Application of the Landsat TM/ETM+, KOMPSAT EOC, and IKONOS to Study the Sedimentary Environments in the Tidal Flats of Kanghwa and Hwang-Do, Korea

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Abstract: The west coast of the Korean Peninsula is famous for its large tidal range (up to 9 m) and vast tidal flats. With comparison the sedimentary environments of open and close tidal flat using remote sensing, we select Kanghwa tidal flat and Hwang-Do tidal flat in Cheonsu Bay. Prior to surface sediment discrimination using remote sensing, sedimentary environments including intertidal DEM, hydraulic condition, and relationship between grain size and various tidal condition are investigated. Remote sensing has the potential to provide synoptic information of intertidal environments. The objectives of this study are: (i) to generate an intertidal digital elevation model (DEM) using the waterline method of Lansat TM/ETM+, (ii) to investigate the tidal channel distribution using texture analysis, and (iii) to analyze the relationship between surface grain size by using *in-situ* data and intertidal DEM and tidal channel density by using high-resolution satellite data such as IKONOS and Kompsat EOC. The results demonstrate that satellite remote sensing is an efficient and effective tool for a surface sediment discrimination and long term morphologic change estimation in tidal flats.

Keywords: KOMPSAT EOC, IKONOS, Landsat TM/ETM+, Tidal flat, Kanghwa, Hwang-Do, DEM, Surface sediment distribution

1. Introduction

The west coast of the Korean Peninsula is famous for its large tidal range (up to 9 m) and vast tidal flats. Sedimentation and/or erosion on the Korean tidal flats are significant due to the high tidal energy. Land reclamations, which have occurred on a large scale such as Incheon New Airport project, Saemanguem project, and Seosan reclamation project, have also accelerated environmental changes in the tidal flat. Generally, tidal flats show dynamic morphologic changes that arise from high tidal energy and sediment transportation. The driving force of coastal changes results from sediment budget processes, tectonic processes, marine energy processes, relative sea-level movements, and human impacts (Fletcher, 2000). Among these, the sediment budget process is very important, especially to ecological systems, and is directly related to surface sediment distribution. The sediment budget can be estimated only if one is able to measure the total morphologic change that has occurred in a certain period, and if one can discriminate about the types of sediments. It is, however, very difficult to estimate morphologic change from field observation alone, because of the limited accessibility, short exposure to air, and lack of suitable transportation. Remote sensing, combined with *in situ* surveying, is an effective tool for monitoring tidal flat environments. With improving spectral resolution and the spatial resolution, the application of satellite remote sensing to tidal flat analysis is increasing. In addition, it is possible to monitor rapid changes in the tidal flats, owing to the improvement in the temporal resolution of the available Earth observation satellites. Therefore, field measurements and remote sensing techniques have become accepted as complementary tools in geomorphology (Kevin *et al.*, 1999). The objectives of this study are: (i) to generate an intertidal digital elevation model (DEM) by the waterline method using several Lansat TM/ETM+ in a short period, (ii) to investigate the tidal channel distribution and density using texture analysis, and (iii) to analyze the relationship between surface grain size by using *in-situ* data and intertidal DEM and tidal channel density by using high-resolution satellite data such as IKONOS and Kompsat EOC for surface sediment classification.

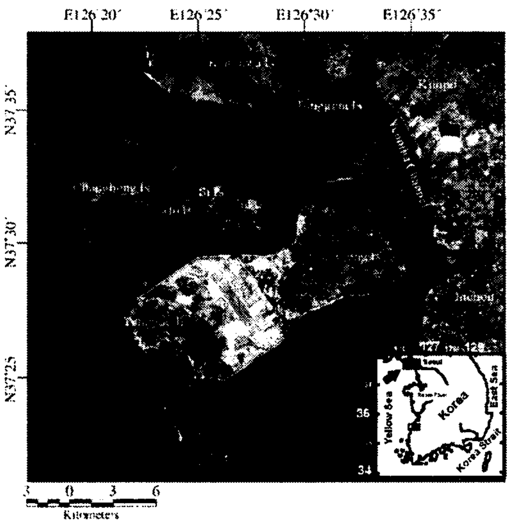

Fig. 1 Location map of Kanghwa tidal flat

2. Study Areas and Data

Two sites for this study are chosen: i) Kanghwa tidal flat which is open type and one of the biggest flats on the west coast of Korea and ii) Hwang-Do tidal flat in Cheonsu Bay that is surrounded by Anmyeon-Do and Korean peninsula. The southern tidal flat of Kanghwa Island with an area of approximately 90 km^2 is one of the biggest flats on the west coast of Korea (Fig. 1). The sediment distribution in Kanghwa tidal flat can be classified into mud flat, mixed flat, and sand flat environments, according to the textural characteristics. The sand content, and the mean grain size generally increases on moving towards the sea. The mud flats are located the eastern part of the Kanghwa tidal flat, the sand flats near the western part, and the mixed flats in a broad transition zone between the mud flats and the sand flats. Hwang-Do tidal flat, which is a closed type and has 2 km wide and 5.2 km long, is located on the central west coast of the Korean Peninsula as shown in Fig. 2. Tides are semidiurnal with a mean tidal range of 459 cm (spring 633 cm; neap 286 cm). Maximum tidal current velocities in the main tidal channel are 1.0 m/s during flood and 0.7 cm during ebb.

To carry out grain size analysis, samples were collected from the top centimeter of the surface sediment at 230 and 58 sites of Kanghwa and Hwang-Do tidal flats by van Veen Grab Sampler, respectively. After removing any carbonate and organic materials, the grain size measured using the Gradex 2000 Particle Size Analyzer and the Sedigraph 5100. For our study, we acquired a total 30 Landsat TM and ETM+ images (path/row: 116/34 and 116/35) during 3 years. Geometric rectification was conducted using 1:5,000 and 1:25,000 scale topographic maps. A horizontal accuracy of less than 0.3 pixels (corresponding to 10 m on the ground) was achieved after geometric rectification. We used Landsat TM/ETM+ data to extract the waterlines and to analyze the relationship between tidal channel distribution and density and grain size using high-resolution satellite data such as KOMPSAT-1, IKONOS.

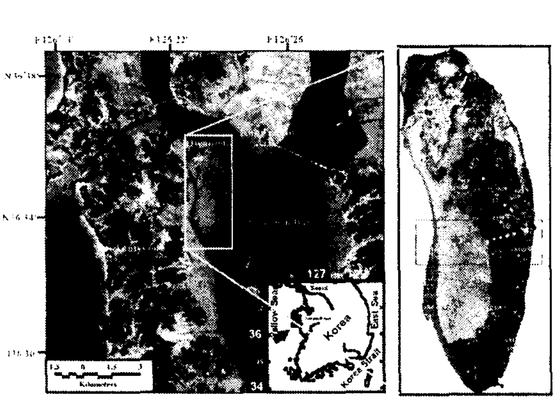

Fig 2. The Landsat ETM+ image of the Cheonsu Bay with a location map. The magnified IKONOS image is the Hwang-Do tidal flat. The blue and yellow points represent the sampling position for grain size.

3. Methods

1) Intertidal DEM Generation

The waterline method exploits the different tide conditions that are rendered in each image as a topographic contour line. The principal tactic in the waterline method is to collect as many images as possible, since the tidal conditions are different in almost all the images. The tidal flat DEM can be generated by stacking all the waterlines acquired over a given short period. The waterline method is based on three assumptions; (i) that the waterline represents an equal elevation at the moment of image acquisition; (ii) that topographic change is negligible during the period of data acquisition; and (iii) that the absolute elevation of each waterline is known. The accuracy of the resulting DEM from the waterline method largely depends on the accuracy of the waterline extracted from a given image, and of the absolute elevation assigned to the waterline (Lohani *et al.*, 1999). Although the core idea of the waterline method is straightforward, it is not such a simple task to the extract waterline from a tidal flat. Ryu *et al.* (2002) investigated the characteristics of the spectral reflectance from a tidal flat, and described in detail the waterline extraction process. We extracted our waterlines by applying the procedures of Ryu *et al.* (2002). The waterline method also requires a reference elevation of the extracted waterline. Tide level data from a tide gauge or hydrodynamic tide model can be used for this purpose (Mason *et al.*, 1997; Chen and Rau, 1998; Klocke *et al.*, 1999). Because of the relatively large tidal range and high velocity, a general hydrodynamic tide model could not be used in this study. It may be more appropriate to use tide gauge data than data from the hydrodynamic tide model, but data from the local hydrodynamic tide model would still be required if the tide gauge was deployed far away from the study area.

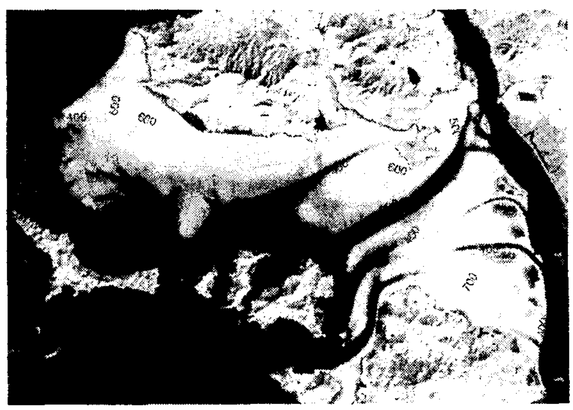

Fig. 3. A digital elevation model of Kanghwa tidal flat constructed using waterline method

2) Tidal Channel Extraction

Tidal channels play a fundamental role in the hydrodynamic and morphological processes operating within a tidal basin. Geomorphological interest in tidal channels was initially stimulated by their similarity to river channels. Several early studies found that the geomorphological characteristics of tidal channels were similar to those of terrestrial channels and concluded that the former were formed in response to draining of the tide from the marsh (French and Stoddart, 1992). However, fundamental differences exist between tidal channels and terrestrial channels, the most important being the bidirectional flow in tidal basins. Furthermore, the drainage density of creek networks is higher (Steel, 1996). Tidal channel distribution is related to surface sediment type. Generally, complex and meandering tidal channel is well developed in mud flat and straight and simple channel is distributed in sand flat. For extracting the channel network, we used the high-resolution satellite data such as KOMPSAT EOC and IKONOS images (Fig. 4).

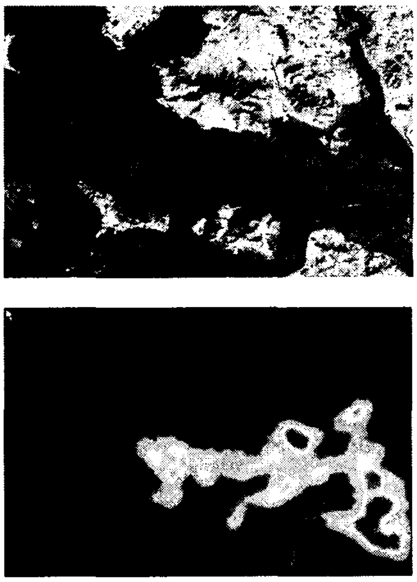

Fig. 4. Upper panel is a KOMPSAT EOC image overlaid extracted tidal channel and lower panel is the channel density distribution map.

4. Result and Discussion

To generate the Kanghwa intertidal DEMs, we selected seven images that were suitable for generating an intertidal DEM after reviewing 11 images that were taken over a time interval of 16 months. We assigned the absolute elevation using tide gauge. The intertidal DEMs were then generated using the minimum curvature interpolation technique. Since neither the sedimentation nor the erosion in an upper tidal flat is usually significant, most scientists are interested in lower tidal flats. The generated DEMs themselves provide

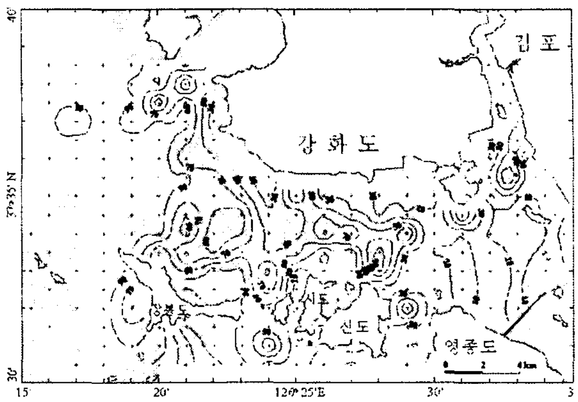

Fig. 5. Sand percent distribution of surface sediment in Kanghwa tidal flat

useful information for intertidal morphologic change and surface sediment distribution. In the inner tidal flat of Kanghwa, it is relatively higher than outer tidal flat and intertidal channels and creeks are well developed on mud flats (Fig. 3 and 4). In contrast, the surface topography is relatively smooth in the outer tidal flat and tidal channel density is poorly developed, where the sand and/or mixed flats are dominant. As shown in Fig. 5, the surface sediment type is well matched with intertidal DEM and channel density map. A similar process was applied to eight TM/ETM+ images selected out of 11 available images taken over a time interval of 20 months between March 2000 and November 2001 in Hwang-Do tidal flat of Cheonsu Bay.

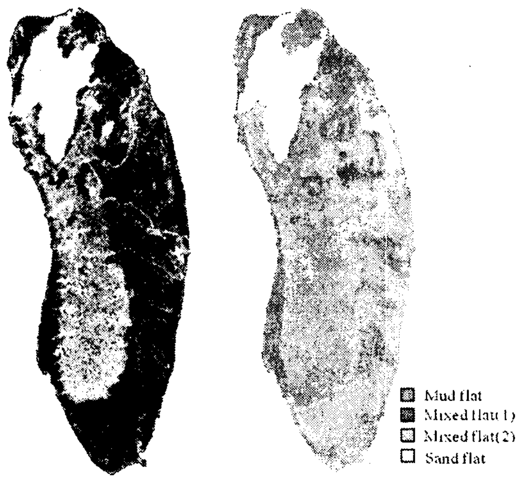

Fig. 6. Left image is the texture map and right is the sedimentary facies classification map using IKONOS

To investigate the tidal channel distribution, we analyzed texture of Kangwha and Hwang-Do tidal flat using IKONOS images. The results coincide with tidal channel patterns and surface sediment types. A boundary of mud flat and sand ridge in texture and DEM is clear. The texture map highly corresponds to the sedimentary facies map using supervised classification

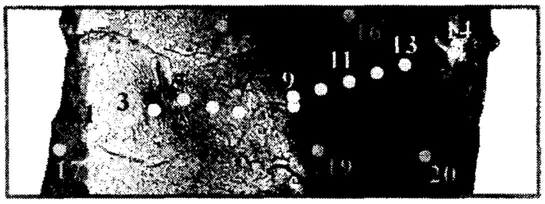

Fig. 7. IKONOS RGB (432) composite. Yellow and blue points represent the sampling positions for surface grain size in the Hwang-Do tidal flat.

method, as shown in Fig. 6. To evaluate the surface sediment map, we conducted the field measurements including grain size sampling, digital photograph, GPS, and descriptions of tidal environments. In Fig. 7, yellow points is the sampling sites for the grain size analysis. Table 1 shows the grain size analysis of the Hwang-Do tidal flat. Grain size distribution is revealed mud flat from C1 to C3, mixed flat from C4 to C8 and sand flat from C9 to C14. Grain size distribution is well matched with IKONOS RGB (432) composite image. In the bright area of IKONOS image, mud cracks and tidal channels are well developed. It is mud-dominant and has little surface water and relatively higher topography. In the dark area of image, sand flat is well developed and has a lot of surface water due to the relatively lower surface topography.

Table 1. Grain size analysis of the Hwang-Do tidal flat

Station	Composition (%)			Sediment Type (by Folk)	Surface water
	Sand	Silt	Clay		
1	22.58	50.74	26.68	sM	X
2	19.23	56.22	24.55	sZ	X
3	26.94	53.89	19.17	sZ	X
4	61.51	29.81	8.68	zS	O
5	37.80	45.53	16.67	sZ	O
6	47.23	38.42	14.35	sZ	a little
7	46.51	40.26	13.23	sZ	a little
8	50.23	38.68	11.09	zS	a little
9	79.91	15.59	4.50	zS	O
10	79.06	16.11	4.84	zS	O
11	73.39	19.95	6.66	zS	O
12	64.04	23.89	12.07	mS	O
13	76.87	14.36	8.77	mS	O
14	92.92	0	0	S	O

It is difficult to classify the intertidal surface sediment using only remotely sensed spectral data because there is the surface water in tidal flat according to short exposure time. For enhancing the classification accuracy, we consider the circumstance of tidal surface including grain size, surface water, tidal channel network. The results demonstrate that satellite remote sensing is very useful for understanding the tidal environments. Airborne LIDAR or InSAR is recommended for incorporation with optical images in future work.

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