

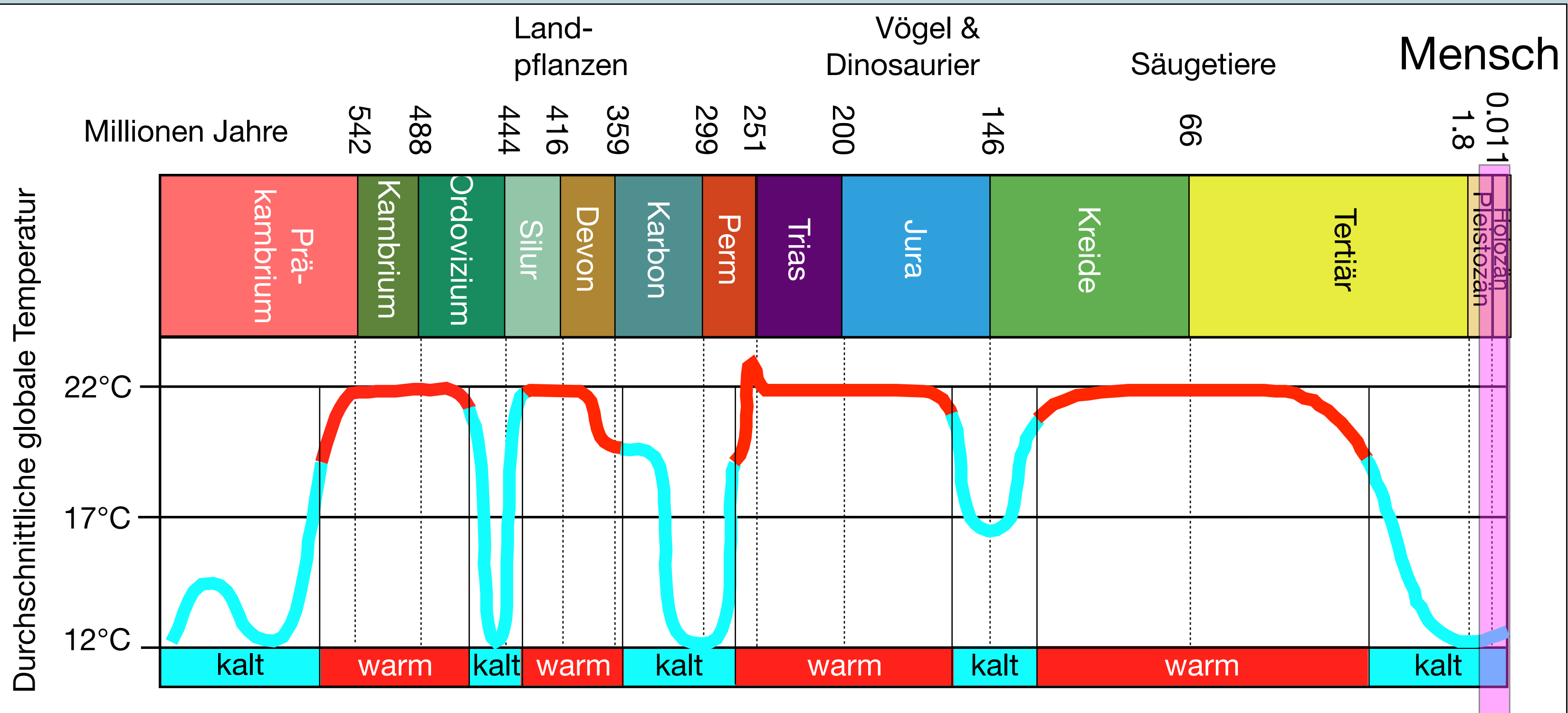
800.000 Jahre Klimageschichte - Aktuelle Ergebnisse der antarktischen Eiskernbohrungen

Hans.Oerter@awi.de



Geographisches Kolloquium Leuphana Universität Lüneburg, 29. Nov. 2011

Temperaturänderung auf geologischer Zeitskala



verändert nach: www.geologieinfo.de/palaeoklima

Wo wurde bereits gebohrt ?

Arktis (Grönland)

60° N

Meereis
Nordpol

Grönland

NEEM

2008-2011

2538 m
>108 ka

GISP2

1989-1993

3053 m,
>110 ka

GRIP

1990-1992

3029 m,
>105 ka

NorthGRIP

1996-2003

3090 m,
123 ka

Antarktis

60° S

Antarktische
Halbinsel


Südpol

Westantarktis

Ostantarktis

source: ArcInfo/G. Rotschky

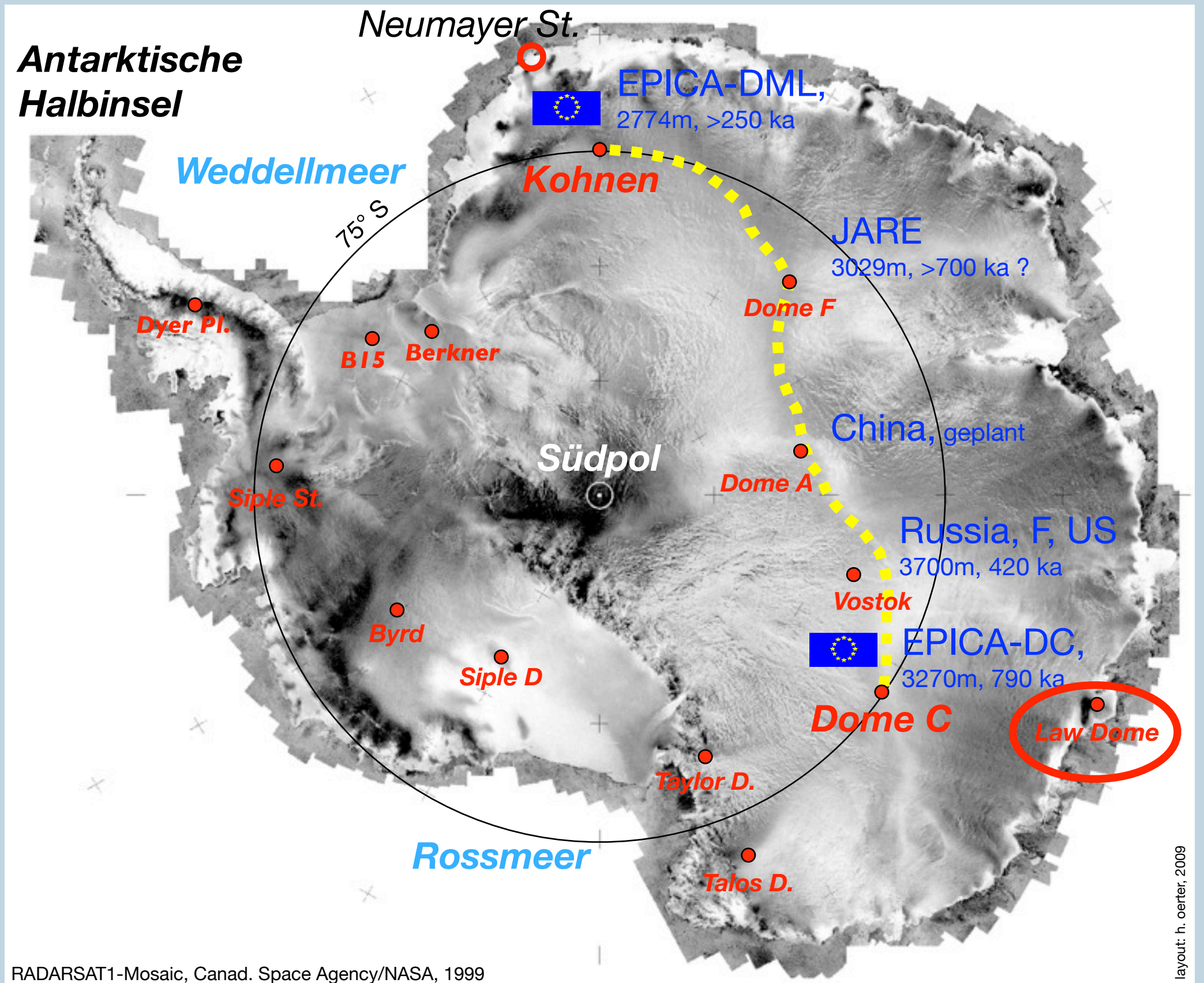
Tiefe Eisbohrkerne in der Antarktis

 European Project for Ice Core Drilling in Antarctica (EPICA) 1996-2008

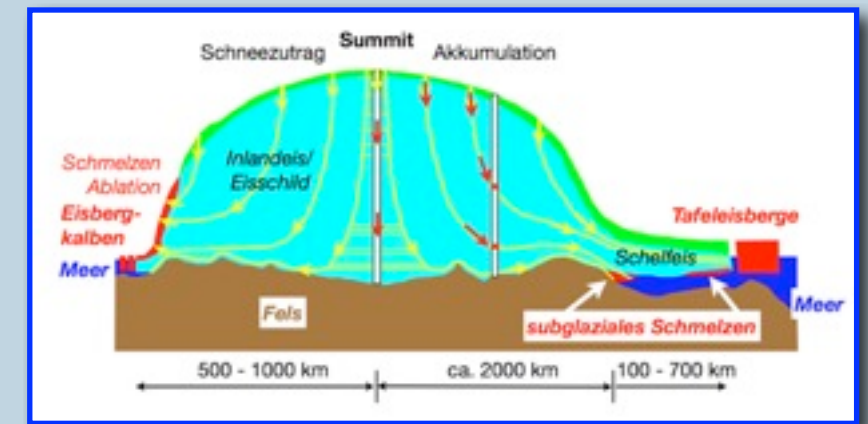
Oerter et al., *Polarforschung* 78 (1-2), 1-23 (2009)
www.polarforschung.de

 Haupteisscheide der Ostantarktis

Law Dome: hohe Akkumulationsrate (640 mm WW); Eiskern an dem rezente (1006-1978 AD) CO₂ - Konzentrationen bestimmt wurden.



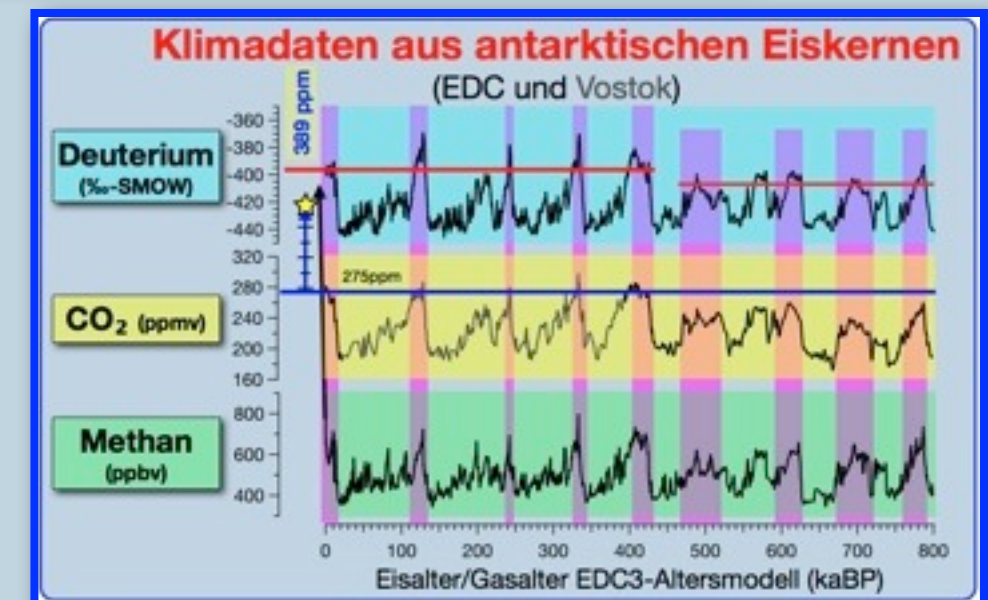
➔ Wie ist der Antarktische Eisschild aufgebaut ?



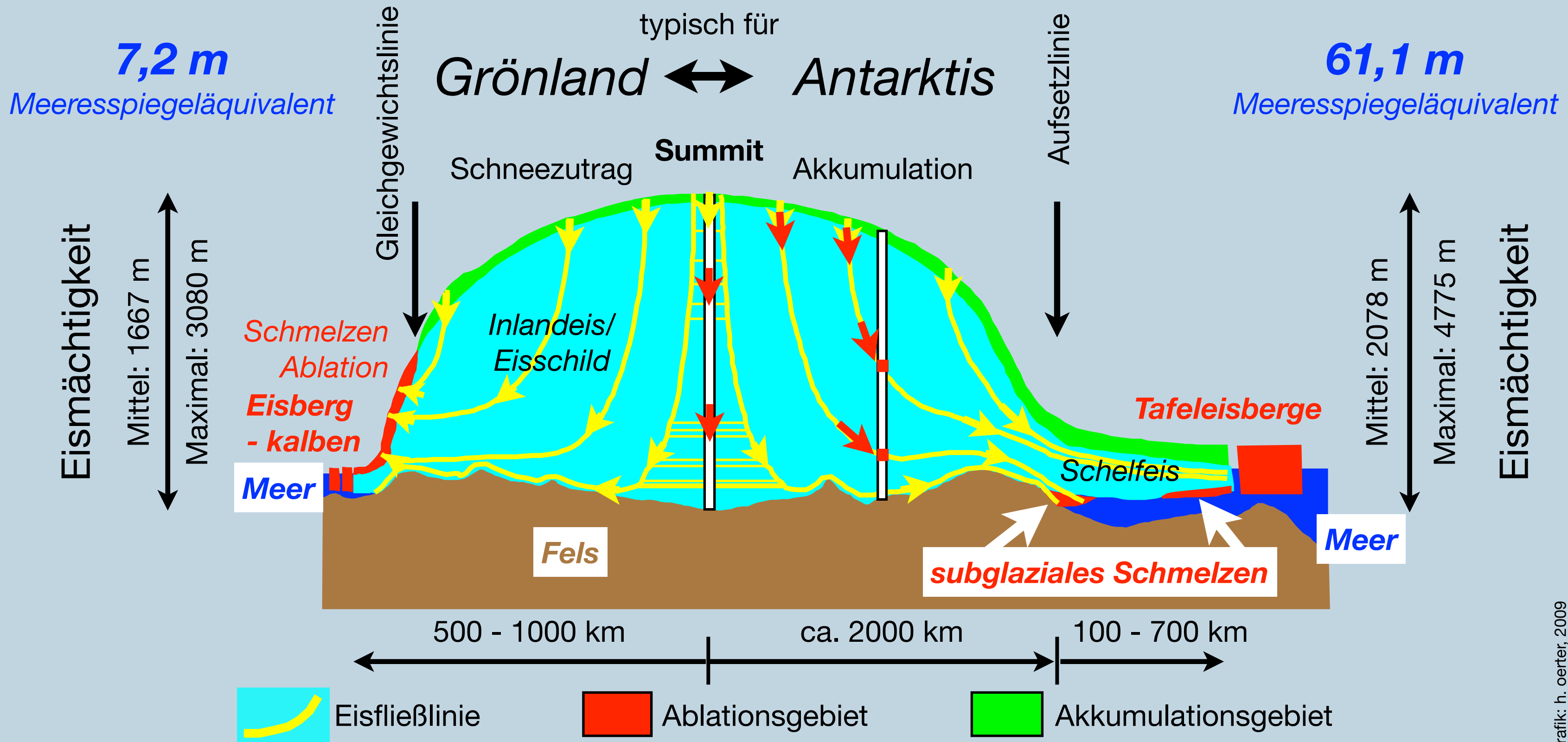
➔ Wie bohrt und zerteilt man einen Eisbohrkern ?



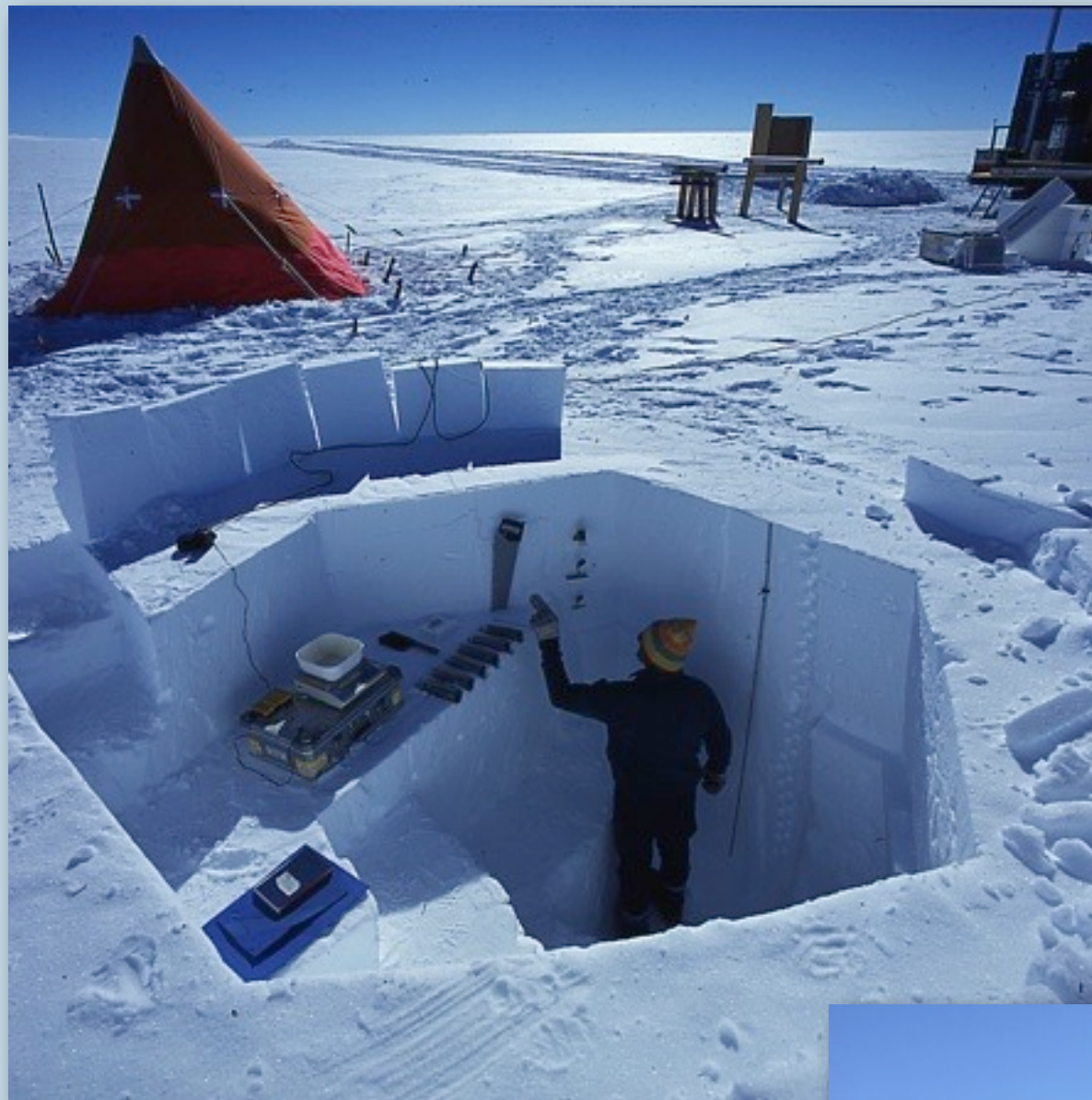
➔ Welche Klimainformation enthält ein Eisbohrkern ?



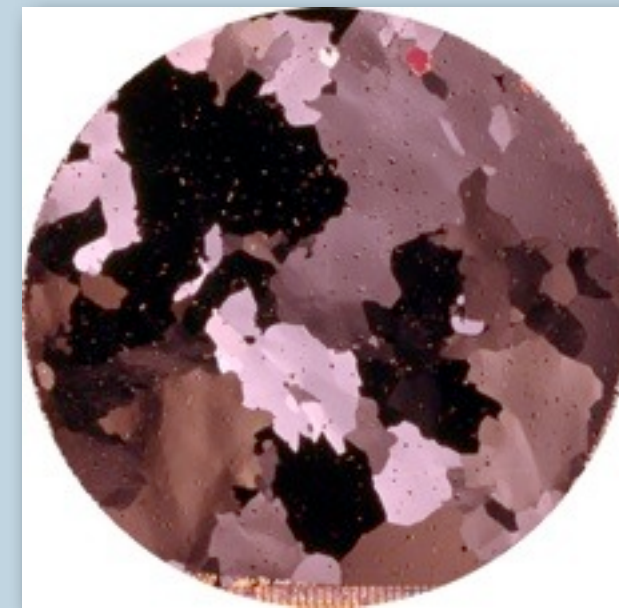
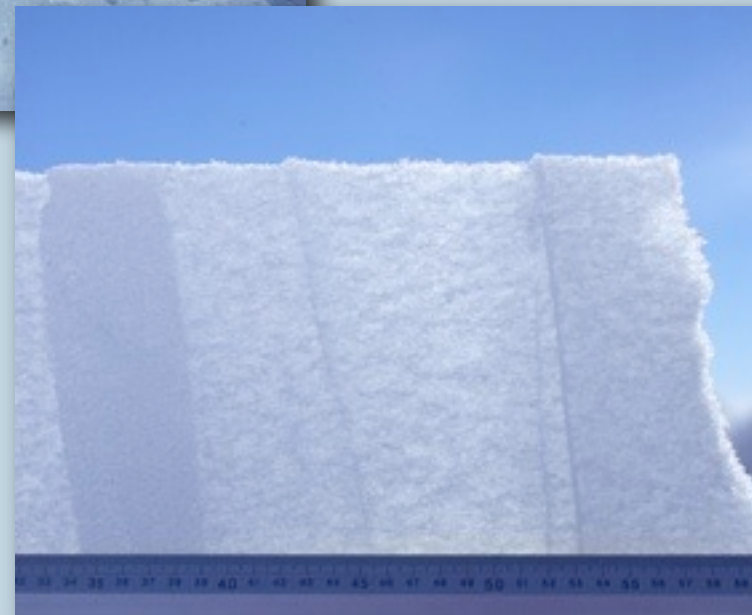
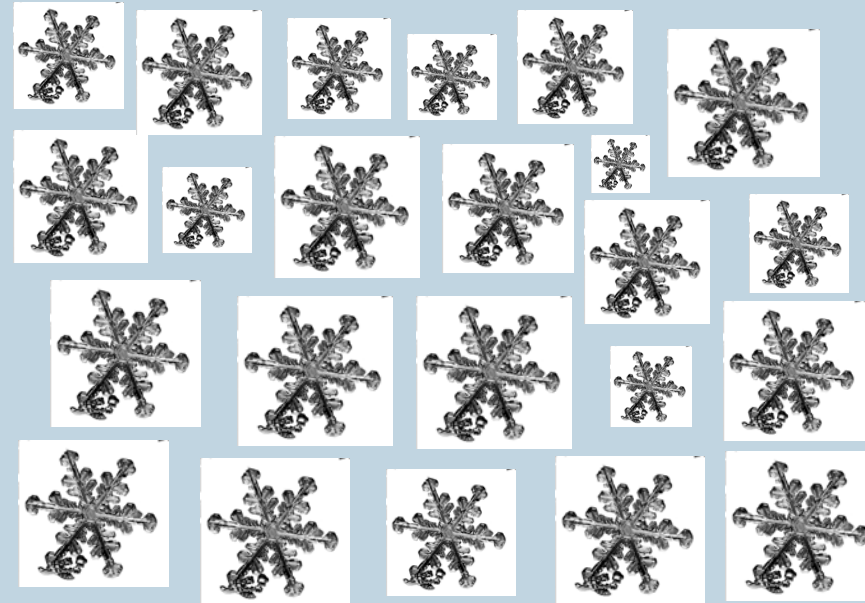
Schematischer Querschnitt durch einen Eisschild

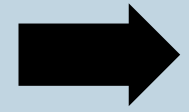


grafik: h. oerter, 2009



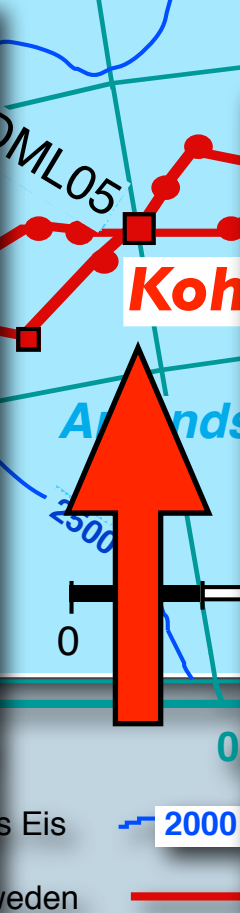
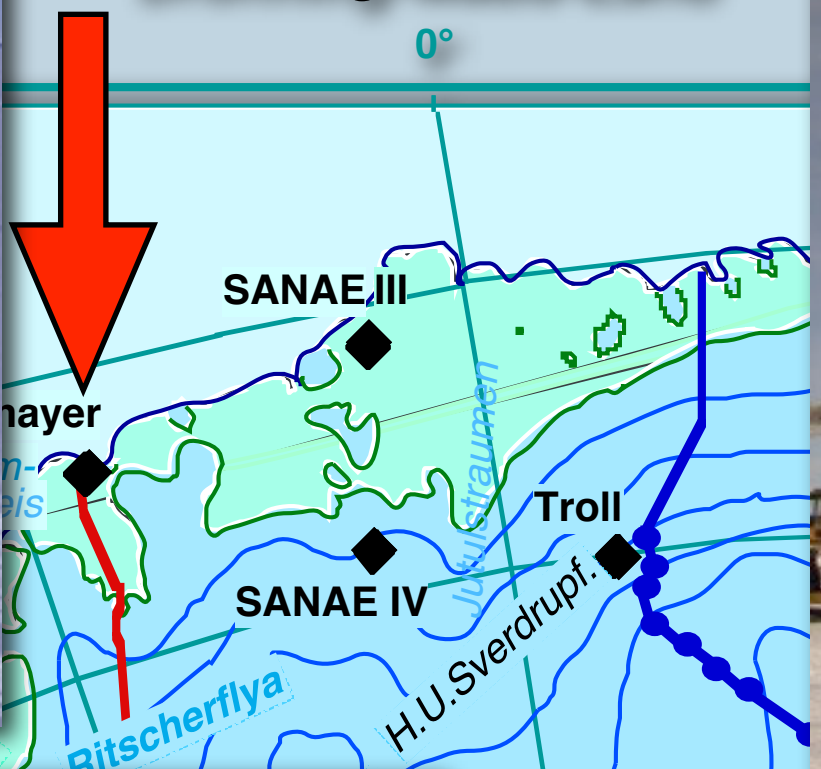
Ein Eisschild baut sich aus über einander liegenden Jahresschichten auf.





Wie bohrt und zerteilt
man einen Eisbohrkern ?

Dronning-Maud-Land



Kohnen-Station

75°S, 0 °E, 2882 m

Funk, PC, e-mail

Messe

Küche

Sanitärcontainer

2 Schlafräume
à 4 Pers.

Schneesmelze

Generator

Lager

Werkstatt

Zum Bohren

Kohnen-Station

75°00'09"S, 00°04'06"E,
2892 m (WGS84)

Bohrzeitraum: 2001-2006

Mittlere Jahres-
temperatur: -44.6 °C

Akkumulationsrate:
64 kg m⁻²a⁻¹

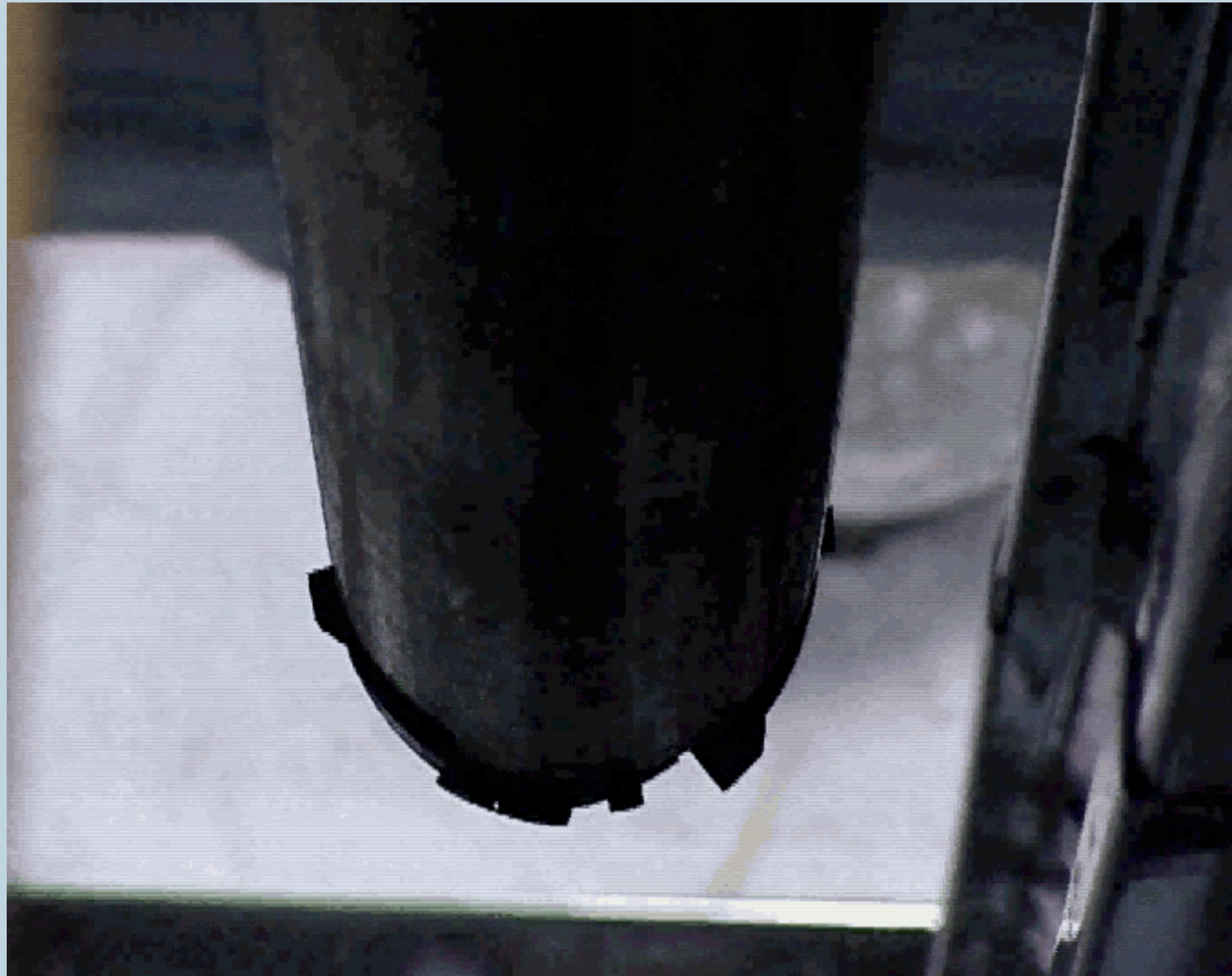
Eis-Fließgeschwindigkeit:
0,756 m/a

Eisdicke: 2782 ±10m

Länge Eiskern: 2774,1 m



photo: hans oerter, 2006



Archiv AWI/Kipfstuhl

Antitorque



innen: Chips-Kammer



Motor & Elektronik



Hüllrohr



Bohrturm



Kernrohr & Bohrkrone





Das Eislabor am Alfred-Wegener-Institut in Bremerhaven

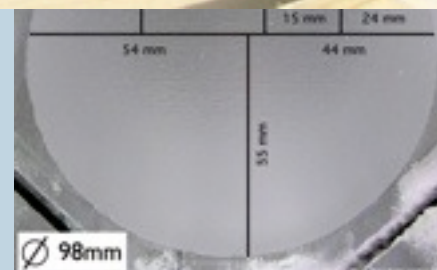
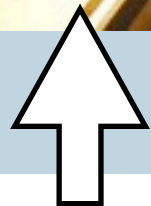
Horizontalsäge



photos: hans oerter, 2002

foto: hans oerter, 2009

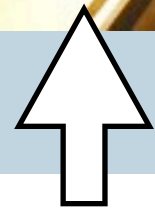
Auspacken des Kerns



Das Eislabor am Alfred-Wegener-Institut in Bremerhaven

Horizontalsäge

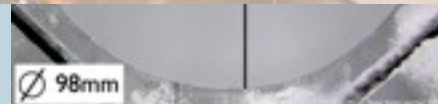
Line-Scan



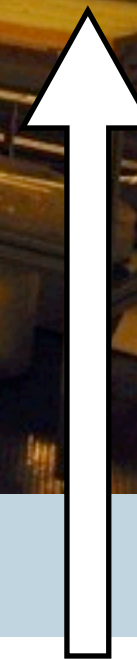
Auspac



foto: hans oerter, 2003



photos: hans oerter, 2002



Vorbereitung für Line-Scan

Das Eislabor am Alfred-Wegener-Institut in Bremerhaven

Horizontalsägen

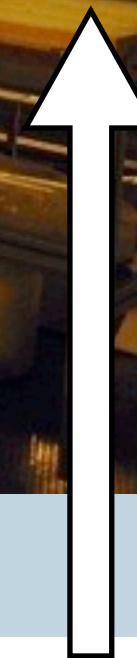


foto: hans oerter, 2003

Längs- und Querschnitte



photos: hans oerter, 2002

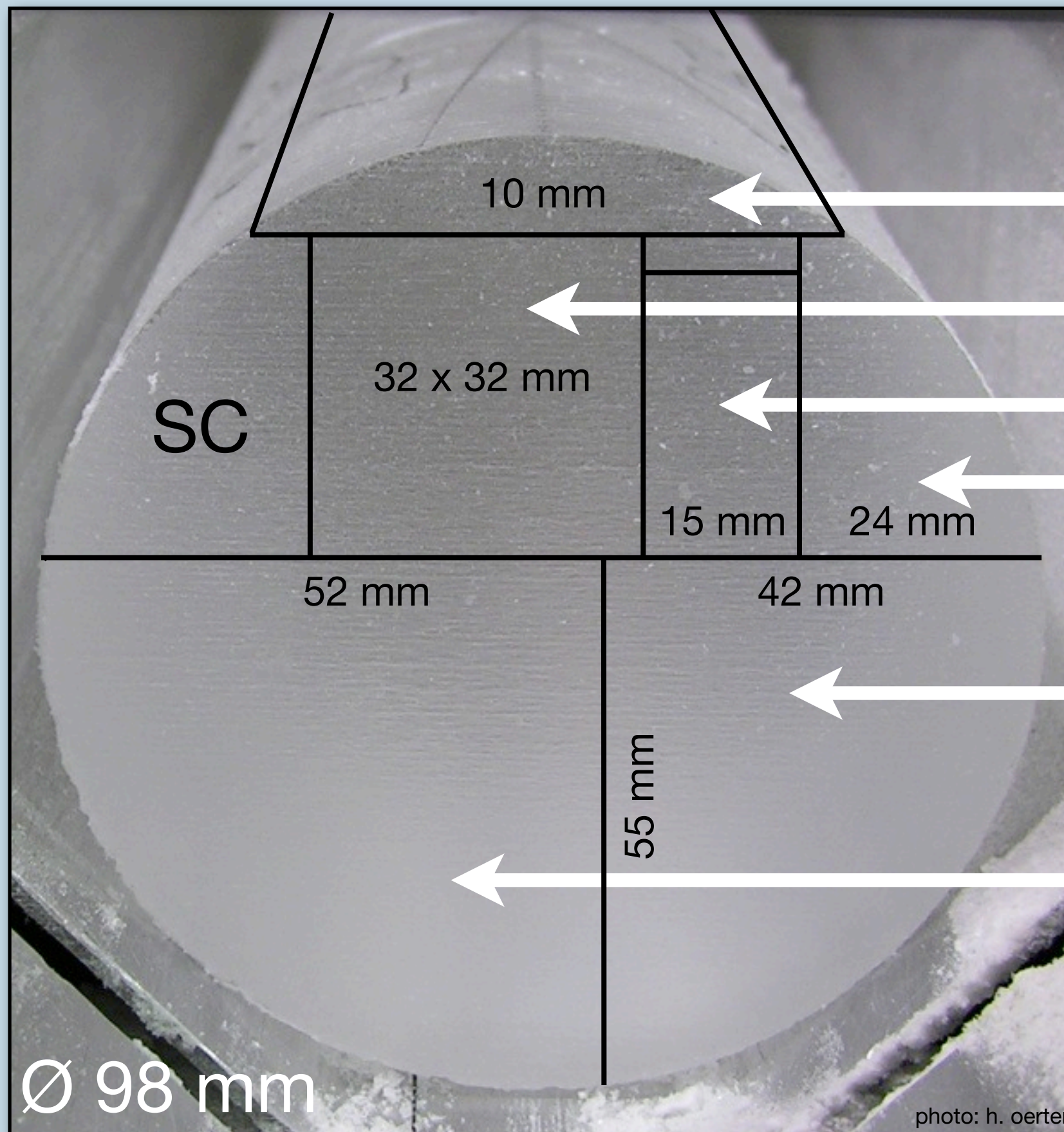


Vorbereitung für Line-Scan



Auspacken des Kerns

Schnittplan

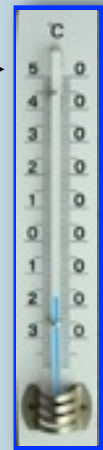


Dünnschnitte

Cont. Flow Analysis (CFA)

$\delta^{18}\text{O}$, $\delta^2\text{H}$ →

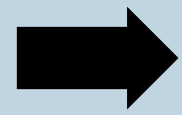
^{10}Be



Gase, Staub

Archiv

SC: verfügbar für Steering Committee

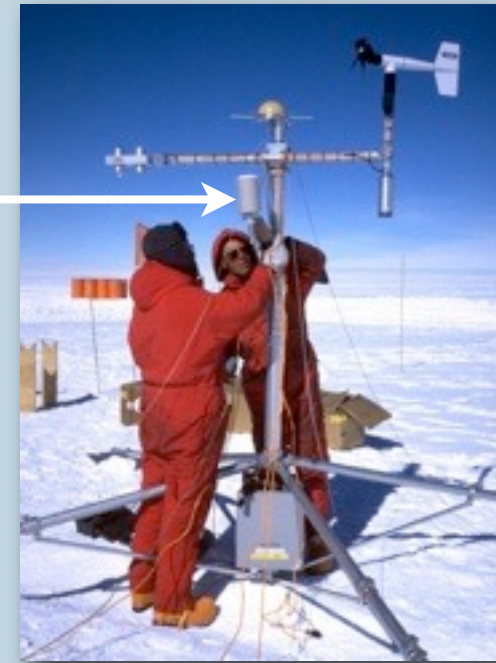
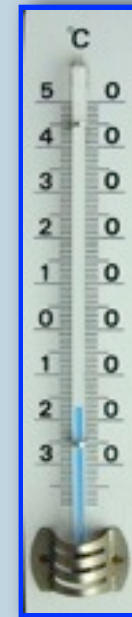


Welche Klimainformation
enthält ein Eisbohrkern ?

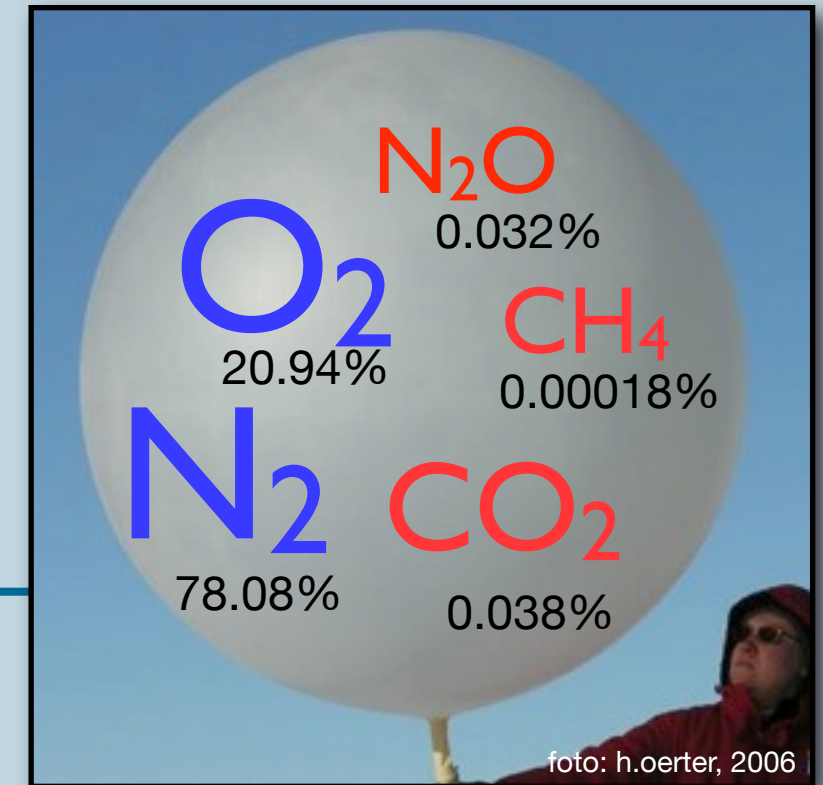
Das Klima-Archiv Eis speichert Informationen zu:

$\delta^{18}\text{O}$, $\delta^2\text{H}$, stabile Isotope

Lufttemperatur



Gasgehalt in der Atmosphäre

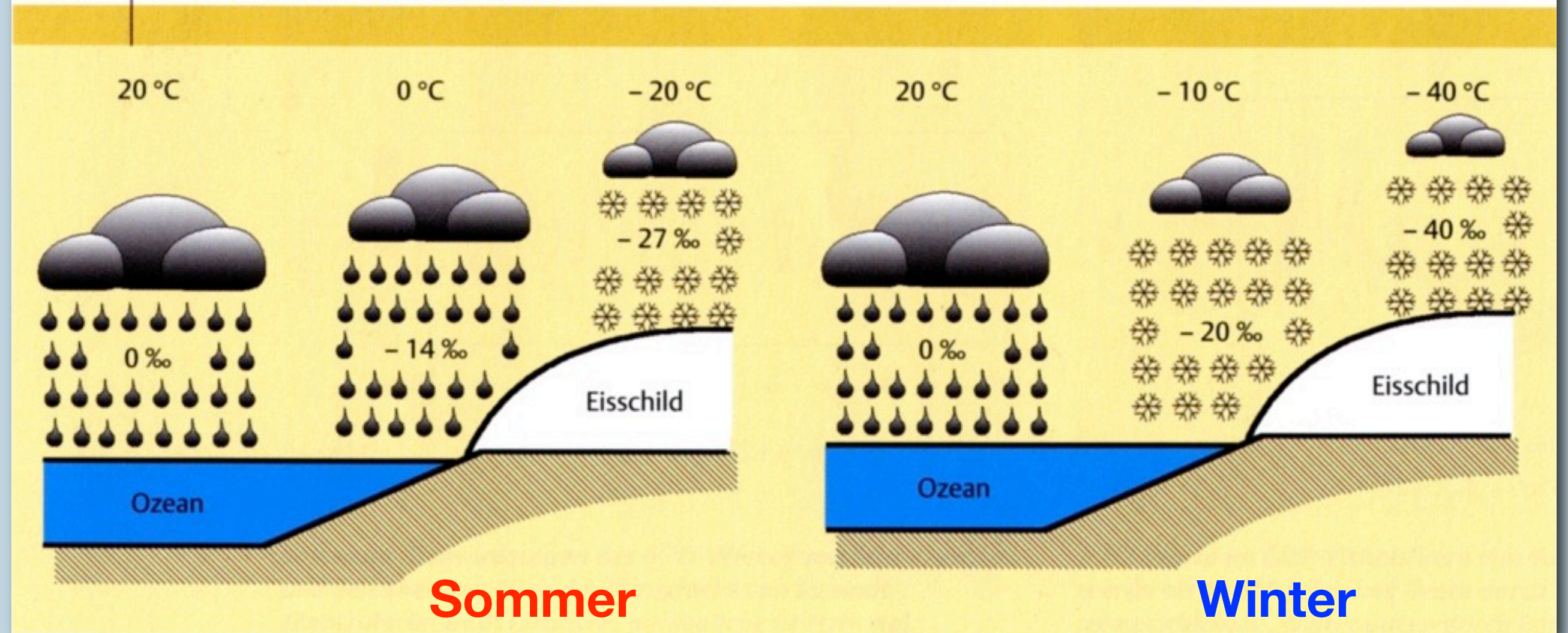


Aerosole



Das „Isotopenthermometer“ ($\delta^{18}\text{O}$ vs. Temp.)

ABB. 1 | ISOTOPENFRAKTIONIERUNG aus: B. Stauffer, 2001: Das „Isotopenthermometer“ im ewigen Eis. *Physik in unserer Zeit*, 32.Jg. (3), 106-113



SMOW:
Standard
Mean Ocean
Water

$$\delta^{18}\text{O} = \left(\frac{C_{\text{Probe}}}{C_{\text{Standard}}} - 1 \right) * 1000 \text{ ‰ SMOW}$$

Isotopenverhältnisse (Konzentrationen in ppm)

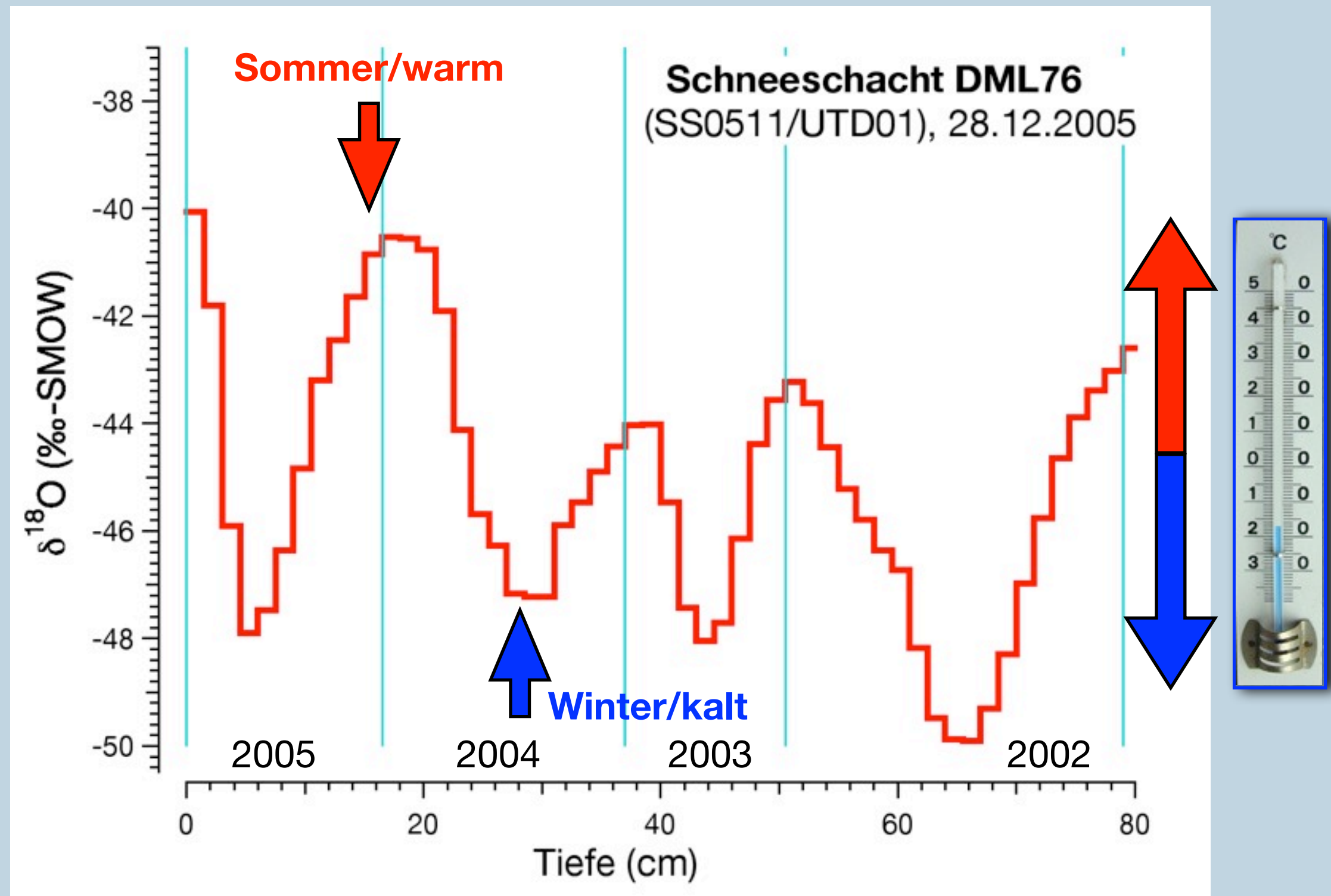
Sauerstoff:	^{16}O	^{17}O	^{18}O
	997 600 ppm	400 ppm	2 000 ppm
Wasserstoff:	^1H	^2H (Deuterium)	
	999 850 ppm	150 ppm	

Das „Isotopenthermometer“ ($\delta^{18}\text{O}$ vs. Temp.)

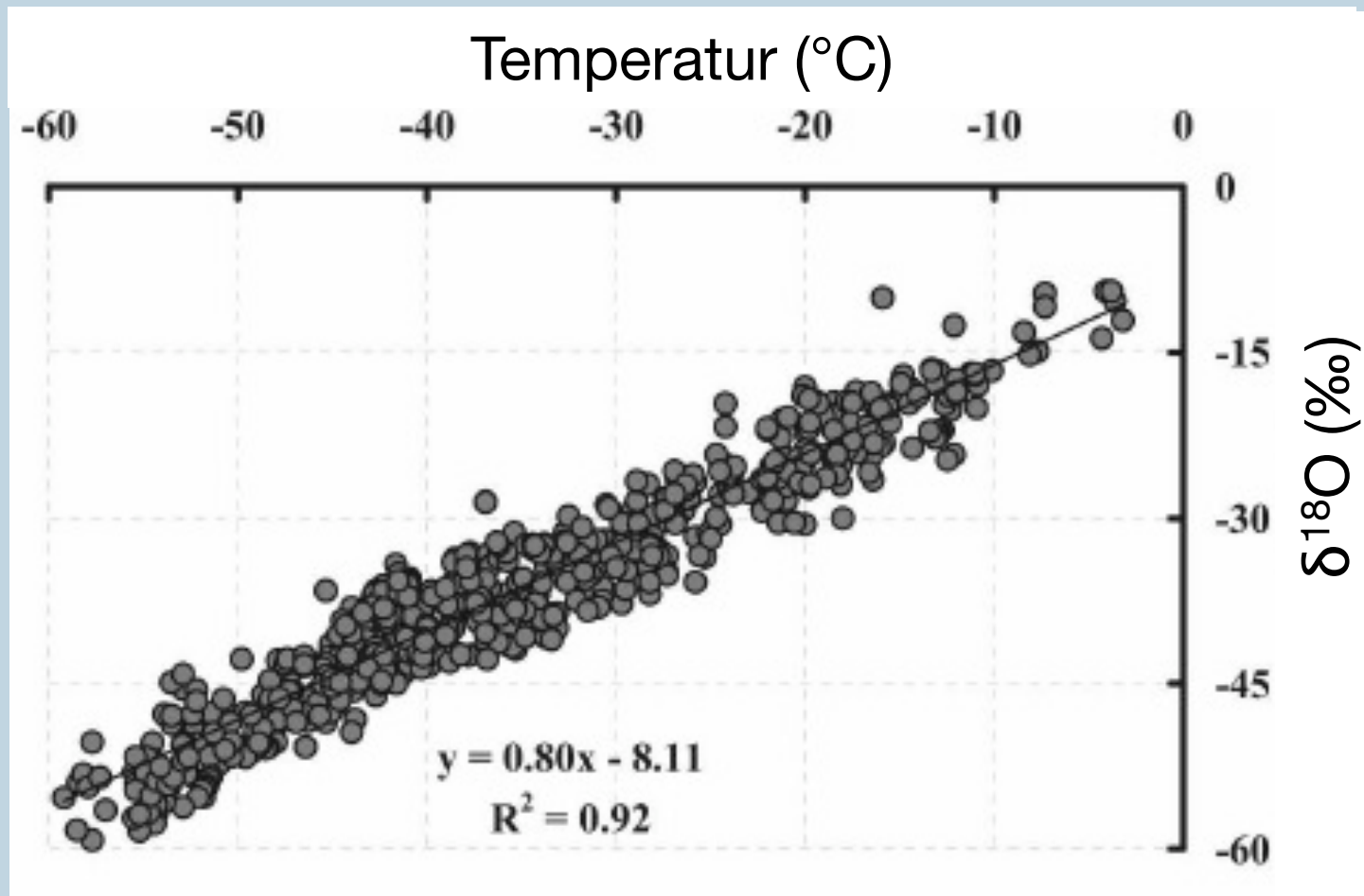
stabile Isotope zeigen saisonale Schwankungen, mit hohen Werten im Sommer und niedrigen Werten im Winter

W. Dansgaard: Stable isotopes in precipitation. Tellus 16, 436-468 (1963)

„Isotopenthermometer“ muss kalibriert werden

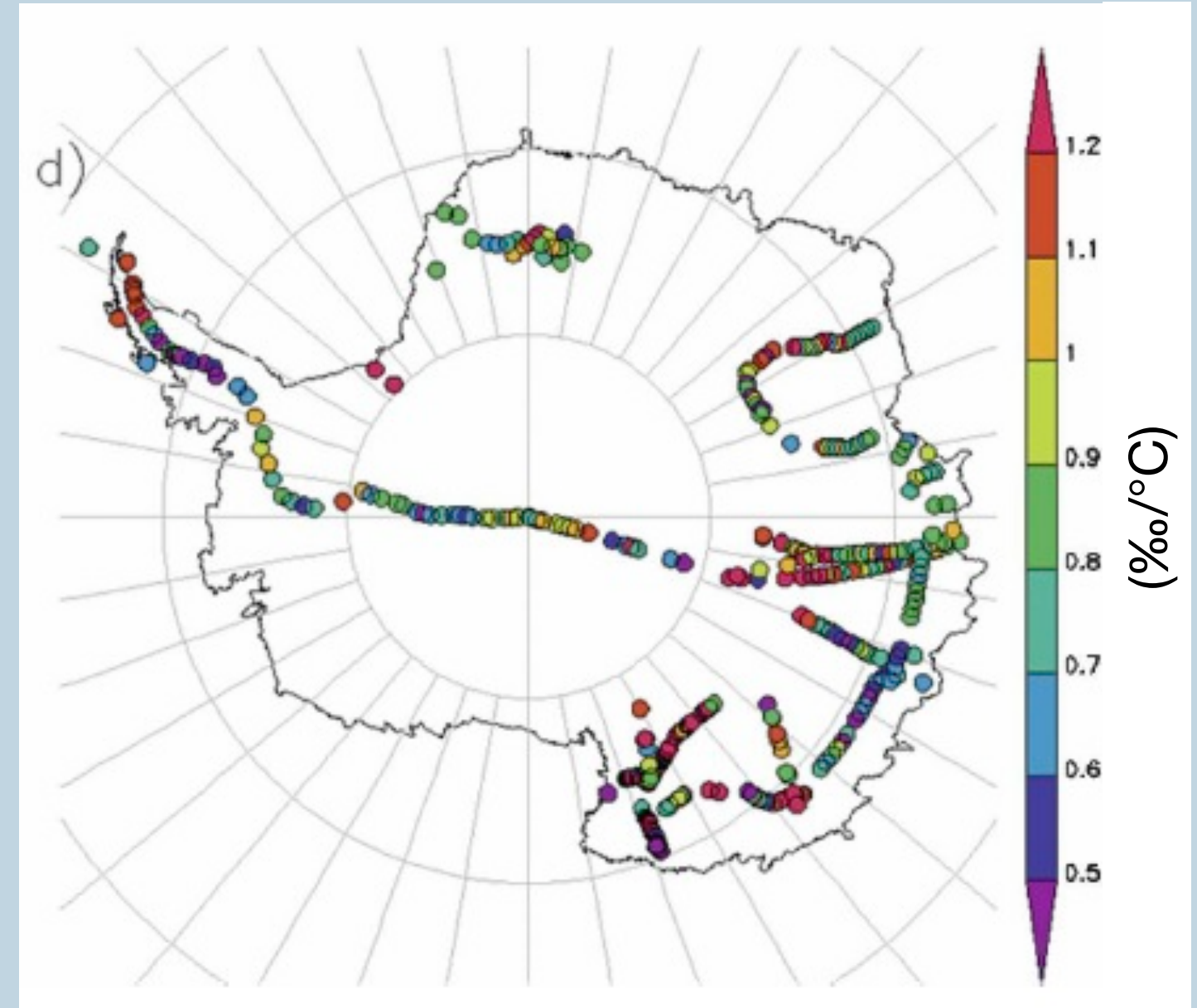


Kalibrierung Isotopenthermometer



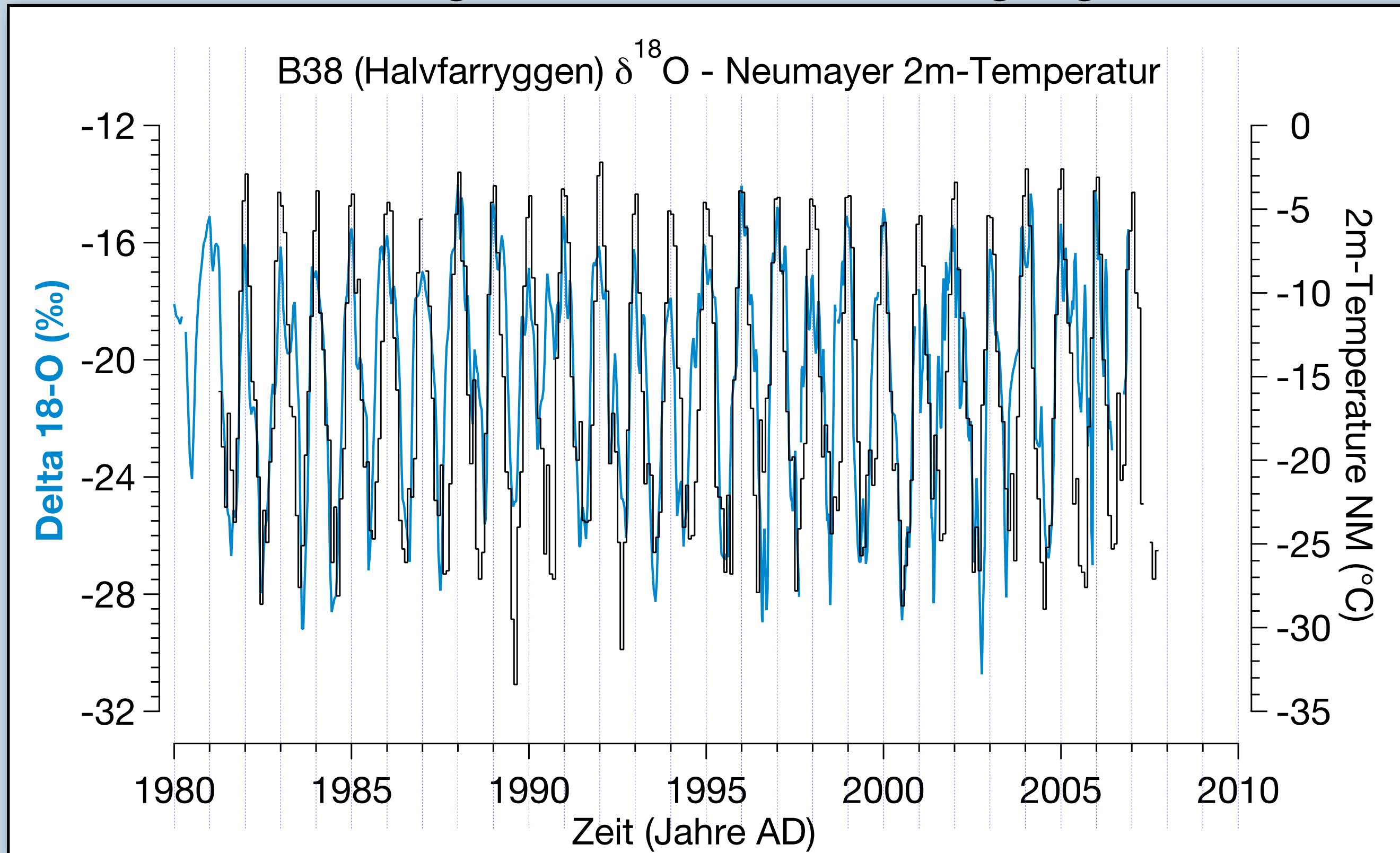
Masson-Delmotte, V. et al. (2008): A Review of Antarctic Surface Snow Isotopic Composition: Observations, Atmospheric Circulation, and Isotopic Modeling. *Journal of Climate* **21**, 3359-3387.

$$\delta^{18}\text{O} (\text{‰}) = 0.80 \times T (\text{°C}) - 8.11$$



Lokaler Gradient für
 $\delta^{18}\text{O}$ - Temperatur (‰/°C)

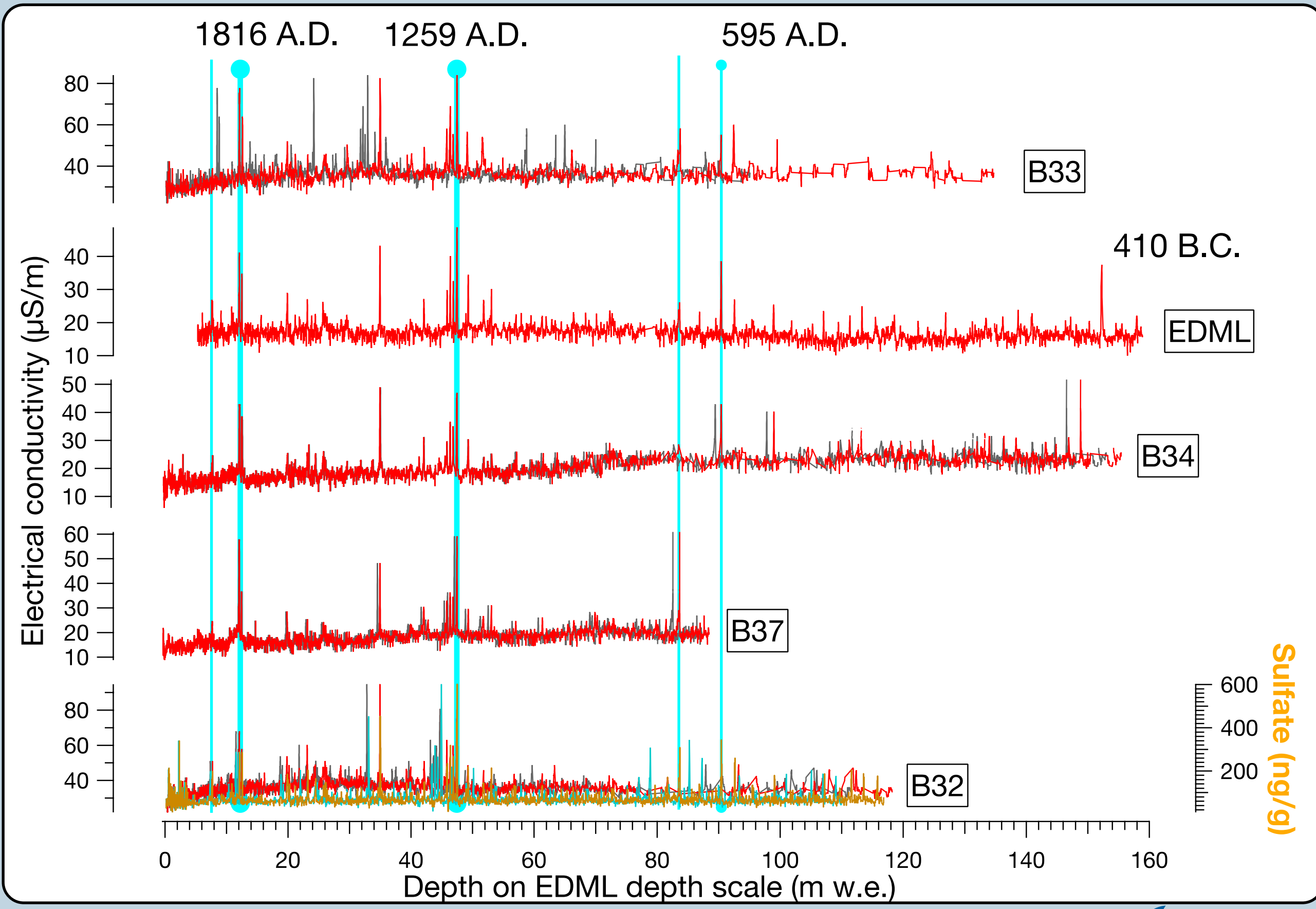
Datierung von Eiskernen: Jahresgänge



Fernandoy, F. et al.: Stable-isotope ratios and accumulation rates in East Antarctica. *Journal of Glaciology*, Vol. 56, No. 198, 673-687 (2010)

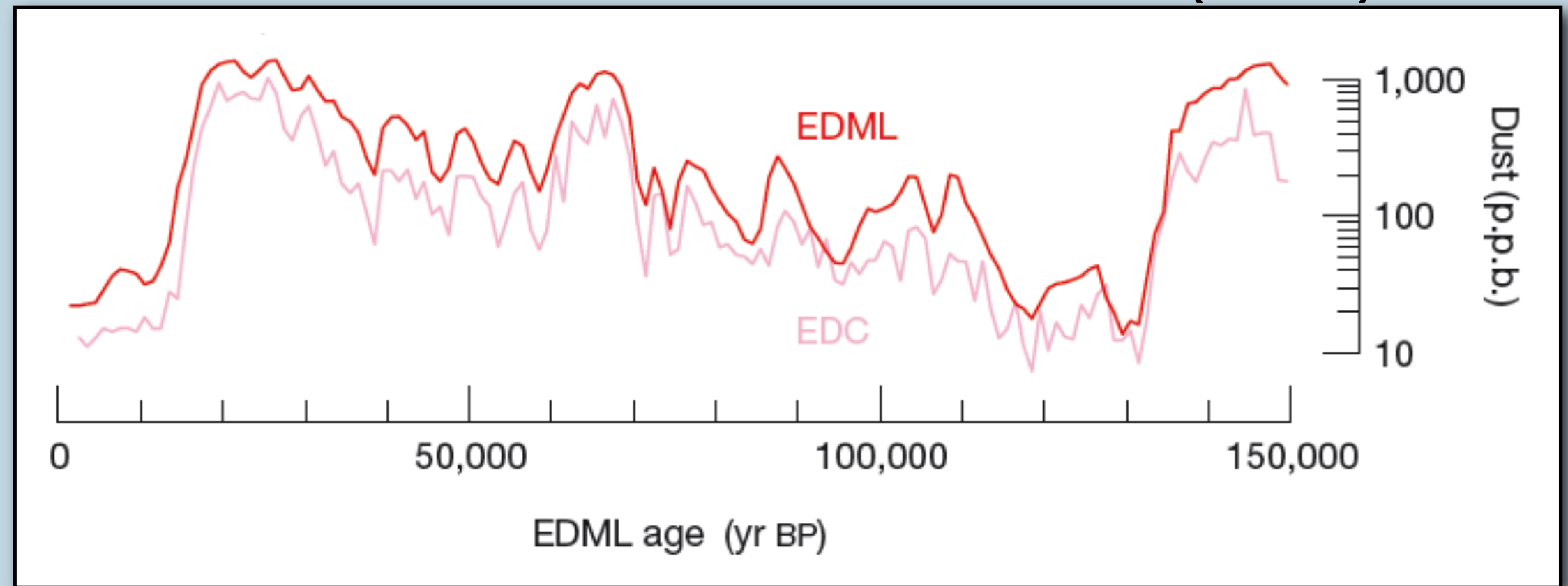
Datierung von Eiskernen: bekannte Zeithorizonte, z.B. Vulkanausbrüche

Referenzhorizonte: Tambora 1816 A.D. Unknown 1259 A.D.

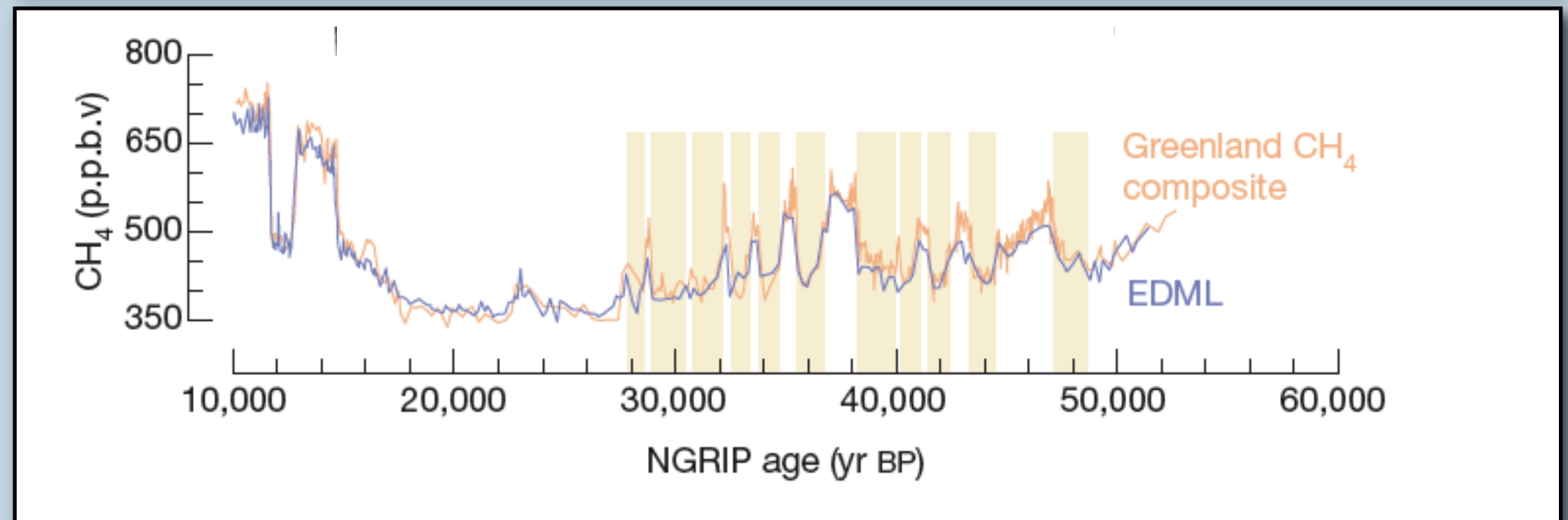


Synchronisation mit Staub und Methan (N-S)

Staubgehalt:
EDML - EDC



Methangehalt:
Grönland - EDML



aus: EPICA community members: One-to-one coupling of glacial climate variability in Greenland and Antarctica. *Nature* Vol. 444, 9 Nov 2006, 195-198

10 - 60 ka BP

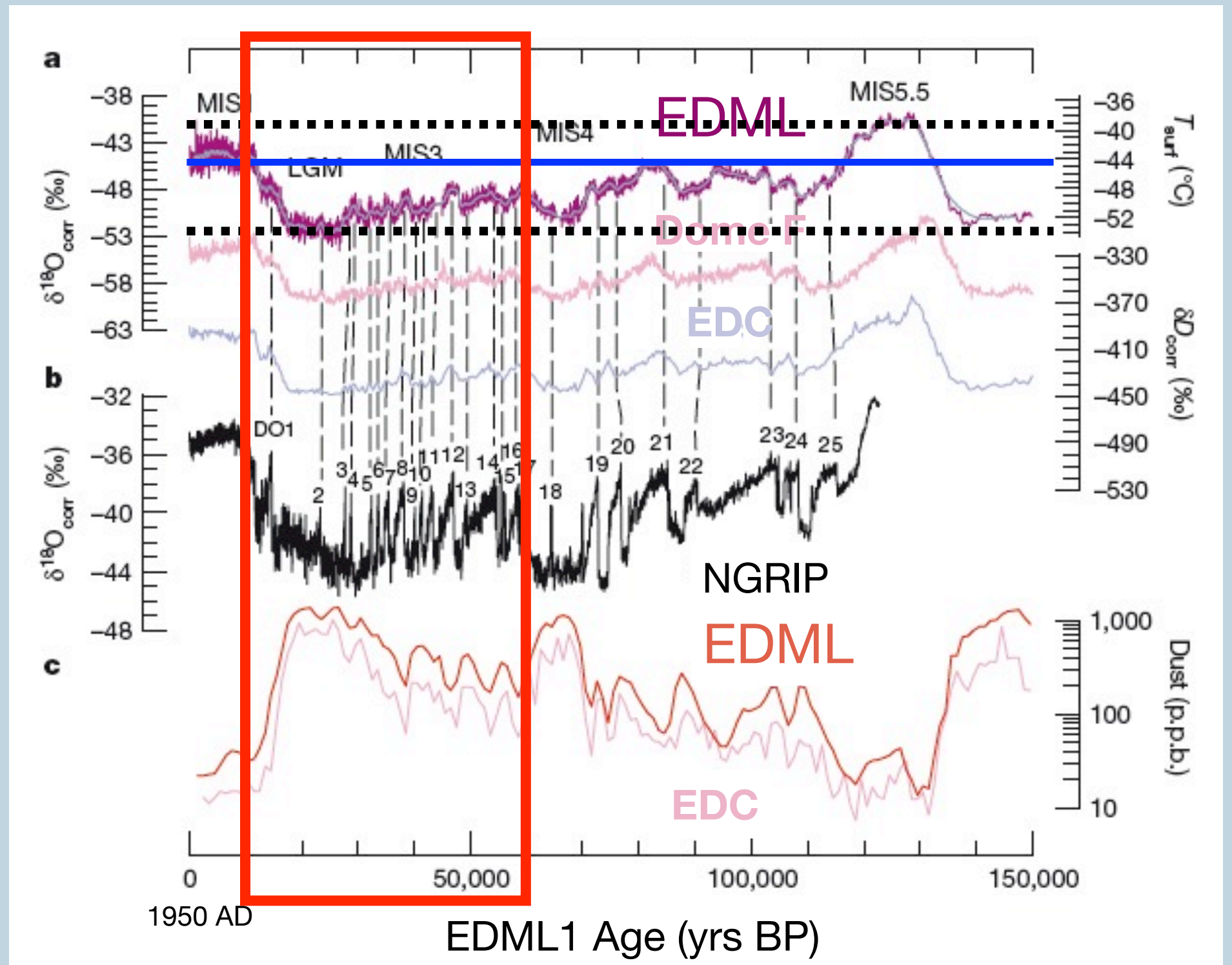
Hohe Co-Varianz zwischen den Antarktischen Eiskernen EDML, Dome F und EDC

$\delta^{18}\text{O}$ -Spitzen in der Antarktis korrespondieren mit DO-Ereignissen in Grönland. $\delta^{18}\text{O}$ -Spitzen in EDML deutlicher als in EDC und Dome F

Synchronisation EDML und EDC u.a. mit Staubgehalt.

Kaltphasen: hoher Staubgehalt

Warmphasen: niedriger Staubgehalt



Quelle: EPICA Community Members: *Nature*, **444**, 195-198, (2006). data: doi:10.1594/PANGAEA.552235

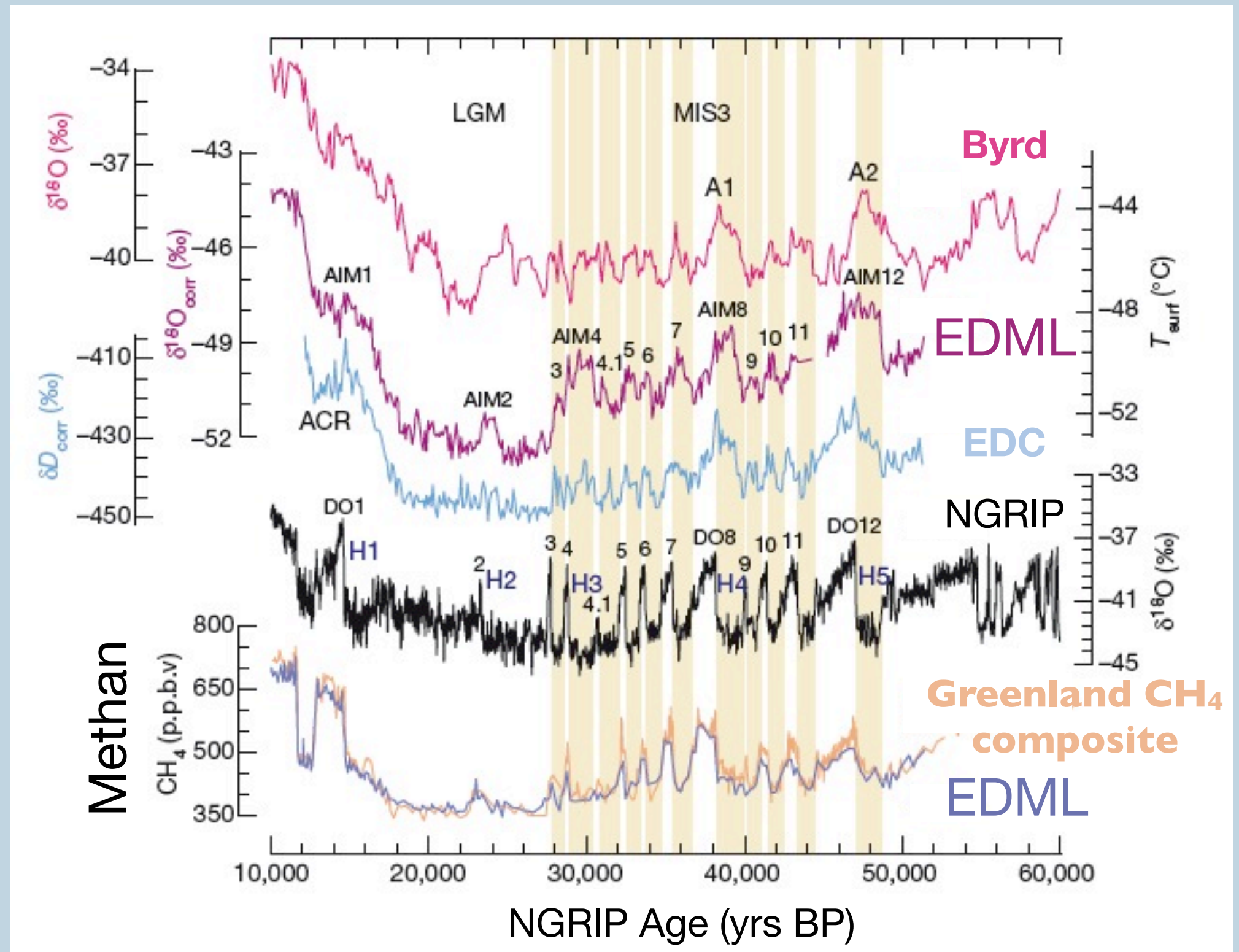
farbig gezeichnet sind
Kaltphasen im Norden

A1 und A2 bereits im Byrd-Kern
erkannt und DO 8 und DO 12
zugeordnet.

Neue Nomenklatur: AIM
Antartic Isotope Maximum

Synchronisation EDML und
NGRIP mit Methangehalt.

Kaltphasen: niedriger Methangehalt
Warmphasen: hoher Methangehalt

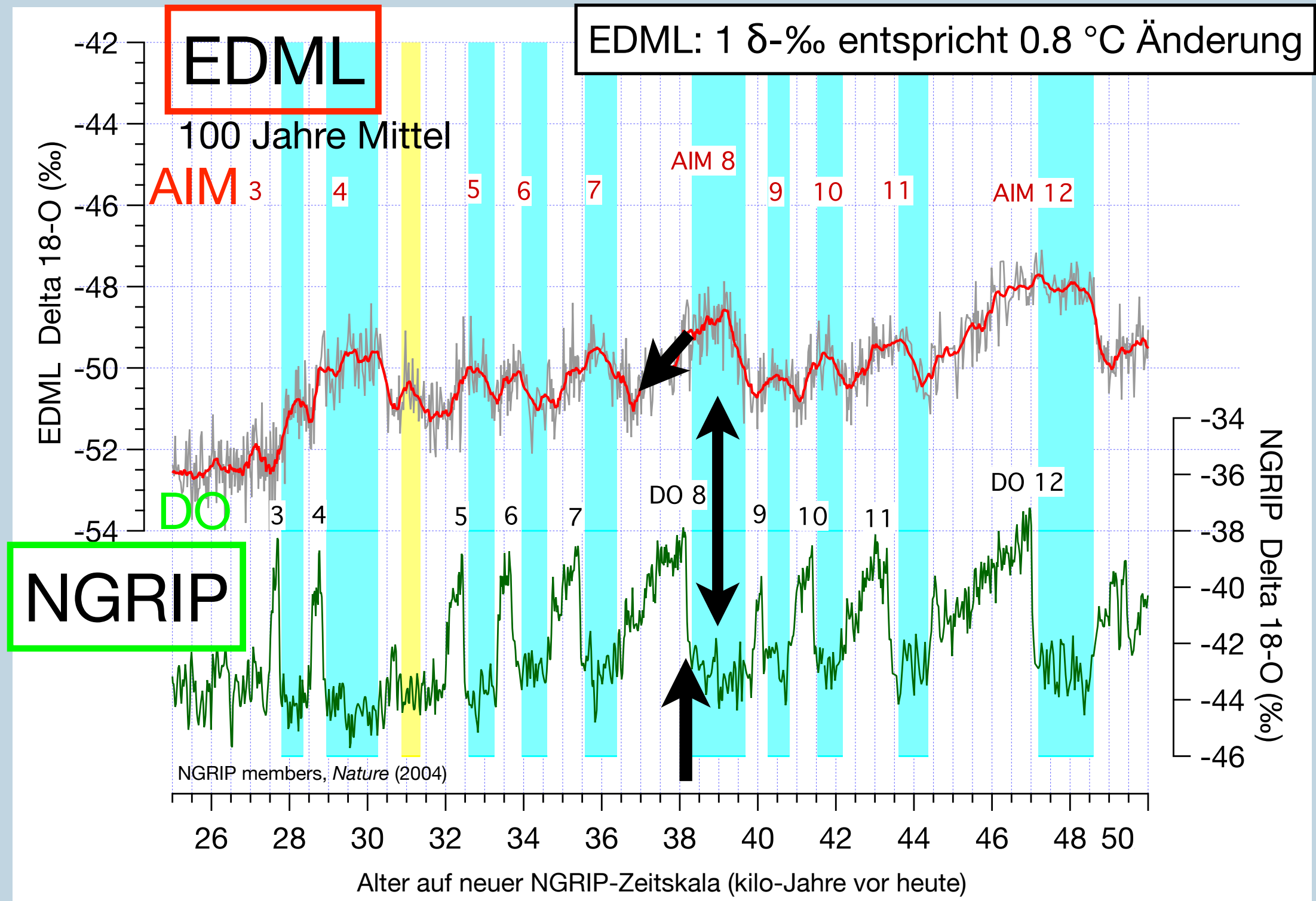


Quelle: EPICA Community Members: *Nature*, **444**, 195-198, (2006). data: [doi:10.1594/PANGAEA.552235](https://doi.org/10.1594/PANGAEA.552235)

Vergleich Antarktis (EDML) - Grönland (NGRIP)

Jedes Antarktische Isotopen Maximum (AIM) im EDML-Kern entspricht einem DO Ereignis in Grönland (NGRIP)

In der Antarktis beginnt die Erwärmung in einer Kaltphase (Stadial) des Nordens, die Abkühlung in einer Warmphase (Interstadial)

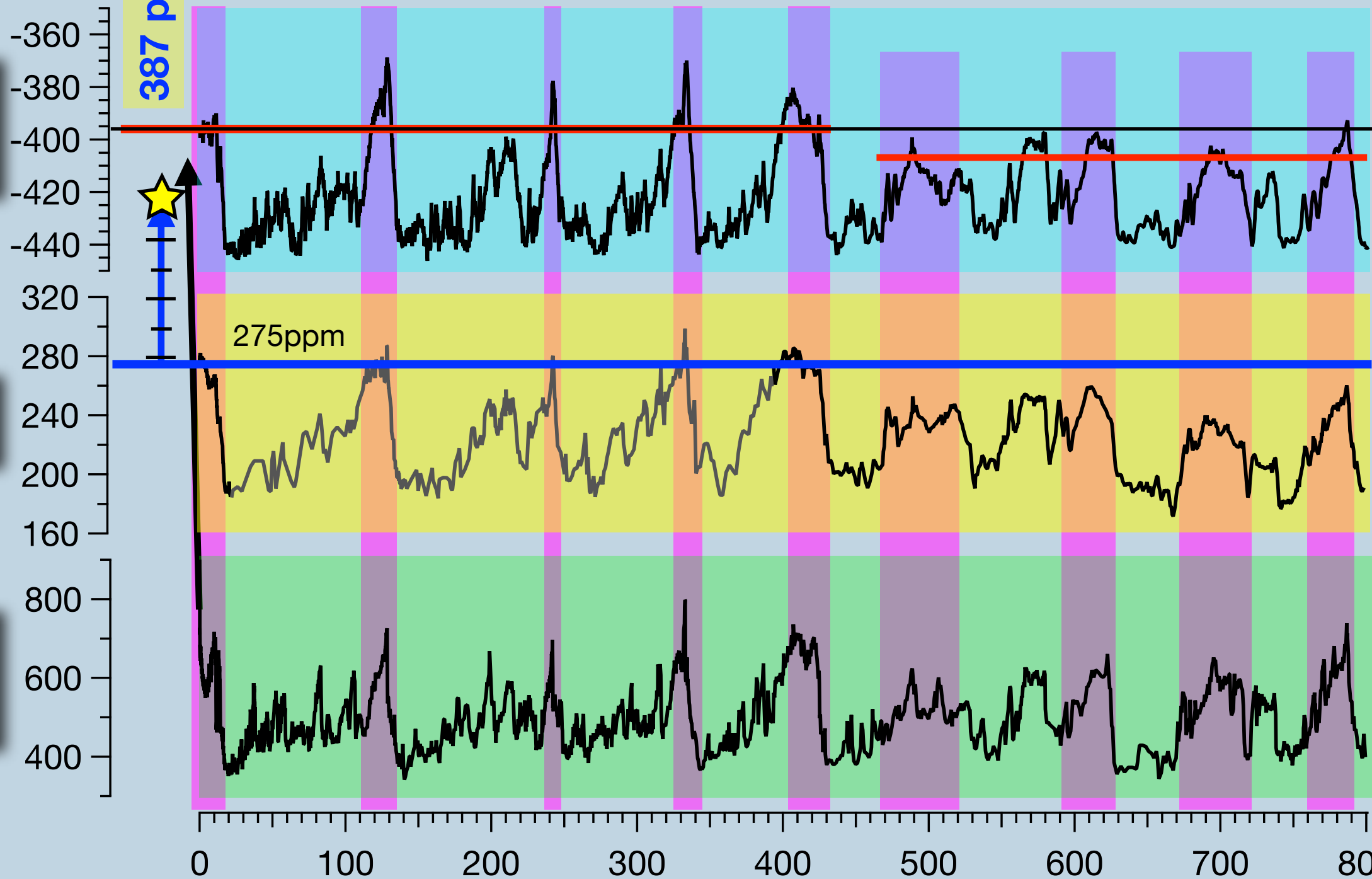


Quelle: EPICA Community Members: *Nature*, 444, 195-198, (2006). data: doi:10.1594/PANGAEA.552235

Klimadaten aus antarktischen Eiskernen

(EDC und Vostok)

Deuterium
(‰-SMOW)

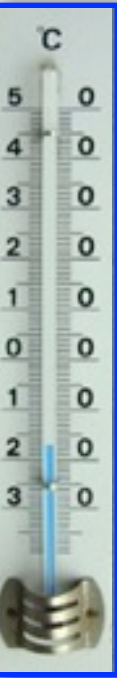


CO₂ (ppmv)

Methan
(ppbv)

Eisalter/Gasalter EDC3-Altersmodell (kaBP)

+5°C
-10°C



Quellen (NOAA/WDC
Paleoclimatology:

Jouzel et al.(2007):
Science 317, 793-796

Lüthi, D.et al. (2008):
Nature 453, 379-382

Loulerque, L. et al.
(2008): *Nature* 453,
383-386

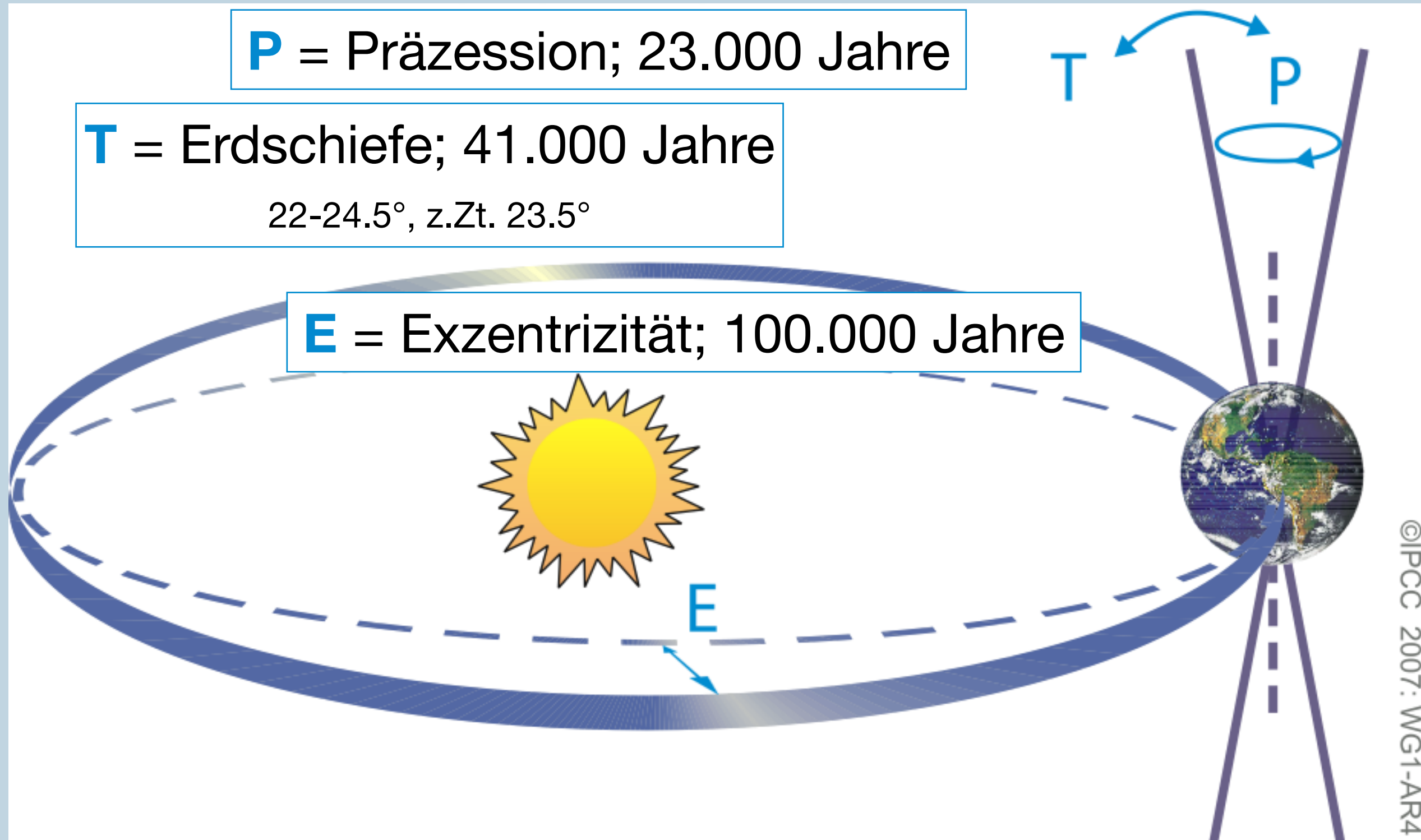
Erdumlaufbahn - Milankovitch-Zyklen

P = Präzession; 23.000 Jahre

T = Erdschiefe; 41.000 Jahre

22-24.5°, z.Zt. 23.5°

E = Exzentrizität; 100.000 Jahre



©IPCC 2007: WG1-AR4

*On the Influence of Carbonic Acid
in the Air upon the Temperature of
the Ground*

Svante Arrhenius

Philosophical Magazine and Journal of Science
Series 5, Volume 41, April 1896, pages 237-276.

This photocopy was prepared by Robert A. Rohde for Global Warming Art (<http://www.globalwarmingart.com/>) from original printed material that is now in the public domain.

Arrhenius's paper is the first to quantify the contribution of carbon dioxide to the greenhouse effect (Sections I-IV) and to speculate about whether variations in the atmospheric concentration of carbon dioxide have contributed to long-term variations in climate (Section V). Throughout this paper, Arrhenius refers to carbon dioxide as "carbonic acid" in accordance with the convention at the time he was writing.

Contrary to some misunderstandings, Arrhenius does not explicitly suggest in this paper that the burning of fossil fuels will cause global warming, though it is clear that he is aware that fossil fuels are a potentially significant source of carbon dioxide (page 270), and he does explicitly suggest this outcome in later work.

THE
LONDON, EDINBURGH, AND DUBLIN
PHILOSOPHICAL MAGAZINE
AND
JOURNAL OF SCIENCE.

[FIFTH SERIES.]

APRIL 1896.

XXXI. *On the Influence of Carbonic Acid in the Air upon the Temperature of the Ground.* By Prof. SVANTE ARRHENIUS*.

I. *Introduction: Observations of Langley on Atmospheric Absorption.*

A GREAT deal has been written on the influence of the absorption of the atmosphere upon the climate. Tyndall † in particular has pointed out the enormous importance of this question. To him it was chiefly the diurnal and annual variations of the temperature that were lessened by this circumstance. Another side of the question, that has long attracted the attention of physicists, is this: Is the mean temperature of the ground in any way influenced by the presence of heat-absorbing gases in the atmosphere? Fourier ‡ maintained that the atmosphere acts like the glass of a hot-house, because it lets through the light rays of the sun but retains the dark rays from the ground. This idea was elaborated by Pouillet §; and Langley was by some of his researches led to the view, that "the temperature of the earth under direct sunshine, even though our atmosphere were present as now, would probably fall to -200° C., if that atmosphere did not possess the quality of selective

* Extract from a paper presented to the Royal Swedish Academy of Sciences, 11th December, 1895. Communicated by the Author.

† 'Heat a Mode of Motion,' 2nd ed. p. 405 (Lond., 1863).

‡ *Mém. de l'Ac. R. d. Sci. de l'Inst. de France*, t. vii. 1827.

§ *Comptes rendus*, t. vii. p. 41 (1838).

Phil. Mag. S. 5. Vol. 41. No. 251. April 1896. S



Svante Arrhenius

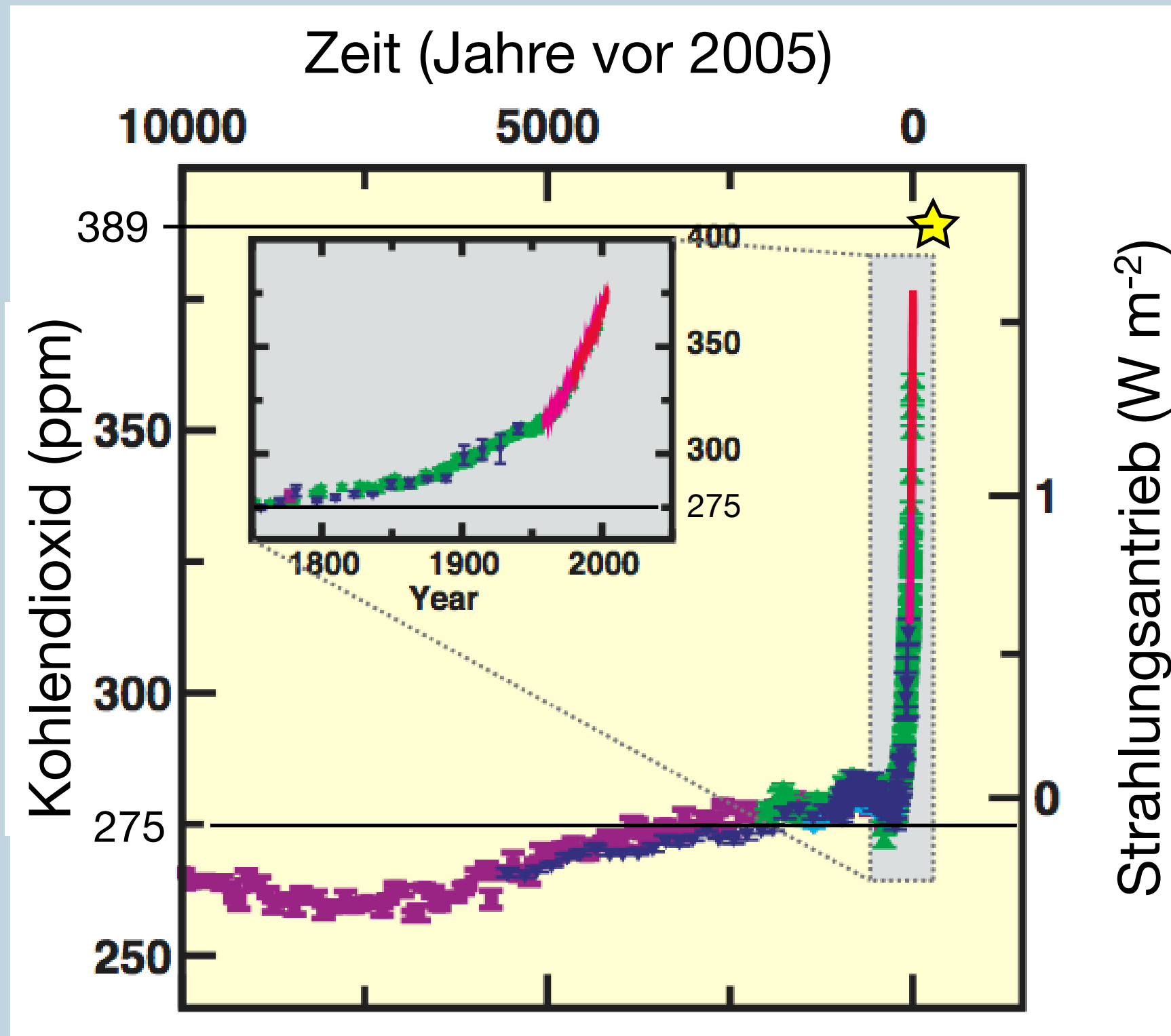
Prof. Dr. Svante Arrhenius

* 19. Febr. 1859 auf Gut Wik bei Uppsala

† 02. Okt. 1927 in Stockholm

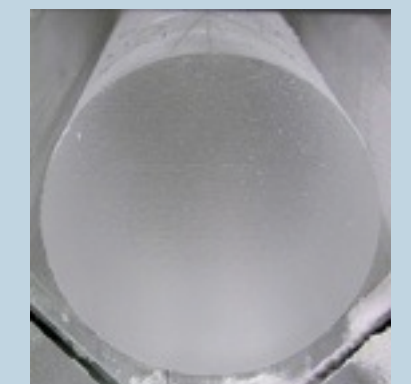
1903 Nobelpreis für Chemie

Kohlendioxid-Gehalt der Atmosphäre



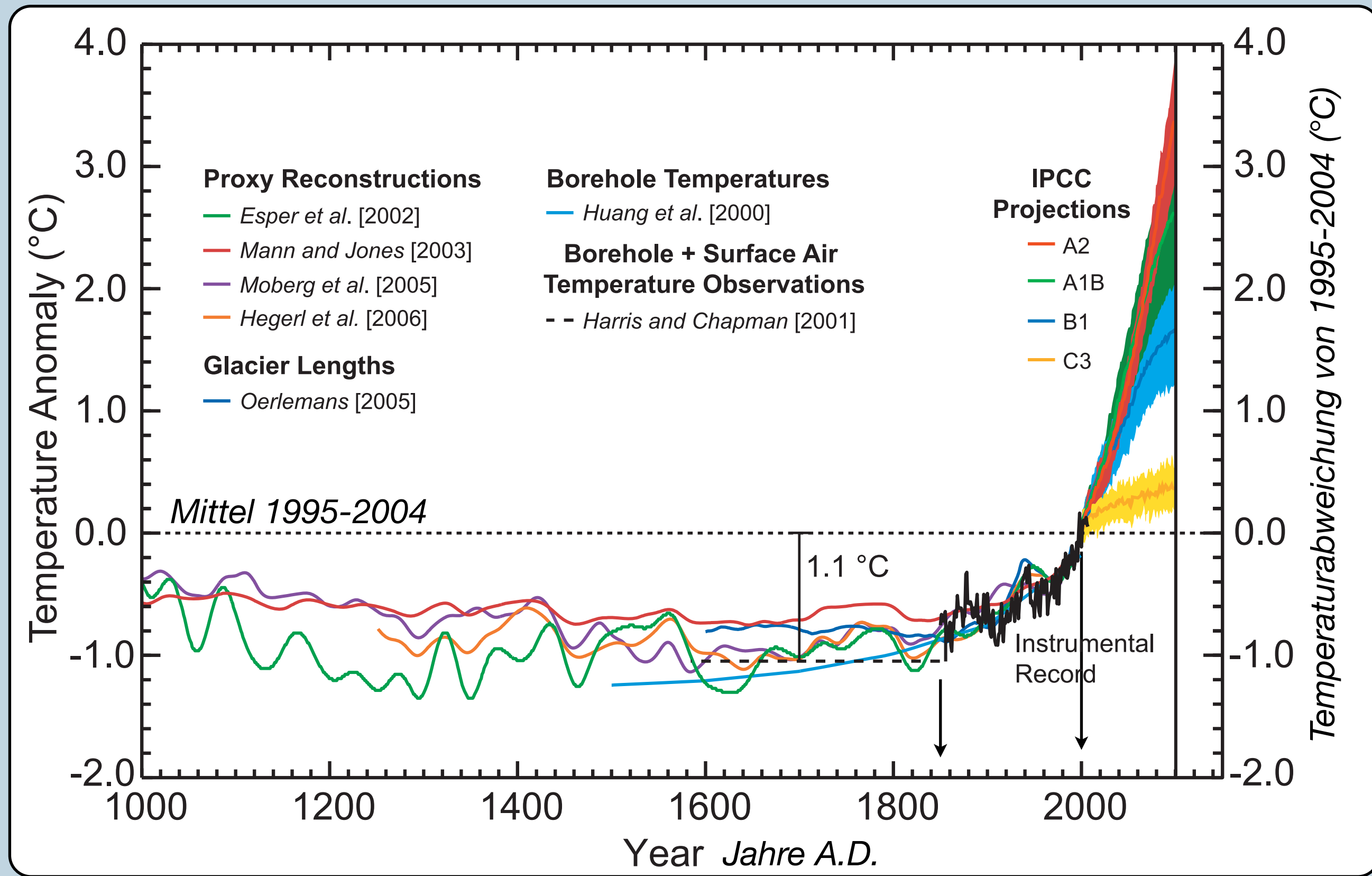
Messung an Luftproben seit 1958

Messung an Eisproben



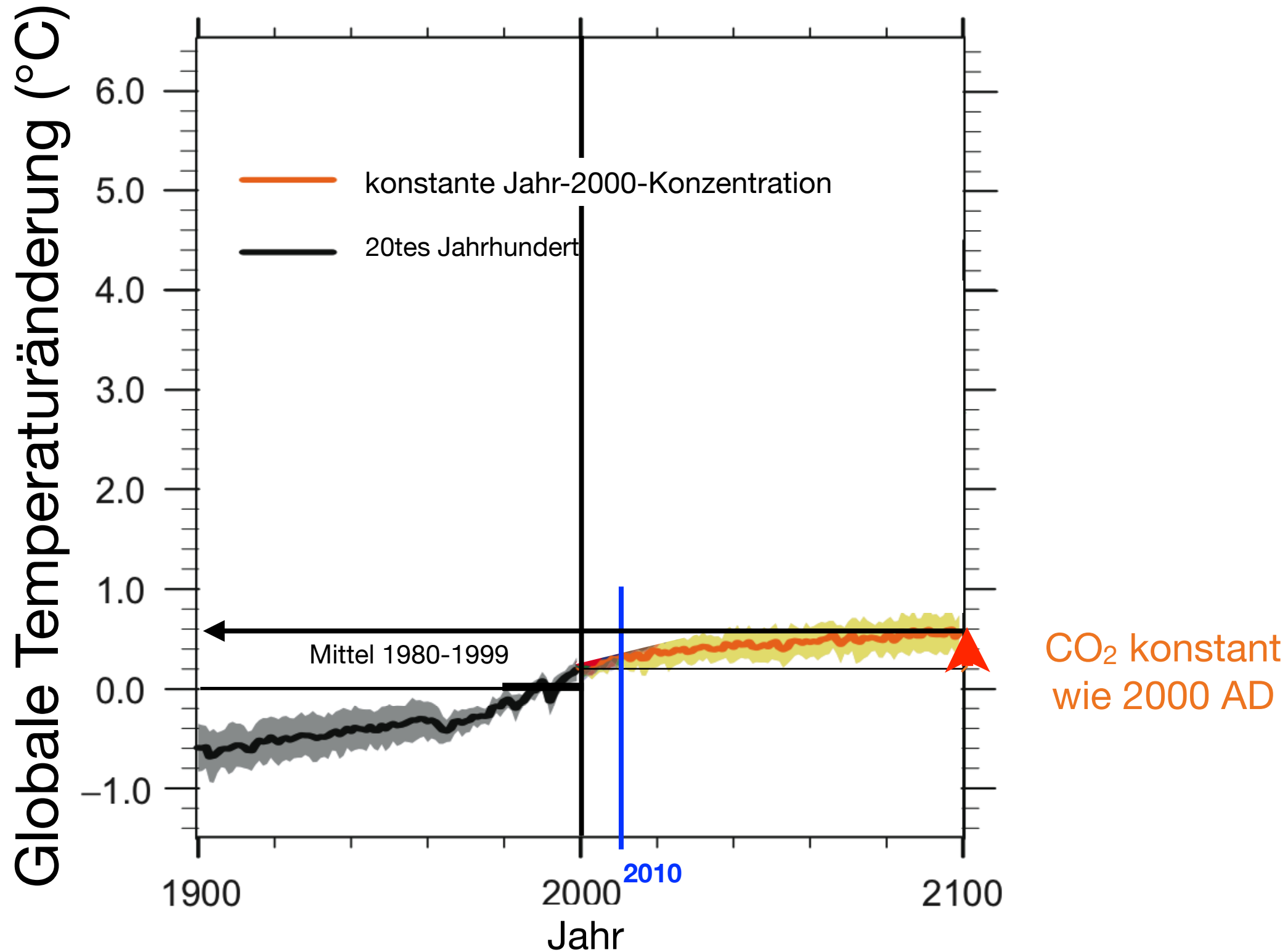
Quelle: IPCC, Climate Change 2007: The Physical Basis, Summary for Policy Makers (www.ipcc.ch)

Klimaänderung: Vergangenheit, Gegenwart und Zukunft

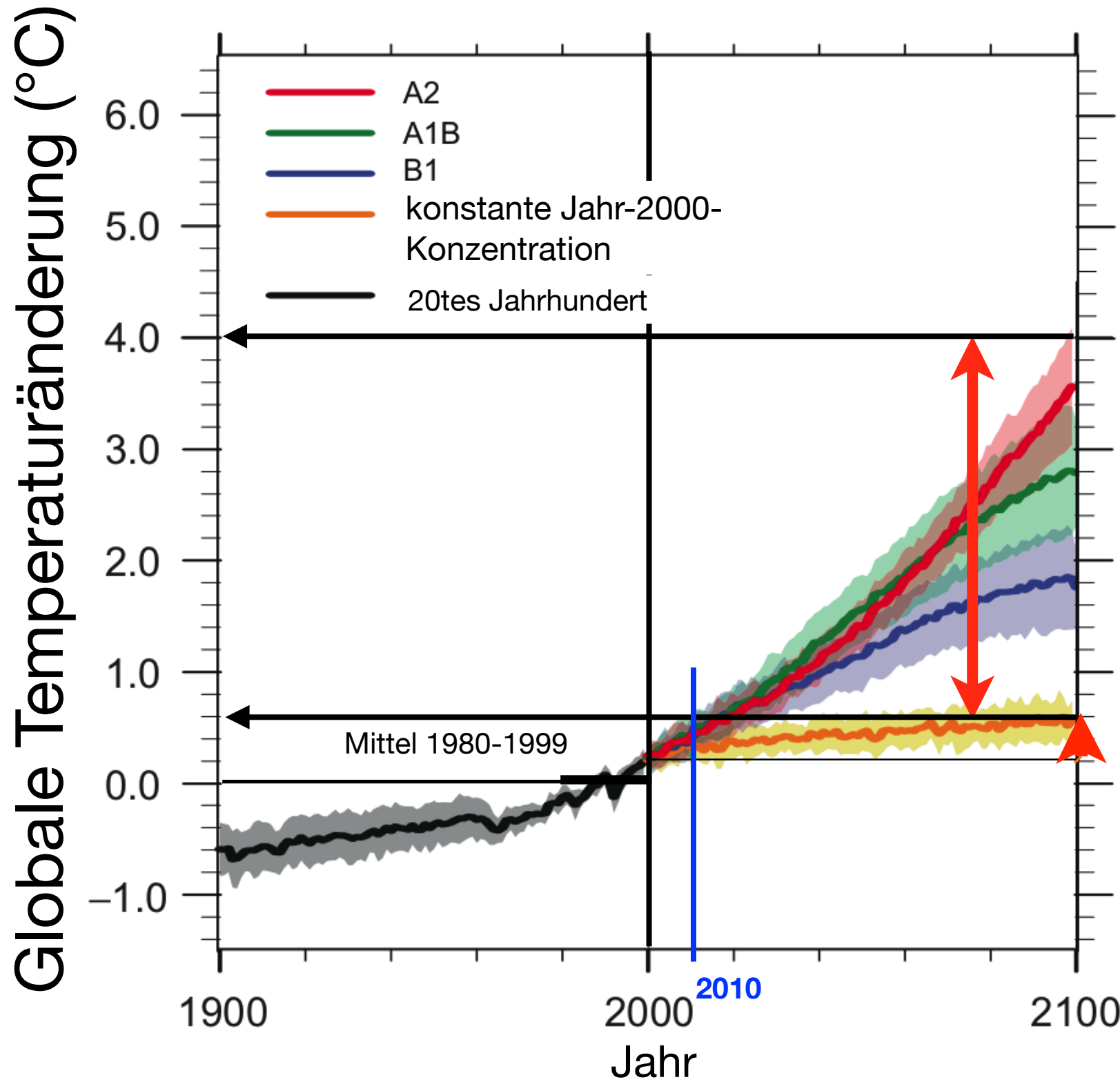


Informationen basierend auf IPCC- Report 2007: Möglicher Bereich für Temperaturerhöhung

source: IPCC, Climate Change 2007: The Physical Basis, Summary for Policy Makers (www.ipcc.ch)



Informationen basierend auf IPCC- Report 2007: Möglicher Bereich für Temperaturerhöhung

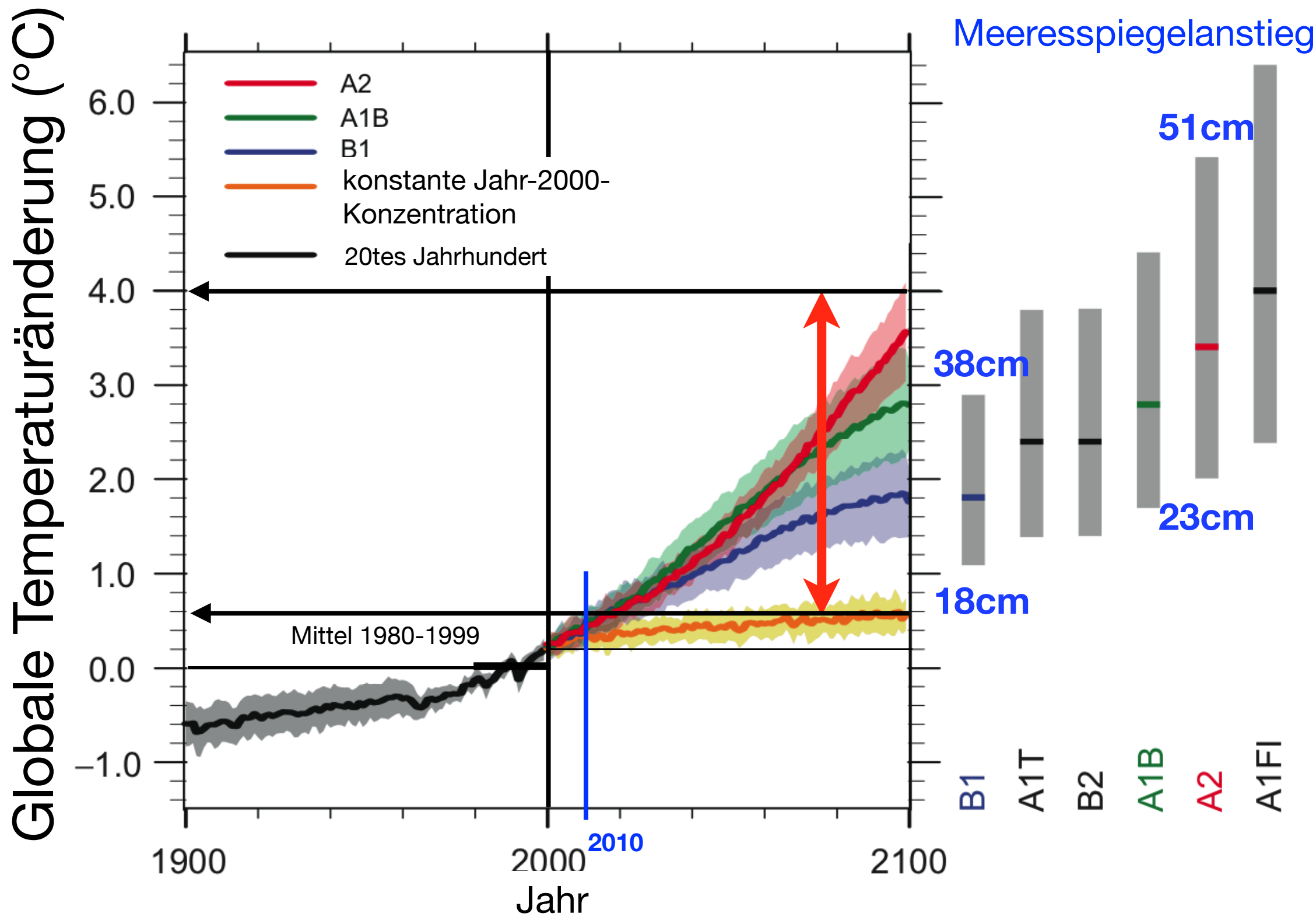


CO₂ konstant wie 2000 AD

Quelle: IPCC, Climate Change 2007: The Physical Basis, Summary for Policy Makers (www.ipcc.ch)

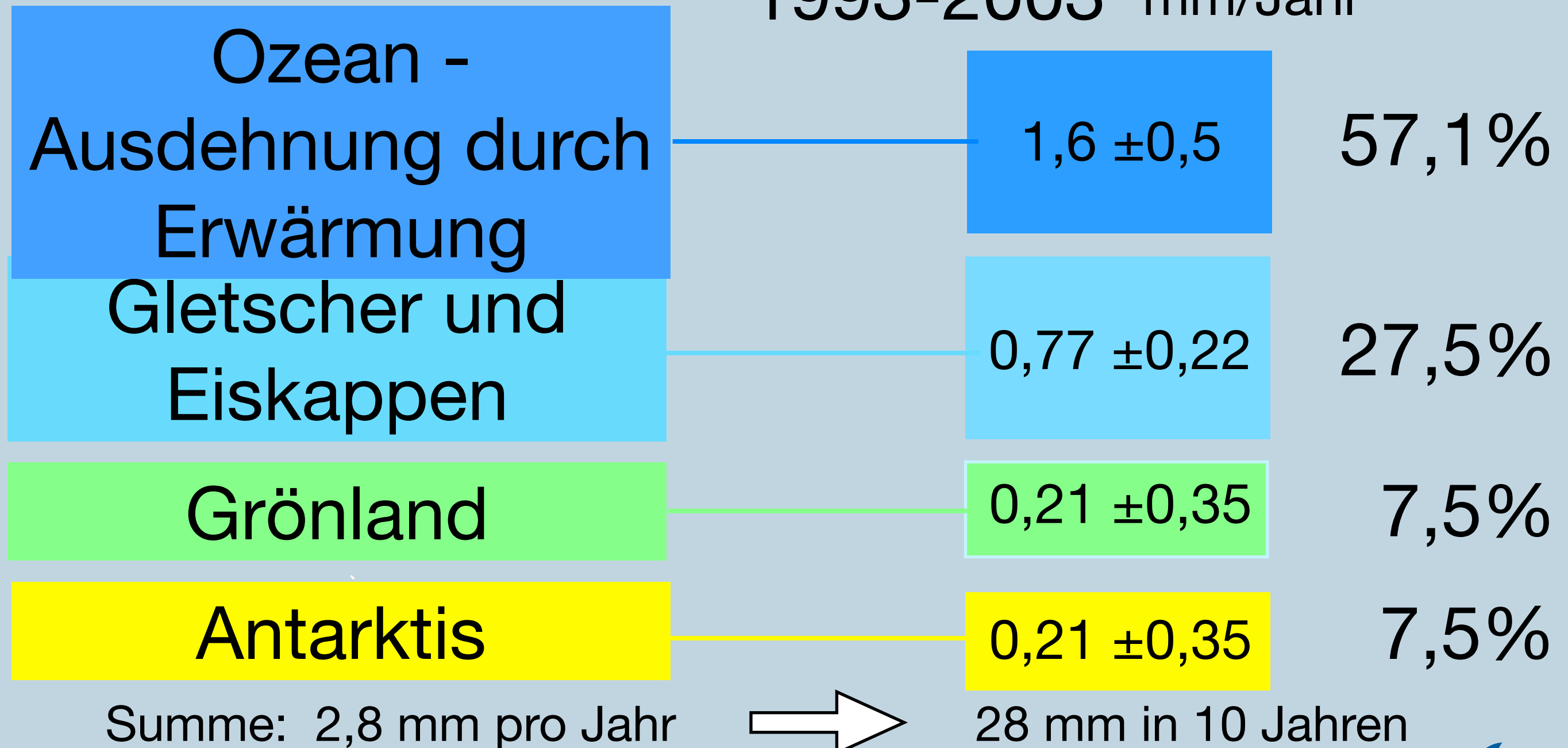
Informationen basierend auf IPCC- Report 2007: Möglicher Bereich für Temperaturerhöhung

Quelle: IPCC, Climate Change 2007: The Physical Basis, Summary for Policy Makers (www.ipcc.ch)

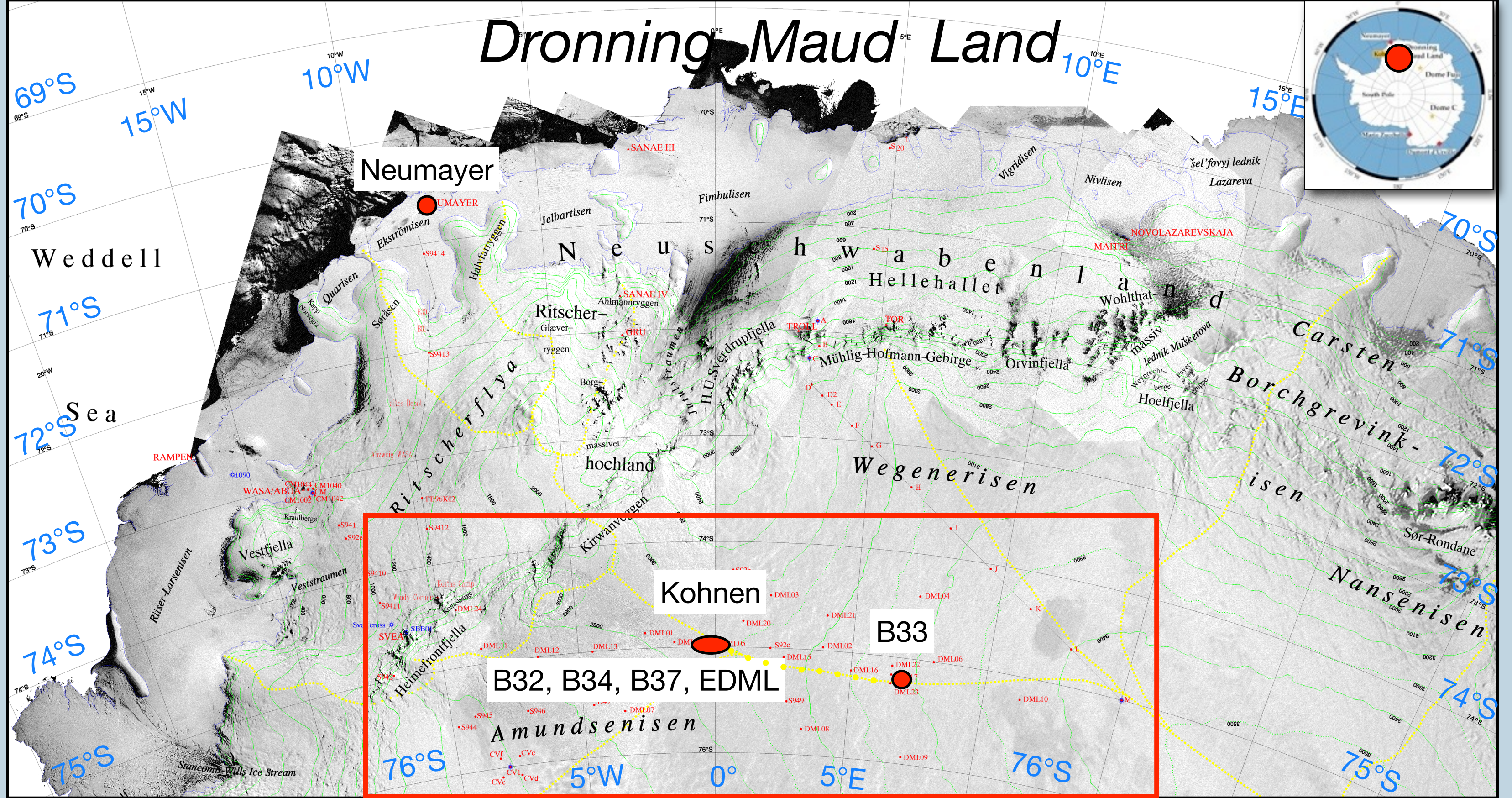


Information aus IPCC-Report 2007: Was verursacht Meeresspiegelanstieg ?

1993-2003 mm/Jahr



Dronning Maud Land



Satellite Image Map Dronning Maud Land 1:2000000, Draft Vers.4.2, BKG, Frankfurt am Main, Nov.1998 (detail)

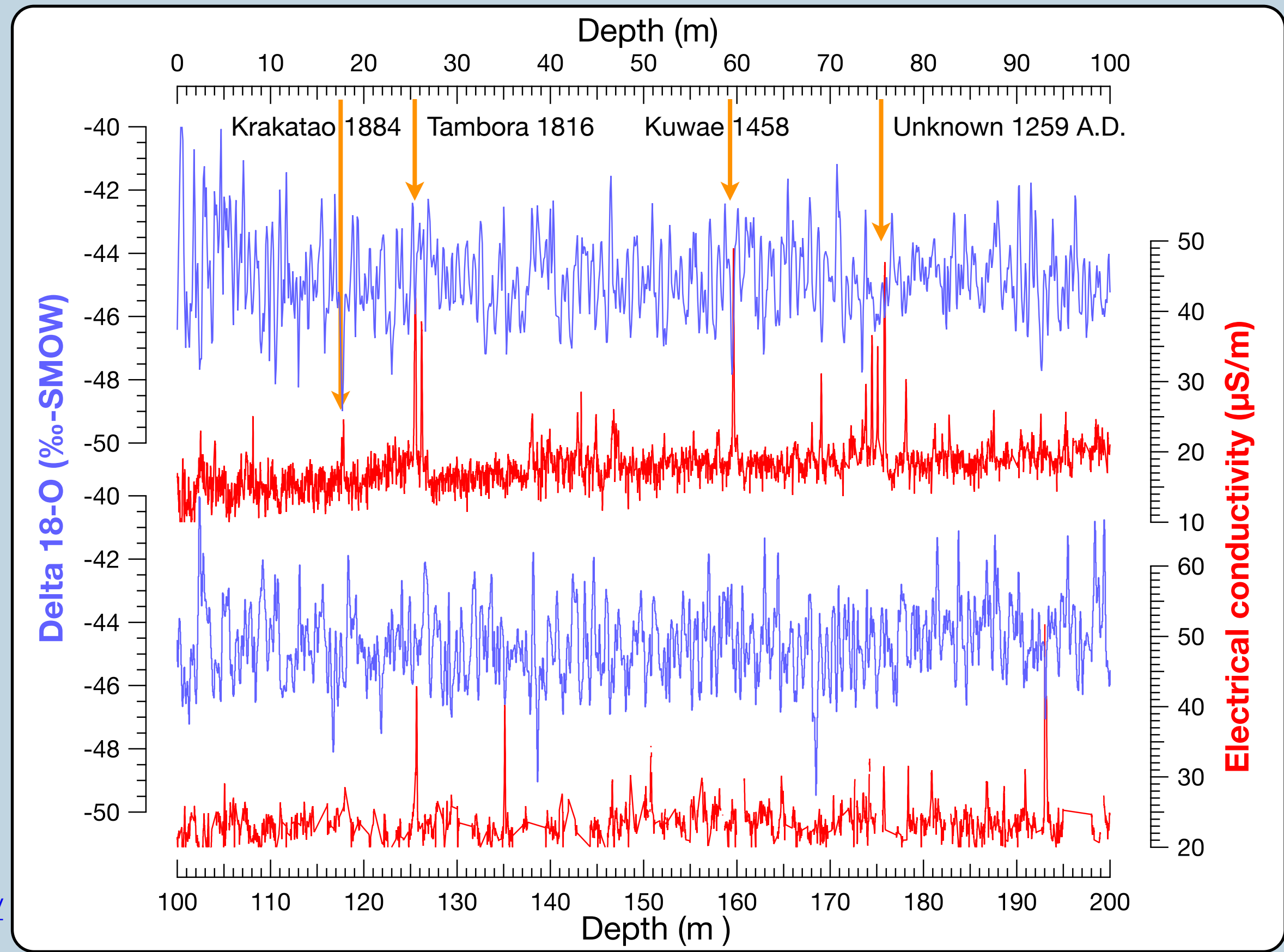


Beispiel für Eiskern- untersuchungen: $\delta^{18}\text{O}$ und di-electric profiling (DEP)

Eiskern B34

Bohrdatum: Jan. 2004
 Länge.: 0.0669° E
 Breite: -75.0008° S
 Höhe: 2882 m ü.Meer
 ca. 200m W von EDML
 Tiefe: 200.5 m
 Akkum.-Rate: 65mm kg m⁻²a⁻¹
 Mittl. Temperatur: -44.6 °C
 Probenlänge für $\delta^{18}\text{O}$:
 0-50m: 10 cm
 50-100m: 6.67 cm
 100-200m: 5 cm

Vulkanchronologie nach Kern B32. Traufetter et al., J.Glac. **50**, 137-146 (2004); [doi:10.1594/PANGAEA.104881](https://doi.org/10.1594/PANGAEA.104881)



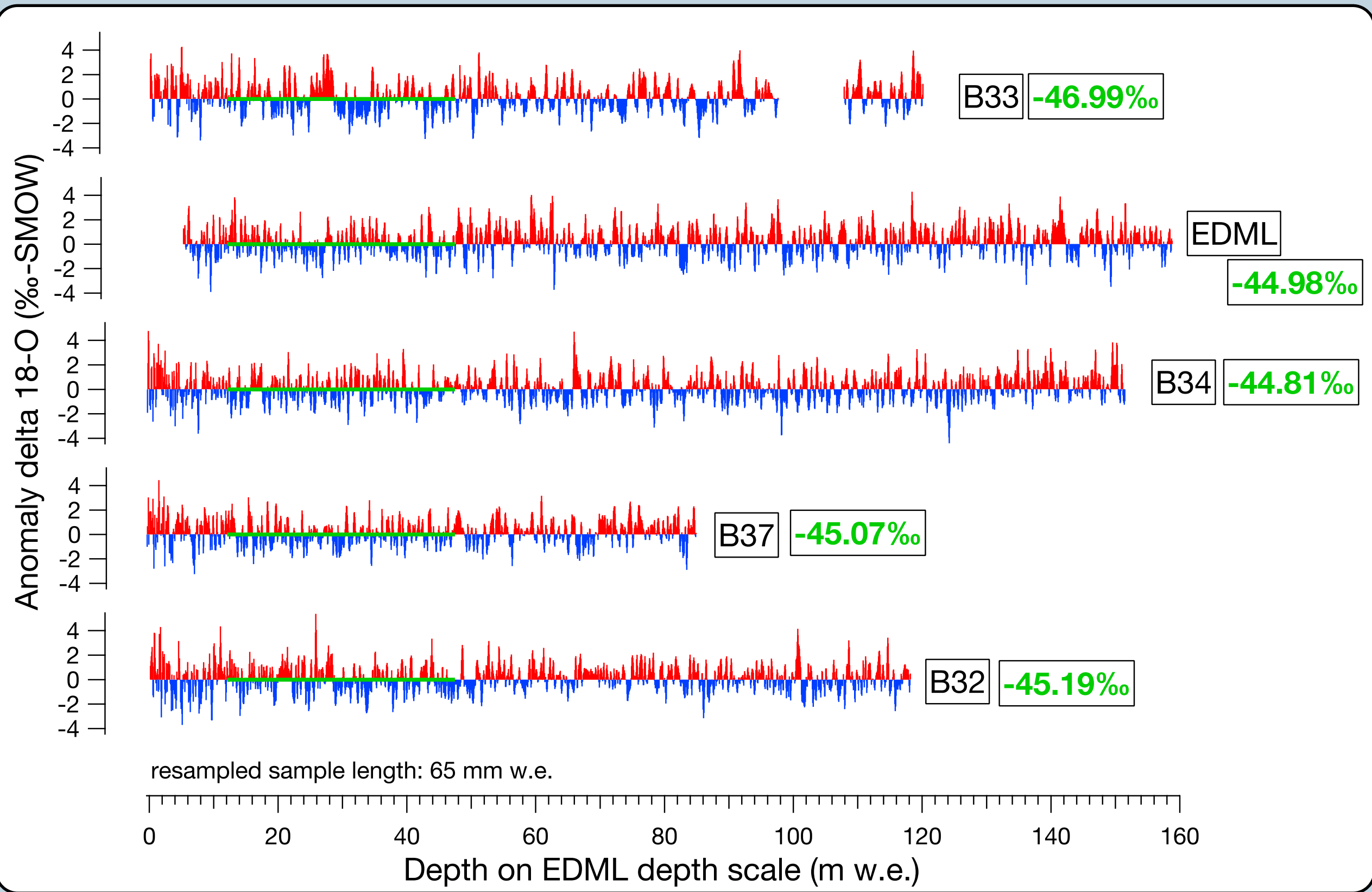


Abweichung $\delta^{18}\text{O}$ vom Mittelwert für 1259-1816 A.D.

Urspr. Tiefenauflösung:
 0-50m:
 10cm (35-70mm WW)
 50-100m:
 6.7cm (47-56mm WW)
 >100m:
 5cm (42-45mm WW)

vereinheitlichtes
 Probenintervall 65 mm WW

0 = mean 1259-1816 A.D.



¹⁸O Daten B32 von Graf et al., Ann. Glac. **35**, 195-201 (2002); doi:10.1594/PANGAEA.104862.



EDML-Eiskern

DML Stapel

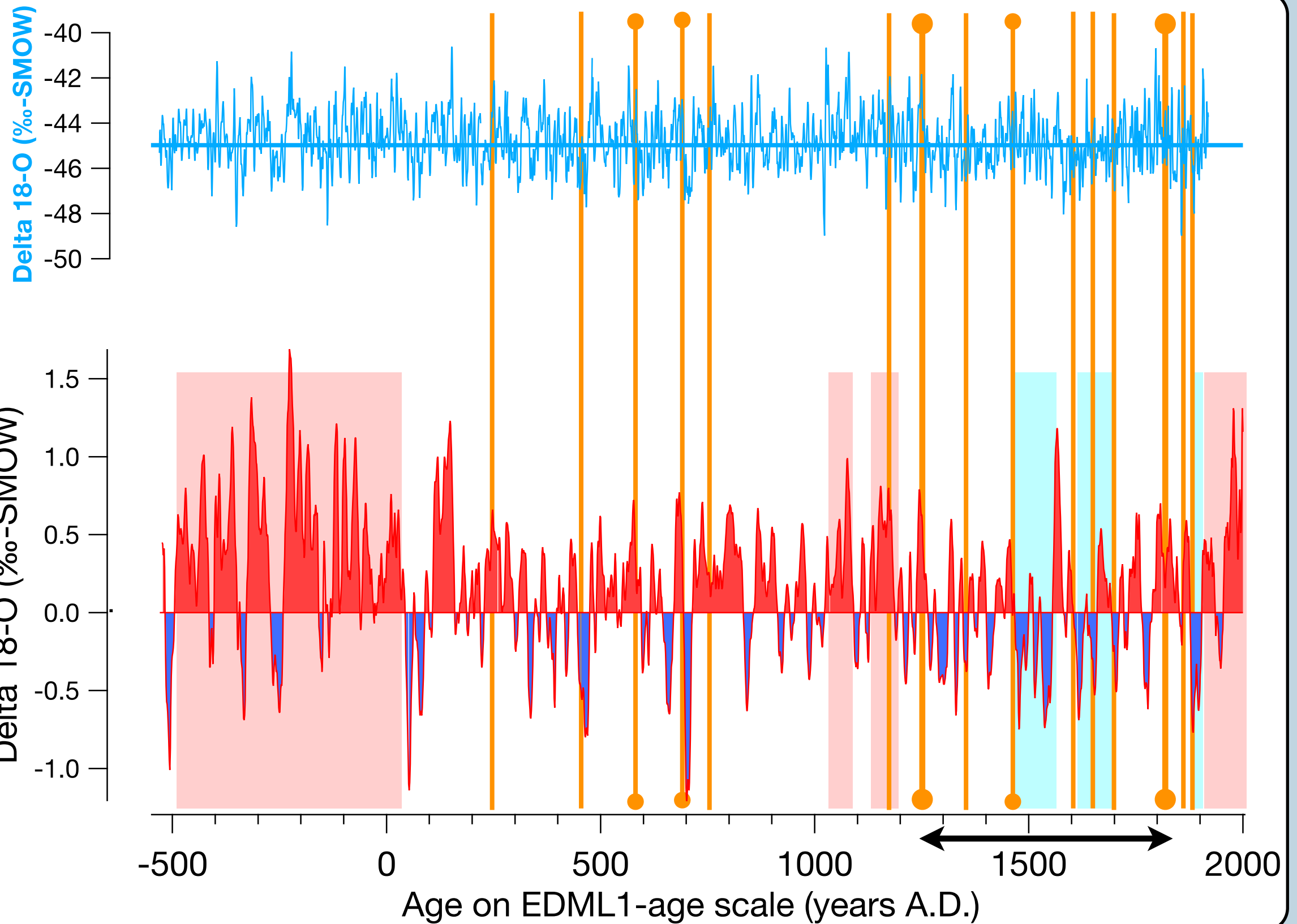
B32, B34, B37,
EDML, B33

0 = Mittel 1259-1816 A.D.

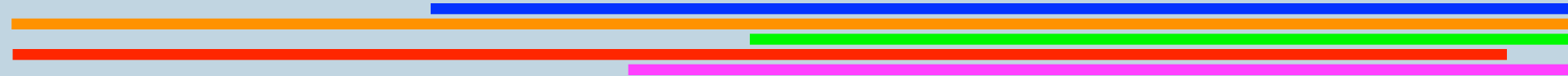
Probenintervall 65mm WW

Gleitendes Mittel 11 Pr.

Temperaturgradient:
0.7 ‰/°C



Time overlap:



Stapelung (11 Kerne) Jahresmittel

Abweichung vom
Mittel 1801-1997:

1801-1905:

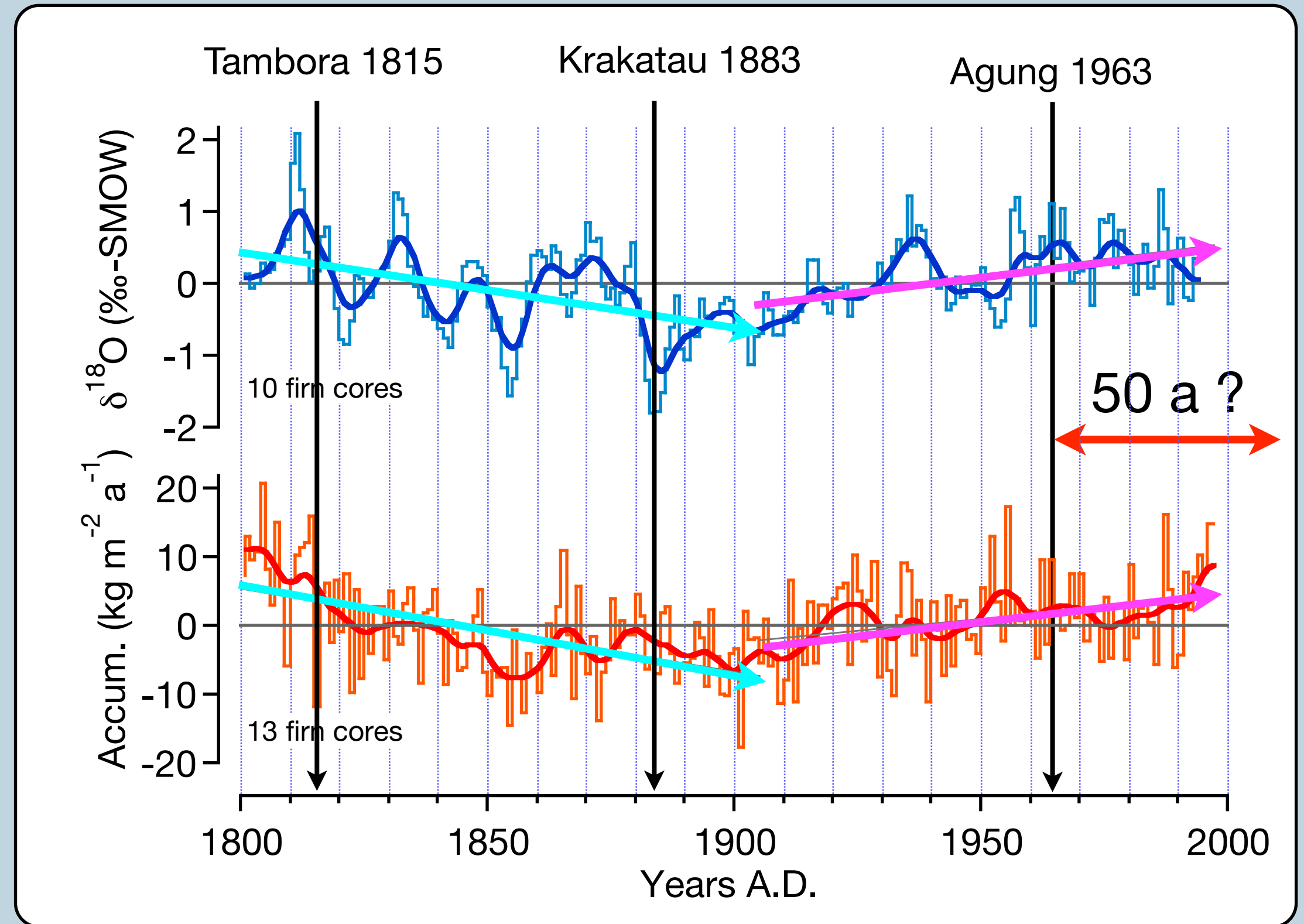
$\delta^{18}\text{O}$: -0.010 ‰/a

Acc.: $-0.120 \text{ kg m}^{-2}\text{a}^{-1}/\text{a}$

1905-1997:

$\delta^{18}\text{O}$: $+0.009 \text{ ‰/a}$

Acc.: $+0.068 \text{ kg m}^{-2}\text{a}^{-1}/\text{a}$

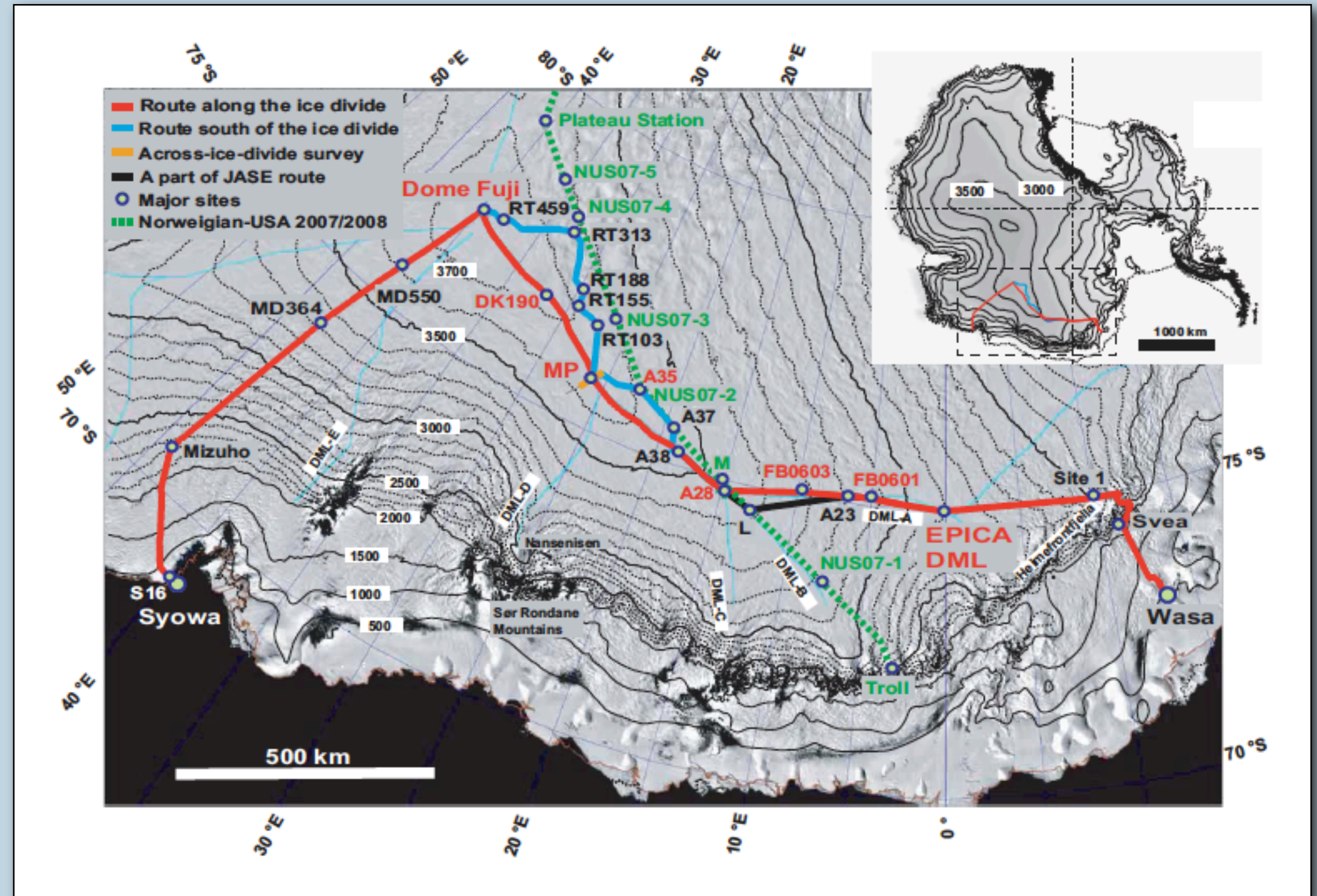


Oerter et al.: Accumulation rates in Dronning Maud Land, Antarctica, as revealed by dielectric-profiling measurements of shallow firn cores. *Annals of Glaciology* **30**, 27-34 (2000)

JASE 2007/08

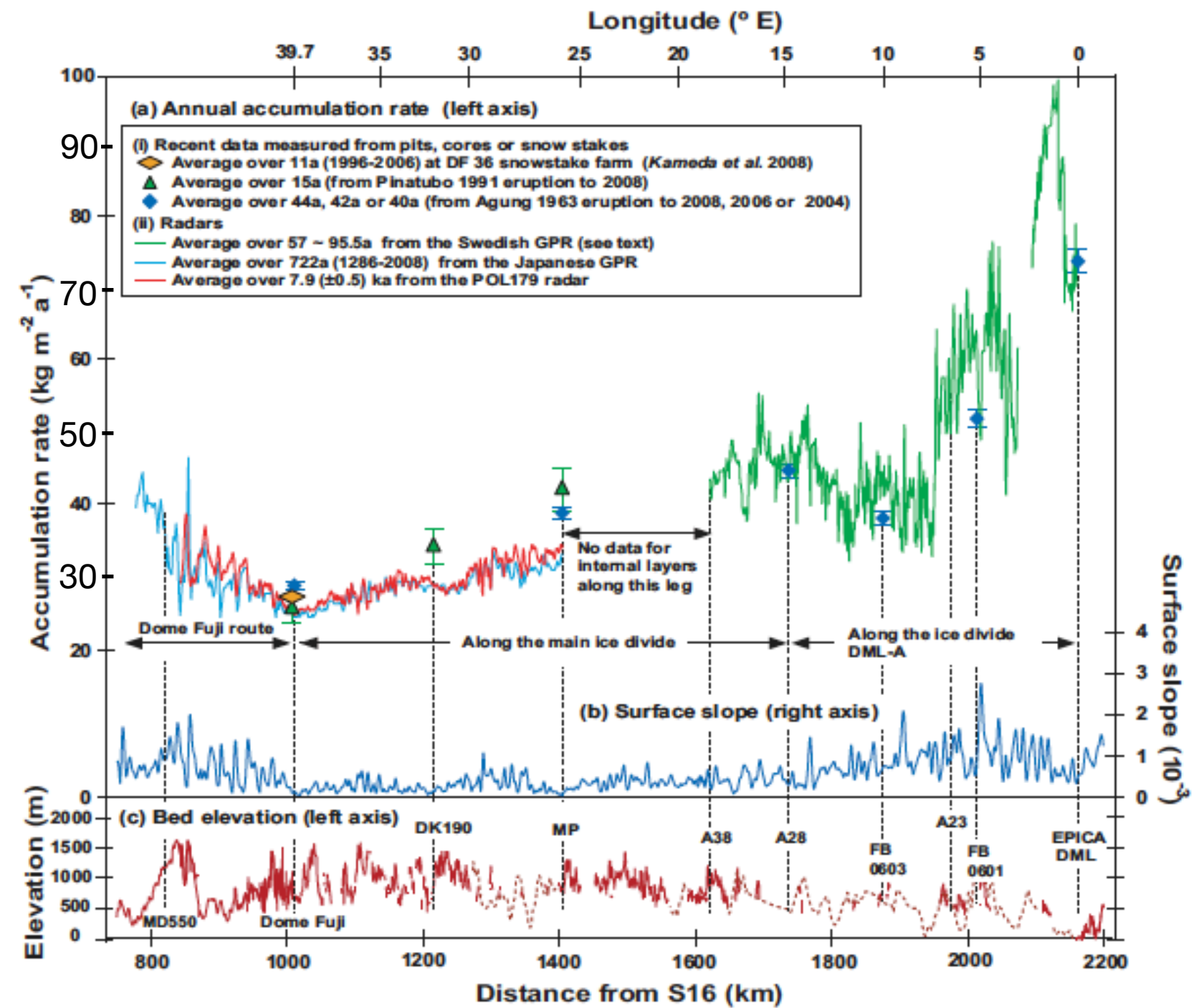
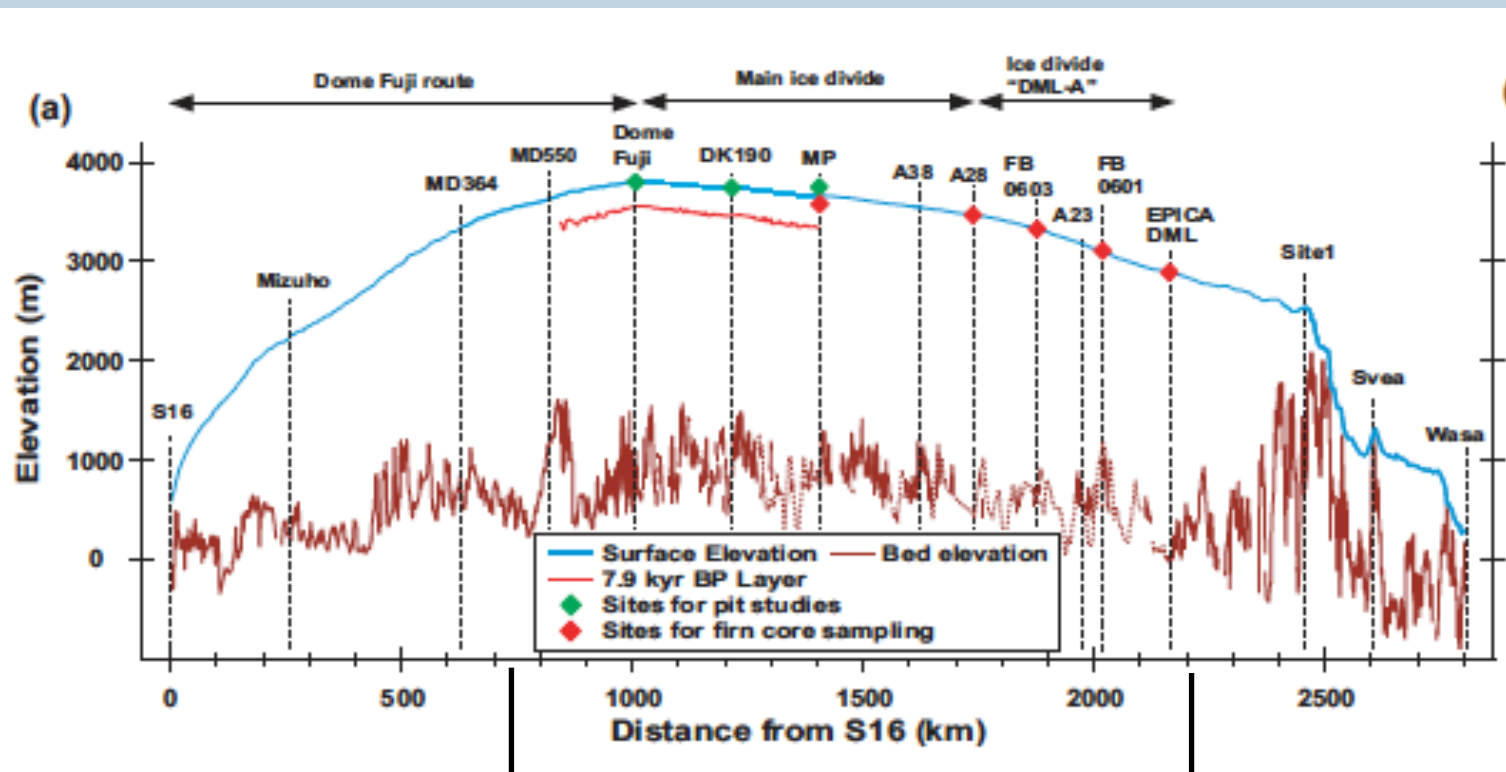
Japanese Swedish
Antarctic Expedition
across Dronning
Maud Land (DML)
im Südsommer
2007/2008

2800 km Länge



S. Fujita et al. (2011): Snow accumulation in Dronning Maud Land, East Antarctica. *The Cryosphere*, 5, 1057–1081.
www.the-cryosphere.net/5/1057/2011/

Japanese Swedish Antarctic Expedition across Dronning Maud Land (DML)



S. Fujita et al. (2011): Snow accumulation in Dronning Maud Land, East Antarctica. *The Cryosphere*, 5, 1057–1081. www.the-cryosphere.net/5/1057/2011/

- Eis ist ein Archiv für Veränderung von Temperatur und Gasgehalten
- Eis-Archiv in Grönland 123.000 Jahre, in der Antarktis 800.000 Jahre
- Treibhausgehalte heute erheblich höher als die, die man im Eis in der Vergangenheit nachweisen kann.
- „Global change“ in der Ostantarktis bisher nur schwer erkennbar
- Globus verträgt Klimaveränderung, aber welche Auswirkungen haben diese auf die Menschen ?