Why should we care about Greenland watersheds?
Reactions, runoff, and rising sea level

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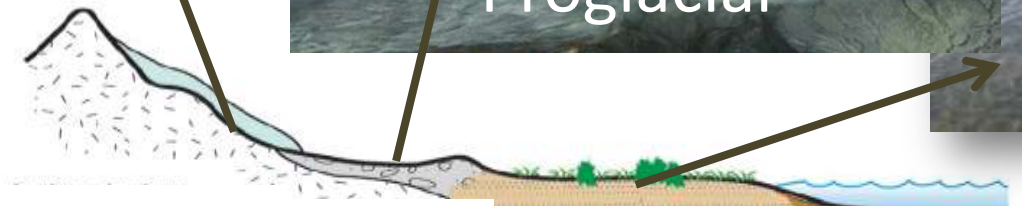
Greenland Watersheds

Increasing exposure age/extent of weathering

Watershed types:



Subglacial

Water system under the ice

Proglacial

Melt water discharged from the ice sheet

Deglacial

Water from annual precipitation and permafrost melt

Modified from Anderson, 2007, Ann. Rev. Earth Planet Sci

Significance: Watershed Variations

~20ky

Now

Mostly deglacial

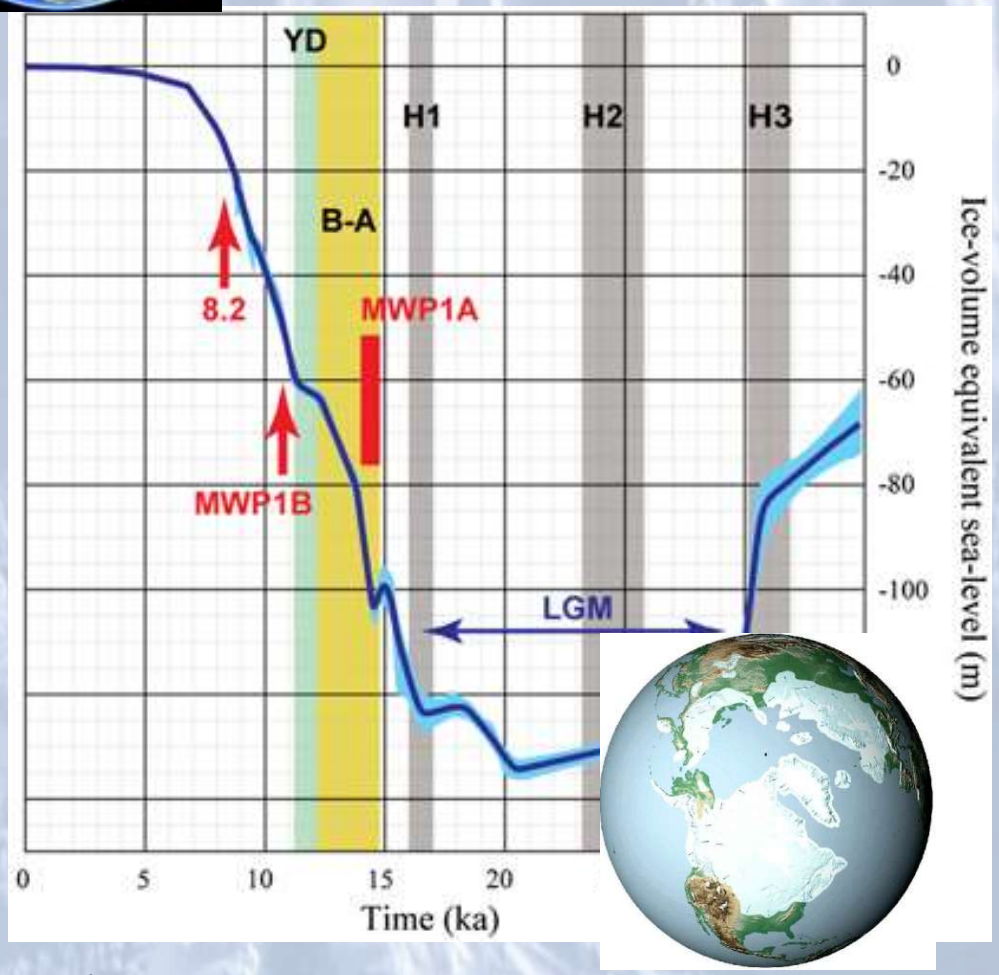
Much weathered material

Last Glacial Maximum

All sub- & pro-glacial

Much fresh material

Implication 1: Sea level rise

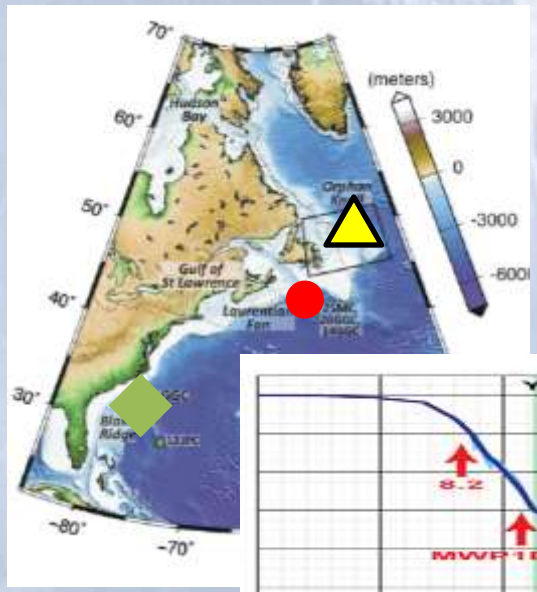


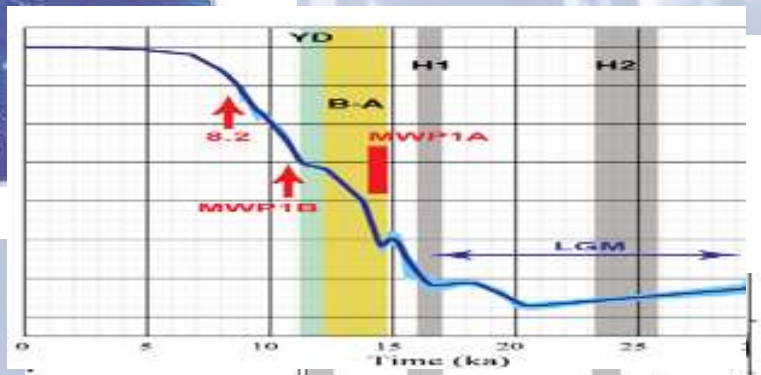
- Spectacular events:
  - (MWP1A) 14.5 – 14.0 ka BP $\geq$ 40 mm/yr
  - Reflect rapid collapse of continental ice sheets
- Change in the material fluxes:
  - To ocean: isotopes & nutrients (?)
  - With atmosphere: CO_2

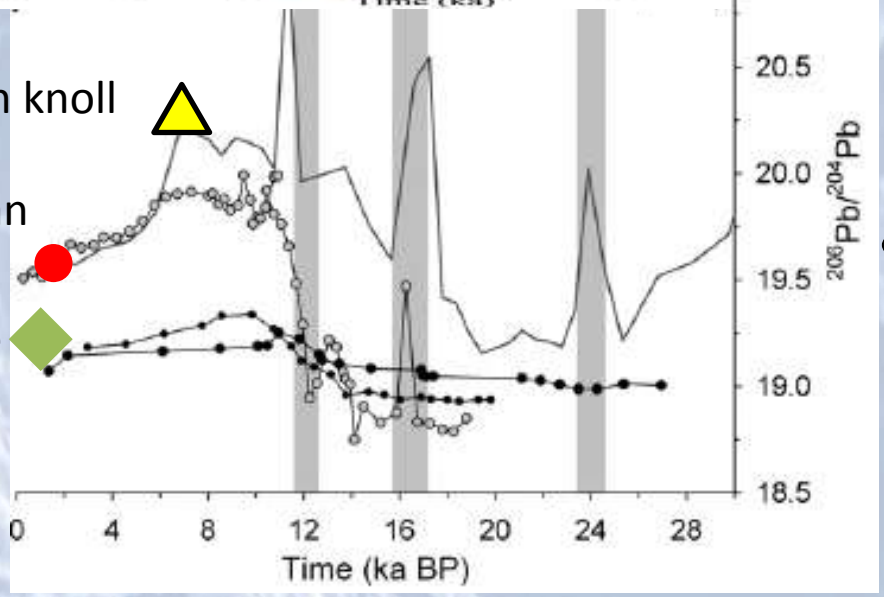
Forward in time

Lambeck et al., 2014, PNAS

Implication 2: Runoff (and fluxes)



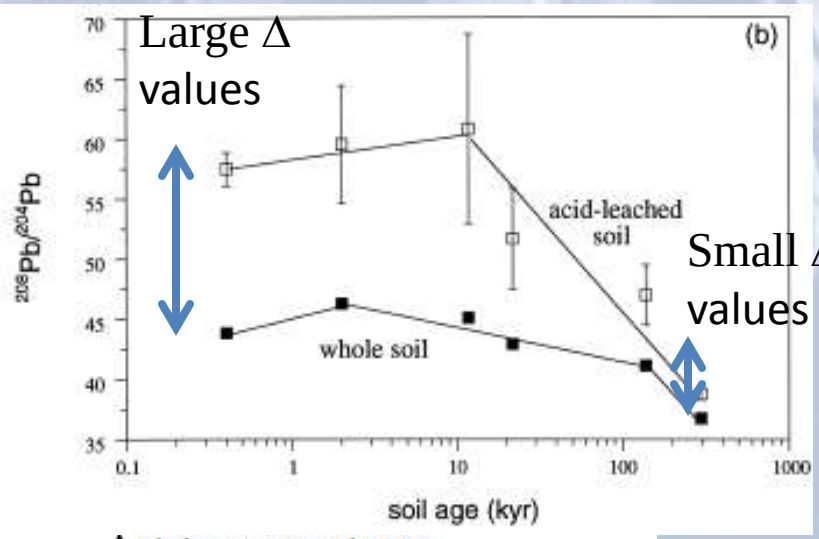




- Systematic shifts in Pb isotopes in North Atlantic sediments:
  - Rapid increase during rapid SL rise
  - Gradual drift down following SL rise
- Reflect changes in runoff composition (reactions)

Lambeck et al., 2014, PNAS; Gutjahr et al., 2009, EPSL; Kurzweil et al., 2010, EPSL; Crocket et al., 2012

Implications 3: Reactions



Small Δ values

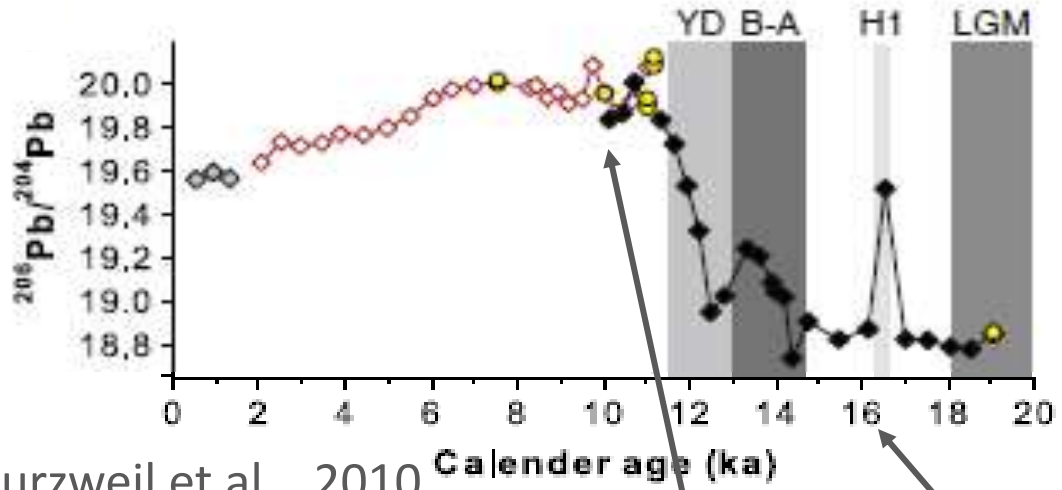
- Offset between whole rock and leached material
  - Represent weathering products
- Offset increases with younger material
- Causes:
  - Change in minerals being weathered (Sr)
  - Availability of radiogenic isotopes in damaged crystal lattices (Pb)

Upper: Harlavan et al., 1998, GCA; Lower: Blum and Erel, 1997, GCA

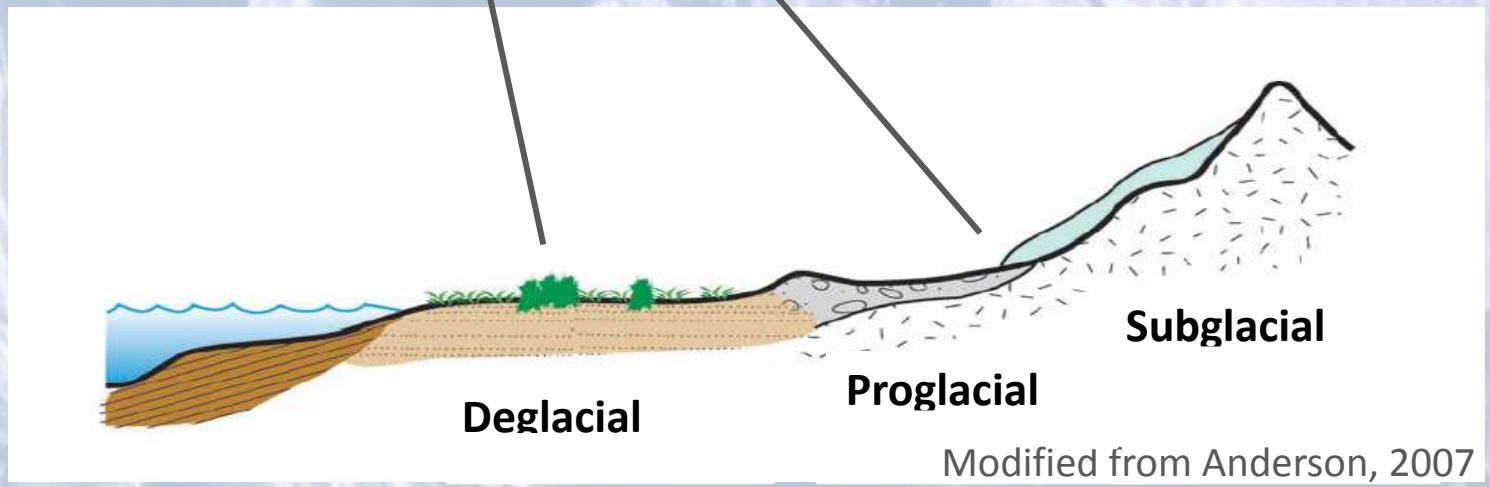
Hypotheses

- Hypothesis 1:
  - Weathering extent/products should vary across watershed types
- Hypothesis 2:
  - Solutes in addition to Pb should vary with runoff

Laurentian Fan, North Atlantic



Kurzweil et al. , 2010

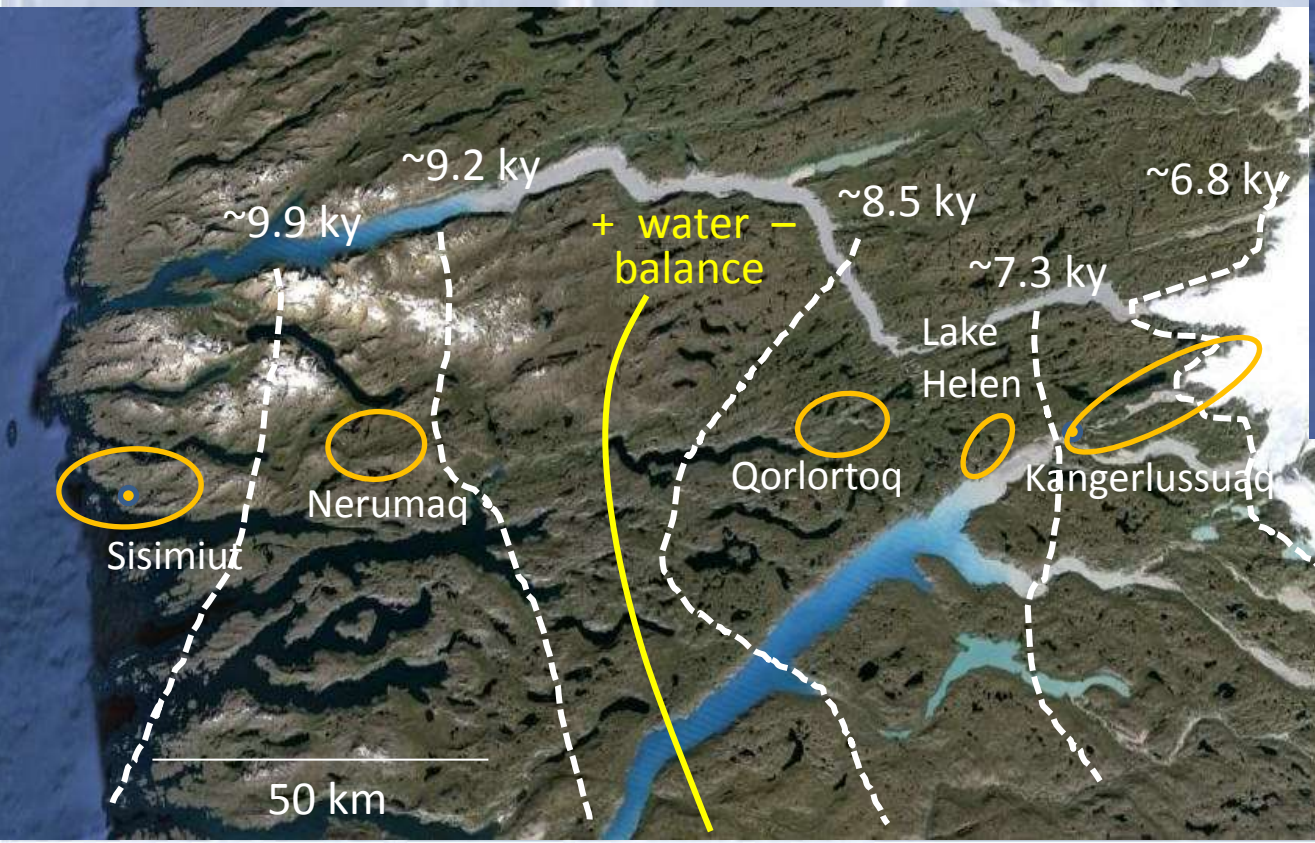


Modified from Anderson, 2007

Field Areas for Tests

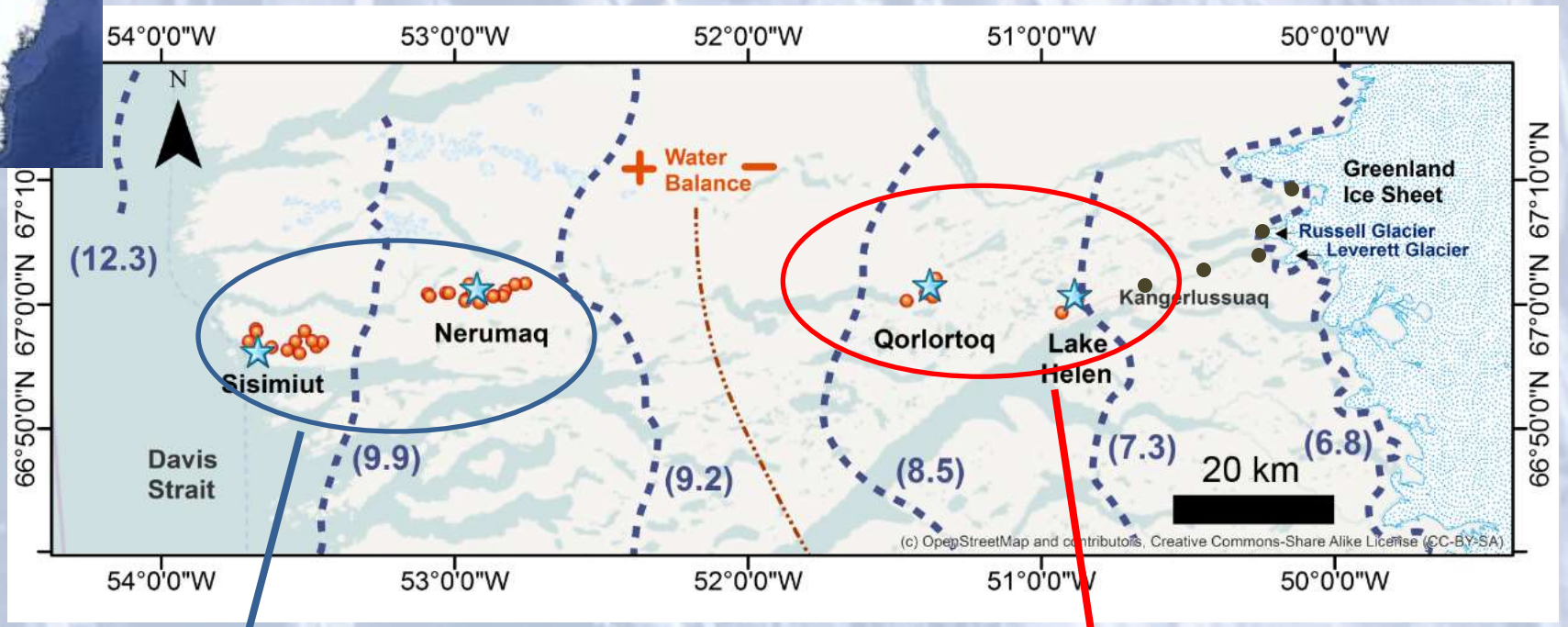
~125 km transect coast to GrIS

- Similar lithologies (Nagssugtoqidian)
- Gradient in exposure age of moraines
- Gradient in precipitation vs. evaporation



Google Earth

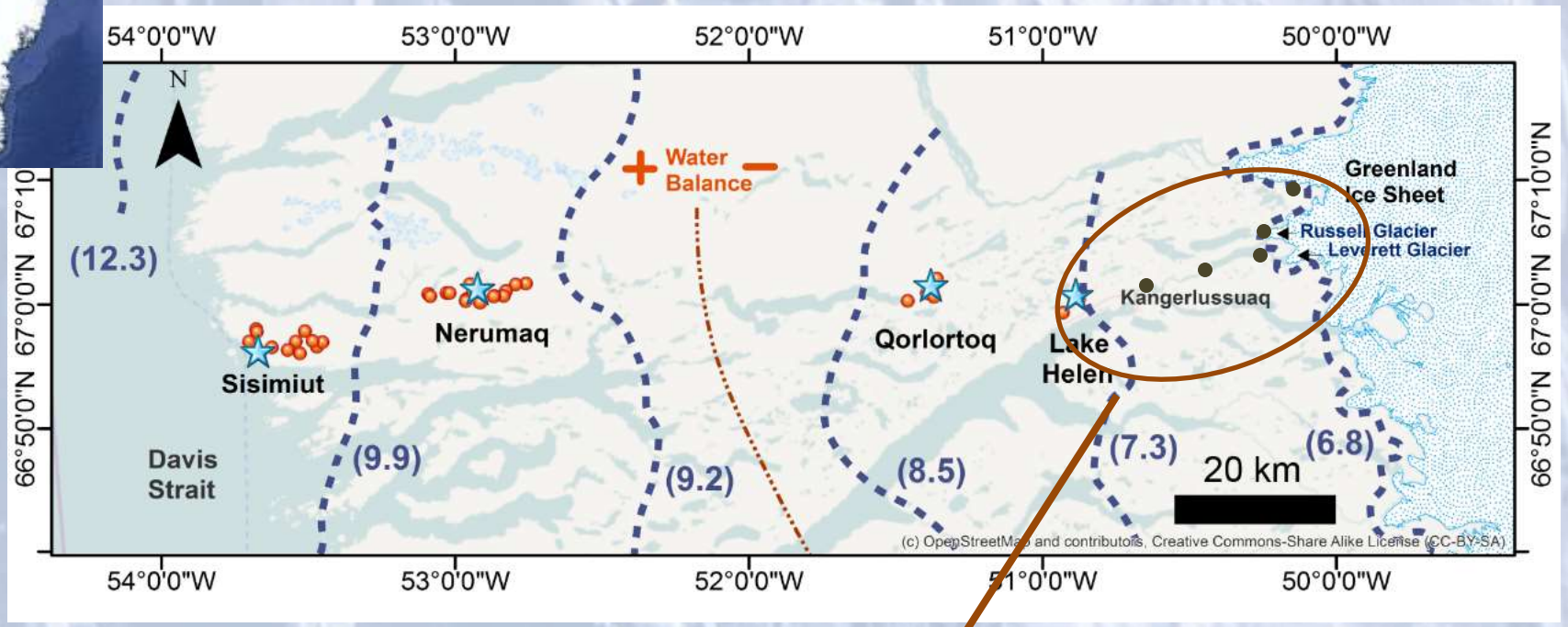
Two types deglacial watersheds



Coastal, wet, older moraines;
More congruent weathering?
(cool colors upcoming figures)

Inland, dry, younger moraines;
Less congruent weathering?
(warm colors upcoming figures)

One proglacial watershed

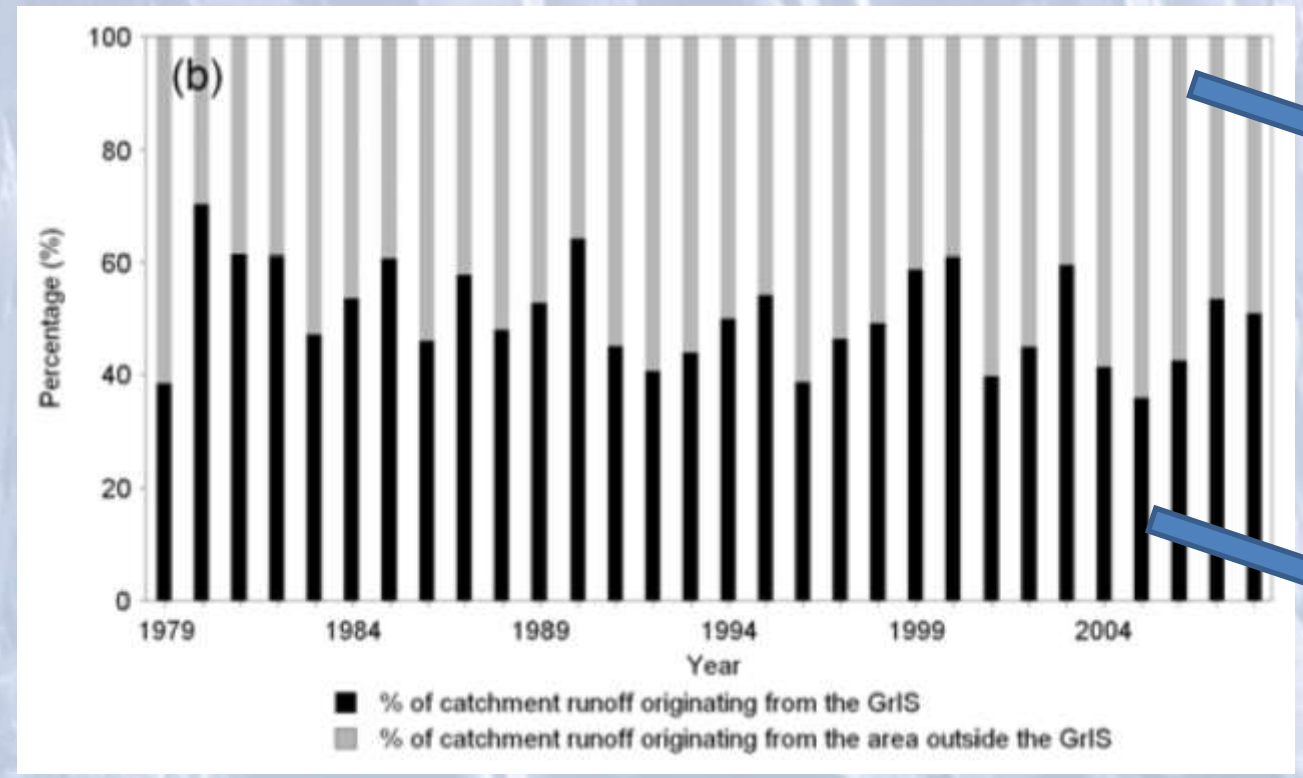


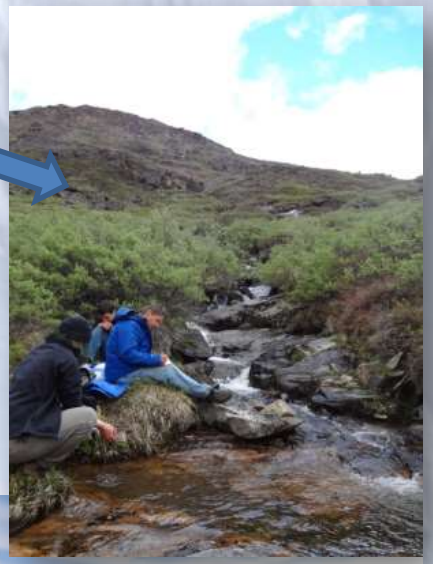
- Watson River (Akuliarusiarsuup Kuua)
  - Does hyporheic exchange affect weathering?
- Sampled 4 times over 2 years
  - Including pore waters

Melt season: Watson River to Kangerlussuaq fjord

Melt season: Watson River vs Tractor

Discharge: Proglacial vs Deglacial



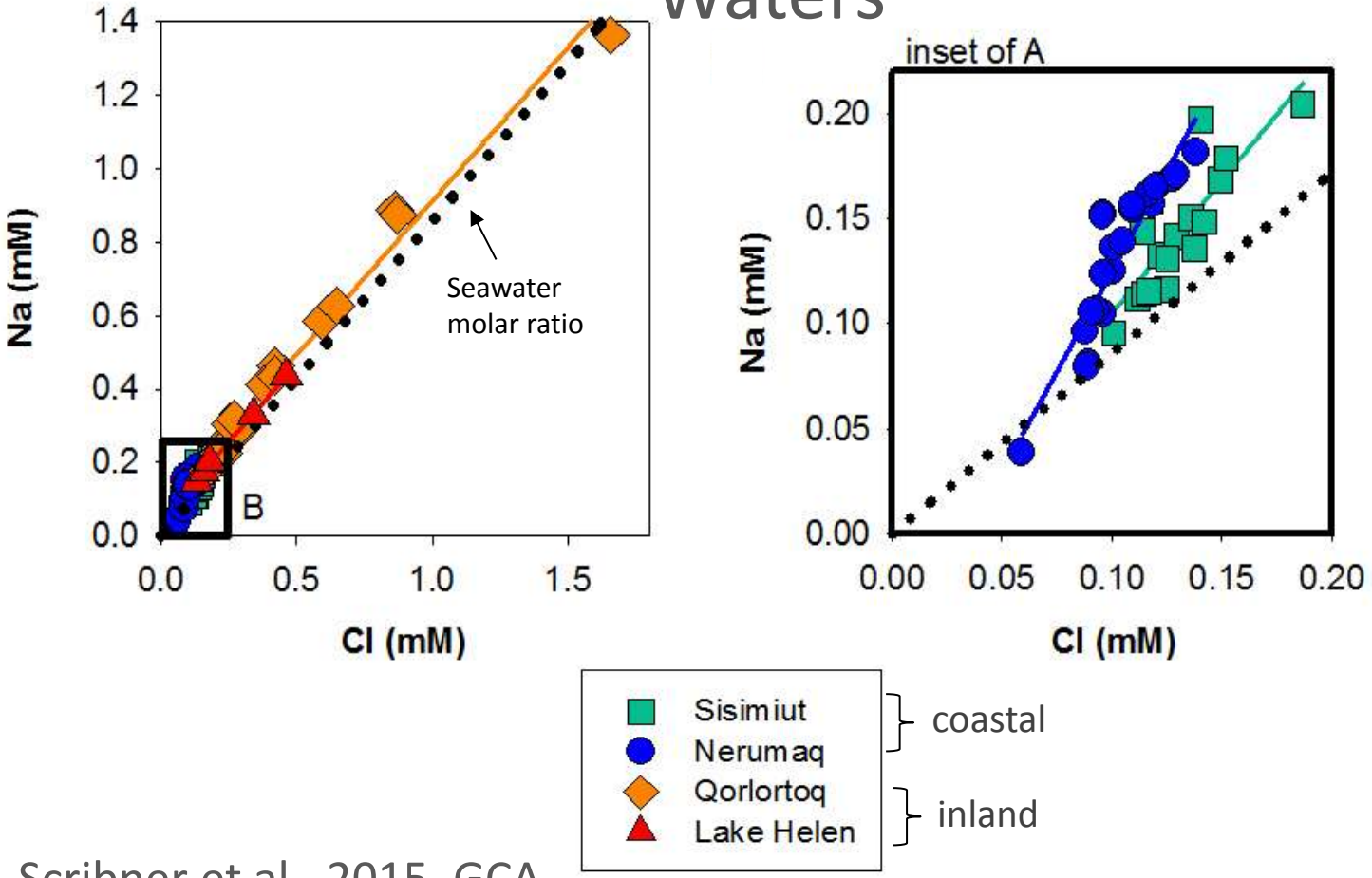


- Watersheds of western Greenland
- Similar amounts of discharge from deglacial and Greenland ice sheet
- Is composition different within deglacial watersheds?

Mernild et al., 2010, The Cryosphere

Na vs. Cl

Waters



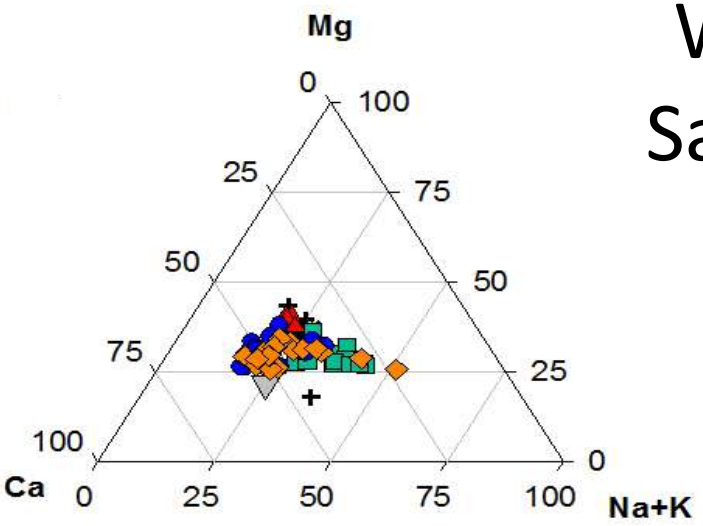
Scribner et al., 2015, GCA

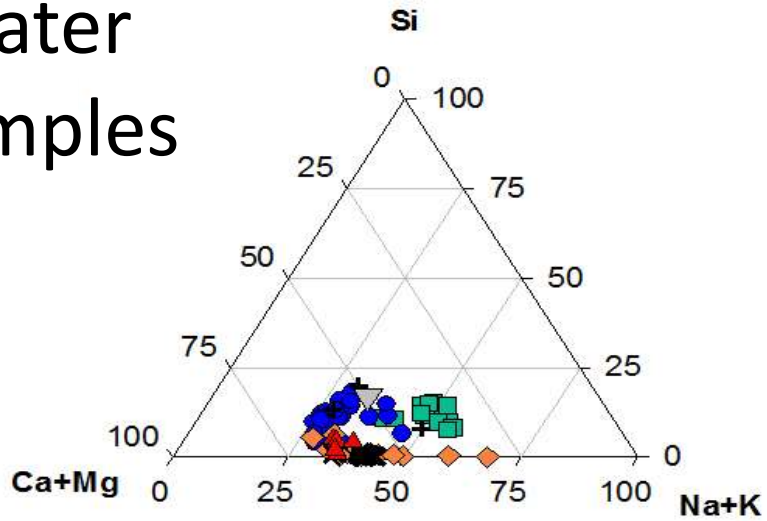
Excess Na in coastal watersheds

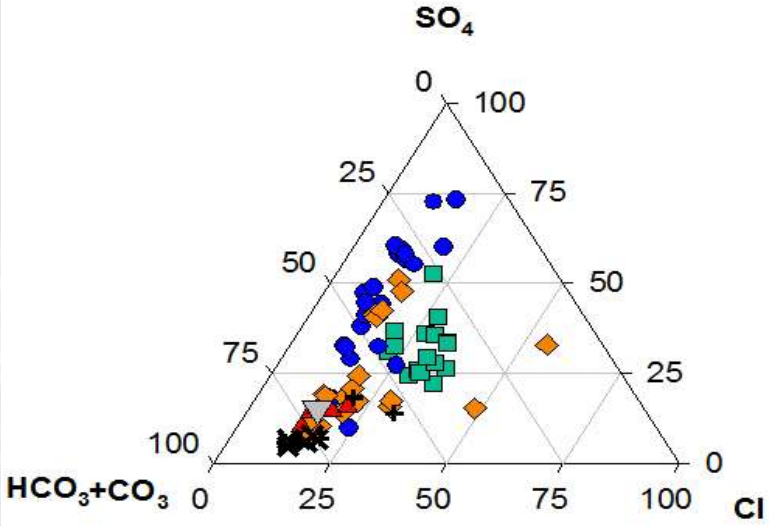
Likely source- plagioclase ($NaAlSi_3O_8$) weathering

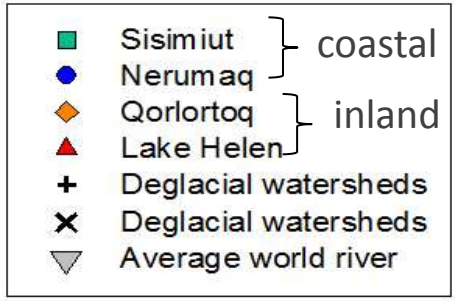
Major Cations and Anions

Water Samples









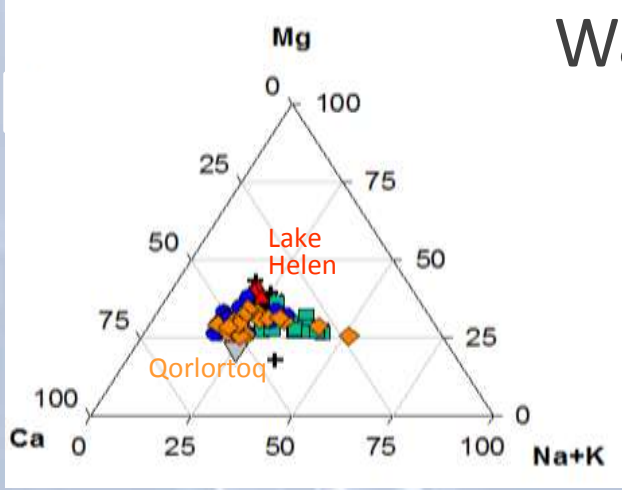
Wimpenny et al., 2010
Ryu and Jacobson, 2014
Meybeck, 1987

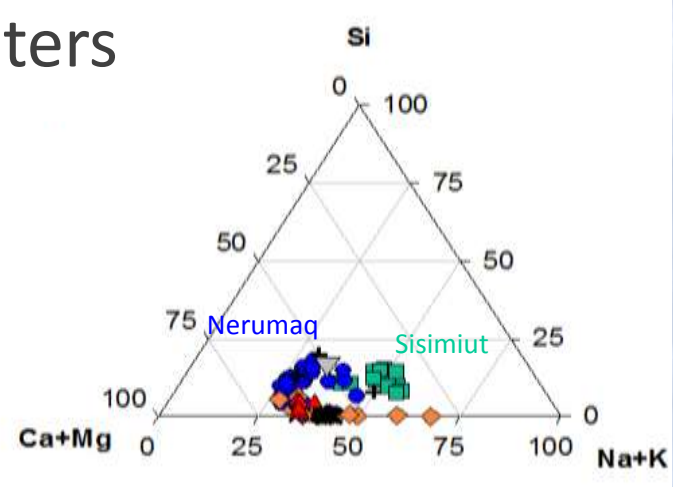
Scribner et al., 2015, GCA

Major cations- Ca
Si higher in coastal watersheds
Transition from carbonate alkalinity to SO_4

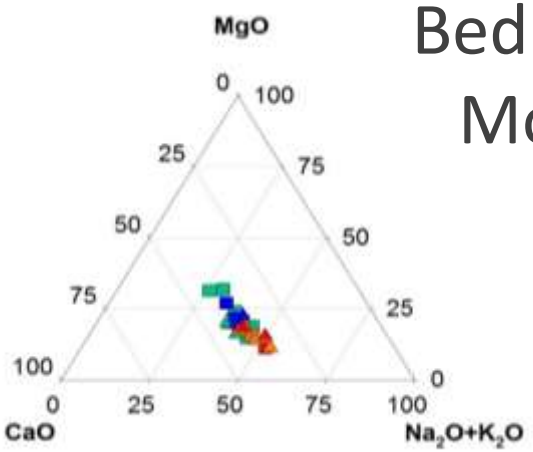
Waters vs. Bedload

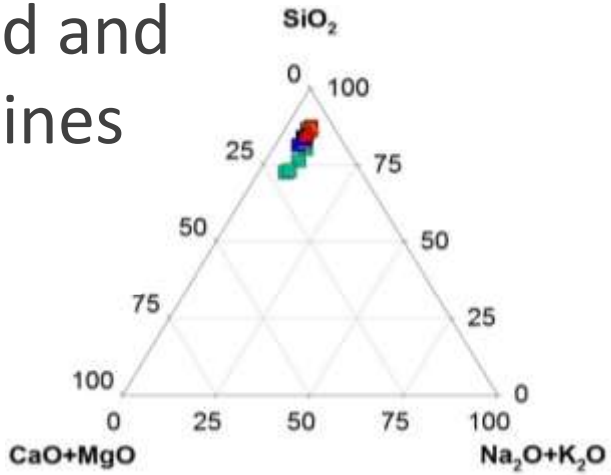
Waters





Bedload and Moraines

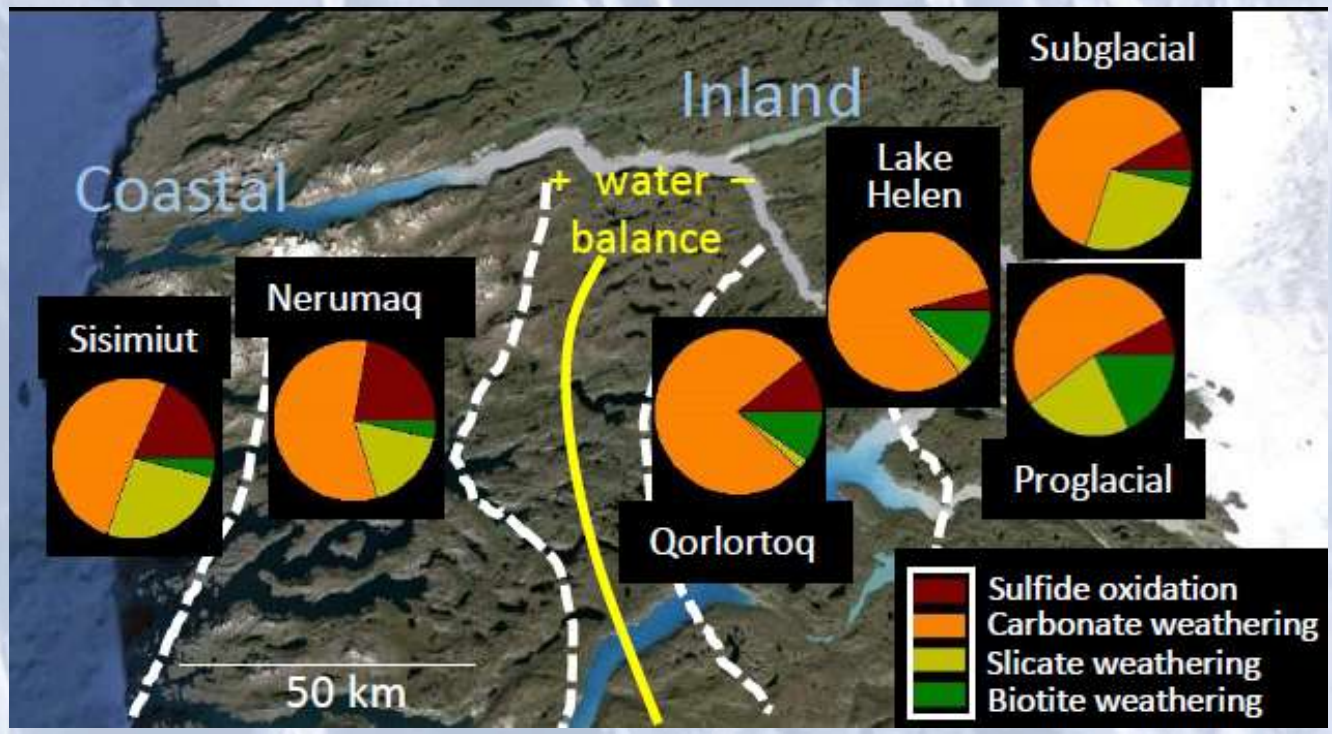




Coastal waters = higher Na+K, Si

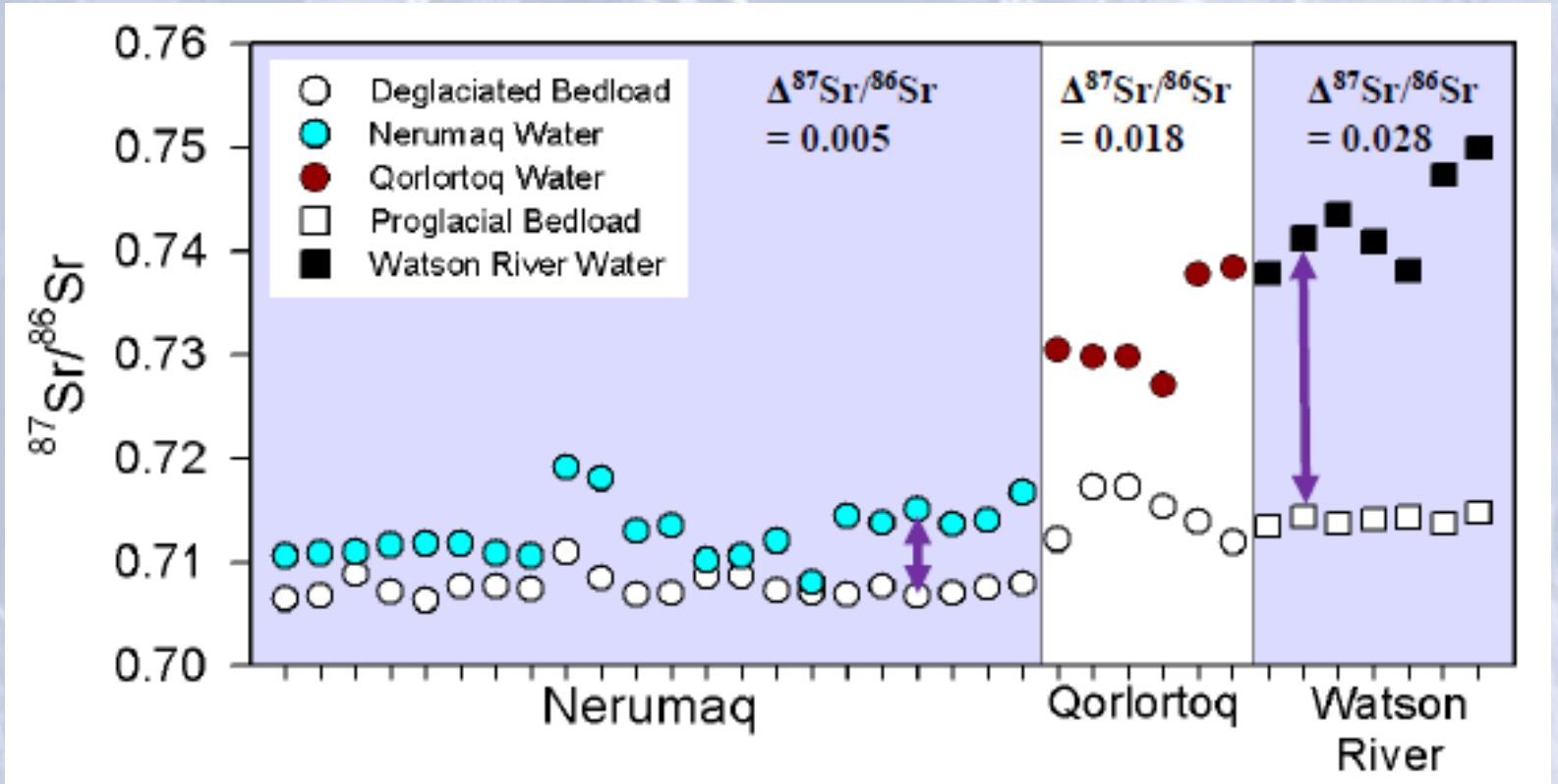
Coastal bedload = lower Na+K, Si

Weathered Minerals



- Inland deglacial – carbonate, little silicate
- Coast deglacial & Proglacial – increased silicate
- Coastal – sulfide
- Proglacial – increased biotite over subglacial

$\Delta^{87}Sr/^{86}Sr$

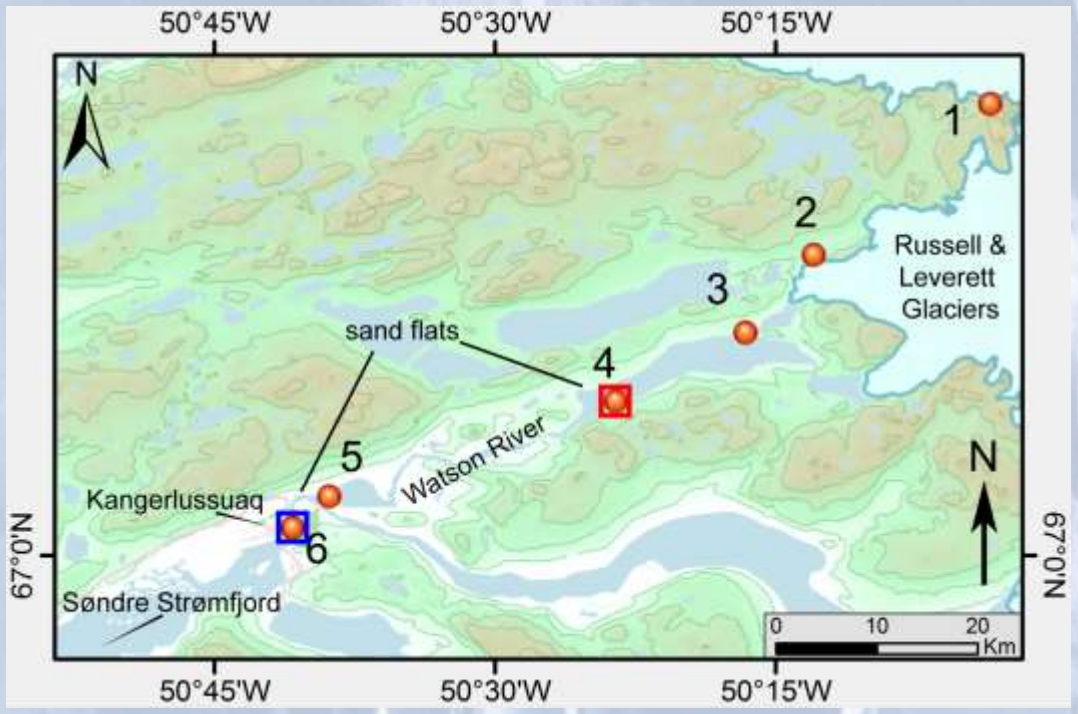


- Small $\Delta^{87}Sr/^{86}Sr$ ratio reflects more congruent weathering
- Large $\Delta^{87}Sr/^{86}Sr$ ratio reflects less congruent weathering
- Surprise that 7 ky old moraines have incongruent weathering – reflects little precipitation

Scribner et al., 2015, GCA

Quick summary - deglacial

- Weathering extent increases toward coast
  - More silica and sulfide, less carbonate
  - Less biotite weathering
  - More congruent Sr isotope ratios
- Causes:
  - Longer exposure times - but not that different (3ky)
  - Precipitation greater – likely largest cause



Proglacial Watson River

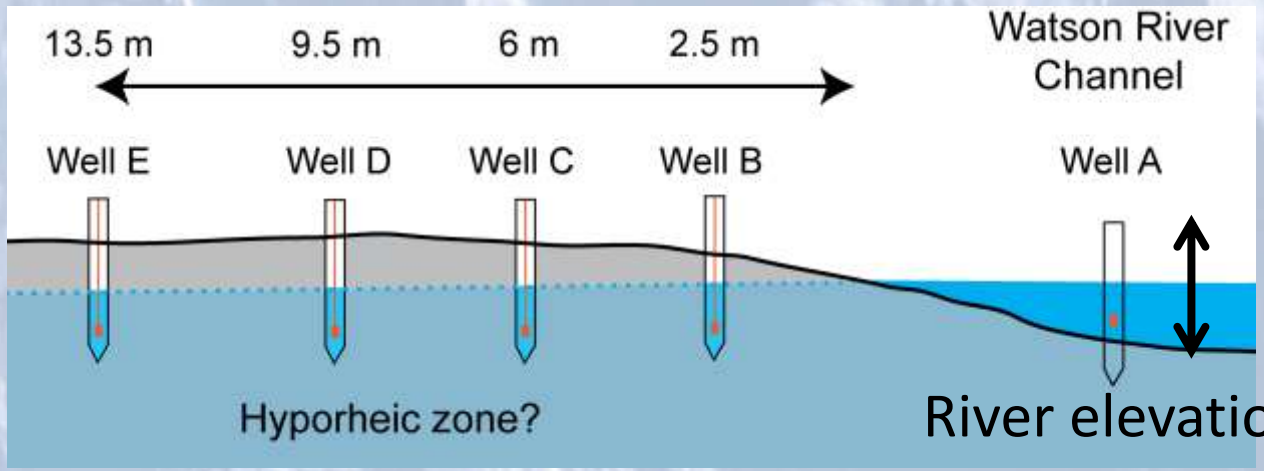
- Two sandur sites
  - Large glacial outwash plains
- Hyporheic exchange & weathering?

- Watson River – Time lapse photography; 9 pm to 9 am

Thanks to Mike Davlantes

Head and chemistry measurements

- Sample pore water
  - "vapor probe"
- What reactions occur?
- What is exchange?
  - Piezometer – measure K



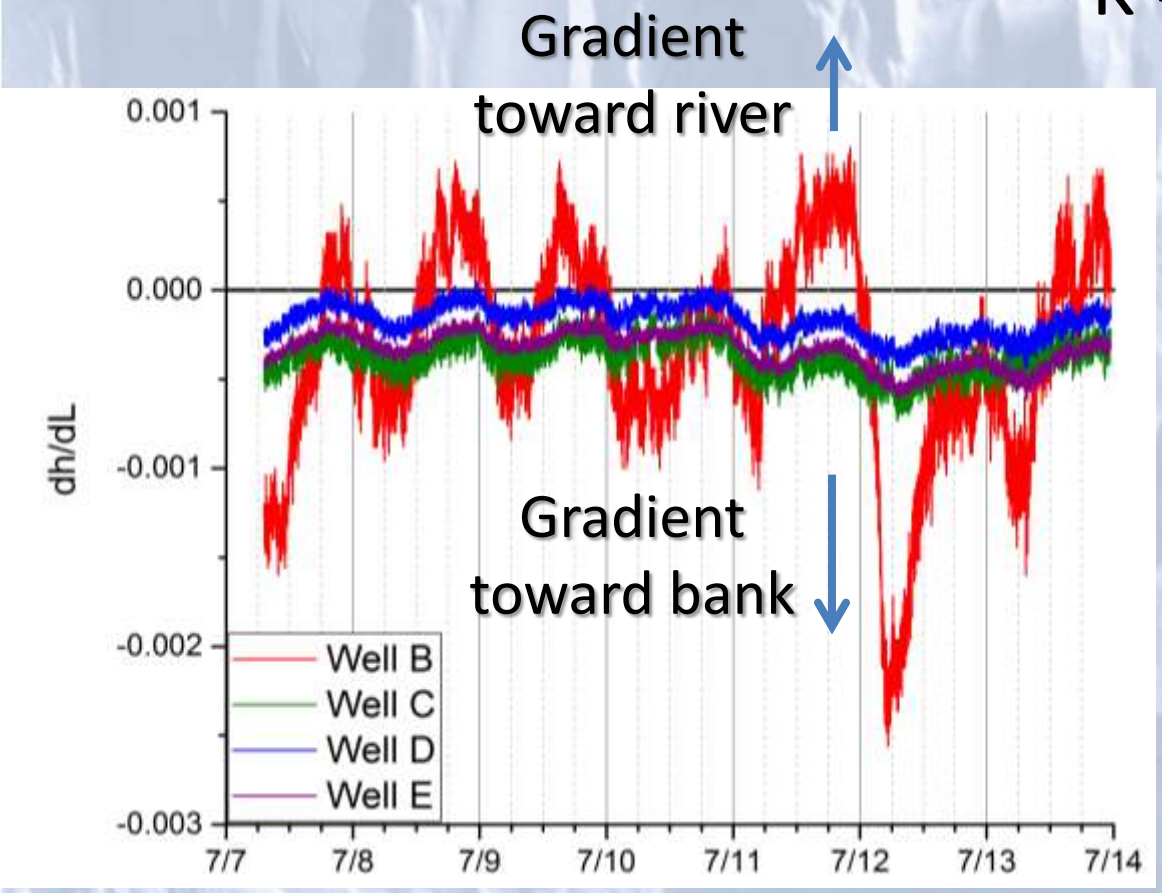
River elevation variations

- Transect of piezometers
- Instrumented with CTDs

Deuerling et al., in prep.

Head Gradients and Flow Direction

$K = 10^{-4}$ TO 10^{-5} m/sec

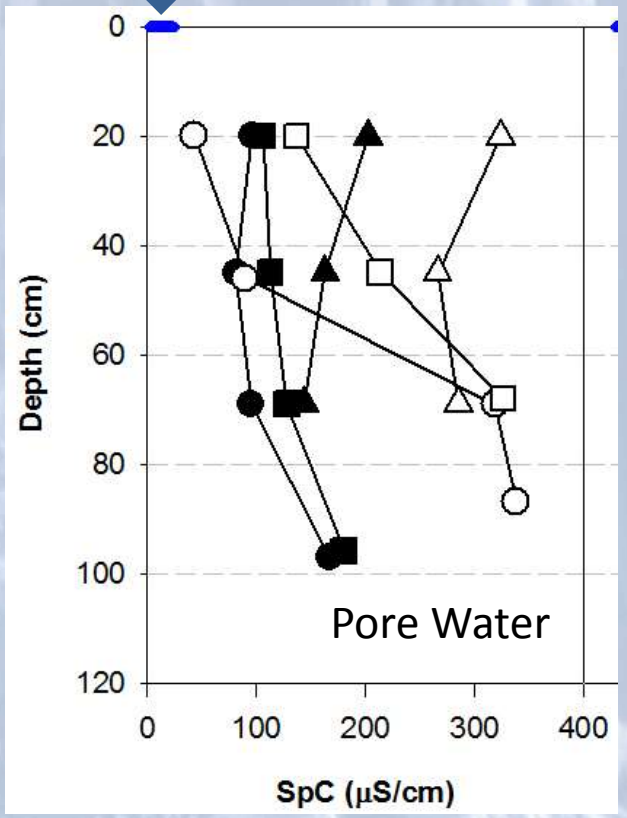


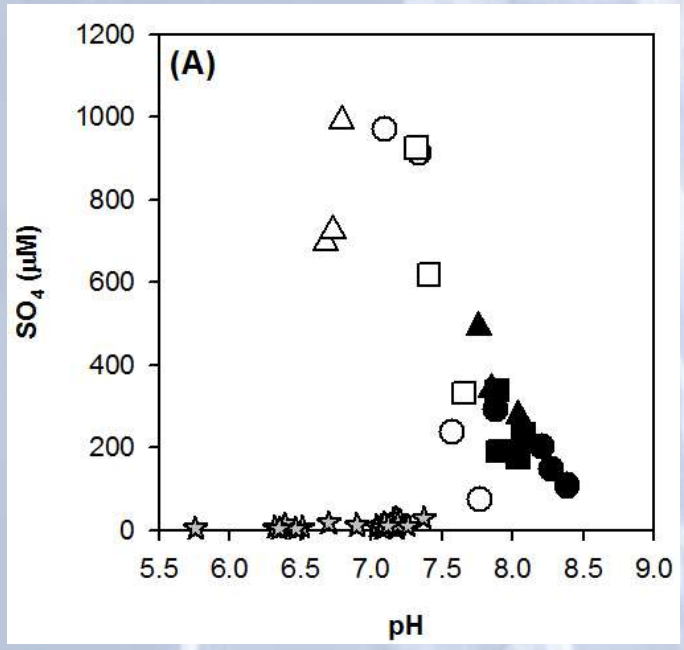
- Distal Site:
  - Gradients oriented toward bank
- Proximal site:
  - Diel alterations
- Sampling time:
  - Increasing melt
  - Increasing stream stage

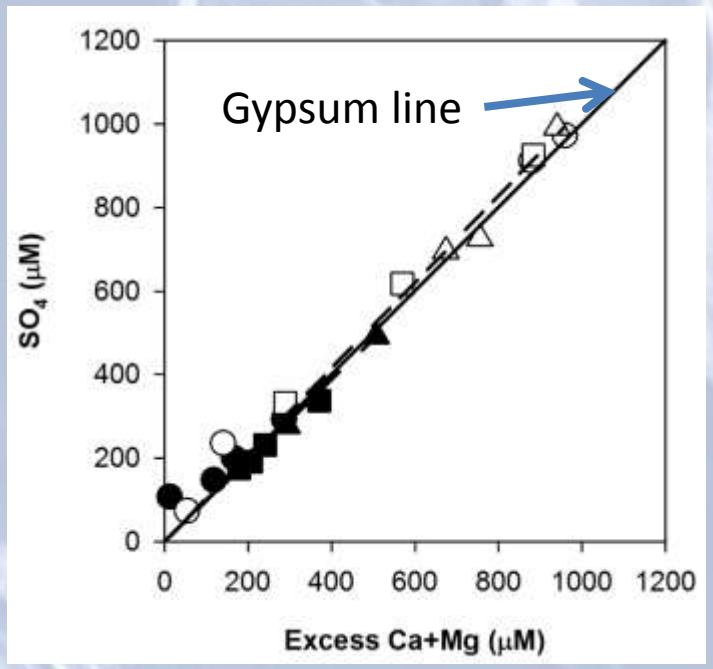
Deuerling et al., in prep.

Pore water composition

Range of Watson River water

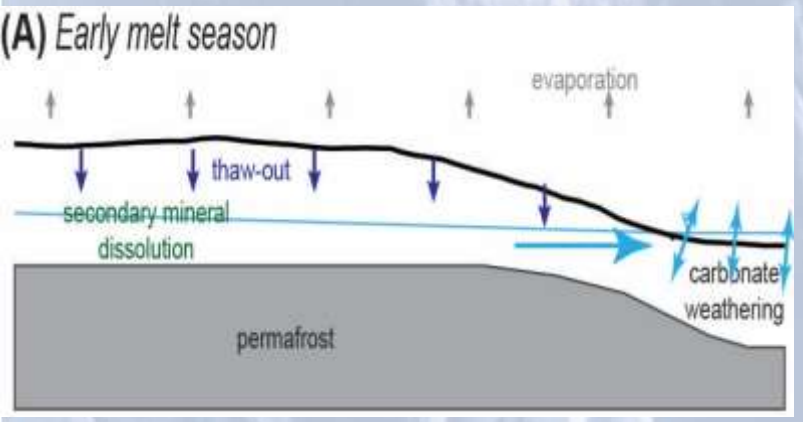


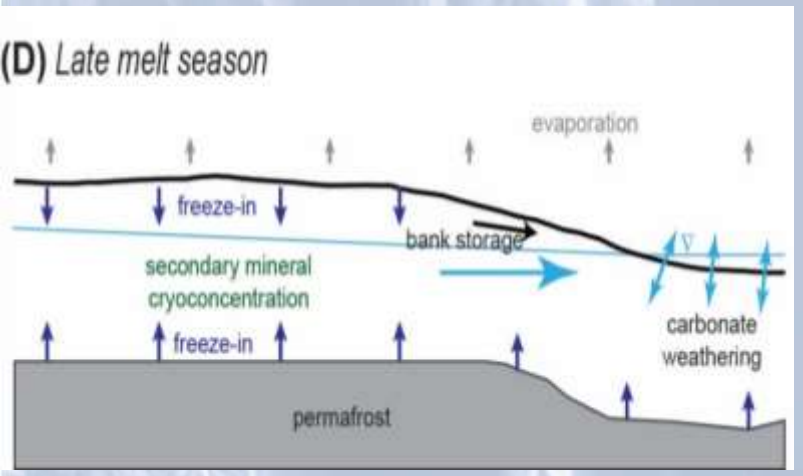




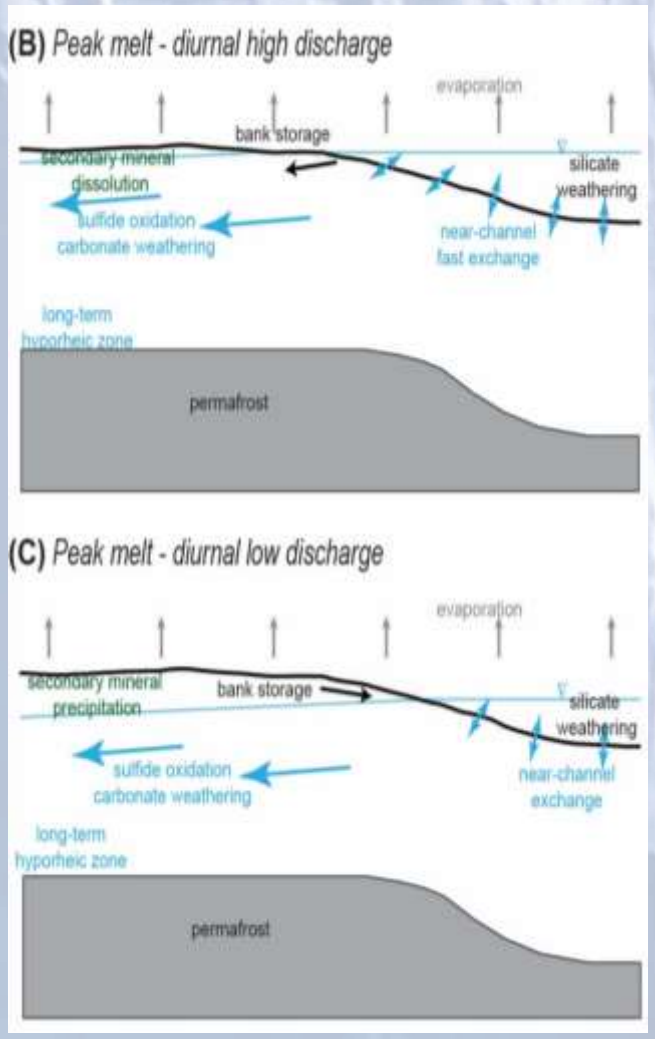
- Decrease pH:
  - Sulfide oxidation
  - Atmospheric CO_2
- Correlation reflects gypsum reaction
  - Cryogenic concentration
  - Subsequent dissolution

Summary - proglacial





- Early and late melt season
- Discharge from banks



- Peak melt season
  - Diurnal variations
- Recharge to banks
- Dissolution of primary and secondary minerals

Deuerling et al., in prep.

Conclusions

- Distinctly different weathering process
  - Between subglacial, proglacial, and deglacial watersheds
  - Across deglacial watersheds
  - Exchange in sandurs important weathering sites in proglacial systems

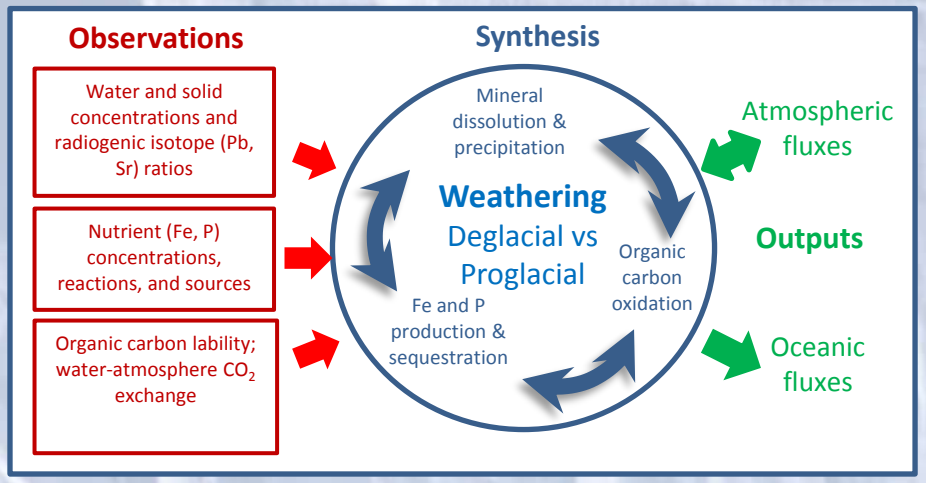
- Muskox pizzas are actually quite tasty

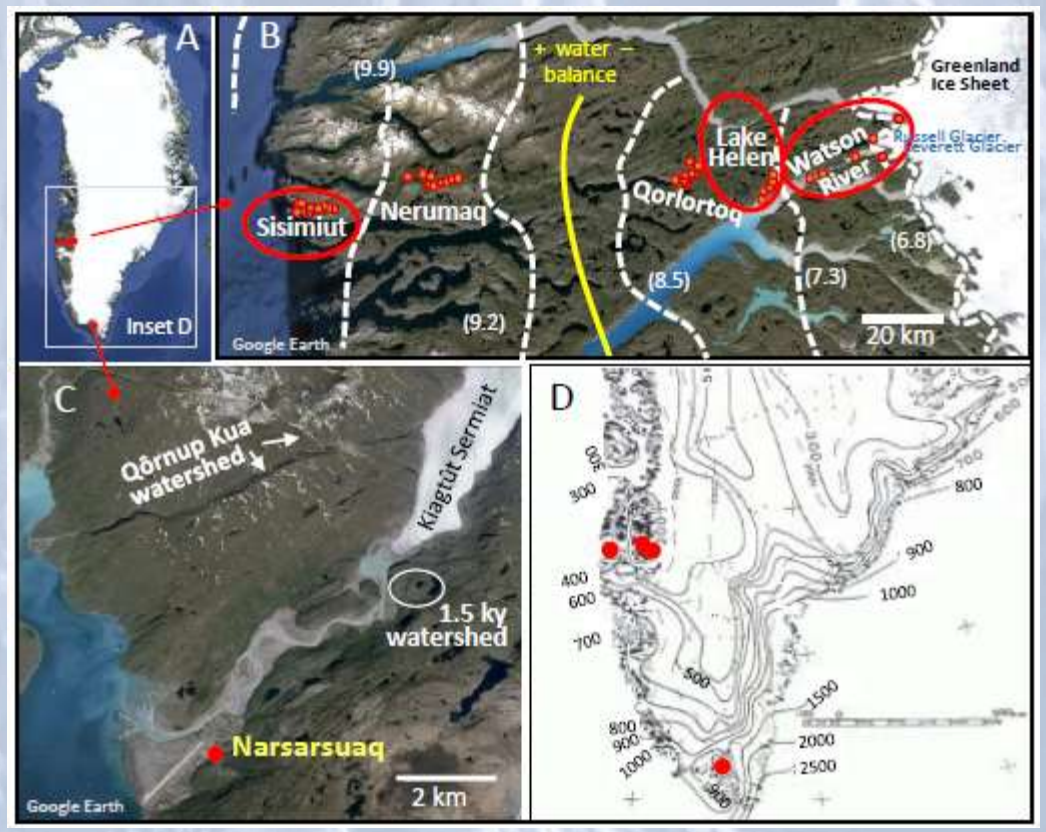
Implications

Non-edible wildlife annoying, but not so dangerous

- Retreat of ice sheets:
  - Increase deglacial fluxes
  - Area of intense weathering expands
- Will alter/has altered elemental, nutrient(?), CO_2(?) and isotopic fluxes
  - Use proxies for interpreting past changes
  - Predict future changes

Future Directions

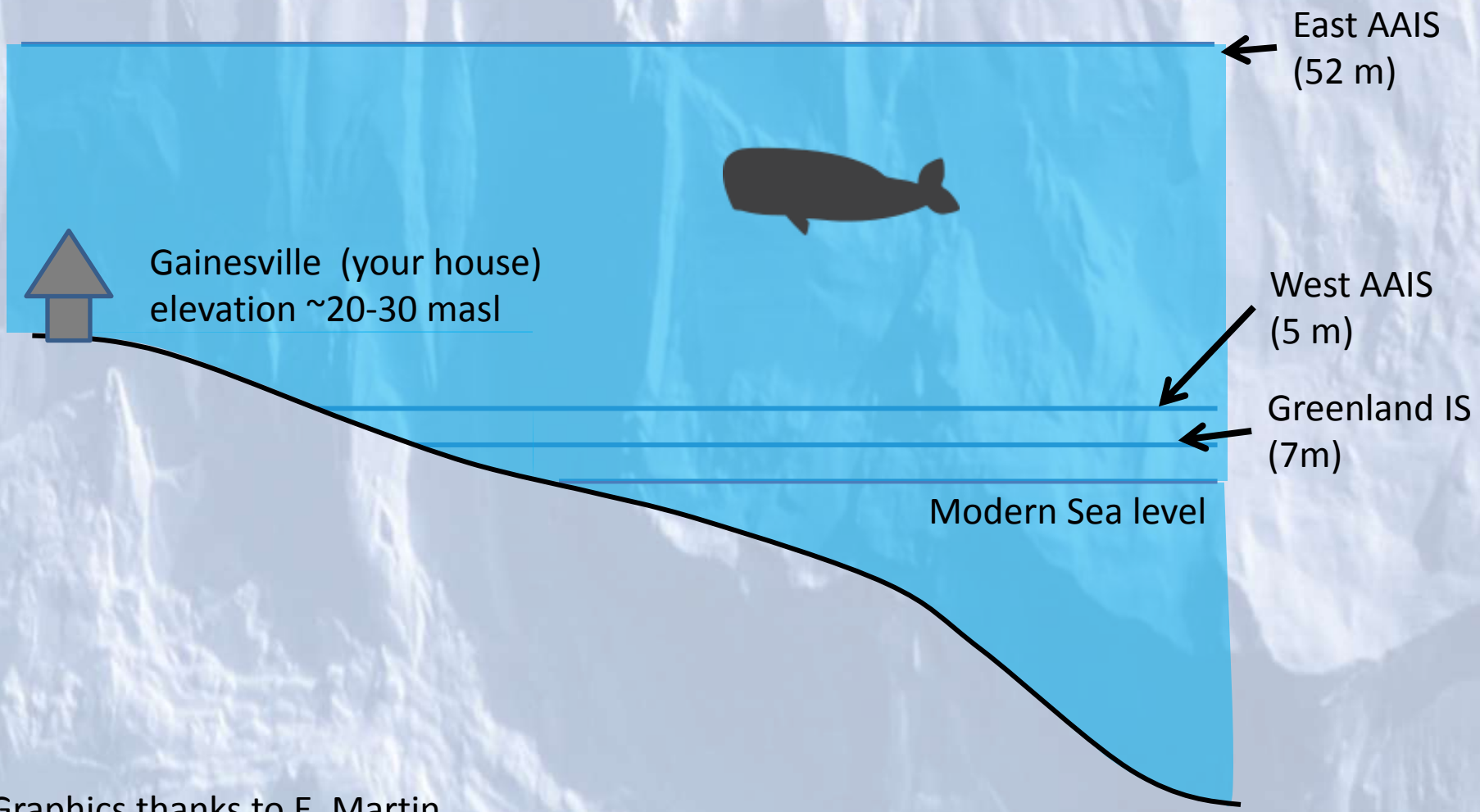




- Expand field sites
  - Narsarsuaq > 2000 mm precipitation
  - 1.6 ky moraines
- Evaluate fluxes
- Expand mineral reactions
  - Nutrients (P, Fe, C)
  - OC lability changes

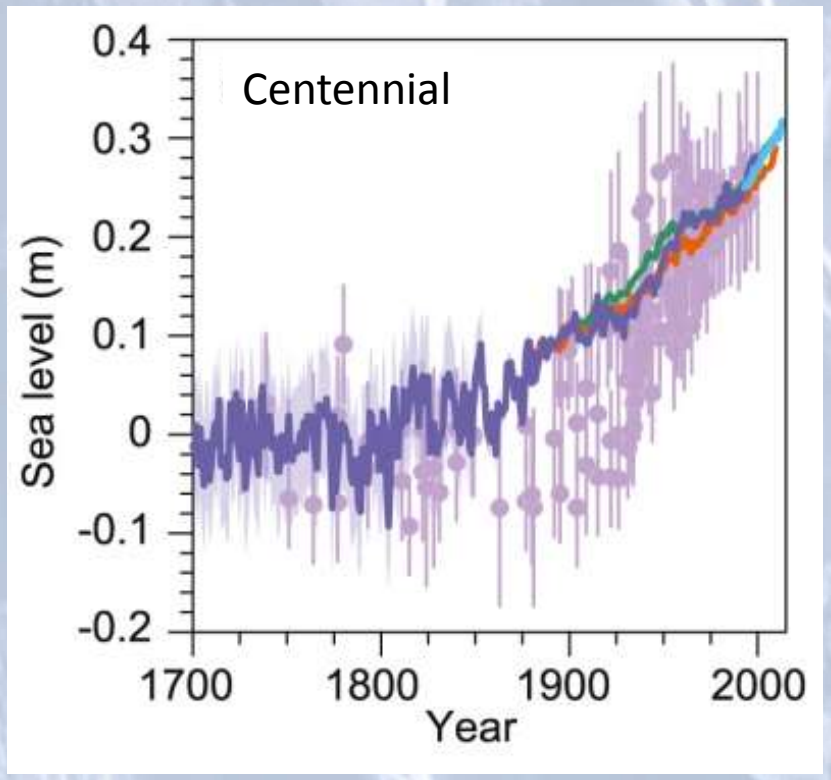

???
Questions
???

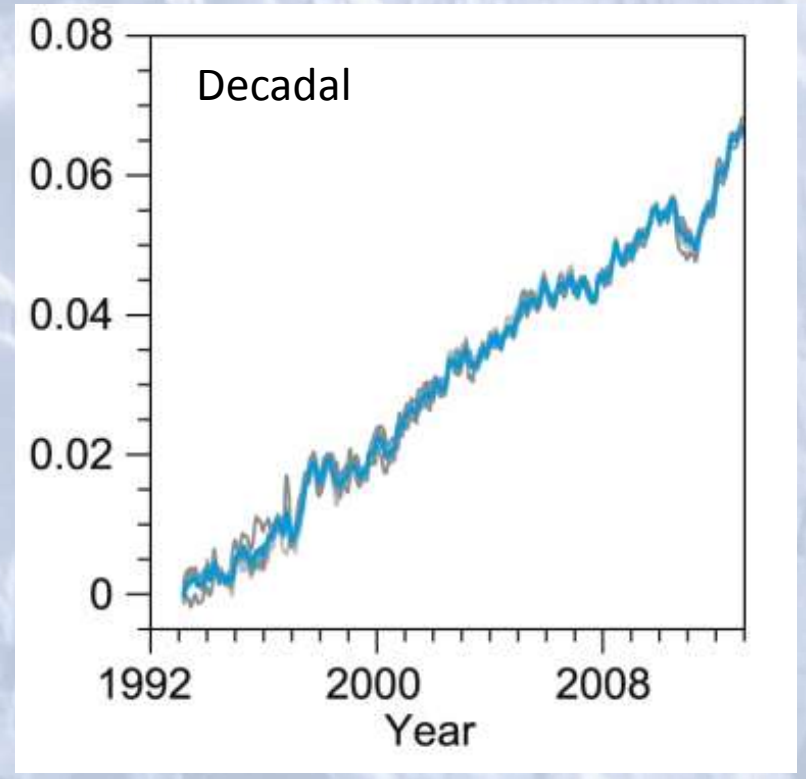
Continental ice sheets and sea level



Graphics thanks to E. Martin

Measured sea level records



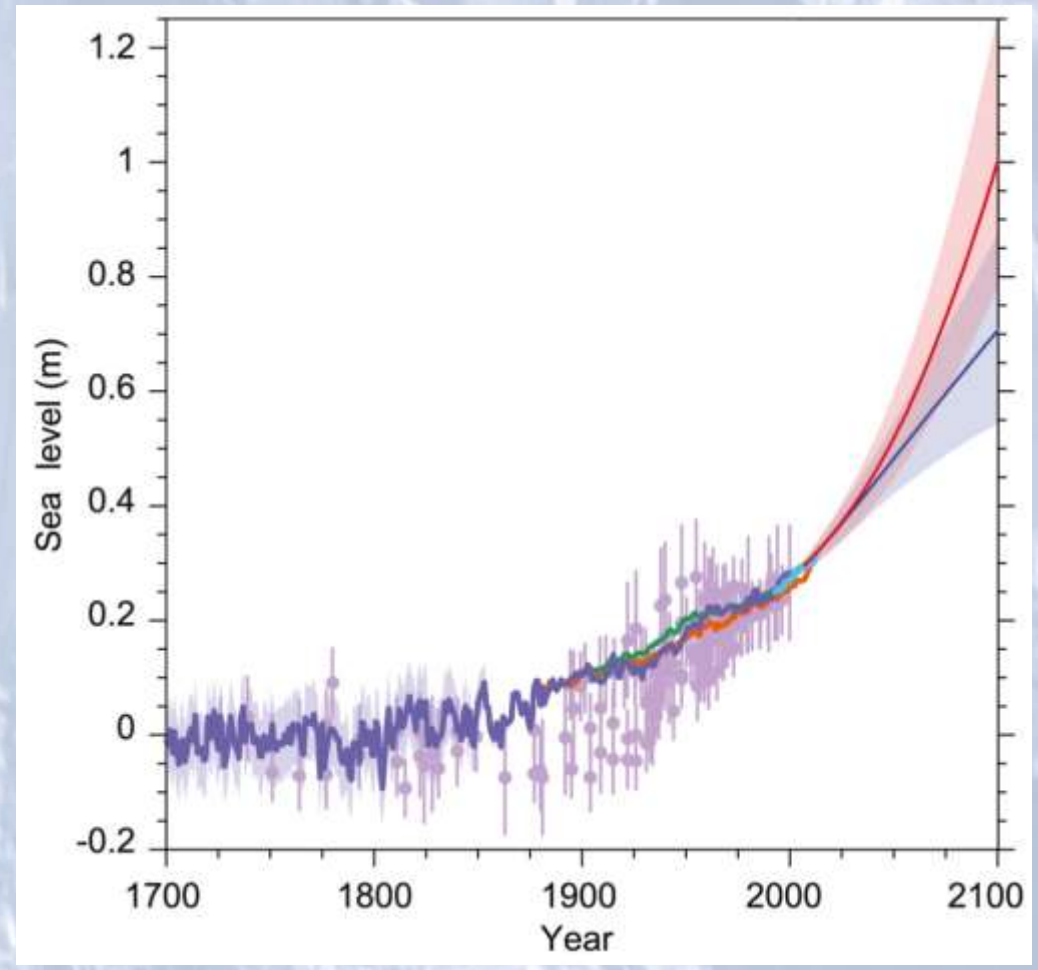


- Longer term records - Salt marshes, tide gauges, altimetry
- Tide gauge increase *very likely* 1.7 mm/yr 1901 - 2001

- Satellite-based altimetry – compilation 5 groups
- Increase *very likely* 3.2 mm/yr 1993-2012

IPCC, 2013 5th AR

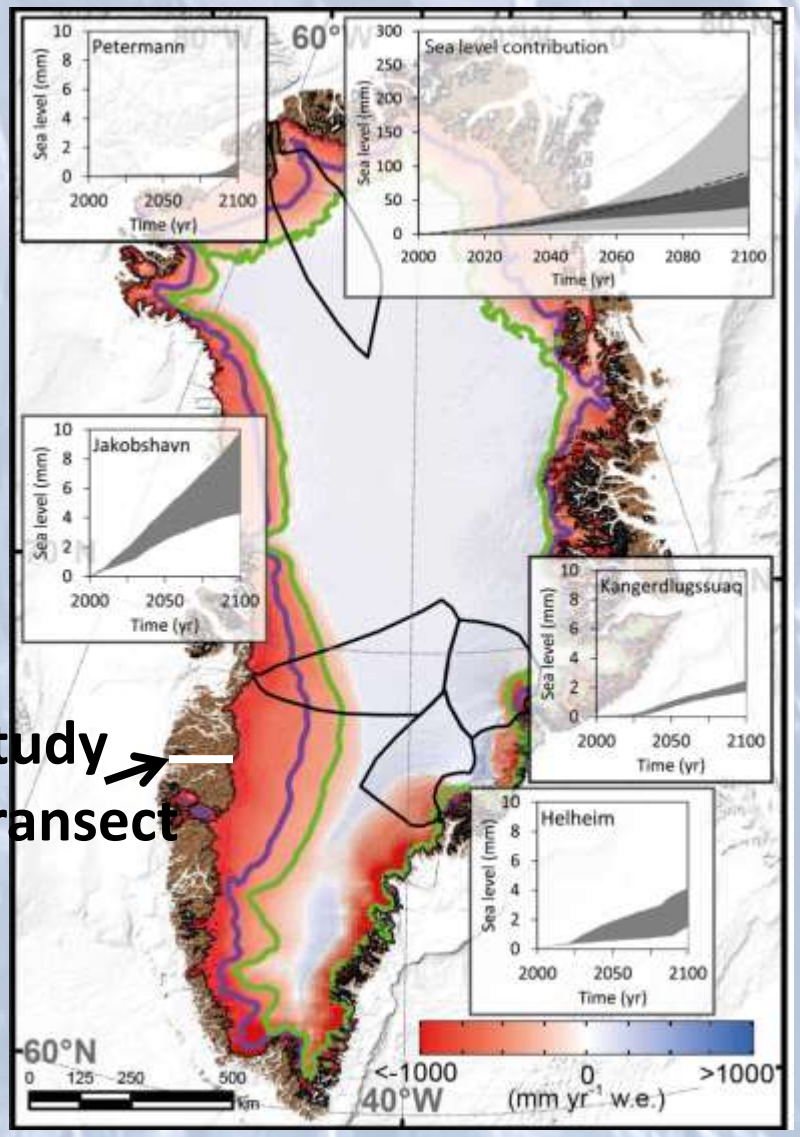
Sea level projections



- Compilation of models
- Projection of global mean sea level for two extreme scenarios (RCP2.6 and RCP8.5 – process based)
- Thermal expansion greatest contributor (30-55%)
- Glacial melting (not Antarctica) second largest contributor (15 – 55%)
- *Likely* that rate of sea level rise will increase in 21st century
  - e.g., >3.2 mm/yr

IPCC, 2013 5th AR

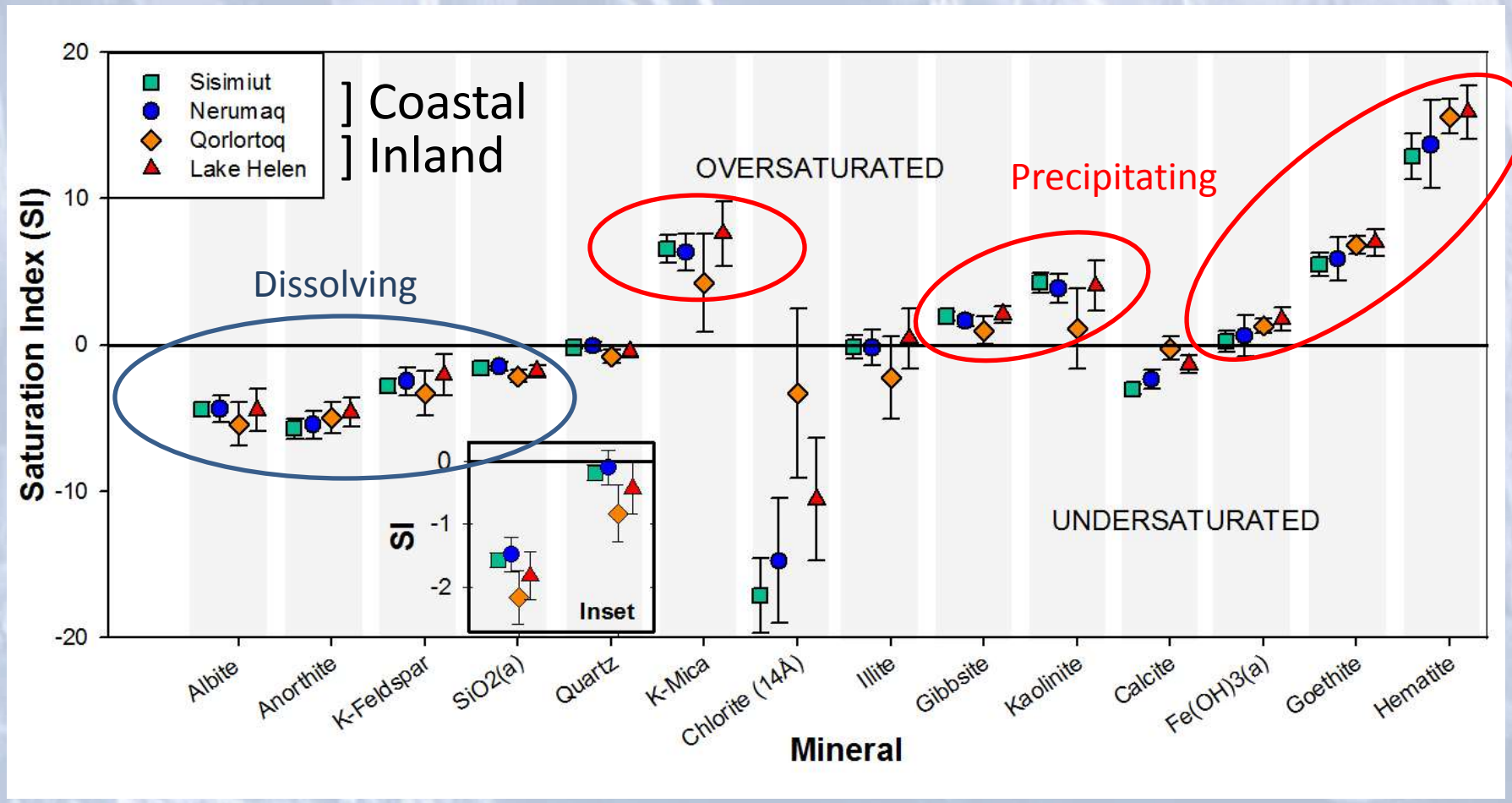
Greenland – a modern ice sheet



- Model of surface mass balance for 21st century
  - Red – mass loss; blue – mass gain
- Equilibrium lines
  - Purple now, Green 2100
- Insets: contribution to SL rise from outlet glaciers & ice sheet
- Question:
  - How might weathering change as ice sheet retreats?
  - Study transect in W Greenland

IPCC, 2013 5th AR

Saturation states of watershed waters

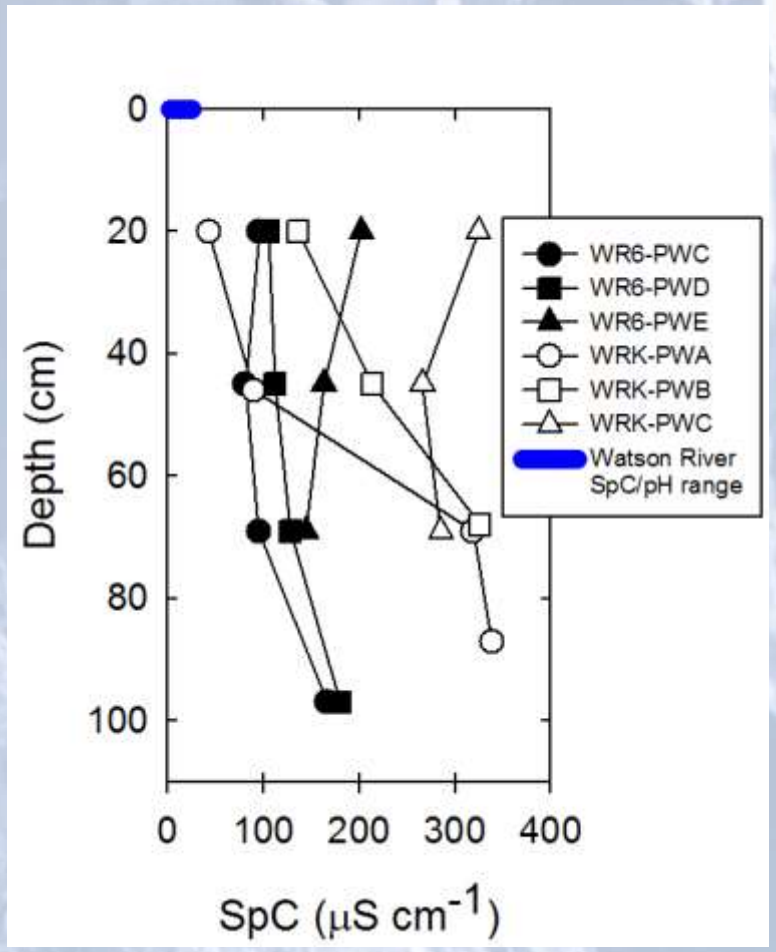


- Feldspar minerals undersaturated
- Clays and oxides supersaturated

Scribner et al., submitted, GCA

- Temporary piezometers (“vapor probe”)
- Sample pore waters for chemical compositions

Specific Conductivity vs depth



- Both locations show nearly order of magnitude increase in river over pore water
- Two possible causes
  - Cryogenic concentration
  - Weathering
- Variations in elemental compositions indicate weathering important