Outer Fall Region Broadband Ambient Noise Characterization
Maine Department of Marine Resources, Large Whale Conservation Program
Final Report-March, 2013
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I. Introduction

Ambient noise in the world's oceans has been studied as early as the 1940s, and more recently, its impact on sensitive marine mammal populations has been met with growing concern. Marine mammals have evolved with the presence of naturally-derived ambient noise throughout their habitats, including wind (Piggott, 1964; Zakarauskas et al., 1990), waves, precipitation, geologic events, cracking sea ice (NRC, 2003), and even other organisms (Wenz, 1962; Kraus and Rolland, 2007; Tyack, 2008). The dominating human-generated contributors to ambient noise have, however, been increasingly demonstrated as harmful to aquatic populations spanning far beyond marine mammals (McCauley, 2003; Slabbekoorn and Peet, 2003; Brumm et al., 2004.) Anthropogenic sound sources include activities such as commercial ship traffic, coastal construction, oil exploration and drilling, sonar systems, and fishing (NRC, 2003). Steadily increasing human activities, predominantly ship traffic, over the past 150 years have resulted in elevating background noise levels, which occupy low frequency bandwidths (Payne and McVay, 1971; Andrew et al., 2002; NRC, 2003). Evidence of this phenomenon has been documented on a global scale. Two studies comparing previously characterized ambient noise from the 1960s to the 1990s and early 2000s in California found an 8-12 dB increase in noise less than 100 Hz (Andrew et al., 2002; McDonald et al., 2006). Both studies attributed the rise in ambient noise to shipping, and McDonald et al. (2006) hypothesized that the local noise increase was representative of the entire Northeast Pacific due to the widespread growth of the commercial shipping industry. Early estimates from the Western North Atlantic identified similar increases (Ross, 1993). Wenz (1962), emphasizing wind and ship noise contributions to ambient noise levels, found local anthropogenic components between 10 and 1000 Hz. These components dominated the spectra between 20 and 500 Hz with distant shipping present primarily under 100 Hz. The Northwest Atlantic has also experienced broadband ambient noise increases, with frequencies peaking around 80 Hz and reaching as high as 900 Hz during the winter on the eastern Canadian continental shelf (Zakarauskas et al., 1990). This study compared noise levels to those recorded in the same area by Piggott (1964) and reported significantly higher received levels below 100 Hz within the 26 year time period, though the disparity may be due to differences in propagation conditions.

The acoustic repertoires of large, endangered baleen whales inhabiting the Western North Atlantic consist primarily of low frequency vocalizations under 1 kHz (Watkins, 1981; Stimpert and Au, 2011; Kraus and Rolland, 2007), occupying the same bandwidth as anthropogenic sound sources. The co-occurrence of anthropogenic and biological sound in the lower frequency range has been shown many times to interfere with marine mammal communication. Non-lethal interference is most often manifested in the form of masking, where background noise exceeds

the amplitude of a signal, and the call is obscured (Clark et al., 2009). Many cetaceans have found short-term anti-masking strategies, ranging from increasing the amplitude of their signal (Parks et al., 2009; Parks et al., 2007; Holt et al., 2011), increasing signal length (Miller et al., 2000; Fristrup et al., 2003), shifting signal frequency to a bandwidth not occupied by noise (Parks et al., 2007; Castellote et al., 2012), cessation of vocalizing all together (Risch et al., 2012), or vacating the area of high noise (Holt et al., 2011; Castellote et al., 2012). In some cases, monitored environments with high ambient noise have shown many simultaneous reactions by impacted individuals such as shortened signal duration, decreased signal bandwidth and peak frequencies, and habitat displacement (Castellote et al., 2012). One particularly significant study demonstrated the impacts of anthropogenic noise occurring over a long temporal scale. Results indicated that north Atlantic right whales in the Bay of Fundy, a habitat characterized by high vessel traffic and thus high ambient noise, were vocalizing at higher starting frequencies and over greater bandwidths than southern Atlantic right whales off Argentina, a habitat with significantly less ship traffic and ambient noise (Parks et al., 2007). Additionally, the same study showed that both of these populations have made long-term changes by increasing the start frequency of calls over a 50 year time period, presumably a result of globally increasing ocean ambient noise.

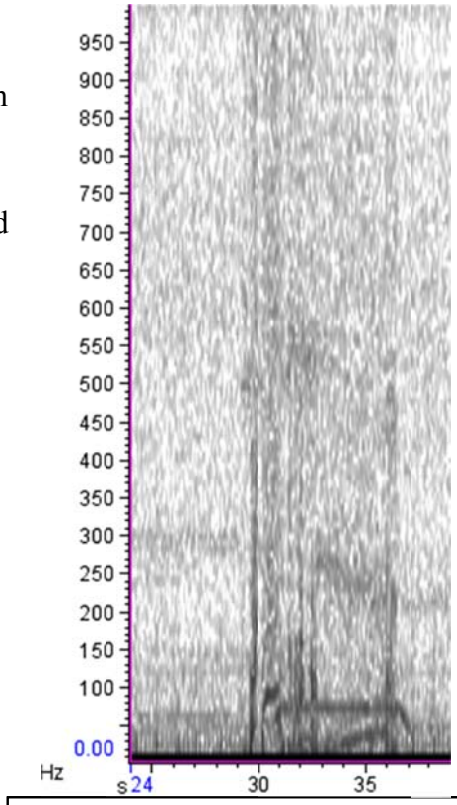
Though it has been demonstrated that many species of cetaceans in varying geological locations have found ways of coping with increased ambient noise, these coping mechanisms likely come at a cost. Noise channels heavily dominated by anthropogenic sources have been shown to reduce the amount of effective communication space available to whales (Tyack, 2008; Parks et al. 2007). While it is difficult to demonstrate in free-ranging animals, chronic stress due to noise can suppress reproduction, inhibit growth, and impact the immune system's ability to respond to infection (NRC, 2003). These effects could have serious implications for the survival and recovery of species, such as the North Atlantic right whale, that are already struggling with slow population growth (Kraus, 1990). Due to their endangered status, stress introduced in breeding grounds, critical habitats, or any areas of high use by this population can have an enormous impact on fecundity and survivability. In 2008 an aerial survey discovered a previously unknown North Atlantic right whale wintering ground in the Jordan Basin area, about 70 miles south of Bar Harbor, Maine. It has since been suggested that this area could also be a mating ground for the species (Dawicki, 2008).

The present study aims to characterize ambient noise levels in the newly discovered wintering ground across the frequency range that North Atlantic right, and other large whales inhabiting the area, frequently utilize. This characterization addresses the acoustic environment that whales are exposed to when utilizing the area, and investigates temporal variation in RLs. To date there are no ambient noise characterizations in the Jordan Basin area.

II. Methods

Recordings

Two marine autonomous recording units (MARUs) were deployed in the Outer Fall region of the Gulf of Maine, from October 14 2010 to May 14 2011, recording for a total of seven months. The locations of each unit, 43° 18.226, -68° 37.306 and 43° 26.186, -68° 23.693 (figure 1), were selected to spatially and temporally overlap with 2008 and 2009 sightings of right whales in the same area from aerial surveys conducted by National Marine Fisheries Service (Dawicki, 2008). The units were set 22.53 kilometers apart, and due to an onboard equipment malfunction, unit depths are only estimated to be approximately 600 feet. Each MARU unit was equipped with batteries, memory disk storage, a microprocessor and acoustic communication circuitry sealed in a 17 inch glass sphere and an externally mounted hydrophone. An acoustically-triggered release mechanism allowed for surface retrieval. Both MARUs continuously recorded at a 2 kHz sampling rate with 12-bit resolution. Hydrophone frequency response was -168 dB re 1V/µPa between 10 Hz and 32 kHz with a flat frequency response between 20 and 800 Hz. MARU units are typically anchored to the sea floor with sandbags. However, prior experience in the northern Gulf of Maine utilizing this anchoring system (unpublished data) did not withstand the rocky substrate, strong current and stormy weather environment. Instead, anchors constructed of concrete and rebar were substituted, and the anchoring tethers were made up of three meter length Uniline, weighing 81 kg total.



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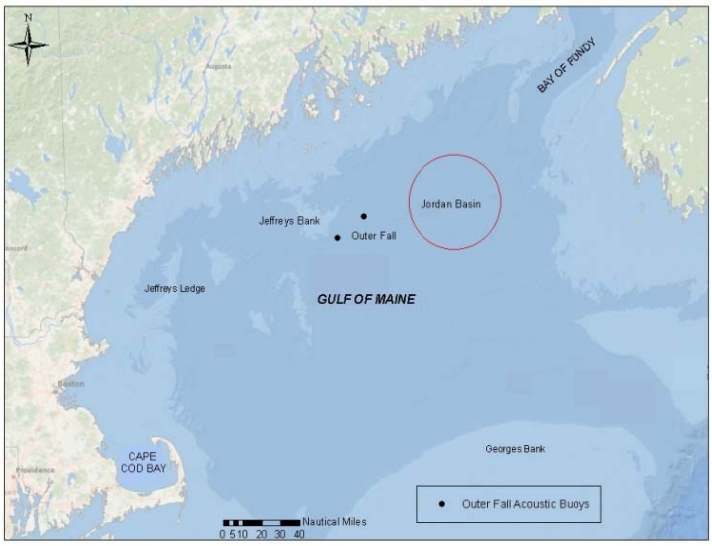

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Analysis

A custom MATLAB script was created to calculate averaged received levels (RL) of ambient noise in linear scale. Script results were converted back to dB re 1 µPa units. The script was run over various time scales across the recording period in order to identify periodicities or factors impacting the data. The script used a 50% sample overlap, 2048 pt. FFT and frame length, and

used a Hanning window. The script included a function to remove the nearly seven seconds of data every three minutes throughout the dataset of broadband, internal noise as the pop-up unit's hard drive spun (figure 2). Removing these events calculated the most accurate ambient noise levels.

Four temporal variables were tested on the data to look for an effect on ambient noise levels in the Outer Fall region, including hourly, daily, diel, and seasonal variations. Diel parameters were defined using daily local sunrise and sunset times recorded on the U.S. Naval Observatory Astronomical Applications website. Buoy variation and RLs were averaged over two different frequency ranges, and a difference in RL between the two ranges was also tested. All factors examined were chosen for their relevance to the Outer Fall habitat and whale acoustic activity. Data from both pop-ups fit a normal distribution, and paired T-tests, correlation and regression analyses were used to evaluate each variable's significance on ambient noise levels in SYSTAT 11 and SAS, and their subsequent relevance to right whale use of the area.

III. Results

A summary of variable means is displayed in table 1, descriptive summary of both buoys' RLs is represented in table 2, and daily RLs plotted across the recording period is shown in figure 3. In order to determine if there is a difference between the two recording units' RLs, a paired sample t-test was run on RLs in the 10-1000 Hz range. Paired t (5082) = 0.22, p=.82, indicating no significant difference between the two buoys' calculated RL. Significance of difference was also calculated for both buoys' RLs over two different frequency ranges, 10-1000 Hz and 10-400 Hz, in order to identify relative ambient noise band occupation. A paired sample t-test was used, resulting in paired t(5082)=85.84, p=0.00 for buoy 97, and paired t(5085)=84.94, p=0.00 for buoy 149. These indicate that there is a significant difference in RLs between the 10-1000 Hz and 10-400 Hz band range on both buoys.

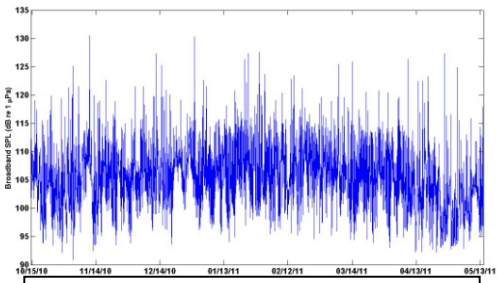


Figure 3: daily received levels plotted over entire recording period. Buoy 149 on top, 97 below.

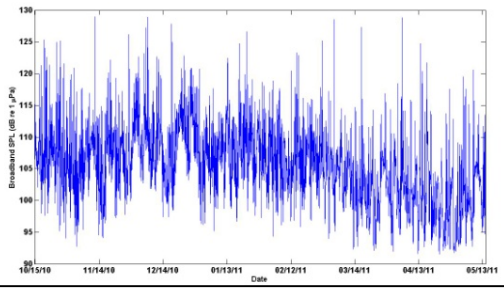


Figure 3: RL plotted over entire recording period, buoy 149 left, 97 right.

Temporal Analysis

A temporal analysis was done in order to identify any relationship between RLs and increases in ambient noise over various time-scales that may be relevant to whale use of the habitat. A Pearson Product-Moment Correlation test was conducted for each buoy to examine the relationship between each time-scale variable and the RLs calculated in the 10-1000 Hz frequency range. Table 3 summarizes the r- and p-values for each variable and buoy. The table indicates that day of the week, day and night, and hour of the day are not significantly related to

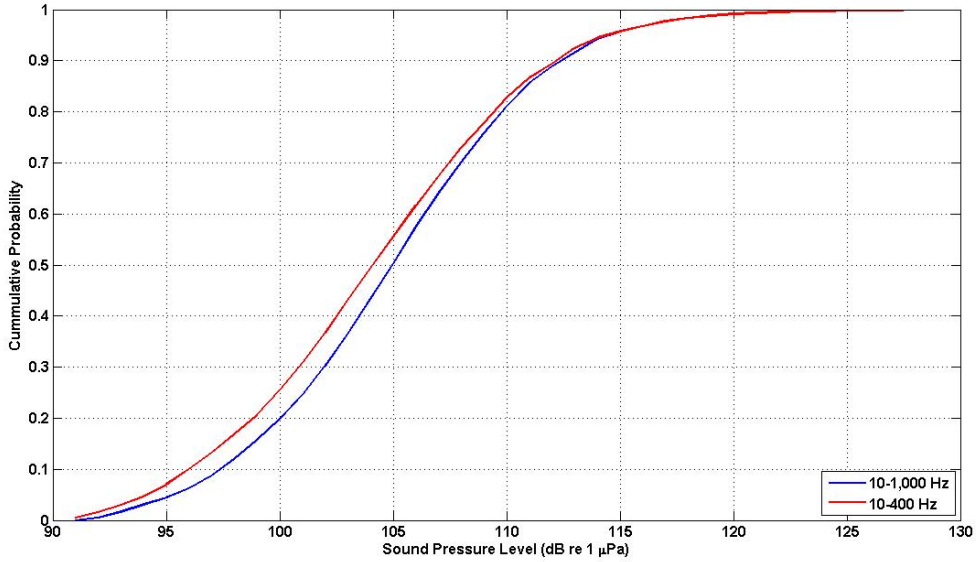
ambient noise levels in the 10-1000 Hz frequency band, and thus daily, hourly, and diel variations do not significantly explain ambient noise from either buoy. However, season, specifically winter and spring, are significantly correlated to < 0.001, and buoy 97 is more strongly correlated than buoy 149. A linear multiple regression analysis was run to further determine the strength of the significant relationships discovered in the Pearson correlation. Spring and winter were included in this analysis, as well as the diel variable. Though the diel relationship was not found to be significant, it was the next strongest relationship after winter, and thus was included. Table 4 summarizes results from buoy 97, and table 5 summarizes results for buoy 149. These results show spring on buoy 97 as having the strongest relationship with RLs in the 10-1000 Hz frequency range with a t value of -26.8, significant to <0.0001. Winter on the same buoy holds a strong relationship with a t-value of 6.22 and significant to <0.0001. These relationships indicate a significant noise reduction in spring and a less severe, though still very significant increase in noise in the winter. The second buoy shows a strong relationship for spring with a t-value of -2.48 significant to 0.0132, and winter as also having a strong correlation with a t-value of 12.33 significant to <0.0001. These values indicate a weaker noise reduction in spring than buoy 97, and a stronger noise increase in winter than buoy 97. Both buoys indicate an insignificant relationship with diel RLs as expected, and the difference between its t-value and those of the seasonal variables are very different.

IV. Discussion

The goal of this study was to investigate and report ambient noise levels in this newly discovered right whale wintering ground, and discern if ambient noise levels peak over temporal scales relevant to whales utilizing the Outer Fall region. Ambient RLs were calculated for each buoy, indicating an overall average across the recording period of 105.48 dB re 1 μPa in the 10-1000 Hz range from buoy 149, and 105.50 dB re 1 μPa from buoy 97. RLs averaged over defined temporal scales throughout the recording period were examined in order to identify increases in ambient noise, some of which may be relevant to right whales. Mussoline et al. (2012) reported right whale acoustic activity peaked during twilight and dark hours in Stellwagen Bank National Marine Sanctuary and Jeffreys Ledge, two known right whale summer and winter habitats. If right whales in Outer Fall are also more acoustically active during night time hours, a concurrent peak in ambient noise could impede their ability to communicate. However, this study found no diel variation in ambient noise. Hourly and week day RLs were also tested in order to determine if there is a certain time of day or day of the week where ambient noise is significantly louder, and thus potentially impacting the sensitive population of right whales found to be using the region. However, these temporal variables were also found to have no impact. The only factor that was found to explain the variability of ambient noise during the recording period was season. These results indicated that RLs recorded during the spring season were significantly quieter, while winter was significantly louder. Statistically, this is an important habitat characterization of the Outer Fall region as right whales are, to date, known to inhabit the area during the winter season only. The simultaneous presence of right whales and peak in ambient noise could interfere with foraging, communicating, socializing and reproducing. However, an average RL of 107-108 dB (buoys 149 and 97 respectively) during winter is biologically not a significant difference from the region's measured mean of 105 dB. This minimal difference of 3-

4 dB would likely not have a biological impact that differs from those resulting from the average habitat's noise level.

Received levels were also calculated in two different frequency ranges, 10-1000 Hz and 10-400 Hz. This was also done by Hatch et al. (2008), who concluded that because RLs between the two bandwidths were not different, most sound energy was concentrated under 400 Hz. While discerning more specifically what frequency range ambient noise is dominating in the present study still needs to be calculated, having also measured noise in the two frequency bandwidths is informative. Statistically, RLs between the two frequency ranges are significantly different. Figure 4 represents cumulative probability plots and illustrates the percentage of time noise is at a certain level in each of the recording ranges. This difference indicates that noise is not concentrated under 400 Hz, as was found in Hatch et al. (2008), suggesting anthropogenic noise is not the biggest contributor to ambient noise. It is currently unknown what anthropogenic activities take place in the Outer Fall region, particularly in winter, and it is possible that both fishing and shipping are taking place in the area. It is relatively well known that Boston, Massachusetts, Portland, Maine, and multiple locations in Canada, house large shipping terminals, and subsequently have high traffic official and unofficial shipping lanes. Outer Fall is geographically located such that vessels transiting from Boston or Portland to Bay of Fundy ports would travel not too distant from the region. However, it appears that if they are, their acoustic presence is not enough to dominate the spectra measured in this dataset.



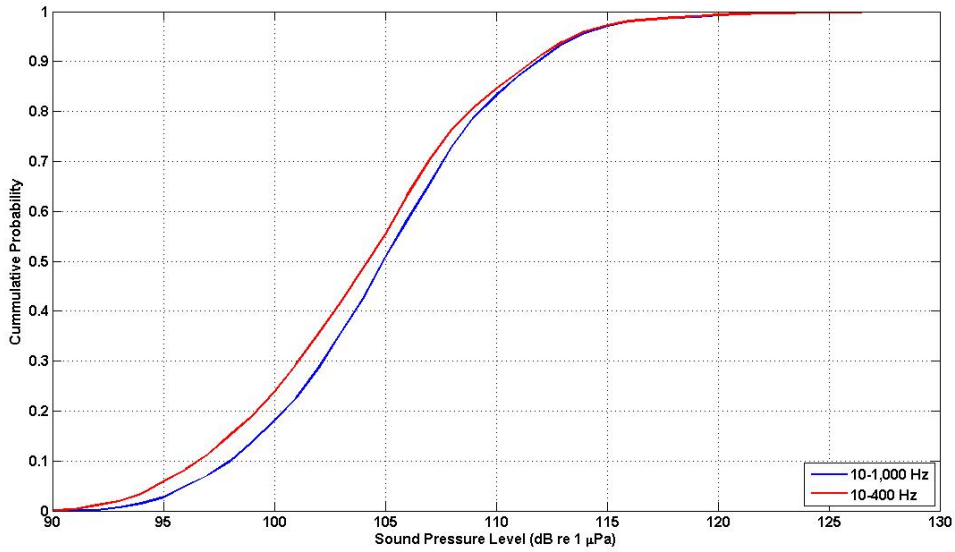


Figure 4: cumulative probability plot, buoy 149 top and 97 bottom.

The cumulative probability plots also indicate that 50% of the time, noise levels reached 105 dB. Acoustic harassment regulations is the topic of many continuing discussions and is currently under review by NOAA Fisheries', however, permits are currently required under the Marine Mammal Protection Act of 1972 for human activities that could result in baleen whales receiving impulse sound levels of 160 dB re 1µPa, or impulse sound levels of 120 dB re 1µPa (NOAA, 2005). While Outer Fall did not experience noise levels at 120 or 160 dB on average, RLs did reach 120 dB just over 1% of the time, and the maximum sound level experienced in this habitat was 130.49 dB. The higher RLs were only reached on occasion, and could be a result of a close pass from a larger, slow moving vessel by the pop-up units. However it is important to figure out what is causing RLs to reach such high, harassment-level thresholds and monitor future seasons to ensure these events do not increase in occurrence.

While this acoustic characterization study generally finds a low influence of anthropogenic sound, these findings do not necessarily mean right whales are not being negatively impacted by anthropogenic sound sources, and in order to make that assessment more work needs to be accomplished. This characterization serves as a starting point to further investigate a habitat used by a critically endangered species to mate. There is much work to be completed, both within this project, as well as in the Outer Fall region in general.

Future work

Within this dataset, near future goals include establishing what frequency bands are most concentrated by ambient noise to better asses where noise is concentrated, and thus allow for stronger interpretations of source contributors, relate mean RL to a biological level, and measure

noise in the 50-350 Hz range in order to compare Jordan Basin to other known habitat areas (specifically those measured in Parks et al., 2009).

The importance of this habitat to the right whale's survivability makes continual temporal monitoring of Jordan Basin critical. Ensuring that findings from this dataset are not anomalous and do not change for the worse over time by adding to the dataset from this area should be accomplished. Further, using concurrent AIS data from larger vessels to further understand the presence of anthropogenic sound in Jordan Basin is important. Finally, it is recommended to analyze this dataset on a much finer scale in order to identify direct impacts of anthropogenic sound sources on acoustic behavior of right whales.

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Tables:

Variable	RL Means (dB re 1µPa) Buoy 149	Buoy 97
0	105.89	105.72
100	105.75	105.52
200	105.60	105.69
300	105.89	106.06
400	105.74	105.95
500	105.97	105.72
600	105.60	105.59
700	105.50	105.80
800	105.58	105.54
900	105.40	105.21
1000	105.17	105.30
1100	104.96	105.34
1200	105.33	105.33
1300	105.64	105.58
1400	105.74	105.52
1500	105.62	105.17
1600	105.66	105.26
1700	105.52	105.30
1800	105.25	105.37
1900	105.28	105.27
2000	105.00	104.98
2100	104.94	105.46
2200	104.99	105.53
2300	105.45	105.82
day	105.25	104.95
night	105.67	105.96
Fall	104.66	106.84
Spring	104.15	101.63
Winter	107.00	108.00
10-1000 Hz	105.48	105.50
10-400 Hz	104.66	104.72

Table 1: RL means by variable

	Buoy 149	Buoy 97
N of cases	5086	5083
Minimum	90.871	91.55
Maximum	130.496	128.96
Range	39.625	37.409
Median	105.432	105.462
Mean	105.478	105.502
Standard Dev	5.355	5.829

Table 2: descriptive statistics summary, RL units are dB re 1µPa

Factor	R-Value Buoy 97	P-Value Buoy 97	R-Value Buoy 149	P-Value Buoy 149
Fall	0.12322	<.0001	-0.08177	<.0001
Winter	0.36793	<.0001	0.24475	<.0001
Spring	-0.48854	<.0001	-0.18201	<.0001
Day/Night	0.08576	<.0001	0.03863	0.0059
Monday	0.04067	0.0037	0.03803	0.0067
Tuesday	-0.01394	0.3203	0.01183	0.399
Wednesday	0.03493	0.0128	0.03674	0.0088
Thursday	0.01664	0.2356	0.01397	0.3193
Friday	-0.0653	<.0001	-0.06552	<.0001
Saturday	-0.00642	0.6472	-0.01326	0.3443
Sunday	-0.00562	0.6888	-0.0208	0.138
Hour of Day	-0.02219	0.1136	-0.03699	0.0083

Table 3: Pearson Product-Moment Correlation test run on both buoys and each time-scale variable

Analysis of Variance					
Source	**DF**	**Sum of Squares**	**Mean Square**	**F-Value**	**Pr>F**
Model	3	42269	14090	548.85	<.0001
Error	5079	130383	25.67		
Corrected Total	5082	172651			

Parameter Estimates						
Variable	**DF**	**Estimate**	**Error**	**t-value**	**Pr>|t|**	**RL Mean**
Intercept	1	106.48	0.274	389.1	<.0001	
Winter	1	1.15	0.186	6.22	<.0001	108.00
Spring	1	-5.18	0.193	-26.8	<.0001	101.63
Day/Night	1	0.23	0.229	1.59	0.112	
Root MSE	5.067	**R-Square**	0.245			
Dependent Mean	105.5					
Coefficient Variable	4.802	**Adjusted R-square**	0.244			

Table 4: Linear Multiple Regression results, buoy 97

Analysis of Variance					
Source	**DF**	**Sum of Squares**	**Mean Square**	**F-Value**	**Pr>F**
Model	3	8938.48	2979.49	110.61	<.0001
Error	5082	136897	26.94		
Corrected Total	5085	145836			

#

Parameter Estimate						
Variable	**DF**	**Estimate**	**Error**	**t-value**	**Pr>|t|**	**RL Mean**
Intercept	1	104.45	0.280	372	<.0001	
Winter	1	2.34	0.190	12.3	<.0001	107.00
Spring	1	-0.49	0.198	-2.48	0.013	104.15
Day/Night	1	0.14	0.148	0.92	0.358	
Root MSE	5.19	**R-Square**	0.061			
Dependent Mean	105.5					
Coefficient Variable	4.921	**Adjusted R-Square**	0.061			

Table 5: Linear Multiple Regression results, buoy 149