Salt water intrusion in the Mekong River estuary, Vietnam: Observation at the Co Chien River from 2000 to 2002

Masaaki TATEISHI*, Van Lap NGUYEN**, Thi Kim Oanh TA**, Takao TOKUOKA***, Ayumi FUKITA***, Kiyokazu NISHIMURA†, Shigeo MATSUDA†† and Akira SUZAKI†††

Abstract

Salt water intrusion in the Mekong River has been studied using a newly-developed acoustic reflection profiling system (Model SC-3). This system determines the spatial distribution of the halocline by measurements of water quality, especially of salinity. This system was made by improvement of a 200 kHz precision echo sounder. In the intermediate flow seasons of Dec., 2000 and Jan., 2002, salt water was present only downstream of the mound at 8 km in ebb tide, but progressed upstream beyond the mound at 14 km toward flood tide. A typical wedge-like profile was obtained at the observation toward flood tide on 28 Dec., 2000. Time series echo-sounding profiles obtained from ebb tide toward rising tide on 2 and 4 Jan., 2002 at the river mouth station is in accordance with each salinity profile. In the low flow season of May 2001, salt water reached as far upstream as the mound at 28 km near flood tide, and possibly entered the pool at 33 km. The echo-sounding salinity profiles and the surface salinity data reveal the presence of strongly vertically-mixed water in the entire area invaded by salt water, although partly stratified structures may be formed during slack tide. The present echo-sounding system has proven to be very effective in unraveling the time-space behavior of salt water intrusion in the Mekong River.

Key words: Acoustic reflection profiling system, Mekong River, Salinity, Salt water intrusion, Tidal change.

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* Department of Geology, Faculty of. Science, Niigata University, Niigata 950-2181, Japan
** Sub-Institute of Geography, Vietnam Academy of Science and Technology, Ho Chi Minh City, Vietnam
*** Tokuoka Laboratory for Studies of Brackish Water Environments, Matsue 690-0823, Japan
† Geological Survey of Japan, AIST, Tsukuba 305-8567, Japan
†† Clovertech Inc., Musashino 180-0006, Japan
††† Senbon Denki Co. Ltd., Numazu 410-0011, Japan
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Introduction

The Mekong River is the third longest river in Asia. It splits in several tributaries in its downstream reaches in the Mekong Delta estuary. Physiographic data of the Mekong Delta were reported by Gagliano and McIntire (1968). They showed that the surface intrusion of salt water of 400 ppm salt, which is approximately equivalent to contact between freshwater and salt water, was depicted as a seasonal isohaline map. The intrusion of salt water was also reported in the Vietnam Hydrometeorological Atlas by Nguyen T.H. et al. (1994) as the limits of maximum salinity of 1 and 4 ‰ (psu) (Fig. 1). The surface salt water intrusion in the Mekong River is known to reach 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, and has been surveyed extensively in the Mekong River estuary. Nguyen V.L. et al. (2000) also described recent salt water intrusion in the low flow season, based on the data of Hydrometeological Center data and land use maps. They stated that the maximum limit of this intrusion was roughly in accord with the coastline at 3000-2000 yr. B.P., and had extended more than 20 km inland during the past 20 years. Salt water intrusion is expected to be exacerbated further upstream on the Mekong River due to human- and/or nature-induced phenomena including underground subsidence and coastal erosion, construction of large dams in up-stream areas and sea level rise. The combination of these factors could cause severe damage to water resources and agriculture in the Mekong River Delta.

Precise observations of salt intrusion in the Mekong River estuary have been reported by Wolanski et al. (1996) 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 length of about 50 km in the downstream reaches. Time series observations (13 hours) were also performed 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, the saline intrusion extended some 50 km up-river with vertical stratification in salinity.

We have observed saline intrusion in the Co Chien River, a tributary of the Mekong River (Fig. 1). Our observations were mainly based on an acoustic reflection profiling system developed for 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 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. Observations were carried out on three occasions (27-29 Dec., 2000 in the intermediate flow season, 5-6 May, 2001 in the low flow season, and 2-4 Jan., 2002 in the intermediate flow

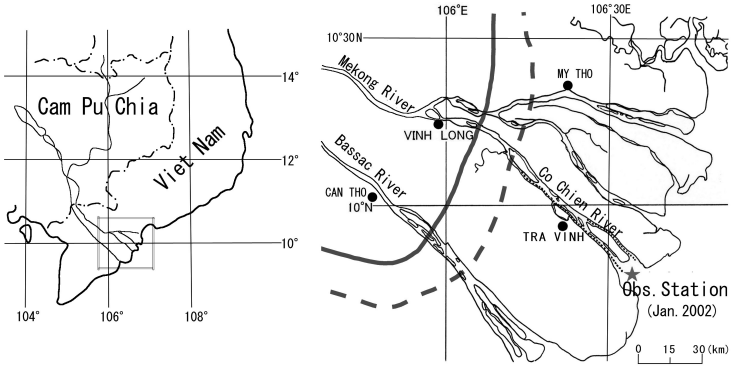


Fig. 1. The Co Chien River, a tributary of the Mekong River has been surveyed mainly on the basis of acoustic observation methods. The solid line shows the surface intrusion limit of salt water by Gagliano and McIntire (1968). The dashed line indicates the surface intrusion limit of saltwater (in Vietnam Hydrometeorological Atlas by Nguyen et al., 1994).

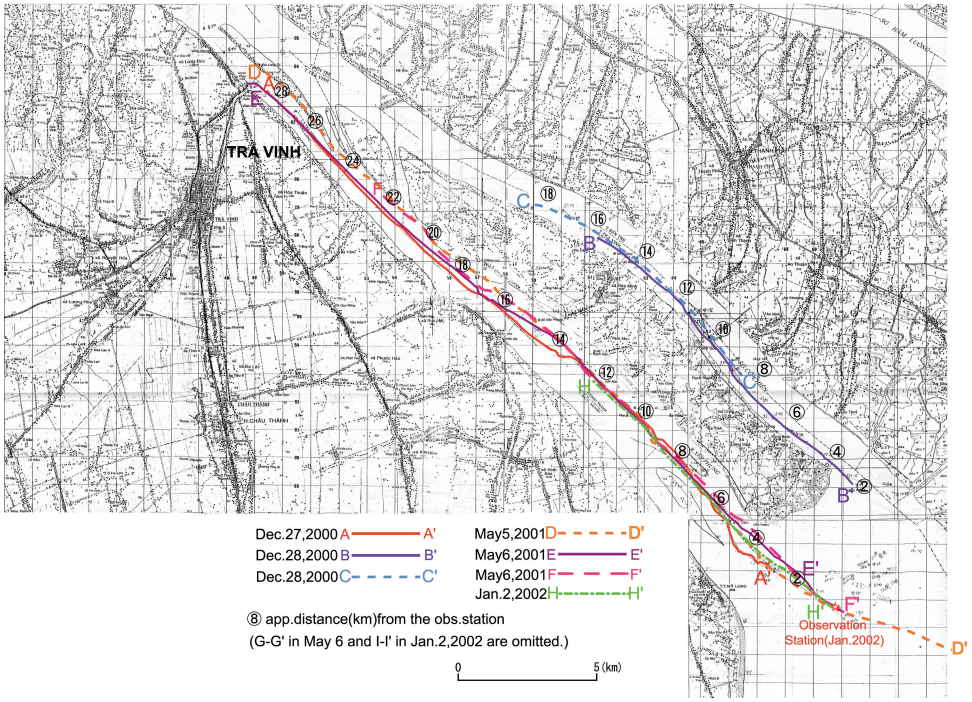


Fig. 2. The SC-3 echo sounding survey routes (routes G-G' of 6 May, 2001 and I-I' of 4 Jan., 2002 are omitted. These are roughly the same as routes F-F' and H-H', respectively. The topographic map is from the sheet 6228 Tra Vinh (1:100,000, Viet Nam).

season. The routes of surveys are shown in Fig. 2, and acoustic reflection profiles in the intermediate flow season and low flow season are shown in Figs. 3 and 7, respectively. The numerals shown in each profile indicate the distance from the tentative observation station at the river mouth where the third observation was done in Jan. 2002. Our echo sounding surveys had identified mound-like topography near the 14 and 8 km points. These are marked in the above figures, and each of them are called the 14 km and 8 km mounds. Mound-like topographies have also been found near the 28 and 45 km points, called the 28 km and 45 km mounds respectively, in the survey upstream toward Tra Vinh Port in 29 Dec., 2000, although the data are not shown in the present paper. These mound-like structures considered to have roles as barriers against salt intrusion.

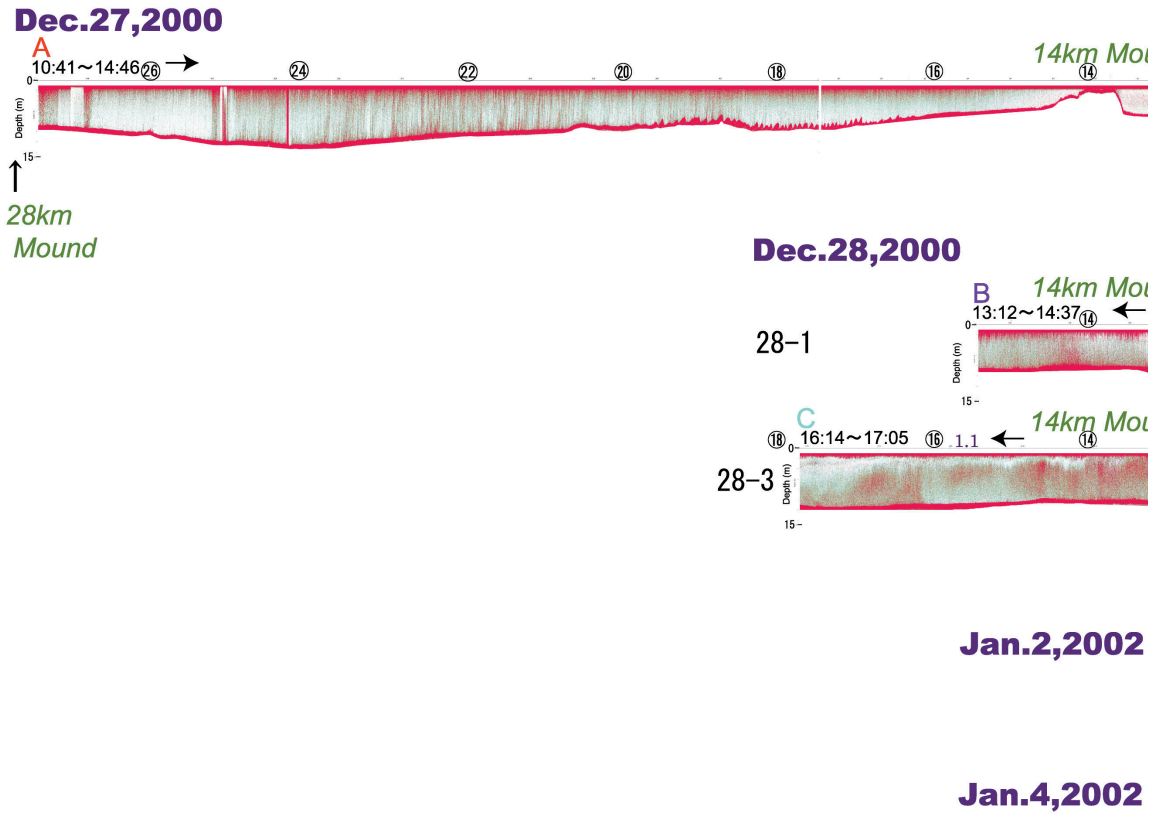
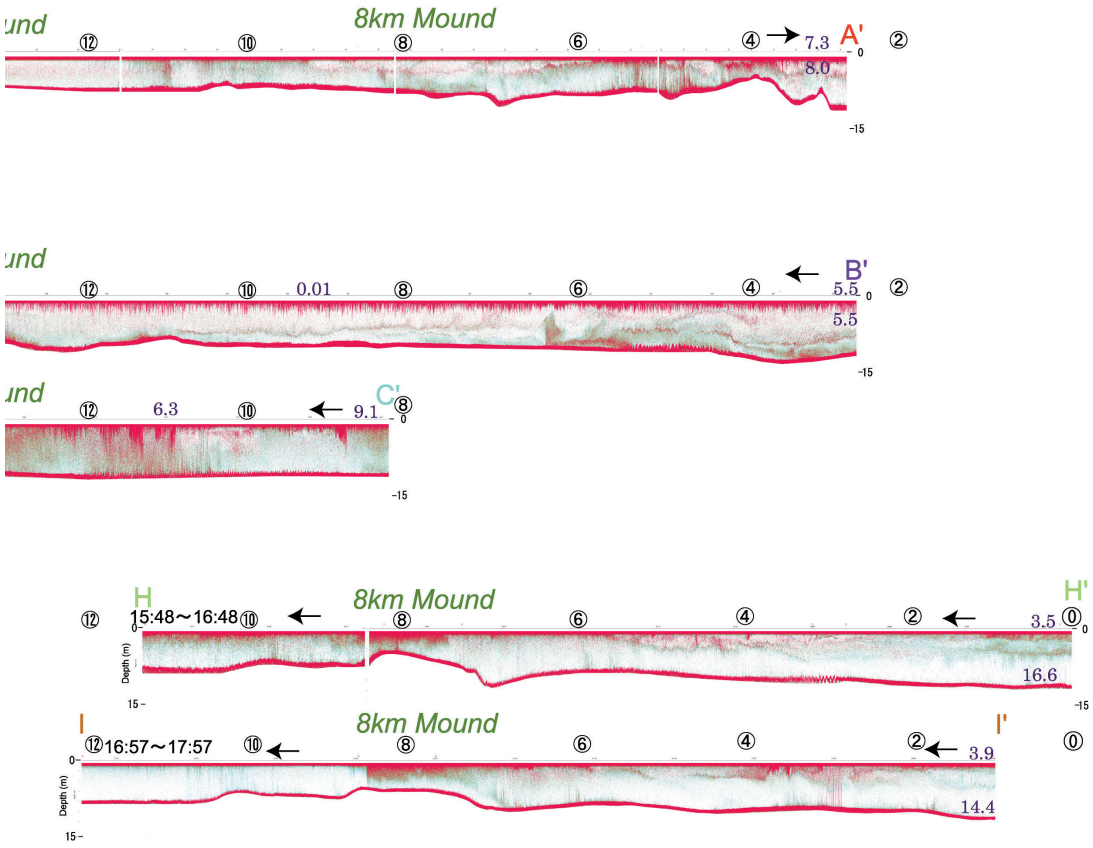


Fig. 3. Representative SC-3 echo-sounding profiles in the intermediate flow season (Dec., 2000 and

Observation in the intermediate flow season

27 and 28 Dec., 2000 (Figs. 3 A-A', B-B', C-C')

Preliminary SC-3 echo-sounding survey was attempted in the Mekong River and was confirmed to be useful for understanding the time-space distribution of saline intrusion. In 27 Dec. observation was made from Tra Vinh Port, heading downstream around ebb tide. Fig. 3 A-A' shows the presence of faintly stratified in the saline water in the downstream reaches. We inferred that salt water did not extend beyond the 14 km mound. In 28 Dec., the survey was carried out downstream area of the tributary of the Co Chien River toward flood tide. Fig. 3 B-B' apparently shows the invasion of saline water below fresh water, a situation approaching



Jan., 2002).Circled numerals: distance (km) from the river mouth station benchmarked in 2002 survey. Other numerals: Salinity in psu.

that of a salt wedge. Fig.3 C-C' is the same profile about 3 hours later. Highly mixed conditions prevailed over the entire traverse toward flood tide, and saline water extended beyond the 14 km mound, progressing further upstream.

2 and 4 Jan., 2002 (Figs. 3 H-H', I-I', Figs. 4, 5)

Time series water level data was measured at Tra Vinh Port from a floating pier between 1 and 4 Jan. (Fig. 4). We selected a benchmark observation station at the river mouth, where named the 0 km point in this paper, and temperature and salinity were measured at two horizons, about 1 and 2 m water depth at ebb tide by using a COMPACT-CT (Allec Densi Co.

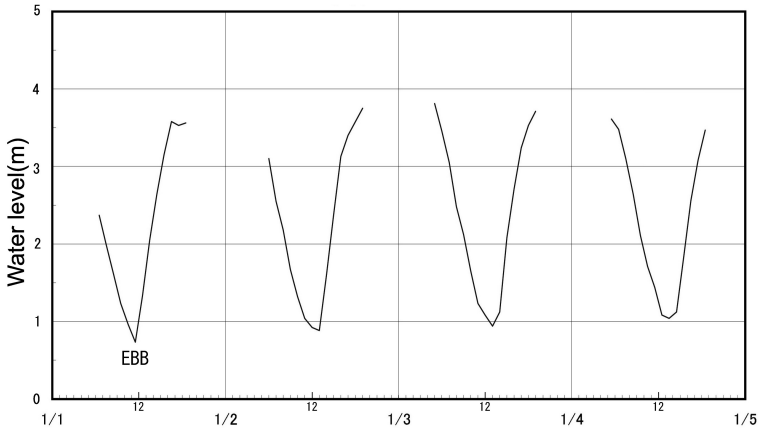


Fig. 4. Time-series plot of the water level at Tra Vinh Port (1 to 4 Jan., 2002)

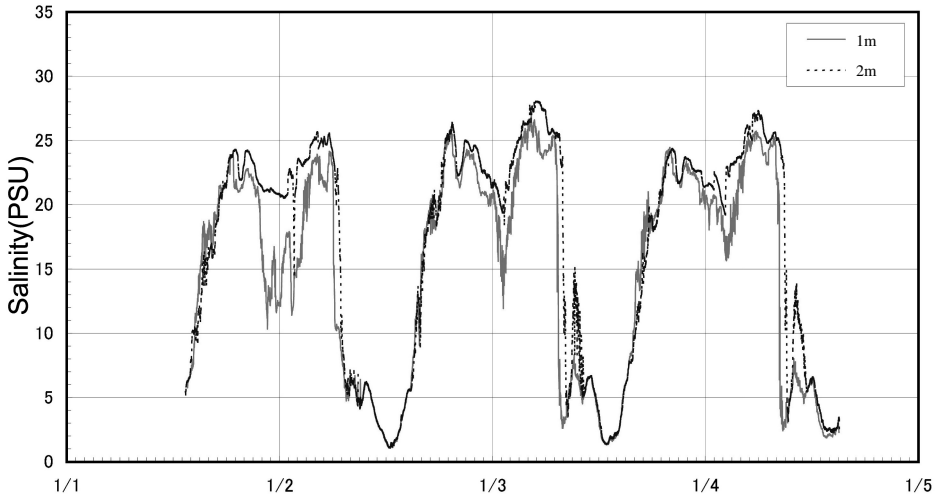


Fig. 5. Time-series plot of salinity at two horizons (1 and about 2 m depth in ebb tide) at the river mouth observation station (1 to 4 Jan., 2002)

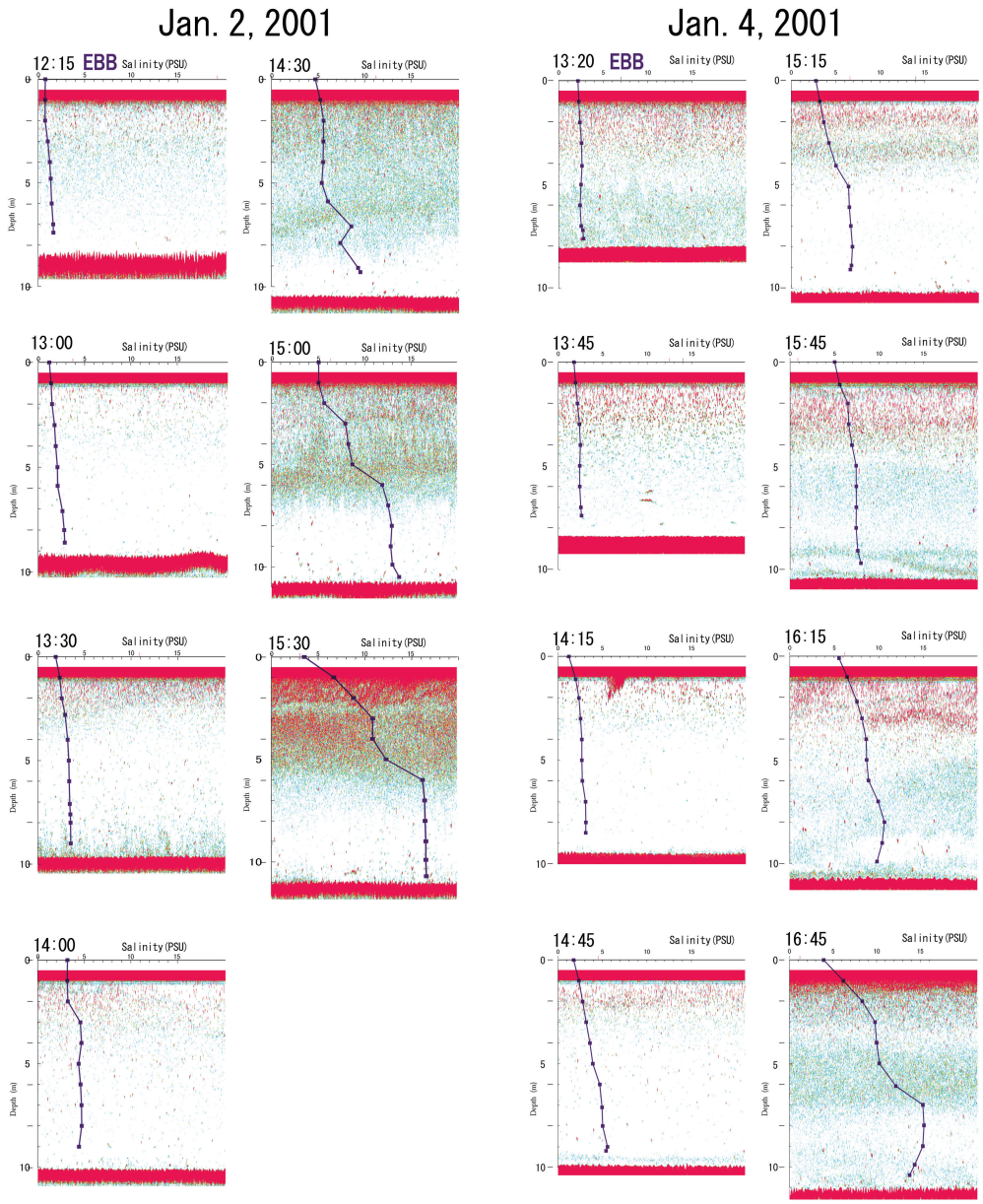


Fig. 6. Time-series salinity and SC-3 echo-sounding records at the river mouth observation station (2 and 4 Jan., 2002)

Ltd.). Salinity changes at two horizons (Fig. 5) are concordant, with the water level change at Tra Vinh Port, 28 km upstream. Salinity increased toward flood tide and decreased toward ebb tide at the two horizons. The time series difference of salinity between two horizons suggests the existence of well mixed saline water toward rising tide, whereas some salinity stratification occurred during high tide.

Echo-sounding and salinity profiles were carried out at this station at 30 minute intervals on 2 and 4 Jan. The observations began at ebb tide. Results are shown in Fig. 6. It is apparent that the time series changes of salinity gradient from ebb tide to rising tide are in accordance with the changes in reflection patterns.

Following the above station observation in 2 and 4 Jan., observations towing SC 3 were carried out, heading upstream near flood tide. The acoustic profiles are shown in Fig. 3 (H-H' and I-I'; the latter route is roughly the same as the former, and is not shown in Fig. 2). Moderately mixed condition prevailed over the whole area, but faintly stratified condition was visible in the lower reaches in both surveys. The acoustics show that saline water extended beyond the 8 km mound.

Observation in the low flow season

5 and 6 May, 2001 (Fig. 7 D-D', E-E', F-F', G-G')

Echo-sounding survey was made on 5 and 6 May, and representative profiles are shown in Fig. 7. The time series water level was measured at Tra Vinh Port using a floating pier. Results are shown in Fig. 8. On 5 May, echo-sounding survey was carried out toward ebb tide, heading upstream (Fig. 7 D-D'). The echo-sounding profile indicated some stratification was present in the downstream reaches. Salinity profiles obtained at several points indicated weak stratification in the upper layer, although well mixed conditions prevailed over the whole area. Acoustics show salt water intruded beyond the ridge at the 14 km from the river mouth, penetrating up to the 22 km point. Echo-sounding survey was carried out along several routes on 6 May (Fig. 7 E-E', F-F', G-G'; Route G-G' is omitted from Fig. 2). These observations were carried out toward flood tide, and the acoustics show strongly mixed conditions prevailed over the whole areas. This was confirmed by salinity profiles obtained at several stations. Series measurements of surface salinity also indicated gradual increase of salinity toward the downstream, suggesting strongly mixed condition prevailed. At Tra Vinh Port, we obtained a surface salinity value of more than 1 psu at ebb tide, suggesting salt invasion had proceeded further upstream.

Conclusions

A schematic profile of salt intrusion in the Mekong River during the intermediate and low flow seasons is presented in Fig. 9. In the intermediate flow season, salt water was present

only downstream of the 8 km Mound at ebb tide, but progressed upstream beyond the 14 km Mound toward flood tide (Fig. 3). The B-B' echo-sounding profile in Fig. 3 apparently indicated the appearance of a saline wedge, although salt water was generally mixed vertically. Time series echo-sounding profiles obtained at the river mouth station from ebb tide toward rising tide were in accordance with each salinity profile (Fig. 6). In the low flow season, salt water reached as far as the 28 km Mound toward flood tide, and possibly entered the pool at 33 km. Echo sounding profiles, salinity profiles and surface salinity data indicate that vertically well mixed salt water was present in the entire area invaded by salt water. However, some of our data suggests that partly stratified structures may be formed during slack tides if salt wedge conditions are approached. This needs to be confirmed by further echo sounding profiles.

Acknowledgements

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References

Gagliano, S.M. and McIntire, W.G., 1968, Reports on the Mekong River Delta. *Technical Report,* Coastal Studies Institute, Louisiana State University, no. 57, 143p.

Nguyen Van Lap, Ta Thi Kim Oanh and Tateishi, M., 2000, Coastal variation and saltwater intrusion on the coastal lowland of the Mekong River Delta, Southern Vietnam. *Abstract for Thai-Japanese Geological Meeting: The comprehensive assessments on impacts of sea-level rise*, Division of Geological Survey of Thailand, 184-190.

Nguyen Trong Hieu, Tran Thanh Xuan, and Nguyen Ngoc Thuy, eds., 1994, *Vietnam Hydrometeorological Atlas*. Hydrometeorological Service, State Programme of Scientific Technical Progress 42A, Vietnam National Committee.

Nishimura, K., Tokuoka,T., Ueno, Y., Sampei, Y., Suzaki, S., Matsuda, S., Kubota, S. and Suzuki, S., 2001, Development of Aquatic Environment Measurement Systems of Estuaries and Coastal Lagoons. *Proc. Oceans 2001 Conference*, Pub. Marine Technology Society, 1342-1347.

Tokuoka, T., Sampei, Y., Nishimura, K., Suzaki, A., Matsuda, S., Kubota, S., Suzuki, S. and Ueno, Y., 2001, Development of saline wedge observation system (Introduction of Poster Exhibition at TECHNO-OCEAN 2000). *LAGUNA*, 8, 101-110.

Wolanski, E, Nguyen Huu Nhan and Simon Spagnol, 1998, Sediment dynamics during low flow conditions in the Mekong River Estuary, Vietnam. *Jour. Coastal Research*, **14**, 472-482.

Wolanski, E, Nguyen Ngoc Huan, Le Trong Dao, Nguyen Huu Nhan and Nguyen Ngoc Thuy, 1996, Fine-sediment dynamics in the Mekong River Estuary, Vietnam. *Estuarine, Coastal and Shelf Science*, **43**, 565-582.

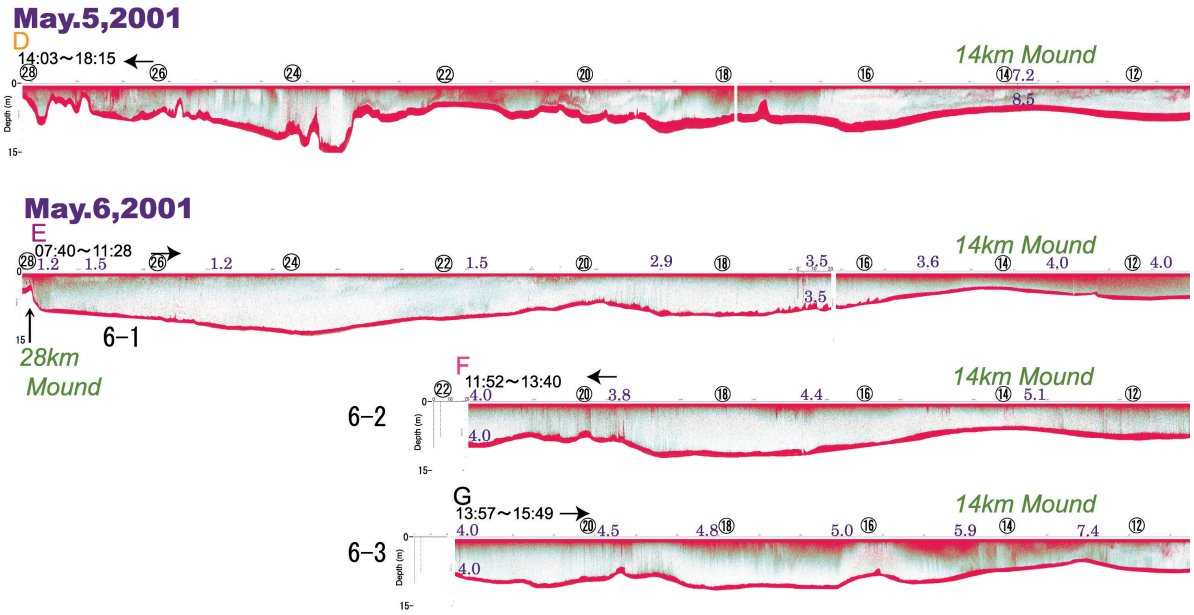


Fig. 7. Representative SC-3 echo-sounding profiles during the low flow season (May, 2001). Circled numerals:

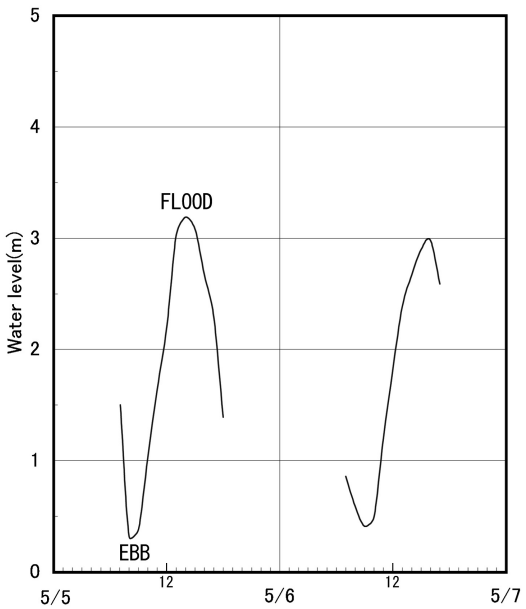
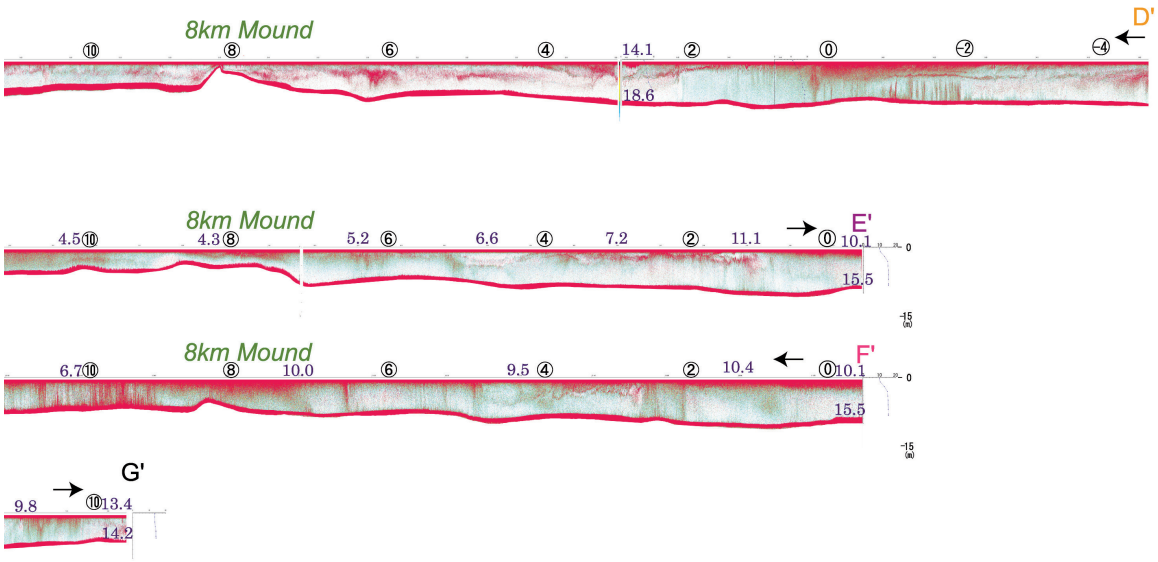


Fig. 8. Time-series plot of the water level at Tra Vinh Port (5 and 6 May, 2001).



distance (km) from the river mouth station benchmarked in 2002 survey. Other numerals: Salinity in psu.

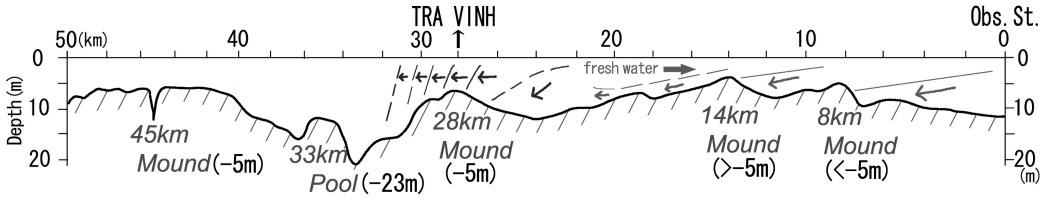


Fig. 9. Schematic profile of the Co Chien River and conceptual illustration of salt water intrusion in the intermediate and low flow seasons.