Recent work on riverine fluxes to the Arctic Ocean with a brief overview of Earth System modeling gaps in linking land to ocean

Joel Rowland

Los Alamos National Laboratory

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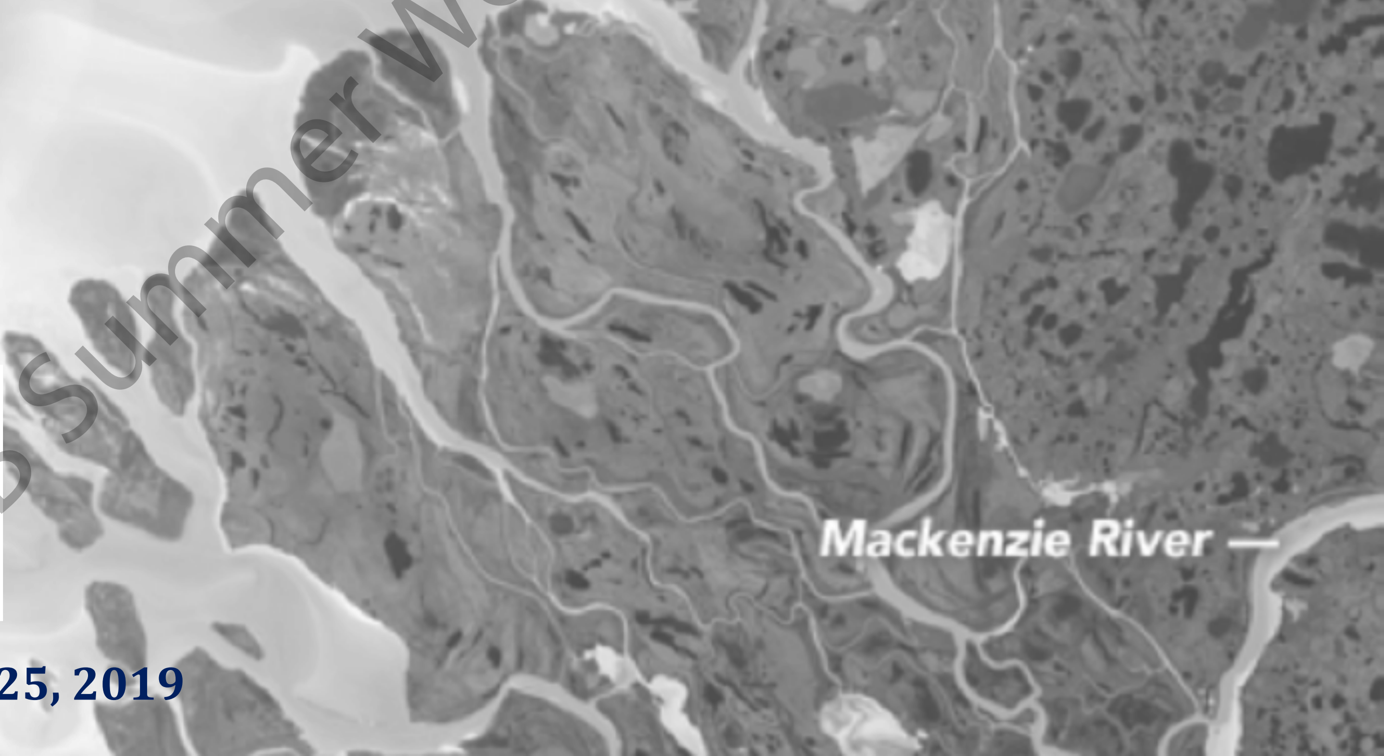
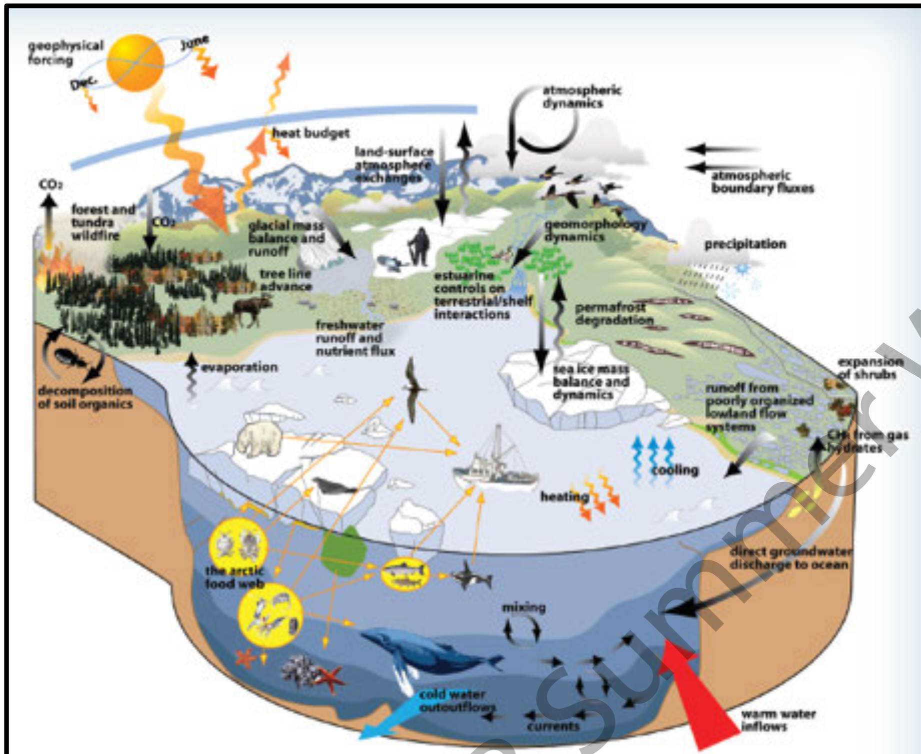
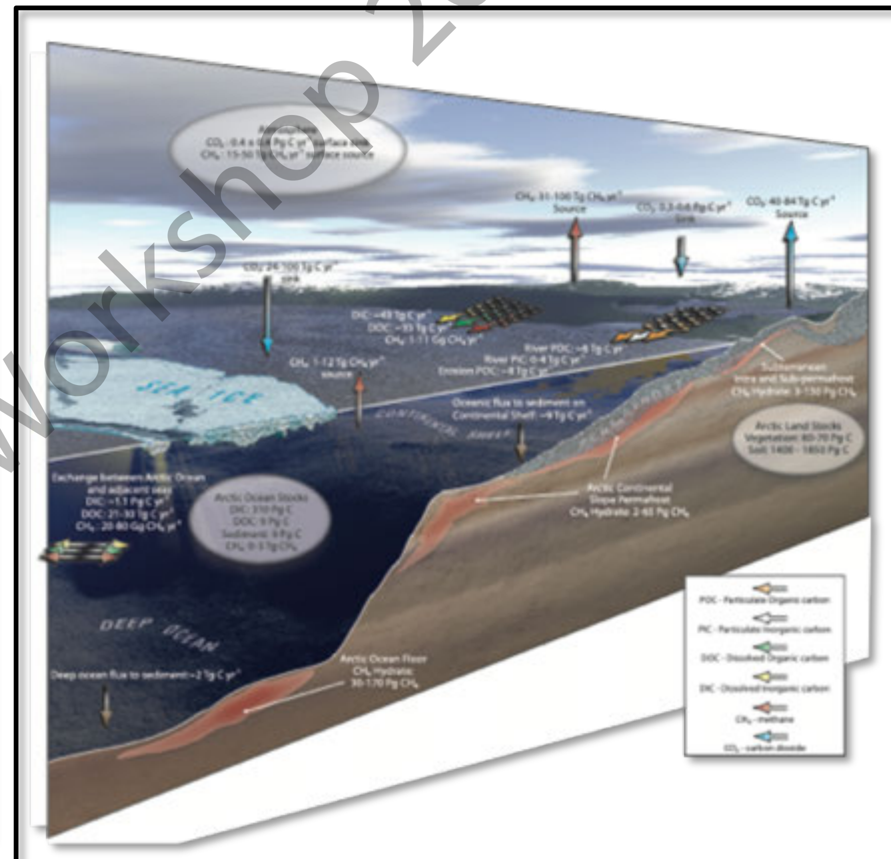


OCB Workshop: June 25, 2019

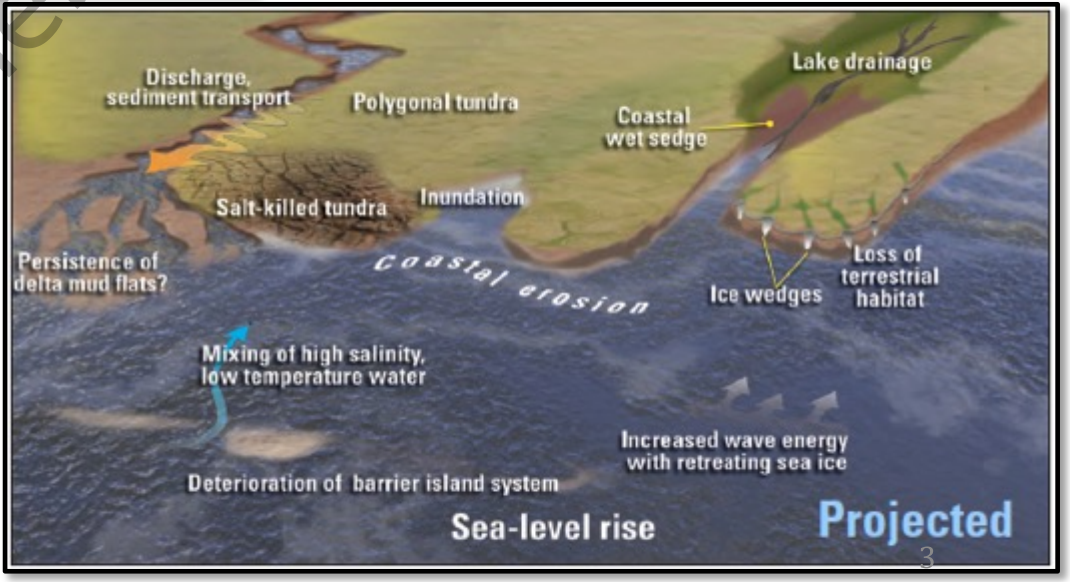
Linking land to ocean in Arctic





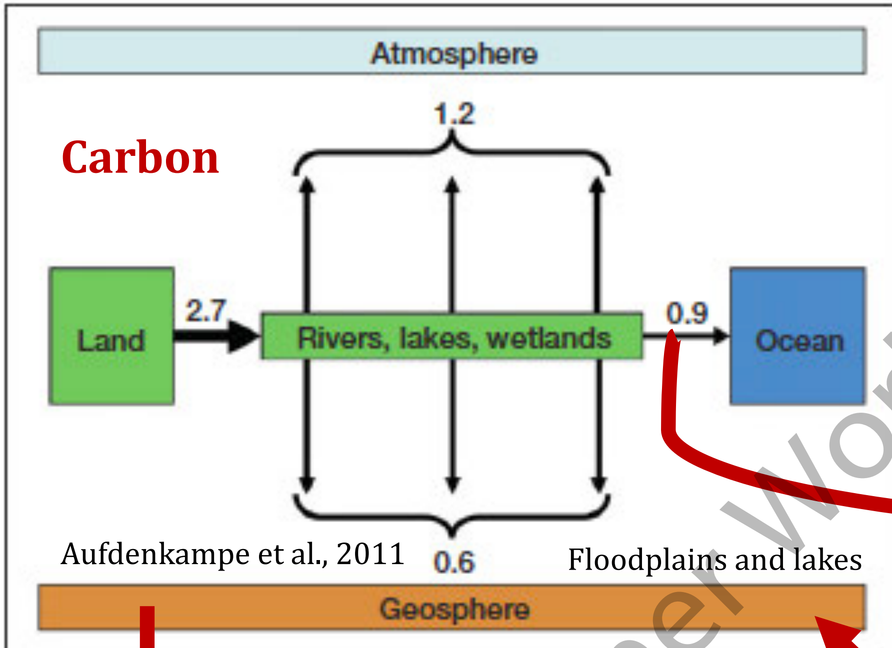
Roberts et al, 2010 – Science Plan for RASM

What do we know now versus what we will need to know in the future



Wildreach Report 2008

How do floodplains and deltas influence river fluxes to the ocean?

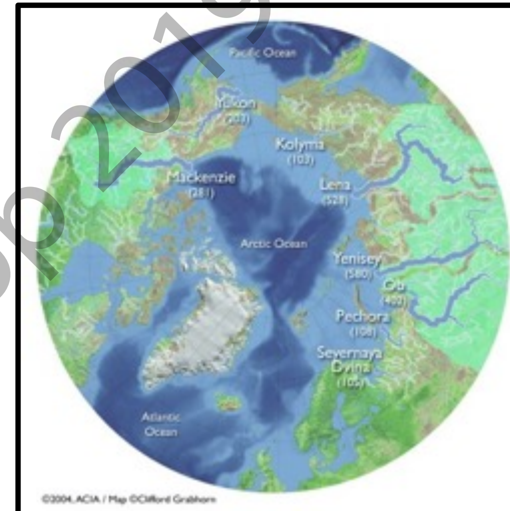


Yukon River Delta

Unique aspects of the Arctic

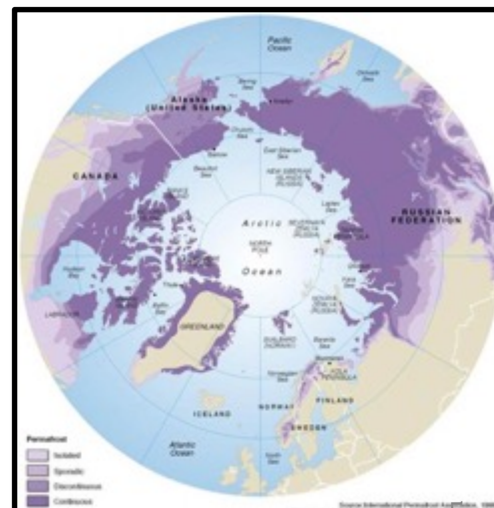
- 10% of the world fresh water discharge
- Permafrost – 24% of northern hemisphere
- 1024 Pg C in 0-3m of permafrost soils (Tarnocai et al. 2009
- Rapidly warming
- Observed changes in hydrology (Rawlins et al. 2010)
- Loss of sea ice, changes in landfast ice

River Discharge



(numbers) – discharge in km^3/yr

Permafrost



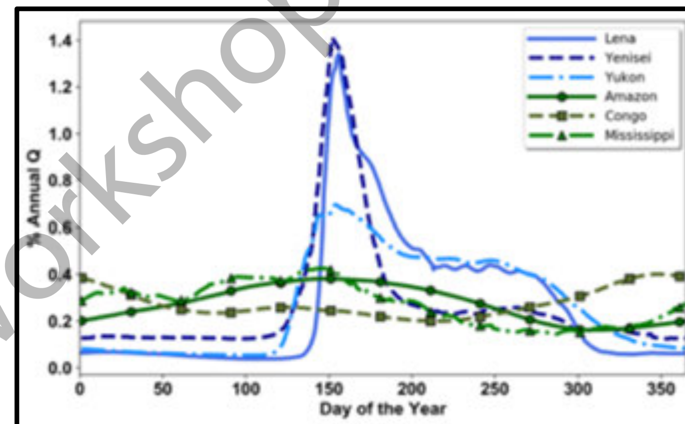
Terrestrial fluxes strongly controlled by permafrost, highly seasonal dynamics

Permafrost & Ground Ice

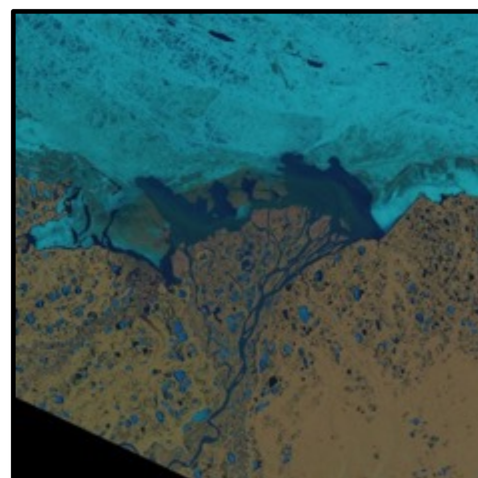
Yukon River

Selawik River, AK

Hydrology



Sea ice

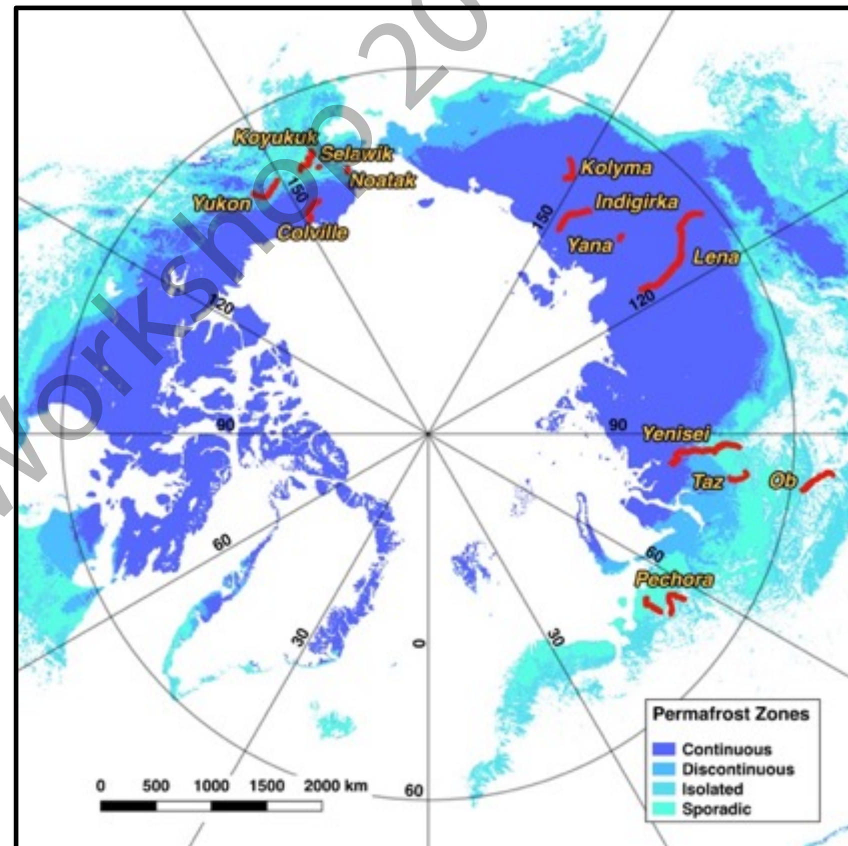


Colville, Ak

River-floodplain fluxes

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 km^2 (Selawik)
  - 2 million km^2 (Lena)
- Channel widths:
  - 50 m – 10 km (total of all threads on Lena)

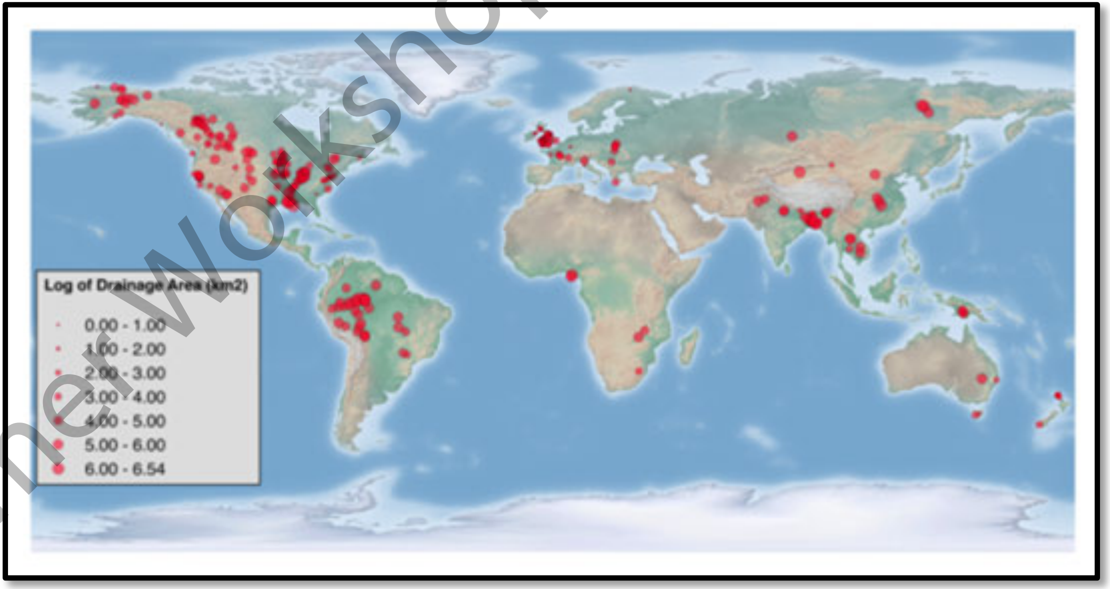


Background permafrost map from Globpermafrost

Do Arctic rivers differ from the rest of the globe?

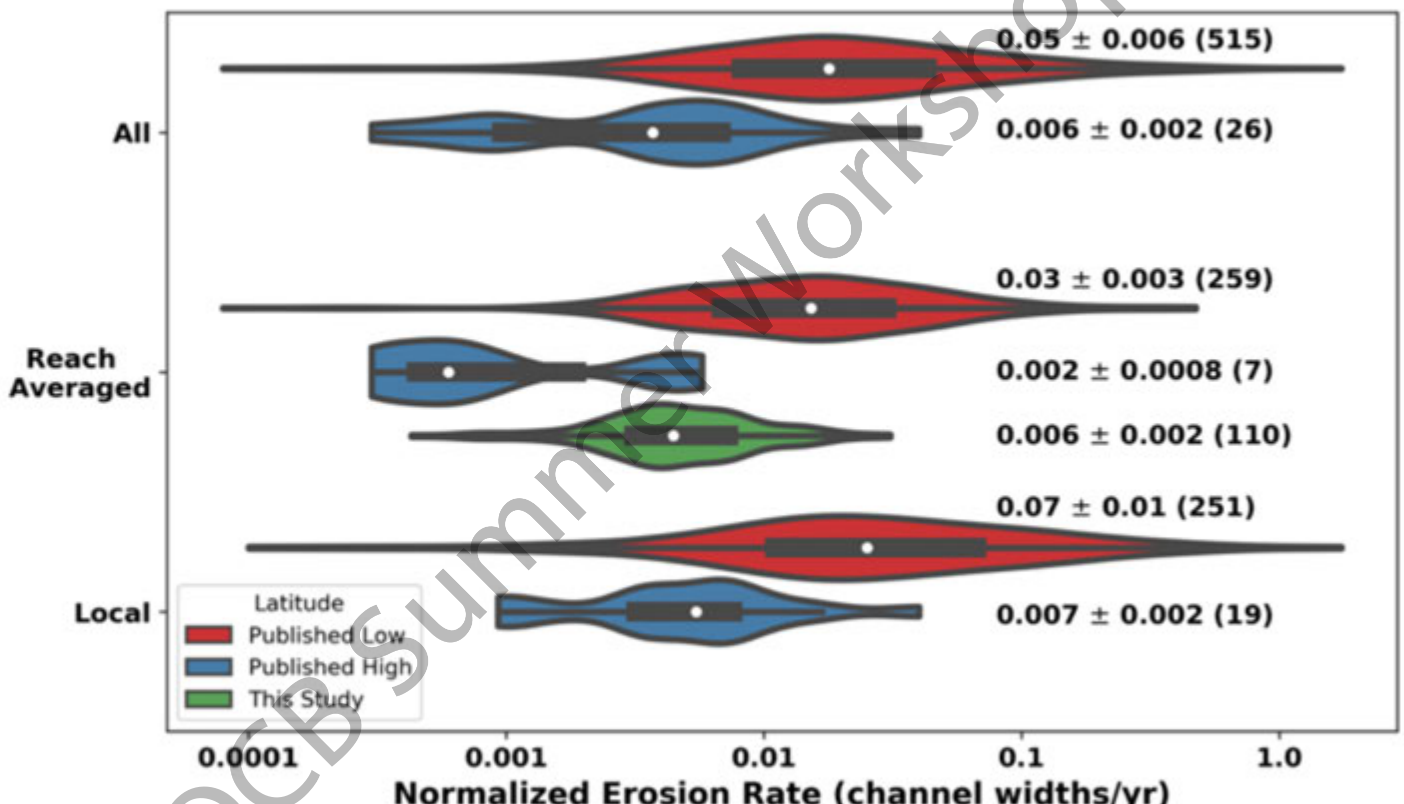
Compiled data from 159 English language references

- 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)

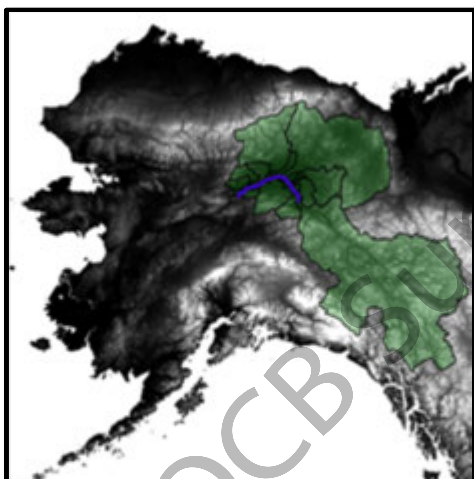


Low latitude statistically different from high latitude by all measures (Wilcoxon p-value < 0.001)

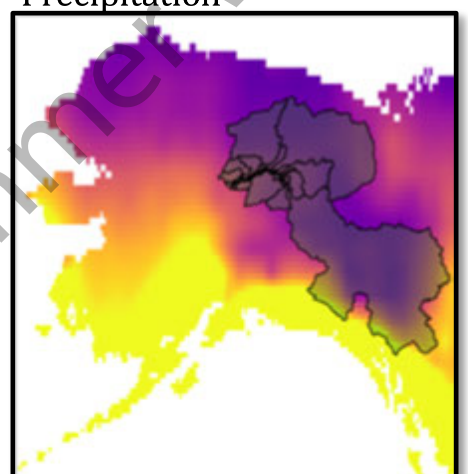
Upscale and link to sediment and carbon fluxes within the rivers

- 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.

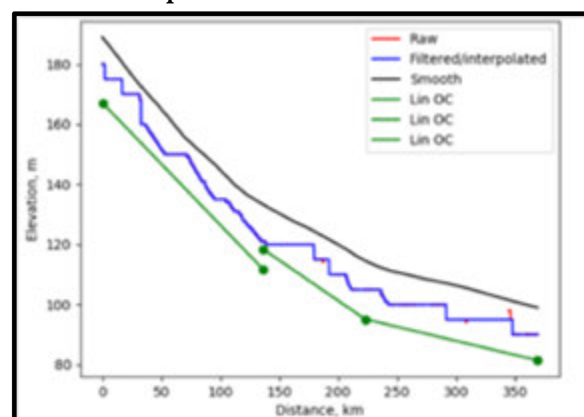
Topography



Precipitation

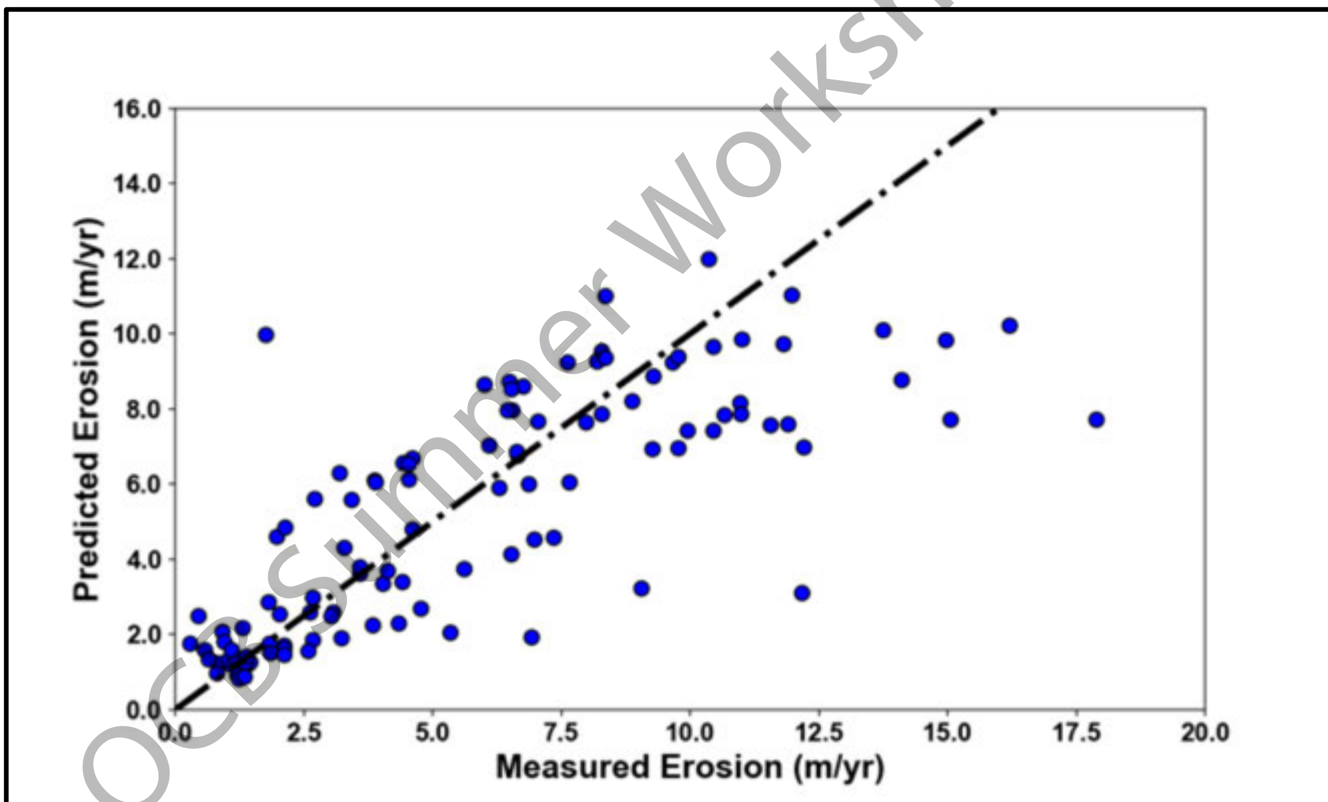


River Slope



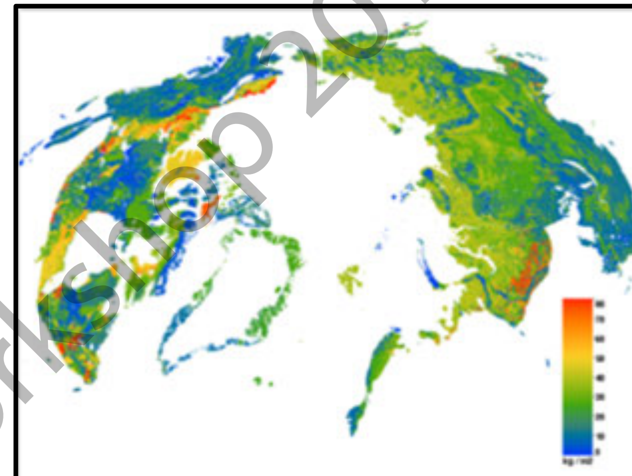
Preliminary model for Arctic river erosion

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

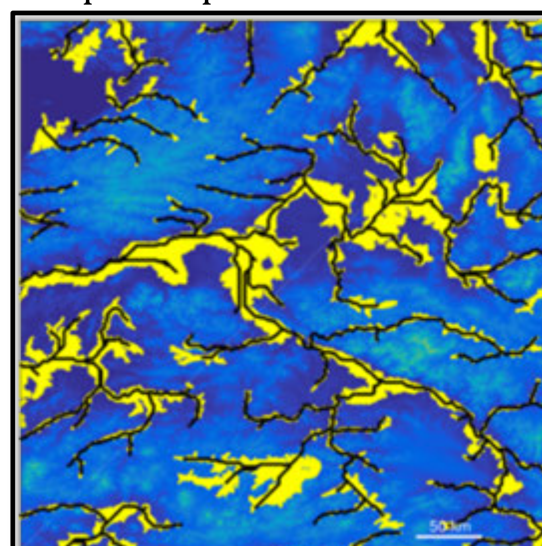


Scaling to pan-Arctic and linking to soil organic carbon

SOC estimates



Map floodplain reaches



- 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

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**	**6.4 ± 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 = 34 Tg/yr
POC = 5.8 Tg/yr
DOC (Holmes et al., 2012)
POC (McClelland et al., 2016

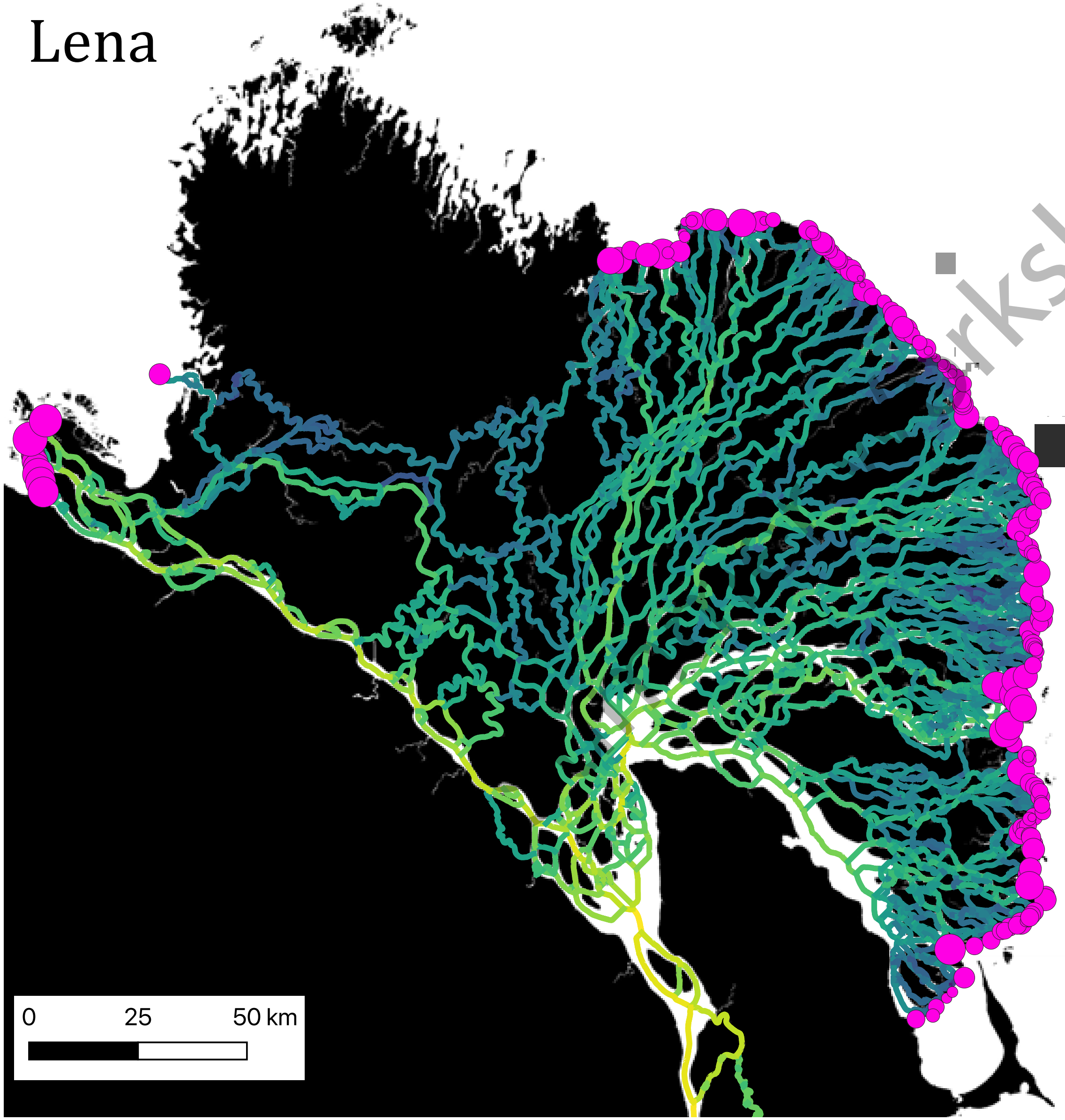
How do Arctic deltas affect land-ocean fluxes?

Anastasia Piliouras (LANL)

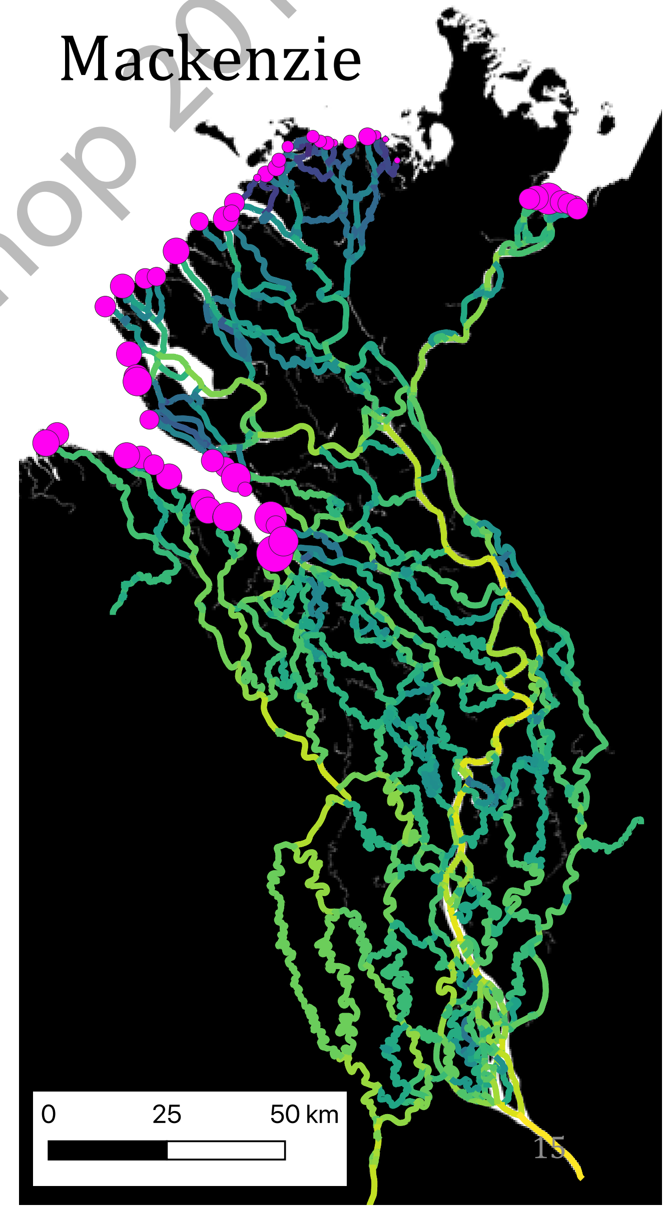
- Channel networks – spatial patterns of riverine flows
- Transient or permanent storage in lakes – timing and magnitude of fluxes
- What features of Arctic deltas influence spatial and temporal distribution of inputs to the ocean?
- How do ice cover and permafrost affect delta morphology and channel dynamics?

Channel network structure affects spatial patterns of fluxes

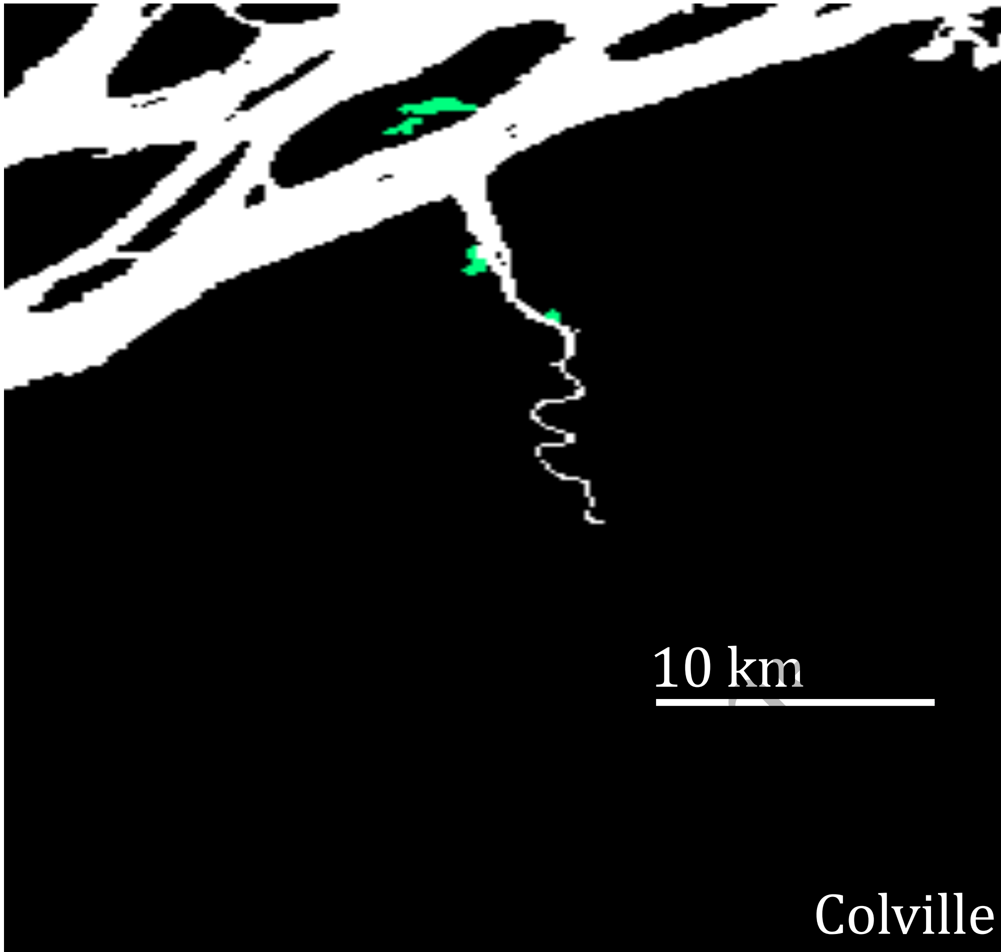
Lena

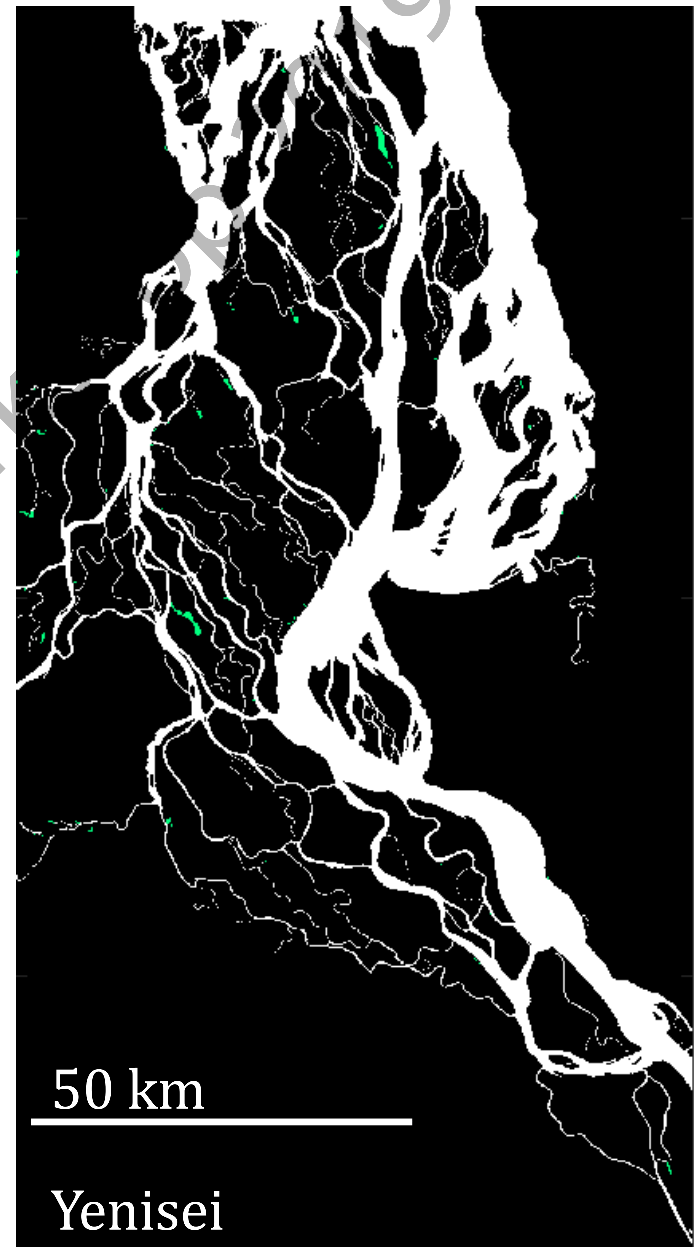


Mackenzie



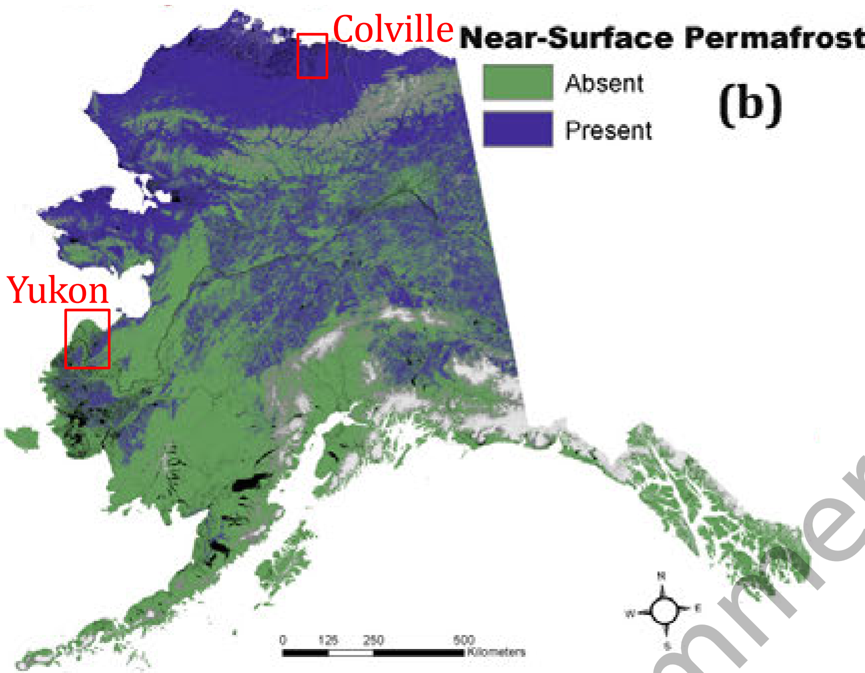
Lake connectivity determines storage potential





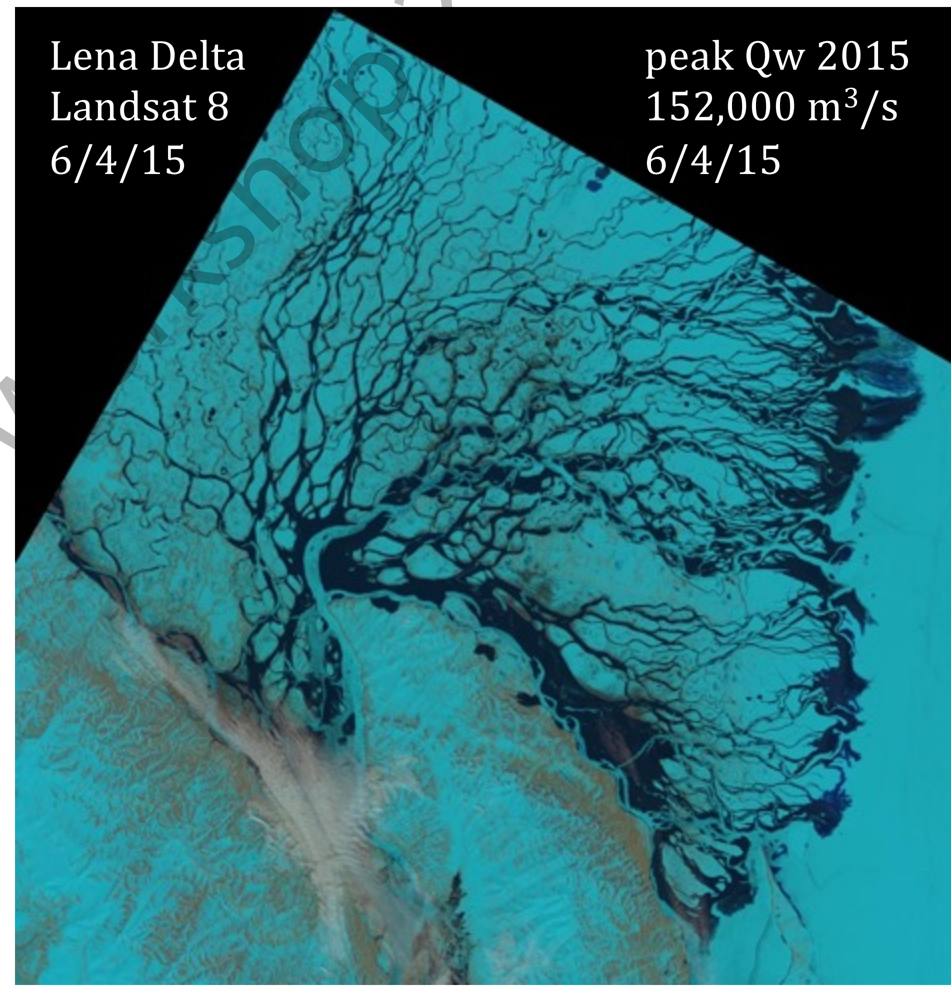
- Amount of connected lakes varies between deltas
- Influences availability of storage and biogeochemical changes

Effects of Ice and Permafrost on Delta Dynamics



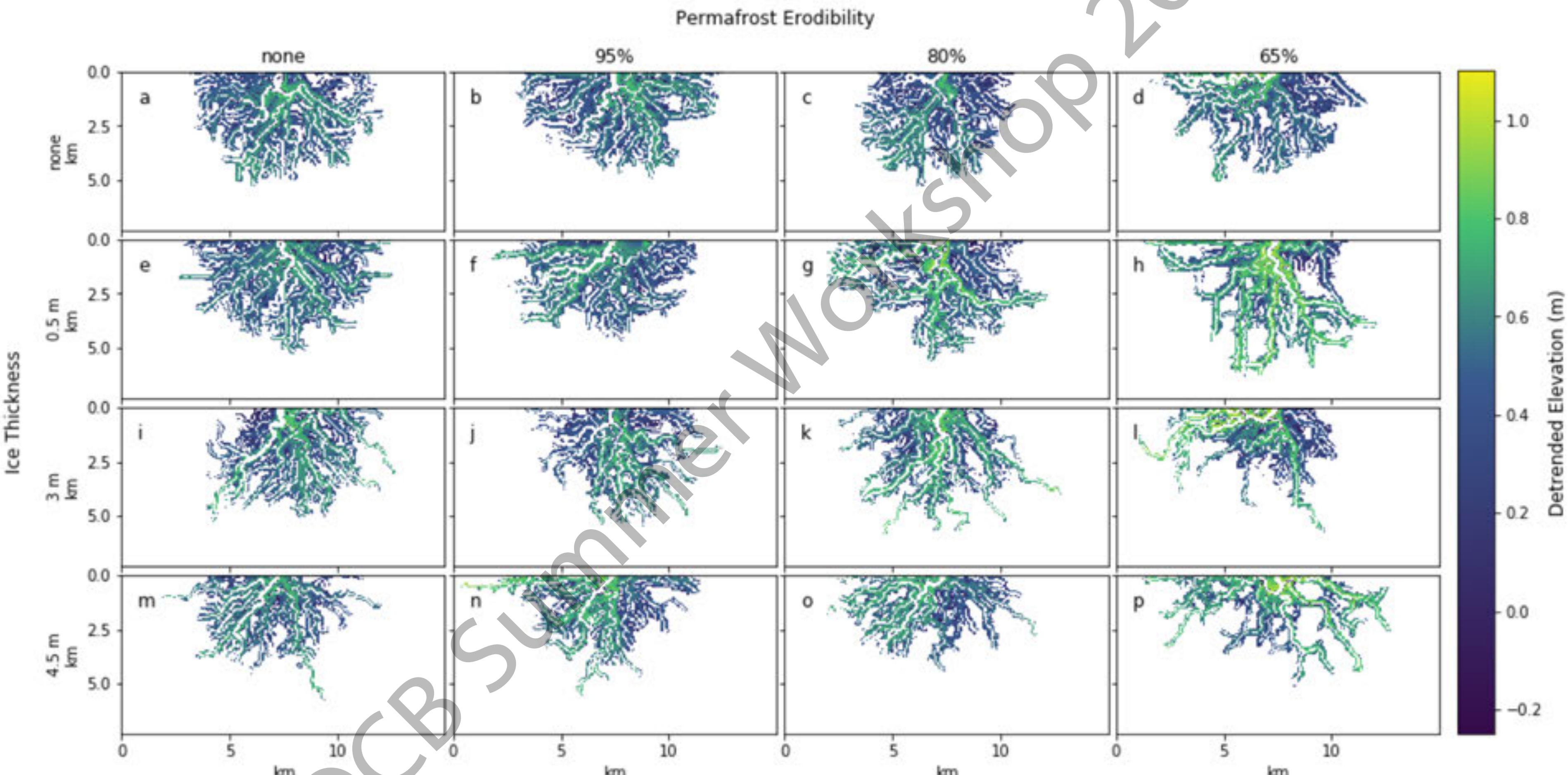
Pastick et al., 2015

- Permafrost and ice should influence flow and transport.
- What are the larger-scale effects on deltaic landscapes?



Use of a reduce complexity model to explore the influence of permafrost and ice on deltas

R. Lauzon & A. Piliouras



Maps of detrended elevations show permafrost erodibility has a stronger effect than ice thickness on overbank deposition. More resistant permafrost encourages more deposition near channels.

Summary of ice and permafrost effects in model

- Ice and permafrost limit channel mobility
  - leads to stable channel mouths – few locations delivering most of the material
  - warming -> more mobile channels, less particulate storage in delta plain
- Ice and permafrost fundamentally change sediment partitioning onshore vs offshore
  - offshore delivery to 2m ramp + deep ocean (incised channels); onshore overbank deposition helps keep up with SLR
  - warming -> less offshore delivery of particulates, delivery focused closer to shore; less overbank deposition – increased likelihood of drowning

DOE – Laboratory funded Arctic efforts

High-Latitude Application and Testing of Earth System Models (HiLAT-RASM)

Next Generation Ecosystem Experiment (NGEE) Arctic

Energy Exascale Earth System Model (E3SM)

- Model Prediction Across Scales (MPAS)
  - MPAS-Ocean
  - MPAS-CICE

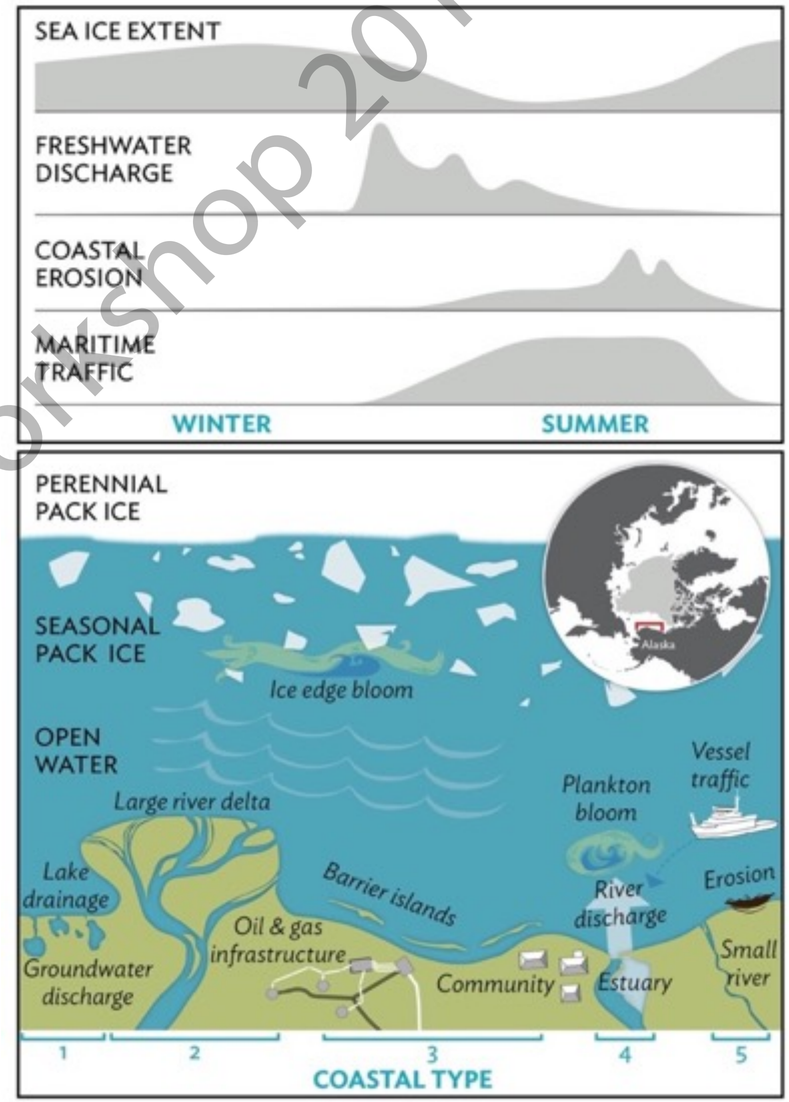
Interdisciplinary Research for Arctic Coastal Environments (InteRFACE)

Model Benchmarking – International Land Model Benchmarking (ILAMB) and IOMB (Ocean)

- New effort for Ocean Model Benchmarking

INTERFACE – Under review, FY19 start

- Permafrost hydrology
- Sea ice (land fast) and ocean dynamics (waves, tides)
- Marine biogeochemistry (emphasis on benthic)
- Coastal change
- Resources, transportation, and settlements
- Intensive focus on North Slope of Alaska, with pan-Arctic and global connections

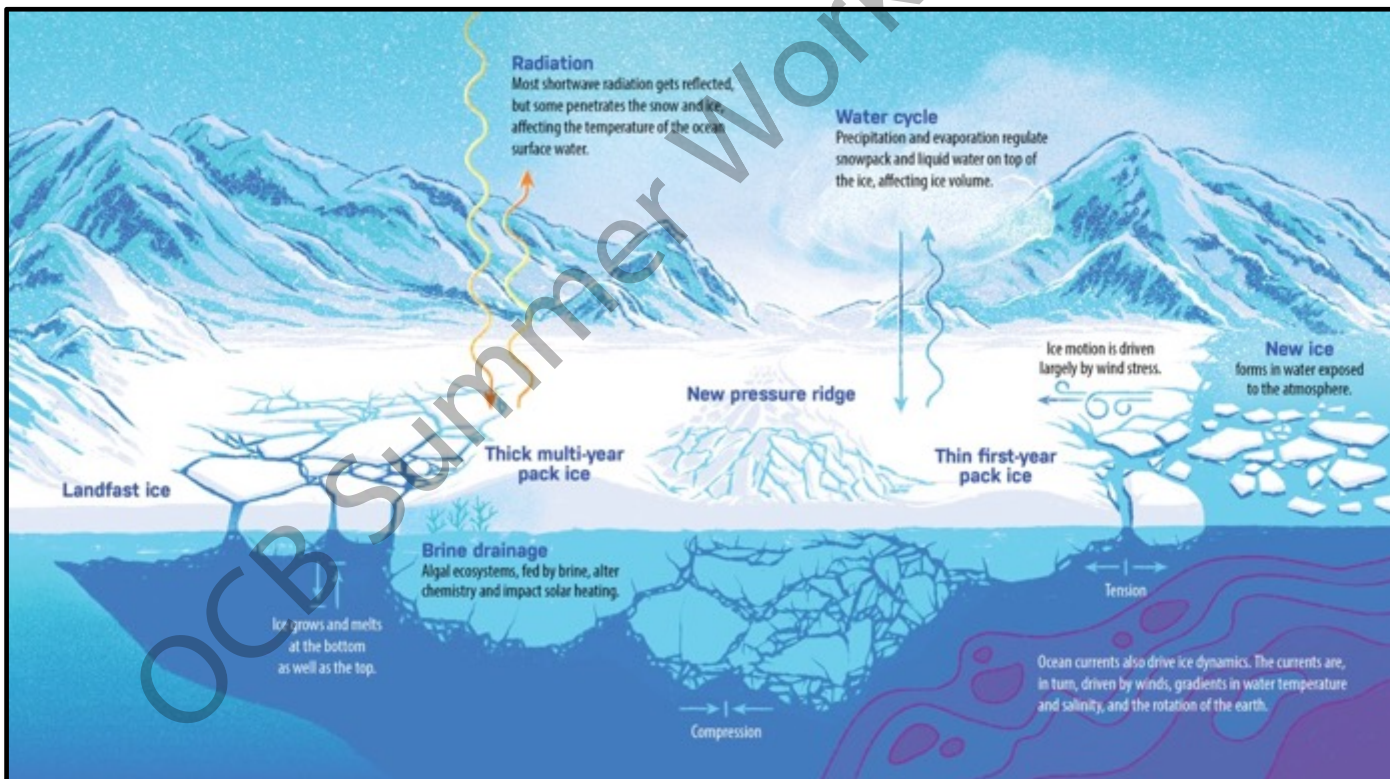


Modeling Gaps: Rivers and coasts

- Accurate and dynamic river fluxes, model evaluation
  - Nutrients
  - Sediment
  - Heat
- Ability to capture seasonality and future shifts in seasonality
- Coastal dynamics and influence of fluxes to coastal ocean

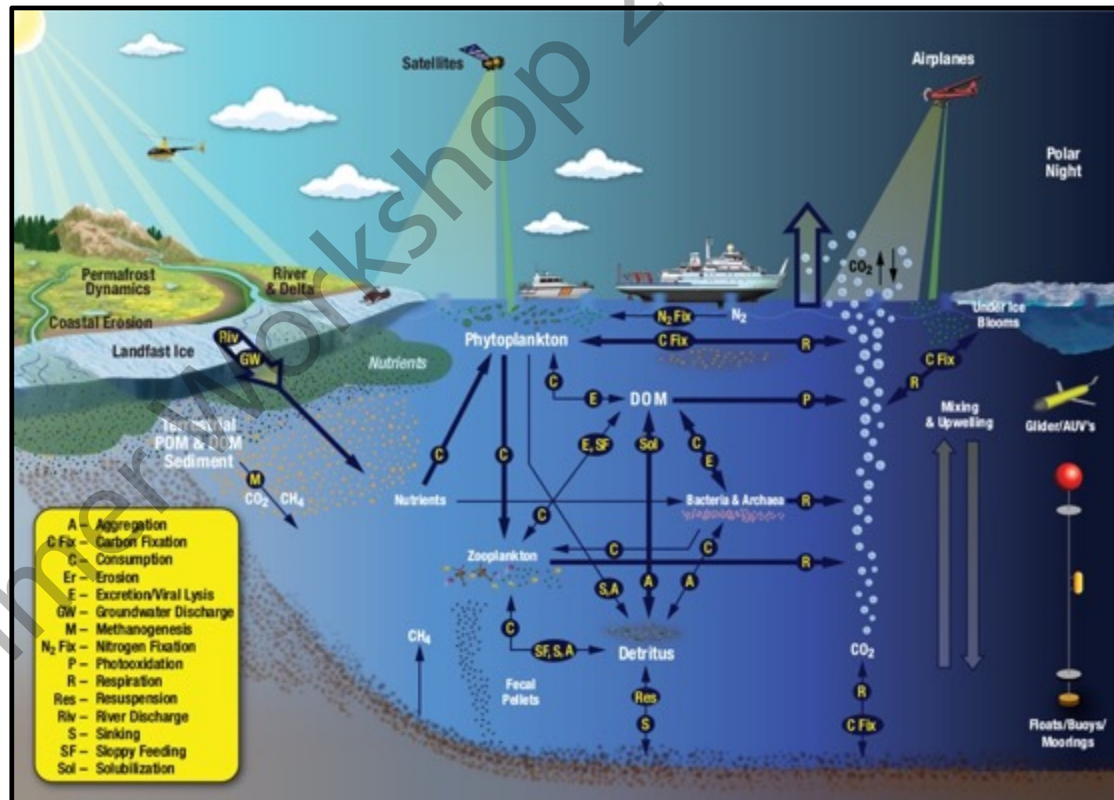
Modeling Gaps: Ocean and Sea Ice

- Landfast Ice
- Parameterization for vertical ocean mixing
- Waves and tidal influence on ice and shelf dynamics



Modeling Gaps: Biogeochemistry

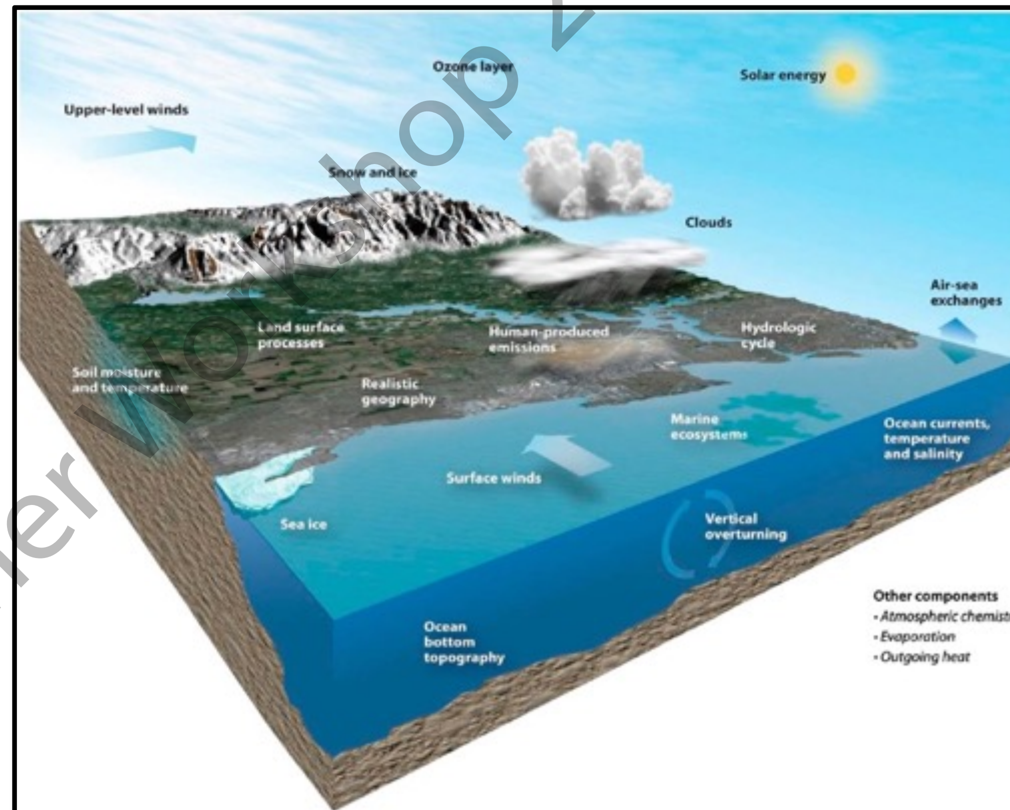
- River
  - In-river
  - Fluxes to river
- Coastal Erosion
  - Rates and patterns of fluxes
  - Nutrient fluxes
- Marine
  - Benthic
  - Sediment
    - Water column
    - Sea ice
  - Controls on light
  - Influence of mixing
  - Seabed releases of clathrates



Arctic-COLORS

Modeling Gaps: Coupling across land-ocean interface

- River to ocean
- Ocean to coast
- Waves to ice
- Need to identify and incorporate critical two-way feedbacks



Lique et al 2015

Acknowledgements

U.S. DEPARTMENT OF ENERGY | Office of Science

Subsurface Biogeochemical Research

Regional and Global Model Analysis (RGMA)

Collaborators and Co-authors

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