Global River Slope (GloRS): a New Geospatial Dataset for Riverine Modeling and Analysis

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This research is funded as part of a National Science Foundation -- Geography and Spatial Sciences (GSS) Program, grant (number 1561082)

Introduction

- Rivers' longitudinal gradient (i.e. slope) is a key parameter in fluvial hydrology, hydraulics, and geomorphology.
- Riverine slope affects a multitude of fluvial variables such as flow velocity and sediment transport.
- Limitations in the availability and accuracy of river slope data constrain the fidelity of fluvial modeling, particularly at large scales.
- Traditional slope calculation algorithms cannot accurately predict river slopes as these algorithms are based on cell-by-cell calculation, which is only suitable for hillslopes and steep streams.
- The **Global River Slope (GloRS**; Cohen et al., 2018) dataset calculation, validation and analysis is presented herein.

Methodology

- GloRS is based on a simple principle of calculating slope from elevation depression over the length of a river segment.
- Slope for a given river segment length is calculated using the difference between its highest and the lowest elevation (derived from an underlying DEM), corresponding to its most upstream and downstream locations respectively.
- Calculated using global-scale stream network and DEM through an automated GIS procedure with new stream conditioning and grid upscaling procedures.
- GloRS v1.0 (Cohen et al., 2018) and v1.1:
  - 15 arc-sec resolution (~460 × 460 m) SHuttle Elevation Derivatives at multiple Scales (HydroSHEDS) DEM and stream-network were used.
  - 1 arc-min etopo DEM was used for high (>60°) latitudes.
  - Stream segments were split to limit their length to a maximum of 50km.
- Upscaling:
  - Upscaling a river slope layer to coarser spatial resolution is warranted for large-scale fluvial modeling frameworks (e.g. WBMsed; Cohen et al., 2013, 2014).
  - Standard GIS resolution-conversion tools average the cell values of the high-resolution grid-cells, leading to overestimation of river slope as both the main channel and its tributaries are averaged.
  - An upscaling procedure was developed and used to upscale GloRS from 15 arc-sec to 6 arc-min:
    - GloRS v1.0 - extracts the minimum slope value of the underlying high-resolution layer.
    - GloRS v1.1 - extract the slope value of the grid-cell with the maximum contributing area value in the underlying high-resolution layer.

Validation

- Two datasets were used to evaluate the accuracy of GloRS: observed slope values obtained from literature sources, and the National Hydrography Dataset Plus Version 2 (NHDPlusV2) stream network.
- A total of 34 river slope observations were collected (Fig. 1; from: Hinton et al. (2016), Williams and Rosgen (1989), Graf (1984), Knott and Lipscomb (1985), Jones and Seitz (1979).
- Upscaling product (6 arc-min) resulted in similar correlation as the fine resolution products (15 arc-sec).
- An adjustment equation was used to improve GloRS values in low-slope locations (Fig. 2a):

$$S_a = S_o\,(216.84S_o + 0.111)$$

where S_a is adjusted and S_o is original values.

- GloRS corresponded well to observed slope values with large biases (~1 order of magnitude) in 3 (out of 34) sites (Fig. 2b).

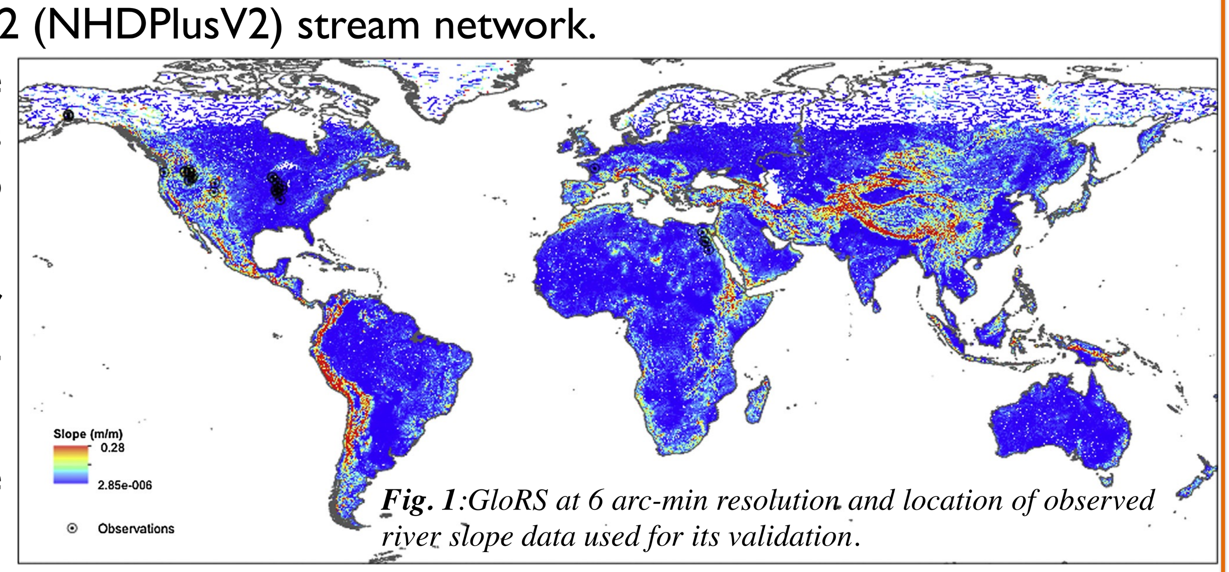

Fig. 1: *GloRS at 6 arc-min resolution and location of observed river slope data used for its validation.*

- NHDplus resulted in a weaker correlation, higher RMSE and greater difference in mean from observed slope compared to GloRS in 25 observation points (excluding 9 non-contiguous U.S. sites) (Table 1).

Table 1
Comparison between river slope databases in discrete number (N) of points.

Comparison	N	R^2	RMSE	Difference in Averages
GloRS 6-min vs. Observations	34*	0.64	0.0016	(0.0019 − 0.001) = 0.0008
GloRS 15-sec vs. Observations	34*	0.63	0.0034	(0.0031 − 0.001) = 0.002
Adjusted GloRS vs. Observations	34*	0.63	0.0016	(0.0015 − 0.001) = 0.0004
NHDPlus vs. Observations	25**	0.48	0.0078	(0.003 − 0.0012) = 0.0017
GloRS 6-min vs. Observations	25**	0.5	0.0019	(0.0024 − 0.0012) = 0.0011
GloRS 6-min vs. NHDPlus	173^	0.5	0.0025	(0.0023 − 0.003) = −0.00076

* Observations.
** Subset of the observation dataset (excluding non-contiguous U.S. sites).
^ Random points.

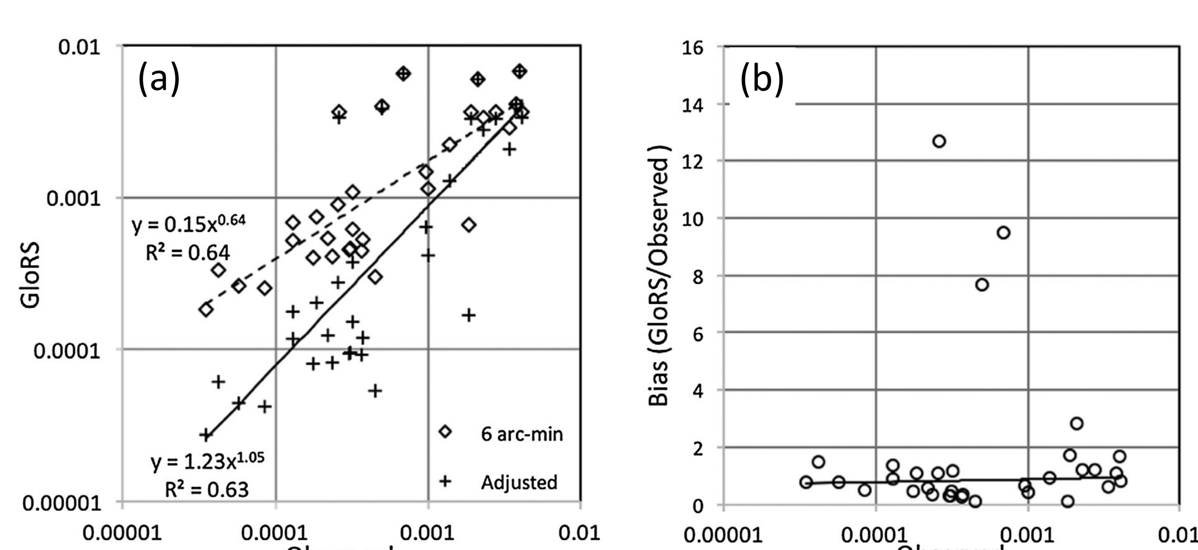

Fig. 2: *Comparison between observed river slope (n = 34) and initial and adjusted 6 arc-min GloRS (a) and bias relative to observed values for adjusted 6 arc-min GloRS (b).*

Distribution Analysis

Average continental river slope (Fig. 3) range by a factor of nearly 6 between the continents, with Australia having the lowest average (0.0006) and Asia the highest (0.0035). Low river slope averages in Australia are expected given the absence of a significant continental mountain range, attributable to its generally older basement geology. South America is particularly interesting as it includes both very high river slope values, concentrated along the narrow Andes, and extensive areas of relatively low sloping rivers (primarily within the Amazon Basin) (Fig. 1), resulting in the greatest variability in river slope (Fig. 3). The continents show relatively similar coefficient of variance, except for Oceania whose river-slope values are dominated by small mountainous Islands (primarily Papua and New Zealand); while average river-slope is high, variability within the islands is small.

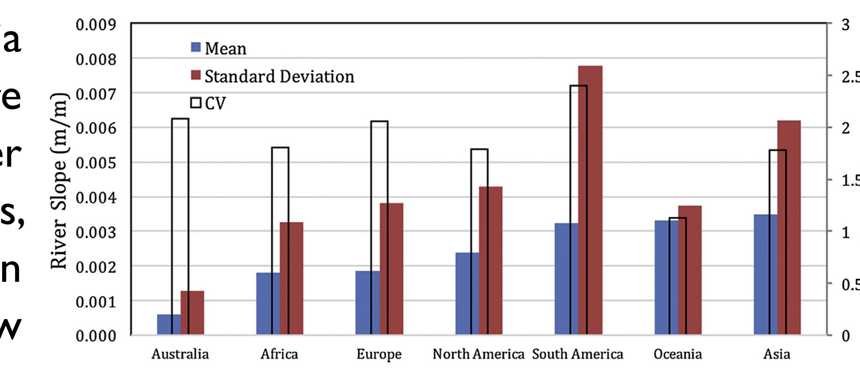

Fig. 3: *Average, standard deviation and coefficient of variation in river slope based on the adjusted 6 arc-min GloRS.*

Of the world's 30 largest river basins, three Asian rivers (Indus, Ganges-Brahmaputra, and Yangtze) have the highest average slope (Fig. 4a). These rivers are among the world's most tectonically active basins. Fig. 4b demonstrates that there is no direct link between basin size and its average river slope.

High within-basin variability in river slope is associated with rivers draining continental mountain ranges (Fig. 5). Central Asian basins yielded the highest variability followed by South American basins. The most homogenous basins are clustered in northeast Europe (e.g. Volga and Don Basins). Basins with high CV (Fig. 5 right) include large rivers draining mountain chains and developing extensive floodplains. Typically, these rivers are those draining into the passive margin side of large continental plates.

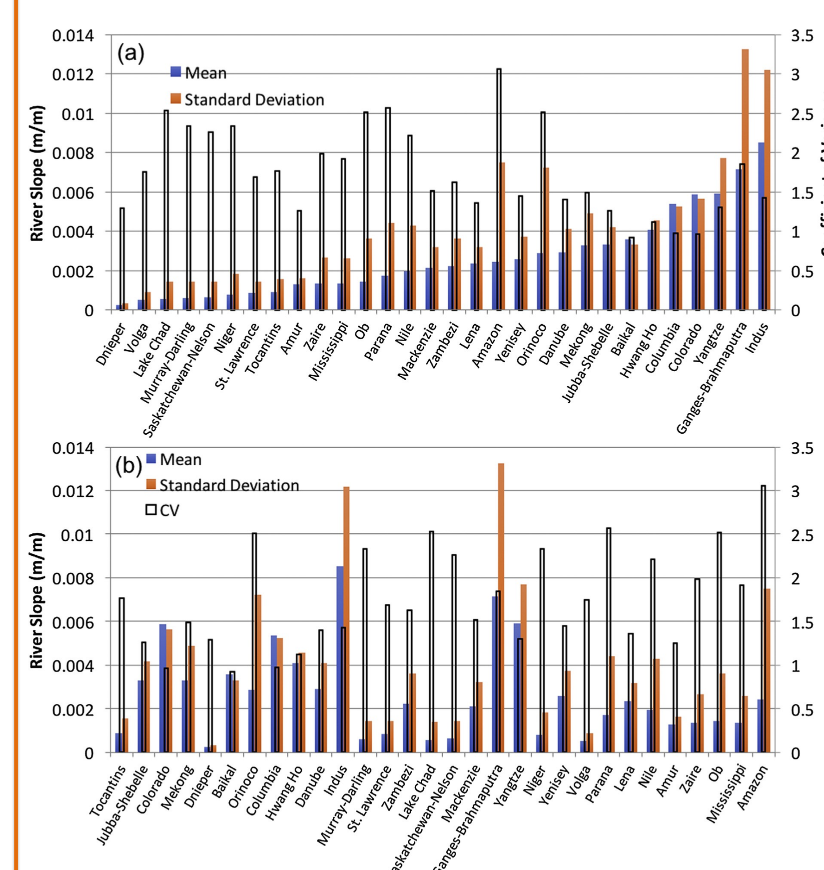

Fig. 4 (top): *Mean and standard deviation in river slope in the world's 30 largest river basins sorted by (a) average river slope and (b) basin size (increasing from left to right).*

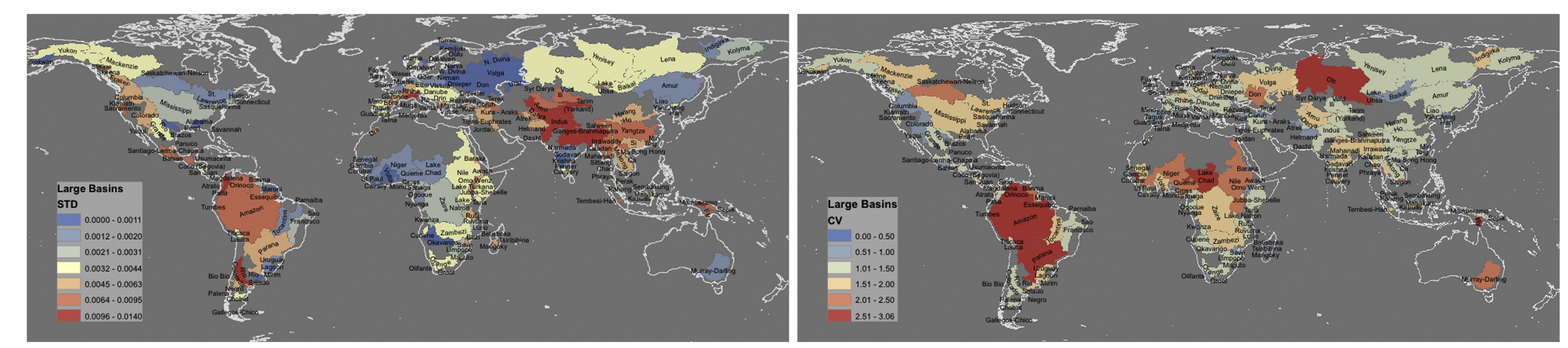

Fig. 5: *Standard deviation (left) and Coefficient of Variation (CV) (right)of river slope based on the adjusted 6 arc-min GloRS.*

Controlling Factors

An exploratory exercise was conducted to investigate the potential influence of different factors on river slope by testing the correlation between basin-averaged river slope as the dependent variable (n=234) and basin-statistics (mean, max, STD, and range) of lithology, discharge, sediment flux, precipitation and terrain slope.

Basin-averaged terrain slope explains 67% of the variability in basin-average river slope. This is an expected outcome given that rivers draining steep terrain have high slopes. This suggests that 37% of the variability in basin-averaged river slope is explained by other factors. A semi-empirical regression model based on the above analysis and our general assertions about the underlying drivers and mechanisms that may control river slope is proposed (Fig. 6):

$$RS = 10^{11.82}\,TS^{0.86}\,Q^{0.17}\,Q_s^{0.19}\,T^{6.18}$$

where RS (m/m) is river slope, TS is terrain slope (m/m), Q is discharge (m^3/s), Qs is sediment flux (kg/s) and T is temperature (°C).

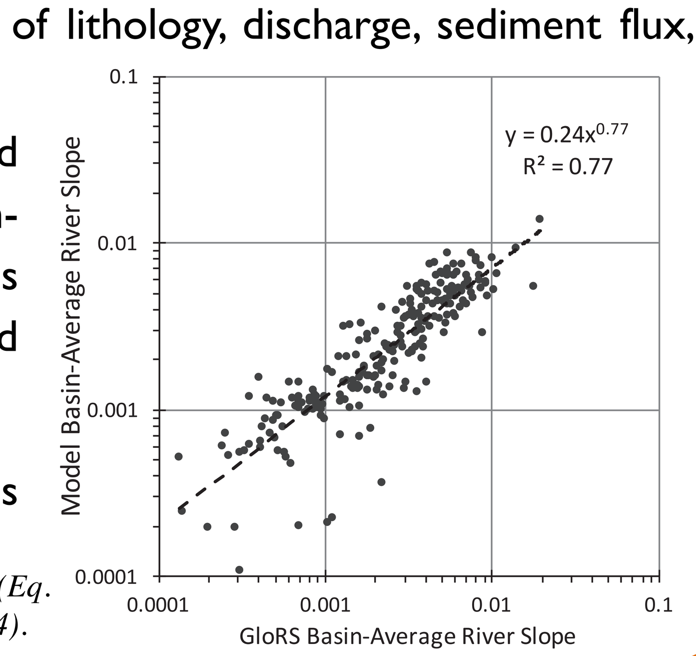

Fig. 6: *GloRS vs semi-empirical model (Eq. (2)) basin-averaged river slope (n = 234).*

Conclusions

- A new Global River Slope (GloRS) geospatial dataset was developed based on automation of a simple GIS approach of calculating elevation depression for each river segment.
- The calculation is based on (relatively) high-resolution DEM and stream network and upscaled to a courser resolution for use in global hydrology and geomorphic models.
- Good correspondence is achieved with observed values after applying a value-scaled adjustment equation.
- Continental and basin-scale distribution analysis highlight interesting new insights about the distribution of river slope and its links to topographic and geologic characteristics.
- We found that 67% of the variability in river slope is explained by average basin topography and an additional 10% was explained by its its climatic, hydrological and geomorphic characteristics.

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