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Short communication: The Topographic Analysis Kit (TAK) for TopoToolbox

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Abstract. Quantitative analysis of digital topographic data is an increasingly important part of many studies in the geosciences. Initially, performing these analyses was a niche endeavor, requiring detailed domain knowledge and programming skills, but increasingly broad, flexible, open source code bases have been developed to increasingly democratize topographic analysis. However, many of these still require specific computing environments and/or moderate levels of knowledge of both the relevant programming language and the correct way to take these fundamental building blocks and conduct an efficient and effective topographic analysis. To partially address this, we have written the Topographic Analysis Kit (TAK) which leverages the power of one of these open source libraries, TopoToolbox, to build a series of high-level topographic analysis tools to perform a variety of common topographic analyses, including generation of maps of normalized channel steepness or χ and selection and statistical analysis of populations of watersheds. No programming skills or advanced Matlab capability is required for effective use of TAK. In addition, to expand the utility of TAK, along with the primary functions, which like the underlying TopoToolbox functions require Matlab and several proprietary toolboxes to run, we provide compiled versions of these functions that use the free Matlab Runtime Environment for users who do not have institutional access to Matlab or all of the required toolboxes.

1 Introduction

The efficient, quantitative analysis of digital topographic data is a primary underpinning of modern tectonic geomorphology research (e.g., Kirby and Whipple, 2012; Whittaker, 2012). Initially, there were a limited number of community standard algorithms to analyze topographic data, including the widely used 'Stream Profiler', a hybrid set of functions between ArcGIS and Matlab for analyzing normalized channel steepness (k_{sn}) (Wobus et al., 2006). The code landscape has changed significantly in recent years and several relatively complete and distinct sets of analysis tools and libraries now exist for completing an array of complex topographic analyses, e.g. LSD Topo Tools (e.g., Mudd et al., 2014), TopoTools (Perron, 2010), and TopoToolbox (Schwanghart and Kuhn, 2010; Schwanghart and Scherler, 2014), among others. Of these, TopoToolbox is written in Matlab, making it widely accessible as Matlab is common in many academic environments and is a relatively easy language to learn, and includes a variety of functionality. TopoToolbox is also perhaps the most flexible, serving as a broad code base that is populated with a wide array of versatile functions that do much of the heavy lifting of topographic analysis. On the other hand, TopoToolbox contains few 'finished products', i.e. single functions that allow for complex analysis out of the box. This makes TopoToolbox an extremely flexible and powerful community resource, but it also means that using the functions included with TopoToolbox effectively requires 1) an understanding of both the Matlab language and general programming techniques and 2) a thorough understanding of the correct methodology for chaining together multiple building blocks into an analysis tool tailor-made for the application of interest. Most recently, there has been an increasing number of more complex analysis tools built using TopoToolbox, e.g. ChiProfiler for analyzing k_{sn} on streams (Gallen and Wegmann, 2017), KZ-Picker for automatic knickpoint detection (Neely et al., 2017), and DivideTools for analyzing drainage divide stability (Forte and Whipple, 2018). Here we present a new body of functions, the Topographic Analysis Kit (TAK) that is designed to be a relatively complete set of basic topographic analysis tools that includes a variety of common tasks including batch processing of stream net maps and continuous grids of k_{sn} and χ, fitting k_{sn} values to selected stream profiles that largely replicate and improve upon the original Stream Profiler routines, selection of portions of stream networks, projection of longitudinal profiles of stream segments, automated processes for selecting, clipping and analyzing catchment averaged quantities, and construction of multi-variate swath profiles.

2 Principles of Design for TAK

The functions included with TAK are designed to leverage the power and broad codebase of TopoToolbox (Schwanghart and Kuhn, 2010; Schwanghart and Scherler, 2014) and with the following principles in mind: 1) limit the required knowledge of the Matlab language or general programming techniques by users to successfully, quickly, and robustly analyze topographic data, 2) provide an update to the established methodologies for common tasks (e.g. fitting stream profile segments to measure k_{sn}) originally introduced with 'Stream Profiler' (Wobus et al., 2006) , 3) bundle together other common functions with important controls (e.g. proper treatment of outlet elevations and incomplete channel networks for maps of χ and k_{sn} respectively), 4) introduce a framework for efficiently partitioning landscapes into series of small non-overlapping watersheds for a 'basin-averaged' style of topographic analysis (e.g., Forte et al., 2016), and 5) provide compiled versions of these functions so that users who do not have access to Matlab (or all required toolboxes) can use these tools in a simple environment. In the following sections, we briefly present the broad types of work flows possible with TAK (Figure 1) and then discuss the rationale behind the set of tools for analyzing landscapes from a 'basin averaged' perspective. We do not discuss functions or underlying algorithms in detail here, but as a supplement (and within the code repository) we include a detailed user manual that lays out proper usage of these tools and discusses how they work. Additionally, the header of each function lays out its intended purpose, required and optional inputs, and outputs.

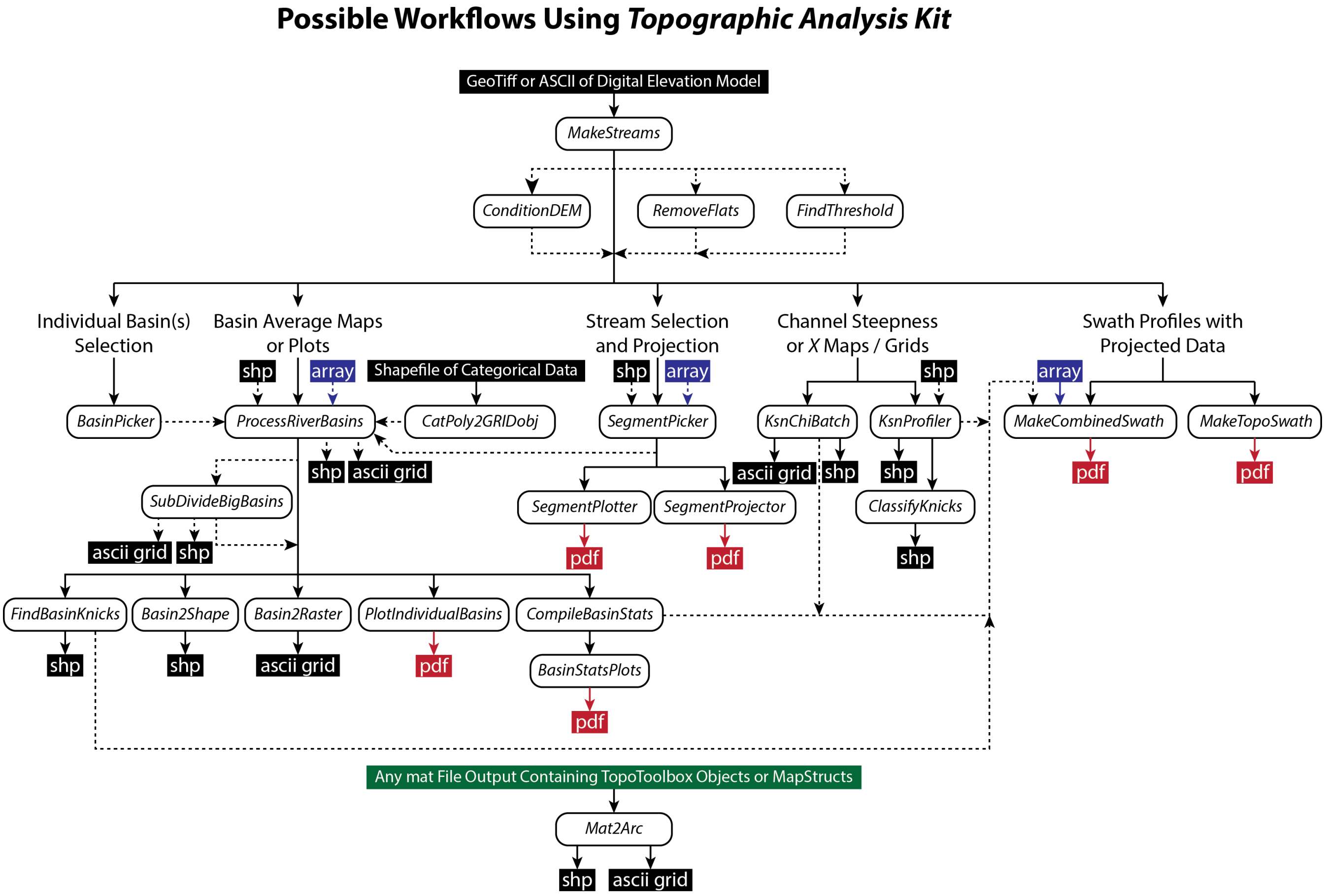

Figure 1. Suggested work flows through TAK functions depending on desired outcome and purpose of analysis. Also highlighted are the nature of the outputs produced by different functions.

3 Possible Work Flows

If using TAK exclusively, the entry point for all subsequent functions is the MakeStreams function which generates TopoToolbox versions of the required inputs for subsequent functions, specifically a DEM along with flow routing and stream network information (Figure 1). None of the subsequent functions require use of this initial function, users may generate valid TopoToolbox objects however they see fit, but MakeStreams does offer several built in options for data preparation that may be useful, e.g. automatic identification and removal of true flat areas. There are also three companion functions for further basic data preparation for stream profile smoothing (ConditionDEM), removal of flat area from stream networks (RemoveFlats), and refinement of stream network definition relating to minimum threshold areas (FindThreshold). Stream smoothing is an essential data preparation step for many topographic analyses and TAK relies on the variety of algorithms included within TopoToolbox to handle smoothing or river profiles (e.g., Schwanghart and Scherler, 2017), all of which are bundled within the

ConditionDEM function. As described in the user manual, it is not required that ConditionDEM is run as all TAK functions which require a smoothed river profile will use the 'mincosthydrocon' TopoToolbox function to calculate a linearly interpolated, smoothed channel profile, unless this is overridden by providing an alternatively conditioned DEM produced by the ConditionDEM function. After preparing and/or refining the basic datasets, the pathway through TAK functions depends upon the desired style of analysis or figures, but there are three broad (not mutually exclusive) paths: stream network analysis, basin averaged analysis, and swath profiles.

3.1 Stream Network Analysis

Included within this group of functions are tools for sub-setting stream networks (SegmentPicker), plot selected segments (SegmentPlotter), and projecting portions of longitudinal profiles of streams (SegmentProjector). Also included are tools for generating maps of both k_{sn} and χ for entire stream networks (KsnChiBatch, e.g. Figure 2B) and for manually fitting k_{sn} values to segments of streams (KsnProfiler). The KsnProfiler function is similar in many ways to the recently published ChiProfiler (Gallen and Wegmann, 2017), but includes some extra functionality modeled after the original Stream Profiler tools (Wobus et al., 2006), e.g. options to manually define the initiation of channels based on slope-area or χ-elevation data and, through the use of the companion ClassifyKnicks function, manually assign classifications to boundaries identified while fitting stream networks. As with the original Stream Profiler, KsnProfiler uses the slope derived from a linear fit of an interpolated version of the χ-elevation relationship to calculate k_{sn}. The primary differences between the original Stream Profiler and KsnProfiler are: 1) use of KsnProfiler does not explicitly require usage of ArcGIS for either picking streams or processing the shapefile (which means it's also significantly faster as the construction of the shapefile in Stream Profiler was the most computationally time consuming step), 2) users can select segment boundaries on χ-elevation plots in addition to slope-area or longitudinal profiles, 3) there is variety in how streams for analysis are selected including some automated selection schemes, and 4) there is explicit control on how the function deals with overlapping portions of stream networks (i.e. portions of stream networks that could potentially be fit multiple times depending on the streams selected for analysis).

3.2 Basin-Averaged Analysis

Several functions are provided to simplify the process of partitioning landscapes into series of watersheds. There is a function that allows for interactive selection of basins to analyze (BasinPicker), the output of which can be directly passed to the main function within this group, ProcessRiverBasins. ProcessRiverBasins also accepts a range of other input types for defining locations of watersheds, including fully automated procedures based on a user provided outlet elevation. ProcessRiverBasins will generate individual files for each watershed containing clipped versions of a variety of grids and vector data (e.g. local relief, maps of k_{sn}, etc) including user provided rasters (e.g. precipitation) or polygon shapefiles containing categorical data (e.g. geologic maps) along with statistics for each basin that summarize the clipped basins (e.g. basin averaged local relief, basin averaged k_{sn}, etc). There are a variety of companion functions for automatically subdividing these large basins (SubDivideBigBasins, e.g. Figure 2C), manual identification of knickpoints within basins (FindBasinKnicks), plotting profiles of each basin's stream network (PlotIndividualBasin), generating outputs to display these basins as shapefiles (Basin2Shape) or

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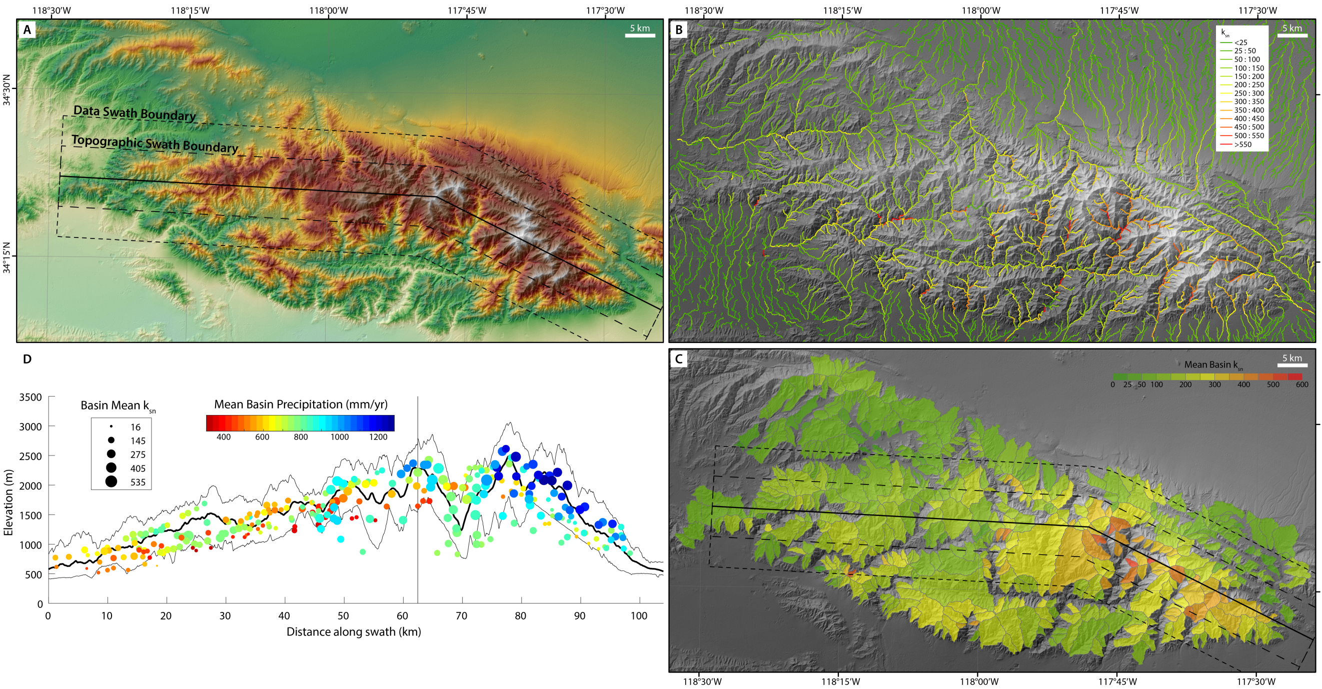

Figure 2. Example products output from TAK (with some compilation in ArcGIS and editing in a graphics program). A) Shaded elevation map of the San Gabriel Mountains in southern California with outlines of a combined swath profile. B) Normalized channel steepness map from KsnChiBatch. C) Map of basin averaged k_{sn} using ProcessRiverBasins and SubDivideBigBasins (using the trunk division method and a max basin size of 25 km^2). D) Swath profile with 10 km sampling width for the topography and 20 km sampling width for the basin data, basins are located based on their centroid location and mean elevation, colored by their mean annual precipitation averaged from 1981-2010 (data from PRISM Climate Group, Oregon State University, http://prism.oregonstate.edu, downloaded 1 June 2018), and scaled by their mean k_{sn}.

rasters (Basin2Raster), generating compiled tables of statistics and merging these with other data a user may have for basins, e.g. erosion rates (CompileBasinStats), and basic exploration of relationships between basin averaged values (BasinStatsPlots). To make these functions flexible, but also efficient, the SubDivideBigBasins function can use a variety of schemes to subdivide basins (avoiding the user having to choose large numbers of basin outlets to generate a large population of watersheds), including on the basis of confluences, stream order, and confluences with the trunk stream within a basin network.

3.3 Swath Profiles

There are two functions for constructing swath profiles. The basic MakeTopoSwath is largely a wrapper around the swath construction tool in TopoToolbox but includes additional options to plot the output and directly control the vertical exaggeration of the plots. There is also the MakeCombinedSwath function to create figures pairing topographic swaths with a variety of other point and vector data that is projected onto the swath profile by the function (e.g. Figure 2D).

4 Utility of Basin Averaged Methods

A common procedure in quantitative topographic analysis is relating topographic metrics (e.g. k_{sn}) to an empirical measure of a driving force (e.g. erosion rate) to elucidate more general relationships between surface or tectonic processes and topographic form (e.g., Safran et al., 2005; Cyr and Granger, 2008; Ouimet et al., 2009; DiBiase et al., 2010; Bookhagen and Strecker, 2012; Carretier et al., 2013; Godard et al., 2014; Lague, 2014; Scherler et al., 2014, 2017) or similarly using spatial variations in topographic metrics to infer spatial variation in process or driving forces (e.g. Kirby and Whipple, 2001; Kirby et al., 2003; Hodges et al., 2004; Dorsey and Roering, 2006; Whittaker et al., 2008; Morrell et al., 2015; Adams et al., 2016; Forte et al., 2016; Rossi et al., 2017). In both cases, because of the significant noise inherent in topography, the appropriate way to consider the topographic metric of interest is not strictly on a point or stream section basis, but rather in some spatially averaged form, explicitly in the former (e.g. comparing catchment averaged erosion rates to catchment averaged topographic metrics) and more implicitly in the latter. With this idea in mind, Forte et al. (2016) suggested visualizing and analyzing topographic data (even in the absence of formally spatially averaged empirical quantities like erosion rates) in a basin-averaged sense. The functions included in TAK for basin-averaged analysis and described previously are designed to simplify the creation of maps and plots to analyze data in this way (Figure 2C), making exploratory statistical analysis of spatially averaged topographic data extremely easy.

5 Conclusions

The functions included within TAK allow a user to quickly and easily perform the majority of 'standard' topographic analyses. TAK is built on top of the powerful and flexible TopoToolbox code base, but is specifically designed to lower the bar of entry for researchers wishing to include robust, quantitative topographic analysis in their work, hopefully expanding the community of those using topographic analysis and elevating the quality and reproducibility of published topographic analyses. Additionally, by providing compiled, standalone versions of the TAK functions, we make an effort to expand access of robust and simple topographic analysis to institutions and individuals who do not have access to Matlab, which, while a common fixture in many academic settings, is not ubiquitous.

Code availability. The TAK functions are available as Matlab code or compiled executables for either Windows or Mac OS X. Codes and executables are available on GitHub (https://github.com/amforte/Topographic-Analysis-Kit). The functions and executables are updated and expanded periodically. Use of any of these functions in published results should include a reference to this paper.

Author contributions. A.M. Forte was responsible for code and algorithm development and implementation of all TAK functions. K.X. Whipple contributed to theoretical underpinnings of algorithm structure and output and was the primary tester for code resilience. A.M. Forte and K.X. Whipple both contributed to the text.

Competing interests. The authors declare that they have no competing interests.

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