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OPTICAL REMOTE SENSING IMAGERIES WERE USED TO RECONSTRUCT TIME-VARYING TIDAL FLAT TOPOGRAPHY

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ABSTRACT

Tidal flats (TFs) make up around 7% of the entire coastal shelf area on the planet. Due to the water-impermeable nature of current remote sensing methods (e.g., radar used for WorldDEMTM and Shuttle Radar Topography Mission DEM, and optical stereo-pairs used for ASTER Global Digital Elevation Map Version 2), TFs are not accessible in most global digital elevation models (DEMs). This issue, however, may be avoided by utilizing remote sensing imageries to monitor land exposure at various tide heights on each return. This study uses Landsat-4/-5/-7/-8 Thematic Mapper (TM)/Enhanced TM Plus/Operational Land Imager imageries to rebuild topography of a TF, the Hsiang-Shan Wetland in Taiwan, in order to reveal its creation and temporal changes since the 1980s. To generate an inundation probability map, we first identify water regions by applying a modified normalized difference water index to each Landsat picture and normalizing the odds of water exposure. To turn the probabilities into real heights, this map is scaled using tidal amplitudes derived from the DTU10 tide model. A water level-area curve is constructed after the DEM is built in the intertidal zone, and the accuracy of the DEM is verified by sea level (SL) at the time of each Landsat snapshot. A 22-year dataset of 227 Landsat sceneries (1992–2013) is examined and compared to tide gauge data. With a correlation value of 0.93, the root-mean-square differences in SL exceed 48 cm, indicating that the current method is effective for creating accurate coastal DEMs and those products may be used to estimate immediate SL. This research demonstrates how an archive of optical remote sensing imageries may be used to investigate the development of intertidal zones. The method proposed in this research has the potential to aid in the quantification of SL since the dawn of the optical remote sensing era.

KEYWORDS: *Tidal Flat Digital Elevation Model Landsat Radar Altimetry Tide Model*

1. INTRODUCTION

The US National Oceanic and Atmospheric Administration (NOAA) defines intertidal zones as coastal zones between the mean higher high water (MHHW) and mean lower low water (MLLW) lines. Soft sediment deposition forms tidal flats or mudflats, which are important substrates in intertidal zones. Globally, tidal flats account for around 7% of total coastal shelf area. Due to the water-impermeable nature of current remote sensing techniques, most global digital elevation models (DEMs) do not cover these regions. For example, neither the German Aerospace Center's (DLR) World DEMTM produced by the TerraSAR-X and TanDEM-X missions (Krieger et al., 2007) nor the Shuttle Radar Topography Mission's (SRTM) C/X-band DEM built by Spaceborne Imaging Radar-C/Xband Synthetic Aperture Radar cover tidal flats (TFs). The ALOS World 3D-30m product from the Japan Aerospace Exploration Agency (JAXA) has data gaps in several regions. The Advanced Spaceborne Thermal Emission and Reflection Radiometer has the same issue. The International Society for Photogrammetric and Remote Sensing, Inc. is a non-profit organization dedicated to the advancement of photogrammetry and remote sensing (ISPRS). Elsevier B.V. is the publisher. All intellectual property rights are retained **[1].**

Homepage of the ISPRS Journal of Photogrammetric and Remote Sensing: www.elsevier.com/locate/isprsjprs (ASTER) aboard the National Aeronautics and Space Administration's (NASA) Earth Observing System Terra, which produces the Global Digital Elevation Model using a stereo pair of optical pictures. Another prominent global DEM, the Global Multi-resolution Terrain Elevation Data, has a similar problem; it is mainly made up of SRTM and other regional high-resolution data sources, such as ICESat laser altimeter observations. These DEM outputs have limits in coastal areas, and most sea–land interfaces show obvious discontinuity.

The significant morphological variations produced by ocean tides, currents, and river flows in estuaries make TF mapping difficult.

Airborne Light Detection and Ranging (LiDAR) instruments or ship-based single/multi-beam echo sounders are popular approaches for measuring coastal bathymetry. Using current techniques, DEM accuracy levels are several centimeters, with occasional variations of 20 cm . However, due to shallow water restrictions or high water turbidity, these techniques are ineffective in intertidal zones. It's expensive and time-consuming to conduct a comprehensive TF survey and maintain an updated DEM on a regular basis. Only a few regional DEMs including bathymetric/topographic data were published for storm surge research and tsunami mapping (NOAA National Geophysical Data Center, 2015) **[2].**

Another reason for the failure of traditional techniques to extract coastal DEM is a one-time gathering of satellite pictures. At low tides, a swath of remote sensing pictures has the ability to construct intertidal bottom topography. However, from a worldwide viewpoint, the confluence of tidal conditions and the design of such a mission is virtually unachievable. Remote sensing imageries may be used to observe bottom isobaths. Presented a series of improvements of coastal DEM utilizing synthetic aperture radar (SAR) pictures and the waterline technique. Feng et al. (2011) presented a process for determining the bottom topography of Poyang Lake, China, utilizing the Moderate-resolution Image Processing Technique **[3].**

250 m spectral bands on the Imaging Spectroradiometer (MODIS). Their research used MODIS water/land borders as well as in-situ gauge stations to recreate bathymetry contour lines. The remainder of the elevation model was subsequently filled using kriging interpolation.

Their model achieved 0.88 m accuracy when compared to a field survey performed fifty years earlier. At more stable regions with less inter-annual fluctuation, the mean standard deviation was 0.49 m.

However, tide gauges may not be readily accessible in many coastal areas. As a result, the primary goal of this research is to rebuild a coastline DEM and show its temporal variability without relying on ground observations. To give bottom information, we combined an archive of Landsat images with a tidal model.The topography of TFs, as well as its temporal variations, are ecogeomorphologically significant and may be used as proxies for predicting immediate sea level (SL), which is particularly beneficial to nearshore areas. Since the advent of altimetry satellites two decades ago, global SL variations have been intensively investigated. However, because to land pollution in radar echoes, monitoring coastal SL poses a difficult job in satellite altimetry, preventing waveform retrackers from estimating water location and height . Because radar waveforms near shorelines must be carefully managed by complex retracking algorithms, nearshore water level is separated from wide ocean situations. Current pulselimited radar altimeters have difficulty reaching coastal regions, save for realistic alternatives utilizing developing SAR altimetry (conceptually comparable to synthetic aperture radar that uses delay-Doppler). As a result, the second goal of this research is to see whether rebuilt coastal DEMs can offer adequate SL information when compared to existing altimetry techniques **[4].**

The goal of this research is to investigate a conceptually distinct approach to problem solving and to overcome the difficulties described above in mapping coastal topography and calculating coastal SL. To rebuild a DEM for TFs, a probability approach is presented that uses a series of Landsat optical remote sensing imageries and a tidal model (TF-DEM).

We take use of TF's well-known feature. Because of the flat landscape, water extends quickly as the water level rises. As a result, water level-area curves for such TF-DEMs are constructed, and Landsat-based SL is estimated using water area calculated from each co-registered satellite picture. We chose the Hsiang-Shan Wetland (HSW), a TF in Taiwan's northwest, as our research location to illustrate potential methods for coastal DEM reconstruction and SL estimate.

The research area is introduced in Section 2. The data and techniques used to reconstruct the TF-DEM are presented in Section 3. Section 4 compares the performance of the Landsat-based SL, tide model, and altimetry against those of the tide gauge. Section 5 looks at TF-DEM mistakes and how they may be used to estimate SL. Section 6 summarizes the method's contributions and limitations.

HSW is a saltwater marsh in northern Taiwan, near the city of Hsinchu. With a total size of about 16 km2, this region completely encompasses the Keya and Yangang Estuaries. From east to west, the width is 2 kilometers, while the length of the coastline is 15 kilometers. The Ramsar Convention classified HSW in the Eastern Asia-Pacific Water Bird Protection Network in 1996. Fiddler crabs and a variety of uncommon and endangered migratory bird species call this region home. the red and yellow lines represent the ground tracks of the Jason-2 and Environmental Satellite (Envisat) altimetry missions, respectively. Panel (b) enlarges the green box that encompasses HSW and Envisat pass #225 and Jason-2 pass #51 near HSW are utilized to test the performance of the radar altimeter in this topographic configuration. Panel (b) has a natural-color backdrop made out of a low-tide picture captured by the Landsat-8 Operational Land Imager (OLI) (LC81180432014276LGN00), with RGB from bands 4, 3, and 2. The gray area in the center is the HSW mudflat, while depositing at Hsinchu Fishery Harbor to the north is mainly due to the stiff structure's groin effect. In situ data consists of an acoustic tide gauge near the port that is maintained by Taiwan's Central Weather Bureau. Due to a lack of gauge data, we can only verify SL for different independent observations and tide model forecasts from 1992 to 2013**[5].**

The modeling method for coastal DEM used to estimate SLs is shown in Fig. 2. For water identification, we first collect less cloudy Landsat-family images and use the modified normalized difference water index (MNDWI) **[10].** An inundation probability map (0–100 percent) is formed by accumulating sequences of water appearance through time, which is equal to the relative elevation difference between high and low tides. As a result, we use the DTU10 tidal model as our height reference to translate flooding probability into real elevation by using physical unit-length boundaries. Simulating a submerged region under stepping water K.-H. Tseng et al. / ISPRS Journal of Photogrammetric and Remote Sensing 131 (2017) 92–103 93 levels yields a water level-area curve. Finally, tidal gauge data is used to verify Landsat-based, altimetry observed, and DTU10 projected SLs.

2. DISCUSSION:

There is no independent reference for verifying TF-DEM in our research region, and this scenario is likely to occur in most TFs globally. As a result, we provide an alternate technique for evaluating products indirectly.DEM is utilized to determine SL, which is then compared to tide gauge data to check contour correctness at various levels Ate water level-area curve is initially made by counting the area below the water level. The height spacing is 10 cm. A cumulative curve forms the blue curve. The total number of inundated pixels, as well as the inundation area in square kilometers (right ordinate). In this illustration, the area of water is measured. runs between 1.94 and 2.39 meters; this is the same range as theThe slope of this border is defined by Hl and He in Section 3.3The steepness of the terrain at a given point is linked to the changing curve height. For instance, a significant rise in water area around 0.5 to 1At this level, 0 m implies that the landscape is flat **[6].**

To calculate matching water levels, the water area estimated from each Landsat picture is crossed with this curve. For Landsat 4, 5, 7, and 8, indicate time and corresponding DTU10 tidal heights, accordingly. (b) Tidal heights are shown by a histogram of Landsat scenes. (For the purpose of interpreting)The reader is directed to the online version of this article for the references to color in this figure legend.) records of gauge A linear interpolation was used to acquire in situ data. at concurrence of a 6-minute tide gauge time series Indicators applied to Included in the comparison are the correlation coefficient and the root-mean-square after removing the means, of discrepancies (RMSD) between two time series to disregard the change in datum between data sets The term RMSD is defined asIn the period 1992–2013, the RMSD of Landsat-based SL using long-term mean TF-DEM is 51 cm, and the correlation coefficient is 0.94 **[7].**

There are a total of 272 Landsat pictures in this collection. In addition, the two indications any problematic contour in the DEM is used to indicate DEM quality. Has an effect on the predicted SL at that level, as well as adjacent levels. As a result, at all levels, RMSD and linearity are utilized to evaluate DEM. (c), where the correlation value is 0.98 and the RMSD is calculated These results are better than Landsat-based estimations by 28 cm during the same time period. In contrast to tides, we only see outlier’s seldom. Data gauging Atmospheric forces, such as storm surge, may be to blame for these meter-level inaccuracies. These leaps, on the other hand, without data modification, they are still included in our study.

Ten meters (absolute) from the year 2000 until the present, data has been collected. STS-99 mission in 2000–present 11-day mission in 2000–present100 percent coverage rate 100 percent coverage rate 100 percent coverage rate 100 percent coverage rate 100 percent coverage rate 100 80 percent of the Earth's landmass is covered by water.Data is lacking in this area. Due to a lack of ASTER data, none of the following areas have data.cloud cover that is always present (provided)DEMs created by other DEMs)Area with a steep topography (due to geology)to the properties of radar)None Mission to the Moon Multiple sources TerraSAR-XTanDEM-X Terra Space Shuttle Endeavour (NASInterferometry X-Band Remote Sensing Technique (Visible to the naked eye thermal-infrared)C-Band InterferometryFor horizontal and vertical datum's, the World GeodeticSystem 1984 (WGS 84) is used.Geoid for the Earth Gravitational Model 2008 (EGM08).Horizontal geoid is WGS 84, while vertical geoid is EGM96.From left to right, ASTER GDEM2, SRTM-C, and GMTED2010 are displayed.

Satellite altimetry sea level

We also conduct two altimetry passes near HSW to verify accuracy and evaluate the efficacy of conventional altimetry. a method for calculating coastal) and (b) show howEnvisat pass #225 and Jason-2 pass #51 provided time series.correspondingly . RMSD measurements .Envisat's correlation coefficient is 0.91, which is at 58 coma level comparable to current research in the areaHowever, Jason-2's measured SL across the HSW region is lower. When compared to the data, misleads the determination of the waveform's leading edge andIn the retracking procedure, this results in an incorrect time location. This is a problem. At 133 cm, the RMSD is 0.06 and the correlation coefficient is 0.06.

Another issue regarding the validity of the model is its temporal dynamics.TF-DEM long-term average As a result, TF-DEM patterns must change. be addressed as well. In various epochs, we may reconstruct TF-DEM.to use the same method to investigate morphology as a result of coastal processes workflow. Figure 9 depicts the separation of TF-DEM during a five-year period. the years 1995 through 2015 Because of this, images from before 1995 are not included. The amount of scenes required to create smooth surfaces is inadequate.DEM is a digital elevation model. This time series study reveals a tiny dune at a high height. In the years 1995–1998, to the northwest of HSW (#1), the dune, on the other hand, deteriorated**[8].**

Owing to typhoon waves and high monsoon waves throughout the season this the dune has sunk many meters from 15–20 years ago. The systemA meandering dendritic type developed into a tidal channel.a linear dendritic form at #2; the 0 m contour area has been expanded as outwash sediments have accumulated as a consequence of the deposition process. In addition, these figures show the state of the HSW coastline's erosion For instance, the muddy surface around #3 has degraded, despite its lower elevation. A similar procedure occurs at the north end of HSW (#4). The general results provided by Taiwan's coastal management accord with HSW's erosion condition.

The information provided in Researchers may use the results of this study to assess sediment movement and morphological change in HSW. Because to the observation deck construction, there is clear silt buildup around #5.rather than a natural occurrence This set of graphs enables you to examine coastal processes in various locations and their spatiotemporal relations Using historical Landsat data, this research reconstructs coastal DEM at one typical TF along Taiwan's west coast, the HSW.Coastal SL observation from a different perspective. ips. connections.

Finally, SL estimation is performed using this collection of temporal TF-DEMs.For each of the four epochs; we create a water level-area curve. For Landsat pictures, find the associated SLs **[9].**

Shows the results. Utilizing temporal TF-DEMs to demonstrate modest improvementThe total RMSD is 48 cm, and the correlation coefficient remains constant. at a comparable level Temporal TF-DEMs, which include just a few variables, are a kind of temporal TF-DEM.In estimating SL, pictures with a short time period have comparable accuracy and capacity.The TF-DEM file is verified and then manually modified to blend with the other files. a global DEM to show its potential to reduce emissions Disparity in sea–land connections. shows the findings of SRTM.List DEMs that have been combined We replace ocean grids with SRTM as a template.by reconstructing the TF-DEM inside the chosen intertidal bordering geoidal height; it is subtracted by 2 m randomly to approachTo enhance visibility, use the MLLW datum. In comparison to the natural color pictures, the shorelines are more realistic.

However, in the case of various parts of the modified and original interface exist as a result of the initial DEM's inaccuracy of the coastline edge Orin supratidal zones, our product has been mismodeled. Modification of These deficiencies is beyond the scope of this study and should be investigated further relation to fusion technology. This probability technique has a vertical error connected with it.accu has a stronghold over the market.

3. CONCLUSION:

Using historical Landsat data, this research reconstructs coastal DEM at one typical TF along Taiwan's west coast, the HSW.pictures and predictions from the DTU10 tide model The precision of the TF DEM reaches 48 cm as a missing component of widely used global DEMs, while comparing data from adjacent tide gauges in an indirect way This reconstruction is a crucial stage in the process of modifying global DEMs.Pre-defined land-ocean masks, such as those found in the Global Self consistent, Hierarchical, High-resolution Geography Database, may be used.(GSHHG), resulting in truncated coastal margins and staircase-like coasts. We also show the merged version of DEM by adhering to the following guidelines. To provide a clean surface, the terrain was rebuilt using existing SRTM data. Near the interface, there is a smooth and realistic transition. Contributions of these kind Changes to the global DEM include a better knowledge of coastal issues. Morphology, as well as coastal engineering and management support the techniques used in this research can be replicated. Landsat photos and tidal prediction are both accessible worldwide, thus many other TFs may benefit from them. When satellite images are used, this process is also enhanced in terms of resolution and sampling frequency. possible for shingle-beach or cliff-type coasts if the slope is not too steepThe slope of the water level-area curve is gentle. This research provides a proof-of-concept for such a process, which may also aid in addressing problems Coastal SL observation from a different perspective.

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