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# Optimization of Influencing Factors in Tidal Current Data Assimilation Modeling in Macro Tidal Estuary, Gyeonggi Bay, South Korea

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**ABSTRACT**

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The study investigates the effect of the model prediction accuracy improvement using data assimilation technique in macro-tidal estuary, such as the Gyeonggi Bay (GGB), South Korea. The observation data used in this study is a tidal current measurement from Acoustic Doppler Current Profiler (ADCP) mooring device. GGB is located at the middle west coast of South Korea, and it is semi-closed estuary that has a tidal range over 6.8 m. To take the irregularity of coastline into account, this study utilized the Finite Volume Coastal Ocean Model (FVCOM), which has the flexible advantage of grid resolution by using unstructured triangular grid system. When applying data assimilation into the coastal model, various parameters, such as scaling factors and correlation lengths are needed to be adjusted to find out the best performance. Total 25 cases used in Taylor diagram showed that different influencing factors are required to be optimized at each observation location. It means that parameters in data assimilation depend on the physical dynamic system via complicated geometry. The optimized parameters not only increase by the tidal range but also it is offset by the effect of river discharge. The horizontal influence range of data assimilation with all observed locations becomes even less than the result applying only one location. It is estimated that the phenomena occurred due to strong tidal currents and interference between the range of influence. The sensitivity of data assimilation parameters in tidally dominated coastal area indicates that a systematic way of choosing the most optimized site-specific parameters are required in macro tidal area.

**ADDITIONAL INDEX WORDS:** *FVCOM, data assimilation, tidal current, coastal model.*

## INTRODUCTION

Investigators have studied the development of coastal forecast system to improve a modeling accuracy using data assimilation (DA). Park *et al.* (2015) developed a high-resolution coastal circulation model with DA to improve the accuracy of the SST forecasting over the Yellow Sea. This technique has been developed not only to improve model accuracy in the coastal area but also to offer a information of coastal disaster, such as oil spills and marine accidents. Considerable progress has recently been made toward understanding the coastal DA technique to improve coastal prediction. Gu, Woo, and Kim (2019) assimilated using limited observation to induce improvement of salinity stratification for estuary safety. Scott and Mason (2007) assimilated with calibrated parameters such as sediment transport rate and coefficient to improve coastal area morphodynamic model. Also, Ullman and Wilson (1998) used the temporal and spatial variability of the bottom drag coefficient via DA to change the vertical structure in an oscillatory boundary layer showing that the damping effect of stratification on turbulent mixing cause a reduction of the bottom drag coefficient. However, most of the assimilation techniques to optimized parameters have been restricted to empirically controlled in each research area. It is necessary to determine the optimized parameters in DA for both the reduce of computational cost and the accuracy of coastal prediction. Especially in the coast, the optimized parameters determine due to environmental characteristics such as tidal current and river discharge.

Most authors reported previously that current DA apply in coast where the tidal effect was not significant. Kurapov *et al.* (2005) assimilated ADCP data into a coastal model where off Oregon is wind-driven circulation in an area of simple shelf during the upwelling season. However, although the effect of DA with coastal model was demonstrated, little attention has been paid to research on the sensitivity of parameters in DA on the macro tidal estuary with the extremely complex coastline and high tide. The objective of this study is to estimate optimized parameter of DA in macro tidal estuary. The Gyeonggi Bay (GGB) in Korea is macro-tidal flat that has a tidal range larger than 6.8 m (Yoon and Woo, 2011). The accuracy of coastal prediction is usually sensitive to limited tidal current observation.

This study is composed as follows: (1) The observed ADCP

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bottom-mooring data from 4-location of GGB is applied DA using the unstructured grid numerical ocean model and (2) The parameters in DA for the best condition analyzed by Taylor diagrams. (3) The influence range (IR) of DA investigated in tidally dominated coast.

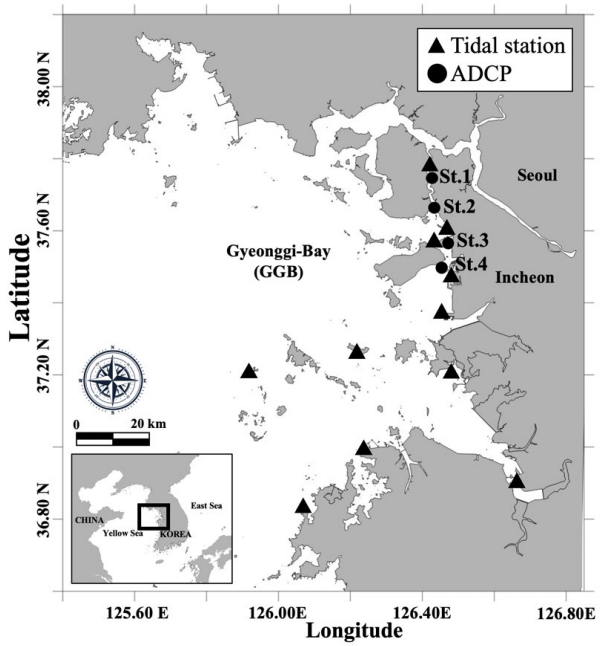



Figure 1. Research area and measurement location (Triangles means tidal station, dots means ADCP mooring location).

## METHODS

### Data Assimilation and Parameters

The purpose of DA using observation data is to improve model accuracy, and the types of DA method are diverse. In this study, the basic concept of DA called Optimal Interpolation (OI) is described. Estimates from DA approach for estimating statistical method that is the basis of OI it is 'Cressman analysis'. It is calculated as follows from the estimate (Kantha and Clayson, 2000):

$$\frac{\partial \alpha(x,y,z,t)}{\partial t} = F(\alpha, x, y, z, t) + G_\alpha \frac{\sum_{i=1}^{N} W_i(x,y,z,t)(\alpha_o - \alpha_p)_i}{\sum_{i=1}^{N} W_i(x,y,z,t)} \quad (1)$$

where, $\alpha_o$ is observation and $\alpha_p$ is prediction at i-th position. F(α, x, y, z, t) is model data. And $G_\alpha$ means Scaling factor. Scaling factor is introduced because an ensemble of model states sampled over a long period may have a large seasonal or interannual variance, which is inadequate to represent the instantaneous forecast error variance:

$$W_i(x, y, z, t) = w_{xy} \cdot w_\sigma \cdot w_t \cdot w_\theta \quad (2)$$

$$w_{xy} = \begin{cases} \frac{R^2 - r^2}{R^2 + r^2}, & 0 \le r < R \\ 0, & r > R \end{cases} \quad (3)$$

$$w_\sigma = \begin{cases} 1 - \frac{|\sigma_{obs} - \sigma|}{R_\sigma}, & |\sigma_{obs} - \sigma| \le R_\sigma \\ 0, & |\sigma_{obs} - \sigma| > R_\sigma \end{cases} \quad (4)$$

$$w_t = \begin{cases} 1, & |t - t_0| < T_w/2 \\ \frac{T_w - |t - t_0|}{T_w/2}, & T_w/2 \le |t - t_0| \le T_w \\ 0, & |t - t_0| > T_w \end{cases} \quad (5)$$

$$w_\theta = \frac{||\Delta\theta| - 0.5\pi| + c_1\pi}{(0.5 + c_1)\pi} \quad (6)$$

The weight function used here considers the temporal and spatial variation. Total weight likewise has a value between 0 and 1. Where, R is the search radius, r is the distance from the location where the data exist. $R_\sigma$ is the vertical search range. $T_w$ is one-half the assimilation time window. $\Delta\theta$ is the directional difference between the local isobaths and the computational point with $c_1$ constant ranging from 0.05 to 0.5.

Before applying DA into the background model, various kinds of numerical experiments were conducted to calculate the weight for the model and the observation data calculated previously in the observation station. The scaling factor and correlation radius based on the numerical experiment were used to calculate the weight of observation and model data in the domain. Based on the estimated weight, OI was used based on the unstructured grid ocean numerical model at the GGB to suggest the best state of ocean prediction and the empirical correlation.

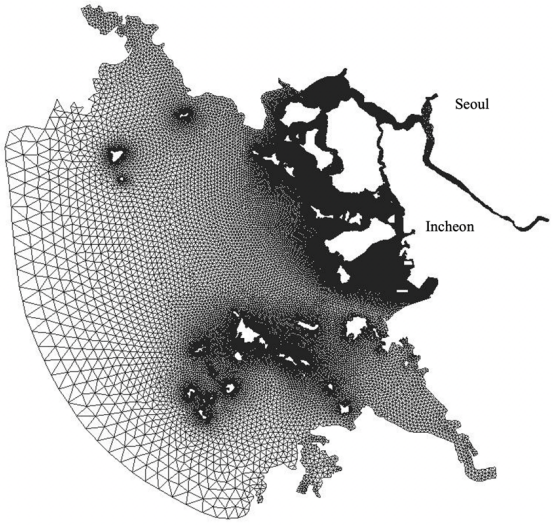



Figure 2. GGB unstructured model domain.

**Tidal Current in GGB**

Park *et al*. (2002) have reported that GGB is considerably influenced by the barotropic and baroclinic pressure gradients. GGB has not only includes 3 major rivers but also a tidal range more than 6.8 meters of spring tide and 3.5 meters in the neap tide. Figure 1 shows experimental DA used in the current measurement performed in the total of four stations. On the bottom layer for each station, ADCP was observed during at least 33 days or more.

**Numerical Model-FVCOM**

This study used Finite Volume Coastal Ocean Model (FVCOM) to applying DA. FVCOM developed by Chen, Liu, and Beardsley (2003) is appropriate to consider a complex coastal bathymetry using the unstructured grid system and effective computation resource via the finite volume method (FVM). This can be solved numerically using calculations of the flow in finite difference method (FDM). Also, the unstructured grids of FVCOM are used like a finite element method (FEM). Thus, in a technical perspective, FVCOM has been blended between simple discrete from the FDM and the efficiency of the geometric flexibility from FEM.

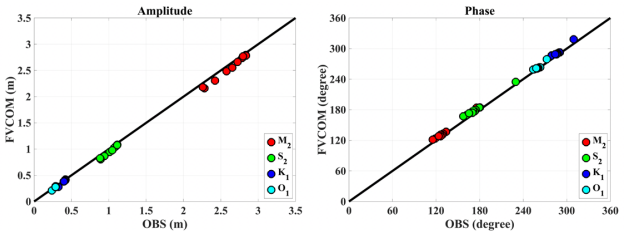



Figure 3. Comparison tidal components amplitude (left panel) and phase (right panel) for each tidal station.

Figure 2 shows the background model domain for tidal simulation in the GGB. The complex and irregular geographic characteristics of the coastline of GGB were implemented with an unstructured grid, and the 30 second grid water depth of the seas near Korea provided by Korea Institute Ocean Science Technology (KIOST), and National Astronomical Observatory (NAO.99b) was used for tidal boundary conditions. The verification of tide model was conducted based on the measurement at tidal station operated by the Korea Hydrographic and Oceanographic Agency (KHOA).

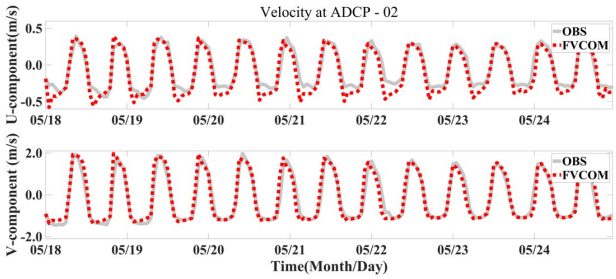



Figure 4. Comparison velocity timeseries between model (FVCOM) and measurement (OBS) at the St.2.

In order to validate model accuracy, continuous 1-year long tidal data are prepared for each tidal station. In addition, 4 tidal constituents ($M_2$, $S_2$, $K_1$, $O_1$) are extracted each tidal station from KHOA for comparison with the simulated model result. In Figure 3, the dots are placed on a crossline. It means the model fully reproduces very well almost like the observation values.

Table 1. *Skill score of velocity each ADCP mooring location at GGB.*

| Observation | Surface | Middle | Bottoms |
|---|---|---|---|
| ADCP St. 1 | 0.767 | 0.511 | 0.603 |
| ADCP St. 2 | 0.968 | 0.971 | 0.816 |
| ADCP St. 3 | 0.866 | 0.939 | 0.734 |
| ADCP St. 4 | 0.884 | 0.932 | 0.579 |

Figure 4 shows the correlation between the observed data and the simulated results. Murphy (1989) suggested skill scores based on Mean-Square Error to process the term involving the correlation coefficient between the forecast and observations. In this study, the result shows the skill scores each ADCP layer to validate velocity. (Table 1). The maximum skill score is 0.971, and it means that the model highly correlates with the observation. However, several scores are low at the middle-bottom layer because of the limitations of the model due to high tide and river discharge. This background model validation result based on Gu, Woo, and Kim (2019).

**Application of Data Assimilation**

The most influence on the observed data in OI is the scaling factor and the correlation length. Thus, the experiment is prepared while changing two parameters to find the best conditions. Table 2 shows parameters condition each assimilation cases number. When applying assimilation, vertical sigma weight for weight function is obtained by interpolation from top to bottom sigma layer.

Table 2. *Experiment case number table by condition of parameters in DA.*

| Scale Factor/ Correlation Length(km) | 1.0 | 3.0 | 6.0 | 9.0 |
|---|---|---|---|---|
| 0.1 | 01 | 02 | 03 | 04 |
| 0.5 | 05 | 06 | 07 | 08 |
| 1.0 | 09 | 10 | 11 | 12 |
| 2.0 | 13 | 14 | 15 | 16 |
| 3.0 | 17 | 18 | 19 | 20 |
| 4.0 | 21 | 22 | 23 | 24 |

To determine effect of DA, this study use ‘Taylor diagram’. The Taylor diagram is a representation of the diagram using Correlation Coefficient (CC), Centered Root Mean Square Difference (CRMSD), Standard Deviation (STD) between observation and model data. This is a statistical analysis to determine which best conditions between the observations and model (Taylor, 2001).

## RESULTS

Figure 5 shows sample of the Taylor diagram at St. 1. It shows that the best condition of 25 experiments has the smallest statistical error. For example, the best condition in St.1 is case

number 9 via the Taylor diagram. Table 3 shows that best condition is different at each ADCP mooring point. Because of this comprehensive treatment of the Taylor diagram, this result was successful in realizing the existence of best condition cases.

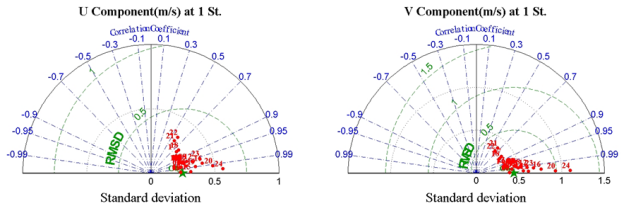



Figure 5. Taylor diagram of U, V component (m/s) at St. 1. The best condition case number (red dots) placed on concentrated around the observation (green dot) due to error covariance of best condition case smaller than other cases.

Figure 6 shows that the optimized parameters affect the IR. It means the difference between the calculated values (*i.e.*, speed) in the model with and without DA. Figure 6(a) shows IR is affected only at the near channel, while in Figure 6(b), IR on the salt and fresh water-mixed layer is even larger than Figure 6(a). The IR at Figure 6(c) and (d) is shown along the tidal creeks caused by high river discharge and tidal currents.

Table 3. *Information of Best condition cases number with statistics terms each location.*

| St. | | Best Case No. | STD | RMSD | CC |
|---|---|---|---|---|---|
| 1 | U | 09 | 0.429 | 0.046 | 0.959 |
| | V | 09 | 0.441 | 0.037 | 0.947 |
| 2 | U | 13 | 0.620 | 0.049 | 0.961 |
| | V | 13 | 0.725 | 0.040 | 0.965 |
| 3 | U | 15 | 0.363 | 0.027 | 0.938 |
| | V | 15 | 0.632 | 0.035 | 0.925 |
| 4 | U | 20 | 0.257 | 0.040 | 0.970 |
| | V | 20 | 0.520 | 0.071 | 0.957 |

Table 4 means optimized parameters increase far from the coast. For example, St.1 required optimized scale factor is 1.0 but St.4 required 3 times than St.1. It means that the optimized parameters need to amplify the sensitivity of scaling effect. Alternatively, the spatial dependency of the correlation length is not as obvious as the scaling factor, although the furthest point (St. 4) shows the largest value (9.0 km) compared to the smallest value (1.0 km) at the closest point (St. 1). This location dependency of the parameters could be caused by physical and geographical characteristics of oceanic process and it requires further study.

## DISCUSSION

The objective of this study was to investigate the effect on optimized parameters of DA in the tidally dominated estuary. The results suggest that the parameters in the DA required different optimal values at each observation. It is shows that the scale of optimal parameters depends on observation rather than models. In the coastal model which model prediction accuracy is low due to nonlinearities such as turbulence, the optimal parameters increased due to the dependence on the observation values. However, this study shows that the optimal parameters decreases when the observation location is close to the river mouth. This reason is that the effect of current DA interference by both the strong river discharge and the tidal current via tidal creeks.

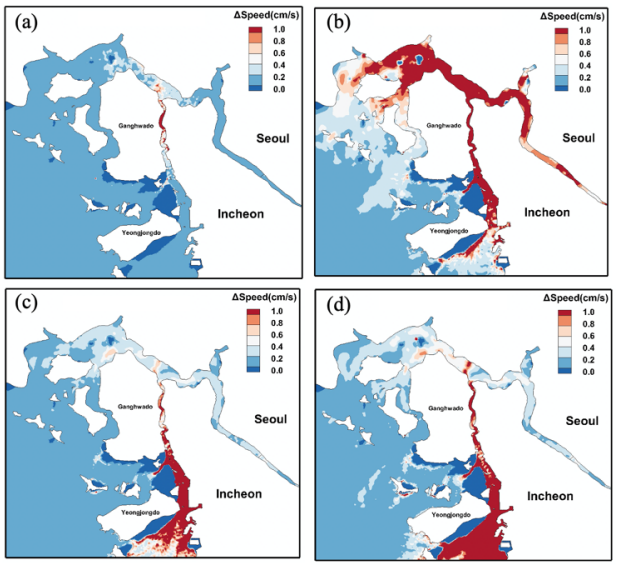



Figure 6. The horizontal distribution of IR. The difference in current speed between DA result and without DA.

The influence range of optimal parameters in coastal DA can be explained by tidal dominated estuary. Figure 7 shows IR distribution by optimal parameters at all observation location. In contrast to Figure 6, the IR has been reduced in all observation station. This reason for reduced impact is offset by overlapping the IR with each other. In particular, the influence range of the estuary channel where the impact was greatest has affected it from all observation. And the IR at other observation has changed locally. The optimal parameters with only one observation have an independent IR. However, the multivariate observations reduce the IR due to estuary circulation between high tide and river discharge.

Table 4. *Optimized parameters values at each location.*

| | St.1 | St.2 | St.3 | St.4 |
|---|---|---|---|---|
| Scale Factor | 1.0 | 2.0 | 2.0 | 3.0 |
| Correlation Length(km) | 1.0 | 1.0 | 6.0 | 9.0 |

## CONCLUSIONS

This paper introduces an empirical case study to determine the IR of coastal DA using optimized parameters. The parameters in DA such as scaling factor and correlation length are adjusted to find optimized with observation. Total 25 cases result with Taylor diagram showed that IR are differently required to be optimized

at each location. It means that parameters in the DA depend on the physical dynamic system via complicated geometry.

The optimization value of parameters in the DA presented in this study has limitations to apply the whole coastal region. However, this study is served well as a tool to generate the initial framework to test later on improved coastal forecast. Based on the current study, this result expect that the various applications of DA technique could be possible for coastal ocean modeling. There has been a growing interest in the forecast system because they are expected to improve prediction accuracy.

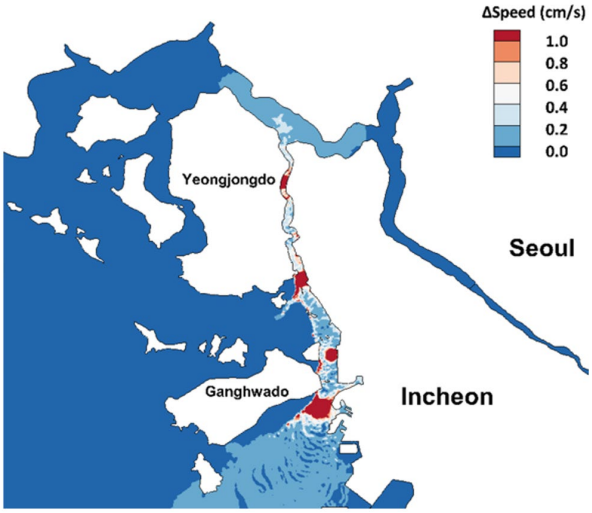



Figure 7. As in Figure 6, but the horizontal distribution of IR using optimized parameters at each location.

## ACKNOWLEDGMENTS

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