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Editorial

Understanding earth surface processes from remotely sensed digital terrain models

1. Introduction

Understanding earth surface processes relies on modern digital terrain representations and depends strongly on the quality of the topographic data. In the last decade, a range of new remote sensing techniques has led to a dramatic increase in terrain information. Both Terrestrial Laser Scanner (TLS) and Airborne Laser Swath Mapping technology (ALSM), using LiDAR (Light Detection And Ranging) technology, now provide high resolution topographic data with notable advantages over traditional survey techniques. A valuable characteristic of these technologies is their capability to produce sub-meter resolution Digital Terrain Models (DTMs), and high-quality land cover information (Digital Surface Models, DSMs) over large areas.

New topographic data have opened avenues for hydrologic and geomorphologic studies including analysis of surface morphology (Staley et al., 2006; Frankel and Dolan, 2007), landsliding (McKean and Roering, 2004; Glenn et al., 2006; Tarolli and Tarboton, 2006; Van Den Eeckhaut et al., 2007), channel network structure (James et al., 2007; Lashermes et al., 2007), river morphology (Charlton et al., 2003; Thoma et al., 2005; Mason et al., 2006; Jones et al., 2007; Heritage and Hetherington, 2007; Milan et al., 2007; Cavalli et al., 2008; Vianello et al., 2009; Notebaert et al., 2009), river bathymetry (Hilldale and Raff, 2008), tectonics (Hilley and Arrowsmith, 2008; Kondo et al., 2008), numerical flood models (Cobby et al., 2001; Casas et al., 2006; McMillan and Brasington, 2007; Mason et al., 2007), and the links between terrain and ecological patterns (McKean et al., 2008; Gutiérrez-Jurado et al., 2007), among others.

In addition to these high resolution technologies, the Shuttle Radar Topographic Mission (SRTM) and the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) topographic products have allowed detailed analyses in large regions where the level of previous terrain data was either coarse or of poor quality.

SRTM collected topographic data over nearly 80% of Earth's land surface, creating the first-ever near-global data set of land elevations to generate the most complete high resolution digital topographic database of Earth (90 m DEM) (Rabus et al., 2003; Farr et al., 2007). Applications of SRTM terrain products range from analysis of earth surface features (Bubenzer and Bolten, 2008; Eshani and Quiel, 2008; Rennó et al., 2008) to modelling applications (Falorni et al., 2005; Vivoni et al., 2005; Verstraeten, 2006). The work of Hancock et al. (2006), for example, demonstrated that for broad-scale qualitative assessment of large catchments, the SRTM data are of significant benefit. However, they indicated the inability of coarse resolution of SRTM data to correctly capture catchment area and critical stream junctions.

ASTER, on board the NASA's TERRA satellite, provides an opportunity to obtain high resolution (though less than TLS or LiDAR) terrain data from photogrammetric processing of stereo Visible Near Infrared (VNIR) sensor data. With this technology, it is possible to generate DEMs in heterogeneous terrain conditions, anywhere with coverage and with a spatial resolution of 30 m (Hirano et al., 2003; Fujisada et al., 2005). ASTER data have been established as useful for geological studies (Abrams, 2000), earth surface feature analysis (Bubenzer and Bolten, 2008), landsliding (Fourniadis et al., 2007) and volcano hazard mapping (Hubbard et al., 2007), among others.

2. Background and objectives of special issue

This special issue brings together studies on the innovative use of remotely sensed DTMs for Earth science applications for obtaining new understanding of earth surface processes. The idea for this issue arose from a session on “Remotely sensed DTM for Hydrogeomorphic Applications” convened the proponents as well as William E. Dietrich and Salvatore Grimaldi, during the 2007 Annual Fall Meeting of the American Geophysical Union, held in San Francisco, California. The three oral and one poster sessions attracted 41 abstracts from North America, Europe and Asia, providing an opportunity to review methods, discuss challenges, and evaluate recent technological advances in the use of remotely sensed topographic data for Earth surface processes. Some of the posters and presentations discussed during the meeting sessions were developed into the papers appearing in this special issue. Our goal is to share advances in landscape analysis that are significantly improved by the use of different remotely sensed data sets. We decided to consider a range of remotely sensed technologies in order to offer the scientific community different options and perspectives from recent work. The sequence of contributions is arranged according to the spatial characteristics of the techniques and methods concerned: from very high resolution data collected by TLS, to a progressively coarser resolution data from LiDAR, STRM, and ASTER remotely sensed technology.

The following provides a brief introduction to each contribution.

2.1. TLS applications

Milan and Heritage used TLS data for grain roughness height recognition of an exposed bar and river bed surface. The novelty of this study is the application of TLS to determine the full population of grain roughness in gravel-bed rivers. Grain roughness was extracted through determination of twice the local standard deviation of all the elevations in a 0.15 m radius moving window over the data cloud. The values were then designated to each node on a 5 cm grid, allowing grain roughness DTMs to be produced. Comparisons are made between TLS-derived grain roughness and grid-by-number sampling suggesting the technique could replace conventional grid-by-number sampling methods, which are subject to errors related to low sample size and sampler bias. The investigation also demonstrates that conventional grid-by-

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number sampling techniques are inaccurate between 3.0 and 8.9% in 50% of simulated sample cases with maximum errors exceeding 70%.

Guarnieri et al. used high resolution TLS for analysis of small-relief marsh morphology. The novelty of this work is the use of a new filtering scheme to TLS data that selects the lowest values within moving windows, whose optimal size is determined with the aid of a limited number of ancillary Differential GPS data. This approach allows the separation of laser returns coming from the low marsh vegetation from those coming from the marsh surface itself. The overall result is a new observation technique producing DTMs and DSMs in areas with very low relief, which is shown to provide unprecedented high resolution and high-accuracy characterizations of marsh morphology.

2.2. Airborne LiDAR applications

Aggett and Wilson explored the assimilation of a high resolution topographic surface from LiDAR data into a one-dimensional hydraulic model to study the avulsion hazard potential of a gravel-bed river. The major advance of this work is the use of high resolution topographic data to develop rapid scenario-based spatial assessments of fluvial processes and hazards under different flow conditions using a 1-D hydraulic model. The high resolution DTM facilitates overlay and evaluation of modeled scenario results in a spatially explicit context containing considerable detail of hydrogeomorphic and other features influencing hydraulics (bars, secondary and scour channels, levees). This offers advantages for: (i) assessing the avulsion hazard potential and spatial distribution of other hydrologic and fluvial geomorphic processes; and (ii) exploration of the potential impacts of specific management strategies on the channel.

The work of Anders et al. discussed how channel incision in Alpine landscapes can be modeled over time by using high resolution LiDAR data. A new approach was used to simulate drainage basin evolution in which channel incision is incorporated in high spatial detail. The research demonstrated a computationally-efficient simulation through combination of a vector-based channel incision model and a grid cell-based hillslope erosion model. High resolution elevation data were useful in extracting landscape information to analyse geomorphological activity and in making reconstructions of the former topography of deglaciated catchments. The combined vector/grid-cell model and high resolution data open up new modelling opportunities to simulate geomorphological dynamics in greater detail.

Finding the optimal scale of representation of dominant landforms is the main goal of the work of Tarolli and Dalla Fontana. They addressed the effectiveness of high resolution LiDAR DTMs to capture the detail of the hillslope-to-valley transition morphology, and recognize the hollow morphology and the related channel heads. Novelty of this work is the use of threshold ranges identified as *n*-times the standard deviation of curvature as an objective method for recognition of hollow morphology, and channel network extraction. The results of this work indicated that: 1) high resolution DTMs are required to interpret the hillslope-to-valley transition based on the slope–area relationship, 2) finer DTMs permitted the recognition of the topographic signature of valley incision by debris flows from the slope–area diagram, and 3) curvature computed from a high resolution DTM facilitated the discrimination of convergent hollow morphology around the surveyed channel heads.

Kasai et al. discussed how it is possible to utilize LiDAR-derived DTM for the evaluation of deep-seated landslides in a steep and erodible area. The surface texture was investigated by using the eigenvalue ratio and slope filters calculated from a high resolution LiDAR DTM. This study suggests that DTM analysis with appropriate filters can remotely provide information about possible “hot spots” of deep-seated landslide activity, and can help land managers wanting to reduce landslide risk and potential disasters. LiDAR data analysis also contributes to widening our knowledge of on-going geomorphic processes associated with deep-seated landslides as well as other erosion types, and furthers our understanding of the geomorphic system.

Arrowsmith and Zielke analyzed a strip of ALSM data along the south-central San Andreas Fault in California to characterize the tectonic geomorphology of this rapidly slipping (~35 mm/yr) fault zone in a semi-arid environment. The landforms clearly show both the most recent slip zones associated with the last several earthquakes as well as the broader belt of deformation active over the last few to tens of kyr. They also make methodological contributions with respect to optimal DTM processing with local binning approaches and comparisons of different fault and landform mapping strategies showing that the ALSM DTM-based mapping provides useful and complementary information as aerial photographic and field-based approaches.

2.3. Airborne LiDAR vs. SRTM application

The work of Wechsler et al. contributed an intriguing prototype analysis of asymmetry of rock damage based on hypothesized covariation in surficial processes manifest in geomorphic signals along the central San-Jacinto Fault of southern California. The open source TauDEM software package (http://www.engineering.usu.edu/dtarb/taudem) was used to compare several morphometric parameters, including Drainage density (Dd), on both sides of the fault, using LiDAR and SRTM data. The LiDAR data proved more useful for observations at the scales of the fault process zone than the lower-resolution SRTM data. The high resolution LiDAR data permitted focus on a single fault trace, eliminating the effects of parallel nearby faults. There is a correlation between drainage density and proximity to the fault, with zones of structural complexity along the fault displaying the highest Dd. The northeast side of the fault is apparently more damaged at the scale of the observed data, in agreement with other studies.

2.4. ASTER applications

Kawabata and Bandibas focused on the use of an Artificial Neural Network (ANN) to quantitatively model the relations between landslide occurrence and geologic/geomorphic factors, and to generate landslide susceptibility maps. The novelty of this work is the development of a method of data integration, processing and generation of landslide susceptibility map using ANN. The results show that an efficient landslide mapping system could be developed using ASTER images as the main source of geomorphic factors. Results also indicate that determining the accuracy of the trained ANN in the study area is difficult because areas where no landsliding occurred could actually be unstable, thus, have high probability of future landslide occurrence.

The work of Santini et al. investigates the role of pre-processing methods for remotely sensed DEMs on landslide triggering modeling. An important contribution is the parameter estimation procedure discussed for the PEM4PIT (Physically-based approach for PIT filling and/or flat areas treatment) DEM correction method. The research investigated the influence of different terrain analysis procedures on results of the slope stability model SHALSTAB (SHAllow Landsliding STABility) (Montgomery and Dietrich, 1994) using remotely sensed ASTER DEMs, and assessed which procedures are more appropriate for describing terrain instability. The choice of DEM processing method is not trivial and influences the shallow landslide hazard mapping at a regional scale.

3. Concluding remarks

We would like to thank the authors of the papers for accepting the burden and meeting the standards that production of this issue has thrust upon them; numerous referees for their careful comments on individual manuscripts; Takashi Oguchi (Editor in Chief of the Journal) for helpful suggestions and advices during special issue proposal evaluation; and Adrian Harvey (Editor of Special Issues) for his advice during the review process.

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Paolo Tarolli
Department of Land and Agroforest Environments, University of Padova, Agripolis, viale dell'Università 16, 35020 Legnaro (PD), Italy
Corresponding author. Tel.: +39 049 8272695; fax: +39 049 8272686.
E-mail address: paolo.tarolli@unipd.it (P. Tarolli).

J Ramon Arrowsmith
School of Earth and Space Exploration, Arizona State University, Tempe, AZ, 85287-1404, USA

Enrique R. Vivoni
School of Earth and Space Exploration
School of Sustainable Engineering and the Built Environment, Arizona State University, Tempe, AZ, USA

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