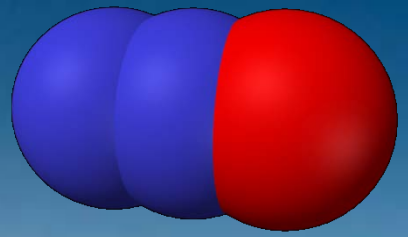
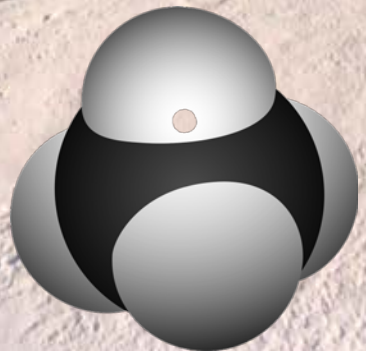
CENTRE FOR ICE AND CLIMATE

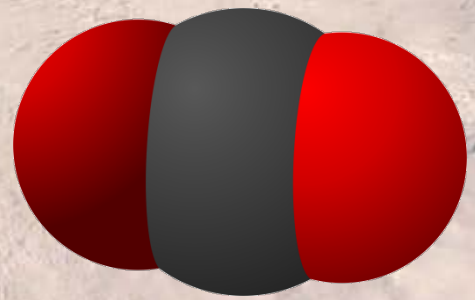
GIFT Workshop EGU2014



CLIMATE INFORMATION FROM ICE CORES (PART 1)

Thomas Blunier





- About me
- Greenhouse effect
- Ice coring and ice core records
- Recent atmosphere, last 1000 years
- Distant past (Glacial-Interglacial)
- Rapid climate change

Thomas Blunier

Professor, Centre for Ice and Climate, Niels Bohr Institute, University of Copenhagen.

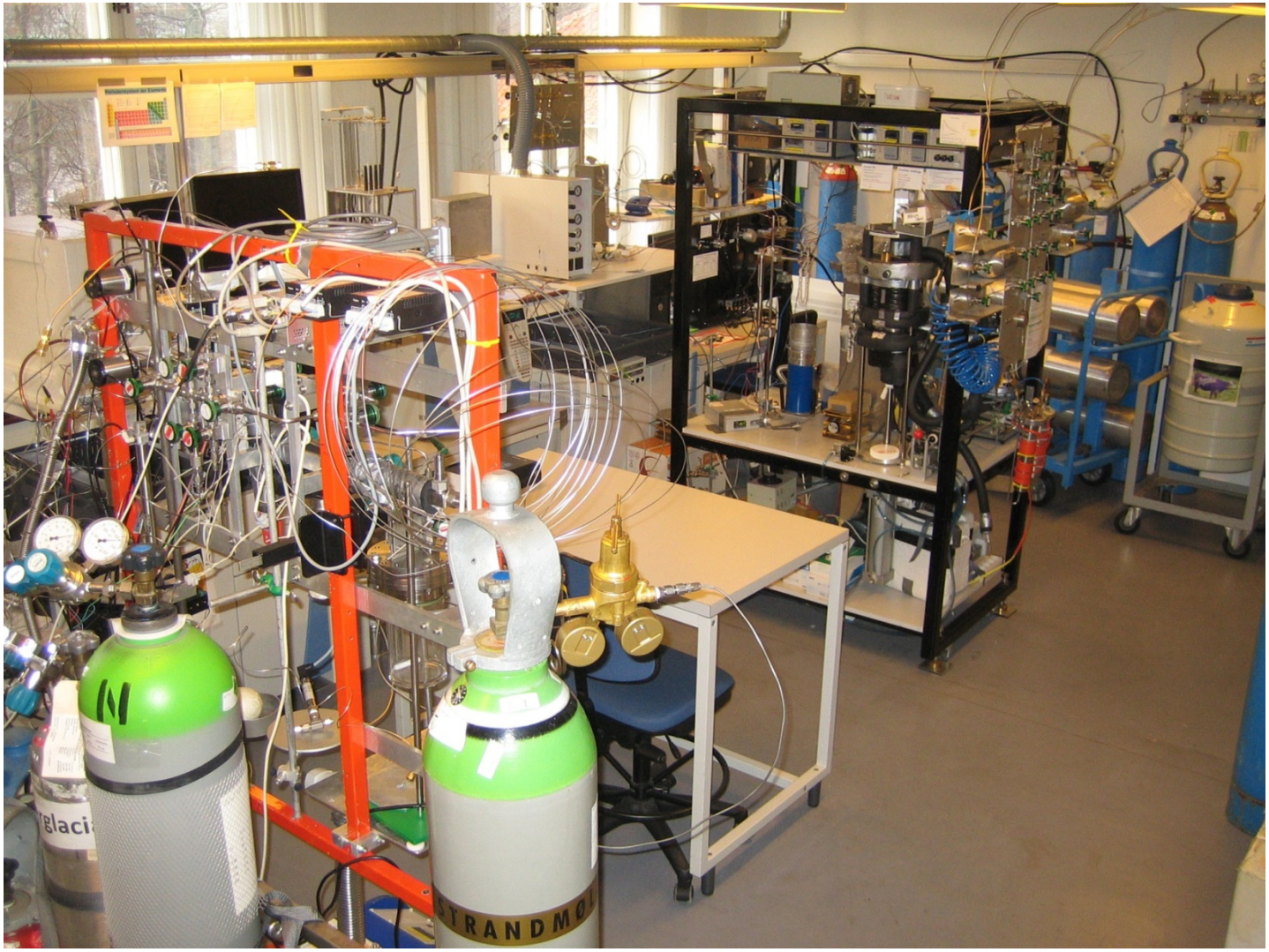
www.iceandclimate.dk

Part of ice core science since 1991.

Head of the trace gas group.

My lab in Copenhagen

CENTRE FOR ICE AND CLIMATE



Composition of the atmosphere

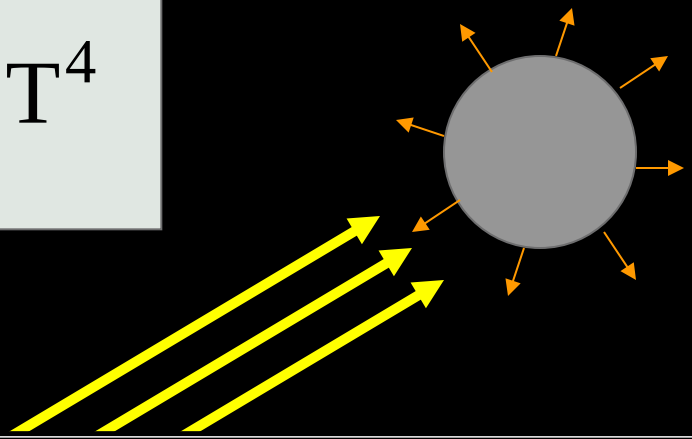
CENTRE FOR ICE AND CLIMATE

Gas	%	ppm
Nitrogen (N_2)	78.084	780'840.000
Oxygen (O_2)	20.946	209'460.000
Argon (Ar)	0.934	9'340.000
Carbon dioxide (CO_2)	3.9050E-02	390.500
Neon (Ne)	1.818E-03	18.180
Helium (He)	5.240E-04	5.240
Methane (CH_4)	1.803E-04	1.803
Krypton (Kr)	1.140E-04	1.140
Hydrogen (H_2)	5.500E-05	0.550
Nitrous Oxide (N_2O)	324.2E-05	0.324
Carbon Monoxide (CO)	1.000E-05	0.100
Xenon (Xe)	9.000E-06	0.090

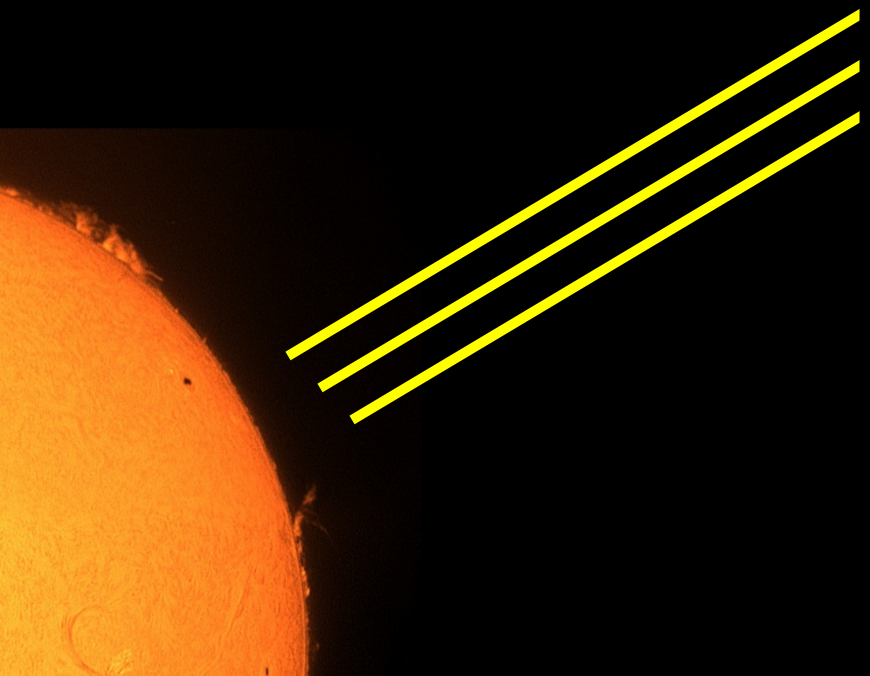
IPCC 2013, status 2011

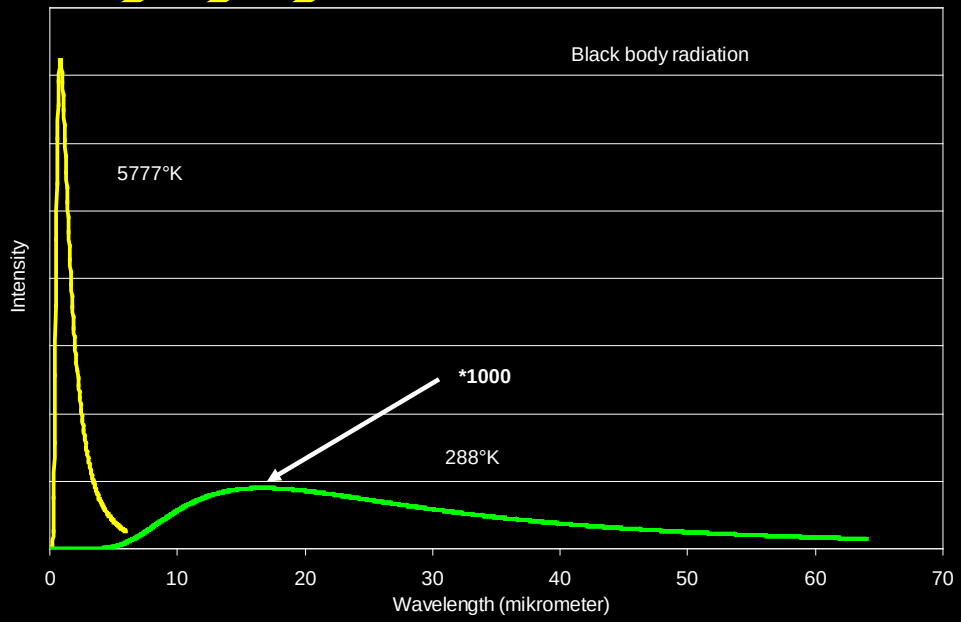
Greenhouse effect
Blackbody

$$\pi \cdot r_E^2 \cdot S_0 = 4 \cdot \pi \cdot r_E^2 \cdot \sigma \cdot T^4$$



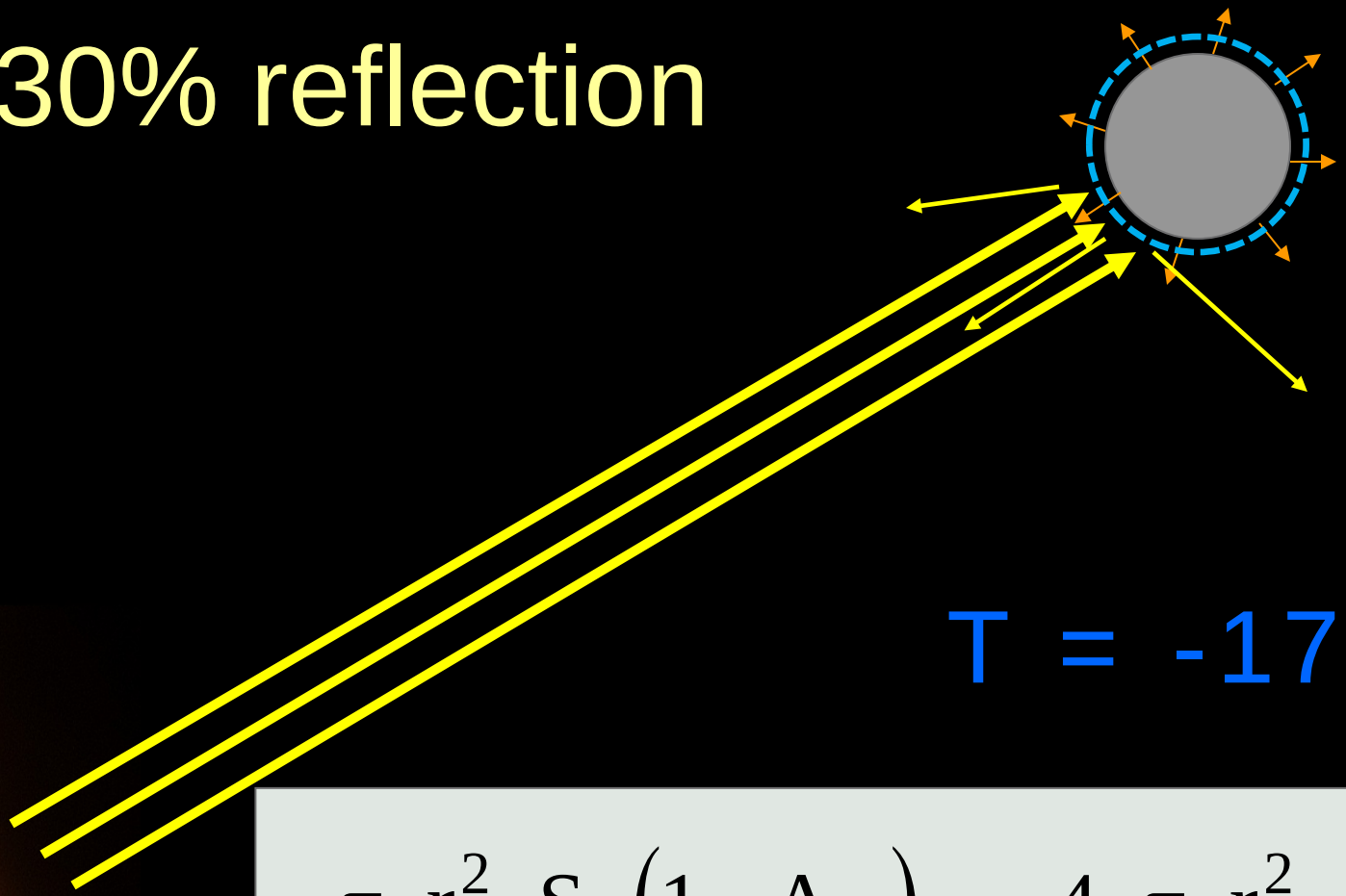
T = 7°C





CENTRE FOR ICE AND CLIMATE

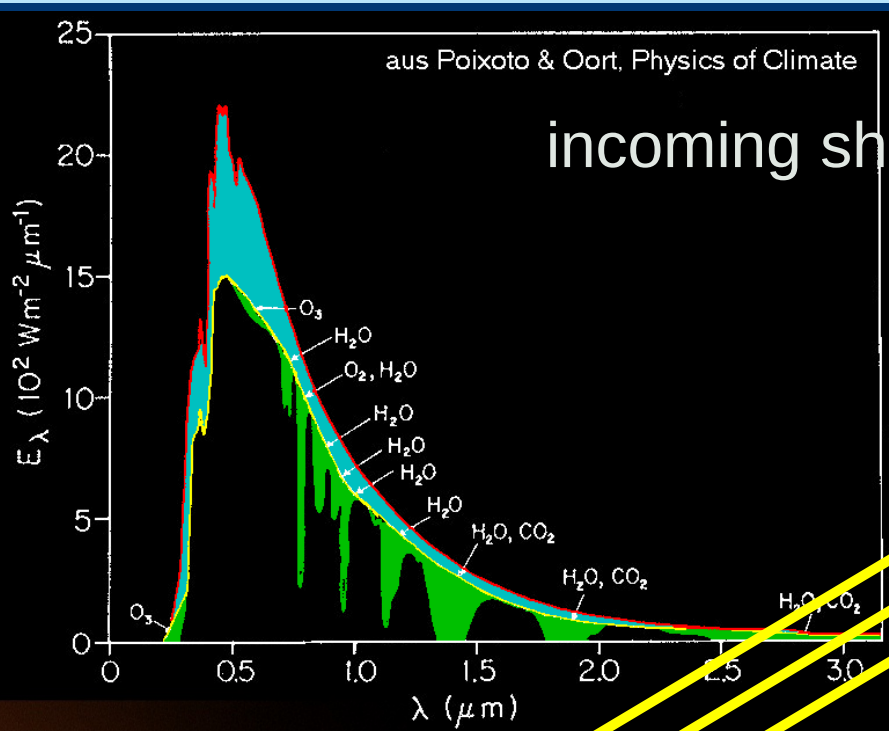
30% reflection



T = -17°C

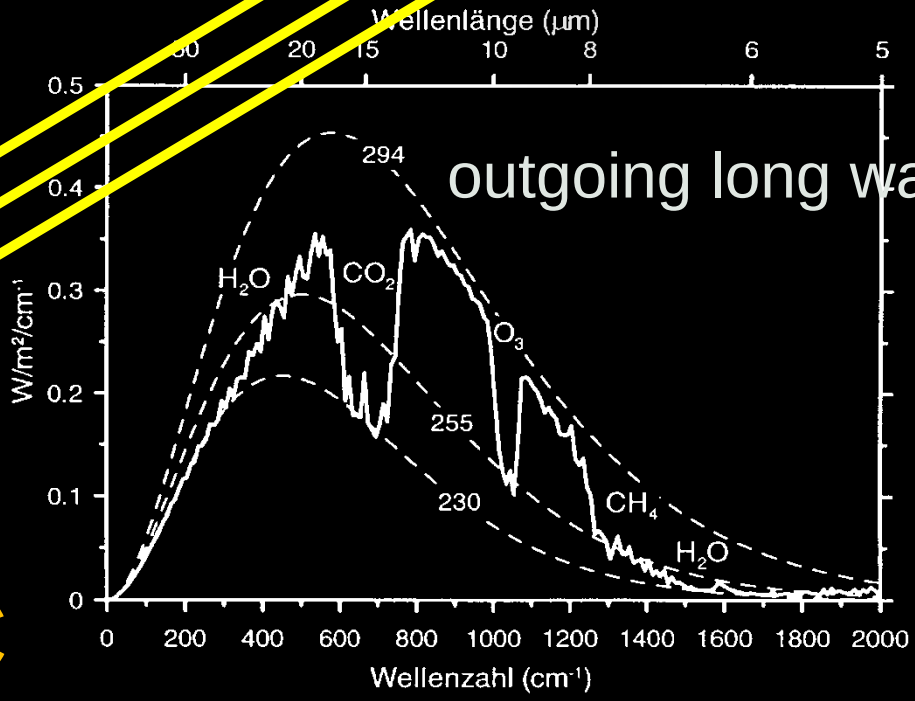
$$\pi \cdot r_E^2 \cdot S_0 \left(1 - A_p\right) = 4 \cdot \pi \cdot r_E^2 \cdot \sigma \cdot T^4$$

Greenhouse effect



incoming short wave

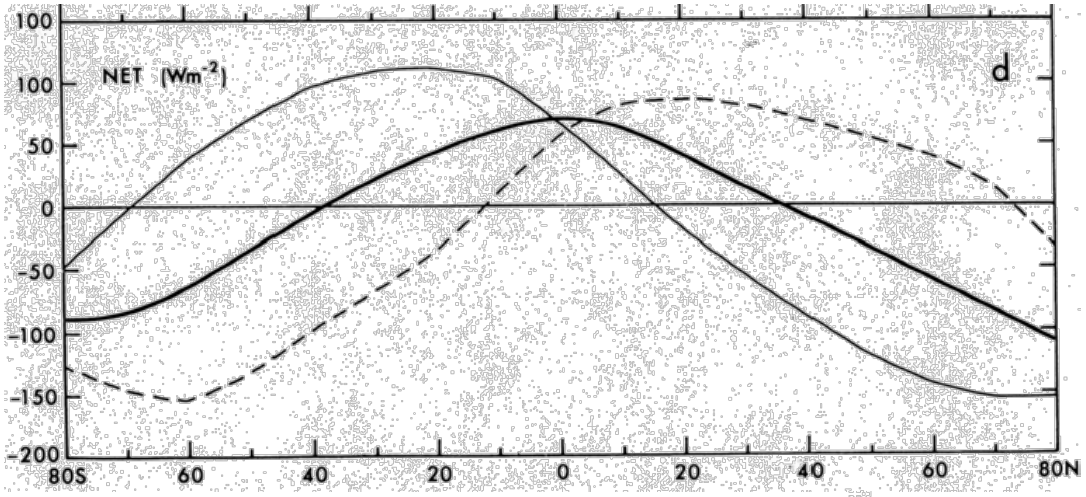
outgoing long wave



T = ~15°C

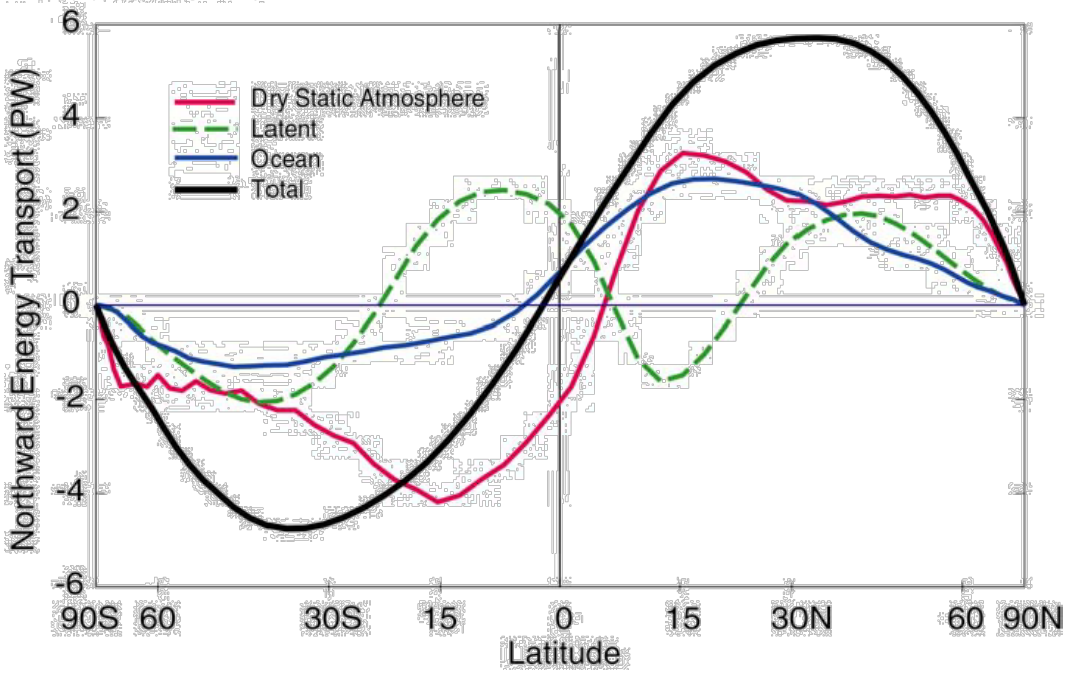
Thermische Emission von Erdoberfläche plus Atmosphäre über einem wolkenfreien Gebiet mit einem Interferometer. Schwarzkörperstrahlung für verschiedene Temperaturen sind gestrichelt eingezeichnet.

Redistribution of Energy



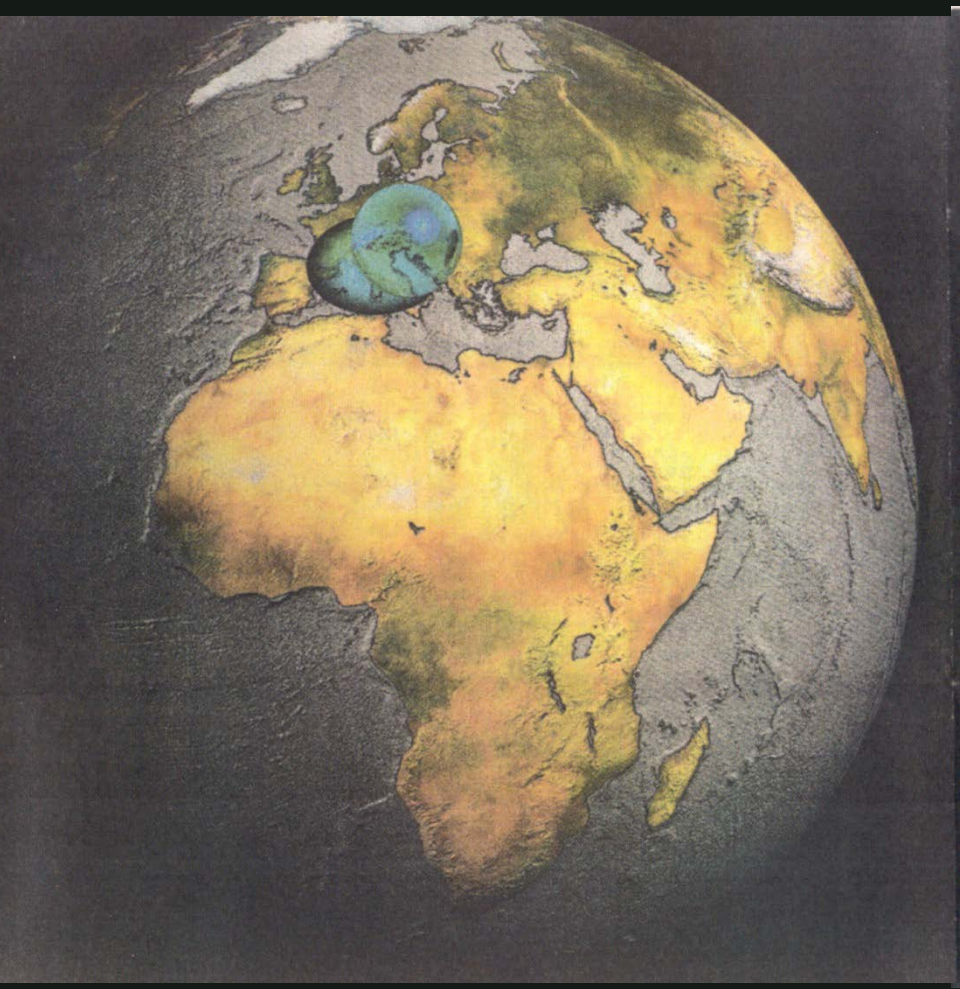
Radiation balance (winter, summer, and annual mean) as a function of latitude (Peixoto & Oort, 1992)

Annual mean meridional heat transport in atmosphere (latent and dry) and ocean (Ocean Circulation & Climate, 2001)

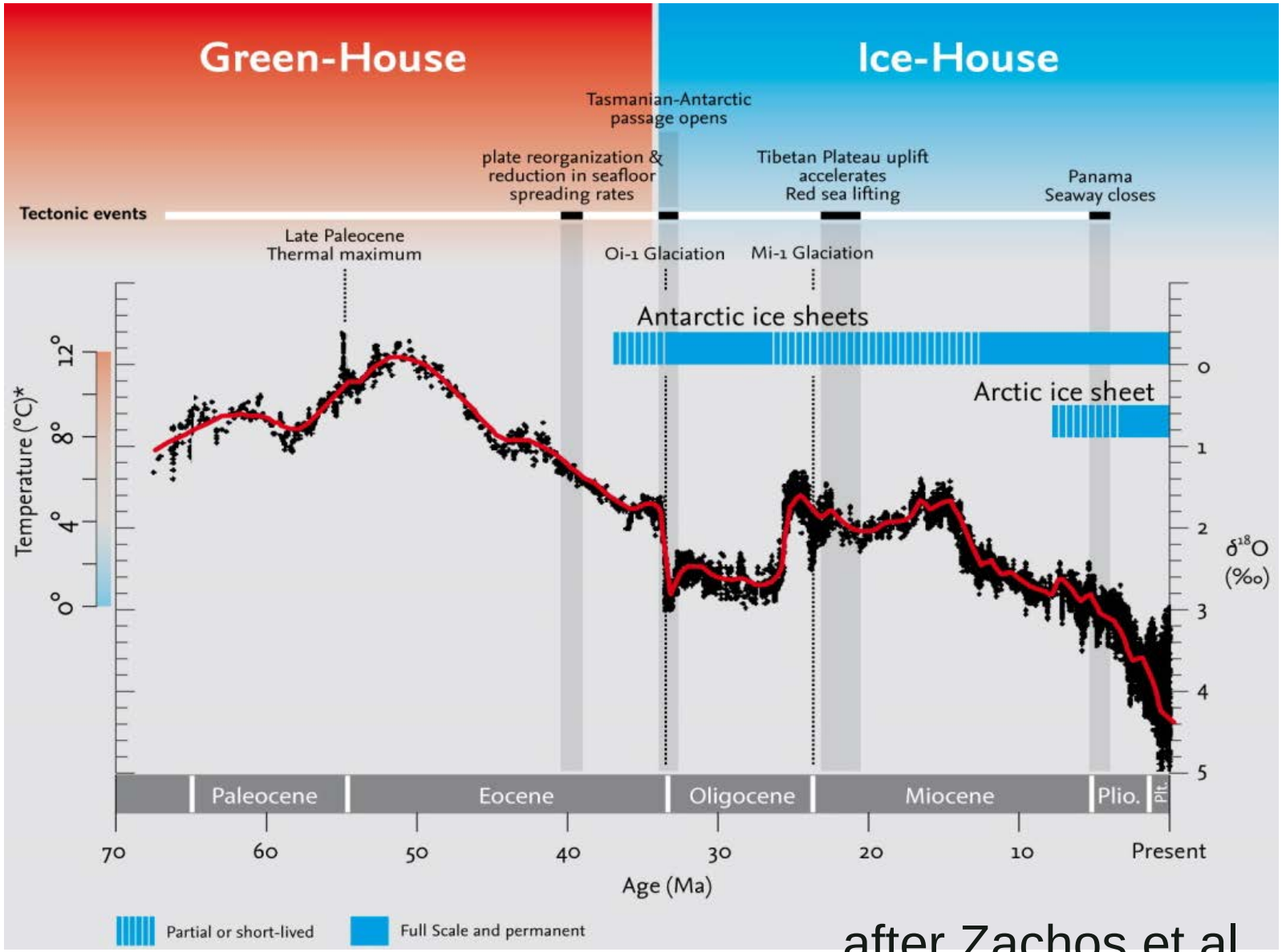


What makes the climate system

CENTRE FOR ICE AND CLIMATE



Adam Nieman

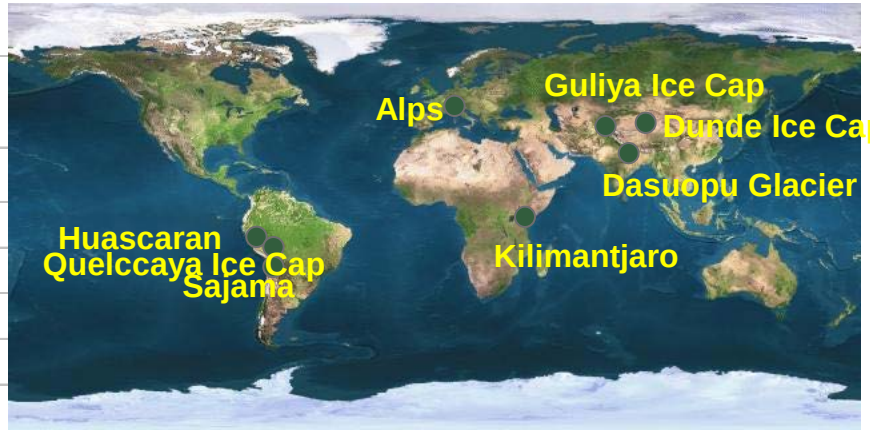


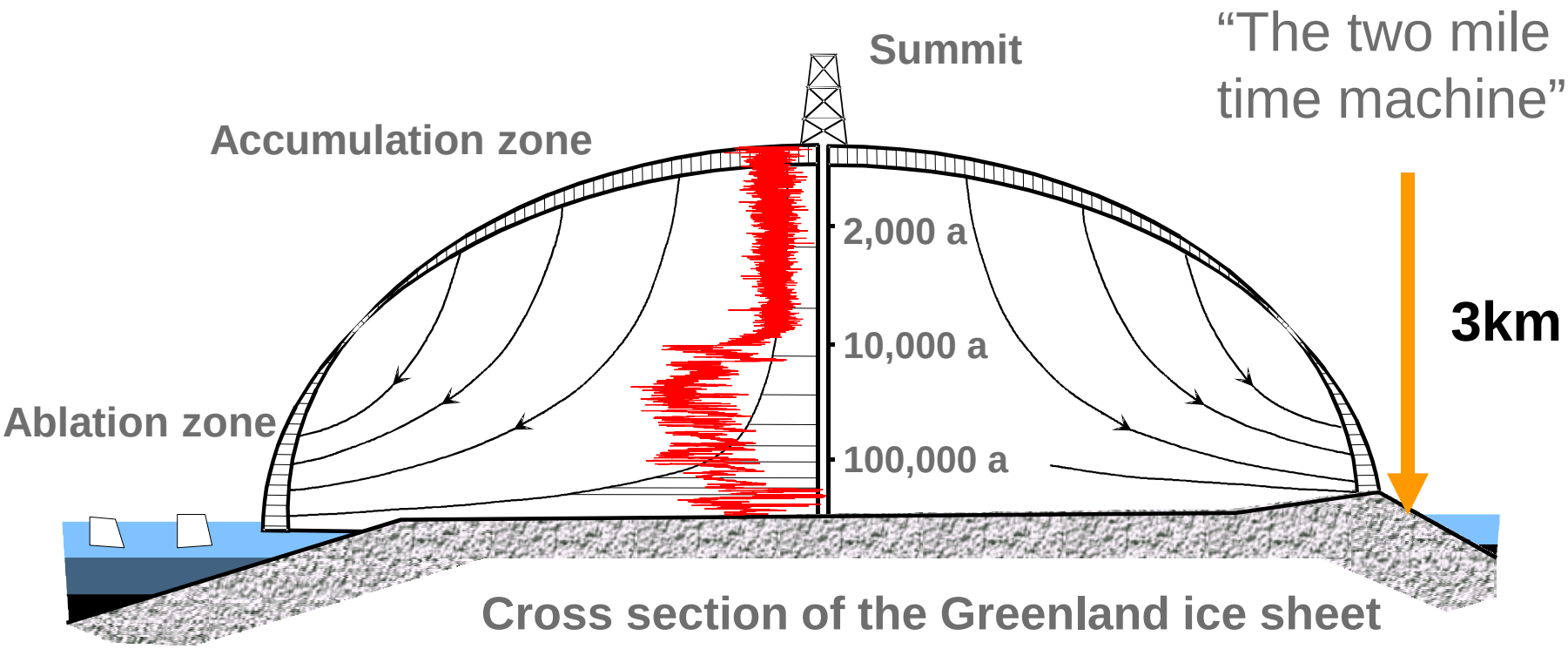
after Zachos et al., 2001

Ice archives on earth

CENTRE FOR ICE AND CLIMATE

Region	Ice volume	Instantanious sea level rise
	[km^3]	[m]
Glaciers	180'000	0.45
Greenland	2'620'000	6.55
Antarctica	**30'109'800**	**73.44**
Total	**32'909'800**	**80.44**



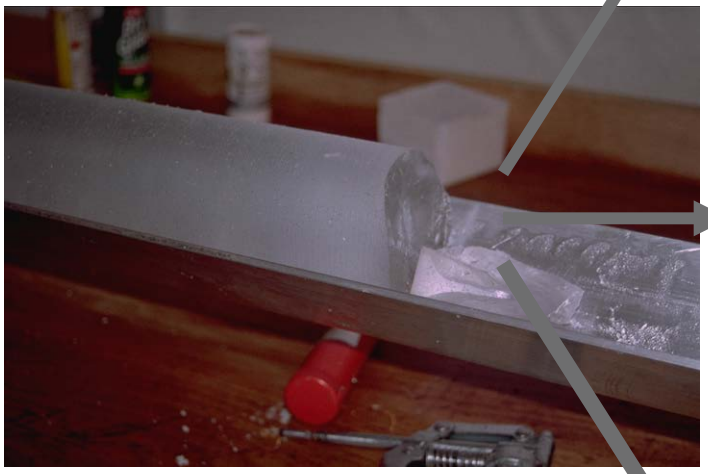


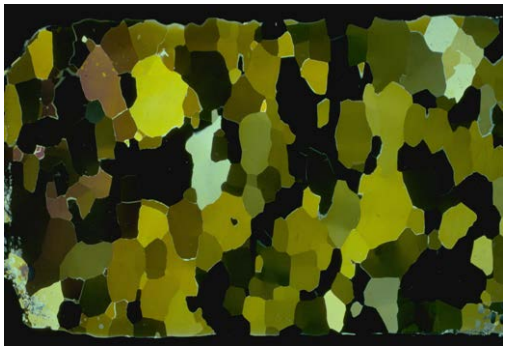
"The two mile time machine"

Continuous climate records

Greenland: ~120,000 years

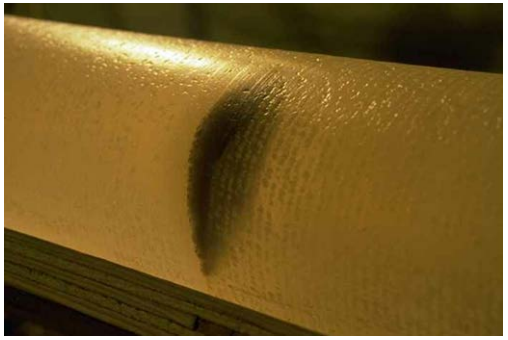
Antarctica: ~800,000 years





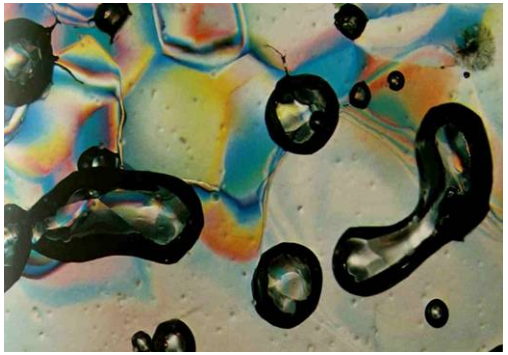
Precipitation

Water



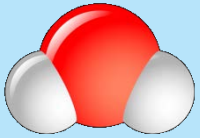
Whatever is

Trapped in the Ice



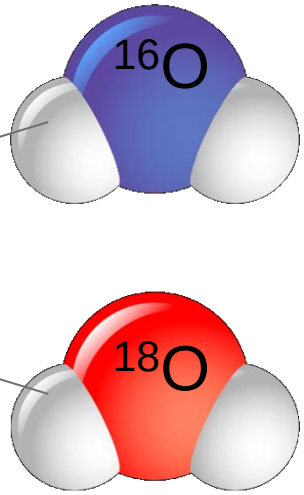
Air bubbles

Isotope thermometer



CENTRE FOR ICE AND CLIMATE

Name	Abundance
$H_2{}^{16}O$	99.76%
$H_2{}^{18}O$	0.205%



$$\delta^{18}O\ [‰] = \left(\frac{{}^{18}R - {}^{18}R_{Std}}{{}^{18}R_{Std}} \right) \cdot 10^3 \ ; \qquad {}^{18}R = \frac{[18]}{[16]}$$

Proxy indicator for temperature (see next presentation)

Chemical impurities in ice cores

CENTRE FOR ICE AND CLIMATE

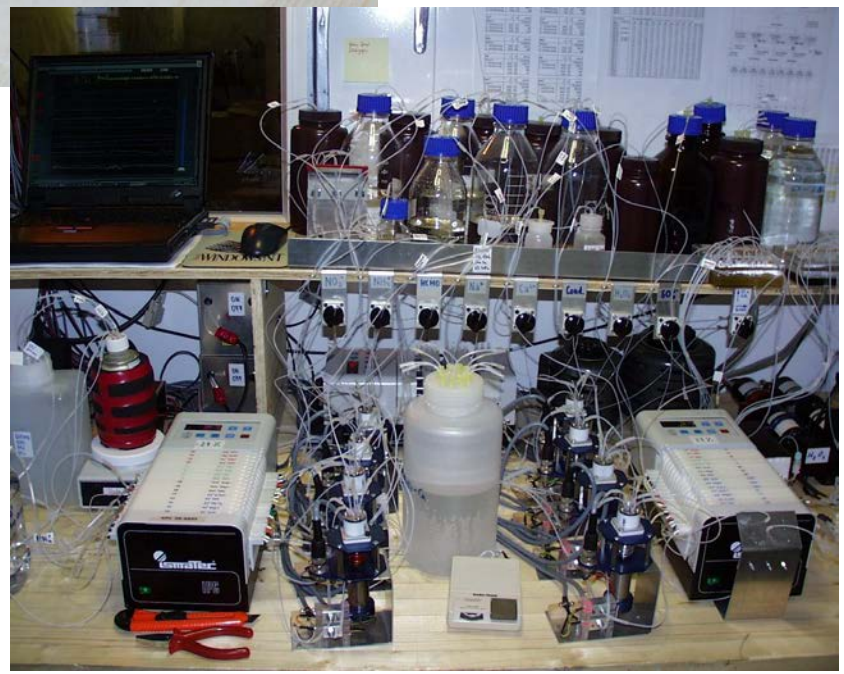
Na^+
Sodium

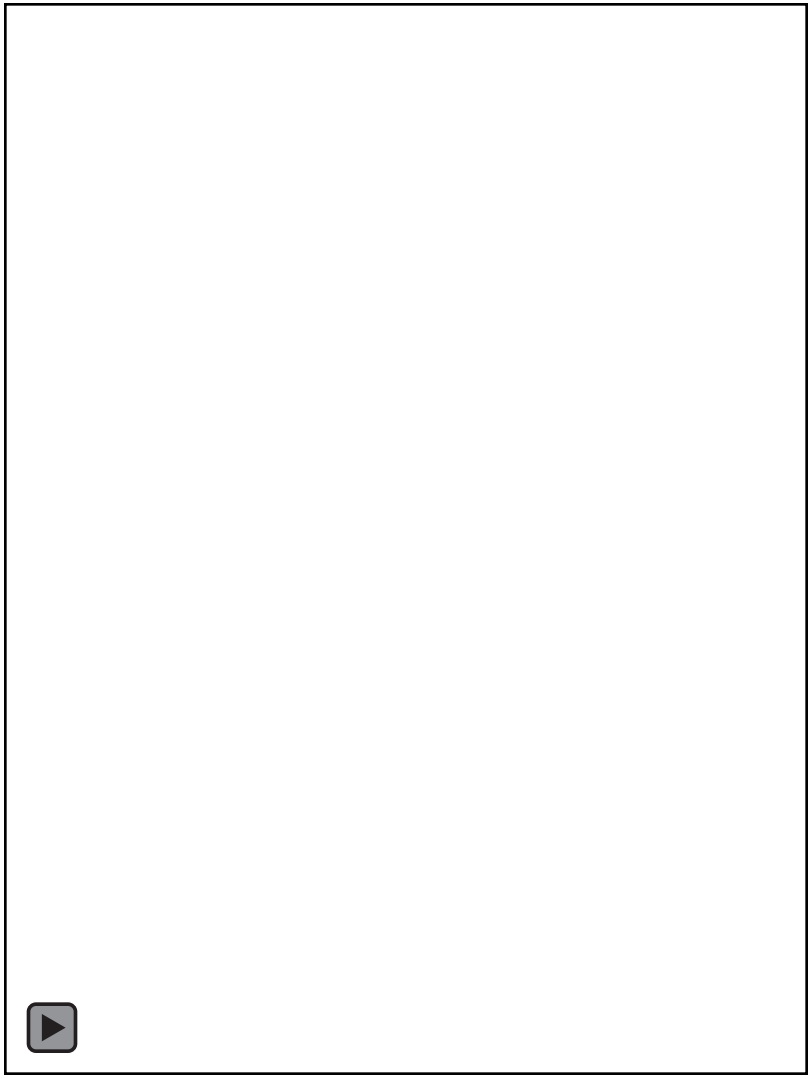
Ca^{2+}
Calcium

SO_4^{2-}
Sulfate

NH_4^+
Ammonium

NO_3^-
Nitrate



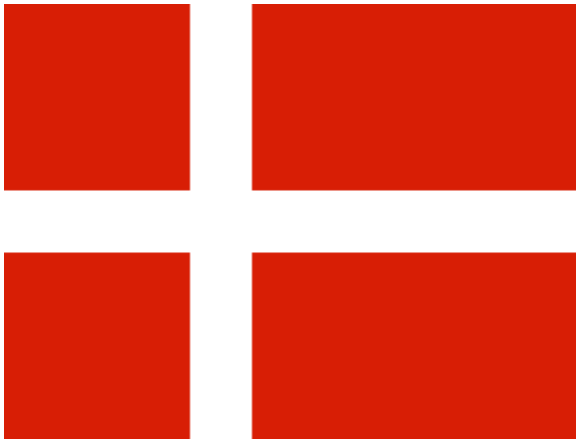


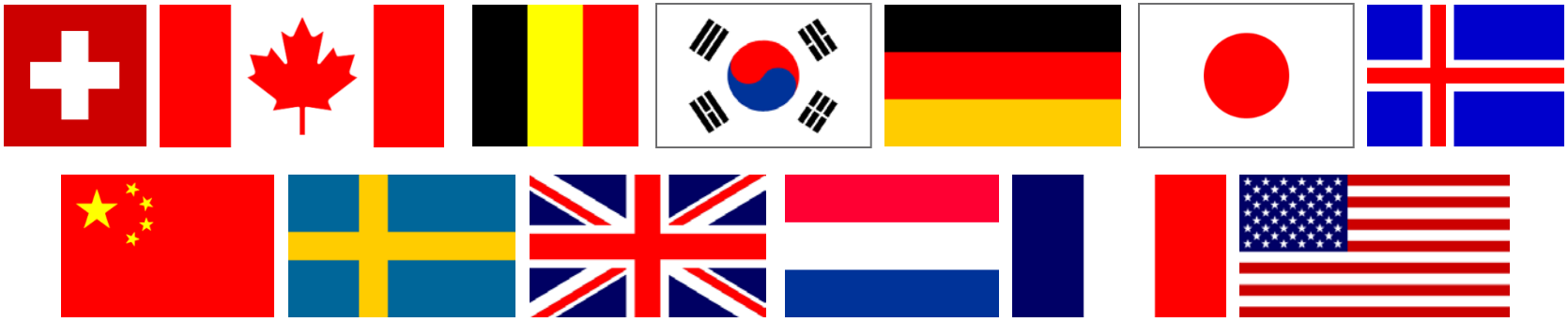
CENTRE FOR ICE AND CLIMATE

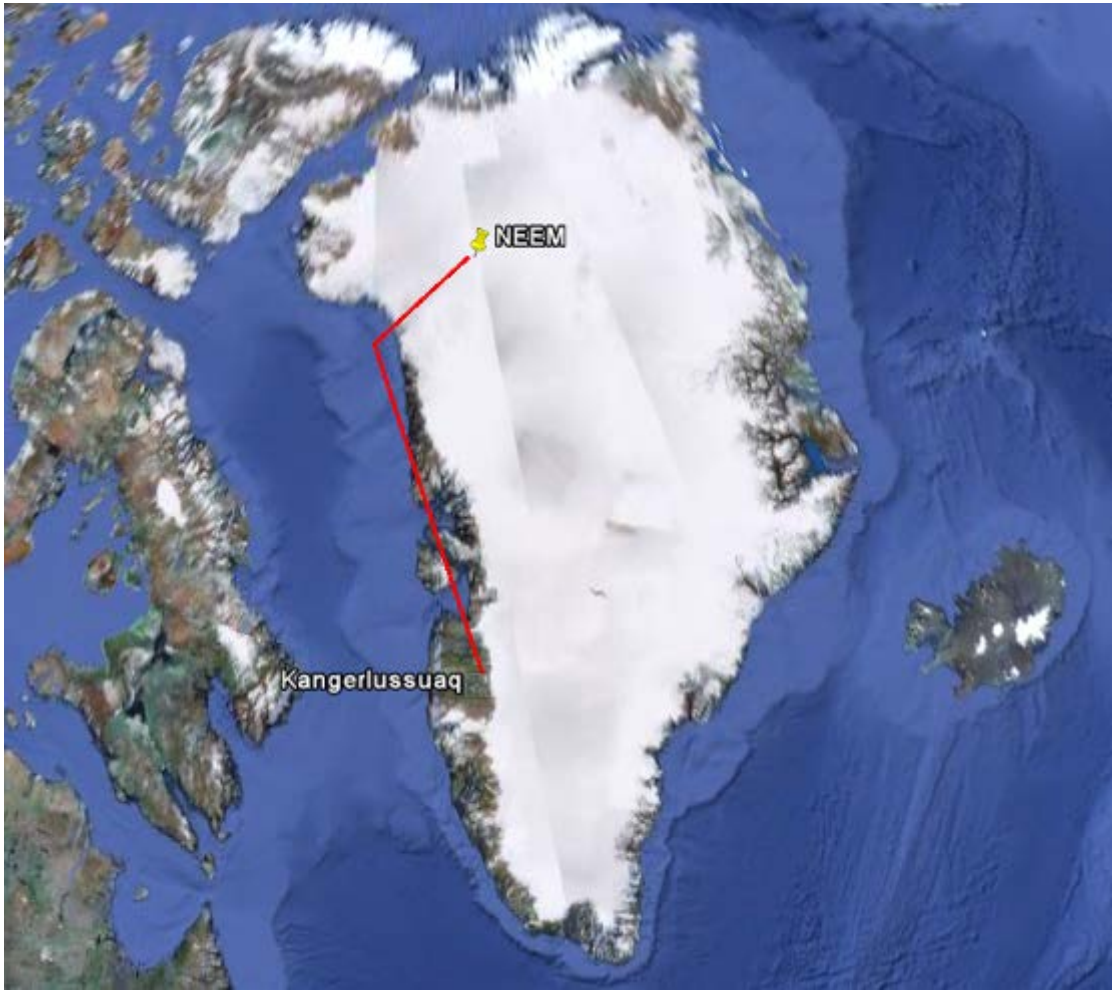
NEEM

77.43°N, 51.10°W

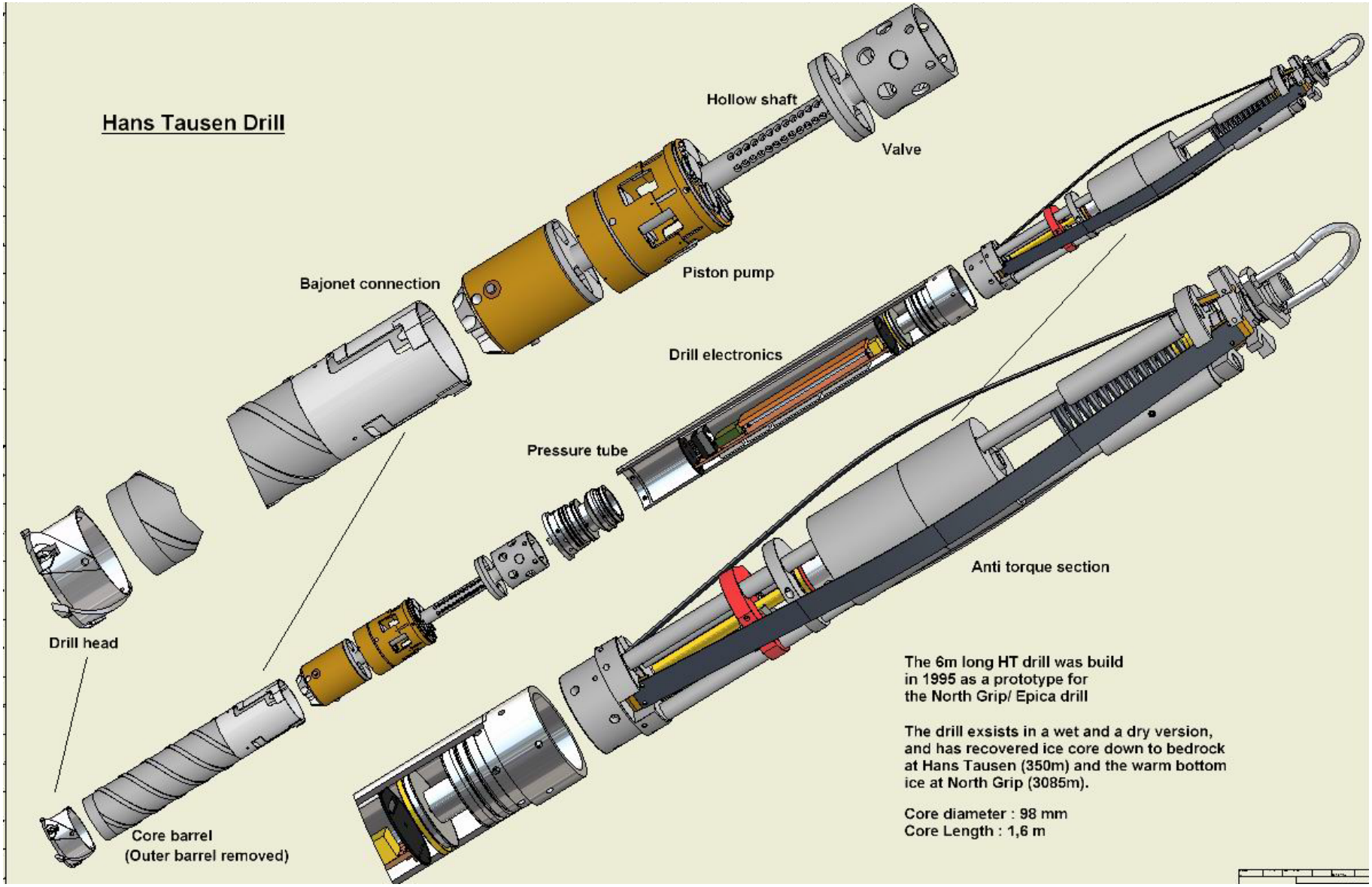
Bedrock has been reached Tuesday July 27, 2010 at the deep ice core drilling site NEEM on the Greenland Ice Sheet at the depth of 2537,36 m






NEEM
Kangerlussuaq

CENTRE FOR
ICE AND CLIMATE

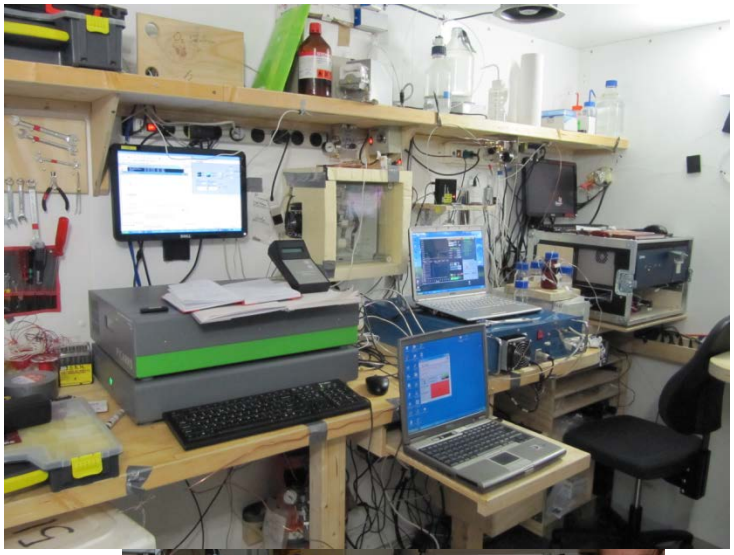

Hans Tausen Drill
Hollow shaft
Valve
Piston pump
Bajonet connection
Drill electronics
Pressure tube
Anti torque section
Drill head
Core barrel
(Outer barrel removed)
The 6m long HT drill was build in 1995 as a prototype for the North Grip/ Epica drill
The drill exsists in a wet and a dry version, and has recovered ice core down to bedrock at Hans Tausen (350m) and the warm bottom ice at North Grip (3085m).
Core diameter : 98 mm
Core Length : 1,6 m

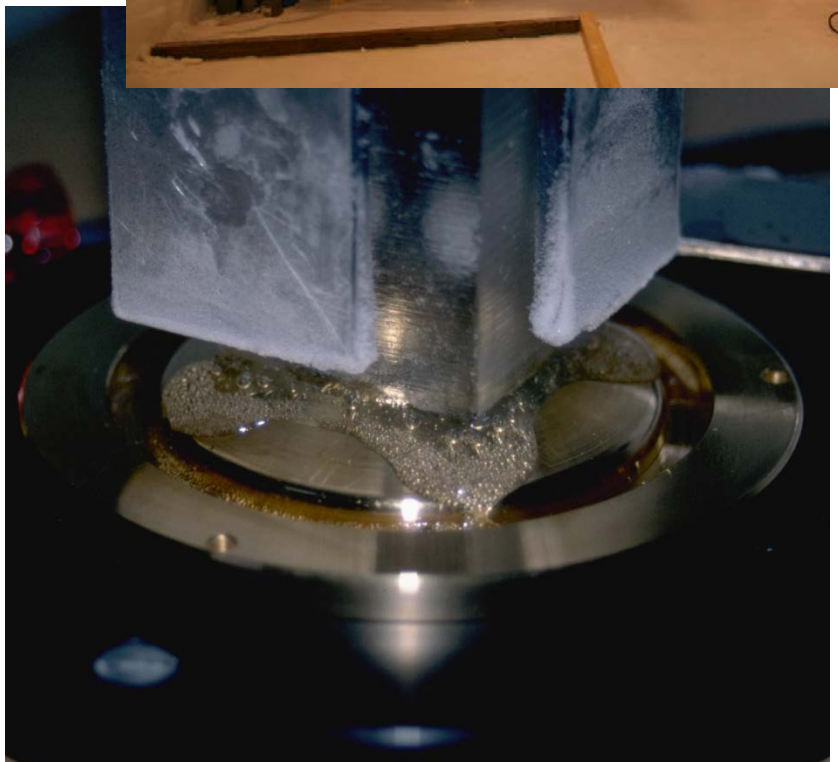

HEMA

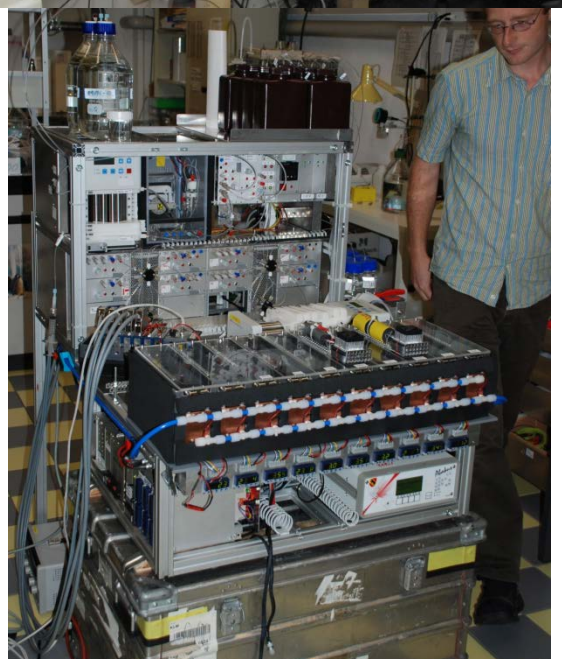

HEMA

Continuous chemistry measurements

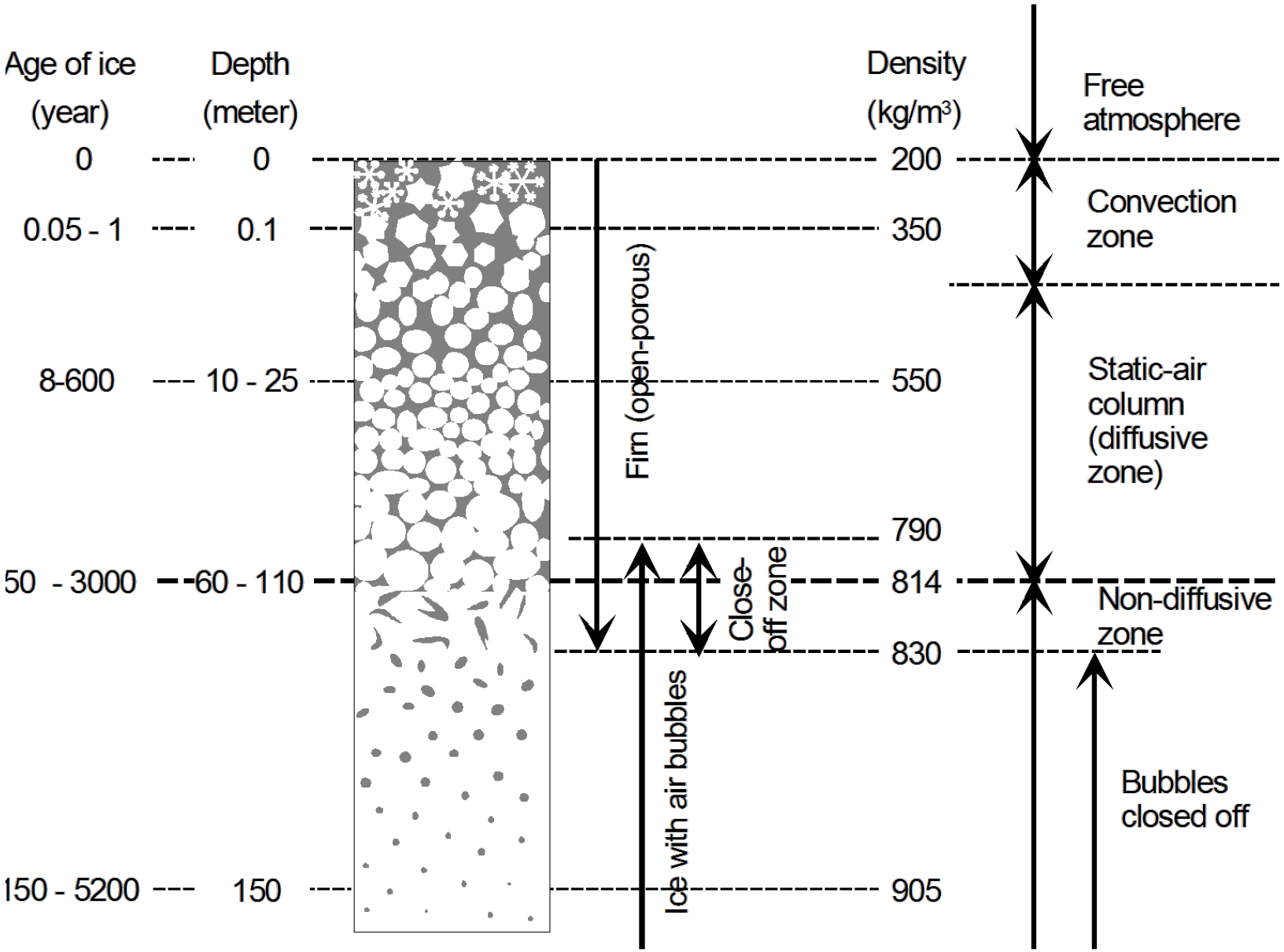
CENTRE FOR ICE AND CLIMATE

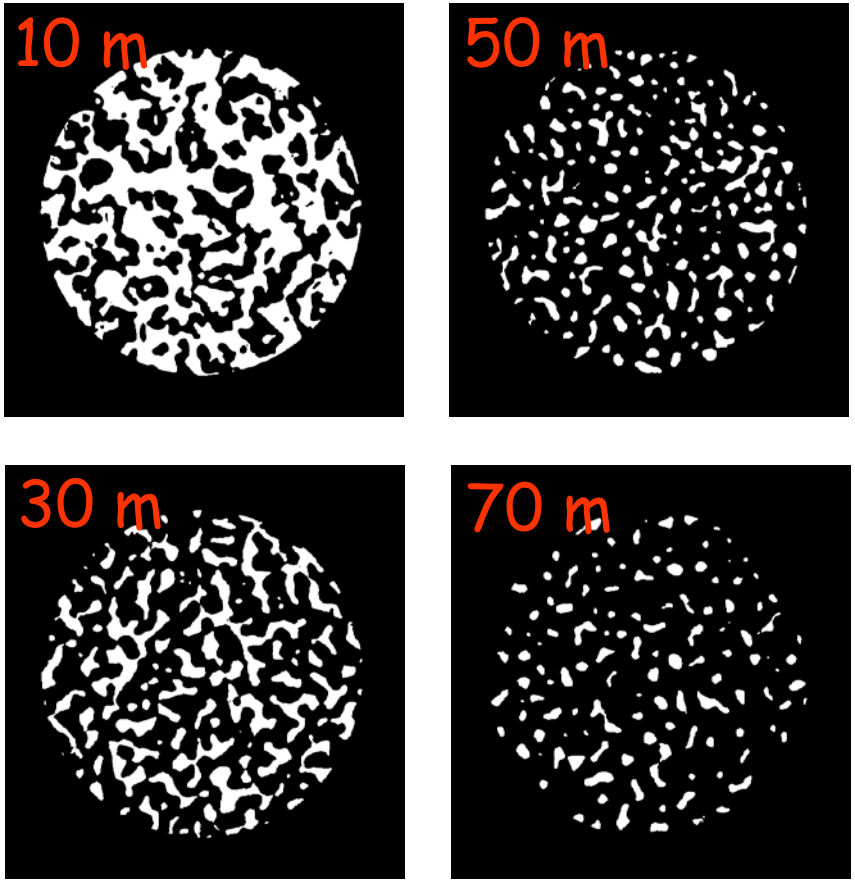




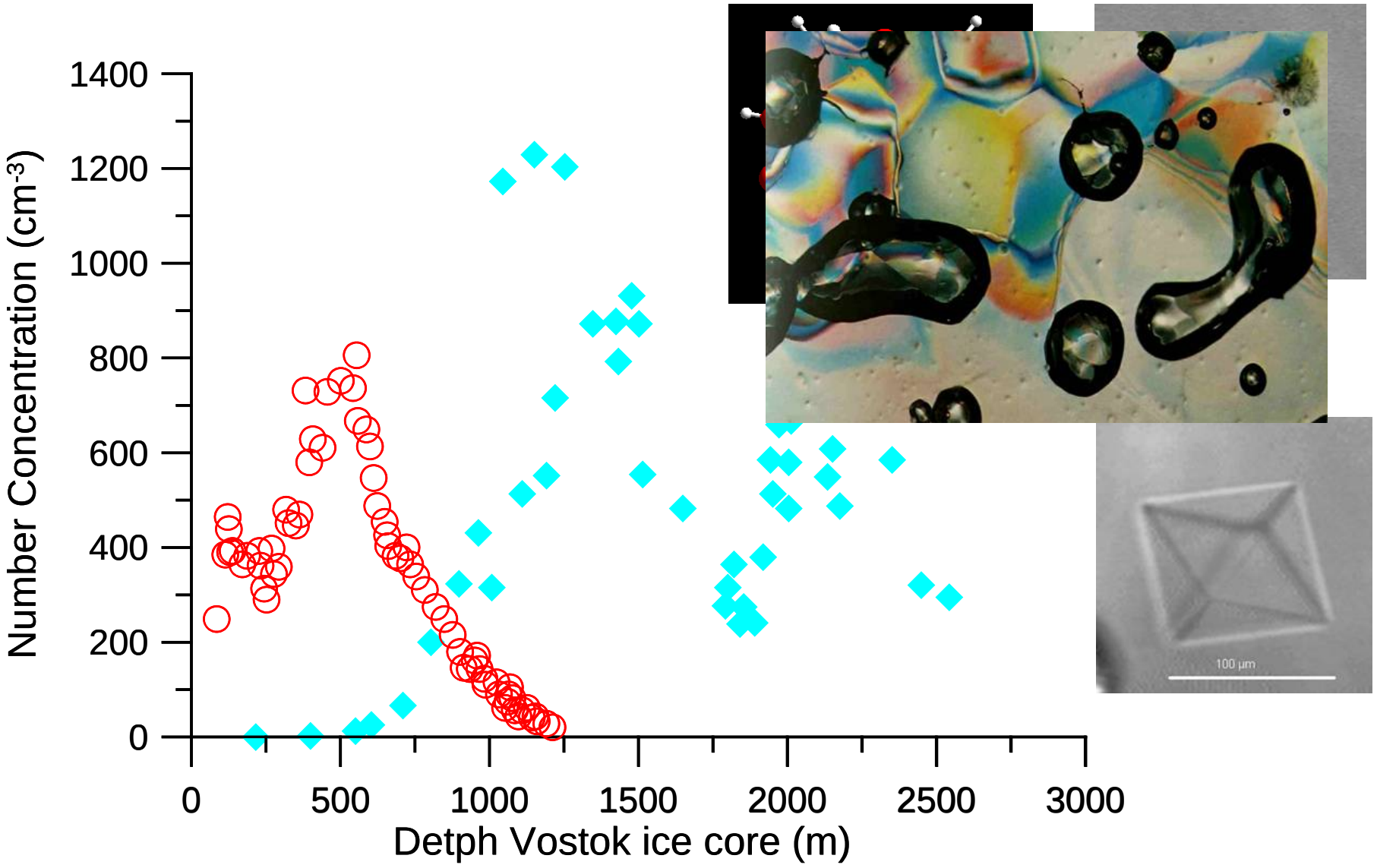


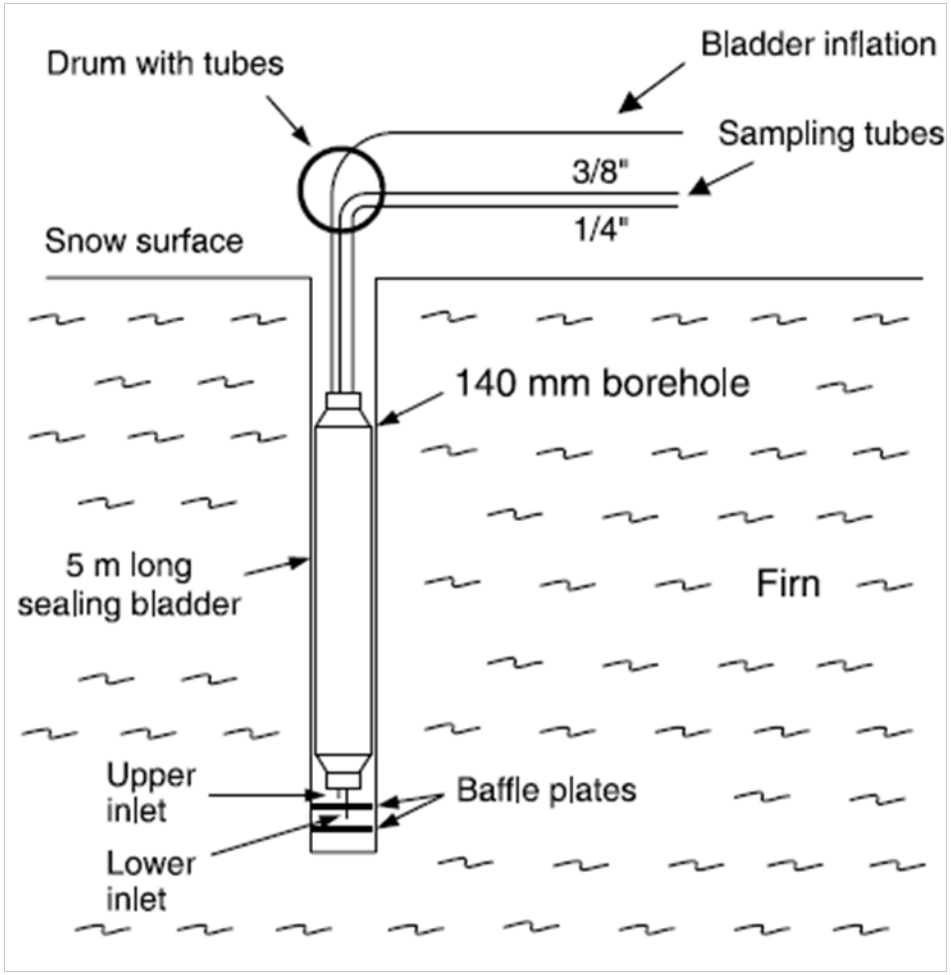
Gas occlusion

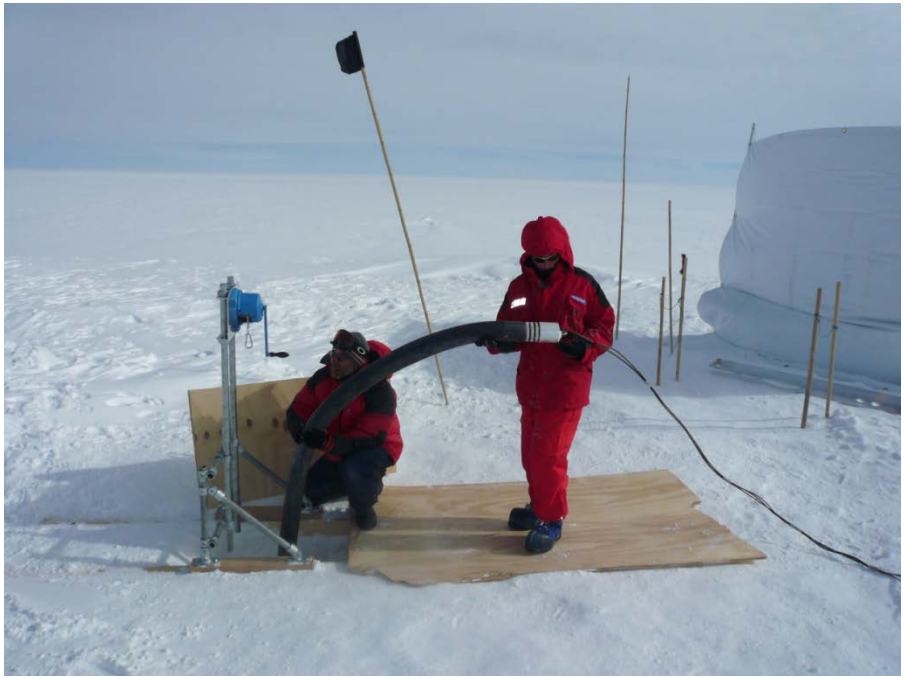




Pore space in polar firn. White: pores.
(B33 Dronning Maudland, Antarctica)
Johannes Freitag, AWI, not published


Number Concentration (cm-3)
1400
1200
1000
800
600
400
200
0
0
500
1000
1500
2000
2500
3000
Detph Vostok ice core (m)
100 µm

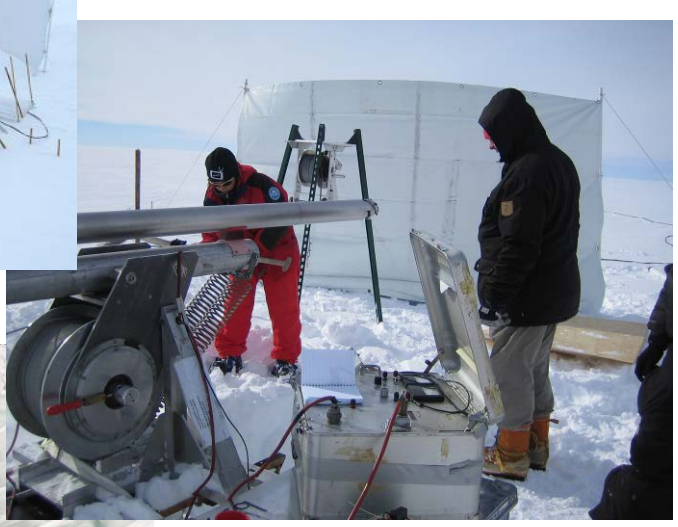

Drum with tubes
Bladder inflation
Sampling tubes
3/8"
1/4"
Snow surface
140 mm borehole
5 m long
sealing bladder
Firn
Upper
inlet
Baffle plates
Lower
inlet

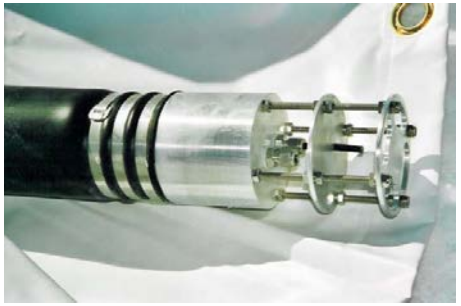


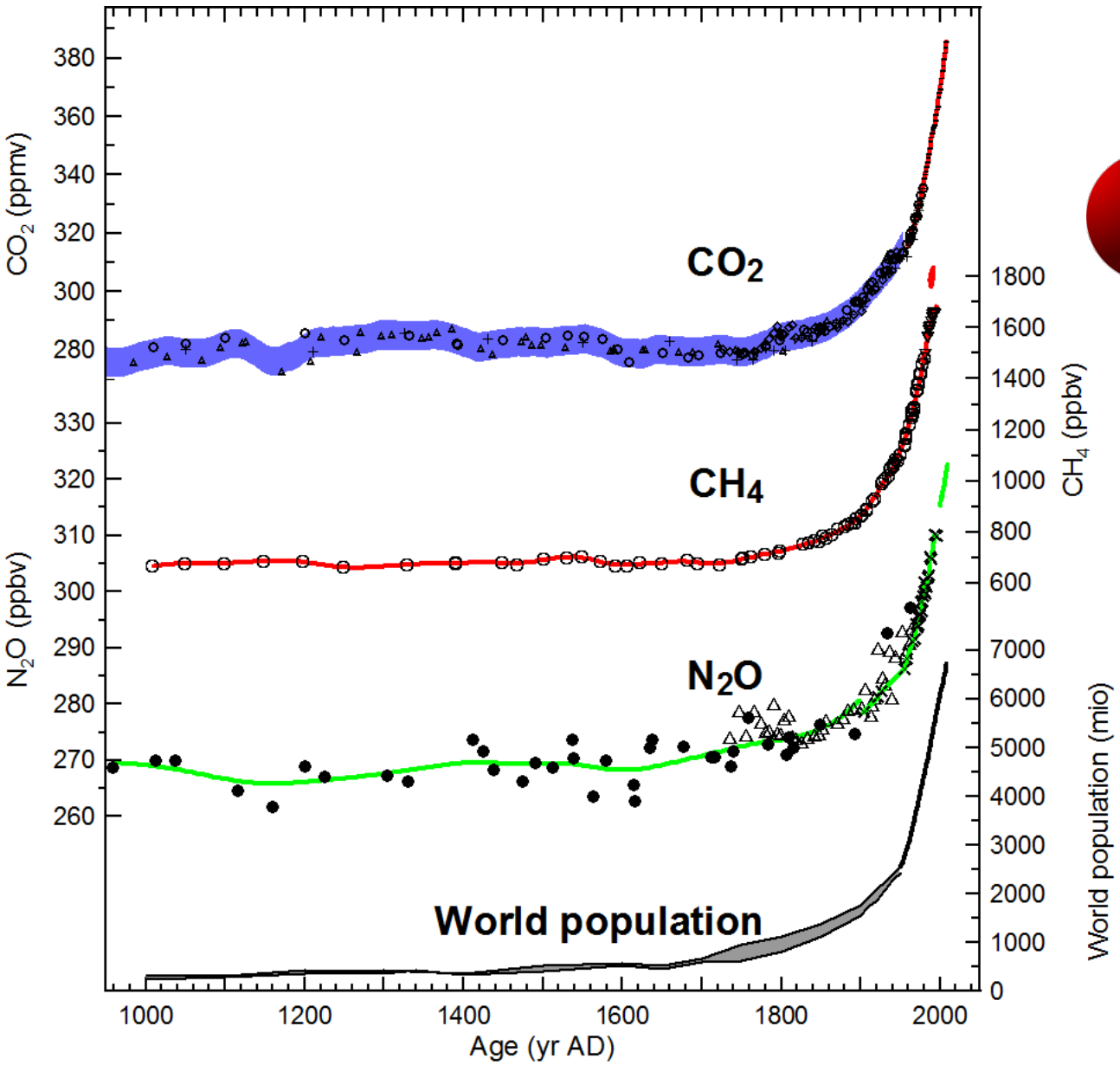
NEEM 2008

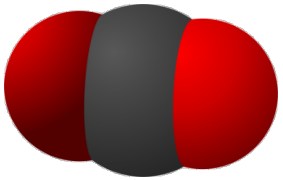
Firn gas sampling NEEM 2008

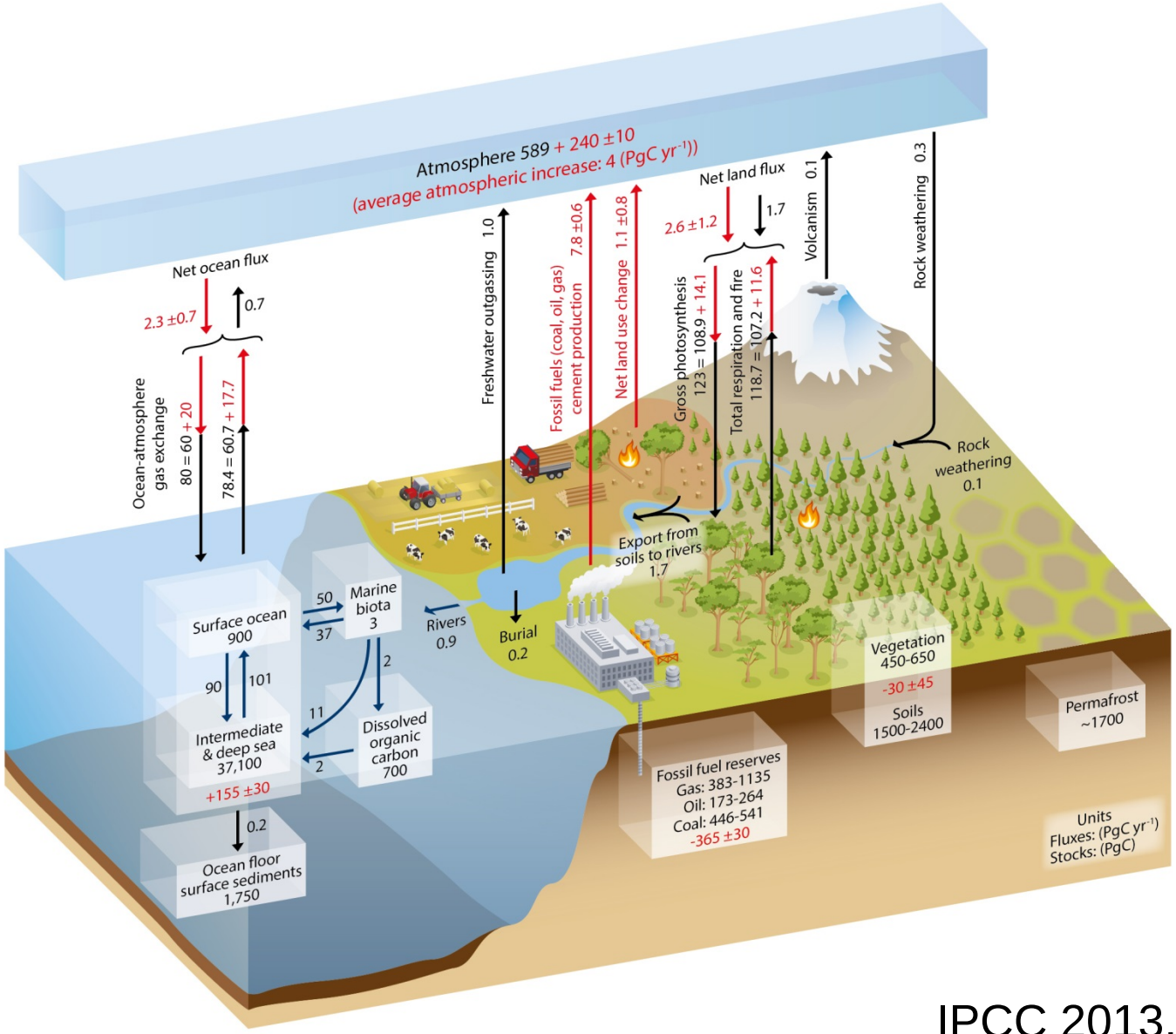
CENTRE FOR ICE AND CLIMATE





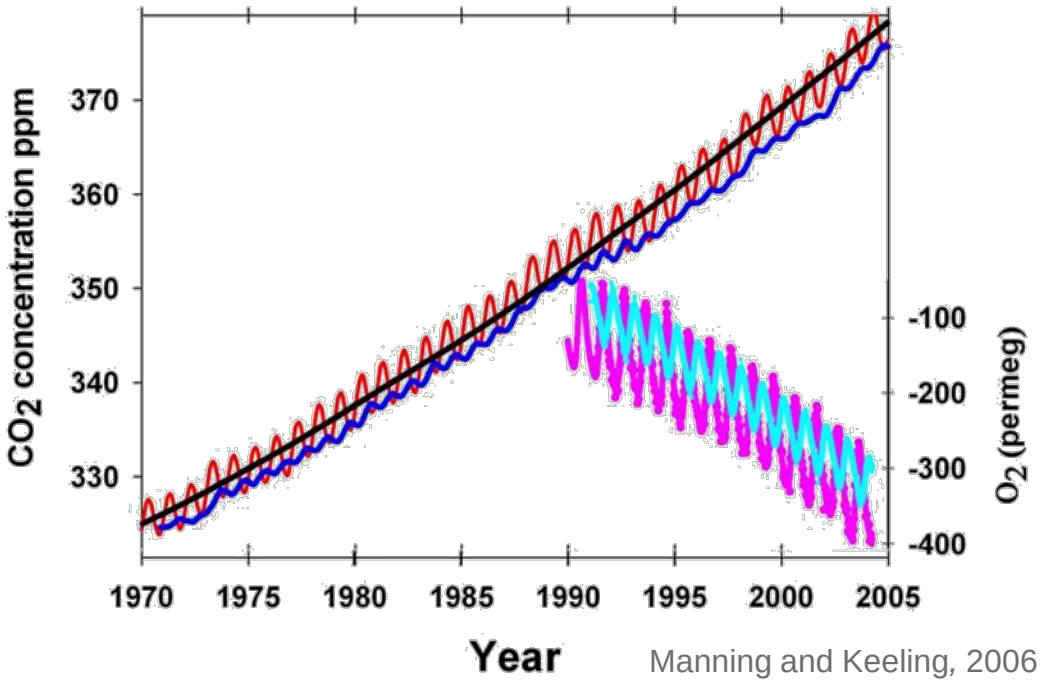

CO2 (ppmv)
380
360
340
320
300
280
CO2
CH4
330
320
310
300
290
280
270
260
N2O (ppbv)
N2O
World population
1800
1600
1400
1200
1000
800
600
7000
6000
5000
4000
3000
2000
1000
0
CH4 (ppbv)
World population (mio)
1000
1200
1400
1600
1800
2000
Age (yr AD)





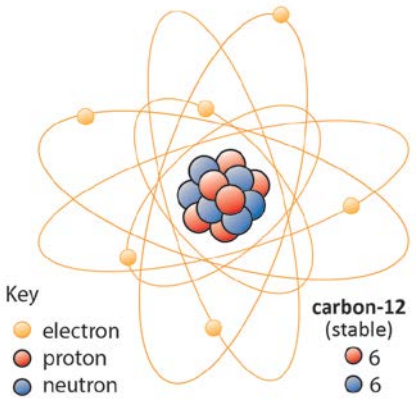
IPCC 2013, Figure 6.1

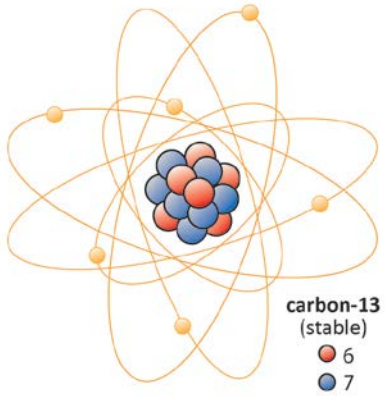
CO_2 <-> O_2

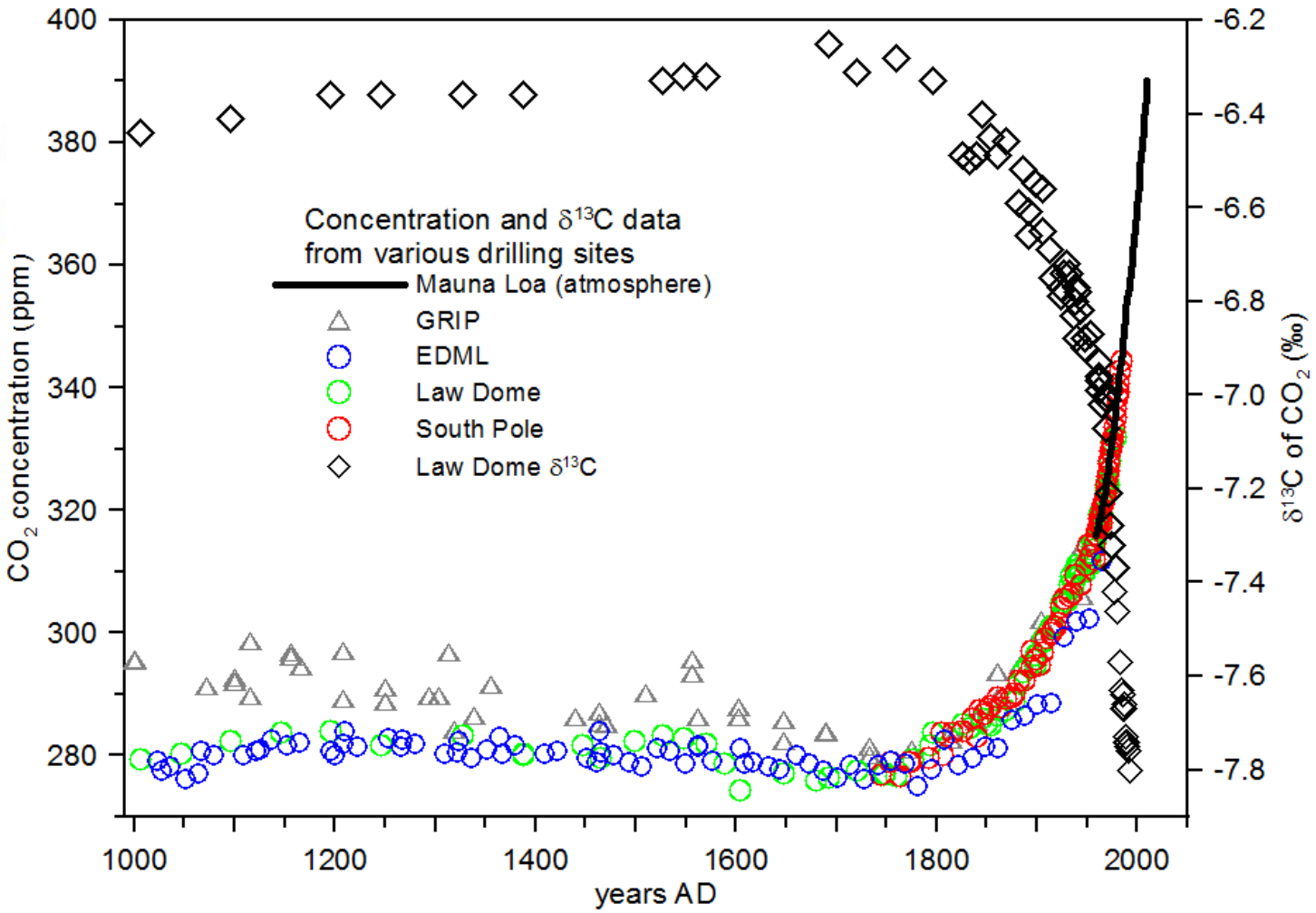


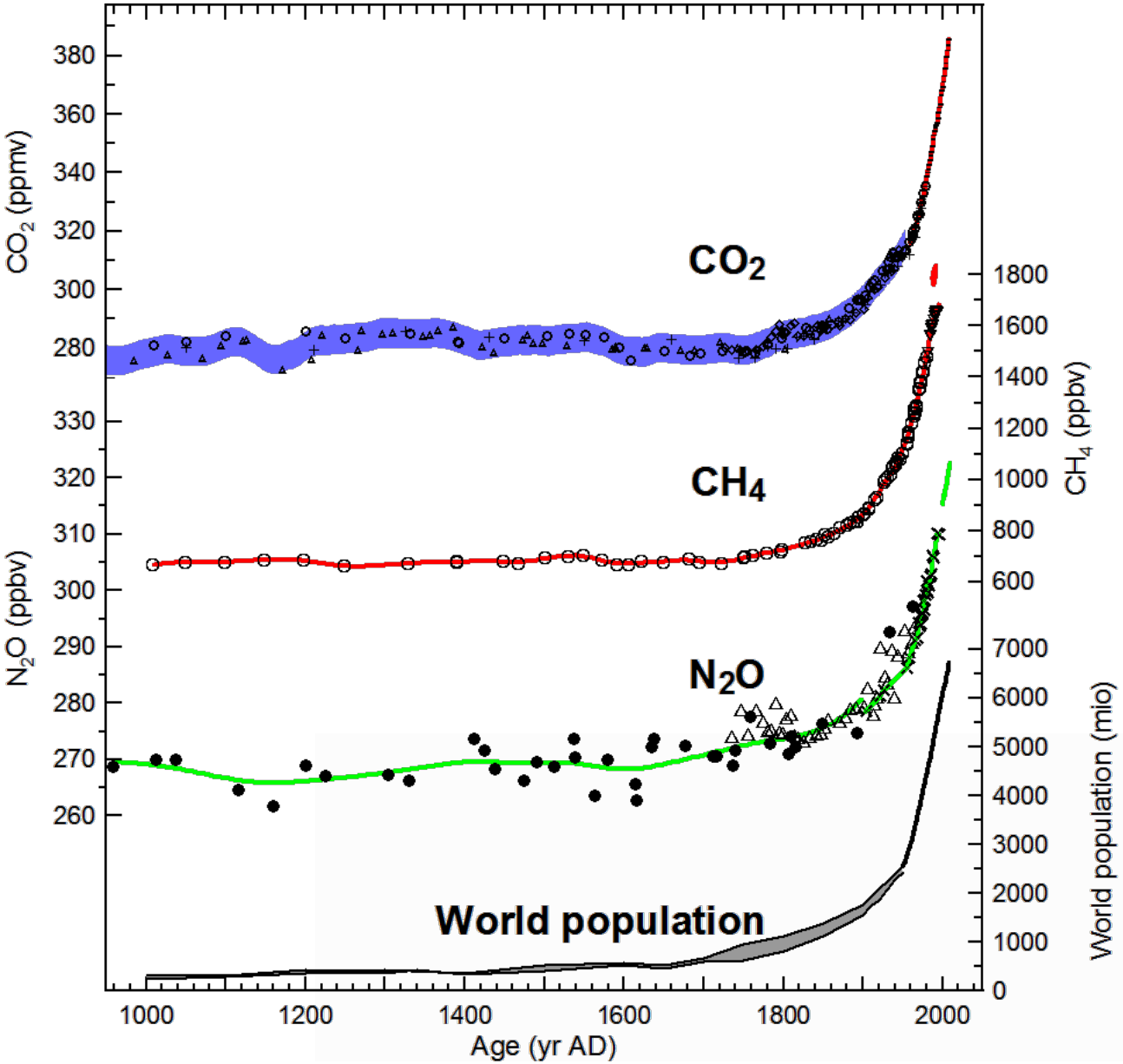
Manning and Keeling, 2006

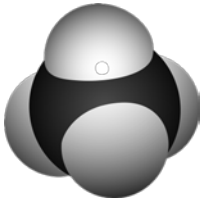
$$C_6H_{12}O_6 + 6O_2 \underset{\text{Photosynthese}}{\overset{\text{Respiration}}{\rightleftharpoons}} 6CO_2 + 6H_2O$$


Key
electron
proton
neutron
carbon-12
(stable)
6
6

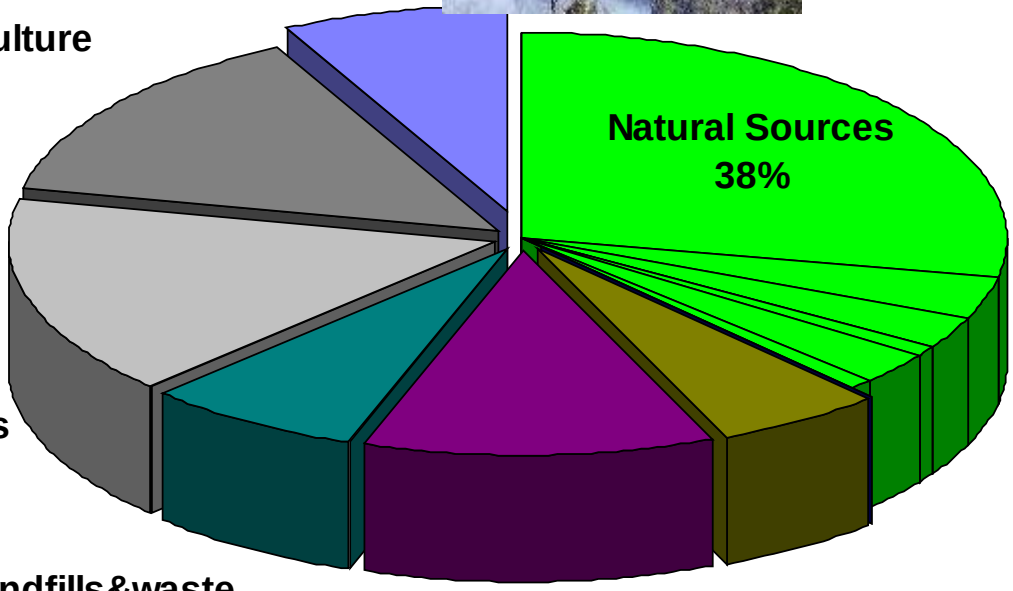

carbon-13
(stable)
6
7

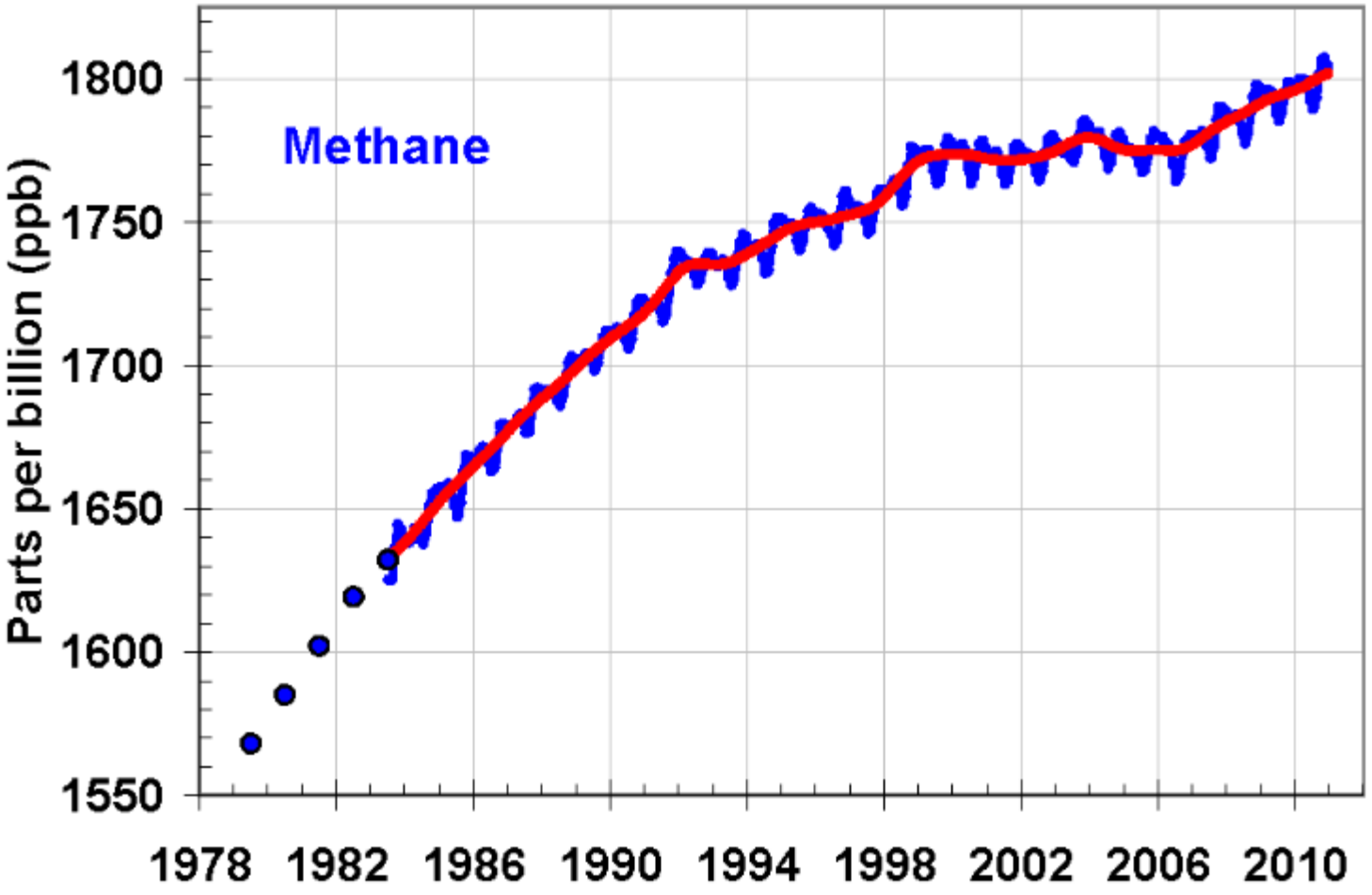

Concentration and δ13C data
from various drilling sites
Mauna Loa (atmosphere)
GRIP
EDML
Law Dome
South Pole
Law Dome δ13C
CO2 concentration (ppm)
δ13C of CO2 (‰)
years AD
400
380
360
340
320
300
280
-6.2
-6.4
-6.6
-6.8
-7.0
-7.2
-7.4
-7.6
-7.8
1000
1200
1400
1600
1800
2000

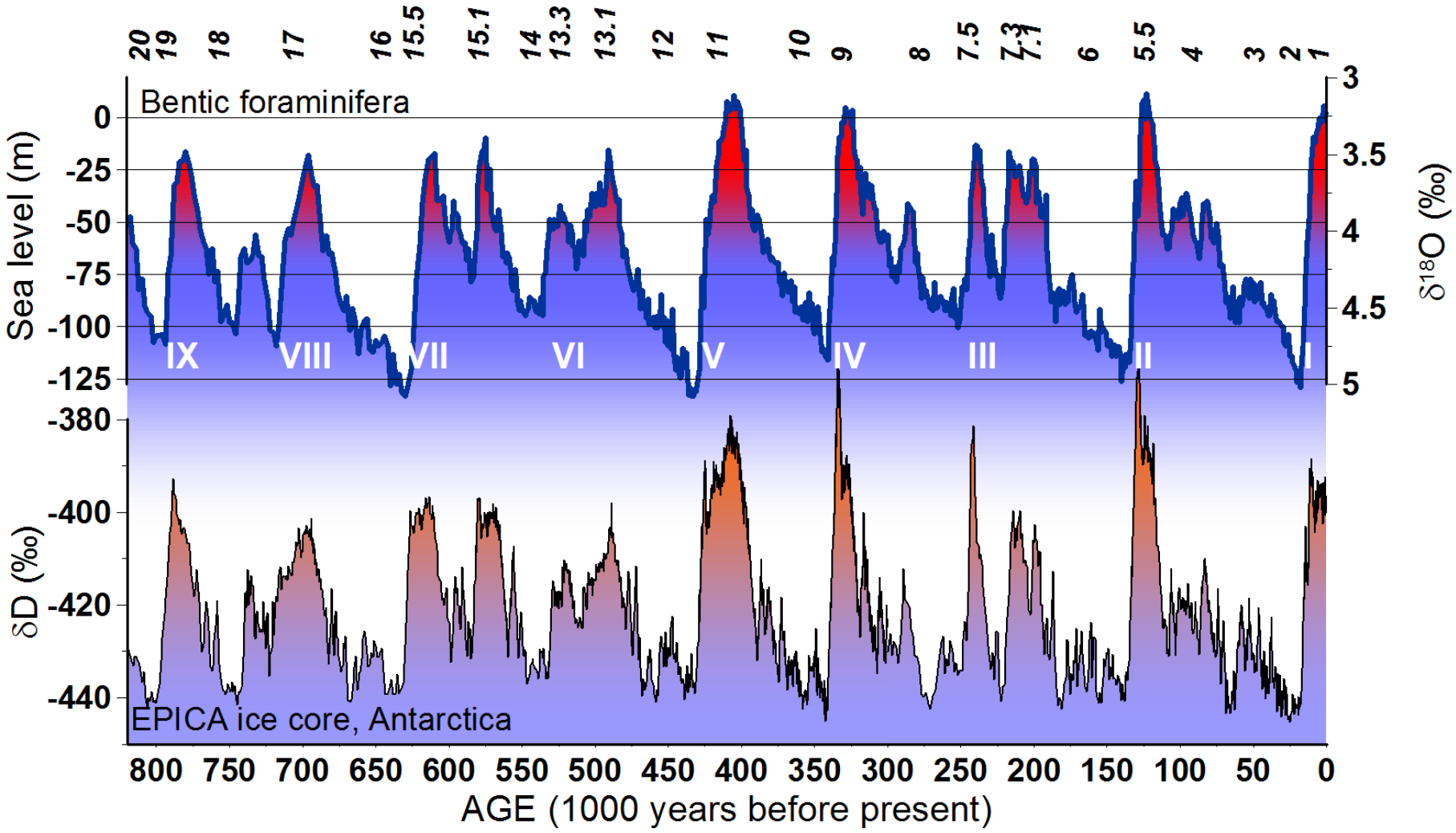

CO2 (ppmv)
380
360
340
320
300
280
CO2
CH4
330
320
310
300
290
280
270
260
N2O (ppbv)
N2O
World population
1800
1600
1400
1200
1000
800
600
7000
6000
5000
4000
3000
2000
1000
0
CH4 (ppbv)
World population (mio)
1000
1200
1400
1600
1800
2000
Age (yr AD)



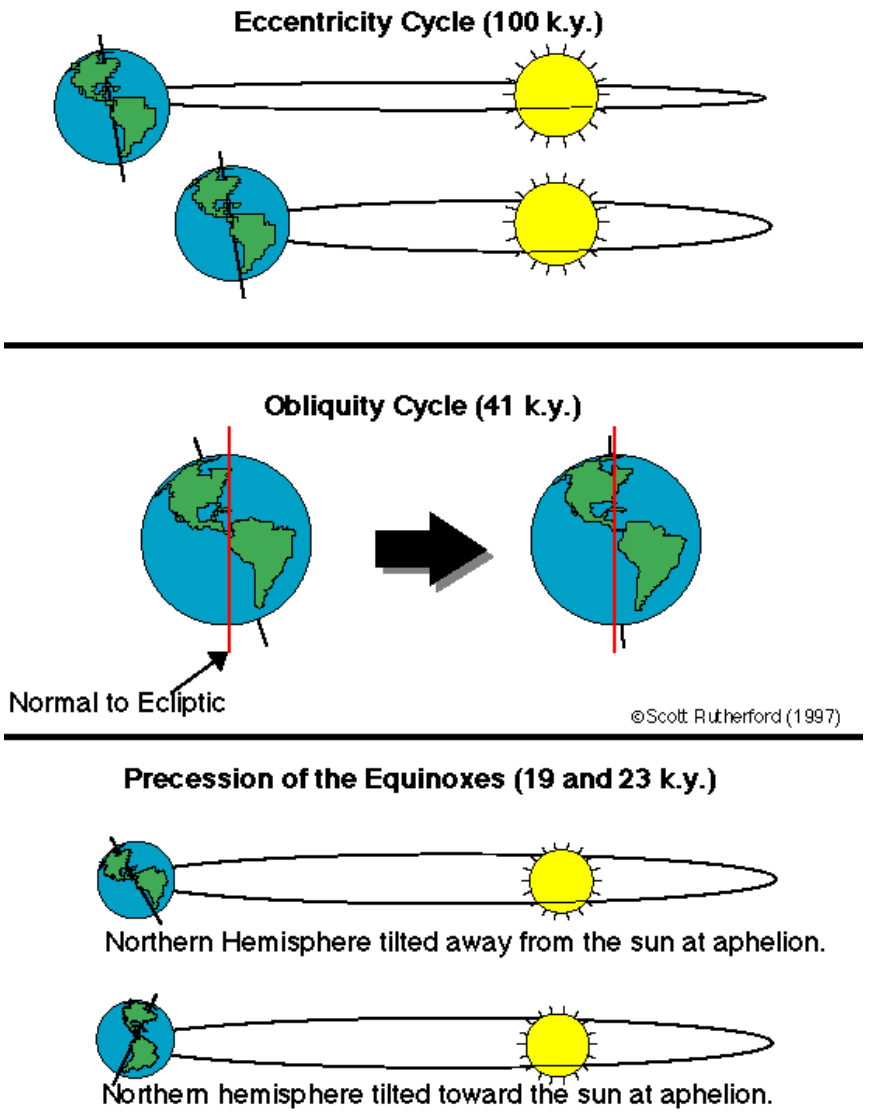
Anthropogenic methane sources

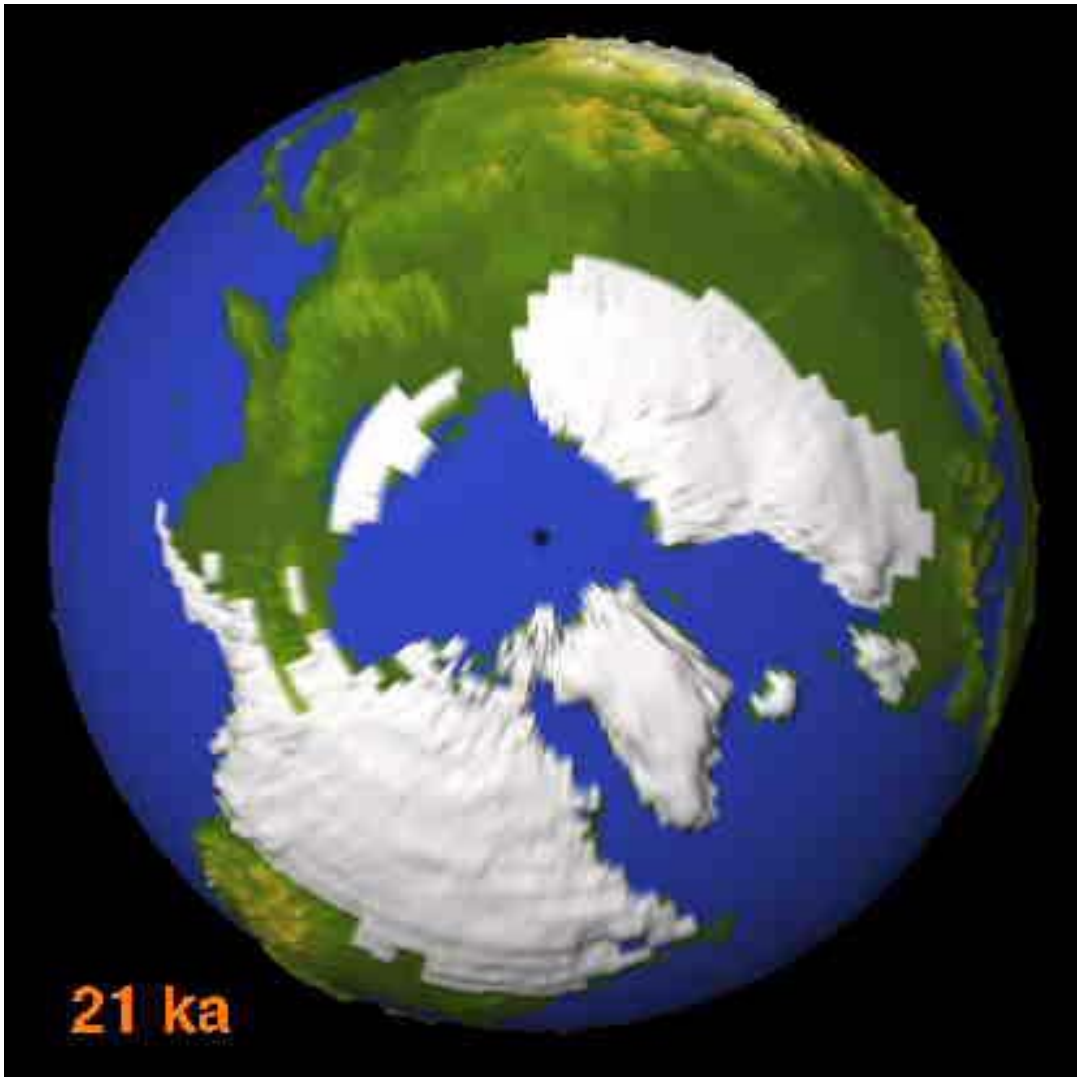



Methane
Parts per billion (ppb)
1800
1750
1700
1650
1600
1550
1978
1982
1986
1990
1994
1998
2002
2006
2010


20 19 18 17 16 15.5 15.1 14 13.3 13.1 12 11 10 9 8 7.5 7.3 7.1 6 5.5 4 3 2 1
Bentic foraminifera
Sea level (m)
0
-25
-50
-75
-100
-125
IX
VIII
VII
VI
V
IV
III
II
I
3
3.5
4
4.5
5
δ18O (‰)
-380
-400
-420
-440
δD (‰)
EPICA ice core, Antarctica
800 750 700 650 600 550 500 450 400 350 300 250 200 150 100 50 0
AGE (1000 years before present)

A large portion of the long term changes occurs on orbital frequencies.

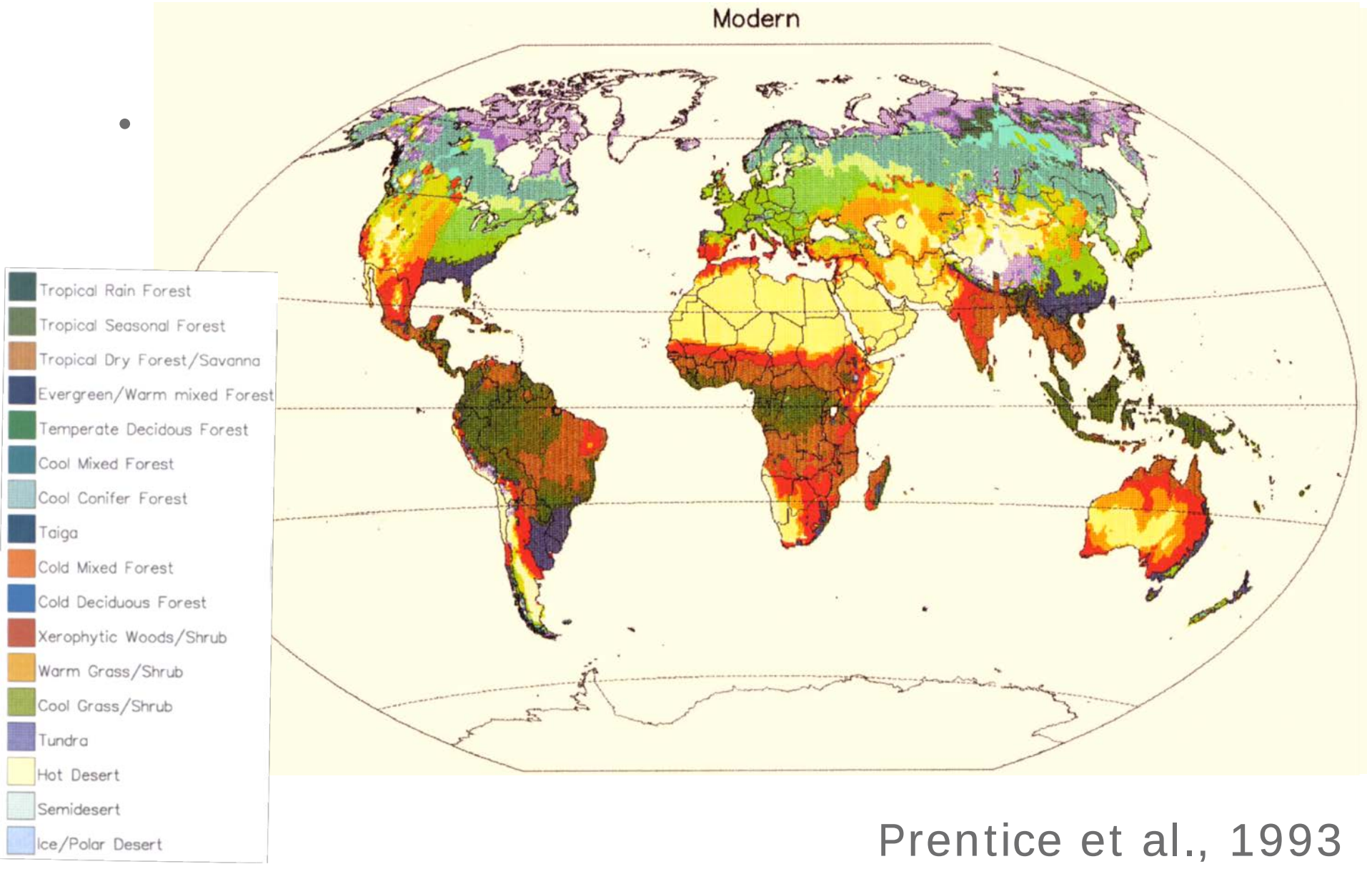




Based on Peltier

http://jesse.usra.edu/public/jesse_html

Distribution of vegetation zones



Prentice et al., 1993

The PIMP2 LGM model results (PIMP2 = Paleoclimate Modeling Intercomparison Project)

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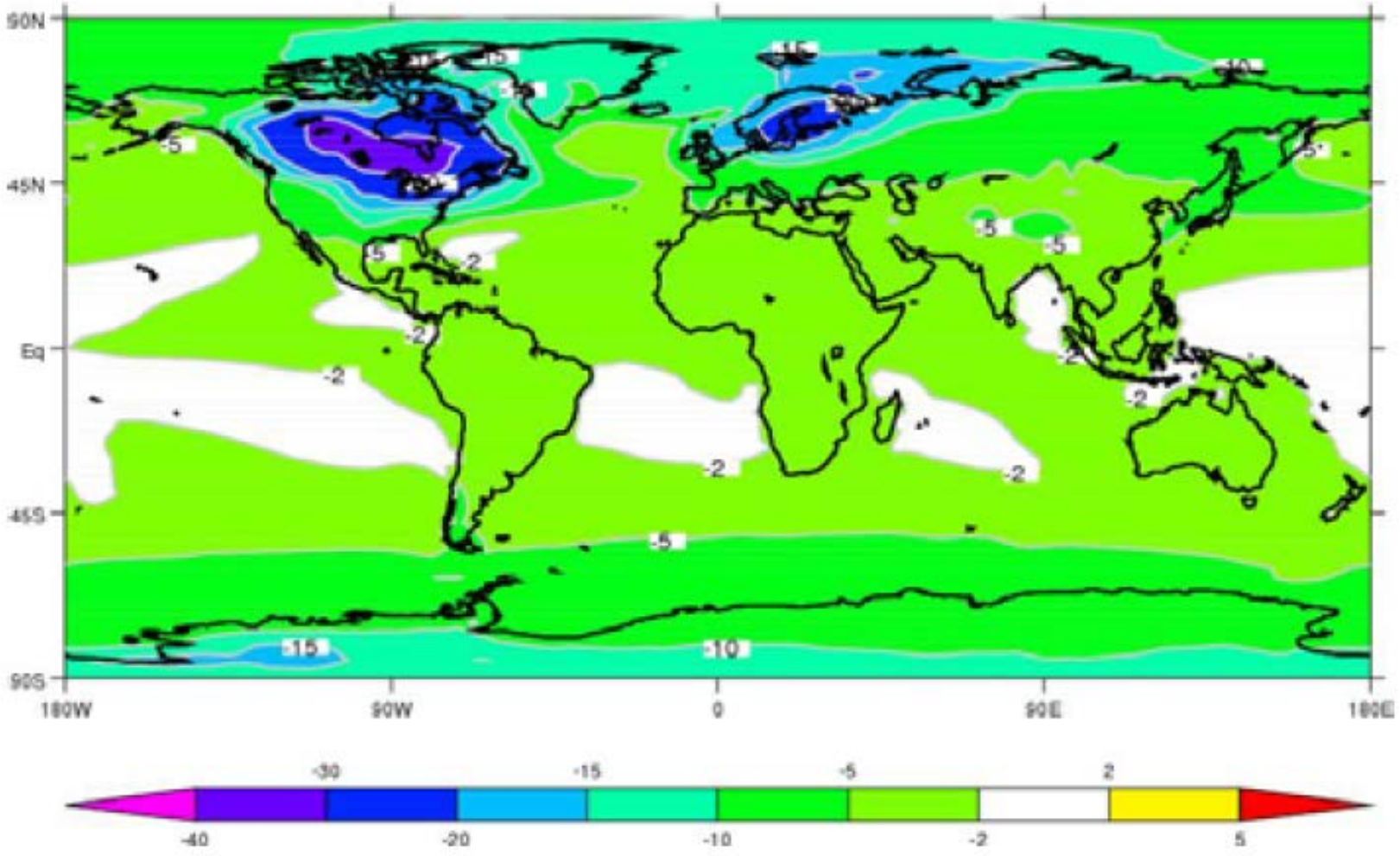
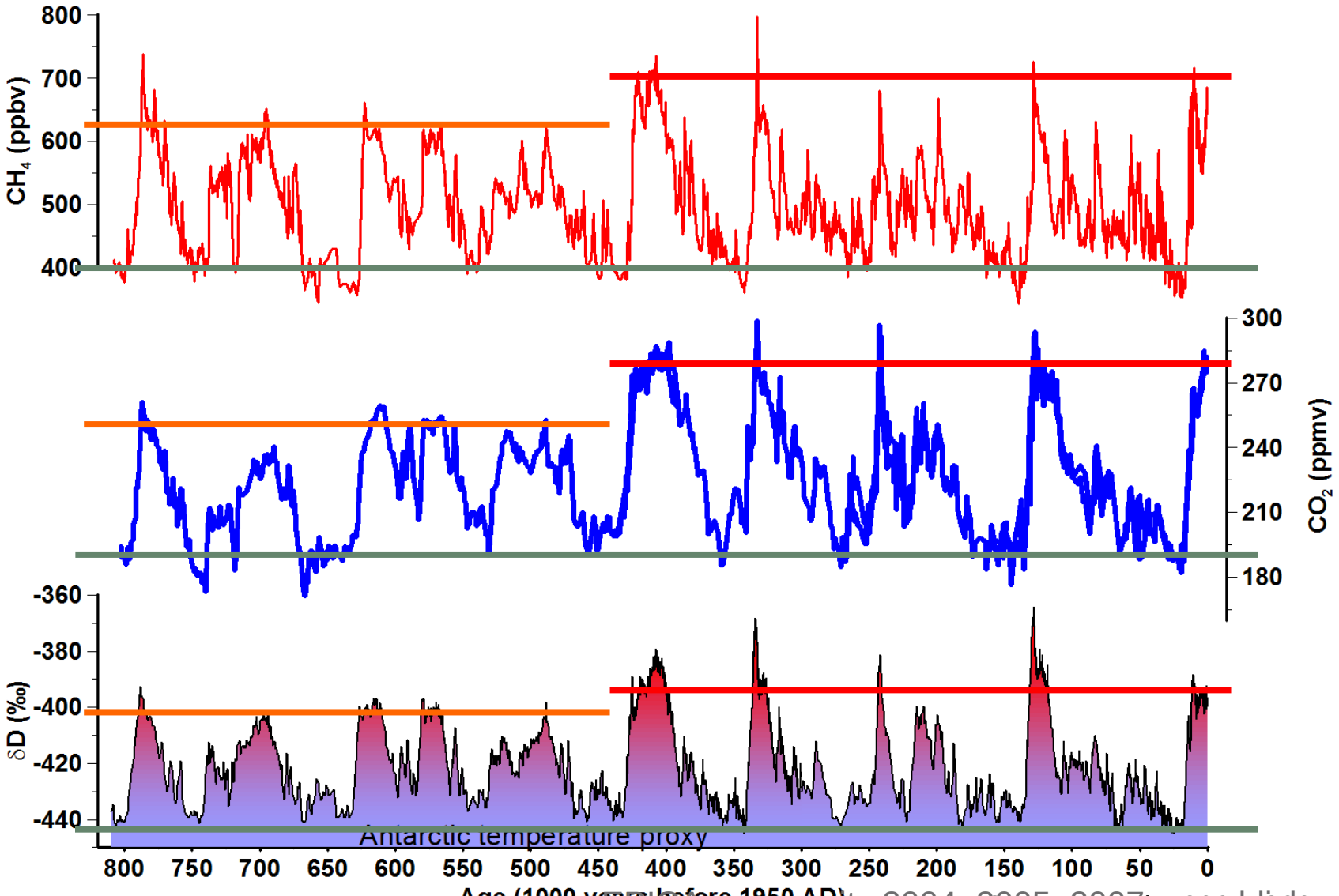


Annual mean LGM changes in temperature (°C)

Braconnot et al., Climate of the Past, 2007



EPICA community 2004, 2005, 2007 unpublished data

Comparison glacial vs. „today“

- Mean global temperature was 3 to 8°C lower.
- Huge ice masses on the North American continent and Europe.
- Sea level was about 120m lower
- Massive reduction of vegetation
- 30% Lower CO_2

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Ballpark numbers for glacial interglacial change

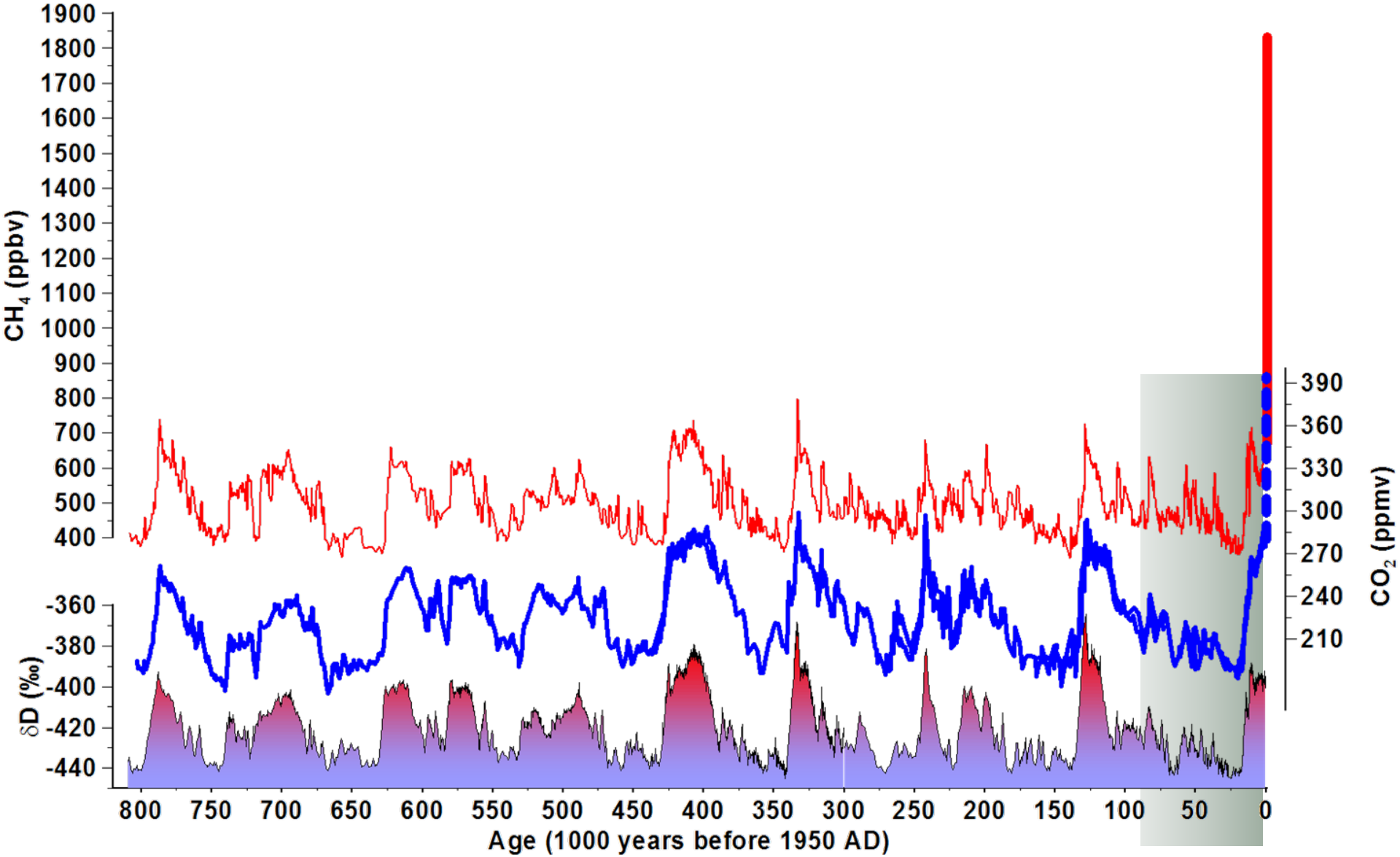
50% Greenhouse effect

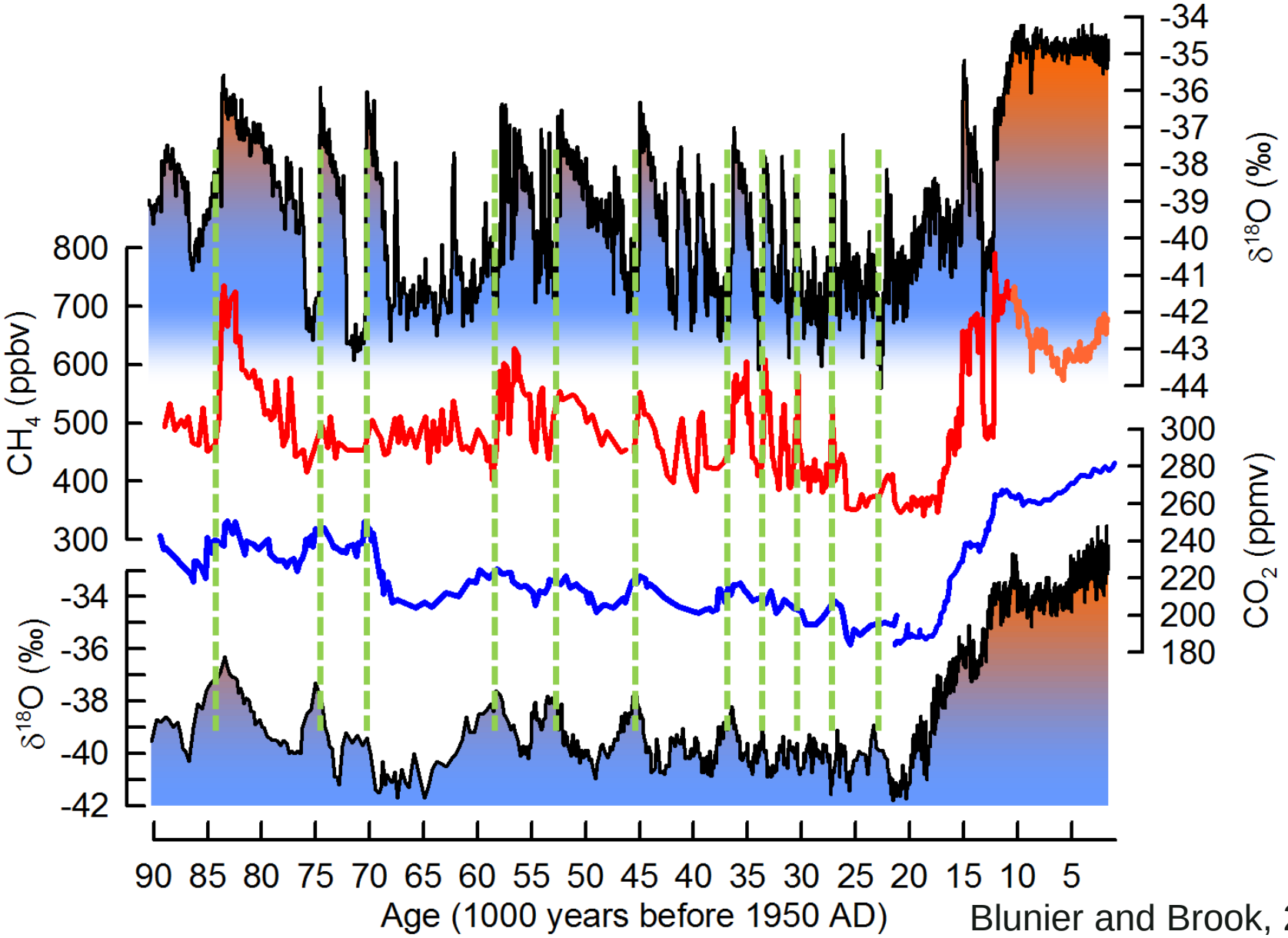
- Water vapor
- CO_2

50% Albedo

- Ice sheets
- Sea ice cover
- Vegetation
- Clouds

What about the trace gases?





Blunier and Brook, 2001

The great ocean conveyor belt

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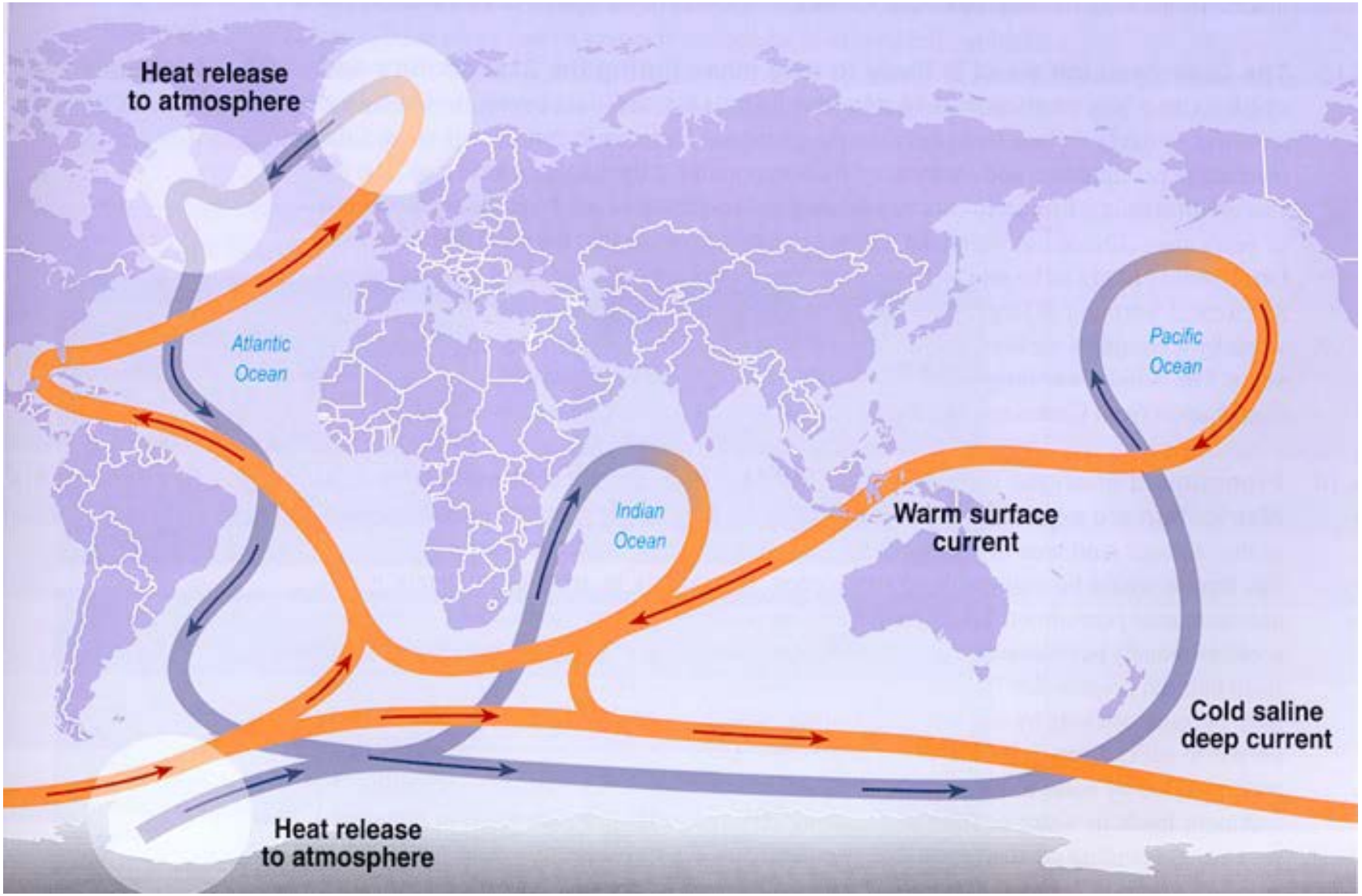
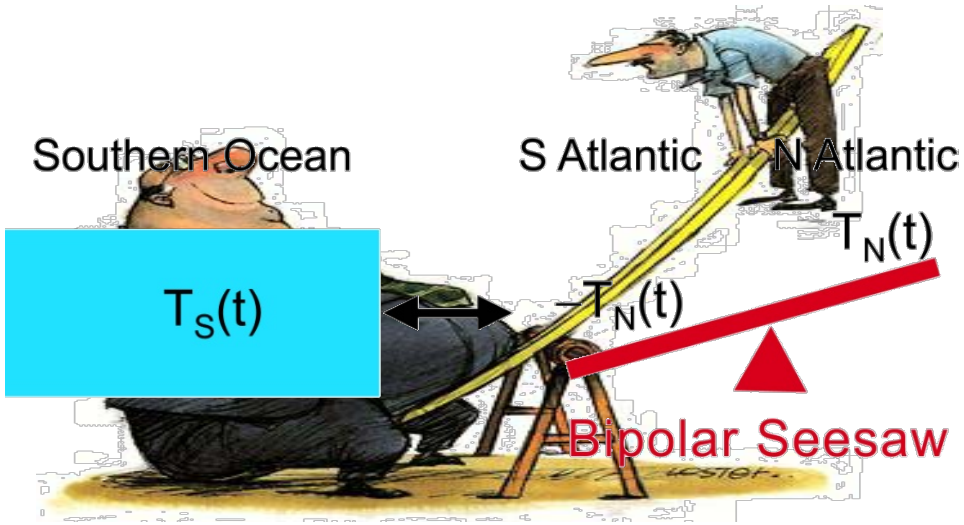
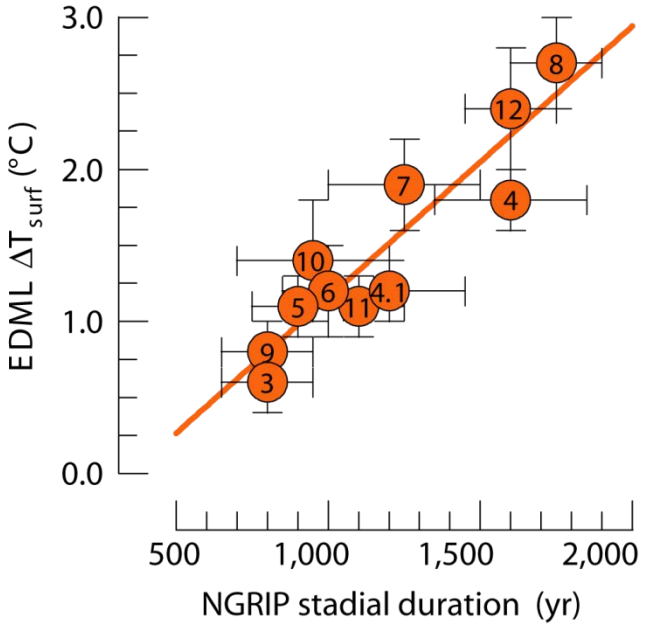


IPCC 2001

Antarctic temperature increases





EDML Community Members, 2006

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- Important climate changes in the northern hemisphere on millennial time scale.
- Similar changes in the tropics (Methane)
- Different pattern in Antarctica at the same pace.
- Consistent pattern between Greenland and Antarctic temperature variations.

- Internal variability!

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Thank you for your attention