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Numerical Simulation of Fortnightly Modulations of the Convergence Zone by Residual Volume Transport in a Macrotidal Estuary

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ABSTRACT

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This study examines the fortnightly modulation of convergence zone by residual volume transport of main channel using a numerical model in the tidally dominated Han River estuary (HRE), South Korea. The numerical model, EFDC (Environmental Fluid Dynamics Code), was simulated for 124 days, from May to August 2009, and used observed freshwater discharge for major rivers of HRE. The residual volume transport discharged into the HRE from the Yeomha channel and Seokmo channel had a ratio of 44:56 over thirty days under normal freshwater conditions. The model results show that a temporal variation of the residual volume transport (Lagrangian transport = Eulerian transport+Stokes transport) is formed near the Yeongjong Bridge with spring-neap variability, and net transport is outflowed to the west through the channel between Ganghwa and Yeongjong. Due to magnitude change of the residual volume transport by fortnightly (spring-neap) modulation, convergence zone (junction location of residual volume transport) show upward and downward spatial variation. We found that the convergence zone moves downstream during the spring period because of; 1) strong net downward barotropic flow by increased sea level difference between upstream and downstream during the spring tide; 2) decreased baroclinic flow towards the upstream of the main channel, caused by intensified tidal mixing during the spring period; and 3) increased outflow through the tidal flat channel between Ganghwa and Yeongjong during the spring period.

ADDITIONAL INDEX WORDS: *Fortnightly modulations, convergence zone, residual volume transport, macrotidal estuary*

INTRODUCTION

Gyeonggi bay (GGB) and Han River estuary (HRE) are located along the central coast of the Korean peninsula, and are a semi-enclosed region (Figure 1). The area consists of large and small islands and channels, with a complicated coastline, and a large tidal flat. The region is well known for its macrotidal characteristics with a tidal range more than 8.5 m. The HRE has a very complicated spatio-temporal variability of water circulation, which are due to tidal characteristics (Song and Woo, 2011; Woo and Yoon, 2011; Yoon and Woo, 2013), seasonal variations in freshwater discharge (Park *et al.*, 2002), mixing with seawater and the development of stratification (Jeong *et al.*, 2007).

The HRE is not easily accessible because it is close to the Military Demarcation Line between North and South Korea, and so it is difficult to obtain consistent observations of tide and tidal current. Due to the lack of observational data, it is difficult to gather the data required, not only for studies on the physical mechanism of the HRE but also for the revision and verification of numerical models. In terms of the limitations on the observational data, it is important to collate the most accurate verification and revision data.

The unique qualities of each channel determined by three freshwater inflow; GGB, which comprises many channels; and the seawater circulation of the HRE (Park *et al.*, 2002). In addition, volume transport of each channel will show spatio-temporal differences associated with the variability of spring–neap tides and the seasonal variation of inflowing freshwater. The difference in volume transport of each channel will directly influence the transfer of sediment and suspended material. This study constructed a high-resolution model with polysynthetic connections between the open seas of GGB and HRE. This study examined the ratio of residual volume transport of each channel and difference of the Yeomha channel depending on the time (spring–neap) variability.

METHODS

This study uses a three-dimensional hydrodynamic model, Environmental Fluid Dynamics Code (EFDC), which was developed by Hamrick (1996). EFDC has been successfully used in various water regions such as coasts, estuaries, lakes, wetlands, and reservoirs by many researchers (*e.g.*, Jin, Hamrick, and

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Tisdale, 2000; Park *et al*., 2005; Shen, Boon, and Kuo, 1999; Zuo *et al*., 2006). The structure of the basic model is similar to that of the Princeton Ocean Model (POM) of Blumberg and Mellor (1987), and a detailed explanation of the theoretical background and numerical technique is described in Hamrick (1996).

The present numerical model is applied to the HRE which extends 130 km in the east-west direction and 126 km in the north-south direction. The gridding system in this model uses orthogonal curvilinear coordinates (743 and 454 cells in x and y directions) in the horizontal direction and sigma coordinates (20 layers) in the vertical direction. A varying-size grid structure is used to better present estuary bathymetric and to resolve the complex shoreline. The size of grids varies, with relatively smaller cells near the main channel and the Han River (50~200 m) and increasingly larger cells seaward. The number of total water cells is 52,829 and the model time step is 4 s. The open boundary conditions are specified using the harmonic constants of five major constituents (M_2, S_2, N_2, K_1, and O_1) evaluated. In order to examine the accuracy of numerical model results, calibration and verification were conducted using observation data which include water level, tidal current, and salinity (Yoon and Woo, 2015).

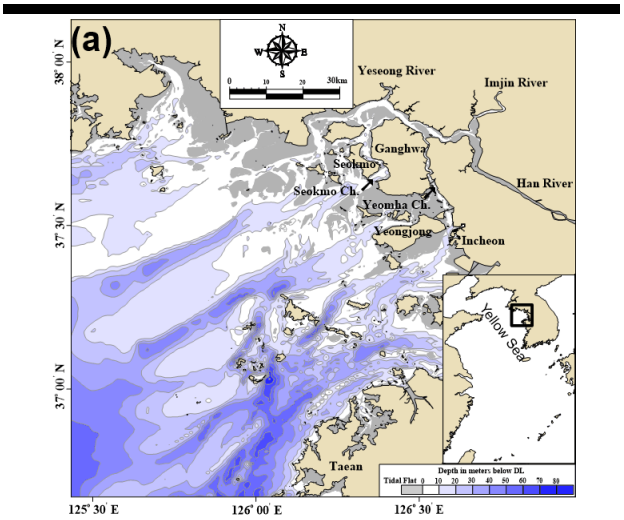


Figure 1. Map of the Han River estuary (Yeomha and Seokmo channel) and Gyeonggi bay, South Korea (a). The insert in (a) shows Gyeonggi bay (box) in the Korean peninsula.

RESULTS

Residual Volume Transport

The calibrated and verified numerical model was used to calculate the residual volume transport on a side of each channel based on (1). According to these equations, when a cross section of a channel has vertical and horizontal grid number of N and an area of a_n with a velocity of u_n passing through the cross section, then the residual volume transport (Q) can be expressed as follows:

$$Q = \left\langle \sum_{n=1}^{N} u_n \cdot a_n \right\rangle = \sum_{n=1}^{N} \langle u_n \rangle \cdot \langle a_n \rangle + \sum_{n=1}^{N} \langle U_n \cdot A_n \rangle \quad (1)$$

$$U = u - \langle u \rangle \quad (2)$$

$$A = a - \langle a \rangle \quad (3)$$

Here, < > represents an average for tidal cycle. U and A are tidal constituents of the flow velocity and the cross-sectional area, defined as (2) and (3). The first term of (1) is Lagrangian volume transport (L), the second term is Eulerian volume transport (E), and the last term is the Stokes drift volume transport (S).

Figure 2 shows the 30-day average for volume transport with normal river discharge conditions in the Ganghwado and Northern coast of Seokmodo, including the Imjin River, Yeseong River, and the Han River, which are locations of freshwater inflow. The figure presents Eulerian (E), Stokes (S) and Lagrangian (L) transport for each site. Negative and positive values represent the downstream (South and West) and upstream directions (North and East), respectively, of the residual volume transport. For the 30-day period of normal river discharge, direction of the L residual transport in Yeomha (Y1 cross-section), Seokmo (S1 cross-section), and Gyodong (R5 cross-section) channels was found to offshore. The Lagrangian residual transport outflow from R1 to the HRE is -772 m^3/s, and -121 m^3/s from the R2. Thus, the residual transport flow into the Yeomha channel of the east side of Ganghwado is -368 m^3/s; the residual transport flow through a northern channel of the Ganghwado is -471 m^3/s. In other words, about 56% (R4/R3 ratio) of the transport flows out of GGB from the Han River and the Imjin River through R4, whereas 44% (Y1/R3 ratio) of the transport outflows through Y1.

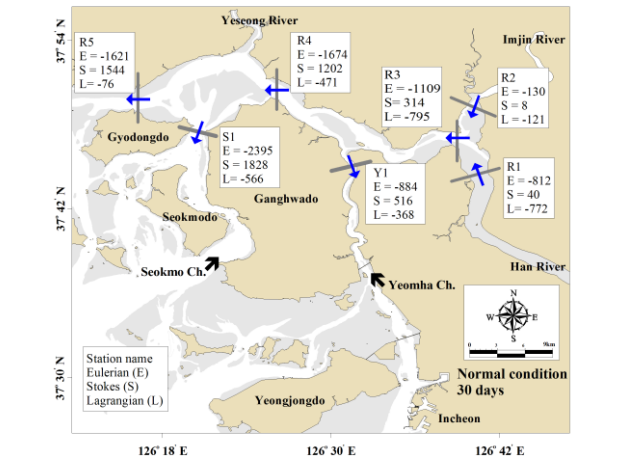


Figure 2. Residual volume transport at cross-sections during 30 days with normal freshwater discharge. Arrows indicate transport direction, and positive and negative values indicate flooding and ebbing directions, respectively.

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The net volume transport over 30 days with normal river discharge was also calculated for Yeomha channels on the east side of the Ganghwado, the Southern coast of Yeongjong, and Incheon harbor (Figure 3). From Seodo downstream, the E decreases while the S increases. This leads to an increase in net volume transport flow from offshore to upstream. The Yeongjong Bridge (Y2 Southern coastline and Y3 Northern coastline) formed a region where the net volume transport out-flowing from upstream converges with the net inflow of the transport from offshore. Observing the side of the G3 cross-section, the study confirmed that residual volume transport leaks into HRE through the channel between Ganghwa and Yeongjongdo. Also, since there is a sign of outflow into the west side in both G1 and G2, although the scale of the tidal flat channels between Ganghwado and Yeongjongdo, including depth and width, is smaller than the main channels, they have a profound impact on material transfer and the inflow and outflow of seawater into this area.

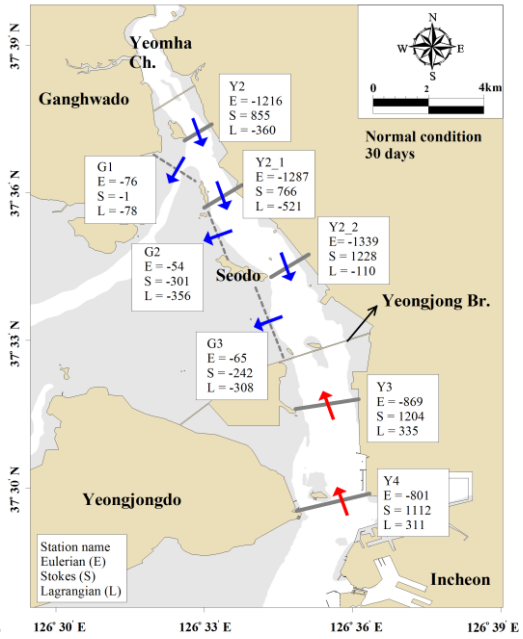


Figure 3. Residual volume transport rate at cross-sections of Yeomha channel and Incheon Harbor during 30 days with normal river discharge condition.

Fortnightly Modulation of Residual Volume Transport

The residual volume transport of four tidal cycles is present during spring and neap tide for normal river discharge (Figures 4, 5). During neap tides, a convergence zone is formed in the waters between the Y2_1 and Y2_2 cross-section, which is then found to flow out via G3 cross-section. However, during spring tide, waters converge between cross-sections Y2_2 and Y3, and the residual volume transport then flows out via G2 cross-section. Unexpected results were obtained, because the spring tide typically accompanies stronger ebb and flow, and stronger tidal currents compared to neap tides, so the study assumed that the leakage would appear on the south (downstream direction) of the area where the waters converge during neap tides.

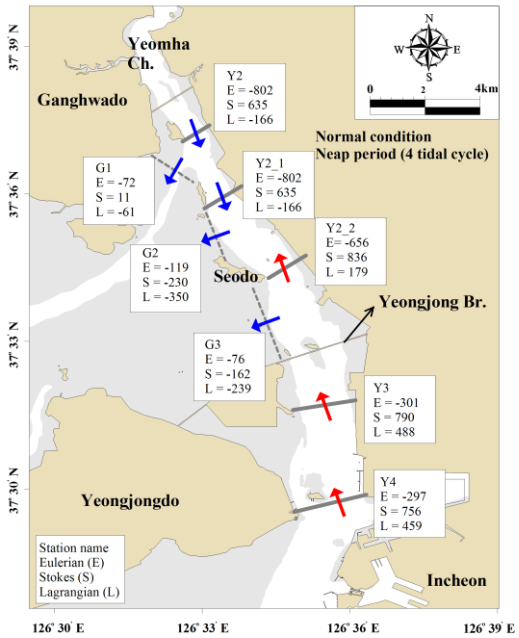


Figure 4. Residual volume transport rate at cross-sections of Yeomha channel during neap tide.

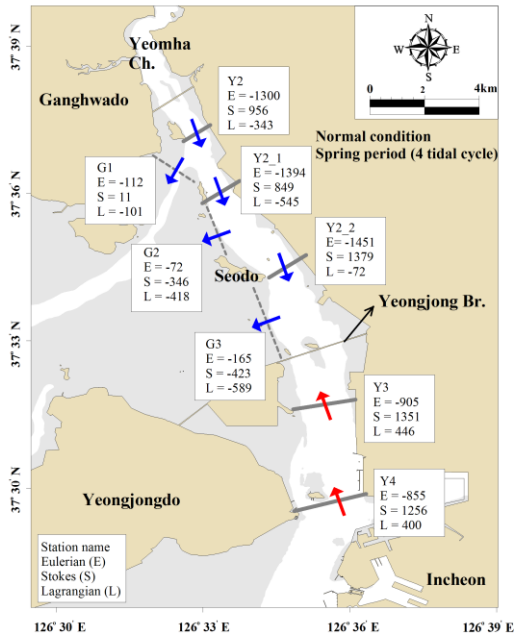


Figure 5. Residual volume transport rate at cross-sections of Yeomha channel during spring tide.

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DISCUSSION

The study suggests three reasons for the downstream shift in convergence during neap tides. For the Y2_2 cross-section, during spring tide the *E* value is greater than *S*, while during neap tides *E* is smaller than *S*. In other words, the tidal changes between spring and neap tides create a difference in residual pressure, which then shifts the convergence zone to the area between Y3 and Y2_1 cross-sections. The variations in residual barotropic pressure are caused by upstream–downstream fluctuations in residual pressure of the sea water level between spring and neap tides. The *E* value associated with this residual pressure increases during spring tide, and the downstream residual volume transport increases.

Stacey, Burau, and Monismith (2001) proposed (4) to calculate the velocity of baroclinic forcing:

$$u_g = \frac{1}{\rho}\frac{\partial \rho}{\partial x} g H^2 / u_* \quad (4)$$

Here, *H* represents depth of the water, and u_* is vertical mixing, a friction velocity that alternates turbulent current. When the friction velocity increases, there is an increase in the mixing and a decrease in the baroclinic forcing. During neap tides, velocity is lower than during spring tides, so there is a decrease in mixing and an increase in baroclinic forcing. These results appear to follow those of Nunes Vaz, Lenon, and de Silva Samarasinghe (1989), where an increase in baroclinic pressure leads to an increase in net volume transport under the baroclinic pressure. Kang and Iorio (2008) researched the change in baroclinic pressure flow caused by the strength of stratification when there is the maximum velocity and slack time.

According to (4), the friction velocity during spring tide is greater than for neap tides. Therefore, for an identical change in horizontal density, the velocity u_g in neap tides is lower than that of the spring tide. Thus, Table 1 shows the calculation u_g of spring- and neap tides with regard to horizontal density changes in the direction of the main channel between Ganghwa and Choji Bridge. When the baroclinic current in the upstream direction is created by the density difference between spring and neap tides, the current during neap tides is always stronger than that of spring tide; therefore, residual volume transport under baroclinic pressure increases in the upstream direction and the location of the convergence also shifts upstream

Table 1. *Scale of baroclinic flow and density gradient. Friction velocity is calculated by* $u_*^2 = C_D U^2$, *where* C_D *(=0.0025) is drag coefficient.*

	Spring period	Neap period
$\frac{1}{\rho}\frac{\partial \rho}{\partial x} g H^2$ (m²/s²)	1×10^{-4}	1.5×10^{-4}
u_g (m/s)	0.21	0.31

CONCLUSIONS

High-resolution EFDC numerical model was constructed to understand the transport mechanism associated with spring–neap variability, and to quantify residual volume transport around the HRE. The numerical model results were calibrated, and then verified using the tidal harmonic constant and observed velocity data. The residual volume transport flowing in and out from each channel of the HRE area was calculated, and the numerical model was found to satisfactorily represent the tide and tidal currents that are the main external conditions of the HRE. The residual volume transport has a ratio of approximately 44:56 for the Yeomha and Seokmo channels during a 30-day period of normal river discharge. A convergence zone of the residual volume transport occurs around Yeongjong Bridge. The converged residual volume transport flows out via the tidal flat between Yeongjongdo and Ganghwado in the west. The residual volume transport convergence zone moves upstream or downstream in relation to baroclinic transport and the difference between Stoke drift and Eulerian transport volume, which fluctuates according to the spring–neap variability.

ACKNOWLEDGMENTS

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LITERATURE CITED

Blumberg, A.F. and Mellor, G.L., 1987. A description of a three-dimensional coastal ocean circulation model. *In:* Heaps, N.S. (ed.). *Three Dimensional Coastal Ocean Models.* Washington, DC: American Geophysical Union, pp.1-16.

Hamrick, J.M. 1996. *User manual for the environmental fluid dynamics computer code.* Department of Physical Sciences, School of Marine Science, Virginia Institute of Marine Science, College of William and Mary, 446p.

Jeong, J.H.; Kim, K.J.; Yang, K.H.; Chang, Y.Y.; Park, S.H., and Kim, Y.T., 2007. Study on the temporal and spatial variations of salinity by freshwater discharge in Gyeonggi Bay. *Journal of Environmental Impact Assessment*, 16(6), 421-432.

Kang, K.R. and Iorio D.D., 2008. A study of estuarine flow using the roving ADCP data. *Ocean Science Journal*, 43(2), 81-90.

Nunes Vaz, R.A.; Lenon, G.W., and de Silva Samarasinghe, J.R. 1989. The negative role of turbulence in estuarine mass transport, *Estuarine Coastal Shelf Science*, 28, 361–377.

Park, K.; Jung, H.-S.; Kim, H.-S., and Ahn, S., 2005. Three-dimensional hydrodynamic eutrophication model (HEM-3D): application to Kwang-Yang Bay, Korea. *Marine Environmental Research*, 60, 171–193.

Park, K.; Oh, J.-H.; Kim, H.-S., and Im, H.-H., 2002. Case study: Mass transport mechanism in Kyunggi Bay around Han River mouth. *Journal of Hydraulic Engineering*, 128, 257-267.

Shen, J.; Boon, J.D., and Kuo, A.Y., 1999. A modeling study of a tidal intrusion front and its impacts on larval dispersion in the James River estuary, Virginia. *Estuaries*, 22, 681–692.

Song, Y.S. and Woo, S.-B., 2011. Periodic characteristics of long period tidal current by variation of the tide deformation around the Yeomha Waterway. *Journal of Korean Society of Coastal and Ocean Engineers*, 23(5), 393-400.

Stacey, M.T.; Burau, J.R., and Monismith, S.G., 2001. Creation of residual flows in a partially stratified estuary. *Journal of Geophysical Research*, 106, 17013-17037.

Woo, S.-B. and Yoon, B.I., 2011. The classification of estuary and tidal propagation characteristics in the Gyeong-Gi Bay, South Korea. *In:* Furmanczyk, K.; Giza, A., and Terefenko, P. (eds.), *Proceedings, 11th International Coastal*

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Symposium. Journal of Coastal Research, Special Issue No. 64, pp. 1624-1628.

Yoon, B.I. and Woo, S.-B., 2013. Tidal asymmetry and flood/ebb dominance around the Yeomha channel in the Han River Estuary, South Korea. *In*: Conley, D.C.; Masselink, G.; Russell, P.E., and O'Hare, T.J. (eds.), *Proceedings, 12th International Coastal Symposium. Journal of Coastal Research*, Special Issue No. 65, pp. 1242-1246.

Yoon, B.I. and Woo, S.-B., 2015. The along-channel salinity distribution and its response to river discharge in tidally-dominated Han River estuary, South Korea. *Procedia Engineering*, 116, 763-770.

Zou, R.; Carter, S.; Shoemaker, L.; Parker, A., and Henry, T., 2006. An integrated hydrodynamic and water quality modeling system to support nutrient TMDL development for Wissahickon Creek. *Journal of Environmental Engineering*, 132, 555-566.

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