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Abstract

Airborne pollutants contribute to ocean acidification and hence to the associated chlorophyll content level. Previous work showed that falling aerosols causing ocean acidification would in turn result in bleaching and productivity loss in coral reef builders. Chlorophyll content has been used as a measure of the concentration of the photosynthetic pigment chlorophyll a (the most common "green" chlorophyll) in the ocean. In our work we have monitored the change in chlorophyll content obtained from the Moderate Resolution Imaging Spectroradiometer (MODIS) sensor on board Terra/Aqua satellites from 2000-2009 over selected pilot areas. Moreover, we have used the Goddard Chemistry Aerosol Radiation and Transport (GOCART) NASA chemical model to simulate sulfate, dust, black carbon (BC), organic carbon (OC), and sea-salt aerosols content over the urban centers close to the areas where chlorophyll content is showing a significant decline. These parameters would reflect the natural versus anthropogenic origin of the aerosols falling over ocean waters. We expect to observe an overall decrease in chlorophyll content on the surface of the ocean. Hence, our findings may suggest that the effects of falling air pollutants in the ocean will be so detrimental as to gradually cause a decrease in photosynthetic producing material over several years.

Keywords: Chlorophyll, Black Carbon, Satellite Sensing, GOCART

Introduction

Ocean acidification is an extremely concerning issue today primarily because of it's effects on marine organisms, due to an unprecedented increase in pH level throughout the ocean. Almost a third of the excess carbon dioxide produced by both natural and man-made processes settles into the ocean. As mass amounts of carbon dioxide have been absorbed into the ocean since the industrial revolution, scientists have measured that pH levels have gone down 0.1 units, which actually causes a rise in acidity (as pH levels go down, acidity is increased: for example, going from 0.15 to 0.30 is considered a decrease in pH, and an increase in acidic level). High acidic levels cause calcium carbonate, which is the main skeletal material for many marine organisms as well as the primary reef building material where abundant habitats thrive, to dissolve. Organisms such as shellfish towards the bottom of the food chain are now going extinct because their shells are literally dissolving, therefore causing large amounts of them to die. Portions of coral reefs are also dissolving, which affects all of the organisms that depend on the reef as a living habitat. As pH levels continue to increase, many food webs will be altered, and humans will see a dramatic decrease in the amount of fish production, which many people around the world depend on. The concern of ocean acidification is one shared by many scientists and policymakers who have observed how rapidly the acidic levels in the ocean have been increasing, and how scary such an occurrence is for the future of our oceans.

Airborne pollutants contribute to ocean acidification and hence to the associated chlorophyll content level. Previous work showed that falling aerosols causing ocean acidification would in turn result in bleaching and productivity loss in coral reef builders. Chlorophyll content has been used as a measure of the concentration of the photosynthetic pigment chlorophyll a (the most common "green" chlorophyll) in the ocean. In our work we have monitored the change in chlorophyll content obtained from the Moderate Resolution Imaging Spectroradiometer (MODIS) sensor on board the Aqua satellite from 2000-2009 along the California coastline. Moreover, we have used the Goddard Chemistry Aerosol Radiation and Transport (GOCART) NASA chemical model to simulate sulfate, dust, black carbon (BC), organic carbon (OC), and sea-salt aerosols content over the urban centers close to the areas where we expect chlorophyll content to show a significant decline. These parameters reflect the natural versus anthropogenic origin of the aerosols falling over ocean waters. We expect to observe an overall decrease in chlorophyll content on the surface of the ocean. Hence, our findings may suggest that the effects of falling air pollutants in the ocean will be so detrimental as to gradually cause a decrease in photosynthetic producing material over several years.

We hypothesize that if black carbon aerosols settle into the ocean along the western California coast over time, then chlorophyll content on the surface of the ocean will show an overall decrease. In composing our research, we will observe data over the years of 2003, 2007, and 2009 during the months of January and July. Looking at two regions, the close coastal region and the further out open ocean region, we will compare patterns of chlorophyll growth to that of black carbon content. We expect to see a relationship between the decrease in chlorophyll with the increase of black carbon. The reason why we predict that chlorophyll content will decrease as black carbon increases if because we believe that excess amounts of black carbon, which creates a highly acidic environment in the ocean, will overwhelm photosynthetic production so as to kill off some amount of photosynthetic producing material. In other words, we expect to identify the effects of ocean acidification as extremely harmful to ocean vegetation, due to high pH levels continually increasing as a result of an increased presence of black carbon aerosols settling into the ocean.

Mythology

First we picked a location: the California coastline. Then we browsed data using the Goddard Earth Sciences Data and Information Services Center, through the GIOVANNI-NASA website. On GIOVANNI we decided on the

Moderate Resolution Imaging Spectroradiometer (MODIS) sensor on board the Aqua satellite as our means of collecting data. We then observed chlorophyll content along the California coast in January of 2003, 2005, and 2007. Then we observed chlorophyll content along the California coast in July of 2003, 2005, and 2007. Next we observed data through the Goddard Chemistry Aerosol Radiation and Transport (GOCART) model. On GOCART we observed the content of black carbon along the western California coast in January of 2003, 2005, and 2007. We proceeded to observe the black carbon content in July of 2003, 2005, and 2007. After observing all of the data through the MODIS-Aqua satellite and GOCART model, we then made a chart correlating the months and years being observed, with the chlorophyll content both directly along the coastline of western California, and further off of the coastline of western California in open ocean water. Lastly, we re-evaluated all data, both from the GIOVANNI website, and from the charts and graphs we composed, to make a conclusion of our research.

Analysis of Black Carbon on Chlorophyll

The data we collected throughout our research showed several things. Firstly, in comparing the months of January and July, generally chlorophyll content along the western California coast is more abundant during the summer times, which is fairly predictable given the warmer temperature causing more photosynthetic productivity.The month of July, in 2003, 2005, and 2007, consistently showed more chlorophyll content than January. In addition, there was typically more chlorophyll content closer to the coast then farther out in open water. Secondly, chlorophyll content was more abundant in southern California, but showed a higher concentration in certain areas of northern California. The region from San Francisco to Monterey Bay showed the highest concentration of chlorophyll, which we assume is due to the large amount of kelp beds that are notorious in that region of northern California.

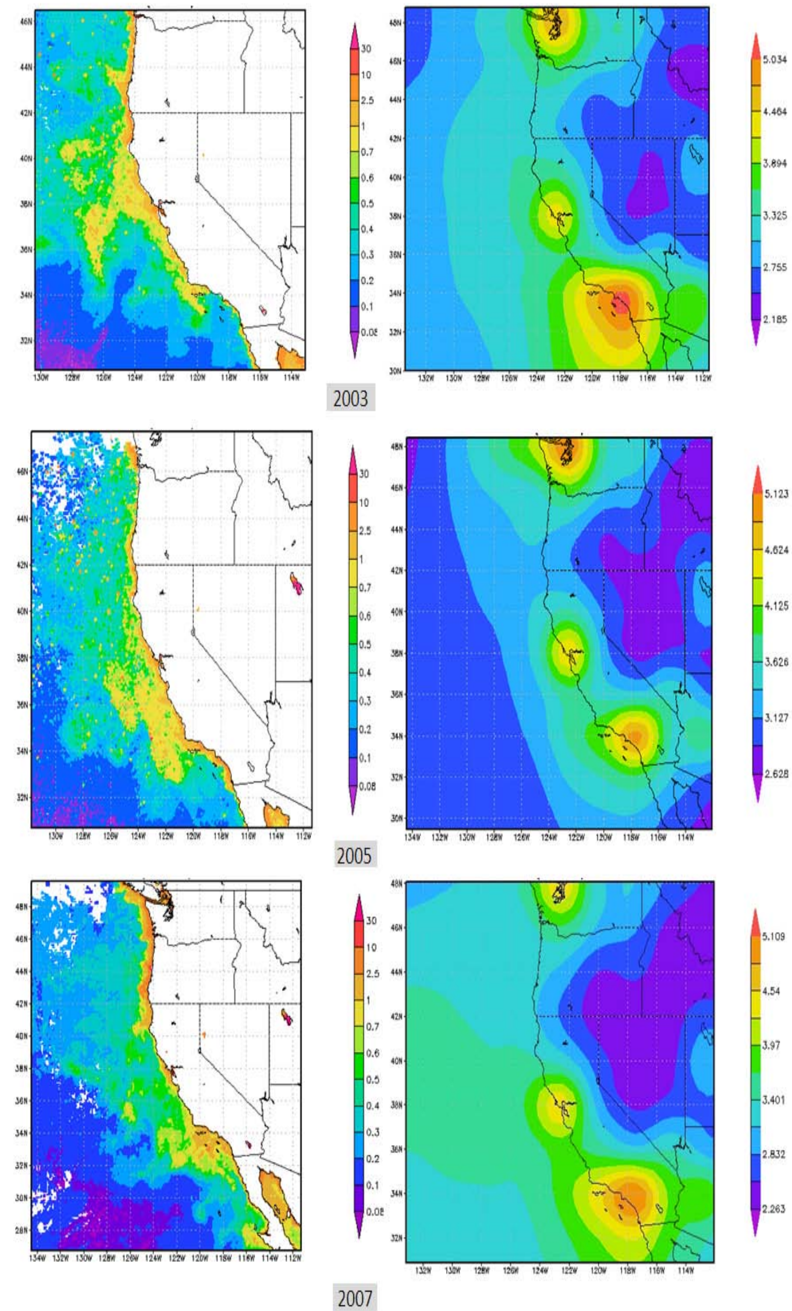


Figure 1: Chlorophyll content (a) versus Black Carbon (b) during January 2003, 2005 and 2007

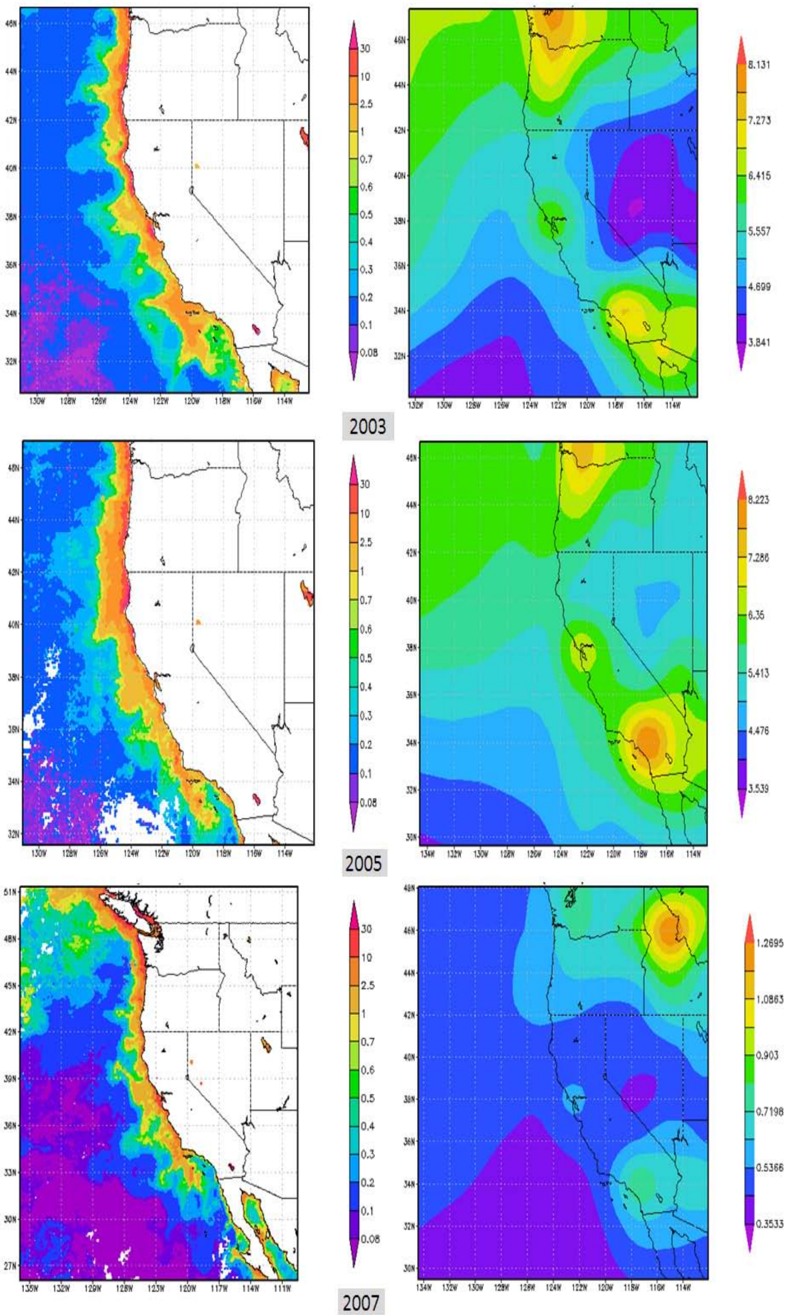


Figure 2: Chlorophyll content (a) versus Black Carbon (b) during July 2003, 2005 and 2007

In our research, we broke up our parameters along the western coast of California into two sections: the close coastal region, and the open ocean region further off of the coast. When comparing the average amounts of chlorophyll content along the close coastal region in January for the years of 2003, 2005, and 2007, to that of July of the same years, a pattern appeared: chlorophyll content was higher in 2003 than in 2005, but lower in 2003 than 2007. Therefore, chlorophyll content went from high to low, to it's highest in 2007. The open ocean coastal region showed almost the same pattern, with some variation in July of 2005 having higher numbers than in 2003, and 2007, and January of 2007 showing the highest numbers of all three years. Overall, January showed small fluctuation and fairly low chlorophyll content, whereas July proved to show more chlorophyll content along both regions.

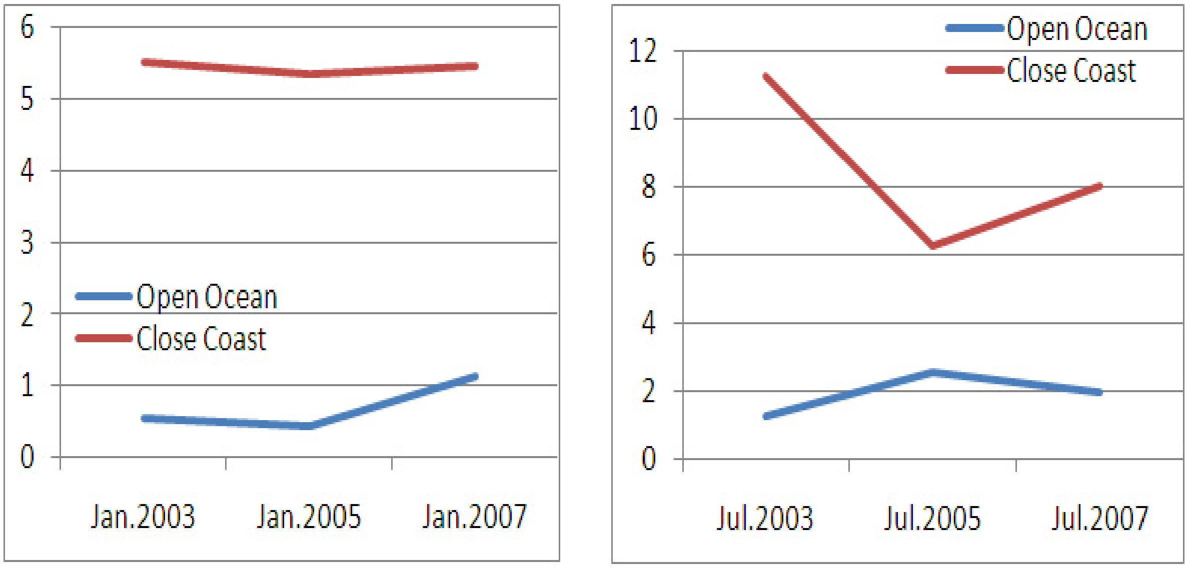


Figure 3: Chlorophyll Content in the open Ocean and along the coast during January and July of 2003, 2005 and 2007

Remarkably, black carbon content showed almost the exact same pattern as chlorophyll content in both regions during January and July. The open ocean region in January of 2003, 2005, and 2007, shows black carbon content going from high to lower, to its highest in 2007, where 2005 shows the least amount. The open ocean region in July of the same years increases in 2005 from 2003, and then drastically drops in 2007. July of 2007 shows the least amount of black carbon from any year during both January and July, along both regions. The close coastal region in January of all three years shows black carbon decreasing, respectively. The close coastal region in July of all three years does not show the same pattern as January: black carbon content is highest in 2005, and lowest in 2007, with 2007 displaying the vast decrease previously noted. Ultimately, black carbon content is always more concentrated along the close coastal region of western California, which is the exact same case with chlorophyll showing its most abundant and concentrated amounts along the same region.

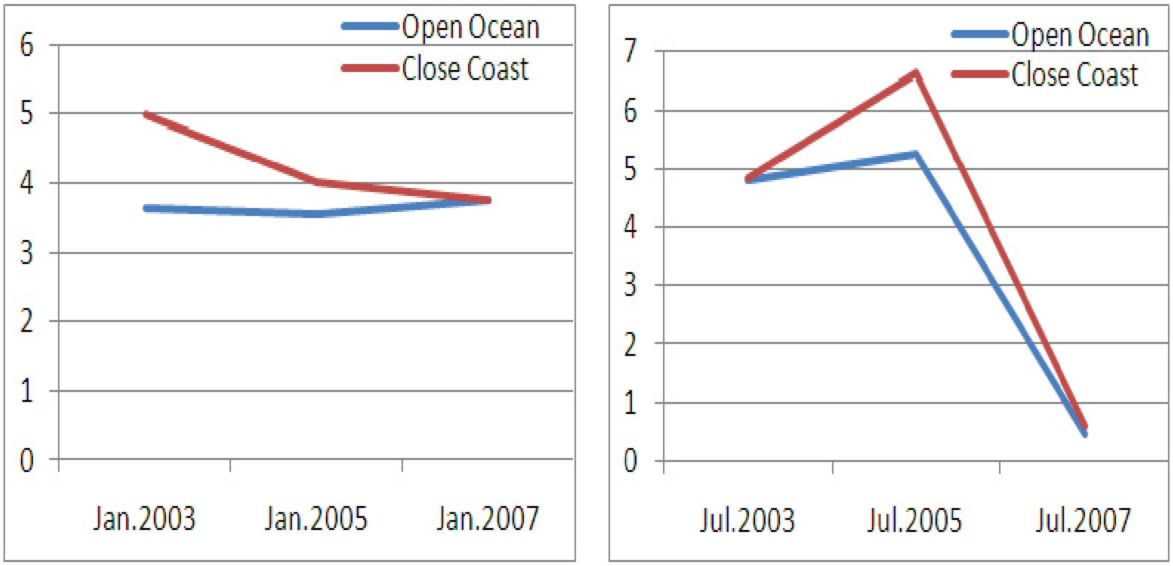


Figure 4: Amount of Black Carbon on Surface of Ocean during January and July of 2003, 2005 and 2007

Conclusions

After extensive research, our hypothesis was ultimately proven wrong: chlorophyll content along the western California coast did not correlate with black carbon content by showing a decrease in chlorophyll content as black carbon amounts increased. Our results were almost consistently the inverse of our hypothesis. However, a very interesting relationship between chlorophyll content and black carbon content was discovered. There appeared to be a direct correlation between the fluctuation of chlorophyll content and black carbon content over the years. Generally, as carbon content increased, so did chlorophyll. In observing the month of January during all three years, for example, the pattern of chlorophyll content growth is exactly the same as black carbon content increase: there was more chlorophyll and black carbon present in 2005 than in 2003, and even more amounts of both in 2007. Although there were slight variations in the patterns of the amounts of both chlorophyll and carbon over the years, the months consistently showed very similar, if not exactly the same, patterns. One of the most interesting things discovered about black carbon content was its dramatic decrease in 2007, far more than any other fluctuation observed over all three years. In relation to our hypothesis, such a discovery was completely unexpected. We expected to see an overall increase of black carbon content from 2003 to 2007, causing a decrease in chlorophyll content. When re-evaluating our data, it actually seems perfectly logical that chlorophyll content would increase as carbon dioxide content increased because of chlorophyll's need for carbon dioxide in photosynthesis. As carbon dioxide is released into the air, and eventually settles into the ocean, vegetation absorbs it in order to continue its photosynthetic production.

In reference to ocean acidification, our research showed that measures of ocean acidification effects cannot be obtained by observing chlorophyll and black carbon content. In other words, chlorophyll and black carbon do not have a directly correlating relationship with the effects of ocean acidification. The detrimental effects of ocean acidification are more closely associated with the decrease and dissolving of calcium carbonate in the ocean, and not the growth loss of vegetation. Although creating a highly acidic and polluted environment within the ocean is a horrible result of ocean acidification, vegetation is not as highly affected by ocean acidification as one would expect. Our research does not reveal the terrible effects of ocean acidification, which is primarily due to the fact that remote sensing satellites cannot penetrate deep enough into the ocean to produce results needed to measure such effects.

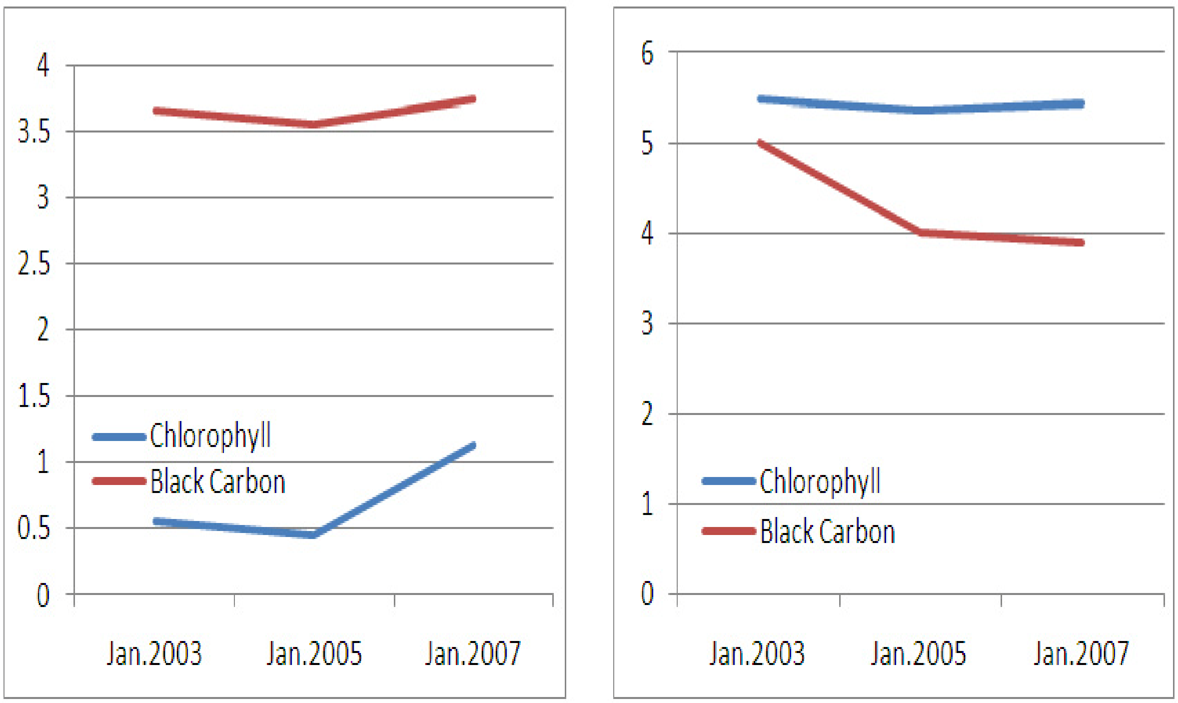
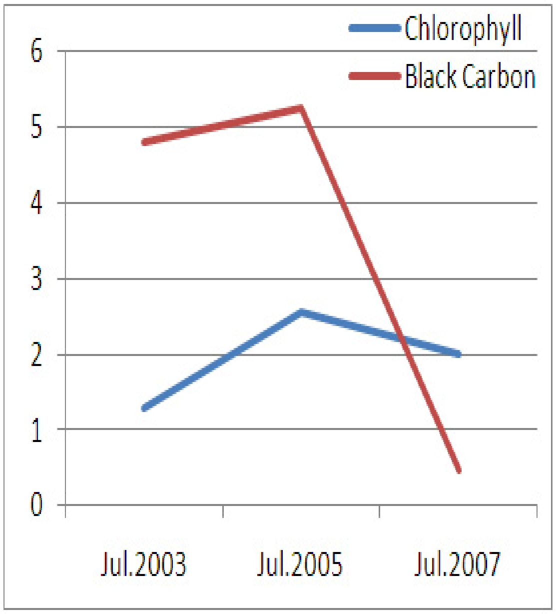


Figure 5: Black Carbon Compared to Chlorophyll in the open Ocean and along the coast during January of 2003, 2005 and 2007



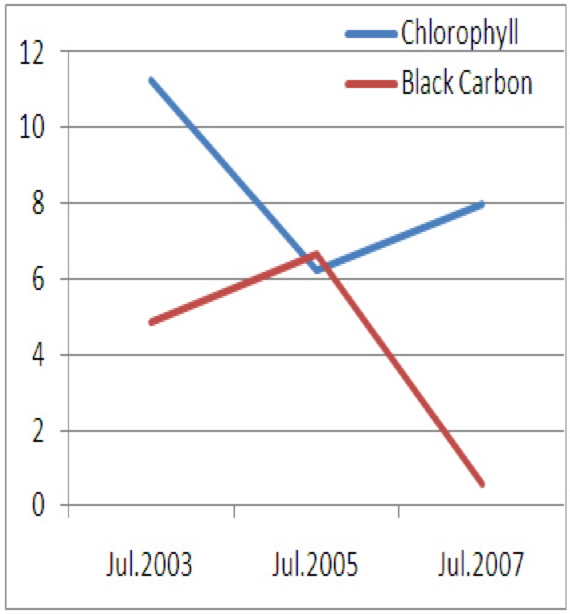


Figure 6: Black Carbon Compared to Chlorophyll in the open Ocean and along the coast during July of 2003, 2005 and 2007

In the future, extensive research that could be done in order to further test the relationship between chlorophyll content and black carbon content could include measuring water and air temperature. In measuring water temperatures, pH levels could be obtained in order to test for any correlation between pH levels and water temperature with chlorophyll content. Since it is an agreed fact by scientist and policy makers around the world that black carbon does in fact increase the pH levels in the ocean, one could perform an experiment that directly measures the pH levels in a specified parameter of the ocean in order to identify the exact percentage relationship between black carbon and pH levels. In addition, using different models, sensors, and satellites could potentially give different results than those obtained by our experiment.

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