Coastal Dynamics 2017
Paper No. 263

TYPHOON WAVES ON CORAL REEFS

Ana Vila-Concejo[1], Stephanie Duce[1,2], Masayuki Nagao[3], Yosuke Nakashima[4], Mayuko Ito[5], Kazuhiko Fujita[5] and Hironobu Kan[6]

Abstract

Tropical storms in coral reefs have both destructive and constructive effects. Here we present wave data from a field campaign in a coral reef during Tropical Storm Malou in September 2016. We deployed our instruments on the forereef in an area with spurs and grooves and measured maximum wave heights of 7.5 m and maximum significant wave heights of 3.8 m. There were no remarkable changes in peak period over the course of the storm. Nearbed maximum velocities reached 2 m/s on the outer forereef. Most of the waves dissipated their energy in the outer forereef; this poses questions about the percentages of wave energy that is dissipated on the forereef versus the reef crest. Hydrodynamic datasets during storm events are rare and invaluable in understanding wave dissipation by coral reefs. Our measurements were taken under a major bleaching event and we observed post-storm damage during instrument retrieval. Bleaching usually implies coral cover reduction for at least a few years, thus lowering the energy dissipation capability of this reef.

Key words: tropical storms, hydrodynamics, wave dissipation, morphodynamics, ecomorphodynamics, field measurements, coasts and climate

1. Introduction and Regional Setting

Coral reefs are among the most iconic landscapes on Earth. The physical structure of coral reefs provides: habitat for coral communities; physical foundation for habitable land; buffering to coastal erosion by modulating ocean impact upon coastlines (Vila-Concejo and Kench, 2017). The ecology, geomorphology and evolution of coral reefs is closely linked to their hydrodynamic regimen (e.g., Lenihan et al., 2015; Rogers et al., 2016; Duce et al., 2016 and Dechnik et al., 2016). However, coral reefs are typically remote and difficult to access, therefore, hydrodynamic datasets are scarce and storm datasets are even scarcer. Here we present wave data collected during a tropical storm in September 2016. Tropical storm (TS) Malou formed on the 6th of September 2016 with maximum sustained winds of 74km/h and gusts to 111 km/h (Japan Meteorological Agency); that same day, approximately at 6pm local time, TS Malou impacted the island of Kume (Figure 1) some 100 km west of Okinawa (Japan). Minimum pressure at the time was 1000 hPa with associated winds of 20 m/s (Japan Meteorological Agency).

Kume Island is a volcanic (high) island surrounded by fringing reef located on the South China Sea. Hateno Hama reef is located on its eastern side and consist of a sandy spit surrounded by barrier reef (Kan, 2011) (Figure 1). Tides in the area are microtidal and incident waves are seasonal. The dominant wave direction is from the NNW, with wave height sometimes exceeding 3 m during the winter monsoons from November to February (Kayanne et al., 2016).Waves and winds also approach from the south predominantly during September. The region is subjected to numerous typhoons each year occurring over the summer months (May-September) (Kan, 1995), during which, significant wave height often exceeds 3 m (Kayanne et al., 2016).

[1]Geocoastal Research Group. School of Geosciences, The University of Sydney, 2006 NSW, Australia. ana.vilaconcejo@sydney.edu.au

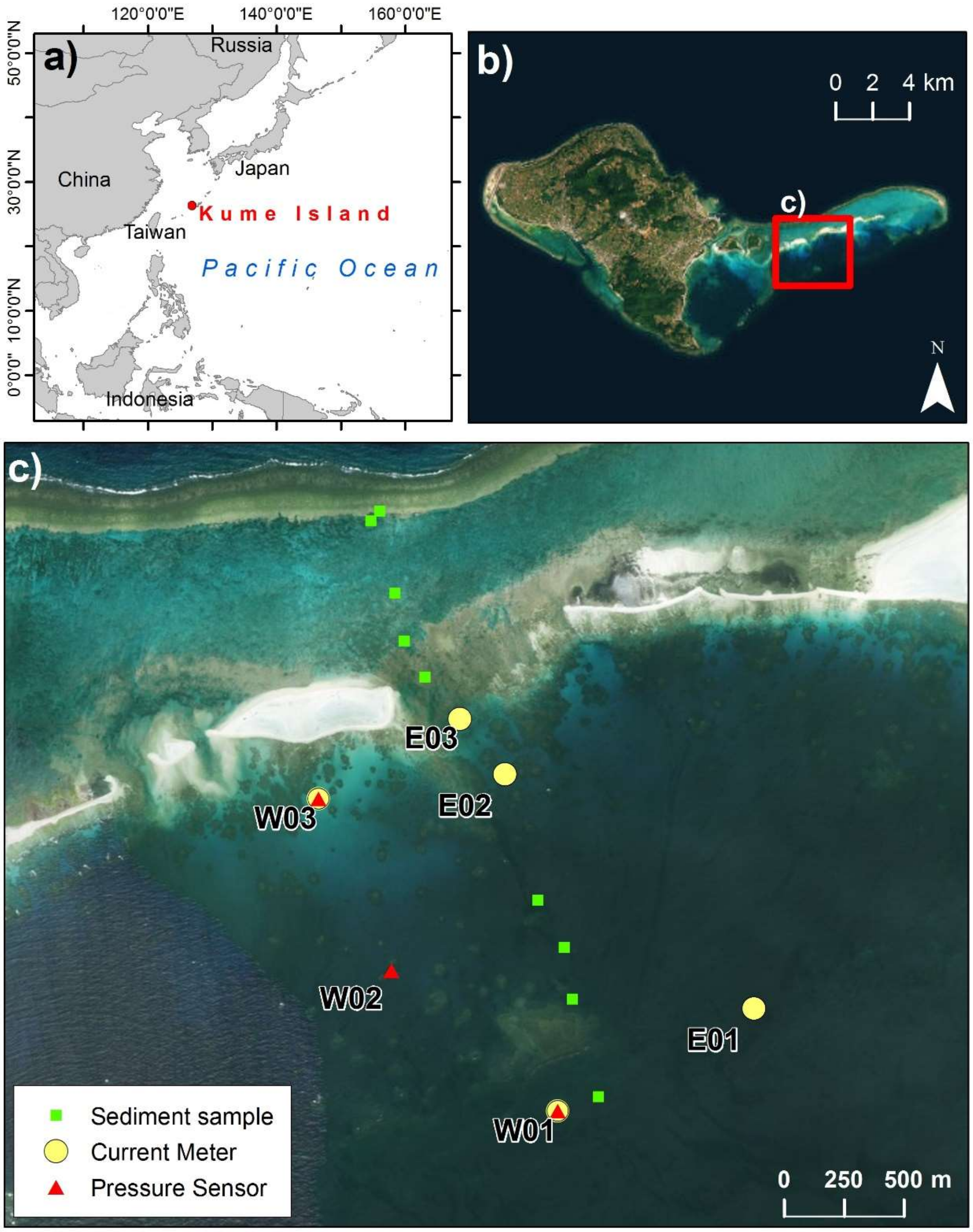

Figure 1. Kume Island is located in the South China Sea in Southern Japan, some 100 km west from Okinawa (a); Hateno Hama Reef is located on the eastern side of the island and consists of a sandy cay surrounded by barrier reef (b); this paper presents the results obtained with three pressure sensors located off Hateno Hama Reef (c)

2. Methods

Three sets of pressure transducers (PTs) Acquistar 2PTx were deployed along an across-shore transect on the southern fore reef and barrier reef lagoon of Hateno Hama Reef, Kume Island so they recorded at 4 Hz continuously from 15h on the 3rd of September until 03h on the 8th of September 2016 (local time). The PTs were deployed in three locations, W1, W2, and, W3, (Figure 1) at depths of 5.6, 2.0, and 3.9 m, respectively. While the PT at W3 was deployed on a shallow sandy bottom, the PTs at W1 and W2 were deployed on patches of coral reef surrounded by deeper water approximately 20 and 15 m depth respectively (Table 1 and Figure 2).

Standard spectral analysis was used to process the PT data with the difference in wave power between instruments being used to calculate the average rate of wave dissipation in different parts of the reef. All data was corrected for depth attenuation of hydrostatic pressure. Maximum near bed velocities were obtained according to Lowe et al., (2005).

Table 1. Location of deployment of pressure transducers. Average depth of the PTs and the approximate depth nearby the coral where the PTs were deployed.

Site	Latitude	Longitude	Depth of PT deployment (m)	Approximate seafloor depth next to deployment (m)
W1	26.325388889	126.871138889	5.6	20
W2	26.330638889	126.864888889	2.0	15
W3	26.337083333	126.862166667	3.9	4

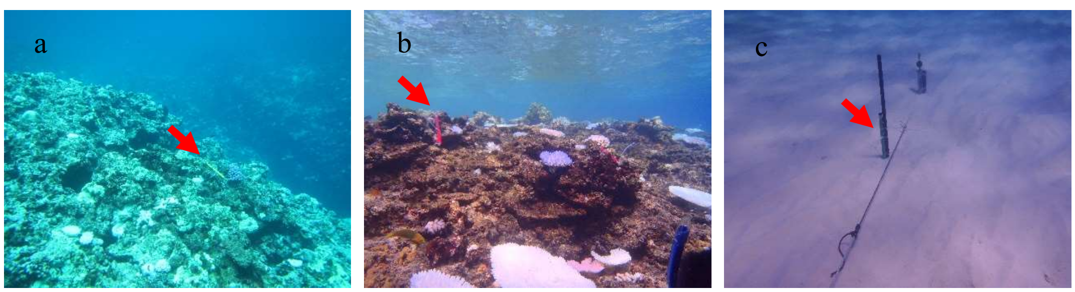

Figure 2. Field photos showing the PTs deployed at W1 (a), W2 (b), and W3 (c)

3. Preliminary Results and Discussion

Preliminary data analyses show that under non-storm conditions, the significant wave height (*Hs*) at the outermost deployment location was less than 1 m (Figure 3). *Hs* decreased to less than 0.5 m, and was strongly tidally modulated, at the inner station (W3). Maximum near bed velocities were between 0.2 and 0.5 m/s for the outer deployment locations (W1 and W2), with minimum velocities (<0.2 m/s) occurring at W3.

During TS Malou we measured maximum *Hs* of 3.8 m at W1 and wave dissipation over the reef was remarkable with *Hs* mostly below 1 m at W3. Figure 3 shows that most of the wave dissipation occurred between W1 and W2 with maximum wave heights at W1 reaching 7.5 m, 2.9 m at W2, and 2.5 m at W3.

Peak periods (*Tp*) did not increase during TS Malou; this reflects the close geographic proximity of the Typhoon. In fact, there is an increase in short period waves, probably related with the strong winds that were affecting the study area as a consequence of the tropical storm. Maximum near bed velocities were mostly near 1 m/s but reached maximal values between 1.5 and 2 m/s in the outer deployment locations (W1 and W2) and decreased to less than 0.5 m/s in the inner location (W3). Even though *Hs* was larger at W1 than at W2, W1 and W2 had similar maximum near bed velocities because of the shallow depth of the deployment at W2 (Table1 and Figure 2).

Our results show that most of the wave energy was dissipated in the forereef area, well before reaching the reef crest (Figure 1). This is in agreement with other studies undertaken on wave dissipation on forereefs (Duce, 2017; Monismith et al., 2015; Rogers et al., 2016) and contrasts with the long-held assumption that the vast majority of the wave energy dissipation occurs at the reef crest. This study was undertaken on the forereef of a coral reef that presented spurs and grooves, the extent to which the spurs and grooves affected wave energy dissipation is yet to be determined.

More analyses are necessary to investigate the wave power and energy fluxes across the reef and the implications for coral breakage and transport during storm conditions. Storms in coral reefs are both destructive and constructive, the destructive effects include different degrees of coral breakage and the constructive effects are the subsequent transport of the coral rubble to form rubble ramparts and islands (Vila-Concejo and Kench, 2017).

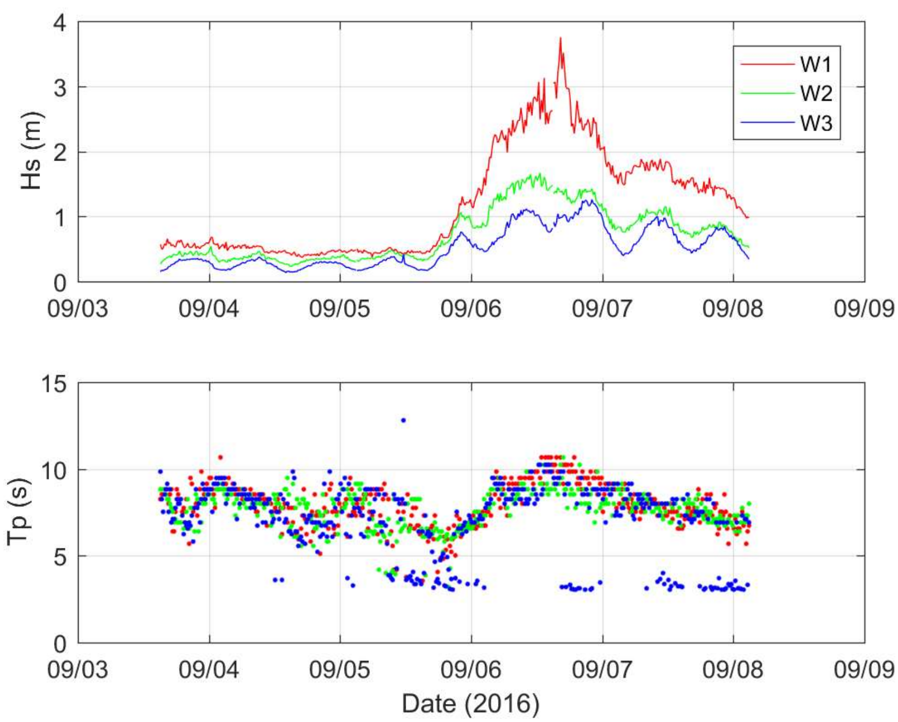

Figure 3. Significant wave heights (m) and peak periods (s) measured on W1, W2, and W3. Please note that W1 is the outermost pressure transducer.

4. Concluding Remarks

The dataset presented here represents a unique opportunity for analysing the potential physical impacts of tropical storms in coral reef environments. Tropical storm Malou in September 2016 brought waves with maximum *Hs* of 3.8 m and maximum wave heights of 7.5 m; the near bed maximum velocities reached 2 m/s. Wave dissipation over the forereef was remarkable and that poses questions about the actual percentages of wave energy that are dissipated over the forereef, the reef crest, and the reef flat.

This fieldwork campaign was undertaken during the 2016 global bleaching event; bleaching was very recent and intense, with most corals bleached down to depths of at least 30 m. Some broken and dislodged corals were observed during instrument retrieval after TS Malou. As corals bleach and die they become more fragile and the effects of subsequent storms in the area will likely create new coral rubble and smooth the existing seabed by breaking and removing the dead corals. Recent studies (Kayanne et al., 2016) have shown how large storms following a bleaching event can significantly change the morphology of coral islands. Future studies will possibly link the 2016 bleaching event and subsequent tropical storms (including Malou) with morphological change in Hateno Hama reef.

Wave energy dissipation in forereefs dominated by spurs and grooves is mostly driven by the bottom friction, with the roughest reefs being those with the highest coral cover (Duce, 2017). Whether the reefs surrounding Kume Island and Hateno Hama will have time to recover before the next bleaching event (>10 years are needed) will determine future wave attenuation and shoreline protection.

Acknowledgements

Vila-Concejo acknowledges funding from ARC FT100100216 and JSPS S16710. This work was partially funded by JSPS KAKENHI (16H06309, 16H02940). Xylem Asia (Sontek Japan) also sponsored this fieldwork.

References

Dechnik, B., Webster, J. M., Webb, G. E., Nothdurft, L. D., Zhao, J.-X., Duce, S., Braga, J. C., Harris, D. L., Vila-Concejo, A. and Puotinen, M., 2016. Influence of hydrodynamic energy on holocene reef flat accretion, Great Barrier Reef. *Quaternary Research*, 85, 44-53.

Duce, S 2017, The form, function, and evolution of coral reefs spurs and grooves PhD, The University of Sydney.

Duce, S., Vila-Concejo, A., Hamylton, S., Webster, J. M., Bruce, E. and Beaman, R. J. 2016. A morphometric assessment and classification of coral reef spur and groove morphology, *Geomorphology,* Vol. 265, pp. 68-83

Kan, H 1995, Typhoon effects on sediment movement on reef edges and reef slopes, in Bellwood, O (ed.), *Recent advances in marine science and technology '94.*, Pacon International and James Cook University, Townsville.

Kan, H 2011, Rykyu Islands, in Hopley, D (ed.), *Encyclopedia of Modern Coral Reefs: structure, form and process*.

Kayanne, H, Aoki, K, Suzuki, T, Hongo, C, Yamano, H, Ide, Y, Iwatsuka, Y, Takahashi, K, Katayama, H, Sekimoto, T and Isobe, M 2016, Eco-geomorphic processes that maintain a small coral reef island: Ballast Island in the Ryukyu Islands, Japan, *Geomorphology,* vol. 271, pp. 84-93.

Lenihan, H. S., Hench, J. L., Holbrook, S. J., Schmitt, R. J. and Potoski, M., 2015. Hydrodynamics influence coral performance through simultaneous direct and indirect effects. *Ecology*, 96, 1540-1549.

Lowe, RJ, Falter, JL, Bandet, MD, Pawlak, G, Atkinson, MJ, Monismith, SG and Koseff, JR 2005, Spectral wave dissipation over a barrier reef, *Journal of Geophysical Research: Oceans,* vol. 110, no. C4, pp. n/a-n/a.

Monismith, SG, Rogers, JS, Koweek, D and Dunbar, RB 2015, Frictional wave dissipation on a remarkably rough reef, *Geophysical Research Letters,* vol. 42, no. 10, pp. 4063-4071.

Rogers, JS, Monismith, SG, Koweek, DA and Dunbar, RB 2016, Wave dynamics of a Pacific Atoll with high frictional effects, *Journal of Geophysical Research: Oceans,* vol. 121, no. 1, pp. 350-367.

Rogers, J. S., Monismith, S. G., Koweek, D. A., Torres, W. I. and Dunbar, R. B., 2016. Thermodynamics and hydrodynamics in an atoll reef system and their influence on coral cover. *Limnology and Oceanography,* 61:6, 2191-2206.

Vila-Concejo, A and Kench, PS 2017, Storms in coral reefs, in Ciavola, P andCoco, G (eds.), *Coastal Storms: Processes and Impacts*, John Wiley and Sons.