Below we include the original comments of the three reviewers of our manuscript, 'Short Communication: The Topographic Analysis Kit (TAK) for TopoToolbox' along with our general response to particular comments (e.g. addressed, rebuttal, etc) followed by a more detailed response describing the action taken to address the comment, or in the case of rebuttals, our reasoning for not specifically addressing the comment.

Reviewer 1 (A. Duvall)

This short communication, "The Topographic Analysis Kit (TAK) for TopoToolbox" by Forte and Whipple presents a series of streamlined tools and workflows. Building off of the TopoToolbox, these new functions perform a variety of digital topographic data analyses considered essential to many modern tectonic geomorphology studies. As was the case with TopoToolbox and the recent publication of other valuable analysis code such as LSD Topo Tools, the authors provide a big service to the tectonic geo- morphology community with this excellent contribution. I expect it will be used heavily by the community.

Because the TAK is designed specifically in the form of workflows to 'finished products' (such as channel steepness maps or topographic swath profiles), and because the authors also released a version of the code to use in the free Matlab Runtime Environment, the toolset holds special promise to break down technologic and economic barriers to quantitative topographic analysis. Beyond its obvious importance as a research tool, I also view the TAK as an important teaching resource, especially because of the detailed Users Guide that accompanies the code and this publication (supplement).

The manuscript is well written, clear and concise, and nicely illustrated. Although I recognize that this is a short communication and is not meant to be a thorough compendium on surface processes, tectonic geomorphology metrics, and fundamentals of landscape analysis, I do think it would benefit from the addition of a few paragraphs before section 3.1. These paragraphs could describe, at least in general, the main value and purpose of the three broad analysis paths (stream network analysis, basin averaged analysis, and swath profiles). The current section 4 (Utility of Basin Averaged Methods) would be bumped up into this section. As is, it seems a little tacked on to the end.
Reply: *Addressed:* We agree that providing a little more context for the utility of these techniques would be good. Instead of doing exactly what was suggested by Reviewer 1 (and 3), we have included these descriptions at the beginning of each subsection (i.e. Stream Network Analysis, Basin Averaged Analysis, and Swath Profiles). The text discussing the utility of the Basin Averaged Analysis (originally Section 4) has been moved to the front of the Basin Averaged Analysis tools section and a new section (with a new, more substantial example) has been added.

I also suggest a few technical corrections:

Page 1, Line 22: add a comma after accessible and after environments, remove the word and after environments.

Reply: *Addressed:* Change made.

Page 2, Line 1: remove the words "perhaps the most" after also
Reply: *Addressed:* Change made.

Page 3, Figure 1: Because this toolkit is meant to include even those who are true beginners to digital analysis, you might consider defining some of the terms/abbreviations in this figure in the caption (for example, shp or array).
Reply: *Addressed:* We have defined, or clarified, what the input and output data types mean in this figure within the caption.

Page 5, Figure 2: I think panel C should be on the left side and panel D on the right side (swapped as to what it is currently). Usually we read from left to right, so I expected C to follow B, sitting below A.
Reply: *Addressed:* We have made the suggested change.

Page 5, Line 6: Could add a simple definition of a swath profile at the start of this section.
Reply: *Addressed*: We have added a simple definition of a swath profile in the opening line of this paragraph.

Page 6, Line 23: Worth noting that beyond academic settings, those without access to Matlab could include local or national government employees and/or consultants who also have a need for this type of topographic analysis tool.
Reply: *Addressed:* We have expanded the list of end users who might find the compiled versions useful.

Comments on Supplement: TAK Manual v.1.0

Section 3, page 5: ". . ..it is expected that all of the datasets your provide are in the same projection system." "your" should be "you"
Reply: *Addressed:* The error has been fixed.

Section 8.1, page 22: Update the place holder [Link to Journal Site] after Forte and Whipple (2018) call out.
Reply: *No Change Made*: The text in question is an actual hotlink to the journal site including the PDF of the referenced paper.

Section 13, page 56: ". . ..whether submitting and issue" "and" should be "an"
Reply: *Addressed:* The error has been fixed.

I hope the authors and editors find this review useful. I enjoyed reading the manuscript and working through the TAK code. – Alison Duvall, University of Washington

Reviewer 2 (S. Hergarten)

In this short communication a software toolbox for performing morphometric analyses is presented. As quantitative geomorphology apparently becomes more and more important for unraveling the geologic history, the need for software implementations accessible without deeper knowledge in programming has increased in the last years. The toolbox presented here can be seen as some kind of front-end for TopoToolbox and provides more functions "coming out of the box" as well as compiled versions that can be used without MATLAB. I am quite sure that the new toolbox will receive considerable interest although there are already several other toolboxes on different levels available.

However, I am not completely convinced that the type of presentation really fits well into Earth Surface Dynamics. The manuscript itself does not contain much information going beyond listing the main capabilities of the toolbox. In turn the supplement (the manual of the software) is rather technical. When I looking at other examples of papers mainly presenting new tools published in ESurf (e.g., TopoToolbox 2 by W. Schwang- hart and D. Scherler, the recently published tools for quantification of changing Earth surface margins by J.M. Lea or my own one on swath profiles) I get the impression that these papers have much more focus on the ideas, algorithms, performance and potential limitations of the presented tools.
Reply: *Rebuttal:* While we concede that the Short Communications highlighted by the reviewer have focused on algorithms or limitations, we would argue that the content of our manuscript, at least with our understanding of the guidelines, fits within the description of this manuscript type, *"Short communications report new developments, significant advances, and novel aspects of experimental, modelling, and theoretical methods and techniques which are relevant for scientific investigations within the journal scope. Manuscripts of this type should be short (a few pages only). Highly detailed and specific technical information such as computer programme code or user manuals can be included as electronic supplements."* Ultimately, whether the manuscript in it's current, revised, form fits within the definition of a Short Communication paper will be up to the editor.

For this specific field: We know that river profile analysis can be a challenge in detail, smoothing of river profiles is nontrivial, and the interpretation of χ maps is also anything but trivial. For a paper (also for a short communication) in ESurf I would expect more information and discussion about the ideas behind the presented toolbox that could indeed make these geomorphic analysis accessible to a larger group of researchers and avoid potential pitfalls. In the present form of the manuscript I would even guess that a note about the availability of the new toolbox and a short presentation of its capabilities on Wolfgang Schwanghart's TopoToolbox web page would do a better job in propagating the software.
Reply: *Partially Addressed, Primarily Rebuttal:* While we appreciate the reviewer's opinion, there is little in terms of actionable changes that can be made based on this comment. The reviewer highlights both profile smoothing and the calculation of chi as areas where better documentation is required, however in both the main text and supplement we are explicit that we are using the smoothing algorithms implemented in TopoToolbox (and cite the paper where those algorithms were described). Similarly, in the original submission we describe in the supplement that the functions for calculating chi maps are based on our previously published work (Forte & Whipple, 2018, EPSL) that goes through in detail the considerations necessary for

constructing a chi map (we have added a brief description and citation to this in the main text in the revised version). In regards to whether '*a note about the availability of the new toolbox and a short presentation of its capabilities on Wolfgang Schwanghart's TopoToolbox web page would do a better job in propagating the software'*, this may be true. This is a great suggestion for increasing visibility of our paper. We hope to be able to add a blog post about TAK to Wolfgang's web page that includes a link to a published esurf Short Communication. However, we still see great value in primarily publishing and disseminating this work through the esurf Short Communications venue.

Reviewer 3 (D.E.J. Hobley)
In this short submission, the authors present a new front-end interface for the existing TopoToolbox landscape analysis software. The novelty of this software is built largely on enhancing ease of use of the underlying code, on permitting access to the TopoTool- box without a Matlab license, and on enhancing and expanding several of the analyses in TopoToolbox. Given ESurf's recent more explicit focus on landscape evolution soft- ware, I would view this submission as appropriate for the journal – especially given its status as a Short Communication. However, I would happily defer to the AE's view on this. The actual algorithms underlying the analyses are not laid out in the manuscript, though there is an explicit statement of this, and a direction of the reader to the user manual. The material presented feels very much like an incremental advance in terms of science and techniques, but I would say the submission is still warranted in laying out how this front end works, and what advantages it offers the user (a little more on this below).
Reply: *Rebuttal*: There is indeed no intended significant advance in either science or underlying algorithmic technique (generally speaking). This is not hidden – as all reviewers have recognized, we are describing and disseminating a powerful, easy to use, and open-access, open-source "front end" to the powerful TopoToolbox which is otherwise limited by the substantial learning curve required to implement desired analyses. So ultimately there are few clever new algorithms to be described. Rather than accomplishing a scientific or fundamental algorithmic technical advance, our aim is to facilitate potential scientific advances by the readership of esurf. As this apparent mis-understanding dominates this reviewer's comments, we have clarified this point in both the revised text and revised user manual: all underlying functions not explicitly described in the user manual are contained within Matlab or TopoToolbox and have been described elsewhere.

I believe this submission has no major issues preventing its publication. However, there are in my view a number of moderate niggles where more specific information could be provided to the reader to really sharpen the utility of the text as a description of software functionality. Most of these are listed as technical line items at the end of this text but I wanted to pull out the most significant three beforehand:

1. A large part of the novelty of this submission derives from its use of the Matlab Runtime Environment to avoid the user needing a Matlab licence. However, almost no direct information is provided on this in the body text. This needs rectifying. I would recommend a (short!) new section doing this job either before the current section 3 or after the current

section 4. This section should introduce what the MRE is (I've never used it; I imagine that's common); whether this is truly open source (it's not, but that's OK); and what the interface is (graphical? How is it different to "normal" Matlab? Is it web based? Etc etc). You should also state explicitly that the user can deploy TAK in Matlab proper as well. This section should also briefly outline *how* this makes the TAK interface novel – i.e., what are other analysis software packages using as their interfaces, and how is the TAK method better? This kind of detail will let the reader much more easily assess if this is the software package for them. (I appreciate a lot of this is in the Manual, but defending the novelty up front in the actual manuscript seems necessary.) This section should also include a clear and definitive statement on input/output data types – i.e., you say TAK ingests DEMs and shapefiles, but specifically are these ARC formatted only? If not, what else is permitted (NetCDF? If just naked ASCII, how are projections defined?) For the output, you talk unspecifically in the text about tables and arrays, but you should be specific that these come out as Matlab-proprietary Tables and Arrays, which can be exported to more familiar formats in the MRE (if they can?). Again, I get that this is in the Manual, but it's pertinent up front as it relates to the accessibility of TAK to the user through the Matlab interfaces.
Reply: *Addressed*: We have added a new section 'Matlab vs Compiled Versions' which describes (briefly) the difference between the Matlab and compiled version of TAK and clarifies how the compiled version deals with proprietary Matlab data types, e.g. if the Matlab version takes a Matlab array as input, the compiled version then instead takes a text file that includes the same data or similarly, if the Matlab version outputs a Matlab array, the compiled version will output a text file containing the same data. We have also added some clarification to section 3 of the user manual (Preparing Datasets for TAK) on which file formats are supported for input and output. All of the inputs and outputs (not considering the Matlab functions which output Matlab proprietary data types) are generally file types readable by a variety of programs. E.g. While ESRI ASCII files and shapefiles were initially proprietary data types for raster and shapefiles, respectively, both of these are readable and writeable by most standard open source GIS tools (e.g. QGIS, GDAL, OGR, etc).

2. The manuscript is explicit that it isn't going to review the underlying algorithms for the analyses. I'm not sure if I'd have made that call, but I think it's OK in the actual manuscript, especially given the Short length. However, I'm not sure that the detail in the Manual is sufficient to cover what's needed either. At the very least, each of the major topographic algorithm sections needs to be anchored to information about the actual methods directly – and ideally, ought to give explicit credit to the designers as well via actual referencing. If these are truly novel techniques either from these authors or novel in TopoToolbox underneath, then say that. Otherwise, you want statements along the lines of "This function implements a modification/implementation of the [whatever reference] algorithm for [doing whatever], as described fully in the Topo- Toolbox manual [direct link to algorithm in the TT manual/webpages]/the TopoToolbox publication". The user shouldn't have to go through the whole chain of (this paper) -> (this manual) -> (TopoToolbox website) -> (TopoToolbox manual index) -> (TopoToolbox section about algorithm) -> (original paper by someone else describing the method) to be able to access this information.

Reply:*Partially Addressed:* We appreciate the reviewer's goal of ensuring that users are provided with an in-depth understanding of what software is doing and of course that prior work is properly attributed. With the original and especially the revised text and user manual we feel that we have achieved this goal. As stated above we now make it very clear that all fundamental underlying algorithms are part of Matlab or TopoToolbox and have been described elsewhere. We do not replace or re-write any core TopoToolbox functions, but rather harness them in a user-friendly front-end, the user operation of which is described in detail in a user manual . for TAK in which we have attempted to document virtually all functionality included in TAK. Interestingly, the user manual elicited opposite reactions from 2 of the 3 reviewers, with reviewer 2 considered it 'rather technical' where as reviewer 3 indicates here that it is not technical enough. An important clarification from above is worth repeating: there are virtually no new underlying algorithms in TAK to be described. All the fundamental algorithms (for extracting a stream network, for example) are within TopoToolbox and have been described in published papers, e.g. Schwanghart & Kuhn, 2010; Schwanghart & Scherler, 2017; Schwanghart & Scherler 2017. Moreover, the first reviewer in contrast was quite happy with the original manual. Given this context, to partially address this particular comment we have added even more detail on what is being done with various functions and/or particular options of functions throughout the user manual. However, in most cases, there are no new algorithms to be described. For functions which are implementing some sort of published algorithm or procedure, we were already explicit in referencing the prior work (e.g. we already specified that the methodology by which normalized channel steepness was calculated is the same as in Stream Profiler and described in Wobus et al, 2006). We have also generally tried to clarify that in most cases, these codes are not establishing new algorithms or procedures, but rather using standardized procedures. Beyond instances like this, it seems like addressing the reviewers comment would require compiling a list of every Matlab or TopoToolbox function used in each TAK function and spelling that out in the user manual, which seems both excessive and counterproductive. Finally, we do want to highlight again that as described in what constitutes a Short Communication, the guidelines are somewhat explicit that the main submission be short , i.e. '*a few pages only'* and that, *'Highly detailed and specific technical information such as computer programme code or user manuals can be included as electronic supplements'*.

3. Please slightly expand on why the community uses these kinds of tools in the intro, even if just a bit. Probably only a couple of sentences needed, but will anchor the manuscript more strongly – see RC1's comments.
Reply: *Addressed:* Good idea, see response to similar comment by Reviewer 1.

Minor recommendations:
P1Ln 9 – Several sentences in the manuscript get very long and tough to read. Here's one: probably break at "analyses", and restart "These include. . ."
Reply: *Addressed:* We have made this highlighted change and have generally tried to shorten or break up sentences in other places in the manuscript to make it more readable.

P2Ln1 – "perhaps the most flexible". This seems like an unnecessary (unjustified?) judgement call. Either make direct comparisons between TAK and the other options available, or just remove this and stick with being purely descriptive of TAK.
Reply: *Addressed:* This phrase was removed and now simply indicates that TopoToolbox is flexible.

P2Ln12 – again, very long sentence. Break at ". . .stream profiles. These. . ."?
Reply: *Addressed:* We have broken this sentence up per the suggestion.

P2Ln 21/22 – "with important controls". On what? As written this doesn't make sense to me. Is it just a grammar problem?. Rephrase, and also be more specific.
Reply: *Addressed*: We have rephrased this sentence to be more clear that we were trying to bundle the production of particular products, like normalized channel steepness maps, with important pre-processing steps, like ensuring that the stream network has a complete accounting of drainage area for all streams, so that inexperienced users would at least be aware that these are things you should do as part of these analyses.

P2Ln29 – "discusses how they work". I don't think it does; I read this and believed I would find implementation details in the manual, and they aren't there. Probably just delete the clause (or add those algorithms! I'd love this, but I'm guessing you really don't want to. . .)
Reply: *Partially Addressed:* We are unclear exactly what the reviewer was hoping to find in the manual, but we would dispute the idea that 'implementation details… aren't there' as we generally include descriptions of what the codes are doing or how the behavior of the code changes depending on the options being used by the user. As stated above, we now make it clearer that all fundamental underlying functions are contained within Matlab or TopoToolbox. Also note that we are after all also releasing the source code of our "front end". We have attempted to strike a balance between describing all operational details in the manual and overwhelming users with too much detail. That being said, in the revised user manual, we have provided additional details for some options and functions where appropriate. At this point it is rather exhaustive as a user manual and is now nearly 100 pages long.

Fig. 1 – define "shp", "array" in the caption (see also below)
Reply: *Addressed:* We made this change in response to a similar comment from Reviewer 1.

P4Ln26/27 – This sentence is very vague, both on what the "range of other input types" is, and what the "fully automated procedures" are. Also seems there's a major non-sequitur here – a procedure is not an input type!? Rewrite for clarity and be more specific about what you mean by both "other input types" and "procedures".
Reply: *Addressed:* We have rewritten this sentence (now two sentences) specifying how users can select basins for the ProcessRiverBasins function.

P4Ln28 – "individual files". Again, be specific about which kinds of files (see also 1, above).
Reply: *Addressed:* We have specified that these are Matlab mat files.

P5Ln1 – Ditto. “tables” -> “Matlab Tables”.
Reply: *Addressed:* Change made.

P5Ln3-5 – You’re starting to actually talk methods in the main text here, so in this one specific place I don’t think you can get away without an explicit reference to the algorithm(s). i.e., what do you mean by “a variety of schemes”, and whose schemes are they?
Reply: *Addressed:* We have modified this sentence to clarify that by ‘scheme’ we mean criteria for identifying new pour points for smaller basins within larger basins. We have also clarified the following sentence, which did list these criteria in the original draft, but is now more explicit.

P6, Code Availability section – A touch more specificity here again, please. I assume those executables you refer to need the Matlab Runtime Environment to work, so say so. Also give information on the fact that a user will need either a licenced Matlab copy, or to download(/use online? I don’t know, which is why you should say) the MRE to make use of the software. Where can they find/download the MRE? Given that the software updates periodically, to comply with code publication best practice please highlight exactly which snapshot of the code this paper specifically describes at time of publication (i.e., as of right now, I would recommend “. . .expanded periodically; this text refers specifically to the code as of commit 8fad562 on 9th July 2018.”) Although you say it in the paper, also add for maximum clarity “The TAK manual is also avail- able through Github, or can be downloaded as a supplement of this publication” (or equivalent statement).
Reply: *Addressed:* We have significantly modified the ‘Code Availability’ section. We now: 1) specify that the user manual is available on the GitHub page, 2) specify that the versions of the code discussed in this paper refer to the codes as of release v.1.0.2., 3) clarified that the Matlab Runtime Environment is free, and 4) clarify that the GitHub repository includes two versions of the executables (for both Mac OS X and Windows), one that will that install the Matlab Runtime Environment along with the TAK executable and standalone versions of the executables for users that have previously installed the Matlab Runtime Environment. See also our response to Reviewer 3’s point number 1.

Compare Results

Old File:	versus	New File:
TAK_v2_red.pdf		**TAK_v4_red.pdf**
9 pages (381 KB)		**14 pages (625 KB)**
11/26/18, 5:43:19 AM		11/26/18, 5:43:03 AM

Total Changes

389

Content

90 Replacements

123 Insertions

46 Deletions

Styling and Annotations

16 Styling

114 Annotations

Go to First Change (page 1)

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 code bases, TopoToolbox, to build a series of high-level topographic analysis tools to perform a variety of common topographic analyses. These including generation of maps of normalized channel steepness or χ and selection and statistical analysis of populations of watersheds. No programming skills or advanced mastery of Matlab 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. TopoToolbox is also extremely 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 a 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, an increasing number of more complex analysis tools have been 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. These include batch processing of stream net maps and continuous grids of k_{sn} and χ and fitting k_{sn} values to selected stream profiles that largely replicate and improve upon the original Stream Profiler routines. TAK also includes a variety of tools for the 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. Here we describe some of the basic functionality of TAK and provide a representative example of the potential utility of the set of functions for selecting and analyzing watersheds in a basin averaged approach.

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 functions for producing common products (e.g. producing maps of χ and k_{sn}) with important controls or preprocessing steps necessary for careful analysis of the outputs (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., Bookhagen and Strecker, 2012; 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 describe the differences between the native Matlab and compiled versions, present the broad types of workflows possible with TAK (Figure 1), and then present a simple case study to show the type of analysis that is simplified with the basin averaged style of analysis implemented in TAK. We do not discuss functions or underlying algorithms in detail here, but as a supplement (and within the code repository, see Code Availability) 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.

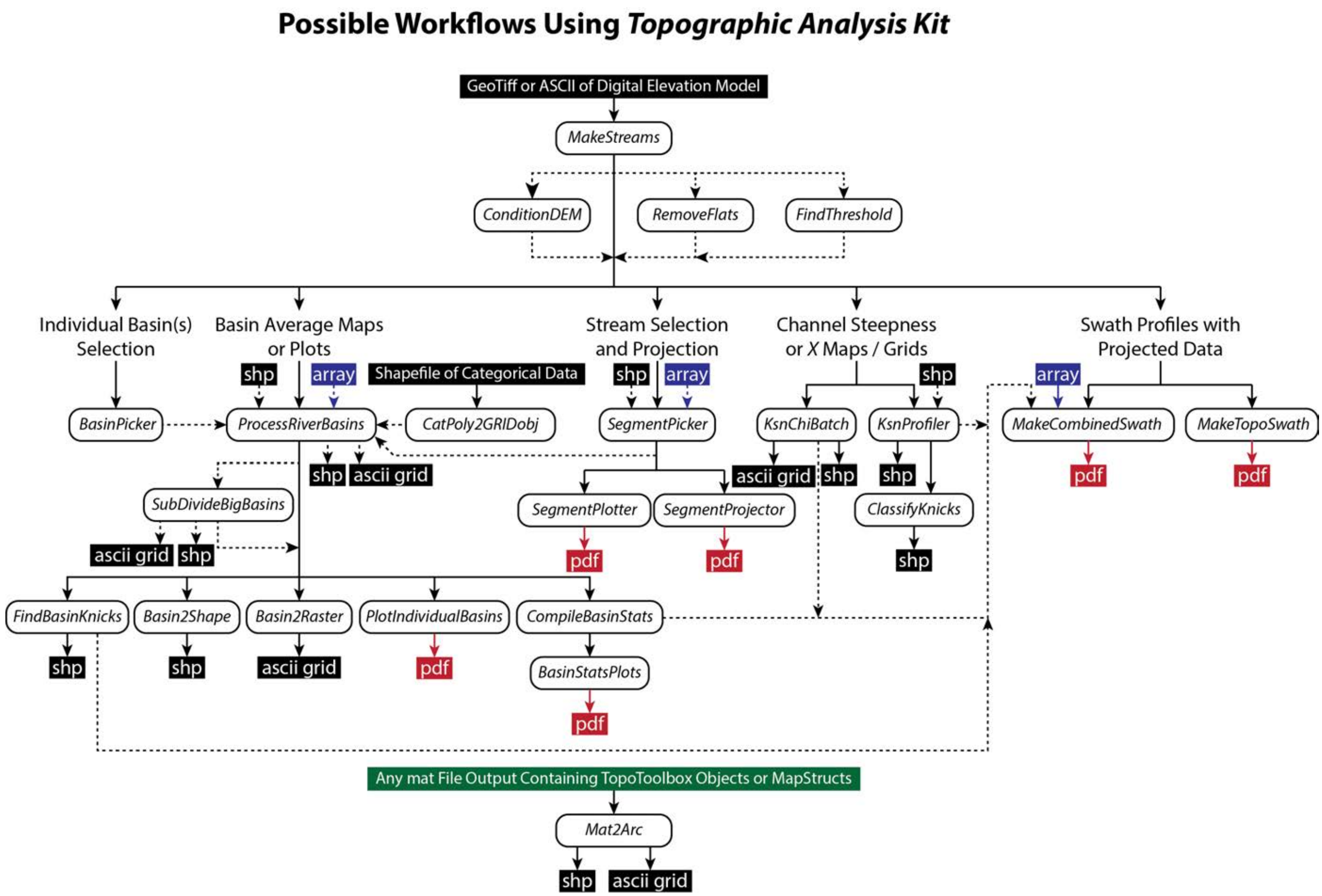

Figure 1. Suggested workflows through TAK functions depending on desired outcome and purpose of analysis. Also highlighted are the nature of the outputs produced by different functions. Definitions of inputs and outputs: shp - a shapefile containing vector data, the geometry of which, e.g. points, lines, polygons, depends on the tool in question; array - a Matlab array, i.e. a matrix of numbers; ascii grid - an ESRI Ascii text file that is interpretable as gridded raster data with projection information by many GIS programs; pdf - a figure output as a PDF.

3 Matlab vs Compiled Versions

To use the TAK Matlab functions, in addition to having downloaded the free TopoToolbox functions, a user must have licensed versions of Matlab, along with the Image Processing, Mapping, Statistics and Machine Learning, and Optimization Toolboxes, which depending on affiliation could cost upwards of $6150 (prices circa 2018) to fully license. If a user does not have access to Matlab, or all of the required toolboxes, they can instead use the compiled versions. These compiled versions rely on the Matlab Runtime Environment (MRE), which is a free program distributed by Mathworks, the maker of Matlab, for running compiled versions of Matlab code. The GitHub repository (see Code Availability) includes an executable that will download and install the MRE on a user's machine. After the MRE is installed, running the compiled versions is largely similar to running the Matlab functions, i.e. functions are run from a command line, but instead of being run from a command line within Matlab, they are run from the OS specific comamnd line (terminal in Mac OS X or the command prompt in Windows). When running the compiled functions, to avoid or translate from proprietary Matlab data formats, inputs and outputs for some functions differ between the Matlab functions and the compiled versions. For example, a function which in the Matlab versions take a two column Matlab array as an input, instead accepts the name of a text file containing a two column array of data (with any standard delimiter) in the compiled versions. Similarly, for TAK Matlab functions which output Matlab proprietary data types (e.g. Matlab arrays or Matlab tables), the compiled versions will instead write out this information as text files or other data types (e.g. ESRI Ascii grids or shapefiles) that are readable by third party programs. A more comprehensive treatment of the different usage of the compiled vs Matlab TAK functions is available in the user manual in the supplement and in the code repository (see Code Availability).

4 Possible Workflows

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 such as lakes or playas. There are also three companion functions for further basic data preparation for stream profile smoothing (ConditionDEM), removal of mostly flat areas, i.e. those that are not identified with the simple filter in MakeStreams, 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 described in the sections below: stream network analysis, basin averaged analysis, and swath profiles.

4.1 Stream Network Analysis

Stream network analysis is a fundamental part of most quantitative topographic investigations and is especially important for tectonic geomorphology. The utility of maps of streams colored by the normalized channel steepness index, k_{sn}, for characterizing the active tectonics of erosional landscapes, and specifically using maps of k_{sn} to identify zones of more or less active rates of rock-uplift is well documented (e.g., Kirby and Whipple, 2001; Wobus et al., 2006; Whittaker, 2012; Kirby and Whipple, 2012). Similarly, maps of stream networks colored by χ, as defined by Perron and Royden (2013), are increasingly used to interrogate the topological stability of a stream network (e.g., Willett et al., 2014; Beeson et al., 2017; Forte and Whipple, 2018). In constructing TAK, we have included a variety of functions designed to make stream network analysis simpler. 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). Production of k_{sn} maps with the KsnChiBatch function is largely similar to the results of Stream Profiler, but includes additional methods for aggregating noisy k_{sn} values beyond a simple averaging over a specified length scale, including calculating length averaged k_{sn} values on trunk streams separately from low order streams or calculating length-averaged k_{sn} values on individual stream segments separately (regardless of stream order or size). The production of χ maps with KsnChiBatch incorporates all of the necessary preprocessing steps described in Forte and Whipple (2018) for ensuring that the χ values in χ maps are controlled for outlet elevation and include complete accounting of drainage area. 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} (e.g., Harkins et al., 2007; Perron and Royden, 2013). 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 are selected for analysis 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).

4.2 Basin-Averaged Analysis

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

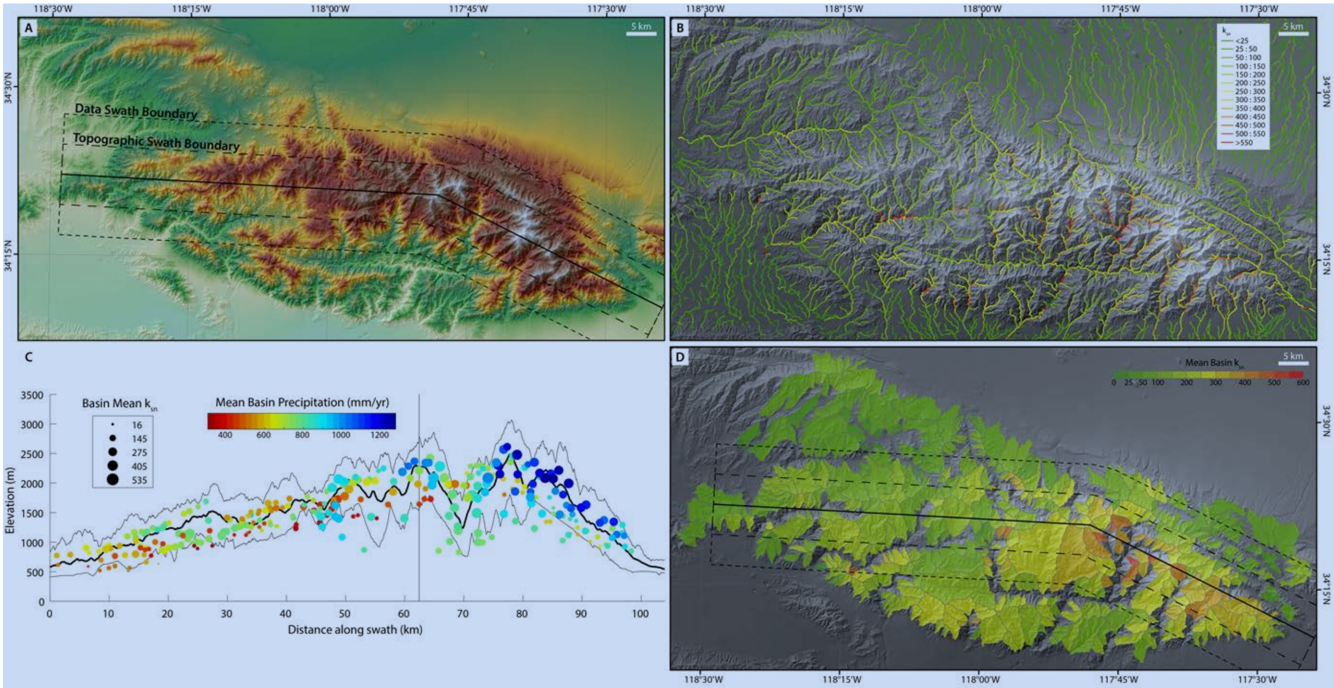

Figure 2. Example products output from TAK (with some compilation in ArcGIS and editing in a graphics program). A) Shaded elevation map of the San Gabriel Mountains in southern California with outlines of a combined swath profile. B) Normalized channel steepness map from KsnChiBatch. C) Swath profile 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}. D) Map of basin averaged k_{sn} using ProcessRiverBasins and SubDivideBigBasins (using the trunk division method and a max basin size of 25 km^2)

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more implicitly in the latter. With this idea in mind, it has also been suggested that visualizing and analyzing topographic data (even in the absence of formally spatially averaged empirical quantities like erosion rates) in a basin-averaged sense can be a useful alternative (or complementary) method to traditional stream network analysis for analyzing landscapes (e.g., Bookhagen and Strecker, 2012; Forte et al., 2016). The functions included in TAK for basin-averaged analysis are designed to simplify the creation of maps and plots to analyze data in this way (Figure 2D), making exploratory statistical analysis of spatially averaged topographic data extremely easy. In detail, 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. Selection of basins for ProcessRiverBasins is based on the locations of 'river mouths' (i.e. pour points) and can be selected in TAK using BasinPicker or in a GIS program of the users choice and passed to ProcessRiverBasins as either a list of x, y coordinates or a shapefile of points. Alternatively, ProcessRiverBasins can automatically select basins based based on user provided outlet elevations. ProcessRiverBasins will generate individual Matlab mat 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 rasters (Basin2Raster), generating compiled Matlab 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 criteria to identify pout points within the clipped basins which are then used to 'subdivide' basins (avoiding the user having to choose large numbers of basin outlets to generate a large population of watersheds). Options for identifying new pour points within larger basins include using the location of confluences, 'outlets' of streams with a particular stream order, and confluences with the trunk stream within a basin network.

4.3 Swath Profiles

Swath profiles, which broadly defined, are cross-sections through data where that data is sampled across a specified width as opposed to along a single line, can be a useful tool for both analyzing topography but also conveying a more intuitive sense of the topography or other data (e.g., Burbank et al., 2003; Bookhagen and Burbank, 2006). Specifically, swath profiles can be more representative of topography because more traditional cross-sections can be highly biased by the choice of line of section location. We include two functions for constructing swath profiles with TAK. 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 2C). This can be a useful visual tool for displaying a variety of related data in topographic context on a single figure (e.g., Whipple et al., 2016; Forte et al., 2016)

5 Case Study of Basin Averaged Routines

While we feel they are unique in their ease of use or detailed capabilities, the TAK functions related to stream network analysis and swath profiles are largely extensions or incremental improvements of well established tools and methods, and thus the potential for these functions to be useful is likely self-evident to workers familiar with general principles in topographic analysis. In contrast, the functions related to basin averaged analyses are largely unique and we believe facilitate a host of possible, large-scale analyses. As an example, we present a simple application of some of these functions to a large-scale problem, specifically exploring broad, potential relationships between topographic form, climate, and rock type. Similar analyses have been presented before, e.g. Zaprowski et al. (2005), but with substantially smaller datasets, potentially for the simple reason that the absence of tools, like the ones we provide, make such analyses incredibly time consuming.

In detail, we use the functions MakeStreams, ProcessRiverBasins, SubDivideBigBasins, CatPoly2GRIDobj, Basin2Shape, and CompileBasinStats along with a SRTM 90 meter digital elevation model of North America, the PRISM mean annual precipitation dataset, and a shape file of compiled state geologic maps from the USGS which contains rock types (Horton et al., 2017) to select and analyze a large suite of watersheds within the continental US (Figure 3). We started the analysis by using the outlets of all streams defined with a threshold area $>$ 1e9 km^2 as the river mouth input to ProcessRiverBasins. This was run with the result of converting the geologic map shapefile into a raster using the CatPoly2GRIDobj function. After initial basin selection, we ran SubDivideBigBasins using the location of confluences with the trunk stream of basins larger than 1000 km^2 to automatically subset these basins, which resulted in a total of 1250 individual basins (Figure 3). We then used CompileBasinStats to aggregate all of the data from these basins. From there, because quantities like drainage area, mean k_{sn}, mean precipitation, best-fit concavity, percentage of the basin occupied by the most abundant rock-type, and what that most abundant rock-type are automatically calculated by CompileBasinStats, it is simple to filter basins and compare topographic metrics as a function of lithology (Figure 3).

From this point, a variety of observations or comparisons can be made, for example we compare how well this data fits with an expected simplified relationship between k_{sn}, uplift rate, and mean precipitation rate, like the one used by D'Arcy and Whittaker (2014),

$$k_{sn} = (U/(K * P^m))^{(1/n)} \tag{1}$$

where U is uplift rate, K is an erosional efficiency constant, P is mean precipitation rate, and m and n are empirical constants (Figure 3). Or we could explore potential relationships between quantities like basin concavity and mean precipitation, a relationship suggested to exist in some work (e.g., Zaprowski et al., 2005). This at first appears incredibly messy, e.g. the middle panel of plots in Figure 3, but after we begin to further filter the dataset and eliminate basins that may contain large knick-points (i.e. watersheds without major knick-points should have nearly linear χ-elevation relationships, and thus the R^2 of the χ-elevation relationship should be near unity), the range of concavities shrinks dramatically.

Ultimately, we do not wish to interpret too much from these data, but rather we present this as an example of the ease of producing this dataset using TAK. To produce the underlying data for Figure 3 required approximately 5 days of computation time, but less than 1 hour of actual personal interaction with the data. The tasks that required direct interaction with the data were 1) using a GIS program to crop the North America dataset into three large chunks (this was required because of the size of the dataset and the inherent limitation within Matlab that all data must be loaded into memory), 2) manually filtering the outlets of streams to be included and used by ProcessRiverBasins to avoid streams that primarily drained areas which were not covered by the PRISM or geologic map datasets, and 3) exploring different criteria of filtering the resulting table of aggregated values. To produce a more robust, interpretable dataset, more time would have been required to more carefully select initial river mouth

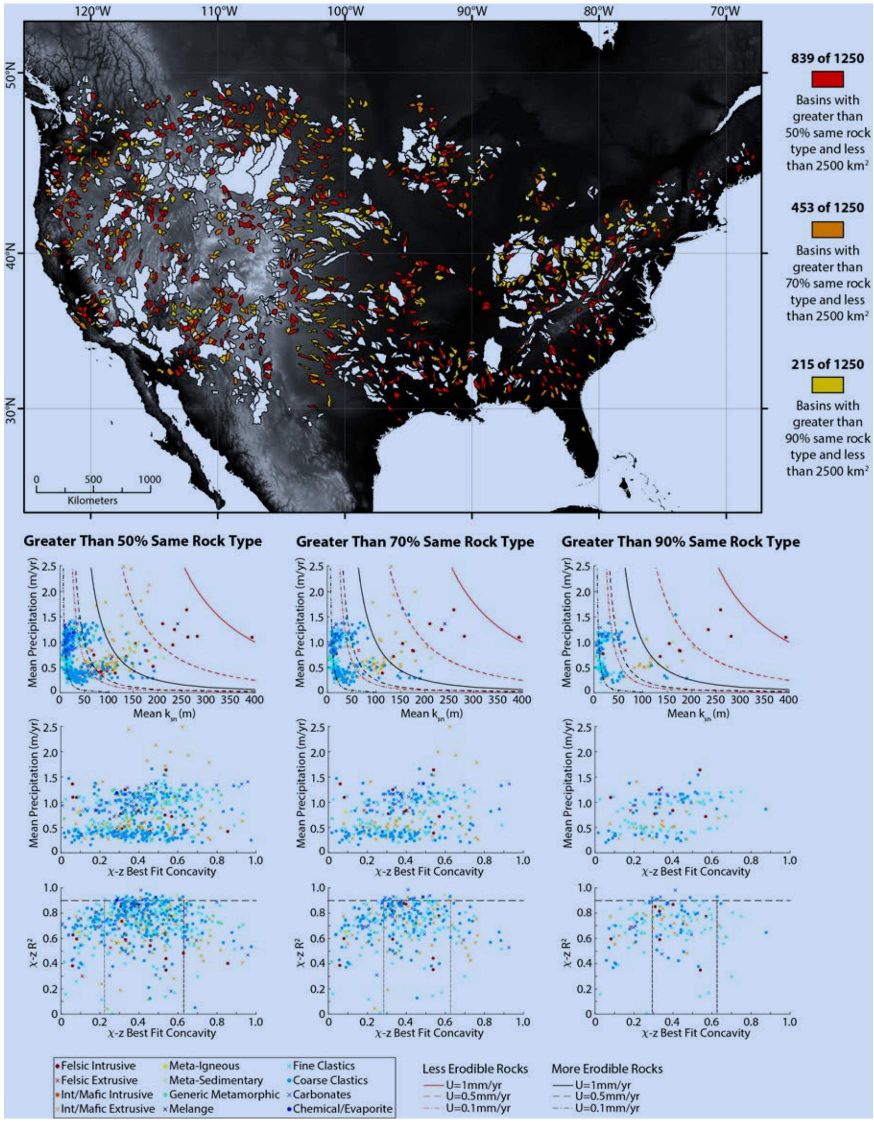

Figure 3. Top: Topography of North America showing the extents of the 1250 basins extracted. Colored basins represent basins which meet the established criteria based on drainage area and percent of the catchment occupied by a single rock type. White basins are excluded based on the criteria. Bottom: Plots of basin averaged values comparing the relationships between mean k_{sn} and mean precipitation, best-fit concavity and mean precipitation, and best-fit concavity and the R^2 value for the χ-elevation relationship for watersheds with 50% (left), 70% (center), and 90% of the catchment comprised of the same rock type. Colors of the dots indicate the dominant rock-type for the watershed. Guidelines on the k_{sn} and mean precipitation plot are calculated using equation (1) and assuming values of m=0.5 and n=1, the range of uplift rates shown at the bottom of the figure, and for two 'K' values equating to less (red) and more (black) erodible rocks. Horizontal line in the bottom plots mark a R^2 of 0.90 and the vertical lines indicate the range of concavities above that R^2 value. See text for additional description.

locations, but the point remains that the functions provided with TAK make such an analysis, incorporating multiple, diverse datasets, extremely easy.

6 Conclusions

The functions included within TAK allow a user to quickly and easily perform the majority of 'standard' topographic analyses and especially in the case of the basin averaged analysis set of functions, expand the scope of the types of analyses which users can perform easily. 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 or teaching, 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, agencies, organizations, and individuals who do not have access to Matlab, which, while a common fixture in many academic or research settings, is not ubiquitous.

Code availability. The TAK functions are available as Matlab code or compiled executables for either Windows or Mac OS X. Matlab functions, executables, and the user manual are available on GitHub (https://github.com/amforte/Topographic-Analysis-Kit). The Matlab functions, executables, and user manual are updated and expanded periodically. The versions of the code referenced in this paper refer specifically to release v.1.0.2. To successfully use the Matlab codes, users must have a licensed copy of Matlab along with licenses for the Mapping Toolbox, Statistics and Machine Learning Toolbox, Optimization Toolbox, and the Image Processing Toolbox. To use the compiled versions, users must install the Matlab Runtime Environment (MRE), which is available for free from Mathworks. For both Mac OS X and Windows, there is a single executable that will install both the MRE and the TAK executable. If users already have MRE installed, the executables are also included as separate files within the GitHub repository. 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 development and implementation of all TAK functions. K.X. Whipple contributed to theoretical underpinnings of topographic analysis methods, defining desired outputs, and was the primary tester for code resilience. A.M. Forte and K.X. Whipple both contributed to the text.

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