Monitoring Temporal Coastline Variation of Taiwan's Outlying Islands by Multiple Satellite Imageries and Tide Models

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ABSTRACT: Three of Taiwan's outlying Islands including Kinmen, Penghu and Matsu are observed for their coastline changes in this study. These islands with unique geography and climate are the habitats for various protected and vulnerable species. However, due to human and natural forces, the erosion and accretion along the coastal zone has affected the environment and threatened local ecosystems. Therefore, we aim to monitor changes along the coast for environmental sustainability. It is usually challenging to define the range of intertidal zone and reconstruct coastal DEM in a large area by means of traditional land surveying. Hence, we develop a workflow that utilizes multiple optical remote sensing satellites, including Landsat series and Sentinel-2, to track the long-term variation of coastline. We first collect historical cloud-free images since the 1980s and calculate the Modified Normalized Difference Water Index (MNDWI) to identify water pixels. After computing water appearance probability of each pixel, we convert it into actual elevation by introducing the DTU10 tide model for high tide and low tide boundaries. A digital elevation model (DEM) of the intertidal zone is reconstructed and compared with in situ DEM collected by an Unmanned Arial Vehicle (UAV). Finally, we define the up-to-date intertidal zone and estimate temporal changes of nearshore sediment.

1. Introduction

1.1 Background

Taiwan has three outlying islands including Kinmen, Penghu and Matsu, as shown in Figure 1. These three islands located in the west of Taiwan have an area about 152 km^2, 127 km^2 and 30km^2, respectively. These three outlying islands not only have coastal wetlands but also have unique ecological environment. However, the accurate boundary of such intertidal zone has not been determined due to the restriction of ground survey. In fact, tidal flats comprise about 7% of total coastal shelf areas all over the world (Stutz and Pikey 2002). In the past, tidal flat areas are difficult to be delineated due to the impermeable nature of remote sensing techniques used for creating global digital elevation models (DEMs), such as using radar or optical stereopairs. Therefore, they are unable to offer a model to obtain the information about the elevation of coastline. In this study, we assume that the terrain remains unchanged and use the relationship between sea level and inundation area to estimate the elevation of coastal topography.

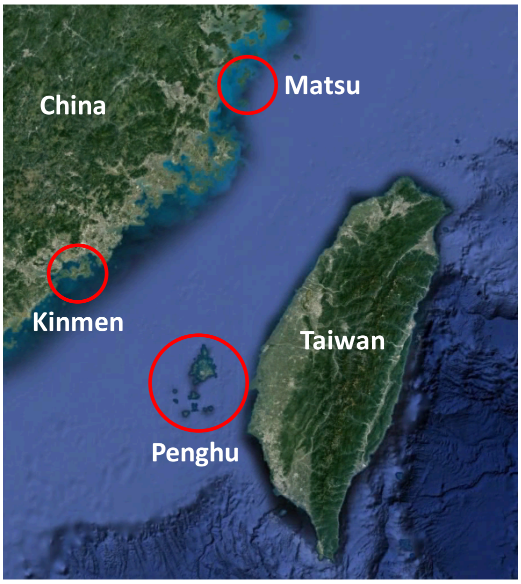


Figure 1. Geographical location of three outlying island.

1.2 Satellite imageries

As one of the most commonly used satellites, the Landsat series was operated by NASA and USGS since 1972 as the launch of Landsat-1. Following that, the Landsat-5/-7/-8 with 30 m ground resolution have been widely used in many surface process studies. Currently, several new missions including Sentinel-1/-2 operated by ESA join to serve as the Earth observation missions. Sentinel-2 constellation consists of two identical satellites, Sentinel-2A and Sentinel-2B since 2015, and provides 10 m resolution image in visible band. Sentinel-1 offers C-band synthetic aperture radar (SAR) imaging since 2014, it also comprises a constellation of two polar-orbiting satellites that enable to acquire imagery regardless of the weather. The abovementioned missions are widely known as useful resources for monitoring environment parameters, measuring water areas, and detecting land cover changes. In this research, we choose five missions including Landsat-5/-7/-8 and Sentinel-1/-2 for water identification. The optical satellite images can efficiently classify water areas by using multispectral analysis, such as the reflectance contrast from green band and near infrared band, while the intendsity of radar satellite image is utilized to classify water and add more details in the reconstructed DEM.

1.3 Objective

In this research, we aim to develop a model to calculate the change of coastline and the relationship curve between water level and water area, by using an integration of the Landsat-5/-7/-8 and Sentinel-1/-2 satellite data, and the DTU10 (Technical University of Denmark) tide model. An inundation chance model is firstly built while the tide model provides height information to translate relative inundation chance into actual surface elevation.

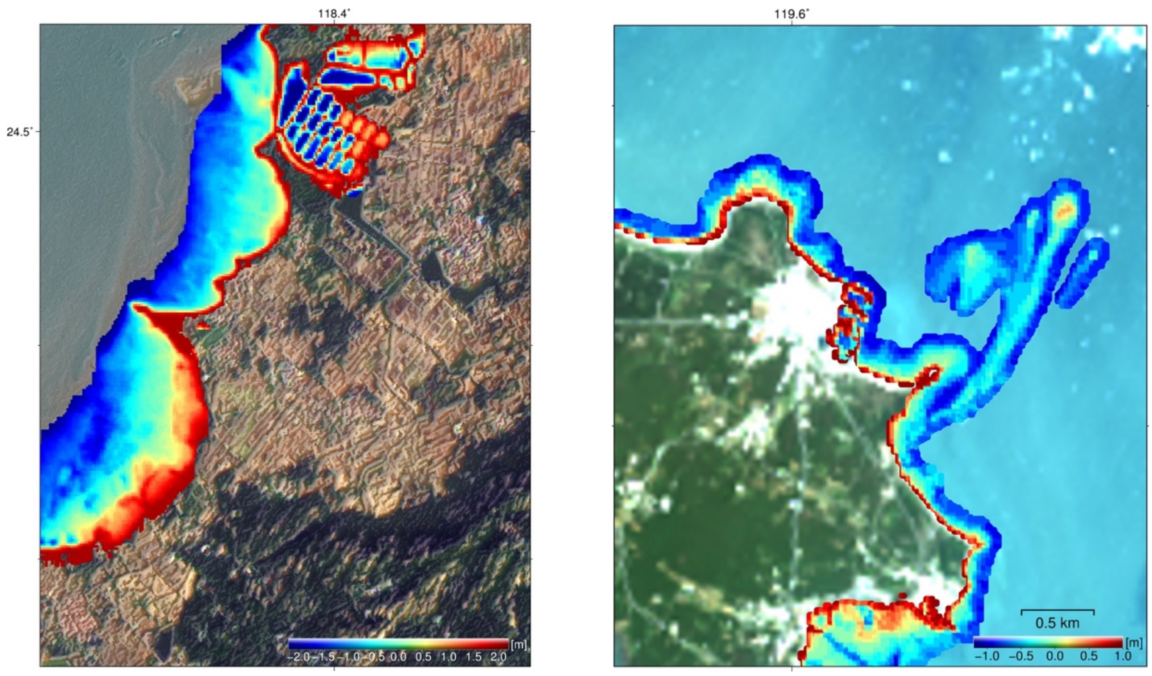
2. Methodology

We choose cloud-free Landsat images from 1996-2016 and Sentinel-2 images to calculate the MNDWI, as shown in Equation (1). In this equation, “Green” means green band of Landsat and Sentinel-2. For Landsat-5/-7, the green band is band 2, however, in the Landsat-8 and Sentinel-2 is band 3. The other parameter “MIR” means the mid-infrared band. For Landsat-5/-7, the infrared band is band 5, however, in Landsat-8 and Sentinel-2 it is band 6. The physical nature of a water body has strong reflectance in green band and strong absorption in mid-infrared band. For Sentinel-1, we use the reflectance intensity to detect the water. Then the water has low intensity of reflectance and we can detect and set the threshold to classify the water and non water. Therefore, when the value of MNDWI lower than 0, it means another sort of surface types in the pixels and we can use this feature to monitor the change of coastline.

$$MNDWI = \frac{Green - MIR}{Green + MIR} \quad (1)$$

3. Result and discussion

In figure 2, we demonstrate the part of Kinmen and Penghu coastal DEM recovered from Landsat image data from 1996-2016. We can further determine the intertidal zone of Kinmen by defining the contour of the mean higher high water (MHHW) and the mean lower low water (MLLW) in Figure 3. However, because these two figures are automatic generated from the model, it requires additional manual editing to correct the uncertain boundary due to cloud contamination.



(a) (b)

Figure 2. Coastal DEM recovered from Landsat/Sentinel images and DTU10 tide model. (a) The north part of Kinmen (b) The northeast part of Penghu.

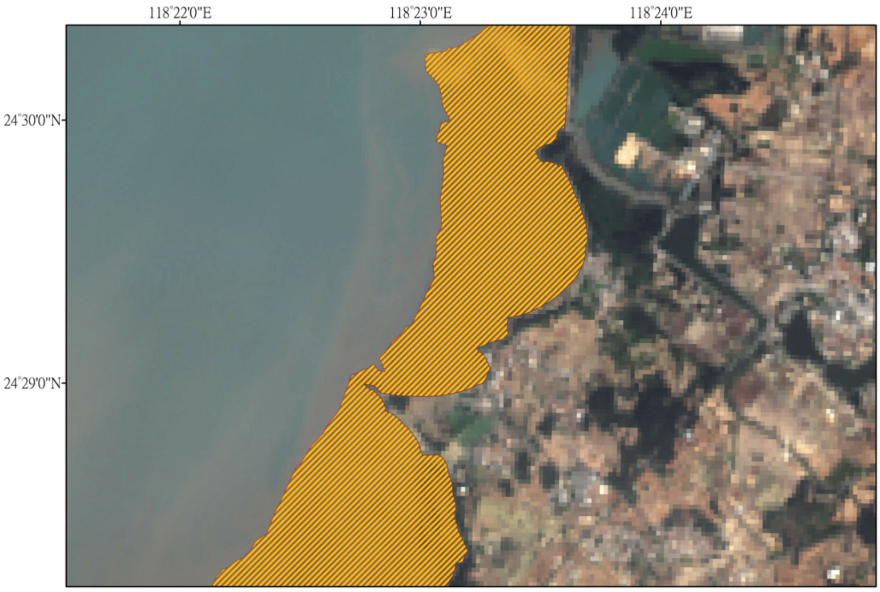


Figure 3. Intertidal zone determined from Kinmen DEM

4. Conclusion

In this study, we demonstrate a synthetic approach by using optical imageries and DTU10 tide model to recover coastline changes in Kinmen. The technique first reconstructed the coastal DEM that can be further used to derive multiple tidal lines in this area. It is particular useful for large tidal flats that is impossible to conduct field surveys. In the future, we will add more SAR images and mid/high resolution optical images to increase the accuracy of the DEM model, and to decrease the error while defining the coastline.

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