A DEM CONSTRUCTION METHOD FOR INCONSTANT INTER-TIDAL ZONE BASE ON SHORT-INTERVAL, HIGH FREQUENCY MODIS DATA SET: A CASE STUDY IN THE DONGSHA SANDBANK OF THE JIANGSU RADIAL TIDAL SAND-RIDGES

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ABSTRACT:

Surface elevation is a critical data for geo-science study. As far as some regions with rapidly-changing in landform, analyzing the surface elevation of different periods help provide scientific basis for regional economic & social sustained development. Jiangsu coast is force tide zone, and the complicated sediment dynamical environment, gently rolling tidal-flat landform, huge spatial difference in tidal-flat moisture content changing with the time, geomorphic type and tidal condition, sediment concentration differing in sea area, season and tidal period. It is difficult to retrieve tidal-flat elevation information from RS imageries. Massive, high frequency and complete in temporal series of MODIS imageries on the study area since 2000 have been accumulated. The study takes Dongsha Sandbank as a case study area, and attempts to formulate a construction method for historical DEM based on short-interval, high frequency MODIS RS imageries data set. Starting point of the study is: shorelines of exposed tidal flat changes period with time because the tidal regime of research area is semi-diurnal tide. Contours of the sandbank in different RS imagery differ from each other due to the following factors: 1) Difference caused by spatial and temporal evolution of the sandbank itself. 2) Difference caused by the huge difference of tidal-level between different imaging moments. If the time interval is short enough, the factor of sandbank evolution can be ignored, and the leading difference of the sandbank shoreline in the two RS imageries reflects the influence of tidal-level difference. For this reason, DEM of the inter-tidal zone construction framework was discussed.

1. INTRODUCTION

Surface elevation is one of the most important essential data for geo-science study. As far as some region with rapidly-changing in landform (such as inconstant tidal-flat of coast zone), to analysis surface elevation of the different periods, can work out the evolution laws of regional landform, and increase the prognosis & prediction ability, and provide scientific basis for regional economic & social sustained, coordinated development.

Remote sensing finds a widely application in coastal ground elevation information retrieval, the construction method can be summarized into the following: 1) DEM construction method based on stereoscopic pair measurement. DEM can be built from stereoscopic imageries, such as SPOT, Radar, ASTER or aerial image. For example, Stephen (1988) extracted topography from SPOT data; Gong (2000) built digital surface model (DSM) of tidal flat in Florida from aerial stereo-pairs acquired from high resolution airborne data and analyzed the coastal salty sand zone displacements. Akira Hirano (2003) took four study sites around the world to validate DEM production accuracy derived from ASTER stereo image data (ASTER 3N & 3B data), using the Desktop Mapping System (DMS) software. 2) Ground elevation information retrieval method based on the soil moisture content, which retrieve ground elevation information from satellite infrared measurements according the relationship between tidal-flat elevation and soil moisture content of the tidal-flat. Wang (2003) once built a regression model between soil moisture and DN value of the TM image data to retrieve tidal-flat terrain information cooperation with GIS technology. 3) Bottom relief retrieval method based on water depth remote sensing, that is, bottom relief can be estimated using water depth remote sensing technology such as wave spectrum bathymetric method, statistics model or water column scattering method based on remote bathymetric model. Huang (2002) built a model to retrieve the bottom relief of Yangtze river near Nantong city based on the relationship between TM remotely sensed imageries and in situ data. Similar research (Di, 1999; Huang, 2000; Wang, 2006) can also be found.

Jiangsu coast is force tide zone, and is famous for its Radial Tidal Sand-ridges Offshore the centre coast. The complicated sediment dynamical environment, gently rolling tidal-flat landform, huge spatial difference in tidal-flat moisture content changing with the time, geomorphic type and tidal condition, sediment concentration differing in sea area, season and tidal period, which lead to a embarrassing situation that it is rather difficult to retrieve tidal-flat elevation information from single RS imagery using the method mentioned above. In addition, construction the digital elevation model of Radial Tidal Sand-ridges by regular ground survey method is restricted by the spacious & muddy tidal-flat surface, close-set tidal creek, complicated weather and hydrodynamic condition and other factors, and there are only three periods' contoured bathymetric charts of the Radial Tidal Sand-ridges mapped (1963, 1979 and 1992, and the 1992's bottom relief map is updated in the base of 1991 locally survey) due to the atrocious surveying condition.

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To enhance the dynamic evolution research of the inconstant inter-tidal zone, a DEM construction framework base on short-interval, high frequency MODIS data set was discussed in the paper with a case study in the Dongsha Sandbank of the Jiangsu Radial Tidal Sand-ridges.

2. STUDY AREA AND DATA COLLECTION

Dongsha Sandbank is one of the largest sandbanks in the Radial Tidal Sand-ridges Offshore the Center Jiangsu Coast, situated on the Dongsha Sand Ridge between Xiyang Tidal Channel and Xiaobeichao Tidal Channel, with a general trend of north by west, in the northern Radial Sand-ridges (Figure 1). Dongsha Sandbank is made of Niluoheng Sandbank, Tuanzisha Sandbank, Sanzidi Sandbank, which are separated from the main body by shallow seawater in high-tide level. Dabeigang Tidal Channel, Doufuzhayaomen Tidal Channel and Chenjiawu Tidal Channel isolate Dongsha Sandbank from adjacent sandbanks such as Sanyazi Sandbank, Liangyuesha Sandbank, Northern Tiaozini Sandbank and Tiaozini Sandbank. Tidal regime in Jiangsu Radial Sand-ridges region is semidiurnal tide, and area of exposed tidal flat changes with time because of different tidal level. According to the comprehensive coast zone & tidal-flat resource survey conducted from 1980 to1984, the highest elevation of Dongsha Sandbank was about 5.8m (Ren, 1985; Zhang,1992). Interpreted from the latest imagery taken by Terra in Apr 11, 2008, the main body covered an area of more than 431.3km^2 above 164cm tidal level, about 40km long and 20km wide. As far as its peripheral location, Dongsha Sandbank serves as an important barrier to the inner sandbanks such as Tiaozini Sandbank and has a direct impact on the process of Tiaozini Sandbank merging into mainland (Liu, 2004).

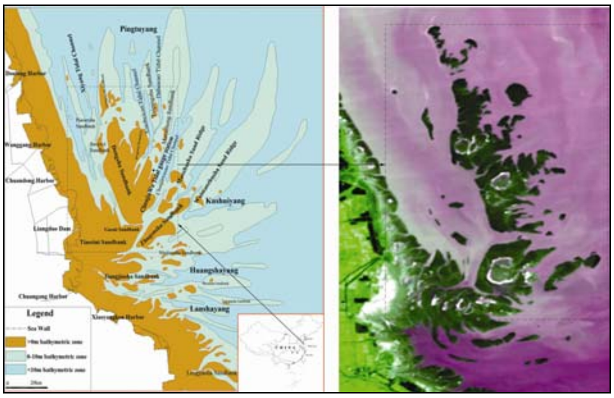

Figure 1. Left: location of Dongsha Sandbank; Right: RS imagery of Dongsha Sandbank (MODIS sensor of Terra, in Apr 11, 2008)

Moderate Resolution Imaging Spectro-radiometer (MODIS) is carried by the EOS series satellites such as Terra & Aqua (Michael, 1999). As for its spatial resolution, band 1 & band 2 is 250m, which is very fit to large-space and moderate scale information inversion, and applies more and more widely in earth resource, environment & climate study (Christopher, 1998). As for its updating frequency, they are both sun-synchronous satellite (Terra imaging in the morning of the zone time, while Aqua imaging in the afternoon), at least 2 scenes of 250m resolution images can be acquired a day, and massive, high frequency and complete in temporal series of the satellite imageries on the study area since 2000 have been accumulated. All the MODIS data used in the paper (1085scenes in total, among it, 546 acquired by Terra and 539acquired by Aqua) were downloaded from Goddard Space Flight Center (GSFC) web (Level 1 and Atmosphere Archive and Distribution System, http://ladsweb.nascom.nasa.gov). Tide gauge in 2003 was also collected to approximately simulate the sea level of the image-moment of the RS imageries.

3. METHODS

Tidal regime in Dongsha Sand-ridges region is semi-diurnal tide, and shoreline of exposed tidal flat changes with the changing tidal level. Contours of the sandbank in different RS imageries differ from each other due to the following factors: 1) Difference caused by spatial and temporal evolution of the sandbank itself, such as morph-adjustment because of the change in the sand-provision condition. 2) Difference caused by the huge difference of tidal-level between different imaging moments, which lead to different shape in the RS imagery. It can be clear that, the factor of sandbank evolution can be ignored if the time interval between the imaging moments of two RS imageries short enough, and the leading difference of the sandbank shoreline in the two RS imageries mainly reflects the influence of tidal-level difference.

In the research area, tide datum of the Radial Tidal Sand-ridges area is 292cm below local mean sea level in the tide gauge published after 1984, while sea datum is coincide with the tide datum. For this reason, to extract the shoreline of the sandbank and calculate the tidal-level of the image-moment according to the corresponding tide gauge, DEM of the inter-tidal zone can be constructed based on massive, high frequency and short-interval serial sandbank shorelines of different tidal level.

The technology routine (Figure 2) of the inter-tidal zone DEM construction method base on short-interval, high frequency MODIS data-set mainly include the following taches: batch pre-processing method for massive MODIS imageries, shorelines extraction method based on supervised classification, temporal interpolation method of the tidal-level and inter-tidal zone DEM rebuilding method.

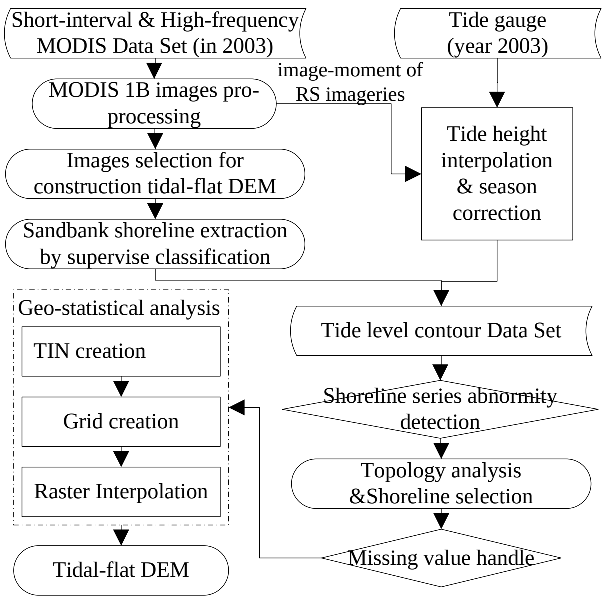

Figure 2. Flow-chart for tidal flat DEM construction

3.1 Massive MODIS 1B data pre-processing based on image partition

All remote sensing images have to be previewed first and picked out the satisfying subset of images Because the following factors: Firstly, the study area locates along the coast where the weather conditions are rather complex, cloud, rain, snow, haze and other weak weather factors have great influence on imaging of MODIS, and shorelines of sandbank can hardly be extracted if tidal levels are too high so as to totally submerge sandbank. Secondly, it is difficult to distinguish from remote sensing images whether sandbank is exposed in case the study area is away from the nadir. Thirdly, MODIS 1B used in the paper is the 5-minute-Granule standard data provided by NASA, each scene of which covers wide area and has a data quantity of more than 170m per-scene. Besides, professional software has to be employed to browse MODIS 1B and the browsing efficiency is markedly influenced by the hardware condition. In addition, the format of MODIS 1B is HDF-EOS Swath (namely the strip format within which each scene is made up of 204 swathes, and taking a 250m resolution image for example, the width of a single strip is 40 pixels), so overlaps must appear at the two ends of swathes due to the spherical surface of the earth which may cause bowtie effects once swathes make up of the remote sensing image. Therefore, 1085 scenes of MODIS 1B of 2003 has to be pre-processed so as to extract the study area, eliminate bowtie effects, geo-correct MODIS images into uniform geographic reference system and select high-quality (less geometrical distorted and smaller influenced by weather) subset of MODIS to retrieve the elevation of tidal flat.

Pre-process of massive MODIS 1B images in current researches can not meet the requirements. For instance, sharewares developed by NASA, MRTSwath, creates standard geographic grids in term of the satellite's ephemeris and projects images onto grids according to their geographic coordinates, which can both locate the coordinates and eliminate bowtie effects at the same time. However, MRTSwath has to additionally download certain geographic location files (namely the MOD03 data) and doesn't have strong ability of batch processing. HDF-browse developed by ScanEx Research and Development Center of Russia is able to wipe off bowtie effects according to characters of MODIS images but loses the 1×1km coordinate data of MODIS 1B images. Most commercial remote sensing software build up Geo Lookup Table (GLT) with coordinate data of MODIS 1B images, calculate correlative coefficients of overlapping pixels and pre-process images. For example, ENVI 4.3 is able to effectively pre-process images by building irregular triangulation but costs long time (processing a scene of image on an Intel P4 1.7 computer takes 23min), neither can batch images; ERDAS Imagine 9.2 has a great ability of batch processing but can not well eliminate bowtie effects.

Analysis on characters of MODIS 1B images indicates that overlapping pixels exist between neighbouring swathes but not within a single swath. Every 4 pixels have a set of latitude and longitude values in the 250m resolution MODIS 1B image. Thus, the paper presents the method of tiling pre-process as follow (Figure 3): reading the Swath data using the function HDF API library; tiling the whole image into several tiles so that each tile contains no overlapping pixels but those can be references whose geographic coordinates are known; calculating the output range of every tile and rectifying tiles with a normal low order polynomial correction; re-sampling pixels in every tiles by the 2×2 window with inverse-distance weighted interpolation; mosaicing the rectified tiles to be a whole image according to corner coordinates. Whether there are overlaps can be judged by coordinates of rectified pixels while mosaicing and the average of overlapping pixel values would be used as output in order to avoid bowtie effects if overlaps do occur.

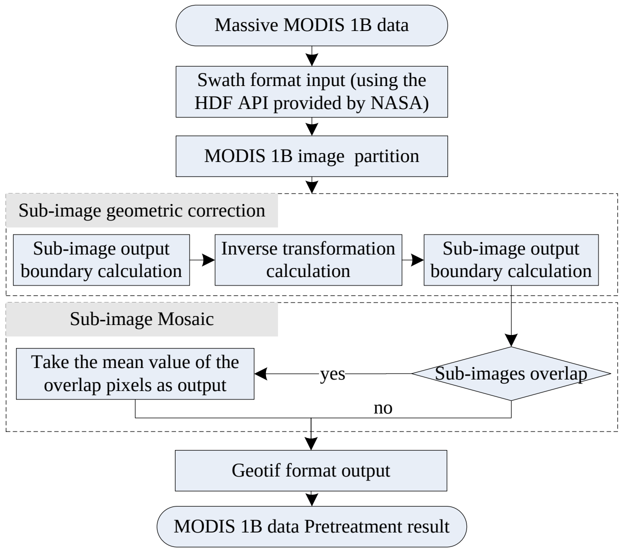

Figure 3. Pre-processing flow-chart of massive MODIS 1B data based on image partition

Methods mentioned above were implemented in development tool Visual C++6.0. 1085 scenes of MODIS 1B images collected were pre-processed, the study area was subset, bowtie effects were eliminated and images were adjusted to WGS 84 coordinate system. All procedures cost 28 hours and 30 minutes. In order to browse more efficiently, the MODIS images were output into Geo-tiff format. Overlaid with 1:250000 vector map of land within the study area, linear objects (such as rivers) in MODIS images excellently matched those in vector map, bowtie effects were effectively eliminated, the accuracy of geometrical location on land was 0.1 pixels at the satellite bottom point and 0.3 pixels at the edges.

3.2 Analysis on usability of multi-phase MODIS images

According to the analysis on 1085 phases of MODIS 1B images collected in 2003, imaging of sandbank in remote sensing images were affected by many factors and qualities of imaging varied, which represented in following aspects: (1) certain shorelines of exposed sandbank could not be extracted from MODIS images (10 scenes in total, including 1 scene of Terra and 9 scenes of Aqua) because tidal levels were high enough to totally submerge sandbank within imaging moment; (2) Affected by weak weather conditions, especially by cloud, rain, snow and haze, exposed areas of sandbank might be totally or partially covered so as to weaken the visibilities of sandbank (454 scenes in total, including 217 scenes of Terra and 237 scenes of Aqua); (3)MODIS images were blur due to research area is far away from the nadir (31 scenes in total, including 13 scenes of Terra and 18 scenes of Aqua); (4) Dongsha sandbank was not involved into collected MODIS images of the study area (375 scenes in total, including 190 scenes of Terra and 185 scenes of Aqua).

Due to the above factors, only 19.82% of the total MODIS images, thus 215 phases of images (including 125 scenes of Terra and 90 scenes of Aqua), in which shorelines of sandbank were clear enough to retrieve past elevations of tidal flat at inter-tidal zone of sandbank, were selected in the way of visual estimation on qualities of multi-phase remote sensing images. Figure 4 shows the result of analysis on usability of images from Aqua & Terra in January, 2003.

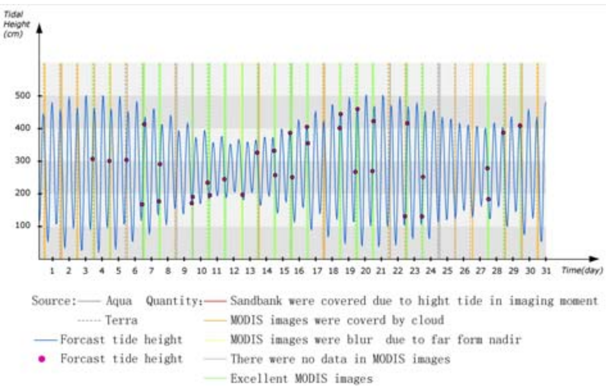

Figure 4. Usability analysis result of multi-phase MODIS images acquired in Jan, 2003

3.3 Tide level interpolation at moments of MODIS imaging

The tidal regime in middle coast of Jiangsu is the regular semidiurnal tide whose tidal levels change dynamically. The objective of the paper is to retrieve elevations of tidal flat at inter-tidal zone by extracting shorelines of tidal flat according to multi-phase remote sensing images within a short interval of time. The exposed area of sandbank (namely the shoreline) directly concerns with the tidal levels, higher the tide level is, little the tidal flat exposed. Taking the measure data of tidal levels from tidal gauge stations along Jiangsu coast as offshore elevations at moments of imaging seems to be a good method. However, because most tidal gauge stations along the coast of Jiangsu are locating under sluices at estuaries of rivers or drainage channels, the evolution of sand bars under sluices, influence of river runoffs, propagation and transformation of tides in shallow sea, all may induce the false measurements of tidal gauge stations(Shi, 1996). Especially at the time of low tidal level, the “infidelity” phenomenon is rather serious (Wang, 2004). Resulting from past field investigations, actual tidal levels are very different from measurements of tidal gauge stations along Jiangsu coast, because Dongsha Sandbank is far off the coast (the shortest distance from the sea-wall to sandbank edge is up to 21km). China Tidal gauges (Vol. 1) of each year provide daily tidal hours and tidal levels of the high and ebb tide at Chenjiawu tidal gauge station. Thus, this paper interpolated tidal levels from Chenjiawu tidal gauge station in south of Dongsha Sandbank to simulate offshore elevations of the study area at moments of imaging. Because of the regular semidiurnal tide in middle Jiangsu coast, the temporal changes of tide level are close to cosine curve. Tidal levels at moments of imaging can be calculated with formula (1) or formula (2), in which H is the tide level in given time to be interpolated, H_{low} is the tide level in ebb tide period, H_{hi} is the tide level in high tide period, T is the duration of rise, A is the tide range and t is the interval between any moment and the moment of ebb or high tide.

$$H=H_{low}+A\times(1-COS(t/T\times180^{o})/2 \quad (1)$$

$$H=H_{ji}-A\times(1-COS(t/T\times180^{o})/2 \quad (2)$$

3.4 Extract of shorelines of sandbank from MODIS images

Band 1 of MODIS is the red band (0.62-0.67μm), and Band 2 is the near-infrared band (0.841-0.876μm). Seawater and sandbank are extremely distinct and digital number of sandbank is much lower than seawater in Band 1. But in Band 2 seawater and sandbank are not distinct enough to discriminate. The paper extracted the exposed sandbank from MODIS images by supervised classification in order to ensure the accuracy of extraction. Methods were that collecting various training data (such as sandbank, seawater, cloud and etc.) from each MODIS image by seed-growing arithmetic in order to create certain signature patterns for classification, and classifying using minimum distance method; correcting classifications result of each image on screen according to the personal experience so as to improve the accuracy, then converting classifying results from raster to vector. Processes above (supervised classification, convert from raster to vector format) dealt with massive MODIS images, and were implemented by batch processing with the spatial modelling tools of ERDAS Imagine 9.2.

3.5 Retrieve of historical DEM of inter-tidal zone

As shorelines of exposed sandbank changes along with tidal levels, shorelines extracted from different phases of remote sensing images usually don't wholly overlap. The more shorelines between the highest and lowest tidal level in a short period of time, the better elevations of sandbank can be retrieved. Nevertheless, the shape of sandbank will probably alter a lot depending on the condition of sand supply if the time interval is too long, which may result in overlaps and intersections of shorelines at different tidal level. The paper overlaid together shorelines of sandbank extracted from MODIS images within a given interval, valued them with the corresponding tide level, visual judged the spatial relationship of them and eliminated illogical ones. Then, TIN was built and DEM of inter-tidal zone was created.

4. RESULTS

Analysis on all usable MODIS images in 2003, in spring, autumn or winter, more than 10 phases of high-quality MODIS images per month can be used, in which tidal levels were equally distributed at moments of imaging. Contrarily, there were few (3 phases in July, 8 phases in August & 7 phases in September) phases of MODIS images good enough in summer because of weather conditions (Figure 5). So in the paper, intervals for constructing DEM of inter-tidal zone were set to 1 month in spring, autumn and winter but 3 months in summer.

The paper managed to build DEM of inter-tidal zone in winter and summer of 2003. There were totally 34 phases (14 phases of Aqua in which the highest tidal level at the moment of imaging was 460cm and the lowest was 184cm(Figure 7a); 20 phases of Terra in which the highest tidal level at the moment of imaging was 409cm and the lowest was 131cm(Figure 7b)) of usable and high-quality MODIS 1B images in January of 2003(Figure 7c); and there were only 18 phases (the highest tidal level at the moment of imaging was 454cm and the lowest was 147cm) of usable and high-quality MODIS 1B images in summer (July, August & September) of 2003(Figure 7d). Obviously, just using MODIS images from Aqua or Terra in January of 2003 to build DEM of inter-tidal zone might miss some useful tidal-flat elevation information and cause different results. From images of Aqua elevations of inter-tidal zone could be retrieved within the tidal range of 184-460cm (Figure 7a and 7b), but from images of Terra elevations of inter-tidal zone could be retrieved within the tidal range of 131-409cm. In this case, MODIS images of Aqua and Terra were all used to retrieve elevations of inter-tidal zone at Dongsha Sandbank (Figure 7c and 7d).

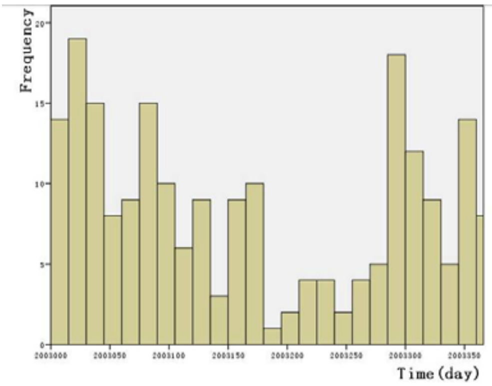

Figure 5. Amounts of usable & high-quality MODIS images in different months

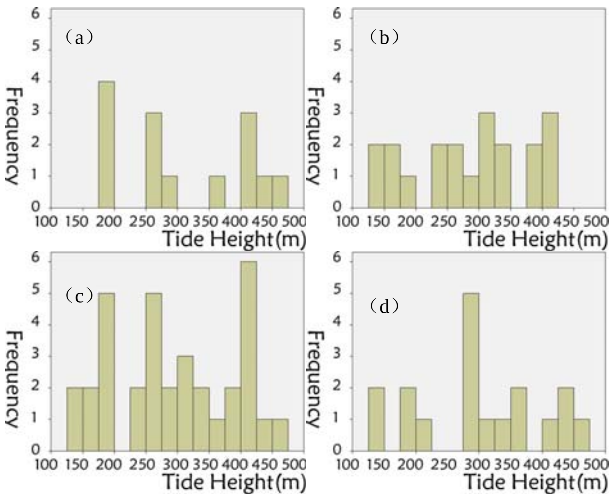

Figure 6. (a) Frequency distribution of tidal levels from usable & high-quality MODIS images of Aqua in January of 2003; (b) Frequency distribution of tidal levels from usable & high-quality MODIS images of Terra in January of 2003; (c) Frequency distribution of tidal levels from usable & high-quality MODIS images of both Aqua & Terra in January of 2003; (d) Frequency distribution of tidal levels from usable & high-quality MODIS images of both Aqua & Terra in summer (July, August & September) of 2003

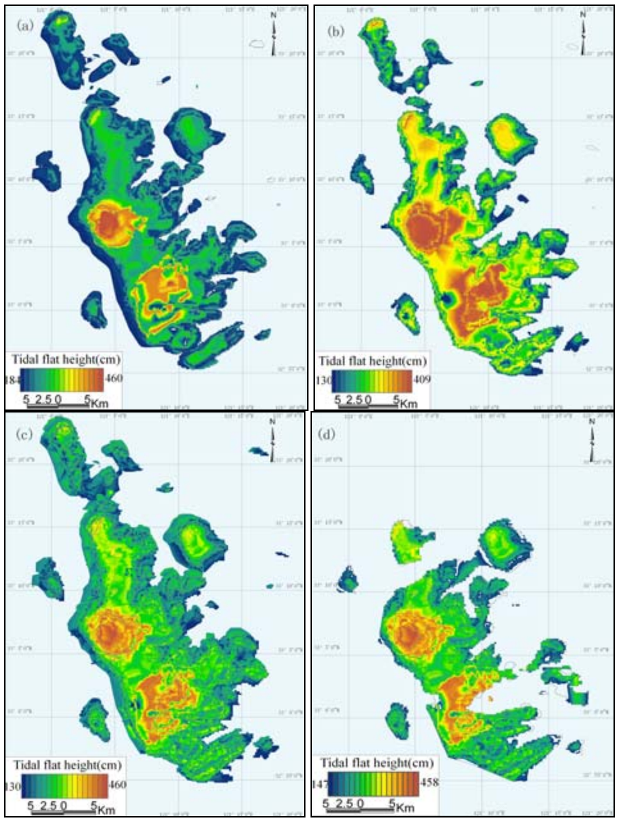

Figure 7. (a) DEM of inter-tidal zone at Dongsha Sandbank retrieved (from Aqua images dataset) in January of 2003; (b) DEM of inter-tidal zone at Dongsha Sandbank retrieved (from Terra images dataset) in January of 2003; (c) DEM of inter-tidal zone at Dongsha Sandbank retrieved (integration from of Aqua & Terra image dataset) in January of 2003; (d) DEM of inter-tidal zone at Dongsha Sandbank retrieved (integration from of Aqua & Terra image dataset) in summer (July, August & September) of 2003

5. CONCLUSION AND DISCUSSION

5.1 Conclusion

Taking Dongsha Sandbank as the test area which situated at the radial tidal sand-ridges offshore the coast of Jiangsu, the paper studied the technical framework that how to retrieve the historical DEM of inter-tidal zone with massive phases of MODIS images in a short period of time. In the framework, batch of MODIS 1B images, calculation of offshore elevations at moments of imaging and other important techniques were researched, and also usability of MODIS images for retrieving elevations was analyzed. Studies above showed that:

(1) Dataset of short-duration and multi-phase MODIS images can be used to retrieve the historical DEM of tidal flat at changeful coast. DEM of inter-tidal zone at Dongsha Sandbank of Jiangsu in January and July of 2003 was built in the paper. DEM of inter-tidal zone within the tidal range of 0-130cm was not capable to be built because remote sensing images at such low tidal level had not been collected.

(2) Analysis on usability of MODIS images from Aqua and Terra indicated that there were more usable and high-quality MODIS images in spring, autumn and winter, but less in summer. Accordingly, the interval for building DEM of inter-tidal zone was 1 month in spring, autumn and winter but 3 month in summer.

5.2 Discussion

The paper tried to bring forth a DEM construction method for inconstant inter-tidal zone base on short-interval, high frequency MODIS data set and carried out a case study in the Dongsha Sandbank of the Jiangsu Radial Tidal Sand-ridges. There are a few deficiencies needing deeper study:

(1) The retrieval DEM need to be validated by further in Situ data. Dongsha Sandbank is far away from the land and is

separated by broad Xiyang tidal channel. Synchronous or quasi-synchronous ground elevation of tidal-flat is lacked to validate the precision of the retrieval DEM due to the bad measurement conditions. In Situ elevation data of the tidal-flat should be measured, and source and spatial pattern of the error need to be studied in the further work.

(2) DEM retrieval based on synthetically analysis of the same or similar spatial resolution remotely sensed imageries. Obviously, the more remotely sensed imageries of the same region during a short interval, the more shorelines of the sandbank can be derived from RS data, and the better precision of the DEM is. Contrast to arid region, bad imaging conditions including cloud, rain, snow and haze have great influence on optical Remote Sensing in the coast zone due to complicated meteorology. In this meaning, the same or similar scale RS imageries acquired by the other multi-source sensor such as WFI (carried by CBERS) or CCD (carried by HY-1A/B) will greatly enhance the elevation retrieval result. In addition, spatial resolution of the preview imageries of MSS, TM, ETM+, SPOT, CBERS, ASTER distributed by EROS (Earth Resource Observation & Science, USA), EOC (Earth Observation Center, JPN), China RSGS (China Remote-Sensing Satellite Ground Station, CHN) are from 120m to 360m, in which there is huge difference between land region and ocean zone. These offers a detail data support for moderate scale sandbank evolvement simulation.

(3) DEM retrieval based on synthetically analysis of different spatial resolution remotely sensed imageries. Generally speaking, higher the spatial resolution of the remotely sensed imagery is, lower the temporal resolution covering the same region is, and more economic costs need to be invested into the research correspondingly. Temporal resolution of the MODIS is up to twice a day, which is rather high, but its low spatial resolution restricts the retrieval DEM precision. How to make full use of the temporal resolution advantage of the MODIS data to product higher resolution DEM of inter-tidal zone in temporal, horizontal & vertical dimension, combining with higher spatial resolution remotely sensed imagery such as Landsat-7 ETM+ data.

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