La Niña's effect on the primary productivity of phytoplankton in the equatorial Pacific

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Summary

Phytoplankton form the base of the food chain in the world’s oceans; their declining or increasing populations can have major impacts on the abundance of other marine species. An important question to be asked is: how might a major oceanic change, such as a La Niña event, affect the primary productivity of phytoplankton communities? Primary productivity is a measure of the rate at which new organic matter is produced through photosynthesis by primary producers such as phytoplankton. The rate at which primary production occurs in the ocean is largely controlled by two major physical factors: solar radiation availability and the physical forces that bring nutrients up from deep water. This study wants to determine if the latter can be influenced by a La Niña event. A La Niña event is defined by lower sea surface temperatures in the equatorial Pacific. Typically, water in the ocean is characterized by warmer, less dense water residing on top of colder, denser water. The lower sea surface temperatures induced by a La Niña event could reduce the intensity of this layering, or stratification, in the upper water column. With the stratification weakened, water is more likely to move vertically throughout the water column. Water that is normally deeper, denser, and colder than the overlying water is now much more likely to move upwards toward the surface in a phenomenon that is called upwelling. The depths from which this upwelling water originates are often devoid of primary producers and consequently, are rich in nutrients. This upwelling nutrient-rich water could, in theory, cause an increase in phytoplankton primary productivity. Data were collected from four different stations surrounding the Hawaiian Islands aboard the *R/V Thomas G. Thompson* from 27 December 2010 – 5 January 2011. Water samples were collected from 3 different depths (100 meters, 50 meters, and the surface) using Niskin bottles attached to a CTD rosette. Dissolved oxygen (DO) concentrations were used as an indicator of primary productivity. The DO concentration of each

sample was calculated using the Carpenter modification of the Winkler titration method. Temperature data was also collected. When the data were compared with past non-La Niña years, there were no evident increases in phytoplankton primary productivity. More sampling locations, along with more frequent sampling throughout the length of the La Niña event, would provide a more comprehensive understanding of the interaction between such an event and phytoplankton communities.

Abstract

A La Niña event is generally characterized by a decrease in sea surface temperatures in the equatorial Pacific. Such a decrease could potentially weaken the stratification in the upper water column enough to facilitate increased upwelling of cold, nutrient-rich water. To test whether a La Niña event could increase phytoplankton primary productivity in the waters surrounding the Hawaiian Islands, temperature data and water samples were collected aboard the *R/V Thomas G. Thompson* from 27 December 2010 – 5 January 2011 from 4 different stations from three different depths (100 meters, 50 meters and at the surface). Water samples were then incubated in light and dark boxes for 24 hours. After the incubation period, the Carpenter modification of the Winkler titration was performed to determine the dissolved oxygen (DO) concentration of each sample. Dissolved oxygen concentrations were used as an indicator of primary productivity. Water samples had an average dissolved oxygen concentration of 4.79 mL L^{-1} and an average net primary productivity of 2.251 µmol C L^{-1} day^{-1}. The most productive stations were off of the northern coast of Molokai and at Lōʻihi Seamount with net primary productivity values of 6.944 µmol C L^{-1} day^{-1} and 5.567 µmol C L^{-1} day^{-1}, respectively. Compared to the values obtained by previous studies from non-La Niña years, the results of this study are much lower. These differences indicate that a La Niña event does not necessarily increase phytoplankton productivity. When compared with previous studies on La Niña's affect on upwelling though, these results appear to be inconclusive and require further study with more sampling locations.

Introduction

Phytoplankton are various types of planktonic, unicellular algae that convert inorganic materials (e.g. nitrate, phosphate) into new organic compounds (e.g. lipids, proteins). They are the dominant primary producers in the pelagic realm and without them, life in the oligotrophic waters surrounding Hawaii would not be possible. Understanding how global climate events, such as a La Niña event, can affect phytoplankton is important because they are central in the transfer of energy throughout the food web. A phytoplankton population that rapidly increases in abundance could cause every trophic level that succeeds it to increase as well. Hawaii's tuna industry is a major commercial fishery that at one point comprised nearly 70 percent of the state's annual landings (Hudgins and Pooley 1987). Understanding how such a fishery might react to a change in phytoplankton productivity could be very beneficial.

While there have been several intensive field studies that have documented phytoplankton productivity in the center of the North Pacific central gyre and the eastern Pacific, little is known about the phytoplankton in the coastal waters surrounding Hawaii (Allen et al. 1996; Brix et. al 2006; Nicholson 2008). Gundersen et. al (1976) conducted six cruises over the course of a year where common phytoplankton species, among other things, were documented. Pennate diatoms and silicoflagellates were the dominant types of phytoplankton although dinoflagellates were also detected. No coccolithophorids were found. *Nitzschia* were the most common diatoms found and *Ceratium breve* were the most common dinoflagellates found in the samples.

An El Niño event is a quasiperiodic climate pattern that is characterized by a weakening of the trade winds, a warming of sea surface temperatures in the equatorial Pacific, and the suppression of upwelling off the coast of Peru by intrusions of this warm, nutrient-poor, surface water. Conversely, during a La Niña event, the easterly trade winds strengthen and upwelling of nutrient-rich deep water intensifies along the West coast of South America; this cold upwelling water can cause sea surface temperatures to drop by as much as five degrees Celsius (Gorgues et al. 2010). This large drop in temperature can drastically weaken the stratification in the upper water column, further strengthening upwelling along the equator and the coast of South America.

The studies performed by Friederich et. al (2002) and Benson et. al (2002) are particularly relevant. Both articles examine the 1997-98 El Niño and the subsequent 1999 La Niña and their effects on upwelling along the California coast. Friederich et. al (2002) found that the El Niño period between July 1997-1998 inhibited upwelling. They found that the La Niña period between late summer and autumn of 1998 exhibited strong upwelling while late August to mid-November was characterized by weak upwelling. Benson et. al (2002) also found that with the arrival of El Niño in 1997, the California coast experienced decreased upwelling. They also found that while primary productivity was down all along the coast, the reduction in productivity was much greater beyond 50 km from shore. Unfortunately, Benson et. al did not comment on La Niña's affect on upwelling and primary productivity. Another pertinent article is the study performed by Chavez et. al (1999). They too examined the 1997-98 El Niño and the 1999 La Niña although they focused on their effects in the central equatorial Pacific. Like Friederich et. al (2002) and Benson et. al (2002), they found that El Niño restricted upwelling while La Niña enhanced upwelling. They also noted that during the 1999 La Niña there were elevated levels of macronutrients.

The waters surrounding Hawaii are oligotrophic and as such, a large flux of nutrients from upwelling could have major impacts on the autotrophic community (Ringuet and Mackenzie 2005). This study aims to determine whether a La Niña event affects phytoplankton primary productivity. The expected change is that phytoplankton primary production will increase due to the large influx of nutrients.

Materials and Methods

Field Methods

Water samples and temperature data were collected aboard the *R/V Thomas G. Thompson* from 27 December 2010 – 5 January 2011. To compare my data with previous years, I had to sample from sites that had already been studied so that I would be able to make a fair comparison. CTD casts were performed at four different stations; 2 of the 4 stations (stations #1 and #3) had previously been examined by Bienfang and Szyper (1981) and Laws et al. (1984) (Fig. 1). There was another site that had been tested by Laws et al. (1984) near station #1, that I was hoping to sample as well but unfortunately, the boat was unable to travel there due to the site being in close proximity to the Kalaeloa Airport. Stations #2 and #4 were sampled solely for the sake of increasing the amount of data on the subject and did not serve any actual purpose for my study. Water samples were collected at three standard sampling depths (100 meters, 50 meters, and the surface). These 3 depths were chosen because they had been used in previous studies, and because they were all above the bottom of the euphotic zone. Samples below the euphotic zone would be insignificant since there is little to no photosynthesis and consequently no primary production. My three standard depths were sampled for all of the stations except for the station (station #3) off the northwestern coast of the Island of Hawaiʻi (the Big Island). The water was shallow at this station (~80 meters), so a 100 meter sample was not collected.

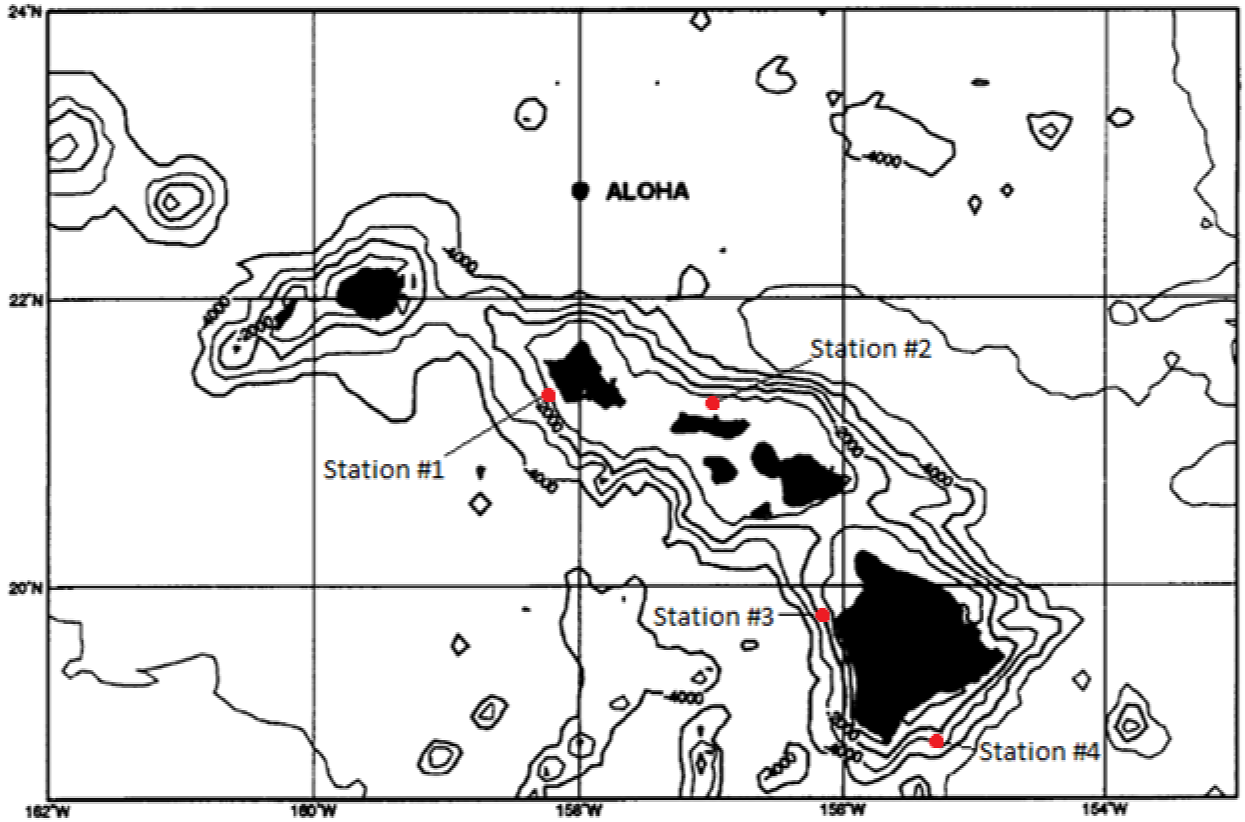

Figure 1. Map of the Hawaiian Islands with stations sampled marked as red dots (modified from Bingham and Lukas 1996).

Temperature data were collected with the hope that it might give some indication of the strength of the stratification and consequently, the strength of the upwelling, in the water column. Temperature data were collected in the form of depth plots using the Sea-Bird SBE 9plus CTD mounted on the rosette.

Dissolved oxygen (DO) concentrations were used as an indicator of primary productivity (Mountford 1969). Water samples were collected using Niskin bottles attached to a CTD rosette. Nine water samples were collected for each depth, with 3 depths sampled at each station, for a total of 27 samples collected for each station. After the CTD was brought back on to the ship, 9 water samples were immediately titrated and their DO concentrations determined (3 flasks for each depth; triplicates were performed for each sample). Of the remaining 18 water samples, 9 were put into a "light box" and 9 were put into a "dark box" to incubate for a period of 24 hours. The light and dark boxes consisted of two clear Plexiglas boxes that were set up on the fantail of the *Thompson*. The boxes were hooked up to hoses that continually circulated the boxes with seawater so that the temperatures of the incubated samples were consistent with that of the ocean. The dark box was covered with a black tarp to prevent any solar radiation from reaching the incubated water samples, while the light box had nothing covering the actual box. Samples were kept in mesh bags to simulate the amount of solar radiation that would reach a water parcel at depth. All samples in the light and dark boxes were weighted down with metal hooks to keep them from bouncing around and breaking. After the 24 hour incubation period, the samples were removed from the light and dark boxes and titrated to determine dissolved oxygen concentrations.

Analytical Methods

Since photosynthesis has not occurred in the dark sample, it is a measure of oxygen consumption by respiration. The light sample allows for measurement of both photosynthesis and respiration. Gross primary productivity was calculated by subtracting the DO concentration of the dark sample from the DO concentration of the light sample. Respiration was then calculated by subtracting the DO concentration of the dark sample from the DO concentration of my initial sample. Once these were calculated, subtracting the respiration value from the gross primary productivity value gave the net primary productivity. These results were then converted into μmol fixed C L^{-1} $hour^{-1}$ for gross primary productivity and net primary productivity.

The Carpenter modification of the Winkler titration method was chosen to measure DO, as it is a reliable and accurate method (this particular variation has an accuracy of 0.1%, Carpenter 1966). The Carpenter modification differs from the original Winkler method in that the water samples are not transferred from their original collection flask for titrating. One of the most significant sources of error in previous Winkler methods is the loss of the iodine produced after the sample has been acidified, usually due to these sample transfers (Codispoti 1988). By eliminating transfers, the Carpenter method significantly reduces this source of error. The Winkler method was also chosen to measure DO because it has been in use for over a hundred years (since Lajos Winkler published said method in his doctoral dissertation in 1888), making comparison of my data with previous studies' results easier (Winkler 1888).

Results

A total of 90 samples were collected over the course of the cruise: 27 water samples were collected from stations #1, #2, and #4 and 9 samples were collected at station #3. Dissolved oxygen concentrations (mL/L), average gross primary productivity (µmol C L^{-1} day^{-1}) and average net primary productivity (µmol C L^{-1} day^{-1}) were calculated for all four stations (Table 1). Stations #2 (off of the northern coast of Molokai) and #4 (Lōʻihi Seamount) exhibited the highest DO concentrations and the highest average net primary productivity. Stations #1 and #3 exhibited negative average net primary productivities. All of the stations, except for station #1, exhibited a negative average gross primary productivity.

Table 1. Dissolved oxygen concentrations, gross primary productivity, and net primary productivity for all four sampled stations.

Station #	Average DO Concentration (mL/L)	Average GPP (μmol C L^{-1} day^{-1})	Average NPP (μmol C L^{-1} day^{-1})
Oahu			
1	4.769	1.612	-1.889
Molokai			
2	4.818	-0.259	6.944
Hawai‘i			
3	4.735	-0.024	-1.616
4	4.841	-0.629	5.567

Temperature data obtained from CTD casts were plotted versus pressure in decibars which is essentially equivalent to depth in meters (Figure 2). Temperature data from station #1 is in red and data from station #3 is in blue (Figure 2). While the CTD cast at station #3 was significantly shallower than the cast at station #1, a few things can still be noted from the plot. First, both surface temperatures were virtually identical. Second, the temperature in the upper 100 m of the water column at station #1 decreased much faster than the temperature at station #3.

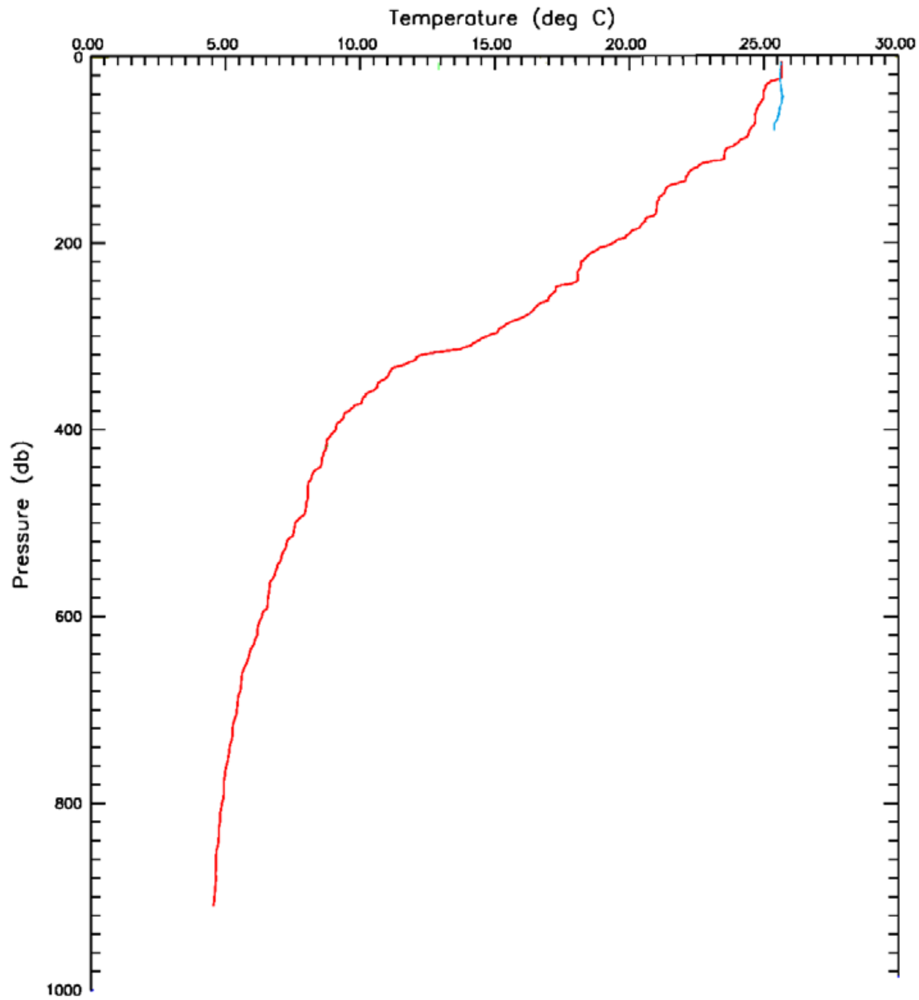

Figure 2. A temperature-pressure plot obtained with data from CTD with station #1 in red and station #3 in blue.

Discussion

I had hypothesized that a La Niña event would increase the upwelling of nutrient-rich deep water (due to reduced stratification in the upper water column from reduced sea surface temperatures) which would in turn cause phytoplankton productivity to increase. Looking at my data, stations #1 and #3 actually have a negative average net primary productivity. This implies that the phytoplankton at these stations are using up resources faster than they can produce useful chemical energy. While this is not unusual for the oligotrophic ocean surrounding Hawaii, I had not expected to see negative numbers during a La Niña event (Sharp et. al 1980).

Laws et al. obtained an average net primary productivity of 1.26 µmol C L^{-1} day^{-1} at station #1 during the winter of 1984. Compared with my value of -1.899 µmol C L^{-1} day^{-1}, my hypothesis that a La Niña event could increase productivity does not seem to be supported (Figure 3). Bienfang and Szyper (1981) did not collect productivity data but instead documented dissolved oxygen concentrations. At station #3, they recorded values ranging between 4.8 to 6.1 mL L^{-1} for the euphotic zone (the euphotic zone that they observed was very similar in depth to the one that I observed: ~120 m) (Figure 3). My findings of 4.7 to 4.8 mL L^{-1} for the euphotic zone are on the lower end of the aforementioned spectrum and along with my data from station #1, it is obvious that a La Niña event does not necessarily increase phytoplankton primary productivity.

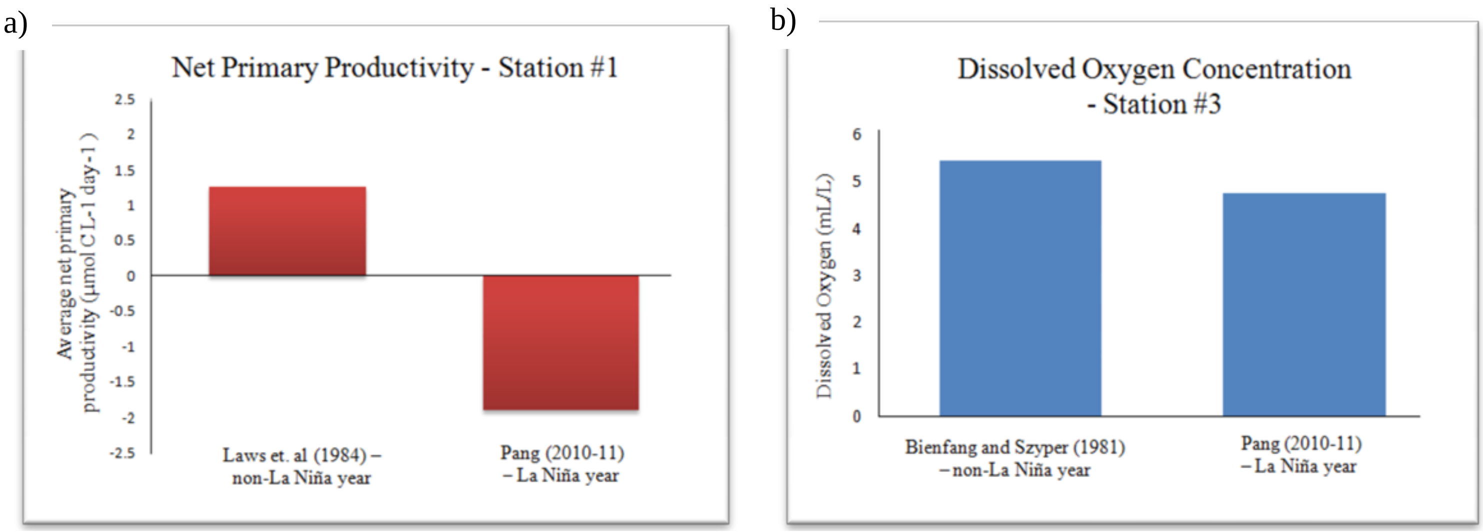

Figure 3. a) Average net primary productivity at station #1 as observed by Laws et. al (1984) and this author. b) Dissolved oxygen concentrations at station #3 as observed by Bienfang and Szyper (1981) and this author.

There are many mechanisms that may have contributed to DO/primary productivity turning out lower than expected. The La Niña event may have already begun to dissipate by the time that the sampling was conducted. However, the weekly ENSO Cycle update prepared by NOAA indicates that although sea surface temperature anomalies in the equatorial Pacific are beginning to weaken, it is likely that La Niña conditions will persist through May 2011 ("ENSO Cycle: Recent Evolution, Current Status and Predictions").

While the current La Niña event may persist to May 2011, it is possible that by the time the samples were collected, sea surface temperatures had risen enough to increase stratification and hinder upwelling. Winter, non-La Niña year temperature data from Bingham and Lukas (1996) was laid on top of temperature data from stations #1 and #3 (Figure 4). Bingham and Lukas' sea surface temperature data is cooler than the data obtained from stations #1 and #3 and the temperature between 300-500 m is also warmer. Chavez et. al's (1999) study on La Niña's affect on upwelling around the Hawaiian Islands found that most of the upwelling water was coming from depths below 200 m. If we assume that this holds true for Bingham and Lukas' data, it does appear that the water column was less stratified with cooler sea surface temperatures and warmer water below 200 m. Unfortunately, I was unable to find any non-La Niña temperature data from the same locations as the ones sampled. While Bingham and Lukas' (1996) datum is not from the exact same location, it gives some indication of the strength of upwelling due to differences in temperature in the upper water column. Ideally, calculating the Brunt-Väisälä frequency for station #1 and for any non-La Niña year would have been much more informative and reliable as to the strength of stratification in the water column. Regrettably, I was unable to find any non-La Niña density data that I would have been able to calculate the Brunt-Väisälä frequency with.

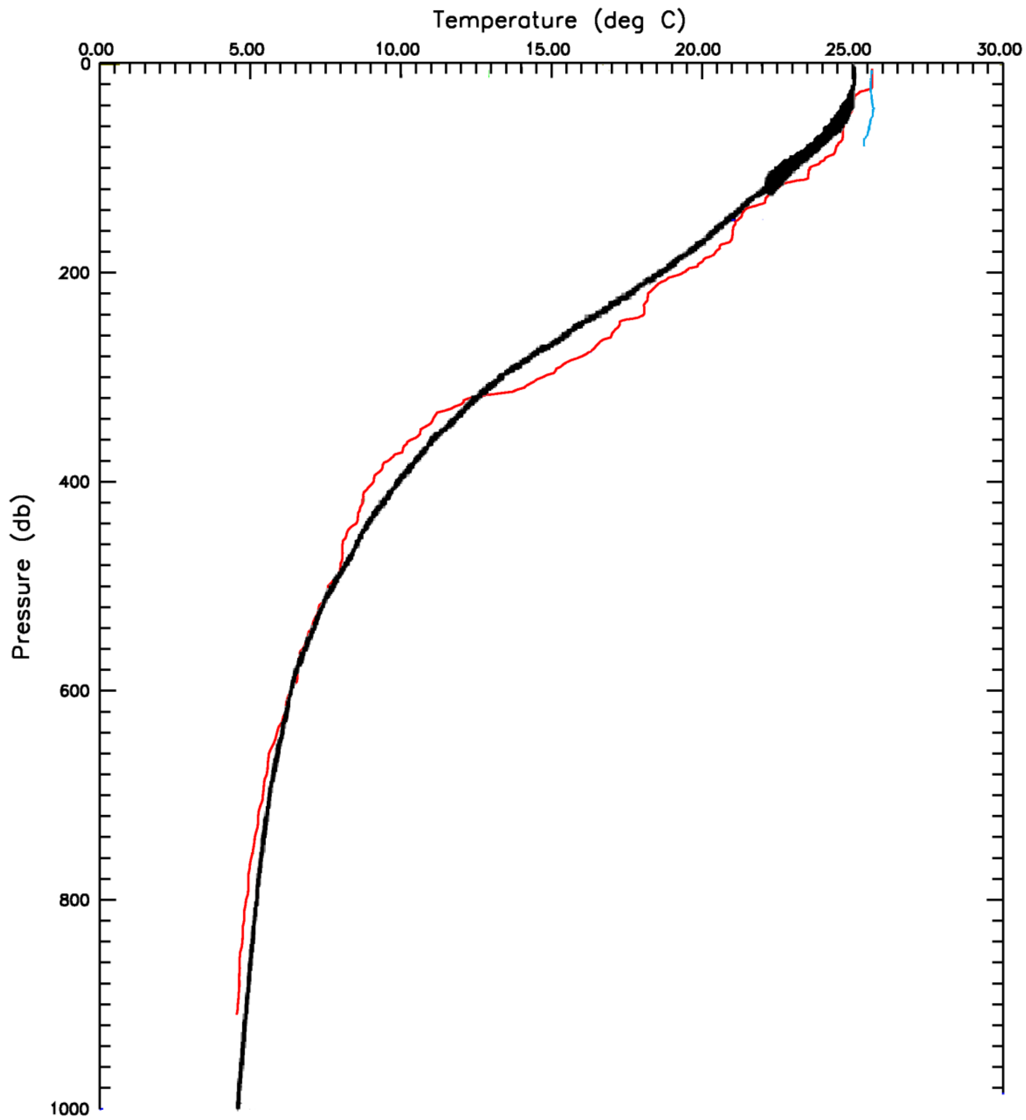

Figure 4. A temperature-pressure plot obtained with data from CTD with station #1 in red, station #3 in blue, and Bingham and Lukas' (1996) in black.

Sea surface temperature contour charts from December 2001 and December 2010 were also obtained from NOAA's National Weather Service: Environmental Modeling Center website. The contour chart from 2001 was chosen as to provide a broader range of non-La Niña years for comparison. The observed sea surface temperature from December 2001 is slightly cooler than the observed sea surface temperature from December 2010, indicative of weaker stratification and stronger upwelling in the upper water column.

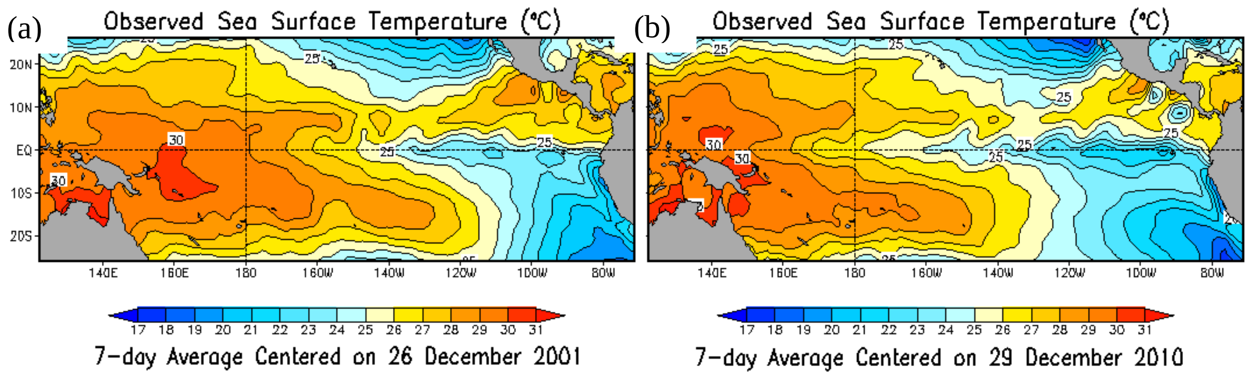

Figure 5. Sea surface temperature contour charts from (a) December 2001 and (b) December 2010 (from NOAA’s National Weather Service: Environmental Modeling Center website).

While I cannot conclusively say that a La Niña event won’t ever increase productivity, with the data I have available, I have to assume that the 2010-2011 La Niña did not increase primary productivity. But, without further study, with more sampling locations over a longer time scale, these results are inconclusive when compared with the results of Friederich et. al (2002), Benson et. al (2002) and Chavez et. al (1999) in providing a concrete relationship between a La Niña event and phytoplankton productivity.

Recommendations for Future Studies

There are a few things that I would have done differently if I had the opportunity to do my project again. The main thing that I would have changed is where I would have placed my light and dark boxes. While placing them on the fantail made sense at the time (e.g. close to the CTD, practically all of the research took place on the fantail, etc.) and was actually the only place I could put them (i.e. it was the only open spot on the ship that was close to a seawater valve for my hoses), the shadows produced by various equipment at certain times throughout the day probably did not allow the maximum amount of sunlight for my light box as was possible. In an ideal world, placing them on the bow would have worked out much better. Finally, more sampling locations, would have been able to provide more conclusive data.

Conclusion

The average net primary productivity that I obtained at station #1 (off of the western coast of Oahu) was -1.899 µmol C L^{-1} day^{-1} (Figure 3). This is far lower than the 1.26 µmol C L^{-1} day^{-1} observed by Laws et. al (1984) for the same station from a non-La Niña year. The average dissolved oxygen concentration that I obtained for station #3 (off of the northwestern coast of Hawai'i) was 4.75 mL/L (Figure 3). Bienfang and Szyper (1981) obtained an average dissolved oxygen concentration of 5.45 mL/L for the same station for a non-La Niña year. Bingham and Lukas' (1996) temperature data was also compared with my temperature data from station #1 (Figure 4). Overall, it was indicative of weaker stratification and stronger upwelling due to cooler surface temperatures and warmer deep water (300-500 m). Finally, sea surface temperature contour charts were compared from December 2001 and December 2010 (Figure 5). Again, sea surface temperatures for the non-La Niña year were slightly cooler than the La Niña year indicating that upwelling was more intense in the non-La Niña year. The results from my study seem to indicate that a La Niña year does not necessarily increase phytoplankton primary productivity. But after reviewing the data obtained by Friederich et. al (2002), Benson et. al (2002) and Chavez et. al (1999), I feel that without further study with more sampling locations, the results are inconclusive in providing a concrete relationship between a La Niña event and phytoplankton productivity.

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