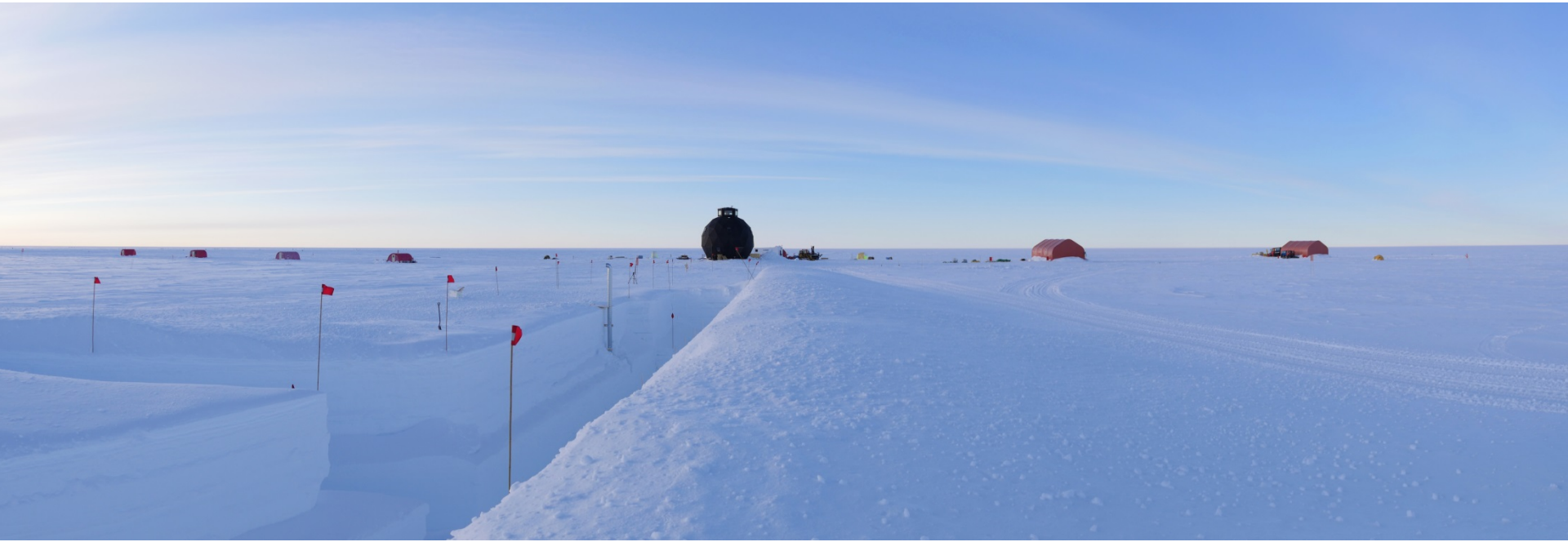
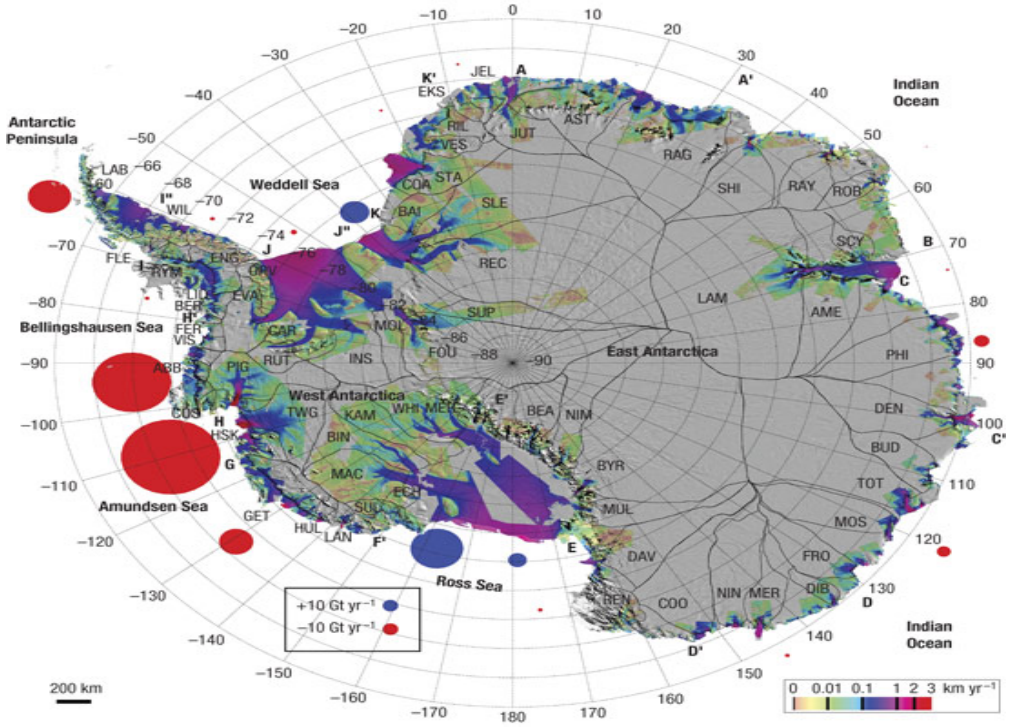
Iskerner og andre kilder fortæller om fortidens bratte klimaskift.

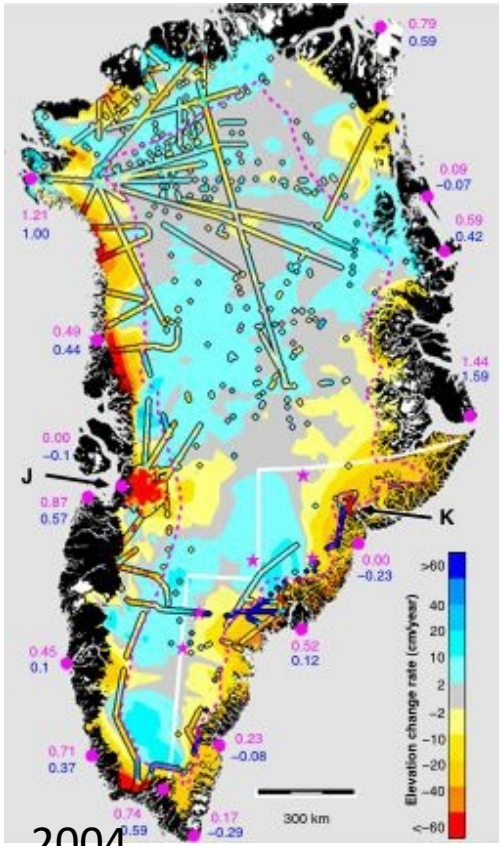


Præsenteret af Jørgen Peder Steffensen, Center for is og klima ved Niels Bohr Institutet.
Foredrag til ”Big Bang”, Aarhus og København 25. januar 2019.

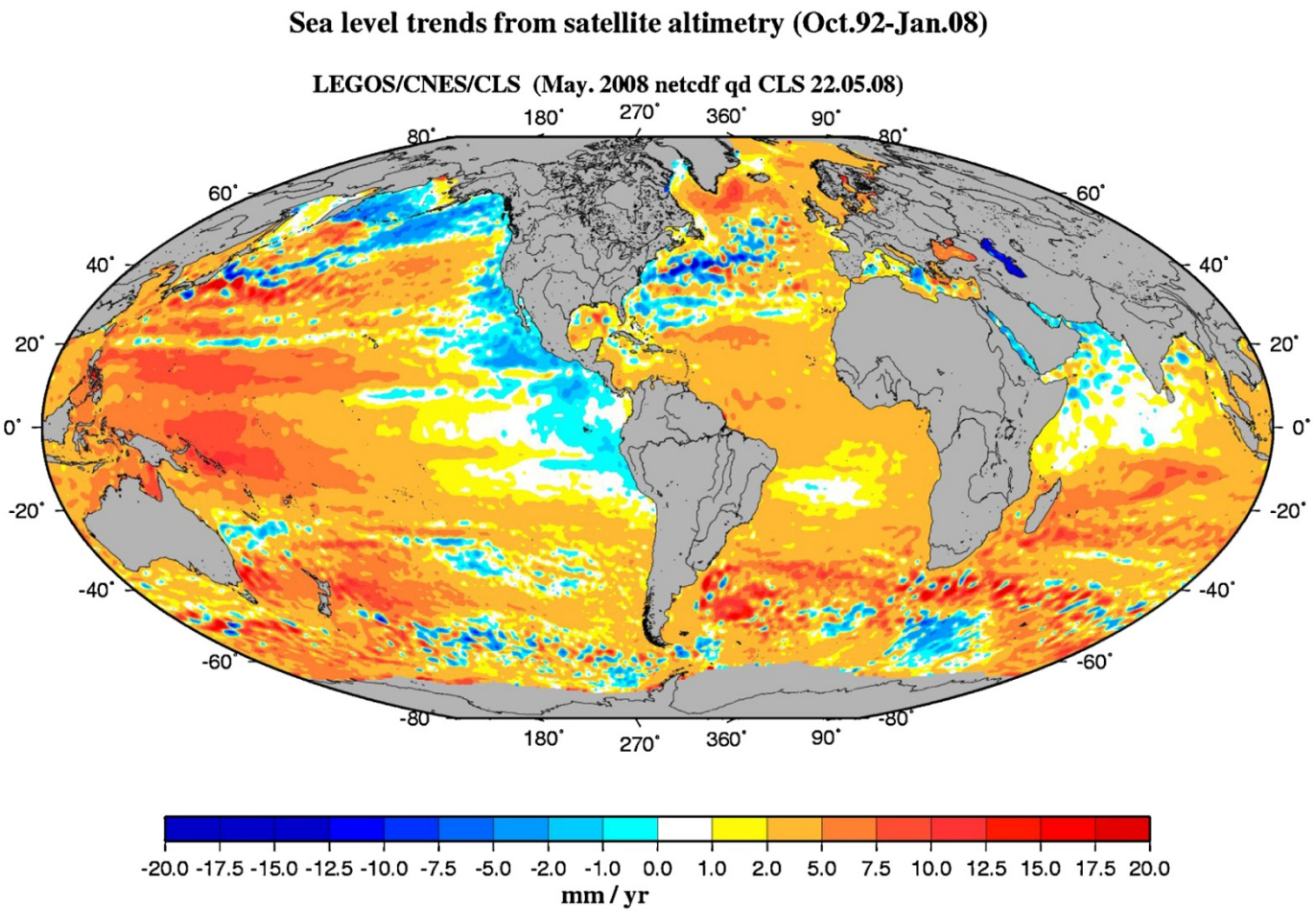
Skrumper isen?



E. Rignot, Nature Geoscience, 2008



Krabil et al, GRL, 2004



Cazenave, C. R. Geoscience, 2008


Tirslundstenen

De parallelle veje ved Glen Roy, Skotland
Diskuteret og overvejet af Charles Darwin og Andre Agassiz

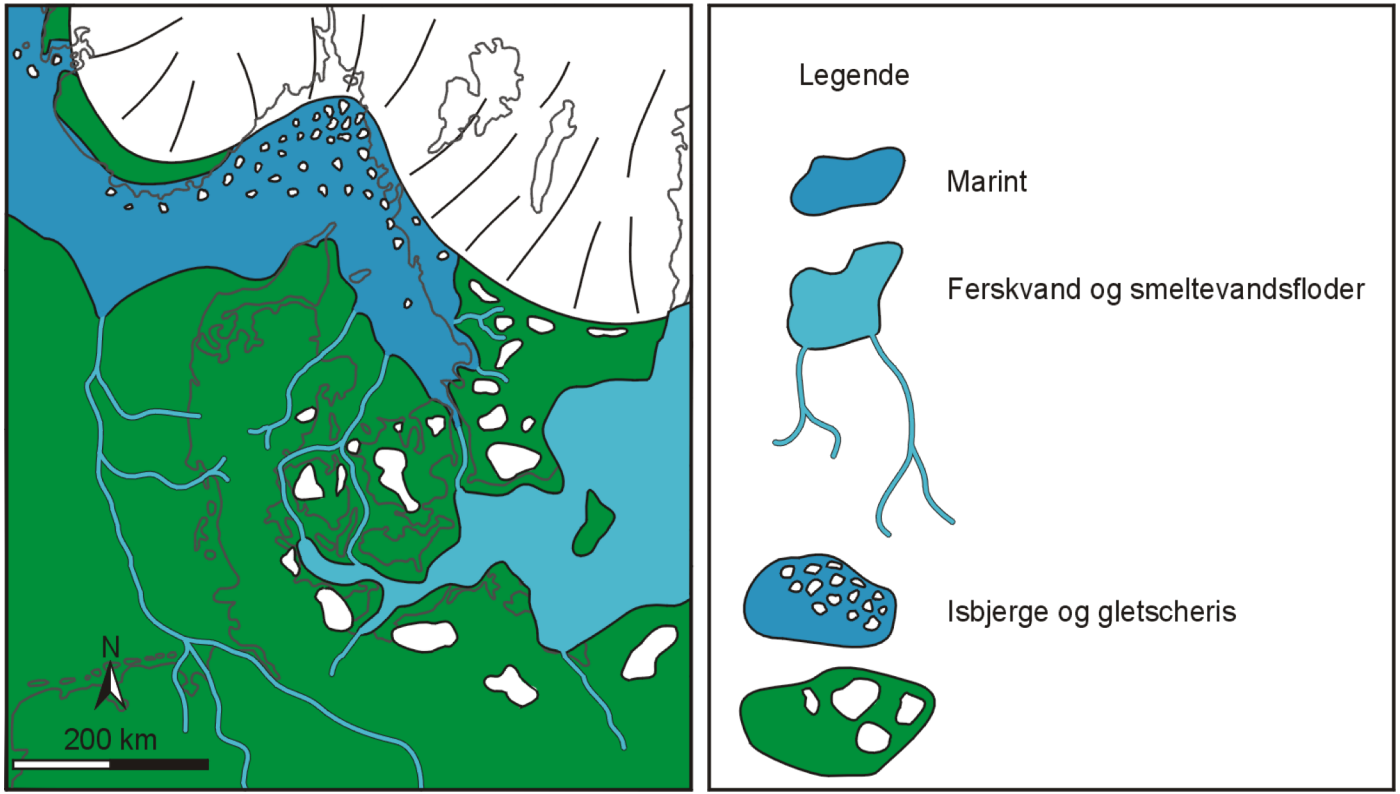

Kangerlussuaq fjorden mod NØ, april 2015.

Lidt om mudder.

Les Cwynar ved Splan Pond i New Brunswick , Canada

Mudderet indeholder ofte pollen

Den aktive is for 15-16.000 år siden Houmark Nielsen



Tidlig opdagelse af klimavariationer ved istidens afslutning: Hartz, H. og V. Milthers (1901) Det senglaciale Ler i Allerød Teglværksgrav. Meddelelser fra Dansk geologisk Forening 8: 31-60.

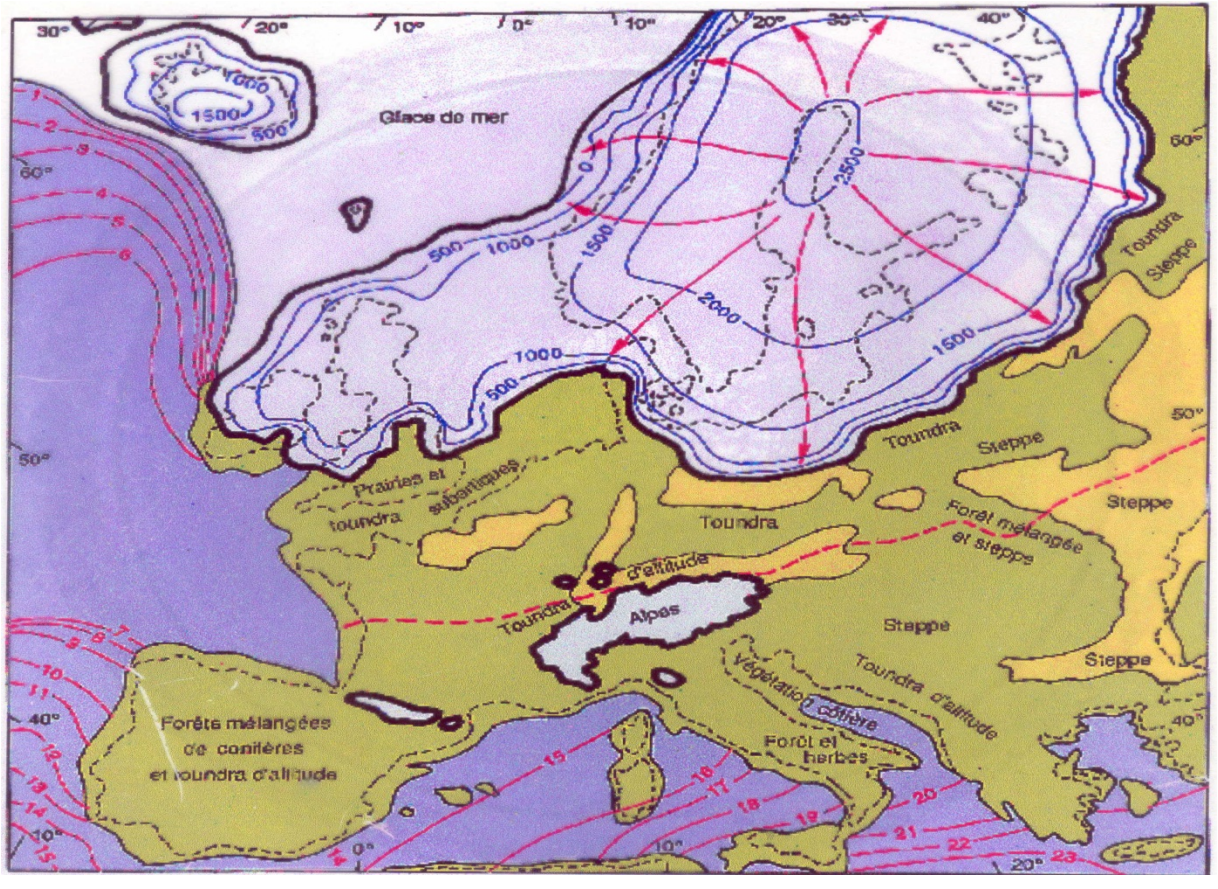
Slotseng bassinet

Nanna Noe-Nygaard

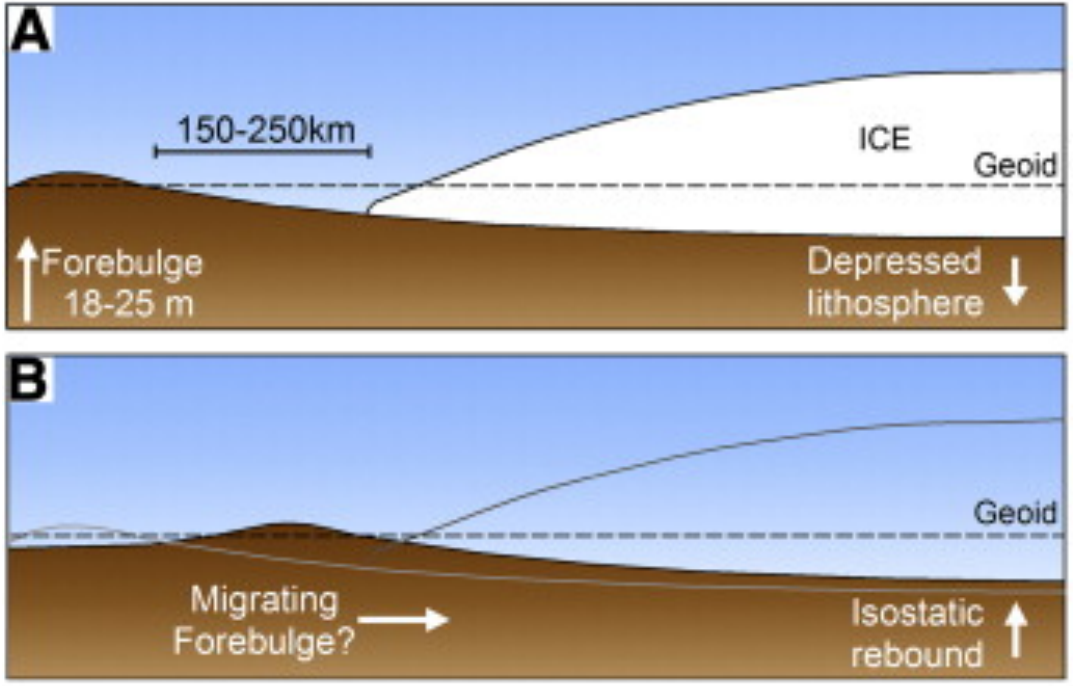
Bølling Allerød overgangen

Fodspor af rensdyr eller hjort i Allerød gyttje.
ca.14000 år gammelt

Europa for 25.000 år siden



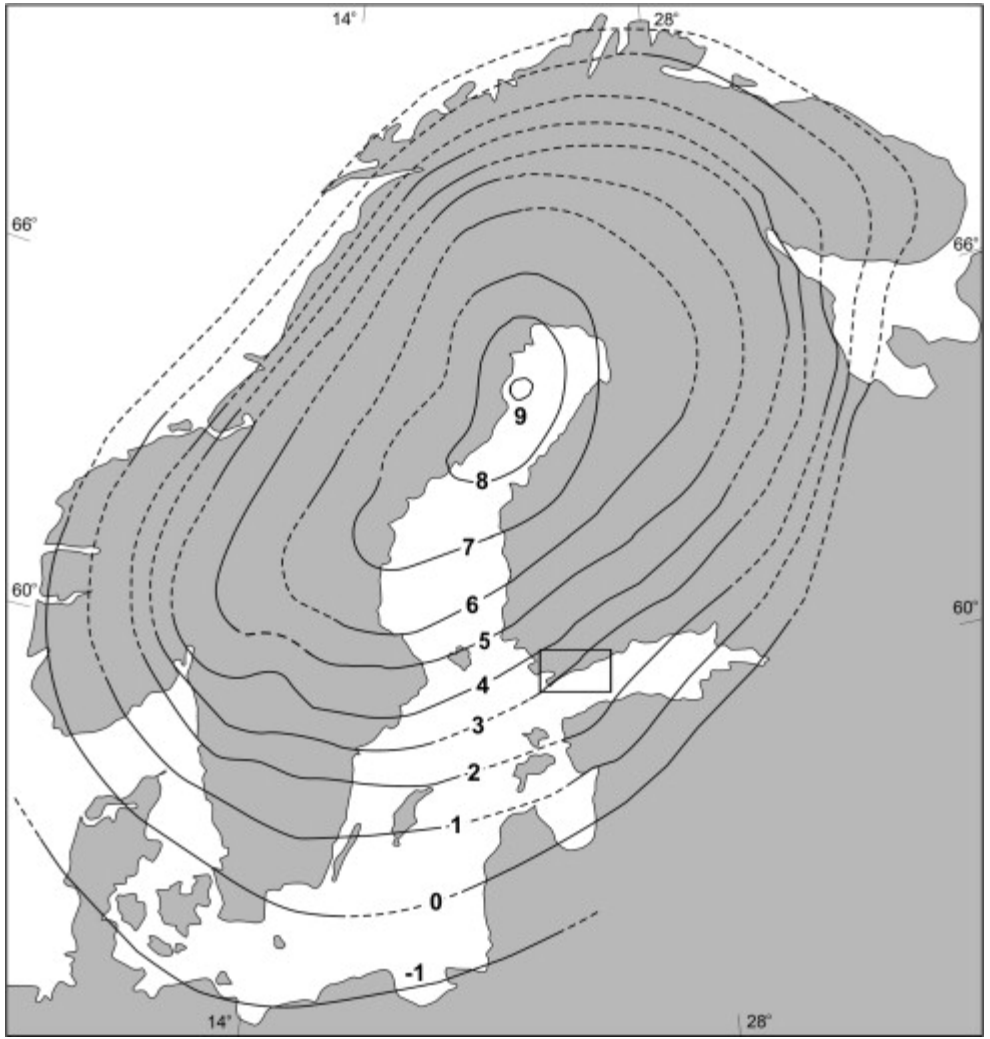
”puklen” foran isen

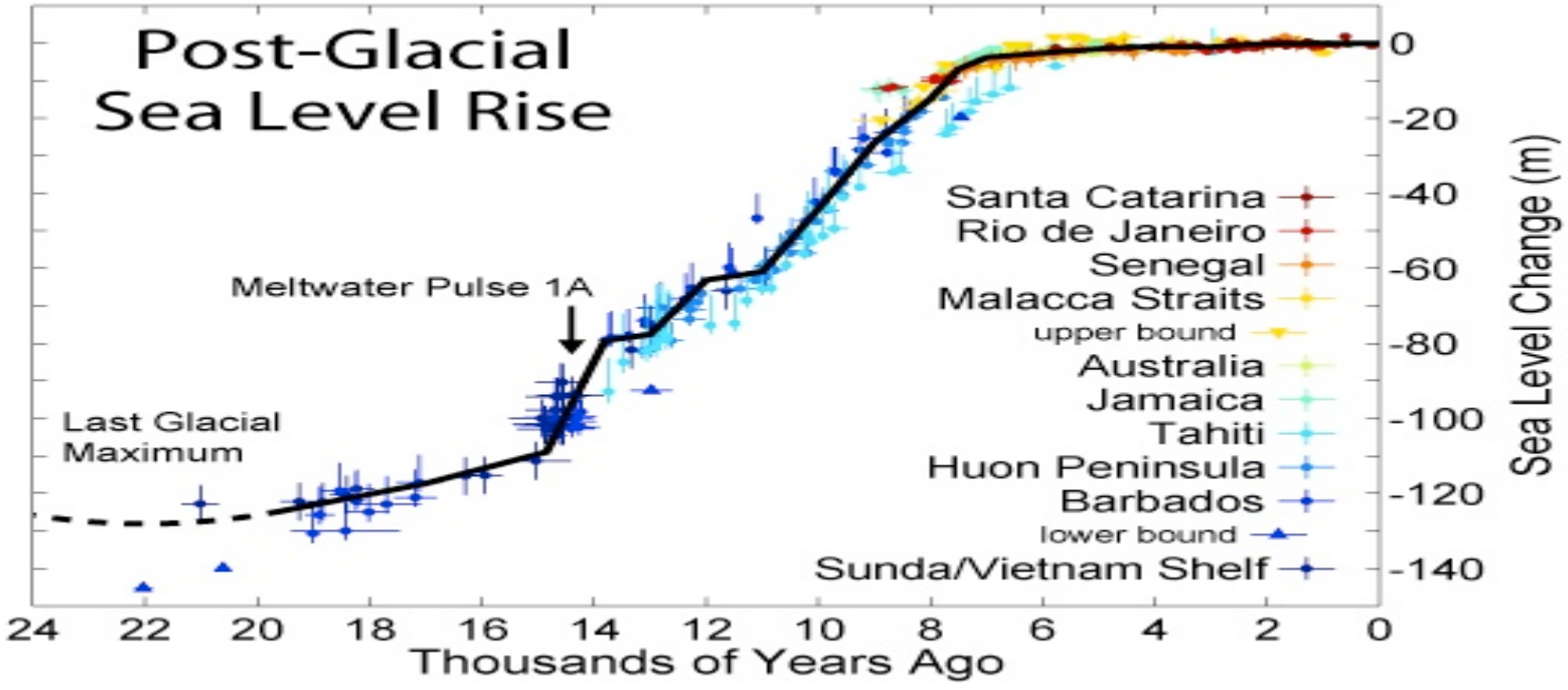


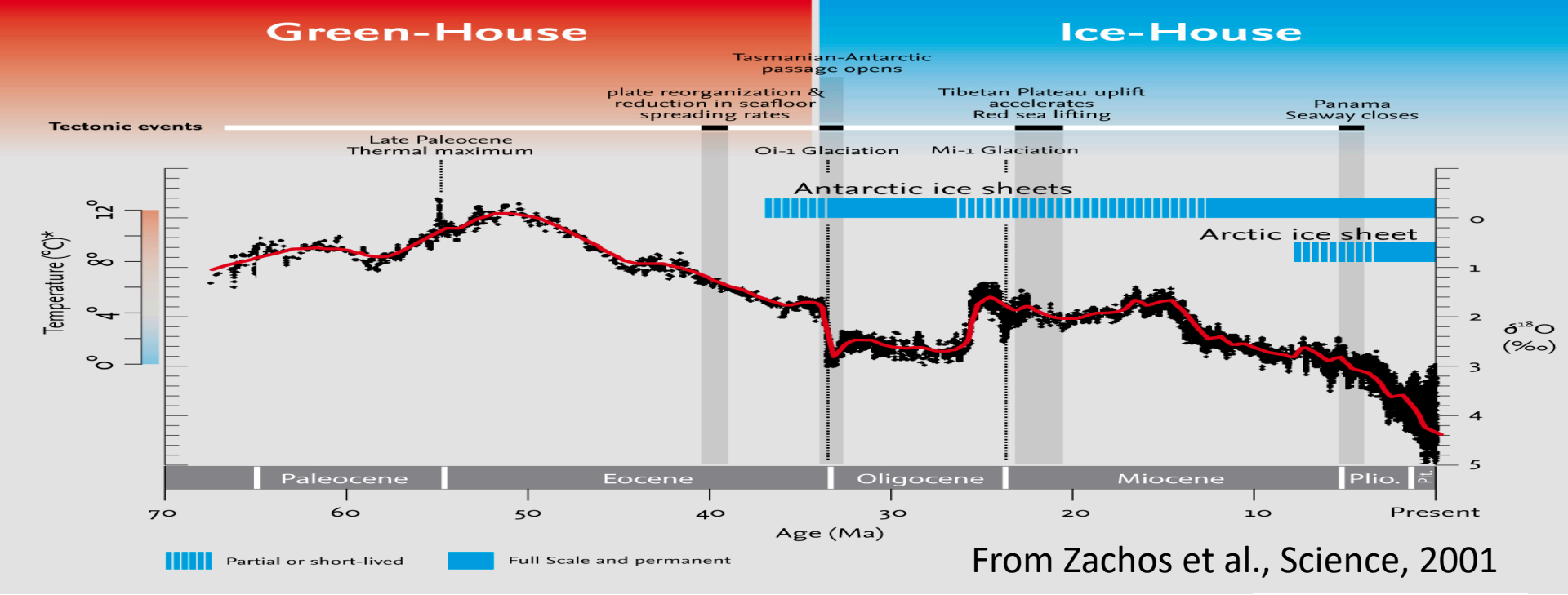
Fra Oakley, 2012, QRS

- Nuværende rater for landhævning i mm/år.

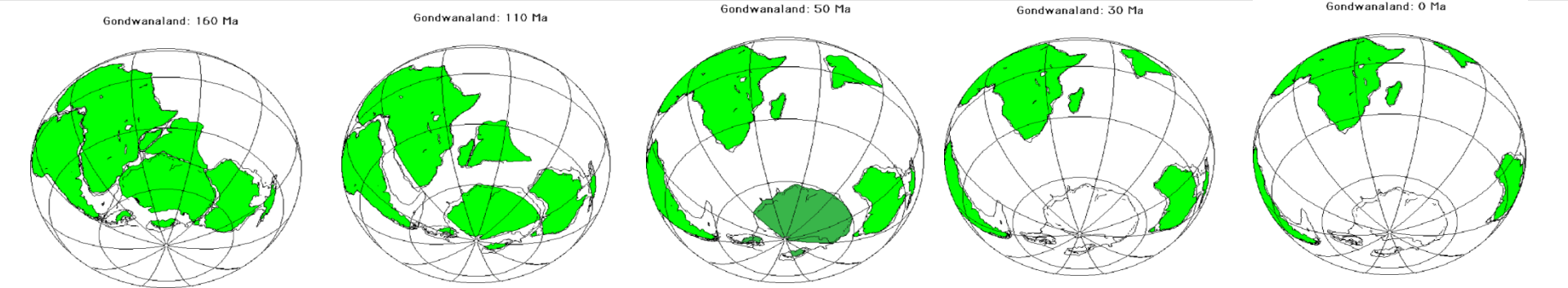
Fra: Miettinen et al., Marine Geology 2007.



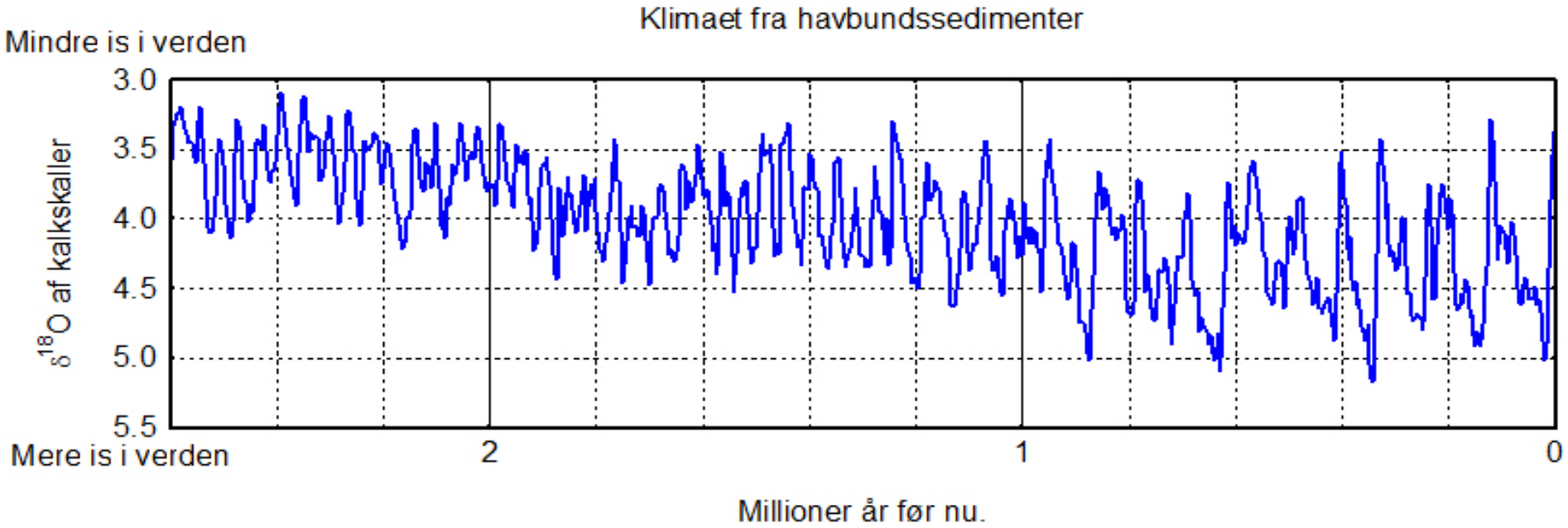

Post-Glacial
Sea Level Rise
Meltwater Pulse 1A
Last Glacial
Maximum
Santa Catarina
Rio de Janeiro
Senegal
Malacca Straits
upper bound
Australia
Jamaica
Tahiti
Huon Peninsula
Barbados
lower bound
Sunda/Vietnam Shelf
0
-20
-40
-60
-80
-100
-120
-140
Sea Level Change (m)
24
22
20
18
16
14
12
10
8
6
4
2
0
Thousands of Years Ago



From Zachos et al., Science, 2001

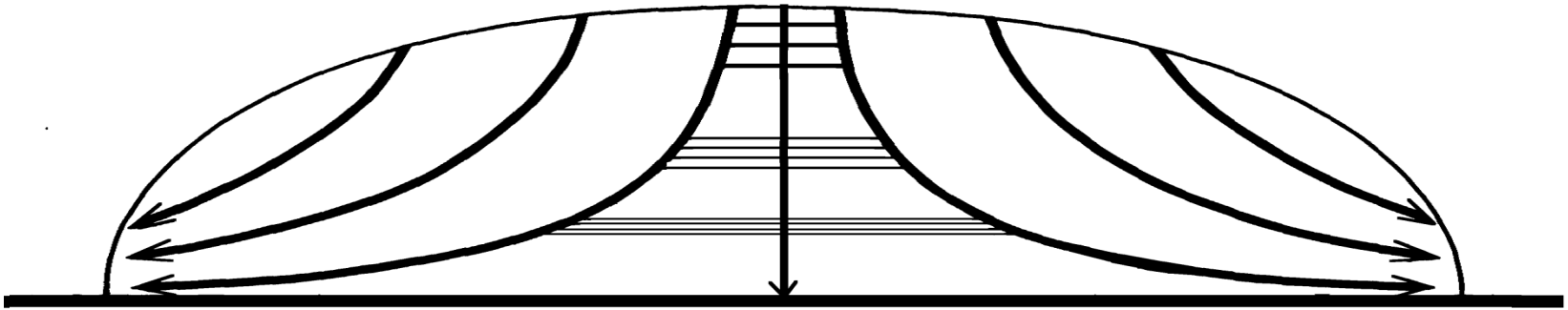


Klimahistorien i de sidste 2.6 millioner år

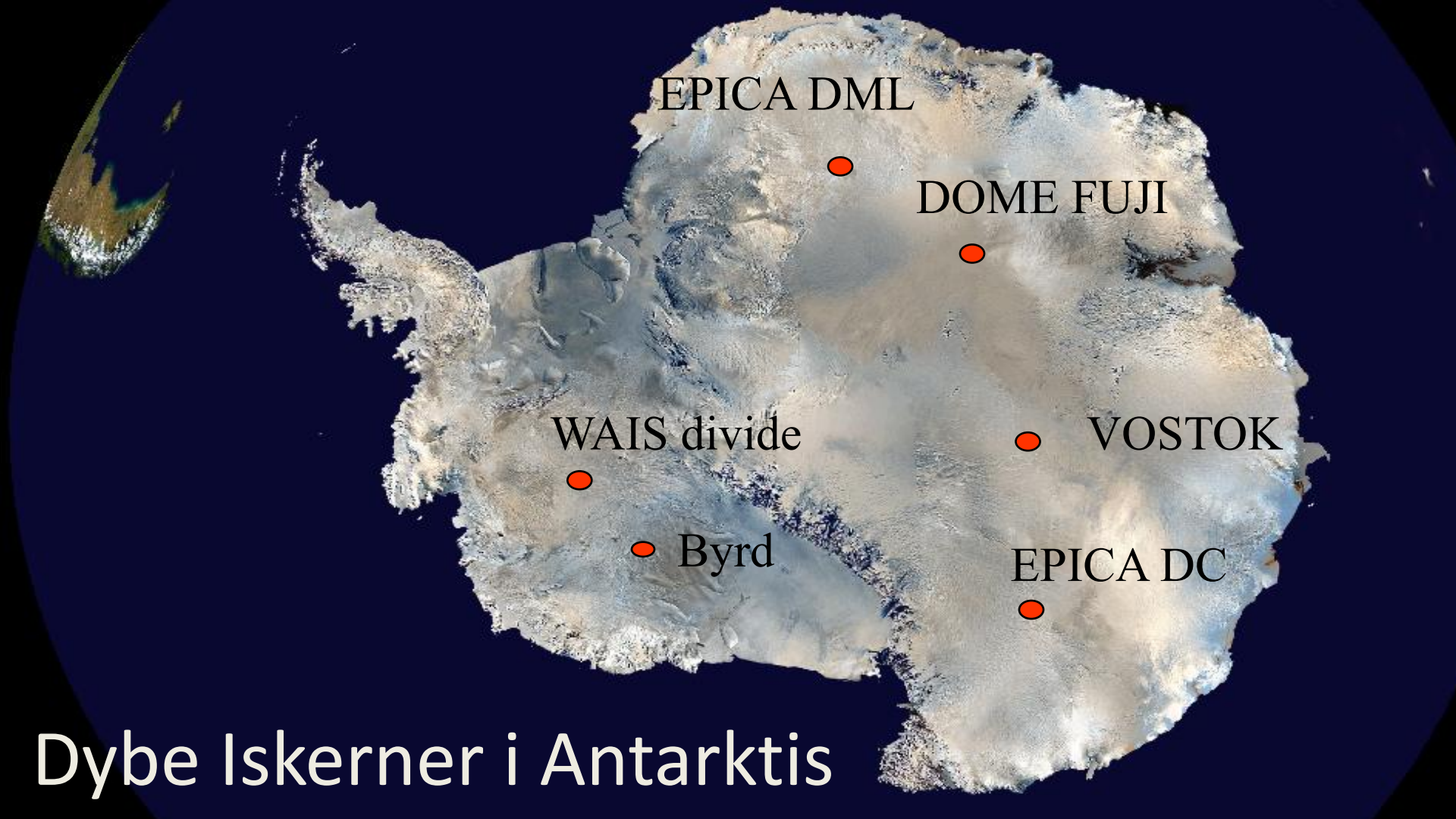


Data fra ODP-677 (ODP, Ocean deep Drilling Programme)

Indlandsisen i tværsnit

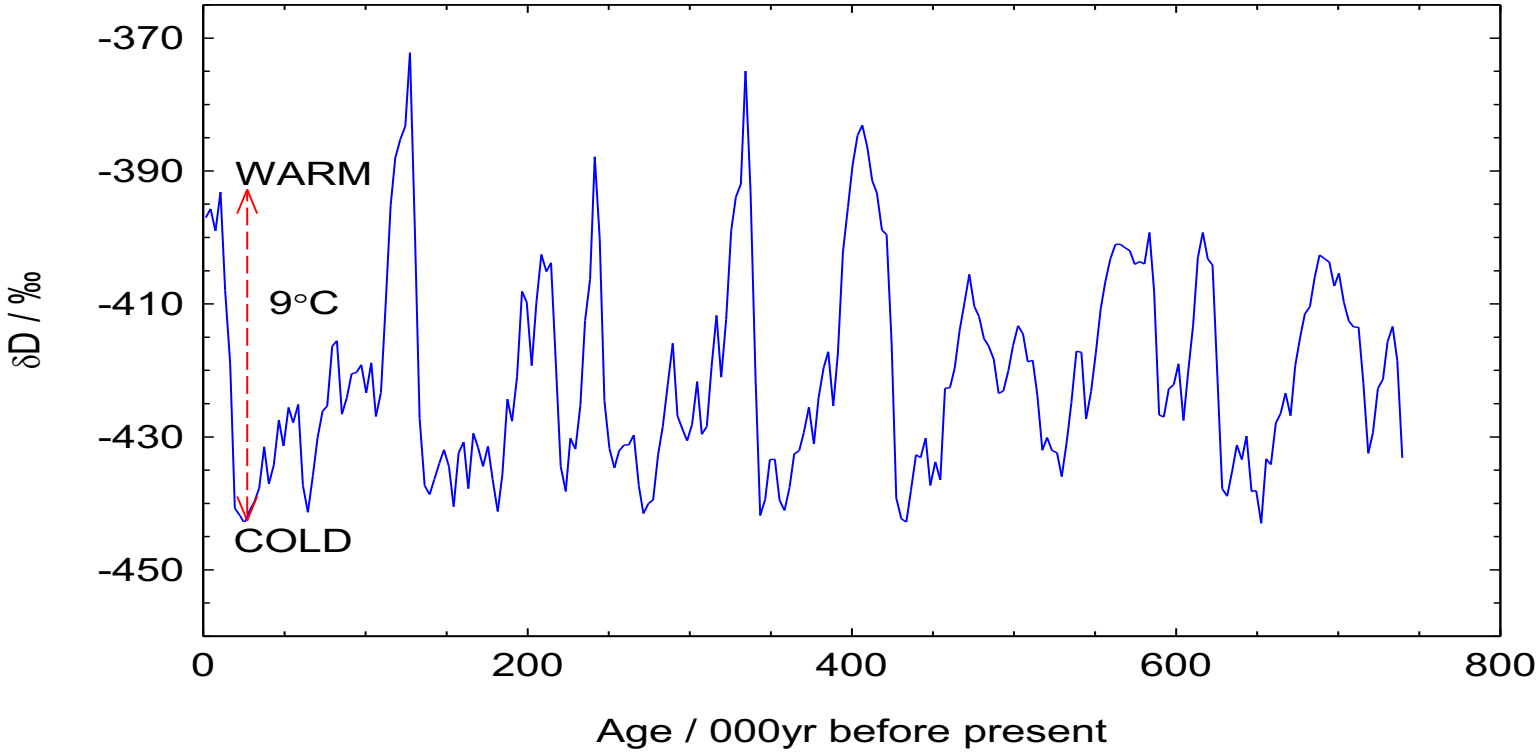


DomeC, 2004/2005



Dybe Iskerner i Antarktis

Antarktisk klima i 740.000 år

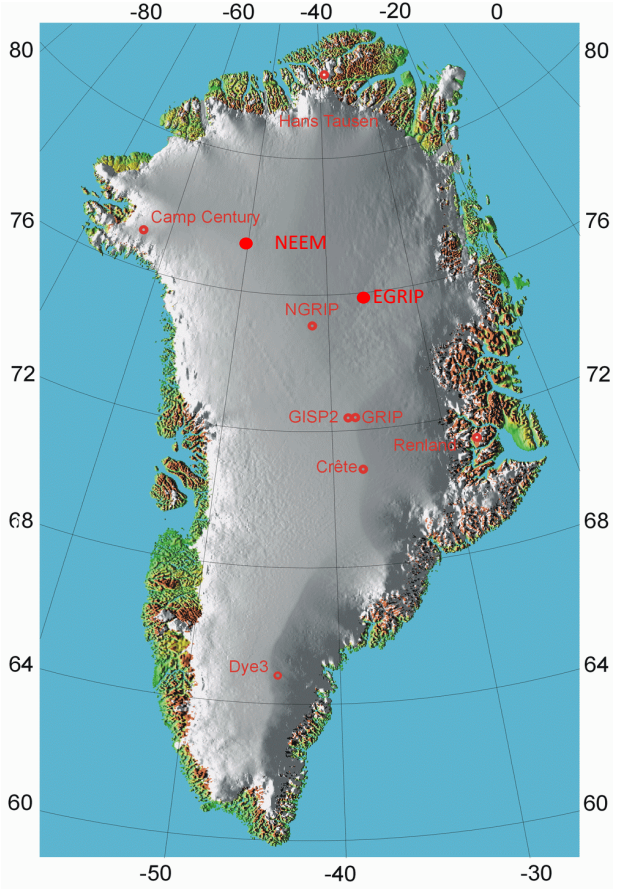


Dybe iskerner i Grønland

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	15-20	(2550 m)

GRIP = Greenland Ice Core Project (EU)

GISP = Greenland Ice Sheet Project (US)

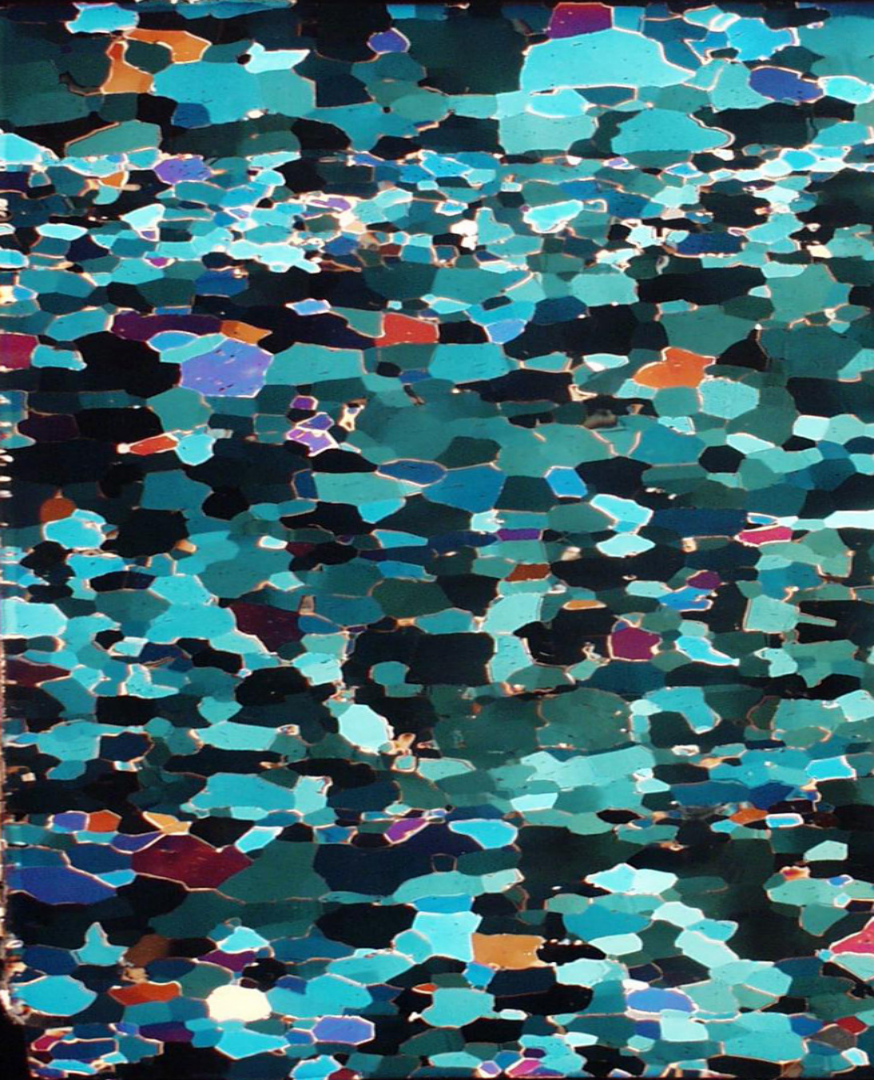


EGRIP lejren, august 2016

Forsyninger ankommer

Ice core drilling


THE
NORTH
FACE



Iskernedata
en indkøbsseddel

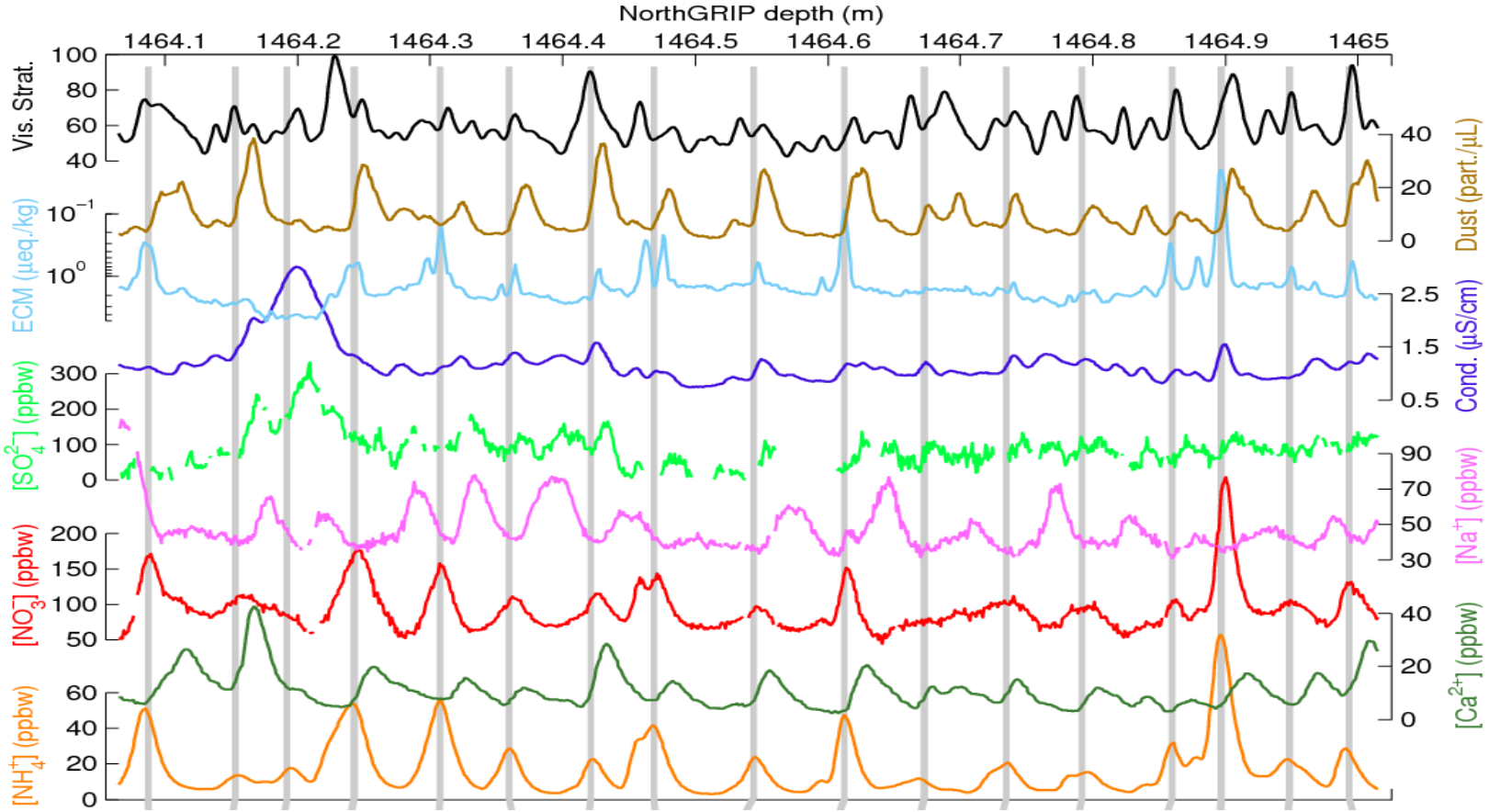
- Isen selv: ^{18}O , ^{17}O , ^{16}O, ^{1}H og ^{2}D
- Kontinentalt støv, vulkansk aske, mikrometeoriter og biologisk materiale.
- Ioner: Cl^-, NO_3^-, SO_4^{2-}, F^-, H^+, Na^+, K^+, NH_4^+, Mg^{2+}, Ca^{2+}
- Gas i luftbobler: CO_2, CH_4, O_2, N_2, SF_6.
- Radioaktive isotoper: ^{10}Be, ^{36}Cl, ^{210}Pb,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

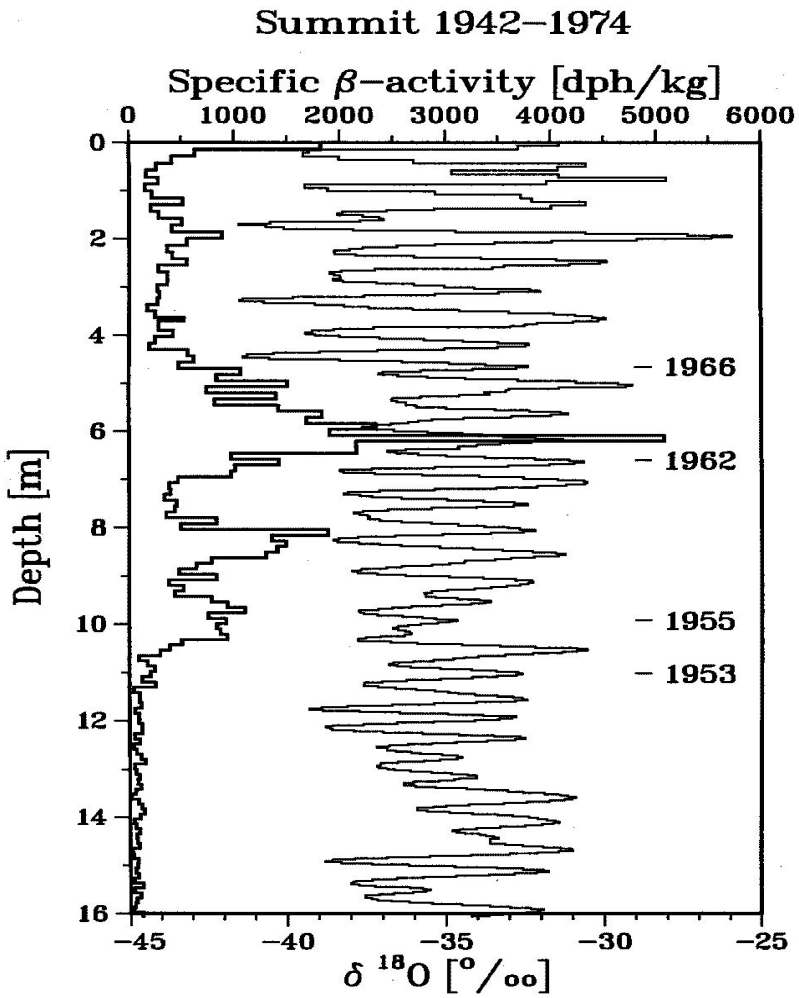
Natural ice through polarized light
(sample size : 4 x 10 cm)


HEMA
626

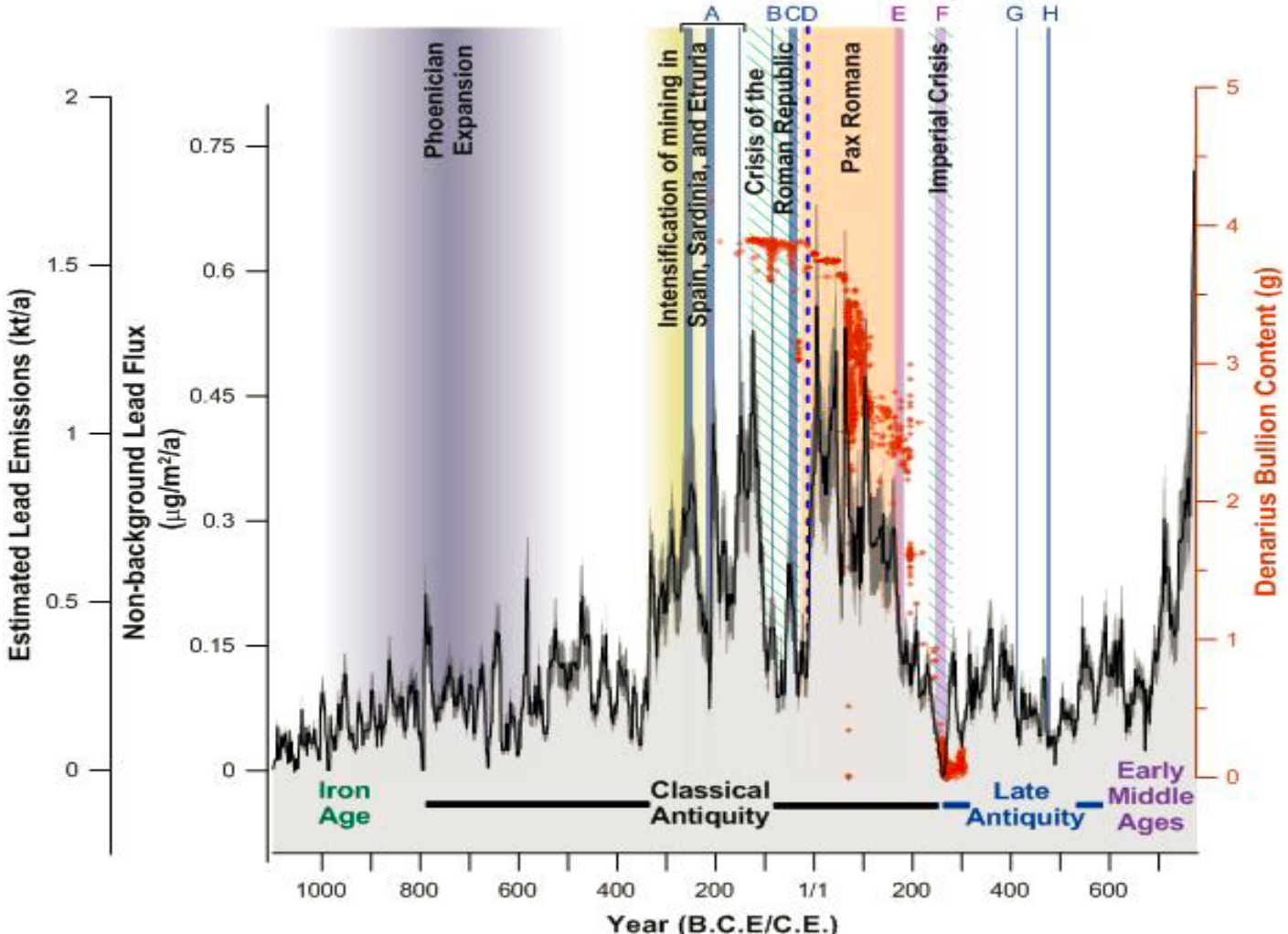

PIERRO

Optælling af årlag i tidlig Holocæn

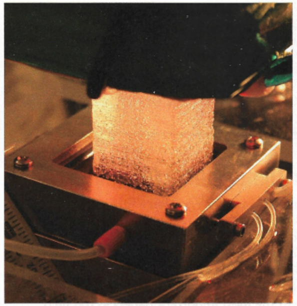




From Clausen and Hammer, Annals of Glaciology, 1988



McConnell et al, PNAS, 2018



Ice core samples from Greenland show fluctuations in lead measurements that match historical records of changes in metal production in ancient Rome.

Ice Capsule to Ancient Europe

A column of Greenland ice has offered insight into the politics and economics of ancient Rome.

Layers of Greenland's ice contain lead and other metals that had drifted hundred of miles from Europe between 1235 B.C. and A.D. 1257, according to a May paper in *PNAS*. Researchers found that fluctuations in the lead measurements matched historical records of changes in European metal production related to wars, epidemics and imperial expansion.

Researchers have previously studied lead in ice cores using a time-intensive method that provided less precise information. The instrumentation used in the new study, however, is faster and able to produce far more complete data. By sampling a column of ice from the center of a larger ice core, the new method also reduces the risk of contamination from modern sources. Researchers obtained over 21,000 measurements of minute lead concentrations from an ice column 423 meters long — just over a quarter of a mile. They assigned lead values to specific years by finding the ice layer with the highest sulfur concentrations, which formed during a volcanic eruption in A.D. 1257. Researchers then counted each annual layer backward in time.

The team focused on an ancient Roman period, roughly from the third century B.C. to the third century A.D. They found that lead levels increased with Phoenician trade and the Pax Romana, a period of economic prosperity, and decreased during the Punic Wars and Antonine Plague.

Lead author Joseph McConnell and colleagues hope to do a detailed analysis of Greenland ice cores further back in time.

FROM TOP: JOE MCCONNELL; CANUTO AND AULD-THOMAS/PACUNAM; 3D4MEDICAL/SCIENCE SOURCE; ALEXIS PANTOS; BLACK SEA MAP/EEF EXPEDITIONS

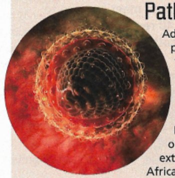
FURTHER AFIELD

Maya Megalopolis

For the first time, archaeologists glimpsed the enormity of the Maya civilization, which peaked about 1,500 years ago. Planes flew over 800 square miles of northern Guatemala as an onboard lidar system pulsed lasers downward and measured the reflecting beams, making a 3D scan of Earth's terrain that revealed archaeological features hidden by vegetation.

Some 60,000 previously unknown structures were revealed by the images, says Thomas Garrison, co-leader of the project. The findings tripled population estimates of the Maya civilization to 15 million. The team aims to survey an additional 4,000 square miles.

Pathogens of the Past



Advances in capturing and reading pathogen aDNA from skeletons led to several breakthrough 2018 studies on ancient human diseases, leprosy and syphilis.

In May, two separate teams found hepatitis B sequences in Eurasian remains up to 7,000 years old. Some of the virus strains are now extinct, while others resemble modern African strains — suggesting that the virus, which today affects nearly 260 million people, has a complicated, globe-trotting history.

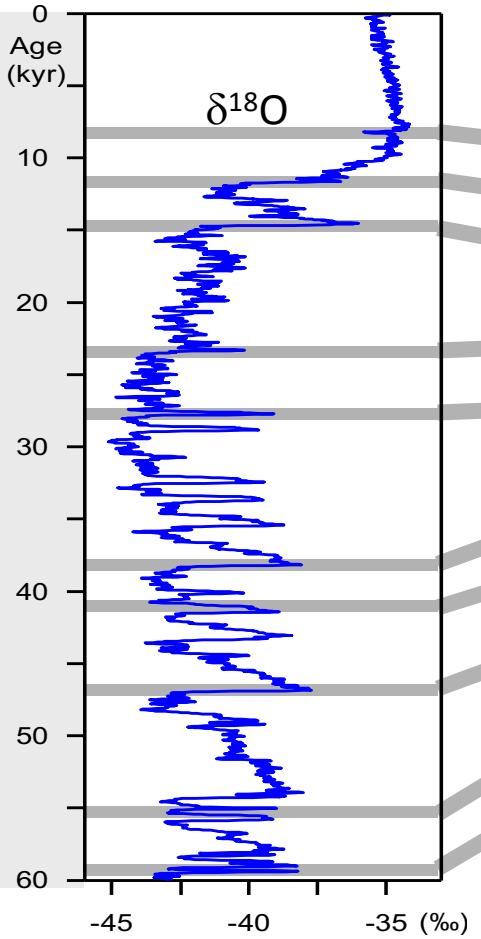
The First Bakers

Bakers may have preceded farmers, based on 24 bread crumbs found in stone hearths built by hunter-gatherers in Jordan 14,000 years ago. In a paper published in *PNAS* in July, archaeologists analyzed the samples' speck-sized air bubbles and plant bits, concluding they were once unleavened flatbread, made from wild grains and tubers. It would be another 4,000 years until Near Easterners domesticated cereals.

Under the Sea

Thanks to the Black Sea's unusual chemistry — 90 percent of the water column is oxygen-starved and can't support wood-eating microbes — archaeologists have found numerous ancient shipwrecks, still in excellent shape, over the years. In October, researchers announced their greatest find yet: a 2,400-year-old Greek merchant ship, the oldest intact shipwreck on Earth. Located more than a mile beneath the waves, the well-preserved vessel is the first example of a Greek ship previously known only from depictions in art.

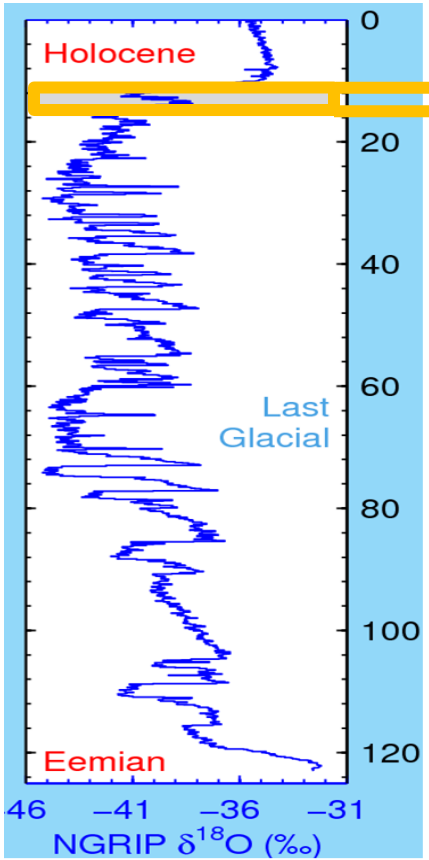
GICC05 aldre

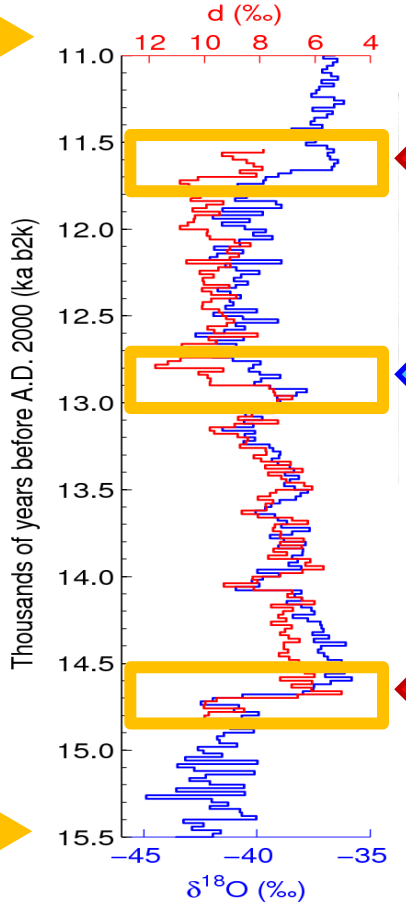


Begivenhed	Alder (b2k)	MCE
8.2 begivenheden	8,236 ±	47
Transitionen	11,703 ±	99
Bøllings start	14,692 ±	186
GIS 2 begyndelse	23,350 ±	600
GIS 3 begyndelse	27,800 ±	850
GIS 8 begyndelse	38,200 ±	1450
Laschamp	41,250 ±	1650
GIS12 begyndelse	46,900 ±	1800
Z2 askelag	55,450 ±	2150
GIS17 begyndelse	59,450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

b2k = Før A.D. 2000 (BP = b2k – 50yr)
MCE = Maximum tællefejl
GIS = Grønland Interstadial

Studiet af dynamikken af abrupte klimaændringer





Holocæn

opvarmning

GS-1 (Yngre Dryas)

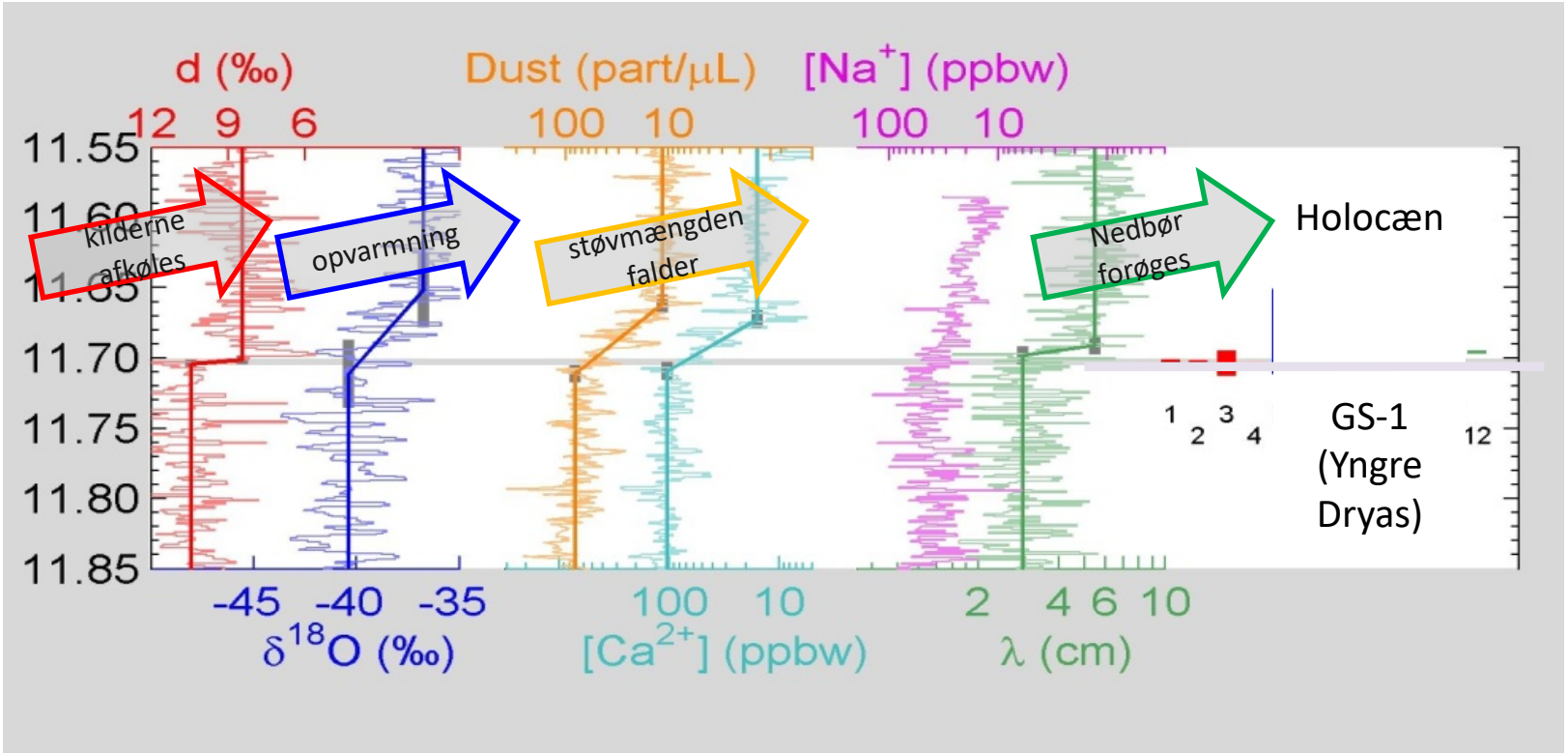
afkøling

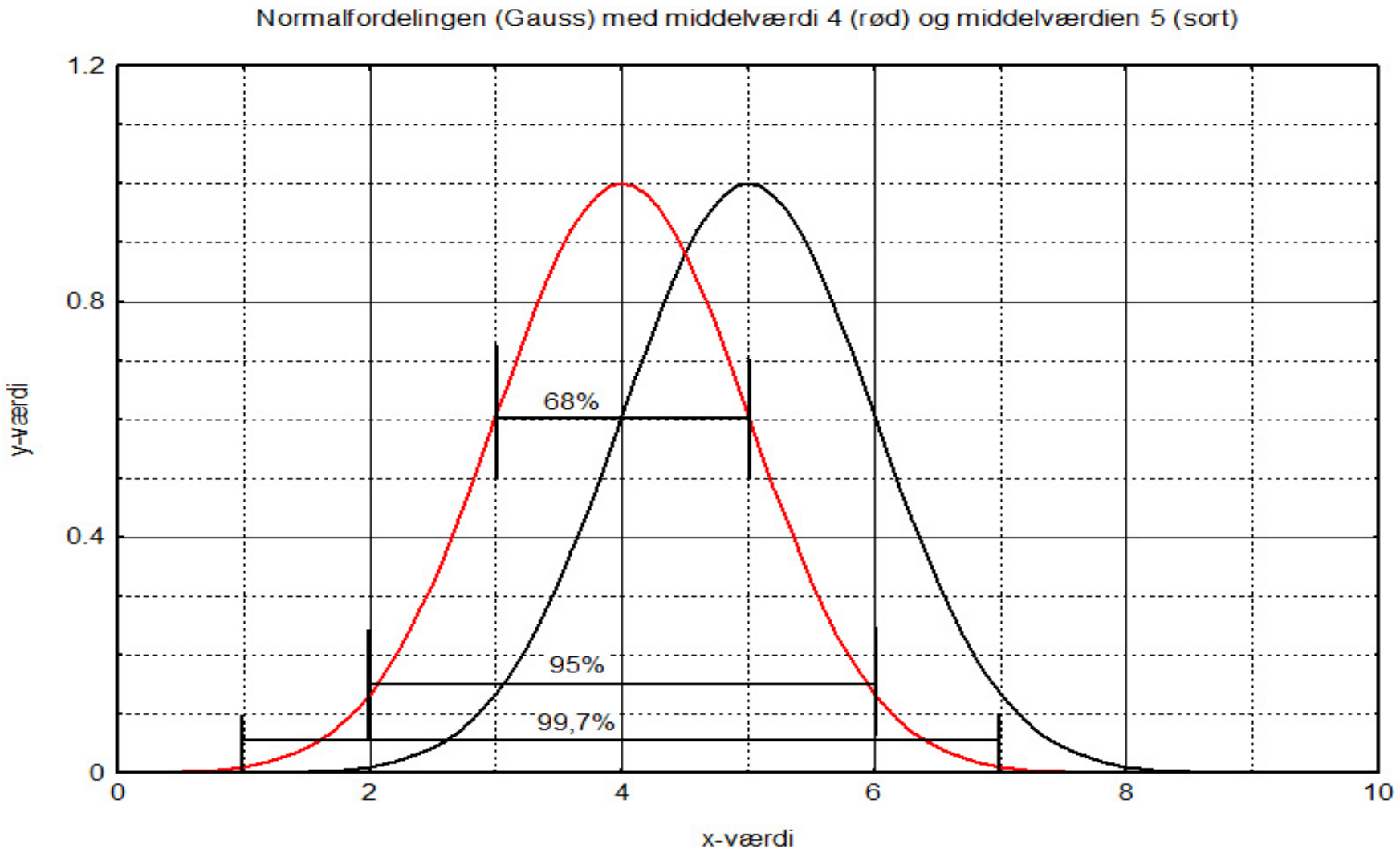
GI-1 (Bølling og Allerød)

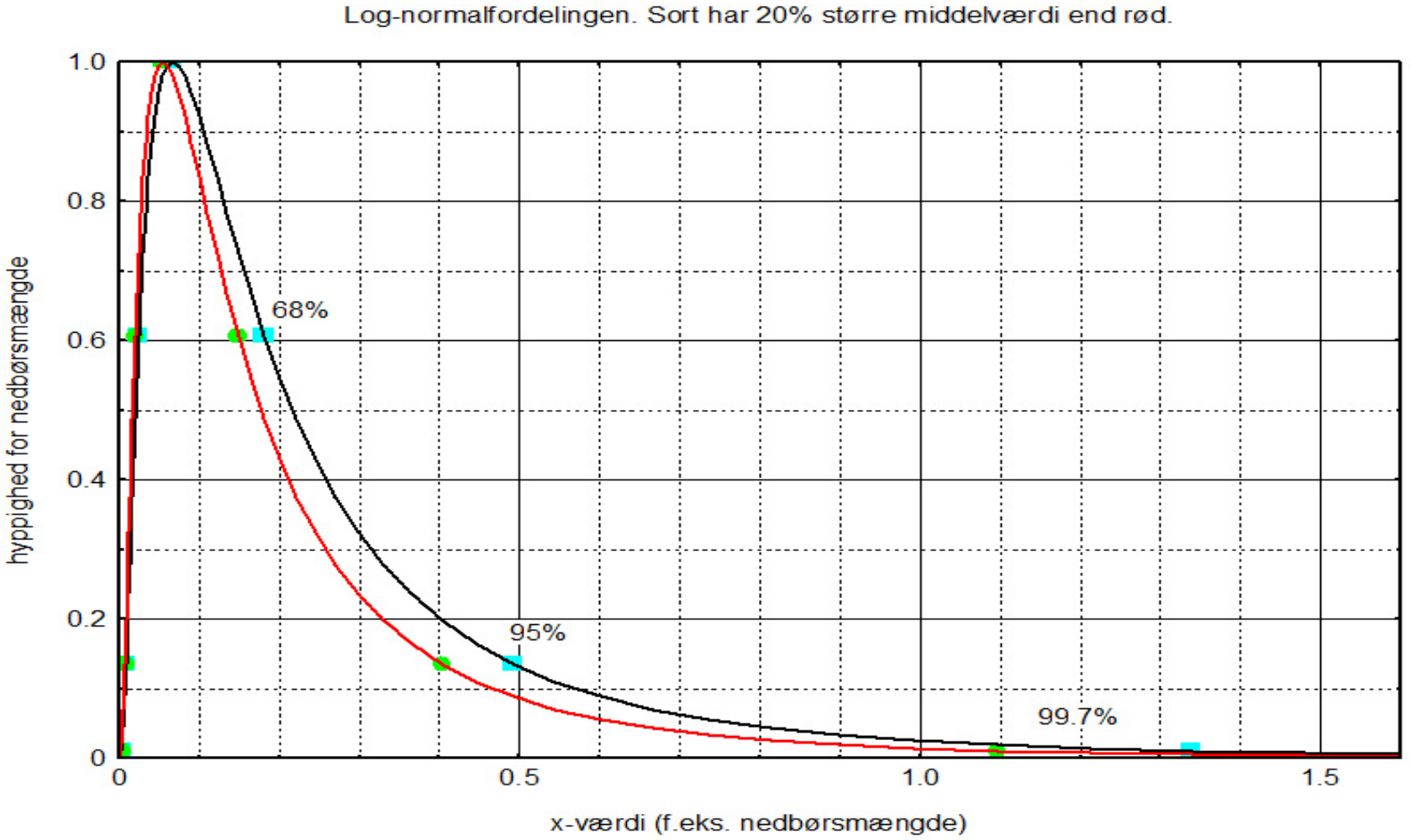
opvarmning

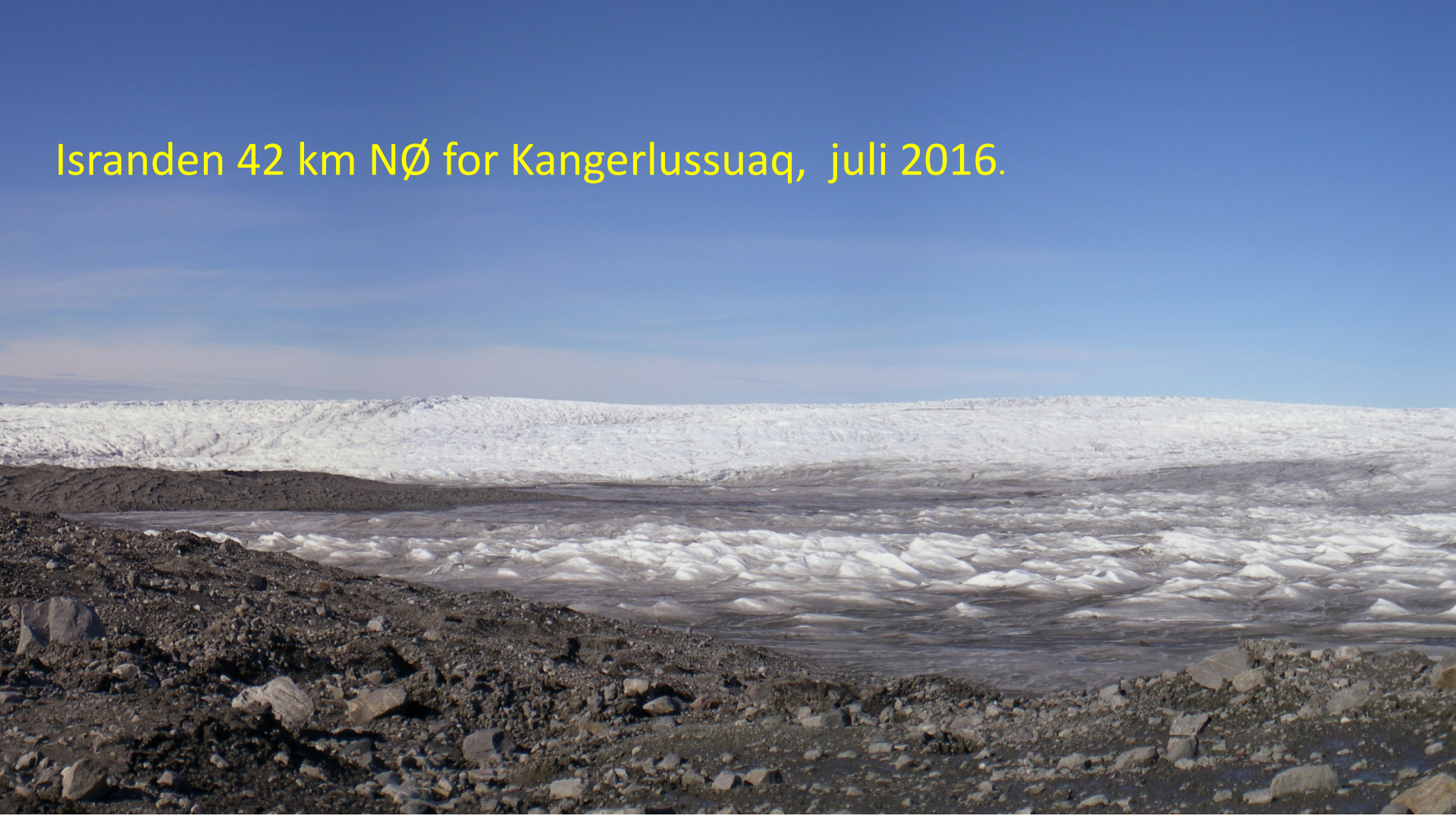
GS-2 (Ældste Dryas)

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

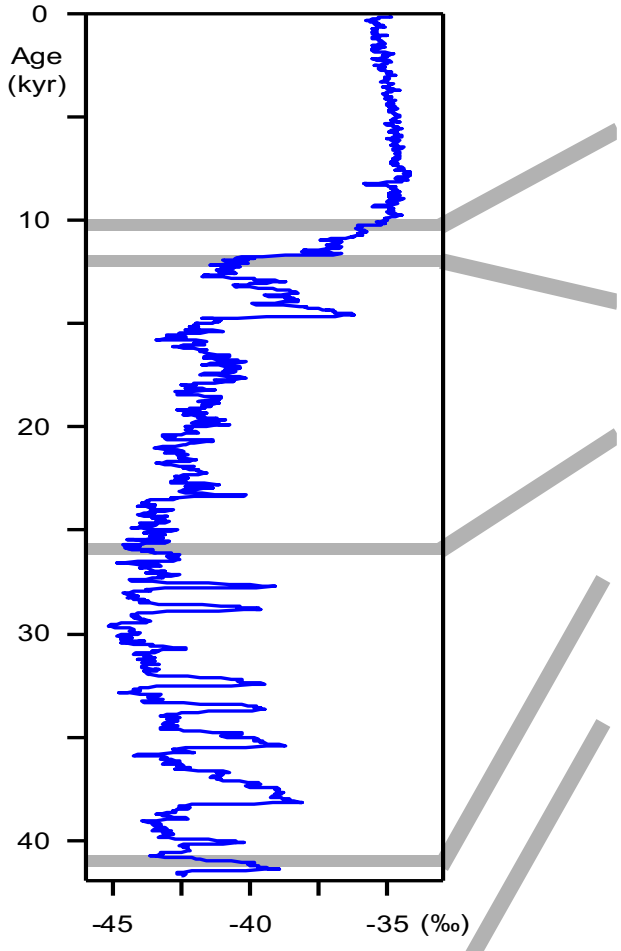



Normalfordelingen (Gauss) med middelværdi 4 (rød) og middelværdien 5 (sort)
1.2
0.8
0.4
0
y-værdi
68%
95%
99,7%
0
2
4
6
8
10
x-værdi


Log-normalfordelingen. Sort har 20% større middelværdi end rød.
hyppighed for nedbørsmængde
x-værdi (f.eks. nedbørsmængde)
1.0
0.8
0.6
0.4
0.2
0
0
0.5
1.0
1.5
68%
95%
99.7%


Isranden 42 km NØ for Kangerlussuaq, juli 2016.

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)

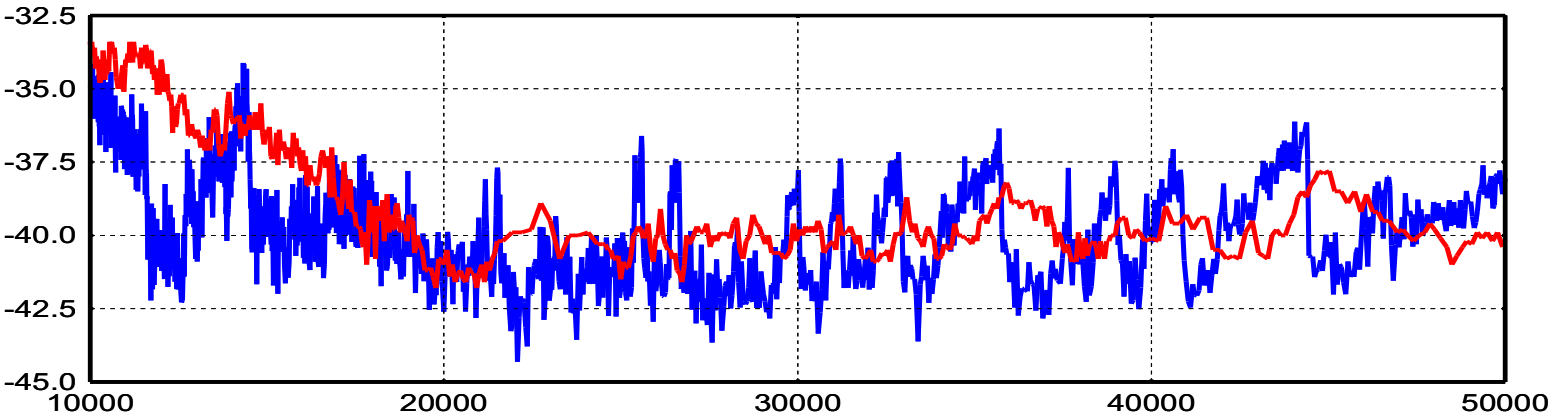
Laschamp event

40.4 ± 2.0 ka cal BP (Guillou et al., 2004)
Ligger tæt ved GIS10

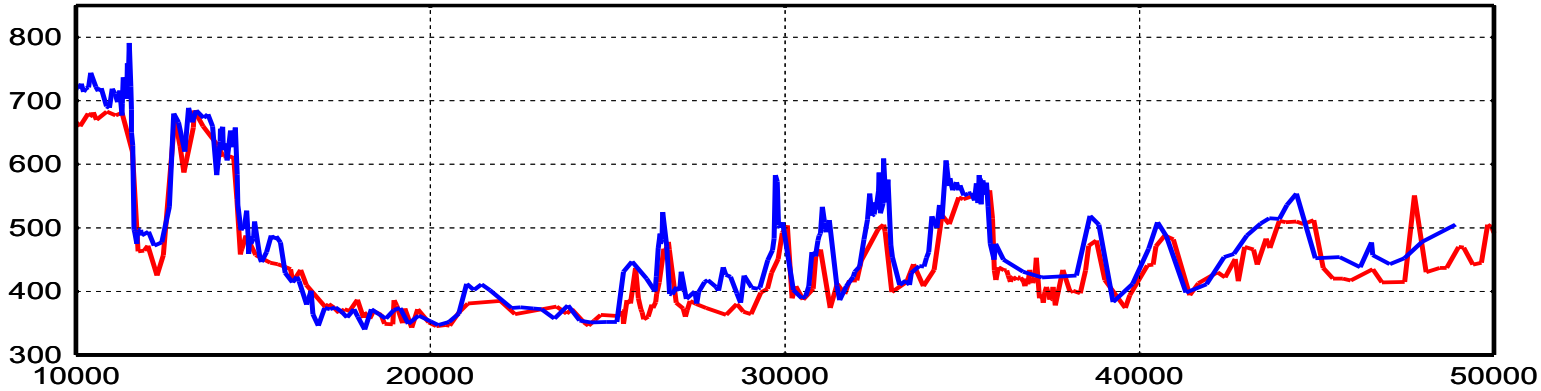
Z2 tephra

~55 ka cal BP

Isotoper
(Temperatur)



Metan konc.
(ppbv)

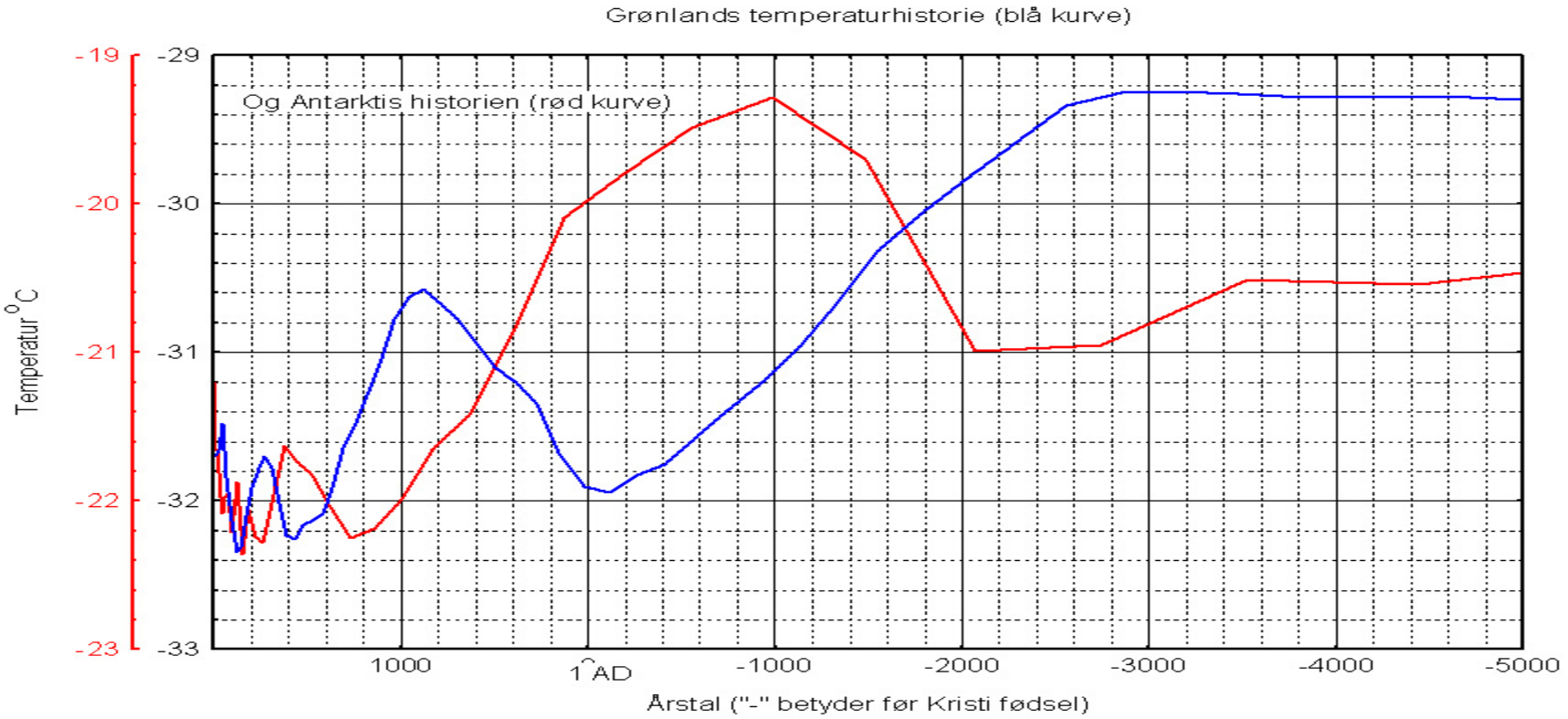


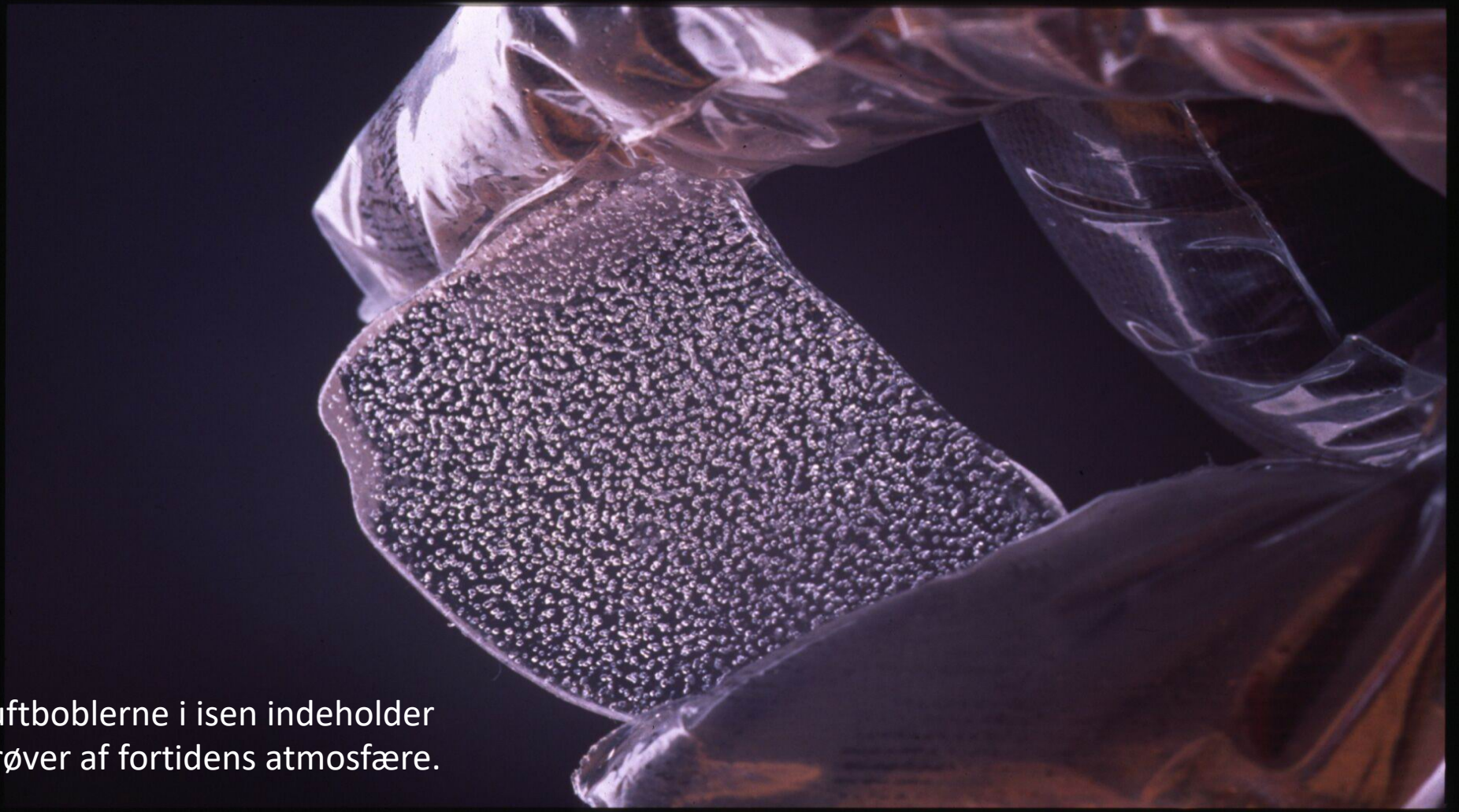
Tid før nu.

Blå kurve: Grønland; Rød Kurve: Antarktis

Kilde: Blunier et al., 1998, Nature

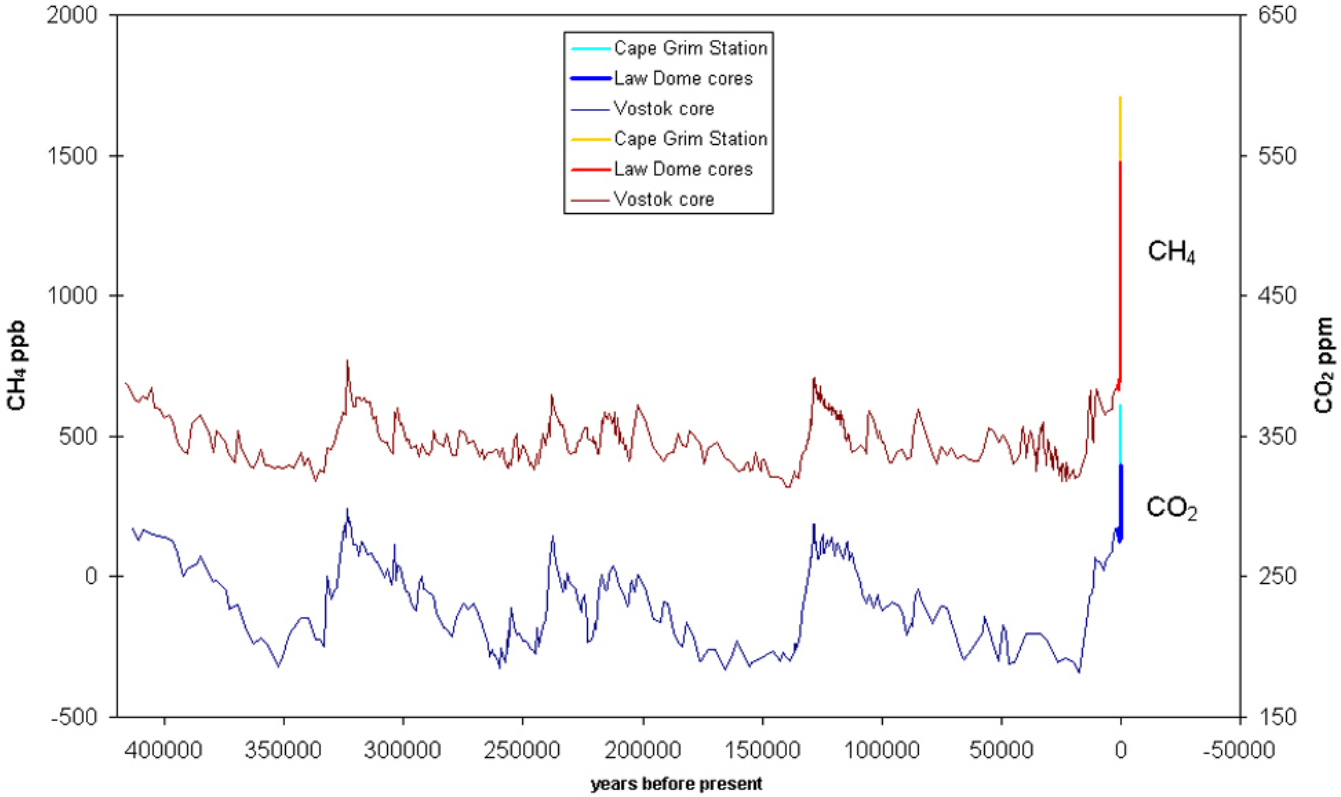
Temperaturhistorien siden istiden





Luftboblerne i isen indeholder prøver af fortidens atmosfære.

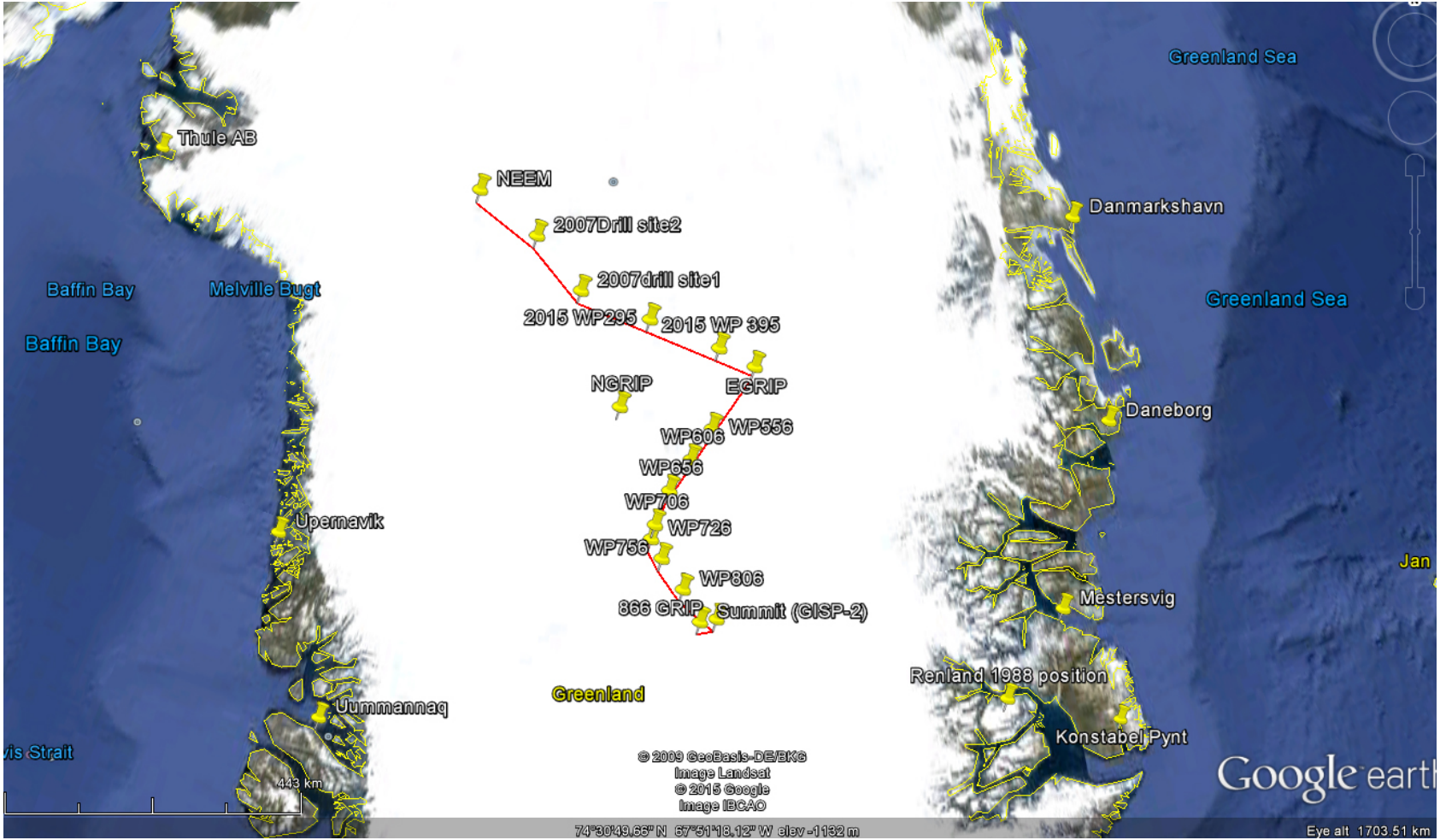
Stigningen i CO_2 og metan.



Data compiled by David Etheridge, CSIRO

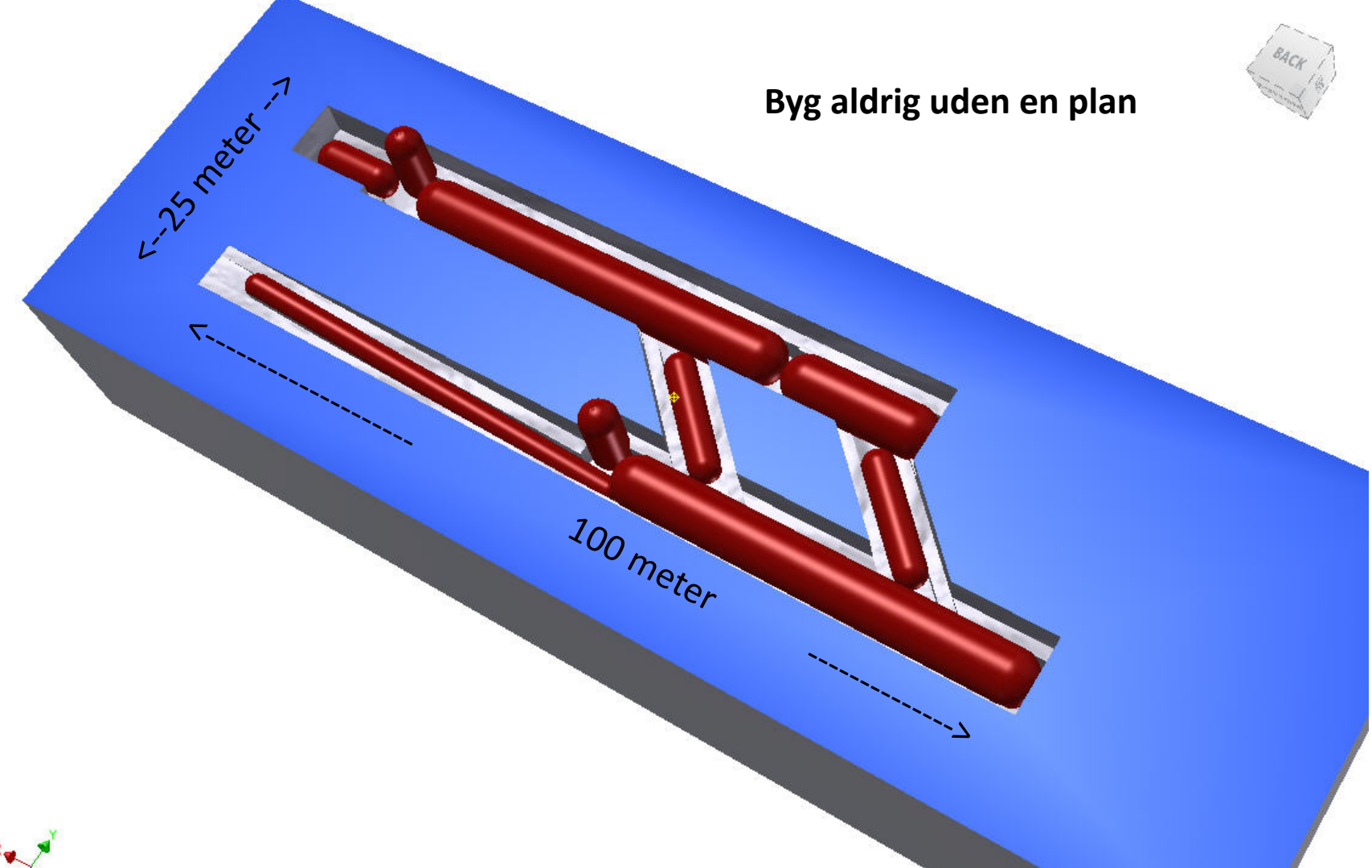
Bunden ved 2538 m, juli 2010


Vil du vide mere ?
www.iskerner.dk
www.isarkiv.dk


Thule AB
Baffin Bay
Melville Bugt
Baffin Bay
Upernavik
Uummannaq
vis Strait
443 km
NEEM
2007Drill site2
2007drill site1
2015 WP295
2015 WP 395
NGRIP
EGRIP
WP606
WP556
WP656
WP706
WP726
WP756
WP806
866 GRIP
Summit (GISP-2)
Greenland
© 2009 GeoBasis-DE/BKG
Image Landsat
© 2015 Google
Image IBCAO
74°30'49.86" N 67°51'18.12" W elev -1132 m
Greenland Sea
Danmarkshavn
Greenland Sea
Daneborg
Jan
Mestersvig
Renland 1988 position
Konstabel Pynt
Google earth
Eye alt 1703.51 km

Ankomst til EGRIP, Maj 2015

Byg aldrig uden en plan

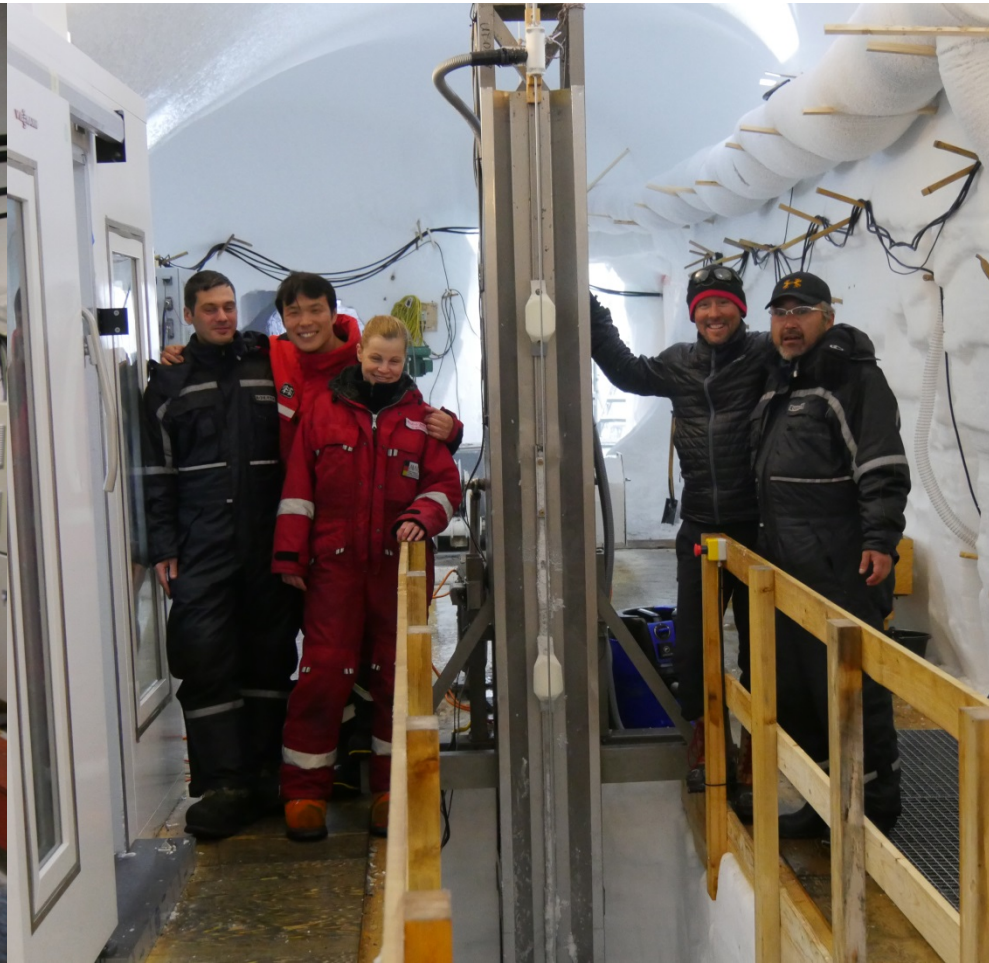



Udgravning af snehuler, EGRIP maj 2016.

Balloner på plads, EGRIP maj 2016.

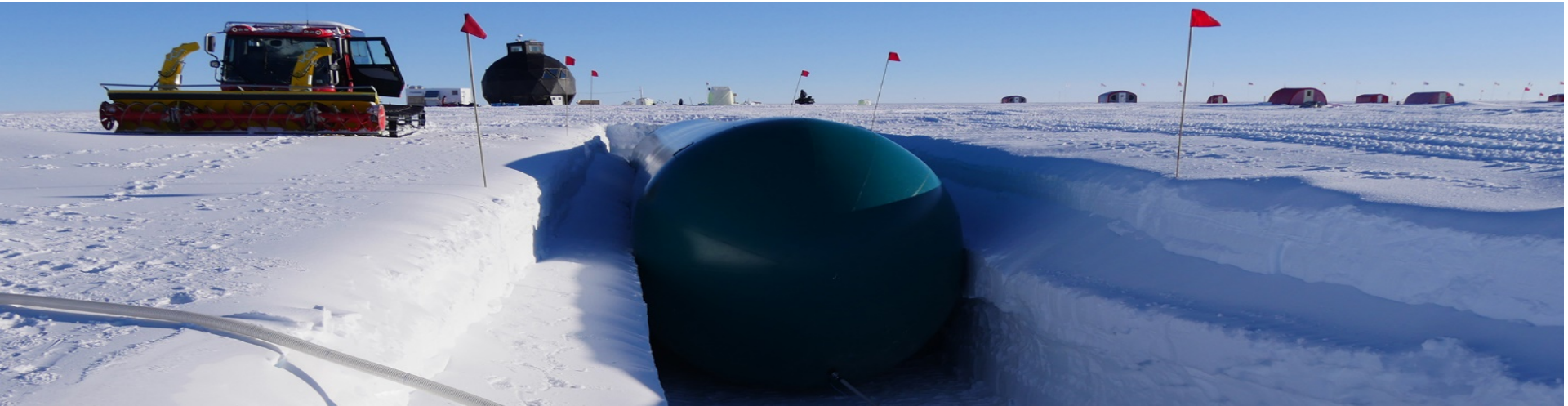
Den rå snehule, EGRIP maj 2016.

NEEM boring og EGRIP boring



Borehallen tilpasset det lange bor.

Bygning af ny koncertsal

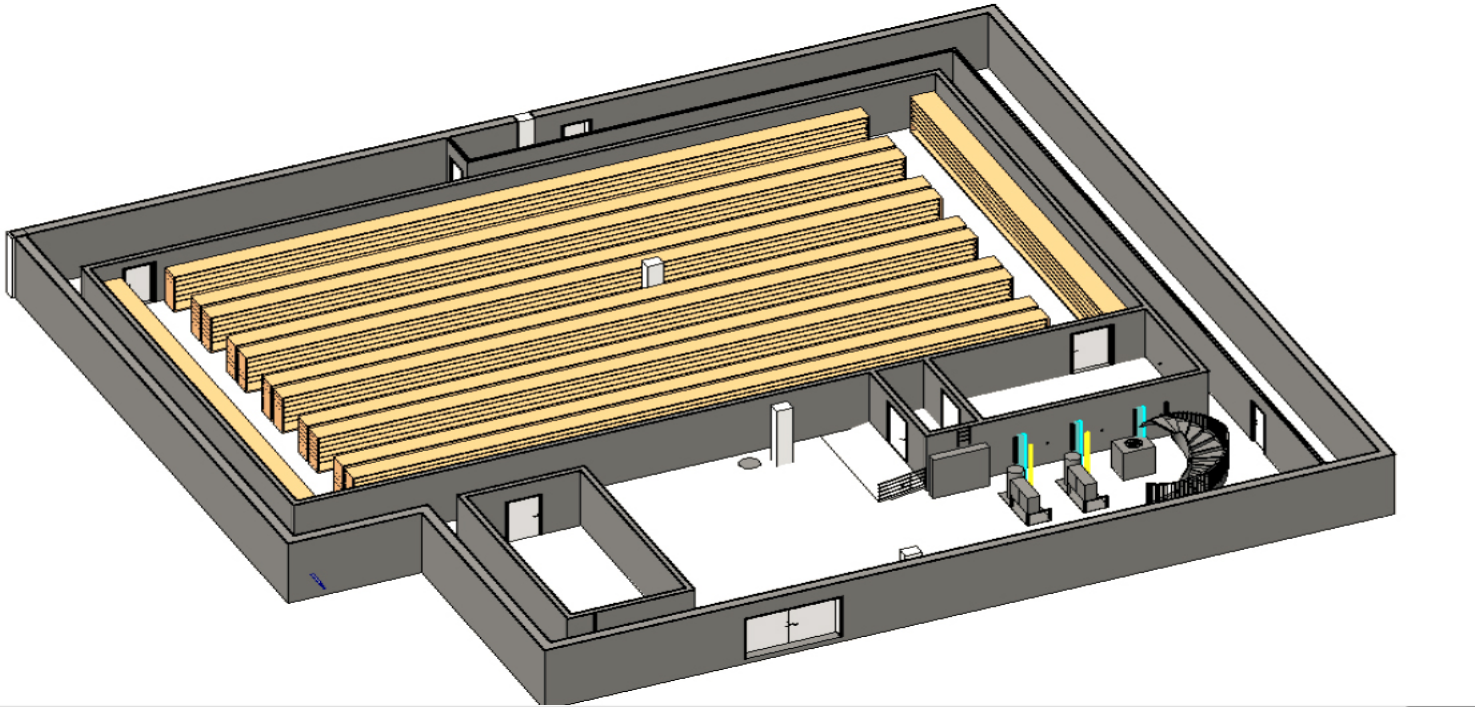


Det færdige produkt. Ismusiker: Terje Isungset.

Man gør kun fremskridt efter nøje studier og analyse

New Copenhagen Ice core freezer. Cooling system: Trans- and subcritical CO_2

Overview



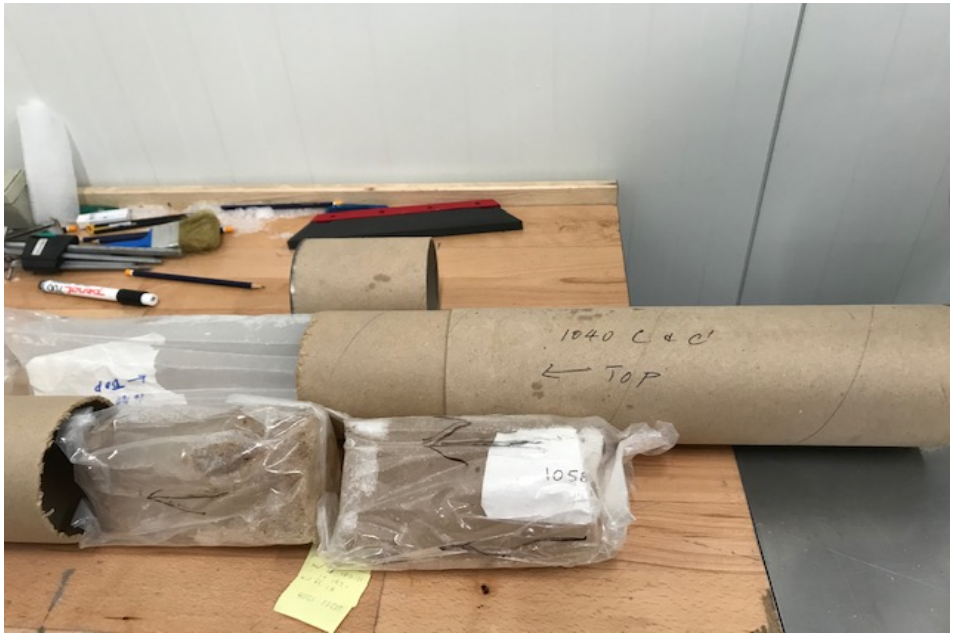
New shelves installed with former HCØ boxes in position.

A total of 13 racks (cap. 1,946 crates) will contain all ice.

Copenhagen repository.

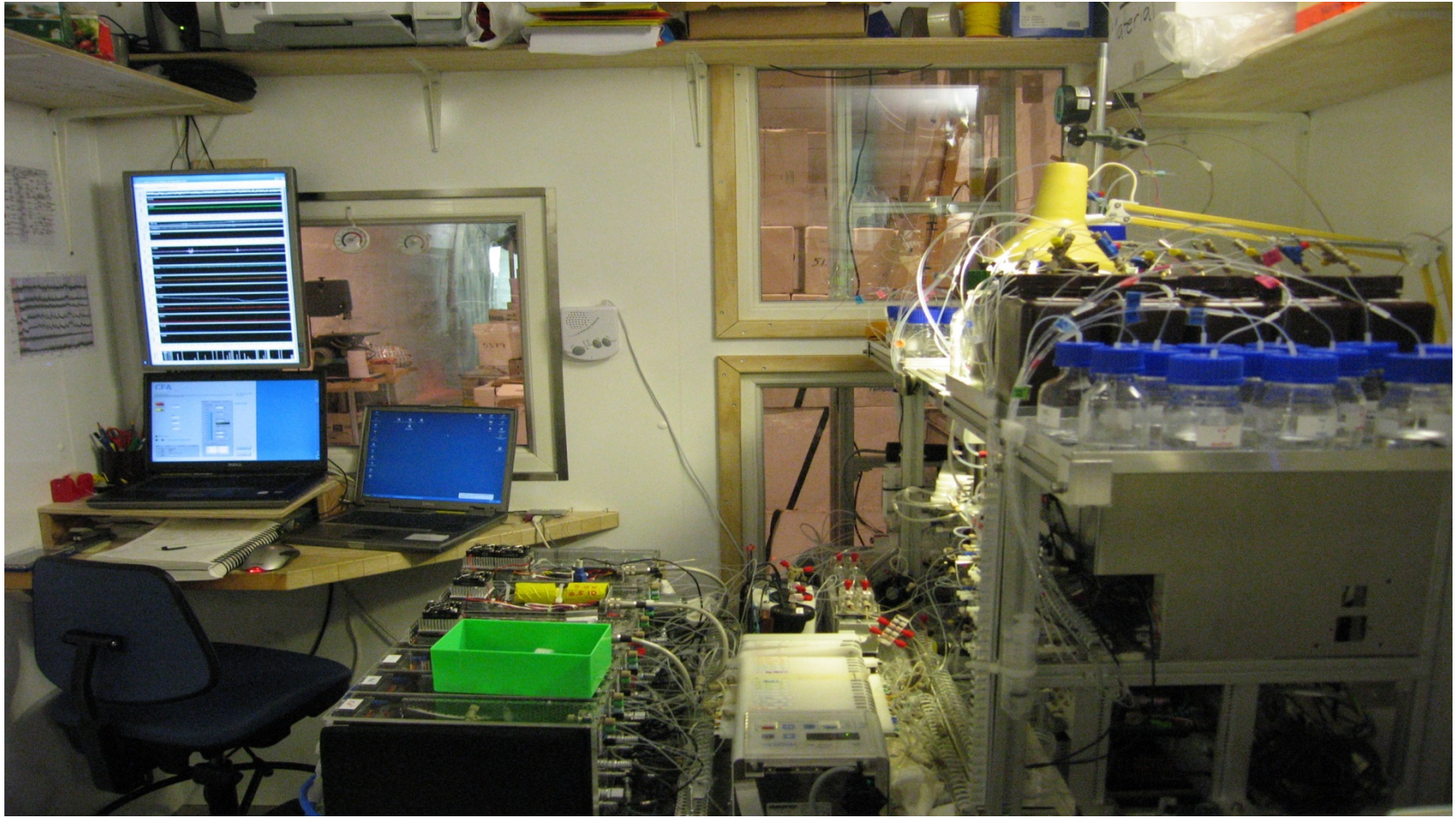
- Ice core and snow samples mainly from Greenland and Antarctica with some samples from South America, Iceland and Europe.
- 8 deep ice cores, 15230 m length in total.
- 8 intermediate ice cores, 3013 m length
- 15-20 shallow cores, more than 2000 m length
- Snow and ice samples from 20 locations.
- All stored in 1,900 boxes.

Several cardboard tubes contained ice. Here are three sections of tube #1040 (top of silty ice Camp Century).
Depth: 1334.31 m to 1335.75 m.



Interessante tal i klimadiskussionen.

- 1 kg oksekød giver 14 kg CO_2
- 1 liter Jet A-1/benzin giver 2,64/2,40 kg CO_2
- Standard flyøkonomi: 0,027 liter per passager km.
- Flytur t/r Thailand 20.000 km 540 liter = 1425 kg CO_2
- Dette svarer til 100/400 kg oksekød/svinekød.
- Bemærk: Kødberegning er fra CO_2 ækvivalenter af metan. Kulstoffet er ”genbrugt” fra planter og solskin. Brændstoffet er netto tilførsel af kulstof fra undergrunden. Disse ting er ikke direkte sammenlignelige.



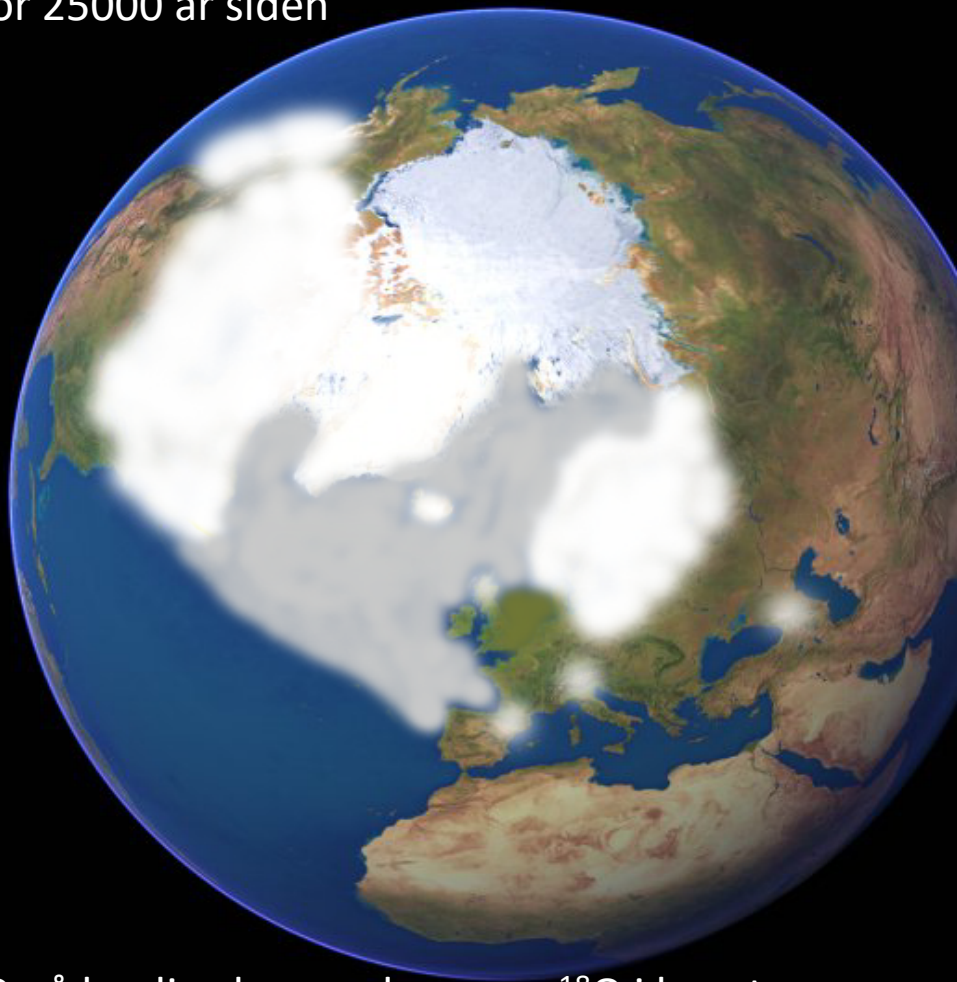
Tøvelte på Møn

De parallelle veje ved Glen Roy, Skotland
Diskuteret og overvejet af Charles Darwin og Andre Agassiz


Kangerlussuaq fjorden mod NØ, april 2015.

Nu:

For 25000 år siden



Når der er meget is med lavt indhold af ^{18}O på landjorden, er der mere ^{18}O i havet.

Vigtige isotoper i Palaeoklimaforskningen

- Stabile isotoper, f.eks. ^{16}O og ^{18}O i vand H_2O og i kalk (drypsten, koraller og skaller) $CaCO_3$.
- Radioaktive isotoper i jordskorpen: ^{40}K (1,3 mia. år) som henfalder til ^{40}Ar (stabil). Og ^{238}U (4,5 mia.år) som henfalder til ^{234}U (247.000 år) og senere til ^{230}Th (80.000 år).
- Radioaktive isotoper dannet ved kosmisk stråling i atmosfæren: ^{14}C (5730 år), ^{10}Be (1,4 mio. år), ^{36}Cl (310.000 år) og ^{81}Kr (230.000 år)

One Thousand Centuries of Climatic Record from Camp Century on the Greenland Ice Sheet

W. Dansgaard, S. J. Johnsen, J. Møller, C. C. Langway, Jr.

One Thousand Centuries of Climatic Record from Camp Century on the Greenland Ice Sheet

Abstract. *A correlation of time with depth has been evaluated for the Camp Century, Greenland, 1390 meter deep ice core. Oxygen isotopes in approximately 1600 samples throughout the core have been analyzed. Long-term variations in the isotopic composition of the ice reflect the climatic changes during the past nearly 100,000 years. Climatic oscillations with periods of 120, 940, and 13,000 years are observed.*

Use of the oxygen-18 concentration in glacier ice as an indicator of past climatic conditions was proposed in 1954 (*1*). The concentration of O^{18} in precipitation, particularly at high latitudes, is determined mainly by its temperature of formation. Decreasing temperature of formation leads to decreasing content of O^{18} in rain or snow. Analysis of stable isotopes has become an important method in studies of ice

Few methods exist for dating a deep ice core. Some advances have been made with C^{14} dating (*8*) in which the carbon dioxide of occluded atmospheric air contained in huge blocks of glacier ice is measured for radiocarbon. Recently a technique for sampling C^{14} from ice *in situ* was tested in Greenland and Antarctica (*9*). These studies required a minimum of 1 ton of glacier ice.

Another way of dating an ice core is to determine the annual layers by measuring the seasonal oscillations in the O^{18} content in small vertical increments containing about 10 cm^3 of the core and then to count the summer maxima continuously from the surface downward. Unfortunately, various processes tend to diminish the isotopic gradients in snow and ice. For example, molecular diffusion in the firn and solid ice, hastened by the progressive plastic thinning of the layers with depth, gradually obliterates the oscillations that remain after firnification. This process alone establishes a limit

V_x proportional to $x \cdot y$ from $y = 0$ to $y = h$ (= 400 m),

V_x proportional to x, but independent of y, from $y = h$ to $y = H$ (= 1367 m),

x being the distance from the ice divide, y the distance from the bottom, and H the thickness of the ice sheet in meters of ice. Here H equals 1367 m of ice, instead of 1390 m of core, to correct for the low firn densities in the upper layers.

Basic mass balance considerations led to the following expressions for the vertical velocity components:

$$V_y = -\frac{a}{2H-h}(2y-h), \quad H \geqq y \geqq h$$

$$V_y = -\frac{a}{h(2H-h)}y^2, \quad h \geqq y \geqq 0$$

and, thereby, to the age of the ice at a distance y from the bottom:

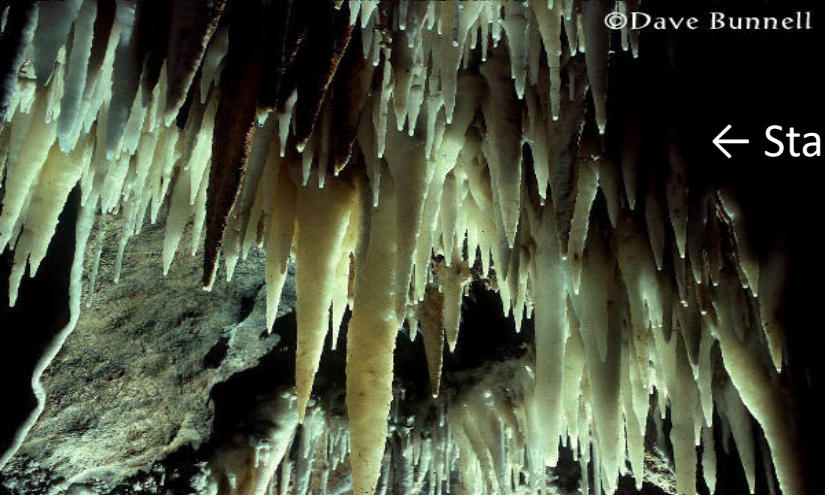
$$t = \int_H^y \frac{dy}{V_y}$$

The results of the calculations are

Science, 1969.
Iskernernes fødsel i studier af palaeo-klimaet

Drypsten, koraller og foraminiferer (Kalk, vand og kedelsten)

- Drypsten: Når regnvand løber gennem lag med kalk, opløses noget af kalken og vandets $^{16}O/^{18}O$ udveksles med kalkens O i $CaCO_3$. Drypstenens kalk får derfor nedbørens $^{16}O/^{18}O$.
- Koraller og foraminiferer: Disse dyr benytter havets vand til dannelse af kalkskaller. Derfor har korallerne og skallerne det $^{16}O/^{18}O$ som havet havde på dannelsestidspunktet.
- Alderen bestemmes ved Uran-Thorium metoden.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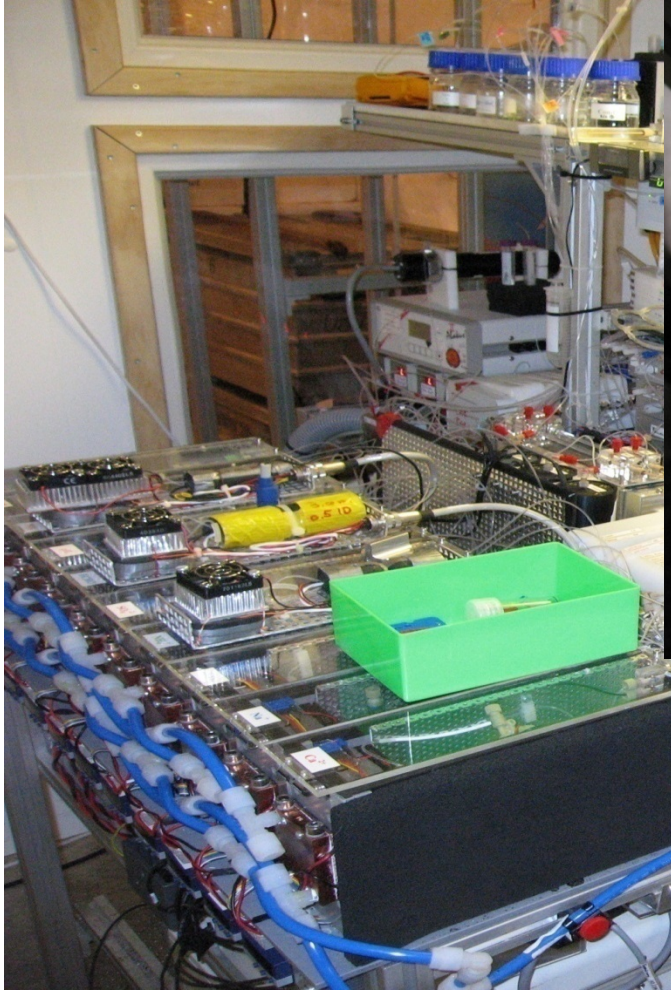

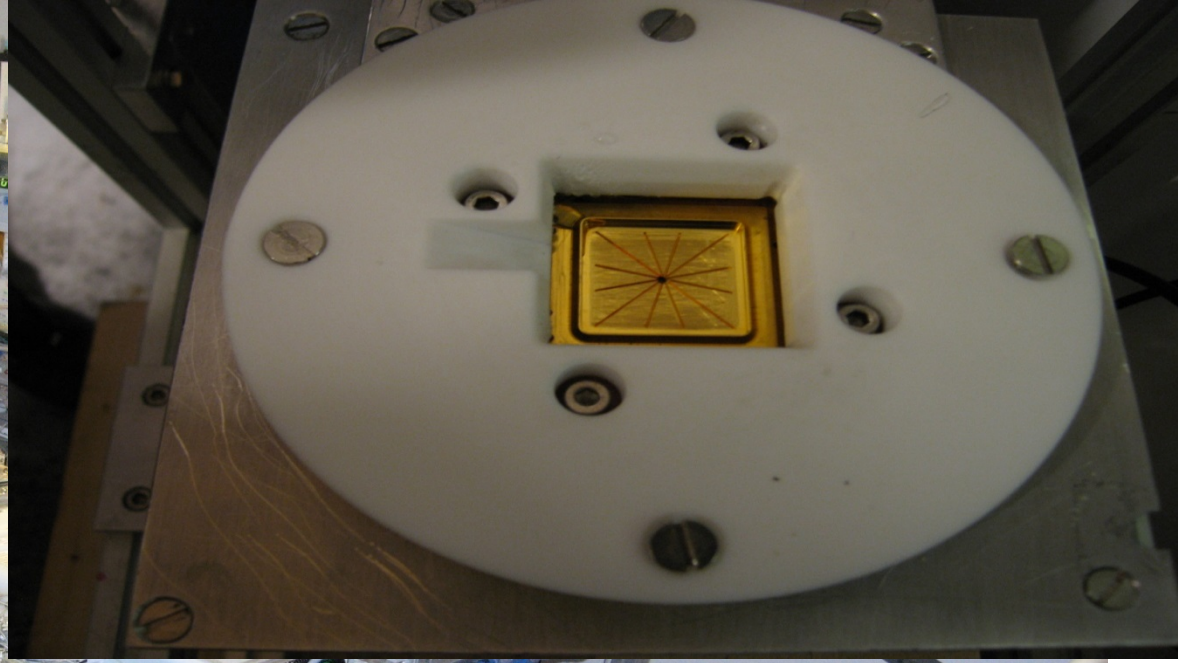

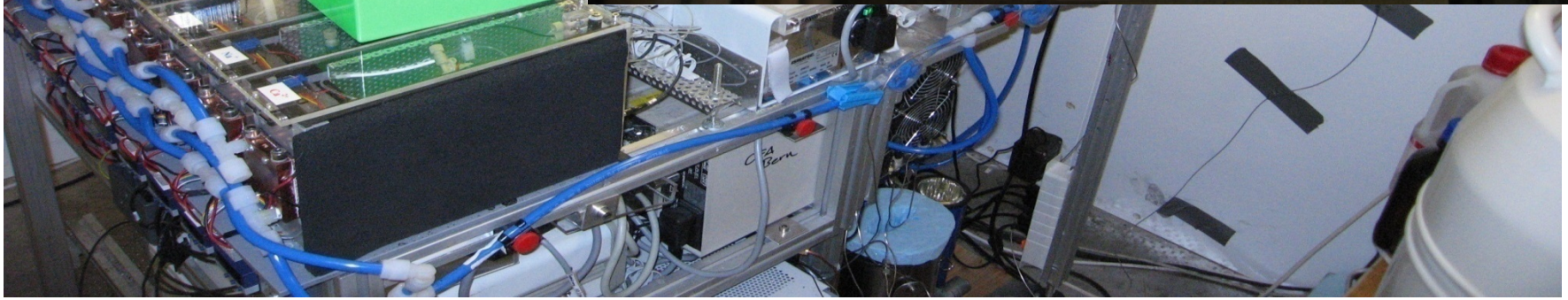

NEEM Fysiske egenskaber