Keck Institute for Space Studies Workshop, August 8-11, 2017:
"Unlocking the climate record stored within Mars' Polar Layered Deposits"

Terrestrial Ice Sheets in Climate Studies

Stratigraphy – Ice Cores - Climate Archive

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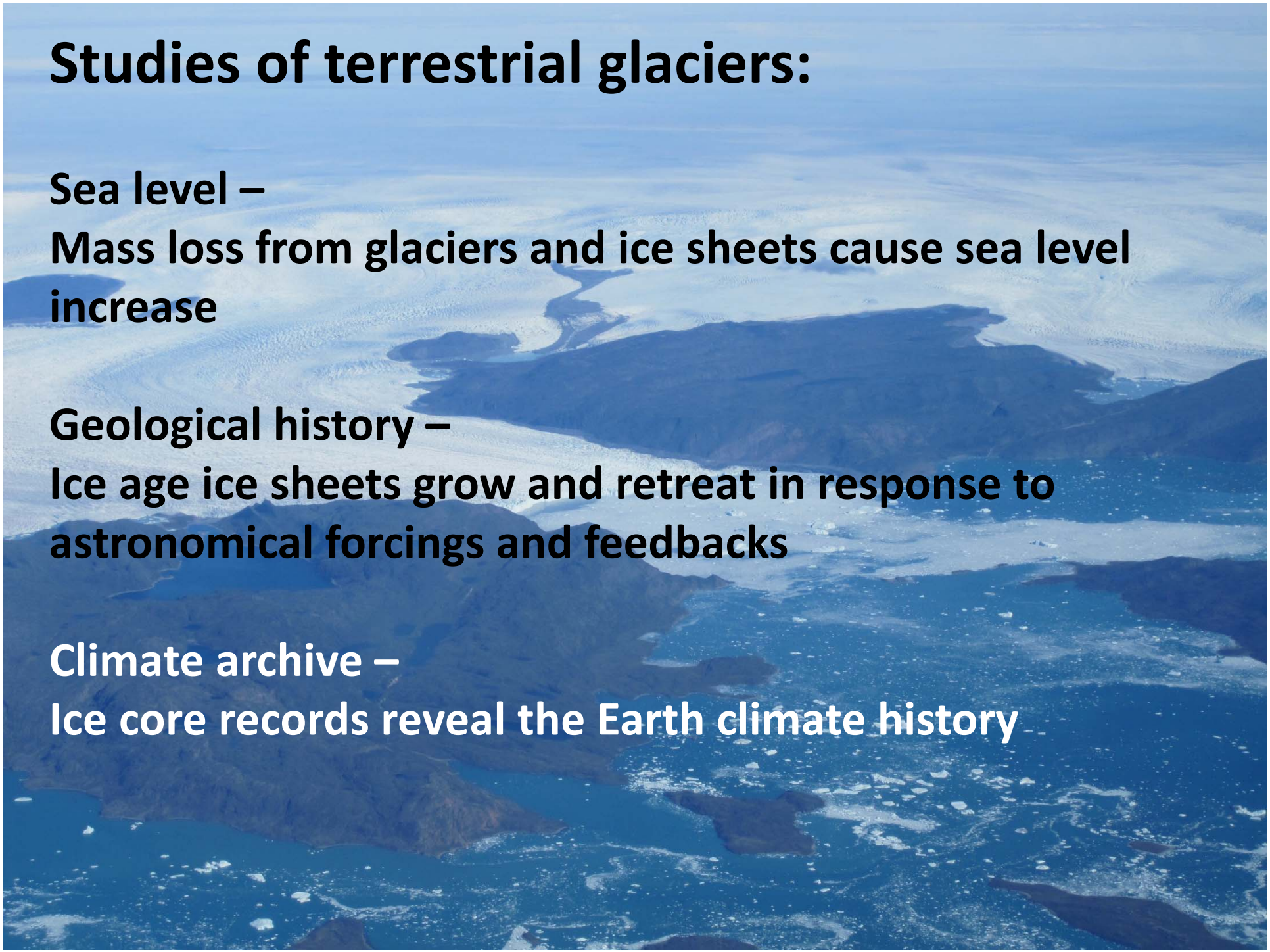
East Greenland Ice Core Project, NorthEast Greenland, July 29, 2017



Studies of terrestrial glaciers:

Sea level –
Mass loss from glaciers and ice sheets cause sea level increase

Geological history –
Ice age ice sheets grow and retreat in response to astronomical forcings and feedbacks

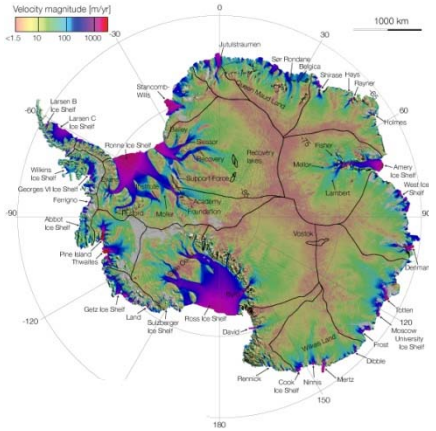
Climate archive –
Ice core records reveal the Earth climate history

Greenland

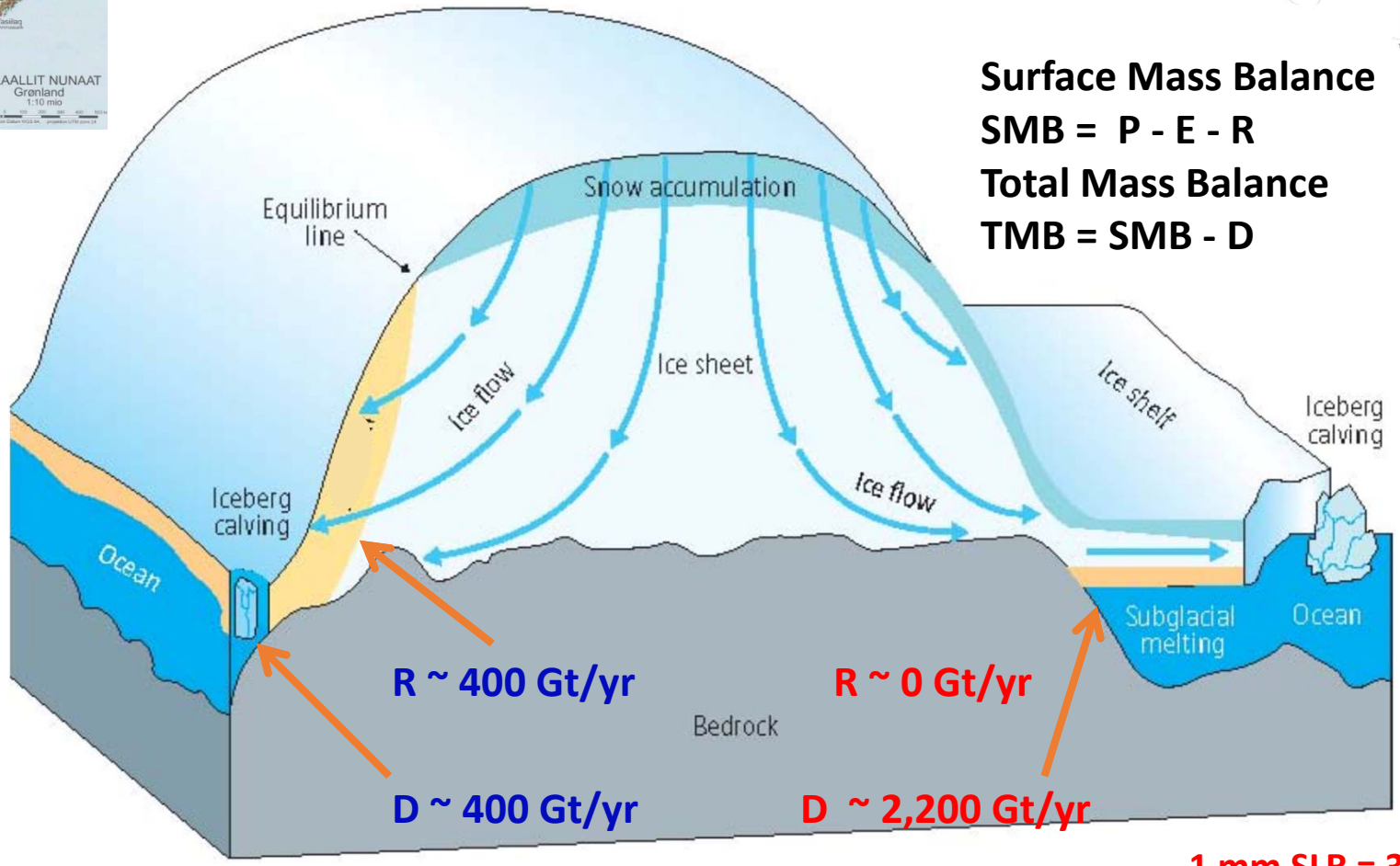
P ~ 24 cm/yr or 600 Gt/yr
SLR ~7 m

Antarctica

P ~ 17 cm/yr or 2,200 Gt/yr
SLR ~ 56 m



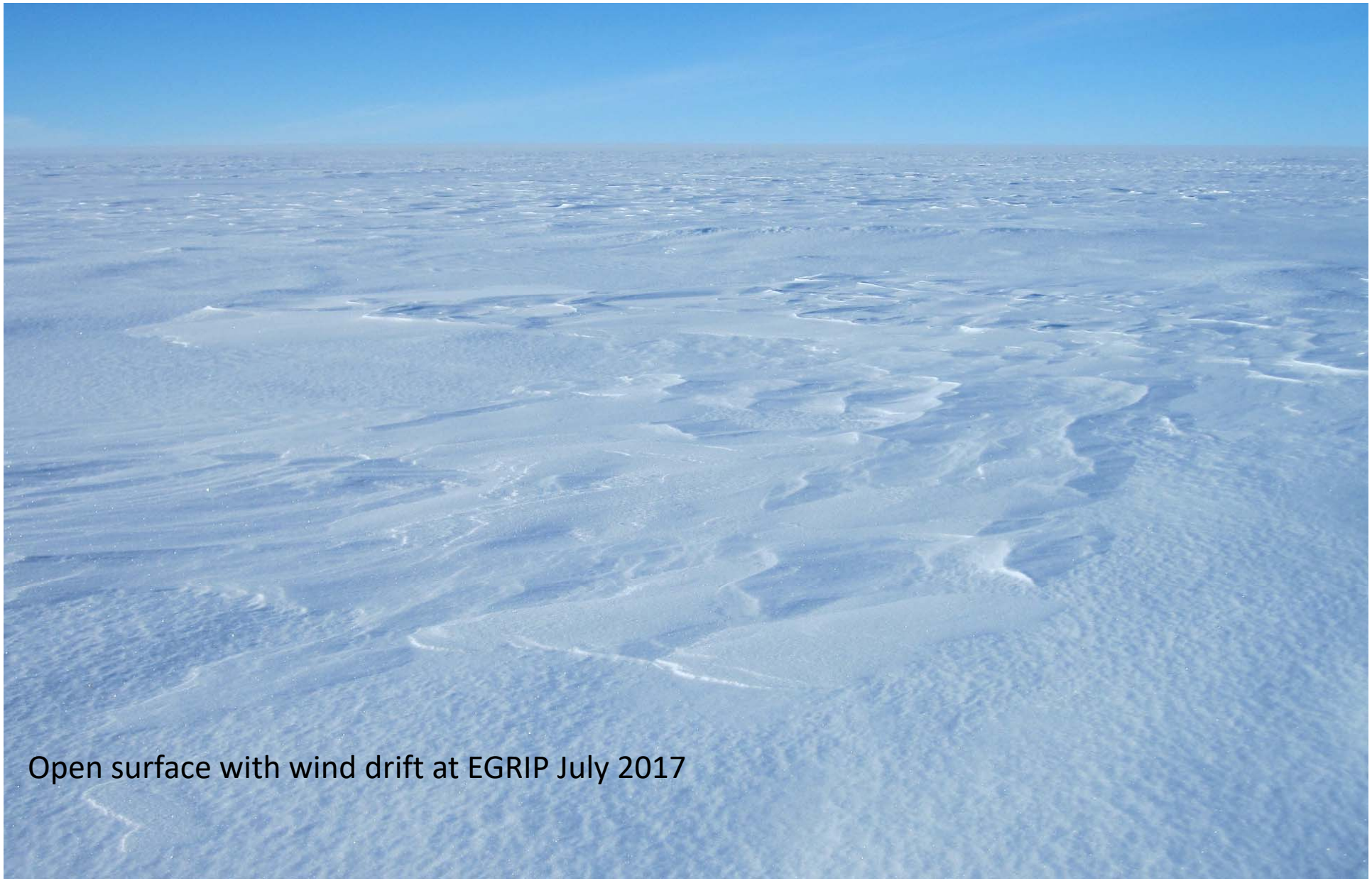
Surface Mass Balance
SMB = P - E - R
Total Mass Balance
TMB = SMB - D



1 mm SLR = 360 Gt/yr

P=precipitation E=evaporation
R=runoff D=discharge into ocean

The vast high-elevation interior regions of the Greenland ice sheet: cold temperatures, snow and wind.



Open surface with wind drift at EGRIP July 2017

The vast high-elevation interior regions of the Greenland ice sheet: cold temperatures, snow and wind.

After snowfall
At EGRIP July 2016

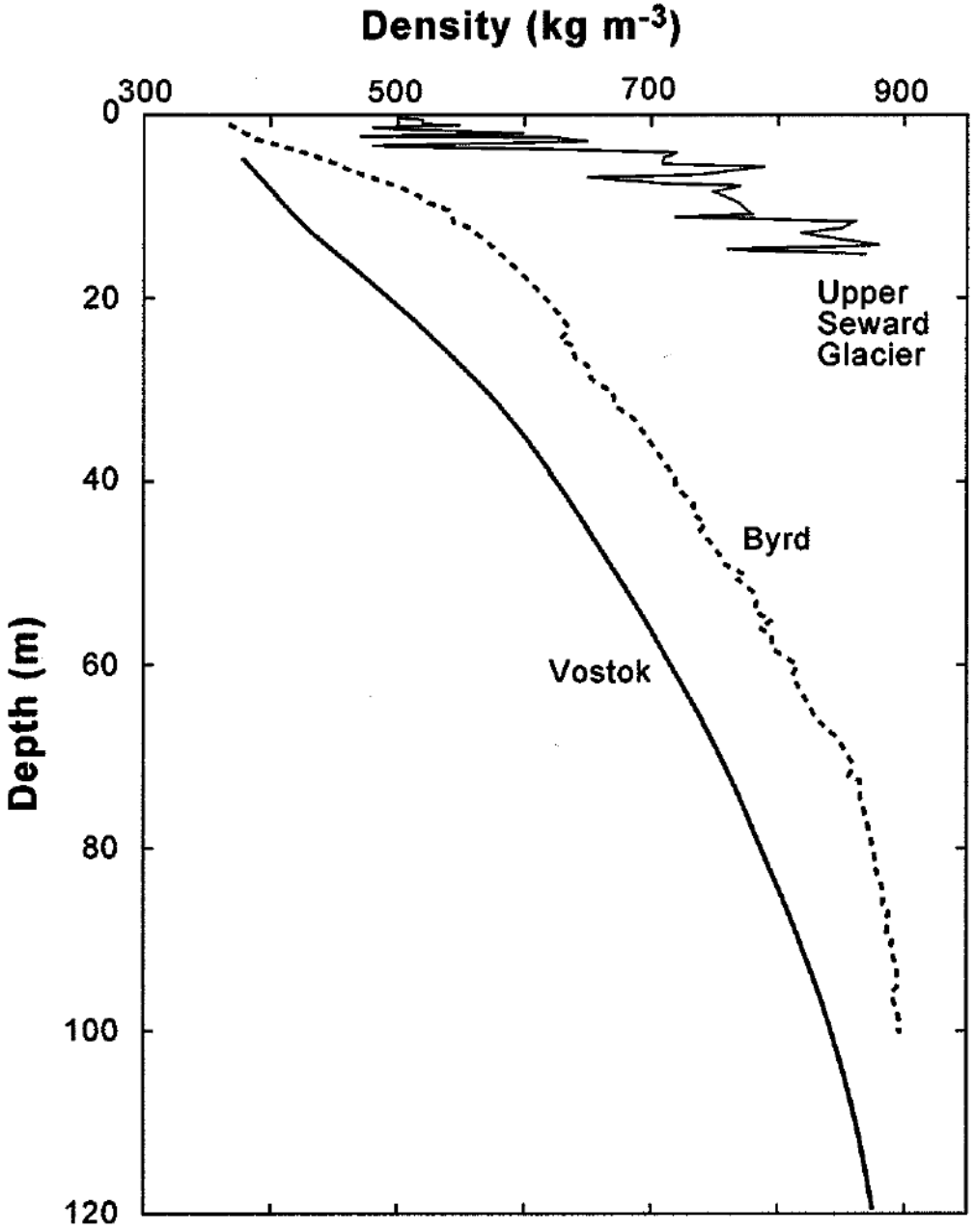
Snow blowing
At NEEM
June 2008

Collapsing
trenches
At NEEM
June 2012

Layers in the Ice

Snow structure revealed in a double pit.

Sampling the top meters with hand-auger, in pits or with tubes



Cuffey and Paterson, 2010

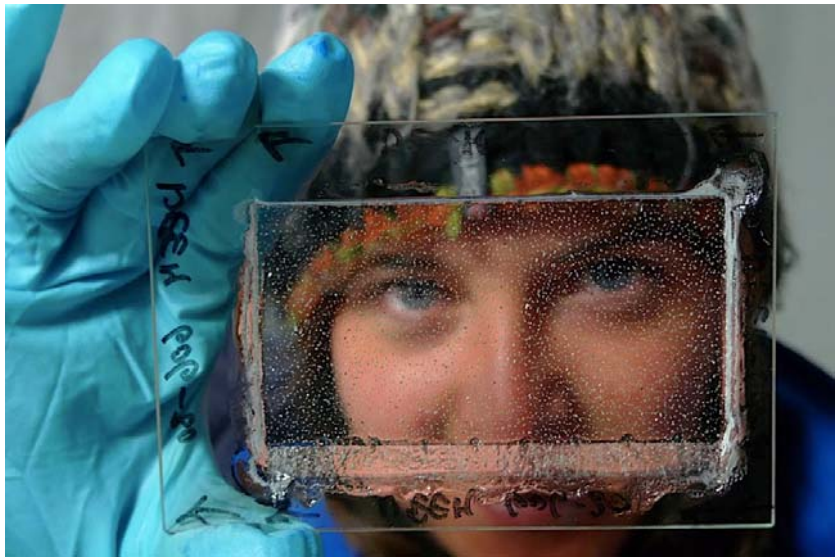
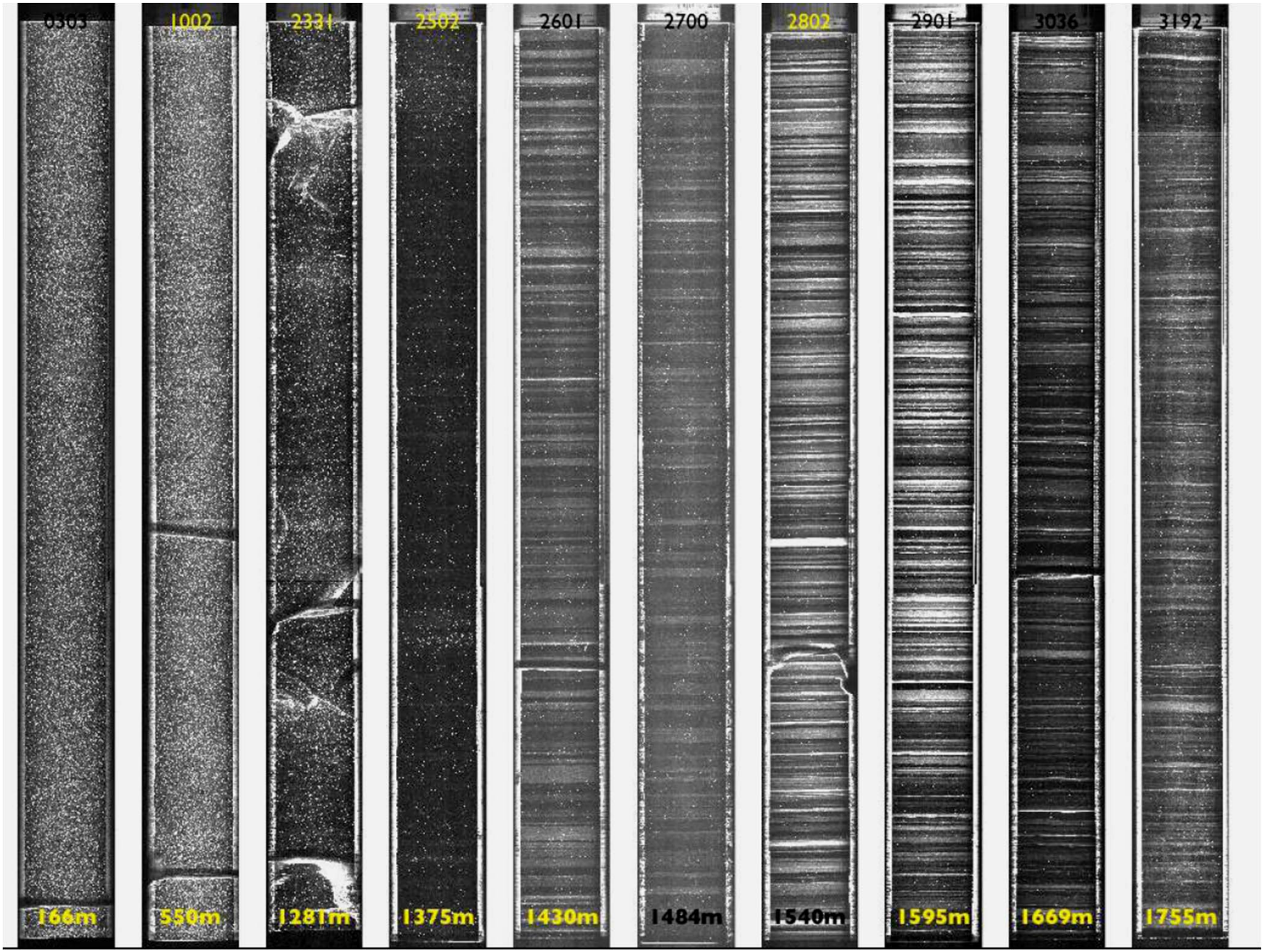


Image credit: www.icecores.dk



Svensson et al. 2005, Journal of Geophysical Research

NorthGRIP Continuous Flow Analysis (CFA) and Visual Stratigraphy (VS)

Continuous high-resolution profiles of the concentrations of Ca^{++}, Na^{+}, NH_4^{+}, SO_4^{--}, NO_3^{-}, the electrolytical conductivity, the amount of insoluble dust, and the visible intensity grey scale.

Wet chemical analysis

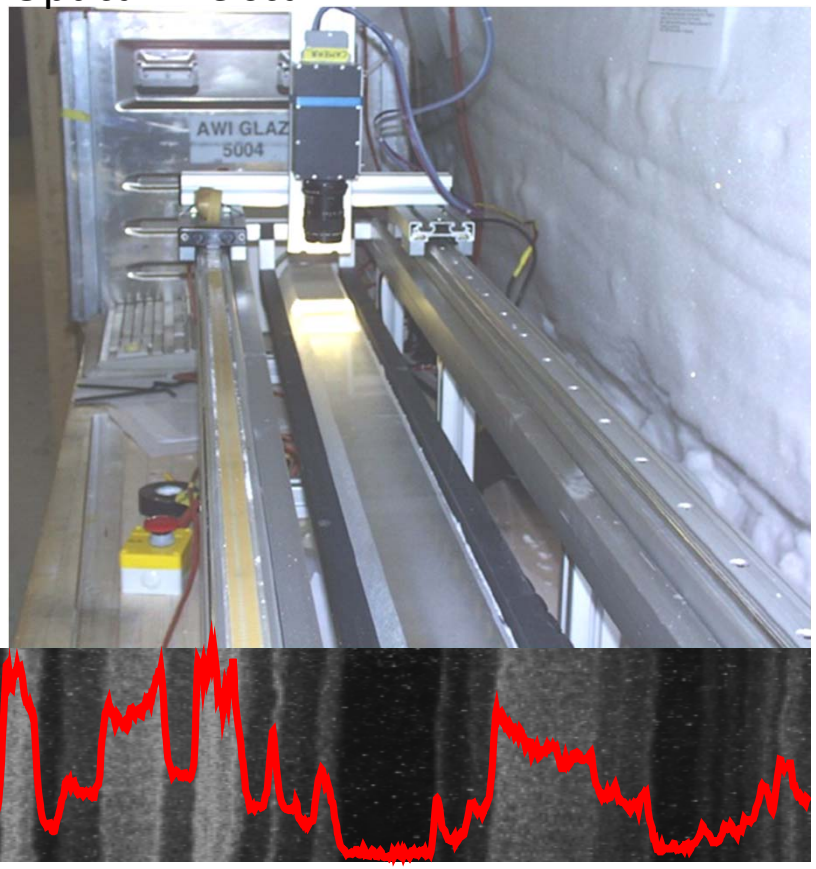
Röthlisberger et al. 2000

Ruth et al. 2003

Bigler, 2004

Svensson et al., 2005

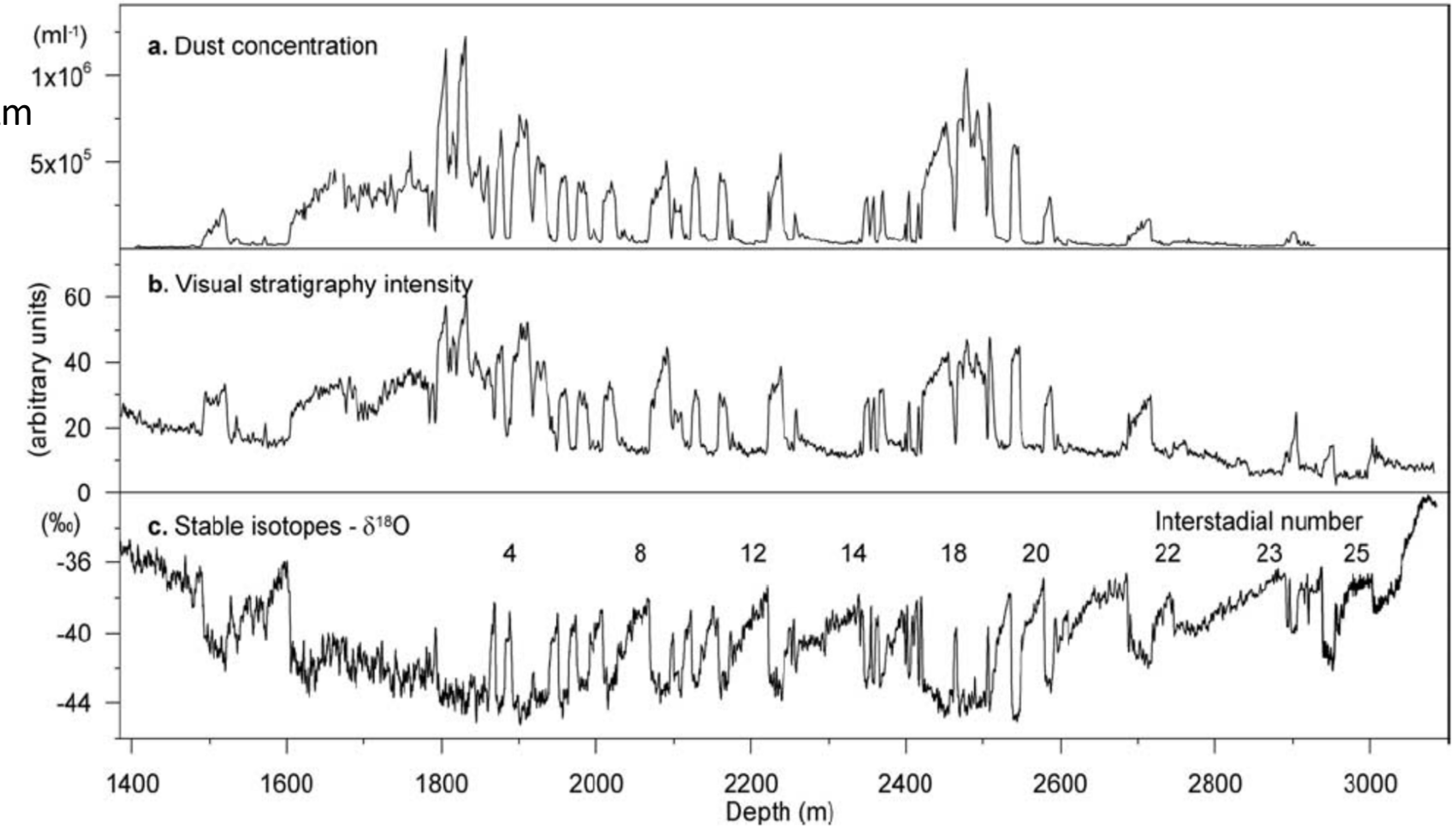
Optical line scan



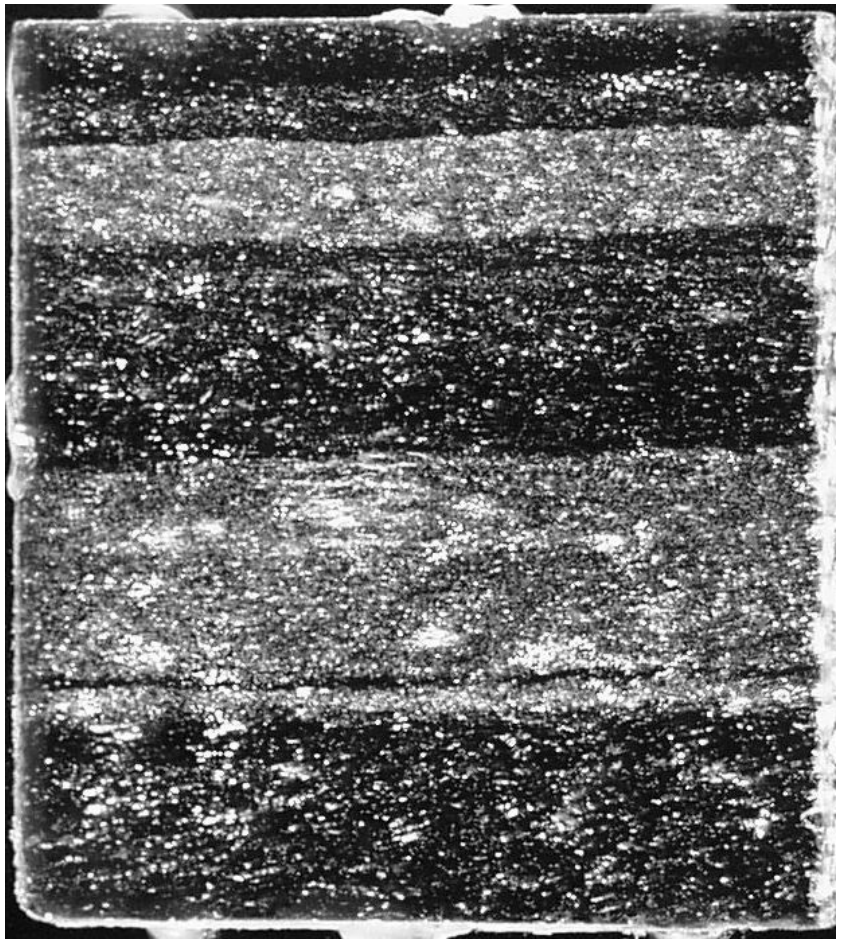
The deep visual layers are caused by increased concentration of insoluble dust particles.

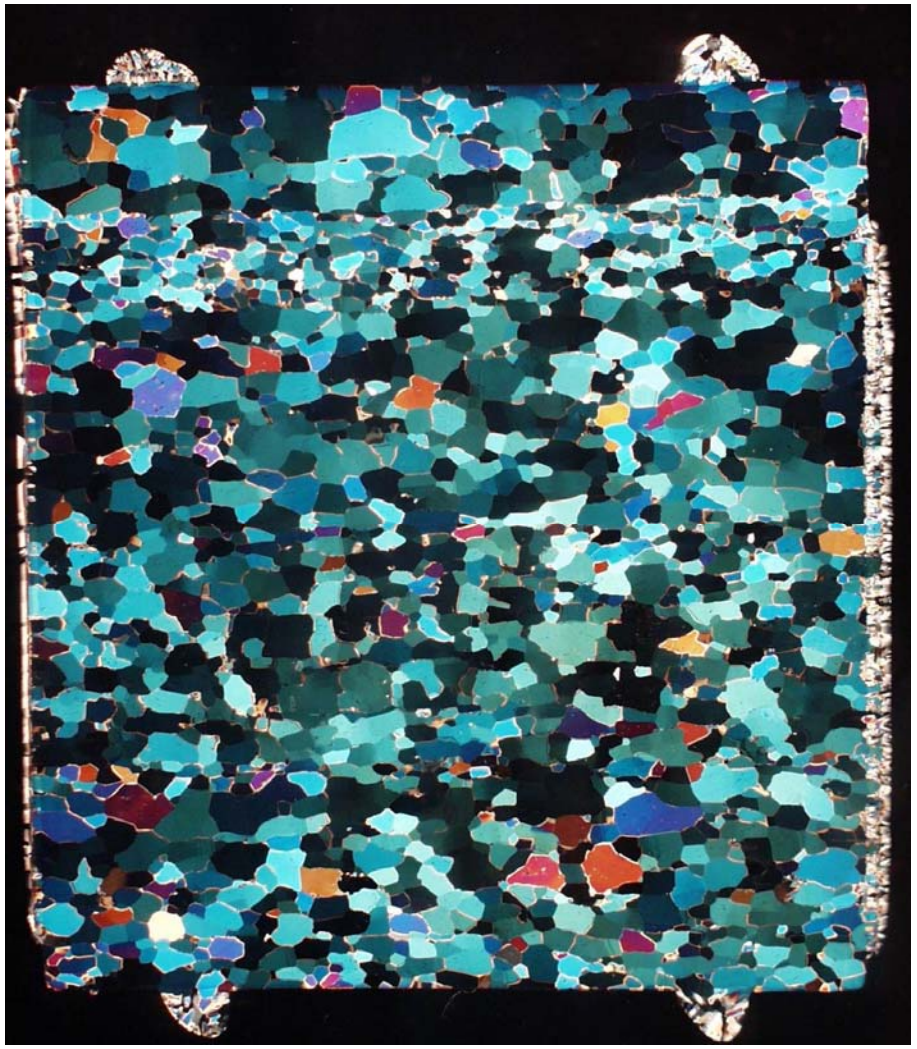
Dust concentration is enhanced during cold glacial stadials

No >1µm

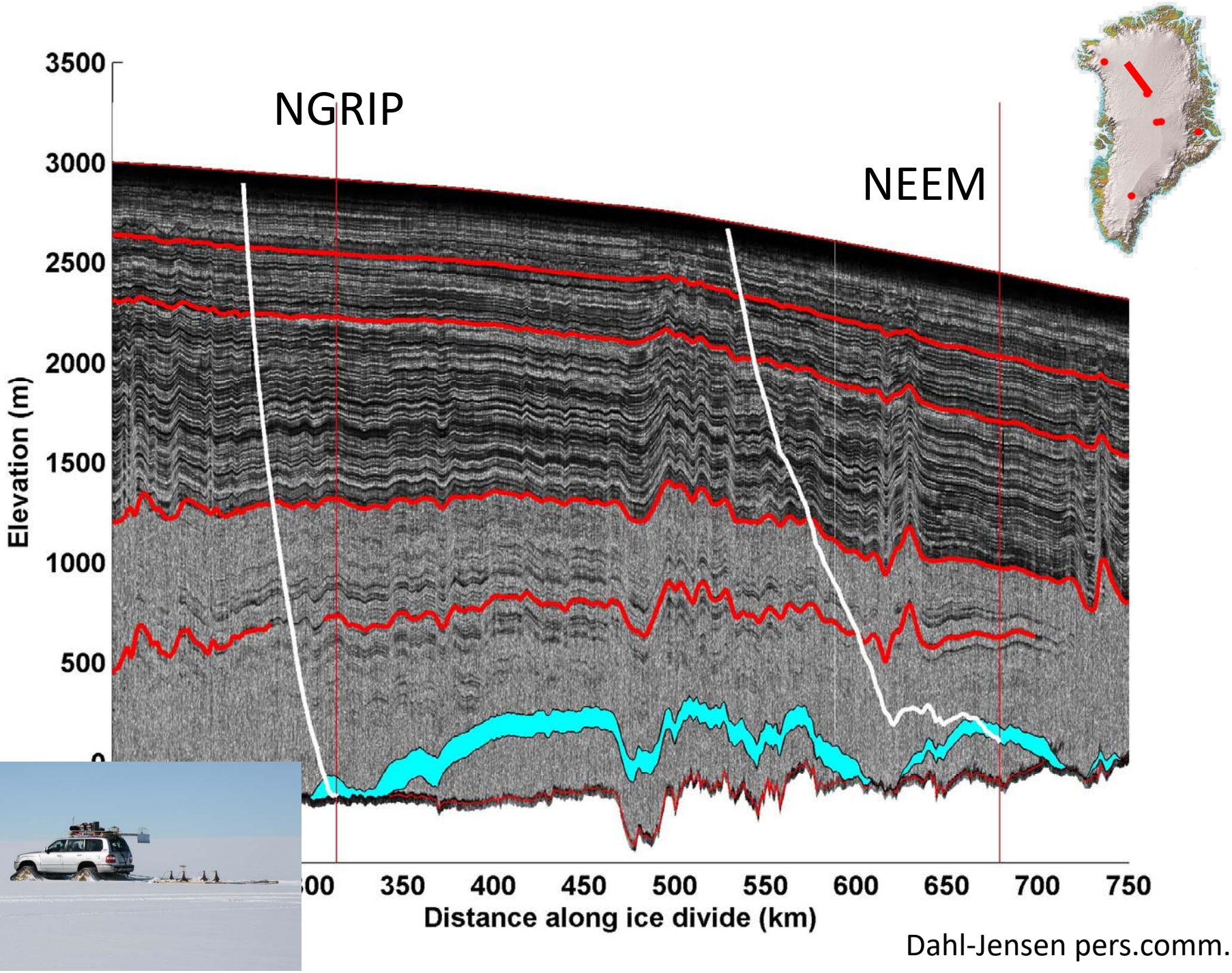


Svensson et al 2005





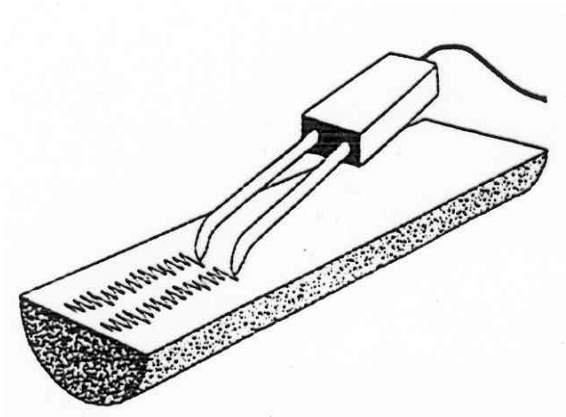
Svensson et al 2003



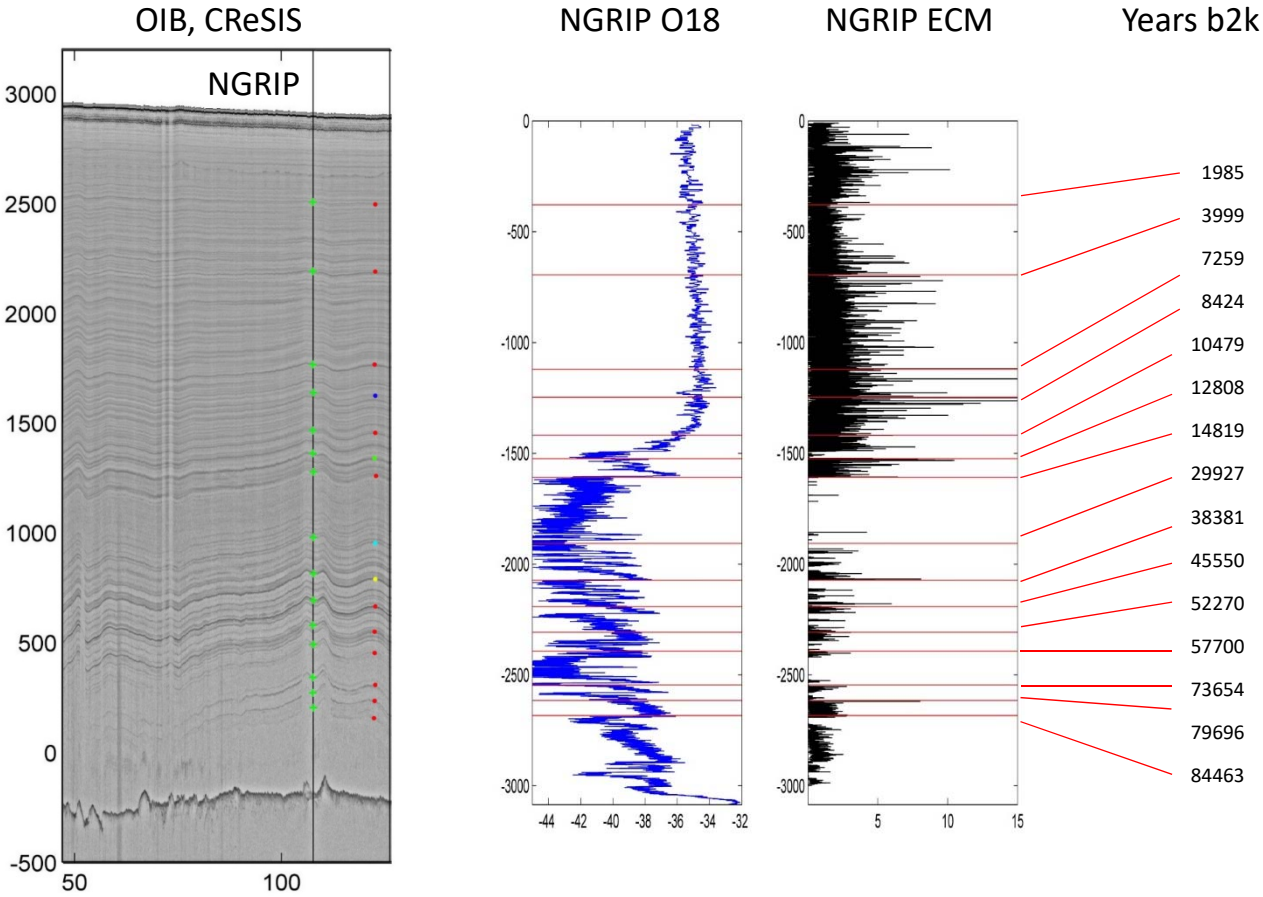
Dahl-Jensen pers.comm.

Electrical Conductivitity Measurement (ECM)

- Fast, high resolution (1mm)
- H^+ ions
- Good indicator of volcanic events



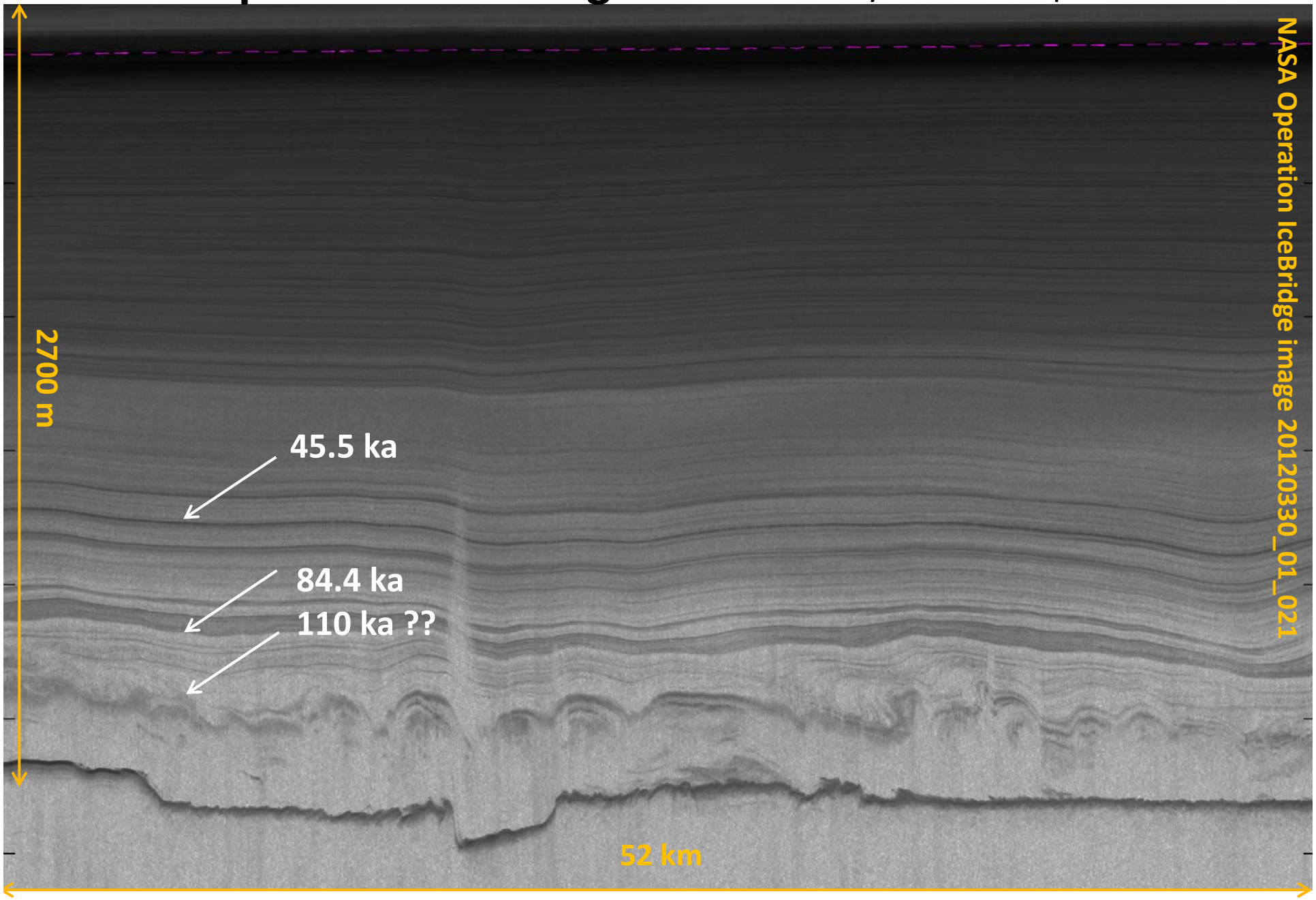
Relation between radar layers and chemical impurities



At NGRIP the internal layers have been mapped against the ice core data and can be dated using GICC05ext. There is a shift of 28 m between the RES depths and the ice core depths.

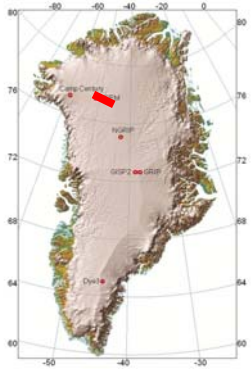
Dahl-Jensen pers.comm.

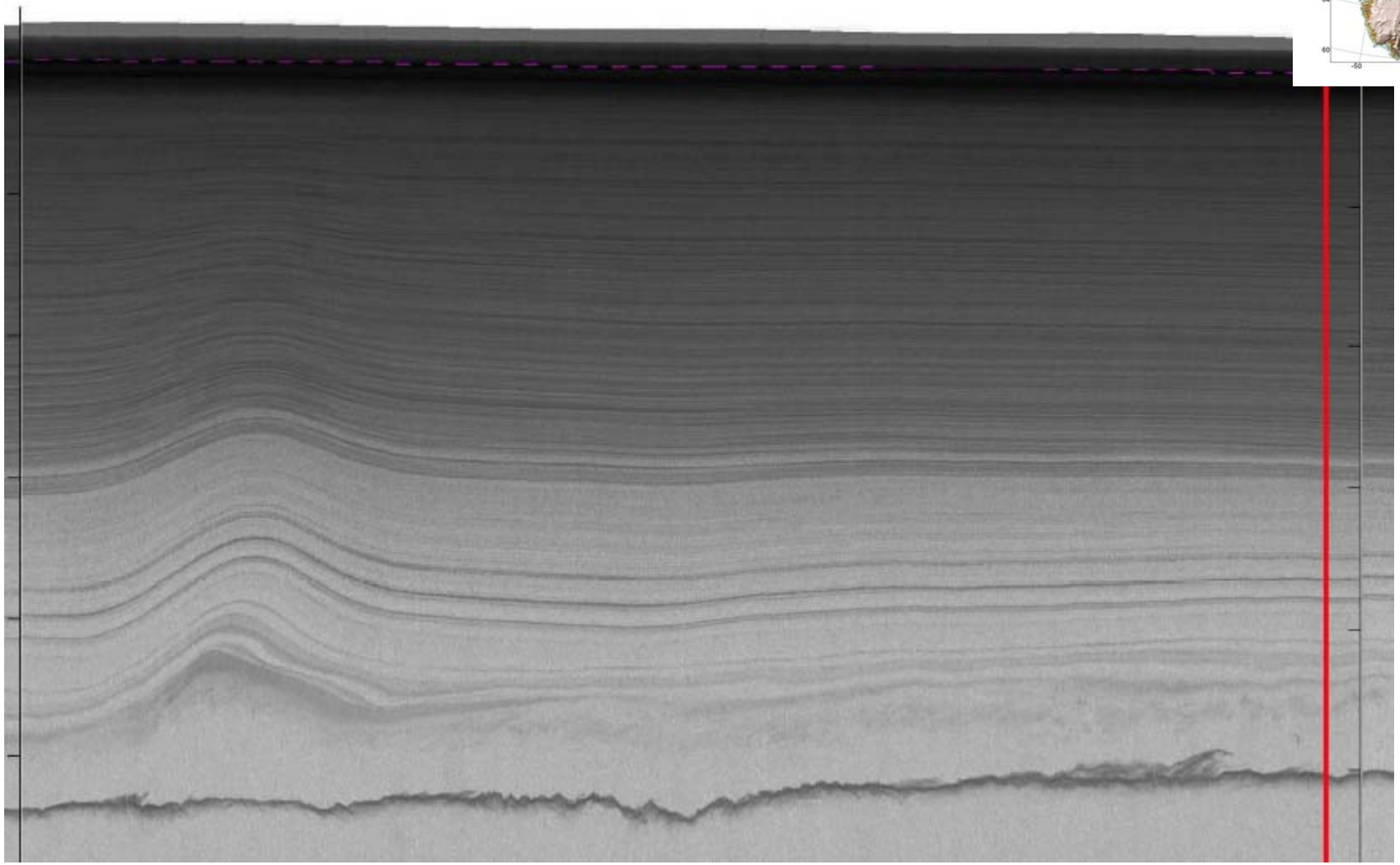
NASA Operation Ice bridge Airborne surveys of Earth's polar ice



NASA Operation Ice bridge

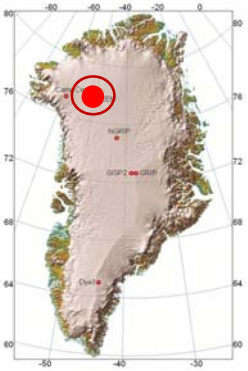
Radar stratigraphy upstream from the NEEM ice core site





Appr. 60 km long section upstream from NEEM. Ice thickness is 2.5-2.6 km

NEEM 2010

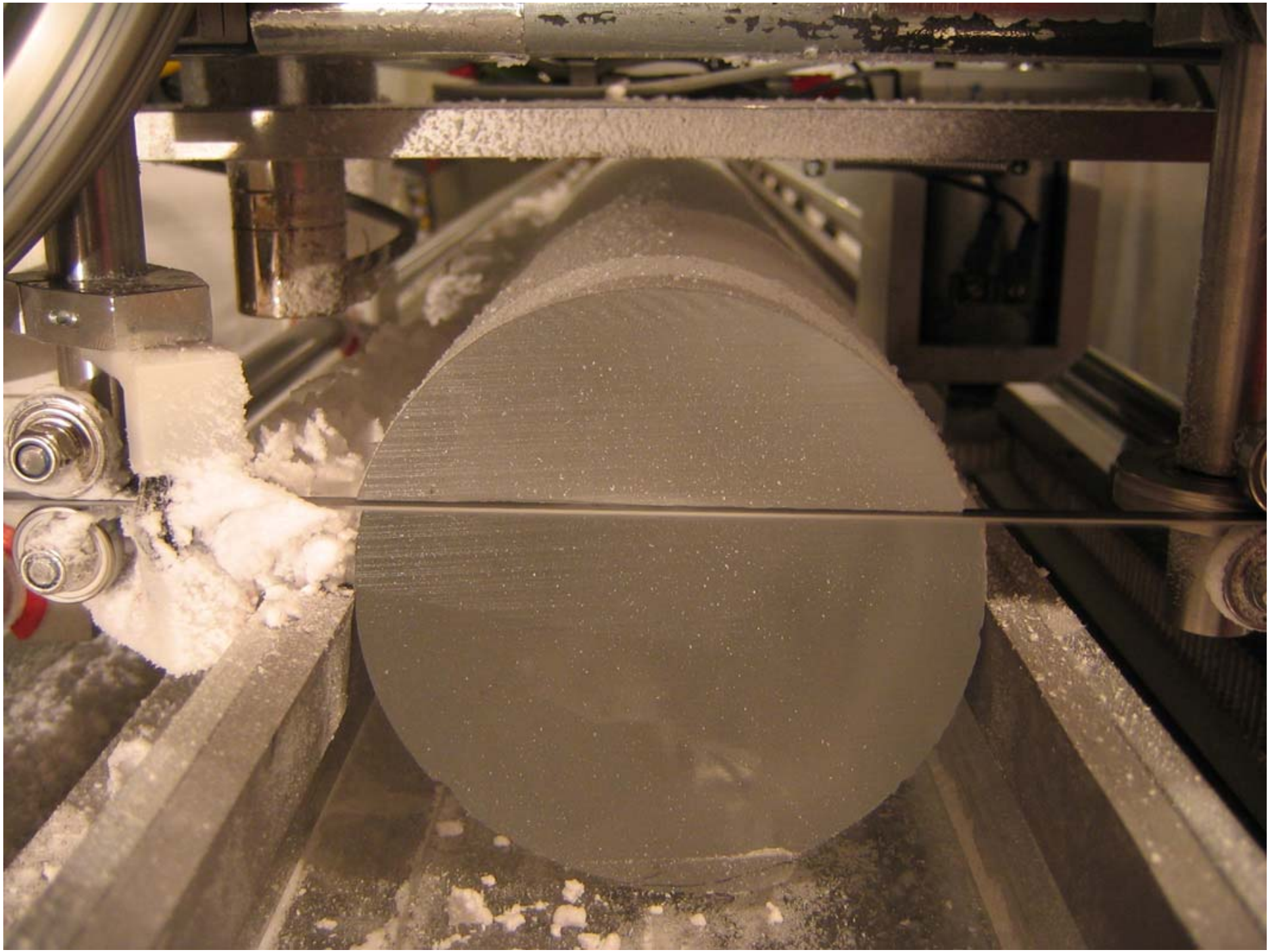


Bottom reached in 2537,36 m depth

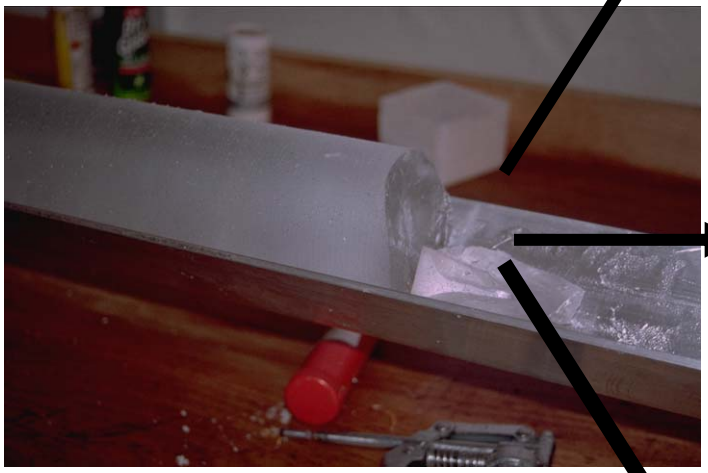
Granite stones and gravel in the bottom meters

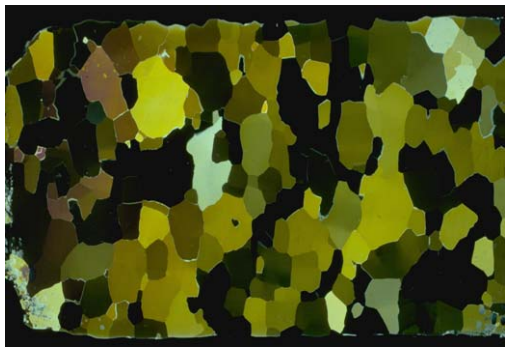
Bottom rock/soil core drilled at 2522 m depth at NEEM, 14 june 2012

Ice core drilling at EastGRIP, July 2017



The climate archive in ice cores



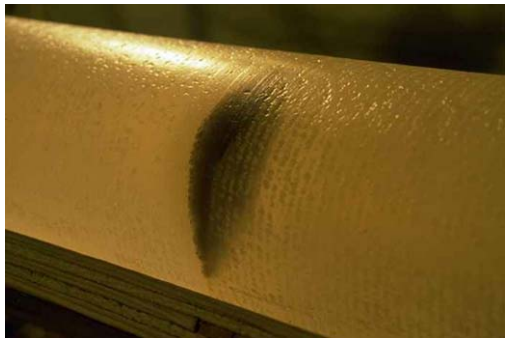


The ice matrix:

Water isotopes $\delta^{18}O$, δD

Accumulation rates

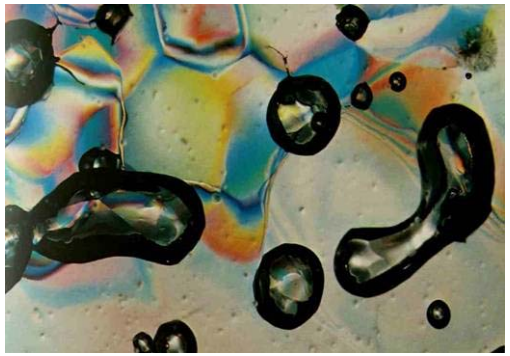
Crystal size and orientation



Impurities:

Continental dust, tephra

Soluble impurities



Airbubbles:

Trace gases

On-line impurity analysis

Na^+

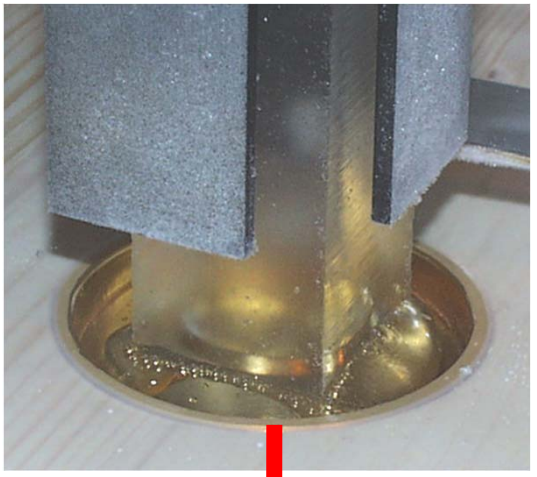
Ca^{2+}

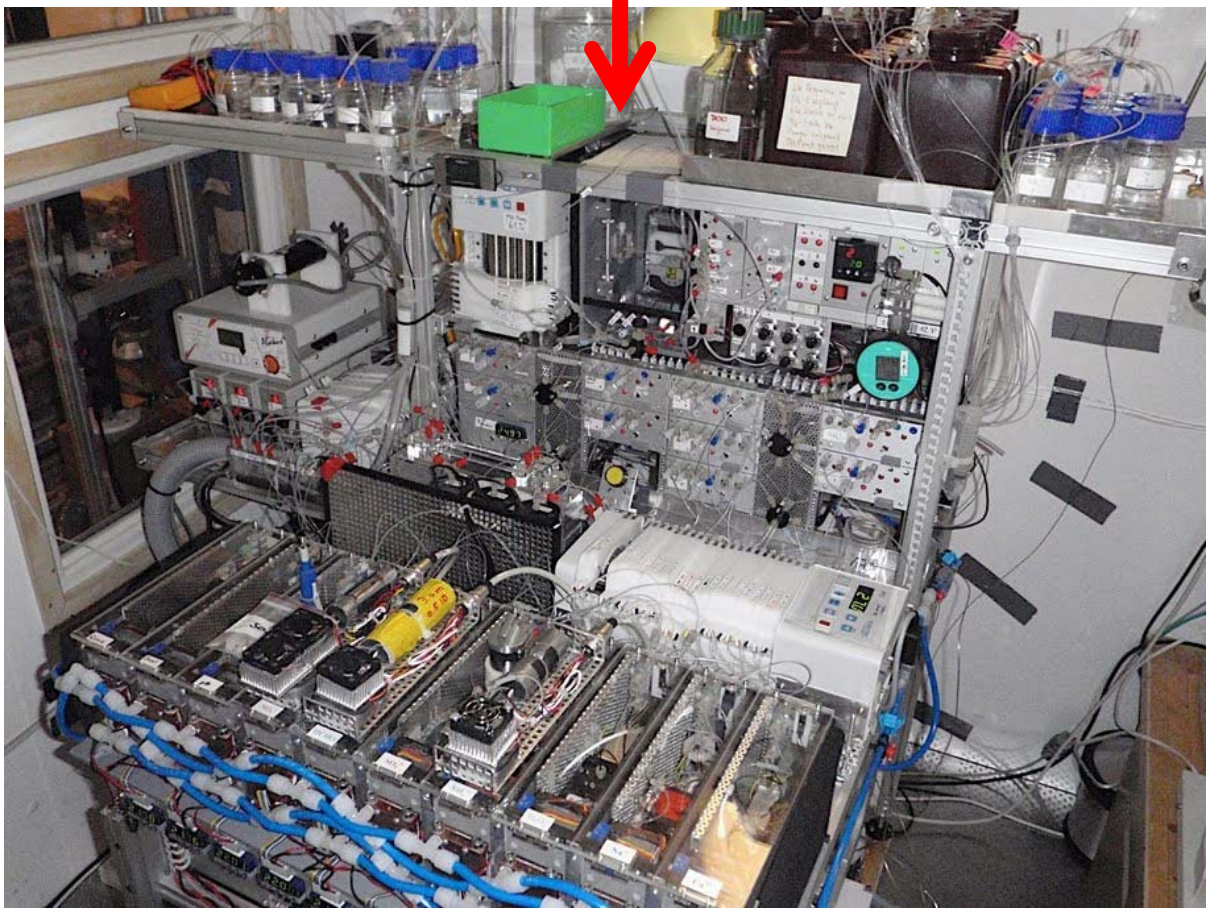
SO_4^{2-}

NH_4^+

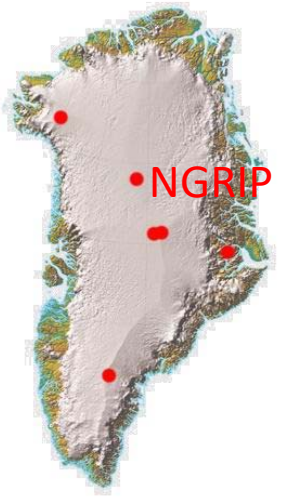
NO_3^-

+ water isotopes and more

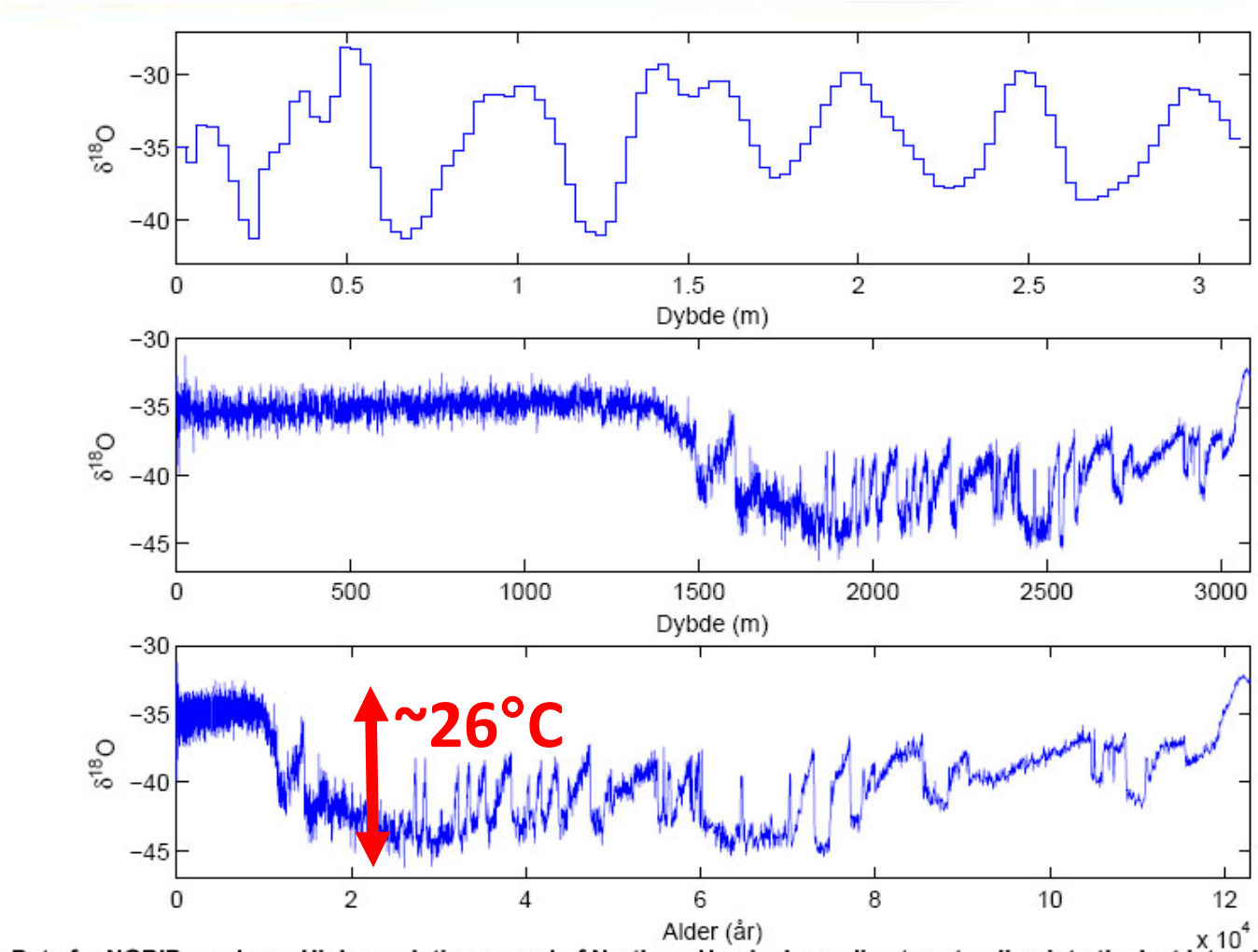




Climate history from the NorthGRIP core



$\delta^{18}O$

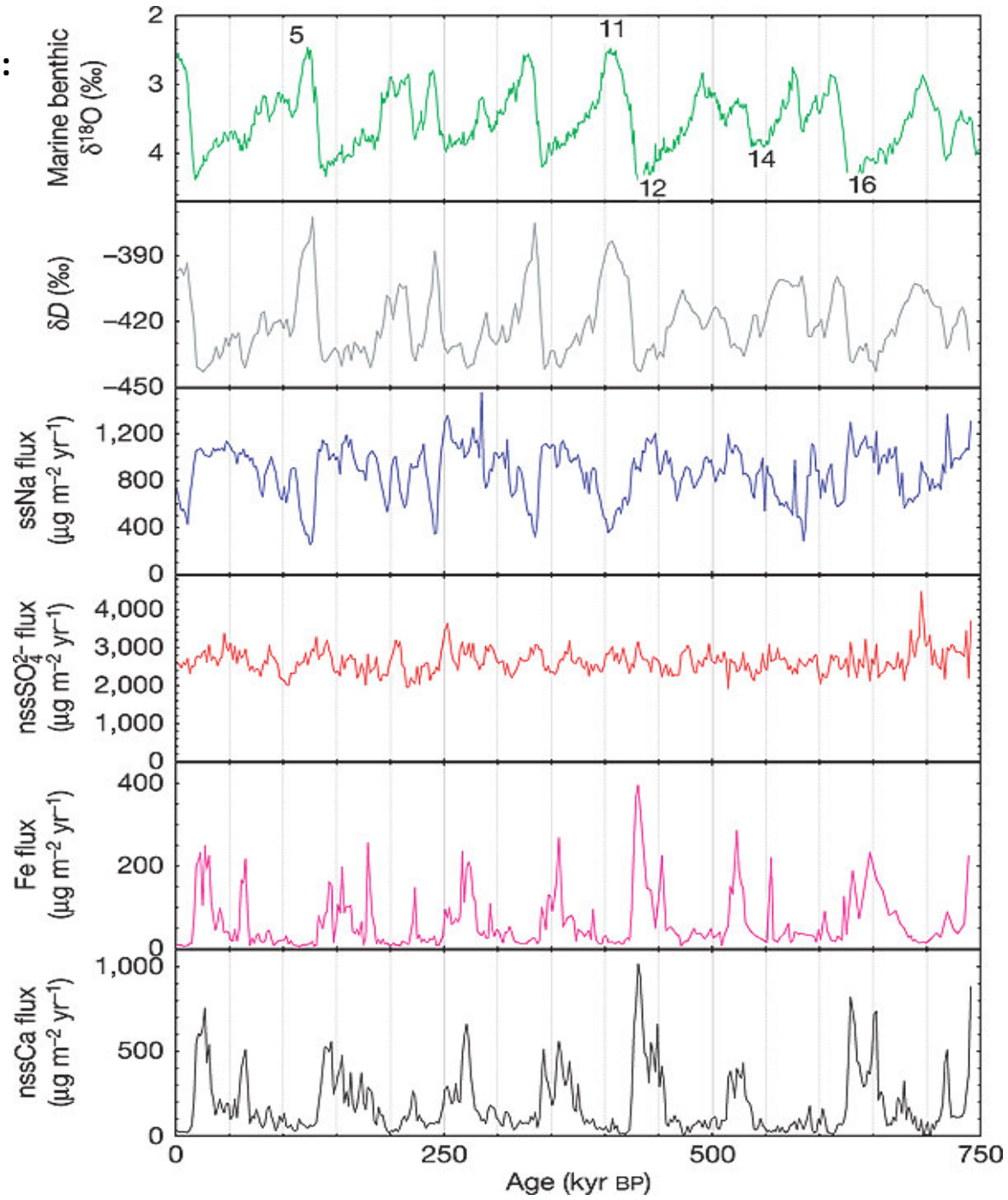


120 kyrs BP

Data fra NGRIPmembers: High-resolution record of Northern Hemisphere climate extending into the last interglacial period Nature, Vol. 431, p. 147-151, 2004 .

Climate record from ocean sediments:
Indicate the volume of continental ice

Chemical impurities in the Dome C Ice core, Antarctica:
They vary in concert with climate and suggest stable forcings



Wolff et al, 2006

Summary

- Ice cores contain an undisturbed stratigraphic record of ~100 kyrs (Greenland) and ~1 mill. Yrs (Antarctica). Older layers are disturbed by flow or removed by basal melt.
- Ice cores records provide climate proxies with a resolution of timescales from years to 100 kyrs.
- Ice core climate proxies inform on past climate dynamics. However, interpretation of the proxies is not straight forward.
- Access to the ice core climate archive depends on a variety of techniques – using a suite of instruments from very simple to highly specialized.

Open surface with wind drift at EGRIP July 2017