The effects of a deep seamount on nutrient, oxygen and chlorophyll distributions in the water column

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S199
Stanford at Sea
June 10, 2005

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Abstract:

This research project is part of a collaboration to characterize the physical, chemical and biological effects of an unnamed seamount on its surrounding oceanic environment in the subtropical Pacific gyre at 18.739ºN by 157.067ºW between the big island of Hawaii and Christmas Island. This research project focuses on the physical and chemical structure of the water column and the position and intensity of the DCM. This project analyzes temperature, density, nutrients, fluorescence, extracted chlorophyll *a*, and dissolved oxygen. We found a general lifting of isotherms, isopycnals, isolines of fluorescence and the DCM across the seamount, and higher concentrations of PO_4 and dissolved O_2 over and downstream of the seamount. The seamount was encompassed by a cyclonic eddy at the time the research was conducted. However, comparisons between the changes across the seamount and through the rest of the eddy suggest that the seamount does indeed affect the surrounding oceanic environment, intensifying the uplifting trends and potentially leading to an increase in the standing biomass of primary producers as determined by fluorescence measurements.

Introduction:

Underwater mountains called seamounts disrupt the topography of the ocean floor in the Pacific. These topographic features affect the flow of water nearby, and may cause physical changes such as the formation of Taylor Columns (Dower et al., 1992) and the uplifting of isotherms, isopycnals (Genin and Boehlert, 1985) and nutrient isolines (Comeau et al., 1995). This upward deflection of deeper, nutrient rich water may lead to an increase in primary production and standing biomass of primary producers if its effects reach up into the euphotic zone where there is enough light for photosynthesis (Genin and Boehlert, 1985; Furuya et al., 1995; Odate and Furuya, 1998). For example, Genin and Boehlert (1985) documented a cold dome of uplifted isotherms that penetrated the lower euphotic zone above Minami-Kasuga Seamount (21_ 36'N, 143_ 38'E), which was associated with higher chlorophyll concentrations. They hypothesized that the

uplifted isotherms brought nutrients up into the euphotic zone where they were used by primary producers to make increased amounts of chlorophyll. The uplifted isotherms only reached up to 80m depth, and that is where the intensification of the deep chlorophyll maximum (DCM) was observed. This close correlation between the increase in chlorophyll *a* concentrations and the uplifted isotherms supported their hypothesis.

Odate and Furuya (1998) found that cold, nitrate-rich water was uplifted and that the subsurface chlorophyll maximum was intensified downstream of Komahashi No. 2 Seamount (29_ 52'N; 133_ 18'E) (Odate and Furuya, 1998). Furuya et al. (1995) studied Komahashi No. 2 seamount and found similar results. This supports the theory that seamounts can cause the uplifting of nutrients that leads to an intensification of biological activity. Additionally, these findings suggest that biomass supported by seamount environments is sometimes swept downstream.

Comeau et al. (1995) observed a shallowing and intensification of the subsurface chlorophyll maximum as well as a 10-fold increase in primary production over Cobb Seamount (46_ 45'N; 130_ 48'W). They also found that nutrient isolines were domed upward over Cobb Seamount. This would seem to suggest that the increase in biological activity was caused by the upwelling of nutrients; however, in this case the uplifted nutrients did not reach up into surface waters. Comeau et al. (1995) argued that Cobb Seamount is affected by the sub-arctic gyre and therefore nutrients are not as much of a limiting factor for photosynthesis. They proposed that the increase in biological activity near Cobb Seamount was instead caused by increased stability of the upper water column and the associated improved subsurface light regime.

The Comeau et al. (1995) experiment highlights the importance of the location of a seamount in determining the ways that it affects the surrounding oceanic environment. Not many seamounts have been studied in the region between Hawaii and Christmas Island, where we conducted our research. Therefore, part of the significance of my research comes from simply by characterizing the chemical, oxygen and chlorophyll *a* structure of the water column near a seamount in this region.

Studying the effects of seamounts on the structure of the water is an important area for scientific exploration because seamounts may be significant sources of biological productivity in open oceans. Within the larger picture of the oligotrophic subtropical

North Pacific Ocean gyre, seamount-induced biological hotspots could make up a large part of the primary production of the region (Odate and Furuya, 1998). Additionally, seamounts may cause some of the patchiness of biological activity found in the ocean by temporarily inducing a hotspot of biological activity, which is then swept downstream (Genin and Boehlert, 1985).

Measuring nutrient distributions in the water column is a vital step in understanding the link between the physical effects of a seamount on the flow of the water and the biological activity concentrated in the vicinity of the seamount. Without studying nutrients it is harder to determine the cause and effect relationships between the physical and biological characteristics of the seamount environment.

I focused my research on determining the physical and chemical structure of the water column across an unnamed seamount in the subtropical Pacific gyre at 18.739ºN by 157.067ºW. I characterized the position of isotherms and isopycnals and measured the vertical distribution of phosphate in the water-column surrounding the seamount. I also measured the fluorescence signal, the concentrations of extracted chlorophyll *a,* and the concentrations of dissolved oxygen in order to assess whether deflected isotherms and isopycnals and uplifted nutrients translated into an increased phytoplankton biomass.

I hypothesized that the seamount would cause the upward deflection of nutrients and that the uplifting of nutrients would correlate with uplifted deeper water. However, I predicted that no nutrients would be brought all the way up into the euphotic zone and be translated into an increase in biomass because the seamount we sampled is 824m deep (Donohowe, 2005) and the uplifting effect decays with elevation above the seamount (Genin and Boehlert, 1985). Therefore, I did not predict a significant change in the intensity of the Deep Chlorophyll Max (DCM) due to the seamount. However, because the uplifting of isotherms can cause the subsurface chlorophyll maximum to be uplifted even when nutrients are not brought all the way up into the euphotic zone (Comeau et al., 1995), I predicted that I would observe a shallowing of the DCM.

Materials and Methods:

I measured the levels and vertical distributions of nitrate, phosphate, dissolved oxygen and chlorophyll a in the water column upstream, directly above, and downstream of an unnamed seamount between Hawaii and Christmas Islands (18.739ºN by 157.067ºW) in order to assess whether the seamount is causing changes in the distribution of nutrients and the concentrations of primary producers. Phosphate is a useful molecule to measure because it is one of the major nutrients in seawater and is often a limiting factor for biological activity. Phosphate is also generally indicative of Nitrate, another vital nutrient. Oxygen levels at different depths indicate biological activity because oxygen is produced during photosynthesis and consumed in respiration. I will also be determining concentrations of chlorophyll *a* as a more direct indicator of the presence of primary producers.

The equipment that I plan to use is the carousel, which has 12 Niskin bottles that can close at discrete depths, a fluorometer attached to the carousel, a surface fluorometer attached to the ship, and a CTD. My analysis of the nutrient levels at different depths, as well as the oxygen levels and extracted chlorophyll *a* will be based on water samples that I get from the carousel. I will get other chlorophyll *a* data from a fluorometer attached to the carousel in order to try to correlate nutrient levels with the presence of primary producers. A fluorometer is an instrument that measures the volts of light re-emitted by chlorophyll *a* when known quantity of light is shone on a water sample. I will use the CTD to get salinity, temperature and depth information. The CTD information will also be useful in determining the depth and structure of the thermocline.

We completed 3 sampling sites during a crossing of the seamount: one station upstream from the seamount, one over the seamount and one station downstream of the seamount. At each of these sampling stations took water samples at twelve different depths: one sample at 10m, one sample every twenty meters from 20m to 100m depth, and then samples at 125m, 175m, 250m, 350m, 450m and 600m. It was important to sample deeper than the euphotic zone, where a rise in phytoplankton in response to increased nutrients would be observed, because the seamount we sampled is deep and we

realized that its effects on nutrient distribution and concentration of primary producers might not reach up all the way through the water column. Genin and Boehlert (1985) sampled down to 500 m depth to capture downward deflected isotherms. However, the Minami-Kasuga seamount, which they were working on, extends up to 260 m depth and is significantly shallower than the seamount that we sampled. I am particularly interested in whether upwelled nutrients are associated with an increase in the biomass of primary producers. Therefore, I will sample more densely within the euphotic zone

In order to determine phosphate concentrations from the water samples taken by the carousel, I will follow the chemical protocols outlined in Strickland and Parson's *A Practical Handbook of Seawater Analysis*.

To determine the levels of reactive phosphorous at low levels, the seawater sample is reacted with a composite reagent containing molybdic acid, ascorbic acid, and trivalent antimony. The result is a blue-colored complex, which is extracted with isobutanol. The extinction rate of the resulting solution is measured with a spectrophotometer at 6900 _ (Strickland and Parsons, 1972).

To determine the levels of dissolved oxygen, I will add a divalent manganese solution to the seawater sample followed by a strong alkali. Any dissolved oxygen will then oxidize an equivalent amount of divalent manganese to basic hydroxides. This solution is then acidified in the presence of iodide so that the oxidized manganese reverts to the divalent state and iodine, equivalent to the original dissolved oxygen content of the water is liberated. This iodine is titrated with standardized thiosulphate solution.

Data Analysis and Interpretation:

My data describes the structure of temperature, density, phosphate, dissolved oxygen, fluorescence and chlorophyll *a* in profiles of the water column. I plotted temperature and density versus depth in order to derive a picture of the thermocline and uplifted isotherms and isopycnals. I then compared my chemical data with my data about the physical structure of the water column to locate common patterns.

I present my data in figures that show the changes in vertical structure and distribution of phosphate, dissolved oxygen fluorescence, chlorophyll *a,* density and temperature across the seamount.

Results

Three stations were completed in the direct vicinity of the seamount: station 004 was upstream of the seamount, station 005 was close to being over the peak of the seamount and station 006 was downstream of the seamount. Additionally, three sampling stations were completed further downstream (SE) of the seamount that progressed through a cyclonic eddy and an anticyclonic eddy.

The thermal structure of the water column over our six sampling sites are represented in Figure 1. The CTD data collected at these six stations clearly show an uplifting of isotherms in the surface 300m across the seamount. For example, the 22 degree C isotherm rose from 130m at station 004 to 120m at station 005 and 110m at station 006. The surface isotherms sunk back down farther downstream of the seamount: the 22 degree C isotherm appeared at 120m at stations 007 and 008. Then, at station 009, within the anticyclonic eddy, the 22 degree C isotherm was pushed down to 140m depth.

Between 300m and 430m depth, isotherms sunk deeper over the peak of the seamount (station 005). For example, the 7.9 degree C isotherm sunk from 380m at station 004 to 410m at station 005 over the seamount summit and then rose again to 375m at station 006, downstream of the seamount. Between 430m and 770m depth, isotherms were uplifted over the summit.

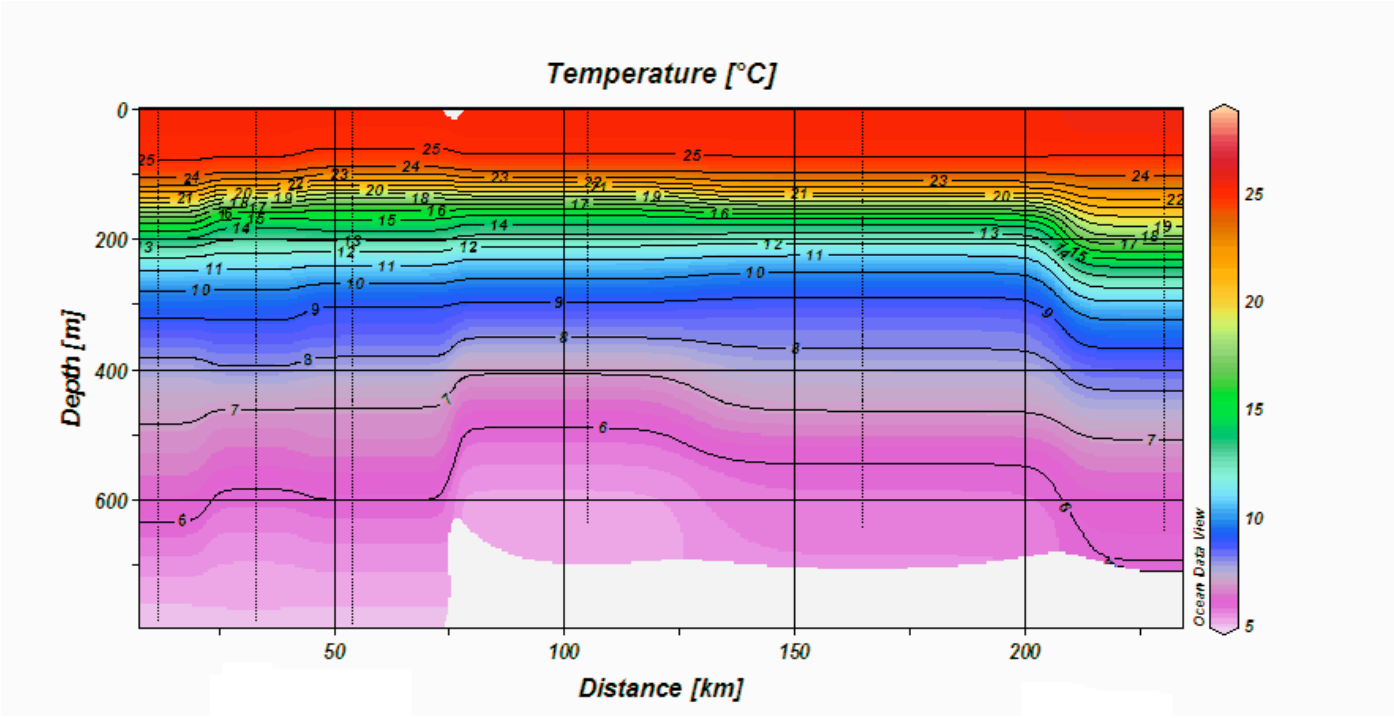

Figure 1. Progression of the vertical thermal profile of the water column across the six sampling stations (stations 004 to 009). Each of the dotted vertical lines represents a station, beginning on the left with station 004, and progressing from left to right up through station 009 all the way to the right of the figure. Isotherms in the surface 300m rise across the seamount, and then sink slightly by stations 007 and 008 and then sink more dramatically by station 009.

The density structure of the water column is depicted in Figure 2. The CTD data collected at the three sites across the seamount show that isopycnals are uplifted across the seamount. For example, upstream of the seamount, at station 004, the sigma-theta 25.3 Kg/m^3 isopycnal is at 175m depth. By station 005, over the summit of the seamount, the 25.3 Kg/m^3 isopycnal had risen to 155m depth, and by station 006, downstream of the seamount, the 25.3 Kg/m^3 isopycnal had risen to 145m depth. The largest rises of isopycnals occurred between 100m and 180m depth. In this depth range, the isopycnals generally rose by 25-30m from station 004 to station 006.

In accordance with the thermal structure of the water column, the isopycnals between 300m and 430m depth sink directly over the peak of the seamount and then rise back up downstream of the seamount. The 26.5 Kg/m^3 isopycnal demonstrates this

pattern. Between 430m and 770m depth, the isopycnals rise by station 005 and then sink back down by station 006. For example, the 27 Kg/m^3 isopycnal follows this trend.

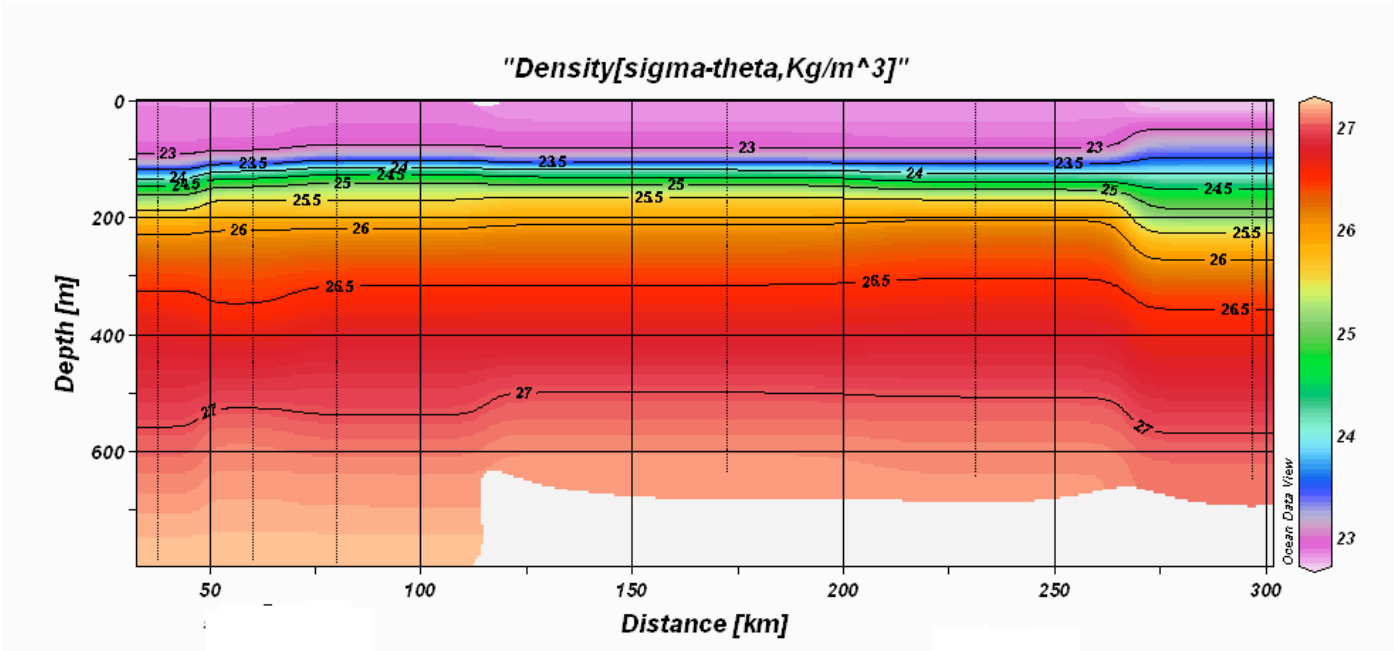

Figure 2. Progression of the vertical density profile of the water column through our transect of six stations. Each dotted vertical line represents a station, beginning on the left with station 004 and progressing from right to left through station 009. Isopycnals in the surface 250m of the water column rise across the seamount (station 004 through station 006).

The PO_4 data from the Niskin bottles of the carousel is displayed in Figure 3. There is more PO_4 present in the top 450m of water at stations 005 and 006, over and downstream of the seamount respectively, than at station 004. In the surface 50m, there is a .25 to .35 uM difference in PO_4 concentration between station 004 and stations 005 and 006. At a depth of about 125m, the closest bottle depth to the Deep Chlorophyll Maxima (DCM) at stations 004, 005, and 006 as determined by the fluorometer sent down on the carousel, the concentration of PO_4 increased by .133 uM from station 004 to station 005 and by .105 from station 005 to station 006.

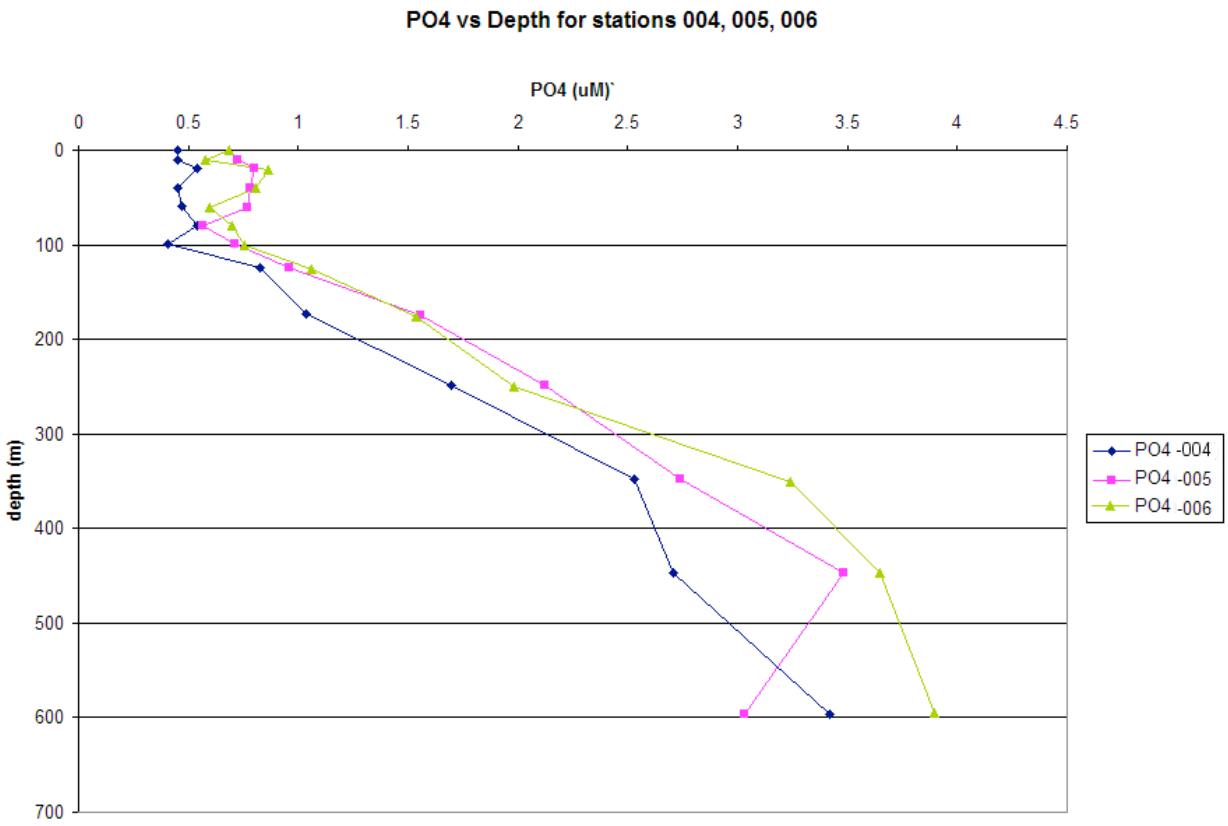

Figure 3. Niskin bottle PO_4 data from stations 004, 005, 006 (upstream, over and downstream of the seamount). There is more PO_4 present at stations 005 and 006 than at station 004 from 0m to 450m depth. There is a .25 to .35 uM difference in PO_4 concentrations at comparable depths in the surface 50m.

The fluorescence data from the fluorometer attached to the carousel is displayed in Figure 4. This data shows uplifting of isolines of fluorescence across the seamount, including uplifting of the DCM. The depth of the DCM rose from 135m at station 004 (upstream of the seamount), to 120m at station 005 (over the seamount) to 115m at station 006 (downstream). Then, at station 007, deeper within the cyclonic eddy, the DCM sank back down to 120m depth.

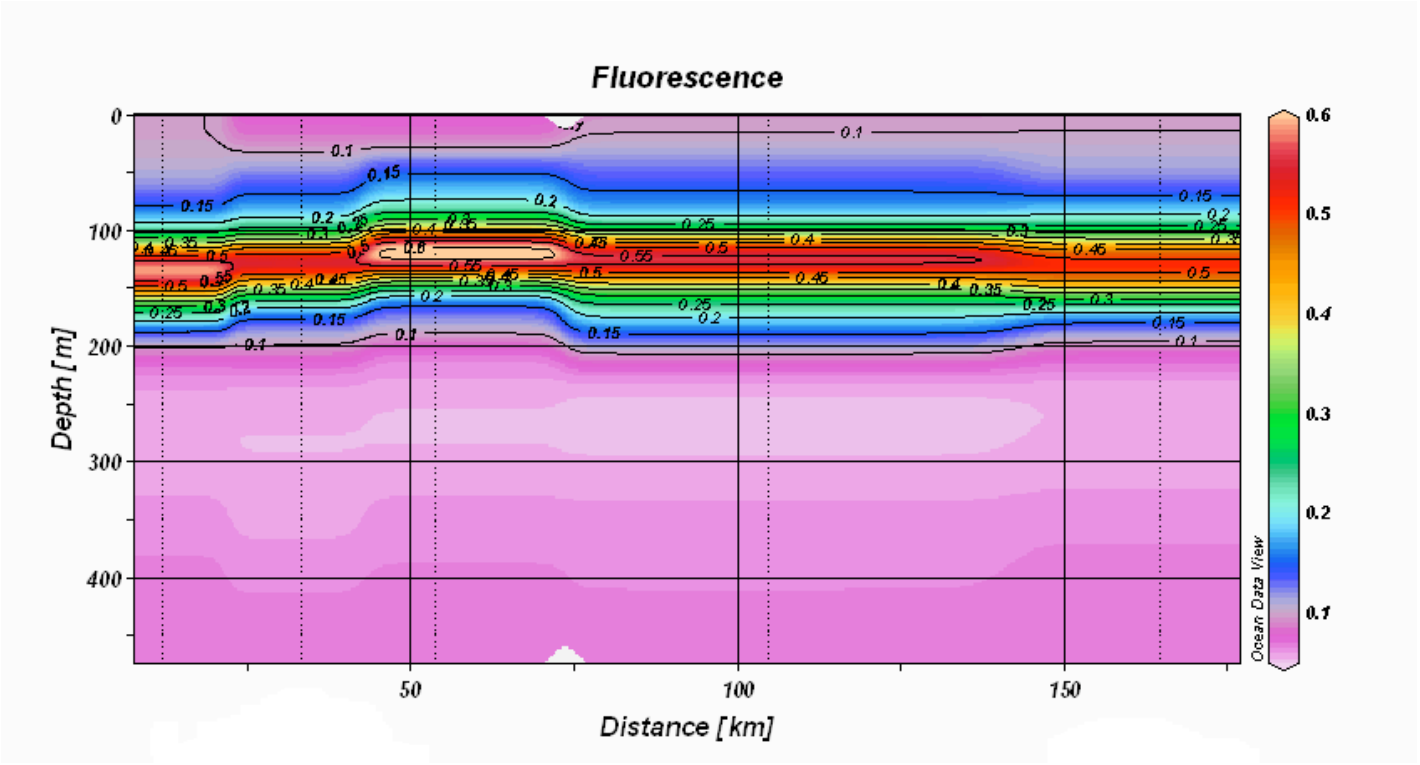

Figure 4. A section through our transect showing the progression through the vertical fluorescence profiles of the six sampling stations. Each dotted vertical line represents a sampling station, beginning on the left with station 004 and progressing from right to left through station 009. Across the seamount (004, 005, 006) the fluorescence readings from 50m to 200m depth indicate a lifting of primary producers and a lifting of the DCM. This figure also shows that the intensity of the fluoresence reading changes across the seamount, going from .818 volts at station 004 to .792 volts at station 005 to .836 at station 006.

The three stations that pass across the seamount all have noticeably more intense fluorescence readings than any of the surrounding stations (Figure 5). However, within the three seamount stations, station 006, downstream of the seamount, has the highest intensity fluorescence peak, measuring .836 volts. Station 004, upstream of the seamount, has a fluorescence reading of .818 volts and station 005, over the seamount has a smaller fluorescence reading of .792 volts. This indicates that upstream of the seamount there is a relatively medium sized DCM, as measured by fluorescence, over the seamount there is a relatively small DCM and downstream of the seamount there is a relatively large DCM.

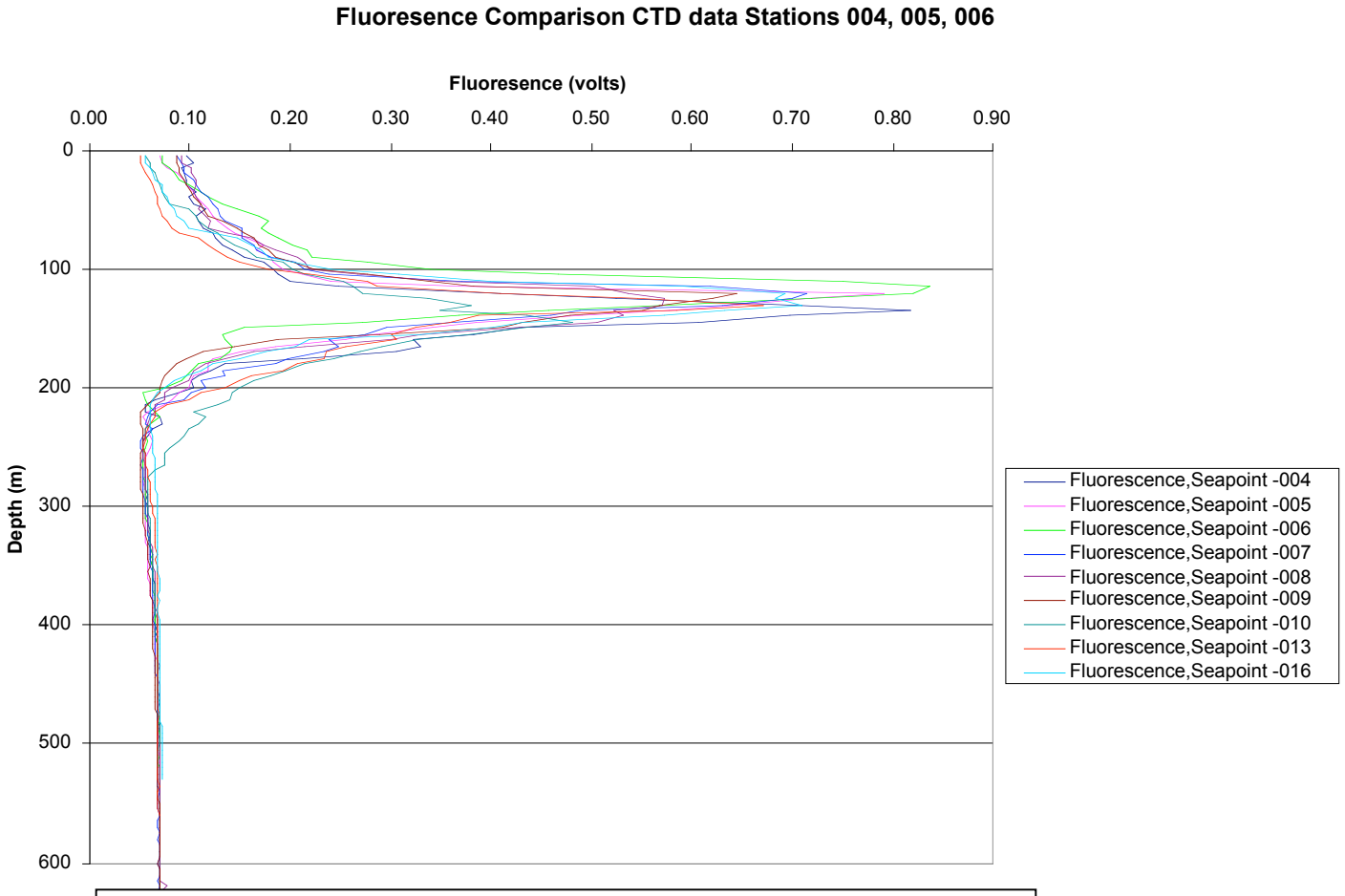

Figure 5. Vertical fluorescence profiles of all of the CTD stations taken down to 11 degrees N latitude. This figure shows that the three seamount stations (004, 005 and 006) have higher intensity fluorescence readings than any of the other stations that we sampled within the oligotrophic subtropical oceanic gyre.

The dissolved Oxygen data from the Niskin bottle water samples is depicted in Figure 6. There is more dissolved Oxygen in the surface 250m of stations 005 and 006, over and downstream of the seamount, than in the surface waters of station 004, upstream of the seamount. The difference in concentrations of dissolved oxygen between station 004 and stations 005 and 006 range from 0.78 ml/l to 2.80 ml/l.

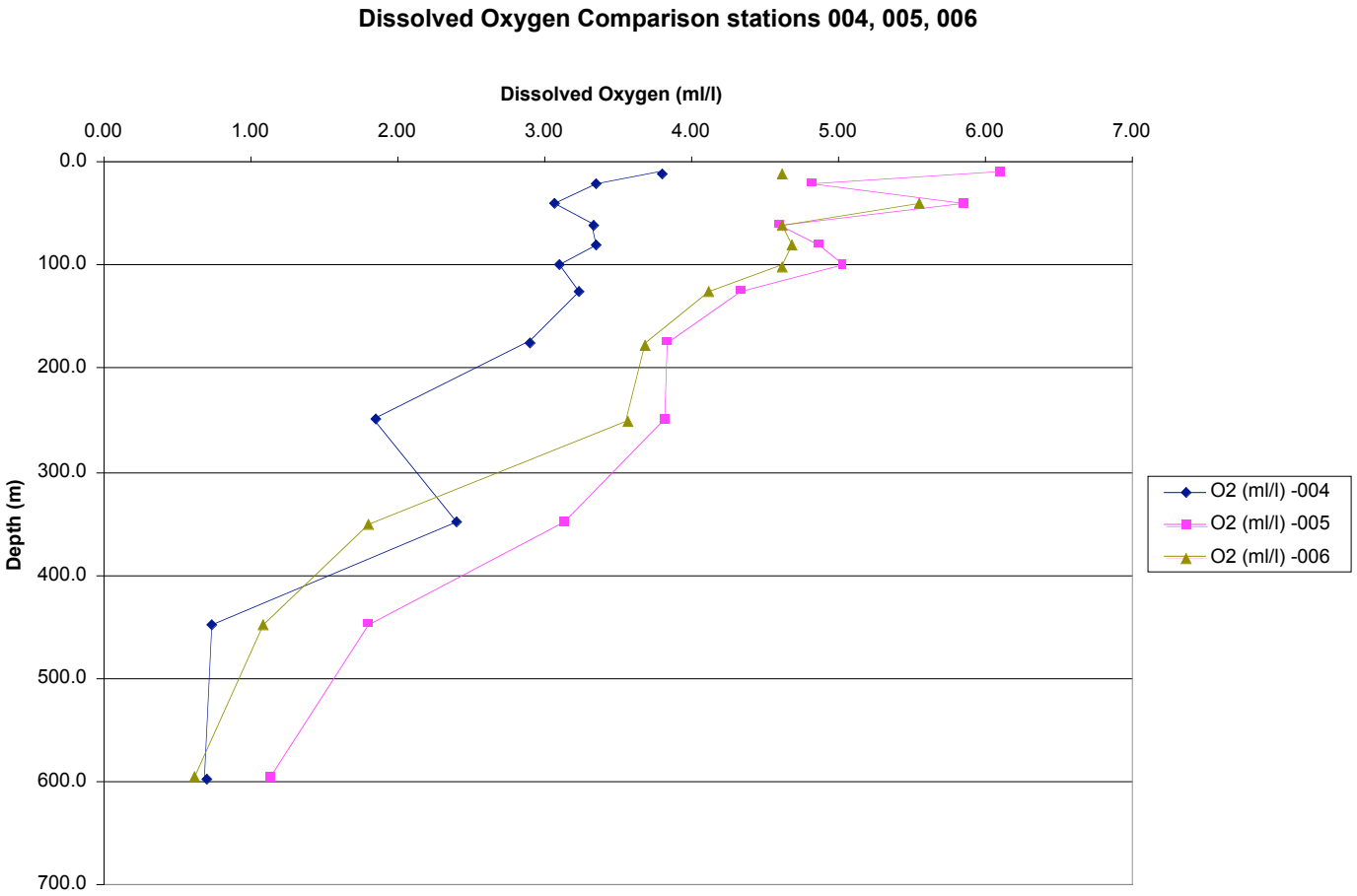

Figure 6. Dissolved Oxygen profiles from stations 004, 005, and 006. There is more dissolved Oxygen in the surface 250m of stations 005 and 006, over and downstream of the seamount, than in the surface waters of station 004, upstream of the seamount.

Discussion

There is a clear uplifting of isotherms and isopycnals over the seamount. The three seamount stations are within the periphery of a cyclonic eddy that stretches down to the southwest. This suggests that the lifting that we observed over the seamount might be due to the effects of the cyclonic eddy and not to the seamount. However, comparing the three stations closer to the seamount (004, 005, 006) to the three stations farther downstream (007, 008, 009) shows that the uplifting trend across the seamount is

relatively rapid and distinct. Also, the isotherms in the surface isotherms rise steadily across the seamount and then sink back down by the next station, which is actually closer to the core of the eddy. Therefore, if the physical changes in the water column were solely due to the eddy, one would expect the uplifting to become more intense at the stations closer to the eddy core. However, this was not the case, and therefore, it is probable that the seamount, or some other factor aside from the cyclonic eddy, contributed substantially to the physical, chemical and biological changes observed across the seamount.

Another clear trend in the data showed the uplifting of nutrients, as indicated by phosphate, from upstream to over and downstream of the seamount. The levels of phosphate were roughly equivalent over and downstream of the seamount, and both higher than the phosphate levels upstream of the seamount. This suggests that the seamount caused nutrient rich waters to be upwelled.

More PO_4 present at stations 005 and 006 than at station 004 could partially be explained by their closer proximity to the eye of the cyclonic eddy, which causes upwelling. Additionally, there was slightly more PO_4 present at station 006 than at station 005 at ~125m depth, which is the closest Niskin bottle depth to the DCMs of stations 004, 005, and 006. This could also be explained by station 006's closer proximity to the eye of the cyclonic eddy. This slightly higher concentration of PO_4 at station 006 could partially explain the increase in the fluorescence reading at station 006. However, this could only be a partial explanation, because the more dramatic increase in PO_4 from station 004 to station 005 did not yield an equivalent increase in fluorescence. In fact, there was a decrease in the intensity of fluoresence from station 004 to station 005. Therefore, other mechanisms are most likely at play.

Levels of PO_4 increase a lot below the DCM. The beginning of the large increases of concentrations of PO_4 around 120m depth coincide with the DCM. The large standing biomass of the DCM is probably supported by this increase in PO_4.

A clear trend revealed by the fluorescence data was the uplifting of the DCM across the seamount. The lifting of isolines of fluorescence coincided with the lifting of isotherms and isopycnals. The DCM rose across the seamount and then sank back down by station 007. The shallowest DCM that we sampled was station 006, downstream of

the seamount even though stations 007 and 008 are closer to the core of the eddy. This suggests that some of the uplifting effects are independent of the effects of the eddy; and it is likely that the seamount is causing the uplifting trend.

In order to characterize the DCM, I used the fluorescence profile rather than extracted chlorophyll *a* data collected from the 12 Niskin bottle water samples at each station because the fluorescence data is continuous and could better define the position of the DCM in the water column. The extracted chlorophyll *a* data shows the DCM at the same depth for each of the stations because the bottles were fired at almost exactly the same depths and the variance in the position of the DCM was too small to be detected by the grain of our bottle depths.

The three stations across the seamount (004, 005, 006) had higher intensity fluorescence readings at the DCM than any of the surrounding stations. This suggests an increase in the standing biomass of primary producers and could be indicative of an increase in primary productivity. However, it is interesting that among the three seamount stations, the intensity of the fluorescence readings did not increase across the seamount. Instead, there was a drop in fluorescence over the seamount and then a large increase in fluorescence downstream.

Part of the cause for more fluorescence directly downstream of the seamount than over the seamount could be that there was more light available to the phytoplankton due to the lifting of the DCM. However, the DCM only lifted five meters, from 120m at station 005 to 115m at station 006, and we cannot know if those five meters were particularly significant because we did not measure light attenuation with a Secchi disk at our stations.

The difference in fluorescence between the three seamount stations may be insignificant considering that all three of the stations have much more intense fluorescence readings than any of the surrounding sites, however, I will propose a couple of mechanisms to explain the fluorescence data.

Any mechanisms controlling the DCM must account for the lifting of the DCM across the seamount. One possible mechanism for this lifting is that the phytoplankton are swept up along with the isopycnals across the seamount. However, this simple explanation does not account for the lower concentration of primary producers over the

seamount and the higher concentration downstream of the seamount that are indicated by our fluorescence data. Therefore, to try to explain the decrease in the fluorescence measurement directly over the seamount, I propose that there are zooplankton eating up the phytoplankton. However, if this is the case, then according to the uplifting mechanism that I proposed, we would expect to see the same diminished fluorescence reading downstream of the seamount because that reduced population of phytoplankton would have been swept downstream. It is possible that the phytoplankton could have reproduced in the interim to somewhat replenish their numbers, but it does not make sense that the fluorescence reading would have increased so dramatically (relatively). Therefore, this mechanism does not satisfactorily explain the fluorescence situation.

A second possible mechanism to explain the fluorescence data is that nutrients that are uplifted by the seamount allow primary producers to proliferate. The phytoplankton can take advantage of the higher levels of nutrients and more abundant light. According to this mechanism, one would expect to see large fluorescence measurements over and downstream of the seamount, with the downstream measurement possibly even larger that that directly over the seamount because the phytoplankton will have had more time to utilize the uplifted nutrients. However, the situation that we observed across the seamount did not quite match the expected results from this mechanism either. The station directly over the seamount had the lowest fluorescence measurement of all three seamount stations. Once again, perhaps this decrease over the seamount was caused by feeding zooplankton. However, Schwartz (2005) found that the station directly over the seamount had the smallest zooplankton biomass of the three seamount stations. This could be explained by predation of fish, eating the zooplankton that have eaten the phytoplankton.

The dissolved oxygen data gives more information about the mechanism at work over the seamount. The general trend of dissolved oxygen across the seamount is that the upstream station has lower levels of dissolved oxygen than the stations over and downstream of the seamount, which are roughly equivalent. I will propose two explanations for this trend in dissolved oxygen. The first explanation is that there is comparable primary productivity occurring over and downstream of the seamount. This could corroborate with our low fluorescence measurement over the seamount and high

measurement downstream of the seamount because comparable rates of primary productivity can be achieved by a small biomass of primary producers with a high turnover rate and a large biomass of primary producers with a low turnover rate. Therefore, the phytoplankton over the seamount that are potentially being eaten by zooplankton would have a high turnover rate, while the phytoplankton downstream would have a larger standing biomass but a lower turnover rate.

A second possible explanation that includes the dissolved oxygen data is that there is more oxygen being produced at the downstream station because there is more photosynthesis happening there than over the seamount. However, the downstream station and the station directly over the seamount could still have comparable dissolved oxygen levels if the downstream station also had more zooplankton performing aerobic respiration, and using up the dissolved oxygen present in the water. This explanation agrees well with the fluorescence and dissolved oxygen data as well as with the zooplankton data collected by Schwartz (2005) over the same unnamed seamount at 18.739ºN by 157.067ºW.

Conclusion

Overall, the results of my research showed that there was a general trend of lifting across the seamount. I observed the lifting of isotherms, isopycnals, isolines of fluorescence, the DCM and of phosphate. This lifting trend could be indicative of an effect called the Island Mass Effect where current flow is disrupted by a topographical feature, causing downstream randomization of flow and the mixing and uplifting of deeper water. Donohowe (2005) did not observe this randomization of flow in the ADCP data for this unnamed seamount. However, the Island Mass Effect is still one possible explanation for the lifting trends across the seamount.

The three seamount stations (004, 005, 006) had the highest intensity fluorescence readings of any of the nearby stations, and among them the station directly over the seamount had the lowest fluorescence measurement and the station downstream of the seamount had the highest. This unexpected result may be insignificant, but a similar pattern arose in Schwartz's research (2005) of zooplankton around the same seamount.

Therefore, I proposed some mechanisms to explain the uplifting trends of isotherms, isopycnals, nutrients, isolines of fluorescence, the DCM the higher dissolved oxygen concentrations over and downstream of the seamount along with the anomalous fluorescence measurements.

During the time of our sampling, the seamount was encompassed by the edge of a cyclonic eddy. Therefore, the effects of the seamount were intricately and inextricably intertwined with the effects of the eddy, and our data was confounded. However, by analyzing the seamount stations in the bigger picture of the eddy, it seems probable that the seamount contributed significantly to the physical, chemical and biological effects that were documented.

Future researchers could measure light attenuation at their sampling stations in order to get an idea of the relationship between the placement of the DCM with respect to light intensity and the intensity of the DCM fluorescence readings.

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