Cyclonic Mesoscale Eddy Impact on Zooplankton Vertical Migration at Station ALOHA in the Coast of Hawaii

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Abstract

Light intensity over the course of a day sets the circadian rhythm for the vertical movement of microorganisms across the entire ocean. This research focused on the distribution of zooplankton at station ALOHA off the coast of Hawaii and examines the influence of cyclonic eddies on the vertical migration of zooplankton. I hypothesize that eddies increase vertical migration of zooplankton abundance. The null as evidenced by changes in zooplankton dry weight with depth was there would be no increase in the overall dry weight biomass when eddies pass through the station.

Eddies that pass over station ALOHA were identified from satellite altimetry based on sea surface height anomalies. Hawaii ocean time series cruise data was used to determine the distribution of the zooplanktons at this station. The zooplankton data covered 1994-2017, nearly a 26year time series. Zooplankton dry weight in (g.m^2) was used to estimate the abundance of zooplankton at three different depth with a maximum depth of 175m. This paper aims to answer at what depth is there a significant difference in Zooplankton distribution during day and night? If there is a difference, how does the presence of eddies impact the distribution of zooplankton? The influence of eddies was compared to without the influence of eddies at the respective depth. Eddies properties like age, amplitude, velocity, radius, and polarity were all compared with zooplankton distribution in the absence of eddies to understand if there was a statistically significant difference in the influence of eddies. There were two findings in this paper. (1) The zooplankton distribution was significantly different between the depth of 75-175m. (2) Radius, Polarity, Amplitude, and age of eddies had significant impact on the vertical migration of zooplankton.

Keywords: Zooplankton dry weight, Distribution, Diel vertical migration, Eddies

Summary

Diel vertical migration is a synchronous vertical movement of organisms all over the ocean. This common phenomenon throughout the ocean is controlled by Light over a course of a day. Day and night set the rhythm for the vertical movement of microorganisms across the ocean. This paper looked at two things pertaining to zooplankton organisms at station ALOHA off the coast of Hawaii. (1) Is there a significant difference between day and night in Zooplankton vertical movement at this station and at what depth is it significant? (2) How does the presence of cyclonic eddies impact the vertical movement of zooplankton? Cyclonic eddies are a counterclockwise circulation in the ocean in the northern hemisphere. They have important implications in ocean mixing and nutrient distribution across the world's ocean. Cyclonic eddies are impacted by Radius, Polarity, Amplitude, velocity, and age. This research looked at two different data sets. First a Hawaii Ocean Time series cruise data where scientists collected samples of zooplankton dry-weight at three different depth between 0-175m to understand the abundance of zooplankton. The second data set was a satellite data determined at seas surface height at station ALOHA to identify eddies and their different properties. By comparing these two data sets there were two findings. (1) There was significant difference between day and nigh in zooplankton vertical migration between 75-175m depth and (2) Eddies had a significant impact in the increase of zooplankton vertical movement compared to when eddies were not present. Radius, Polarity, Amplitude, and age had significant impacts on the increase of zooplankton vertical movement.

Introduction

Diel vertical migration is a synchronous movement of organisms like zooplankton and fish in the vertical water column. This common phenomenon throughout the ocean is controlled by a biological rhythm. Light intensity over a course of a day sets the circadian rhythm for the vertical movement of microorganisms. Circadian rhythm is a biological clock that allows organisms to adapt to the environmental cycles to regulate their physiological processes. (Häfker et.,al 2017) This is an energy-consuming phenomenon so why exactly is this happening? Because vertically migrating microorganisms like zooplankton are avoiding predators that hunt in light time. [Tarling et al., 2003] Some models of research are studying closely with the consideration of different size organisms and other factors to better understand the threshold of light intensity and animals diel vertical migration behavior. According to [Berge et al., 2008] diel vertical migration also has a seasonal variability as well.

Vertical migration is an important biological pump as well as a redistribution of carbon and nutrients in the upper ocean. This means that the spatial and temporal structure of the pelagic food web is highly impacted by vertical migration. [Bianchi et al., 2013]. In relation to the food web, mesoscale eddies are another important mechanism to transport nutrients. Eddies have a dynamic impact on animal migration. For example, mesoscale eddies were found to be a transport mechanism for the migration of a Japanese eel in the Western North Pacific Ocean. [Yu-Lin et al., 2017]. My research intends to explore if eddies impact the DVM of zooplankton.

My research will use two datasets to explore zooplankton vertical migration. Zooplankton has a size of 0.2 mm, making it easy for cruise ships to use micro nets to fish out and study the abundance of the biomass in a day-night cycle. The first dataset is from the School of Ocean Science and Technology at the University of Hawaii. They have been collecting mesoscale zooplankton with a size of 0.2-20mm size from the surface to 175m depth every month since 1994. Collecting data like abidance of zooplankton weight, carbon, and Nitrogen. Cruise data was collected at Station ALOHA indicated by the star in Figure 1.

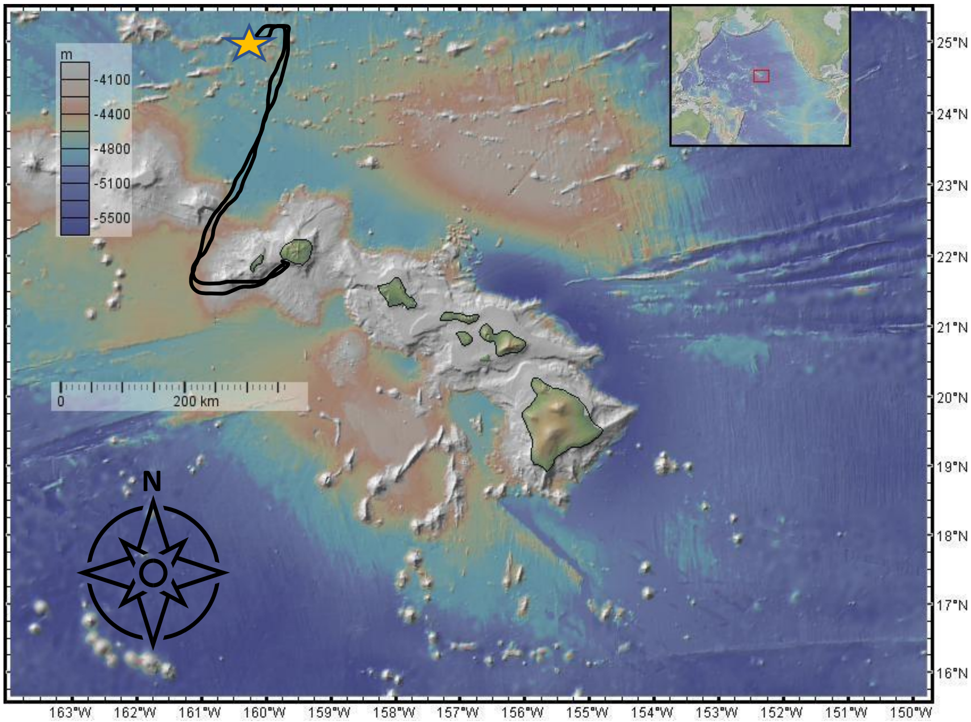

Figure 1 Hawaii Ocean Time-series (HOT) location of Station ALOHA (star) and cruise path to collect Zooplankton

The focus of my analysis will be the distribution of dry weight zooplankton and mesoscale cyclonic eddies. Instead of abundance of zooplankton to measure the distribution, I used the dry weight of zooplankton due to missing data.

Methods

The Hawaii ocean time series (HOT) collect samples on zooplankton abundance at Station ALOHA at least once a month during the day and night from 1994 – 2017 to better understand the zooplankton community structure. Microzooplankton with the size of 0.2-20 mm are collected by obliquely towing a net at approximately 1 knot, from the surface to approximately 175m and then back to the surface. Towing time is approximately 20-30 minutes. At Station ALOHA, 6 net tows are scheduled per cruise. Three at midnight (2200 - 0200) and three at mid-day (1000 - 1400) with 202-µm mesh netting. The tows are subsequently size-fractioned and analyzed for meso zooplankton in dry and wet mass, volume, and depth. The cruise takes the path shown in Figure 1.

The Eddy trajectory data was collected from satellite altimetry which was detected and tracked by algorithms developed by [Chelton et al.2007]. Eddies are identified using the sea surface height and using mathematical models' velocity, age, polarity, radius, and other features of eddies were calculated.

The first step was to understand whether the distribution between day and night at the three different depths were statistically significant. Zooplankton dataset (Hawaii Ocean Time series) was retrieved from CMAP database in the form of panda data frame. Using python, The HOT data was filtered according to day and night for each of the three different depths (0-75m, 75-110m, 110-175m). I used dry-weight zooplankton as an indicator for zooplankton abundance. A t-test was used to determine whether there was significant difference in (p value < 0.05) dry-weight between day and night for a given depth.

The next step was to add several columns to the zooplankton data frame to include the properties of the matching eddy if it exists. If no eddy matched the zooplankton data, the column would remain empty. This was important step in identifying eddies to separate eddies from non-eddy data.

Next, tolerance parameters were defined for spatial and temporal overlap of each eddy with Station ALOHA sampling. For spatial parameters I chose, 50km in longitude and latitude around station Aloha as the average radius of eddies identified was about 78 km. Time parameters were set to 1 day. These parameters were used to co-localize the observed zooplankton data with the respective eddy data. After separating the eddy data from non-eddy zooplankton data, I compared the distribution of zooplankton with and without the influence of eddies to understand if there is an increase or decrease in zooplankton abundance. This is critical step in answering whether eddies have significant impact on vertical migration. Next, I compared eddies with different properties to understand which properties of eddy impact vertical migration of zooplankton. Eddies with the properties of Age, Velocity, Polarity, Radius and Amplitude were compared individually with the distribution zooplankton distribution without the influence of eddy.

Results

This section finds the result of what depth zooplankton vertical migration is significantly observed. Zooplankton vertical migration was significant between the depth of 75-175m. According to the distribution at the three different depth, 0-75m was not significant when comparing dry-weight distribution of zooplankton. After a t-test between the Figure 2 and Figure 3 the p value was $0.189>0.05$. At this depth there is an increase during the day by 0.104g/m^2. While there is an average zooplankton distribution at this depth the p value is not significant. At 75-110m Figure 4 and Figure 5 the distribution of Zooplankton abundance was significant with the p value of 0.01<0.05. The average Zooplankton dry-weight abundance increased by 0.088 g/m^2 during the day. At 110-175m Figure 6 and Figure 7 the distribution of Zooplankton abundance was significant with the p value of 0.003<0.05. The average Zooplankton dry-weight abundance increased by 0.128 g/m^2 during the day. Overall, the data collected on the cruise has more data at the bottom 75-175m depth where Zooplankton abundance is significantly different between day and night.

Distribution of Zooplankton Dry Weight at three different depth.

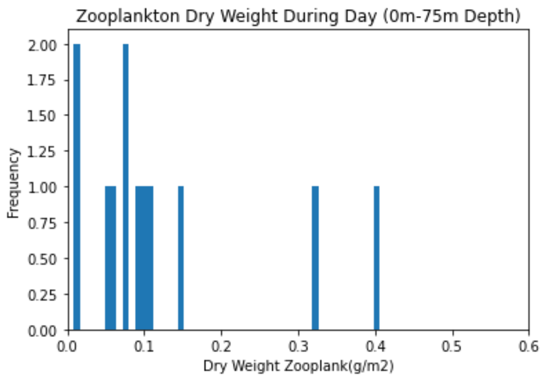

Figure 2 Zooplankton distribution at station Aloha at 0-75m depth during day. There are 12 data points with an average of 0.121 g/m .

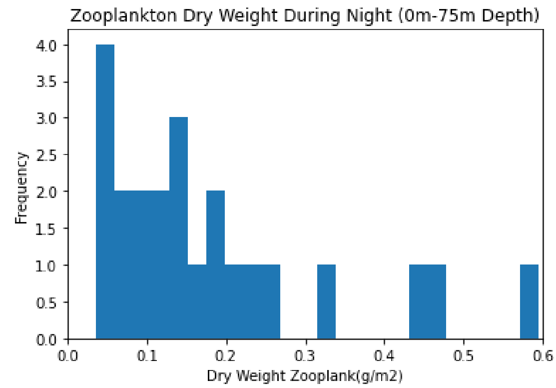

Figure 3 Zooplankton distribution at station Aloha at 0-75m depth night. There are 24 data points with an average of 0.2527 g/m .

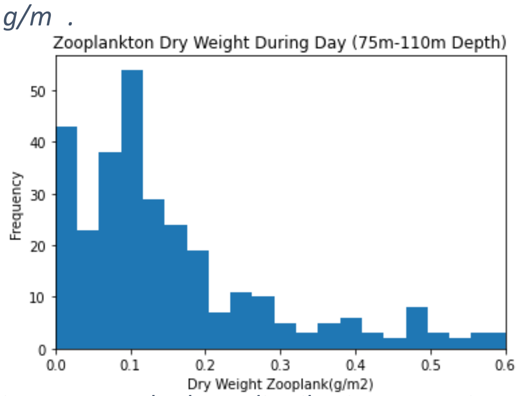

Figure 4 Zooplankton distribution at station Aloha at 75-110m depth during day. There are 318 data points with an average of 0.198 g/m .

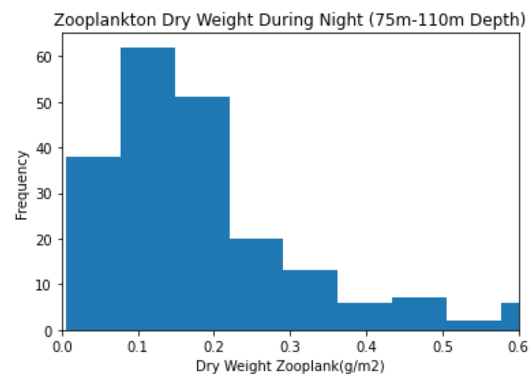

Figure 5 Zooplankton distribution at station Aloha at 75-110m depth night. There are 234 data points with an average of 0.287 g/m .

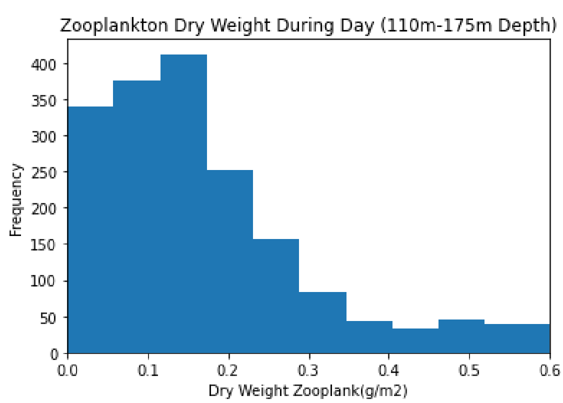

Figure 6 Zooplankton distribution at station Aloha at 110-175m depth during day. There are 2002 data points with an average of 0.245 g/m . The distribution is significant with the p value of 0.004.

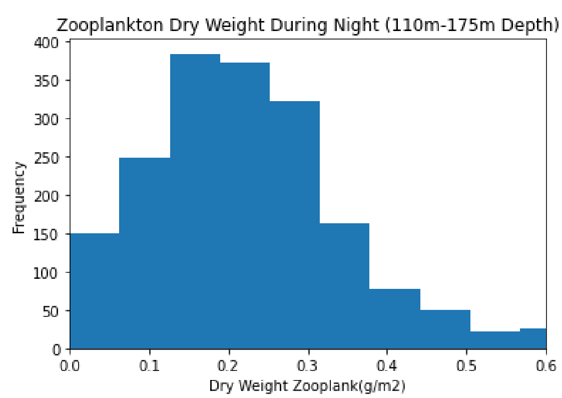

Figure 7 Zooplankton distribution at station Aloha at 110-175m depth night. There are 2172 data points with an average of 0.373 g/m .

Eddy vs Non-eddy (Day+Night)

This section compares the results of zooplankton distribution when an eddy passes through station Aloha and when there is no influence of eddy at the depth of 0-175m with day and night combained. Figure 8 and Figure 9 show zooplankton distributions at depth of 0-175m depth and the difference between these two Figures as significant with a p value of 0.041<0.05. The amount of data at this depth are 3683 when an eddy was present compared to the 1121 samples collected when eddies weren't present. There is an increase in zooplankton abundance by 0.0241g/m^2 and the difference is significant.

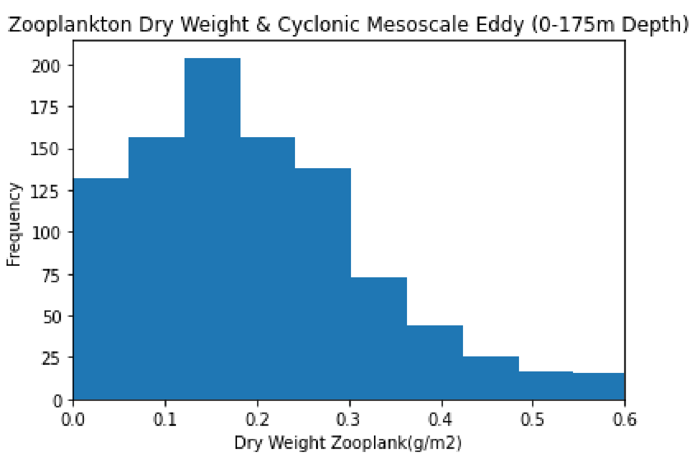

Figure 8 Zooplankton distribution at station Aloha at 0-175m depth during day+night. There are 1121 data points with an average of 0.319 g/m^2.

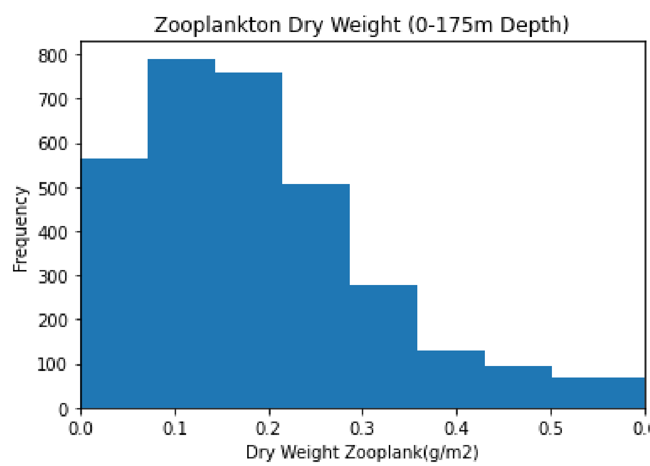

Figure 9 Zooplankton distribution at station Aloha at 0-175m when Eddies pass through station Aloha during day+night. There are 3683 data points with an average of 0.296 g/m^2.

Eddy impact on the Zooplankton Dry Weight distribution by Age, Velocity, Polarity, Radius and Amplitude (Day+ Night)

Eddy Impact on Zooplankton Vertical Migration

This section will compare different properties of eddies like age, velocity, polarity, radius and amplitude. Based on each property of eddy, I will compare it to (Figure 9) zooplankton abundance with no eddies. Figure 8 &9 are both comparison of zooplankton comparison with eddies presents and when eddies aren't present with day + night combined. The reset of this section will be comparing means of zooplankton distribution

Age

After a statistical analysis of eddies age, I decided to separately analyze eddies with ages of 0-90 days (young eddies) and 90-406 days (old eddies). 406-day eddy is the oldest eddy observed from the data. I compared the impact of young eddies 0(-90) on zooplankton abundance at 0-175m. The mean abundance was significantly different when only young eddies were compared to no eddies (Figure9,10) with a p value 0.003<0.05. There was an increase in zooplankton abundance by 0.04 g/m^2. When I compared zooplankton distribution of eddies between 90-400 days old with (Figure 11) with non-eddies (Figure 9) the difference was not significant with a p value of 0.461>0.05. This is a decrease in zooplankton abundance by -0.015 g/m^2. Younger eddies increased the overall zooplankton abundance at station ALOHA.

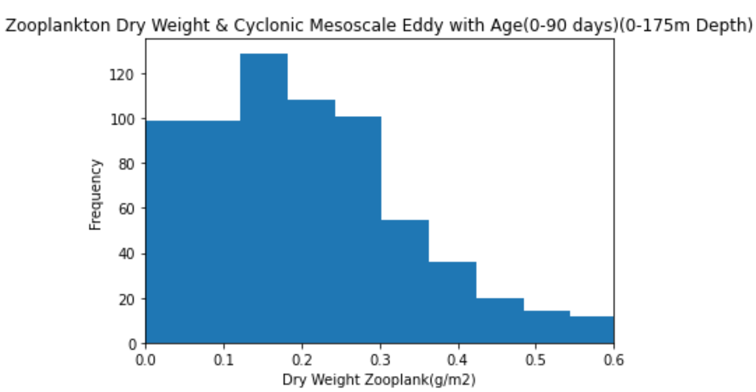

Figure 10 Zooplankton distribution at station Aloha at 0-175m when Eddies with the age of 0-90 days are passing through station Aloha. There are 791 data points with an average of 0.336 g/m^2

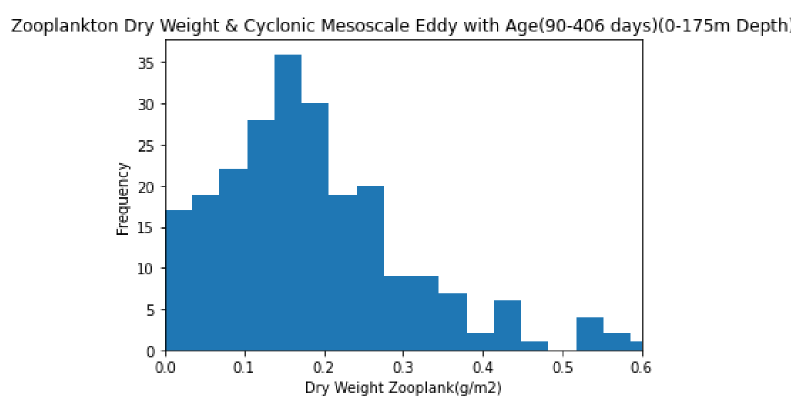

Figure 11 Zooplankton distribution at station Aloha at 0-175m when Eddies with the age of 90-406 days are passing through station Aloha. There are 264 data points with an average of 0.279 g/m^2

Polarity

When polarity of eddies was compared with and without the presence of eddies in Figure 9, there was an increase in zooplankton abundance when eddies were polar. There was an increase of 0.17g/m^2 in zooplankton dry weight but the data was not significant p value of 0.295>0.05. Figure 13 shows zooplankton distribution when there are non-polar eddies passing through the station with an average 0.33g/m^2. When compared with Figure 9 where no eddies were identified, there is a significant increase in eddies with a p value of 0.047<0.05. This is an increase of 0.029g/m^2 where polar eddies have significant increase in zooplankton abundance.

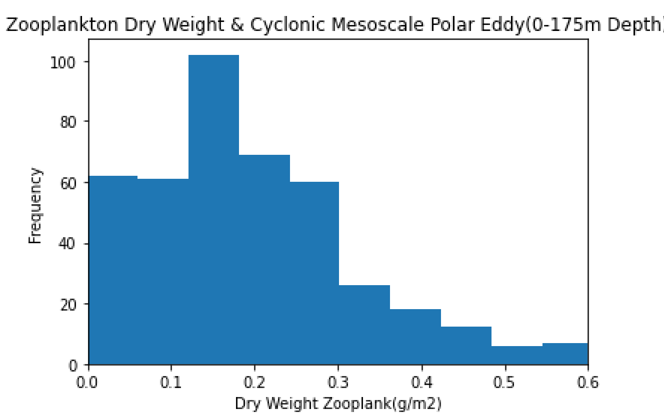

Figure 12 Zooplankton distribution at station Aloha at 0-175m when polar Eddies pass through station Aloha. There are 492 data points with an average of 0.313 g/m^2.

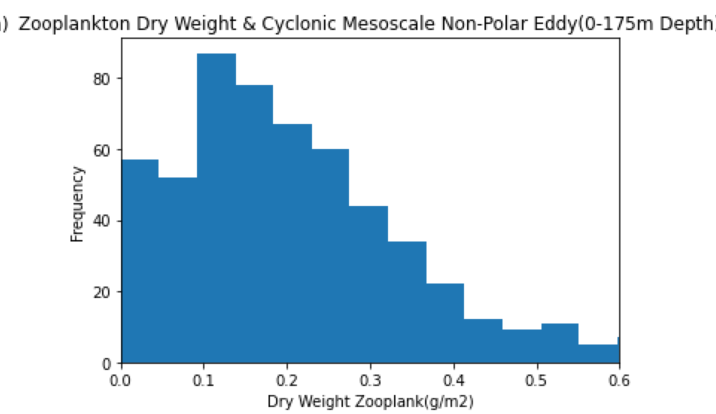

Figure 13 Zooplankton distribution at station Aloha at 0-175m when polar Eddies pass through station Aloha. There are 492 data points with an average of 0.342 g/m^2

Amplitude

There are 498 eddies identified with the amplitude of 0-6m with an average of 2.75 m amplitude in the between the 0-50% of the data and 600 eddies with 8.08 m amplitude in 50-maximum % of the data. Zooplankton distribution when eddies pass through station ALOHA in Figure 14 compared to Figure 9 with no influence of eddies the difference was significant with a p value of 0.009<0.05. This is a difference of 0.043g/m^2. When Figure 15 with a high amplitude eddy is compared with non-eddy distribution in Figure 9 the difference is not significant with a p value of 0.817>0.05. There is still an increase of 0.004g/m^2 in average zooplankton distribution between Figure 15 and Figure 9 but the data isn’t significant. This means that eddies with 0-5m amplitude increase zooplankton abundance vertically compared to eddies with 5-18 m amplitude.

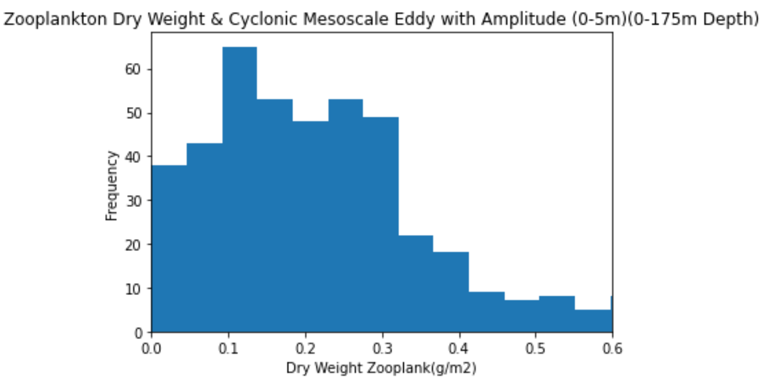

Figure 14 Zooplankton distribution at station Aloha at 0-175m when Eddies with amplitude 0-5 m pass through station Aloha. There are 498 data points with an average of 0.3391 g/m .

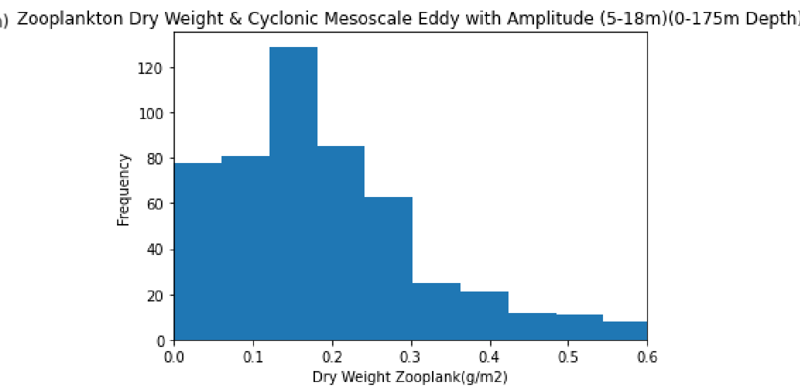

Figure 15 Zooplankton distribution at station Aloha at 0-175m when Eddies with amplitude 6-18 m pass through station Aloha. There are 600 data points with an average of 0.3391 g/m .

Velocity

At the depth of 0-175m eddies with the velocity between 0-20cm/s and 20-40cm/s was observed. There were 587 Eddies with 0-20cm/s velocity in Figure 16 at this depth and the distribution when compared with non-eddy in Figure 9 the difference was not significant with a p value of 0.079>0.05. There was an increase in zooplankton distribution of 0.027g/m□ when an eddy was present. Comparing non eddy distribution Figure 17 where eddies with velocity of 20-40cm/s the difference was not significant with a p value of 0.156>0.05 even though there was an increase in zooplankton abundance of 0.023g/m□ when an eddy was present. Overall velocity of eddies has little to no significant impact on zooplankton vertical migration.

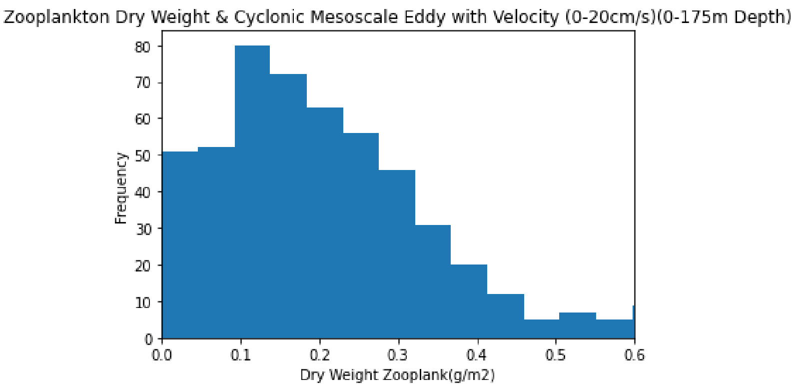

Figure 16 Zooplankton distribution at station Aloha at 0-175m when Eddies with Velocity 0-20cm/s pass through station Aloha. There are 587 data points with an average of 0.322 g/m .

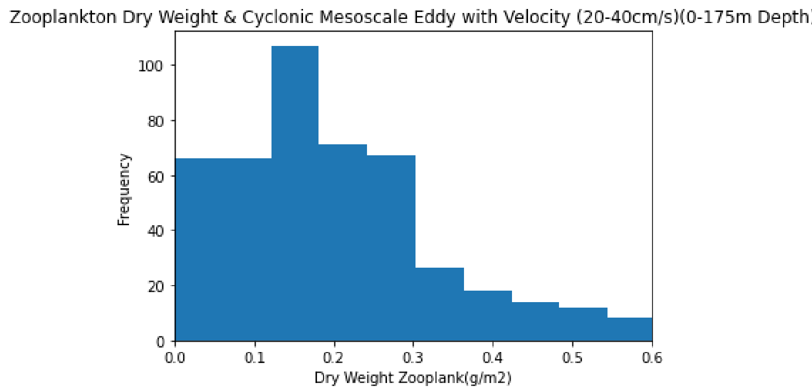

Figure 17 Zooplankton distribution at station Aloha at 0-175m when Eddies with Velocity 20-40cm/s pass through station Aloha. There are 528 data points with an average of 0.318 g/m .

Radius

Eddies with radius of 0-85 km and 85-142 km that passed through station ALOHA were also compared with Figure 9 where there were no eddies were identified. Eddies with a radius of 0-85 km in Figure 18 were statistically significant with a p value of 0.01<0.05 with an increase of 0.063g/m^2 in zooplankton abundance compared to when eddies were not present in Figure 9. There was an increase of 0.06g/m^2 of zooplankton abundance when 0-85km eddy was present compared to no eddies. When comparing Figure 19, eddies with a radius of 85-142 km with Figure 9 where no eddies were identified, the difference was not significant with a p value of 0.106>0.05. There was a decrease of 0.025g/m^2 in average zooplankton abundance with the large radius eddies. Meaning eddies with smaller radius will increase zooplankton vertical migration compared to eddies with larger radius.

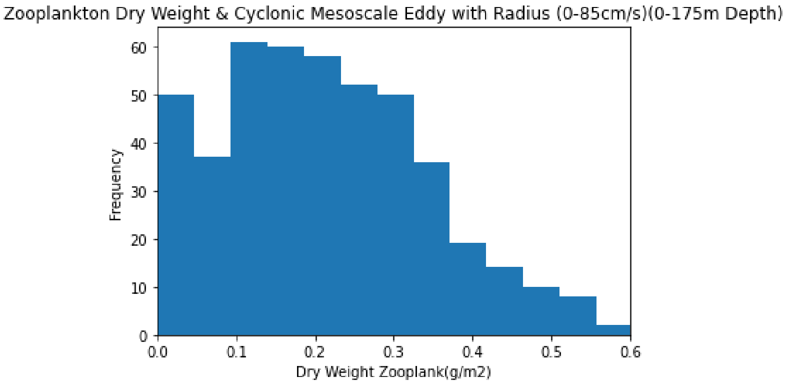

Figure 18 Zooplankton distribution at station Aloha at 0-175m when Eddies with Velocity 0-85km pass through station Aloha. There are 546 data points with an average of 0.358 g/m^2.

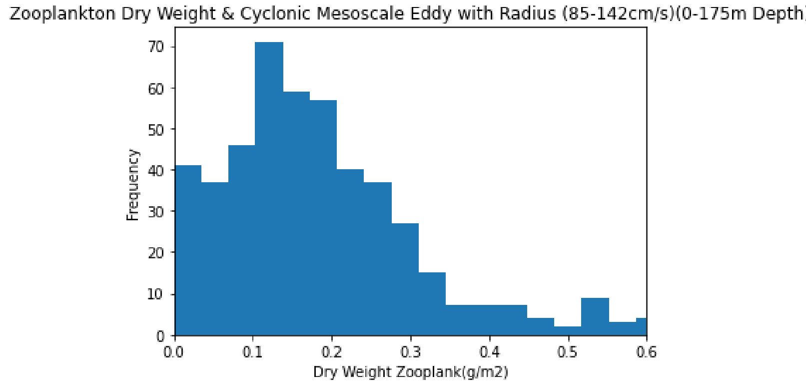

Figure 19 Zooplankton distribution at station Aloha at 0-175m when Eddies with Velocity 0-85km pass through station Aloha. There are 534 data points with an average of 0.0.271 g/m^2.

Discussion [1]

The distribution of the observed Zooplankton vertical migration in Figure 2- Figure 7 at the three different depth (0-75, 75-110m, 110-175m) was the first insight of the observed HOT data. It was important to not only understand if there is difference in in zooplankton abundance between day and night but also helps inform which is the best depth to analyze the influence of eddies. There was not a significant difference at 0-75m depth in the abundance between day and night but there was an increase of zooplankton abundance between day and night. Some possible explanations are there is not enough samples taken at this depth and there is a lot of turbulence at this depth as well. Observed zooplankton distribution at 75-175m was statistically significant between day and night. This was expected as light intensity in a 24-hour cycle is what controls vertical migration but if more samples were collected in the surface the surface depth could be significantly different. For the main analysis of answering eddies impact on zooplankton vertical migration, I decided to include the surface depth because there was an increase and with the lack of samples if would not change the overall analysis because the larger signal would come from

75-175m depth. Photic zone for station ALOHA seems to be above 90m depth as shown in Figure 20. The focus of my analysis starts between 0-175m.

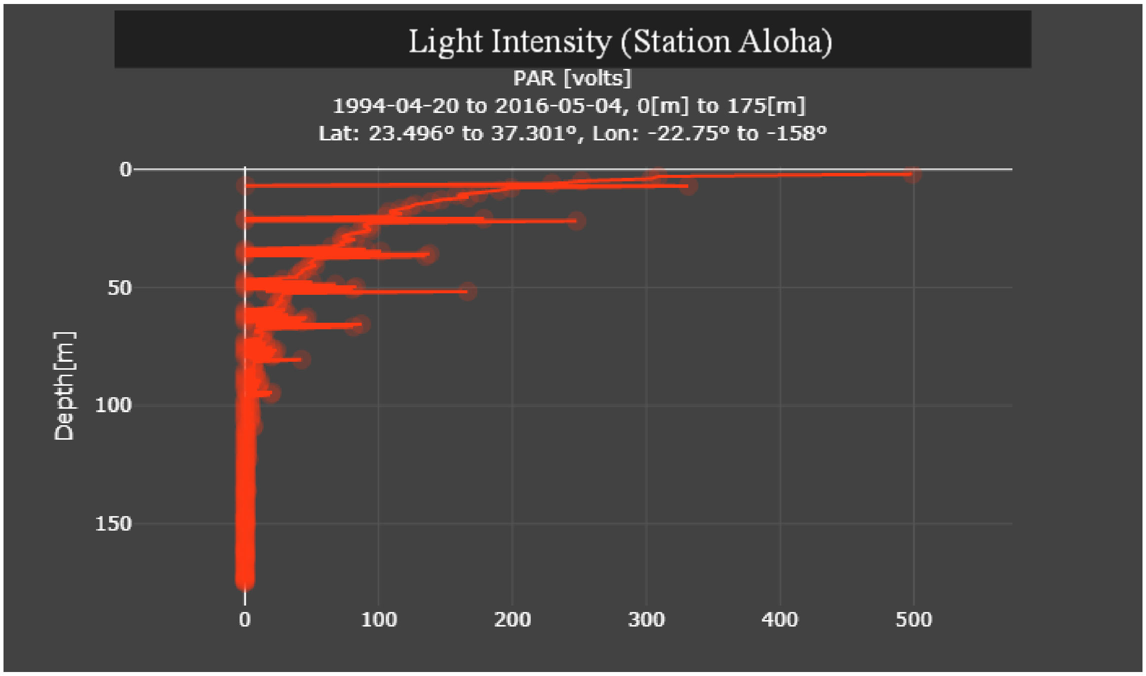

Figure 20 Par is proxy for the light intensity. This graph shows the light intensity at station Aloha, where data was collected.

As shown in Figure 8 and Figure 9 that zooplankton vertical migration increased significantly when eddies passed through Station ALOHA through 0-175m depth. The statistical difference between these two Figures is determined by the spatial parameter of 50 km in latitude & longitude as well as a temporal parameter of 1 day at station Aloha. This distribution may be even more statistically significant if the spatial parameter was increased to 78km because that is the average radius of all eddies identified at this station. If I were to decrease the Spatial parameter, the number of eddies identified could decrease.

The second parameter is the temporal parameter which was set at 1 day. As shown in Figure 16 and 17, velocity 0-30 cm/s and velocity were 30-75cm/s there was no statistically significant increase in zooplankton distribution. The average velocity of eddies at this station is about 32 cm/s which is 27.5 km/day. By setting the temporal parameter by 1 day, I am getting all eddies that are traveling at this speed. If the perimeter was set at 2 days, the number of eddies identified will increase the statistical difference when compared with overall zooplankton distribution in Figure 9 because the number of eddies passing through the station will increase. With the current temporal and spatial parameters, velocity is not significant to zooplankton vertical migration.

Age wasn't significant when eddies were present but like all the other properties, my results could hold a different result if my analysis was done in a more in-depth method. When analyzing the eddy properties, the grouping of age for example was broken into old and young eddies. I determined that eddies were old and young by looking at the overall age statistics and determined that any age bellow the 50% of the overall age data will be young and anything above 50% was considered old. Most of the time the average of each property was above or below the 50% threshold. I believe this was the best way to analyze the data impartially instead of setting the cut of close to the mean because that would be influencing the overall data. After analyzing eddy properties, radius had the most significant increase in zooplankton vertical migration. Even though velocity difference wasn't significant the average zooplankton abundance increased. Because my parameters were set to influence those two parameters the only conclusion with my parameters are radius is the most significant property of eddies to influence zooplankton vertical migration.

Conclusion

Zooplankton vertical migration is significantly increased between day and night at 75-175mdepth. Further research needs to be done to collect and understand vertical migration in 0-

75m depth to clearly determine if there is an increase and decrease in vertical migration. Eddies do influence zooplankton vertical migration significantly and eddies radius is the most significant property to influence zooplankton vertical migration. Furthermore, questions like polarity, age, amplitude, and other matrix filters need to be studied on their own merits. With a more precise analysis each eddy property will give insight in understanding cyclonic eddies. Furthermore, spatial and temporal parameters on eddies need to be studied because they are important factors in identifying the number of eddies passing through station ALOHA. This will help determine impacts of eddy have on zooplankton vertical migration in the clearest contrast.

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