

Fizyka Procesów Klimatycznych

Paleoklimatologia

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AKTUALNOŚCI

Paleoklimatologia: o co w tym w ogóle chodzi?

7 SIERPNIA 2017 - 8 MINUT CZYTANIA

SHARE



„Kto mierzył koncentracje dwutlenku węgla w atmosferze dwa tysiące lat temu?”, „Skąd znamy temperaturę z czasów, gdy nie było jeszcze termometrów?” – podobne pytania nurtują wielu czytelników Wykopu, Wirtualnej Polski i innych portali. Pomoże na nie odpowiedzieć nasz nowy cykl artykułów, którego bohaterką jest paleoklimatologia, czyli badania dawnego klimatu Ziemi.

Cykl artykułów o metodach paleoklimatologii:

[Paleoklimatologia: o co w tym w ogóle chodzi?](#)

[Co nam powie skład izotopowy węgla](#)

[Izotopy tlenu a temperatura](#)

[Aktywność słoneczna i radioaktywne izotopy](#)

[Sekrety rdzeni lodowych](#)

[CO₂ – jeśli nie rdzenie lodowe, to co?](#)

[Drzewa, korale i stalaktyty](#)

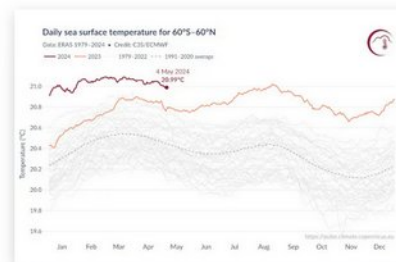
Zostań naszym fanem

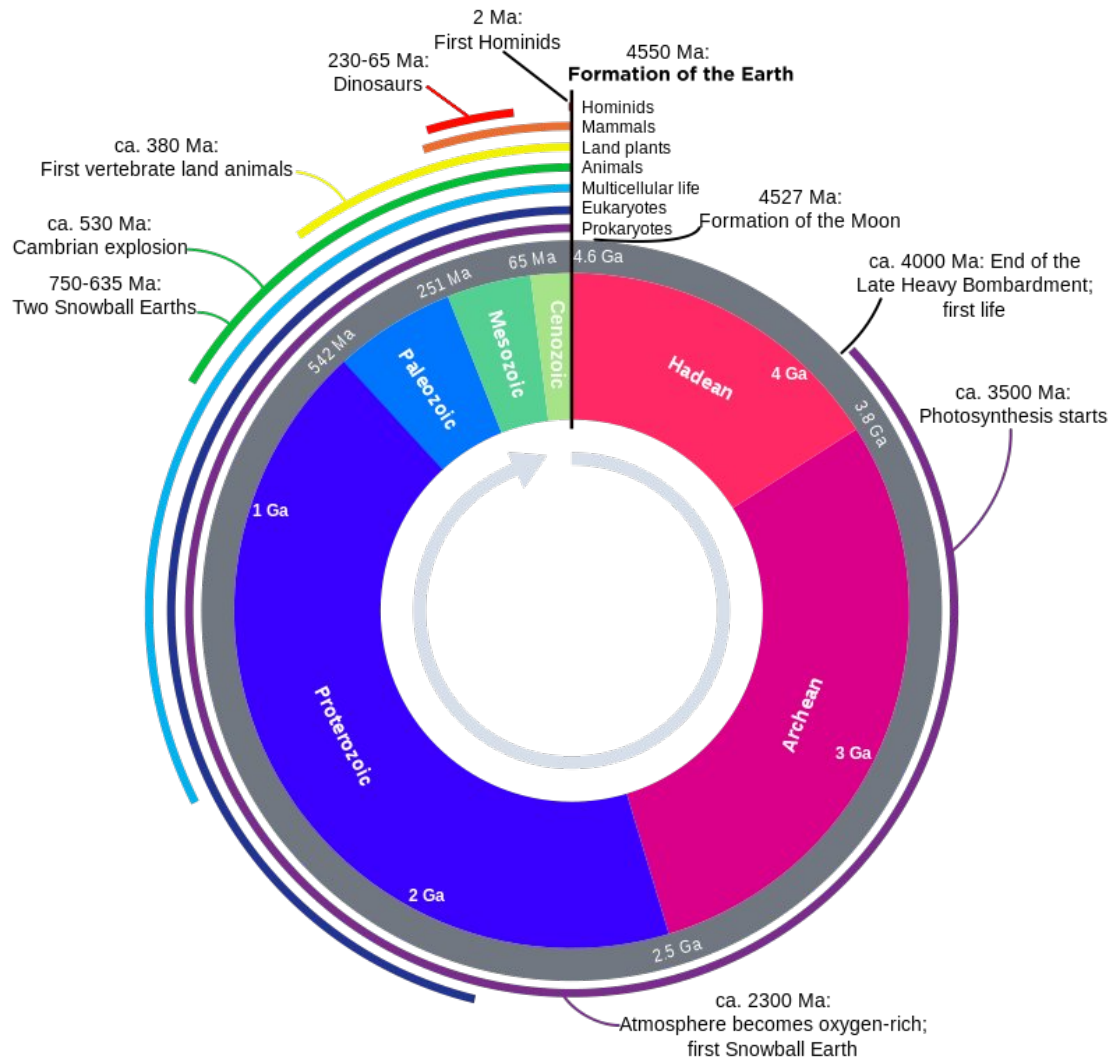


Wspieraj na Patronite.pl

Wykres na dziś

Temperatura powierzchni morza – rok rekordów



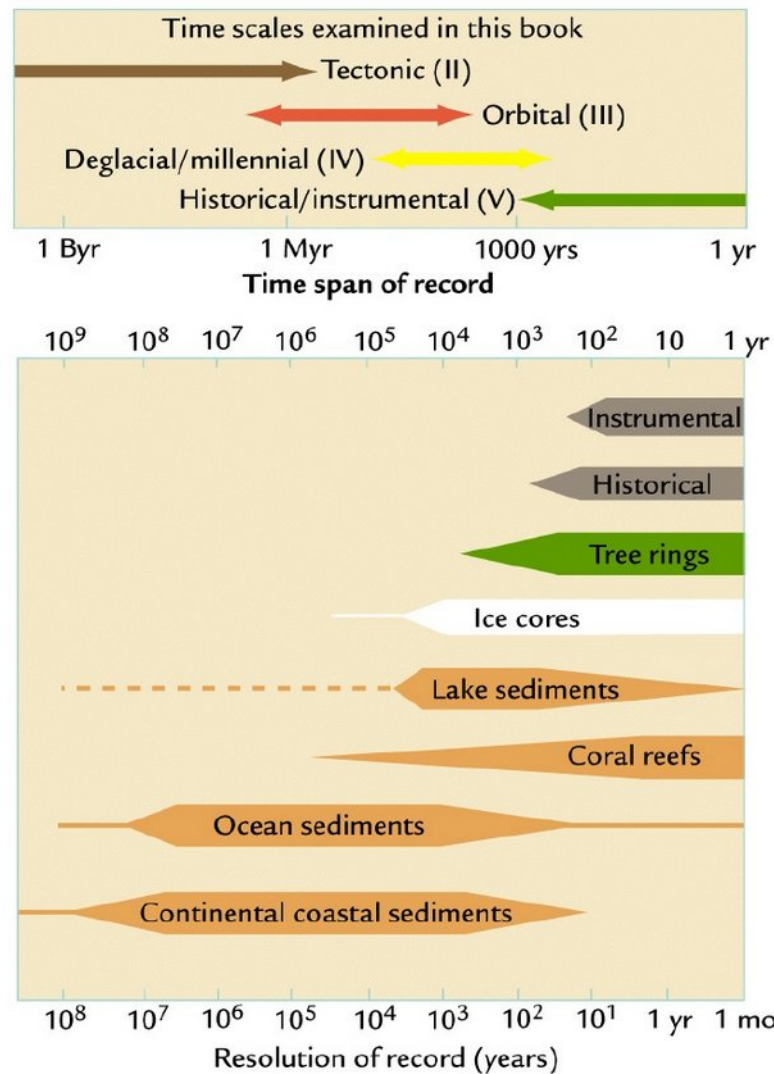


Dane z przeszłości:

- z pomiarów

- z zapisków historycznych

- proxy



Layers Results

NOTE: Visit Paleo Search for additional data not shown on this map.

Paleo Networks

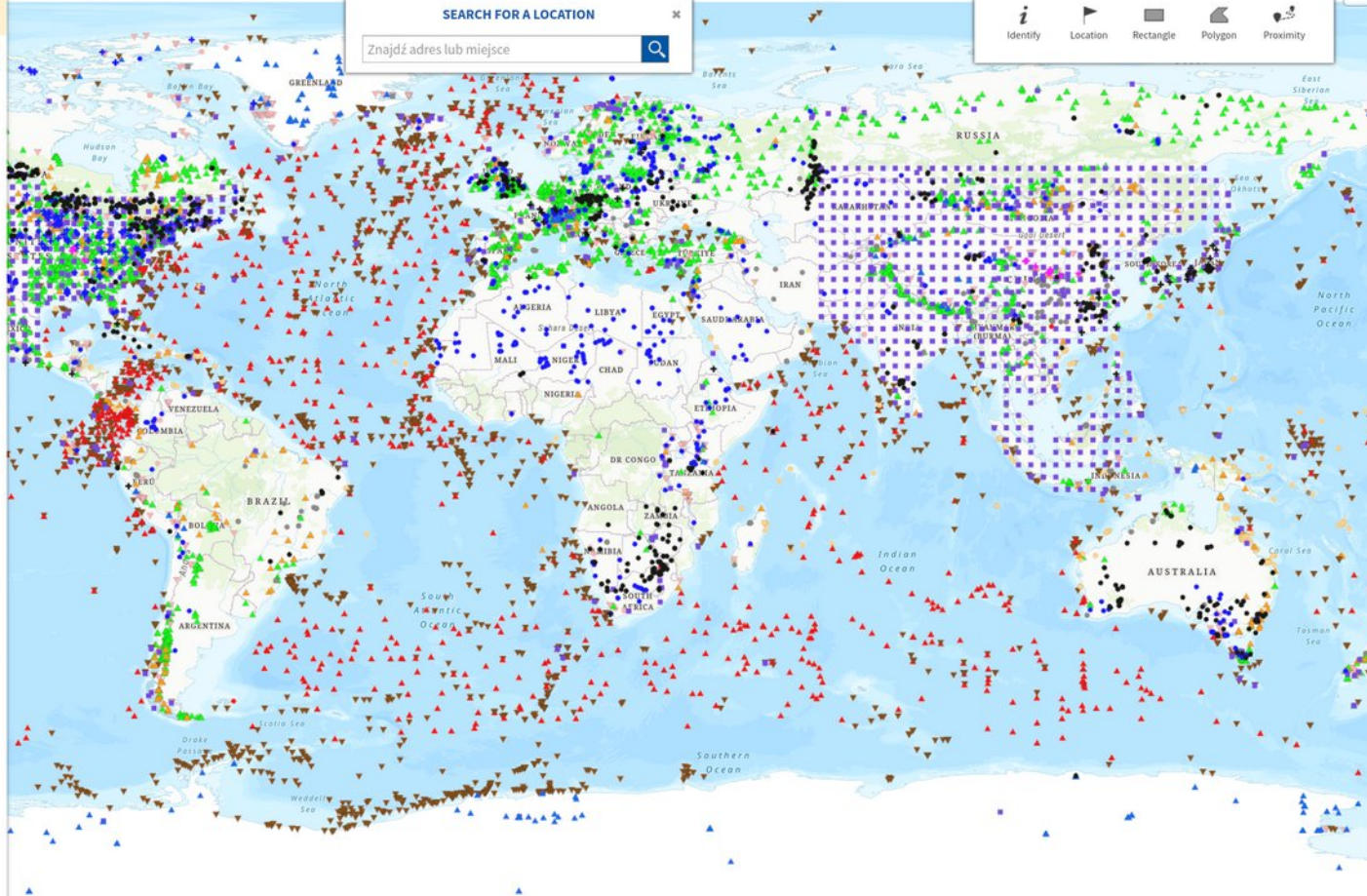
- ☒ Borehole •
- ☒ Climate Reconstructions ■
- ☒ Coral ○
- ☒ Historical +
- ☒ Ice Core ▲
- ☒ Insect ■
- ☒ Lake Level ●
- ☒ Loess *
- ☒ Macrofossil +
- ☒ Ocean (CLIMAP) ▲
- ☒ Ocean (non-CLIMAP) ▼
- ☒ Paleofire ▲
- ☒ Paleolimnology ▼
- ☒ Pollen ●
- ☒ Speleothem •
- ☒ Tree Ring ▲
- ☒ Other Collections ○

SEARCH FOR A LOCATION

Znajdź adres lub miejsce

PALEO NETWORKS TOOLS

- Identify Location Rectangle Polygon Proximity



(lat: 0433° Long: 45331°)

100km
100mi

Dating methods

- 1.1 Radiometric dating
- 1.2 Fission-track dating
- 1.3 Cosmogenic nuclide geochronology
- 1.4 Luminescence dating
- 1.5 Incremental dating
- 1.6 Paleomagnetic dating
- 1.7 Magnetostratigraphy
- 1.8 Chemostratigraphy
- 1.9 Correlation of marker horizons

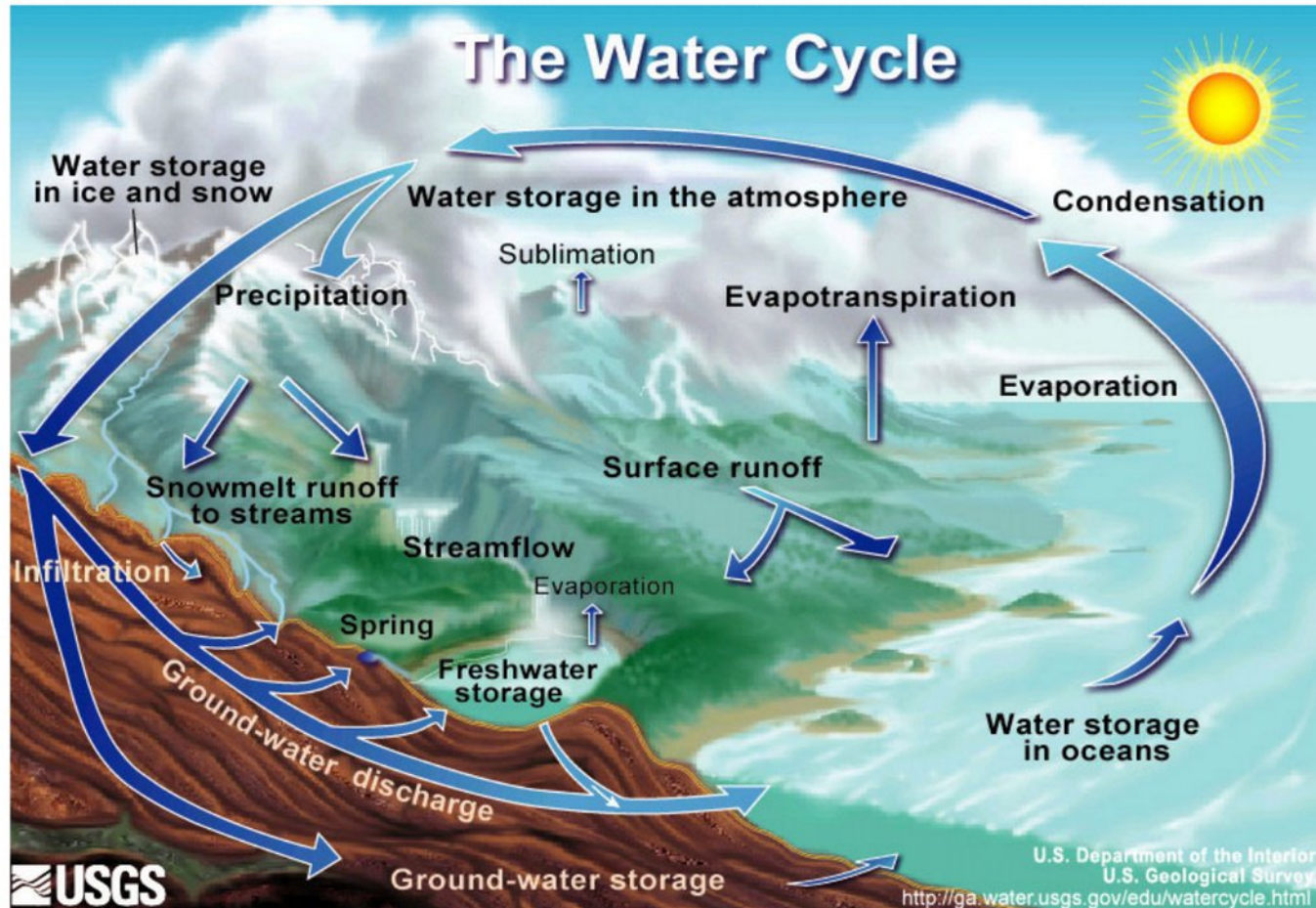
Radiometric dating

TABLE 3-1 Radioactive Decay Used to Date Climate Records

Parent isotope	Daughter isotope	Half-life	Useful for ages:	Useful for dating:
Rubidium-87 (⁸⁷ Rb)	Strontium-87 (⁸⁷ Sr)	47 Byr	100 Myr	Granites
Uranium-238 (²³⁸ U)	Lead-206 (²⁰⁶ Pb)	4.5 Byr	>100 Myr	Many rocks
Uranium-235 (²³⁵ U)	Lead-207 (²⁰⁷ Pb)	0.7 Byr	>100 Myr	Many rocks
Potassium-40 (⁴⁰ K)	Argon-40 (⁴⁰ Ar)	1.3 Byr	>100,000 years	Basalts
Thorium 230 (²³⁰ Th)	Radon-226* (²²⁶ Ra)	75,000 years	<400,000 years	Corals
Carbon-14 (¹⁴ C)	Nitrogen-14* (¹⁴ N)	5,780 years	<50,000 years	Anything that contains carbon

**Daughter is a gas that has escaped and cannot be measured.*

$\delta^{18}\text{O}$ - Tracer of the water cycle



$\delta^{18}\text{O}$ - Tracer of the water cycle

- Delta notation:

$$\delta^{18}\text{O} = \left(\frac{\left(\frac{^{18}\text{O}}{^{16}\text{O}} \right)_{\text{sample}}}{\left(\frac{^{18}\text{O}}{^{16}\text{O}} \right)_{\text{standard}}} - 1 \right) * 1000 \text{ ‰}$$

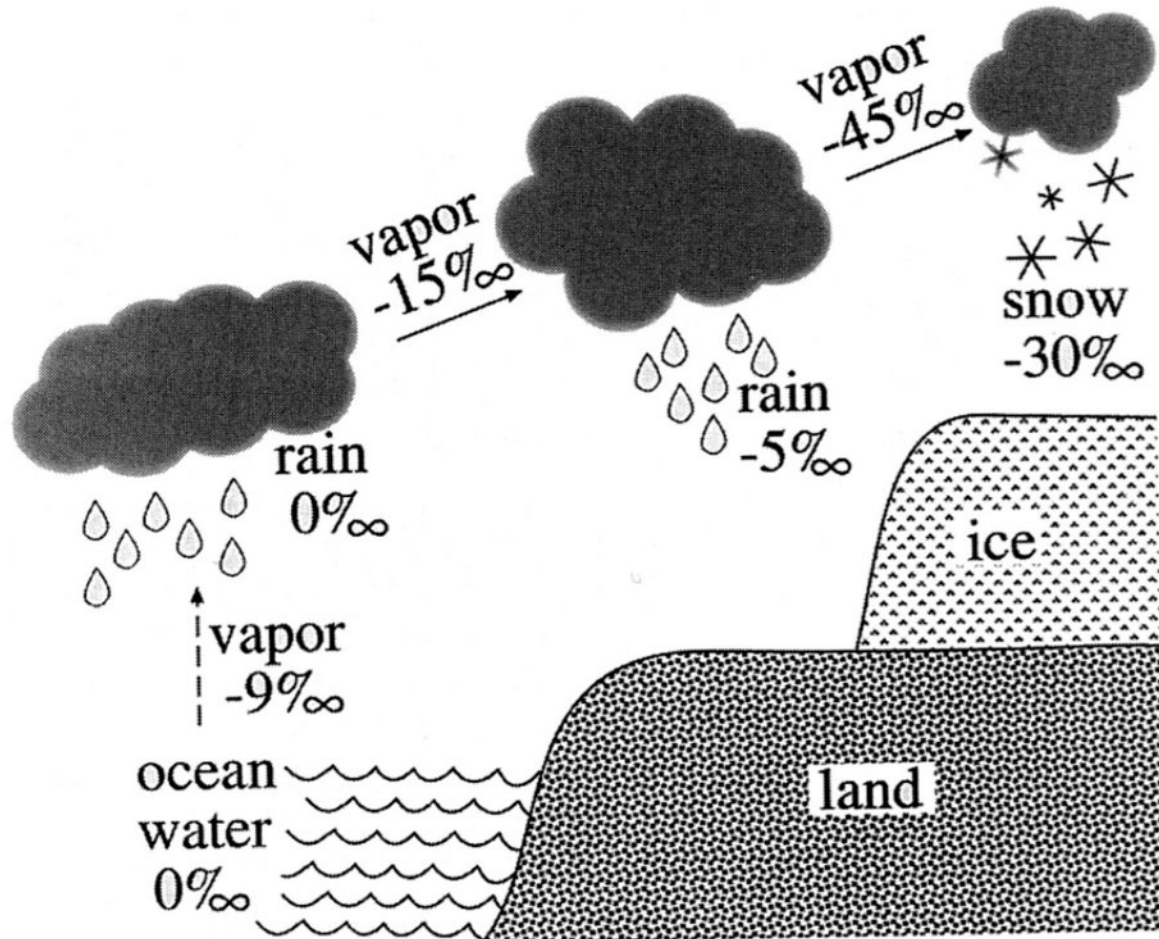
- A positive δ value means that the ratio of the heavy to the light isotope is higher in the sample than it is in the standard
- Units reported as “per mil” or ‰
- Standard:
V-SMOW: Vienna-Standard mean ocean water
or
V-PDB: Vienna - Pee Dee Belemnite

Isotope systematics in the hydrological cycle:

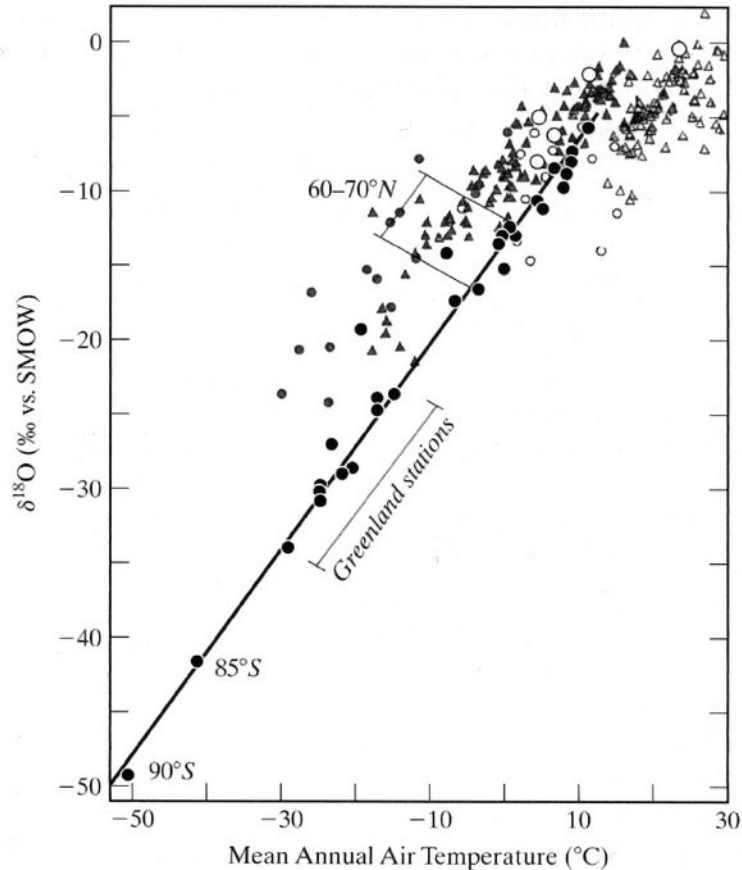
The isotope composition of natural meteoric waters (which form the main reservoirs of freshwater on earth, ice caps, lakes, rivers and groundwater) is determined by three main factors.

- 1) The isotopic composition of the source of the moisture i.e. the ocean, the largest water reservoir on earth.
- 2) Processes of fractionation during evaporation from the ocean.
- 3) Fractionation processes during condensation in the cloud and precipitation to the ground.

Isotope water cycle



Temperature effect

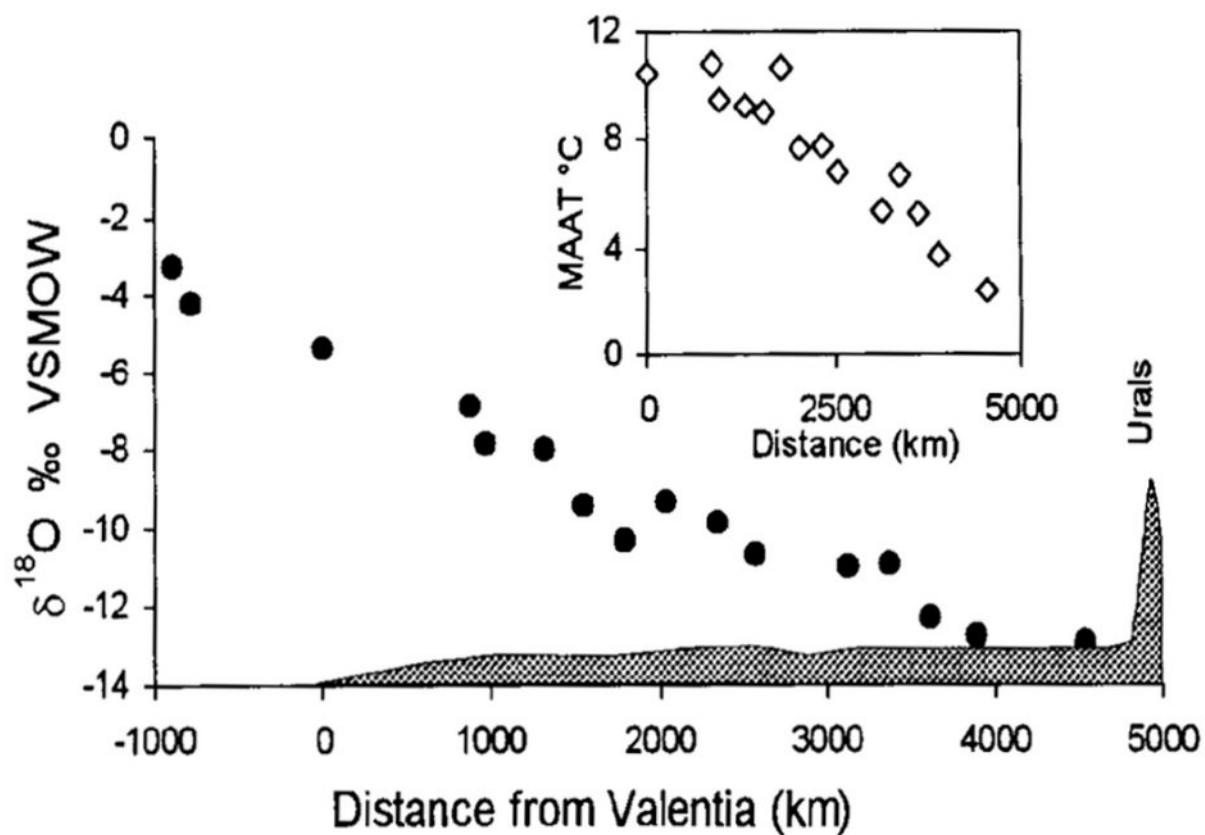


- Strong overall $\delta^{18}\text{O}$ - surface temperature relationship for locations in the extra-tropics
- Can be used for calibrating the $\delta^{18}\text{O}$ record in ice cores

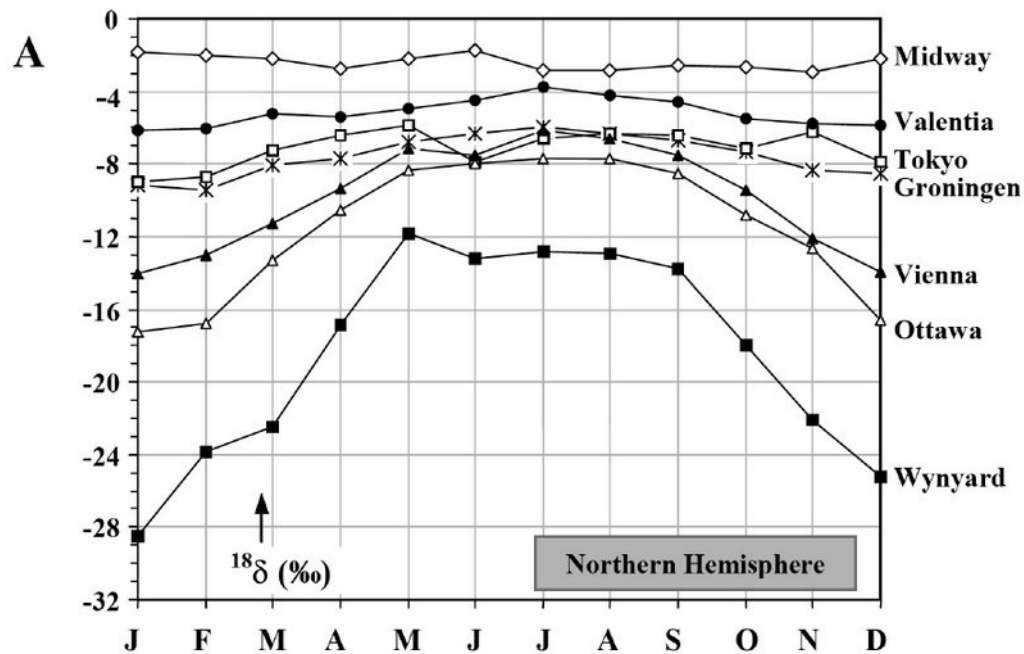
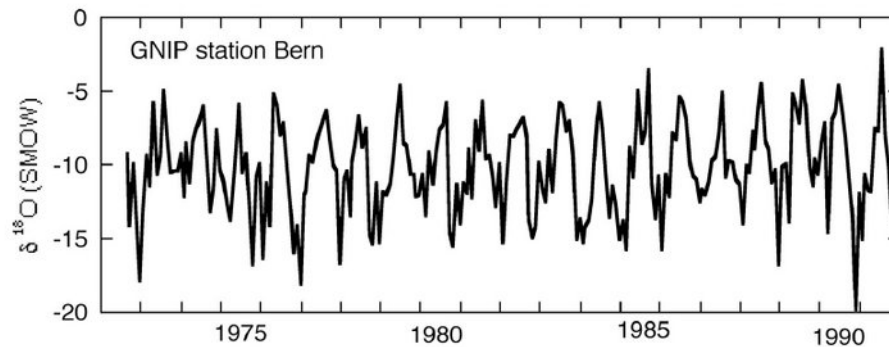
FIGURE 4.12: Effect of mean annual air temperature on the oxygen isotope composition of meteoric precipitation. The effect is largest and most linear at high latitudes, where condensation occurs close to the land surface. Circles are annual data from Dansgaard (1964); open diamonds are summer data, closed diamonds winter data, from Fricke and O'Neil (1999).

From Zachery Sharp, 2007, Principles of stable isotope geochemistry

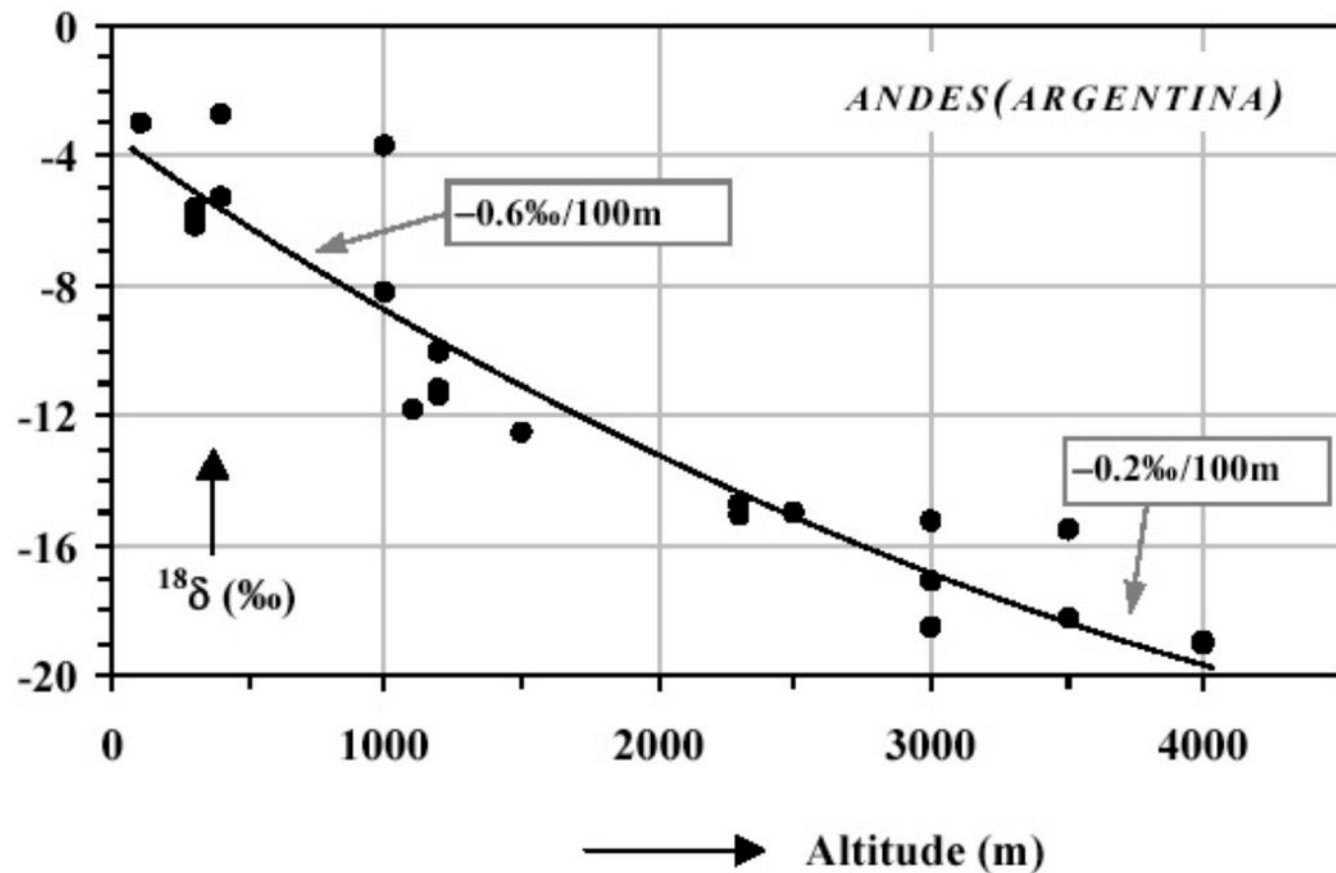
Continental effect



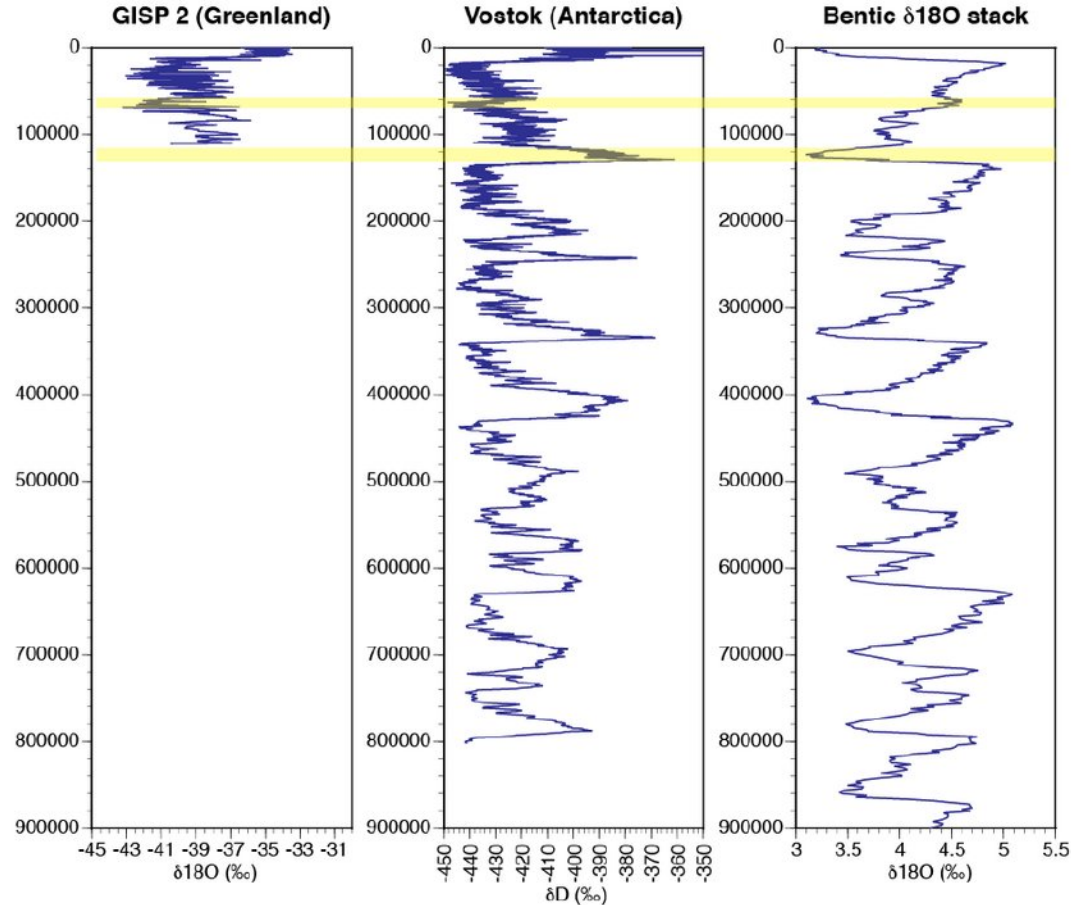
Seasonal effect



Altitude effect



$\delta^{18}\text{O}$ signal in different climate archives



■ H_2^{16}O

Abundance:

- $^{16}\text{O} = 99.7621$
 $^{17}\text{O} = 0.03790$
 $^{18}\text{O} = 0.20004$
- $\text{H} = 99.9844$
 $\text{D} = 0.01557$

$\delta^{18}\text{O}$: Temperature dependence

- Shell material from marine organisms like mussels, brachiopods and snails in different water temperature
- Empirical relationship
- $T(^{\circ}\text{C}) = 16.9 - 4.2(\delta^{18}\text{O}_{\text{C}} - \delta^{18}\text{O}_{\text{W}}) + 0.13(\delta^{18}\text{O}_{\text{C}} - \delta^{18}\text{O}_{\text{W}})^2$
- $T(^{\circ}\text{C}) = 16.5 - 4.80(\delta^{18}\text{O}_{\text{calcite}} - \delta^{18}\text{O}_{\text{water}})$
- 1 per mil shift in $\delta^{18}\text{O}$ (under equilibrium conditions) is equal $\sim 4^{\circ}\text{C}$ temperature shift

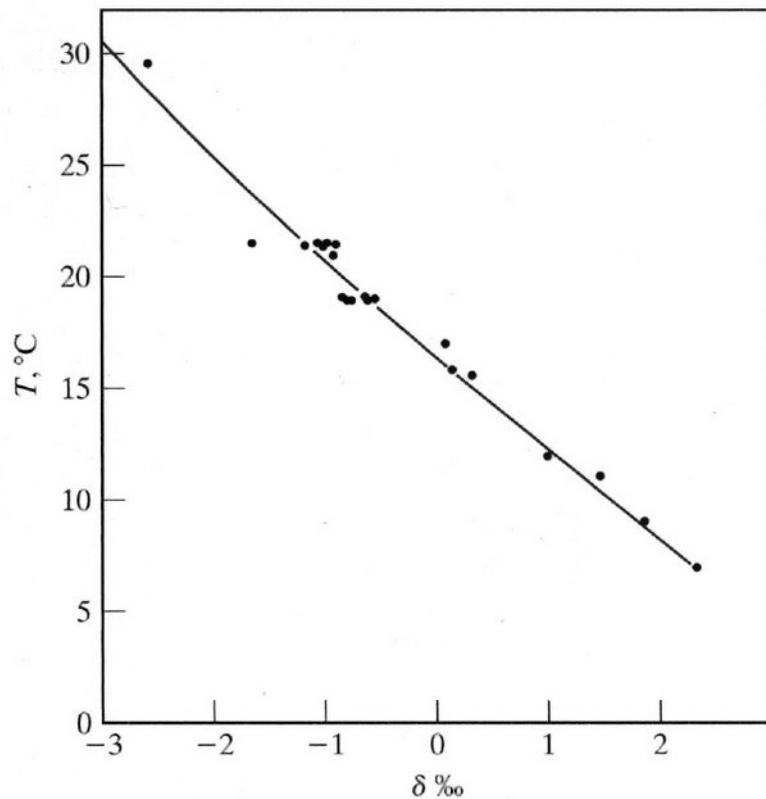
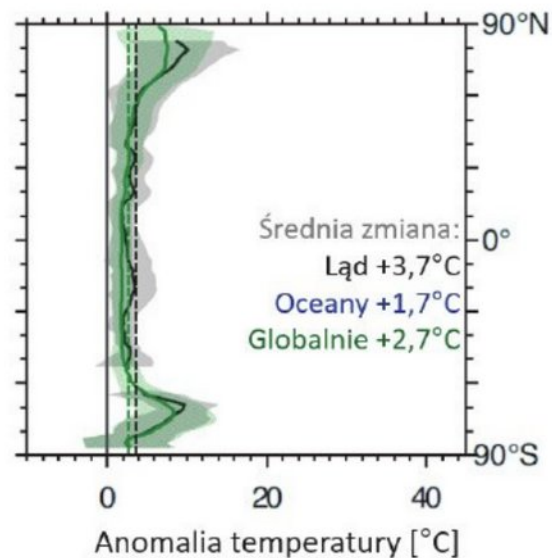
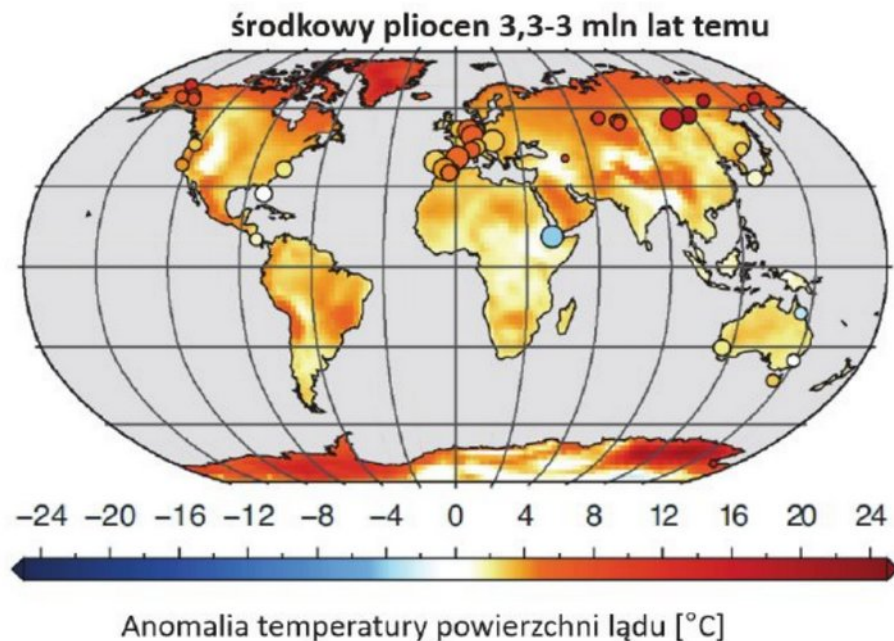
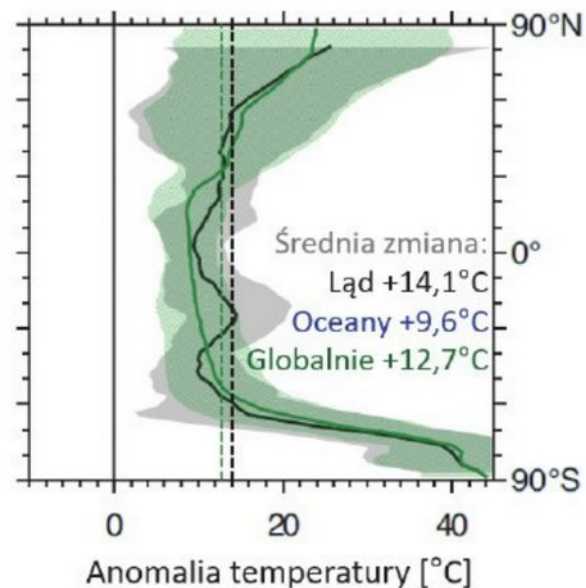
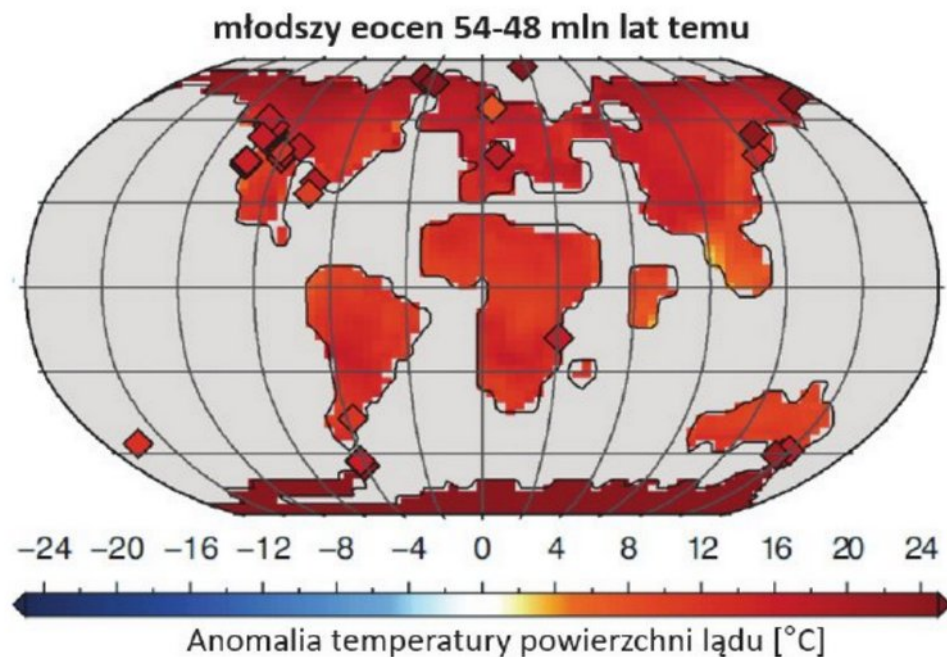


FIGURE 6.2: Plot of Epstein et al.'s (1953) corrected data set for determining the fractionation factor for carbonate–water. The x -axis ($\delta\text{‰}$) refers to the $(\delta_c - \delta_w)$ of equation (6.4), while $T(^{\circ}\text{C})$ is the measured water temperature. Reprinted with permission from the Geological Society of America.



Ilustracja 3.2.2. Anomalie temperatury w środkowym pliocenie, na krótko przed powstaniem lądolodu Grenlandii, względem poziomu z epoki przedprzemysłowej. Na wykresie po prawej stronie czarna linia pokazuje najbardziej prawdopodobne anomalie temperatur na różnych szerokościach geograficznych nad lądami, a zielona globalne; rozmyte pasy pokazują przedział ufności 2σ (prawdopodobieństwo 95%).



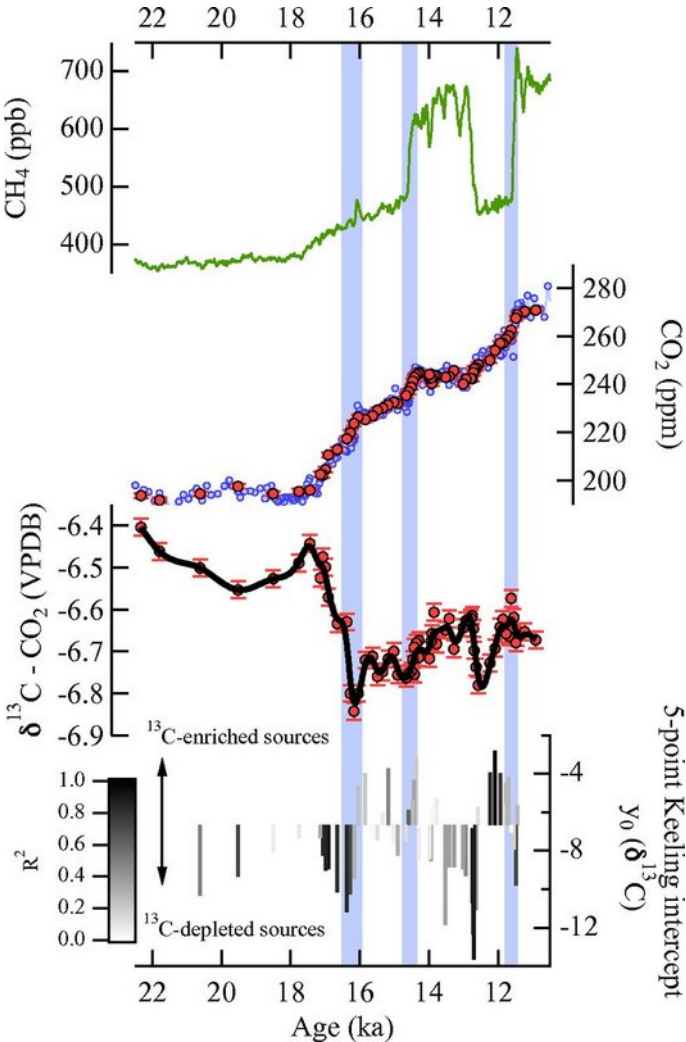
Ilustracja 3.2.3. Anomalie temperatury w młodszym eocenie względem poziomu z epoki przedprzemysłowej. Na wykresie po prawej czarna linia pokazuje najbardziej prawdopodobne anomalie temperatur na różnych szerokościach geograficznych nad lądami, a zielona – nad lądami i oceanami łącznie; rozmyte pasy pokazują przedział ufności 2σ .

Carbon isotopes characterize rapid changes in atmospheric carbon dioxide during the last deglaciation

Thomas K. Bauska, Daniel Baggenstos, Edward J. Brook, Alan C. Mix, Shaun A. Marcott, Vasil...
+ See all authors and affiliations

PNAS March 29, 2016 113 (13) 3465-3470; first published March 14, 2016; <https://doi.org/10.1073/pnas.1513868113>

$$\delta^{13}\text{C} = \left(\frac{\left(\frac{^{13}\text{C}}{^{12}\text{C}} \right)_{\text{sample}}}{\left(\frac{^{13}\text{C}}{^{12}\text{C}} \right)_{\text{standard}}} - 1 \right) \times 1000 \text{ ‰}$$



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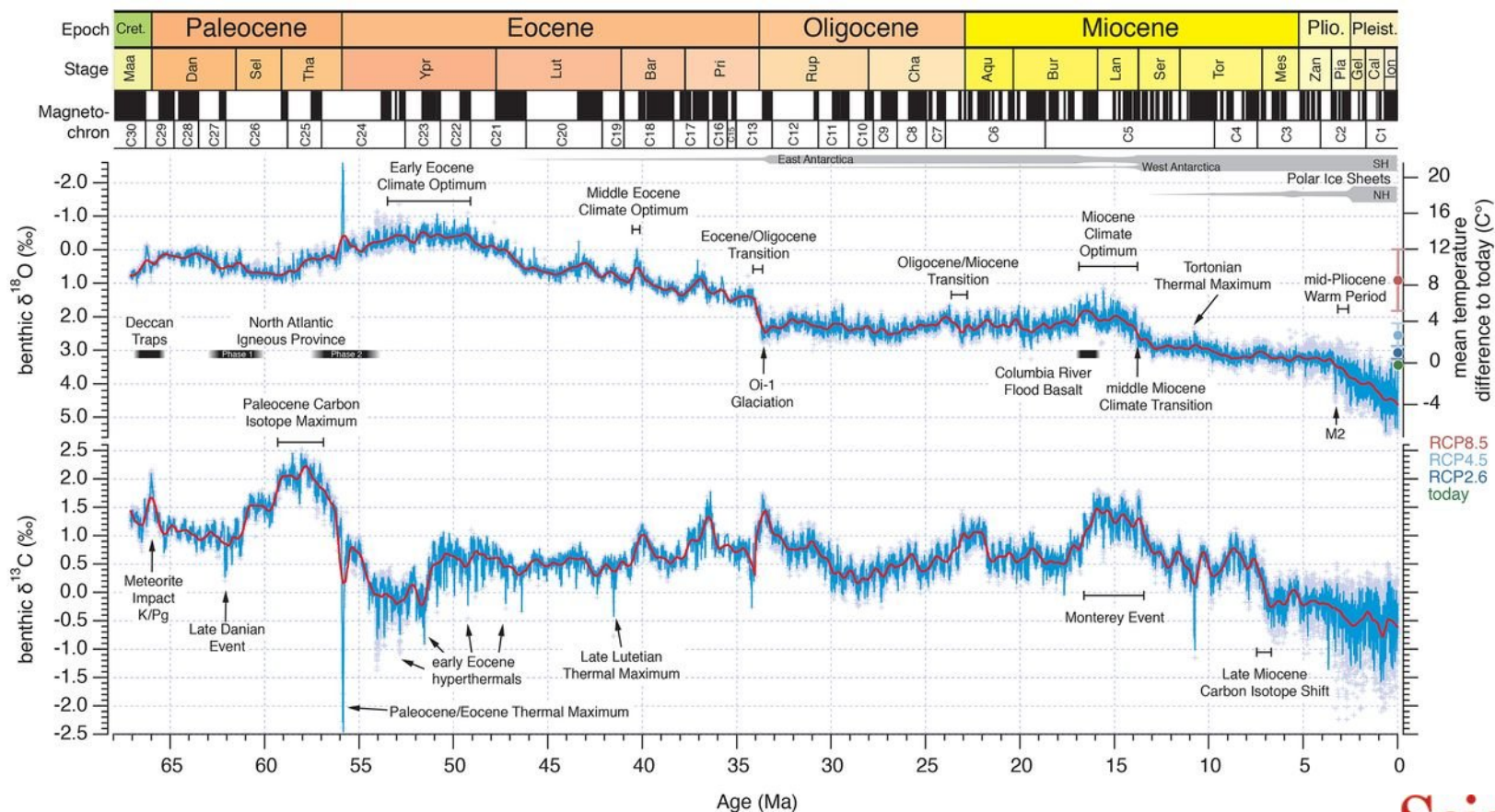
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Fig. 1 Cenozoic Global Reference benthic foraminifer carbon and oxygen Isotope Dataset (CENOGRID) from ocean drilling core sites spanning the past 66 million years.



Porównanie zmian średniej temperatury globu i koncentracji CO₂ w atmosferze od czasów dinozaurów (65 milionów lat temu) do teraz z możliwym antropogenicznym globalnym ociepleniem (450 lat).

https://websites.pmc.ucsc.edu/~jzachos/images/CENOGRID_Cartoon_withProjection_alternate.png

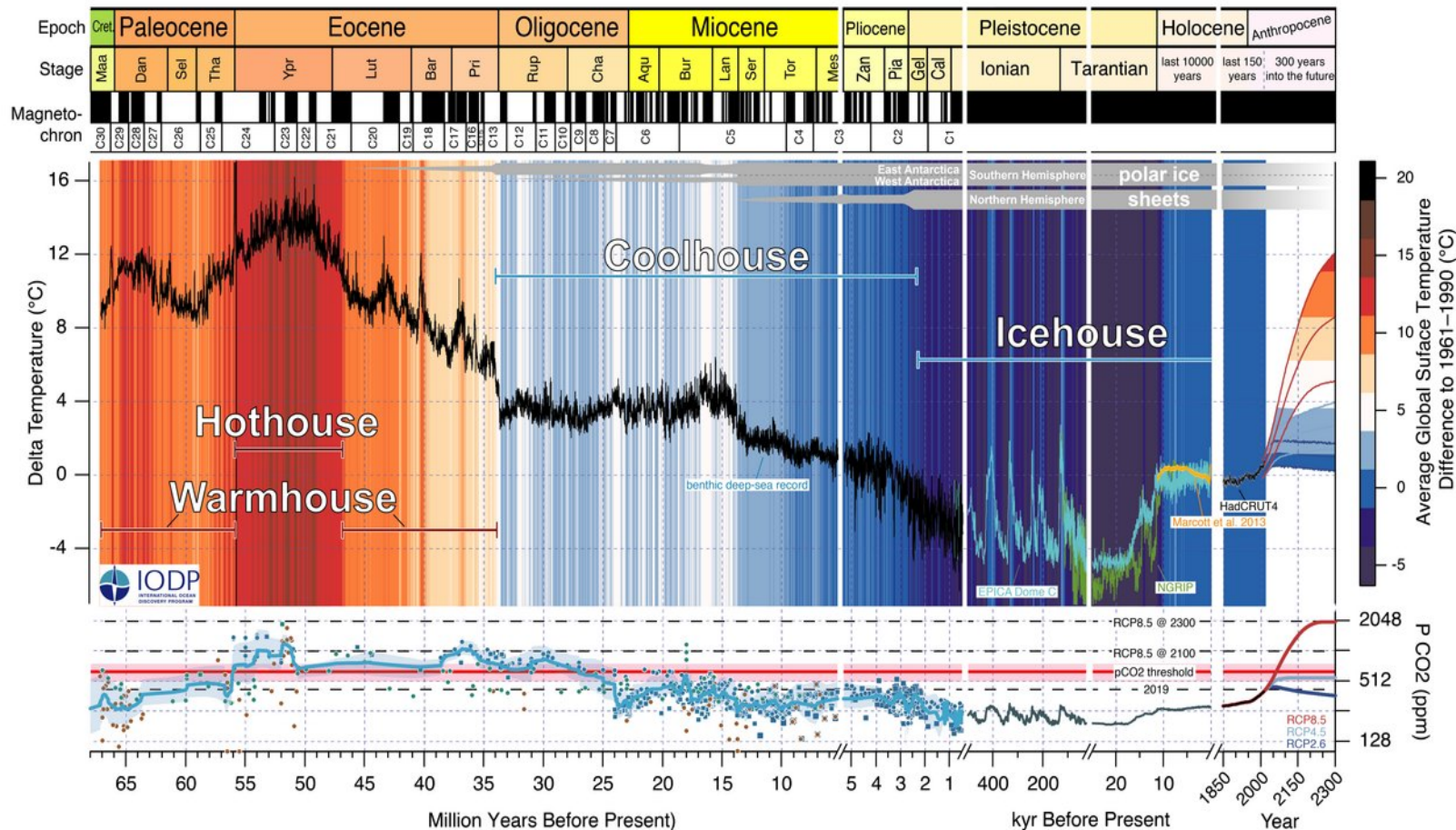
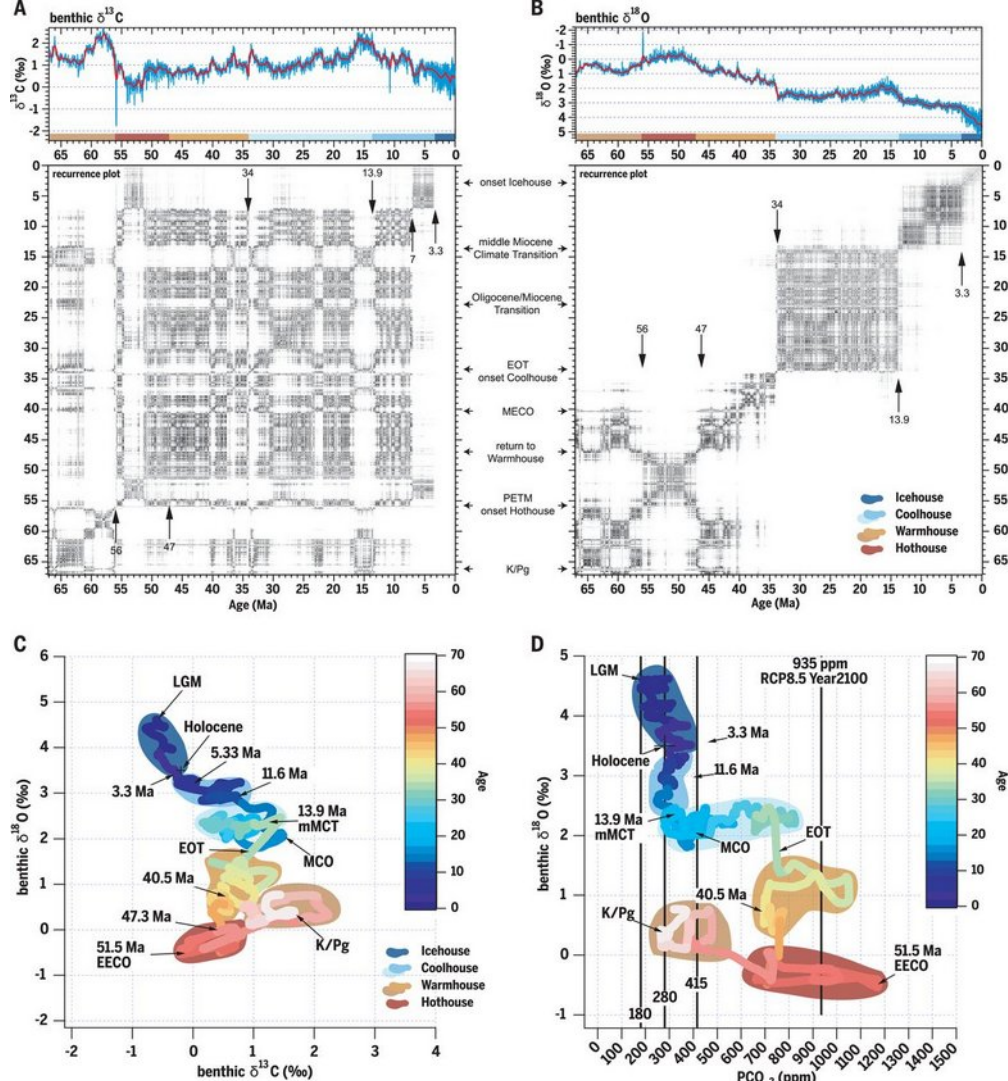
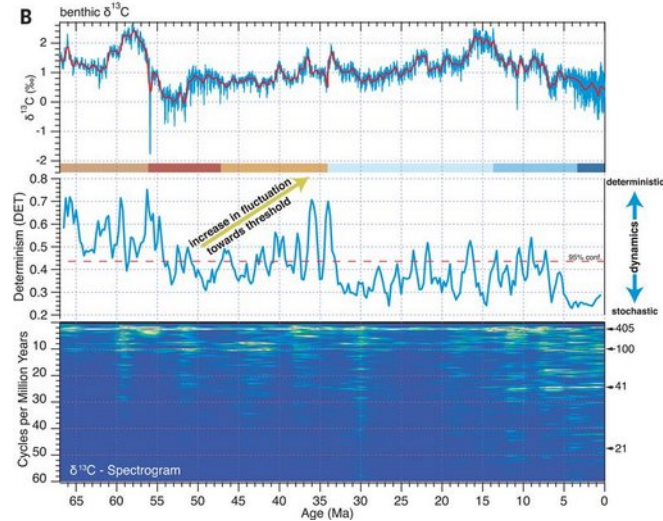
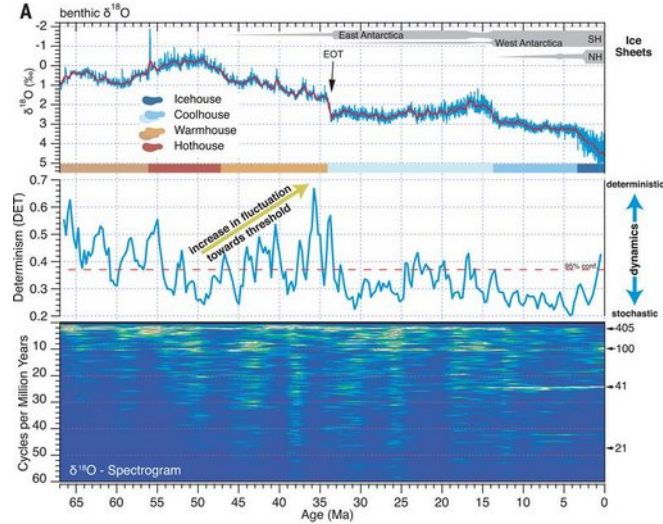
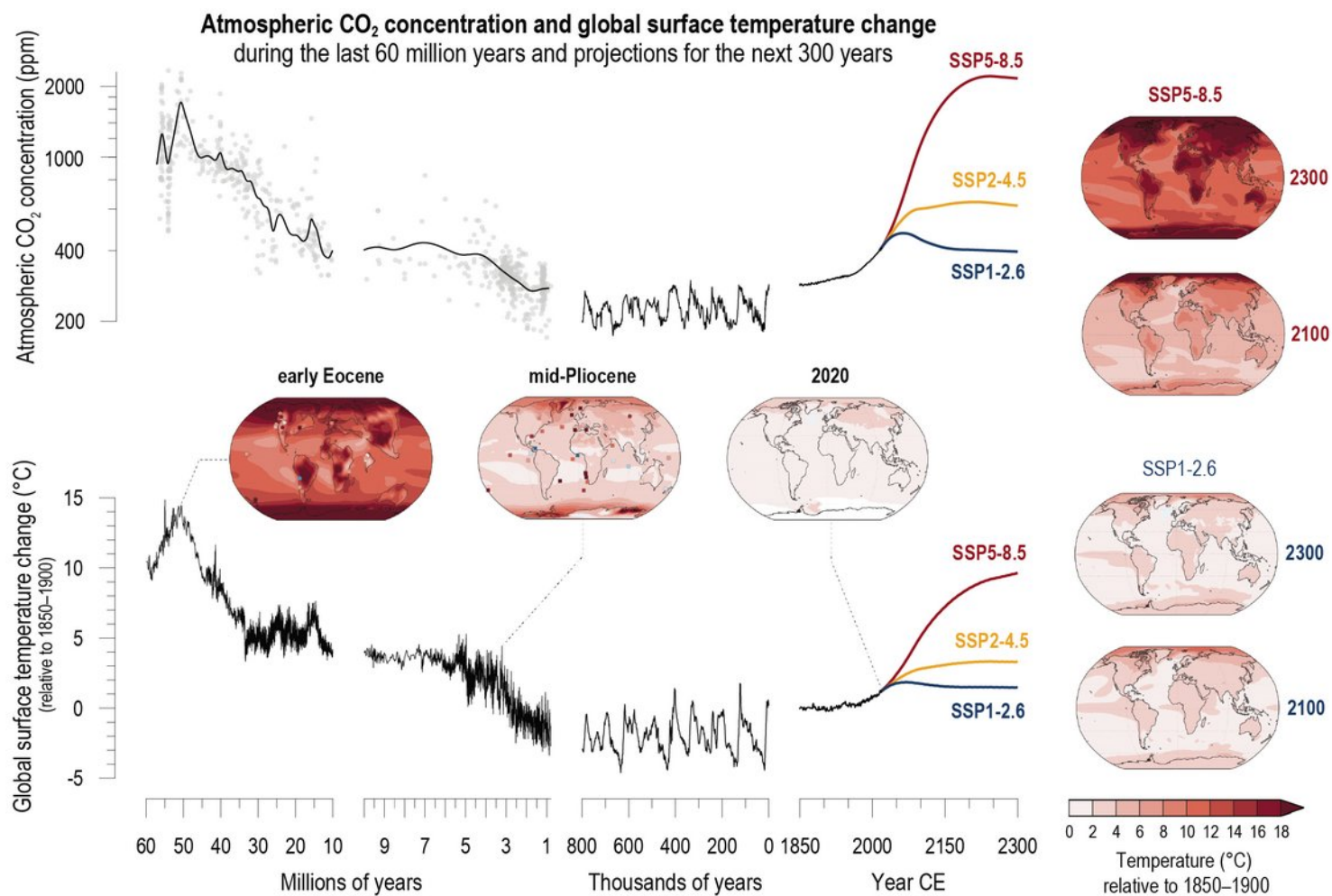


Fig. 2 Climate states of the Cenozoic.



Quasi-periodic changes and determinism in the global reference carbon cycle and oxygen isotope record.

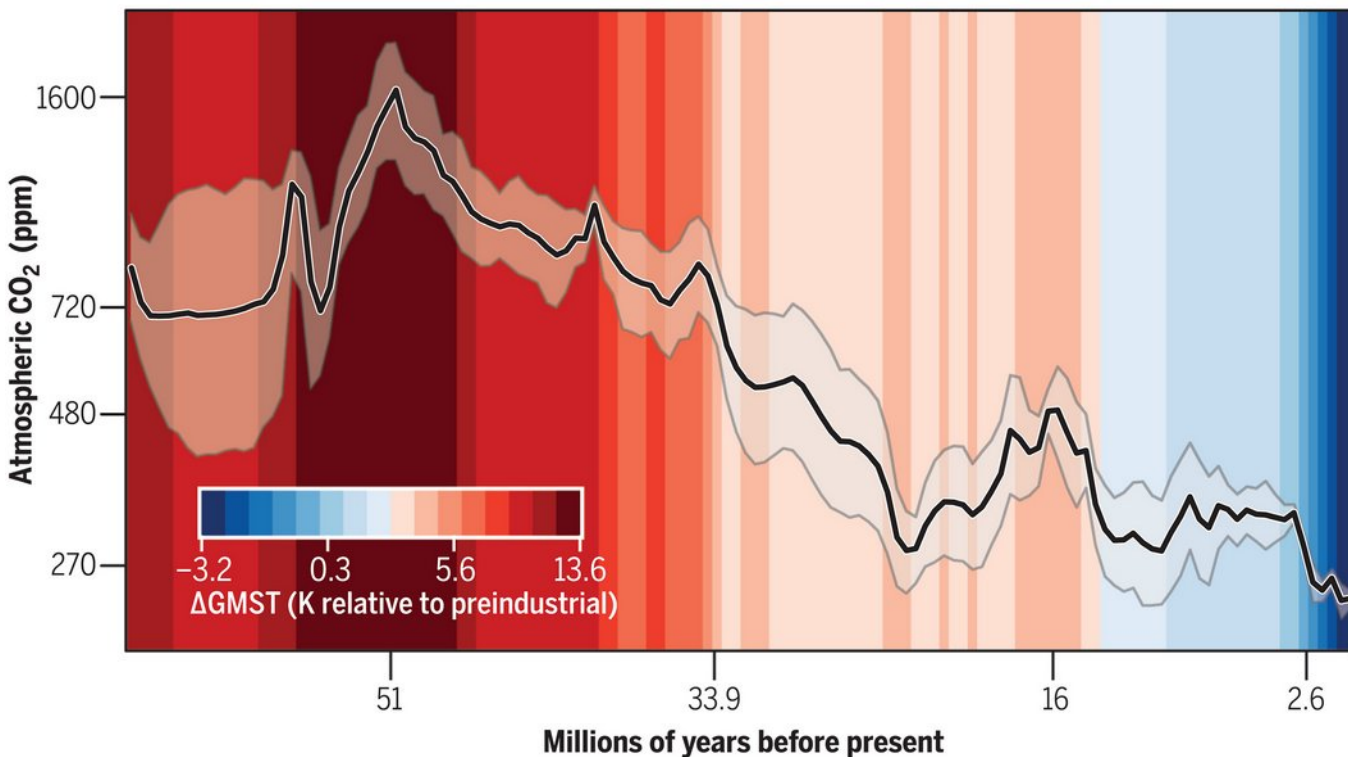




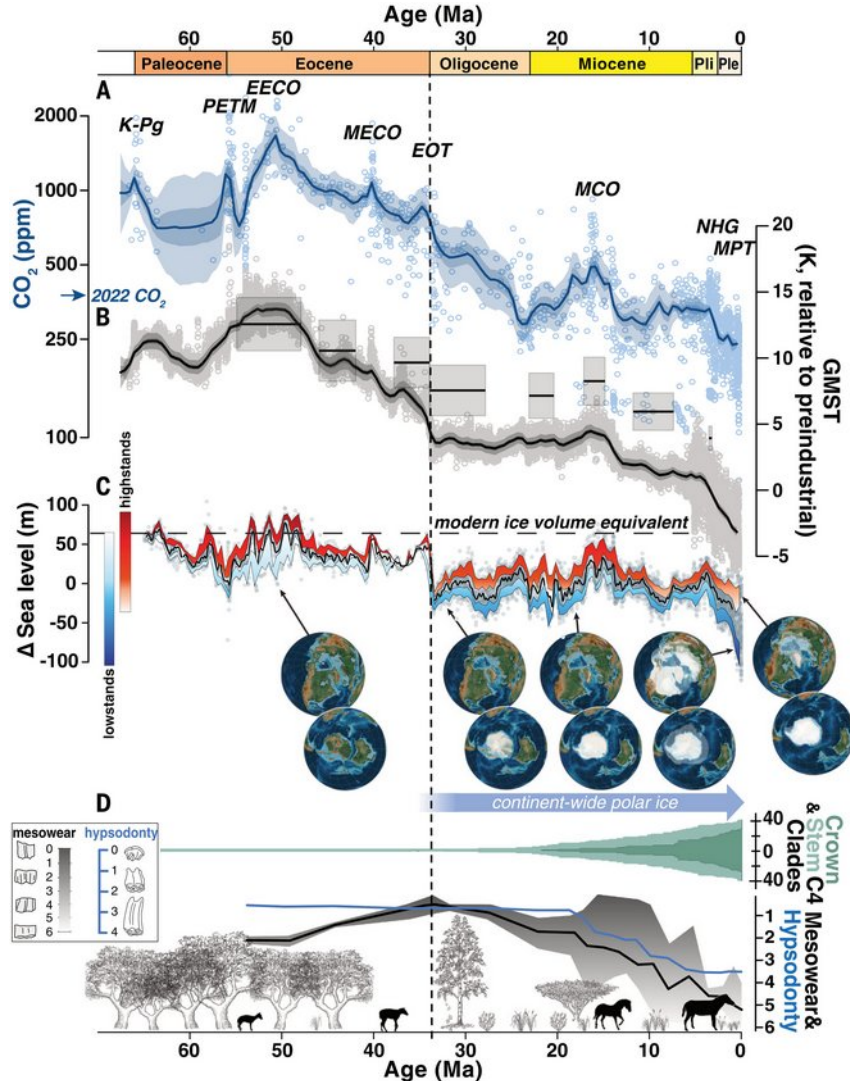
Toward a Cenozoic history of atmospheric CO₂

THE CENOZOIC CO₂ PROXY INTEGRATION PROJECT (CENO-PIP) CONSORTIUM [Authors Info & Affiliations](#)

SCIENCE • 8 Dec 2023 • Vol 382, Issue 6675 • DOI:10.1126/science.adf5177



Community-vetted quantitative CO₂ record. Paleo-CO₂ (including 95% credible intervals) is superimposed on the GMST trend over the past 66 million years. Age and CO₂ labels highlight notable climate extrema and transitions as described in the text.



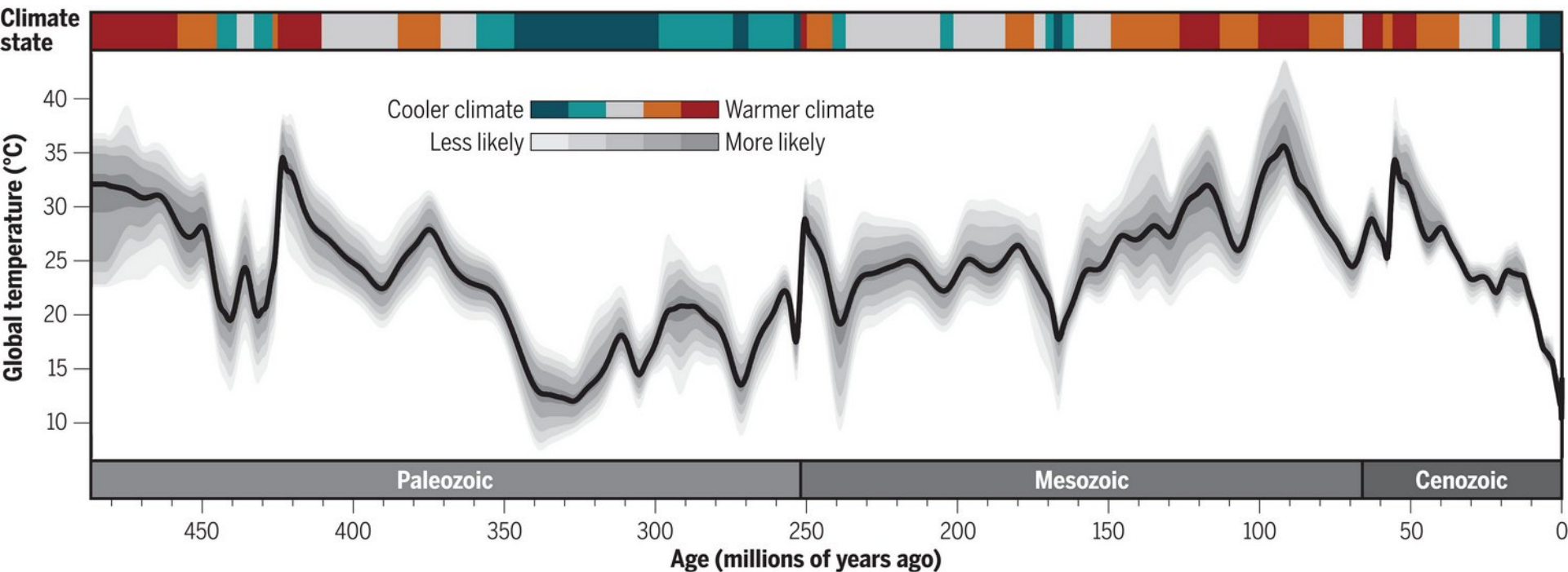
Category 1 paleo-CO₂ record compared to global climate signals. The vertical dashed line indicates the onset of continent-wide glaciation in Antarctica. (A) Atmospheric CO₂ estimates (symbols) and 500-kyr mean statistical reconstructions (median and 50 and 95% credible intervals: dark and light-blue shading, respectively). Major climate events are highlighted: K-Pg, Cretaceous/Paleogene boundary; PETM, Paleocene Eocene Thermal Maximum; EECO, Early Eocene Climatic Optimum; MECO, Middle Eocene Climatic Optimum; EOT, Eocene/Oligocene Transition; MCO, Miocene Climatic Optimum; NHG, onset of Northern Hemisphere Glaciation; and MPT, Mid-Pleistocene Transition. The 2022 annual average atmospheric CO₂ of 419 ppm is indicated for reference. (B) Global mean surface temperatures estimated from benthic $\delta^{18}\text{O}$ data following Westerhold et al. (43) (solid line, individual proxy estimates as symbols, and statistically reconstructed 500-kyr mean values shown as the continuous curve, with 50 and 95% credible intervals) and from surface temperature proxies (gray boxes) (45). (C) Sea level after (66) with gray dots displaying raw data; the solid black line reflects median sea level in a 1-Myr running window. High- and lowstands are defined within a running 400-kyr window, with lower and upper bounds of highstands defined by the 75th and 95th percentiles, and lower and upper bounds of lowstands defined by the 5th and 25th percentiles in each window. Globes depict select paleogeographic reconstructions and the growing presence of ice sheets in polar latitudes from (116). (D) Crown ages show that C4 clades, with CCMs adapted to low CO₂, initially diversified in the early Miocene, and then rapidly radiated in the late Miocene (117). Flora transition from dominantly forested and woodland to open grassland habitats based on fossil phytolith abundance data (96). North American equids typify hoofed animal adaptations to new diet and environment (103), including increasing tooth mesowear (black line; note the inverted scale), hypsodonty (blue line), and body size.

A 485-million-year history of Earth's surface temperature

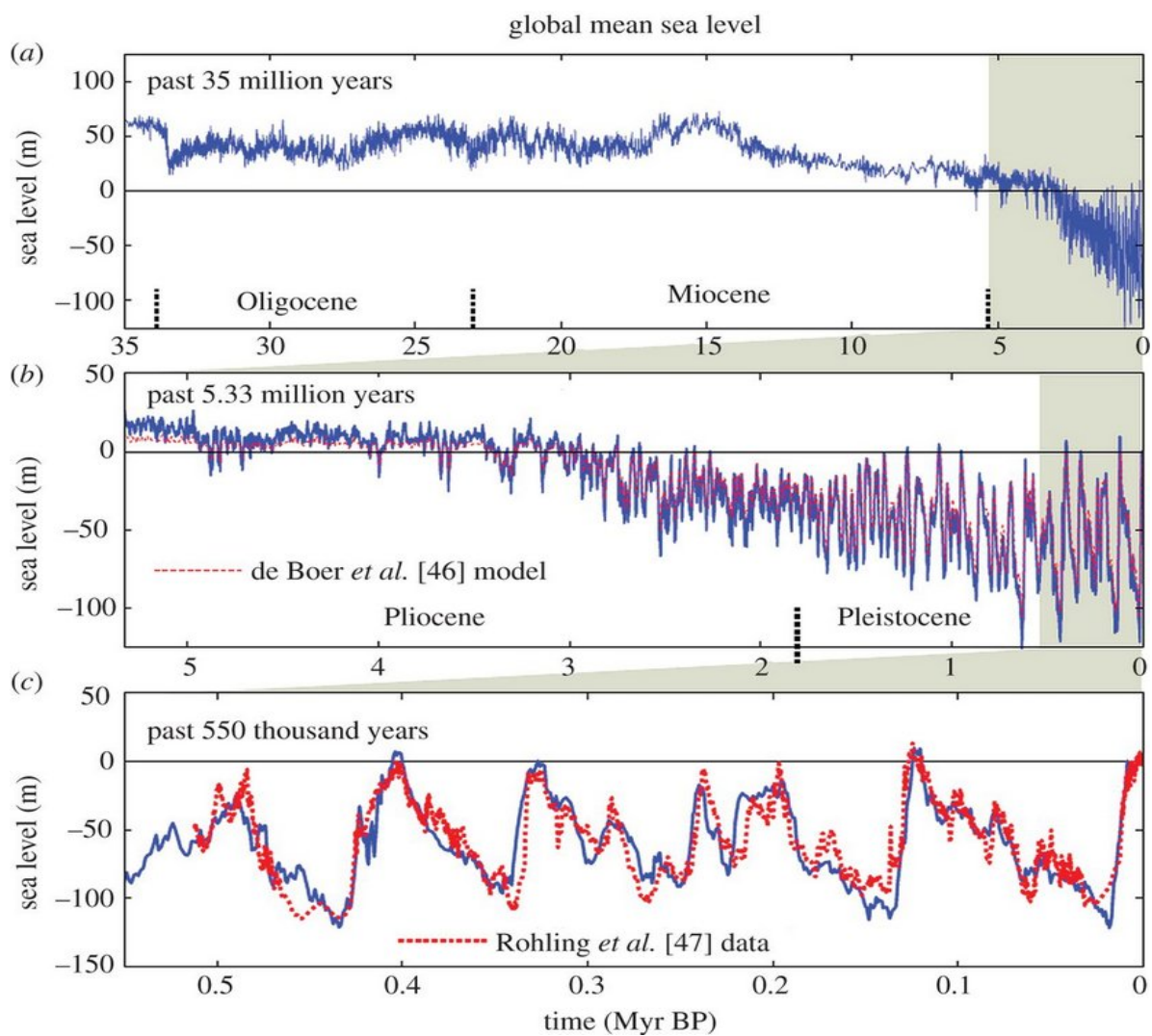
EMILY J. JUDO · JESSICA E. TIERNEY · DANIEL J. LUNT · ISABEL P. MONTAÑEZ · BRIAN T. HUBER · SCOTT L. WING · AND PAUL J. VALDES · [Authors](#)

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SCIENCE · 20 Sep 2024 · Vol 385, Issue 6715 · DOI: 10.1126/science.adk3705

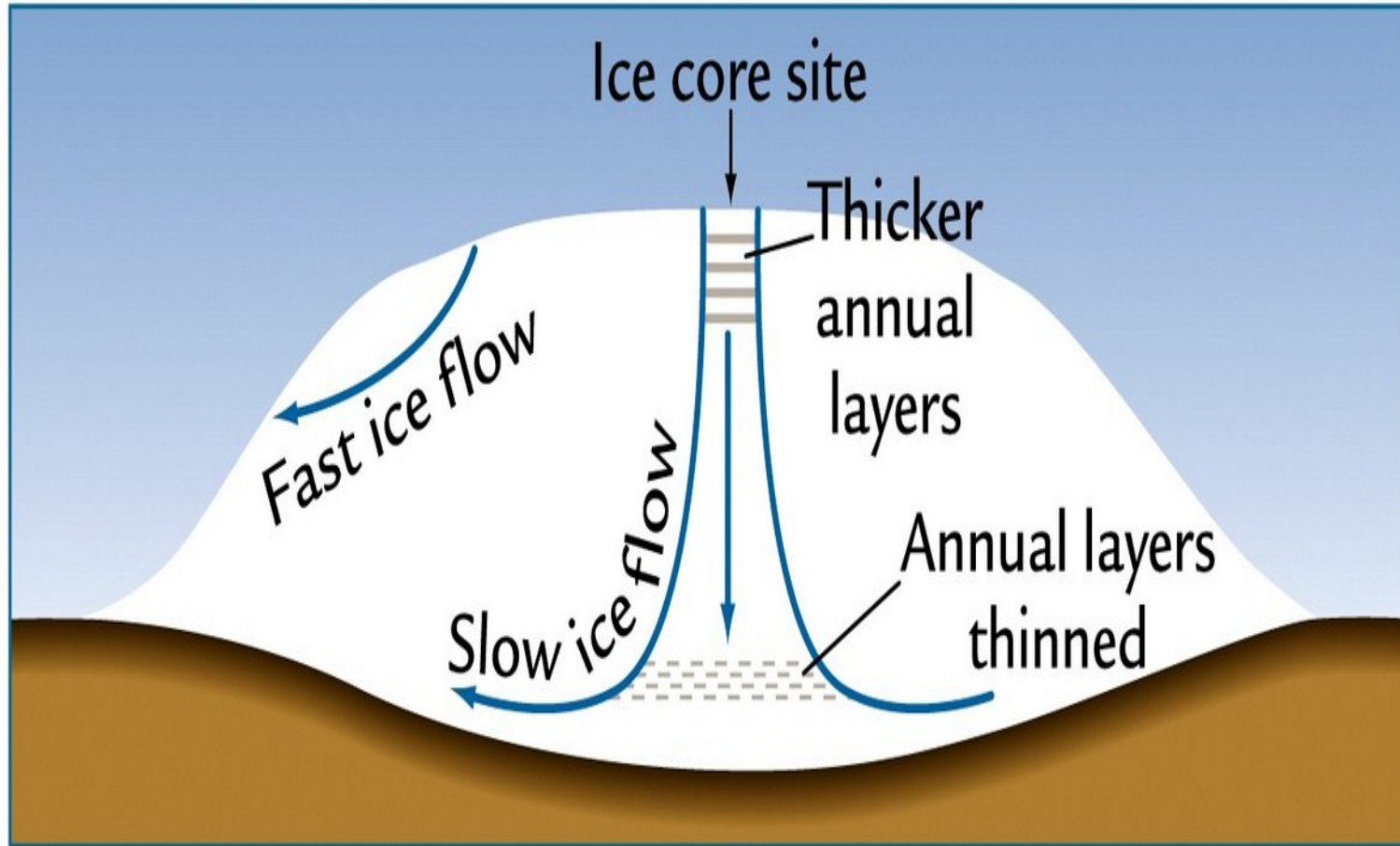


PhanDA global mean surface temperature across the last 485 million years. The gray shading corresponds to different confidence levels, and the black line shows the average solution. The colored bands along the top reflect the climate state, with cooler colors indicating icehouse (coolhouse and coldhouse) climates, warmer colors indicating greenhouse (warmhouse and hothouse) climates, and the gray representing a transitional state.



Deep ocean temperature in (a) the Pliocene and Pleistocene and (b) the last 800 000 years. High-frequency variations (black) are five-point running means of the original data [4], whereas the blue curve has a 500 kyr resolution. The deep ocean temperature for the entire Cenozoic era is in figure 1b.

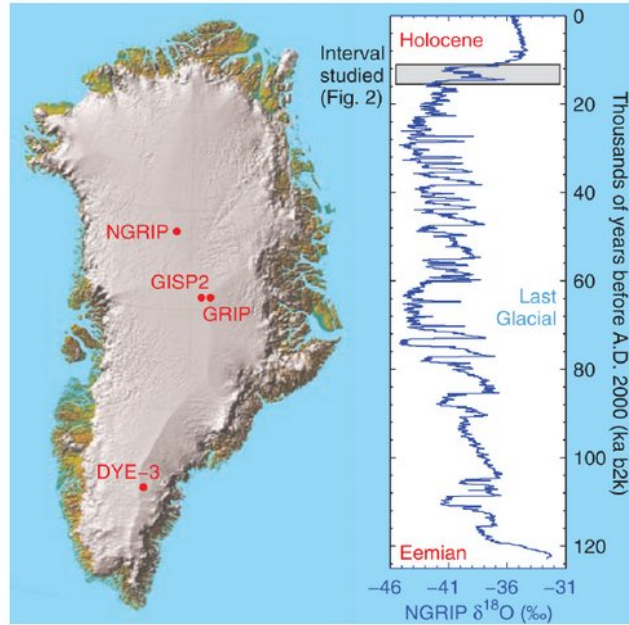
Ice Cores and Ice Sheet Flow



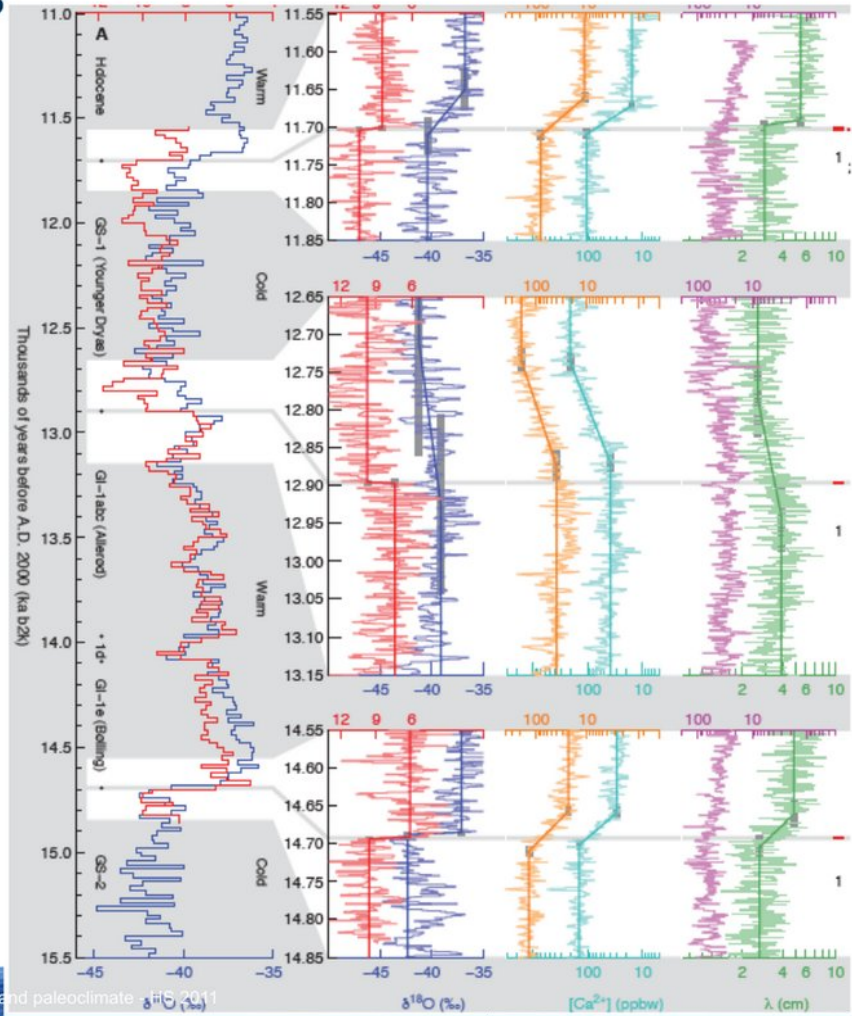
Application in ice cores

Abrupt climate change

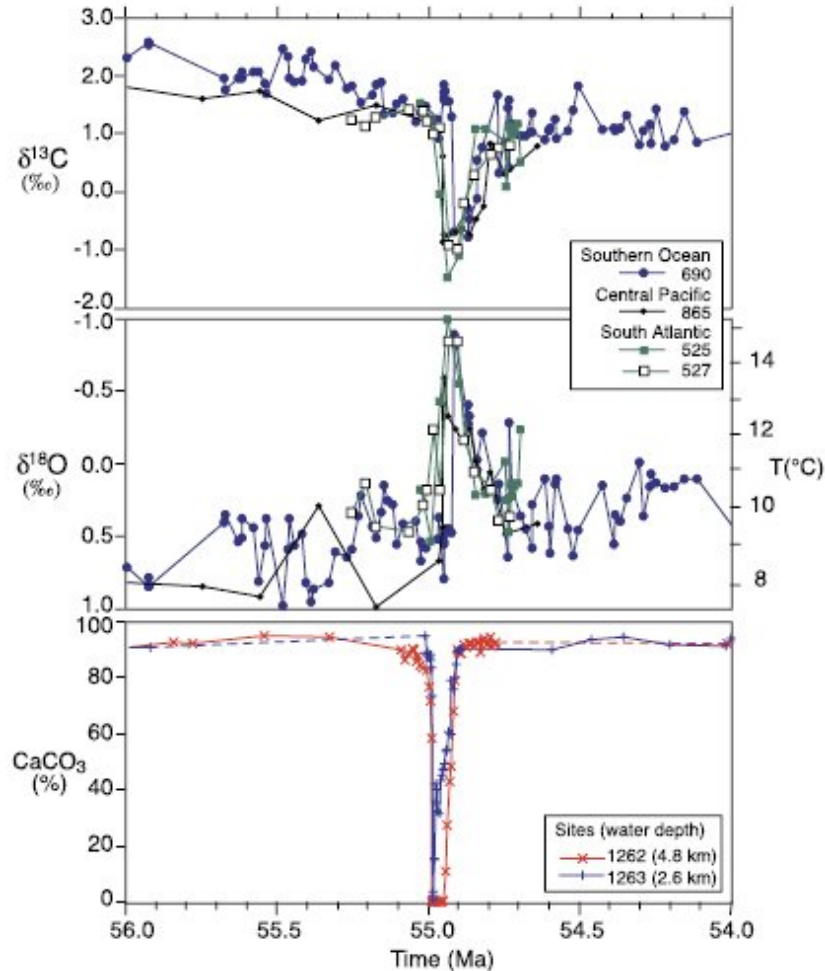
- Study the long ice record in Greenland



Steffensen et al, Science, 321, 1. August 2008



Abrupt Climate Change – przykład: PETM



The Palaeocene-Eocene Thermal Maximum as recorded in benthic (bottom dwelling) foraminifer (*Nuttallides truempyi*) isotopic records from sites in the Antarctic, south Atlantic and Pacific (see Zachos et al., 2003 for details). The rapid decrease in carbon isotope ratios in the top panel is indicative of a large increase in atmospheric greenhouse gases CO_2 and CH_4 that was coincident with an approximately 5°C global warming (centre panel). Using the carbon isotope records, numerical models show that CH_4 released by the rapid decomposition of marine hydrates might have been a major component (~2,000 GtC) of the carbon flux (Dickens and Owen, 1996).

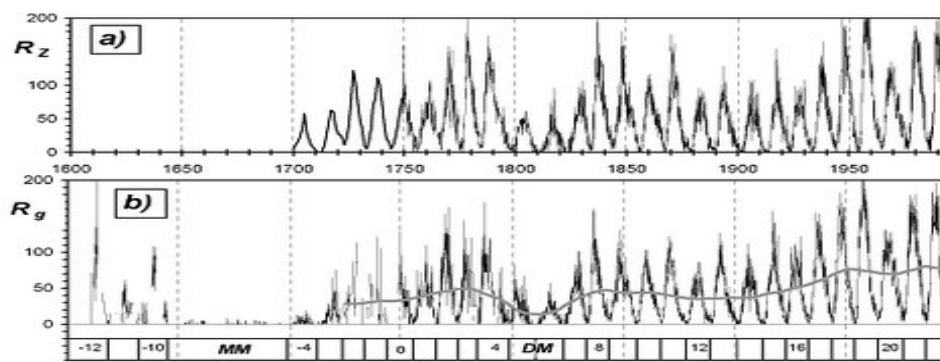


Figure 1: Sunspot numbers since 1610. a) Monthly (since 1749) and yearly (1700 – 1749) Wolf sunspot number series. b) Monthly group sunspot number series. The grey line presents the 11-year running mean after the Maunder minimum. Standard (Zürich) cycle numbering as well as the Maunder minimum (MM) and Dalton minimum (DM) are shown in the lower panel.

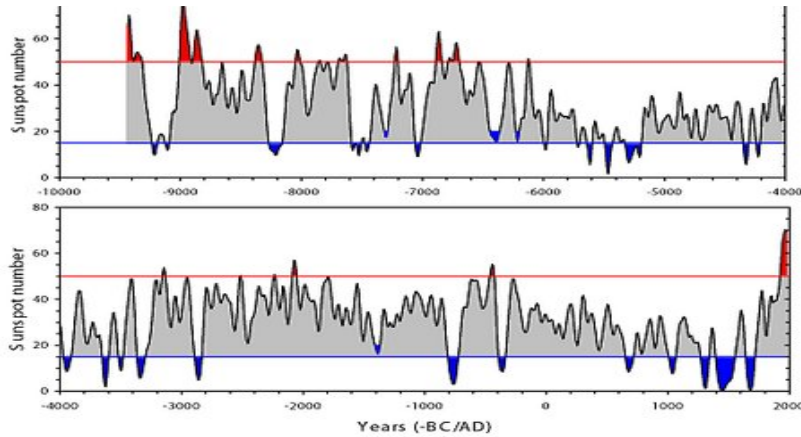


Figure 17: Sunspot activity (over decades, smoothed with a 12221 filter) throughout the Holocene, reconstructed from ^{14}C by Usoskin *et al.* (2007) using geomagnetic data by Yang *et al.* (2000). Blue and red areas denote grand minima and maxima, respectively.]

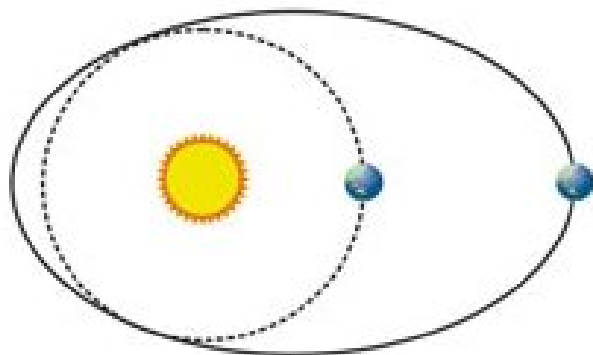


PLAMY NA SŁÓŃCU

I.G. Usoskin "A History of Solar Activity over Millennia"
Publication URI:

<http://www.livingreviews.org/lrsp-2008-3>

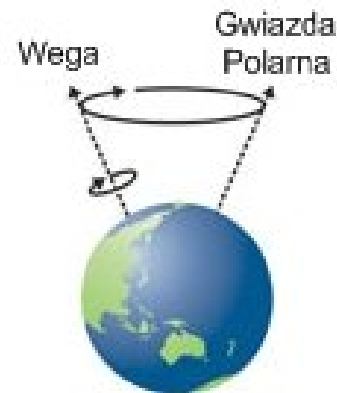
Cykle Milankovicia



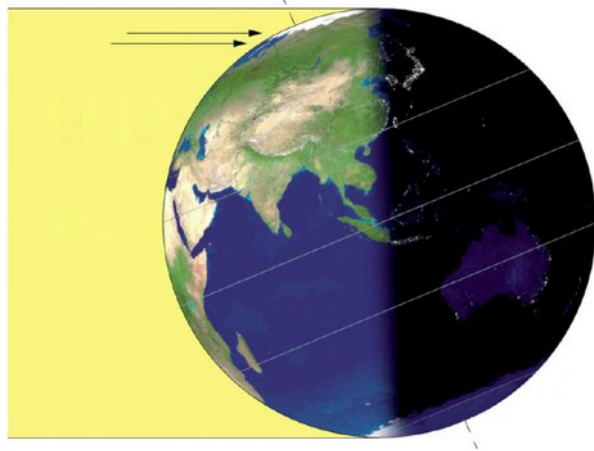
mimośród



nutacja



precesja



Lato na półkuli północnej. Kiedy północna półkula Ziemi otrzymuje latem więcej energii (czemu sprzyjają dwie niezależne sytuacje – mniejsza od średniej odległość Ziemi od Słońca oraz większe nachylenie osi obrotu Ziemi), lata w Arktyce są cieplejsze, co prowadzi do zaniku czapy polarnej.

Problem nachylenia osi:

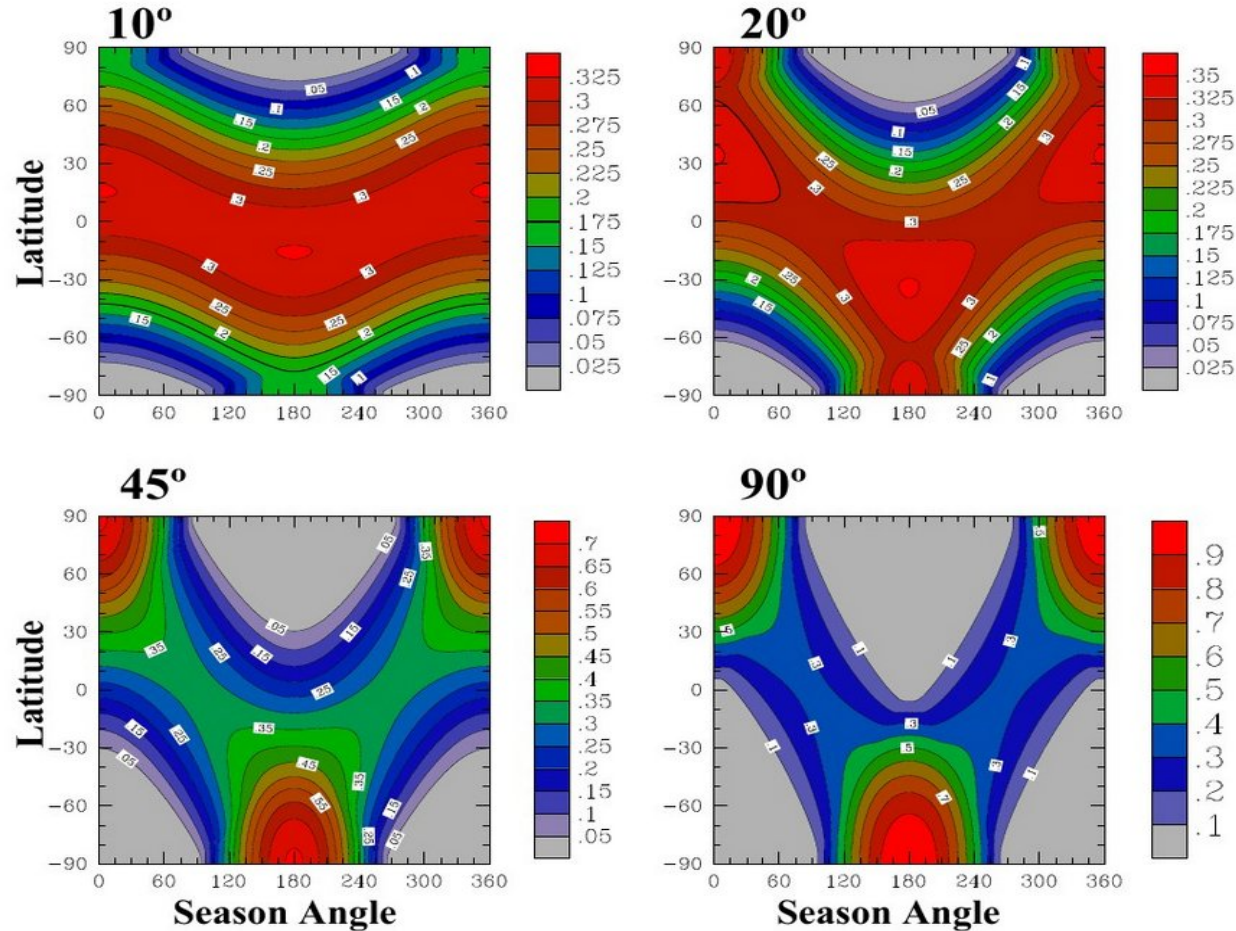
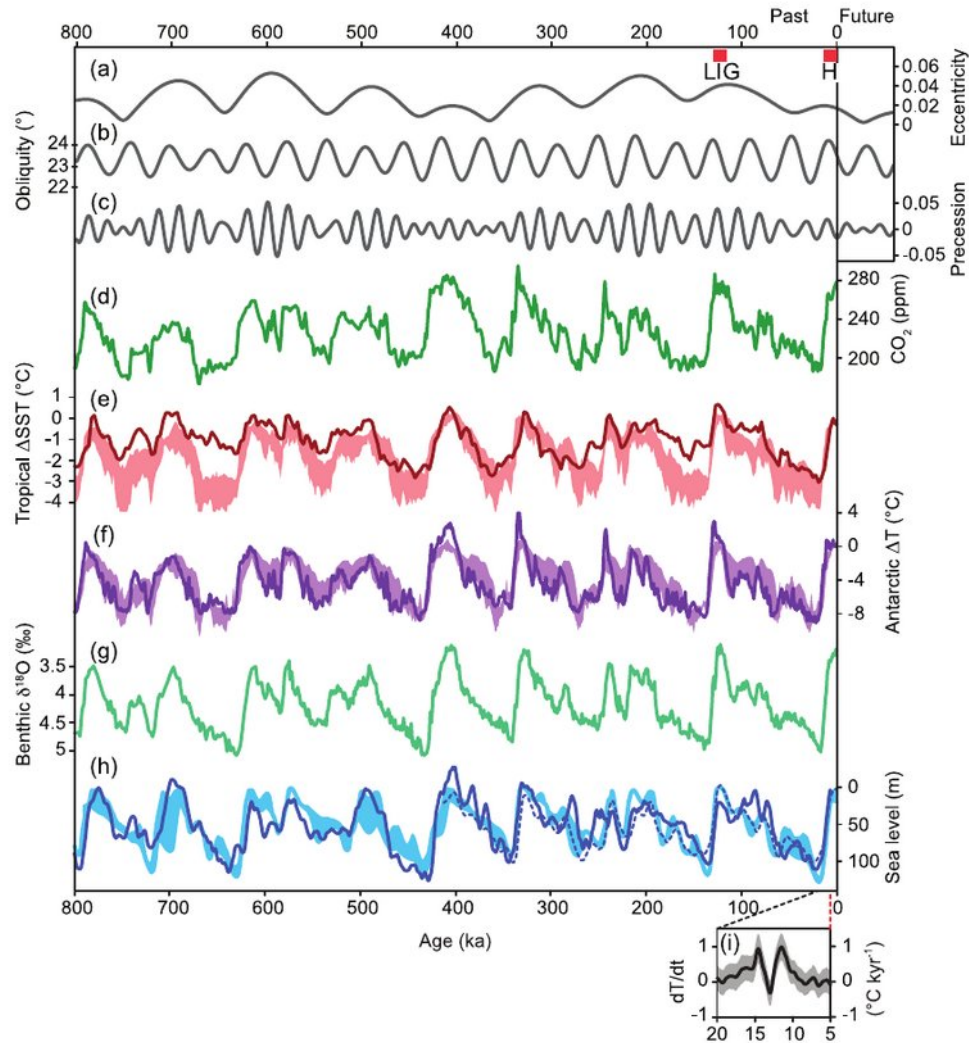
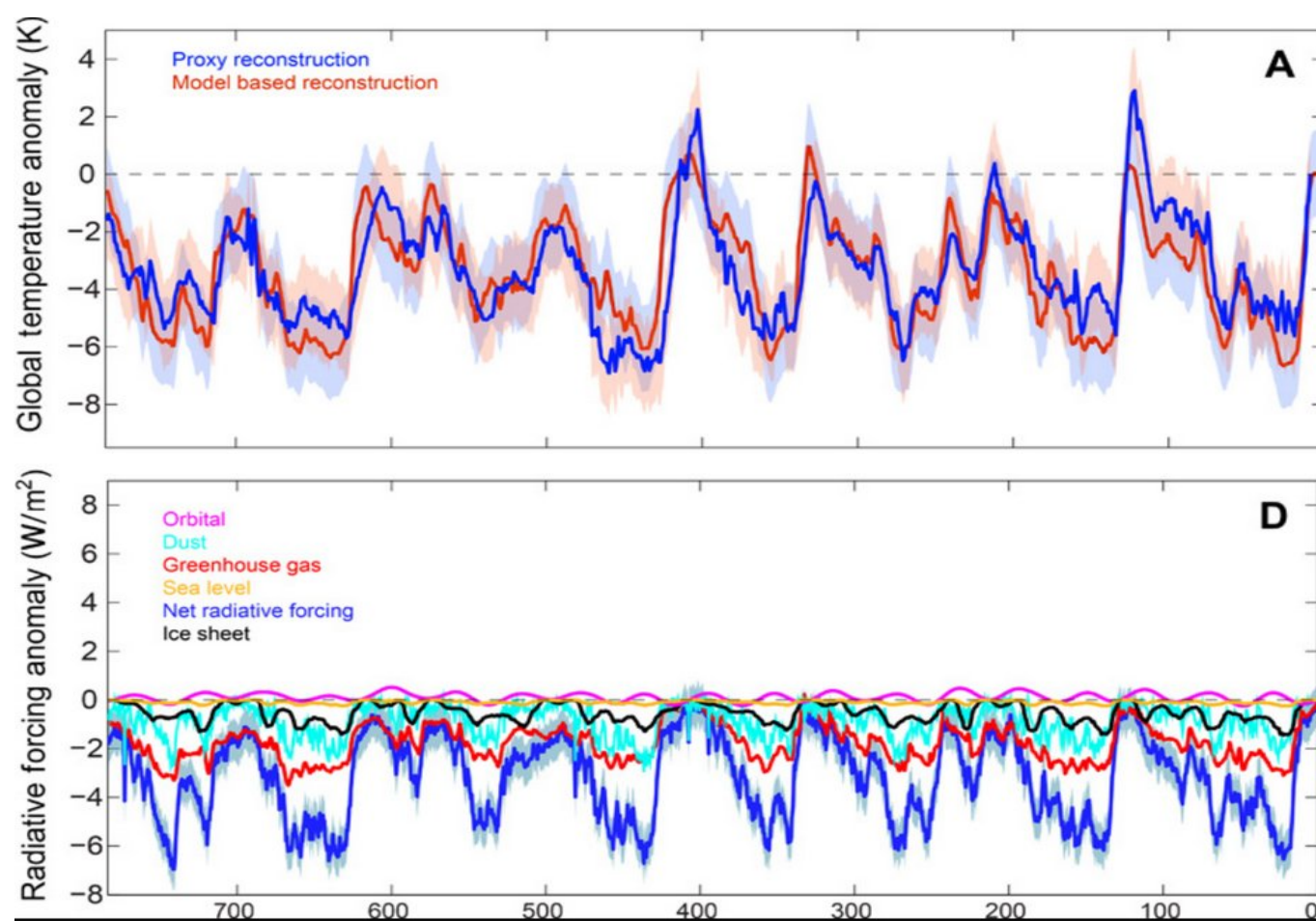


Fig. 7.5: The seasonal and latitudinal distribution of daily-mean flux factor for four different values of the obliquity. In these plots, a circular orbit has been assumed. To obtain the daily mean energy flux incident on each square meter of the planet's surface, one multiplies the flux factor by the solar constant. For example, if the solar constant is 1000W/m^2 , the incident solar flux at the pole during the Summer solstice is about 700W/m^2 if the obliquity is 45° .

(Pierrehumbert, „Principles of planetary climate”)



Wymuszenia
orbitalne
i ich efekty
zapisane w
proxies.
(IPCC 2013)



Mechanizm epok lodowych:
Wymuszenia orbitalne (D) i **sprzężenia (D)** skutkują **zmianami w bilansie radiacyjnym (D)** i dalej odpowiednią **zmiennością temperatury (A)**.

Friedrich et al., Science
 Advances 09 Nov 2016:
 Vol. 2, no. 11, e1501923
 DOI:
 10.1126/sciadv.1501923

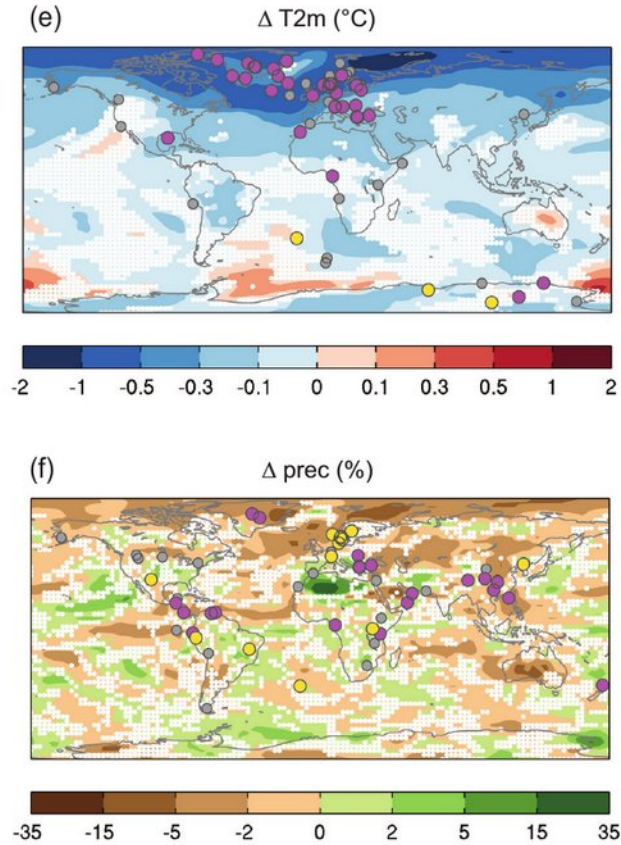
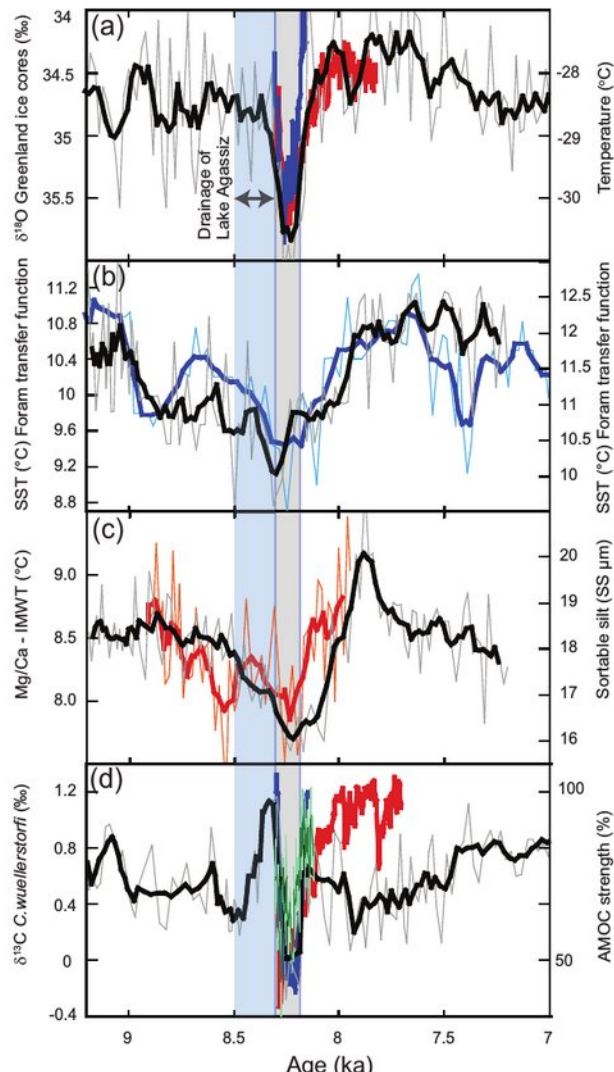
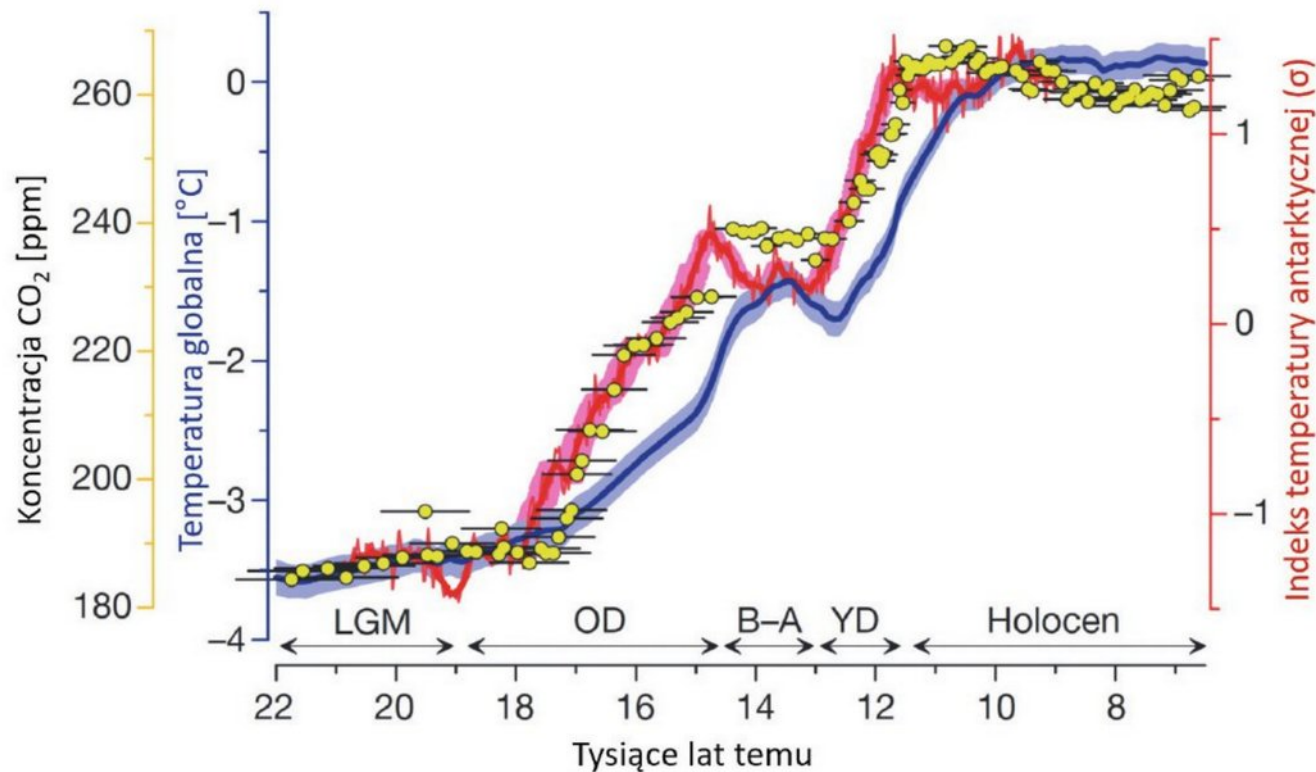
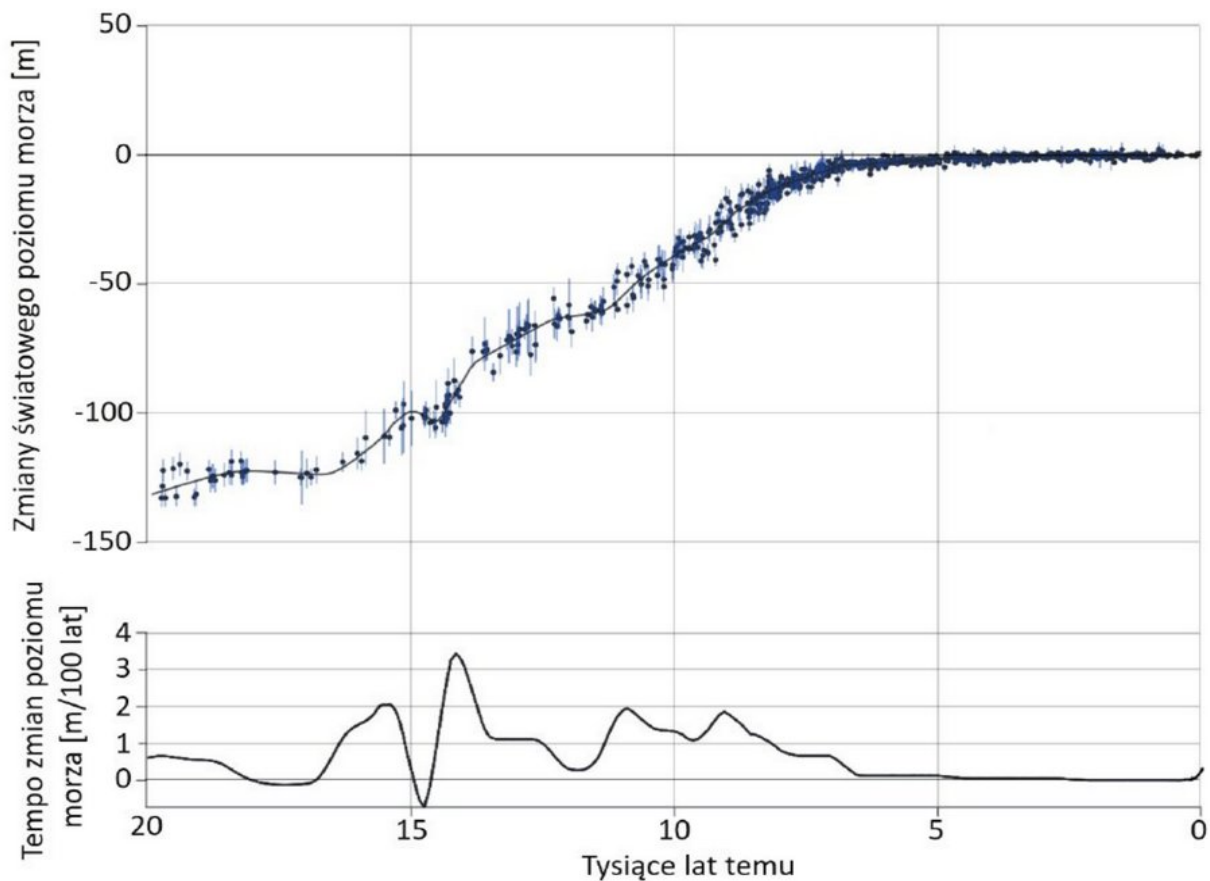


Figure 5.18 |
Compilation of
selected
paleoenvironmental
and climate model
data for the abrupt
Holocene cold event
at 8.2 ka, documenting
temperature and
ocean-circulation
changes around the
event and the spatial
extent of climate
anomalies following
the event (IPCC 2013)



Ilustracja 3.1.6. Średnia globalna temperatura (niebieska linia) określona na podstawie wskaźników klimatycznych, temperatura Antarktydy (czerwona linia) określona na podstawie rdzeni lodowych i atmosferyczna koncentracja CO₂ (żółte kółka). Zaznaczony stopień niepewności 1σ. Zaznaczone są okresy: maksimum ostatniej epoki lodowej (LGM), starszy dryas (OD), Bølling-Allerød (B-A), młodszy dryas (YD) oraz holocen.



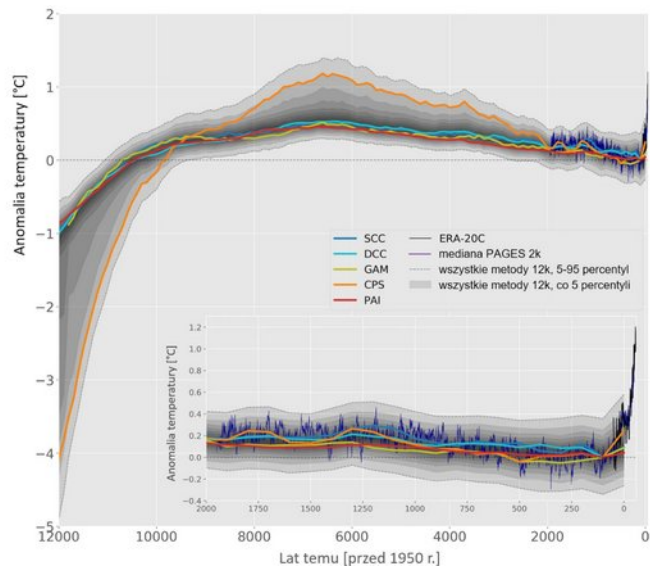
Ilustracja 3.1.11. Górny panel: zmiana światowego poziomu morza w ciągu ostatnich 20 tys. lat (czarna linia), na podstawie pośrednich wskaźników poziomu morza (czarne kropki z pionowymi niebieskimi liniami pokazującymi stopień niepewności). Dolny panel: Tempo zmiany światowego poziomu morza uśrednione w interwałach 500 lat (z wyjątkiem zmian z ostatniego stulecia).



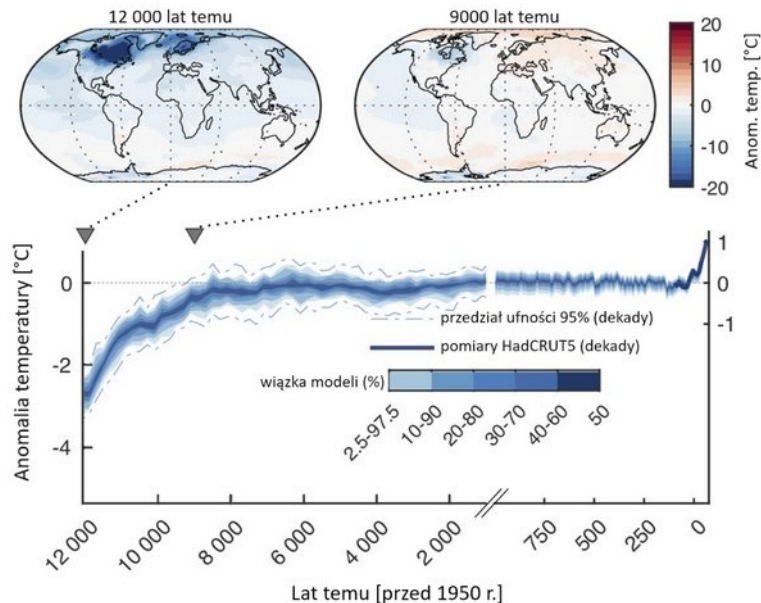
AKTUALNOŚCI

Zagwozdzka temperatur holocenu

16 SIERPNIA 2021 - 10 MINUT CZYTANIA

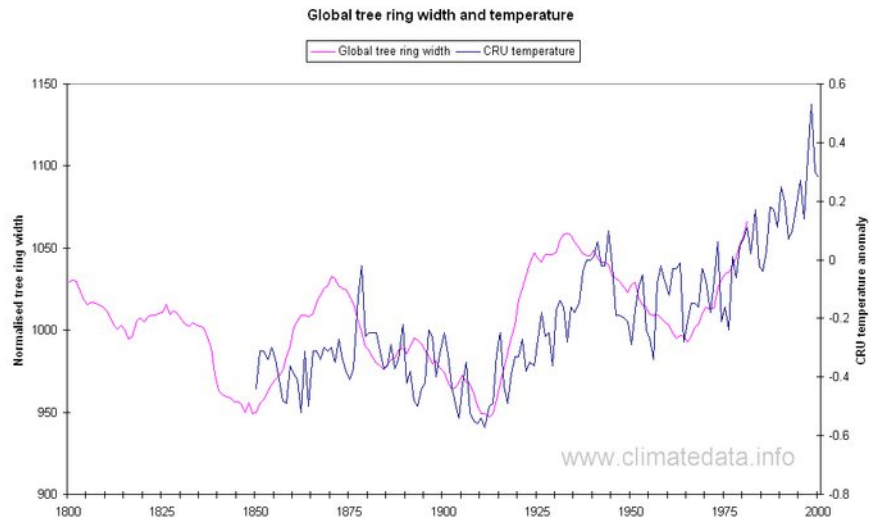


Zrekonstruowane średnie roczne temperatury globalne dla pięciu różnych metod (kolorowe linie) oraz średnia (linia szara, pasy obrazują przedziały ufności co 5 procentyli). Fioletowa linia mediana rekonstrukcji PAGES 2k. Źródło Kaufman i in., 2020.



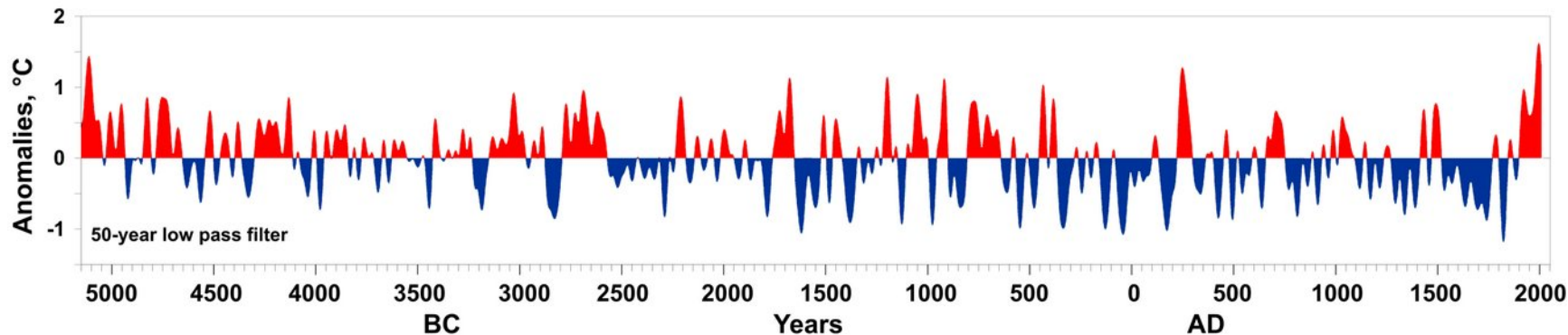
Rekonstrukcja zmian średniej temperatury powierzchni Ziemi (niebieska linia z przedziałami ufności) oraz pomiary instrumentalne w serii HadCRUT5 (ciemnoniebieska linia od 1850 r.) dla ostatnich 12 000 lat. W panelach na górze zrekonstruowane anomalie temperatury w różnych miejscach na powierzchni Ziemi odpowiednio 12 000 i 9000 lat temu. Anomalia temperatury względem okresu przedprzemysłowego 1000-1850. Źródło Osman i in., 2021

Słoje drzew



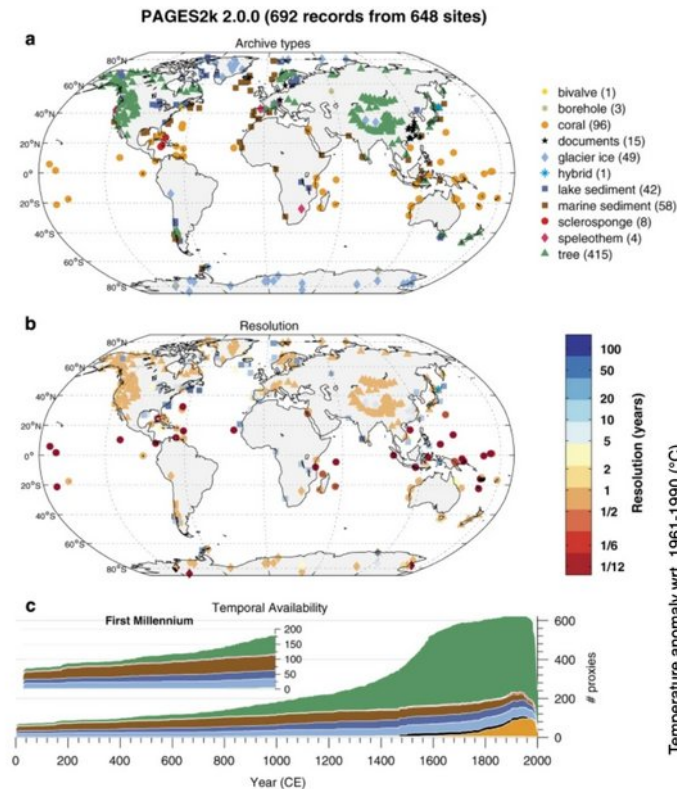
Na podstawie szerokości i struktury słojów określa się warunki panujące w poszczególnych latach.

Letnie anomalie temperatury



Wielorakie rekonstrukcje: multiproxy.

Figure 1: Spatiotemporal data availability in the PAGES2k database.



Data Descriptor | [Open access](#) | Published: 11 July 2017

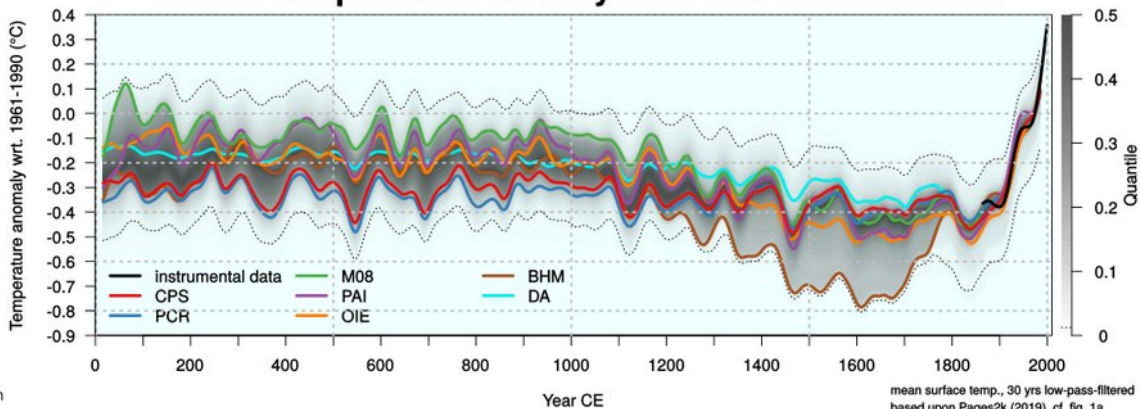
A global multiproxy database for temperature reconstructions of the Common Era

[PAGES2k Consortium](#)

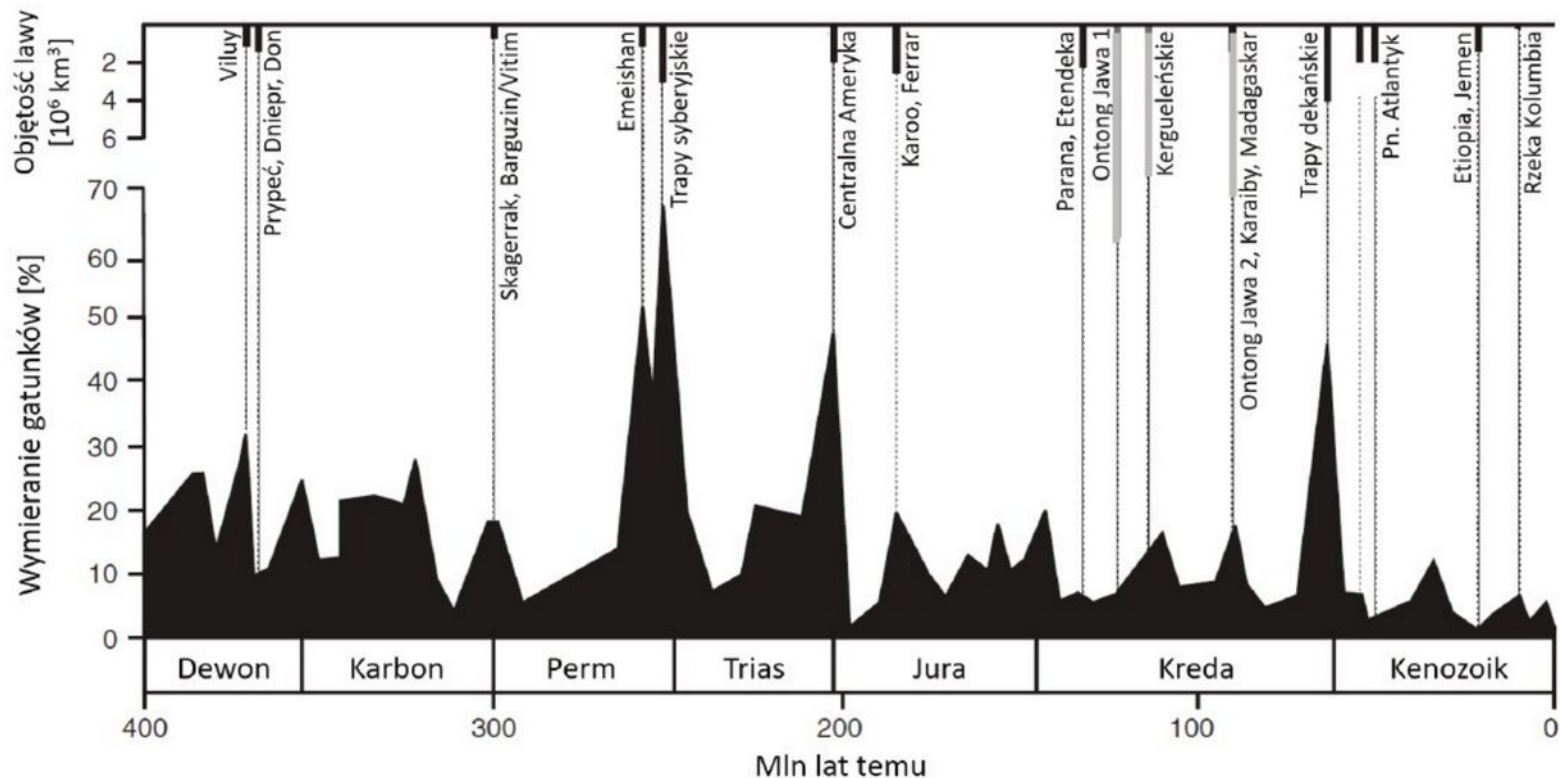
Scientific Data 4, Article number: 170088 (2017) | [Cite this article](#)

61k Accesses | 257 Citations | 1023 Altmetric | [Metrics](#)

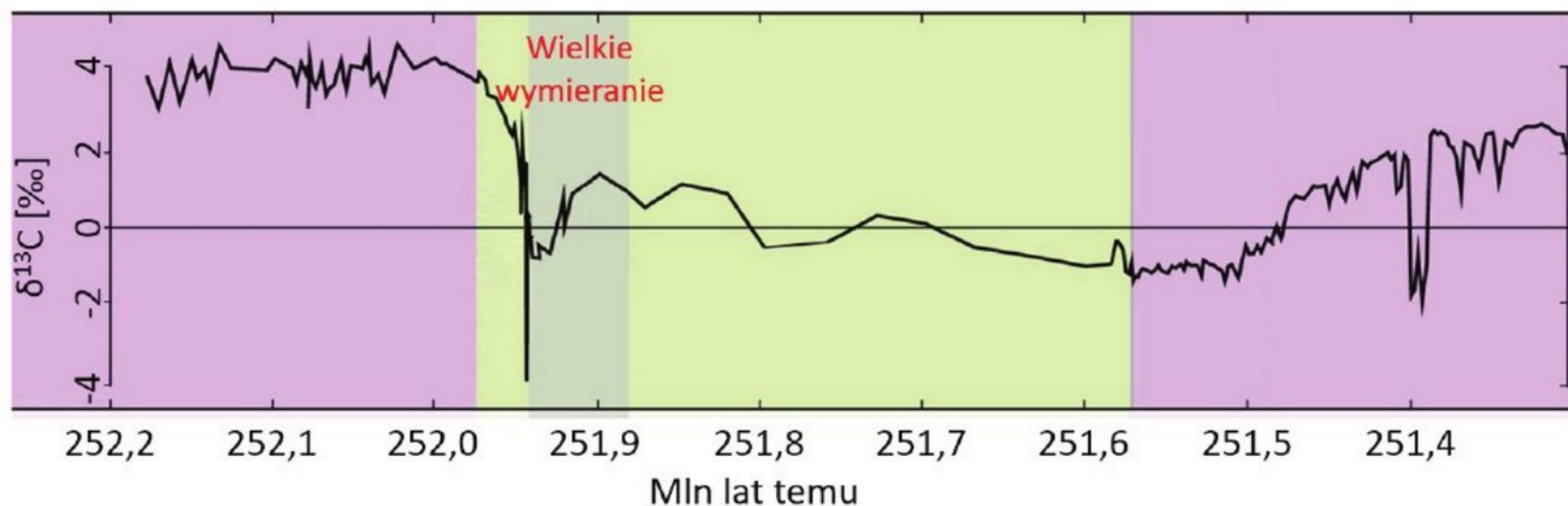
Global temperature history over the Common Era



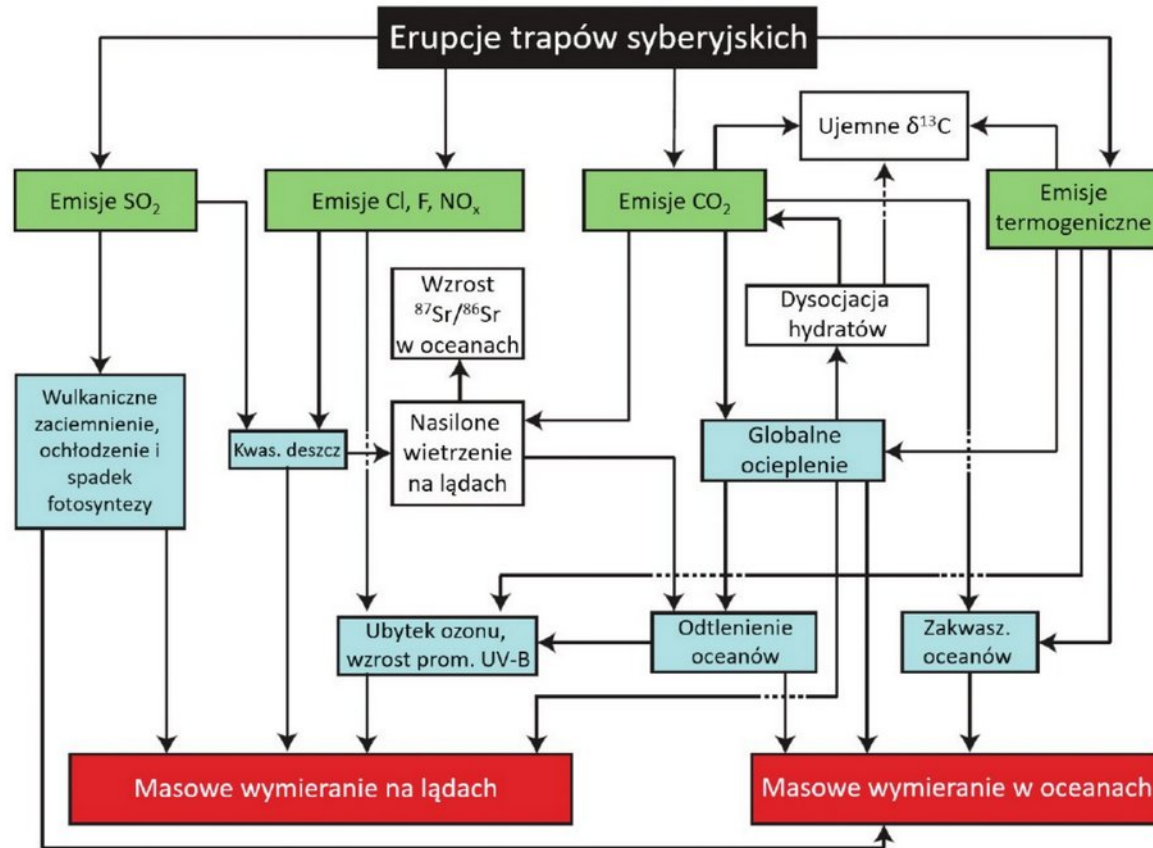
(a) Geographical distribution, by archive type, coded by color and shape. (b) Temporal resolution the PAGES2k database, defined here as the median of the spacing between consecutive observations. Shapes as in (a), colors encode the resolution in years (see colorbar). (c) Temporal availability, coded by color as in (a).



Ilustracja 3.4.1. Skala wymierań gatunków w ostatnich 400 mln lat (na dole) vs objętość wielkich prowincji magmatycznych (na górze). Kontynentalne wylewy bazaltu pokazane są jako słupki w kolorze czarnym, oceaniczne w kolorze szarym. Wyraźnie widoczna jest korelacja pomiędzy wielkimi wymieraniami a wylewami lawy z wielkich prowincji magmatycznych.



Ilustracja 3.4.2. Zmiany $\delta^{13}\text{C}$, pokazujące bardzo szybkie wprowadzenie do cyklu węglowego bardzo dużych ilości lekkiego izotopu węgla (pochodzenia organicznego) 251,94 mln lat temu. Kolorowe tła prezentują stadia erupcji wulkanów trapów syberyjskich (fioletowe – wylewy powierzchniowe, zielone – wylewy podpowierzchniowe). Okres wielkiego wymierania jest zaznaczony szarym polem.



Ilustracja 3.4.3. Diagram podsumowujący procesy zachodzące podczas wielkiego wymierania na przełomie permu i triasu. Zielone prostokąty: bezpośrednie działanie wulkanów. Niebieskie prostokąty: bezpośrednie mechanizmy eksterminacji życia. Stosunek izotopów ⁸⁷Sr/⁸⁶Sr w różnych rodzajach skał jest różny, jeśli przyspieszają procesy wietrzenia skał lądowych, powoduje to zmianę stosunku izotopu strontu w osadach oceanicznych.

Geological Society of London Scientific Statement: what the geological record tells us about our present and future climate

Caroline H. Lear^{1*}, Pallavi Anand², Tom Blenkinsop¹, Gavin L. Foster³, Mary Gagen⁴, Babette Hoogakker⁵, Robert D. Larter⁶, Daniel J. Lunt⁷, I. Nicholas McCave⁸, Erin McClymont⁹, Richard D. Pancost¹⁰, Rosalind E.M. Rickaby¹¹, David M. Schultz¹², Colin Summerhayes¹³, Charles J.R. Williams⁷ and Jan Zalasiewicz¹⁴

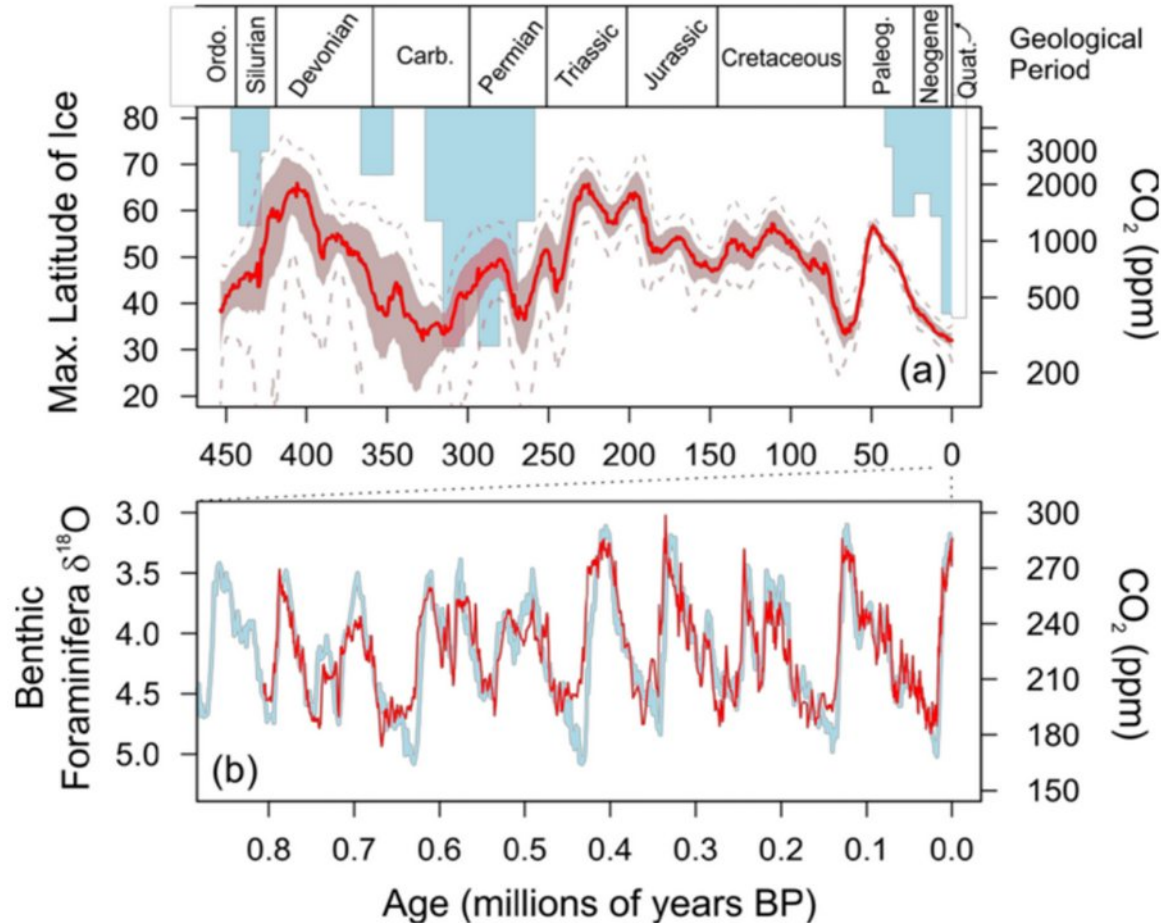
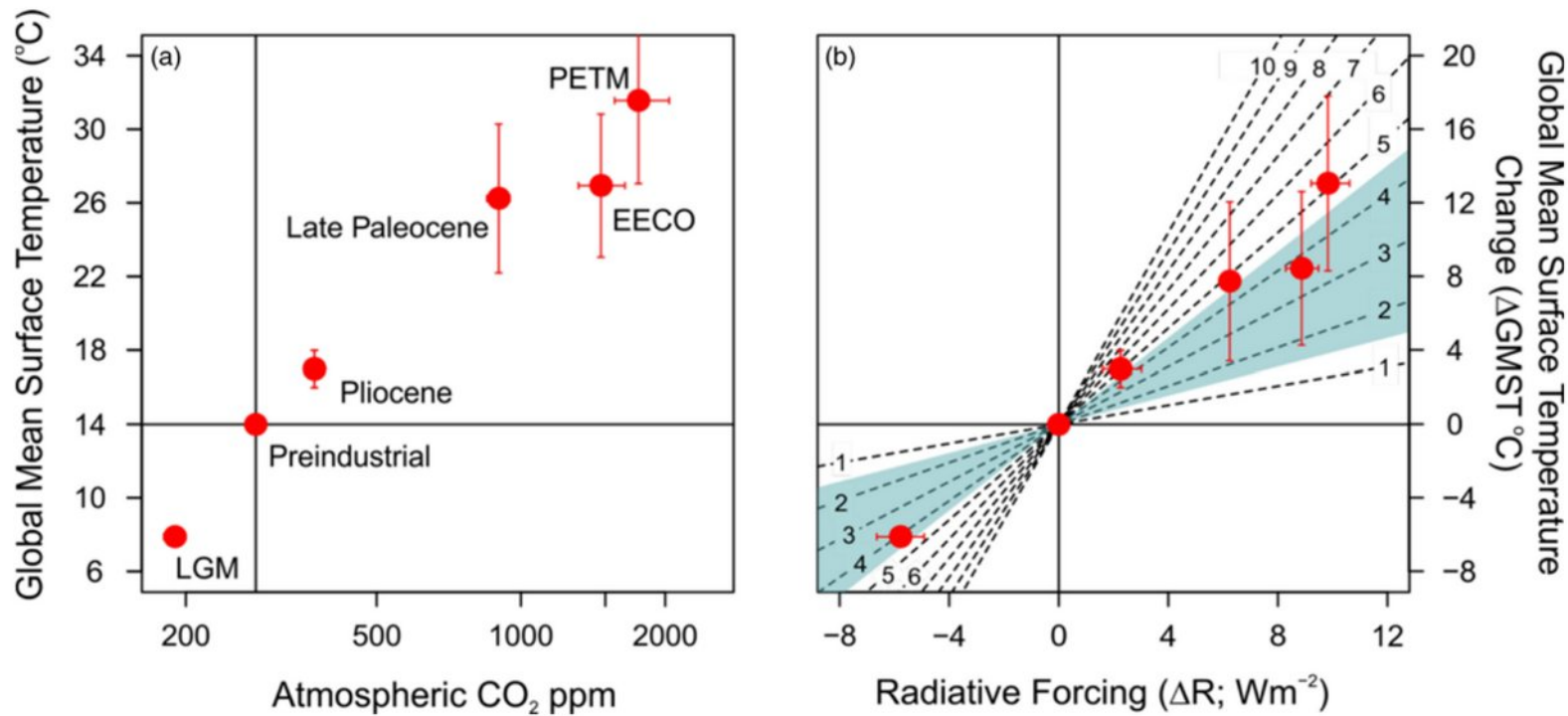


Fig. 1. Carbon dioxide and climate through the Phanerozoic.

(a) Latitudinal extent of continental ice deposits shown as blue bars (left axis) and atmospheric CO₂ content (red, right axis).

(b) A close-up of the last 0.8 million years comparing CO₂ from ice cores (red, right axis) with benthic foraminiferal oxygen isotope ratios (δ¹⁸O) (blue, left axis).



(a) The relationship between atmospheric CO₂ concentration and global mean surface temperature (GMST) for five time intervals where both variables have been recently well constrained by geological data.

(b) The relationship between radiative forcing (ΔR in W m⁻²) and global mean surface temperature (Δ GMST) relative to pre-industrial values. Contours show equilibrium climate sensitivity from 1 to 10 °C per CO₂ doubling, and the blue band shows the canonical IPCC range of Equilibrium Climate Sensitivity of 1.5 to 4.5 °C per CO₂ doubling.