Author's Response to Reviewer Comments

Authors comments in **bold**, text added to the manuscript are in red and line numbers refer to those in the track changed document.

We would like to thank reviewer 2 for their constructive comments on this manuscript. We would like to address each of your comments and the changes we have made to the paper in response to your feedback. Within our responses, text highlighted in red is that which has been changed or added to the manuscript.

Editor:

Thanks for your patience.

Reviewer #2 has asked for some more clarifications. I would like to highlight his comments on the different results produced by CEM and CEM2D. Under this light, it could be worthwhile to discuss when and where CEM2D would be the preferred option and when it would be appropriate to stay with CEM.

Thanks.

Lutz Gross

GMD Topical Editor

Thank you for your response, we have addressed comments from Reviewer 2 below. We have added some additional details related to the numerical schemes used in the model, particularly relating to the calculation of the local shoreline orientation and avalanching scheme. We have also emphasized where CEM2D or CEM would be the preferred model, building on analysis throughout the manuscript where we have discussed and explained differences in model outputs.

Reviewer 2:

1	In my previous round of comments, I recommended: "Please present more details on the governing equations, variables, shoreline identification, transport schemes, diffusion schemes, etc." Unfortunately, I feel that I must ask for that again. In particular, I am still a bit unclear on the calculation of the shoreline angle, and I would like to see some more of the numeric/algorithmic details. For example, in response to my previous comment (i.e., comment #10), the authors mentioned: "the shoreline angle so the angle may be 0, 22.5, 45, 67.5 or 90 degrees". This is certainly better than 0, 45, 90 degree increments (like I thought was the case previously), but I think the method could still be improved to be better than 0, 22.5, 45, 67.5 or 90 degrees. If you look three grid points on either side, then would this give you 15 degree increments? And, if you look four grid points on either side, then would this give you 10 degree increments? I'm guessing that 4 grid points on either side (i.e., 10 degree increments) would probably be sufficient. If you

	have any mathematical details to present on this, then I would greatly appreciate seeing more of the detail.

Whilst we agree that by increasing the number of grid points either side of the cell in question would increase the range of degree increments able to be calculated, though this raises a series of issues itself. Changing the number of cells also effectively smooths the angle and this may have positive and negative impacts in that smaller variations within coastal cell positions may be ignored (smoothed) or have a disproportionate impact. Given then the 'on-off' 'wet-dry' nature of cells being used to count the shoreline, it may well be that smoothing or accounting for the shoreline angle over a greater length of cells may be advantageous but of course, too long a length may result in features being effectively ignored thereby a constant angle coming into effect and the impact of shoreline angle being made redundant. The smoothing or not effect, will also depend upon the spatial resolution being used in the model. This, in effect, becomes another parameter that would be required to be taken into account in any sensitivity testing. At present, we feel the current method, as used in CEM, generates enough variation in shoreline angle to capture the coastal dynamics we aim to simulate. It is, of course, something that could be investigated in future developments of the model.

We appreciate your comments, however, and have added some additional text to make the calculation of the local shoreline orientation clearer and be upfront if this represents any limitation. We feel that this additional text, along with the existing explanation and figure (5), the manuscript sufficiently describes how the model works and we hope that this is satisfactory:

> **L131: "The local shoreline orientation is identified by computing the angle between a shoreline cell and two neighbouring shoreline cells. This forces the shoreline angle to be either 0, 22.5, 45, 67.5 or 90 degrees."**

To try and keep the paper concise and to the point, we have not elaborated with the discussion points on smoothing above. However, this comment (and the above discussion) will be in the online published review and therefore available as a point of reference.

We have also added further explanation and equations to the manuscript, detailing the avalanching technique. Details of this are given in response number 3.

2	It appears the modeled shorelines on Figures 14 and 15 are fairly "staircased" or jagged. Can you please comment on whether this issue of limited angular resolution is contributing to that jaggedness. Overall, CEM seems to have a much smoother representation of the shoreline than CEM2D.

The reason for the staircase appearance that the reviewer refers to in Figures 14 and 15, is related to the representation of sediment as vertical fill in cells as opposed to horizontal (see Section 3). In CEM the partial horizontal fill of sediment in a cell is recorded in the outputs giving it a smoother representation of the shoreline. As discussion in response number 1, computing the horizontal fill of each shoreline cell is part of the ongoing development of CEM2D and it is intended to appear in future iterations of the model. Having partial horizontal fill will give CEM2D a smoother representation of the shoreline. We have added a line in the text to explain this:

L136: "and it can also lead to a more irregular representation of the shoreline."

3	Previously, I also asked a question about "how the longshore transport redistributed in the cross-shore". The authors mention a "steepest descent method" (which means something else to me, i.e., an optimization method). I think more algorithmic details are still needed on this. It is clear qualitatively what they are doing in Figure 6, but it's not clear quantitatively what the method is doing, and thus I recommend more details, equations, etc. In the context of beach erosion models, I would maybe call this an "avalanching scheme" after Roelvink et al., (2009) "Modelling storm impacts on beaches, dunes and barrier islands" – Coastal Engineering.

Thank for referencing the work of Roelvink et al., (2009). The avalanching method used in XBeach are somewhat similar to the methods we use in CEM2D and so we have taken up your suggestion of using the term "avalanching" instead. We agree that this is perhaps a better description of the method used in CEM2D and have therefore updated the text accordingly:

L142: "Rather than assuming shore-parallel contours, material is dispersed across the surf zone based on an avalanching scheme that is somewhat similar to that used in other coastal evolution models (e.g. XBeach (Roelvink *et al.*, 2009))(Fig. 6)."

We have also added some additional details to the description, as requested:

L151: "To carry out this redistribution procedure, an algorithm sweeps the entire model domain and identifies where a critical angle has been exceeded between a cell and its neighbour (Eq. 3).

$$\frac{\Delta_z}{\Delta_w} > m_{cr} \qquad (3)$$

where z is depth, w is cell width and m_{cr} is the critical slope. The material is then redistributed amongst the orthogonal surrounding cells until the critical slope angle is no longer exceeded (Fig. 6)."

4	Validation: I agree with the other reviewers comment that "Presenting a new model requires validation" and that "we need validation/proof that CEM2D mimics the natural landscape evolution." I also agree with authors' approach to try to validate against existing models, in the absence of a better validation test case. Shorelines with high-angle wave instabilities are quite a rare natural phenomenon, and it's even less likely that good data exists on them. I wish I could offer any suggestion to resolve this, but I really don't have a good solution. I'm guessing that I would leave it up to the editors to mediate. The biggest problem that I'm still struggling with, in terms of the model validation, is why the results in CEM and CEM2D in Figures 10 and 11 look so drastically different, to me. Yes, they both capture some degree of the high wave angle instability features, but I am not entirely satisfied with the authors response in comment #13. To me, if the validation of CEM2D hinges on is ability to reproduce results similar to CEM, then there is perhaps still some work to be done on this front, because they still seem to be producing very different behaviors.

We really appreciate the reviewer's acknowledgement of the limitations associated with validating a model of this kind and of our appropriate approach to this difficult task. Further development of CEM2D will continue to evaluate model performance not only against the behavior of other models like CEM but against natural systems as more data becomes available.

We have explored in the manuscript where model outputs differ between CEM and CEM2D. The results suggest that CEM2D better represents natural features in increasingly asymmetric wave climates compared to CEM, measured against example case study sites throughout the manuscript. For instance, CEM appears to perform better under a symmetrical wave climate (e.g. capes), and CEM2D performs better when simulating highly asymmetric wave climates (e.g. spits). As noted in the paper, the avalanching scheme in CEM2D allows sediment accumulations to be detached from the continuous shoreline without becoming static (L.280). CEM2D is therefore able to better represent these highly complex spit features that evolve with sediment accumulations that do detach from the continuous shoreline. We have included some additional text in the manuscript to discuss where CEM or CEM2D would be the preferred model option, based on this analysis:

> **L291: "Considering that all site-specific conditions controlling the evolution of capes are not represented in CEM2D or CEM, the models are able to predict a comparable shoreline type to that observed in this natural system. However, CEM2D overpredicts the directional skew and so CEM may be the preferred option in this instance."**
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> **L300: "demonstrates the ability of CEM2D to reflect the asymmetry of landforms formed under asymmetric wave climate conditions compared to CEM; CEM2D may, therefore, be the preferred model in this instance."**
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> **L315: "Ashton and Murray (2007) suggest that the wave climate is favoured towards an asymmetry (A) of 0.8 along the entire spit and under these conditions, reconnecting spits form in CEM2D (Fig. 11), suggesting that CEM2D may be there preferred tool to use in this conditions."**
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> **L427: "These evaluation techniques have demonstrated that CEM2D is able to simulate shoreline instabilities in accordance with theories of high-angle wave instability, to mimic the behaviour of natural environments under given wave climate conditions and to generally reproduce the results of the original one-line CEM, although some differences are observed as discussed throughout (Ashton and Murray, 2006a). In particular, the results show that CEM2D shows increasing model performance with increasing wave asymmetry compared to CEM. This is likely due to its ability to handle detached sediment accumulations that form during the evolution of reconnecting and flying spits, under these wave conditions. It may, therefore, be more appropriate to use CEM2D over CEM when modelling environments with asymmetric wave climates, but CEM where wave approach is highly symmetrical."**

Changing the dimensionality of the model and enabling dynamic cross-shore evolution in CEM2D makes it the preferred model to use where the evolution of the bathymetry, including (for instance) morphological inheritance, is important or of interest:

L438: "Importantly, restructuring and increasing the dimensionality of sediment transport in the model allows us to explore how the profile of the coastal system changes with the shape of the shoreline, as well as concepts such as morphological inheritance. Where this is considered particularly important or of interest, CEM2D would be the preferred model to use over CEM."

The ability to model a variable water level in CEM2D offers an advantage over CEM, particularly when considering the impacts of sea level rise over the timescales these models are intended for:

L457: "A key component of CEM2D is its variable water level, which offers an added advantage over the use of CEM particularly when considering the impacts of sea level rise over the timescales these models are intended for."