SEASONAL DISTRIBUTION OF CHLOROPHYLL-A CONCENTRATION DEDUCED FROM MODIS OCEAN COLOR DATA IN THE EDDY AREA HYUGA-NADA EAST KYUSHU SEAWATER

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ABSTRACT:

Total primary production resulting from the photosynthetic process can be defined as the amount of organic matter produced in a given period of time. It is proportional to the chlorophyll-a (chl-a) values in the surface layer of the ocean. The MODIS board on Aqua satellite measures visible and infrared radiation in 36 wavebands, providing simultaneous images of chl-a concentration and sea surface temperature (SST) in the upper layer of the sea. The seasonal distribution of chl-a concentration during one year from April 2005 to March 2006 was examined. Light has a role of starting the seasonal cycle. The Kuroshio Current in this area induces many oceanographical features affecting to the change of seasonal control. The chl-a concentration is also seasonal, which is low in summer and high in winter. In summer, the meandering of Kuroshio Current induces strong eddies and increases the chl-a concentration. In autumn, the delayed small autumn bloom occurred until last December due to the Kuroshio Current. When the Kuroshio axis moves far from the coast, the coastal water dominates and increases the concentration even in the winter. The spring bloom starts early at the beginning of March and decreases during the spring.

1. INTRODUCTION

Marine productivity including fish and sea mammals depends entirely by the productivity of photosynthetic organism. Primary production is linked to fishery yield through bottom-up processes. The effect of light and nutrients are indeed important, but what we can see of the production in waters in the world differs sharply from what we might predict basing merely on the variation of light and nutrient. The local hydrographical features are major importance in mediating how these control mechanisms work (Mann, 1980).

The east of Kyushu Island is located just close to the upper border of tropical latitude where light has a role of starting the seasonal cycle. The Kuroshio Current in this area induces many oceanographical features affecting to the change of seasonal control.

Total primary production resulting from the photosynthetic process can be defined as the amount of organic matter produced in a given period of time. It is proportional to the chl-a values in the surface layer of the ocean (Zagaglia *et al*, 2004). The MODIS on board Aqua satellite measures visible and infrared radiation in 36 wavebands, providing simultaneous images of chl-a concentration and SST in the upper layer of the sea. We examined the seasonal change of chl-a concentration and hydrographical feature that affect to chl-a concentration.

2. DATA AND METHODS

2.1. Study Area

The study area is located in the east of Kyushu Island Japan called Hyuga-nada, where Kuroshio Current flows. The Kuroshio flows out to the Pacific Ocean from the East China Sea through Tokara Strait and then turns northeastward along the east coast of Kyushu Island, turns again off Ashizuri Cape and flows along the south coast of Japan commonly (Kawabe, 1995). The study area is between 2 turning points Tokara Straight and Ashizuri Cape. It is very interesting to study in this area using truly synoptic chl-a concentration and SST images deduced from MODIS Ocean Color Data

2.2. Data

MODIS data is the main data in this study. MODIS is a key instrument aboard Aqua (EOS PM) Satellites. Aqua MODIS are viewing the entire Earth's surface every 1 to 2 days, acquiring data in 36 spectral bands, or groups of wavelengths. The data used are one year temporal data from April 2005 until March 2006 representing spring season (6 images), summer (5

images), autumn (6 images) and winter (8 images). Almost 2 images of data are processed in each month.

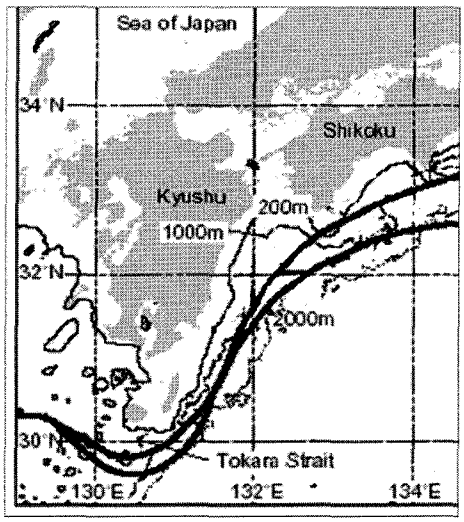

Figure 1. Location of study area and typical path of the Kuroshio according Kawabe (1995)

The data was downloaded from Goddard Earth Science, Data and Information Service Center, National Aeronautic and Space Agency (NASA) USA. The downloaded data is level 1A. For ocean color application, we used from band 8 until band 16, and for SST used band 31 and band 32.

2.3. Data Calculation and Processing

Radiometric corrections to the data must be necessary to remove the atmospheric radiance. Once the radiance signal has been corrected for atmospheric light scattering, the signal is then corrected for the solar zenith angle. The radiometric correction was followed to the Gordon and Wang (1994) algorithm. Chl-a concentration algorithm was developed based on semi analytical, bio optical of remote sensing reflectance (Rrs). From Rrs we calculated the chl-a concentration by standard algorithm called chl_oc3 in MODIS Ocean Color Discipline website. Sea Surface Temperature (SST) derivation is deduced on the basis for the MODIS V.2 pre-launch SST algorithm, the Miami Pathfinder SST (mpfsst) algorithm, developed at the University of Miami's Rosenstiel School of Marine and Atmospheric Science (Brown, 1994)

The data was processed by SeaDAS 4.6, starting from level 1A, generate geolocated data, then process to level 1B. We calculated the normalized water leaving radiance, chl-a concentration and SST by MSL12. For the map to the map projection, we use projection menu, and then we transferred the image to ENVI software to make the image to image registration for each data. We also used our handmade program running under Visual Basic for data analysis.

2. RESULT AND DISCUSSION

We are starting the discussion at the summer season when the growth rate of phytoplankton slows down due to the lack of nutrient (Valiela, 1980). For examining the seasonal change, we extracted the value of chl-a concentration in the transect line from the coast to the ocean at the middle of Hyuga-nada area (see Fig. 4) almost perpendicular to Kuroshio axis.

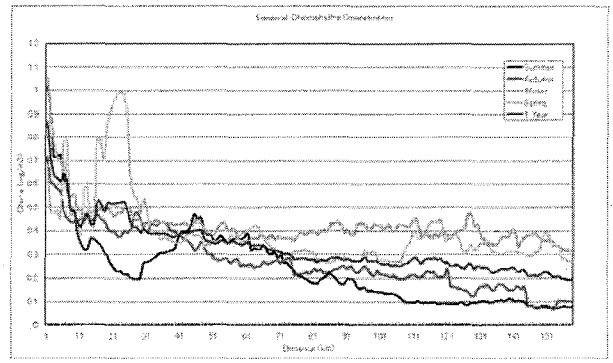

Figure 2. The chl-a concentration along the transect line averaged over the four season and 1 year.

The averaged chl-a concentration was high at just near coastal area 1.9 – 0.5 mg/m^3 up to 10 km from the coast, in 10 – 100 km it was 0.47 mg/m^3 maximum and gradually decreases until 0.1 mg/m^3, over 100 km, it is almost the same about 0.1 mg/m^3. The high concentration in coastal area is common because of the nutrient supply from the land, in the area far away from coast, there is really oceanic water where the concentration is low due to poor nutrient.

We found interesting phenomena along 40 – 70 km where the Kuroshio Current flows. The chl-a concentration was relatively high between 0.47 – 0.3 mg/m^3, almost the same as the annual average (see Fig. 2). The chl-a images explained this phenomenon clearly. On the first image (27th July 2005), eddy was not found, only small vortex in the coastal area that didn't affect to the amount of chl-a concentration in the Kuroshio water.

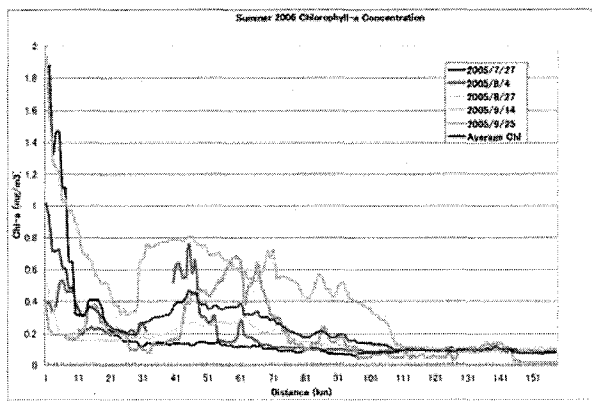

Figure 3. The chl-a concentration during summer 2005. showing the increase due to the eddies

On the second (4th August 2005), third (27th August 2005), forth (14th September 2005) images, eddies were found and their size and phases extend to the wide area where chl-a concentration increased (note: images not shown in this paper).

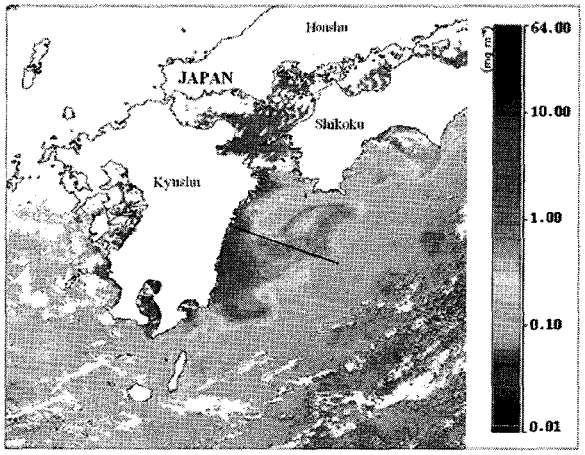

Figure 4. The eddy mixed the coastal water with Kuroshio water increased the chl-a concentration on 14th September 2005. The black line denoted the transect line.

The chl-a images and the extracted value of concentration showed that eddy increased the chl-a concentration by water mixing between coastal waters and Kuroshio waters (see Fig. 3). Ebuchi and Hanawa (2000) suggested based on SSH (Sea Surface High) variations that eddy might be generated in Kuroshio extension region, propagating westward in the Kuroshio re-circulation region.

Average SST during the summer season is not so fluctuant at the transect line. The difference is only about 1° C. SST is about 27.5° C just near the coast and then higher between 10-40 km from the coast about 28° C, lower between 40-70 km and higher again until 28.5° C at more than 70 km. There was not significant difference in SST between coastal water and Kuroshio water.

Trend of average chl-a concentration in the autumn season was different from the one in summer season, the trend along the transect line was higher than summer season, except in coastal area and eddies areas. At the coastal area, the concentration was lower than the summer season. The increase of chl-a concentration is induced by cooling process during the autumn, which is caused by water mixing between top and bottom water. The strong wind can deepen the mixing process. The surface waters that were nutrient-deficient are replaced by waters that have abundant nutrients and there is often an autumn bloom of rapid phytoplankton growth (Mann, 1980).

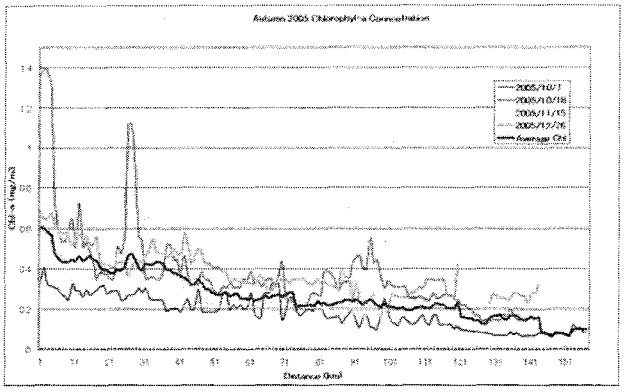

Figure 5. The chl-a concentration during autumn 2005. The high on 18th October 2005 due to eddy (magenta line) and 26th December 2005 (cyan line) indicated autumn bloom

During the autumn only two images showed the high chl-a concentration that is second (18th October 2005) and sixth images (26th December 2005) (see Fig. 5). The increasing chl-a concentration in second image was induced by strong eddies. The increasing of chl-a concentration shown in sixth image was not induced by eddy. Autumn bloom is unusual in December. Stowe (1979) showed the graph of autumn bloom in end of September. The delay of autumn bloom indicated that Kuroshio Current plays dominant role even in autumn. The autumn cooling on the surface water did not make water mixing in the beginning and the middle autumn. The SST value during the autumn is still more than 25° C except at the end of autumn in the sixth image, when the SST is about 20° C.

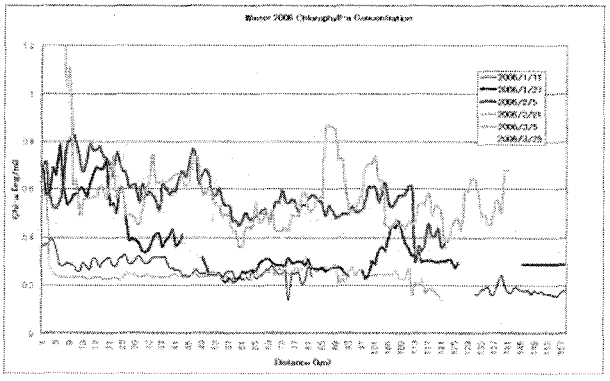

Figure 6. The chl-a concentration during winter 2006.

Average chl-a concentration during the winter season was higher than the autumn in almost all regions from the coastline until offshore region (see Fig. 2). Actually, the phytoplankton growth is low in the winter due to the lack of sunlight (Stowe, 1979). However, the result above indicated another condition. Hyuga-nada is just near the border between tropical area and temperate area, the sunlight increases early, the spring bloom also starts early. The chl-a images showed that blooming begins in the early march (see Fig. 6). It might make the

chl-a concentration in the winter higher than in autumn.

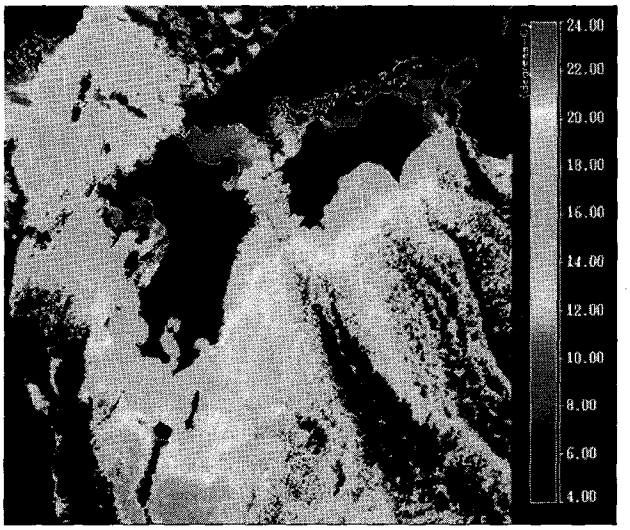

Figure 7. The Kuroshio axis moved far from the coast was indicated by high degree of SST on 5th February 2006

However, in the 27th January image, the chl-a increased in the area until 40 km from the coastline and in the 5th February image almost in all area. The beginning of February is still in winter, but the chl-a already increases as the spring bloom. The increase of chl-a concentration at this time was not the bloom due to surplus of nutrient as the bloom in beginning of spring. If we see the chl-a images, the increase begins from 27th January image but only area inside 40 km from the coast, and the became wider until the end of the transect line on 5th February. This indicates that there was spreading out of coastal water with high concentration to the offshore due to the moving of Kuroshio axis far from the coast even in winter. The moving of Kuroshio axis can be seen in SST images at the same time. In winter, Kuroshio waters can be seen clearly on the SST images. Also, according to the Japan Coast Guard on Quick Bulletin of Ocean Condition, the Kuroshio flows just near the Toi Misaki peninsula on the end of December, moving far on end of January and beginning of February. This data also explained that autumn bloom in December is due to nutrient supply from bottom because of cooling. In the end of December, the Kurioshio Axis exists still just nears the Toi Misaki peninsula.

Spring bloom started at the early March on 5th March 2006 (see Fig. 6). The high chl-a concentration continues until last of March. Moreover, the chl-a concentration in Kuroshio water becomes higher, but in coastal water it is not so different from the usual condition. It indicated that the spring bloom also occurred in the area source of Kuroshio Current at Okinawa Island.

During spring, there was not special evidence, the chl-a concentration is high at the beginning of April and then decreased gradually until the end of spring.

4. CONCLUSION

Hyuga-nada is temperate latitude that basically the seasonal affected due to the change of heat flux. The position just near the border with tropical latitude, Kuroshio Current flows, and near the big island make the oceanography feature became special. The chlorophyll-a concentration was affected by seasonal, which low in summer and high in winter. In summer, the meandering of Kuroshio Current induce strong eddies and increase the chlorophyll-a concentration. In fall, the small autumn bloom delay due to the flowing of Kuroshio Current until last December. Some time when the Kuroshio axis move far from the coast, the coastal water dominates and increasing the concentration even in the winter. The spring bloom happen early start from beginning of March and decreasing of chlorophyll-a concentration average during the spring.

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