REPORT DOCUMENTATION PAGE	Form Approved OMB NO. 0704-0188

The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggesstions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA, 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any oenalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.
PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.

1. REPORT DATE (DD-MM-YYYY) 04-07-2018	2. REPORT TYPE Final Report	3. DATES COVERED (From - To) 23-Sep-2013 - 22-Sep-2017

4. TITLE AND SUBTITLE Final Report: Constraining the Topographic Signature of Erosion Rates and Processes Using High Resolution Topography	5a. CONTRACT NUMBER W911NF-13-1-0478
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER 611102
6. AUTHORS	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAMES AND ADDRESSES The University of Edinburgh Old College The University of Edinburgh -	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS (ES) U.S. Army Research Office P.O. Box 12211 Research Triangle Park, NC 27709-2211	10. SPONSOR/MONITOR'S ACRONYM(S) ARO 11. SPONSOR/MONITOR'S REPORT NUMBER(S) 64552-EV.18

12. DISTRIBUTION AVAILIBILITY STATEMENT

Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

The views, opinions and/or findings contained in this report are those of the author(s) and should not contrued as an official Department of the Army position, policy or decision, unless so designated by other documentation.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	15. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Simon Mudd
UU	UU	UU	UU		19b. TELEPHONE NUMBER 004-465-0253

RPPR Final Report
as of 04-Sep-2018

Agency Code:

Proposal Number: 64552EV **Agreement Number: W911NF-13-1-0478**

INVESTIGATOR(S):

Name: Simon M. Mudd
Email: simon.m.mudd@ed.ac.uk
Phone Number: 00446502535
Principal: Y

Organization: **The University of Edinburgh**
Address: Old College, Edinburgh, Scotland, EH8 9YL,
Country: GBR

DUNS Number: 229044300 EIN: 44-444444
Report Date: 22-Dec-2017 Date Received: 04-Jul-2018
Final Report for Period Beginning 23-Sep-2013 and Ending 22-Sep-2017
Title: Constraining the Topographic Signature of Erosion Rates and Processes Using High Resolution Topography
Begin Performance Period: 23-Sep-2013 **End Performance Period:** 22-Sep-2017
Report Term: 0-Other
Submitted By: Simon Mudd Email: simon.m.mudd@ed.ac.uk
Phone: (004) 465-02535
Distribution Statement: 1-Approved for public release; distribution is unlimited.

STEM Degrees: 5 **STEM Participants:** 0

Major Goals: The goal of the project was to test 7 hypotheses:

- H1: All else equal, the erodibility coefficient (K) will vary linearly with MAP.
- H2: All else equal, the erodibility coefficient K will scale with the tensile strength of the lithologic units.
- H3: All else equal, the coefficient K will be inversely proportional to discharge variability.
- H4: All else equal, the erodibility coefficient (K) will be nonlinearly related to erosion rates (e.g., K = aE^alpha), with an exponent alpha that is less than 1.
- H5: Drainage density is sensitive to erosion rate
- H6: There is a step change in topographic roughness as landscapes reach a threshold erosion rate, and this threshold is a function of climate.
- H7: There are step changes in topographic roughness and topographic scaling signatures between bare Earth, grassland and forested landscapes.

Accomplishments: The proposal succeeding in testing all but one of the hypotheses, although one of the remaining hypotheses was only partially tested. We explain the results of these tests below, the associated papers, and why we were not able to test all seven hypotheses.

- H1: All else equal, the erodibility coefficient (K) will vary linearly with MAP.

Tested. It does not! A counterintuative result. Published in Harel et al. (2016)

- H2: All else equal, the erodibility coefficient K will scale with the tensile strength of the lithologic units.

Tested, albeit partially. There was not enough data on tensile strungth but we did test against lithologic type and found strong correlations. Published in Harel et al. (2016).

- H3: All else equal, the coefficient K will be inversely proportional to discharge variability.

Tested: there seems to be little correlation between rainfall statistics and erodibility. (Harel et al., 2016). Thus runs counter to prevailing theory and needs to be further explored. We now believe lithology and sediment supply are the dominant controls.

- H4: All else equal, the erodibility coefficient (K) will be nonlinearly related to erosion rates (e.g., K = aE^alpha), with an exponent alpha that is less than 1.

Tested, shown to be true (Harel et al., 2016). This implies that the slope exponent in bedrock fluvial incision laws should be greater than 1. This has implications for using river profiles as recorders of uplift history. Petroleum companies use this information to understand deposition rates through time so this result calls into question some methods for reconstructing uplift history.

- H5: Drainage density is sensitive to erosion rate

Tested in Clubb et al. (2016): increases in erosion rates lead to increased drainage density. Again this suggest the slope expont is greater than 1.

- H6: There is a step change in topographic roughness as landscapes reach a threshold erosion rate, and this threshold is a function of climate.

Partially tested in Milodowski et al (2016) and further tested in a still unpublished paper that suggests roughness scales with erosion rate.

- H7: There are step changes in topographic roughness and topographic scaling signatures between bare Earth, grassland and forested landscapes.

Yet to be tested. Gathering erosion rate, biome data and lidar data was a bit too ambitious given the other accomplishments of the project but the algorithms all exist for this to be done in the future.

Training Opportunities: The project involved active participation of four PhD students and a masters student (Fiona Clubb, David Milodowski, Stuart Grieve, Boris Gailleton, Declan Valters).

All of these students retrieved extensive training in both scientific method development and software development. They are all now proficient with open source software design, collaborative software engineering, software testing and continuous integration.

Four these students (one is still undetaking his PhD) moved on to either research software engineer positions (Grieve, Valters) or PDRA positions focused on computation (Milodowski, Clubb). Both Clubb and Grieve have accepted positions as UK lecturer (equivalent to assistant professors in the United States).

Results Dissemination: The project resulted in 11 peer review publications and 5 software packages that have been released as open source software. Users have used personal communication to describe use cases but the software is being used by the United States Geological Survey, the Geological Surveys of Maine and Kentucky, the Chinese Earthquake Administration, and numerous academic users throughout the world.

Honors and Awards: One of the papers from this research was awarded the Wiley Award for best paper in Earth Surface Processes and Landforms in 2017

Protocol Activity Status:

Technology Transfer: Nothing to Report

PARTICIPANTS:

Participant Type: PD/PI
Participant: Simon Marius Mudd
Person Months Worked: 6.00
Funding Support:
Project Contribution:
International Collaboration:
International Travel:
National Academy Member: N
Other Collaborators:

RPPR Final Report
as of 04-Sep-2018

Participant Type: Postdoctoral (scholar, fellow or other postdoctoral position)
Participant: Marie-Alice Harel
Person Months Worked: 15.00 **Funding Support:**
Project Contribution:
International Collaboration:
International Travel:
National Academy Member: N
Other Collaborators:

ARTICLES:

Publication Type: Journal Article Peer Reviewed: Y **Publication Status:** 1-Published
Journal: Water Resources Research
Publication Identifier Type: DOI Publication Identifier: 10.1002/2013WR015167
Volume: 50 Issue: 5 First Page #: 4283
Date Submitted: Date Published:
Publication Location:
Article Title: Objective extraction of channel heads from high-resolution topographic data
Authors:
Keywords: Topographic analysis, channel networks, hydrology, geomorphology
Abstract: Fluvial landscapes are dissected by channels, and at their upstream termini are channel heads. Accurate reconstruction of the fluvial domain is fundamental to understanding runoff generation, storm hydrology, sediment transport, biogeochemical cycling, and landscape evolution. Many methods have been proposed for predicting channel head locations using topographic data, yet none have been tested against a robust field data set of mapped channel heads across multiple landscapes. In this study, four methods of channel head prediction were tested against field data from four sites with high-resolution DEMs: slope-area scaling relationships; two techniques based on landscape tangential curvature; and a new method presented here, which identifies the change from channel to hillslope topography along a profile using a transformed longitudinal coordinate system. Our method requires only two user-defined parameters, determined via independent statistical analysis. Slope-area plots are tradition
Distribution Statement: 1-Approved for public release; distribution is unlimited.
Acknowledged Federal Support:

Publication Type: Journal Article Peer Reviewed: Y **Publication Status:** 1-Published
Journal: Journal of Geophysical Research: Earth Surface
Publication Identifier Type: DOI Publication Identifier: 10.1002/2015JF003747
Volume: 121 Issue: 10 First Page #: 1724
Date Submitted: 7/4/18 12:00AM Date Published: 9/30/16 10:00PM
Publication Location:
Article Title: The relationship between drainage density, erosion rate, and hilltop curvature: Implications for sediment transport processes
Authors: Fiona J. Clubb, Simon M. Mudd, Mikaël Attal, David T. Milodowski, Stuart W.D. Grieve
Keywords: Geomorphology
Abstract: Drainage density is a fundamental landscape metric describing the extent of the fluvial network. We compare the relationship between drainage density (Dd) and erosion rate (E) using the Channel-Hillslope Integrated Landscape Development (CHILD) numerical model. We find that varying the channel slope exponent (n) in detachment-limited fluvial incision models controls the relationship between Dd and E, with n > 1 resulting in increasing Dd with E if all other parameters are held constant. This result is consistent when modeling both linear and nonlinear hillslope sediment flux. We also test the relationship between Dd and E in five soil-mantled landscapes throughout the USA: Feather River, CA; San Gabriel Mountains, CA; Boulder Creek, CO; Guadalupe Mountains, NM; and Bitterroot National Forest, ID. For two of these field sites we compare Dd to cosmogenic radionuclide (CRN)-derived erosion rates, and for each site we use mean hilltop curvature as a proxy for erosion rate where CRN-derived
Distribution Statement: 1-Approved for public release; distribution is unlimited.
Acknowledged Federal Support: **Y**

Publication Type: Journal Article Peer Reviewed: Y **Publication Status:** 1-Published
Journal: Earth Surface Processes and Landforms
Publication Identifier Type: DOI Publication Identifier: 10.1002/esp.3923
Volume: 42 Issue: 1 First Page #: 24
Date Submitted: 7/4/18 12:00AM Date Published: 1/1/17 12:00AM
Publication Location:
Article Title: Detection of transience in eroding landscapes
Authors: Simon M. Mudd
Keywords: Geomorphology, Erosion
Abstract: Past variations in climate and tectonics have led to spatially and temporally varying erosion rates across many landscapes. In this contribution I examine methods for detecting and quantifying the nature and timing of transience in eroding landscapes. At a single location, cosmogenic nuclides can detect the instantaneous removal of material or acceleration of erosion rates over millennial timescales using paired nuclides. Detection is possible only if one of the nuclides has a significantly shorter half-life than the other. Currently, the only practical way of doing this is to use cosmogenic in situ carbon-14 (14C) alongside a longer lived nuclide, such as beryllium-10 (10Be). Hillslope information can complement or be used in lieu of cosmogenic information: in soil mantled landscapes, increased erosion rates can be detected for millennia after the increase by comparing relief and ridgetop curvature. This technique will work as long as the final erosion rate is greater than twice the i
Distribution Statement: 1-Approved for public release; distribution is unlimited.
Acknowledged Federal Support: **Y**

Publication Type: Journal Article Peer Reviewed: Y **Publication Status:** 1-Published
Journal: Earth Surface Dynamics
Publication Identifier Type: DOI Publication Identifier: 10.5194/esurf-5-369-2017
Volume: 5 Issue: 3 First Page #: 369
Date Submitted: 7/4/18 12:00AM Date Published: 7/1/17 12:00AM
Publication Location:
Article Title: Geomorphometric delineation of floodplains and terraces from objectively defined topographic thresholds
Authors: Fiona J. Clubb, Simon M. Mudd, David T. Milodowski, Declan A. Valters, Louise J. Slater, Martin D. Hur
Keywords: geomorphology, flooding, terraces, software
Abstract: Floodplain and terrace features can provide information about current and past fluvial processes, including channel response to varying discharge and sediment flux, sediment storage, and the climatic or tectonic history of a catchment. Previous methods of identifying floodplain and terraces from digital elevation models (DEMs) tend to be semi-automated, requiring the input of independent datasets or manual editing by the user. In this study we present a new method of identifying floodplain and terrace features based on two thresholds: local gradient, and elevation compared to the nearest channel. These thresholds are calculated statistically from the DEM using quantile–quantile plots and do not need to be set manually for each landscape in question. We test our method against field-mapped floodplain initiation points, published flood hazard maps, and digitised terrace surfaces from seven field sites from the US and one field site from the UK. For each site, we use high-resolution DEMs
Distribution Statement: 1-Approved for public release; distribution is unlimited.
Acknowledged Federal Support: **Y**

RPPR Final Report
as of 04-Sep-2018

Final Progress Report

Constraining the topographic signature of erosion rates and processes using high resolution topography, PI Simon M Mudd

Foreword

This ARO project focussed on new methods for extracting information about erosion rates, erosion processes (e.g., river erosion, landslides and debris flows, or soil erosion on hillslopes), and extraction of the temporal changes in these processes. These advances, amongst other things, could be used to identify changing tectonic activity using high resolution data. Much of the work for the project involved methodological advances: we developed new algorithms for i) extracting drainage networks ii) determining channel steepness iii) exploring variations in drainage density iv) detecting topographic roughness to identify bedrock outcrop vs soil v) metrics for determining relief and hillslope length across landscapes to look for evidence of tectonic activity. The resulting algorithms has been published as five separate software packages (Clubb et al., 2017a,b,c; Mudd et al. 2017; Mudd et al. 2018). These algorithms have been associated with eleven peer-reviewed publications.

Problem Statement

Earth's terrestrial surface holds stores a vast amount of information in its shape, and for well over a century geologists and geographers have hypothesized that the geometry of the Earth's surface can be used to infer information such as how fast the landscape is eroding, if there are active faults, and how susceptible different portions of the landscape are to landslides. Early pioneers such as G.K. Gilbert and R.E. Horton began to suggest quantitative relationships between topographic form and erosion rates, and theories predicting the topographic outcome of different erosion processes (e.g., landslides, floods, human disturbance) were available in the 1950s and 1960s.

The main barrier to applying these theories was the lack of topographic data. Even in the early 90s, workers were still using paper topographic maps to determine river and hillslope profiles. This did not lend itself to studying the topographic outcome of different erosion rates and processes at the landscape scale.

Topographic data is no longer a barrier: the last decade has seen rapid advances in the collection and distribution of topographic data. In 2009, the ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) mission, a joint Japanese-NASA mission, produced a 30 metre resolution near-global DEM followed by a 30 metre Shuttle Radar Topography Mission (SRTM) product released in 2014.

The increase in resolution continues apace, with products at 12 metre resolution or better being produced in the last few years by the Japanese and German space agencies (ALOS and TanDEM-X missions, respectively). At the same time large quantities of lidar data are becoming available. These data are most often delivered as point clouds and 12-20 points per square metre are now not uncommon.

We now can see far more detail than was possible even a decade ago, but with increased resolution come increased computational cost. What does this increase in resolution mean for analysing topography for applications in natural hazards, hydrology, geomorphology and allied fields? A simple answer to that question is simply to look at the features visible from different resolutions (Figure 1). At 90 and 30 metre resolution few features are visible, but a linear feature emerges when the resolution is 10 metres, and the linear feature is shown to be controlling drainage network evolution and the paths of channels at 1 metre resolution. This feature is the San Andreas Fault in California (the site is to the West of Bakersfield). High resolution topographic data allows us to see channels, hillslopes, landslides, and faults: these features are difficult if not impossible to identify on low resolution data.

This ARO project developed a series of tools for extracting information from these new and expanding datasets. They tools are open source and distributed to the wider geomorphology community. They have been used to explore some fundamental questions about how landscapes erode. Below the primary findings are described.

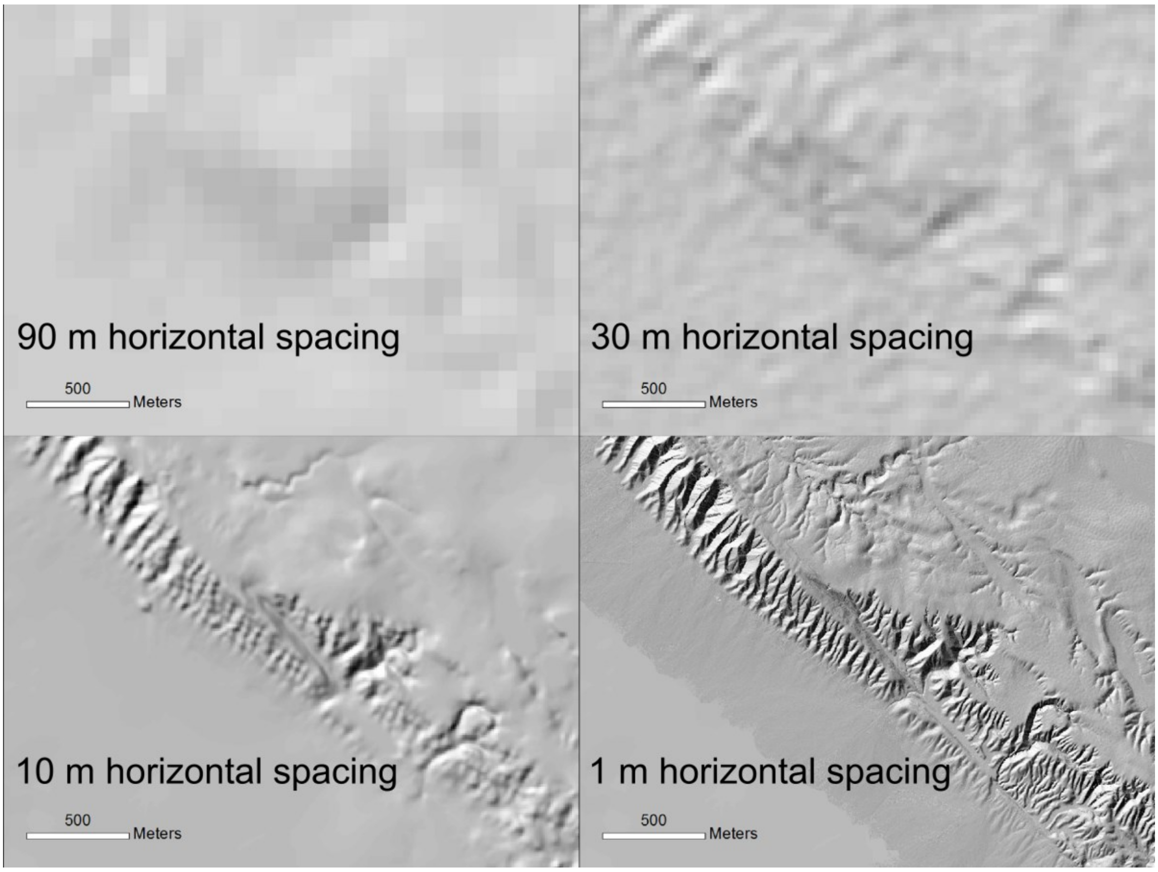

Figure 1: Different features visible from different topographic data resolutions.

Summary of Most Important Results

One of the key goals of the project was to link landscape characteristics to erosion rates and modes of erosion and previous theory had suggested that ridgetops were reliable recorders or erosion rate information. We wanted to link these features to the channel network, however, and we needed reliable methods of extracting channel networks from topographic data. We tested several methods of network extraction against field data, and developed a new method that can locate channel heads to within <20 metres of field mapped channel heads (Clubb et al., 2010). We also tested these methods for grid resolution and found that one channel extraction method that uses spectral filters plus a statistical method for determining threshold landscape curvature was relatively insensitive to grid resolution up to grid sizes of 10 meters (Figure 2, Grieve et al., 2016a).

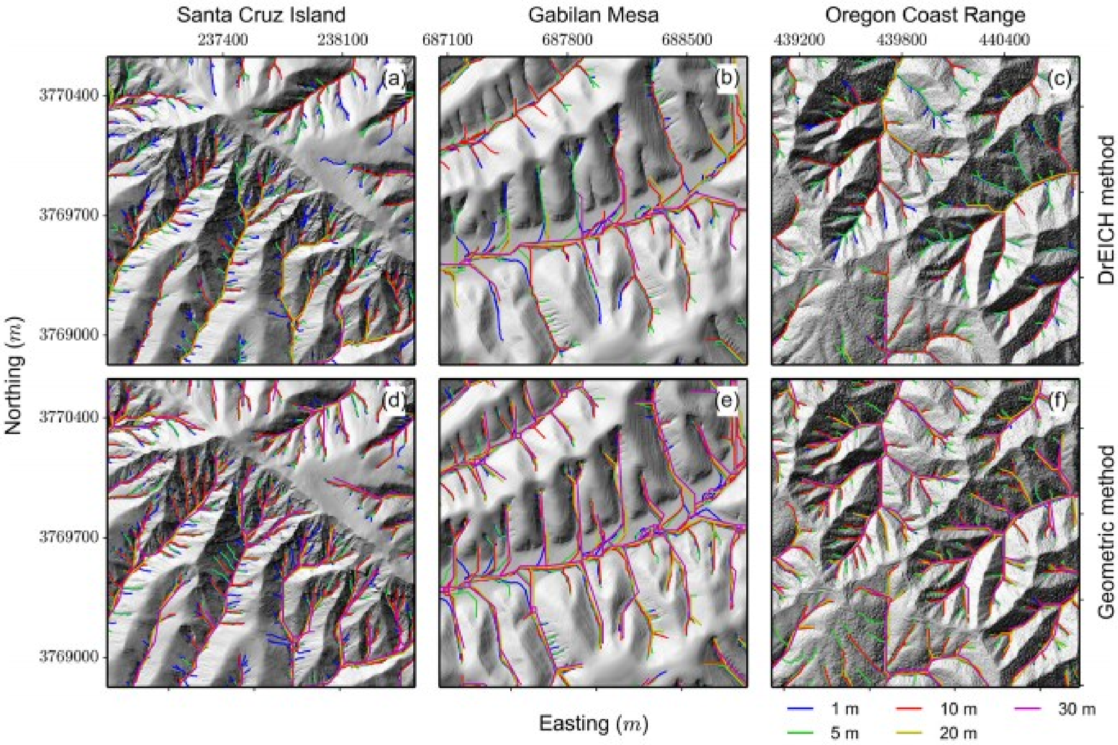

Figure 2: Influence of grid resolution on drainage network extraction in three sites in the USA. We find that drainage networks based on geometric methods (which use tangential curvature to detect the tips of drainage networks) are relatively insensitive to grid resolution up to a resolution of ~10 meters. Figure from Grieve et al., 2016a.

Linking the hillslope and channel themes of this project, we explored how drainage density, fundamentally set by the competition between fluvial and hillslope processes, was modulated by erosion rates. We used drainage extraction algorithms, developed for this project in 2014, to quantify drainage density across erosion rate gradients in five landscapes and compared the results with numerical models of landscape evolution. The result, consistent with our work on river profiles, is that the *n* exponent in fluvial incision laws is likely greater than 1. To our knowledge, this is the first quantitative exploration of how drainage density responds to changes in erosion rates (Figure 3).

We also developed algorithms that traced lines of steepest descent from the hillcrests to channels (Grieve et al., 2016b). This allowed us to explore how relief varied with hillslope length across a wide range of landscapes. In order to predict how rapidly a hillslope erodes, we need to quantify the relationship between sediment flux and hillslope properties such as topographic gradient, which are called “sediment flux laws”. In the Grieve et al. (2016b) study we demonstrated that the relief-hillslope length relationship could be used to test the correct sediment flux law and we found a nonlinear relationship between flux rates and topographic gradient was most consistent with measured data. This paper won the 2017 Wiley award for best paper in Earth Surface Processes and Landforms.

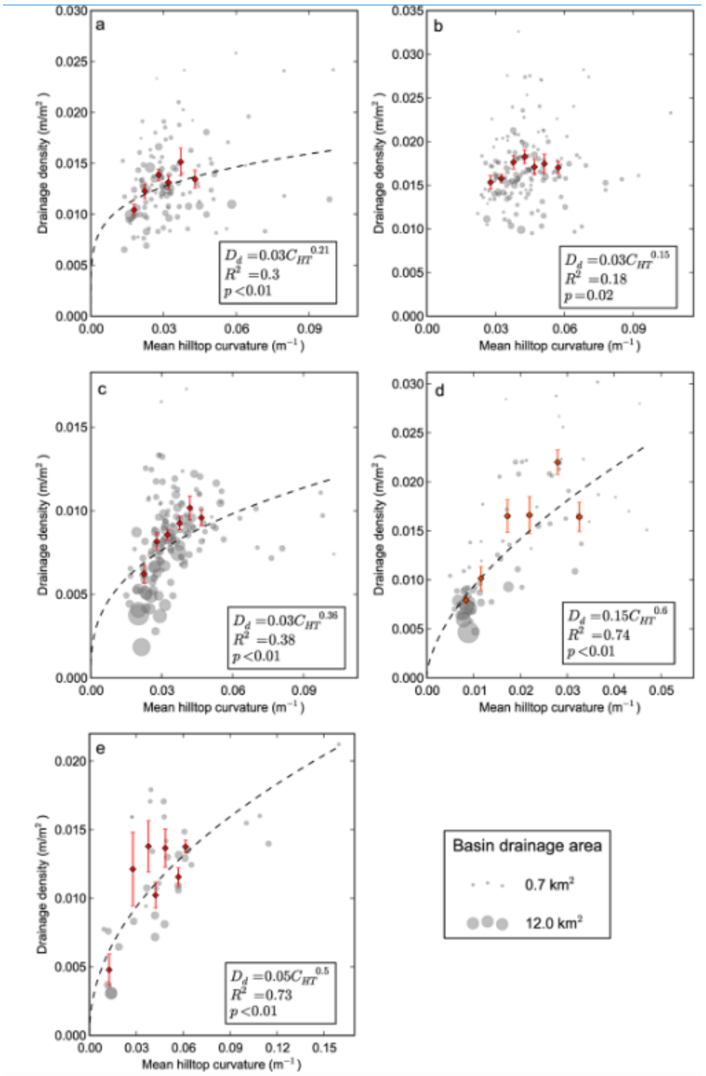

Figure 3: Drainage density as a function of hilltop curvature (which we have previously shown to be a proxy for erosion rate) across 5 landscapes **a)** Feather River, CA, **b)** San Gabriel Mountains, CA **c)** Boulder Creek, CO **d)** Guadeloupe Mountains, NM **e)** Bitterroot National Forest, ID. Figure from Clubb et al., (2016).

We also explored how topographic roughness could be used to predict the presence or absence of soil in eroding landscapes. This algorithm could then be used to demonstrate how at higher erosion rates soils not only become thinner, but also become more patchy (Milodowski et al, 2015). This algorithm can be used to determine rocky areas and boulders in landscape from topographic data alone.

The project also explored how river channels could be used to explore differences in erosion rates. We developed new methods for normalizing river profiles for drainage area, which is necessary because headwaters are steeper than large downstream channels regardless of erosion rate. Our method then was used to explore if relatively steep channels correlated with extensive damage during large flood events (Devrani et al., 2015). This software (Mudd et al., 2018) can be used for detecting increases in fault activity (Mudd, 2017), and has been used by agencies such as the United States Geological Survey and the Chinese Earthquake Administration (personal communications).

We wished to use the algorithms for extracting channel steepness to understand the effects of climate and lithology on the relative erodibility of bedrock channels. To do this, however, we also needed erosion rate information. Many studies of erosion rates use cosmogenic nuclides such as ^{10}Be and ^{26}Al to determine erosion rates over millennial timescales, but there was no consistent method for calculating these rates, so we developed one (Mudd et al., 2016). This method now lies behind the erosion rate calculations of a global compilation of erosion rates (https://earth.uow.edu.au/).

This method for computing erosion rates was then used to compare relative erodibilities across a wide range lithologies and climates. In doing so, we were able to demonstrate that systematic climatic and lithologic values for erodibility could be computed (Harel et al., 2016; Figure 4).

Quantifying how river profiles respond to climate and lithology was one of the key aims of the project: this work proved to be quite challenging due to technological barriers, but after developing several new algorithms for processing erosion rates and analysing river channels we have finished analysing a global dataset of erosion rates and river profiles. The results were published in 2016 (Harel et al., 2016).

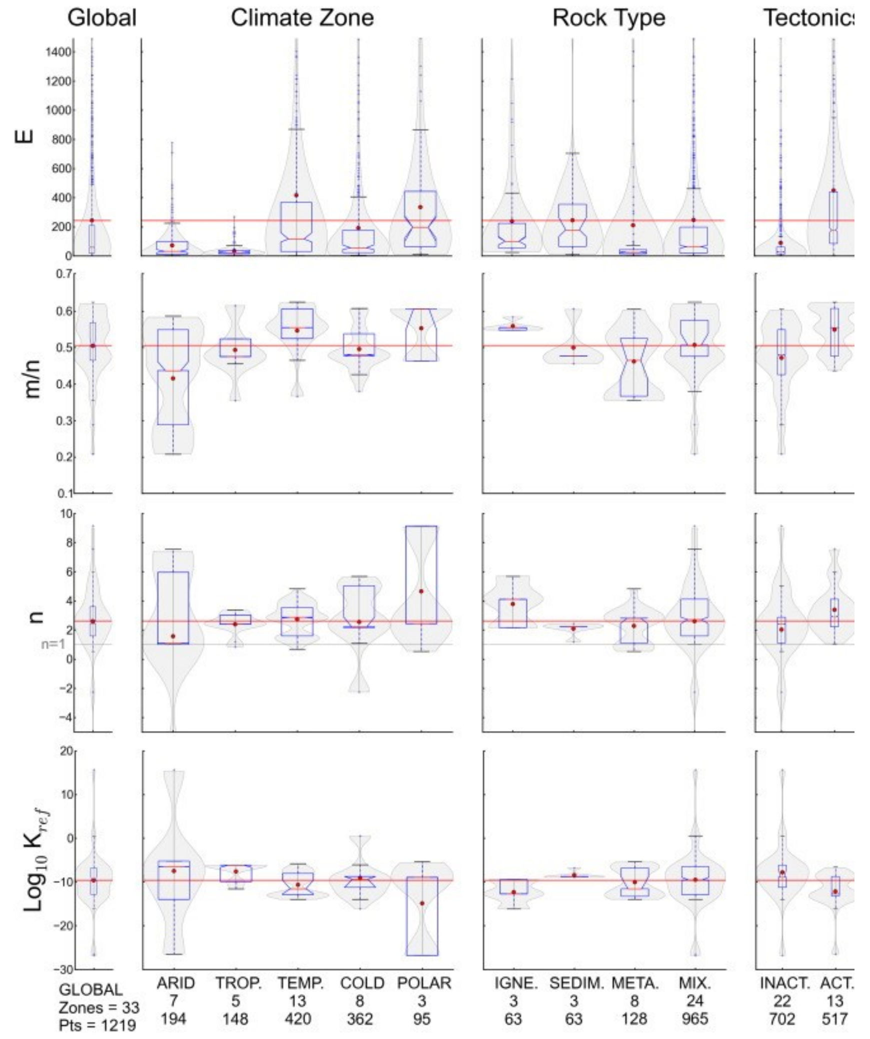

Figure 4: Controls of different climate, bedrock type and seismic activity on erosion rates (E), channel concavity (m/n), the slope exponent (n), and erodibility (K_{ref}) based on 1219 erosion rates. Figure from Harel et al., (2016).

This analysis found several fundamental results. Firstly, river erosion rates is typically thought to scale with discharge (which is modulated by climate) and channel slope. The relationship between erosion rates and channel slope is proposed to be a power relationship, i.e., E is proportional to S^n where n is some exponent. The value of this exponent fundamentally controls how channel networks respond to climate and tectonic forcing. If $n = 1$, channels perfectly preserve changing uplift rates. If $n > 1$, it means that rapid uplift rates will move upstream erasing the record of slower erosion rates.

A number of authors have assumed $n = 1$ and used river profiles to reconstruct histories of erosion and uplift across continents. Such reconstructions are of great value to the oil industry as the timing and rate of past erosion rates controls sediment delivery to basins and the timing of this delivery sets the potential for petroleum formation, and there have been around 20 publications using this technique since 2011. Our study finds that in almost all of our study sites (there were 70 with enough data to make meaningful comparisons) the slope exponent, n, is equal to 2 or greater (Figure 2), meaning that reconstructing uplift from channel profiles is dubious, at best.

The second key finding of this studies runs counter to prevailing theory that erodibility (K_{ref}) should scale with precipitation or other climate metrics. We found little variation in the erodibility as a function of precipitation, meaning that the main drivers of erosion must be driven by something other than precipitation (most models use a linear relationship between discharge, driven by precipitation, and erosion rates). While a negative result, this calls into question our theories about what drives channel incision: we suspect the factor missing from our analysis is sediment supply, although we do not have sufficient data at this time to test this hypothesis.

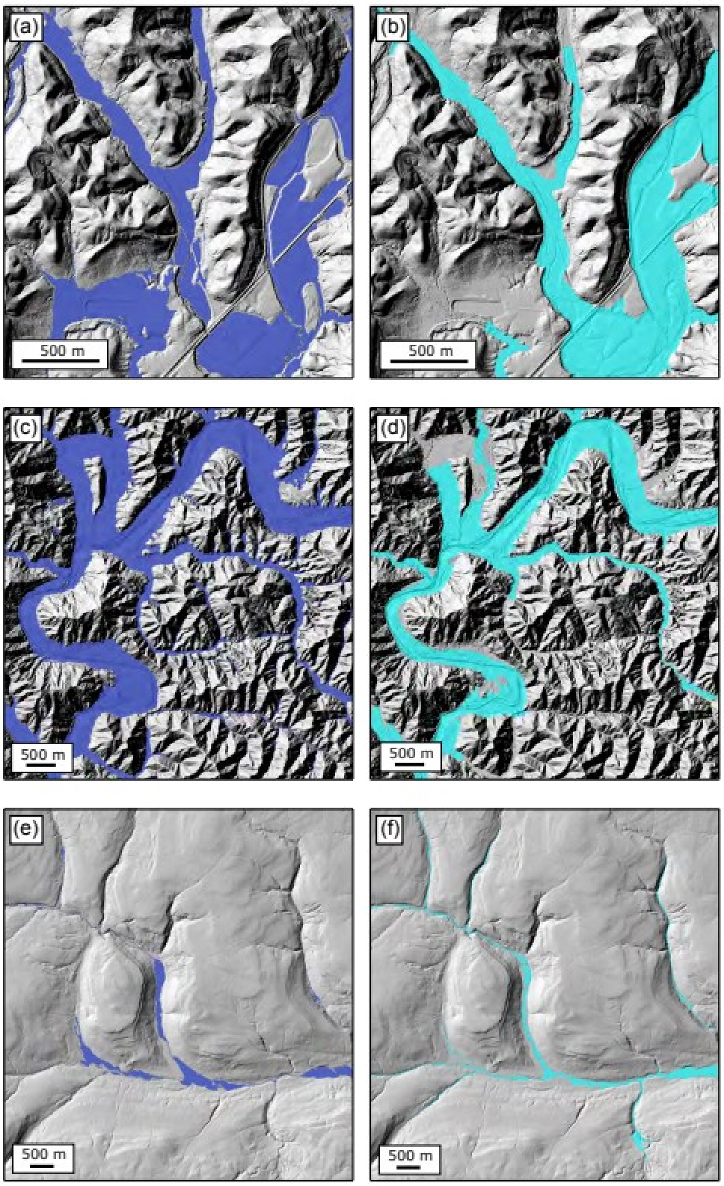

Figure 5: Shaded relief maps for each field site showing a comparison between the predicted floodplains (a, c, e) and the published FEMA/EA maps (b, d, f). (a–b) Mid Bailey Run, OH. (c–d) Russian River, CA. (e–f) River Swale, UK. Figure from Clubb et al., (2017d).

We then went on to explore the presence of terraces and floodplains in the landscape. We explored geomorphic floodplains: flat areas next to channels. We wanted to determine if simple geometry could give similar results to detailed hydrologic modelling. Our new algorithm performed well against floodplains mapped by both the Federal Emergency Management Agency (FEMA) in the USA and the Environment Agency (EA) in the UK. FEMA and EA flood maps involve many person days (sometimes person-months) of hydrologic modelling whereas our method only requires a few minutes of computation. It should not be seen as a substitute for hydrological modelling but is a very efficient way to identify potential problem areas for further investigation.

This work also enabled us to identify fluvial and terraces (Figure 6), which can give insight into changing erosion rates and tectonic uplift and tilting through time. We are currently using this method to explore controls on river evolution in both the Mendocino Triple Junction region and in the Himalayas.

Overall the ARO project produced a number of new methods for exploring high resolution data and we were able to quantitatively test theories about both the processes that shape our landscapes and about how landscapes respond to changes in erosion and uplift rates.

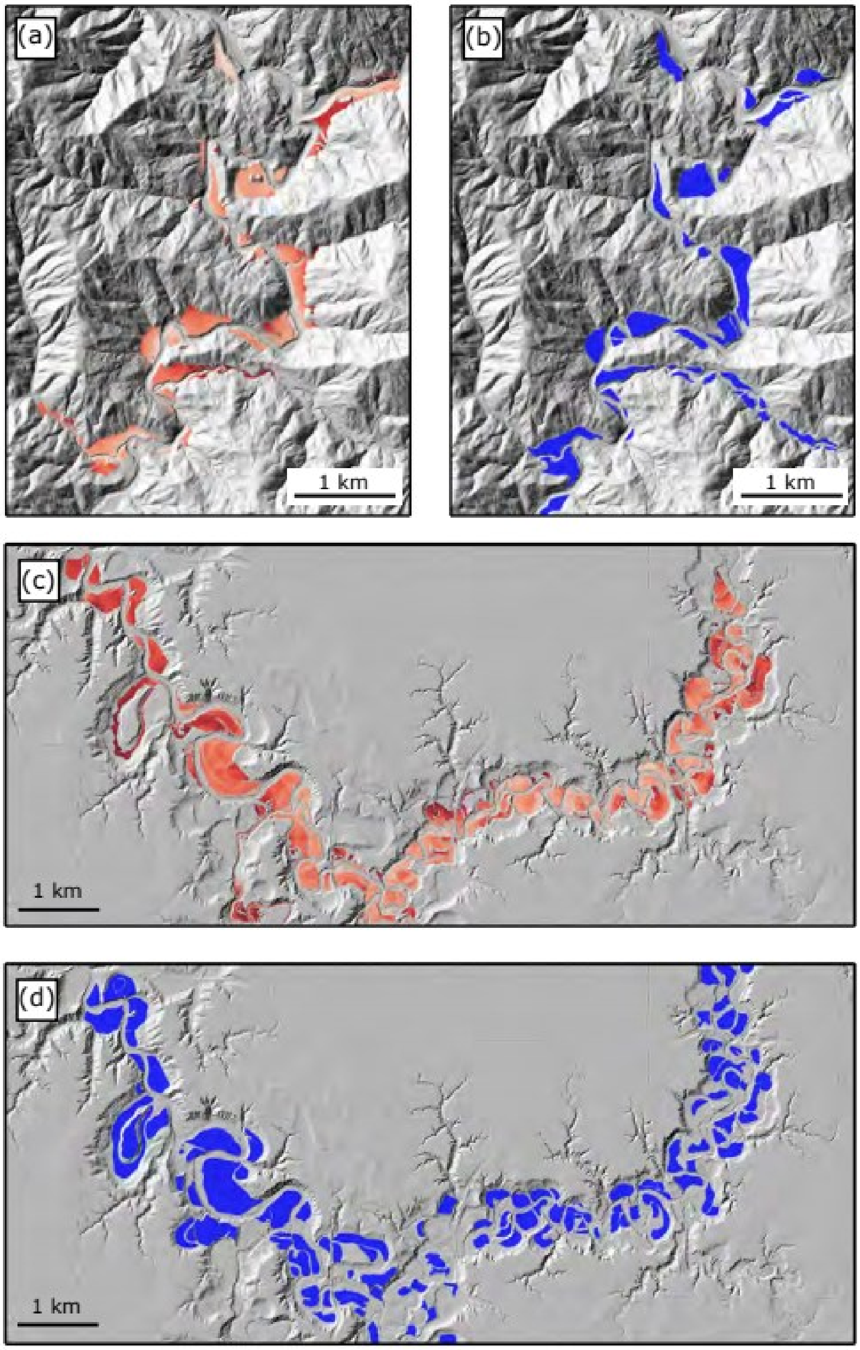

Figure 6: Shaded relief maps for two field sites with lidar derived DEMs showing a comparison between predicted terraces (red) and the digitised terraces (blue). The predicted terraces are coloured by elevation compared to the channel, where darker red indicates higher elevation. (a–b) South Fork Eel River, CA. Maximum terrace height is 43 m. (c–d) Le Sueur River, MN. Maximum terrace height is 9.5 m. Figure from Clubb et al., (2017d).

References

Clubb, F.J., Mudd, S.M., Milodowski, D.T., Hurst, M.D., Slater, L.J., 2014. Objective extraction of channel heads from high-resolution topographic data. Water Resour. Res. 50, 4283–4304. https://doi.org/10.1002/2013WR015167

Clubb, F.J., Mudd, S.M., Attal, M., Milodowski, D.T., Grieve, S.W.D., 2016. The relationship between drainage density, erosion rate, and hilltop curvature: Implications for sediment transport processes. Journal of Geophysical Research-Earth Surface 121. https://doi.org/10.1002/2015JF003747

Clubb, F.J., Mudd, S.M., Grieve, S.W.D., Milodowski, D.T., Valters, D.A., Hurst, M.D., 2017a. LSDTerraceModel v1.0. Zenodo. https://doi.org/10.5281/zenodo.824205

Clubb, F.J., Mudd, S.M., Milodowski, D.T., Grieve, S.W.D., 2017b. LSDDrainageDensity v1.0. Zenodo. https://doi.org/10.5281/zenodo.824423

Clubb, F.J., Mudd, S.M., Milodowski, D.T., Grieve, S.W.D., Hurst, M.D., 2017c. LSDChannelExtraction v 1.0. Zenodo. https://doi.org/10.5281/zenodo.824198

Clubb, F.J., Mudd, S.M., Milodowski, D.T., Valters, D.A., Slater, L.J., Hurst, M.D., Limaye, A.B., 2017d. Geomorphometric delineation of floodplains and terraces from objectively defined topographic thresholds. Earth Surface Dynamics 5, 369–385. https://doi.org/10.5194/esurf-5-369-2017

Devrani, R., Singh, V., Mudd, S.M., Sinclair, H.D., 2015. Prediction of flash flood hazard impact from Himalayan river profiles. Geophysical Research Letters 42, 5888–5894. https://doi.org/10.1002/2015GL063784

Grieve, S.W.D., Mudd, S.M., Milodowski, D.T., Clubb, F.J., Furbish, D.J., 2016a. How does grid-resolution modulate the topographic expression of geomorphic processes? Earth Surface Dynamics 4, 627–653. https://doi.org/10.5194/esurf-4-627-2016

Grieve, S.W.D., Mudd, S.M., Hurst, M.D., 2016b. How long is a hillslope? Earth Surface Processes and Landforms 41, 1039–1054. https://doi.org/10.1002/esp.3884

Grieve, S.W.D., Mudd, S.M., Hurst, M.D., Milodowski, D.T., 2016c. A nondimensional framework for exploring the relief structure of landscapes. Earth Surface Dynamics 4, 309–325. https://doi.org/10.5194/esurf-4-309-2016

Harel, M.-A., Mudd, S.M., Attal, M., 2016. Global analysis of the stream power law parameters based on worldwide Be-10 denudation rates. Geomorphology 268, 184–196. https://doi.org/10.1016/j.geomorph.2016.05.035

Milodowski, D.T., Mudd, S.M., Mitchard, E.T.A., 2015. Topographic roughness as a signature of the emergence of bedrock in eroding landscapes. Earth Surface Dynamics 3, 483–499. https://doi.org/10.5194/esurf-3-483-2015

Mudd, S.M., Harel, M.-A., Hurst, M.D., Grieve, S.W.D., Marrero, S.M., 2016. The CAIRN method: automated, reproducible calculation of catchment-averaged denudation rates from cosmogenic nuclide concentrations. Earth Surface Dynamics 4, 655–674. https://doi.org/10.5194/esurf-4-655-2016

Mudd, S.M., Jenkinson, J., Valters, D.A., Clubb, F.J., 2017. MuddPILE the Parsimonious Integrated Landscape Evolution Model. Zenodo. https://doi.org/10.5281/zenodo.997407

Mudd, S.M., 2017. Detection of transience in eroding landscapes. Earth Surface Processes and Landforms 42, 24–41. https://doi.org/10.1002/esp.3923

Mudd, S.M., Clubb, F.J., Gailleton, B., Hurst, M.D., Milodowski, D.T., Valters, D.A., 2018. The LSDTopoTools Chi Mapping Package. Zenodo. https://doi.org/10.5281/zenodo.1291889