

subsequent microphysical responses, into macroscopic cloud models that can then be incorporated into global climate models.

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Environmental Responses to a Land Reclamation Project in South Korea

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In 1991, South Korea embarked on an ambitious project to reclaim nearly 401 square kilometers of land and tidal flats from the Yellow Sea by building a system of two dikes extending 33 kilometers across the mouths of the Dongjin and Mangyeong rivers, offshore of the Saemangeum district (see Figures 1a and 1b). Called the Saemangeum Reclamation Project, the endeavor will allot about 283 square kilometers of the reclaimed land for crop production (mostly rice) through irrigation of the rivers' estuaries, which will be extended by about 23 kilometers when the bay fills up. The rest of the reclaimed land will be a water reservoir for agricultural use [Lie *et al.*, 2008].

The construction of the Saemangeum Reclamation Project's northern dike was completed in June 2003; the southern dike was finished in April 2006. Two gaps in the southern dike allow water exchange, and two gates control the water level inside the dikes. The reclamation project, the biggest such endeavor in South Korea, is expected to be completed around 2030.

Since the dikes have been constructed, satellite-derived images have been used to demonstrate marine environmental responses observed from ocean color data inside and outside the dikes during and after the dikes' construction. The results show that after closure of the dikes, water transparencies drastically increased and the amount of suspended sediments in the region decreased. The changes may reflect the significantly diminished tidal currents in

the Saemangeum region now that the dikes are in place.

Satellite-Observed Drastic Changes in Marine Environment

NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) on board the Aqua satellite provided a full suite of observations for marine environmental responses to the reclamation project. Data from July 2002 to December 2008 covering the Saemangeum area were processed for ocean optical and biological products using the recently developed near-infrared (NIR) and shortwave-infrared (SWIR) atmospheric correction algorithm [Wang, 2007; Wang *et al.*, 2009b]. In particular, this study used two MODIS-derived products: the normalized water-leaving radiance at a 645-nanometer wavelength, $nL_w(645)$, and the diffuse attenuation coefficient at a 490-nanometer wavelength, $K_d(490)$. The $nL_w(645)$ data can be used to represent water opacity and can be directly related to the total amount of suspended sediment in the coastal waters [Miller and McKee, 2004]. The $K_d(490)$ data, derived using a new algorithm applicable for the turbid coastal waters [Wang *et al.*, 2009a], can be directly related to water turbidity.

Two MODIS true-color images at 250-meter spatial resolution were acquired on Julian day 221 (in August) in both 2003 and 2008 (before and after the completion of the southern dike). From these two images, it is easily seen that water inside the dikes is clearer in 2008 (Figure 1d) than in 2003 (Figure 1c). Figures 1e–1h provide the MODIS-derived $nL_w(645)$ composite images

in the region for the summers (June–August) before (2003 and 2005) and after (2006 and 2008) the completion of the dikes. The images show that $nL_w(645)$ values significantly declined after the completion of the dikes (Figures 1g and 1h) compared with results before the dikes' completion (Figures 1e and 1f). Particularly in summer 2008 (after the dikes had been completed for more than 2 years), the $nL_w(645)$ values were similar for regions inside and outside the dikes (Figure 1h). Time series of the MODIS monthly $nL_w(645)$ and $K_d(490)$ results from July 2002 to December 2008 for regions both inside and outside the dikes (see Figure 1b) are shown in Figures 1i and 1j. Note how after completion of the dikes, water inside the dikes more closely resembles water outside the dikes.

A Closer Look at Seasonal Variability Before and After Dike Completion

The mean values of $K_d(490)$ and $nL_w(645)$ for the periods before (July 2002 to March 2006) and after (April 2006 to December 2008) the completion of the dikes were also calculated both inside and outside the dikes. Water turbidity, represented by $K_d(490)$, shows highs in winter and lows in summer both inside and outside the dikes before the dikes' completion.

Before April 2006, $K_d(490)$ values inside the dikes were significantly higher (mean value of 1.76 per meter) than outside (mean value of 0.92 per meter). However, $K_d(490)$ values have since decreased to averages of 1.09 per meter inside and 0.77 per meter outside, though the decrease for the outside region is relatively small. In addition, seasonal variations of $K_d(490)$ almost disappeared inside the dikes after they were completed. Similar to the time series of $K_d(490)$, significant

reduction of $nL_w(645)$ also occurred after the completion of the dikes.

Implications and Next Steps

In general, the construction of dikes across the Dongjin and Mangyeong river mouths has resulted in clearer waters inside the dikes. The decrease in seasonal variability for both $K_d(490)$ and $nL_w(645)$ after completion of the dikes is likely due to severely reduced tidal range and tidal current speed in the region [Lee *et al.*, 2008]. The significantly reduced tidal current decreased the ability of sediments within the water column to become resuspended, leading to drastically higher water transparency with significantly lower MODIS-measured $K_d(490)$ and $nL_w(645)$ values. In short, the dikes block tidal currents, allowing particulate matter released by the Dongjin and Mangyeong rivers to settle.

In situ measurements such as Secchi depth, a measure of water clarity determined by the depth in the water at which a pattern on a submerged disk is no longer visible, and the total suspended sediment data obtained in the regions both inside and outside the dikes between 2003 to 2008 have confirmed satellite observations of significantly reduced total suspended sediment inside the dikes. Further, in situ measurements also confirm that the tidal range and tidal current speed decreased by more than 80% after the completion of the dikes [Lee *et al.*, 2008].

Monitoring and evaluating marine environmental changes in the region using satellite data and in situ measurements will continue as the reclamation project progresses. In particular, studies will focus on ocean biomass and primary production variations in the region. The long-term environmental and societal impacts of the project are yet to be seen and assessed.

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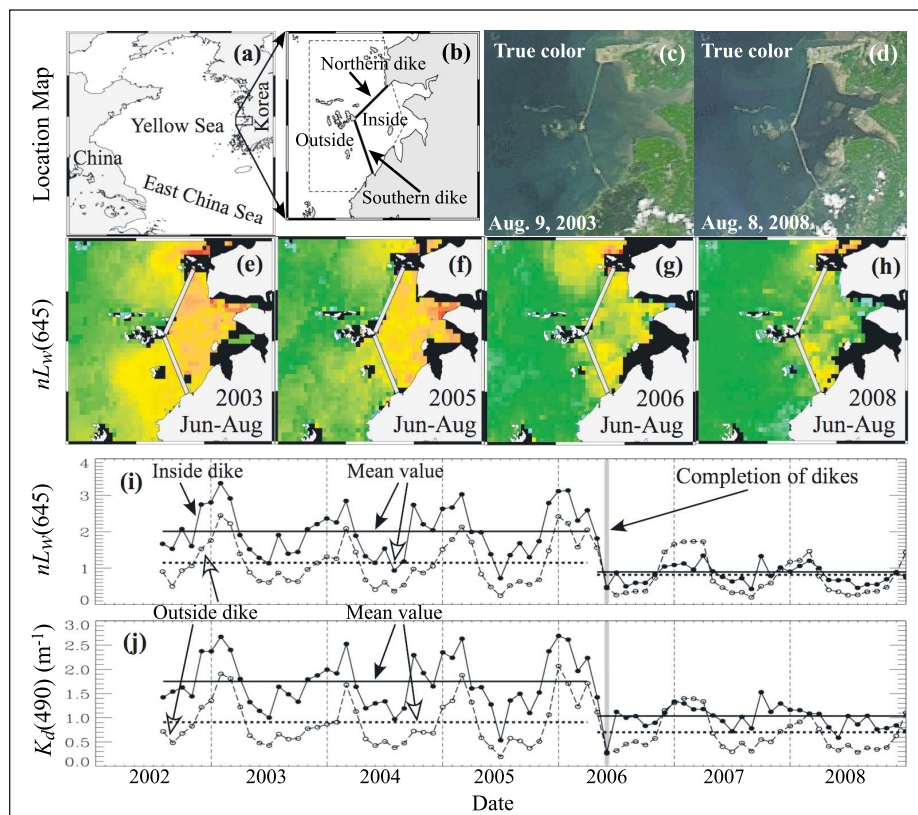


Figure 1. (a and b) Maps of the Saemangeum reclamation area on the middle west coast of Korea. (c and d) Moderate Resolution Imaging Spectroradiometer (MODIS) true-color images (250-meter spatial resolution) on Julian day 221 in 2003 and 2008, respectively. (e–h) MODIS-derived normalized water-leaving radiance at a wavelength of 645 nanometers, $nL_w(645)$, for the summers (June–August) of 2003, 2005, 2006, and 2008, respectively. (i and j) MODIS-derived time series (July 2002 to December 2008) for $nL_w(645)$ and the diffuse attenuation coefficient at a wavelength of 490 nanometers, $K_d(490)$, for the region inside (solid curve) and outside (dashed curve) the dikes, respectively. Note how the water inside the dikes becomes more transparent through time.

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