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GeoNet: An open source software for the automatic and objective extraction of channel heads, channel network, and channel morphology from high resolution topography data

Harish Sangireddy [a], Colin P. Stark [b], Anna Kladzyk [a], Paola Passalacqua [a, *]

[a] Department of Civil, Architectural and Environmental Engineering, Center for Research in Water Resources, The University of Texas at Austin, Austin, TX, USA
[b] Lamont-Doherty Earth Observatory, Columbia University, Palisades, New York, USA

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ABSTRACT

Extracting hydrologic and geomorphic features from high resolution topography data is a challenging and computationally demanding task. We illustrate the new capabilities and features of GeoNet, an open source software for the extraction of channel heads, channel networks, and channel morphology from high resolution topography data. The method has been further developed and includes a median filtering operation to remove roads in engineered landscapes and the calculation of hillslope lengths to inform the channel head identification procedure. The software is now available in both MATLAB and Python, allowing it to handle datasets larger than the ones previously analyzed. We present the workflow of GeoNet using three different test cases; natural high relief, engineered low relief, and urban landscapes. We analyze default and user-defined parameters, provide guidance on setting parameter values, and discuss the parameter effect on the extraction results. Metrics on computational time versus dataset size are also presented. We show the ability of GeoNet to objectively and accurately extract channel features in terrains of various characteristics.

Software

Name GeoNet
Developer GeoNet team
Contact https://sites.google.com/site/geonethome/
Software required The MATLAB version of GeoNet requires: Image Processing Toolbox, Mapping Toolbox, and Statistics Toolbox. A version of GeoNet combined with gdal libraries is available for use without the Mapping Toolbox. The Python version of GeoNet requires: GRASS GIS, Python libraries NumPy, scikit-fmm, and SciPy.
Availability https://sites.google.com/site/geonethome/source-code, http://opentopo.sdsc.edu/tools/listTools

1. Introduction

Channels are an integral part of the Earth system topography and morphology as they transport water, solids, and solutes from upstream regions to the coast, support habitat for various species, and are critical sources of fresh water. The identification of these transport pathways is essential, for example, for understanding the hydrologic cycle, land surface-atmosphere interactions, and the Earth surface response to environmental change.

Several methods have been proposed to extract channel networks from digital elevation models (DEMs) (e.g., Montgomery and Dietrich, 1988; Tarboton et al., 1988; Montgomery and Foufoula-Georgiou, 1993; Costacabral and Burges, 1994; Giannoni et al., 2005; Hancock and Evans, 2006). Commonly, these methods follow a work-flow consisting of: (a) DEM pit filling, (b) flow direction assignment (either using the D8 or Dinfinity method (Tarboton, 1997)), (c) computation of flow accumulation, (d) identification of catchment boundaries, and of (e) catchment outlets, and (f) extraction of channels based on a flow accumulation threshold or a combination of area, slope, and/or terrain curvature (e.g., Tarboton and Ames, 2001; Lacroix et al., 2002; Orlandini et al., 2003; Tesfa et al., 2011; Sofia et al., 2011; Yang et al., 2014; Cazorzi et al., 2013; Sofia et al., 2014a,b; Bhowmik et al., 2015). This work-flow

* Corresponding author.
E-mail address: paola@austin.utexas.edu (P. Passalacqua).

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is common to methods that use a raster dataset as input and differs from work-flows used to analyze triangulated irregular networks (e.g., Jones et al., 1990; Nelson et al., 1994; Vivoni et al., 2004; Zhou et al., 2011) and extract networks from contour elevation data (e.g., Moretti and Orlandini, 2008).

The explosive growth of high resolution data acquisition systems (e.g., airborne, terrestrial, mobile laser scanning systems) and data dissemination applications and related services (e.g., National Elevation Dataset http://viewer.nationalmap.gov/viewer/ and OpenTopography http://www.opentopography.org/) are generating petabytes of data. The vast spatial extents and fine spatial resolutions allow us to map landscape features (e.g., rivers, floodplains, landslide scars) and improve the understanding of the underlying geomorphic processes at scales over which such processes act, transforming the way we analyze landscapes (Tarolli and Dalla Fontana, 2009; Glennie et al., 2013; Passalacqua et al., 2014, 2015; Tarolli, 2014; Harpold et al., 2015).

Improved data, though, require improved analysis methods. When applied to high resolution topography data, in fact, the classic channel network extraction work-flow described above has some shortcomings, e.g., the pit filling operation, which alters the original input DEM and can remove important land surface information and the definition of a flow accumulation threshold, which is based on the assumption that all channels begin at the same flow accumulation value, which is usually not valid (McNamara et al., 2006). Recently developed methods for the extraction of channel heads and channel networks from high resolution topography data (e.g., Lashermes et al., 2007; Passalacqua et al., 2010a; Orlandini et al., 2011; Tesfa et al., 2011; Pelletier, 2013) are able to map channel networks at the correct drainage density by avoiding the strict use of a flow accumulation threshold.

One of these methods is GeoNet (Passalacqua et al., 2010a), an open source, automatic method for channel head, channel network, and channel morphology extraction from high resolution topography data. The method combines nonlinear filtering of elevation data, to smooth small scale variability and enhance features of interest, a statistical analysis of curvature, to identify the set of likely channelized pixels, and geodesic minimization principles to extract channel heads and channel centerlines. GeoNet has been applied and tested on a steep and natural landscape (Passalacqua et al., 2010a), a heterogeneous mountainous watershed (Passalacqua et al., 2010b), and a flat and engineered landscape (Passalacqua et al., 2012). The method was coded in MATLAB and C, with limitations to the size of input datasets.

In this paper, with the aid of three study sites representing natural (Tennessee Valley, CA), flat and engineered (Le Sueur River, MN), and urban landscapes (Little Walnut Creek, TX) (Section 2), we present the work-flow (Section 3) and the new capabilities of GeoNet (method and software). The most recent version of GeoNet has been improved in filtering natural and road features and in the identification of channel heads (Section 4). The code is available in MATLAB and Python and allows integration of software libraries for data access, algorithm development and integration with GIS software such as ArcGIS, QGIS, and GRASS GIS (Section 5). The work-flow steps are described and tested on the study sites (Section 6) and metrics of computational time versus input dataset size are provided. A discussion of the results and the conclusions of this work are in Section 7.

2. Study sites

2.1. Natural landscape: Tennessee Valley, CA

The Tennessee Valley catchment lies north of San Francisco in Marin County, California (Fig. 1). This catchment has been studied extensively by previous authors; of particular interest for our application is work done on channel initiation and the availability of field surveyed channel heads and channel network (Montgomery and Dietrich, 1988, 1989; Dietrich et al., 1993). The terrain is characterized as mostly soil mantled, with local bedrock outcrops on ridges and on steep slopes. High resolution topography data at 1 *m* resolution are available (http://www.opentopography.org/).

2.2. Flat and engineered landscape: Le Sueur River Basin, MN

The Le Sueur River Basin is located in southern Minnesota (Fig. 2). It has been extensively studied as it is a major source of sediment to the Minnesota River (Gran et al., 2009, 2011; Belmont et al., 2011). Due to the presence of natural channels, artificial drainage ditches, roads, and overall small topographic gradients, the watershed poses several challenges to classic feature extraction algorithms (Passalacqua et al., 2012). High resolution topography data are available (Gran et al., 2009, 2011; Belmont et al., 2011). The data used here are at 3 *m* resolution.

2.3. Urban landscape: Little Walnut Creek, TX

Little Walnut Creek is located in Travis County and is part of an urban suburb of the larger metropolitan area of Austin, Texas (Fig. 3). We chose this area as first application of GeoNet to an urban landscape. With the term ‘urban’ we indicate an engineered landscape that presents multiple features typical of an urban setting including stormwater collection systems such as curbs, gutters, and inlets (region A in Fig. 3), roads (region B in Fig. 3), and bridges (region C in Fig. 3). These engineered features have modified the shape of the landscape and the flow of water, resulting in parallel surface and subsurface flow.

High resolution topography data was made available by the City of Austin as a classified point cloud file in LAS file format. The ESRI LAS Dataset Tools in ArcGIS were used to convert the points classified as ground to a 1 *m* resolution raster grid. The building footprints for this region (Fig. 3) were also obtained from the City of Austin.

3. GeoNet work-flow

The GeoNet method consists of three major components: (i) nonlinear filtering of the elevation data, (ii) identification of likely channelized pixels through the statistical analysis of curvature, and (iii) channel heads and channel network extraction based on geodesic minimization principles. The work-flow of GeoNet (Fig. 4) begins by reading the input bare-earth DEM. The mean slope of the raw input DEM is computed to define whether the terrain is steep (slope $\geq 5°$) or flat (slope $\leq 5°$) (McCullagh, 1978) (this slope value can be modified if desired). If the terrain is steep, the curvature is set to geometric, while in flat terrains the curvature is set to laplacian.

Nonlinear filtering is applied to remove small scale variability. In engineered landscapes the nonlinear filtering operation follows the application of a median filter that removes features such as roads. Slope and curvature are computed on the filtered DEM and the qq-plot of curvature is used to identify the convergent features of the landscape and obtain the set of likely channelized pixels. This set of pixels represents a first estimate of the channel network. Upon computing flow accumulation, the skeleton of likely channelized pixels is refined based on the user-defined skeleton thinning parameter (*Parameters.flowThresholdforSkeleton* in the code) (Passalacqua and Foufoula-Georgiou, 2015).

The cost function is used to compute geodesic distances via the