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Detection of Low Salinity Water in the Northern East China Sea During Summer using Ocean Color Remote Sensing

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Abstract : In the summer of 1998-2001, a huge flood occurred in the Yangtze River in the eastern China. Low salinity water less than 28 psu from the river was detected around the southwestern part of the Jeju Island, which is located in the southern part of the Korean Peninsula. We studied how to detect low salinity water from the Yangtze River, that cause a terrible damage to the Korean fisheries. We established a relationships between low salinity at surface, turbid water from the Yangtze River and digital ocean color remotely sensed data of SeaWiFS sensor in the northern East China Sea, in the summer of 1998, 1999, 2000 and 2001. The salinity charts of the northern East China Sea were created by regeneration of the satellite ocean color data using the empirical formula from the relationships between *in situ* low salinity, *in situ* measured turbid water with transparency and SeaWiFS ocean color data (normalized water leaving radiance of 490 nm/555 nm).

Key Words : Salinity, Ocean Color, Remote Sensing, Yangtze River, SeaWiFS.

1. Introduction

The East China Sea is an important area not only as a good fishing ground but also as a nursery and spawning area for many kinds of fishes. A great variety of marine environments are encountered in the northern East China Sea specially, ranging from the Kuroshio-dominated edge of the Pacific Basin to the shallow, run off-freshened water reaching to the Yellow Sea and East China Sea. There are severe atmospheric forcing and time-grained-sediment fluxes on the vast span of shallow water less than 100m depth.

During the summer season, the overall heating of the surface water and the following stratification of surface layer water does not allow convection to mix up the sea water from the surface to the bottom. Therefore, the surface temperatures are considerably higher in August ; 27~29°C, but the surface salinities are much lower in August ; 25~28 psu in the East China Sea because of the run off from the Yangtze River with turbid fresh water (Chikuni, 1985).

The Yangtze River Valley is the well-known site for disastrous floods in 1990, 1911, 1915, 1931, 1935, 1950, 1954, 1959, 1991 and 1998. The worst Yangtze River Flood occurred in the summer of 1931, which was after the drought of 1928~'30, that had killed more than 3.7

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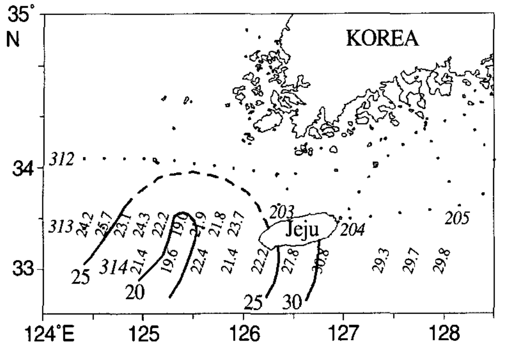

Fig. 1. Distribution of the measured field surface salinity (psu) around the waters of Jeju Island in August, 1996.

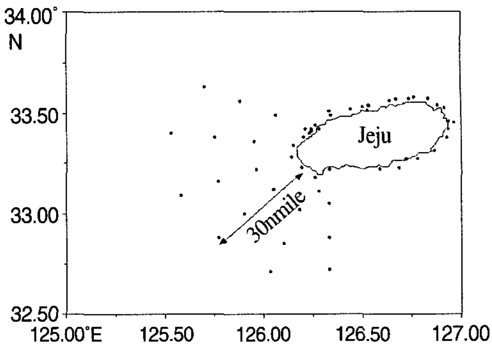

Fig. 2-1. Map showing the extended coastal stations for monitoring low salinity water around the Jeju Island in summer season since 1997.

million people. In July and August, floods from torrential rains killed 3.7 million people by drowning, disease and starvation. The flood affected 51 million people a quarter of Chinas population at that time (Cox, 2000).

In the summer of 1996, low salinity water less than 19 psu from the Yangtze River, hit the coastal water around the Jeju Island which is located in the southern part of the Korean Peninsula (Fig. 1). Marine organisms around the coastal area of the Jeju island were severely damaged by low salinity water. The damage was amounted to 6 million US dollar by just one occurrence in 1996. After that occurrence, Korean National Fisheries Research and Development Institute (NFRDI) had to set up the monitoring system on semi-real time base and the surveys were carried out using research vessels since 1997 (Fig. 2-1, 2-2). However, we need real time monitoring system to detect the distribution of low salinity water around the waters of the Jeju Island.

The salinity itself has no direct colour signal. However, Monahan and Pybus (1978) showed that yellow substance (the optically active component of dissolved organic carbon, DOC) in waters off the West Coast of Ireland could be related to salinity through the colour signal. There were relationships between optical properties of coastal water and salinity observed in fields. Spatial distributions of surface salinity matched the Secchi depth and the water colour determined using

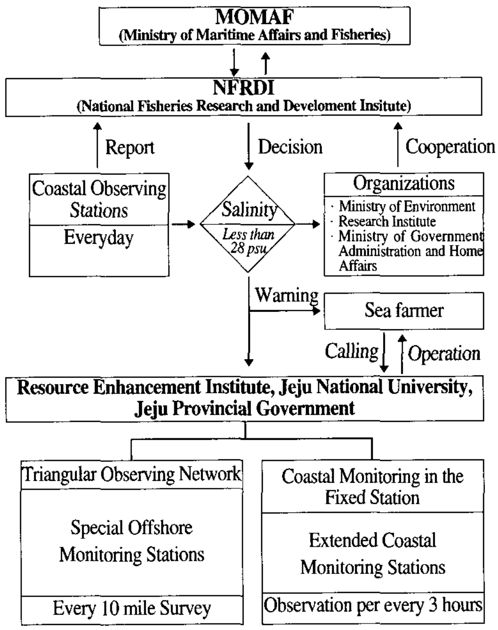

Fig. 2-2. Observing system for monitoring of low salinity off Jeju Island since 1997.

Forel scale (Steen and Hoguance, 1990; Hoguance, 1997). A negative relationship between salinity and yellow substance was found in the Kattegat of the Baltic Sea by Højerslev et al. (1996).

The aim of this study is to relate the low salinity of the northern part of East China Sea to the turbid water from the Yangtze River using satellite ocean color data

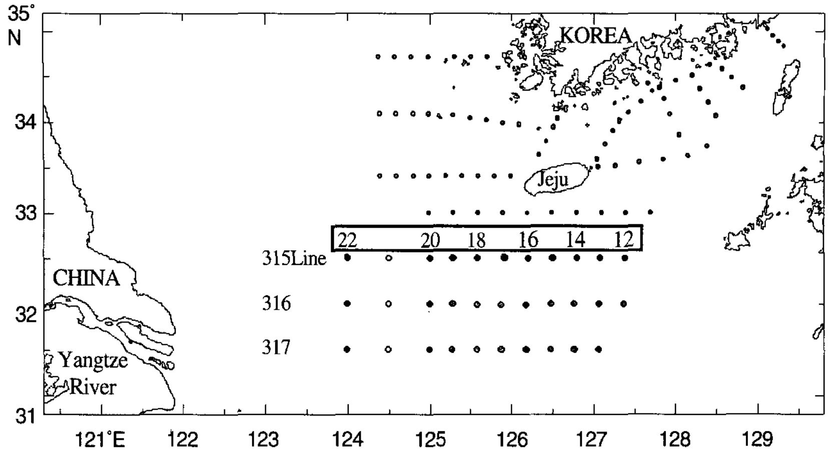

Fig. 3. Station map of the NFRDI research cruise.

2. Materials and methods

The oceanographic data including temperature (°C), salinity (psu, Practical Salinity Unit), transparency (m) and total suspended solid (mg/*l*) were collected in August 1996～2001 on board research vessels of the NFRDI in Korea (Fig. 3). The particulate filters were weighed to give a measure of suspended solid (SS) in every other observing station. Secchi depths (transparencies) were measured using a standard white Secchi disc at daytime. The data of colour bands from SeaWiFS sensor were received through the antenna located at NFRDI for 4 years (1998~2001).

To relate the satellite ocean color to *in situ* salinity, we tried to get several empirical relationships between *in situ* SS, transparency and *in situ* salinity, and between *in situ* SS, transparency and the ocean color band ratio (490nm/550nm) in normalized water leaving radiances(nLw) from SeaWiFS sensor.

3. Results

First of all, there was relationship between *in situ* SS and *in situ* transparency in the East China Sea in 2000

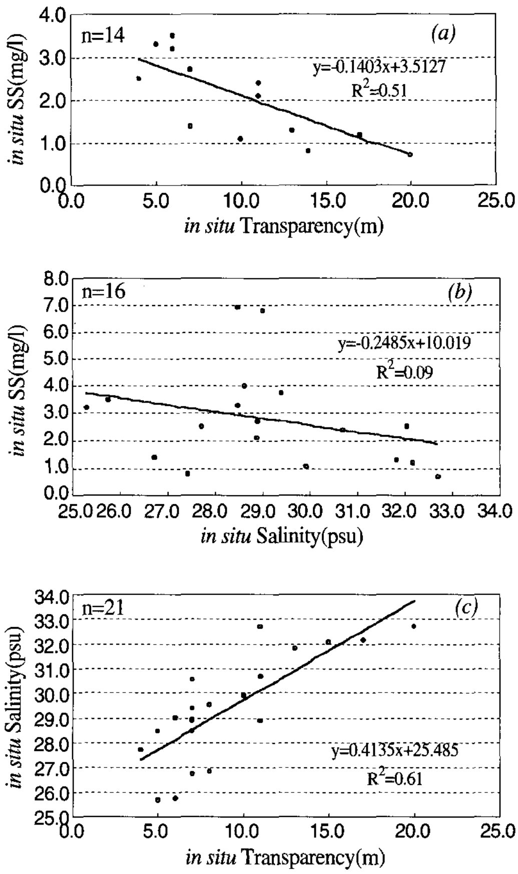

Fig. 4. (a) Relationship between *in situ* suspended solid (SS) and transparency in the northern part of the East China Sea in August, 2000. Relationship between (b) suspended solid, (c) transparency and salinity.

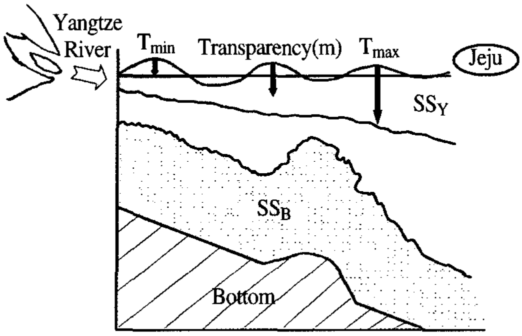

Fig. 5. Schematic diagram of the vertical distribution of resuspended solid from the shallow bottom and surface suspended solid from the Yangtze River. SS_Y represents the surface turbid water from the Yangtze River. SS_B represents resuspended sediment from sea-bottom caused by sea wave. Estimated transparency is very high in the waters around Jeju Island than one in the coastal water of the Yangtze River.

(Fig. 4(a)). The relationship between *in situ* SS and *in situ* salinity in the East China Sea was not obvious (Fig. 4(b)), because most of the total suspended solid come from the bottom layer in the southern Yellow Sea. Even though most SS come from the bottom, the surface turbid water from the Yangtze River was detected by transparency parameter related to the optical water property from the upper side to the bottom side in Fig. 4(c) and like the schematic diagram of Fig. 5. Actually, we found that good relationships between *in situ* surface salinity and *in situ* transparency in the northern part of the East China Sea in 1996, 2000 and 1996~2001, as mentioned below and shown figure 6.

$$Salinity_{in\ situ} = 1.9024 \times transparency + 6.648,\ (n = 11, R^2 = 0.70) \text{ in 1996.}$$

$$Salinity_{in\ situ} = 0.4135 \times transparency + 25.485,\ (n = 22, R^2 = 0.61) \text{ in 2000.}$$

$$Salinity_{in\ situ} = 0.3844 \times transparency + 26.600,\ (n = 66, R^2 = 0.58) \text{ for 6 years (1996~2001).}$$

However it was difficult to find out the match up data between *in situ* data and SeaWiFS satellite data during

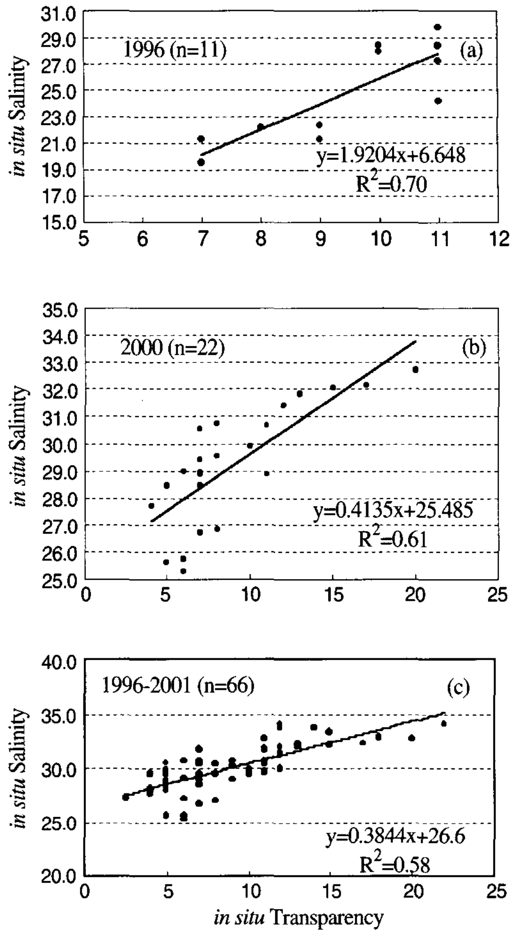

Fig. 6. Relationship between the measured salinity (psu) and the *in situ* transparency (m) in August (a)1996, (b)2000 and (c)the years (1996~2001).

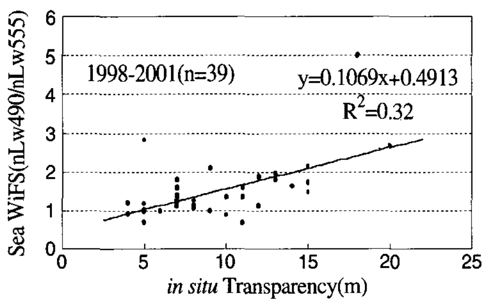

Fig. 7. Relationship between the measured field transparency (m) and the band ratio (nLw490/nLw555) from the SeaWiFS satellite. 39 data sets for transparency were matched between NFRDI's vessel and SeaWiFS satellite in same spatio-temporal domain within 3 days and 2 km^2 since the last 4 years, 1998~2001.

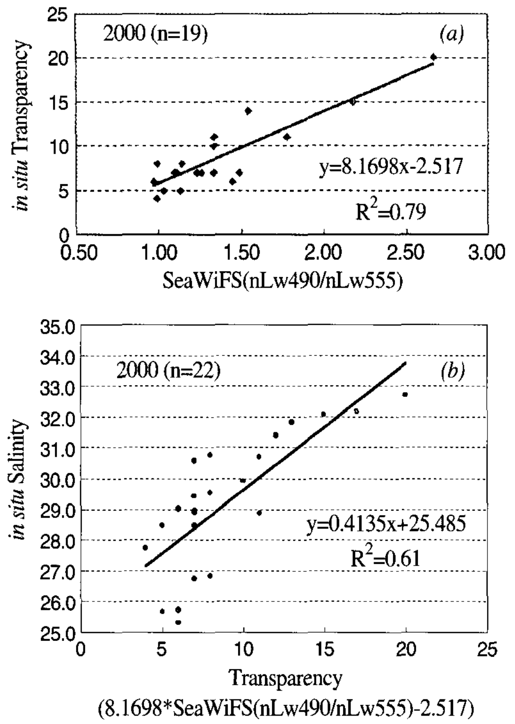

Fig. 8. Relationship between (a) the in situ transparency (m), (b) the in situ salinity (psu) and the estimated transparency using the band ratio (nLw490/nLw555) from the SeaWiFS satellite in same spatio-temporal domain in August 6th, 2000.

(a) Match up data sets (19 numbers) between the measured transparency from NFRDI's vessel and band ratio (nLw 490/nLw 555) from SeaWiFS.

(b) Match up data sets(22 numbers) between the measured salinity from NFRDI's vessel and the estimated transparency related to the SeaWiFS band ratio.

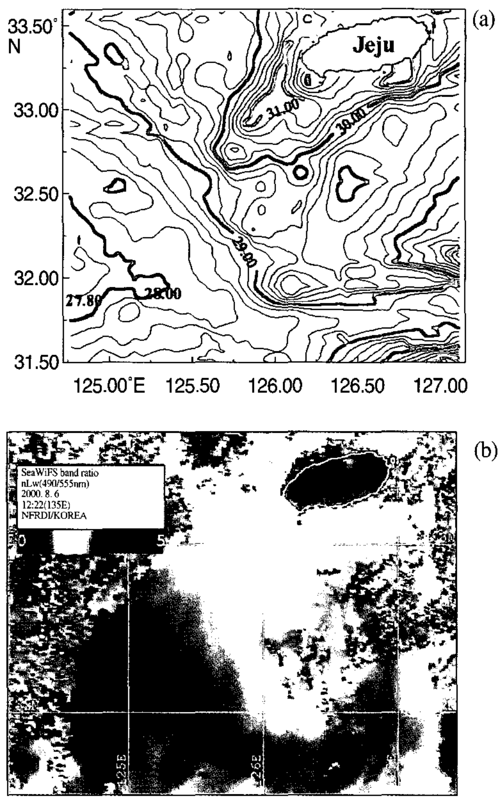

Fig. 9. (a) Distribution of the estimated surface salinity (psu) using the satellite ocean color data with the formula from the relationships between *in situ* salinity, transparency (m) and (b) SeaWiFS band ratio (nLw490/nLw555) around the waters of Jeju Island in August 6, 2000.

the past. 39 data sets for transparency were matched up between NFRDIs vessel and SeaWiFS satellite in same spatio-temporal domain within 3 days and 2 km2 since the last 4 years (1998~2001) (Fig. 7).

In case of August 2000, the close relationship between the *in situ* transparency and the ratio of SeaWiFS normalized water leaving radiance (nLw490/ nLw555) was obtained using 19 matched up data for just one year, 2000. Therefore, we were able to set up the simple algorithm related to estimating salinity, using the relationship between *in situ* salinity and the estimated transparency (8.1698 × SeaWiFS (nLw490/ nLw555) − 2.517) with the band ratio (nLw490/nLw555) from the SeaWiFS (Fig. 8). When we used only this relationship (Salinity $_{(psu)}$ = 0.4135(8.1698 × SeaWiFS (nLw490/nLw555)2.517) + 25.485, R^2= 0.61) in 2000 among the other relationships during 1998 ~ 2001, we were able to generate the distribution chart of surface salinity using SeaWiFS data with 1 km spatial resolution in August 6, 2000 (Fig. 9).

The distribution of low salinity water in the East China Sea was generated by developing a simple algorithm in this study in August in 1998, 1999, 2000 and 2001 (Fig. 10a′, b′, c′ and d′). The result of

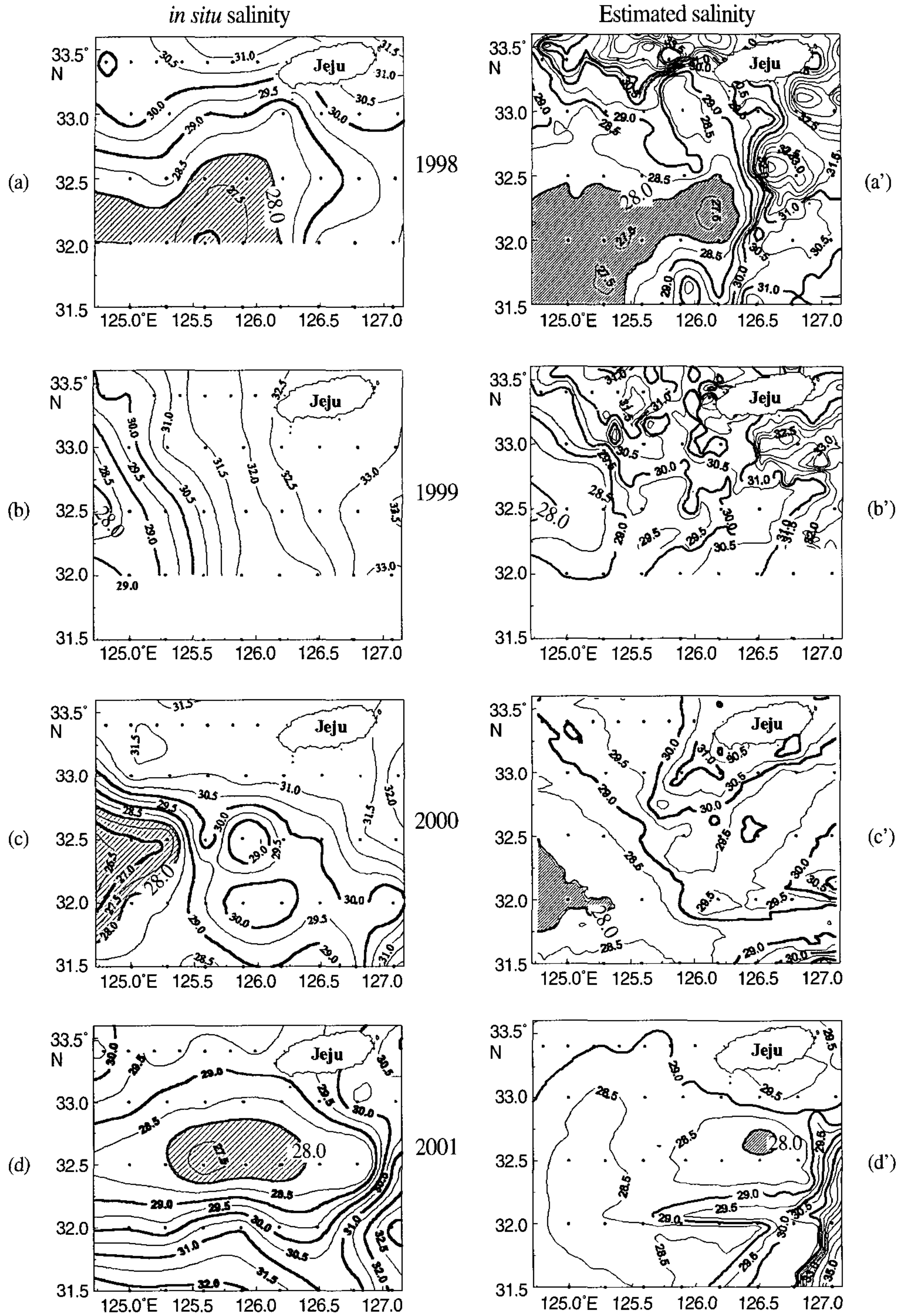

Fig. 10. Distribution of surface salinity (psu) in August during 1998-2001. Measured field surface salinity in (a) 6-8 Aug., 1998, (b) 12-20 Aug., 1999, (c) 4-6 Aug., 2000, (d) 17-23 Aug., 2001. Estimated surface salinity from the SeaWiFS data using the developed regional algorithm in (a') 4 Aug., 1998, (b') 19 Aug., 1999, (c') 6 Aug., 2000, (d') 16 Aug., 2001.

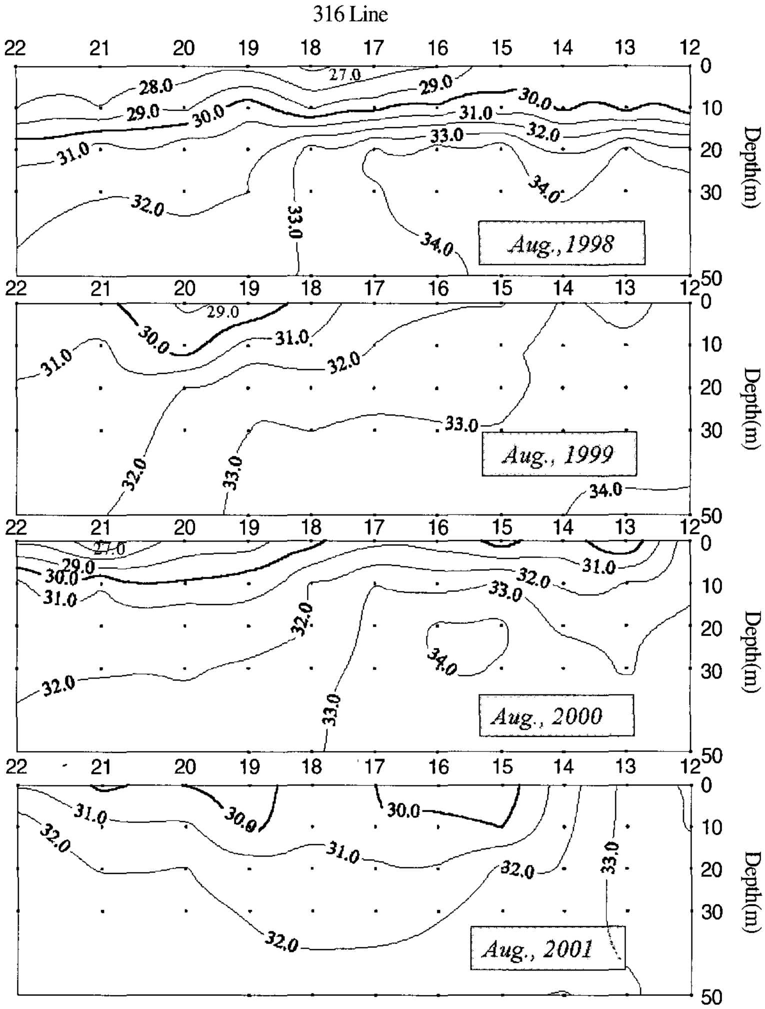

Fig. 11. Vertical distribution of salinity (psu) at 316 oceanographic observing line in the northern part of the East China Sea.

comparison between the estimated salinity derived from the ocean color satellite and the *in situ* salinity at the stations located between Yangtze River and the waters of Jeju Island, are shown in figure 10. The distribution of 28.00 psu isohaline in the field around Jeju Island on 6~8 August, 1998 (Fig. 10a) was very similar to the one the estimated salinity from satellite data on 4th August, 1998 (Fig. 10a′). The distribution of 29.00 isohaline in the field in 12~20 August, 1999 (Fig. 10b) was similar to the one the estimated salinity on 19th August, 1999 (Fig. 10b′). However, some parts of the East China Sea were covered with clouds. Therefore, SeaWiFS ocean color imagery was not good enough to estimate salinity. The distribution of 28.00 psu isohaline in the field in 4~6 August, 2000 (Fig. 10c) was similar to the one in the estimated salinity on 6th August, 2000 (Fig. 10c′). The distributions of 28.00 and 28.50 psu isohalines in the field in 17~23 August, 2001 were similar to those in the estimated salinity on 16th August, 2001.

The horizontal and vertical distributions of 28 psu

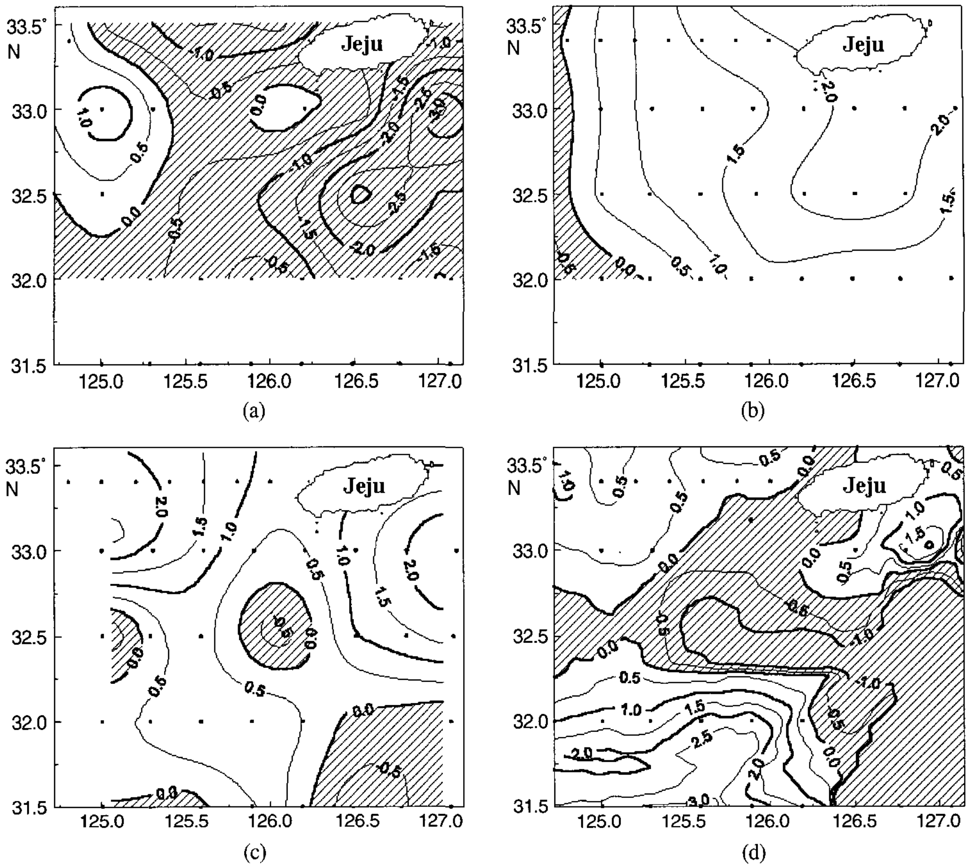

Fig. 12. Horizontal distribution of the differences in salinity (psu) between the measured salinity in field and the estimated one from satellite data in (a) 1998, (b) 1999, (c) 2000 and (d) 2001.

isohaline in the field were wider in 1998 and 2000 than those of 1999 and 2001 (Fig. 10, Fig. 11). The accuracies were around 0.5 ~ 1.0 psu in the western waters of Jeju. However, the highest error ranges (1.5 ~ 3.0 psu) occurred in some part of the southeastern waters of Jeju, the Kuroshio current region (Fig. 12).

4. Conclusions

The resource of the terrestrial sediment material in the deep-water area of the southern Yellow Sea was mainly originated from the abandoned Yellow River and the modern Yellow River. The amount range of surface total suspended solid (SS) was 0.6 to 13.30 mg/*l*. The SS content of the bottom ranged from 1.28 to 209.44 mg/*l* which was the highest SS content value in the water column. Obviously, the main reason was resuspension of sediments caused by sea wave (Cai *et al.*, 2001; Lee *et al.*, 2003). However, we were able to detect the main dilution waters from the Yangtze River using the oceanographic parameter of transparency, which was distinguished from the resuspension of sediments in the seabed.

Our study area, the offshore of the Yangtze River, where turbid waters originated from the Yangtze River

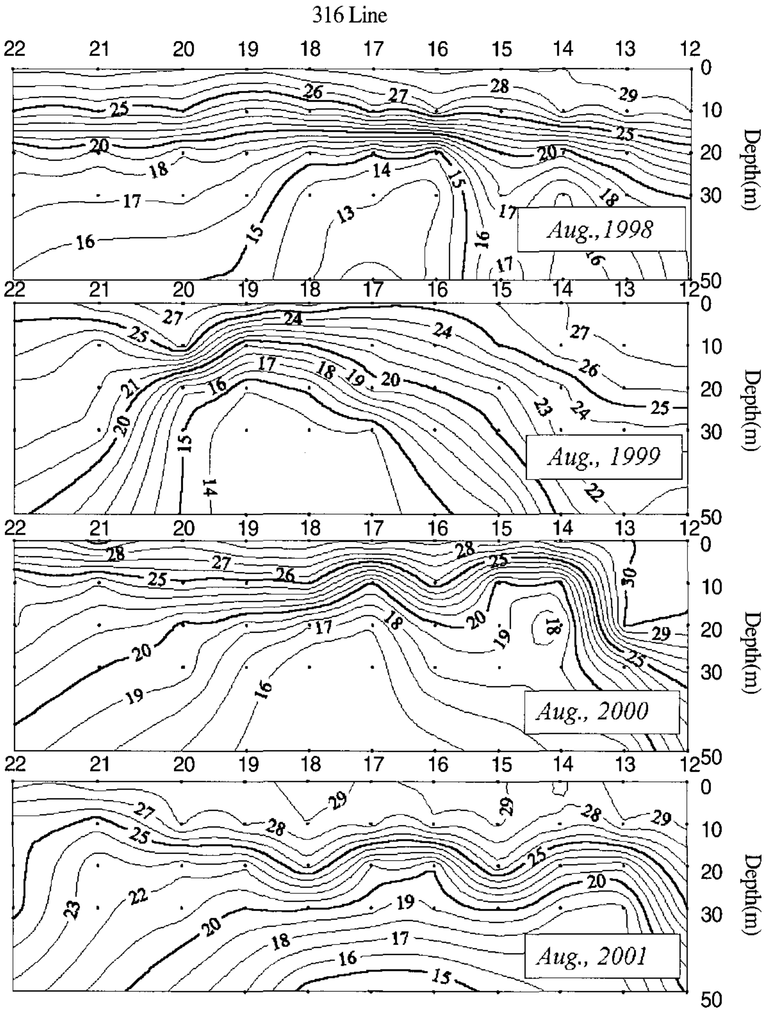

Fig. 13. Vertical distribution of temperature (°C) at 316 oceanographic observing line in the northern part of the East China Sea.

meet with the clear Kuroshio warm waters which Secchi depths is about 25m. These kind of oceanic conditions in the study area make an ideal region for the salinity detection using ocean color. Therefore, the detection of salinity through an optical signal (the estimated transparency from ocean color satellite) due to yellow turbid water from the Yangtze River would be a sensible approach to monitor the low salinity in the northern part of the East China Sea during every summer season.

The reason, why the vertical and horizontal distributions of 28 psu isoline in the *in situ* field and the satellite estimated field were wider in 1998 and 2000 than those of 1999 and 2001, is due the presence of very strong thermocline at about 10 m depth in the western part of 316 observing station (32 N) in 1998 and 2000 (Fig. 13). We think that the strong thermocline prevented low salinity in surface layer water from mixing with high salinity in deep layer water.

A simple algorithm, using in the relationships between the measured salinity, transparency and the reflectance ratio of SeaWiFS, shows good agreement with the real salinity distribution, which thereby confirms our hypothesis. The developed algorithm will be useful for early detection and quantification of the change in surface salinity densities, of the East China Sea in summer season.

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