CRCP Project #417: Inter-Disciplinary Study of Flow Dynamics and Sedimentation Effects on Coral Colonies in Faga‘alu Bay, American Samoa: Oceanographic Investigation Summary

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Abstract

Water flow in Faga’alu bay was investigated using a year of data collected from in-situ oceanographic equipment. Waves and tides were measured on the forereef and reef flat and the outflow currents were measured in the reef pass. Flow dynamics in the bay are predominantly forced by waves breaking over the shallow reef to the south of the channel, which force the majority of the water to exit the bay through the single main channel in the reef. Wave height and tidal height were both strong influences on flushing time however due to the volume of water forced over the reef during wave events flushing rates increase proportionally with wave height. Flushing time in the lagoon was calculated to be approximately 33 hours during low wave events, decreasing to less than 2 hours during the highest wave event of the year. The bay is relatively enclosed, limiting the swell window and large wave events are uncommon. The largest wave event of the year had a peak significant wave height (H_{sig}) of less than 1.6 m which is low for the region. Since flushing is strongly wave dependent pollutants and sediment have a greater likelihood of settling and causing harm to the ecosystem, compared to bays or estuaries with better flushing mechanisms. Comparing these oceanographic data with the biological component of this project suggests that in general areas with better flushing, and subject to higher wave energy, were found to be healthier than those sheltered from incident waves. The interest in Faga’alu’s watershed may be well advised since the low energy in the bay may require more focused attention on storm water management compared with other watersheds, in order to limit run-off and mitigate damage caused by sedimentation and pollution.

1. Introduction

1.1. Background

The following are the oceanographic results from a National Oceanic and Atmospheric Administration (NOAA) Coral Reef Conservation Program (CRCP) funded project entitled: Inter-disciplinary study of flow dynamics and sedimentation effects on coral colonies in Faga'alu Bay, American Samoa (Project ID #417). This was a two year project from 2012 through 2013. This project was to examine the susceptibility of coral reefs in Faga'alu Bay to land-based sources of pollution (LBSP) and to develop a biological and oceanographic assessment of the distribution and effects of terrigenous sediments in nearshore coral habitats. This is in order to help support the development and implementation of Conservation Action Plans (CAPs), watershed management plans and facilitate data collection pertinent to management aimed at reducing impacts of land-based sources of pollution and sedimentation. The overarching objectives were to provide a greater understanding of circulation and residence time in the bay for sediment, freshwater and pollutants and use biological surveys to provide a comprehensive assessment of coral reef benthic demographics in relation to patterns of sediment-stress and LBSP.

1.2. Project Motivation

Ongoing studies by San Diego State University found that sedimentation in Faga'alu Bay is likely caused by run-off from the open plan quarry above Faga'alu village (*Biggs 2011*). Benthic surveys by DMWR and anecdotal evidence from local partners suggest that flows within the bay are dominated by wave events forcing water over the reef to the south. This water is subsequently forced northward and eastward, eventually exiting the bay via the anthropogenically altered reef pass. During heavy precipitation events, northerly flow transports sediments from the river onto the smaller northern reef flat and out the pass onto the forereef. Oceanographic instrumentation and benthic studies presented here were designed to test these hypotheses and provide an assessment of flow patterns. Colleagues at San Diego State University (SDSU) have already initiated efforts in their watershed study and hypothesize, from historical discharge data that the majority (90%) of sedimentation discharged into Faga'alu Bay is occurs during the 5-10 largest storm/precipitation events annually. These storms are to be targeted in the water sample investigation. NOAA's Pacific Islands Regional Office has been working with the community in Faga'alu, where a local Watershed Committee has been established and is committed to improvement of the watershed and downstream coral reef ecosystems in their bay.

2. Methods

2.1. Geography

Faga'alu is a coral reef-rimmed bay and watershed located on the south side of Tutuila Island, American Samoa (Figure 1). It has a single riverine input that passes through an open plan cement quarry in the valley before passing through rural small-holdings, through the village, and finally into the bay. Much of the sedimentation originates in the quarry, entering the bay during times of heavy rain (SDSU). The bay is enclosed on three sides by land as it is positioned on the western side of the inlet to Pago Pago Harbor, a large very deep natural harbor that is sheltered from swells due to its right angled shape, and winds due to the high topographic relief. The bay itself has a shallow reef crest that is exposed at strong low tides, and shallow reef flat and back reef leading to a single deep reef pass. The fore-reef drops off steeply and most wave energy breaks directly on the reef shelf, forcing water shoreward over the reef crest.

2.2. Oceanographic Study

In order to measure the water motion in Faga'alu Bay the Coral Reef Ecosystem Division (CRED) oceanography team deployed three sensors around the bay that yielded data; two Seabird Electronics wave and tide recorders (WTRs) and one Nortek Aquadopp acoustic Doppler current profiler (ADCP; Figure 1). The ADCP was deployed with an additional external battery pack for extended battery life. The WTRs recorded waves for two 20-minute wave bursts per hour, at 2 Hz sampling frequency with tides measured every hour. The ADCP was deployed in 15 meters of water, and was programmed to sample currents at every meter of depth once every 60 seconds. This gave 15 depth current readings every minute for the entire year deployment. We originally deployed two ADCPs as part of this study however the shoreward ADCP was vandalized less than a month into the project resulting in no usable information. The remaining ADCP located in the channel was deemed sufficient for the scope of this project and all other instruments ran correctly and yielded almost a year of data, the intended timeline for this project.

The WTR on the forereef of the bay (WTR-1), in 15m of water, recorded the incident wave field, while the WTR on the reef (WTR-2), in 1m of water, measured the wave and tide influence within the bay (Figure 1 and Table 1). The ADCP was deployed at the reef pass, in the middle of the outflow channel in order to record the bulk water flow in and out of the channel.

Table 1. Oceanographic instrumentation and deployment information

Instrument	Latitude	Longitude	Depth (m)	Deployment Date	Recovery Date
WTR	-14.29198	-170.67863	0.9	07-Apr-12	02-Apr-13
WTR	-14.29298	-170.67515	13.4	08-Apr-12	03-Apr-13

ADCP	-14.28976	-170.67895	14.9	08-Apr-12	04-Apr-13

All work was conducted using standard open circuit SCUBA diving techniques under the auspices of the NOAA dive center. Oceanographic instruments were deployed by the Coral Reef Ecosystem Division in April 2012 during the American Samoa Reef Assessment and Monitoring Program (ASRAMP) cruise HA1201, aboard the NOAA Ship *Hi'ialakai* (R334). The instruments were retrieved during a land-based field mission in April 2013.

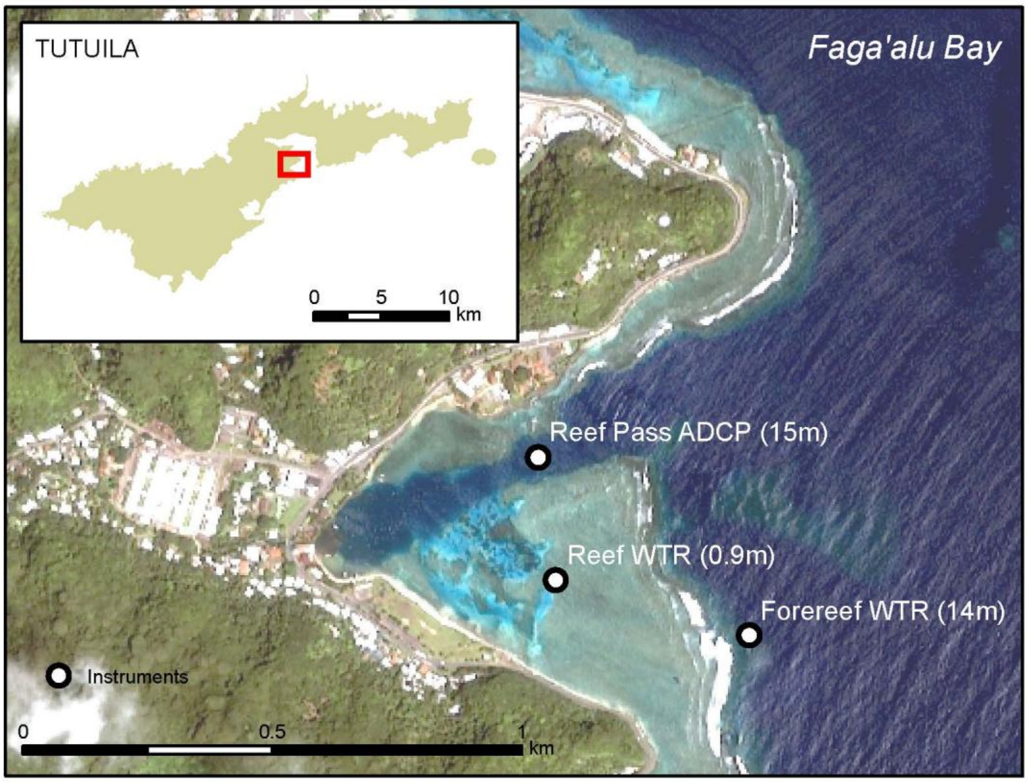

Figure 1. Geographic setting and oceanographic instrumentation deployments between April 2012 & April 2013 in and around Faga'alu Bay, American Samoa

2.3. Flushing Time Calculations

Faga'alu Bay flushing times were calculated using the following assumptions that: 1) water in the channel flows seaward; 2) current speed is homogenous with depth; 3) water velocity is zero at the channel-water interface. Volume of the bay as well as depth and width of the channel were calculated using the bathymetry from GIS. The flushing time was calculated as the volume of the bay divided by the total outflow volume. Since the majority of the input to the bay is from overtopping waves, salinity differences from riverine input were ignored for the calculation of flushing at this level of analysis. A further analysis would take into account riverine input, and rainfall data for variations in volume inputs.

3. Results

3.1. Wave and Tide Observations

Waves and tides were recorded in the bay and on the forereef (Figure 2A). The incident wave field was a relatively weak wave forcing, compared with other forereef areas around the Pacific. Over the time period of data collection (9th April 2012 to 2nd April 2013), significant wave height peaked at 1.7m, although wave heights > 1m were rarely observed. The sheltered position of the bay, in the mouth of the natural harbor, means that the bay is only open to a narrow swell window. South swells then have to refract west to hit the reef directly, reducing their energy further. Reef flat wave heights were orders of magnitude smaller than the incident waves due to the strong attenuation after breaking over the shallow reef; a typical result for shallow reef regions. Since the water depth at the reef crest is almost zero at low tide, cross-reef transport of water and waves are completely dependent on the tidal range and wave setup. Significantly greater wave energy can transport across the reef at high tide compared with low (Figure 2 A & B).

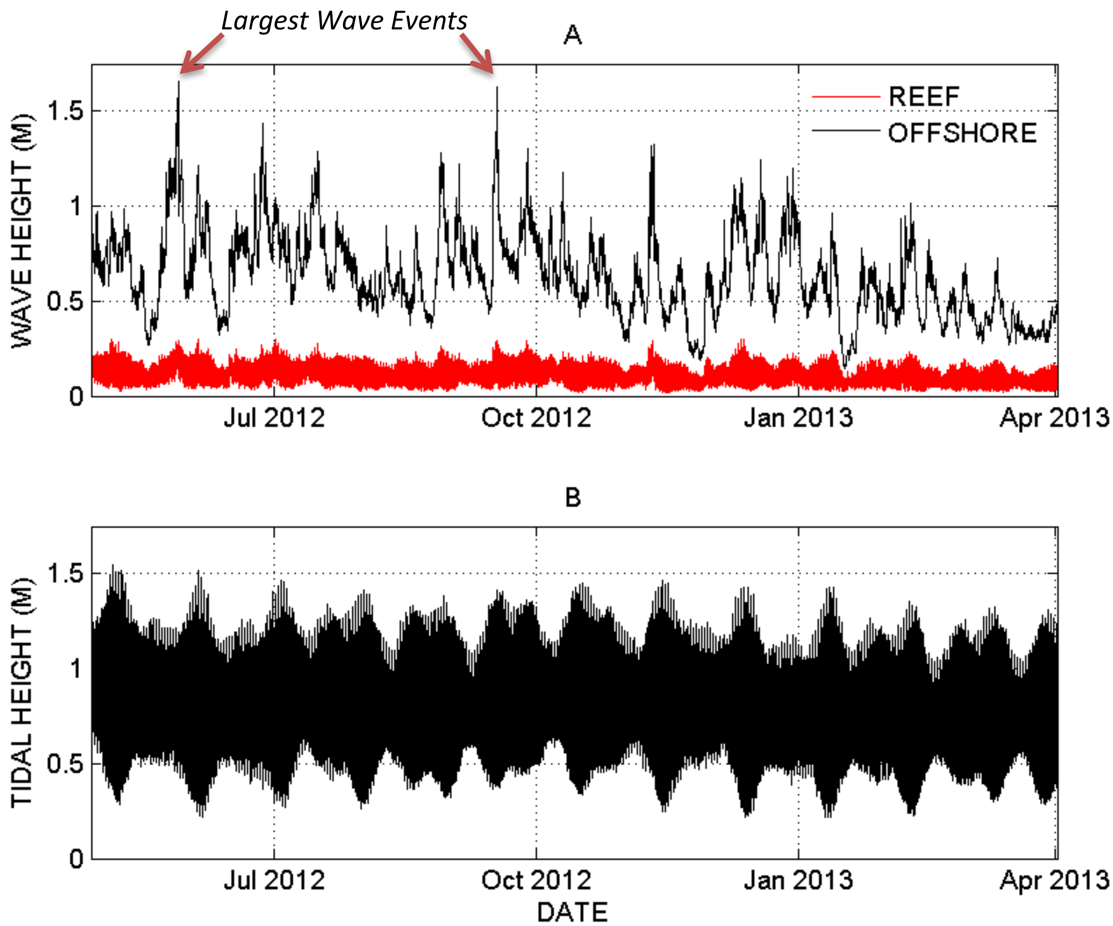

Figure 2. Timeseries of significant wave height (A) and tidal height (B) on the reef flat and forereef.

3.2. Current Observations

Currents in the channel were positively correlated with wave and tide events, with stronger outward flow associated with greater wave heights and increased tide level ($R^2 = 0.874$, $p < 0.05$; Figure 3). The mean current speed was 0.14 ms^{-1} (± std, 0.07) and mean direction was 108^o (± 30^o). Therefore, current direction was predominantly eastward, directly out of the channel (Figure 4). It is reasonable to infer that the major forcing mechanisms for water movement in the bay are waves and tides, with wave influence increasing linearly with tide.

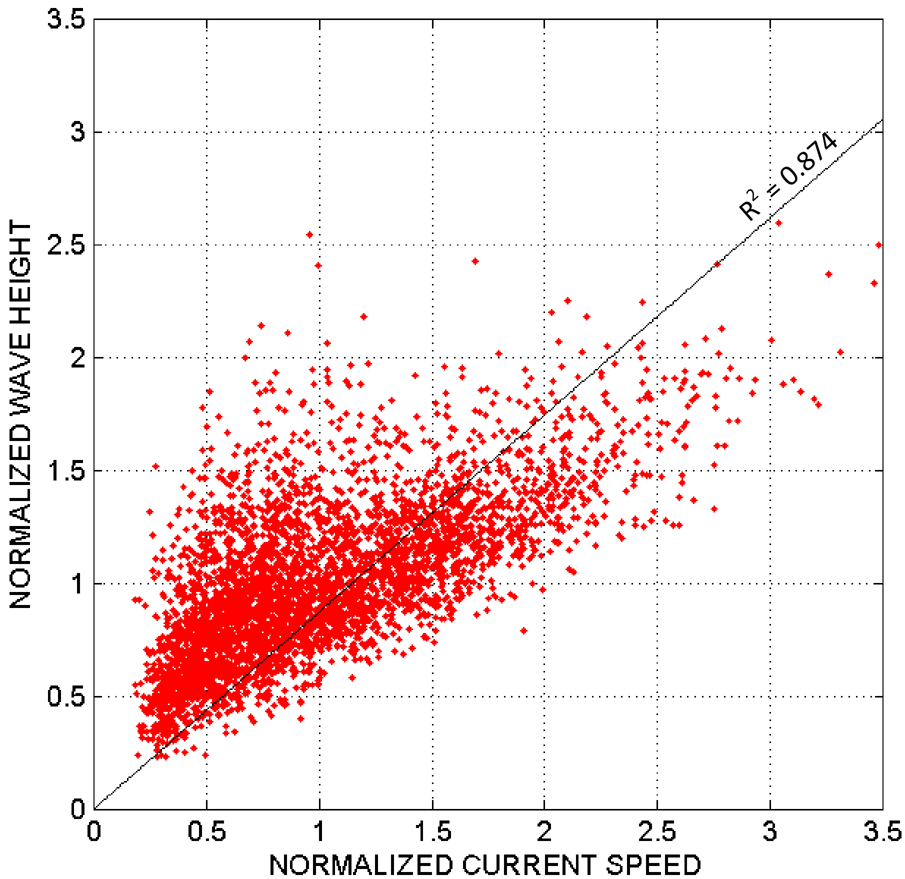

Figure 3. Relationship between channel current speed and forereef wave height (R^2 = 0.874, p < 0.05).

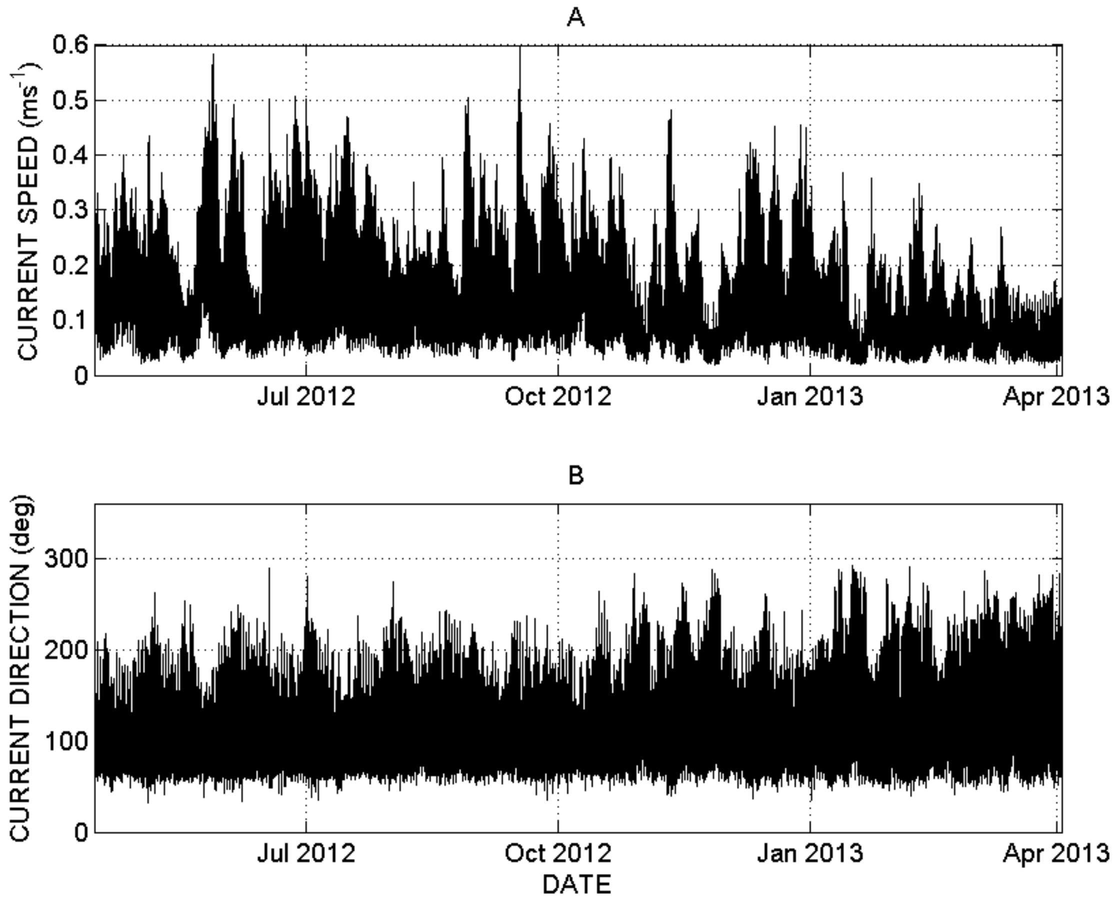

Figure 4. Timeseries of depth averaged current speed (A) and direction (B) in the reef channel.

3.3. Peak Wave Event – Wave height, current speed and flushing rate / High and Low Tide

The data presented herein supports the hypothesis that incident waves are the greatest driving forcing mechanism of water motion in the bay – the largest wave event was chosen to highlight the interaction between wave forcing and flushing rates.

Wave height during the study peaked on 28-May-2012. Significant wave height reached 1.65 m and high tide peaked at 0.3 m (Figure 5). Peak wave height was over 1.4 m for a full 12-hour tidal cycle enabling us to observe similarly sized high waves at both high and low tide. During this event, currents were heavily modulated by the tidal height; however wave events appeared to have a greater influence in current outflow (Figure 5). During the peak of the May 28 wave channel flow at high tide was 0.6 ms^{-1} three times the current speed it observed during high tide with minimal wave forcing (21-May-2012 , Figure 5). Water motion in the bay is strongly affected by wave events.

Flushing time is significantly quicker during large waves compared to flushing from tidal motion alone.

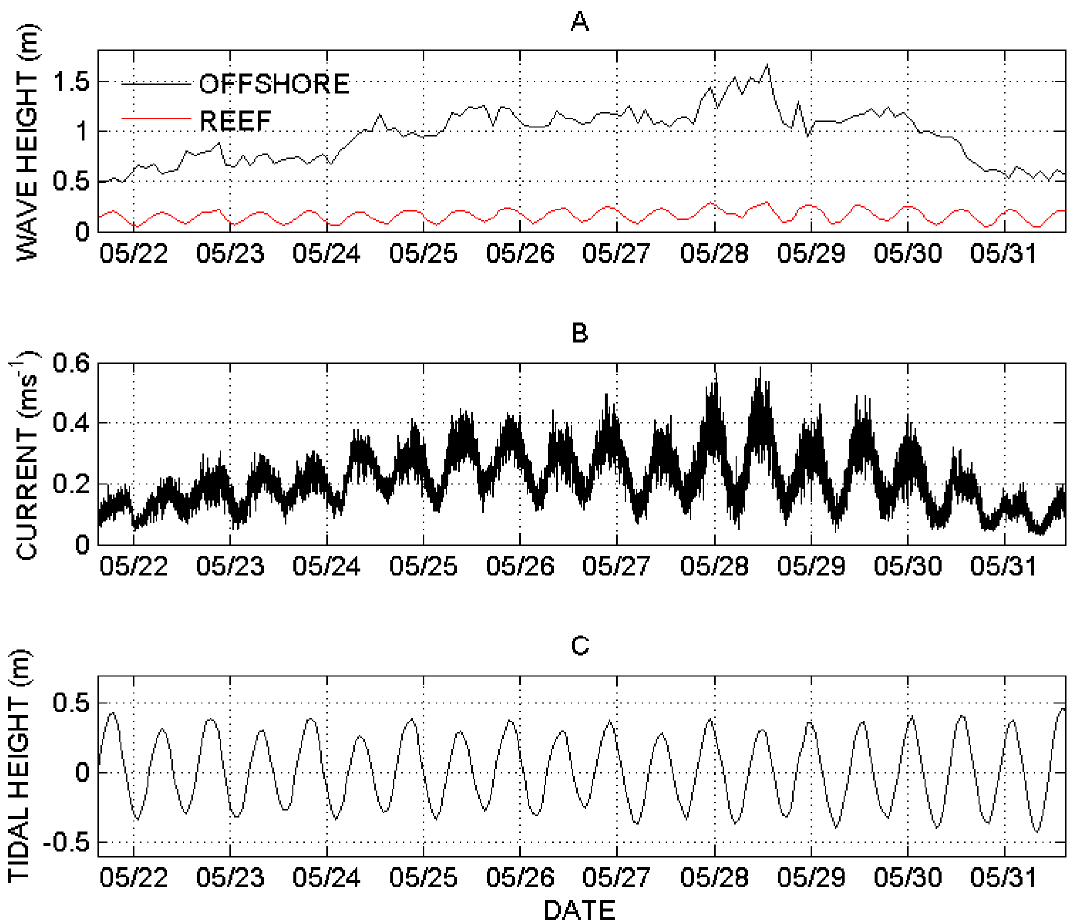

Figure 5. Wave height (A), current speed (B) and tidal fluctuation (C) during the largest swell event of the year, 28-May-2012.

3.4. Flushing Time

Using the Surface Volume tool in ArcGIS 10.3 and bathymetric data derived via LIDAR, the calculated volume of Faga'alu Bay was 677,448 m^3. The cross-sectional area of the channel was also calculated at the position of the channel ADCP to be 390 m^2. Owing to the relatively small volume of the bay, calculated flushing times varied from just a few hours to a small number of days over the study period. Flushing time was shortest during high tide and high wave events, with a total flushing time of < 1 hr. during the highest observed wave and tide event, whereas during periods of low waves, flushing times were ~33 hrs. (Figures 6 & 7)

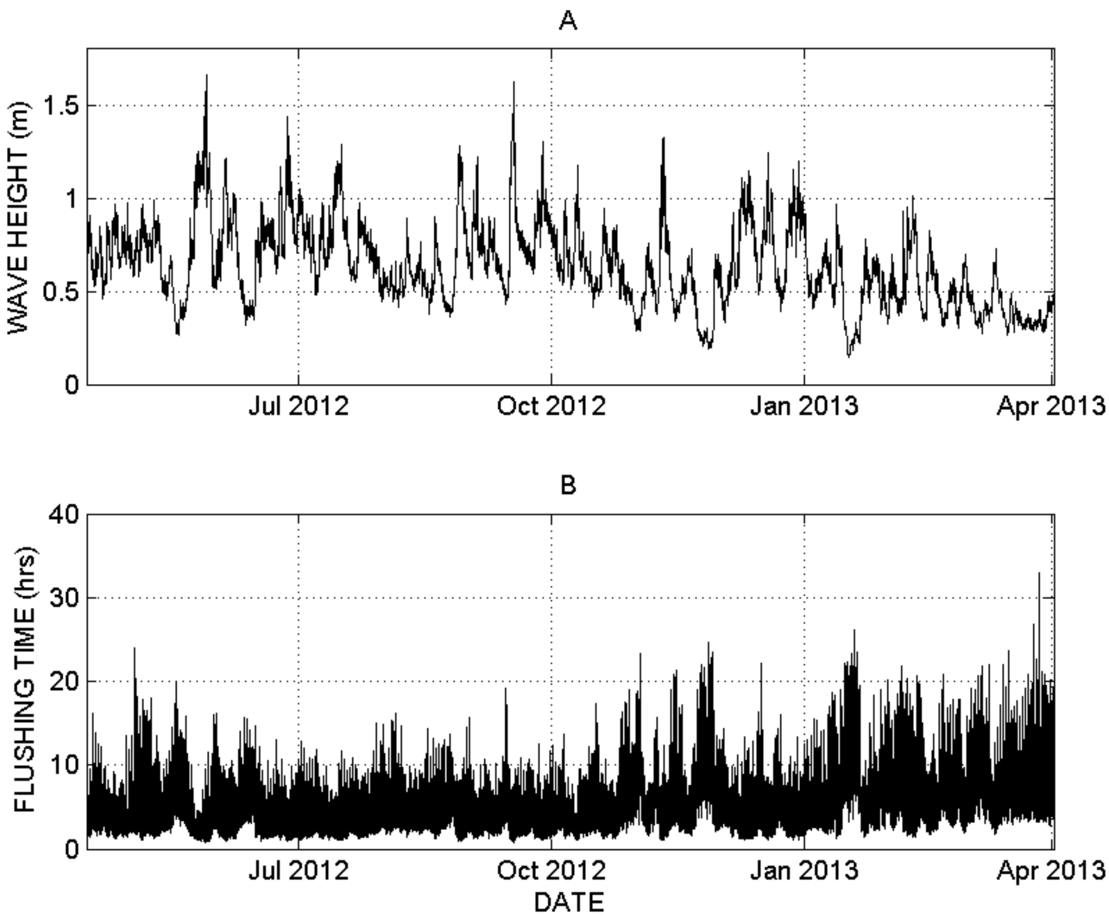

Figure 6. Wave height (A) and flushing time (B) are shown indicating that flushing time decreases with increasing wave height

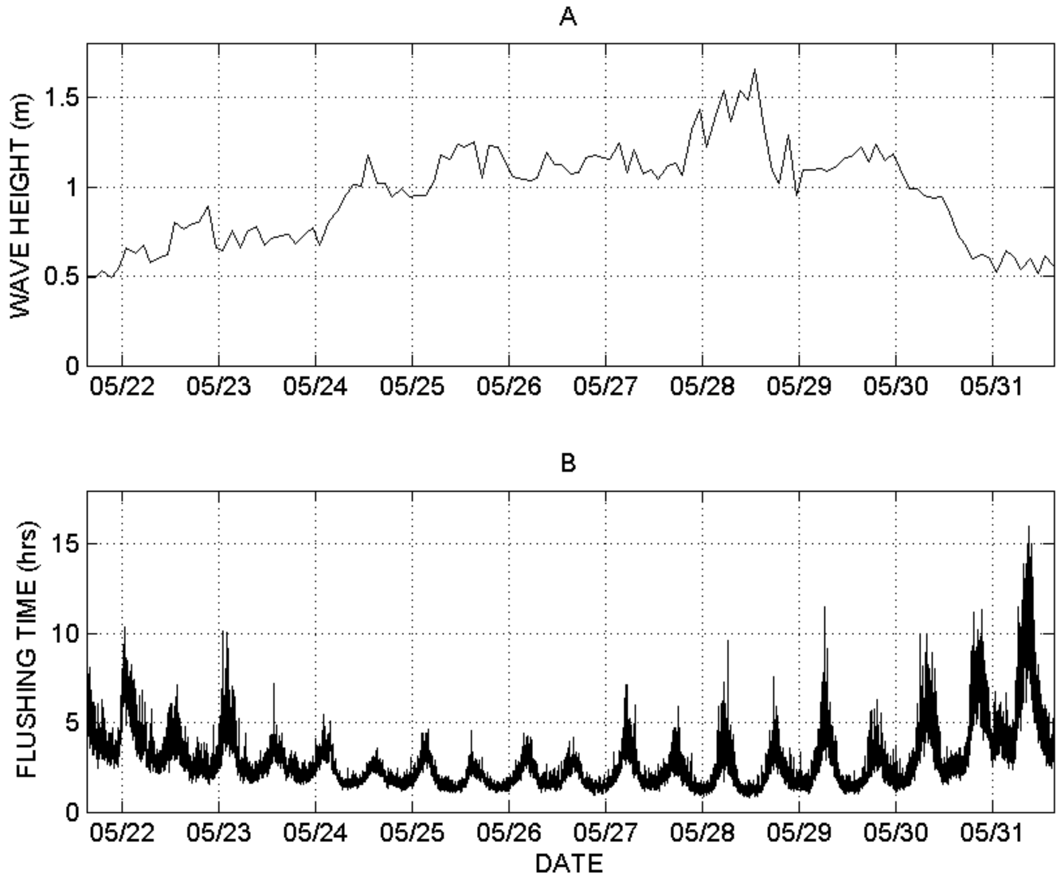

Figure 7. Wave height (A) and flushing time (B) during 10 days over the largest swell of the study.

3.5. Temperature Observations

Ocean temperature was recorded by both WTR instruments. Forereef and reef flat ocean temperatures were very similar. The reef flat observed stronger diurnal heating and cooling, but the mean temperature at 1m depth was 28.69 ^{o}C while the mean temperature at 14m was 28.60 ^{o}C (Figure 8 A). It is unusual for forereef temperatures to be as high as reef flat temperatures. The temperature difference between the forereef and reef flat was so little there was no clear relationship between reef temperature and incident wave height during the study period, indicating that wave action likely has little influence on reef flat temperature fluctuations. During the largest observed wave event, reef temperature declined by <1^{o} C, but didn't appear to be directly correlated to the wave event itself (Figure 8 B). Wave events were therefore not found to be a source for cooling the reef at Faga'alu.

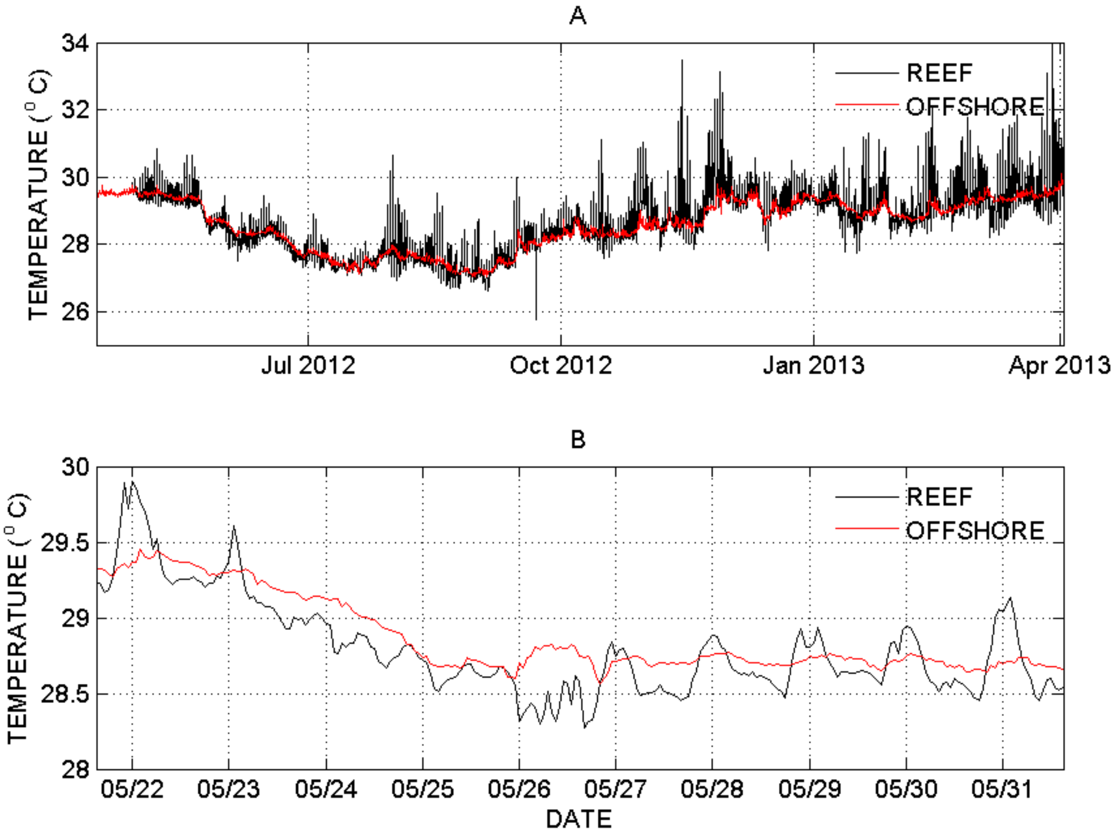

Figure 8. Water temperature on the forereef and in the bay during the full time period (A), and during the peak wave event (B).

4. Discussion

Biological surveys gave a quantitative view of reef health around the bay (Vargas-Angel 2013). The CRED benthic team used multiple surveys that measured percentage coral cover, calcifying coralline algae, turf algae, disease and bleaching, coral generic richness, coral density and calculated a reef builder ratio. These metrics showed that live coral cover was nearly twice as high along the south compared to northern portion of the reef while levels of turf algae were greater along the northern forereef and backreef compared to the other sampled portions of the bay. The northern areas of the Faga'alu reef are directly affected by terrigenous siltation and runoff impacts (Figure 9).

While there are other factors that influence coral reef benthic communities (e.g. temperature), our findings suggest that that wave forcing and subsequent flushing is likely a major influence on reef dynamics in Faga'alu Bay, based on the metrics described in the benthic document, those that gave a measure of reef health mapped proportionally with level of wave exposure. Based on these metrics, the low energy northern reef had the least healthy reef system while the more energetic southern forereef had the most healthy reef system. In addition to wave events forcing flushing, a stronger wave regime would be more effective at suspending sediments and removing them from the reef. The northern reaches of the bay are heavily affected by sedimentation, which directly influences coral growth. During rain events, increased sediment, pollution and containments flow into the bay and eventually settle on benthic reef organisms. Increased sedimentation can result in coral mortality and drive shifts in coral reef benthic community structure, from a coral dominated to an algal dominated community. Wave-drive resuspension and transport of sediments from the reef out the bay is the principle mechanism for removal of excesses sediment from the reef community. Although flushing rates are relatively rapid (particularly during wave events), certain areas within the bay are less influenced by incoming wave energy and therefore have increased vulnerability to the effects of sedimentation. Proper mitigation of incoming sediment could improve areas within the bay that currently showing poor ecosystem health.

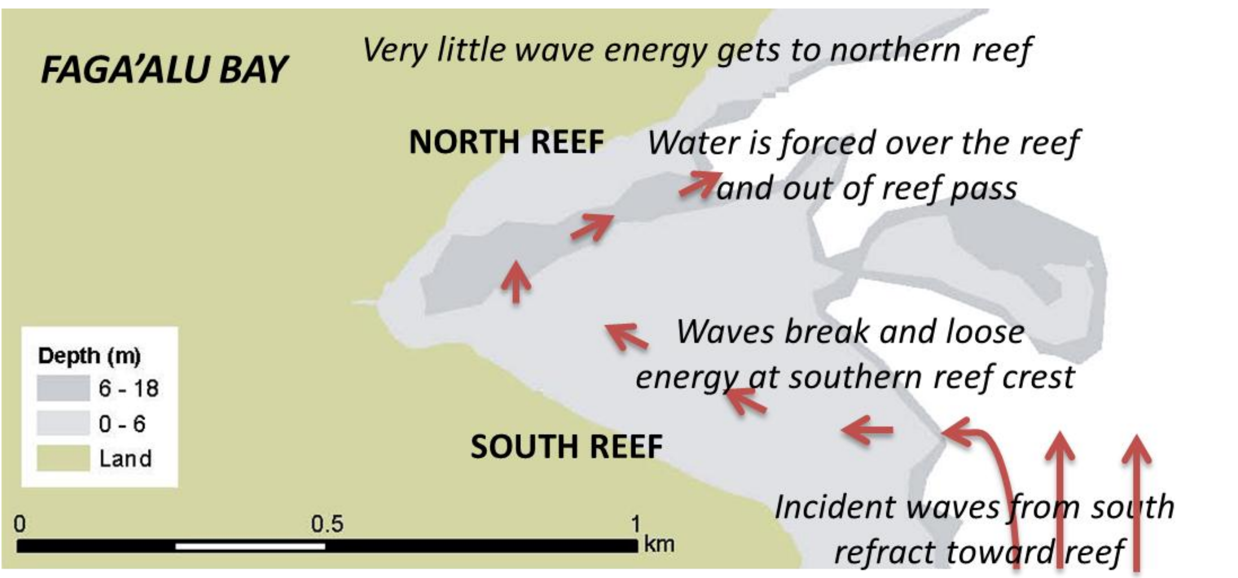

Figure 9. Schematic of water motion within Faga'alu Bay. Waves lose energy through refraction, breaking and propagation over the shallow reef. Very little energy reaches the northern reef.

References

Biggs, T. (2011) Sediments and water quality in Faga'alu Watershed. Presentation given to Coral Reef Advisory Group, American Samoa

Vargas-Angel, B. (2013) Benthic Survey Summary: Inter-Disciplinary Study of Flow Dynamics and Sedimentation Effects on Coral Colonies in Faga'alu Bay, American Samoa.