Salt water intrusion in the Mekong River estuary, Vietnam: Observation at low flow season in May 2005

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Abstract

Salt water intrusion in the Mekong River, Vietnam, was studied using a towing type echo-sounder (Model SC-3) and water quality meter (TPM CLOROTEC) observation instruments during spring tide of the low flow season in May, 2005. Observations were taken at two stations located at points 26 and 8 km from the river mouth. Measurements were taken at hourly intervals for 24 hours during one week, using several instruments set on the river bottom. A joint towing observation system using echo-sounder and water quality meters has been proved its usefulness for analyzing the time-space behavior of salt intrusion in the Mekong River. Precise measurements of tide-related phenomena including water level, bottom currents and water quality (temperature, salinity, turbidity and chlorophyll-a) at two stations revealed detailed movements of the saline water-mass.

Key words: Acoustic reflection profiling system, Mekong River, salinity, salt water intrusion, tidal change.

Introduction

Our group has observed salt intrusion in the Co Chien River, a tributary of the Mekong River, Vietnam, on several occasions during 2000 to 2002. The work was based mainly on

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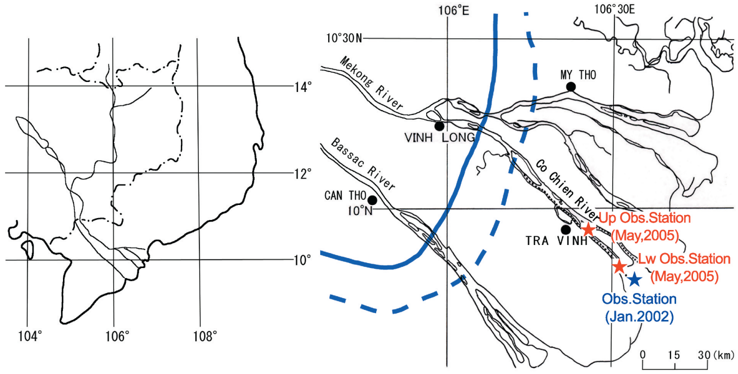


Fig. 1. Index map. The Up and Lw observation stations at May, 2005 in the Co Chien River are shown by the red stars. Surface intrusion limits of salt water in the Mekong River by Gagliano and McIntyre (1968) and by Nguyen et al. (1994) are shown by the solid blue (1 ‰, psu) and dashed blue lines (4‰, psu), respectively.

echo-sounding survey, and confirmed the usefulness of the method for understanding the time-space distribution of saline intrusion (Tateishi et al., 2006). Following these studies, we attempted a more comprehensive survey of salt intrusion in the same river, at spring tide during the low flow season in May, 2005. The method utilized various instruments, including echo-sounding survey. The results are described in this paper.

Surface intrusion of 400 ppm salt, which is approximately equivalent to the contact between freshwater and salt water, was first depicted as a seasonal isohaline map by Gaglinano and McIntire (1968). Intrusion of salt water was also reported in the Vietnam Hydrometeorological Atlas by Nguyen et al. (1994) as the limits of maximum salinity of 1 and 4 PSU (Fig. 1). It is generally known that the surface salt water intrusion in the Mekong River reaches more than 50 km inland in the low flow season, compared with less than 20 km in the high flow season. The extent of salt water intrusion has a pronounced effect on sediment, soils, vegetation, and agriculture. Nguyen et al. (2000) described recent salt water intrusion in the low flow season, based on Hydrometeological Center of Vietnam data.

Precise observation of salt intrusion in the Mekong River estuary has been reported by Wolanski et al. (1966) for the high flow season, and by Wolanski et al. (1998) for the low flow season in the Bassac River. Vertical profiles of temperature, salinity and suspended sediment concentration were analyzed at stations spread over a channel about 50 km in length in the downstream reaches. Time series observations for 13 hours were also taken at two stations in these studies. They reported that a salt wedge was present in the high flow season, but was flushed out of the mouth of the estuary at low tide. In the low flow season, saline intrusion extended about 50 km upstream, with vertical stratification in salinity.

Tateishi et al. (2006) reported salt intrusion in the Co Chien River in 2000 to 2002, mainly on echo-sounding survey, but also supported by water quality instruments. A conceptual illustration of salt water intrusion was proposed. In the intermediate flow season, at ebb tide salt water was present only downstream of a mound situated 8 km from the river mouth. However, intrusion progressed upstream beyond a mound situated at 14 km toward flood tide. Conversely, in the low flow season, salt water was strongly mixed, and toward flood tide reached as far as a mound situated 28 km from the river mouth. It may also have entered a pool located around 33 km from the river mouth.

Observation methods

We have systematically observed saline intrusion in the Co Chien River. Our observations were mainly based on an acoustic reflection profiling system developed from spatial distribution surveys of haloclines (Model SC-3, Senbon Denki Co., Ltd., Tokuoka et al., 2001; Nishimura et al., 2001). This system was made by improvement of a 200 kHz precision echo-sounder. The system measures reflection amplitude, and detects the weak reflector caused by the rapid

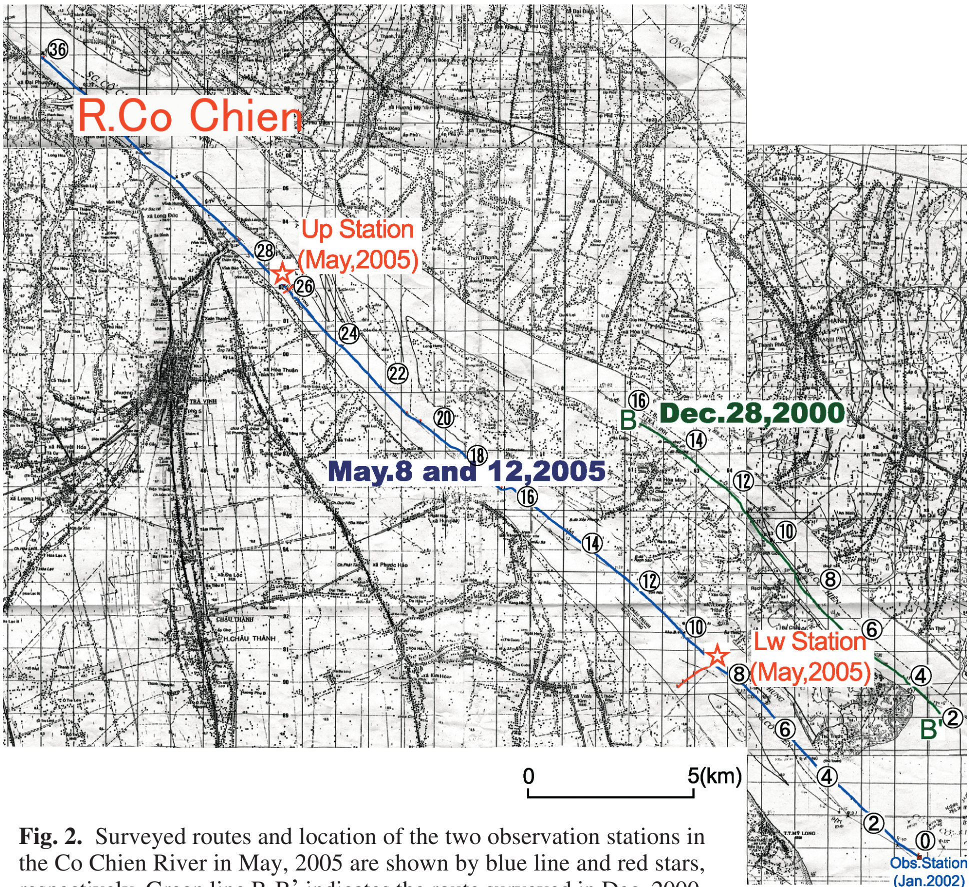


Fig. 2. Surveyed routes and location of the two observation stations in the Co Chien River in May, 2005 are shown by blue line and red stars, respectively. Green line B-B' indicates the route surveyed in Dec. 2000. Circled numbers indicate the distance in km from the river mouth.

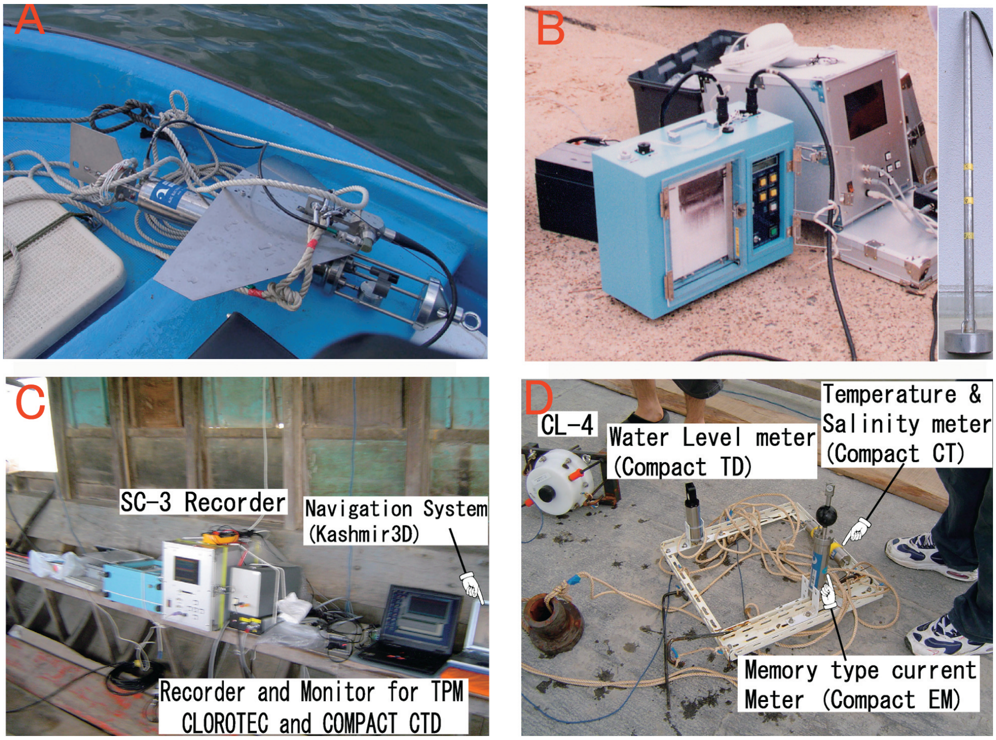


Fig. 3. Various observation instruments. A: Towing water quality meter (TPM CLOROTEC). B: Acoustic reflection profiling halocline system (Model SC-3). C: Recorders of TPM CLOROTEC, SC-3, and GPS navigation system set in the ship.D: Various instruments for measurements of water-level, current direction and speed, temperature, and salinity, as set on the bottom of channel.

change of acoustic impedance at the halocline. Distribution of the halocline and the thickness of the salt water layer can be recorded as profile records. An attempt was made to jointly use a twoing type of water quality instrument (TPM CLOROTEC, Alec electronics, Co., Ltd.) with the echo-sounder. The towing surveys were made three times, along the routes shown in Fig. 2. The numerals in the figure indicate the distance from the initial observation station at the river mouth used in Jan. 2002 (Tateishi et al., 2006). Our observations were also based on several instruments such as water level, current, and water quality meters, positioned at two stations. These were located at the 26 km point (Up Station; UP; Fig.2) and the 8 km point (Lower; Lw). We set these instruments on bottom, and performed all observations within a one week period. Observations were made at both stations at hourly intervals for 24 hours. The instruments are illustrated in Fig. 3.

The above three observations were performed at spring tide during the low flow season in May, 2005.

1. Observations by towing type instruments of echo-sounder (SC-3) and water quality meter (TPM CLOROTEC)

Traversing surveys to clarify salt intrusion were carried out three times using the SC-3 and TPM CLOROTEC. These were; (1) 8 May, 2005, from the Up Station downstream to the 0 km point; (2) in the morning of 12 May, from the Up Station toward the Lw Station; and (3) , in the evening of 12 May, from the 0 km point upstream to the 33 km point, via the Lw and Up Stations.

2. One week observation of water level, bottom currents and water quality at two stations

The instruments used to obtain time series data of water depth (COMPACT TD, Alec-electronics, Co., Ltd.), currents (direction and velocity, COMPACT EM, Alec-electronics, Co., Ltd.) and water quality (temperature and salinity, COMPACT CT, Alec-electronics, Co., Ltd.) were set on the river bottom at the two stations. Temperature and salinity of the upper water layers at both stations were also measured by COMPACT CT. The observation stations and instruments were secured to pile constructed by fishermen for hanging fishing nets .

3. Observations for 24 hours at two stations

Observations for 24 hours at hourly intervals were carried out at the above two stations on 8 to 9 May (Lw Station) and 11 to 12 May (Up Station). The stations were maintained from a boat at anchor. Vertical distribution of temperature, salinity, turbidity and chlorophyll-a were measured by the COMPACT CTD (Alec-electronics, Co., Ltd.). The SC-3 was also used from the boat to obtain echo-profiles of the water mass at each interval.

Results

1. Observations by towing type instruments of echo-sounder (SC-3) and water quality meter (TPM CLOROTEC)

(1) Observation, 8 May, 2005 (Fig. 4)

After setting the instruments at the Up Station, the towing survey began at 11:07 from the 26 km point toward flood tide, heading downstream, and ended at the 0 km point at 14:37 . The echo-sounding profile shown in Fig. 4 suggests strongly mixed salt water conditions prevailed over the entire traverse. The TPM CLOROTEC was maintained at about one meter below the surface. The salinity data obtained gradually increased from 2 PSU at the start point to 20 PSU at the end of the traverse, in accordance with the echo-sounding data. The turbidity and chlorophyll-a data obtained are also shown in the Fig. 4.

(2) Observation, 12 May, 2005 (Figs. 5, 6)

After removing the instruments set at the Up Station, the first survey of 12 May began at 08:55 toward ebb tide, heading downstream from the Up Station, and ending at the Lw stations

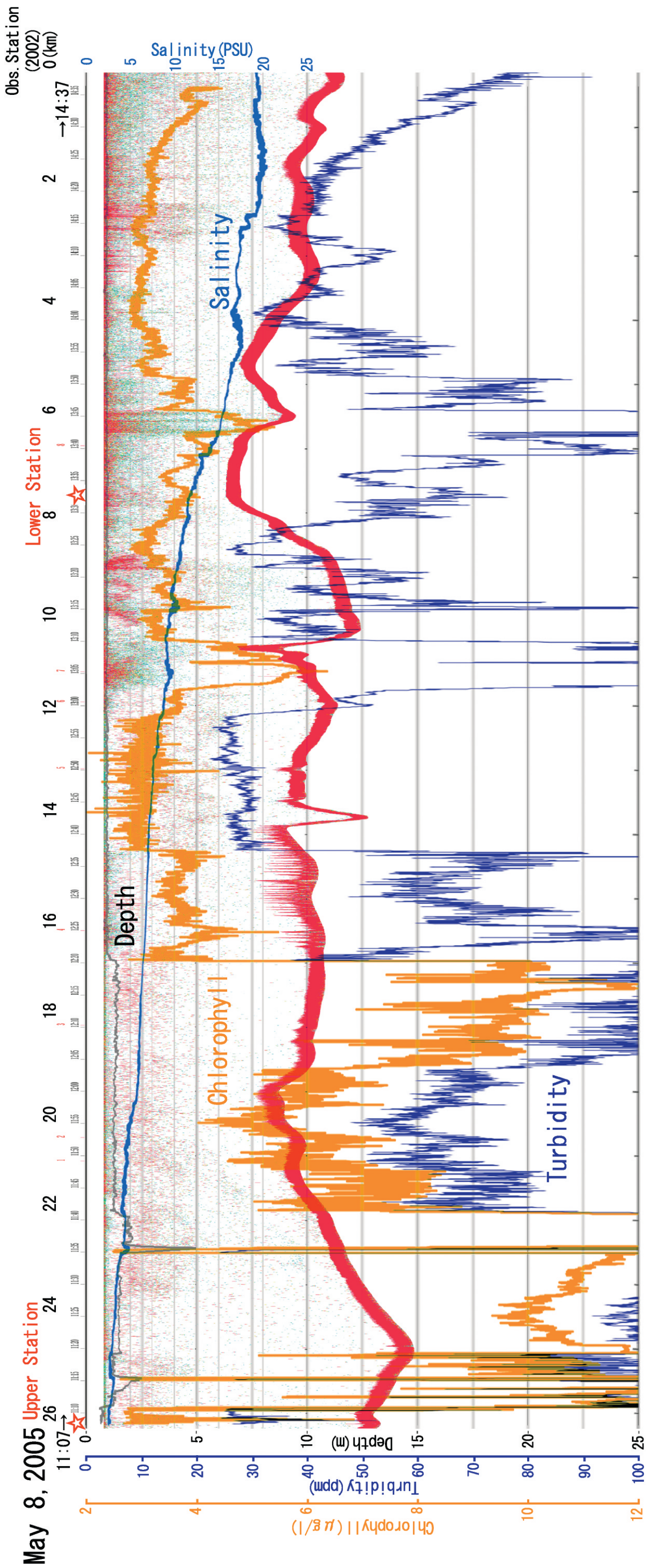


Fig. 4. Echo-sounding profile obtained by the SC-3 echo-sounding instrument and successive changes of temperature, salinity, turbidity and chlorophyll-a, from 11:07 to 14:37, May 8, 2005.

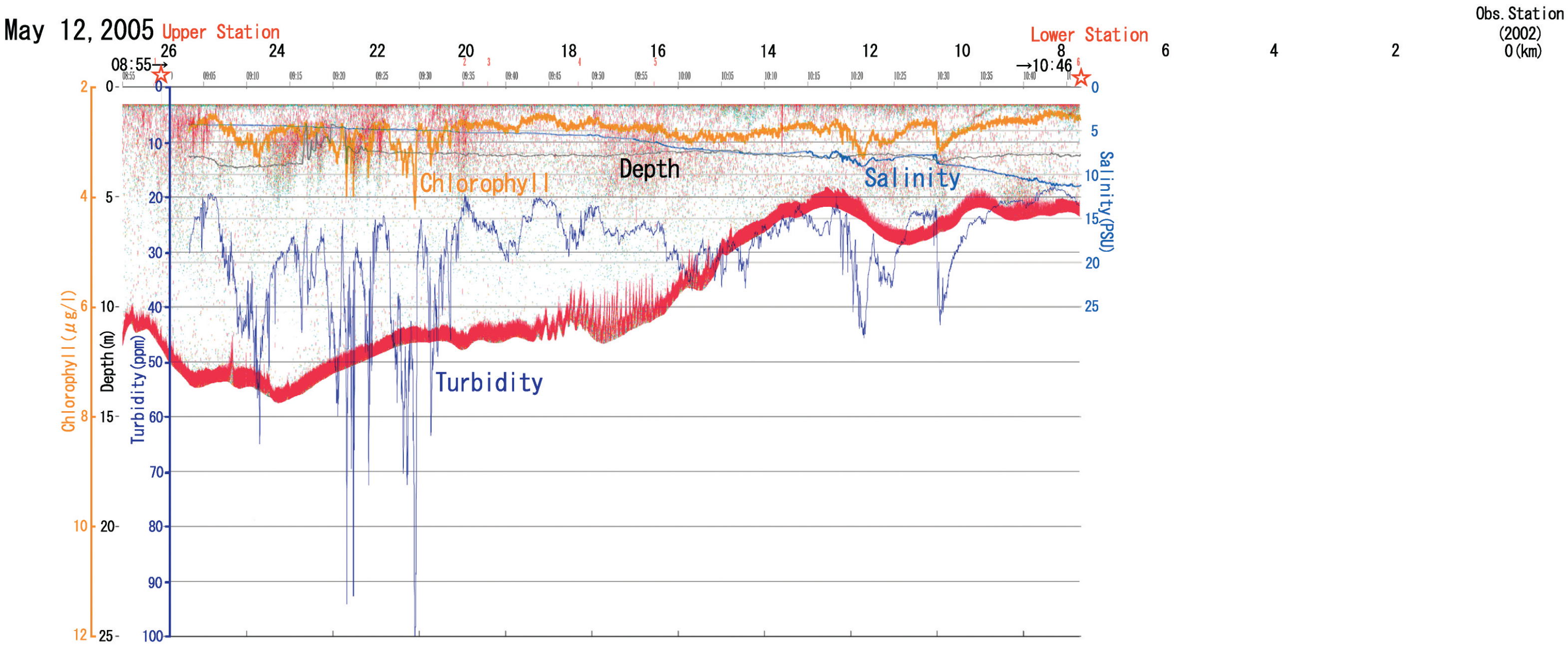


Fig. 5. Echo-sounding profile obtained by the SC-3 echo-sounding instrument and successive changes of temperature, salinity, turbidity, and chlorophyll-a, from 08:55 to 10:46, May 12, 2005.

at 10:46. The data are shown in Fig. 5. The echo-sounding profile suggests strongly mixed salt water conditions were prevailed over the entire traverse. The TPM CLOROTEC was maintained at a depth of about 3 m below the surface. Salinity data gradually increased from 2 PSU at the start point to 12 PSU at the end point, again in accordance with the echo-sounding data. Turbidity and chlorophyll data are also shown in Fig. 5.

The second survey started from the 2002 observation station (Tateishi et al., 2006) toward flood tide at 13:17, after removing the instruments set at the Lw Station, heading upstream to the 36 km point via the Lw and Up Stations, and ending at 17:05. The data are shown in Fig. 6. The echo-sounding data indicated strongly mixed salt water conditions, weakly stratified structures were observed in the downstream reaches. The TPM CLOROTEC was maintained about 3 to 4 m below surface throughout the survey. Salinity data decreased upstream from 22 PSU at the 0 km point to 14 PSU at the 8 km point. In the upstream reaches, salinity data also decreased gradually from 3 PSU at the 18 km point to 2 PSU at the 36 km point. Turbidity and chlorophyll-a data are also shown in the fig. 6. Their behavior was mostly similar to each other. Turbidity tended to increase gradually from 2 ppm at the 24 km point to 4 ppm at the 36 km point.

2. One week observation of water level, bottom currents and water quality at Up and Lw Stations, 8 to 12 May, 2005 (Figs. 7 - 9)

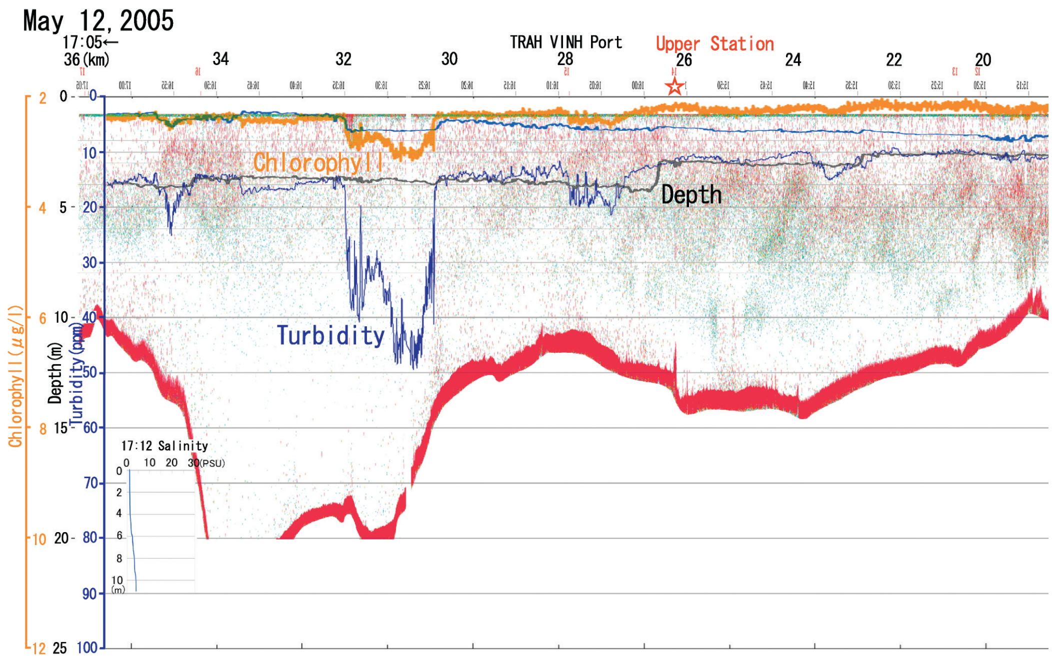


Fig. 6. Echo-sounding profile obtained by the SC-3 echo-sounding instrument and successive

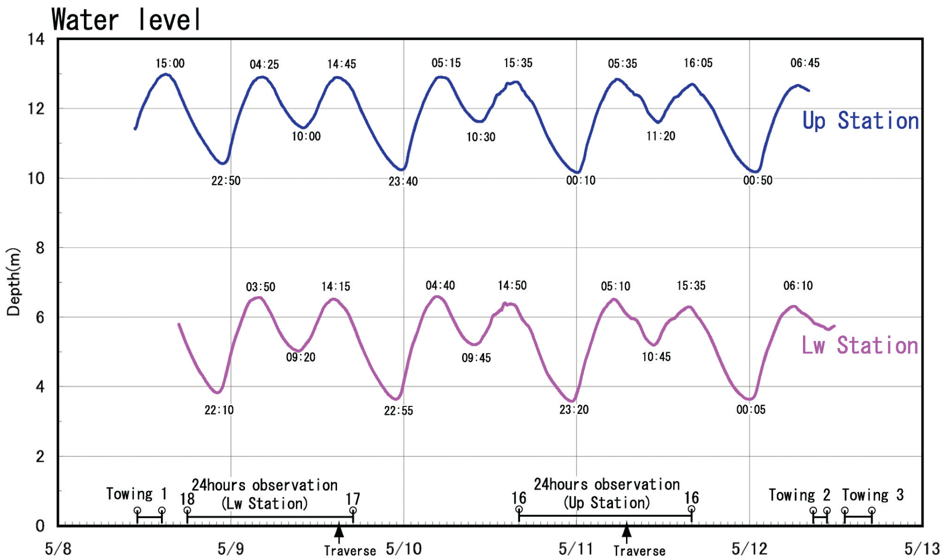
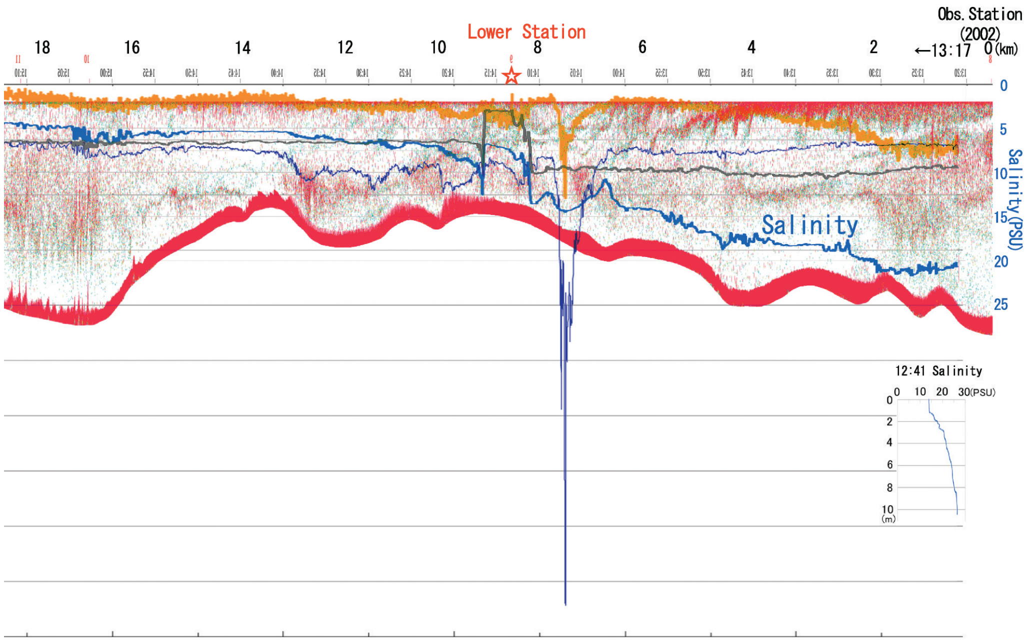


Fig. 7. Time-series plots of the water level at the two observation stations between May 8 and 12, 2005. The time lag of the highest and lowest water level at the Lw and Up stations were evident. Time ranges of the observations by towing SC-3 (- 3 times) and 24 hours observations by water quality instruments at the Up and Lw stations are also indicated in the lower part of the figure.



changes of temperature, salinity, turbidity, and chlorophyll-a, from 13:17 to 17:05, May 12, 2005.

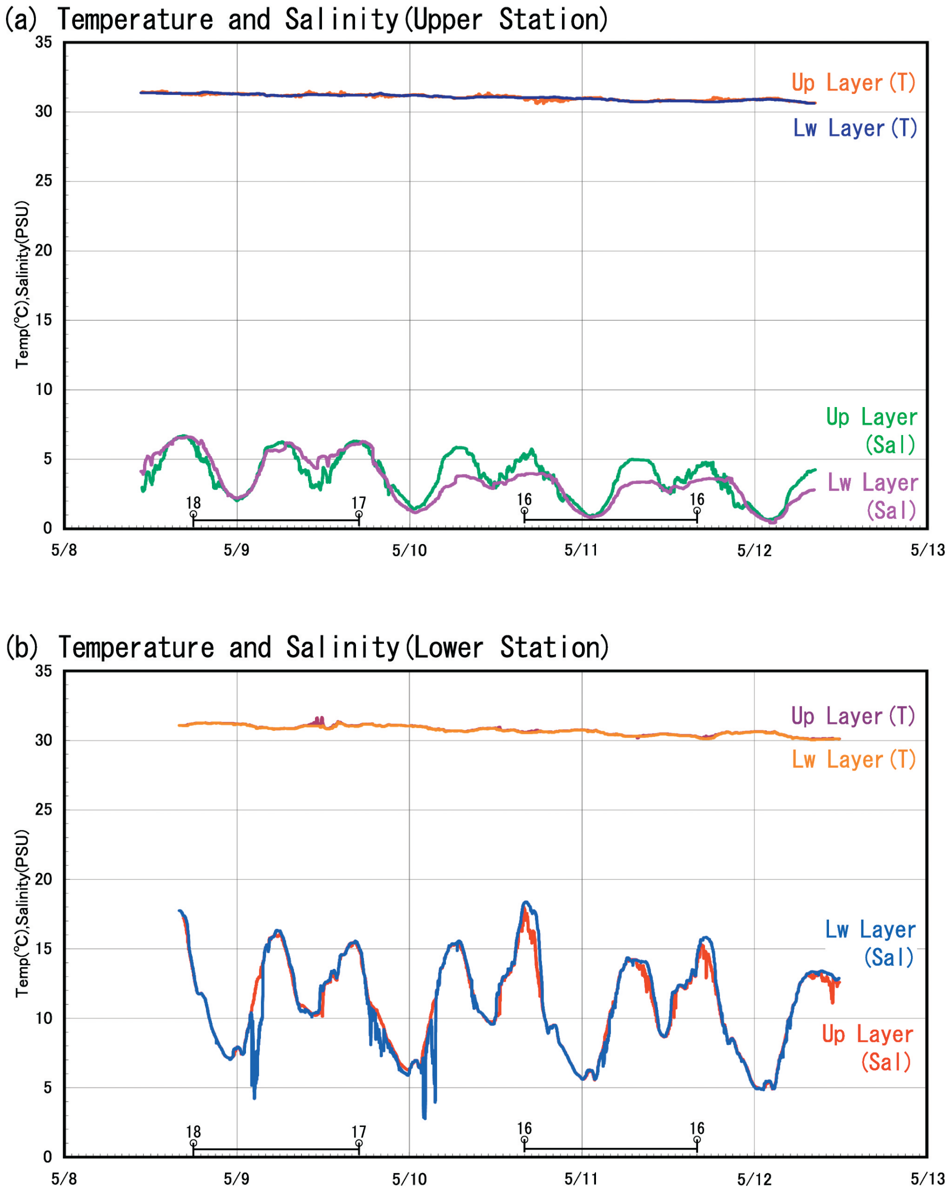


Fig. 8. Time-series plot of temperature (T) and salinity (Sal) at the shallow (Up layer) and bottom depths (Lw layer) of the Up Station (a) and the Lw Station (b) between May 8 and 12, 2005. The temperature isn't changed in the Up and Lw stations in every time. However, the salinities are changeable, especially, in the Lw station.

Time series data of water level, current trend /velocity, temperature and salinity were measured on the river bottom at the Up and Lw stations between 8 and 12 May, 2005. Figure 7 shows that semi-diurnal tides with range of 3 m and a maximum diurnal inequality of

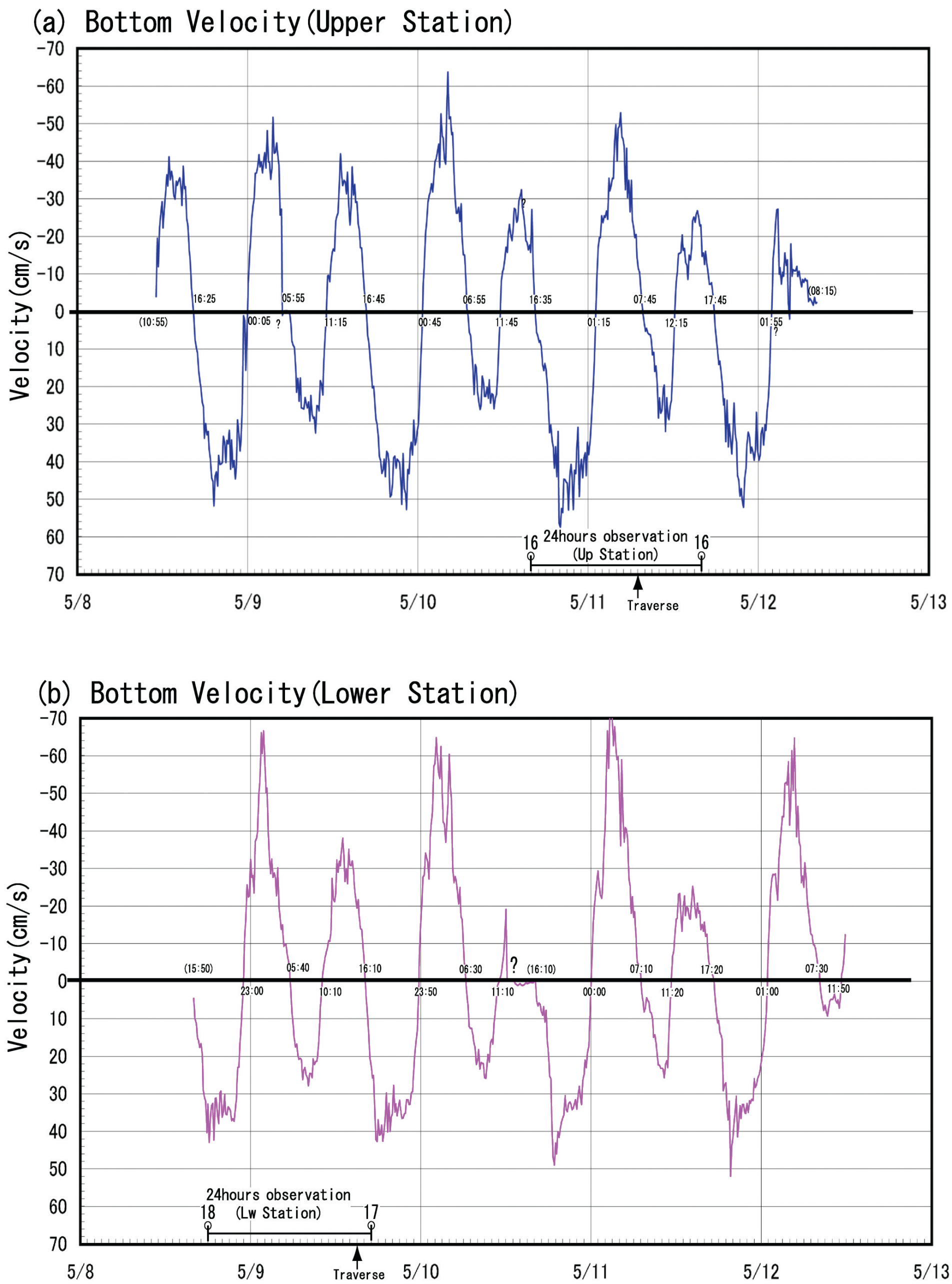


Fig. 9. Time-series plot of the bottom velocity at the Up Station (a) and the Lw Station (b) between May 8 and 12, 2005. The minus and plus velocities show up- and down-currents, respectively.

about 1 m prevailed. The times of floods and ebbs at two stations shown in the figure, indicate time gaps between the two stations. Time series data of temperature and salinity of the upper and bottom layers at both stations are shown in Fig. 8. Data obtained by bottom-set

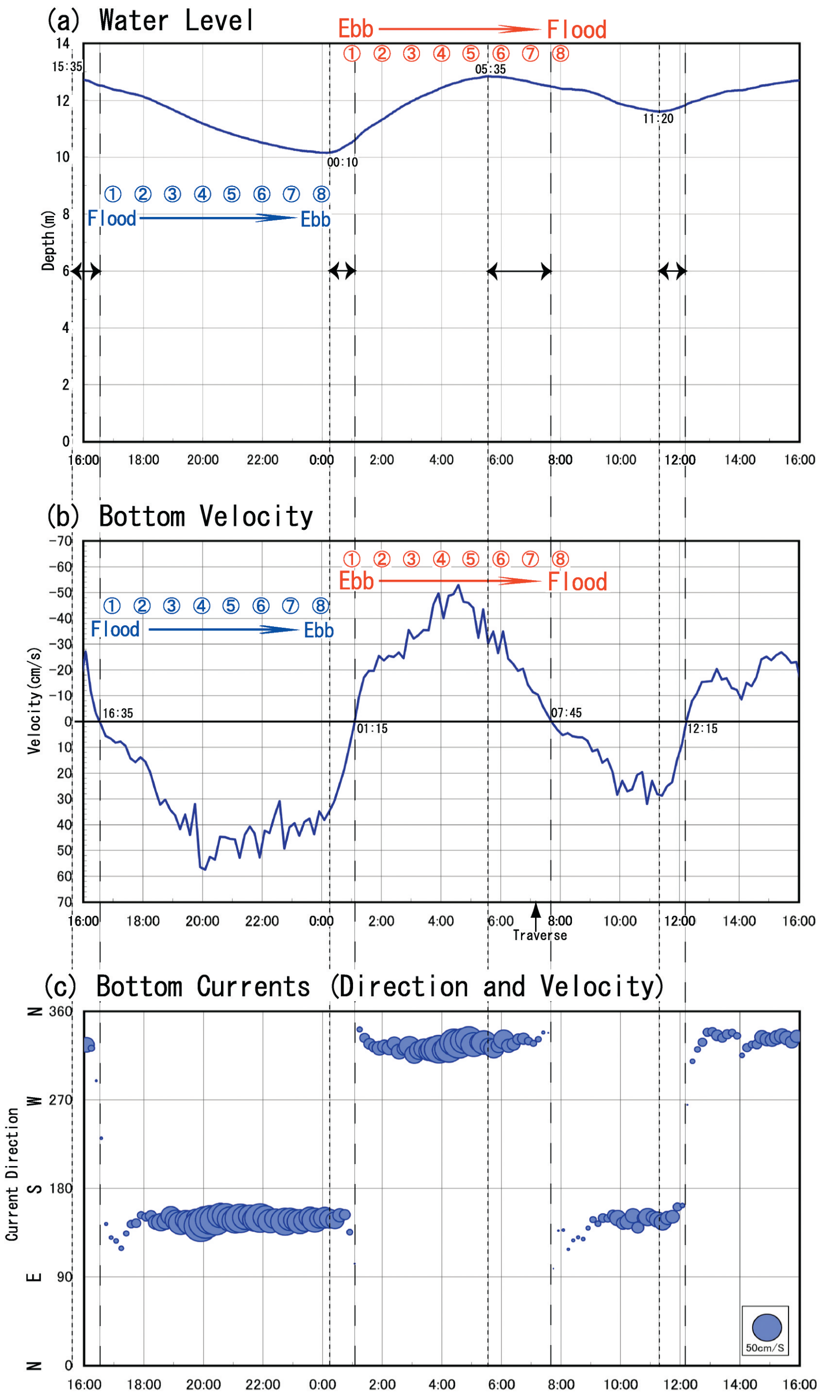


Fig. 10. Time-series plot of (a) water level, (b) bottom velocity and (c) bottom current direction/celocity at the Up station over 24 hours, May 10 to 11, 2005. Circled numbers indicate times from start of flood and ebb tides, when the water quality was measured (Figs. 11, 12). The velocity of bottom current in (c) is shown by the size of circle drawn in the lower right corner.

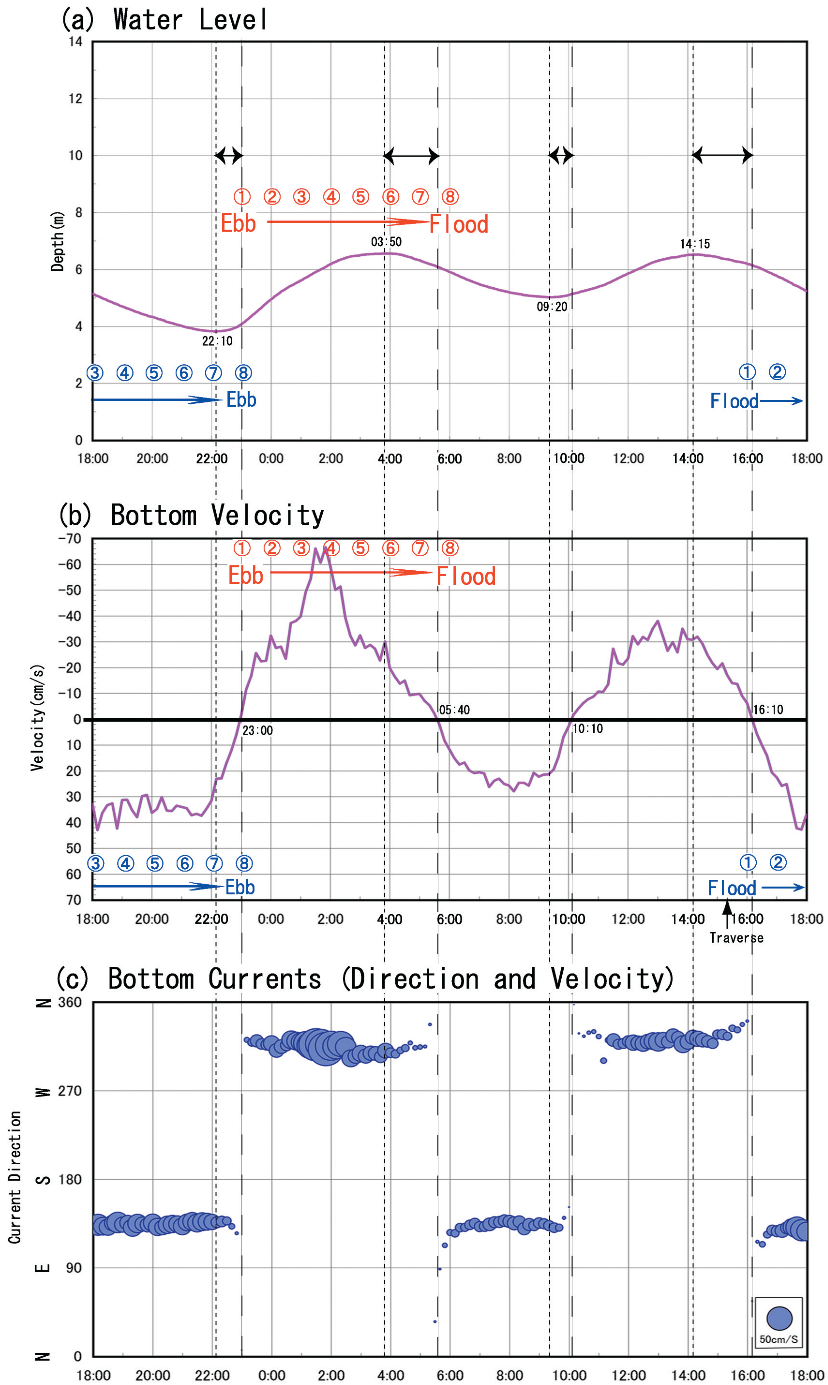
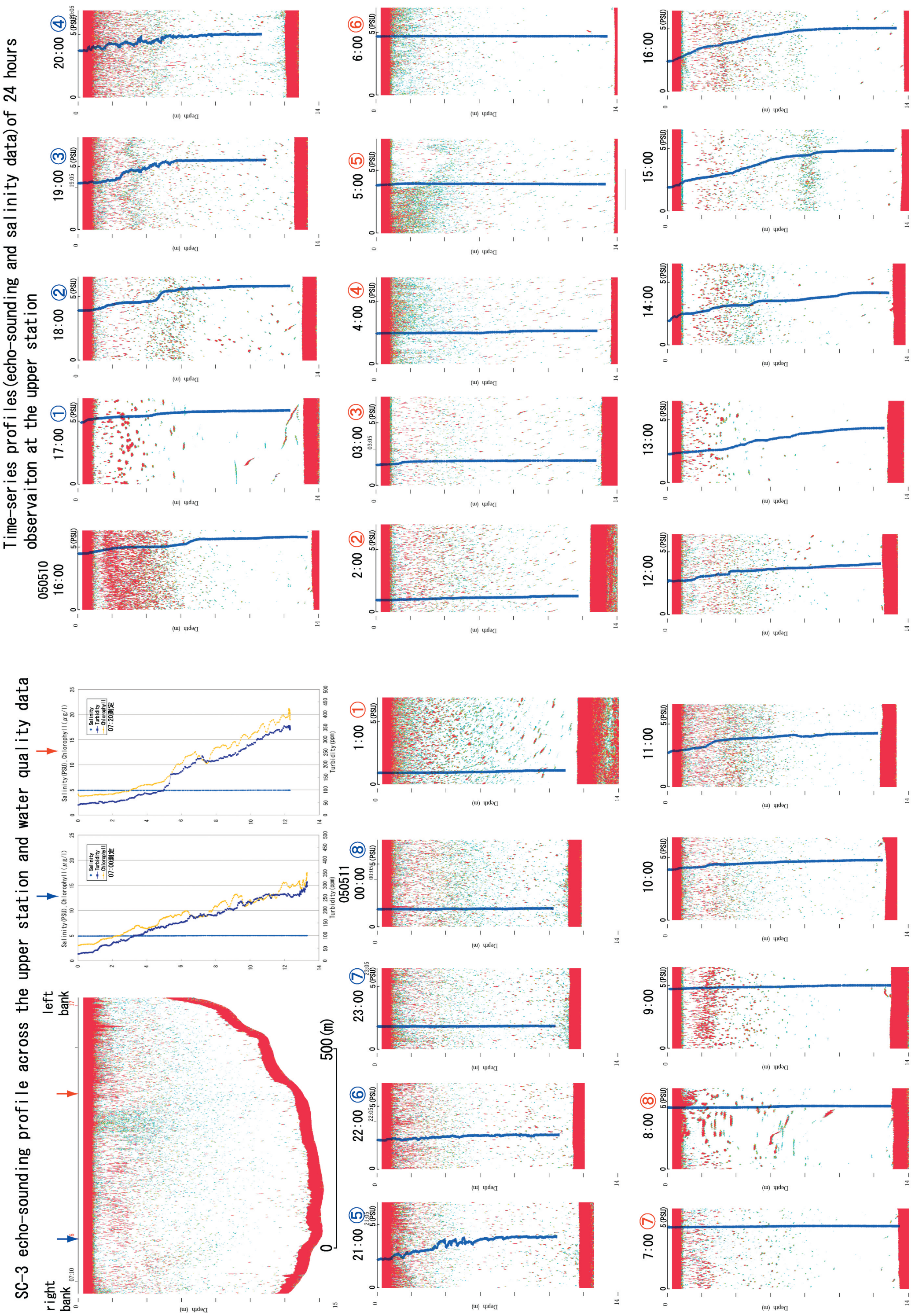


Fig. 11. Time-series plot of (a) water level, (b) bottom velocity and (c) bottom current direction/velocity at the Lw station over 24 hours, May 10 to 11, 2005. Circled numbers indicated times measured the water quality (Figs. 13, 14), and the bottom current velocity in (c) is shown by the size of circle drawn in the lower right corner.


SC-3 echo-sounding profile across the upper station and water quality data
right bank
left bank
0
500(m)
Time-series profiles(echo-sounding and salinity data)of 24 hours observaiton at the upper station
050510 16:00
17:00 ①
18:00 ②
19:00 ③
20:00 ④
21:00 ⑤
22:00 ⑥
23:00 ⑦
050511 00:00 ⑧
1:00 ①
2:00 ②
03:00 ③
4:00 ④
5:00 ⑤
6:00 ⑥
7:00 ⑦
8:00 ⑧
9:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
5(PSU)
Depth (m)

instruments indicated some abnormal time series changes of salinity. This may have been caused by tentatively overlain deposits on the instruments at both stations. In the both layers, temperature is mostly constant around 31-32℃ at both stations. Salinity data obtained by the instruments set in the upper layer at both stations indicated regular time series changes of salinity. Salinity of the upper layer indicated regular changes between flood and ebb tides at both stations, and was always higher at the Lw Station than at the Up Station. Salinity changes of the upper layer were consistent with the water level fluctuations in both stations shown in Fig. 7. These data apparently indicate tidal regression and transgression of strongly mixed and vertically stratified water-masses. Time series data of current velocity on the bottom surface were obtained at both stations (Fig. 9). It is obvious that time gaps existed between high/low water levels (Fig. 7) and flood/ebb tides (Fig. 9). It is notable that up-currents are larger than down-currents at the Lw Station, and that up- and down-currents are mostly equal at the Up Station.

3. Observations for 24 hours at Up Station (8 to 9 May, 2005) and Lw Stations (10 to 11 May, 2005) (Figs. 10 - 15)

Time series data of water level and currents on the bottom of the river at the Up and Lw Stations are shown in Figs. 10 and 11, respectively. Time gaps between high/low water levels and flood/ebb tides indicated by bottom water trend and velocity are clearly recognize in these data.

(1) Upper Station

Echo-sounding profiles and vertical changes of salinity each hour are shown collectively in Fig. 12. A transverse echo-sounding profile across the Up Station is also shown in the same figure, in addition to vertical changes of salinity and chlorophyll-a at two points. Echo-sounding profiles indicated the existence of strongly mixed conditions each hours; this is supported by vertical profiles of salinity. Weak stratification sometimes appeared in the upper layers in several echo-sounding profiles, and also in the salinity profiles. Vertical changes of salinity and turbidity of one tidal cycle (ebb to flood, and flood to ebb) are picked up from the observation data and are shown collectively in Fig. 13. Regular changes of salinity in accordance with tidal changes were apparent. Time series changes of turbidity are also shown in Figure 13. The changes of salinity gradient found in upper layers from flood tide to ebb tide (1 to 5 in the lower part of Fig. 13) were in accordance with the respective echo-sound profiles shown in Fig. 12.

(2) Lower Station

The echo-sounding profiles and vertical change of salinity each hour are shown collectively in

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⬅ **Fig. 12.** Echo-sounding and water quality data obtained during 24 hours observation at the upper station on May 10 to 11, 2005. The cross-section of the Co Chien River and vertical change of salinity, turbidity, and chlorophyll-a measured at 07:00 are also shown at the lower left. The measure time indicated by circled number is shown in Fig. 10.

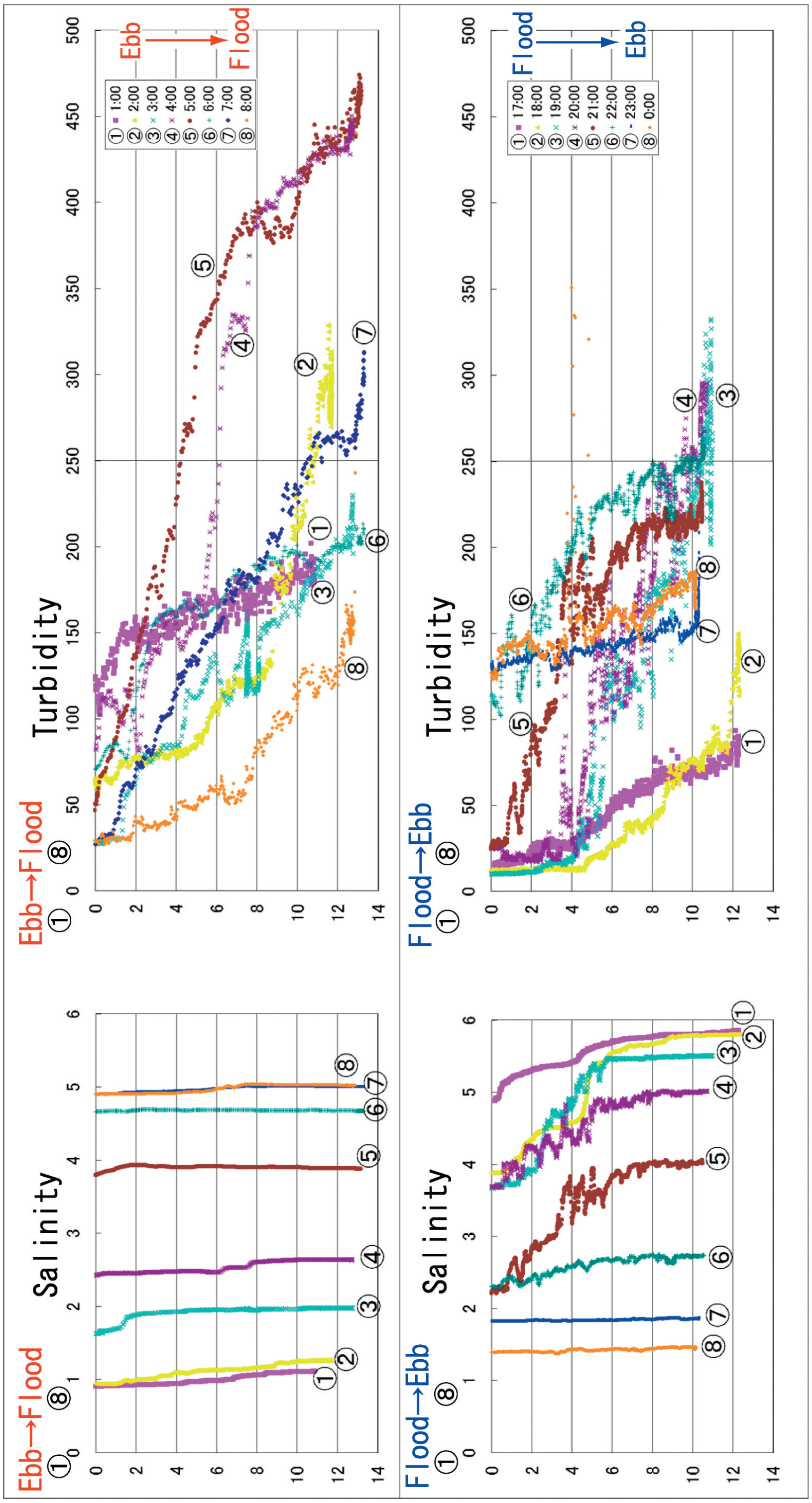

Fig.13. Time-series changes of salinity (left) and turbidity (right) obtained during 24 hours observation at the upper station on May 10 to 11. Circled numbers indicating measure time is shown in Fig. 10.

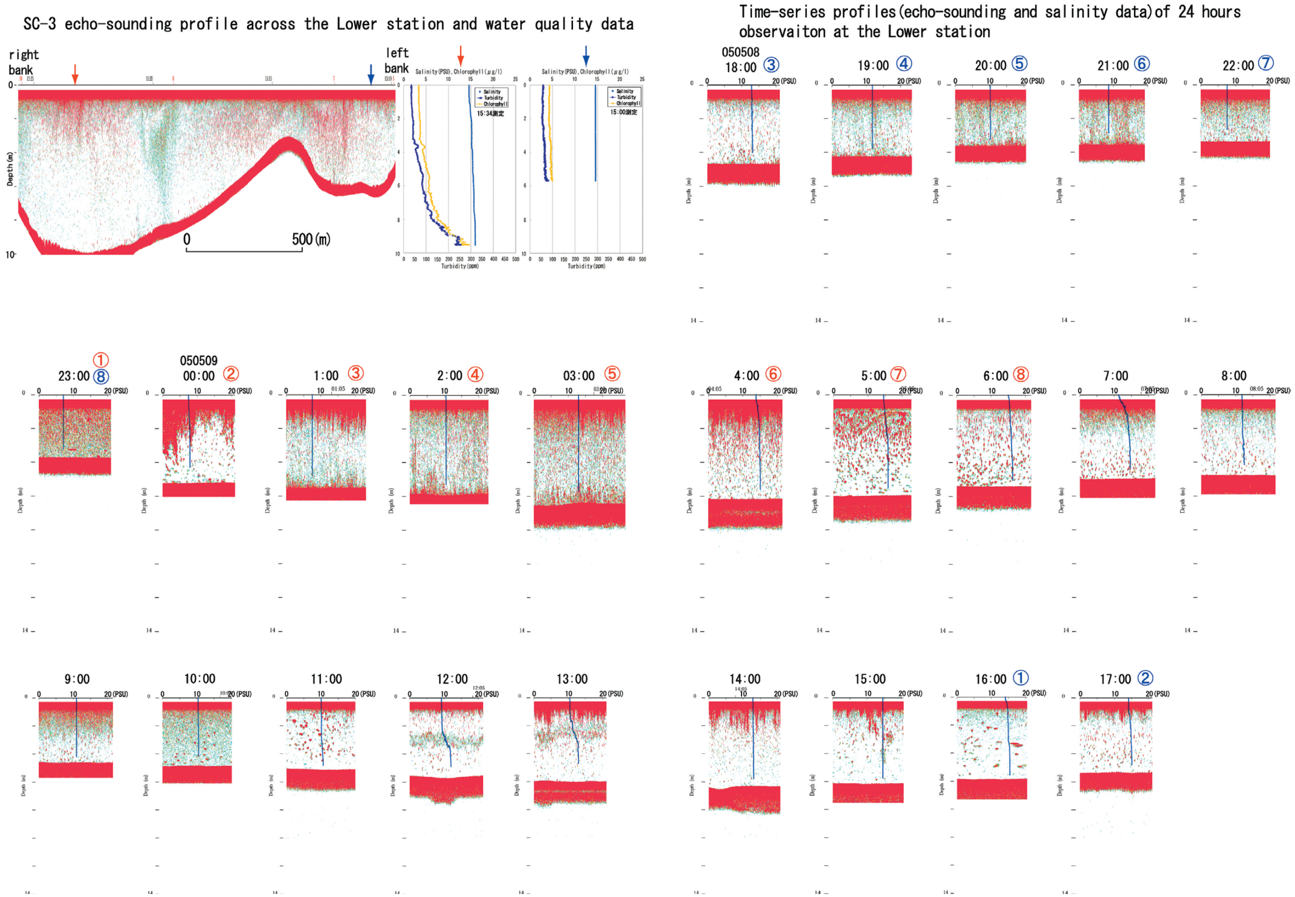

Fig. 14. Echo-sounding and water quality data obtained during 24 hours observation at the lower station on May 8 to 9, 2005. The cross-section of the Co Chien River is shown at the upper left. Vertical change of salinity, turbidity, and chlorophyll-a in the point of blue and red arrows were measured at 15:00 and 16:34, respectively. The measure time indicated by circled numbers is shown in Fig. 11.

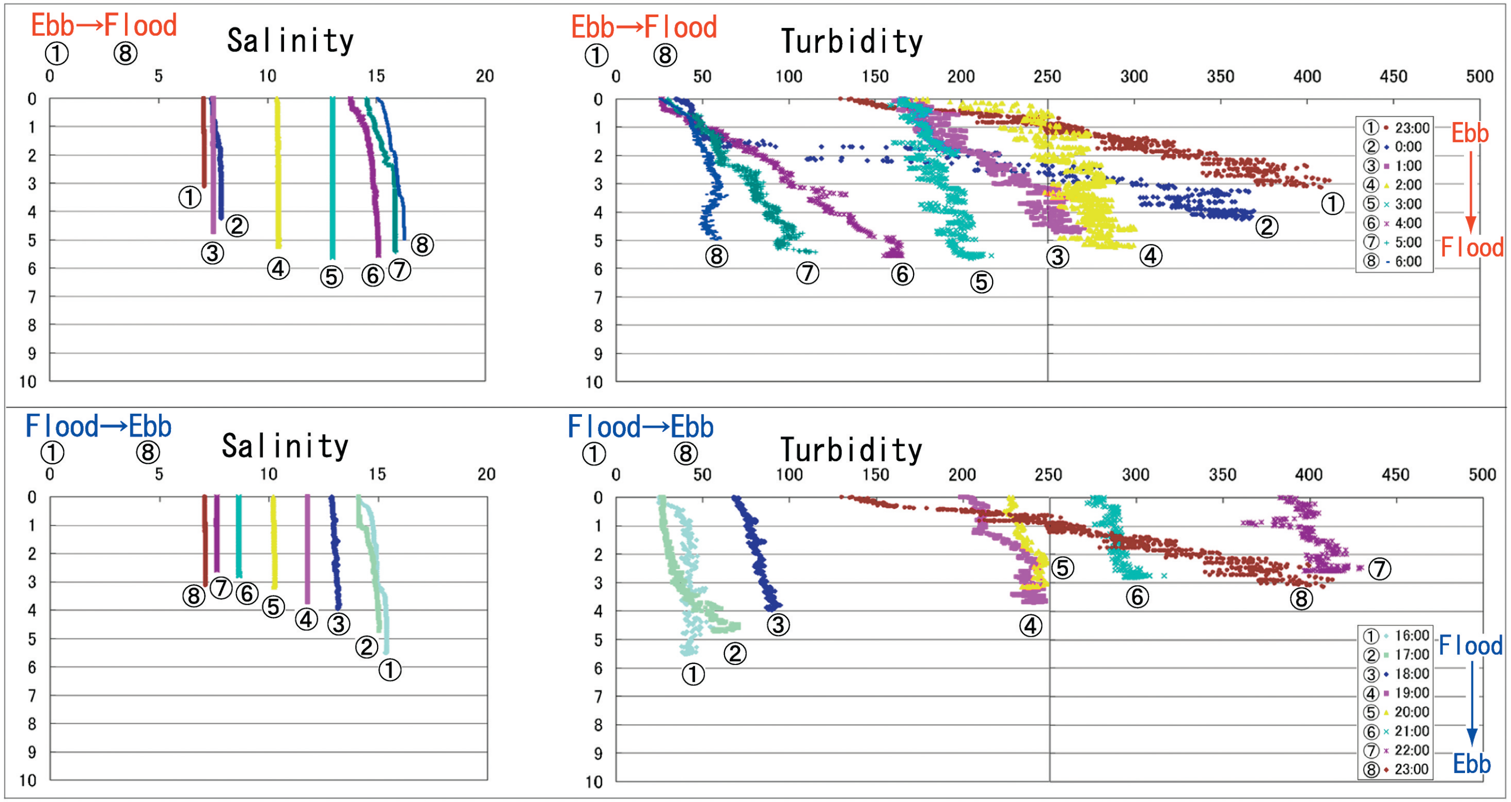

Fig.15. Time-series changes of salinity (left) and turbidity (right) obtained during 24 hours observation at the lower station on May 8 to 9. Circled numbers indicating measure time are shown in Figs. 11 and 14.

Fig. 14. A transverse echo-sounding profile across the Up Station is also shown in the same figure, in addition to vertical changes of salinity and chlorophyll-a at two points. Echo-sounding profiles indicated the existence of strongly mixed conditiosn at each hour, as supported by vertical profiles of salinity. Stratifications were present in the echo-sounding profiles of 12:00 and 13:00, also consistent with salinity profiles. Vertical changes of salinity and turbidity of one tidal cycle (ebb to flood, and flood to ebb) are detected from the observation data (Fig. 15). Regular changes of salinity in accordance with tidal changes are evident. Time series changes of turbidity are illustrated in figure 15. Highly mixed conditions prevailed throughout the tidal cycle, in accordance with the echo- sounding profiles.

Discussion and Conclusion

1. Towing surveys by echo-sounder SC-3 and water quality meter TPM CLOROTEC have revealed strongly mixed conditions of salt intrusion into the Co Chien River at spring tide in the low flow season. Fig. 6 indicates completely mixed conditions prevailed at least 36 km upstream from the river mouth. Salinity data obtained by TPM CHLOROTEC indicated gradually decrease from 22 PSU at the 0 km point to 2 PSU at the 36 km point. Completely mixed salt water conditions were also evident in Figs. 4, 5. Fig. 16 shows a schematic illustration of salt intrusions in the Co Chien River at low flow season (present study) and in the intermediate flow season (Dec. 28, 2000, Tateishi et al., 2006). Partly stratified structures like a saline wedge are visible in the latter. Echo-sounding profiles between the two sections are quite different, and illustrate the usefulness of the echo-sounding method for the study of saline invasion.

2. Turbidity data obtained by towing TPM CHLOROTEC (Fig. 6) indicate gradual increase in turbidity from the 18 km point upstream to the 36 km point. This may be related to the gradual decrease of salinity over the same reach. It is generally accepted that turbidity maximum appears around the head of the saline wedge in weakly and moderately mixed rivers (Riethmuller et al., 1988; Sugimoto, 1988). The above relation may infer the appearance of turbidity maximum in the upper reaches of the study area.

3. Observations of water level, bottom currents and water quality for one week at two stations situated 26 and 8 km from the river mouth have provided precise data for tides and tide-related changes of currents and salinity. Semi-diurnal tides with a range of 3 m prevailed in the area during the measurements (Fig. 7). Salinity of the upper layer at both stations changed regularly between flood and ebb tides, indicating tidal regression and transgression of strongly mixed (vertically stratified) salt water (Fig 8). Time series data of current velocity on the bottom surface were obtained at both stations (Fig. 9), and time gaps between high/low water levels and flood/ebb tides can be recognized (Fig. 9). The observation that up-currents at the Lw Station were larger than down-currents may be important for evaluating tide-related sedimentation.

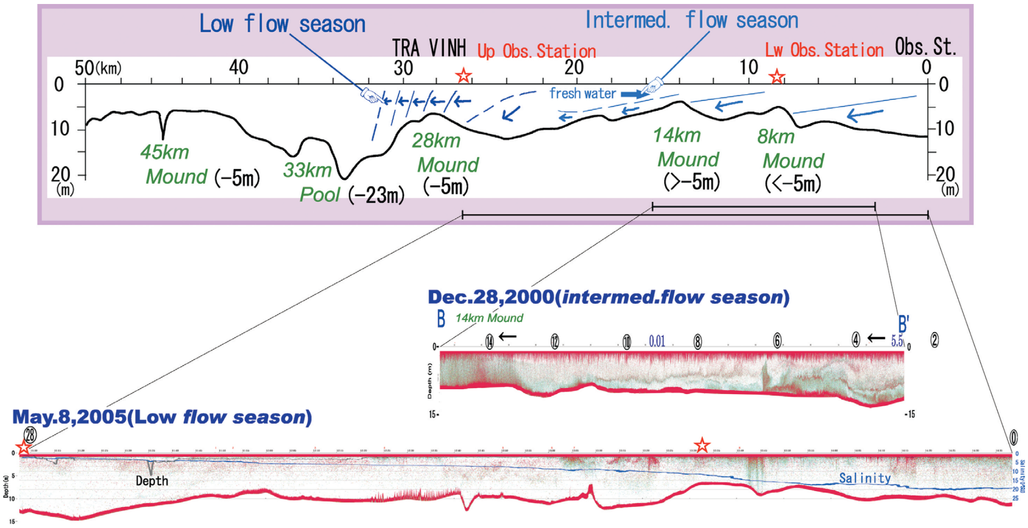

Fig. 16. Schematic illustration of salt intrusion in the Co Chien River in the low and intermediate flow seasons (revised from Tateishi et al., 2006) and representative echo-sounding profiles of the intermediate flow season (Dec. 28, 2000; Tateishi et al., 2006) and low flow season (this paper).

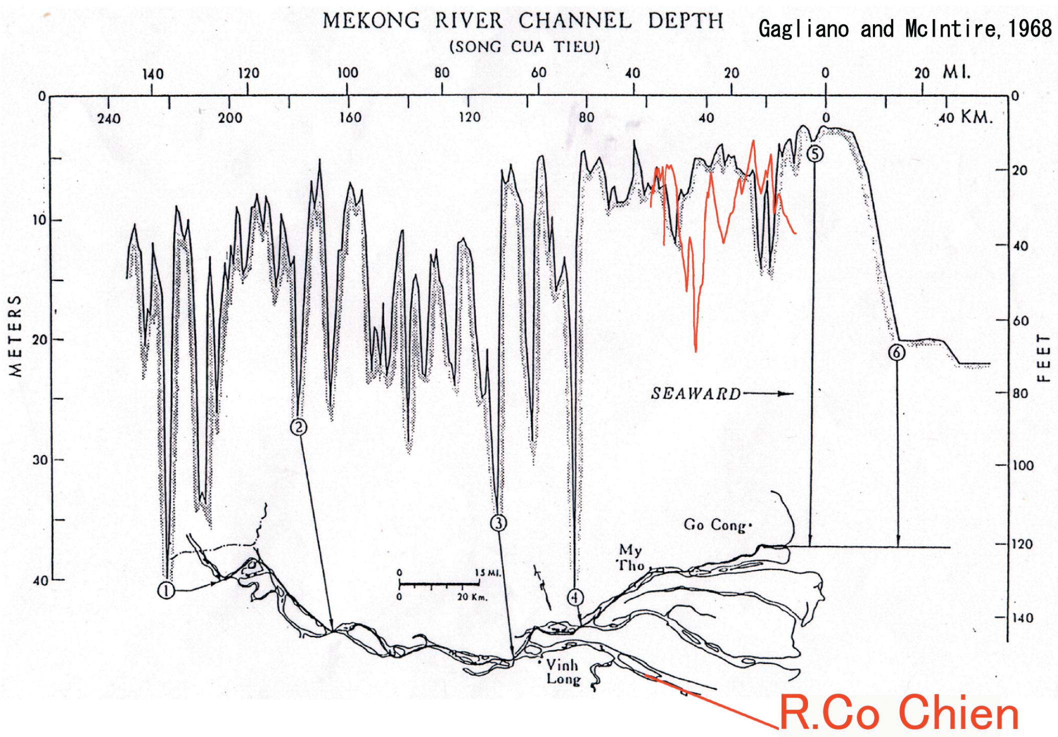

Fig. 17. Mekong River Channel Depth (Gagliano and McIntire, 1968) and that of the Co Chien River shown by red line.

4. Observations made over 24 hours at two stations have revealed detailed movements of tides and tide-related changes in water quality. Vertical changes of salinity through time indicate vertically stratified structure of the water-masses, although partly stratified conditions are approached at slack tides (Figs. 12-15).

5. Tateishi et al. (2006) proposed a conceptual illustration of salt water intrusion in n the intermediate and low flow seasons. In reference to the present study, typical salt water invasions in the intermediate and low flow seasons are shown in Fig 16. Echo-sounding profiles of the two seasons are quite different, indicating the usefulness of the present survey method in determining time-space distribution of salt invasion in big tidal rivers such as the Mekong.

6. Channel depth of the Mekong River was generally illustrated by Gagliano and McIntire (1968), and is shown in Figure 17. This indicates channnels deepen successively upstream. The channel depth of Co Chien River, the target of our present study, have been added to the figure. The existence of upward-deepening channels has an important meaning for the future crisis of the Mekong Delta estuary environments (Nguyen, et al., 2000). Water level rise, water diversion schemes, and dredging for sand resourses now going on or are planned for the upper reaches of the Mekong River. These activities could easily promote more extensive salt intrusion further upstream.

Acknowledgements

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