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Comparison Between Pervious Oyster Shell Habitat (POSH) Unit and Reef Ball Performance Along an Eroding Shoreline in Northeast Florida

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By

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ABSTRACT

This study compared two methods of shoreline protection – the common Reef Ball and the novel Pervious Oyster Shell Habitat (POSH). Both structures are meant to attenuate wave energy and subsequently reduce shoreline erosion. While Reef Balls have a long, documented history of effectively mitigating beach erosion, POSH units are new structures and their effectiveness had not yet been previously assessed. Clusters of POSH units and Reef Balls were deployed at the Timucuan Ecological and Historic Preserve's shoreline at Kingsley Plantation. Wave staffs were placed seaward and shoreward from these clusters and wave heights were measured over a holiday weekend during approximate worst-case boat wake conditions. Data showed no statistically significant difference between Reef Ball and POSH performance, although it is interesting to note that in both cases, sometimes apparent wave height amplification as opposed to attenuation was observed as waves passed over the structures. However, we note that results presented here are for a limited range of tidal conditions and studying a greater tidal range could lead to different conclusions about the POSH units' relative effectiveness.

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1. INTRODUCTION

1.1 BACKGROUND INFORMATION

The Florida Intercoastal Waterway (ICW) consists of 5,000 kilometers of aquatic passageways flowing along the Atlantic Ocean and Gulf of Mexico. The ICW is as diverse as the region's terrain and is made up of natural inlets, saltwater rivers, bays, and sounds, including manmade canals. Northeast Florida is home to a variety of these estuarine habitats, including salt marshes, mangroves, and oyster reefs (Radabaugh et al. 2017). The coastal ecosystems provide nutrient filtration, shoreline protection and habitat for many aquatic organisms (Shafer et al. 2003). Oyster reefs are an important component of the salt marsh ecosystems, but they are declining at a disturbing rate due to coastal degradation and are at risk due to coastal development, anthropogenic impacts, and sea-level rise. (Beck et al. 2011).

The magnitude of human impact by land development and occupation along the ICW is well understood, but the implications of the intensive vessel traffic that supports maritime and recreational pursuits is poorly quantified (Bilkovic et al. 2019). However, some work has been conducted recently in this area. For example, Price et al. (2005) conducted a study where erosion along the ICW was quantified at the Guana Tolomato Mantanzas National Research Reserve (GTM-NERR), just south of Duval County, FL. From 1970/1971 to 2002, nearly 70 hectares (approximately 170 acres) of shoreline habitat were degraded by erosion along the 64.8 kilometers of channel within the GTM-NERR. Because of the relatively short fetch lengths in this area, erosion due to wind waves was likely small (Houser 2010 and Roo; Troch 2015) and most of this erosion was attributed to boat wake action (Price et al. 2005). In fact, data from the Florida Inland Navigation District (2022), suggest that 20,000 registered vessels utilize the ICW annually in Duval County (i.e., the Jacksonville, FL metropolitan area) and this has an

approximately $362 million economic impact on the region. As Forlini et al. (2021) pointed out, boat traffic produces intermittent burst of higher flow velocities, accelerations and stresses on the bed which may increase turbidity and destabilize sediments. The vulnerability of the shoreline is a complex sediment transport problem with time domains of minutes (boat wake) to days (tides) to years (seasonal) that is not well understood, however the erosion effects are apparent.

1.2 EROSION MITIGATION TECHNIQUES

When faced with an eroding shoreline, there are numerous traditional methods that have been developed over the years to mitigate erosion. For example, hardened structures like seawalls, bulkheads, riprap, or breakwaters, have been used in some locations. While seawalls and bulkheads effectively stabilize upland soil, these structures induce seaward scour and halt natural upslope migration of vegetation in estuarine environments. In addition to harmful ecological effects, riprap and breakwaters are often very expensive to build and maintain and result in a “rocky shoreline” that is often undesirable.

In recent years, much work has been conducted on living shoreline development as an alternative to these traditional measures for shoreline retention. Overall, the commonality among most living shorelines is that they utilize natural resources for the long-term health of the shoreline. One of the advantages to the living shoreline approach is that living shorelines often contain oyster reefs, and oysters tend to attract more oysters. As such, these oyster reefs may be able to accommodate additional sea-level rise via this positive oyster recruitment feedback loop. Results from previous studies suggest that additional oysters help further enhance biodiversity (Morris et al. 2018; Rodriguez et al. 2014, Uddin et al. 2021).

1.3 OYSTER RECRUITMENT TECHNIQUES

1.3.1 Traditional Methods

Several methods have been developed in recent years to enhance oyster recruitment associated with living shoreline development. These efforts include Reef Balls ®, oyster bags/meshes, gabions filled with oysters, oyster castles, crab traps coated with concrete, reef prisms (Wallace et al. 2022), and Oysterbreak™ (Wayfarer Environmental Technologies, 2022). Although these methods range in effectiveness there are some negative environmental implications (Bersoza Hernández et al., 2018). For example, while gabions or oyster bags, may be effective for a while, eventually the bags or the gabions' timber will degrade and leave a disorganized collection of oysters along the coast that can easily be transported by tides and waves. Oyster bags have another significant disadvantage in the sense that after the bags have degraded, harmful microplastics may be released into the environment. Large plastic meshes may entangle marine wildlife (Barry 2022). Reef Balls are comprised entirely of concrete that utilizes Portland cement. While Reef Balls are effective at attracting oysters and aquatic organisms, Portland cement production is a leading cause of worldwide carbon emissions (Uddin et al. 2021); a greener solution with a smaller carbon footprint would be preferable. Concrete coated crab traps and oyster castles are similar – solutions with a lower carbon footprint would be preferable.

1.3.2 Pervious Oyster Shell Habitats

In an effort to develop a method that overcame these issues, Uddin et al. (2021) developed Pervious Oyster Shell Habitats (POSH). As described by Uddin et al. (2021), POSH units consist of oyster shells in a specified gradation that are held together with Portland cement. These structures are similar to concrete except oysters are used as the matrix's aggregate as

opposed to sand and gravel. While Portland cement is not ideal for the reasons mentioned above, Uddin et al. (2021) showed that a typical POSH unit uses 54% less Portland cement than a similarly sized Reef Ball. Thus, while production of POSH units is not yet carbon neutral, it is very low, relatively speaking.

POSH units display many of the same advantages as other green oyster recruitment technologies in the sense that they appear to attract oysters very quickly – presumably taking advantage of oysters' tendency to be attracted to both concrete and other oysters – or maybe, more generally, calcium carbonate. Two comparison studies from Cope et al. (accepted, 2023a and 2023b) appear to indicate that POSH units attracted more shoreward organic material (i.e., other oysters) than Reef Balls, while computational data from these studies suggest that POSH units may locally reduce shoreline erosion under certain tidal conditions. While these results are promising, Cope's work (2023a and 2023b) relied exclusively on computational fluid dynamics (CFD) and did not include any field data.

1.5 GOALS AND OBJECTIVES

The goal of this study was to extend previous work from Cope et al. (accepted, 2023a and 2023b) and Uddin et al. (2021) and directly compare POSH unit performance with Reef Ball performance in the context of reducing shoreline erosion from boat wake action using field data. Please note that Reef Balls were chosen as the basis of comparison simply because they are one of the most common and widely adopted green coastal stabilization methods. In future work, it would be interesting to compare all the aforementioned green alternatives' performances, but this was beyond the scope of this study.

2. METHODOLOGY

2.1 SITE LOCATION

The GTM-NERR location studied by Price et al. (2005) is by no means unique in the sense that many areas of ICW shoreline in northeast Florida are known to be eroding, and many suspect that this is due to boat wake action. One such site is Timucuan Preserve – a national preserve on Fort George Island, FL, approximately 47.5 km northeast from the GTM-NERR (Fig. 1). Like the GTM-NERR location, fetch lengths are relatively short in this location. Thus, like at GTM-NERR, wind wave action is usually small and most waves would be expected to be induced by water vessel traffic.

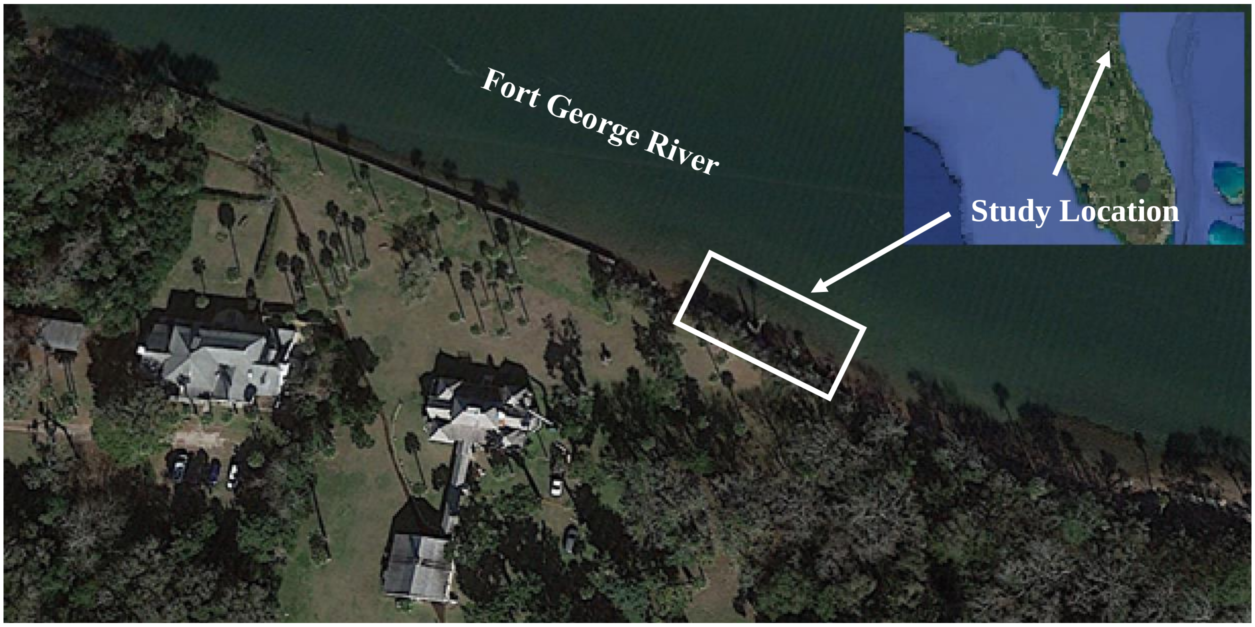

Figure 1 – Location map showing location in the State of Florida and a zoom-in of the shoreline

2.2 SEDIMENT PROFILE

A survey was conducted along the Timucuan Preserve's shoreline to analyze the beach profile and the sediment characteristics. The survey extended to approximately 43 m offshore (approximately the middle of the ICW) with a maximum depth of 3.8 m. As shown below in

Figure 2, the tidal range was approximately 1.9 m. Visual observations indicated significant erosion of the beach face near the high tide water level.

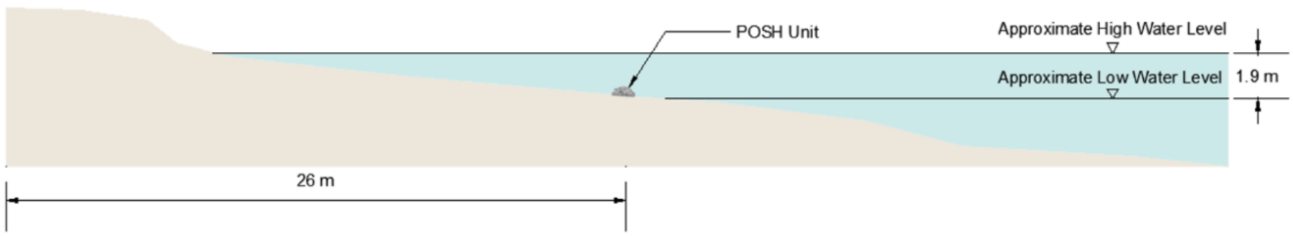

Figure 2 – Beach profile of the shoreline at Kingsley Plantation.

Following American Society for Testing and Materials (ASTM) C136-01 (ASTM 2021), a sediment grain-size distribution was computed using four representative specimens (Fig. 3). All samples were classified as SP according to the Unified Soil Classification System (USCS; ASTM D2487-06) with a median diameter (d_{50}) of 0.193 mm.

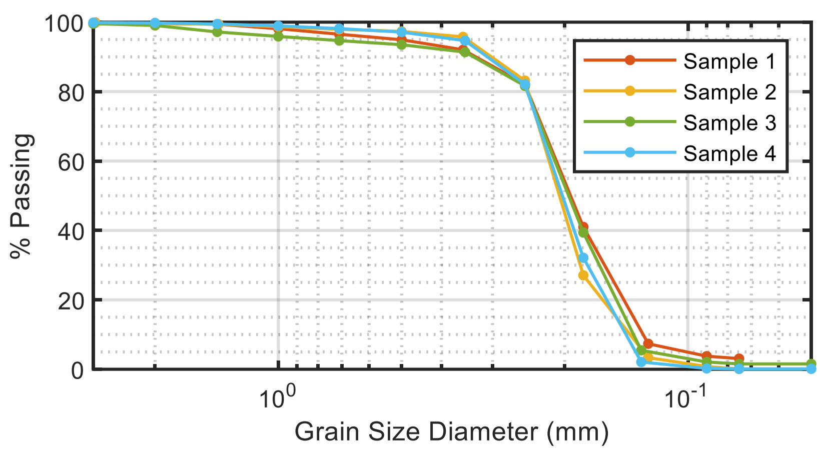

Figure 3 – Grain size distribution curve

2.3 REEF BALLS

Three Reef Balls were commercially acquired. These structures were cast from concrete using standard Reef Ball guidelines (reefball.org, 2020). Specifics of the mix are shown below in Table 1. The structures are dome-shaped mounds with top diameters of approximately 23 cm and base diameters of approximately 46 cm. Six cavities were incorporated in each structure.

Table 1**.** Mix proportions of a unit cubic meter of Reef Ball (adapted from reefball.org, 2020)

Constituent	Amount per m^3
Cement	356 kg
Aggregate	1068 kg
Sand	688 kg
Water	142 kg
Force 10K	30 kg
Grace Microfibers	0.3 bag
ADVA Flow 120/140	1 dose

2.4 POSH UNIT CONSTRUCTION

Three POSH units were constructed using the "optimized mix" guidelines from Uddin et al. (2021). Specifics of the mix are shown below in Table 2. Note that as shown in Table 2, the POSH units utilize less than half the cement per cubic meter used in a Reef Ball. All shells were obtained from the GTM-NERR oyster recycling program (i.e., recycled oyster shells from local restaurants in the Jacksonville, FL area) and were dried in open air for at least six months prior to construction to satisfy federally mandated quarantine protocol. During construction, all shells, concrete, water, and admixture were mixed in a standard concrete mixer for at least one minute and then the mixture was poured into hexagonal molds (Fig. 4). Each structure was covered with a polyethylene sheet (i.e., Visqueen®) during curing to mitigate evaporation, and the structures were allowed to cure for at least seven days prior to deployment.

Table 2: Mix proportions of a unit cubic meter of POSH concrete.

Constituent	Amount per m^3
37.5-mm Oyster	403 kg
25-mm Oyster	257 kg
Cement	165 kg
Water	66 kg
Admixture	327 ml

Figure 4 – Construction of POSH unit. (a) The hexagonal mold – the bowl in the center of the mold is left in-place to utilize less material and reduce the structures' mass, thereby making deployment easier; (b) Shows a filled mold after an oyster/cement pour; and (c) shows the resultant structure after curing and extraction from the mold.

2.5 DEPLOYMENT

The three POSH units were deployed at approximately the mid-intertidal mark along the shoreline at Timucuan preserve, approximately parallel with the shoreline, with a spacing of 5 cm between each unit. Similarly, 2 m to the east, the three Reef Balls were deployed approximately parallel with the shoreline, with a spacing of 5 cm between each unit (Fig. 5).

Figure 5 – Images showing (a) the POSH units just after deployment at the site; and (b) the Reef Balls just after deployment at the site

2.6 WAVE GAUGES

After POSH unit and Reef Ball deployment, Ocean Sensor Systems Wave Staffs (OSSI-010-002E) with accuracies of $\pm$0.75 cm were deployed approximately 30 cm both seaward and shoreward from each unit cluster to measure wave height as waves moved across the unit clusters (see Fig. 6 below). These 3-meter staffs were jetted into the soil approximately 2 meters with stainless steel pipe, then coupled with PVC pipe to create vertical columns. The wave staffs were connected to the Sensor Systems, Inc. Wave Staff Synchronizer (OSSI-012-012), then transmitted to a field laptop via RS232 serial data stream.

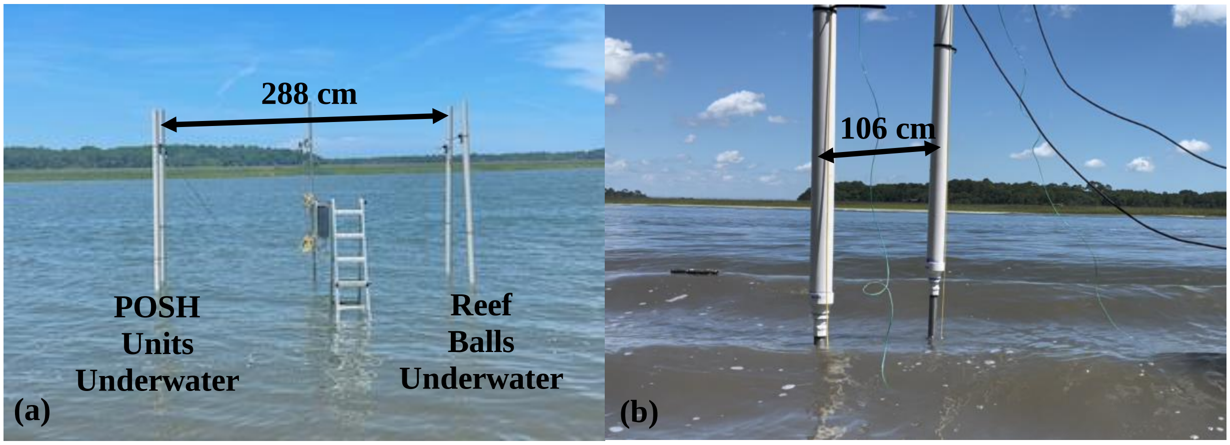

Figure 6 – Images of wave staffs. (a) Shows the wave staffs deployed around the Reef Balls and POSH units; (b) shows a close-up of two wave staffs around a POSH cluster

2.7 DATA COLLECTION

Data were collected during two "worst-case" boat traffic days – over the 4th of July weekend and Memorial Day 2022 (i.e., holiday weekends during the summer when one would expect the most boat traffic). In an effort to show the most meaningful data, investigators focused data collection during tidal ranges where they believed the units would have the greatest net effect – from approximately mid-tide +/- 1.5 hours. During each day of data collection, approximately 100 watercrafts per hour were observed going east-to-west (i.e., toward the ocean) during the mornings and approximately the same number of watercrafts were observed returning during afternoons. Water elevation data were collected at a sampling rate of 5 Hz on Memorial Day and at a rate of 20 Hz over the 4th of July. Tidal ranges were relatively typical on both days when compared to predicted values with maximum deviation from predicted values of approximately 11 cm (NOAA 2022).

2.8 DATA ANALYSIS

Data analysis focused on the 4th of July data because the lower sampling rate in the Memorial Day dataset appeared to return slightly aliased results. However, it is noteworthy that

investigators observed similar boat traffic quantity on both holidays, which is why we mention the Memorial Day data.

The water elevation data were analyzed using Mathworks' MATLAB (2022). Specifically, water elevations at each wave staff were plotted as a function of time. Then, spectral analysis was conducted to determine the dominant wave frequencies during data collection at each wave staff location. Spectral energy was plotted as a function of frequency for each wave staff, and these curves were numerically integrated via a trapezoidal integration algorithm to yield spectral power. Differences in spectral power were compared both shoreward and seaward using a t-test.

Next, based upon the rate of boat traffic, a sample size of 21 boats per day was chosen for in-depth analysis. Standard z-test analysis indicated that this sample size would yield a confidence level of 95% that data was within 20% of the measured value. The 21 watercraft/day were randomly selected from the data, and each of these data subsets were demeaned. Then, data seaward/shoreward from the POSH units/Reef Balls were plotted on the same set of axes and each wave's maximum water elevation was extracted from the plots using a combination of manual analysis (i.e., manually picking each peak from each plot) and MATLAB's built-in 'findpeaks' command. Then, attenuation was computed by subtracting demeaned seaward peak wave data from demeaned shoreward peak wave data. Thus, a positive result indicates that a wave was attenuated while a negative result indicates that the wave height increased as the wave passed over the structure. Attenuation was plotted as a function of incident wave height to determine if the structures functioned as designed (i.e., attenuated wave) more often under certain wave height conditions.

Results (see below) indicated that most of the time, wave heights increased as the waves passed over the structures and mean attenuation for both the Reef Balls and POSH units returned negative values. Standard t-tests were used to analyze whether there was a statistically significant difference between POSH and Reef Ball mean attenuation. Results (again, see below) suggested that there may be statistically significant differences in attenuation, but this difference was small and failed to take instrument accuracy into account. Thus, data were removed that were below the cumulative accuracies of the seaward and shoreward wave staffs (i.e., data that showed less than 1.5 cm of attenuation), and the statistical analysis was repeated. Finally, a last set of analysis was performed where only situations where data were out of the instruments' error range and the POSH/Reef Ball achieved positive attenuation (i.e., the structure functioned as designed) was performed.

3. RESULTS

Raw time-series data from the 4th of July are presented in Fig. 7 and Fig. 8 below during morning data collection (i.e., data collection during a flood tides) and afternoon data collection (i.e., data collection during an ebb tide) respectively. Spectral data are presented in Fig. 9 and Fig. 10 for morning and afternoon collection respectively while results from spectral integration are presented in Table 3. Four examples (two from the Reef Ball cluster data and two more from the POSH unit cluster data) of typical data from the 21 boats selected for in-depth analysis are presented in Fig. 11. For each wave (i.e., each peak in Fig. 11), attenuation was defined as the difference between seaward data (i.e., blue lines in Fig. 11) and shoreward data (i.e., red lines in Fig. 11). Attenuation histograms are presented in Fig. 12 while a plot of attenuation as a function of incident wave height is presented in Fig. 13. As noted in Section 2.7, a t-test was used to determine if there were statistically significant differences between attenuation around the Reef

Ball and POSH unit clusters using all the data and by excluding data that was within the instruments' error bands. Statistics associated with each dataset are presented in Table 4 while t-test results are presented in Table 5.

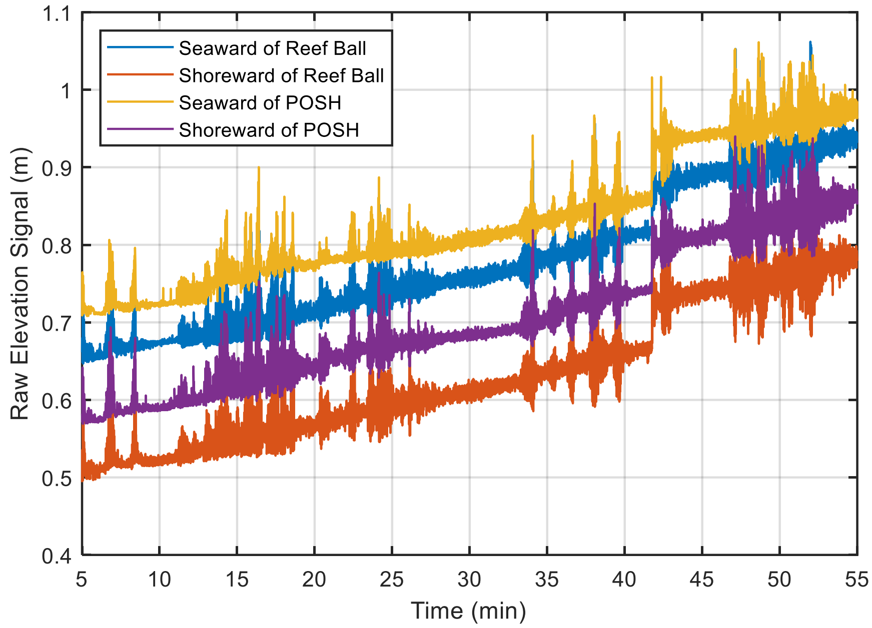

Figure 7 – Raw elevation data from wave staffs showing water depth as a function of time during the morning of data collection on July 4, 2022 (flood tide)

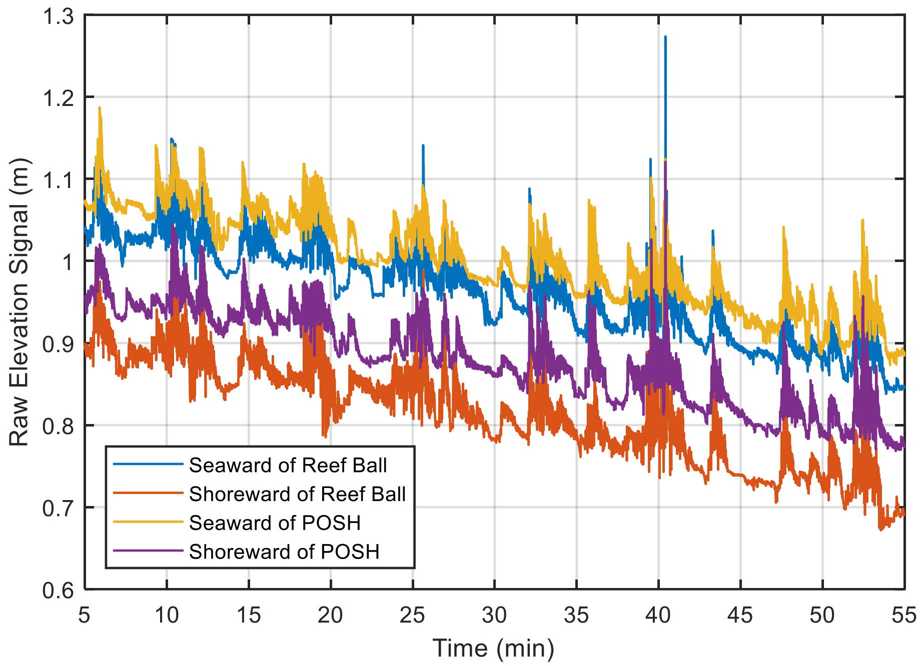

Figure 8 – Raw elevation data from wave staffs showing water depth as a function of time during the afternoon of data collection on July 4, 2022 (ebb tide)

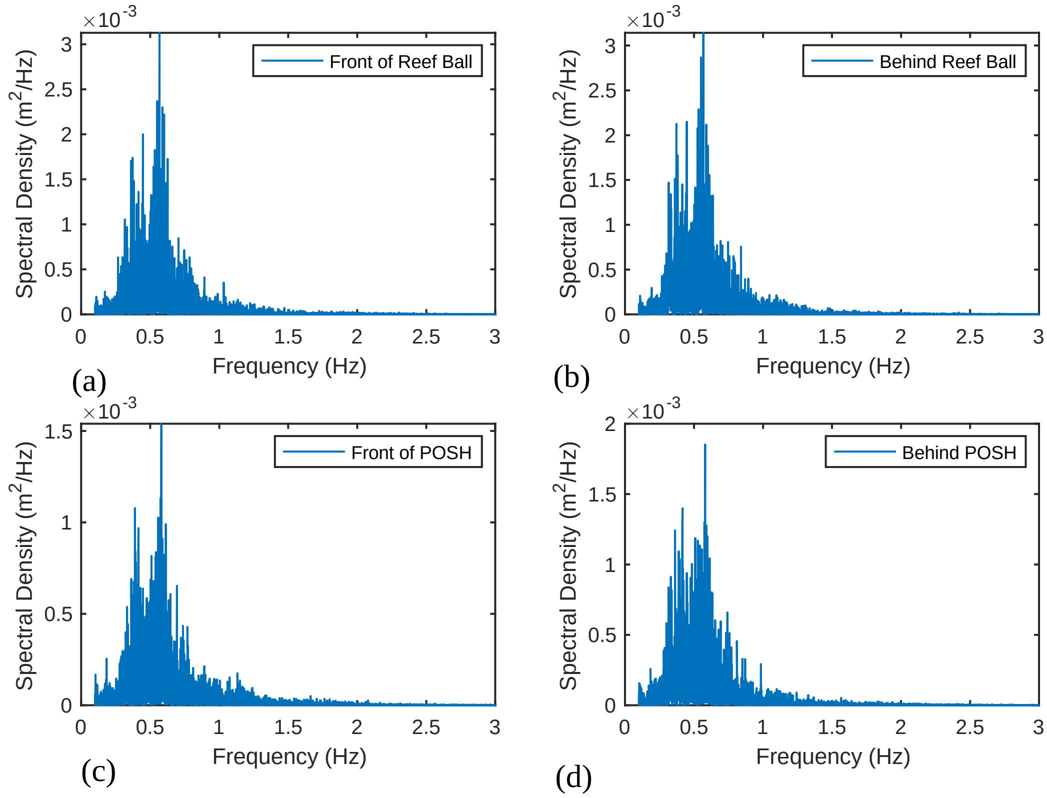

Figure 9 – Spectral density plots from morning data collection on July 4, 2022. (a) Front of Reef Ball, (b) Behind Reef Ball, (c) Front of POSH and (d) Behind POSH

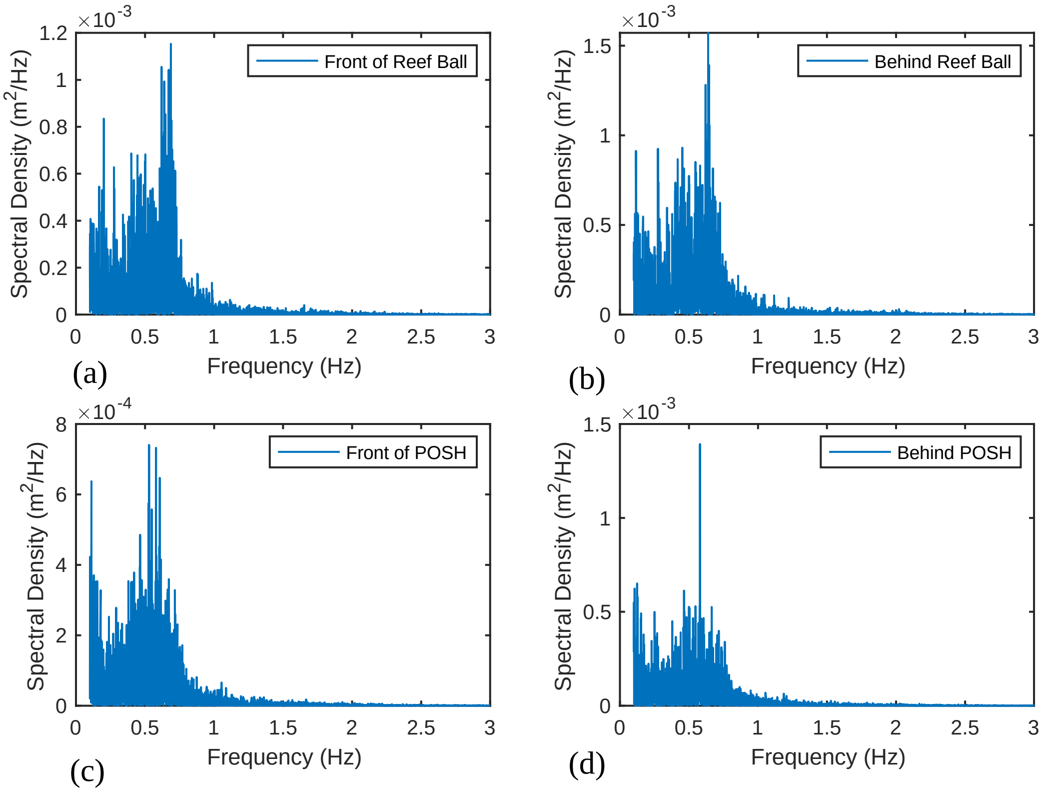

Figure 10 – Spectral density plots from afternoon data collection on July 4, 2022. (a) Front of Reef Ball, (b) Behind Reef Ball, (c) Front of POSH and (d) Behind POSH

Table 3. Integration results of Spectral Density vs frequency

	Power (watts)			
	Morning	Afternoon	Average	Δ
Reef Ball Seaward	0.000198	0.000106	1.519E-04	-
Reef Ball Shoreward	0.000206	0.000129	1.674E-04	1.548E-05
POSH Seaward	0.000116	0.000065	9.051E-05	-
POSH Shoreward	0.000142	0.000078	1.102E-04	1.968E-05

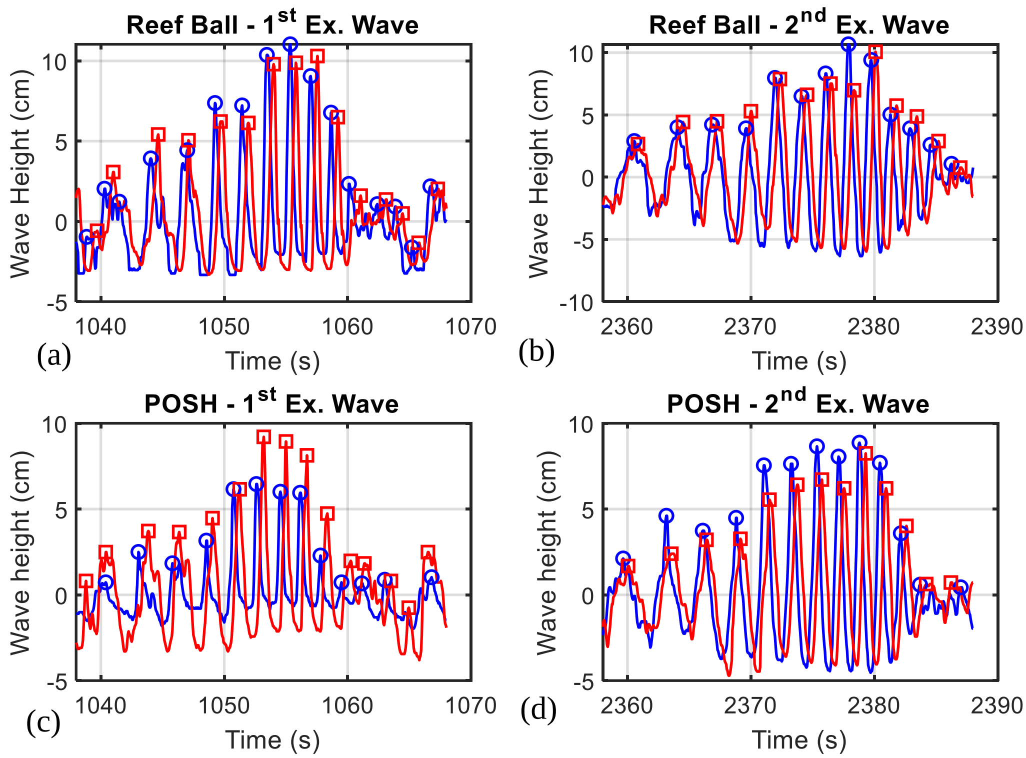

Figure 11 – Examples of zoom-in data used for in-depth analysis. In this figure, the blue lines represent data seaward of the unit cluster while the red lines represent data shoreward from the unit cluster. The circles and squares denote peaks that were found using ‘findpeaks’ and later manually verified by hand. (a) and (b) show data for two waves shoreward and seaward from the Reef Ball cluster while (c) and (d) show data for two waves shoreward and seaward from the POSH units.

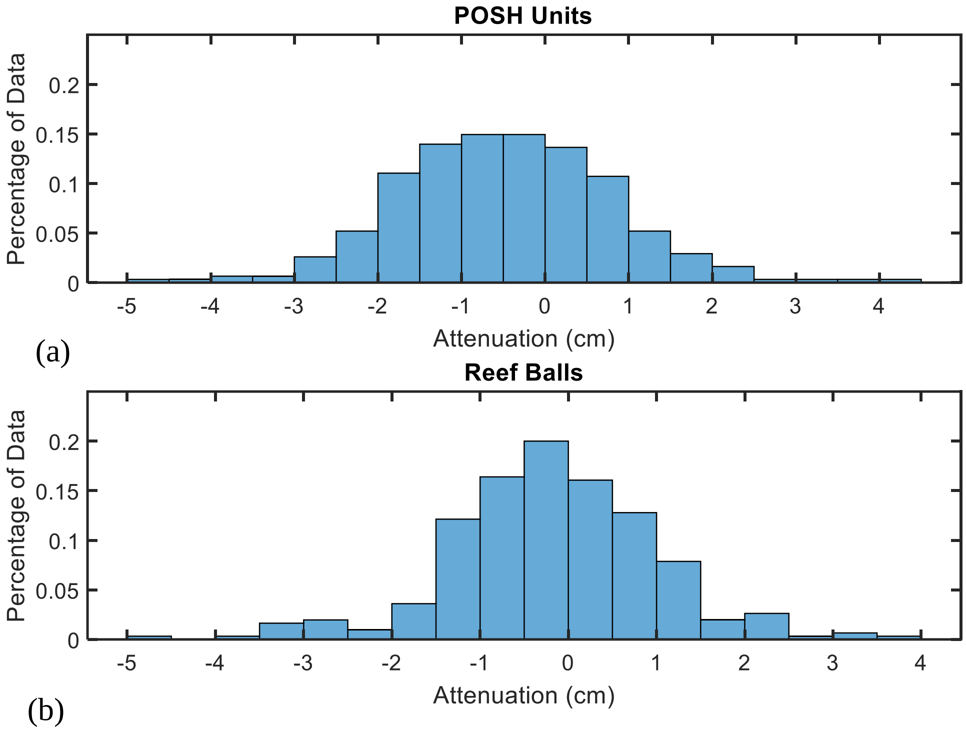

Figure 12 – Attenuation histograms showing data from the (a) POSH unit cluster; and (b) Reef Balls unit cluster; all raw data included

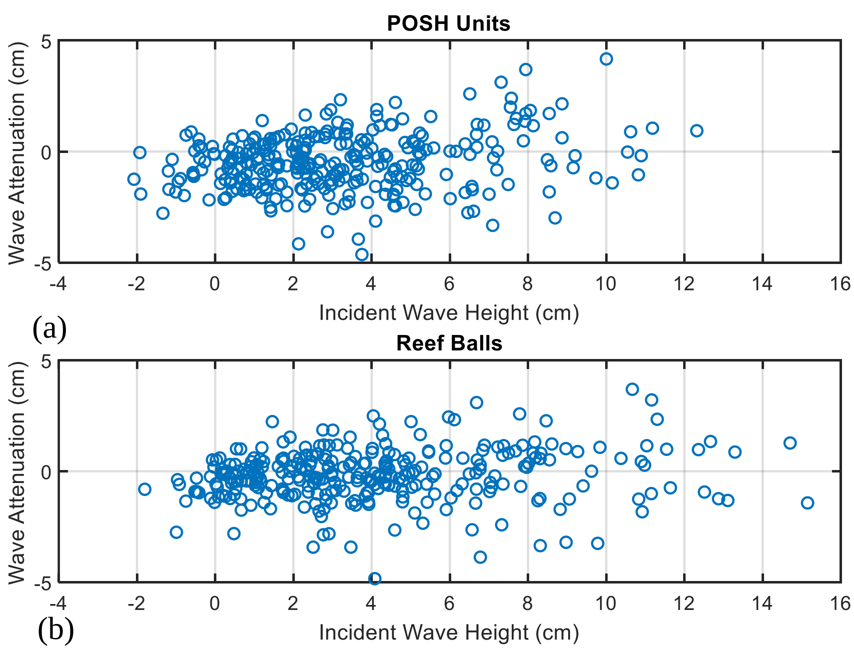

Figure 13 – Wave Attenuation as a function of incident wave height around the (a) POSH unit cluster; and (b) the Reef Ball unit cluster; all raw data included

Table 4. Statistical data from each data population

Dataset	Mean Attenuation (cm)	Median Attenuation (cm)	Min Attenuation (cm)	Max Attenuation (cm)	Standard Deviation (cm)
All POSH Data	-0.46	-0.49	-4.64	4.17	1.28
All Reef Ball Data	-0.19	-0.21	-4.84	3.69	1.18
POSH Data Excluding Error Bands	-1.21	-1.83	-4.64	4.17	1.96
Reef Ball Data Excluding Error Bands	-0.58	-1.70	4.84	3.69	2.48
POSH Data Excluding Error Bands w/ Positive Attenuation Only	2.23	1.95	1.58	4.17	0.74
Reef Ball Data Excluding Error Bands w/ Positive Attenuation Only	2.28	2.25	1.54	3.69	0.59

Table 5. t-test results from all data

Dataset	Mean Attenuation (cm)	Std. Error Difference	t	df	95% Confidence Interval of Difference		Significant Difference?
					Lower	Upper	
All Data	0.27	1.23	-2.75	611	-0.47	-0.08	Yes
Data Excluding Error Bands	0.63	2.15	-1.56	125	-1.42	0.17	No
Data Excluding Error Bands w/ Positive Attenuation Only	0.05	0.67	-0.22	34	-0.50	0.41	No

4. DISCUSSION

4.1 ELEVATION DIFFERENCES

Raw elevation data appeared to show that despite investigators' best efforts, the POSH unit cluster was not placed at the same elevation relative to the waterline. As shown in Fig. 7 and Fig. 8, mean seaward water elevations at the POSH unit cluster was approximately 7 cm higher than mean water elevations at the Reef Ball unit cluster. Data showed significant boat traffic during both the morning and afternoon data collection sessions.

4.2 SPECTRAL ANALYSIS

Spectral data showed that dominant frequencies during the morning data collection session were semi-bimodal with dominant frequencies observed near 0.4 Hz and 0.6 Hz indicating dominant wave periods of 2.5 s and 1.7 s. These periods are typical of boat wakes and the difference between the periods may be explained by different watercraft configurations (i.e., engines, dimensions, speed through the channel, etc.). Because these two dominant frequencies are so close to one another, filtering the signals from one another to analyze Reef Ball/POSH performance as a function of each dominant wave period was not possible.

Integration of the spectral distributions showed that more spectral energy was observed shoreward of both the Reef Ball and POSH clusters. This was unexpected since the structures were installed to *reduce* wave energy, not exacerbate the issue. As shown in Table 3, the differences in shoreward/seaward energy were similar for both the Reef Ball cluster and the POSH unit cluster. However, the data appeared to indicate that shoreward of the POSH units there was a greater amplification of spectral energy than there was shoreward of the Reef Balls.

4.3 STATISTICAL INTERPRATATION OF WAKE SAMPLES

Fig. 11 shows two typical scenarios shoreward/seaward from the POSH unit and Reef Ball clusters. In the first example wave train, waves were slightly lower (less than 1 mm) shoreward of the Reef Ball cluster and slightly higher (between less than 1 mm and 2 cm) shoreward of the POSH unit cluster. In the second wave train example, performance was opposite – waves were slightly higher shoreward of the Reef Ball and slightly lower shoreward of the POSH unit. Note that these results are typical in the sense that any apparent amplification and/or attenuation was usually within the error bands associated with the wave staffs, and thus, during the error exclusion analysis, most of these data points were removed.

Fig. 12 and Fig. 13 give a better overall illustration of observed results. As shown in both figures, most of the time, wave heights were slightly higher (i.e., negative attenuation) shoreward of both the Reef Balls and POSH unit clusters. Fig. 13 shows no apparent correlation between attenuation (positive or negative) and incident wave height. And, once again, data suggest that the presence of either a Reef Ball or a POSH unit under the tidal conditions and water elevations presented here does very little to reduce wave energy.

Statistical data in Table 4 and Table 5 indicate that there was a significant difference in wave behavior as waves passed over the Reef Ball cluster when compared to waves passing over the POSH unit cluster when all data were analyzed. As shown, negative attenuation (i.e., an increase in water-level) was significantly higher shoreward of the POSH units than it was shoreward of the Reef Balls. However, when data within the instruments' error bands was excluded, there was no statistical difference between attenuation over the Reef Ball cluster when compared to the POSH unit cluster. However, we also note that in both cases, most of the time

when data were outside of the error bands, negative attenuation (i.e., amplification) was observed with both the POSH unit cluster and the Reef Ball cluster.

It is not yet clear why amplification was often observed as waves passed over the unit clusters, although it is likely due to the structures having a negligible effect on the waves when compared to beach-induced wave runup and/or nonlinear shoaling effects as Forlini et al. (2021) observed. Likewise, the differences in incidents where apparent amplification were observed between the Reef Ball and POSH unit clusters could be caused by slightly different bathymetry seaward of the unit clusters and/or the units' positions relative to the shoreline. These issues could be compounded by situations where multiple watercraft wakes interacted with one another and created wakes from varying distances. Additionally, a consideration of the potential reflection off the shoreline could create a node or anti-node at the shoreward wave staff, which could indicate a perceived amplification or attenuation. The non-linearity of the wake and numerous wake starting and ending points complicates an accurate determination of the effects due to reflection. In future work, investigators hope to analyze these factors under controlled conditions, such as a wave channel or field test with one boat on a calm day utilizing specified distance and speed. However, in the interim, results still showed no significant difference between POSH unit and Reef Ball performance, and this result is encouraging, albeit somewhat anticlimactic since neither unit cluster showed significant reduction in wave energy. Again, in future work, other unit configurations will be studied to determine if they more effectively affect wave performance. The data presented here are preliminary and are only applicable to a very specific geometry – i.e., a row of units, placed side-by-side, under specific tidal conditions relative to the structures.

4.4 OYSTER RECRUITMENT

While wave energy reduction was similar for both sets of structures, oyster recruitment was significantly different. Oyster recruitment on POSH and Reef Ball structures was compared a year following deployment (see Fig. 14). An elastic trellis netting was laid over each structure to define 15x15 cm squares. The number of oysters per square was counted to measure oyster density. Barnacle densities were measured in conjunction to assess potential impacts of barnacles on oyster settlement and substate preference by barnacles. Due to structural differences between the POSH and Reef Ball, only the sides of the structures could be accurately compared for oyster and barnacle densities. Density values were adjusted to fit individuals/100 cm^2.

Data were logarithmically transformed to fit a normal distribution and compared with independent samples t-tests. Oyster densities were significantly greater on the POSH ($p < 0.000$). Mean oyster density for the POSH was 4.97 oysters/100 cm^2 (+/- 0.24 SE), and the Reef Ball had a mean density of 0.91 oysters/100 cm^2 (+/- 0.13 SE). Barnacle densities were low, highly variable and densities did not differ among structures ($p > 0.05$). Barnacle densities on the POSH were 0.68 barnacles/100 cm^2 (+/- 0.17 SE) and 1.19 barnacles/100 cm^2 (+/- 0.41 SE) on the Reef Ball. These data suggest then that the POSH units attracted significantly more oysters than the Reef Balls. Looking ahead, these data would suggest that the POSH units should increase in effectiveness over time faster than the Reef Balls.

Figure 14 – Oyster growth on (a) POSH Units; and (b) Reef Balls after 1 year

4.5 CONSTRUCTION COMPARISON

POSH units and Reef Balls are similar in many ways – they are both mound-shaped structures that utilize Portland cement, are meant to attract oysters, and seed a living shoreline. However, from a constructability standpoint, the two structures are very different. Reef Balls can be constructed manually but building a mold that would achieve the Reef Ball shape would be very difficult. Usually, Reef Balls are purchased commercially as was done in this study, but this may be expensive.

On the other hand, POSH molds may be assembled via common materials. During this study for example, standard nominal 5-cm by 10-cm lumber (i.e., 2x4s) was used in conjunction with standard 122-cm by 244-cm (4-ft by 8-ft) plywood sheeting. Aggregate for the POSH units was obtained at no cost and utilized recycled materials. Overall, the POSH units are constructable for less than $20/unit. Beyond these advantages, pouring a POSH unit is very easy, relatively speaking, because the oyster shell/cement/water mixture has no slump. As such, once the mixture is in the form, it can be formed into a dome-shape with very little work. Lastly, it should be noted that as discussed by Uddin et al. (2021), POSH units are lower weight than similarly sized Reef Balls, which makes field deployment less labor intensive.

5. SUMMARY AND CONCLUSIONS

The ICW is a highly utilized natural resource that is significantly impacted by boating activities. In this study, the researchers sought to compare Reef Ball and POSH unit performance in the context of reducing wave energy. Results indicated that both clusters of structures did very little to attenuate the wave energy, and, in fact, much of the time, apparent wave amplification was observed instead of wave attenuation, which may indicate that natural wave runup needs to be considered when placing structures such as these. Despite this, there was no statistically significant difference in attenuation (or amplification) data when Reef Balls were compared directly. However, we reiterate this study utilized only one unit configuration under a very limited range of relative water levels. In future work, investigators aim to study different configurations of units, configurations with more units, and expanded tidal ranges in a controlled environment.

More holistically however, the POSH units show some promise if their effectiveness at reducing wave energy can be better understood. In particular, the POSH units recruited significantly more oysters than the Reef Balls after only one year – presumably indicating that they should increase in effectiveness faster than Reef Balls over time. In addition, construction of the POSH units was not very labor intensive and inexpensive when compared to similar efforts and cost that would have been associated with Reef Ball construction.

ACKNOWLEDGEMENTS

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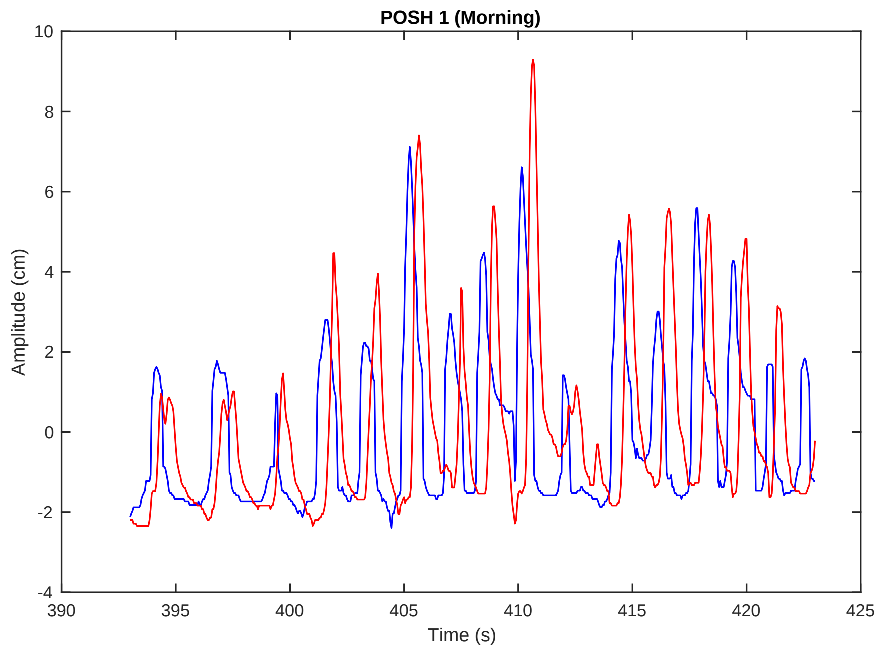
APPENDIX: WAVE DATA



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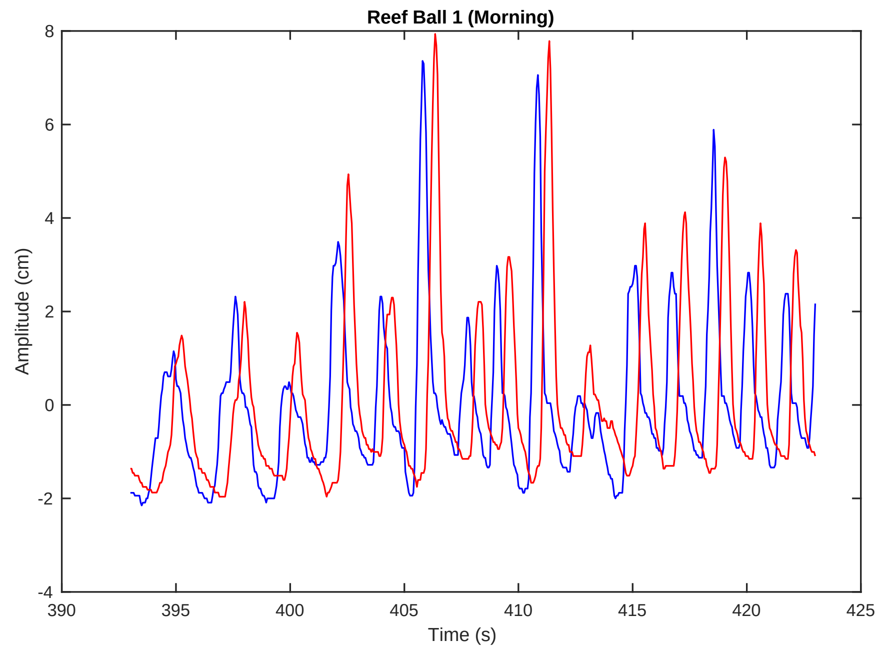

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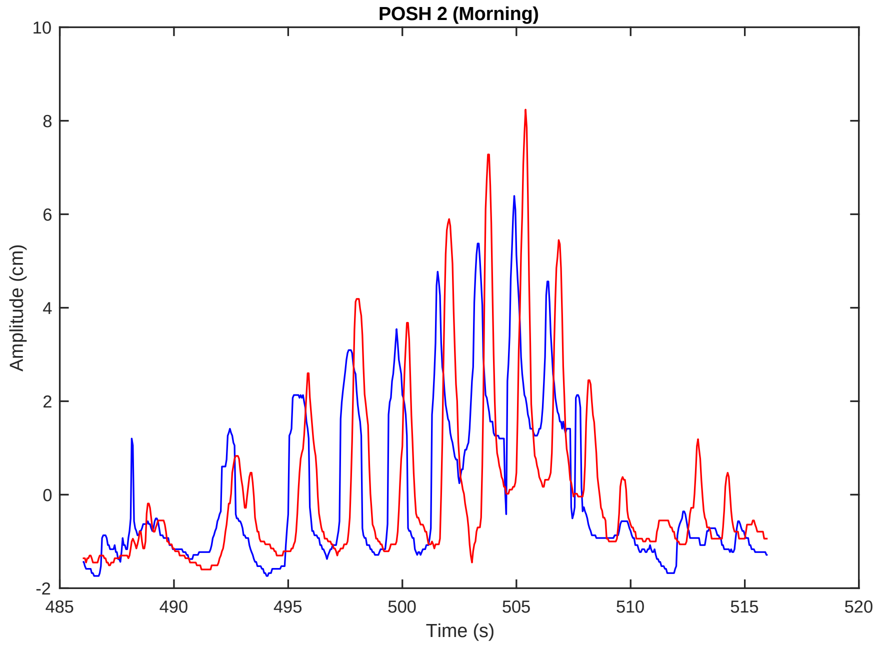

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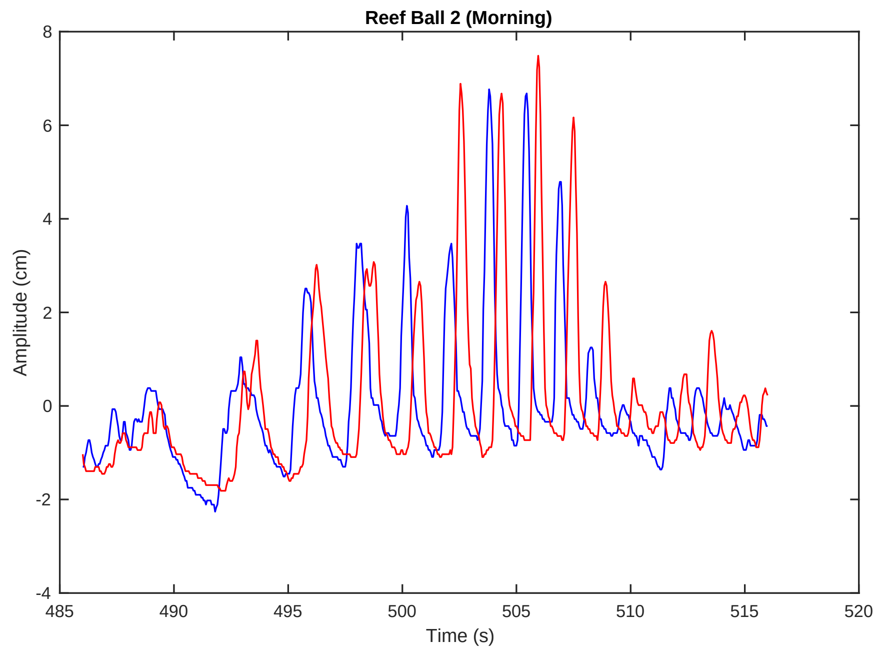

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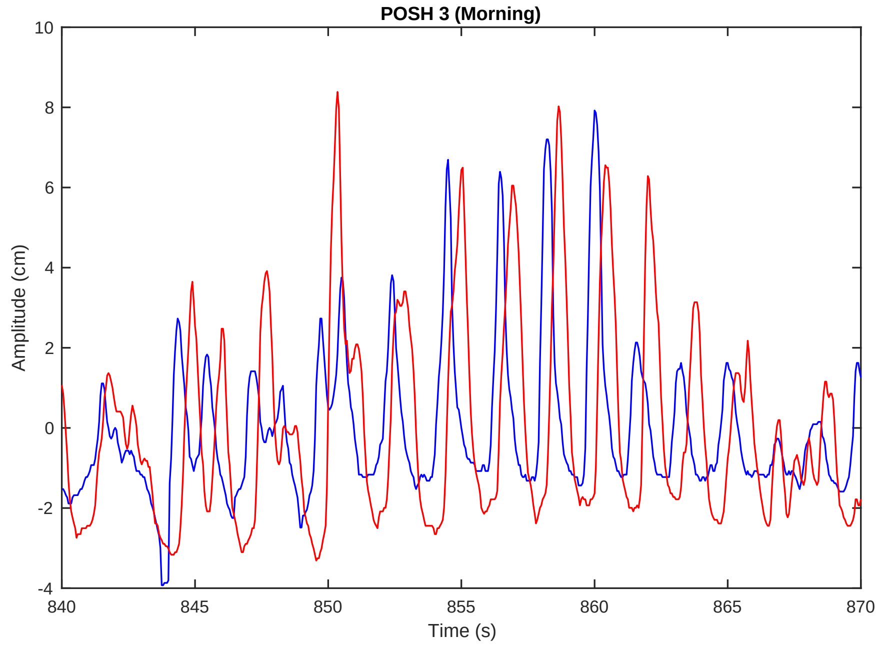

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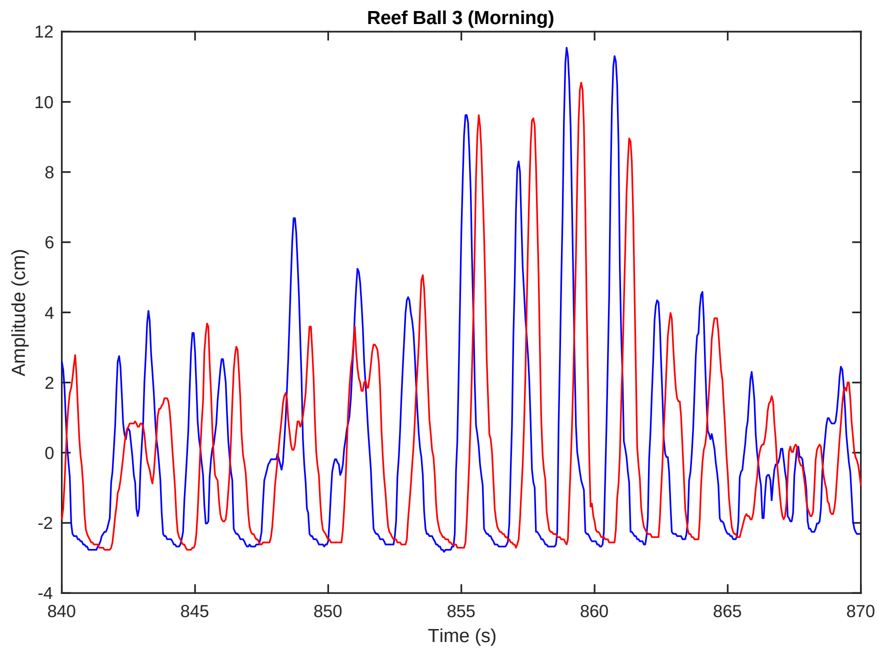

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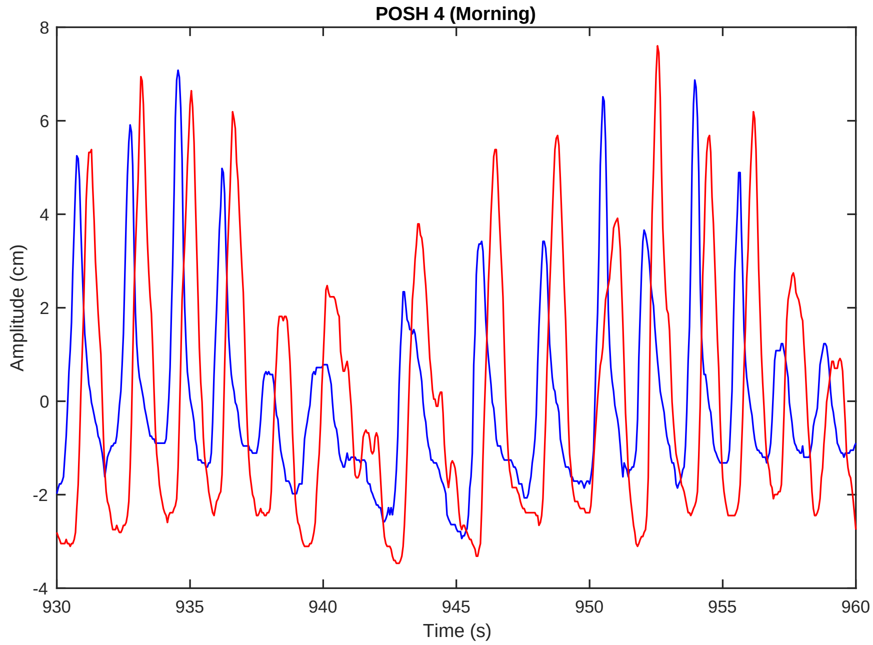

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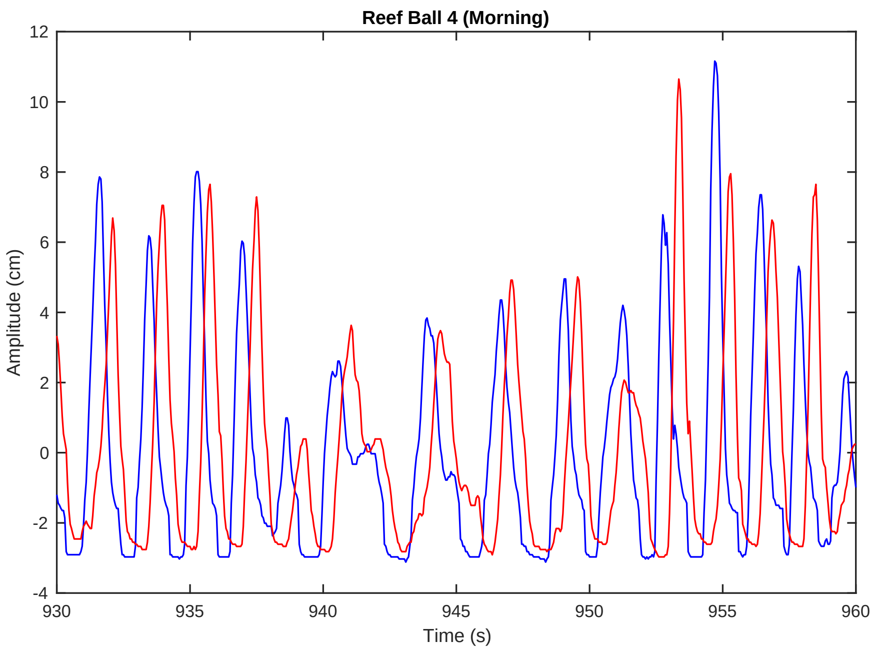

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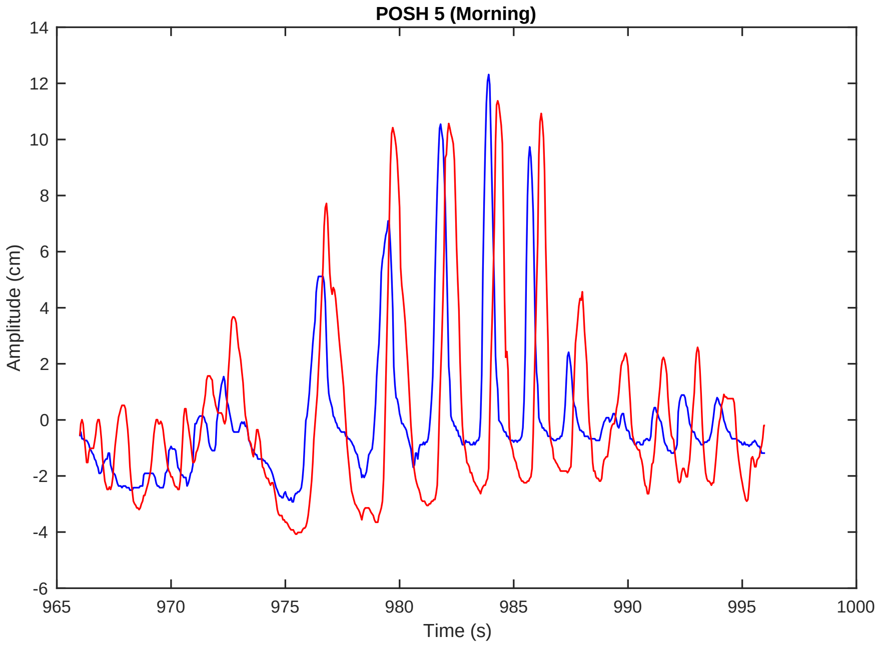

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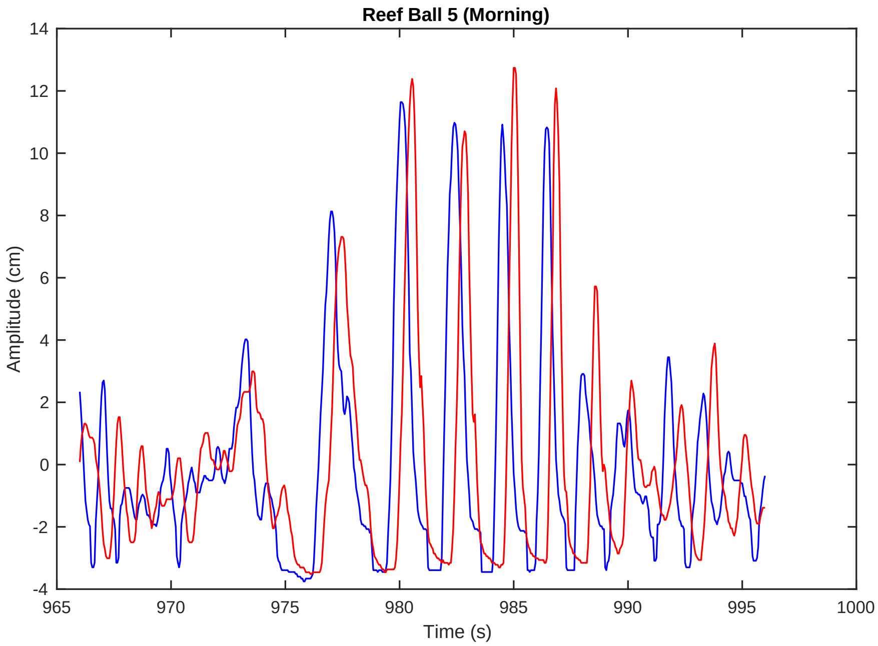

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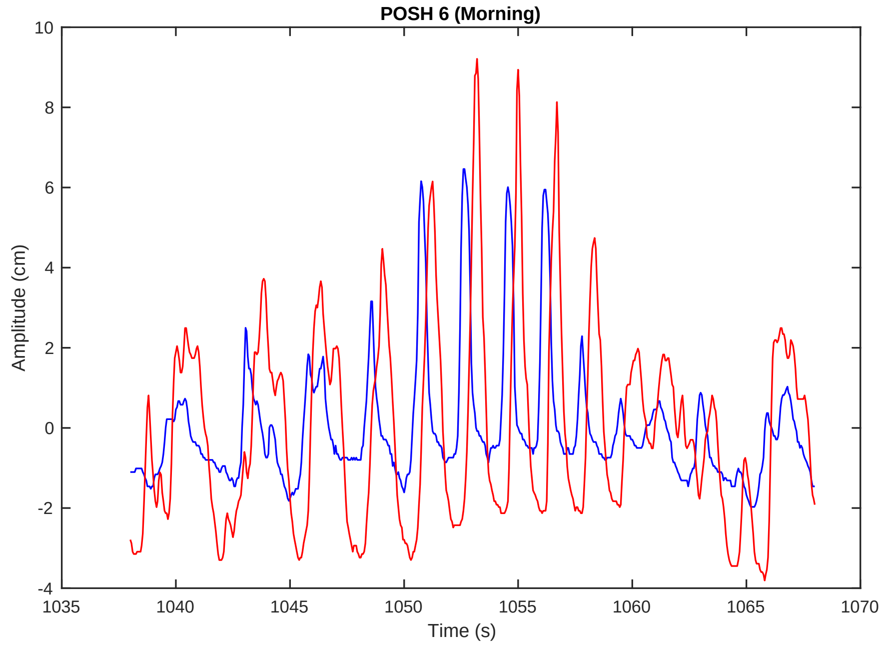

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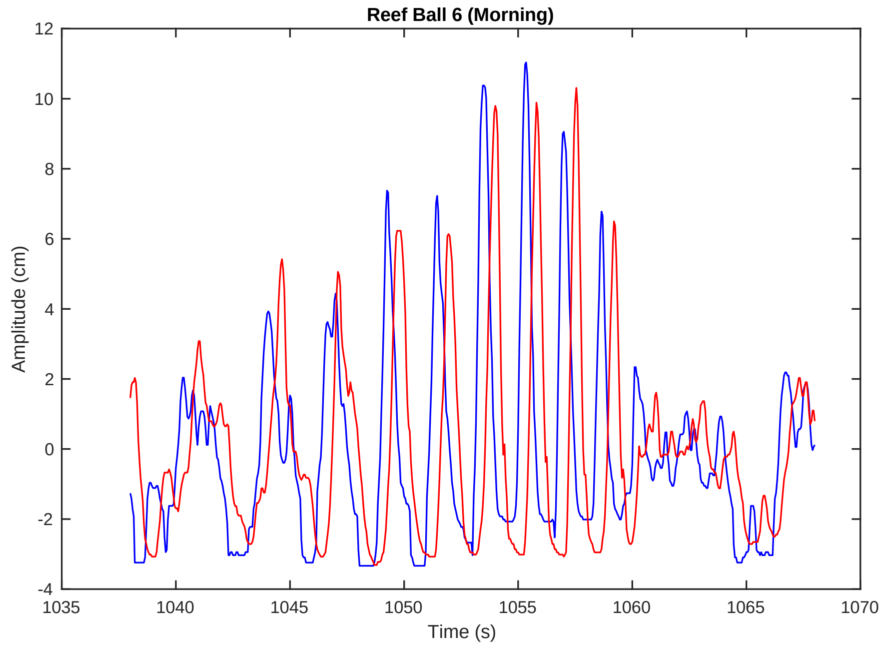

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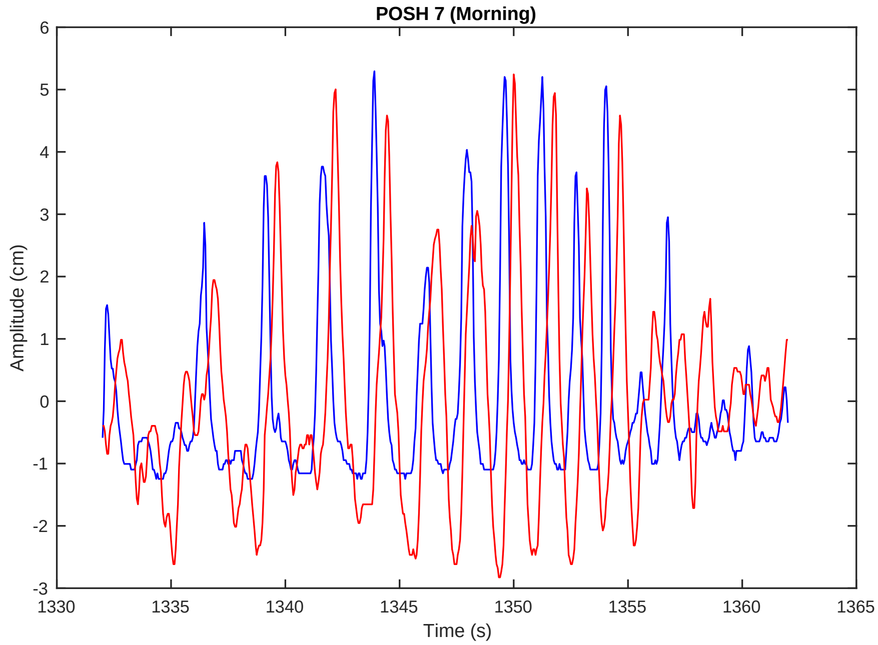

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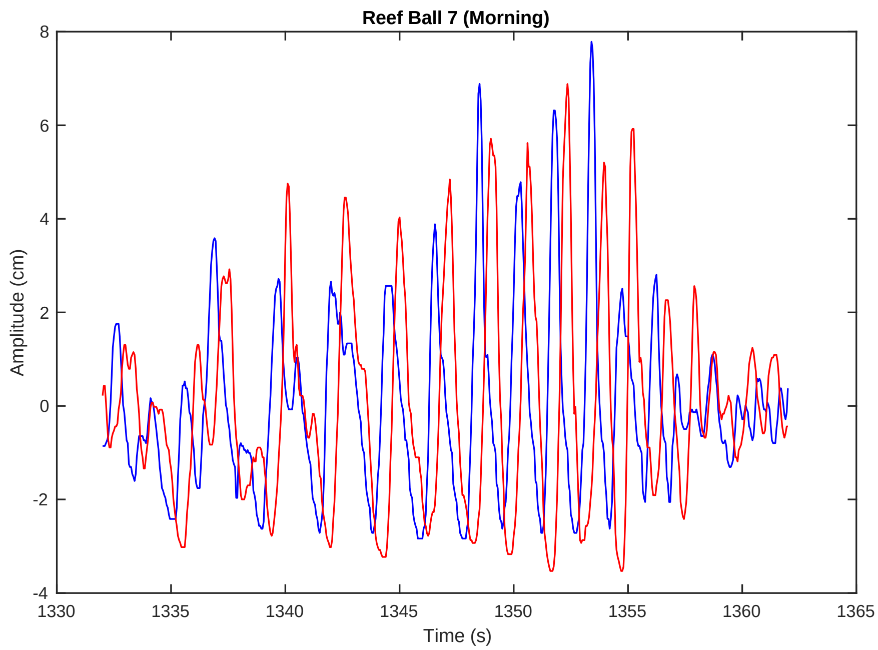

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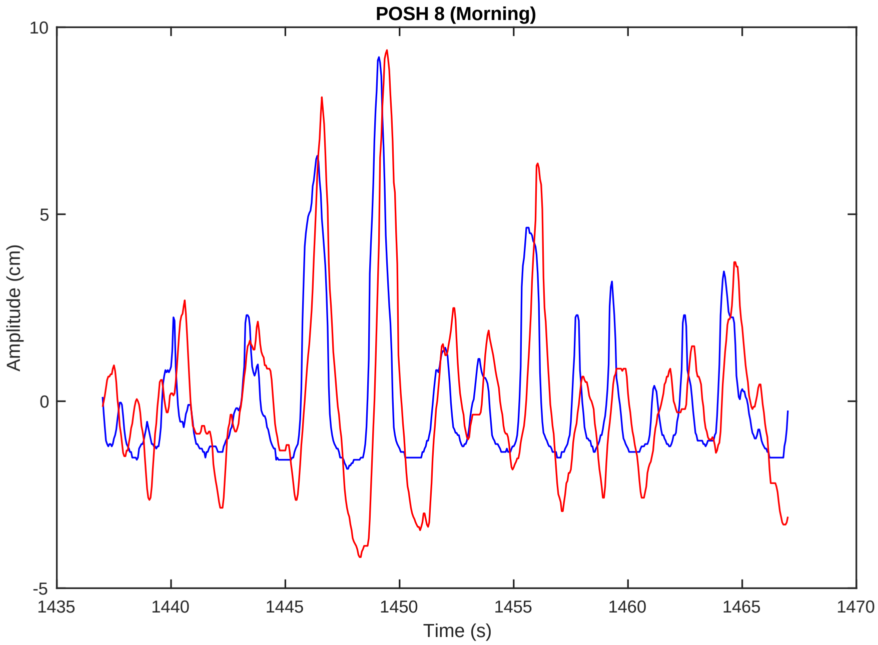

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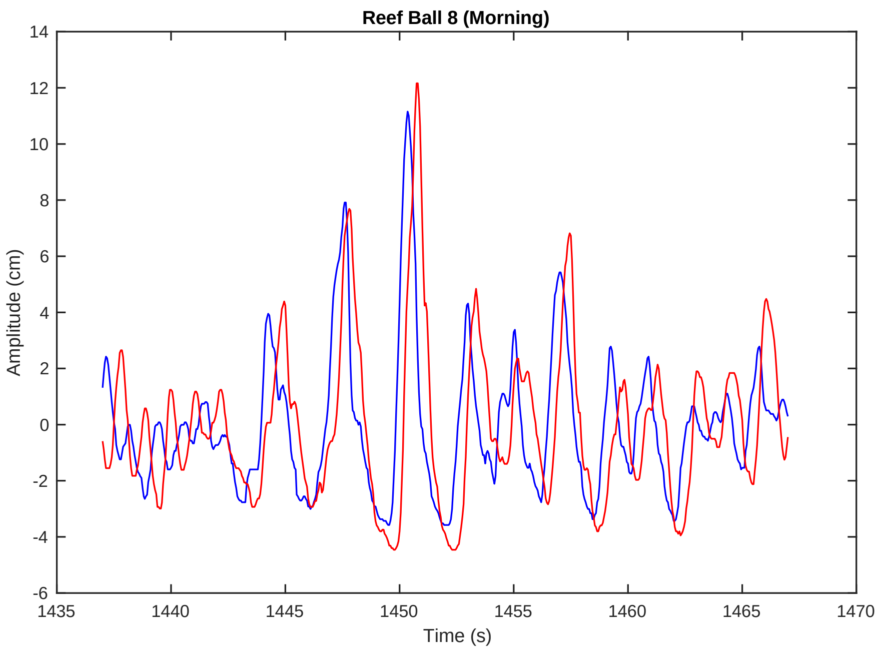

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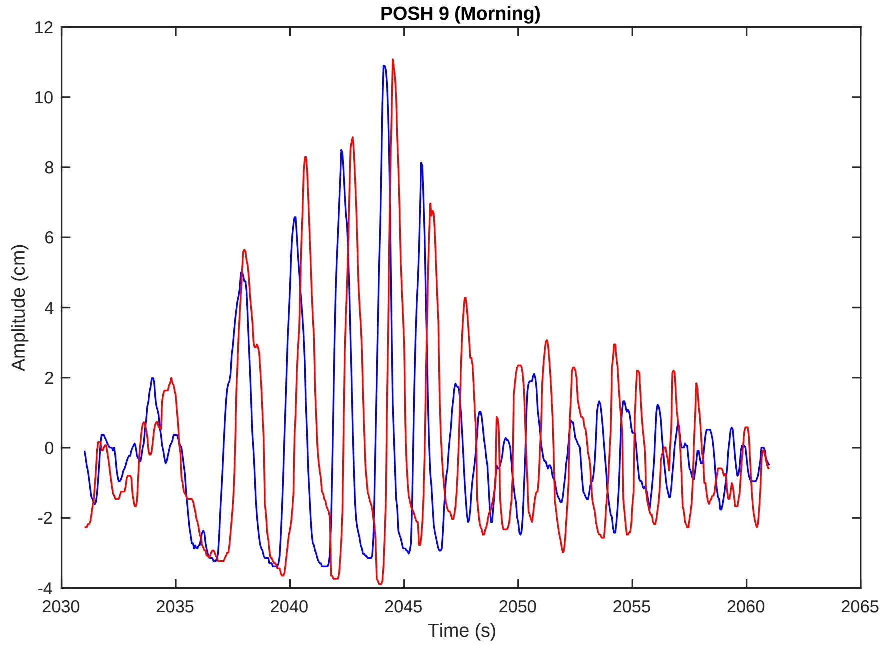

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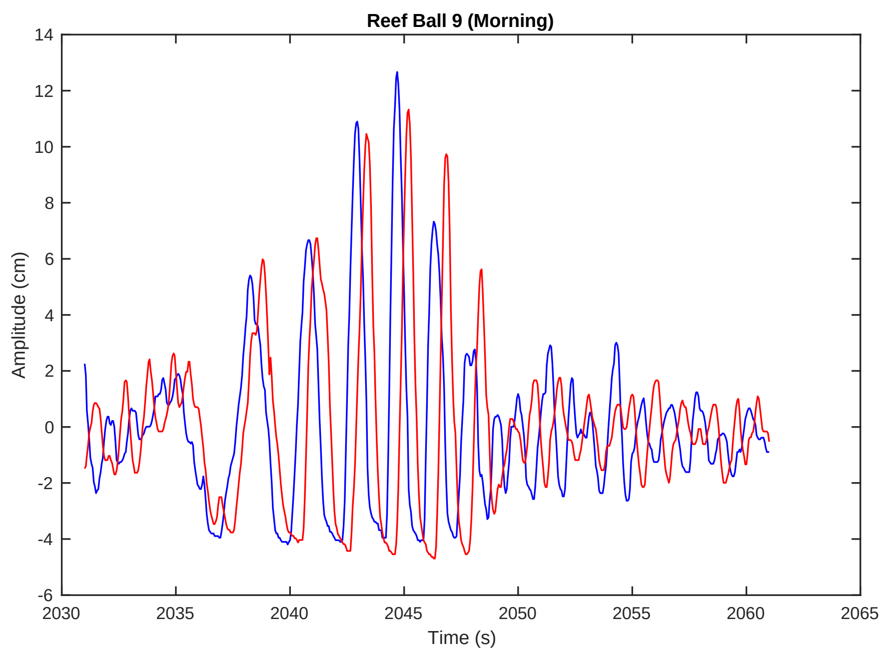

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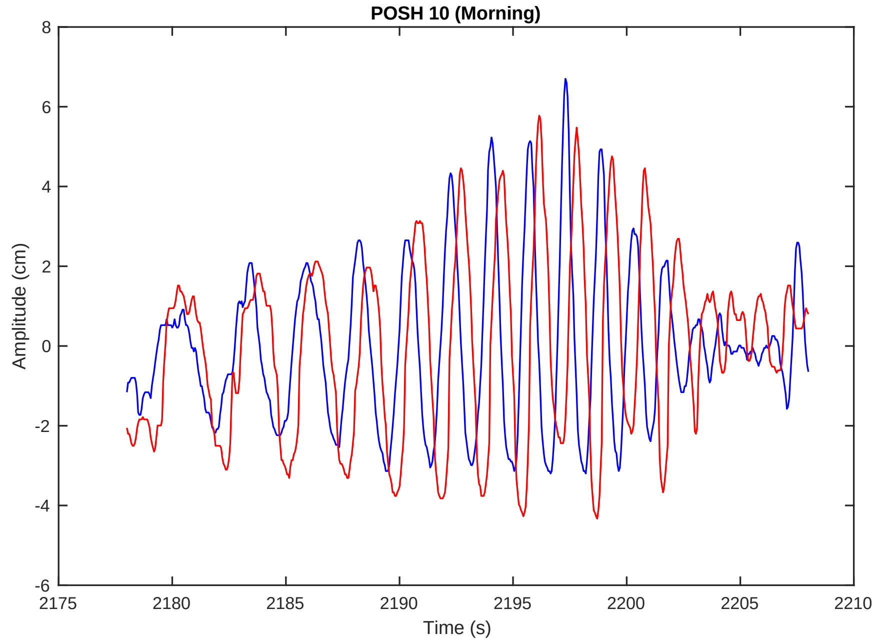

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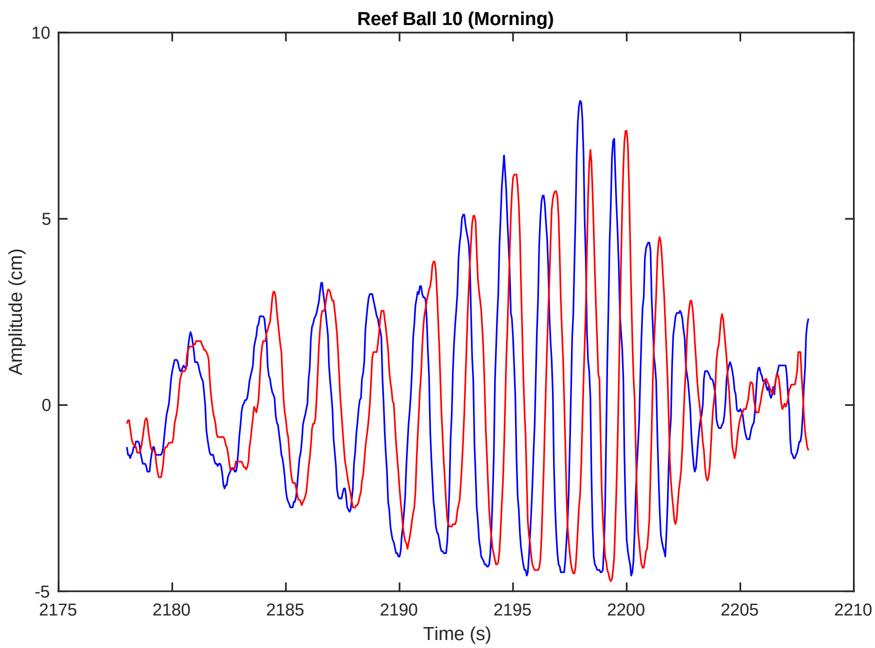

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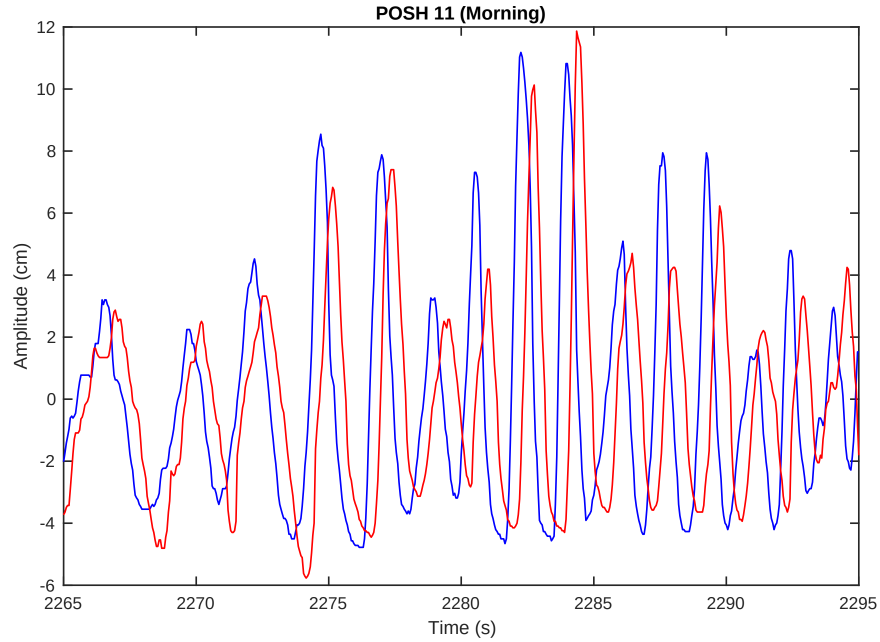

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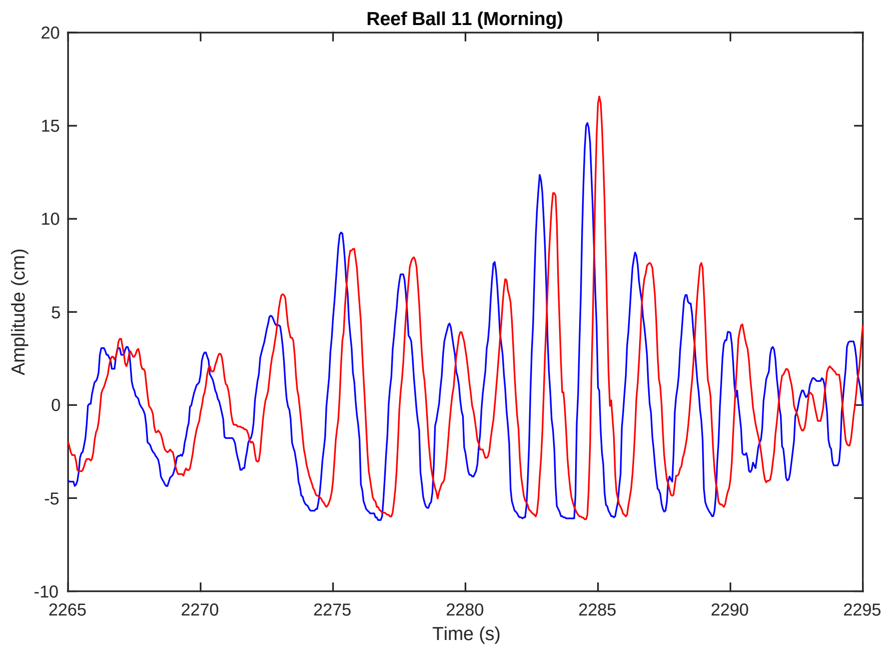

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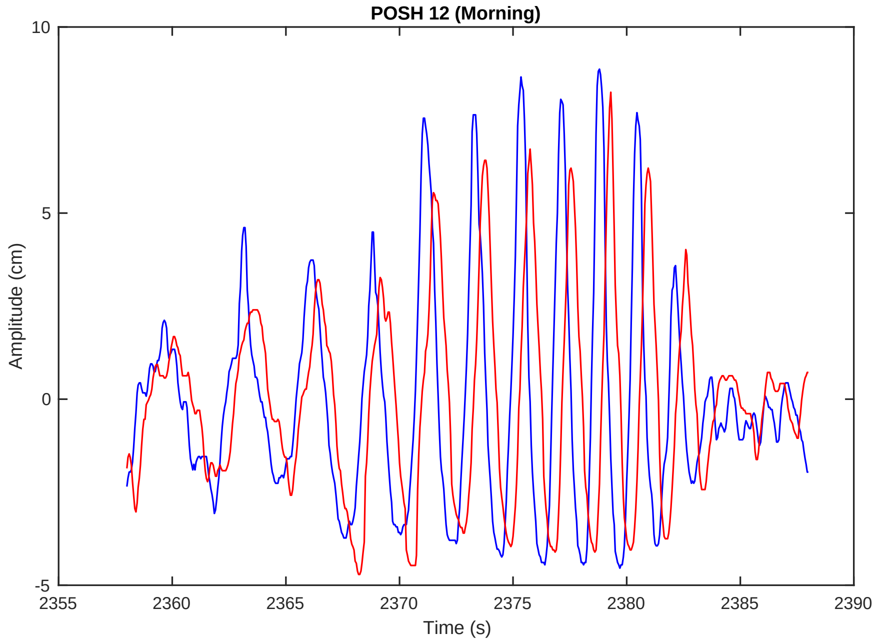

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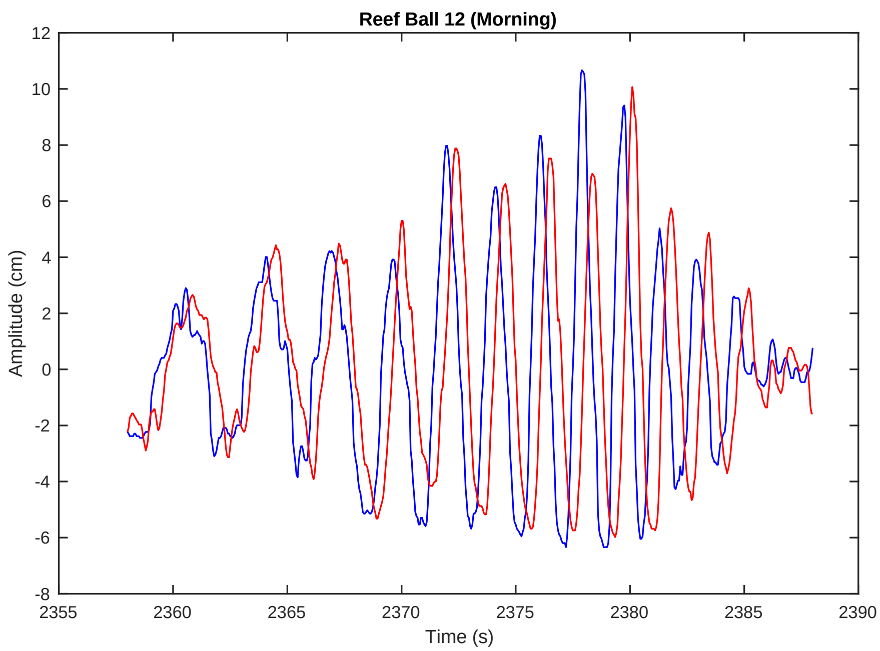

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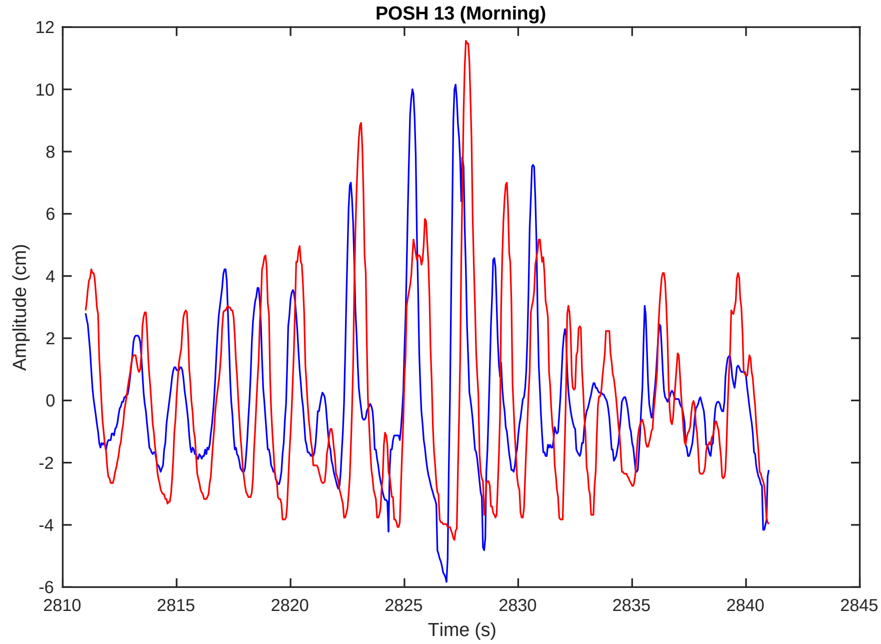

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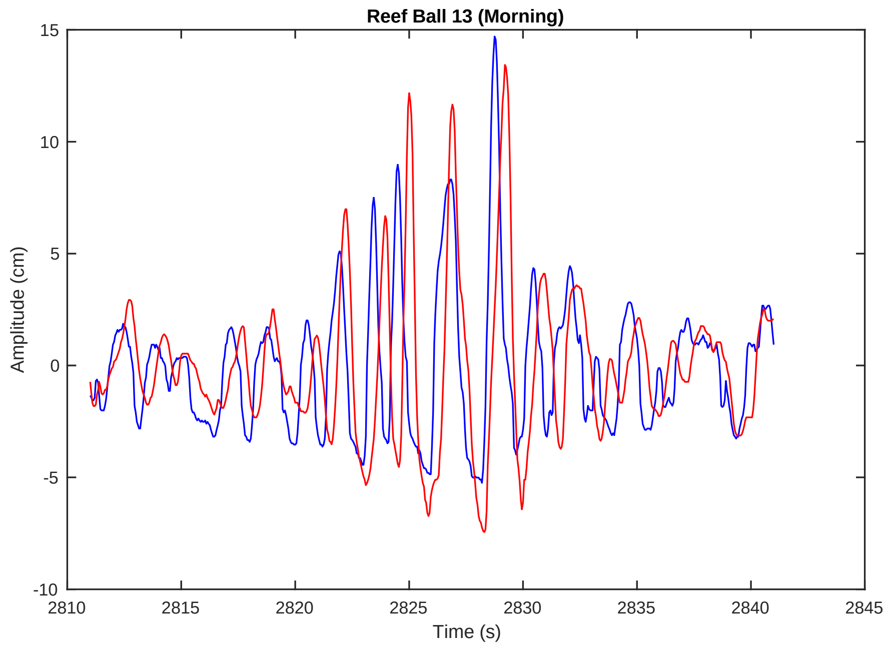

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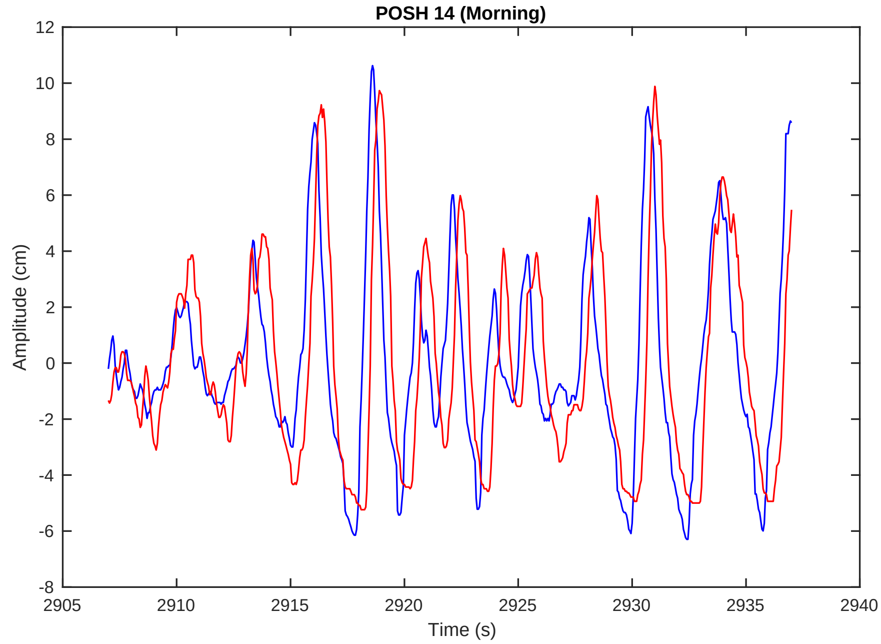

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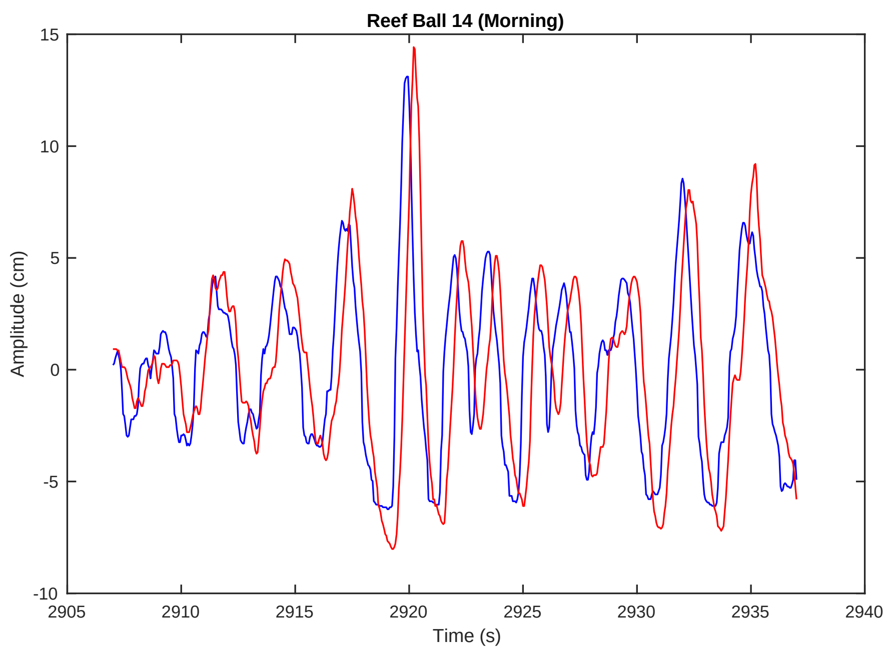

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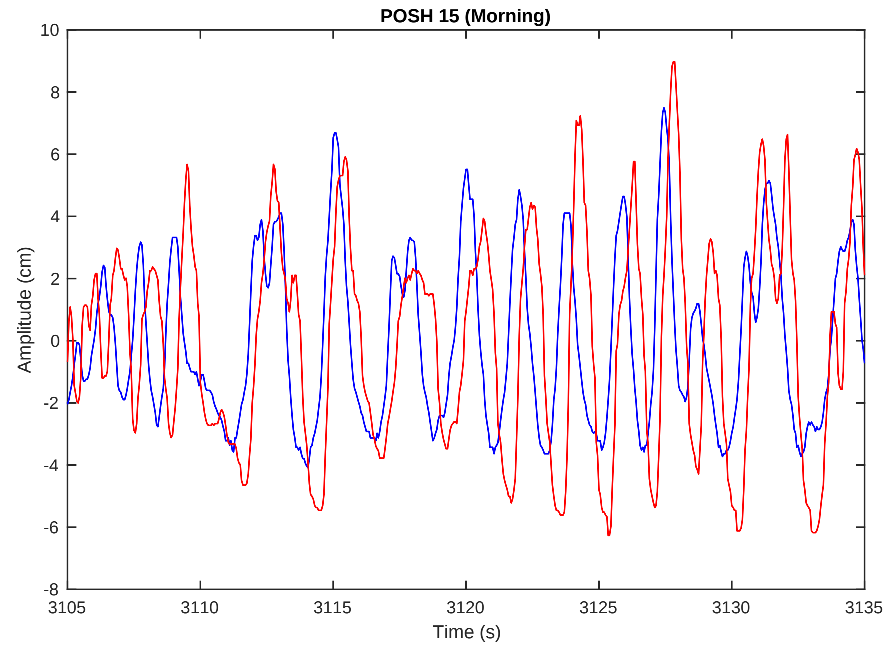

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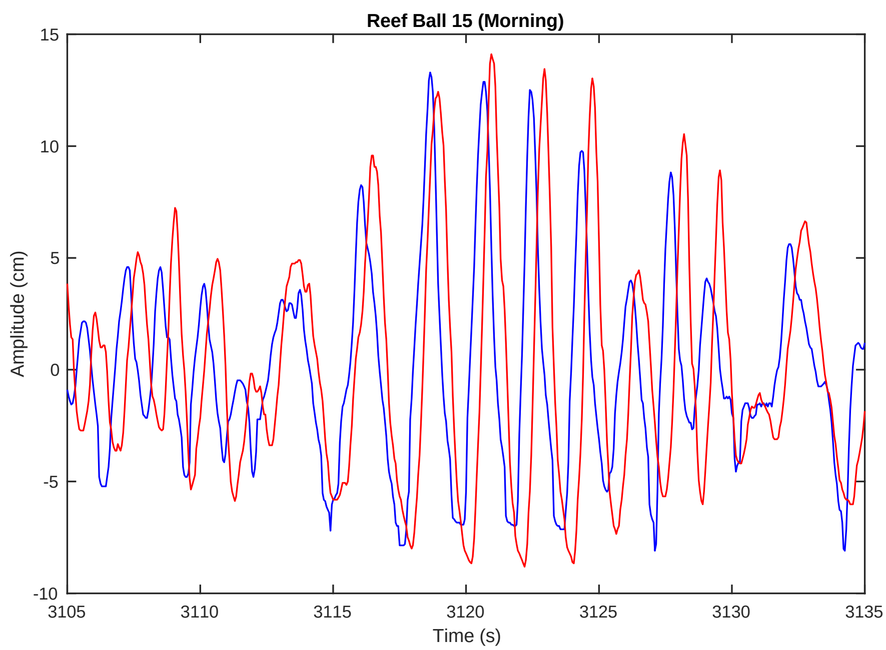

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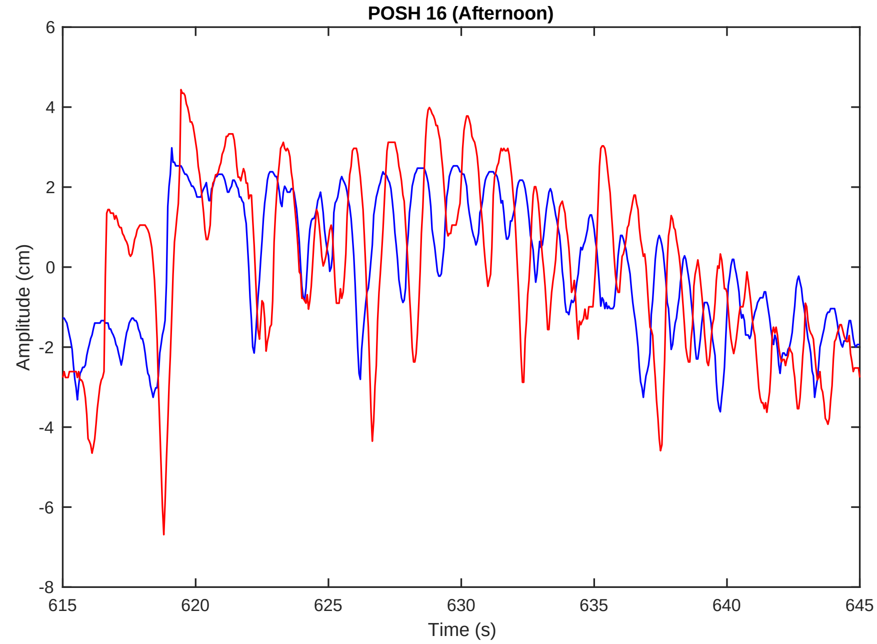

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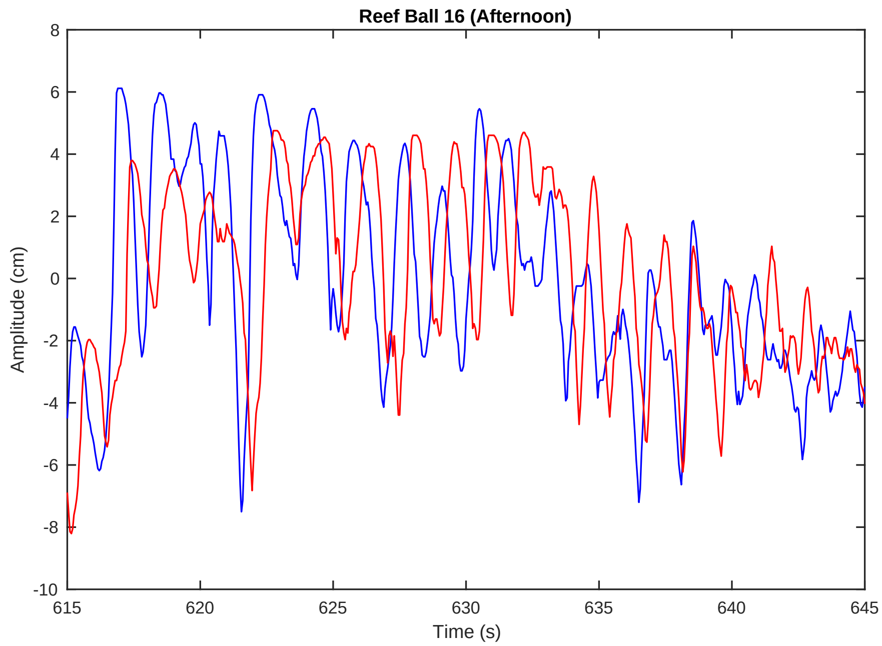

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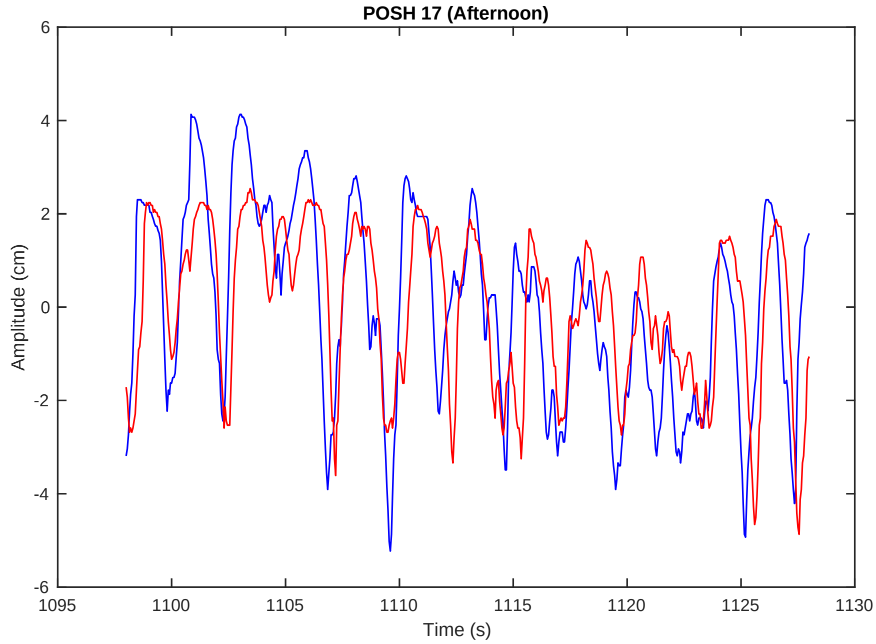

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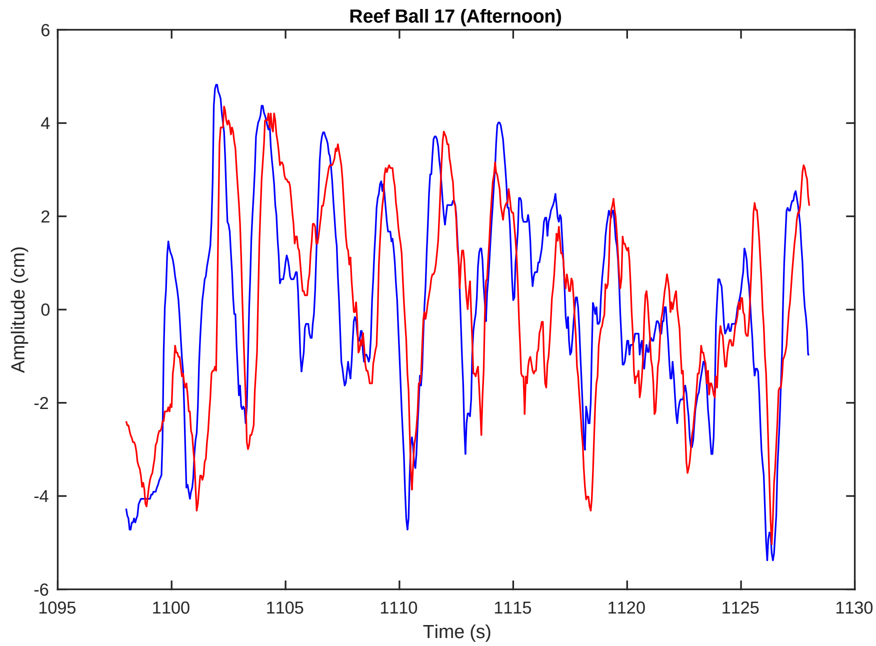

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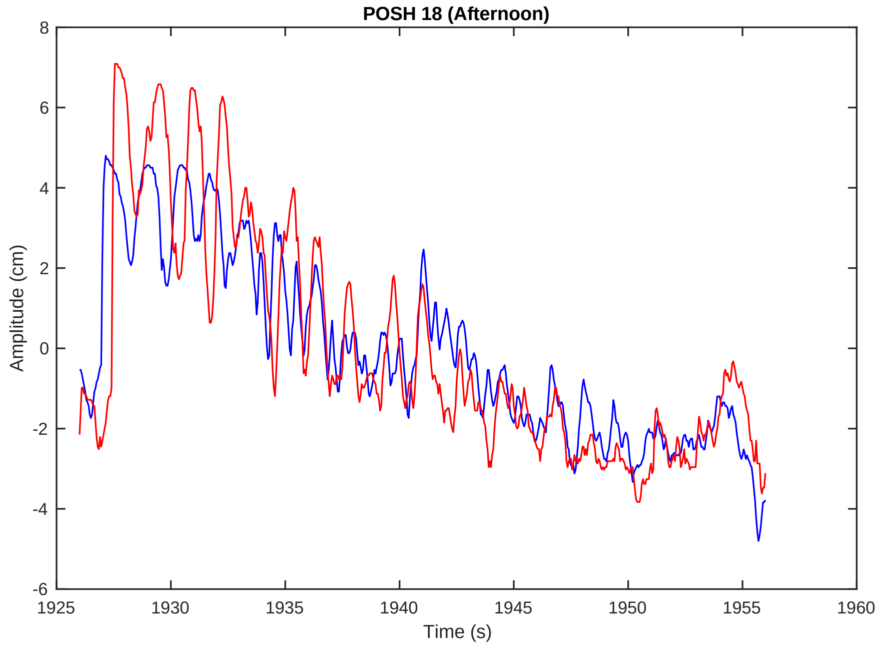

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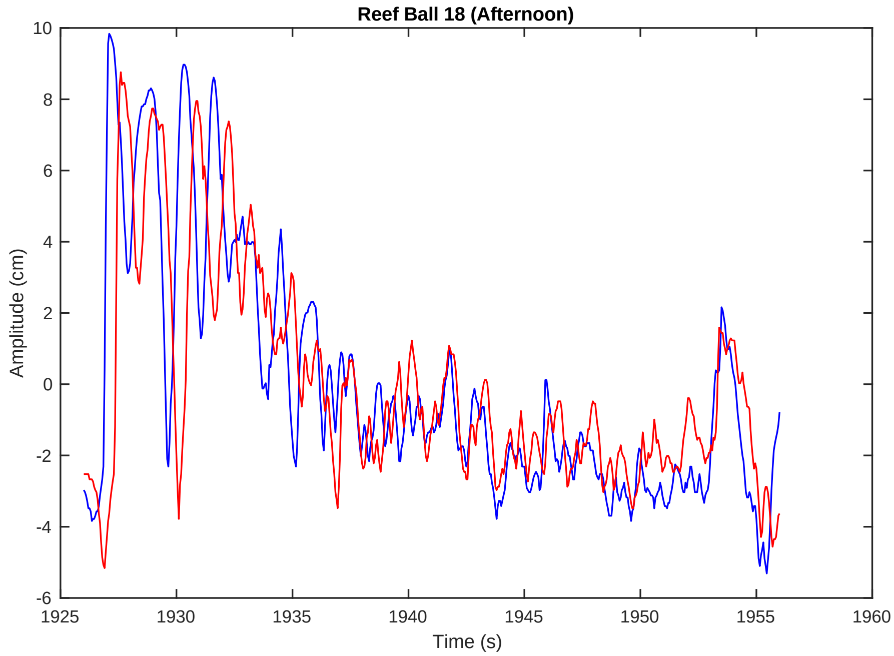

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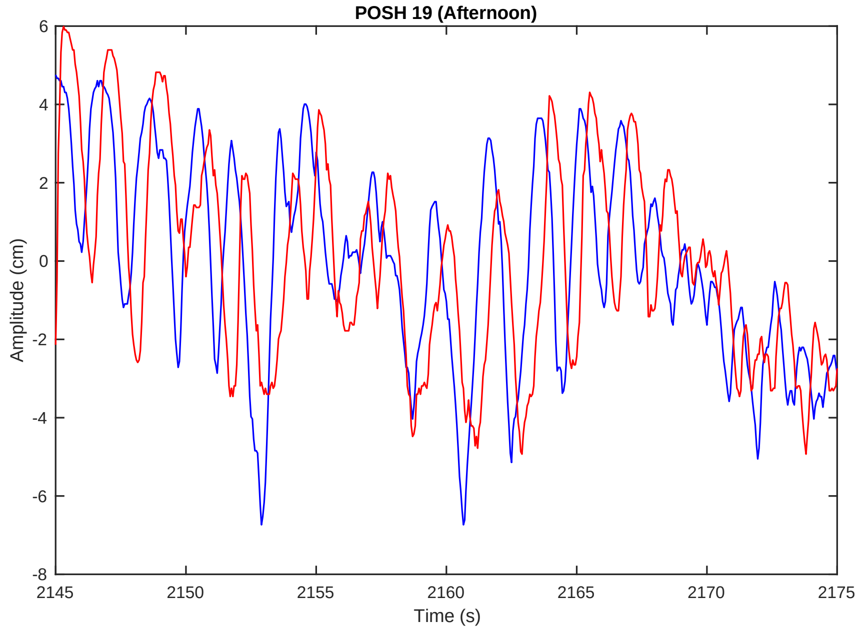

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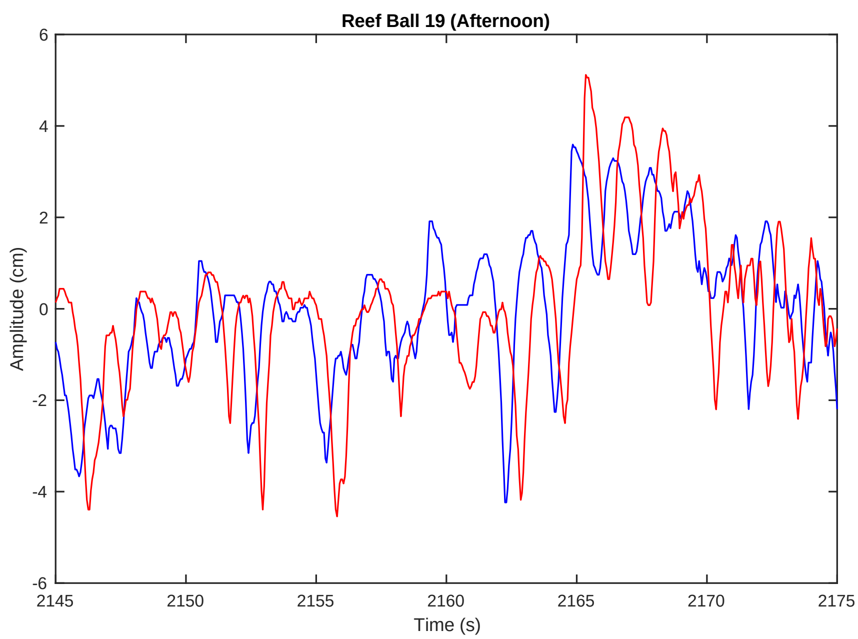

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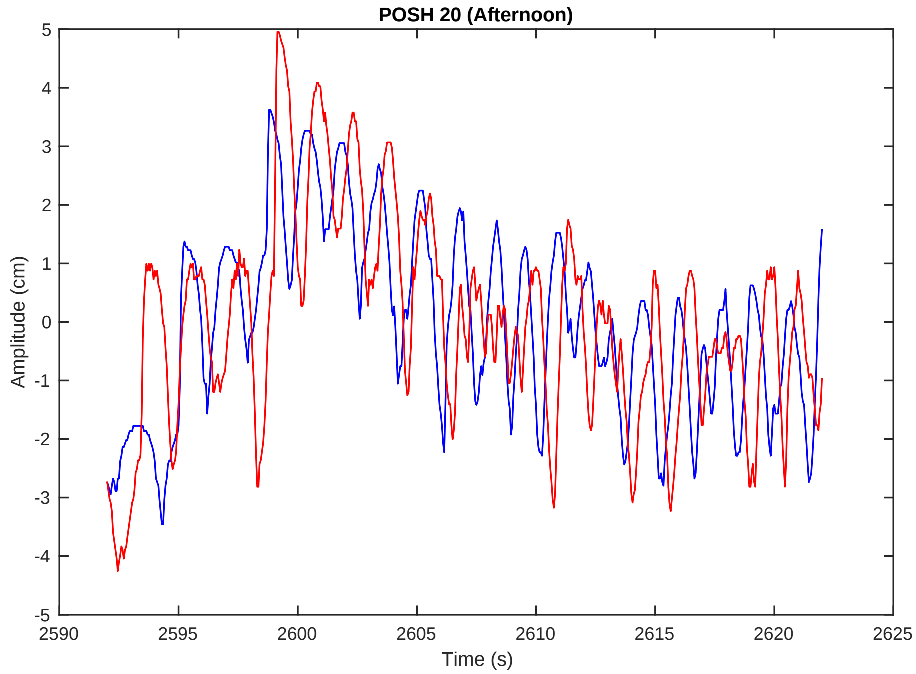

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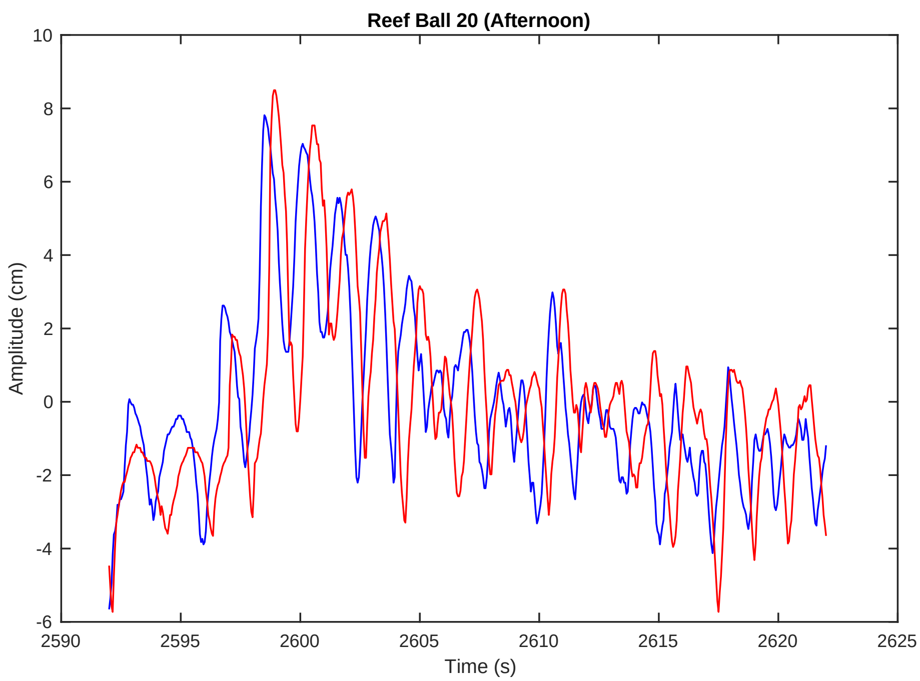

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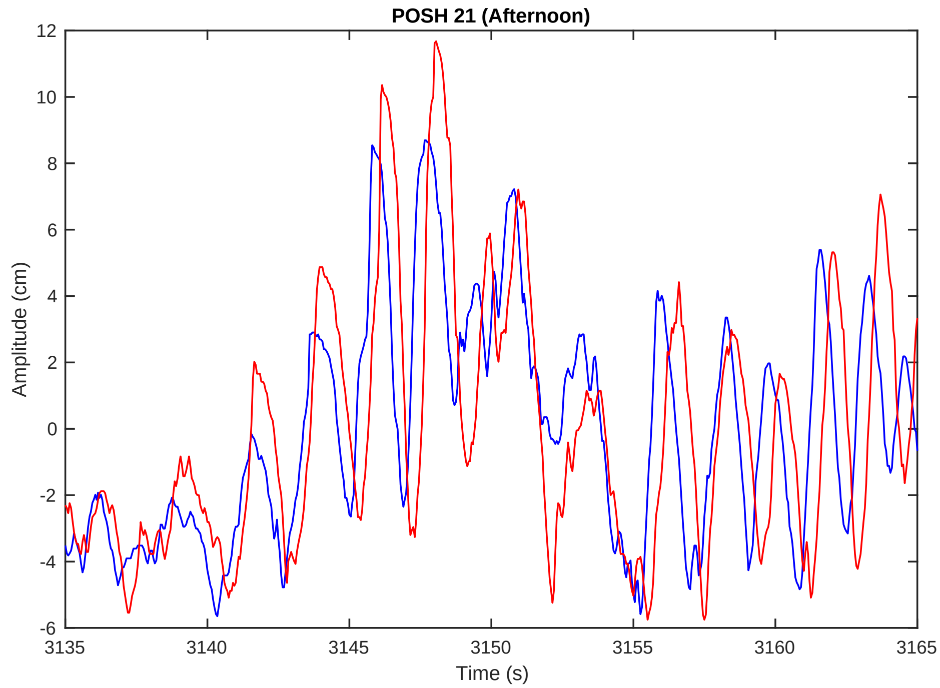

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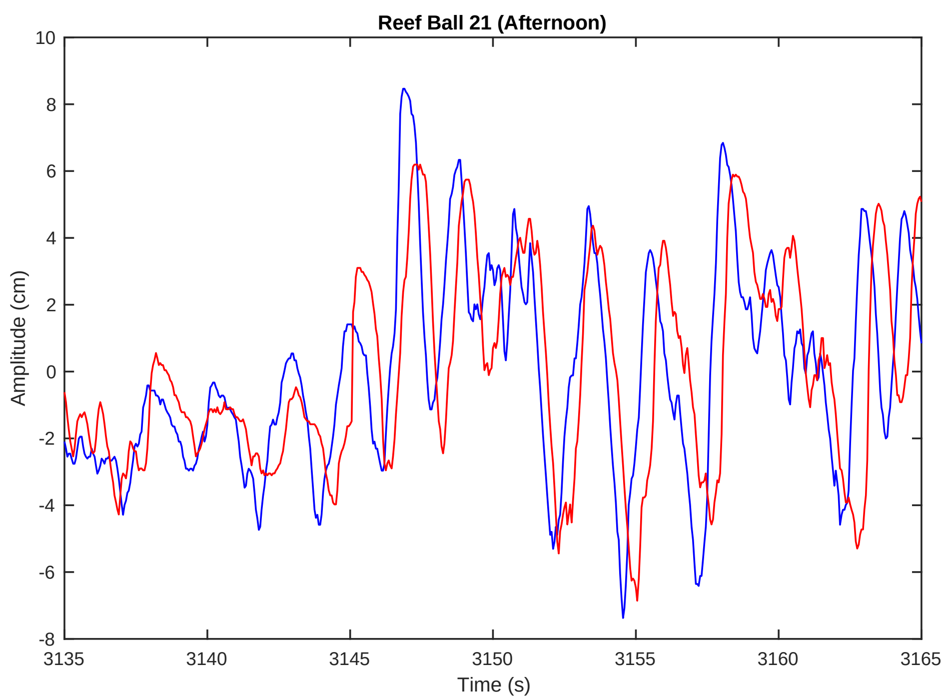

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