Pleistocene records from polar ice cores: the atmospheric perspective

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The reconstruction of the pattern and tempo of Quaternary climatic changes is essential to understand the present-day climate and foresee its future developments.

The Earth’s paleoclimatic history is preserved in natural materials accumulating progressively over time and responding to environmental and climatic conditions.

Tree rings

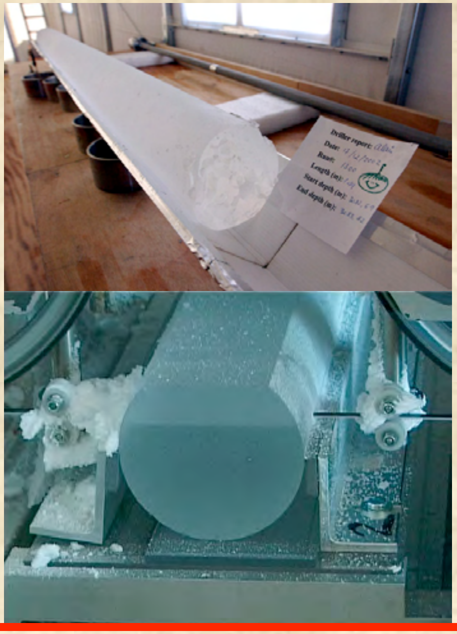
Varves

Peat Bogs

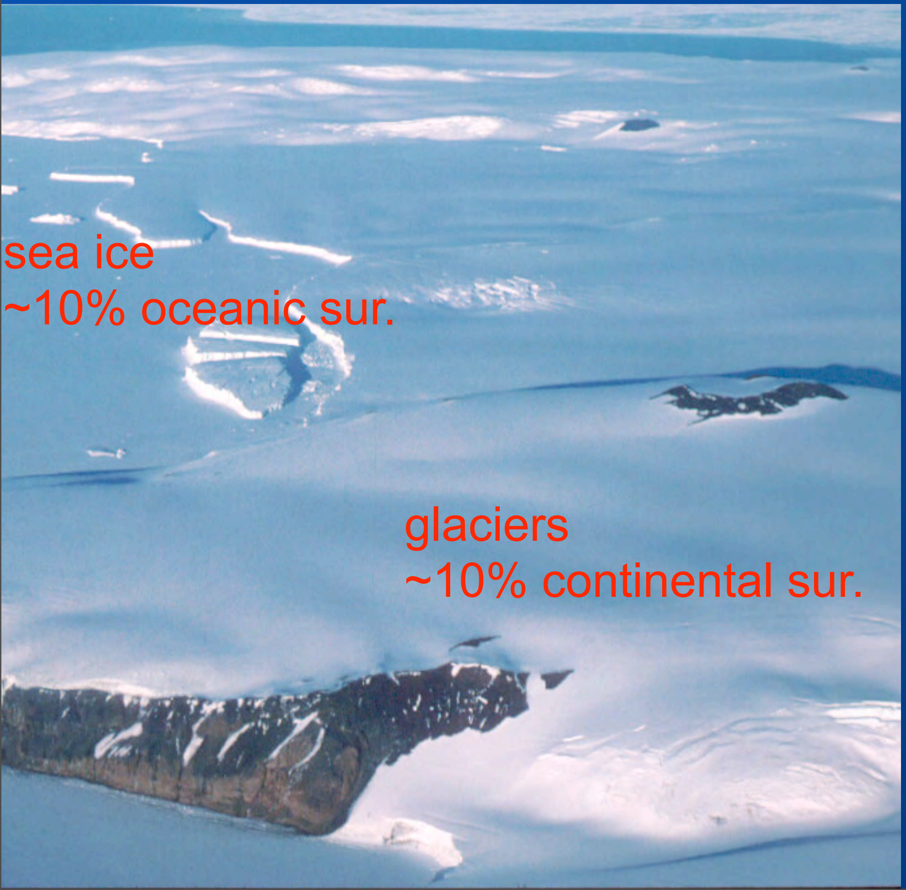
Marine Sediment cores

Loess Deposits

ICE CORES



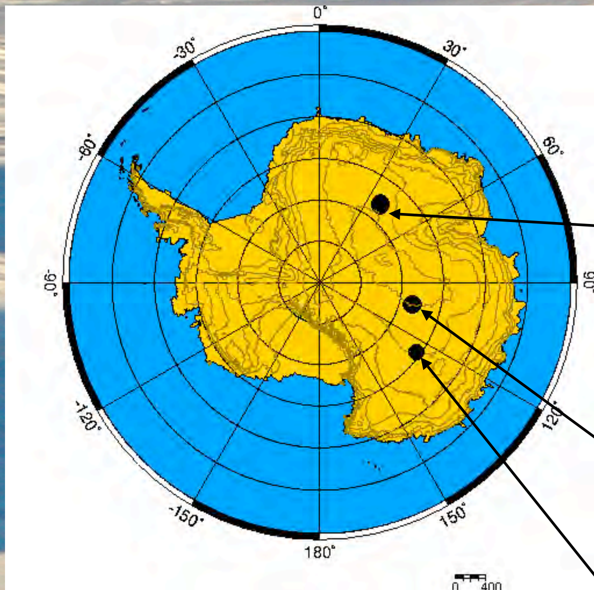
"solid" water on the Earth: The **Cryosphere**



Polar glaciers
(~ 99.8 % vol.)

Mountain glaciers
(~ 0.2 % vol.)

Ice cores from the low-accumulation sites of East Antarctica offer a unique archive for long-term climatic and atmospheric history



Longest ice core climatic sequences available today:

<u>Dome Fuji</u> ice core (*Watanabe et al., 2003*)
330,000 years

<u>Vostok</u> ice core (*Petit et al., 1999*)
420,000 years

The recent extension of the **<u>EPICA-Dome C</u>** ice core to 3200 m depth (February 2003) allowed to obtain <u>the longest climatic sequence</u> from polar ice cores (ca. **800,000 years B.P.**)

Several proxies can be investigated in ice cores:

Stable isotopes of water	[$\delta^{18}O$, δD, d excess]
Soluble components	[marine (Cl, Na, K, Mg, SO_4,…), terrestrial (NO_3, Ca, K, organic acids), biological from oceans (SO_4, MSA, …) volcanic (H_2SO_4, HCl, HF, …)]
Gas in air bubbles	[CO_2, CH_4, N_2O, …]
Ice crystals	
Heavy Metals	[Pb, Cd, Ni, Zn, Rh, Pa, …]

Insoluble microparticles [minor amounts of volcanic material, soot, micrometeorites, mainly **dust**]

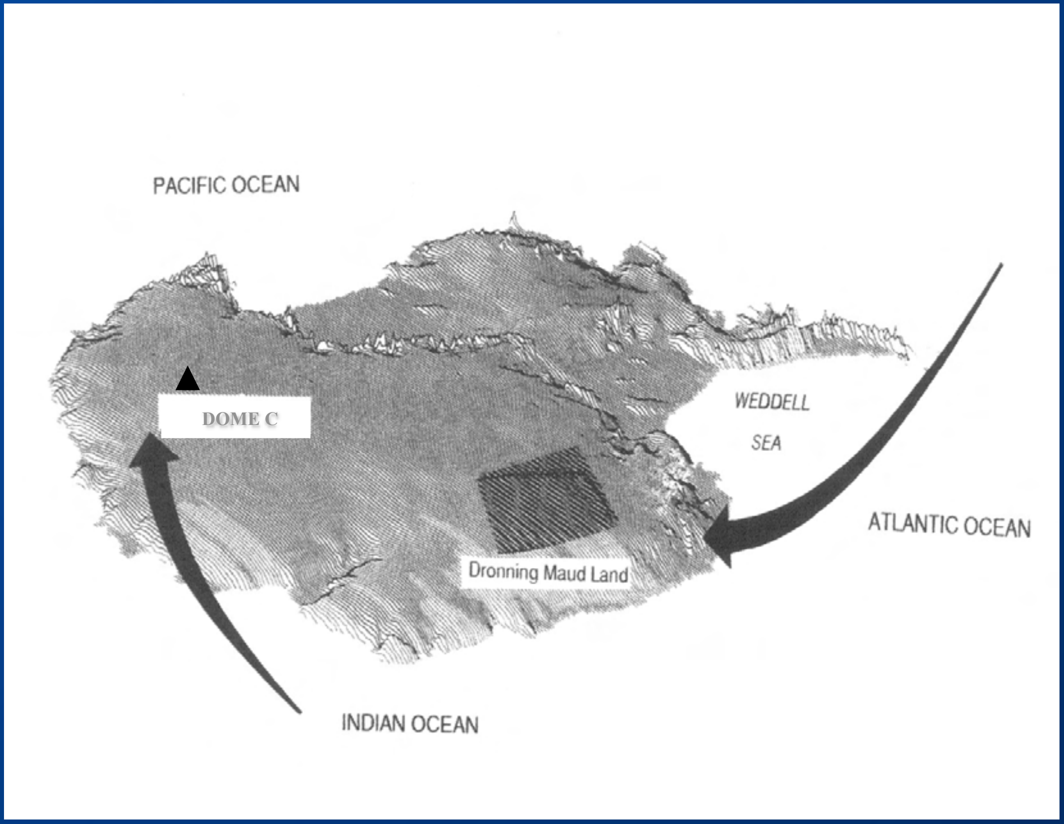
Dust = Windblown mineral aerosol of continental origin

EUROPEAN PROJECT FOR ICE CORING IN ANTARCTICA

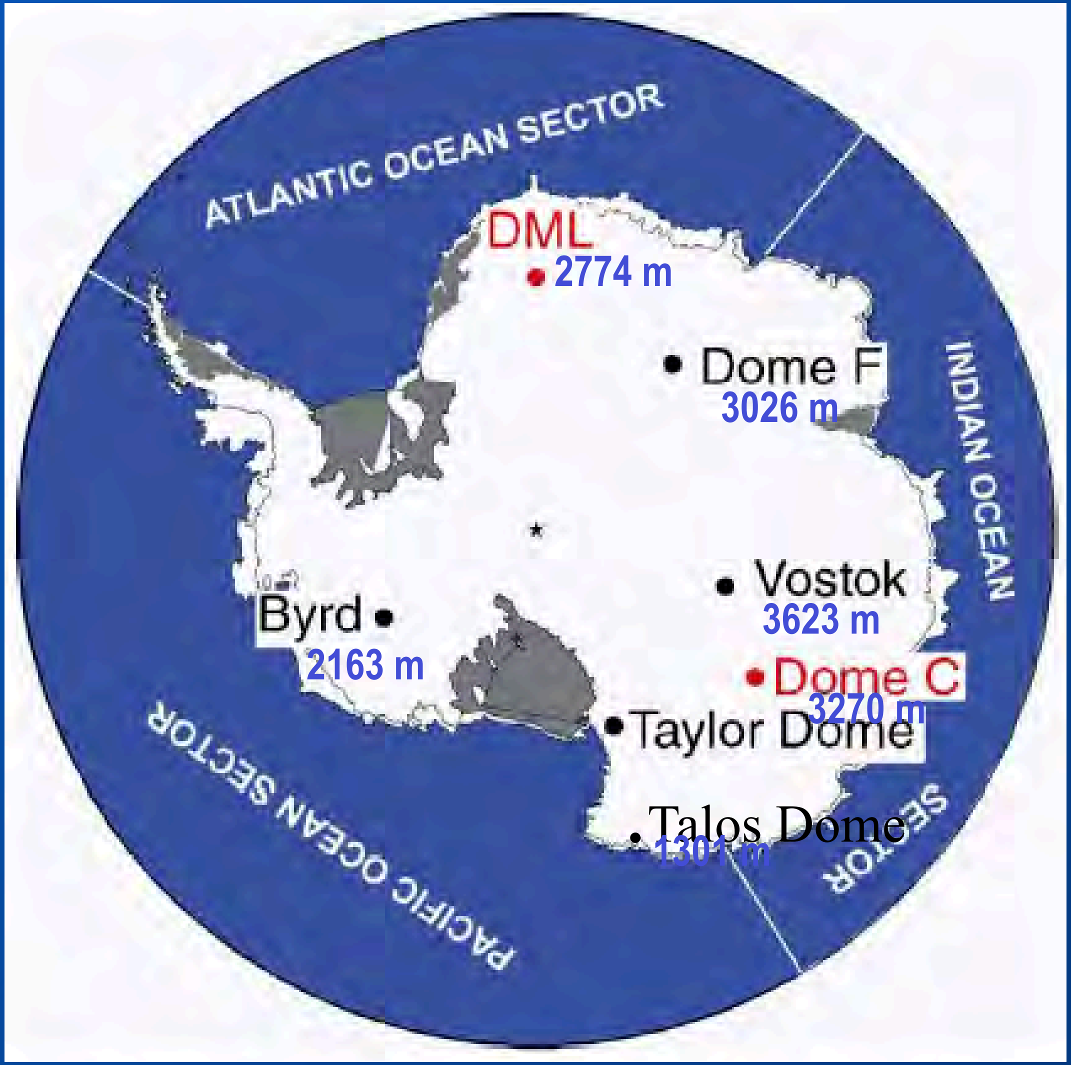
EPICA Project

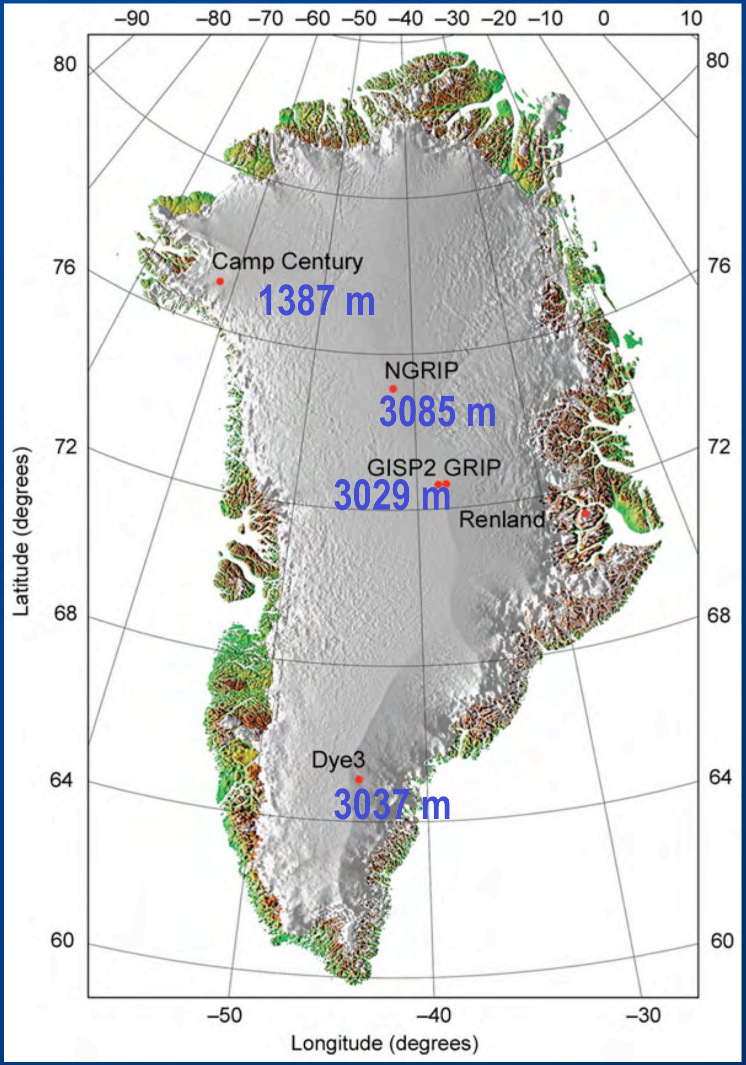
Starting 1996 founded by UE and 10 National Antarctic Programs

Two ice cores in the East Anntarctic Plateau:
 - Dome C (Pacific sector), for reconstruct the last 500 ky of climatic history
 - Dronning Maud Land (Atlantic Sector), for the climatic comparison with the Greenland ice cores (northern Hemisphere)

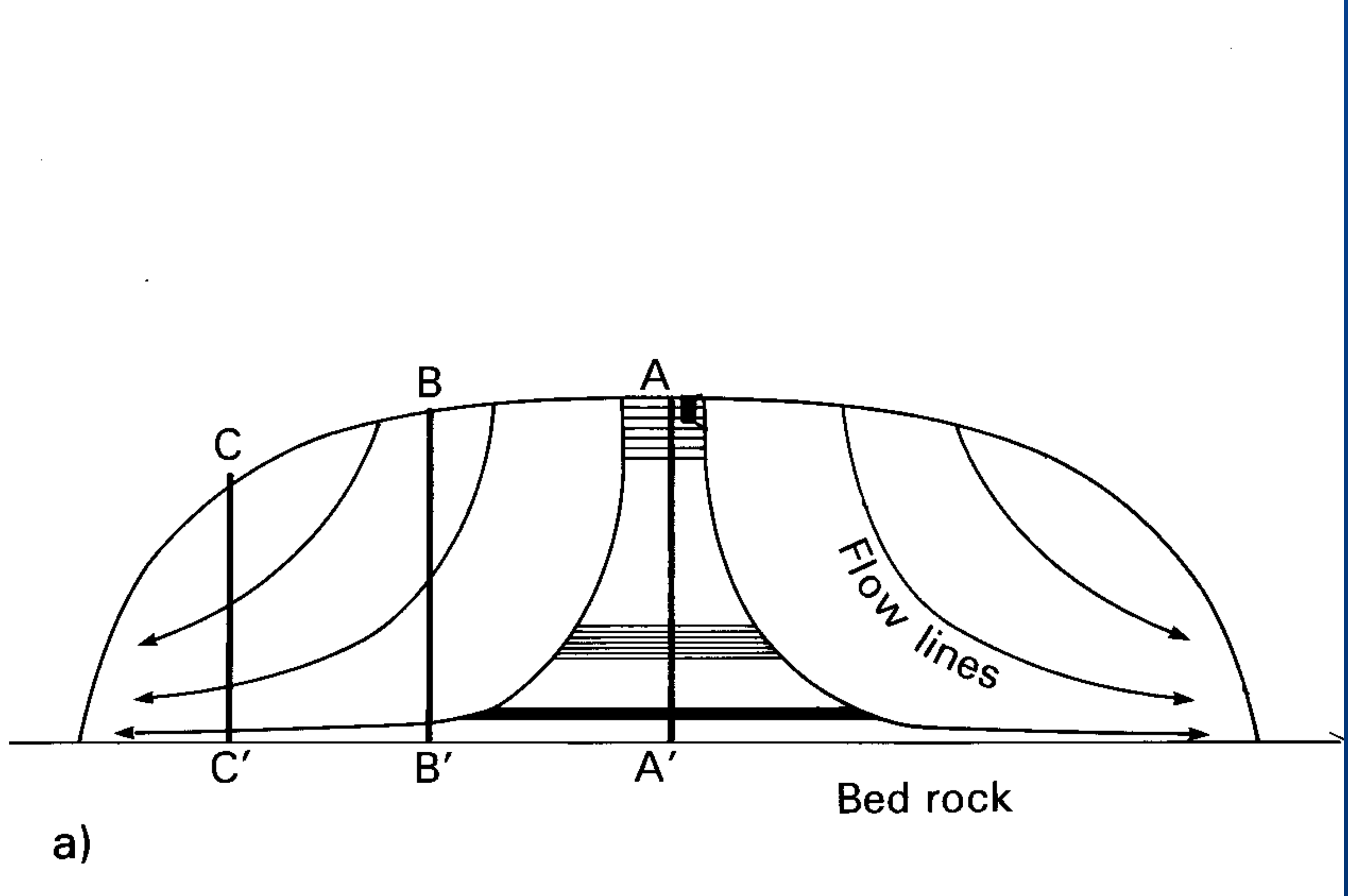


Ice cores in Antarctica and Greenland

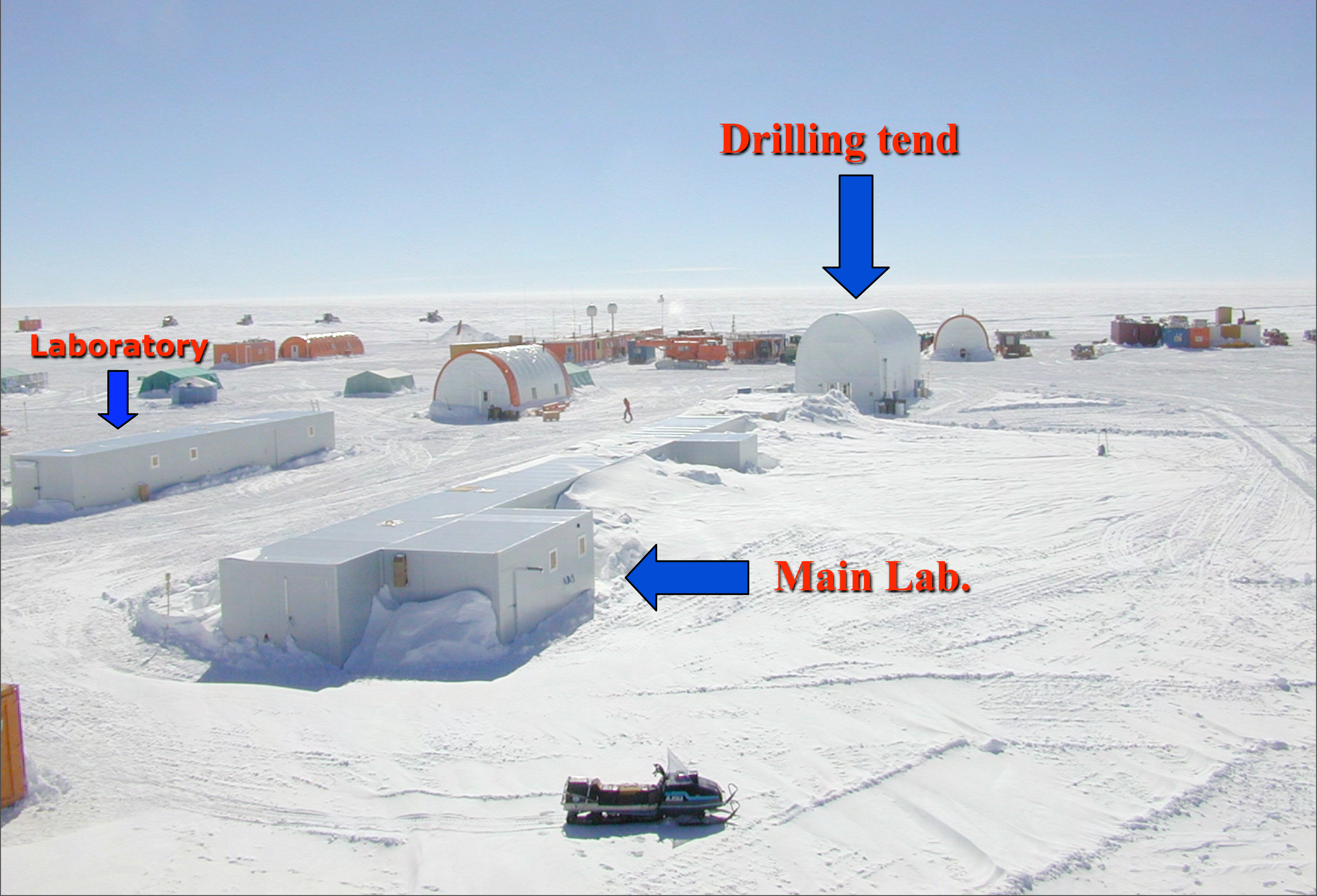




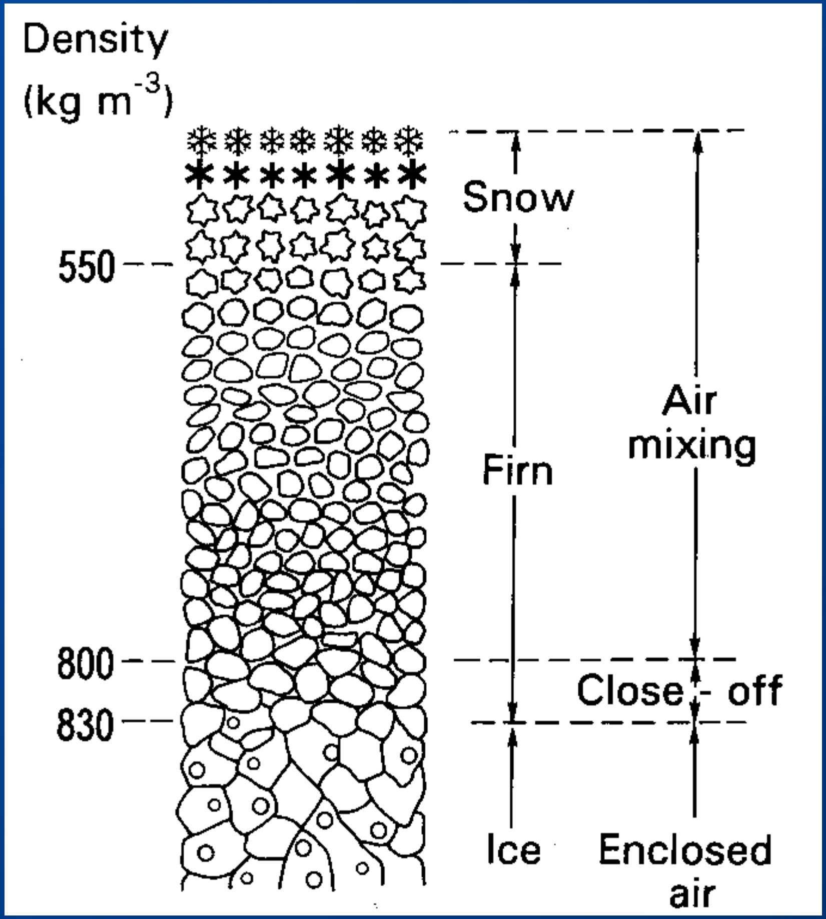
Sketch of polar glacier with the different geometry and ice flow.



EPICA at Dome C, close to the Concordia Station



How the air should be trapped in the ice



Legrand, Jouzel and Raynaud (1995)

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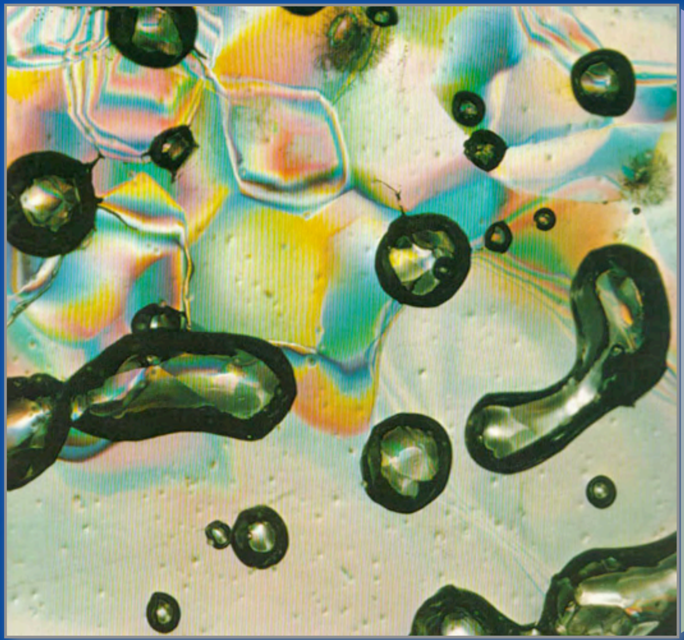
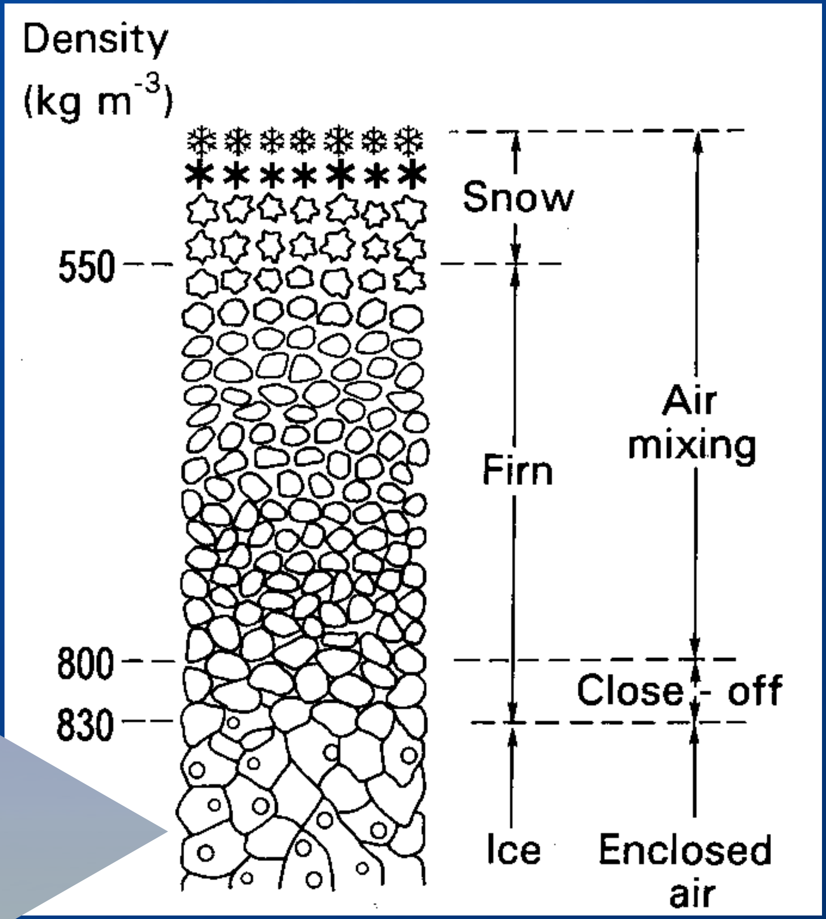




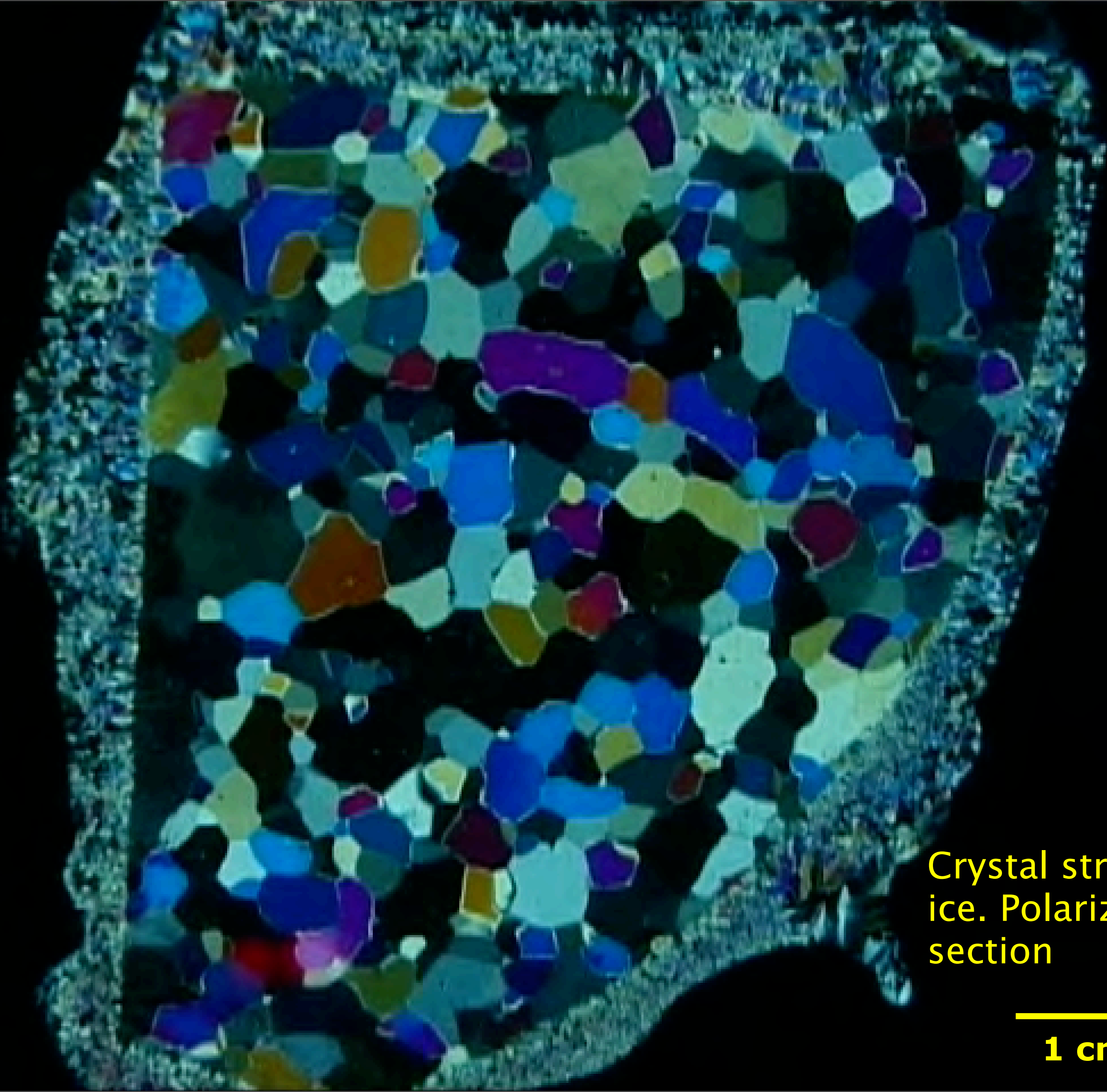
Legrand, Jouzel and Raynaud (1995)


Drilling
operations at
EPICA-DC

ice core after drilling operations

Main lab for ice core processing

Electrical conductivity measurements



Crystal structure of ice. Polarized thin section

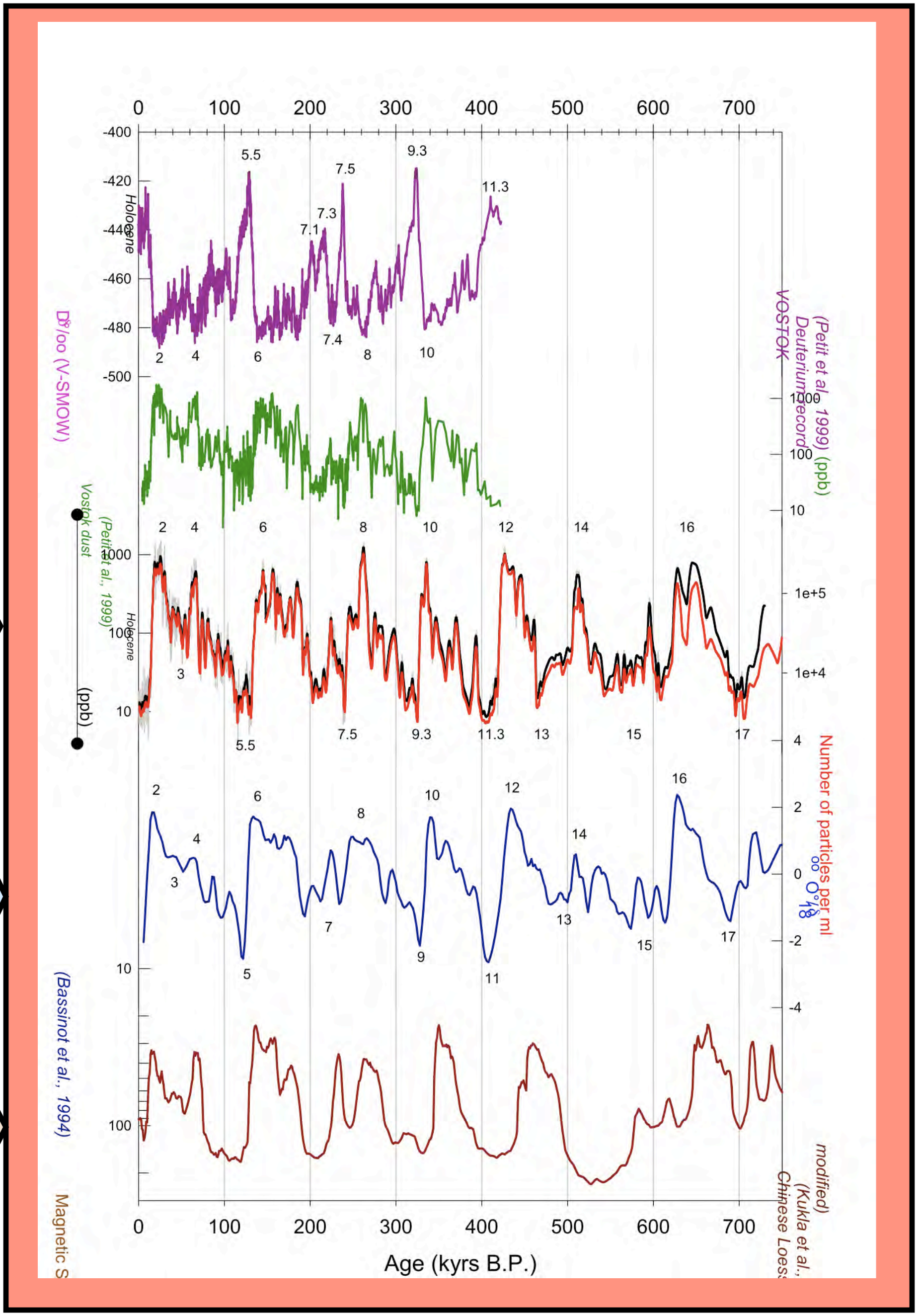
1 cm

A preliminar dating allows to estimate an age of **730-750 kyr B.P.** at ca. 3138 m depth *(7 Climatic Cycles)*

New EPICA Dust Record

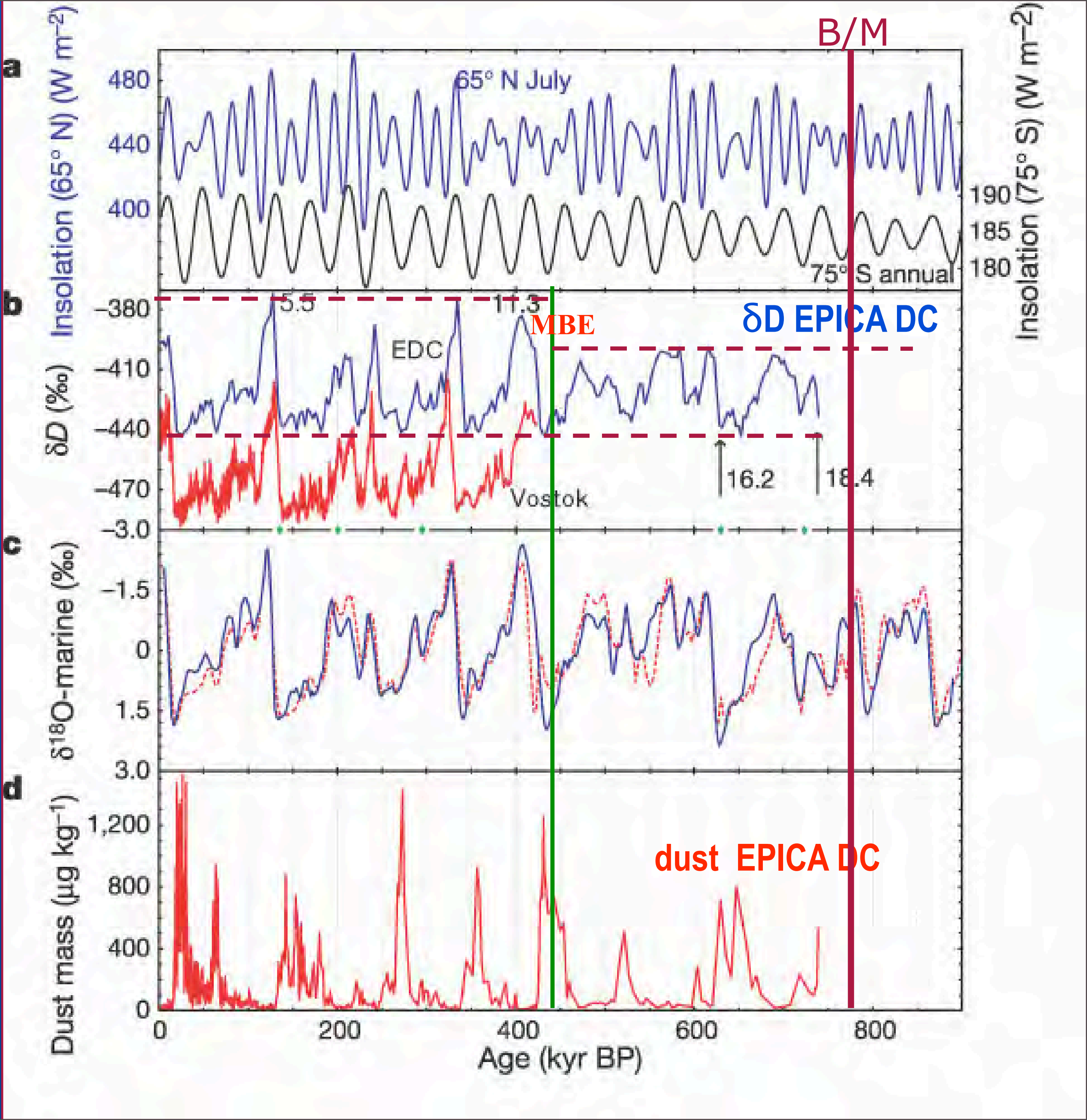
Global ice volume (Bassinot et al., 1994)

Chinese Loess deposit



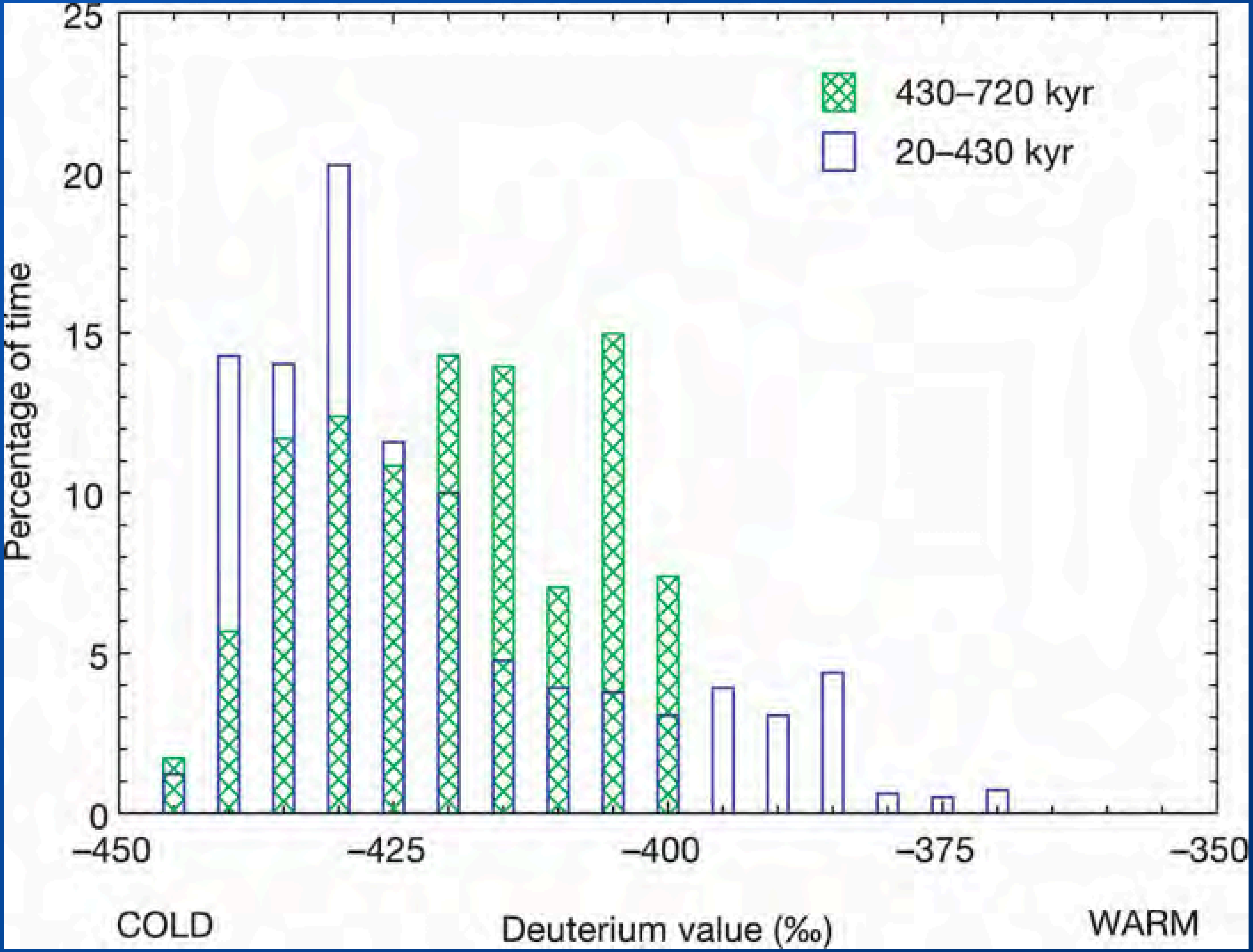
EPICA DC

The last 8 cycles: δD and dust EPICA DC in comparison with marine $\delta^{18}O$ and insolation records. Change in amplitude at ~ 430 kys "*Mid Bruhnes Event*"



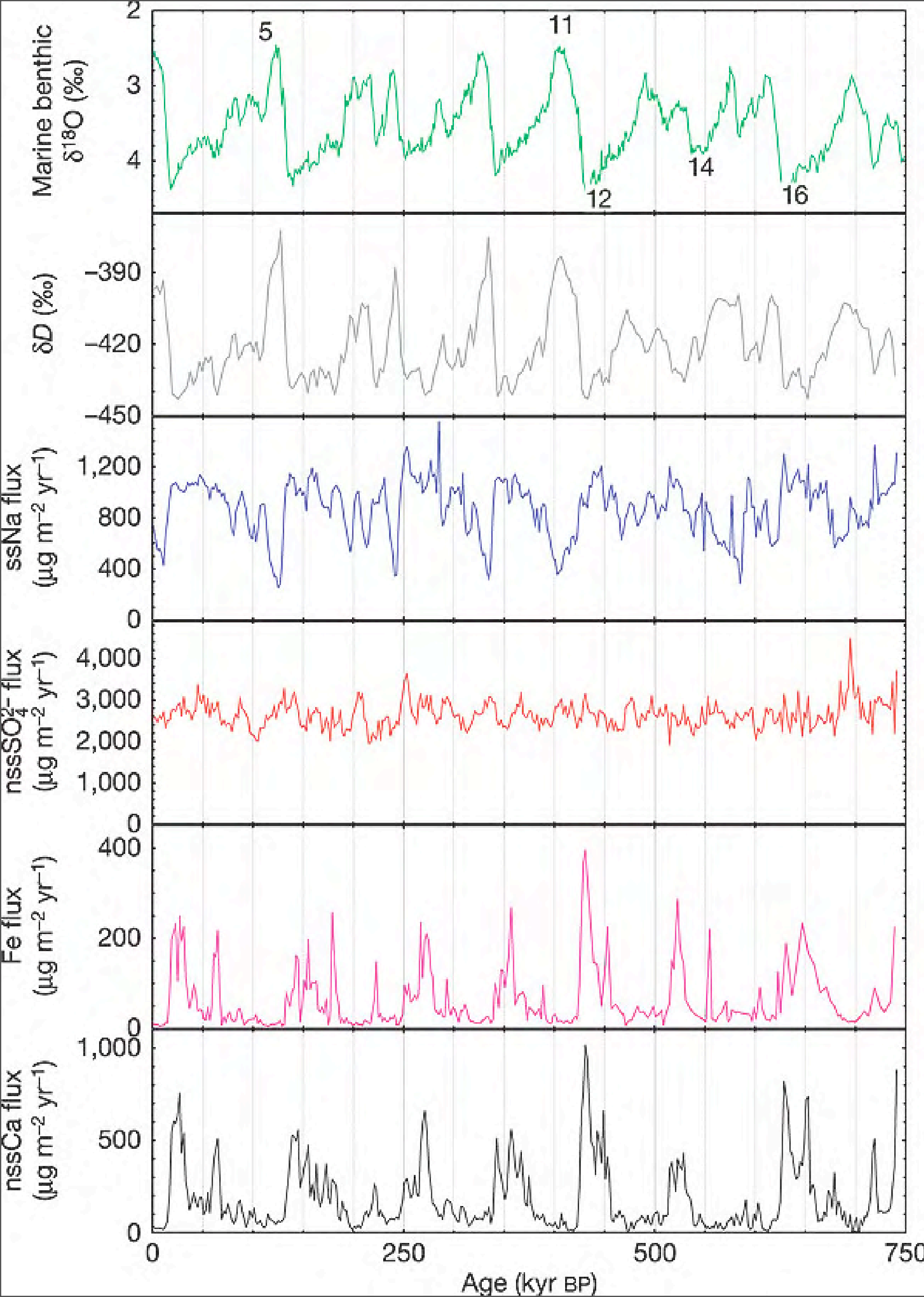
EPICA community members, 2004

EPICA DC



Histogram of δD, before (green) and after (cyan) the MBE

EPICA community members, 2004



EPICA DC

Change in flux of some chemical compounds in the last 750 kys over the Antarctica

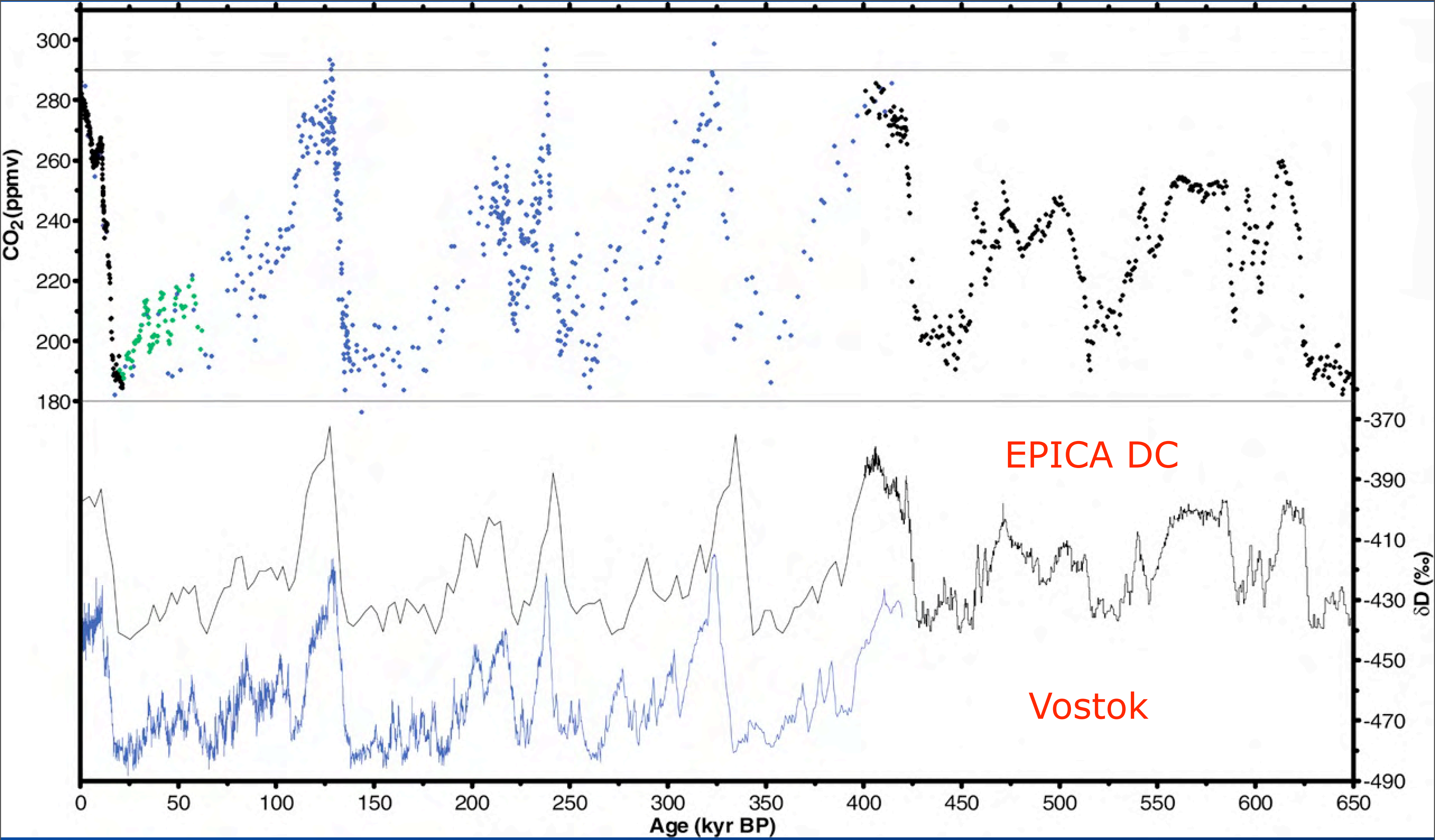
Na

SO_4

Fe

Ca

Wolff et al. 2006



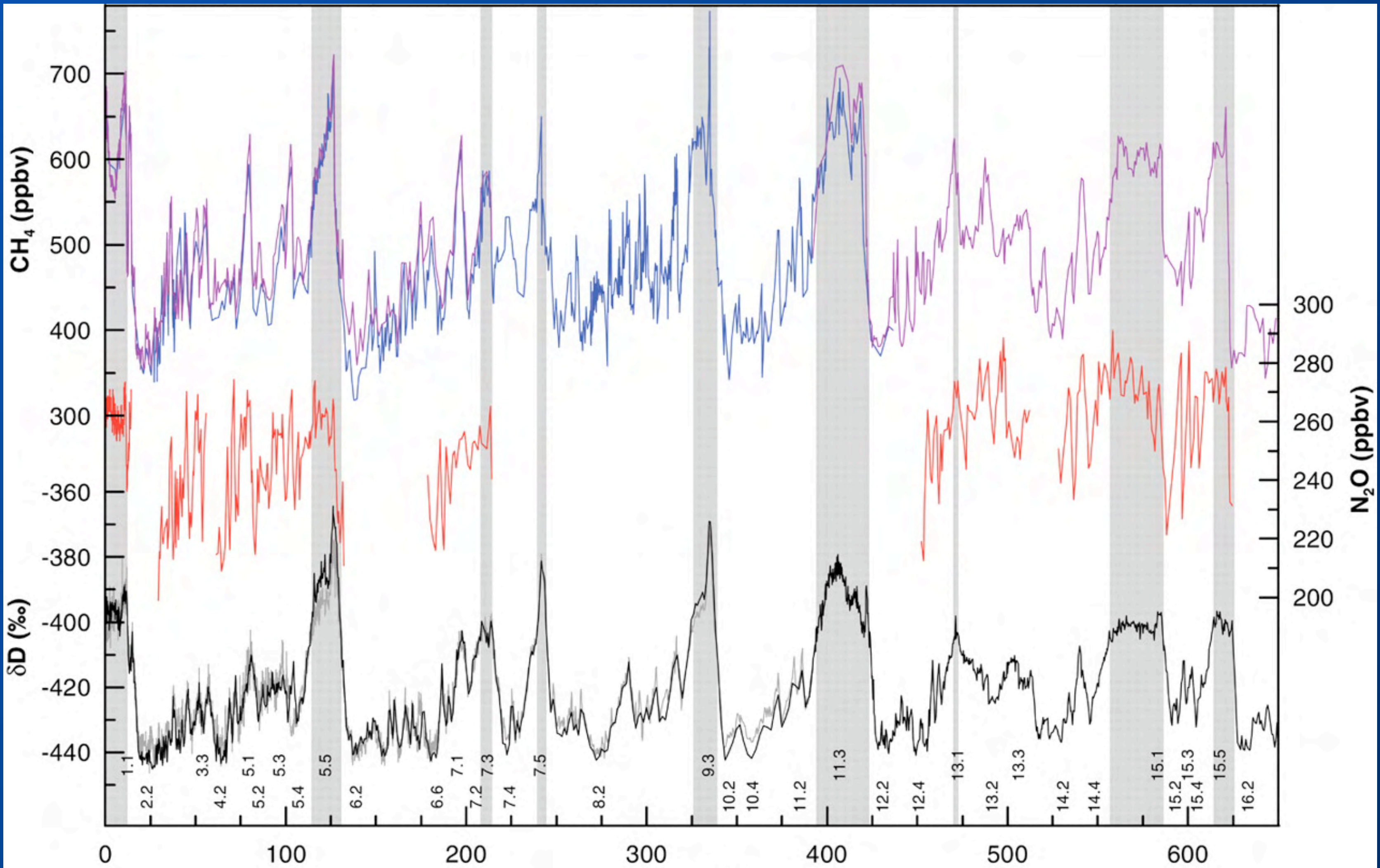
CO_2 record of the last 650 ka

black EPICA DC
blue Vostok
green Taylor Dome

Siegenthaler et al., 2005

EPICA DC: CH_4 and N_2O records for the last 650 kys

The methane over the Antarctica, in tpre-industrial era, never grow above the 773 ppbv. Before 430 kys, with mild interglacials, the CH_4 concentration reach maximum 600 ppbv. (minimum holocenic value).



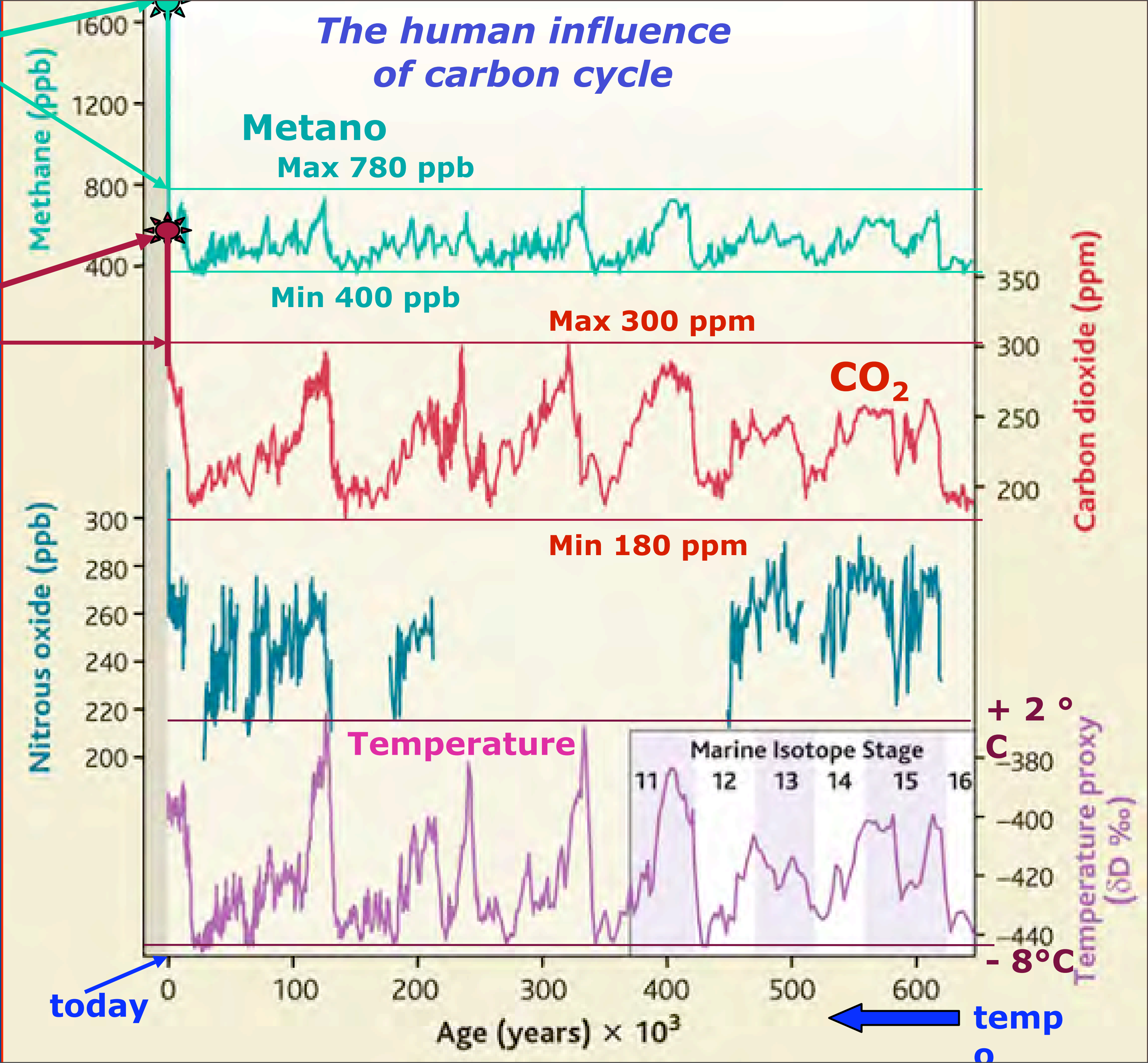
Spahni et al., 2005

Methane
2006
1780 ppb
+ 130%
in 200 years

CO_2
2006
380 ppm
+ 35 %
in 200 years

EPICA DC GHG's and T° in the last 650 kys.

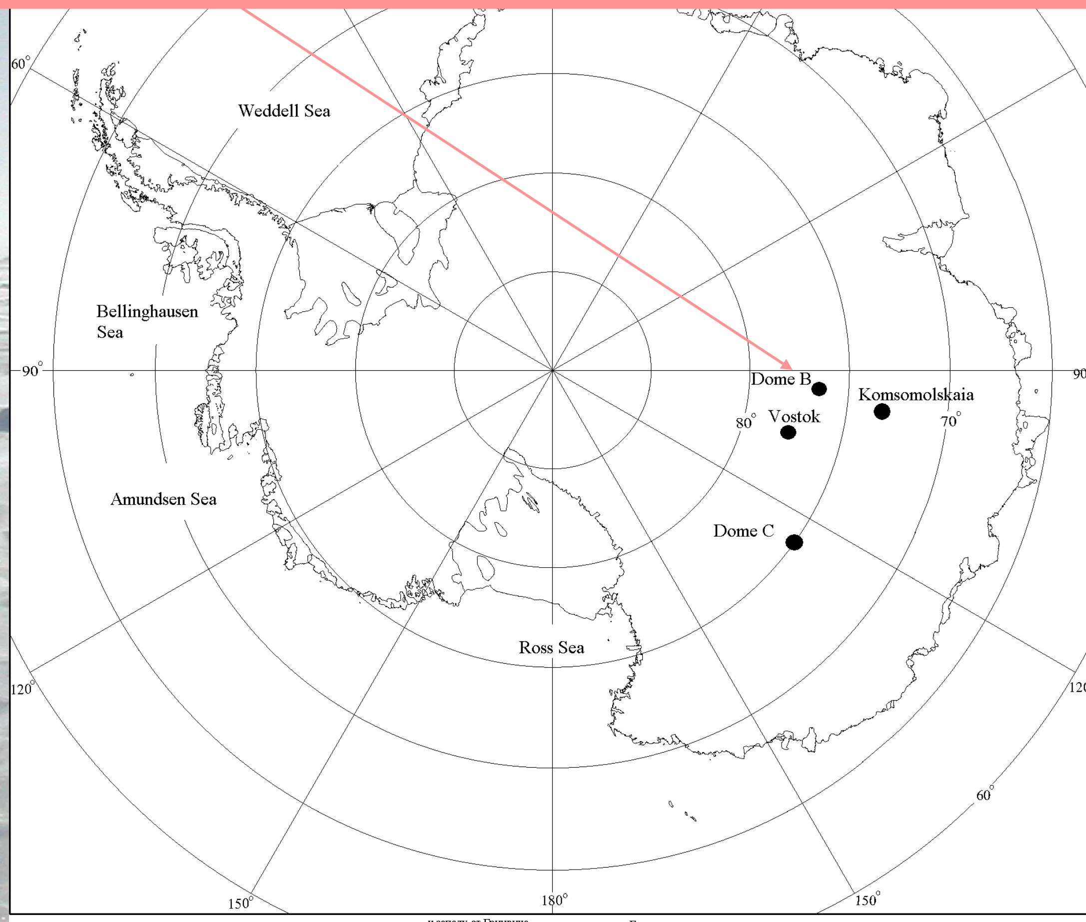
(Brook, 2006)



Dome B (DB) (77° 05’ S, 94° 55’E; 3650 m a.s.l.)

The site is located 320 km upflow from Vostok, 870 km far from Dome C.

Core drilled during the 1987/88 season (33rd Soviet Antarctic Expedition)



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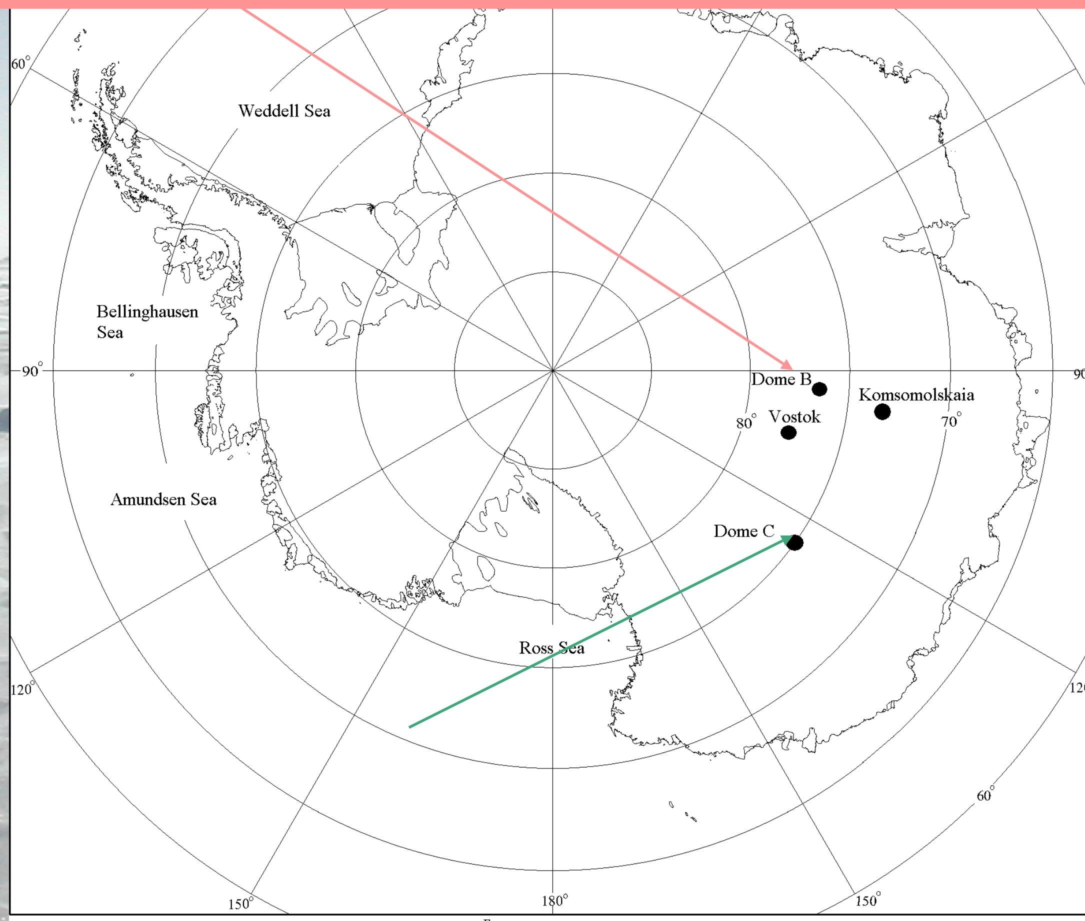

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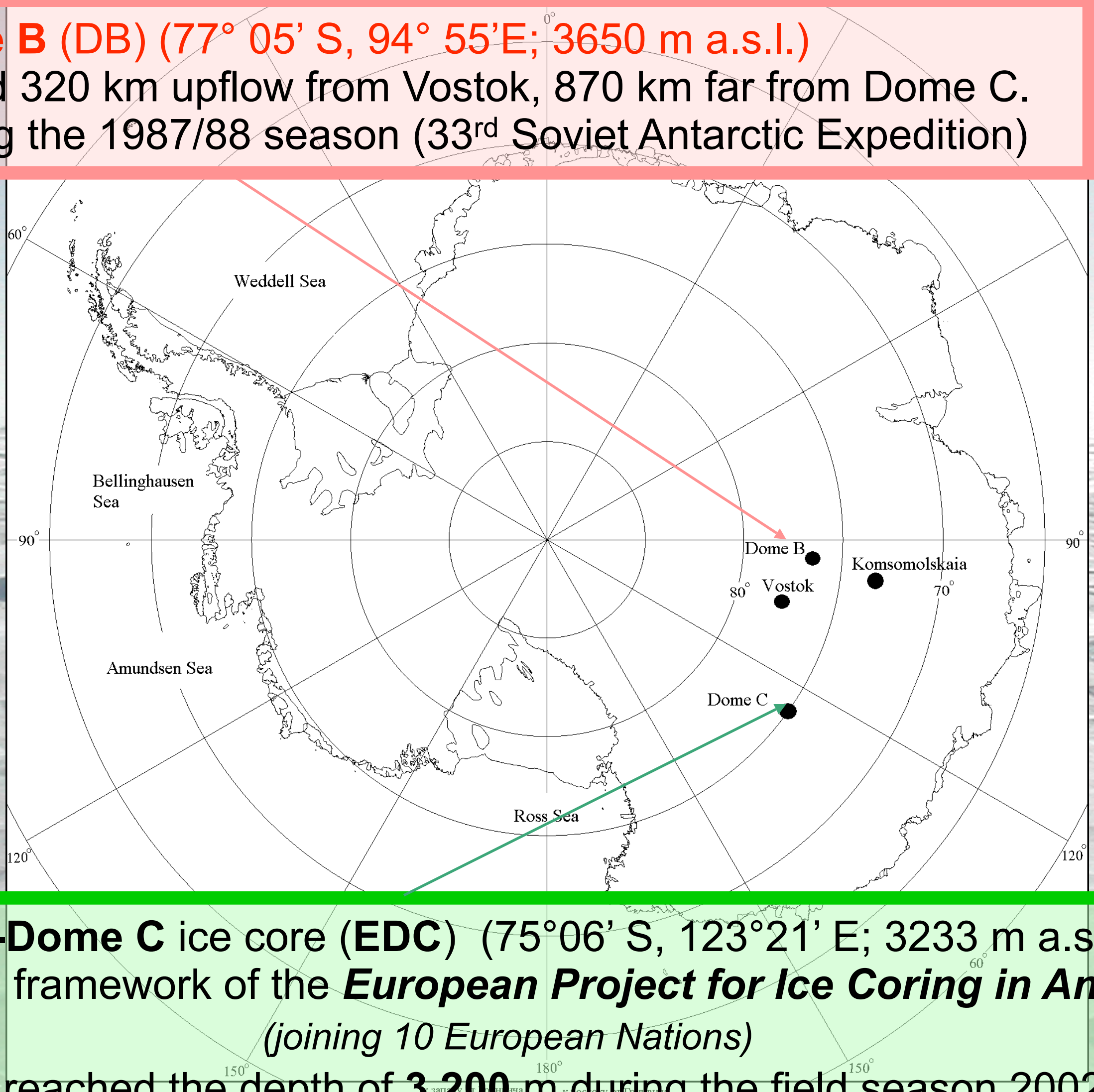

EPICA-Dome C ice core (**EDC**) (75°06’ S, 123°21’ E; 3233 m a.s.l.)
Drilled in the framework of the ***European Project for Ice Coring in Antarctica***
(joining 10 European Nations)
The ice core reached the depth of **3,200** m during the field season 2002/03, and **preserves the longest climatic memory from polar ice cores** (about **750,000 years**).

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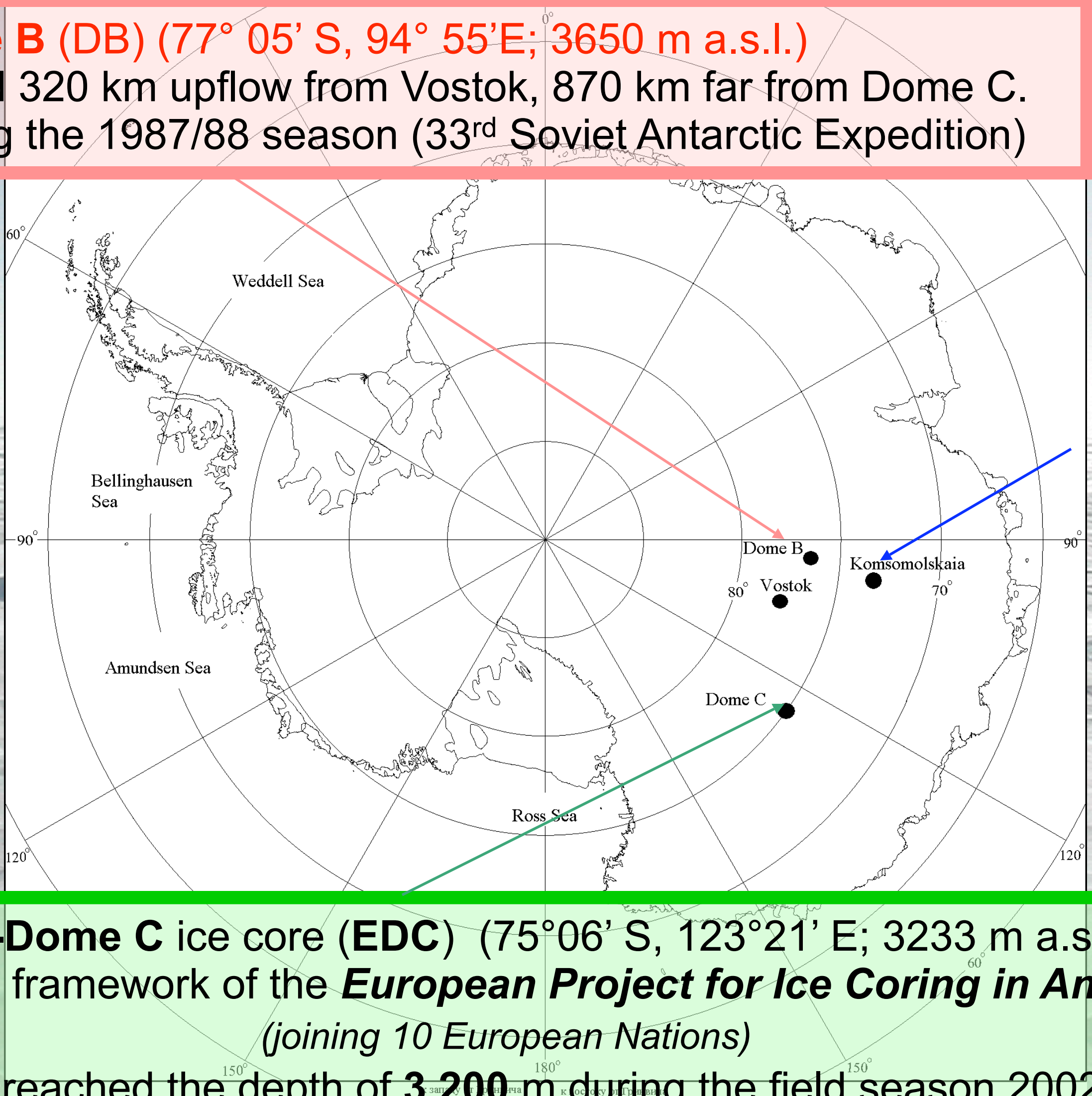

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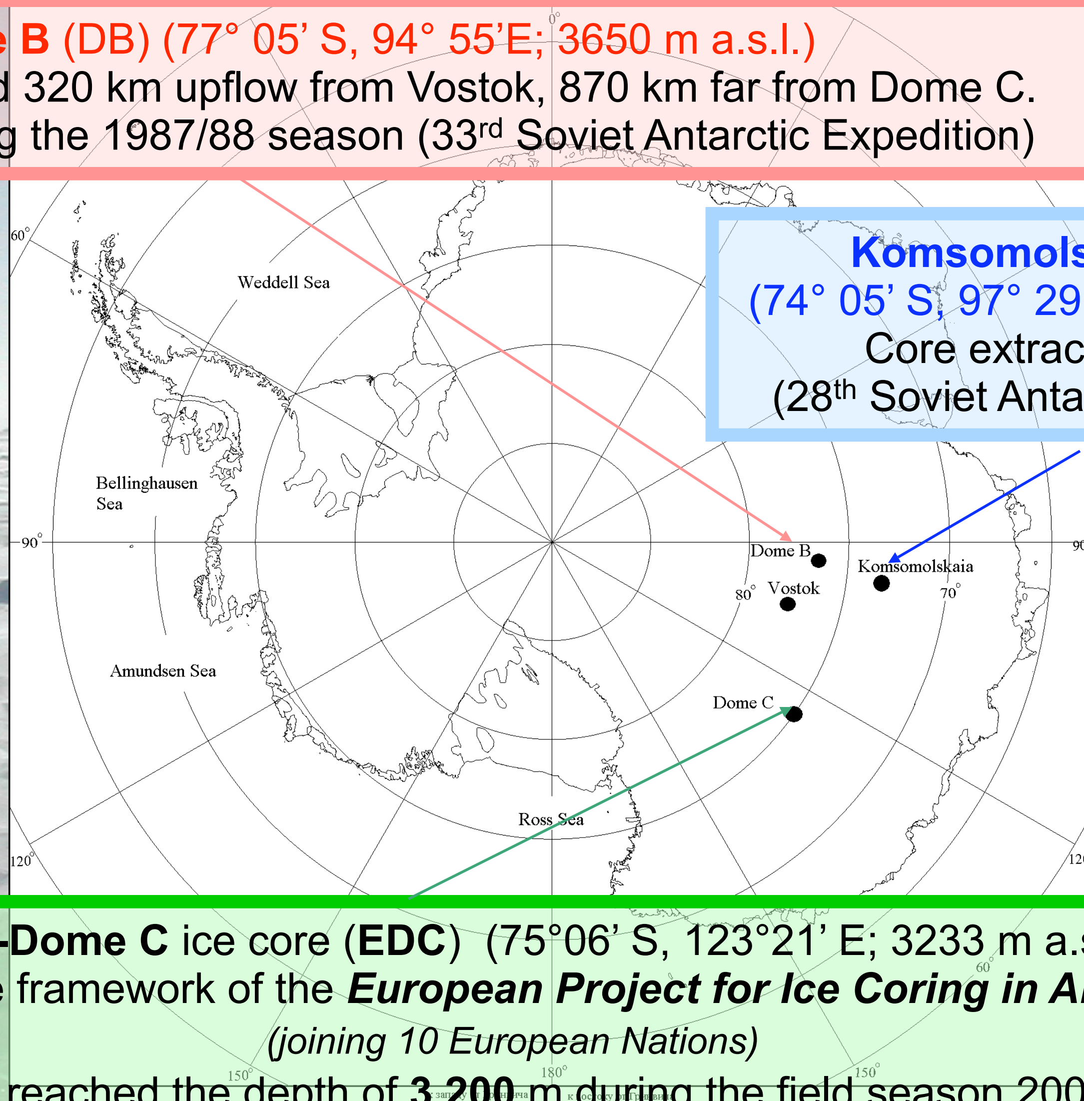
Komsomolskaia (KMS)
(74° 05’ S, 97° 29’ E; 3500 m a.s.l.)
Core extracted in 1983
(28th Soviet Antarctic Expedition)



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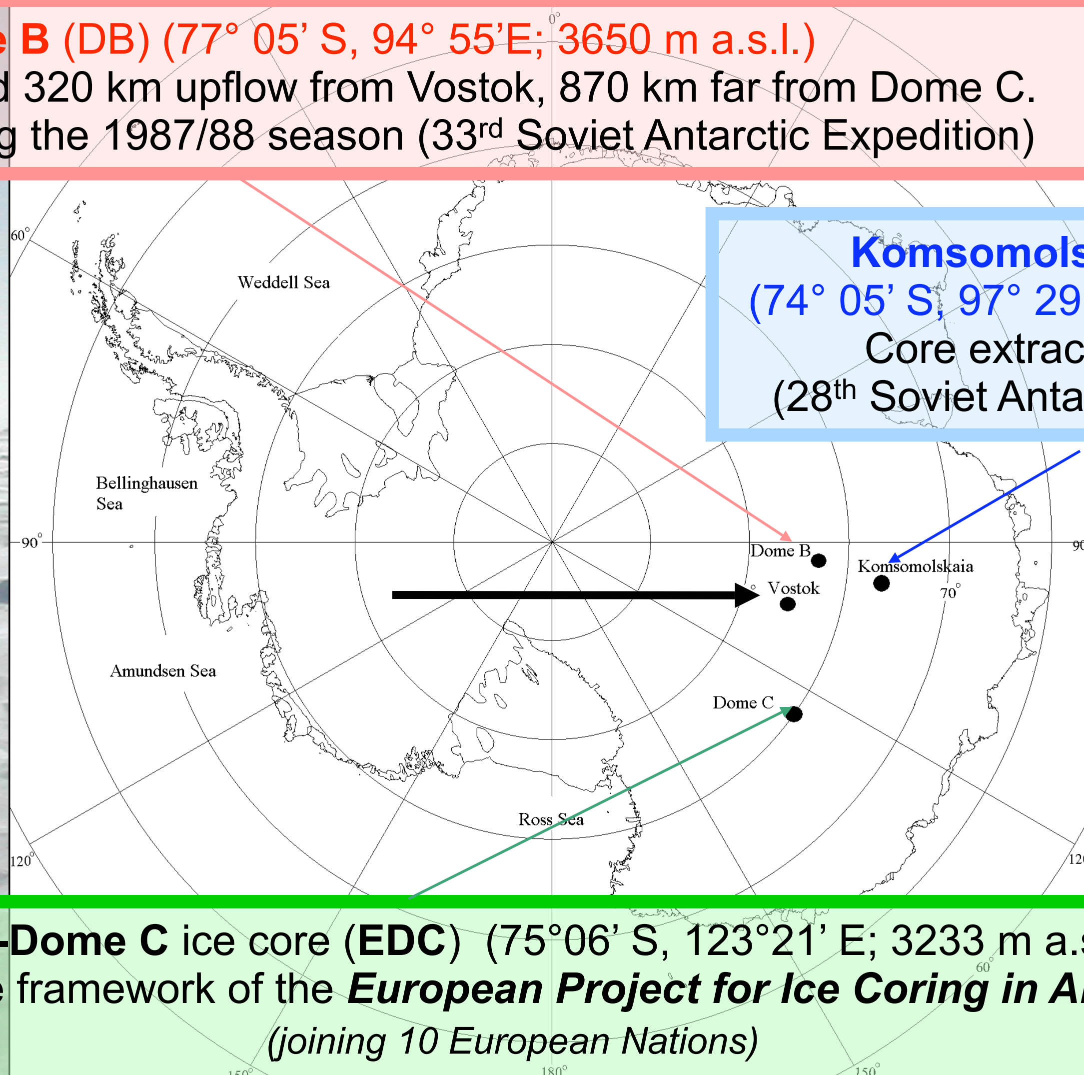

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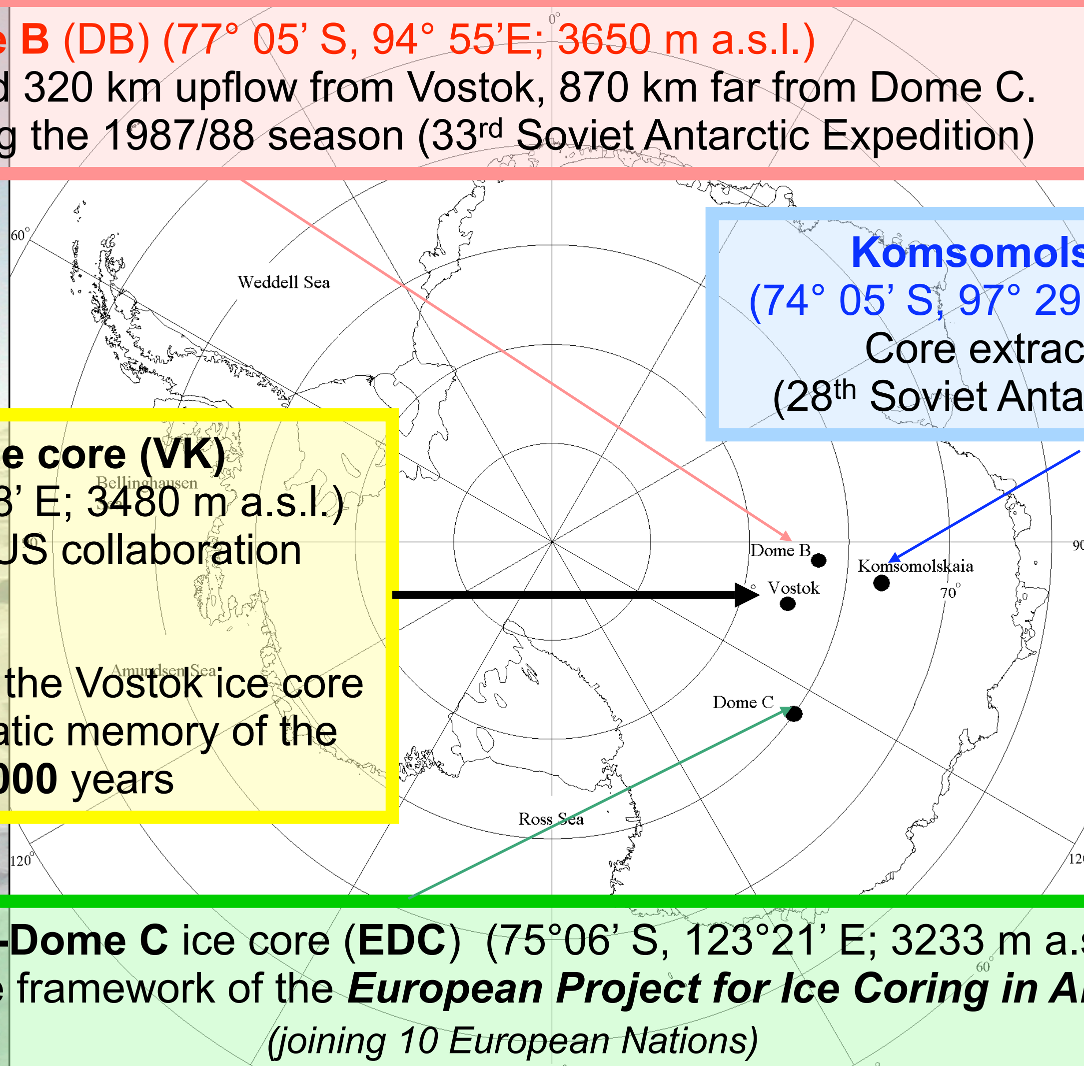

VOSTOK ice core (VK)
(78° 05’ S, 106° 48’ E; 3480 m a.s.l.)
Russia-France-US collaboration

The first 3310 m of the Vostok ice core preserve the climatic memory of the last **420,000** years

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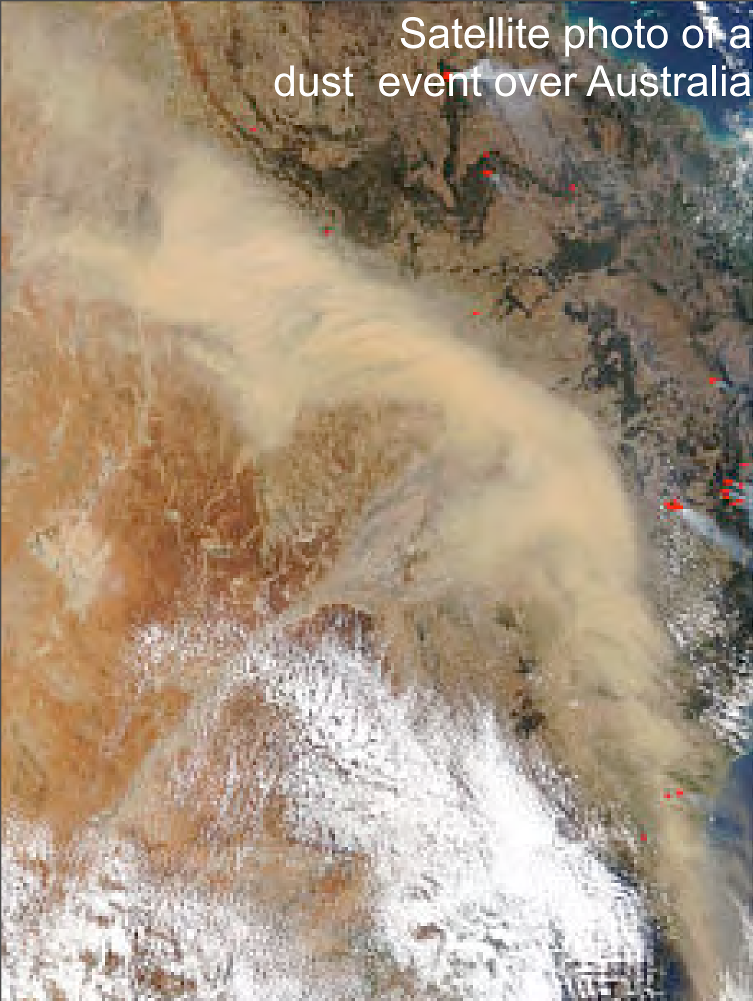
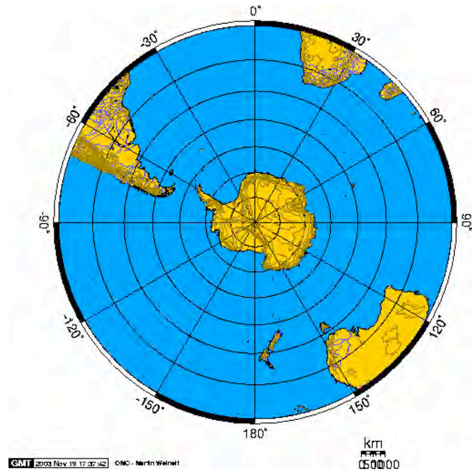
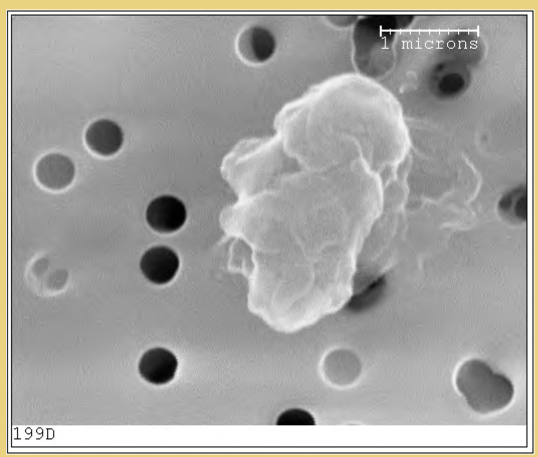
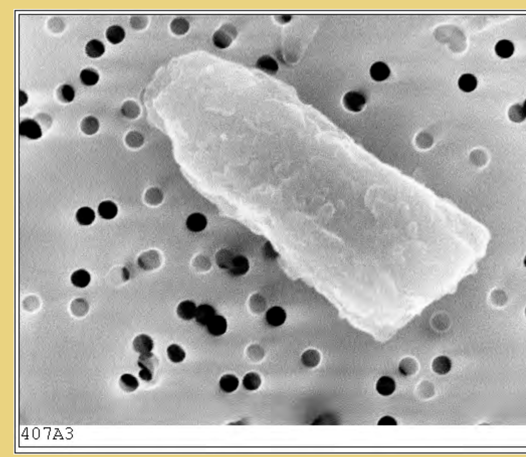




Dust deflated from arid regions of the Southern Hemisphere, injected into the mid-high Troposphere and transported long-distance can reach the interior of the East Antarctic Plateau.

During long-range transport, the <u>dust is graded</u> and a <u>mineralogical selection occurs</u>. The dust plume is progressively enriched in ***quartz, clays*** *and* ***feldspars***.



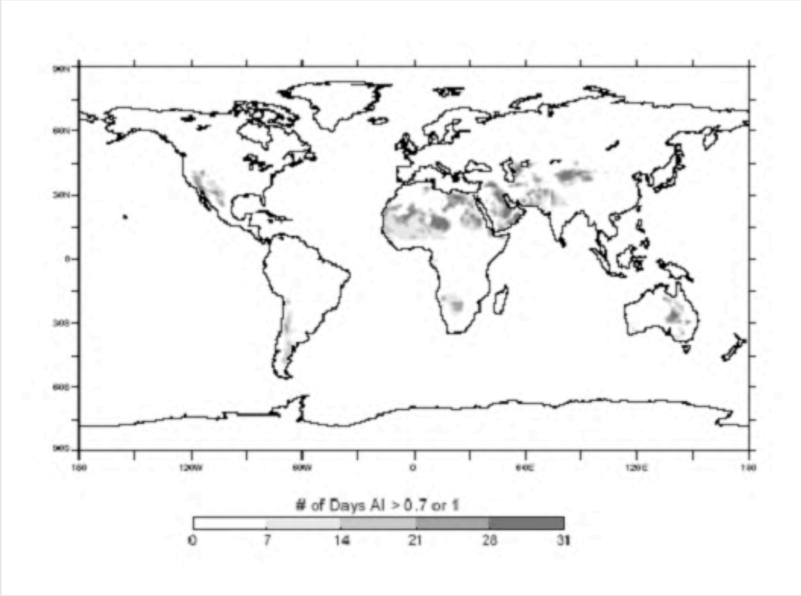


Minerals entrapped in Vostok ice core (after Gaudichet et al., 1992):

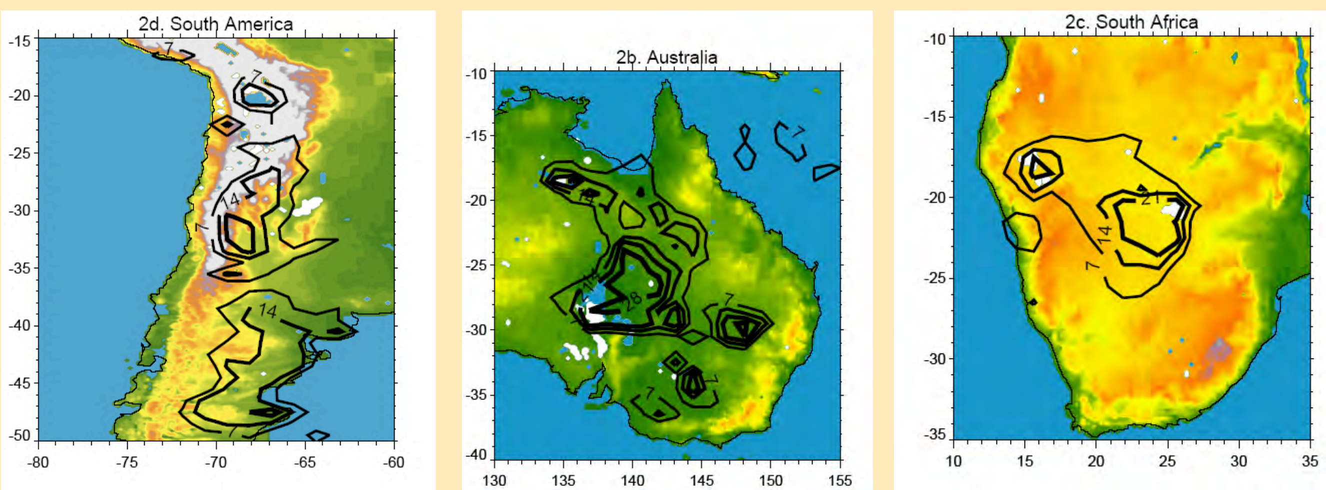
40% clays (mainly Illite),
15% crystalline silica,
15% feldspars
minor amounts of pyroxenes amphiboles, metallic oxydes, volcanis glasses.

The regions providing the bigger dust fluxes at present time are primarily associated to little or no ground cover, erodible surfaces and seasonal wetness.

(Mahowald et al., 1999)



Global distribution of dust sources identified through TOMS (Total Ozone Mapping Spectrometer) sensor on NIMBUS-7 satellite (Prospero et al., 2002).



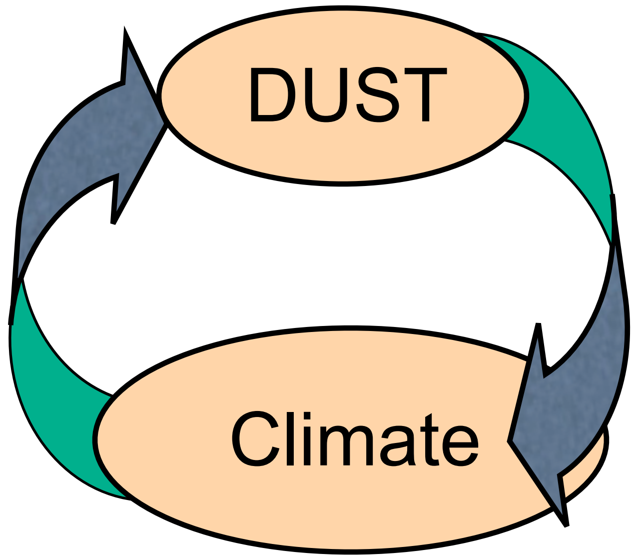
Major dust « hot spots » in the Southern Hemisphere for present time (Prospero et al., 2002).

The dust cycle is tightly linked to the climate system:

Continental Aridity

Hydrological cycle

Atmospheric circulation (transport)



Radiative effect

Atmospheric reactions

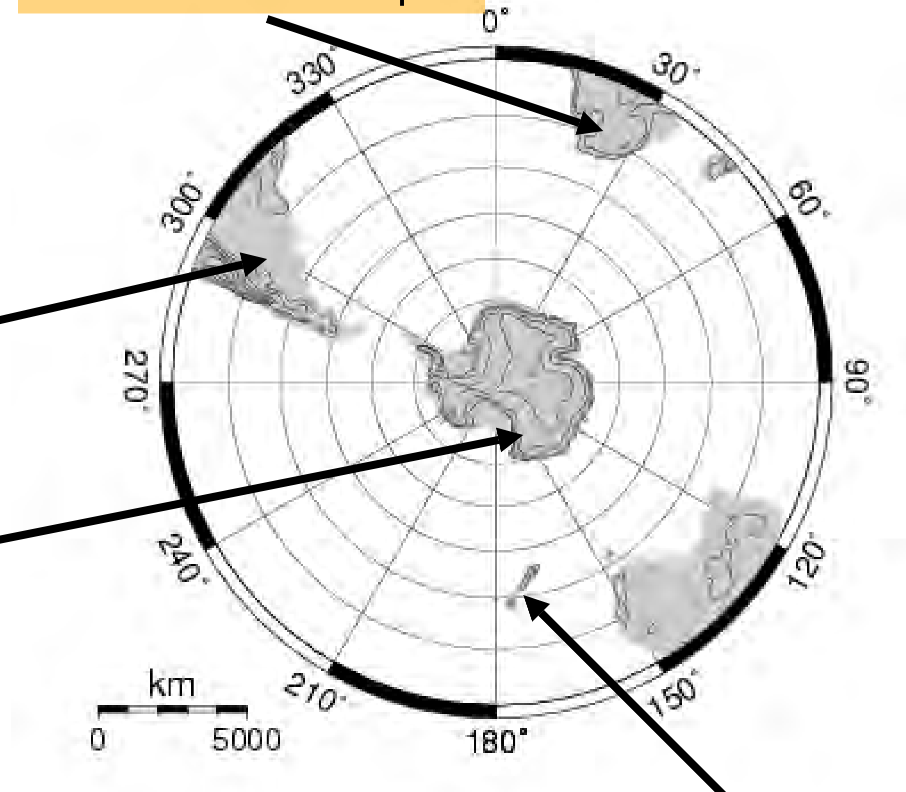
Fertilization of the oceans and CO_2 uptake

The investigation of past changes in atmospheric dust load and transport patterns are an essential tool for paleo-climate and paleo-environmental reconstructions.

Sources (PSA)

In this study, more than **50** samples have been collected from ***South America, South Africa, New Zealand,*** *and the exposed areas of* ***Antarctica.***

South Africa: **5** samples



Southern South America (>30°S): **24** samples

Antarctica (Dry Valleys): **9** samples
Northern Victoria Land : **1** sample

New Zealand: **15** samples

No samples from Australia have been analysed in this study.

A Franco-Australian project is in course
(Dr. M. Revel-Rolland).

The Antarctic **Dry Valleys** and **New Zealand** have been documented for the first time

No samples from the **Antarctic Peninsula** have been collected; geologically similar to southern South America.

Dust Variability investigated by **Coulter Counter** technique

(physical approach)

DUST CONCENTRATION in ice

Number of particles per ml of ice

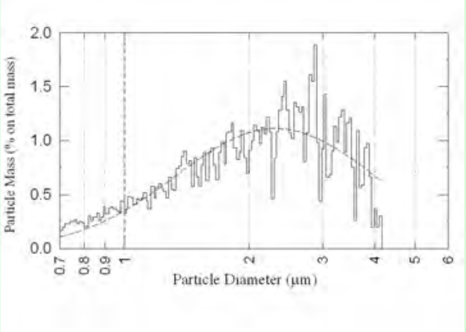
Dust mass (ppb or ng_{dust} / g_{ice})

estimated assuming average density of 2.5 g/cm^3

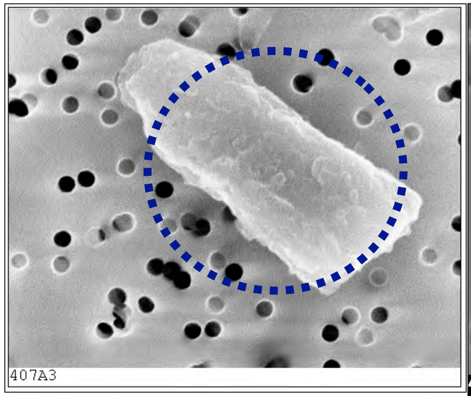
DUST SIZE DISTRIBUTION

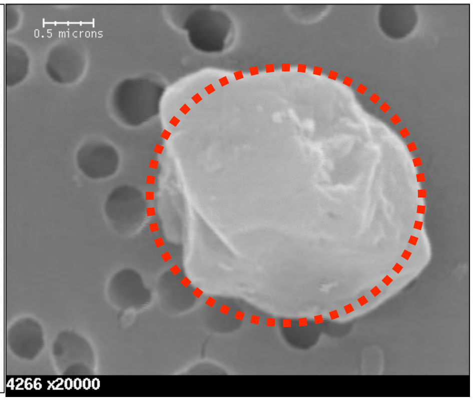
(particles with diameter 0.7-20 μm)

256 Channels of measurement



Particle diameter is equivalent to diameter of a spherical particle





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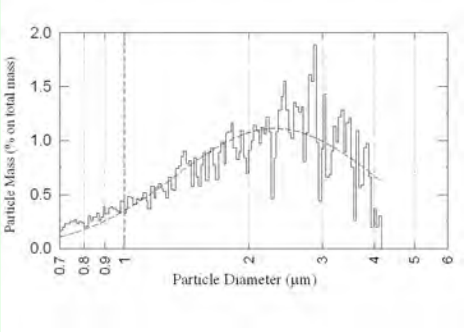

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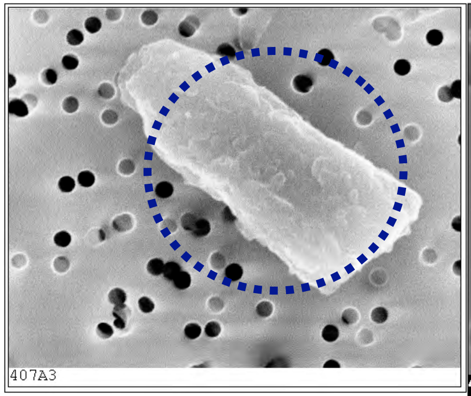
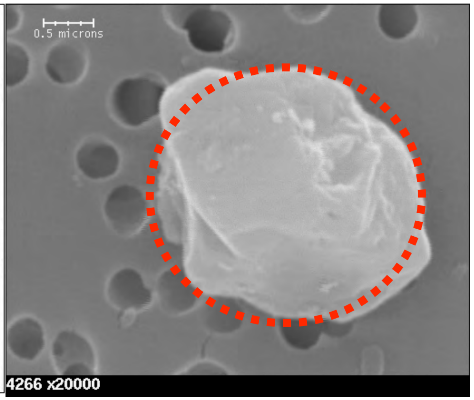
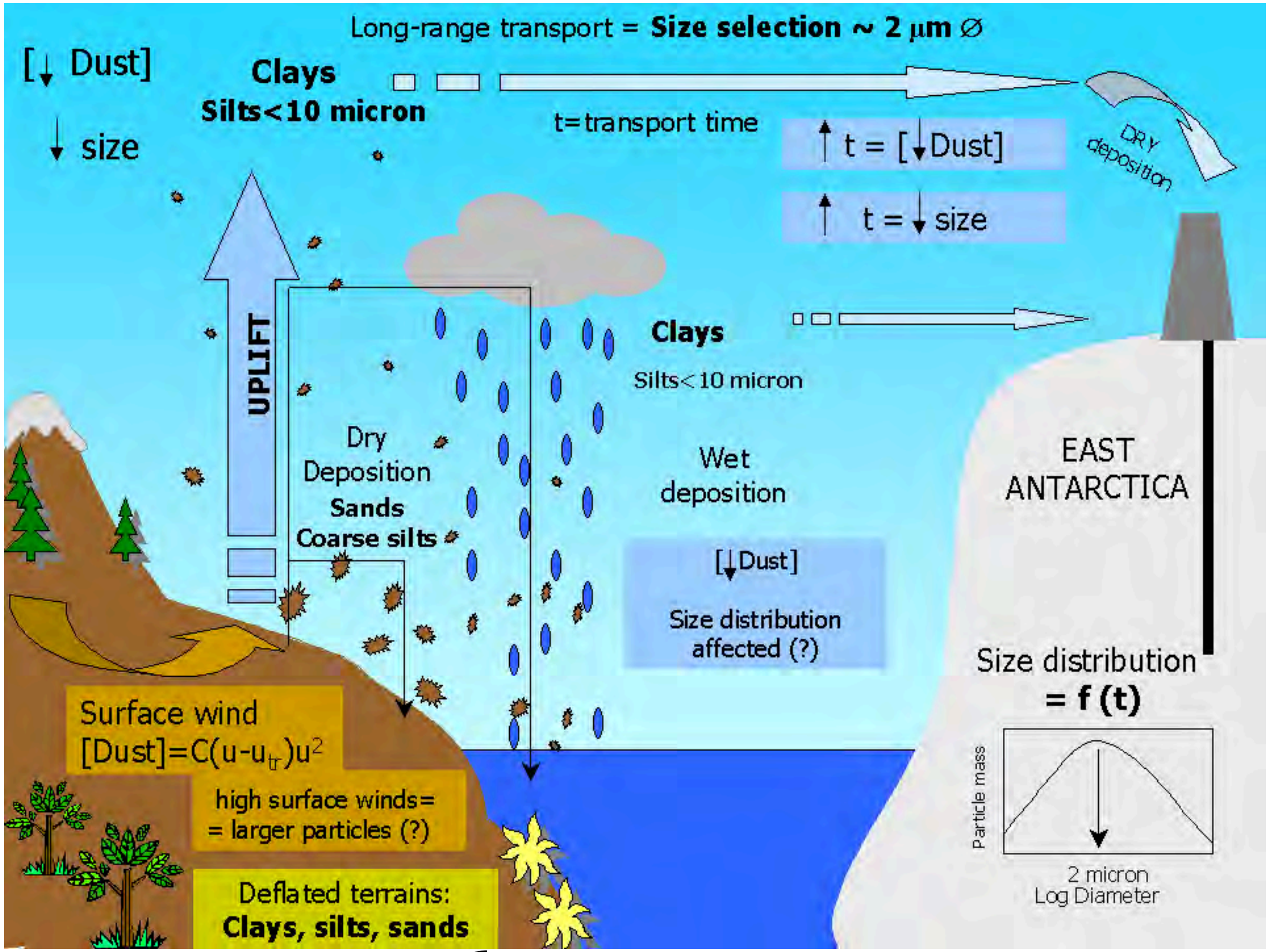




WHAT INFORMATION?



$$[\mathrm{Dust}]_{ice} = \begin{cases} \text{f (source strength)} \\ \text{f (dry/wet deposition efficiencies)} \\ \text{f (t)} \\ \text{f(accumulation rate in ice)} \end{cases}$$

Dust size distribution in ice = f (t)

The Last climatic transition in East Antarctica

the first (low-resolution) dust record from EPICA-Dome C ice core

LGM/Holocene
dust concentration ratio of ca. ***53***
(i.e. 26 in flux)

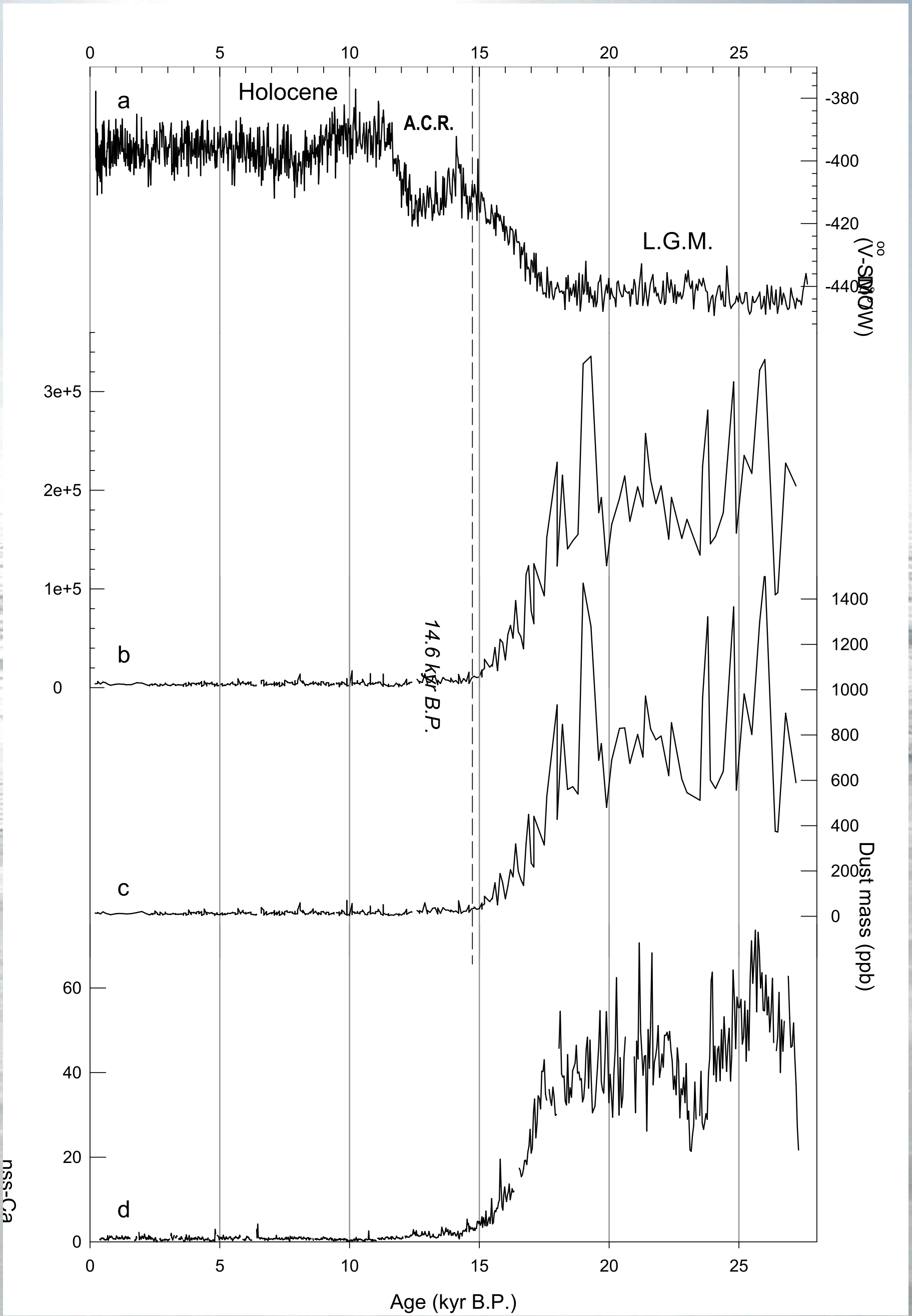
750 +/- 300ppb (LGM) 14 +/- 8 ppb (Holocene)

Previous results:
***Vostok** ca. **24** from Petit et al., 1990*
***Dome B** ca. **35** from Jouzel et al., 1995*
***Old Dome C** ca. **28** from Royer et al., 1983*

Post-glacial dust fall starts at **18 kyrs B.P.**

14.6 kyrs B.P. : Holocene dust levels are reached

Delmonte et al., 2002a



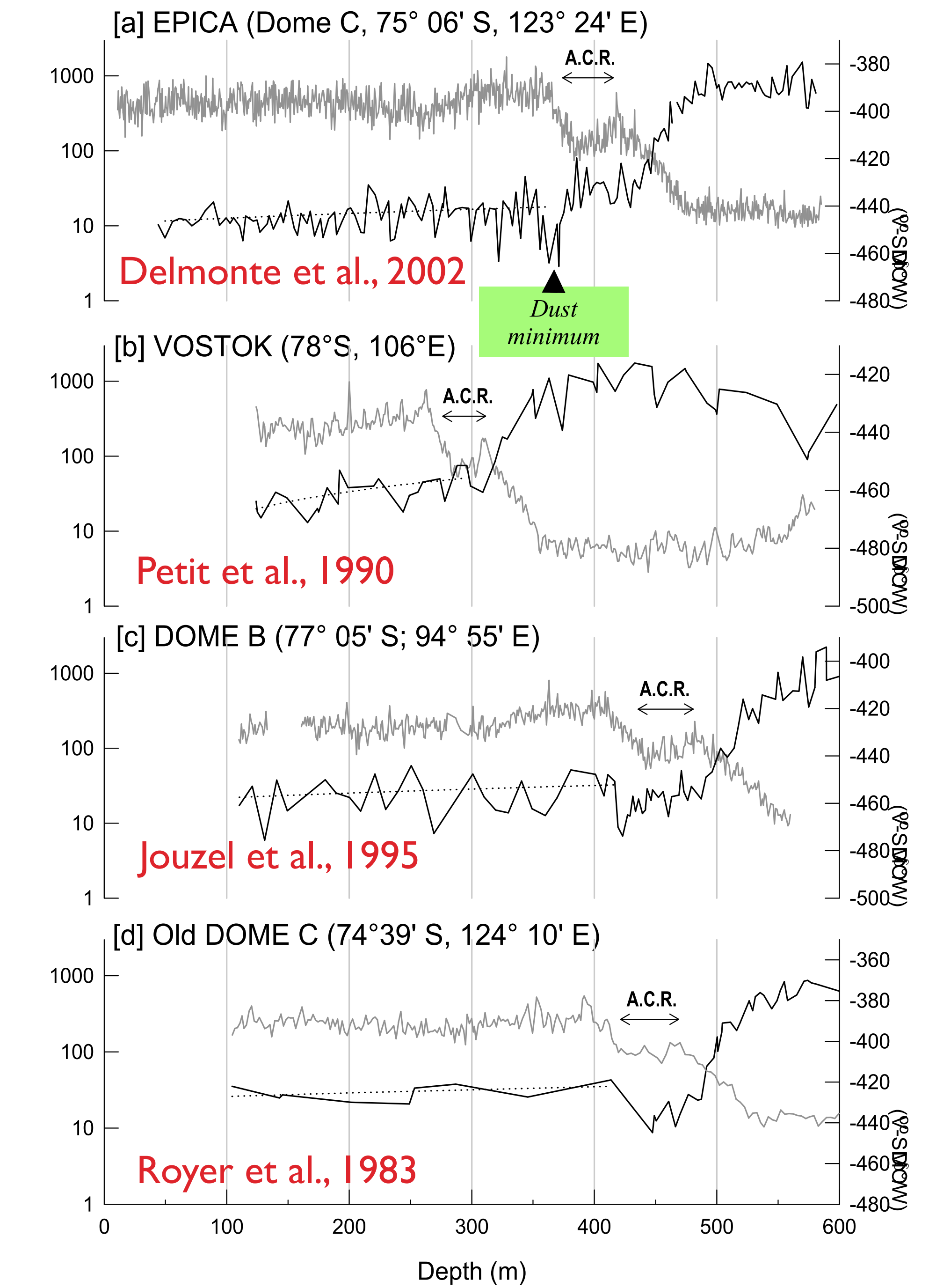
New features arising from the first EDC record:

A shallow re-increase of dust During the **Antarctic Cold Reversal** (ACR) phase, not observed in previous studies

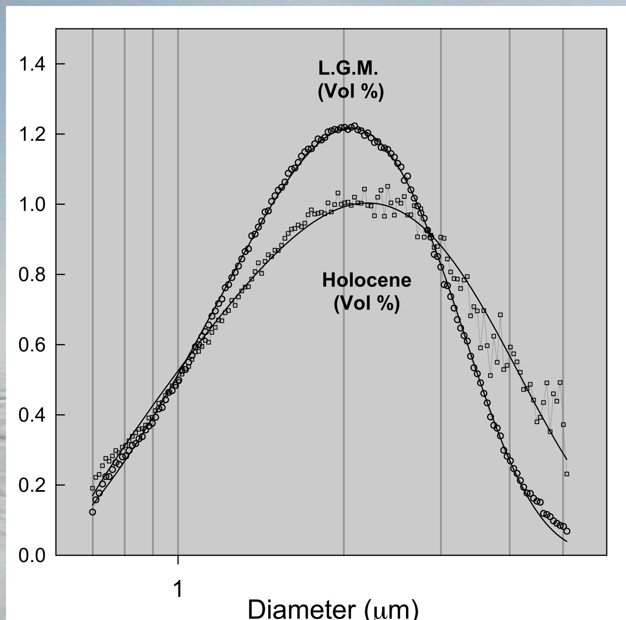
Return to colder conditions in the Southern Hemisphere?

A **pre-Holocene dust minimum** spanning 800-1000 years

Humid period at the dust source region(s)?

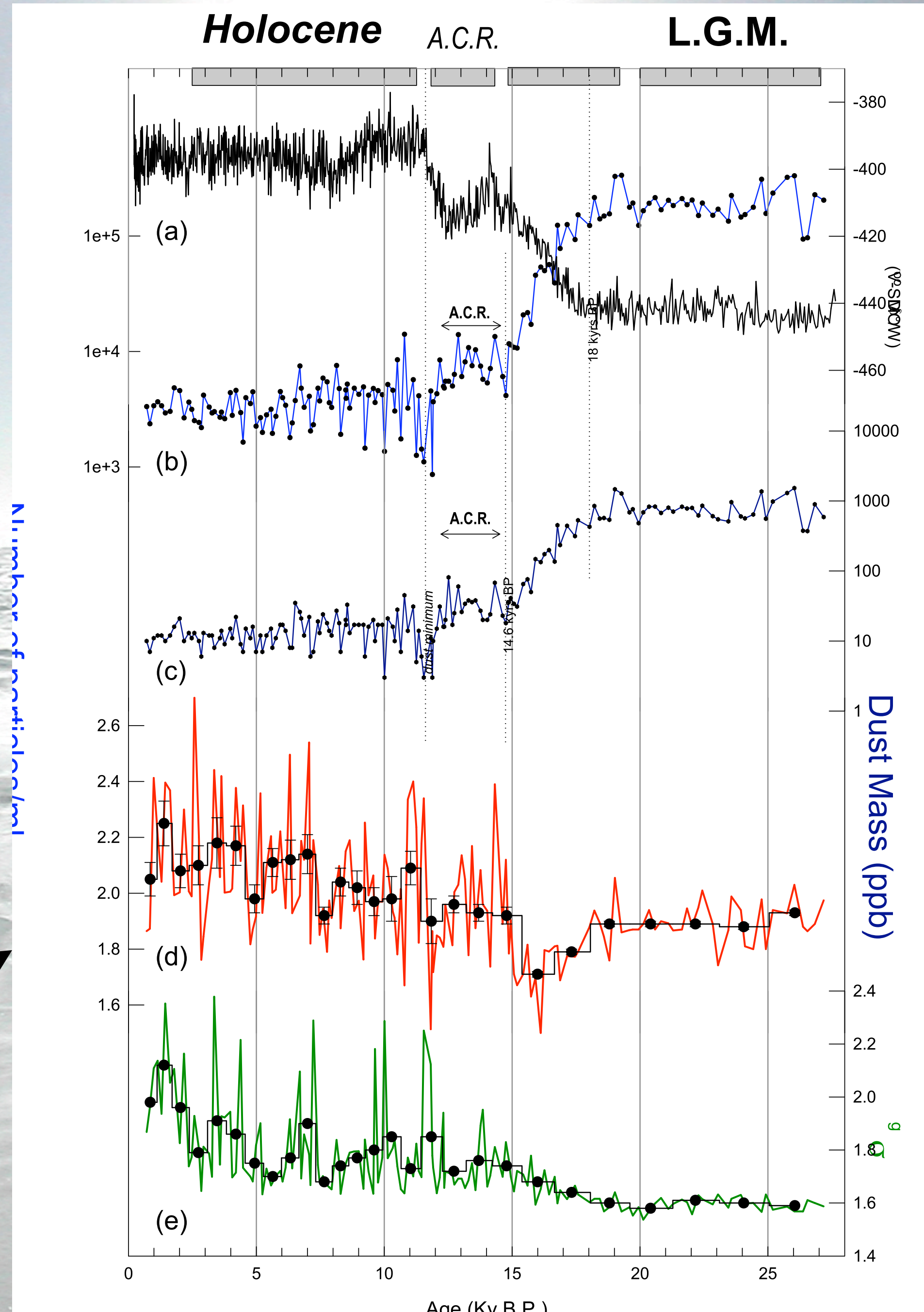


First (low-resolution) dust record from EPICA-Dome C *(Delmonte et al., 2002a)*



Slightly **smaller particles** during the **LGM** with respect to the Holocene

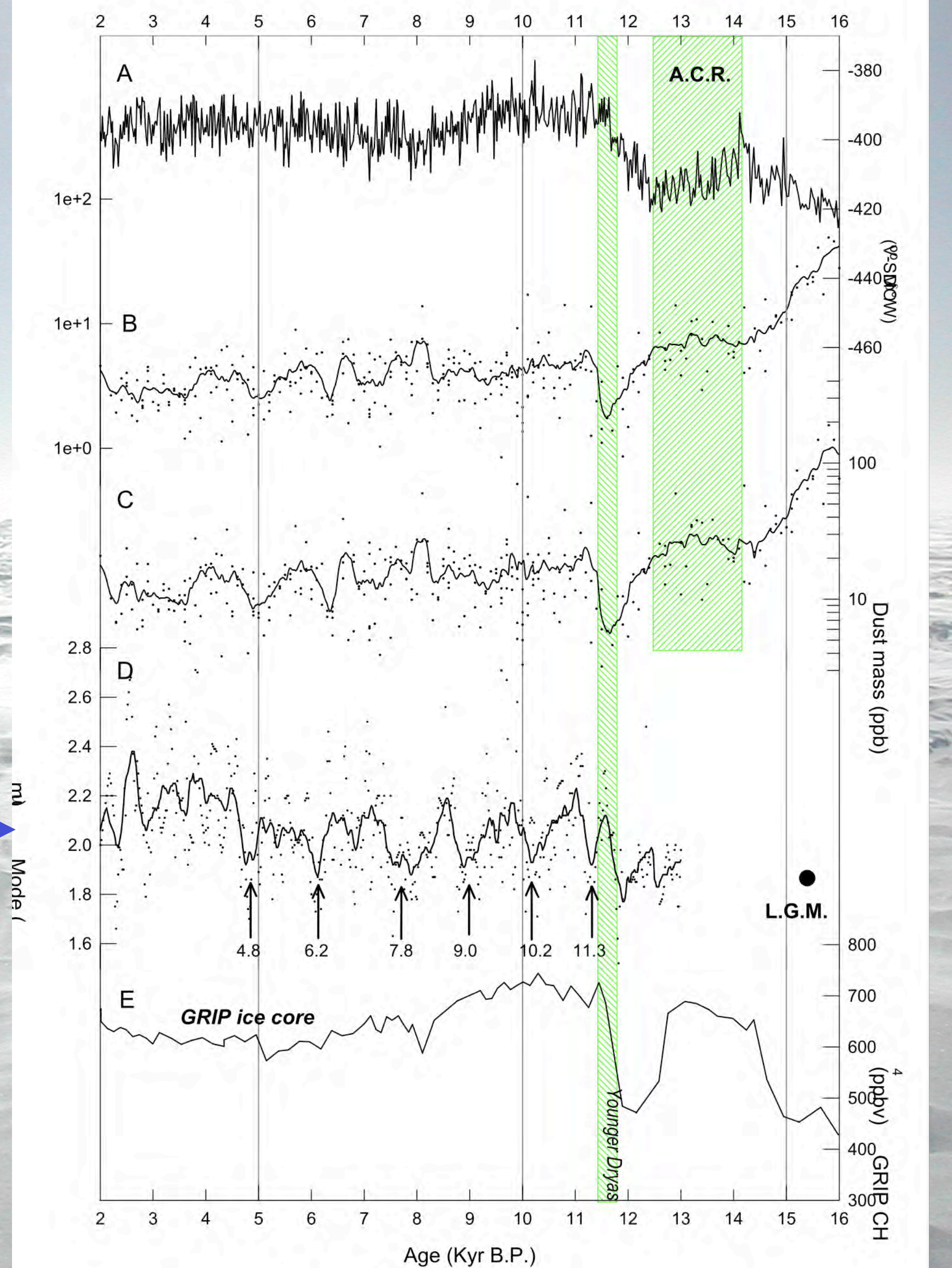
Modal value of lognormal function fitting the particle volume (mass)-size distribution



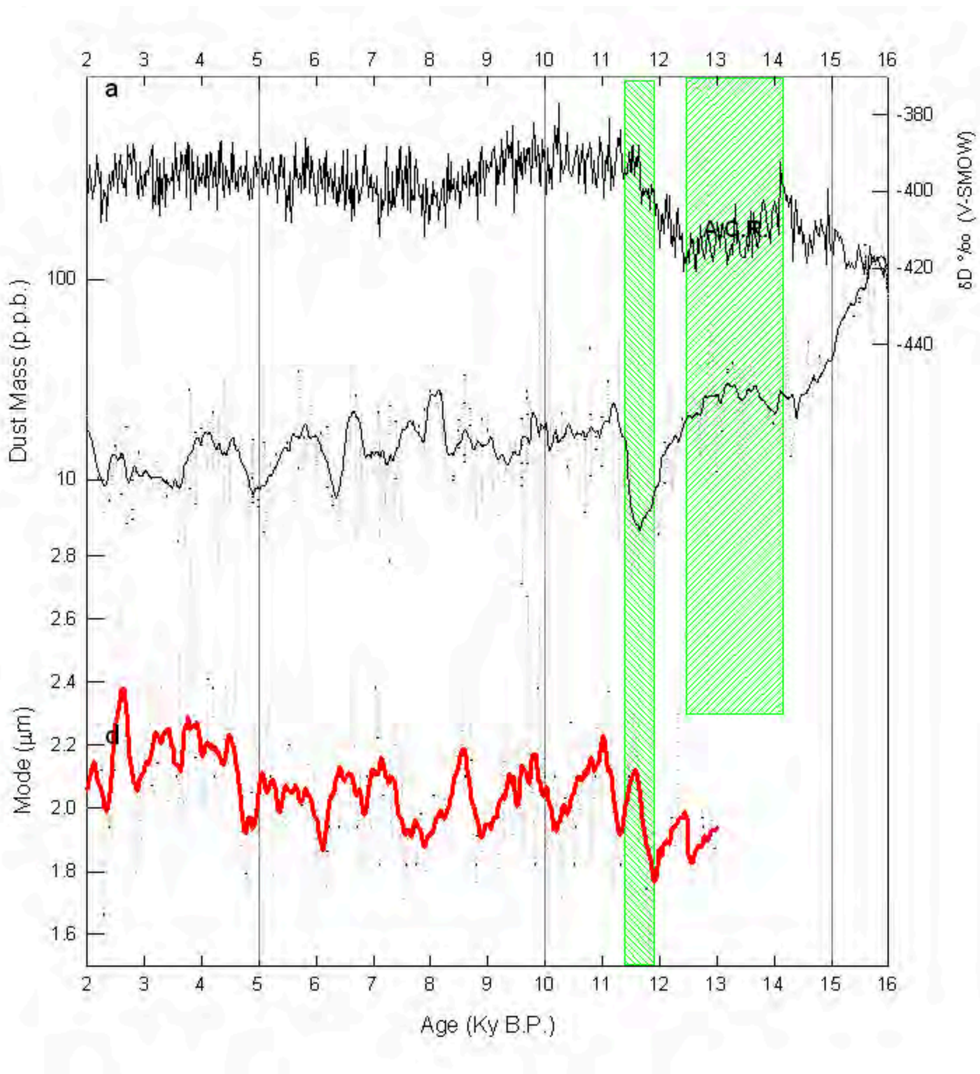
High resolution EPICA-Dome C dust record: the last transition and the Holocene

Documentation of the **PRE-HOLOCENE DUST MINIMUM** (spanning 800-1000 years) that seems synchronous with the CH_4 increase after the Younger Dryas

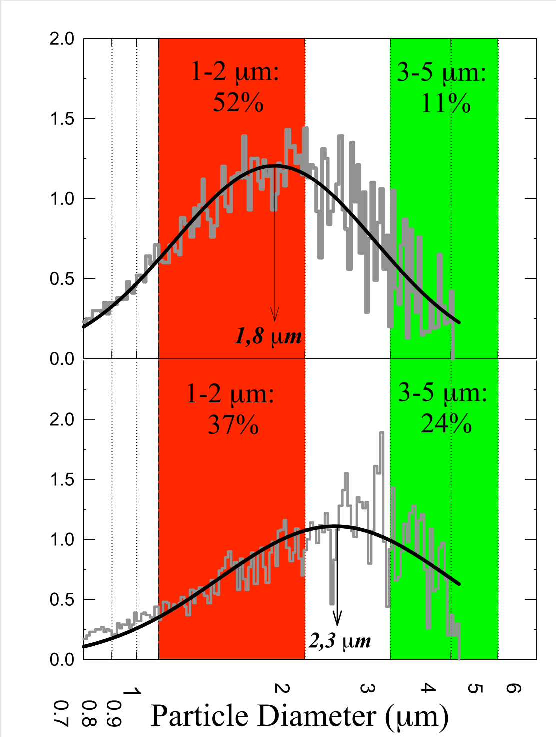
Evidence for MILLENNIAL and SECULAR-SCALE oscillations of dust size from 2 to 13 kyrs B.P.



The **<u>short-term fluctuations</u>** observed during the **deglaciation** remind the variability of dust size characterizing the EDC record during the last **13** kyrs B.P.
(Holocene and late Deglaciation)

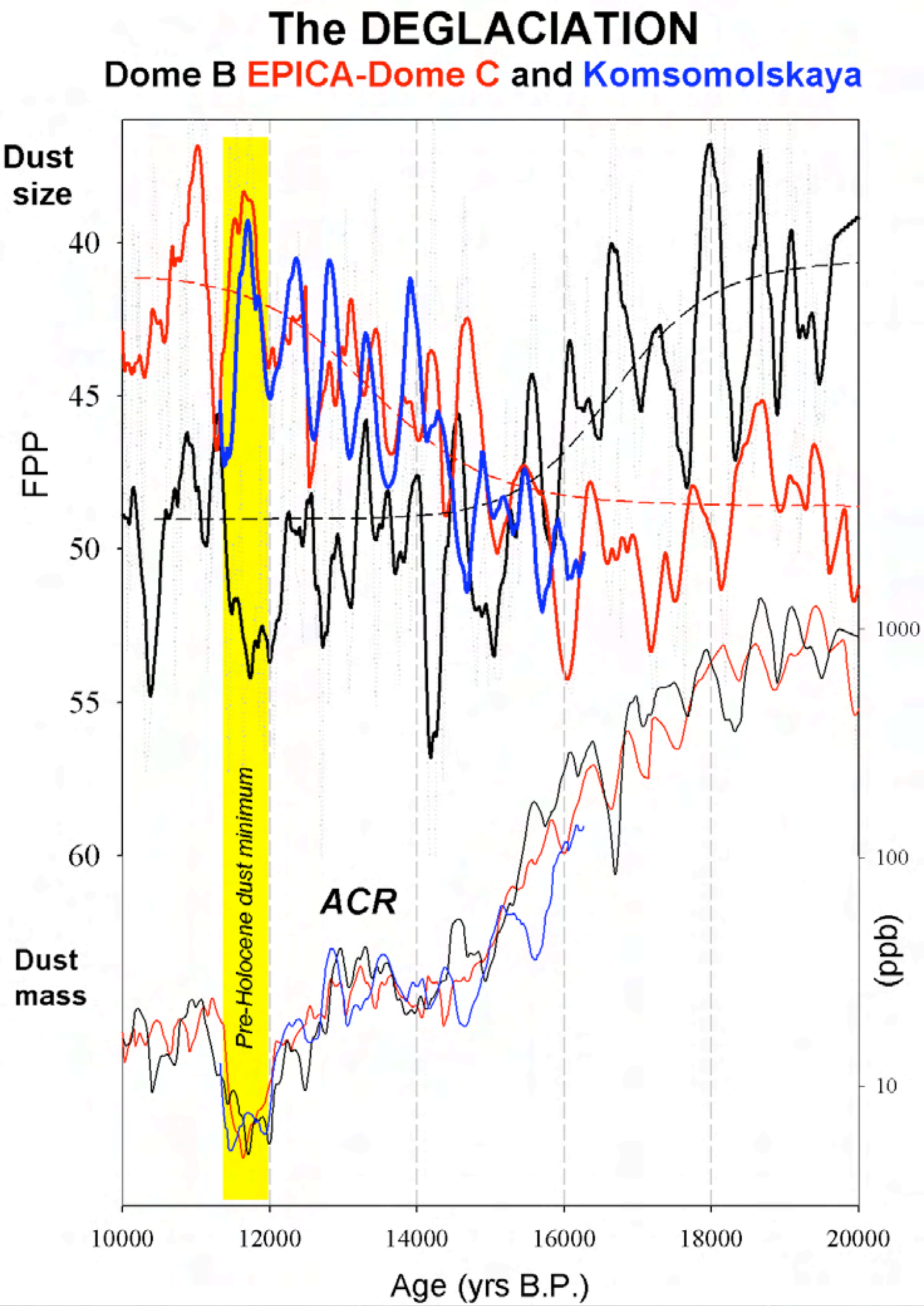


Holocene dust size variations



Dust <u>concentrations are very low</u>

<u>Size changes very small</u> but significant (around **0,5 µm**)



Delmonte et al., submitted to Clim Dyn

The particle size evolution in **Komsomolskaia** ice core is very similar to **Dome C** during the deglaciation

(while Vostok is more similar to Dome B according to Briat et al., 1982)

Millennial to centennial-scale oscillations are superposed to the main trend of the dust size changes

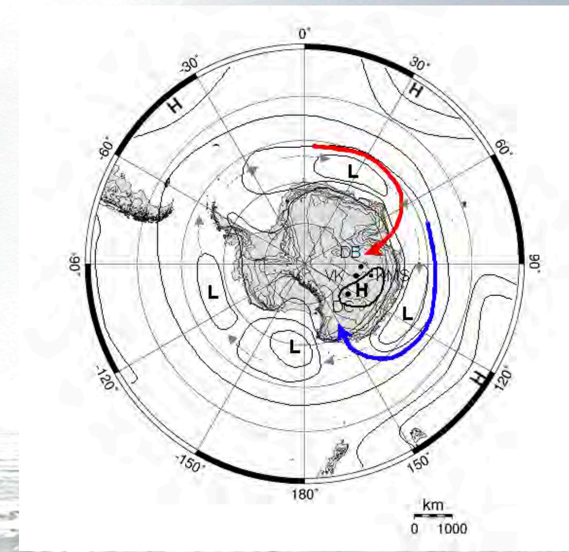
In correspondance to the ***Pre-Holocene dust minimum*** (*chronological marker*) these short-term oscillations are clearly in a**ntiphase**!

REGIONAL VARIABILITY OF DUST TRANSPORT

Δ DUST SIZE between Dome C and Dome B during LGM
(sharing the same source)

LENGTH OF DUST PATHWAY
[longer pathways enhancing dust grading (*finer dust*)]

Controlled by the PRESSURE FIELDS
over the Antarctic and the Circumantarctic



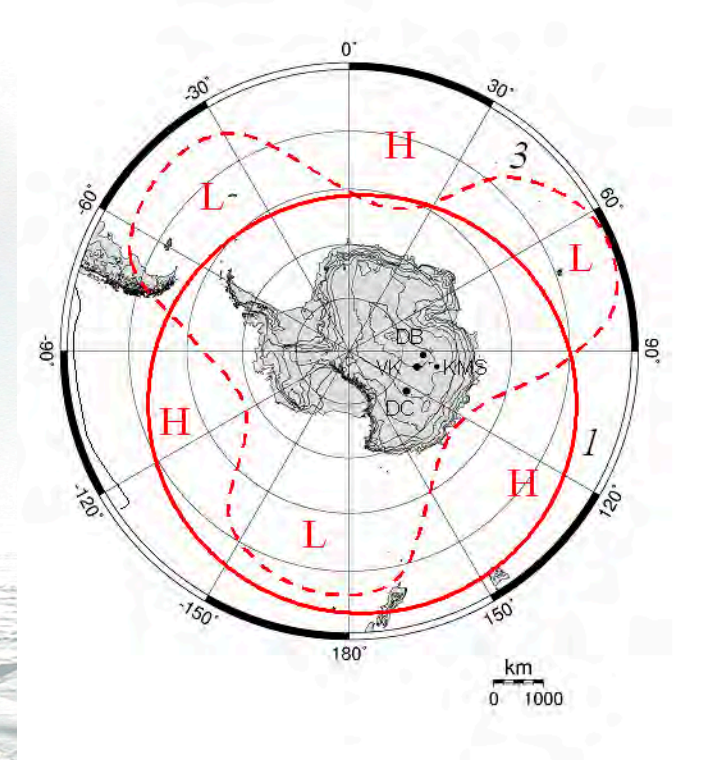
Horizontal dimension → *Zonal and Meridional circulation in the Southern Hemisphere*

Vertical dimension → *Altitude of transport*

Horizontal Dimension

Zonal circulation (*West to East*) represents the *dominant component* of the atmospheric circulation at the high latitude of the Southern Hemisphere.

The zonal circulation, is embedded at any time with **perturbations** taking the form of ***waves,*** allowing the **meridional** exchanges of different air masses.



Schematic illustration of standing waves 1 and 3 (after Tyson, 1986, modified).

Wavenumbers 1 to 3 define more-or-less stationary waves associated to longitudinally-positioned structures (highs and lows) distorting the zonal circulation.

Wavenumbers 1 to 3 together account for a large percentage of the total variance of the 500 hPa pattern (Tyson, 1986).