Integration of Multi-Source Spatial Information for Coastal Management and Decision Making

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Abstract

This paper presents the second-year outcomes of our Digital Government project "Digitalization of Coastal Management and Decision Making Supported by Multi-Dimensional Geospatial Information and Analysis". One of the primary objectives of the second year is to develop and integrate multiple spaceborne, airborne, and in-situ remotely sensed measurements, spatio-temporal databases, coastal hydrological modeling, and geospatial information analysis for coastal management and decision making. The developed coastal management and decision-making system includes applications for coastal mapping and change detection, water surface modeling and analysis, on-site coastal management and decision-making, and web-based spatial data manipulation. Studies have also been conducted on uncertainties in the used coastal spatial data. The above system has been tested at a pilot site along Ohio's Lake Erie shore and is to be applied to a new test site in Tampa Bay, Florida.

1. Introduction

This paper presents the second-year outcomes of our Digital Government project "Digitalization of Coastal Management and Decision Making Supported by Multi-Dimensional Geospatial Information and Analysis". The goal of the three-year project is to investigate and develop technologies to enhance the operational capabilities of federal, state, and local agencies responsible for coastal management and decision making. The research team is developing a spatio-temporal data model for inter-governmental agency operations that will enable agencies to account for the dynamic nature of coastal zones in policy formulation and implementation. Multiple high-resolution spaceborne and in-situ remote sensing measurements are being combined with spatio-temporal databases, coastal hydrological modeling, and geospatial information analysis to provide detailed information for highly efficient modeling and forecasting capabilities along with a high degree of coordination between coastal management and policy making. The research project is being carried out primarily along the Lake Erie coastline. The research results are to be applied to a new test site in Tampa Bay, Florida. The research team has worked with local and federal agencies to explore the possibilities of implementing the developed system in their operations. The results of the first year of the project were presented at the 2002 Digital Government Conference (Li et al., 2002). The major tasks of the research and their interrelationships are illustrated in Figure 1.

2. Major Research Objectives And Outcomes

In the second year, the research team integrated spaceborne and in-situ remote sensing measurements and coastal hydrological modeling and forecasting for the Lake Erie site, along with the continued efforts in system development, coastal spatial infrastructure, and decision-making research. The data set used includes high-resolution satellite imagery, aerial photographs, satellite altimetry data, tide-gauge water levels, and laser ranging observations. It is employed in an integrated spatio-temporal coastal management and decision-making system that includes an Internet-based, mobile coastal spatial management subsystem, a web-based data inventory subsystem, and a distributed database framework subsystem. Great efforts are made in using the integrated information for the generation of tide-coordinated shorelines. Studies have also been conducted on the uncertainties inherent in the coastal geospatial databases. The following sections present the highlights of recent developments and outcomes the research team has accomplished. More detailed project progress and results are described in other papers of this conference.

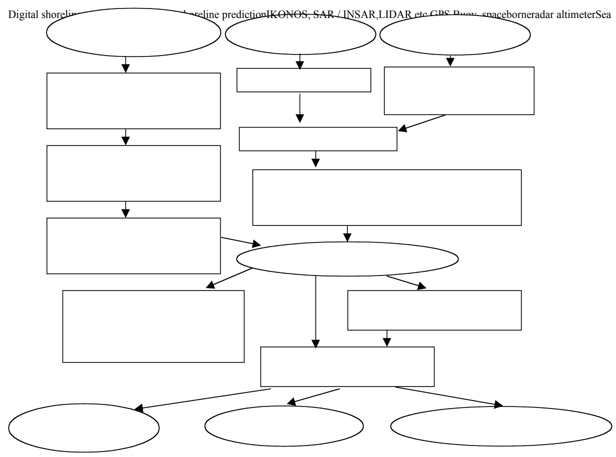

Figure 1. Research Tasks

2.1. Monitoring Coastal Changes using Multi-dimensional Geospatial Data

In order to improve the accuracy of the IKONOS stereo imagery product, we performed a systematic analysis of the impact of different adjustment models and ground control point (GCP) distributions on the accuracy of IKONOS geopositioning. The use of different quantities of GCPs for each model was also compared. Experimental results indicate that the number, accuracy, and distribution of GCPs greatly affect the results of the adjustment. We were able to produce stable and satisfactory results on the level of 1 to 2 meters using the performed analysis. A process for the automatic extraction of shorelines from 4-meter resolution multispectral and 1-meter resolution panchromatic IKONOS images was also performed. Figure 2 shows the automatically extracted shoreline as a bright green line. The 3D positions of the shoreline points are refined using the developed technique. The ultimate accuracy of the 3D shoreline is estimated to be 2-3 meters.

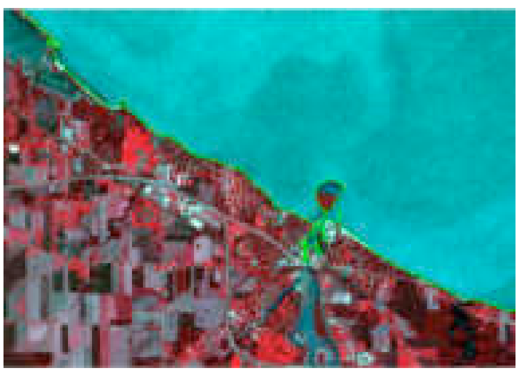

Figure 2. Automatically Extracted and Refined Shoreline

In the second year of the project, we began investigating a new test site in Tampa Bay. The project team visited local and federal agencies during the week of November 2-9, 2002. The purpose of the visit was to make presentations on the coastal management system we had developed and to discuss data availability and exchange as well as to discover the research demands in this site. After discussions with local agencies, we decided to study the Terra Ceia area in Tampa Bay, an area of high seagrass concentration that has been degrading in recent years. Our research tasks will be to develop a monitoring system for identifying changes in seagrass mass using high-resolution satellite images, airborne aerial photographs, and hydrological modeling; and to explore the generation of a tide-coordinated shoreline in this area. To begin the research in this area, the research team collected water gauge station measurements. Satellite altimetric data were also acquired and processed. In addition, the team conducted a GPS survey to establish a network of ground control points (GCPs) that will be used in image processing.

2.2. Water Surface Modeling

Gauge-station water measurements, altimetric data from the TOPEX/POSEIDON (T/P) mission, and altimetric data from the European Remote Sensing Satellite ERS-2 mission were used to calculate mean water surfaces in Lake Erie and Tampa Bay. In Lake Erie, the mean water surface was derived using gauge-station data and satellite altimetric data from the period 1999-2001. In November, 2001, a GPS buoy campaign was conducted at Marblehead, Ohio, for the determination of the local Lake Erie geoid height. Mean high water (MHW), mean lower-low water (MLLW) and mean water averages were computed for Tampa Bay using water level data from four tide-gauge stations. The mean water averages for the Tampa area were also calculated using T/P and ERS-2 altimetry data.

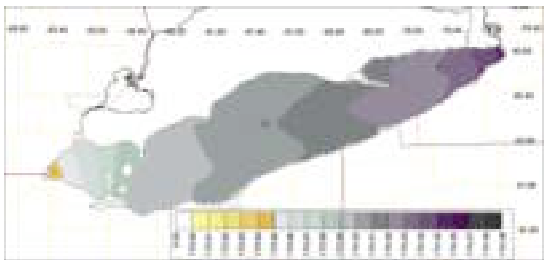

Figure 3. Three-year (1999-2001) Mean Water Surface

The Great Lakes Forecasting System (GLFS) circulation model is being used to determine mean water level surfaces for Lake Erie for the most recent 19.2 year tidal epoch. The circulation model is a modified version of the Princeton Ocean Model. This model requires various meteorological data and water gauge data. Using these data, the circulation model was run for the years 1999, 2000 and 2001. Current model outputs include the hourly water surface elevations at 6,320 grid points. From the model outputs, the MHW, MLLW, and mean water surfaces have been calculated for the period 1999-2001. Figure 3 shows the three-year mean water surface.

2.3. Spatio-temporal Data Integration for Coastal Management and Decision Making

The integrated spatio-temporal data is being utilized in a coastal management and decision-making system. The data includes: water level observations from 15 gauge stations around Lake Erie taken during 1999-2001, water surfaces generated by the Great Lakes Forecasting System during 1999-2001, satellite altimetry data (averaged from 1999-2001), the USGS DLG shoreline, IKONOS satellite stereo imagery and aerial photographs, nautical charts, bathymetry data, parcel data, and other data.

A data inventory system was developed for Tampa Bay that was created using ArcIMS technology, which is an improved version based on the system for Lake Erie. The existing data for Tampa Bay are listed on the developed web site. Users are able to check data availability. Currently the data set includes USGS DEM, USGS DOQQ, USGS DLG, NOAA shorelines (MHW and MLW), bathymetry, and water gauge data. As part of the information infrastructure, a distributed database framework was built to handle differences in GIS data location/format and provides a tool for the overall system to access various distributed databases regardless of the way the data are originally stored. The developed system currently supports data access locally or through HTTP and FTP protocols.

The coastal management and decision-making system is implemented using these data. As part of the system, an Internet-based and mobile coastal spatial management system has been developed (Li et al., 2003). The system consists of three subsystems: a mobile spatial field work subsystem, a shoreline erosion awareness subsystem, and a coastal structure permitting subsystem. This system has been tested along the southern Lake Erie coastline. The mobile spatial subsystem is used for on-site analysis and evaluation. The coastal structure permitting subsystem is used as a decision-making tool. The shoreline erosion awareness subsystem is used as an evaluation tool for coastal residents in Sandusky, and now in Painesville, OH. They will be demonstrated at the conference.

2.4. Tide-Coordinated Shoreline Generation and Assessment of the Multi-source Data

Currently the multi-source spatio-temporal data are analyzed and used to develop a scheme to study the effects of water level and temporal changes on shoreline geometric characteristics. This is implemented by intersecting the coastal terrain models (CTM) with water surfaces. The coastal terrain model is generated by merging the topographic data of the coastal zone with the near-shore bathymetry. Different water surfaces were simulated as horizontal surfaces at different elevations. The shorelines were generated by intersecting the CTM with the simulated water surfaces. Then we began the analysis process. Different polynomials were used to model the shoreline geometric characteristics. Figure 4 shows the relationship between water levels and an individual coefficient of one of the polynomial models. We will analyze temporal nature of polynomial coefficients vs. water gauge observations.

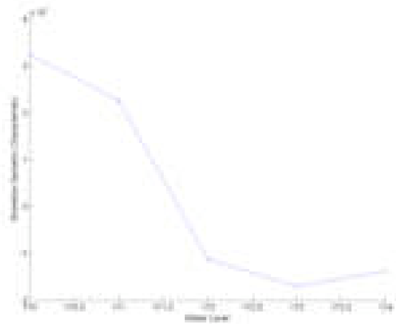

Figure 4. Analysis of CTM Derived Shorelines

Quality and accuracy assessments of the data have also been made to ensure reliability of the data. The horizontal positional accuracies of the gauge stations were verified based on their relative positions with respect to the USGS DLG shoreline to ensure the quality of the water gauge data. The local accuracy of hindcast mean water surface was checked against the three-year averaged mean water gauge data. The average difference is 3cm and the maximum difference reaches 8cm (±2cm). Both differences are within the range of the deviations of the water gauge data (14cm-24 cm). The three-year average of the T/P altimetry observations were compared with the hindcast mean water surface. The average difference is 19cm (±7cm). This is due to the systematic shift between the altimetric data datum and the hindcast datum. Further analysis of the surface differences is being conducted.

3. Conclusions

The research project is progressing successfully. Multiple high-resolution spaceborne and in-situ remote sensing data sources are combined with spatio-temporal databases, coastal hydrological models, and geospatial information to provide detailed information for developing the above reported algorithms, data integration, and the system. Most of these are implemented on the Lake Erie site. The Tampa Bay site will be used to further study and verify tidal coordinated aspects of the project.

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References

Li, R., K.W. Bedford, C.K. Shum, J.R. Ramirez, A. Zhang and K. Di (2002). Digitalization of Coastal Management and Decision Making Supported by Multi-dimensional Geospatial Information and Analysis. Proceedings of the 2002 NSF National Conference for Digital Government Research, May 20-22, Los Angeles, CA.

Li, R., X. Niu, T. Ali, R. Ma and A. Elaksher (2003). Development of a Web-Based, Mobile, Spatial System for Coastal Management and Decision Making. Proceedings of the 2003 ASPRS Annual Convention, May 5-9, Anchorage, AK.