Studying the Greenland ice sheet: Implications for climate past and present.

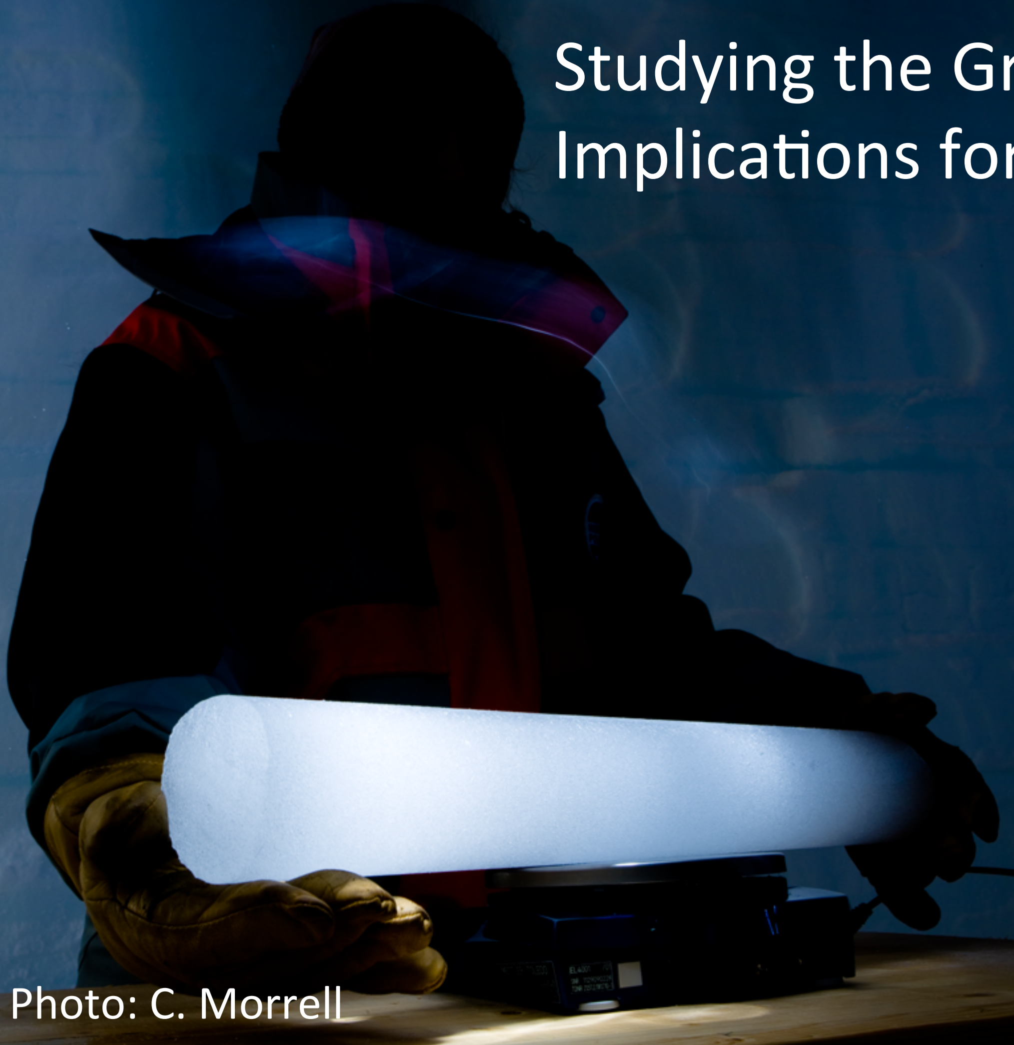


Photo: C. Morrell

Dorthe Dahl-Jensen
Professor, Niels Bohr Institute
University of Copenhagen
Denmark

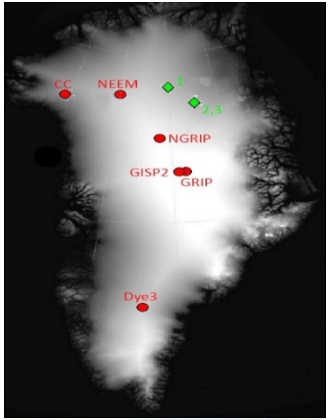
An old research group

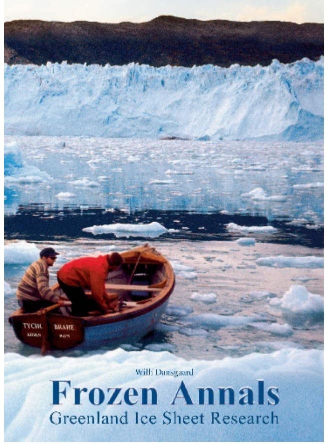
1951: Professor Willi Dansgaard did the first mass spectrometer observations of stable water isotopes in rain and ice

The Ice and Climate research group has since then drilled 8 ice cores from surface to bedrock on the Greenland ice sheet.

www.iceandclimate.dk

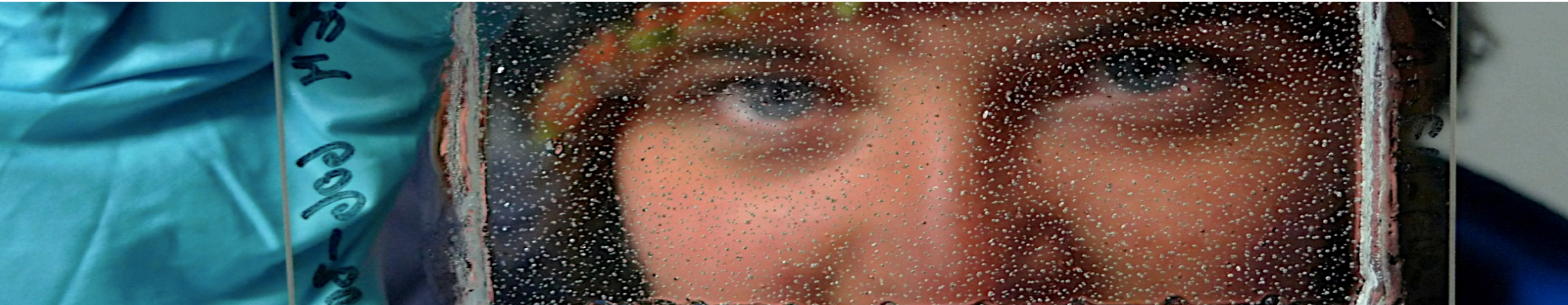
www.iceandclimate.nbi.ku.dk/publications/frozen_annals/





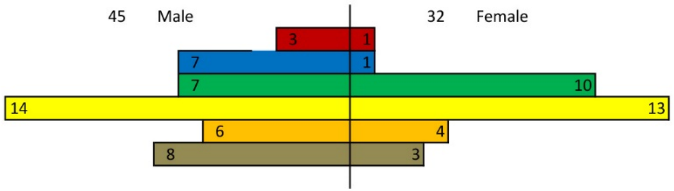
VISION

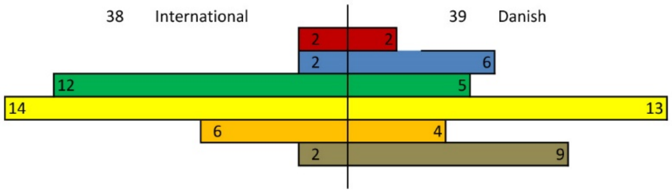
To contribute to an <u>improved understanding</u> of the present and past <u>warm interglacial periods</u> by <u>studying ice cores</u>, and <u>developing models</u> to explain observations and predict the ice sheet response to climate change.



Ice and Climate Team (77)

		NBI	CIC/DG	External
Professor	4	100%	0%	0%
Ass. Professor	8	70%	20%	10%
Post Doc	17	0%	30%	70%
PhD	27	40%	20%	40%
Master	10			
Adm/TAP/VA	11	50%	0%	50%
	77			





Water Isotopes

Greenhouse Gases

Aerosols and Stratigraphy

Ice Sheet Modelling

Theory and Modelling

Earth System Modelling

DNA and Evolution

Playground

IT

Teaching

Outreach

Logistics

Drilling

Danish National Research Foundation

Deep Ice Core Drilling Projects

CENTRE FOR ICE AND CLIMATE

Mayor player in organizing international deep ice core drilling projects in Greenland

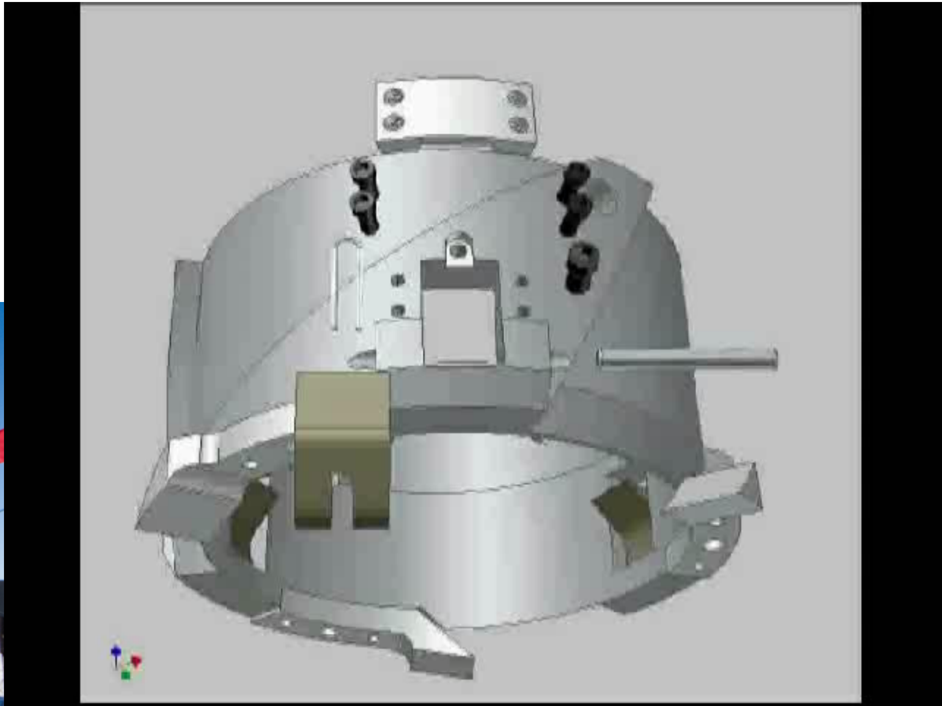
Old tradition – results in a strong group

Logistics coordination in collaboration with US NSF

Development of Drill Technology

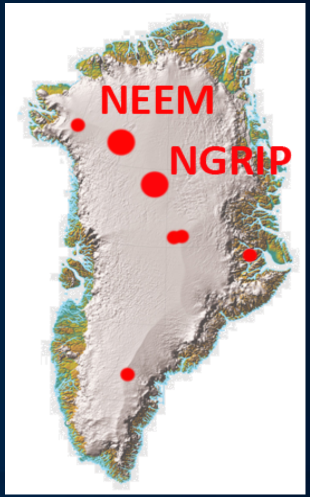
Pioneering in development of ice core drills.
Deep drill (4000 m)
Intermediate drill (1000 m)
Shallow drill (200 m)

Workshop at NBI is important
Interaction between scientists and mechanics



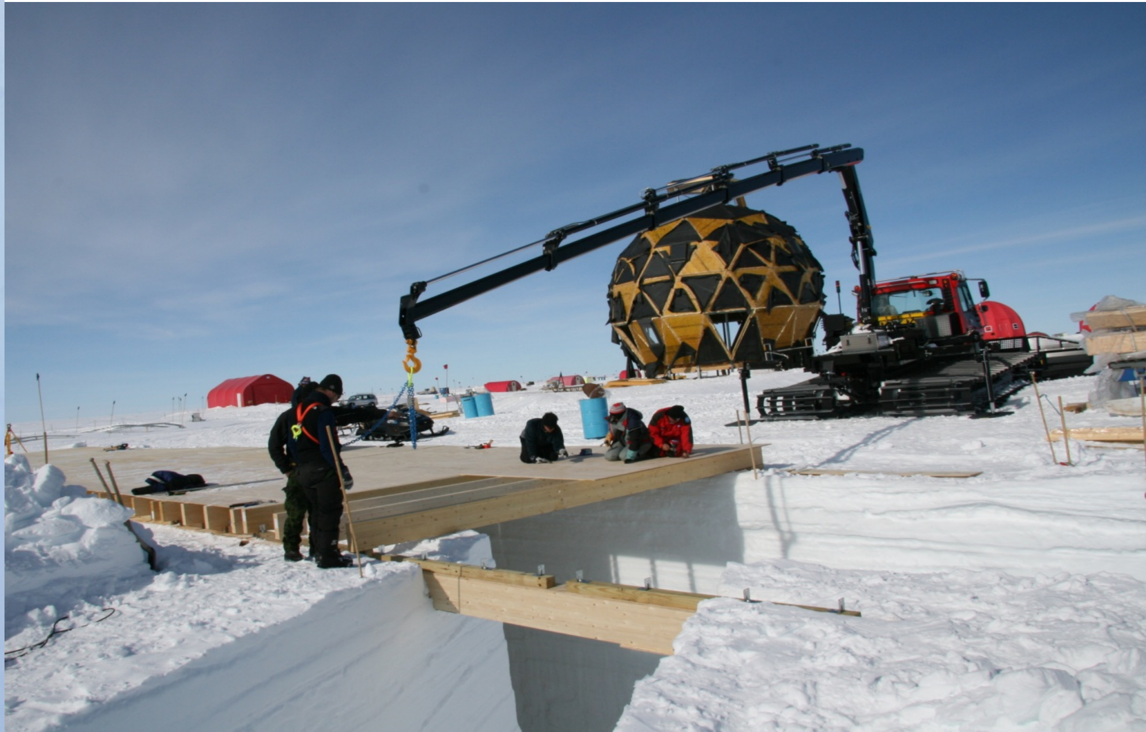
NEEM

Ice core Project



2008

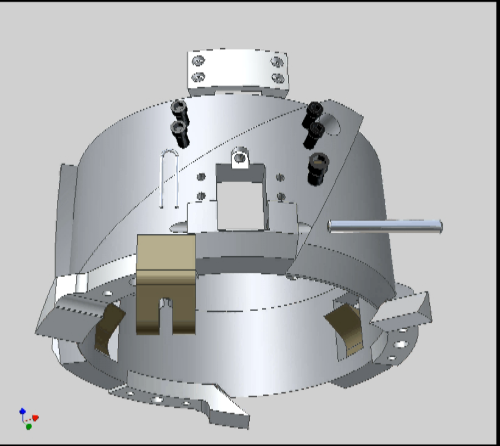
2008



The Danish deep drll

Length of drill: 13 m
Ice core diameter: 9.8 cm
Length of ice cores: 3.5 m

NEEM ice thcknes : 2538 m

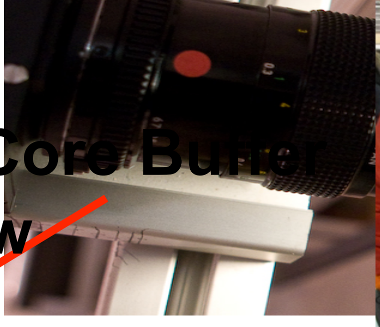


ECM

Line Scan

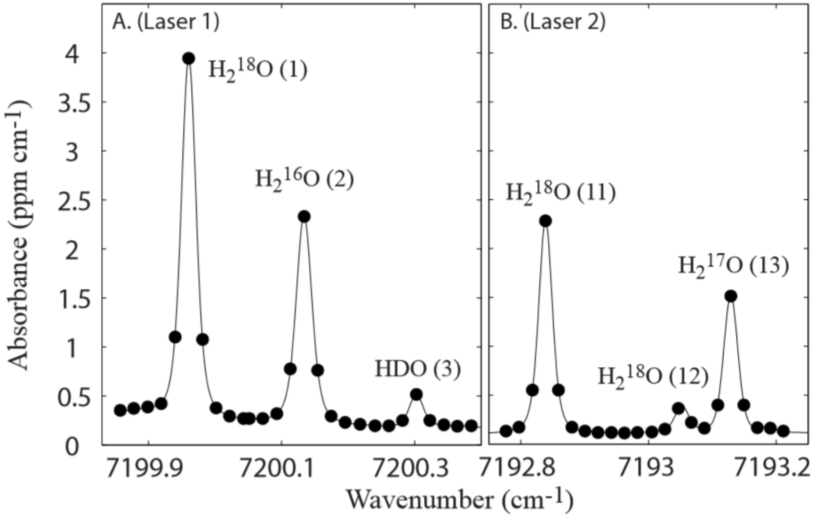
Swiss Saw

Core Buffer



Cutting samples for Isotopes, pp, gas ect

Water Isotopes



Steig et al., Atmos. Meas. Tech., 2014

Instrument development for ^{16}O, ^{17}O, ^{18}O measurements on H_2O

Co-developed by Picarro developers, Dr. Vasileios Gkinis (CIC/Instaar) and Professor Eric Steig (Univ. of Washington)

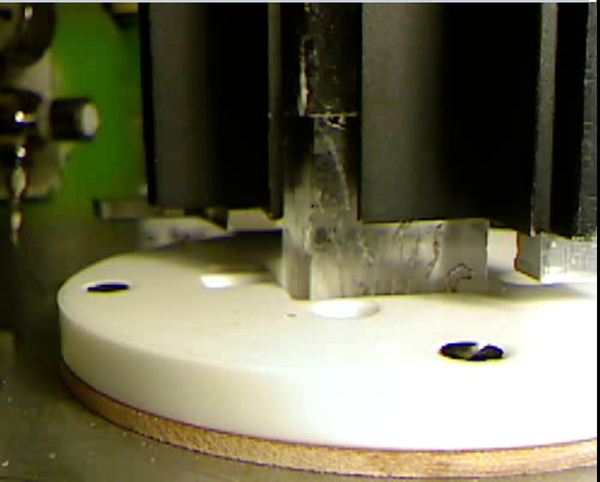
PICARRO UNIVERSITY of WASHINGTON UNIVERSITY OF COPENHAGEN INSTAAR University of Colorado Boulder

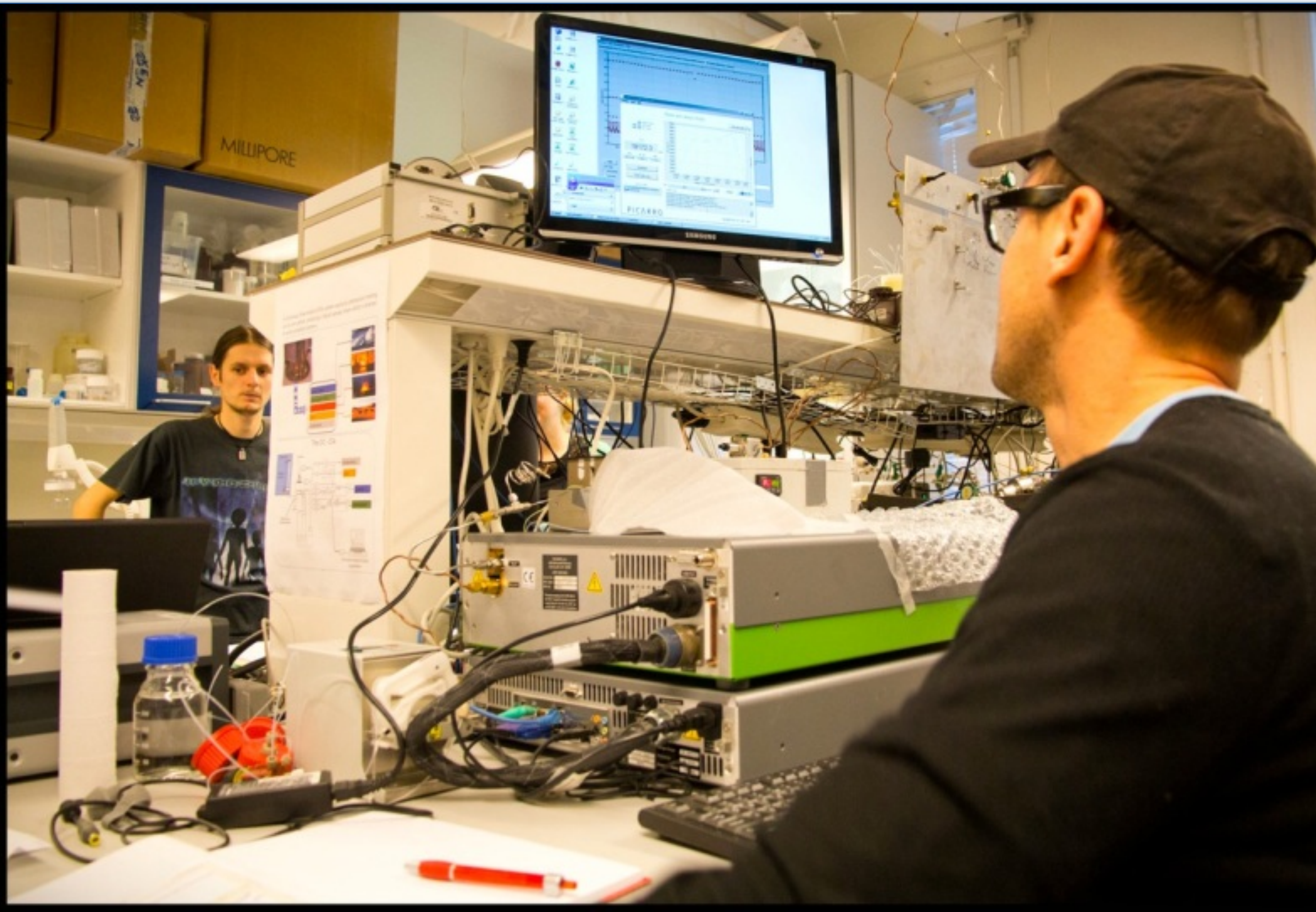
Danish National Research Foundation

Water Isotopes

CENTRE FOR ICE AND CLIMATE

A slab of ice is melted on a warm melt head and the water and air is used to measure water isotopes and methane



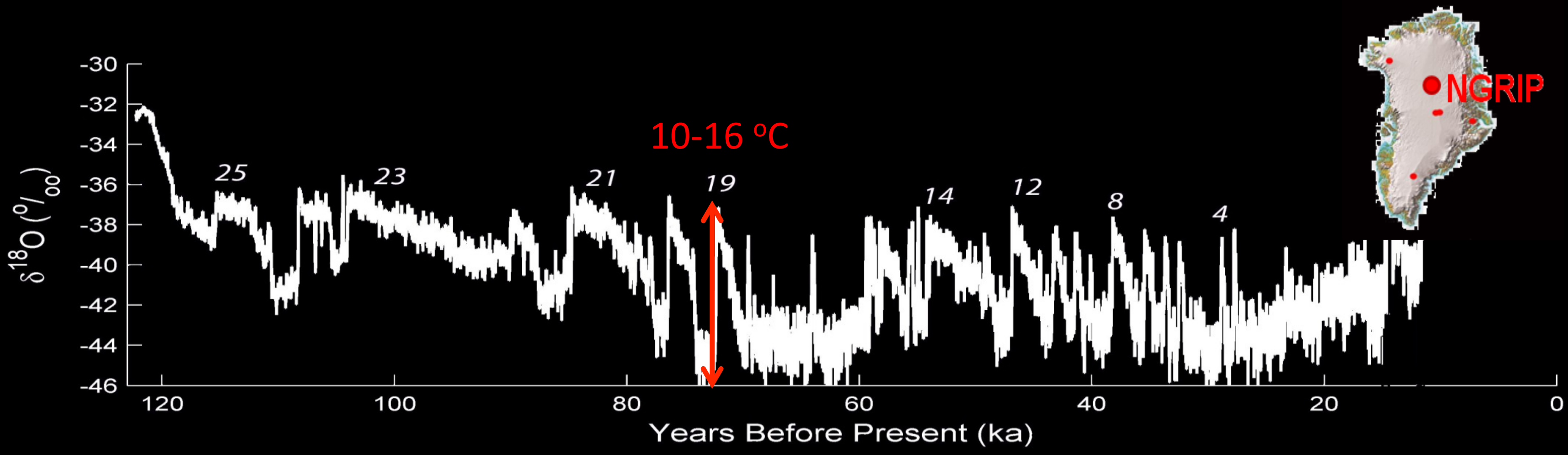


Dansgaard-Oeschger events

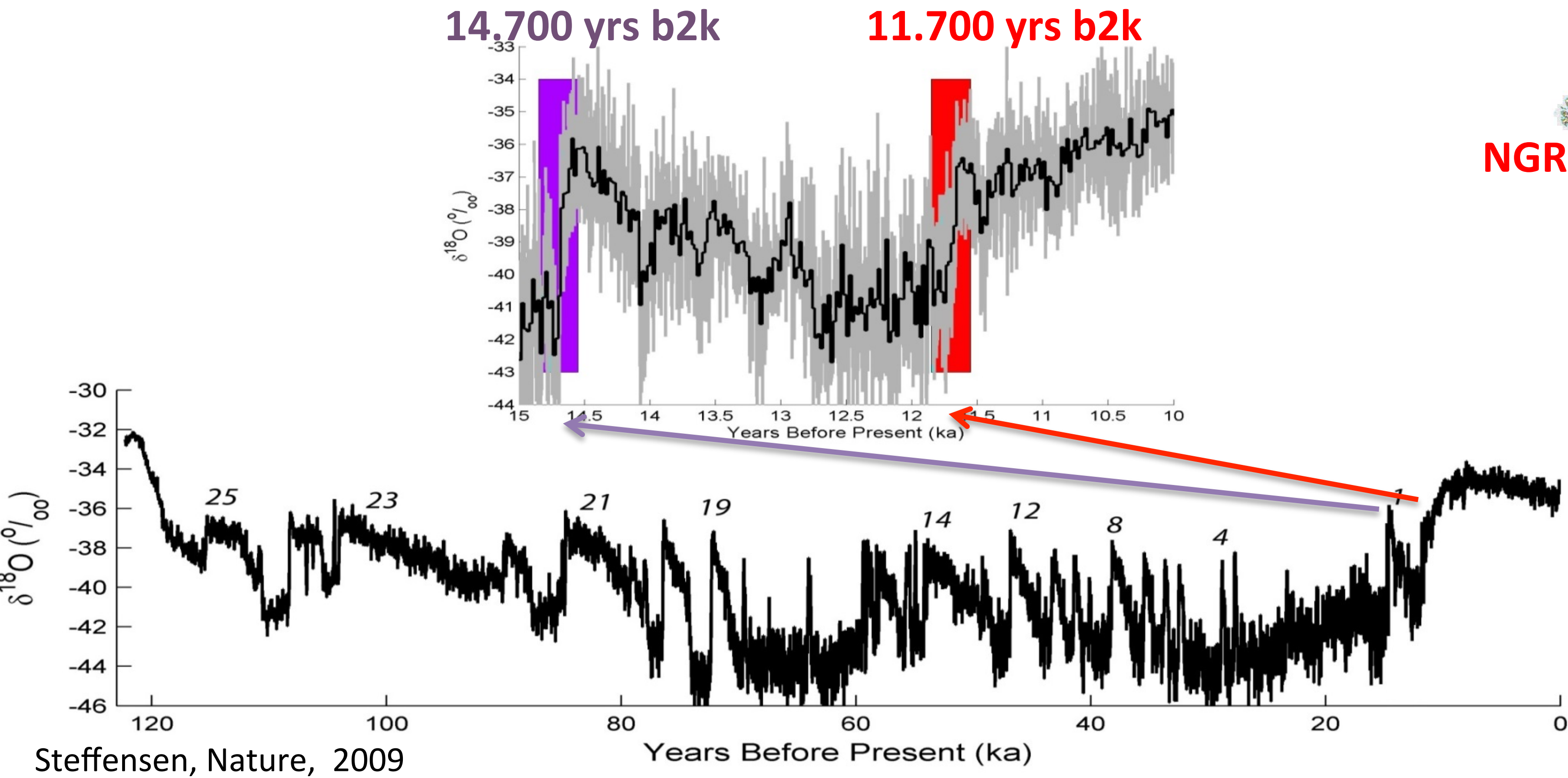
During the last glacial periode 115.000 years to 11.700 years before present 25 abrupt events occured.

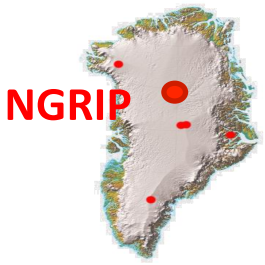
-Dansgaard-Oeschger events
-Interstadials and stadials

NGRIP, Nature, 2004



25 VERY aprupt changes during the LG



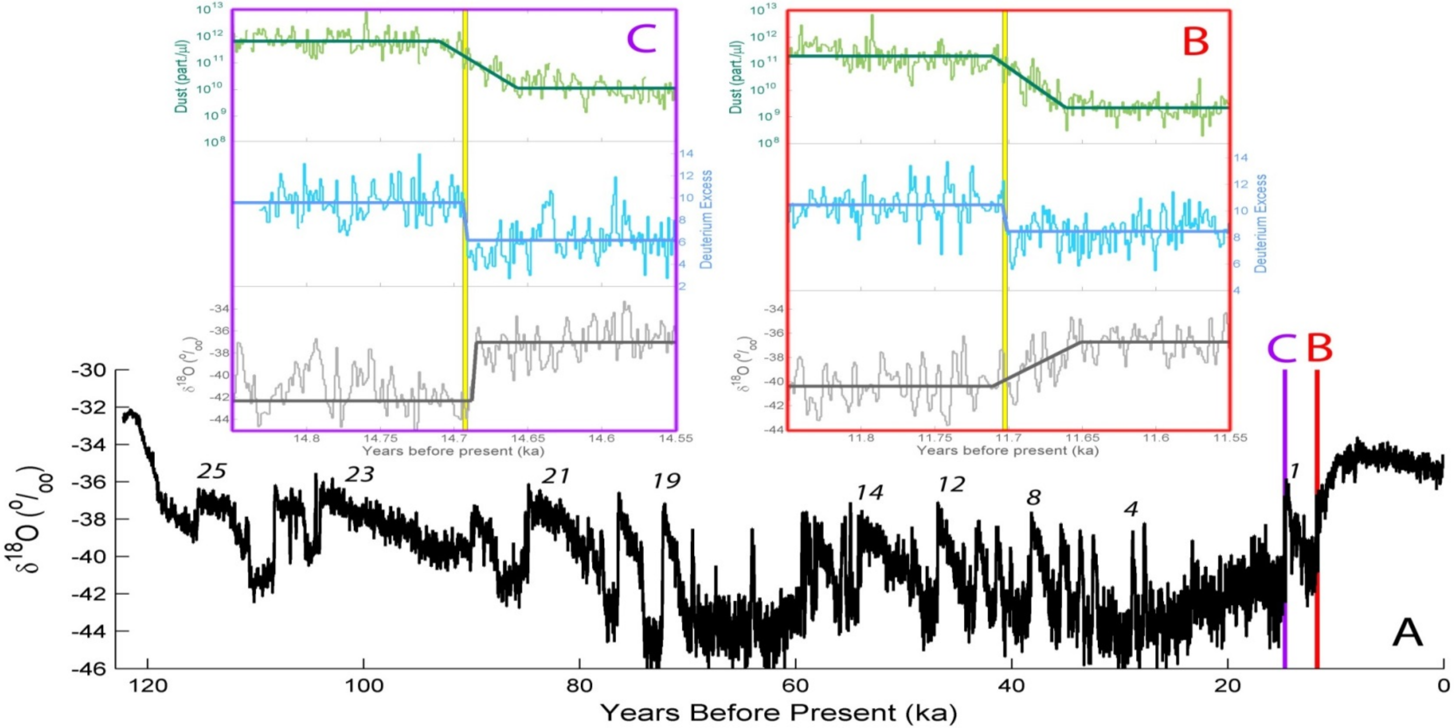


Steffensen, Nature, 2009

25 VERY aprupt changes during the LG

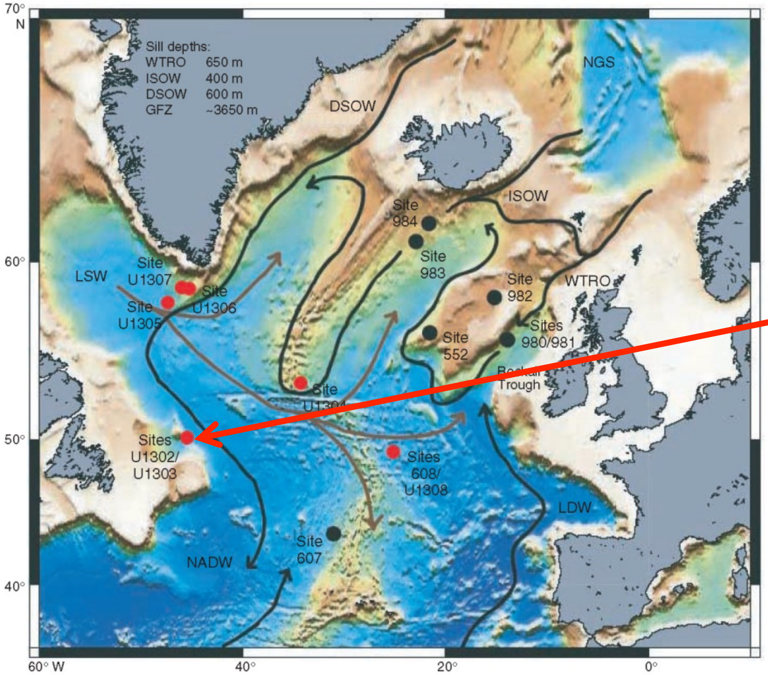
14.700 yrs b2k

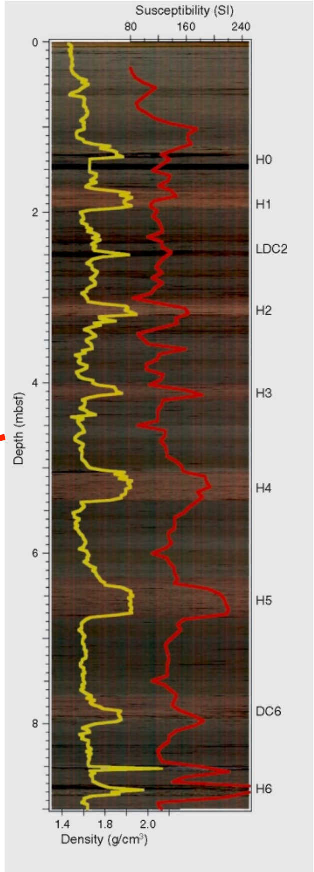
11.700 yrs b2k



Steffensen, Nature, 2009

Coupling of DO events and Heinrich event



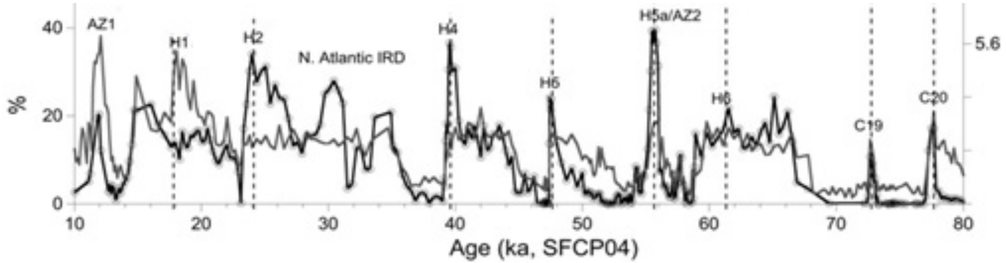


Detrital carbonate layers define the Heinrich event and color the sediment cores red

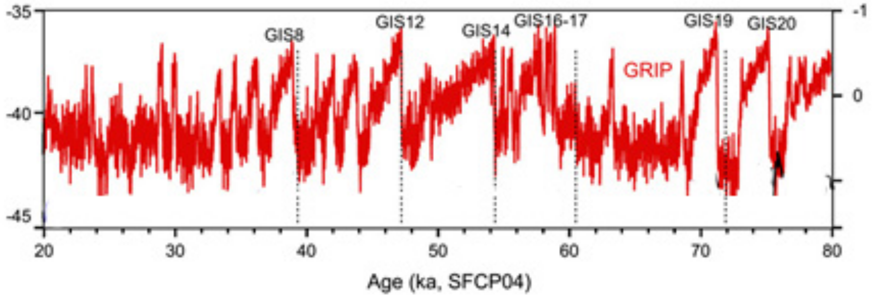
Cores close to the Hudson Bay show these layers

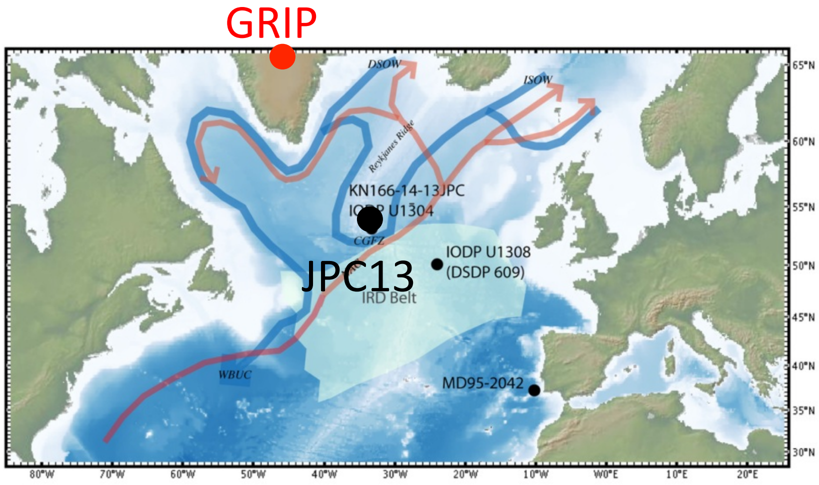
Images from IODP expedition 303 Report

Ice rafted debris during Heinrich events



Marine core:
IRD (ice rafted debris)



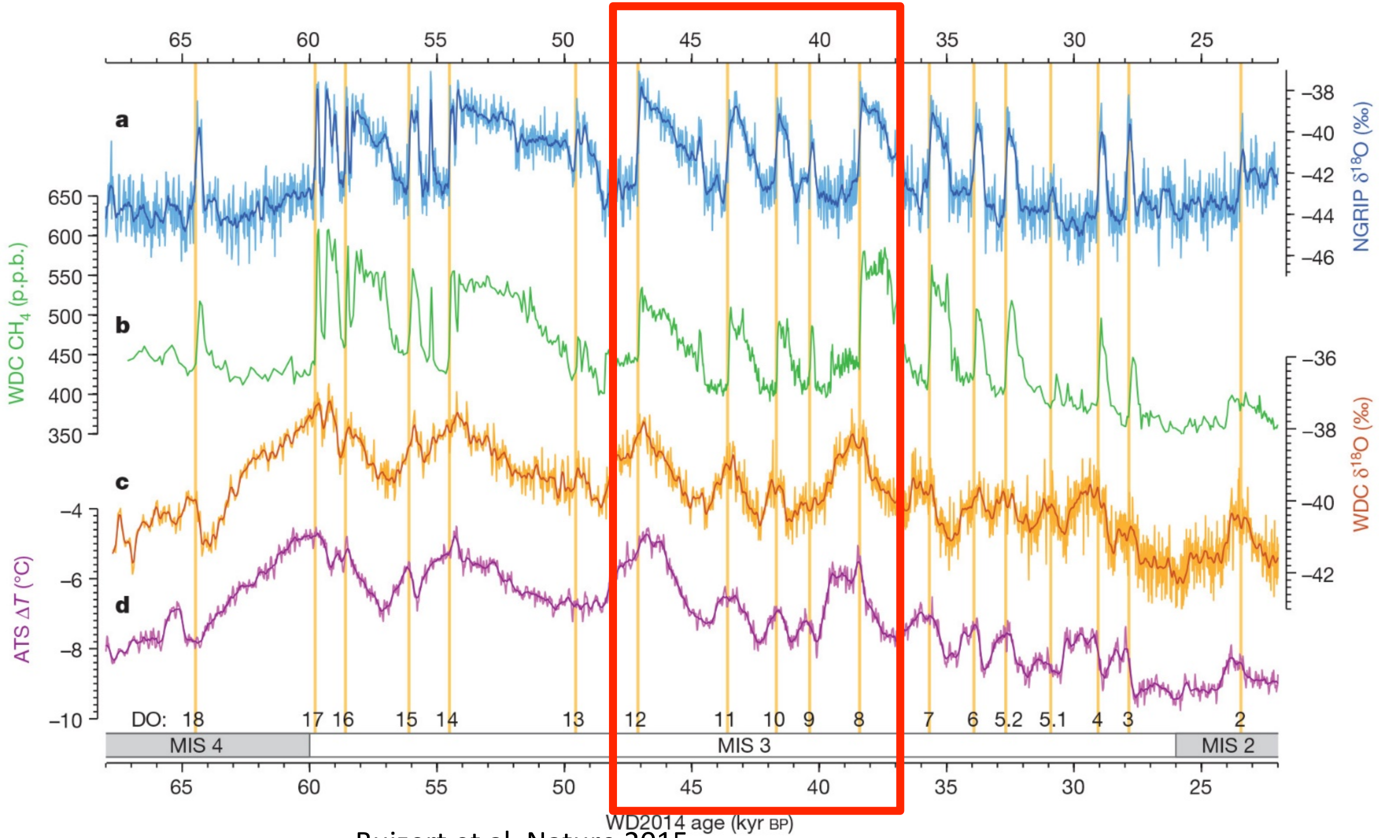


Ice core:
$\delta^{18}O$ (stabe water isotopes)

Hodall, QSR, 2010

Buizert et al, Nature 2015

Bipolar Seesaw

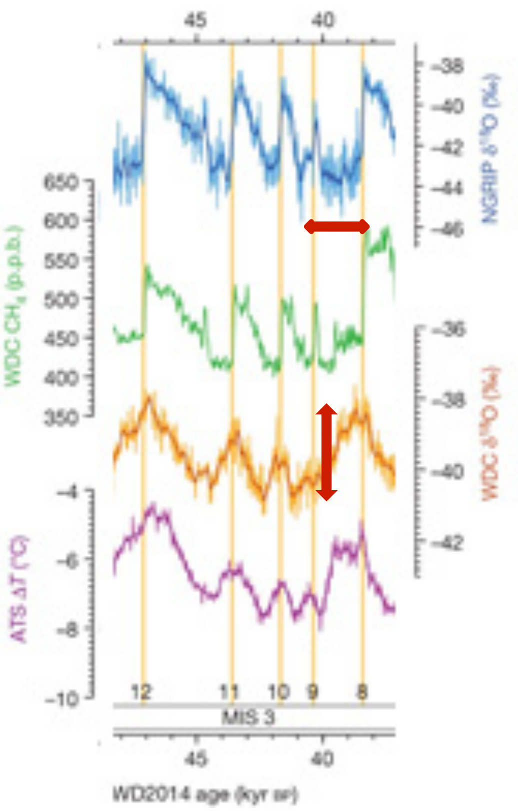


Buizert et al, Nature 2015

North: NGRIP, NEEM

South: WAIS, EDML

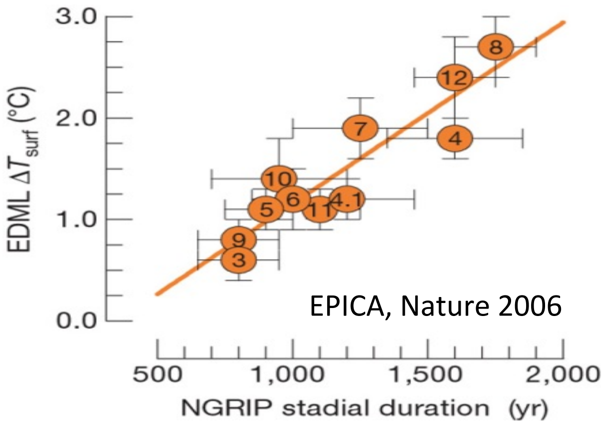
Bipolar Seesaw

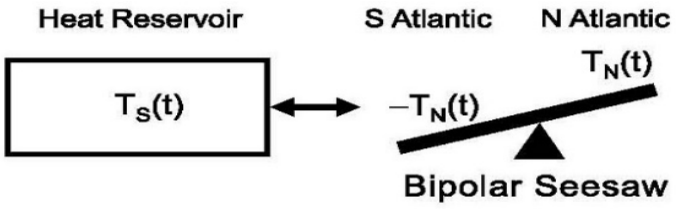


North: Stadial duration

South: Warming

Buizert et al, Nature 2015





$$\frac{d\,T_S(t)}{d\,t} = \frac{1}{\tau}[-T_N(t) - T_S(t)].$$

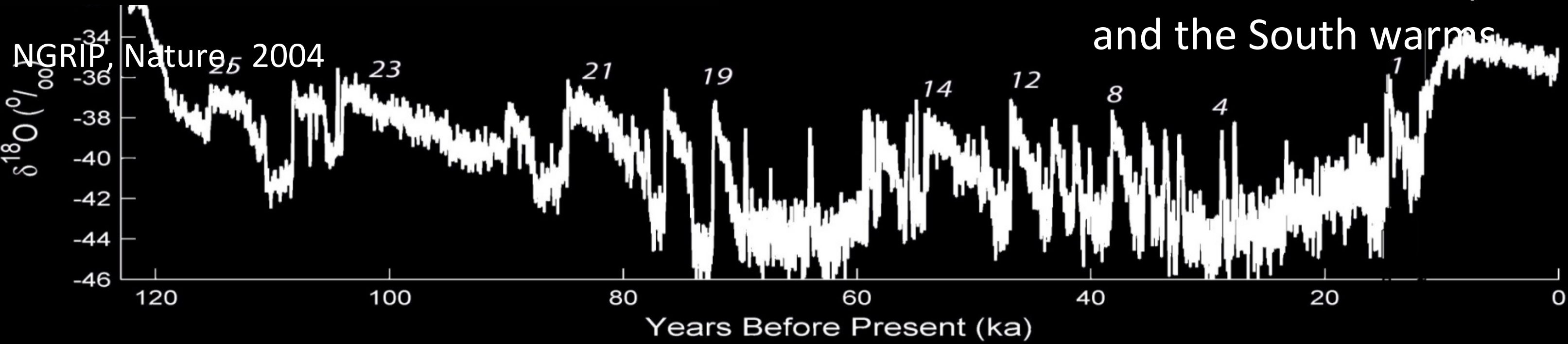
Stocker and Johnsen, 2003, Palaeoceanography

NASA/Goddard Space Flight Center Scientific Visualization Studio

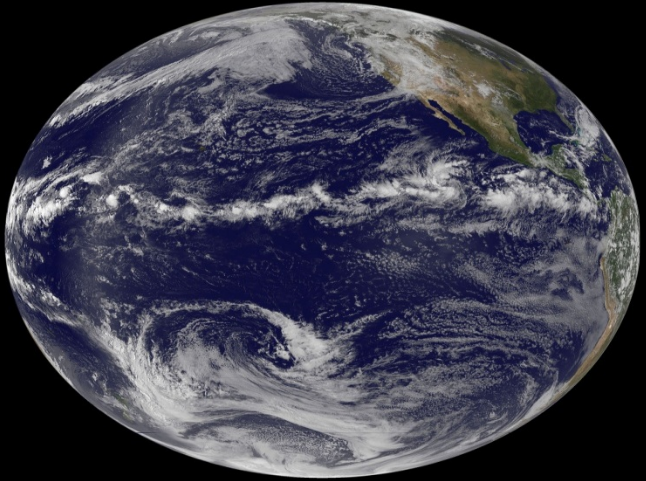
The Bipolar Seesaw

During the Warm Interstadials the Thermohaline Circulation is strong and North is ‘stealing’ heat from the South

During the Cold Stadials the Thermo-haline cirulation stops or is reduced and the South warms



NGRIP, Nature, 2004



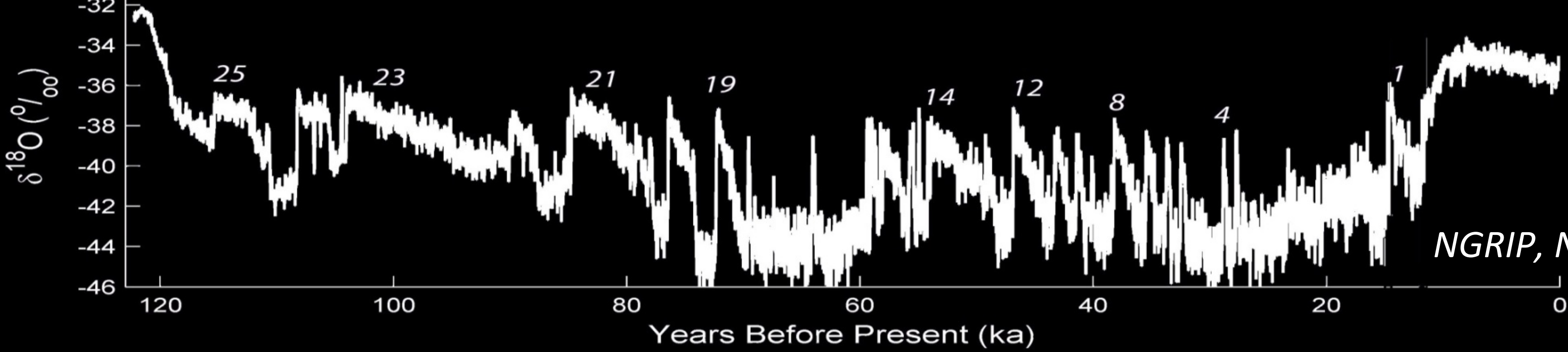
The role of the ITCZ

Inter Tropical Convergence Zone

When the North cools the ITCZ is pushed southwards

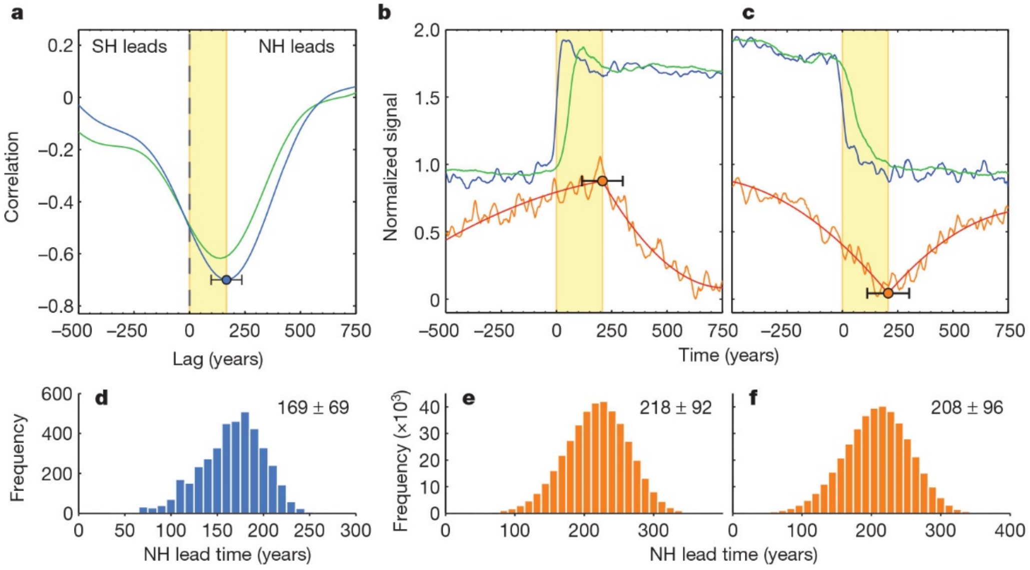
The dust change in the Greenland ice core changs first indicating a first change in the subtropical

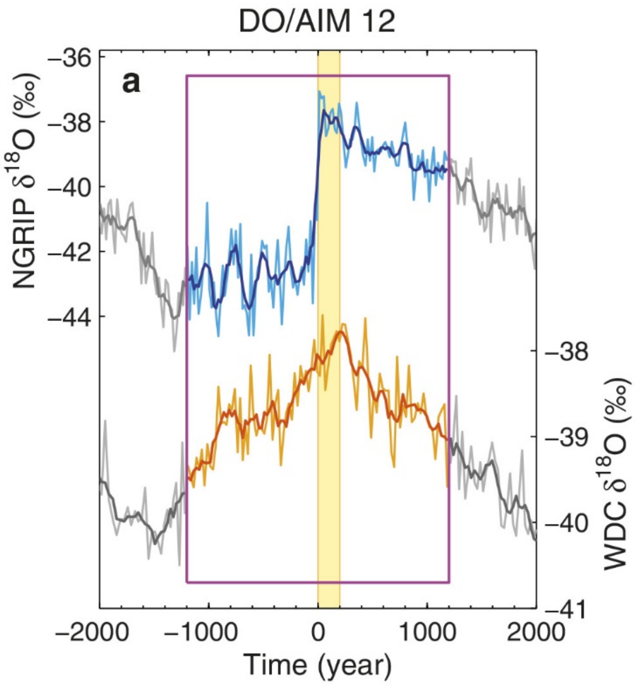
These big and rapid climate changes are internal



NGRIP, Nature, 2004

Bipolar Seesaw - timing





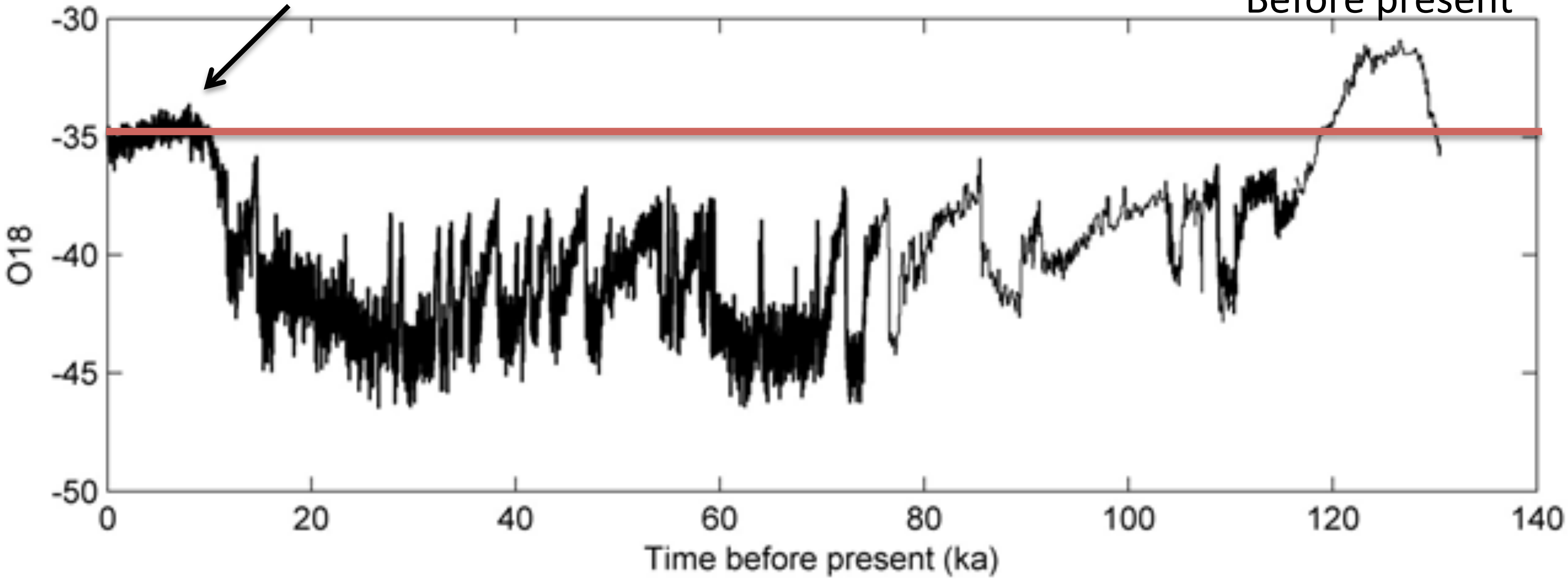
A care study using statisics off all DO event show that the North leads the South with 200 years.

Buizert et al, Nature 2015

NEEM ice cores reaches 128 ka BP

Climatic Optimum
5.000 – 8.000 before present

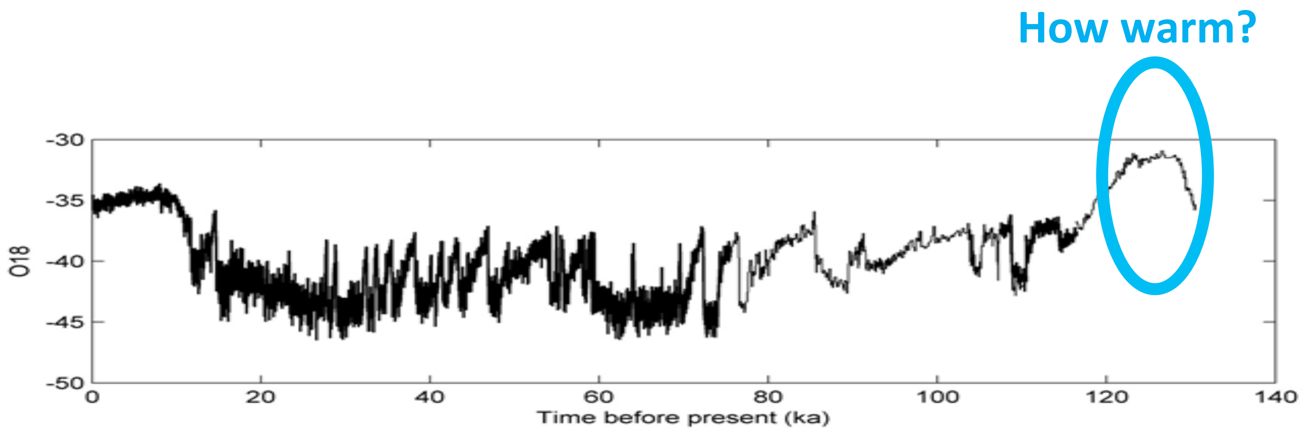
Eemian period
115.000-130.000
Before present

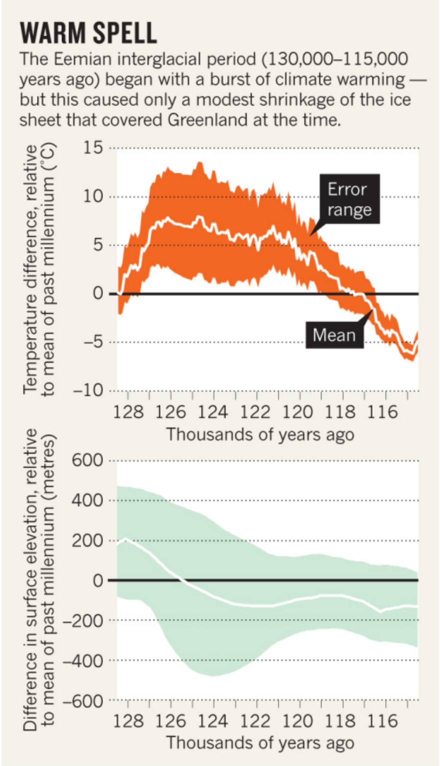


It was warmer during the Eemian

128 – 116.000 before present it was 5 °C warmere.
The ice thickness was 400 m reduced at NEEM (At present 2550 m)

The Greenland ice sheet at most lost 25 % volume
The volume of the Greenland ice sheet is equivalent to 7 m SLR
25% is equivalent to 2 m SLR





Dahl-Jensen, 2013
Nature

Danish National Research Foundation

CENTRE FOR ICE AND CLIMATE

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The Greenland ice sheet at most lost 25 % volume

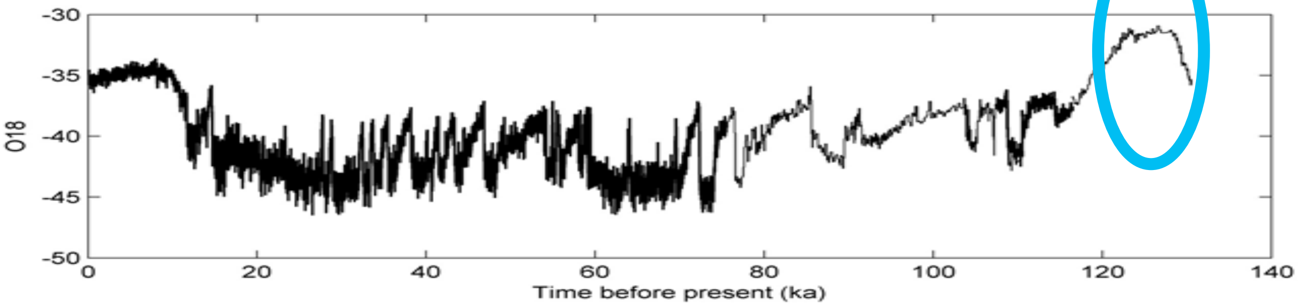
The volume of the Greenland ice sheet is equivalent to 7 m SLR

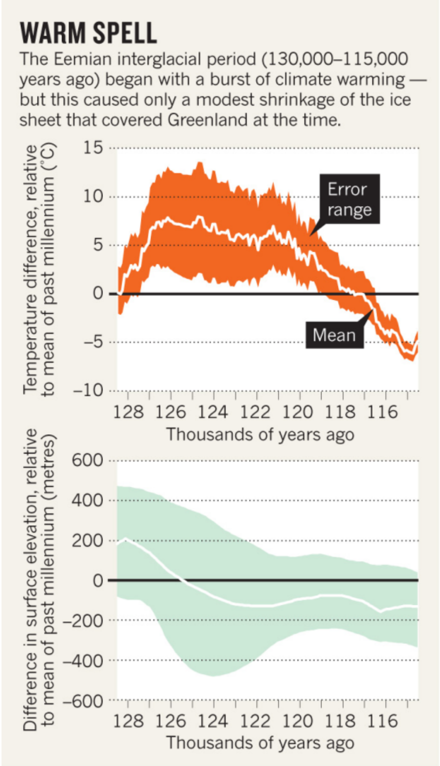
25% is equivalent to 2 m SLR

The SLR was 6-9 m during the Eemian

This implies a mass loss from Antarctica too

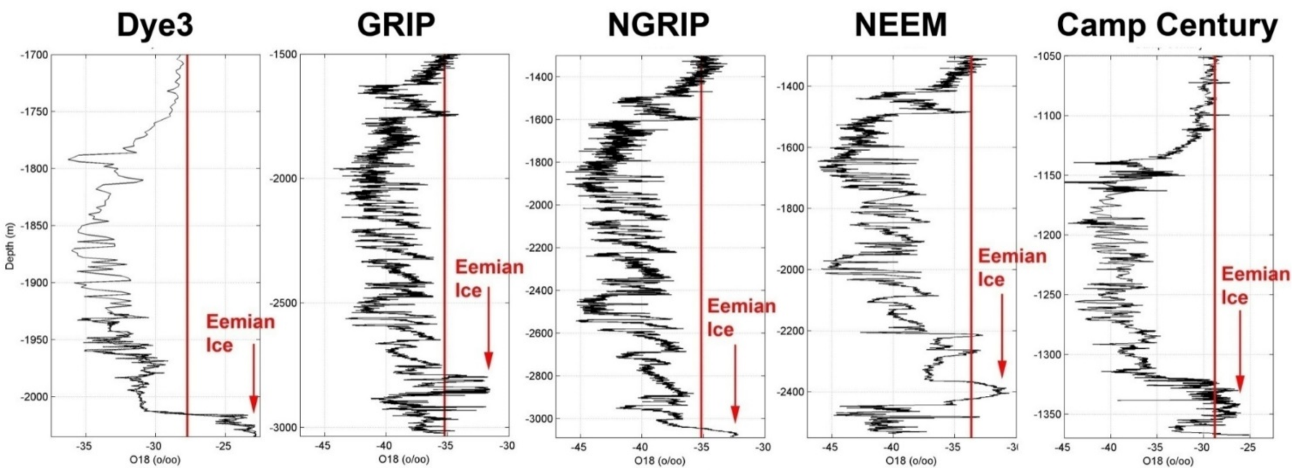
How warm?

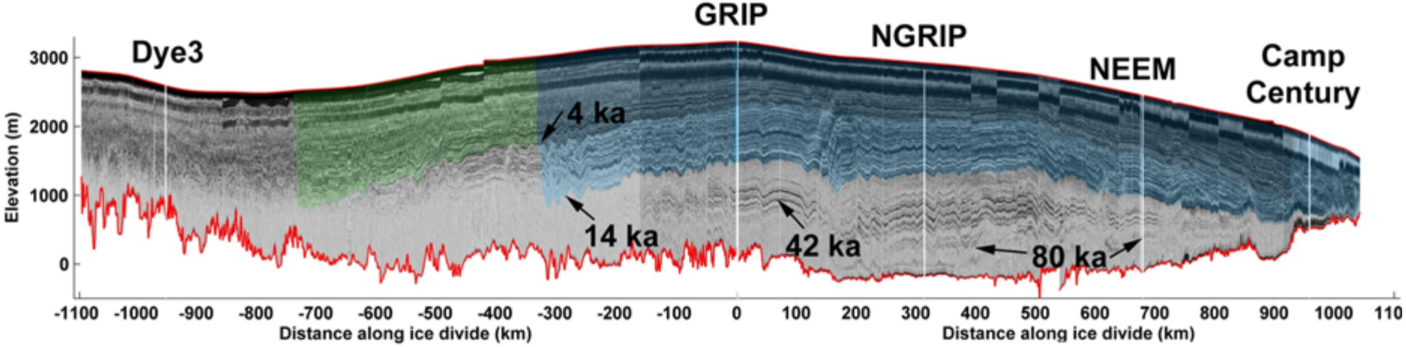


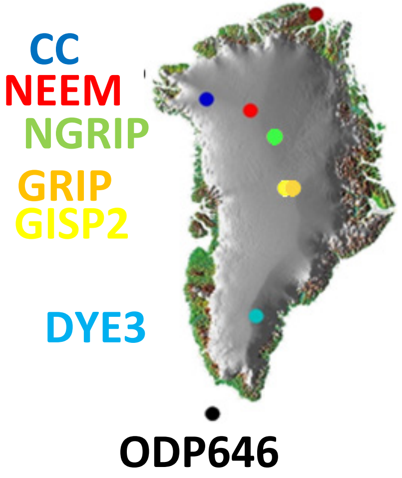


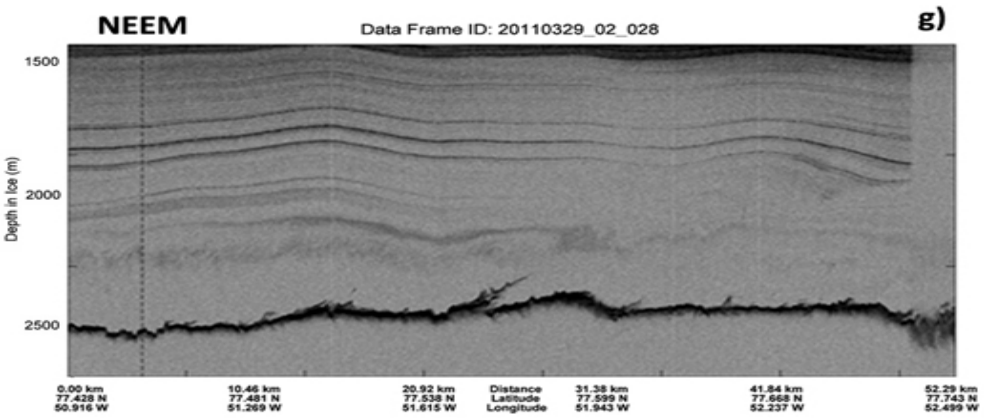
Dahl-Jensen, 2013 Nature

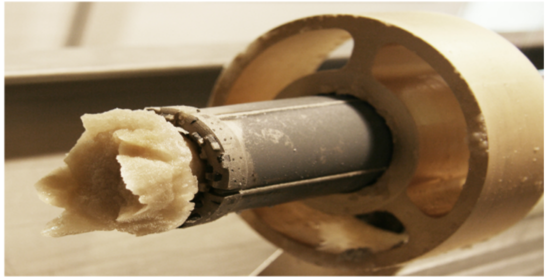
Deep Drilling Sites in Greenland

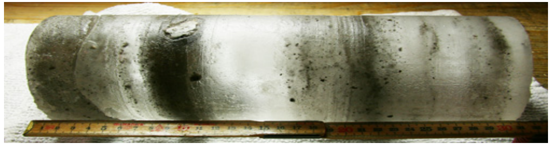


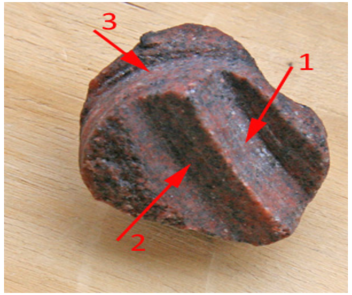












2010

2011

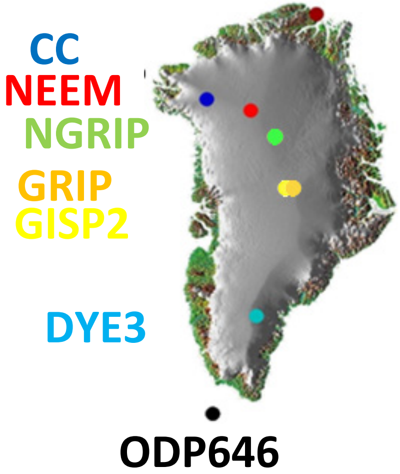
2012


10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200 210 220 230 240 250 260 270

Basal Material is found in all ice cores

NGRIP

Drilled: 2008-2012
Ice Thickness: 3090 m
Basal Material: none
Basal Temperature: -2deg C
Willow+Spruce



Basal material is found in all ice cores

GRIP GISP2

Drilled: 1996-1999

Ice Thickness: 3025 3060 m

Basal Material: 3 25 m

Basal Temperature: -8 deg C

Dated to be old

CC

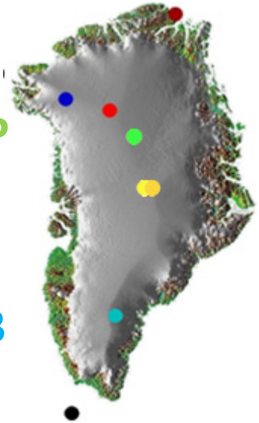
NEEM

NGRIP

GRIP

GISP2

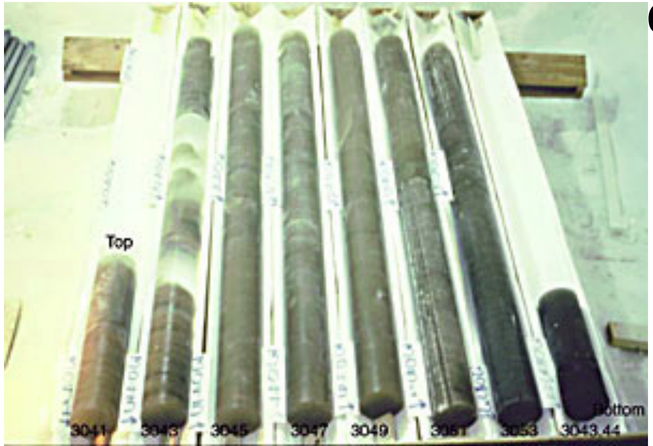
DYE3



ODP646

GRIP

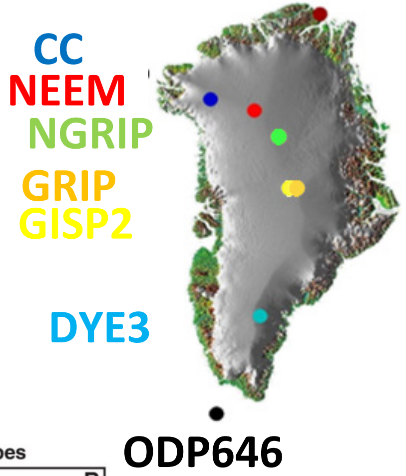
GISP2



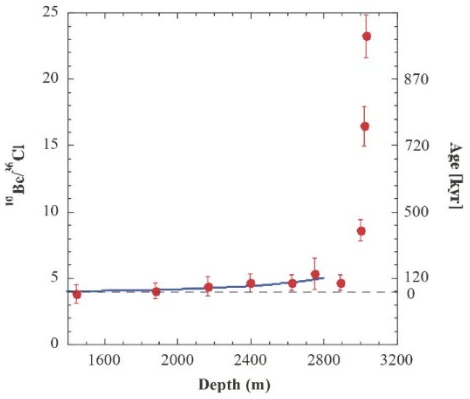
Basal Material is found in all ice cores

GRIP GISP2

Drilled: 1996-1999
Ice Thickness: 3025 3060 m
Basal Material: 3 25 m
Basal Temperature: -8 deg C
Dated to be old – 1-2.5 mill year old

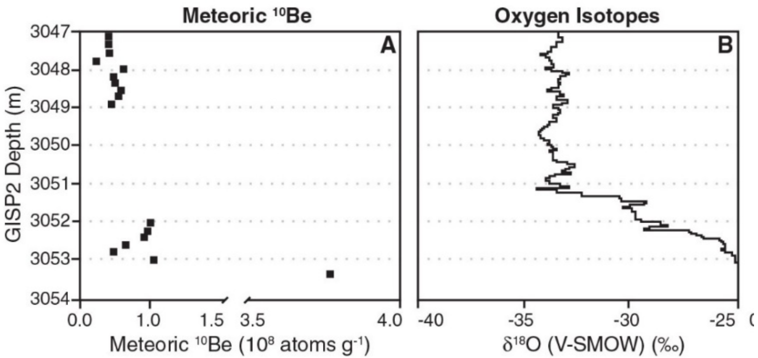


GRIP

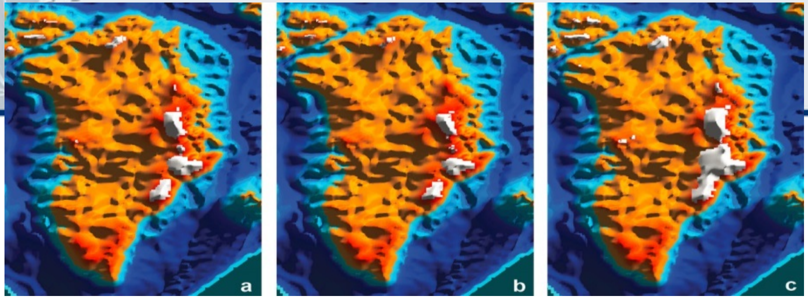


Willerslev, 2007

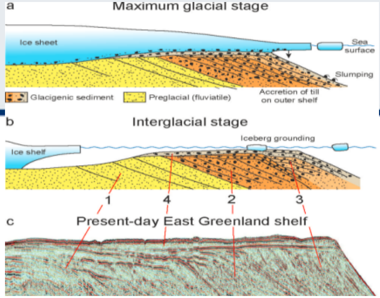
GISP2



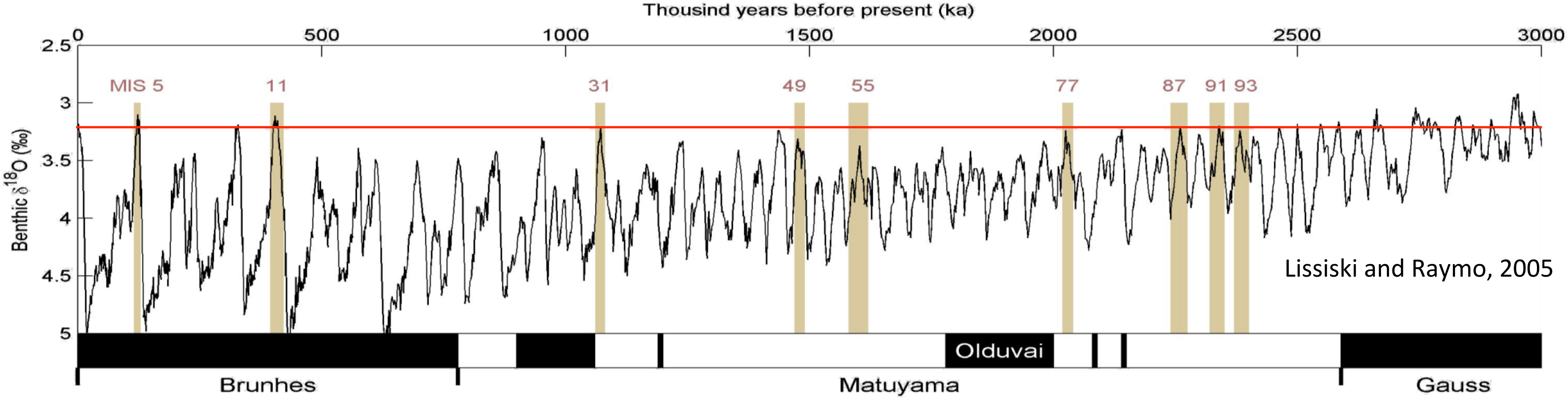
Bierman, 2014



Solgaard, JoG, 2012



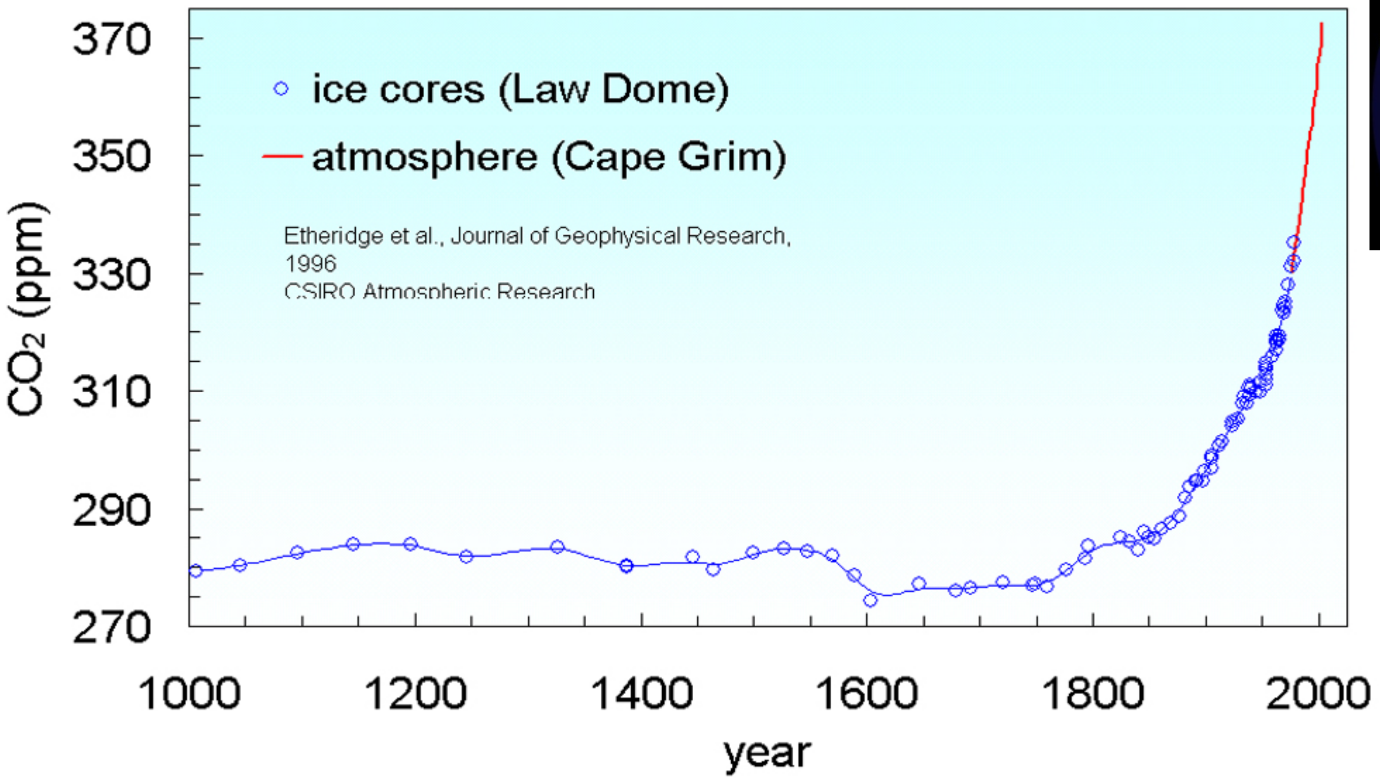
Subdivisions of the Quaternary System			
System	**Series**	**Stage**	**Age (Ma)**
Quaternary	Holocene		0–0.0117
	Pleistocene	Tarantian	0.0117–0.126
		Ionian	0.126–0.781
		Calabrian	0.781–1.806
		Gelasian	1.806–2.588
Neogene	Pliocene	Piacenzian	**older**

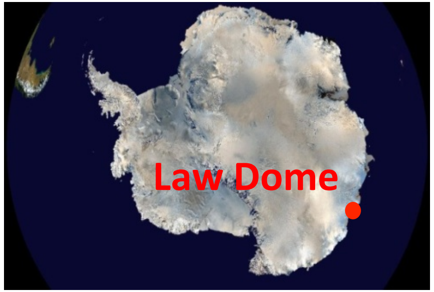


Lissiski and Raymo, 2005

Air bubbles in the ice trap air from past climate periods in the ice.

Greenhouse gas CO_2





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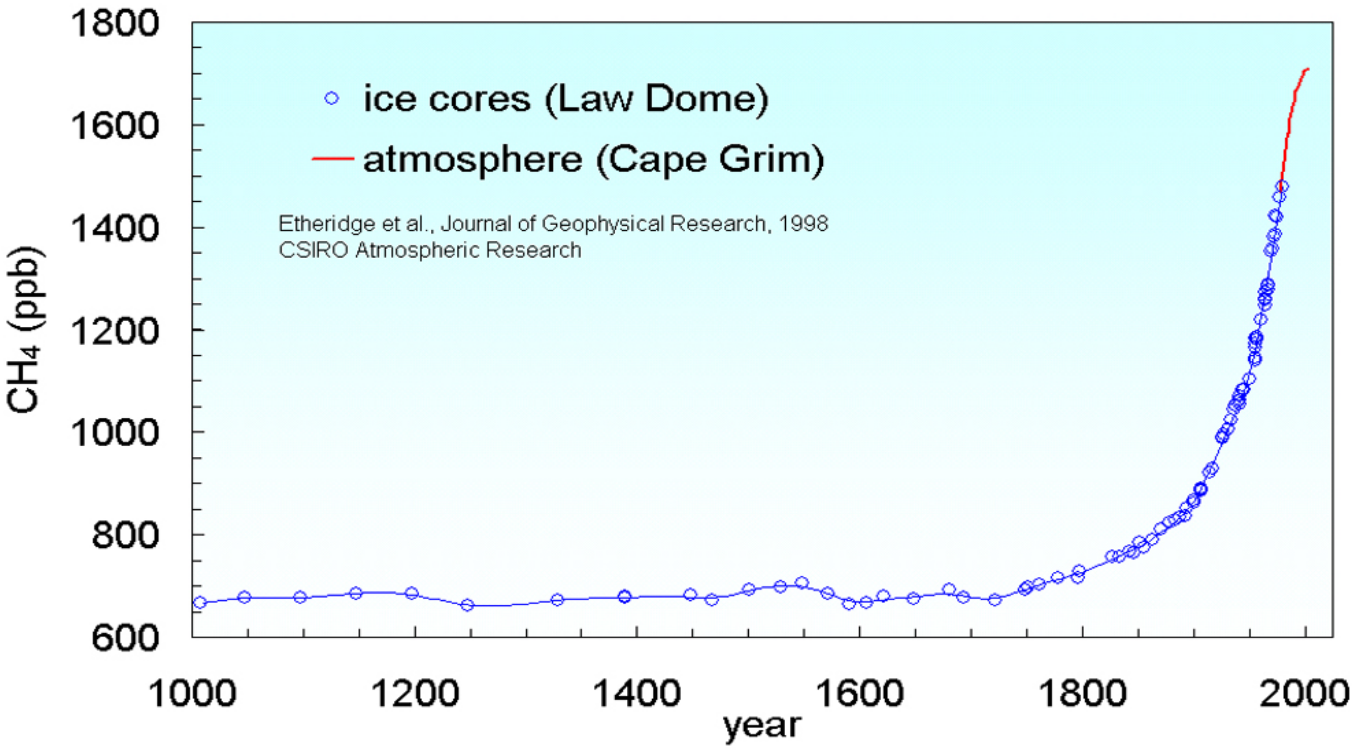
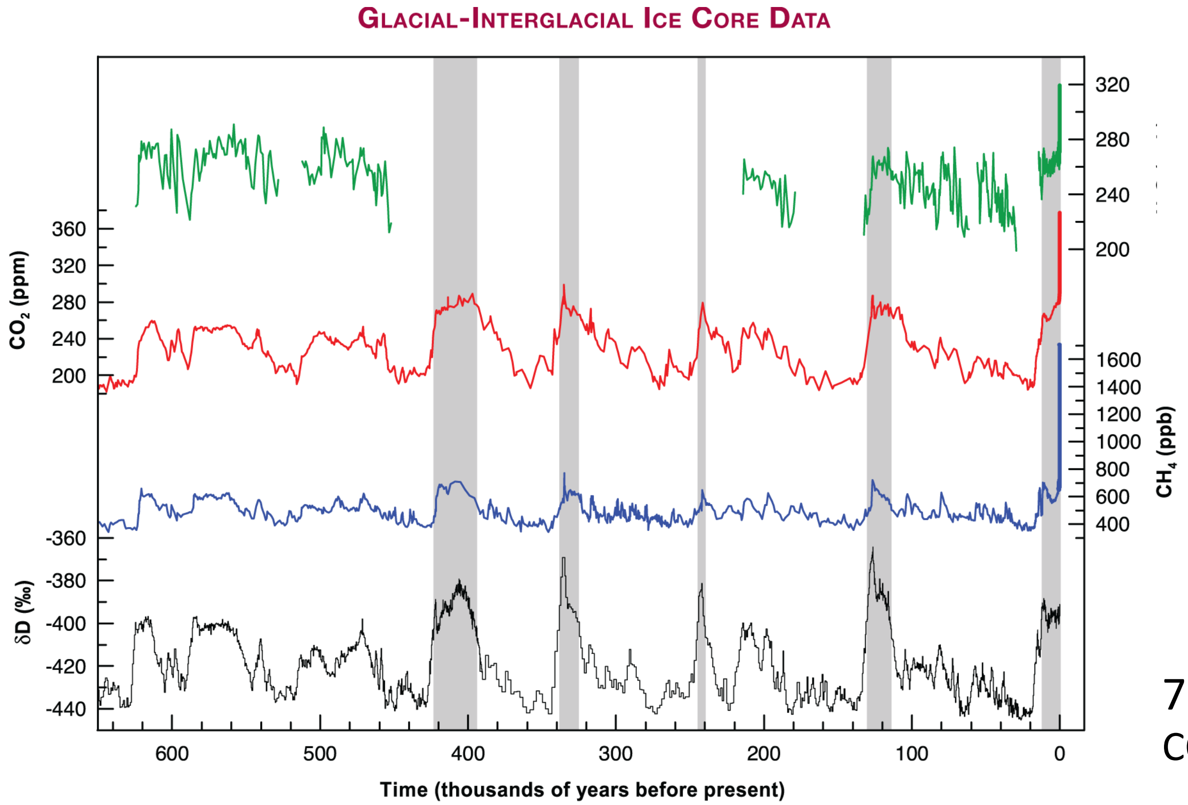
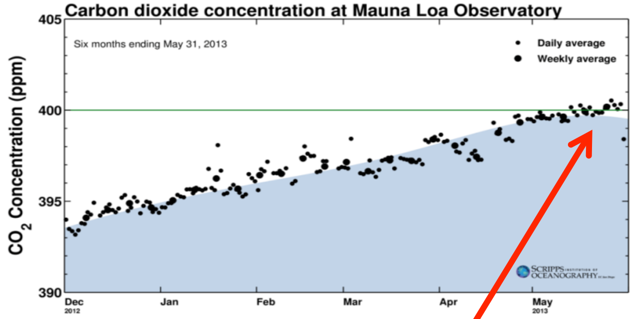
Greenhouse gas CH_4

CENTRE FOR ICE AND CLIMATE



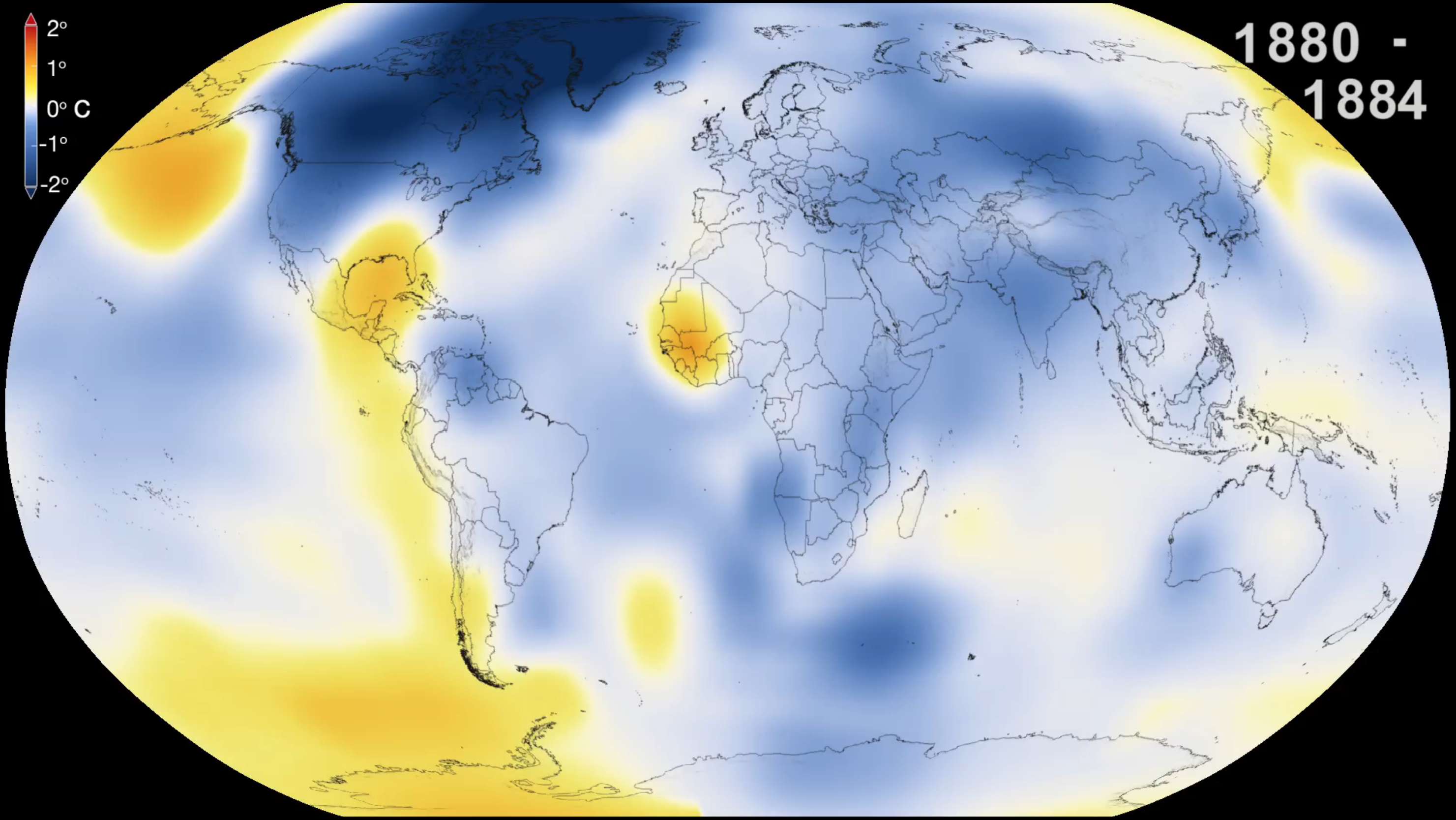
600.000 year greenhouse gas records





7 May 2013:

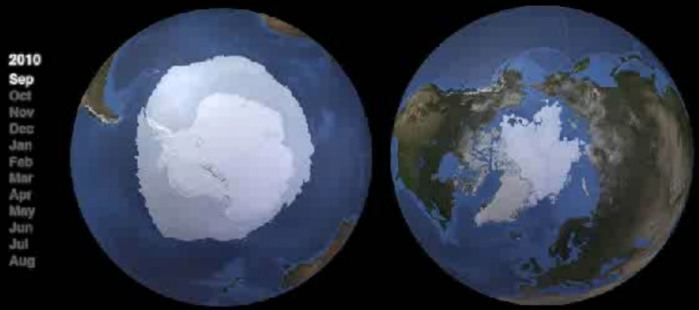
CO_2 concentration at exceeded 400 ppm



The global mean temperature has increased 0.57ºC since 1951-1980

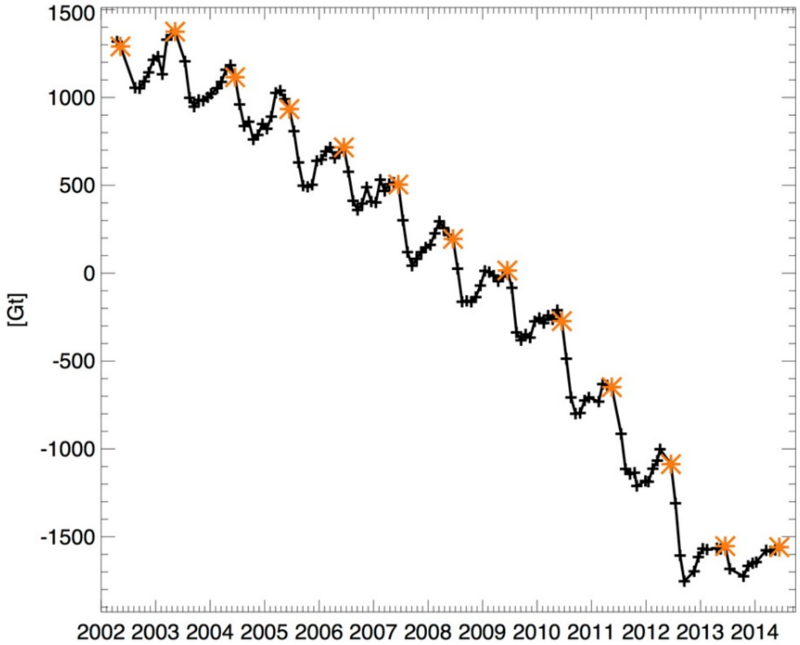
Source:J.Hansen, NASA GISS

Where is the ice?

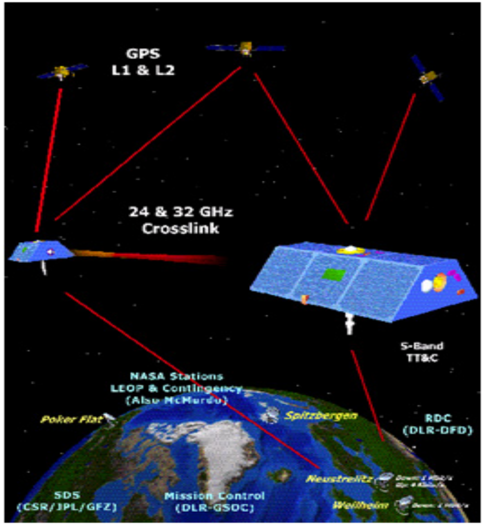


	Area (mill. km^2)	Volume (mill. km^3)	Sea Level Equivalent (m)
Greenland	1.71	2.95	7.4
Antarctica	12.1	29	73
Ice Caps and Glaciers	0.68	0.18	0.6
Sea Ice	25	0.05	0

GRACE: Mass loss from Greenland



GRACE



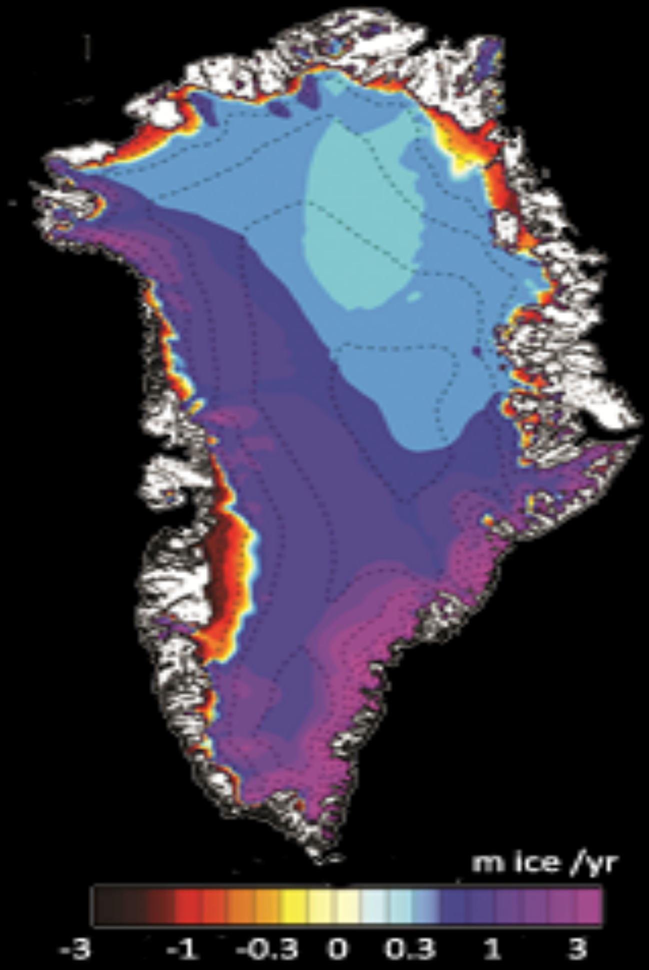
Sasgen, EPSL, 012+update, 2003-2014:

MASSETAB: 237 Gt/yr

Rignot, GRL, 2011+update

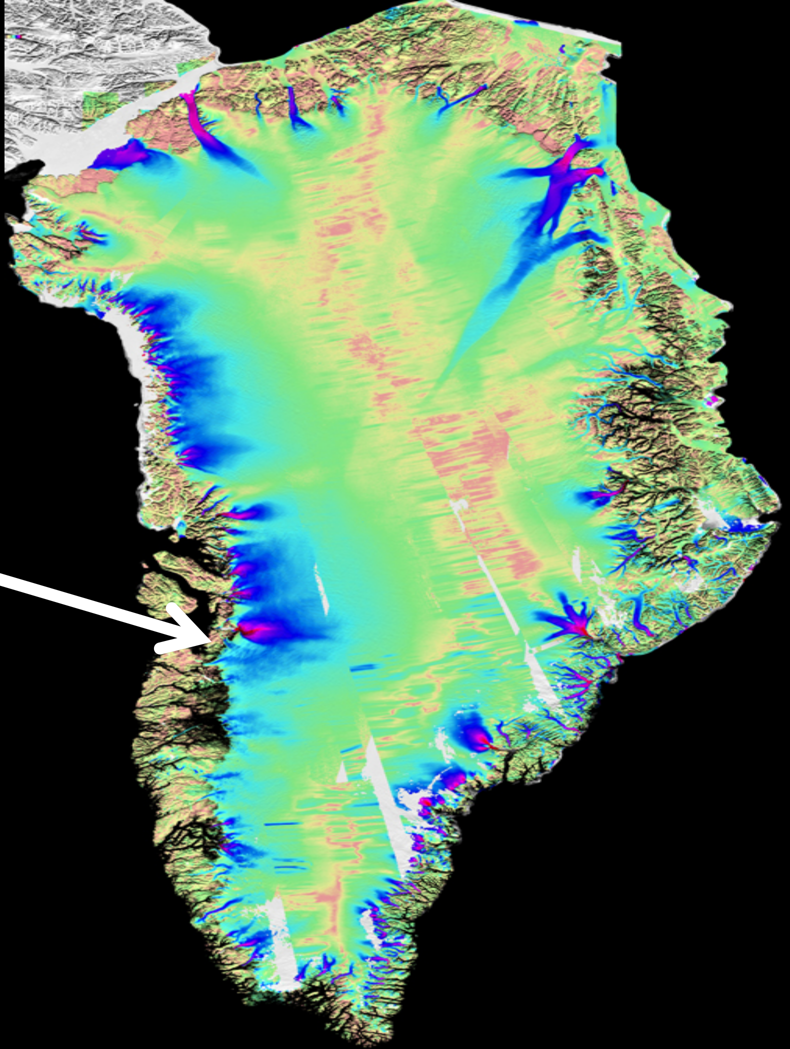
Acceleration: 17 Gt/yr^2

50% of the mass loss is from melt along the margins.



50% of the mass loss is from Calving ice from ice streams

Jakobshavn
isstrøm

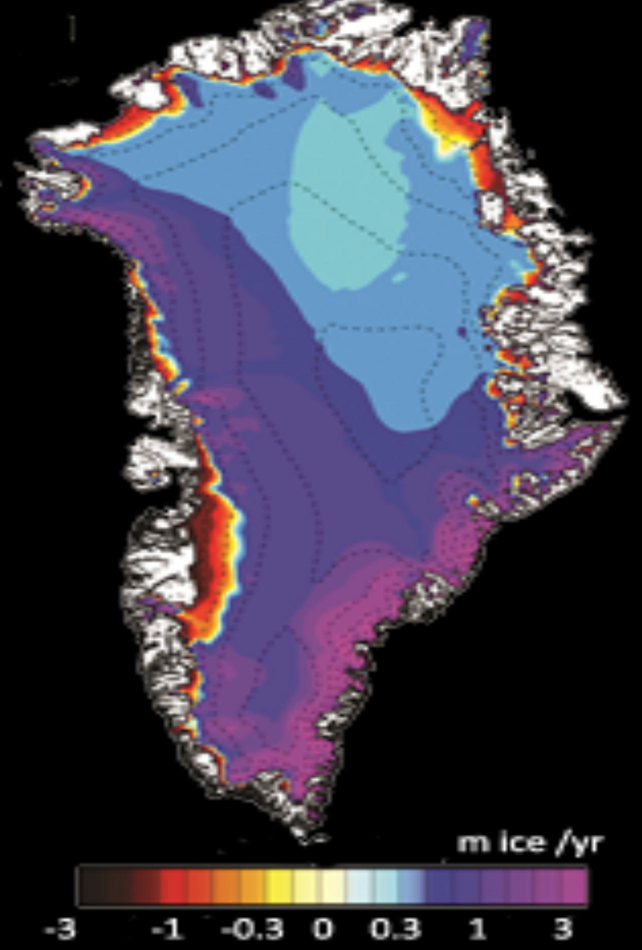


Balance:

Accumulation	+560 Gt/yr
Melt	-400 Gt/yr
Ice Discharge	-400 Gt/yr

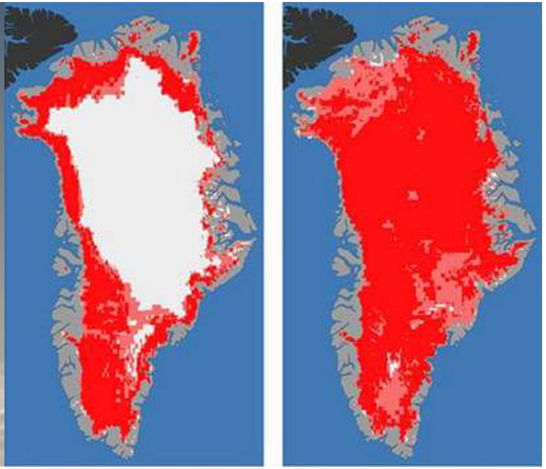
Greenland looses 240 Gt each year

This is equivalent to 0.7 mm SLR of the observed 3 mm/yr



NEEM July 2012

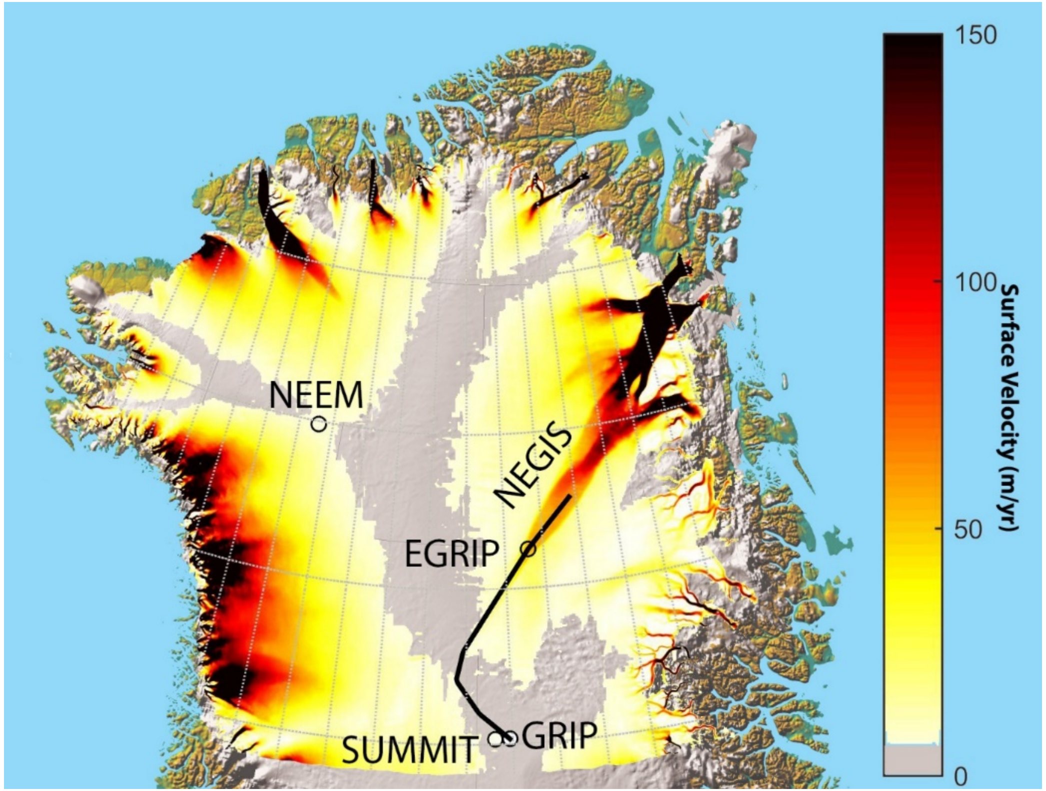
Rainbow at NEEM



8 July 2012 12 July 2012
NASA infrared satellite images

We had rain at NEEM during the extrem warm event 12 July 2012.
Surface melt will be more frequent in a warming climate.

EGRIP – a new ice core project



In North East Greenland, **the biggest ice stream in Greenland** begins right at the central ice divide and cuts through the ice sheet in a wedge shape to feed into the ocean through three large ice streams (Nioghalvfjerds isstrømmen, Zachariae isbræ and Storstrømmen).

1. Climate of the last 50.000 years
2. Deformation of an ice stream

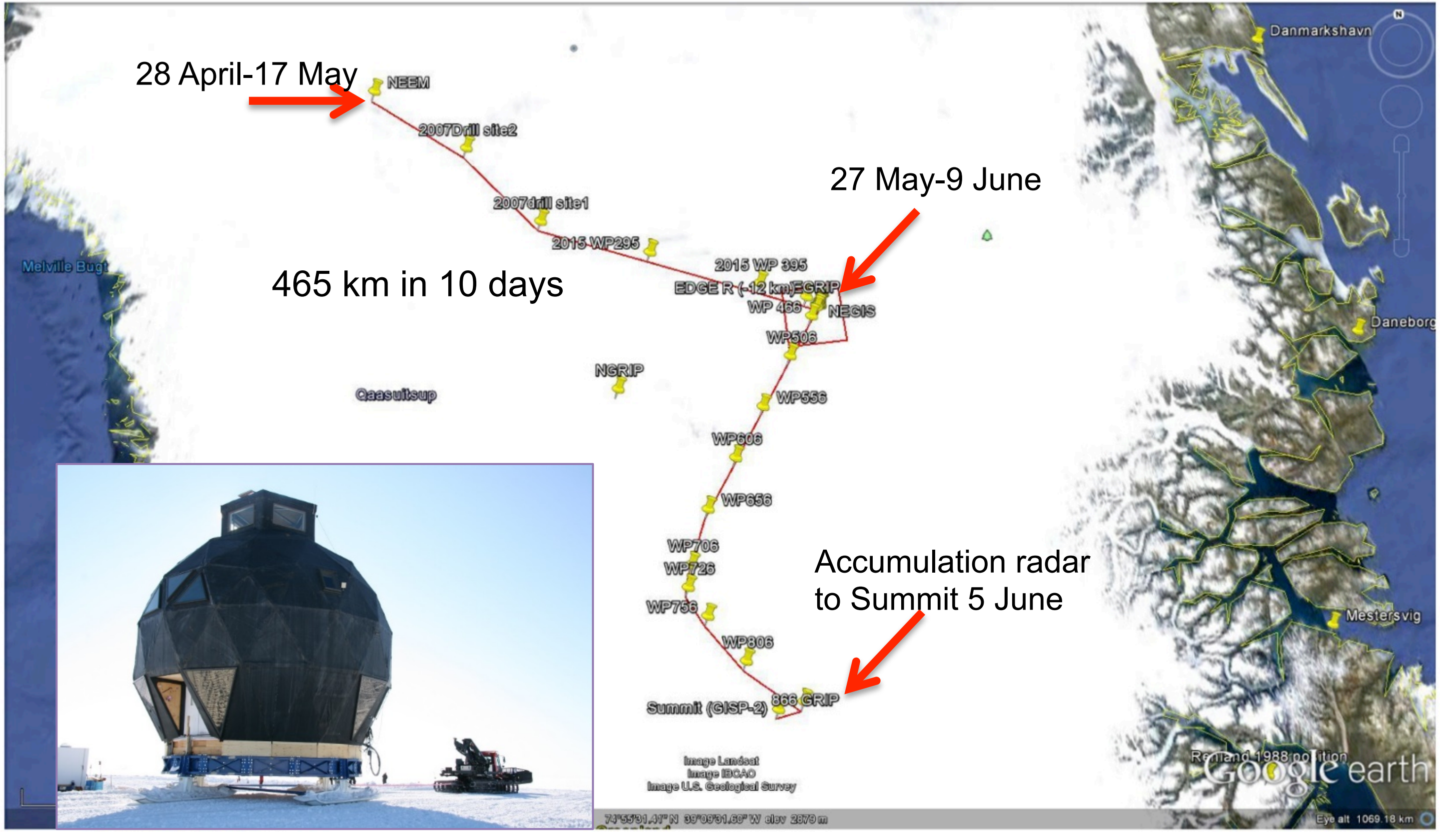
NEEM – preparing to move

NEEM – preparing to move

NEEM – preparing to move

NEEM – preparing to move

EGRIP – 2015


28 April-17 May
NEEM
2007Drill site2
2007drill site1
2015 WP295
465 km in 10 days
27 May-9 June
2015 WP 395
EDGE R (-12 km)EGRIP
WP 466
NEGIS
WP506
NGRIP
Qaasuitsup
Melville Bugt
WP556
WP606
WP656
WP706
WP726
WP756
WP806
Accumulation radar
to Summit 5 June
Summit (GISP-2)
866 GRIP
Danmarkshavn
Daneborg
Mestersvig
Image Landsat
Image IBCAO
Image U.S. Geological Survey
Google earth
Eye alt 1069.18 km

EGRIP – 2015

EGRIP – 2015

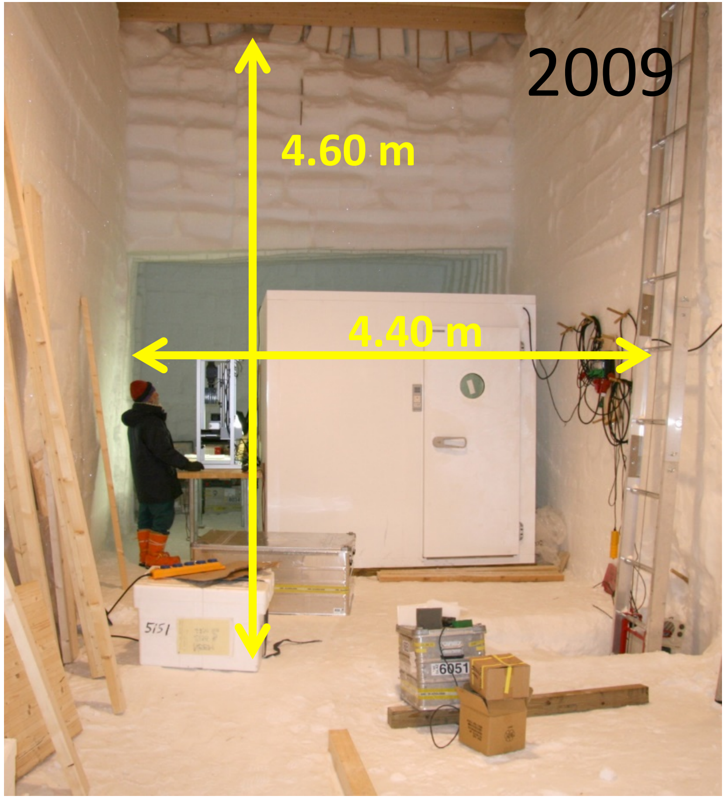
EGRIP – Time Line

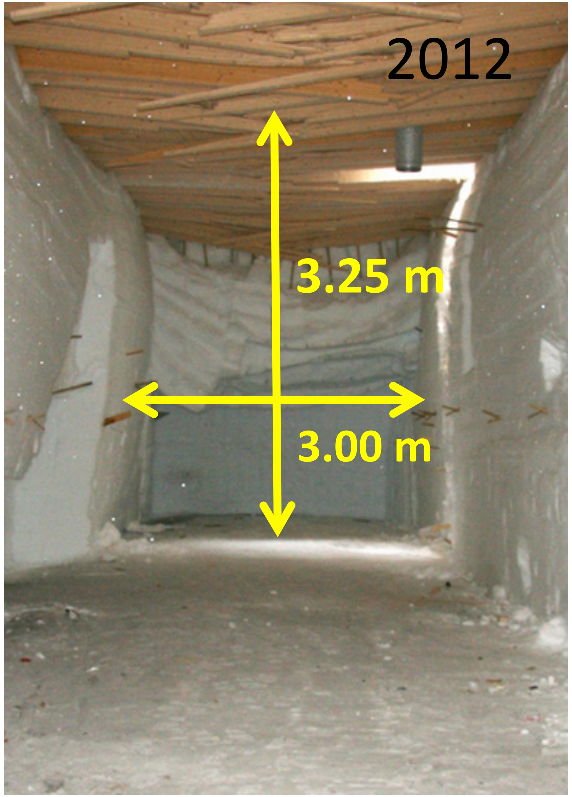
Year	2016	2017	2018	2019	2020
Drill depth	100 m	1200 m	2550 m		
Processing ice		0 - 500 m*	500 - 1500 m	1500 - 2550 m	
Borehole logging		End of season	Beginning and end of season	Whole season	Beginning of season
RES	YES	YES	?	?	?

Table 1 Time line of the ice-core drilling and processing in the field

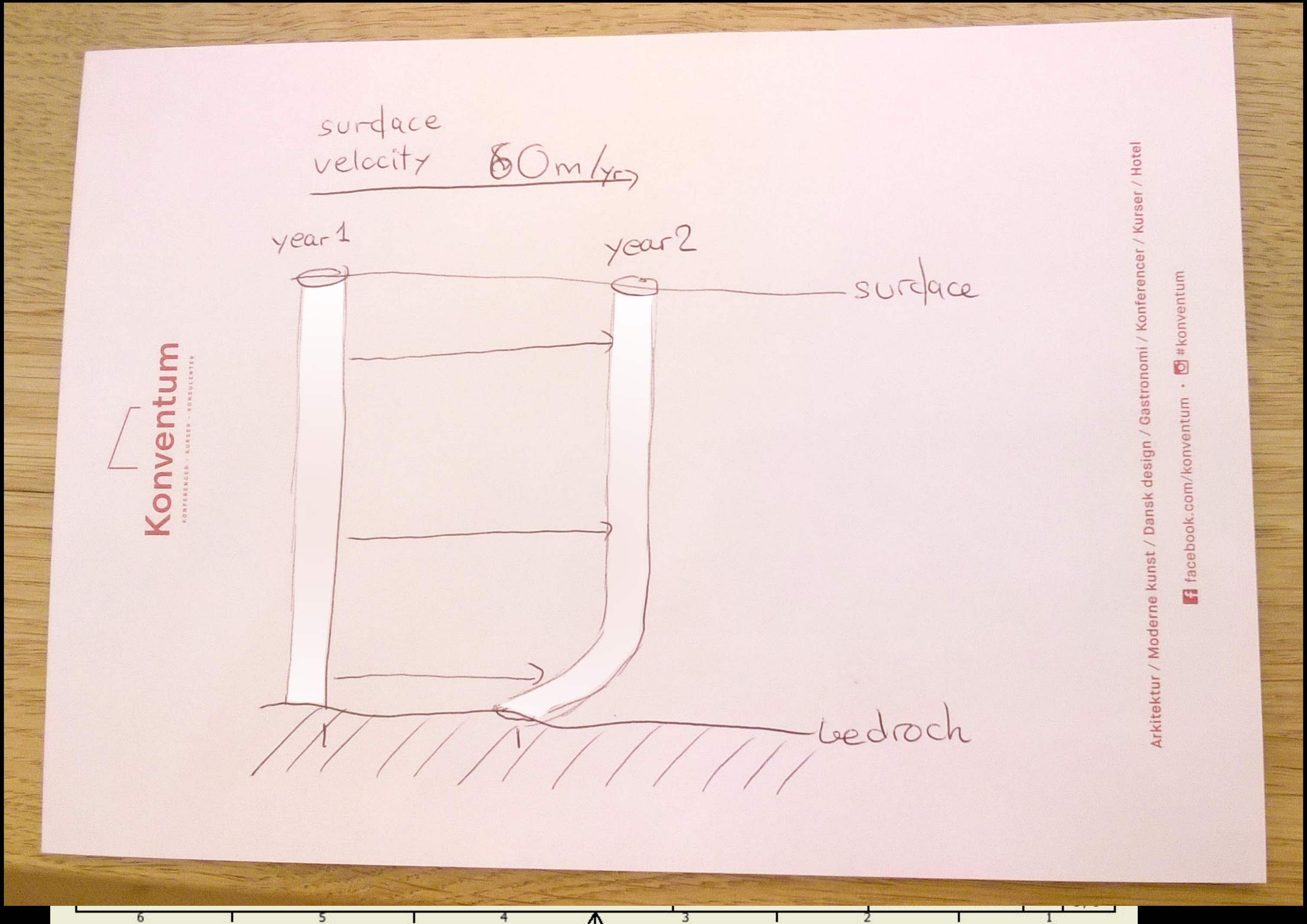
*Ice becomes brittle below 500 m, so the ice will have to be left unprocessed for a year to relax before cutting

EGRIP – New trench technology





EGRIP – New trench technology


surface velocity 80m/yr
year 1
year 2
surface
bedrock
Konventum
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Arkitektur / Moderne kunst / Dansk design / Gastronomi / Konferencer / Kurser / Hotel
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Short summary

1. The climate system can have abrupt changes without external forcing
2. 120.000 years ago was a warmer period than the present and sea level was 6-9 m higher
3. The Greenland ice sheet needs more than 10 ^{o}C warming to disintegrate
4. Greenhouse gas concentrations are higher than observed the last 800.000 years
5. At present the Greenland ice sheet is loosing 250 Gt each year and the loss is increasing

THANKS for your attention!