G E U S

Linking glaciers, ocean and atmospheric variability – lessons from marine sediment archives

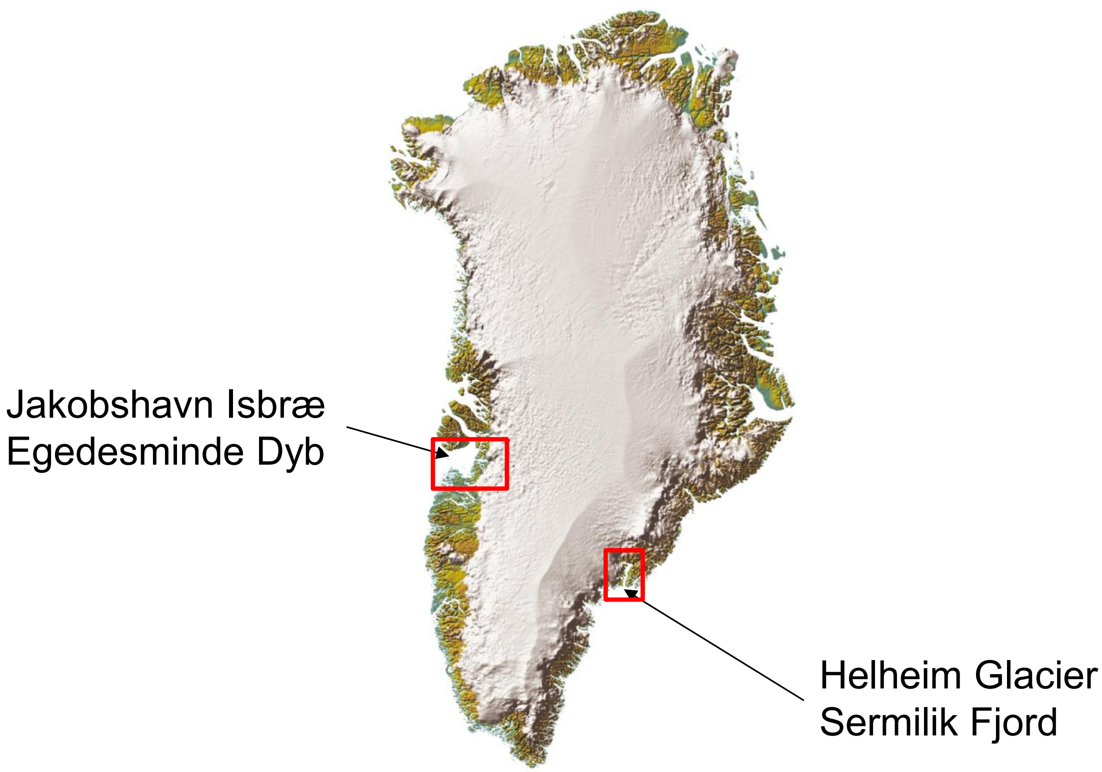
Camilla S. Andresen

Work in collaboration with amongst others: Andreea Elena Stoican, Kristian K. Kjeldsen, Kurt H. Kjær, Antoon Kuijpers, Fiamma Straneo, Dave Sutherland, Jerry Lloyd, Mette Juncker Hansen, Aleksandra Grycel, Marie-Alexandrine Sicré, Anne Jennings, Sabine Schmidt

:

Greenland Ice sheet reconstructions

- and its interaction with ocean, sea ice and climate



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Findings

1. The climate drivers behind outlet glacier instability during the past 100 years

2. The late 1930s and early 2000s glacier retreat events

3. Fjord circulation intensity changes on inter-annual time scales

4. The potential effect on submarine glacier melt of ambient ocean water

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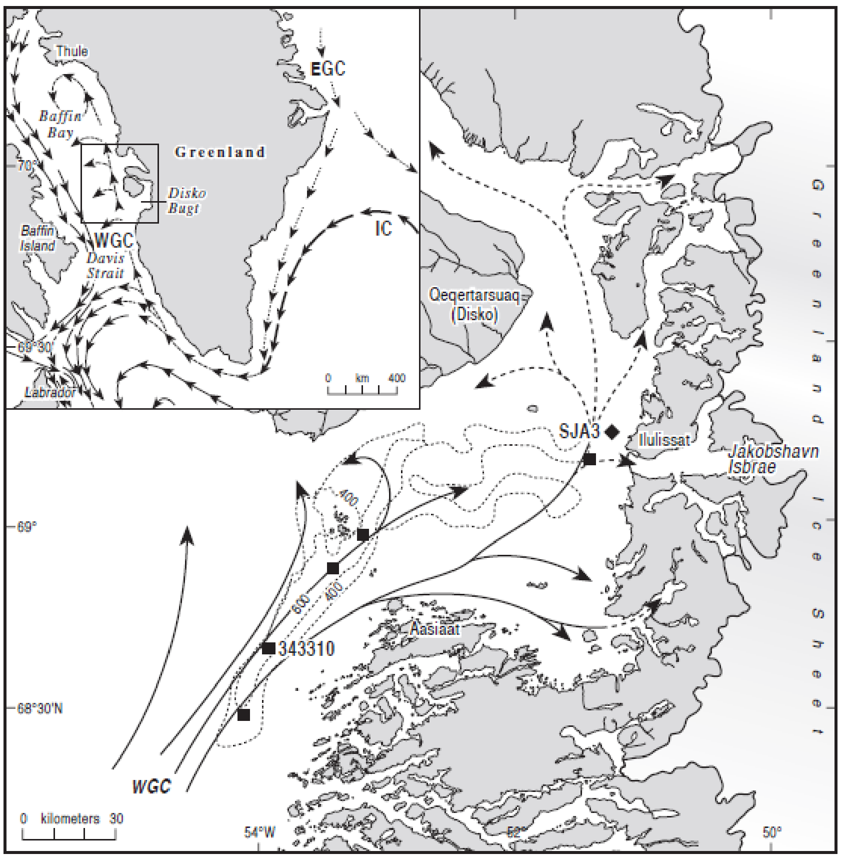
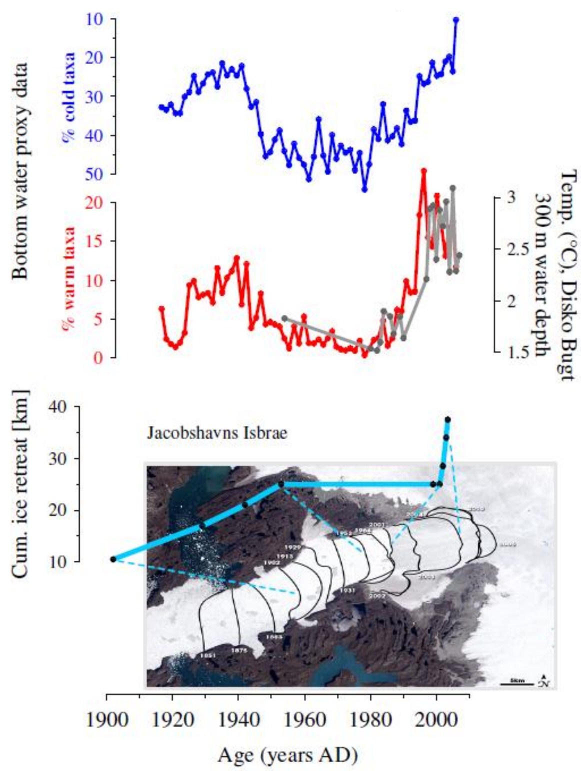
Subsurface water by Disko Bay



Lloyd et al. 2011

Subsurface water by Disko Bay

Bottom-living foraminifera



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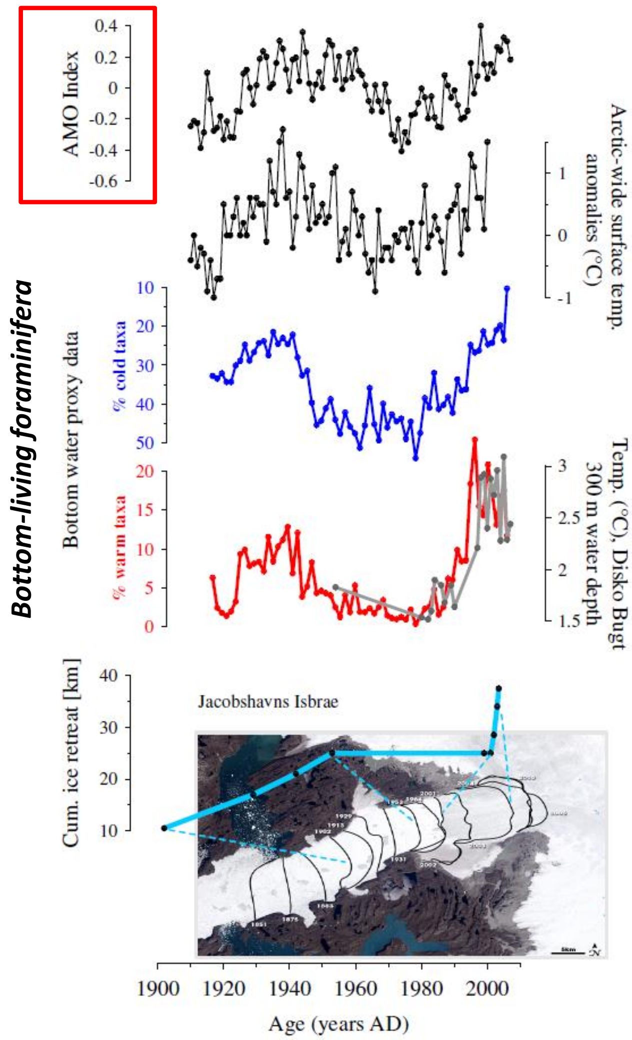

Lloyd et al. 2011

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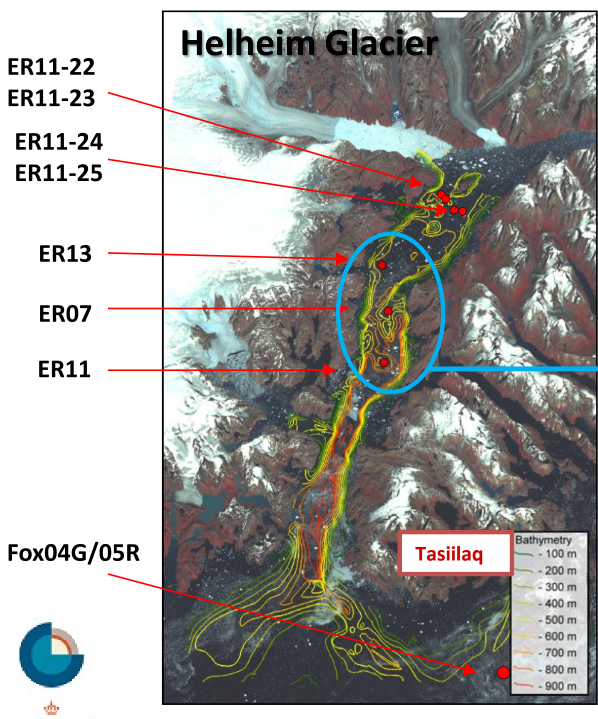
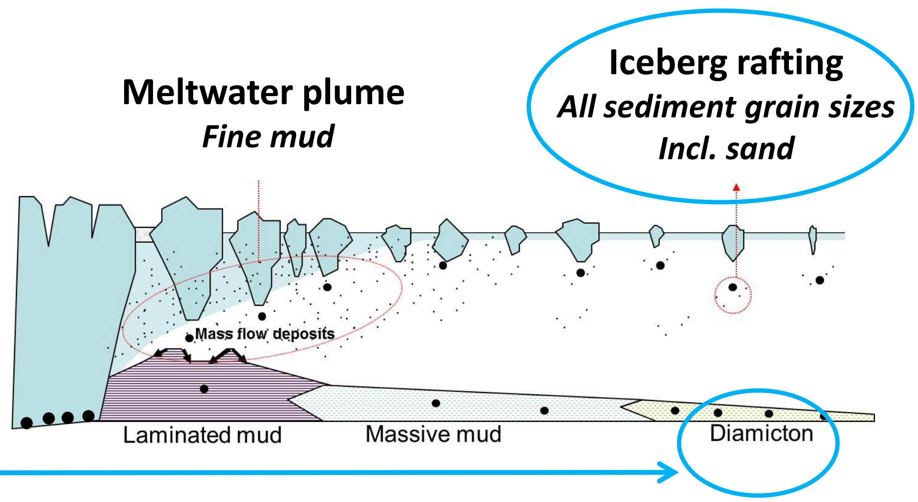
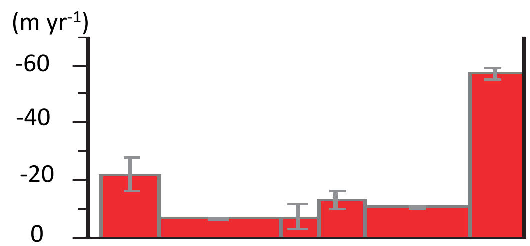
Constructing a calving record for Helheim Glacier





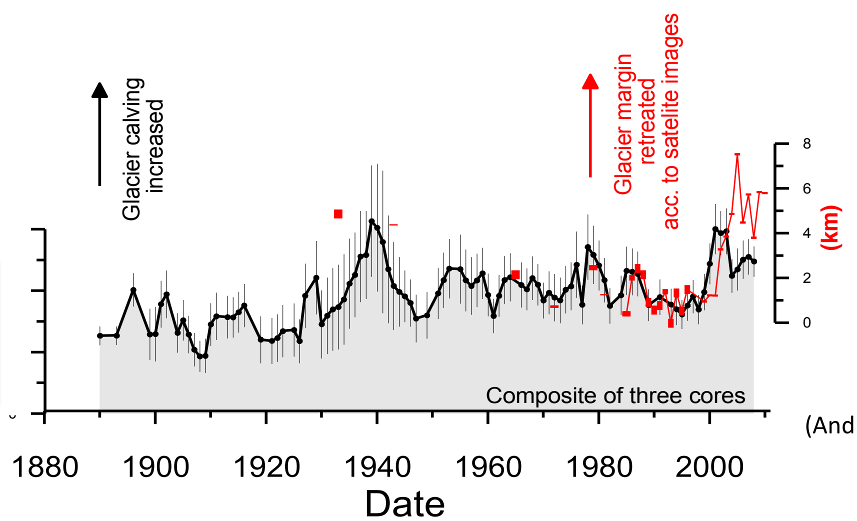
Constructing a calving record for Helheim Glacier

↑ **Retreat rate from marine-terminating glaciers in southeast Greenland increases**



(Bjørk et al. 2012)

↑ **Calving from Helheim Glacier increases**



(Andresen et al. 2012)

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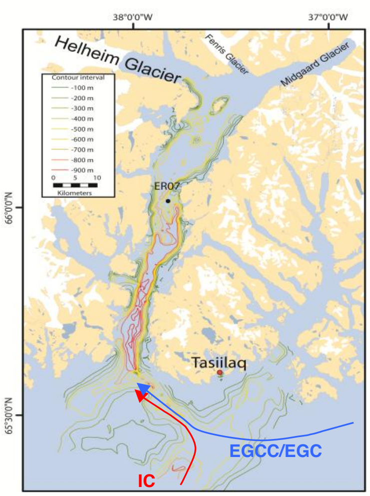
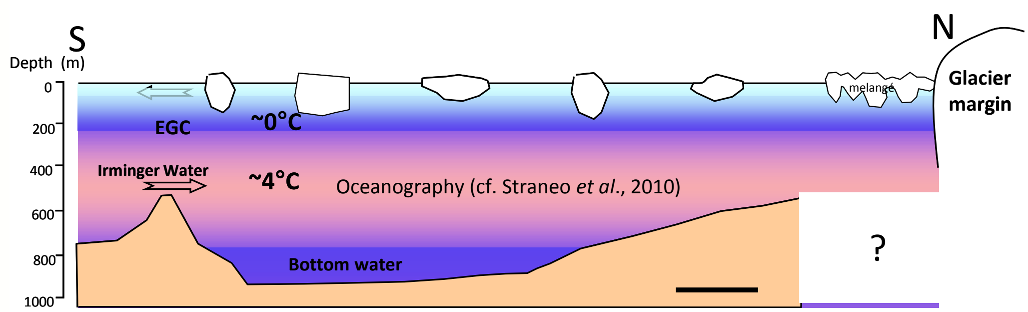
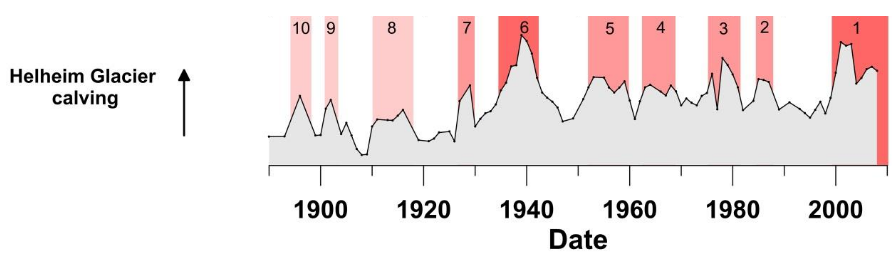
Comparing the calving record with climate indices







(Andresen et al. 2012)

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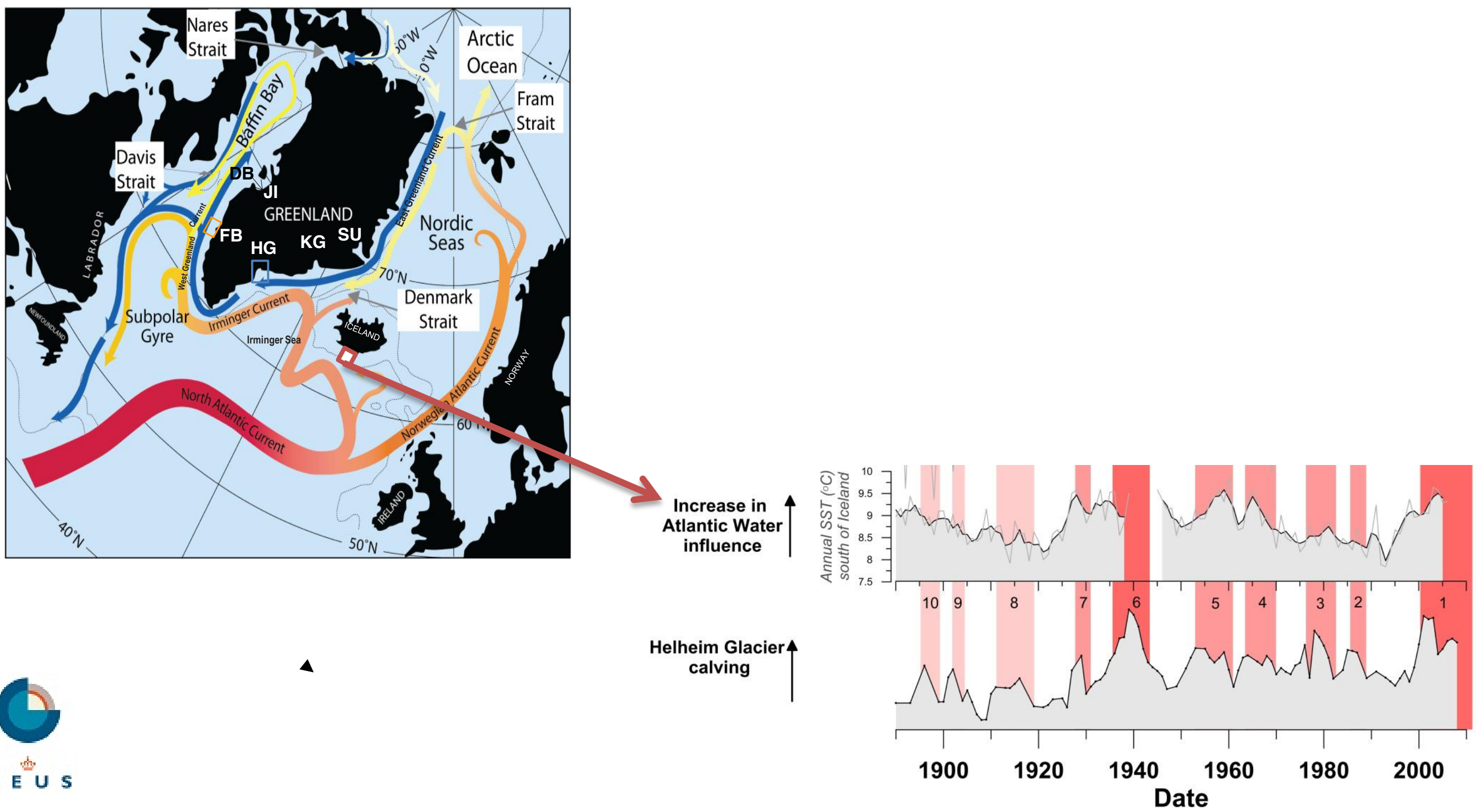

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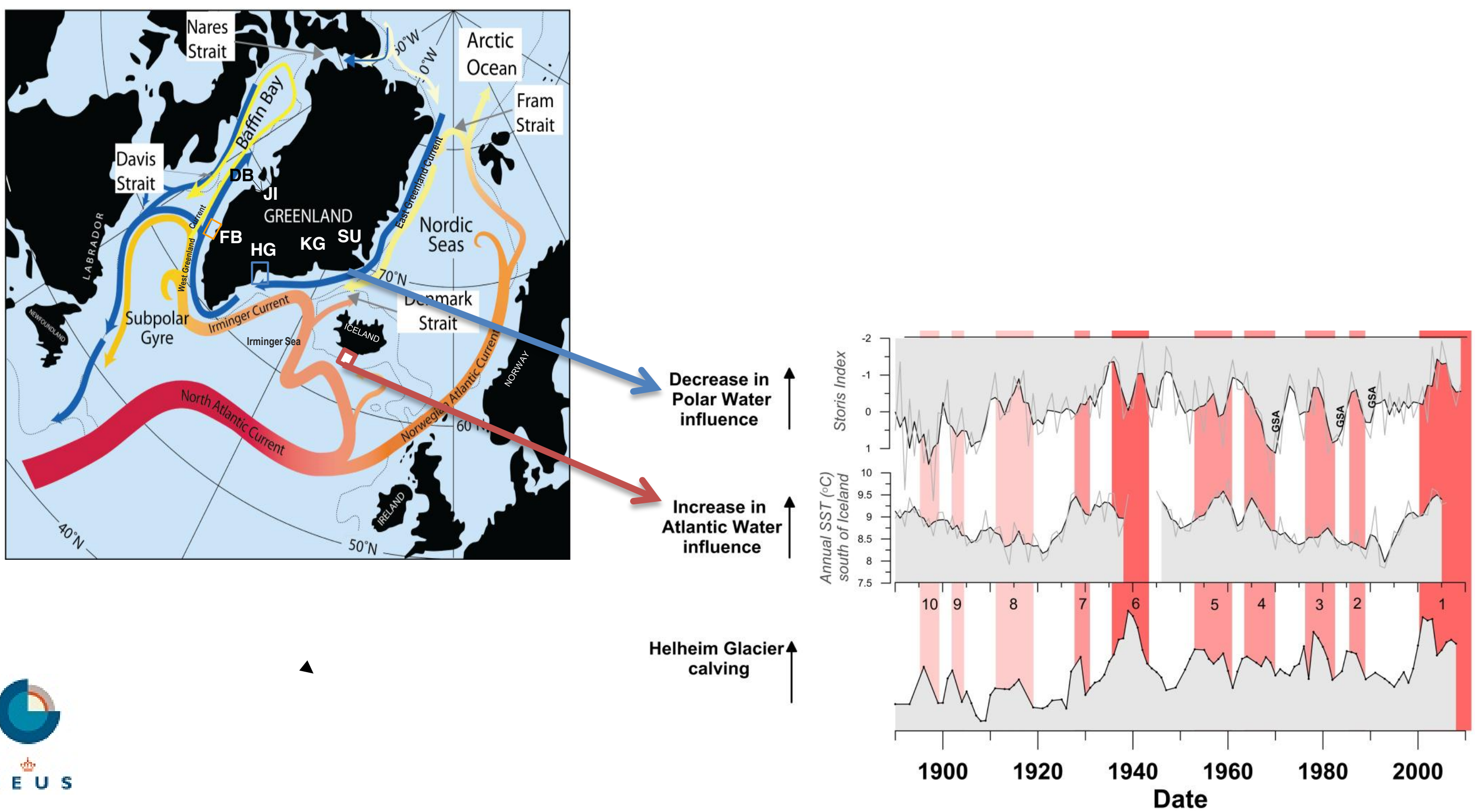

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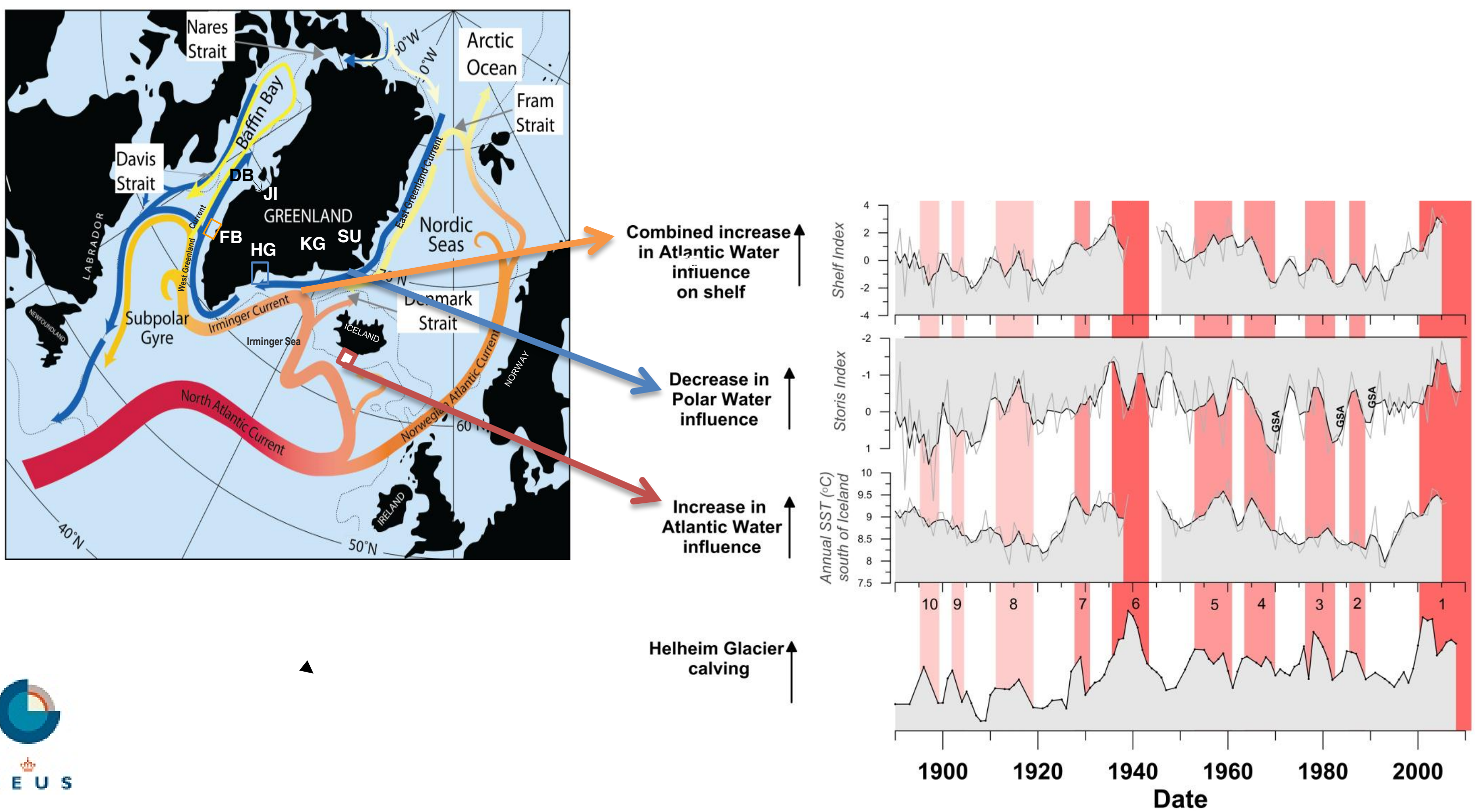

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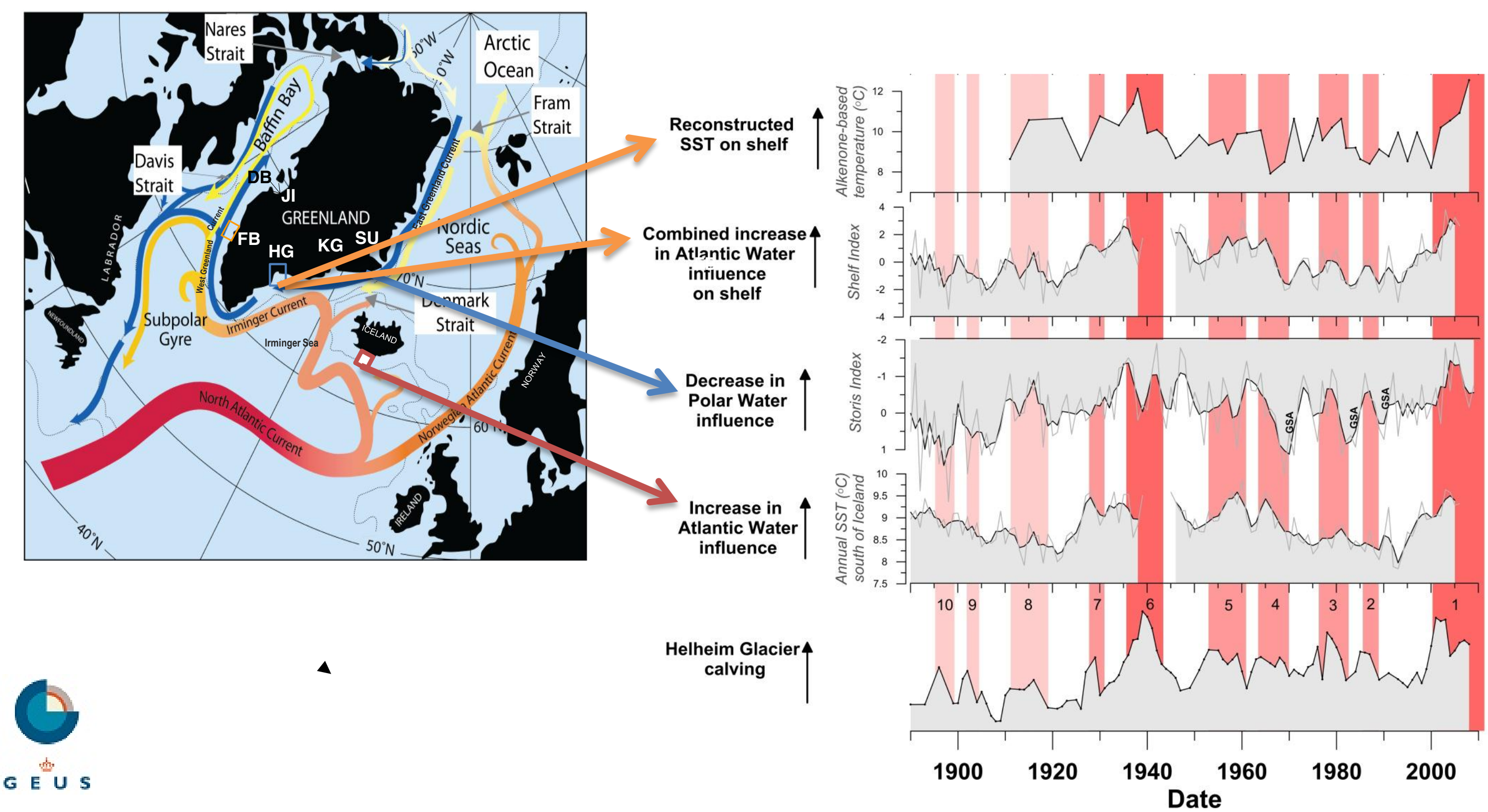

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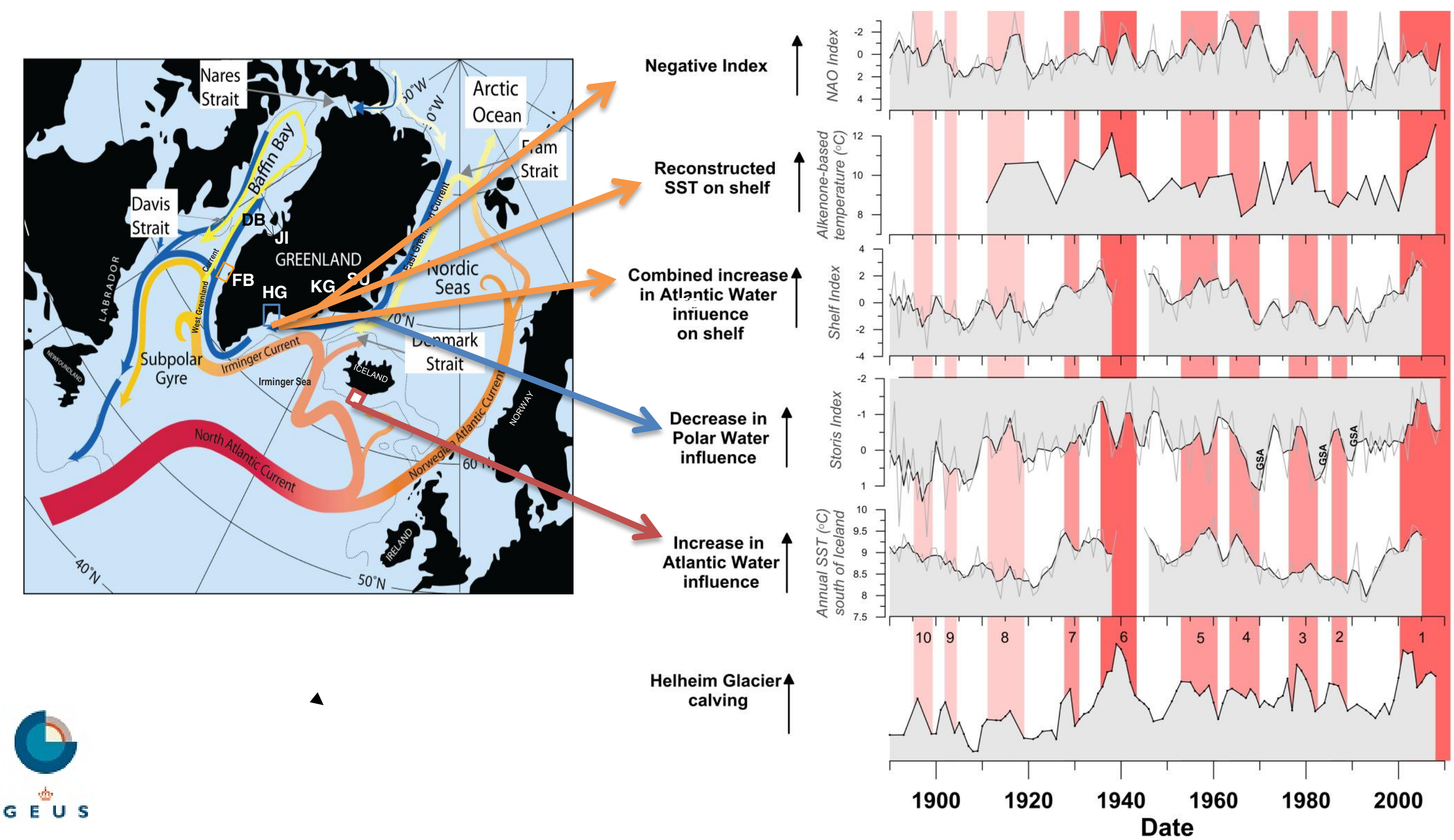

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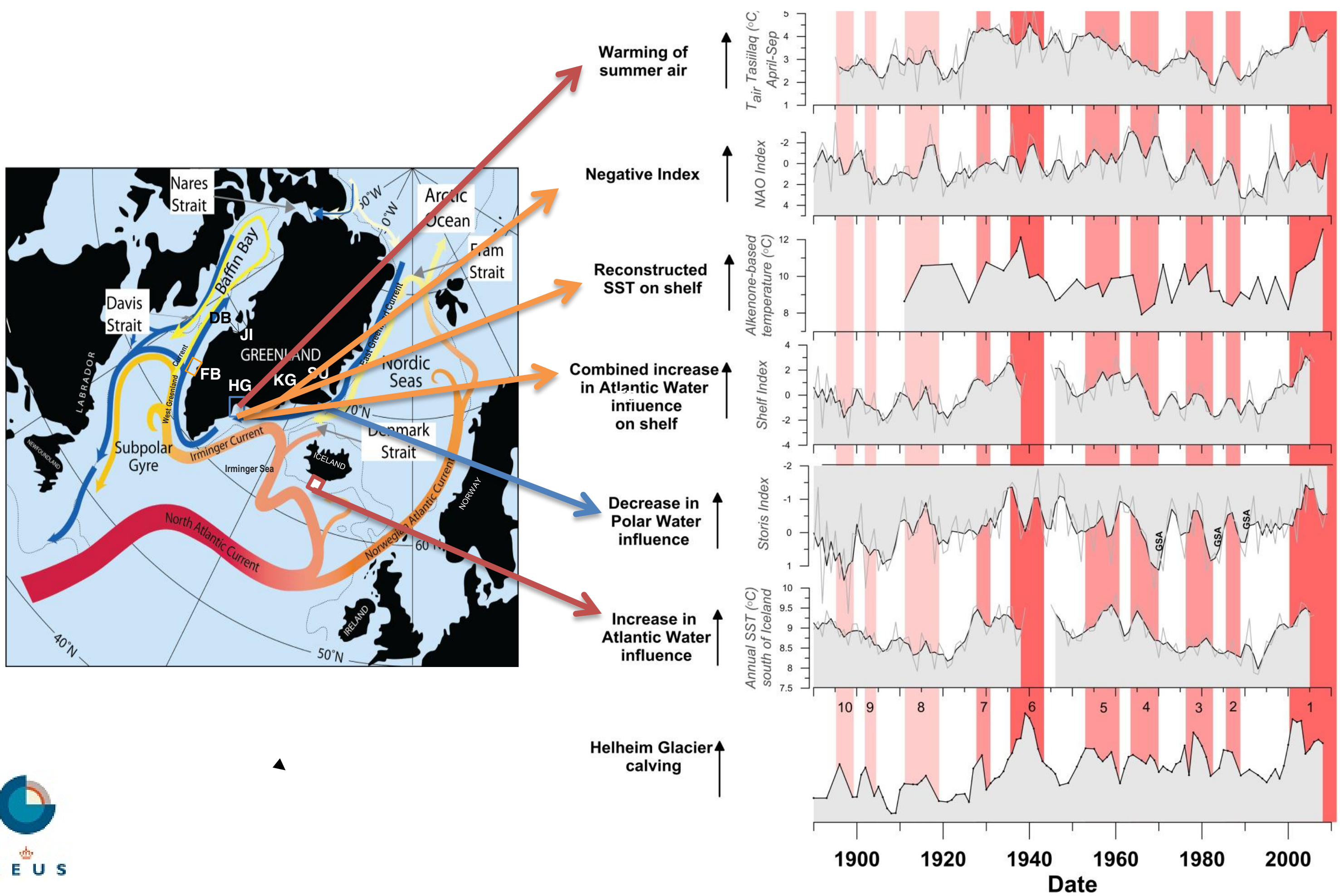

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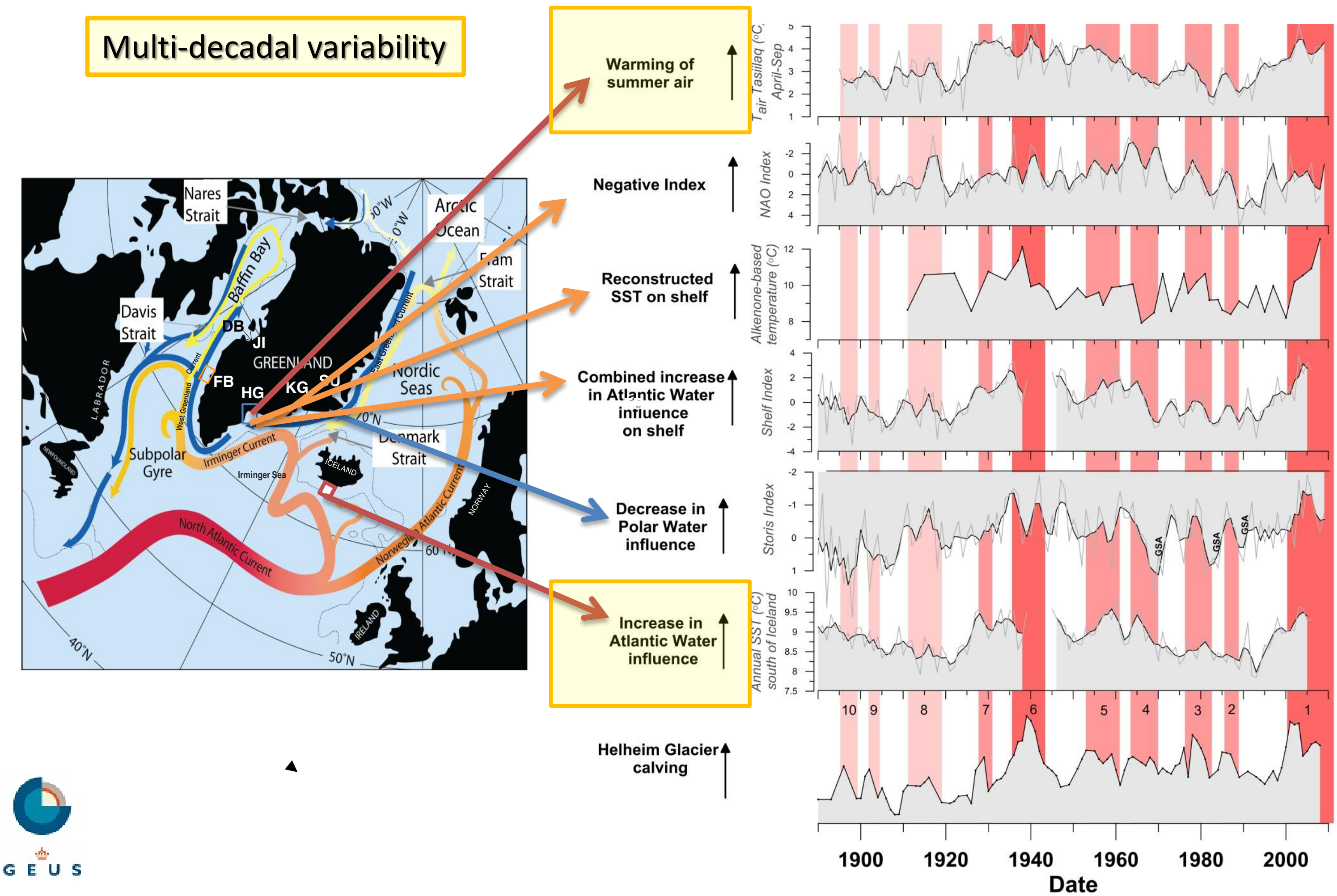
Comparing the calving record with climate indices

Multi-decadal variability



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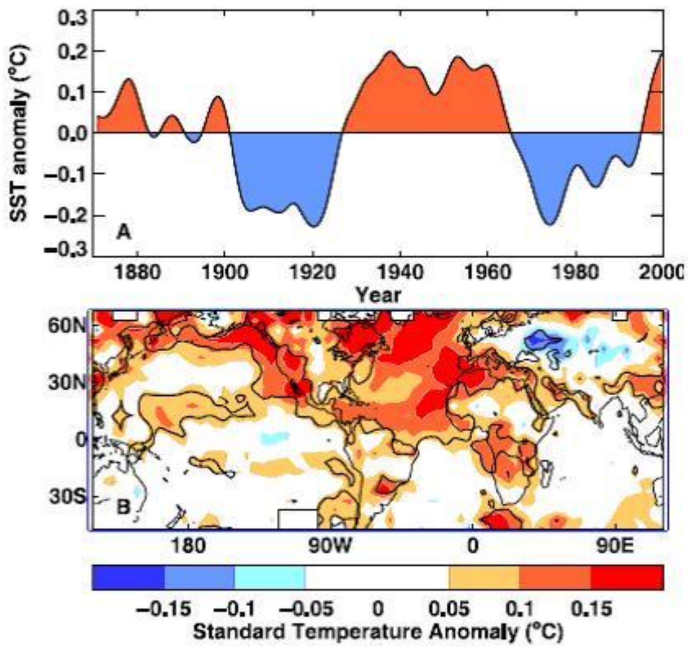
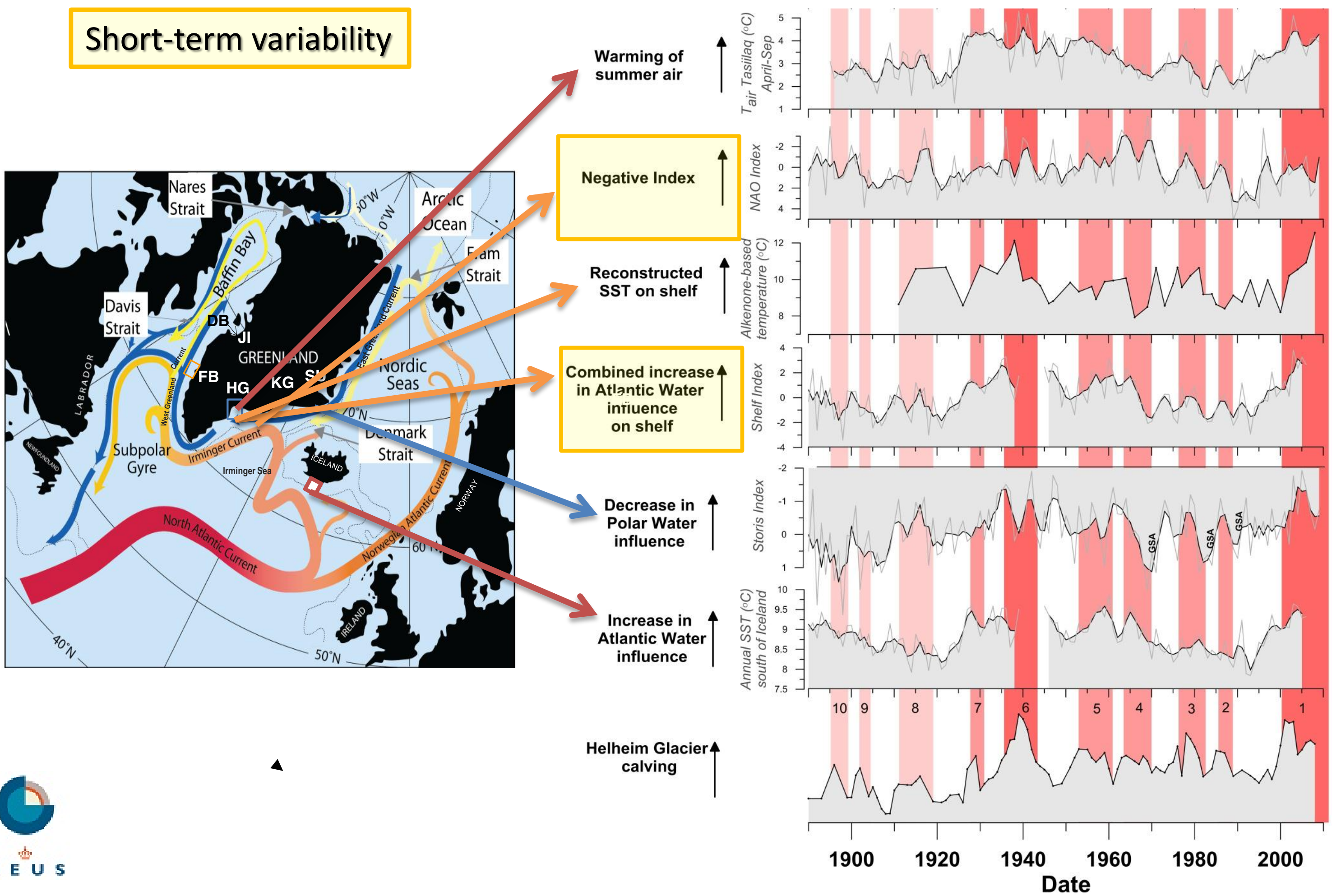
AMO
Atlantic Multidecadal Oscillation



(From Knight *et al.,* 2005)

Comparing the calving record with climate indices



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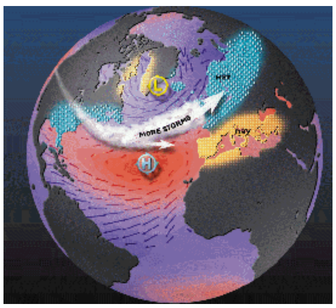
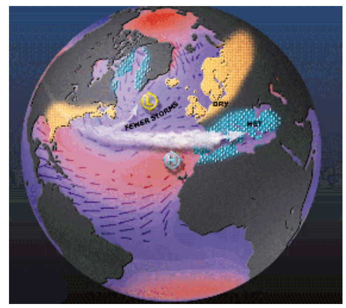
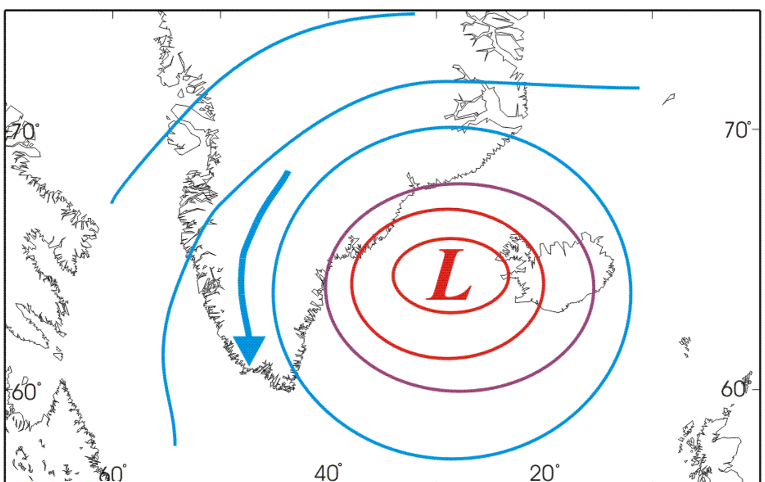
North Atlantic Oscillation

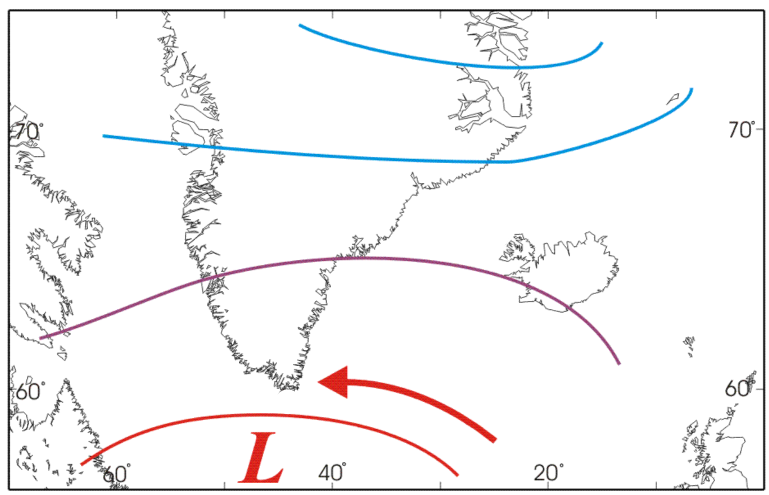


Positive index



Negative index





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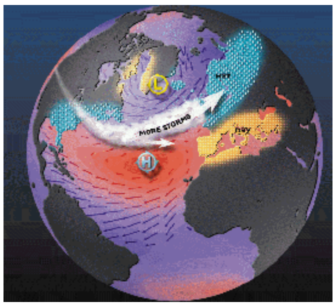

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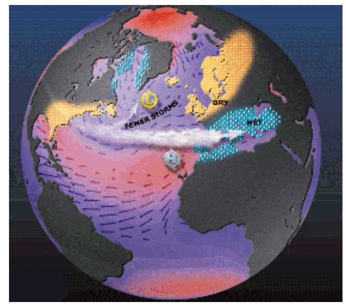

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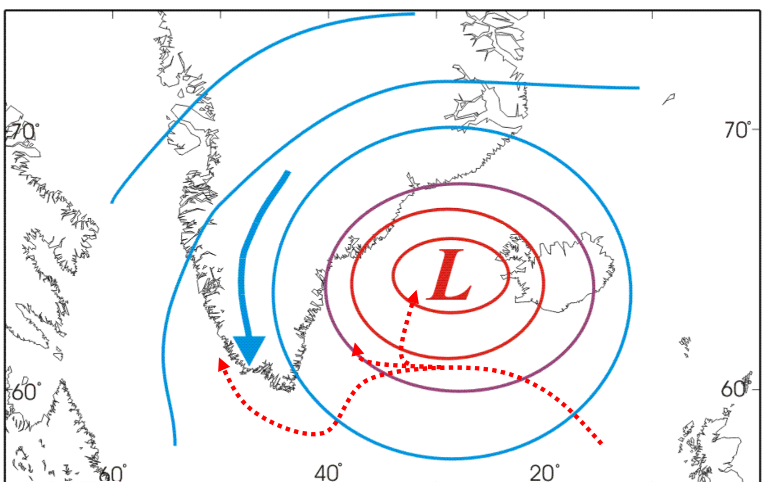

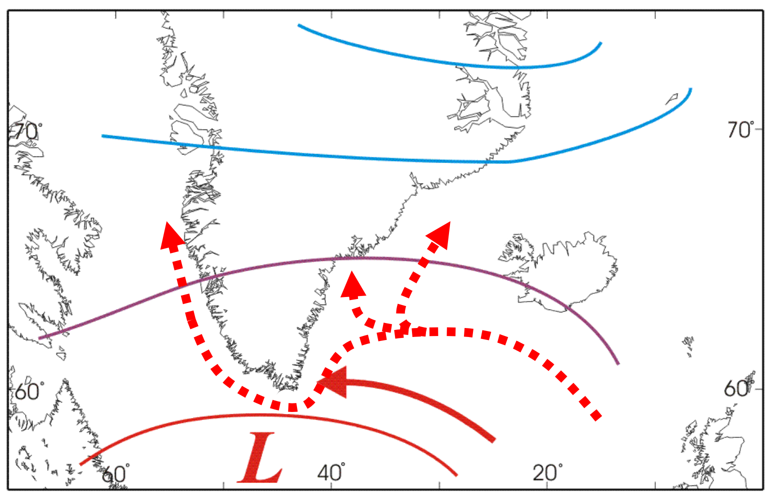

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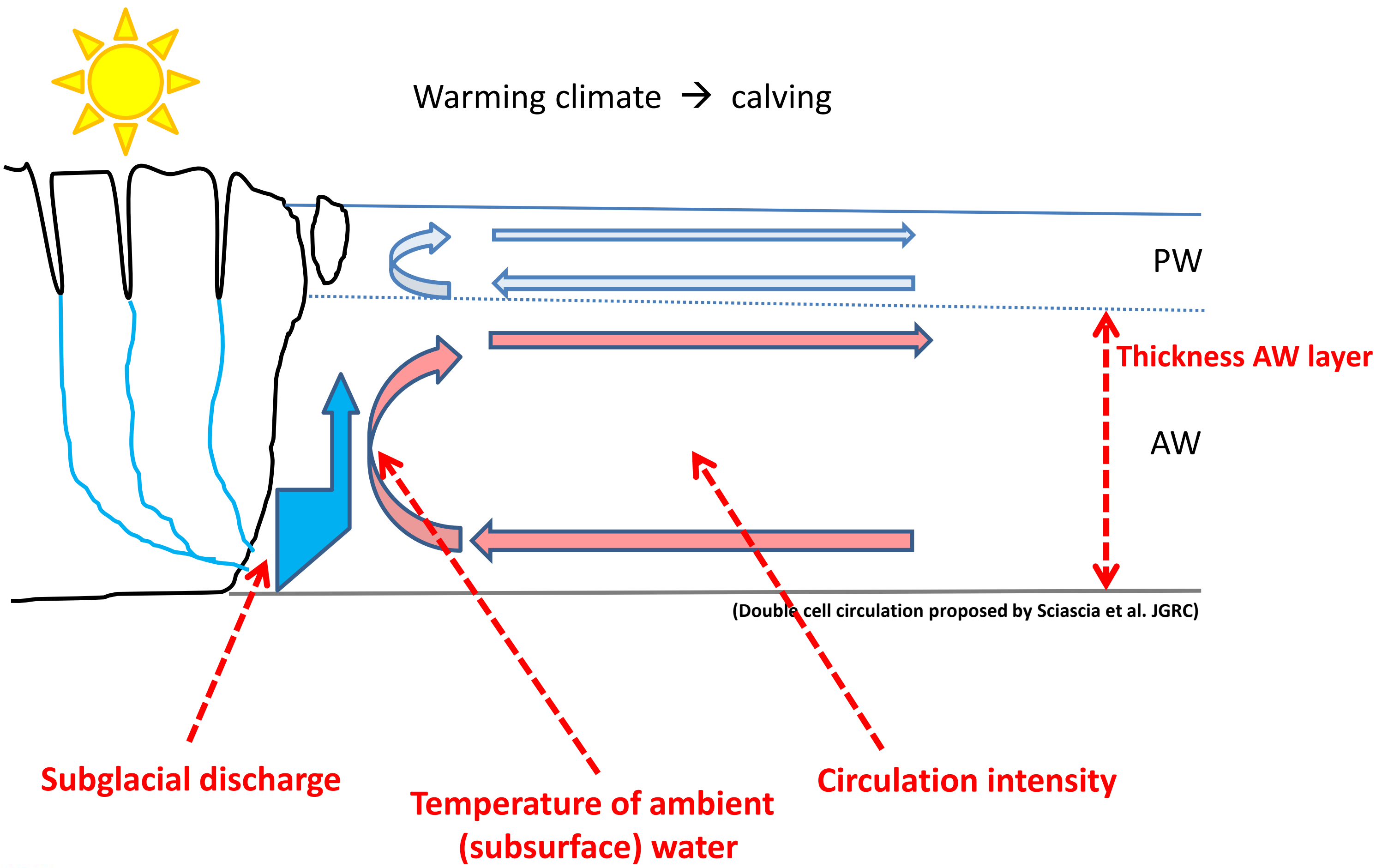
Warming climate → calving
PW
Thickness AW layer
AW
(Double cell circulation proposed by Sciascia et al. JGRC)
Subglacial discharge
Temperature of ambient (subsurface) water
Circulation intensity

GEUS

Timing of instability of Jakobshavn Isbræ and Helheim Glacier concurs with:

- a positive Atlantic Multi-decadal Oscillation
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GEUS

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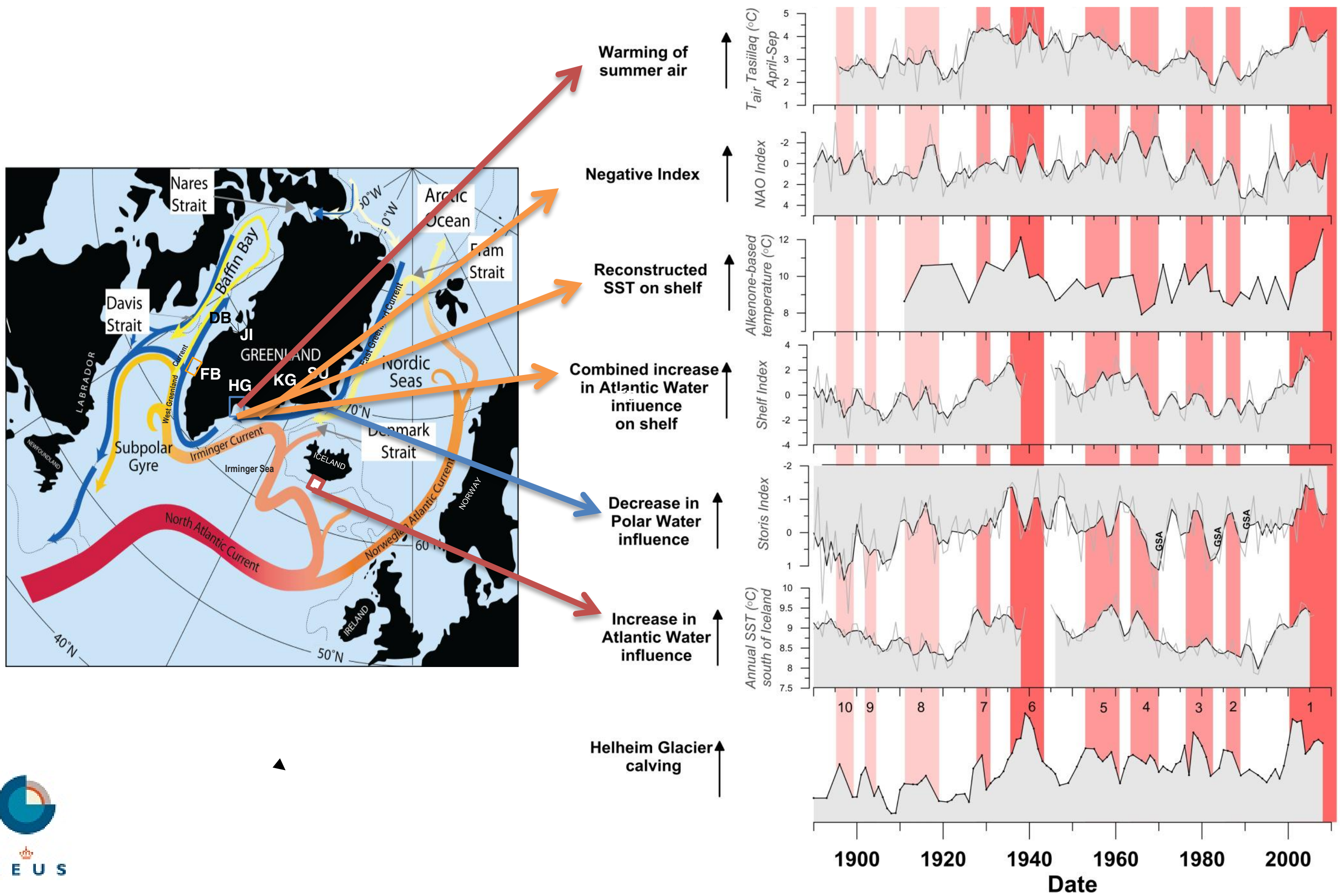
The late 1930s and early 2000s marked glacier retreats



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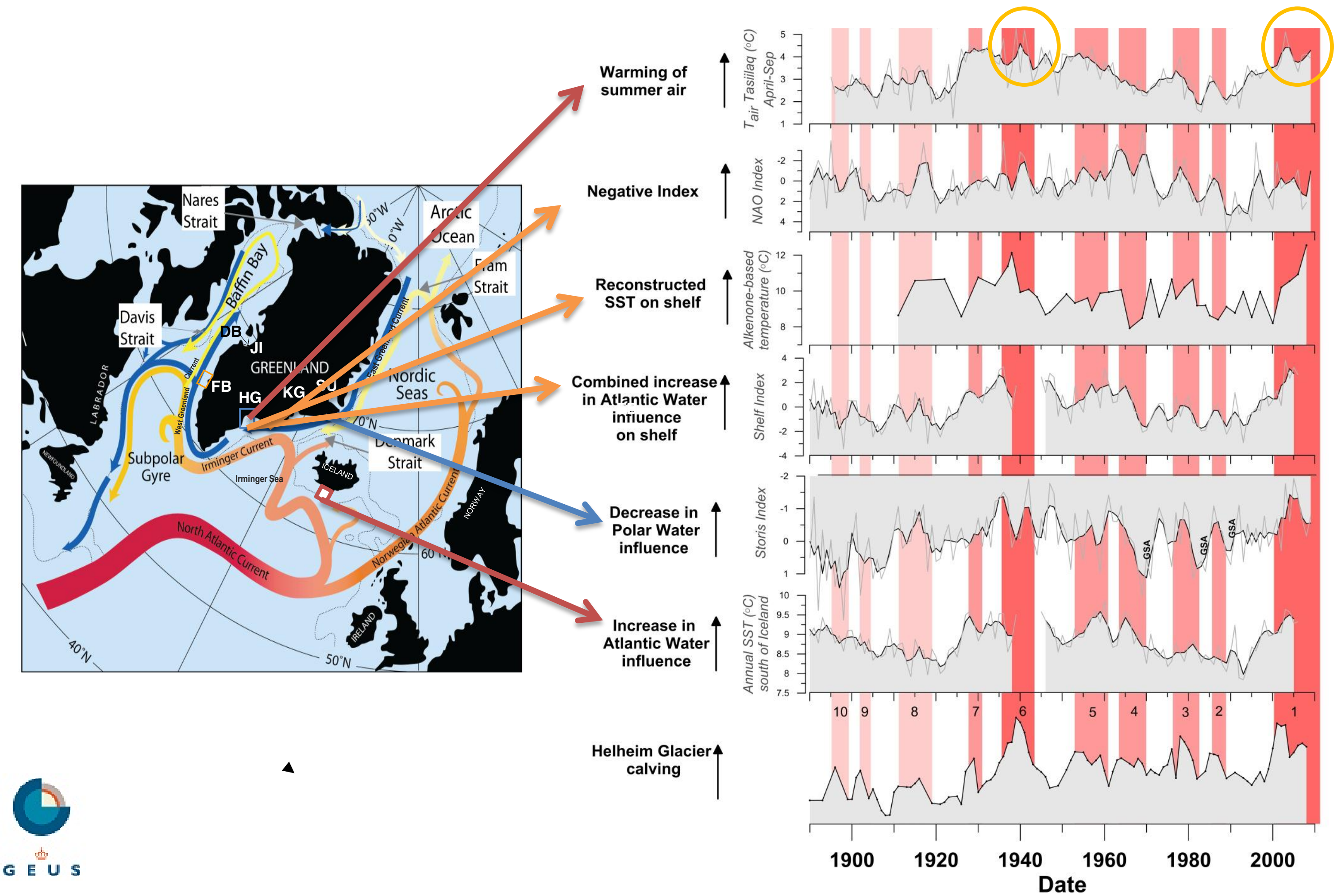

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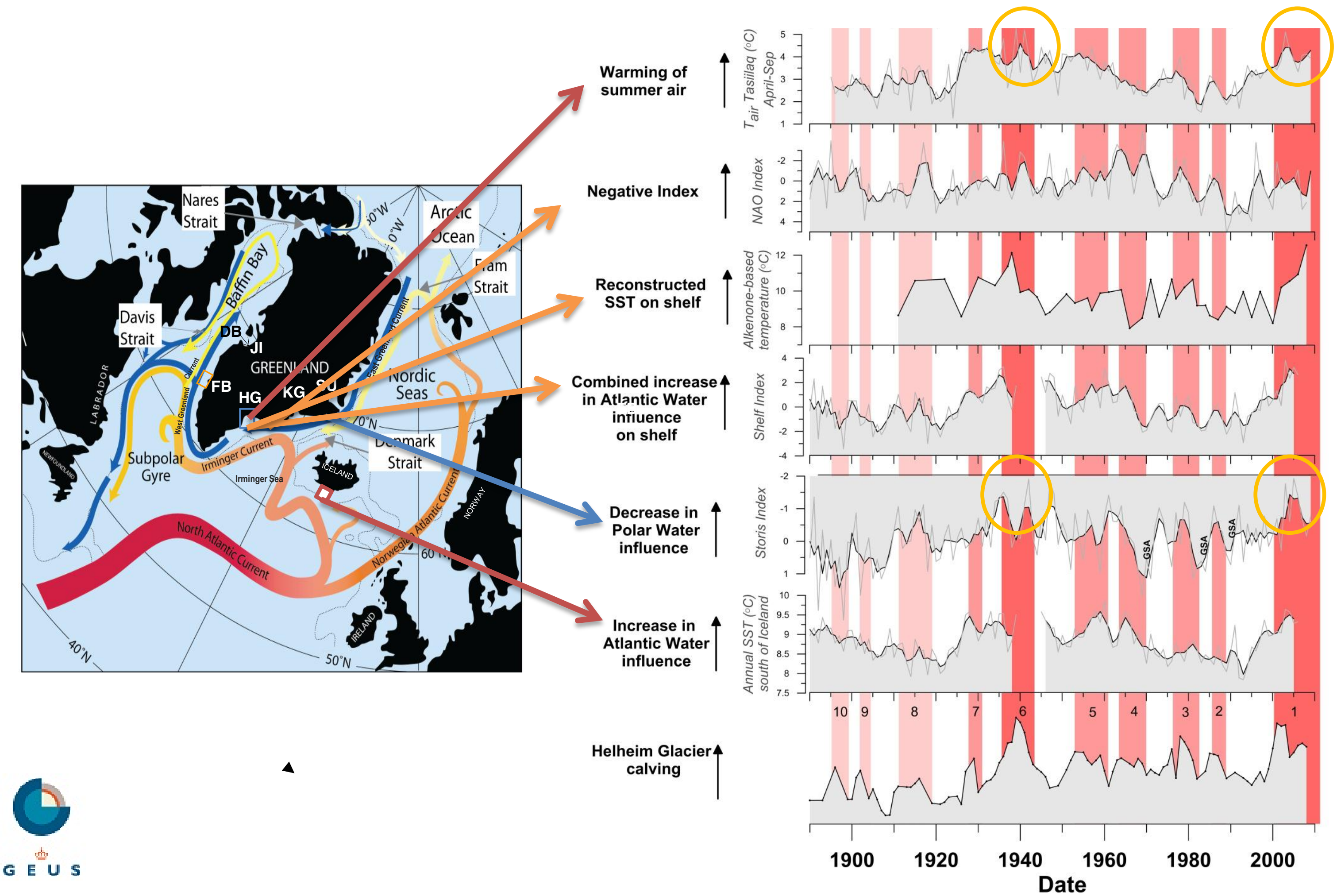

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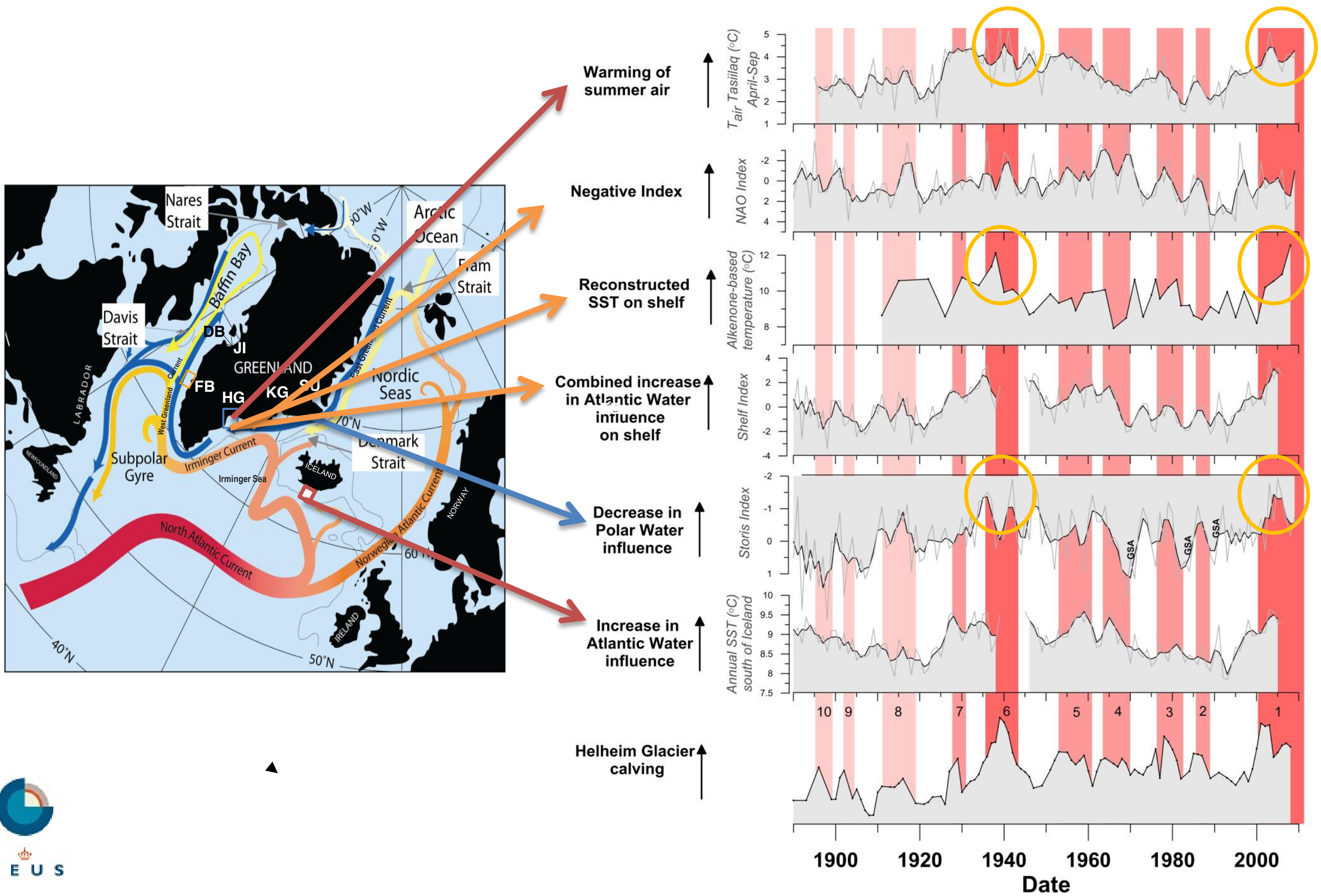

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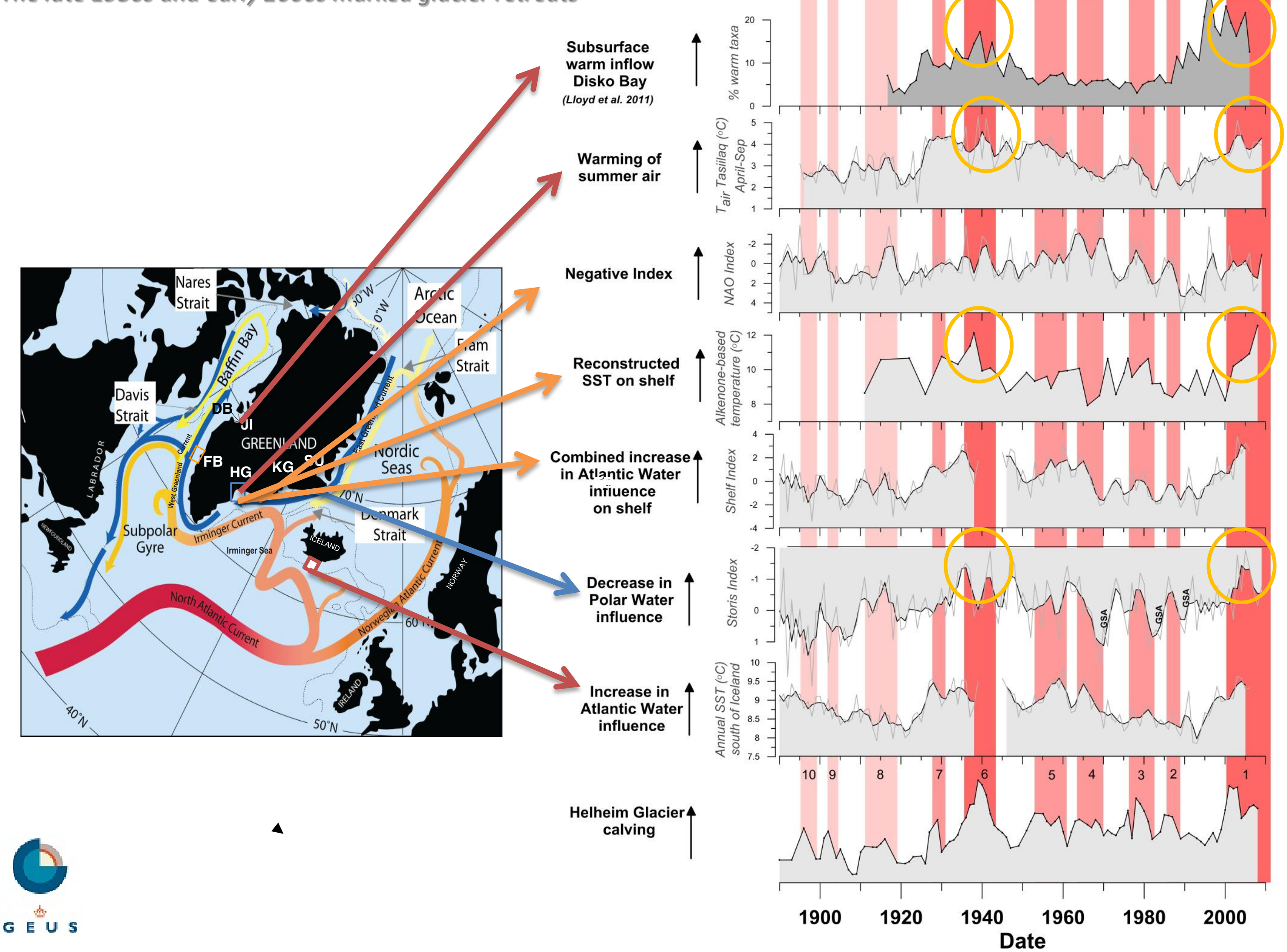

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The late 1930s and early 2000s episodes of marked glacier retreat of Jakobshavn Isbræ and Helheim Glacier may stand out due to the coincidence of:

Subsurface warming of the ocean around Greenland
Record low sea ice occurrence
Record warm summer air

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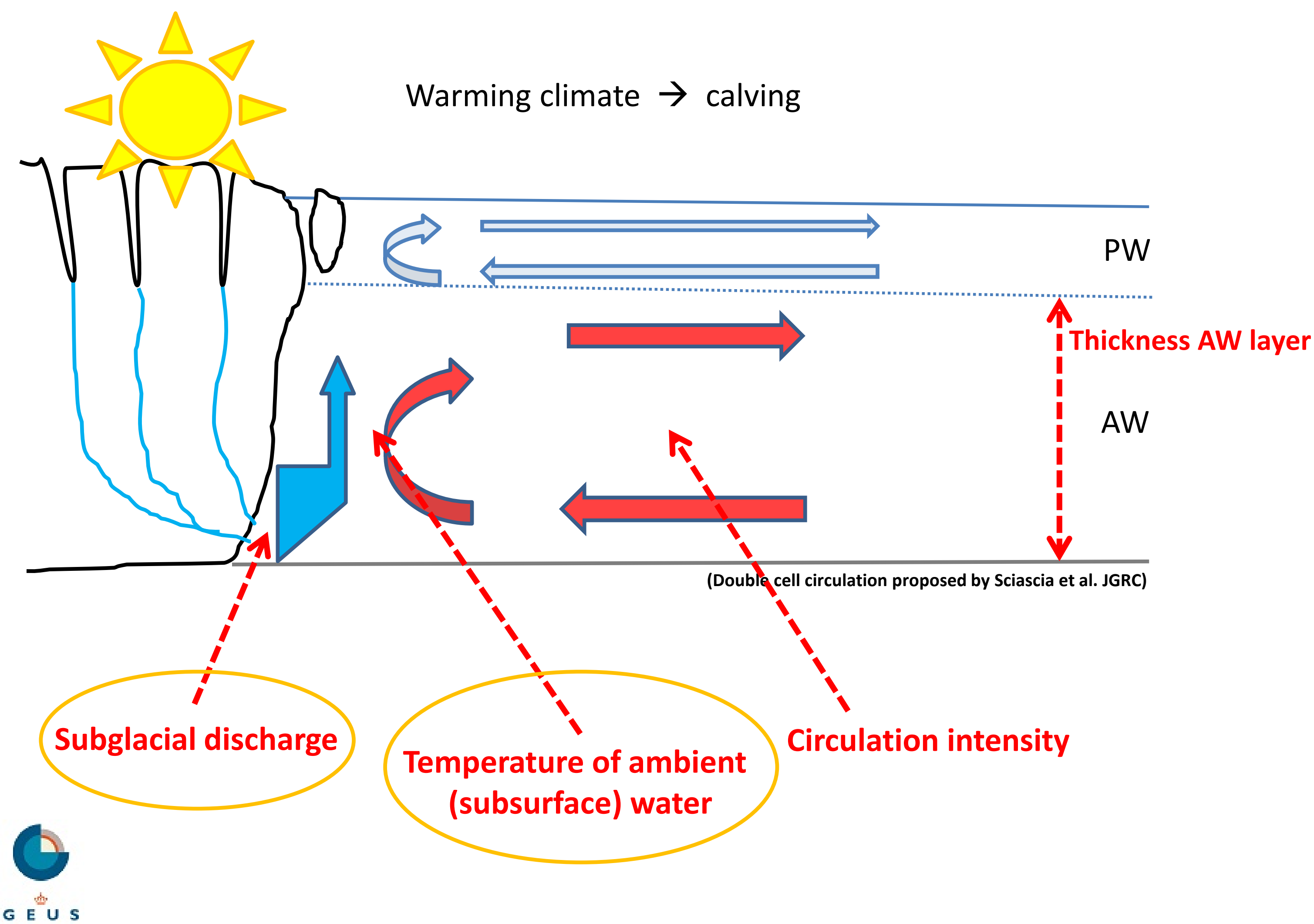
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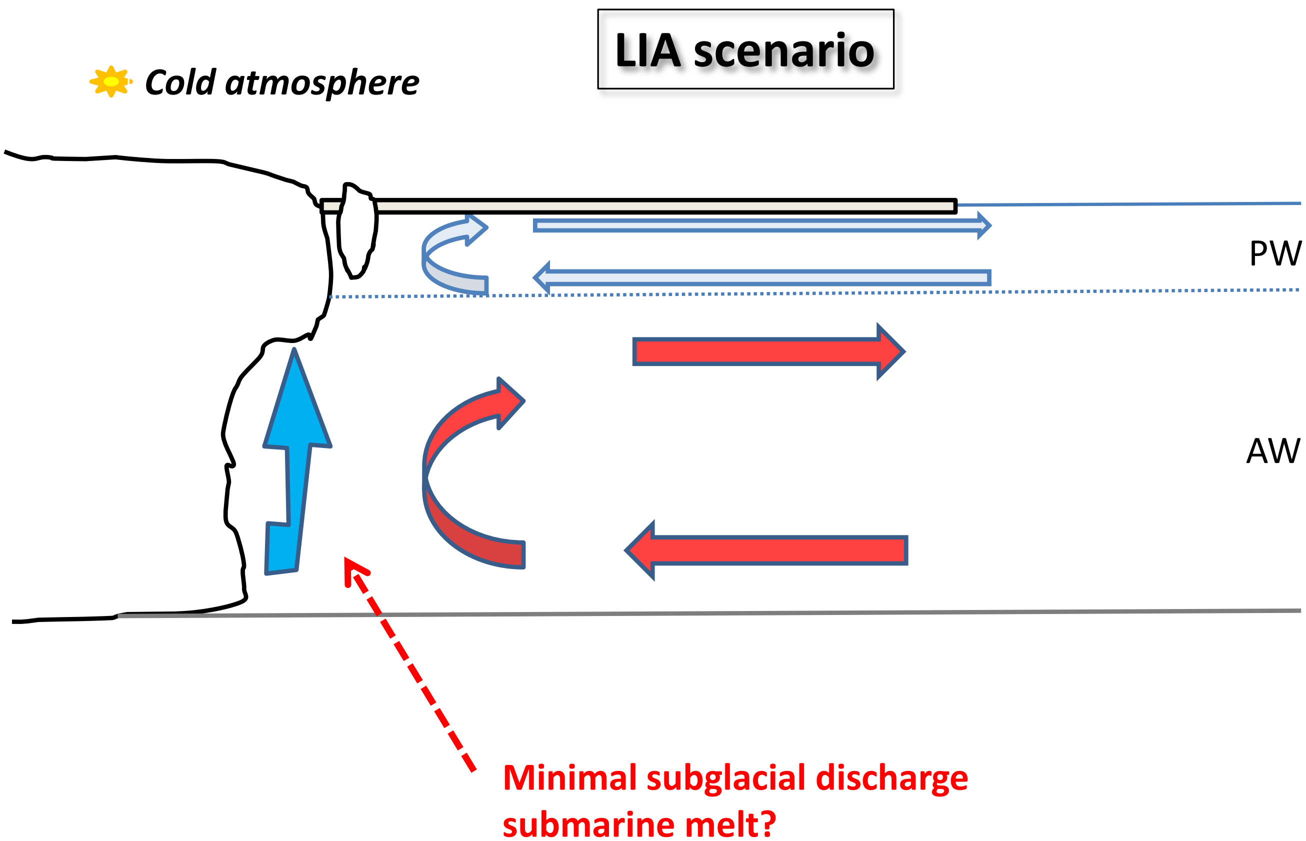
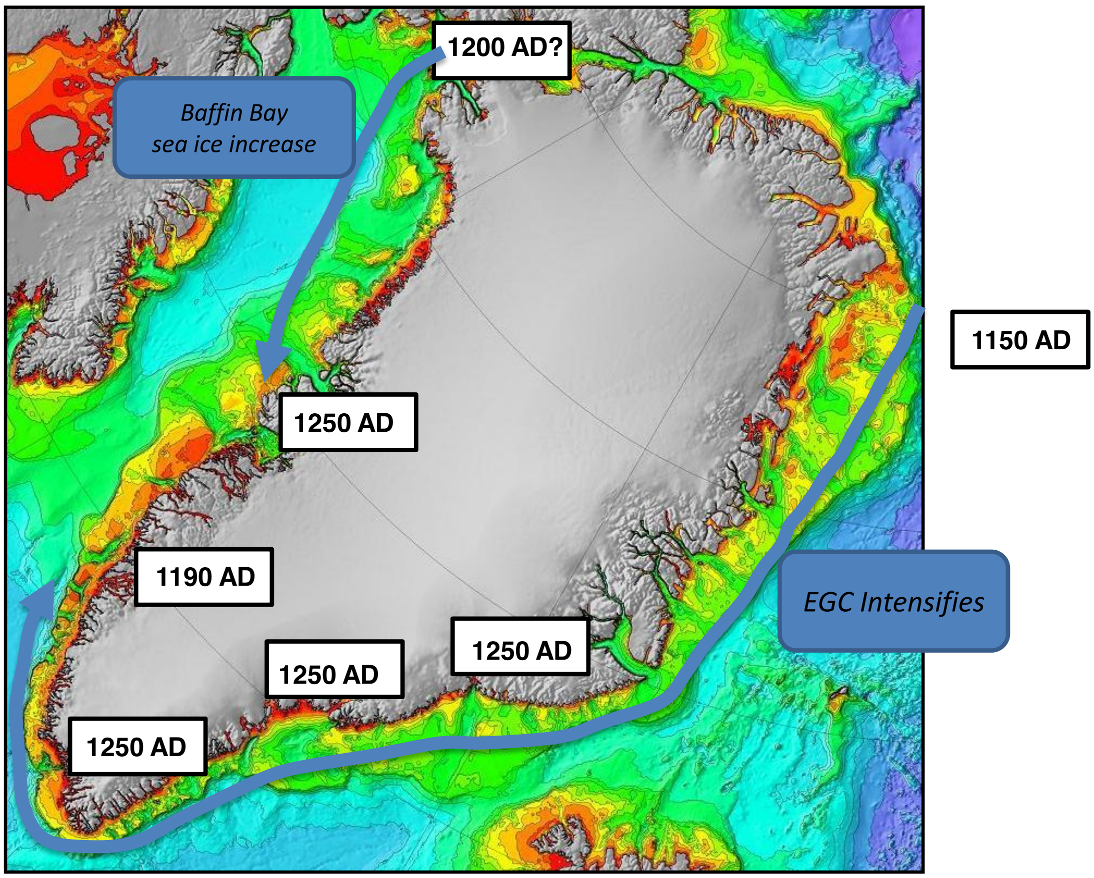
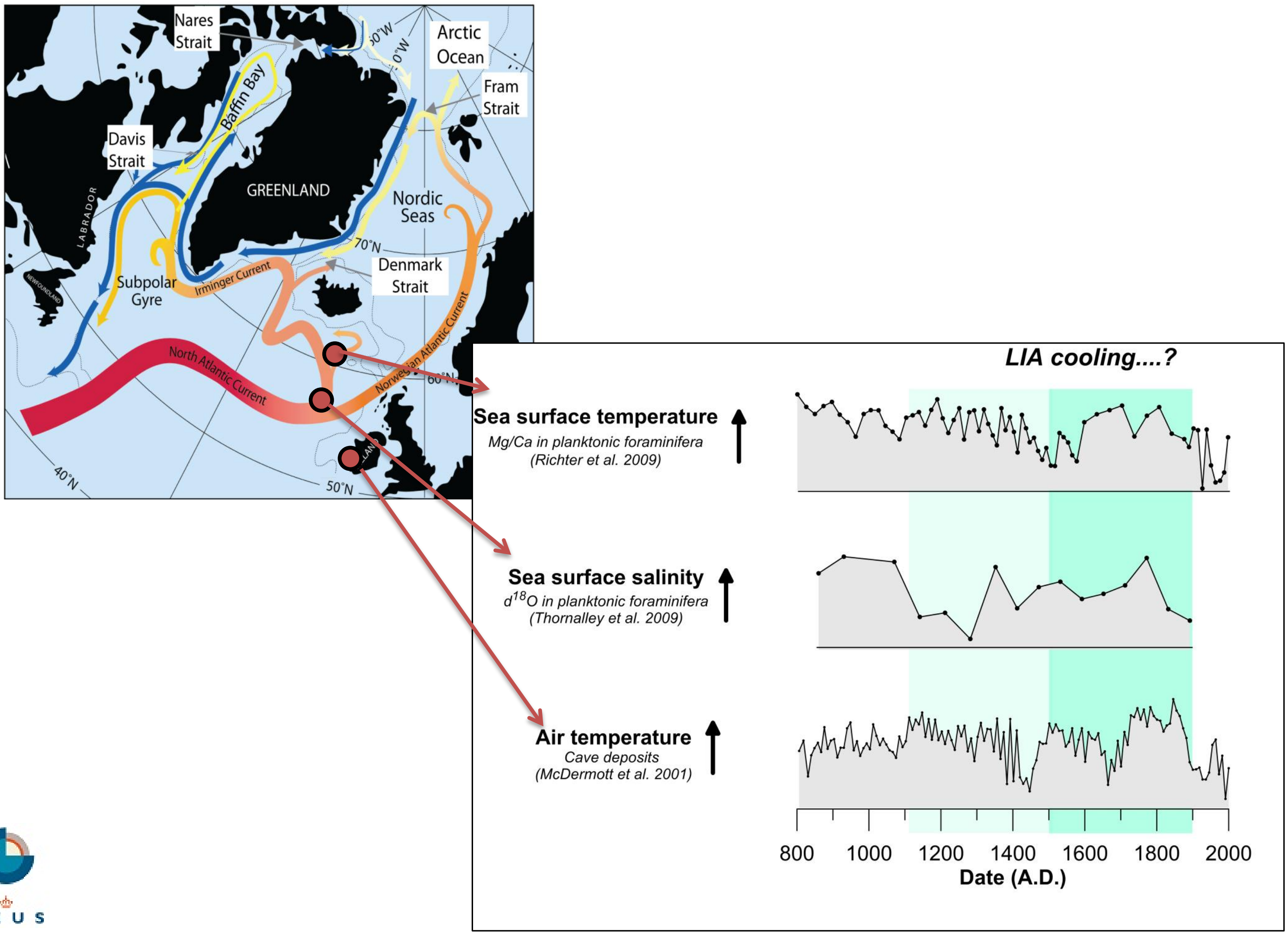

LIA scenario
Cold atmosphere
PW
AW
Minimal subglacial discharge
submarine melt?

Little Ice Age submarine melt

Onset LIA
Associated oceanographic change



Little Ice Age submarine melt



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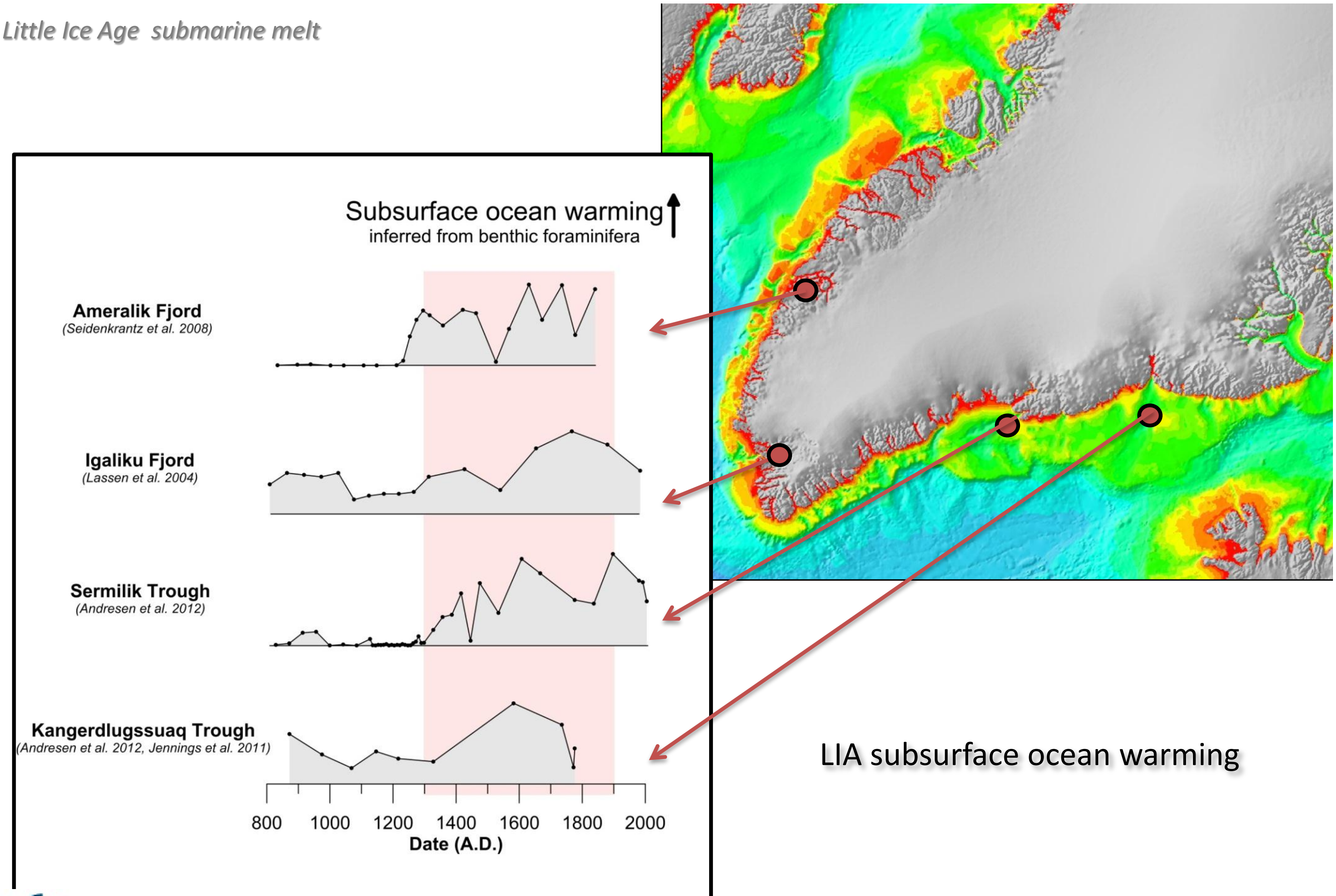
Little Ice Age submarine melt



LIA subsurface ocean warming

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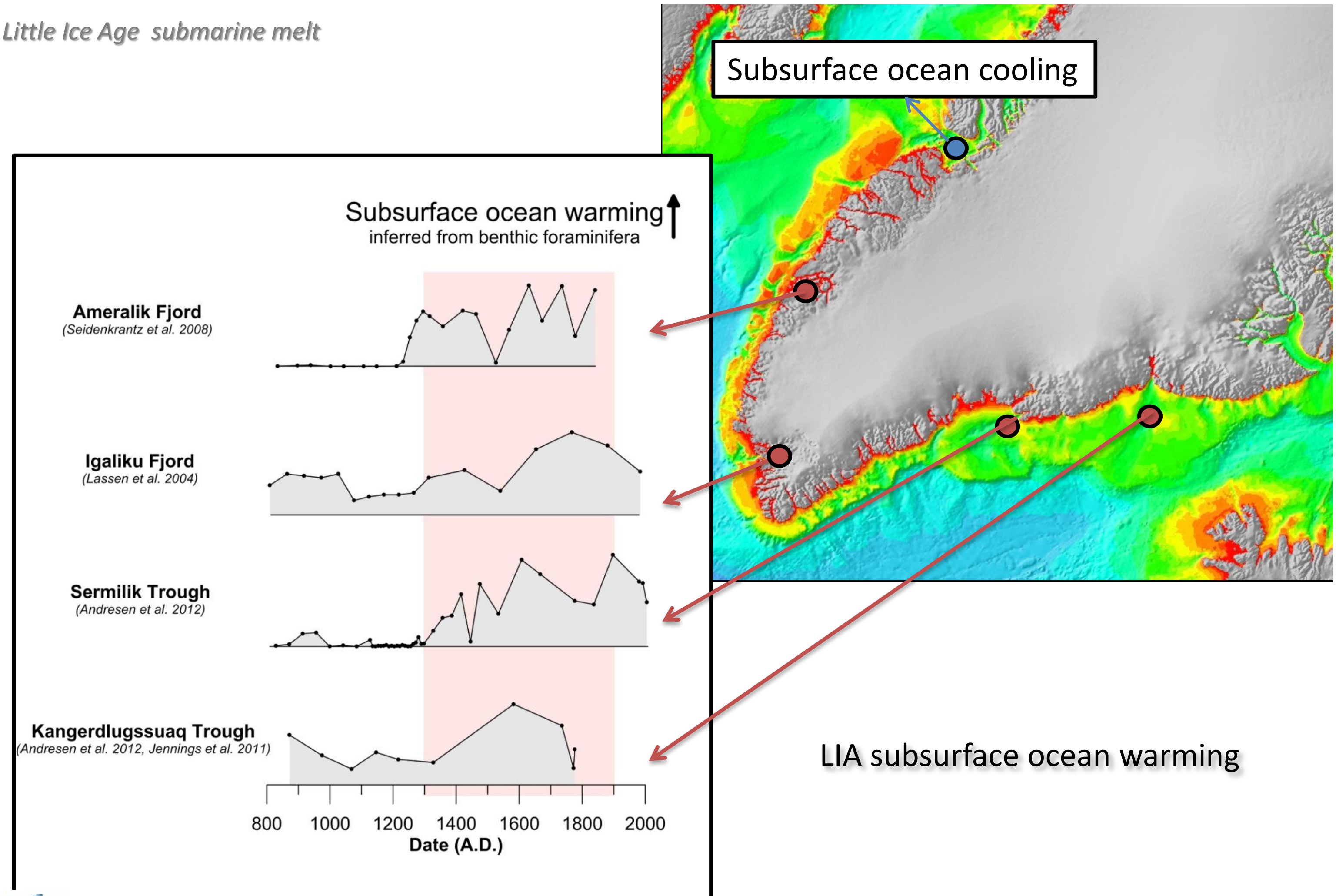
Little Ice Age submarine melt



LIA subsurface ocean warming

GEUS

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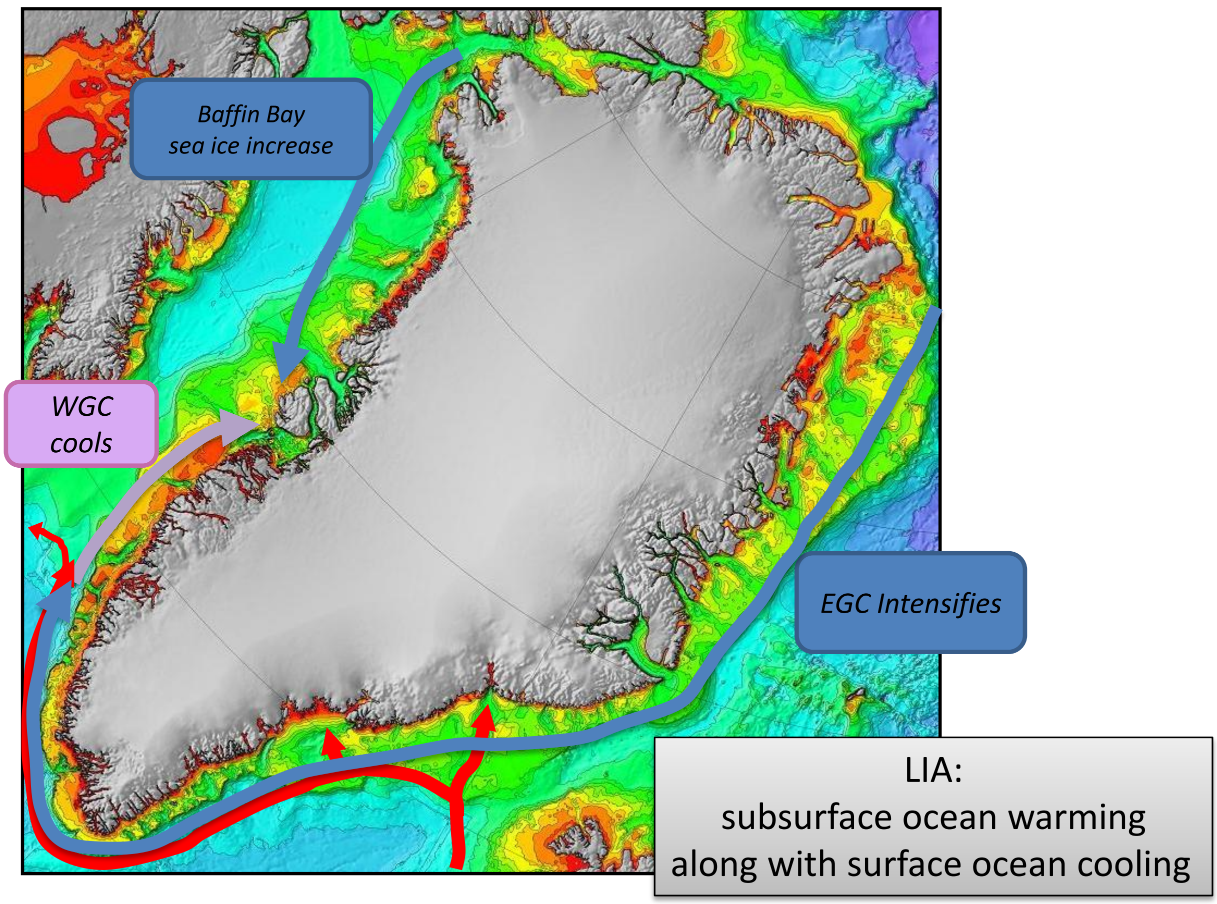

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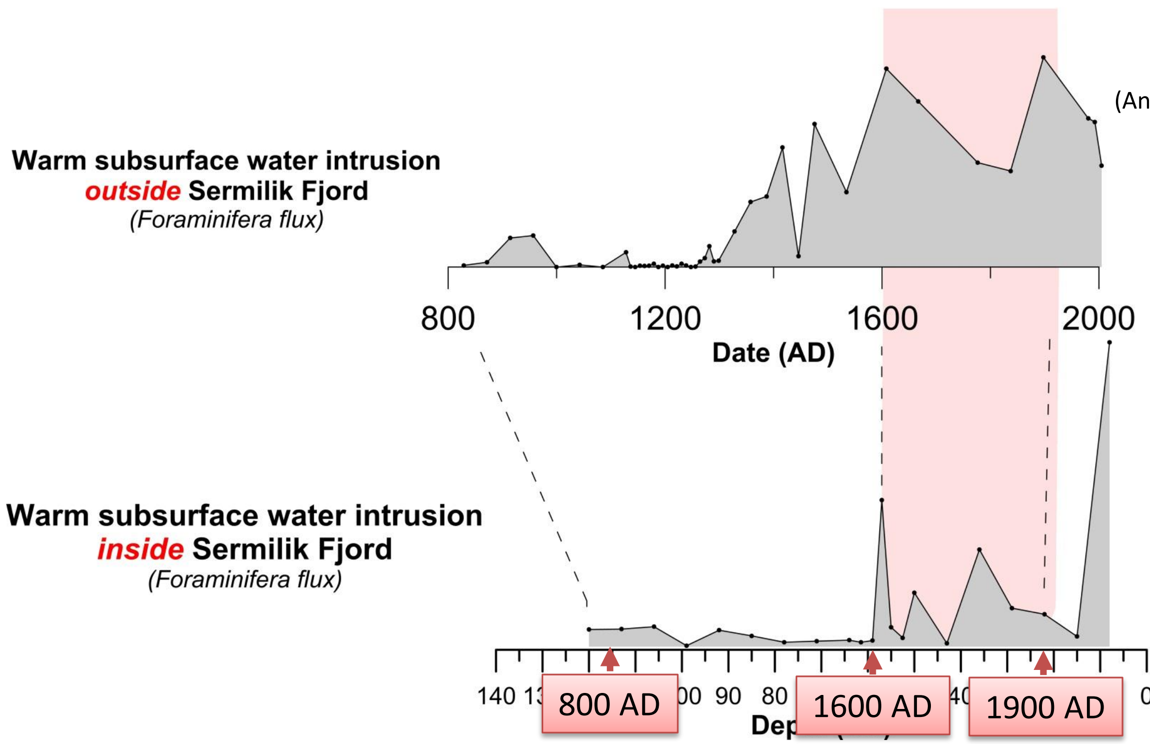
Little Ice Age submarine melt



(Andresen et al. 2013)

(Stoican et al. In prep)

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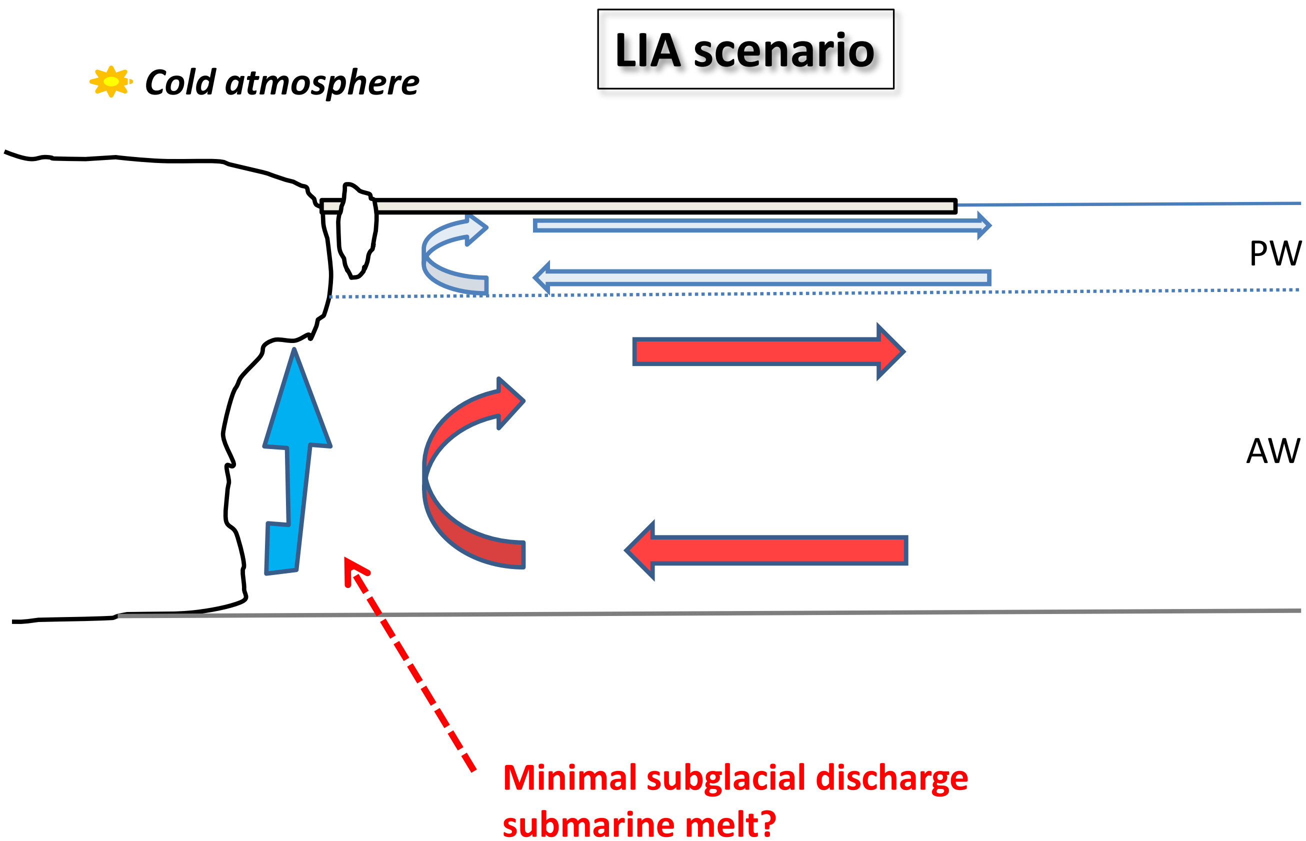
LIA scenario
Cold atmosphere
PW
AW
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submarine melt?

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What happened to the large outlet glaciers during the LIA?

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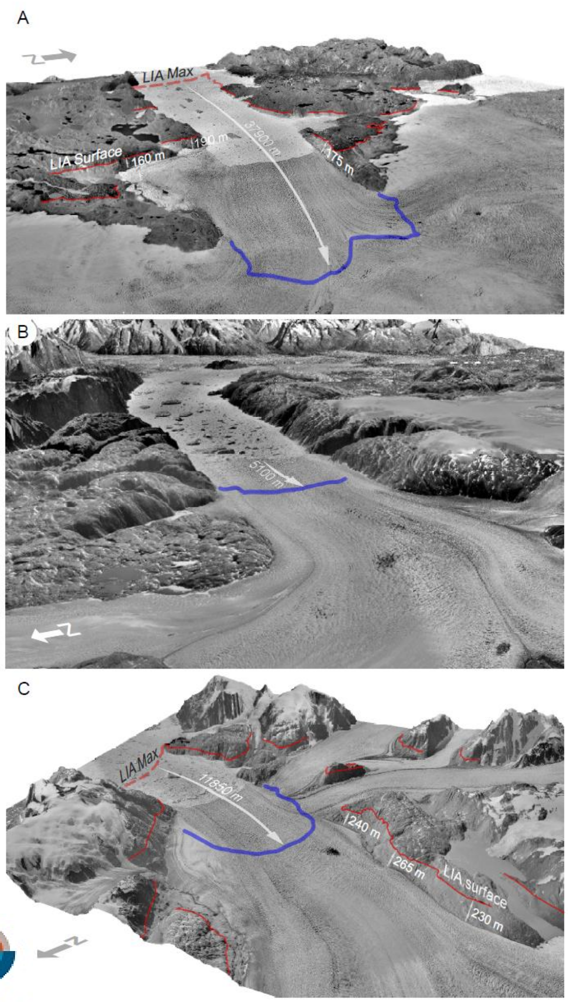
Little Ice Age submarine melt

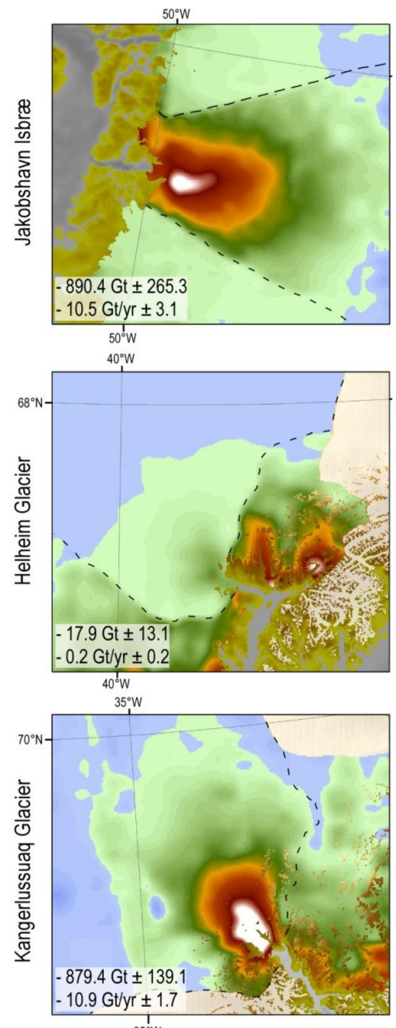
Mass loss since the LIA (1900 AD) untill 1980s



Jakobshavn Isbræ

Helheim Glacier

Kangerdlugssuaq Glacier



(Kjeldsen et al., submitted)

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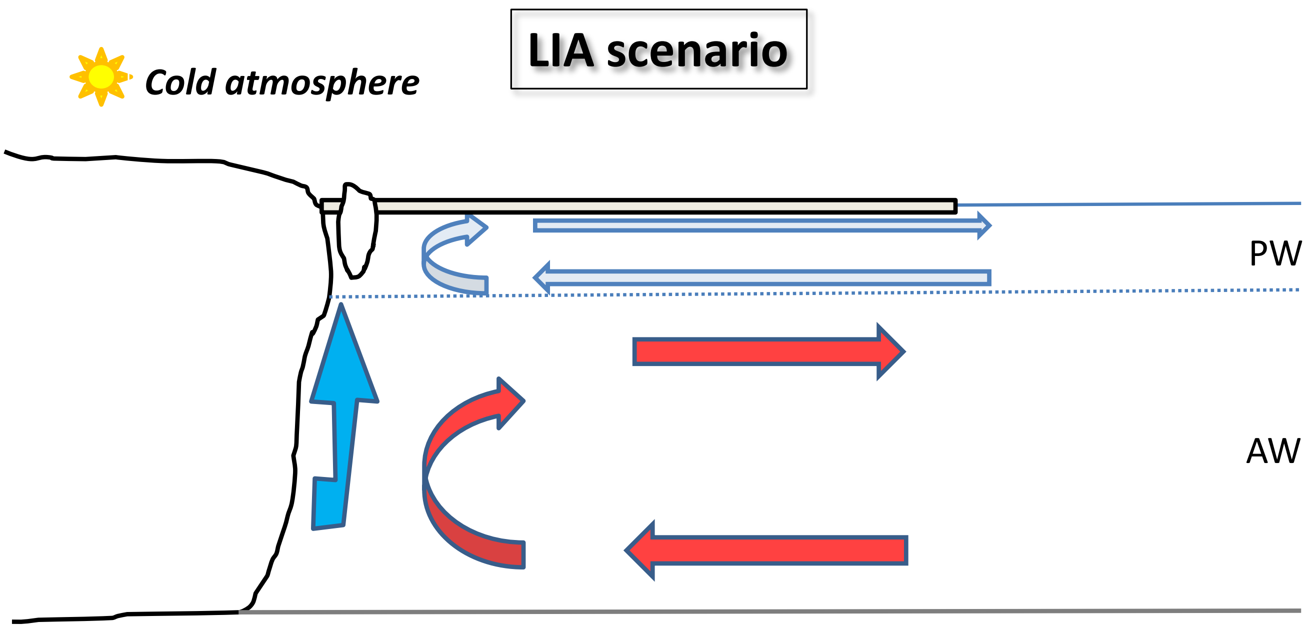
Little Ice Age submarine melt



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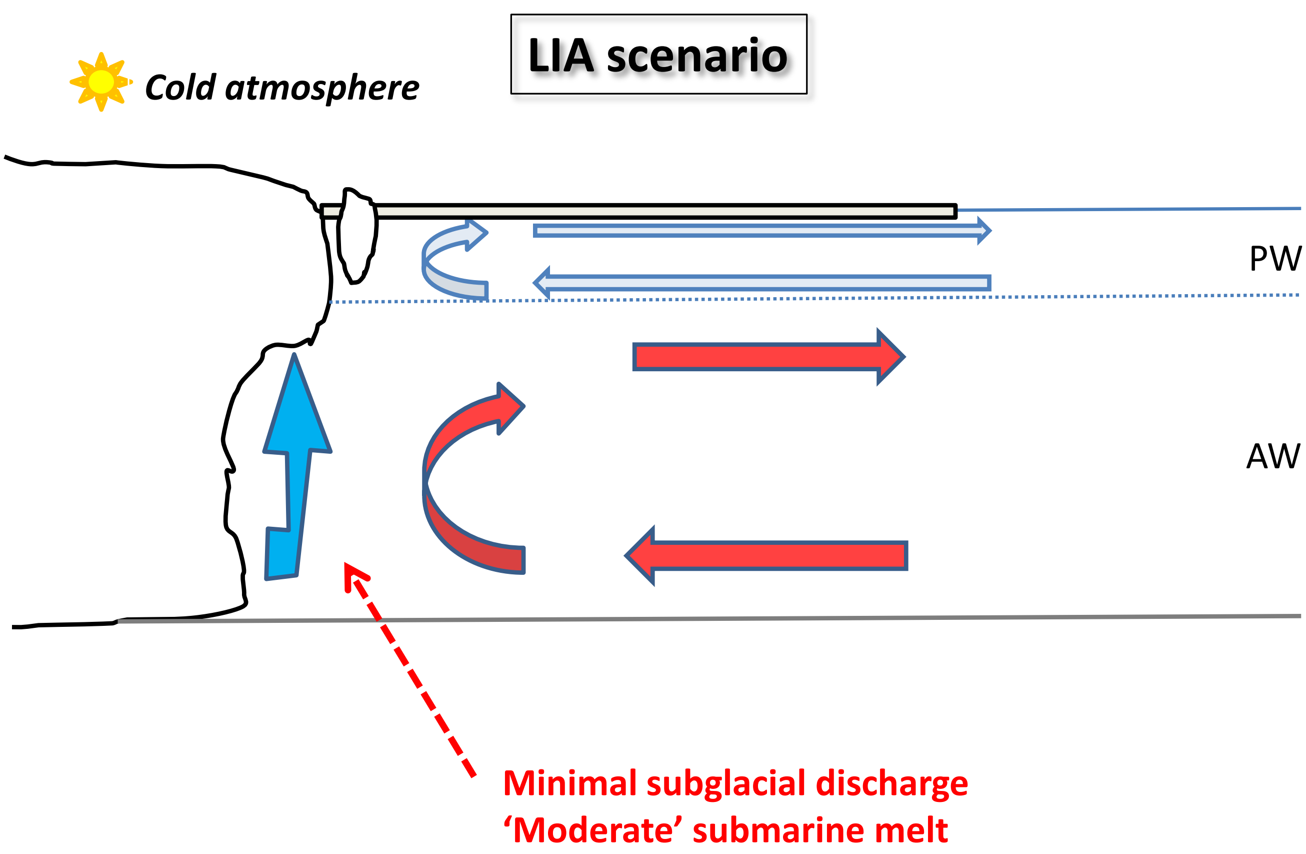

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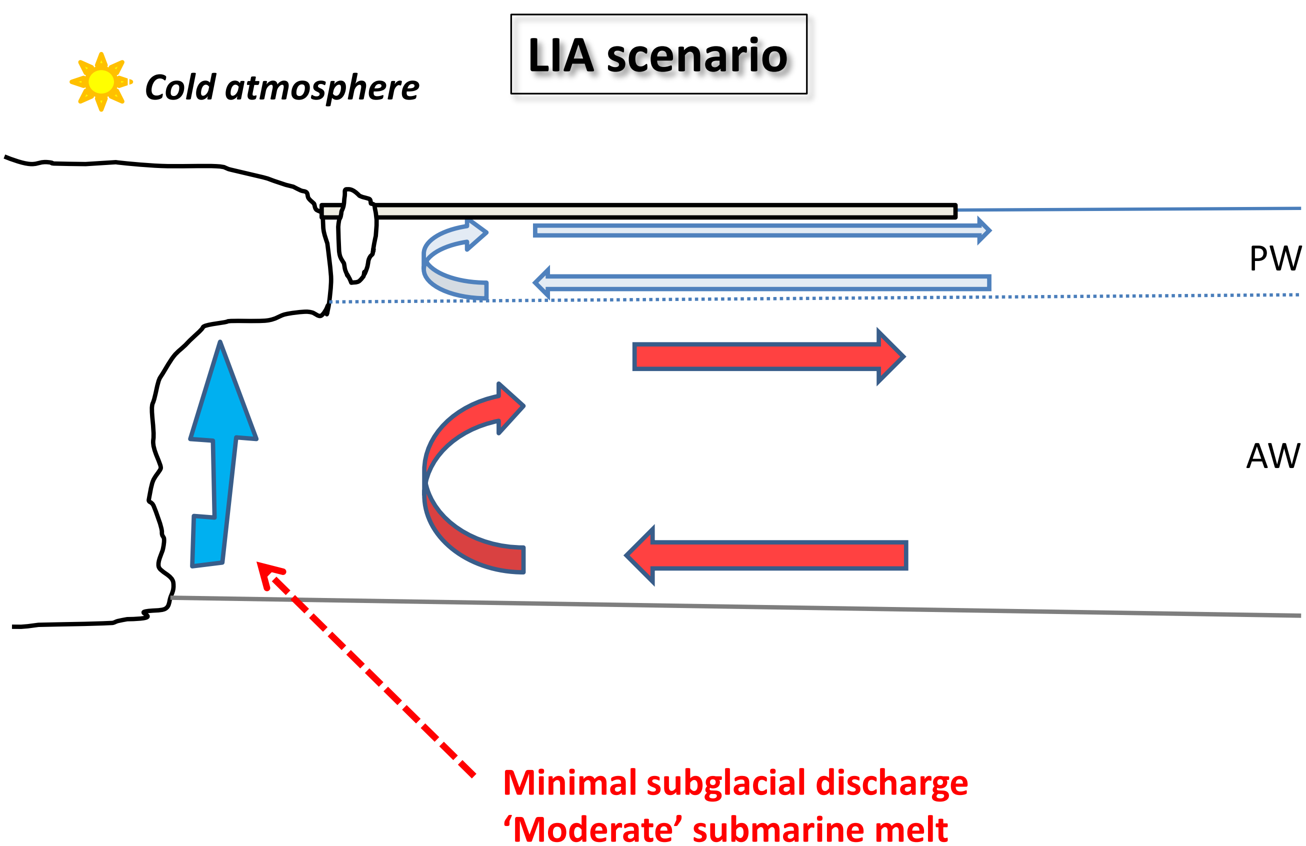
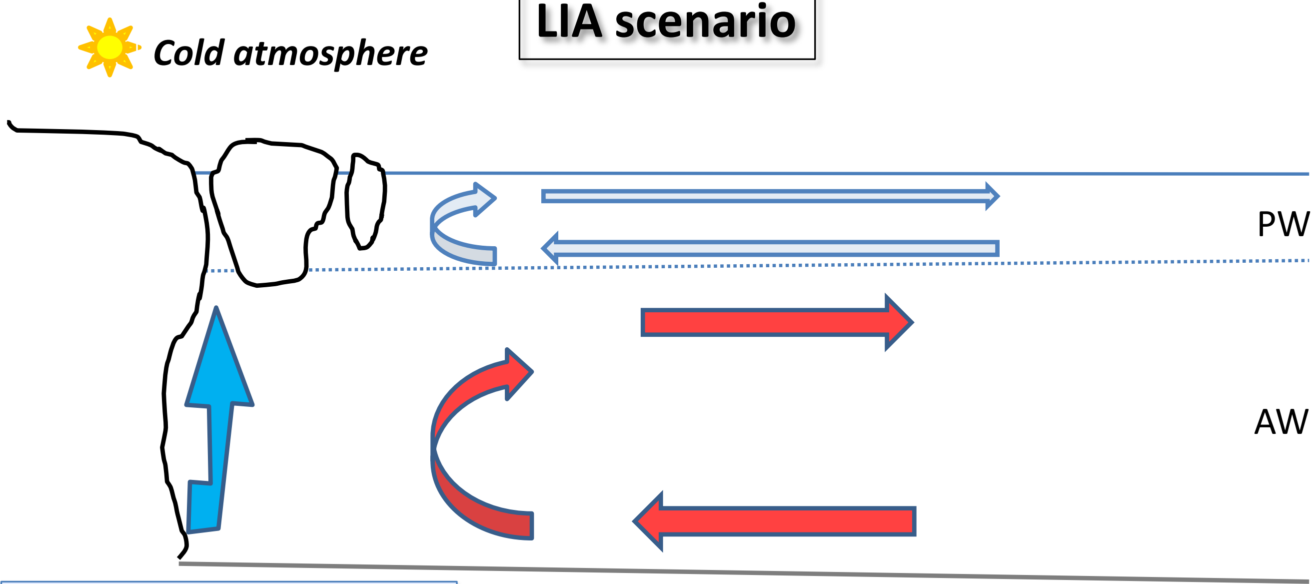


LIA scenario



Glacier unable to advance

So in spite of atmospheric cooling Helheim Glacier did not advance during the LIA - maybe because of the warming subsurface layer in the fjord in relation to high SSTs in the Irminger Sea

In regions with quite warm subsurface waters these have the potential to trigger glacier instability even with minimal glacier discharge

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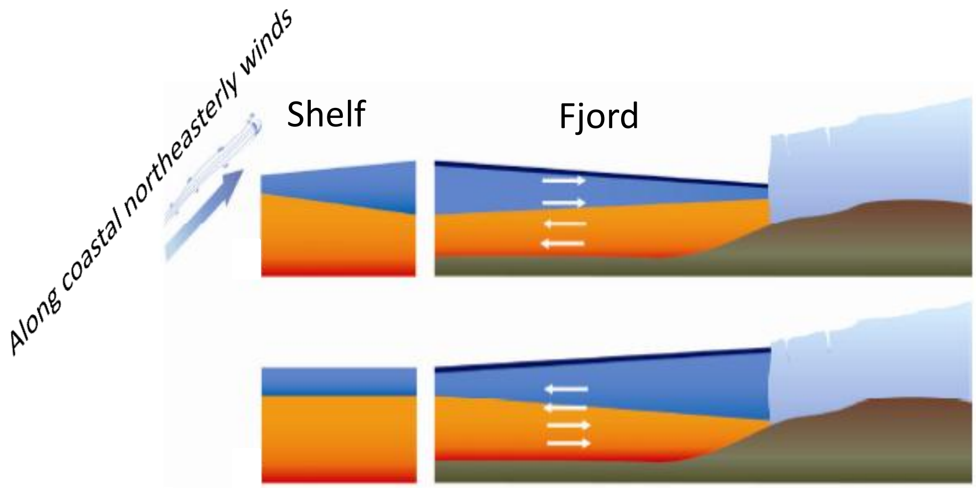
Circulation intensity ?



Straneo et al. 2010

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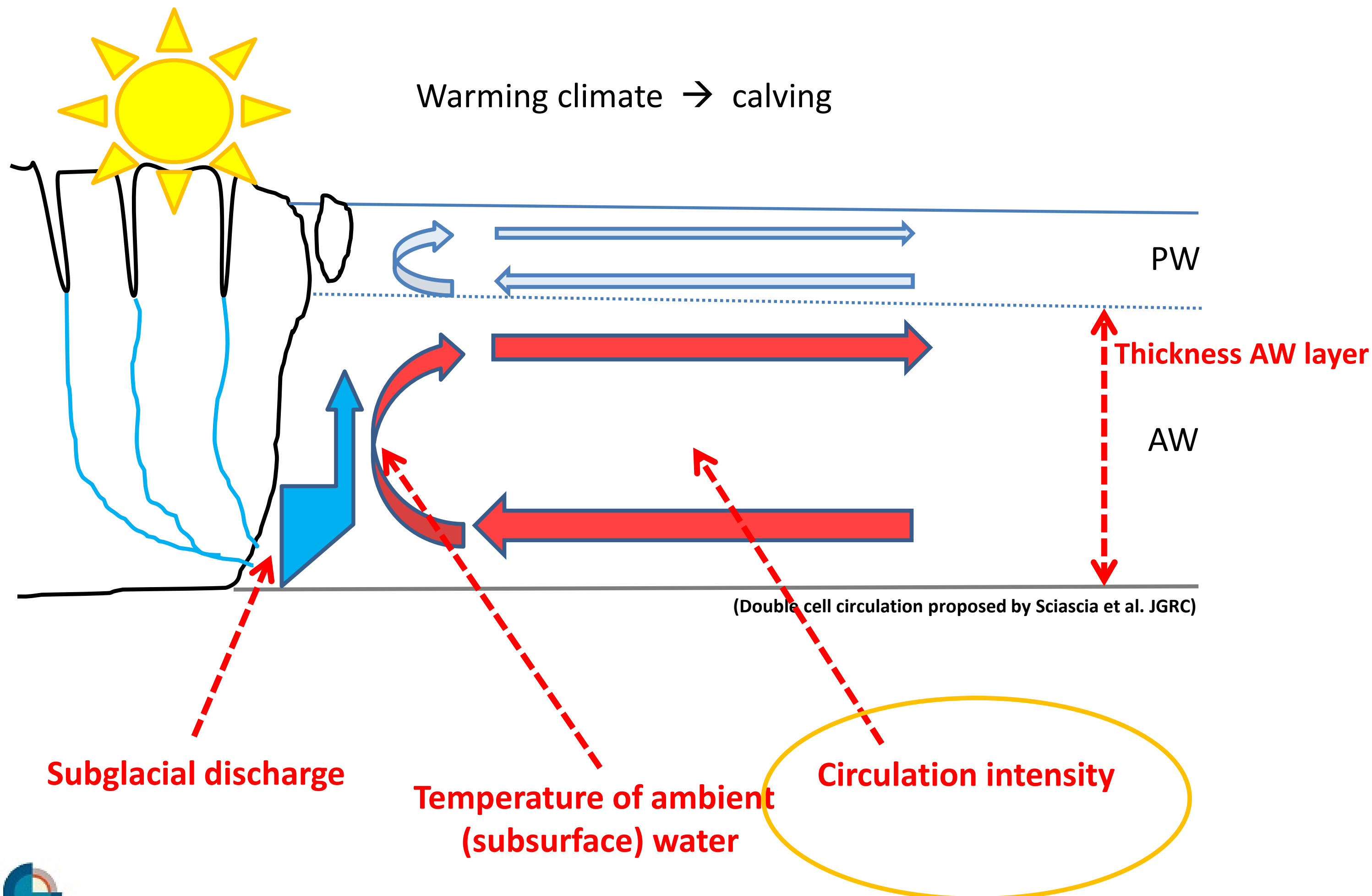
Circulation intensity – Sermilik Fjord



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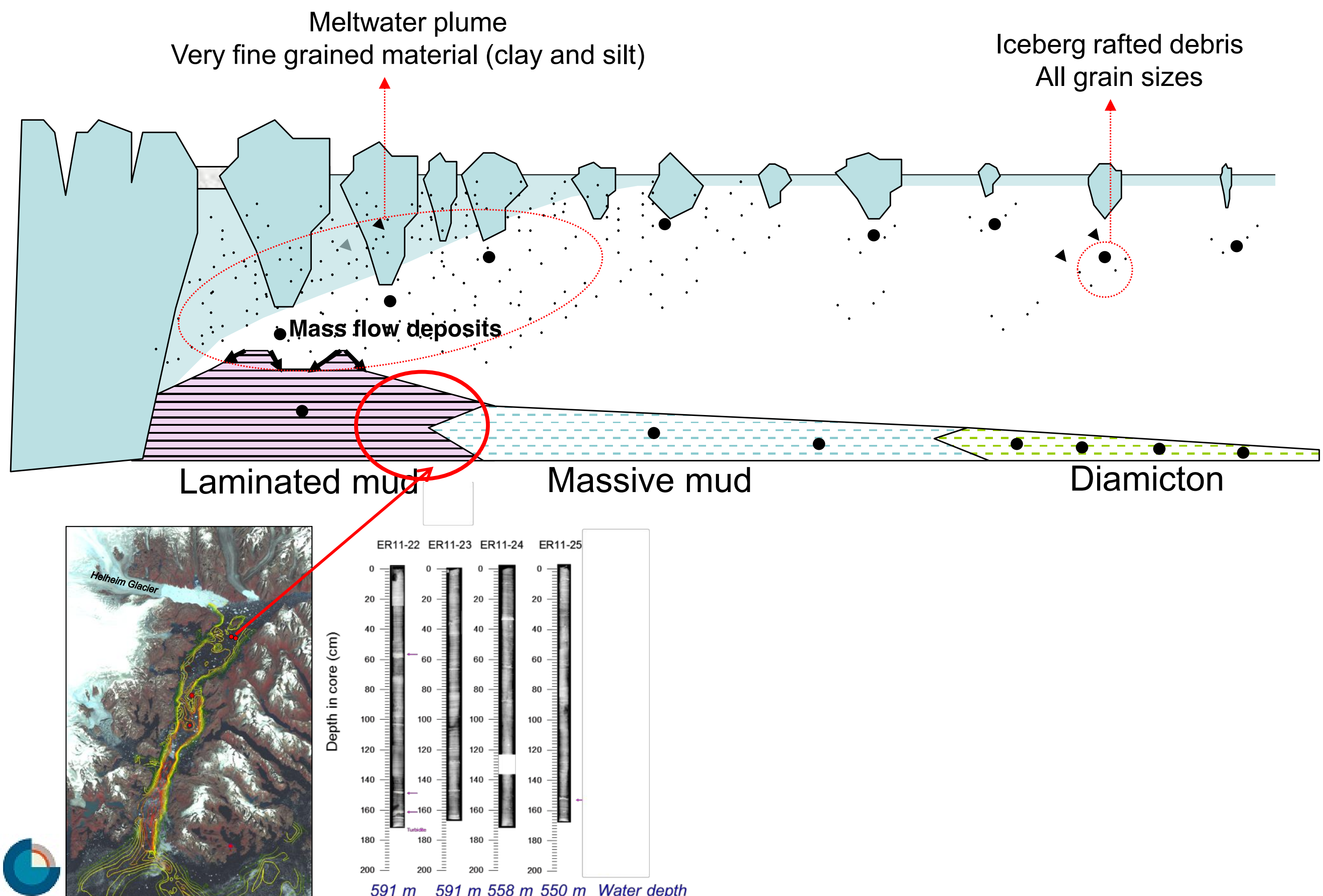

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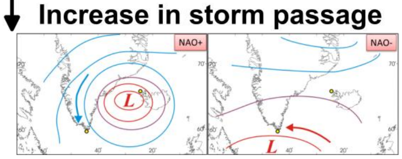
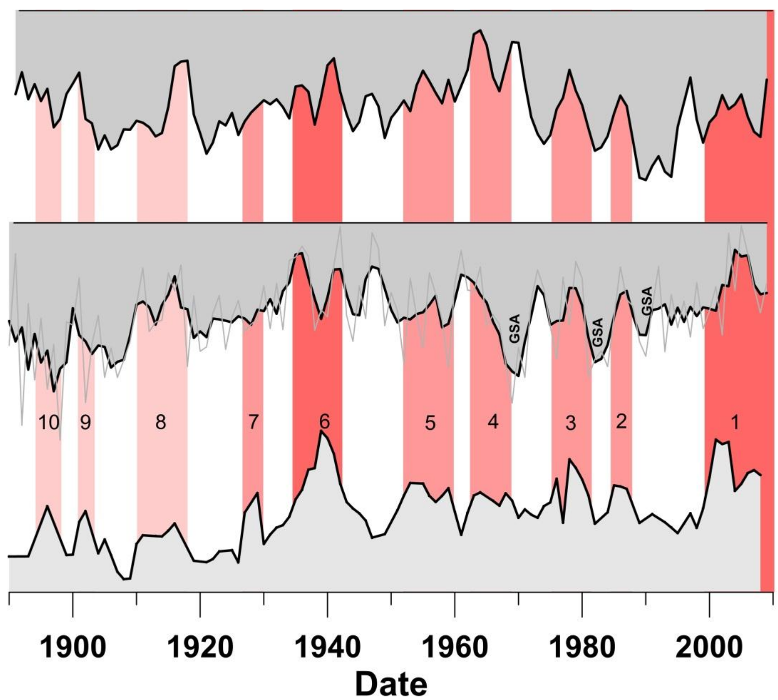
Circulation intensity – Sermilik Fjord

Positive NAO index
Increase in storm passage



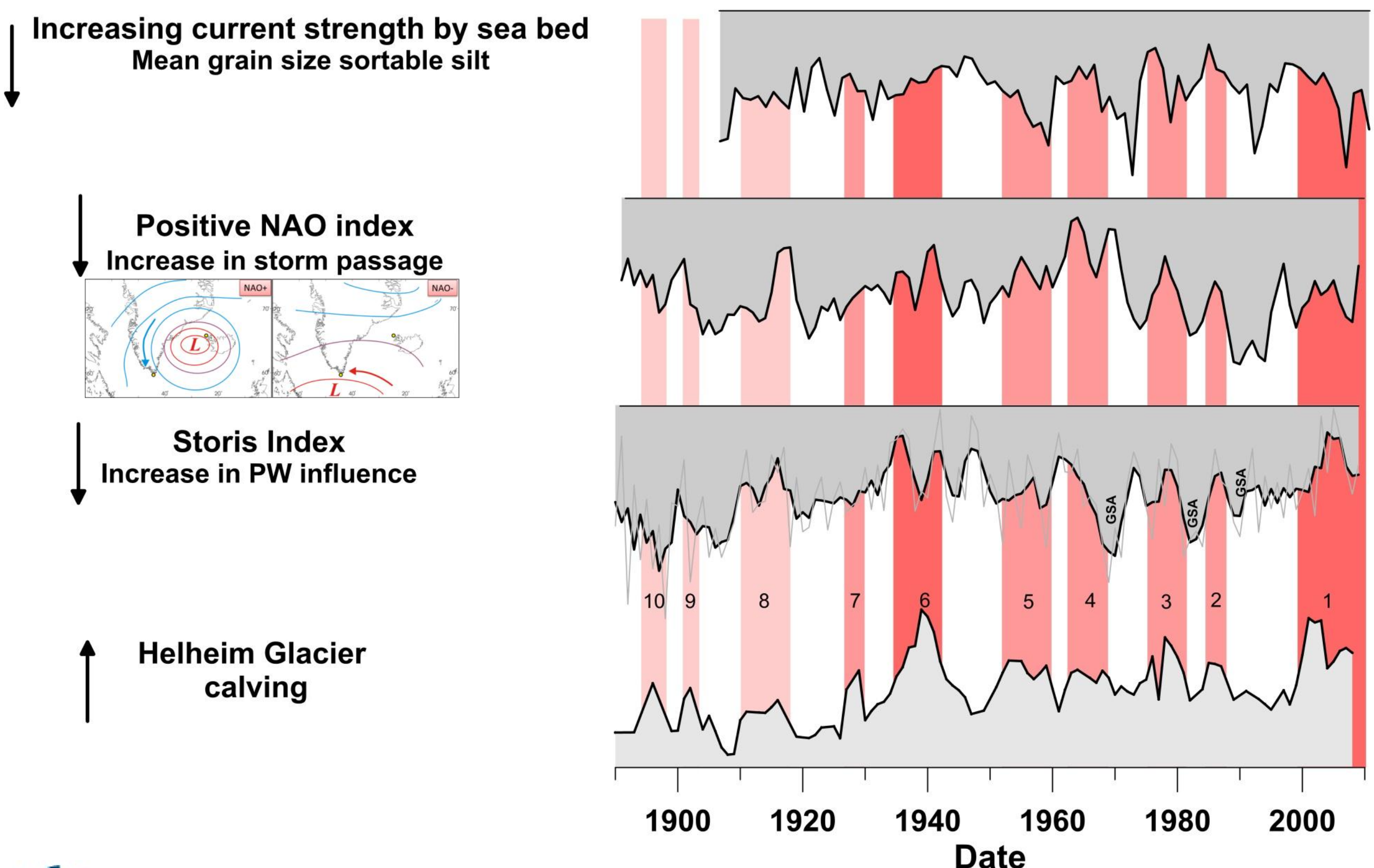
Storis Index
Increase in PW influence

Helheim Glacier calving



(Andresen et al. In prep)

Circulation intensity – Sermilik Fjord



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(Andresen et al. In prep)

On inter-annual time scales episodes of increased fjord circulation are linked with a positive NAO index and increased sea ice occurrence on the shelf - thus a climatic setting impeding calving rates in spite of marked renewal rate

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Summary of findings

1. Timing of instability of Jakobshavn Isbræ and Helheim Glacier concurs with:

- a positive Atlantic Multi-decadal Oscillation
- a negative North Atlantic Oscillation index
- decreased sea ice occurrence around Greenland

2. The late 1930s and early 2000s episodes of marked glacier retreat of Jakobshavn Isbræ and Helheim Glacier may stand out due to the coincidence of: Subsurface warming of the ocean around Greenland, record low sea ice occurrence and record warm summer air

3. In regions with quite warm subsurface waters these have the potential to trigger glacier instability even with minimal glacier discharge

4. On inter-annual time scales episodes of increased fjord circulation are linked with a positive NAO index and increased sea ice occurrence on the shelf - thus a climatic setting impeding calving rates in spite of marked renewal rate

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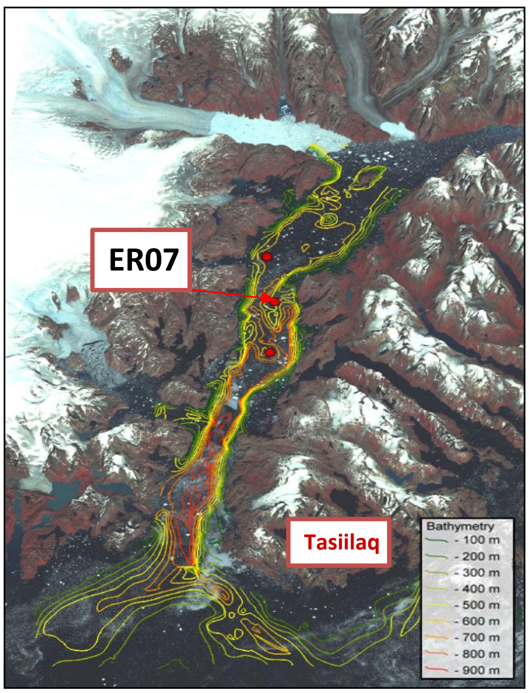
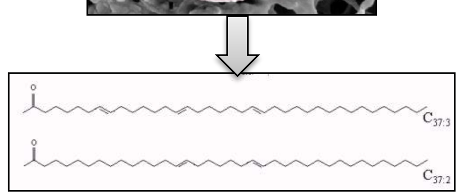
Comparing the calving record with ocean temperature proxy



Temperature reconstruction via alkenone analysis



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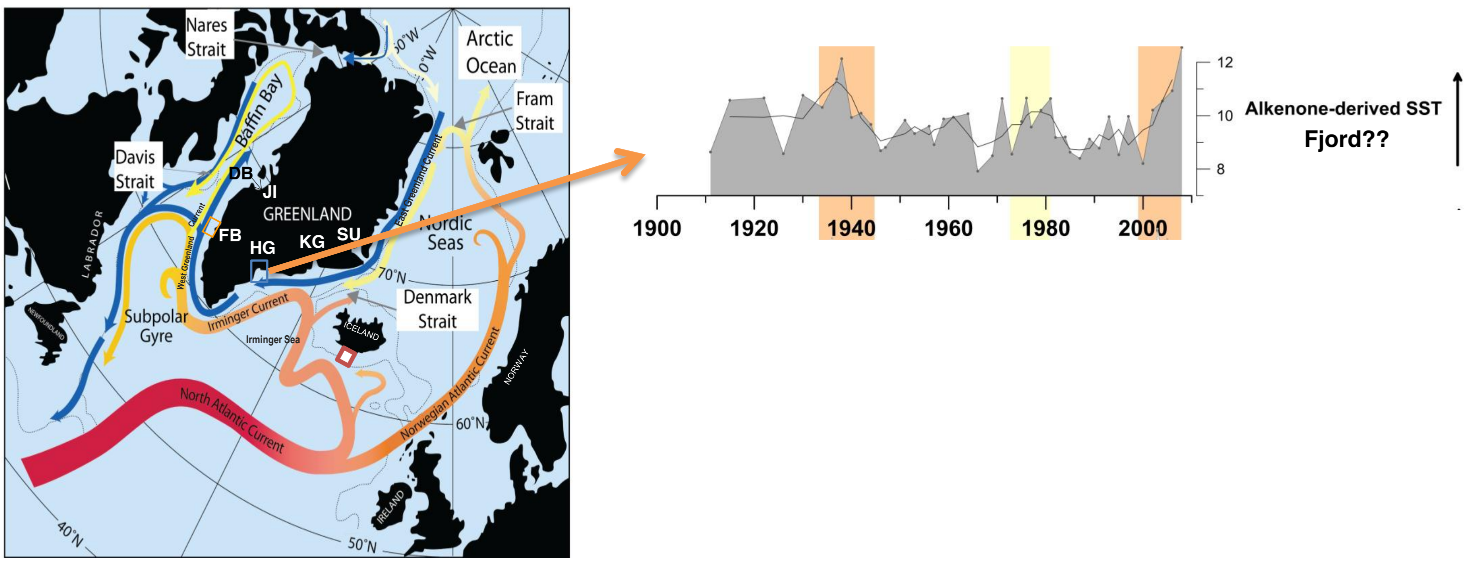
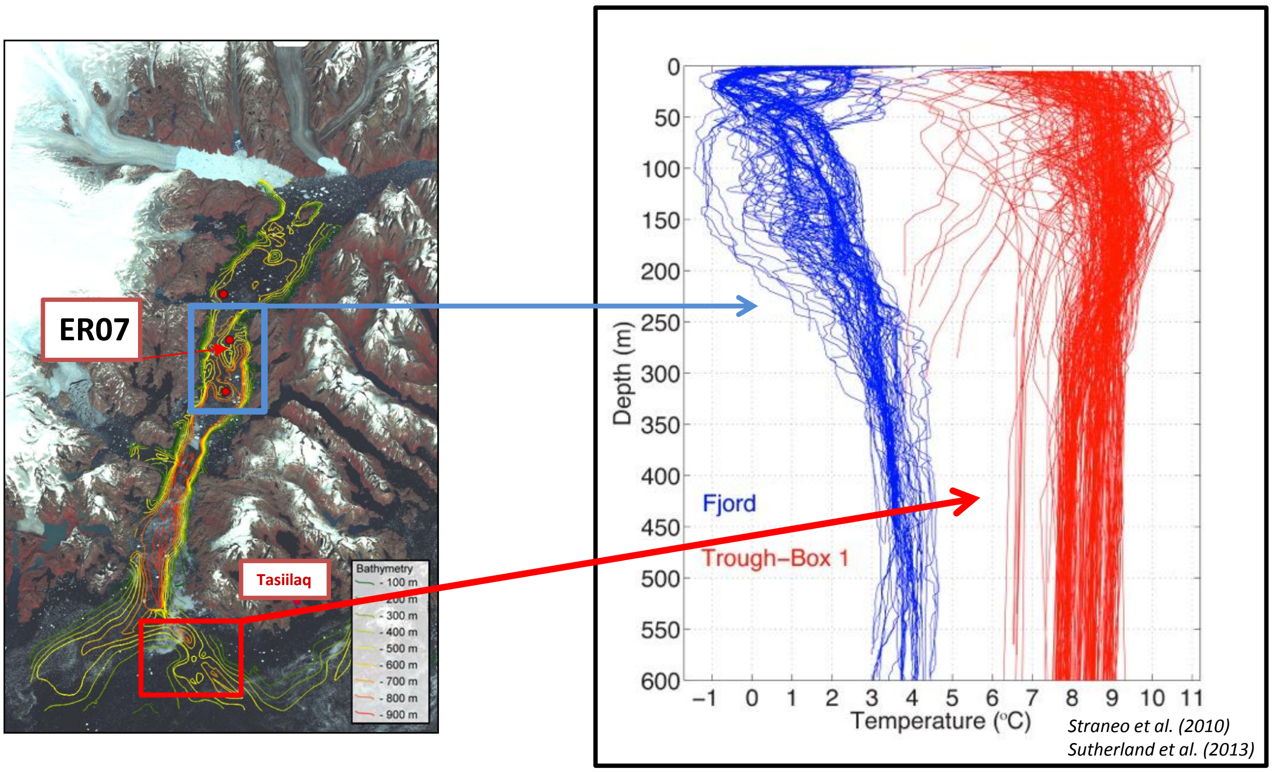


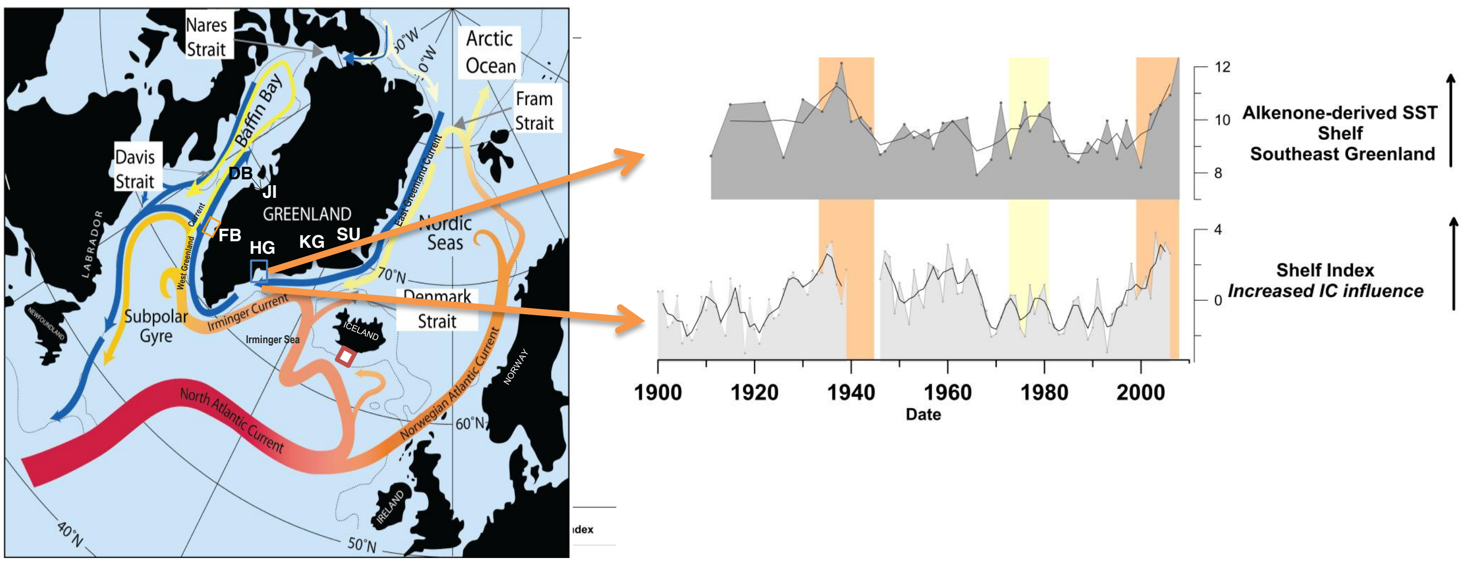
(Andresen et al. submitted)

Comparing the calving record with ocean temperature proxy

Oceanographic data

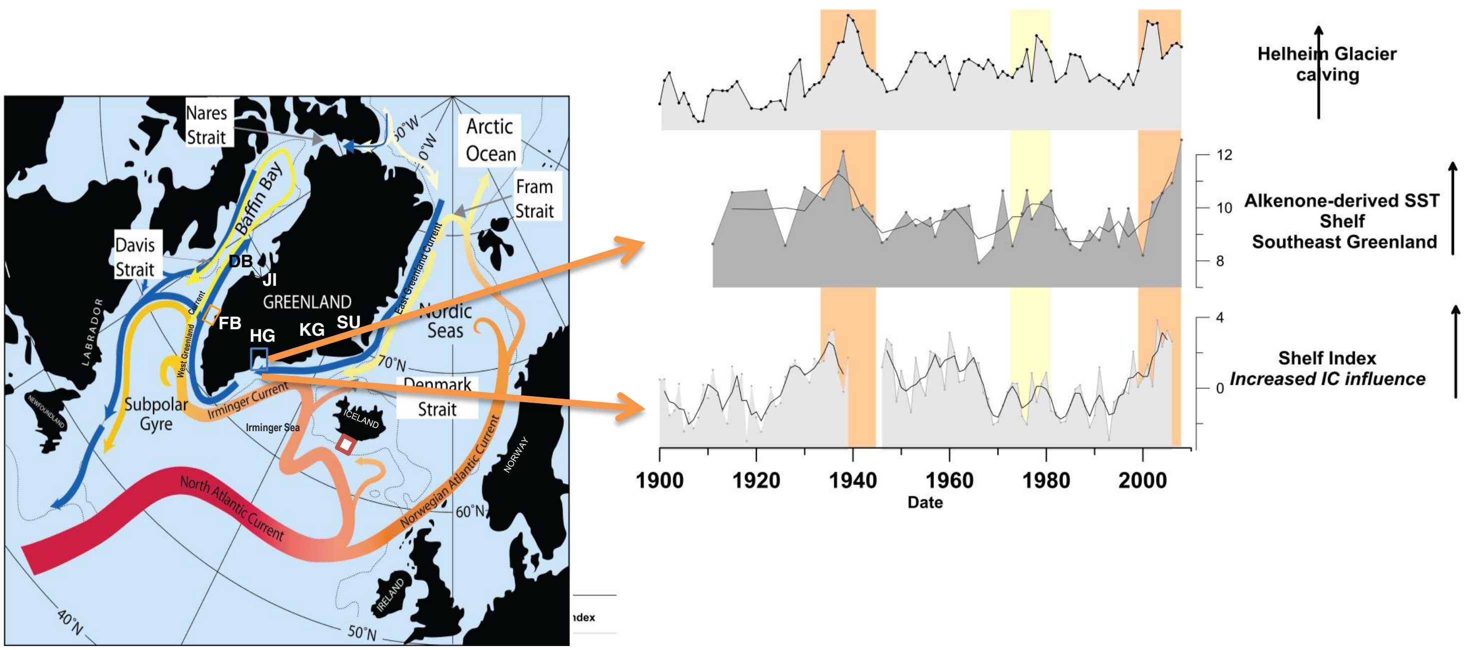


Comparing the calving record with ocean temperature proxy



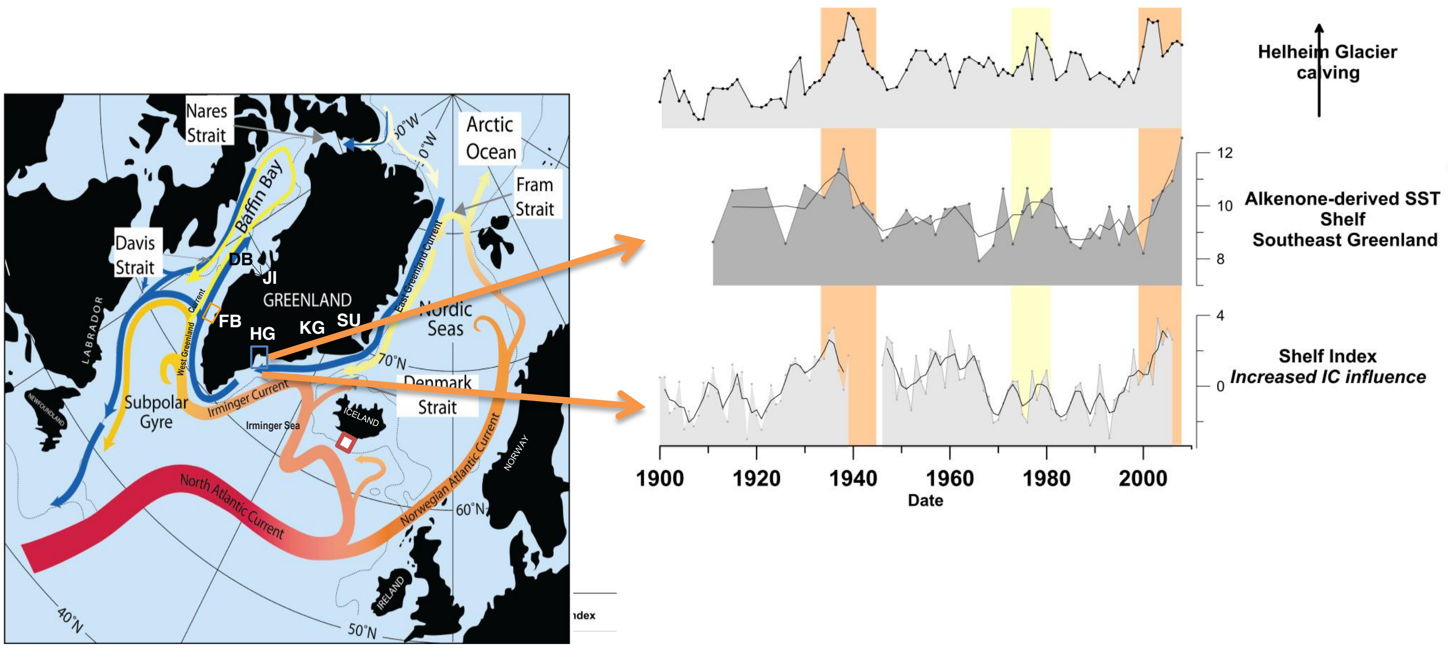
(Andresen et al. submitted)

Comparing the calving record with ocean temperature proxy



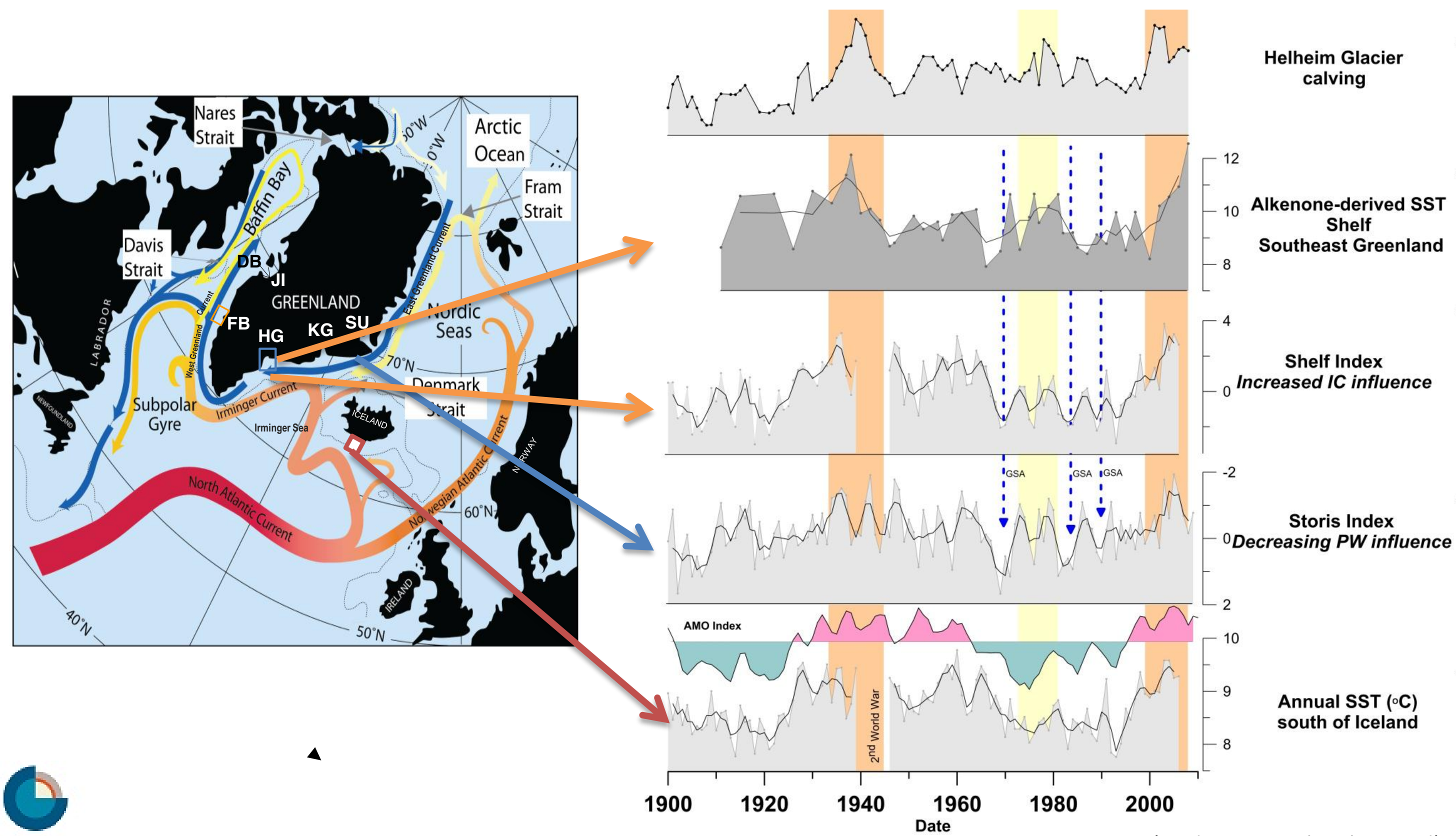
(Andresen et al. submitted)

Comparing the calving record with ocean temperature proxy



(Andresen et al. submitted)

Comparing the calving record with ocean temperature proxy



(Andresen et al. submitted)

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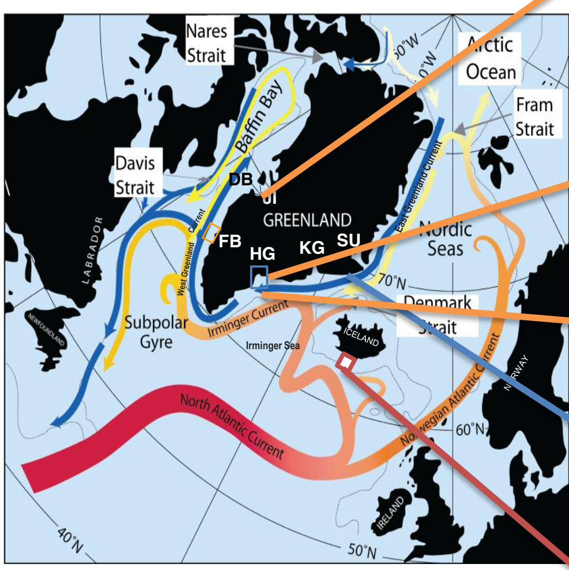
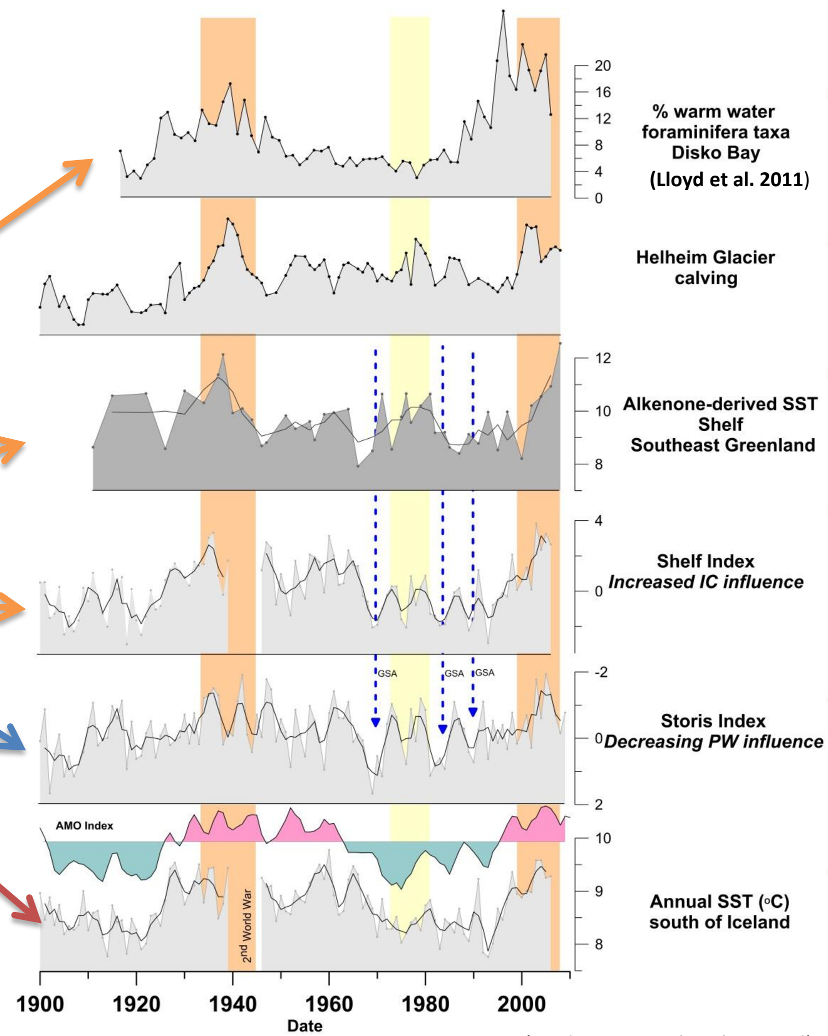
Comparing the calving record with ocean temperature proxy

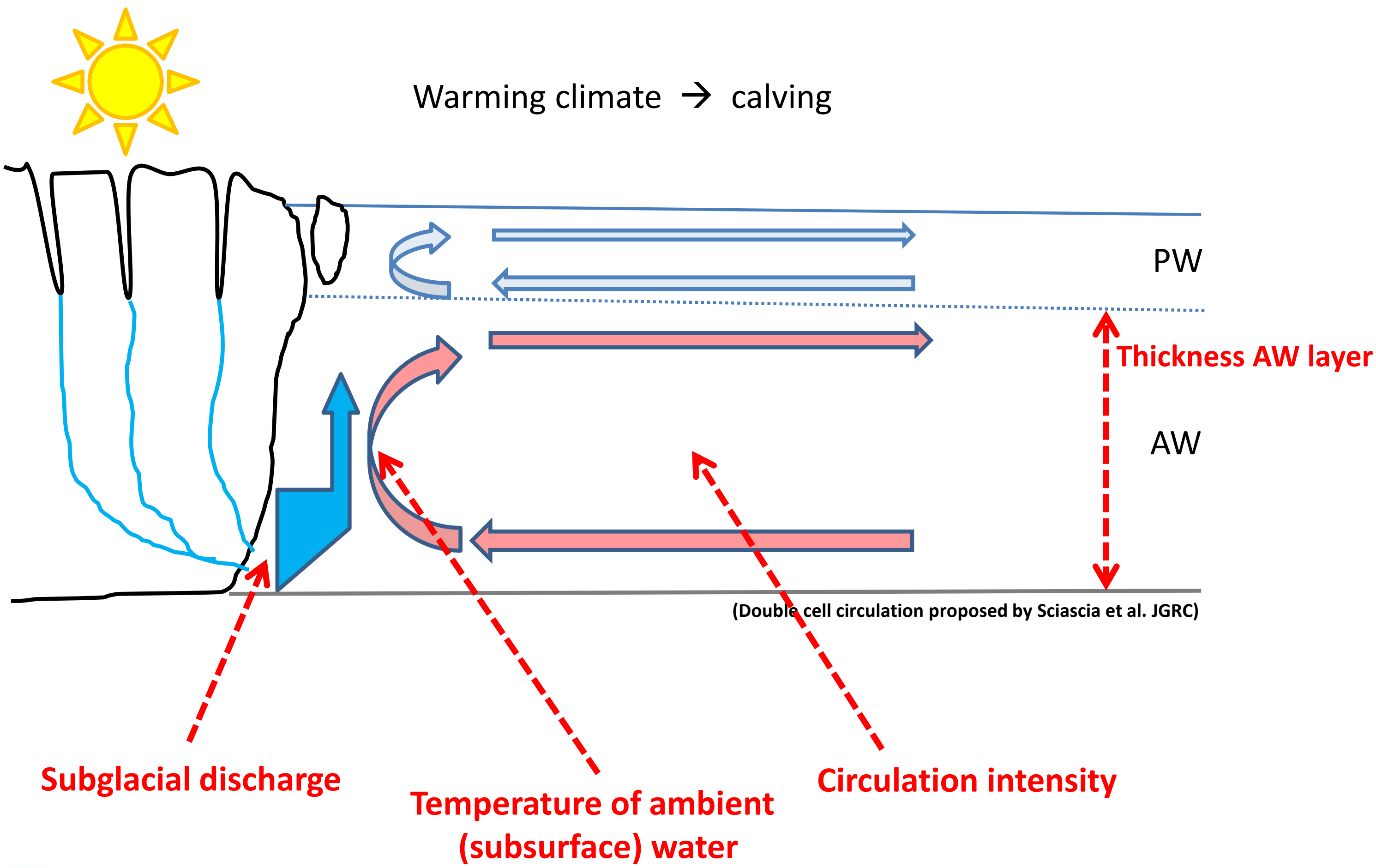




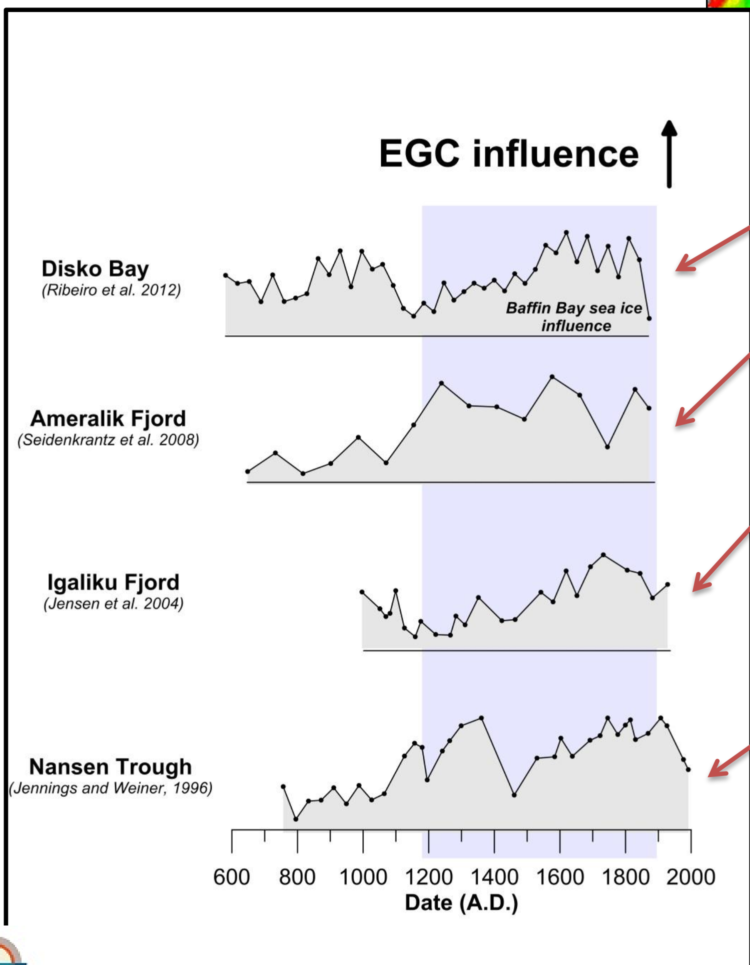
GEUS

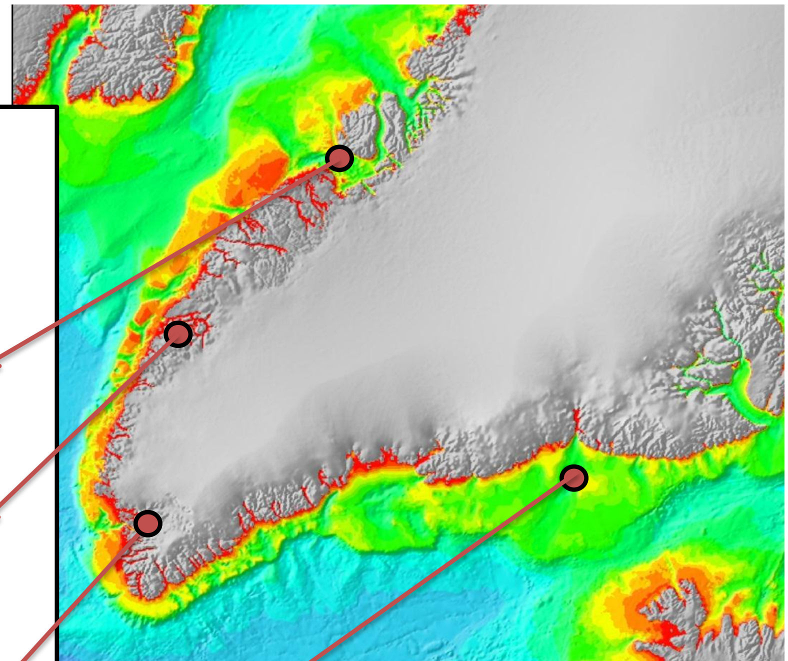
(Andresen et al. submitted)

Comparing the calving record with ocean temperature proxy



The Little Ice Age – climate scenario



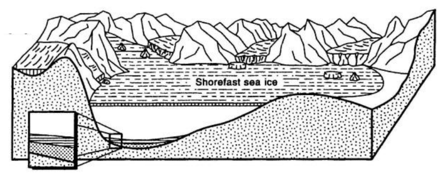


LIA surface ocean cooling

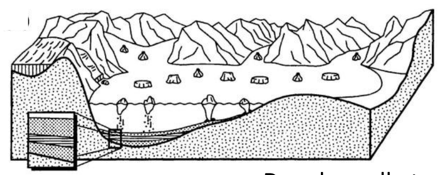
GEUS

The Little Ice Age – analysing fjord cores

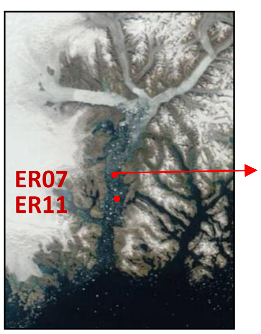
Mud



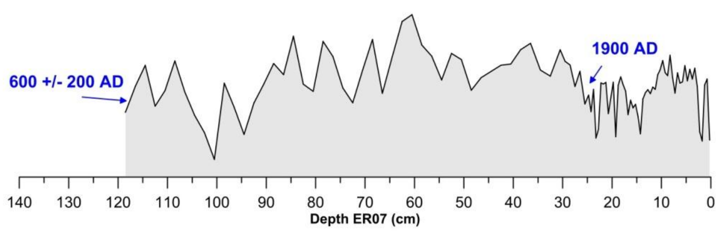
Mud with sand and pebbles



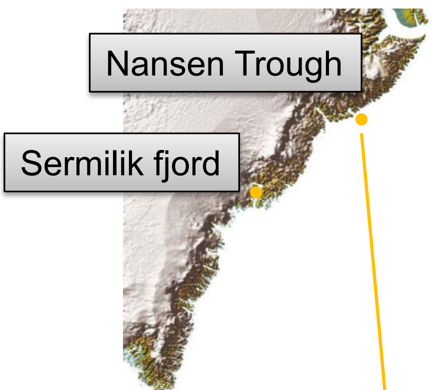
Dowdeswell et al. 2000

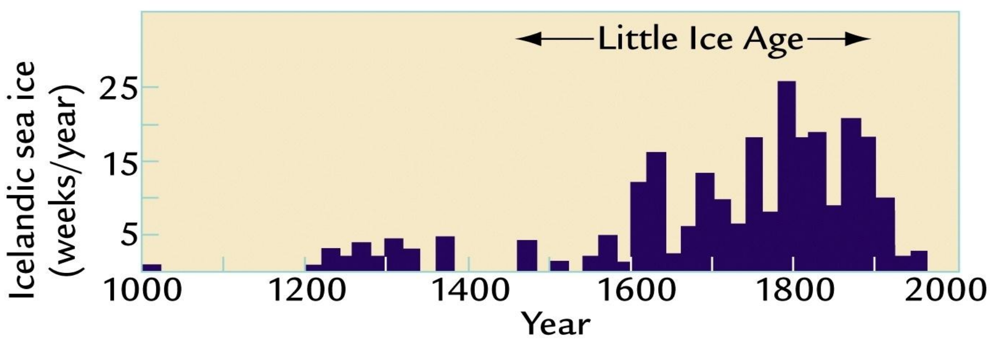


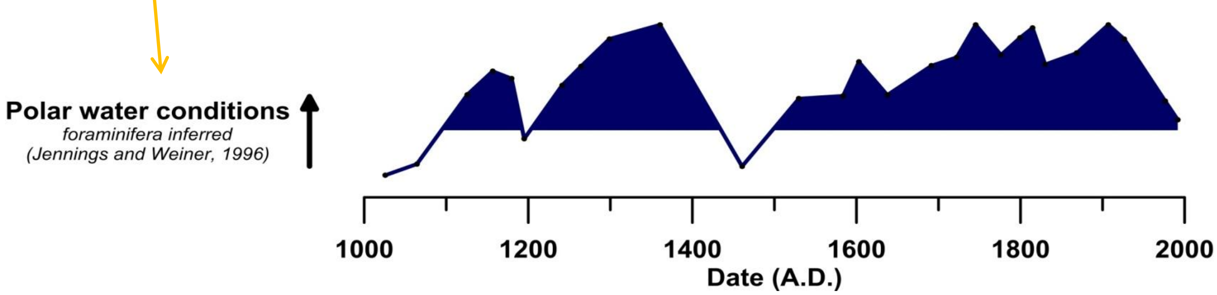
Decreasing iceberg rafting in Sermilik Fjord
clay content core
Cooling



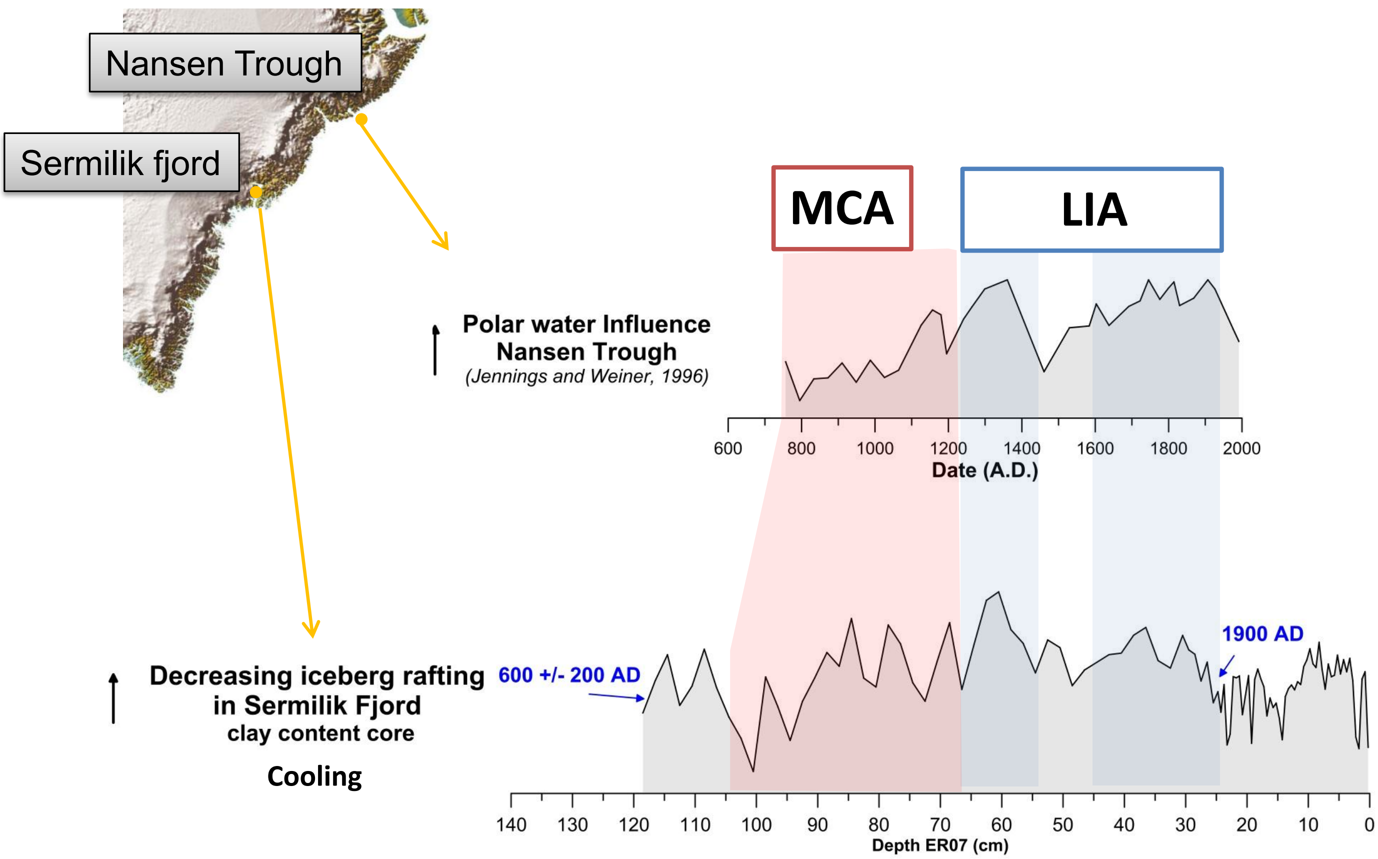
The Little Ice Age – analysing fjord cores





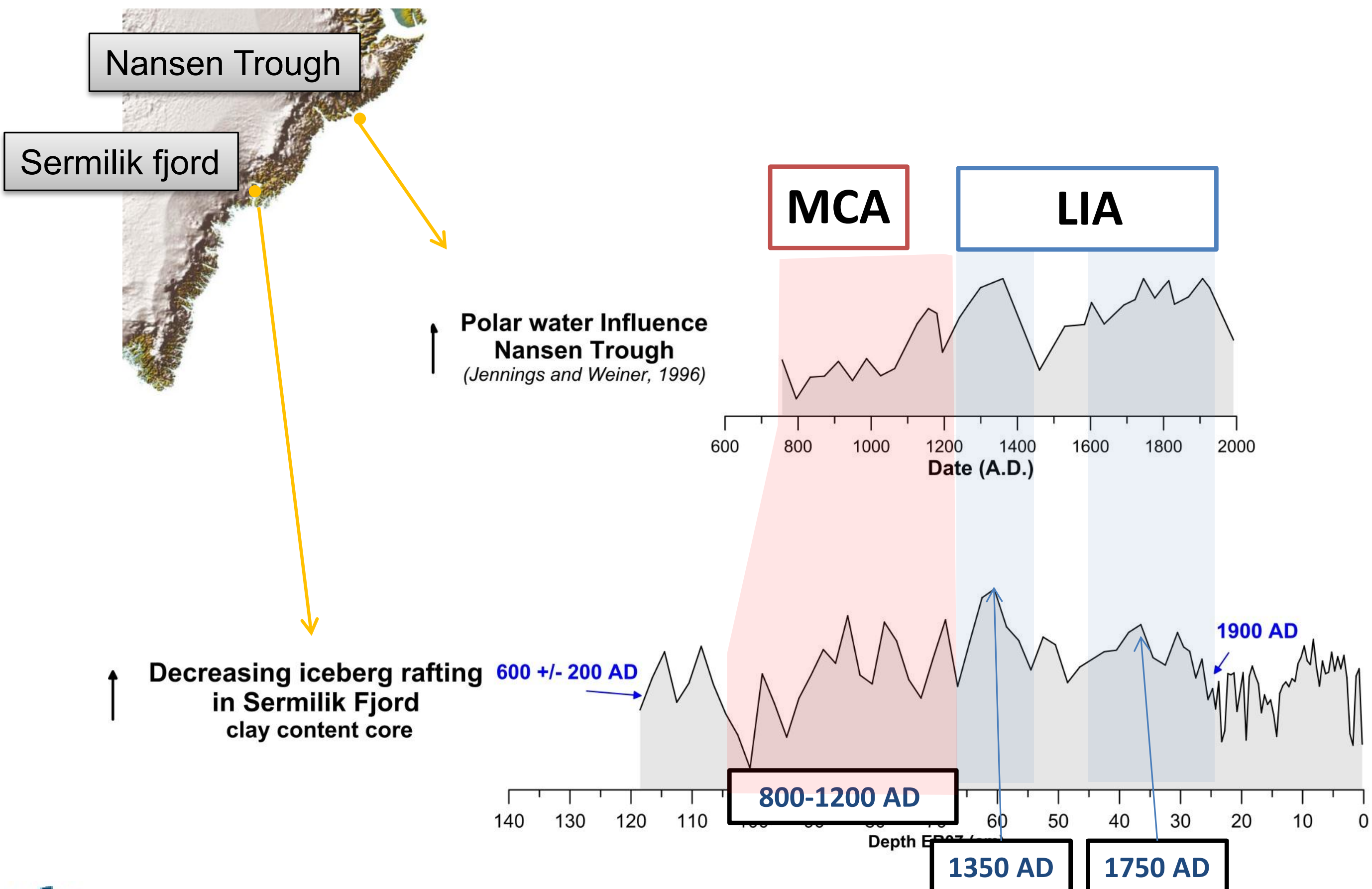


GEUS


Nansen Trough
Sermilik fjord
MCA
LIA
Polar water Influence
Nansen Trough
(Jennings and Weiner, 1996)
600
800
1000
1200
1400
1600
1800
2000
Date (A.D.)
Decreasing iceberg rafting
in Sermilik Fjord
clay content core
Cooling
600 +/- 200 AD
1900 AD
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
Depth ER07 (cm)

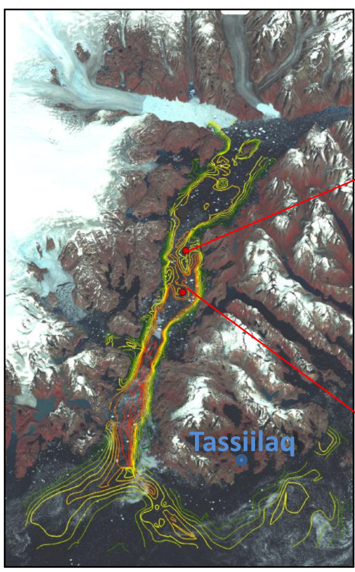
GEUS

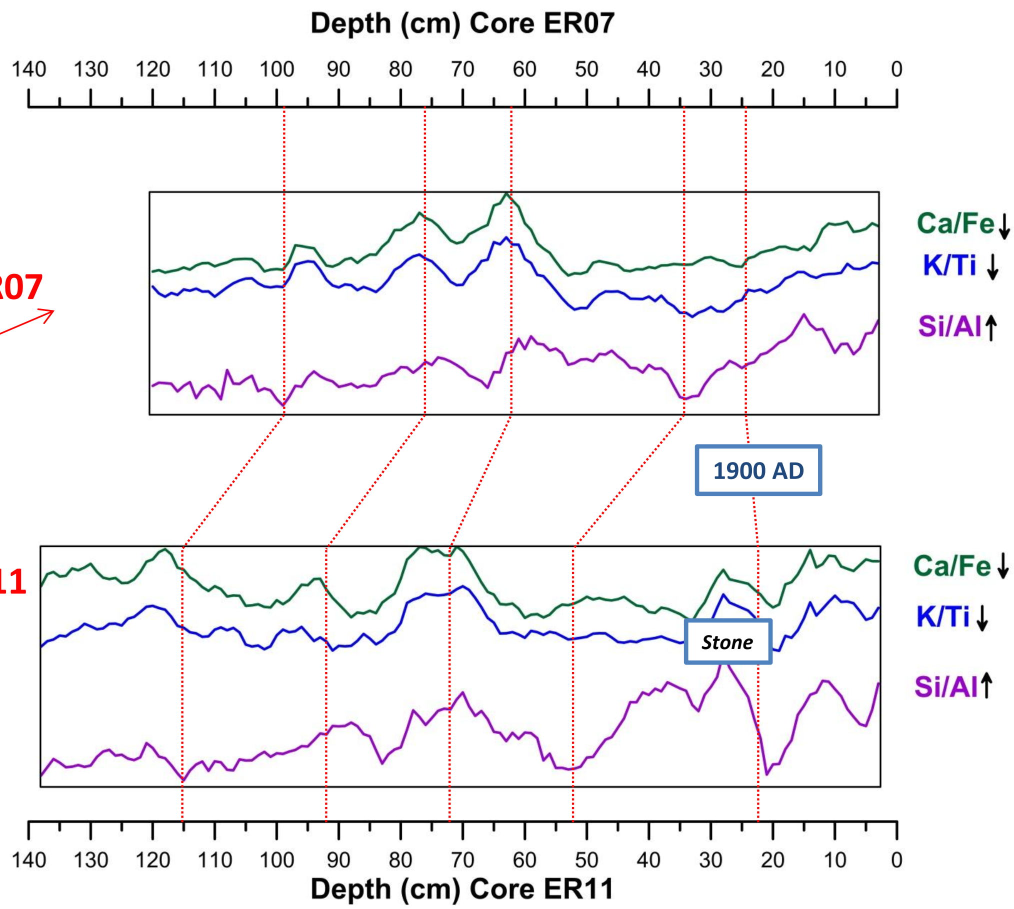
The Little Ice Age – analysing fjord cores



GEUS

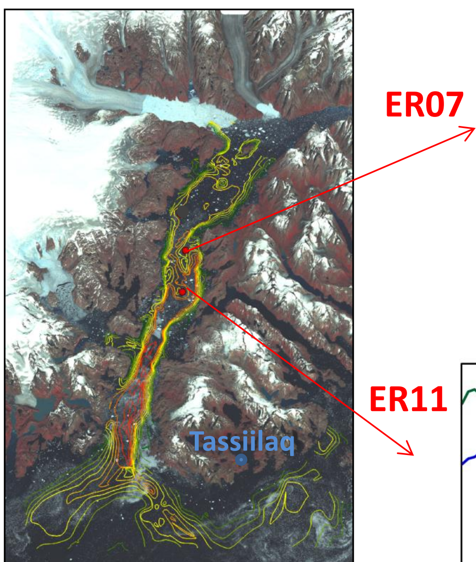
XRF-based correlation of two mid-fjord cores

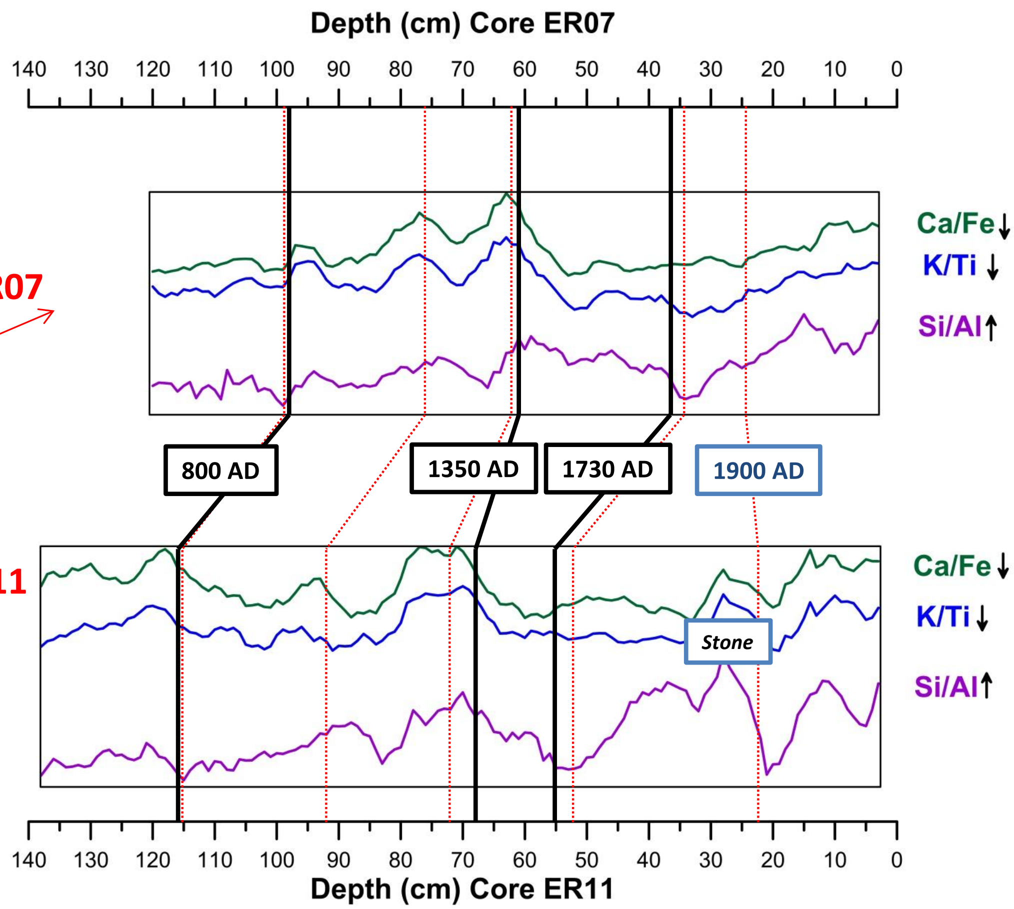




GEUS

XRF-based correlation of two mid-fjord cores

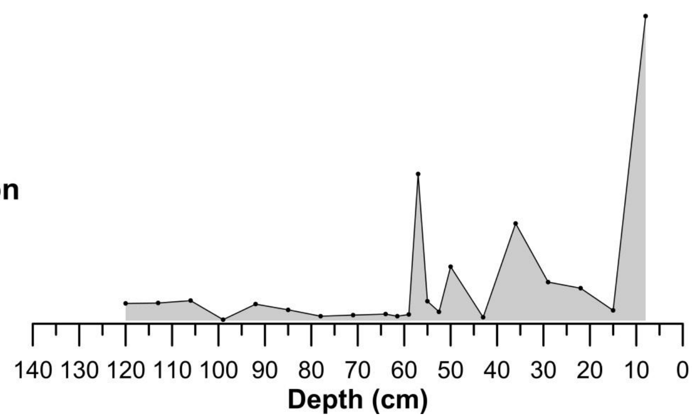




GEUS

The Little Ice Age – analysing fjord cores

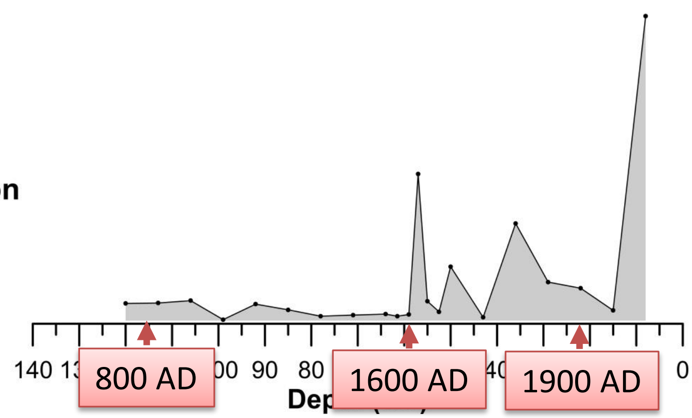
Warm subsurface water intrusion
***inside* Sermilik Fjord**
(Foraminifera flux)



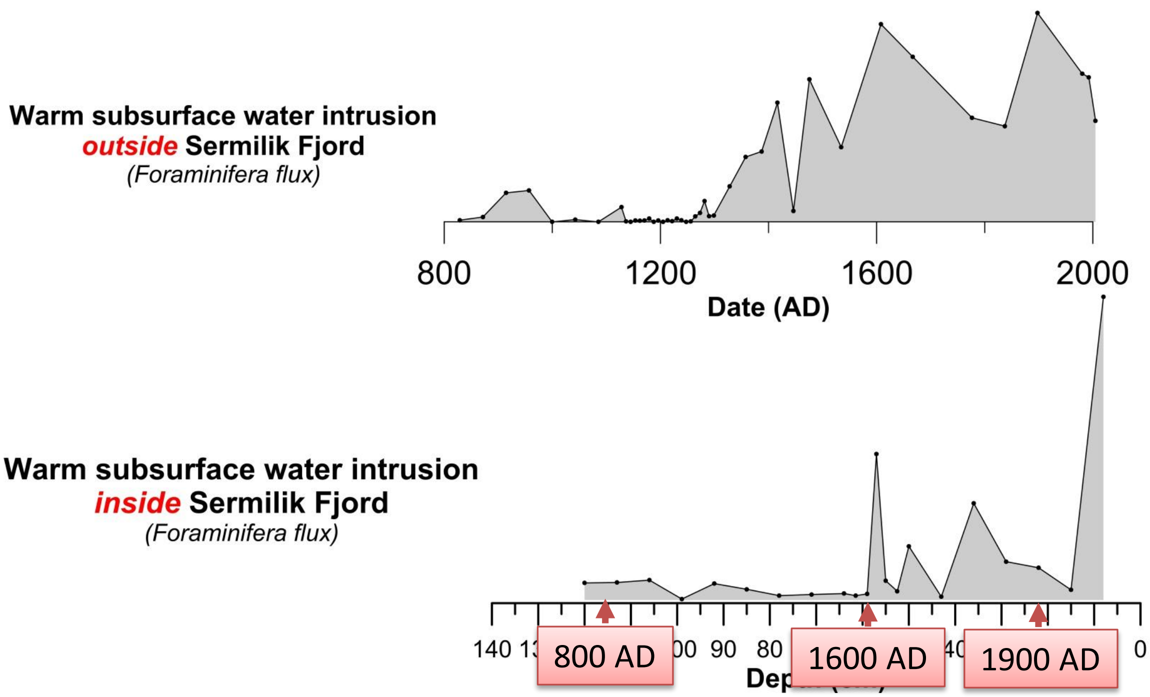
GEUS

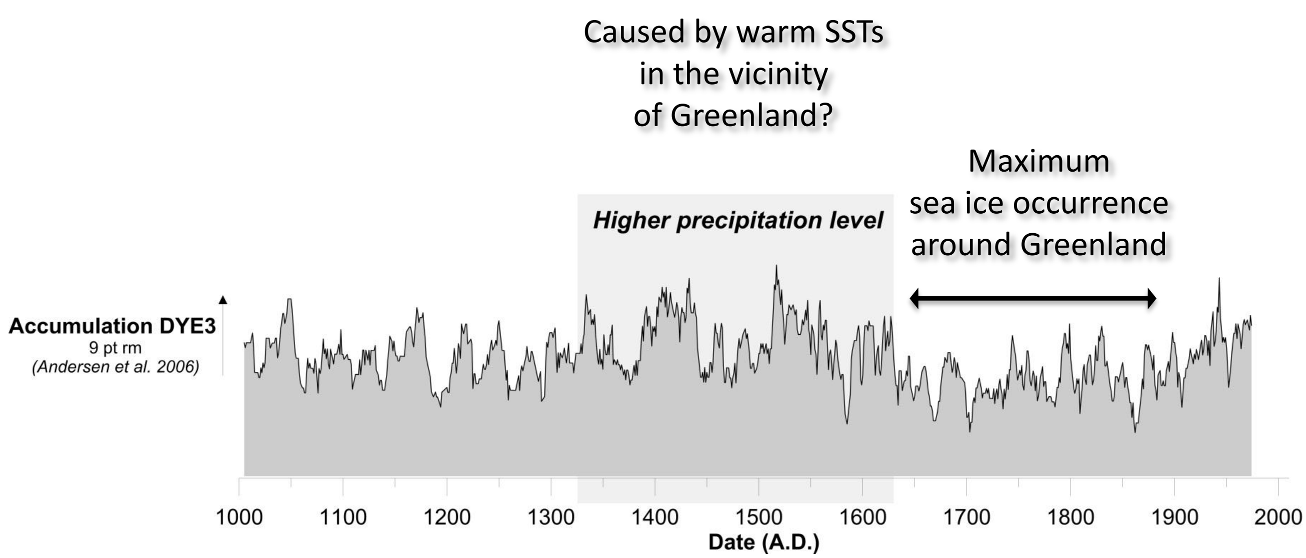
The Little Ice Age – analysing fjord cores

Warm subsurface water intrusion *inside* Sermilik Fjord
(Foraminifera flux)

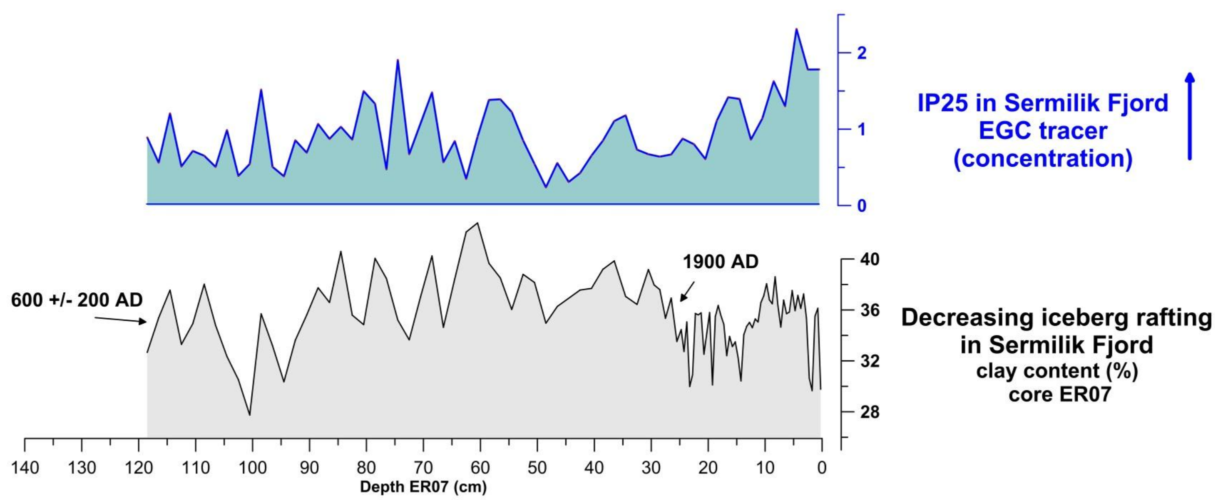


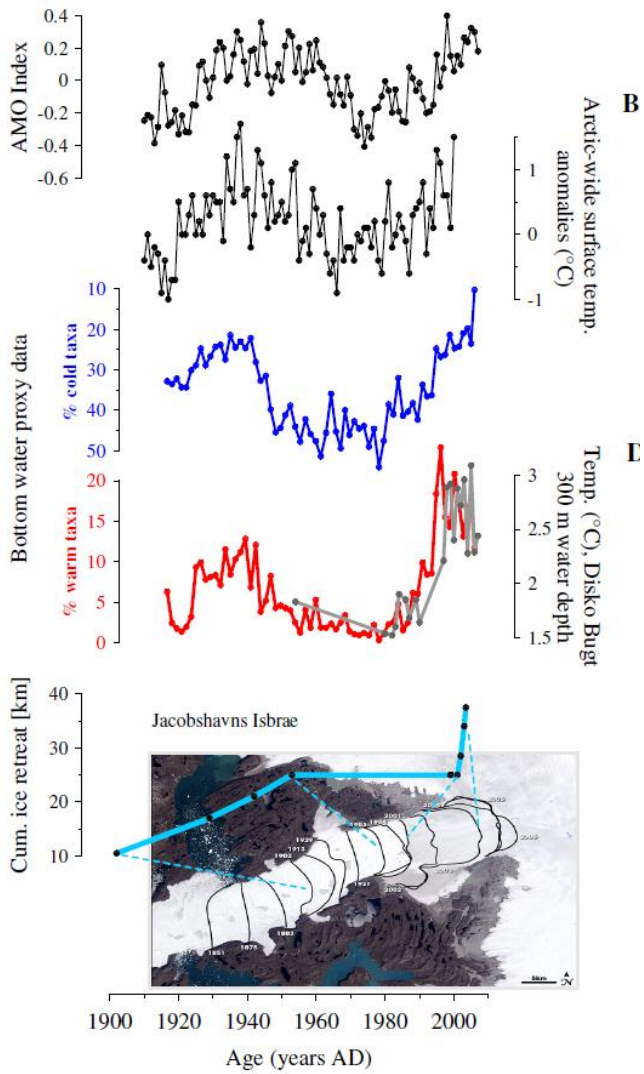
The Little Ice Age – analysing fjord cores



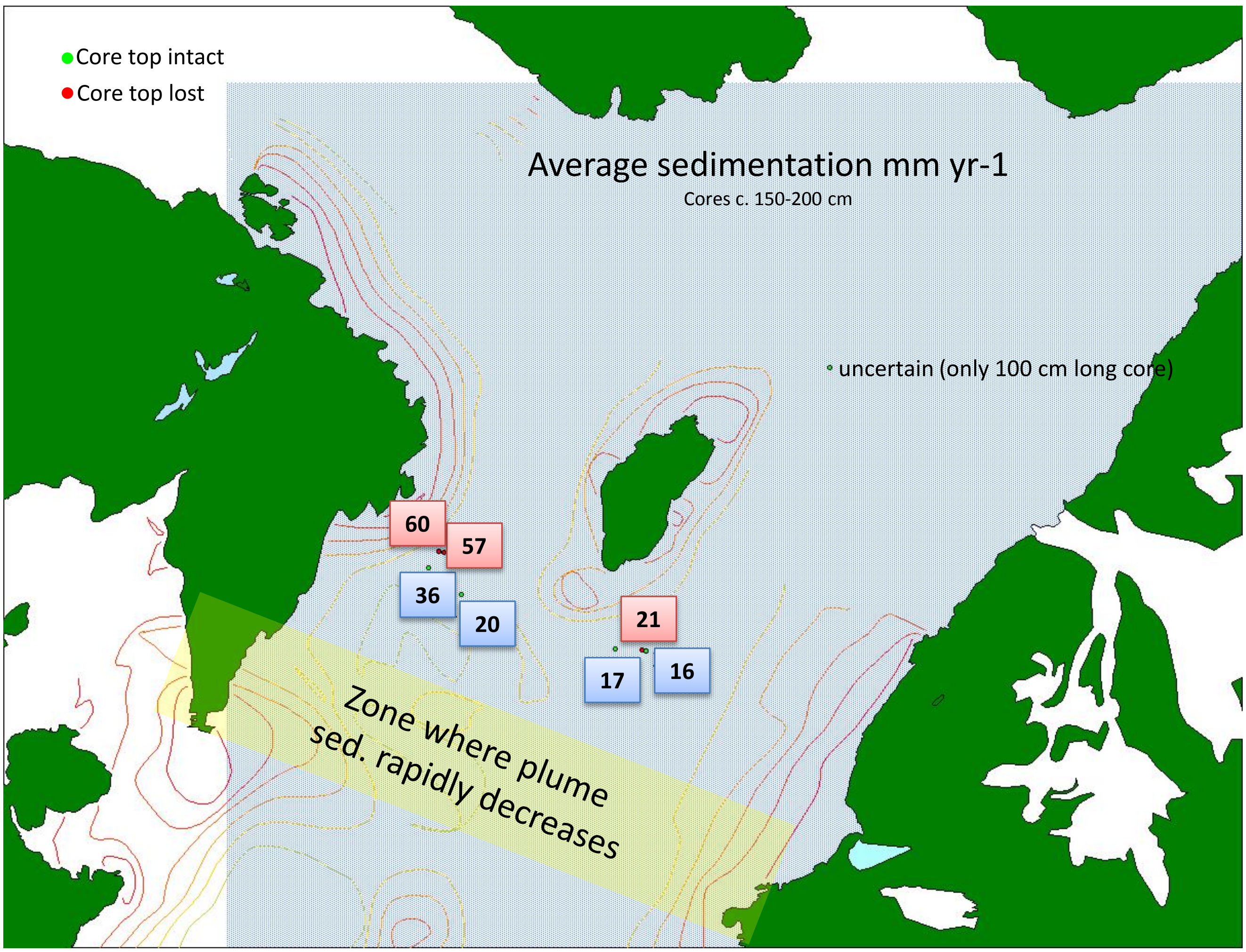


Caused by warm SSTs
in the vicinity
of Greenland?
Maximum
sea ice occurrence
around Greenland
Higher precipitation level
Accumulation DYE3
9 pt rm
(Andersen et al. 2006)
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
Date (A.D.)


IP25 in Sermilik Fjord
EGC tracer
(concentration)
600 +/- 200 AD
1900 AD
Decreasing iceberg rafting
in Sermilik Fjord
clay content (%)
core ER07
Depth ER07 (cm)
140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
0 1 2
28 32 36 40



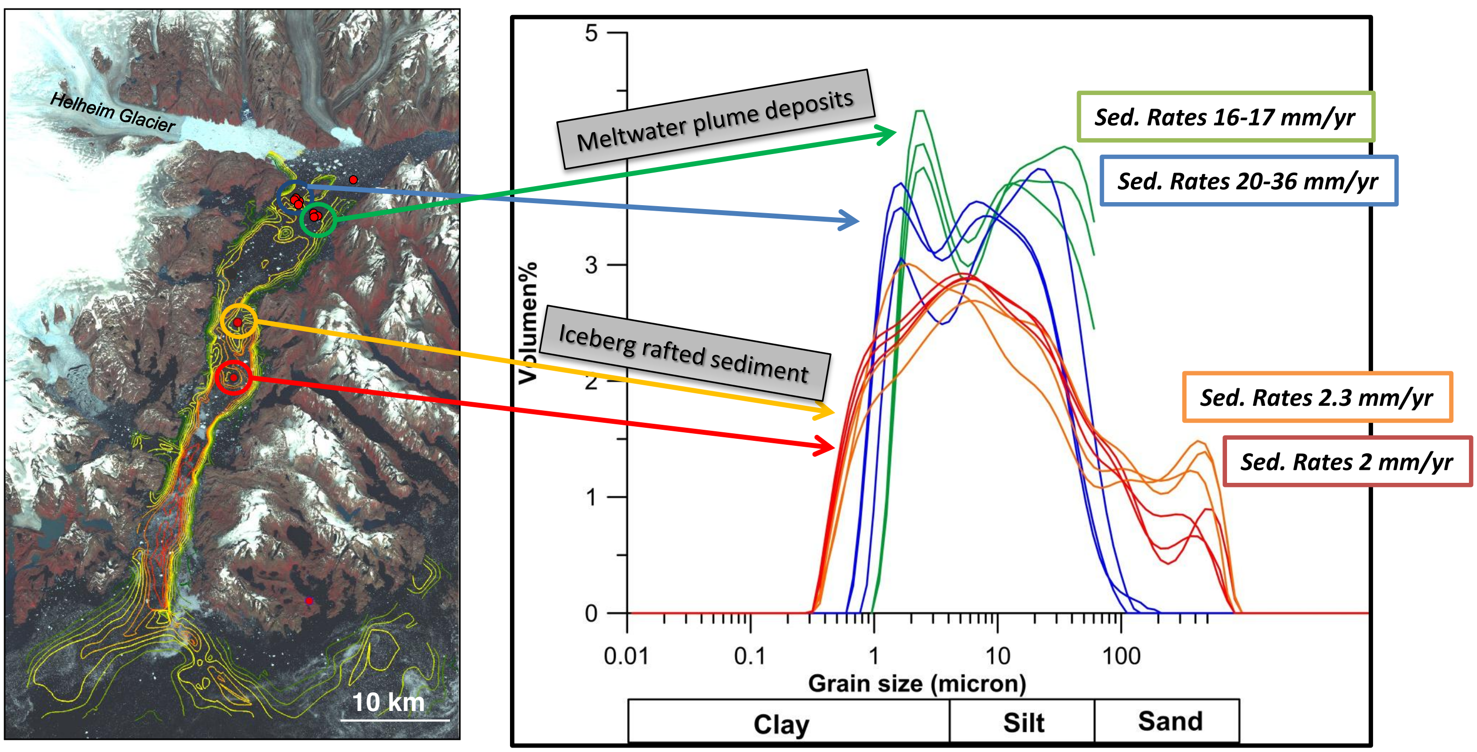
AMO Index
B
Arctic-wide surface temp. anomalies (°C)
Bottom water proxy data
% cold taxa
% warm taxa
Temp. (°C), Disko Bugt 300 m water depth
Cum. ice retreat [km]
Jacobshavns Isbrae
Age (years AD)



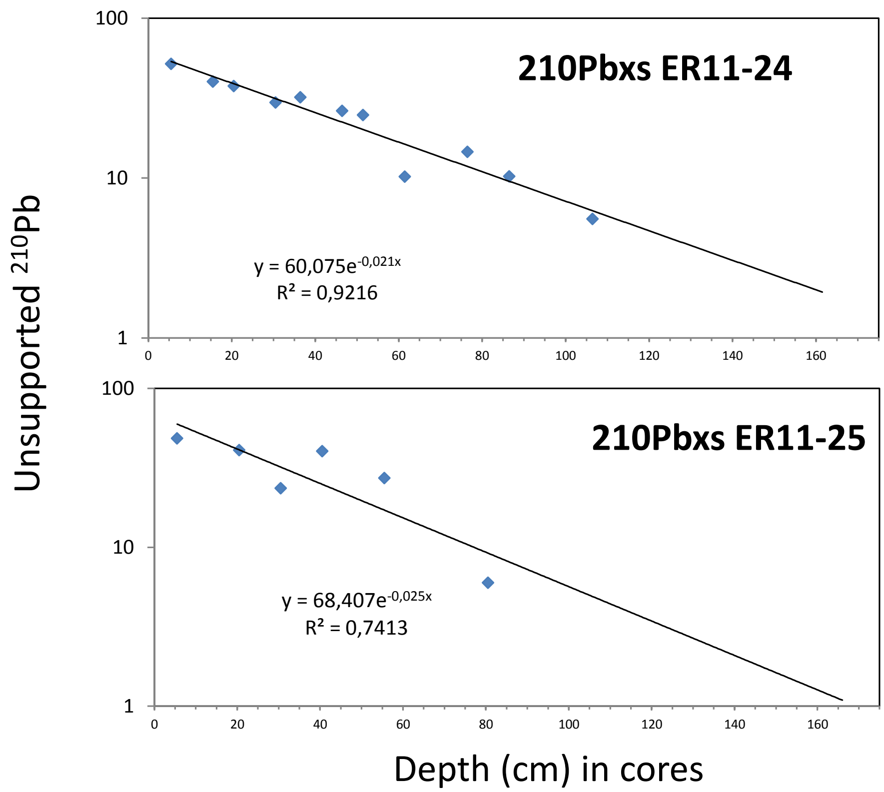
Core top intact
Core top lost
Average sedimentation mm yr-1
Cores c. 150-200 cm
uncertain (only 100 cm long core)
60
57
36
20
21
17
16
Zone where plume
sed. rapidly decreases

Comparing the calving record with current strength proxy

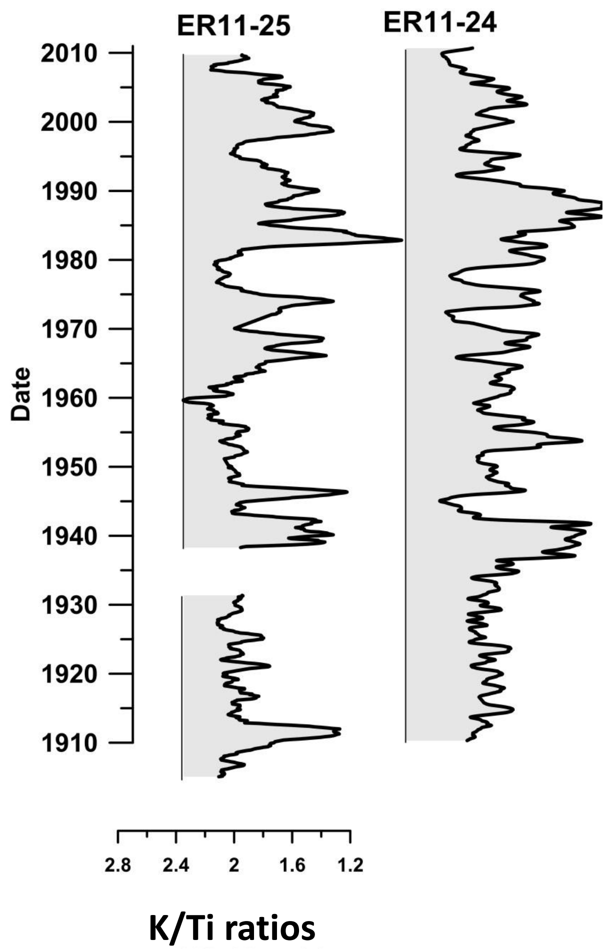
Grain size distributions



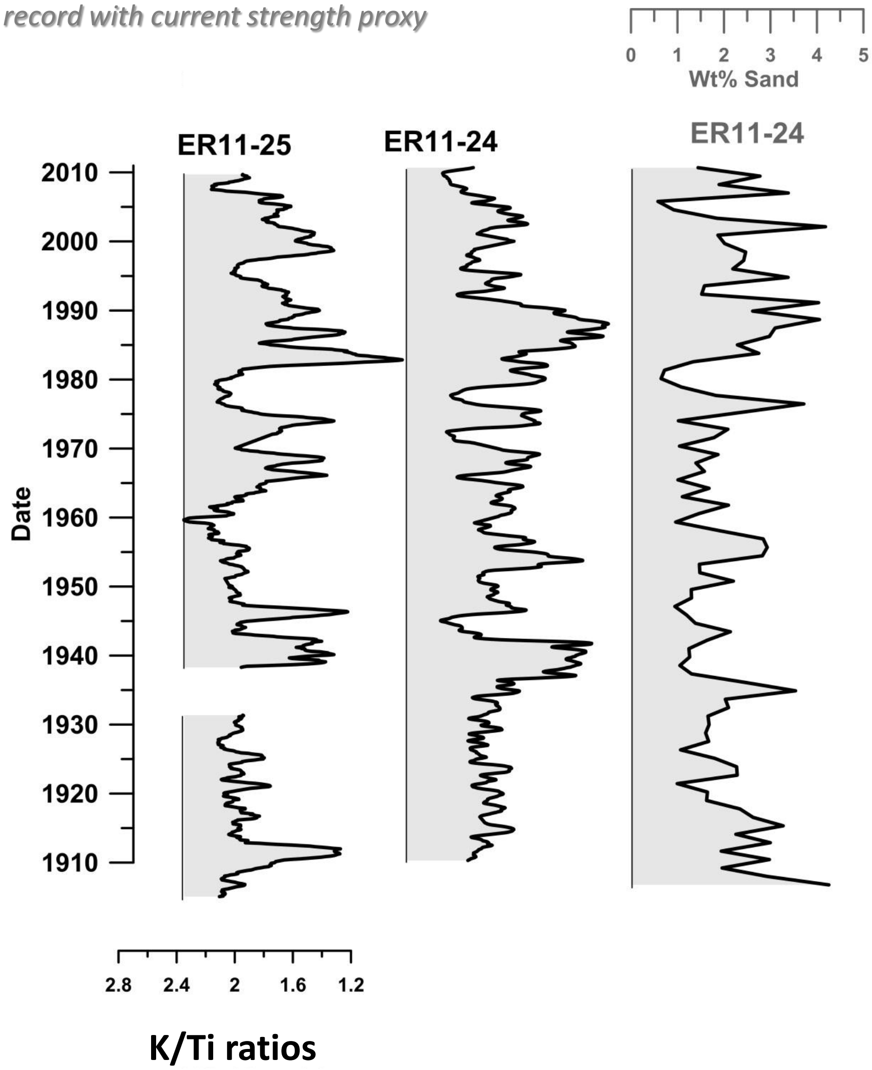
^{210}Pb dating of the meltwater plume sediment



Comparing the calving record with current strength proxy



Comparing the calving record with current strength proxy



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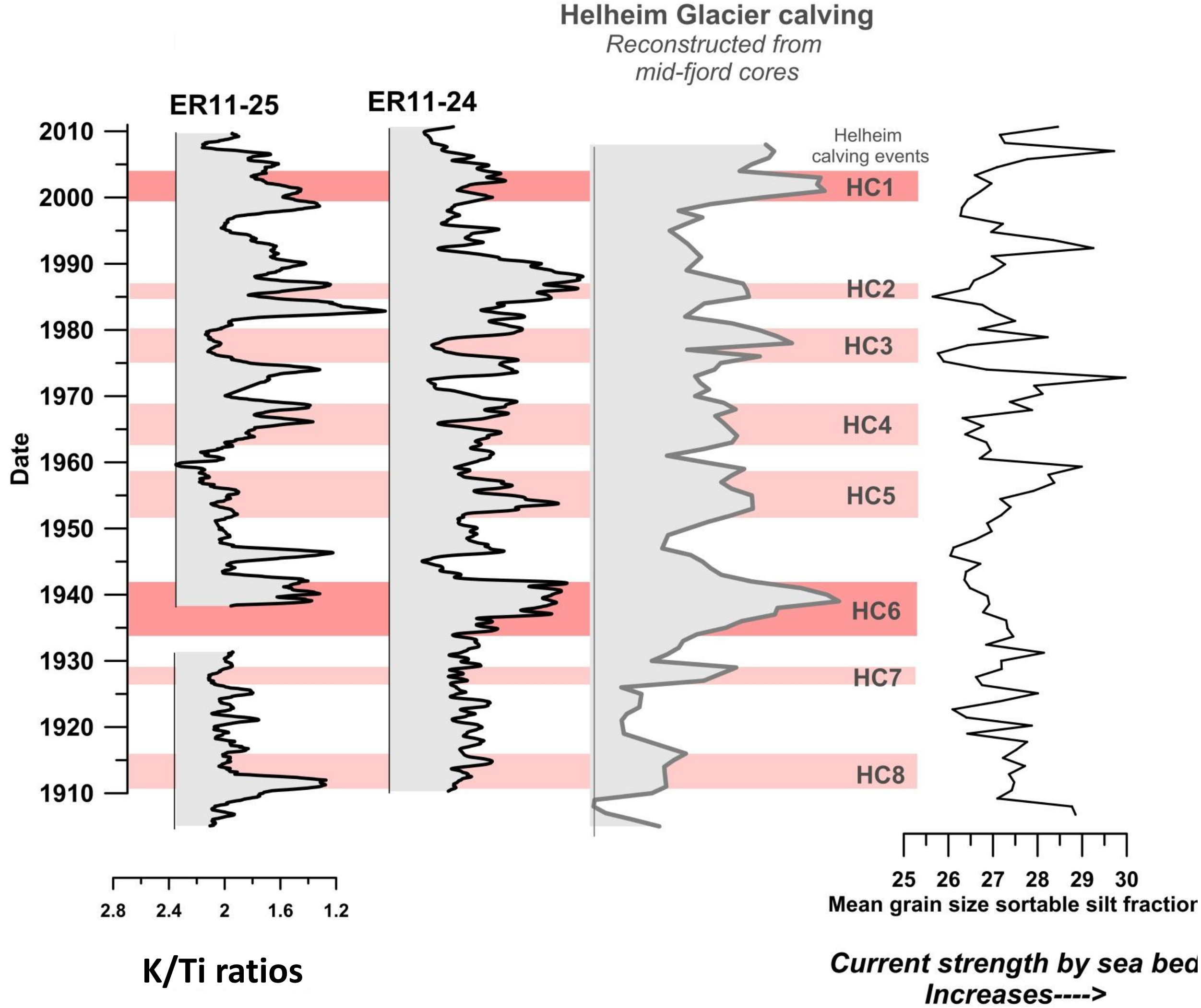
Comparing the calving record with current strength proxy

Helheim Glacier calving

Reconstructed from

K/Ti ratios

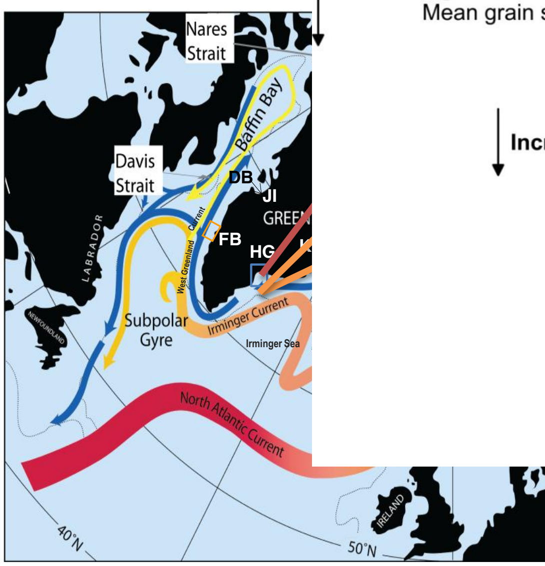
Comparing the calving record with current strength proxy



GEUS

Comparing the calving recc

Increasing current strength by sea bed
Mean grain size sortable silt



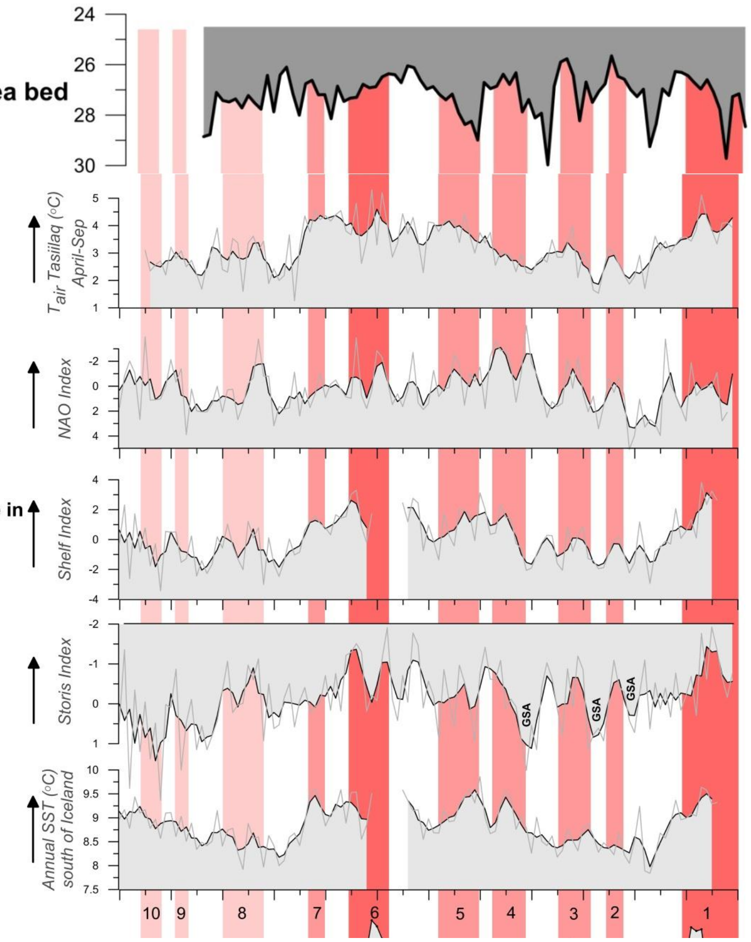
Warming of summer air

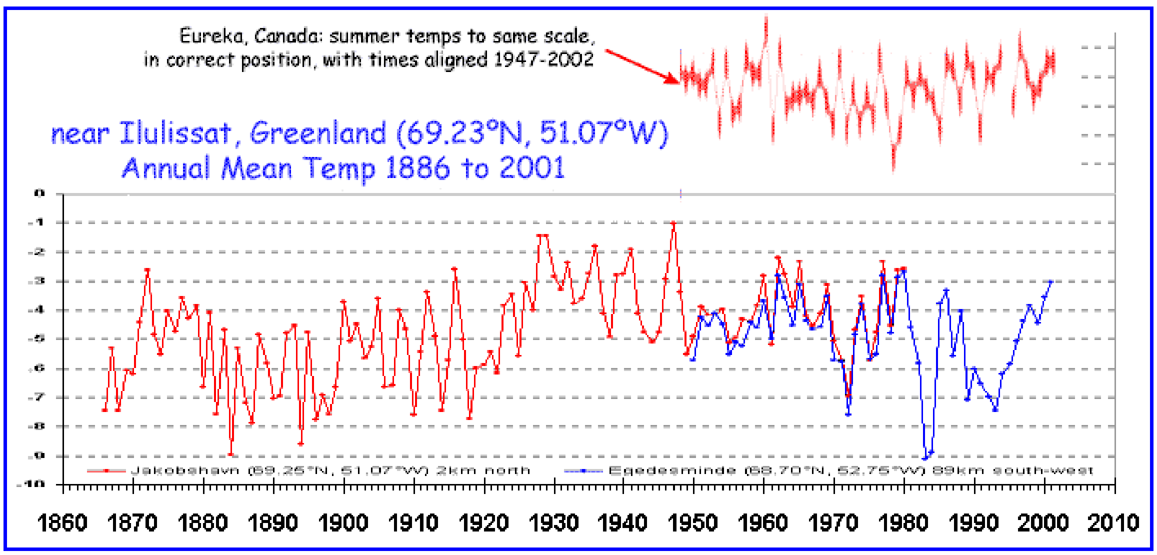
Negative Index

Combined increase in Atlantic Water influence on shelf

Decrease in Polar Water influence

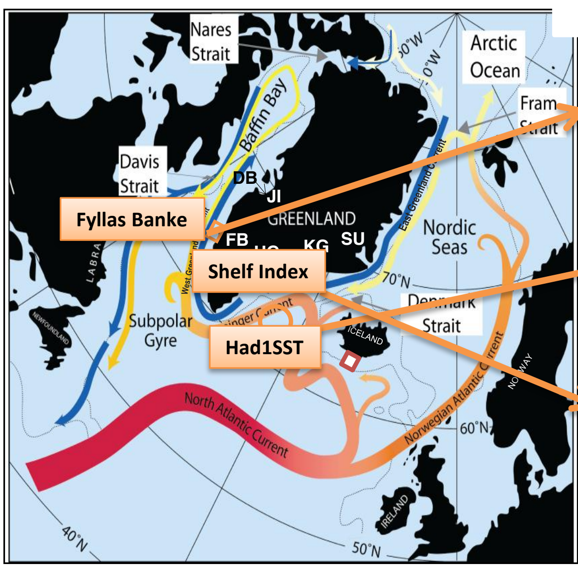
Increase in Atlantic Water influence

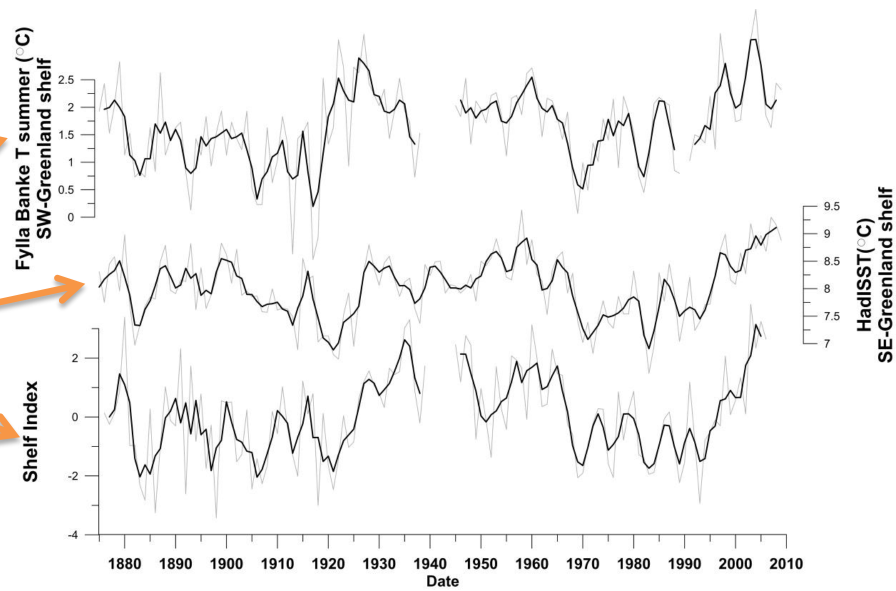



Eureka, Canada: summer temps to same scale,
in correct position, with times aligned 1947-2002
near Ilulissat, Greenland (69.23°N, 51.07°W)
Annual Mean Temp 1886 to 2001
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
Jakobshavn (69.25°N, 51.07°W) 2km north
Egedesminde (68.70°N, 52.75°W) 89km south-west
1860
1870
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010

Comparing the calving record with climate indices

Verifying the Shelf Index



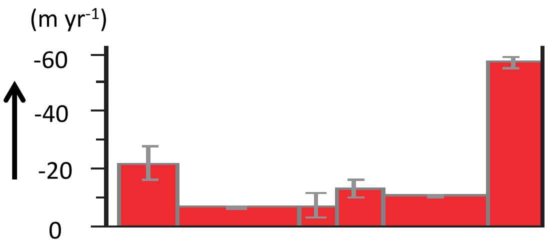


(Andresen et al. 2012)

GEUS

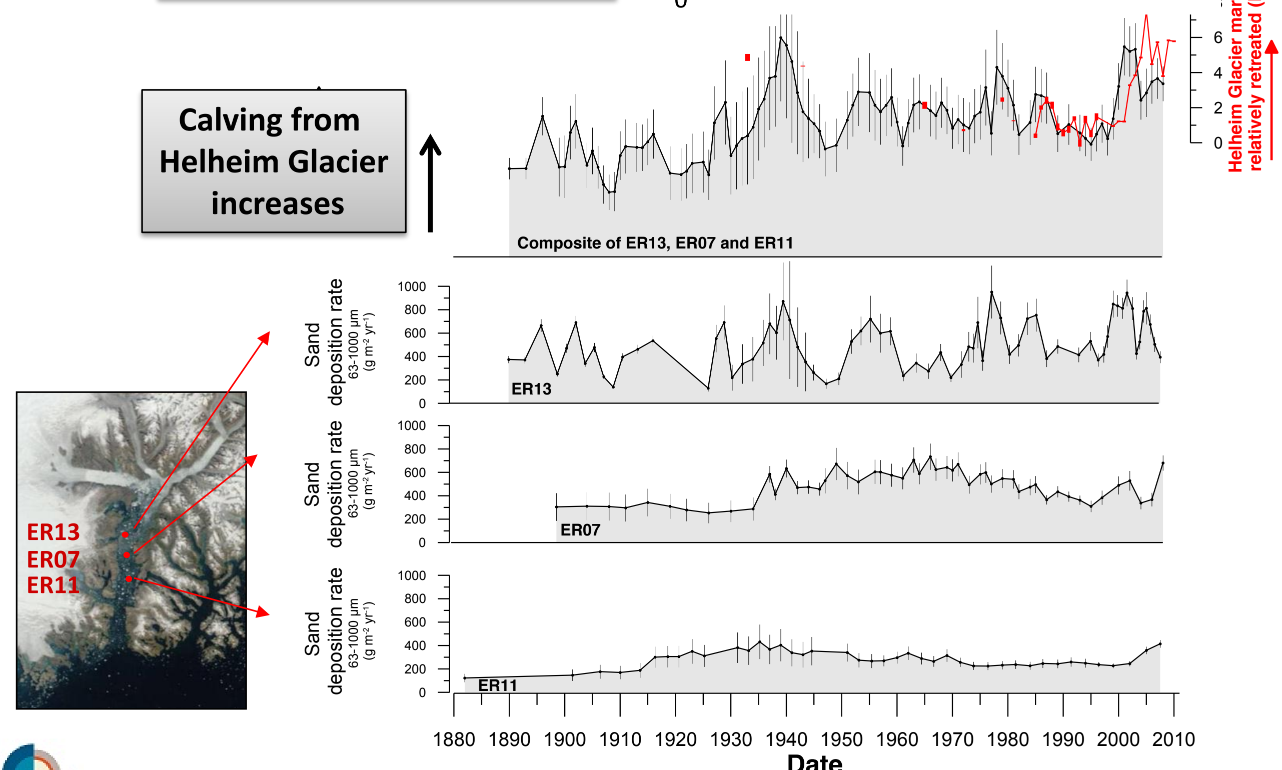
Constructing a calving record

Retreat rate from marine-terminating glaciers in southeast Greenland increases



(Bjørk et al. 2012)

Calving from Helheim Glacier increases



(Andresen et al. 2012)