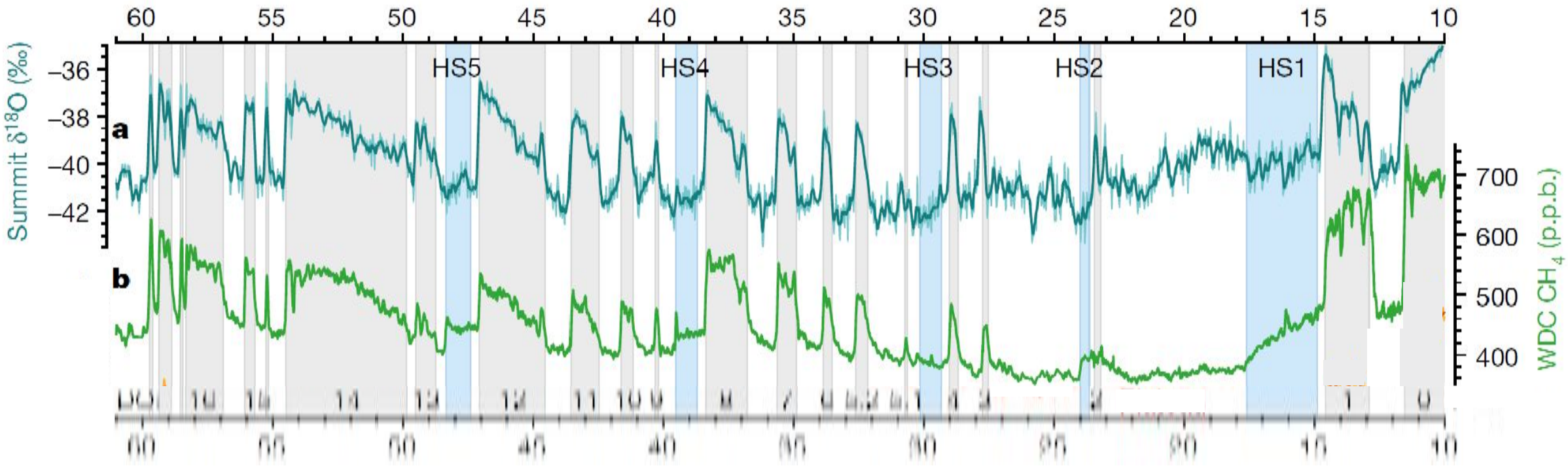
The Greenland fingerprint of DO events in observations and models

Christo Buizert, Todd A. Sowers, Kyle Niezgoda, Thomas Blunier, Vasileios Gkinis, Margaret Harlan, Chengfei He, Tyler R. Jones, Helle A. Kjaer, Jesper B. Liisberg, Zhengyu Liu, J. Andrew Menking, Valerie Morris, David Noone, Sune O. Rasmussen, Louise C. Sime, Jørgen P. Steffensen, Anders Svensson, Bruce H. Vaughn, Bo M. Vinther, and James W.C. White

29th Annual CESM Workshop , Boulder CO

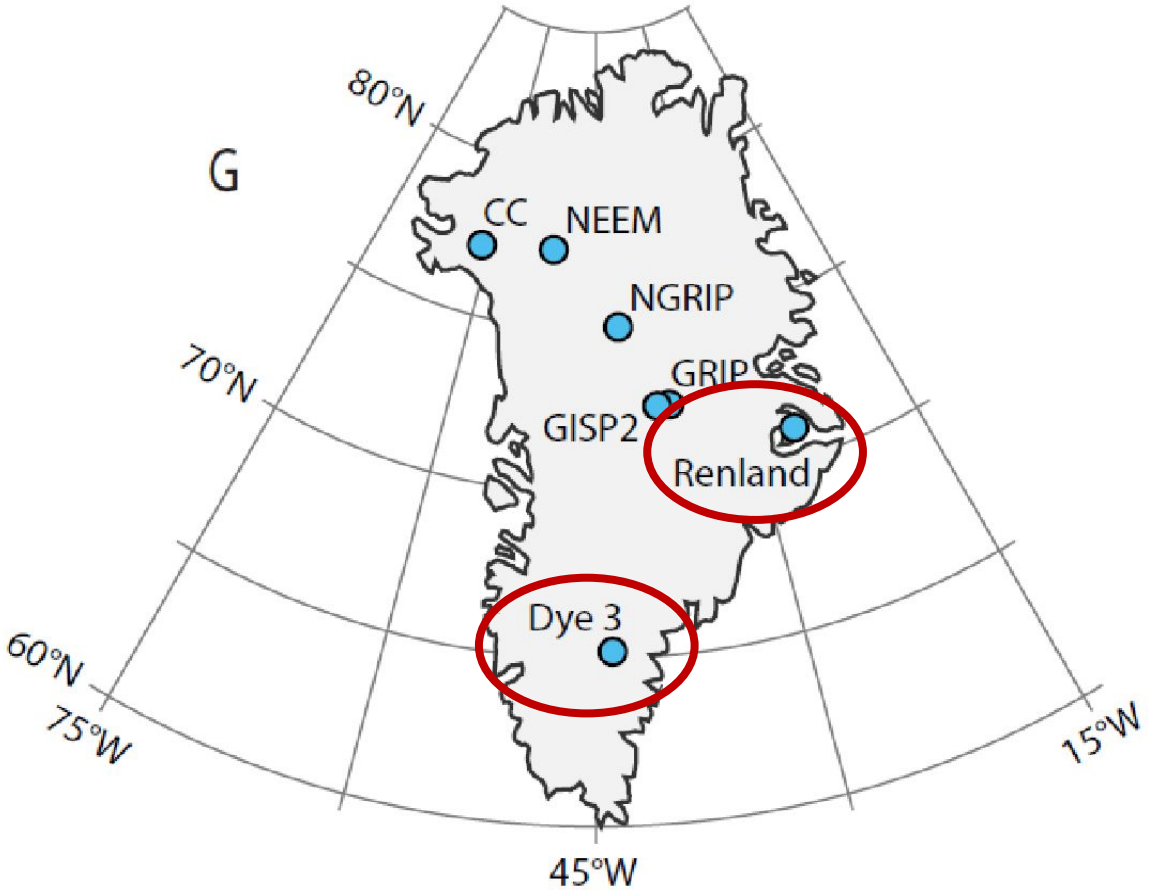
June 12, 2024

Introduction: Dansgaard-Oeschger events



1. Compile Greenland ice core DO event data
2. Compare to isotope-enabled model simulations
3. Use framework to improve understanding of DO dynamics

Ice cores and proxies



Catalogue changes in:

- Site temperature (from $\delta^{15}N\text{-}N_2$)
- The $\delta^{18}O$ of ice (proxy for site temperature proxy)
- Deuterium excess of ice (proxy for vapor source conditions)
- Accumulation rate

The models

HadCM3:

PNAS

Impact of abrupt sea ice loss on Greenland water isotopes during the last glacial period

Louise C. Sime[a,1], Peter O. Hopcroft[b], and Rachael H. Rhodes[c,2]

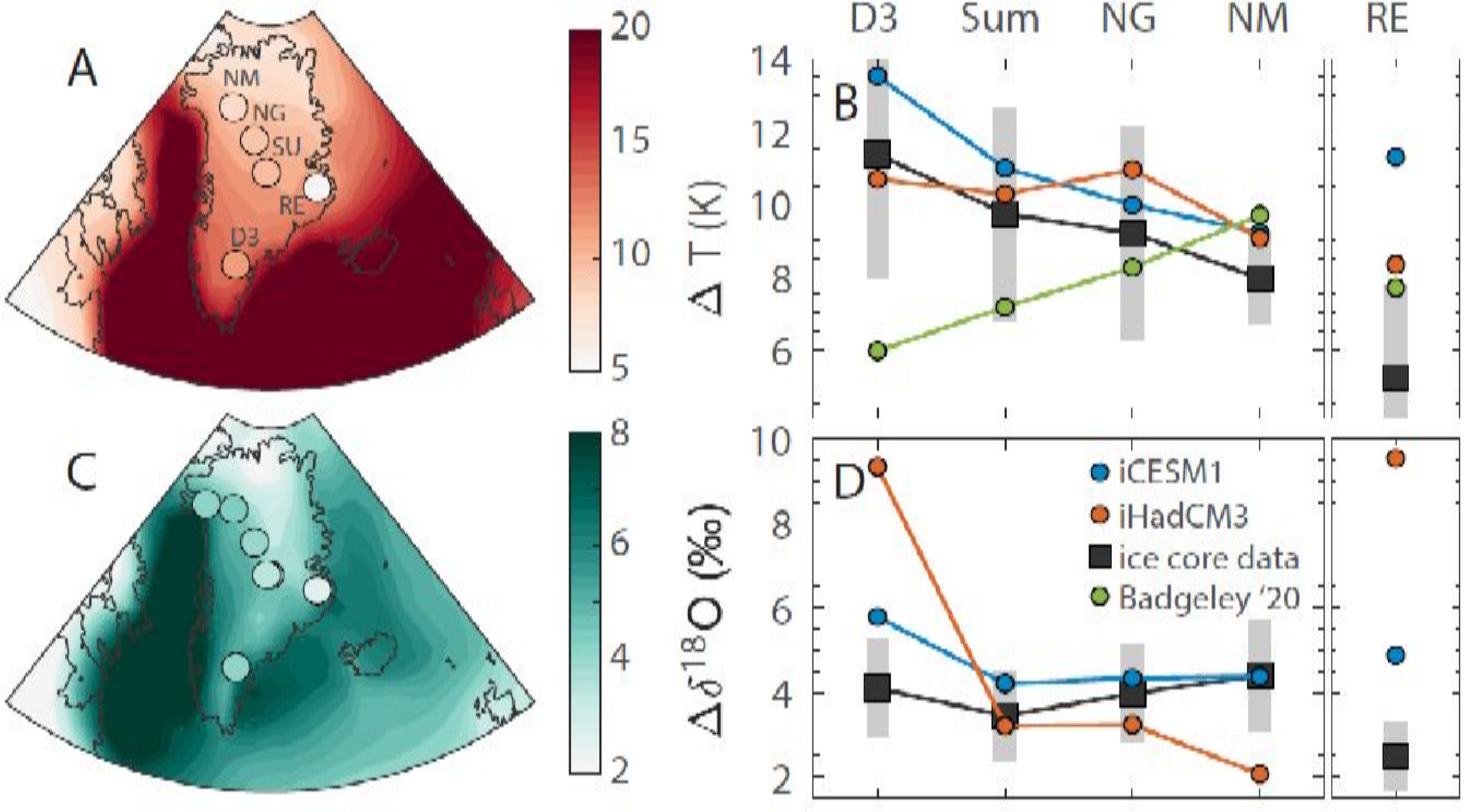
CESM:

SCIENCE ADVANCES | RESEARCH ARTICLE

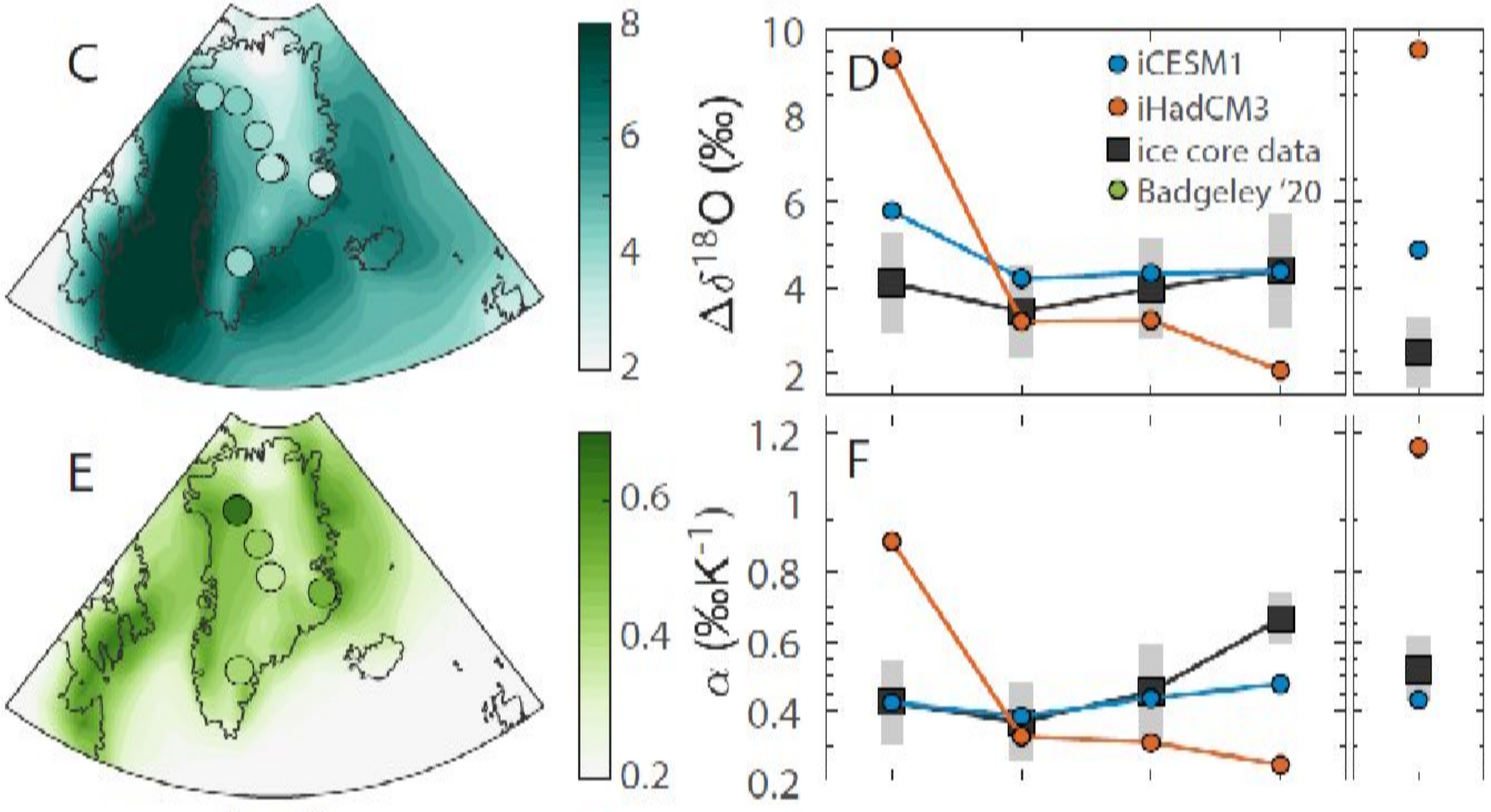
Abrupt Heinrich Stadial 1 cooling missing in Greenland oxygen isotopes

Chengfei He[1,2,3], Zhengyu Liu[2,4]*, Bette L. Otto-Bliesner[5], Esther C. Brady[5], Chenyu Zhu[3,6], Robert Tomas[5], Christo Buizert[7], Jeffrey P. Severinghaus[8]

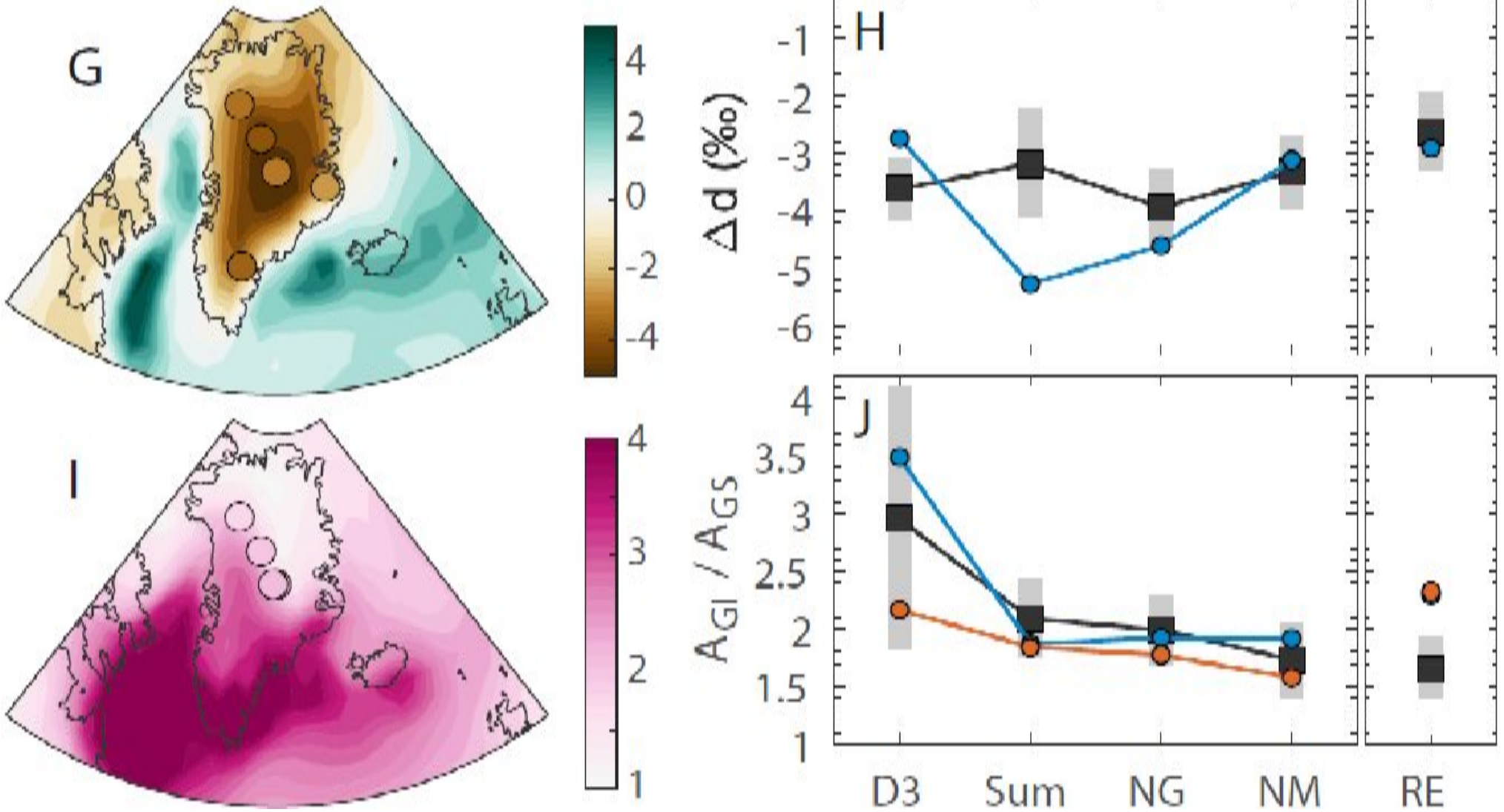
Spatial Fingerprint Pt. 1



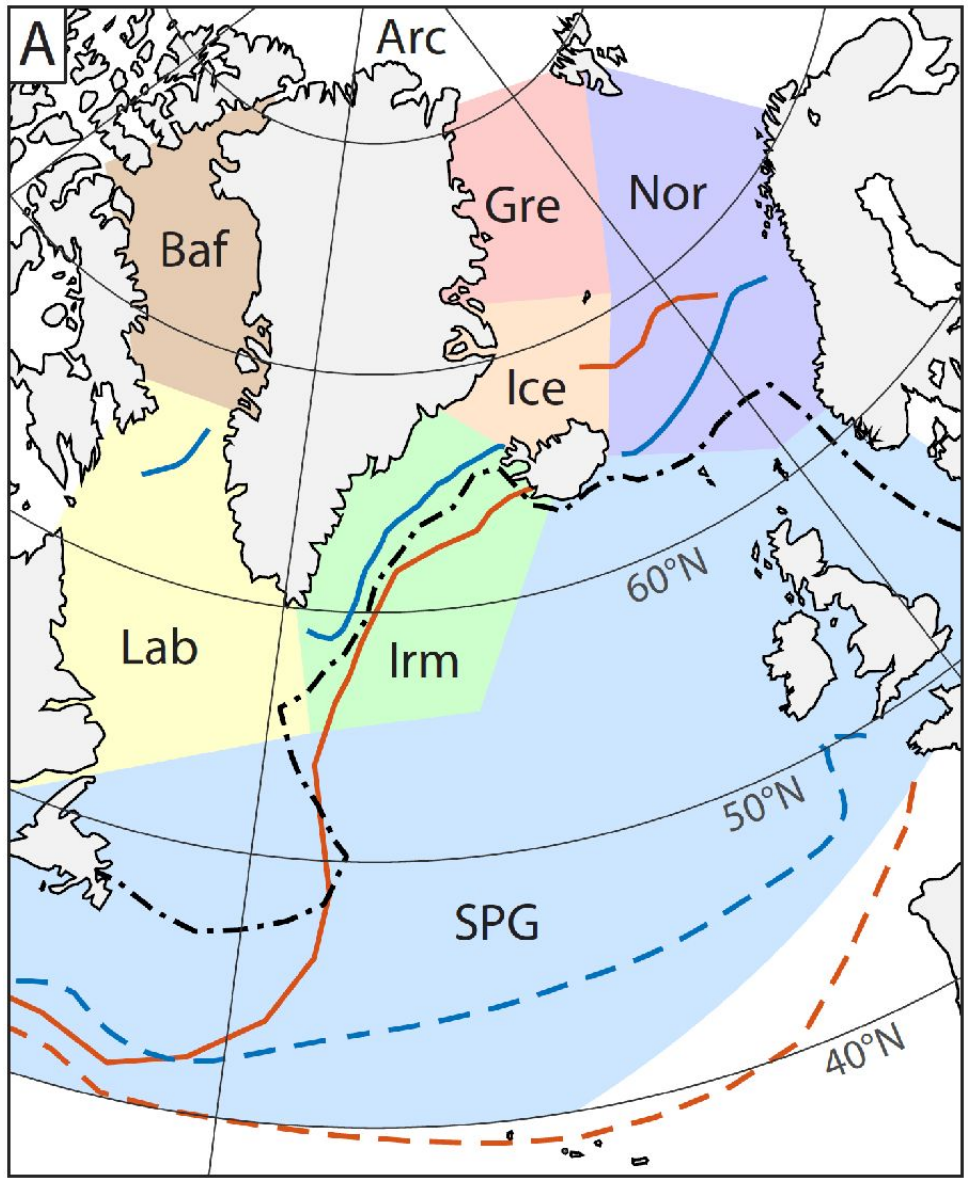
Spatial Fingerprint Pt. 2



Spatial Fingerprint Pt. 3



The link to sea ice



Models (CESM, HadCM3) have skill in simulation DO events.

Large migration of winter sea ice edge across DO event.

Focus in Sub Polar Gyre (SPG)

Series of Idealized atmosphere-only DO experiments: Apply sea ice anomalies to different sectors of N-Atlantic

Idealized sea ice experiments

What is needed to explain Greenland DO fingerprint:

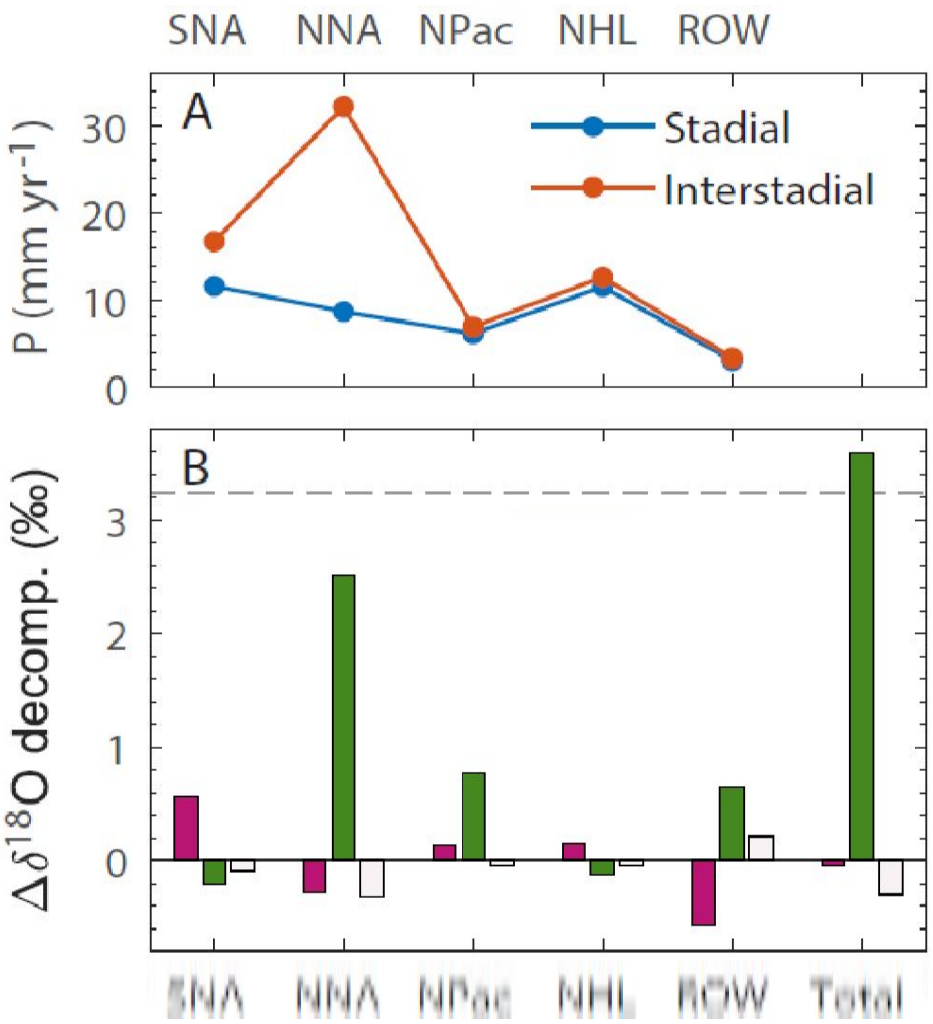
(1) Winter sea ice cover in stadial SPG is **sufficient condition**

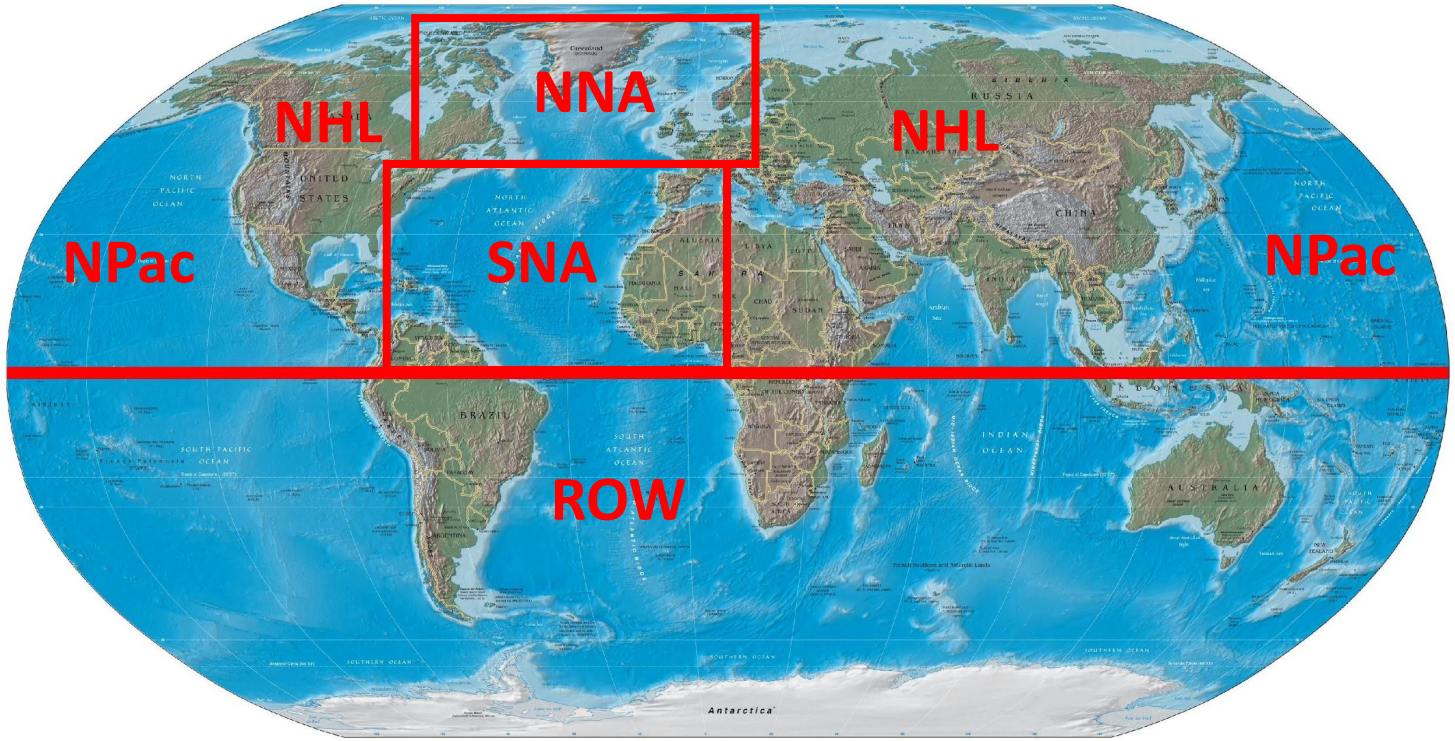
(2) Sea ice variations in the Nordic seas alone insufficient

(3) SST alone is insufficient

(4) Winter sea ice cover in stadial SPG *may be* a **necessary condition**

Moisture tagging experiments





Distillation *en route*

Changing vapor source distribution

Other

Conclusions

(1) New records of δ^{15}N-N_2 from Dye-3 and Renland cores

(2) Spatial multi-proxy fingerprints of DO signal across Greenland

(3) Coupled models have skill at simulating DO signals

(4) Idealized model simulations suggest SPG stadial winter sea ice cover is *sufficient* to explain DO, and may be *necessary*

(5) The δ^{18}O and *d* isotopic signals reflect changes in source region distribution, not Rayleigh distillation or ΔT

Nordic seas?

Dansgaard-Oeschger cycles: Interactions between ocean and sea ice intrinsic to the Nordic seas

Trond M. Dokken,[1,2] Kerim H. Nisancioglu,[1,2,3] Camille Li,[2,4] David S. Battisti,[2,5] and Catherine Kissel[6]

Sea ice and millennial-scale climate variability in the Nordic seas 90 kyr ago to present

Ulrike Hoff[1], Tine L. Rasmussen[1], Ruediger Stein[2,3], Mohamed M. Ezat[1,4] & Kirsten Fahl[2]

Water mass exchange between the Nordic seas and the Arctic Ocean on millennial timescale during MIS 4–MIS 2

Tine L. Rasmussen

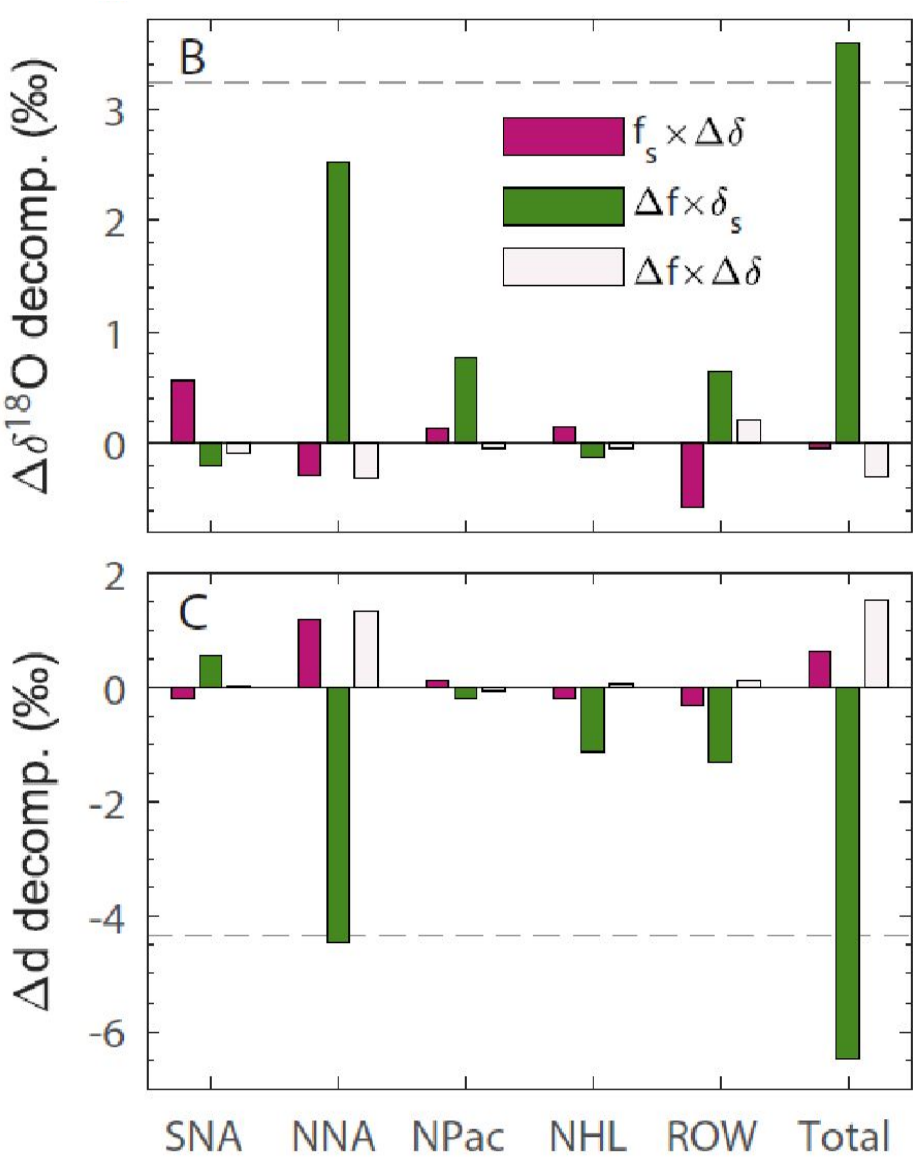
Evolution of the central Nordic Seas over the last 20 thousand years

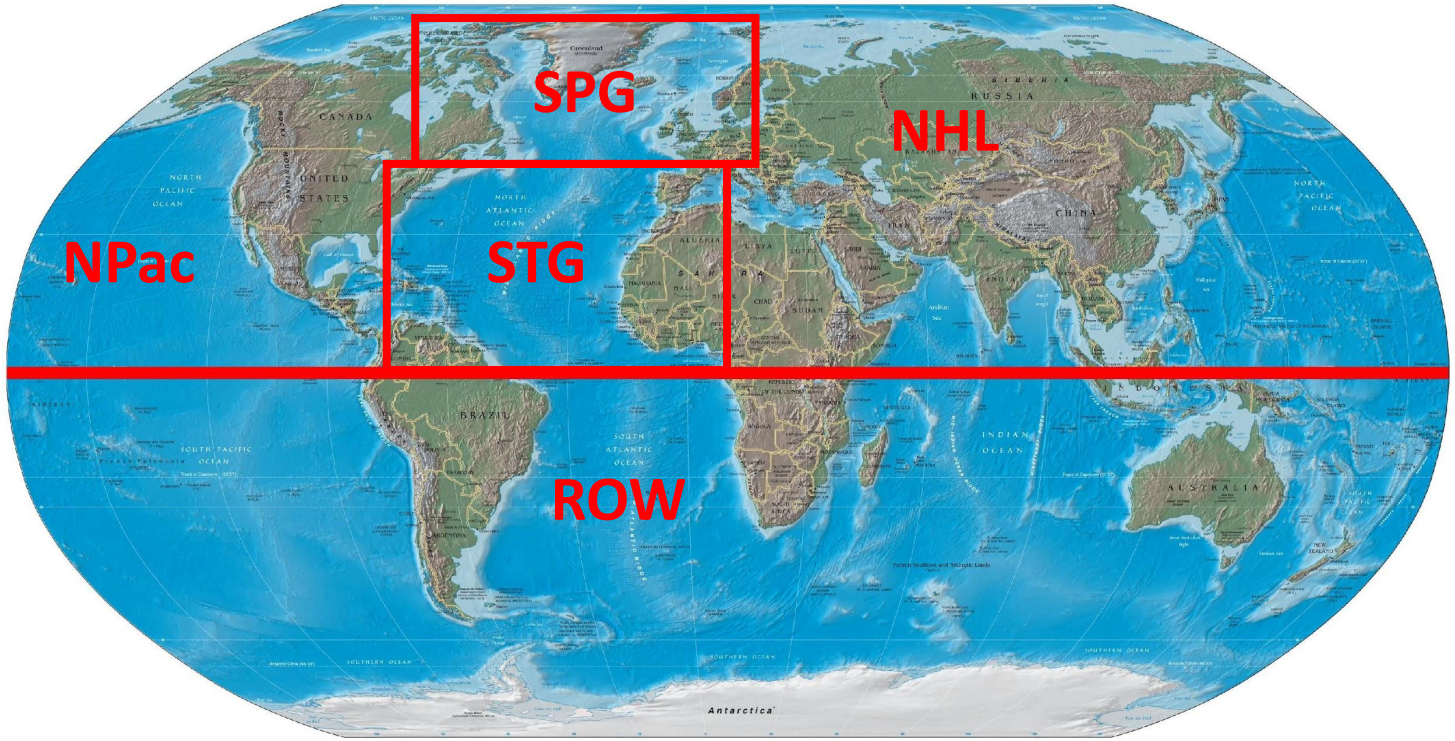
M.M. Telesiński [a, b, *], H.A. Bauch [a, b], R.F. Spielhagen [a, b], E.S. Kandiano [a, 1]

Persistent intermediate water warming during cold stadials in the southeastern Nordic seas during the past 65 k.y.

Mohamed M. Ezat[1,2*], Tine L. Rasmussen[1], and Jeroen Groeneveld[3]

Moisture tagging experiments

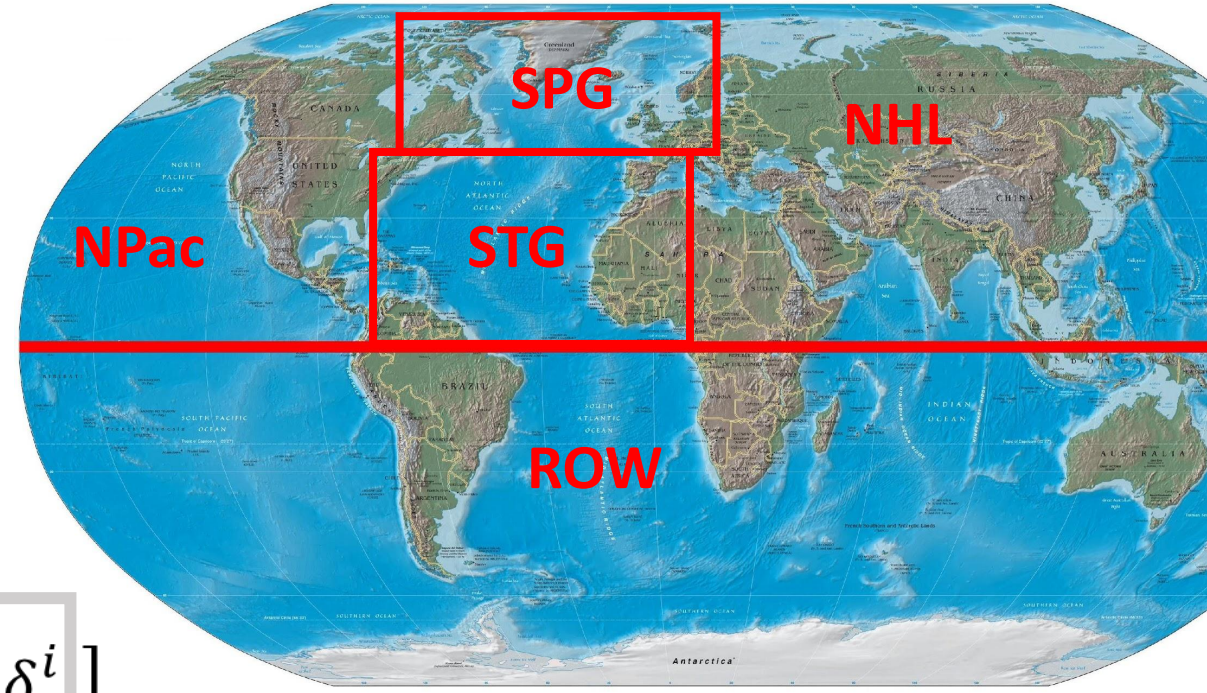




$$\Delta\delta^{18}O = \sum_{i \in tags} \left[f_S^i \times \Delta\delta^i + \Delta f^i \times \delta_S^i + \Delta f^i \times \Delta\delta^i \right]$$

Moisture tagging experiments

$$\delta^{18}O = \sum_{i \in tags} [f^i \times \delta^i]$$



$$\Delta\delta^{18}O = \sum_{i \in tags} [f_S^i \times \Delta\delta^i + \Delta f^i \times \delta_S^i + \Delta f^i \times \Delta\delta^i]$$

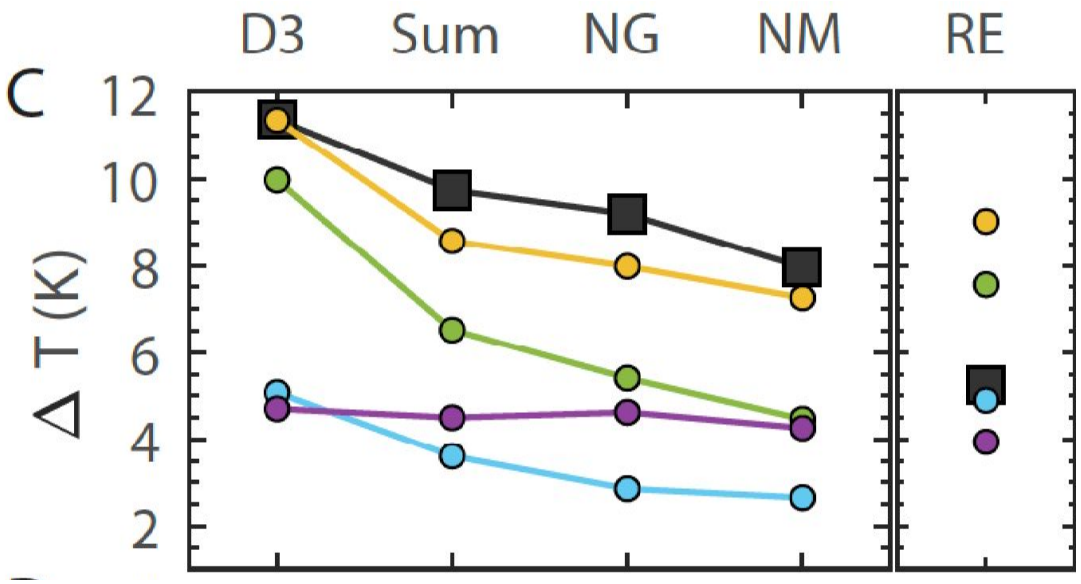
Changes in isotopic fractionation (source areas stay same)

Changes source areas (fractionation stays same)

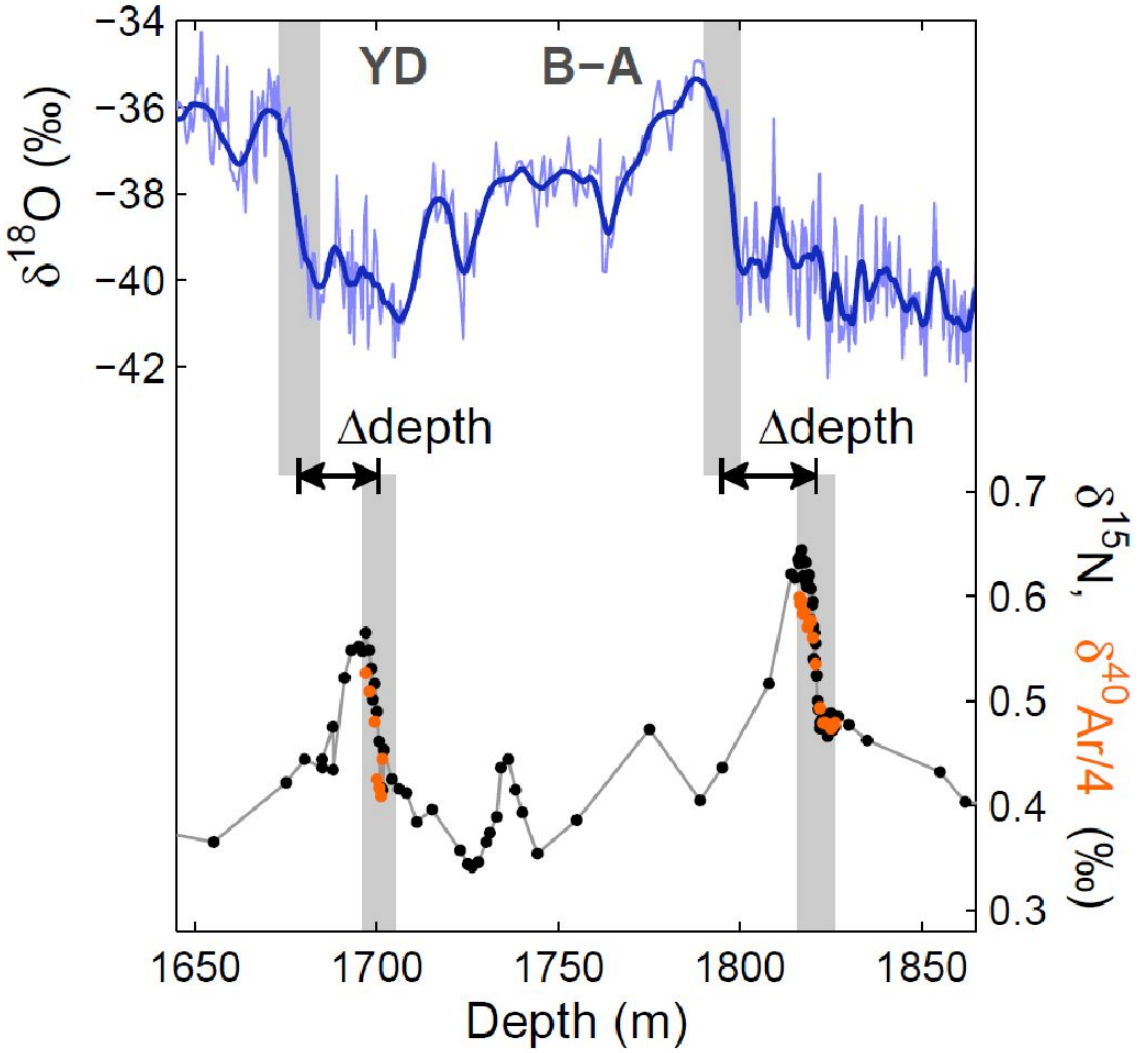
Cross product

Idealized sea ice experiments

ΔT (K) ↓ Stadial / Interstadial →	SIC: minus Nor Ice Gre SST: CTRL	SIC: minus Nor Ice SST: CTRL	SIC: minus Nor SST: CTRL	SIC: CTRL SST: CTRL	SIC: plus Lab SST: CTRL	SIC: plus Irm SST: CTRL	SIC: plus Irm Lab SST: CTRL	SIC: plus Irm Lab SPG SST: CTRL	SIC: plus Irm Lab SPG SST: minus 1°C	SIC: plus Irm Lab SPG SST: minus 2°C	SIC: CTRL SST: minus 4°C	SIC: CTRL SST: minus 8°C
SIC: minus Nor Ice Gre SST: CTRL	8.94											
SIC: minus Nor Ice SST: CTRL	8.29	8.94										
SIC: minus Nor SST: CTRL	6.12	6.73	8.94									
SIC: CTRL SST: CTRL	5.40	5.96	8.15	8.94								
SIC: plus Lab SST: CTRL	5.21	5.77	7.94	8.73	8.94							
SIC: plus Irm SST: CTRL	3.09	3.40	5.39	6.15	6.34	8.94						
SIC: plus Irm Lab SST: CTRL	2.97	3.26	5.19	5.95	6.14	8.72	8.94					
SIC: plus Irm Lab SPG SST: CTRL	4.77	3.83	2.23	1.88	1.86	3.33	3.53	8.94			3.87	4.75
SIC: plus Irm Lab SPG SST: minus 1°C	5.50	4.56	2.72	2.13	2.04	2.71	2.91	8.11	8.94		3.19	4.02
SIC: plus Irm Lab SPG SST: minus 2°C	6.12	5.19	3.24	2.55	2.40	2.32	2.48	7.46	8.27	8.94	2.72	3.49
SIC: CTRL SST: minus 4°C	2.57	2.74	4.78	5.53	5.73	8.35	8.58				8.94	
SIC: CTRL SST: minus 8°C	2.11	1.97	3.91	4.65	4.85	7.47	7.70				8.03	8.94

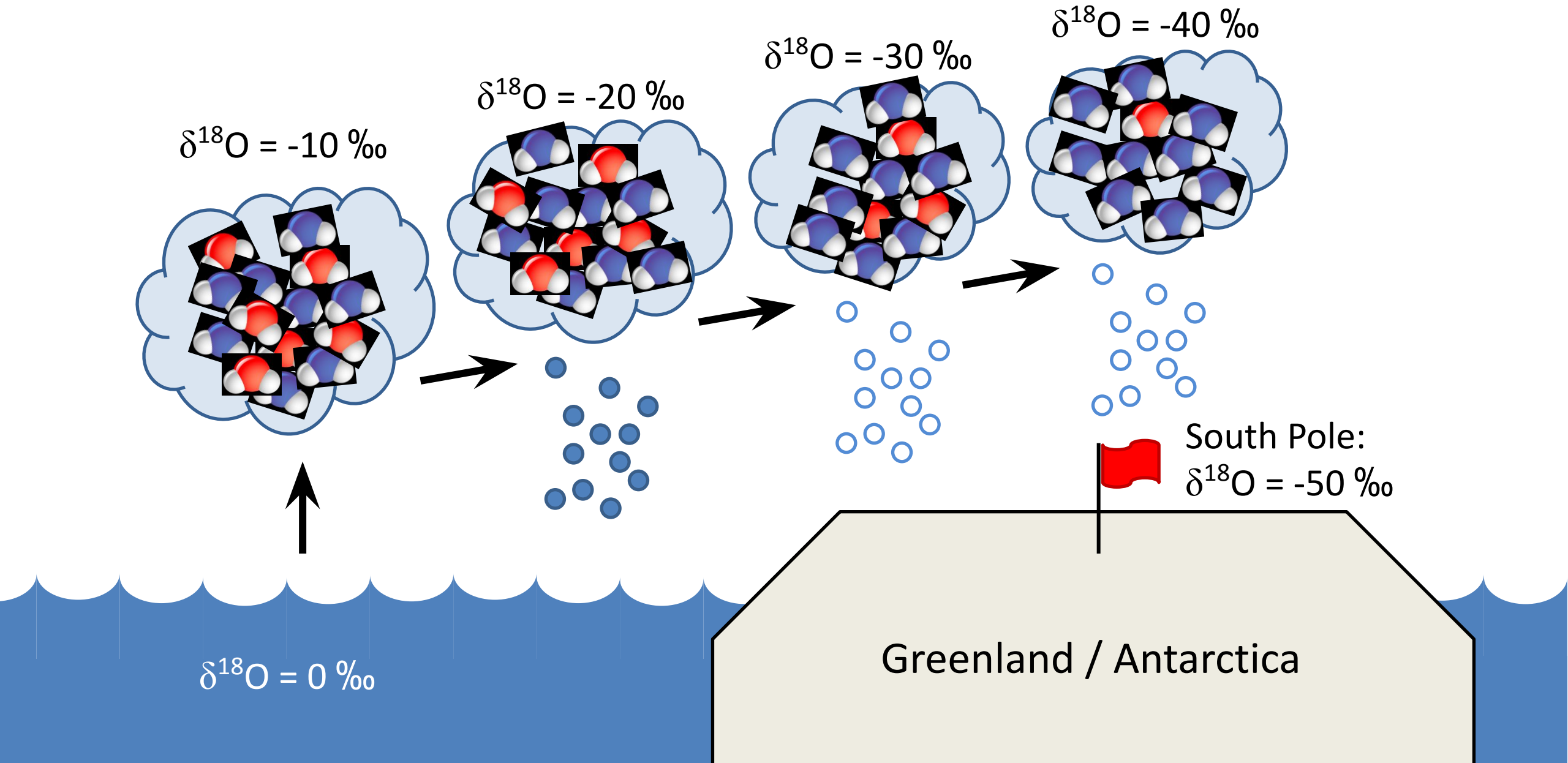


δ^{15}N-N$_2$ as proxy for ΔT

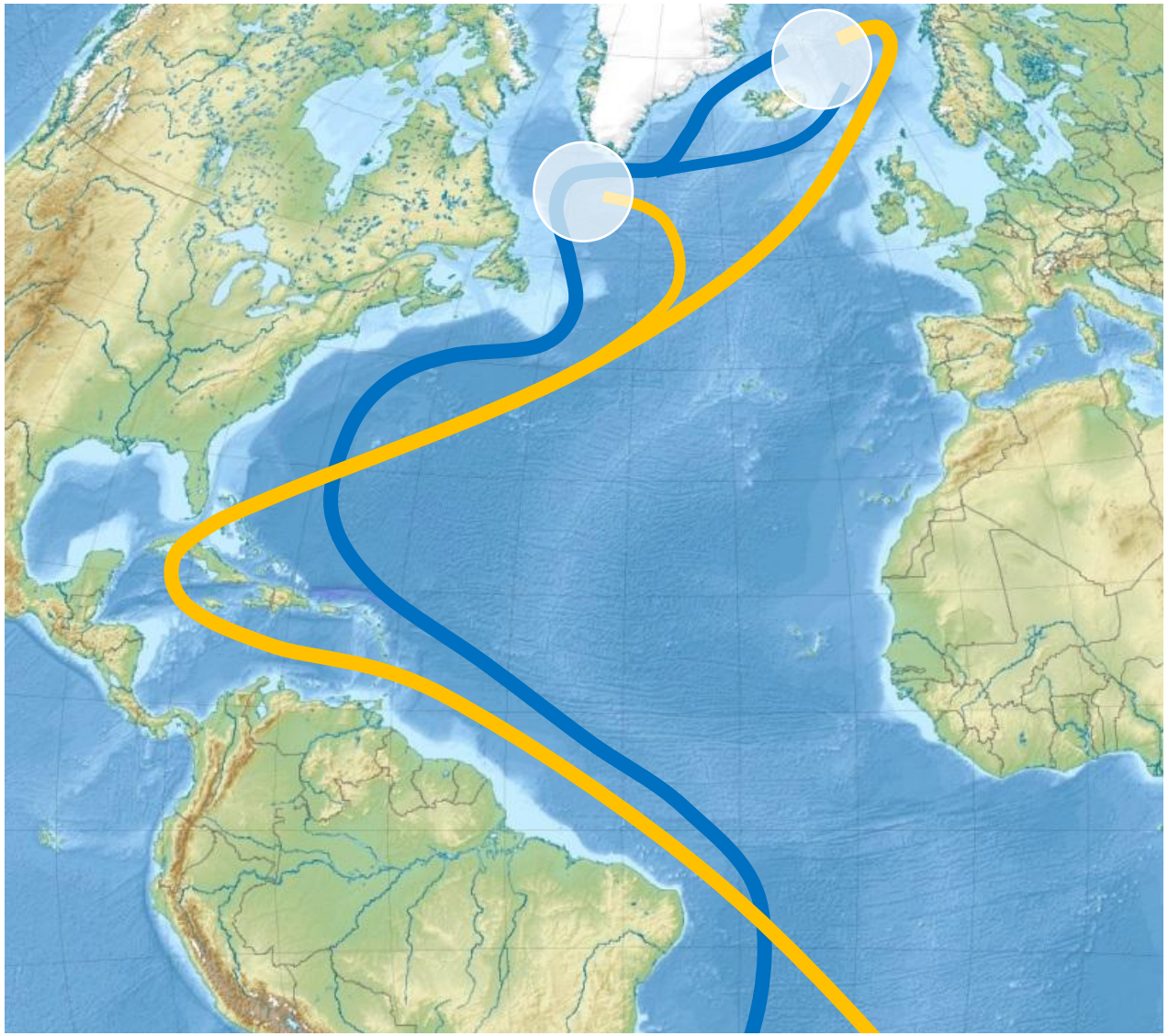


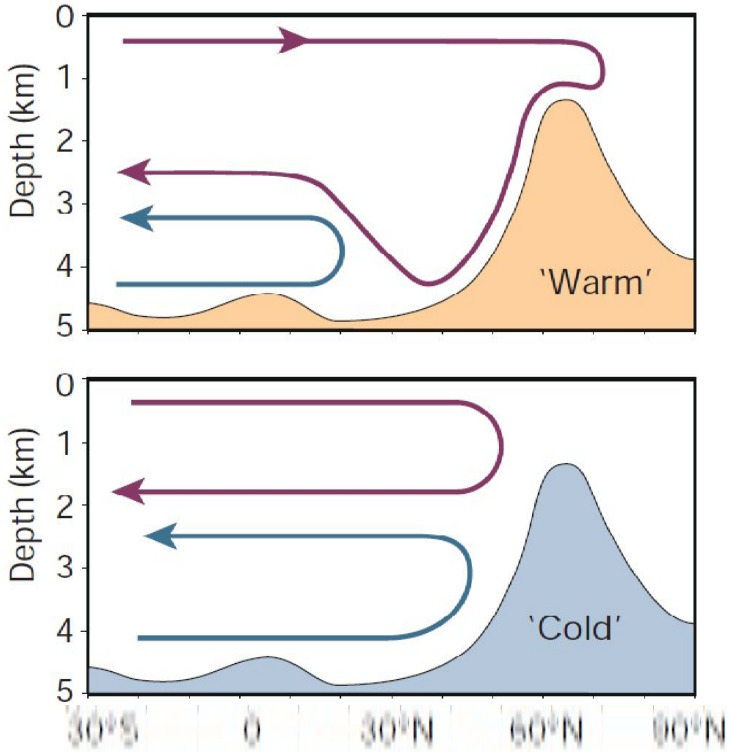
- Each abrupt DO event has a transient excursion in δ^{15}N-N$_2$
- Caused by thermal fractionation in firn layer
- DO event magnitude ΔT proportional to δ^{15}N-N$_2$

The water isotope thermometer: Rayleigh distillation



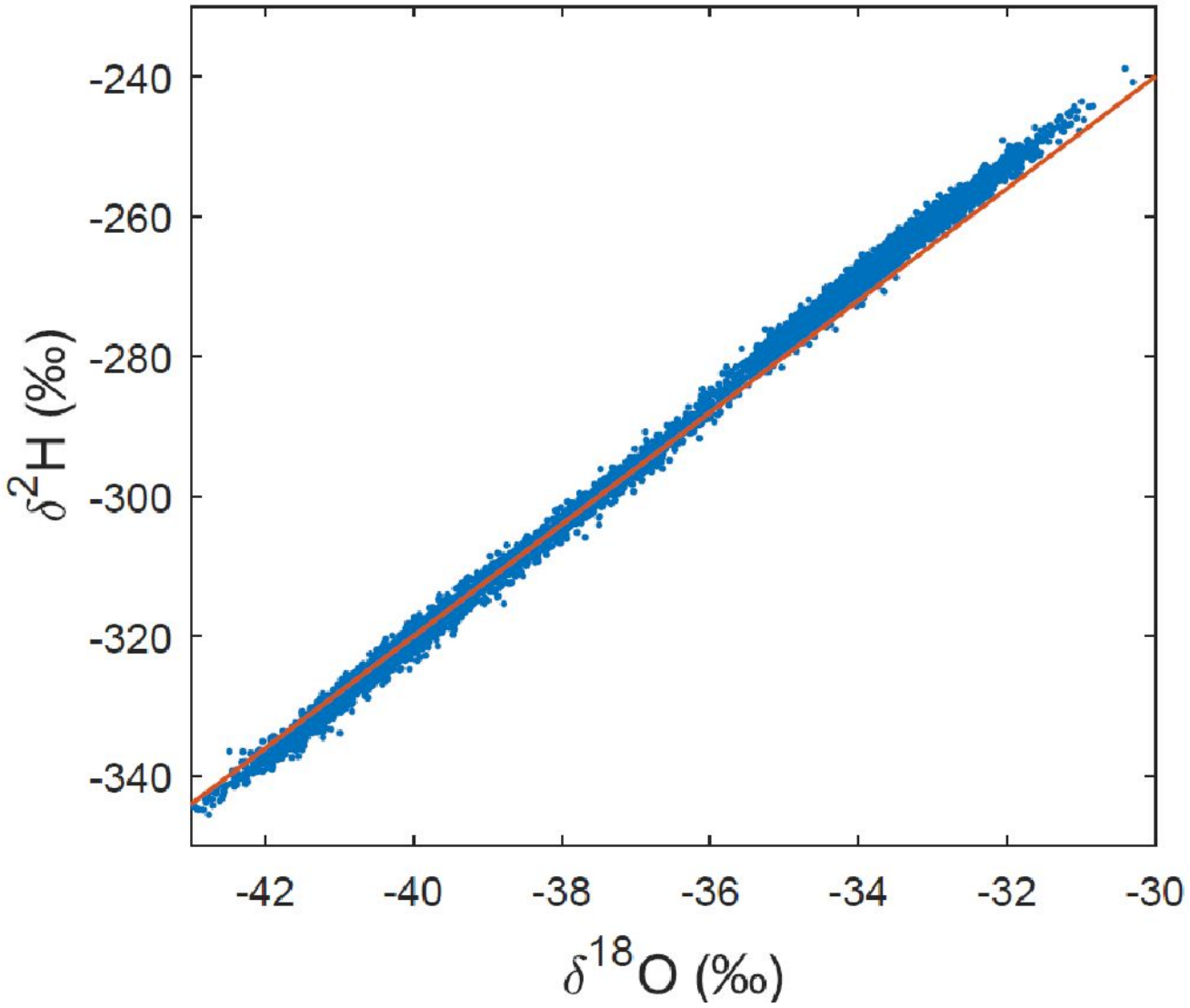
Atlantic Meridional Overturning Circulation





[Rahmstorf 2002]

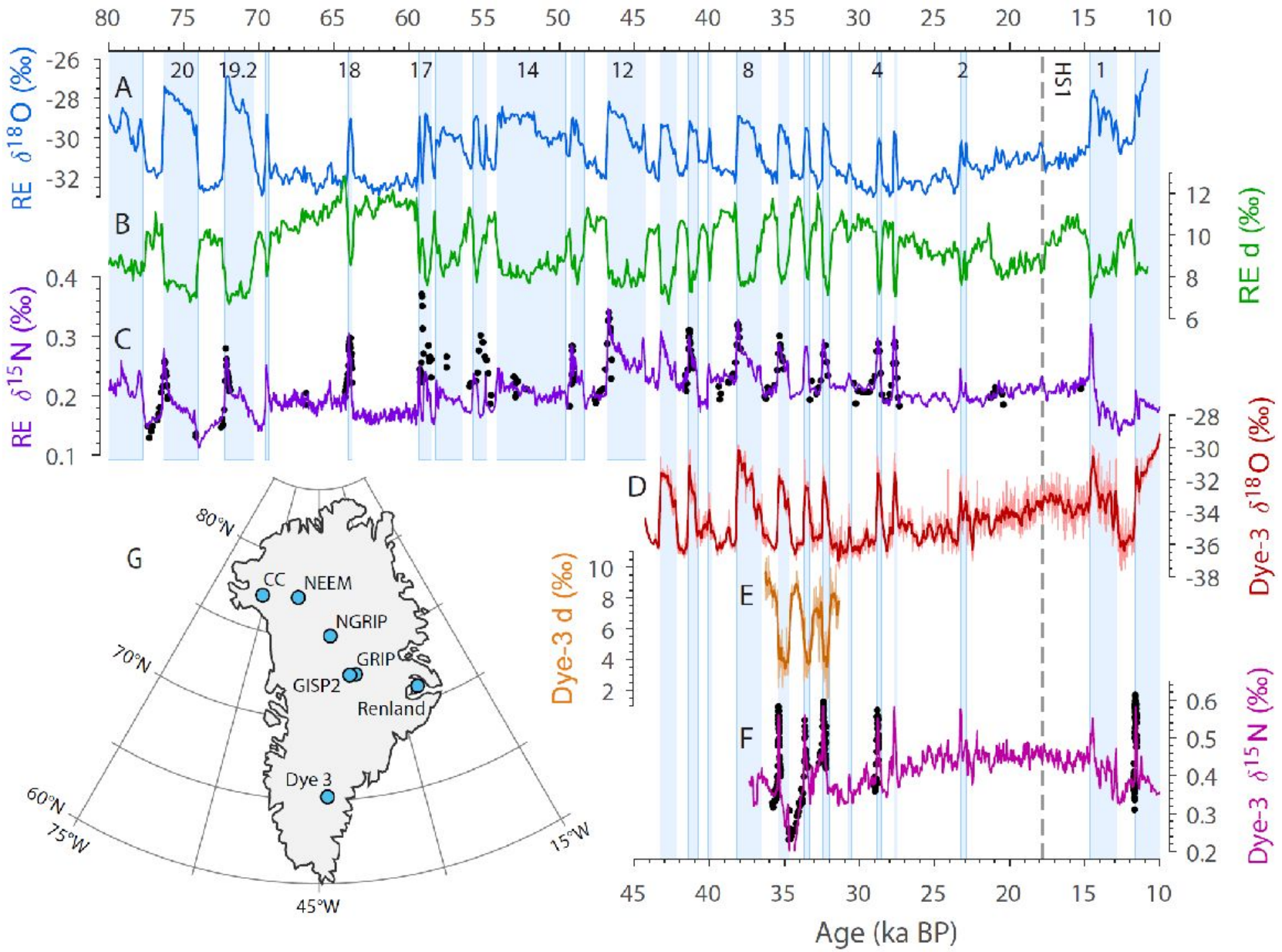
Deuterium excess



Traditional definition:
$d = \delta^2H - 8 \times \delta^{18}O$

d reflects kinetic fractionation during **evaporation**;
- positively correlated with source SST
- anti-correlated with rel. humidity

New Dye-3 and Renland data



Nordic seas?

Dansgaard-Oeschger cycles: Interactions between ocean and sea ice intrinsic to the Nordic seas

Trond M. Dokken,[1,2] Kerim H. Nisancioglu,[1,2,3] Camille Li,[2,4] David S. Battisti,[2,5] and Catherine Kissel[6]

Sea ice and millennial-scale climate variability in the Nordic seas 90 kyr ago to present

Ulrike Hoff[1], Tine L. Rasmussen[1], Ruediger Stein[2,3], Mohamed M. Ezat[1,4] & Kirsten Fahl[2]

Water mass exchange between the Nordic seas and the Arctic Ocean on millennial timescale during MIS 4–MIS 2

Tine L. Rasmussen

Evolution of the central Nordic Seas over the last 20 thousand years

M.M. Telesiński [a, b, *], H.A. Bauch [a, b], R.F. Spielhagen [a, b], E.S. Kandiano [a, 1]

Persistent intermediate water warming during cold stadials in the southeastern Nordic seas during the past 65 k.y.

Mohamed M. Ezat[1,2*], Tine L. Rasmussen[1], and Jeroen Groeneveld[3]