Multi-source Coastal Data Analysis

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1.0 Introduction

This paper presents results from the second year of a project on coastal management and decision making sponsored by the National Science Foundation Digital Government Program and carried out by a multidisciplinary research team. As one of the primary goals of the project, tide-coordinated shoreline modeling and mapping requires the integration of multi-source spatio-temporal data that include high-resolution digital elevation models (DEM) derived from IKONOS satellite images and aerial photographs, bathymetric data, water gauge data, satellite altimetric data, and water surfaces derived by a hydrodynamic hindcast model (Li et al., 2002b). Quality and accuracy assessment of these data has been made to ensure reliability of the outcomes of the data integration. The resulting shorelines derived from the integrated data are then evaluated for accuracy in comparison with traditional shorelines determined from tide-coordinated aerial surveys.

Shoreline mapping and shoreline change detection are critical to many applications, including navigation, coastal zone management, coastal environmental protection, and sustainable development. In order to depict dynamic characteristics of shorelines, tide-coordinated shorelines are mapped based on mean lower-low water (MLLW) and mean high water (MHW). In the United States, MHW and MLLW calculated over a period of 19.2 lunar years are used to define zones of federal and/or state jurisdiction and also used to determine land ownership.

To achieve efficient and cost effective tide-coordinated shoreline mapping, Li et al. (2002a) proposed two approaches to generate highly accurate, tide-coordinated shorelines from either instantaneous shorelines or a digital coastal terrain model along with a tide-coordinated water surface. In the second approach, a digital coastal terrain model (CTM) contains topographic information in a narrow zone of the coast and near-shore bathymetry. The water surface is depicted by a water surface model (WSM) that was produced by a hydrodynamic modeling system. The digital tide-coordinated shoreline (DTS) is created digitally by an intersection of the CTM and WSM.

2.0 Study Area and Data

The study area along the Lake Erie shore covers 11km of shoreline, stretching from Sheldon Marsh to Oberlin Beach, Ohio. The multi-source coastal data consist of DEMs derived from high-resolution IKONOS satellite images and aerial photographs, bathymetric data, GPS survey data, water gauge data, satellite altimetric data, and hindcast water surfaces.

Two high-resolution DEMs are generated, one from aerial photographs and another one from IKONOS satellite stereo images. Bathymetric data of Lake Erie acquired originally from NOAA was combined with these two DEMs, respectively, to produce two coastal terrain models. Any gaps between the bathymetric data and the DEMs were interpolated.

A hydrodynamic hindcast model from The Great Lakes Forecasting System (GLFS) Laboratory is being used to hindcast the MHW, MLLW, and MW (mean water) surfaces for Lake Erie. Calculations of fluctuations in the water level from a referenced elevation were performed on a 2x2km rectangular grid. The determination of the model datum was based on water gauge data obtained from three U.S. National Ocean Service (NOS) gauge stations: 3085 (located near Toledo, OH); 3063 (Cleveland, OH); and 3020

(Buffalo, NY). In this study, hindcast MHW, MLLW, and MW water surfaces were produced for a three-year period from January 1, 1999 to December 31, 2001. There should be a systematic assessment of the compatibility between this model and observations from space borne and in-situ sensors. To evaluate the reliability of these water surfaces, three-year averages of water gauge data from fifteen tide-gauge stations around Lake Erie shore and those of TOPEX/POSEIDON (T/P) satellite altimetric data were used as references. The datum conversion accuracies between these water level data are considered in the study.

3.0 Experiments

Experiments were carried out to evaluate the quality and compatibility of the above multi-source spatio-temporal data. A satellite, such as IKONOS, can provide one-meter or sub-meter high-resolution stereo imagery, which is sufficient to generate DEMs, orthophotos and 3D shorelines. IKONOS 1m Geo images were examined using the rational function (RF) model (Ma et al., 2003). Systematic errors were detected based on GPS control points. This experiment has shown that systematic errors can be corrected using either the Affine transformation or a shift correction. The improved accuracy reached the level of 1.5 meters horizontally and 3 meters vertically.

The horizontal accuracy of water gauge stations was compared with the USGS DLG shoreline. The geographic coordinates of the gauge stations were obtained from the Center for Operational Oceanographic Products and Services (http://co-ops.nos.noaa.gov/). The accuracies of these coordinates are up to 0.1arc minute, or around 180 meters. A USGS DLG hydrographic shoreline was used as the reference shoreline. The distances from eight gauge stations in the United States to the DLG shoreline were measured. They ranged from 5 to 114 meters. Four stations in Ohio were also compared with the DOQQ. These distances were manually verified. Considering the horizontal accuracy of the DLG shoreline (12m) and the gauge location accuracy of 0.1arc minute (Li et al., 2002a), the horizontal accuracy of the gauge stations is within an acceptable range.

Three-year (1999-2001) average hindcast MHW, MLLW, and MW surfaces have been interpolated to 2x2m rectangular grids using the Kriging method. The RMS of the interpolation errors is 0.0002m. These surfaces were then compared with the water gauge data. The average absolute difference is 3.15cm and the maximum difference reaches 8cm. The standard deviation is 2.28cm. The water gauge data were also interpolated into these three kinds of water surfaces in order to visualize any trends in water level distribution. The differences between the hindcast water surfaces and the water gauge surface are shown in Figure 1. In the water gauge surfaces, the water levels in the northern part of the lake are higher than those of the southern part. This corresponds to the results of the GPS buoy field surveys conducted by the Geodesy Laboratory research team of The Ohio State University (Cheng, 2001). The hindcast water surfaces show that water levels in both parts of the lake were virtually the same. The average difference between these two kinds of MW surfaces is 2.7cm, and the maximum difference reaches 9.0cm.

The three-year averages of the T/P satellite altimetric data were also compared with the hindcast MW surface. The average absolute difference is 19.36cm and the standard deviation is 7.13cm. There is a systematic shift between the altimetric data and the MW surface. The datum for these three kinds of water-level data sets (gauge, altimetric, and hindcast water surface) is NAVD88. The T/P data is based on the ellipsoid height. Before converting its datum to NAVD88, first it had to be converted to the GRS80 ellipsoid height, which possibly introduced errors up to several millimeters into the data because of the differences in the ellipsoids. In converting the GRS80 ellipsoid height to NAVD88, additional errors (up to 18.2cm approx.) were introduced, considering the accuracy of the geoid parameters. Most of the bias between the altimetric data and the hindcast water surface can be explained by the accumulation of these errors. Figure 2 shows the MW surface interpolated from the MW water gauge data and the altimetric data, and the differences between this surface and the hindcast MW surface. The average difference between the hindcast water surface and the surface generated from the water gauge and altimetric data is

7.9cm and the maximum difference researches 28.2cm, which represents, mainly, the 18.2cm datum conversion errors. Research is underway to address this issue and reduce the effect.

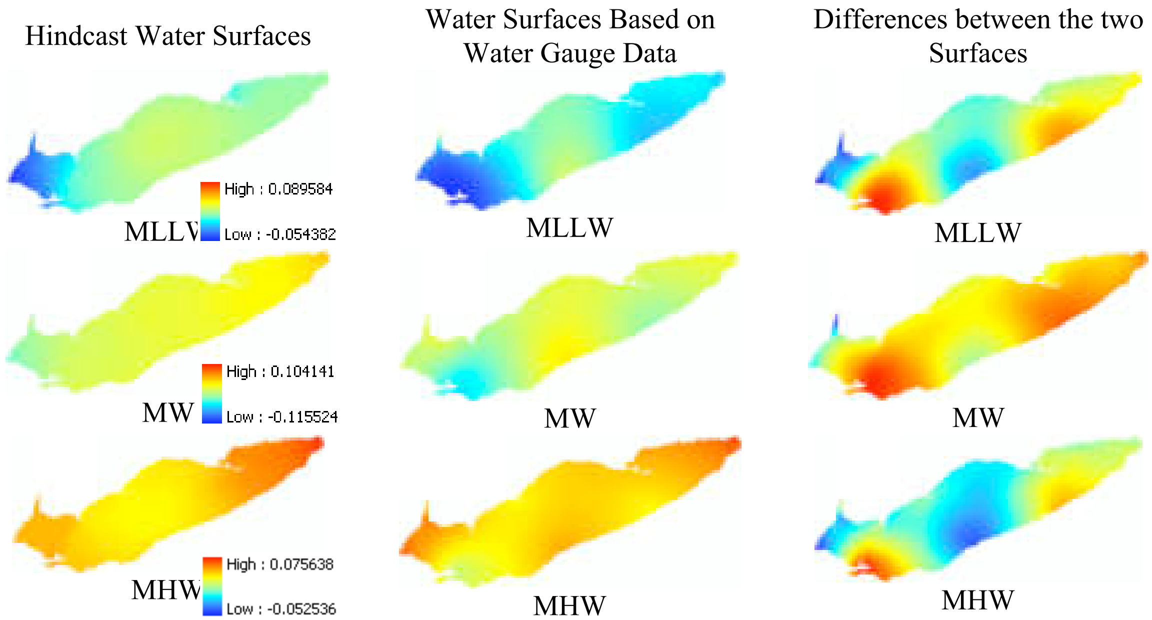

Figure 1. Comparison between Hindcast Water Surfaces and Water Gauge Surfaces

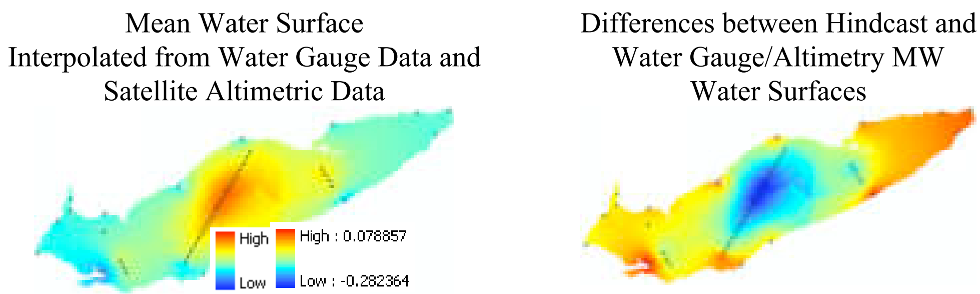

Figure 2. Differences between the Hindcast MW Surface and the Water Gauge/Altimetric Surface

Three digital, tide-coordinated shorelines (MHW, MLLW, and MW) were produced, each based on the linear intersection between one of the three hindcast water surfaces and a CTM generated from IKONOS DEM and bathymetric data. In the study area, differences between these water surfaces are only within 20cm and the vertical accuracy of the IKONOS DEM reaches the level of 3m. As a result, these three shorelines are very close to each other. Therefore, only the digital MW shoreline is displayed in Figure 3. Another shoreline digitized from the IKONOS orthophoto is displayed in Figure 3 as a comparison. The digital shoreline fits most of the 11km shoreline. The only place where a significant difference (up to 118.19m) between the two shorelines lies is in the northwestern part of the study area (see highlighted area). This represents a large area of sand beach and very shallow water. In the CTM, this interpolated area demonstrated gaps between the bathymetric data and the DEM. The bathymetric data was compiled using historic hydrographic sounding data collected since 1903 and the IKONOS imagery was taken on March 19, 2001. The erosion during this long time period created the big gap between the DEM and the bathymetry, which explains the difference between the two shorelines. Such gaps between the bathymetric data and the DEM highly influence the quality of the digital shoreline. A water penetrating LIDAR bathymetric survey using SHOALS (Scanning Hydrographic Operational Airborne LIDAR Survey) should be helpful in filling these gaps. Except for the highlighted area, it can be concluded that the generated digital shoreline is comparable to the shoreline derived from the orthophoto.

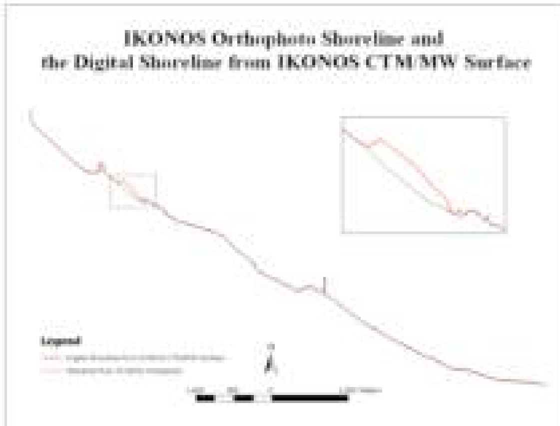

Figure 3. Comparison between the Orthophoto and the Digital Shorelines

4.0 Future Work and Conclusions

Based on the comparison between the short three-year hindcast water surfaces, water gauge data and altimetric data, the quality of the hindcast water surface has been found to be reliable. Accuracy analysis of datum conversion will be studied in the future research. More research incorporating the extended 19.2 lunar year data and other additional data sources will be carried out to assess the quality, estimate coastal changes, and perform coastal management. Tidal influence will be a challenge when we deal with data in the Tampa Bay project area.

5.0 Acknowledgements

We would like to acknowledge the efforts of Dr. Kaichang Di, Dr. Ahmed Elaksher, and Dr. Sean O'Neil along with our team of graduate research associates. In addition, we would like to acknowledge our governmental collaborators: Commander Jon Bailey at NOAA National Geodetic Survey; Dr. Bruce Parker and Dr. Kurt Hess at the Office of Coastal Survey; Dr. Abby Sallenger at the USGS Coastal and Marine Geology Program; John Watkins, Justin Reinhart, and Don Guy at the Ohio Department of Natural Resources; and Darrell C. Webster and Richard Kotapish at the Lake County Commission of Ohio. This research was supported by the Digital Government Program of NSF, Grant No. 91494.

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