MONITORING AND MODELING NATURAL AND ANTHROPOGENIC TERRAIN CHANGE

Spatial analysis and simulations of impact on landscape processess

Helena MITASOVA, Russell S. HARMON, David BERNSTEIN, Jaroslav HOFIERKA, Richard McLAUGHLIN

The present day topography is the result of complex interactions between natural processes and human activities. Quantification and modelling of these interrelated influences and their effect on landscape processes can provide a foundation for sustainable land management. We investigate these interactions within two fundamentally different environments affected by different kinds and degrees of development activity: a coastal barrier island environment and a piedmont urbanized landscape. We present methods and applications for GIS-based modelling and visualization of topography, its structure and evolution using data acquired by modern mapping technologies including lidar. The impact of anthropogenic topographic change on landscape processes is investigated using numerical simulations of water flow and sediment transport with the aim to design effective land management strategies.

KEYWORDS

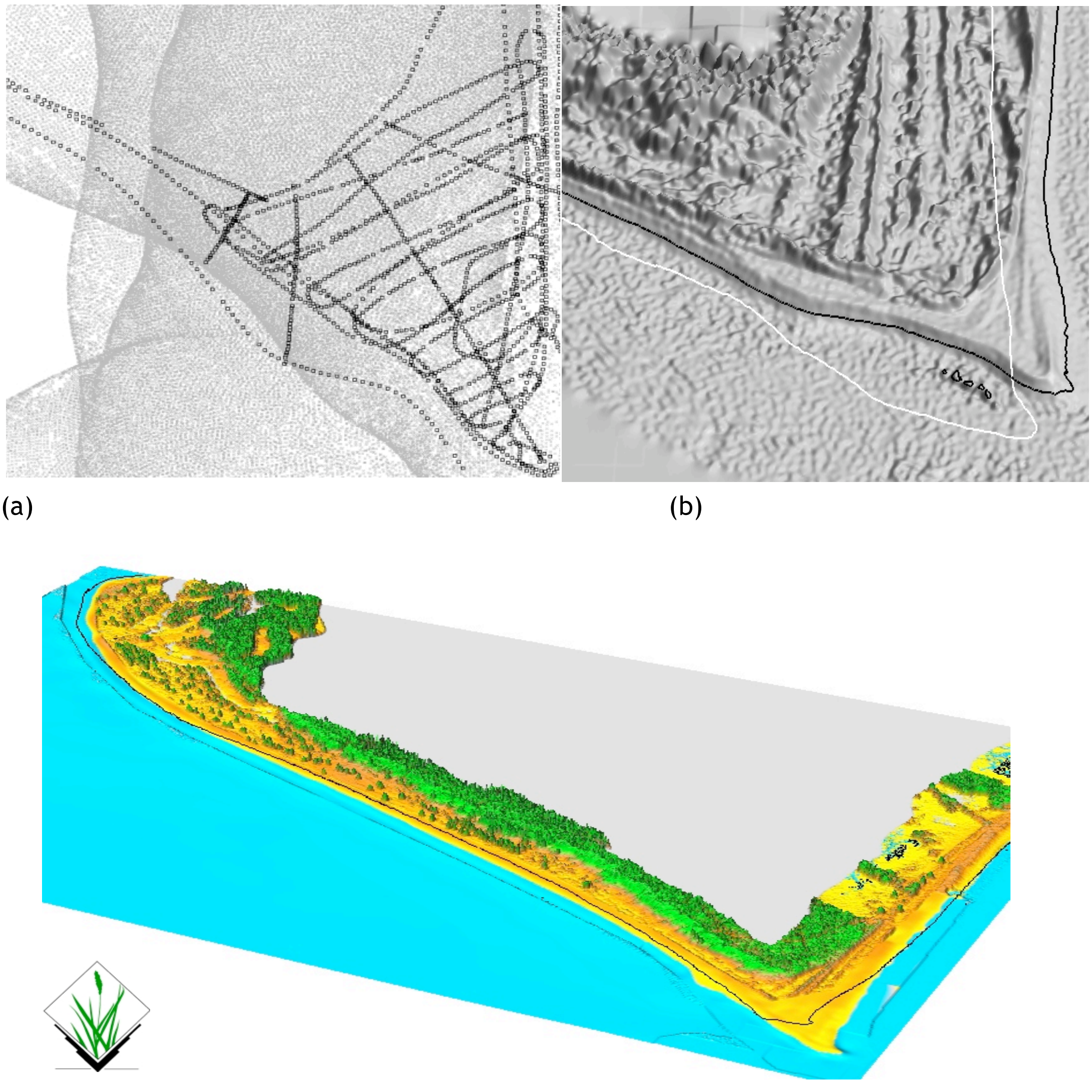
Landscape Evolution, Topographic Change, Coastal Erosion, Sediment Control, Open Source GIS.

INTRODUCTION

Natural processes and human activities drive changes in landscapes that are not always compatible with each other. These changes often create conflicts between economic development and the need to preserve natural resources. Integration of new mapping and monitoring technologies, process-based models and GIS analysis provides an opportunity to monitor and model the landscape evolution at high spatial and temporal resolutions, predict the possible impacts of human activities and explore options to minimize the negative consequences. Airborne laser scanning (lidar), real-time kinematic GPS (RTK-GPS), sonar sea bottom surveys, and multispectral remote sensors provide a greatly enhanced capabilities to gather 3-D georeferenced data for large areas at unprecedented speed, recurrence interval, and spatio-temporal resolution (Queija et al., 2005). Terrain models based on such data provide critical information for areas with rapidly changing topography that is typical of many coastal regions, as well as for areas with intensive development, typical for rapidly expanding urban areas. The capacity to acquire such geospatial data currently by far exceeds the capability to analyze and apply the data for improving understanding of dynamic landscapes or for a wide range of decision making tasks. The underlying problem is related to the fact that such geospatial data sets are several orders of magnitude larger than those for which current GIS tools were designed, and they have different spatial distributions and properties than data acquired by traditional methods. Therefore, methods for processing this type of data and new types of landscape process simulation tools are being developed that can take advantage of the rich information available in this geospatial data for solving land management problems such as landscape modification for damage prevention or mitigation, pollution control, or hazard prevention. The methods and tools implemented in open source GIS are demonstrated using case studies from the state of North Carolina.

COASTAL TOPOGRAPHIC CHANGE

The issues of interaction between natural processes and development were investigated within two environments affected by different kinds and degrees of human activity: a coastal barrier island and a piedmont urbanized landscape. Topographic change in the coastal study area is driven by interaction between human intervention and natural forces. Anthropogenic activities include navigation canal dredging and sand disposal on beaches while the natural processes impact the topography through major storms, such as hurricanes and a slower, continuous erosion and accretion. The barrier island study uses a temporal sequence of digital elevation data obtained by lidar and real time kinematic GPS to monitor the changes in beach morphology during a period of hurricane landfalls followed by a major engineering project. Comparison of erosion rates and changes in beach morphology show complex evolution pattern that includes shoreline rotation, accelerated short term erosion rates and rapid growth of the Cape Fear (Mitasova et al. 2004). Contrary to the general perception, the highest beach erosion rates are observed during years with relatively calm weather compared to the years with direct hurricane impacts. Also the spatial pattern of long term rates used for coastal management is quite different from the the most recent short term rates, indicating a need for continuous monitoring.



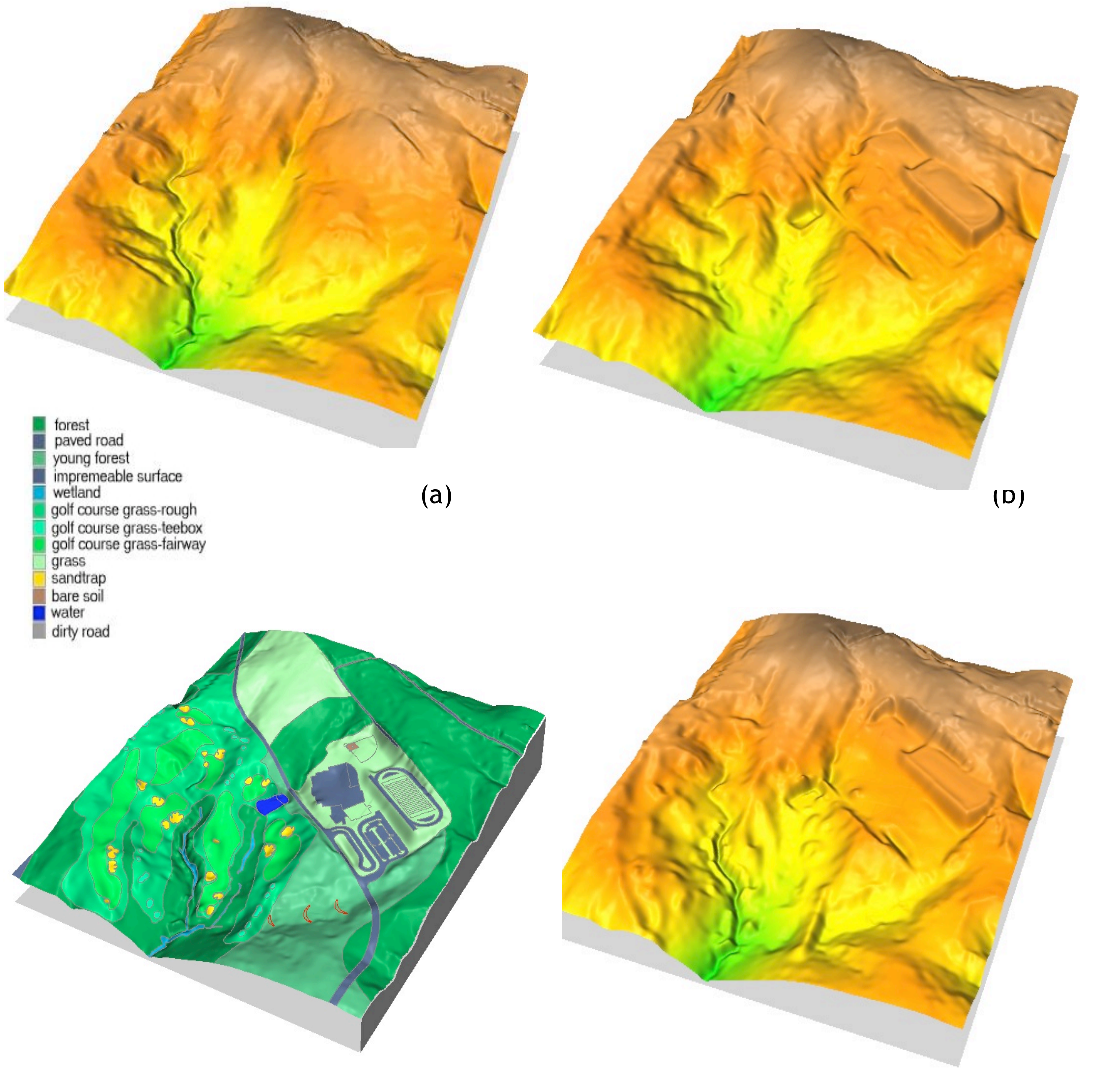
(a) (b)

(c)

Figure 1 Monitoring coastal topographic change at Cape Fear, North Carolina, USA: (a) sampling pattern from lidar (1997, grey) and real time kinematic GPS (2002, black) surveys; (b) shorelines derived from the interpolated DEMs (2002 white, 1997 black) draped over the 1997 model; (c) lidar-based model of Bald Head Island beaches and Cape Fear.

IMPACT OF TERRAIN CHANGE DUE TO URBAN DEVELOPMENT

The combined impacts of change in land use, modifications of topography and implementation of conservation measures are being investigated at a subwatershed of North Carolina State University Centennial Campus using lidar and photogrammetric data combined with a process-based model for simulation of water and sediment transport. The simulations use a stochastic computational approach based on the duality between particles and fields for solving the governing continuity equations by a path sampling method (Mitasova et al., 2002). The study indicates that changes in topography compensate, to certain extent, the negative impacts of land cover change and that the greatest impact of construction will be on the streams outside the disturbed site, in spite of their protection by vegetative buffers. The fact that the spatial range of land use change impacts extends well beyond the affected site requires that the models capture not only the specific processes at the disturbed locations or for given control structures, but that they can simulate the combined effects of spatially distributed landscape changes and control measures at a larger spatial scale.

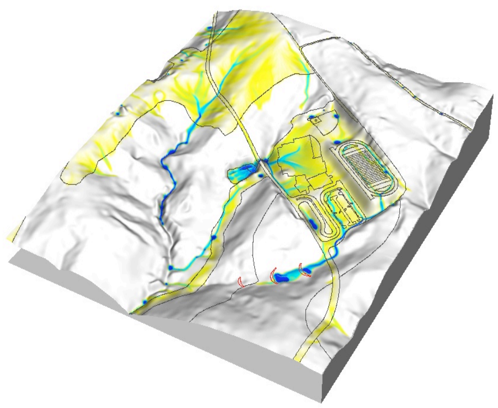


c) (d)

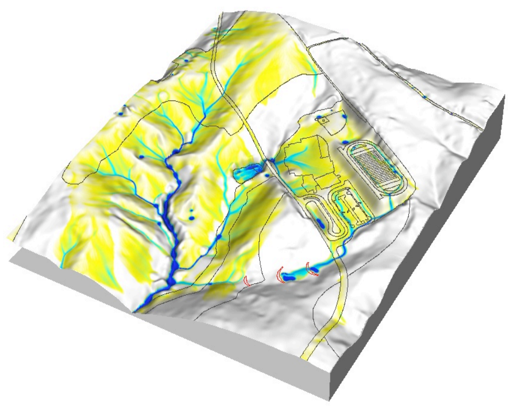
Figure 2 Evolution of topography at a ~100 acre location that is undergoing transformation from secondary forest to a partially urbanized land use that includes a school and a future golf course. Pre-development terrain (a) is flattened to build a school with a parking lot and sports facilities. Future plans include development of a golf course leading to further terrain modifications. Terrain models were interpolated from (a) digital contours, (b) lidar point cloud, and (c) CAD data using the spatial interpolation module v.surf.rst in GRASS GIS.

CONCLUSIONS

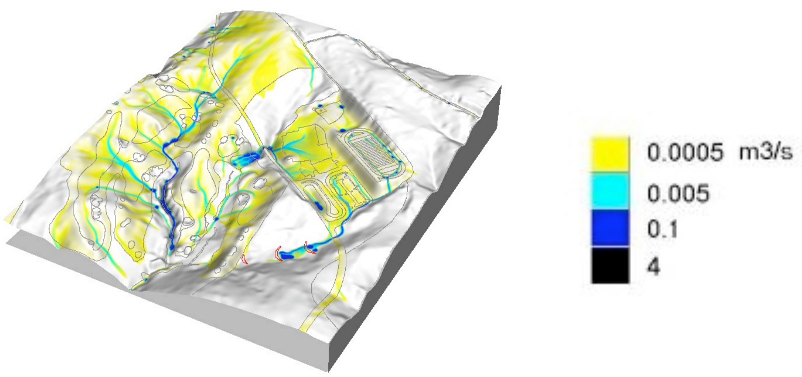
Both case studies demonstrate that the higher spatial and temporal resolution of terrain data can provide better understanding of some unexpected consequences of development and creates opportunities for adopting more sustainable approaches to coastal and urban landscape management. They also illustrate the current capabilities of open source geospatial technology for topographic data processing, analysis, modelling and visualization (Neteler and Mitasova, 2004).



(a)



(b)



(c)

Figure 3. Spatial pattern of water discharge (a) for the current conditions; (b) during development of golf control measures are implemented in addition to the mandatory stream buffer; (c) after the golf course is finished. The water flow was simulated in GRASS GIS using an experimental module r.sim.water.

ACKNOWLEDGMENTS

Significant contributions to this paper, in the form of data collection and valuable discussions, were provided by Tom Drake (ONR) and Rob Austin (NCSU). The support by the National Research Council and U.S. Army Research Office is gratefully acknowledged. Airborne Topographic Mapper LIDAR data used in this paper were collected in partnership with the National Oceanic and Atmospheric Administration (NOAA) Coastal Services Center, the NASA Wallops Flight Facility, the U.S. Geological Survey Center for Coastal and Regional Marine Geology, and the NOAA Aircraft Operations Center.

REFERENCES

Mitasova H., Hofierka J. and Mitas L. GRASS and modeling landscape processes using duality between particles and fields. Proc. OSFS GIS - GRASS conf. 2002, Ciolli M., Zatelli P. Eds, Trento, Italy, Sep 2002.

Mitasova H., Drake T.G., Harmon R.S., Bernstein D. 2004 Quantifying rapid changes in coastal topography using modern mapping techniques and GIS. Env & Eng Geoscience 10, 1-11.

Neteler M., Mitasova H. 2004 Open Source GIS: A GRASS GIS Approach, Second Ed, Springer/Kluwer.

Quieja V.R., Stoker J.M., Kosovicj J.J. Recent USGS applications of lidar, Photogr. Eng. & RS, Jan 2005.

AUTHORS INFORMATION

Helena MITASOVA
hmitaso@unity.ncsu.edu
North Carolina State University

Jaroslav HOFIERKA
hofierka@geomodel.sk
University of Presov, Slovakia

Russell S. HARMON
russell.harmon@us.army.mil
Army Research Laboratory

Richard MCLAUGHLIN
rich_mclaughlin@ncsu.edu
North Carolina State University

David BERNSTEIN
dave@geodynamicsgroup.com
Geodynamics, LLT