Science afternoon ”Polar research in Estonia”
20.09 2023

Recent Achievements and future prospects of ice core science

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Outlines:

- Short history of ice core research:
- Some great names
- Major highlights
- The future of ice coring:IPICS & EuroPICS

Willi Dansgaard

- One of the pioneers of ice core research and isotopic geochemistry, Dr. Willi Dansgaard

A beginning

- 1952:discovered O18/T correlation in precipitation
- “The O18- abundance in fresh water”,
- Geochim, et Cosmochim Acta 6, 1954
- “Stable isotopes in precipitation” Tellus 16, 1964

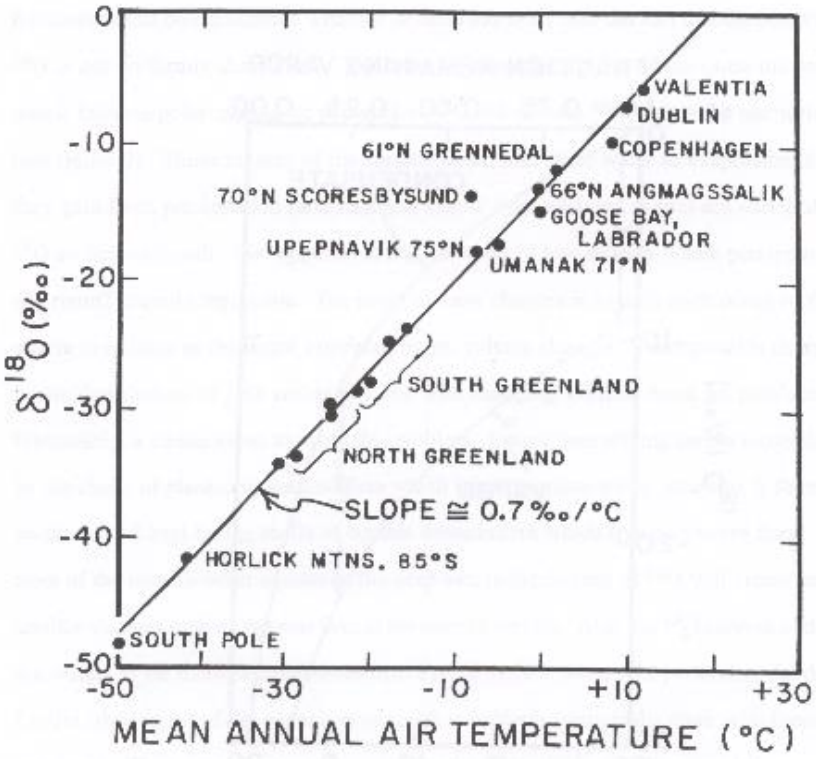
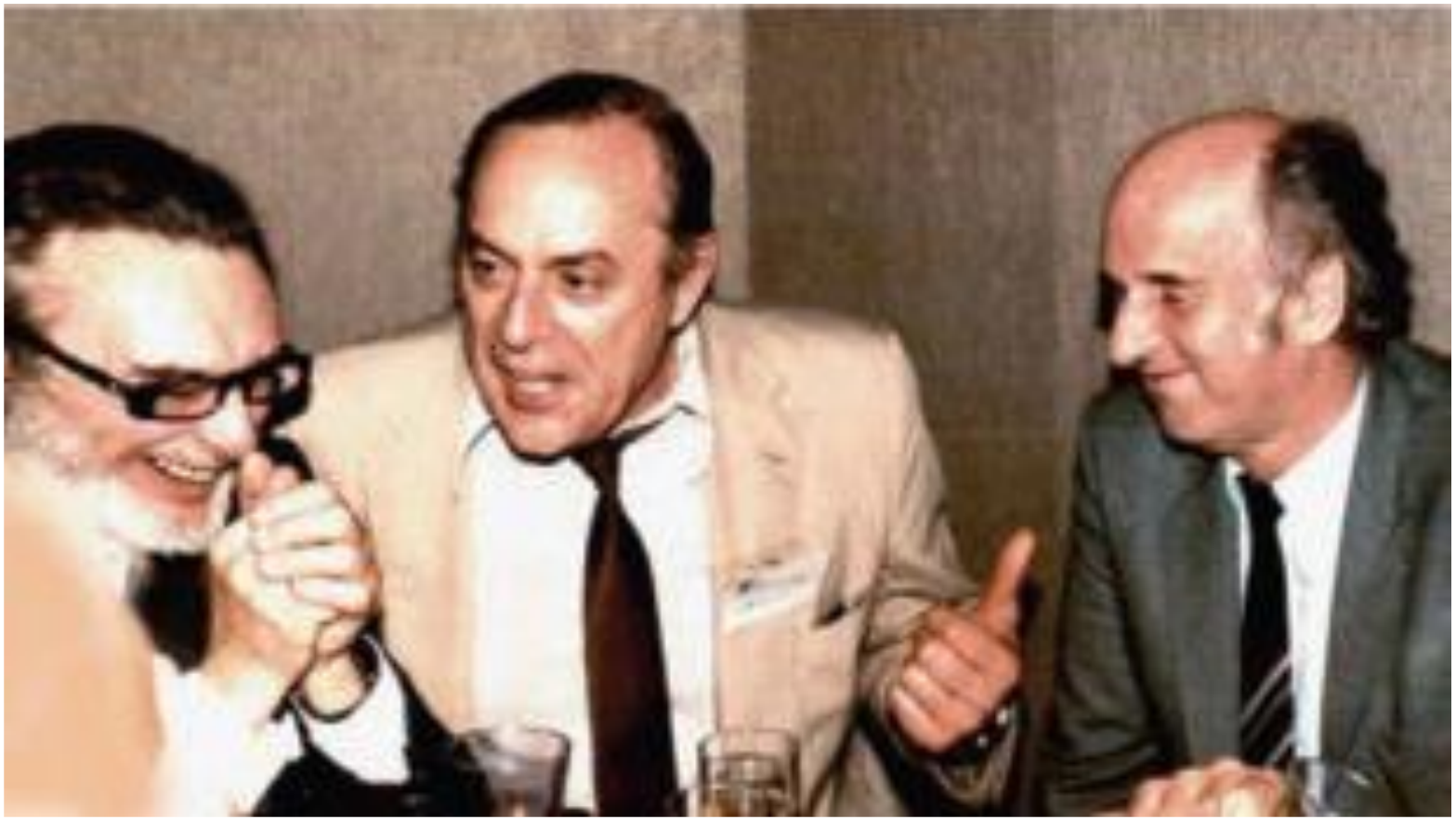


Figure 7. Observed $\delta^{18}O$ in average annual precipitation as a function of mean annual air temperature (Dansgaard, 1964). Note that all the points on this graph are for high latitudes (>45°). The $\delta^{18}O$ values are calculated as follows:

$$\delta^{18}O = \frac{^{18}O/^{16}O_{sample} - ^{18}O/^{16}O_{std.}}{^{18}O/^{16}O_{std.}} \times 1000$$

Three musketeers



Formation of glacier ice

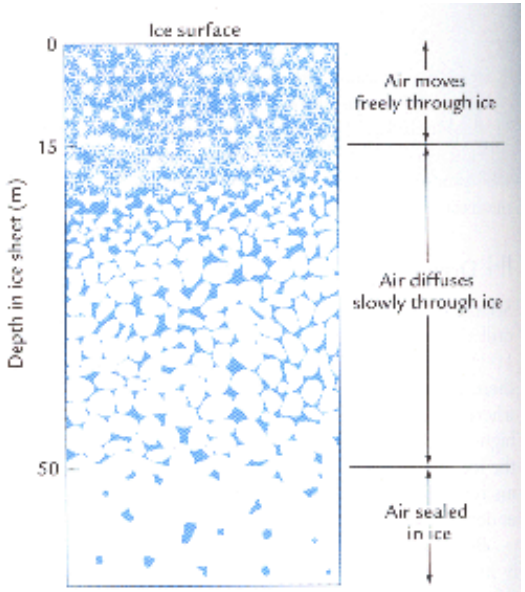
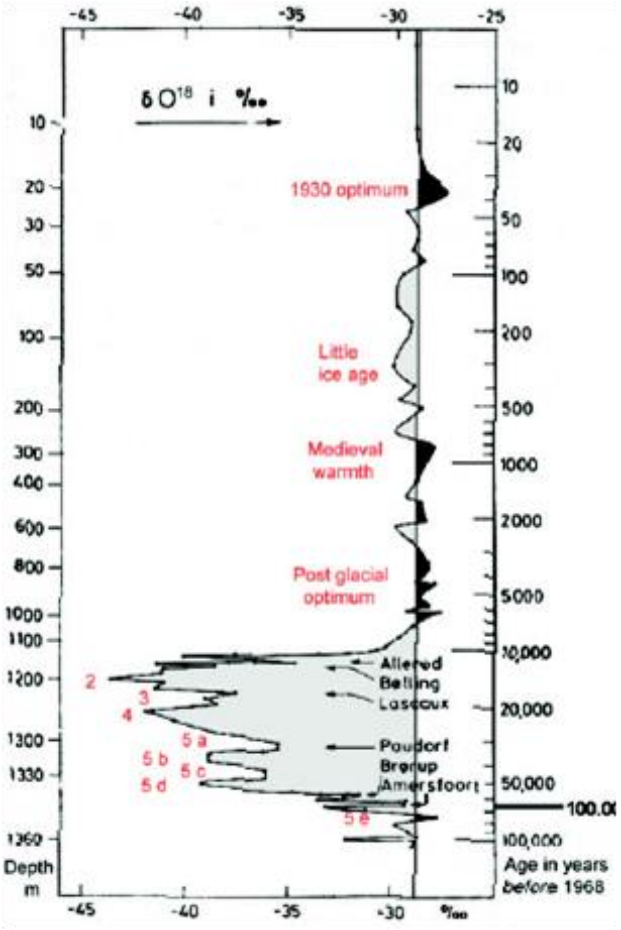
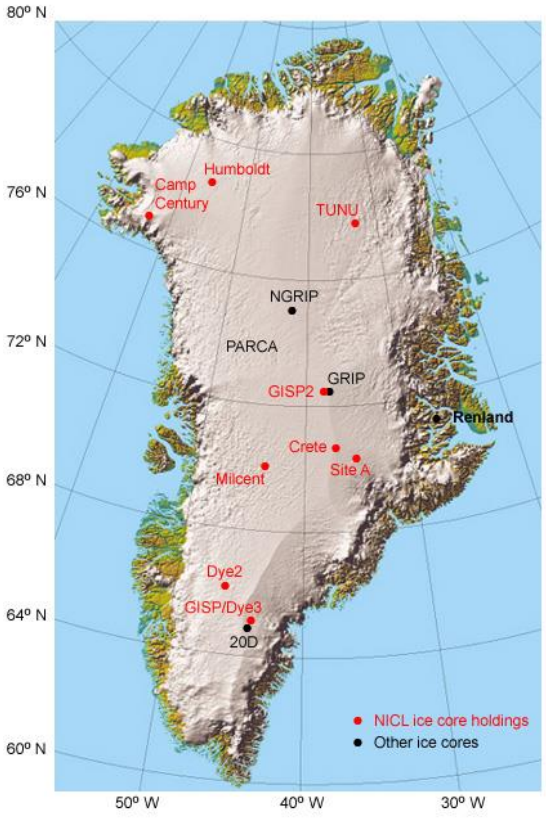


FIGURE 11-3 **Sintering: Sealing air bubbles in ice** Air moves freely through snow and ice in the upper 15 m of an ice sheet, but flow is increasingly restricted below this level. Bubbles of old air are eventually sealed off completely in ice 50 to 100 m below the surface. (Adapted from D. Raynaud, "The Ice Core Record of the Atmospheric Composition: A Summary, Chiefly of CO_2, CH_4 and O_2," in *Trace Gases in the Biosphere*, ed. B. Moore and D. Schimel [Boulder, Colo.: UCAR Office for Interdisciplinary Studies, 1992].)

Camp Century 1966



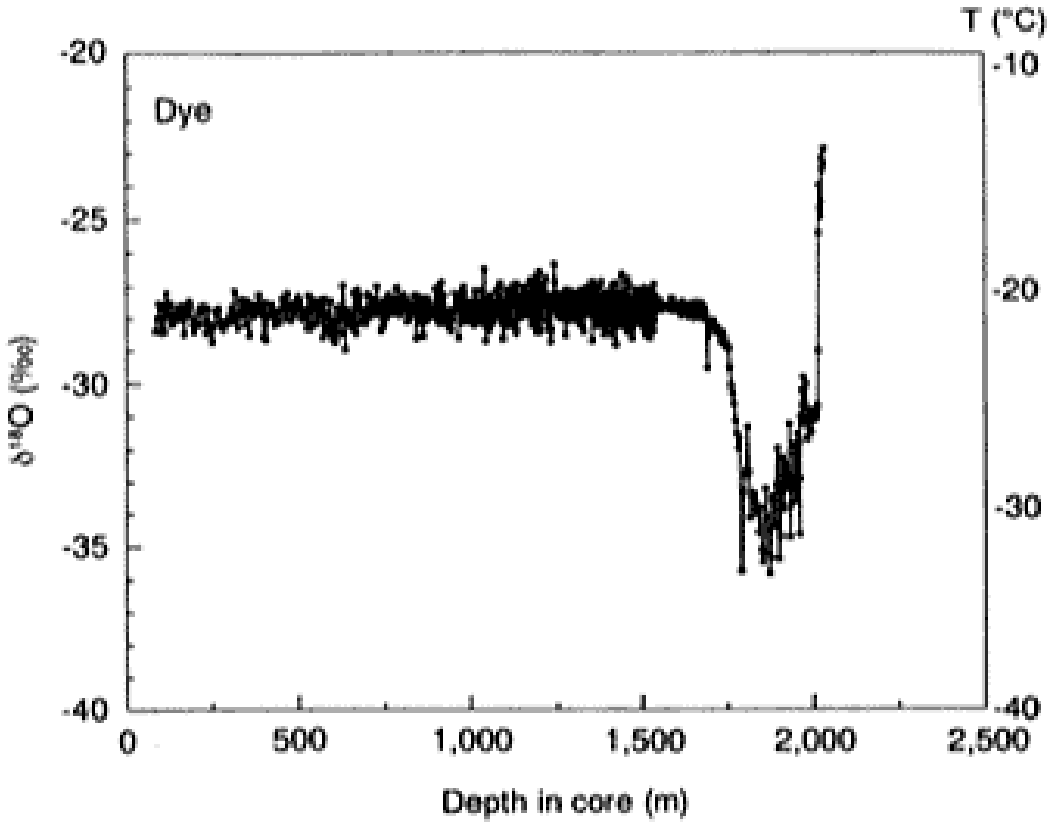
Deep ice core sites on Greenland



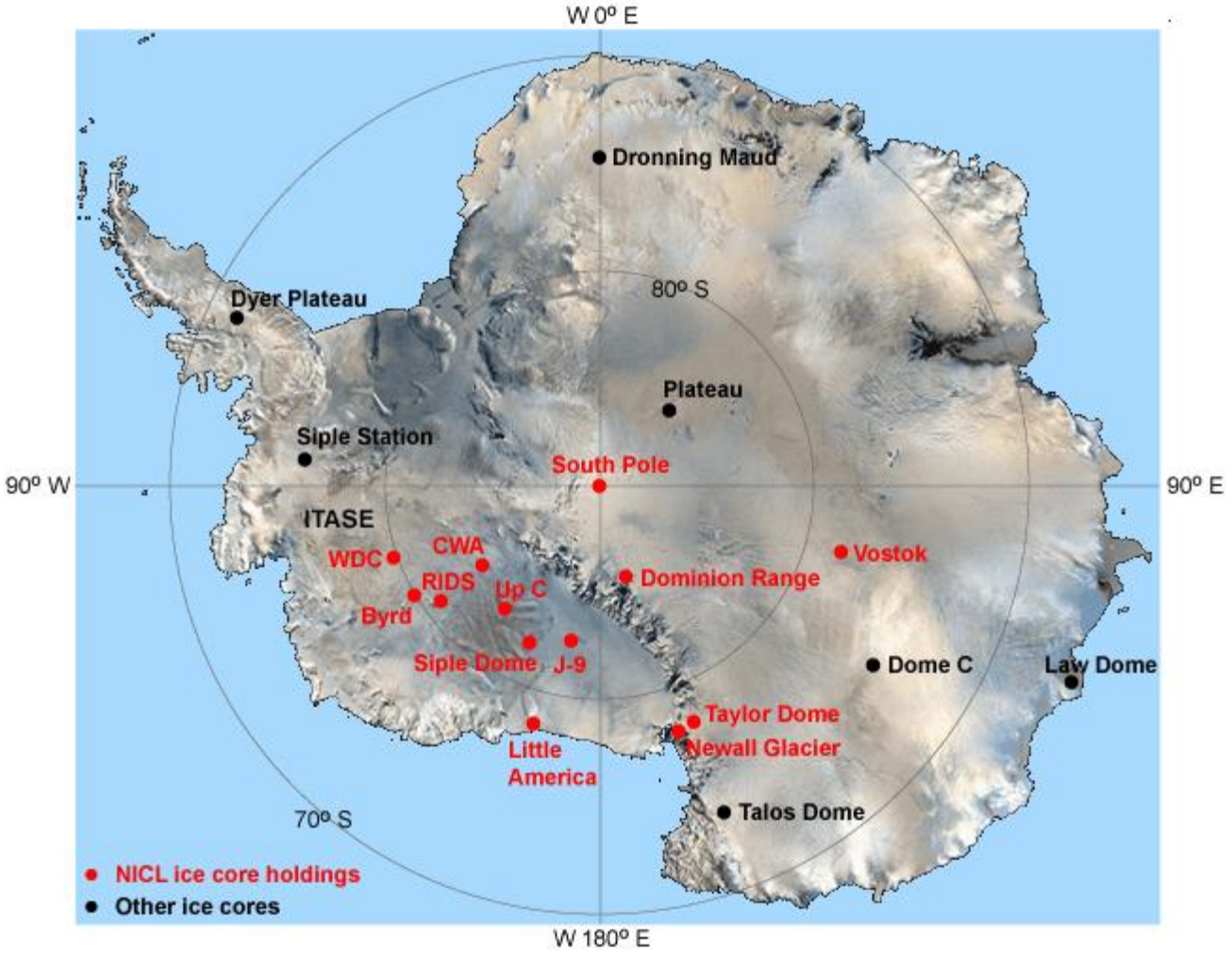
Next deep drillings

- Byrd, West Antarctica, 1968, 2164m,
- 80 000 years
- Dye 3, Greenland, 1981, 2037m,
- 30 000years
- GRIP&GISP, 1992, 1993 3029m,
- ~ 100 000 years
- Vostok, Antarctica 1970s – 1996, 3623m
- 400 00 years
- Dome C, Antarctica, 1970s, 900m
- 30 000 years

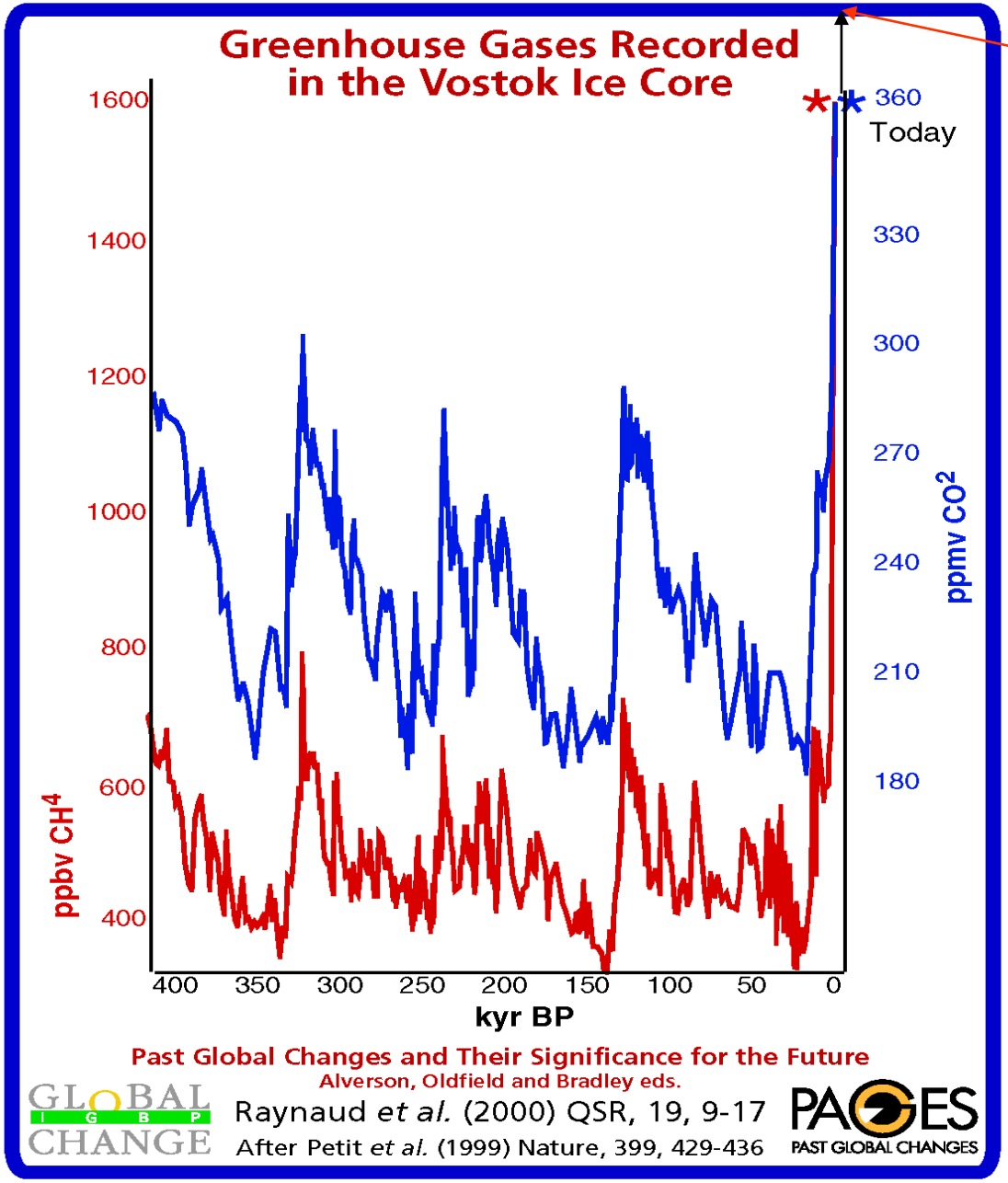
Dye 3, rapid changes



Deep ice core sites in Antarctica



En 2003 :
465 ppmv CO_{2eq}



376 en 2003

en 1995

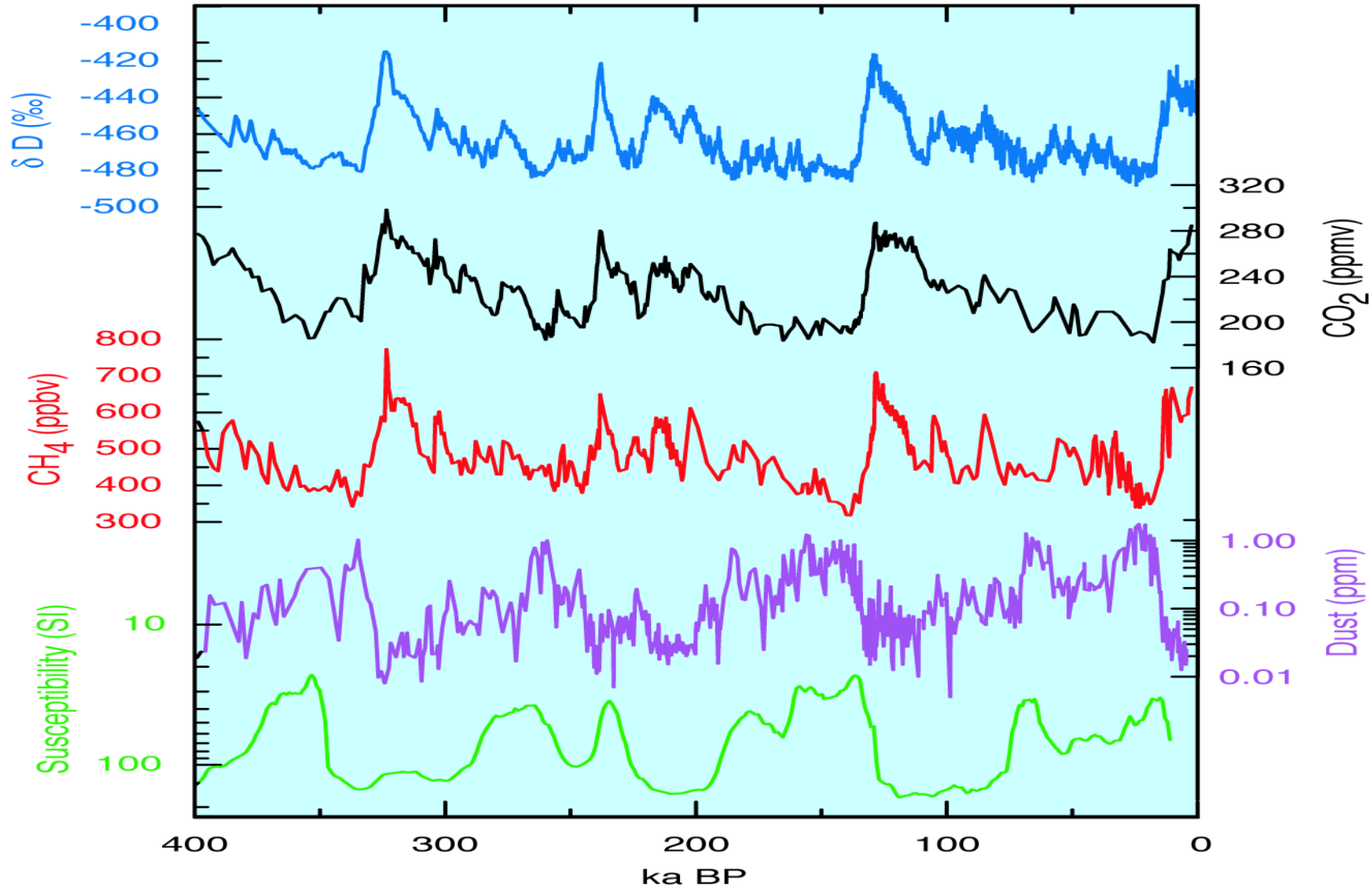
accroissement

2000-01 : 1.5

2001-02 : 2.0

2002-03 : 2.5

Four Climatic Cycles:
Climate Records Over the Last 400,000 Years



Paleoclimate, Global Change and the Future

Alverson, Bradley and Pederson eds., 2002

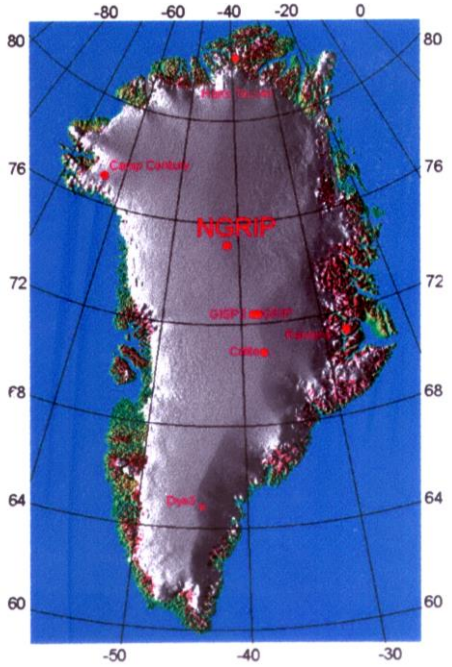
Chapter 2: D. Raynaud et al., fig. 2.2, p. 19

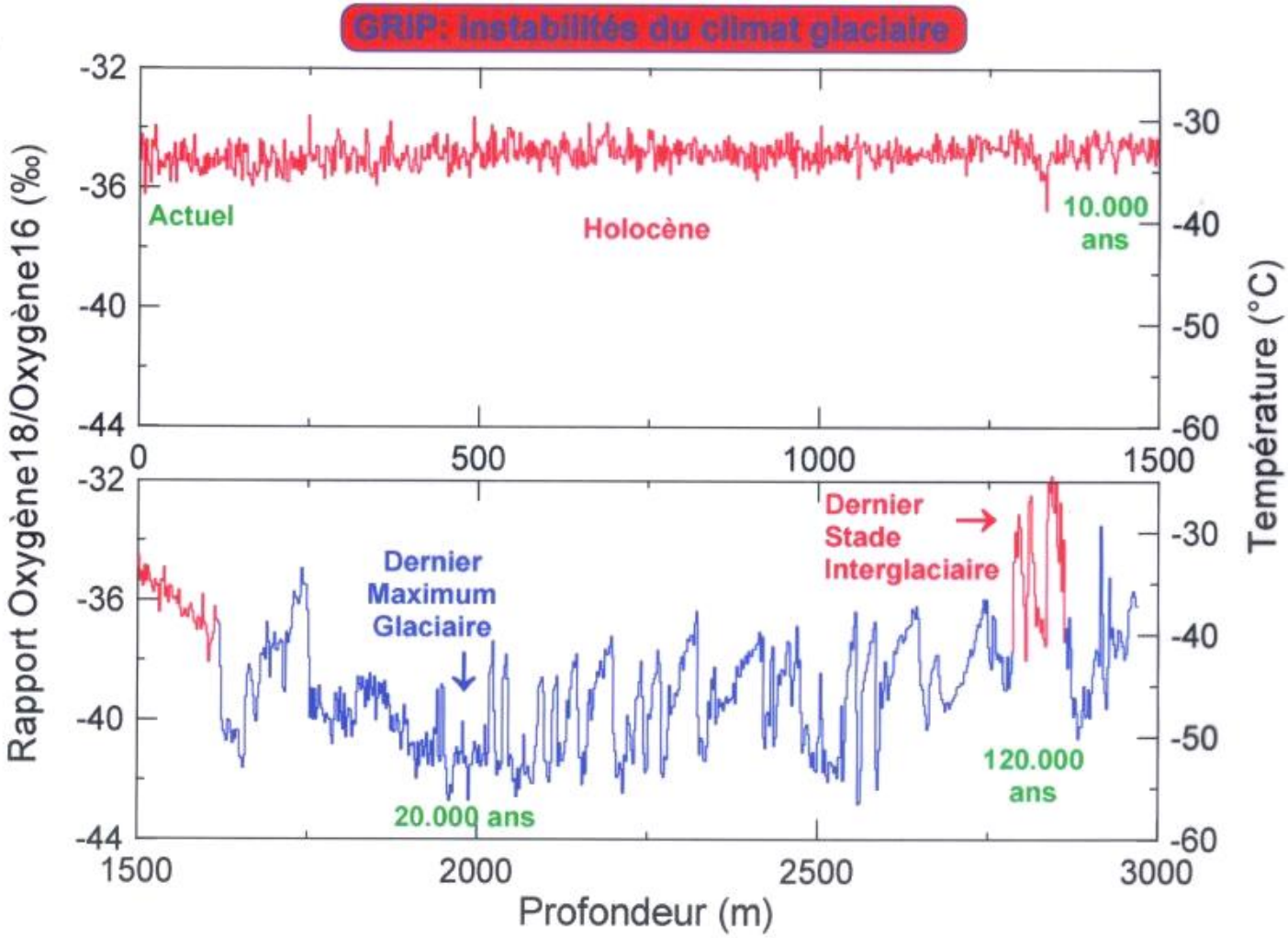
GLOBAL CHANGE IGBP

PAGES PAST GLOBAL CHANGES

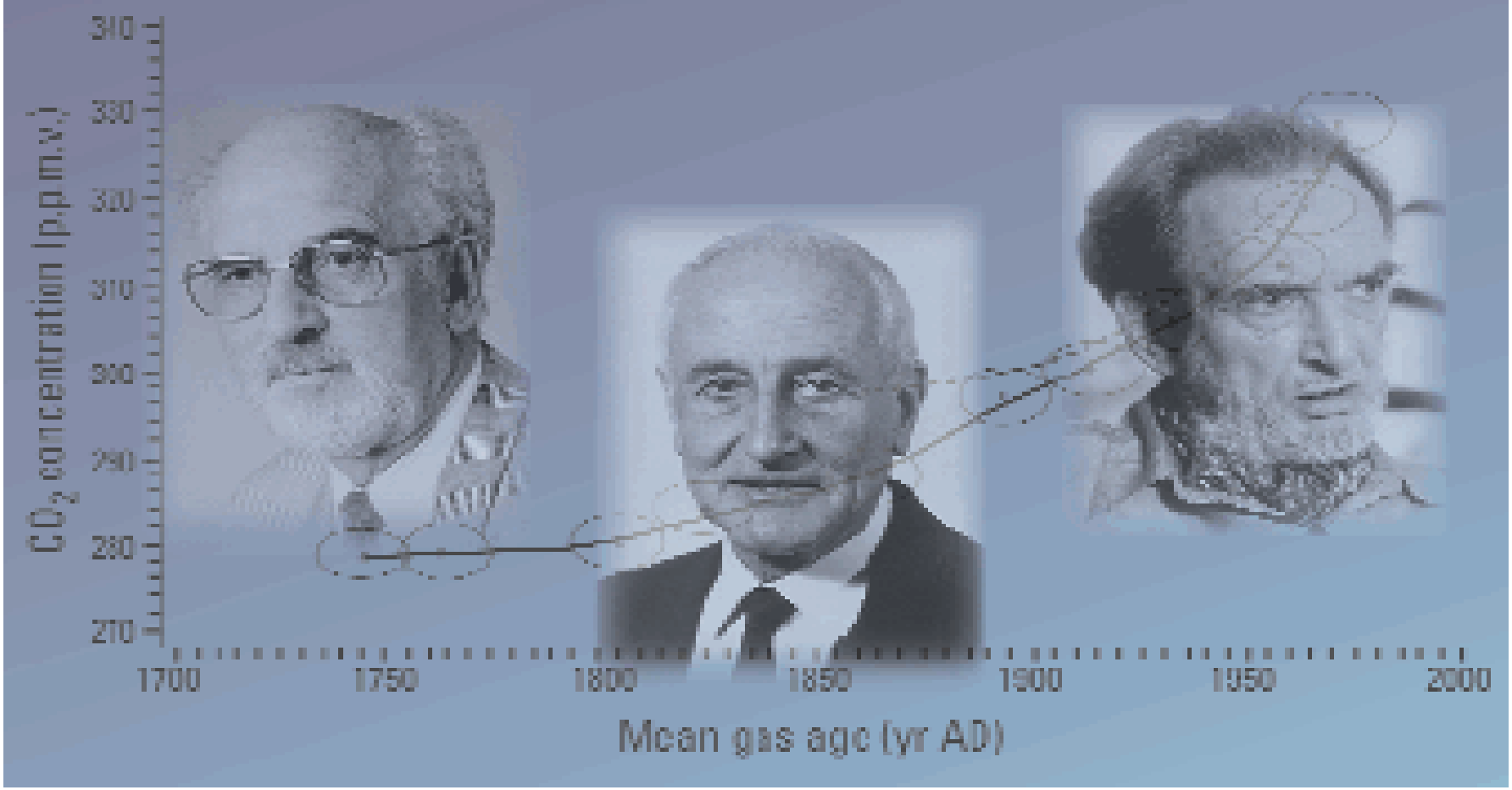
GRIP (Central Greenland, European Project)

Rapid climatic changes during the last glacial and the following transition





GRIP and GISP2 (US) compares well back to ~ 100 kyr BP



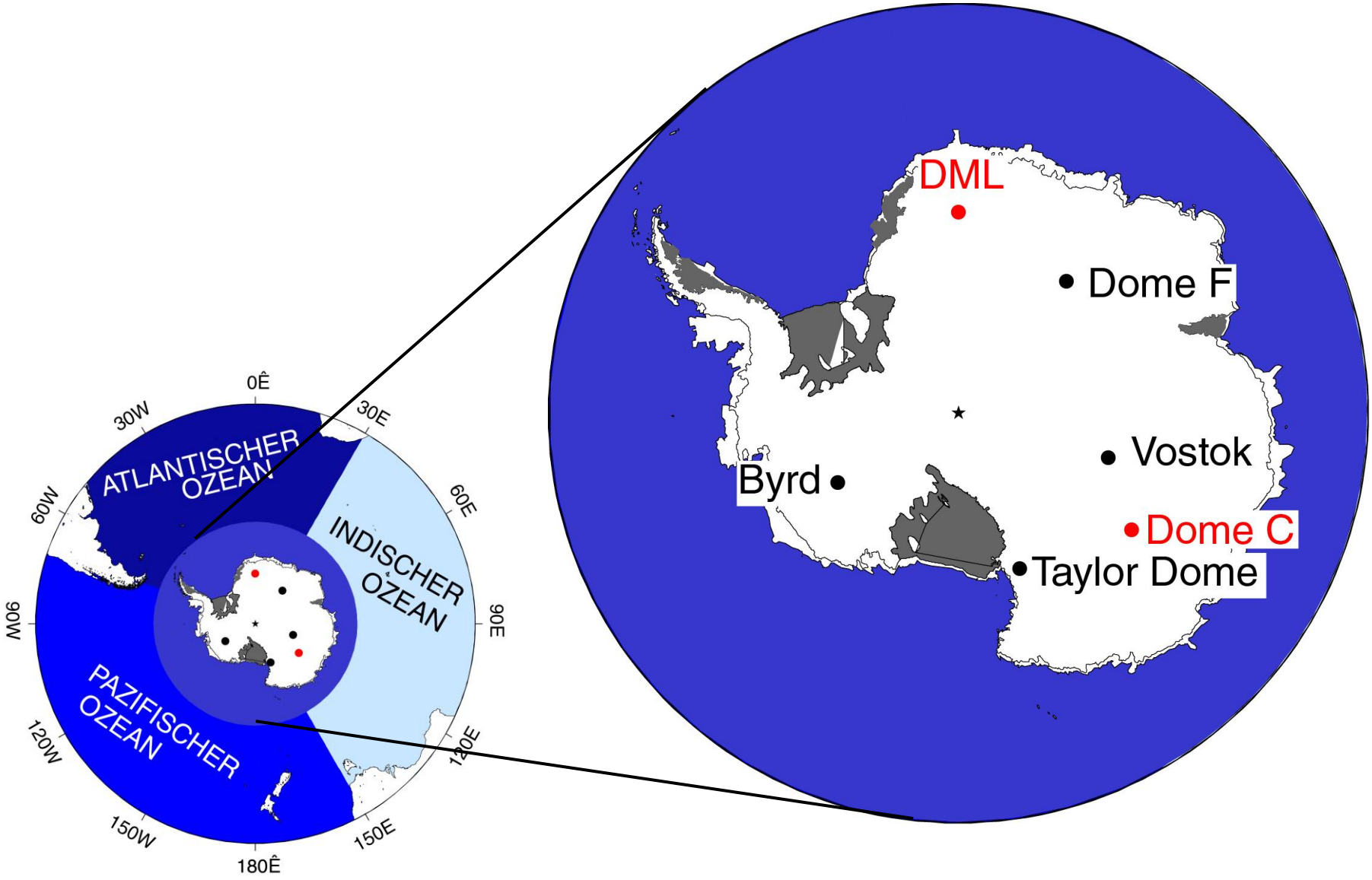
The Icemen cometh. (l. to r.) Hans Oeschger, Claude Lorius, and Willi Dansgaard were awarded the 1996 Tyler Prize for their documentation of climate change through analysis of ice.

Graph source: Neftel A, Moor E, Oeschger H, Stauffer B. Evidence from polar ice cores for the increase in atmospheric CO2 in the past two centuries. Nature 315(May 2):45-46 (1985). MacMillan Magazines Ltd.

European Ice Core Science

European Project for Ice Coring in Antarctica

- European Project for Ice Coring in Antarctica (EPICA) : Two deep ice cores



The situation of deep ice core research in 1993

- Success of GRIP (1992) and GISP2 (1993)
- Vostok ice core then covered 220 kyr (other cores Byrd and Dome C)
- Of particular relevance to EPICA was a workshop on "Ice sheet climate interaction"

  in Aghia Pelaghia (Crete, 17-22/9/1993)

Six key questions raised in the Science Plan (1994)

- Are the rapid climatic changes of the last climatic cycle global events, or have they been restricted to a large region of the Northern Hemisphere ?

- Is a warm period of stable climate lasting 10 000 years an exception for the last 500000 years ?

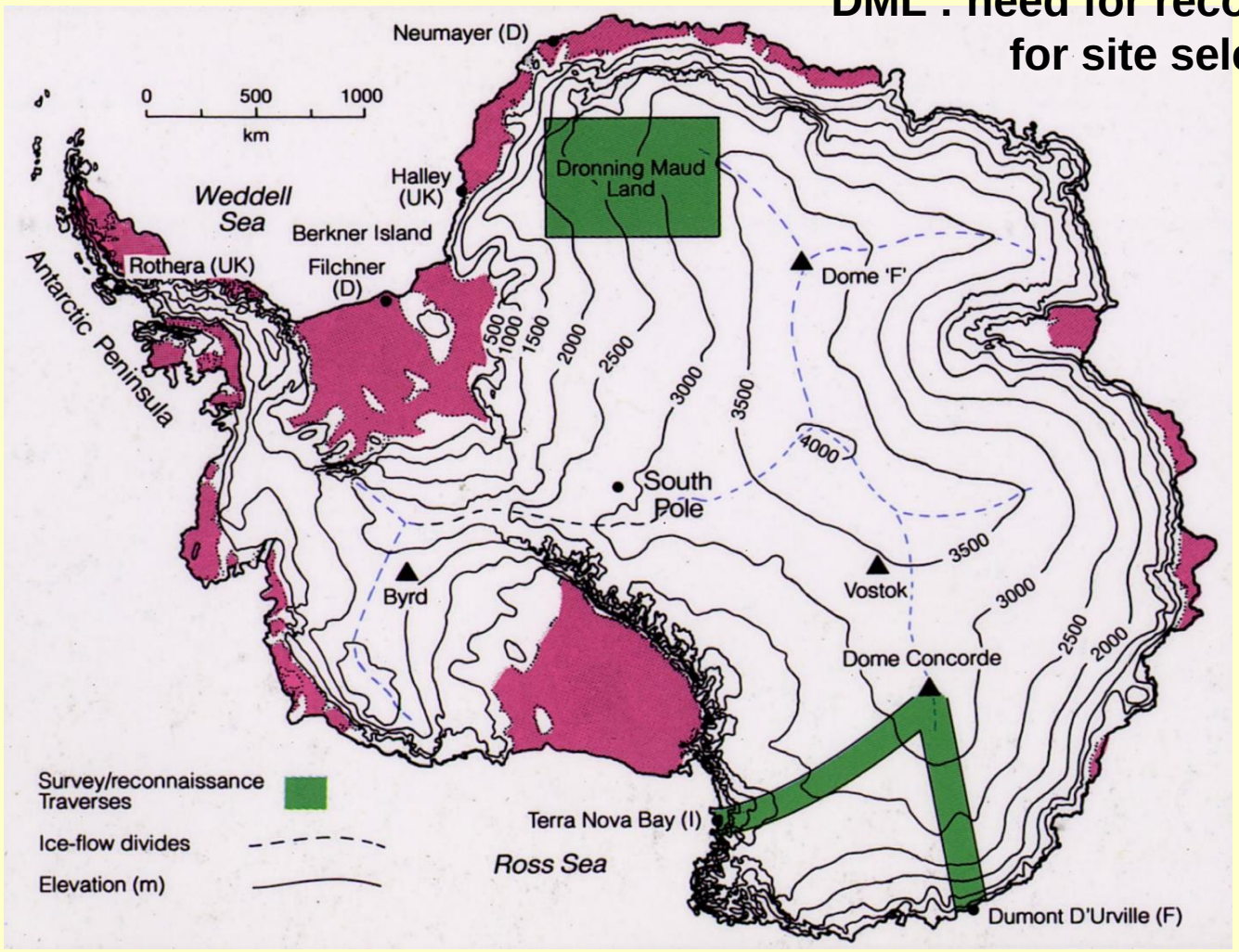
- Are rapid climatic changes also observed in previous climatic cycles ?

- Does the transitions from the glacial to warm periods and back follow always the same pattern or is there a variety of mechanisms involved ?

- Are global climate changes always triggered in the Northern Hemisphere or is also the opposite sequence possible ?

- How are global climate changes coupled between the two hemispheres ?

Dome C : pre- existing summer station
DML : need for reconnaissance
for site selection



Dome C: 75° 06´S 123° 23´E; 3233 m asl
T= –55° C

1995-1996:		Camp construction
1996-1997:		Drill installation and start of drilling
Dec	1998:	Drill is stuck in 780 m depth
Dec	1999:	Start 2nd drilling
Jan	2001:	Depth: 1459 m; age: >70 000 years
Jan	2002:	Depth: 2870 m; age: >500 000 years
Jan	2003:	Depth: 3190 m; age: >800 000 years
Jan	2004:	Depth: 3270 m; age: ?

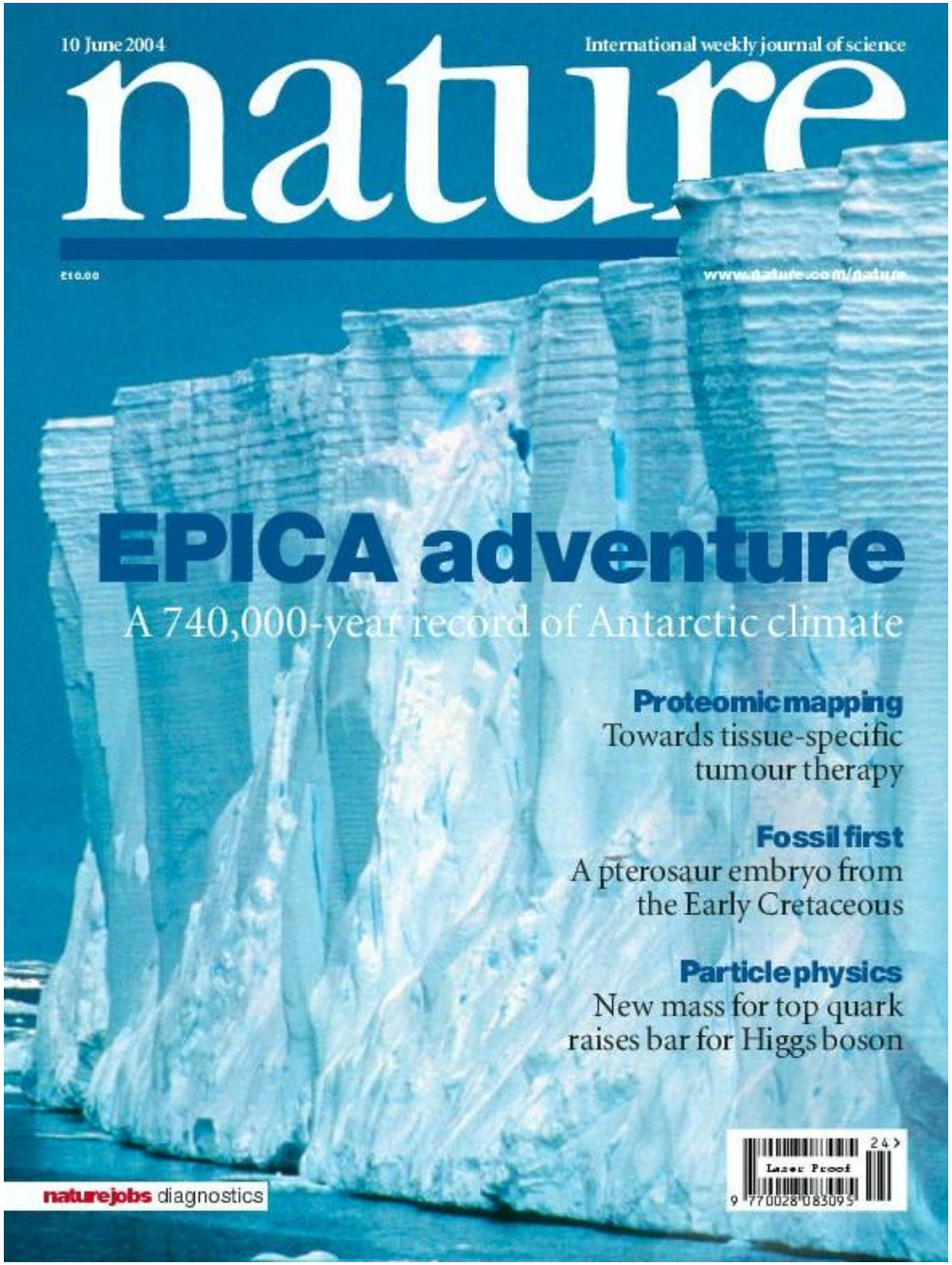
10 June 2004

International weekly journal of science

nature

£10.00

www.nature.com/nature



EPICA adventure

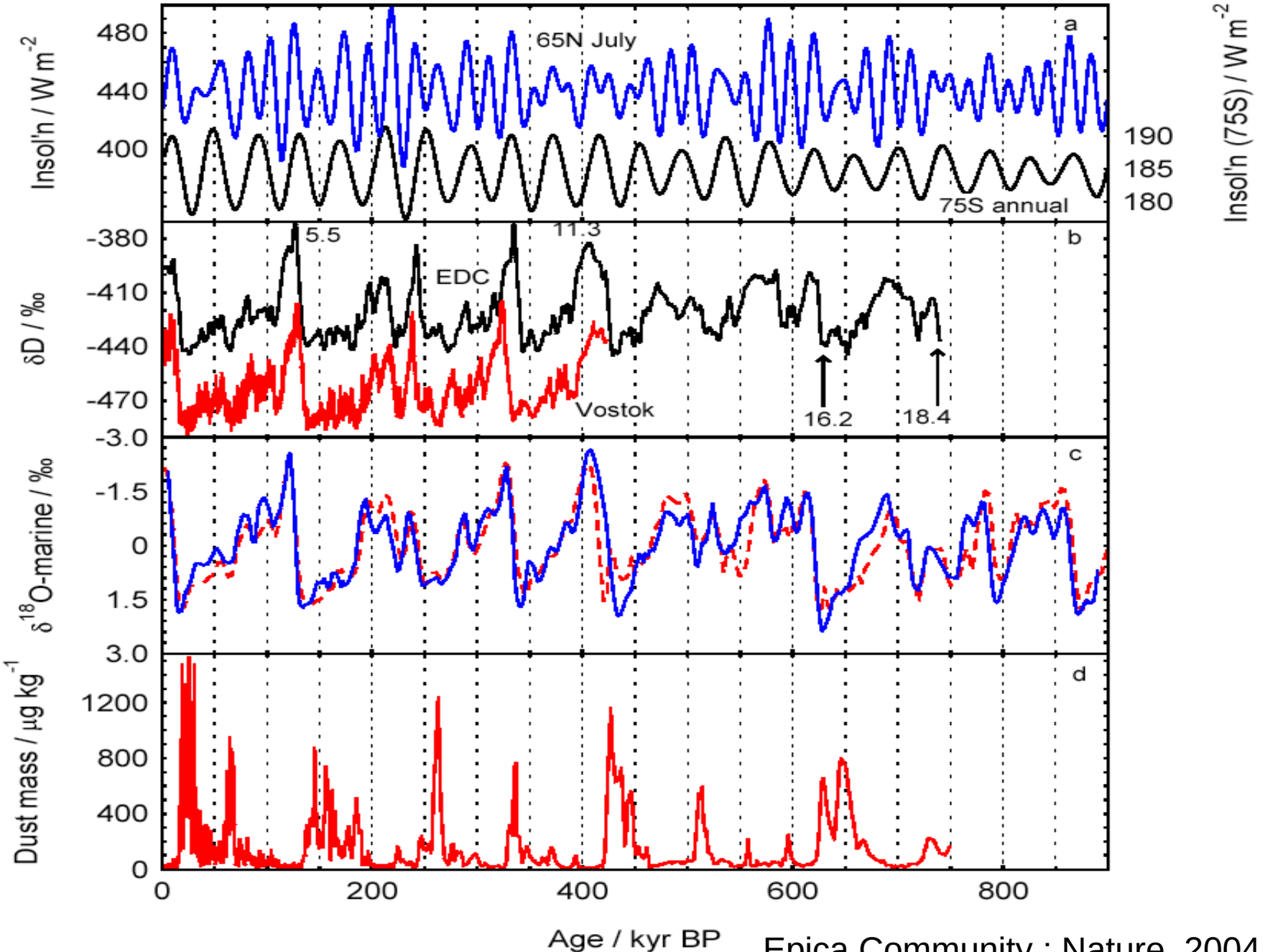
A 740,000-year record of Antarctic climate

Proteomic mapping
Towards tissue-specific tumour therapy

Fossil first
A pterosaur embryo from the Early Cretaceous

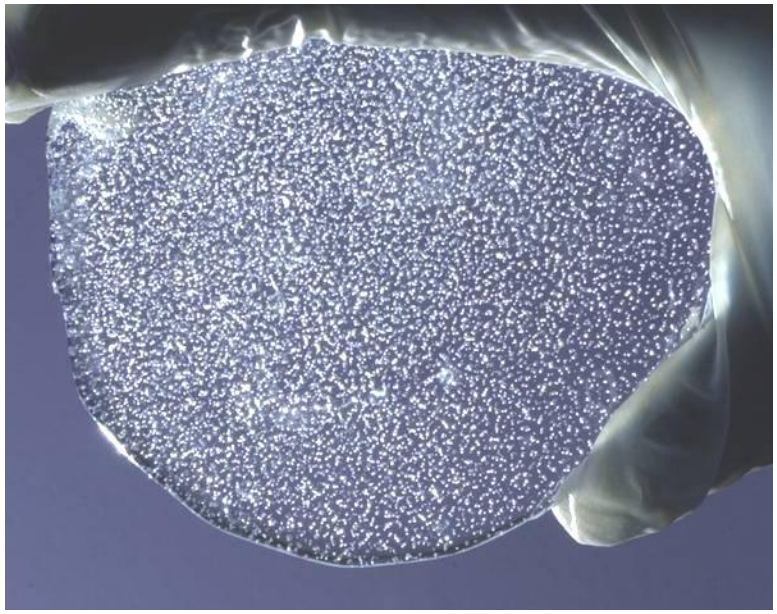
Particle physics
New mass for top quark raises bar for Higgs boson

24>
Laser Proof
9 770028 083095



Epica Community : Nature, 2004

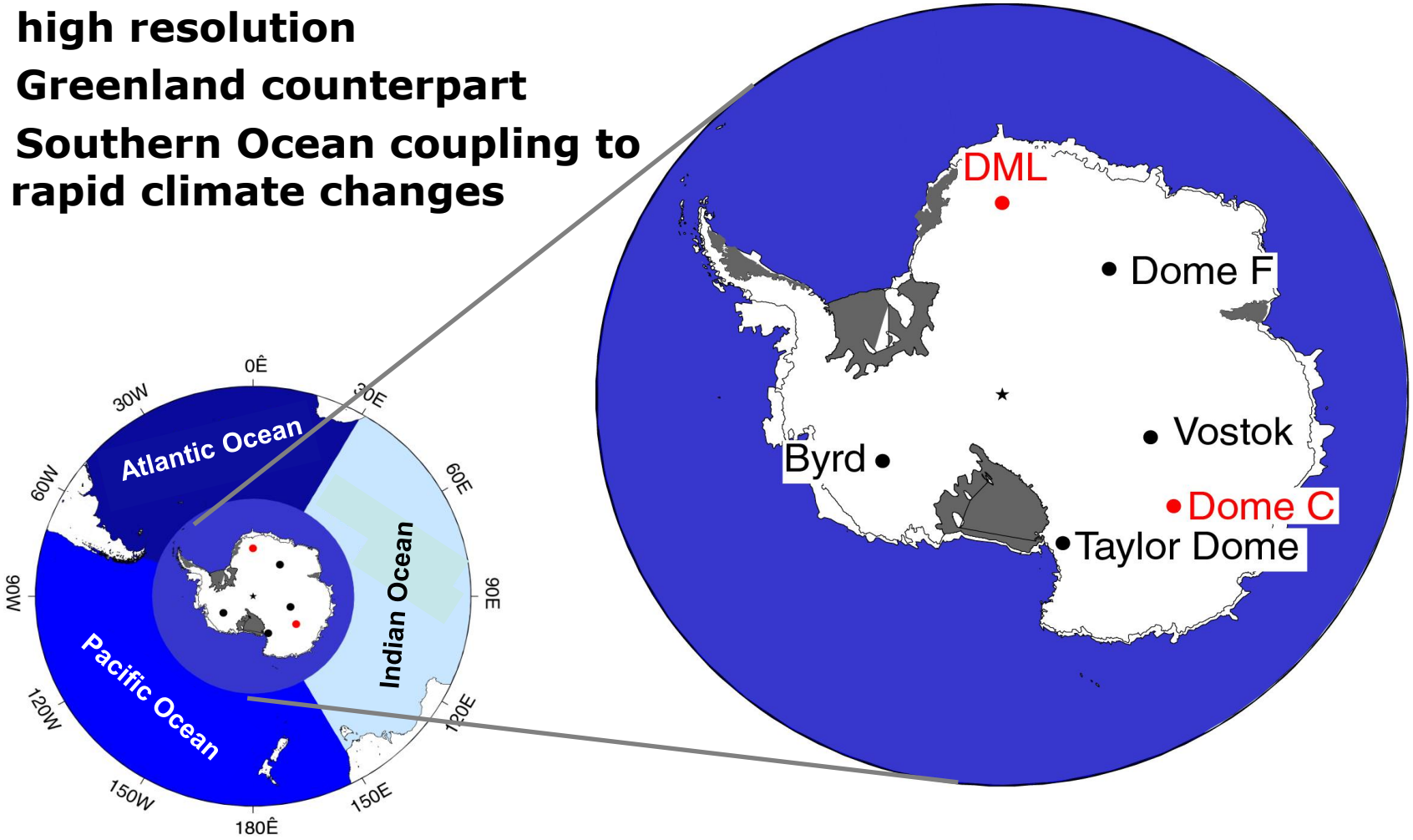
Overview



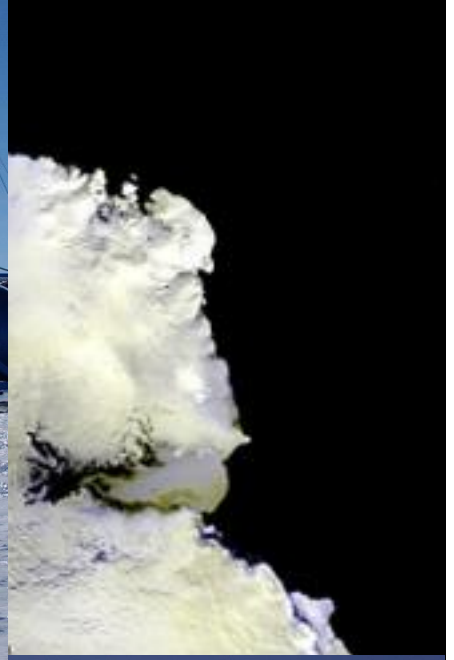
1. ***Why ice cores?***
2. ***Why 2 new ice cores?***
3. ***Technical achievement: 2 drillings to bedrock!***
4. ***Scientific highlights!***
   - ***ice core time coverage doubled***
   - ***recent CO_2 and CH_4 never reached in last 800,000 years***
   - ***interhemispheric coupling of rapid climate changes***
5. ***The European dimension***
6. ***Summary***

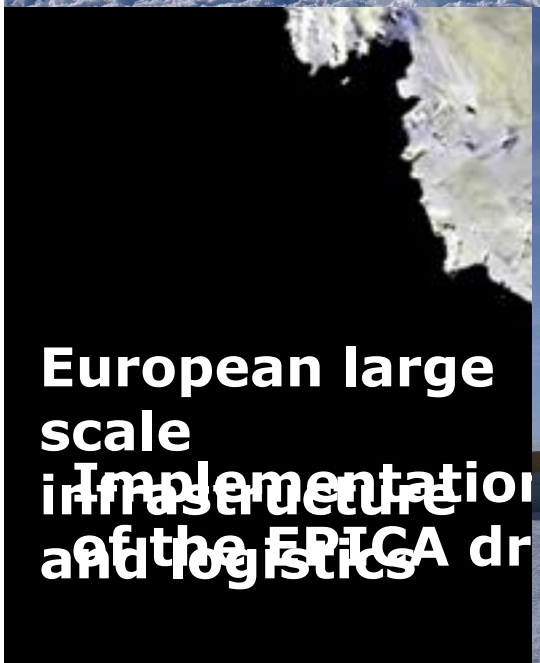
Why 2 new ice cores from Antarctica?

- ❄ high resolution
- ❄ Greenland counterpart
- ❄ Southern Ocean coupling to rapid climate changes



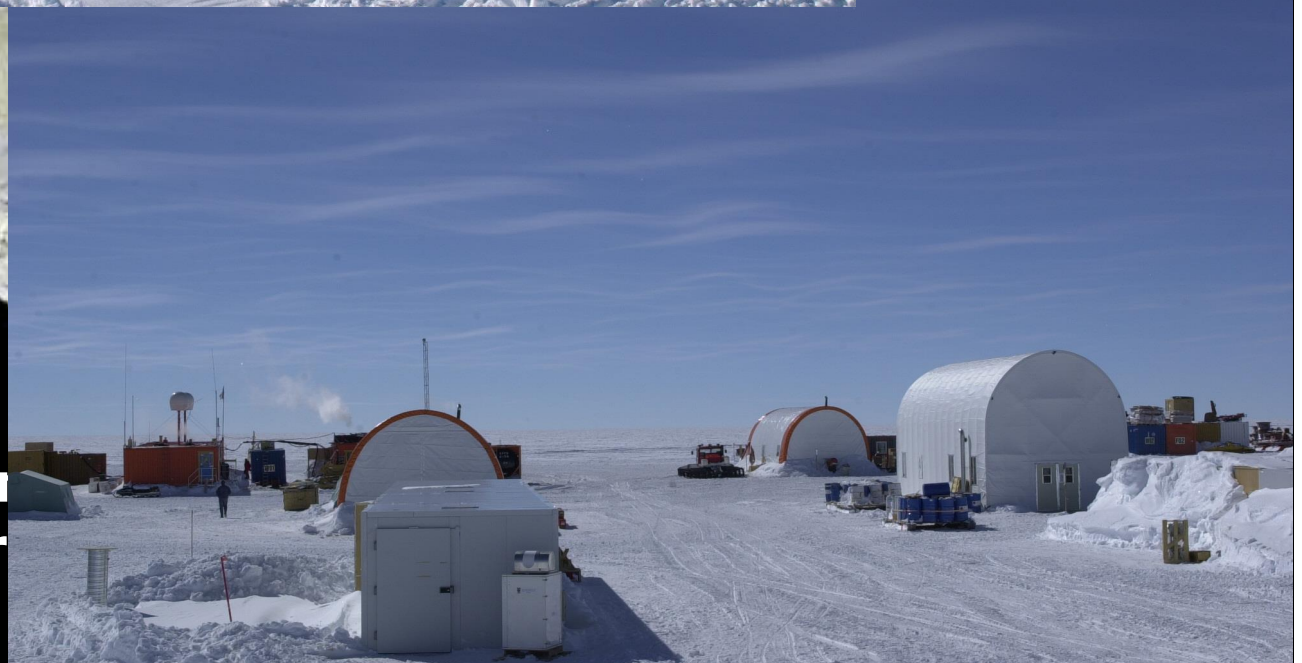
- ❄ longest ice core paleorecord, novel methods
- ❄ integration with marine records and models
- ❄ drivers of climate and biogeochemistry



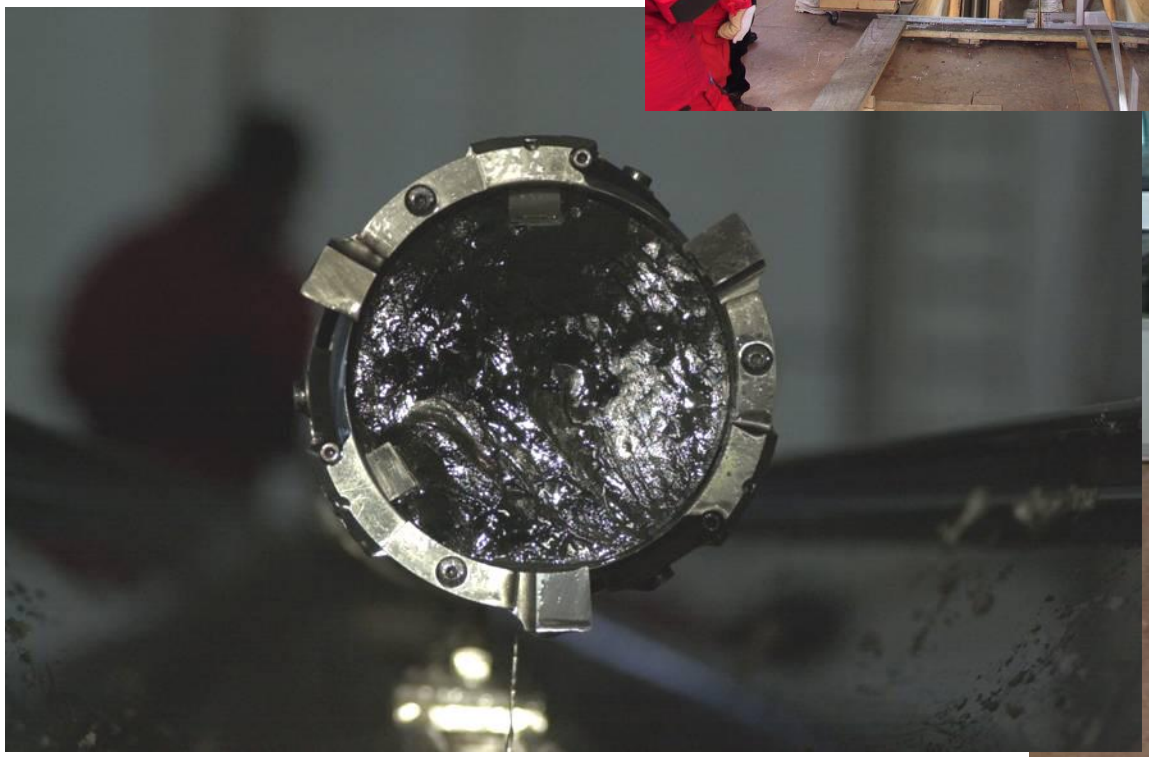


European large scale infrastructure and logistics

Implementation of the EPICA dr



Ice Core Drilling



Showcase of European Research and Technology

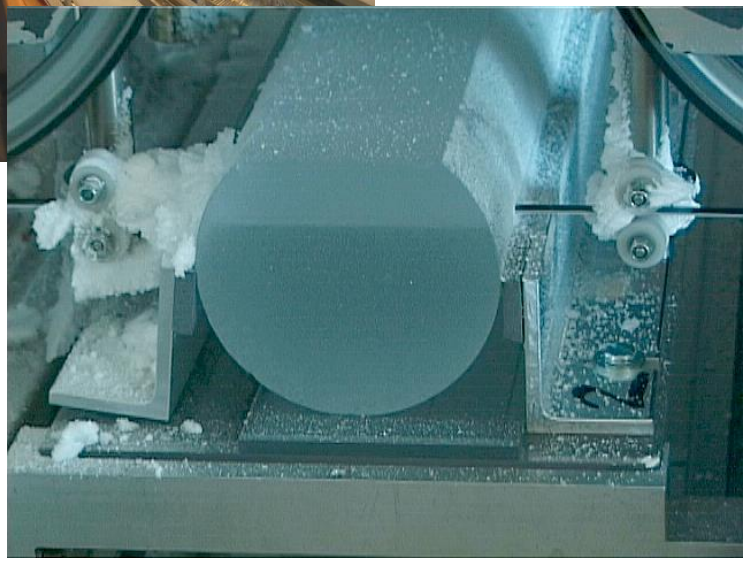
Air sampling in firn and ice

- **Firn pumping**
- **melting, cracking or sublimation of glacier ice**

Analyses

joint European expertise and analytical capacity

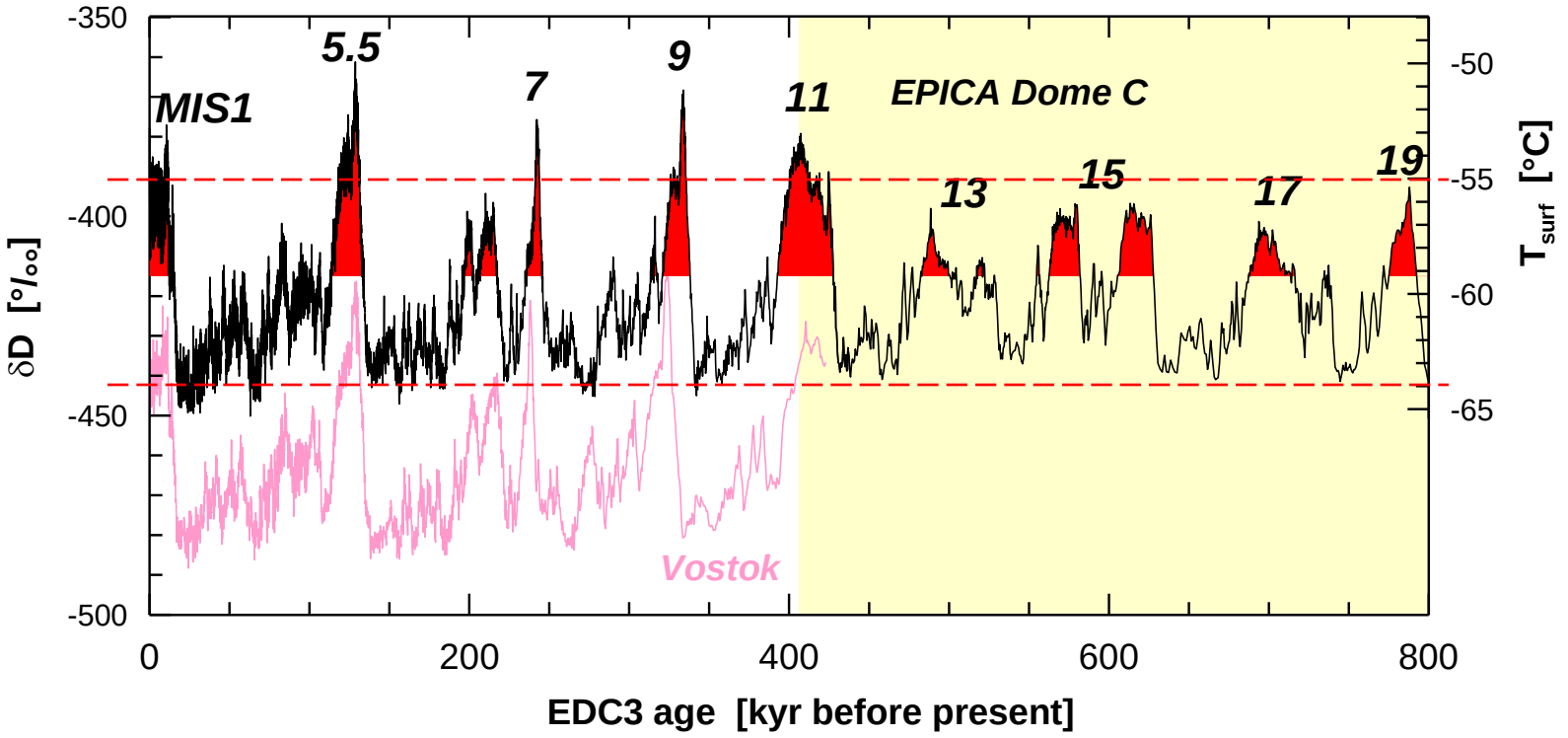
- ❄ **physical ice properties**
- ❄ **stable water isotopes (δD, $\delta^{18}O$)**
- ❄ **particulate and dissolved aerosol tracers in the ice**
- ❄ **cosmogenic radioisotopes and extraterrestrial dust**
- ❄ **gas composition in air bubbles**
- ❄ **ice sheet and climate modeling**
- ❄ **atmospheric observations and meteorology**



Scientific highlights: Temperature

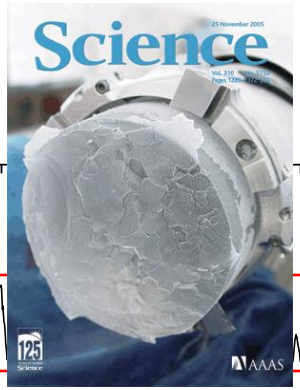
❄ **EDC doubles the climate history covered by ice cores**

❄ **lukewarm interglacials prior to 420,000 yr before present**



(EPICA community members 2004, Jouzel et al., 2007)

Greenhouse gases

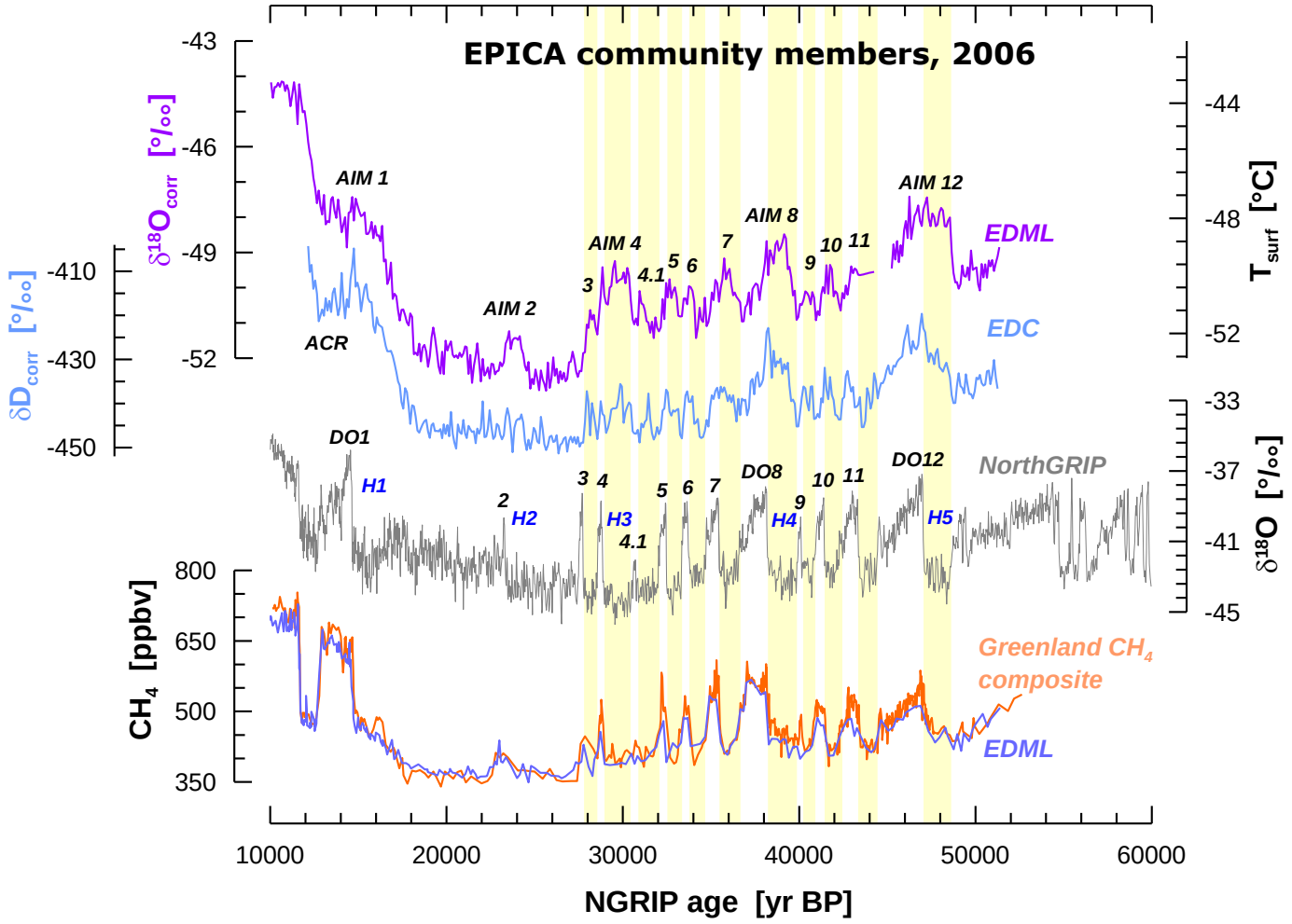


(Siegenthaler et al, 2005, Spahni et al., 2005, Lüthi et al., 2008, Loulergue et al., 2008)

- ❄ CO_2 (and CH_4) show lower interglacial levels
- ❄ CO_2 dominated by Southern Ocean (mixing, iron fertilization)

Scientific highlights: Bipolar coupling

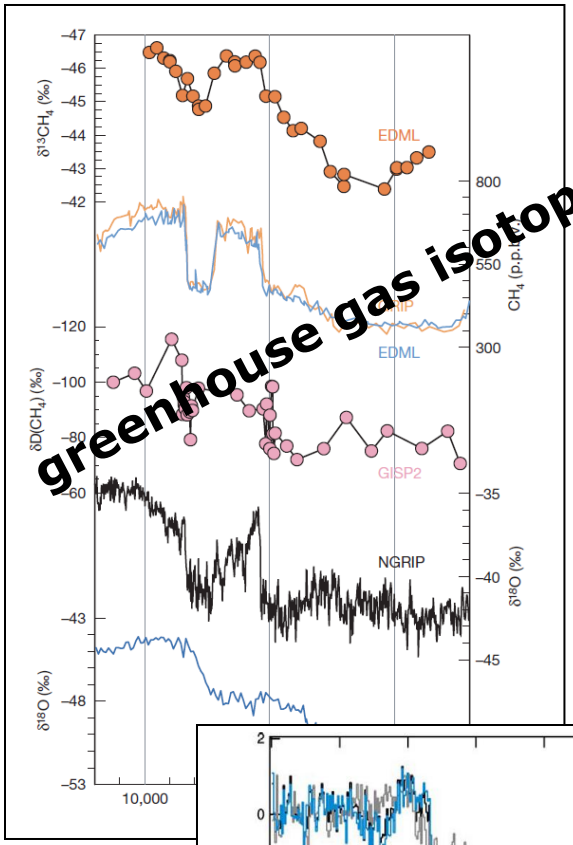
- ❄ every rapid warming in Greenland (DO) has a counterpart in Antarctica (AIM)
- ❄ Antarctic warms when Greenland cold and vice versa
- ❄ one-to-one bipolar seesaw pattern for each event



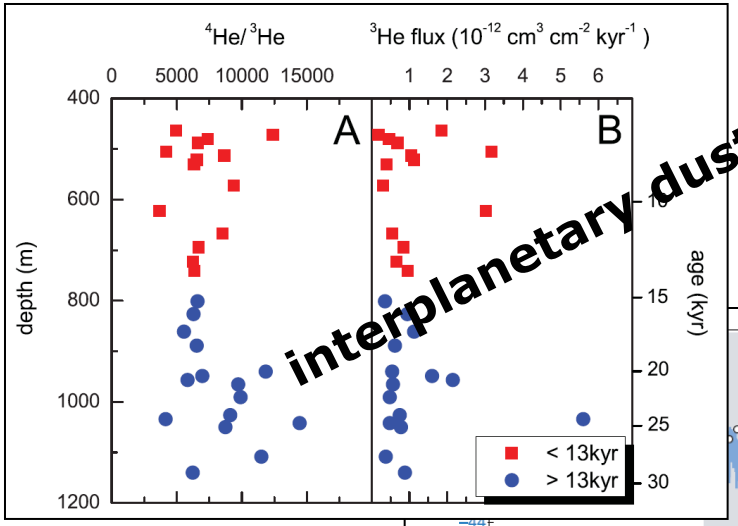
New tracers

creative windows to new insights

Fischer et al., 2008



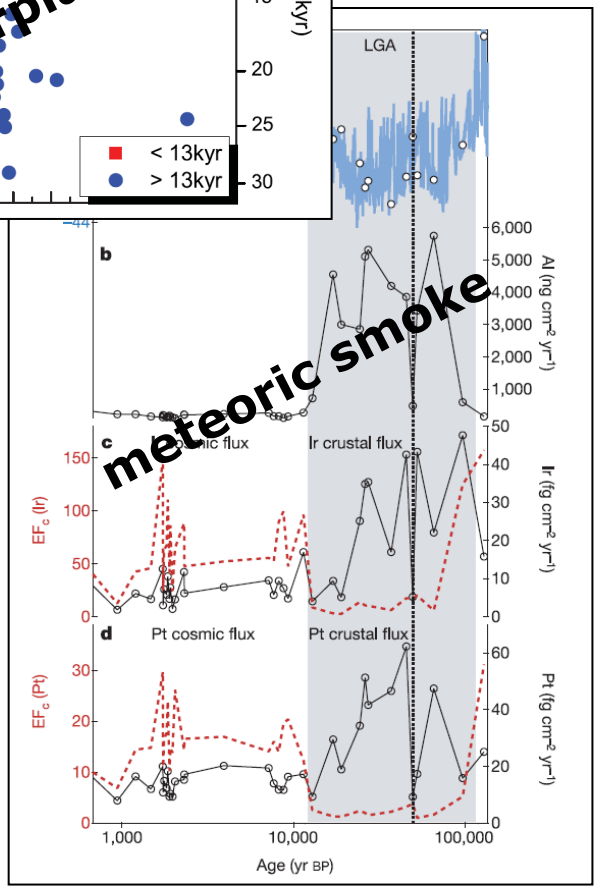
greenhouse gas isotopes



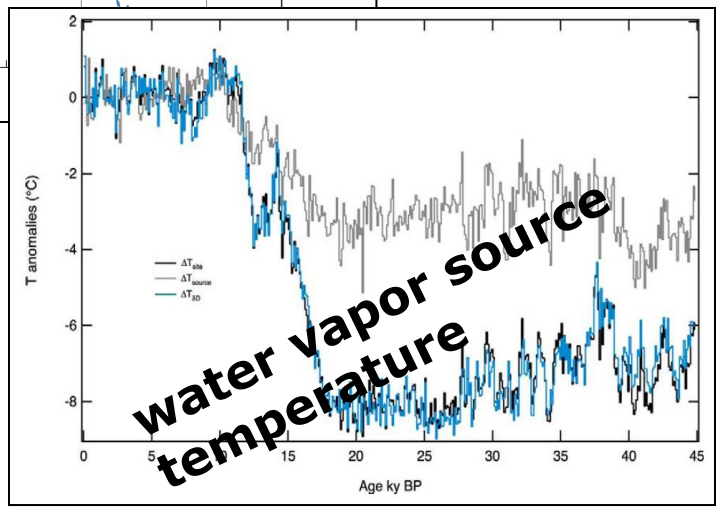
interplanetary dust

Winckler & Fischer, 2006

Gabrielli et al., 2005



meteoric smoke



water vapor source
temperature

Stenni et al., 2001, 2003

EPICA: The European Dimension

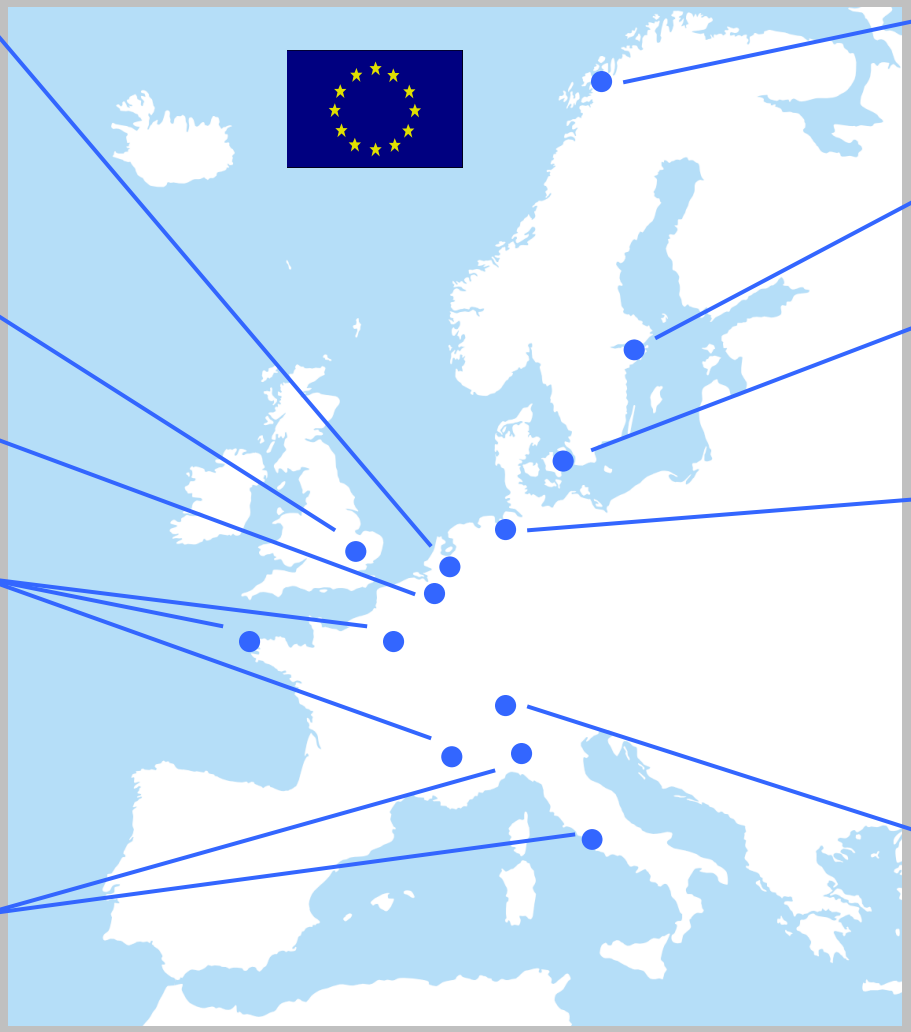
UUtrecht: meteorology, mass balance, ice sheet modeling, radiocarbon

BAS: *logistics*, aerosol, gases, phys. properties

UBrussels: basal ice, ice sheet modeling

IPEV: *logistics*
CNRS/CEA: *drilling*, isotopes, aerosol, gases, cosmogenic isotopes, phys. properties, modeling

ENEA: *logistics, drilling*
UMilano: isotopes, aerosol, geophysics



NPI: *logistics*, aerosol, mass balance, phys. properties

UStock: *logistics*, aerosol, mass balance

UCPH: *drilling*, isotopes, aerosol, phys. properties, modeling

AWI: *logistics, drilling*, isotopes, aerosol, gases, extraterrestrial dust, mass balance, phys. properties, modeling, geophysics

UBern: *drilling*, aerosol, gases, cosmogenic isotopes, phys. properties, climate modeling

❄ **successful implementation requires large logistic and analytical capacity as well as specialization**

Summary: a few numbers

- **EPICA: outstanding technical achievements, iconic scientific results**
- **so far about 200 peer reviewed papers, 14 Nature and Science publications**
- **educating the scientific leaders of tomorrow: ~20 master and ~40 PhD theses**
- **basis of joint European ice core community - now world leader in ice core research**
- **project and community building possible through long-term European support (EU) and integration (ESF):**

  costs: ~35 M€ logistics + ~10 M€ for science
  EU contribution: 12.8 M€ in 4 funding periods (EPICA I-III, EPICA-MIS in FP 4-6)
- **successful example of strategic science support on the European level**

EPICA: The European Dimension

- ❄ **EPICA sets new standards**
  European leadership in ice core research

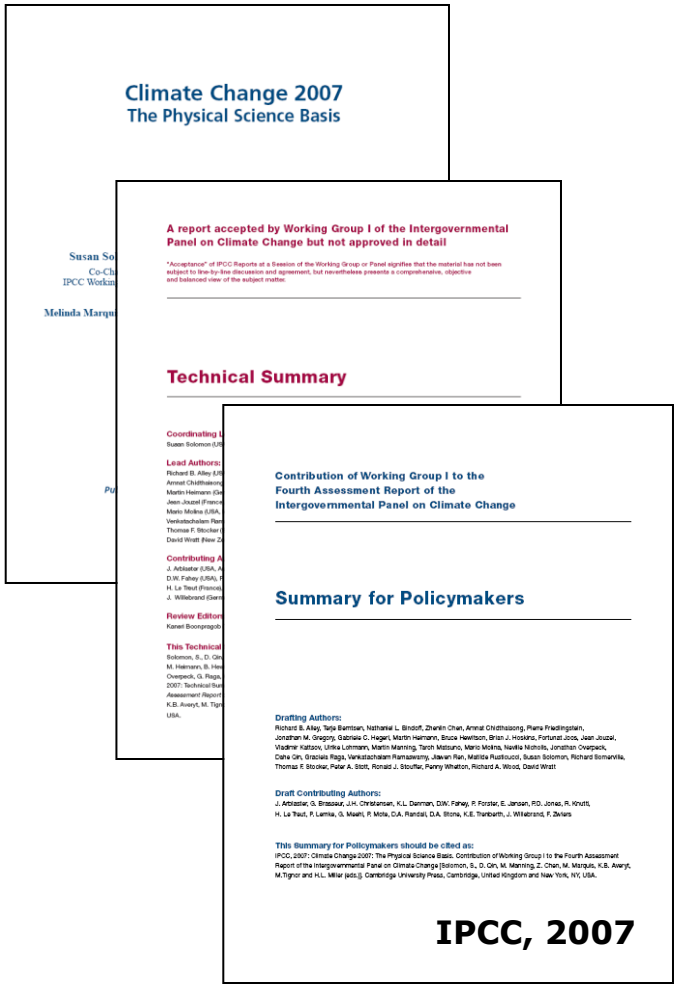
- ❄ **Only possible by European integration and continued support**

- ⇨ **New ice core projects**
  (IPICS: NorthEEM, Oldest Ice)

- ❄ **EPICA provides the basic data on climate variability, climate forcing, sea level change to assess future changes**

- ❄ **3 IPCC lead authors within EPICA**

- ❄ **outreach in media and public**
  (DFG Communicator Prize 2007)



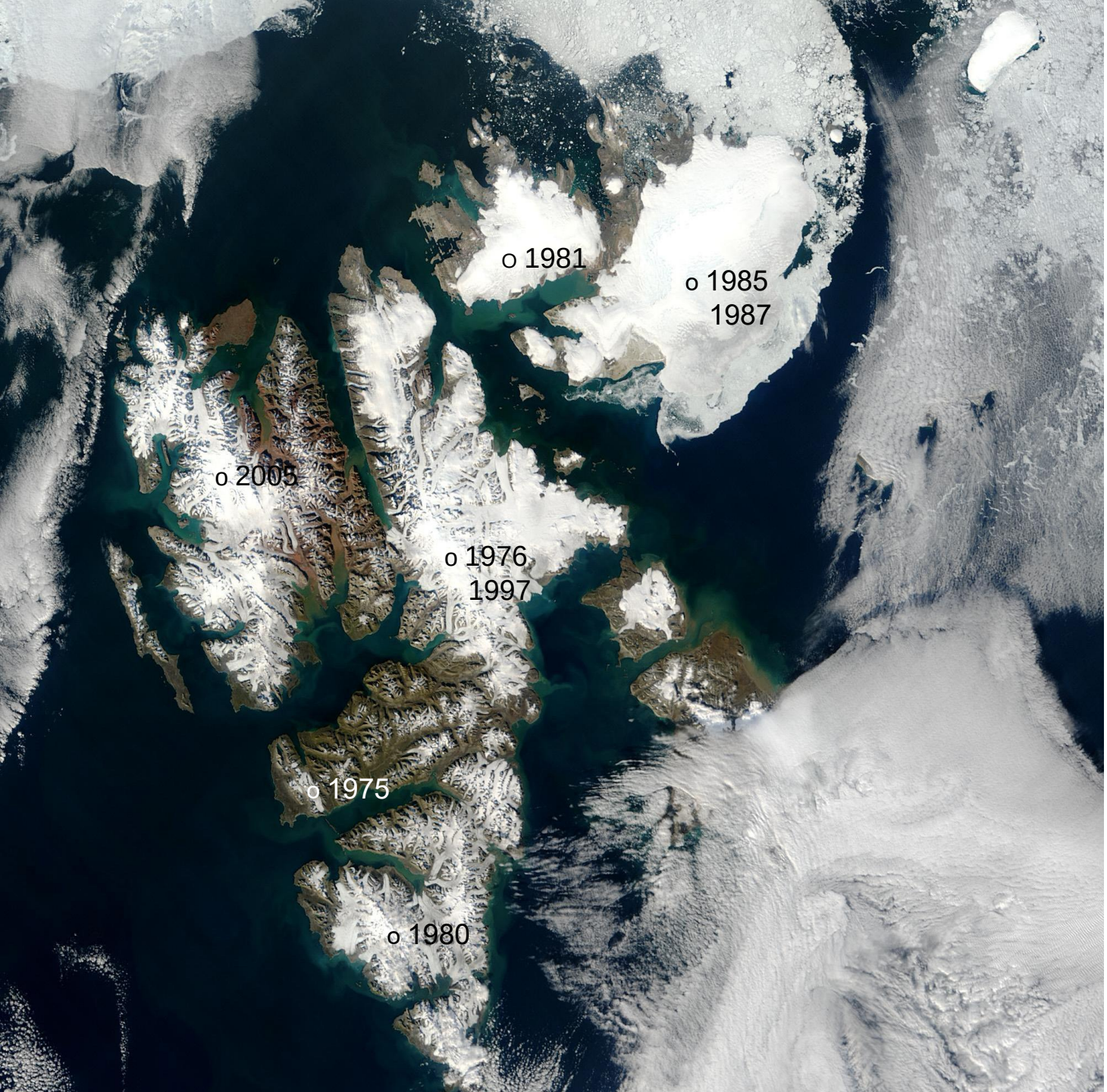
Ice core research in Tallinn

Research in 1975-1991

- Ice cores (Polar-Ural, Svalbard, Severnaya Zemlya, Antarctica)

Svalbard

- 1975-1987 in cooperation with Institute of Geography (Moscow), Later on cooperation with Norwegian Polar Institute, Tromsö



1975
Gronfjordbreen-
Fridtjovbreen

1976 Lomonosovfonna

1980 Amundsenisen

1981 Vestfonna

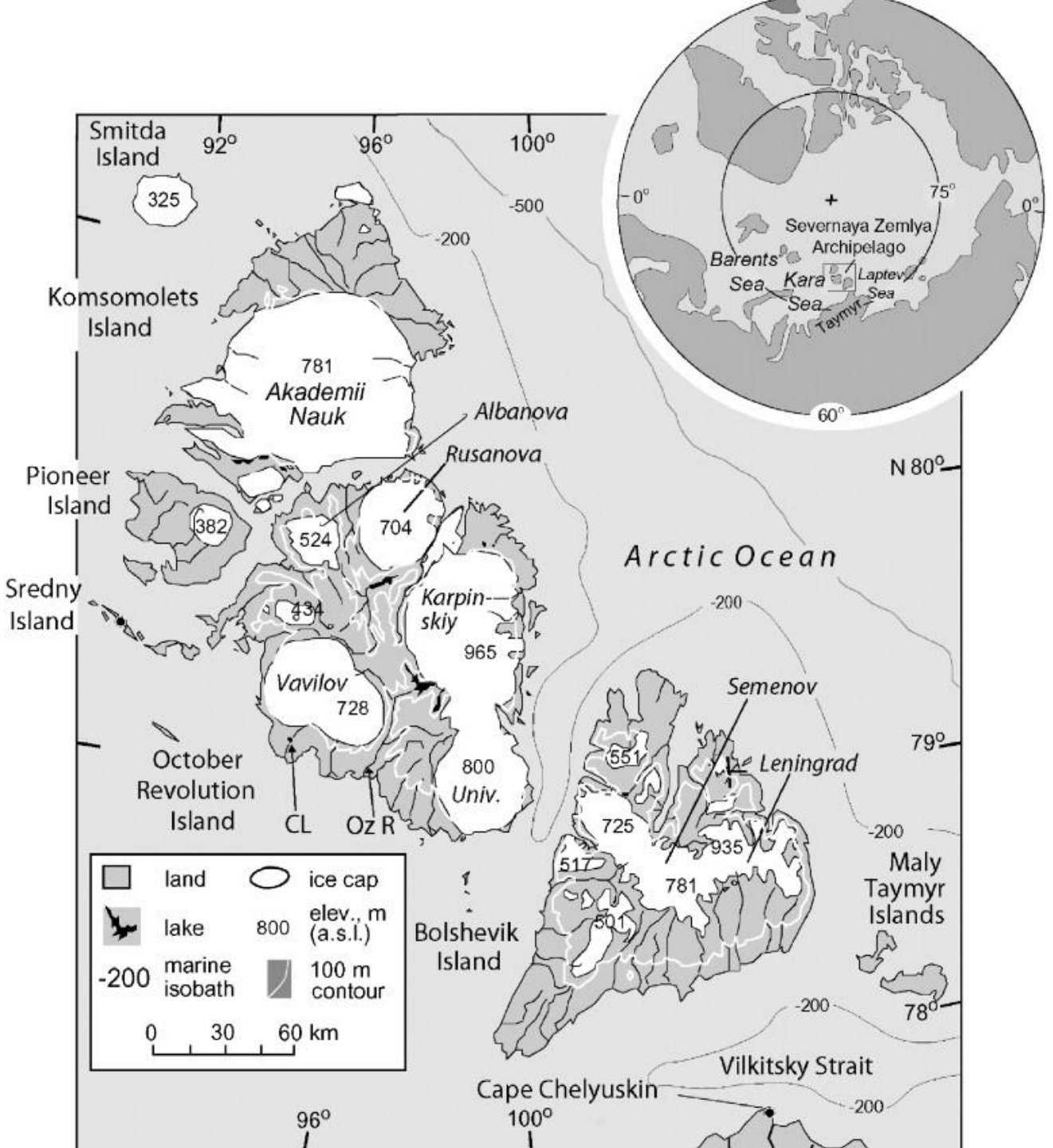
1985 Austfonna

1987 Austfonna

Kotlyakov et al, QSR

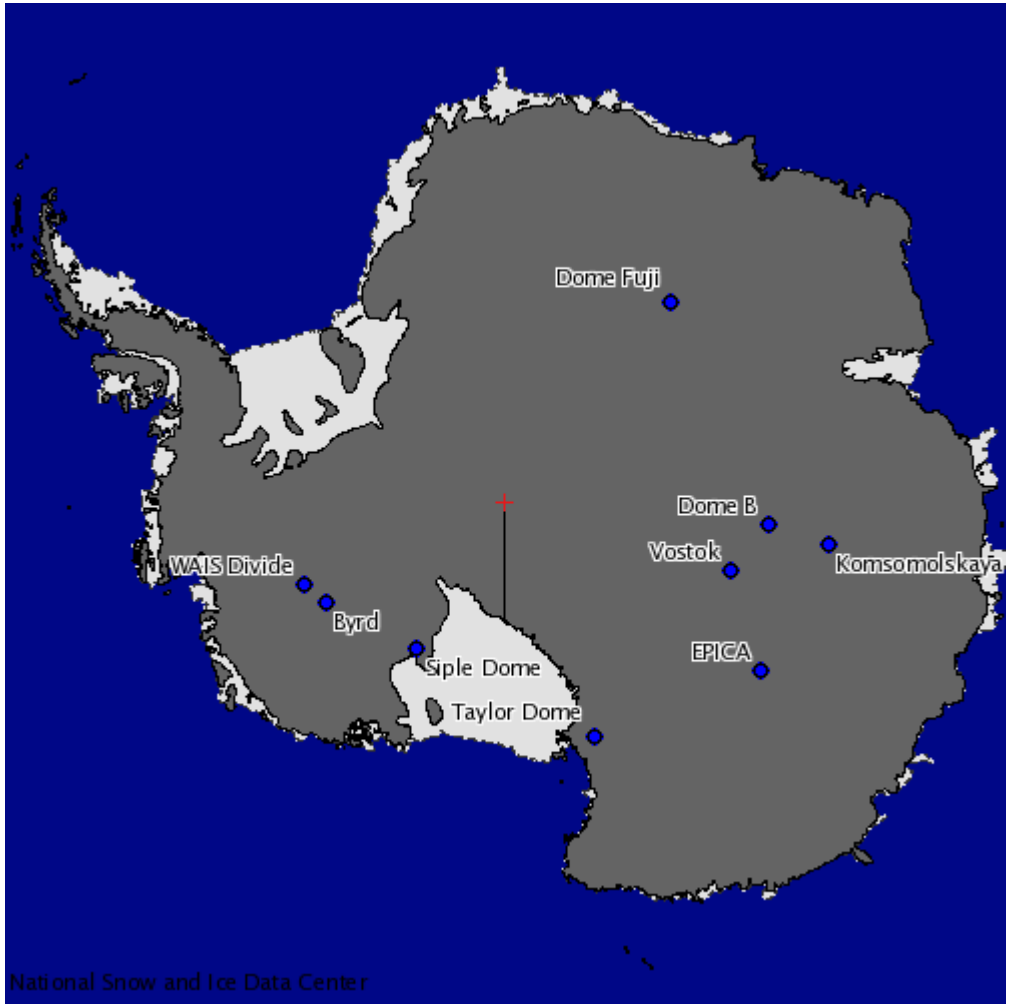
1997 Lomonosovfonna

2005 Holtedahlfonna

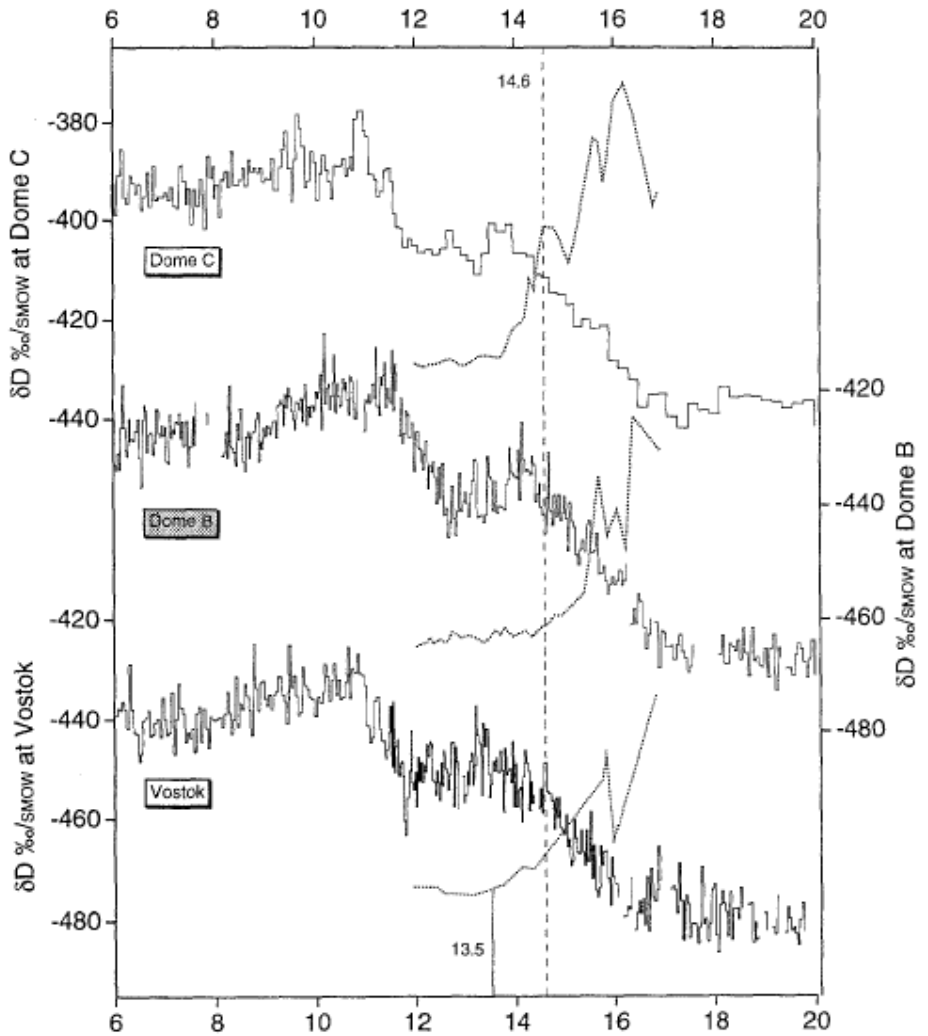

Smitda Island
92°
96°
100°
325
-500
-200
Komsomolets Island
781
Akademii Nauk
Albanova
Rusanova
Pioneer Island
382
524
704
Sredny Island
434
Karpin-skiy
965
Vavilov
728
October Revolution Island
CL
Oz R
800
Univ.
Arctic Ocean
N 80°
Semenov
551
Leningrad
79°
725
935
517
781
501
Bolshevik Island
Maly Taymyr Islands
78°
land
ice cap
lake
800
elev., m (a.s.l.)
-200
marine isobath
100 m contour
0
30
60 km
Vilkitsky Strait
Cape Chelyuskin
96°
100°
0°
75°
Severnaya Zemlya Archipelago
Barents Sea
Kara Sea
Laptev Sea
Taymyr
60°

Severnaja Zemlja 1979

Dome B


Dome Fuji
Dome B
Vostok
Komsomolskaya
WAIS Divide
Byrd
Siple Dome
EPICA
Taylor Dome
National Snow and Ice Data Center

Dome B


6
8
10
12
14
16
18
20
14.6
13.5
-380
-400
-420
-440
-460
-480
Dome C
Dome B
Vostok
δD ‰/SMOW at Dome C
δD ‰/SMOW at Vostok
δD ‰/SMOW at Dome B
-420
-440
-460
-480

The future: IPICS

- International Partnerships in Ice Core Sciences
- Informal international planning group
- Discussing long term new ice coring projects
- Representatives from 21 countries
  - Australia, Belgium, Brazil, Canada, China, Denmark, Estonia, France, Germany, India, Italy, Japan, Korea, Netherlands, New Zealand, Norway, Russia, Sweden, Switzerland, United Kingdom, United States.
- Co-chairs: Eric Wolff (BAS), Ed Brook (OSU)
- Meetings: Washington D.C. 2004, Brussels 2005, Vienna 2008, Oregon 2009,Crans Montana 2022
- Meetings support from NSF OPP, EPC.
- IPY Endorsement
- Links to PAGES, SCAR, maybe IACS/IUGG

Outlook

New ice cores:

International Partnerships for Ice Core Sciences (IPICS)
(http://www.pages-igbp.org/science/initiatives/ipics/)

- **1.2-1.5 Ma ice core from East Antarctica**
- **Greenland Eemian record (140,000 a)**
- **40 ka array of deglaciation dynamics**
- **2 ka array of late Holocene climate variability (ice hockeystick)**

New analyses :

- **subglacial ice: glaciological phenomenon or new habitat???**
- **biology/genetics (Willerslev et al., 2007)**
- **extraterrestrial dust in ice cores (Gabrielli et al., 2006, Winckler & Fischer, 2006)**
- **isotopic studies on greenhouse gases**

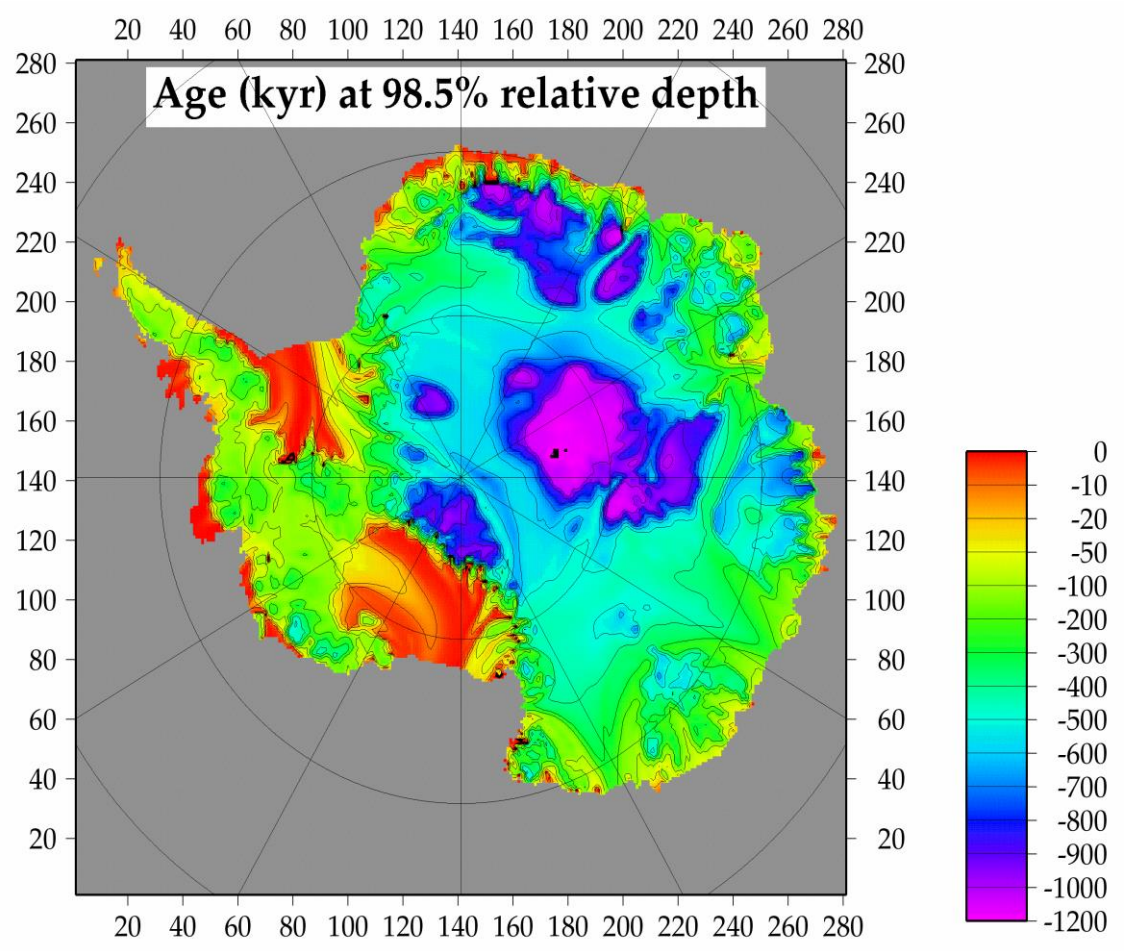
IPICS: The oldest ice core: A 1.5 million year record of climate and greenhouse gases from Antarctica

Main objective: Mid Pleistocene Transition, shift from 40k to 100k world

Steps:

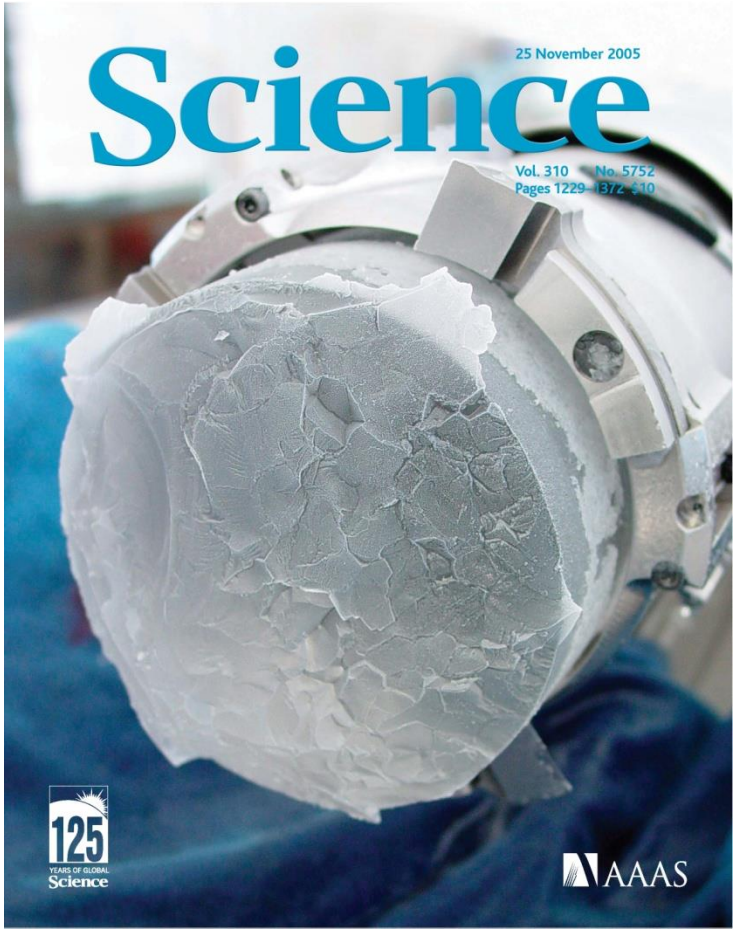
1. Reconnaissance Studies
2. Pinpoint the exact locations of the drill site(s)
3. Assemble teams and money
4. Drilling and science

Time frame 2007-2027



Drilling Technology

- Essential part of IPICS
- Challenges
  - Drilling in colder environments
  - Environmental hazards of fluids, need for replacement fluids
  - Weight/cost of drills
  - Ice quality
  - Replicate coring in one borehole



European and national strategy

- EuroPICS will coordinate but not control
- National labs will retain control over resources and responsibility for maintaining assets: a distributed European laboratory
- Will act at the scale needed for a project
  - For small/medium projects, share information, arrange mutual assistance in national or multinational teams
  - For oldest ice, act at European scale, as with EPICA
  - Identify and seek to fill infrastructure gaps through national and European funding

Continuing the recipe for success "Oldest ice" project

- ✓ A scientific target that all the partners really want to achieve
- ✓ Knowledge that it can only be achieved in a collaboration
- ✓ Organisational help (EuropPICS)
- ✓ Collaboration and trust built up over successive projects, with people working together (e.g in field)
- ✓ Good balance between European, national and laboratory pride and prestige
- ✓ Complementary skills available
- ➢ Some infrastructure is not yet available
- ➢ Financial lubricant will be needed again

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