Author Response to Reviewer #2.

The comments in by Reviewer #2 are in font color black. The authors' responses are in green. The changes to the revised manuscript are in blue. The blue line numbers refer to the section and line numbers in the tracked changes version of the revised manuscript.

A Novel Approach

Anonymous Referee #2

Referee comment on "ArcticBeach v1.0: A physics-based parameterization of pan-Arctic coastline erosion" by Rebecca Rolph et al., Geosci. Model Dev. Discuss., https://doi.org/10.5194/gmd-2021-28-RC2, 2021

General description of the paper

First of all, thank you for allowing me to review the paper. The paper was well written, the problem statement and the solutions are explained in detail. The writers developed a simplified model for large scale modelling despite limited available measurements of the parameters. The authors coupled basically three major numerical modules with different physical processes like cliff and beach erosion with storm surge interactively. The models, albeit simplified, are based on real-world physics. The authors used mainly water level to calibrate the model. The other inputs of the forcing parameters like wind speed, wind temperature and water temperatures were taken from global models.

We sincerely thank the reviewer for his/her feedback on our manuscript, and appreciate the concise description above which we consider to be a very accurate summary of our approach and manuscript.

Major comments

Technical issues

[a] Uniform statistical distribution is used for sensitivity analysis. In Table: 1, a range of the most influential parameters are provided. The range for each environmental parameter is quite broad. Justification to apply uniform distribution is under question. Did the authors try any other distributions with central tendency?

We agree that the applied uniform distribution appears to be an arbitrary selection in the previous version of the manuscript. However, we argue that there is very limited range of observations available for the parameters examined (ground ice, sediment size, cliff height, and the other parameters listed in Table 1). Given that the prior probability distributions of these parameters are unknown, any other distribution would be arbitrary as well. A uniform distribution, however, avoids underestimation of parameter values close the assumed parameter limits. A statement justifying the use of a uniform distribution has been added:

Section 2.6, Lines 241-242: *"We chose a uniform rather than a central distribution because it provides a more comprehensive assessment of error, given that observations are relatively few and so we cannot confidently assess prior probability distributions."*

[b] The authors explained the effect and importance of the 'offset water level' as a proxy for some excluded physical process. Section 4.2.1 might be the place where it may be explained how water level offset indirectly compensates or estimates the notch erosion mechanism [authors did mention that the process is excluded in line 66 and also in Section#1 citing the notch erosion mechanism is not so common] Was equation#1 used to indirectly calculate notch erosion since the equation covers the portion of the cliff that is in contact with warmer seawater? This can be one explanation of why the model works despite excluding the block failure by the wave-created-notch mechanism.

Yes, we appreciate this comment and have now added the following statements to the manuscript that further elucidate and highlight our approach, which the reviewer has correctly explained above:

Section 4.2.1, Lines 432-437: *"Further, our goal is not to explicitly represent some site-specific processes such as notch erosion, but rather indirectly calculate the effects of seawater on retreat by using Equation 1. This approach leaves the opportunity to utilize ArcticBeach v1.0 on a range of coastlines that have different erosional processes which do not include notch erosion as a primary mechanism for retreat (see Section 2.1.3). Notch erosion is thus indirectly calculated in Equation 1 with the terms d_c (water depth at the cliff toe, which must be positive for the erosion module to be activated, see also Figure 1) and l_c which refers to the length of cliff exposed to the seawater."*

[c] Assessment of how the model is performing should be determined. As a proof of concept, the model makes a strong argument. However, the accuracy of the validation is still warranted.

We agree and we have now calculated the root mean square error of both the erosion module and the storm surge module. These have been added in a new table in the text and also in their respective places in the text:

Section 3.1, Lines 271:-272 *The root mean square error (RMSE) of simulated coastline retreat for MK is 7.84 m and 7.23 m for DP (Table 2).*

Coastline retreat [m]	*Water level [m]*
7.84 (MK)	*0.35 (MK)*
7.23 (DP)	*0.16 (Prudhoe Bay)*

Table 2. The root mean square error (RMSE) of simulated coastline retreat and water levels for the study sites. At DP, no observed water levels are available, so the water levels from the nearby tide gauge at Prudhoe Bay were used, as described in Section 2.4. Prior to calculating the RMSE of modelled water levels at Prudhoe Bay, the mean offset between the modelled and observed water level was first removed because the water level observations and water level model correspond different baselines (see Section 2.5).

Section 3.2, Lines 292-293: *"The RMSE for the storm surge model at the MK is 0.35 m. For Prudhoe Bay, the RMSE was calculated after removing the mean offset caused by a different relative baselines described above and was found to be 0.16 m (Table 2)."*

Added to caption of Figure 6: *"… relative to a theoretical still water depth…"*

We have also added the following statements that clarify when an over- or underestimation of modelled retreat occurs, due to our calibration setup:

Section 2.5, Lines 234-237: "*When the annual water level offset exceeds the median of the entire water level offset timeseries, it follows that the modelled retreat will be underestimated for that year, and vice versa. This is due to the calibrated summed water level that is applied to simulate erosion being lower than the annual water level necessary to reproduce the exact erosion rate for the given year."*

Section 3.1, Lines 259-260: *"This over- and underestimation is expected when we examine the annual water level offset values in comparison with the median water level offset value that was used in model calibration (Section 2.5)."*

Added to the caption of Figure 5 (previously Figure 4): "*The years when the observed retreat rates are under(over)-estimated are the same years when the annual values of the so-called 'water level offset', a proxy for the physical processes at this point unresolved by the model, are above(below) the median values. These years are indicated where the red star is above(below) the red dashed line in Figure 9* (previously Figure 8)*."*

Added to the caption of Figure 9 (previously Figure 8): "*When the annual water level offsets (red stars) exceed the median water level offset (red dashed line), the model predictably underestimates observed retreat rates (see corresponding years in Figure 5* (previously Figure 4) *and vice versa)."*

[d] A flow chart may be included in 'Chapter#2: Methods' to describe the methodology concisely. For example, it is not clear from the descriptions when and where the erosion process was 'not simulated' in the model. As understood, two binary switches (on/off) exist in the model: (1) the open water season in the time domain and (2) collapsed but not-yet-eroded sediments on the beach in the space domain.

We thank the reviewer for this suggestion. A flow chart has been added, and we feel that this comment has greatly improved the methodology section of the paper. The reviewer also had those two statements above correct, but to prevent any possible doubt by the reader, a flow chart becomes necessary. This figure has been added to Section 2: Methods of the manuscript:

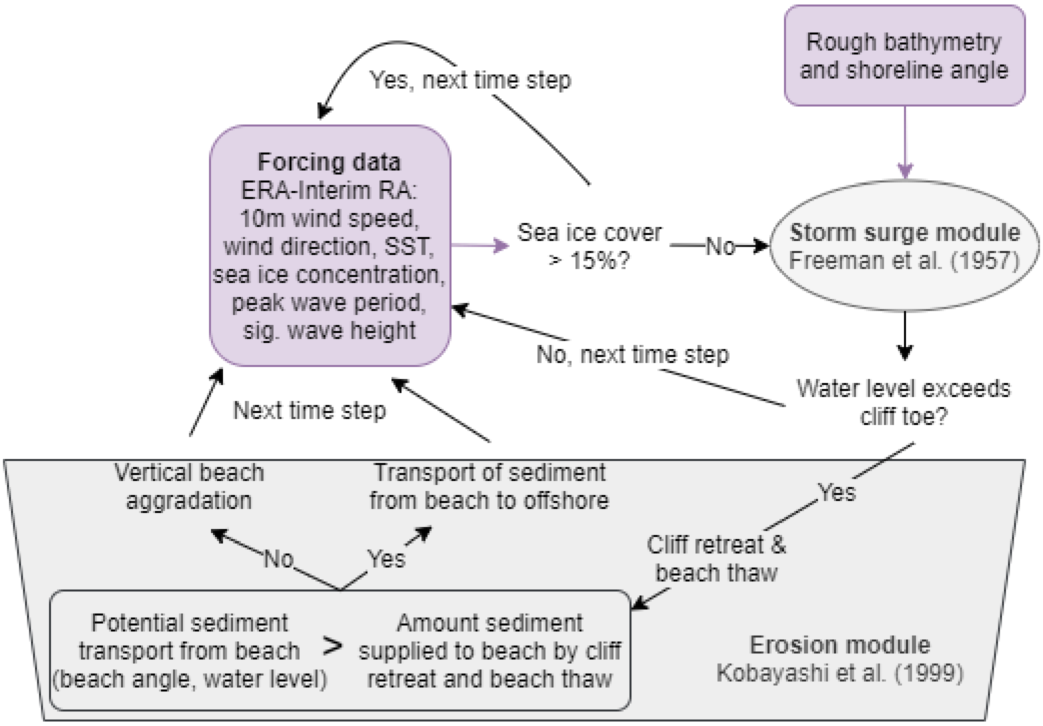

Figure 1. A conceptual flow chart summarizing the main inputs (purple) and processes (grey) of ArcticBeach v1.0. Climate forcing and rough bathymetry are used to drive a storm surge module (Freeman et al., 1957). The resulting water levels are then used to drive the erosion module (Kobayashi et al., 1999). A schematic of the erosion module is given in Figure 2. Under times of sea ice cover at the coast (assumed when sea ice concentration exceeds 15%), erosion is assumed to be negligible and neither module is activated.

Comments in general

Introduction

The introduction is well written. The requirement to establish a pan-Arctic level model is explained. The authors explained sufficiently the requirement of a simple physics-based model and the benefits of such a computationally inexpensive model.

We are glad that the reviewer thinks our introduction is well written and are also delighted to see that he/she sees the need for a computationally-inexpensive numerical model to simulate Arctic coastal erosion.

Methods

The conceptual models are explained in this section. The major numerical modules are erosion module comprising cliff and beach erosion based on thermal energy transfer from water to the cliff via convection and a quasi-steady storm surge model based on wind speed. The conductive heat transfer and solar radiation are not included in the model. The authors did not provide the explanation of excluding the other two heat transfer mechanism but it is reasonable to assume, the *solar radiation* is indirectly included in the seawater temperature inputs, whereas the effect of the *conduction* is ‘felt’ as time-lag which can be ignored when modelled for a long duration.

We appreciate that the reviewer has pointed out the two other heat transfer mechanisms of solar radiation and conduction. We also confirm that, indeed, we chose not to add to these in a new form in the Kobayashi et al. (1999) model (the erosion module of ArcticBeach v1.0). We have now added the following explanation to the manuscript:

Section 2.1.2, Lines 139-143: *"Consistent with the chosen erosion module in ArcticBeach v1.0, Kobayashi et al. (1999), conductive heat transfer and solar radiation are not directly included. Solar radiation can be partially accounted for in the sea surface temperature input and sea ice cover (see Section 2.3). Conduction effects are much smaller than effects of solar radiation over long time periods and are neglected. However, the opportunity to include effects of solar radiation can be implemented in later versions of the model, to include processes such as thaw slumping and 1-D heat-transfer permafrost models as described in Section 4.2.1."*

The authors correctly identified the problem of determining absolute water level at the toe of the cliffs and provided the detailed methodology of circumventing the issue and reaching a reasonable solution. A small description of the statistical method of Monte Carlo is also provided which might be elongated.

Yes, we have elongated the Monte Carlo section by now providing an example which we hope further clarifies our approach:

Section 2.6, Lines 246-250: *"To further illustrate our Monte Carlo method, we will use the example of how changes within a uniform distribution of observed ice content can be expected to change the modelled retreat rates. We ran ArcticBeach v1.0 a total of 500 times for each site, and for each model run, a certain percentage of cliff ice was assigned to a different value each time but within the observed range of 60-90% (given in Table 1). In this example, since all other parameters remained unchanged except ice content, this resulted in a distribution of retreat rates caused by changes in cliff ice content."*

Results

Results are discussed by comparing the outputs of the model with the observations. However, the estimation of the accuracy is not determined. One of the model outcome anomalies is the underestimate of the erosion from 2002 to 2009 is identified, but authors need to provide a strong explanation of the deviation.

We greatly appreciate this comment that the accuracy estimation was not clear enough in the manuscript. We would also like to refer our answer to this reviewer's related comment in letter [c] above, which explains how we addressed the validation of the model in the Results section.

Besides the other changes responding to letter [c] above, we made sure to explicitly mention the underestimation of erosion from 2002-2008:

Section 3.1, Lines 264-272: *"To further illustrate how we can expect when the model will over or underestimate observed retreat, we will take the example of the underestimation of coastline retreat at MK during the period of 2002-2008 (Figure 5a). This underestimation of retreat is caused by the annual water level offsets calculated for 2002-2008 being above the median water level offset used in the model forcing (see red stars above the red dashed line for 2002-2008 in Figure 9a* [previously Figure 8a]*). This means that the calibrated water* *level required to reproduce the observed retreat for 2002-2008 is higher than the median of the calibrated water level to reproduce the observed retreat across the entire timeseries. While bulk calibration inevitably leads to errors for individual years, we find this approach is still able to capture cumulative retreat over a long timeseries well (Figure 5c,d)."*

Grammar and Comprehension

The script is admirably laid out. It is recommended to re-write very few sentences (marked in the attached pdf)

We are glad that the reviewer found the manuscript easy to navigate, but also appreciate the grammatical corrections provided in the supplement. They have all now been implemented.

Abstract, Line 2: 'This change in climate…' to *'Climate change...'*

Line 43: 'than' to '*from'*

Line 191: 'come' to '*comes'*

Line 254: 'given to '*shown'*

Line 419-420: *'...on erosion rates than at MK because ...'* instead of '…of erosion rates than at MK. This is due to …'

Recommendation
The journal paper is recommended to publish with minor modifications. The work provides a novel approach to simulate coastal erosion. This is one of the early efforts to understand Arctic coastal erosion on a global level. The authors chose to use simplified models in favour of lower computation expenses and it is reasonable to exclude some physical processes. The novelty of the work is the coupling of the modules, calibration of the coupled model with water level and application of the model in two different sites.
Please also note the supplement to this comment:
https://gmd.copernicus.org/preprints/gmd-2021-28/gmd-2021-28-RC2-supplement.pdf