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Water and Salt Budgets for the Yellow Sea

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Water and salt budgets in the Yellow Sea and Bohai are analyzed based on the historical data and CTD data collected recently using box models. The amounts of volume transport and of water exchange across the boundary between the Yellow and East China Seas are estimated to be 2,330 – 2,840 km^3/yr and 109–133 km^3/yr, respectively, from the one-layer box model. Corresponding water residence time is 5–6 years. In the Bohai, water residence time is twice as long as that in the Yellow Sea, suggesting that the Yellow Sea and Bohai cannot be considered as a single system in the view of water and salt budgets. The results indicate that water and salt budgets in the Yellow Sea depend almost only on the water exchange between the Yellow and East China Seas. The computation with the coupled two-layer model shows that water residence time is slightly decreased to 4 –5 years for the Yellow Sea. In order to reduce uncertainties for the budgeting results the amount of the discharge from the Changjiang that enters into the Yellow Sea, the vertical advection and vertical mixing fluxes across the layer interface have to be quantified. The decreasing trend of the annual Yellow River outflow is likely to result that water residence time is much longer than the current state, especially for the Bohai. The completion of the Three Gorges dam on the Changjiang may be change the water and salt budgets in the Yellow Sea. It is expected that cutting back the discharge from the Changjiang by 10% through the dam would increase water residence time by about 10%.

Key words: Budget model, the Yellow Sea, Water residence time

INTRODUCTION

As a marginal boundary of the North Pacific Ocean, the Yellow Sea (YS) and Bohai (BS) are one of the most important regions for the global sedimentary and geochemical material cycles. Thus, the estimate of material fluxes in these seas is essential for understanding the global material cycle properly. With the rapid increasing pollutant burden imposed on these semi-enclosed seas the prognostic water quality model is needed for a long-term environmental management. This gives another necessity to study for material budgets in the region.

Water residence time is a key component of the material budgetary study and the use of circulation model is a suitable way to estimate it. However, numerical circulation modeling of the YS and BS has produced different circulation patterns (e.g., Yanagi and Takahashi, 1994; Lee, 1996; Lee *et al*, 2000 etc.). This may occasionally give wrong estimation of material budgets and the box model is still a useful alternative for budget modeling.

In spite of its importance, the study in relation to material budgets in the region is relatively rare. Choi (1998) estimated the turn over time for the YS as about 2.3 years varying from 5 years in spring to 0.8 years in winter based on the meteorologically induced circulation model. While the turn over time for the tide residual circulation for the central YS is computed as 12 years whereas other parts of the region are less than 2 years. Chung *et al.* (1999) studied for budget of dissolved inorganic nutrients in the YS using a simple one-box model described by Gordon *et al.* (1996) and estimated water residence time is about 8 years. Lee *et al.* (1999) analyzed water and salt budgets for the YS using a box model and water residence time estimated is about 5.6 years.

In order to develop a suitable budget model of geochemical tracers in the YS, this paper continues the study undertaken by Lee *et al.* (1999). A layered box model to compute water and salt budgets is considered. The basic approach to build budget models

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*Corresponding author: jhlee@kordi.re.kr in this study is similar to the guideline for biogeochemical budget modeling provided in LOICZ (Land-Ocean Interaction in the Coastal Zone; Goden *et al.*, 1996) program, but the circulation in the layered system is different from LOICZs. Though the use of heat budget may increase the degree of freedom to compute water residence time, it is not considered here because of a great uncertainty for heat fluxes across air-sea interfaces in the YS. In the next section, water masses and the circulation of the YS is briefly reviewed. The data used and the budget models are described in sections 3 and 4, respectively. The results of water and salt budgets focused mainly on water residence time are shown in section 5 and discussion is given in section 6.

WATER MASSES AND CIRCULATION IN THE YELLOW SEA

A budget model cannot be developed properly without understanding the basic oceanographic environment in which the model is applied. The following is a brief review of water masses and the circulation of the YS.

In general, five major water masses are classified in the YS (Lee *et al.*, 2002): Yellow Sea Warm Current Water (YSWCW), Yellow Sea Bottom Cold Water (YSBCW), Korea Coastal Water (KCW), China Coastal Water (CCW) and Changjiang Diluted Water (CDW). It has been explained that the warm and saline YSWCW represents the water mass accompanied by the Yellow Sea Warm Current (YSWC) in winter. However, recent hydrographic data reveal that this water mass originates from the boundary area of the thermohaline front in the region west-northwest of Cheju-do and it remains in the bottom layer of the southern YS even in the summer season with modifying continuously (Lie *et al.*, 2001). The YSBCW formed as a result of winter convection is distributed in the bottom layer of the trough region in summer. Though it has been explained that this water mass occupies almost entire bottom layer of the YS (e.g., Su and Weng, 1994), it should be distinguished from the modified YSWCW. While the YSBCW is classified based more on temperature, the modified YSWCW is identified easily by salinity. The KCW is tidally induced mixed water with run-off discharge from the Korean Peninsula. The direction of water movement is the north and south in summer and winter, respectively. The CCW contains coastal water from the BS and flows to the south throughout the year. The CDW is the major source of fresh water in the YS.

The low salinity water affected by the CDW is the most important factor to estimate water residence time in the YS. The low salinity water in the surface layer of the southern YS that originates from the CCW and CDW in summer has a well-posed annual cycle in its location; it moves to the west in fall, to the south in early winter and then remains in the Yangtze Bank until late spring (Lee *et al.*, 2002). This annual cycle is a key component of the variation of the seasonal circulation in the YS as well as the lateral fluctuation of the warm and saline water in the northwest and southeast direction in winter and summer, respectively.

The seasonal movements of water masses are mainly due to the seasonal variability of atmospheric forcing, i.e., wind and river discharge, which depends on the Asian monsoon system. In winter, the strong northerly wind induces southward coastal currents along both Korea and China coasts. In the interior, it has been believed that the northward YSWC exists. The YSWC may be regards as a result of a direct response or a relaxation response of the southern YS to the strong northerly wind events. In summer, the weak southerly wind and the Changjiang discharge have an influence on the circulation in the upper southern YS. The coastal currents flow to the south and north in China and Korea coasts, respectively, and a cyclonic flow system appears between them. The existence of the YSWC in summer still remains as an open question, e.g., Lie *et al.* (2001) insisted that the YSWC exists in winter only. The circulation in the lower layer is also less understood, though it has been explained that the southward expansion of the YSBCW dominates in the region.

DATA

In order to compute the mean value of salinity in the studied area, the CTD data collected from the Korea-China joint surveys conducted by the Korea Ocean Research and Development Institute and the First Institute of Oceanography of State Oceanic Administration, China during 1996–1998 (Lie *et al.*, 2001) are used. The historical data from Japanese Oceanographic Data Center and Levitus (1981) data are also employed. The sources of the river discharges are Shen *et al.* (1998) and data provided on the web sites (The Global Runoff Data Centre and The Global River Discharge Database). The data of precipitation and evaporation are based on historical data sets (Hirose, 1996 and IRI/LDEO Climate Data Library). The input data and parameter for budgeting are summarized in Table 1.

BUDGET MODELS

Box model

The box corresponding to the YS in the budget model is shown in Fig. 1. The boundary of the box is different from that used in geographic term. For the northern boundary, it is defined as the line connecting between the Santung Peninsula of China and the Ongjin Peninsula of Korea because of the limits of salinity data in the northern YS. In the south, the line connecting from the southwestern tip of the Korean Peninsula to the Changjiang is chosen to estimate water residence time focused more on the interior of the YS. Water residence time in a box depends largely on the fresh water input as will be shown later, that is, it is shorter as the fresh water input increases. In summer, most of the CDW reached in the seas around Cheju-do moves toward the Korea Strait. Thus, if the southern boundary of the box is chosen by the line connecting from Cheju-do to the Changjiang as the dashed line in Fig. 1, it is expected that estimated water residence time is unrealistically short for the interior of the YS.

The vertical hydrographic structure in the YS is characterized by an annual cycle of winter convection and summer stratification except in the coastal region. The typical thickness of the upper mixed layer in summer is about 20 m in the mid YS. In the upper layer, the amplitude of seasonal variation of salinity is relatively large in the south to southeastern parts with its maximum of about 3 psu. However, in the bottom layer, it is smaller than 0.5 psu except for the region near the Changjiang (Lee *et al.*, 2002). This implies that the renewal of water masses in the YS is active in the surface layer. This also indicates that a layered box model is much reasonable to study material budgets. In this study, we formulate budget models for the system of two-layer box without considering the vertical homogeneity of the coastal region.

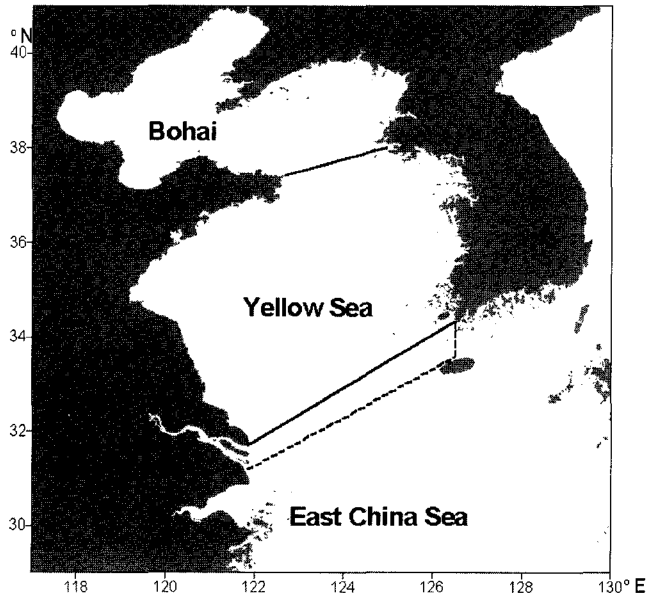

Fig. 1. The model domain.

Water budget

Fig. 2 depicts the layered box model for the water and salt budgets. The budget model is formulated on the basis of the conservation law in a control volume. That is, the amount of input of water and salt into a box should be equal to that of output from the box. The governing equations for water budget in the upper and lower layers can be written, respectively, as

$$\frac{dV_1^u}{dt} = V_{\vartheta} + V_{in}^u - V_{out}^u + V_z \qquad (1)$$

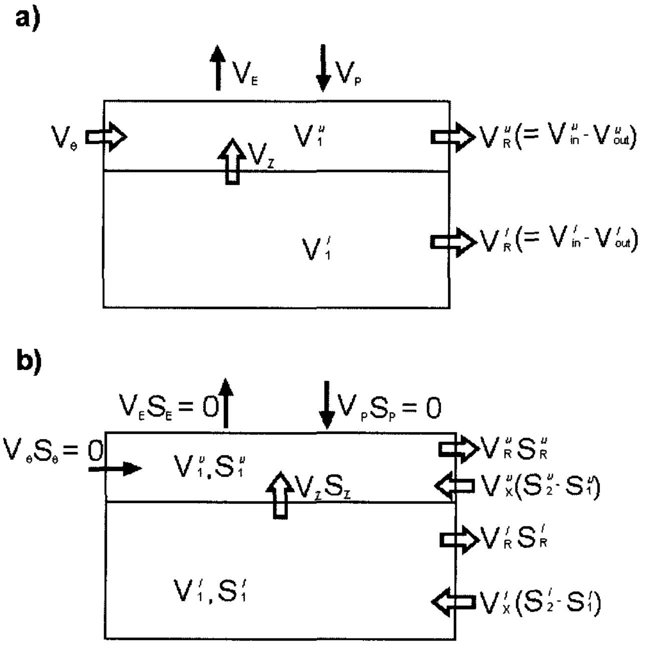

Fig. 2. Schematics of two-layer box model, a) water budget and b) salt budget. V_E and V_P mean evaporation and precipitation, respectively.

and

$$\frac{dV_1^l}{dt} = V_{in}^l - V_{out}^l - V_z \tag{2}$$

where $\frac{dV_1}{dt}$ is the time variation of water volume and V_ϑ, V_{in} and V_{out} represent the volume of fresh water exchange (i.e., river discharge, precipitation, ground water, and evaporation etc.), and advective fluxes due to in- and outflows, respectively. Superscripts *u* and *l* mean the upper and lower layers, respectively, and V_z is the water flux across the interface of the two layers. Terms with positive and negative signs imply output and input to the box, respectively. For V_z, positive sign is upward flux. The water flux associated with freshwater input is given in the upper layer only, while the exchange of salty water is considered both in the upper and lower layers. This differs from the guideline of water and salt budgeting suggested by LOICZ. In the LOICZ modeling node (Gordon *et al.*, 1996), a flow of oceanic water enters to the deep layer, flows upward into the surface layer, and out again from the surface layer, i.e., $V_{in}^u = V_{out}^l = 0$, implying a loop circulation.

The difference between advective flux of inflow and that of outflow in each layer can be defined as a residual water flux, $V_R^u \equiv V_{in}^u - V_{out}^u$ (or $V_R^l \equiv V_{in}^l - V_{out}^l$). Then, the ratio of the total volume to a residual, $|V_1^u/V_R^u|$ (or $|V_1^l/V_R^l|$), implies an estimate of water residence time. If the volume transport in each layer is in the steady state, $V_R^u = -(V_\vartheta + V_z)$ and $V_R^l = V_z$. In the upper layer, the residual water flux is balanced to the fresh water input plus the water flux across the layer interface, while in the lower layer it is balanced to the water flux across the interface only. Defining the total residual water flux, V_R^l as

$$V_R^l = V_R^u + V_R^l = \frac{d(V_1^u - V_1^l)}{dt} - V_\vartheta \tag{3}$$

total water residence time is given by $(V_1^u + V_1^l)/|V_R^l|$. Water residence time here does not consider water mixing in the box.

Salt budget

The salt flux is presented by multiplying salinity, *S*, to the water flux. Salt balance is maintained by a vertical salt flux across the layer interface and lateral exchanges through inflow and outflow in each layer. The salt budget equations corresponding to Eqs. (1) and (2) are written by

$$\frac{d(V_1^u V_1^u)}{dt} = V_\vartheta S_\vartheta + V_{in}^u S_2^u - V_{out}^u S_1^u + V_z S_z \tag{4}$$

and

$$\frac{d(V_1^l V_1^l)}{dt} = V_{in}^l S_2^l - V_{out}^l S_1^l - V_z S_z \tag{5}$$

where the subscripts 1 and 2 mean the inside and outside of a box, respectively, S_ϑ is salinity concomitant with fresh water input and evaporation, and S_z denotes salinity in relation to V_z. In water budget equations, V_z means vertical advection only, while in salt budget equations, the term $V_z S_z$ in Eqs. (4) and (5) includes both vertical advective and vertical diffusive fluxes. This vertical flux term is meaningful only if there is a vertical salinity different between the two layers. Assuming that vertical diffusive flux is much smaller than vertical advective flux and considering is equal to zero and providing salinities in all boxes, Eqs. (1)–(5) yield

$$V_{in}^u = \frac{1}{(S_2^u - S_1^u)}\left[V_1^u \frac{dS_1^u}{dt} + (V_\vartheta + V_z)S_1^u - V_z S_z\right] \tag{6}$$

$$V_{out}^u = \frac{1}{(S_2^u - S_1^u)}\left[V_1^u \frac{dS_1^u}{dt} + (V_\vartheta + V_z)S_1^u - V_z S_z\right] - \frac{dV_1^u}{dt} + V_\vartheta + V_z \tag{7}$$

$$V_{in}^l = \frac{1}{(S_2^l - S_1^l)}\left[V_1^l \frac{dS_1^l}{dt} - V_z S_1^l + V_z S_z\right] \tag{8}$$

and

$$V_{out}^l = \frac{1}{(S_2^1 - S_1^l)}\left[V_1^l \frac{dS_1^l}{dt} - V_z S_1^l + V_z S_z\right] - \frac{dV_1^l}{dt} - V_z \tag{9}$$

If the volume of each layer is in the steady state, it is easily shown that the salt flux doesn't affect on water residence time as in Eq. (3). Then, mixing volume transports in the upper and lower layers can be defined, respectively, as

$$V_X^u = \frac{1}{(S_2^u - S_1^u)}\left[V_1^u \frac{dS_1^u}{dt} + V_R^u S_R^u - V_z S_z\right] \tag{10}$$

and

$$V_X^1 = \frac{1}{(S_2^l - S_1^l)}\left[V_1^l \frac{dS_1^l}{dt} + V_R^l S_R^l + V_z S_z\right] \tag{11}$$

where represents salinity corresponding to the residual volume. The ratio of volume to the residual water flux plus the mixing water flux, $V_1^u/(V_R^u + V_X^u)$ or $V_1^l/(V_R^l + V_X^l)$, is considered as another estimate of water residence time in the box. Water residence time here is obtained considering total water mixing in the box and is longer than that defined in the water budget because the mixing water flux is generally larger than the residual water volume, i.e., $V_R^u << V_X^u$ and $V_R^l << V_X^1$. Eqs. (10) and (11) indicate that the mixing volume flux increases and thus the water exchange time decreases, as the lateral difference of salinity across the boundary of the box decreases. If salinity is in the steady state in each layer, the mixing salt flux is balanced to the residual salt flux. Note that if there is no salinity difference between inside and outside of the box, Eqs. (6)–(11) are not valid.

RESULTS

One-layer model ($S_1^u = S_1^l \equiv S_1$ and $S_2^u = S_2^l \equiv S_2$)

The model equations for salt budget are changed to

$$V_{in}^l = \frac{1}{(S_2 - S_1)}\left[V_1^l \frac{dS_1}{dt} + V_\vartheta S_1\right] \tag{12}$$

$$V_{out}^t = \frac{1}{(S_2 - S_1)}\left[V_1^t \frac{dS}{dt} + V_\vartheta S_1\right] - \frac{dV_1^t}{dt} + V_\vartheta \tag{13}$$

where $V_{in}^t \equiv V_{in}^u + V_{in}^l$, $V_{out}^t \equiv V_{out}^u + V_{out}^l$, and $V_1^t \equiv V_1^u + V_1^l$. Combining these equations yields the total residual water flux as in Eq. (3). If $dV_1^t/dt = 0, V_R^t = |V_\vartheta|$, i.e., the total residual water flux depends only on the flux of fresh water. The total mixing water flux, $V_X^t \equiv V_X^u + V_X^l$ is written by

$$V_X^t = \frac{1}{(S_2 - S_1)}\left[V_1^t \frac{dS_1}{dt} + V_R^t S_R^t\right] \tag{14}$$

where $S_R^t = S_R^u + S_R^l$. If there is no variation in the annual mean salinity, $dS_1/dt = 0$ for the time scale over a year and the total mixing water flux is

$$V_X^t = \frac{V_R^t S_R^t}{(S_2 - S_1)} \tag{15}$$

This equation indicates that the mixing salt flux is balanced by the residual salt flux. Water residence time is given by $V_1^t/(V_R^t + V_X^1)$.

Table 1. The input data used for budget models.

	Bohai	Yellow Sea	Bohai and Yellow Sea
Surface area (km^2)	163,098	311,703	474,800
Volume (km^3)	4,508	14,558	19,067
Volume (upper layer, km^3)	-	4,852	-
Mean salinity (psu)	30.97	32.84	32.64
Salinity (upper layer, psu)	-	32.26	-
Salinity (lower layer, psu)	-	33.42	-
Precipitation (km^3/yr)	134.9	359.5	494.4
Evaporation (km^3/yr)	128.5	352.2	480.7
River discharge (km^3/yr)	14.8	827.2	842.0

The first series of calculations uses the one-layer model. Table 2 shows the results of computation of water and salt budgets using the data described in Table 1. In the case 2, the open boundary is located at the south of the box, i.e., no water exchange occurs between the YS and BS. For the cases 2 and 3, it is assumed that about 12% of the Changjiang discharge enters into the YS based on a rough estimate of the seasonal change of mean salinity in the YS from the data of Korea-China joint survey during 1996–1998. Salinity in the ECS is assumed to be 34.50 psu. The value of $(S_1+S_2)/2$ is used for salinity related to the residual volume, S_R^t, as suggested by Gordon *et al.* (1966). In the case 1, the residual and mixing water fluxes between the BS and YS are 21.2 and 382.9 km^3/yr and corresponding water residence times in the BS are 212.7 and 11.8 years, respectively. In the case 2, the residual and mixing water fluxes are increased to 121.4 and 2,583.8 km^3/yr, and corresponding water residence times are reduced to 120 and 5.6 years, respectively. When the boundary between the YS and BS is opened, the results are changed only a small fraction from the results with the closed boundary. This indicates that the water and salt budgets in the YS depend almost only on the water exchange between the YS and ECS.

Fig. 3 represents the relation between water resident time along with different values of the dif-

Table 2. Results of budget computations with S_R=$(S_1+S_2)/2$ using one-layer model.

	Region of box	Residual		Total (residual+mixing)	
		Water flux (km^3/yr)	Water residence time (yr)	Water flux (km^3/yr)	Water residence time (yr)
Case 1	Bohai	21.2	212.7	382.9	11.8
Case 2	Yellow Sea	121.4	120.0	2583.8	5.6
Case 3	Bohai and Yellow Sea	142.6	133.7	2716.7	7.0

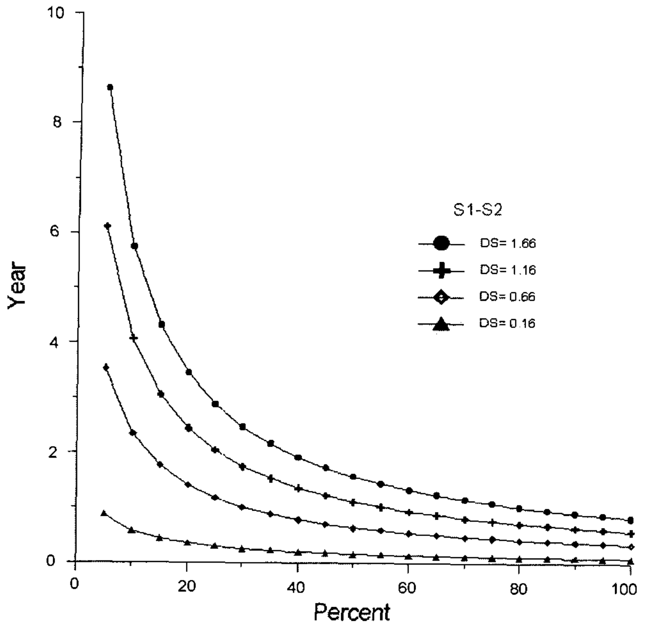

Fig. 3. Water residence time in the Yellow Sea with the one-layer model. The x-axis represents the ratio of the Changjiang discharge that enters into the Yellow Sea to the total discharge. DS means the difference of salinity between the Yellow and East China Seas.

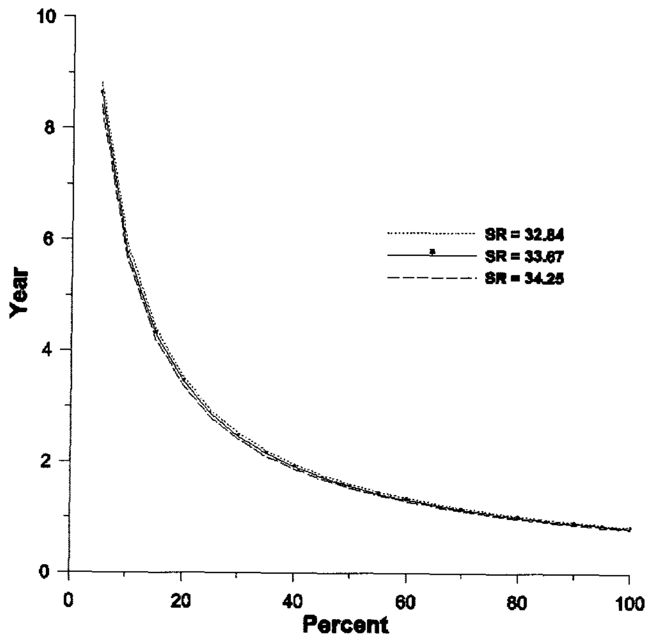

Fig. 4. The sensitivity of S_R^l the value of on water residence time when the difference of salinity between the YS and ECS is 1.66 psu. The x-axis represents the ratio of the Changjiang discharge that enters into the Yellow Sea to the total discharge.

ference of mean salinity between the YS and ECS and with different values of the ratio of the Changjiang discharge that enters into the YS to the total discharge for the case 2. Water residence time is inversely proportional to the Changjiang discharge input ratio. The sensitivity of the Changjiang discharge input ratio to water residence time is severe when the ratio is low. The figure also shows that water residence time decreases as the difference of salinity between the YS and ECS decreases. If the difference of salinity is reduced to 0.16 psu, water residence time is closed to a few months, i.e., within a year, except the case of extremely lower fresh water input ratio. Eq. (15) shows that water residence time decreases to zero as the mean salinity in the YS is closed to that in the ECS.

Fig. 4 exhibits the sensitivity of the value of S_R^l on water residence time when the difference of salinity between the YS and ECS is 1.66 psu. Water residence time only slightly decreases as S_R^l increases. If S_R^l is chosen as a value between S_1 (32.84 psu) and S_2 (34.50 psu), i.e., an up- and downwind schemes for the advective flux, and if the Changjiang discharge input ratio is 12%, the amounts of mixing water flux and of water exchange across the boundary between the YS and ECS are estimated to be 2,330 –2,840 km^3/yr and 109–133 km^3/yr, respectively. Water residence time corresponding to the mixing water flux is about 5–6 years.

Separate two-layer model (V_z=0)

The two-layer model is divided into two cases in accordance with the existence of exchange of water and salt across the layer interface. When the upper and lower layers are disconnected, i.e., the separated two-layer model, budgeting is meaningful only in the upper layer because the annual mean salinity in the lower layer is in the steady state and the lateral mixing water flux doesn't occur. For the upper layer, the layer interface acts as a rigid bottom boundary and the system is equivalent to the previous case. For the lower layer, if the water volume is in the steady state, the residual water flux is zero and the mixing water flux is given by

$$V_X^l = \frac{V_1^l}{(S_2^l - S_1^l)}\frac{dS_1^l}{dt} \tag{16}$$

The relation of V_R^l (= 0)<< V_X^l is still valid. If salinity in the box is in the steady state in each layer, the mixing salt flux is zero V_X^l and the budgeting procedure is meaningless.

Assuming that the Changjiang discharge input ratio

Table 3. Water residence time in the Yellow Sea.

Model	Water residence time (yr)	Remarks
One-layer	5~6	$S_1 \leqq S_R \leqq S_2$
Separate two-layer (upper layer)	1~2	ð
Coupled two-layer (upper layer)	2~3	″, $V_z = O(10^{-7}–10^{-6}$ m/s)
Coupled two-layer (lower layer)	5~6	″, ″
Coupled two-layer (total)	4~5	″, ″

is 12% and with the input values as in Table 1, the mixing water flux across the boundary is estimated to be about 2,543 km^3/yr and water residence time is about 1.9 years in the upper layer. Additional estimations with different values for salinity, S_R^u, with its range from S_1^u (32.26 psu) to S_2^u (34.50 psu) show that the mixing water flux and water residence time have ranges of 2,000–2,900 km^3/yr and 1–2 years, respectively. The result of this case corresponds to water residence time of the low salinity water flowed into the YS that originates from the CCW and CDW.

Coupled two-layer model (V_z 0)

Assuming that both the water volume and the annual mean salinity are in the steady state for each layer, the residual water fluxes are $V_R^u = -(V_\vartheta + V_z)$ and $V_R^l = V_z$, and the mixing volume transports are

$$V_X^u = \frac{V_R^u S_R^u - V_z S_z}{(S_2^u - S_1^u)} \tag{17}$$

and

$$V_X^l = \frac{V_R^l S_R^l + V_z S_z}{(S_2^l - S_1^l)} \tag{18}$$

Unlike in the estuarine system, the salt flux is balanced by the lateral residual salt flux and the interfacial vertical salt flux in each layer. Water residence times based on the water budget and the salt budget are, respectively, $V_1^u/|V_\vartheta + V_z|$ and $V_1^u/(V_R^u + V_X^u)$ for the upper layer. For the lower layer, they are $V_1^l/|V_z|$and $V_1^l/(V_R^l + V_X^l)$.

To apply the coupled two-layer model, the vertical (advective and/or diffusive) water fluxes must be quantified. However, it is not possible to find appropriate values from the measured data or published references in the current state. Hong (2001) showed that the vertical diffusion coefficient is O(10^{-4} m^2/s) at the thermocline depth and two orders larger near the bottom based on a calculation using the tracer conservation equation with the summertime ^{222}Rn data. In this study, we assume that the YS and BS are not different from typical oceanic condition. That is, the relevant values of the vertical velocity and the vertical mixing coefficient are O(10^{-7}–10^{-6} m/s) and O(10^{-4} m^2/s), respectively. The calculation with these values yields that water residence times in the upper and lower layers are 2–3 and 5–6 years. This corresponds to 4–5 years of water residence time for the whole system and indicates that water residence time by using the one-layer model is slightly overestimated. Table 3. summarizes water residence time estimated in this study.

DISCUSSION

A significant result of this study is that water residence time in the BS including the northern YS is twice as long as that in the YS. This is caused by the difference in the amount of river discharges. In the YS, the fresh water input from the Changjiang dominates the budgeting and the precipitation and evaporation are negligible. On the other hand, in the BS the river discharge is only about twice as large as the fresh water input on the sea surface. The decreasing trend of water residence time from the BS to the ECS is consistent with the estimations in the previous studies: Choi (1998) estimated the turn over time as 9.5, 2.5 and 1.5 years for the BS, YS and ECS, respectively, and Chen *et al.* (1999) showed 2.6 years of water residence time for the ECS. Thus, although there is the uncertainty in the input data, it can be concluded that water residence time is longer in the BS and gradually decreases toward the YS and ECS. In addition, the YS and BS cannot be considered as a single system in the view of water and salt budgets.

The estimation errors of the budgets and water residence time are mainly induced by uncertainties of input data in relation to open boundary and interface, i.e., the amount of discharge from the Changjiang that enters into the YS, the value of salinity difference between lateral boxes, and the vertical flux across the layer interface. The sensitivity of the Changjiang discharge input ratio to the water residence time is severe when it is smaller than 20%.

This is the case for the model domain marked by the solid lines in Fig. 2. Therefore, quantifying the amount of the Changjiang discharge that flows into the YS is the most serious problem to improve the budget model in the YS.

Another weakness of this study is the fact that the model does not consider the seasonality of the circulation in the study area. The difficulty also arises in combining the single box model (for the cold season) and the layered one (for the warm season). Though the use of the steady state behavior for the water volume and salinity in the box is a strong assumption in comparison with real situation in the YS and BS, it is appropriate for long-term (over years) water and salt budgeting because the pattern of seasonal variation of water volume and that of salinity are almost the same. However, if the phase of the annual cycle for a tracer concentration differs from that of water volume, it must be carefully take the annual mean of tracer flux.

Changes in rivervine input in the YS and BS are clear due to the increase of human activities such as agricultural use and dam construction. The decreasing trend of the discharge from the Yellow River, which is a major fresh water supplier to the BS, may result that water residence time in the BS is much longer than the current estimation. An interesting question is whether the completion of the Three Gorges dam on the Changjiang affects the water and salt budgets in the YS. It is expected that the completion of the dam will reduce the Changjiang discharge. The result of calculation shows that cutting back the discharge from the Changjiang by 10% through the dam would increase water residence time by more than 10%, i.e., longer than 7 years in the case with the one-layer model budgeting. With the same assumed situation Chen (2000) estimates about 9% reduction in the cross-shelf water exchange in the ECS based on the water and salt balance. Indeed, using box models, Nof (2001) predicts that the decrease of fresh water input from the China into the BS, YS and ECS by10% of total freshwater flux may lead more bottom water formation in the East Sea. In any event, human activities will have important effects on the water and salt budgets in the BS and YS.

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