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10A Modelling reef futures

Climate impacts on hydrodynamics and sediment dynamics at reef islands

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Abstract. This paper investigates the impacts of coral reef morphology and surface roughness on the islands protected by them under different Sea Level Rise (SLR) scenarios. To address this, a simplified coral reef profile was considered. A one dimensional SWAN wave model was setup and run for a large number of different cases of top reef width and depth, lagoon width and depth and surface roughness for a representative mean climate of the Great Barrier Reef (GBR) islands and different SLR scenarios. It is concluded that any change of surface roughness, and reef flat depth and width because of climate change leads to significant changes of water orbital motion and nearshore wave height which are important for ecological processes and longshore sediment transport.

Key words: Reef Islands, Great Barrier Reef, SWAN model, Sea Level Rise.

Introduction

Reefs protect the shore of many tropical islands and beaches from waves. The impact on coral reefs from predicted further rising sea level has been addressed by a few researchers (Graus and Macintyre, 1998; Sheppard et al., 2005; Ogston and Field, 2010; Storlazzi et al., 2011). Potential impacts of climate change on cyclones, SLR, and coral may reduce the effectiveness of fringing and barrier reefs as protection for islands. Increased storminess generates larger waves, and SLR creates deeper water over reefs and lagoons, allowing larger waves, with possibly a different direction to that of the locally generated waves to reach the shore. This leads to a potential significant change of magnitude and direction in wave energy flux at the shore and increased risk of beach erosion.

The impacts of selected aspects of climate change on a sand-cay shoreline within a platform reef under two plausible scenarios are investigated here. Firstly, if coral growth does not keep pace with SLR; secondly, if corals die due to ocean warming and acidification. In the former scenario, reefs may survive but the islands they shelter maybe destroyed or significantly degraded. In the second scenario, both reefs and shoreline will suffer, but coral death elevates the level of bio-eroded sediment supplied to the system and this may partly buffer the impact of SLR on beach erosion.

To address these objectives, a shallow water wave model is setup for an idealized cross section of a fringing coral reef system to access the reef hydrodynamics under the different SLR scenarios. The wave model is used to drive an equilibrium-state shoreline parametric model for reef-islands, which is used to assess the response of the reef-island system to changes in relative crest level and sediment production.

Bathymetry Profile

The idealized cross section of a fringing coral reef considered in this study includes a sloping fore-reef, a shallow top reef flat, a sloping back-reef, a deeper lagoon, and the shore (Fig.1). It is assumed that fore-reef and back-reef have slope of 1:2 (26 degrees), beach has slope of 1:10 (6 degrees), and a depth on the outer fore-reef of 50m. Different values of top reef width and depth and lagoon width and depth are considered here, which comprise in total 540 varying bathymetries. These values are considered according to existing reef dimensions in GBR, with emphasis on Lizard Island (14.67˚S, 145.47˚E) as case study (Fig.2). Lizard Island is located 100 km north of Cooktown within the main GBR lagoon.

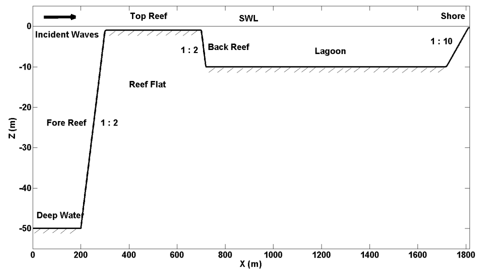

Figure 1: An idealized cross section of a fringing coral reef (scale of axes is not equal).

The base profile used for comparison in this study has top reef width of 400m, depth of 1m, lagoon width of 1000m, and depth of 10m. This profile is assumed to be the most representative of the main reef at Lizard Island according to the available profile survey data in the area.

Figure 2: Lizard Island, located 14.67˚S, 145.47˚E in the Great Barrier Reef lagoon, with surrounding lagoon depth ranging between 20 m and 30 m. (Google Earth)

Coral Surface Roughness

Grain, vegetation, saltation and bed form roughness specify the value of surface roughness in the wave model. Sheppard et al. (2005) recommended friction factor (fw) of 0.1 for a smooth and 0.2 for a rough healthy coral reef from the measurements performed by Nelson (1996) which are equal to Nikuradse roughness (Kn) of 0.04 for smooth and 0.1 for rough reef based on the Madsen formulation in SWAN model. It is assumed that reef has a constant friction coefficient in the whole domain, but it is only a significant factor in shallow areas.

Wind and Wave Climate

Different sources of wind and wave climate are available in the vicinity of the study area. ERA-40 (1958-2001) and ERA-Interim (1989-present) global hindcast wind-wave models from European Center for Medium-range Weather Forecasts (ECMWF) with temporal resolution of 6 hours and spatial resolution of 1.5 degree have long duration of data. However, because of their coarse resolution they do not resolve very well reefs and reef islands. Hardy et al. (2000) have run a local wind-wave model for the GBR with temporal resolution of 1hr and spatial resolution of 1500m covering 1996-2003 (GBR wind and wave atlas). With this resolution, Lizard Island is well resolved and data are available inside (20m depth) and outside (30m depth) of the lagoon. However the duration of this hindcast model is only for 8 years (1996-2003) which is insufficient for accurate modeling.

The Cairns wave buoy is located 240km south of Lizard Island and has the longest wave data record in the GBR lagoon (1975-present). This buoy is located in depths of 15m. Based on these buoy records and their comparison with the GBR wave atlas at a point outside of the Lizard lagoon, waves bigger than 30cm (occur > 85% time) are clustered into 10 groups as shown in Table 1. This table is assumed to be a representative of the wave climate in this area.

Category No.	Hs (m)	Tp (s)
1	0.3(33.9%)	6 (12%)
2	0.5(29.5%)	4 (14.6%)
3	0.75(14%)	4 (11.7%)
4	1 (5.3%)	4 (4.9%)
5	1.25 (1.1%)	4 (1.2%)
6	1.5 (0.05%)	6 (0.02%)
7	1.75 (0.02%)	6 (0.01%)
8	2 (0.01%)	6 (0.01%)
9	2.5 (<0.01%)	6
10	3 (<0.01%)	6

Table 1: Wave climate and percentage of occurrence based on Cairns buoy records and GBR wave Atlas and where Hs is the significant weight height and Tp is the peak wave period.

The Green Island synoptic wind station is located 240 km south of Lizard Island and has recorded wind data since 1993 to present. Based on these station wind records and their comparison with 8 months of Lizard Island wind data and the GBR wind atlas at the nearest point to Lizard Island, winds are clustered into three main groups (Table 2). These tables show that the most probable boundary condition (mean climate) is a significant wave height (Hs) of 0.5m with peak wave period (Tp) of 4 sec and wind speed (WS) of 10 m/s. This is modal wind speed and wave height in natural distribution. We assume that this mean condition will not be influenced by climate change in this study.

Category No.	WS (m/s)	Mean WS (m/s)
1	5 < (21%)	2.5
2	5-15 (78%)	10
3	15-25 (1%)	20

Table 2: Wind speed and percentage of occurrence based on Green and Lizard Islands wind station records and GBR wind Atlas.

Sea Level Rise Scenarios

Considering all different scenarios of SLR and coral death (which creates pseudo SLR), 4 cases of total SLR of 0 (i.e. coral growth keeps up with SLR), 25cm, 50 cm, and 1m (i.e. corals do not keep up with SLR) are chosen for wave modeling in this study.

SWAN model

SWAN is a third-generation wave model that computes random, short-crested wind-generated waves in coastal regions and inland waters (Booij et al., 1996). This model can be run in one dimensional mode and in this case can compute wave induced setup based on exact momentum balance equations.

For different bathymetries (top reef depth and width, lagoon depth and width and surface roughness), and different climate condition (wave, wind and sea level rise), 129600 different cases of the 1D model are setup and run. Friction is based on the Madsen formulation (1988), breaking based on the Battjes and Janssen formulation (1978), and triad interaction and wave setup are enabled in all runs. It is assumed that wind and waves are in the direction of the reef profile and wind is constant over the whole domain. A spreading index of 2 is considered for the parametric wave conditions. The sensitivity of the model to spatial resolution was also investigated and a resolution of 5m was considered as an optimum resolution, which has enough accuracy but which is also time-efficient.

Results and Discussion

A change in wave height influences the amount of energy arriving along the coastline, and in turn, longshore currents and longshore sediment transport. The water orbital motion is known to control a number of key ecological and biogeochemical processes on coral reefs, such as biogeographic zonation, rates of nutrient uptake by coral reef communities, and the transport and dispersal of larval coral and other reef organisms. The effects of changing variables including the surface roughness, the reef flat depth and width and the lagoon width and depths on nearshore Significant Wave Height (SWH or Hs) and the orbital motion near the bottom (Urms) in the middle of the reef flat are discussed here.

Fig. 3-4 show the effect of surface roughness on wave height and orbital velocity for a mean climate condition (Hs=0.5m, WS=10m/s). Decreased surface roughness causes bigger waves reach to shore and larger water motion on the top reef. Coral mortality, because of global warming and SLR, can affect the magnitude of surface roughness, as well as distribution of coral species on the reef.

Fig. 5-10 show the effects of the reef profile dimensions on nearshore wave height and orbital motion in the middle of a rough reef flat for a mean climate condition under different SLR scenarios. According to these figures, for all scenarios, wave height increases when reef flat width decreases and reef flat depth increases. Increased lagoon width increases nearshore wave height because of a greater fetch length, while changes to lagoon depth are insignificant. Orbital velocities decrease as reef flat width increases, while they first increase and then decrease when reef flat depth increases, except for 1m SLR scenario which has a decreasing trend.

It is concluded that any change of surface roughness, and reef flat depth and width because of climate change results in changes to water orbital motion and nearshore wave height, which are important for ecological processes on coral reefs and longshore sediment transport at the shore. Effects will be site specific, for example, a narrow reef responds differently to a wide reef, and deeper reefs have different response to shallow reefs. Further application of this method would provide curves that may be used to determine SLR influence for a wide range of reef bathymetry, as well as changes to existing bathymetry at a particular reef.

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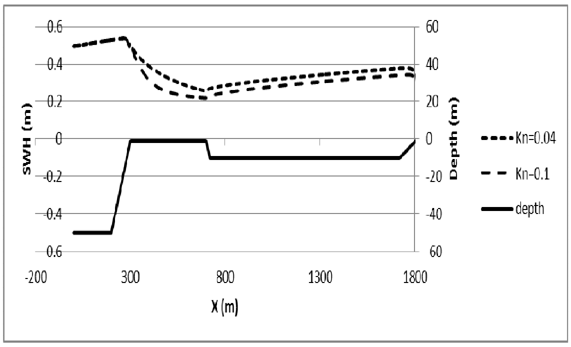

Figure 3: Effect of surface roughness on SWH

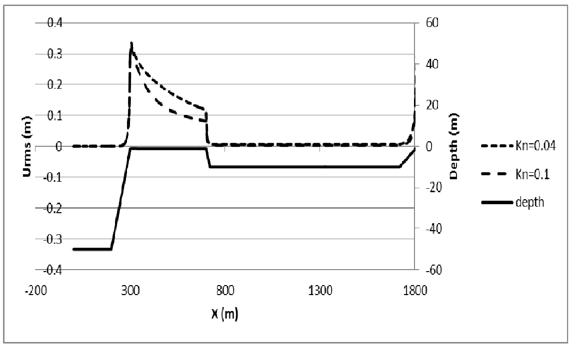

Figure 4: Effect of surface roughness on Urms

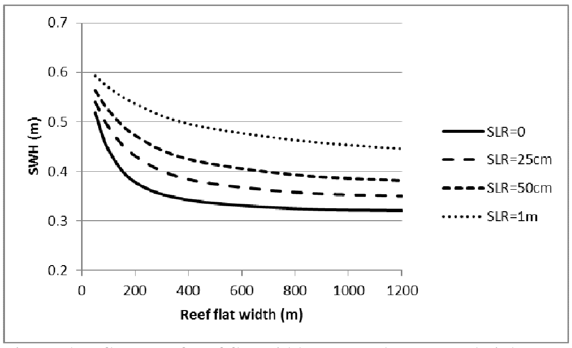

Figure 5: Influence of reef flat width on nearshore wave height

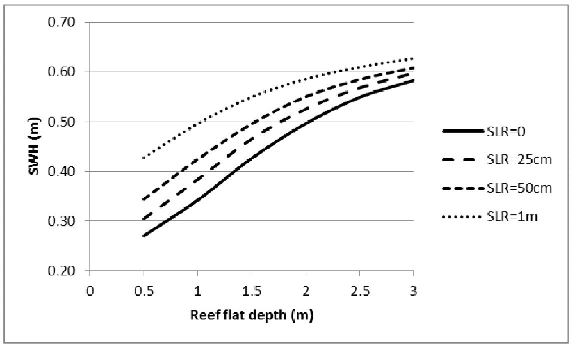

Figure 6: Influence of reef flat depth on nearshore wave height

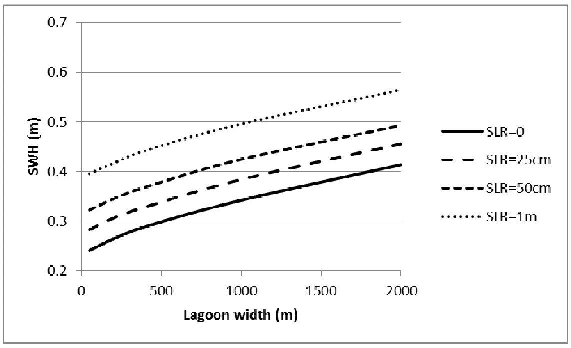

Figure 7: Influence of lagoon width on nearshore wave height

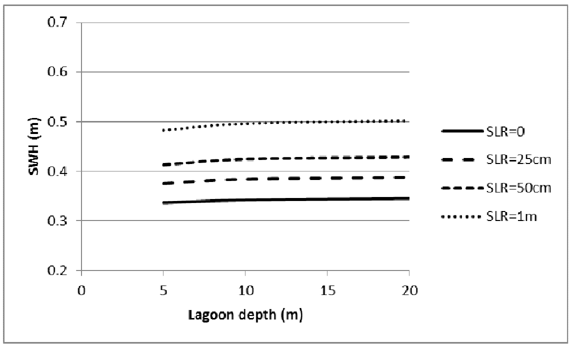

Figure 8: Influence of lagoon depth on nearshore wave height

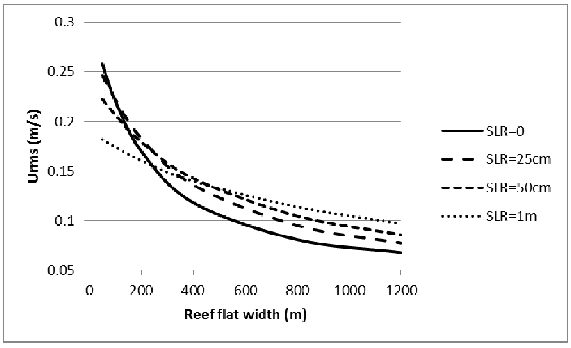

Figure 9: Influence of reef flat width on Urms

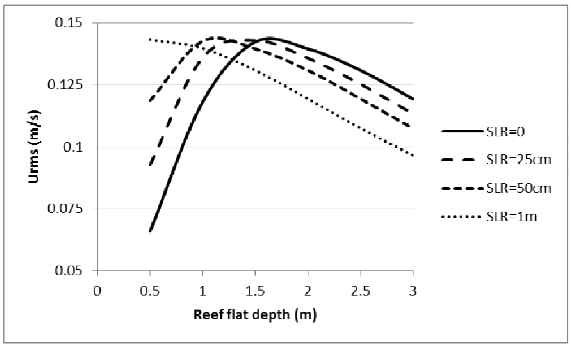

Figure 10: Influence of reef flat depth on Urms