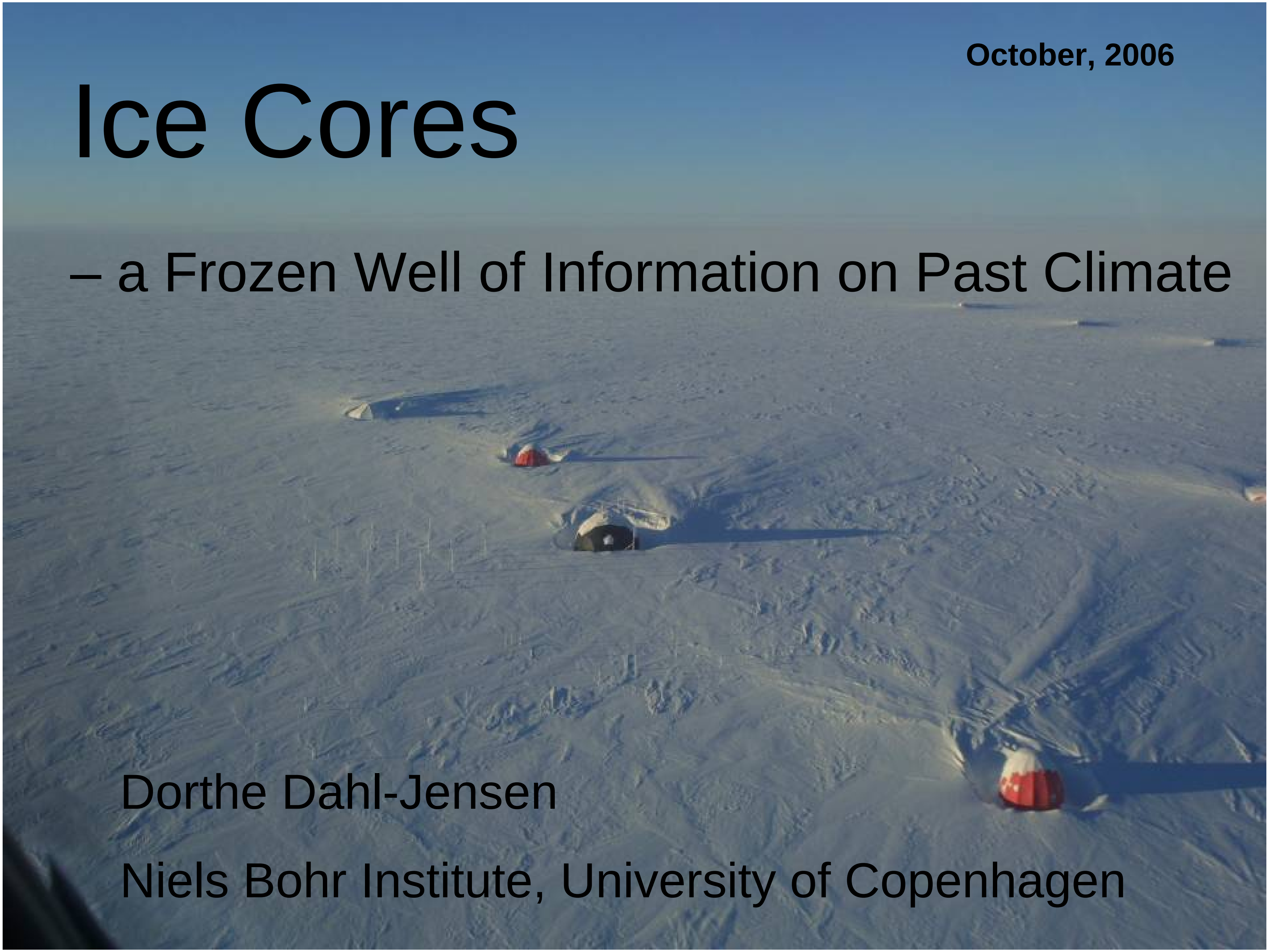


October, 2006

Ice Cores

– a Frozen Well of Information on Past Climate

Dorthe Dahl-Jensen

Niels Bohr Institute, University of Copenhagen

What makes Ice Cores so special?

High resolution climatic records

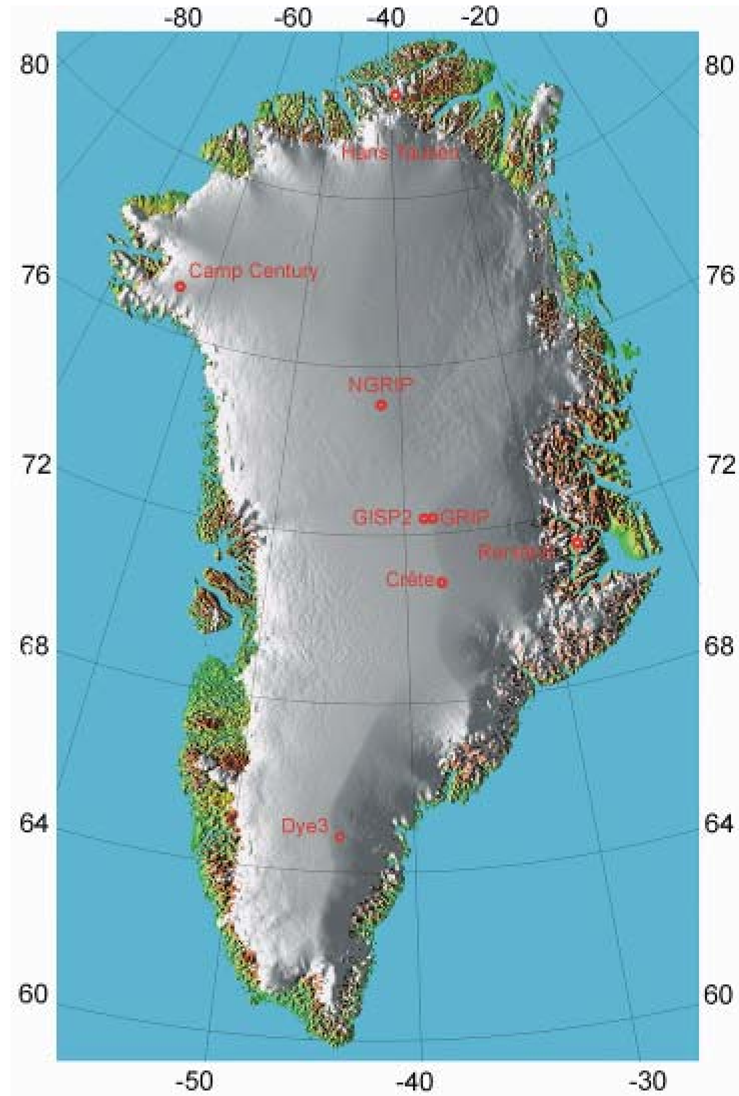
Full dynamics of the coupled atmosphere-ocean-ice climate system are manifested

Deep Ice Cores in Greenland

Project	Year	Depth
Camp Century	64-66	1390 m
Dye-3	79-81	2037 m
GRIP	89-92	3029 m
GISP2	89-93	3053 m
NorthGRIP	97-04	3090 m

GRIP = Greenland Ice Core Project (EU)

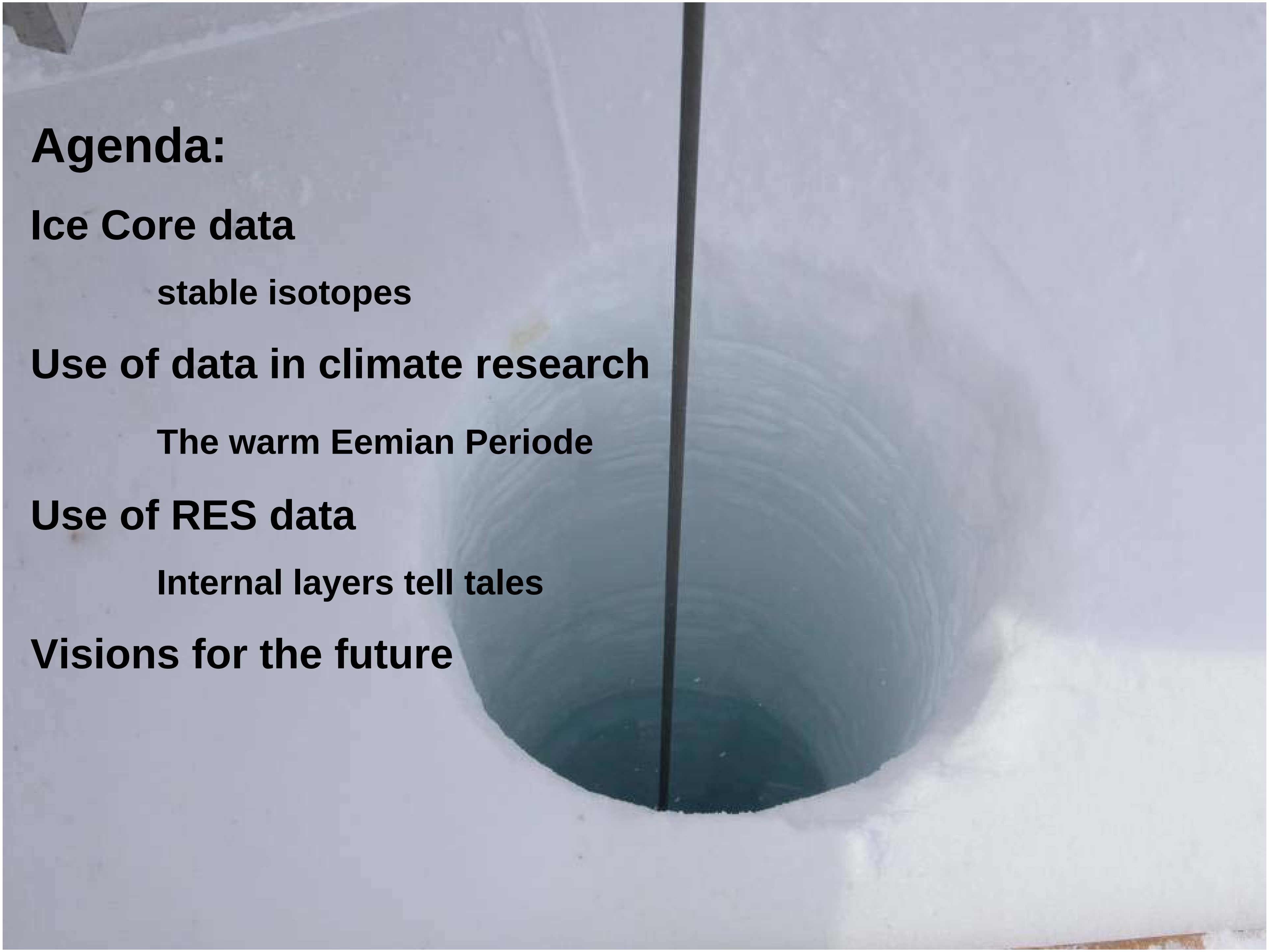
GISP = Greenland Ice Sheet Project (US)



Ice Core data
A shopping list

- The ice: ^{18}O , ^{17}O , ^{16}O, ^{1}H og ^{2}D
- Continental dust, volcanic ash, micro metheorites and biological material
- Ions: Cl^-, NO_3^-, SO_4^{2-}, F^-, H^+, Na^+, K^+, NH_4^+, Mg^{2+}, Ca^{2+}
- Gas in air bubbles: CO_2, CH_4, O_2, N_2, SF_6.
- Radioactive isotopes: ^{10}Be, ^{36}Cl, ^{210}Pb, ^{32}Si, ^{14}C, ^{137}Cs, ^{90}Sr.
- DNA
- Ice Properties
- Bore hole logging: temperature, geometry

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



Agenda:

Ice Core data

stable isotopes

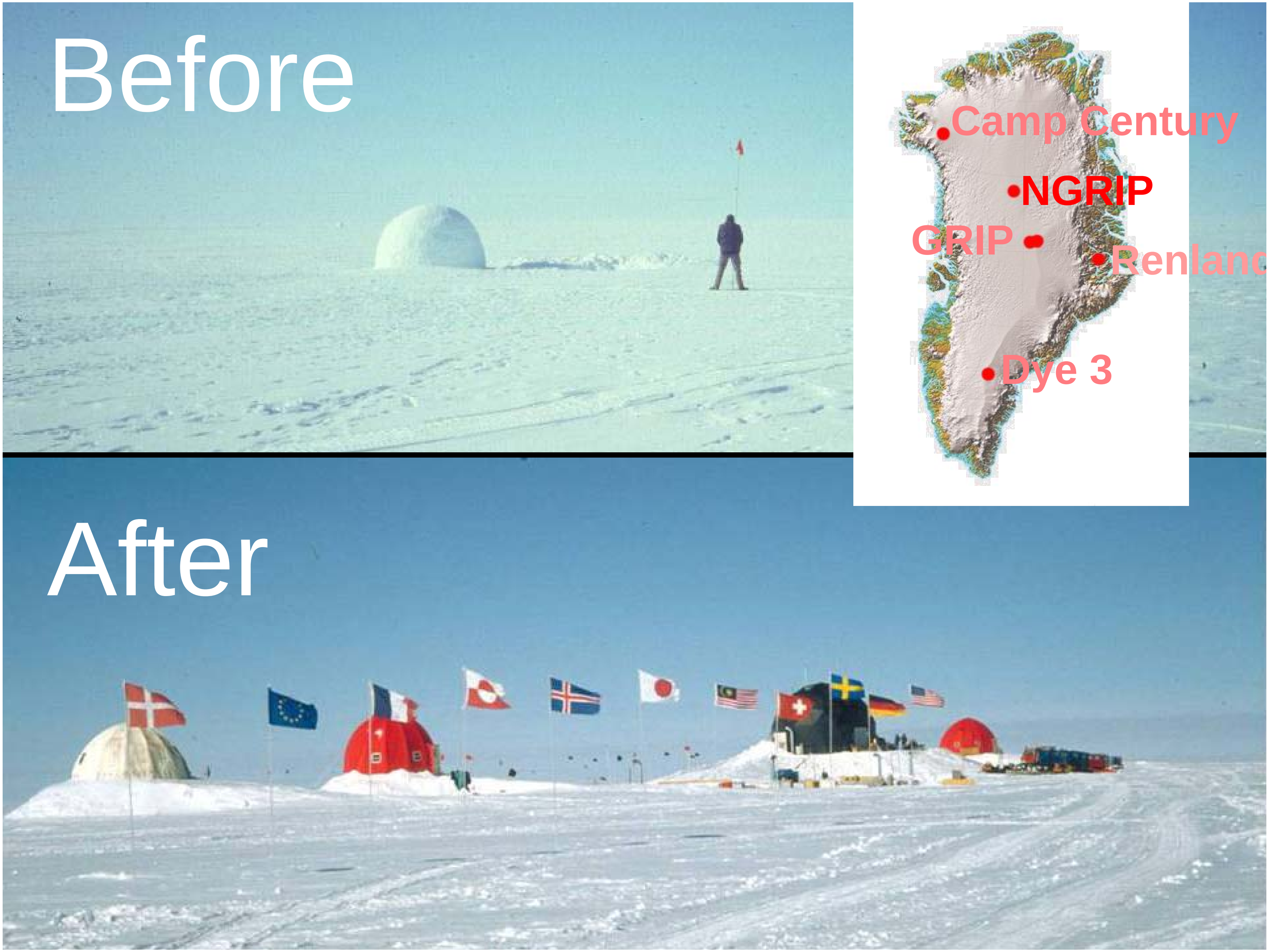
Use of data in climate research

The warm Eemian Periode

Use of RES data

Internal layers tell tales

Visions for the future


Before
After
Camp Century
NGRIP
GRIP
Dye 3

Facts:

Length of drill 11 m

Diameter of ice core 98 mm

Length of ice core 3.5 m

Diameter of borehole 130 mm

Drills:

NorthGRIP

EPICA DomeC

Dome Fujii

Facts:

Length of drill 11 m

Diameter of ice core 98 mm

Length of ice core 3.5 m

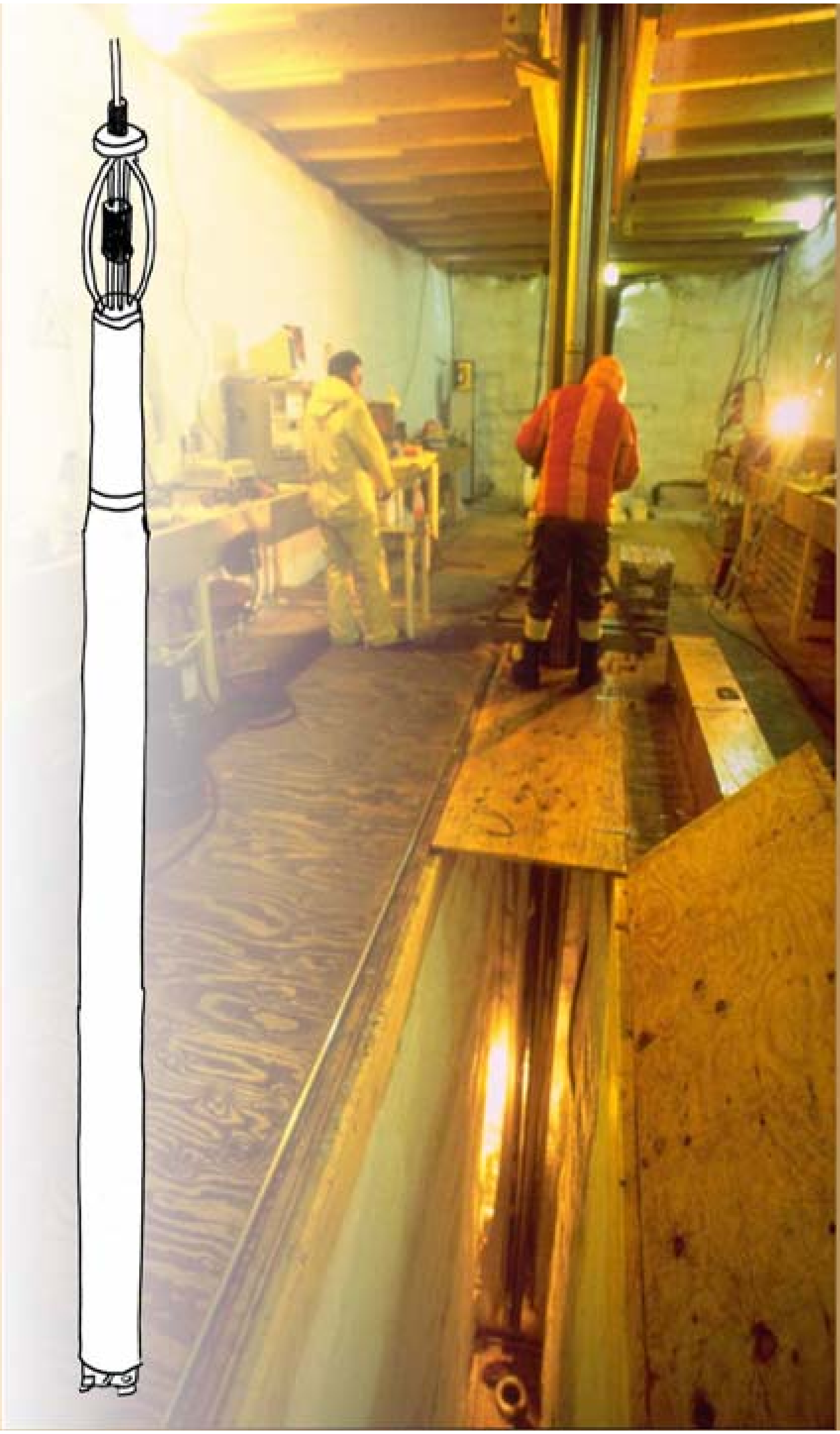
Diameter of borehole 130 mm

Drills:

NorthGRIP

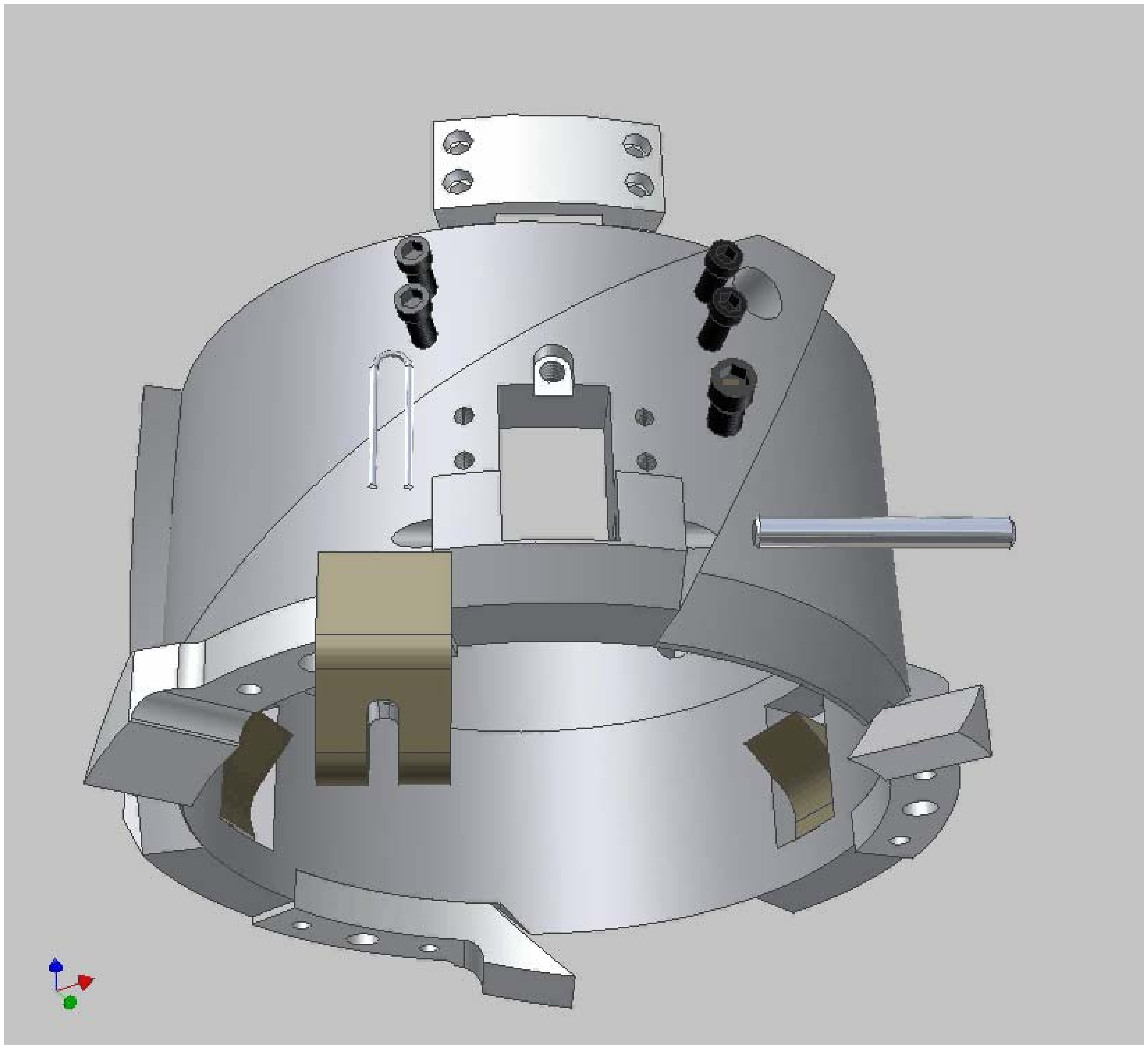
EPICA DomeC

Dome Fujii

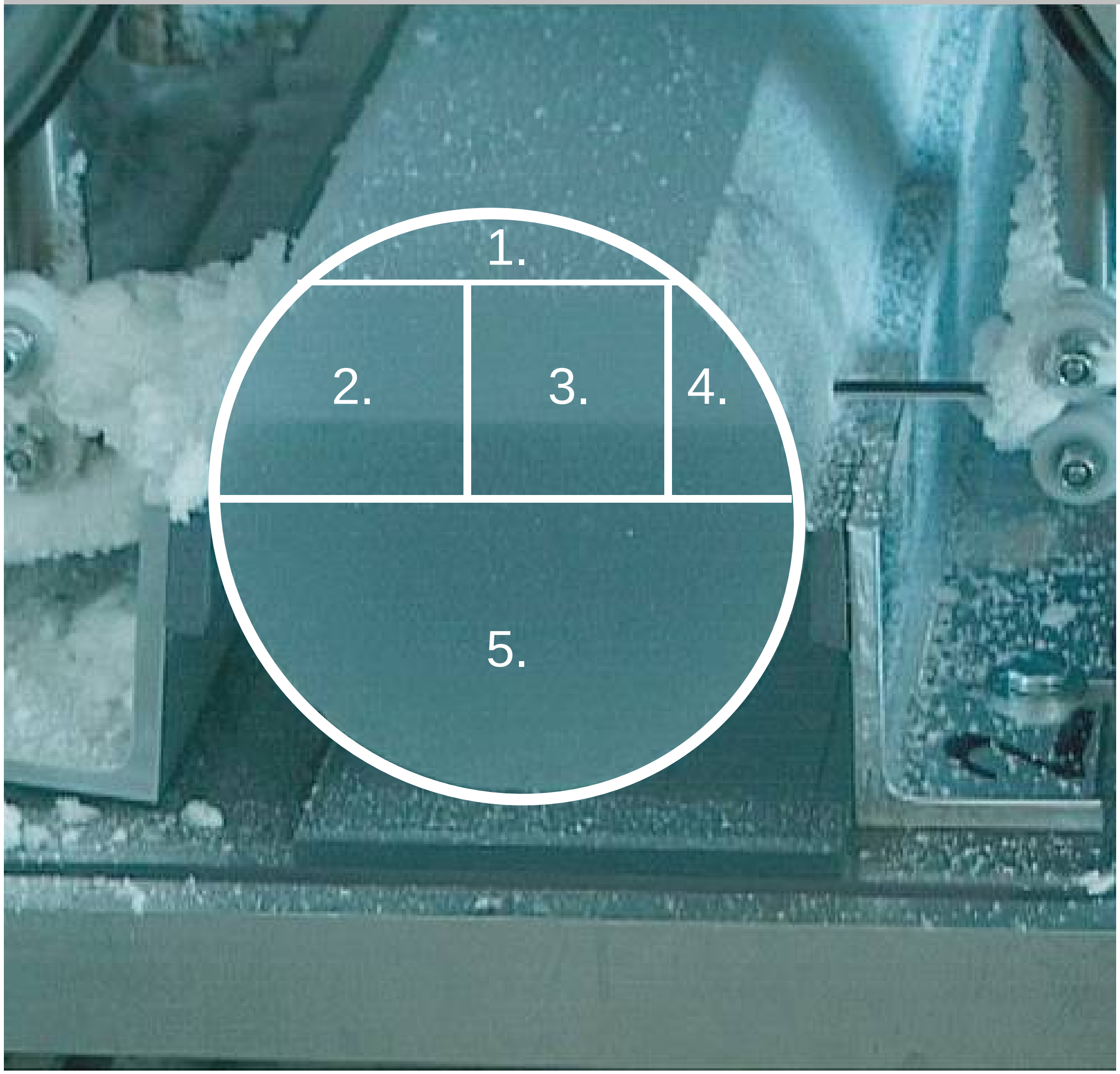


NorthGRIP Drill Head

Design: S.B. Hansen, Niels Bohr Institute



Cutting the ice core



1. Physical Properties
2. Gas analyses
3. Chemical impurities and dust
4. Isotopes samples
5. Main core – to be stored

And:

6. Visual stratigraphy
7. DEP and ECM

Stabile ilt isotope kurver

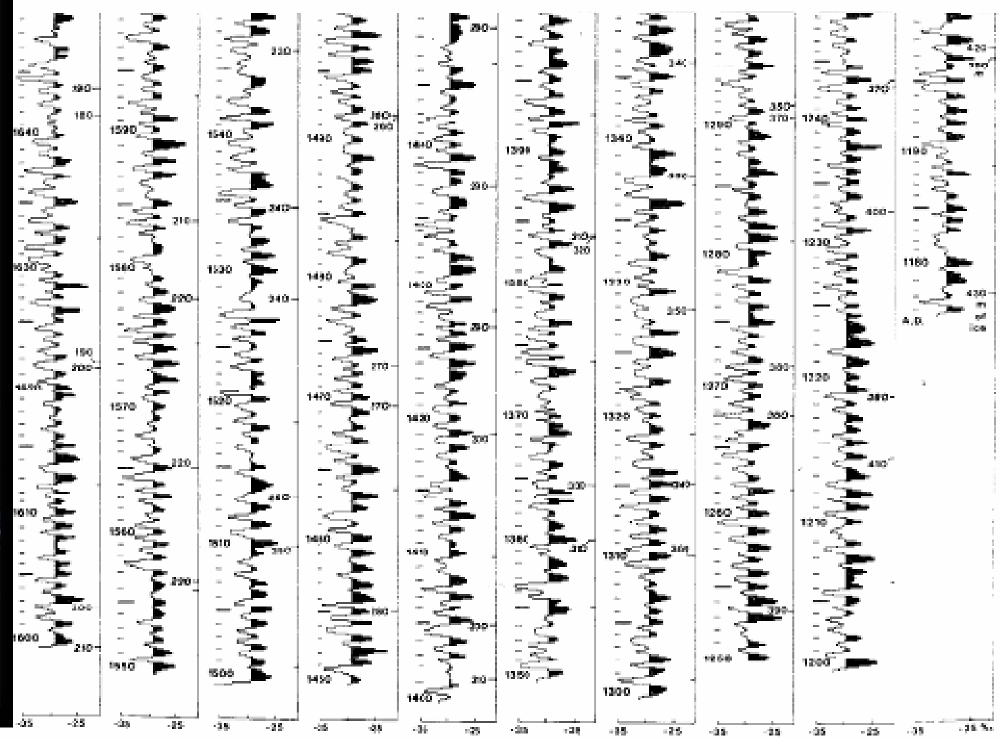
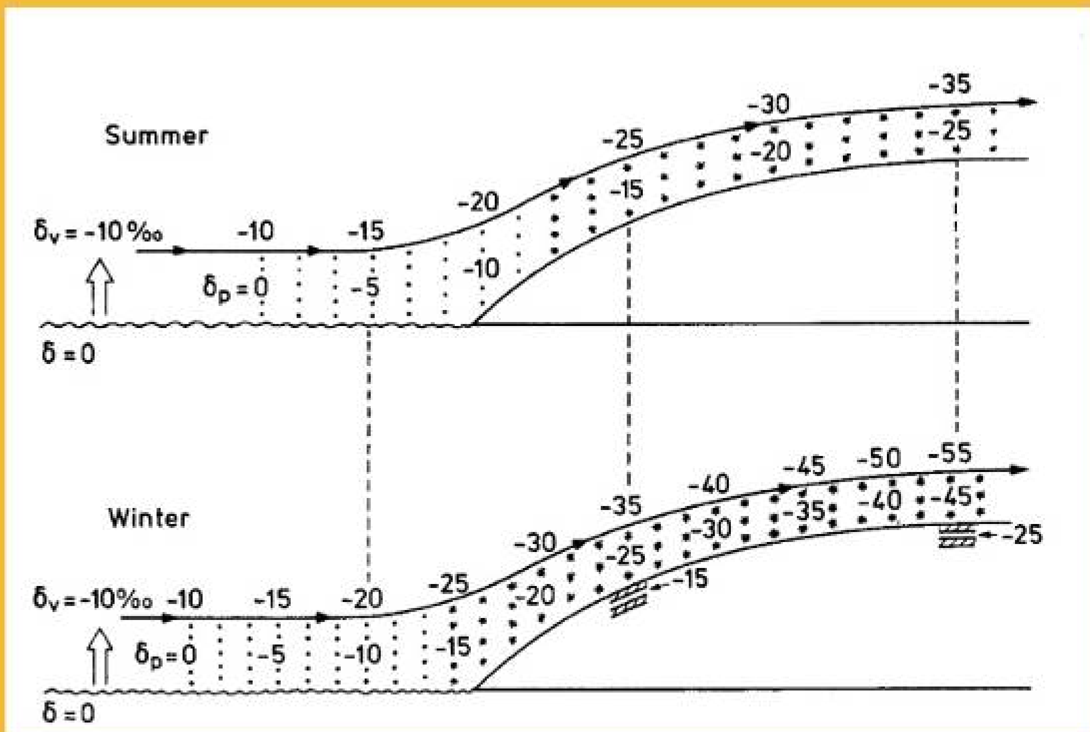
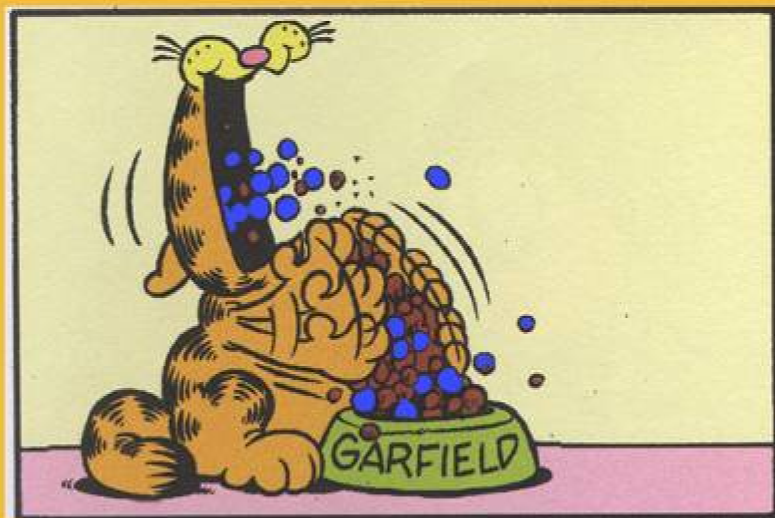


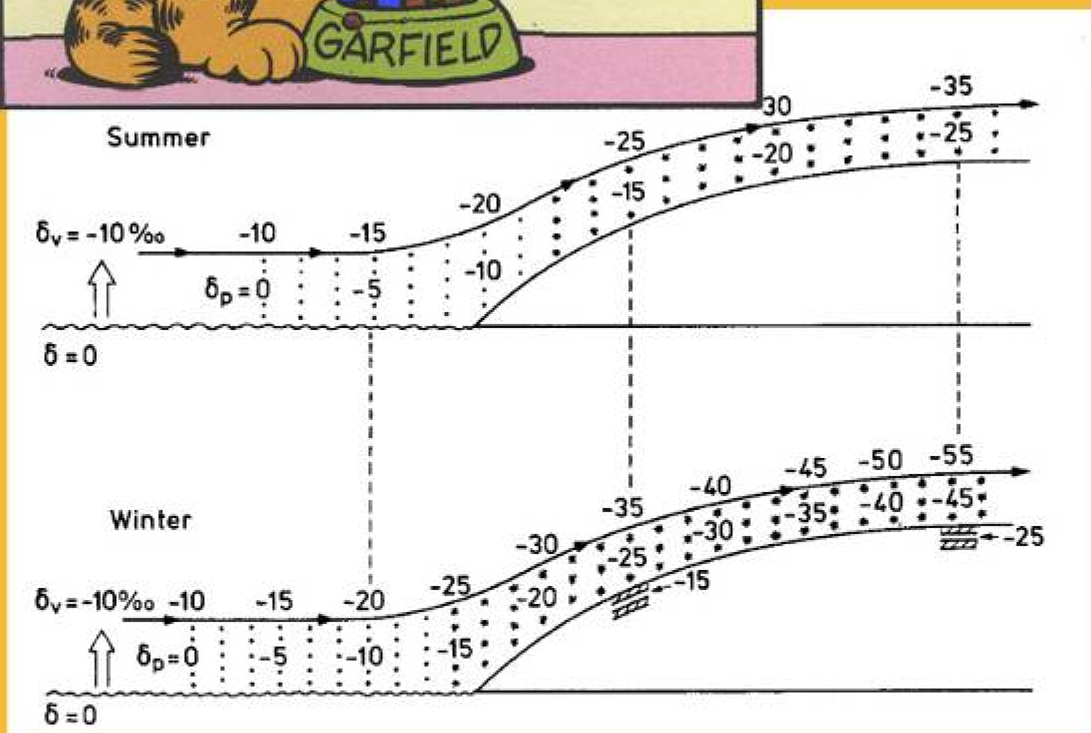
Fig. 4. Continuous δ(^{18}O) profile along the 398 m long GISP ice core from Milcent. Dating (cf. A.D. numbers to the left of the curves) is accomplished by counting summer peaks downward from surface, the interpretation in the upper strata being supported by the specific β-activity profile shown to the outer left. The δ values are plotted along a linear depth scale (normal figures) corrected for varying density, varying accumulation rate and ice thickness up-slope, and for total vertical strain as calculated by two-dimensional ice-flow modelling. The sloping figures are true depths in metres.

[Journal of Glaciology, Vol. 20, No. 82, facing page 12.

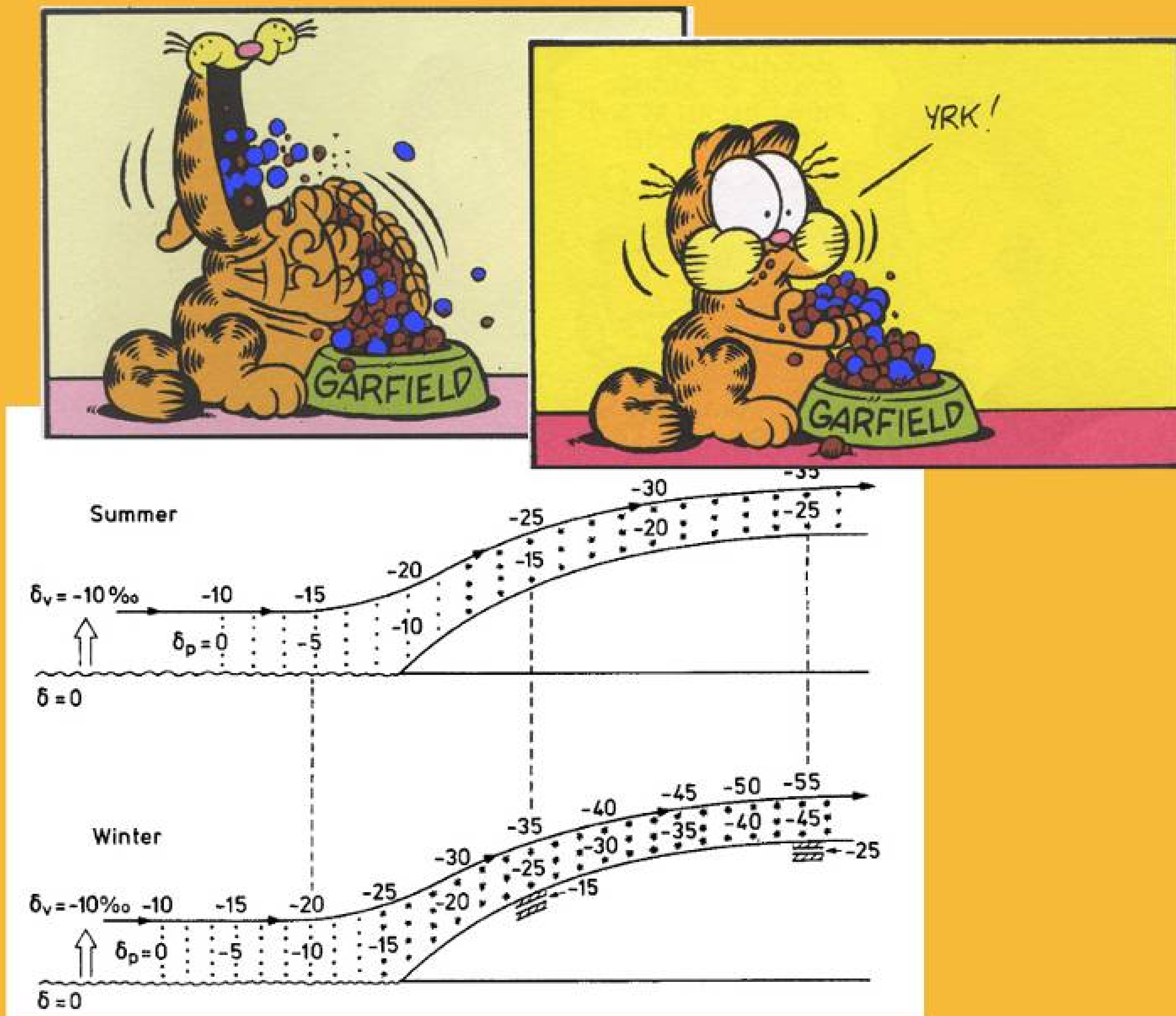


Prof. W. Dansgaard developed the O18-climate relation

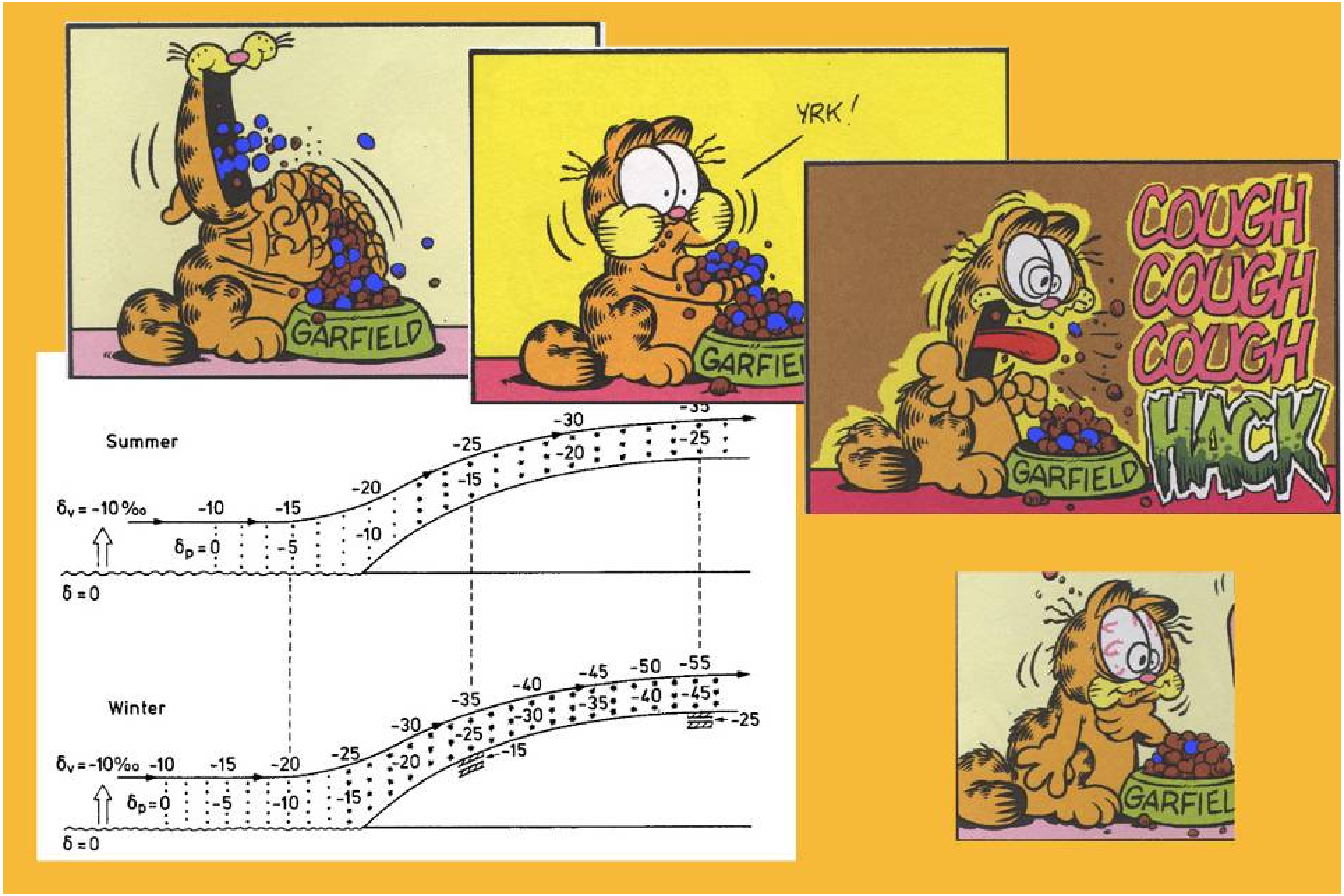




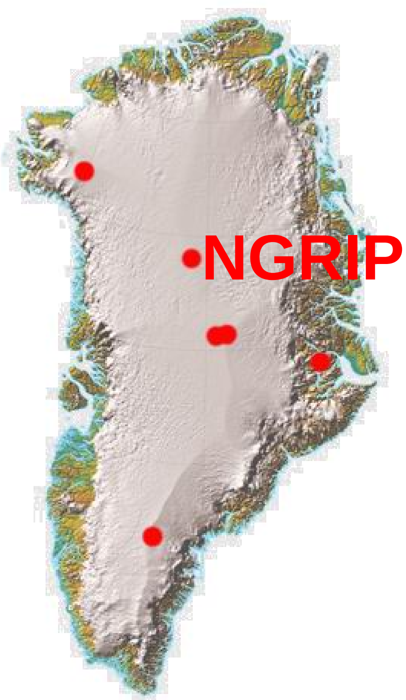
Prof. W. Dansgaard developed the O18-climate relation



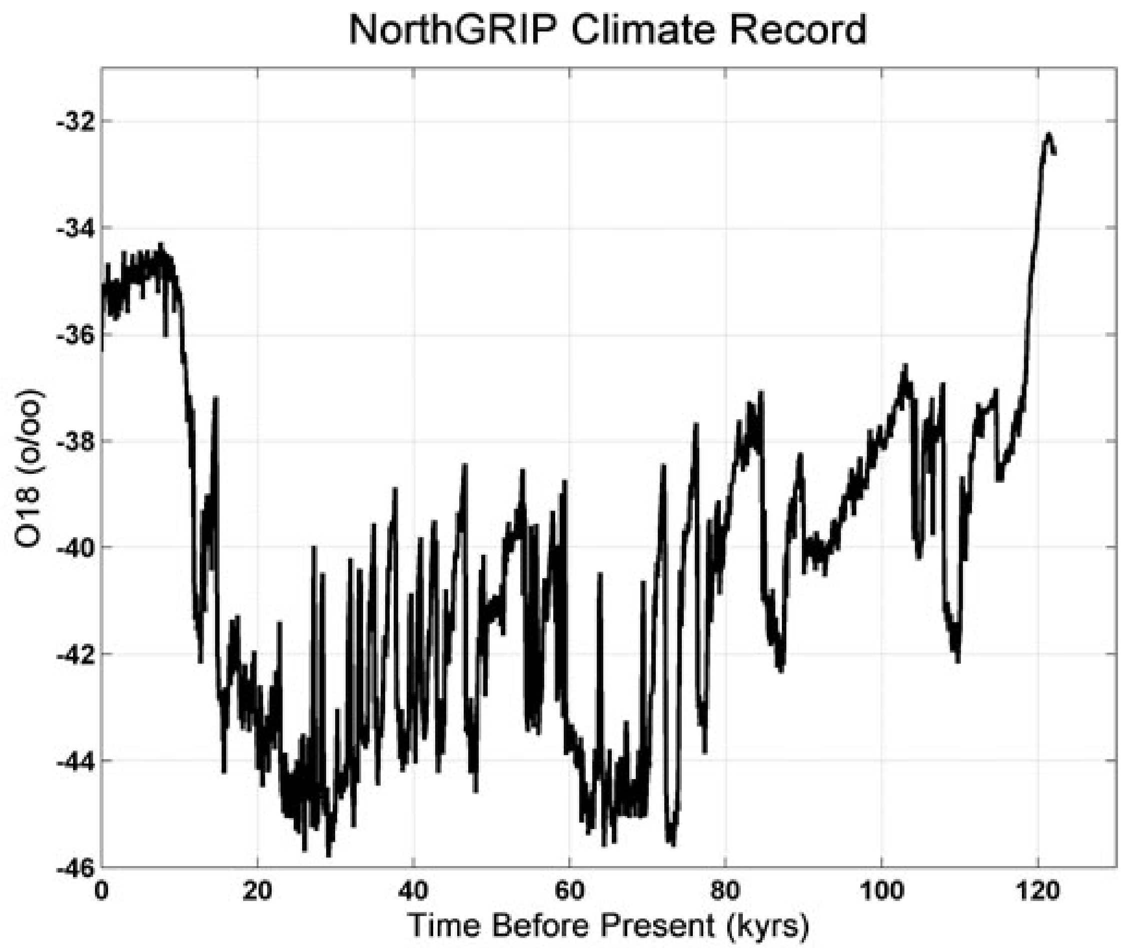
Prof. W. Dansgaard developed the O18-climate relation

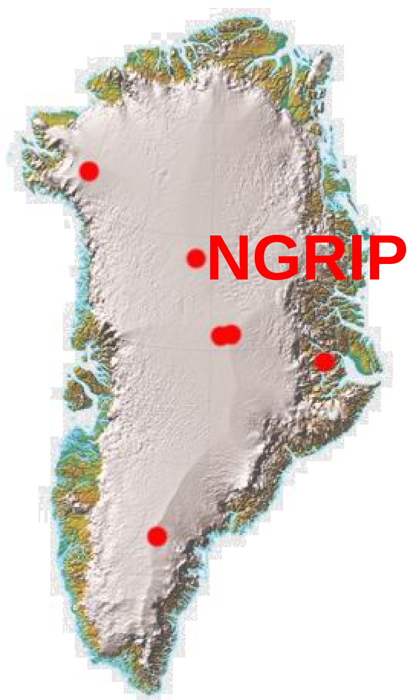


Prof. W. Dansgaard developed the O18-climate relation

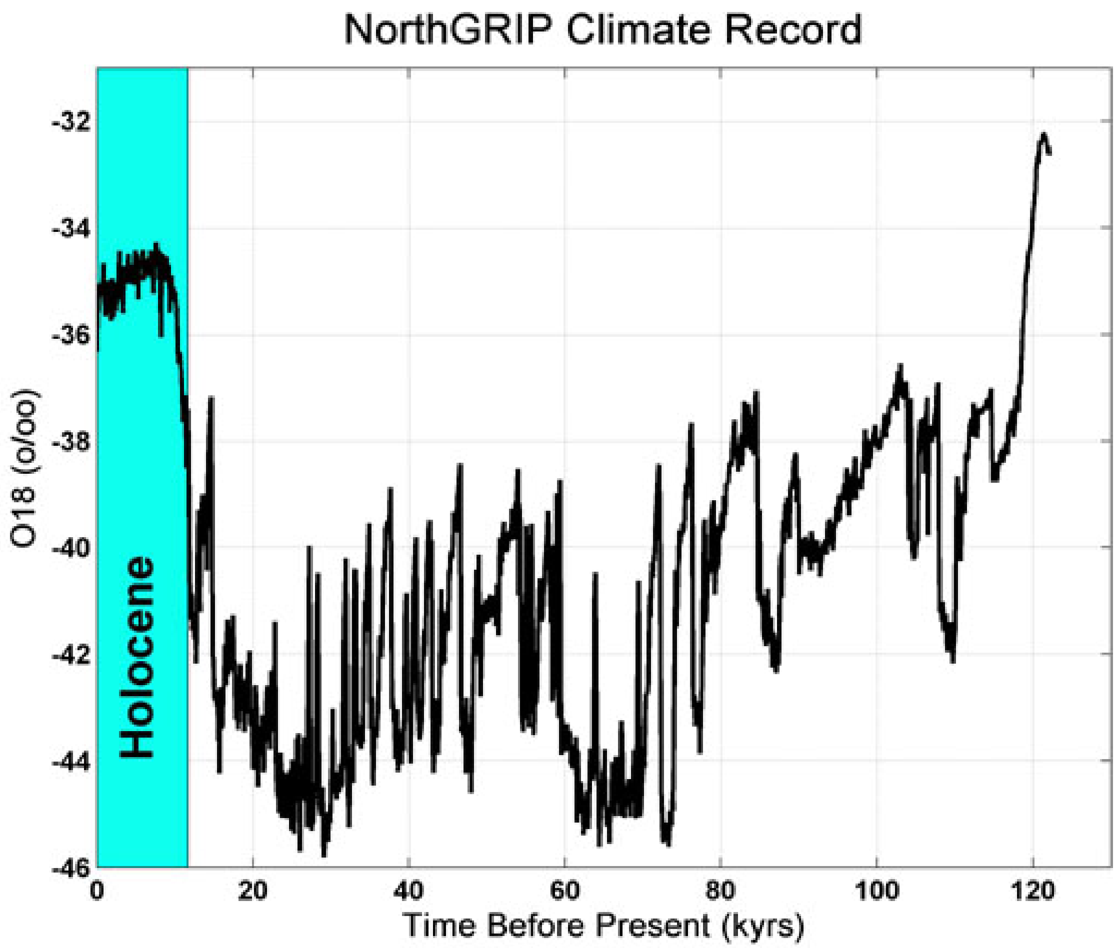


The NGRIP ice core has an undisturbed record reaching 123.000 years back in time



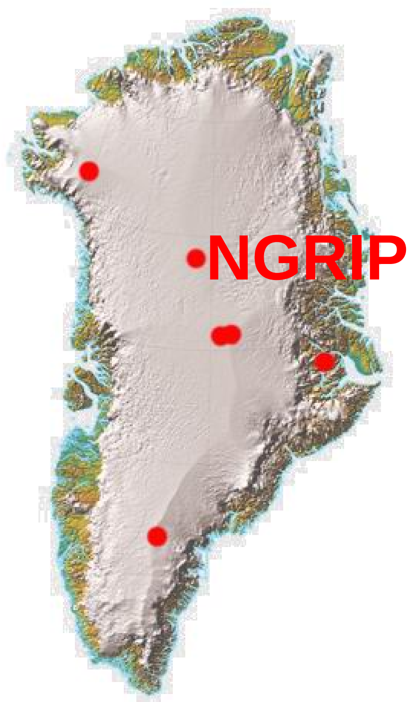


The ice from the Holocene is located between the surface and the depth 1493m.



The transition was 11.703 b2k

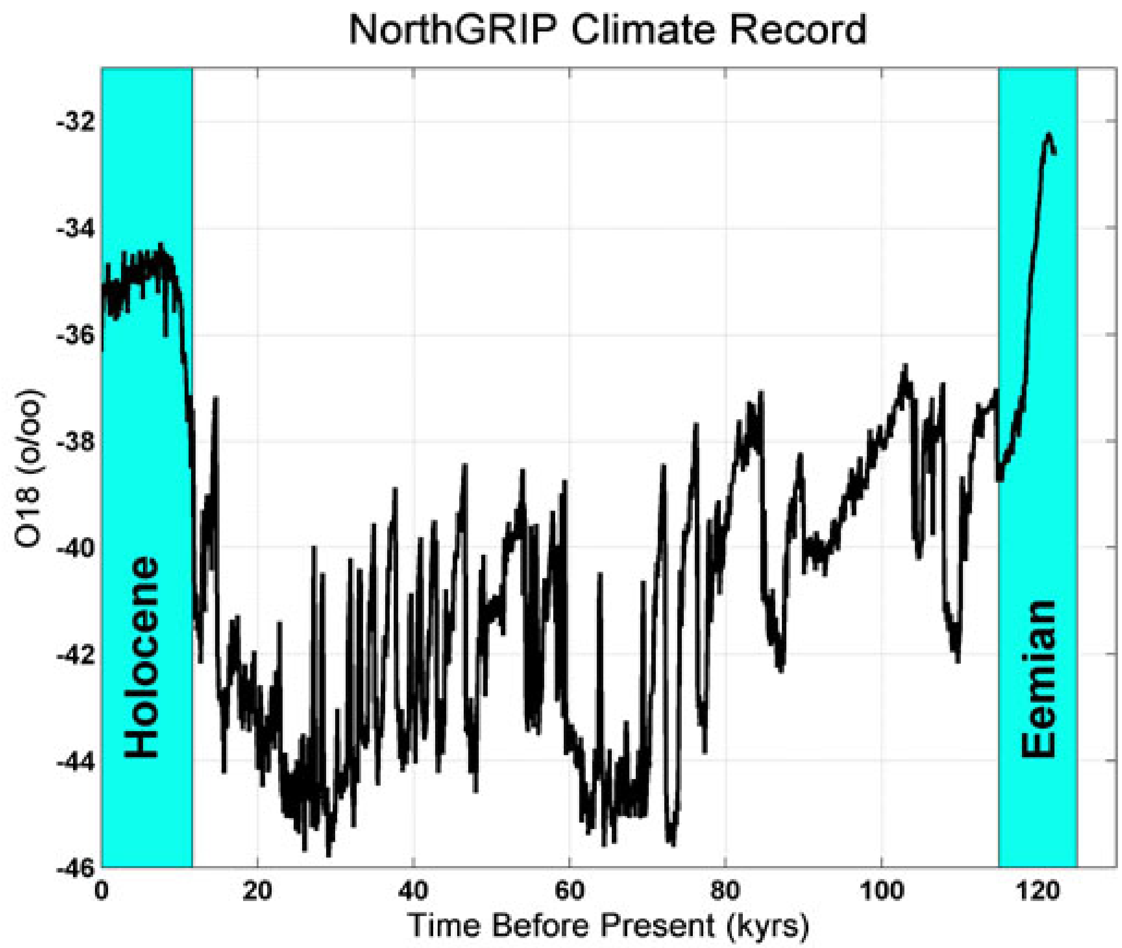
🖰$_{mean}$ = 13 cm

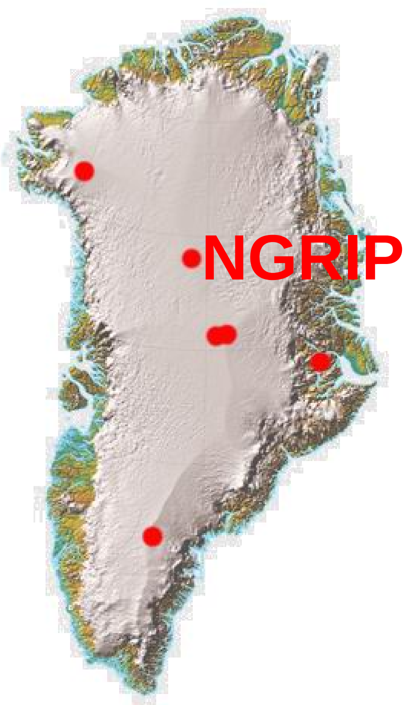


The ice from the Eemian is located between the depths 3000m and 3090m

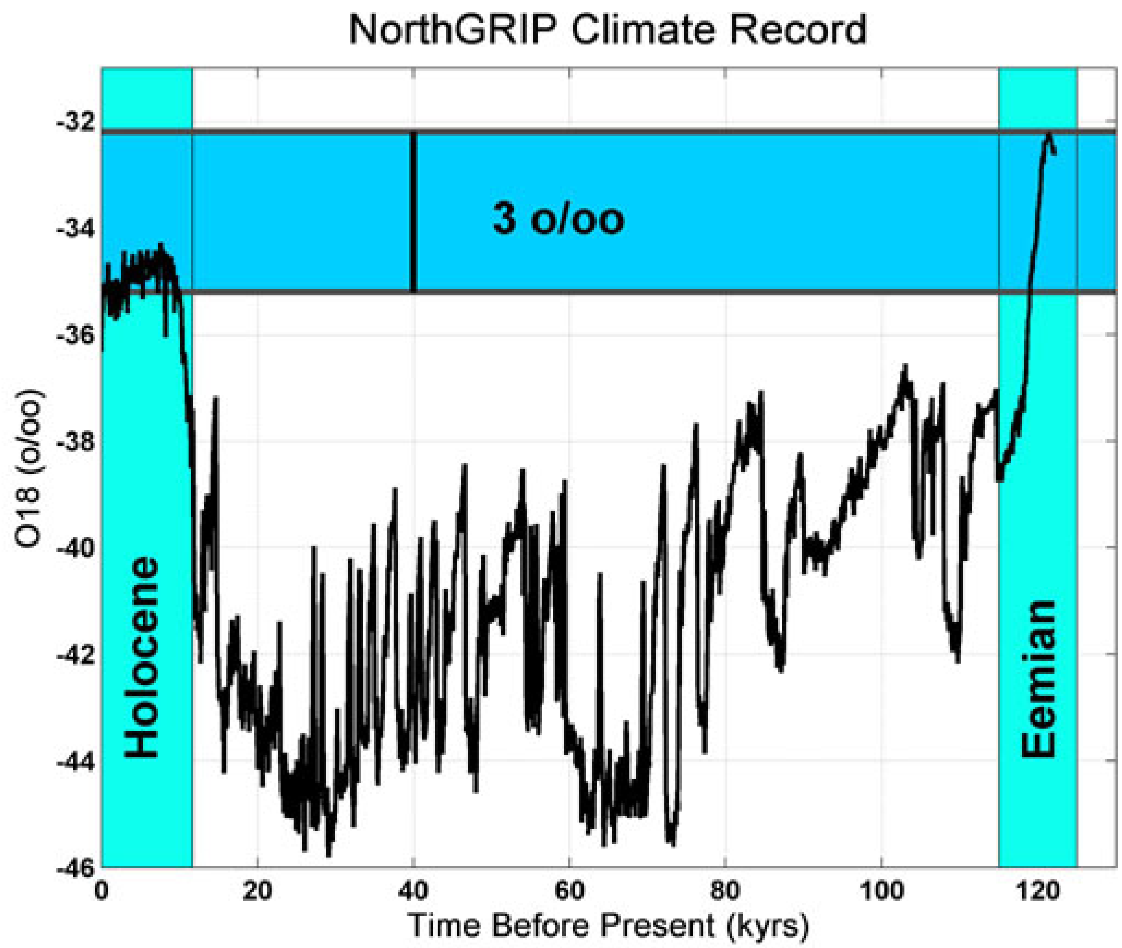
The age of the ice is 123.000-115.000 years

σ_{mean} = 1.1 cm





The difference in isotopic values between the Eemian and the Holocene is 3 o/oo



Central Greenland Ice Cores 89-93

GISP2

Fig. 12.4 *GRIP's headquarters in windy weather. Photo: Ivars Silis.*

Fig. 12.5 *The GRIP camp with tents, and in the background three domes.*

GRIP

Central Greenland Ice Cores 89-93

Fig. 12.10 *Drill master Sigfus Johnsen with the last ice core increment from a depth of 3029 m.*

The Eem problem

nature

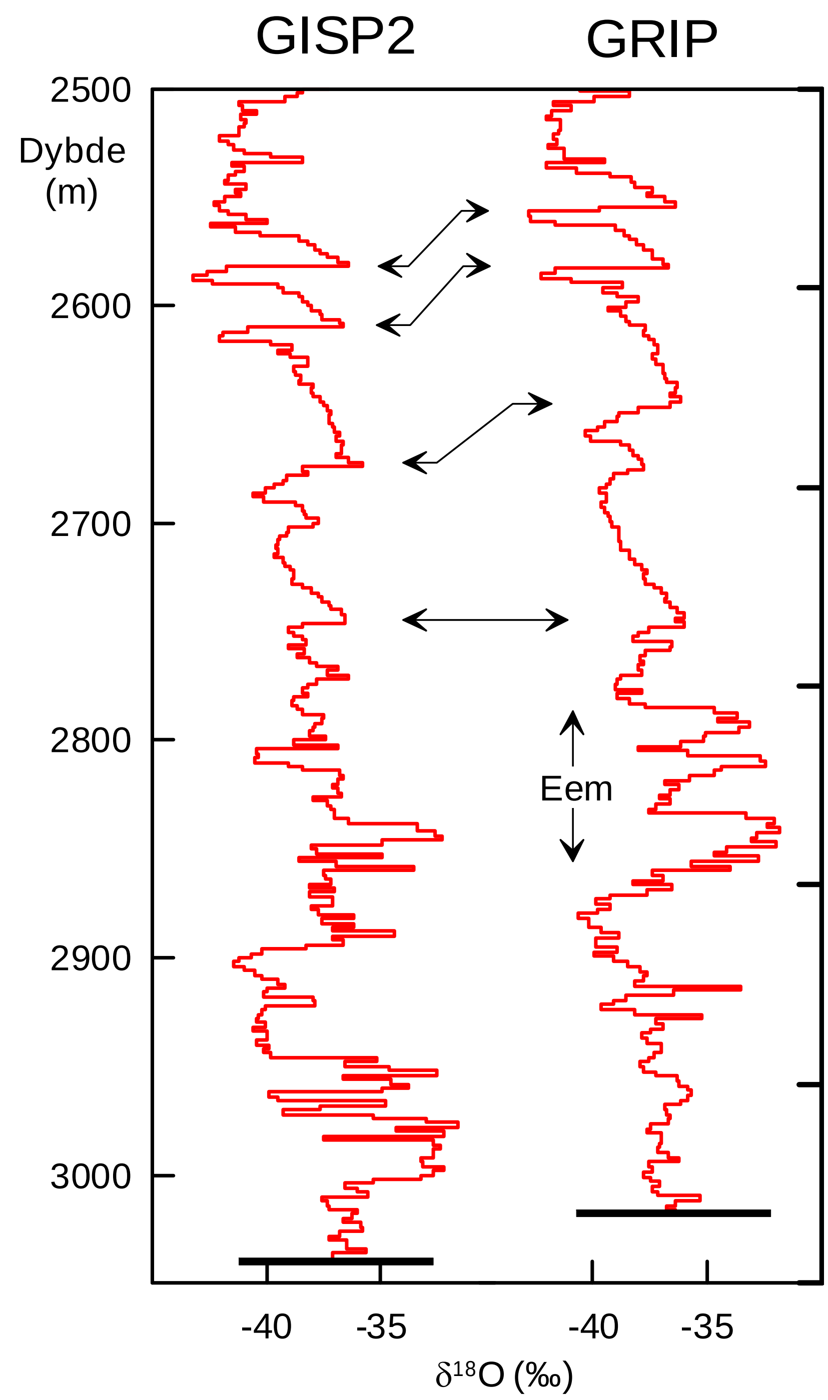
Article

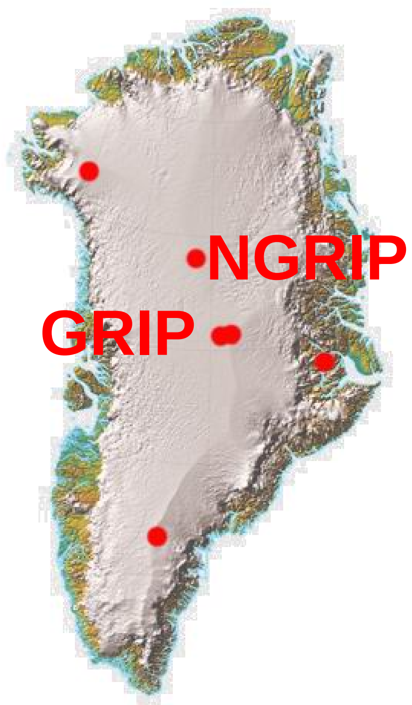
Nature **364**, 203 - 207 (1993)

Climate instability during the last interglacial period recorded in the GRIP ice core

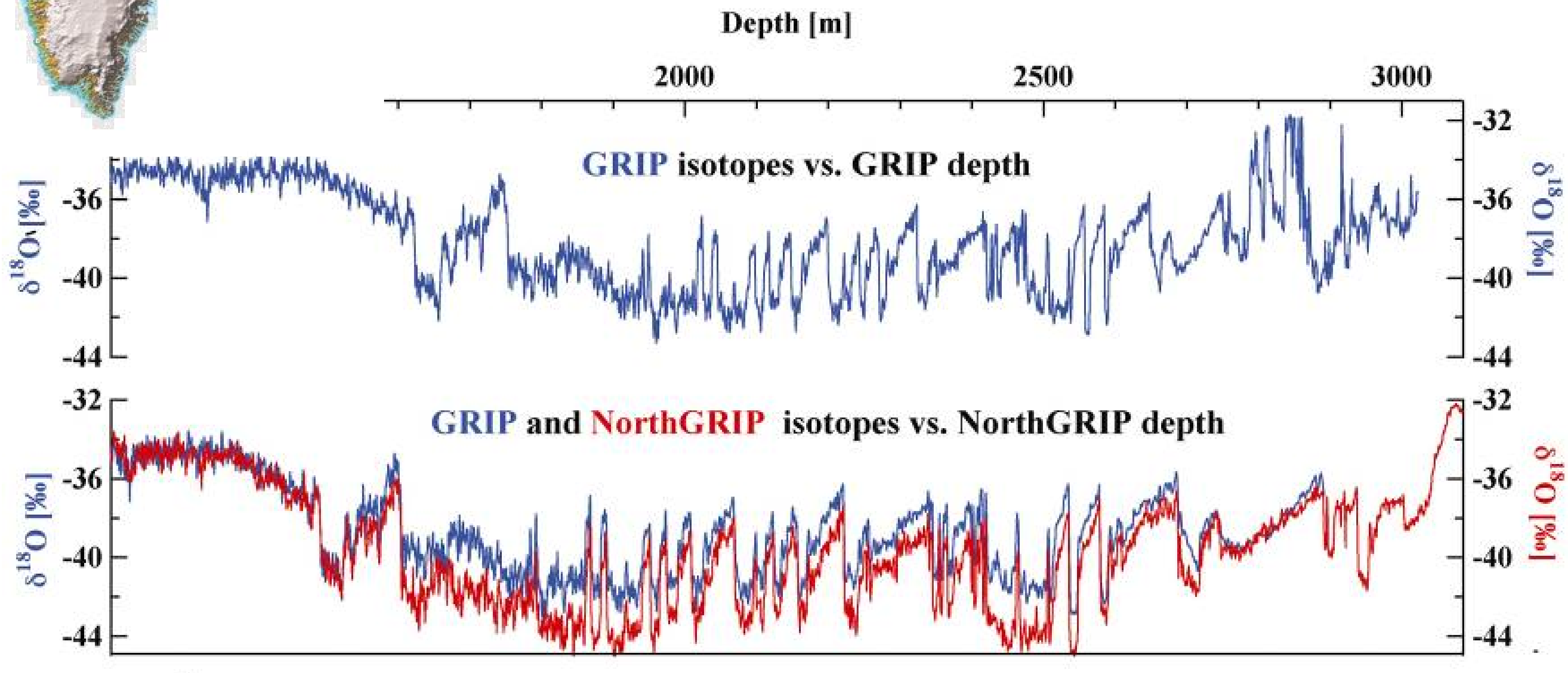
Greenland Ice-core Project (GRIP) Members

Isotope and chemical analyses of the GRIP ice core from Summit, central Greenland, reveal that climate in Greenland during the last interglacial period was characterized by a series of severe cold periods, which began extremely rapidly and lasted from decades to centuries. As the last interglacial seems to have been slightly warmer than the present one, its unstable climate raises questions about the effects of future global warming.



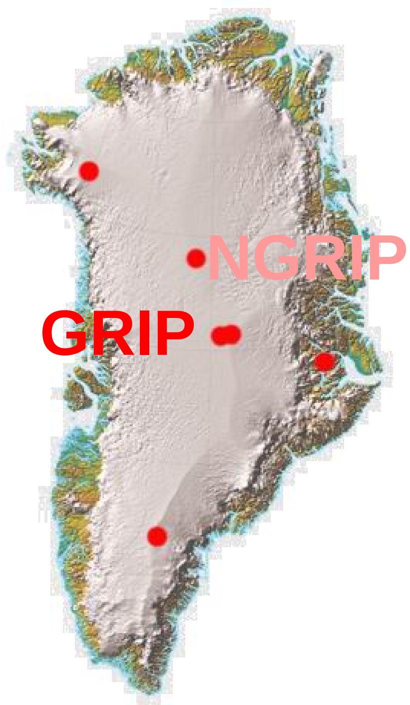


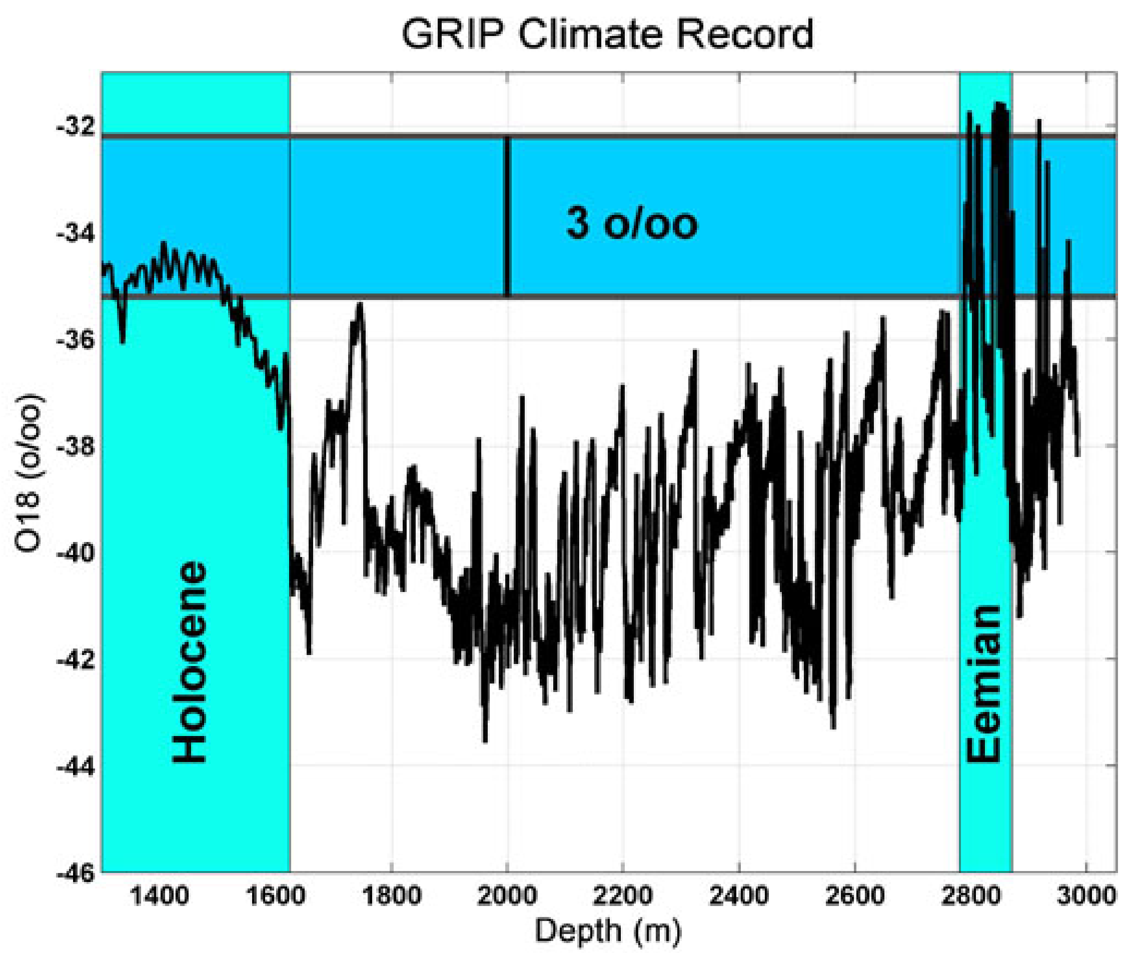
The Eemian ice is disturbed in the GRIP record but has isotopic values of -32 o/oo just like those at NGRIP



Nature, NGRIP Members, 2004

GRIP climate record on a depth scale.





Camp Century 64-66

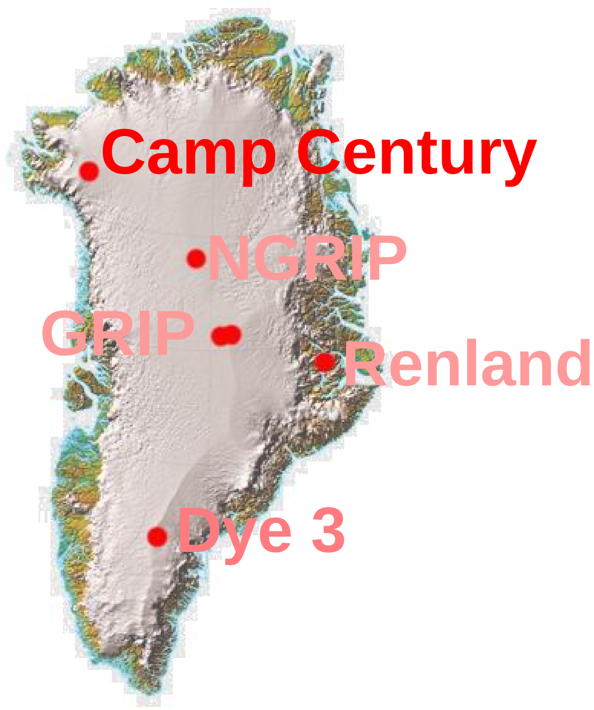
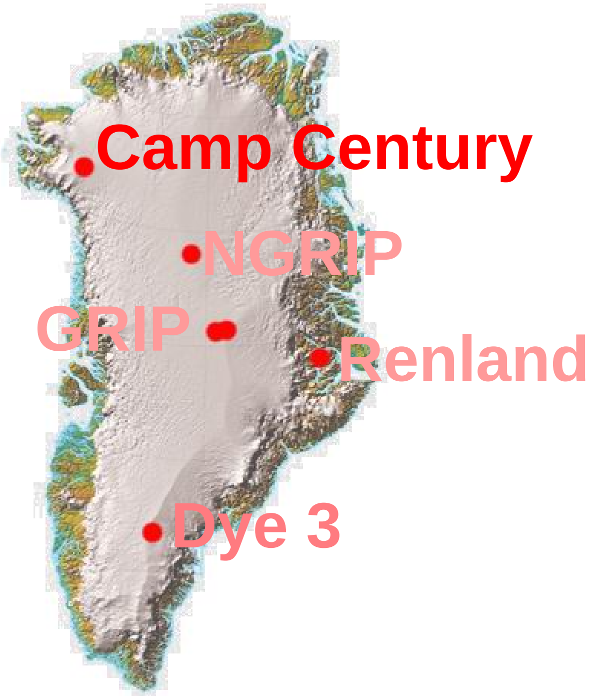


Fig. 5.3 *The American freight and passenger trains, Swings, defied any weather condition (if the refrigerator functioned!)*



Camp Century 64-66

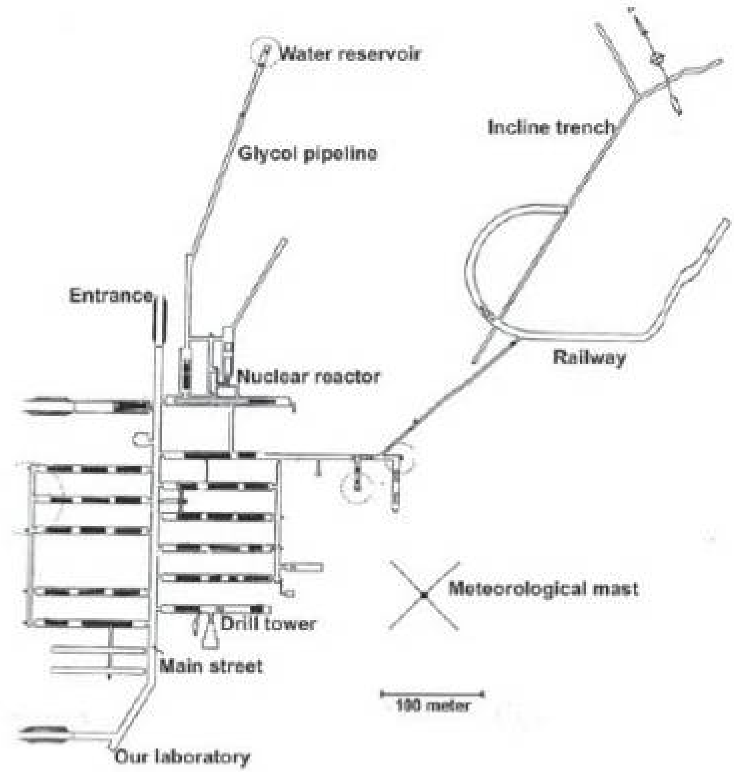
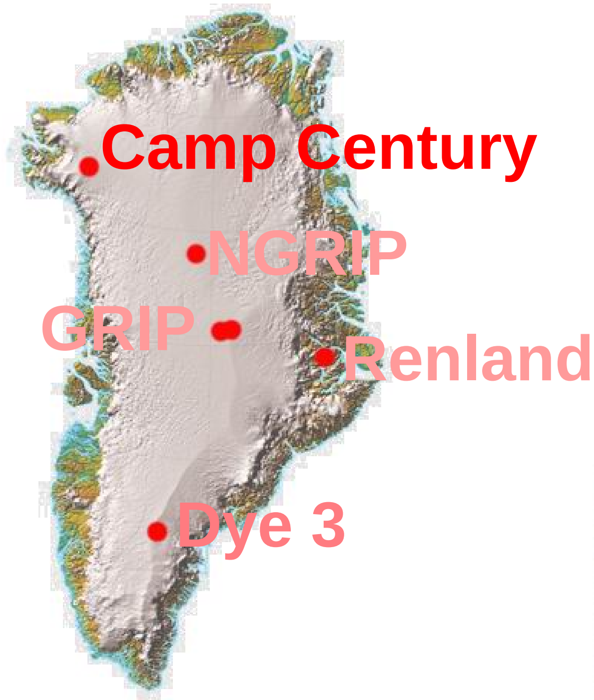
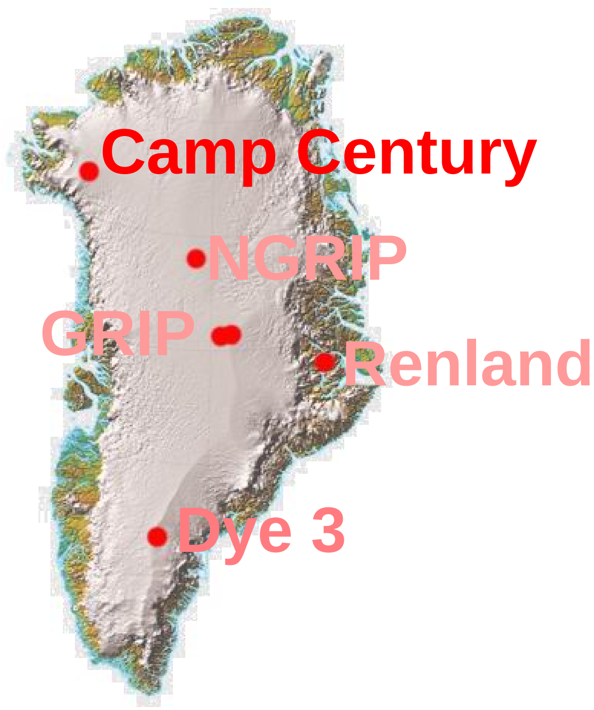


Fig. 5.2 *Map of the sub-surface Camp Century. The fat dashes represent buildings. The distance from the nuclear reactor to the living quarters was only a good hundred metres.*



Camp Century 64-66

Fig. 5.6 *The famous Camp Century deep ice core drill was designed by Lyle B. Hansen and built at U.S. SIPRE (Snow, Ice and Permafrost Research Establishment). In 1966 it penetrated the inland ice to bedrock, and CRREL recovered the first deep ice core in the world. We were not invited to see the drill setup, but the 1390 m long ice core kept us busy for years. Photo: US Army CRREL*



Camp Century 64-66

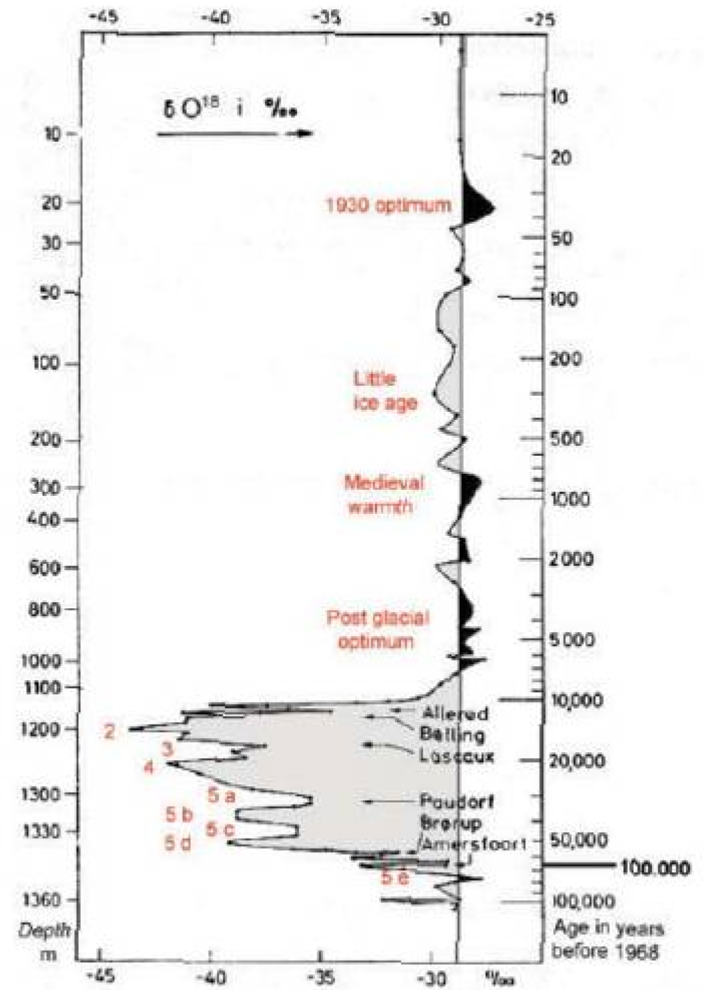
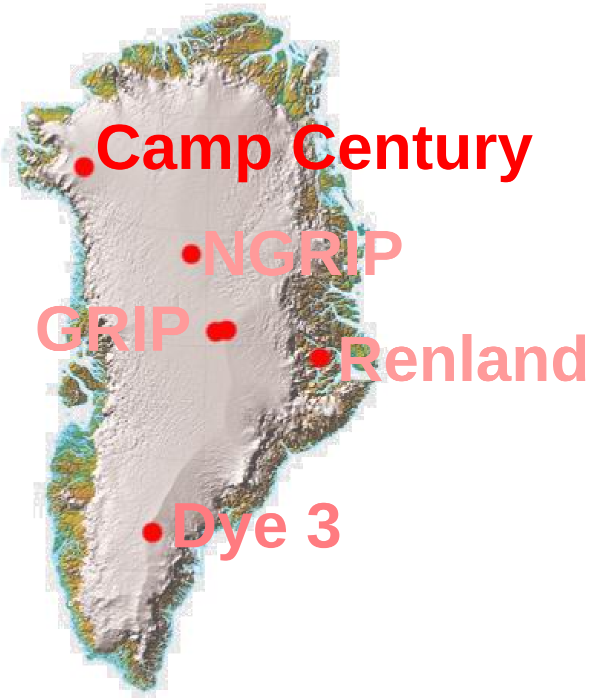


Fig. 6.2 *The δ-profile along the Camp Century ice core plotted on a depth scale to the left and a preliminary logaritmic time scale to the right. The black and grey areas correspond to periods of Greenland temperatures higher and lower than today, respectively. The large grey area reflects the last glaciation. The time scale based on the simple sandwich model is correct, by and large, through the upper 85% of the core, i.e. back to 14,000 years B.P. (before present). The heavy line in the lower right corner marks an age of 100,000 years according to a more advanced ice flow model [ref. 6.4], cf. Box 6.4*



Camp Century 64-66

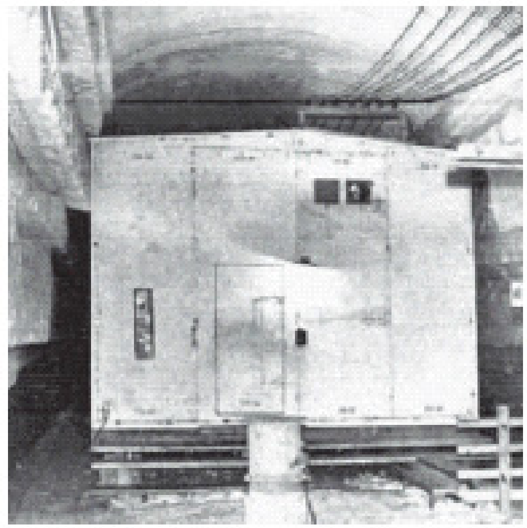
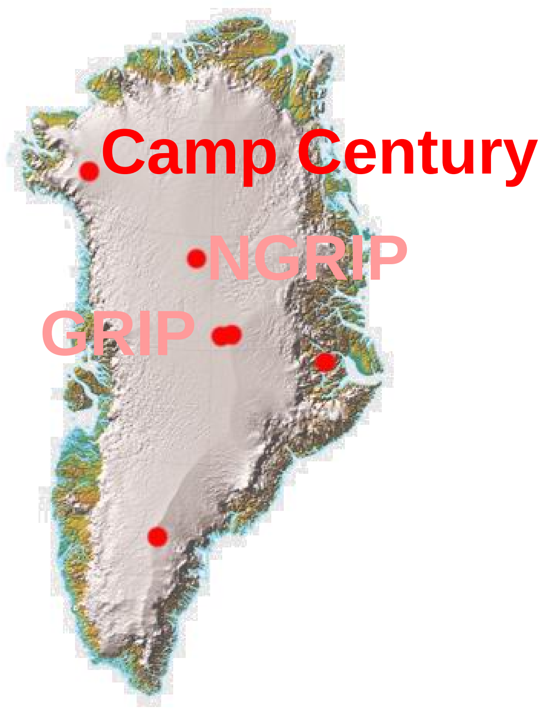


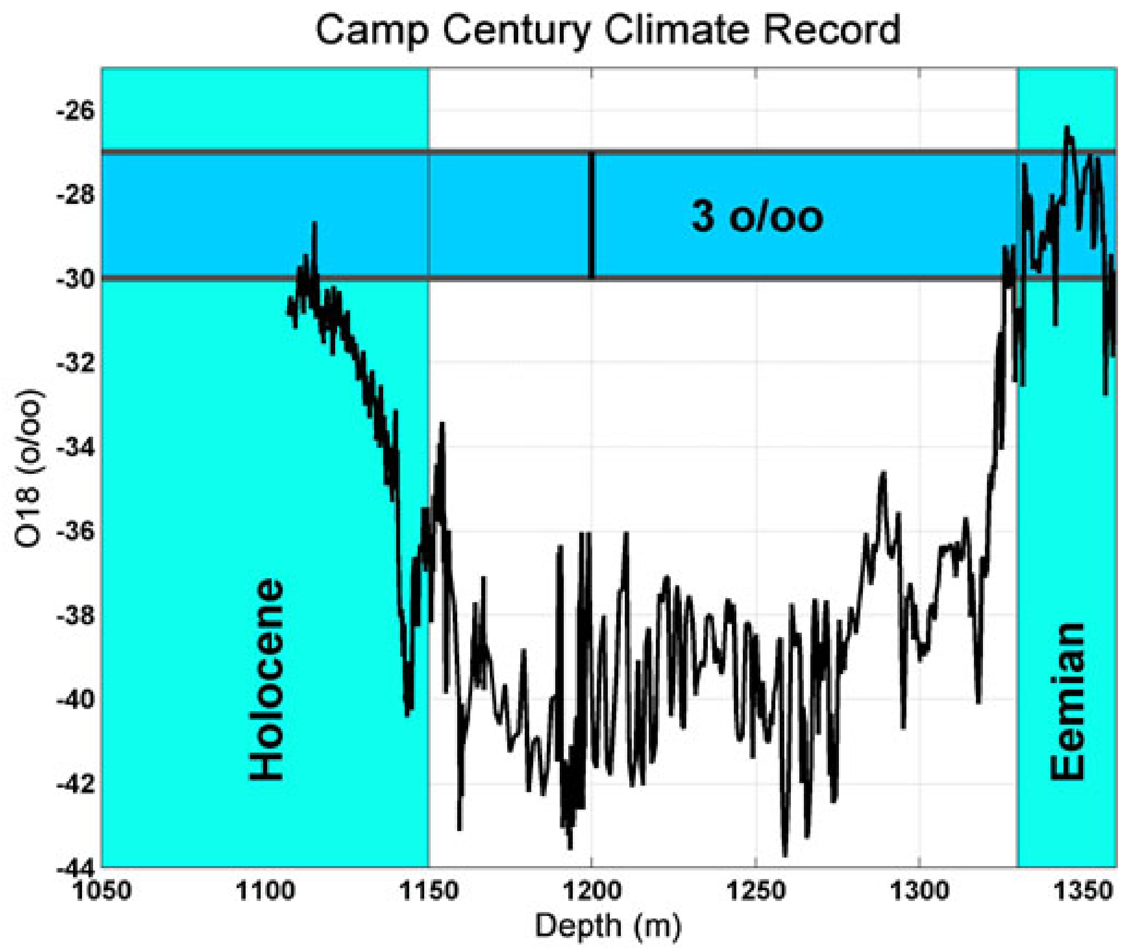
Fig. 6.3 *Our sleeping quarters in 1964 – and 5 years later. Already in 1964, it was difficult to pass the hutments due to hanging ice walls. also called "brain crushers". The high release of energy accelerated the collapse. Photo: USA: CRREL.*

Fig. 6.4 *Sigfus Johnsen visited the closed Camp Century in 1969. Here he is on the way to the water reservoir through the originally 4 m broad galley. The pipes led hot glycol from the nuclear reactor deep into the firn. Photo: USA CRREL.*

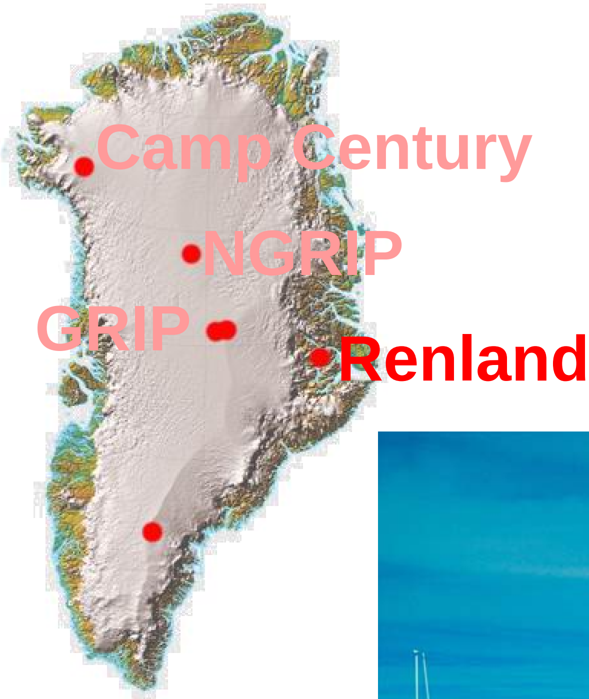


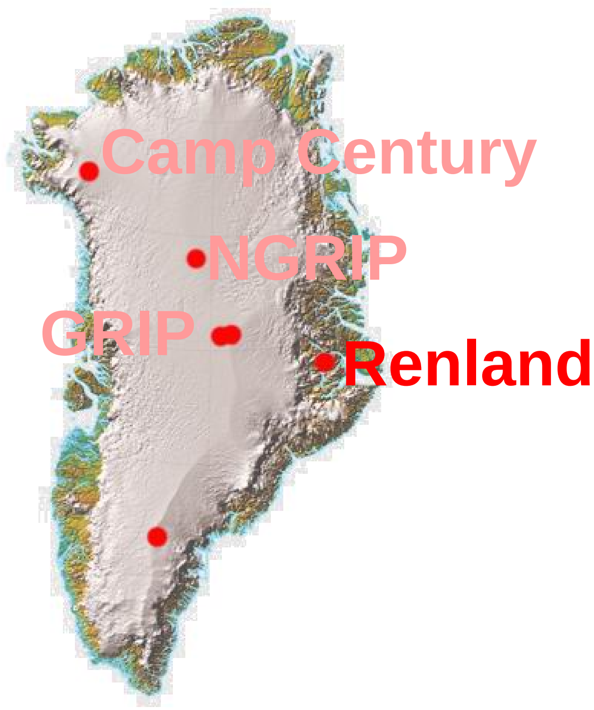
Camp Century climate record on a depth scale. The first ice core drilled in Greenland in 1964-66.

Depth: 1390m

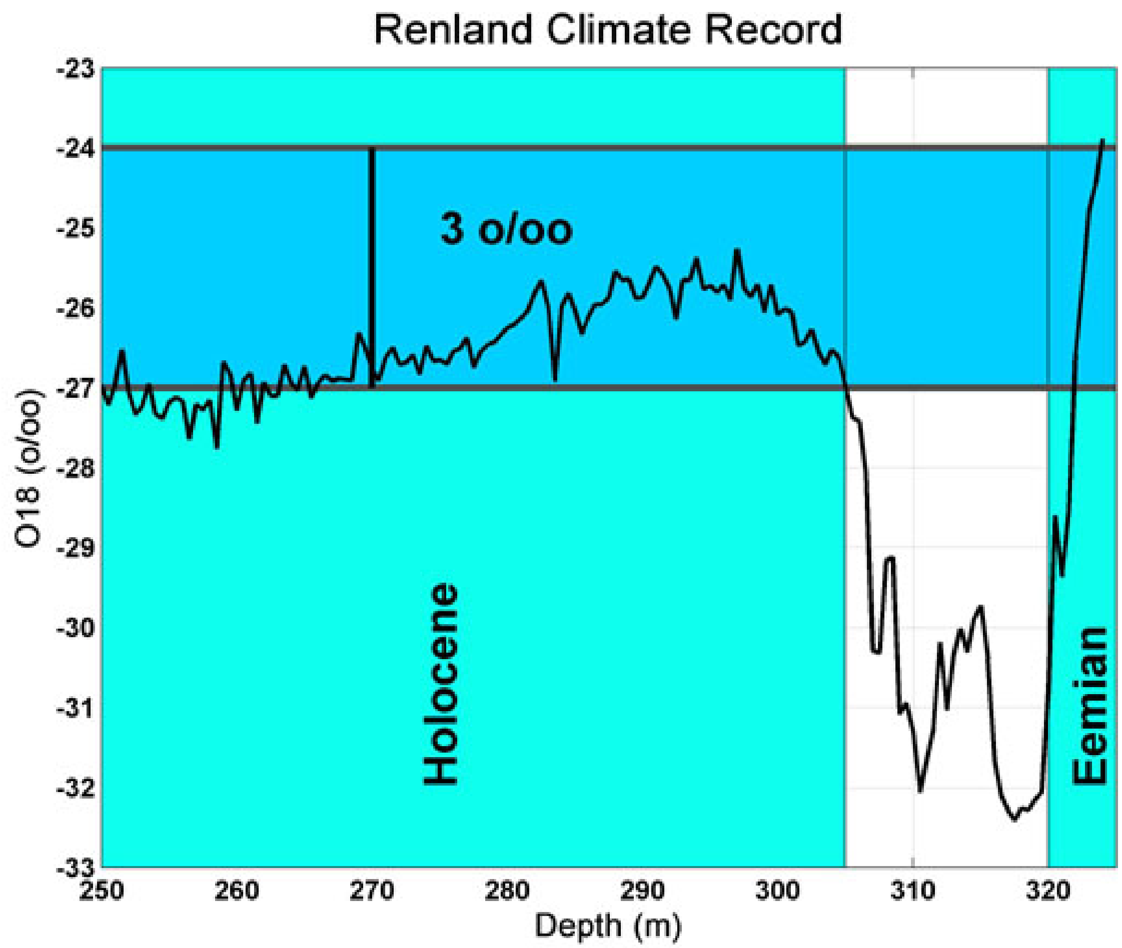


Renland 1988





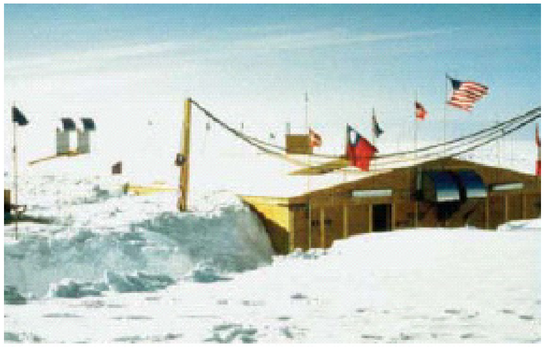
Renland climate record on a depth scale. The intermediate ice core reaches to bedrock at the depth 325m.



Dye3 79-81

Fig. 7.2 *The American radar station Dye 3 in South Greenland*

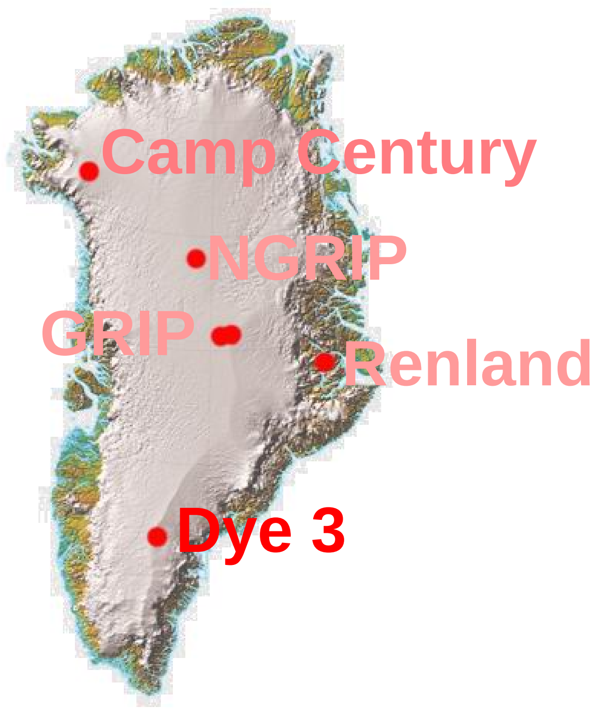
Fig. 10.6 *The Dye 3 drill house in 1979,*



a year later,

and when we stopped in 1981.

Dye3 79-81



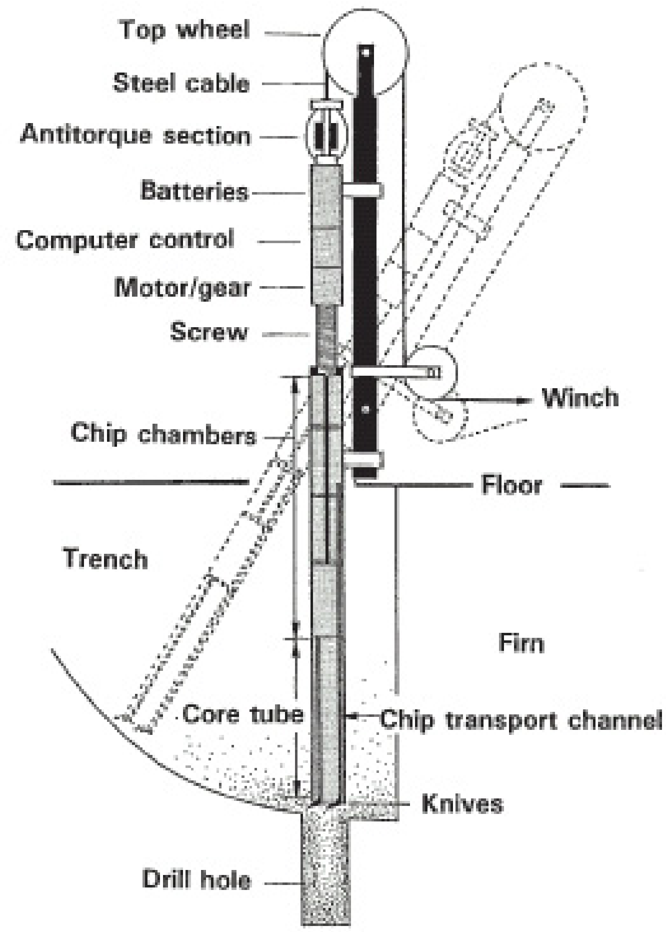
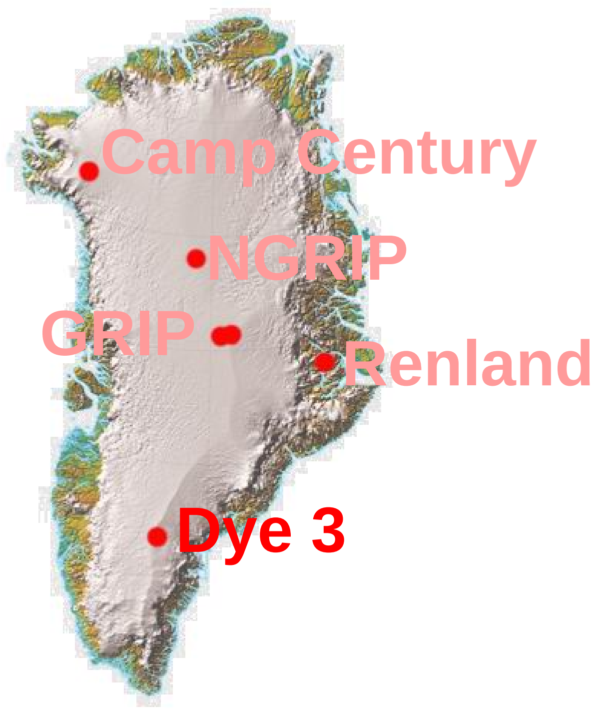
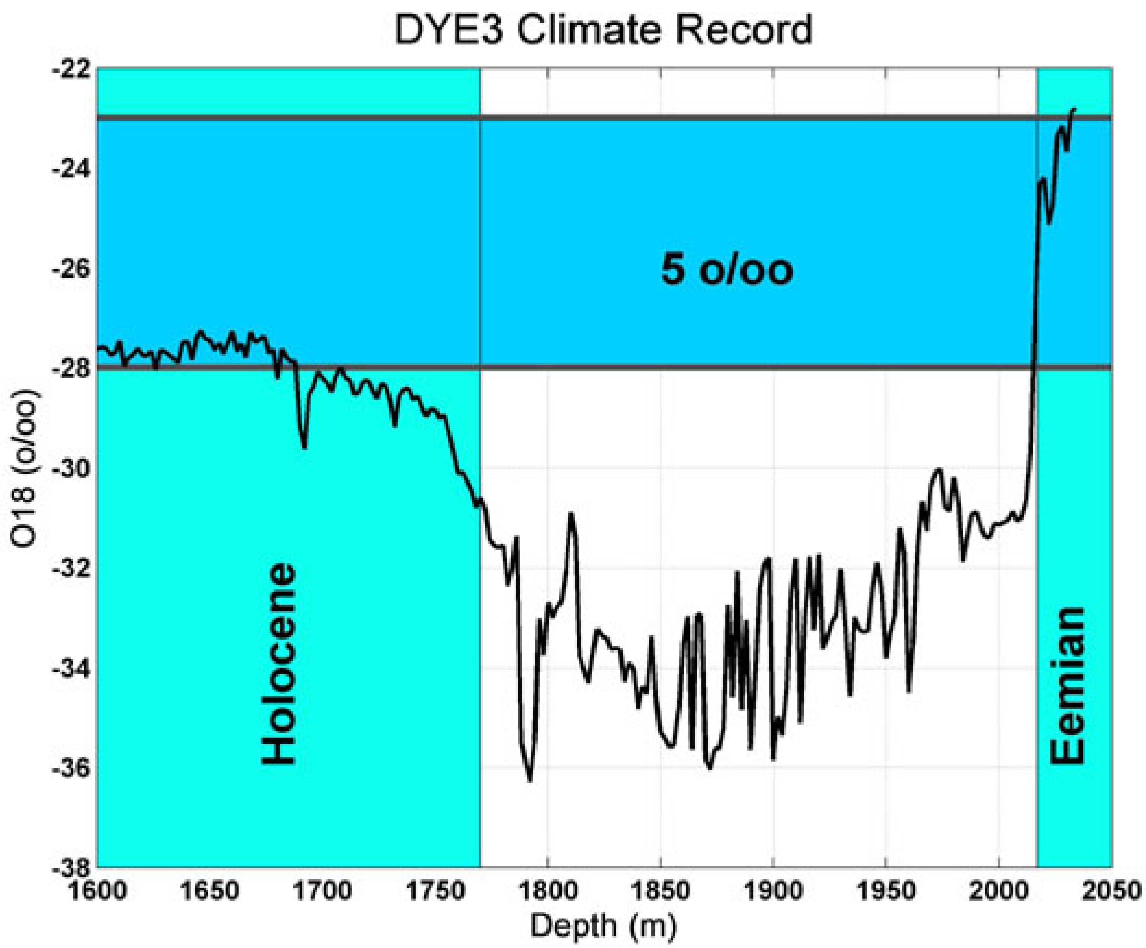


Fig. 10.1 *Principle sketch of ISTUK fixed to the 6.m "tower" (black) after coming up with an ice core increment in the core tube. Like the "Rolls Royce drill", ISTUK can be tilted to horizontal position.*

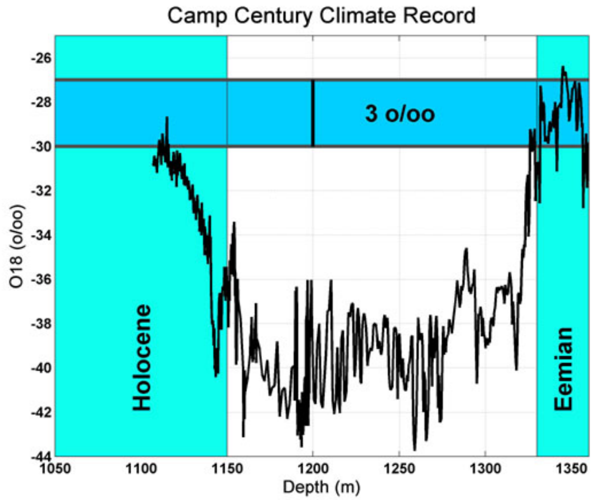
Fig. 10.5 **Top:** *Pálina Kristinsdottir and Claus Hammer working in the science trench.* **Below:** *Dorthe Dahl-Jensen and Jørgen Peder Steffensen at the drill.*

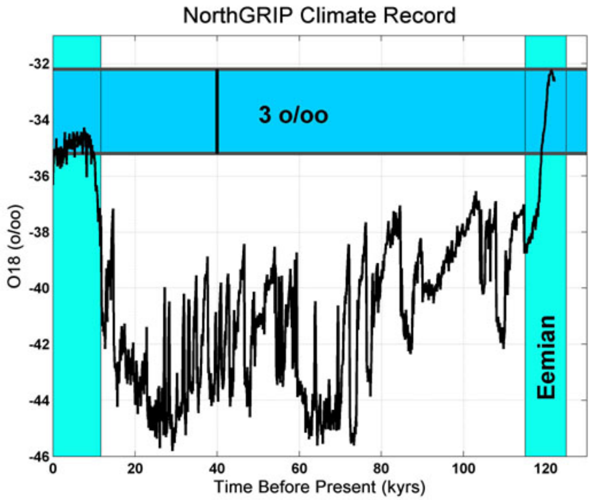


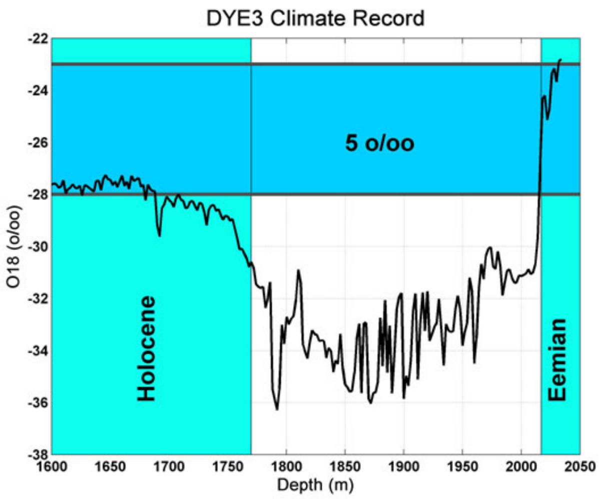
Dye 3 climate record on a depth scale. Depth to bed-rock is 2037m.

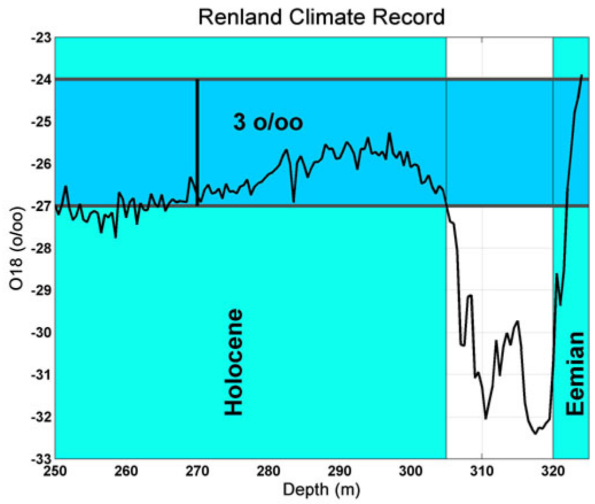


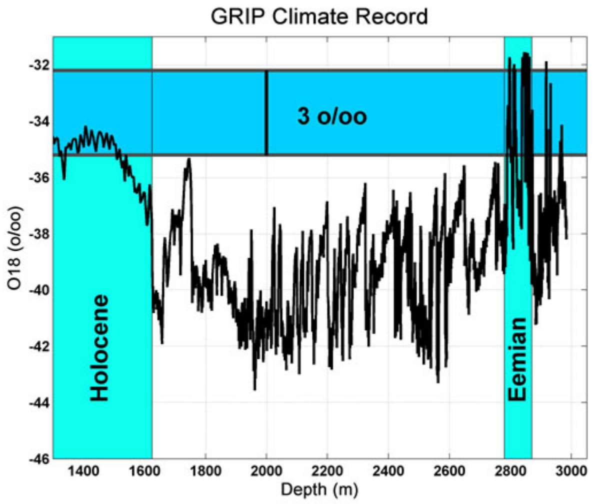
Eemian ice is found in all the deep Greenland ice cores



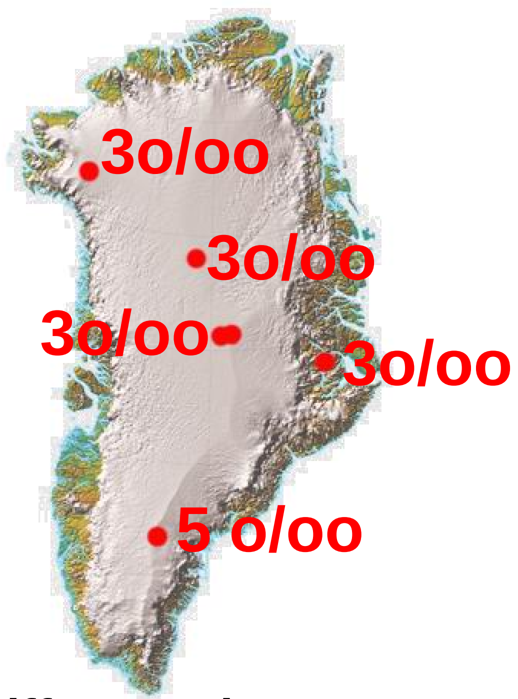




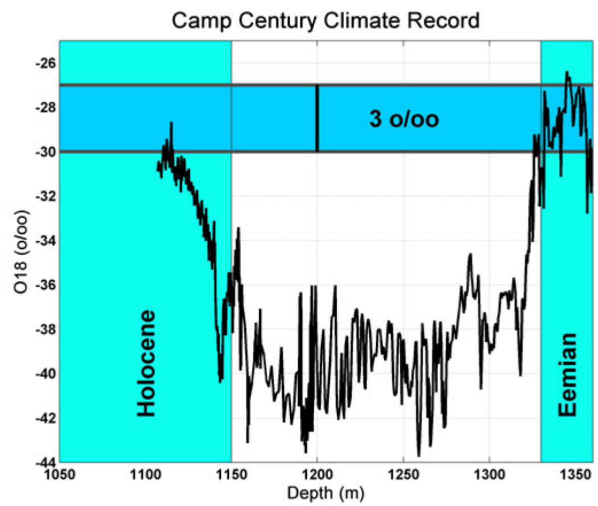


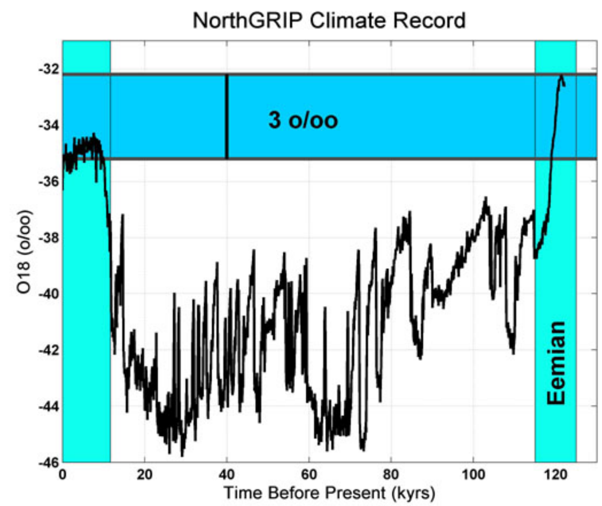


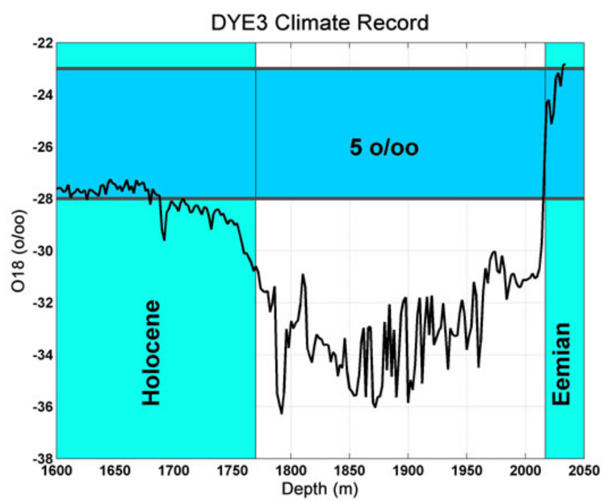
Eemian ice is found in all the deep Greenland ice cores

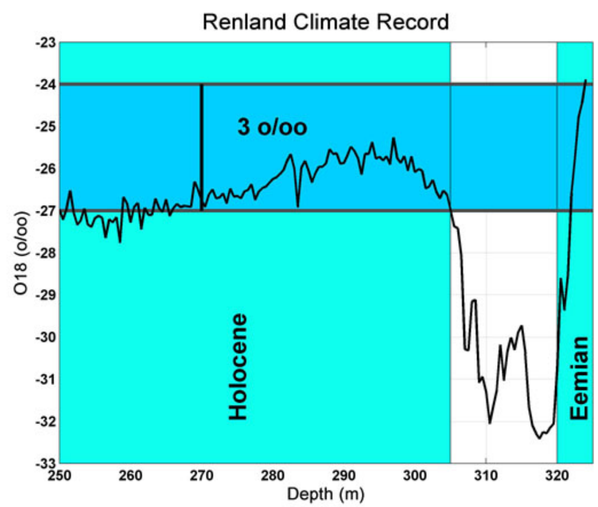


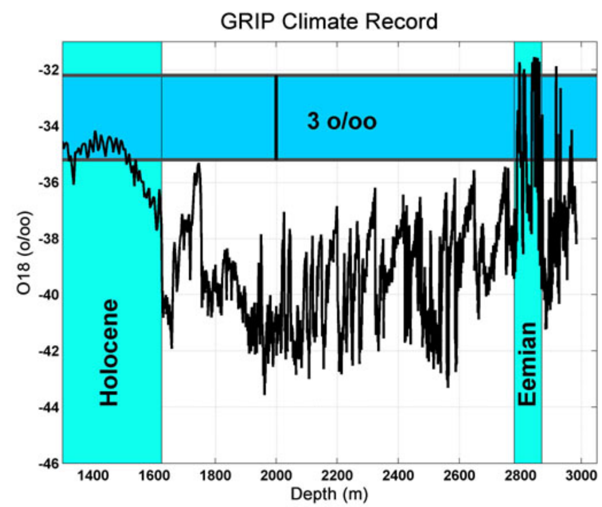
Difference between Eemian and Holocene Isotope values.

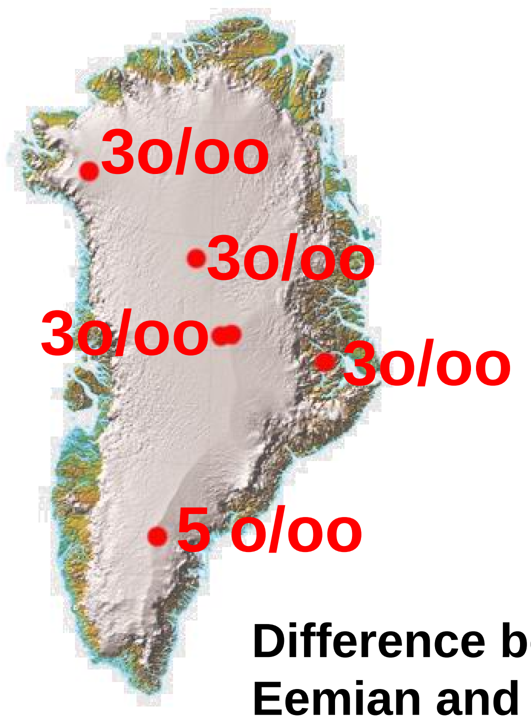












Difference between Eemian and Holocene Isotope values.

The Ice Sheet covered Greenland during the warm Eemian period.

A Warmer Period?

⌧O18 – temperature relation:

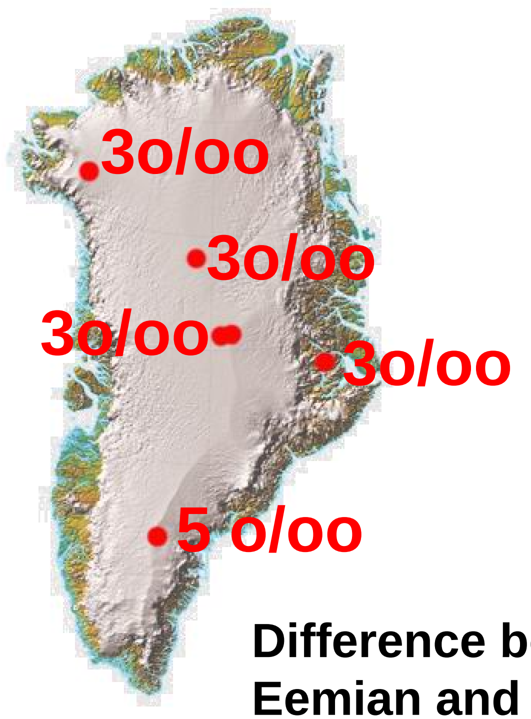
➋[⌧018]/➋T: 0.2 - 0.67 [o/oo]/K

A change of 3 o/oo corresponds to a temperature change of 5-10 K

A smaller Ice Sheet?

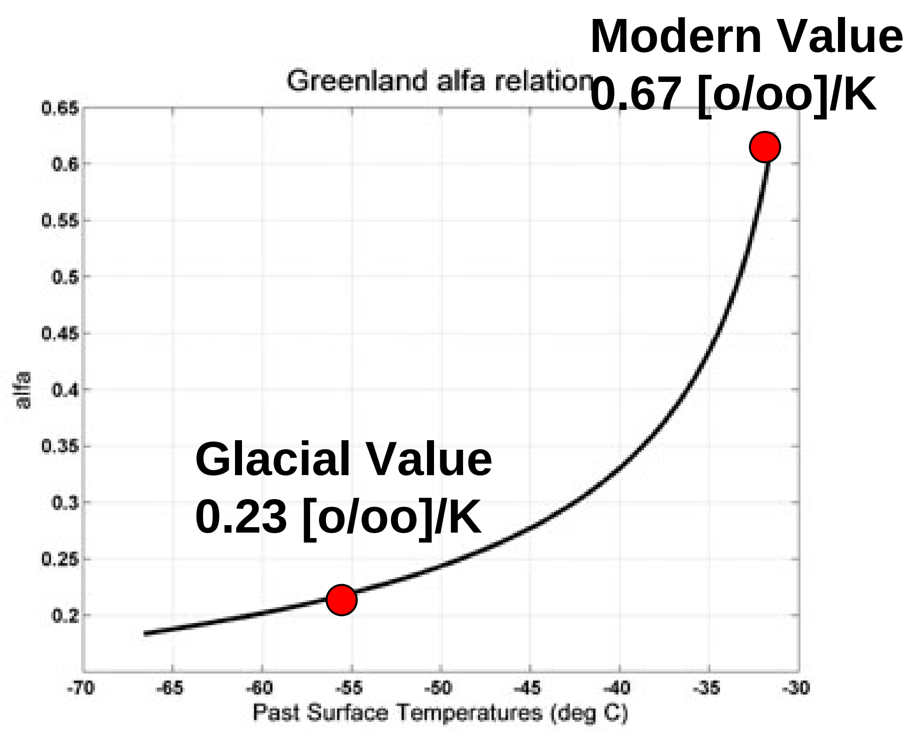
Lapse rate in the atmosphere is 0.6 K/100m

A change of 3 o/oo corresponds to an elevation change of 800 to 1700 m.



The Ice Sheet covered Greenland during the warm Eemian period.

Difference between Eemian and Holocene Isotope values.



A Warmer Period?

⌧O18 – temperature relation:

◑[⌧018]/◑T: 0.2 - 0.67 [o/oo]/K

A change of 3 o/oo corresponds to a temperature change of 5-10 K

A smaller Ice Sheet?

Lapse rate in the atmosphere is 0.6 K/100m

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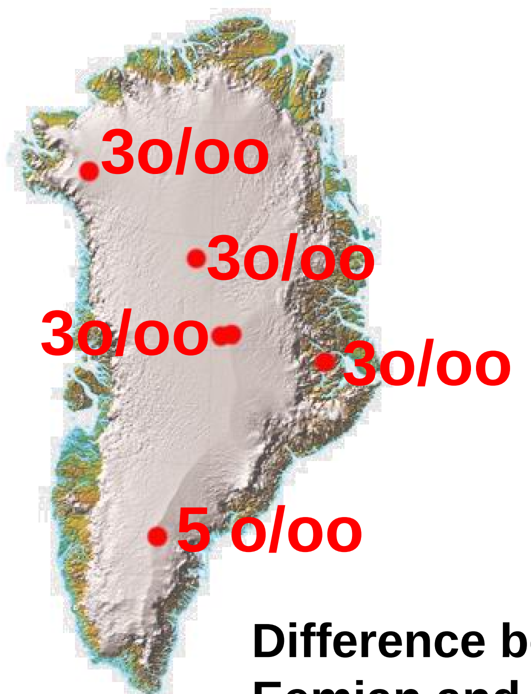
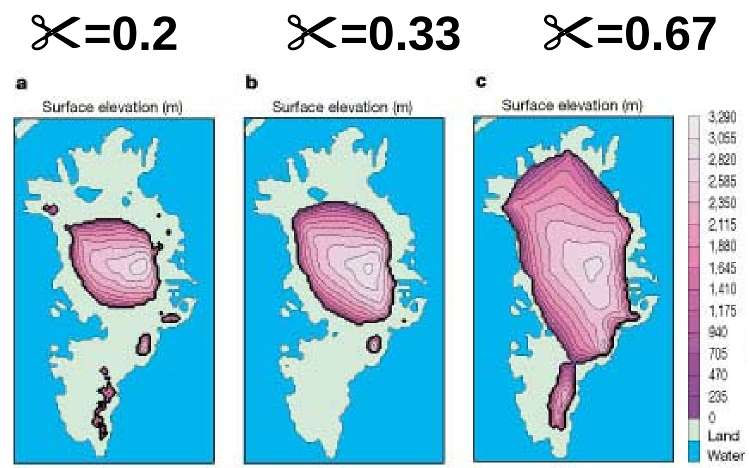


Difference between Eemian and Holocene Isotope values.



Cuffey and Mashall, Nature 2000

A Warmer Period?

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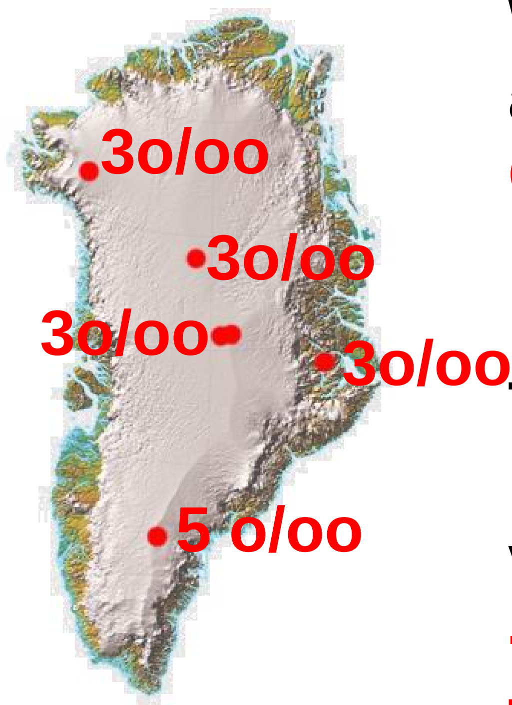
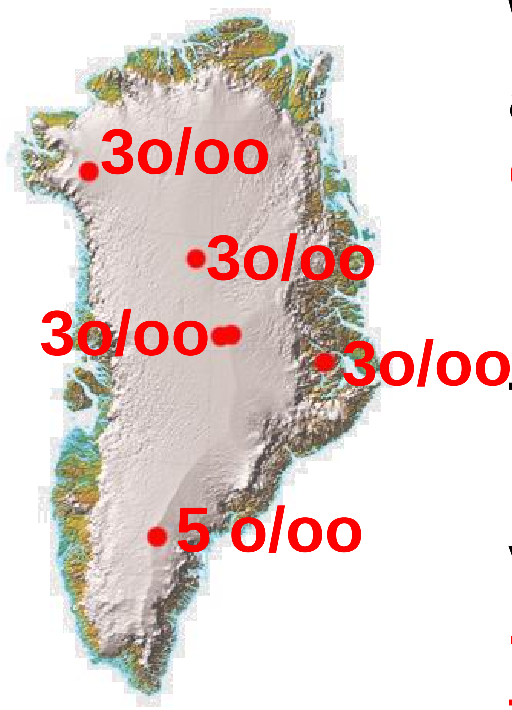


We find Eemian ice in all the deep ice cores and in the intermediate Renland ice core
Greenland has been ice covered during the Eemian period

The observed pattern of differences between present day and Eemian isotopic values can be used to suggest that:
-It was 5 dec warmer in Greenland during the Eemian period. The ice thickness in central and north Greenland where not reduced much while the ice in south Greenland was significantly reduced.



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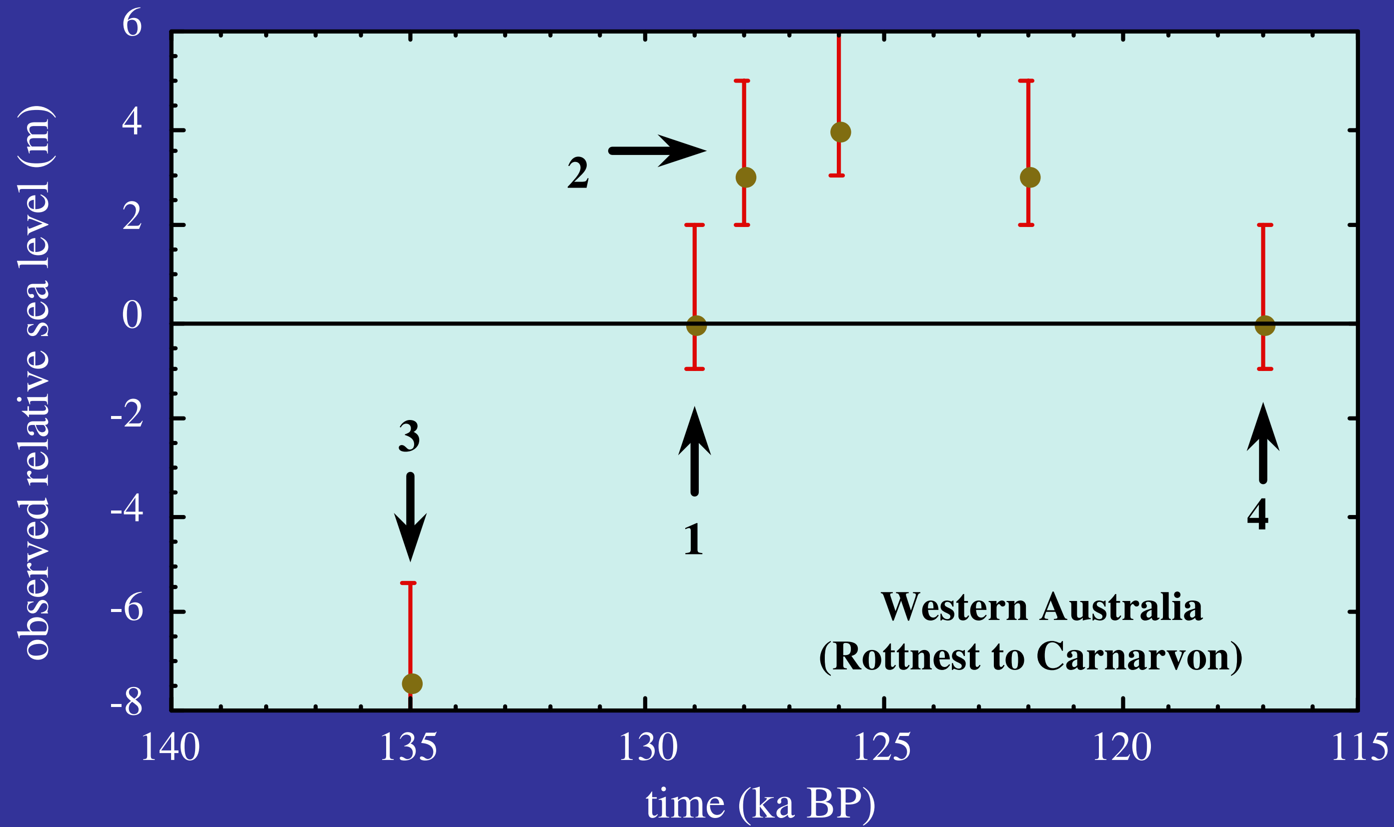
If the whole Greenland ice melted away sea level would rise 7 m. It is not likely that the Greenland Ice Sheet has contri-buted more than 1-2 m to sea level rise during the Eemian period.

Eemian coral reef at ~ 3 m asl from tectonically stable region of Western Australia

Observational evidence of sea levels during the Eemian in Western Australia.



1. Local sea level first reached present elevation at ~ 129 ka BP.

2. Local sea level rose rapidly tyo > 3m at 128 ka and > 4m at 126 ka.

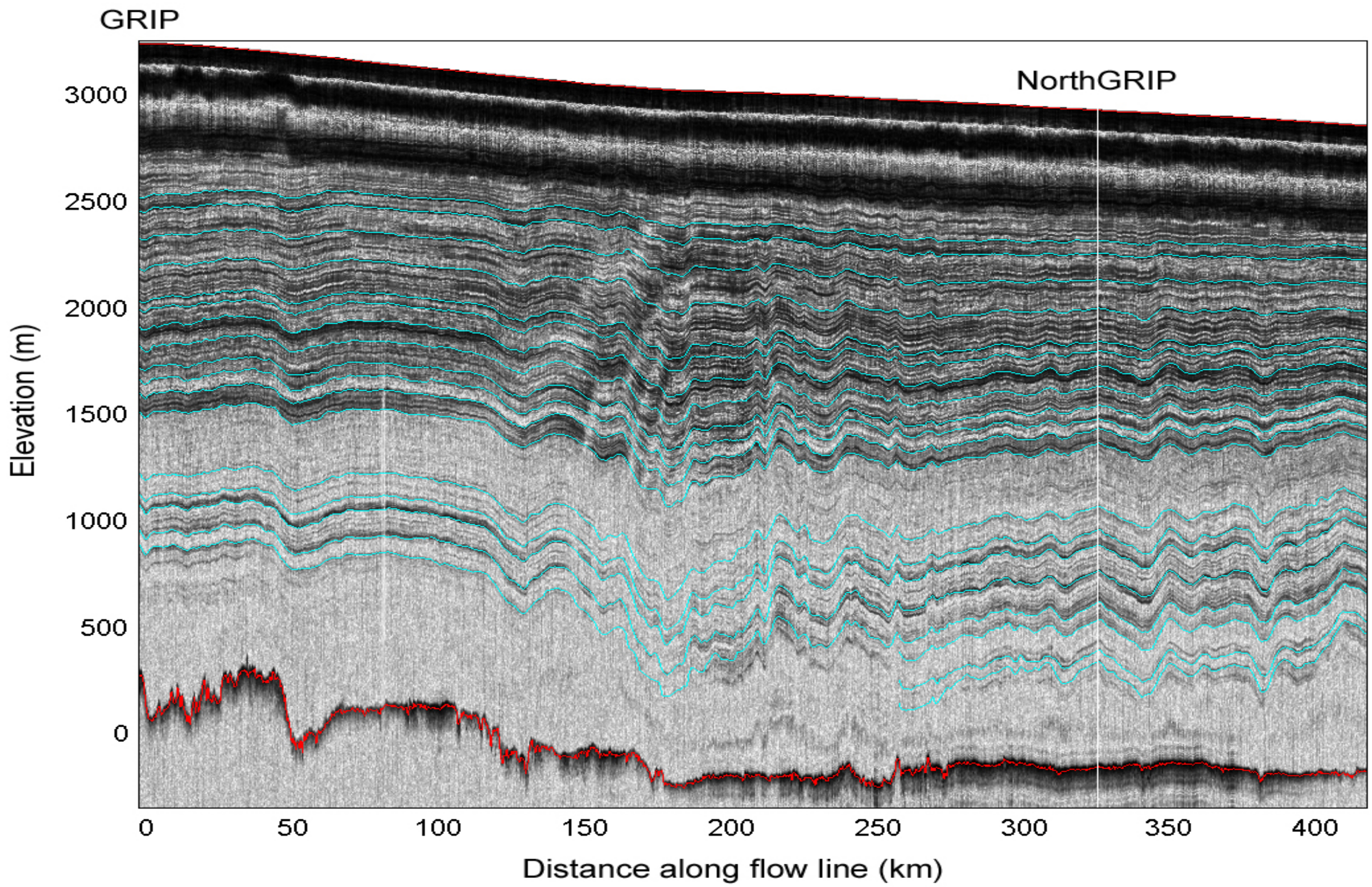
3. Sea level at 135 ka BP at ~ -8 m.

4. Sea level back to present by ~ 117 ka BP.

From Kurt Lambeck, Canberra

Finding Reference Horizons

Radio
Echo
Sounding



Can be used to date the ice

RES: P. Gogineni

What are the internal layers?

ECM RES O18

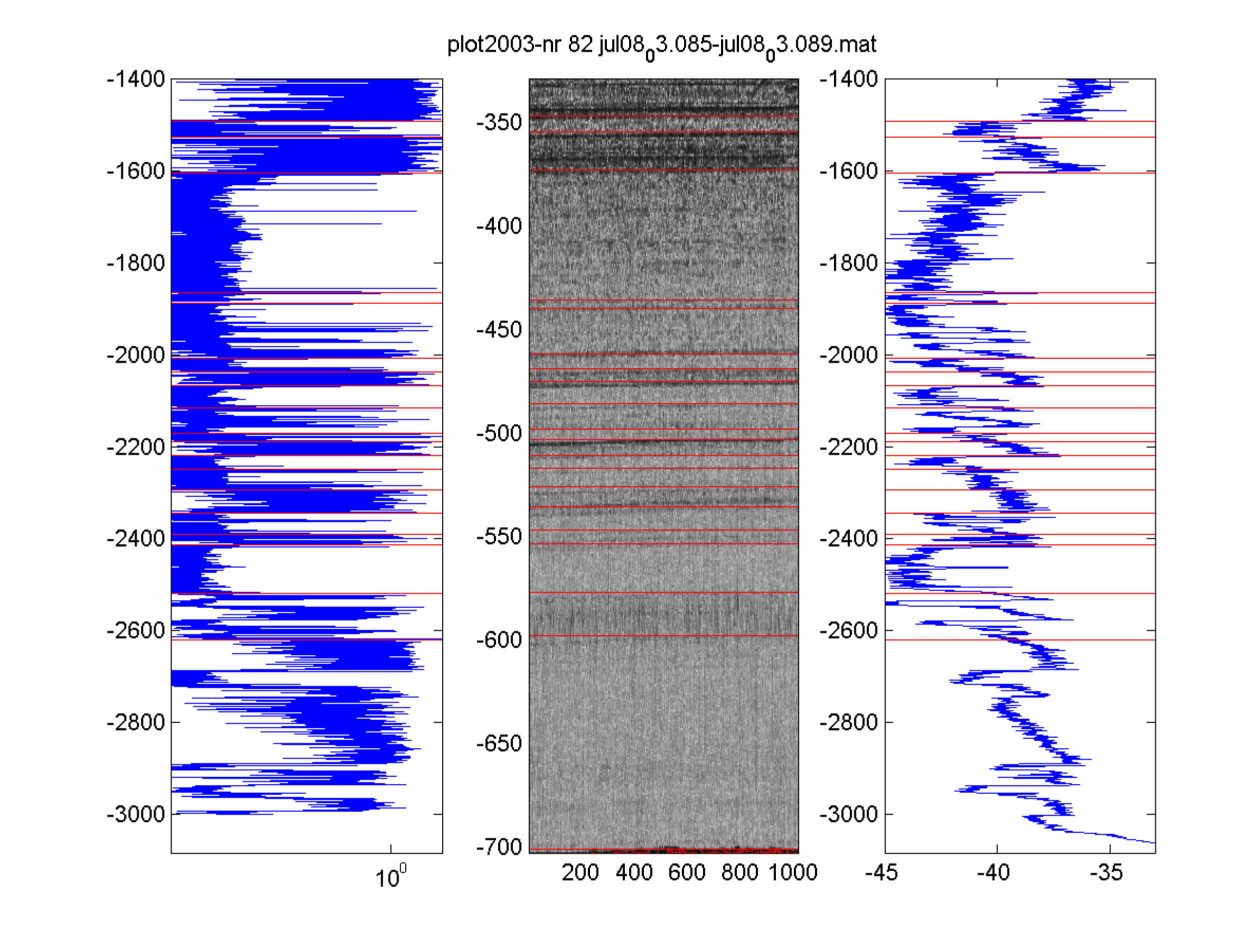
Radar facts:

Airborne

80 MHz

Depth res: 3.8 m

Spatial res: 170m

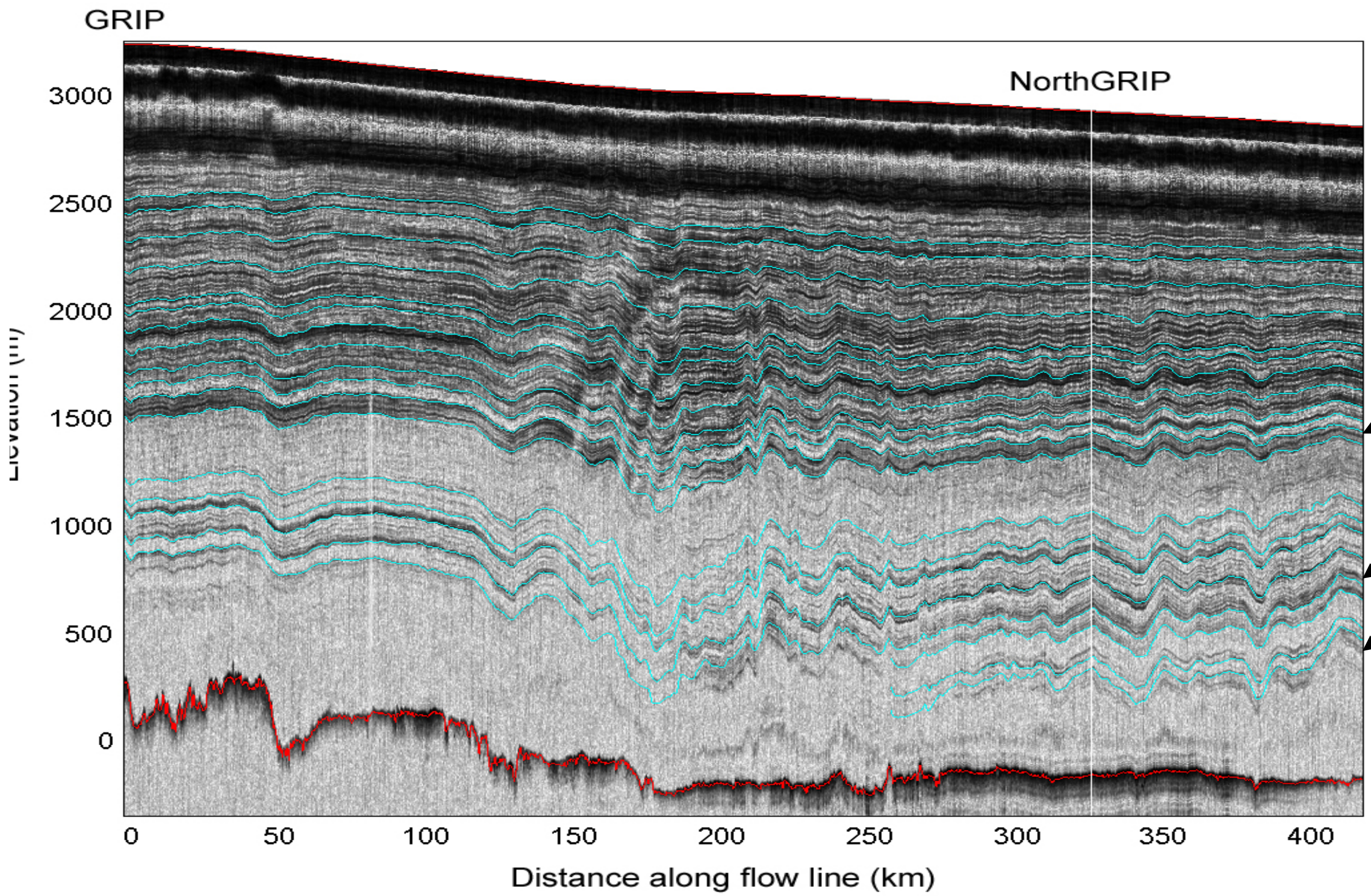


Can be used to date the ice

Data from the NGRIP drill site

Finding Reference Horizons

Radio
Echo
Sounding



Age:

14.000 yrs BP

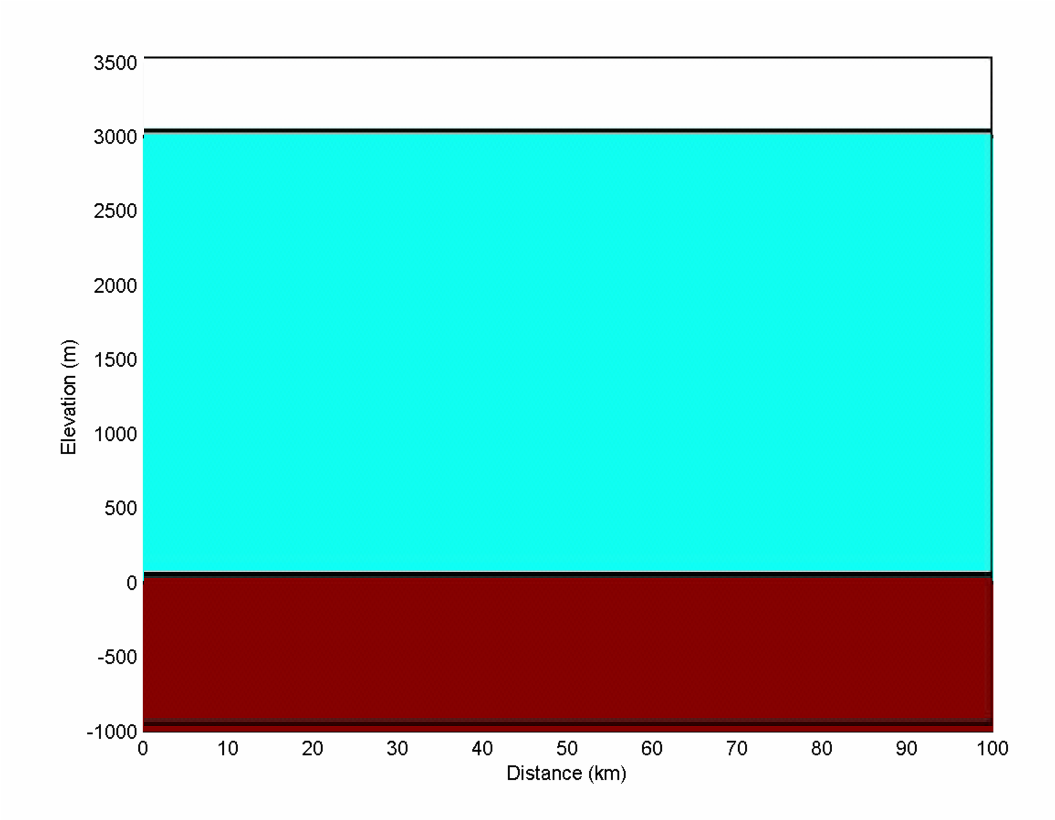
50.000 yrs BP

80.000 yrs BP

Can be used to date the ice

RES: P. Gogineni

Internal RES layers – what do they tell?



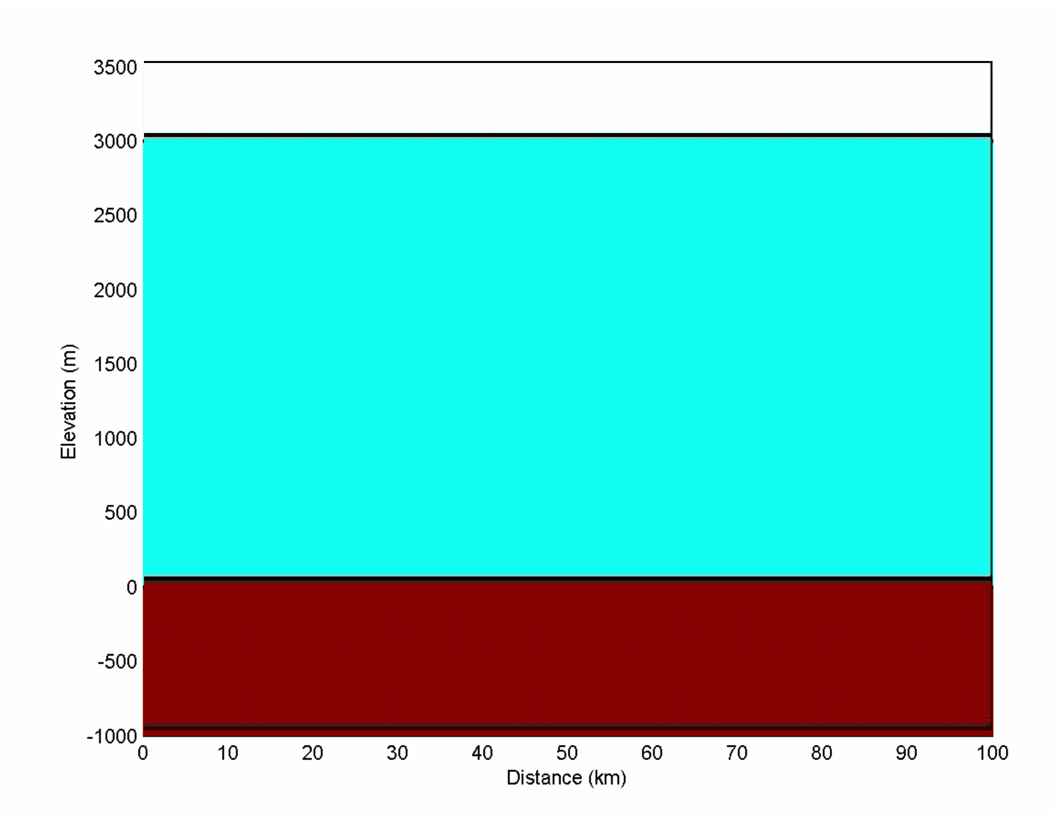
Simulation of RES layers

Follow a layer for 50.000 years as it sinks deeper and deeper in the ice.

Ice thickness 3000m
Accumulation 0.25 m/yr

Tells about the deformation history of the ice

Internal RES layers – what do they tell?



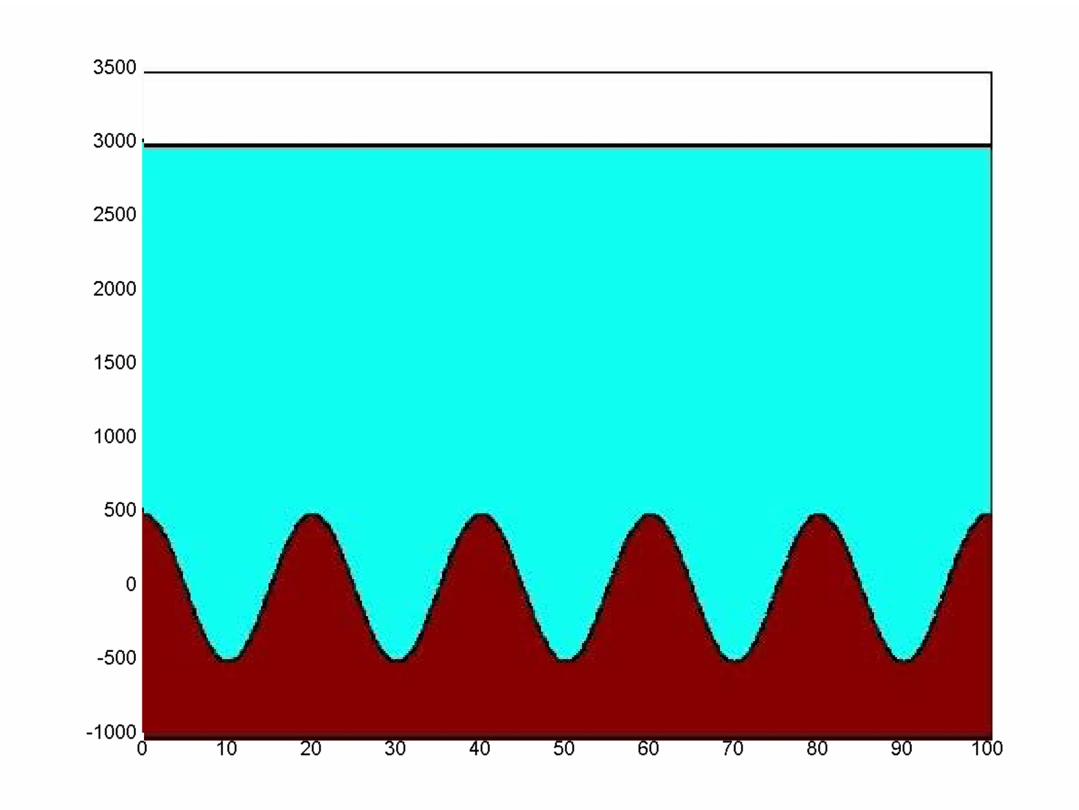
Simulation of RES layers

Start a layer for every 5000 years

Ice thickness 3000m
Accumulation 0.25 m/yr

Tells about the deformation history of the ice

Internal RES layers – what do they tell?



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Let the bedrock have topography

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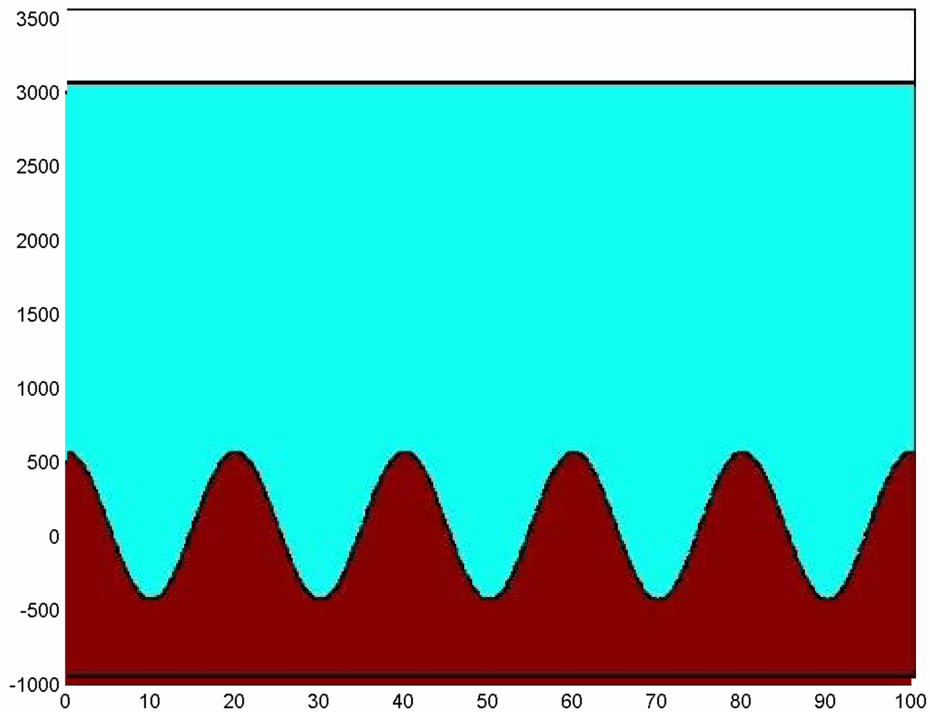

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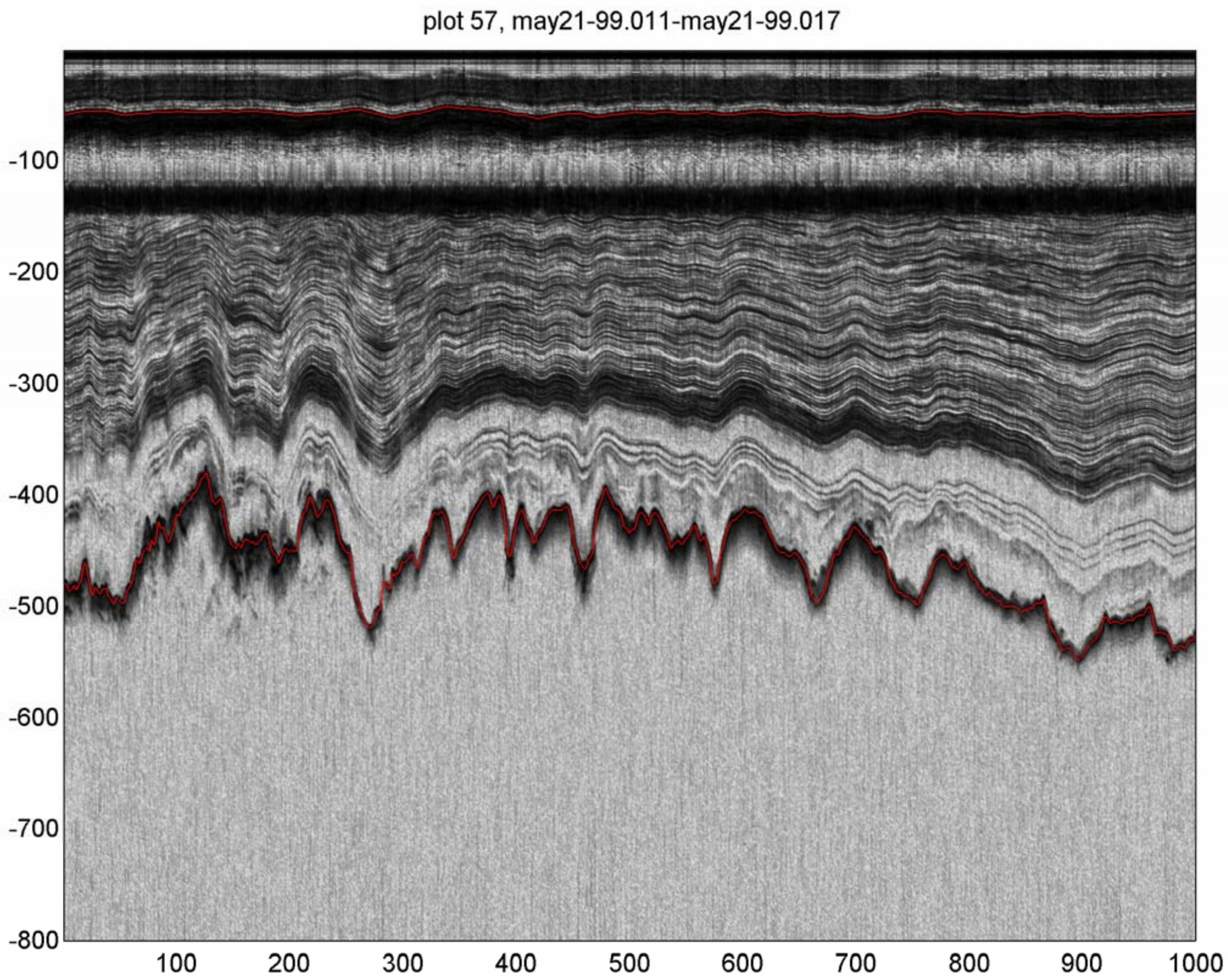

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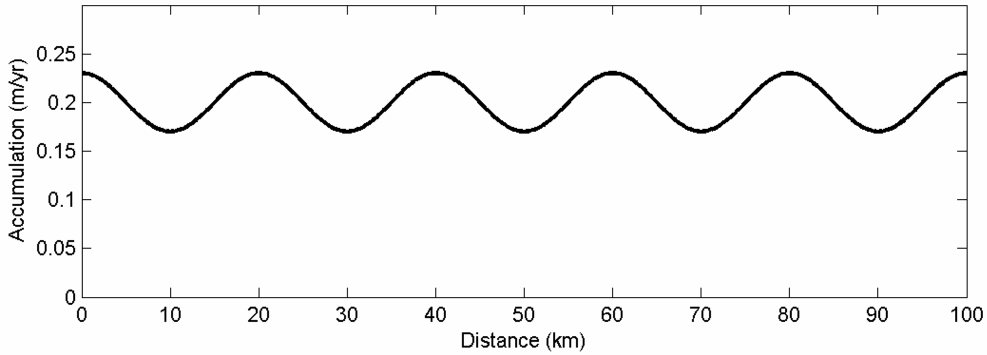
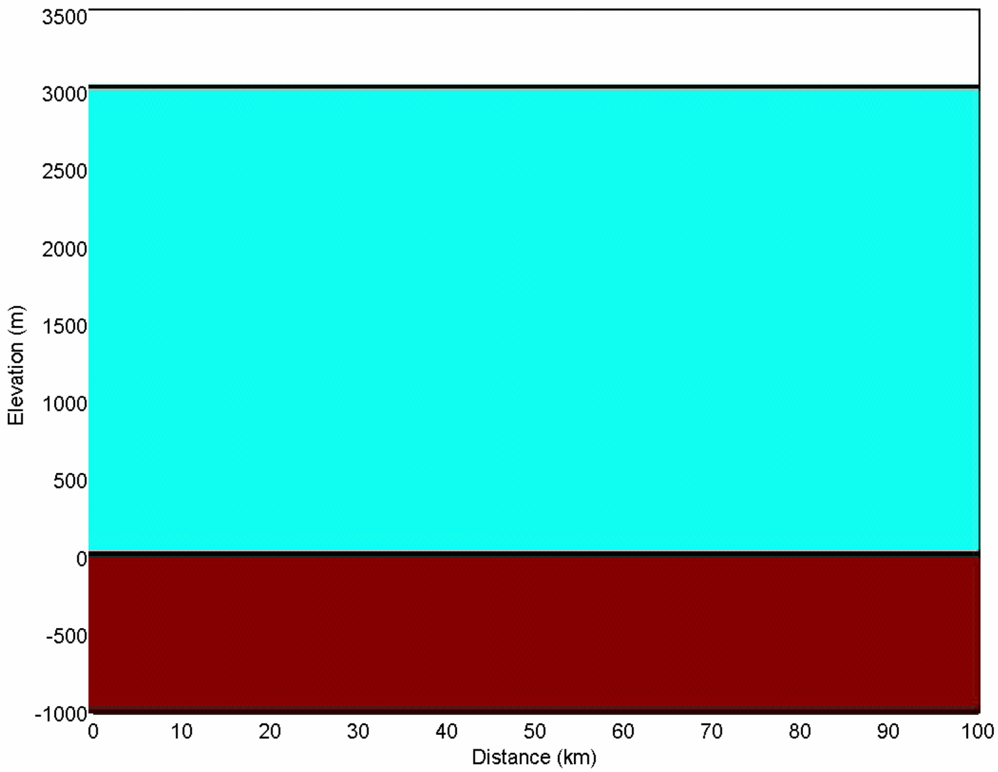




Simulation of RES layers

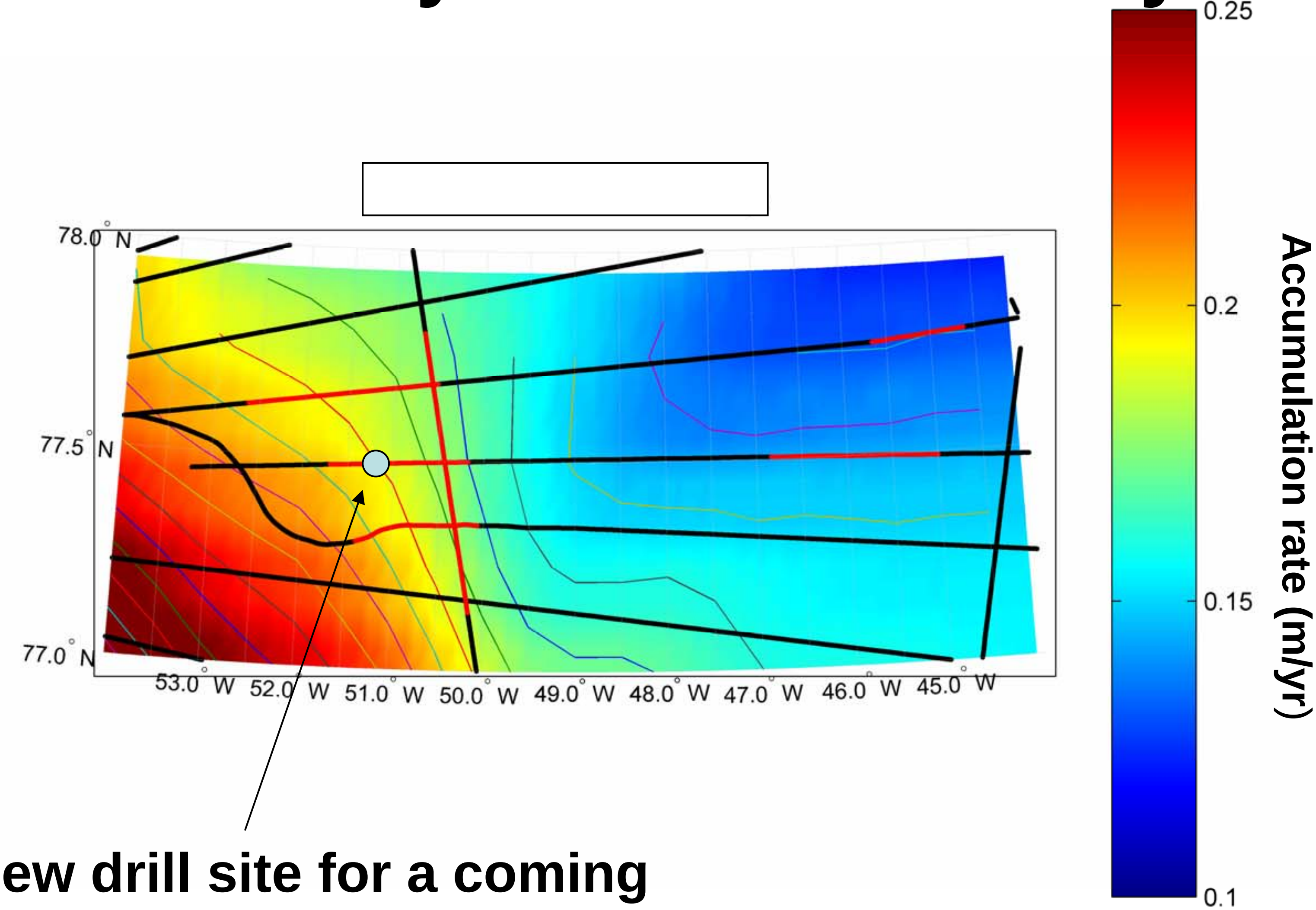
Start a layer for every 5000 years

Let the accumulation vary

Ice thickness 3000m
Accumulation changes along line

Map past and present accumulation

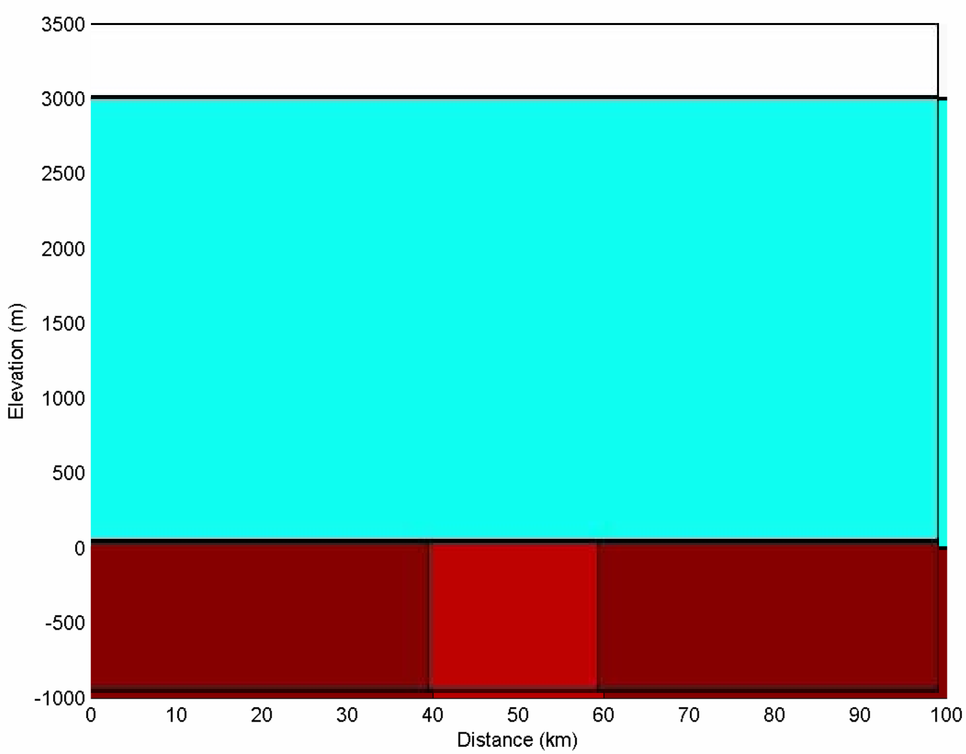
Internal RES layers – what do they tell?



New drill site for a coming Deep drilling

Map past and present accumulation

Internal RES layers – what do they tell?



Simulation of RES layers

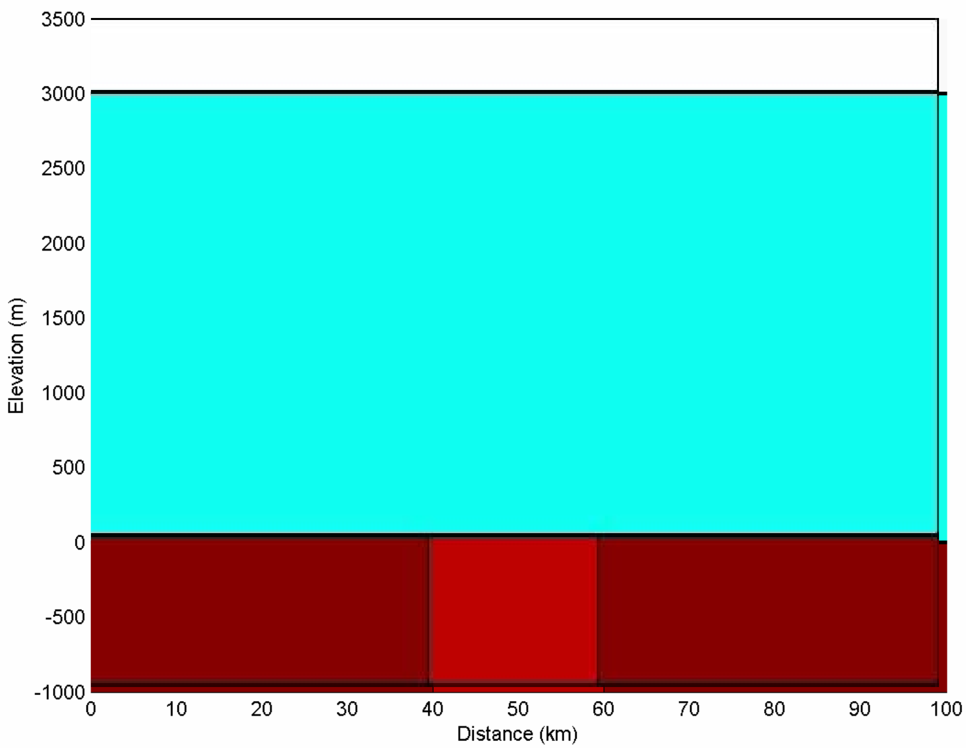
Follow a layer for 50.000 years as it sinks deeper and deeper in the ice.

Add a spot with basal melt

Ice thickness 3000m
Accumulation 0.25 m/yr
Melt rate 0.007 m/yr

Can be used to detect basal melt under the ice

Internal RES layers – what do they tell?



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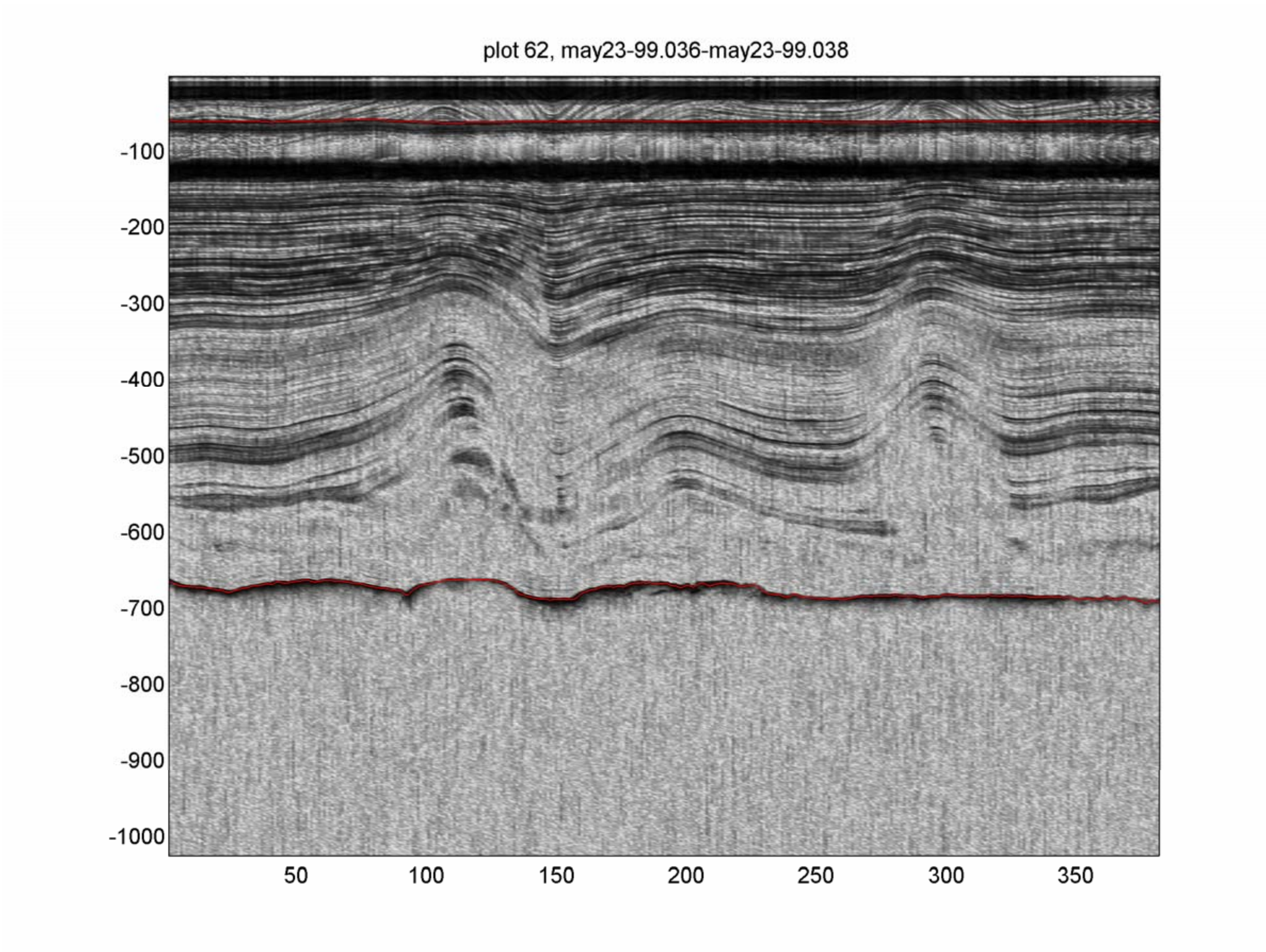

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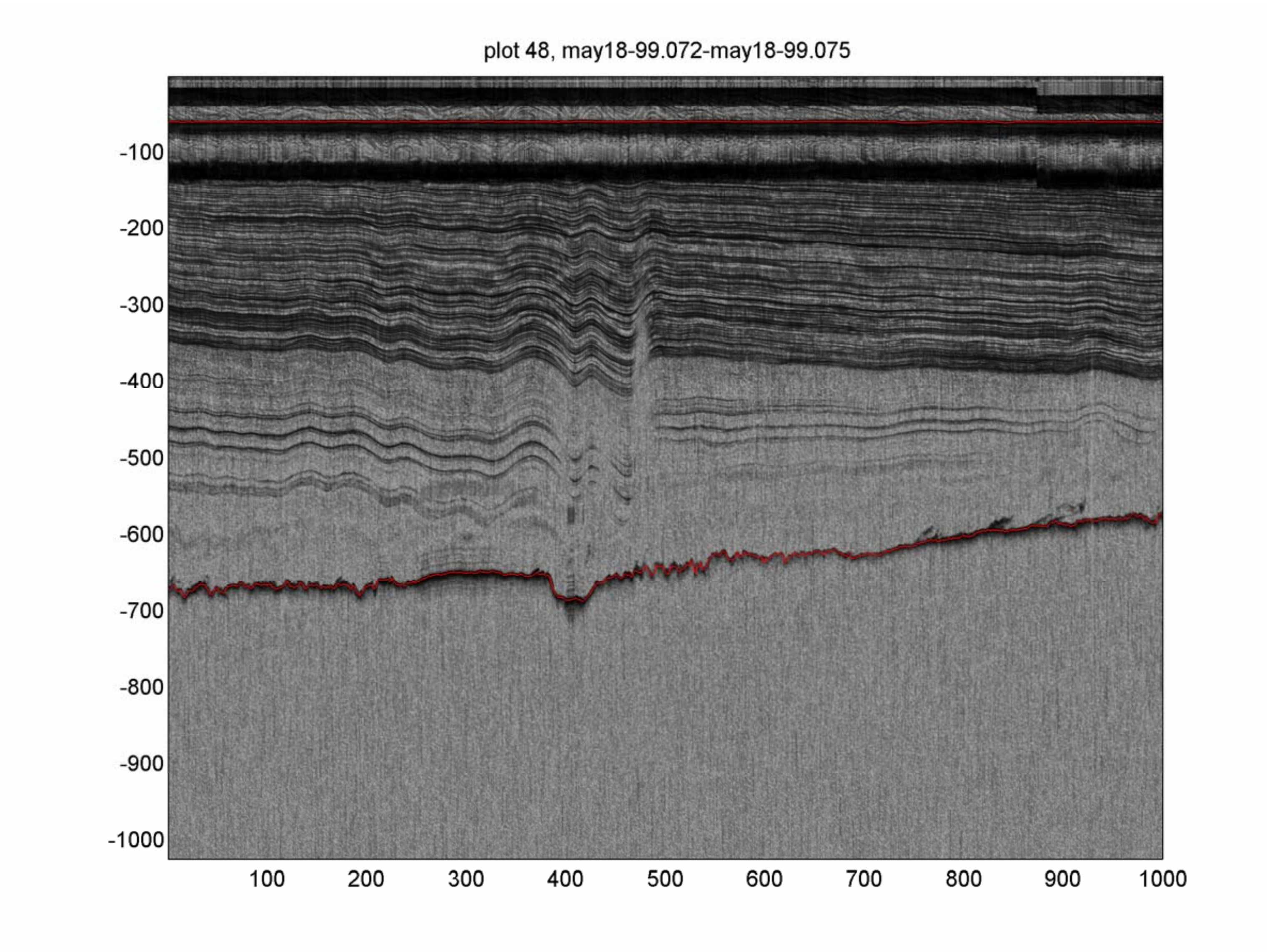
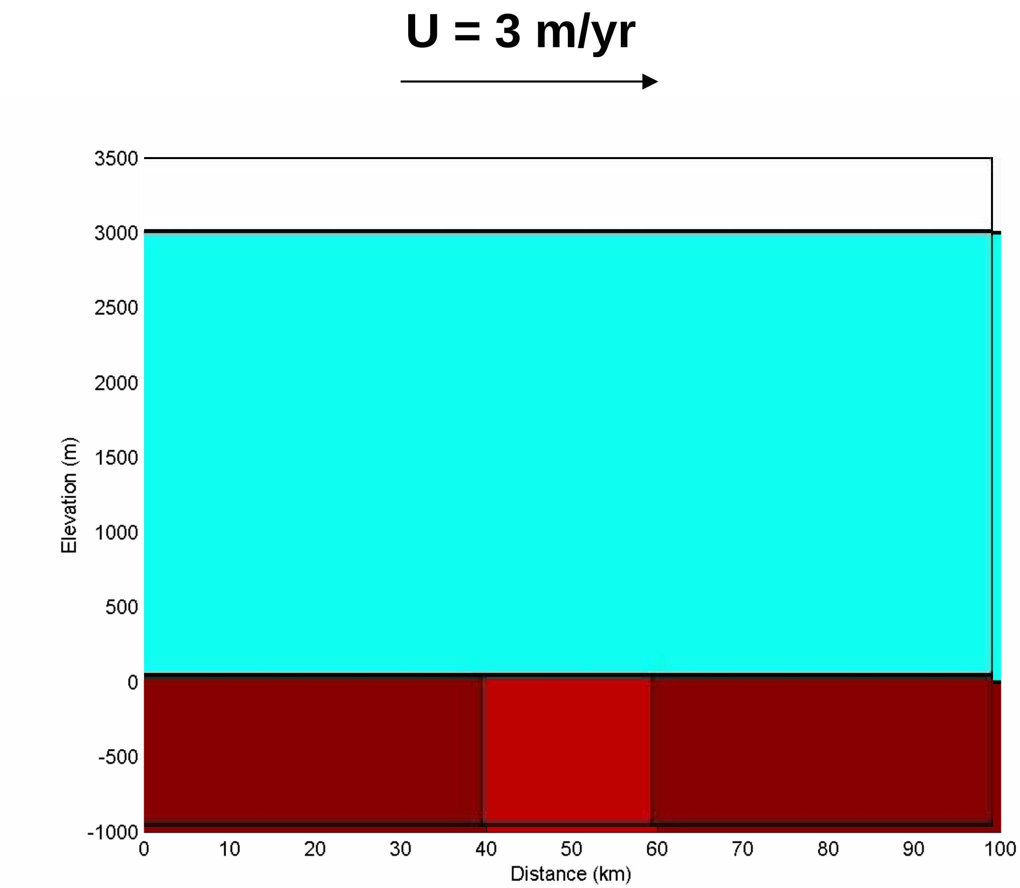


Can be used to detect basal melt under the ice

Internal RES layers – what do they tell?



Simulation of RES layers

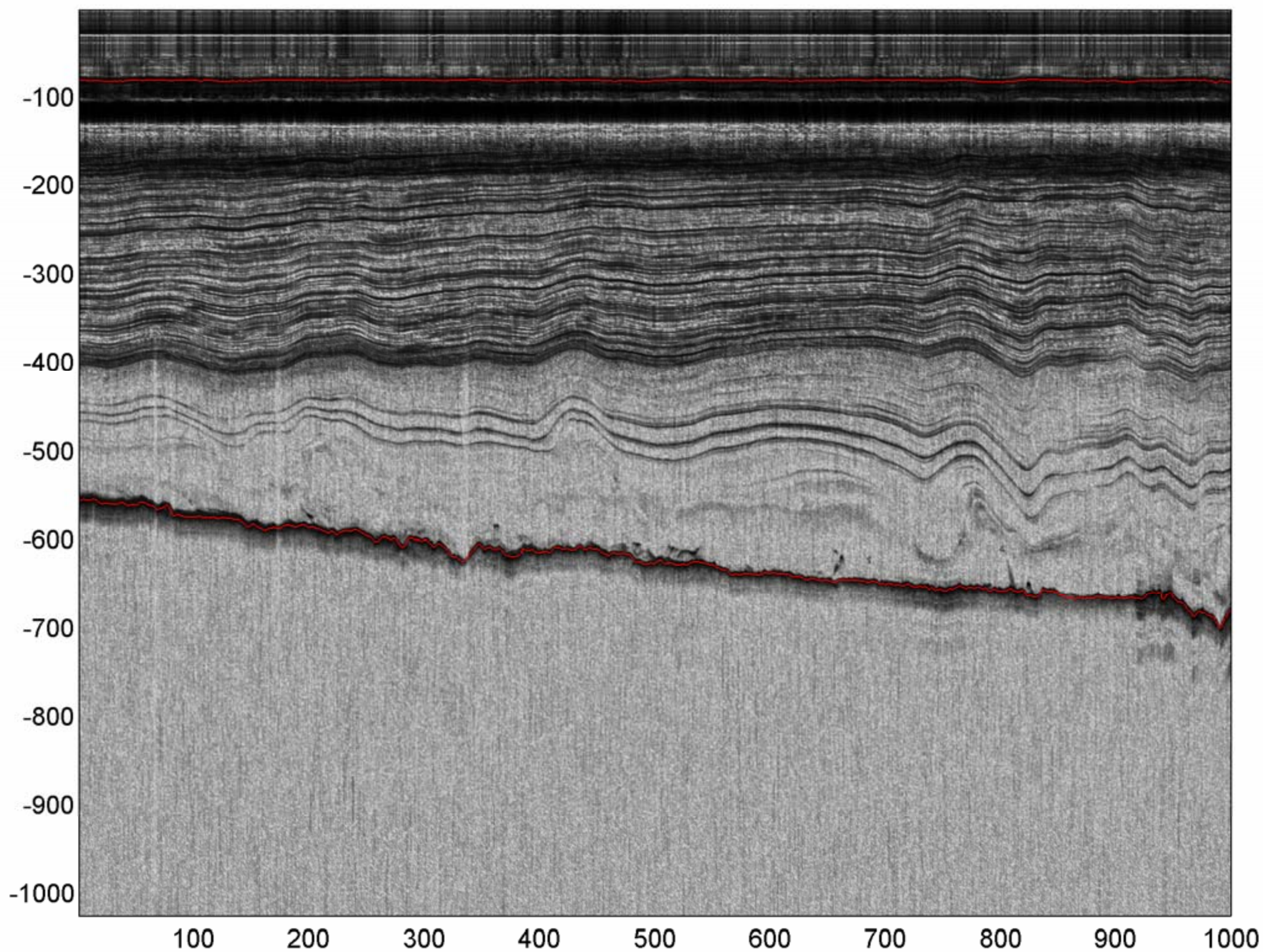
Start a layer for every 5000 years

Add a spot with basal melt
Add horizontal velocity

Ice thickness 3000m
Accumulation 0.25 m/yr
Melt rate 0.007 m/yr
Hor. Velocity 3 m/yr

Can be used to detect basal melt under the ice

Internal RES layers – what do they tell?



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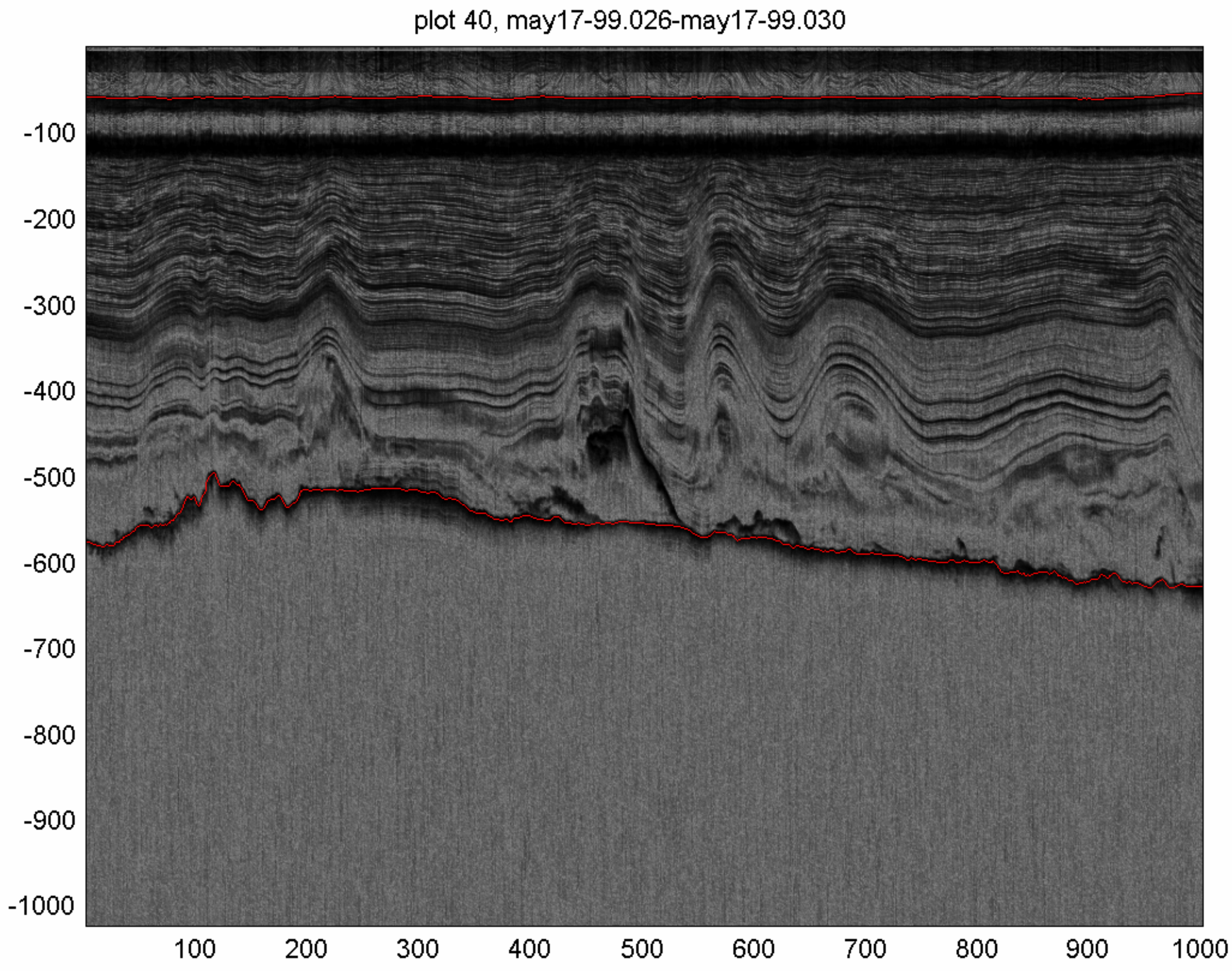
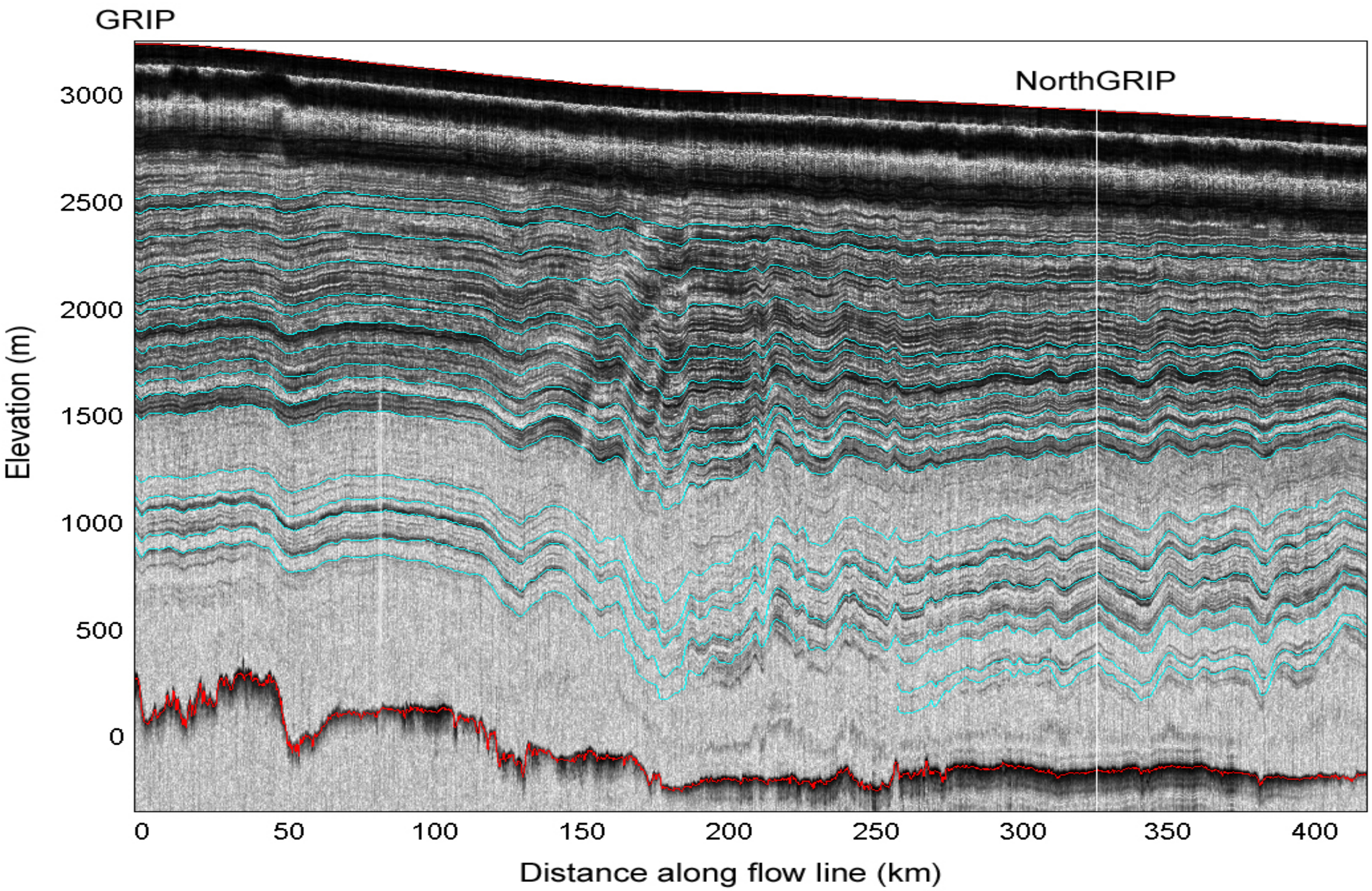


Can be used to detect basal melt under the ice

Finding Reference Horizons

Radio
Echo
Sounding



RES: P. Gogineni

Finding Reference Horizons

Radio
Echo
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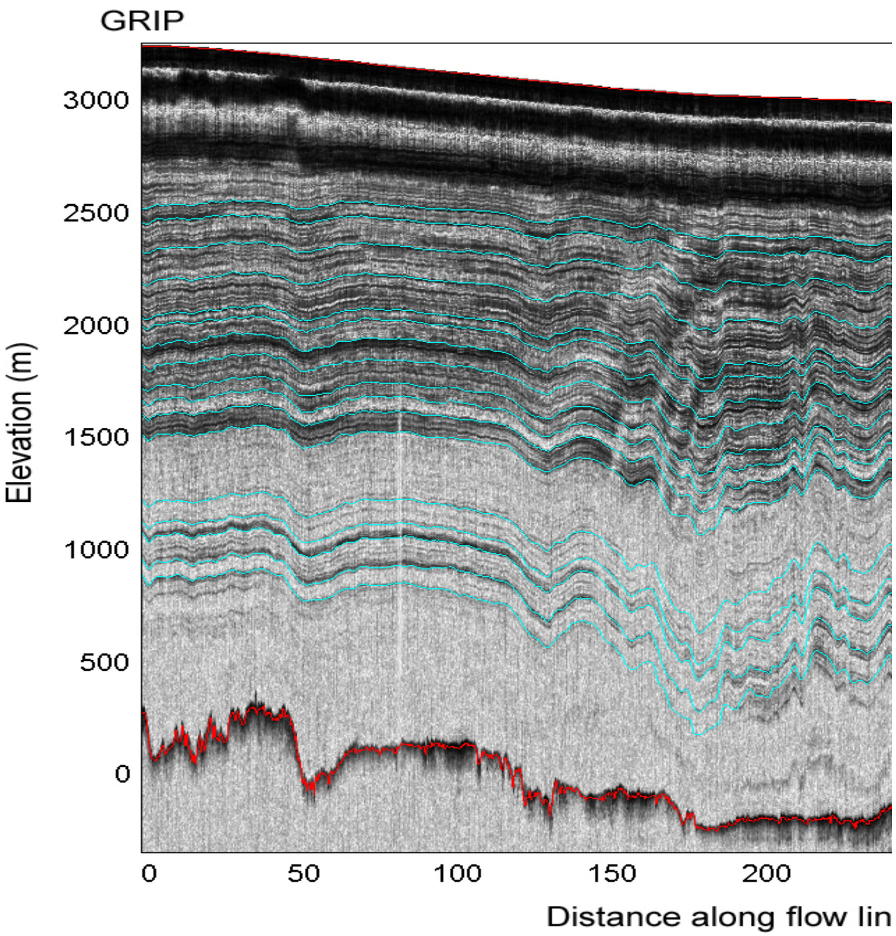
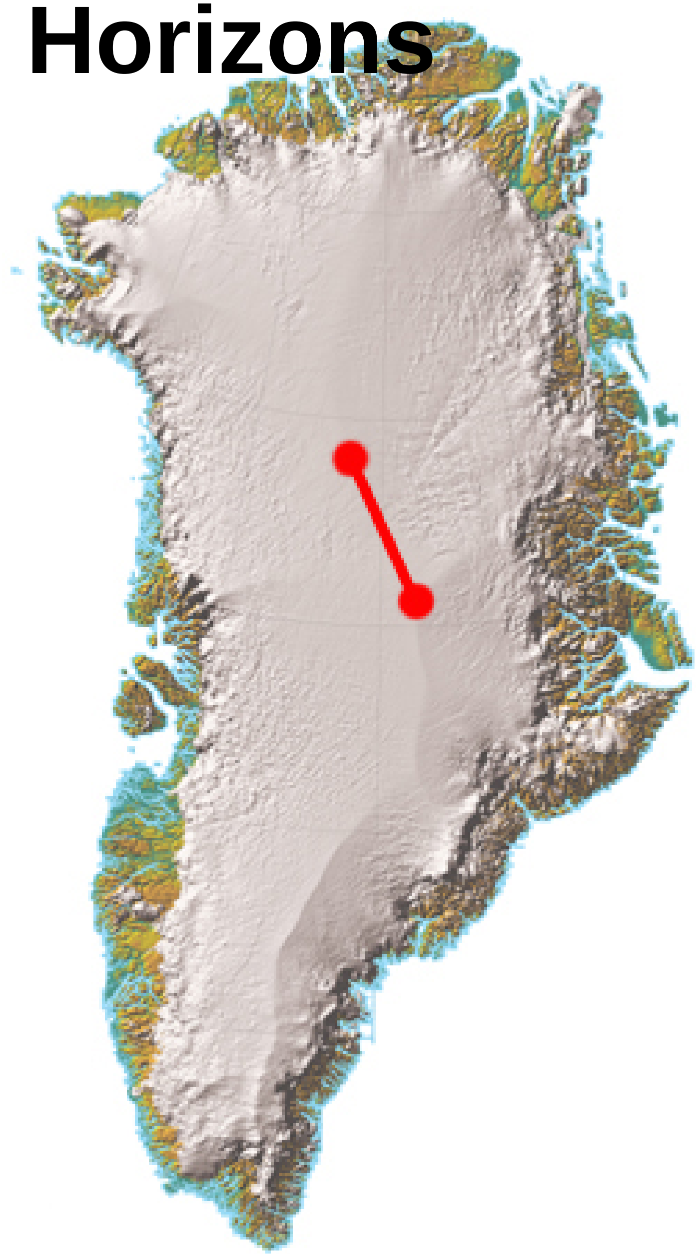
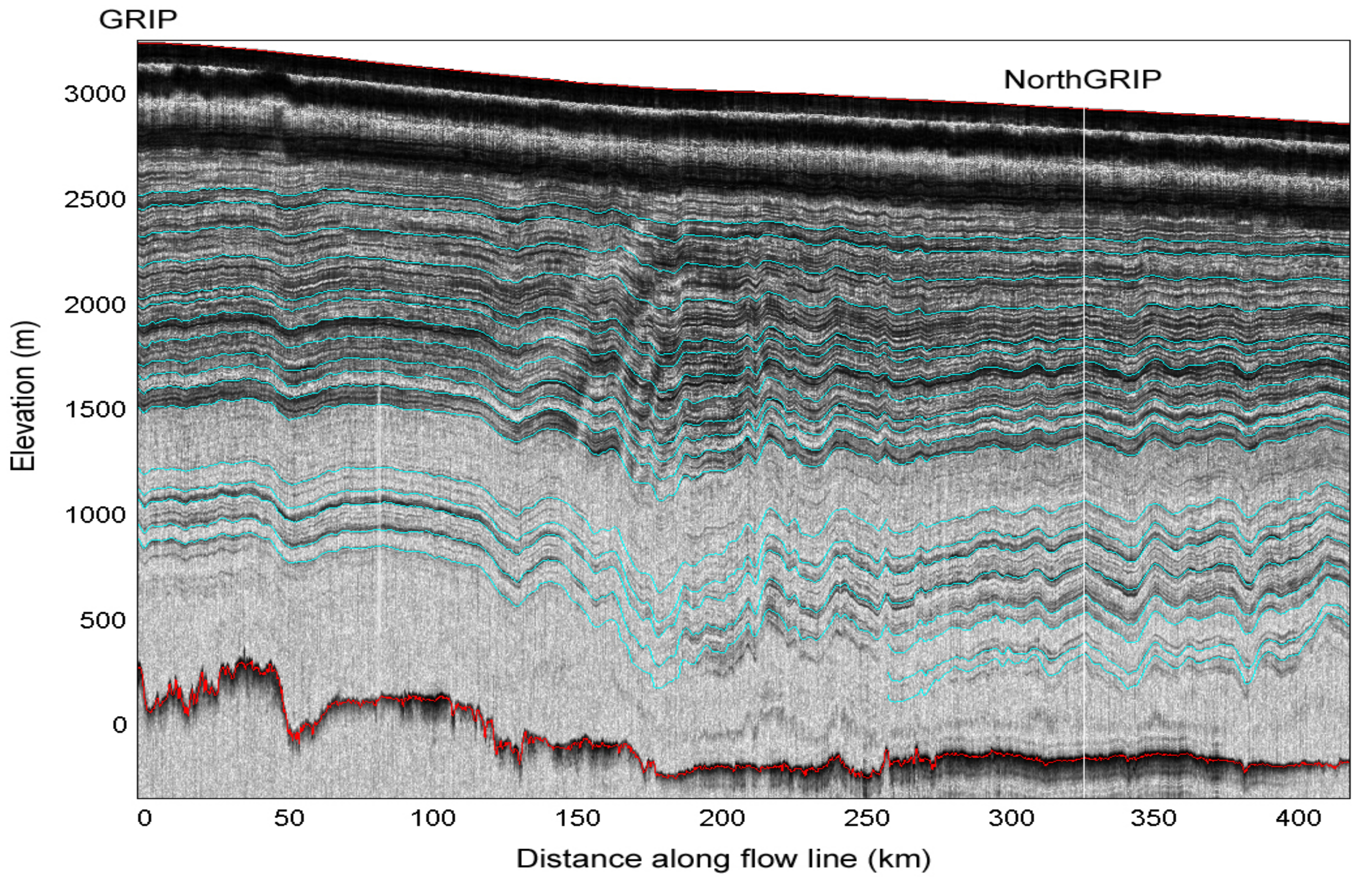
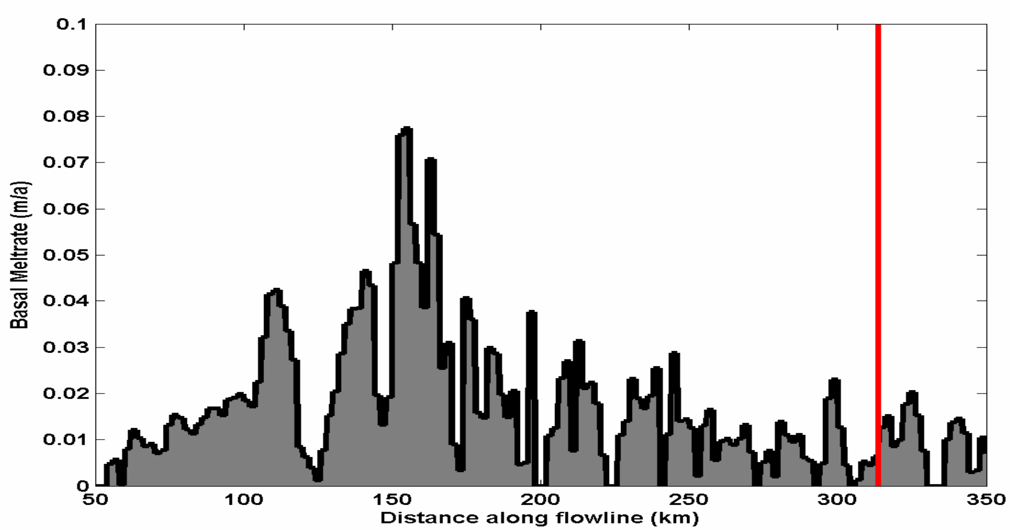




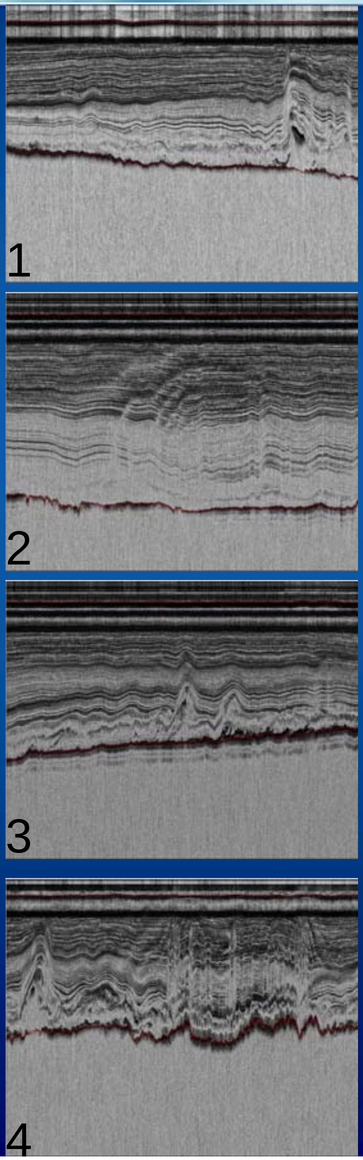
RES: P. Gogineni



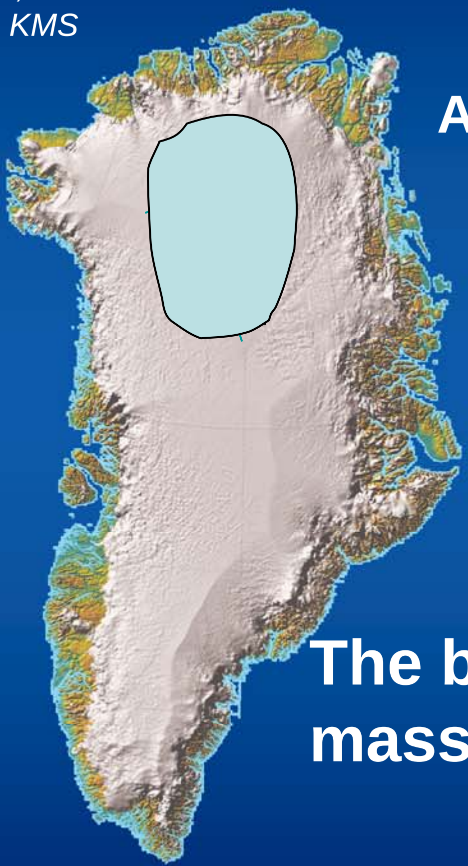


RES: P. Gogineni

Melt under the Greenland Ice Sheet



RES: P. Gogineni, ITTC
Map: S. Ekholm, KMS



Area with basal melt: 40 10^4 km^2

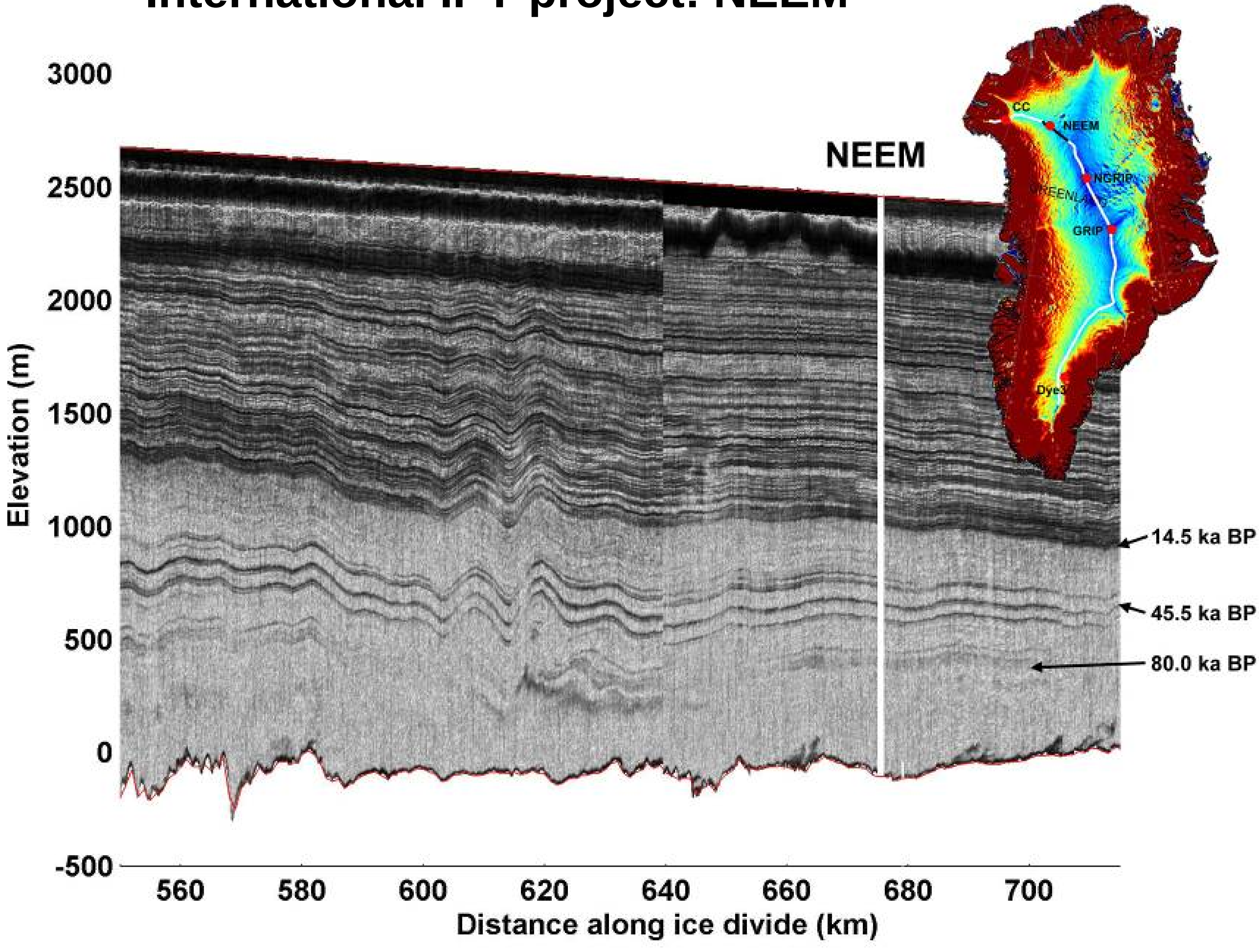
Average melt rate: 1.5 cm/yr

Melt every year: 4 km^3 water

The basal melt is 10% of the mass balance in the melt area

Where does the water drain?
Where are the subglacial lakes?
Impact on sea level changes

International IPY project: NEEM



CIC – Center for Interglacial Climate

Our vision is to contribute to the global climate research and ongoing debate by producing new and innovative ice core records, and to use them for climate studies.