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The Chlorophyll Concentration in the Southwestern East Sea Observed by Coastal Zone Color Scanner (CZCS)

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Monthly mean chlorophyll concentration in the East Sea was estimated from the ocean color observed by the Coastal Zone Color Scanner (CZCS) on Nimbus-7 satellite which had performed various remote sensing missions from 1979 to 1986. The areas of high chlorophyll concentration were found in the sea between Siberia coast and Sakhalin Island, in the Donghan Bay and in the Ulleung Basin. In the southwestern East Sea, especially in the area near Ulleung Island, the yearly maximum chlorophyll concentration occurred in December. The chlorophyll concentration in Ulleung Basin in December was about two times higher than during spring bloom in April. The early winter bloom occurred in the warm side of the front that was formed between warm water from the East China Sea and nutrition rich cold water from the northern East Sea.

Key words: ocean color, winter bloom

Introduction

The Coastal Zone Color Scanner (CZCS) launched in 1978 was the first instrument that measured ocean color from the space. It gathered the ocean color information of the global ocean until 1986 and the chlorophyll concentration estimated from the ocean color data was extensively used for studying the distribution and time variation of phytoplankton in the open ocean.

The time and space variations of chlorophyll concentration of the Adriatic Sea from CZCS data were studied by Barale et al. (1986) and those of the Caribbean and the Sargasso Sea were examined by Muller-Karger et al. (1989 and 1991). Comiso et al. (1993) analyzed the chlorophyll concentration from CZCS in the South Atlantic and the annual cycle of chlorophyll concentration in global ocean was studied by Yoder et al. (1993). The seasonal cycle of phytoplankton pigment in the open ocean was examined by Banse and English (1994). The CZCS data were also used for studying fronts, eddies and other physical oceanographic phenomena. Gordon et al. (1981) observed Gulf Stream rings using pigment signal from CZCS and Brock and McClain (1992) used CZCS pigment concentration data to study coastal upwelling in the Arabian Sea.

The studies on the phytoplankton distribution in the East Sea had been done in limited regions because basin-wide measurements were very difficult and sporadic (Shim and Lee; 1983, Shim and Lee; 1987). Park (1996) analyzed the Secchi depth from the 30 year-long hydrographic station data gathered by National Fisheries Research and Development Institute (NFRDI) of Korea. Based on the assumption that the change of Secchi depth (the level of transparency of the sea water) was related to the phytoplankton biomass, he found that, in the East Sea, the maximum phytoplankton biomass occurred in April and the minimum occurred in summer.

Using high horizontal resolution CZCS data, the horizontal distribution and seasonal variation of phytoplankton biomass in the East Sea were analyzed in this study. The time variability focused on the Ulleung Basin was examined using both CZCS data and *in situ* observations.

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Data

It is known that the color of the atmosphere in the North Pacific is affected by the yellow sand blown from China (Tanaka et al., 1989). To correct this problem, the CZCS data had been reprocessed with modified atmospheric correction in addition to the standard NASA correction procedure (Fukushima et al., 1997). The CZCS data used in this study is Fukushima et al.'s (1997) monthly Nimbus 7-CZCS data from January 1979 to June 1986.

The details of calculating chlorophyll concentration from CZCS observation are reported in Fukushima et al. (1997). In this paper, we briefly describe the formulae to calculate chlorophyll concentration (P). It was calculated from the atmosphere corrected radiances (L_W) at wavelengths of 443 nm, 520 nm and 550 nm using Clark's (1981) formulae,

$$P=5.56\times\left(\frac{L_W(443)+L_W(520)}{L_W(550)}\right)^{-2.252}$$

The horizontal resolution of CZCS data was 3~4 km but the cloud, especially during winter, made difficult to gather good and unbiased observations in the study area. Monthly maps of chlorophyll concentration during CZCS mission were first made and then they were averaged over eight years to get monthly mean chlorophyll concentration distribution.

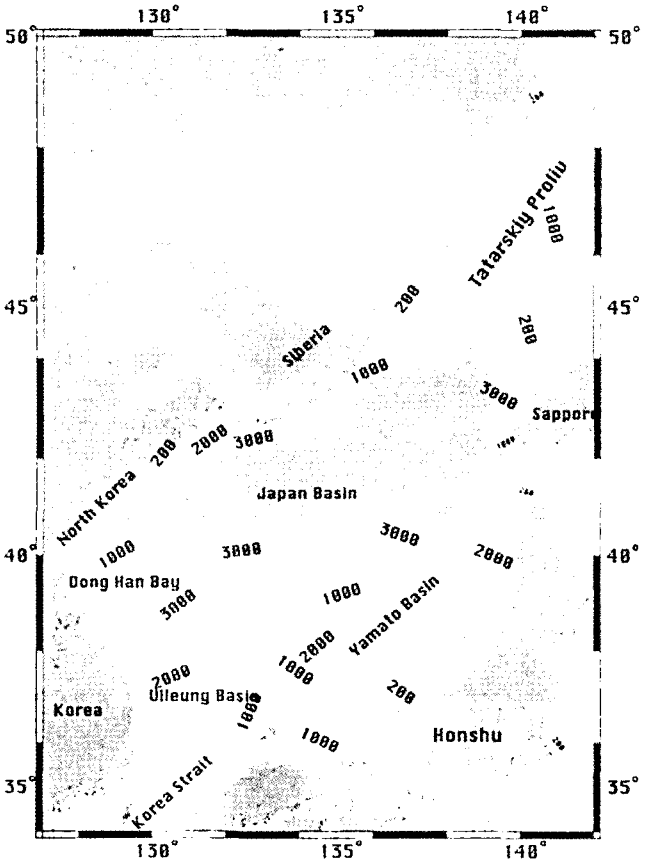

Fig. 1. The topography of the East Sea.

Results

Monthly mean chlorophyll concentration in the East Sea

The monthly mean chlorophyll concentrations from CZCS in the East Sea from 1979 to 1986 are displayed in Figure 2. The chlorophyll concentration in January was very low (less than 0.1 $\mu g/\ell$) in the northwestern East Sea but it was high (higher than 1 $\mu g/\ell$) in the northeastern East Sea. The possible cause of very low concentration in the northwestern East Sea was the cold water formation by strong northwesterly wind (Gwon, 1999) but further study is needed for the explanation of high chlorophyll concentration in the northeastern East Sea. In February, the chlorophyll concentration was very low over the entire East Sea except near Siberian coast. The chlorophyll concentration became higher in March and the rapid phytoplankton growth was observed in the Dong Han Bay and in the eastern East Sea along Honshu Island.

The phytoplankton blooms occurred in most area of the East Sea in April except in the northern half of the Japan Basin. The highest chlorophyll concentration over 10 $\mu g/\ell$ was observed in the Tatarskiy Proliv. High concentration of chlorophyll was also observed in the coastal North Korea. The bloom completely disappeared in June and the chlorophyll concentration was low until October except in the shallow region in the Tatarskiy Proliv.

The phytoplankton growth started along the Korean and the Siberian coast in November and expanded to the interior of the East Sea in December. It was quite interesting that the fall bloom occurred in December, which was later than the open ocean bloom which usually occurs in October (Yoder et al., 1993). Kim et al. (1996) observed a similar early winter particle concentration maximum from their moored sediment trap in the Ulleung Basin. The

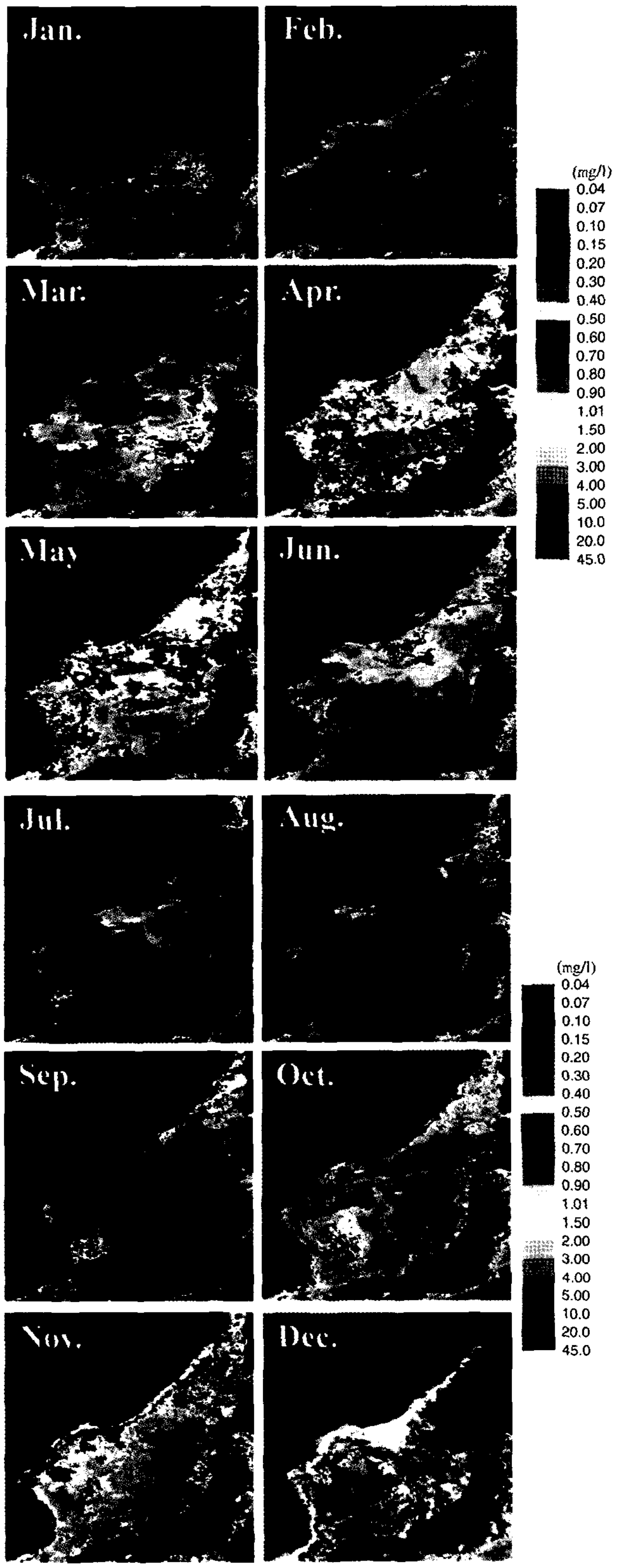

Fig. 2. Monthly mean chlorophyll concentration from CZCS in the East Sea from 1979 to 1986.

possible cause of this early winter bloom in the East Sea was that, in October, the low-salinity water with very low concentration of nutrient from the East China Sea occupied in the surface layer of the southern East Sea. The weak southerly wind (Lee, 1998) in the East Sea also made the low-salinity surface water stable and thus nutrient supply from the deep layer was insignificant.

The most productive region in the East Sea was the Tatarskiy Proliv. The Dong Han Bay and the Ulleung Basin were also found to be very productive area probably by high eddy activities (Lie et al., 1995) and sub-polar front formation.

The chlorophyll concentration in the southwestern East Sea

To analyze monthly variation in the East Sea in detail, the Ulleung Basin where long-term nutrient and zooplankton data were available was chosen (Figure 3). The Ulleung Basin is known to have strong eddies and front formation. The chlorophyll concentration observed by CZCS and vertical distribution of water temperature in December of 1982 are compared in Figure 4. The warm surface water penetrated into the cold water and the high chlorophyll concentration was

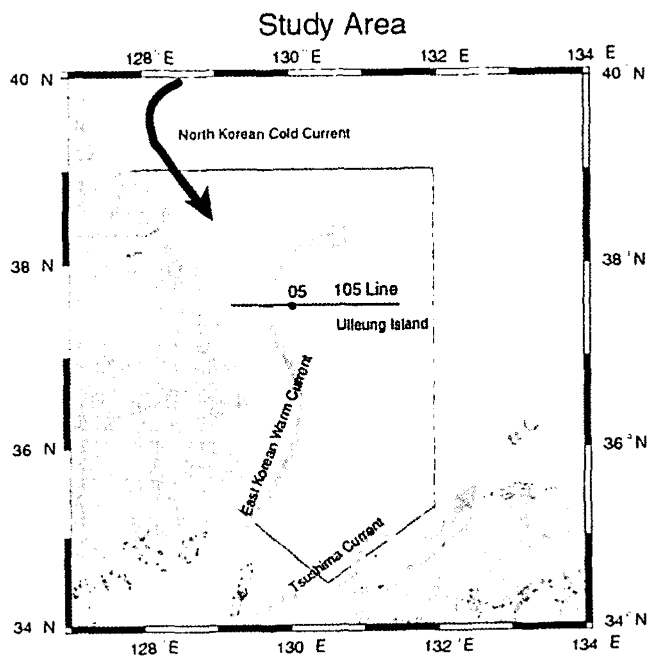

Fig. 3. The boundary of focused study area with schematic view of warm and cold water paths.

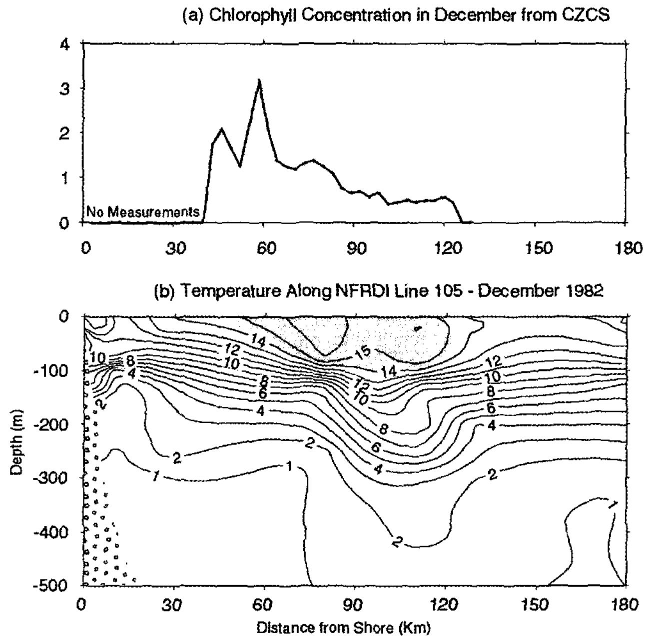

Fig. 4. The (a) chlorophyll concentration and the (b) vertical temperature distribution along the NFRDI bi-monthly hydrographic survey line.

found in the warm water pool with temperature between 14℃ and 15℃.

Bi-monthly mean nitrate-nitrite (NO_2-NO_3), phosphate (PO_4), and CZCS chlorophyll concentration are shown in Figure 5. The CZCS chlorophyll concentration was calculated from nine pixels centered at the hydrographic observation stations and the nutrient data were collected by the National Fisheries Research and Development Institute (NFRDI) during CZCS mission. The highest nutrient concentration was observed in December and February when mixed layer depth was deepened by the strong northwesterly wind (Lee, 19 98). The nutrient concentration was low in summer and October but increased rapidly in December. In the study area, the chlorophyll concentration in December was almost two times higher than that in April. The bi-monthly vertical temperature profiles at station 105-5 (marked in Figure 3) are presented in Figure 6. The mixed layer depth in December and in February was about 100 m but the mixed layer was not present during summer months (June and August). In spring and fall, the mixed layer depth was less than 30 m. The stratification during summer was very strong from surface to 100 m and the nutrient supply from the deep layer was prevented by this strong stratification. The Zooplankton biomass in study area in February (from Hahn et al., 1998; Figure 7) showed not only the highest value in the seas around Korea but also it was the highest biomass in the year which might be related to the phytoplankton bloom in December.

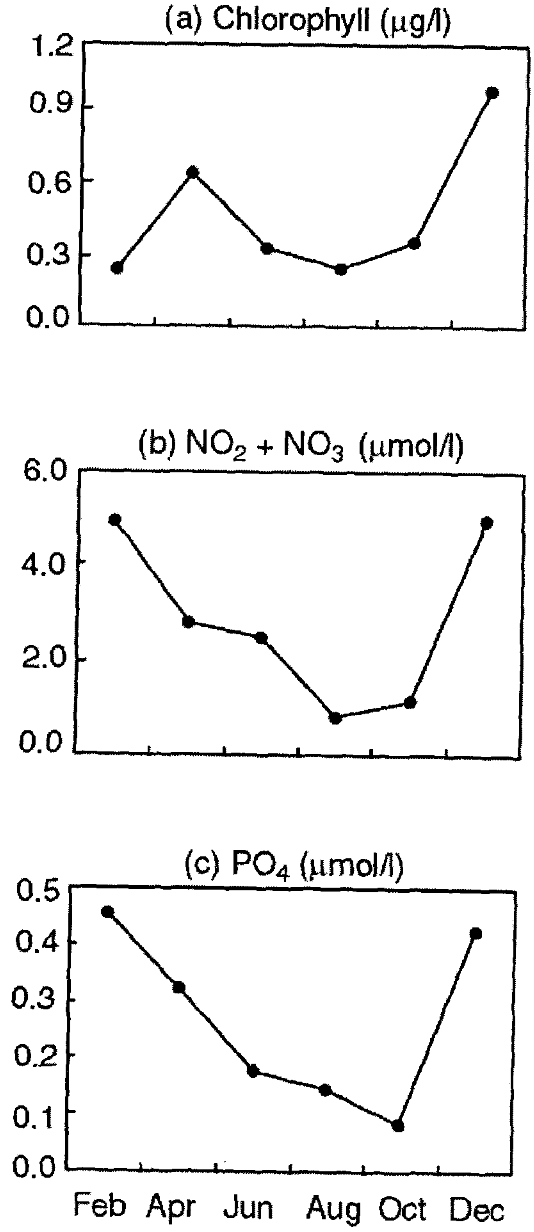

Fig. 5. The seasonal variations of (a) chlorophyll (1979~1986), (b) NO_2+NO_3 (1994), and (c) PO_4 (1994) in the study area.

Discussion

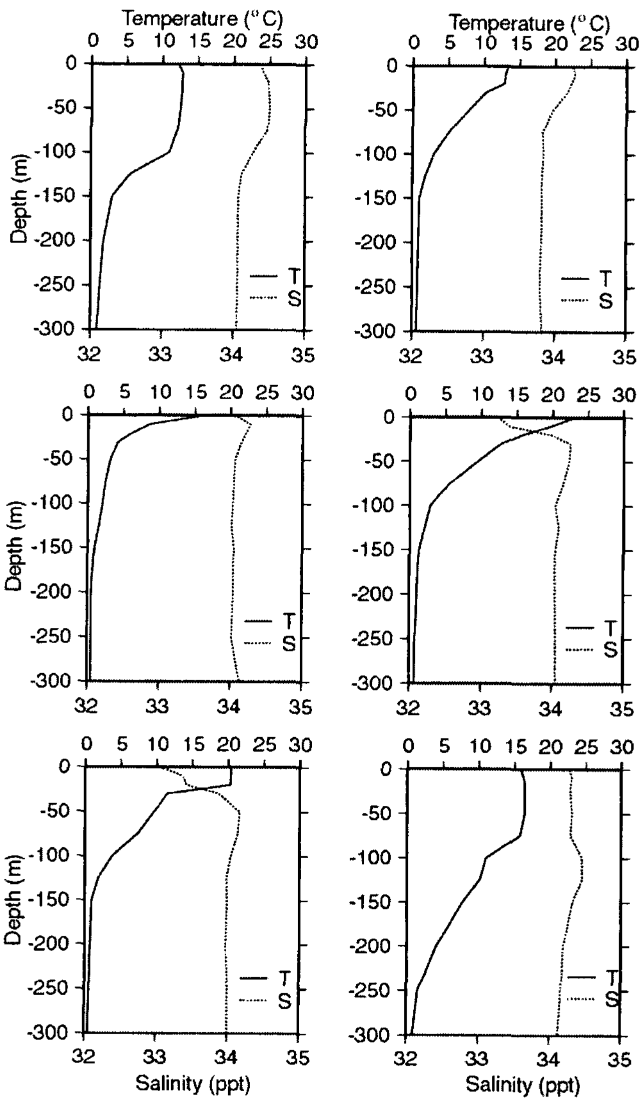

Fig. 6. Bi-monthly vertical profiles of temperature, sigma-t and salinity at station 5, 105 NFRDI cruise track in 1979.

The monthly variations of chlorophyll concentration estimated from CZCS in the East Sea were studied. Although the estimation of chlorophyll concentration from CZCS had some limitations because of cloud and yellow dust blown from the central China, the usefulness of analyzing spatial and temporal variations of phytoplankton biomass in the East Sea was shown in this paper.

The most interesting result was that the fall bloom occured in early December instead in October when most of the open ocean phytoplankton blooms occur. By analyzing the hydrographic data in the southwestern East Sea, it was found that the nutrient concentration in

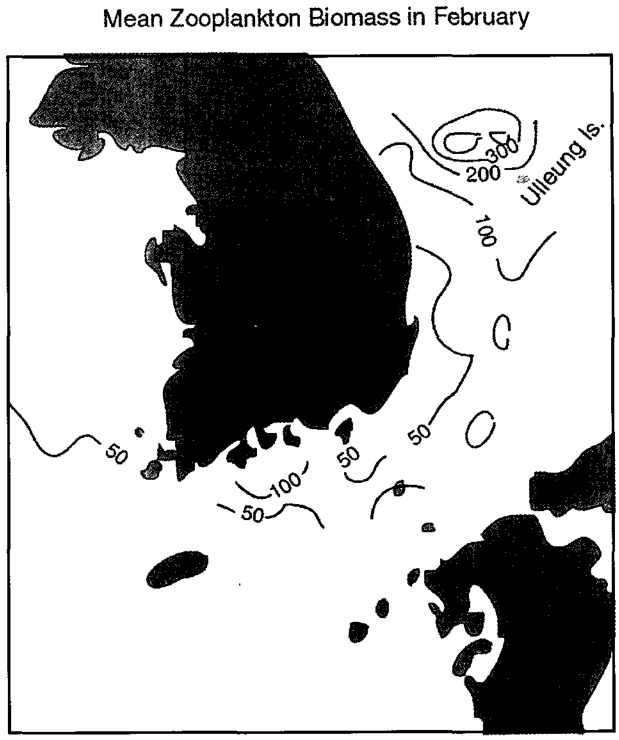

Fig. 7. Horizontal distributions of 30-year mean zooplankton biomass in February (from Hahn et al., 1998).

October was the lowest in the year. The nutrient concentration increased rapidly in December by the strong wind mixing and the deepening of the mixed layer from 30 m in October to 100 m in December. With nutrient supply, the phytoplankton grew rapidly in warm water pool which was originated from the south of the East China Sea. In the north area of Ulleung Island, the phytoplankton bloom in December could cause the highest copepoda biomass in February in the seas around Korea.

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