used as initial condition for further analysis simulations. (referred to in section 5: results)

(iii) It reveals that only a combined scenario forcing, i.e. alternating fair-weather and storm conditions, can result in a surface sediment grain-size distribution that is in agreement with observations (referred to in sections 6 and 7: discussion and conclusion)

In section 5 (results), we replace old Fig. 8 by new Fig. 1N. In analogy to the morphological changes (old Fig.7) we show the relative change in mean sediment grain-size (scale of +- 100 µm) for the simulations initiated with distributed sediments (Fig. 1N).

During storm conditions, changes in sedimentology are similar to old Fig. 8b. For fair-weather conditions, however, there is obviously an increased sediment coarsening in the deep inlet throat for old Fig. 8a compared to Fig.1Na. This is explained by the fact that the coarse sand in the inlet throat was already comprised in the initial condition of the simulation that refers to Fig. 1Na. In old Fig. 8a, the fine sand is winnowed from the inlet throat and transported to the ebb-tidal delta lobe, whereas the fine sand that accumulates at the ebb-tidal delta lobe is significantly less in Fig. 1Na. For the latter it is passed through the inlet throat but origins largely from the updrift and downdrift side of the tidal inlet.

We thus have to adapt the descriptions of the results in section 5 in view of the aforementioned issues. Furthermore, we will change the formerly absolute arithmetic sediment grain-sizes (old Fig. 8) to relative changes of arithmetic sediment grain-size (Fig. 1N). These changes do not interfere with the discussion or our conclusions.

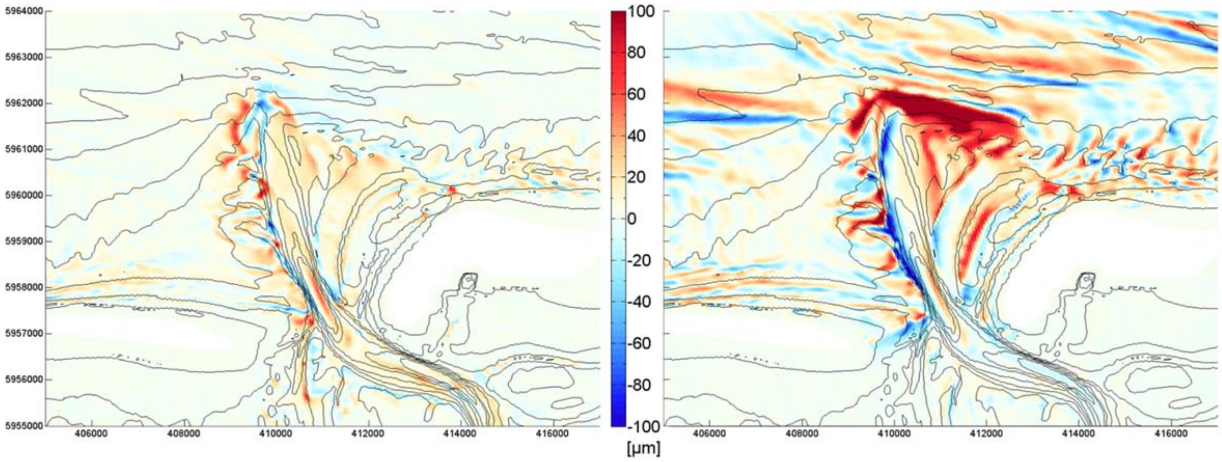

Figure 1N: Change of arithmetic mean surface sediment grain-size as a response to fair-weather (a) and storm (b) conditions; initializations with sediment distribution due to a series of alternating forcing conditions (fair-weather/ storm/ fair-weather) (old Fig. 3a)

P.753, L.20: "figure 8? or figure 3?"

→ Fig. 8 was meant by intention (see clarification above)

P.754, L.6: "Are these runs with or without bed level updating or only to generate sediment distribution?"

→ This question refers to a model setting of Delft3D that enables to run simulations 'without bed level updating' (no change in bathymetry) yet continuous redistribution of sediment fractions. We suppose that the difference in sediment distribution whether bed level updating is activated or not might be insignificant for short to medium term simulations (up to a few months). The setting 'with bed level updating' might even lead to slightly smoother transitions of sediment grain-size at areas with increased bottom gradients, e.g. at channel margins, compared to a setting ‘without bed level updating’.

We thus add at P.753, L.17: “All here presented simulations consider continuous bed level updating. This is clarified against the background that Delft3D allows simulations without bed level updating but redistribution of sediment fractions only.”

P.754, L.7: replace “have been” by “were”

→ ok, corrected

P.754, L.8: How many days was the storm surge run?

→ 5 days… has been added to the sentence: “A simulation of 5 months being forced by fair-weather boundary conditions is followed by a storm simulation of 5 days and another period of 5 months of fair-weather conditions.”

P.754, L.17: spelling of name Roelvink

→ ok, corrected

P.754, L.18: missing comma

→ ok, corrected

P.755, L.2: “see also van der Wegen et al. (2011)”

→ There was an error in our reference list regarding the year of this reference and has been corrected accordingly to “van der Wegen et al. (2011)”. Beyond that, we like to refer here to Dissanayake et al. (2009) as a very convincingly morphodynamic model study on an idealized tidal inlet applying Delft3D.

P.755, L.6: “see also Elias 2013”

→ Unfortunately we did not find any Elias 2013 publication apart from Elias and Hansen (2013) that we have already cited at this passage in the text.

P.755, L.18: “change figure nrs since you already referred to figure 3”

→ We will change figure numbers accordingly.

P.756, L.5 and L.8: “has been” and “have been” change to “was” and “were”

→ ok, corrected

P.757, L.19.: “why don't you plot this in a figure?”

→ Two cross-shore profiles (37 and 38) at the foreshore of the island Langeoog measured by the relevant authorities NLWKN-FSK in October and November 2007 are available allowing the evaluation of morphological changes due to the storm surge event under consideration (Fig. 2N, Fig. 3N). We did not show a direct comparison of measured and modelled morphological changes along these profiles because the bathymetrical data of early 2006 being used to set-up the model bathymetry is not consistent in time with the observed profiles that were measured approx. 1.5 years later.

We thus suggest a qualitative comparison of morphological changes at these profiles (Fig. 2N and Fig. 3N) and modelled patterns of erosion and sedimentation (Fig. 4N) at the foreshore of Langeoog:

Morphological changes between the measured profiles are in the order of 0.5 m to 1m at the surf zone within the first 500 m of the profile. The same order of magnitude is reproduced by the model; in particular the erosion of the upper beach with filling of the trough of the first berm is generally captured by the model. Between 500 m to 2500 m from the dune, the downdrift migration of two shore-oblique sand bars through the transversal profile generates alternations of erosion and deposition of approximately respectively 0.5 m which reveals good qualitative agreement with model predictions. Further offshore, the reliability of the model seems to decrease because of two possible explanations: (a) the model does not reproduce undertow and thus offshore sediment transport, (b) the accuracy of the measurements are in the order of the morphological changes found at the offshore part of the profile.

We suggest including these additional figures (Fig. 2N, 3N and 4N) to the section of supplementary material while clearly stating in section 4.2 the qualitative character of the comparison because of the aforementioned reasons.

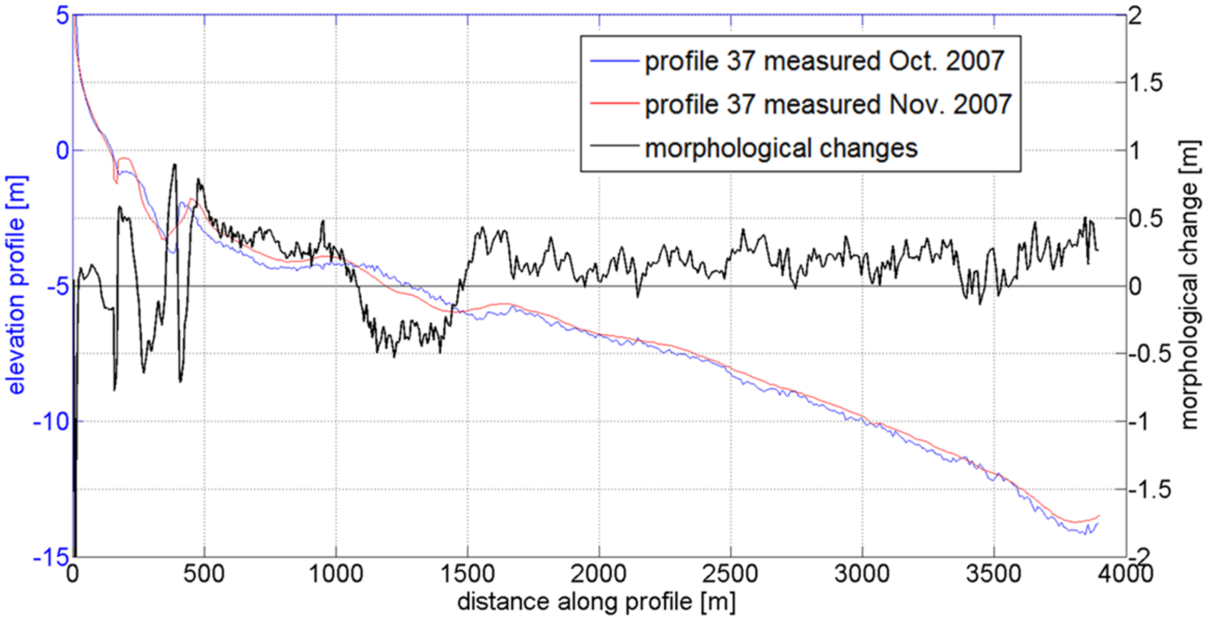

Figure 2N: Elevation of cross-shore profiles at Langeoog island foreshore measured in Oct. and Nov. 2007 and morphological changes as the response to the storm event "Tilo" (data of profile No. 37 with permission of the Coastal Research Station belonging to Lower Saxony Water Management, Coastal Defense and Nature Conservation Agency, FSK-NLWKN)

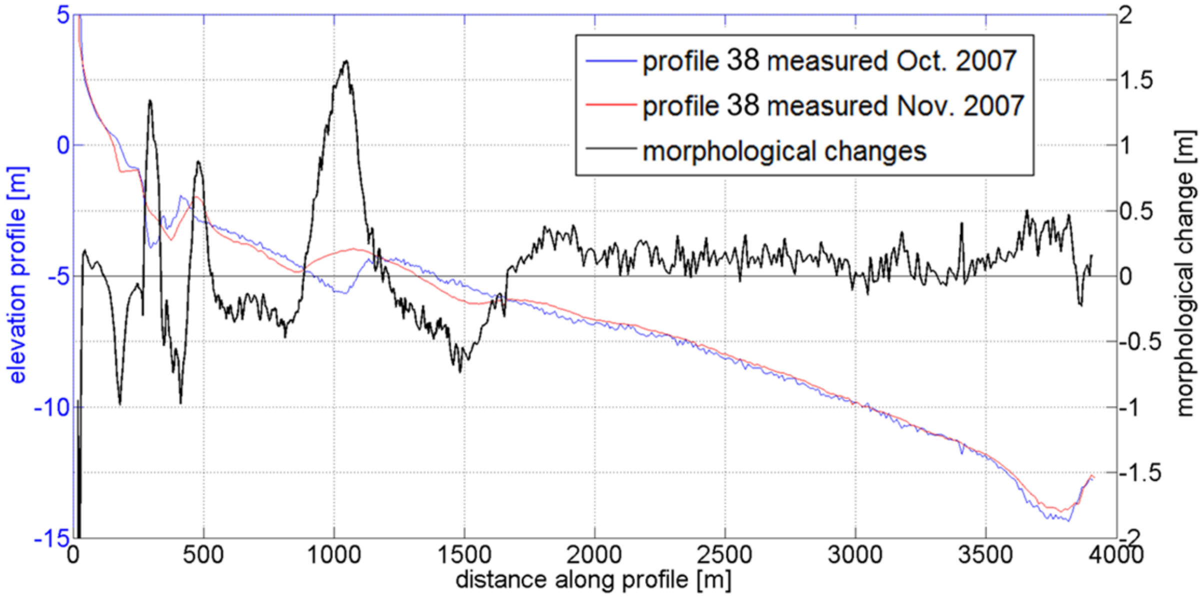

Figure 3N: Elevation of cross-shore profiles at Langeoog island foreshore measured in Oct. and Nov. 2007 and morphological changes as the response to the storm event "Tilo" (data of profile No. 38 with permission of the Coastal Research Station belonging to Lower Saxony Water Management, Coastal Defense and Nature Conservation Agency, FSK-NLWKN)

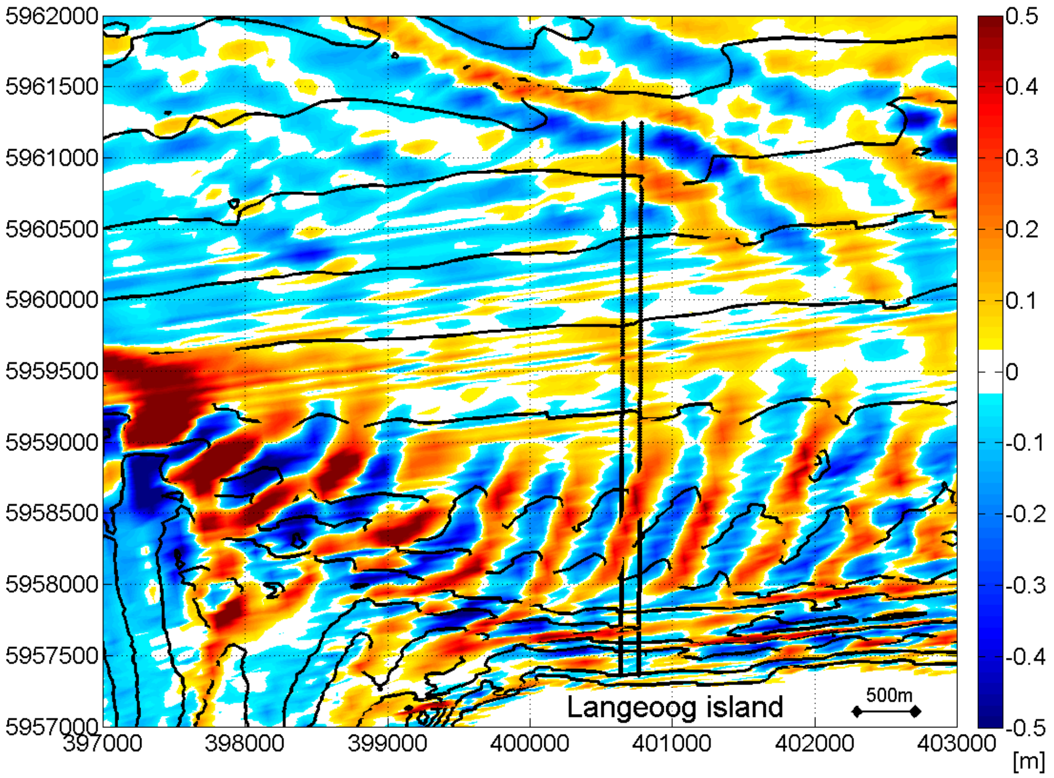

Figure 4N: Morphological changes, i.e. sedimentation (red) and erosion (blue) patterns, predicted by the storm simulation at the foreshore of Langeoog island with position of cross-shore profiles 37 (left) and 38 (right); the initial model bathymetry is based on available measurements of sea bottom elevations of 2006 and thus inconsistent with pre-storm cross-shore profiles of Oct. 2007 shown in Fig. 2N and Fig. 3N.

P.757, L.26.: “delete an article”

→ ok, corrected

P.758, L.9.: “Are these modeled without bed level update, just allowing for sediment redistribution?”

→ These are modelled ‘with bed level updating’ (see above). We suggest including further information in section 3.5 to make clear that we run all simulations ‘with bed level updating’.

P.758, L.18.: “How would you explain the generally darker colour of fig (a) compared to (b); may this be due to the fact that you also out coarser fractions in the initial runs and that finer fraction are simply not returning under fair weather conditions ? if you initially would have deleted coarser fractions west and east of the ebb tidal delta (a reasonable assumption) (or even better; if you would have imposed the measured initial sediment distribution), the mean diameter would have been smaller (and better)…”

→ We described in section 3.5 (P.753, L.18ff) that the equally distributed five sand fractions have an arithmetic mean grain-size of 280 microns all over the model domain. The specification of these 5 fractions is based on observed mean grain-size particle sizes at the tidal inlet but might be too coarse for specific areas, e.g. the foreshore or the backbarrier tidal flats. Here, simulated morphological changes are small and thus sediment redistribution does almost not occur.

However, a preliminary definition of spatial compartments of finer arithmetic grain-sizes (as suggested by the reviewer) is ambiguous as it would lack information regarding the transition of such areas with higher percentages of fine fractions to that of coarser fractions. These artificially imposed borders would reveal inconsistencies to the model results leading to nontransparent interpretations of sediment redistribution.

One central aim of this study was to show the sedimentological response of surface sediments to distinct tide-dominated or wave-dominated conditions exemplarily for the Otzumer Balje tidal inlet with focus on the channels and the ebb-tidal delta. We indented to identify relative changes. It was not our aim to reproduce observations primarily and by any means. We would rather not initiate a simulation with measured sediment data and then validate it with the same measured sediment data! Furthermore, the observed and already spatially interpolated sediment data is restricted to a limited area of the tidal inlet; e.g. data of the delta lobe is not available. This precludes its use as initial condition of the area of interest and least of the entire model domain.

We have described in section 3.5 that our model set-up with respect to the selection of the initial surface sediment grain-sizes has limitations for some areas within the model domain. Our analysis and interpretation of sediment redistributions therefore concentrates largely on the tidal inlet and the foreshore where relative changes are indicated, but where we could show fair agreement with observations for a simulation applying a combination of fair-weather and storm conditions.

P.761, L.14.: replace by “at the northern part of the ebb tidal delta”

→ ok, corrected

P.761, L.25.: “…and because tidal flows are relatively low by the 1.5 m windsetup (same flow through a larger cross section). Or not? There is also remarkable finer sediments in the throat.”

→ Yes, this is an additional explanation that we did not mention here. We therefore add the sentence: “… as the driving wave energy is dissipated at the shallow ebb-tidal delta shoals. In addition, bottom shear decreases as the tidal flow slows down through the relatively increased cross-sectional area of the inlet because of elevated surge levels.”

P.762, L.14.: “replace by “development” (maybe better given the fact that you show only developments and no sign of equilibrium)”

→ ok, corrected

P.765, L.15.: replace by “it is probably”

→ Due to a related comment of the second reviewer, we relativized this to:

”Inside the surf-zone, alongshore wave-induced bottom currents are diverted slightly offshore in a shore-oblique angle due to the opposing ebb-currents. In nature, enhanced offshore-directed currents due to undertow or downwelling (e.g. Niedoroda et al., 1984) may supply additional fine sand to the zone of reduced bottom shear. The latter process is yet not reproduced by the model which still seems a common problem of process-based circulation models and requires further research (Olabarrieta et al. 2011).”

P.766, L.2.: “but also there could be an impact of lower tidal shear stresses due to wind setup and higher cross-sectional area leading to lower tidal velocities”

→ Hoping not to misunderstand your comment, we thus like to clarify that the erosional processes are not only linked to storm conditions. We specify therefore, that erosion of fine-grained sand occurs in the channels during tide-dominated conditions, while on the ebb-tidal delta shoals during wave-dominated conditions:

“…other patterns at the tidal inlet and the foreshore region can be explained by erosional processes where fine sands are winnowed from surface sediments and thus medium to coarse sediment grain-sizes remain, e.g. the bottom of the tidal channels during tide-dominated fair-weather conditions and the ebb-tidal delta shoals during wave-dominated storm conditions.”

P.777, Fig.3: “Are these the result of 10 month modeling (step 2)?”

→ Yes, but we believe that adding all this information in the figure caption would be too long. We thus suggest to add the reference to Figure 3a in section 3.5 already (P. 754, L.12.): “Sect. 4.3, Fig. 3a”

P. 778-P.780, Fig. 4-6: “what do you mean with relative vector scaling? in b this is 4 times samller than in a suggesting that an equal vector length reflects 4 times higher transports in a than in b? what is the value of 1 cm of vector? pls add standard vector to define the scale”

→ Vectors are scaled individually on each figure such that they are visible. Scaling the vectors to reach a common size with a smaller number means that the magnitude is higher. So, here, suspended sediment load is about 4 times higher than bed load transport. Standard vectors are added to each figure for more clarification (Fig. 5N, 6N and 7N).

P.781, Fig.7: replace “have been” by “were”

→ ok, corrected

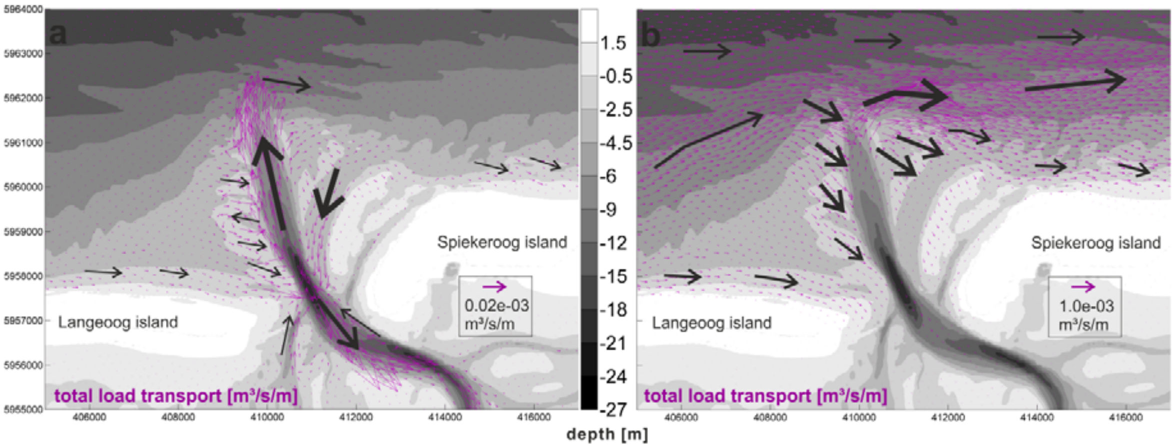

Figure 5N: (old Fig. 4) Residual total load transport for fair-weather conditions (a) and storm conditions (b) and schematic main residual pathways indicated by black arrows; vectors of (a) and (b) have different scales.

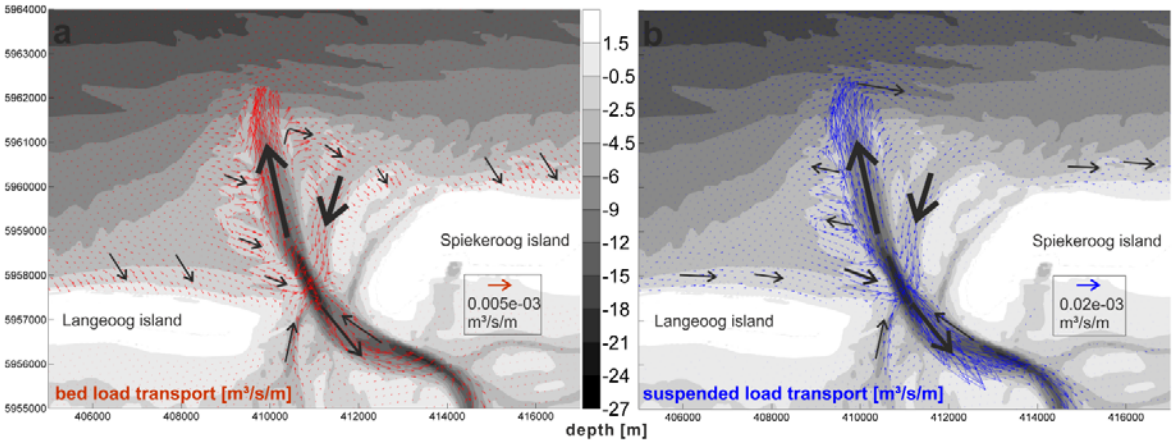

Figure 6N: (old Fig. 5) Residual bed load (a) and residual suspended load (b) transport and schematic main residual pathways indicated by black arrows for fair-weather conditions; vectors of (a) and (b) have different scales.

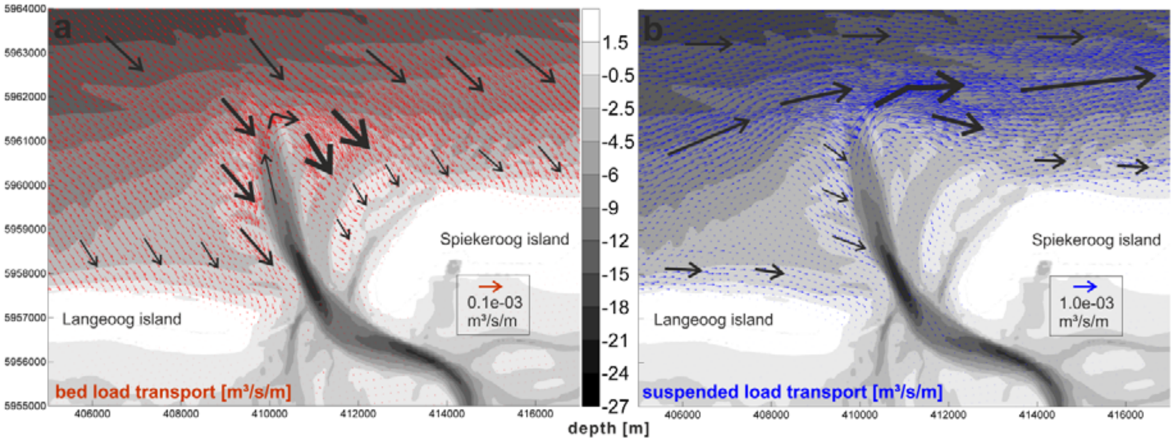

Figure 7N: (old Fig. 6) Residual bed load (a) and residual suspended load (b) transport and schematic main residual pathways indicated by black arrows for high-energy storm conditions; vectors of (a) and (b) have different scales.

Response to reviewer #2, anonymous (received Dec. 31st 2013)

Insufficient description of the modeling system. The setting of Delft3D is not sufficiently described to allow the reader interpreting the numerical results presented in this study and referring to Lesser et al. (2004) is not always helpful.

→ Admittedly, we kept our explanations on model settings and processes within Delft3D rather short. We thus will provide further information and additional references on processes implemented in Delft3D while pointing out noticed model limitations.

For instance, it is not clear what "bidirectional coupling" means (P6, L10): is that two-way coupling? Is the current feedback on the wave field taken into account?

→ Yes, the current feed-back on the wave field is taken into account, though in a depth-integrated manner. We agree that the term "two-way coupling" is apparently more commonly used than "bidirectional-coupling".

We change the sentence providing information on the module coupling:

"Wave measurements available at intervals of 30 minutes are applied as offshore boundary conditions. This coincides with the interval of the sequential two-way coupling between SWAN and the hydrodynamic module (Delft3D-FLOW) that allows the exchange of relevant parameters on curvilinear model grids via a communication file. Wave parameters and the forcing terms associated to gradients in wave radiation stresses computed by SWAN are read by the FLOW module. Once the FLOW execution has terminated the assigned run-time of 30 minutes, bottom elevation, water level and depth-integrated current fields are transferred in the opposite way and used as input to the computation in SWAN. The model will loop through these sequential module applications until the simulation is accomplished."

Then it is not clear if suspension sand fluxes are computed using an empirical transport formula or solving an advection-diffusion equation.

→ Suspended load is treated above and bed load below a reference height (van Rijn, 1993). For simulations including waves the magnitude and direction of the bed load transport are calculated using an algebraic approximation method developed by van Rijn et al. (2003). The method computes the bed load transport accounting for the flow velocity in the bottom computational layer and the near-bed peak orbital velocity in the direction of wave propagation. Suspended sediment entrained in the water column is defined by a reference concentration (van Rijn, 2003) at the reference height. An advection-diffusion equation (van Rijn, 2003) is solved for the current-related suspended transport. The settling velocity of sand is computed following the method of van Rijn (1993) where different suspended grain-sizes are accounted for by empirical formulations. The vertical sediment mixing coefficient follows directly from the vertical fluid mixing coefficient calculated by the k-ϵ turbulence closure model (Rodi, 1984).

The additional information on transport formulae will be incorporated in section 3.1 (modelling system).

Figure 5 and 6 show strong onshore directed bedload transport: is that related to wave asymmetry? If yes, how is wave asymmetry computed?

→ This is partly related to wave asymmetry but also due to the wave streaming in the wave boundary layer. As regards the latter, see the comment on wave-current interaction.

The effects of wave asymmetry on the suspended sediment transports are included based on the non-linear wave approximation modified by Van Rijn (2004) after the method of Isobe & Horikawa (1982). The wave related suspended load transport component is assumed to be equal to the direction of wave propagation. However, the effect of wave asymmetry on the bed load transport is not included.

The references and additional information will be added to section 3.1 (modelling system).

It is surprising that under storm conditions, both bedload and suspended load do not display any offshore component caused by undertows: is this processes adequately represented?

→ The authors are aware of the problem. We do agree that undertow processes may not be reproduced by the model. This seems still a common problem of process-based circulation models and requires further research (e.g. Olabarrieta et al. 2011).

We thus relativize the statement in the sentence (P.21, L.11-15):

”Inside the surf-zone, alongshore wave-induced bottom currents are diverted slightly offshore in a shore-oblique angle due to the opposing ebb-currents. In nature, enhanced offshore-directed currents due to undertow or downwelling (e.g. Niedoroda et al., 1984) may supply additional fine sand to the zone of reduced bottom shear. The latter process is yet not reproduced by the model which still seems a common problem of process-based circulation models and requires further research (e.g. Olabarrieta et al. 2011).”

What is the theory used to compute wave-current interactions in 3D? Is that really through radiation stress or through the dissipation model of Walstra et al. (2000) etc.

→ Wave-current interactions are computed through radiation stress gradients and the additional implementations of Walstra et al. (2000).

Wave forcing due to breaking (by radiation stress gradients computed in SWAN) is modelled as a shear stress in the flow module at the water surface only. We think that a more realistic vertical distribution of the wave forcing would be desirable, where the total radiation stress gradient is correctly split up into surface component bottom component and body force. In particular the ongoing debate about the wave-induced radiation stresses at shoaling and the vertical distribution and implementation within 3D momentum equations (discussed in e.g. Ardhuin and Roland, 2013; Ardhuin et al., 2008; Bennis et al., 2011) reflects on and indicates that important wave-induced processes interacting with the flow circulation may still be inadequately implemented in Delft3D. Slow advancements in this aspect reveal its complexity.

These model limitations have been accepted in the present study assuming only minor effects on the sedimentology and morphology at the tidal inlet. We intended to apply a state of the art and widely used model system while not pursuing any model or process development.

Several other processes are implemented to account for wave effects in 3D simulations: The k-ϵ turbulence closure model has been extended by Walstra et al. (2000) to account for additional turbulence and vertical mixing processes due to dissipation in the bottom wave boundary layer and due to whitecapping and breaking in the surface layer.

Wave streaming as an additional wave-induced current component in the wave boundary layer acts in the direction of wave propagation and is implemented as an additional shear stress over the thickness of the wave boundary layer (Walstra et al. 2000). In 3D simulations, the wave induced mass flux is adjusted for the vertically non-uniform Stokes drift after Walstra et al. (2000).

Mean and oscillatory bed shear stresses interact non-linearly. By use of the parameterization of Soulsby et al. (1993), the wave-current interaction model after Fredsoe (1984) is applied to account for the wave-induced enhancement of the bed shear stress which affects the stirring of sediments and increases the overall bed friction.

Information and references on wave-current interaction will be added to section 3.1 (Modelling system). Apparent shortcomings with respect to the vertical distribution of wave forces implemented in the circulation module are referred to as a future important aspect of investigation.

A general figure with the extensions of the various nested grid would also help, including all the geographic names mentioned in the text for non-European readers (e.g. Denmark, Wadden Sea, East Frisian Barrier Island, Ems, etc.)

→ Fig. 8N will be added to 'section supplementary material'

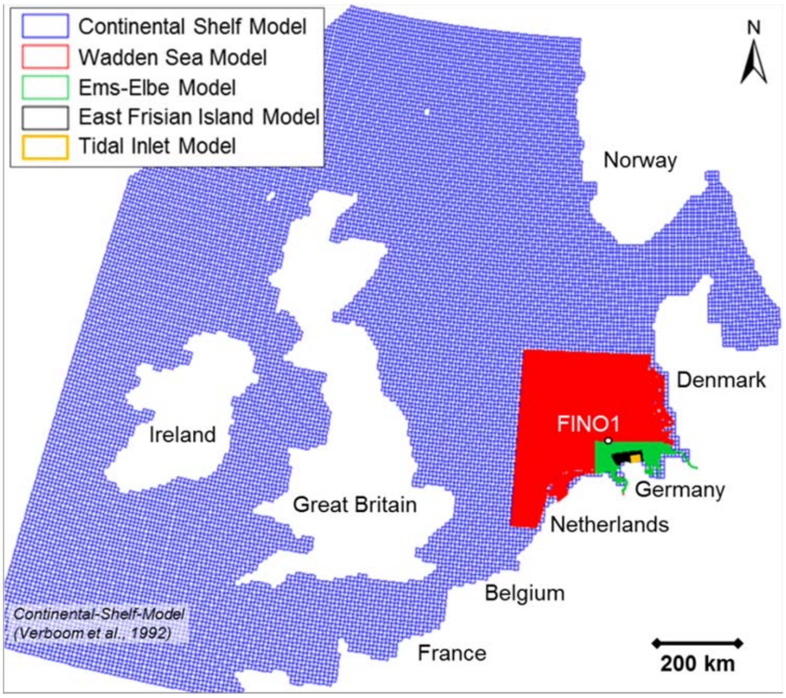

Figure 8N: Cascade of five nested model grids and position of platform FINO1 where wave measurements are applied as offshore boundary condition during storm simulations; wind- and atmospheric pressure fields computed by the German Weather Service (COSMO-EU, COSMO-DE) cover all model grids.

Lack of model validation. This study concludes that short wave contribution is very important in the sediment dynamics of this inlet. However, no model/data comparison is presented for the waves while wave measurements are apparently available both inside and outside the lagoon (section 4.1). A figure showing how waves are reproduced by the model should be included. In particular, the overestimation of wave height inside the backbarrier is interesting: if this problem occurs mostly during the ebb, this could be related to enhanced wave dissipation by counter currents. The importance of this process, that is probably not accounted for in the simulations, was demonstrated at a nearby tidal inlet by van der WestHuysen (2012) and at a shallow inlet by Dodet et al. (2013).

→ Wave data measured in the surf zone at the northshore of the island Norderney during the storm event is digitally not available, making a direct comparison in a figure impossible. The data has been read from a figure of a project report of the Coastal Research Station, NLWKN (Kaiser et al. 2008). The downward looking ultrasound device mounted on a pile produced corrupt data once the distance between water surface and sensor was too small due to unexpectedly high surge levels. For this reason a time-averaged wave height one hour before the failure of the device was compared with time-related, predicted data of the storm simulation. Only the next larger model grid (East Frisian Island Model; see Fig. 8N) enables a wave data comparison located 25 km westerly of the studied tidal inlet. The authors are aware of the limitation of this qualitative comparison but had to cope with the availability of data.

The other available wave measurement of the storm is due to another ultrasound device mounted on a measuring pile in the Accumer Ee inlet at the back-barrier of Langeoog island (data provided by Helmholz Center Geesthacht, HZG), thus not directly at the studied tidal inlet yet still within the most detailed model domain (Fig. 9N, measurement positions added to old Fig. 1). The pile position is located at a hydrodynamic very complex and thus morphologically dynamic location at the junction of the main tidal channel and a tributary. Here, bathymetrical information is only available for spring 2005 and has been incorporated in the model bathymetry, but wave observations were taken 2.5 years later on Nov. 2007. This site is exposed to enhanced morphological changes that influence local wave regime making a calibration of model parameters based on these data ambiguous.

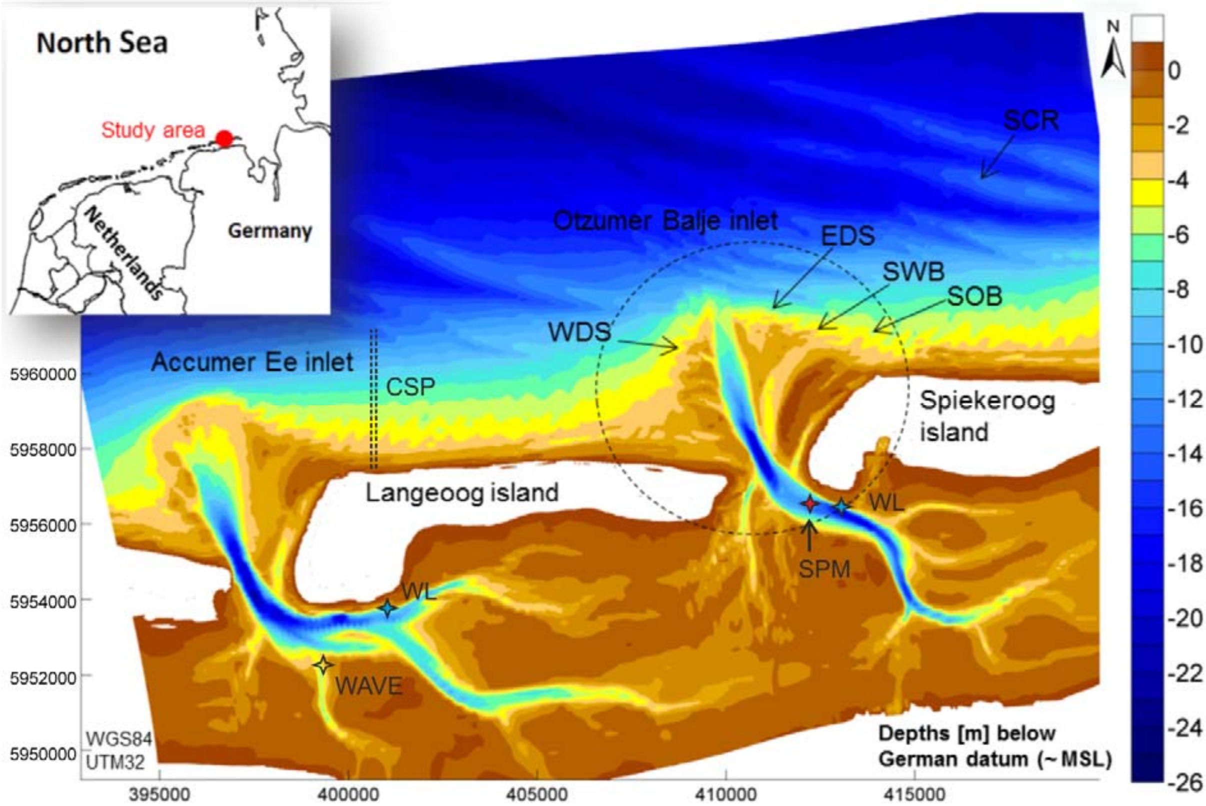

Figure 9N (old Fig.1): East Frisian Barrier island system in the southern North Sea with the study area Otzumer Balje inlet between the islands Langeoog and Spiekeroog and nearshore morphological features such as the western/ eastern ebb-tidal delta shoals (WDS/ EDS), swash bars (SWB), shore-oblique sand bars (SOB) and shoreface-connected ridges (SCR). Measurement positions are indicated as wave (WAVE), water level (WL), suspended matter (SPM) and bathymetry at cross-shore profiles (CSP).

However, these data allow evaluating a root mean square error (RMSE) of 19 cm and qualitatively comparing measured and predicted significant wave heights (Fig. 10N). The agreement with observations is fairly good. Discrepancies are mostly larger during ebb and low water compared to flood.

With the assumption of minor bathymetrical changes during the aforementioned period of 2.5 years, the measuring pile was exposed to the focused ebb-currents in the tributary tidal channel that were opponent to wave propagation. In this case, as supposed by the reviewer, the enhanced wave height during ebb may be a consequence of insufficient wave dissipation due to whitecapping. We applied the saturation based whitecapping formulation after van der Westhuysen (2007) which, however, does not yet incorporate the recently published formulation for the enhanced dissipation of waves on negative current gradients after van der Westhuysen et al. (2012) that was applied in Dodet et al. (2013).

As per our understanding, there may be uncertainty as to the bathymetry at the measuring site. The data are thus considered to be inconsistent allowing for a qualitatively model validation only and not for calibration of model settings.

We agree with the reviewer that an additional figure showing the comparison of modeled versus observed wave heights would improve the trust into the model and in particular into the propagation of wave energy inside the model domain. We will add further information on the in-situ observations, the description of the comparison and a very short comment on possible model skill improvements by using the new whitecapping formulation after van der Westhuysen et al. (2012) and referring to examples of applications in Dodet et al. (2013).

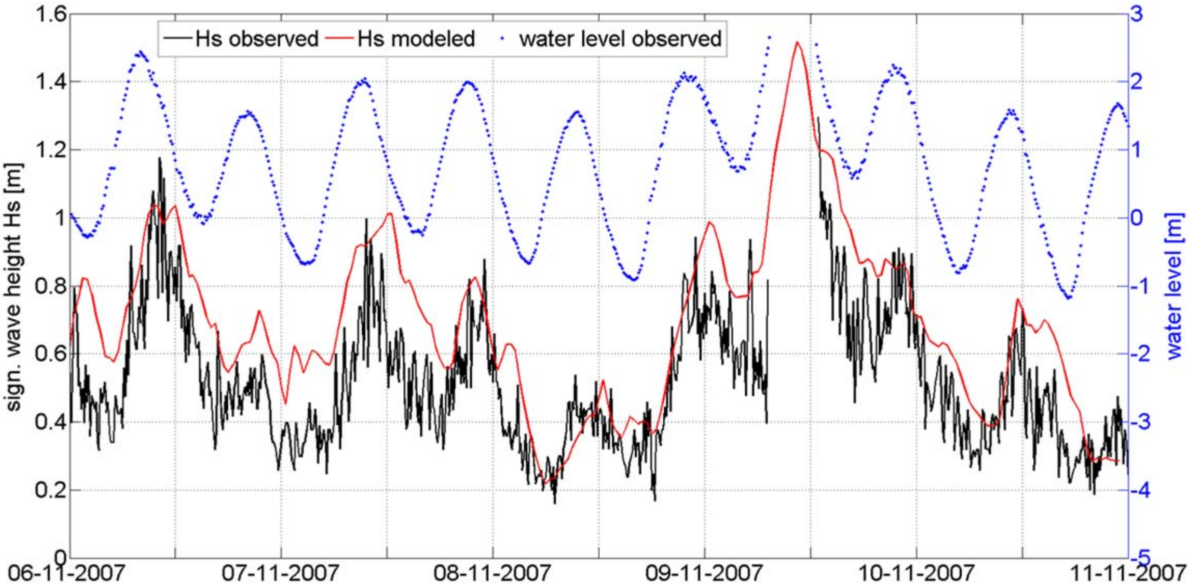

Figure 10N: Observed and modelled significant wave heights and observed water levels in the back-barrier of Langeoog island (measured data provided by Helmholtz-Zentrum Geesthacht); there is a gap in the measurements due to unexpected high water levels close to the storm surge peak

In the same manner, the sediment concentrations are said to be "satisfactorily reproduced" by the model (P. 12, L19): this agreement should at least be quantified and possibly shown on a figure.

→ We specified hourly mean and maximal measured and modelled SPM concentrations for the peak storm tide, respectively for ebb and flood. We did not evaluate the relative discrepancy in view of the fact that this comparison is qualitative.

In-situ SPM concentrations (Badewien et al. 2009), here as measured by a LISST (Laser In-Situ Scattering and Transmissometry) are generally prone to several errors: possible flocculation of finer particles that are recorded as larger ones; sensitivity during calibration of the device itself etc. Also the readings of a pointwise measurement may be biased by local effects, thus of limited applicability to model simulations which integrate information of grid element size.

Anyway during flood tide, SPM concentrations are reproduced with little underestimation of hourly mean and maximal concentrations by approximately 29 % and 8 %, respectively. During ebb tide, however, predicted maximal SPM concentrations of 2mgL-1 are strongly underestimated with respect to measurements (95 mgL-1). In our simulations we did not consider cohesive particles as mentioned in the manuscript which is a possible explanation for significant discrepancies for ebb fluxes. On the other hand, during flood, modelled SPM concentrations are in the same order of magnitude which is very promising. Furthermore, this result is not due to excessive calibration and tuning of model parameters as we still consider the measurements not accurate enough to be used for calibration purposes. We unfortunately did not receive digital data of the measurements and could only take readings of a figure in the paper being referred to.

We agree that due to the above-mentioned facts this comparison is qualitative but nonetheless worth to be quoted, in particular in view of the fact that no better measurements are available here and probably elsewhere during extreme storm conditions.

To clarify this aspect, we suggest modifying the sentence at P.12, L.18-21:

"During flood tide, SPM concentrations at the inlet are due to nearshore wave-induced sand resuspensions. The model reproduces suspended sediment dynamics under these conditions, but underestimates hourly mean and maximal concentrations by approximately 29 % and 8 %, respectively. During ebb tide, however, predicted maximal SPM concentrations of 2mgL^{-1} are strongly underestimated with respect to measurements (95 mgL^{-1})."

Organization of the discussion and lack of physical interpretation. Although it contains valuable information, the discussion is very long and suffers a lack of organization. Reorganizing the discussion with sub-sections (e.g. 6.1 Tide-induced transport; 6.2 Short wave processes; etc) would help future readers.

→ We organized our results (section 5.1 and 5.2) into sub-sections, respectively tide-dominated (fair-weather) and wave-dominated (storm), however, in the discussion this is not evident as we discuss sedimentological and morphological responses with respect to each condition and furthermore highlight the combination of both making a separation not evident. The suggested separation would even increase the length of the discussion as we had to repeat many aspects and/or cross reference to the other section at any one time. Paragraphs will yet be included for a better visualization of the structure of the discussion.

Then, the discussion refers mostly to classical studies on tidal inlets that were published about 30 years ago (e.g. FitzGerald, Hubbard et al.). Although very valuable to a certain extent, these studies are very descriptive and sometimes outdated regarding physical processes. For instance, several authors explained the shoreward migration of ebb-ebb delta sandbars by a so-called wave-induced "bulldozer effect", that has nothing to do with swash. Thereby, it does not seem reasonable to keep calling these sand bars "swash bars". I suggest also referring to more recent studies carried out at wave-dominated and mixed energy tidal inlets (e.g. Olabarrieta et al., 2011; Van der Westhuysen, 2012; Dodet et al., 2013, etc.).

→ Although the recent studies about wave-dominated tidal inlets in Portugal (e.g. Bertin et al., 2009; Dodet et al., 2013) are of great interest with respect to physical explanations of wave-current interaction and also in view of a promising model system, we believe that the comparison of morphological processes of a wave-dominated regime at a very shallow tidal inlet (1-2 m water depth) that connects to an enclosed lagoon with respect to the present study is not evident. The environmental setting is very different from a mixed-energy to slightly tide-dominated inlet system of the present study with a throat that is up to 25 m deep and characterized by ebb- and flood-dominated tidal channels that connect to a back-barrier basin being laterally open to adjacent tidal inlet catchment areas. The studies of earlier authors namely Fitzgerald, Oertel and Hayes are therefore more relevant for our study as they reflect on similar or even the same (East Frisian) barrier island tidal inlets and address morphology as well as sedimentology.

We see two aspects where additional explanations on physical processes could improve the discussion:

P22.,L.16: "Dissanayake et al. (2009) simulated the interaction between inlet tidal currents and alongshore tidal currents for an idealized tidal inlet by applying a process-based model. Residual flow pattern showed that a rotational current field is only developed to the East of the ebb-tidal delta. The physical description relates to the fact that when alongshore current is eastward and inlet current is landward and vice-versa strong directional velocity fields are developed to the West of the inlet, whereas the rotational current field supports the ebb-tidal delta growth at the East. These findings agree with the conceptual hypotheses of Sha (1989) and Sha and Van den Berg (1993)."

P19.,L.17: "On the other hand, coarse sand is transported in landward direction at the ebb-tidal delta shoals also referred as the "bulldozer-effect" (Bertin et al., 2009; Hageman, 1969); the physical explanation is based on a shore-directed component of forces due to wave breaking (radiation stress gradients) over the delta shoal that is not compensated by pressure gradient terms in the momentum balance equation as the associated wave-induced water level set-up is spread into the inlet and the back-barrier basin."

On the other hand, the “bulldozer effect” is often referred to as the process of ebb-tidal delta “shoaling”, thus the prograding of the ebb-tidal delta terminal lobe in onshore direction; however, at the shallow ebb-tidal delta shoals, we assume that this process could yet be superimposed by swash bar migration which during low water and moderate wave conditions are located within a swash zone (Ranasinghe and Pattiaratchi, 2003; Son et al., 2010). Besides, we generally do not agree in changing an established nomenclature as regards the “swash bars” at ebb-tidal delta shoals (Hayes 1979), even though the physical processes involved are miscellaneous and not primarily related to swash.

Would it be possible to compute a sediment balance across the inlet for both fair weather and storm conditions? As in other comparable systems, is the inlet ebbdominated under fair weather conditions and flood dominated under storm conditions?
What is the impact of tidal asymmetry (if asymmetric).

→ We mentioned (P12.,L25) that the aim of the study was not on exchange processes and overall sediment budgets between the back-barrier and the foreshore which demands a different model set-up with increased grid resolution in the back-barrier tidal channels and incorporation of finer and partly cohesive sediment fractions. Furthermore, simplified and synthetic simulations with e.g. tidal forcing only and different synthetic wind directions would increase the insights here. We agree that these aspects are indeed of great scientific interest but would go beyond the scope of the present study and thus have to be addressed in future investigations.

Yet, as we like to answer based on our model set-up and in view of this open discussion, we add some figures showing residual suspended and bed load sediment transports through the inlet cross-section between the islands Langeoog and Spiekeroog integrated over time, sand fractions and depth for fair-weather and storm conditions, respectively (Fig. 11N).

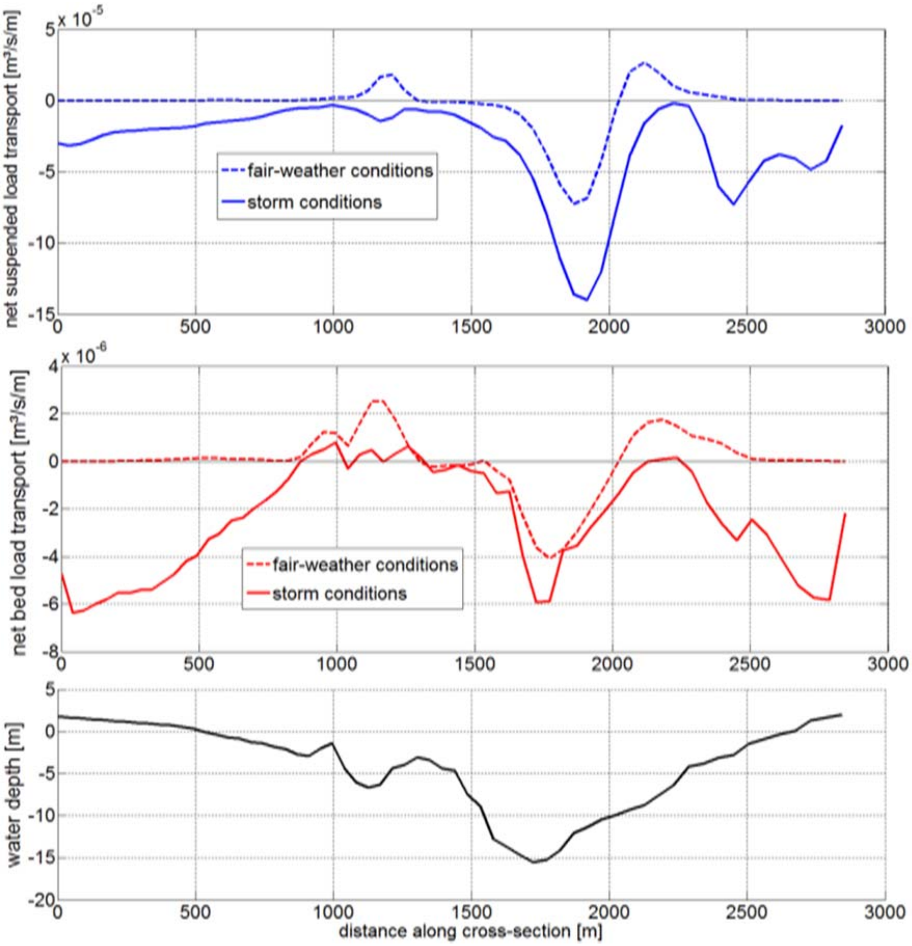

Figure 11N: Residual sediment fluxes for flood (-) and ebb (+) across the tidal inlet Otzumer Balje for fair-weather and storm conditions; lower graph shows the bathymetry along the cross-section

Net sediment fluxes through the entire tidal inlet cross-section during fair-weather conditions:

- At the cross-section, the main inlet channel is flood-dominant, whereas the marginal tidal channels show ebb-dominance, both, for suspended and bed load transport. For a cross-section slightly seawards of the deepest position in the inlet throat, the main channel is however ebb-dominant (not shown here). The net channel flow dominance at different locations within the inlet is shown by Dissanayake et al. (2009) explaining the influence of the phase-shift between alongshore tidal currents versus cross-shore currents in the inlet.

- Net suspended sediment transport is flood-dominated (evaluated as a time series through the inlet, not shown here); this is explained due to the fact that the net flood-directed cumulative volume transport of water predicted by the model contributing to the mass transport through the other watershed basin boundaries (at tidal divides) is enhanced by lateral wind drift effects (Herman, 2007).

- The flood-dominance of suspended load may yet to be overestimated since fine sediments (< 150 microns) are not incorporated in the model set-up, yet would increase the ebb-directed suspended sediment load for southerly wind directions (Bartholomä et al. 2009).

- There is no clear dominance in bed load transport direction and may largely depend on meteorological conditions (i.e. wind and wave directions); furthermore, bed load transports in the vicinity of the cross-section may also be influenced by channel migration pattern and thus cannot be used to explain long-term net fluxes through the inlet!

Net sediment fluxes through the entire tidal inlet cross-section during storm conditions:

- Flood-dominance for both net suspended load and net bed load sediment transports.

- Net bed load sediment transports are enhanced at the margins of the inlet cross-section where water depths are shallow indicating wave-induced transport to be dominant here.

- But then, it has to bear in mind that every storm surge event is individual and the water discharge through the inlet and associated shear stresses are strongly determined by the course of the wind and atmospheric pressure fields. For instance, a storm that ceases just at the peak water level in combination with beginning ebb will generate very strong ebb currents at the inlet. The storm investigated in the present study is however characterized by slowly decreasing wind velocities over the North Sea with the consequence that the surge decreases smoothly and no extreme ebb flow is observed at the inlet.

Along the text minor problems:

-P4, L19: Son et al. (2010) postulated.

→ ok, corrected

-P6, L17 : "the here applied" should be changed to "the sediment transport applied here".

→ ok, corrected

-P7, L23: depending on the beach slope, a 20 m spatial resolution may be too coarse to properly represent wave-induced currents under faire-weather conditions. As a rough guideline, there should be at least 5 nodes accros the breaking zone.

→ The slope is gentle and thus the surf zone expected to be rather wide even during fair-weather conditions. We assume the grid resolution to be detailed enough to properly represent wave-induced longshore currents during fair-weather conditions at least in water depths larger than approximately one meter. We agree that limitations and significantly reduced longshore currents occur at the upper beach slope. However, these are accepted in favor of reasonable computation times. Hansen et al. (2013) satisfactorily applied a cross-shore grid resolution of 12 m at a surf-zone with an increased slope compared to the East Frisian barrier island foreshore. We did not perform a sensitivity analysis on longshore current intensity for fair-weather wave conditions, though we wrote that we assumed the grid size to be sufficiently resolved. We therefore suggest relativizing the statement by adding:

"…and up to 20 m in the breaker-zone, assumed to be sufficiently resolved for proper generation of wave-induced longshore currents during storm conditions. During fair-weather conditions, wavelengths are significantly shorter and the selected cross-shore grid resolution may not be ideally represented at the upper part of the beach, yet certain limitations are here accepted in favor of reduced computational times."

-P8, L.10: "the here reproduced" is not a correct English construction.

→ We delete "here reproduced" as it should be clear that we describe the storm that has been simulated.

-P10, L8 and all along the text: is that the storm surge that is relevant or the storm and associated waves? I believe this is the second option; therefore storm surge should be changed to storm.

→ Indeed, we agree that this needs to be verified for each particular case whether the associated surge or the storm (high wind velocities) are relevant.

–P11, L5: referring to Cayocca here is ambiguous since this author didn't use Delft3D but a preliminary version of the MARS model from IFREMER.

→ ok, corrected

-P13, L16-19 if the model/data comparison is really obvious, it should be shown on a figure. If not, try to moderate and avoid "obvious".

→ Additional figures are suggested in the answer to review of M. van der Wegen.

-Whole discussion: avoid "the here applied". . .

→ ok, corrected

-P21, L. 25: "several such zones" is not correct in terms of English.

→ replaced by "several zones"

-P24, L26: "wave attack" is not very accurate/scientific.

→ replaced by "wave impact"

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