

Response to comments of Referee 1: "The role of the reef-dune system in coastal protection in Puerto Morelos (Mexico)"

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by Gemma L. Franklin, Alec Torres-Freyermuth, Gabriela Medellin, María Eugenia Allende-Arandia, Christian M. Appendini

Referee #1:

Review of "The role of reef-dune systems in coastal protection in Puerto Morelos (Mexico)" by Franklin et al. This paper presents an analysis of the combined impact of reef and dune degradation on determining storm impact. In general I found the paper interesting and conclusions primarily supported (and very timely given recent events), but the analysis a bit lacking. See my detailed comments below, but my general recommendation is that this paper needs a major revision prior to publication. The numerical simulations conducted by the authors can provide much more information about what is causing the observed runup extremes and it would be good to delve a bit deeper into what is going on.

RESPONSE: We thank the referee for his/her comments which have helped us improve the manuscript. A detailed point-by-point response to the referee's comments is provided below. Following the referee's suggestion the revised manuscript includes: (i) a more thorough analysis on the role that storm surge has in the storm impact, and (ii) a detailed study of runup dynamics.

Specific comments

1. Pg 3, lines 5-15. A majority of this information is not relevant, e.g. annual temperature and rainfall do not impact the runup.

RESPONSE: We agree with the referee and hence most of this information has been removed from this section in the revised manuscript. The following text has been removed from the manuscript:

"The climate in the region is hot and humid with a mean annual air temperature of 26.4°C, a maximum of 34.5°C in the summer and a minimum of 13°C in the winter (Merino and Otero, 1991). Rainfall is present all year round, although more intense during the summer, with a mean annual rainfall of 1,041 mm (Caribbean Coastal Marine Productivity Program: CARICOMP, unpublished data for the period 1993-1998). Evaporation varies from 102 mm in December to 178 mm in May (Merino and Otero 1983). The mean relative humidity is 84% (CONANP 2000). The water temperature at the bottom of the lagoon varies seasonally by around 5°C, from 31-32°C in August and September, to 24-25°C between December and March (Coronado et al., 2007)."

2. Pg. 4, line 10. Please specify which model.

RESPONSE: The name of the model and reference have been included. The text has been changed to:

"These data were estimated using the third-generation spectral wave model MIKE 21 SW (Sørensen et al. 2004) forced with wind data from the North American Regional Reanalysis (NARR) (Mesinger et al., 2006)."

3. Pg. 4, line 13. A high r2 does not indicate model performance unless coupled with the regression

slope. The r^2 only tells you how well a model reproduces the variance.

RESPONSE: Further information on the model performance has been included.

"...The mean observed wave height (H_s) and peak period (T_p) were 1.22 m and 6.70 s respectively, compared to the mean reanalysis/hindcast values of 1.31 m and 7.27 s (Rms of 0.33 H_s and 1.59 for T_p with correlation coefficients of 0.90 and 0.51)..."

4. Section 3. I do not see the point in including the flume experiments in this paper. You are essentially calibrating the model on an unrelated data set for a reef/beach profile that was not made to replicate your field site. Essentially you are just showing that SWASH works on reef profiles which has already been shown (Zijlema, 2012, Buckley et al., 2014). Additionally, and while it is unfortunately the case, showing that the model is calibrated at one site does not mean it is calibrated at all other sites. As a result, my preference would be to entirely remove the discussion and comparison with the flume results and use the extra space to further develop the results as they result to the field site. Also I found the discussion of the runs with and without the reef crest confusing.

RESPONSE: The referee's comment is consistent with those from the other two referees in the sense that there is no added value by including the flume experiments in this paper. Therefore, the section on the model validation employing laboratory data has been removed. Therefore, in the revised manuscript we have made reference to previous studies where the model has been validated for reef profiles. The following text has been included in the revised manuscript:

"The model is also capable of simulating wave-current interaction, wave breaking (Smit et al., 2013; de Bakker et al., 2015), and wave-runup (e.g., Brinkkemper et al., 2013; Ruju et al., 2014; Guimarao et al., 2015; Medellín et al., 2016). Furthermore, previous studies (Torres-Freyermuth et al., 2012; Zijlema et al., 2012; Buckley et al., 2014) have shown good agreement on simulating wave transformation on reef profiles."

5. Figure 1. Can the inset be made a higher resolution and zoomed out a bit to provide more geographic context?

RESPONSE: Following the referee's suggestions Figure 1 has been modified to provide a better geographical context and improve its quality. The revised Figure 1 is shown below.

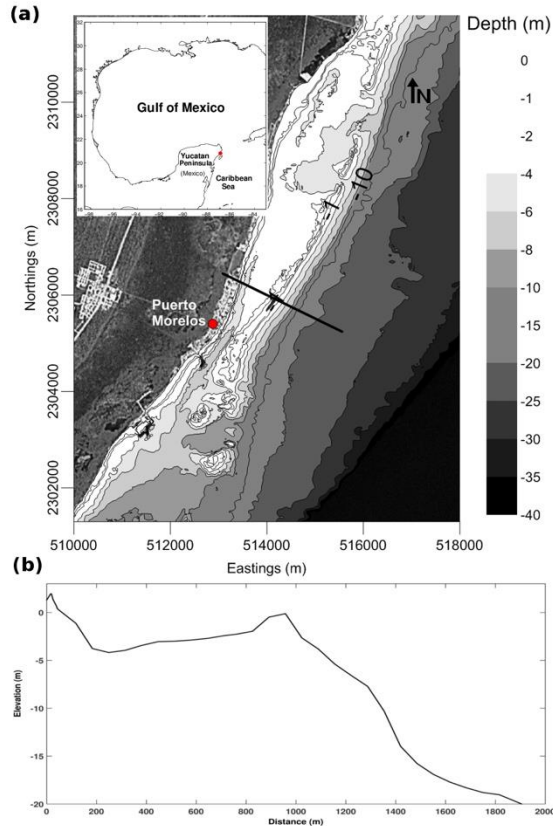


Figure 1R. (a) Map of the study area in the Gulf of Mexico. The solid black line indicates the location of the bathymetric transect used in the numerical model. (b) Bathymetry obtained from the transect indicated on the map (bathymetry courtesy of CONABIO), including a beach profile surveyed in March, 2014 (courtesy of CINVESTAV-Merida).

6. How long is each simulation run for? This is important in determining the validity of the statistics which include long waves.

RESPONSE: The SWASH simulations were run for 3200 s (see line 23, page 6 of the original manuscript), which were sampled for 2700 s after accounting for model spin-up time, considering a constant water level. The simulation time is sufficient to account for long wave statistics.

7. Page 6 line 26. Extreme runup is defined inconsistently.

RESPONSE: We thank the referee for pointing out this inconsistency. Extreme value statistics of runup, often defined as the elevation exceeded by only 2% of runup, is denoted by $R_{2\%}$ (Homan, 1986).

8. Page 6. Line 30. I am confused about the definition of R_{low} . The setup is the average runup so why is this no R_{avg} ? Also it would be helpful to remind the reader that here Z is the tidal level.

RESPONSE: Here, R_{low} is adopted from a previous study (i.e., Sallenger, 2000) where the storm impact scale was introduced for the first time. The term R_{low} consists of the average runup (setup) plus the tidal level and, where applicable, the storm surge. Thus, it represents the low extreme sea level resulting from the aforementioned contributions, which is then compared with morphological features in the beach profile. Therefore, we have maintained this terminology for consistency with previous work (e.g., Stockdon et al., 2007; Medellín et al., 2016; among many others). The revised manuscript includes the following text for further clarification:

“ R_{low} represents the low extreme sea level resulting from the setup, tidal level and storm surge contributions consistent with Sallenger (2000).”

9. Page 6 line 32. As is sort of acknowledged in the discussion, not including surge is a huge limitation of the approach. As the depth of reef submergence directly effects the short wave transmission across the reef the surge is critical in determining the runup (in addition to the fact that the surge adds to the water level from which waves runup). Could you not include this for the simulations suing the hycom model? I find this a major limitation of the current study. High surge also acts as a proxy for the reef degradation, and thus neglecting surge probably causes your results to underestimate the occurrence of over topping.

RESPONSE: We agree with the referee on the importance of including the storm surge. The reason for not including the storm surge contribution in the previous version of the manuscript is the lack of long tidal records in the study area and that the Hycom data only encompasses 16 years of the 30 years of data corresponding to the wave hindcast information. However, we recognise the importance of studying the role of the storm surge using the available information. Therefore, the numerical model has been re-run selecting 300 representative cases, for the 16-year Hycom period (using the same methodology as for the 30 year hindcast), using both the sea surface height obtained from Hycom (including storm surge) and considering only the predicted tide. The numerical results made it possible compare the effect of including this contribution on the extreme water levels and the storm impact. Figure 2R shows R_{high} as a function of the return period while considering the two different scenarios. An increase in R_{high} is observed when storm surge is included. This increase is important since, as recognised by the referee, it acts as a proxy for degradation. When excluded it results in an underestimate of the effects of reef degradation on runup and hence coastal flooding. However, the effect of the storm surge (for the time period available) was smaller than the effect of the reef degrading by 1.1 m but slightly greater than the reef degrading by 0.3 m, particularly for return periods of less than 3 years. These new results are incorporated in the discussion of the revised manuscript.

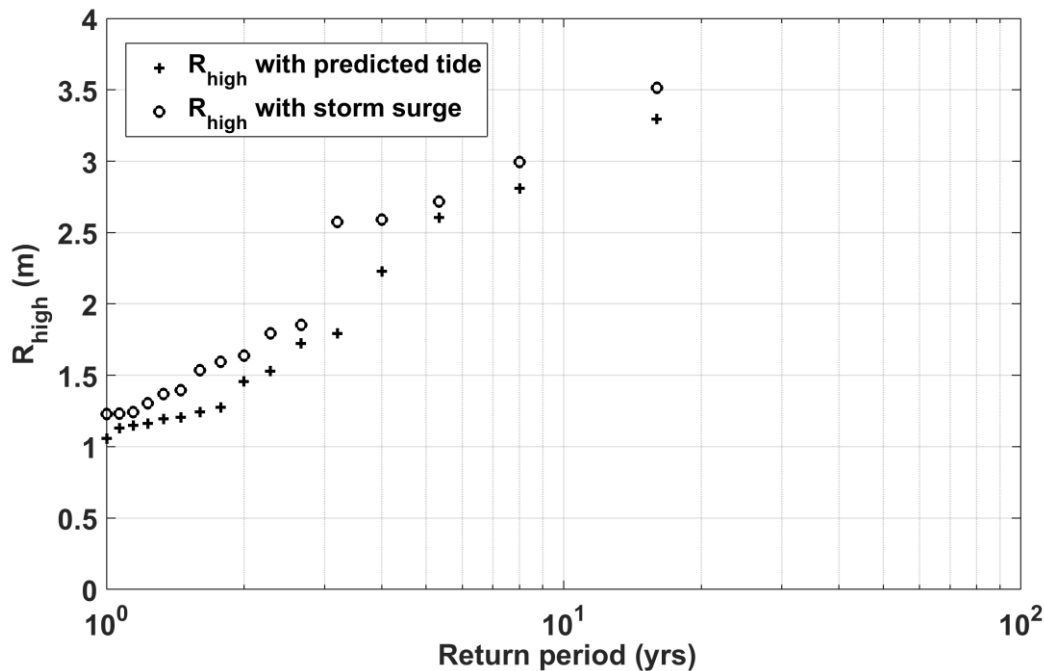


Figure 2R Return value of R_{high} for the model run with the storm surge (open circles) and without (crosses) for the time period of 1993-2008.

10. I think the results section could be considerably beefed up. By using a phase resolving model you allow for a lot of information on the runup dynamics to be gleaned. As has been demonstrated in the available literature reef/lagoon systems can often act as open basins and thus have the potential to enhance/trap IG energy.

RESPONSE: By removing the section on the laboratory validation, there is more room to look into the results in greater detail. Thus, analyses on runup dynamics are further investigated following the referee's suggestion.

Incident and infragravity swash height have been analysed using the parameterisations proposed by Stockdon et al., (2006). For beaches, these authors found incident swash height (S_{inc}) to be best parameterised by a dimensional version of an Iribarren-type relationship ($S_{inc}=0.75\beta(H_0L_0)^{1/2}$, where β is the beach face slope, H_0 and L_0 incident wave height and length respectively). Fig. 3Ra shows the incident swash height for the present study (high and low water contributions are presented in green and red respectively). The 15% exceedance value of water level according to the astronomical tide Z was used for high ($Z \geq Z_{15\%}=0.1636$ m) and low water level ($Z \leq Z_{15\%}=-0.1636$ m). As shown in the figure, Stockdon's parameterisation works fairly well for S_{inc} , particularly for high water levels, although it slightly over predicts the numerical results. Figure 3Rb shows the results of using the same parameterisation for infragravity swash height (S_{ig}), as well as the effect of replacing the beach slope parameter (β) with the reef face slope (β_{reef}) (blue vs. cyan line), which results in an improved fit. Stockdon et al. (2006) found that by excluding beach slope in the parameterisation resulted in the best fit for S_{ig} (Fig 3Rc), which also works fairly well for the high water level S_{ig} values for the present study, although less applicable for more energetic waves. A notable difference between the runup contributions on reef-protected beaches with respect to sandy beaches is that S_{ig} contributions were considerably larger. In order to look at this further, S_{inc} vs. S_{ig} variance was plotted against the Iribarren number (Fig. 4R), showing a clear dominance of S_{ig} contributions under practically all wave conditions. This demonstrates a key difference in the swash contributions on beaches compared to reef environments, where infragravity dominates.

With regards to wave setup $\langle \eta \rangle$, the parameterisations presented by Stockdon et al. (2006), with (a) and without (b) beach face slope, underestimate wave setup for a reef environment (Fig. 5R). The effects of the relative contributions of high and low water to wave setup are less obvious for this profile than for sandy beaches (e.g. Medellin et al., 2016). When the slope of the reef face is used instead of the beach face slope, the parameterisation improves (cyan versus blue line Fig. 5Ra), although it still underestimates the setup values. In the case of the reef environment, there are two setup contributions, one where waves break over the reef and a second at the beach. When both slopes are included in the parameterisation, the fit improves further (not shown).

Finally, when analysing $R_{2\%}$ and comparing it to the complete parameterisation by Stockdon et al. (2006) for beaches, the fit improves considerably when the reef face slope is used instead of the beach face (Fig.6R). However, the runup parameterisations fail to predict the runup during extreme wave conditions. This is mainly ascribed to the underestimation of wave setup. Ongoing work is devoted to improving such parameterisations by incorporating the reef geometry characteristics in new runup parameterisations.

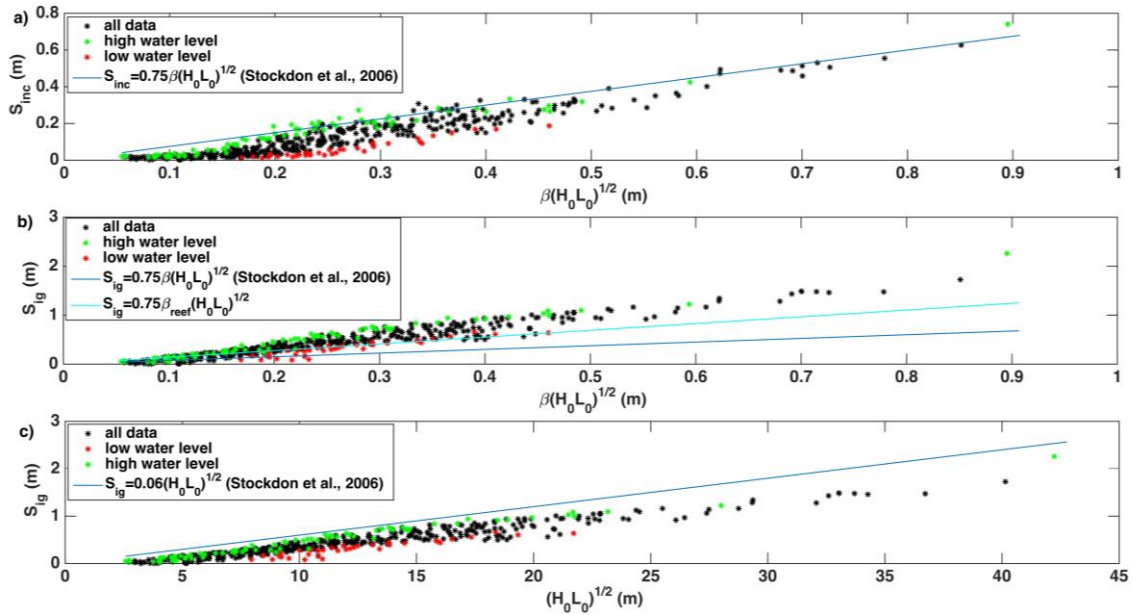


Fig. 3R a) Incident and b) infragravity wash parameterised in a dimensional form of the Iribarren equation and in comparison to Stockdon et al. (2006) (blue line) and a modified form, which includes the reef face slope (cyan line), and c) the parameterisation of S_{ig} excluding the beach slope as suggested by Stockdon et al. (2006). Black dots represent all data, green the values associated with high water levels ($Z \geq Z_{15\%} = 0.1636$ m) and red those associated with low water levels ($Z \leq Z_{15\%} = -0.1636$ m).

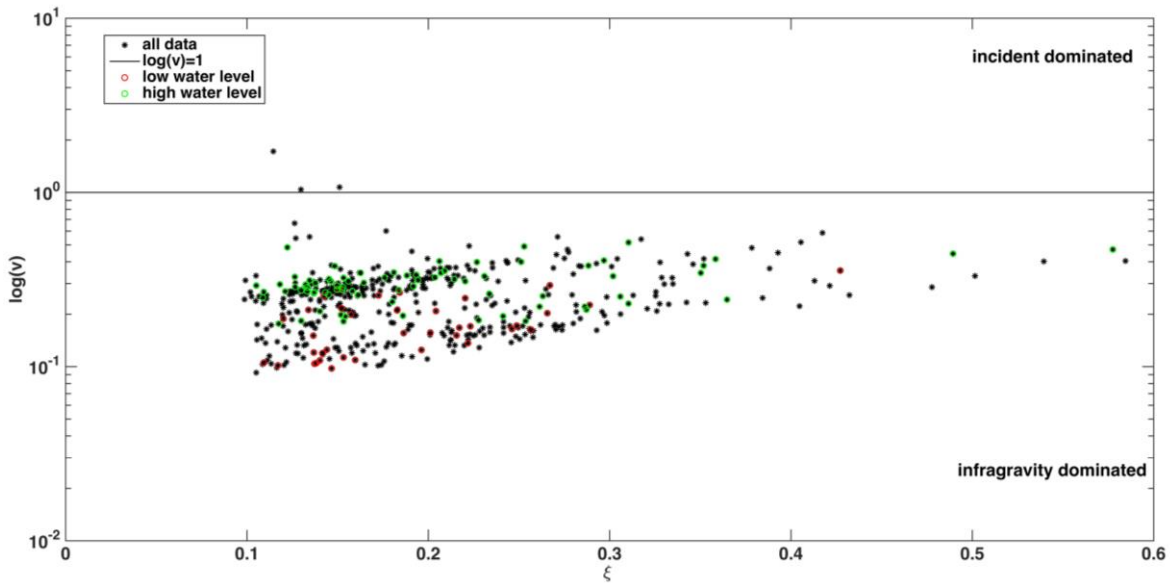


Fig. 4R Ratio of incident to infragravity wash variance (v) against the Iribarren number. The solid line at $\log(v)=1$ divides incident (above) from infragravity (below) dominated values. Black dots represent all data, green the values associated with high water levels ($Z \geq Z_{15\%} = 0.1636$ m) and red those associated with low water levels ($Z \leq Z_{15\%} = -0.1636$ m).

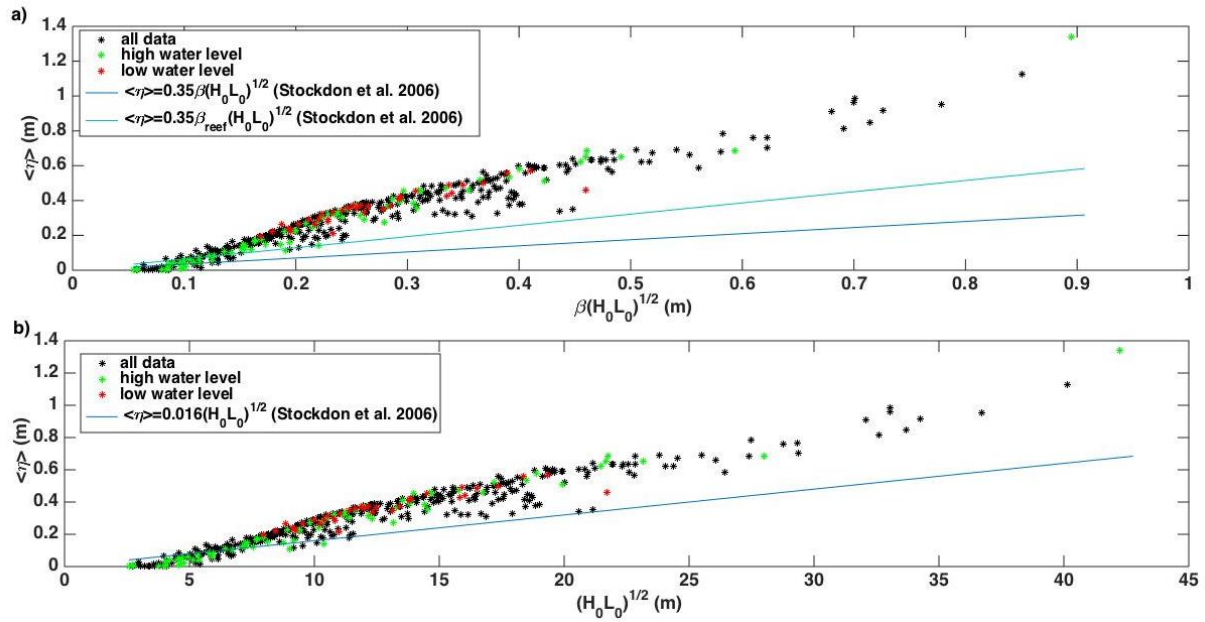


Fig. 5R a) wave setup parameterised in a dimensional form of the Iribarren equation and in comparison to Stockdon et al. (2006) (blue line) and a modified form, which includes the reef face slope (cyan line), and b) the parameterisation excluding the beach slope as suggested by Stockdon et al. (2006). Black dots represent all data, green the values associated with high water levels ($Z \geq Z_{15\%} = -0.1636$ m) and red those associated with low water levels ($Z \leq Z_{15\%} = -0.1636$ m).

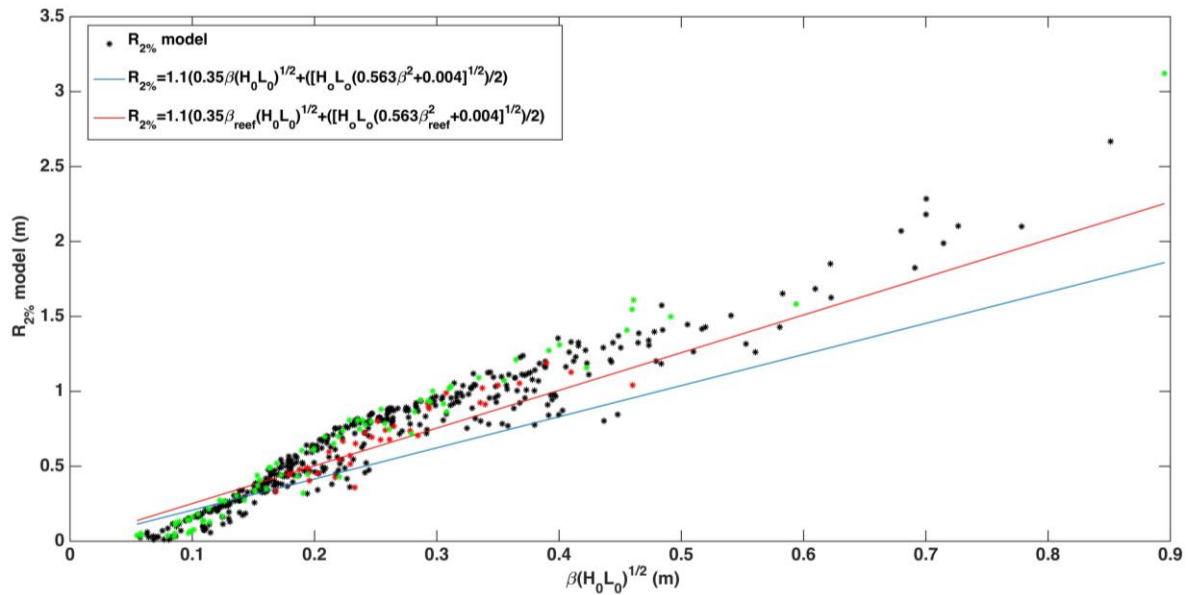


Fig. 6R Extreme runup values ($R_{2\%}$) for the 30 year hindcast data and the complete parameterisation suggested by Stockdon et al. (2006) with the beach face slope (blue line) and reef face slope (blue line). Black dots represent all data, green the values associated with high water levels ($Z \geq Z_{15\%} = -0.1636$ m) and red those associated with low water levels ($Z \leq Z_{15\%} = -0.1636$ m).

11. I like the inclusion of the dune height in the analysis but wonder if treating the dune as an un-erodible feature underestimates the overtopping.

RESPONSE: The current model does not have the option for treating the dune nor the beach as erodible features, and is beyond the scope of the current study. However, a discussion on such limitations is now

included in the manuscript:

“The present approach does not consider the dune or the beach as erodible features. Both play an important role in energy dissipation and hence further research is warranted to investigate their effects on wave overtopping.”