Pacific Island Land Ocean Typhoon (PILOT) experiment

S. J. Boc & K. K. Hathaway
U.S. Army Corps of Engineers, Engineer Research and Development Center, Coastal and Hydraulics Laboratory, Vicksburg, USA

Abstract

The PILOT program sponsored by the U.S. Army Corps of Engineers is designed to acquire data necessary to depict and better understand the physics of the wave–reef interaction. Field sites have been instrumented on the islands of Guam, Oahu and St. Croix. Guam and St. Croix were selected primarily because of their potential of being affected by tropical cyclones annually. In addition, they offer different reef characteristics with favourable physical and logistical settings to study waves, currents, and water levels over reefs. Data were collected from a nearby deep-water directional wave buoy, coastal water-level and meteorological stations, shallow water wave gauges on the reef flats, and a laser-based bathymetric survey. Two storm events were recorded during a St Croix deployment (10 August to 11 November 2008); the first, a swell event, and the second, a wind-sea event, were investigated for different wave transformations over the reef. The first event occurred 30 September–1 October 2008, with a large swell recorded at the offshore Waverider buoy and low wind speeds (~7 mph E-ENE) measured at the St Croix airport. Incident wave heights peaked at 2.7 m with peak periods of approximately 15 s, and an incident direction of 47 degrees (compass direction from true north). This event produced the largest waves observed over the reef in this deployment. Mean water level (setup/surge) was about 0.2 m above normal. The second event occurred with the passing of Hurricane Omar on 16 October 2008. Incident waves (wind seas) peaked at 4.4 m with peak periods of nearly 8 s and directions from about 36 degrees. Although the incident waves were substantially higher, 4.4 m vs. 2.7 m, the peak wave heights over the reef were lower, 0.55 m vs. 0.72 m. Wave energy on the reef was primarily in the infragravity band (20 s–120 s). Surge and setup were similar and only about 0.2 m.
Keywords: reefs, waves, surge, wave setup, hurricane, wave-reef interaction.

WIT Transactions on Ecology and the Environment, Vol 149, © 2011 WIT Press
www.witpress.com, ISSN 1743-3541 (on-line)
doi:10.2495/CP110151

1 Introduction

The Pacific Island Land Ocean Typhoon Experiment (PILOT) Experiment follows from the recommendations stated in the Islands Task Force Report. More specific objectives address topics identified by the FEMA/USACE ad-hoc committee. The PILOT program, sponsored by the US Army Corps of Engineers (USACE), is designed to acquire data necessary to depict and better understand the physics of wave–reef interaction during cyclonic-storm events. Field data are collected to support development of predictive models for coastal inundation and flooding along shorelines of islands lined with fringing reefs. This research will be applied to the development of an effective emergency management system that addresses elevated sea-levels and storm waves associated with land-falling tropical cyclones in island environments. Four field study sites were selected in the Atlantic and Pacific Oceans for this purpose. The two Pacific sites were established at Ipan, Guam and the North Shore of Oahu, HI. The Atlantic sites were on north and south facing shores of St. Croix, USVI. Data presented here are from the north shore of St Croix.

2 Storm events – 2008

Two storm events were recorded during the St Croix (Figures 1 and 2) deployment of the Sea-Bird wave and tide recorders, 10 August to 11 November 2008 (Figure 3) in Pelican Bay, which is located near Christiansted on the island's north shore.

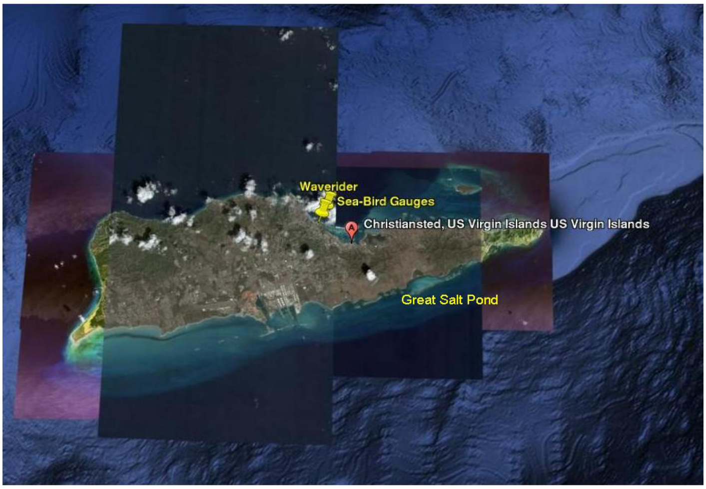

Figure 1: St. Croix north shore site.

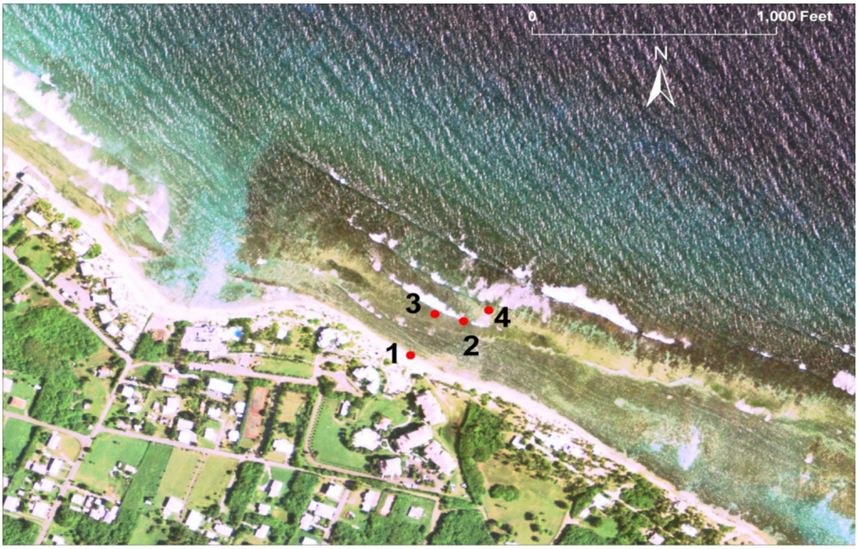

Figure 2: Gauge locations at the St. Croix north shore site.

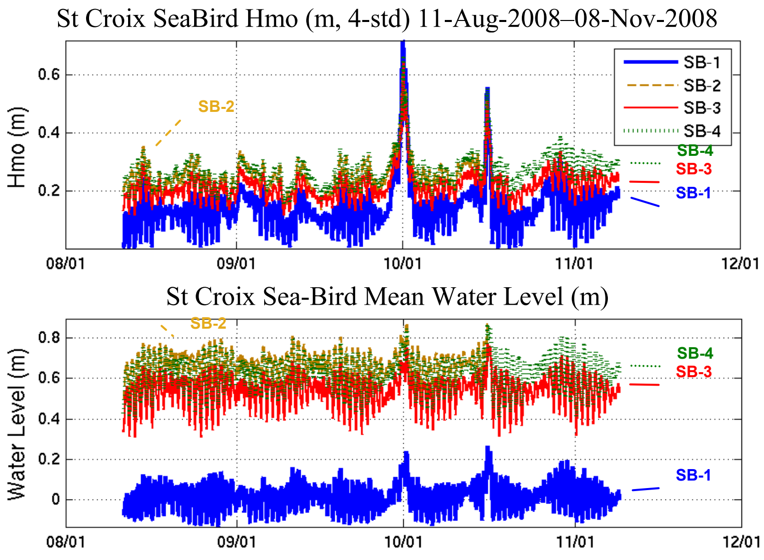

Figure 3: Sea-bird wave and water level.

2.1 Swell event

The first event occurred 30 Sep–1 Oct 2008, with incident large swell and low wind speeds (~7 mph E-ENE) measured at the St Croix airport. Incident wave heights peaked at 2.7 m with peak periods of approximately 15 s, and directions from 47 degrees (compass direction from true north) as measured from the Waverider buoy moored in deep water (255 m) just seaward of the instrumented reef. This event produced the largest waves observed over the reef in this deployment (Figure 3). Mean water level (setup/surge) was about 0.2 m above normal (Figure 4).

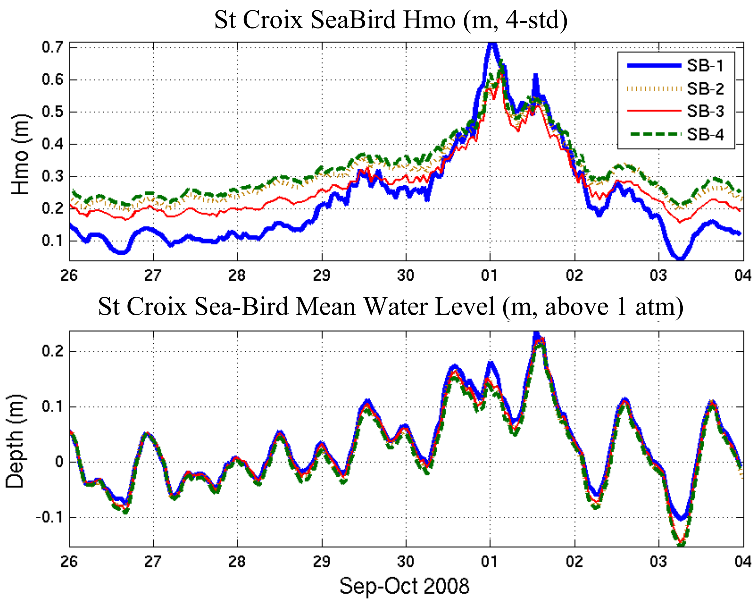

Figure 4: Swell event, 30 Sep to 1 Oct 2008.

A sample of 2-Hz timeseries for the cross-shore gauges near the storm peak shows a dominance of infragravity energy (periods > 20 s, frequencies < 0.05 Hz), increasing towards shore (Figure 5). Incident wave amplitudes have nearly disappeared at the shoreward most gauge.

Wave spectra were computed from 2048 s records using the Welch method with 50% segment overlap of 1024 s segments. A 3-point spectra band average was applied to smooth the spectra. The large segment length and small band averaging were selected to provide some detail in the infragravity band, but resulted in low degrees-of-freedom (dof ~= 14). Users of this spectra data may wish to perform additional smoothing in the incident band to increase the dof.

On 28 September 2008 (0000UTC), prior to swell arrival, spectra for the seaward gauge (#4) were swell frequency dominated; however, the shore gauge (#1) energy was primarily in the infragravity band (Figure 6). It should be noted the wave heights were quite small 0.1 m to 0.25 m at this time. During the swell event, the spectra show infragravity energy dominating with possible distinguishable spectral peaks at 120 s and 93 s period for gauge #4 and #1, respectively. Peak period in the infragravity band were generally higher at the shoreward most gauge #1 (Figures 8 and 9).

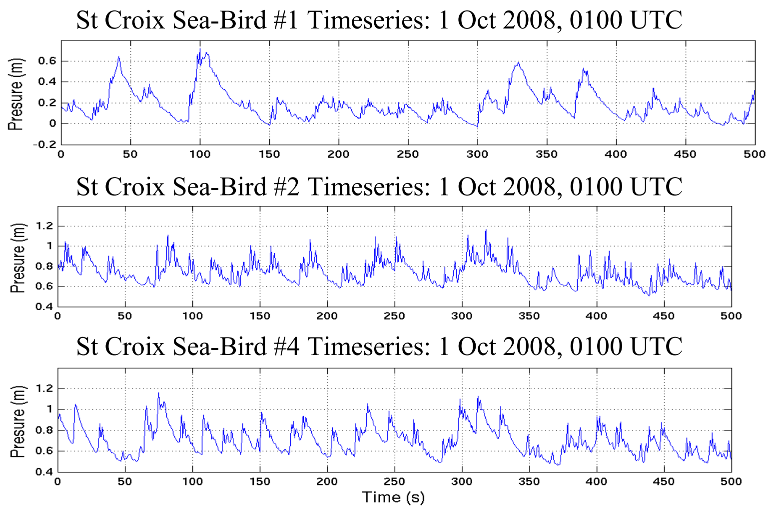

Figure 5: Timeseries near peak of swell event.

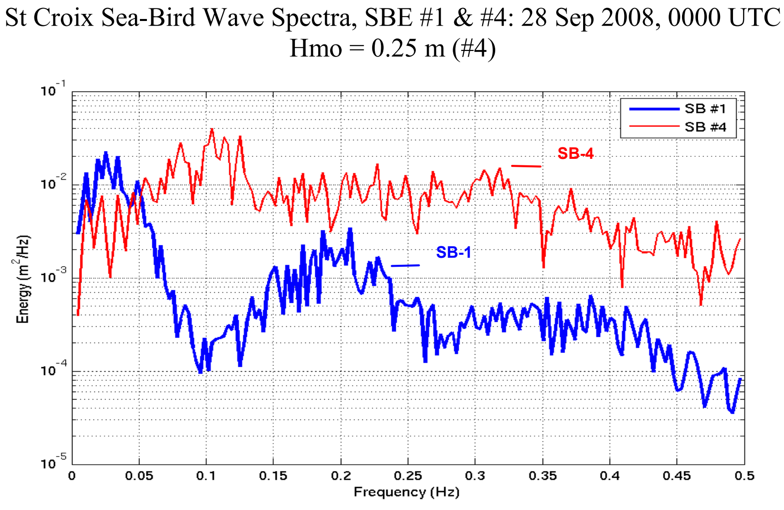

Figure 6: Sea-bird spectra prior to swell event (#1 closest to shore).

2.2 Hurricane Omar

The second wave event occurred with the passing of Hurricane Omar on 16 October 2008. Incident waves (wind seas) peaked at 4.4 m with peak period near 8 seconds and incident directions from about 36 degrees true north as measured at the offshore Waverider buoy. These storm waves were compared to the previous swell event. Although the incident waves were substantially higher during Omar, 4.4 m vs. 2.7 m, the peak wave heights over the reef were lower, 0.55 m vs. 0.72 m (Figure 3). Surge and setup were similar and only about 0.2 m in height (Figure 8). Note that SB-2 stopped functioning at the peak of the storm; only these three lines are plotted in Figure 10 after the storm peak.

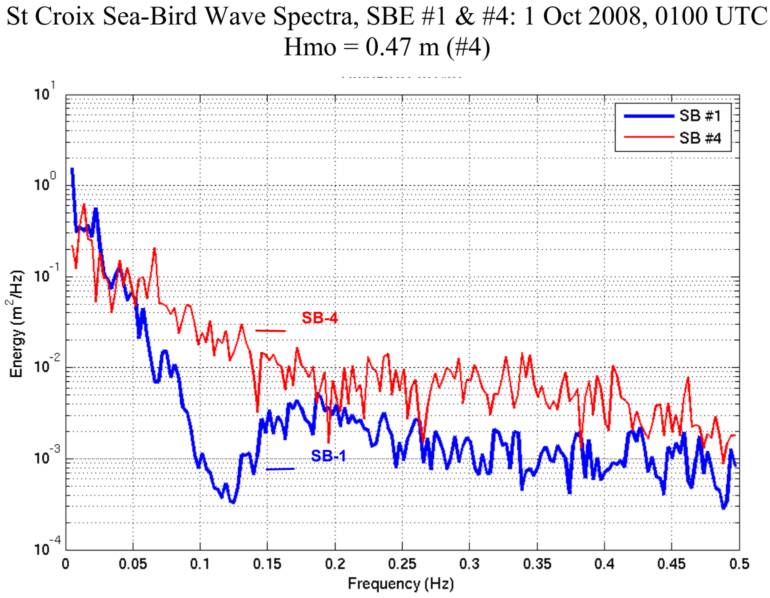

Figure 7: Infragravity dominated spectra during swell event.

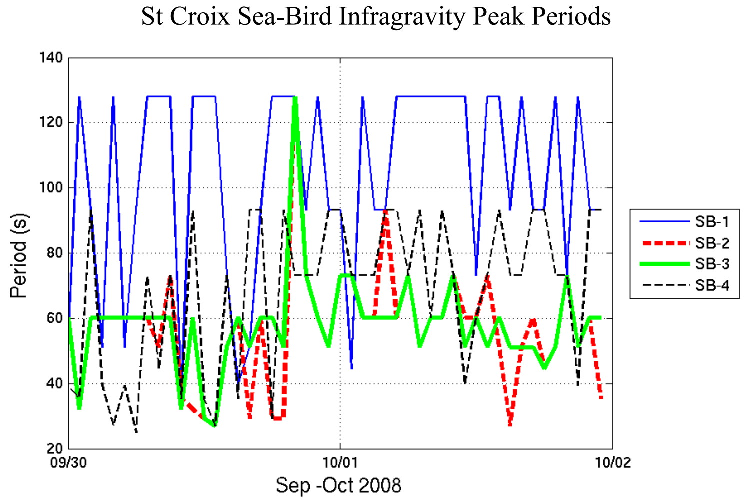

Figure 8: Peak periods in infragravity band in swell event.

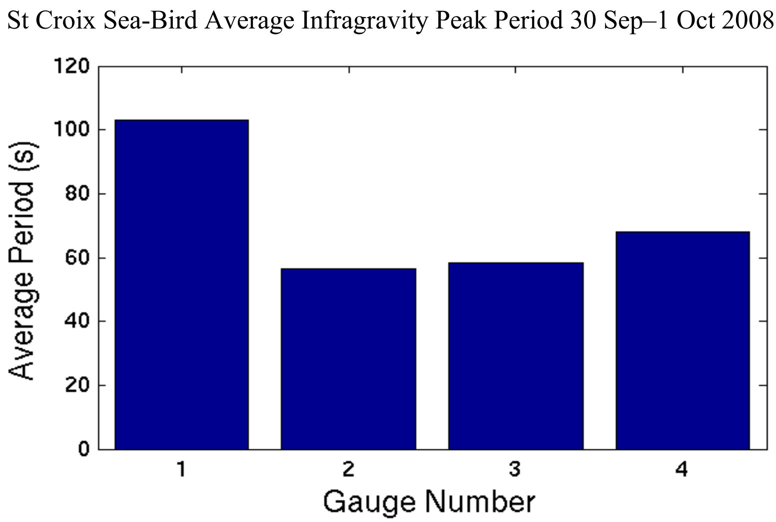

Figure 9: Average infragravity peak period during swell event.

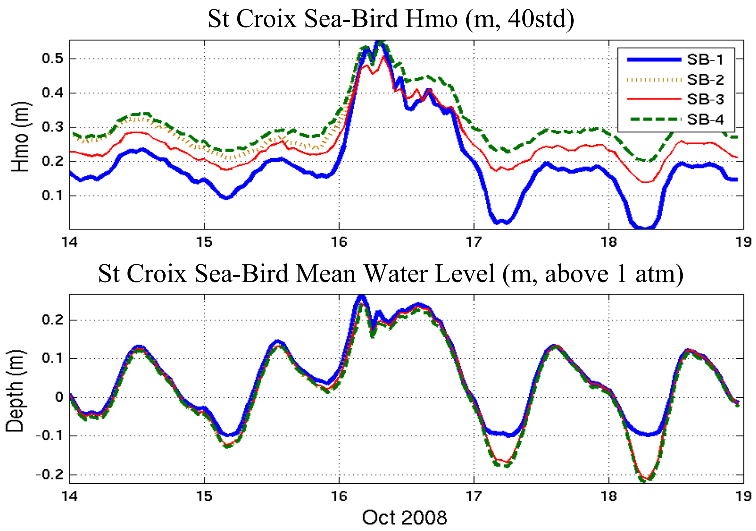

Figure 10: Sea event from Hurricane Omar, 16 October 2008.

A sample of 2 Hz timeseries near the peak of the storm are shown in Figure 11. Infragravity waves were not as obvious in the timeseries as during the swell event since the incident wind-wave energy was not as fully dissipated. Time series from the shoreward most gauge (#1) does have a long-period component of about 100 s.

Spectral analysis used the same method as in the swell event. At the peak of the storm (16 Oct, ~0500 UTC) the shore gauge spectra was infragravity dominated and had a wind-wave peak near 0.15 Hz (~7s) (Figure 12). At that time, the offshore gauge spectra were nearly "white" with little structure in the sea-swell band.

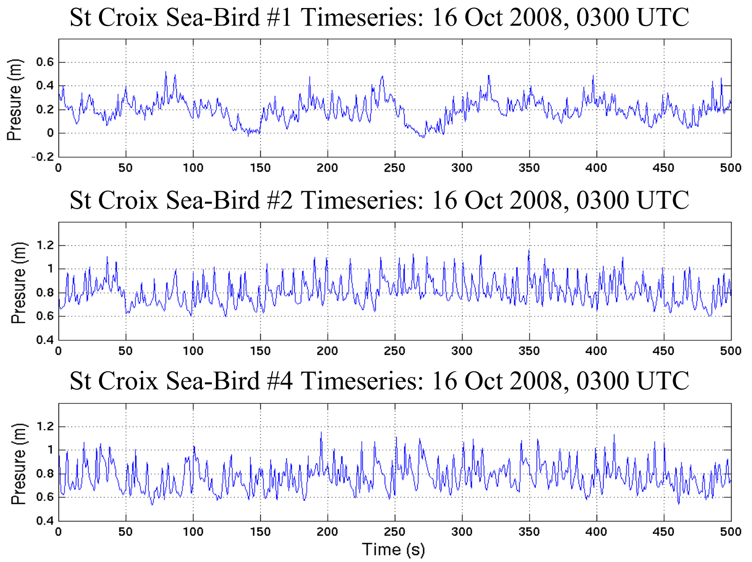

Figure 11: Sample timeseries from wind-sea incident waves.

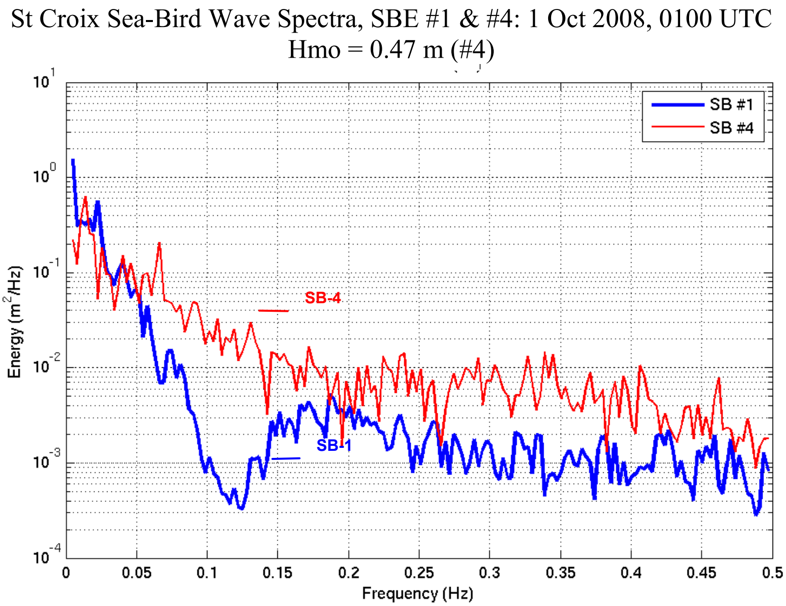

Figure 12: Shoreward most Sea-bird spectra at H. Omar peak wave heights.

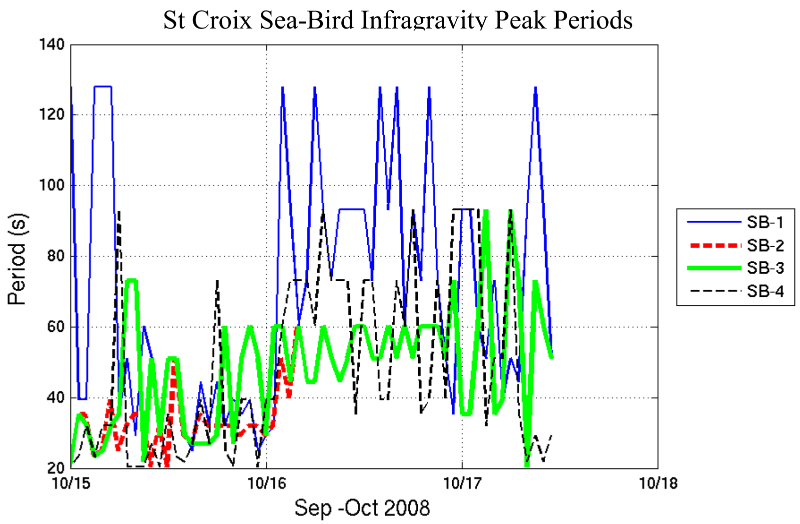

Figure 13: Peak periods in infragravity band during H. Omar.

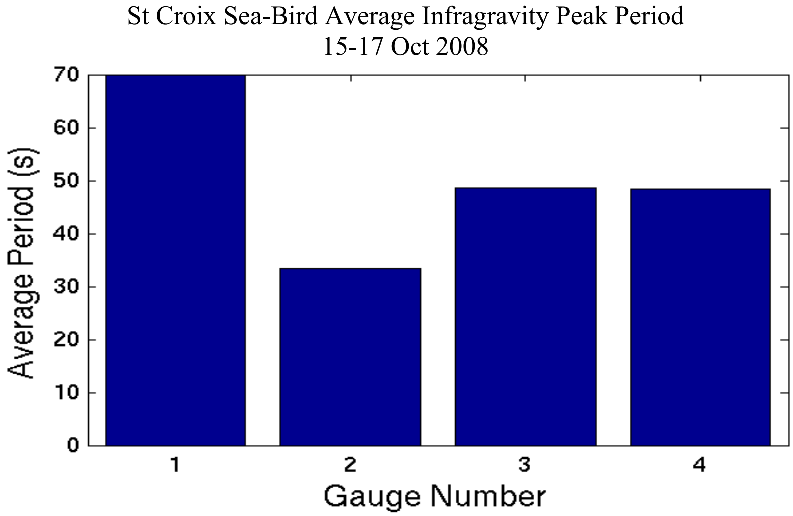

Figure 14: Average infragravity peak period during H. Omar.

Infragravity wave peak periods were generally less in the H. Omar storm than during the swell event (compare Figures 13 and 14 with 8 and 9).

Figures 15 and 16 show a comparison of incident wave spectra (Waverider) with the shoreward most Sea-Bird gauge during the two wave events. It is interesting to see the Sea-Bird spectra show little energy of the peak incident wave frequencies. There may be possible harmonic peaks of the incident peak frequency. These are likely waves that broke at the reef face and reformed at double frequencies.

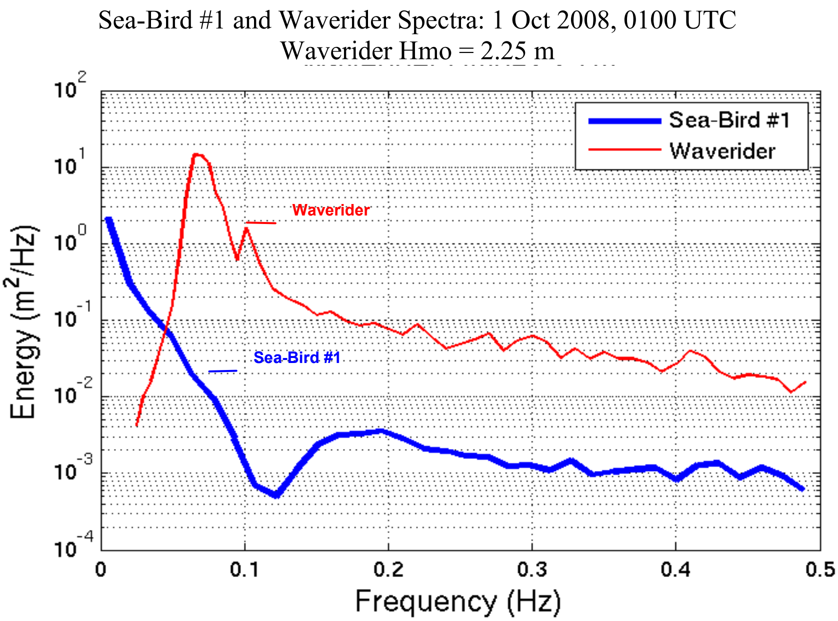

Figure 15: Waverider and SB-1 spectra in swell event.

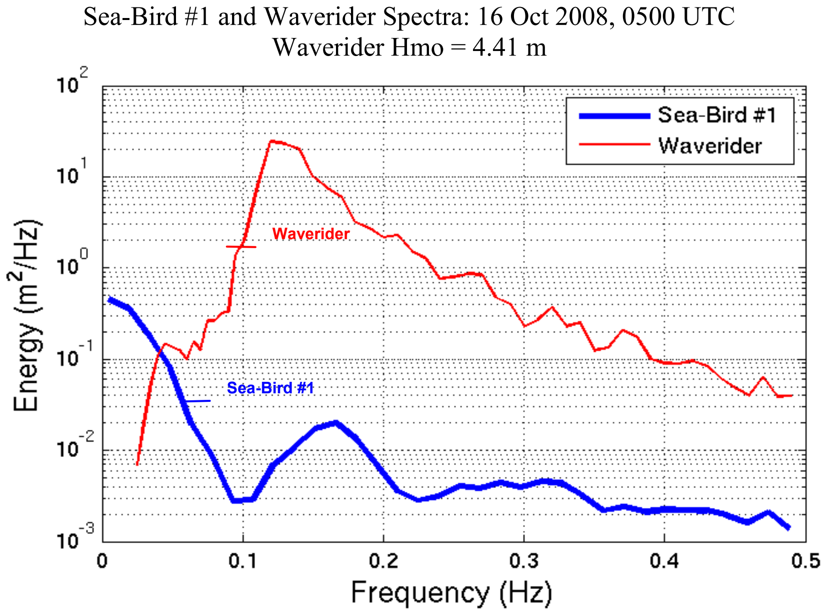

Figure 16: Waverider and SB-1 spectra during H. Omar.

3 Summary

This preliminary examination of the St Croix reef data was consistent with other reef studies (Lowe et al. [1]) where incident band wave energy is highly dissipated over the reef. Several factors are involved in the reduction of incident energy, including non-linear wave-wave interactions transferring energy to higher and lower frequencies, reflection from the steep fore-reef face, wave breaking, and bottom friction as waves propagate over the rough coral surface. All the instruments recorded highly dissipated incident band energy during the two documented storms, and an increase in infragravity energy that dominated the spectra. These long period waves [O (100 s)] could have been generated by incident infragravity energy, possibly by association with wave groups (bound infragravity waves), or by time-varying setup at the reef face caused by breaking wave groups. If the forcing is near the resonant mode of the reef, then water level variations can be enhanced (Pequignet et al. [2]). For this St Croix reef, rough estimates of the quarter-wave resonant mode for an open basin would be O (100 s). Further analysis of the data will look at incident wave grouping for correlations with reef infragravity motions and better estimates of reef resonant frequencies.

This data along with other PILOT site data will be used to improve the parameterizations of wave processes over reefs (Nwogu and Demirbilek [3]). Of particular interest is determining runup during storms to improve modeling of extreme water levels and island inundation (Vetter et al. [4]). Wave runup processes are enhanced with setup at the shoreline, which can have significant temporal and spatial variations over reefs (Jago et al. [5]). Setup observations from the shoreward most gauge, located at the nominal shoreline, provided data for correlating with runup. Extreme runup measurements were recorded from anecdotal information of debris locations and water damage via conversations with the locals, from which elevations were surveyed to the gauge datum. Future work will examine data from other storms and the other PILOT sites, in particular the southern St Croix site with a fringing reef and lagoon.

References

[1] Lowe, R.J., Falter, J.L., Bandet, M.D., Pawlak, G., Atkinson, M.J., Monismith, S.J., and Koseff, J.R. Spectral wave dissipation over a barrier reef. *J. Geophysical Research*, Vol 110, C04001, 16pp, 2005.

[2] Pequignet, A.C., Becker, J.M., Merrifield, M.A., and Aucan, J. Forcing of resonant modes on a fringing reef during tropical storm Man-Yi. *Geophysical Res. Letters*, Vol 36, L03607, 2009.

[3] Nwogu, O., and Demirbilek, Z. Infragravity wave motions and runup over shallow fringing reefs. *J. Waterway, Port, Coastal and Ocean Engineering*, Vol. 136, No. 6, 2010.

[4] Vetter, O., Becker, J.M., Merrifield, M.A., Pequignet, A.-C., Aucan, J., Boc, S.J., and Pollock, C.E. Wave setup over a Pacific Island fringing reef. *J. Geophysical Research*, Vol. 115, C12066, 13pp, 2010.

[5] Jago, O.K., Kench, P.S., and Brander, R.W. Field observations of wave-driven water-level gradients across a coral reef flat. *J. Geophysical Research*, Vol. 112, C06027, 14pp, 2007.