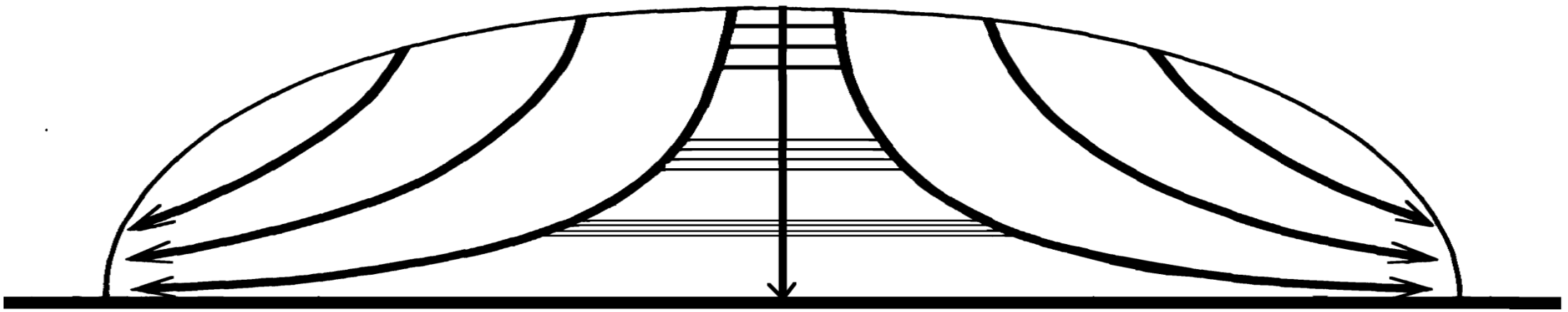
Temadag fysiklærere den 30.Januar 2026: Hvor gammel er Grønlands Indlandsis?

Ved Jørgen Peder Steffensen, sektionen for is, klima og geofysik, Niels Bohr Institutet.

GRIP lejren og skiway, Juli 2025.

Indlandsisen i tværsnit




THE
NORTH
FACE

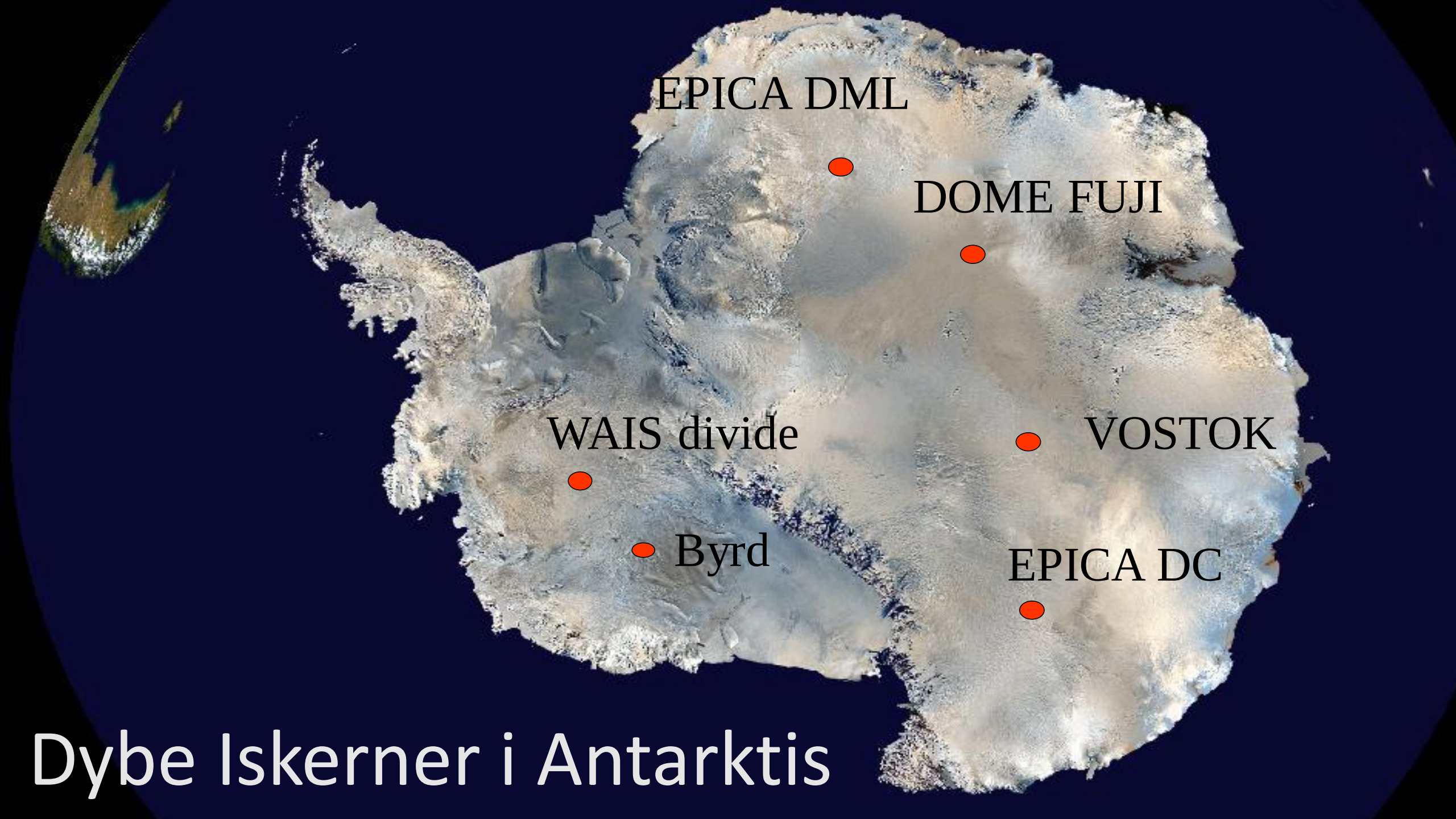
Iskernedata
en indkøbsseddel

- Isen selv: ^{18}O , ^{17}O , ^{16}O, ^{1}H og ^{2}D
- Kontinentalt støv, vulkansk aske, mikrometeoriter og biologisk materiale.
- Ioner: Cl^-, NO_3^-, SO_4^{2-}, F^-, H^+, Na^+, K^+, NH_4^+, Mg^{2+}, Ca^{2+}
- Gas i luftbobler: CO_2, CH_4, O_2, N_2, SF_6.
- Radioaktive isotoper: ^{10}Be, ^{36}Cl, ^{210}Pb, ^{32}Si, ^{14}C, ^{81}Kr, ^{137}Cs, ^{90}Sr.
- DNA
- Isens fysiske egenskaber
- Borehulsopmåling: temperatur, geometri

Naturlig is i polariseret lys
(prøvestørrelse : 4 x 10 cm)


HEMA
626

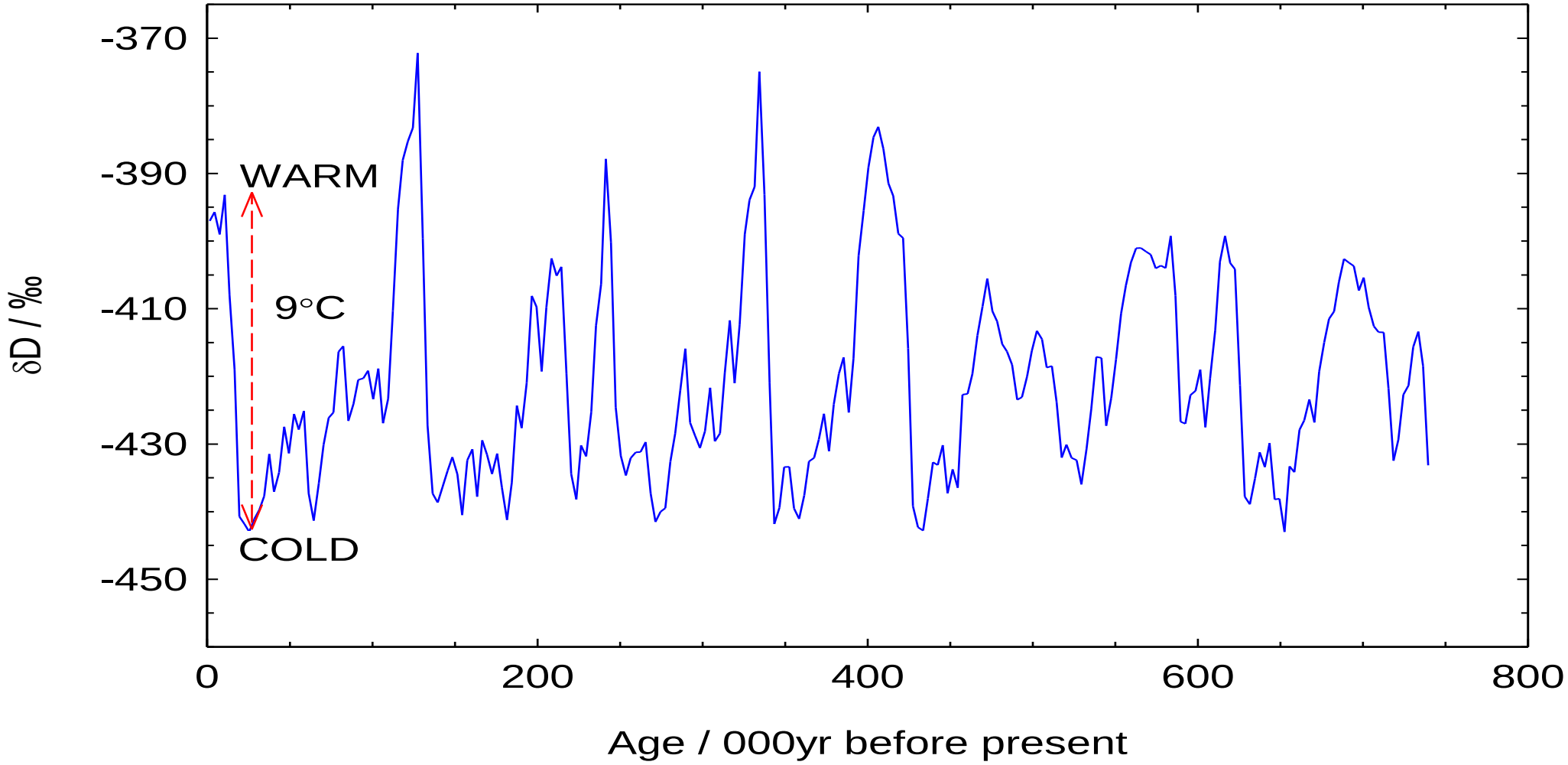

PICARRO



Dybe Iskerner i Antarktis

DomeC, 2004/2005
Foto: Inger Seierstad

Antarktisk klima i 740.000 år

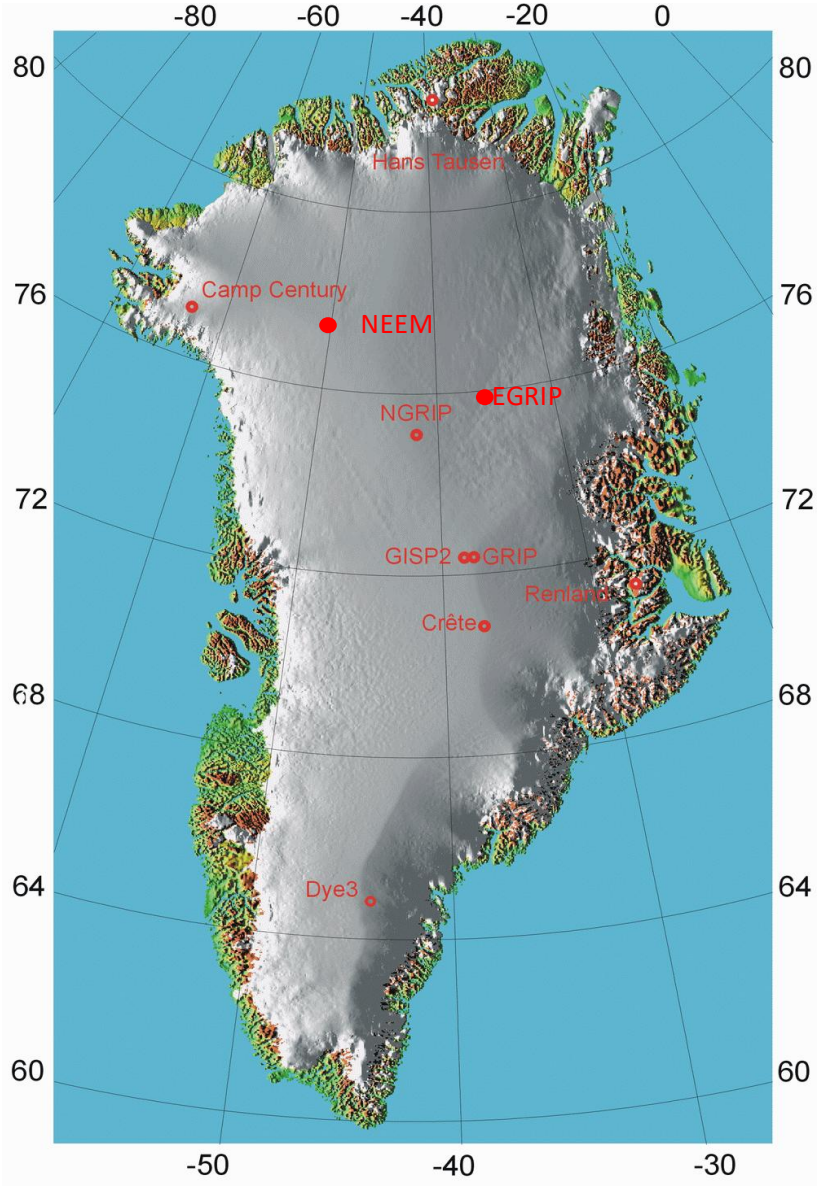


Dybe iskerner i Grønland

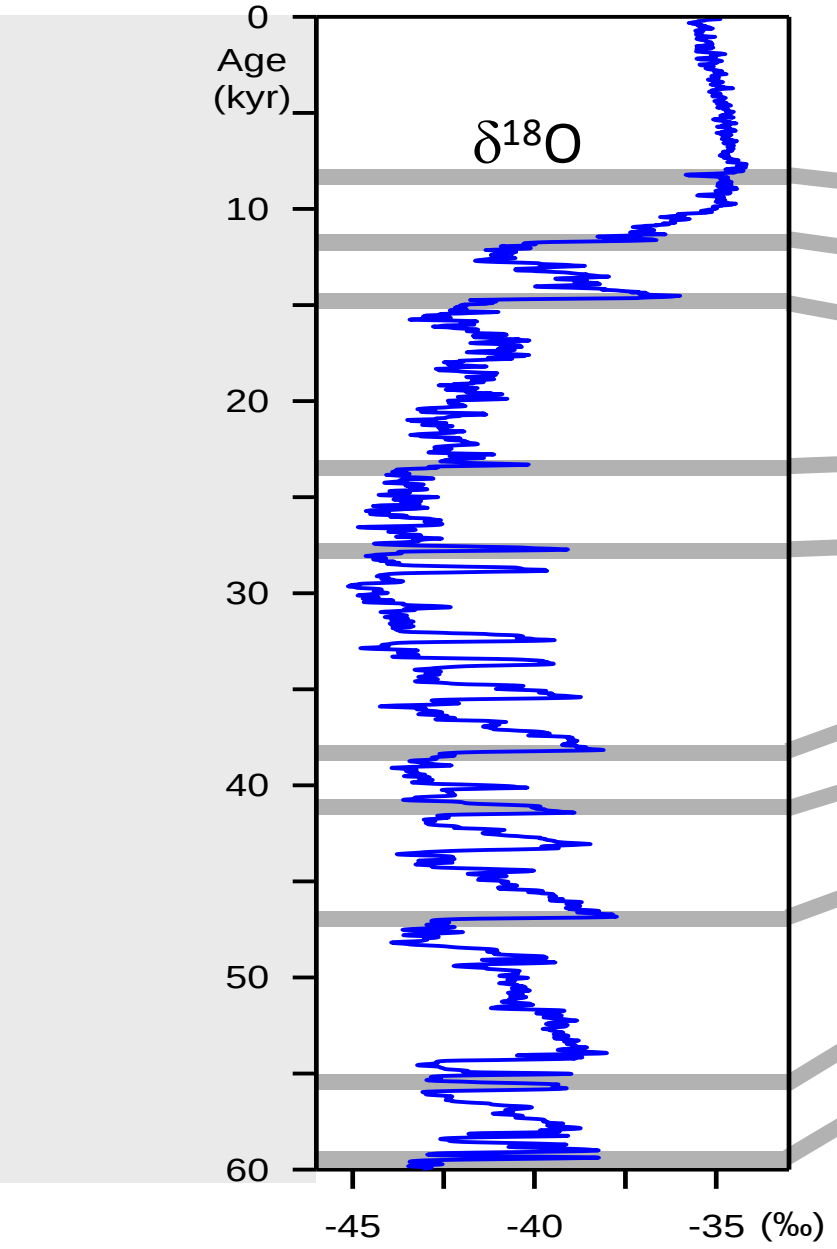
Projekt	År	Dybde
Camp Century	64-66	1390 m
Dye-3	79-81	2037 m
GRIP	89-92	3029 m
GISP2	89-93	3053 m
NorthGRIP	97-03	3085 m
NEEM	07-12	2540 m
EGRIP	15-24	2665 m

GRIP = Greenland Ice Core Project (EU)

GISP = Greenland Ice Sheet Project (US)



GICC05 aldre

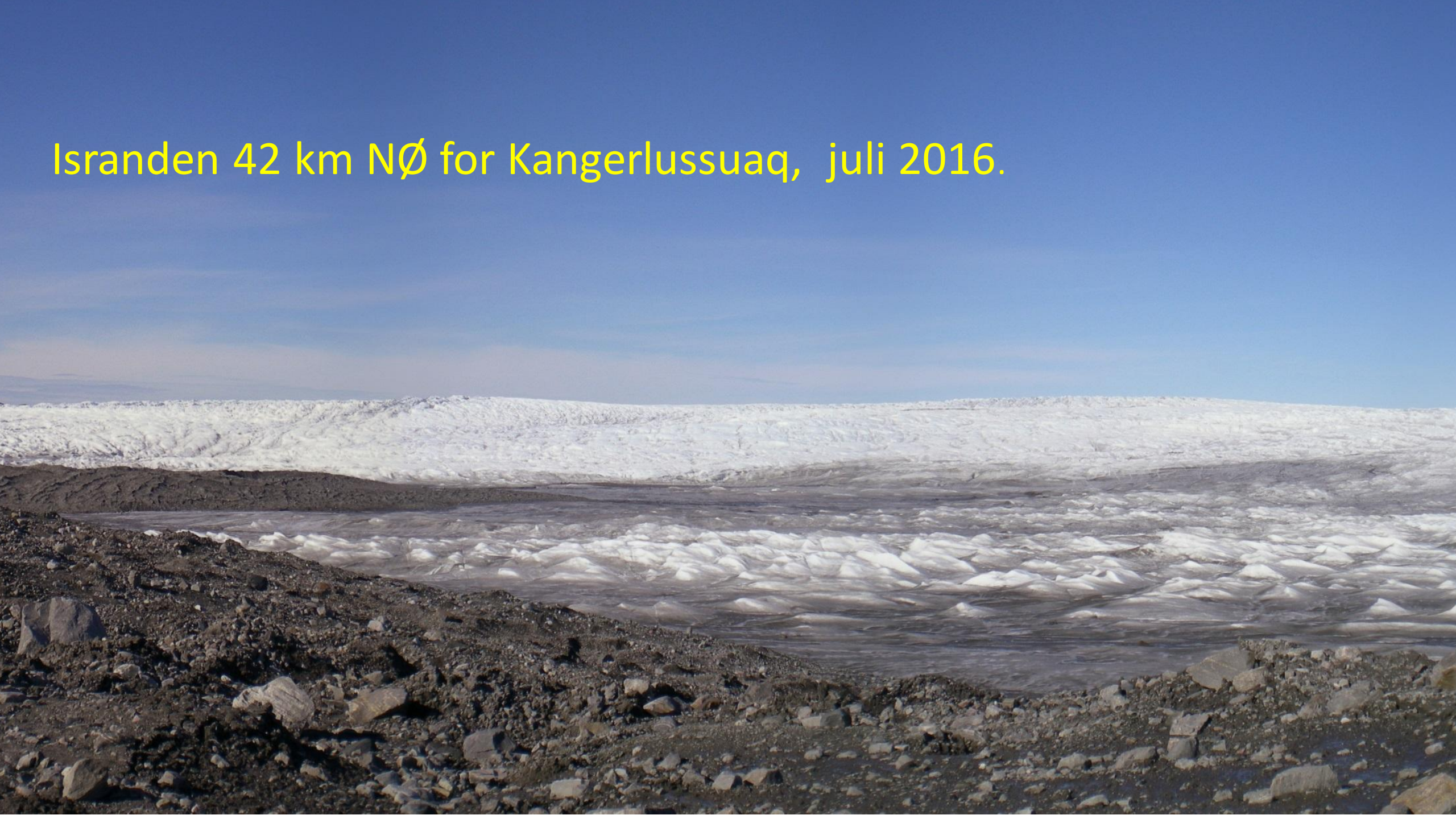


Begivenhed	Alder (b2k)	MCE
8.2 begivenheden	8,236 ±	47
Transitionen	11,703 ±	99
Bøllings start	14,692 ±	186
GIS 2 begyndelse	23,350 ±	600
GIS 3 begyndelse	27,800 ±	850
GIS 8 begyndelse	38,200 ±	1450
Laschamp	41,250 ±	1650
GIS12 begyndelse	46,900 ±	1800
Z2 askelag	55,450 ±	2150
GIS17 begyndelse	59,450 ±	2300

b2k = Før A.D. 2000 (BP = b2k – 50yr)

MCE = Maximum tællefejl

GIS = Grønland Interstadial


Isranden 42 km NØ for Kangerlussuaq, juli 2016.

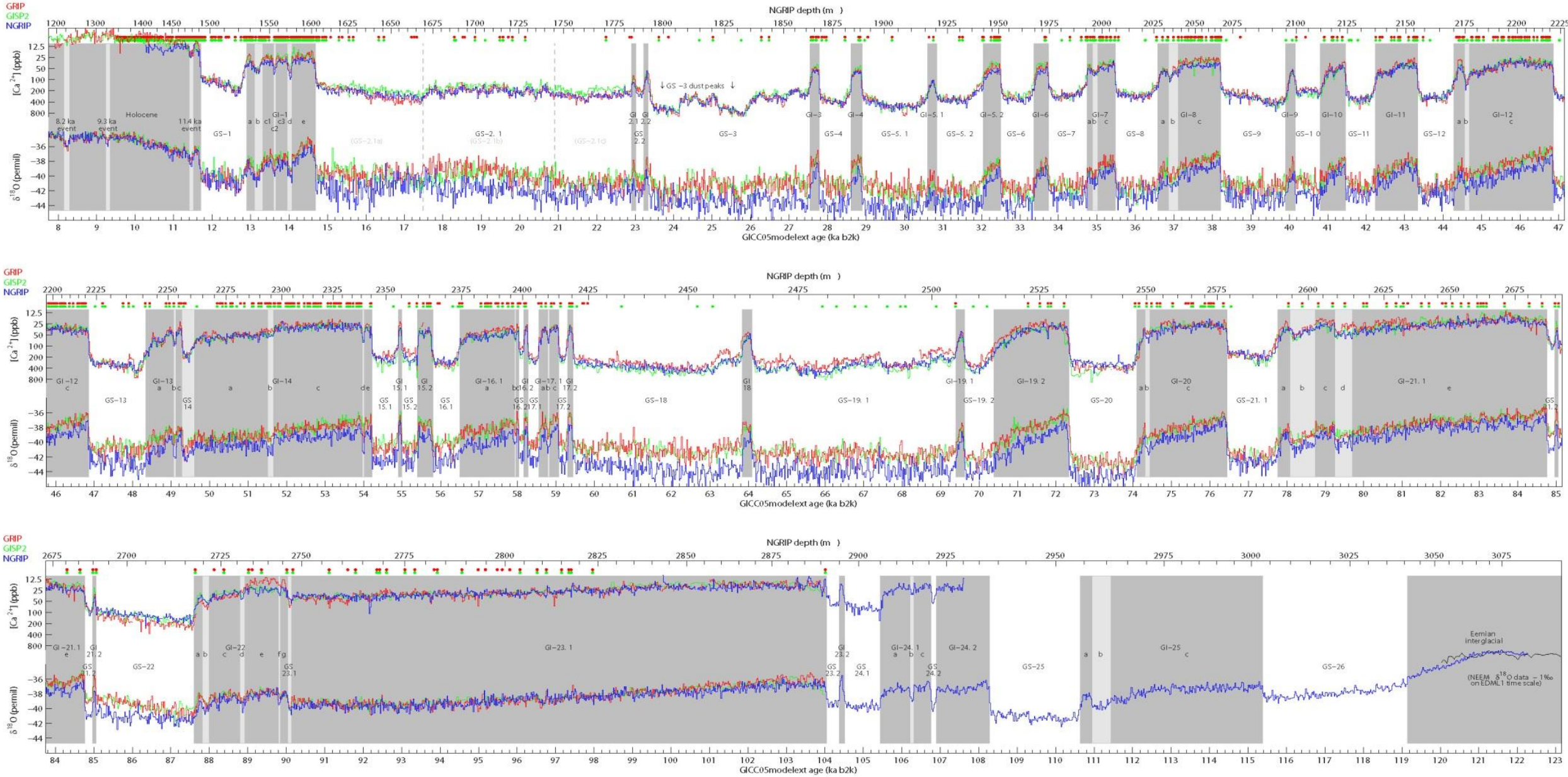
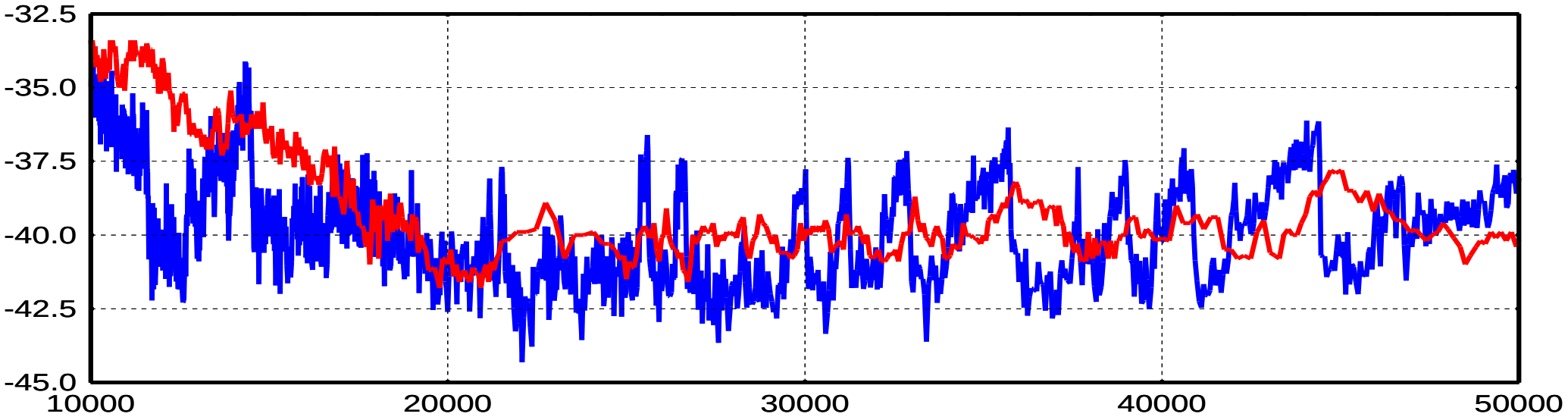
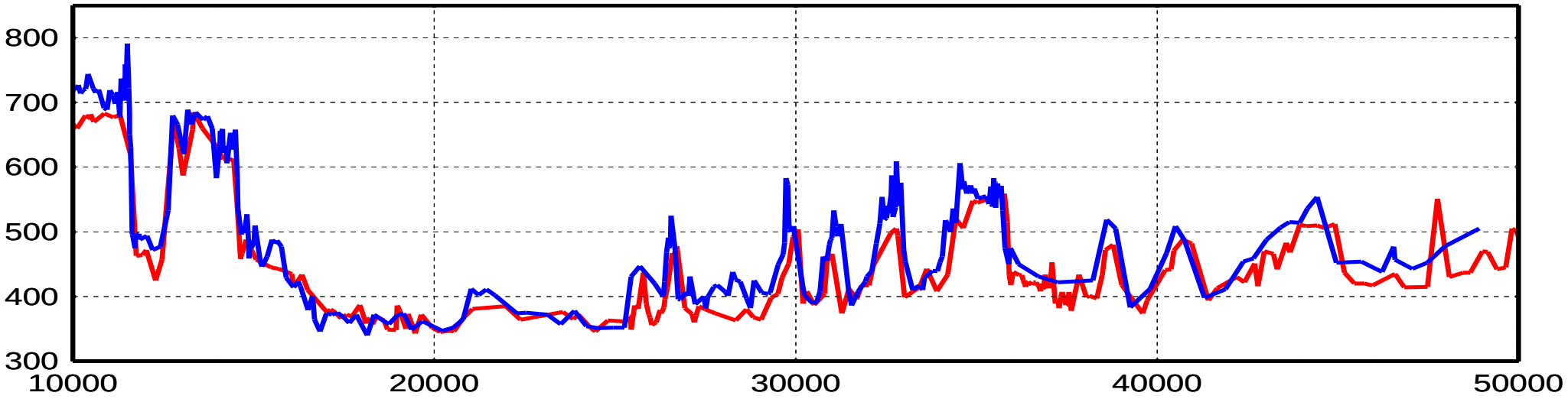


Fig. 1. 20-year average values of $\delta^{18}O$ and $[Ca^{2+}]$ (note the reversed logarithmic $[Ca^{2+}]$ scale; see text for data sources) from GRIP (red), GISP2 (green), and NGRIP (blue) on the GICC05modelext time scale. The dots just below the upper NGRIP depth axis show the position of the match points used to transfer the GICC05modelext time scale from NGRIP to the GRIP (red dots) and GISP2 (green dots) records. The proposed extension of the INTIMATE event stratigraphy scheme is shown with interstadials illustrated by grey shading (light grey indicates cold sub-events). In the Eemian interglacial, NGRIP data are extended by NEEM $\delta^{18}O$ data offset by 2‰ (NEEM community members, 2013). See main text for details on the numbering of stadial and interstadial events. Note the small time overlap between the

Isotoper
(Temperatur)



Metan konc.
(ppbv)

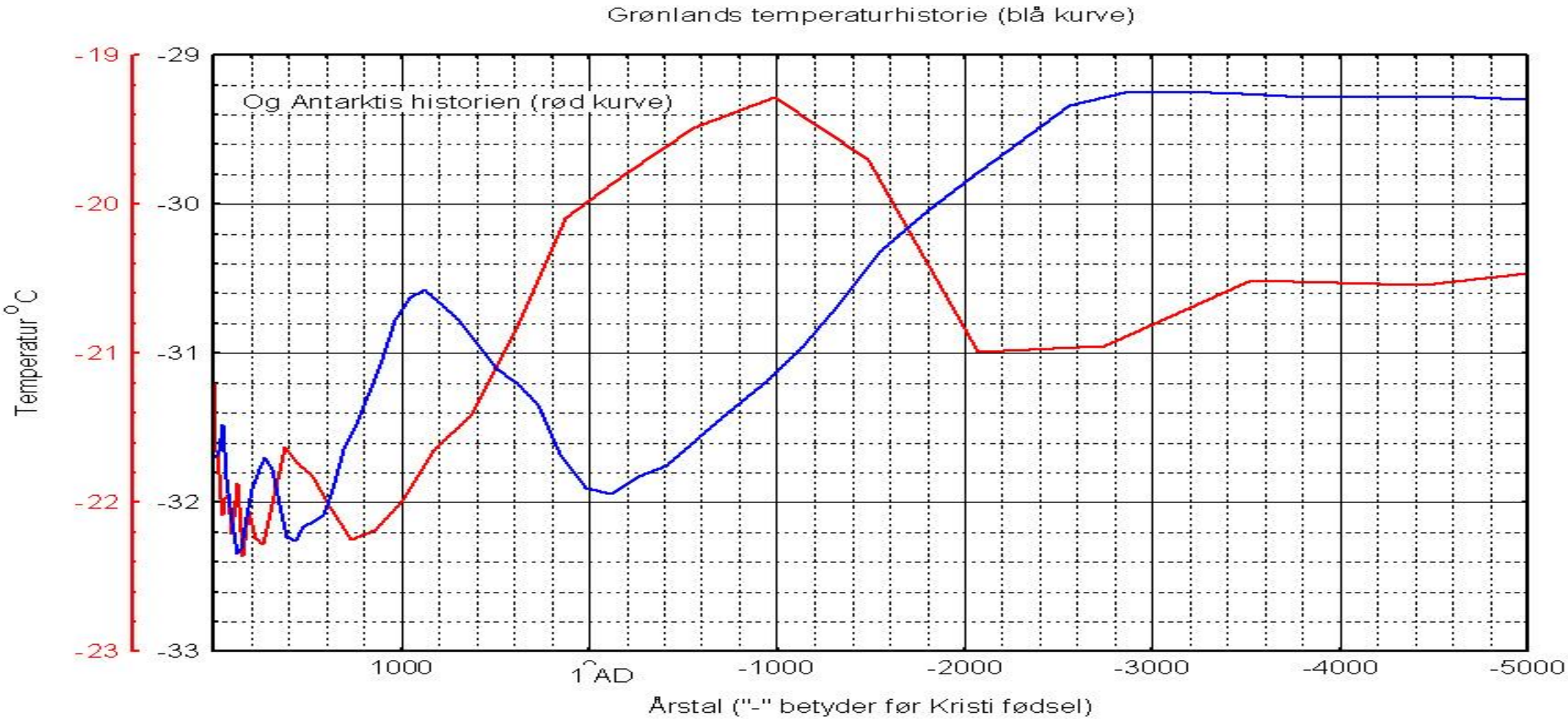


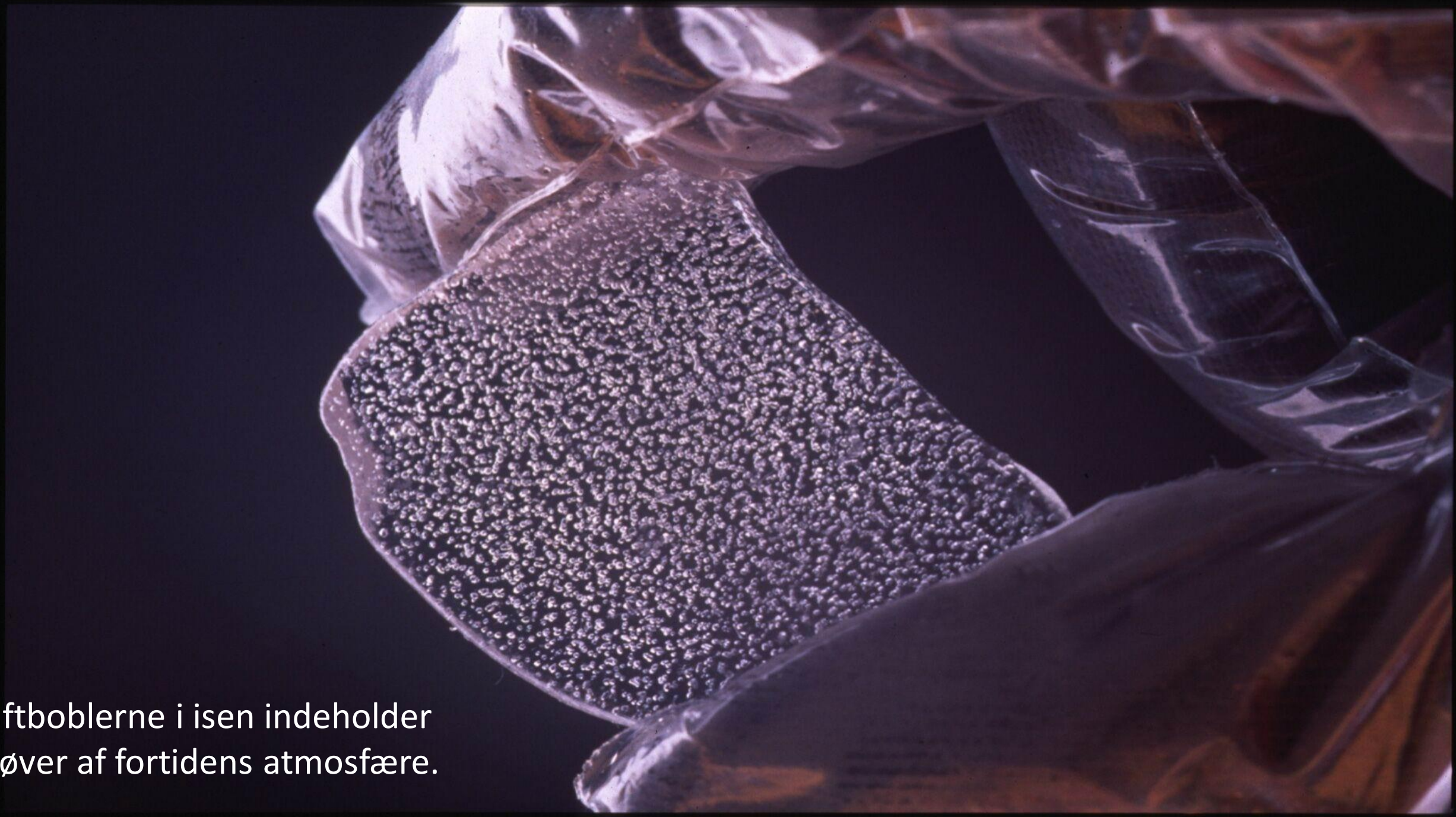
Tid før nu.

Blå kurve: Grønland; Rød Kurve: Antarktis

Kilde: Blunier et al., 1998, Nature

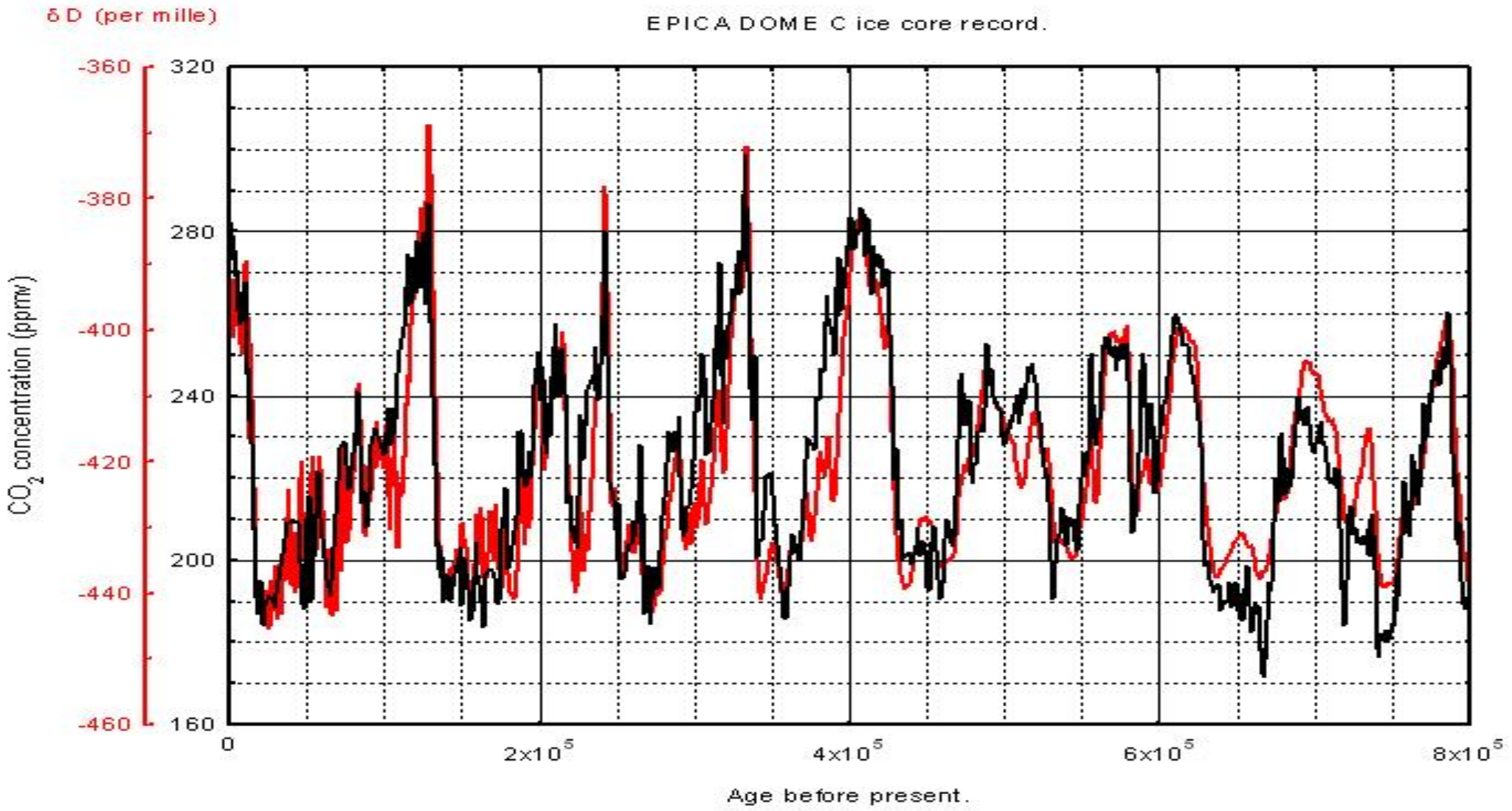
Temperaturhistorien siden istiden og frem til ca. 1970.



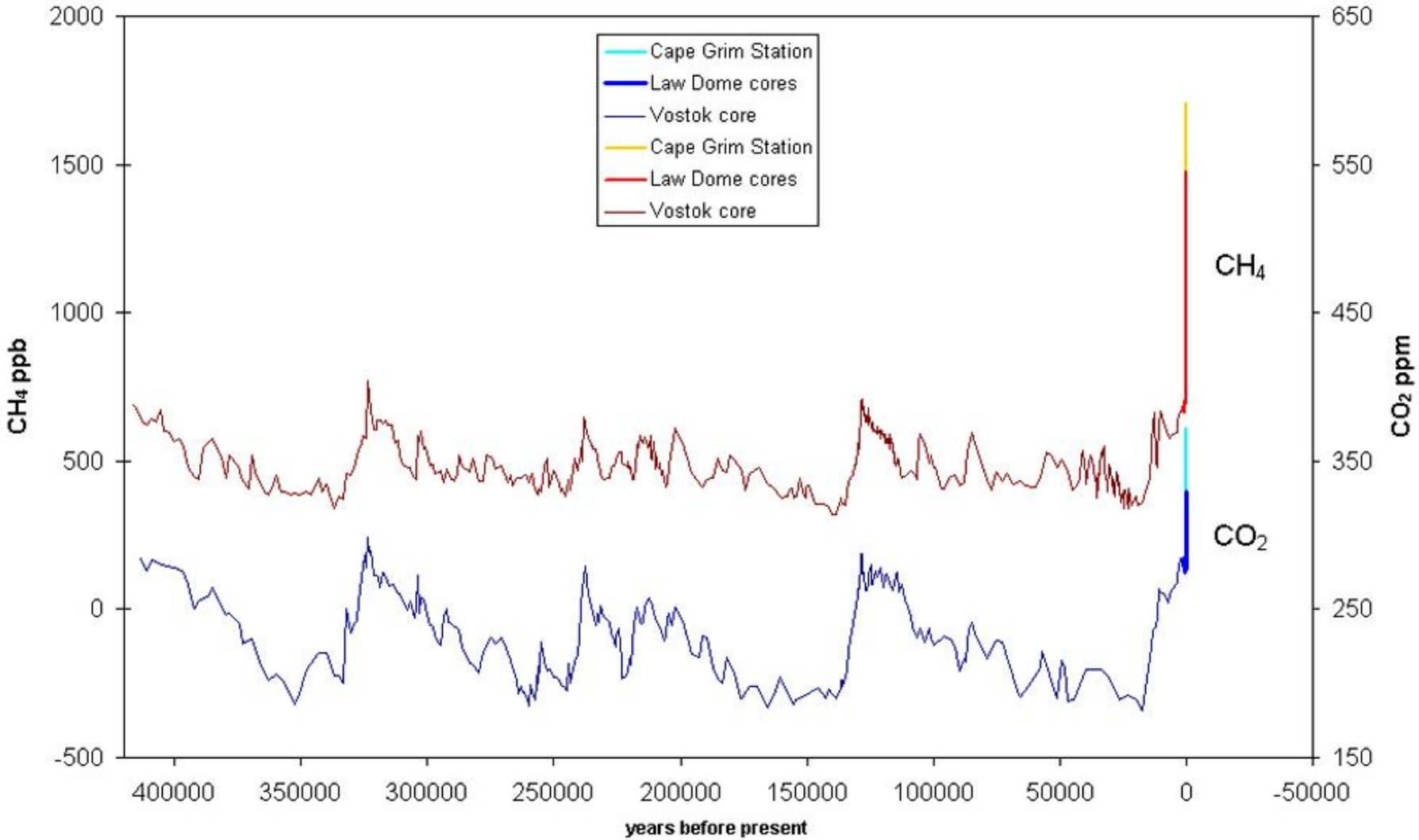


Luftboblerne i isen indeholder prøver af fortidens atmosfære.

Forbindelsen mellem klima og drivhusgassen CO_2 fra målinger på iskernen fra Dome C i Antarktis.



Stigningen i CO_2 og metan.

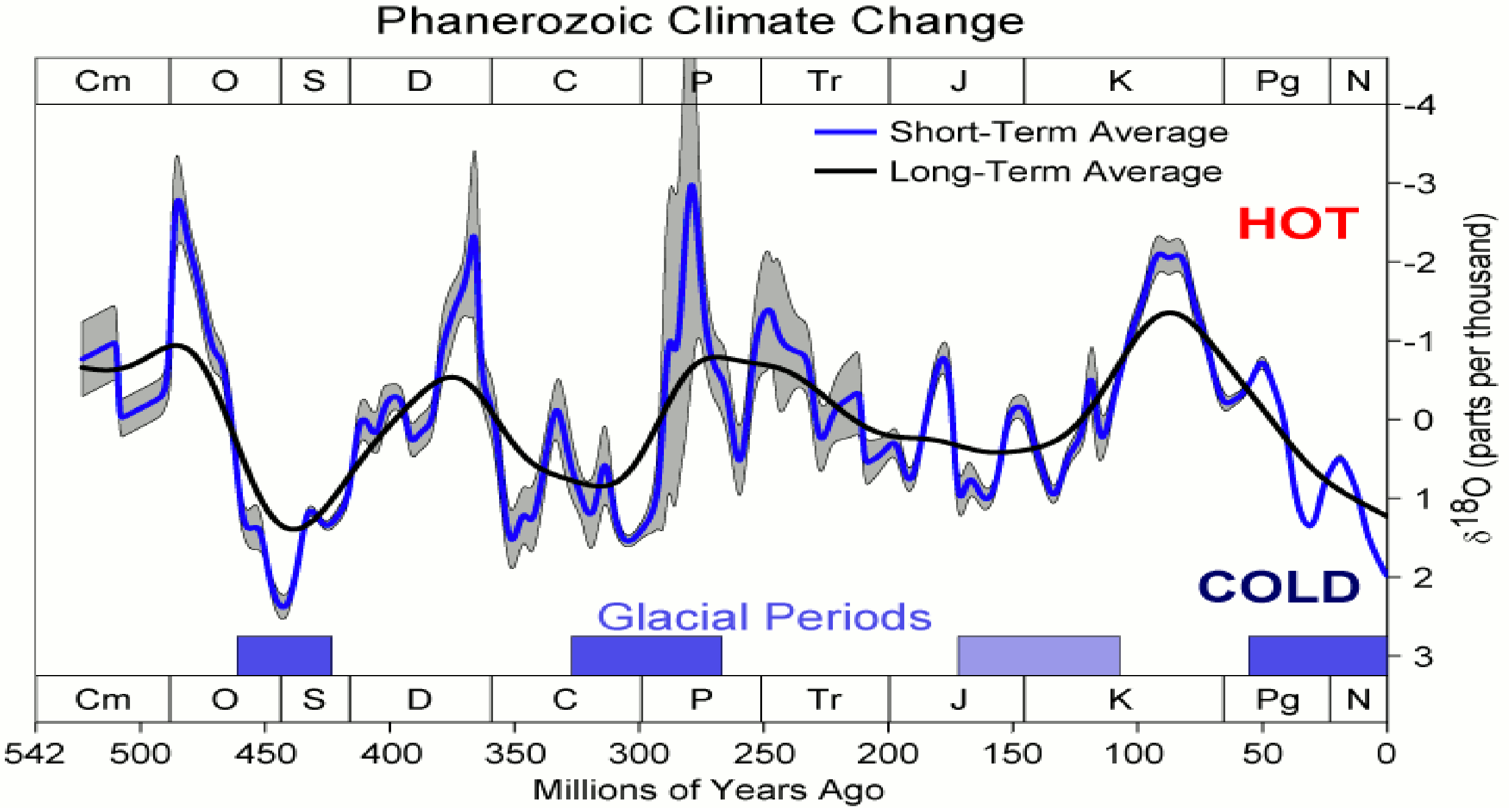


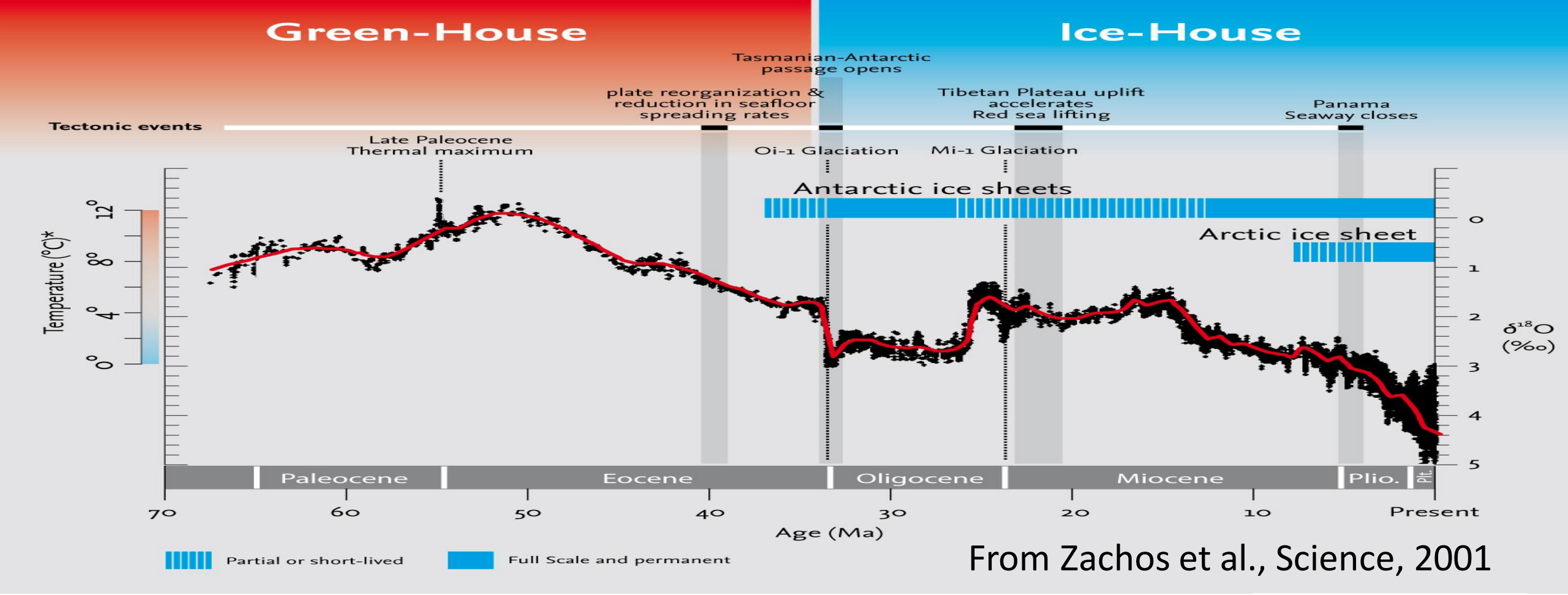
Data samlet af David Etheridge, CSIRO

Drilling camp at little DOME C

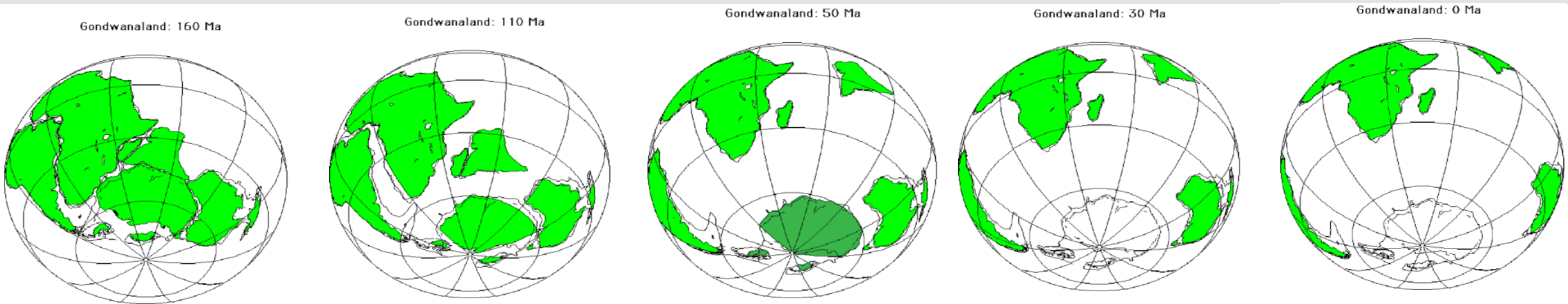
Beyond EPICA oldest ice, PNRA and IPEV

Drilling team at Little Dome C, 24/25

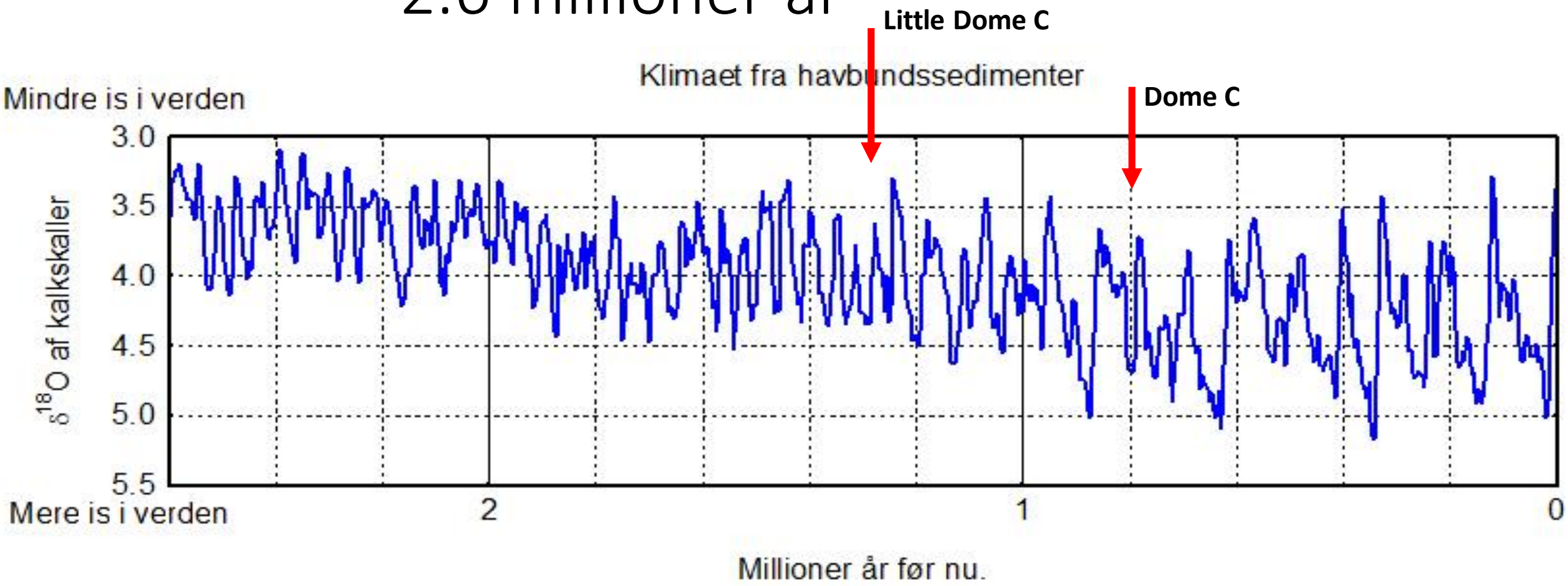

Phanerozoic Climate Change
Cm
O
S
D
C
P
Tr
J
K
Pg
N
Short-Term Average
Long-Term Average
HOT
COLD
Glacial Periods
-4
-3
-2
-1
0
1
2
3
δ18O (parts per thousand)
542
500
450
400
350
300
250
200
150
100
50
0
Millions of Years Ago



From Zachos et al., Science, 2001



Klimahistorien i de sidste 2.6 millioner år



Data fra ODP-677 (ODP, Ocean deep Drilling Programme)

Green2Ice

When was Greenland green?

ERC Synergy project 2023 - 2029

Dorthe Dahl-Jensen

Anders Svensson

Francois Fripiat

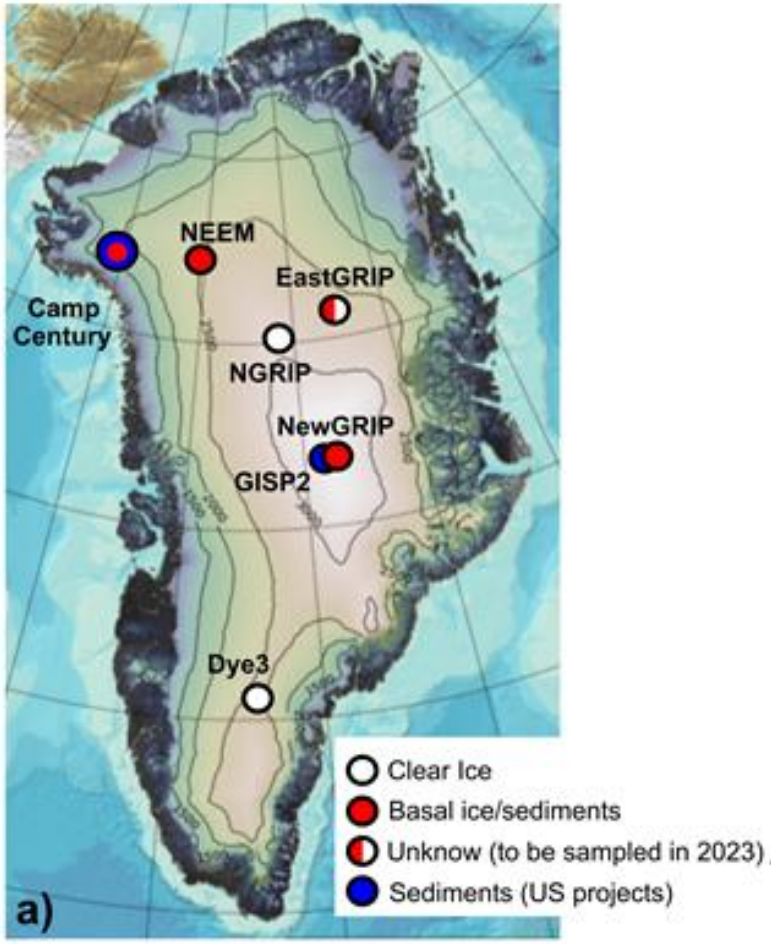
Pierre-Henri Blard

UNIVERSITY OF COPENHAGEN

ULB UNIVERSITÉ LIBRE DE BRUXELLES

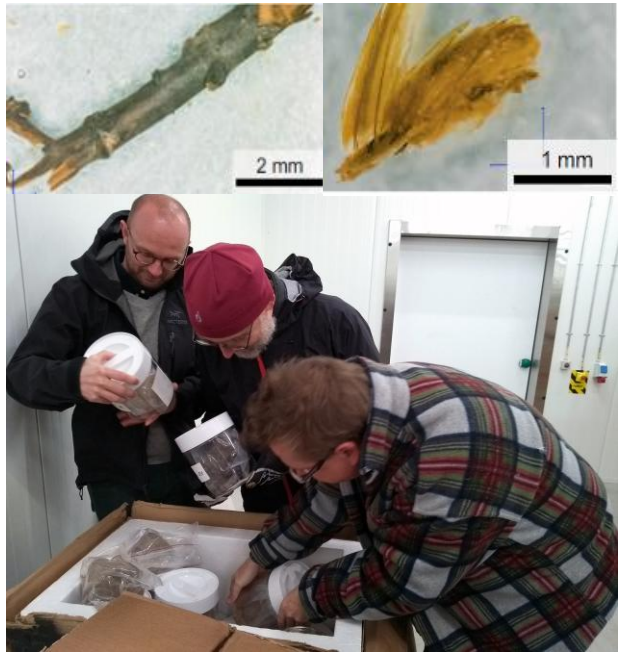
CRPG cnrs

Prøvemateriale fra den dybeste og ældste is i Grønland

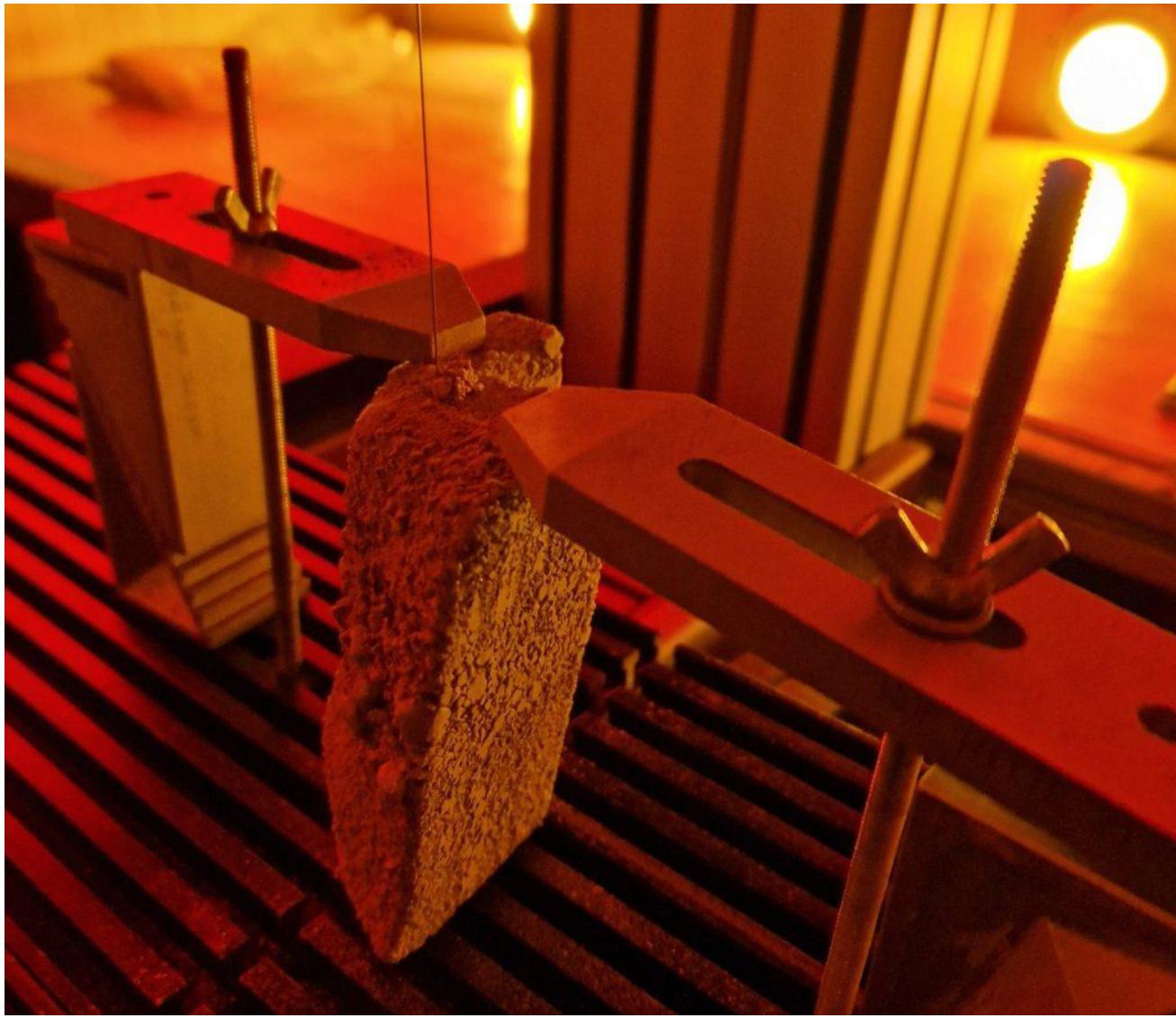


NGRIP (3085 m) bundmateriale fra 2003: Pilebark and knopskel, upubliceret

NEEM (2540 m) bundmateriale fra 2012: 10 cm sten indstøbt i is, upubliceret



Camp Century (1368 m) is boret i 1966 and genfundet i 2019
Kviste og pollen er velbevaret (Christ et al., PNAS, 2021)



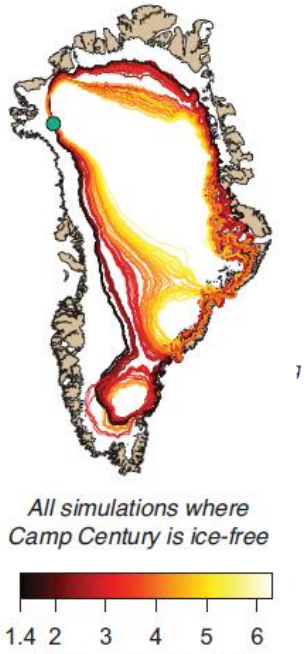
ICE SHEETS

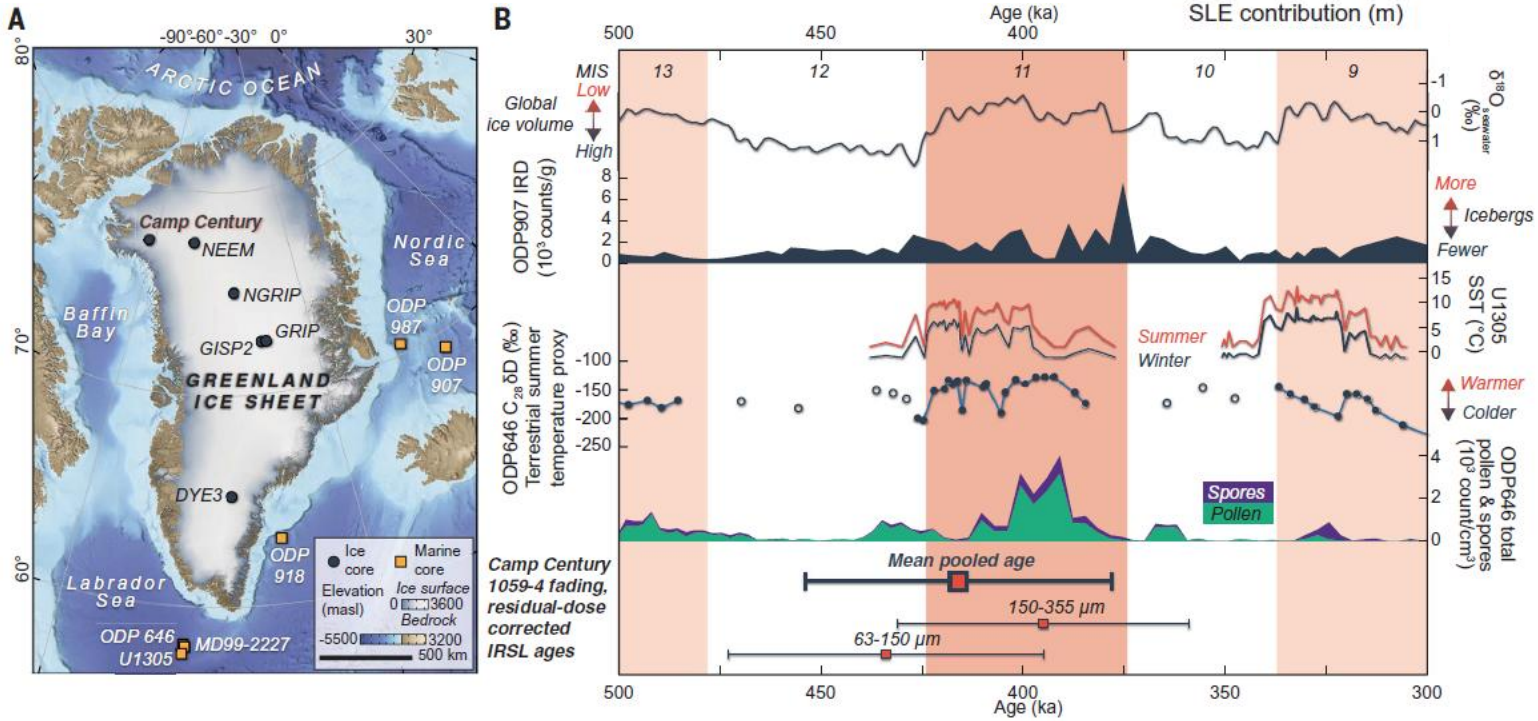
Deglaciation of northwestern Greenland during Marine Isotope Stage 11

(Christ et al., Science, 2023)

Andrew J. Christ[1,2]*, Tammy M. Rittenour[3], Paul R. Bierman[1,2]*, Benjamin A. Keisling[4], Paul C. Knutz[5], Tonny B. Thomsen[5], Nynke Keulen[5], Julie C. Fosdick[6], Sidney R. Hemming[7], Jean-Louis Tison[8], Pierre-Henri Blard[8,9], Jørgen P. Steffensen[10], Marc W. Caffee[11,12], Lee B. Corbett[2], Dorthe Dahl-Jensen[10,13], David P. Dethier[14], Alan J. Hidy[15], Nicolas Perdrial[1,16], Dorothy M. Peteet[7,17], Eric J. Steig[18], Elizabeth K. Thomas[19]

Past interglacial climates with smaller ice sheets offer analogs for ice sheet response to future warming and contributions to sea level rise; however, well-dated geologic records from formerly ice-free areas are rare. Here we report that subglacial sediment from the Camp Century ice core preserves direct evidence that northwestern Greenland was ice free during the Marine Isotope Stage (MIS) 11 interglacial. Luminescence dating shows that sediment just beneath the ice sheet was deposited by flowing water in an ice-free environment 416 ± 38 thousand years ago. Provenance analyses and cosmogenic nuclide data and calculations suggest the sediment was reworked from local materials and exposed at the surface <16 thousand years before deposition. Ice sheet modeling indicates that ice-free conditions at Camp Century require at least 1.4 meters of sea level equivalent contribution from the Greenland Ice Sheet.





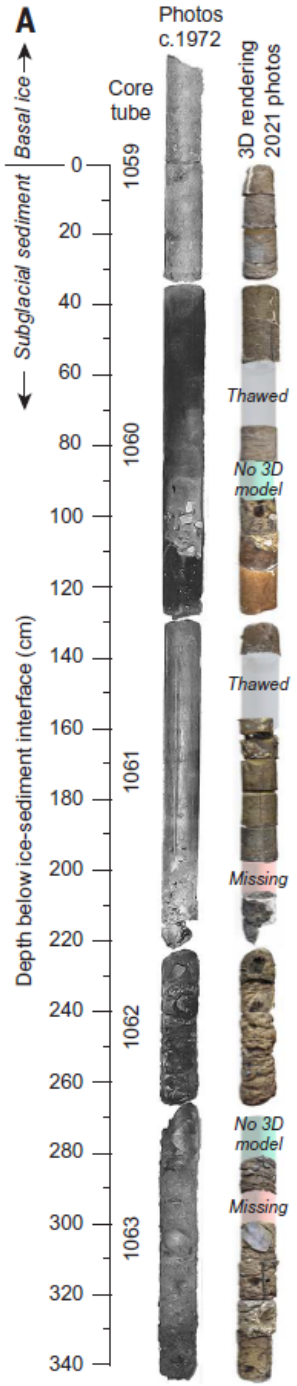


Fig. 1. Overview map and paleoclimate. (**A**) Overview map of Greenland leaf-wax biomarker proxy (solid blue circles and light blue lines) for terrestrial

PNAS BRIEF REPORT | EARTH, ATMOSPHERIC, AND PLANETARY SCIENCES ENVIRONMENTAL SCIENCES OPEN ACCESS

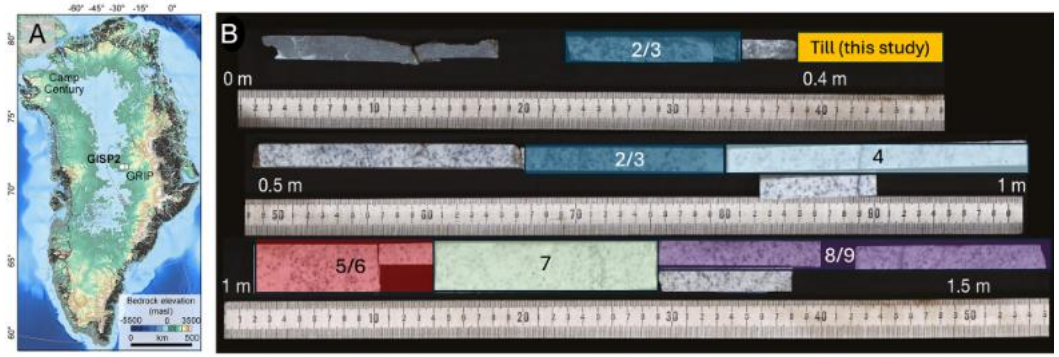
Plant, insect, and fungi fossils under the center of Greenland's ice sheet are evidence of ice-free times

Paul R. Bierman[a,1], Halley M. Mastro[a], Dorothy M. Peteet[b,c], Lee B. Corbett[a], Eric J. Steig[d], Chris T. Halsted[a], Marc M. Caffee[f], Alan J. Hidy[a], Greg Balco[g], Ole Bennike[h], and Barry Rock[i]

Edited by Eric Rignot, University of California Irvine, Irvine, CA; received May 9, 2024; accepted June 17, 2024

The persistence and size of the Greenland Ice Sheet (GrIS) through the Pleistocene is uncertain. This is important because reconstructing changes in the GrIS determines its contribution to sea level rise during prior warm climate periods and informs future projections. To understand better the history of Greenland's ice, we analyzed glacial till collected in 1993 from below 3 km of ice at Summit, Greenland. The till contains plant fragments, wood, insect parts, fungi, and cosmogenic nuclides showing that the bed of the GrIS at Summit is a long-lived, stable land surface preserving a record of deposition, exposure, and interglacial ecosystems. Knowing that central Greenland was tundra-covered during the Pleistocene informs the understanding of Arctic biosphere response to deglaciation.

cosmogenic | interglacial | paleoclimate | paleobotany



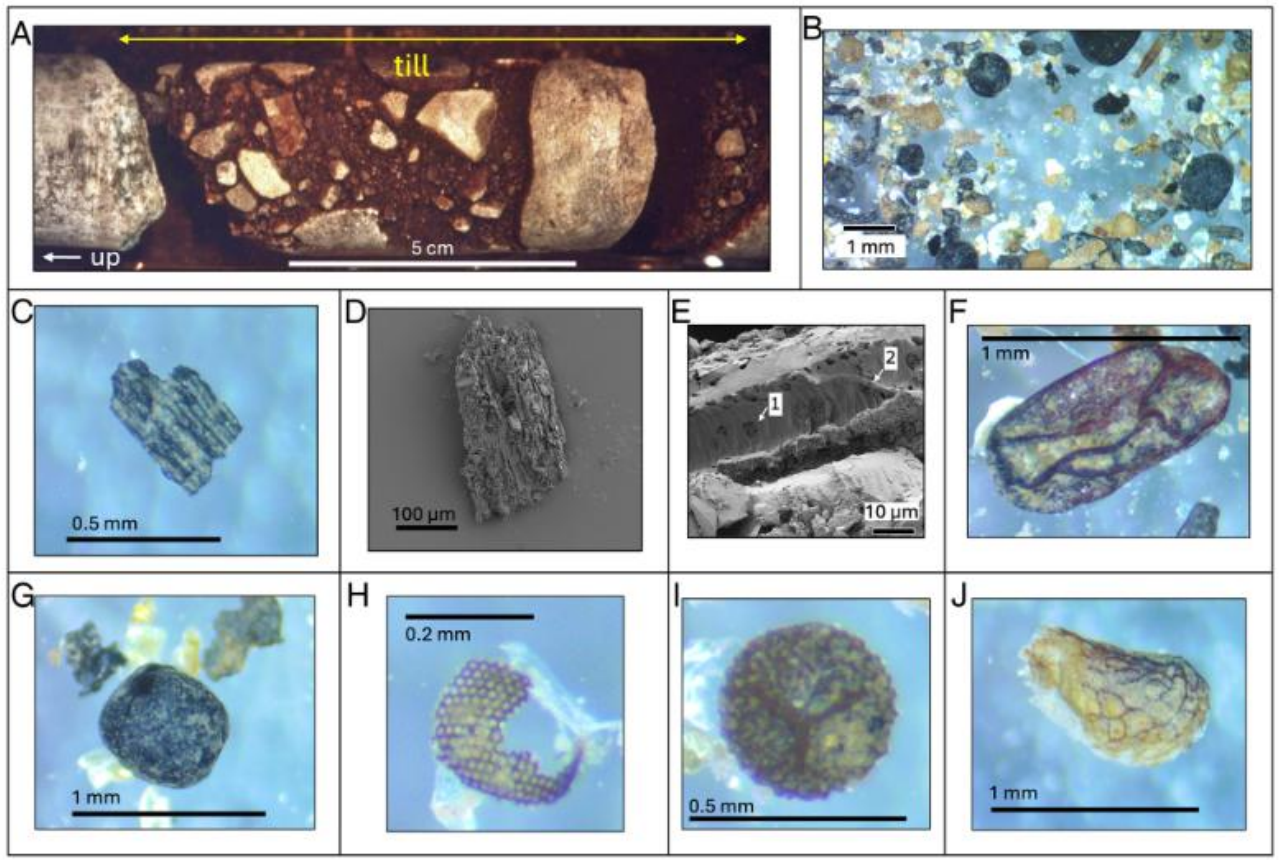
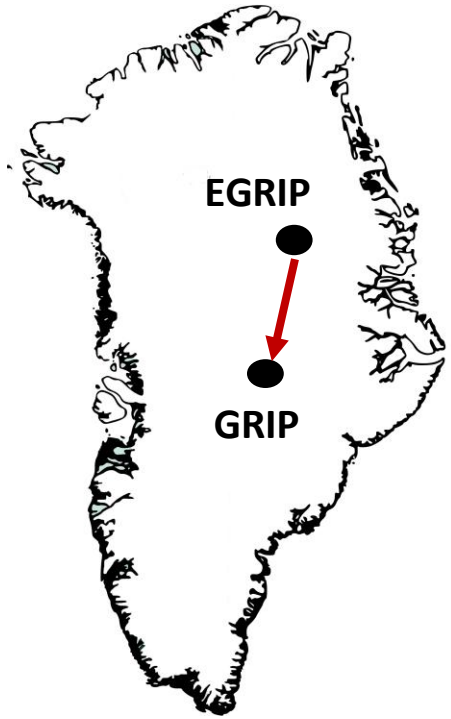
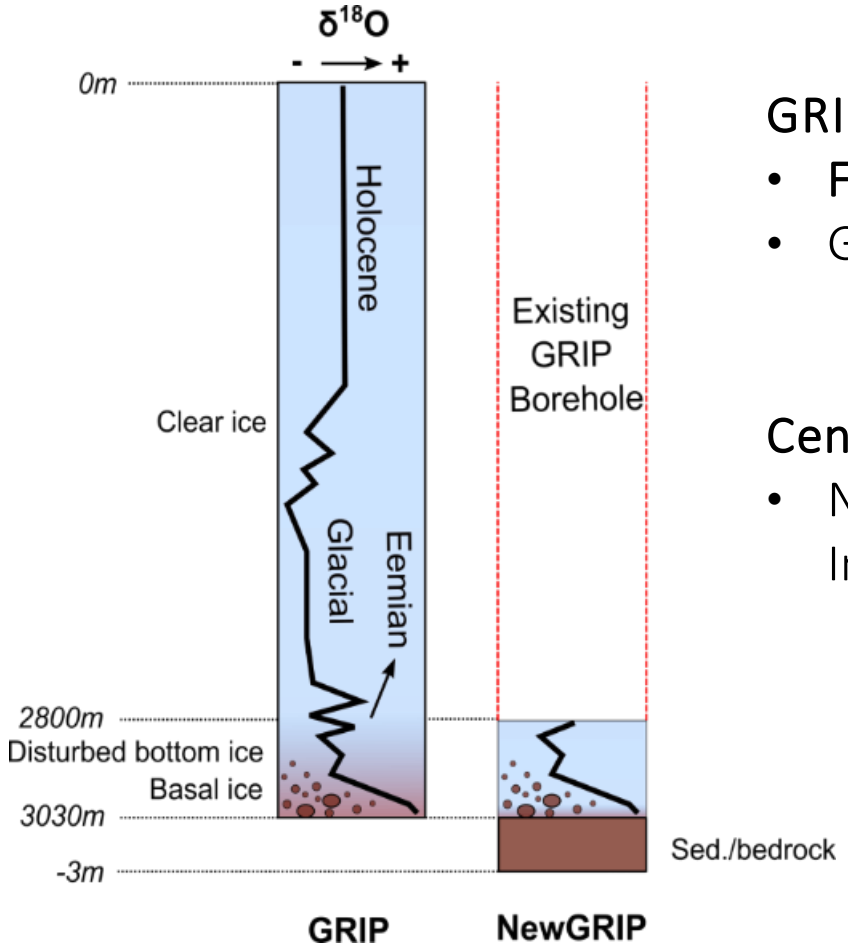


Fig. 2. GISP2 till and macrofossils found in it: (*A*) Photo of the angular-clast-rich till section of the GISP2 subglacial core, taken 1994, up core to left (Credit: T. Gow, supplied by D. Meese). (*B*) Overview of sediment, mostly quartz and fossils. (*C*) Wood fragment. (*D*) Vertical orientation typical of GISP2 wood. (*E*) Wood at higher magnification showing simple pits in lateral vessel wall (1) and distinct simple perforation plate (2), along with the helical thickening typical of GISP2 wood. (*F*) Bud scale of *Salix* (willow). (*G*) Sclerotium of the soil fungus *C. geophilum** (*H*) Insect eye, possibly from a fly*. (*I*) *S. rupestris* megaspore. (*J*) Seed of *Papaver* sect. *Scapiflora*. The asterisk shows macrofossil types also found in Camp Century sediment by ref. 5. Wood fragment images are same specimen.

Gen-boring og boring i underlaget ved GRIP in 2026



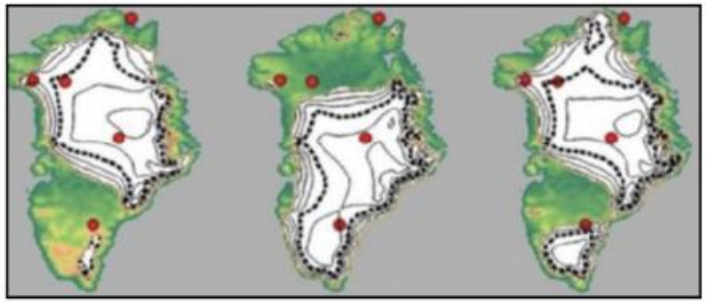


GRIP

- Første Europæiske kerne med sedimenter
- Genbrug af GRIP borehullet

Central beliggenhed

- Nøglen til at evaluere et fuldstændigt kollaps af Indlandsisen.



85% af isvolumet:
Hvor forsvandt isen?

GRIP lejren 1989-1993

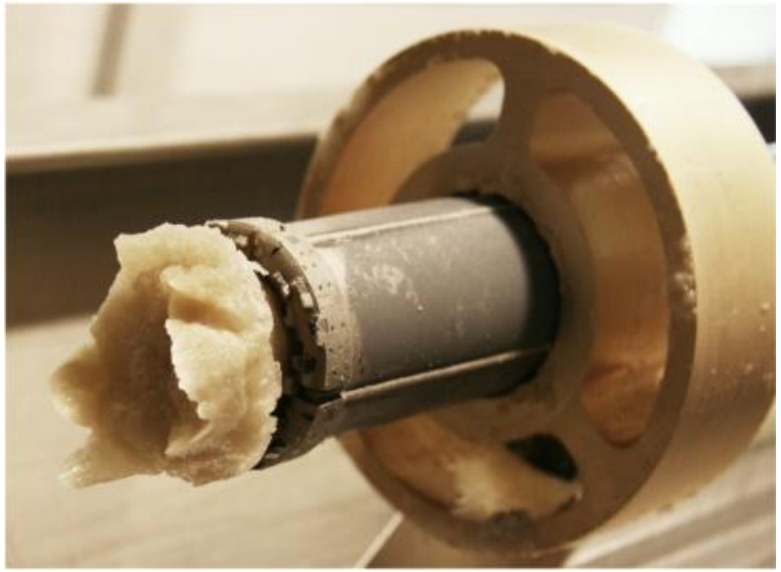
Sigfus Johnsen erklærer stop for boringen ved GRIP i 1992

NorthGRIP 1996-2004

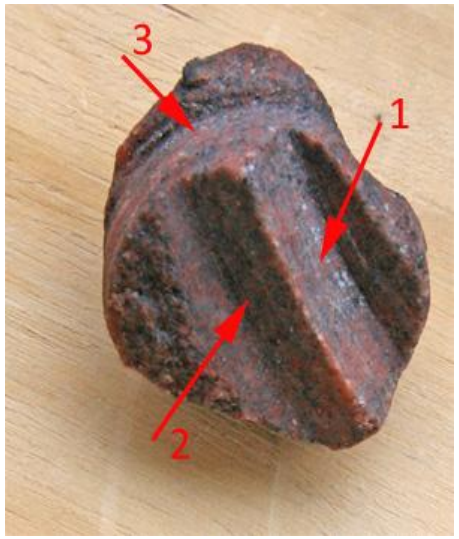
Genfrosset bundvand ved NGRIP i 2003

Vand og bundmateriale ved NEEM

2010



2011



2012


THE UNDERHILLS
OF EGRIP

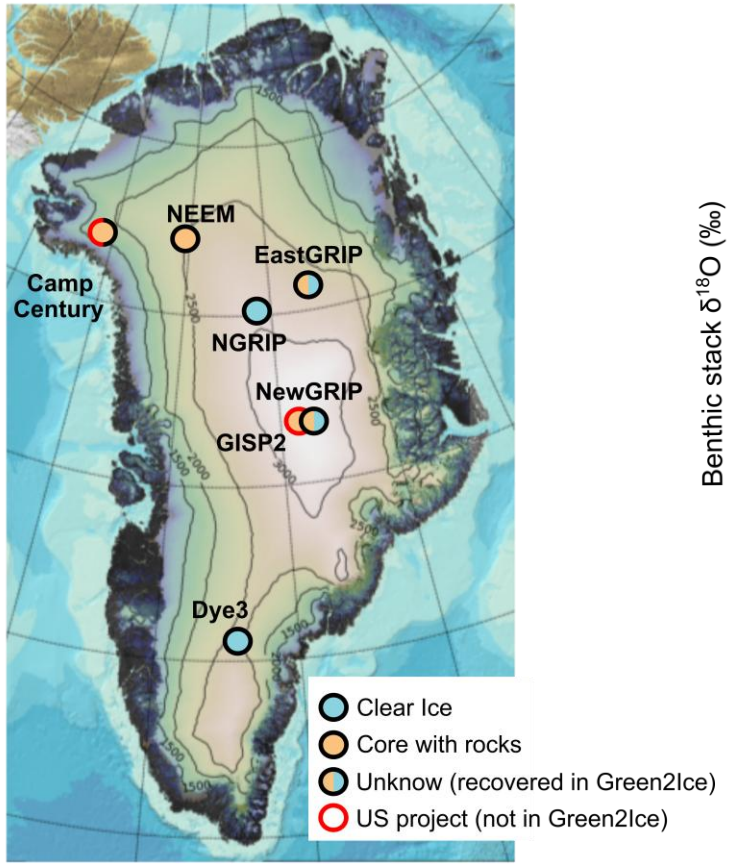

EGRIP 2023 “red light” distriktet

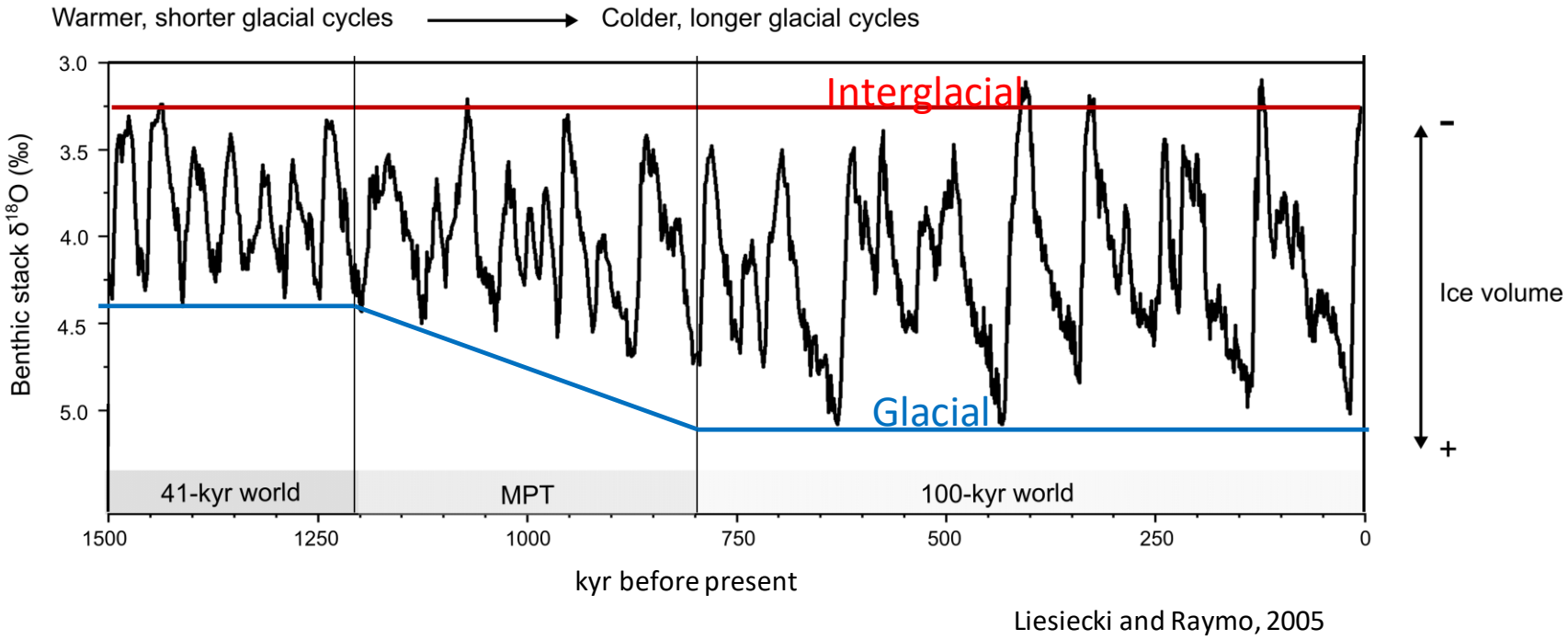
Glade borere med mudder!!
EGRIP 2024 i 2665 m dybde.

Green2Ice - Ideer

Gennem observationer at indkredse Indlandsisens respons under klimaforandringer med forskellig styrke og varighed.

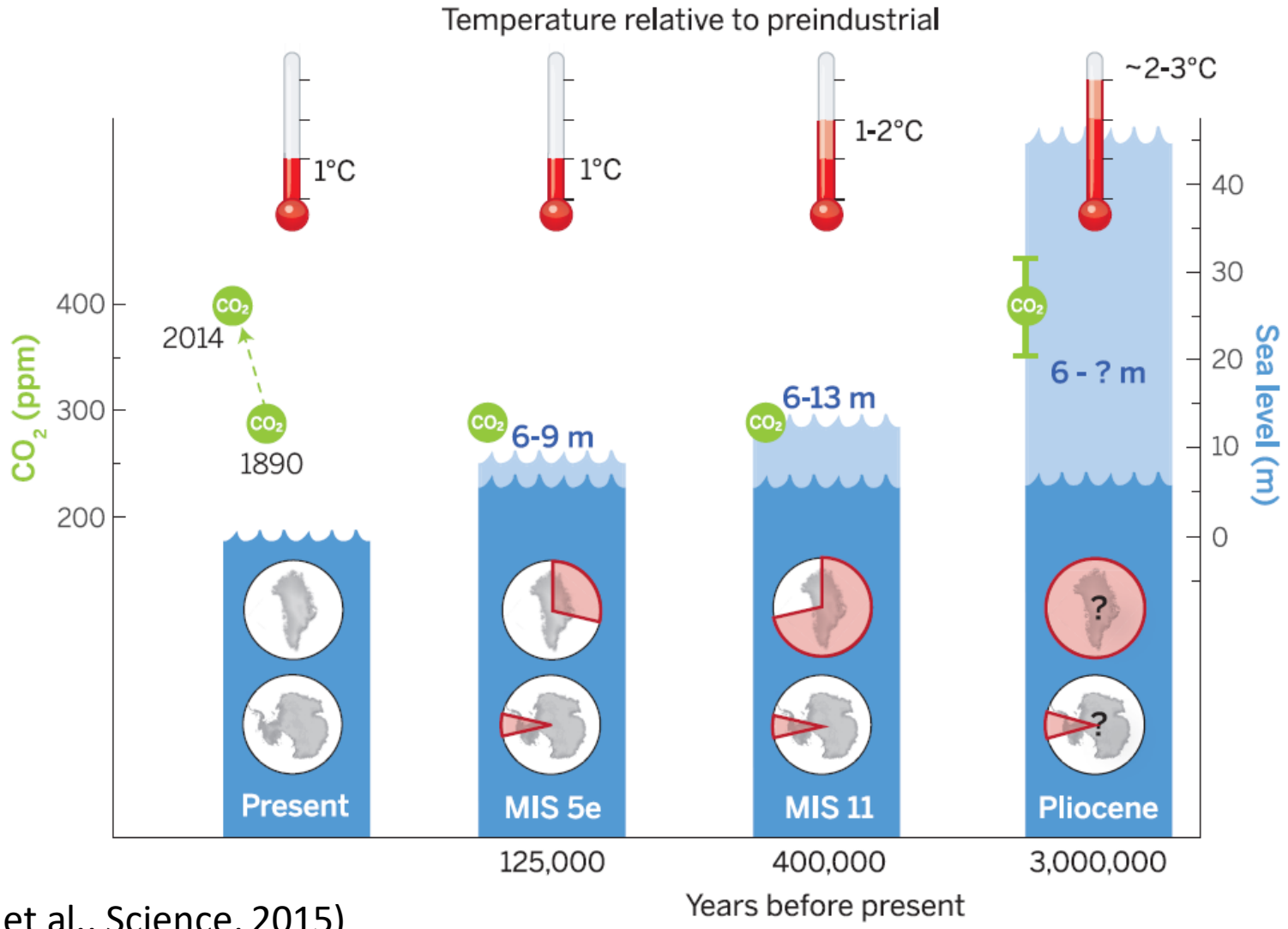
Begyndte den grønlandske indlandsis at blive permanent under Mid-Pleistocene-overgangen (MPT)? Hvorfor?





Liesiecki and Raymo, 2005

Stigning i global middeltemperatur, atmosfærisk CO_2, maximum globalt havniveau, and smeltevandskilder



(Dutton et al., Science, 2015)

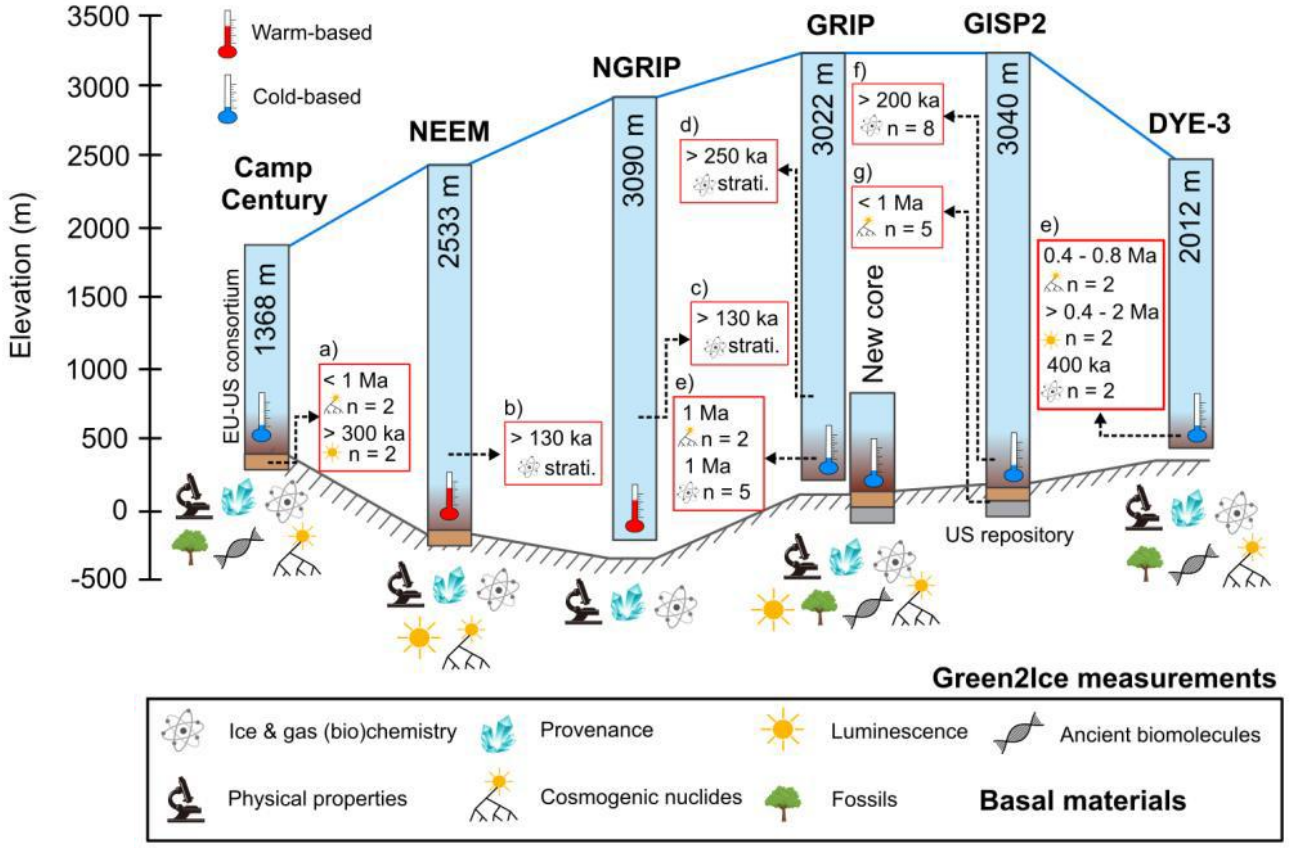
Hvordan daterer man den ældste is i Grønland?

Brug af den dybeste is:

- δ^{40}Ar gas datering
- ^{81}Kr gas datering
- Kosmogent ^{10}Be/^{36}Cl datering
- Stratigrafisk kobling til Antarktis
- Fossiler og gammelt DNA
- Gas diffusion i bundisen

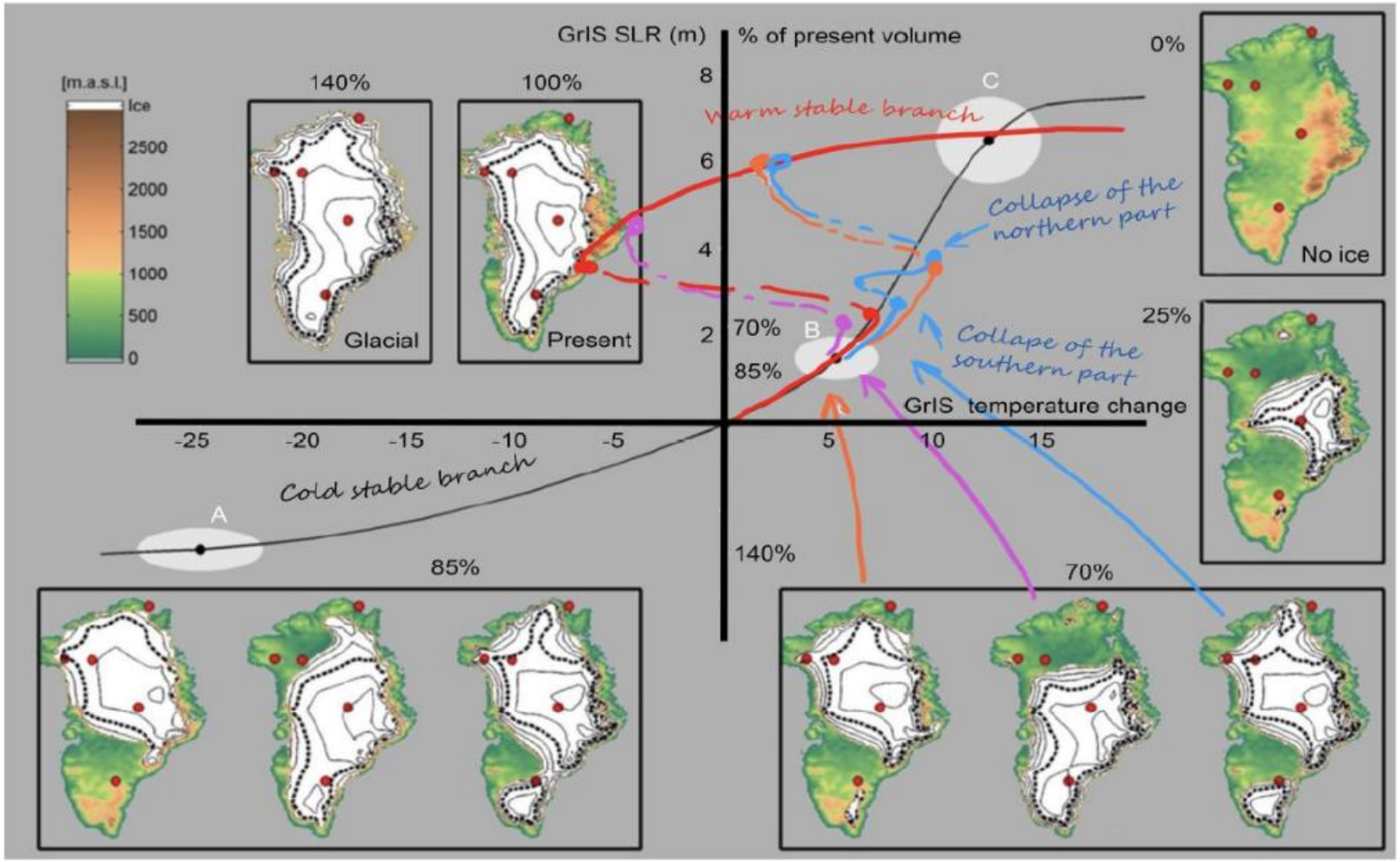
Brug af bundmaterialet:

- Begravelsesaldre fra ^{10}Be and ^{26}Al
- OSL datering



(Revised from Christ et al., 2020)

Grønlands Indlandsis' livsforløb



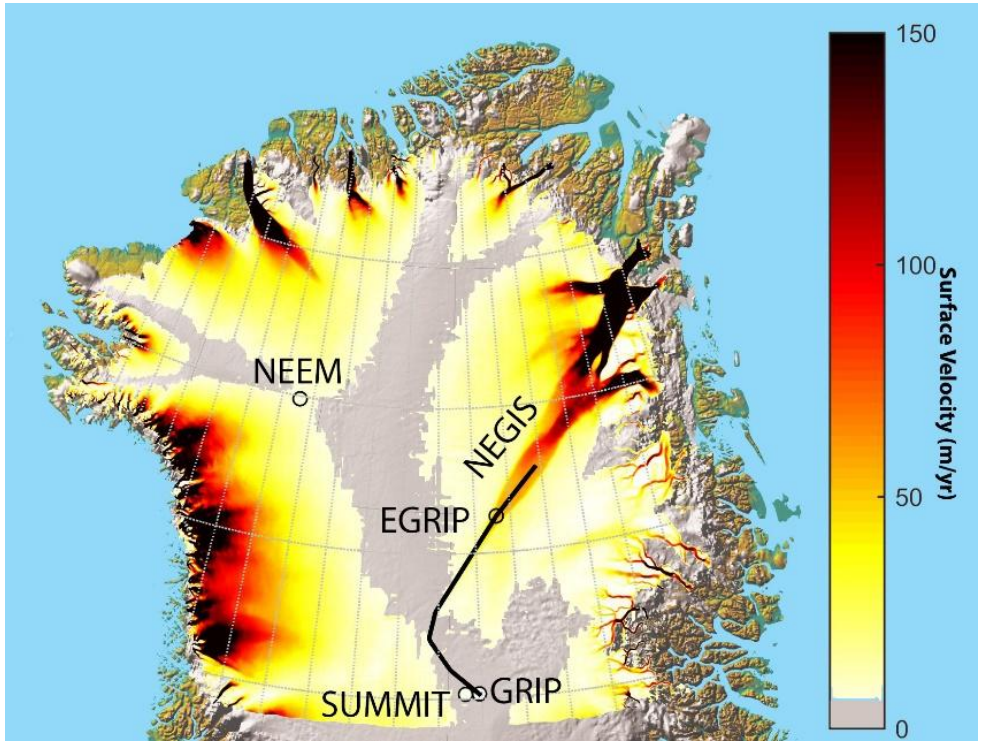
A = 'LGM', B = 'Eem', C = 'Isfrit'

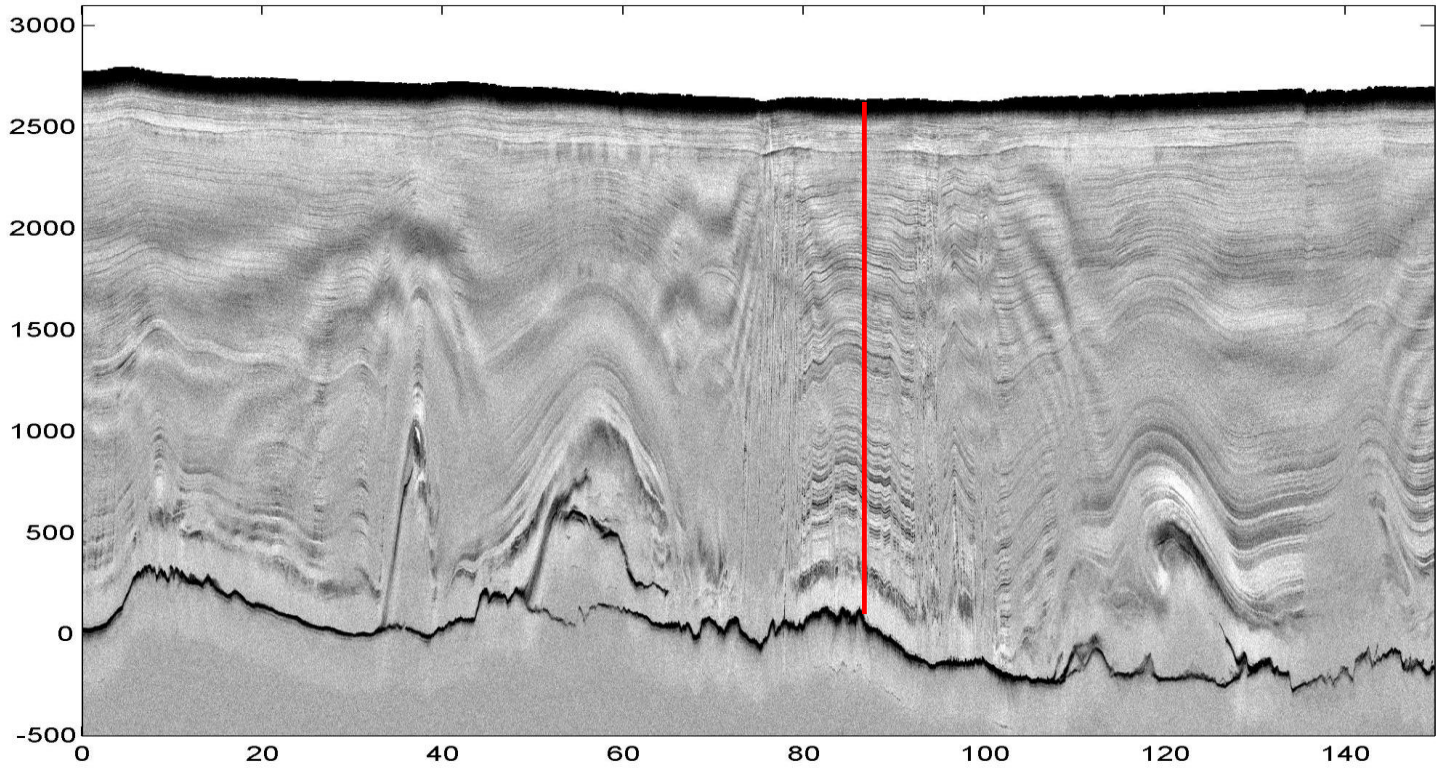
Hvad er Indlandsisens følsomhed overfor klimaforandringer med forskellig styrke og varighed?

Findes der tærskler/omslagspunkter for Grønlandsisen?

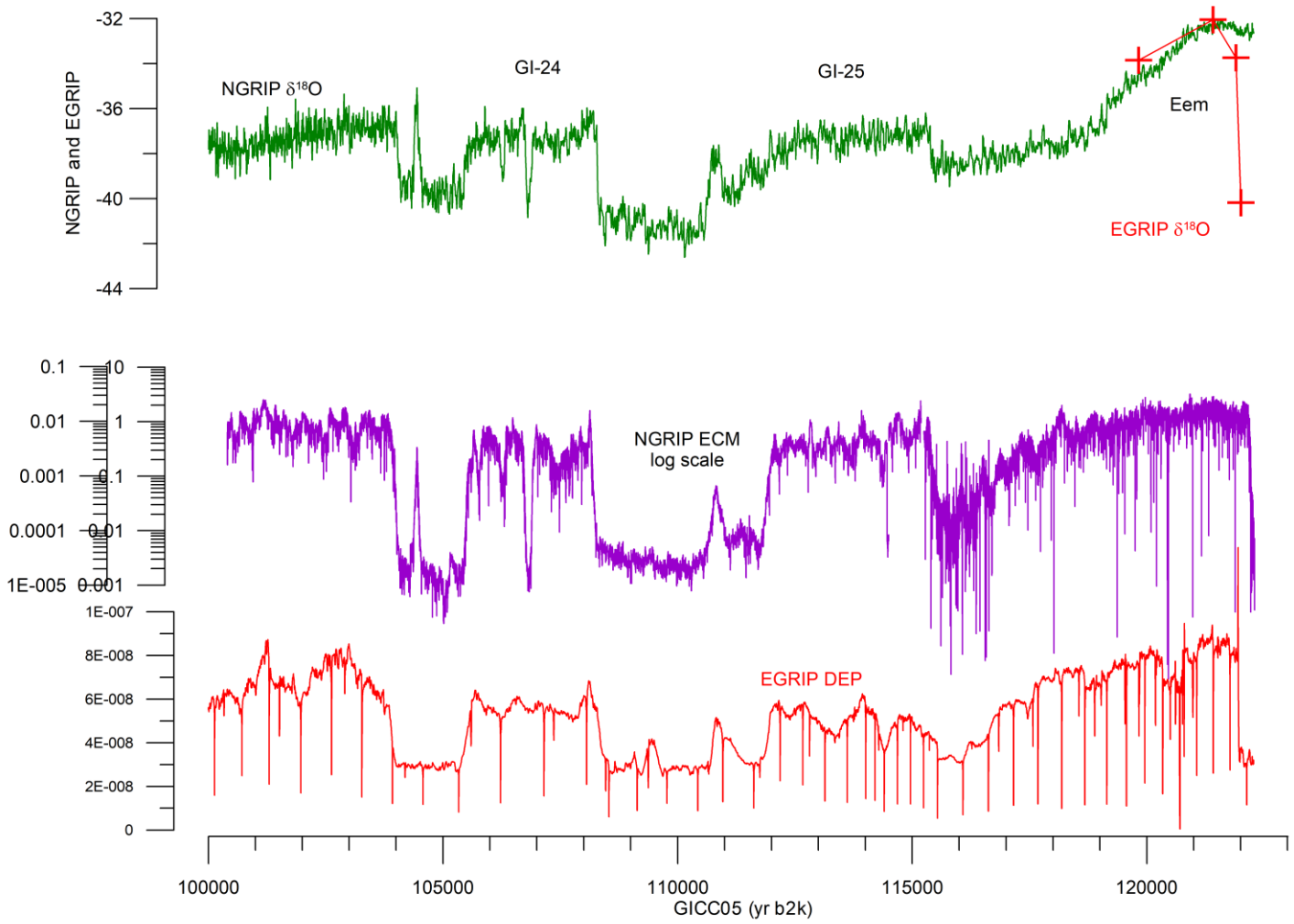
Hvad kan vi opklare om isens fremtidige tab af masse og ændringer i havniveauet**?**

Bunden nås ved EastGRIP 21. Juli 2023

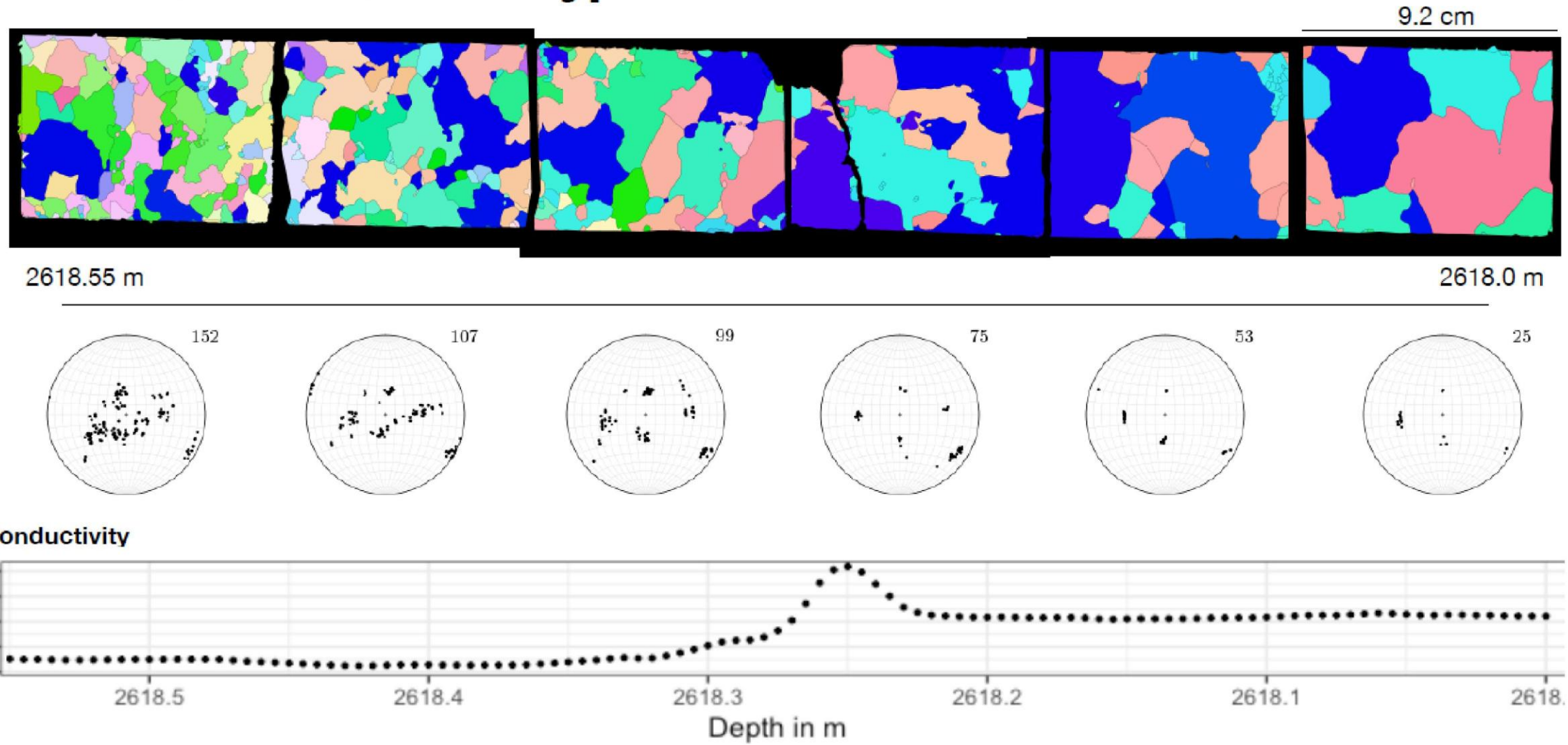




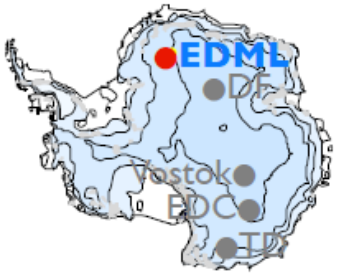
Hvor langt tilbage i tiden rækker EGRIP kernen?

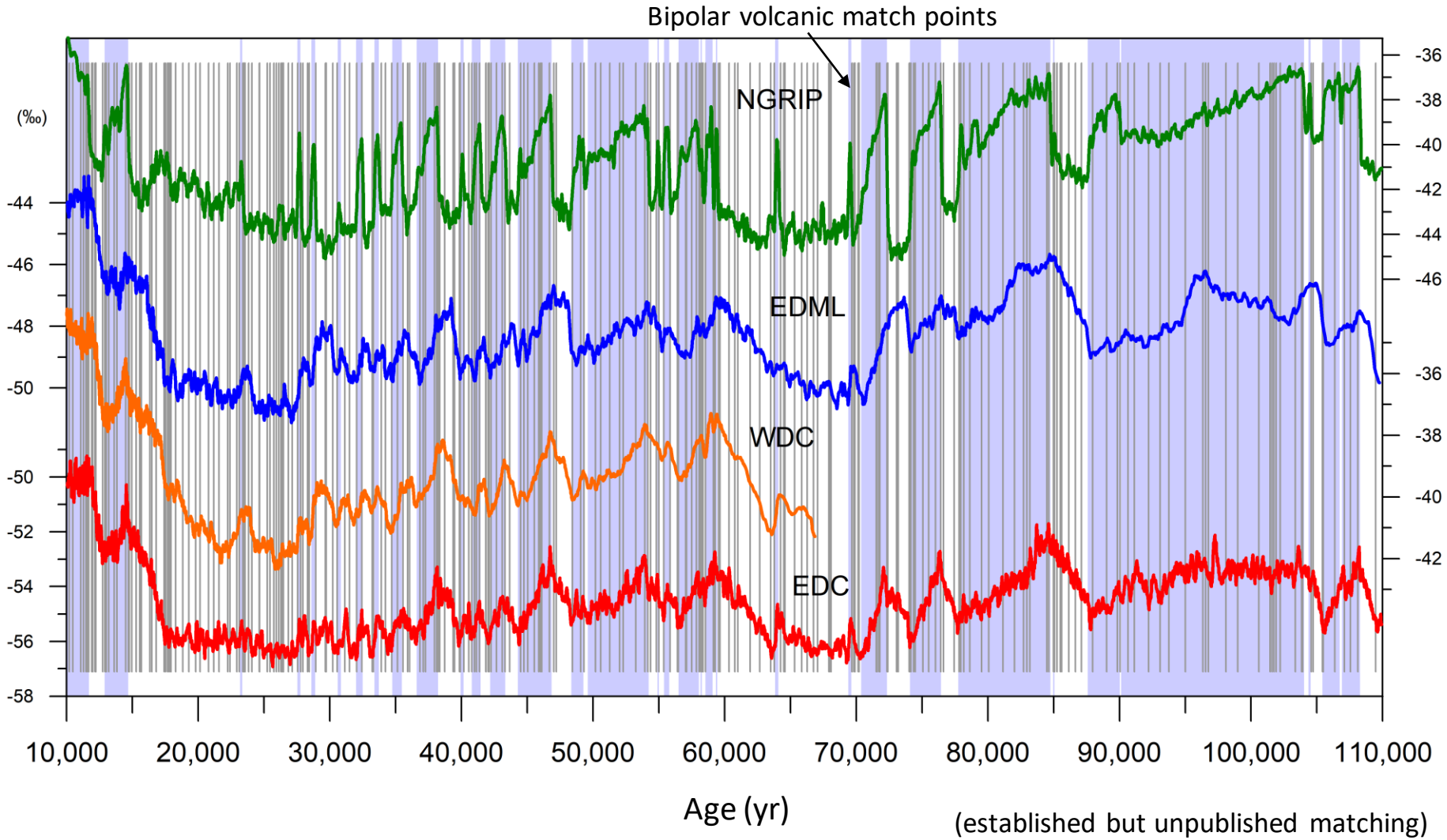


EGRIP 2618 m depth (bag 4761) - onset of ´Eemian´ type ice



Grønland og Antarktis synkroniseret.
Bipolar vulkansk synkronisering fungerer fint i sidste istid.

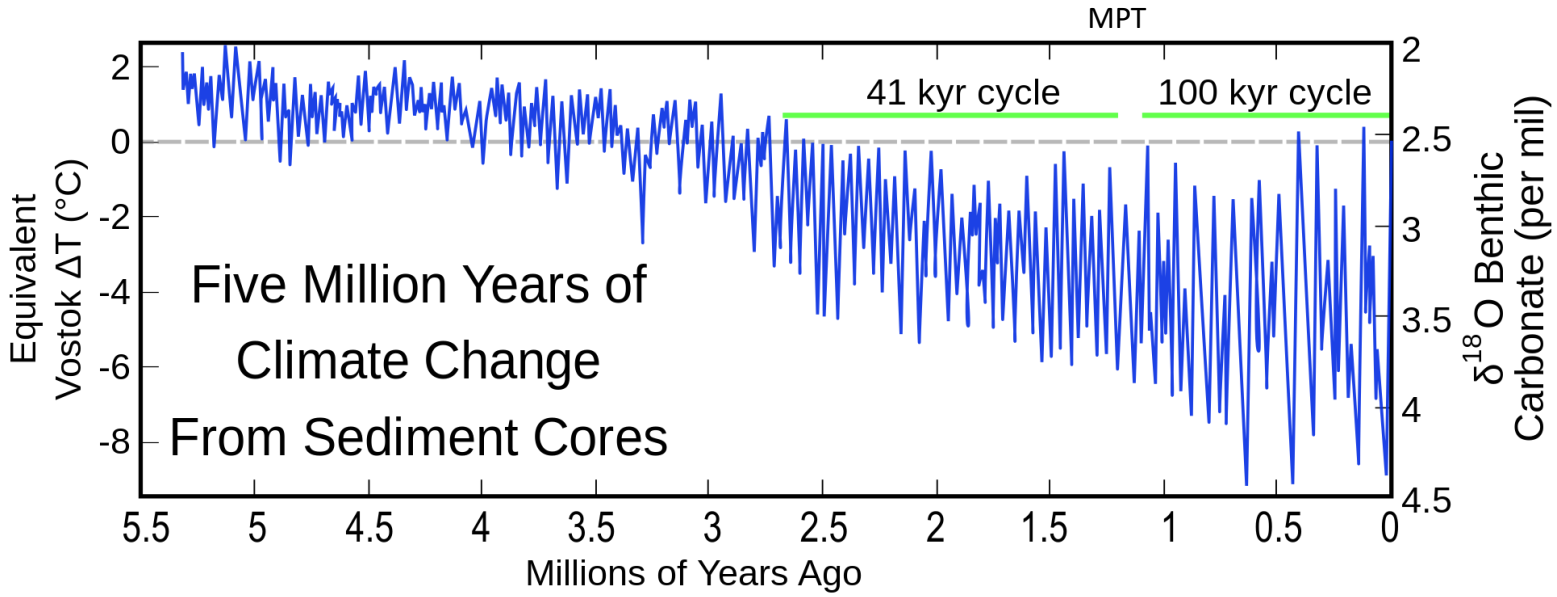




(established but unpublished matching)

I Green2Ice projektet vil vi forsøge at finde svar på nogle enkle spørgsmål:

- Hvor gammel er Indlandsisen?
- Hvordan var klimaet, da Indlandsisen blev dannet?
- Hvor klimafølsom er Indlandsisen?
- Hvad er Indlandsisens fremtid? Nogle tærskler?




EGRIP lejren, Juni 2017
Borested
Feltarbejdet i sommeren 2025.

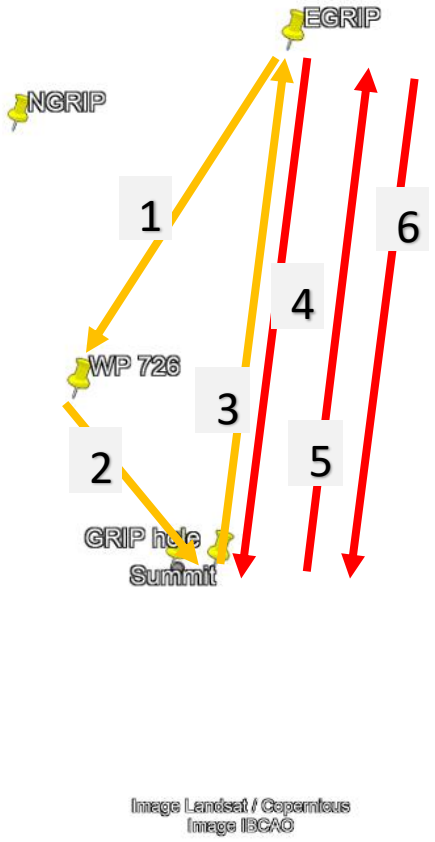

EGRIP, July 2025

1. travers. EGRIP til GRIP
En Pistenbully + slæde + plastic slæde med radar.
2 x Snescootere med bor og udstyr til måling af snekemi.
1 mekaniker/chauffør + 1 sygeplejerske + 6 forskere.
EGRIP-WP726-GRIP: 268km+145km. Korteste afstand mellem ruten og NGRIP: 135km

1. travers. GRIP tilbage til EGRIP.
En Pistenbully + tomme slæder.
1 mekaniker/chauffør + 1 chauffør + 1 læge
GRIP-EGRIP 344km (NEEM-EGRIP 440km).

2. travers. EGRIP to GRIP
Tre Pistenbullyer + dome + tunge slæder + garager.
2 Mekanikere + 4 chauffører + 6 besætning.

3. travers GRIP til EGRIP til GRIP opsamling
To Pistenbullyer + tunge slæder + plastic slæder
2 mekanikere/chauffører + 1 hjælper.



Traverssektioner: 1 og 2: Videnskabelig travers langs flydelinjen (radar, iskerneboring, snekemi).
3: Traversen returnerer. 4: Dome og garage travers. 5 og 6: Opsamling af sidste gods.

EGRIP analysehallen maj 2025.

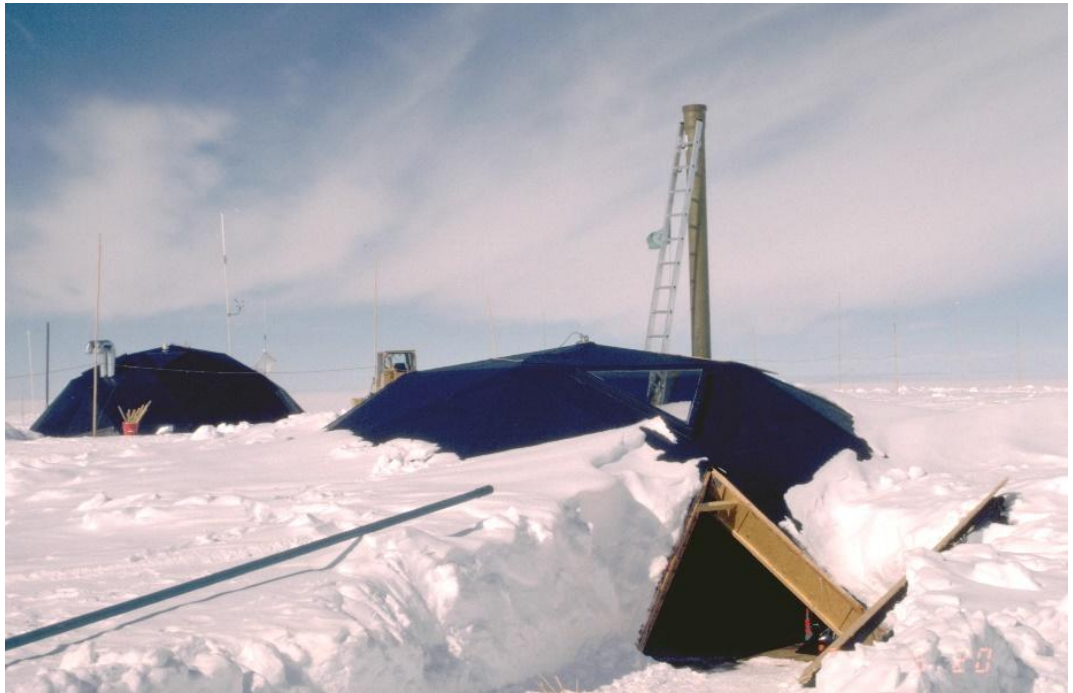
2017

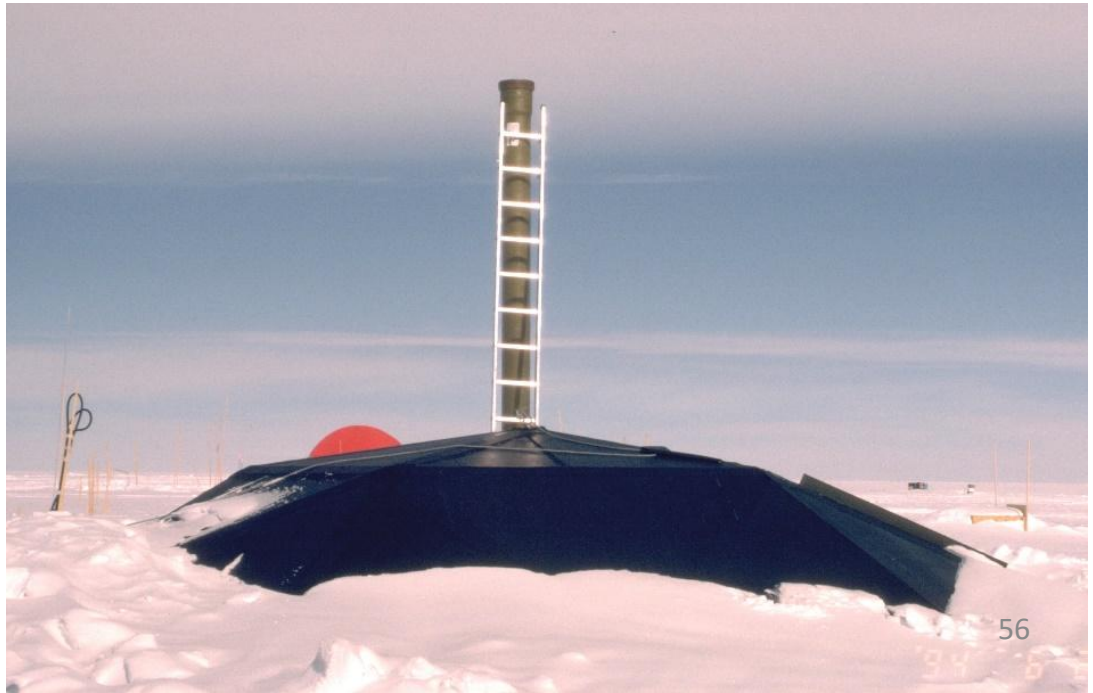

Et sidste kig op ad rampen fra snehulerne ved EGRIP.

En uventet hændelse.

Den videnskabelige travers. Maj 2025

GRIP lejren i 1994





GRIP 2004

GRIP 2010

Det gamle GRIP borehul fra 1993 genfundet.

Det gamle NGRIP borehul fra 2003 genfundet.

Traverstoget på tidligere landingsbane. EGRIP 21. Juni.

Flotte spor.

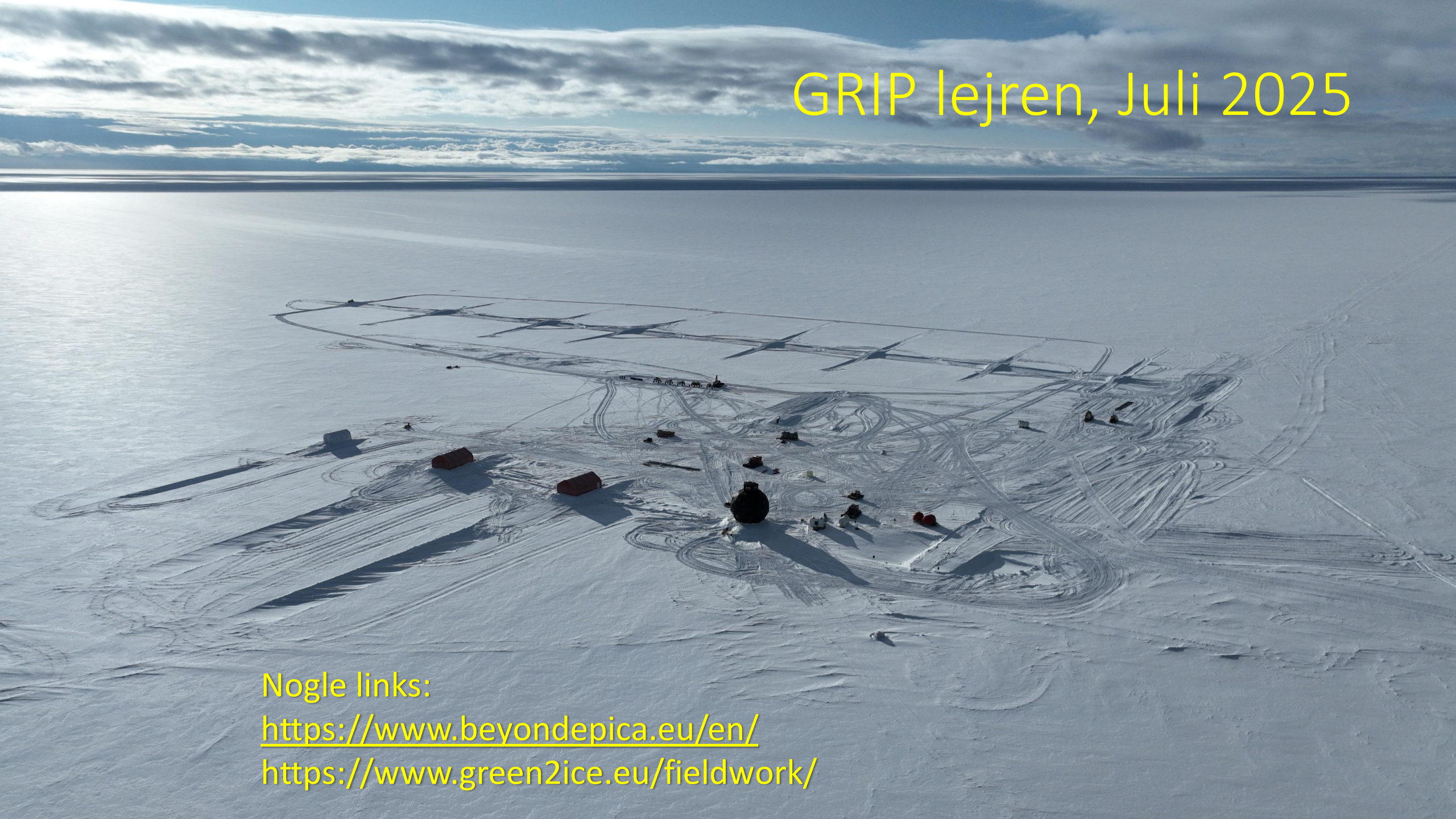
Traverssporene, den 25.Juni

Traversen til GRIP

Den anden og sidste travers ankommer til GRIP, Juli 2025

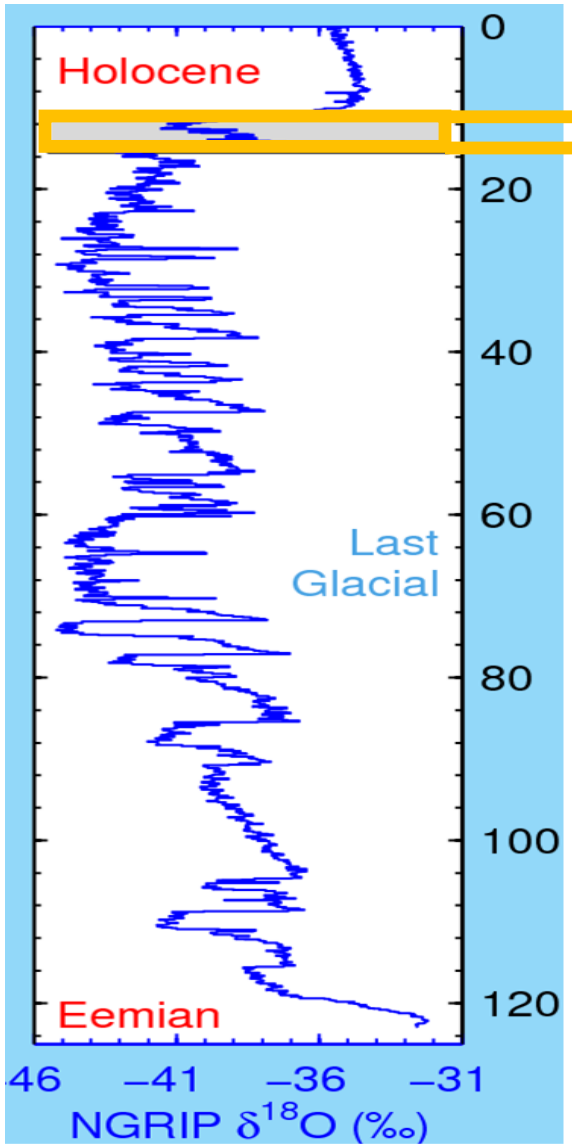
GRIP domen og det gamle borehul

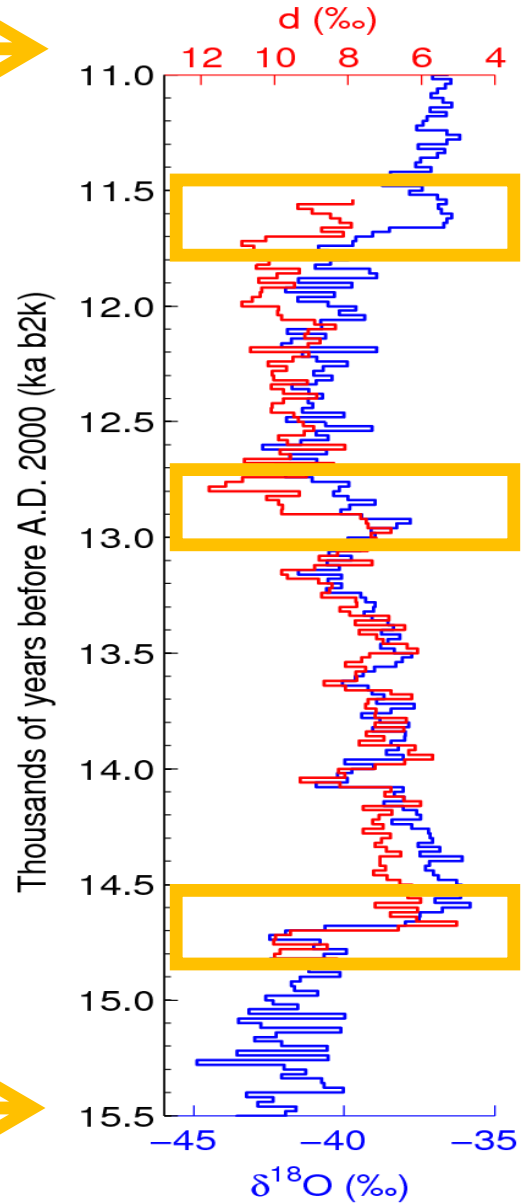
GRIP lejren, Juli 2025



Nogle links:
https://www.beyondepica.eu/en/
https://www.green2ice.eu/fieldwork/

Studiet af dynamikken af abrupte klimaændringer





Holocæn

opvarmning

GS-1 (Yngre Dryas)

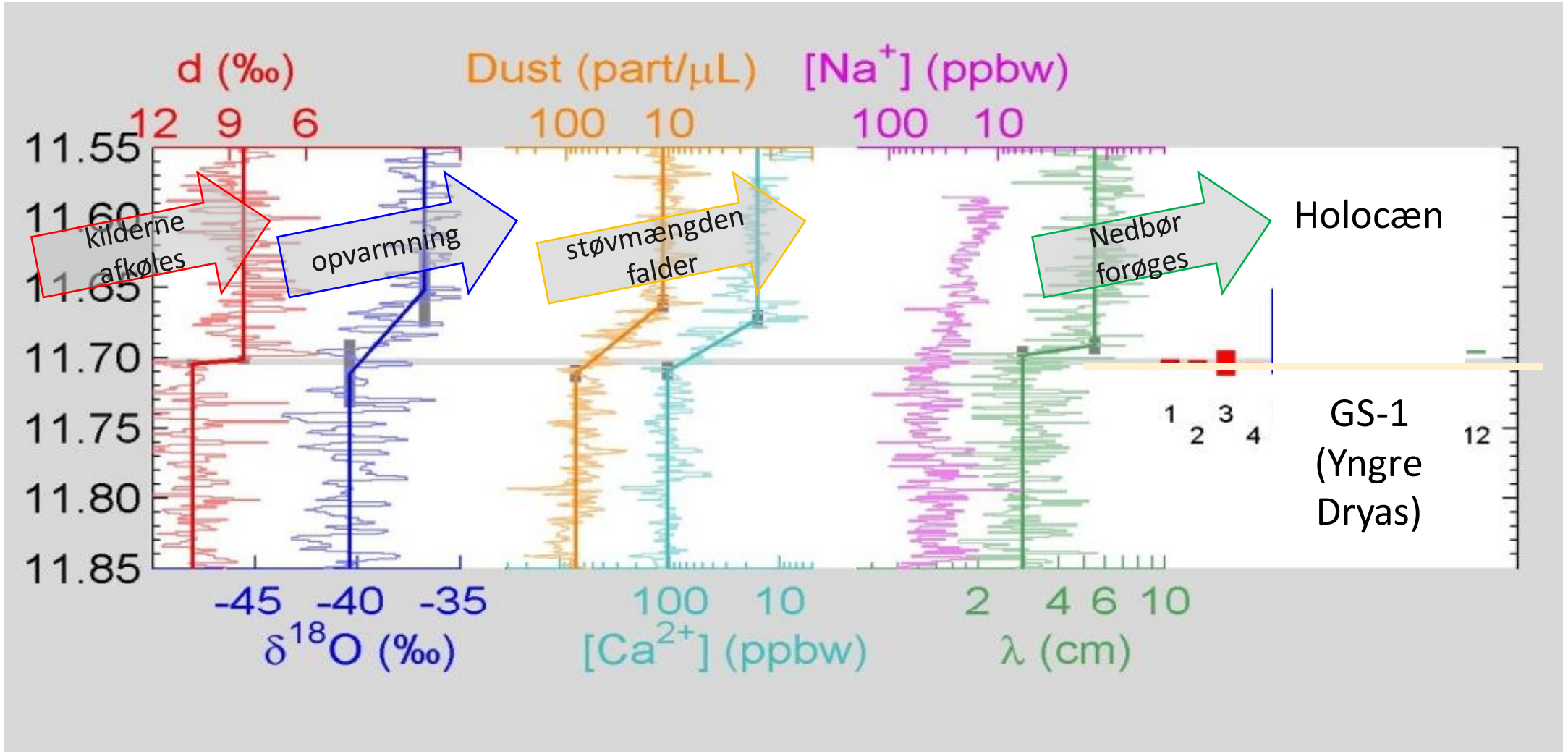
afkøling

GI-1 (Bølling og Allerød)

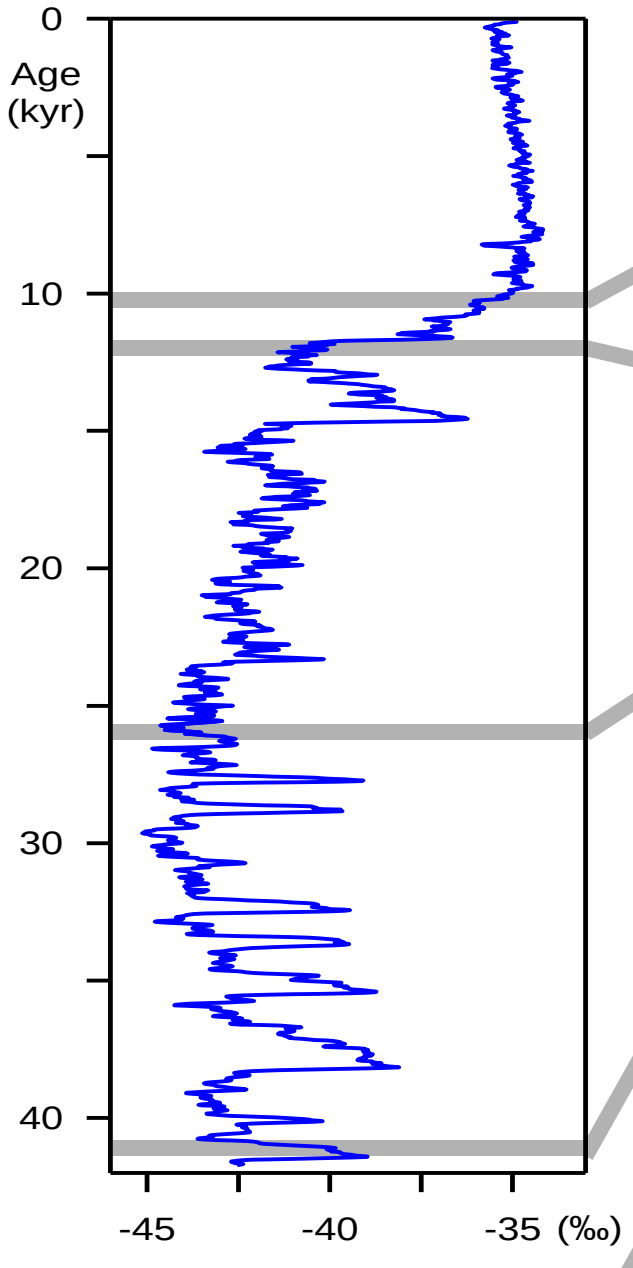
opvarmning

GS-2 (Ældste Dryas)

Abrupt opvarmning fra GS-1 to Holocæn (begyndelsen af Holocen)



Referencehorisonter



Saksunarvatn tephra

9.0 ± 0.1 ^{14}C ka BP (Björck et al., 2001)

Tephra at 1528.6 m i GRIP (Grönvold et al., 1995)

Vedde tephra (Z1)

10,330 ± 65 ^{14}C ka BP (Wastegård et al., 1998)

Tephra at 1639.5 m i GRIP (Grönvold et al., 1995)

Fugloyarbanki tephra

23.2 ± 0.3 ^{14}C ka BP (Rasmussen et al., 2003)

Tephra at 1848.0 m i NGRIP (Davies et al., 2010)

Laschamp event

40.4 ± 2.0 ka cal BP (Guillou et al., 2004)

Ligger tæt ved GIS10

Z2 tephra

~55 ka cal BP

Bunden ved NEEM 2538 m, juli 2010