Monitoring changes in suspended sediment concentration on the southwestern coast of Korea

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ABSTRACT


Concentrations and distribution patterns of suspended sediment (SS) are key indicators of marine environmental change, particularly in coastal areas, which gives good information on the deposition and migration of sediments from land. In this study we analyzed 632 scenes (79 days × 8 scenes) of Geostationary Ocean Color Imager (GOCI) data in order to investigate SS variations relating to tides, tidal currents, bottom morphology, river discharge, and so on. We also compared them to the numerical model of tidal currents for the Yellow Sea. The study area, the coastline of Mokpo, is characterized by shallow water depths (<50 m), a relatively large tidal range (8 m) and by strong tidal currents (1 to 2 m/s). The coastal area of Mokpo shows extremely high SS concentrations (SSC) caused by a resuspension of bottom sediments. GOCI, the world’s first geostationary ocean color observation satellite, can obtain data hourly during daylight. Therefore, GOCI is well equipped for the detailed analysis of time-series variations in SSC with regard to tides and tidal currents along Mokpo. The concentrations and distribution patterns of SS in the study area were mainly affected by tidal currents. During flood tide, SSC showed higher values than during ebb tide, and the SS distribution pattern flowed in a northerly direction. On the other hand, during ebb tide, the SS distribution pattern flowed towards the south. Bottom morphology also displayed a similar pattern to the SS distribution.

ADDITIONAL INDEX WORDS: GOCI (Geostationary Ocean Color Imager), suspended sediment, coastal waters, monitoring
The Geostationary Ocean Color Imager (GOCI) is the world’s first geostationary ocean color satellite and is now continuously observing our study area in its geostationary orbit. Because GOCI provided data every hour from 09h00 to 16h00 local time, we were able to analyze the short-term time series variations in SS distribution (Ryu et al., 2011).

The study area, (i.e., the Mokpo coast), is located on a southwestern coastal part of the Yellow Sea (hereafter referred to as CM) (Figure 1). The area is characterized by shallow water depths (<50 m), relatively strong tidal currents (1 to 2 m/s) and complicated coastlines with numerous islands and extensive tidal flats (Kang et al., 2009). There are semi-diurnal tides with an ebb-dominant tidal flow characterized by long flood and short ebb tides (Byun et al., 2004). Freshwater is supplied to open sea by the Youngsan River. The SSC of this coastal area yielded relatively high values (>20 g/m³). During the winter season extremely high SSC values (>200 g/m³) occurred in shallow areas because of the strong northwest monsoon. In this study, we extracted front lines and current vectors using GOCI SS data, with the aim of observing spatial and seasonal variations as well as tide direction changes.

**DATA**

A total of 632 scenes of GOCI data were used for SS analysis from January 2012 to March 2013. To retrieve the SS concentration from GOCI TOA (top-of-atmosphere) data, atmospheric correction was initially performed for all GOCI images. The modified MUMM approach was used (Ruddick et al., 2000; Choi et al., 2012; Choi et al., 2013; Lee et al., 2013), in which contributions by aerosol and water to satellite reflectance are estimated on a per-pixel basis, with the assumption of spatially constant band-7:band-8 ratios for aerosol reflectance (c) and water reflectance (a). Each GOCI image was converted to radiance on the sea surface (\(L_a\)), and \(L_a\) was converted to remote sensing reflectance (\(R_a\)) using the extraterrestrial solar irradiance (\(E_o\)) values for each GOCI band. For the verification of atmospheric correction, we selected data matched within ±10 minutes to the GOCI observation time. So obtained 25 matching data sets and these GOCI data showed a good correlation with matching in-situ \(R_a\) values (\(R(490) = 0.89, R(555) = 0.95\) and \(R(660) = 0.95\)), as illustrated in Figure 2.

Tidal-, wind- and water depth-data were used for the comparison of SS variations with environmental factors. Data concerning tidal conditions (Jindo & Heuksando tidal station) and wind variations (Heuksando ocean observation station) were obtained from the Korea Hydrographic and Oceanographic Administration website (KHOA, http://www.khoa.co.kr). Current speed and direction data were obtained using a recording current meter (RCM) instrument between 23rd and 28th October 2013 off Mokpo. This data was used for the analysis of SS movement with respect to semi-diurnal tides along with the tidal model.

**METHODS**

**SS Algorithm for GOCI**

We developed a new empirical SS algorithm in a band combination format using 3 bands, as proposed by Siswanto et al. (2011). For the algorithm development, an in-situ dataset of SS concentrations and \(R_a\) data were acquired within our study area. SS concentration (g/m³) was determined by gravimetric means and surface \(R_a\) data were measured by the hyperspectral radiometer of ASD FieldSpec® portable spectroradiometer (Analytical Spectral Devices, Inc.). The equation below shows a newly developed SS algorithm for GOCI data. This algorithm showed best squared correlation coefficients (R²) of 0.97.

\[
SS (g/m^3) = 10^{c0 + c1(555) + c2(490)/555)}
\]

\[
c0 = 0.6567, \ c1 = 28.83, \ c2 = -0.6917
\]

**SS front and current vector analysis**

For SS variation analysis, front lines of SS distribution were extracted and water current vectors were analyzed using time-series GOCI SS data. Front lines were extracted based on the boundary value of a 10 g/m³ TSS concentration. The study area possesses highly turbid coastal waters with shallow water depths, so SS concentration was dynamically decreased offshore. Owing to this characteristic of the area, a SS front was easily extracted and a SS concentration of 10 g/m³ was the best boundary value for extraction. Figure 4 shows extracted front lines for each SS image.

The water current vectors were analyzed using Ocean Surface Current Estimation (OSCE) algorithm developed by Choi et al. (2012). The OSCE is a method for current vector extraction using maximum cross correlation (MCC). GOCI has the advantage of a high temporal resolutions at 1 hour intervals. This unique feature enables the monitoring of dynamic changes in coastal water properties, especially for tidal currents in the CM area. We verified the OSCE results using in-situ RCM measurements obtained on the 23rd October 2013. A numerical model for tidal currents was used for comparison with the current vector analysis, which was developed by Lee et al. (2008) for the Yellow Sea. In situ tidal current data from RCM instrument were also used for comparison with the current vector results.
Figure 3. Comparison of SS distribution according to different tidal conditions of flood (a, c, e, and g) and ebb (b, d, f, and h) tide within same season (a and b for winter; c and d for spring; e and f for summer; and g and h for autumn). Images represent the SS distribution on the 27th Feb., 20th Feb., 26th Apr., 3rd May, 31st Aug., 31st Jul., 18th Oct., and 25th Oct., respectively.
RESULTS AND DISCUSSION

Spatial and seasonal variations

SS distribution off the coast of Mokpo was widely spread out towards the southwest, having higher SS concentrations during spring and winter seasons. Figure 3 showed seasonal SS images processed using GOCI. Figures 3a, c, e, g showed SS distribution maps acquired during flood tide in winter, spring, summer and autumn seasons, respectively. Conversely, Figures 3b, d, f and h showed SS distribution maps acquired during ebb tide in winter, spring, summer and autumn seasons, respectively. SS showed higher values during flood tide than during ebb tide conditions. It is assumed that the resuspension of bottom sediment is stronger during flood tide. This may be owing to a longer flood tide than ebb tide conditions. Byun et al. (2004).

Seasonal variation of SS distribution represented maximum extent during the winter season and minimum extent during the summer season. Maximum SS extent decreased toward the end of winter, whilst the minimum SS extent in summer expanded as winter approached. High SS concentrations and extents during the winter season were owing to strong north-westerly monsoon winds and the resulting resuspension of sediment. To confirm the influence of strong wind for high concentrations and wide areas of expansion, we processed front analysis, extracted from GOCI SS data using boundary value of 10 g/m$^3$, and compared this with wind speed and direction data measured at the Heuksando Ocean Observation Station (Fig. 4). Wind speed during the winter season, during which SS values and areal coverage were greater, was observed to be stronger than for summer months.

Directional variations

Figure 5 displays the results of current vectors extracted from the GOCI SS data – tidal currents calculated from the numerical model and in-situ current data measured by RCM instruments on 26th October 2012. Figure 5a represents current vector results obtained from the GOCI SS data captured at 9 and 10 a.m.; Figure 5b represents the model result at 9:30 a.m.; and Figure 5c represents current direction and speed measured at 9:30 a.m. using RCM. Figures 5d, e, and f represent data obtained at 10:30 a.m., and Figures 5g, h and i represent data obtained at 11:30 a.m. in a same way. The results of current vectors (Figs. 5a, d, g) and tidal currents (Figs. 5b, e, h) showed similar patterns in direction toward southwestern area and reduction of vector size. In the case of in situ current data from RCM, its result at 10:30 a.m. shows very similar patterns to the current vectors and tidal currents at 10:30 a.m. Unfortunately the other data were not matched to the GOCI and model data and may be caused by the instantaneous flow of in situ measurements.

Figure 6 shows time-series variations for fronts (10 g/m$^3$) extracted by the GOCI SS data as well as time-series current vector distributions processed by GOCI on 26th March 2012. During flood tide, currents moved in a clock-wise direction close to shore. During flood conditions, a strong northwesterly-flowing tide appeared along the southern part of Jindo. And along the coastline of Heuksando, currents moved slightly towards a southwesterly direction and changed to northerly a direction. The movement along the Youngkwang coast was toward the northeast.

Figure 4. Seasonal variations for the distribution front of suspended sediment (10 g/m$^3$ boundary) together with wind data (Heuksando ocean observation station).
Figure 5. Comparison of results for tidal current extraction using: (a, d, and g) the current vector method of GOCI TSS data; (b, e, and h) a numerical model for tidal currents; and (c, f, and i) in-situ RCM data.
CONCLUSION

In this study, we analyzed the time-series variation of SS movement and distribution along the coastal area of Mokpo using GOCI data. The Mokpo coastline is mainly affected by tidal currents and bathymetric expression. The flood tide is highly influential on SS distribution in this area. The current vector analysis, using time-series GOCI SS data, provide invaluable information regarding current directions and sediment movement within this area. GOCI current vector results were very well matched to the numerical tide models. If the accuracy of SS algorithms and atmospheric corrections for use on coastlines with extremely high SS concentrations were to be improved, time-series variations (using GOCI data) would be very helpful in coastal environmental monitoring in the northwest Pacific.

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LITERATURE CITED


