Collaborative Research: A synthesis of rapid meltwater and ice discharge changes: large forcings from the ice with impacts on global sea level and North Atlantic freshwater budgets

- **Objectives**:

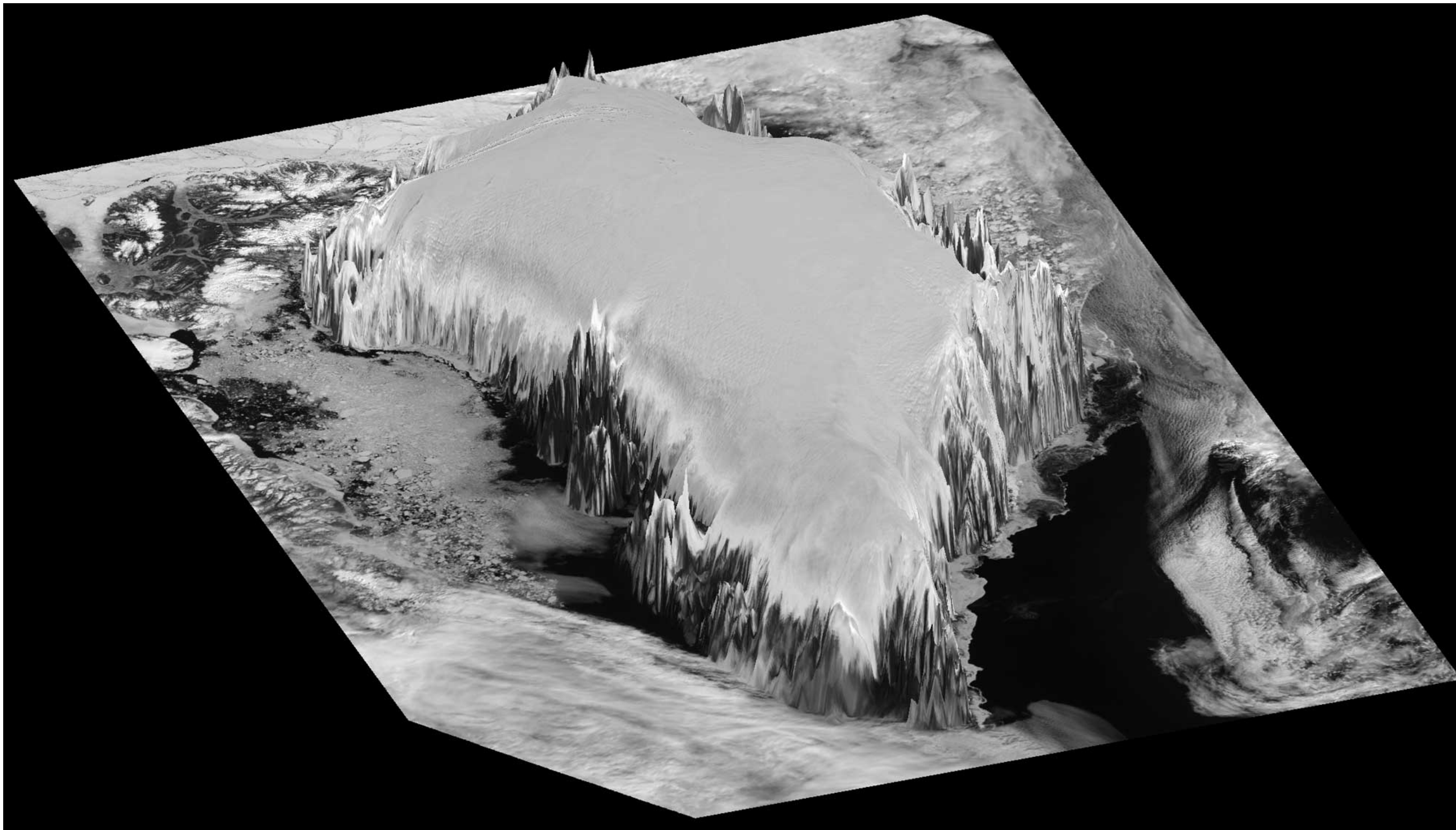
1) an estimate of the large temporal variations in fresh water output from land-based ice in Greenland

2) an improved understanding of the variability of the ice discharge flux from the Greenland *Ice Sheet*

3) use 1 and 2 to investigate to what extent ice discharge variability from Greenland outlet glaciers is attributable to short term climate variability (e.g., through enhanced basal lubrication from surface melt)

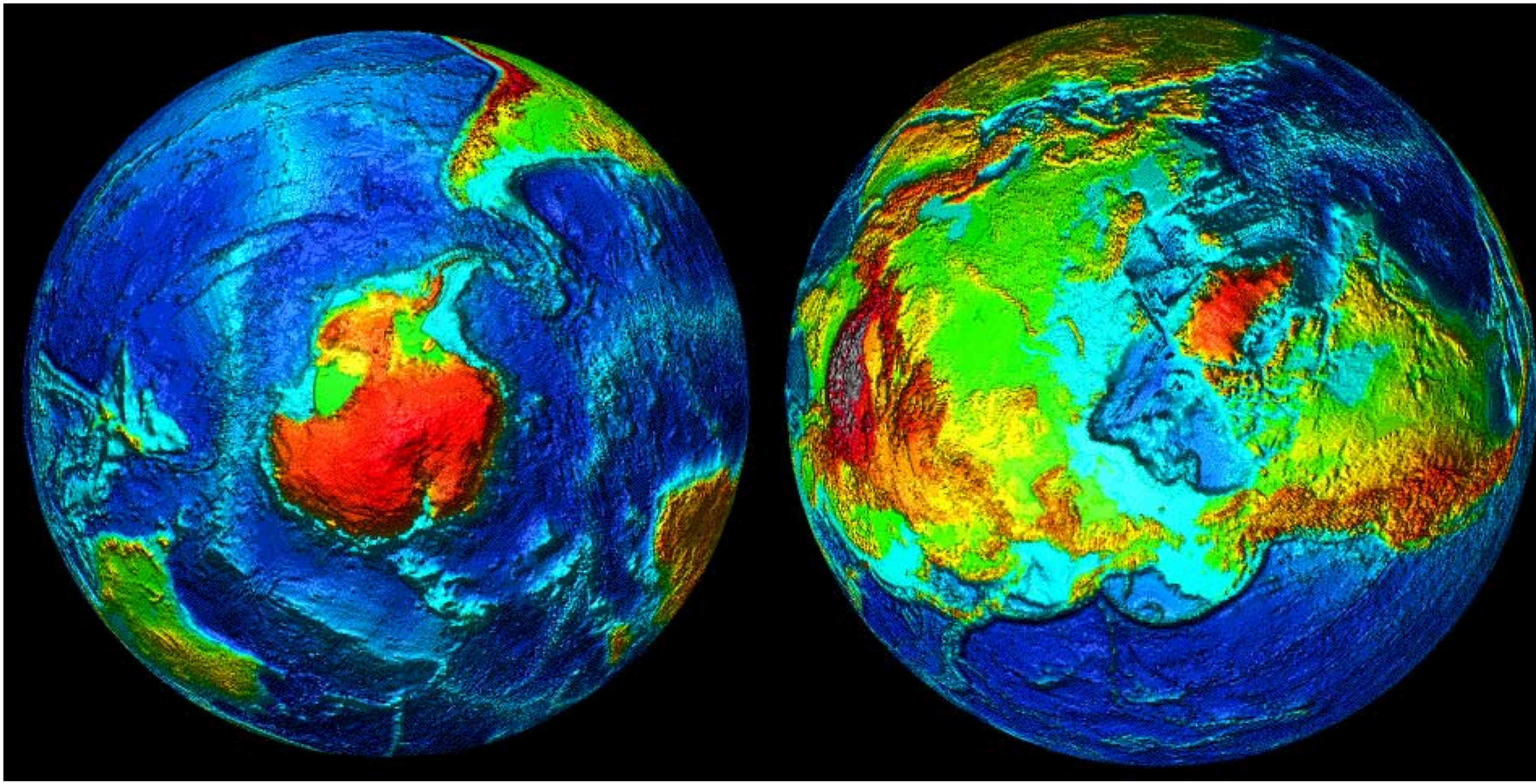
The Greenland Ice Sheet in 3D

(vertical exaggeration just about right for a glaciologist)



Topography of the Earth

at high latitudes, the climate system is at least as effective as plate tectonics in producing high elevation topography, and it does it quicker (both on the way up and the way down)



If you take fresh water out of the ocean, you have to pile it up somewhere. That growing or shrinking pile is part of the climate system. What are the feedbacks here? What can make the pile shrink the fastest? Is that going on now?

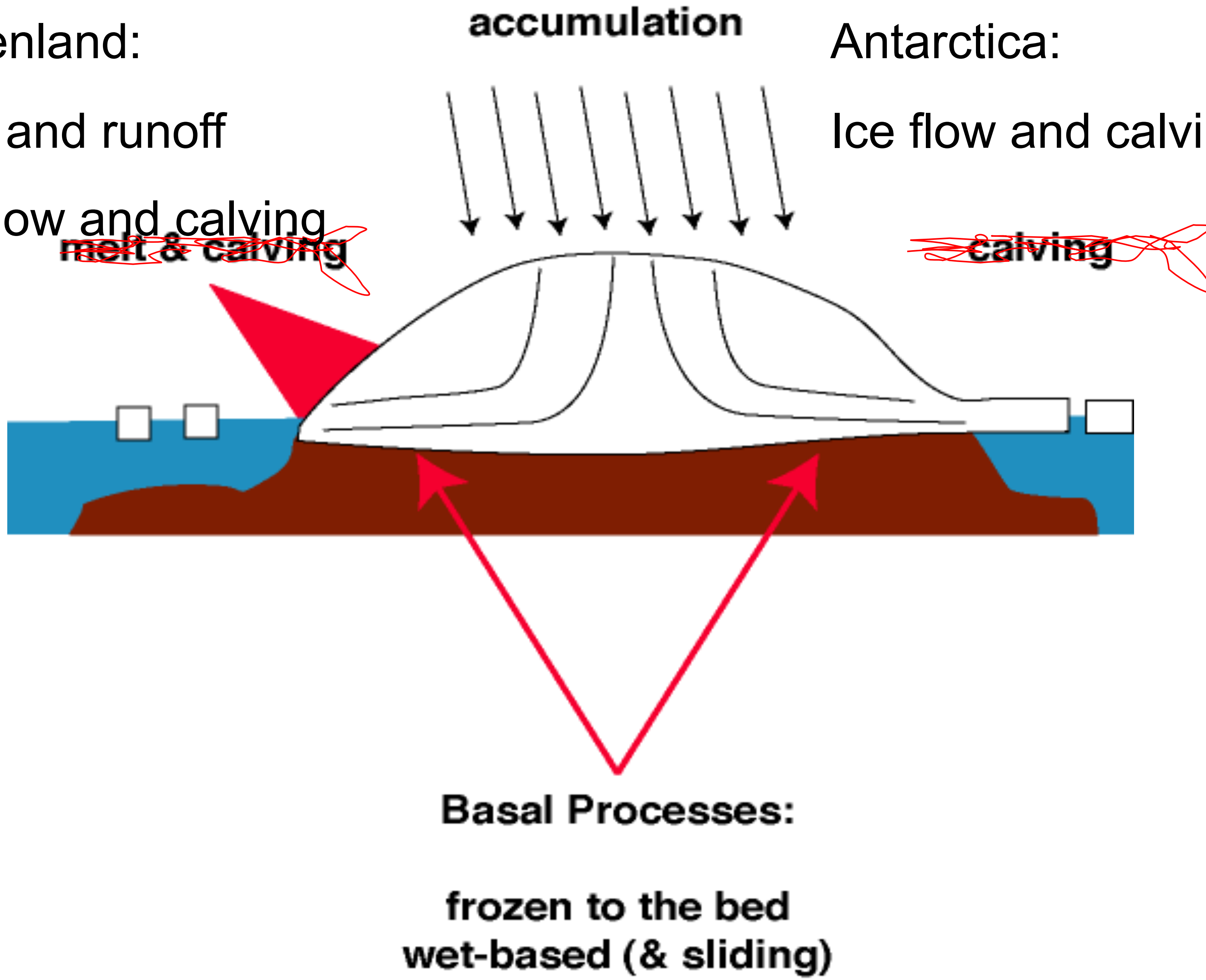
Greenland:

Melt and runoff

Ice flow and calving

Antarctica:

Ice flow and calving



Collaborative Research: A synthesis of rapid meltwater and ice discharge changes: large forcings from the ice with impacts on global sea level and North Atlantic freshwater budgets

- **Objectives**:

1) an estimate of the large temporal variations in melt water output from land-based ice in Greenland

2) an improved understanding of the variability of the ice discharge flux from the Greenland *Ice Sheet*

3) use 1 and 2 to investigate to what extent ice discharge variability from Greenland outlet glaciers is attributable to short term climate variability (e.g., through enhanced basal lubrication from surface melt)

First #2 (#1 has more ties to the other SASS projects, so we will spend more time on it)

2) an improved understanding of the variability of the ice discharge flux from the Greenland Ice Sheet

- Driving questions: How has glacier terminus position and ice thickness varied over the last 100+ years, to the extent that it has been documented? How do present rapid changes compare in this context? How do processes near the termini of glaciers reflect changing climate conditions and/or connections to oceanographic processes?
- Inputs: existing observations (historical, satellite-based, direct measurements of speed up and thinning), models, characterizations of outlet glaciers (condition of calving faces, change in front configuration compared to older observations, present drawdown rates), and understanding of ice discharge processes (position in the tidewater glacier cycle); outputs -> constraints on the variability of ice flow contributions to the fresh water output from the ice sheet

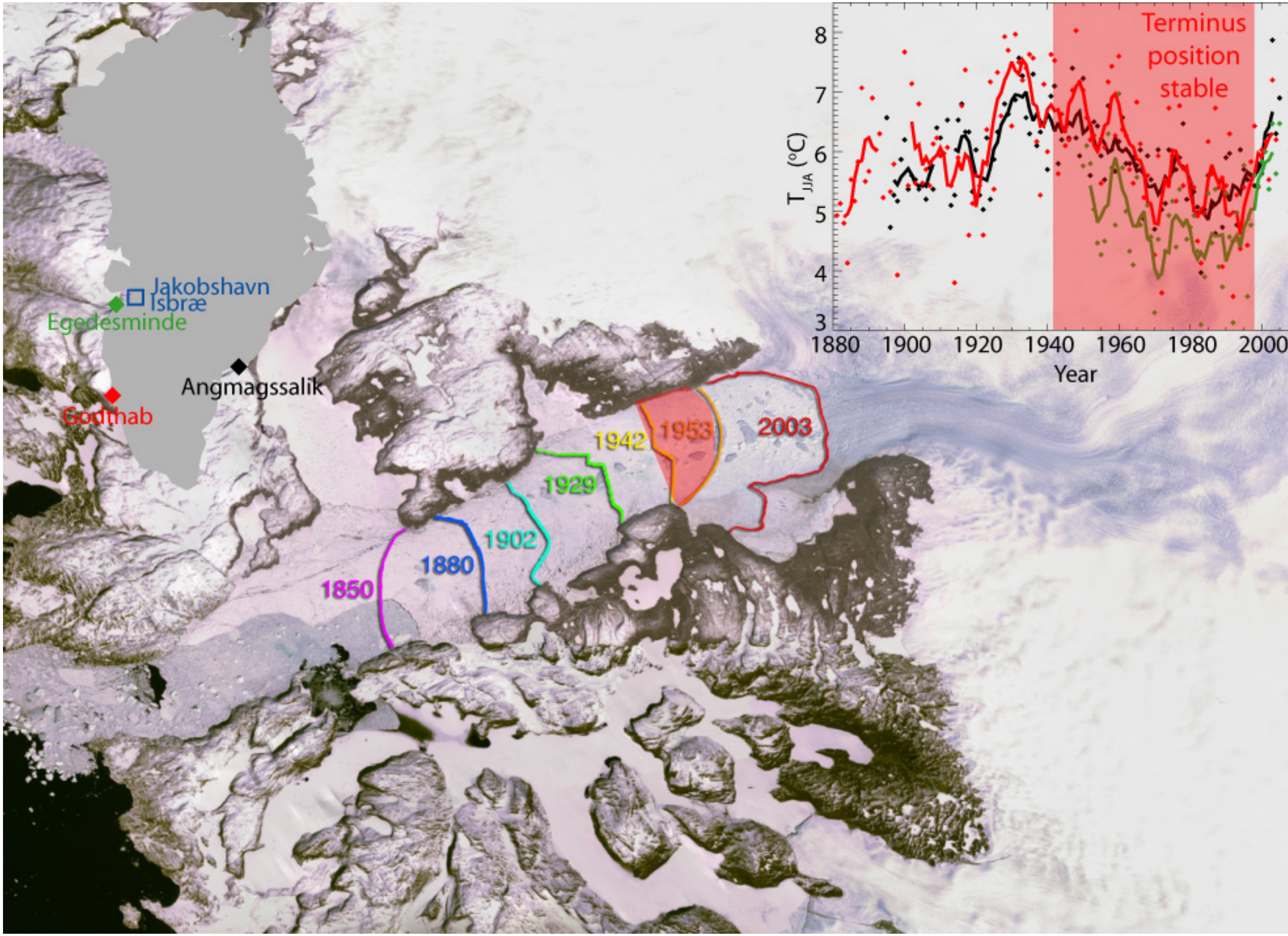
Left out of the last figure is the complexity introduced by the tidewater character of all major outlet glaciers in Greenland

The tidewater glacier cycle as first described by Austin Post:
(tidewater glaciers are those terminating in the ocean)

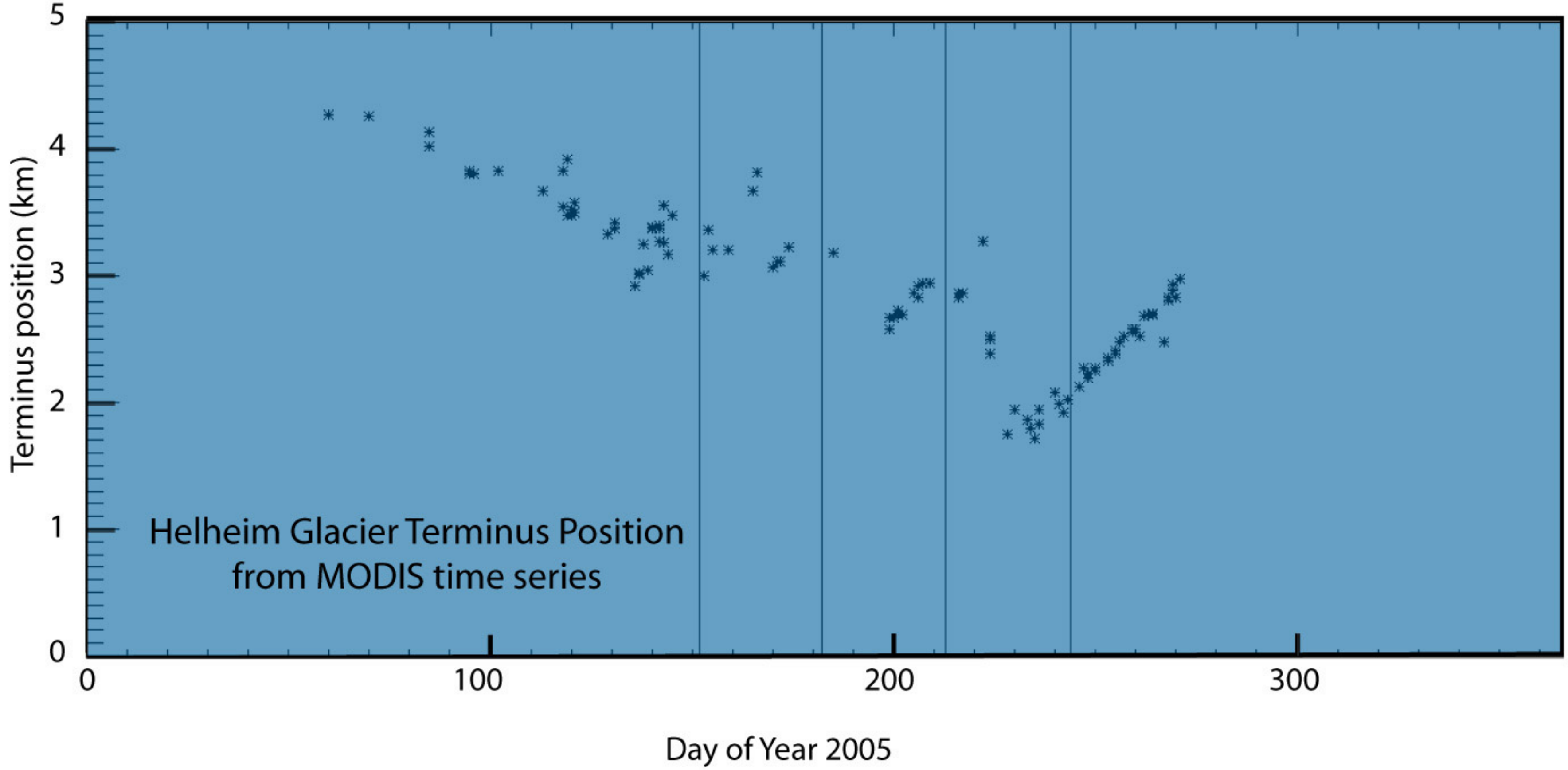
1) Slow advance of the ice front down the fjord, as the glacier moves a stabilizing moraine shoal ahead of it along the bottom - the longer the low elevation part of the glacier gets, the more susceptible it becomes to warm periods

2) A period where the terminus remains in an extended position against the shoal

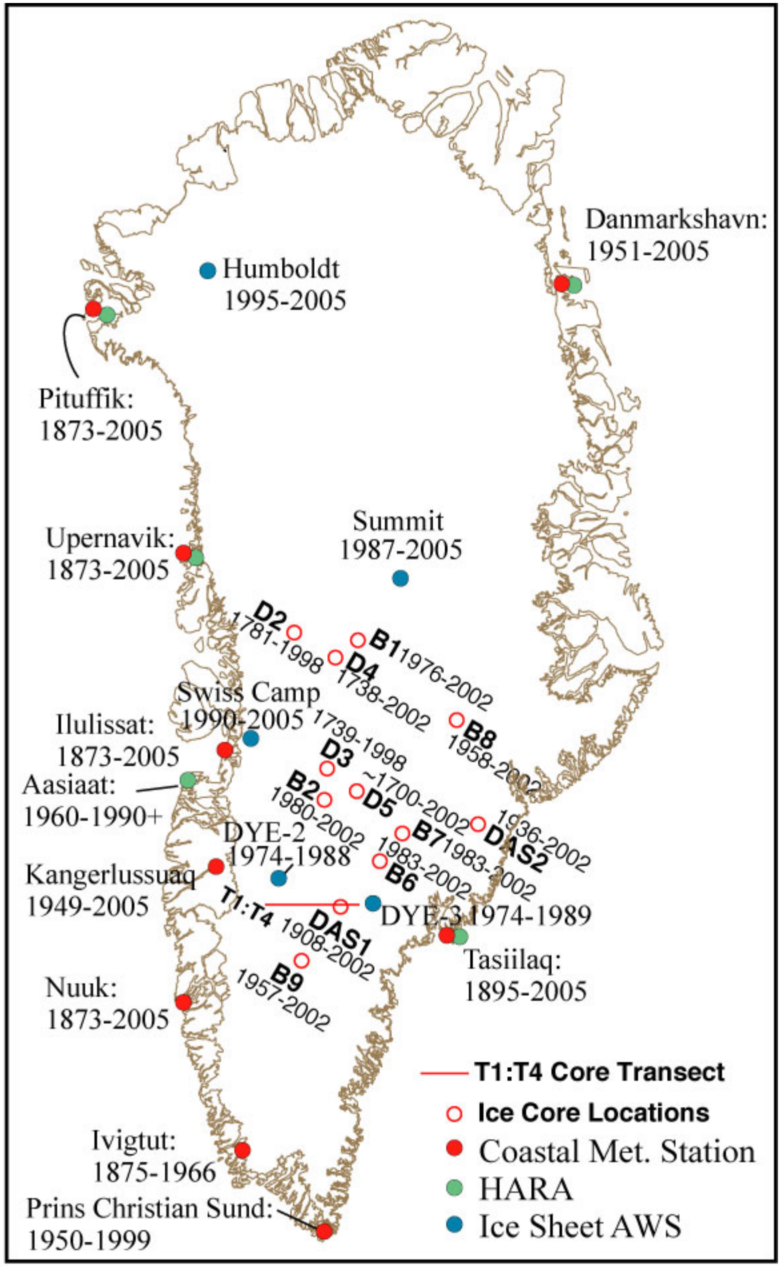
3) Rapid retreat after a thinning glacier backs off of the moraine shoal; this retreat can pause or reverse if conditions or geometry favor stability



Terminus position stable
T_{JJA} (°C)
Year
1880
1900
1920
1940
1960
1980
2000
Jakobshavn Isbræ
Egedesminde
Angmagssalik
Godthab
1850
1880
1902
1929
1942
1953
2003



5
4
3
2
1
0
Terminus position (km)
Helheim Glacier Terminus Position
from MODIS time series
0
100
200
300
Day of Year 2005



1) an estimate of the large temporal variations in melt water output from land-based ice in Greenland

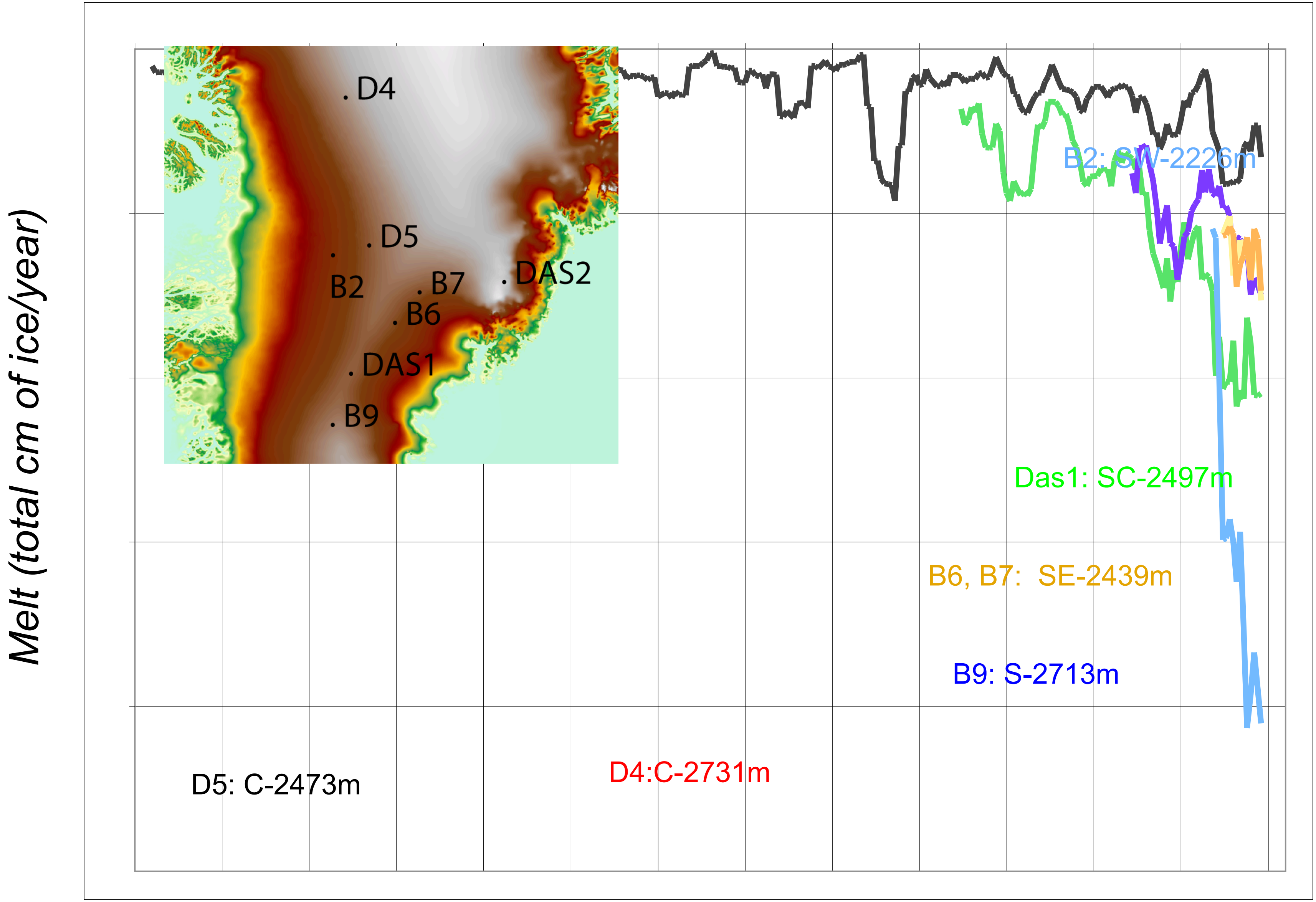
- Driving question: What is the spatial and temporal variability in Greenland Ice Sheet surface melt and runoff over the past 125+ years?
- Inputs: ice-core records of melt, coastal station and on-ice meteorological records, glacier survey data (snow pits, ablation stakes), remote sensing, and output from multi-decadal regional and global climate analyses; outputs -> the longest possible reconstruction of estimated surface mass balance, melt and runoff from the inland ice.

Ice (& Firn) Core Records of Melt Amount

Sarah Das
WHOI

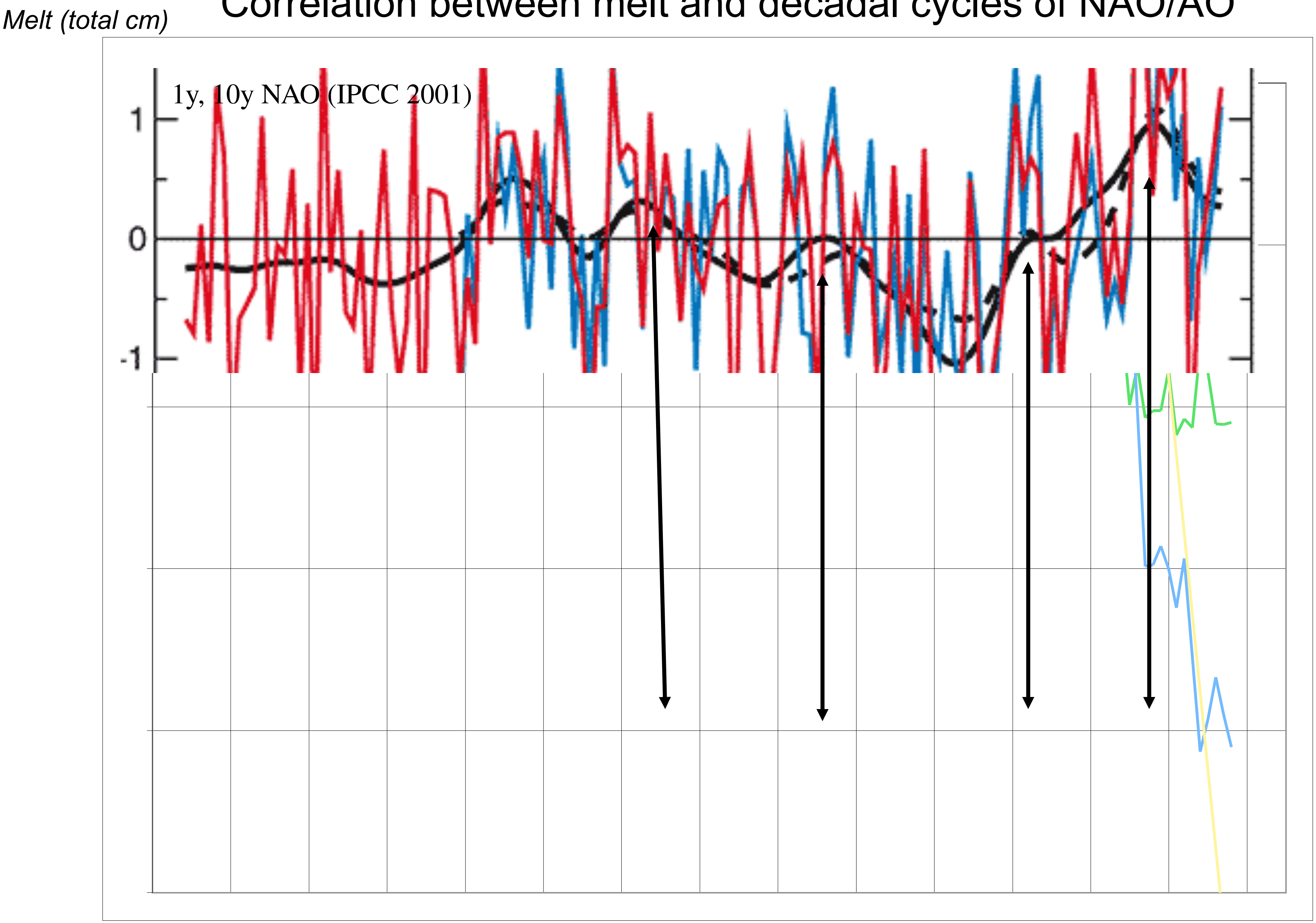
10-yr running average melt amount

(recent record shows 20yr trends between all sites)

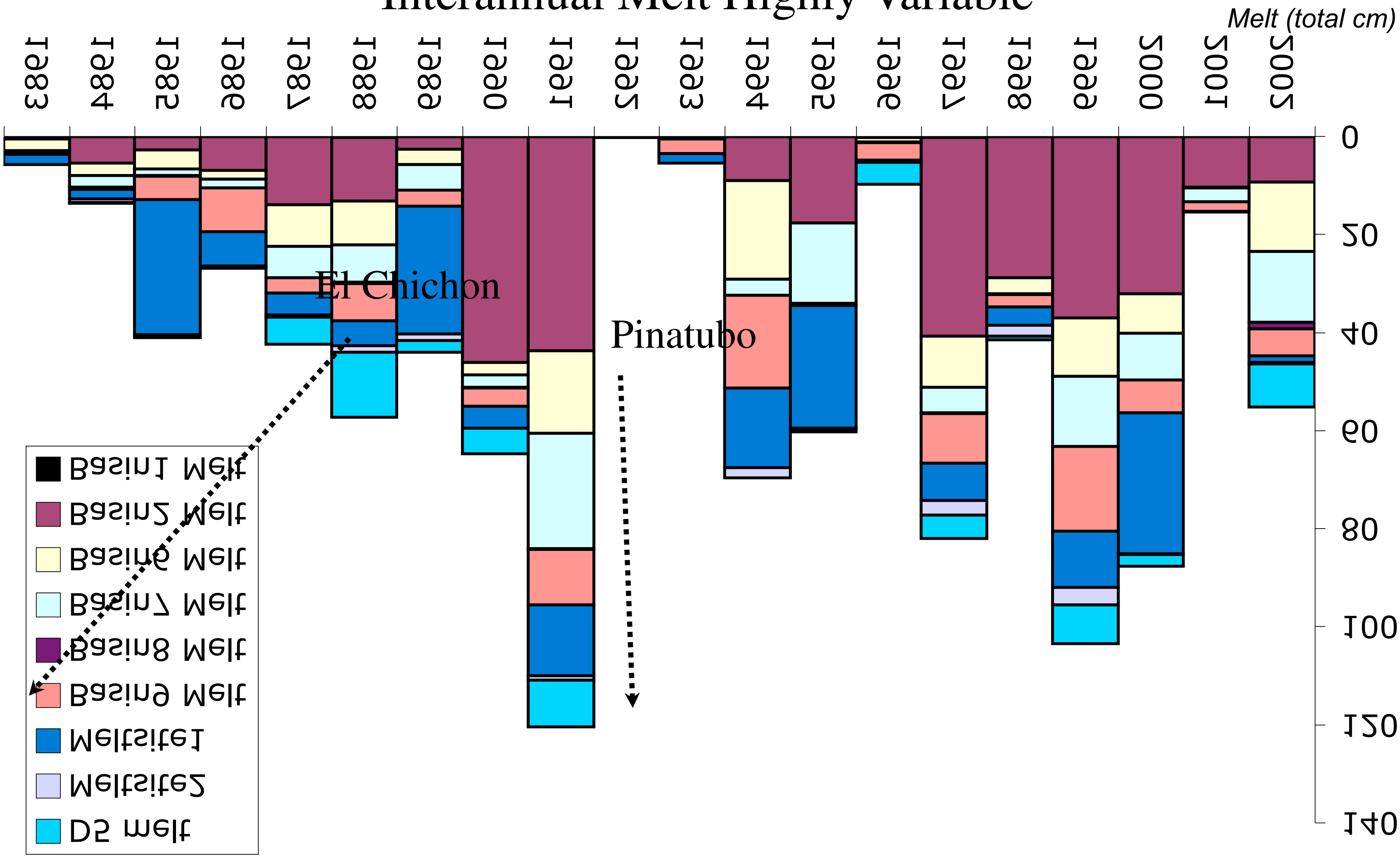


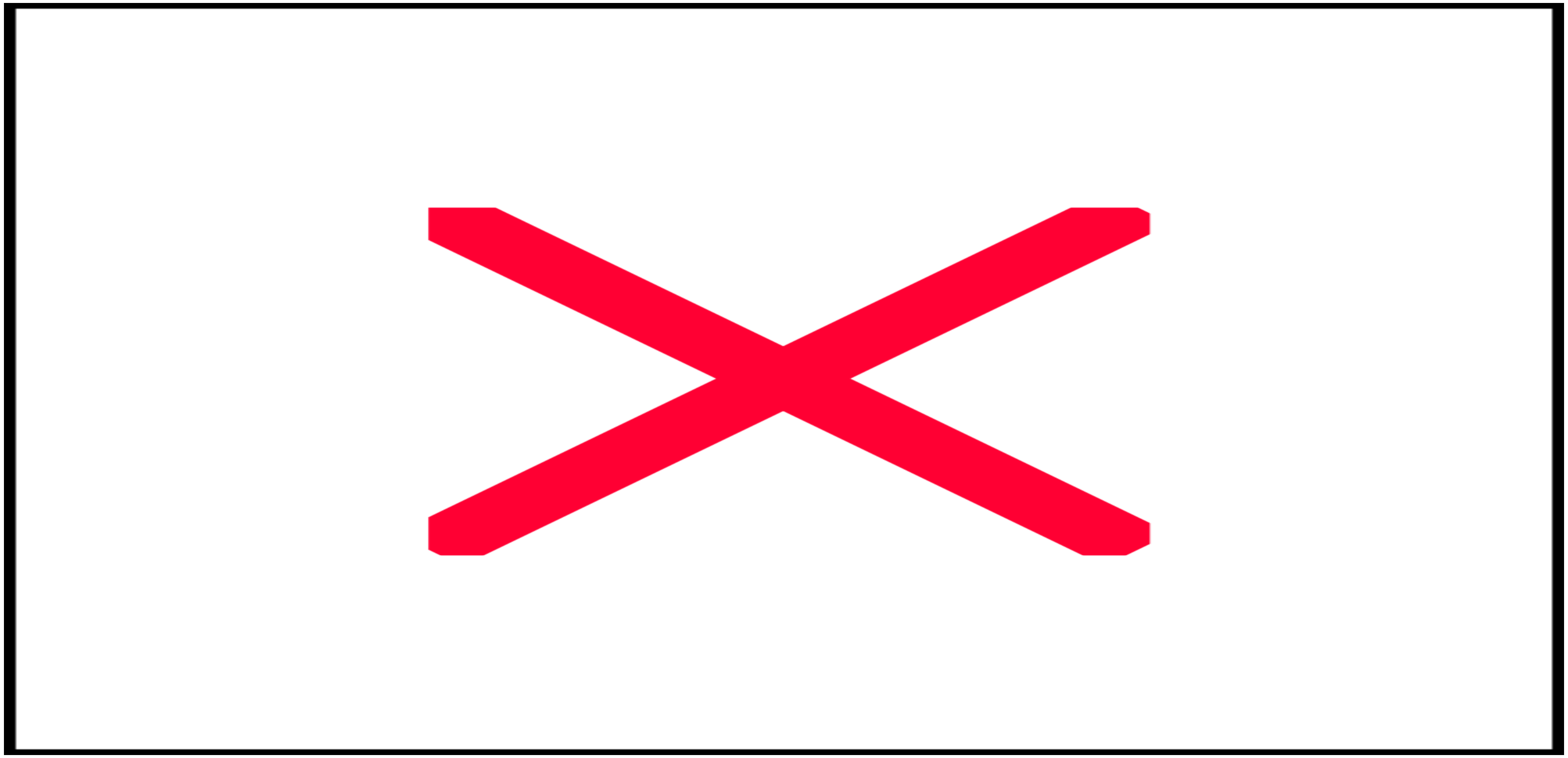
Das2: SE-2936m

20y cycles
Correlation between melt and decadal cycles of NAO/AO



Instrumental period 1983-2002
Interannual Melt Highly Variable





Instrumental-era Greenland Temperature and Ice Sheet Runoff Reconstructions

J. E. Box

Byrd Polar Research Center

Synthesis of Arctic System Science (SASS) Investigator Meeting

26–27 March 2006

Seattle, Washington

Surface Air Temperature Data

- Coastal temperature records
  - Nuuk
    - Seasonal (1873-2001) and Annual (1873-2004)
  - Tasiilaq
    - Seasonal (1895-2001) and Annual (1873-2004)
  - Thule
    - Seasonal and Annual (1947-present)
  - Narsarssuaq
    - Seasonal (1961-present) and Annual (1873-2004)
  - Aasiaat
    - Seasonal and Annual (1951-present)
  - Danmarkshavn (1951-present)
    - Seasonal (1951-2001) and Annual (1948-2004)
- Polar MM5
  - 24 km grid
  - currently 1988-2005
  - (by Feb. 2006) 1958-2005

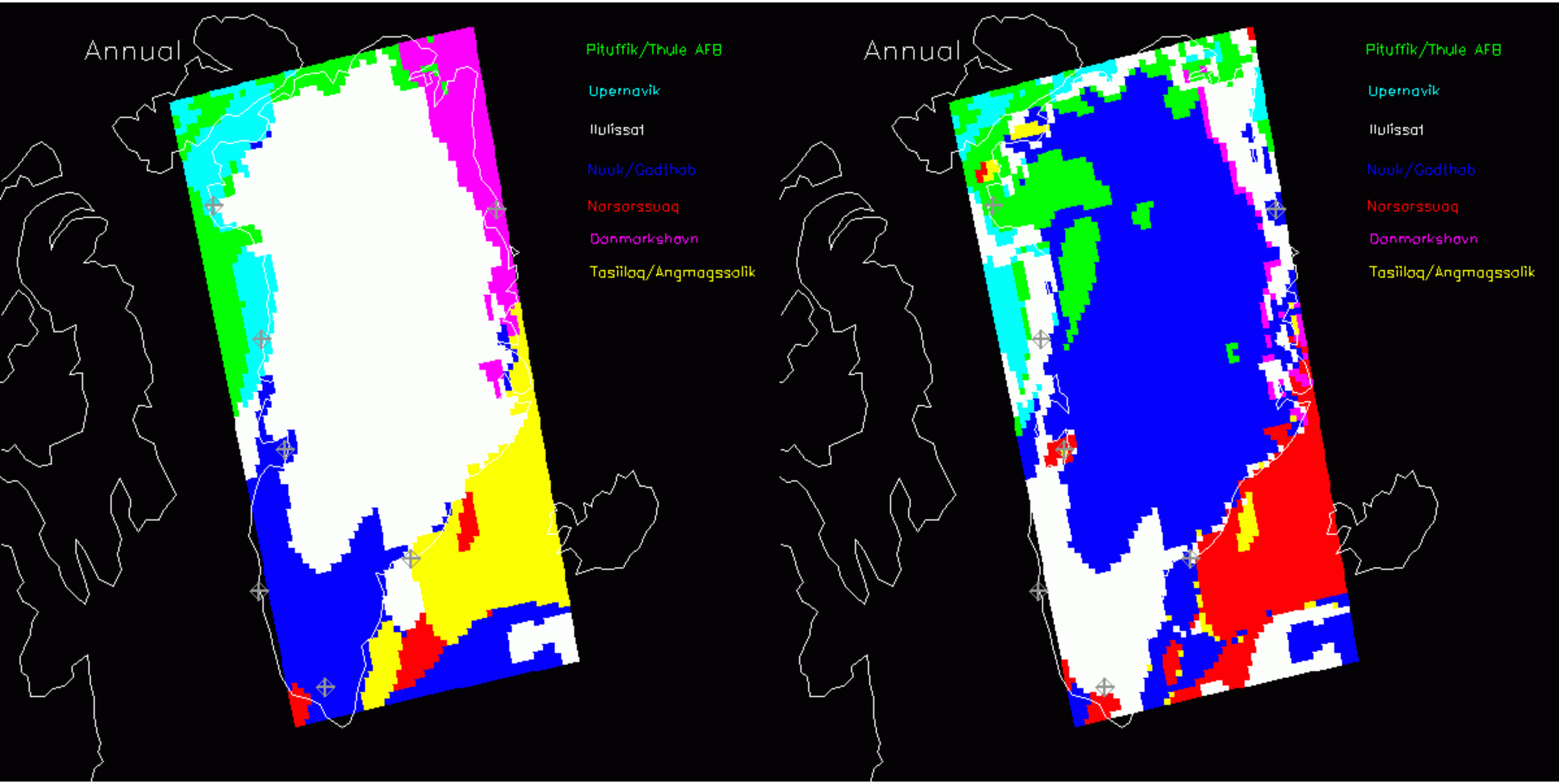
Methodology

- Correlate time series from each coastal station records with time series of each Polar MM5 grid cell
  - Training period
    - currently 1988-2005, (N = 18)
    - (by Feb. 2006) 1958-2005, (N = 48)
- Rank top two sites for each grid cell based on correlation
- Store linear regression coefficients (slope and intercept) for the top two ranked sites on pixel by pixel basis
  - Only store coefficients if above significance threshold
- Use full record to reconstruct seasonal ice sheet temperatures
  - 1873-2004 available for annual means, (N = 132)

Regions of Maximum Correlation

Annual

Dominant Annual Correlations



Highest Rank (Primary) *2nd Highest Rank (Secondary)*

Results of Annual Training

Fraction of grid 'belonging to' each site

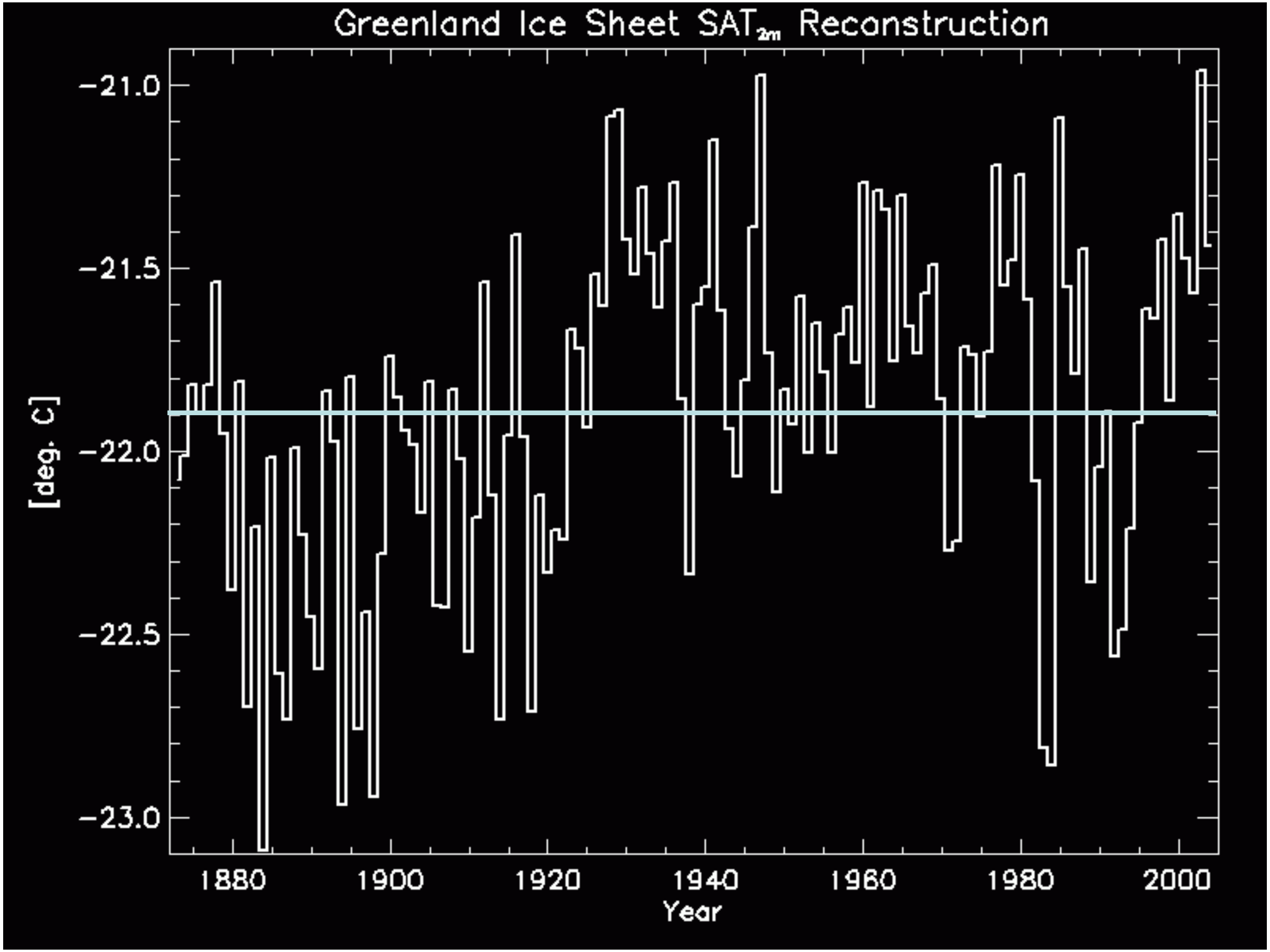
	Thul	**Uper**	**Ilul**	**Nuuk**	**Nars**	**Danm**	**Tasi**
Primary	0.06	0.06	**0.49**	0.15	0.02	0.07	0.13
Secondary	0.10	0.04	0.21	**0.46**	0.14	0.01	0.01
Overall	**0.08**	**0.05**	**0.70**	**0.31**	**0.08**	**0.04**	**0.07**

Ilulissat and Nuuk dominate the annual variance

Annual Training Conclusions

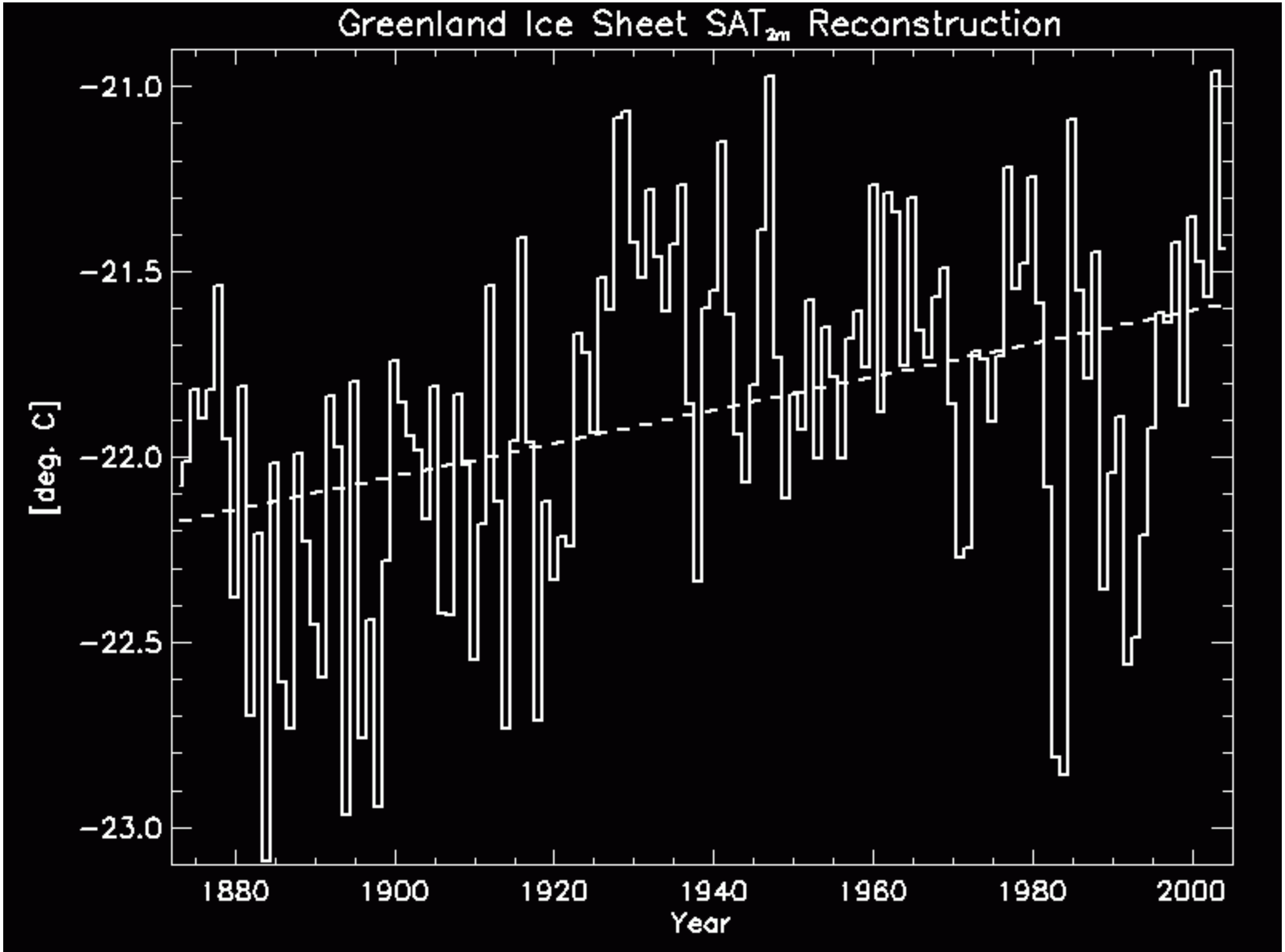
- Iulissat and Nuuk temperatures are better linked with overall ice sheet temperature variability than other sites
- Tasiilaq and Upernavik variability represents maritime locations better than terrestrial locations

Annual Reconstruction

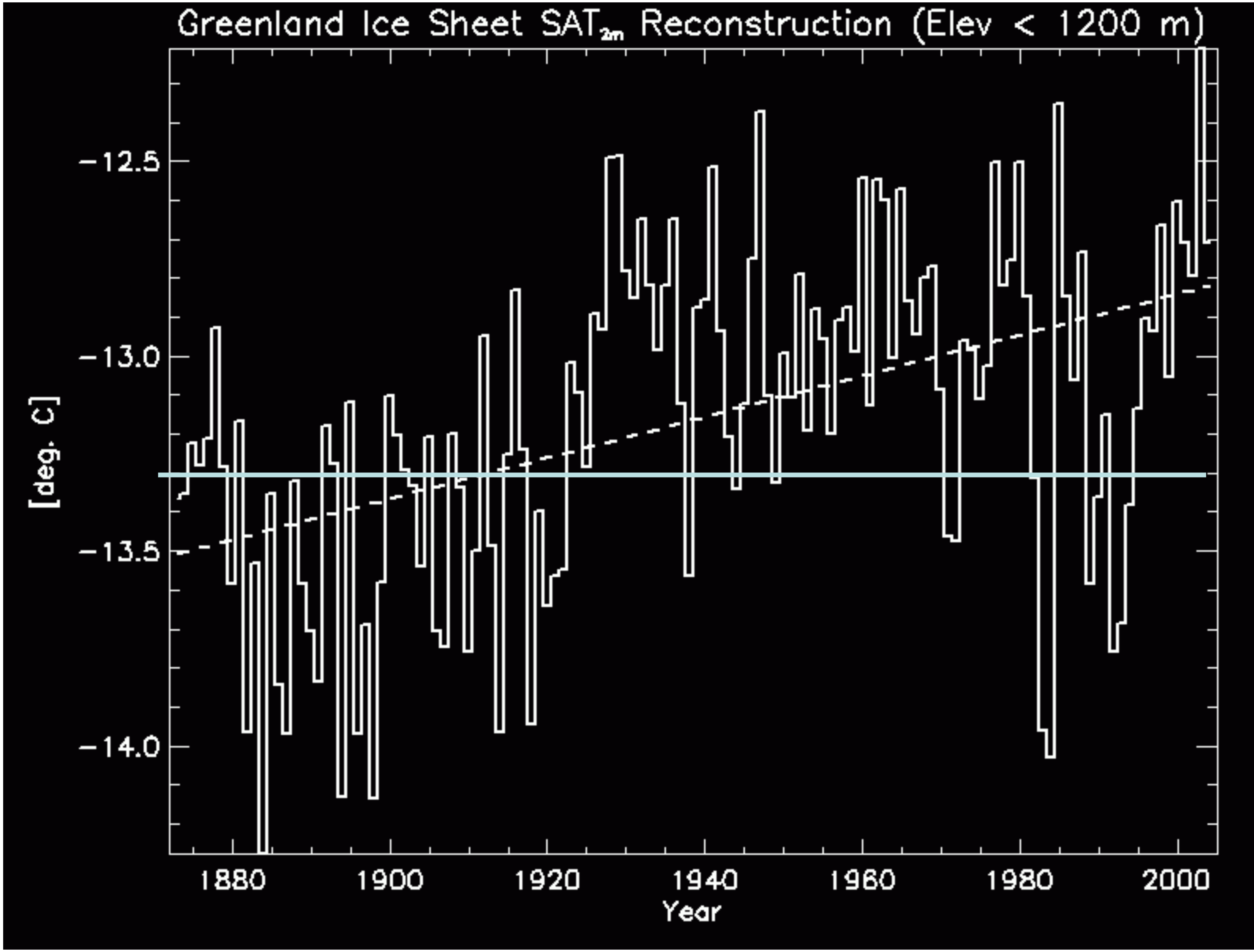


1873-2004 mean: -21.89 C

Greenland Synthesis project, SASS Seattle meeting 3/06



Linear Trend: +0.045 C/ decade, 0.6 K increase over 132 years, r =0.380



1873-2004 mean: -13.16 C

Linear Trend: +0.053 C/ decade, 0.7 K increase over 132 years, r = 0.472

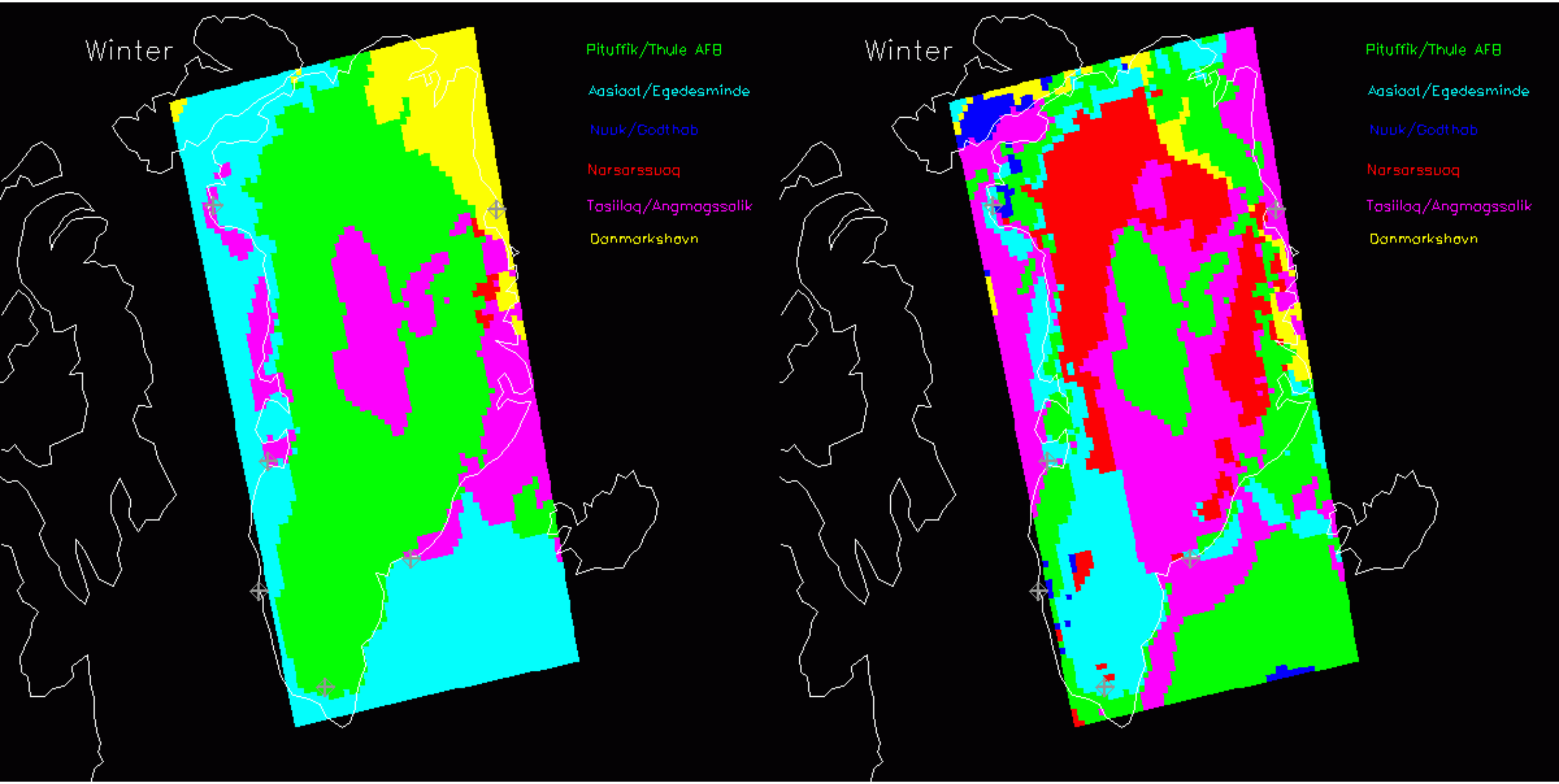
Climatological Conclusions

- Linear model explains < 2/5 of variance
- Inter-decadal oscillations?
- Warming 0.6 C overall, 0.7 C below 1200 m elevation
- 2003 warmest on record, 1883 coldest

Seasonal Correlations

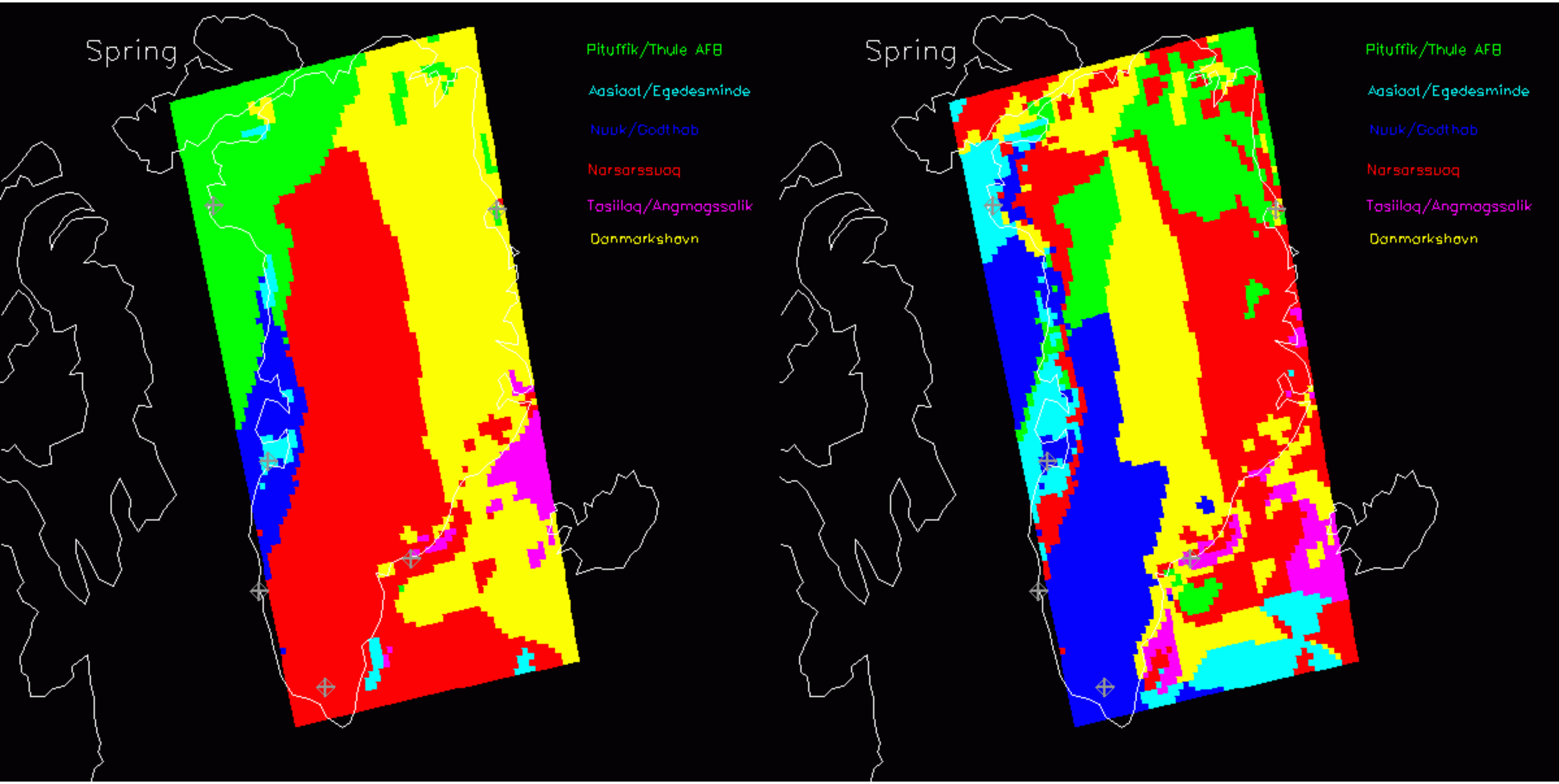
Seasonal

Dominant Seasonal Correlations



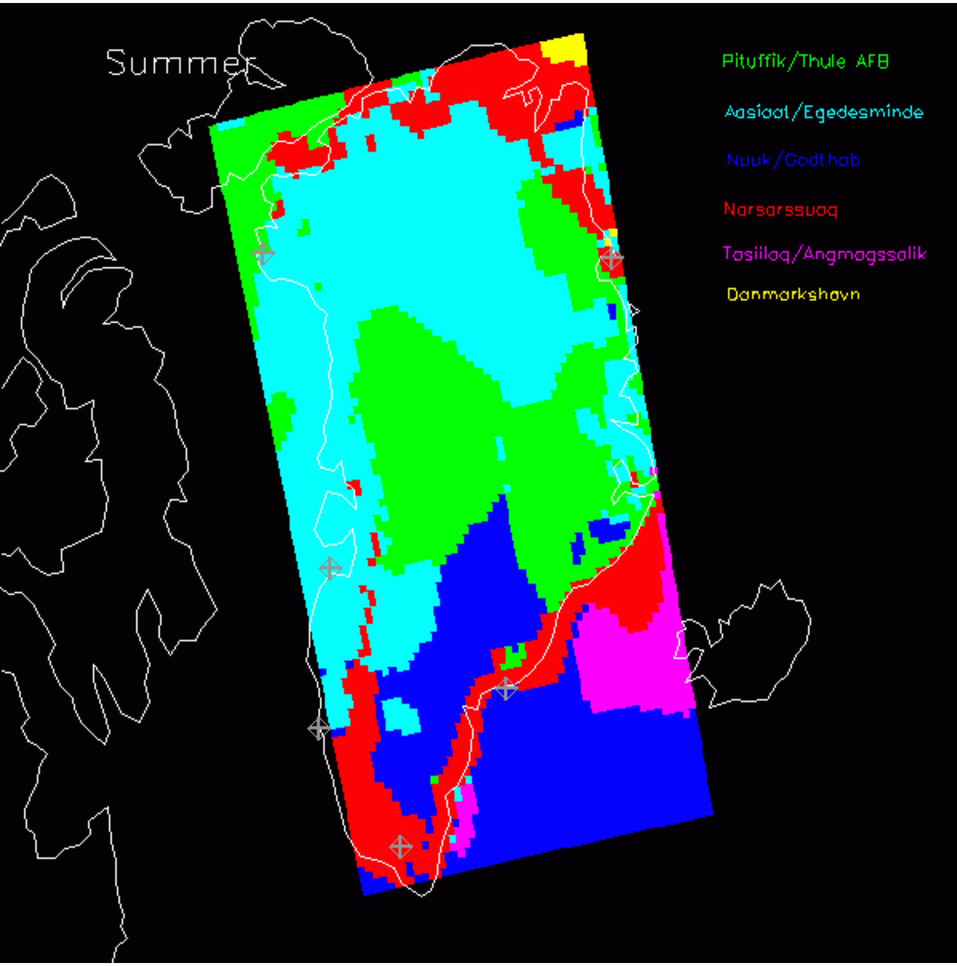
Primary *Secondary*

Dominant Seasonal Correlations

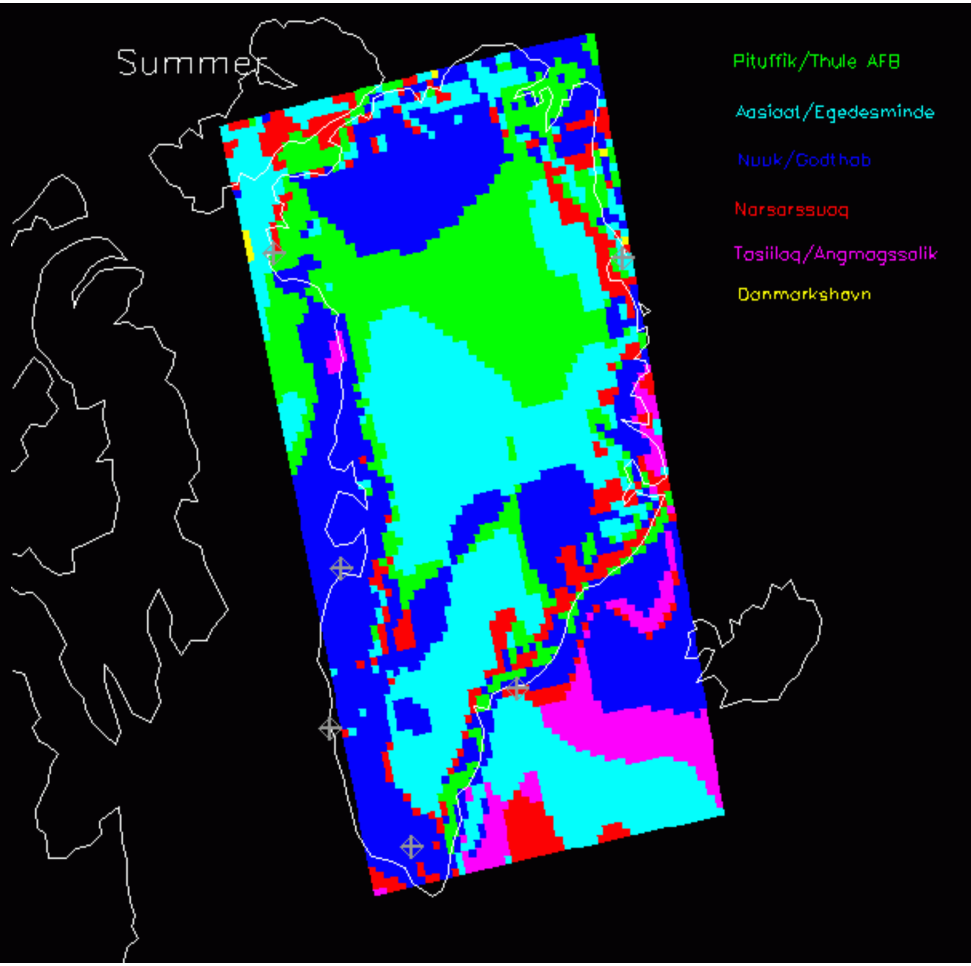


Primary ***Secondary***

Dominant Seasonal Correlations

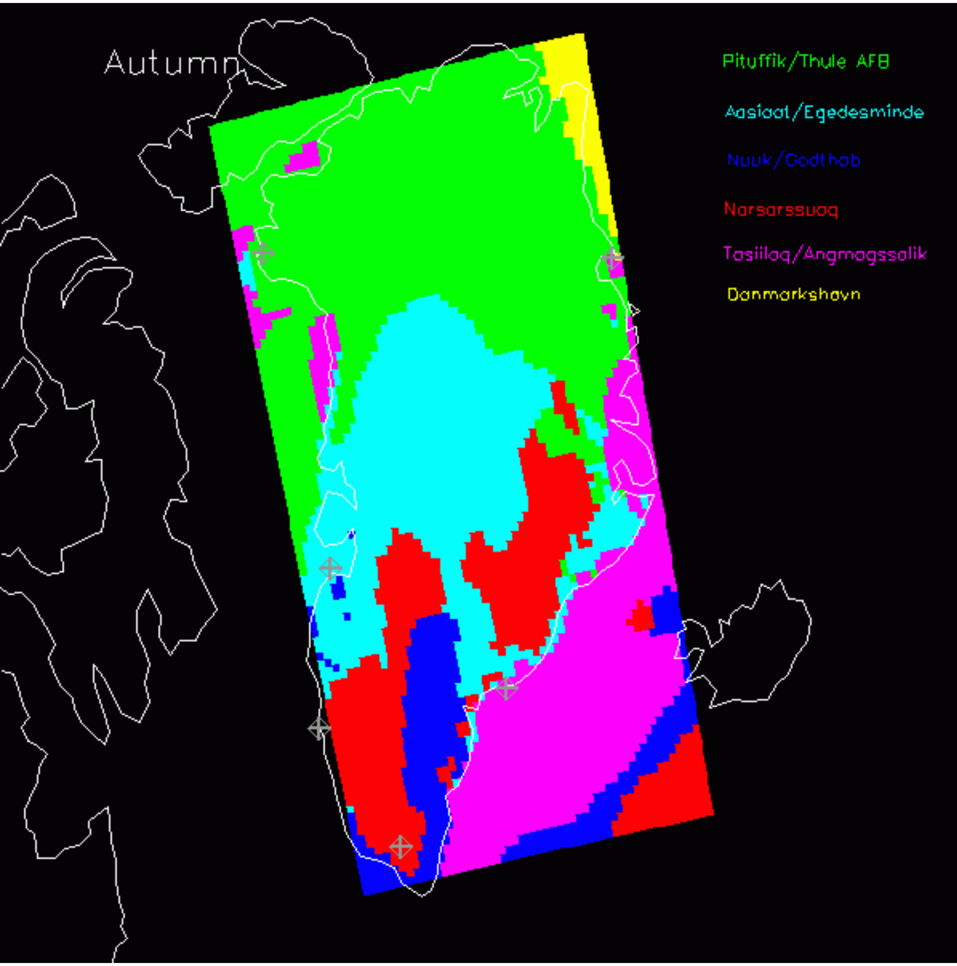


Primary

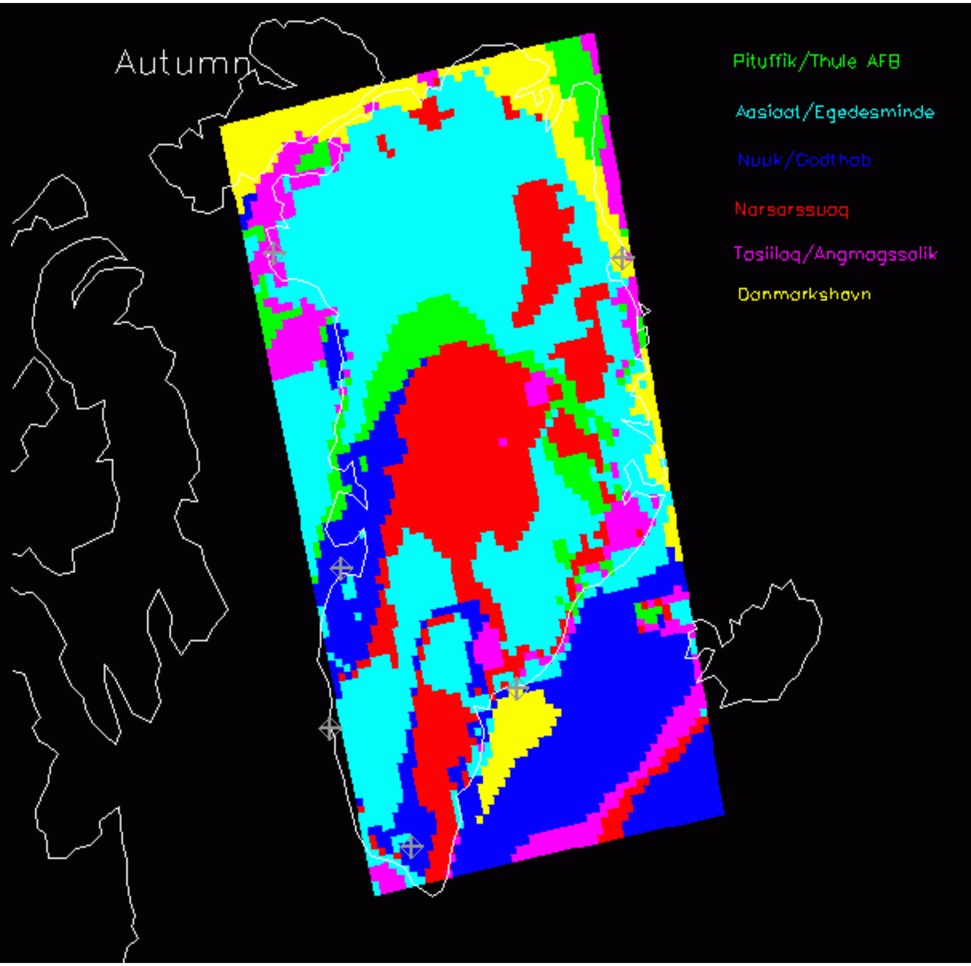


Secondary

Dominant Seasonal Correlations



Primary



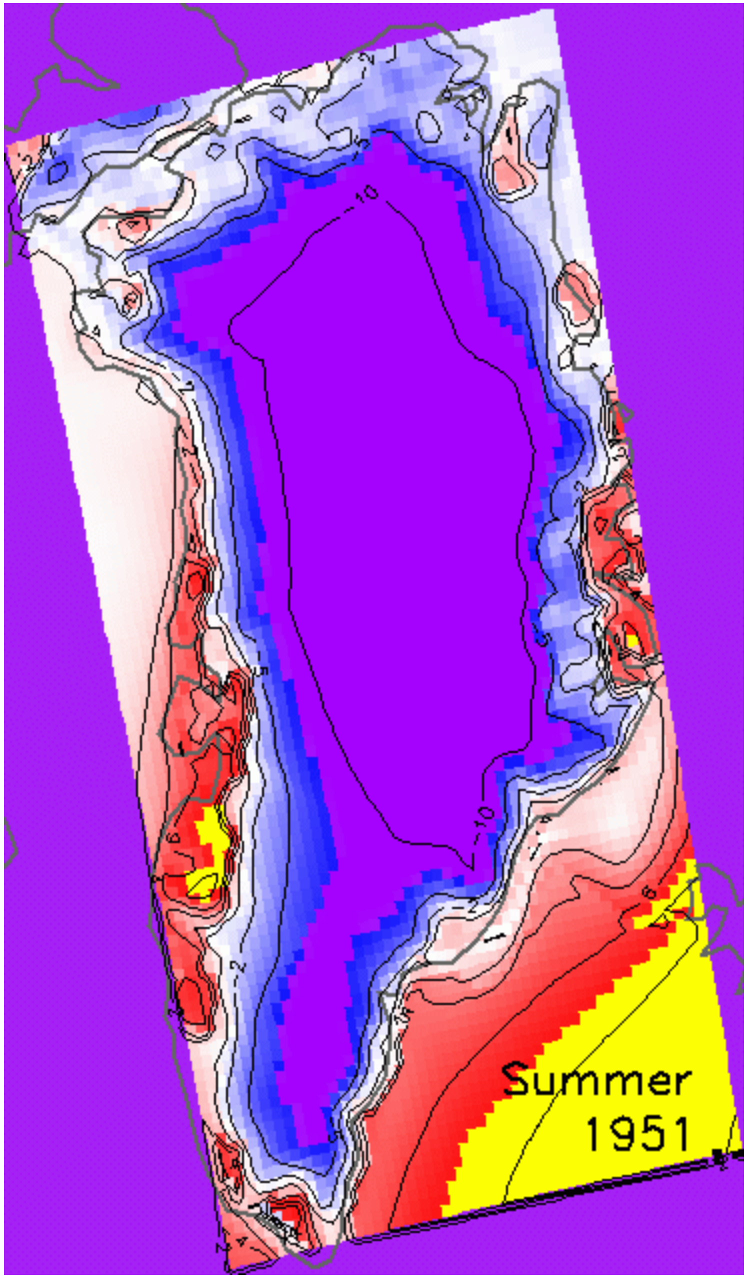
Secondary

Seasonal Training Conclusions

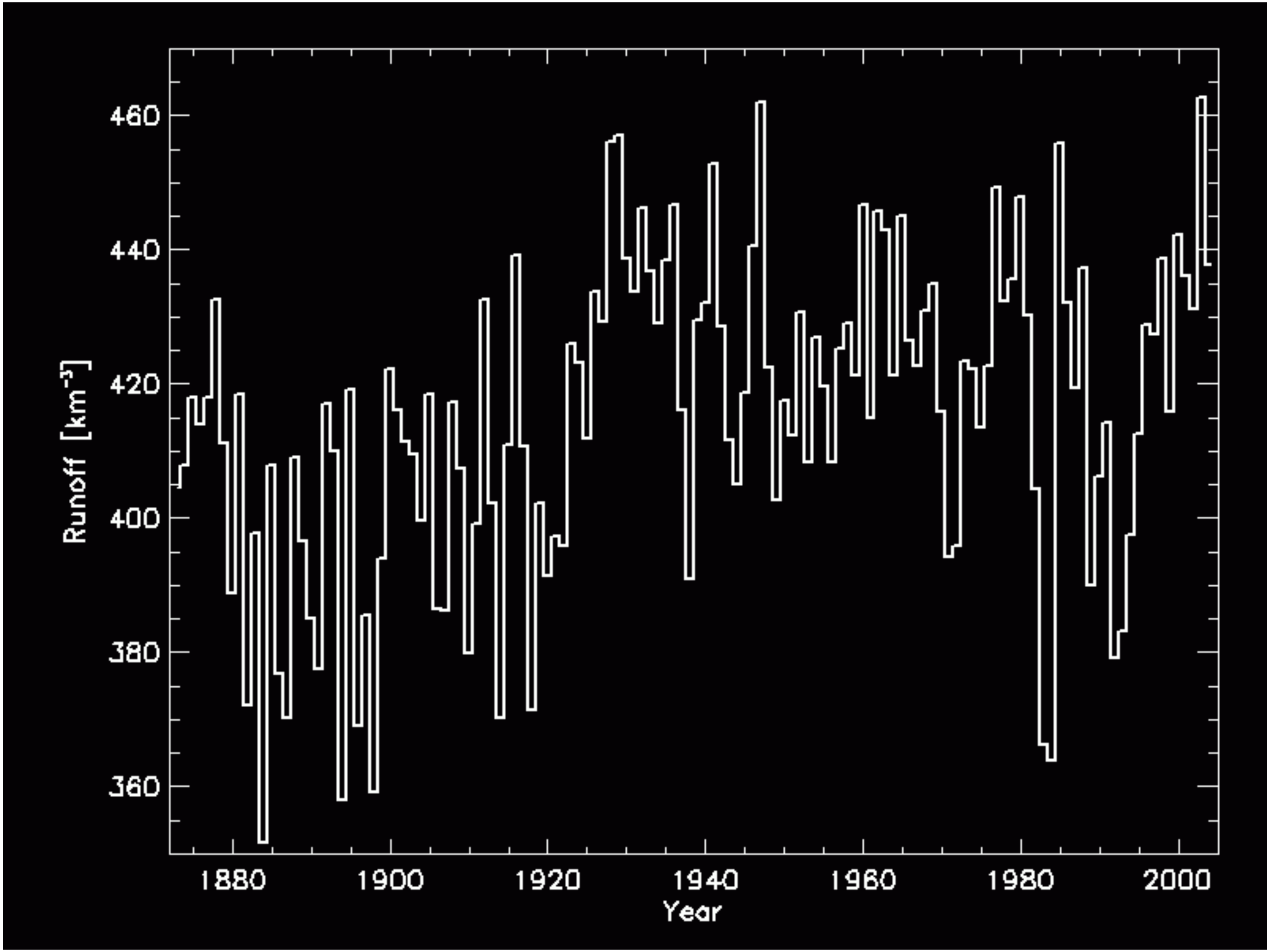
- Need to obtain longer seasonal records
  - Ilulissat
  - Narsarssuaq
  - Ivigtut
- Nuuk series not useful to reconstruct winter temperatures
  - Nuuk winter temperatures never register as primary maximum correlator, hardly as secondary correlator

Reconstruction Results

Seasonal


Summer
1951

Runoff Reconstruction


460
440
420
400
380
360
Runoff [km^{-3}]
1880
1900
1920
1940
1960
1980
2000
Year

3) use 1 and 2 to investigate to what extent ice discharge variability from Greenland outlet glaciers is attributable to short term climate variability (e.g., through enhanced basal lubrication from surface melt)

Researchers:

Ice flow/change:

Mark Fahnestock, UNH, Ice flow and surface melt, RS of large ice sheets

Martin Truffer, UAF, Ice flow (field and modeling) - outlet glaciers

Ian Joughin, APL/UW, Ice flow - RS of large ice sheets and modeling

Byron Parizek, PSU, Ice flow modeling of large ice sheets

Melt/change:

Richard Alley, PSU, ice sheets and climate

Sarah Das, WHOI, ice core records of melt, RS of melt

Jason Box, BPRC/OSU, Polar meteorology/met stations/Atm modeling

David Rausch, PSU, ice sheet/climate connections, tools for data analysis

(Overlaps and connections between these two groups omitted for simplicity)

End of slideshow