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Preface

Geospatial technologies and geomorphological mapping

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1. The symposium

The 41st International *Binghamton Geomorphology Symposium* (BGS) was hosted by the USC Geography Department at the University of South Carolina (USC), Columbia from October 15th to 17th, 2010. The BGS was convened to address the applications and capabilities of modern mapping technology and geospatial analyses to geomorphic science. The scientific basis for generating and understanding modern *digital geomorphic mapping* (DGM) was examined. For the sake of the symposium, the concept of DGM was interpreted broadly to extend well beyond static two- and three-dimensional digital representations. DGM is used here to include three-dimensionally distributed geo-referenced databases, the capabilities of dynamic visualization and virtual reality, remote sensing technologies and applications, geomorphometry and digital terrain modeling, landscape evolution models and other geospatial modeling systems, information-extraction technologies, and a variety of other modern subfields.

No previous BGS has specifically addressed the topic of geomorphic mapping and modern geospatial techniques. Nor, to our knowledge, has any other dedicated geomorphic conference. The time seemed right, therefore, for an integration and synthesis in this field. The need for standardized DGM data structures, tools, analytical protocols, visualization symbology, and reporting errors is growing rapidly as data and analytical systems proliferate. Digital systems that provide data and tools for geomorphic analysis and visualization, which may be referred to as *geomorphic decision support systems* (GDSS), are becoming more common. Even more common are broad-based decision-support systems (DSS) and spatial data clearinghouses that provide geomorphic data and analytical software along with other applications. These resources may provide spatial data and toolboxes that can be accessed remotely and used by a wide range of clients varying in technical or geomorphic training and proficiency. Thus, a coming together of scholars, scientists, and technicians, who routinely develop, provide, and use these data and products, is timely for the purpose of discussing standard procedures and formats and modern capabilities and limitations of these rapidly changing technologies.

2. Papers in this volume

The papers in this volume begin with a broad introduction by Bishop et al. that is followed by the convocation by Alan Howard that opened the Symposium and highlights the use of landscape evolution. Those papers are followed by a series of papers on methods of remote sensing including hyperspectral imaging, LiDAR (Light Detection and Ranging), microwave remote sensing, shallow geophysics, and river mapping. The next section is a series of papers that outline key areas of geographic information science including digital terrain modeling, geomorphometry, spatial and temporal analysis, concepts of scale, applications to snow modeling, and visualization. Finally, a list of posters presented at the Symposium is provided as Appendix A.

2.1. Introduction

Michael Bishop et al., in a paper titled *Geospatial Technologies and Digital Geomorphological Mapping*: *Concepts*, *Issues and Research*, provide a broad overview of a variety of developments, issues, and needs in several geospatial fields related to geomorphology. Advances in remote sensing, geographic information technology, and numerical modeling of surface processes have revolutionized geomorphic analyses (Bishop and Shroder, 2004). New data and methods permit Earth scientists to go beyond traditional mapping to diagnostic assessments and modeling of the surface to achieve an improved understanding of scale, patterns, and processes of features and systems. Early small-scale physiologic maps were highly influential because of their unique visualizations, but are theoretically obsolete. Thus, a resurgence of regional scale mapping is anticipated in the post-tectonic era using modern DGM methods that are reviewed at length. The authors point to the need for standardization of DGM data, methods, and formats, as well as the need to develop and apply theories of GIScience to DGM.

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The Symposium opened with a presentation by Alan Howard, who has long been a pioneer in landscape evolution, simulation modeling, titled *Taking the Measure of a Landscape*: *Comparing Simulated and Natural Landscapes in the Virginia Coastal Plain*, *USA*. Howard simulates the evolution of the Potomac River in Virginia over 3.5 Ma. Difficulties of applying landform evolution modeling (LEM) to a specific landscape are acknowledged, especially in vegetated low-relief regions where base-level changes are involved. The solution here is to generalize hillslope processes, focus on the fluvial system, and incorporate sea level rise and fall over millennial time scales juxtaposed on long-term epeirogenic uplift. The timing of sea level changes is inferred from the oxygen isotope record. The Mars Simulation model (Marssim) is utilized with rock weathering, mass wasting, fluvial detachments, and fluvial transport and deposition components for which the governing functions are briefly outlined. A large number of geomorphometric parameters were measured to compare natural and simulated landscapes for model calibrations and evaluations of results.

2.2. Remote sensing

Fred Kruse, *Mapping Surface Mineralogy Using Imaging Spectrometry*, describes the status of hyperspectral imaging (HSI) and how it can be used for mapping surface mineralogy. Historically, landform identification has been performed dominantly through the use of topographic data; e.g., DEMs, yet the underlying processes are controlled, in part, by structures and geologic materials. Hyperspectral remote sensing (spectrometry) can and should play a more important role in geomorphic mapping. Key spectral signatures of iron, clay, silicate, carbonate, sulfate, and other minerals, can be accurately identified while precisely recording their geographic locations. These capabilities of spectrometry are ideal for the purposes of geomorphic mapping and can be combined with InSAR, LiDAR, or DEM data to enhance interpretability and accuracy of geomorphic and geologic maps. Case histories are presented using HSI with DEMs as visualization tools to improve structural maps, identify sediment sources, and distinguish between relict and active hydrothermal systems.

Remke Van Dam, *Landform Characterization Using Geophysics — Recent Advances*, *Applications*, *and Emerging Tools*, outlines the modern capabilities of shallow geophysical sensors for terrestrial subsurface mapping. Modern developments, strengths, and weaknesses are described for ground penetrating radar (GPR), electrical resistivity (ER), seismicity, and electromagnetic (EM) induction. New developments include multi-offset systems in GPR, multi-electrode systems and time lapse monitoring in ER, and the use of plane-wave EM induction for landform studies. Passive sensing and the use of multiple methods are also discussed. Three case studies illustrate potential uses of some methods: patterned ground in Michigan, glaciotectonic deformation in Michigan, and aeolian dune structures in New Zealand.

The paper by Patrice Carbonneau et al. – read by Mark Fonstad – is entitled *Making Riverscapes Real*. It describes the 'riverscape' approach to modeling the structure and function of rivers, as opposed to qualitative models or quantitative discontinuous approaches such as downstream hydraulic geometry. This paper examines the riverscape approach using 3-cm color aerial photographs with 5-m DEMs for the River Tromie, Scotland. A suite of high resolution remote sensing tools, referred to as the *Fluvial Information System*, is used to extract channel morphological variables including width, depth, particle size, and elevation from which geomorphic and hydraulic variables are drawn such as flow velocity, stream power, Froude number, and shear stress. This high-resolution, spatially distributed approach to river science, which has roots in landscape ecology, demonstrates highly heterogeneous river conditions in the downstream direction. Surprisingly, this finding contradicts prevailing geomorphic theories derived from downstream hydraulic geometry and ecologic theories derived from the concept of the river continuum.

Dorothy Hall et al., *Relationship between Satellite-Derived Snow Cover and Snowmelt Runoff Timing and Stream Power in the Wind River Range*, *Wyoming*, present a paper analyzing 10 years of snow cover in the Wind River Mountains of Wyoming, USA. They compare the extent of snow cover derived from Moderate Resolution Imaging Spectroradiometer (MODIS) data with streamflow and conclude that MODIS-derived snow-cover data can be used to predict streamflow. Spearman rank correlation analysis of the extent of snow-cover explained 89% of the variance in maximum monthly river discharge downstream. They computed stream power for upper Bull Lake Creek proportional to the product of discharge and slope, which was determined from a 300-m DEM derived from Shuttle Radar Topography Mission (SRTM) 30-m data. They found a significant decline in maximum monthly stream power over the 40-year period of available discharge data.

2.3. Geographic information science

The next session began with a paper by Ian Evans entitled *Geomorphometry and landform mapping*: *what is a landform*? This paper outlines several of the challenges before us in the field of geomorphometry, including operational definitions of landforms, treatment of fuzzy boundaries, scale dependencies, and classification. By addressing the question, 'What is a landform?', and noting a difference between landforms and land-surface forms, Evans makes the distinction between *general geomorphometry* concerned with entire landscapes vs. *specific geomorphometry* constrained to a particular landform (Evans, 1972). Although general geomorphometry has dominated the field, as data resolutions improve and analyses focus on increasingly narrow classes of landscapes, general and specific geomorphometry are converging. The paper begins with specific geomorphometry; i.e., difficulties mapping specific landforms such as the need for an accurate ontology of landforms, delimitation of closed polygons, and the presence of fuzzy boundaries. The paper then moves to general geomorphometry.

John Wilson, *Digital Terrain Modeling*, describes the historical evolution of methods and data sources for DEMs. Three general classes of DEM data are identified: (1) ground survey techniques, (2) interpolations from existing topographic maps, and (3) remote sensing; initially using passive sensors but now increasingly using active sensors. Wilson describes the present state-of-the-art for data capture, preprocessing, DEM generation, and calculation of primary and secondary land-surface metrics. The paper includes discussions of the influence of DEM grid-cell spacing on accuracies, filling sinks for mapping drainage networks, use of the ANUDEM model, incorporation of auxiliary information with DEMs, and how LiDAR and RADAR are changing the methods of DEM generation. Much of the paper is concerned with the computation of parameters from DEMs. Finally, the paper addresses the types of errors common to DEMs and how they may be propagated through subsequent analyses and data products.

The paper by Helena Mitasova et al., *Scientific Visualization of Landscapes and Landforms*, opened many virtual doors to how spatial analyses can be presented. The paper begins with a discussion of how the potential for visualization has been expanded and changed by new data resolutions and technological capabilities. The discussion covers visualization techniques ranging from relief shading on static two-dimensional maps to multi-dimensional renditions, time cubes, web-based applications (e.g., Google Earth©), animations, and 3D immersion in interactive virtual environments. Examples are presented using multiple-return LiDAR data to go beyond bare-Earth representations and include vegetation canopies, anthropogenic structures, and modeling of short-term changes in terrain. The paper employs open-source software Geographic Resources Analysis Support System (GRASS) and the *Tangible Geospatial Modeling System* (TanGeoMS) that couples a 3D laser scanner, projector, and a malleable 3D physical model for modeling and geodesign. Case studies are presented of mapping recent debris avalanches in a mountainous area of North Carolina, and dune evolution on a barrier island of North Carolina which involved a space-time voxel modeling approach and use of TanGeoMS.

Thomas Allen et al., *Mapping Coastal Morphodynamics with Geospatial Techniques*, *Cape Henry*, *Virginia*, *U.S.A.*, integrate airborne topographic LiDAR data with digital bathymetry, large-scale vector shoreline data, and spot elevations from photogrammetry to examine coastal morphodynamics on a cuspate foreland in Virginia. Sequential, relict beach ridge and swale topography was mapped and slope and toe depths of modern shore-faces were reconstructed in three dimensions using isobars from bathymetric charts and topographic data to examine the morphology of paleosurfaces; i.e., the morphological patterns, spacing, and derived rates of progradation. Fusing airborne LiDAR data, processed to diminish the impact of vegetation, improved the accuracy and precision of mapping contemporary and paleosurface landforms in this study of coastal evolution and morphodynamics.

Jonathan Phillips presented the keynote presentation at the banquet, *Synchronization and Scale in Geomorphic Systems*. This paper examines methods for testing the importance of 'scale' in geomorphic systems; i.e., the effects of system linkages to coupling and synchronization. Concepts of network and graph theory in geomorphology describe the nature of linkages between geomorphic subsystems and their synchronization at various scales. It begins with a description of small-world networks that efficiently link many components with a limited number of connectors, and, in particular, connected caveman small-world networks (CCSWN) that rely on a single link for at least one of the connections. Three examples are provided: for fluvial systems, for weathering systems, and interactions between fluviokarst systems. These methods allow comparisons of the interactions between subsystems in complex geomorphic systems across scales.

Larry Band et al., *Ecosystem Processes at the Watershed Scale*: *Coupled Ecohydrological and Geomorphological Modeling and Mapping*, extend ecohydrological modeling to include the impacts on geomorphic processes by emphasizing the spatial and temporal patterns of coupled water and carbon cycling in a steep forested ecosystem, and the interaction of forest structure with slope stability on mass movements. Working in the Coweta Basin of Western North Carolina, coupled geomorphic and ecohydrological modeling is used to predict landscapes and to produce long-term assessments of hazards. Remotely-sensed data and GIS analyses are integrated within the Regional HydroEcological Simulation System (RHESSys) model, to link a coupled ecohydrological model that simulates transient water, carbon, and nutrient cycling in a watershed, and mass wasting slope stability analysis. The study demonstrates the potential for real-time updating of the spatial distribution of ecosystem goods and services and assessments of hazards, as well as retrospective and future scenarios of change on watershed dynamics.

Peter Koons et al. presented an important paper on *The Influence of Mechanical Properties on the Link Between Tectonic and Topographic Evolution*. They used mechanical modeling of local stress fields and far-field plate velocities to examine the heterogeneity of material fabric in orogens. The sensitivity of hillslope and fluvial erosion were found to be coupled with large and oriented material strength variations, such that topographic evolution is dominated by tectonically driven rheological response at multiple scales. Their analysis of the anisotropic nature of topography, based upon semivariogram analysis, revealed spatial relationships between topographic characteristics and material strength and deformation. Consequently, they concluded that heterogeneity and anisotropy of material strength in terms of tectonic evolution can significantly contribute to improving Earth-surface process models of erosion, and that detailed geomorphometric analysis of the anisotropic nature of topography is required to produce better erosion potential maps.

Allan James et al., *Geomorphic Change Detection Using Historic Maps and DEM Differencing*: *The Temporal Dimension of Geospatial Analysis*, examine the potential for extending the time dimension of digital change detection to broader historical time scales. They note that historical geomorphic research is needed for large scale studies such as global change and review time analyses in GIScience. Temporal resolutions of historical spatial data can be improved by including geomorphic events in time-cubes and including them when interpolating changes between discrete time horizons. Large errors may be involved when historical cartography or aerial photographs are employed in historical reconstructions and geomorphic change detection (GCD), so an error analysis is essential to such studies. Conceptually, a signal-to-noise ratio – expressed as the ratio of geomorphic change to uncertainty – should be maximized. Thus, such methods are best where geomorphic change has been great and historical data are of high quality. An error budget analysis may be employed to quantify the uncertainties. Three examples of constructing and interpreting DEMs of difference (DoDs) are presented to illustrate the difficulties and utility of GCD over extended periods.

Acknowledgments

We are deeply indebted to Jack Vitek, editor of this special issue, who reads every paper in this issue and provided detailed editorial comments in this issue. Dick Marston provided wise and consoling guidance during times of apparent duress. Will Graf presented the welcome to USC at the opening session. Alan Howard provided a journey into deep time with a convocation presentation in the opening session. Jonathan Phillips provided a thought evoking keynote presentation at the banquet on applications of graph theory. All of the authors are to be thanked for their tireless efforts. Reviewers of the articles in this volume, the true yeomen of any such endeavor, cannot be thanked enough. John Kupfer and Kimberly Meitzen led a field trip to Congaree National Park that involved paddling Cedar Creek (apparently no one was lost to alligators this time).

We are also thankful for the diligent work of Kate Shelton, Jim Twitty, and their support staff at the *USC Continuing Education and Conferences* for registration, logistical support, and organization of the Symposium. Debbie Little was indispensible for her management of the budget for student awards and author travel compensations. Refreshments, airport shuttle vans, posterboards, and numerous other details that allowed the meeting to proceed smoothly were made possible by the valiant efforts of many students of geography courses, and the local arrangements committee consisting of Patrick Barrineau, Subhajit Ghoshal, Kirsten Hunt, Josh Leisen, and Kevin MacLeod. Finally, we are deeply grateful to the *Geography and Spatial Sciences* and *Geomorphology and Land Use Dynamics* programs of NSF for providing funding, which allowed us to keep costs of the meeting at a reasonable level and to provide student travel awards and cash prizes for a student poster competition.

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Appendix A. Posters for Binghamton symposium

Ben Allen,[1] Towson University. The effects of mill dams on suspended sediment yield, Northern Baltimore County, Maryland.

Jane Atha, Texas State Univ., San Marcos. Fluvial wood presence and dynamics over a thirty year interval in forested watersheds.

[1] Second place in student poster competition.

Will Butler, Kansas State Univ. Repeat photography documents short-term landscape changes in geothermal features in Yellowstone National Park, Wyoming.

Christopher L. Coffey, Jeffrey D. Colby, Appalachian State Univ. Optimal drainage pattern delineation and evaluation of the Terrain Data Model.

Christopher Crosby, Viswanath Nandigam, Sriram Krishnan, Chaitan Baru, J. Ramon Arrowsmith, Univ. Calif., San Diego and Arizona State Univ. (Arrowsmith). The OpenTopography Facility: Providing online access to high-resolution LiDAR topography data for geomorphology research.

James T. Dietrich. Texas State Univ., San Marcos. Visualizing small-scale geomorphic features using 3D models derived from Microsoft Photosynth.

Margherita Di Leo; Salvatore Manfreda, Universita' degli Studi della Basilicata, Potenza, Italy. Correlation of hydrological response and local and global slope.

Elizabeth Ervin; Veronica Moore, Florence County & Northwest Missouri State Univ. Working with LiDAR data in Florence County, South Carolina.

Anthony M. Filippi, Inci Güneralp, Joonghyeok Heo, Texas A&M Univ. Algorithmic and data comparisons for river flow-boundary extraction from remote-sensor images.

Subhajit Ghoshal; L. Allan James, Univ. South Carolina. Floodplain and channel change analysis using DEM differencing: Lower Yuba River, California.

Eric Hardin, Paul Paris, Helena Mitasova, Margery Overton, N.Carolina State Univ. Geospatial relationship between the shoreface topography and decadal core-envelope surfaces on a North Carolina's barrier island.

Kirsten Hunt[2]; Michael Hodgson, Univ. South Carolina. Lidar-based morphometry of small gullies under forest canopy in the Southeastern Piedmont.

Daehyun Kim; Yanbing Zheng, Univ. Kentucky. Scale-dependent predictability of landform attributes for soil spatial variability: A spatial regression approach.

Alexandra Lefort, Devon M. Burr, Ross A. Beyer, Alan D. Howard, Univ. Tenn.; Sagan Ctr at SETI Inst; NASA Ames Research Ctr; Univ. Virginia. Mapping and analysis of post-formation modification of sinuous ridges in the Aeolis–Zephyria Planum Region, Mars.

Yingkui Li, Univ. Tenn. Mapping lake level fluctuations from 1972 to 2010 of the Selin Co (Lake), Central Tibet, using Landsat MSS/TM/ETM^{+} images.

Wei Luo, Bartosz Grudzinski, Darryll Pederson, N. Illinois Univ., Kansas St.U. & U. Nebraska, Lincoln. Estimating hydraulic conductivity for the Martian subsurface based on drainage patterns — A case study in the Mare Tyrrhenum Quadrangle.

Nathan Lyons, Helena Mitasova, Ilona Peszlen, Karl Wegmann, N. Carolina State Univ. Geospatial determination of potential hillslope response to an invasive species in the Southern Appalachians.

Marsellos, A.E., Tsakiri, K.G., Univ. Florida. Geospatial statistical analysis using LiDAR intensity and elevation data.

B.A. Miller, C.L. Burras, W.G. Crumpton, Michigan State Univ. (Miller) & Iowa State Univ. Using soil surveys to map Quaternary parent materials and landforms across the Des Moines Lobe of Iowa and Minnesota.

Tomasz Stepinski; Wei Luo, Univ. Cincinnati & N. Illinois Univ. Extracting streams from DEM using simplified terrain openness.

Heather X. Volker, Univ. Memphis. Landslide processes, measures, and predication in Ventura County, California.

Katherine Weaver,[3] Margherita Di Leo, Helena Mitasova, Laura Tateosian, N. Carolina State Univ. Exploring topographic change impacts with a Tangible Geospatial Modeling System.

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[2] Third place in student poster competition.

[3] First place in student poster competition.