Readme

This repository contains driver files, output data and plotting scripts associated with the paper "Detection of channel-hillslope coupling along a tectonic gradient" published in Earth and Planetary Science Letters (Hurst et al., 2019).

Abstract: Landscape morphology reflects the spatial and temporal history of erosion. Erosion in turn embodies the competition between tectonic and climatic processes. Quantitative analysis of topography can therefore reveal the driving tectonic conditions that have influenced landscape development, when combined with theoretical understanding of erosion processes. Recent developments in the automated analysis of high-resolution (<10 m) topographic data mean that integrated analysis of hillslope and channel topographic metrics can pro-vide understanding of the transient response of landscapes to changing boundary conditions. We perform high-resolution topographic analysis of hillslopes and channels in small (<3 km^2) catchments spanning an inferred uplift gradient along the Bolinas Ridge, California, USA, revealing tight coupling between channel steepness and hillslope metrics thought to be proxies for erosion rates. We find that the concavity of channel longitudinal profiles varies inversely with uplift rates, although drainage density increases with uplift rates. Both of these results can be explained by the contribution of mass wasting processes to valley formation in steeper (high uplift rate) landscapes. At the catchment scale, hillslope and channel metrics for erosion are correlated, hillslopes and channels steepen in concert, and hilltops (ridges) get sharper with increased uplift rate. This broad agreement suggests that hillslopes are responding to erosion rates in the channel network, which implies that landscape uplift is relatively stable and prolonged. Hillslope morphology deviates systematically from the steady-state predictions of established geomorphic transport laws, suggesting that hillslope adjustment is ongoing and that relief is growing.

Parameter Files

Detailed instructions on the use of the software are available in the documentation (Mudd et al., 2019a). The topographic analysis conducted for this paper was completed using LSDTopoTools2 (Mudd et al., 2019b). Channels were extracted used a threshold in contour curvature on a filtered digital terrain model (DTM) (Pelletier, 2013; Clubb et al., 2016; Grieve et al., 2016). The channel network was analysed to quantify concavity and normalised channel steepness (Mudd et al., 2018). Hillslopes were analysed to extract hilltop curvature, hillslope gradient and hillslope length (Hurst et al., 2012; Grieve et al., 2016), and spatially link them to the adjacent channel network. The parameter files contain keywords followed values for the topographic analysis that are read by these analysis tools. The parameter files used are described below and links to the associated documentation provided.

File	Description
Bolinas_channel_extraction_params.driver	Parameter file for extraction of channel head locations. For more information, see https://lsdtopotools.github.io/LSDTT_documentation/LSDTT_channel_extraction.html [last accessed 12th June 2019]
Bolinas_ChiTool_movern_params.driver	Parameter file for analysis of channel concavity. For more information, see https://lsdtopotools.github.io/LSDTT_documentation/LSDTT_chi_analysis.html [last accessed 12th June 2019]
Bolinas_ChiTool_channel_segments_params.driver	Parameter file for analysis of channel steepness. For more information, see https://lsdtopotools.github.io/LSDTT_documentation/LSDTT_chi_analysis.html [last accessed 12th June 2019]
Bolinas_hillslope_params.driver	Parameter file for analysis of hillslope morphology. For more information, see https://lsdtopotools.github.io/LSDTT_documentation/LSDTT_hillslope_metrics.html [last accessed 12th June 2019]

Data Files

Output files from LSDTopoTools with results of the analyses.

Data Folder Files	Description
bolinas_all_catchments_centroids.shp	Shapefile containing point data for the centroid position of each analysed catchment used to calculate distance along the Bolinas ridge.
bolinas_all_catchments_centroids.txt	Data on the ID, Drainage Area and Distance along the Bolinas Ridge for each catchment centroid in bolinas_all_cattch-ments_centroids.shp
Bolinas_AllBasins.shp	Shapefile containing polygons defining all the basins analysed along the Bolinas Ridge
bolinas_DEM_sample.bil	A small sample of the topographic dataset used in analysis for test purposes. The topographic data used was the USGS National Ele-vation Dataset 1/9 arc second https://nationalmap.gov/eleva-tion.html, projected to UTM Zone 10N to produce a 3 m resolution digital terrain model (DTM).
bolinas_DEM_sample_HS.bil	A hillshade image of the Bolinas_DEM_sample.bil layer.
bolinas_basin_topo_metrics.txt	Topographic analysis summary results by drainage basin. For each basin analysed the mean, median, standard deviation, standard er-ror, 5th, 16th, 84th and 95th percentiles of hilltop curvature (CHT), hillslope length (LH), slope gradient (SLP) and channel steepness (MChi).
Bolinas_CH_wiener_nodeindices_for_Arc.csv	Coordinates (Easting, Northing) of pixels defined as channel heads according to a threshold in contour curvature applied to the DEM that had been filtered using an optimal Wiener filter (Pelletier, 2013). Data generated using the LSDTopoTools channel extraction tool: https://lsdtopotools.github.io/LSDTT_documenta-tion/LSDTT_channel_extraction.html
Bolinas_HilltopData.csv	Output from hillslope routing algorithm containing results for all hillslope traces conducted. See link to documentation below for more details: https://lsdtopotools.github.io/LSDTT_documenta-tion/LSDTT_hillslope_metrics.html
Bolinas_hillslope_traces.shp	Shapefile containing polyline data mapping hillslope traces for an example area provided in Bolinas_DEM_sample.bil
Bolinas_MChiSegmented.csv	Results of Chi analysis. See: https://lsdtopotools.github.io/LSDTT_documenta-tion/LSDTT_chi_analysis.html
bolinas_junctions.list	A list of node indices in the DEM where the outlets of the analysed catchments reach junctions in the channel network.
bolinas_kirby_data.csv	Reproduction of data in Table 1 from (Kirby et al., 2007).
channel_data folder	Results of Chi analysis. See: https://lsdtopotools.github.io/LSDTT_documenta-tion/LSDTT_chi_analysis.html
m_over_n_data folder	Results of analysis to determine the most likely concavity index for each basin analysed. See https://lsdtopotools.github.io/LSDTT_documenta-tion/LSDTT_chi_analysis.html

Plotting Scripts

Plotting scripts are python scripts that process data and plot the results associated with each figure of the paper. All paths are relative such that the plotting scripts can be run from the command line or a python IDE. These scripts have a number of library dependencies but can be run on the LSDTopoTools vizualisation docker container (see https://lsdtopotools.github.io/LSDTT_documentation/LSDTT_installation.html [last accessed 13th June 2019]).

Plotting Scripts	Description
Fig2_Hillslope_Traces.py	Plots Figure 2 of the paper showing examples of the channel network, hilltop segments and hillslope traces.
Fig3_Determine_Sc.py	Plots Figure 3 from the paper. Script to determine the most appropriate value for Sc by finding the gradient below which 99% of all hillslope traces sit. Plots the result.
Fig4_Plot_DD_Lh_Ksn.py	Plots Figure 4 from the paper showing the distribution of drainage density along the length of the Bolinas Ridge landform. Compares drainage density to hillslope lengths and colour codes everything by channel steepness (proxy for erosion/uplift rates)
Fig5_Plot_Concavity_Results.py	Plots Figure 5 from the paper showing the distribution of concavity along the length of the Bolinas Ridge landform based on the Chi bootstrap and Chi disorder methods.
Fig6_All_Ksn_Profiles.py	Plots Figure 6 from the paper showing the longitudinal profiles of the trunk channel in each basin analysed, shaded by channel steepness index.
Fig7_Metrics_Distance.py	Plots Figure 7 from the paper showing the distributions of dimensionless erosion rate, dimensionless relief and channel steepness index in each basin along the length of the Bolinas Ridge landform.
Fig8_Ksn_Es_Rs.py	Plots Figure 8 from the paper showing the relationships between channel steepness, dimensionless erosion rate and dimensionless relief for catchments along the Bolinas Ridge landform.
Fig9_Spaghetti.py	Plots Figure 9 from the paper showing the median and 90th percentile contour dimensionless erosion rate and dimensionless relief for hillslopes in each basin in comparison to the predictions of a nonlinear sediment flux model.
Fig10_EsRsViolins.py	Plots Figure 10 from the paper showing the orthogonal residuals of dimensionless erosion rate and dimensionless relief derived from hillslope morphology, relative to predictions of the nonlinear sediment flux model.

References

Clubb, F. J., Mudd, S. M., Milodowski, D. T. and Grieve, S. W. D.: The relationship between drainage density , erosion rate , and hilltop curvature : implications for sediment transport processes, J. Geophys. Res. Earth Surf., 121, 1724–1745, doi:10.1002/2015JF003747, 2016.

Grieve, S. W. D., Mudd, S. M. and Hurst, M. D.: How long is a hillslope?, Earth Surf. Process. Landforms, n/a-n/a, doi:10.1002/esp.3884, 2016.

Hurst, M. D., Mudd, S. M., Walcott, R., Attal, M. and Yoo, K.: Using hilltop curvature to derive the spatial distribution of erosion rates, J. Geophys. Res. Earth Surf., 117(2), doi:10.1029/2011JF002057, 2012.

Hurst, M. D., Grieve, S. W. D., Clubb, F. J. and Mudd, S. M.: Detection of channel-hillslope coupling along a tectonic gradient, Earth Planet. Sci. Lett., 2019.

Kirby, E., Johnson, C., Furlong, K. and Heimsath, A.: Transient channel incision along Bolinas Ridge, California: Evidence for differential rock uplift adjacent to the San Andreas fault, J. Geophys. Res. Earth Surf., 112(3), doi:10.1029/2006JF000559, 2007.

Mudd, S. M., Clubb, F. J., Gailleton, B. and Hurst, M. D.: How concave are river channels?, Earth Surf. Dyn., 6(2), 505–523, doi:10.5194/esurf-6-505-2018, 2018.

Mudd, S. M., Clubb, F. J., Gailleton, B., Grieve, S. W. D., Valters, D. A. and Hurst, M. D.: LSDTopoTools Documentation, , doi:10.5281/ZENODO.2560224, 2019a.

Mudd, S. M., Clubb, F. J., Grieve, S. W. D., Milodowski, D. T., Hurst, M. D., Gailleton, B. and Valters, D. A.:

LSDTopoTools2, , doi:10.5281/ZENODO.3245041, 2019b.

Pelletier, J. D.: A robust, two-parameter method for the extraction of drainage networks from high-resolution digital elevation models (DEMs): Evaluation using synthetic and real-world DEMs, Water Resour. Res., 49(1), 75–89, doi:10.1029/2012WR012452, 2013.