Arctic Rivers

How are they changing?

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Observed Changes in Arctic Rivers

7% increase combined yearly water discharge of six largest Eurasian rivers between 1936 – 1999 (Peterson et al., 2002).

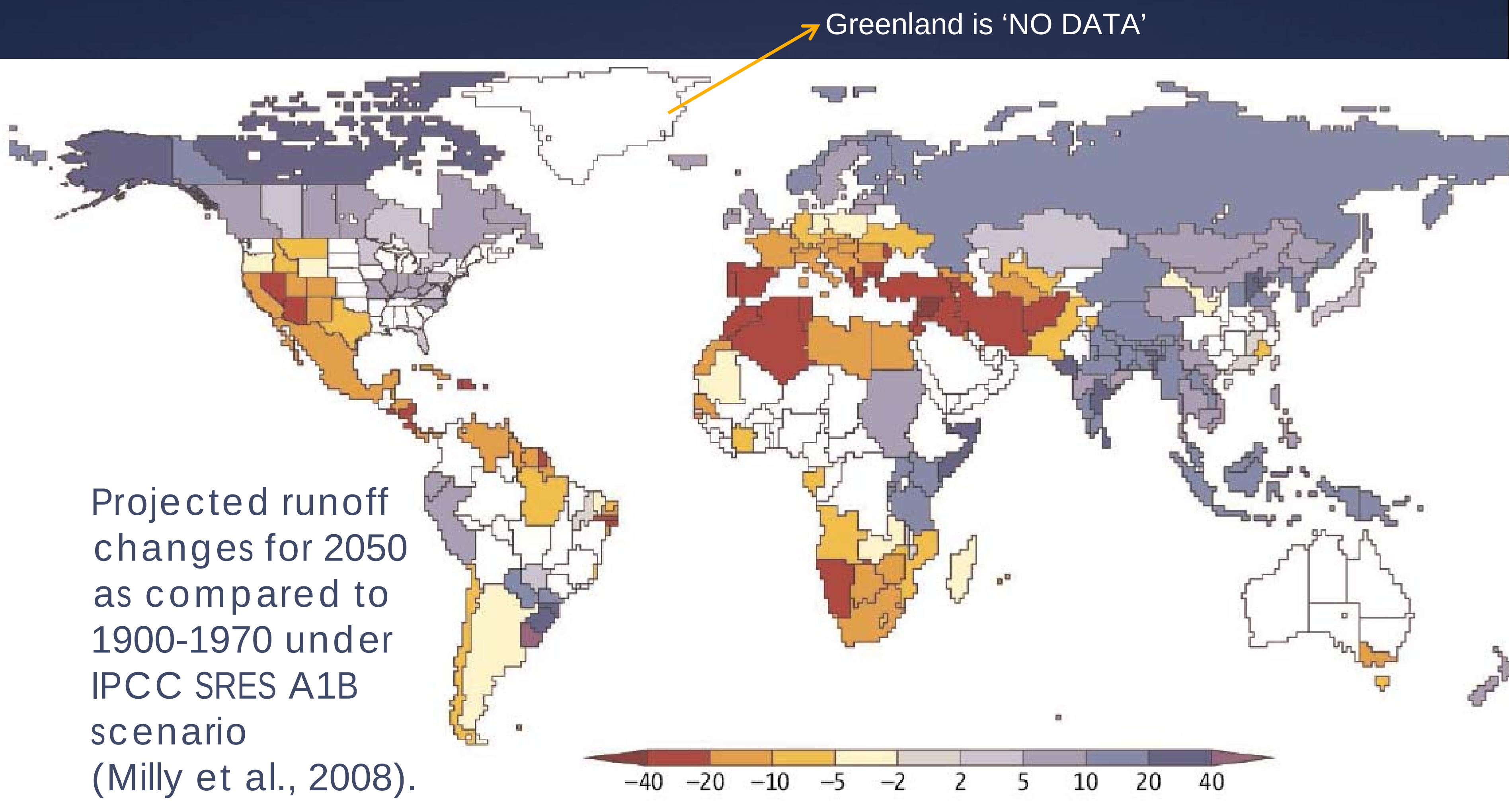
10% decrease in yearly water discharge in Canadian Rivers between 1964 – 2000 (Dery, 2005).

Discussion on causes….ongoing. (Berezovskaya et al., 2004 and McClelland et al., 2004).

How does this influence sediment load?

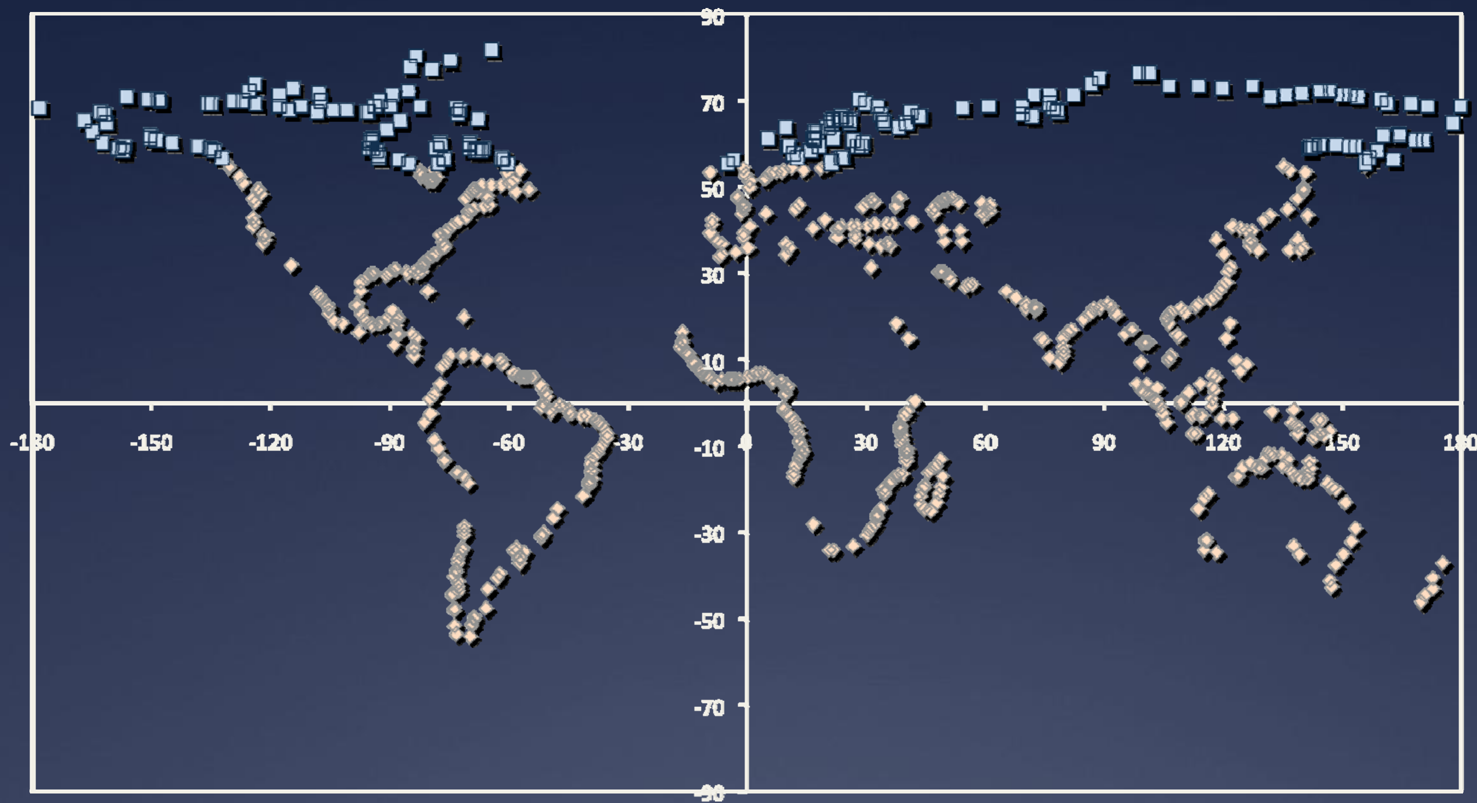
Projected Changes

* Changes in Arctic rivers are integrated signals of changing hydrological conditions in their basins.



Projected runoff changes for 2050 as compared to 1900-1970 under IPCC SRES A1B scenario (Milly et al., 2008).

Database



- 363 ‘Arctic Rivers’ > 55° North
- 1132 lower latitude rivers
- All selected drainage basin areas are over 5,000 km²

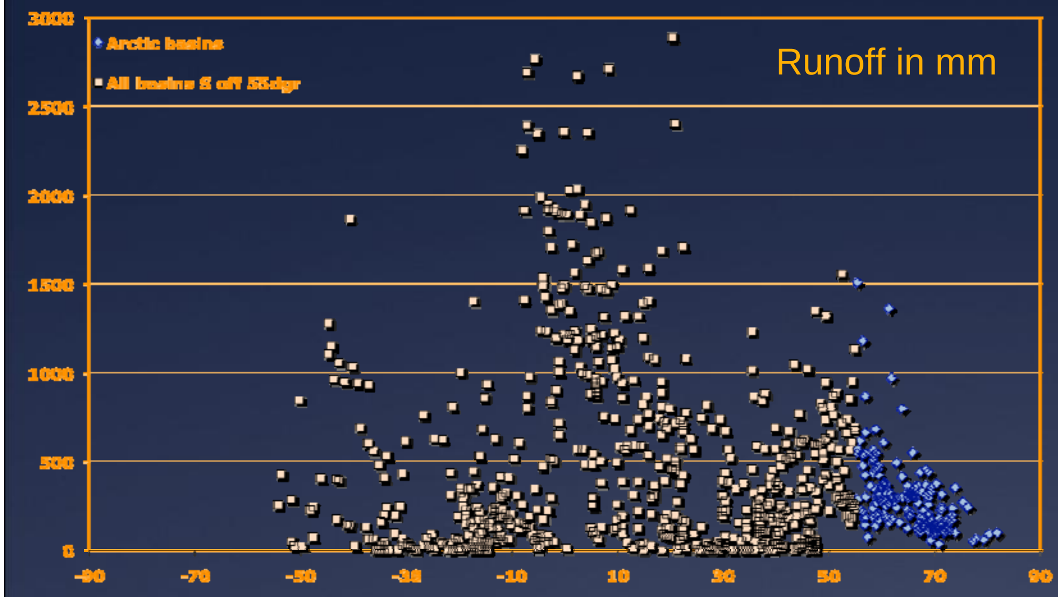
- 50 Rivers have extended time-series

Database Parameters

- **River Drainage Basin Area, Basin Relief** **(GTOPO30 DEM)**
- **Basin Temperature, Precipitation (and statistics)** **(CCR 2005)**
- **Permafrost Area** **(Brown et al., NSIDC, 2001)**
- **Glaciated Area** **(World Glacier Inventory, NSIDC, 2007)**
- **Monthly Water Discharge (Q)** **(USGS, ArcticRIMS, HYDAT, GRDC)**

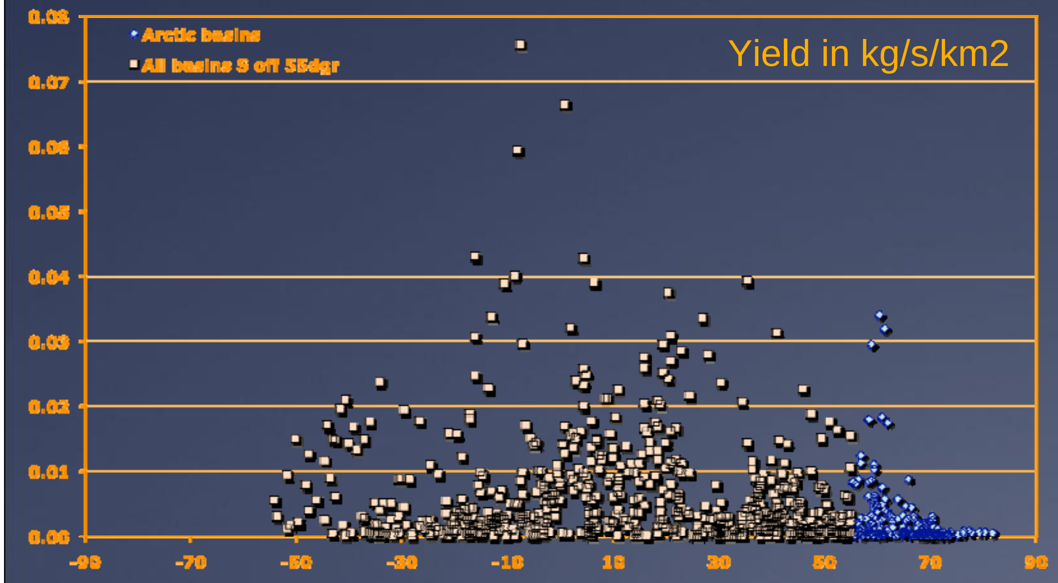
- **Presence/Age of dams and reservoirs** **(World Register of Dams)**

Annual runoff and yield



Arctic basins have less annual runoff than global average

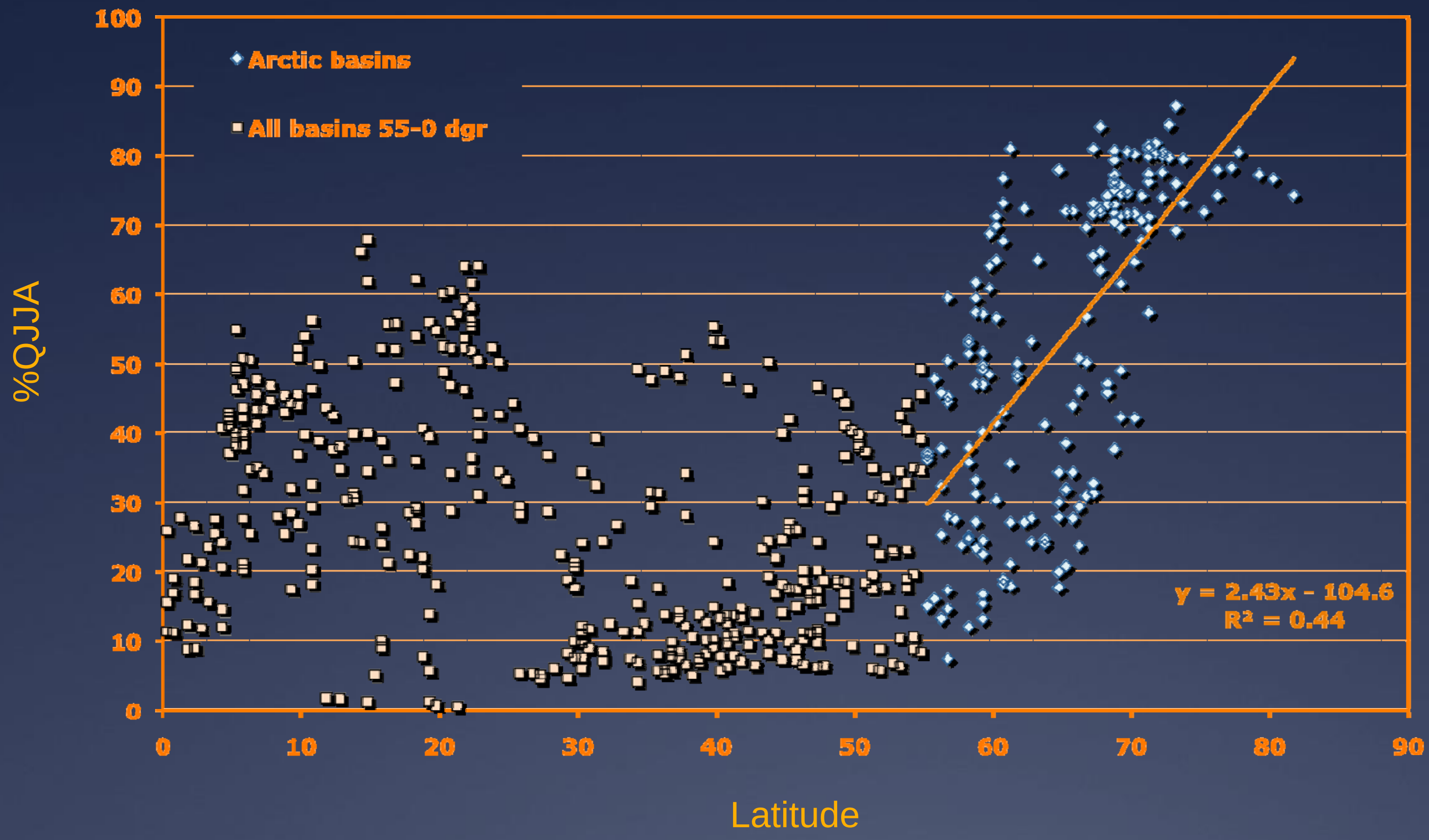
Arctic mean = 0.57 * global mean



Arctic basins have less annual sediment yield than global average

Arctic mean = 0.37 * global mean

Seasonality



Seasonality strongly scales with latitude (and basin temperature). High-latitude basins on average drain 53% of their total water JJA, as compared to 26% for all basins between 55 – 0°N.

Modeling sediment loads

$$Q_s = 0.04 B A^{0.31} R^{0.5}$$

B = glacier extent, lithology, human factors, trapping efficiency

B = I L (1-Te)Eh

A = drainage area →or Q ~ A (r^2= 0.92)

R = relief in km

For mean annual T < 2℃

Glacial erosion factor I = 1+ 0.09 Ag

Trapping efficiency TE = 1- (0.05/√Δt)

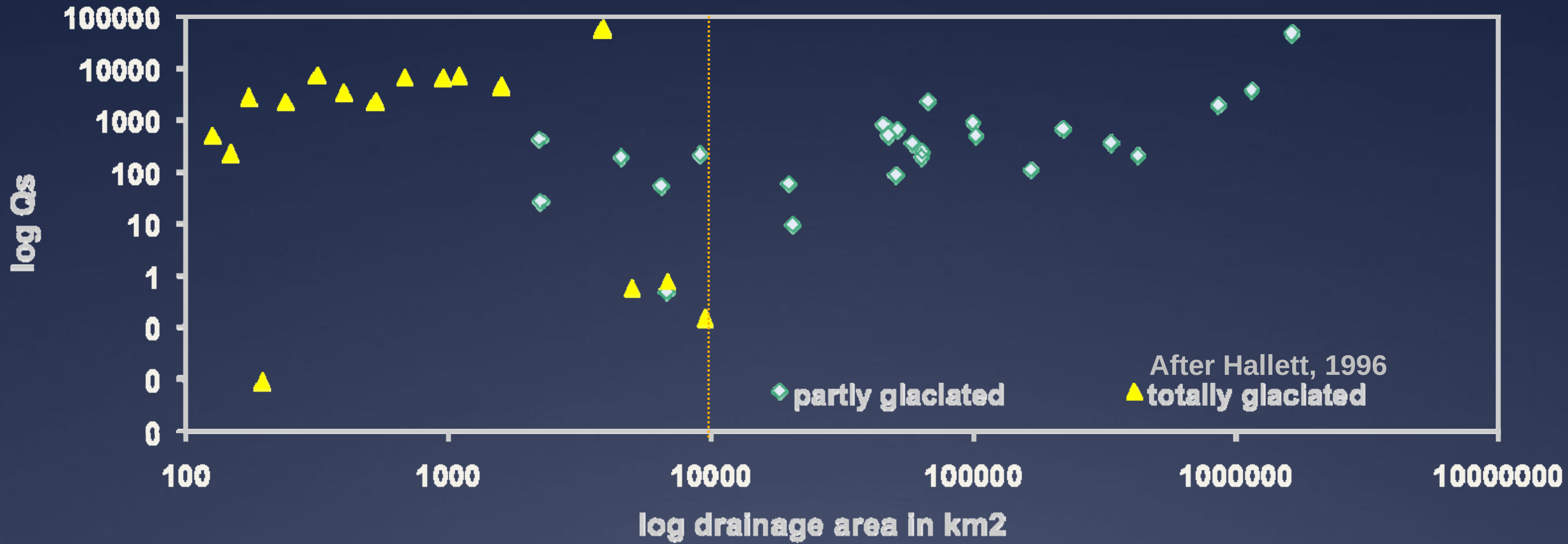
Model accounts for 96% of between river variation of long-term sediment load, (Syvitski & Milliman, 2007)

The big picture

Receiving Ocean	Contributing Drainage Area (km²)	Water Discharge (m3/yr)	Sediment load (Mt/yr)
Arctic	$1.55 * 10^{7}$	$3.12 * 10^{12}$	346.6
Pacific	$2.17 * 10^{6}$	$7.24 * 10^{11}$	87,2
Atlantic	$1.55 * 10^{7}$	$1.02 * 10^{12}$	52,9

Lower estimate of Hasholt et al., (2005) based on combined load data; 324 MT/yr.
Their highest estimate includes a important Greenlandic contribution; 884 Mt/yr.

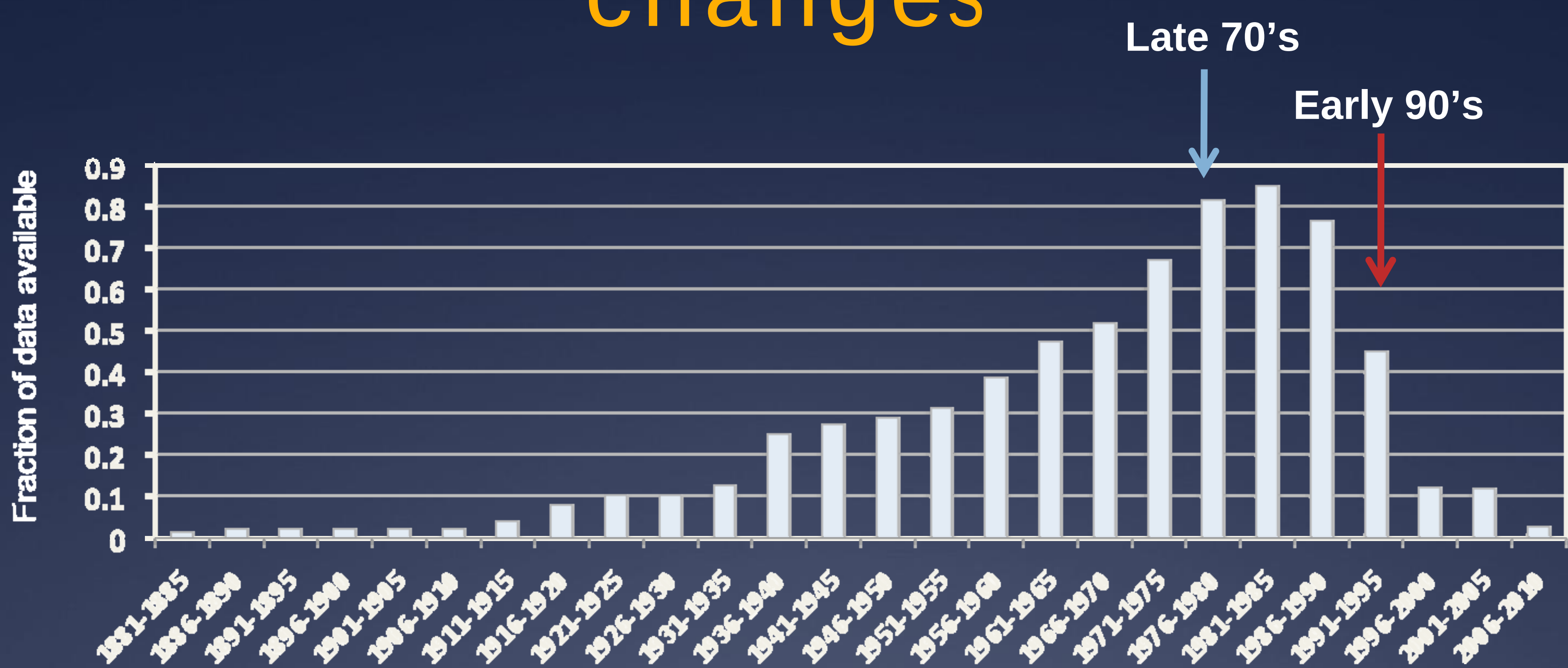
Glacier Impact



Only 40 basins over 10,000 km^2 have significant glacier coverage
Average Ag = 0,92, meaning less than 1 % of drainage area is glacier-covered.

No apparent correlation between glaciated area and annual Qs in larger basins.
But note that a few basins with exceptionally high glaciated area have the highest load.

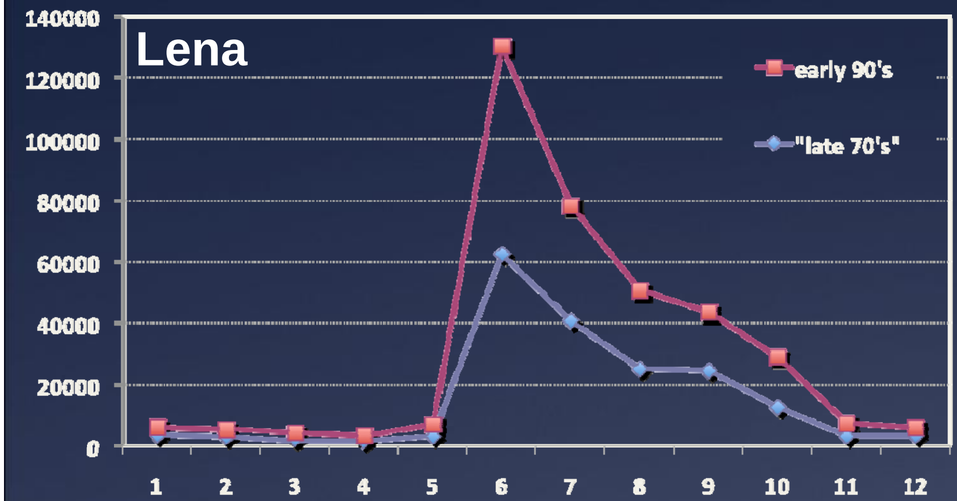
Complexities in assessing changes

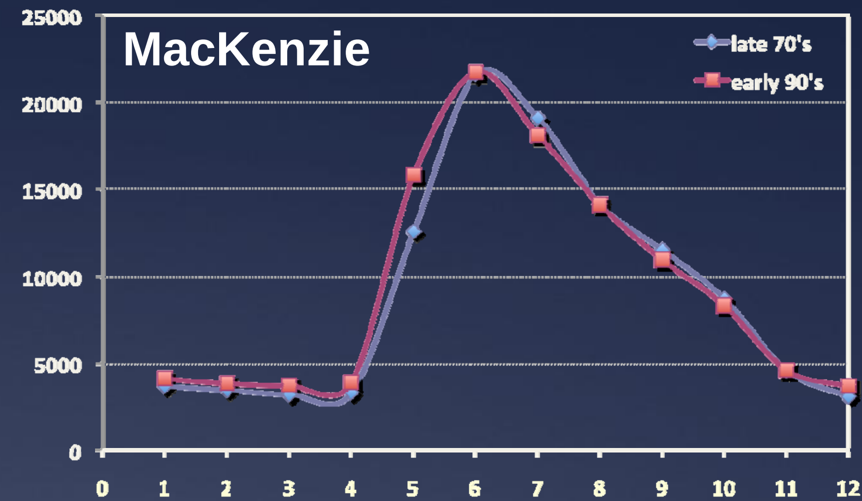


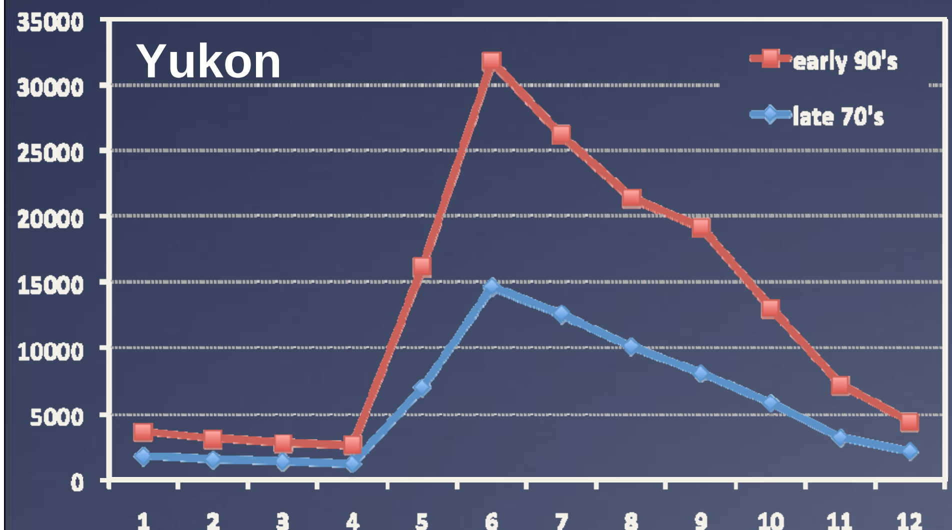
Sparseness of observational data; for 50 rivers only 4 decades with >60% data coverage. Recent data for Eurasian Rivers is difficult to access.

Most available datasets present monthly data
Observational data on sediment is 'orders of magnitude' sparser.

Changes in monthly Q



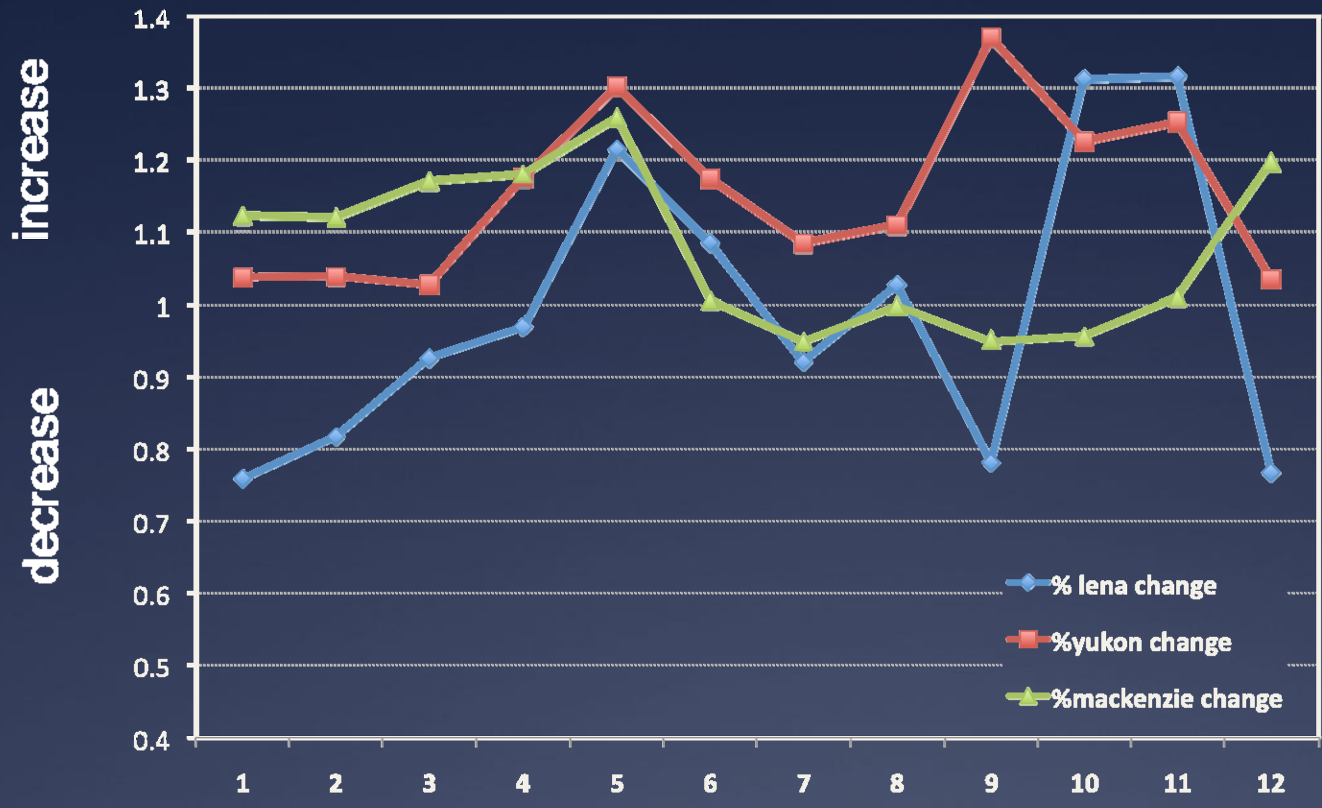




Predicted trends are already observed.

Only 16 rivers out of 178 high-latitude basins are dammed

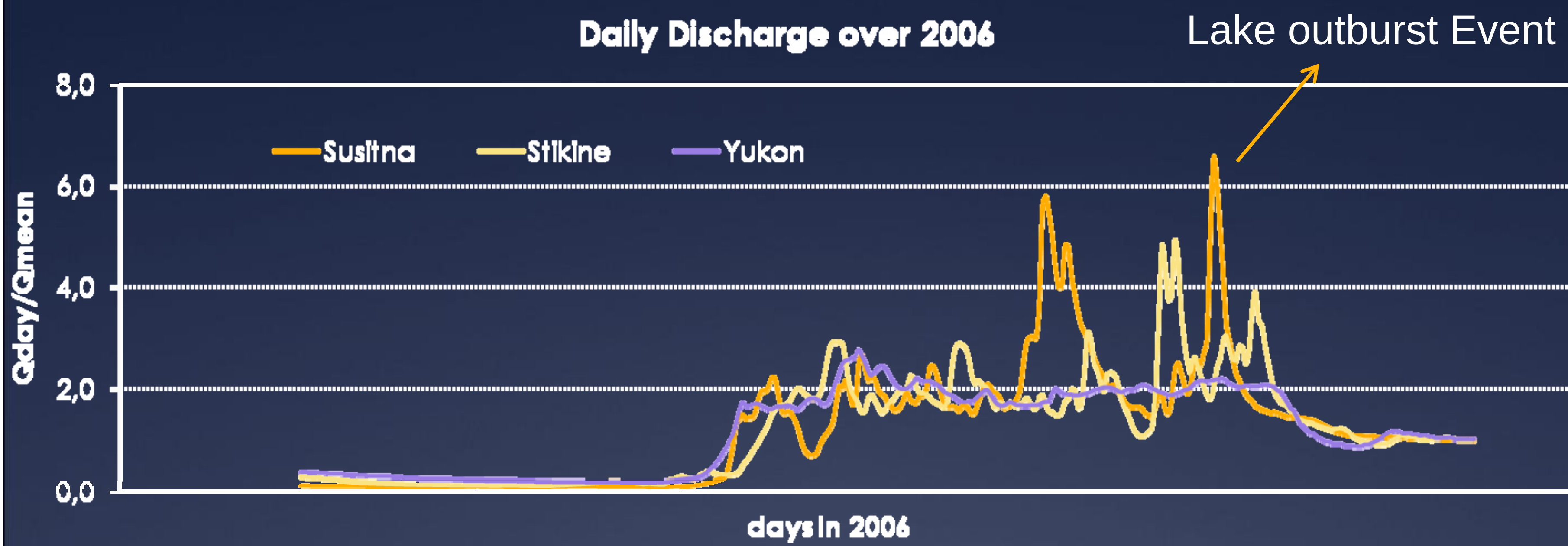
Changes in seasonality



Many rivers show a significant change in seasonality over time of measurement, not only due to damming!

16 rivers out of 178 high-latitude basins are dammed
Trapping efficiency predicts decrease of 3,1 % of total annual Arctic load

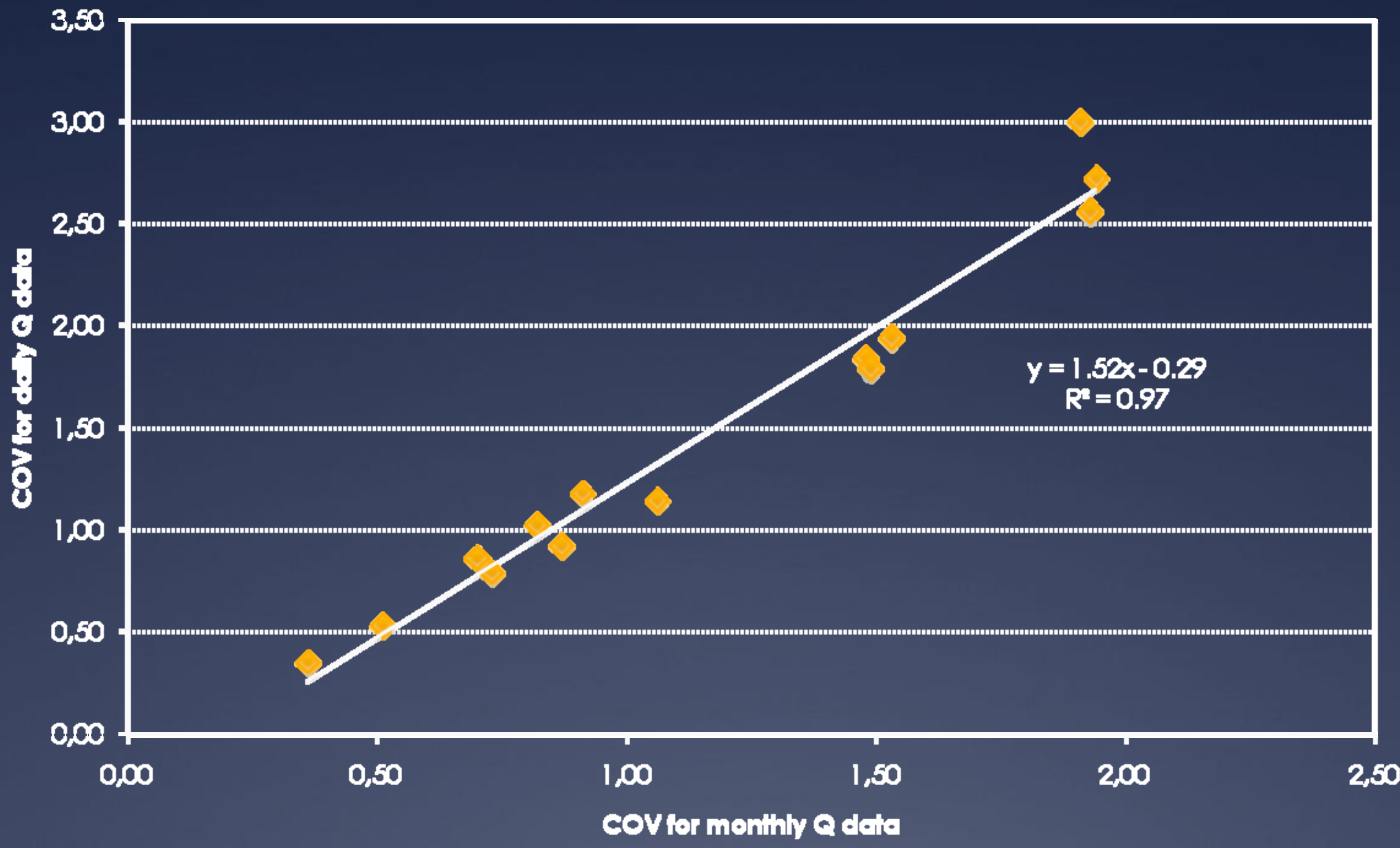
Arctic Rivers: spatial scaling?



Drainage Area

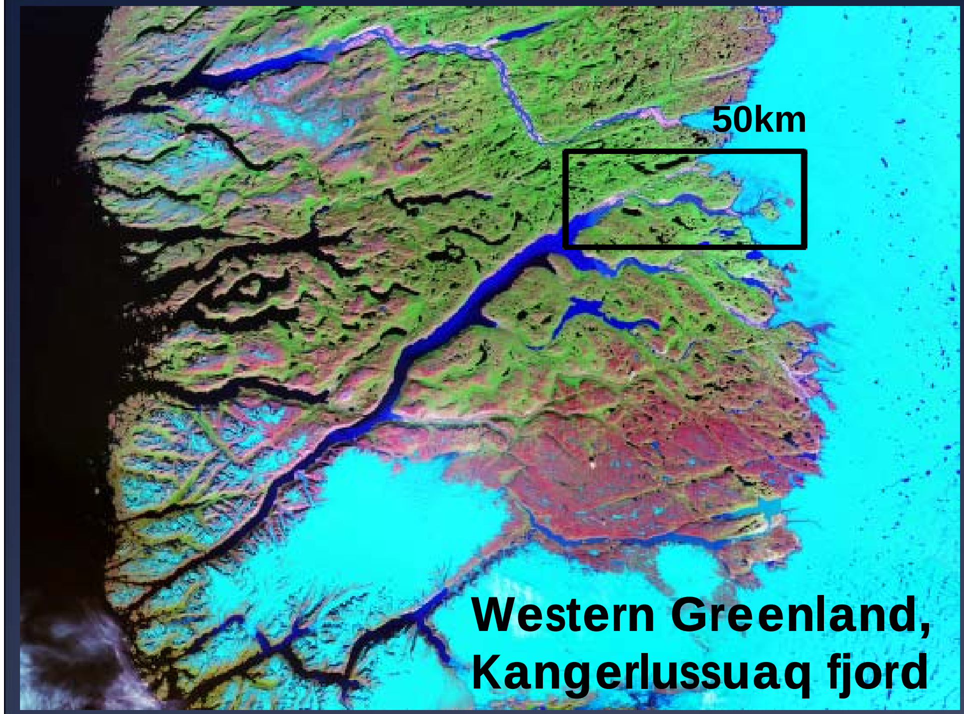
Susitna River	15, 954 km^2
Stikine River	51,592 km^2
Yukon River	831,390 km^2

Scaling relationships



Scaling relationship of 21 yrs of data, monthly variability vs daily variability: for 14 Canadian Arctic Rivers, drainage areas span 1,680,000 km^2 to 11,000 km^2

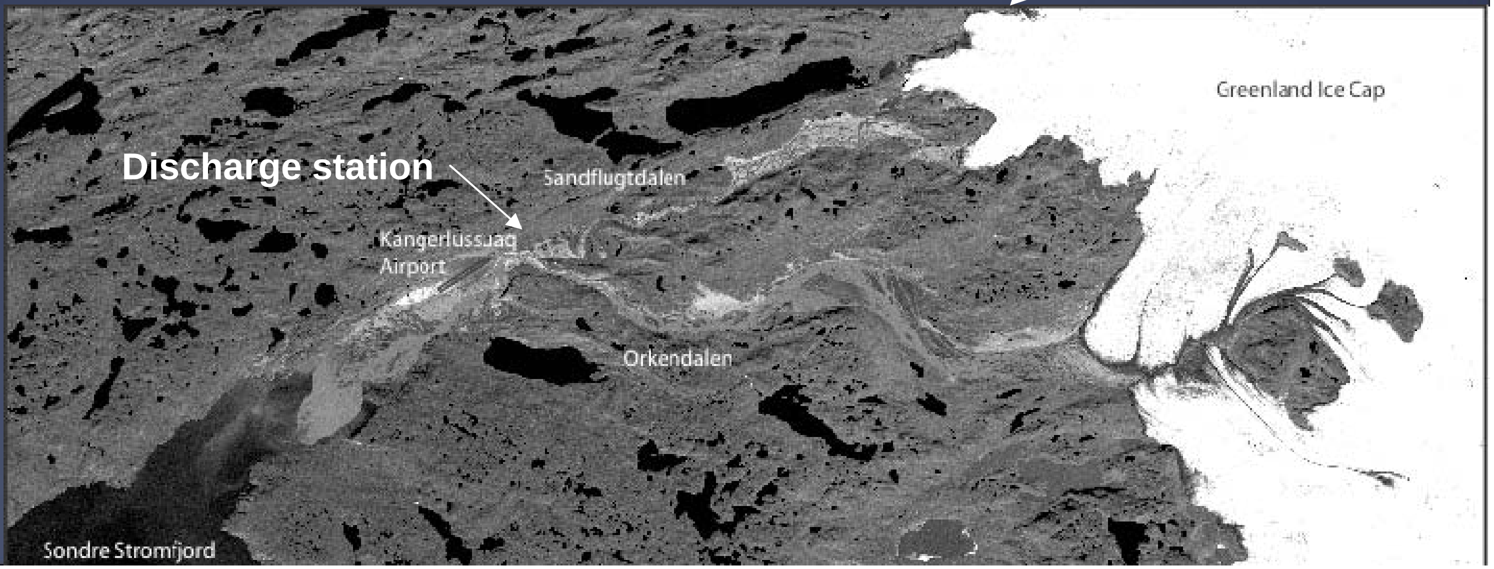
Impacts of events: Watson River



Watson River drains Greenland Ice Sheet.

The drainage basin under the GIS is ~6280 km^2 and two rivers confluence before Kangerlussuaq:

Sandflugtsdalen river (c. 27 km) and Ørkendalen river (c. 31 km)



Ice-dammed lake, 1 km^2

Discharge station at bridge of Kangerlussuaq village

Summer peak discharge

July 26th-August 10th. The peak of the 2007 summer flood.

Watson River is gauged (data courtesy Bent Hasholt, UCD, and Henning Thing, DPC) . Water discharge is c. 1000 m^3 / s and the velocity in the channel is c. 8 m/s. Every second 9 tons of sediment are flushed into the fjord. This adds up to c. 800,000 tons in 24hrs.

August 31st Lake Outburst Flow

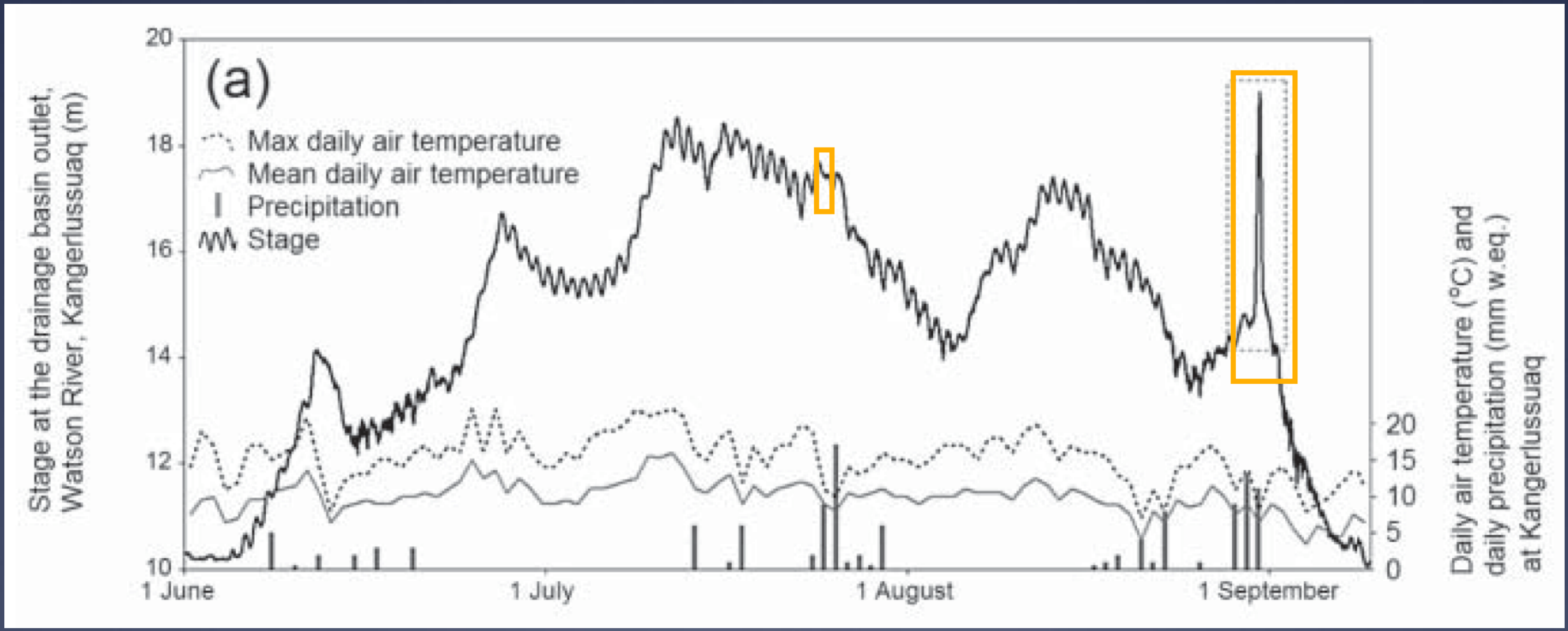
In the night of 31 August 2007 this ice-dammed lake was emptied and the flood reached Kangerlussuaq during the early morning hours. This outburst flood discharged c.28 million tons of water over just 10 hours.

Photos: Mark Begnaud, VECO

Stage Height

4.25 m above August level!

For a medium-sized basin likeKangerlussuaq, this event amounts to about 2% of total annual flow.



Data from Hasholt and Mernild (EOS, 2008)

MODIS imagery of event

MODIS/Terra image, August 27th, 2007
Normal late summer flow

MODIS/Terra image, Sept 1st, 2007
Waning peak event flow?

Remarkably little difference in suspended sediment plume
Hypothesis: the plume was so sediment-loaded, that it went hyperpycal

Conclusions

* Total annual Arctic River water discharge is changing, but spatial variability is evident.
* Arctic Rivers have pronounced seasonality and it is changing.
* In larger-scale basins (>10,000 km^2) the impact of glaciers on sediment load is not as significant as expected. Only in small basins it dominates the budget.
* Scaling relationships need to be establish to make predictions of changes in 'normal' flood events
* We speculate that the frequency of extreme lake outbursts increase in near future…geomorphically important/exceed thresholds..