PATH VARIABILITY OF THE CHANGJIANG DILUTED WATER IN SUMMER

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ABSTRACT The current system of the East China Sea, a marginal sea in the northwest Pacific, has a seasonal variation. The Changjiang Diluted Water, Chinese coastal water in the East China Sea, has different seasonal paths. It flows southward along the Chinese coast within a narrow band in winter and does northeastward the Korea/Tsushima Strait in summer, which has been a subject to many researchers. In particular, low salinity in the South Sea of Korea in 1996 and 1998 was in discord with the Changjiang River discharge and the Changjiang Diluted Water seems to play an important role in occurrence of red tide in the South Sea of Korea in 1997 and on the contrary, disappearance in the next year. These facts suggested that the Changjiang Diluted Water does not flow along the same path in every summer. According to the analyses for path of the Changjiang Diluted Water using ocean color images by SeaWiFS and salinity observations by shipboard CTD in August for recent years, the Changjiang Diluted Water in summer flowed within the range of direction from southeastward to north-northeastward anticlockwise. However, the Changjiang Diluted Water flowed northeastward toward Jeju Island of Korea for the most part. It is necessary to examine the influence of major factors on path variability of the CDW in summer such as surface wind, the Changjiang River discharge and background current.

KEY WORDS: East China Sea, Changjiang Diluted Water, Path, Ocean Color

1. INTRODUCTION

The East China Sea (ECS) has a wide continental shelf which is mainly shallower than 200 meters in the northwest Pacific surrounded by Korea, China and Japan (Fig. 1). Since the schematic of current system in the ECS was presented by Uda (1934), it has been proposed that the current system of the ECS consists of two major currents (Nitani, 1972; Kondo, 1985; Guan, 1994). The one, warm and saline currents of oceanic origin, flows from south to north or northeast. The other, less saline coastal currents, flows generally from north to south along the Korean and Chinese coasts. However, the Changjiang Diluted Water (CDW) which is one of coastal water in the ECS has different seasonal paths; southward flow along the Chinese coast within a narrow band in winter and northeastward flow to the Korea/Tsushima Strait in summer. Under the influence of the CDW, sometimes abnormally low salinity water was detected in the South Sea of Korea in summer. For example, low salinity water less than 19 psu was observed west of Jeju Island in 1996. It caused a great damage to the fish-raising industry around Jeju Island. The mechanism of seasonal change of the CDW path has been a subject to many researchers (Mao and Guan, 1982; Le, 1984; Pu and Xu, 1983; Beardsley *et al.*, 1985; Wang, 1988; Zhao, 1992; Hu, 1994; Guan, 1994; Lie *et al.*, 2003). Principal factors of seasonal change of the CDW path are regarded as the Changjiang River (CR) discharge, monsoonal wind and background current.

It is noteworthy that although the Changjiang River discharge was smaller in 1996 than in 1998, the salinity was lower in 1996 than in 1998 in the northeastern part of the ECS (Kim *et al.*, 1998; Pang *et al.*, 2003). In addition, Yang *et al.* (2000) reported that when the CDW appeared in the South Sea of Korea, red tide occurred in summer 1997. It means that the riverine nutrients of the CR could be a trigger of red tide. On the contrary, there was a study that the appearance of the CDW in the same area was the possible cause for the disappearance of red tide in 1998 (Choi, 2001). These opposite results indicate that the characteristic of the CDW was different in the two years and their paths were likely to be different. Therefore, these facts strongly suggest that there are more than two paths of the CDW in summer.

The purpose of this study was to examine the variability of the CDW path in summer for recent years through the analyses of its path based on the distribution of chlorophyll *a* concentration by SeaWiFS (Sea-viewing Wide Field-of-view Sensor) and salinity observations by shipboard CTD. No attempt has been made at use of SeaWiFS images for the analyses of the CDW path.

2. DATA

The level-3 mapped images of chlorophyll *a* concentration (hereafter ocean color image) by SeaWiFS with a spatial resolution of 9 km in summer from 1998 to 2003, processed by the algorithm OC4 version 4 which was four band and maximum band ratio from NASA, were used for this study. High chlorophyll is used only as a relative tracer for river plume. That is, river plume consistently has values significantly higher than the ambient shelf water. This technique has been successfully used in studies on many river plumes in the world such as Chesapeake Bay estuarine outflow plume (Dzwonkowski and Yan, 2005) and Rio de la Plata plume (Huret *et al.*, 2005). In addition, the distribution of chlorophyll *a* concentration by SeaWiFS in August 1998 agreed well with concurrent surface salinity distribution (Wang *et al.*, 2003) which was partly darned with Korean data in the northeastern part of the ECS (Fig. 1). It was also supporting evidence that the river plume is able to be discriminated by high chlorophyll *a* concentration, especially the Changjiang River plume. Among provided images of various periods, weekly images were selected because of wide area of no data by cloud in daily image and the smoothness in monthly image.

Salinity observations by shipboard CTD were also used to reveal yearly difference of the CDW appearance in the northern part of the ECS in August. The data, provided by Korea Oceanographic Data Center, were obtained in the West, the South Sea of Korea and the northern part of the ECS in August from 1998 to 2003.

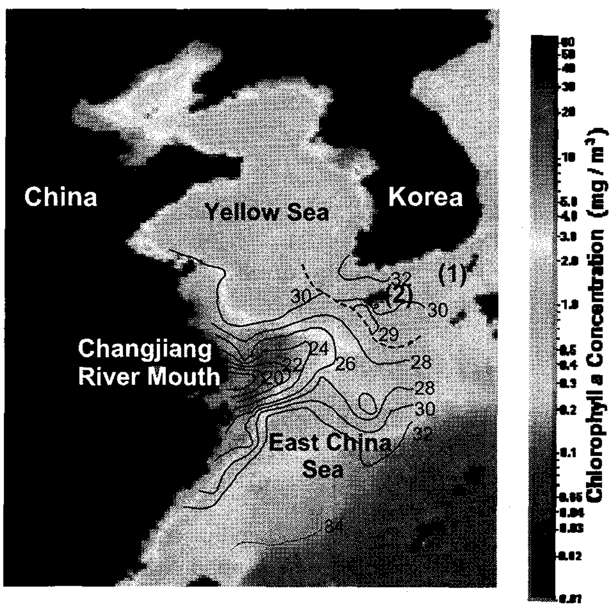

Figure 1. Monthly level-3 mapped image of chlorophyll *a* concentration by SeaWiFS in August 1998 with concurrent surface salinity distribution from Wang *et al.* (2003). The dashed line marks darned area with the Korean salinity data. (1): the Korea/Tsushima Strait, (2): Jeju Island

3. RESULTS

3.1 Paths by ocean color

Four weekly ocean color images in August by year were used to analyze the inter-annual variation of the CDW path in summer. Even though there was no data locally by cloud in the weekly images, analyzing the four images all together made it sufficient to trace the CDW. According to the comparison of satellite-derived chlorophyll *a* imagery with historical *in situ* surface chlorophyll *a* and surface salinity in the ECS (Kiyomoto *et al.*, 2001), spreading pattern of the CDW could be approximated by high chlorophyll *a* concentration such as more than 2.0mg/m^3. Bringing the influence of the CDW into focus, various color scales in the four weekly images were simplified into just containing the high chlorophyll *a* concentration of more than 2.0mg/m^3 and they were piled on all together by year (Fig. 2). That is, all points that chlorophyll *a* concentration was more than 2.0mg/m^3 at least once in the four images were indicated. In Fig. 2, we see that the CDW occupied the area (A) off the mouth of CR which is shallower than 50 meters (dashed line) and spread towards the Korea/Tsushima Strait in general.

However, the CDW spread in different directions in detail. It expanded most eastward as far as 128°E and most southward as far as 30°N in 1998. Consequently, it flowed southeastward from point A. In 1999, the CDW crossed the isobath of 50 meter depth from point A northeastward broadly. However, it did not come near Jeju Island. In 2000, it passed the isobath northeastward from point A. In 2001, we see that it expanded to the Yellow Sea exceptionally. In 2002 and 2003, they were all much the same as that in 2000 except for width of the CDW. Therefore, paths of the CDW can be divided into 3 groups; southeastward in 1998, northeastward in 2000, 2002 and 2003, north-northeastward in 2001.

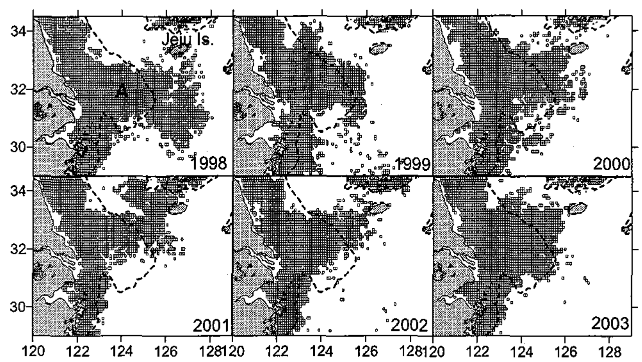

Figure 2. Composites of four weekly mapped images of high concentration of chlorophyll *a* (>2.0mg/m^3) by SeaWiFS in August from 1998 to 2003. Rectangle indicates that chlorophyll *a* concentration at the point was more than 2.0mg/m^3 at least once in August. Dashed lines represent the depth of 50 meters.

3.2 Paths by surface salnity

Since one of principal characteristic of the CDW is low salinity, the CDW can be analyzed by surface salinity distribution. Fig. 3 shows yearly horizontal distribution of surface salinity in August from 1998 to 2003 in the South Sea of Korea and the northern part of the ECS. Although Su and Weng (1994) presented rather high salinity of 31.0-32.0 as the boundary of the CDW, Kim *et al.* (1991) and Hur *et al.* (1999) defined the salinity of the CDW as less than 30 in their analyses. Accordingly it is reasonable that paths of the CDW are classified by the isohaline of 30 psu from horizontal distribution of surface salinity.

In 1998, the isohaline run parallel with the latitude of 33°N generally and extpanded to east of Jeju Island. In other words, the CDW occupied south of Jeju Island broadly. On the other hand, the isohaline run meridional roughly and was close to the isobath of 50 meter depth in 1999. In 2000, the CDW occupied southwest of Jeju Island, a little to south. In particular, it expanded to northwest of Jeju Island in 2001. In 2002 and 2003, we see that the distributions were similar with that in 2000 roughly. Therefore, paths of the CDW also can be divided into 3 groups; eastward in 1998, northeastward in 2000, 2002 and 2003, north-northeastward in 2001.

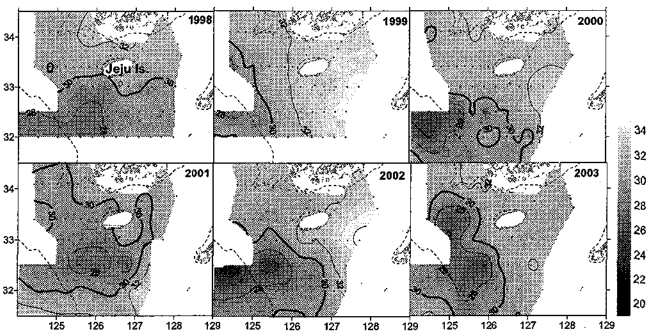

Figure 3. Horizontal distribution of surface salinity in the northeastern part of the East China Sea in August from 1998 to 2003. Dashed and solid lines represent the depth of 50 meters and isohaline respectively.

4. CONCLUSION

By the analysis of historical data over 40 years, Hur *et al.* (1999) showed that the CDW spreads eastward into the Korea/Tsushima Strait gradually from April to September. The CDW paths in summer which are known as northeastward flow toward the Korea/Tsushima Strait in general were classified in detail by ocean color and surface salinity from 1998 to 2003. Though there was the difference between classifications, they were very similar on the whole. That is, this similarity confirmed the capability of tracing the CDW by ocean color calculated by OC4v4 algorithm. On the other hand, the difference was caused by survey period and spatial coverage. In case of surface salinity, survey periods were about 10 days and shorter than that of ocean color. Spatial coverage was also limited in northeastern part of the ECS. Therefore, eastward flow in 1998 by surface salinity seemed to be southeastward flow. Putting the two results together, the CDW flowed northeastward toward Jeju Island of Korea for the most part, and southeastward in 1998 and north-northeastward in 2001 particularly. Besides, the CDW did not approach near Jeju Island of Korea in 1999. In conclusion, the CDW in summer from 1998 to 2003 flowed within the range of direction from southeastward to north-northeastward anticlockwise as shown in Fig. 4.
Prior to path variability of the CDW in summer, the difference of CDW paths in summer and winter has been a subject for many researchers (Mao and Guan, 1982; Le, 1984; Pu and Xu, 1983; Beardsley *et al.*, 1985; Wang, 1988; Zhao, 1992; Hu, 1994; Guan, 1994; Lie *et al.*, 2003; Pang *et al.*, 2003). Principal factors of the seasonal change of the CDW paths are the CR discharge, monsoonal wind, background currents, bottom topography, and tide. Although all the factors seem to be favorable for flow to the Korea/Tsushima Strait in summer, it is clear that the key factors have seasonality. Therefore, the key factors are likely to be the CR discharge, wind and background currents. Although path variability of the CDW in summer is relatively smaller than seasonal change of the CDW path, it also requires that the influence of major factors such as surface wind, the CR discharge and background current on path variability of the CDW in summer should be examined.

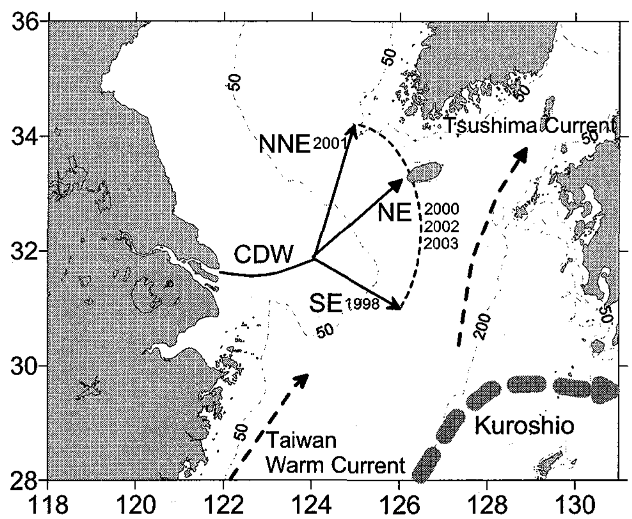

Figure 4. Path variability of the Changjiang Diluted Water in summer.

5. REFERENCES

Beardsley, R. C., R. Limeburner, H. Yu and G. A. Cannon, 1985. Discharge of the Changjiang(Yantze River) into the East China Sea, *Cont. Shelf. Res.*, 4: 57-76.

Choi, H.-Y., 2001. Oceanographic condition of the coastal area between Narodo Is. and Sorido Is. in the southern sea of Korea and its relation to the disappearance of red-tide observed in summer 1998, *'The Sea' J. Korean Soc. Oceanogr.*, 6(2): 49-62.

Dzwonkowski, B., X-H. Yan, 2005. Tracking of a Chesapeake Bay estuarine outflow plume with satellite-based ocean color data. *Continental Shelf Research,* 25: 1942-1958.

Guan, B.-X., 1994. Patterns and structures of the currents in Bohai, Huanghai and East China Seas. In Oceanology of China Seas, Volume 1, ed. by D. Zhou *et al.*, Kluwer Academic Publishers, Netherlands, 17-26.

Hu, D.-X., 1994. Some striking features of circulation in Huanghai Sea and East China Sea. In Oceanology of China Seas, Volume 1, ed. by D. Zhou *et al.*, Kluwer Academic Publishers, Netherlands, 27-38.

Hur, H. B., G. A. Jacobs, and J. Teague, 1999. Monthly variations of water masses in the Yellow and East China Seas, November 6, 1998. *J. Oceanogr.*, 55: 171-184.

Huret, M., I. Dadou, F. Dumas, P. Lazure, V. Garcon, 2005. Coupling physical and biogeochemical processes in the Rio de la Plata plume. *Continental Shelf Research*, 25: 629-653.

Kim, K., K. R. Kim, T. S. Rhee, and H. K. Rho, 1991. Identification of water masses in the Yellow Sea and the East China Sea by cluster analysis. p253-267 In Oceanogrpahy of Asian Marginal Seas, ed. by K. Takano, Elsevior, Amsterdam.

Kim, S. S., W.-J. Go, Y.-J. Jo, P.-Y. Lee, and K.-A. Jeon, 1998. Low salinity anomaly and nutrient distribution at surface waters of the south sea of Korea during 1996 summer(in Korean with English abstract). *'The Sea' J. Korean Soc. Oceanogr.*, 3(3): 165-169.

Kiyomoto, Y., K. Iseki and K. Okamura, 2001. Ocean color satellite imaginary and shipboard measurements of chlorophyll a and suspended particulate matter distribution in the East China Sea. *J. Oceanogr.*, 57: 37-45.

Kondo, M., 1985. Oceanographic investigations of fishery grounds in the East China Sea I. Characteristics of the mean temperature and salinity distributions measured at 50 m and near the bottom, *Bull. Seikai. Reg. Fish. Res. Lab.*, 62: 19-66

Le, K., 1984. A preliminary study of the basis hydrographic features and the current structures off the Changjiang River mouth in the dry season, *Progress in Oceanography*, 21: 387-400.

Lie, H.-J., C.-H. Cho, J.-H. Lee, and S. Lee, 2003. Structure and eastward of the Changjiang river plume in the East China Sea. *J. Geophys. Res.*, 108, 3077, doi:10.1029/2001JC001194.

Mao, H. L. and B. Guan, 1982. A note on the circulation of the East China Sea. *Chinese Journal of Oceanography and Limnology*, 1, 5-16

Nitani, H., 1972. Beginning of the Kuroshio. In Kuroshio, ed. by Stommel and Yoshida, Univ. Tokyo Press, Japan, 129-163.

Pang, I.-C., K.-H. Hyun, J.-H. Moon, and C.-S. Hong, 2003. Changjiang coastal water around Cheju Island in summer and its cause. International Symposium on Oceanographic Environmental Change after Completion of the Changjiang (Yangtze River) Three Gorges Dam, May 15, 2003, Cheju, Korea, 136-143.

Pu, Y. and X. Xu, 1983. The expansion of diluted water in the Changjiang River as seen from the variations in the runoff water, level and salinity. *Marine Science Bulletin* (in Chinese), 2:1-7.

Su, Y.-S. and X.-C. Weng, 1994. Water masses in China Seas. In Oceanology of China Seas, Volume 1, ed. by D. Zhou et al., Kluwer Academic Publishers, Netherlands, 3-16.

Uda, M., 1934. The results of simultaneous oceanographical investigations in the Japan Sea and its adjacent waters in May and June, 1932. *Japan Imp. Fish. Exp. Stations*, 5: 57-190.

Wang, B.-D., X.-L. Wang and R. Zhan, 2003. Nutrient conditions in the Yellow Sea and the East China Sea. *Estuarine Coastal and Shelf Science*, 58: 127-136.

Wang, W., 1988. Yangtze brackish water plume-circulation and diffusion. *Progress in Oceanography*, 21: 373-385.

Yang, J. S., H.-Y. Choi, H. J. Jeong, J. Y. Jeong, and J. K. Park, 2000. The outbreak of red tides in the coastal waters off Kohung, Chonnam Korea: 1. Physical and Chemical characteristics in 1997(in Korean with English abstract), *'The Sea' J. Korean Soc. Oceanogr.*, 5(1): 16-26.

Zhao, B., 1992. Turning mechanism problems of the Changjiang River diluted water. *Acta Oceanologica Sinica*, 11(3): 317-329.