



Temperature reconstruction from polar ice cores: Greenland versus Antarctica

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Paleoclimatology: Natural Archives



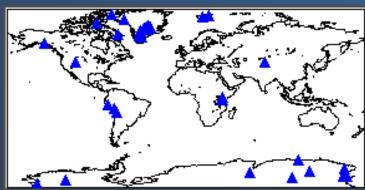
POLAR ICE CORES: Antarctica and Greenland



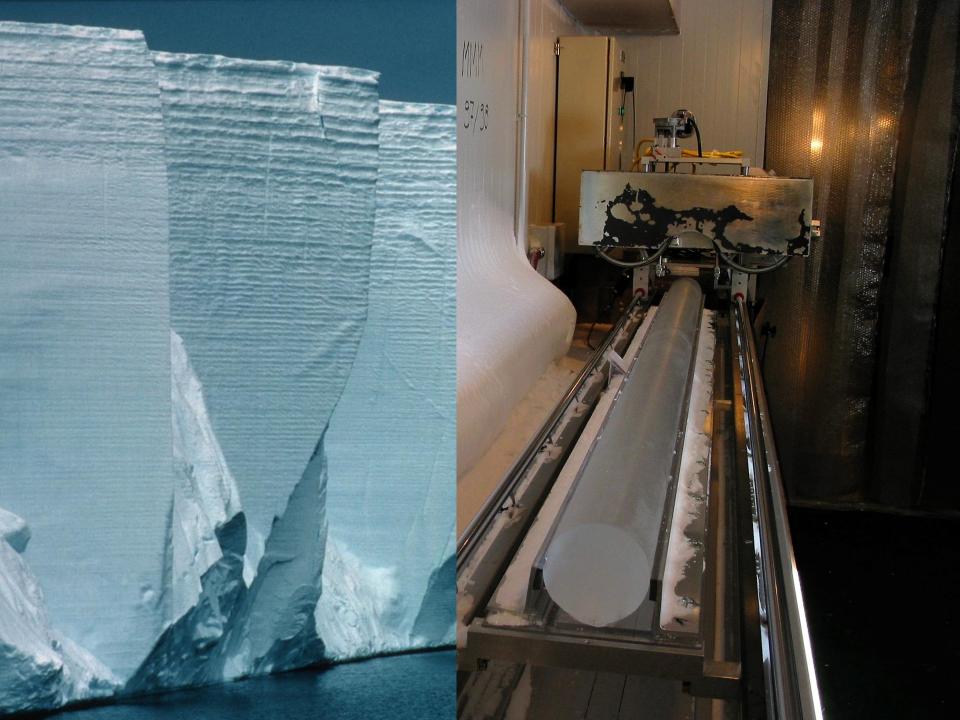


Timescales from decades to hundreds of millennia

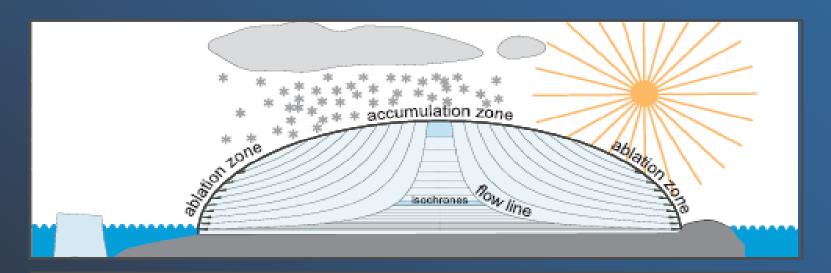
Different proxies (water stable isotopes, aerosol concentrations, CH₄ and CO₂ in air bubbles, dust content etc.)

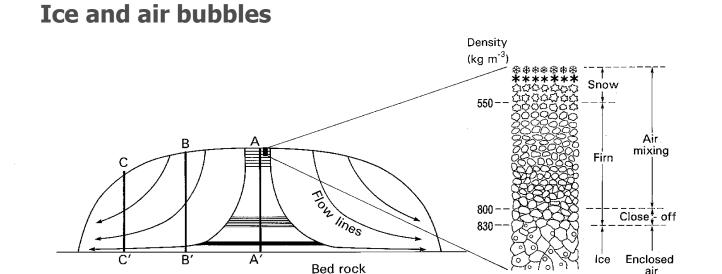


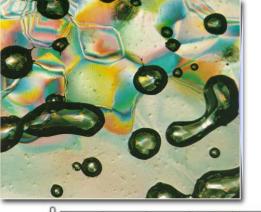
Not only Polar Ice Cores!!!



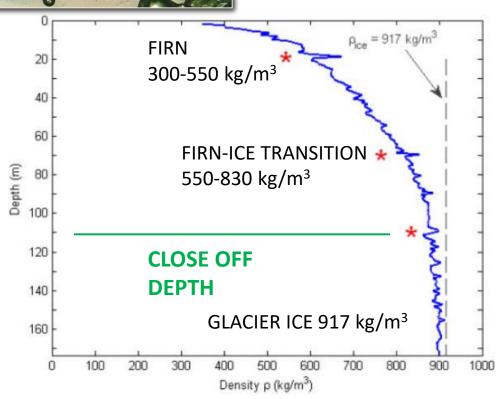
Ice sheet section



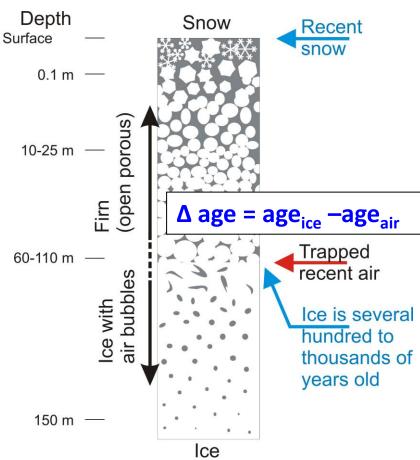




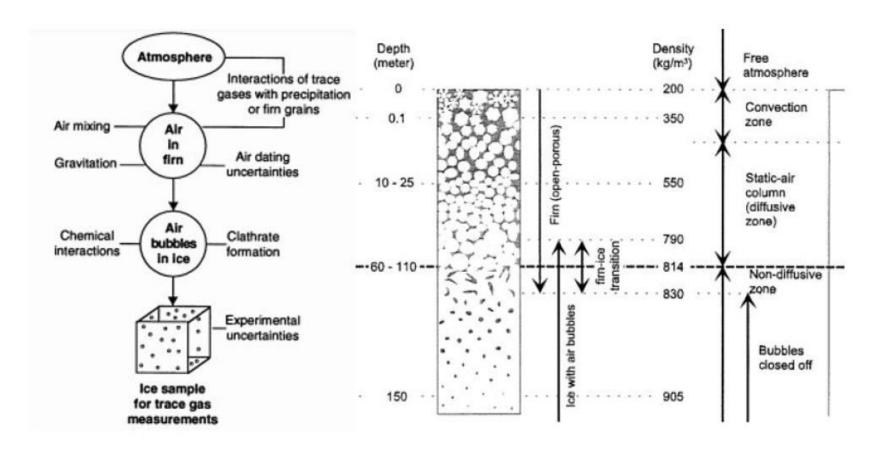
ICE AND BUBBLES

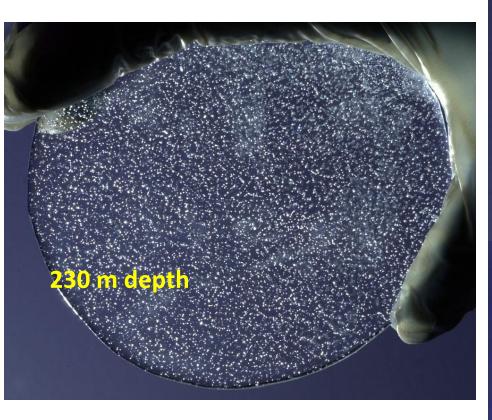


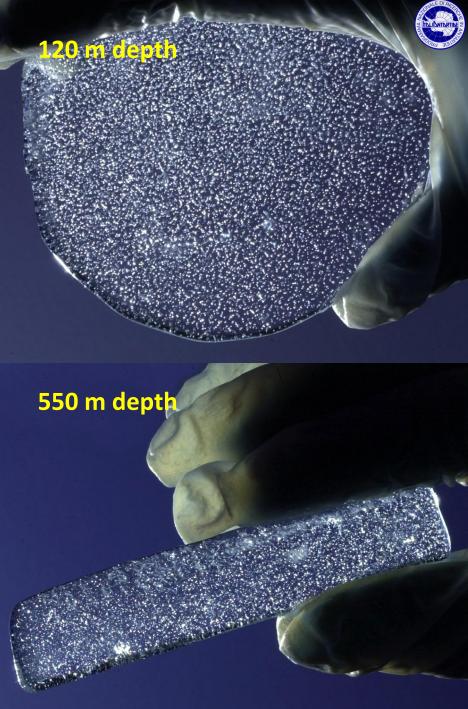
The change of density with depth measured at DYE-3 in southern Greenland (www.nbi.ku.dk)



Schematic of firn-air transition with depth in Greenland (www.nbi.ku.dk)



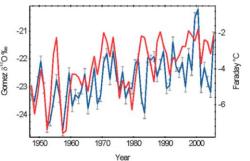






Antarctic ice cores: from decades to hundreds of millennia

THOMAS ET AL.: SIGNIFICANT ANTARCTIC PENINSULA WARMING





air bubbles

Gomez ice core (AAP) Thomas et al., 2009

EPICA Dome C ice core Jouzel et al., 2007



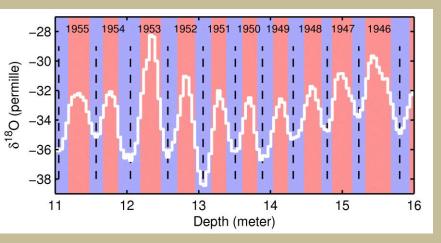
320 Sepical Dome C 320 Sepical Sepical Dome C 240 S

Different proxies (water stable isotopes, aerosol concentrations, CH₄ and CO₂ in air bubbles, dust content etc.)



Dating

Annual layer counting (Greenland, coastal Antarctica)



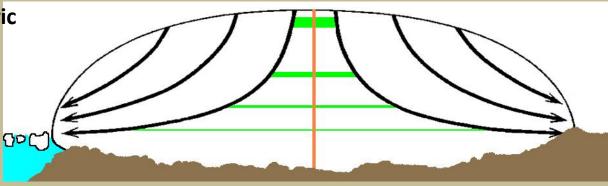
Ice core synchronisation thanks to the well-mixed global atmospheric composition



Volcanic horizons

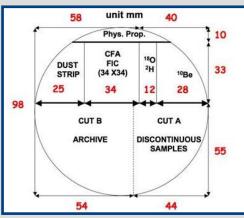


Glaciological modeling: accumulation, thinning, ice flow

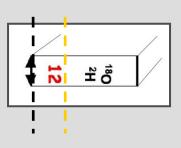


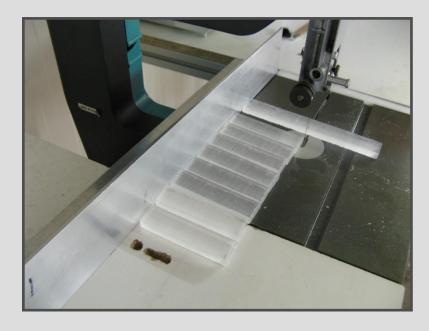


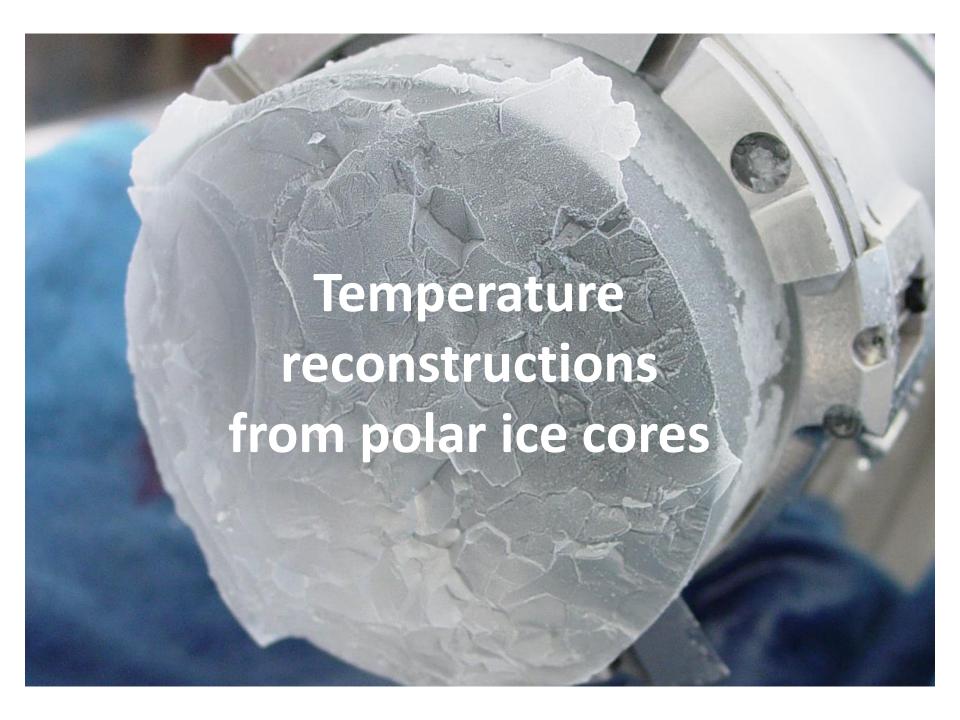




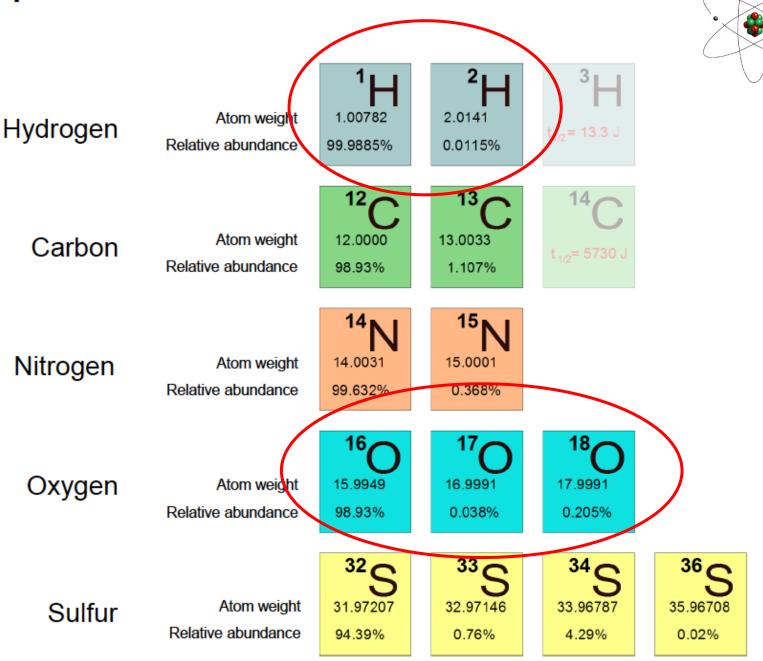








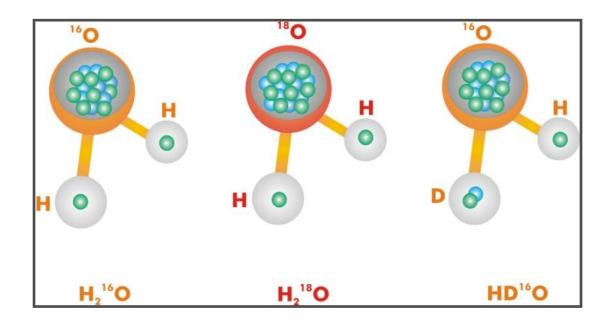
Isotopes



Oxygen and Hydrogen isotopes

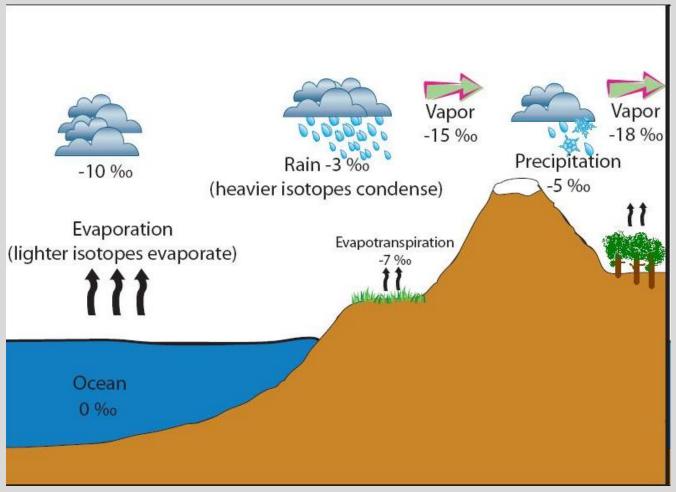
$$\delta = [(R_{sample} - R_{standard})/R_{standard}] \times 1000$$

$$R = (^{18}O)^{16}O \circ D/H)$$
 Standard: V-SMOW

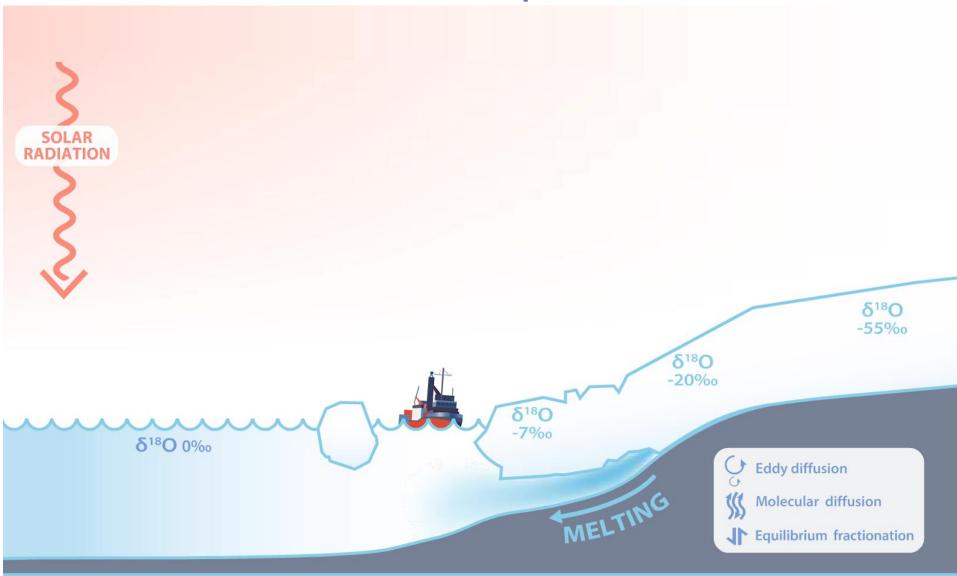


Hydrological cycle and isotopic fractionations

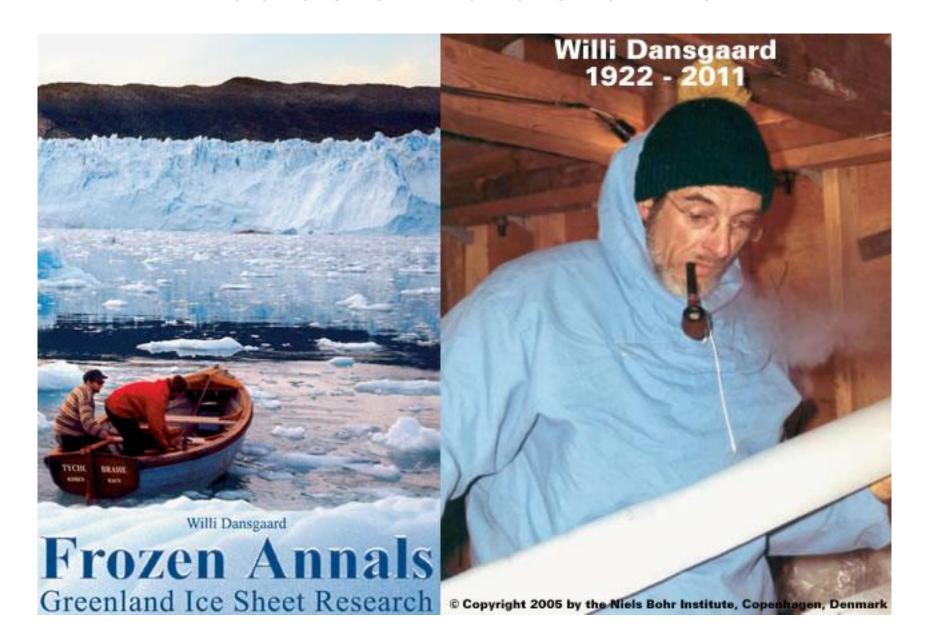
The oxygen and hydrogen isotopes are natural tracers of the hydrological cycle. The relationship between the oxygen and hydrogen isotope composition of precipitation and the condensation temperature derives from the isotopic fractionations occurring at each phase change due to the vapour pressure difference of the water isotopic molecules $HH^{16}O$, $HD^{16}O$, $HH^{18}O$ (vap. p. $HH^{16}O > HH^{18}O$).



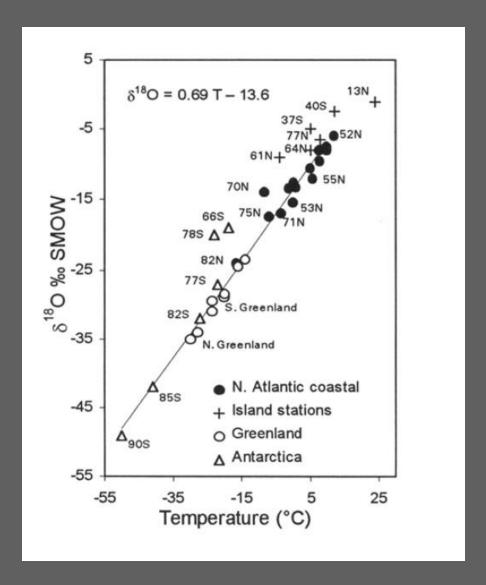
$\delta^{18}O$ and temperature



Ice as climate archive

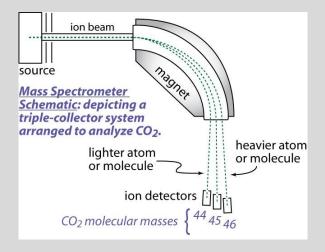


δ^{18} O/T relationship – Dansgaard 1964



Latitudinal, continental, seasonal and altitude effects.

Measurements techniques



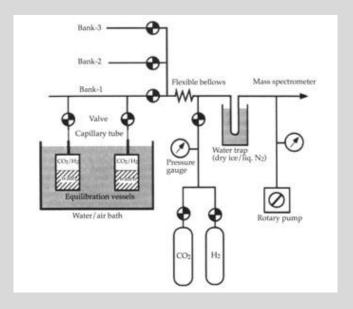


Thermo Finnigan Delta Plus Mas Spectrometer with HDO automatic device.

Isotope Ratio Mass Spectrometer technique (IRMS)

CO₂-H₂/H₂O equilibration method at constant T

 $C^{16}O_2+H_2^{18}O \longleftrightarrow C^{18}O^{16}O+H_2^{16}O$ for oxygen $HD+H_2O \longleftrightarrow H_2+HDO$ for hydrogen 3-5 ml samples





Laser absorption spectroscopy

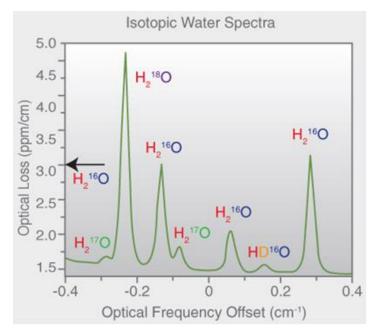
Laser Absorption Spectroscopy (LAS) is the set of analytical techniques that uses a laser pulse to determine the concentration of a gas species based on the specific absorption at a given wavelength, which is characteristic of every single gas molecule (for example: CO_2 , H_2O , H_2S , NH_3).

The advantage of this analytical technique is to determine absolute quantities. The different isotopes that make up a given molecule (e.g. 16 O o 18 O in CO₂, H₂O, ...) give this molecule different absorption properties \rightarrow different

absorption peaks.

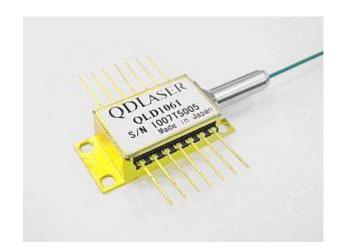


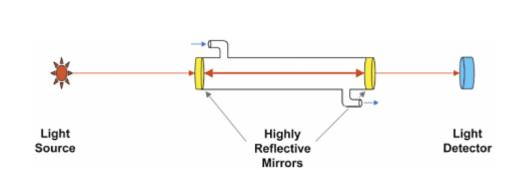
Possibility, through LAS, to discriminate between the different "isotopologues" (molecules characterized by different isotopes)



Laser absorption spectroscopy

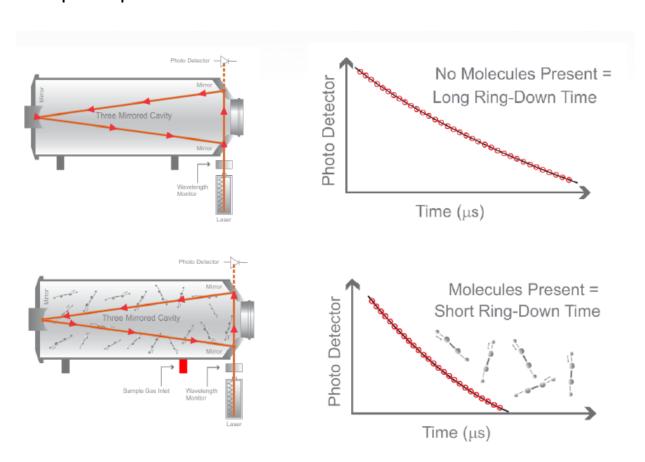
The Cavity Ring-Down Spectroscopy (O'Keefe, 1988) is based on the extinction time of a laser beam in the presence / absence of the sample. The laser pulse travels a long optical path inside a cavity, bouncing between 2 or more high reflectivity mirrors, until the photoreceptor is no longer able to measure it. In the absence of a sample, the extinction of the beam depends only on the non-perfect reflectivity of the mirrors, in the presence of the sample, on the concentration of the absorbent molecules.





The cavity is a small metal box (35 cc) into which the vaporized sample is introduced:

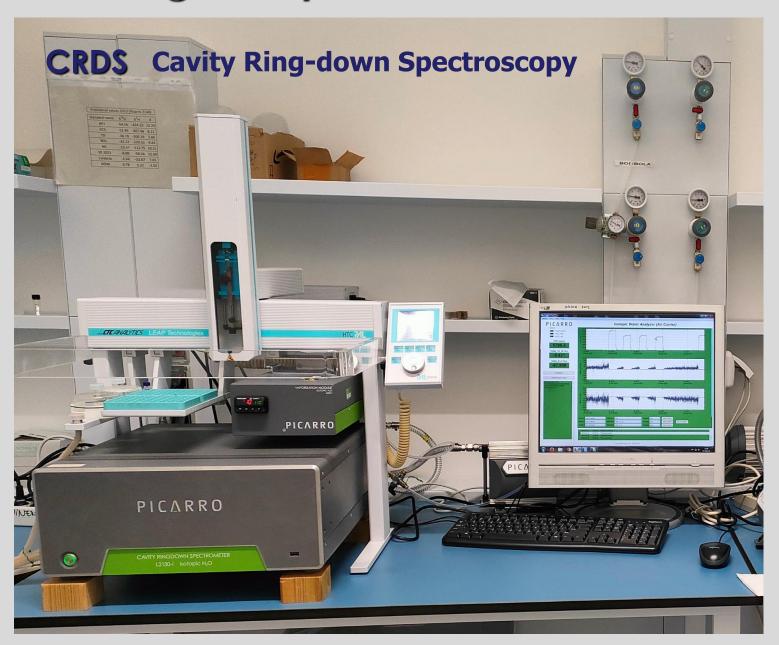
- Constant temperature: 80 (±0.002)°C
- Constant pressure: 35-50 (±0.76) torr
- 3 high reflectivity mirrors (99.995%)
- Optical path>10 km

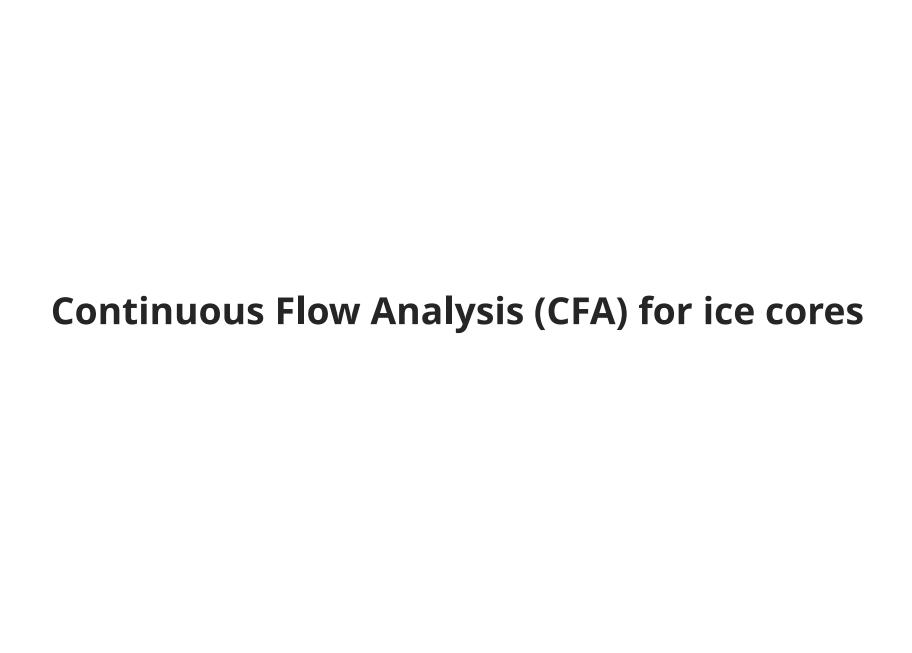


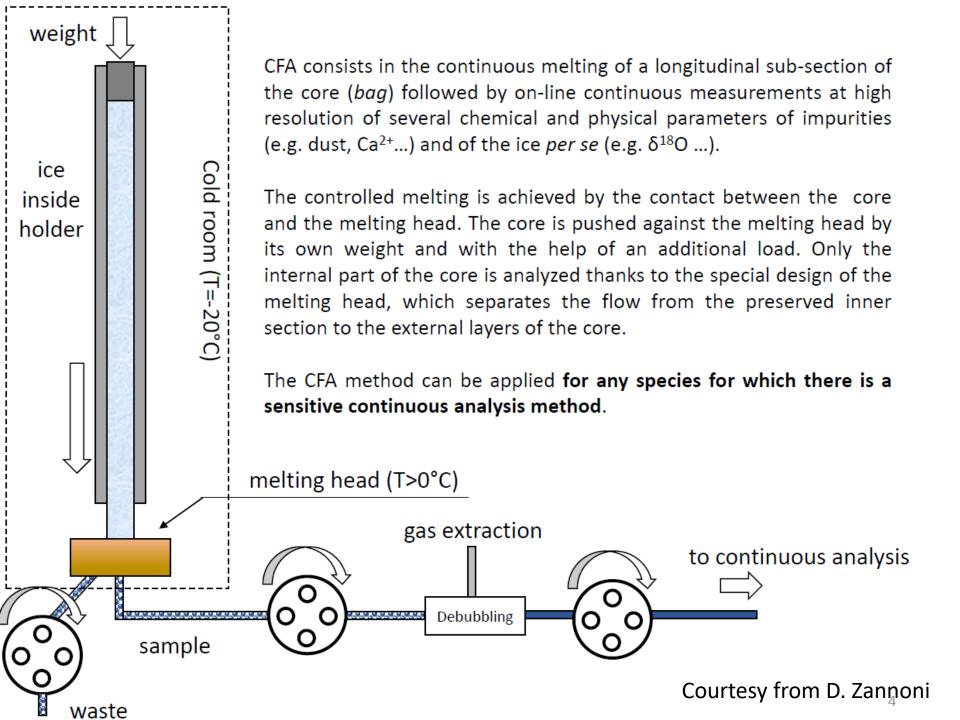
The presence of the analyte in the cavity reduces the decay time of the laser beam

PICARRO

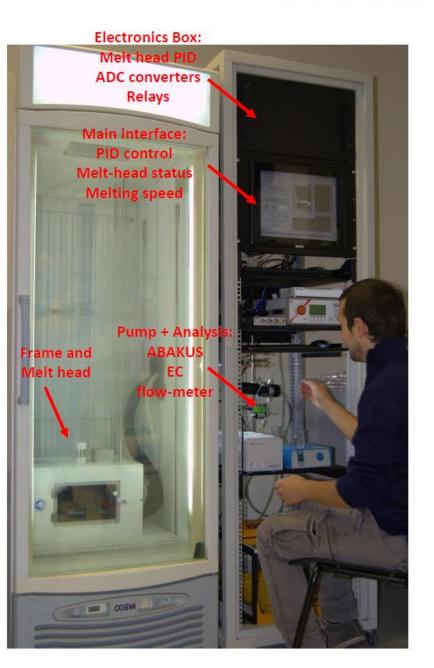
Measuring isotopic molecules with lasers







The CNR-ISP CFA system: work in progress



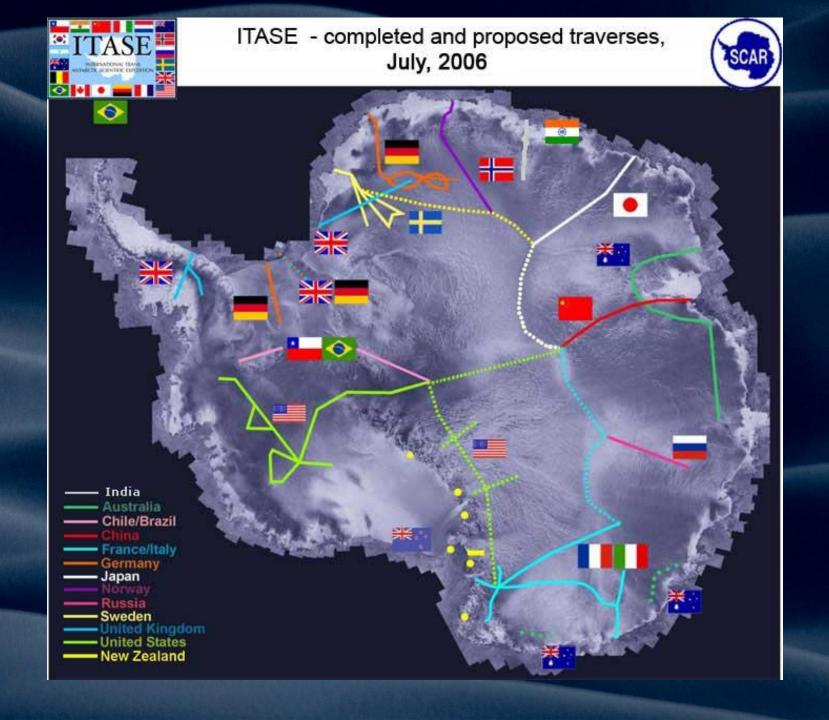
Features we are currently working on:

- Dust particles counting and size distribution (ABAKUS)
- Water Isotopes (CRDS)
- Total Soluble Iron Content (Absorbance)
- Electrical Conductivity (small-volume EC cell)
- Fraction collectors (commercial and DIY)

Software and languages used:

- Process control (LabVIEW, Python, C/C++)
- Data analysis and post processing (R, MATLAB, Python)

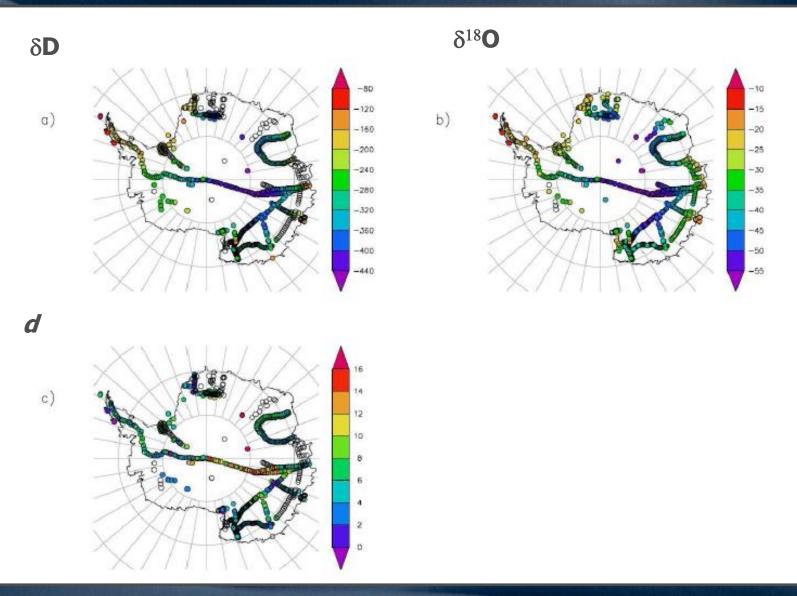
The isotopic proxy calibration issues



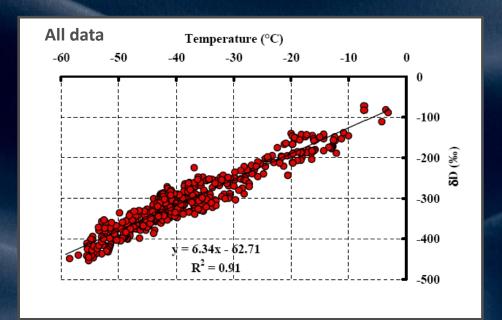




Database of surface snow isotopic composition



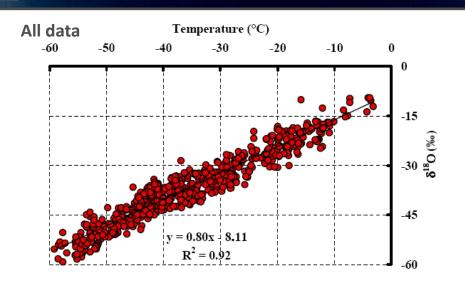
Database of surface snow isotopic composition



Spatial δ/T slopes

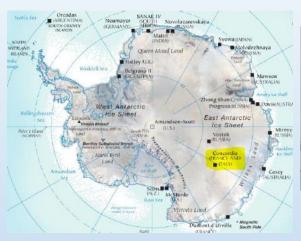
6.34 %/° C for δD

0.8 % ° C for δ^{18} O



Dome C (East Antarctica)

The French-Italian permanent base (Concordia) was established in 2005





75°06'S 123°21'E

Elevation: 3233 m a.s.l.

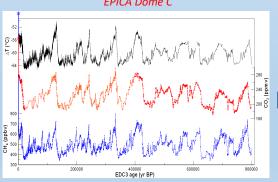
Temperature at 10 m of depth: -54.5°C 2-m Temperature (AWS): -51.2°C (2008-

2016)

Mean snow accumulation rate: 25 kg m⁻² yr⁻¹

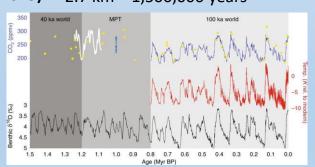
Dome C (2004)

3.3 km – 800,000 years



Ideal place for ice coring!

Little Dome C, about 40 km from Dome C (2025) 2.7 km – 1,500,000 years

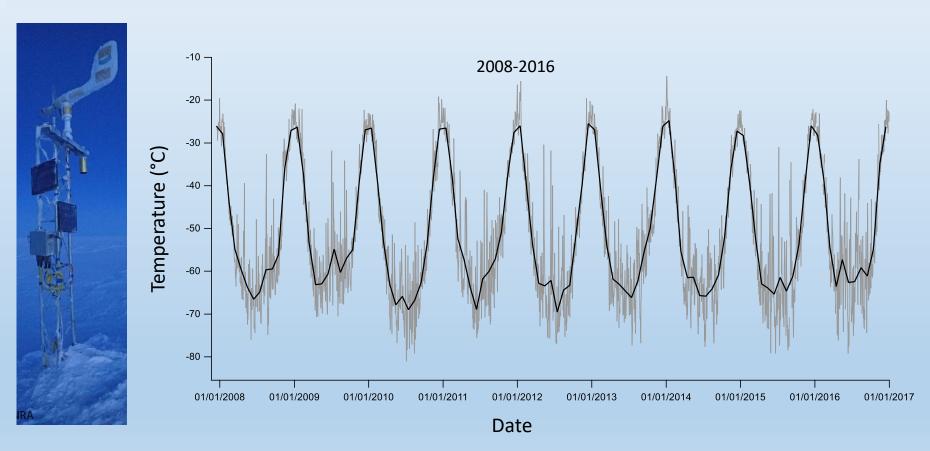




The aim is to retrieve ice up to 1.5 Ma, to reconstruct the climate and directly measure GHGs during the mid-Pleistocene transition

Dome C temperature

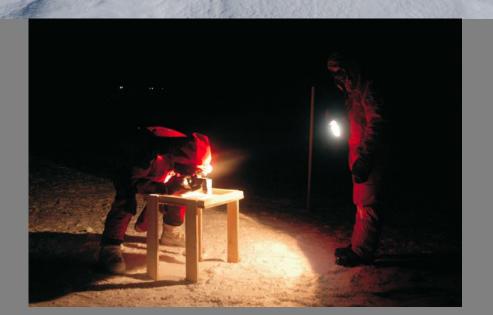
Mean daily (grey) and mean monthly (black) 2-m air temperature (T_{2m}) from the AWS installed by the Antarctic Meteorological Research Centre of the University of Wisconsin-Madison, placed 1.5 km away from the Concordia station



Mean temperature: -51.21°C Max temperature: -14.32°C Min temperature: -81.05°C

- Precipitation is collected on teflon plates (height: 1 m), 800 m from the base
- Daily precipitation collected continuously since 2008 (in progress)
- The first and so-far only multi-year series of isotopes in daily precipitation in Antarctica (snow surface samples collected at Neumayer St. 1981-2000)
- One of the few precipitation series from the East Antarctic plateau
- Surface snow is also collected on a wood table placed on the ground

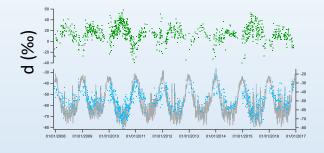
The samples have been analysed by IRMS technique and when the amount was too limited the analyses were performed on a PICARRO Cavity Ring-down Spectroscope.





Isotopic data and temperatures

Sampling period: 2008-2016

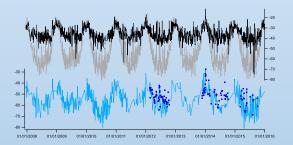


8180 (%)

 δ^{18} O (%)

Temperature (°C)

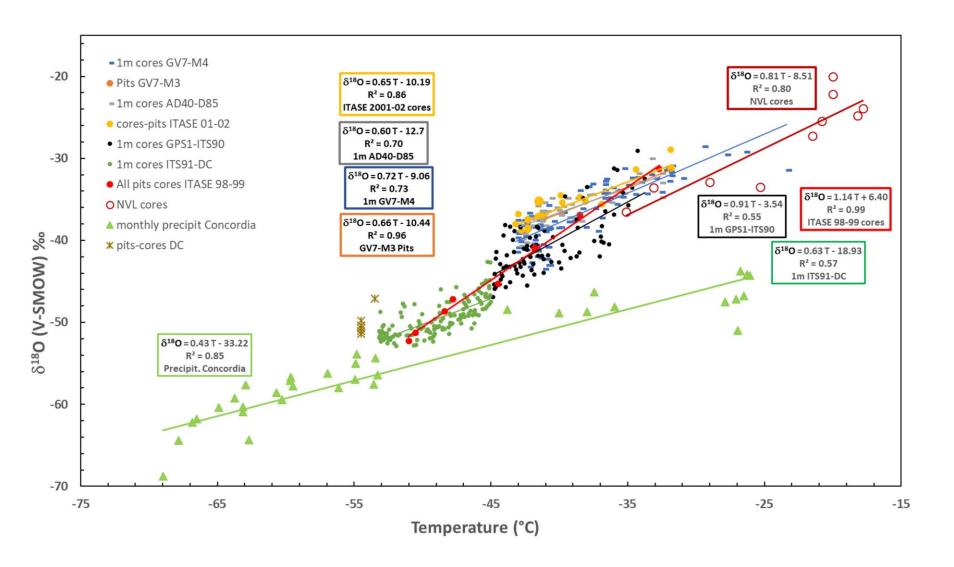
Daily precipitation δ^{18} O and deuterium excess, T_{2m}



Temperature (°C)

 $\delta^{18}\text{O}$ from raised support (continuous line) and surface tablet (dots), $T_{2m}\text{and }T_{inv}$

Spatial δ^{18} O/T slopes in the DC drainage basin + precipitation





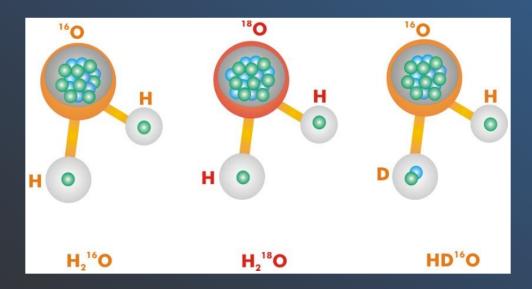
The importance of moisture source temperature variations for paleoclimate reconstruction from Antarctic ice cores: the deuterium excess



 $\delta^{18}O$ and δD

 \bigcup

deuterium excess ($d=\delta D-8*\delta^{18}O$)



Deuterium excess d

$$d = \delta D - 8*\delta^{18}O$$

(Dansgaard, 1964)

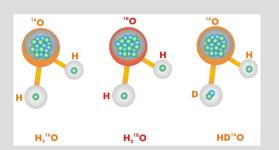
Kinetic fractionations



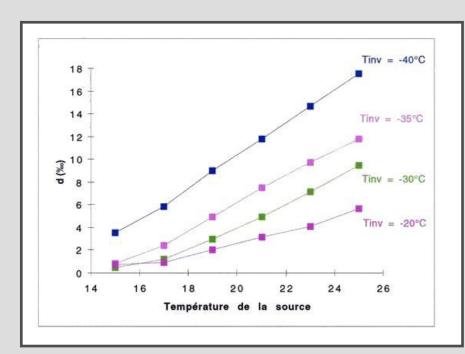
Surface ocean evaporation (SST, h, w)



Snow formation

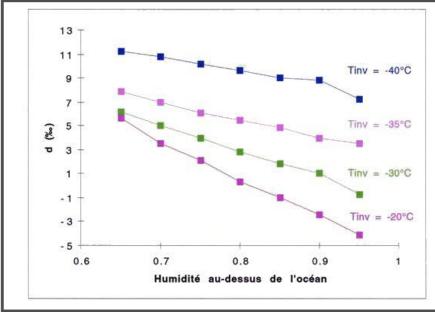


HDO and H₂¹⁸O

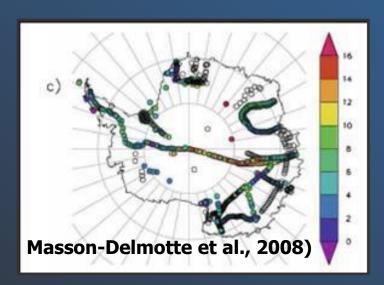


Effect of source SST on deuterium excess variations

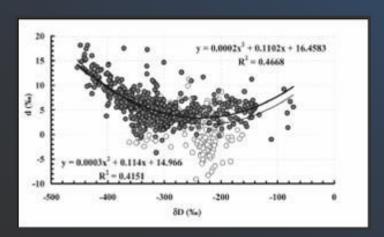




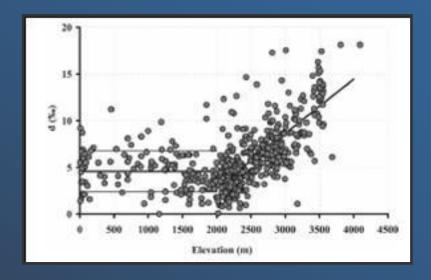
Deuterium excess of Antarctic snow



A negative (parabolic in shape) correlation between d versus δD with a wide d minimum for δD above -250‰.



Primary geographic factors controlling the spatial distribution of d are both elevation and distance from the coast. Marked difference at elevations below versus above 2000 m.



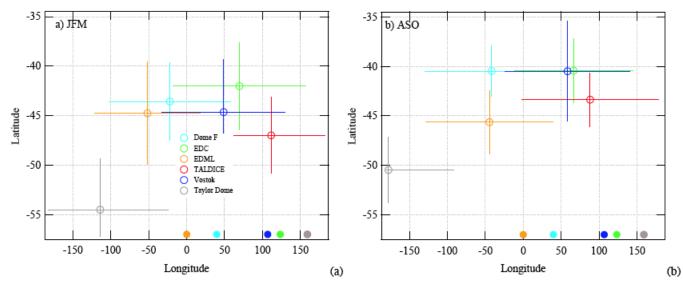
Different moisture advection paths

A dominant supply of moisture provided by cold high latitude ocean sources toward coastal locations and progressive input of moisture provided by more remote sources, transported at high elevation into central Antarctica.

Moisture source origins for deep ice cores

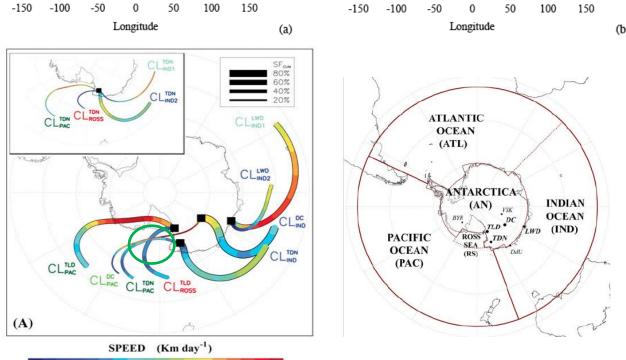
Sodemann and Stohl, 2009

In red TALDICE In green EDC

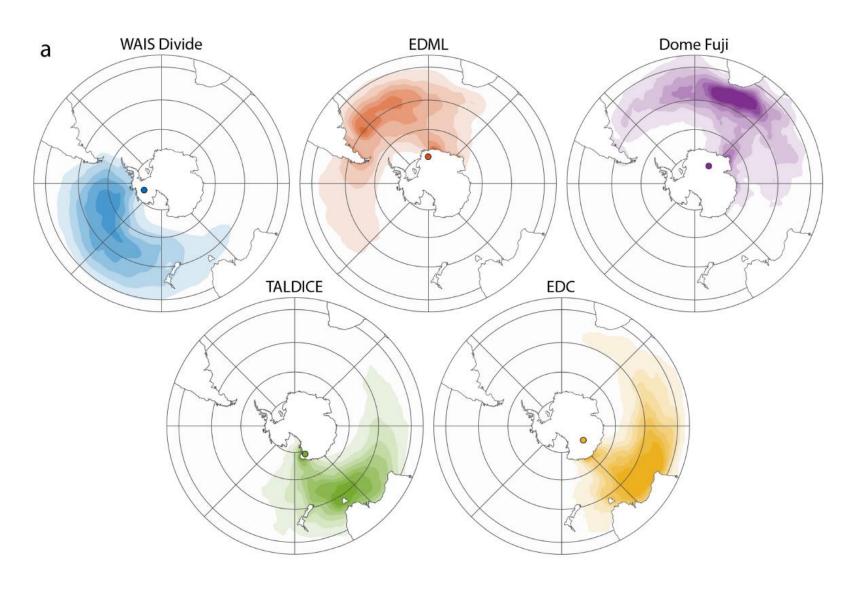


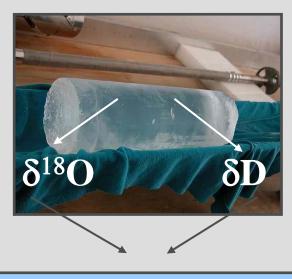
Back-trajectory Models: air mass paths

Scarchilli et al., 2011



Antarctic moisture sources for the five ice cores



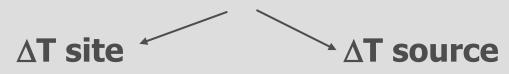


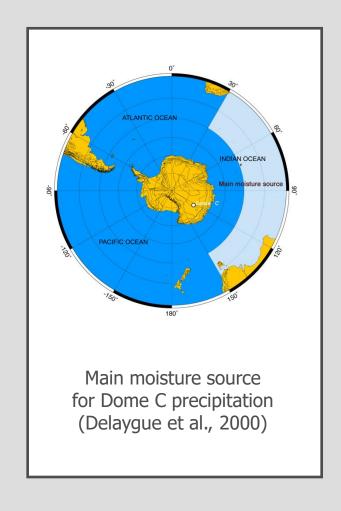
$$d = \delta D - 8\delta^{18}O$$
 (Dansgaard, 1964)

MCIM

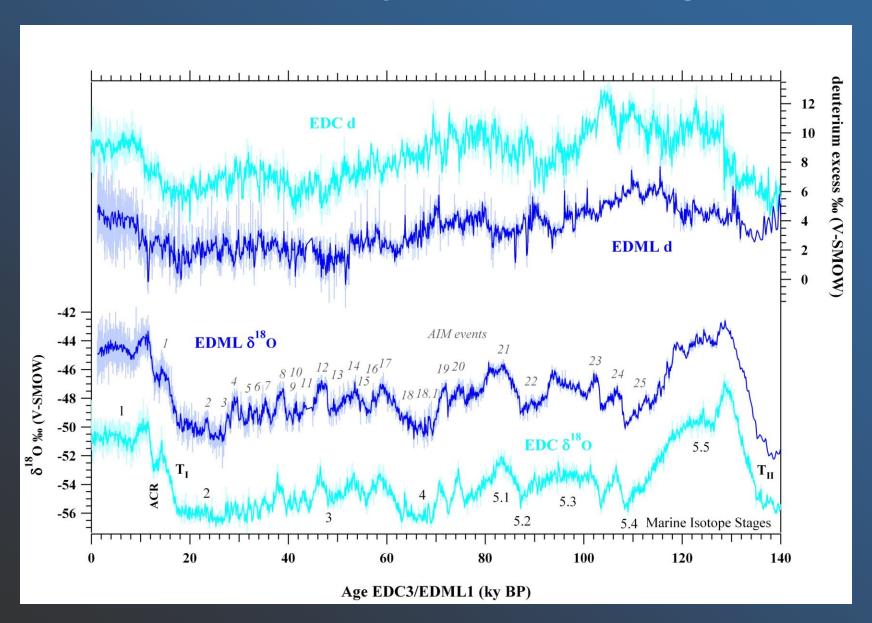
$$\Delta\delta D_{corr} = 7.6$$
 ΔT_{site} - $3.6 \Delta T_{source}$
 $\Delta d_{corr} = -0.5$ ΔT_{site} + $1.3 \Delta T_{source}$

Temperature variations





EDC and EDML isotopic records on EDC 3 age scale



T_{site} and T_{source} reconstructions

For EDC:

$$\Delta T_{\text{site}} = 0.16 \pm 0.02 \Delta \delta D_{\text{corr}} + 0.44 \pm 0.15 \Delta d_{\text{corr}}$$

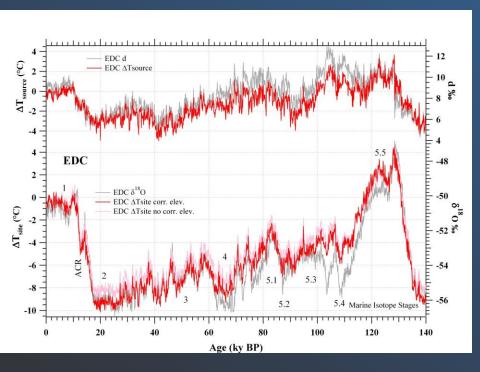
$$\Delta T_{\text{source}} = 0.06 \pm 0.03 \, \Delta \delta D_{\text{corr}} + 0.93 \pm 0.15 \Delta d_{\text{corr}}$$

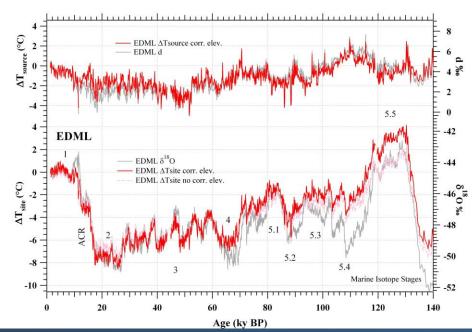
For EDML:

$$\Delta T_{\text{site}} = 0.13 \pm 0.02 \Delta \delta D_{\text{corr}} + 0.57 \pm 0.15 \Delta d_{\text{corr}}$$

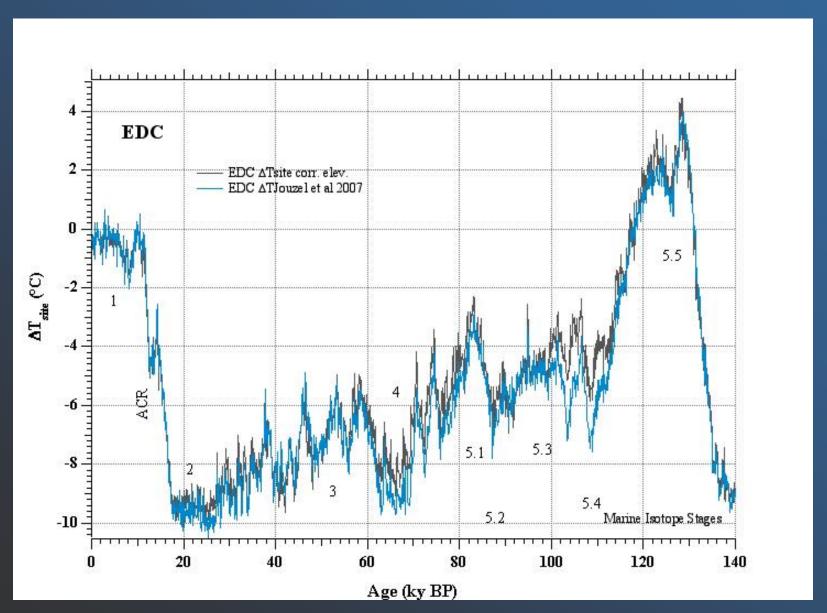
$$\Delta T_{\text{source}} = 0.04 \pm 0.03 \Delta \delta D_{\text{corr}} + 1.12 \pm 0.17 \Delta d_{\text{corr}}$$

ΔT_{site} and ΔT_{source} reconstructions

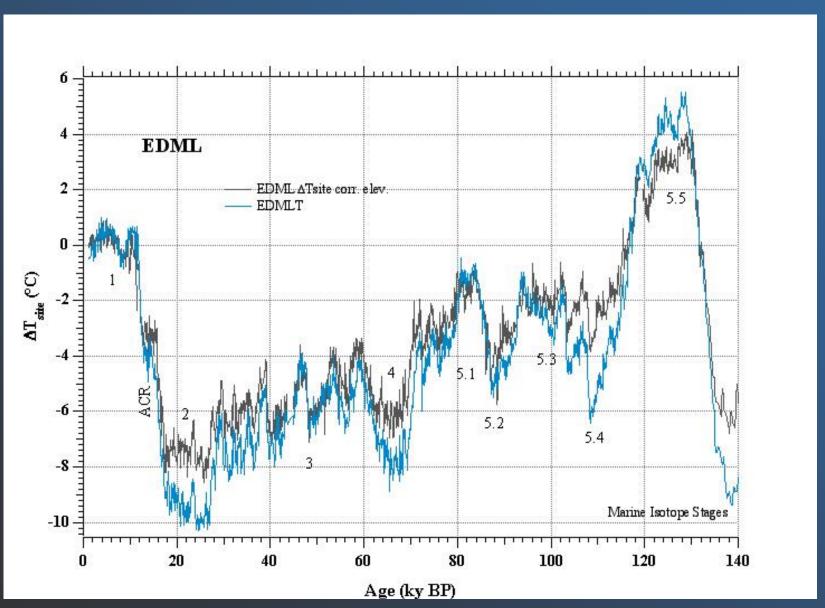




Effect of moisture source correction on ΔT_{site}



Effect of moisture source correction on ΔT_{site}





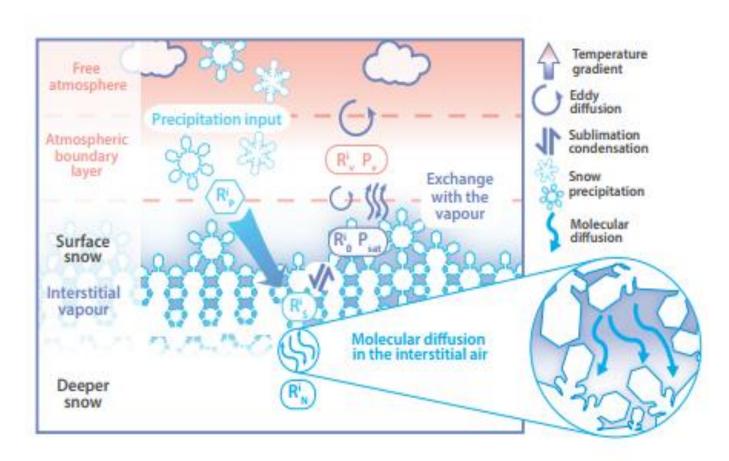


Figure 1. Schematic of the different contributions to snow isotopic composition (Ri X stands for the composition of isotope i in phase X: P is precipitation, V is vapour, S is surface snow, N is the deeper snow, O is vapour at equilibrium with the snow and Pv and Psat are the water vapour partial pressure and the saturated vapour pressure, respectively). Above the surface, both the precipitation and the sublimation—condensation cycles can contribute to the surface composition; in the open-porous firn below the surface, ice crystals can exchange with the air through the pores and may be influenced by wind pumping. Deeper in the firn, molecular diffusion in the interstitial air affects the snow isotopic composition.

Clim. Past, 16, 1581–1598, 2020 https://doi.org/10.5194/cp-16-1581-2020 © Author(s) 2020. This work is distributed under the Creative Commons Attribution 4.0 License.



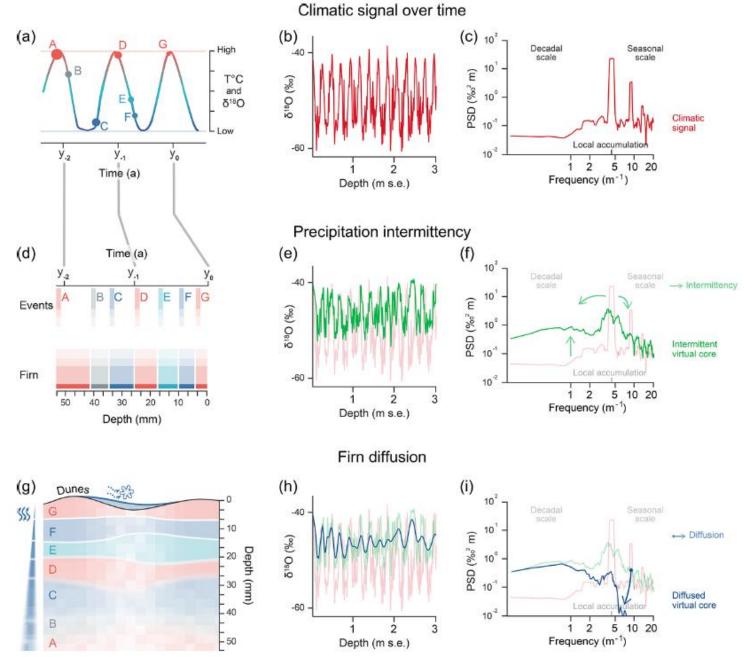


Climatic information archived in ice cores: impact of intermittency and diffusion on the recorded isotopic signal in Antarctica

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¹Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung, Research Unit Potsdam, Telegrafenberg A45, 14473 Potsdam, Germany

²MARUM – Center for Marine Environmental Sciences and Faculty of Geosciences, University of Bremen, 28334 Bremen, Germany



Casado et al., 2020

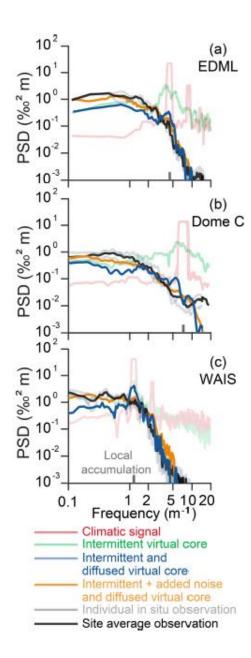
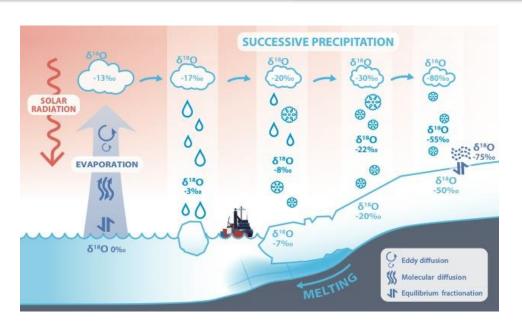
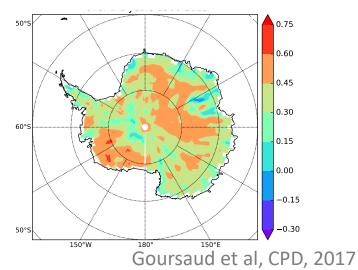


Figure 7. Power spectral density of the virtual ice cores compared to those of isotopes profiles from snow pits from (a) EDML, (b) Dome C, and (c) WAIS: climatic signal (light red), intermittent virtual core (light green), intermittent and diffused virtual core (light blue), intermittent plus added noise and diffused virtual core (orange), and snow pits from the sites (individual: grey; average: black).

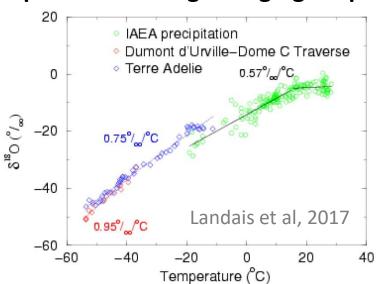
δ^{18} O is influenced by more than temperature

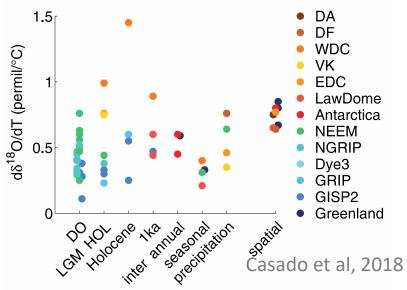


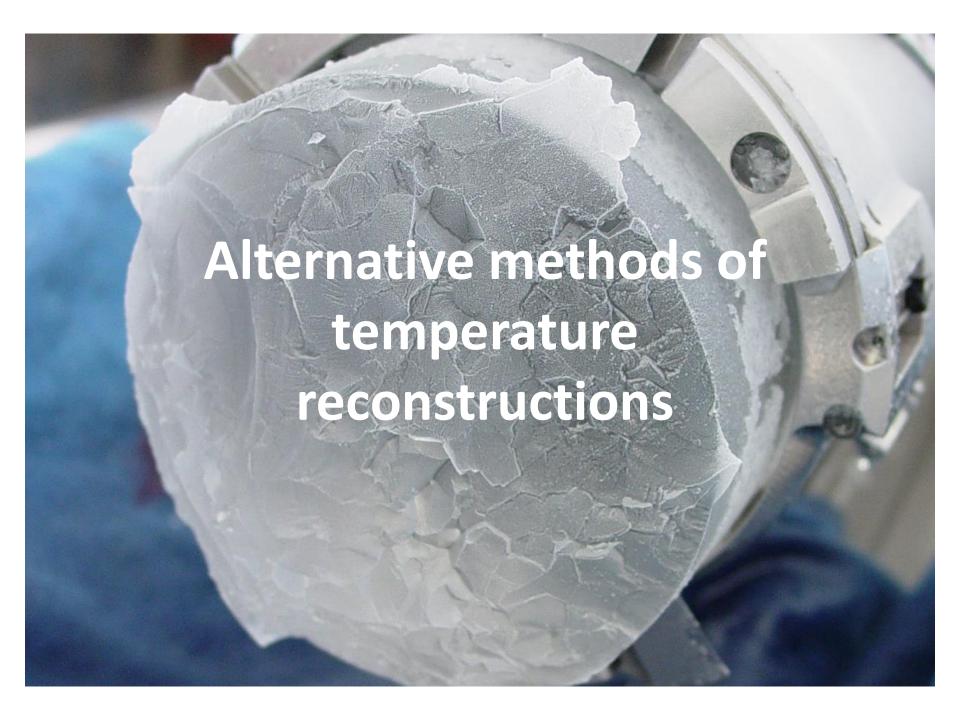
Correlation between $\delta^{18}\text{O}$ and 2m-T in ECHAM-wiso over 1960-2013



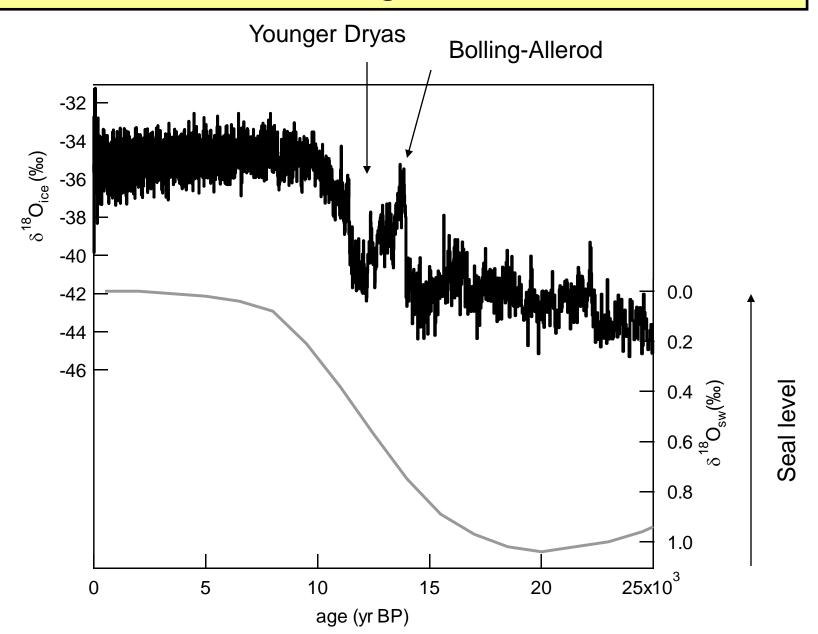
Temperature scaling changing in space and time



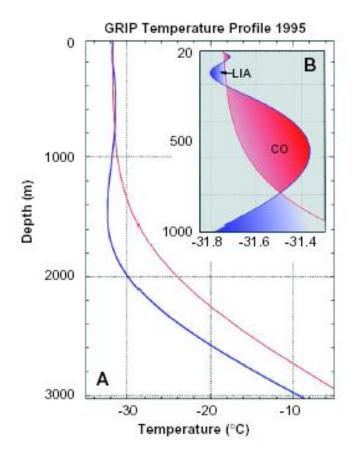




Last Glacial-Interglacial Transition



Change in glacial - interglacial temperature



Why such a difference ?? How to reconcile the 2 thermometers ??

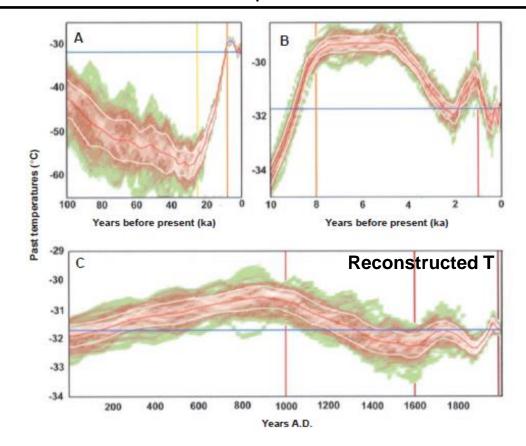
Dahl-Jensen et al., 1998

Isotopic thermometer:

10°C between the Last Glacial Maximum (LMG) and present

<u>Temperature measurement in the borehole:</u>

23°C between LMG and present



Reconstracting the temperature of the past: the limits of the isotopic thermometer

1- Change in seasonality of precipitation:

Today => snow all year

=> Isotopic Thermometer $\delta^{18}O_{mean} = f(T_{mean annual})$

In the past => Snow in summer

=> we interpret the $\delta^{18}O_{\text{meam}}$ in $\,T_{\text{mean annual}}$ when it is a summer temperature.

2- Change in the origin of precipitation

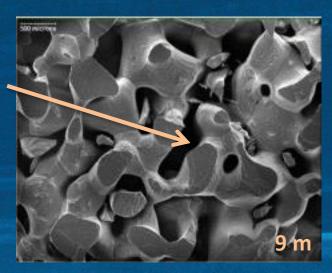
 $\delta^{18}O_{ice}$ reflects the history of distillation ~ f ($T_{ice} - T_{evaporation}$)

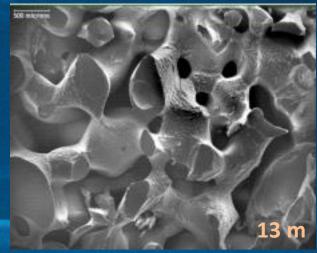
=> If $T_{evaporation}$ changes in the past, the isotopic thermometer that connects $\delta^{18}O_{ice}$ to T_{ice} without taking into account variations in $T_{evaporation}$ is biased.

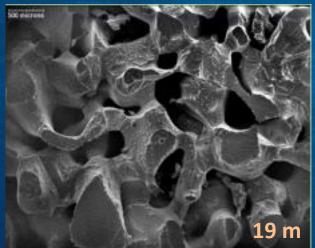
Alternative method: gas diffusion in the firn

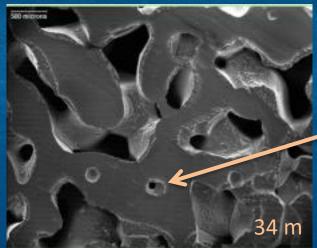
1 mm

Channels in which the air can move by molecular diffusion (bulk motion impossible)





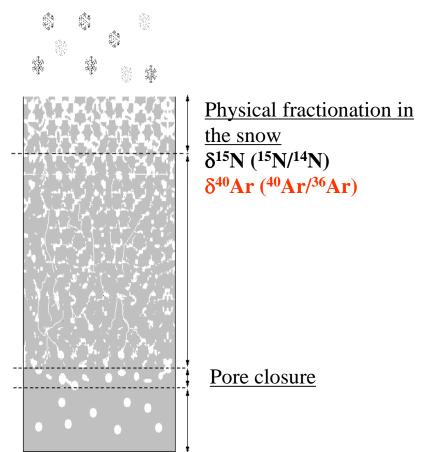




When **bubbles** form, diffusion stops and the **signal is preserved** forever

An alternative method of temperature reconstruction:

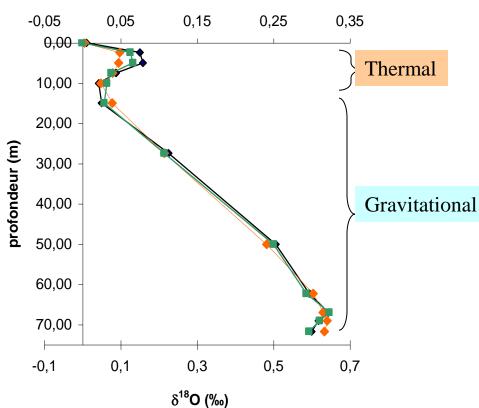




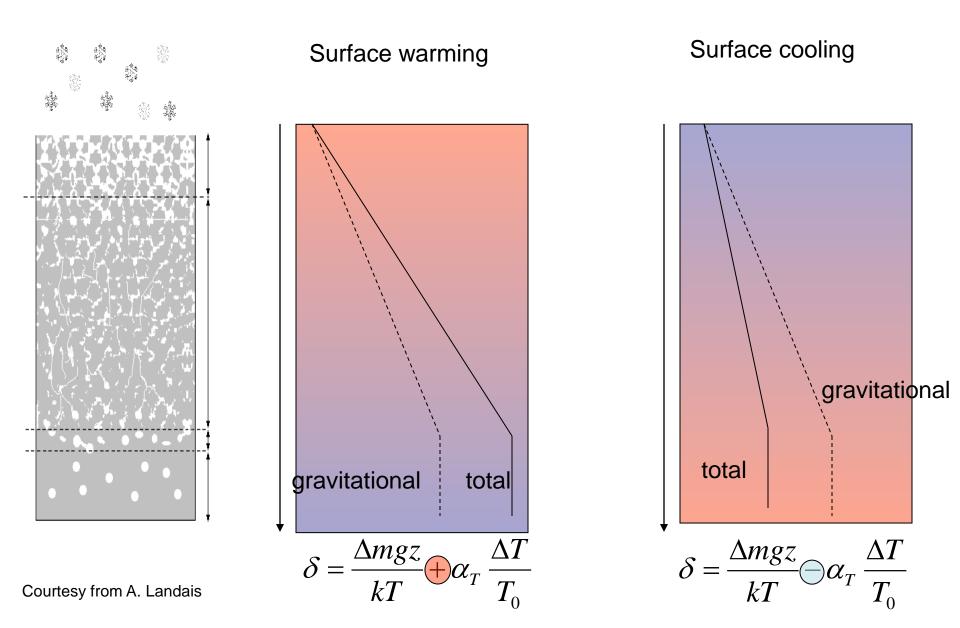
Gravitational fractionation: $\delta = \Delta mgz/RT$

Thermal fractionation: $\delta = \Omega \Delta T$

 δ^{15} N et δ^{40} Ar/4 (‰)



Thermal and gravitational fractionation in the firm



Clim. Past, 10, 887–902, 2014 www.clim-past.net/10/887/2014/ doi:10.5194/cp-10-887-2014 © Author(s) 2014. CC Attribution 3.0 License.





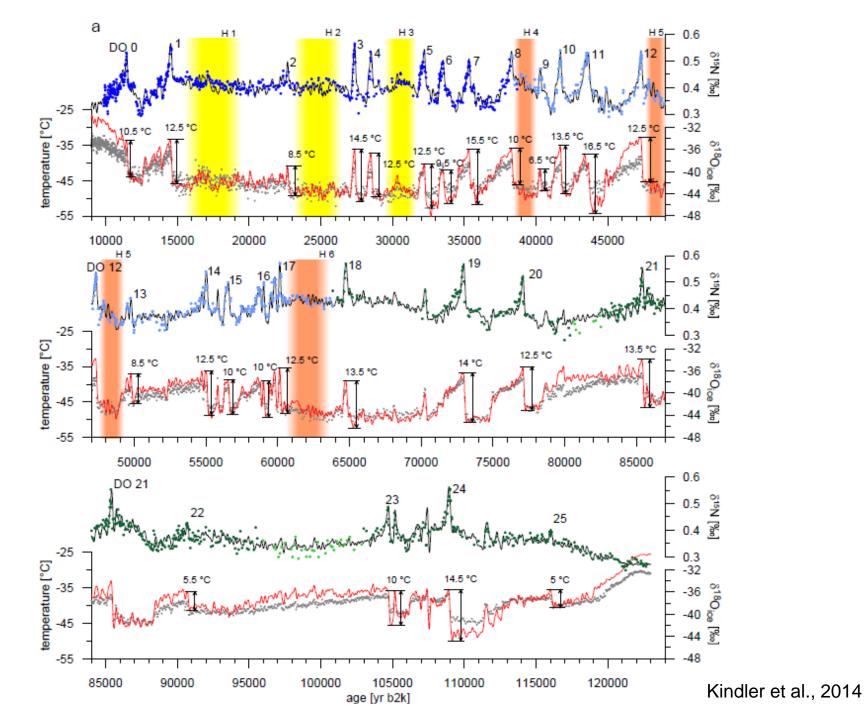
Temperature reconstruction from 10 to 120 kyr b2k from the NGRIP ice core

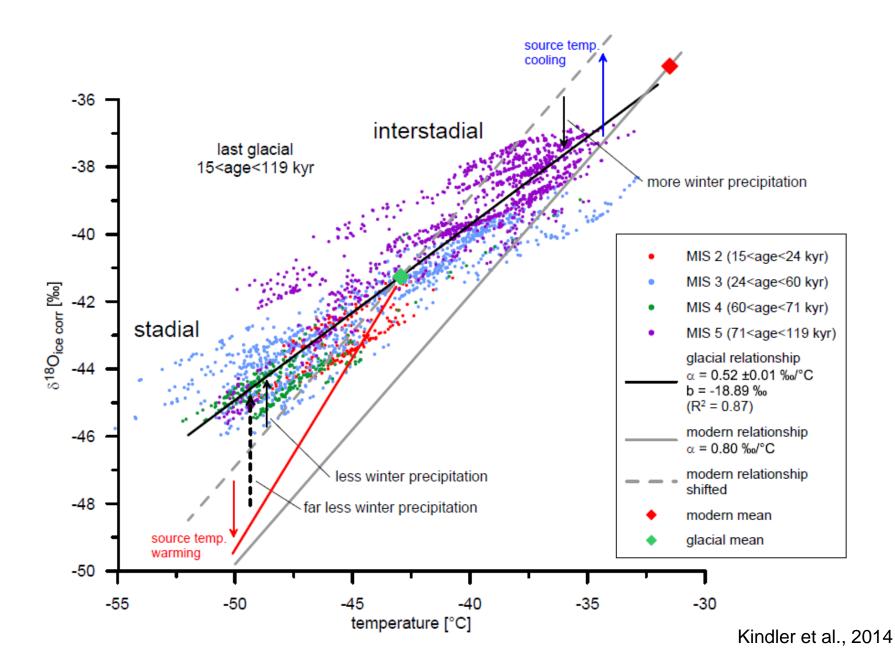
P. Kindler¹, M. Guillevic^{2,3}, M. Baumgartner¹, J. Schwander¹, A. Landais², and M. Leuenberger¹

¹Climate and Environmental Physics, Physics Institute and Oeschger Centre for Climate Change Research, University of Bern, 3012 Bern, Switzerland

²Institut Pierre-Simon Laplace/Laboratoire des Sciences du Climat et de l'Environnement, Gif-sur-Yvette, France

³Centre for Ice and Climate, Niels Bohr Institute, Universtity of Copenhagen, Copenhagen, Denmark





ECHAM5-wiso model simulations

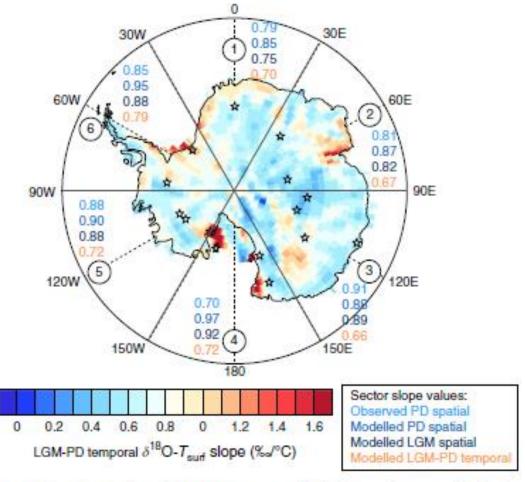
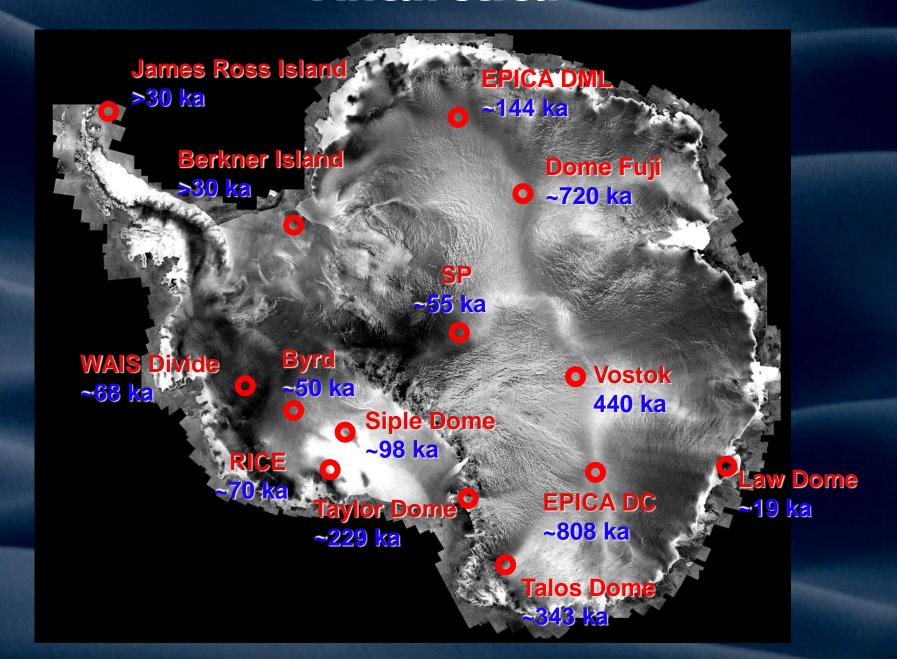


Fig. 5 Map of simulated LGM-PD temporal δ^{18} O- T_{surf} slopes, calculated for the PD and LGM reference simulations. Symbols (stars) mark the position of data from deep Antarctic ice cores, which are used for model evaluation. The numbers in circles indicate the defined six different sectors of Antarctica, for which regional analyses are applied. The coloured row of numbers in each sector states the following δ^{18} O- T_{surf} -slopes: observed PD spatial (light blue), modelled PD spatial (blue), modelled LGM spatial (dark blue), and modelled LGM-PD temporal slope (orange). All slopes are given in ‰/°C

Werner et al.,



Antarctica



European Project for Ice Coring in Antarctica

Dome C

Ice thickness = $3273 \pm 5m$

Tsurf. = -54.5° C

Acc. rate: 25.0 kg m⁻² yr⁻¹

EDC96 ice core (788 m)

~45.000 yrs BP

EDC99 ice core (3200 m)

~ 800.000 yrs BP



Dronning Maud Land

Ice thickness = $2780 \pm 5m$

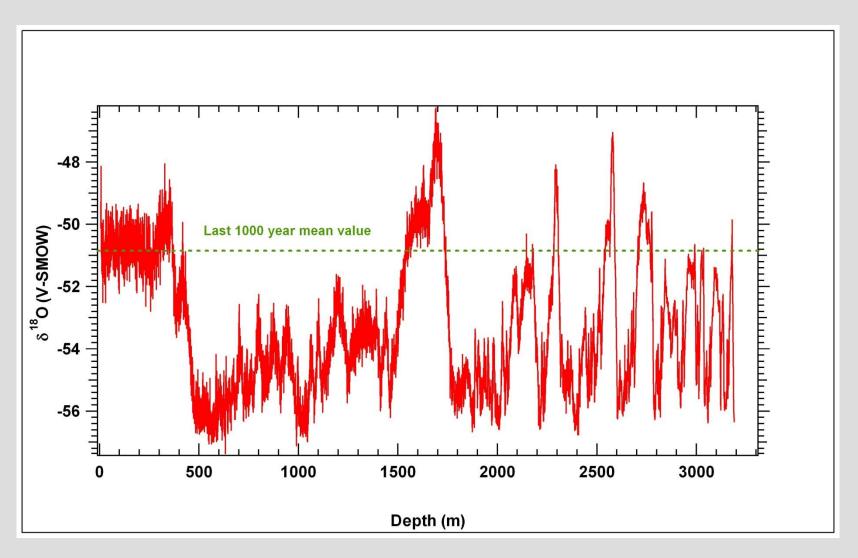
Tsurf. = -44.6° C

Acc. rate: 64 kg m⁻² yr⁻¹

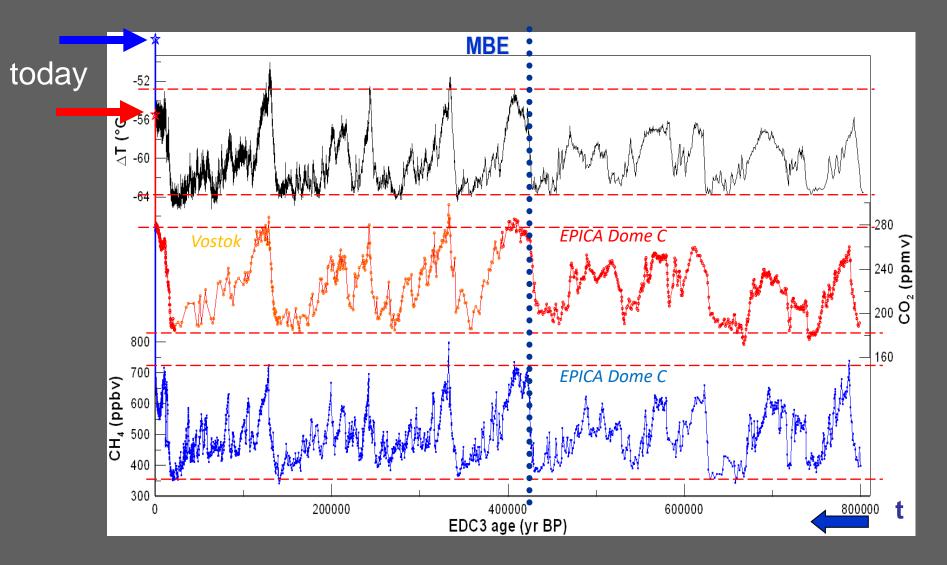
Carota EDML (2565 m)

~150.000 yrs BP

EPICA Dome C δ^{18} O versus depth



The Greenhouse Gas record from EPICA Dome C ice core



No analog of present-day values during the last 800 kyr CO₂ (and CH₄, except MIS 19) show lower interglacial concentrations before 400 kyr BP

Jouzel et al., 2007; Siegenthaler et al, 2005 ; Spahni et al., 2005 ; Lüthi et al., 2008 ; Loulergue et al., 2008.



Interglacial Antarctic-Southern Ocean climate decoupling due to moisture source area shifts

nature

geoscience

A. Landais , B. Stenni , V. Masson-Delmotte¹, J. Jouzel¹, A. Cauquoin , E. Fourré , B. Minster¹, E. Selmo⁴, T. Extier , M. Werner , F. Vimeux , R. Uemura , I. Crotti^{1,2} and A. Grisart

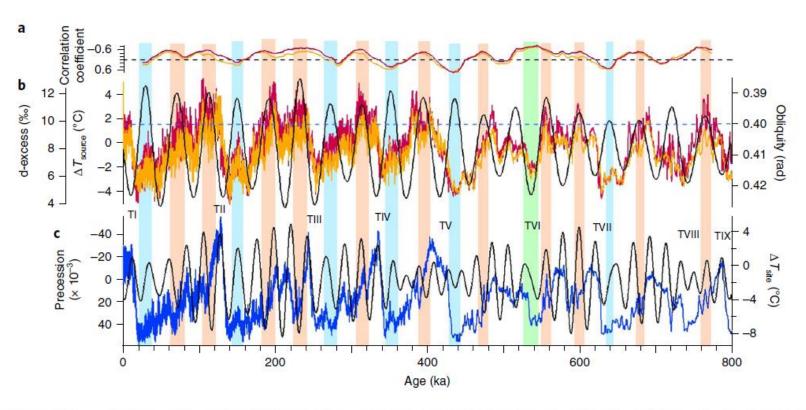


Fig. 3 | Link between ΔT_{source} , d-excess, ΔT_{site} and orbital parameters. **a**, Correlation coefficient between obliquity and ΔT_{source} (orange) and between obliquity and d-excess (red) over a 50 ka sliding window; the dashed black horizontal line indicates a correlation of 0. **b**, EDC d-excess (red), ΔT_{source} (orange) and obliquity (black). **c**, EDC ΔT_{site} (blue) and precession (black). The blue/orange rectangles are associated with obliquity value lower than 0.4 rad (dashed blue horizontal line) with correlation coefficient between ΔT_{source} (or d-excess) and obliquity being positive/negative. A green rectangle indicates the peculiar situation over Termination VI.

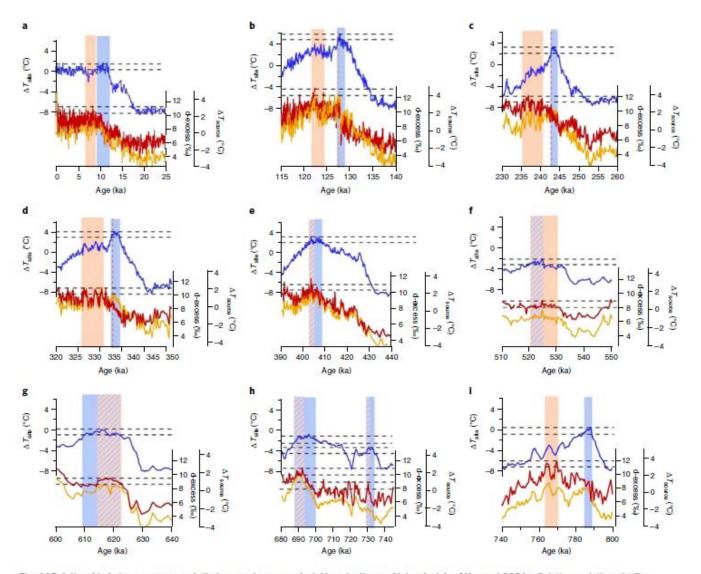
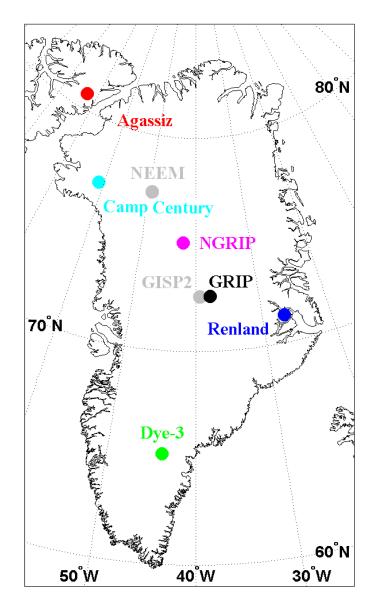


Fig. 4 | Relationship between source and site temperature over glacial termination and interglacials of the past 800 ka. Relative evolution of ΔT_{source} (orange), d-excess (red) and ΔT_{site} (blue) reconstructed from the EDC δD and δ^{IB} O records over the last nine glacial terminations. **a**, Termination I. **b**, Termination III. **c**, Termination III. **d**, Termination IV. **e**, Termination V.I. **g**, Termination VII. **h**, Termination VIII. **l**, Termination IV. The vertical rectangles indicate the timing of the maximum over terminations or over interglacials for ΔT_{site} (blue) and d-excess (red). The blue rectangles include the value of the earliest ΔT_{site} maximum, and the temporal window corresponds to ΔT_{site} values less than 1°C lower (dashed horizontal lines). The orange rectangles include the earlier maximum in d-excess, and the temporal window corresponds to d-excess values less than 1% lower (dashed lines). When ΔT_{site} and d-excess maxima are synchronous, a blue-orange hatched rectangle is displayed. For Terminations III and IV, a vertical orange dashed line shows a first maximum seen in ΔT_{source} only (not in d-excess).

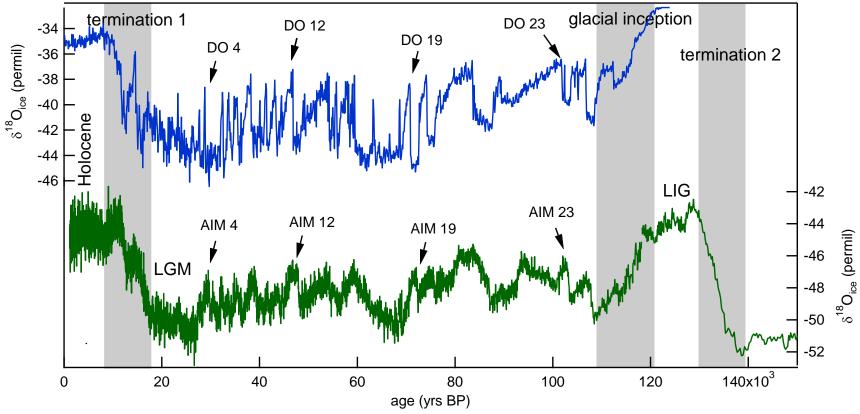
Greenland deep ice cores







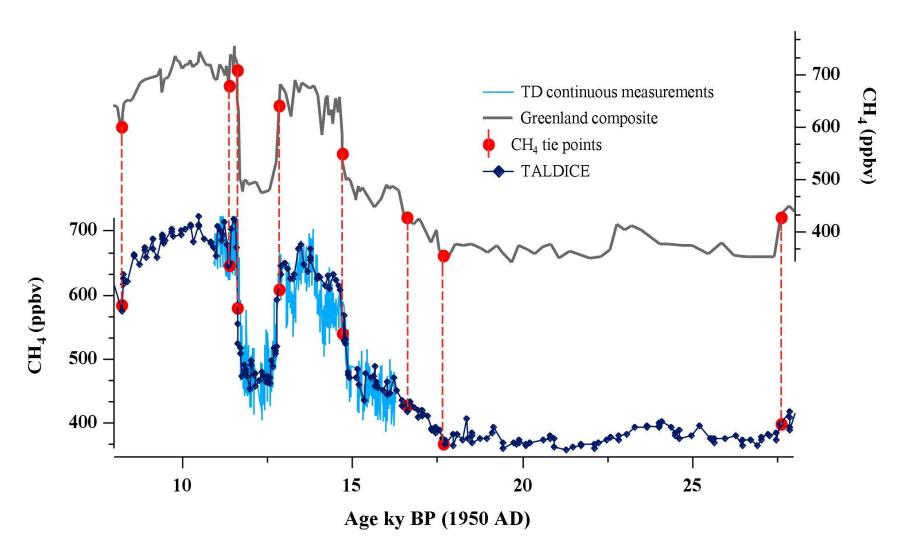
The last climate cycle: Antarctica versus Greenland

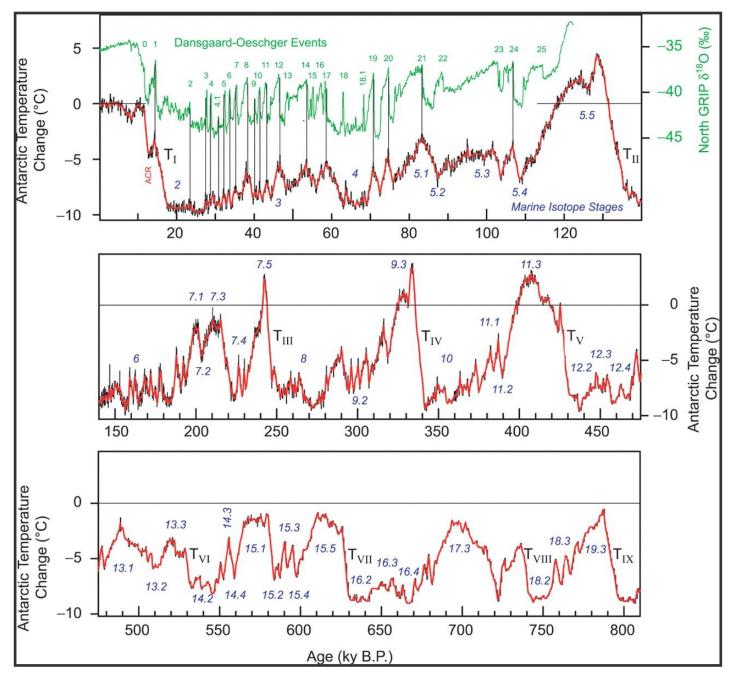


Termination = Deglaciation
Glacial inception = Entry into glaciation
LGM = Last Glacial Maximum
AIM = Antarctic isotopic maximum
DO=Dansgaard/Oeschger event
LIG=Last Interglacial
Holocene=our present interglacial

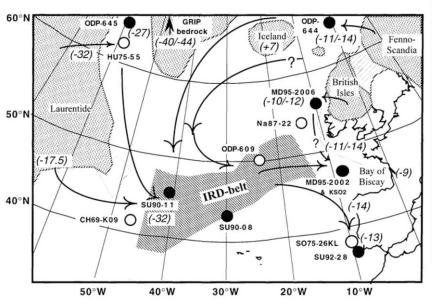
Some definitions

CH₄ synchronization with Greenland





Heinrich Events





Heinrich Events are intermittent periods of iceberg surges and meltweater flow mainly from the Laurentide ice sheet that occurred during glacial times. Iceberg drift and meltwater influx was largest in a belt between 40° and 50° N (Bond et al., 1992; Bond and Lotti, 1995). Enhanced meltwater flux caused a significant decrease in sea surface temperatures and salinities, and it destabilized or even stopped thermohaline circulation in the glacial North Atlantic (Zahn et al., 1997). Heinrich Events are characterized by massive, short-term occurrences of the polar planktonic foraminifer Neogloboquadrina pachyderma (sinistral) and coarse lithic grains of North American origin (Baas et al., 1997, de Abreu et al., 2003). These levels are denominated as Heinrich layers may be used to establish a chronostratigraphic framework for sediment cores (Lebreiro et al., 1996; Schönfeld and Zahn, 2000).

Heinrich Events

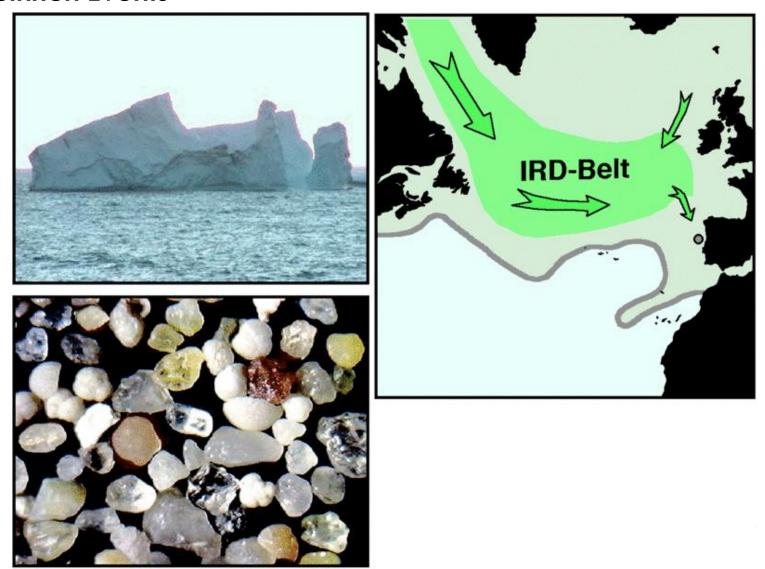
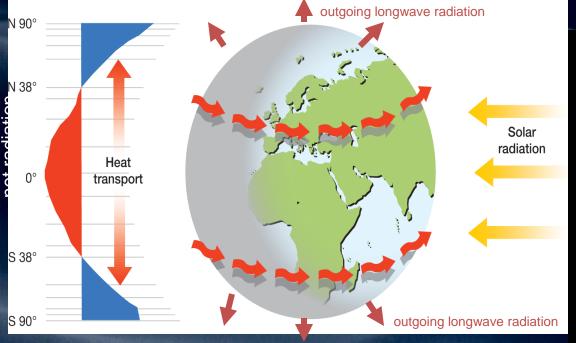
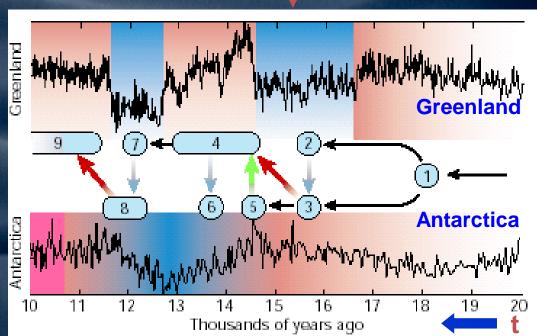


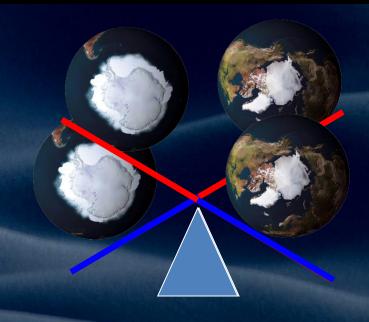
Figure 1. Iceberg, ice-rafted detritus (IRD) from a sediment core, the IRD belt in the north Atlantic, and the location of core MD95-2040.





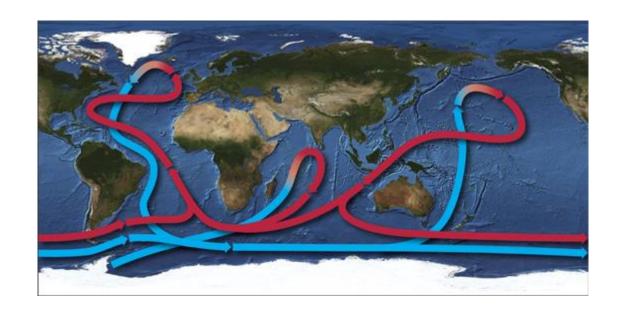
BIPOLAR SEESAW

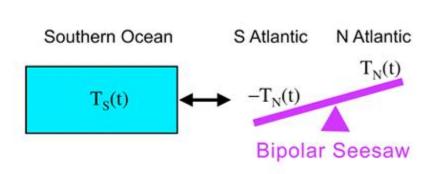


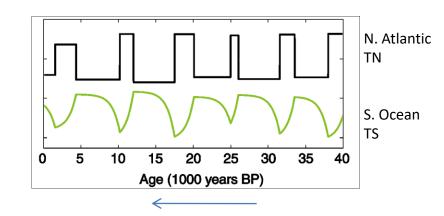


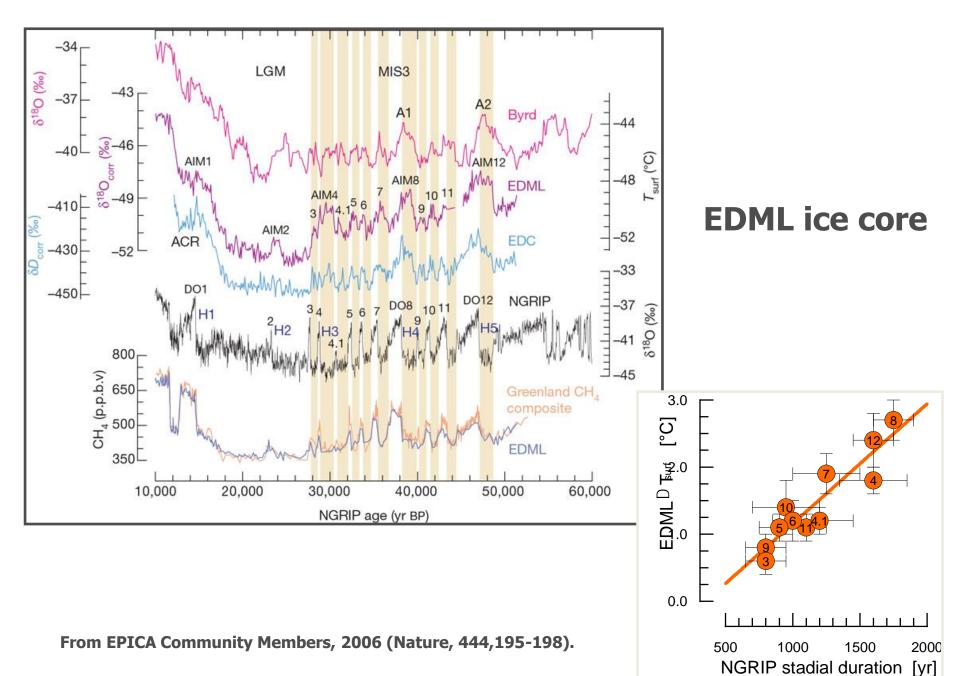
Stocker, 2003

Ice core data confirm bipolar seesaw caused by AMOC





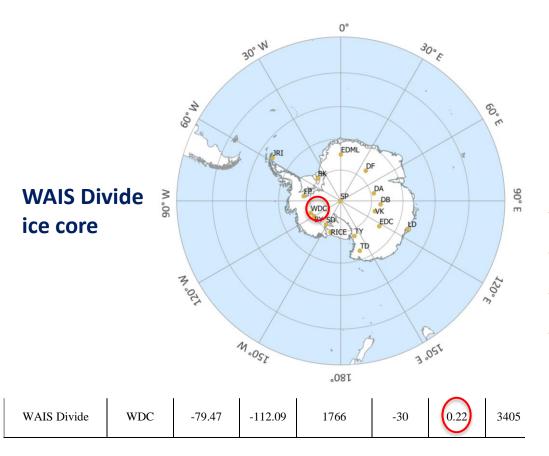


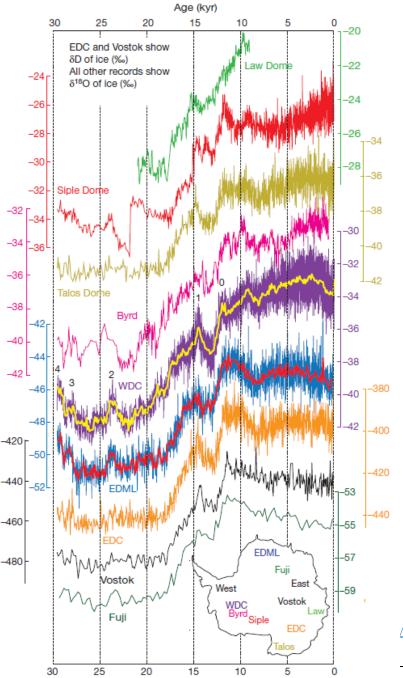




Onset of deglacial warming in West Antarctica driven by local orbital forcing

WAIS Divide Project Members*





Age (kyr)

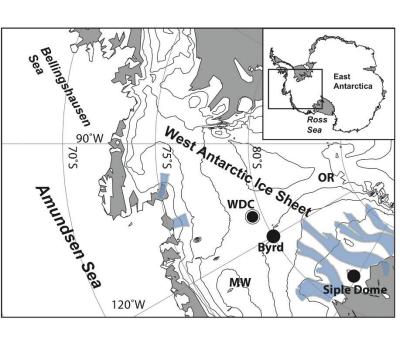
LETTER

Precise interpolar phasing of abrupt climate change during the last ice age

WAIS Divide Project Members*

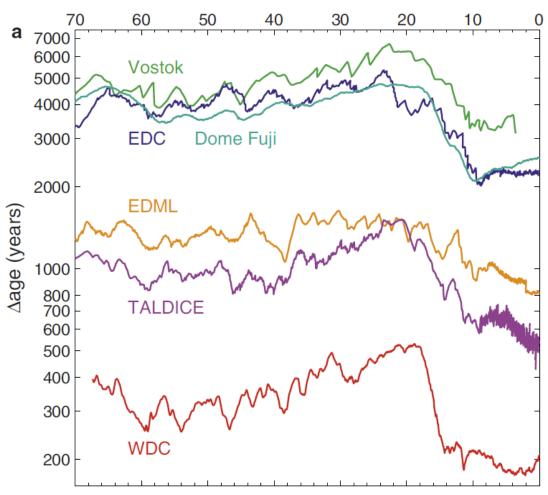
Here we use a recently drilled high-accumulation Antarctic ice core to show that, on average, abrupt Greenland warming leads the corresponding Antarctic cooling onset by 218+/-92 years (2σ) for Dansgaard– Oeschger events, including the Bølling event; Greenland cooling leads the corresponding onset of Antarctic warming by 208+/-96 years. Our results demonstrate a north-to-south directionality of the abrupt climatic signal, which is propagated to the Southern Hemisphere high latitudes by oceanic rather than atmospheric processes. The similar interpolar phasing of warming and cooling transitions suggests that the transfer time of the climatic signal is independent of the AMOC background state. Our findings confirm a central role for ocean circulation in the bipolar seesaw and provide clear criteria for assessing hypotheses and model simulations of Dansgaard–Oeschger dynamics.

Map of West Antarctica showing the location of the WAIS Divide ice core (WDC). Credit: T.J. Fudge



WAIS Divide ice core (1766 m, mean annual T -30°C, high snow-accumulation rate site about 22 cm yr-1 ice eq., drilling depth 3405 m, oldest ice recovered 68 kyr).

Difference between gas age and ice age (Δ age) at WAIS Divide

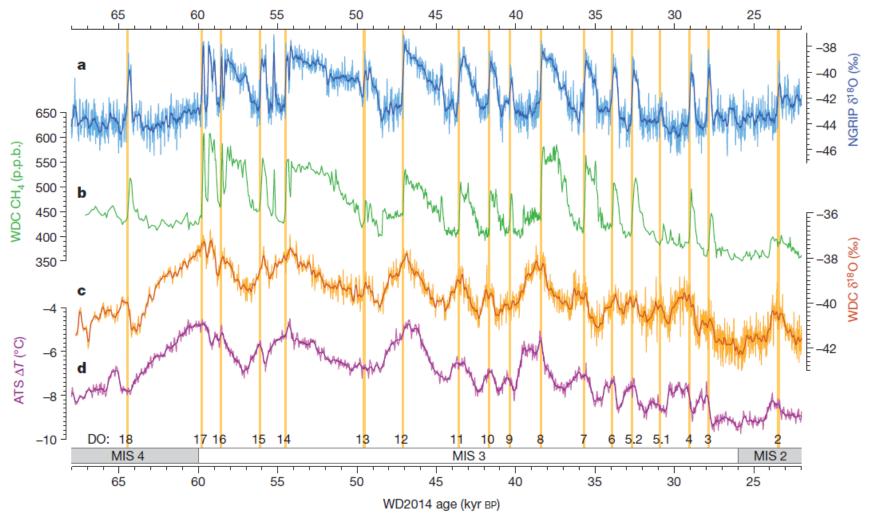




Precise interpolar phasing of abrupt climate change during the last ice age

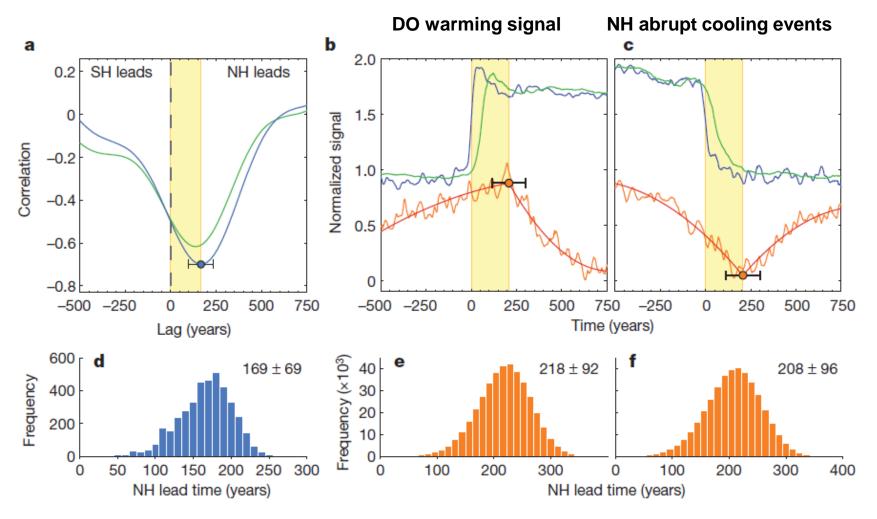
WAIS Divide Project Members*

Records of glacial abrupt millennial-scale climatic variability



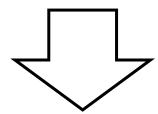
WAIS Divide Project Members, 2015

Interhemispheric phasing of the bipolar seesaw



DO warming signal: abrupt Greenland warming leads the Antarctic cooling onset by 218+/-92 years (2σ) **NH abrupt cooling events:** Greenland cooling leads the onset of Antarctic warming by 208+/-96 years *WAIS Divide Project Members, 2015*

These results demonstrate a north-to-south directionality of the abrupt climatic signal, which is propagated to the Southern Hemisphere high latitudes by oceanic processes.



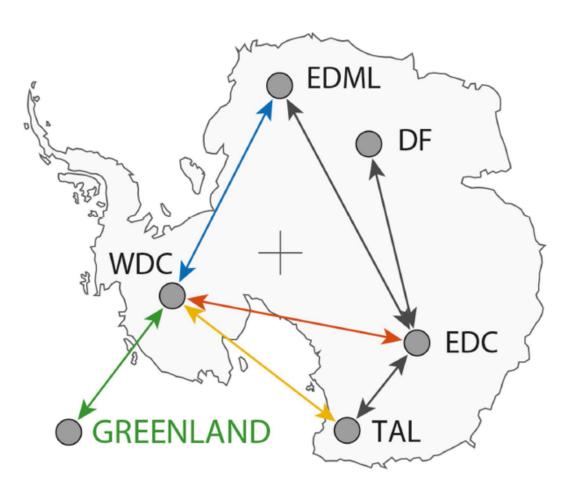
Central role for ocean circulation in the bipolar seesaw



Abrupt ice-age shifts in southern westerly winds and Antarctic climate forced from the north

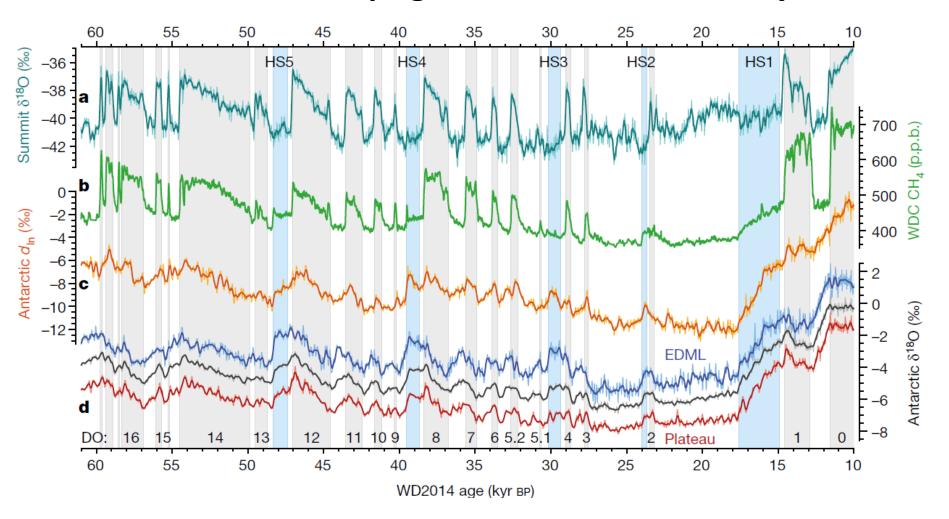
Christo Buizert¹*, Michael Sigl^{2,14}, Mirko Severi³, Bradley R. Markle⁴, Justin J. Wettstein^{1,5}, Joseph R. McConnell⁶, Joel B. Pedro^{7,8}, Harald Sodemann⁵, Kumiko Goto-Azuma⁹, Kenji Kawamura⁹, Shuji Fujita⁹, Hideaki Motoyama⁹, Motohiro Hirabayashi⁹, Ryu Uemura¹⁰, Barbara Stenni¹¹, Frédéric Parrenin¹², Feng He^{1,13}, T. J. Fudge⁴ & Eric J. Steig⁴

Volcanic synchronization of Antarctic ice cores

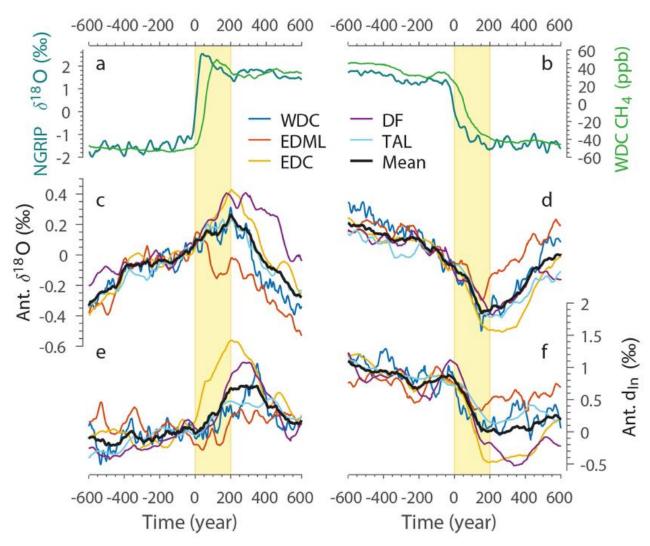


Buizert et al., 2018

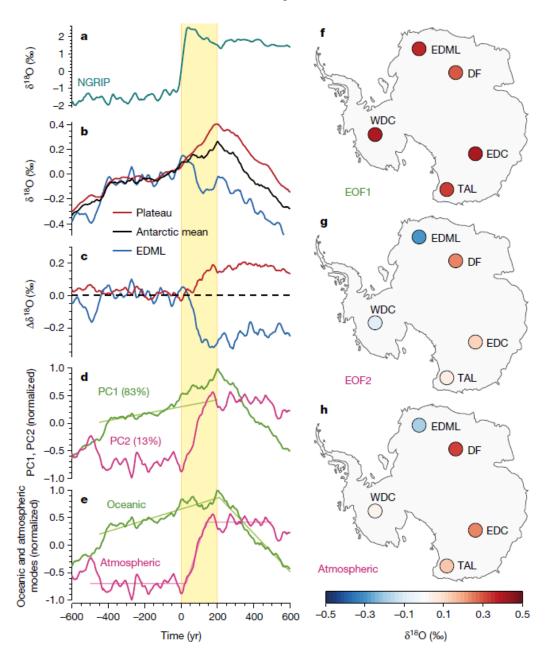
Records of abrupt glacial climate variability



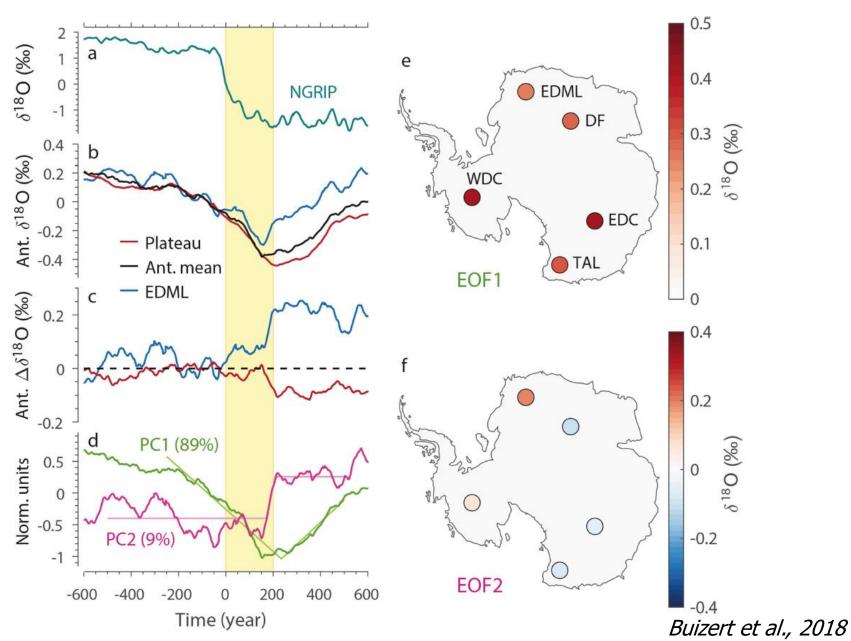
Site-specific stacks of δ^{18} O and d_{ln}



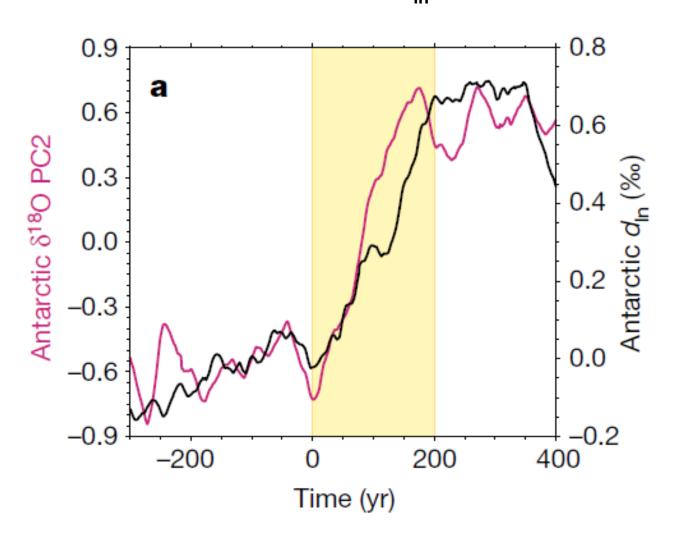
Antarctic climate response to DO warming



Antarctic climate response to DO cooling



Comparison of the PC2 of the five Antarctic δ^{18} O stacks with the Antarctic mean d_{ln} stack



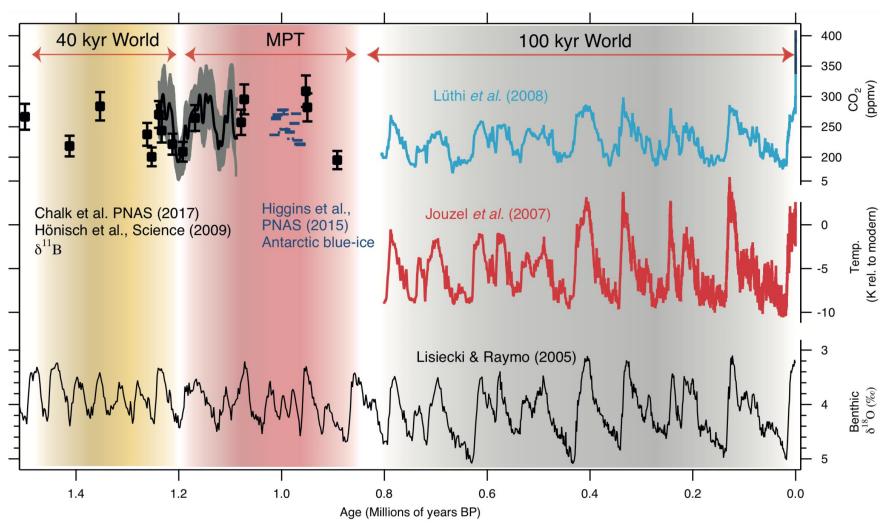
These results show that the Antarctic temperature response to the DO cycles can be understood as the superimposition of two modes:

- a spatially homogeneous oceanic 'bipolar seesaw' mode that lags behind Northern Hemisphere climate by about 200 years:
- 2. a spatially heterogeneous atmospheric mode that is synchronous with abrupt events in the Northern Hemisphere.

Deuterium-excess records suggest a zonally coherent migration of the Southern Hemisphere westerly winds over all ocean basins in phase with Northern Hemisphere climate.



Climate and CO₂ records over the last 1.5 Myr



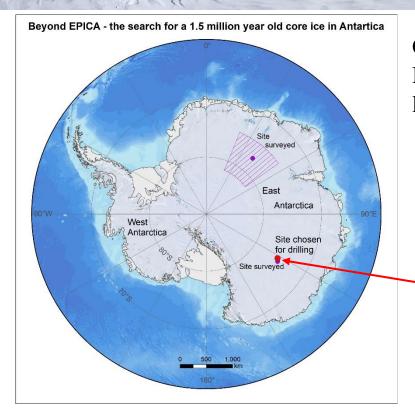
Marine sediment records (bottom, black line) provide the combined sea level and deep sea temperature record over many million years back in time. Existing ice core record of Antarctic temperature (middle, red line) and atmospheric CO_2 (top, light blue line) going back only 800 kyr. Selected marine and blue-ice proxy records provide time slices of CO_2 at low resolution and precision, but no full continuous record (top left).



BEYOND EPICA OLDEST ICE

Beyond EPICA:

The quest for a 1.5 million year ice core



On 1st June 2019 the EU project Beyond EPICA has started. It will last 6 years.

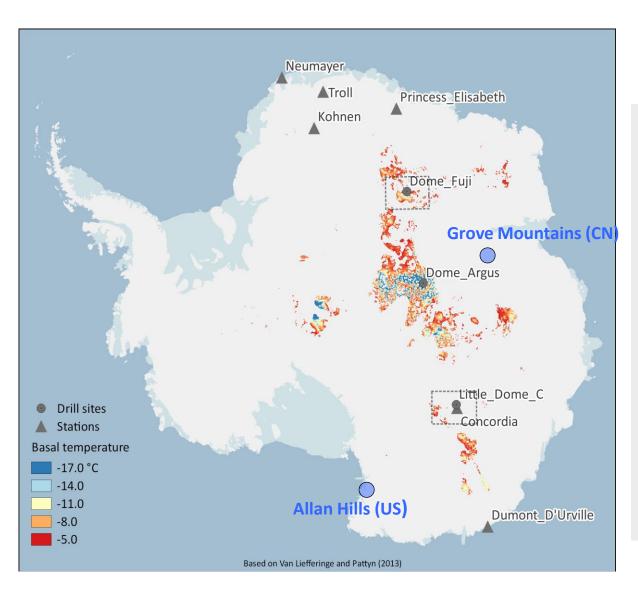
For info, please visit: https://www.beyondepica.eu/

Site chosen for drilling: Little Dome C, 40 km from Concordia station

Info from B. Stenni on behalf of the Beyond EPICA Project Members - Project Coordinator: C. Barbante (UniVE, CNR-ISP)



Where to find such old stratified ice?



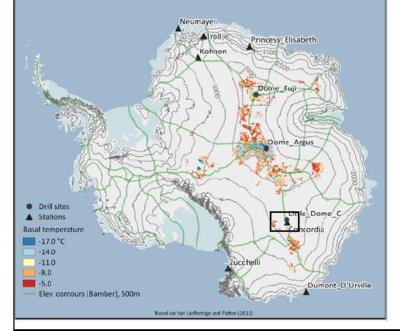
- Deep ice cores
- low accumulation
- Cold
- Cold, flat base
- Not too thick
- Little lateral flow

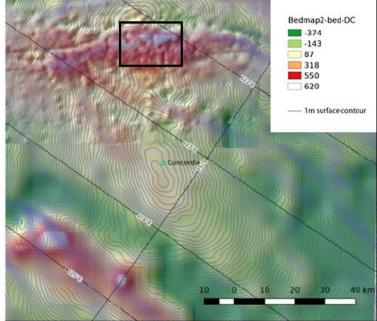
Fischer et al., CP 2013 Van Liefferinge & Pattyn, CP, 2013 Parrenin et al., TC 2017

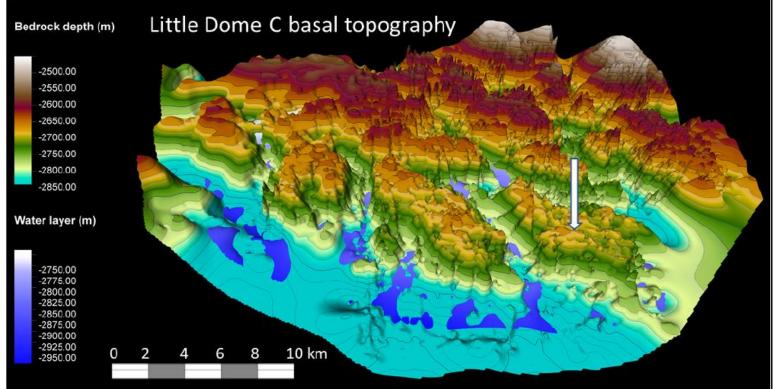
Blue ice areas?

Kehrl et al, GRL 2018

Yan et al, Nature 2019

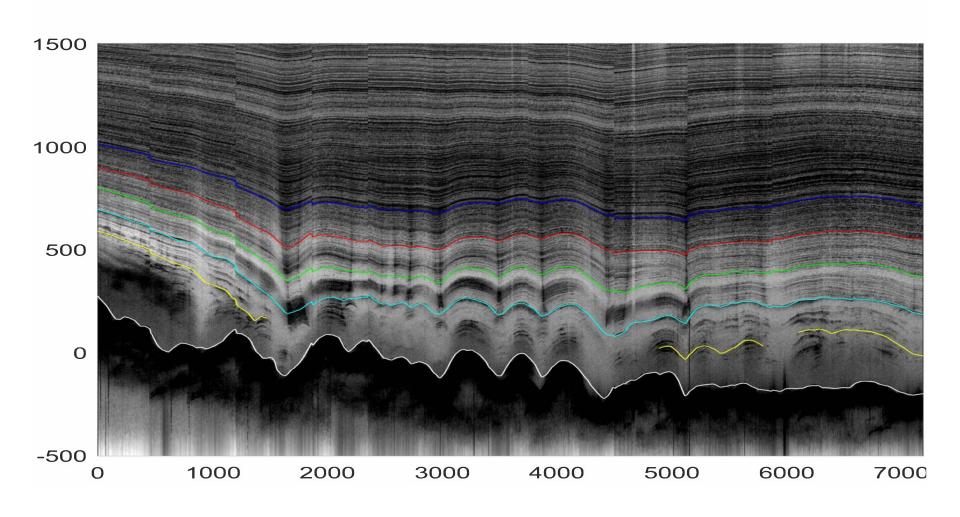






Beyond EPICA – Oldest Ice Core

VHF radar line from LDC (left) to Concordia/EDC (right)



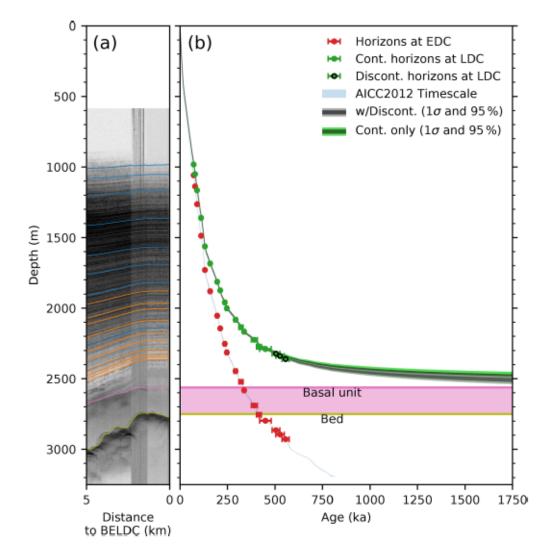
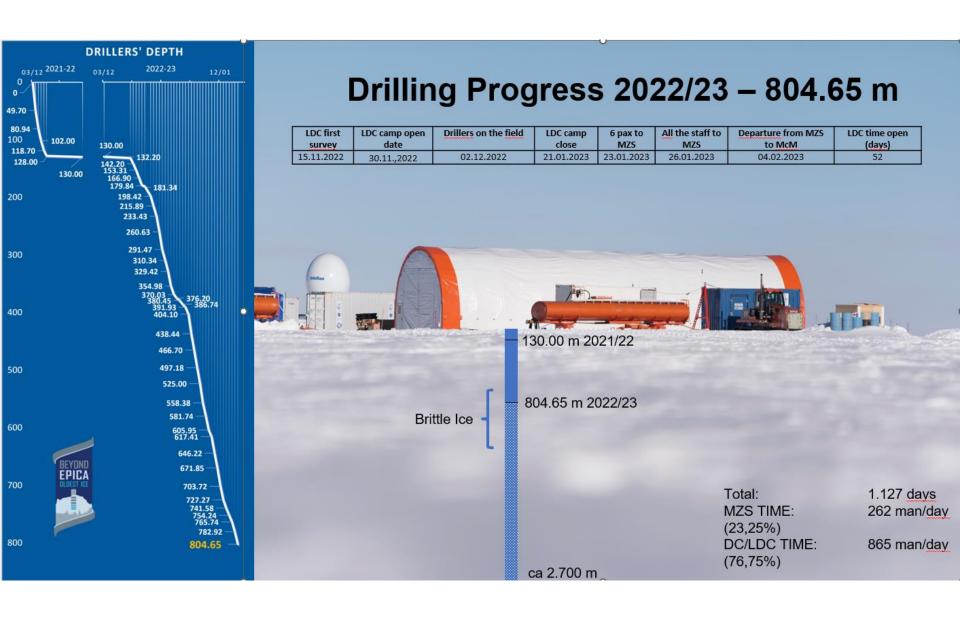


Figure 3. (a) Radargram near BELDC (as in Fig. 2). (b) Depth–age scale at BELDC and EDC. Dots with error bars show traced horizons with age uncertainties; blue line shows AICC2012 chronology (Bazin et al., 2013). The gray shaded regions show model results utilizing constraints from all horizons at 95 % confidence (light) and 1σ (dark). Green shaded region shows the model results with the discontinuous horizons excluded from the analysis.

BELDC Camp, 75.30 °S, 122.45 °E, 28.12.2019









LINKS for web sites and videos

For EU Beyond EPICA project: https://www.beyondepica.eu/en/

For the DEEPICE Project: https://deepice.cnrs.fr/

For EAIIST scientific traverse: https://vimeo.com/377102990

For East GRIP tour

https://eastgrip.org/Camplife.html#guidedtour

https://www.youtube.com/watch?time_continue=18&v=Pk5LP-fBG3c&feature=emb_logo_

COLDEX Project: https://coldex.org/

International Partnerships in Ice Core Sciences (IPICS):

https://www.pastglobalchanges.org/science/end-aff/ipics/intro

Nerilie Abram's video

https://www.youtube.com/watch?v=VjTsj-fi-p0&feature=youtu.be

Thanks for your attention!

