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Stochastic Downscaling of Digital Elevation Models

Luiz Gustavo Rasera, Gregoire Mariethoz, and Stuart N. Lane
Institute of Earth Surface Dynamics, University of Lausanne, 1015 Lausanne, Switzerland (luizgustavo.rasera@unil.ch)

High-resolution digital elevation models (HR-DEMs) are extremely important for the understanding of small-scale geomorphic processes in Alpine environments. In the last decade, remote sensing techniques have experienced a major technological evolution, enabling fast and precise acquisition of HR-DEMs. However, sensors designed to measure elevation data still feature different spatial resolution and coverage capabilities. Terrestrial altimetry allows the acquisition of HR-DEMs with centimeter to millimeter-level precision, but only within small spatial extents and often with dead ground problems. Conversely, satellite radiometric sensors are able to gather elevation measurements over large areas but with limited spatial resolution. In the present study, we propose an algorithm to downscale low-resolution satellite-based DEMs using topographic patterns extracted from HR-DEMs derived for example from ground-based and airborne altimetry. The method consists of a multiple-point geostatistical simulation technique able to generate high-resolution elevation data from low-resolution digital elevation models (LR-DEMs). Initially, two collocated DEMs with different spatial resolutions serve as an input to construct a database of topographic patterns, which is also used to infer the statistical relationships between the two scales. High-resolution elevation patterns are then retrieved from the database to downscale a LR-DEM through a stochastic simulation process. The output of the simulations are multiple equally probable DEMs with higher spatial resolution that also depict the large-scale geomorphic structures present in the original LR-DEM. As these multiple models reflect the uncertainty related to the downscaling, they can be employed to quantify the uncertainty of phenomena that are dependent on fine topography, such as catchment hydrological processes. The proposed methodology is illustrated for a case study in the Swiss Alps. A swissALTI3D HR-DEM (with 5 m resolution) and a SRTM-derived LR-DEM from the Western Alps are used to downscale a SRTM-based LR-DEM from the eastern part of the Alps. The results show that the method is capable of generating multiple high-resolution synthetic DEMs that reproduce the spatial structure and statistics of the original DEM.