Trends and Drivers of Bedload and Suspended Sediment Fluxes in Global Rivers

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Introduction – Bedload Flux Modeling

- Bedload flux measurement and modeling are notoriously challenging.
- Knowledge, analytical and predictive capabilities remain limited, especially for large rivers.
- Several bedload equations have been proposed **with parameterization which allows application within large-scale modeling frameworks**.
- Coupled with recent advances in global hydrology and sediment modeling, (first-order) global-scale bedload models could now be explored.

Methodology

- We introduce a new **bedload** and **suspended bed material (SBM)** modules to the *WBMsed* global hydro-geomorphic model (Cohen et al., 2014).
- *WBMsed* include a suspended sediment flux (SSF) module, using the BQART (Syvitski and Milliman, 2007) and Psi (Morehead et al., 2003) equations.
- Simulate daily water discharge (Q) and sediment fluxes at 6 arc-min resolution (~11km at the equator) in 'Disturbed' or 'Pristine' modes.
- Here we analyze long-term (30 yr) average (1990-2019) 'Disturbed' predictions.
- Mask small rivers; only include grid-cells with $Q>30\ m^3/s$.

SSF Module

- Syvitski and Milliman (2007) summarized global controls on sediment flux with the BQART equation:

long-term Average Discharge [m³/s]

contributing Area [km²]

maximum Relief [km]

long-term Average Suspended Sediment load [kg/s] →

$$\overline{Q}_s = wB\overline{Q}^{0.31}A^{0.5}R\overline{T}$$

← average Temp [°C]

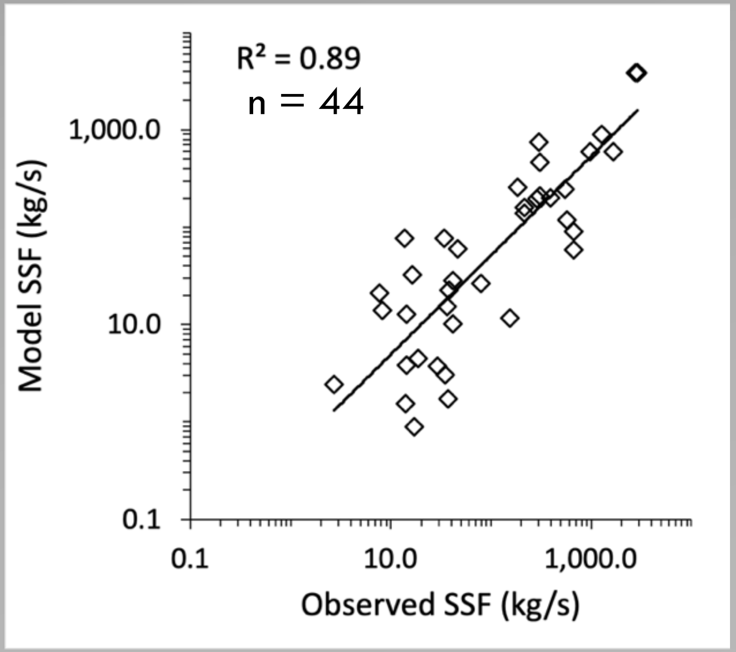
Ice Cover factor

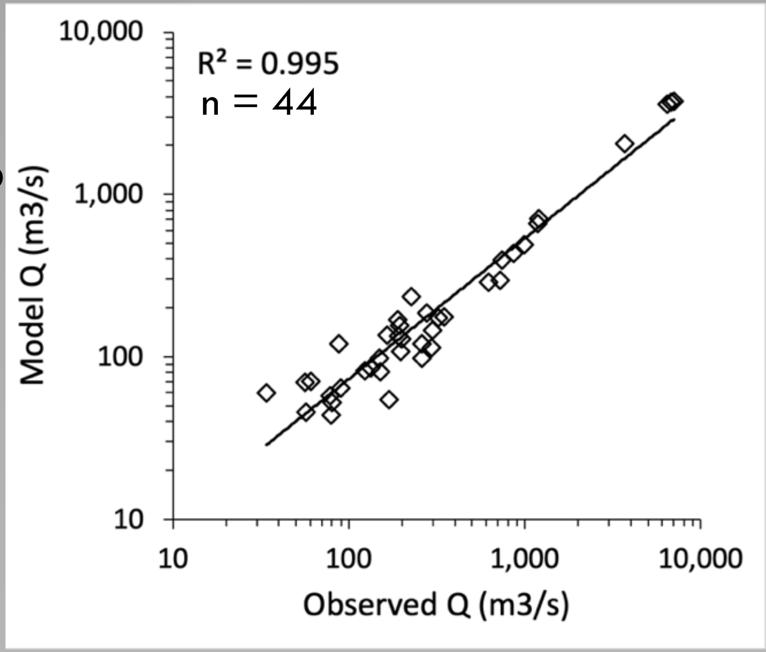
Sediment Trapping by reservoirs

$$B = IL(1-T_E)A_d$$

Lithology Factor

Anthropogenic Factor:
f(Pop. density, GNP)





Bedload Flux Module

<u>Lammers and Bledsoe (2018)</u> following (Bagnold, 1980) bedload transport rate (q_b kg/m/s):

$$q_b = a[\omega - \omega_c]^{\frac{3}{2}} D_s^{-\frac{1}{2}} q^{-\frac{1}{2}}$$

Modified for (kg/s): $$\boldsymbol{Q_b} = \left[a[\omega - \omega_c]^{\frac{3}{2}} D_s^{-\frac{1}{2}} \left(\frac{Q}{w}\right)^{-\frac{1}{2}} \right] w \text{ ; when } \omega > \omega_c$$

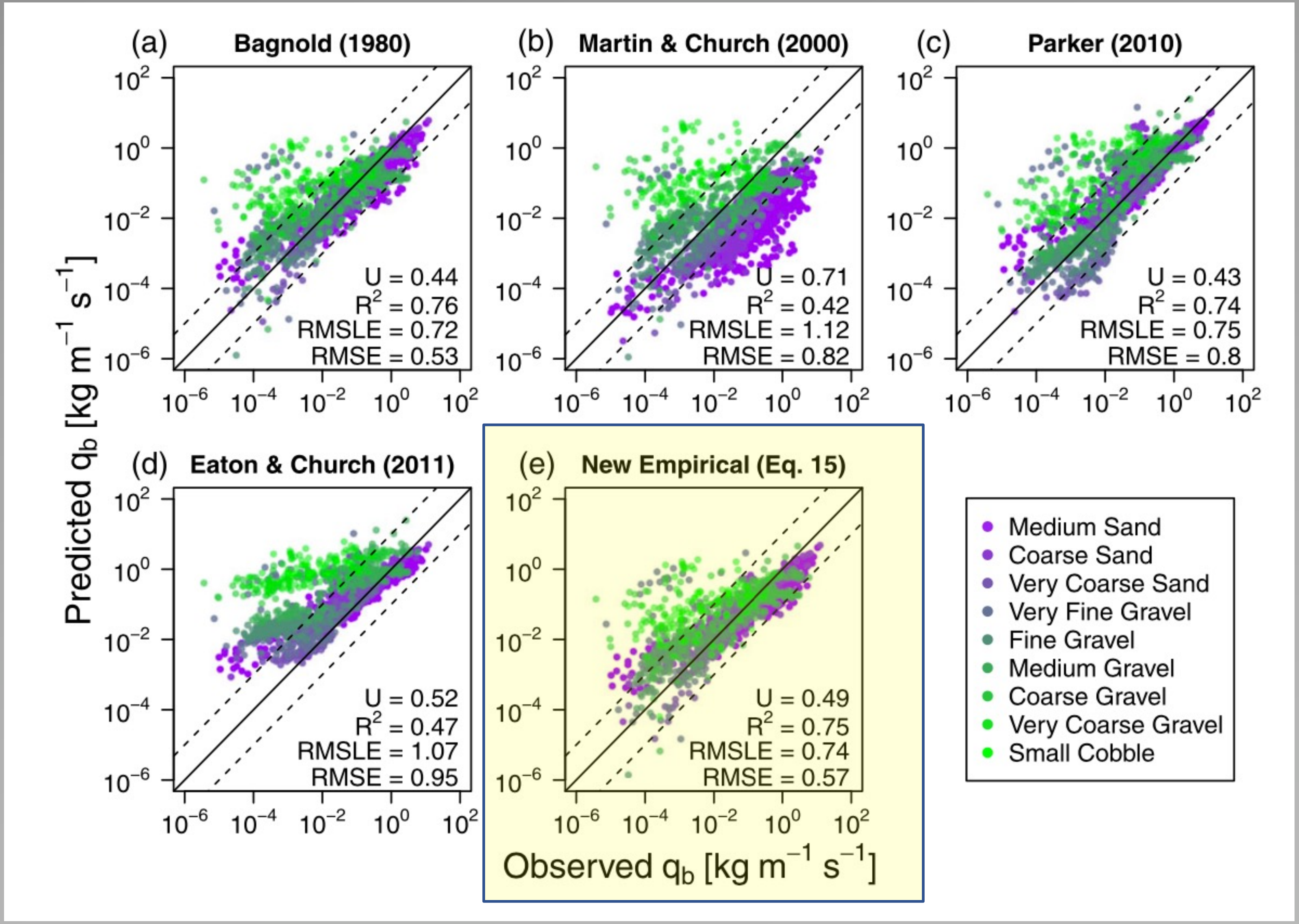
Q – discharge (m^3/s)
ρ - fluid density (kg/m^3)
D_s – representative grain size (m)
q – unit discharge (m^2/s)
w – river width (m)

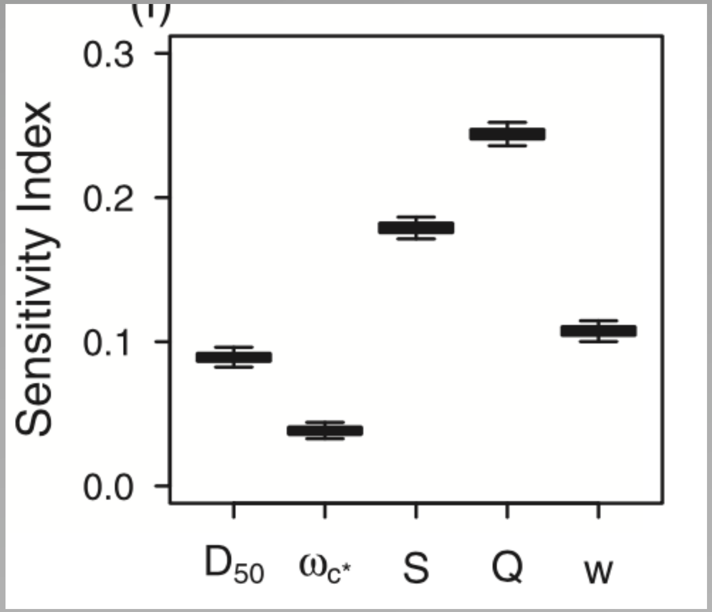
ω – stream power (W/m^2) $= \frac{\rho g Q S}{w}$
ω_c – critical stream power (W/m^2)
S – river slope (m/m)
g - acceleration due to gravity (9.81 m/s^2)
a – coefficient (0.0044)

Lammers, R. W., & Bledsoe, B. P. (2018). Parsimonious sediment transport equations based on Bagnold's stream power approach. *Earth Surface Processes and Landforms*, 43(1), 242-258.

Bedload Flux Equation

Lammers and Bledsoe (2018)

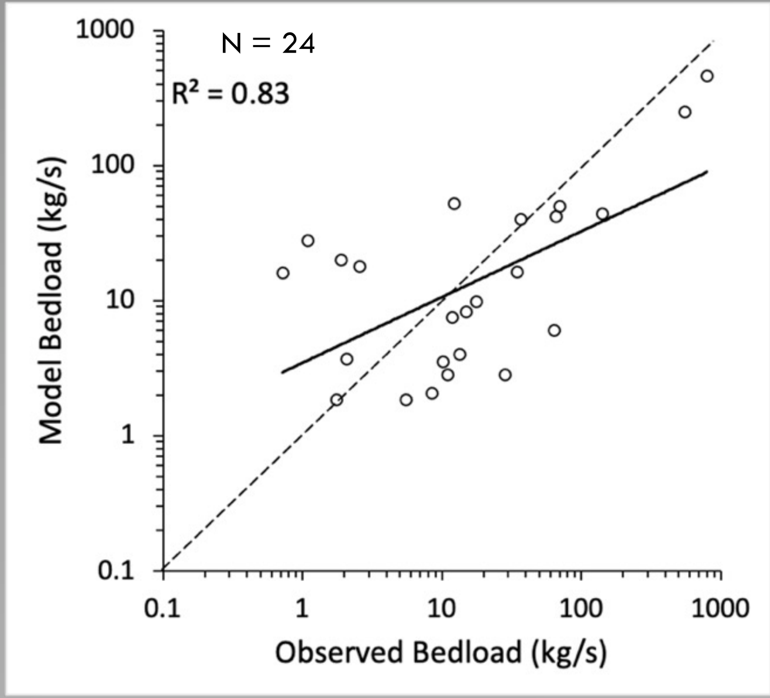




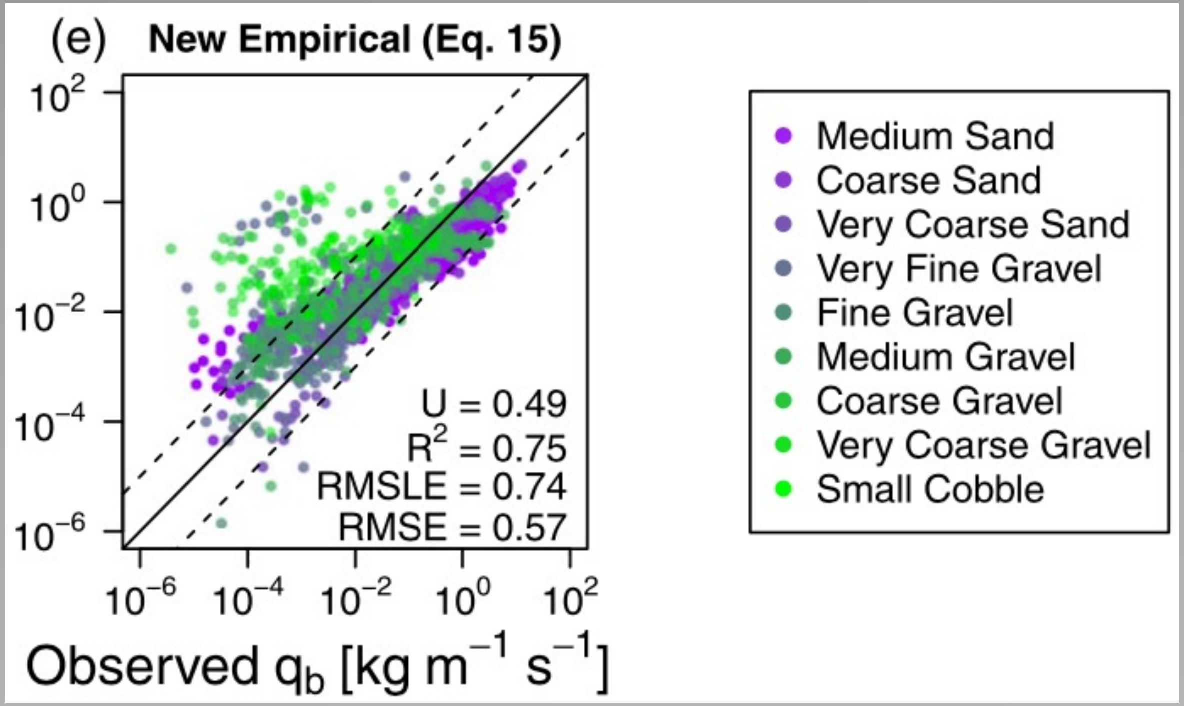
From: Lammers and Bledsoe (2018)

Results – Validation

WBMsed

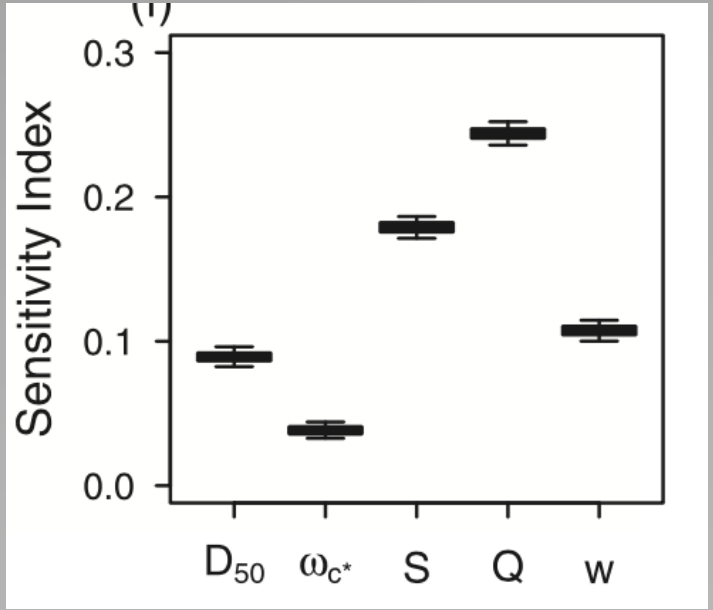


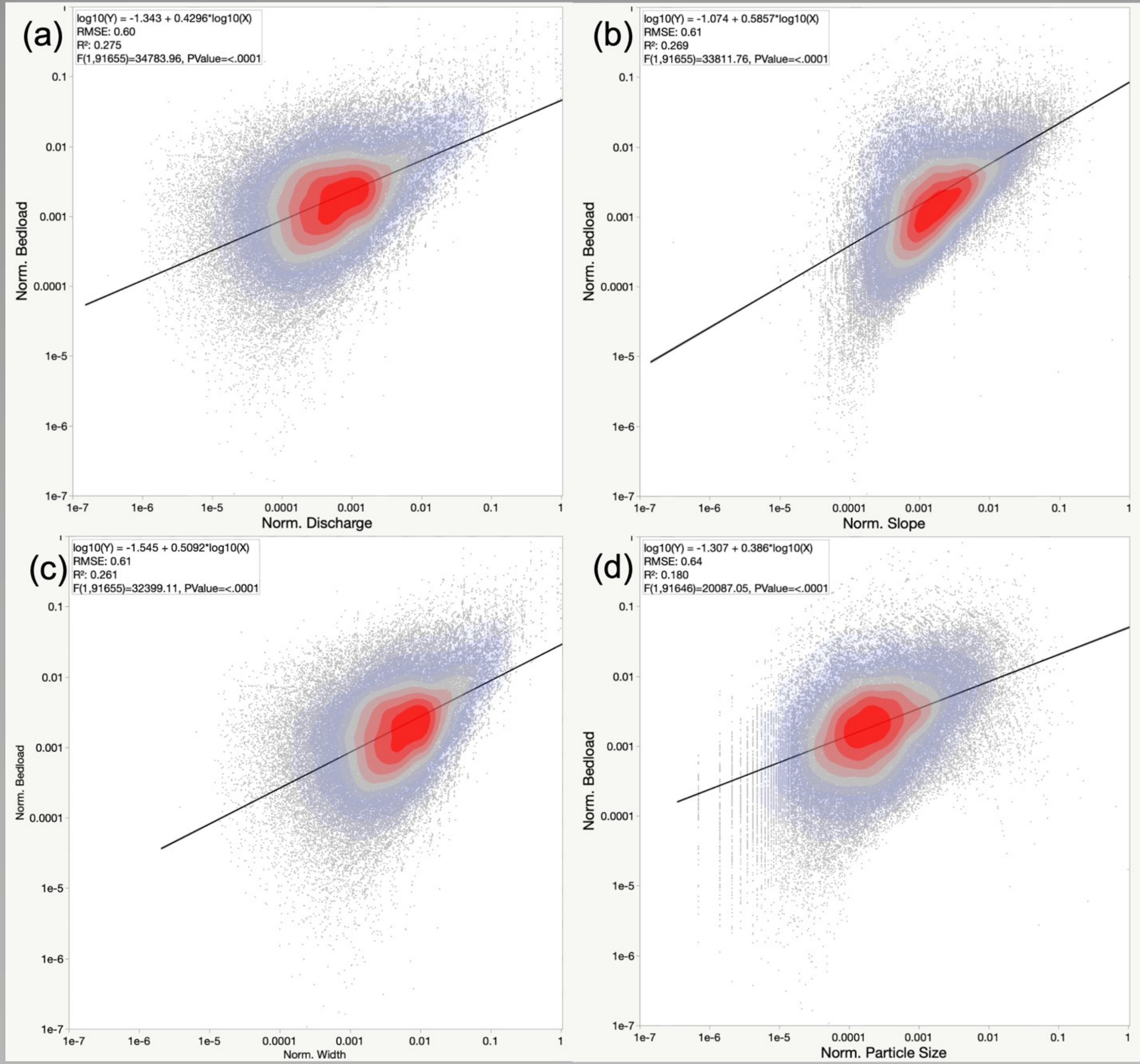
Lammers and Bledsoe (2018)



Results – Spatial Sensitivity Analysis

	Norm. Bedload	
	R^2	Equation Slope
Norm. Discharge	0.27	0.42
Norm. River Slope	0.27	0.58
Norm. Particle Size	0.18	0.38
Norm. River Width	0.26	0.50

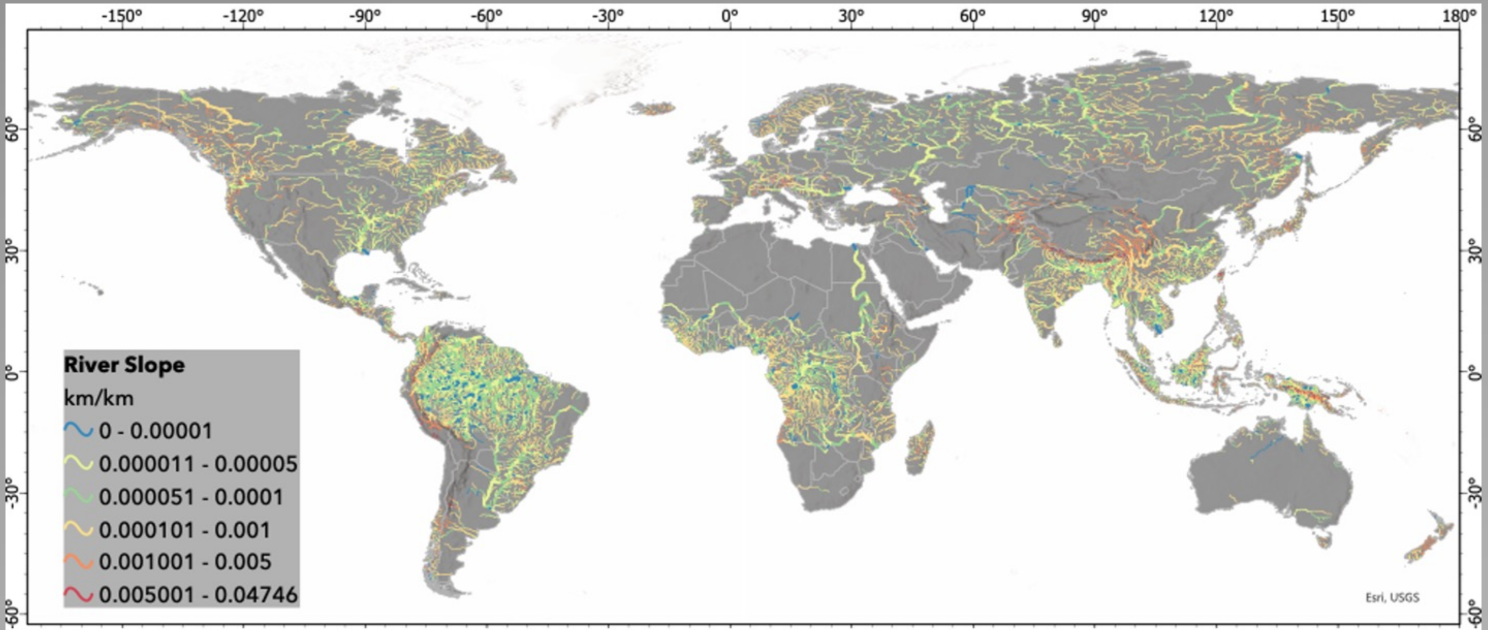


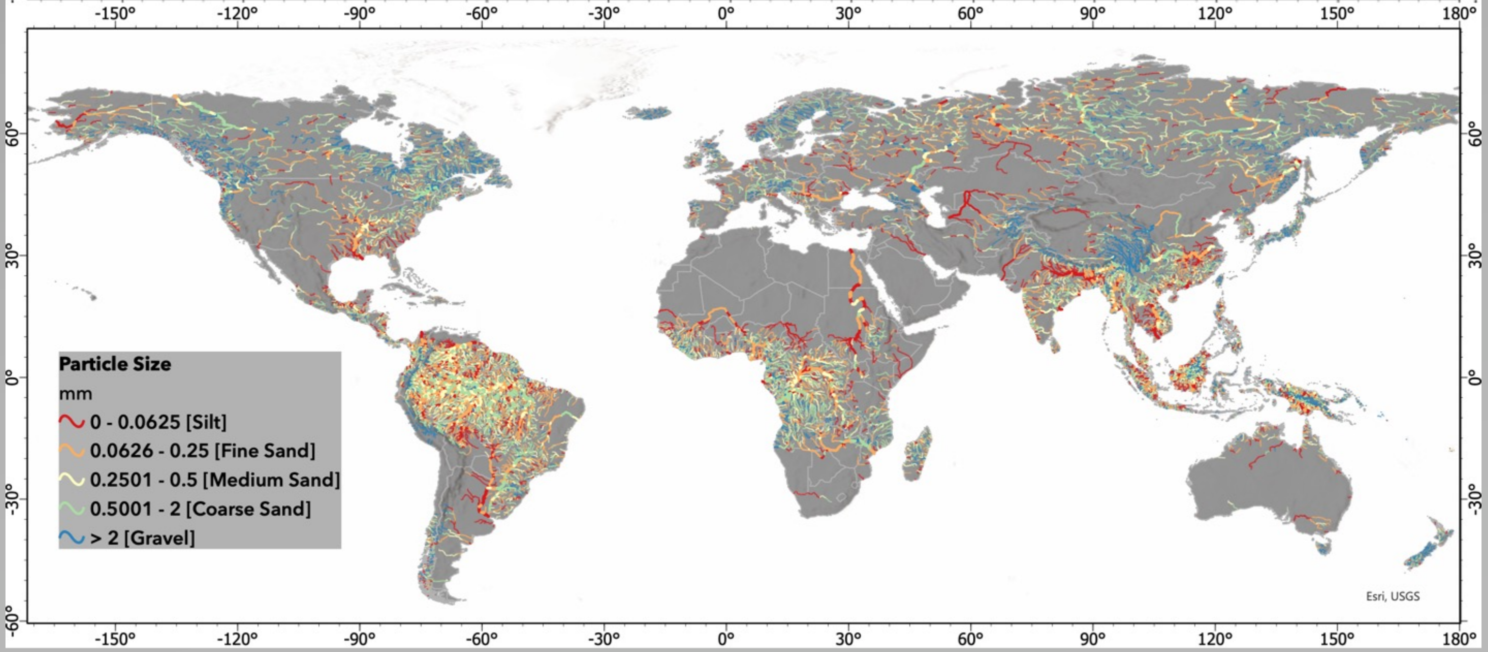


From: Lammers and Bledsoe (2018)

Results - Spatial Sensitivity

Smoothed from Lin et al., 2020



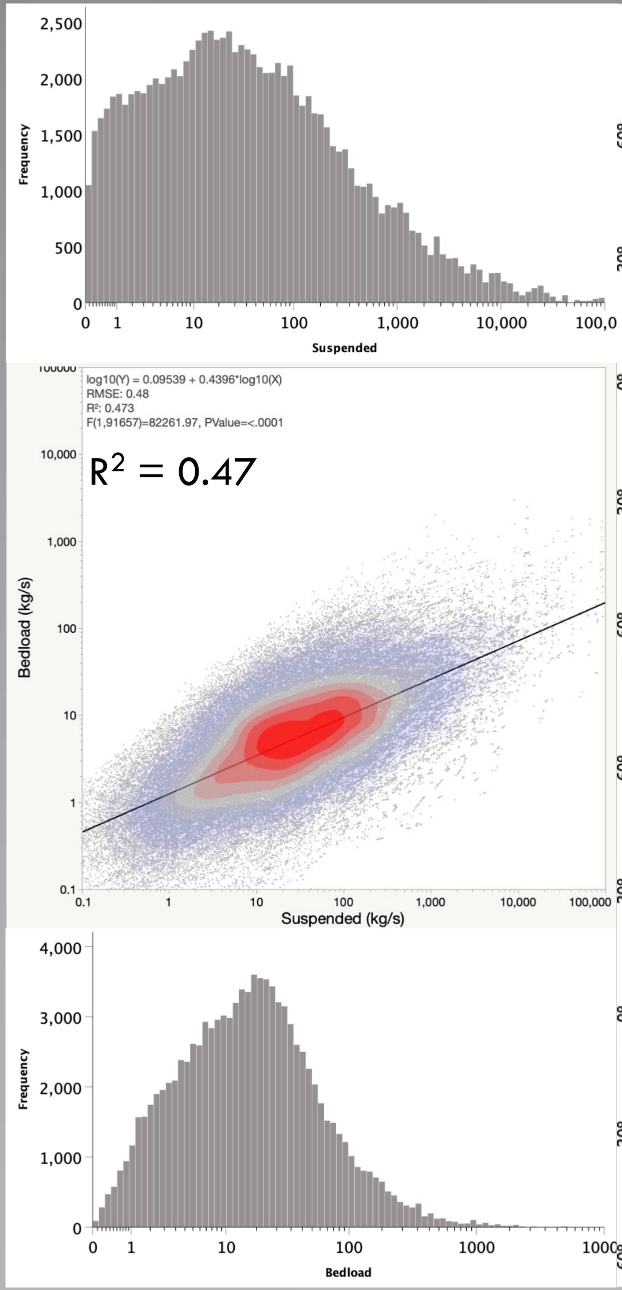


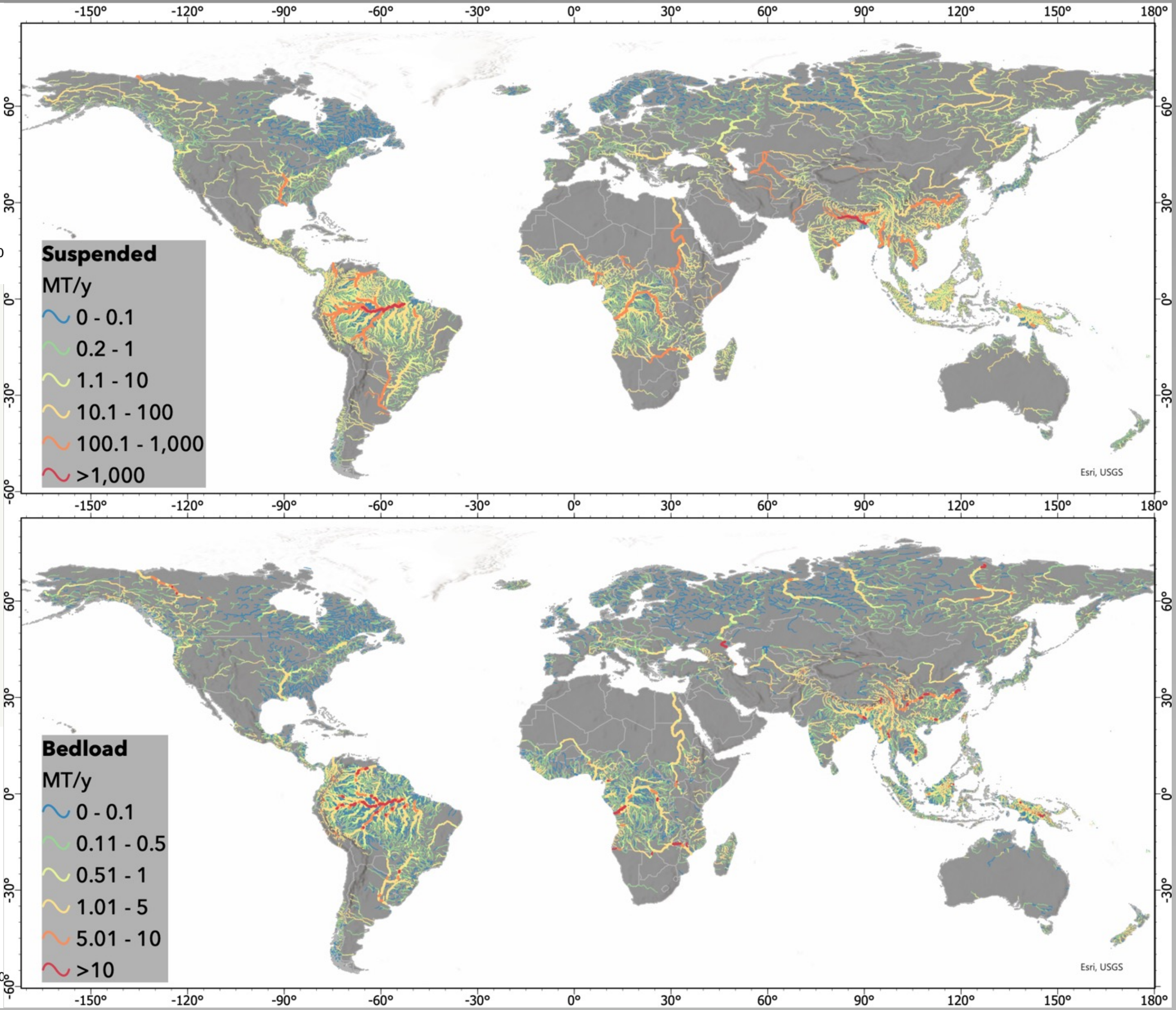
Derived empirically for a large dataset

$$D_s = 3.77\left(\frac{\bar{Q}}{W}\right)^{1.42} S^{1.26}\left(\frac{\overline{Qs}}{W}\right)^{-0.5}$$

$R^2 = 0.9$

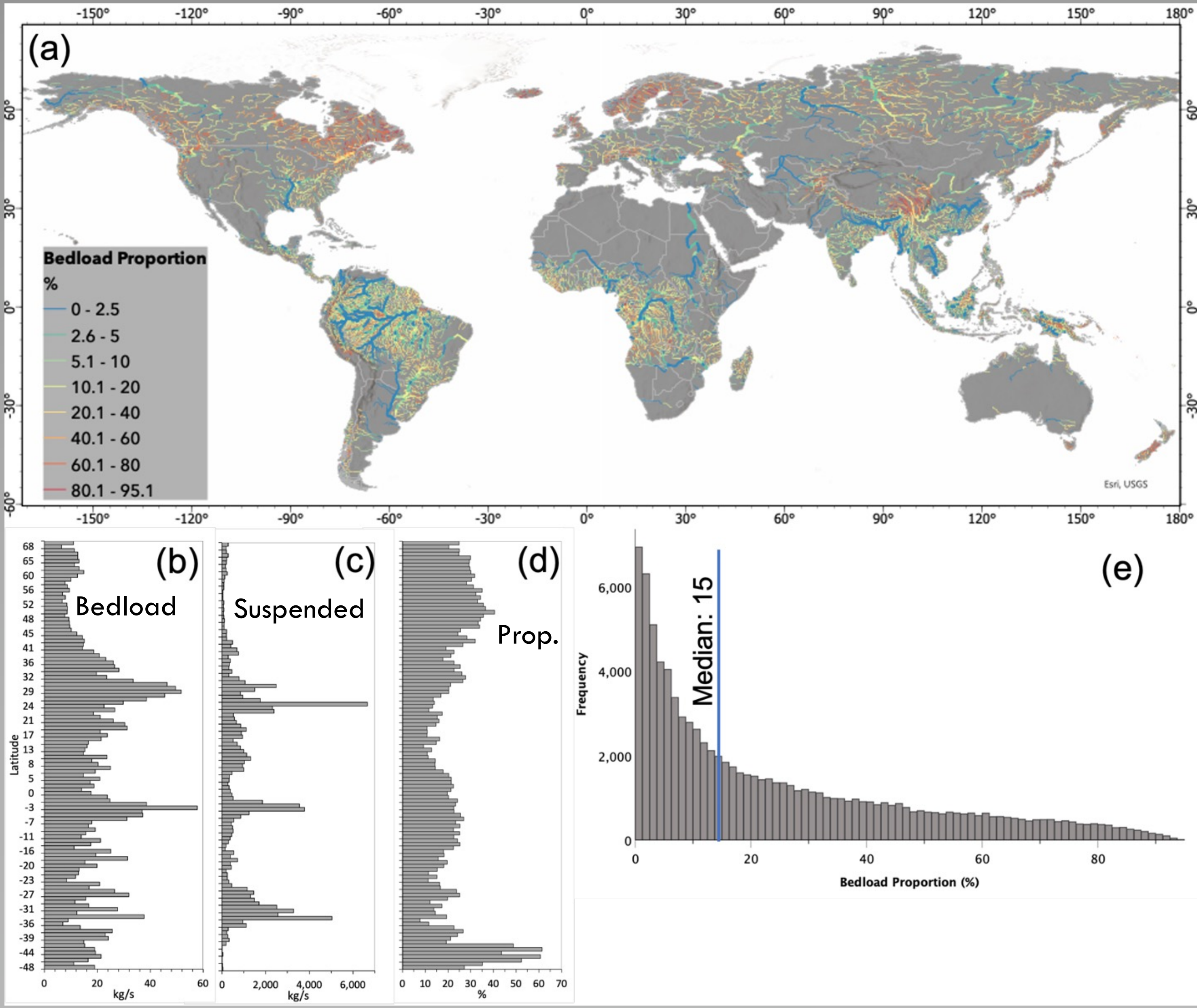
Results – Suspended and Bedload





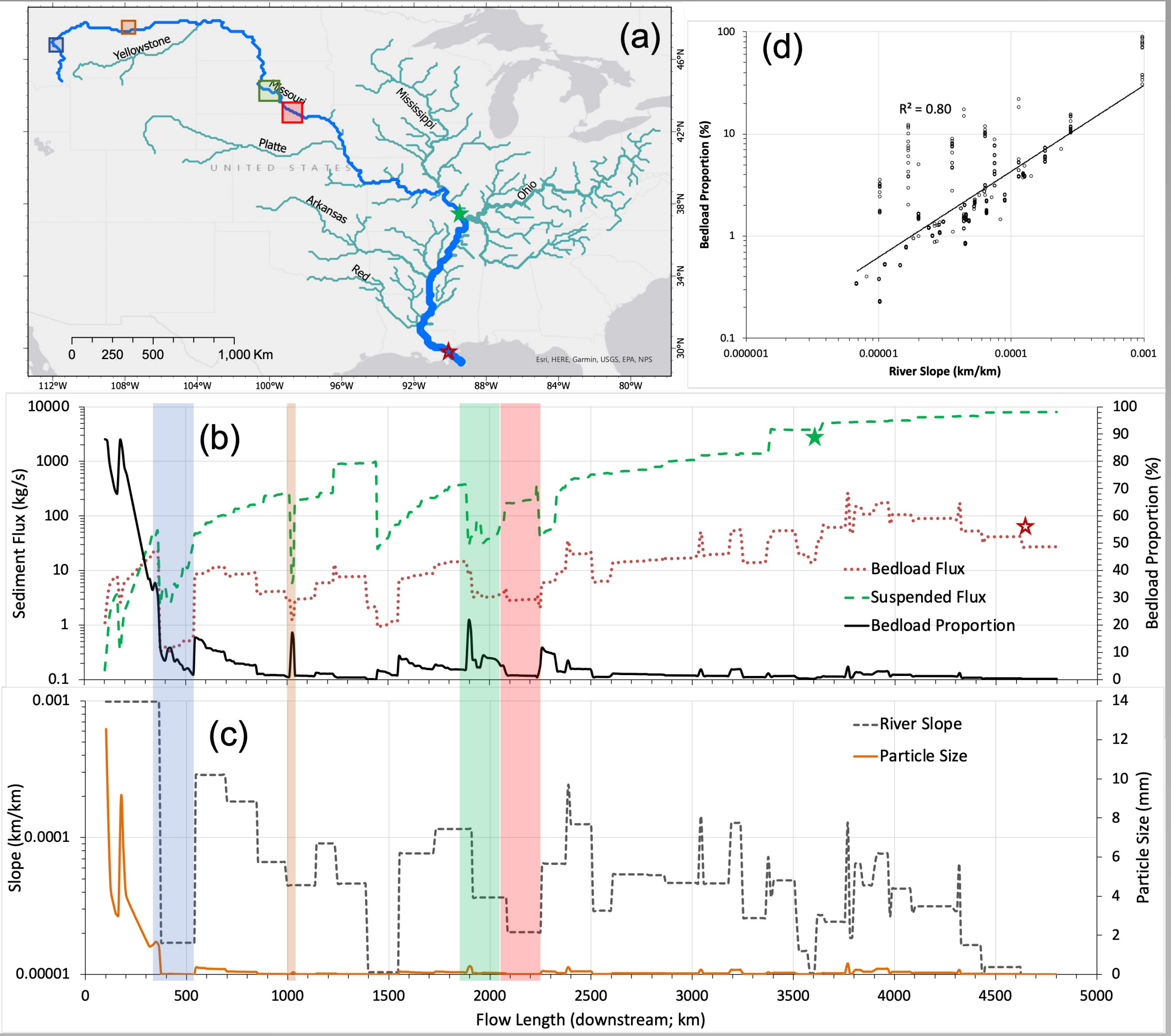
Results – Bedload Proportion

	Mean	Median	Std. Deviation
Discharge [m^3/s] (km^3/y)	960 (30)	121 (3.8)	5679 (179)
Suspended [kg/s] (Mt/y)	657 (20)	30 (0.9)	4169 (131)
Bedload [kg/s] (Mt/y)	19 (0.6)	5 (0.15)	55 (1.7)
Suspended bed-material [kg/s] (Mt/y)	64 (2)	24 (0.7)	149 (4.7)
Wash load [kg/s] (Mt/y)	602 (19)	8 (0.2)	4075 (128)
Total sediment load [kg/s] (Mt/y)	676 (21)	41(1)	4195 (132)
Bedload Proportion [%]	24	15	23
Bedload : Suspended load	0.6	0.2	1.2
River slope [km/km]	0.0003	0.0001	0.001
Bed-material particle size [mm]	1.4	0.2	7.8

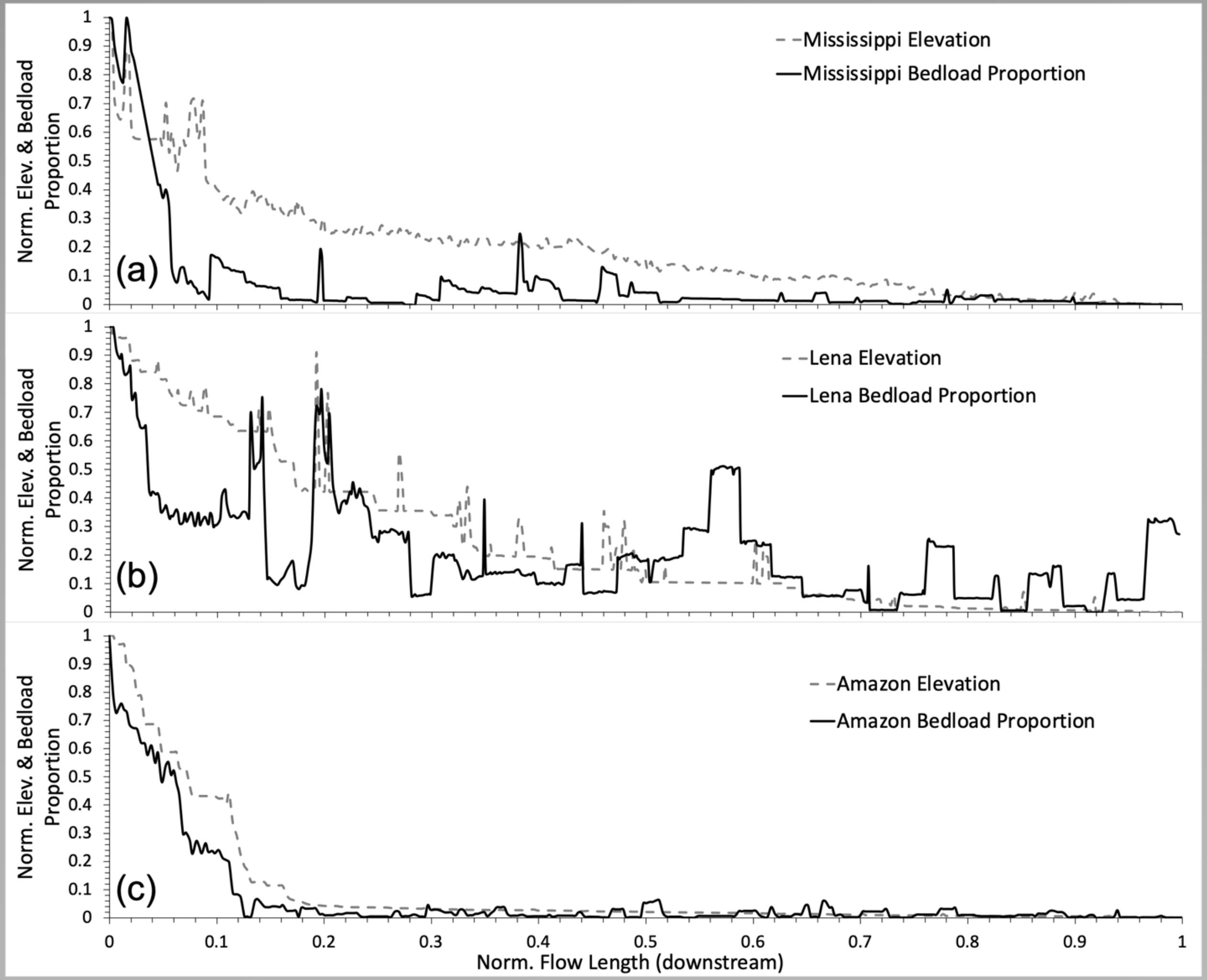


Results – Longitudinal Profile

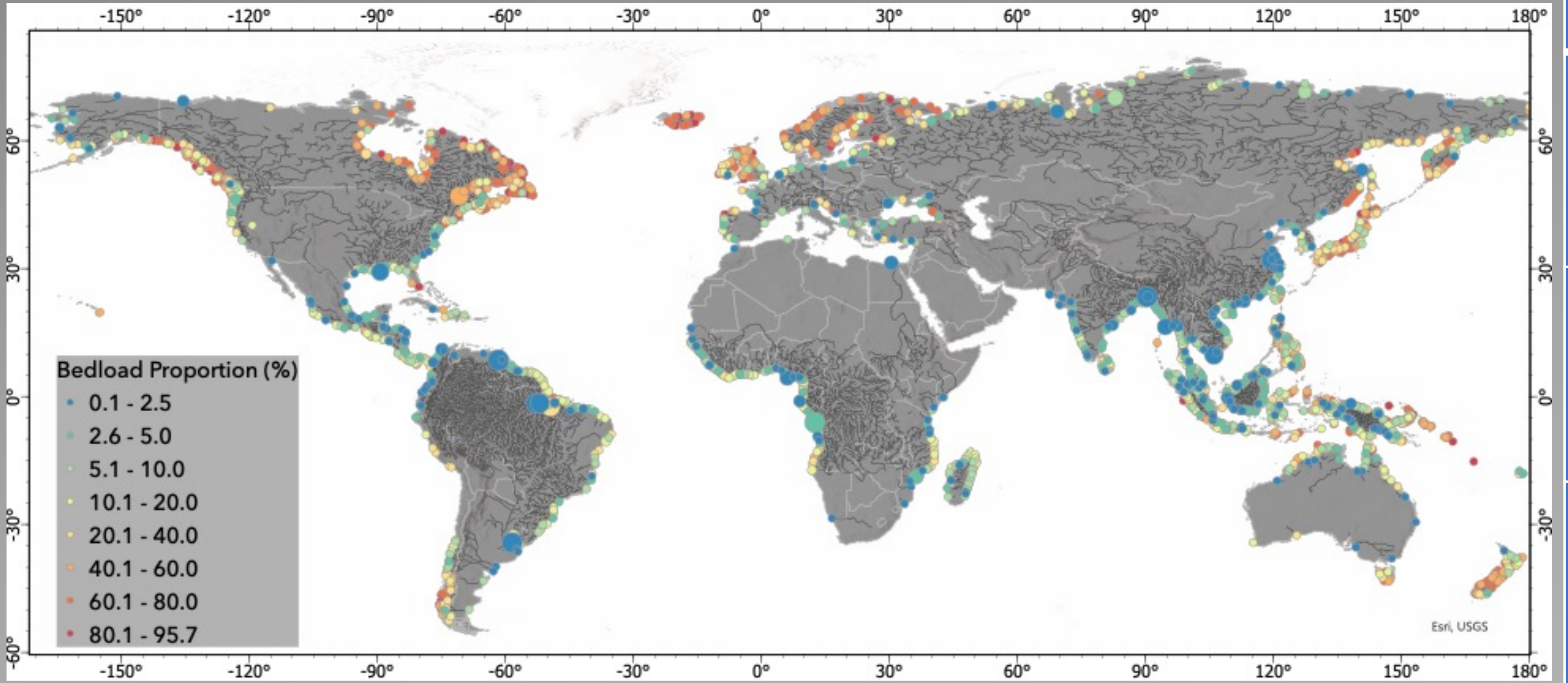
Mississippi/Missouri

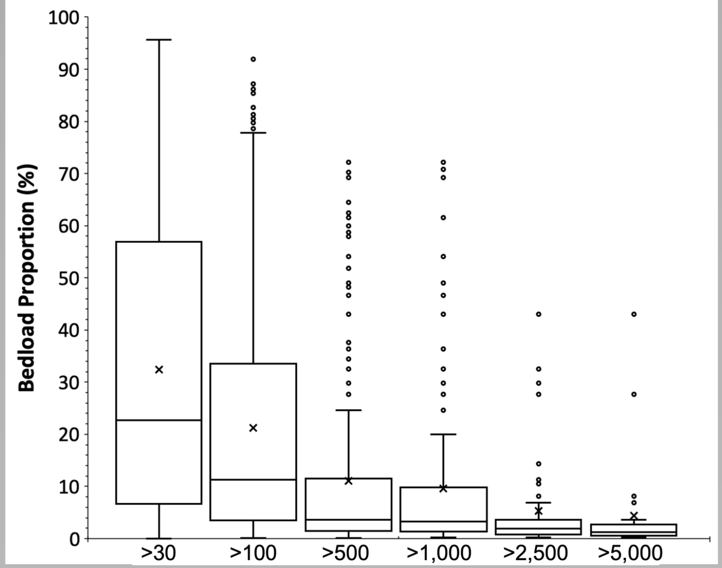


Normalized Profiles



Results – River Outlets





	Filter Q (m^3/s)	Mean	Median	Sum (MT/y); Calculated (%)
Susp. Sediment (kg/s)	>30	321	20	16,636*
	>100	672	72	15,146*
	>500	2408	367	12,223*
	>1000	4261	968	10,984*
	>2500	9337	2371	9,503*
	>5000	15,866	4402	8,172*
Bedload (kg/s)	>30	17	6	1,145
	>100	22	8	661
	>500	42	16	294
	>1000	66	30	239
	>2500	109	56	163
	>5000	140	75	111
Total Sediment (kg/s)	>30	339	34	17,780*
	>100	695	92	15,807*
	>500	2451	388	12,517*
	>1000	4328	1003	11,223*
	>2500	9447	2500	9,666*
	>5000	16,006	4481	8,282*
Bedload Proportion (%)	>30	32	22	6.4*
	>100	21	11	4.1*
	>500	11	3.6	2.3*
	>1000	9	3.2	2.1*
	>2500	5.3	1.9	1.6*
	>5000	4.4	1.2	1.3*

Conclusions

- Bedload predictions are highly sensitive to river slope and particle size.
- Both parameters are challenging to derive/calculate - Further development is needed.
- Bedload both inter- and intra-basin distributions are highly heterogenous and can deviate considerably from suspended flux trends in high altitudes and latitudes.
- Proportion of bedload in total sediment flux decrease dramatically from headwater to coastal river reaches but with considerable variability between basins and along river routes.
- A total global load of 17.8 Gt/y to global oceans is predicted, 14.8 Gt/y as washload, 1.1 Gt/y as bedload, and 2.6 Gt/y as suspended bed material. The largest 25 rivers are predicted to transport more than half of the total sediment flux to global oceans.

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