MARE 105 PRESENTATION TO THE UNIVERSITY OF HAWAI'I DEPARTMENT OF MARINE SCIENCE

Wave Direction and height using the Pacific Islands Ocean Observing System (PacIOOS) Datawell Mark II Waverider Data Buoy located off the coast of Hilo, Hawai'i

DURATION

February 1, 2014 – April 17, 2014

PROJECT LEADERS

Kayleigh Flynn

Marine Science Department
University of Hawai'i at Hilo
The Coastal Data Information Program (CDIP)

ADVISOR

Dr. Steven Colbert
Marine Science Department
University of Hawai'i at Hilo

CONTENTS

FIGURES

TABLES

ABBREVIATIONS

PacIOOS (Pacific Islands Ocean Observing System)
CDIP (Coastal Data Information Program)
IOOS (Integrated Ocean Observing System)
Hs (wave height)
Tp (peak period)
Dp (peak direction)
AWAC (Acoustic Wave and Current)

Abstract

The Pacific Islands Ocean Observing System (PacIOOS) Datawell Mark II Waverider Buoy located outside Hilo, Hawai'i, was placed in the water March 4, 2012. This system measures wave direction and height, and weather conditions that the public can access for commercial and recreational purposes. The wave height, wave period and the directional movement data that was collected from March 2012 to May 2014 were studied. Seasonal variations between these three parameters were observed, and it was found that waves moving into Hilo Bay had either high or low heights as well as short or long periods during certain times during each year of collection. Also, the wave height and period differed based on the direction they were moving from.

Introduction

What waves are and the parameters that are collected about them

Waves occur when energy is transferred from one location to another due to surface disturbances (Davis, 2004). Waves can range in size and are caused by disturbing forces such as wind, storms, tsunami, or landslides (Garrison, 2010). The primary force that drives waves is wind. Depending on how fast winds are blowing over the ocean, the time length and the distance the wind travels determines the size, shape and speed of waves.

There are three parameters that are looked at when looking at wave measurements: height, period and peak direction. Wave height (Hs) is the distance between the wave crest and the adjacent trough. A wave period (Tp) is the amount of time that is required for a wave to travel one wavelength. Wave direction (Dp) is the direction in which the wave is moving.

How waves are measured

There are four different instruments that can measure waves: Ultrasonic sensors, accelerometers, acoustic current profilers and buoys.

Ultrasonic sensors are attached to the bottom of vessels, and emit one to multiple ultrasound pulses that can measure the time lag of an echo (Christensen, 2013). The time difference between the release of a pulse and the return signal can determine the depth of the ocean (Gupta, 2012).

Accelerometers are devices less commonly used that can be attached to buoys and measure wave height (Patra, 2014), along with the sea surface vertical accelerations (Chuang, 2013).

An AWAC (Acoustic Wave And Current) is an instrument that measures the profiles and wave directions in shallow waters over a long period of time (Pederson, n.d.).

This device is placed on the seafloor, and can have beams employed that minimize data volume and increase the deployment time (Pederson, n.d.).

GPS buoys are used more commonly in water depths of 10 meters or less (IOOS, 2009). They measure the motion of the water surface that provides historical data of wave heights and periods (Doong, 2011). Moored buoys are buoys that are anchored off shore. They provide better ability to gather data since they do not require constant handling and can be left unattended for long periods of time (Diwan, 1989).

The best instrument to use for finding the wave height, period and direction are GPS buoys since all three parameters can be gathered at once, rather than each one individually from different instruments.

What is the Coastal Data Information Program

The Coastal Data Information Program (CDIP) provides a monitoring system allowing the public to view waves and beaches along the Unites States coastlines, as well as the Marshall Islands and Samoa. This program includes measurements, archives and analyzed data that can be used by the public, coastal engineers and scientists. All of the data taken from their stations can be found on the CDIP website. On the website there is a link that can take you to all the historic data for all buoy stations that are being used by the CDIP.

Hilo, Hawai'i has a buoy that was placed in the water back in 2012, and is called Station 188. This station was placed at 19 46.89 N 154 58.08 W, which is north east of Hilo past the breakwater. Station 188 has another name, the Datawell Mark II Waverider buoy. Although the buoy has all of its data transferred to the CDIP, the physical buoy was provided by the Pacific Islands Ocean Observing System (PacIOOS).

What is PacIOOS

PacIOOS is an organization that strives to help protect the coastal areas of the Pacific Islands by developing outreach programs, data management and modeling components through an ocean observing system. The Datawell Mark II Waverider buoy that is place north east of Hilo measures wave direction, height and period. It also provides weather conditions that the public can access for commercial and recreational purposes.

Long-term data

A larger number of waves come from the northern direction towards Hilo during wintertime (winter swells), but decrease during the summer time. Waves coming from a southern direction have a lower number of waves during winter but increase during the summer months (trade winds).

Reason for using this buoy

We know which direction the waves come from but what we don't know is how fast or how big these waves are. For my project I looked at the data from the buoy to figure out the long-term trends for speed and size of wave entering Hilo Bay.

Methods

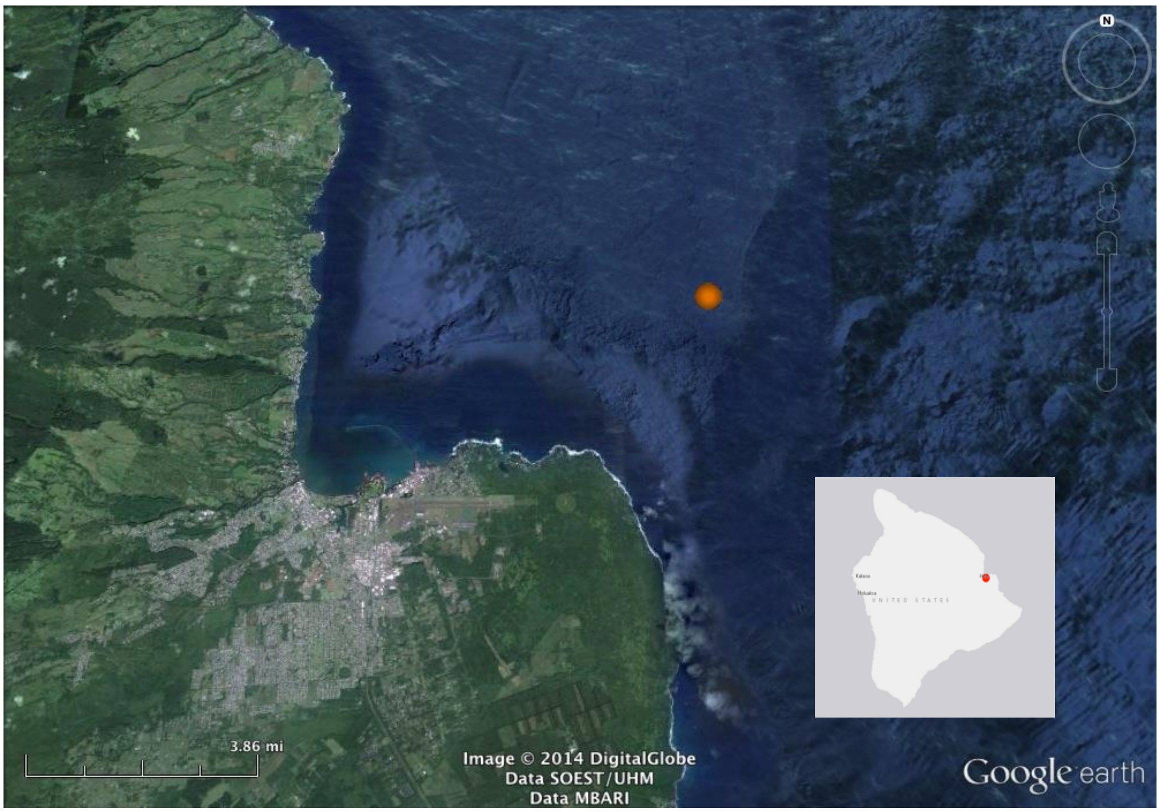

Figure 1. The PacIOOS buoy, located 19 46.89 N 154 58.08 W, is positioned north east of Hilo. Orange dot represents the buoy.

Data that was used for this project was taken from the CDIP website which contained the data history for Station 188. When looking at the historic data, the table showed data from the time of the buoy entered the water to the present. Parameters included the year, month, day, hour, minute, wave height, peak period, peak direction, temperature (surface, middle and bottom), wind speed and direction, and air temperature. The wave height (Hs), peak period (Tp) and peak direction (Dp), along with the corresponding months for each data set was focused on.

The first step was to enter all the data from Station 188 for each month into Excel (Table 1). Once the data was put into the spreadsheet, the second step included highlighting the Hs, Tp and Dp and moving them to another spreadsheet where a fourth column labeled “Dp Correct” was created using the formula =IF(C3<180,C3,C3-360). The Dp Correct stood for the adjustment of direction to be changed from -180 to 180 degrees (the direction was centered around the North, 360to 0, instead of being centered around the South, 0 to 360) (Table 2). The correction of adjustment was created because waves approaching Hilo came from the north and east. West and south waves do not affect this location because they do not reach around the island that far.

Table 1. Raw data from CDIP website that was entered into Excel. Highlighted columns are data focused in project.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	YEAR	MO	DY	HR	MN	Hs	Tp	Dp	Depth	Ta	Pres	Wspd Wdir	Temp	Temp	Temp	Temp
2		U	TC			m	sec	deg	m	sec	mB	m/s deg	Air(C)	Sfc(C)	Mid(C)	Bot(C)
3	2012	3	4	21	19	2.68	14.3	335		8.83		23.2				
4	2012	3	4	21	49	2.52	12.5	335		8.47		23.3				
5	2012	3	4	22	19	2.7	14.3	334		8.81		23.5				
6	2012	3	4	22	49	2.75	14.3	347		8.84		23.5				
7	2012	3	4	23	19	2.59	14.3	335		8.55		23.5				

Table 2. Correction of adjustment (highlighted) for peak direction.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
1	Hs	Tp	Dp	Dp Correct	0.0	0.0	0.0	0.0	0.0	7.3	23.3	14.1	15.4	28.1	11.9	0.0	0.0	100.0
2	m	sec	deg		S	S/SW	W/SW	W	W/NW	N/NW	N	N/NE	E/NE	E	E/SE	S/SE	S	
3	2.68	14.29	335	-25	0	0	0	0	0	1	0	0	0	0	0	0	0	
4	2.52	12.5	335	-25	0	0	0	0	0	1	0	0	0	0	0	0	0	
5	2.7	14.29	334	-26	0	0	0	0	0	1	0	0	0	0	0	0	0	
6	2.75	14.29	347	-13	0	0	0	0	0	0	1	0	0	0	0	0	0	
7	2.59	14.29	335	-25	0	0	0	0	0	1	0	0	0	0	0	0	0	
8	2.47	13.33	337	-23	0	0	0	0	0	1	0	0	0	0	0	0	0	

The third step was to create columns for each direction (Table 2). For each column the formula =IF($D3>=-180,IF($D3<-165,1,0),0) was used to determine which direction waves came from. (It should be known that the formula put into this paper is the formula used for the column after Dp Correct in Table 2, and that the -180 and -165 in the formula changes when moving from one direction to the next).

Once the direction was determined, all northern moving waves were added together for each month in one column, and all eastern moving waves were added together in another column (Table 3).

Table 3. Sum of all northern and eastern directions in relation to their month the data was collected.

New Open Save Print Import Copy Paste Format

	A	B	C
1	Month	NNW/N/NNE	ENE/E/ESE
2	Mar-12	44.6	55.4
3	Apr-12	33.9	66.1
4	May-12	7.9	92.1
5	Jun-12	8.2	91.8
6	Jul-12	0.3	99.7
7	Aug-12	2.5	97.4
8	Sep-12	20.6	79.4
9	Oct-12	33.3	66.7
10	Nov-12	43.3	56.7
11	Dec-12	30.6	69.4
12	Jan-13	36.6	63.4
13	Feb-13	24.7	75.2
14	Mar-13	61.3	38.7
15	Apr-13	33.3	66.6
16	May-13	16.8	83.2
17	Jun-13	16.9	83.1
18	Jul-13	11.0	89.0
19	Aug-13	9.3	90.7
20	Sep-13	39.4	60.4
21	Oct-13	64.5	35.5
22	Nov-13	46.7	53.3
23	Dec-13	36.0	64.0
24	Jan-14	73.5	26.5
25	Feb-14	84.7	15.3
26	Mar-14	76.7	23.2
27			

During the fifth step, six quartiles were created: three for wave height and three for peak period (Tables 4 and 5). Quartiles in the Excel spreadsheet were labeled first (Q_1) quartile, second (Q_2) quartile and third (Q_3) quartile, followed by negative and positive errors.

Table 4. Wave height quartiles along with negative and positive errors.

Month	1ST QT Height	2ND QT Height	3RD QT Height	negative error	positive error
Mar-12	2.1	2.4	2.8	0.3	0.39
Apr-12	1.9	2.1	2.4	0.2	0.25
May-12	1.5	1.9	2.4	0.3	0.55
Jun-12	1.7	2.0	2.2	0.2	0.20
Jul-12	1.7	2.0	2.2	0.3	0.26
Aug-12	1.5	1.8	1.9	0.2	0.15
Sep-12	1.5	1.8	2.0	0.3	0.21
Oct-12	1.5	1.7	1.9	0.3	0.21
Nov-12	1.9	2.2	2.5	0.3	0.32
Dec-12	2.2	2.7	2.9	0.4	0.28
Jan-13	2.2	2.6	3.1	0.4	0.45
Feb-13	2.3	2.6	3.0	0.4	0.37
Mar-13	1.6	1.7	2.1	0.2	0.32
Apr-13	1.5	1.8	2.2	0.4	0.36
May-13	1.3	1.5	1.8	0.2	0.26
Jun-13	1.6	1.8	2.0	0.2	0.21
Jul-13	1.4	1.5	1.7	0.2	0.20
Aug-13	1.4	1.6	1.9	0.2	0.30
Sep-13	1.3	1.6	1.8	0.2	0.21
Oct-13	1.5	1.6	1.9	0.1	0.25
Nov-13	1.6	1.9	2.3	0.3	0.44
Dec-13	1.9	2.1	2.4	0.2	0.28
Jan-14	1.9	2.3	2.7	0.4	0.40
Feb-14	1.6	1.9	2.1	0.3	0.24
Mar-14	1.8	2.0	2.3	0.2	0.35

Table 5. Peak period quartiles along negative and positive errors.

Month	1ST QT Period	2ND QT Period	3RD QT Period	negative error	positive error
Mar-12	8.3	9.1	11.8	0.8	2.67
Apr-12	8.3	9.1	9.9	0.8	0.79
May-12	8.3	9.1	9.1	0.8	0.00
Jun-12	7.7	8.3	9.1	0.6	0.76
Jul-12	7.7	8.3	9.1	0.6	0.76
Aug-12	7.1	7.7	8.3	0.6	0.64
Sep-12	7.7	7.7	9.1	0.0	1.40
Oct-12	7.7	8.3	11.1	0.6	2.78
Nov-12	8.3	9.1	11.8	0.8	2.67
Dec-12	9.1	9.9	11.8	0.8	1.88
Jan-13	9.9	11.1	12.5	1.2	1.39
Feb-13	9.1	9.9	10.5	0.8	0.65
Mar-13	9.1	10.5	14.3	1.4	3.76
Apr-13	8.3	9.1	11.1	0.8	2.02
May-13	8.3	8.3	9.1	0.0	0.76
Jun-13	8.3	8.3	9.1	0.0	0.76
Jul-13	7.7	7.7	8.3	0.0	0.64
Aug-13	7.7	8.3	9.1	0.6	0.76
Sep-13	7.7	8.3	11.1	0.6	2.78
Oct-13	8.3	10.5	12.5	2.2	1.97
Nov-13	8.3	9.9	11.8	1.6	1.88
Dec-13	9.1	9.9	14.3	0.8	4.41
Jan-14	9.9	12.5	14.3	2.6	1.79
Feb-14	11.1	12.5	13.3	1.4	0.83
Mar-14	9.1	11.8	14.3	2.7	2.53

The sixth step was the creation of graphs for the sum of all the directions (Table 3), one graph using the wave height (Hs) quartiles and another graph for the peak period (Tp) quartiles (Tables 4 and 5). A straight-line scatter plot was used to show the sum of all NNW/N/NNE moving directions and all ENE/E/ESE moving directions, and a marked scatter plot was used for both the wave height (Hs) and peak period (Tp). When looking at the marked scatter plots, the second (Q_2) quartile for the scatter plots was focused on and used to represent the wave height and period (Figures 3 and 4). Errors bars were placed where the first (lower fence) and third (upper fence) quartiles were located. Each individual box in the scatter plot represented each month with their respective 2nd quartile and error bar.

Results and Discussion

Northern and Eastern Moving Wave Analysis

Waves that came towards Hilo were divided by their direction: all waves from a northern course were grouped together (North/Northwest, North and North/Northeast), and all waves from an eastern course were grouped as one (East/Northeast, East and East/Southeast). By combining the following directions, the number of waves that entered the bay during certain months of the year was identified.

Since the waves were moving from the northern and eastern directions at different times throughout each year, waves entered the bay area at different intervals during that time. Waves that came in from the North-North West/North/North-North East had greater numbers of waves during the later portions of the winter and spring, between January and March. Winds that came in from the East-North East/East/East-South East have a higher directional movement during the summer months but decrease between January and March as seen in Figure 2.

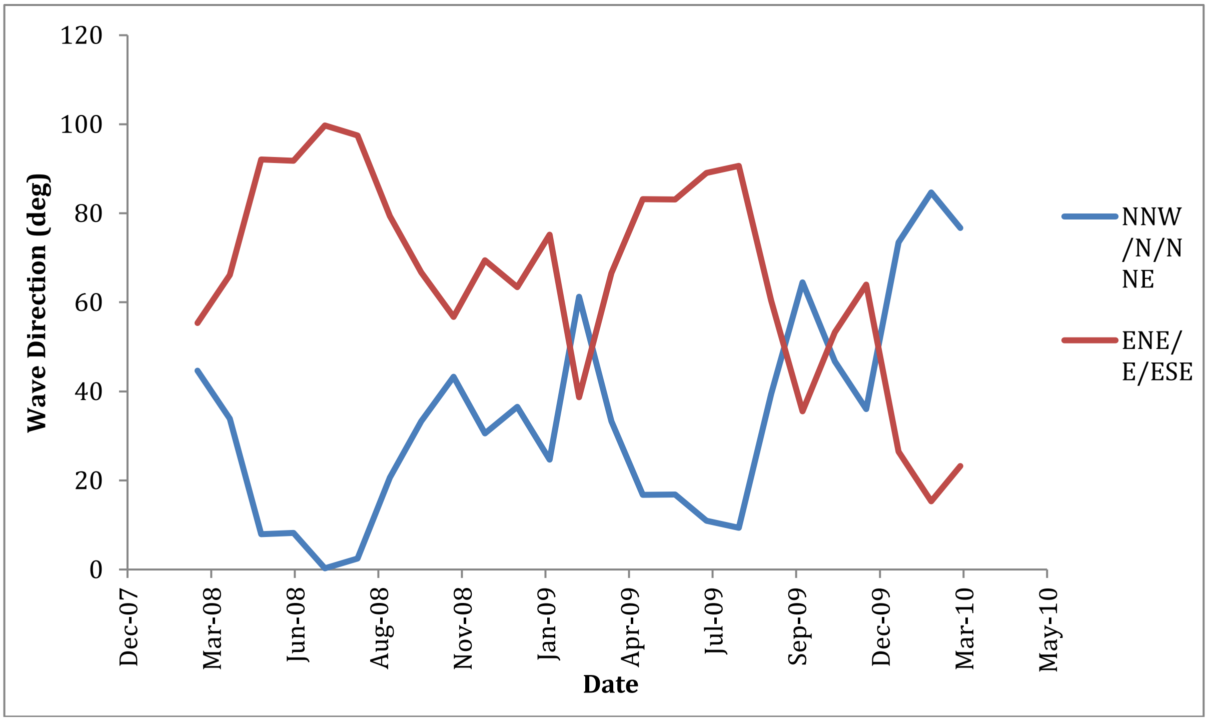

Figure 2. Time series of directional movement of waves coming in from the North-North West/North/North-North East (blue) and East-North East/East/East-South East (red) between March 2012 and March 2014.

Waves that moved from the east were trade winds, and specifically made contact with Hilo Bay during May and August 2012, as well as between April and July 2013. Around 90% of time the trade winds came from the east, and 25-75% of time they were winter swells.

After observing Fig.1, Northern moving waves coming into Hilo Bay had much shorter numbers of waves during the summer time when compared to winter months, when wave quantities increased. Eastern moving waves were the opposite, where there were greater numbers during the summer and fewer numbers during winter.

Wave Height

The average wave height during the trade winds from April to Jun 2013 was ~1.7 meters, and the average height during the winter swell from November 2012 to January 2013 was ~2-2.7 meters (Figure 3). Wave height increased during the winter months when storms were more frequent due to cold air mixing with warm air, and wave heights were lower during the summer months when little to no storms occured.

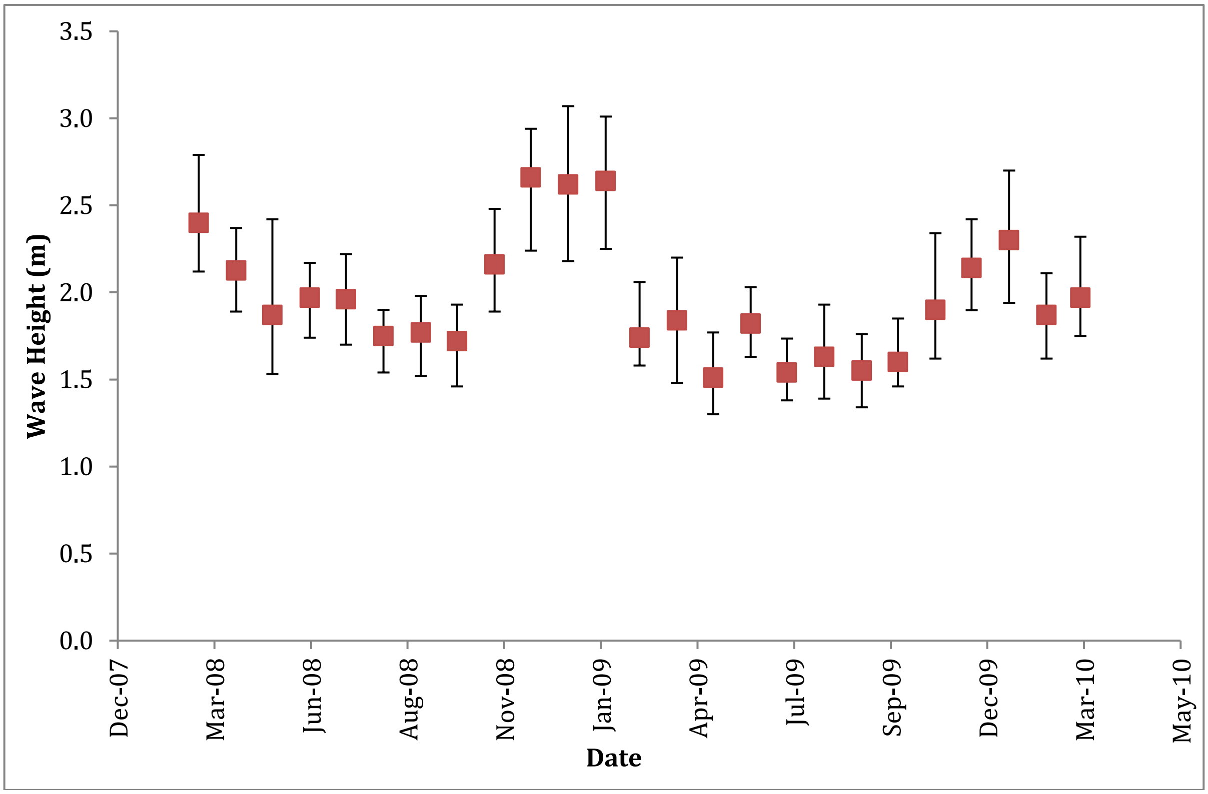

Figure 3. Wave Height (Hs) in meters. Starting year from 2012 to 2014.

Wave Period

Peak periods were associated with winds and swells. Waves tended to have shorter periods when winds were involved, but had longer periods when there were swells. In Fig. 4, peak periods occured during December 2012, as well as between December 2013 and January 2014. Shorter wave periods, on average, were ~8 seconds and longer periods were ~10-14 seconds. Winter swell periods were ~10-11 seconds and summer trade wind periods were ~8.5 seconds.

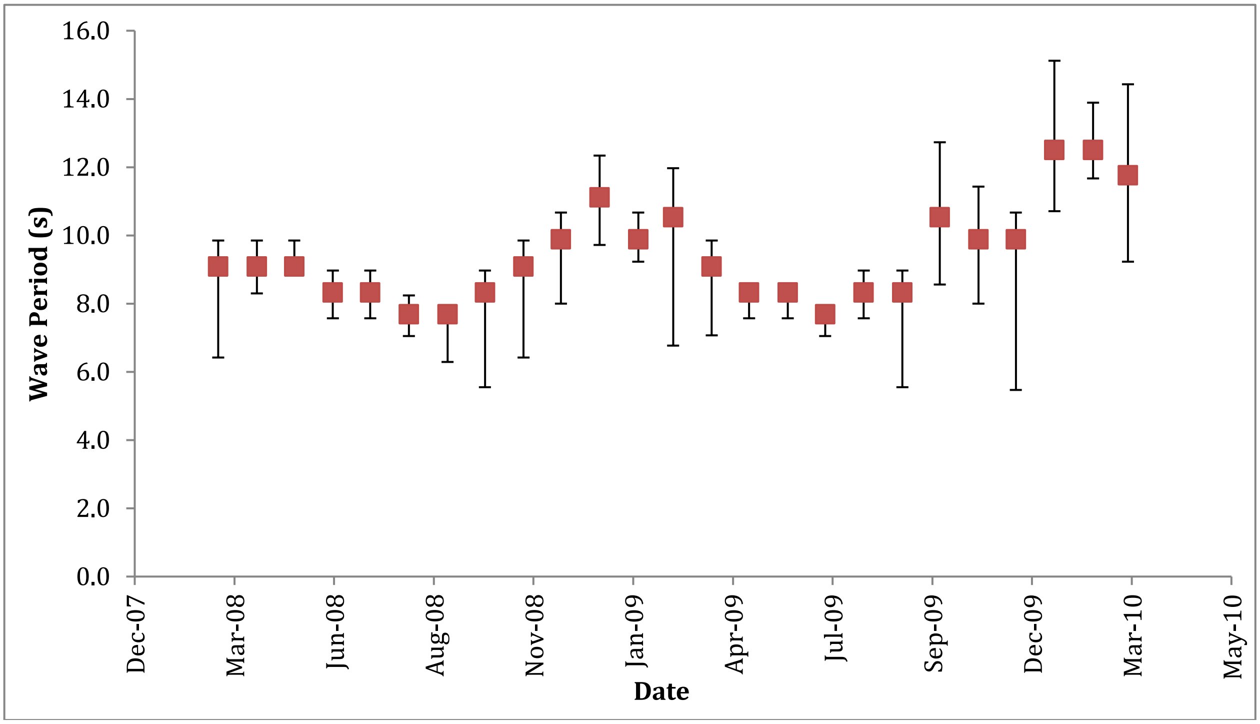

Figure 4. Wave Period (Tp) in seconds. Starting year from 2012 to 2014.

Waves that moved from an eastern direction and toward Hilo had greater strengths during the summer months (May through July) with a significant decrease in waves during the winter months (November through January). Waves that moved from a northern direction had a significantly lower number of waves during the winter months but increase during the summer months. Wave heights were larger between November and January and were quite low from May to July. The period of waves increased between November and January but decreased around the middle of the year.

The increase in wave height and period during the wintertime would account for the fact that there were more storms during the winter months; the winds picked up, creating stronger action on the waves and their movement towards the land. During storms, the waves would pick up speed, increase in size, leading to the increase in period and height.

Conclusion

There are many instruments that can gather wave data such as the accelerometers, acoustic current profiles, ultrasonic sensors and GPS buoy. The best one to use, especially for this project, is the GPS buoy since it can collect a wider range of parameters at once. We knew which way the waves were moving towards Hilo Bay, but after taking the data from the CDIP website and creating visual images of the wave heights and peak periods, it was better understood how fast and big they were over a course of two years.

Acknowledgements

I would like to thank the Coastal Data Information Program for providing access to all data that was used in this project. I would like to thank Steven Colbert for being my mentor and helping me through out this project. I would also like to thank the Marine Option Program for their support.

Sources

Christensen, K.H., Röhrs, J., Ward, B., Fer, I., Broströmd, G., Saetra, O., Breivik, O. (2013). Surface wave measurements using a ship-mounted ultrasonic altimeter. *Methods in Oceanography.* Vol.6, 1-15

Chuang, L.Z., Wu, L., Wang, J. (2013). Continuous Wavelet Transform Analysis of Acceleration Signals Measured from a Wave Buoy. *Sensors.* Vol.13, 10908-10930

Diwan, S.G>, Suryavanshi, A.K., Nayak, B.U. (1989). Operational experiences of datawell waverider buoys. *La mer* 27, 193-199.

Doong, D.J., Lee, B.C., Kao, C.C. (2011). Wave Measurements Using GPS Velocity Signals. *Sensors*. Vol 11, 1043-1058

Gupta, S.D., Shahinur, I.M., Haque, A.A., Ruhul, A., Majumder, S. (2012). Design and Implementation of Water Depth Measurement and Object Detection Model Using Ultrasonic Signal System. *Internation Journal of Engineering Research and Development.* Vol.4, Issue 3, 62-69

Integrated Ocean Observing System (2009). A National Operation Wave Observation Plan. p.13

Patra, S.K., Jena, B.K. (2014). Inter-comparison of wave measurement by accelerometer and GPS wave buoy in shallow water off Cuddalore, east coast of India. *Indian Journal of Geo-Marine Sciences*. Vol.43, 4-49

Pedersen, T., Lohrmann, A. (n.d.) Possibilities and limitations of Acoustic Surface Tracking. *Nortek AS*.