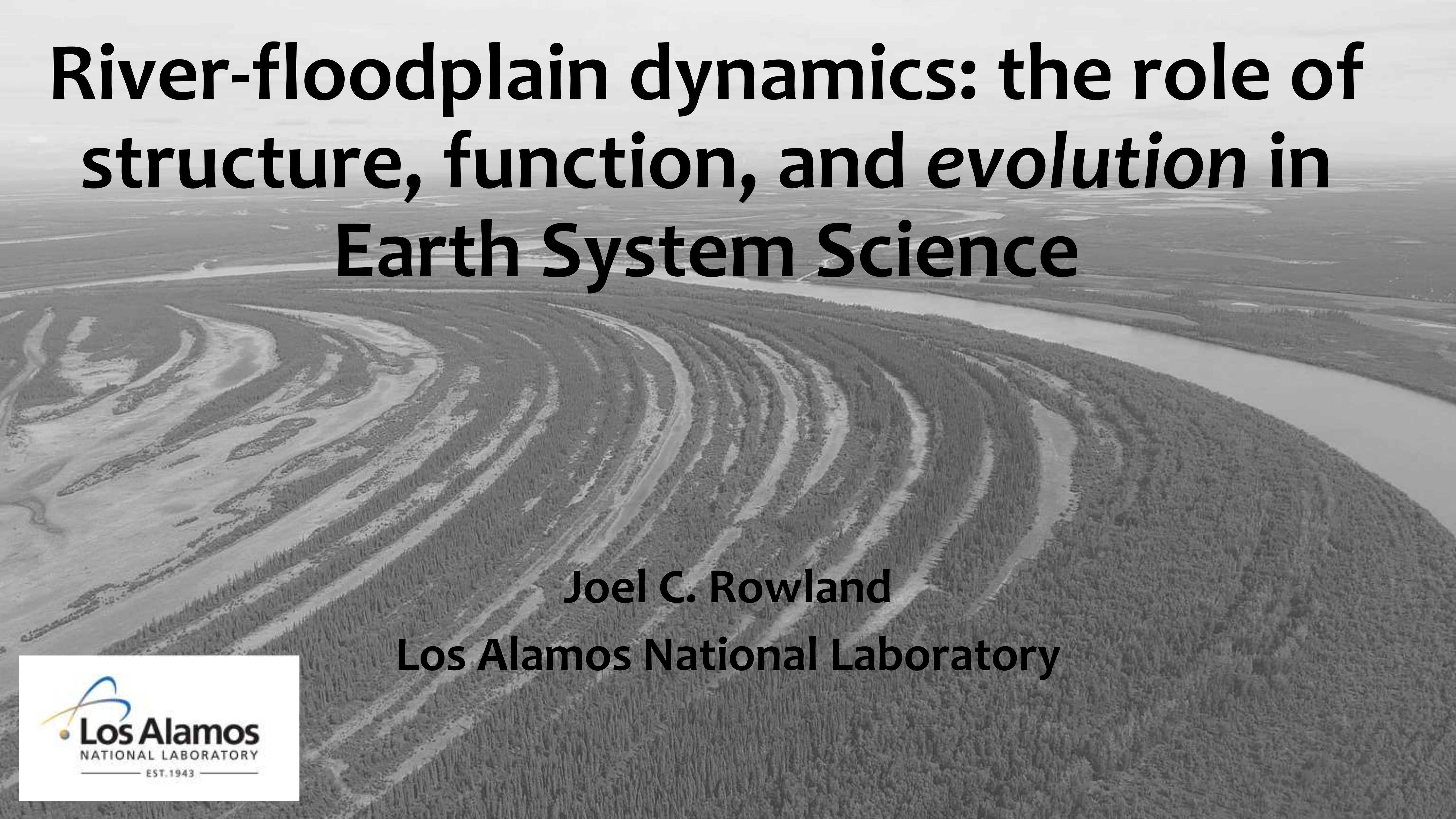
River-floodplain dynamics: the role of structure, function, and *evolution* in Earth System Science



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Postdocs, and Students

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Collaborators

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U.S. DEPARTMENT OF ENERGY | Office of Science

DOE Early Career Award

Subsurface Biogeochemical Research

Structure - How a is system a organized

Koyukuk River, AK

Selawik NWR, AK

Ganges &
Brahmaputra, India

Function - What a system does: transport, store, and transforms

East River, Crested Butte, CO

Evolution – How a system changes

Dynamic equilibrium

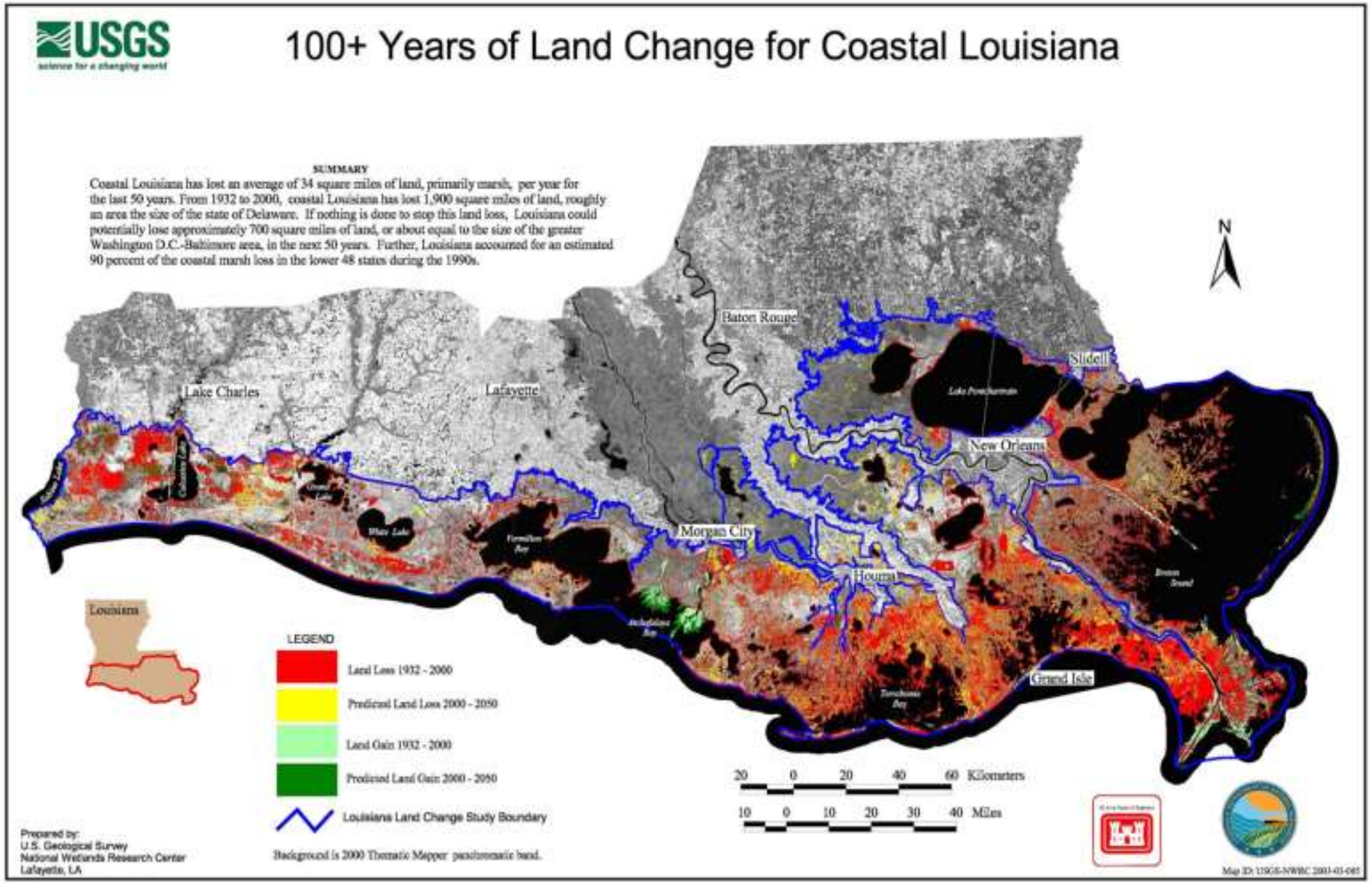
Courtesy of Alex Bryk, UC Berkeley. Compiled with Google Earth Engine

Evolution – How a system changes

Change in state – fundamental shifts in structure and possibly function

LEGEND

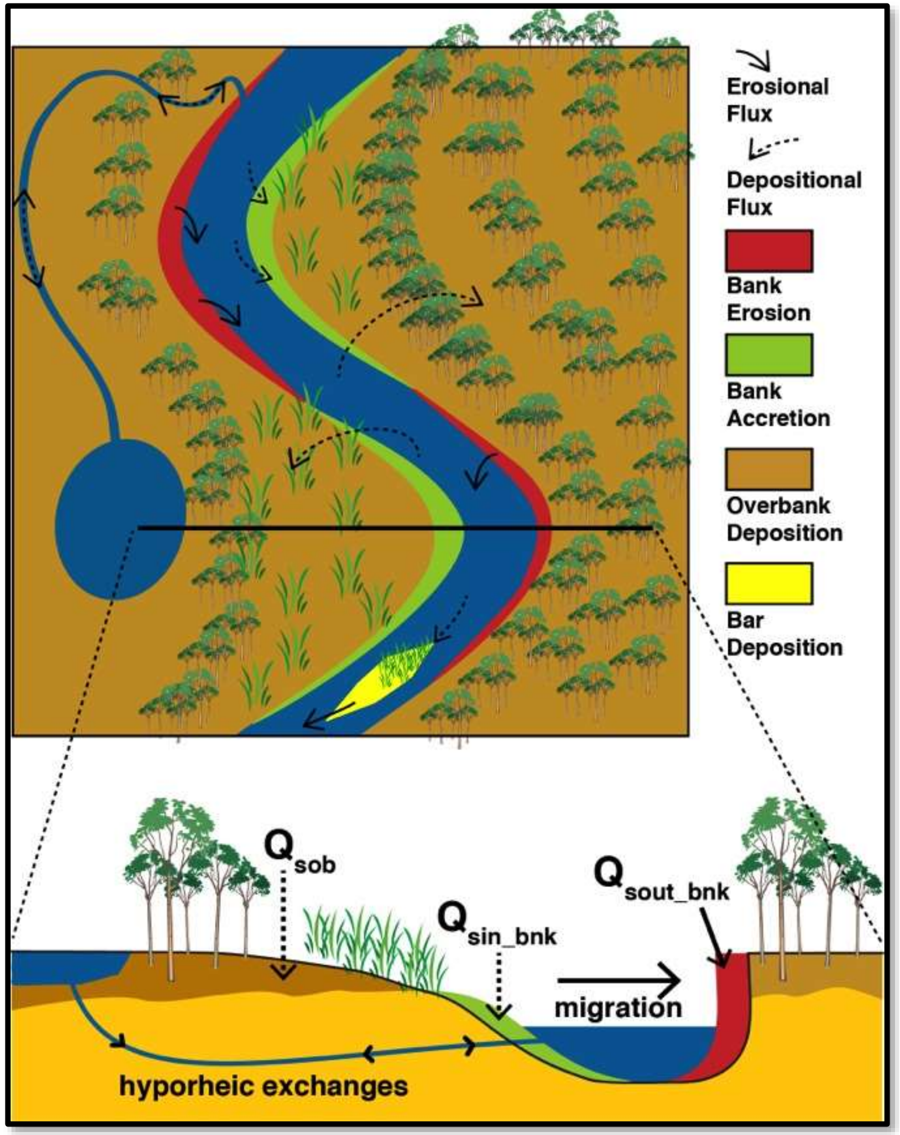
Loss	1932-2000
Pred Loss	2000-2050
Gain	1932-2000
Pred Gain	2000-2050
Study Area	



Early Career Project

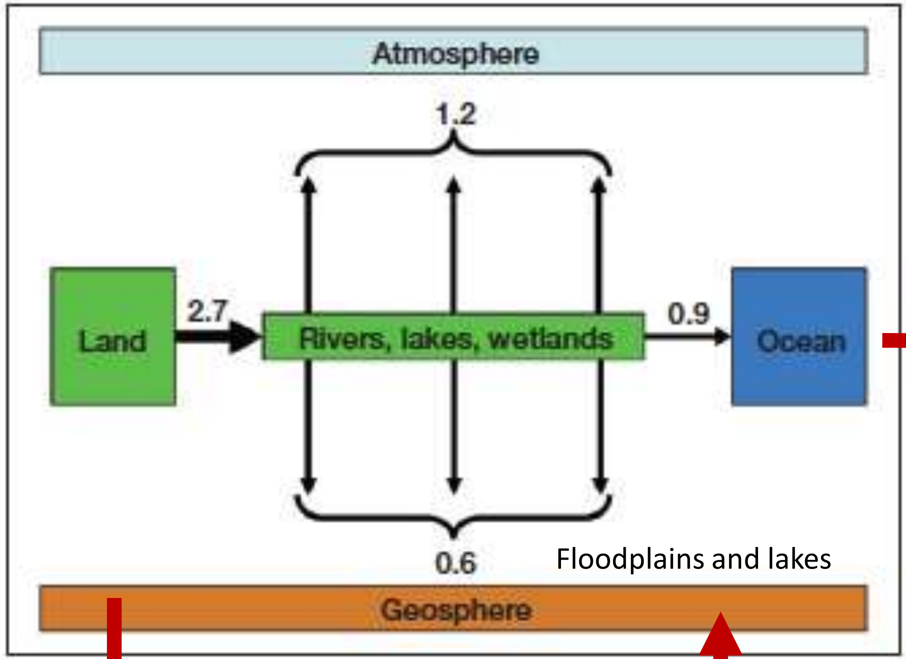
Incorporating the hydrological controls on carbon cycling in floodplain ecosystems into Earth System Models (ESMs)

Central Question: What role do floodplains and their dynamic interactions with rivers play in the storage, transformation, and transport of sediment and biogeochemical constituents through watersheds.



Carbon and sediment fluxes

Hydrosphere has a large role in terrestrial carbon cycle, with very large uncertainties in river sources, sinks, and fate.



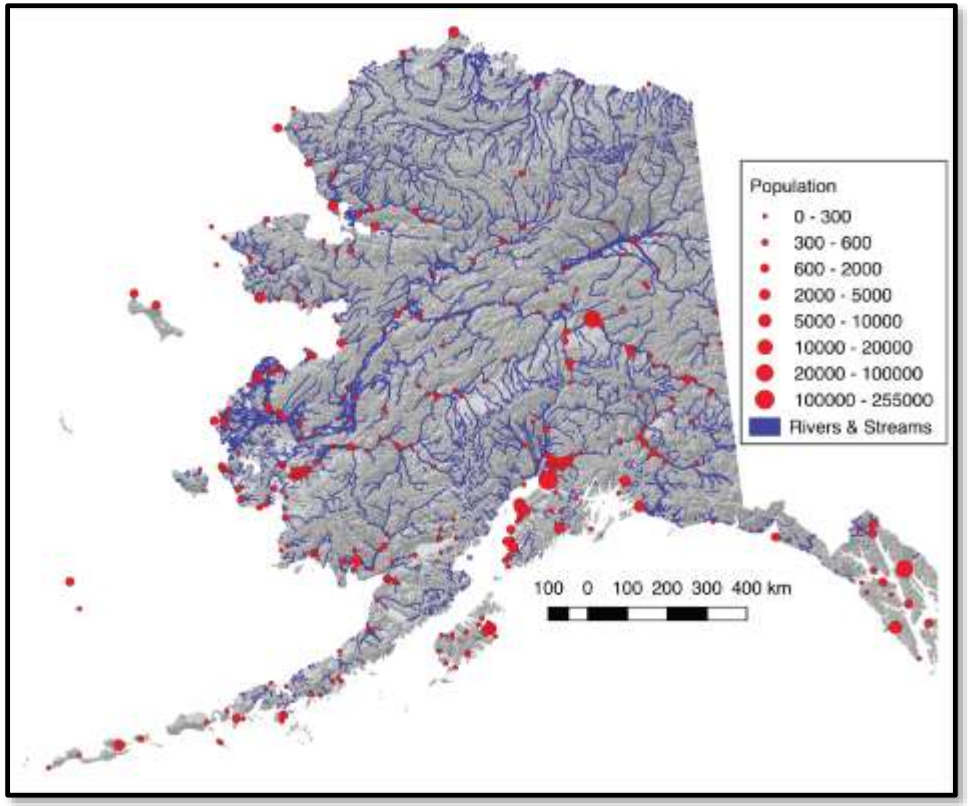
Aufdenkampe et al., 2011

Yukon River Delta

East River, Crested Butte, CO

Koyukuk River, Alaska

Rivers play a critical role in human settlement and economics



For many communities erosion a serious problem

34% of villages or towns within 500 m of river (13% of population)
43% within 1 km(21%)

Huslia, AK – Koyukuk River

Fundamental science

What controls the rate of river movement at any point or time on Earth?

Inherently a multiscale problem

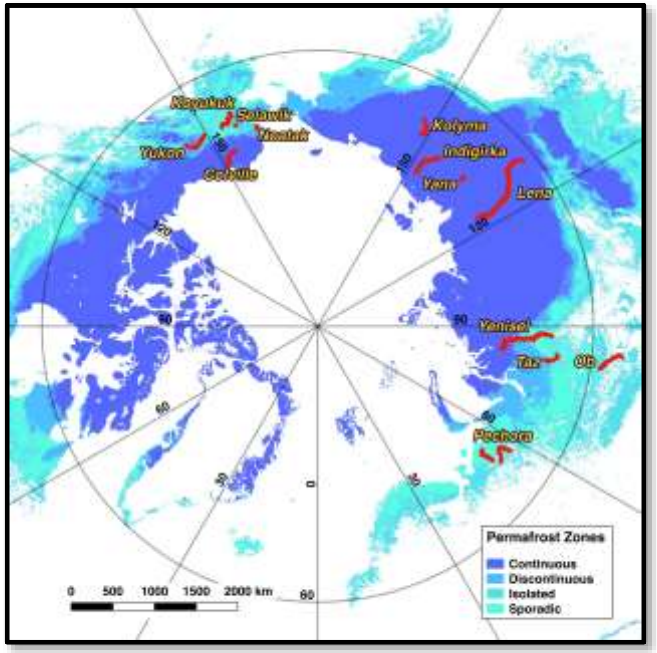
Bank scale

Koyukuk River, Alaska

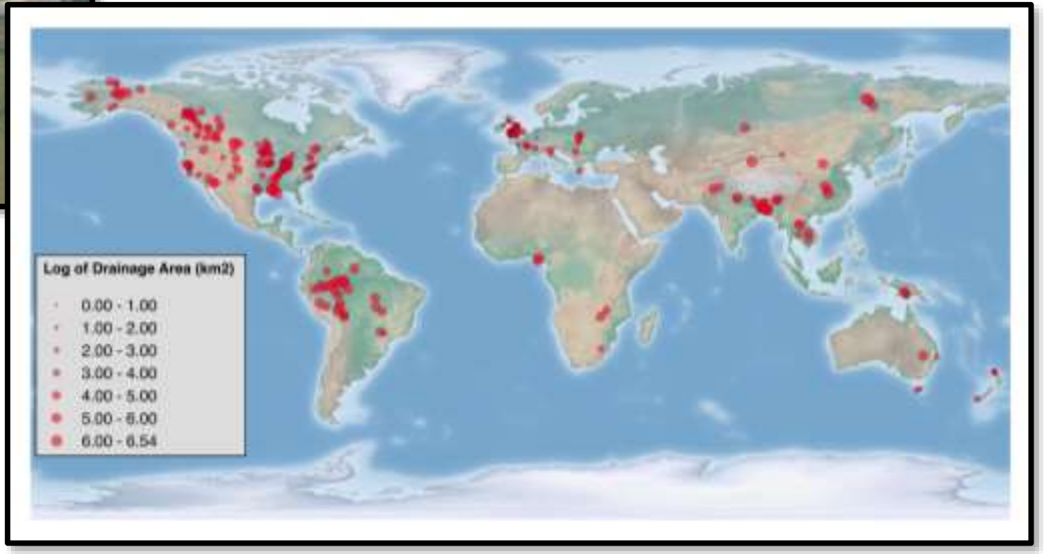
Reach scale

Selawik River, Alaska

Regional



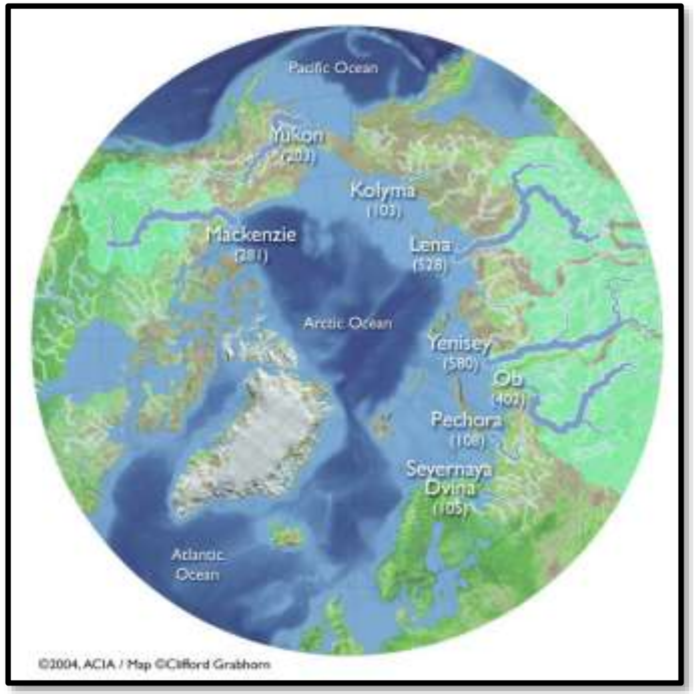
Global



Focused on Arctic as the starting point

- 10% of the world fresh water discharge
- Permafrost – 24% of northern hemisphere
- 1024 Pg C in 0-3m of permafrost soils (Tarnocai et al. 2009
- Rapidly warming
- Observed changes in hydrology (Rawlins et al. 2010)

River Discharge



(numbers) – discharge in km^3/yr

Permafrost

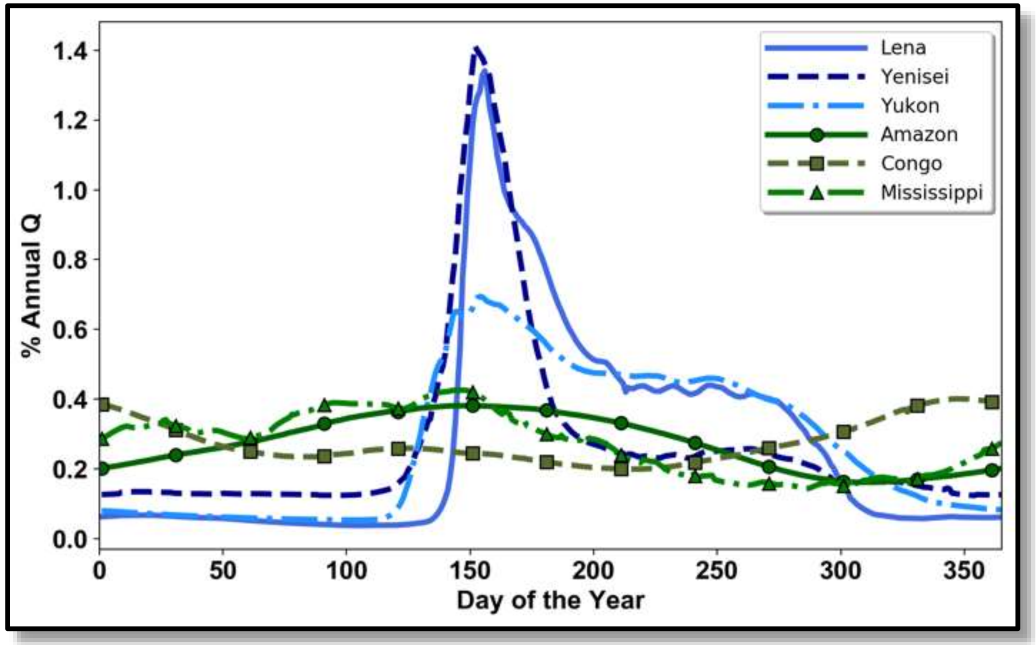
Arctic rivers unique and understudied

Permafrost & Ground Ice

- Thermally controlled bank retreat

Yukon River

Hydrology



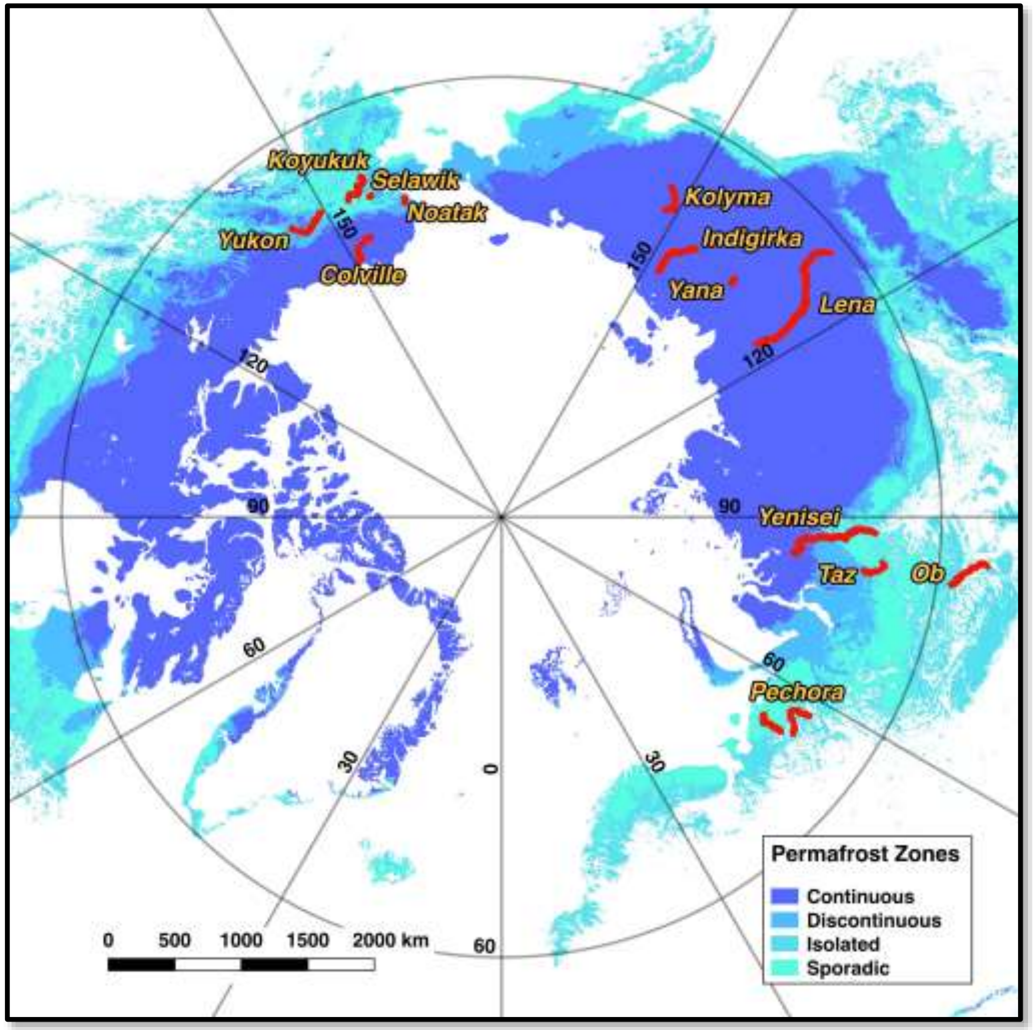
Peak many times the mean

Half the annual flow in a few months

Pan-Arctic scale

Analyzed 14 river segments over 30 different time intervals

- 5,500 km of rivers
- > 11,000 km of measurements
- > 1.6 million individual erosion measurements
- Primarily Landsat, some aerial photographs, SPOT, ASTER, and high-resolution satellite imagery
- Earliest: 1973, most-recent: 2016
- Drainage area:
  - 1,300 km² (Selawik)
  - 2 million km² (Lena)
- Channel widths:
  - 50 m – 10 km (total of all threads on Lena)

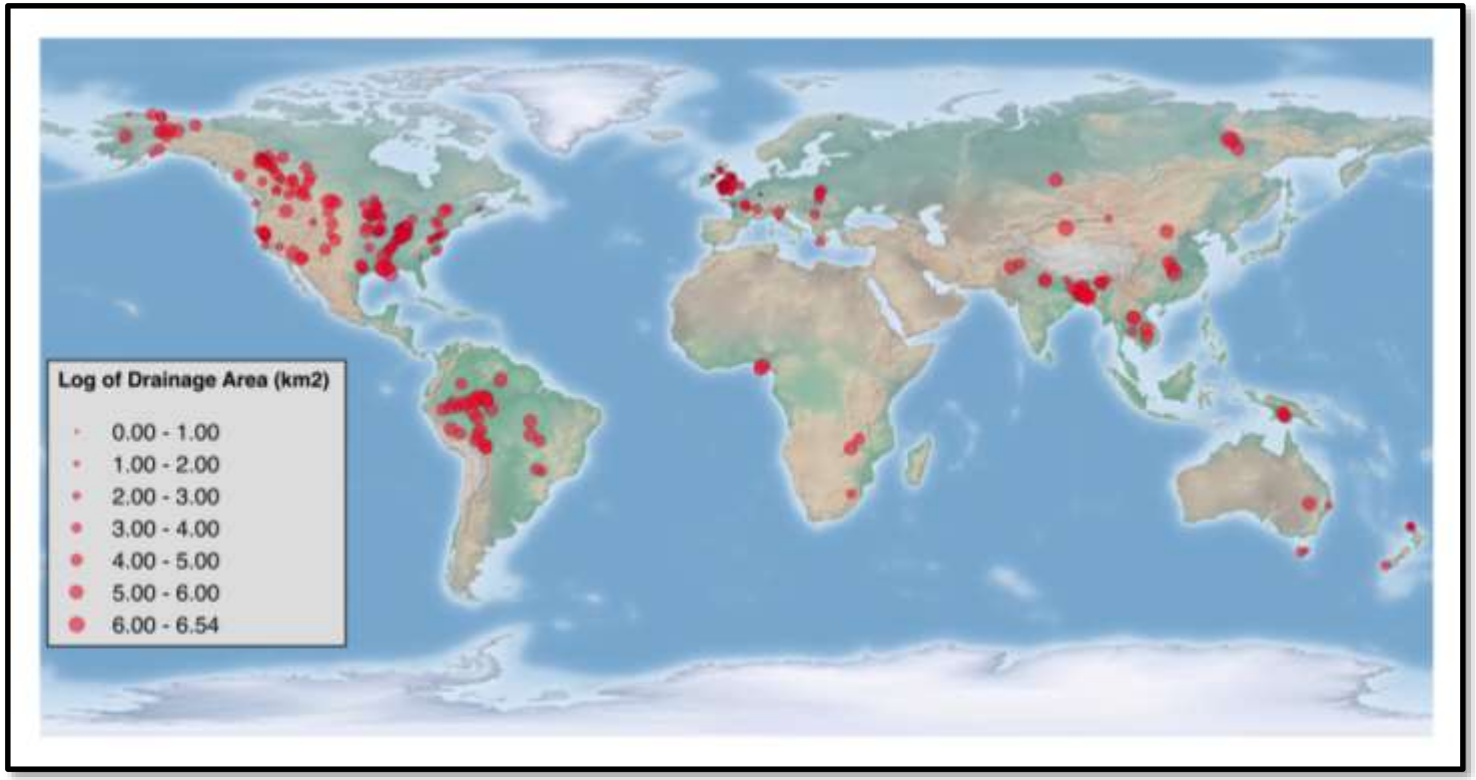


Background permafrost map from GlobPermafrost

Global meta-analysis to provide comparison

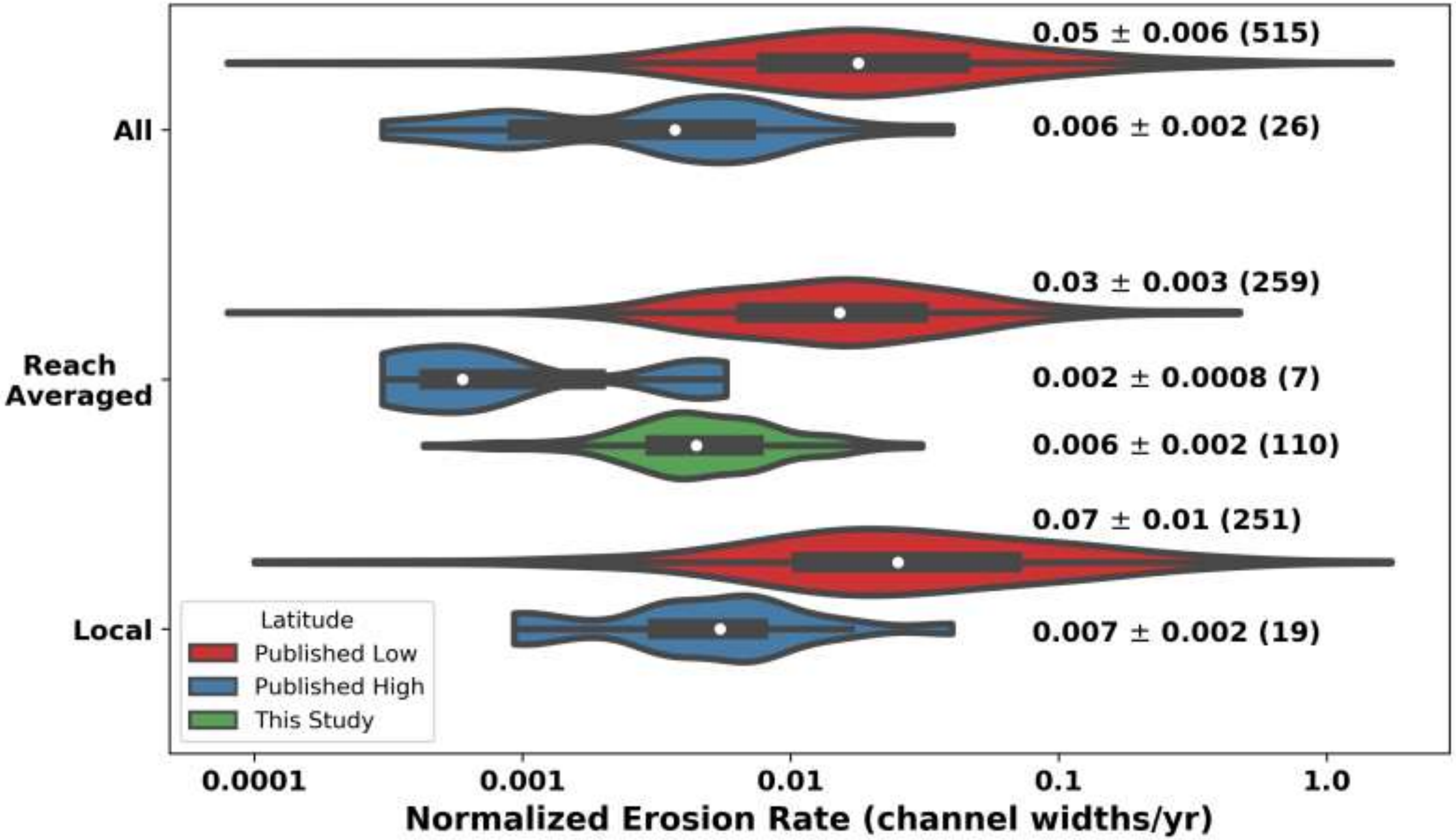
Extracted data from 159 English language references

- 927 individual measurements
- Used regional and global datasets, other published studies and google earth to add drainage area, width and sediment loads
- Averaged based on available width and drainage area (515 low latitude)
- 13 published studies of high latitude rates – 26 unique measurements
- Latitudinal biases in dataset



Low latitude vs high latitude

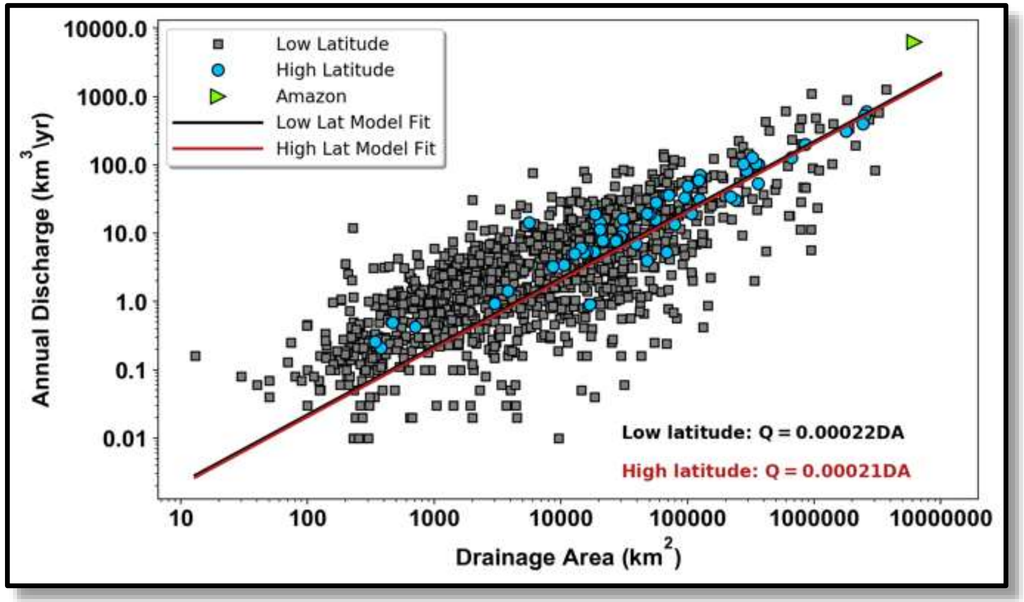
Normalized to control for dependence of erosion on river size (width ∝ drainage area)



Low latitude statistically different from high latitude by all measures (Wilcoxon p-value < 0.001)

Hydrology: Is there less water or does the temporal distribution alter erosion?

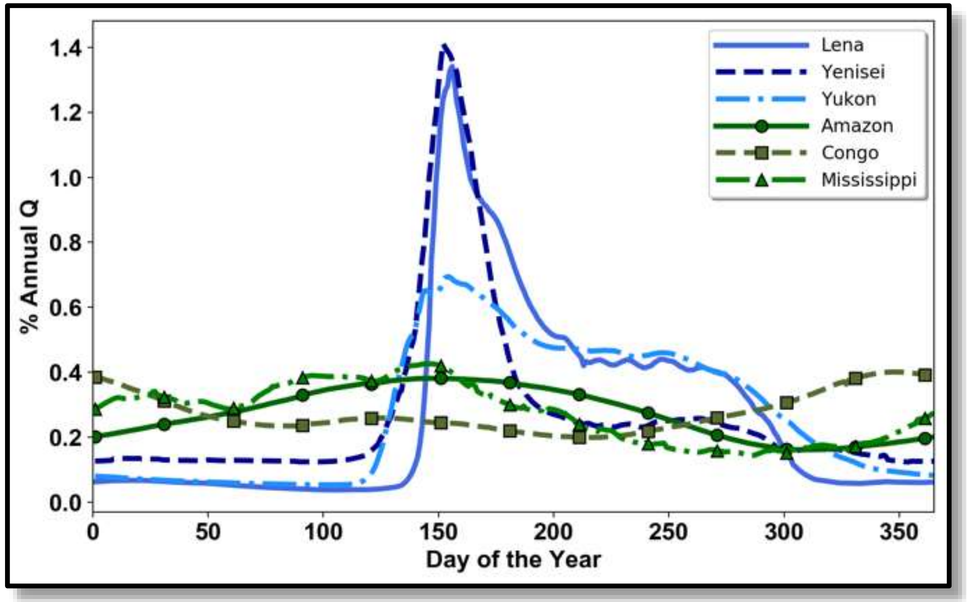
River discharge as a function of basin size



Low latitude: $Q = 2.2 \times 10^{-4} DA$ ($r^2 = 0.55$)
High latitude: $Q = 2.1 \times 10^{-4} DA$ ($r^2 = 0.96$)

Land2Sea Dataset (Peucker-Ehrenbrink 2009)

Erosion scales non-linearly (power < 1) with discharge



Redistributed total Q to match 7 low latitude rivers, maximum increase was 25% for an Amazon hydrology

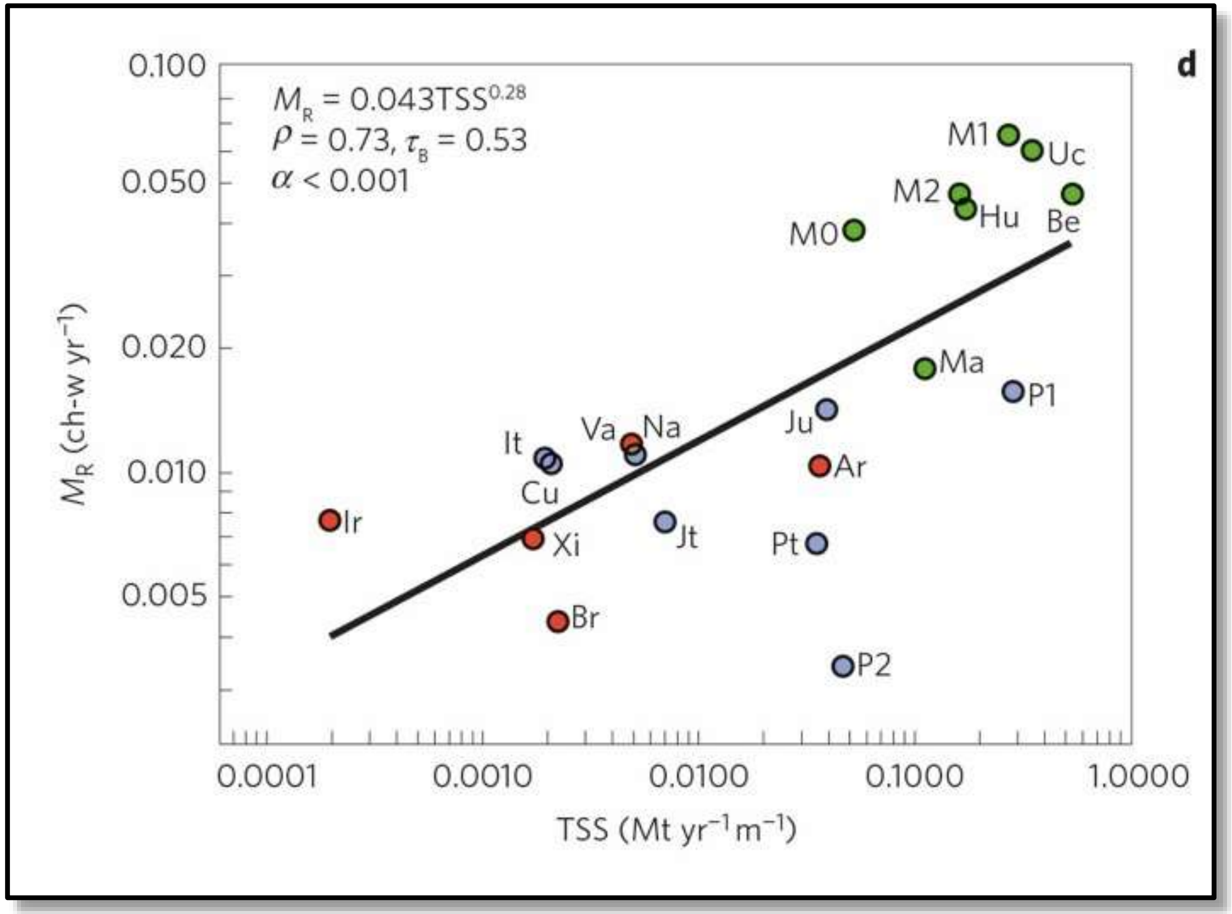
Sediment: Do higher loads drive higher bank erosion?

Theoretical background

- Higher sediment loads leads to greater bar growth
- Bar growth leads to great flow deflection towards banks
- Results in greater bank erosion

Observed correlation between sediment and erosion

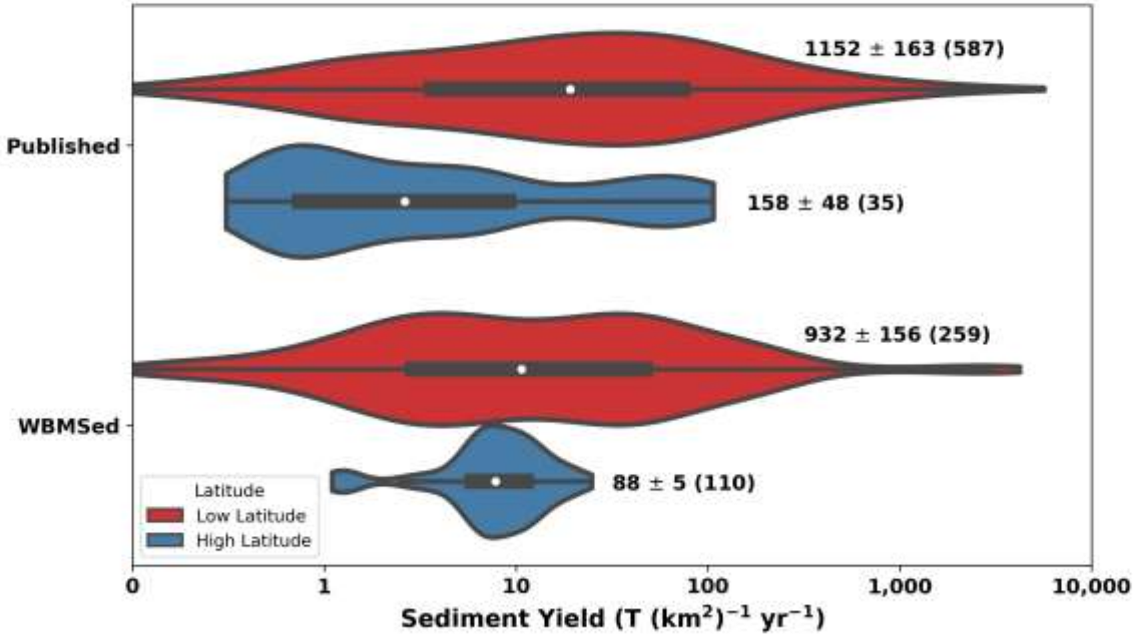
- Amazon
- Experiments
- Models



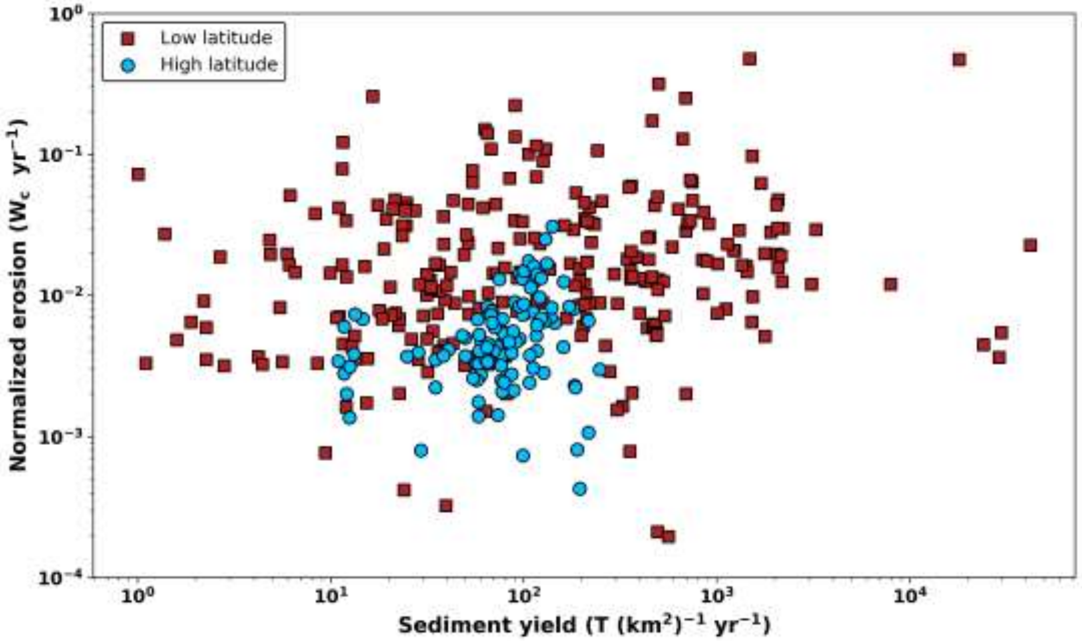
Amazonian Rivers)
(Constantine et al. 2014)

Sediment: Do higher loads drive higher bank erosion?

Sediment Yield (Load/Drainage Area)



Normalized Erosion (Channel Widths/yr)
vs.
Sediment Yield (Load/Drainage Area)

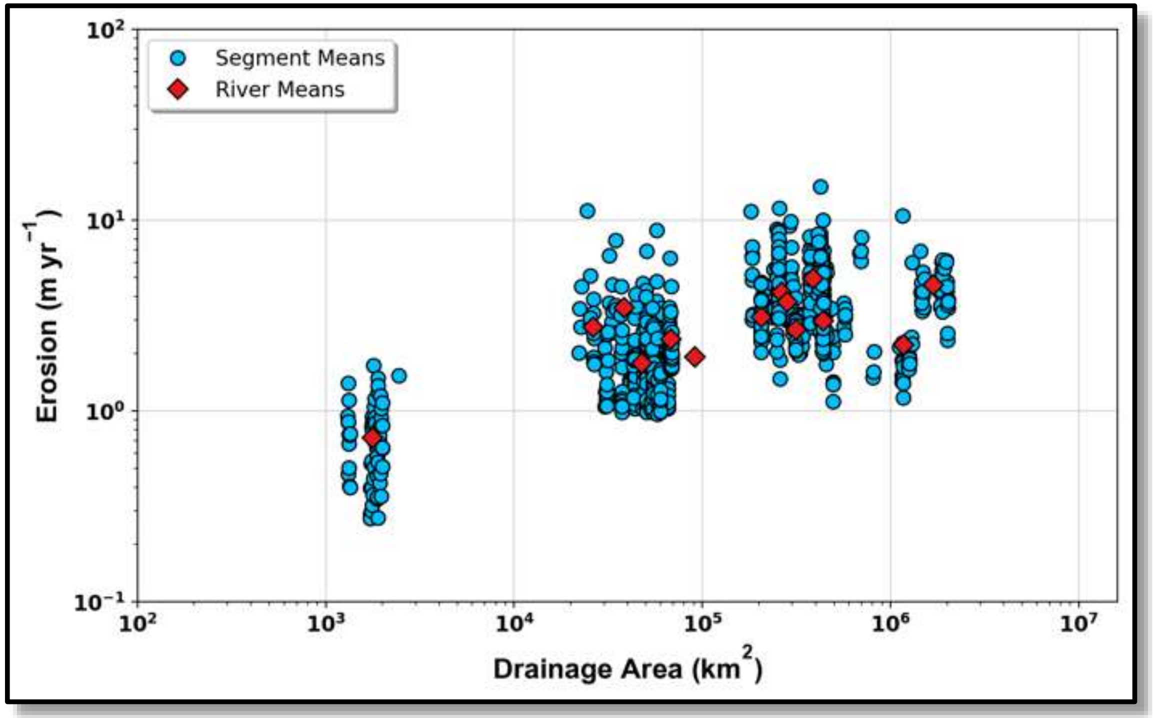


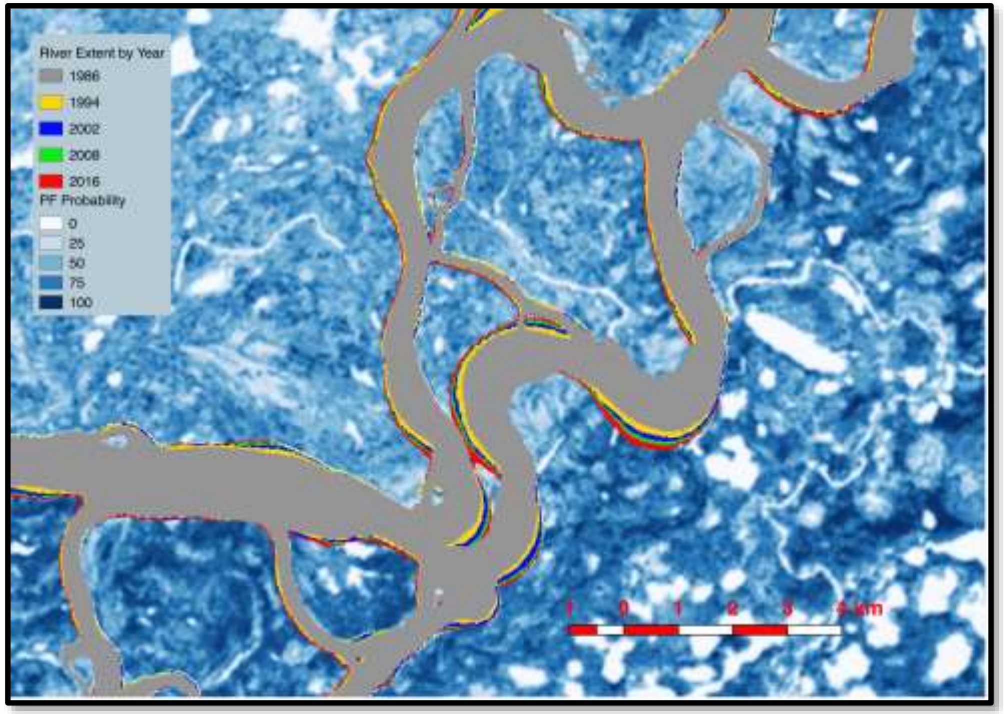
Despite significant differences in high and low latitude sediment yields, no correlation between erosion rates and sediment yield in either high or low latitude rivers systems

Permafrost provides compelling explanation for lower erosion rates

Observe large variability between and within Arctic rivers

- Factor of 10x within individual rivers (Selawik)
- Factor of 10x same river over multiple time periods (Yukon)
- Broad variability between river systems





Yukon River

Temporal variability at a single bend

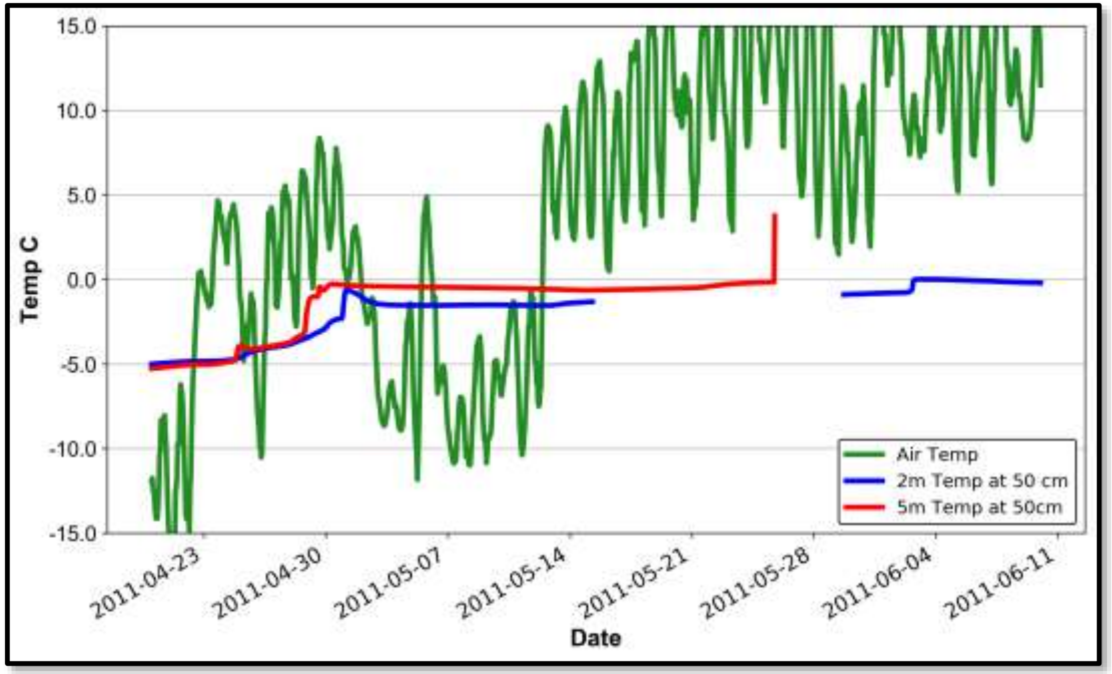
- Long term (1981-2009) rate 3.9±.11 m/yr
- Field observed rate of 3.4 m in 4 days
- Highly variable from year to year

Time Interval	Mean Change (m)	Standard Error (m)
Downstream Bend		
2009 - 2010	-0.61	0.59
2010 - 2011	4.65	0.66
2011 - 2012	0.63	0.54
2012 - 2013	1.56	0.64
2013 - 2014	1.33	0.58
2014 - 2015	3.57	1.38
2015 - 2016	0.42	0.52

Hydrology is dominant but permafrost still important

Likely transport limited most years, but thaw appears to set the pace in extreme years

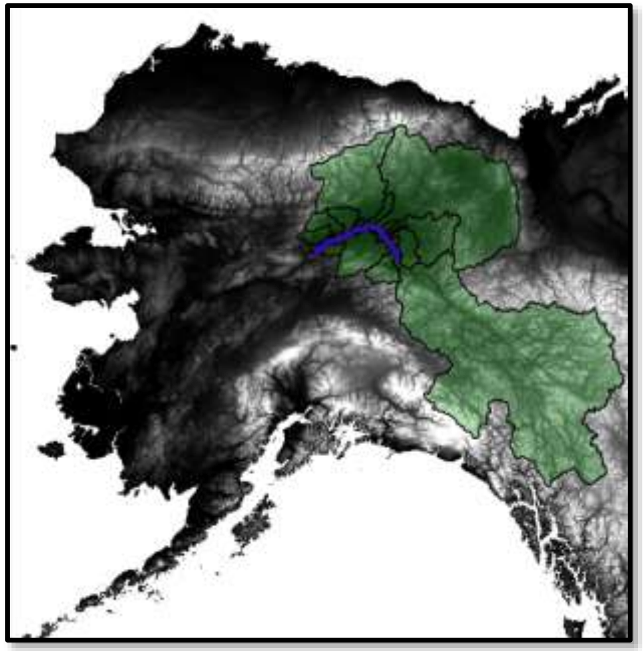
Temperature sensor at 50 cm depth in bank



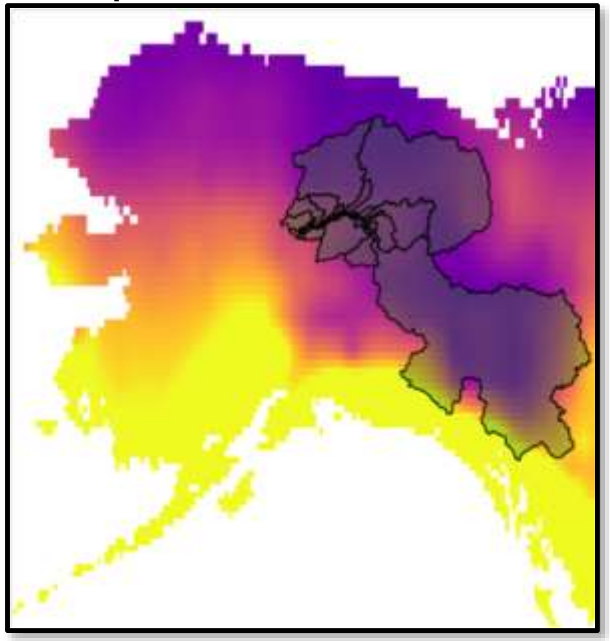
Identifying the controls on erosion to develop predictive understanding

- Preliminary upscaling of erosion measurements
- Use area-based erosion estimates: Area/channel length/time
- Using the recently developed Rabpro software (Schwenk, unpublished) to map contributing drainage basin for each segment of river.
- Extract topographic, hydrological (WBMsed) climatic (GLDAS)), and various landcover and soil attributes.

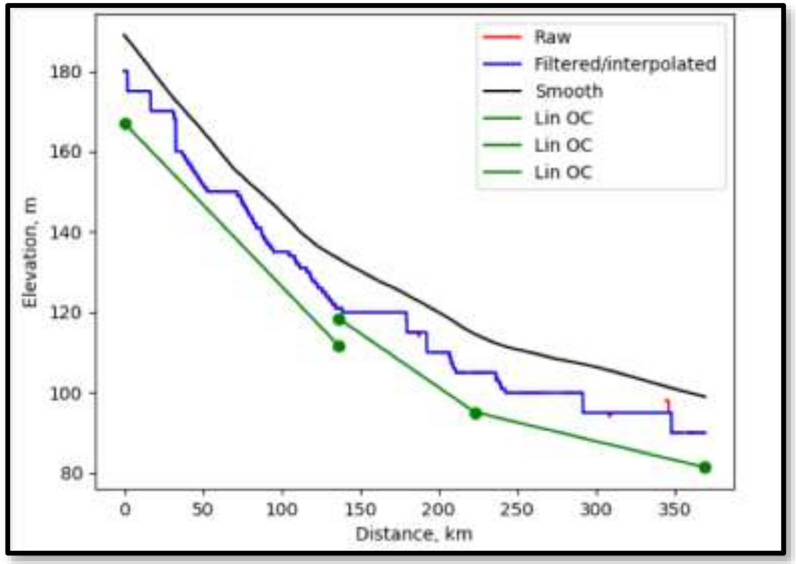
Topography



Precipitation

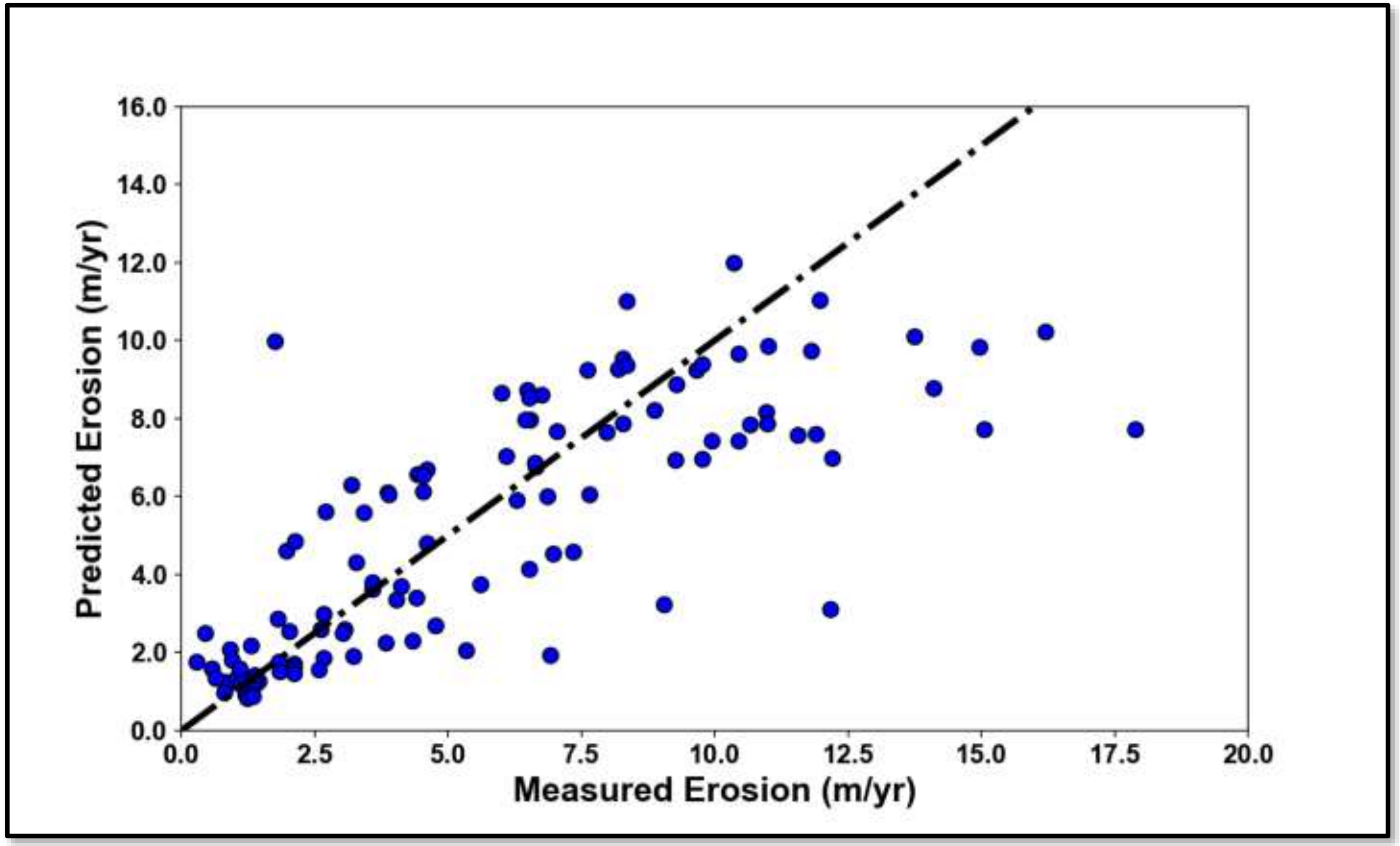


River Slope



Preliminary model for Arctic river erosion

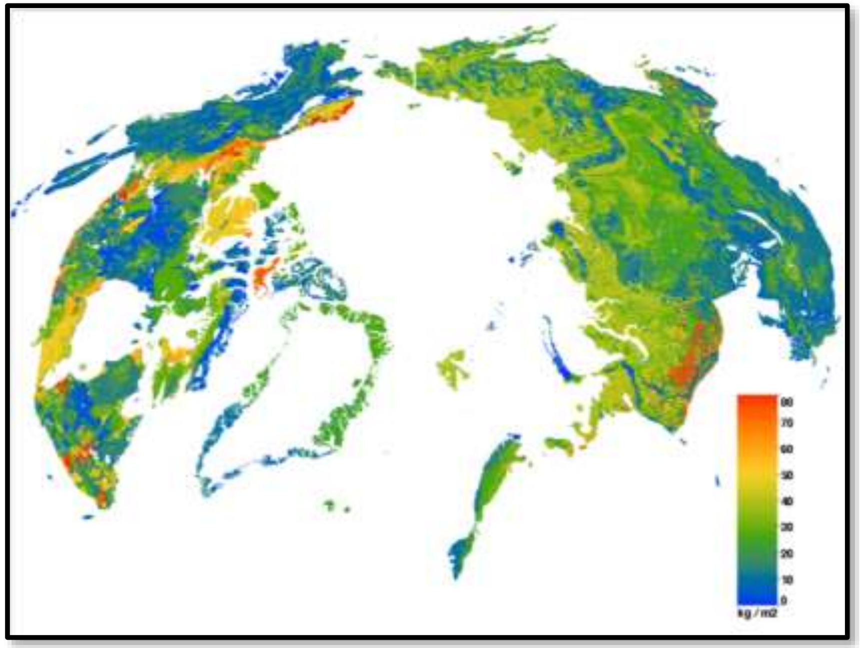
- Rates increase with river discharge, river slope, and mean annual air temperature
- Rates decrease with less flashy temporal distribution of precipitation
- adj $r^2 = 0.67$, $p < 0.0001$



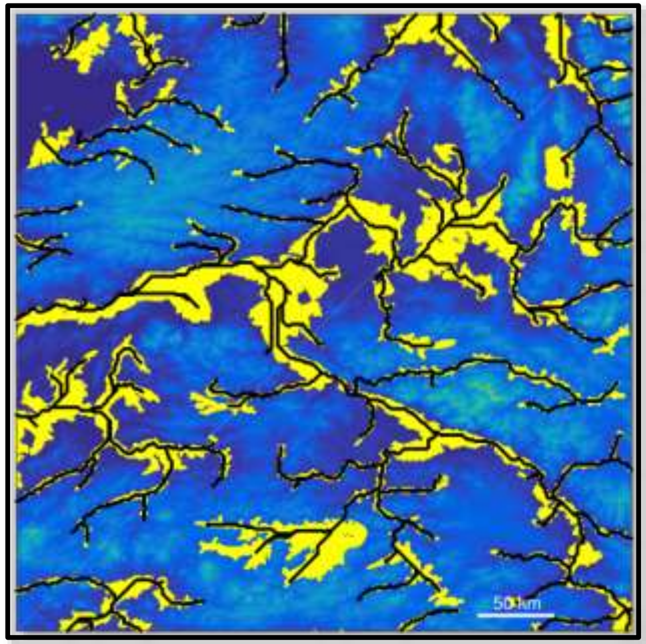
Scaling to pan-Arctic and linking to soil organic carbon

- Selected reaches of 10 of the top 11 largest rivers (by drainage) area and extracted the relevant local predictor variables
- Estimated the amount of soil organic carbon (SOC) released from 0 - 3 m of floodplain soils. Based on ~ 60 reported values of SOC in the NCSCD (Hugelius et al. 2013) we apply a uniform SOC value of 25 ± 6 kgC/m^2 (mean ± SE) for the upper 3 m of all eroding floodplains

SOC estimates



Map floodplain reaches



Pan-Arctic estimates

We estimate a mean flux of 6.4 (Tg/yr) SOC from floodplains to rivers along 10 major Arctic rivers.

Estimated floodplain fluxes

River	Eroded Floodplain Area (km^2/yr)	Carbon Flux (Tg/yr)
Yenisey	4.4	0.33 ± 0.08
Lena	11.3	0.85 ± 0.20
Ob	7.8	0.59 ± 0.14
Mackenzie	17	1.28 ± 0.31
Yukon	39.3	2.95 ± 0.71
Kolyma	1.8	0.14 ± 0.03
Pechora	1.0	0.08 ± 0.02
Indigirka	1.3	0.10 ± 0.02
Olenyok	0.05	0.004 ± 0.001
Taz	1.1	0.08 ± 0.02
Total	**85**	$\mathbf{6.4 \pm 1.5}$

Measured river fluxes

River	DOC (Tg/yr)	POC (Tg/yr)
Ob	4.1	0.57
Yenisey	4.6	0.25
Lena	5.7	0.81
Kolyma	0.81	0.12
Yukon	1.5	0.54
MacKenzie	1.4	0.76

Estimated upscaled pan-arctic totals:
DOC = 39 Tg/yr
POC = 5.8 Tg/yr
DOC (Holmes et al., 2012)
POC (McClelland et al., 2016

Conclusions for the Arctic

- Arctic rivers are different in erosion rates than lower latitude rivers
- The presence of permafrost appears to be a major control of this difference
- The natural evolution of Arctic rivers results in a significant flux of carbon to rivers, and may be a dominant control on the magnitude, quality, and timing of carbon flux from rivers
- The major controls on erosion rates in Arctic rivers (permafrost and hydrology) are very sensitive to changes in climate
- Therefore a current dynamic equilibrium could shift to a change in state

Ongoing contributions to BER science

- Developed a parameterization for representing Arctic floodplain fluxes to rivers in Earth System Models

- Framework and tools to expand to global analysis

- Role of hydrology on sediment and carbon storage and fluxes through floodplains (in collaboration with LBNL SFA)

- Provide a path to linking headwaters to oceans

The role of river-floodplain systems in the linkage of watershed processes from headwaters to ocean

NGEE - Arctic

Watershed SFA

Earth System Model Development

HiLAT-RASM

InteRFACE