WAVE TRANSFORMATION OVER PALM BEACH REEF

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Ocean wave parameters are influenced by shallowing water depth and varying bottom topography. Modelling and in-situ studies have found that as waves propagate over a reef, interaction in the form of friction with the shallower reef can alter wave height, wave spectra, wavelength, and wave direction. Quantifying wave transformation over submerged structures will inform and aid in the design of future coastal protection. The natural reef at Palm Beach on the Gold Coast, Queensland, Australia is a rock-based reef that extends seaward, surrounded by sand bottom. The seaward reef edge is 10 to 16 metres deep while the shore edge is 5 to 9 metres deep, hence the reef shallows towards the shore. The reef is generally exposed to a dominant south easterly swell but Point Danger to the south offers some protection. Waverider buoys were deployed at four strategic locations at the Palm Beach reef and used to determine how the reef influences wave characteristics as waves travel over the reef. Wave transformation occurs, with the presence of Palm Beach reef having an observable influence on wave height and wave direction. Windward to leeward of the reef significant wave height was reduced by up to 12.7 per cent, wave direction changed by up to 13.9 degrees depending on how the measurement station was aligned with propagation over the reef, peak wave period was not changed significantly.

Keywords: wave transformation; natural reef; attenuation and refraction

Introduction

The beaches and waves of the Gold Coast in Queensland Australia are valued, world famous tourist and surfing attractions. Protecting and maintaining the golden sandy beaches, surf conditions and the well-developed beach front comes at a cost. The Gold Coast is home to two permanent sand bypassing systems, to the south at the Tweed River entrance and in the north at the Gold Coast Seaway. These maintain navigable entrances to the Tweed River and the Gold Coast waterways, both popular and important marine traffic routes. The area is subject to significant longshore drift, with over 600,000 cubic meters of sand bypassed by the Tweed Sand Bypassing Project in 2022, northwards from the Tweed River to nourish the beaches of the southern Gold Coast. As well as amenity, the beaches and coastal processes of the Gold Coast are also studied through the lens of coastal protection. The Queensland coast is famous for its numerous reefs including the Great Barrier Reef. There are also many smaller reefs along the coast and the Gold Coast is home to several rock-based reefs and submerged structures that provide an invaluable yet unquantified level of shoreline protection.

Incident wave energy can be reduced at the reef face through breaking waves, reflection and refraction (Young 1989, Gourlay 1994). Ocean wave parameters such as wave height and wave direction are also influenced by shallowing water depths, varying bottom topographies and bottom friction. The impact on wave parameters is collectively referred to as wave transformation. Modelling and in-situ studies are necessary to decern and quantify how waves propagate over natural reefs and ultimately impact on the shoreline. The degree of wave attenuation can be significant across a reef barrier, in field studies found significant wave height to be a function of both the deep-water incident wave height and the depth of reef submergence (Sous 2019, Harris 2013, Young 1989). Also noted by Sous 2019: the lower the water depth the lower the remaining surface wave energy. Reefs on continental shelves can reduce up to 67% of incoming wave energy while fringing reefs can reduce up to 99% at low tide (Elliff et al. 2019 and Costa et al. 2016). (Costa 2016) found that wave attenuation over a fringing coral reef with 4 m freeboard reduced wave height by up to 67%. Ocean wave spectra has been shown to be altered through the transit of waves over a reef barrier with flat spectra on the reef flat and distributed across all frequencies (Young 1989). Energy in the gravity band can be transferred to lower frequencies on the lagoon side of a reef barrier (Sous 2019).

Quantifying wave transformation over submerged structures, such as the natural rock-based reef at Palm Beach, will identify possible effects on beach and surf amenity and inform the design of future coastal protections and surf and beach amenity projects. It is for these reasons, the study and observation of natural reefs in close proximity to beaches is required to establish suitable datasets of wave parameters to inform the mathematical modelling and to quantify the local wave transformations and possible beach response. Therefore, the objective of this study is to quantify the transformation of wave height (as significant wave height) and wave direction (as peak wave direction) over Palm Beach reef through observations by way of deployed instruments Figure 1, and to provide an insight to the amount of coastal protection the reef provides. In 2016 Queensland Government Hydraulics Laboratory (QGHL) undertook

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a study of the natural Palm Beach reef to collect the wave parameters to inform the design of a physical model of the reef and aid in a potential artificial reef design. The study observed the effects of the reef on wave energy and transformation and informs future projects and studies into artificial reefs, an area of interest with increasing demand.

Study Location

The natural reef at Palm Beach Figure 1 and Figure 2, on the southern Gold Coast is a rock-based reef covered with abundant marine life and is a popular location for recreation in the form of diving and fishing. The reef is surrounded by a sandy bottom and extends from 500 m off the beach for 850 m and is 600 m wide at the widest point. The seaward reef edge is 10 to 16 m deep while the shore edge is 5 to 9 meters deep, hence the reef shallows towards the shore. The reef is generally exposed to a dominant south easterly swell.

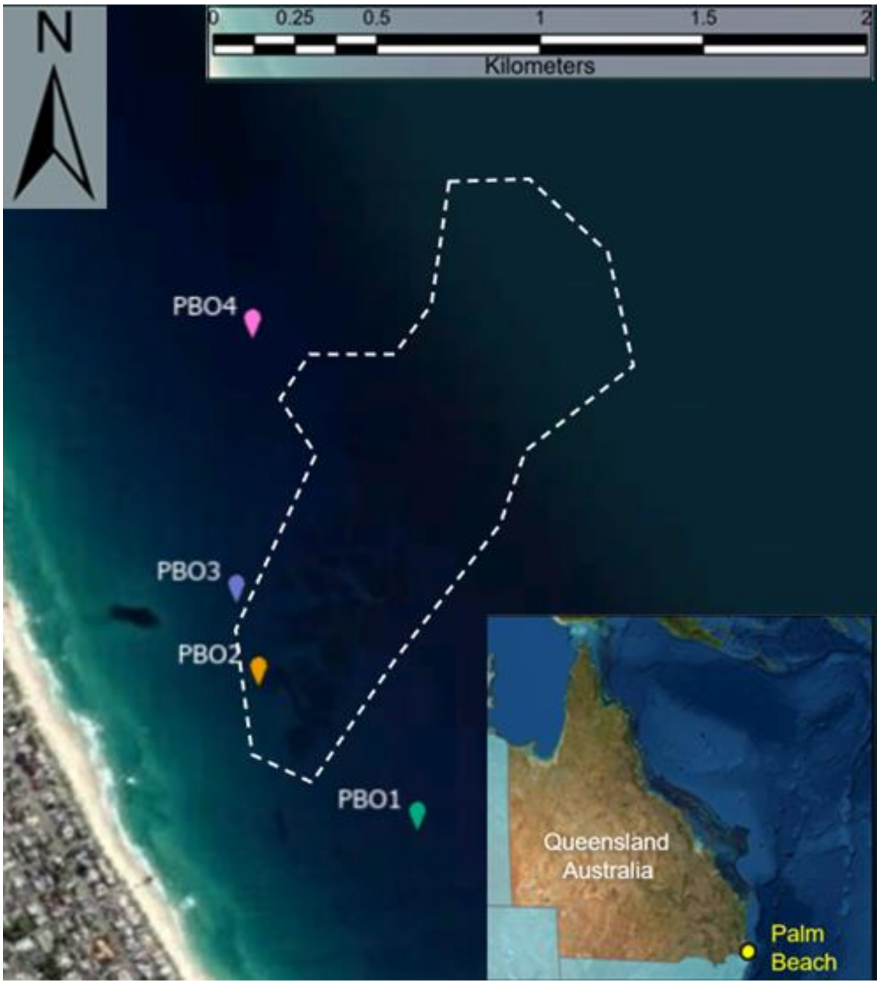

Figure 1 DWR-G4 Wave buoy locations at Palm Beach reef.

Accurate localized wave parameters to inform future studies and projects and for use in physical modelling are unknown for Palm Beach reef. The nearest quality dataset being the Queensland Government Department of Environment and Science wave monitoring site in 16 m of water at Main Beach. This wave buoy site (also known as the Gold Coast wave buoy) is approximately 16 km north of Palm Beach reef. Wave data has been collected at the Main Beach site since 1987.

Instruments and location

The instruments deployed for the study of the hydrodynamics around Palm Beach reef were four DWR-G4 Waverider buoys and the Gold Coast wave buoy at Main beach is a Datawell 0.9m directional Waverider MkIII. The DWR-G4 is Datawell's smallest directional wave measuring buoy and records wave motions with sensors dependent on the Global Positioning System (GPS). The benefits of using the DWR-G4 is a simplified and expedited deployment and retrieval due to their size and simplified mooring and, can be deployed from jet ski or dropped from a helicopter. Some of the draw backs include shorter battery life and data gaps arising from the loss of GPS signal attributed to breaking waves. Both models of Waverider buoy measure wave height, wave period, wave direction and water temperature. The calculation of wave parameters and statistics are done in 30 minute records. The buoys were deployed at four predetermined, strategic locations at Palm Beach. The sites were selected in conjunction with project partners, taking into consideration the known swell direction, reef topography and data requirements for a range of possible future projects.

Figure 2 Palm Beach reef outlined.

The nearshore sites were both seaward and leeward of the reef, to the north and south, from 500 m to 900 m from the beach. The deepest Palm Beach observation point (PBO) was PBO4 at 24 m to the northwest of the reef while the others were around 11.5 m, Table 1. Wave data from the four sites around the reef from two separate deployments are used to determine how the reef influences wave characteristics as waves travel over it. Of the shallow sites, two were located in-shore of the reef (PBO2 and PBO3) while PBO1 was south of the reef.

Table 1. Wave buoy site name, location, and depth.

Buoy	Location	Depth (m)
PBO1	28.114007°S 153.479249°E	11.33
PBO2	28.109683°S 153.474469°E	11.29
PBO3	28.107191°S 153.473845°E	11.75
PBO4	28.099271°S 153.474321°E	23.80

Wave buoy deployment

Wave data from around the reef was collected in two deployments. Deployment 1 was from 25th February 2016 to 10th March 2016 with two buoys in the water at sites PBO2 and PBO4. The goal of this deployment was to test suitability of the DWR-G4 for this study and to generate a comparable dataset to the nearby permanent Gold Coast wave monitoring buoy. The two buoys were prepared by the QGHL and deployed and retrieved by Queensland Surf Life Savers using Jet Ski. Deployment 2 was from 7th July 2016 to 31st August 2016 with four buoys in the water at PBO1 through 4. The buoys were again prepared by QGHL, but this time the deployment and retrieval was undertaken by a City of Gold Coast survey vessel. Unfortunately, the batteries on the buoys at PBO1 and PBO4 failed after about 3 weeks. These two buoys were replaced, and fully charged batteries swapped over into the remaining buoys. After a further 25 days all four buoys were retrieved and returned to QGHL for data retrieval.

Data validation

Data was stored on an internal memory card as 30-minute records inside the buoy, this was used as the basis for quality assurance and for archiving purposes. Data was also transmitted via a high frequency radio connection for real-time monitoring. The data were put through standard quality checks where data points are removed from the record if wave height or wave period are out of a predetermined acceptable range. Several data points were removed, including instances of low frequency artefacts thought to be the result of loss of connection to GPS during breaking waves.

Results deployment 1

A review of the observations from the first deployment shows the data from the permanent wave monitoring buoy at Main Beach, "Gold Coast" gave comparable results to the two Palm Beach reef datasets, Figure 3 and Figure 4.

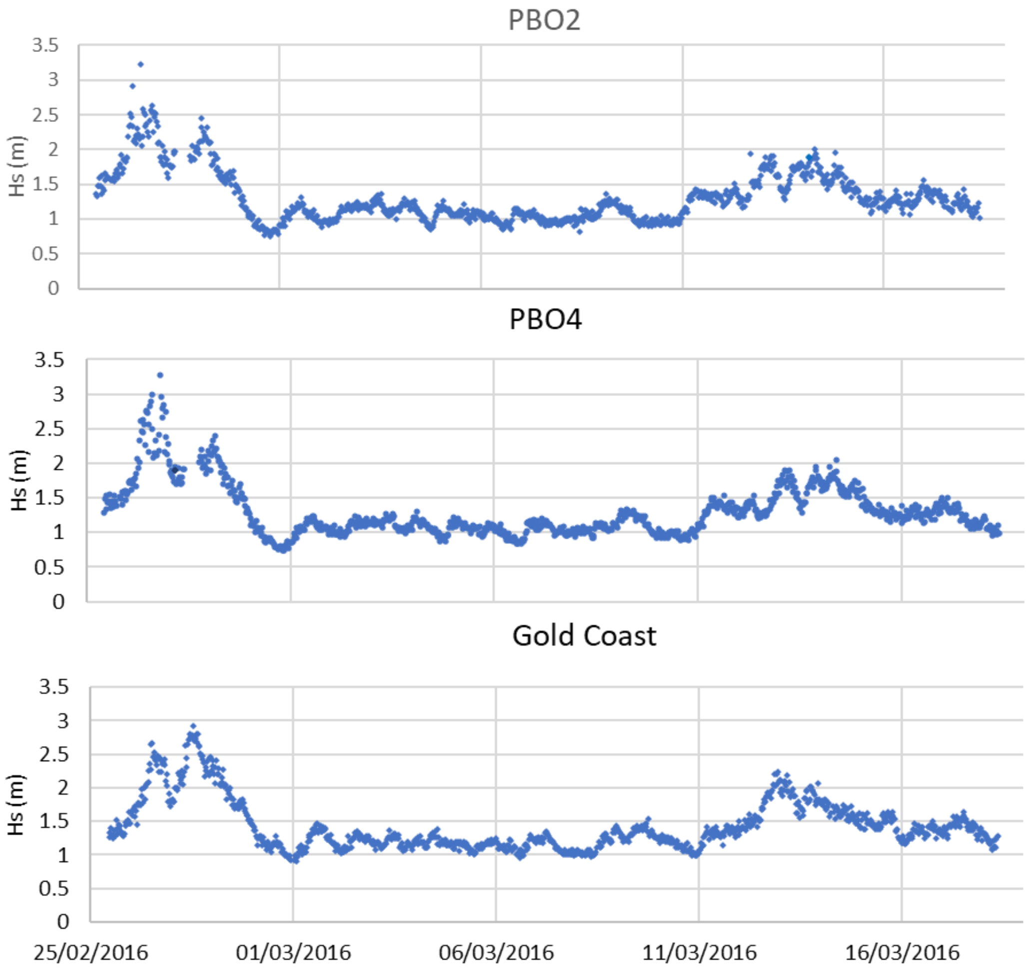

Figure 3 Deployment 1. significant wave height (H_s) at PBO2, PBO4 and the Gold Coast wave monitoring buoy.

Significant wave height (H_s) (average of the highest 1/3 of waves in a 30-minute record) for the reporting period of both Palm Beach buoys was 1.3 m while the Gold Coast was 1.4 metres. The

maximum wave height (H_{max}) the largest wave over a 30-minute record) reached almost 5.9 m at Palm Beach and around 5.5 m at the Gold Coast. A period of large swells generated through the passage of ex-tropical cyclone Winston is evident in all three datasets from the start of the observation period to the end of February 2016. Although it was quite distant from the Palm Beach region, TC Winston was a Category 5 cyclone and the most intense storm of 2016.
Wave period from the first deployment also show comparable data to the permanent wave monitoring buoy at the Gold Coast, Figure 4. Peak energy wave period T_p is the period of the waves with most energy. At Palm Beach, average T_p was around the same as at the Gold Coast at 9.3 seconds. Notably, again we see passage of Ex-tropical cyclone Winston generating longer period swells from the beginning of the observation period to the end of February.

The main difference between the Palm Beach and the Gold Coast site is in the average direction of peak energy waves Figure 5, these were close to easterly at the Gold Coast but more east north-easterly at Palm Beach. This comparison shows that wave period is unlikely to be significantly affected by wave transformation at the scale of this project.

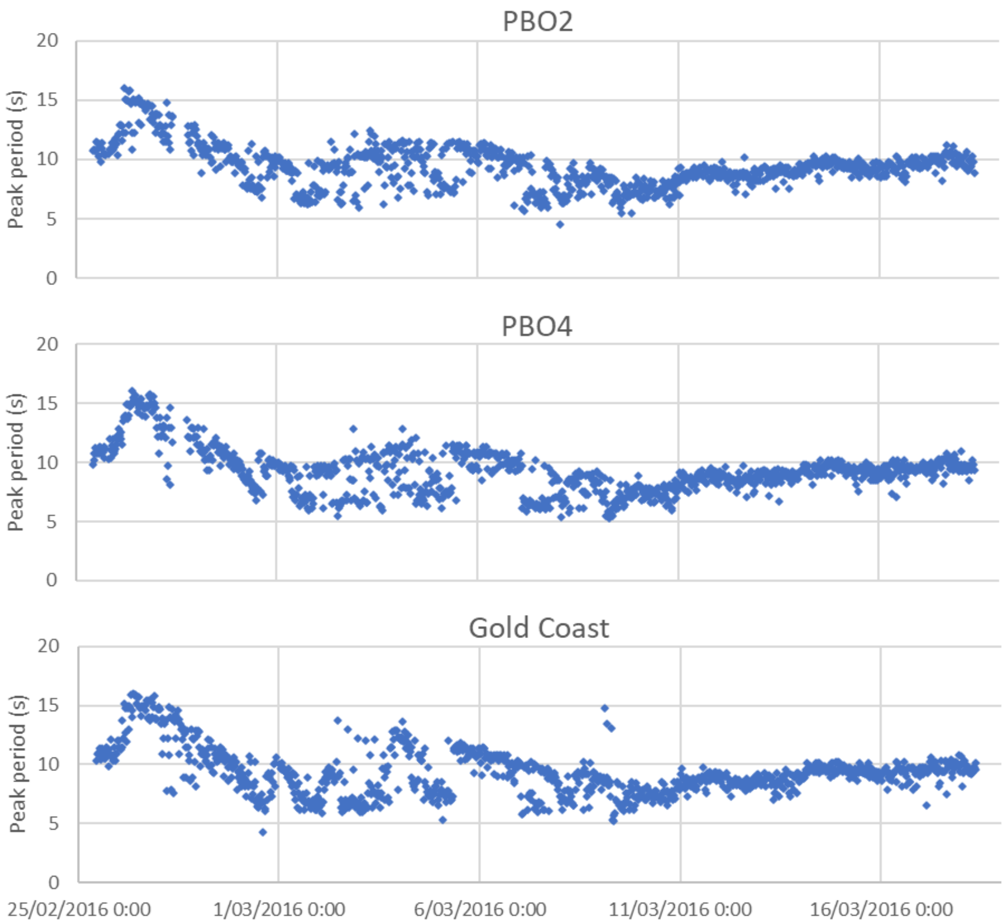

Figure 4 Deployment 1. Peak wave period at PBO4, PBO2 and the Gold Coast.

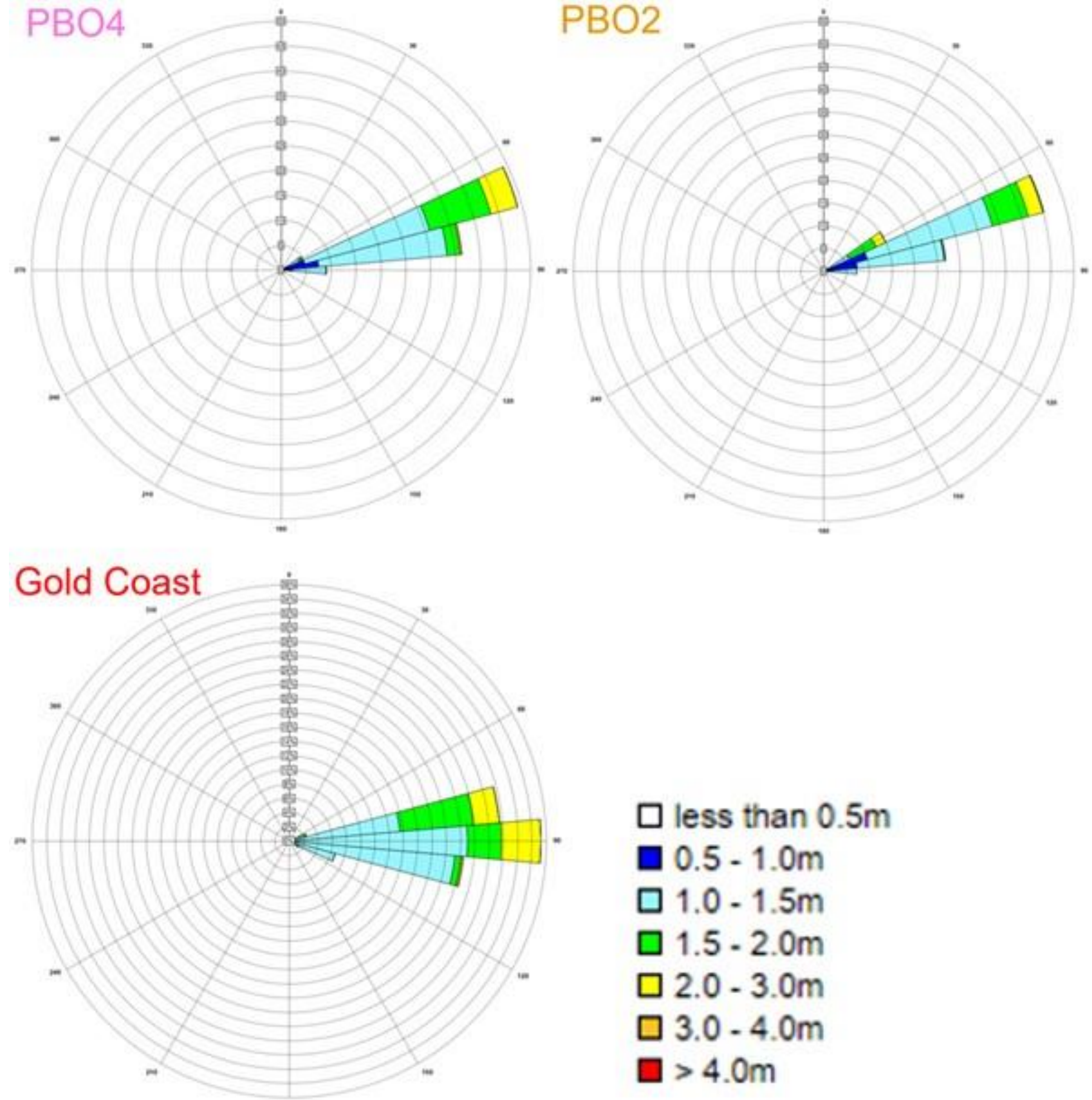

Figure 5 Deployment 1. Peak wave direction at PBO4, PBO2 and the Gold Coast.

Results deployment 2

There are some gaps in the data from deployment 2, as noticeable in Figure 6. There is a large gap in the data from late on the 28th of July to late on the 3rd of August, for both PBO1 and PBO4 which is due to the failure of the onboard batteries. There are also smaller gaps toward the end of the observation period highlighted which are assumed to be loss of connection to GPS during breaking waves when the GPS antenna can become submerged.

As a result, and in order to maintain a fair comparison between complete and simultaneous datasets, it was decided to correct the data to ensure all four PBO sites are of similar completeness. This was done by finding all errors in each dataset for each PBO from deployment 2 and ensuring that gap appeared in all other datasets. This resultant aligned dataset can be seen in Figure 7. Observations from deployment 2 for significant wave height (seen in Figure 6), show H_s variation from outside to inside the reef from 0.89 m at PBO1 to 0.76 m at PBO2 with changes from 5 to 10 degrees in peak wave direction also being noted.

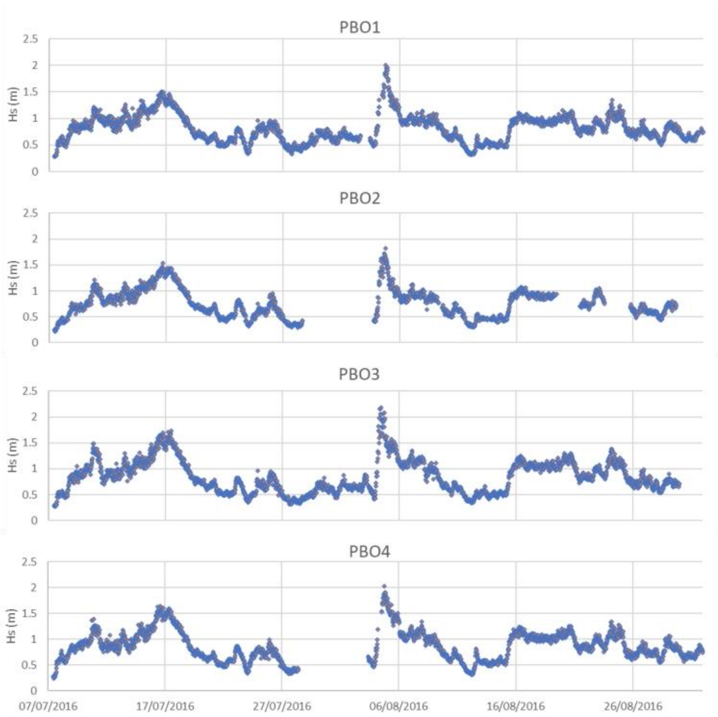

Figure 6 Deployment 2 Significant wave height (H_s) at PBO1,2,3 & 4

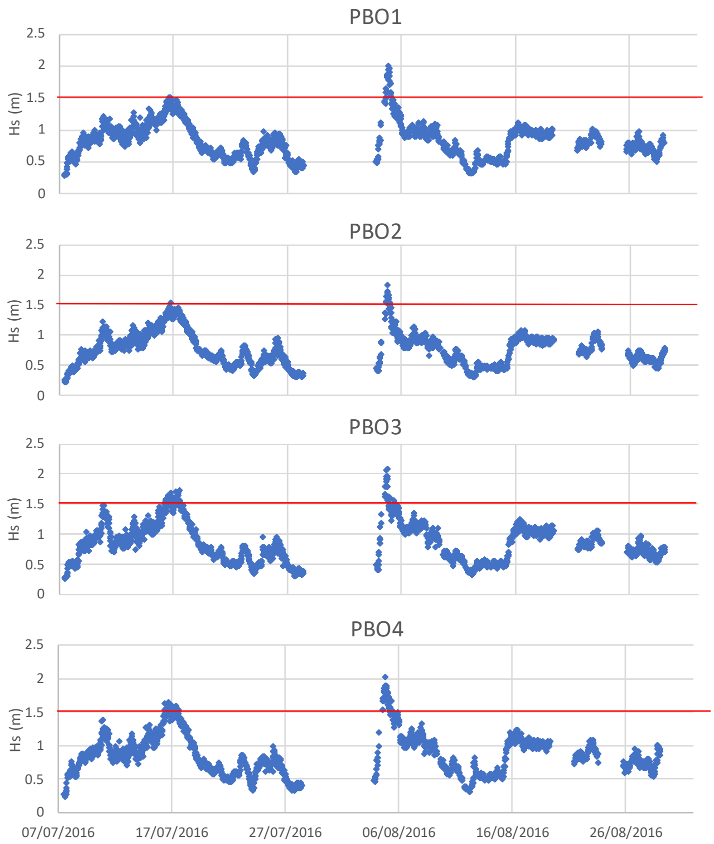

Figure 7 Deployment 2 aligned significant wave height (H_s), at PBO1,2,3 & 4

A review of the aligned observations from deployment 2 in Figure 7 shows variation in significant wave height around Palm Beach Reef Table 2. A red line has been added to the plots at 1.5m to highlight the variations in H_s at each PBO. Table 2 shows results across the observation area, with H_s the highest at 0.84 m at PBO4 and lowest at 0.76 m at PBO2. The longest average peak period T_p in deployment 2 was at PBO2 at 10.91 seconds, while average T_p at PBO3, PBO4 and PB01 were within 1 second of the longest average period. This suggests that wave period is unlikely to be significantly affected by wave transformation at the scale of this project.

Average direction in the corrected deployment 2 data, Table 2, varied from 75.6 degrees true north at PBO2 to 89.5 degrees true north at PBO4. Wave direction in this instance is a much clearer indicator of wave transformation and varied by around 14 degrees as seen by the arrows in Figure 8. This also shows the reef has a greater effect on wave transformation nearer the shore at the shallower sites.

Table 2. Aligned data results (mean)

Buoy	Significant wave height (m)	Peak wave period (T_p)	Wave direction (°T)
PBO4	0.87	10.21	89.5
PBO3	0.86	10.85	82.0
PBO2	0.76	10.91	75.6
PBO1	0.83	10.86	82.6

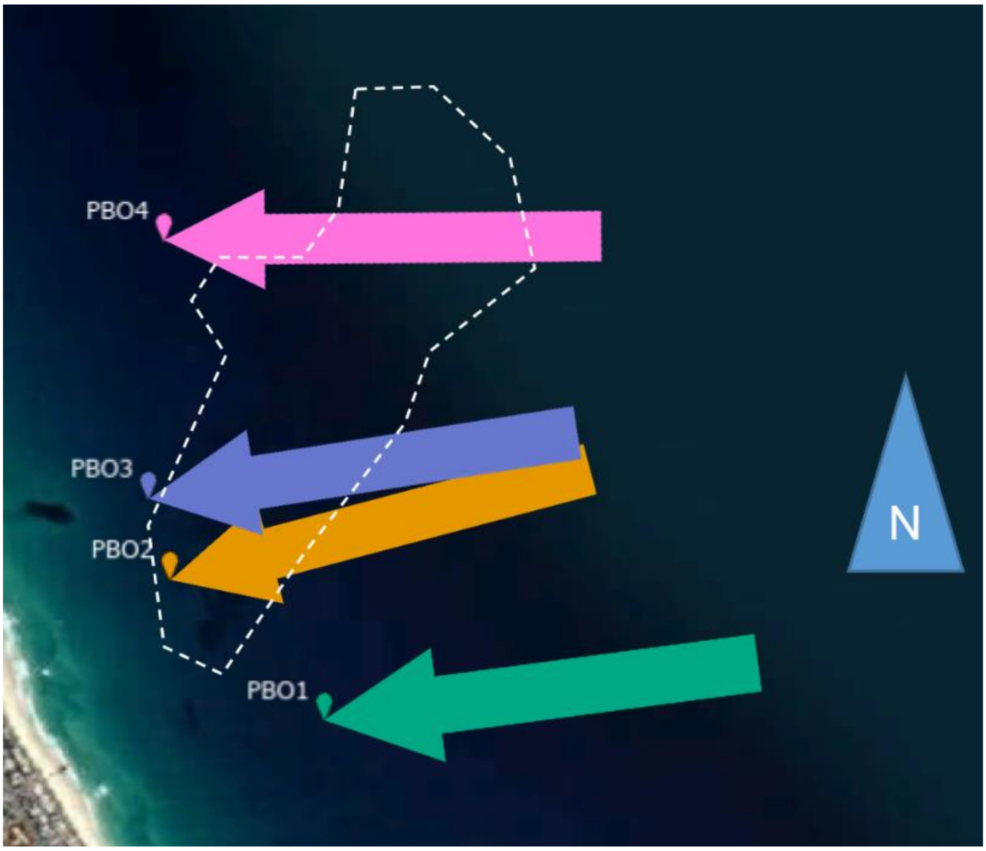

Figure 8 Aligned data, average wave direction at PBO1, PBO2, PBO3 and PBO4.

Discussion

The attenuation of H_s up to 12.7 per cent between PBO2 and PBO4 seen here is not inconsistent with the observations of (Costa 2016). Palm Beach reef is a small rocky reef that is only 600 m wide at its widest point and should provide a lower level of beach protection and wave attenuation than the Brazilian fringing reef of the Costa study. The depth of reef submergence may have also influenced wave attenuation. Wave attenuation over Palm Beach reef was strongest at PBO2 which is in the shadow of the shallowest section of the reef when the waves are from the dominant south-southeast direction. The site that is aligned to the southeast of PBO2 is PBO1 and attenuation between PBO1 and PBO2 was 8.5 %, whereas attenuation between PBO1 and PBO3 was positive, that is, there was an increase in average wave height. This may be due to the reef being deeper towards the southeast from PBO3. The PBO2 site is also in the shadow of most of the reef when the incident waves are from north-northeast whereas PBO3 is north of PBO2 and incident waves from that direction may not pass over the reef prior to PBO3. The PBO4 site had the highest average H_s of all of the sites, most likely due to the water depth of 24 m at the site compared to 11-12 m at the other sites hence PBO4 experiences less shoaling and hence lower attenuation than the other sites.

Wave transformation over Palm Beach reef has been observed in this study. The transformation appears in the form of attenuation of significant wave height through shoaling induced friction dissipation over the shallower reef. Wave refraction or diffraction due to the presence of Palm Beach reef has an observable influence on wave direction particularly at the shallowest site. Windward of the reef to leeward of the reef, average H_s was reduced by up to 12.7 per cent. The average peak energy wave direction changed by up to 13.9 degrees depending on how the measurement station was aligned with propagation over the reef, but peak wave period was not changed significantly.

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