

Response of tidal flow regime and sediment transport in North Male' Atoll, Maldives to coastal modification and sea level rise

Response to anonymous referee-2

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1 Introduction

The authors would like to thank the anonymous referee for taking the time to provide a comprehensive review of the submitted manuscript. We are glad that the referee found that the paper reads well and the overall methodology is ok.

Below, we respond to each of the comments from the referee, and provide a summary of the corresponding changes made.

5 Our responses to the comments are presented in blue italics, and any corresponding modifications to the manuscript are presented in framed boxes.

2 Response to Comments

1. Wind forcing is either not included in your model or simply not described. From the remaining text I understood the first thing, as e.g. "*.. wind driven sediment can be incorporated into the model, however this requires field data currently not*
10 *available for model setup and calibration.*" However, throughout chapter 2 it is often stated that wind dominates the sediment transport in the study area, e.g. "*... studies suggest a wind dominated sediment transport pattern for shallow lagoon areas of the Maldives archipelago*". How can you come up with results like "*The grain sizes predicted by the model compare well with qualitative and quantitative data reported at the coral atolls of the Maldives archipelago, demonstrating that correctly configured tidal models can be effectively used to determine dominant grain size in coral atolls at the atoll*
15 *scale.*", if the major driver is not considered? Do you have a tide-only observation available that allows to draw these conclusions? At this point I would expect a more critical and transparent discussion of the issues/drawbacks related to your setup.

20 *We appreciate that oceanographic wind and wave driven processes drive the sediment change in shallow areas, particularly in and around the surrounding areas of islands. Because these areas are easy to access, the impact of coastal modification and other factors at these locations have been studied by different authors. However, here we focus on the wider atoll basin where the tides dominate the flow. We have highlighted this in several areas of the manuscript, and also included this as a caveat in the areas for improvement and also introduced a new paragraph as below to highlight the issue.*

The impact of wind driven sediment processes has been discussed in several studies, as presented in section 2.3.1, particularly with respect to the attempts to understand the formation of the Maldives, and the presence of faros in the atolls of the Maldives has been attributed to the influence of the changes in the monsoonal wind patterns (Purdy and Bertram, 1993),(Naseer and Hatcher, 2000). However, studies such as Gischler (2006), which attempted to statistically correlate the presence of geomorphological features in the atolls of the Maldives with various different geological parameters, found that wind speed does not have a significant statistical correlation with the abundance of faros and lagoon reefs within the larger atoll basin. Further, the correlation between both the number of lagoonal faros and marginal faro areas with the wind stress were found to be statistically insignificant. Additionally, studies also show that the island shape influences the morphological change of the islands more than wave exposure (Kench et al., 2009). This provides more support to the case that, while winds contribute significantly to the sediment processes in shallow water areas of the atoll (atoll lagoons) (which constitute a small area of the wider atoll basin, as illustrated in grey in Figure 1(b)), the wind influence decreases at larger depths and the tides are the major driver of the sediment transport processes at these depths.

- 25 2. You also mention that "The combined tidal- and wind-driven currents can exceed speeds of 2 m s⁻¹." Any idea regarding the magnitude of tide-only induced currents? Maybe this allows to estimate the proportion of sediments transported from tide-only runs.

30 *Detailed studies of flow velocities for any part of the Maldives is not available in the public domain, making it a significant obstacle to validate the tidal velocities. The tide gauges in the country only record tidal elevations. We quoted one-off figures from the literature which provide indications of the surface current velocities at different locations in the country, and we find that the tidal model can account for a significant percentage of the tidal velocities quoted. However, without validation data we have not quoted the tidal velocities in the manuscript.*

3. Line 30: Haigh et al. (2019) should be cited as it provides the most comprehensive review on tides and tidal changes...
<https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1029/2018RG000636>

35 *We thank the referee for pointing to this comprehensive reference; we have now quoted this study.*

4. Line 173/177 and elsewhere: add Yr or in review to ref. (Rasheed et al.)
We have amended this reference.

5. Line 184: check if this sentence is correct. Seems to be wrong... At least I do not get the message!

We have rephrased the sentence as below as it appears to be confusing. No global coastline dataset provides an accurate depiction of the coastlines of the Maldives, hence we used satellite imagery to derive the coastline data for all islands in the domain for meshing.

Coastline data for two model setups, corresponding to present-day and 1997 coastlines, were extracted from a variety of sources, since widely used global coastline data-sets do not accurately capture all islands within the domain, and no coastline data-sets exist with historical data.

6. Line 313: "Next, we classified the bottom bed sediment for the simulations carried out using the 1997 coastline scenario, as well as under SLR of 2 m." Why did you choose a SLR of 2m? Any justification? *We have rephrased and added the following paragraph to justify the use of 2m SLR. Further, as the paper is concerned with comparing the changes to the sediment of the atoll basin arising due to SLR in the long term and coastal modification in the short term, we believe 2m represents a reasonable choice.*

While it is clear that global mean sea level is rising (e.g., Church and White, 2006; IPCC et al., 2007; Church et al., 2013), the extent and rate of sea level rise is the subject of significant ongoing research. Analysis of long-term tide gauge data (Caldwell et al., 2015) at Hulhule' Island harbour indicates a current local mean sea level rise of ~4.46 mm per year, with an accelerating trend, which is in line with recent studies which quote a SLR rate of 3.93 mm per year over the period 1993–2018 for the Indian Ocean and the South Pacific obtained from observations of sea level (Frederikse et al., 2020). Some sources predict a global rise of 0.75 m to 1.9 m by 2100 (Bindoff et al., 2007), while others predict much larger increases in sea level (Vermeer and Rahmstorf, 2009). The Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC) proposes that a SLR of 1.0 m is unlikely before 2100 (Church et al., 2013). Additionally, studies of glaciological conditions leading to sea level rise indicate that a rise of more than 2 m is unlikely (Pfeffer et al., 2008). Reflecting this, studies incorporating sea level rise scenarios have used varying rates of increase when studying impacts using numerical models. Ward et al. (2012) used a 5 m rise in sea level to study the response of shelf seas to SLR, Pelling et al. (2013) used a SLR of 2 m to study the response of tides in the Bohai Sea and Jiang et al. (2020) used successive rates of SLR up to 2 m to study the response of tides to SLR in a tidal bay. In line with these studies as well as Bamber et al. (2019), which suggests the use of a global total SLR of 2 m for planning purposes in the 21st century, in this work we also consider a SLR of 2 m. This is an important figure as the islands of the Maldives generally have maximum heights of just over 2 m above sea level. Here we make the simplifying assumption that coastlines remain unchanged during the SLR process. This assumption holds true for many of the current coastlines of North Male' atoll, which are completely or partially protected by artificial barriers. While at other locations this assumption is admittedly hard to justify, we feel this is a reasonable and reproducible choice that avoids the addition of further uncertainties over how the coastlines will respond naturally and anthropologically to SLR.

7. Line 343: "... in global mean sea level"

Amended as suggested.

50 8. General comments on the SLR part: The references are rather old and a lot of progress has recently been made regarding SLR projections and individual contributors. You should at least refer to the latest SLR projection from the AR5 and additionally taking recent process understanding (see e.g. Frederikse et al., 2020; <https://www.nature.com/articles/s41586-020-2591-3>) on ice sheet contributions into account (see e.g. Edwards et al., 2019; <https://pubmed.ncbi.nlm.nih.gov/30728522/>). The entire part on SLR seems a bit antiquated. *We have amended and revisited the SLR section completely as per the referee suggestions and included the suggested references as well.*

55 9. Line 348: "...which represents an upper limit of current predictions of SLR to be reached in a century." Says who?

We have amended and revisited the SLR section completely as per the referee's suggestions.

3 Conclusions

We have made revisions to the manuscript as highlighted by the referee and we hope that these revisions are satisfactory. Further, we have provided responses to the issues raised by the referee particularly in relation to wind driven processes which
60 are not discussed in the paper, as well as the assumptions on SLR and its impact on the coastlines. We hope that the responses are acceptable to the referee.

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