MUNI
SCI

07 Past climate changes and how to study them

Lukáš Dolák, MSc, PhD

Question of the day

How can we prove that recent climate change is exceptional and when significant climate changes occurred?

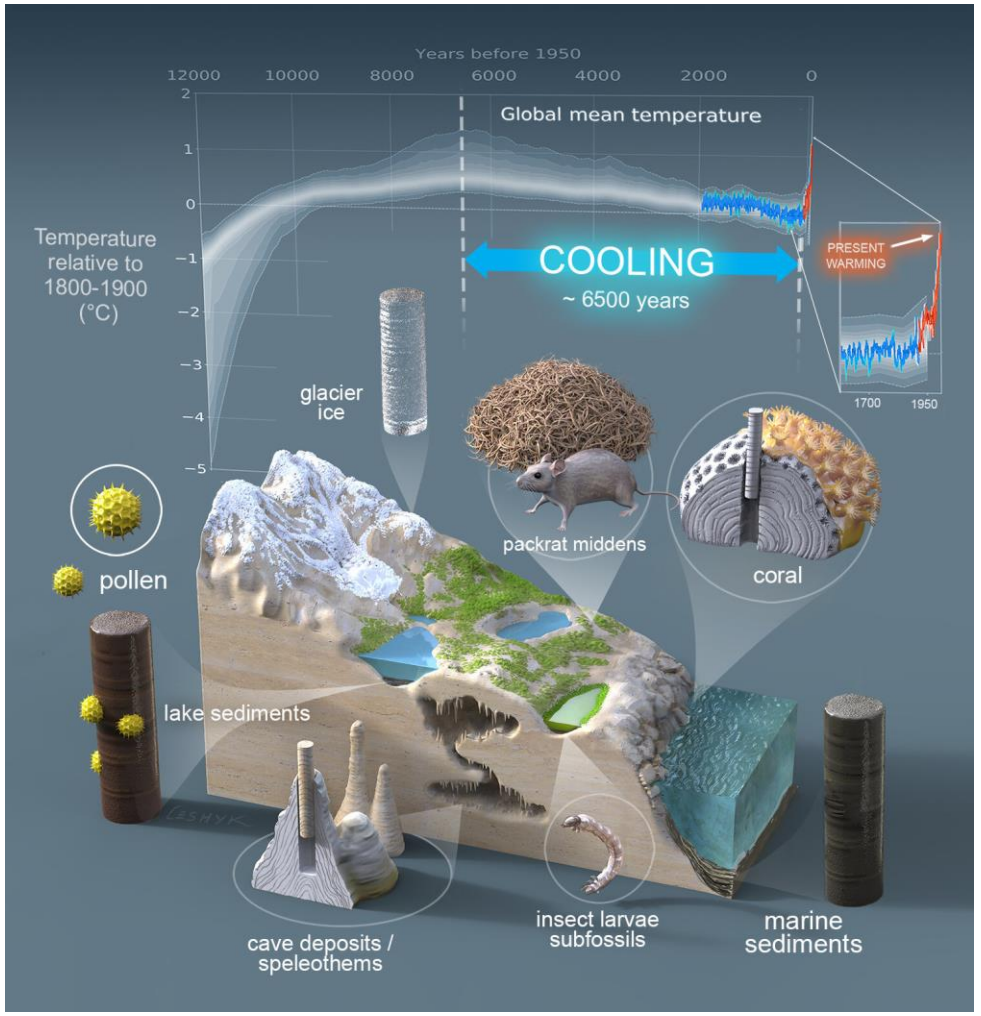
Content of the lecture

1. Palaeoclimatology and historical climatology
2. Archives of nature and selected methods
3. Archives of human society
4. Climate changes in the past
5. Climate in the Quaternary

Palaeoclimatology
and historical climatology

Paleoclimatology

- A scientific discipline that studies climate variability and changes, usually **before the beginning of instrumental measurements** (thousands–millions of years)
- Analysis mostly of **indirect data** (proxy – natural archives)
- **The principle of topicality**:
  - the link between climatic conditions and natural phenomena was the same in the past as it is today



Leshyk, 2020

Historical climatology

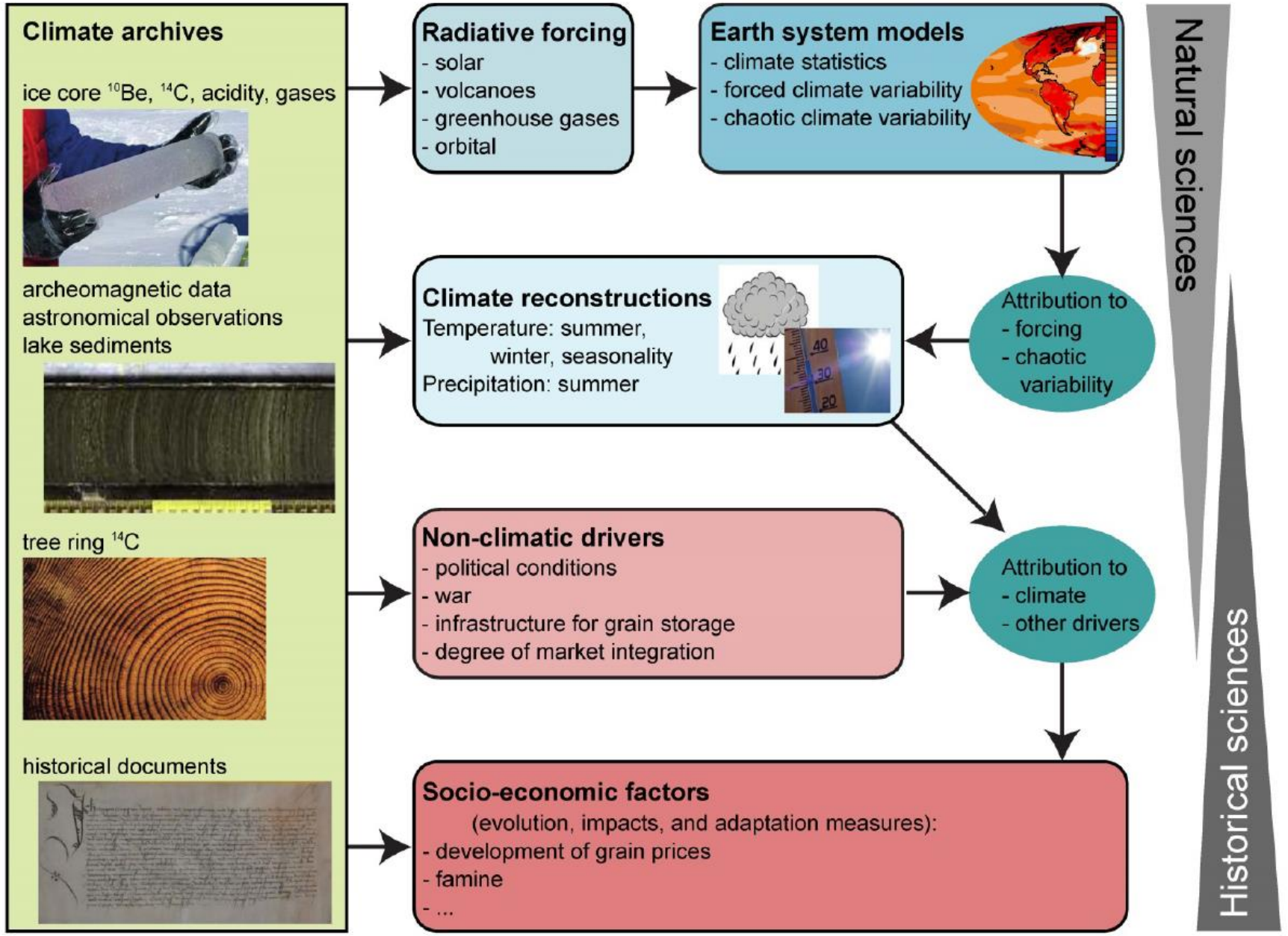
- A scientific discipline at the boundary between **climatology** and **(environmental) history**
- Working mainly with **documentary** and **image sources**
- Filling the space between **palaeoclimatology** and **climatology** in time with the period of instrumental measurements, or overlaping them
- **Development** since **1960** (H. Lamb, E. L. R. Ladurie)
- **Major development** after 1990 (Ch. Pfister, R. Brázdil)

Dividing data sources

- Archives of nature (proxy data)
- Archives of society

Archives of nature and selected methods

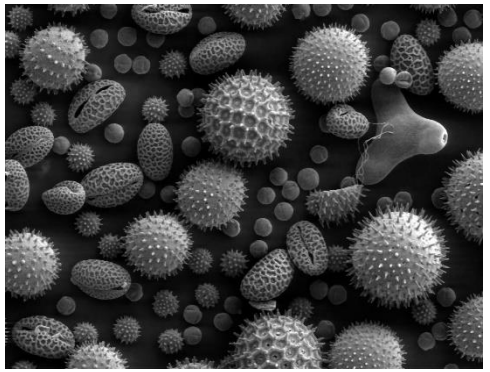
Overview of research disciplines and methods studying past climate and factors influencing climate impacts

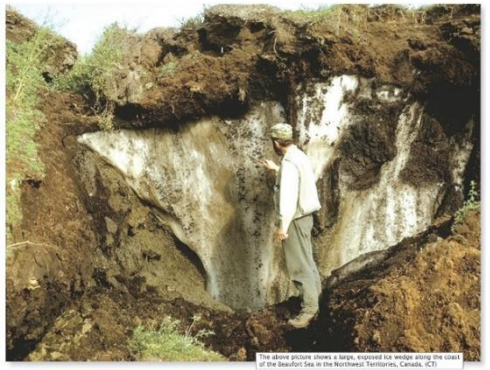


Camenisch et al. 2016

Archives of nature

- Information about the influence of **natural processes** and **humans** on the landscape in the distant past (a period before the archives of human society)
- **Natural processes and data sources**:
  - volcanic eruptions, flood clays, peat bog, tree rings (stalactites, corals...), pollen, ice wedges, varves ...

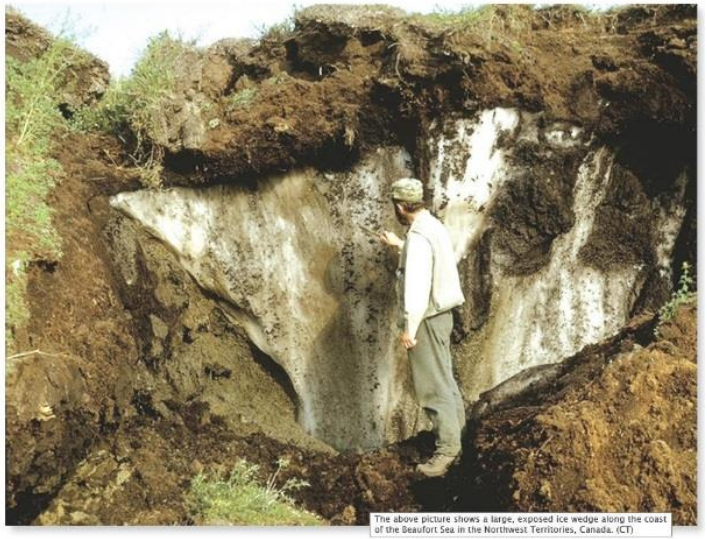




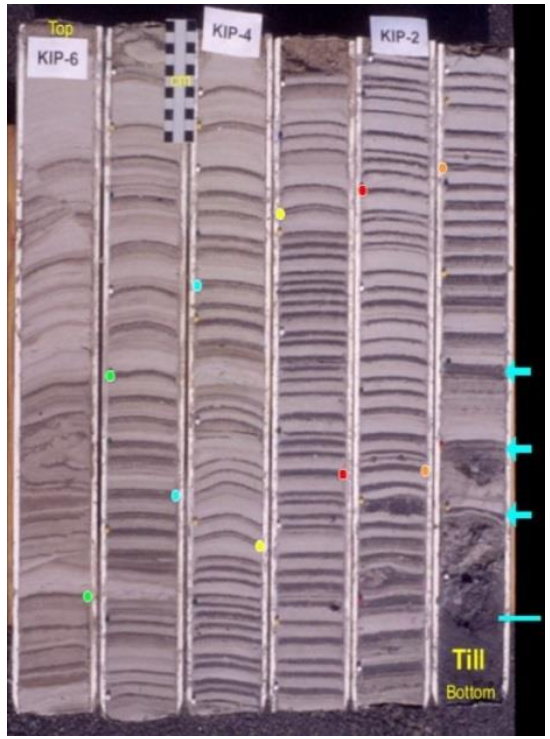
Archives of nature

stalagmite (Hvězdárna UB, 2012)

ice core (Univerzita Washington, 2014)



ice wedge (Jones et al.,, 2009)



glacial sediments (North American Glacial Varve Project, 2014)

ibex (incest.com, 2015)

tree ring (mezistromy.cz, 2015)

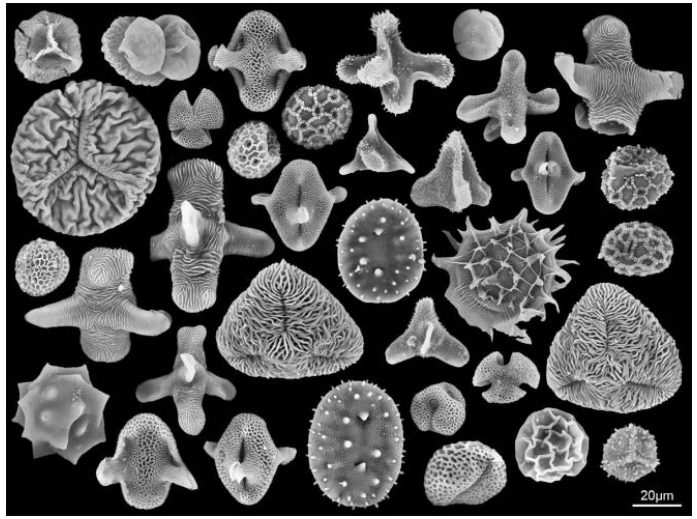
peat bog (region-krkonose.cz, 2018)

Methods working with archives of nature

- Radiometric dating (**radiocarbon method**):
  - origin of the method in the late 1940s
  - abbreviation "BP" (before present) – 1950
  - **advantages**:
    - wide range of applications (archaeology, anthropology, art history)
  - **disadvantages**:
    - use for dating only organic material
    - usefulness of the method up to about 40 000 years BP

Methods working with archives of nature

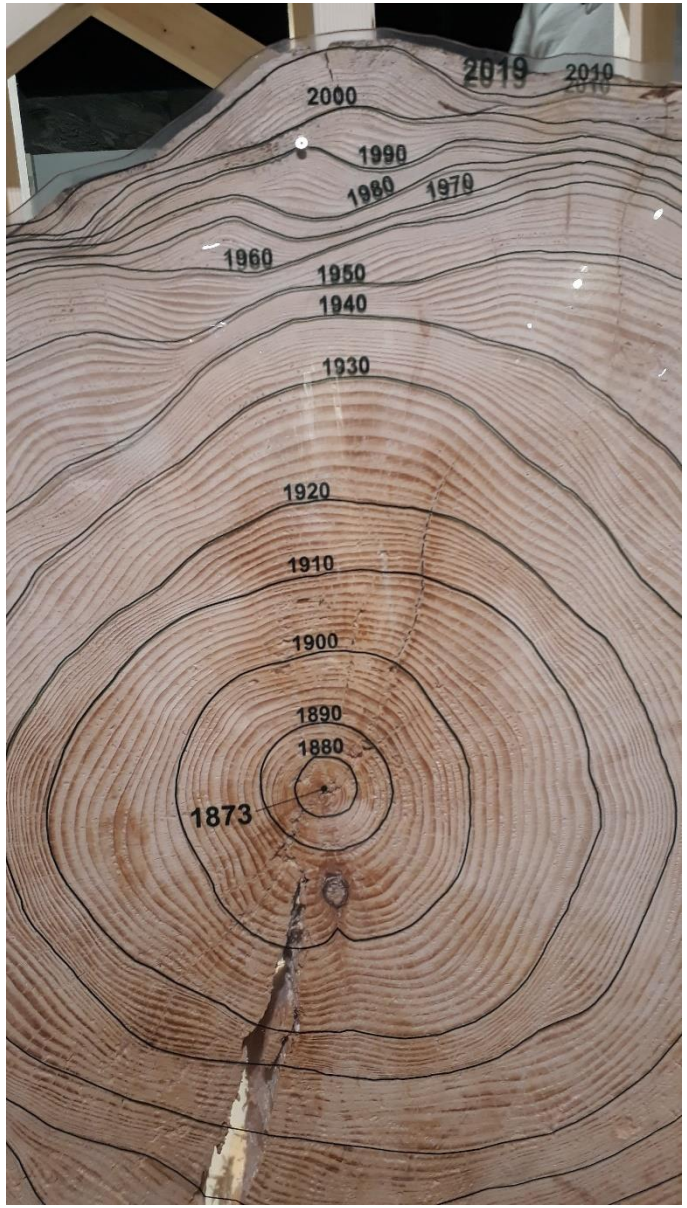
- **Incremental dating**:
  - dendrochronology: analysis of tree rings
  - palynology: study of pollen grains
  - glaciology: glacial layers



geologues-prospecteurs.fr, botany.cz, 2019

Dendrochronology

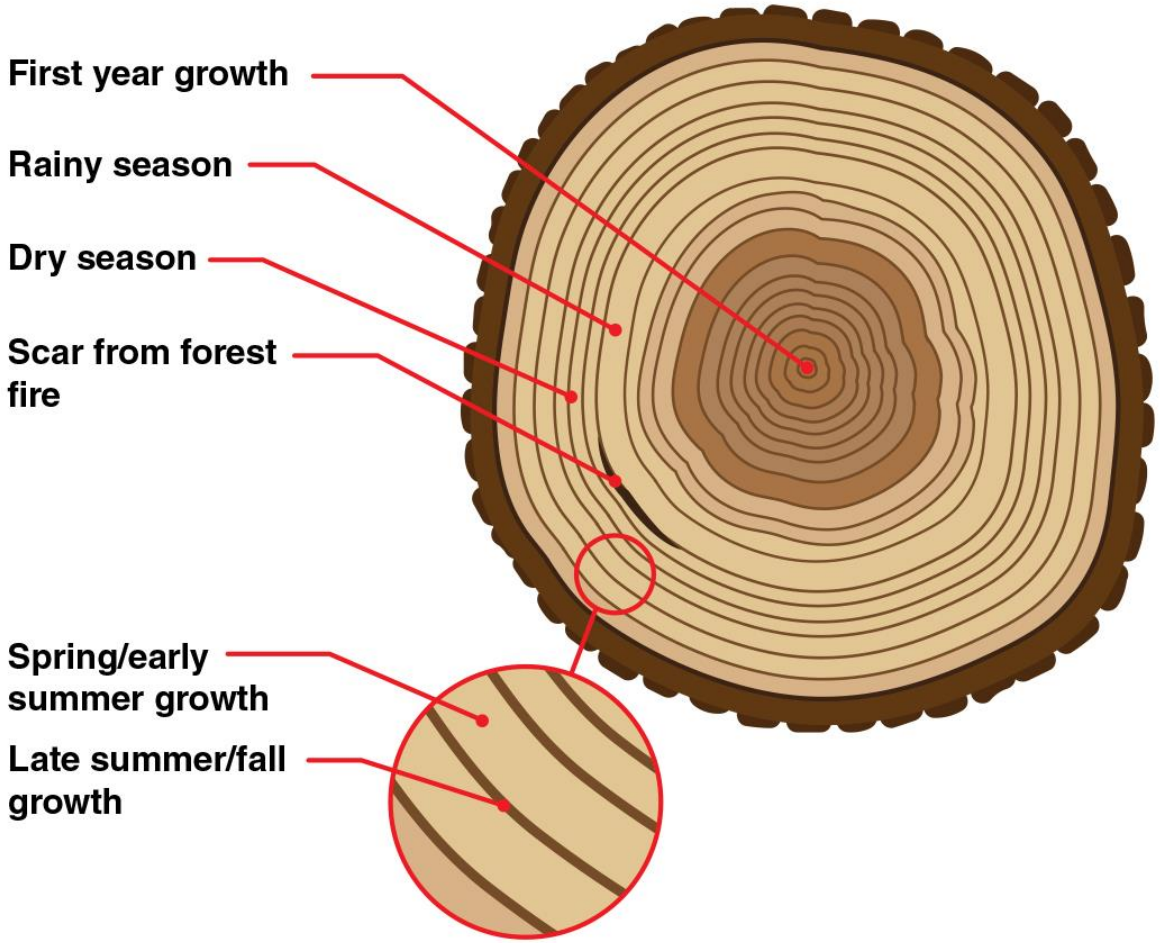
- A method of **dating wood** based on the measurement of the **widths** of the rings or their **density**
- The study of the information stored in tree rings and attempts to explain their causes – reconstructing temperature and precipitation, fires, droughts, earthquakes, volcanic eruptions, insect infestations, dating glacier movements...



Dendrochronolgie, 2020

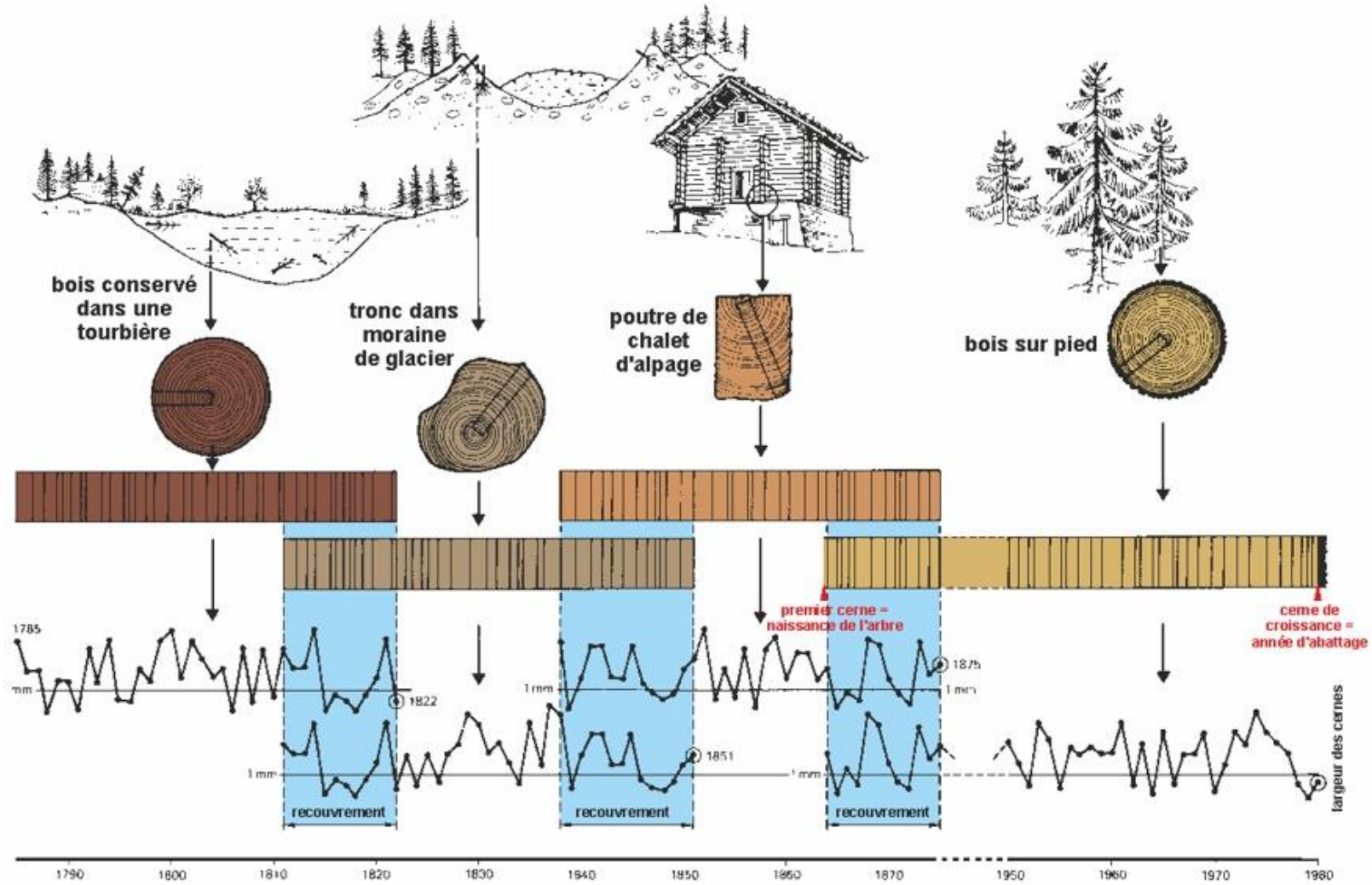
Dendrochronology

- Ring width measured to the accuracy of **0.01 mm**
- **Oldest reconstructed series**:
  - from 10 460 BC (oak and pine)
  - Central Europe (Czech Republic): from 4 682 BC (oak)



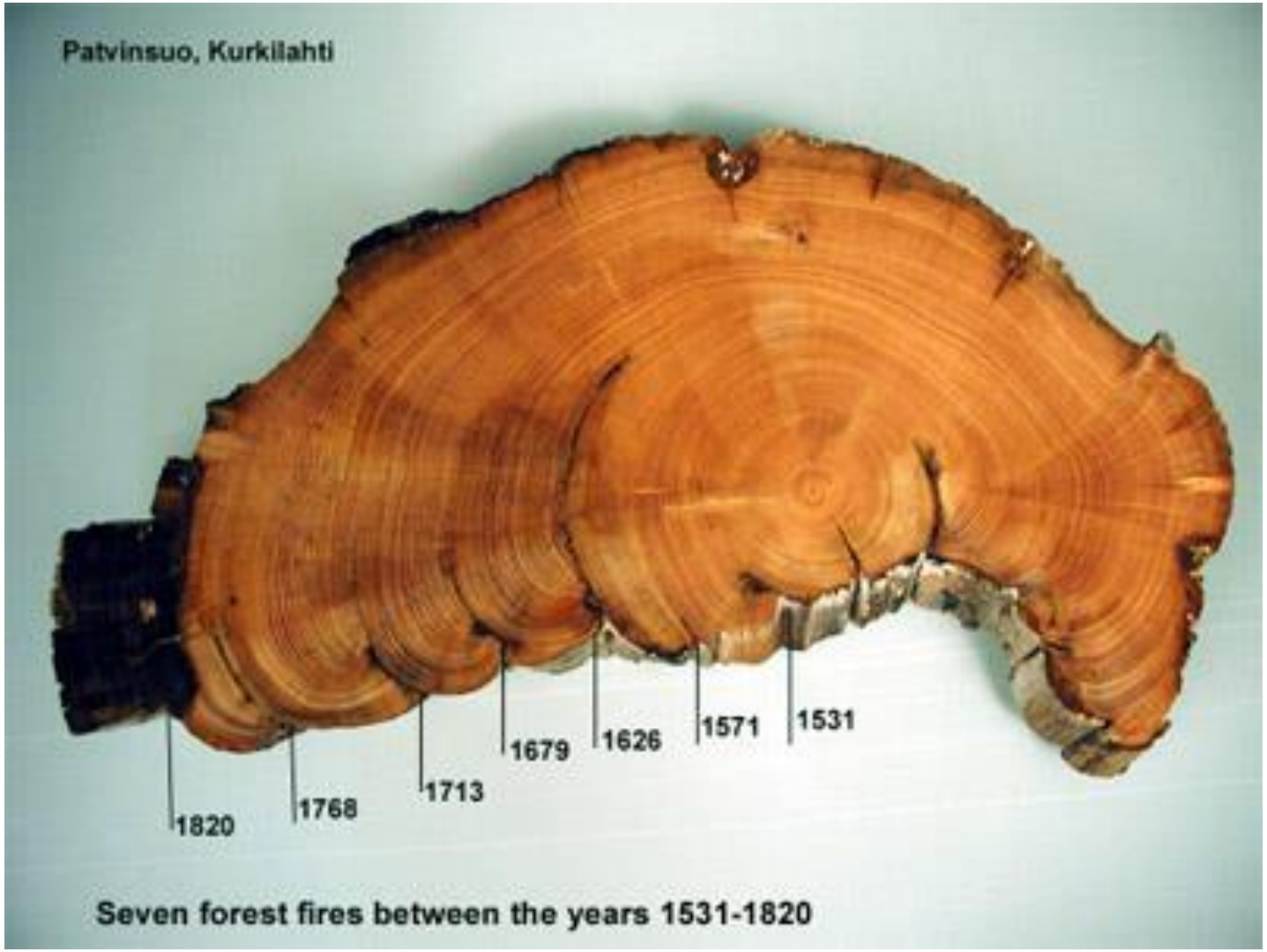
Flickr Creative Commons, 2017

Dendrochronology



Cybis.se, 2018

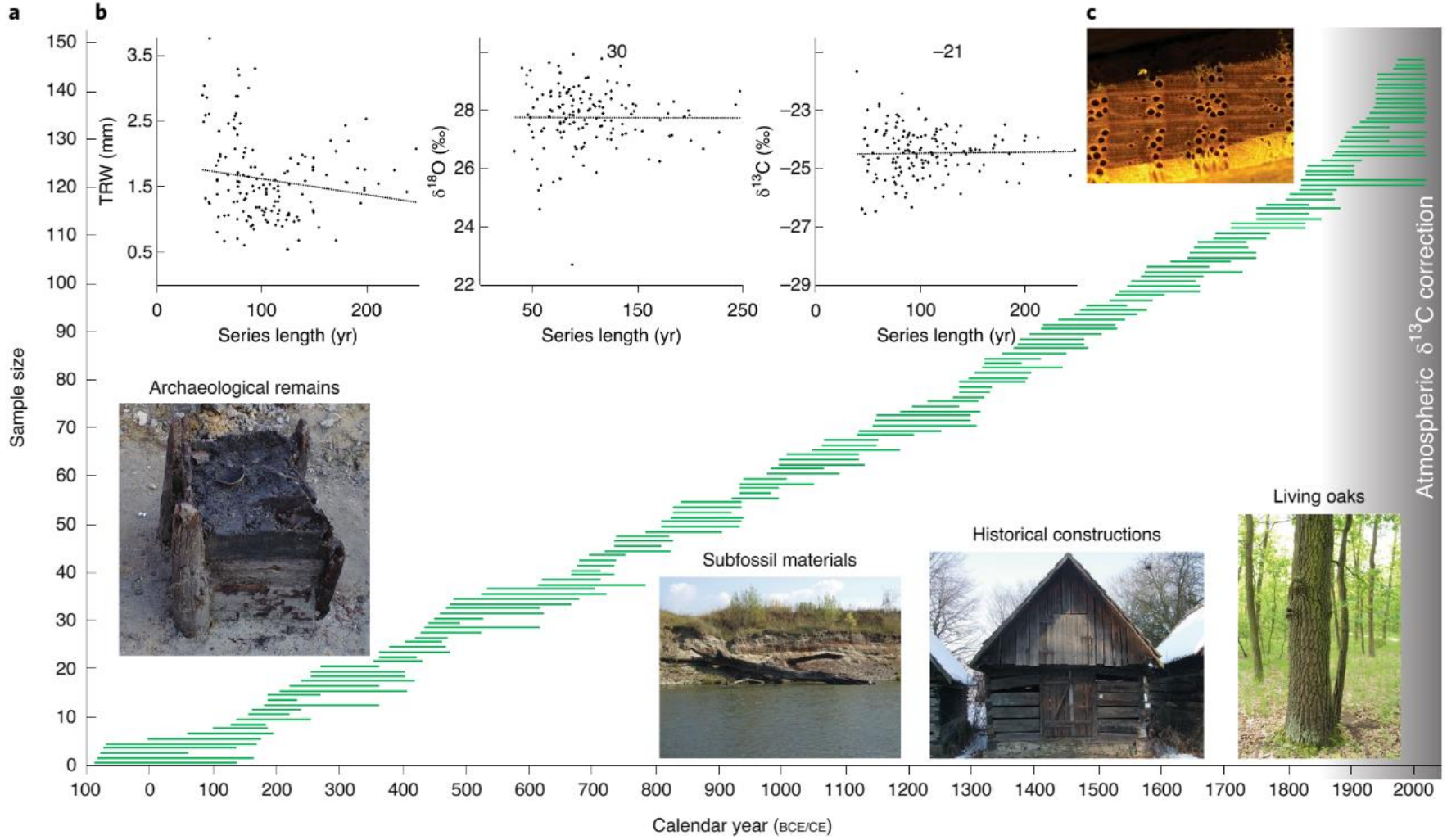
Dendrochronology



Zdroj: thickmust.cf, 2016

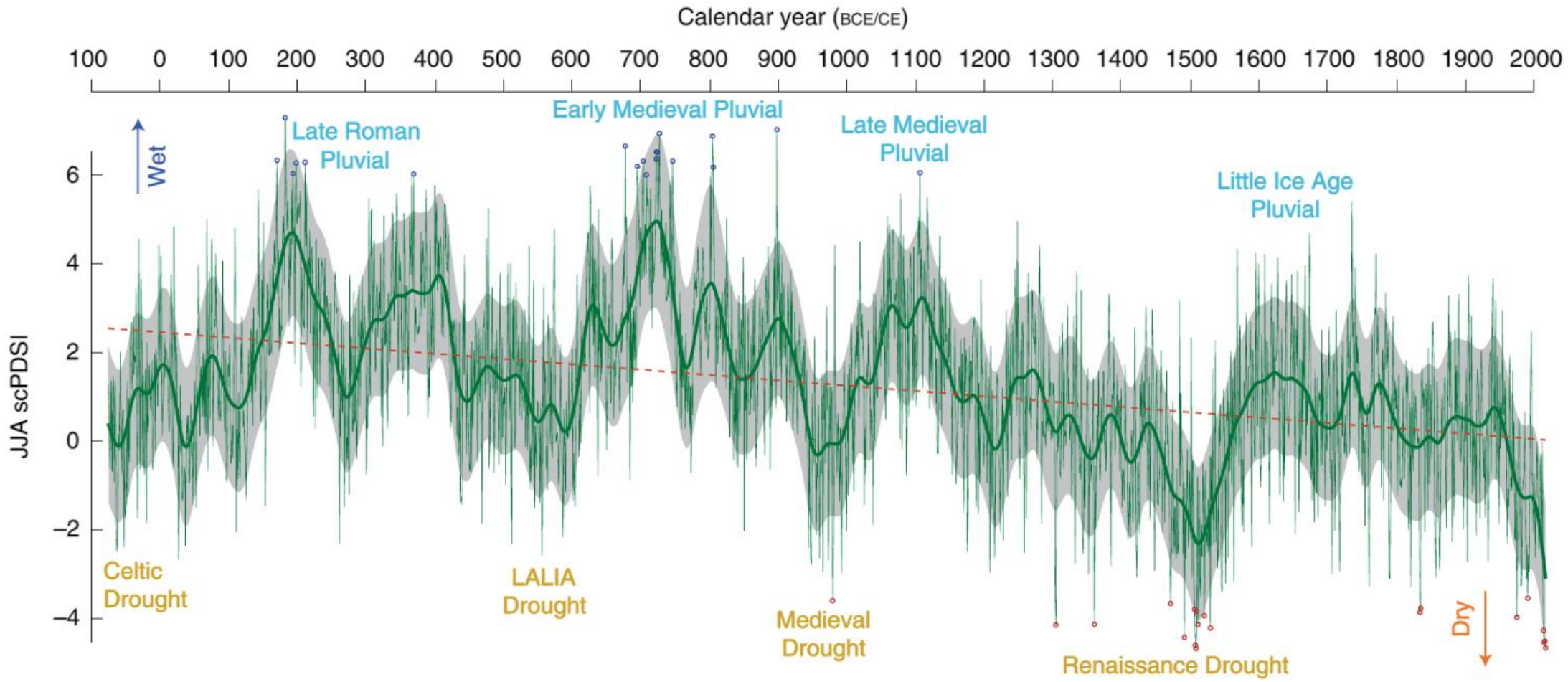
Dendrochronology

European extreme drought episodes and their variability (91 BC–2018 CE)



Büntgen et al. 2021

European extreme drought episodes and their variability (91 BC–2018 CE)



Büntgen et al. 2021

Archives of society

Archives of society

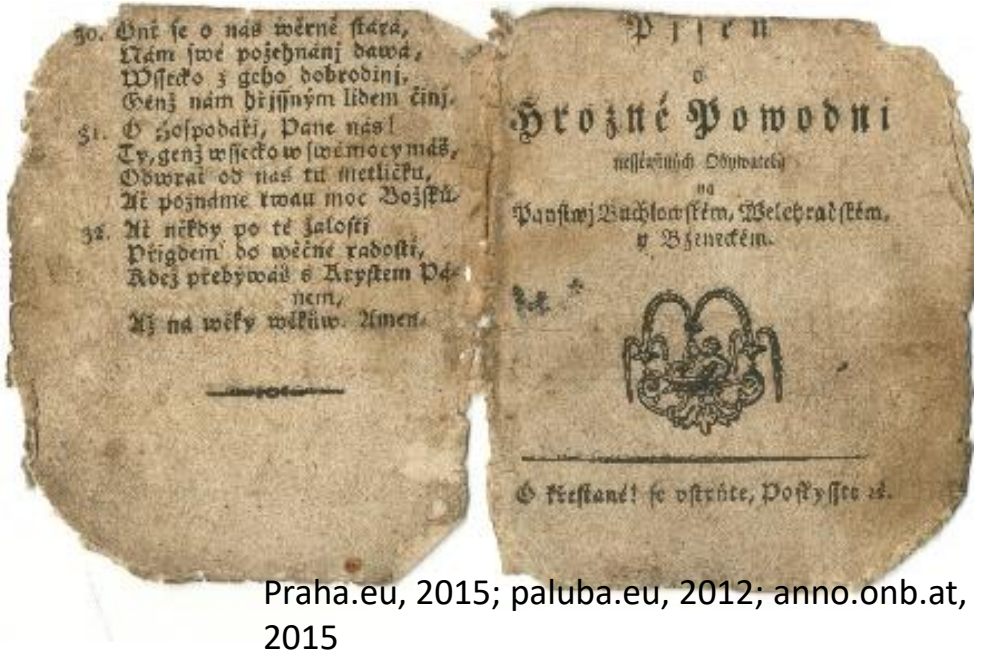
- Archives related to **human activity** or its **remains** (documents, tools, skeletal remains, personal statements, etc.)
- Archives, museums, collections, living historical memory
- **Temporal and spatial diversity of documentary sources** (quantity of documents, level of education of the population, cultural level of a given society, bureaucratization, influence of wars and natural disasters)

Archives of society

Kiss, 2020

Archives of society

- **By type**:
  - early instrumental measurements and observations
  - written sources (chronicles, annals, yearbooks, diaries, correspondence, chronograms, newspapers, etc.)



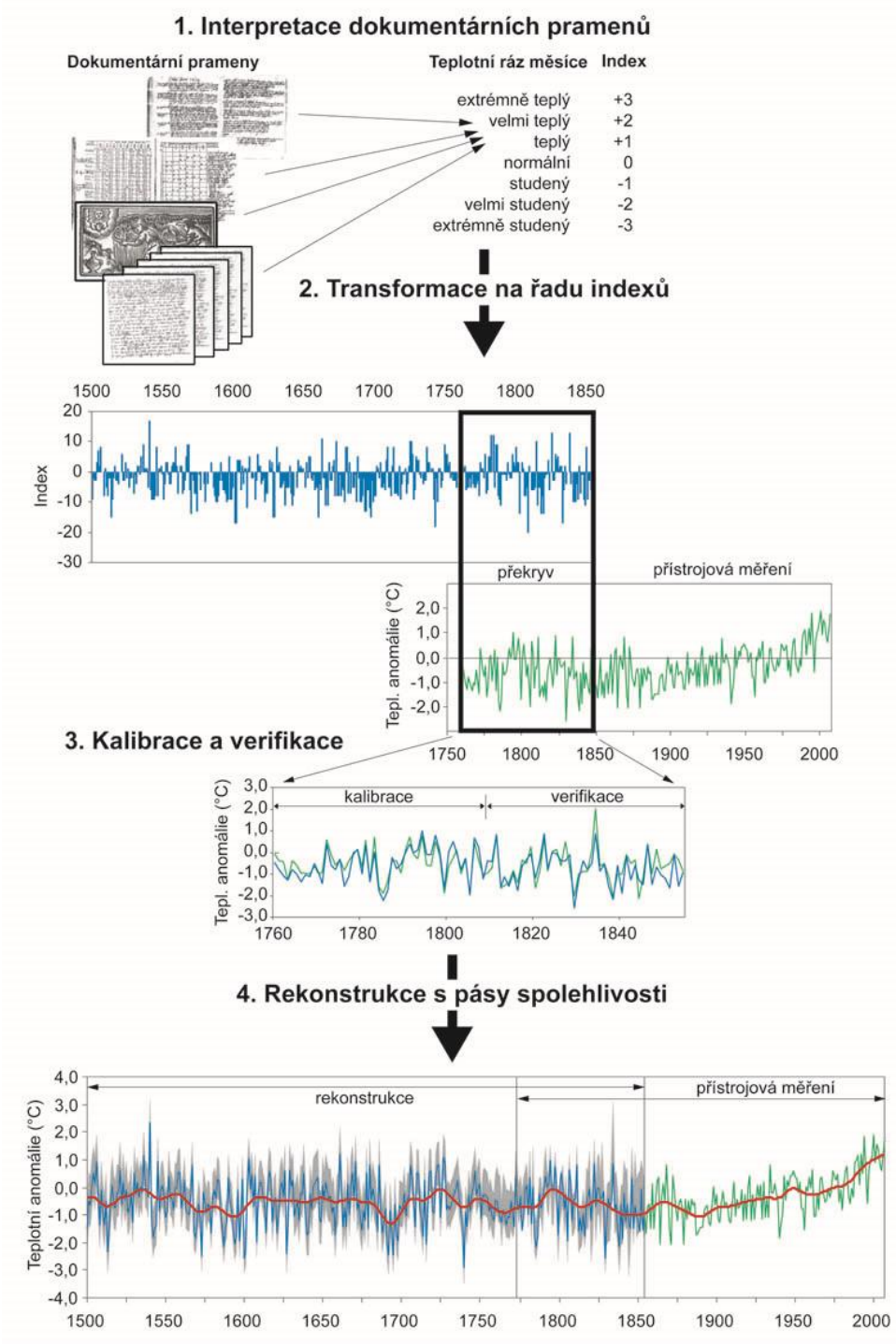
Praha.eu, 2015; paluba.eu, 2012; anno.onb.at, 2015

Archives of society

- **By type**:
  - illustrative sources (maps, paintings, vedutas, etc.)
  - epigraphic sources (flood marks)

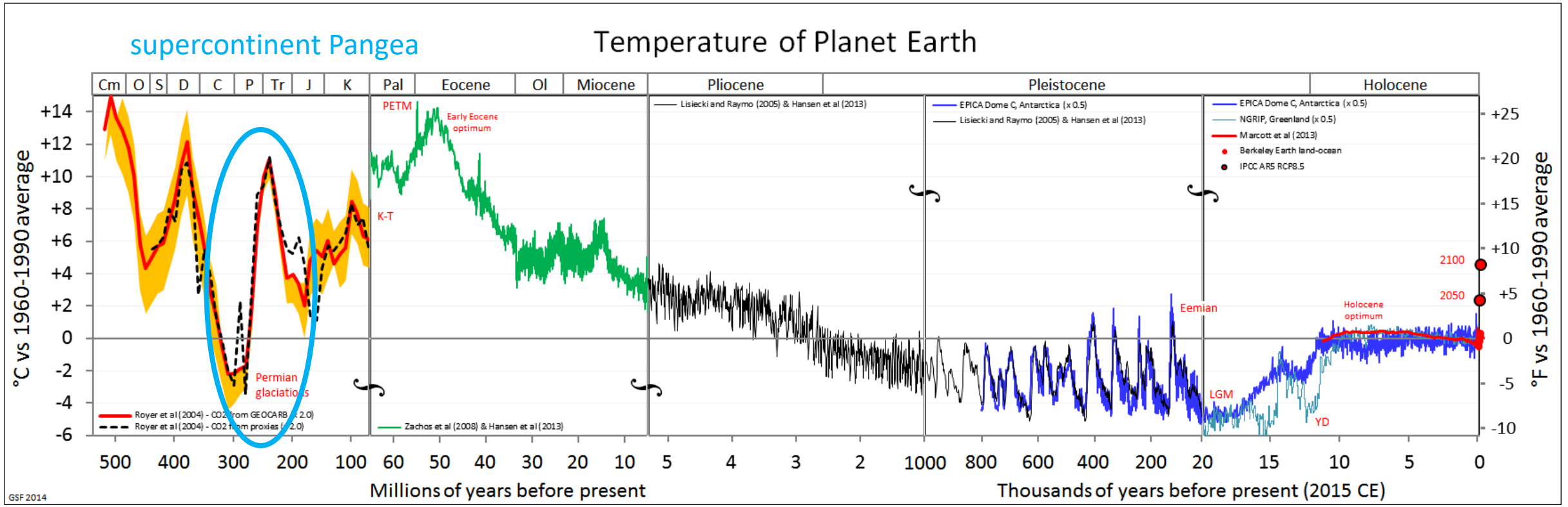
Zdroj: Praha.eu, 2015; anno.onb.at, 2015

Scheme of standard paleoclimatic reconstruction



Climate changes in the past

Air temperature fluctuations (542 Myr–present)



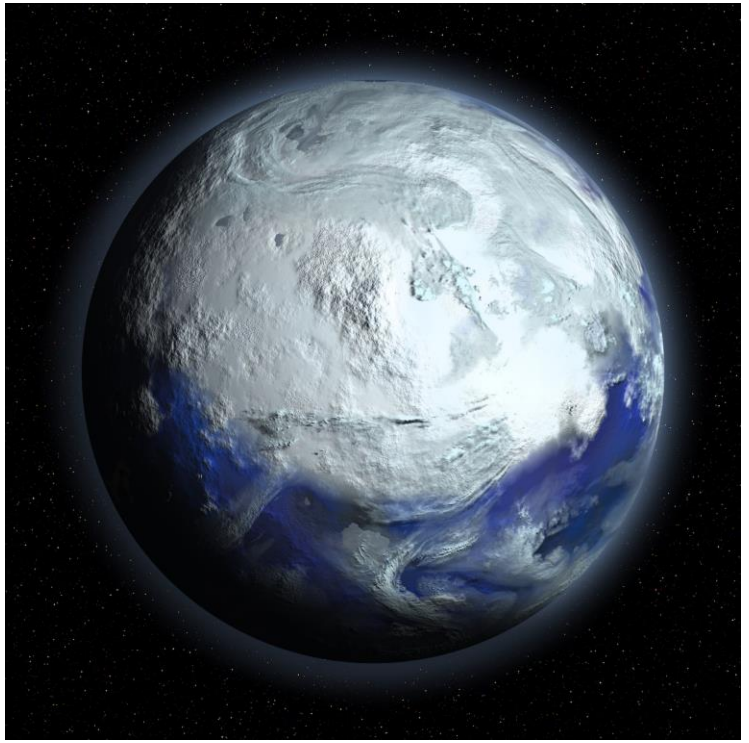
Glen Fergus, 2022

Climate change (4.6–0.6 billion years)

- **4.6–2.9 billion years**: Earth without glaciation, *weak Sun paradox*
  - enhanced greenhouse effect: ca. 100 times higher atmospheric CO_2 concentration, mean temperature up to 60°C
- **2.9–2.8 billion years:** the first (Pongola) glaciation
- **2.4–2.1 billion years**: the second (Huronian) glaciation
  - several possible causes: change in albedo due to continental drift, volcanic activity and reduced sunshine, possible Earth passage of stardust...

Climate change (4.6–0.6 billion years)

- **Snowball Earth hypothesis** (2.2–2.1 billion years and 717–660 million years - Myr)
- Likely freezing of the entire Earth if more than **30% of the planet's surface is glaciated**
- Mean air temperature **about -50°C**, extinction of most organisms (tropics without ice?)
- Ice thickness up to 1 km
- Mean air temperature **up to +50°C at the end of the phases** (boom of life)

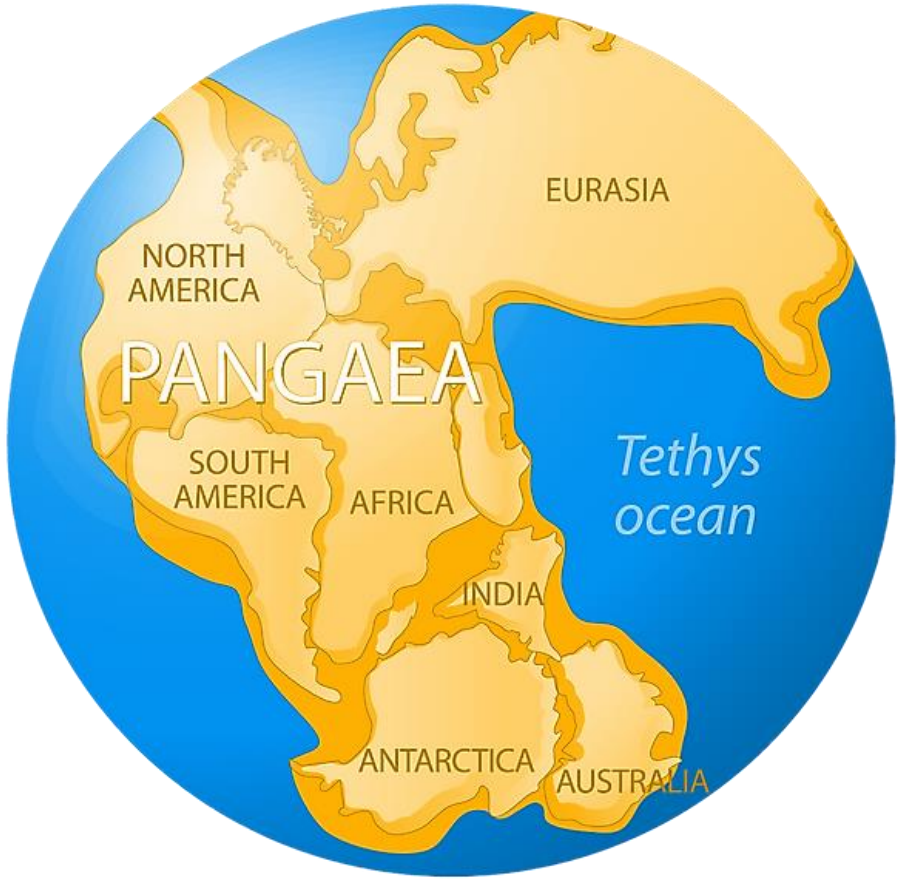


shutterstock.com, 2023

Climate change (542–201 Myr)

- **Cambrian** (542–488 Myr): warm and dry climate far from the equator, lunar landscape
- **Carboniferous** (359–299 Myr): warm and humid climate, dense forests with swamps – the basis for the formation of coal
- **Pangea period** (Permian–Triassic, 299–201 Myr): end of glaciation, warm dry climate, warm summers and cold winters, desertification, end of wetlands, 250 m drop in sea level

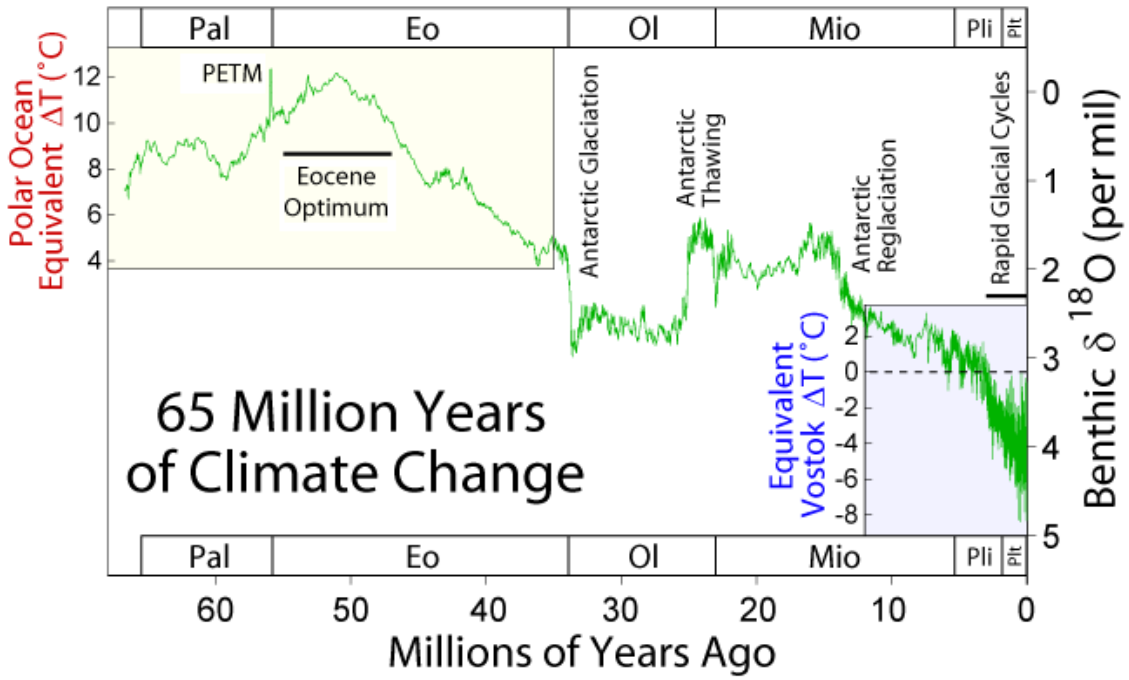
BEFORE



AFTER

Climate change (201–55 Myr)

- **Jurassic–Cretaceous** (201–66 Myr): warm and humid climate - intense charcoal formation
- 55 Myr (Paleogene 66–23 Myr): **Paleocene-Eocene Thermal Maximum (PETM)**
  - >T about 5–8°C/6 000 years
  - extinction of 75–96% of the Earth's species



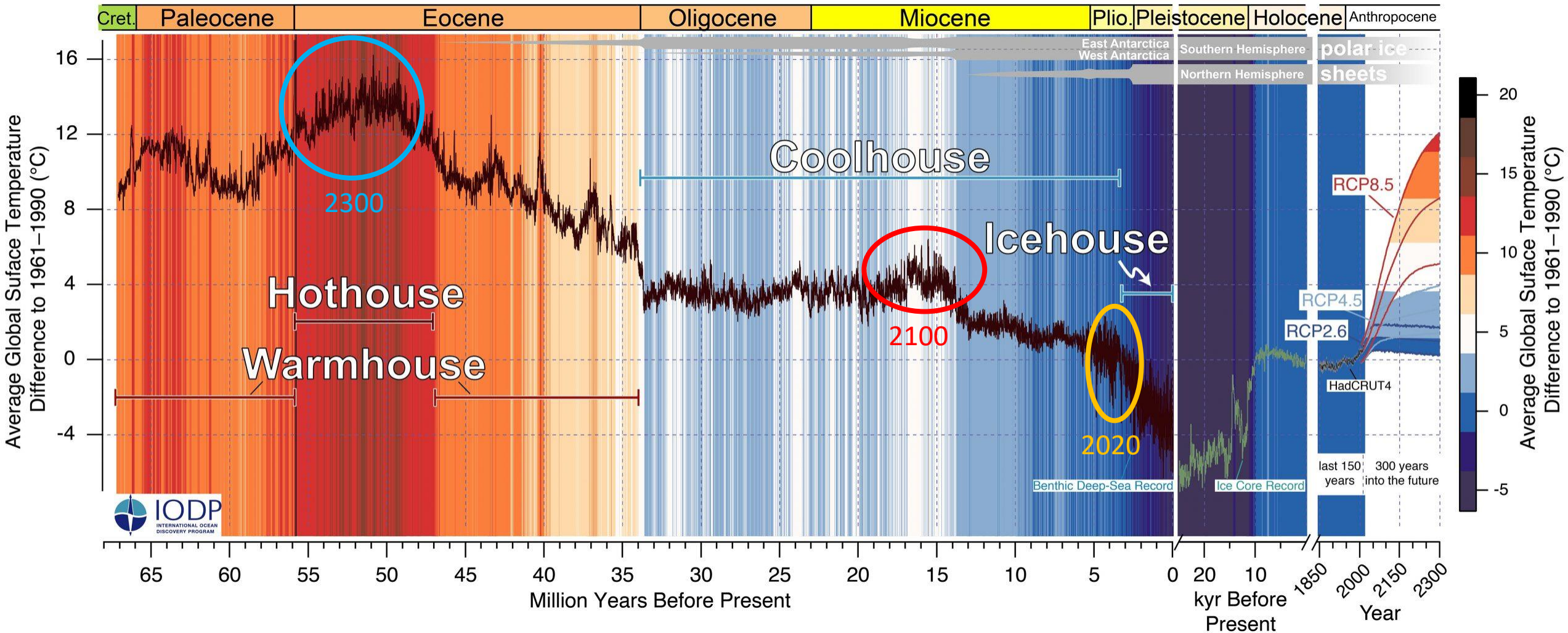
Imagining the Antarctic rainforest 90 million years ago

Zdroj: Alfred Wegener Institute/James McKay (CC-BY 4.0)

The most significant climate changes in the last 65 mil. years

- **Glaciation of Antarctic** (35 Myr)
  – the beginning of a continuous cooling of the planet
- **Glaciation Greenland** (3 Myr)
- Changes in **glacial/interglacial periods** (Pleistocene, 2,6 Myr)
- Beginning of **Holocene** (11 700 BP)
- **Recent climate change** (20^{th}–21^{st} centuries)

Air temperature fluctuations (66 Myr–2 300 CE)



N and S poles without glaciers

(MCO) end of glacier formation

Greenland without a glacier

Westerhold et al. 2020

Climate in the Quaternary

Quaternary (2.6 Myr–present day)

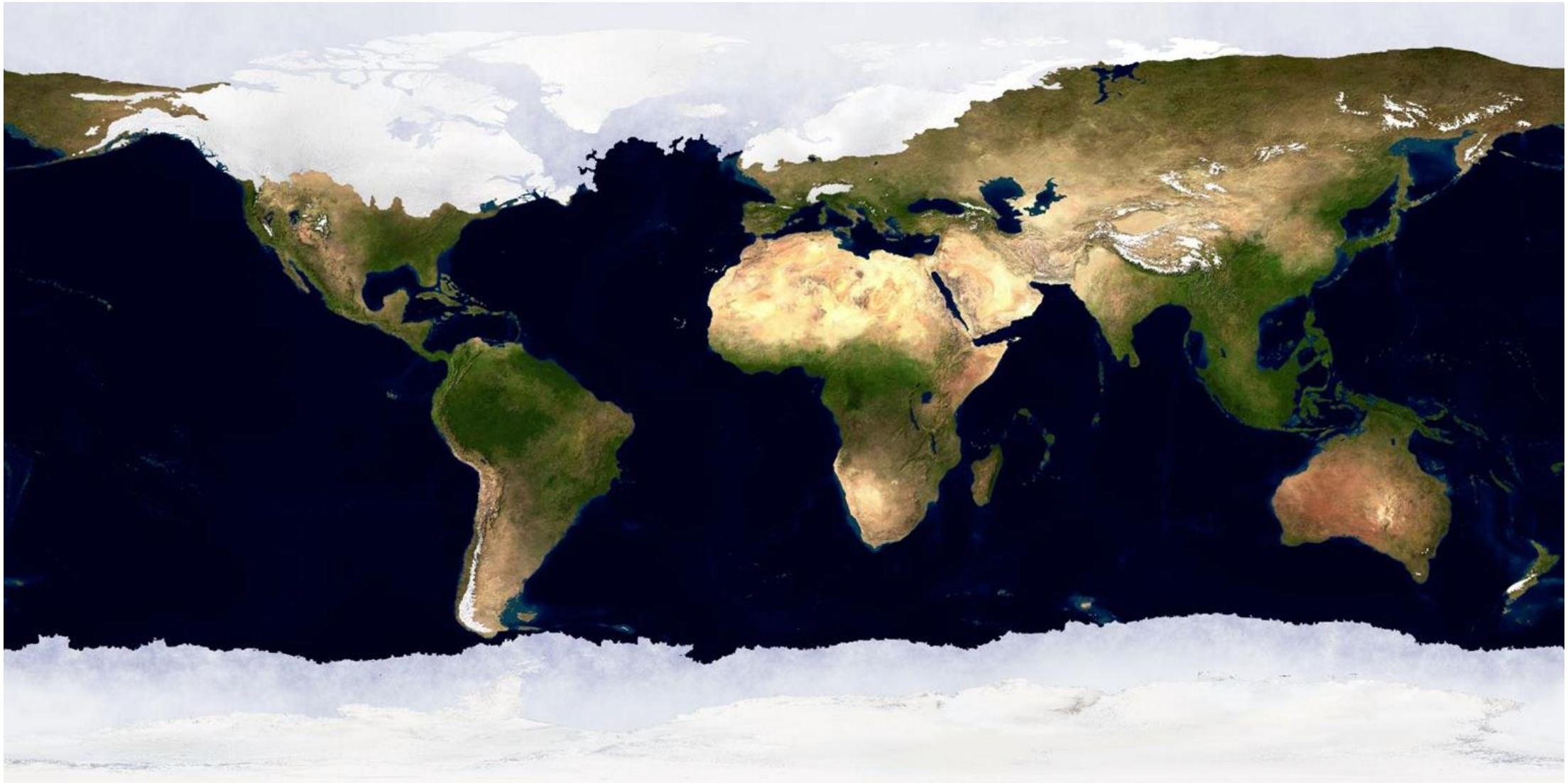
- **Pleistocene** (2.6 Myr–11 700 BP) and **Holocene** (11 700 BP–present day)
  - the youngest and shortest geological period
- **Basics of the current geographical environment**
  - distribution of land, oceans and seas, climate, landscape…
- **Cyclic** and **rapid climate fluctuations** (glacials and interglacials)
- **Period of human development**
  - integral part of ecosystems x influence on climate

Glacial periods (ice ages)

- **Glacials**:
  - approximately 20 glaciations, length 100 000–120 000 years
  - cooler and drier climate (CR T <11–13°C)
  - increase in continentality in W and C Europe

- **Interglacials**:
  - warmer and wetter climate (T >2–3°C)

Last glacial maximum (21 500 years BP)

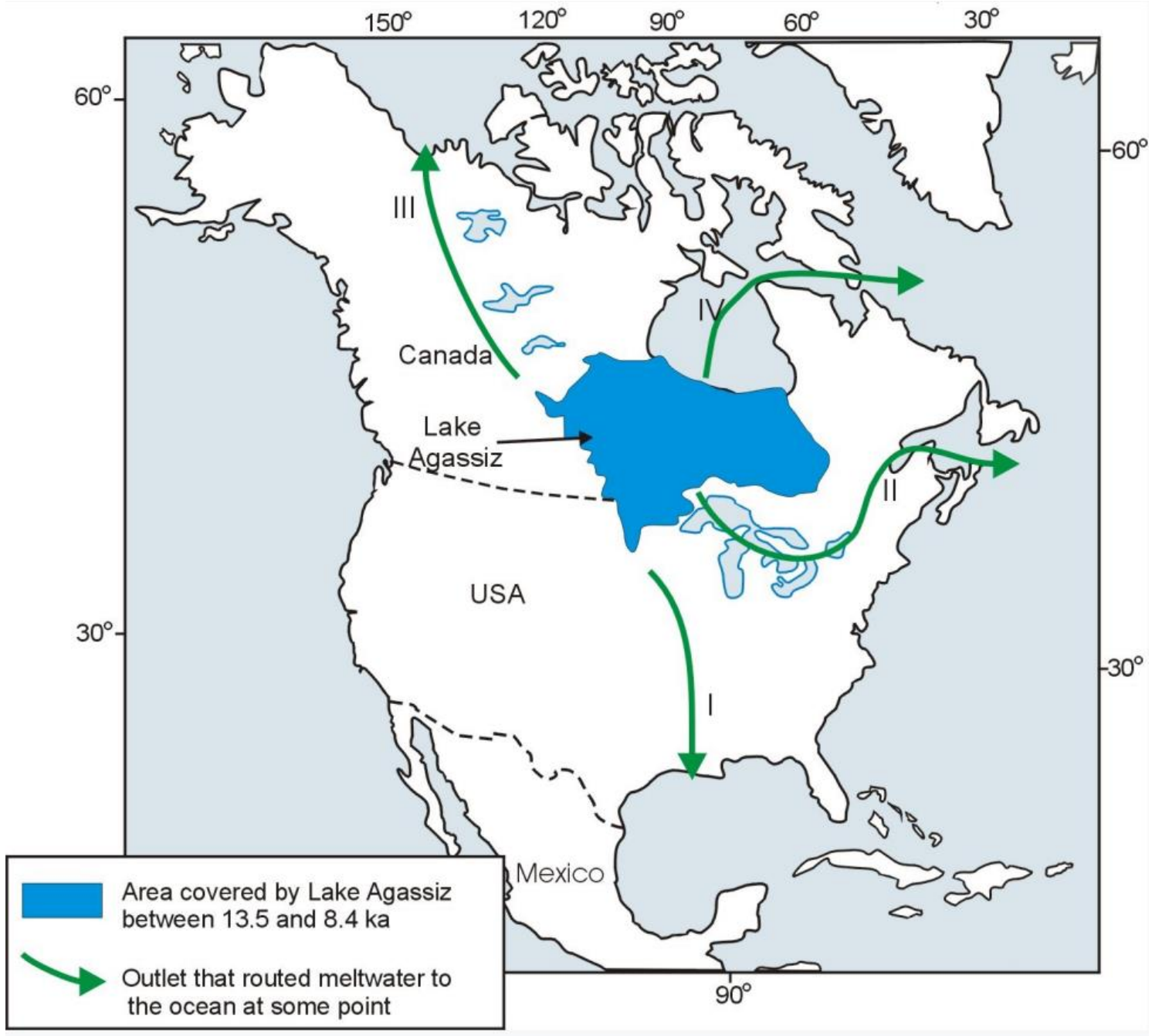


reddit.com, 2021

Major climate changes in the late Pleistocene/Holocene

- **74 000 BP: Eruption** of **Toba** volcano (Sumatra)
  - mean temperature decrease up to 5°C
- **12 900 BP**: cooling (Younger Dryas, Lake Agassiz)
- **11 700 BP: End** of the **last glacial period**
  - warming, stabilisation of climatic conditions – beginning of the Holocene
- **8 200 BP**: sudden cooling of 8 °C/6 months (Lake Agassiz)

Location of Lake Agassiz 13 500 and 8 400 BP



Source: essopenarchive.org, 2023

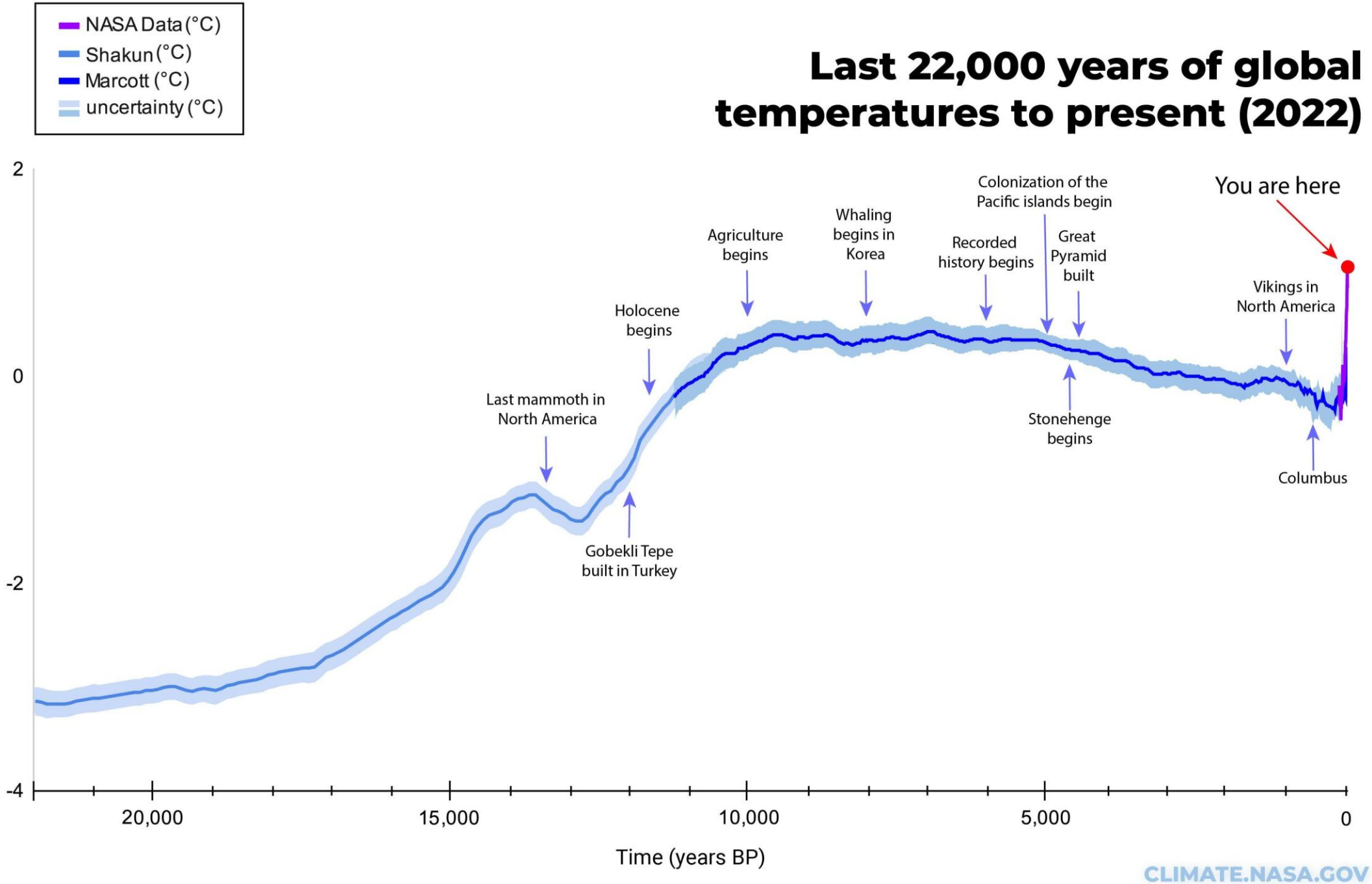
Major climate changes in the late Pleistocene/Holocene

- **Atlantic (8 200–6 000 BP)**
  - **Holocene climatic optimum**
  - warm, humid climate with a balanced climatic course
  - **higher air temperature** (>3°C) and **precipitation** (>650 mm)
  - upper forest boundary >200 m (Holocene peak)
  - **agricultural boom** (not only) in Europe (Neolithic Revolution)

Major climate changes in the late Pleisotcene/Holocene

- **From 6 000 BP**: gradual cooling
- **Around 5 500 BP: the origin of the Sahara**
  - change in the Earth's axis – decrease in solar energy – weakening of the West African monsoon – change from savannah to desert – migration of people to the Nile Valley
- **Holocene**: stable climate with small temperature fluctuations
  - Medieval Climate Anomaly, the Little Ice Age...

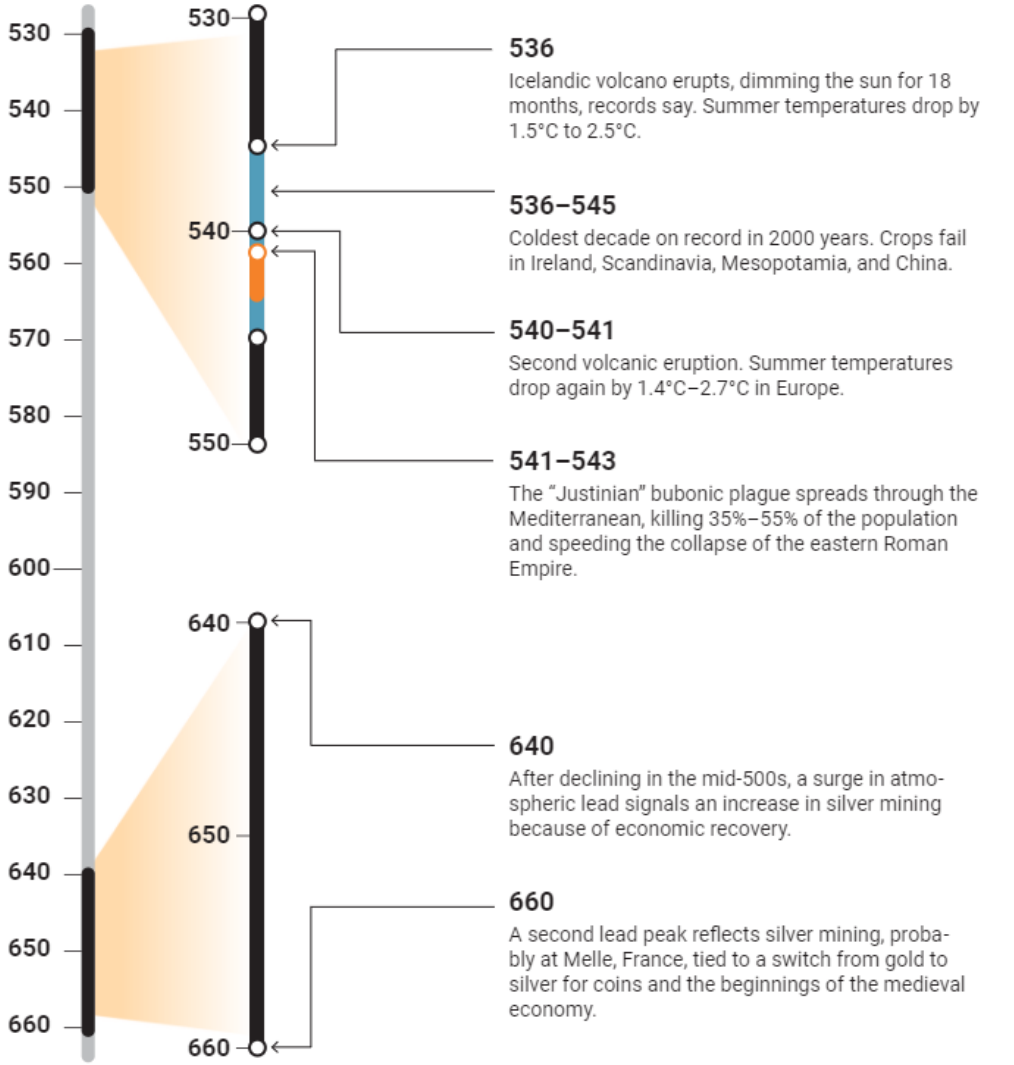
Last 22,000 years of global temperatures to present (2022)



CLIMATE.NASA.GOV

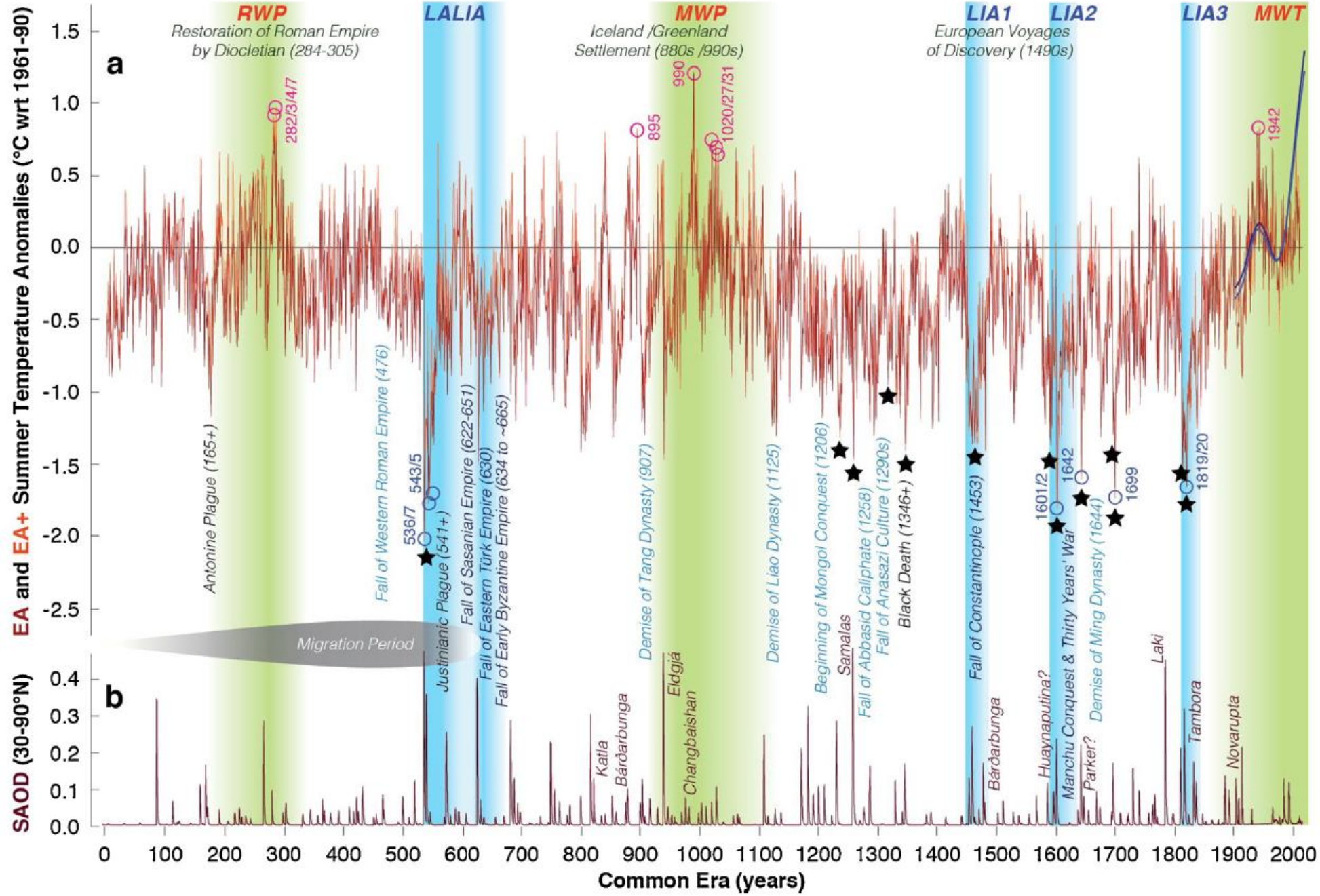
Late Antique Little Ice Age (536–ca 660 CE)

- Strong **volcanic eruptions** in the northern hemisphere: 539, 540, 547
- Significant **temperature drop** in 536 CE in the Mediterranean
- Greatest impact in **Central Asia** and the **Near East**
- **Justinian plague (541–542)**: 25–50 million victims (Byzantium)



(GRAPHIC) A. CUADRA/*SCIENCE*; (DATA) C. P. LOVELUCK *ET AL.*, *ANTIQUITY* 2018; M. SIGL *ET AL.*, *NATURE* 2015; M. MCCORMICK

Air temperature lower (-2°C) than during 1961–1990 CE



Büntgen et al. 2020

Medieval Climate Anomaly (950–1300 CE)

- **Increase** in **air temperature** and **precipitation** in the North Atlantic and Europe (-0.2 to +1.0°C) compared to the previous period
- Overall cooler climate than at present (with the exception of selected years)
- **Possible causes**:
  - intense **solar radiation** (900–1000, 1050–1250)
  - relatively **low** number of **volcanic eruptions** compared to the LIA
  - changes in **land use** and **albedo** (deforestation)

Medieval Climate Anomaly (950–1300 CE)

- Global sea level about 20 cm higher
- Spread of extensive **agriculture** to **higher altitudes** (grains) and latitudes (vines, melons, saffron)
- **Human population growth** and expansion in Europe (Iceland, Greenland, Canada)
- Establishment of **new settlements**: urbanisation, deforestation

Little Ice Age (early 14th century–1850)

- **Gradual climate cooling** (<-1.5°C) in Europe and Asia
- Growth of **mountain glaciers** in Europe and North America (damage)
- **Dryer climate** conditions in the tropics and subtropics (Mediterranean, South America)
- Expansion of the (semi-)deserts of the Sahel

Reschreiter, 1911

Little Ice Age (early 14th century–1850)

- Long **cold winters** with heavy snowfall
- Shifting the **grape-growing boundary** (England, south Norway) 500 km to the south
- More frequent **crop failures** (wheat) and cattle deaths (famines)
- Increase in particular diseases

  (lice - typhus, flea - plague)

medicalnewstoday.com, 2017

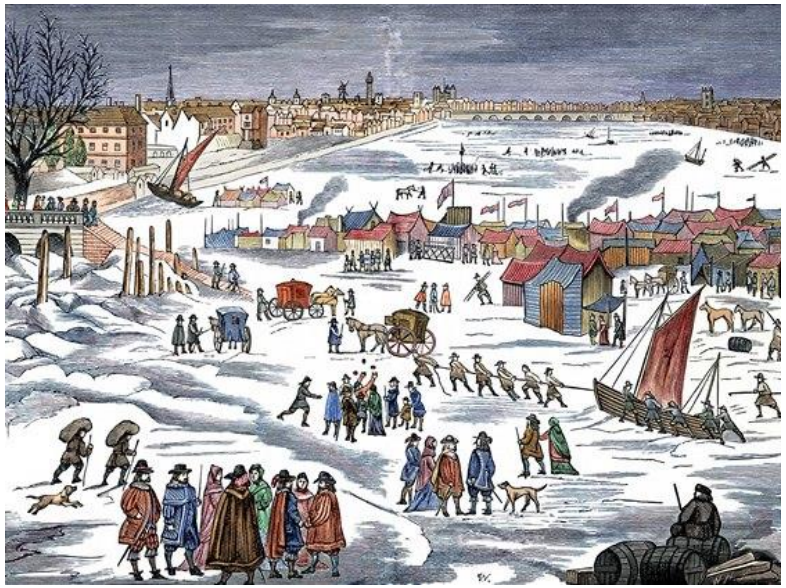
Little Ice Age (early 14th century–1850)

- Freezing of **European rivers** (Rhine, Thames, Rhone), **seas** and **lagoons** (Baltic Sea, Venetian Lagoon - early 14th century)
- Shift of the **floating ice** boundary to the south (restriction of navigation)

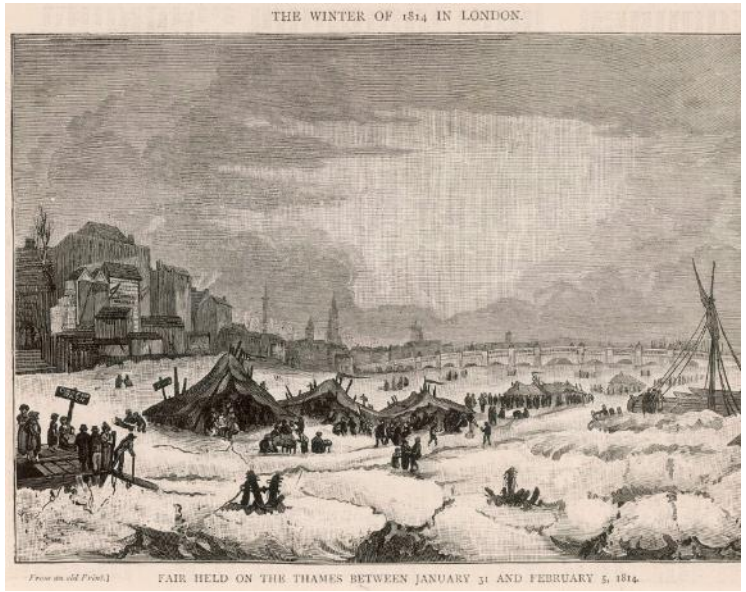
Frozen Venice lagoon, 1709

Libray of the Correr Museum, Venice

Little Ice Age (early 14th century–1850)



frozen river Thames in 1684



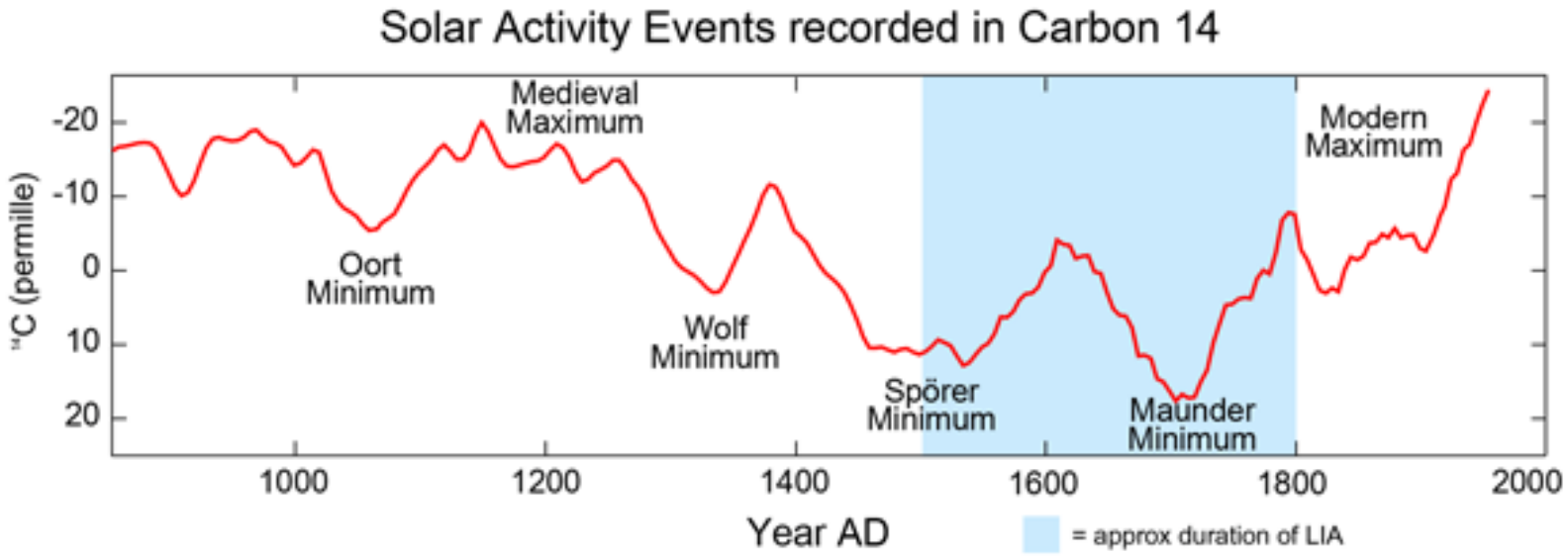
frozen river Thames in 1814

Little Ice Age (early 14th century–1850)

- **Loss** of some **human settlements** (Greenland, Norway -40%, England -4 000 settlements)
- **Cultural and social impacts**:
  - increase in the number of peasant rebellions
  - chiliastic movements
  - witch hunts
  - permanent depressive conditions

Little Ice Age (early 14th century–1850)

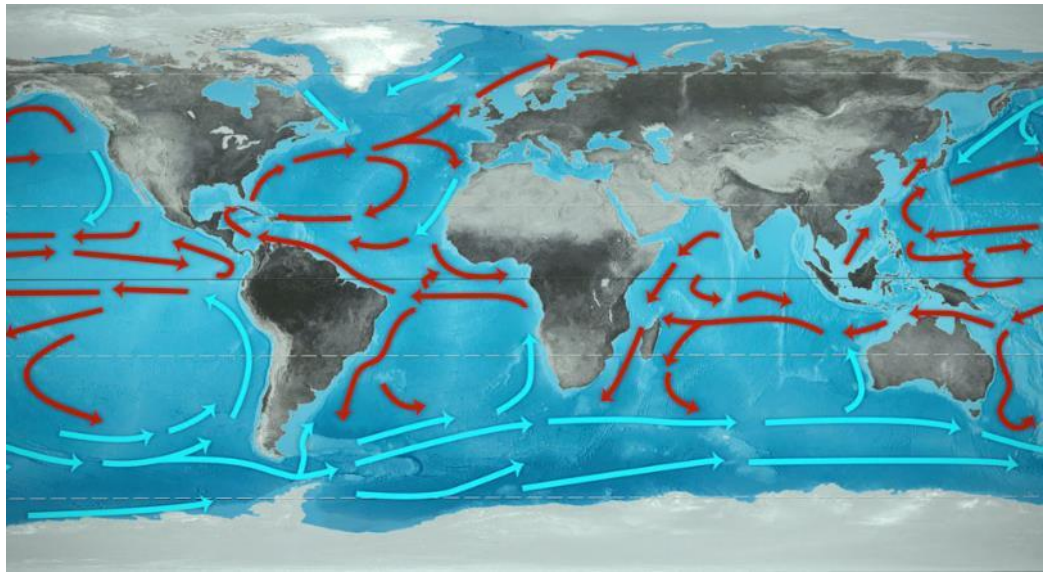
- **Extremely cold periods**:
  - Spörer's minimum (1410–1510)
  - Maunder Minimum (1638–1715)
  - Dalton's Minimum (1790–1830)
- Small climatic optimum (1517–1542)

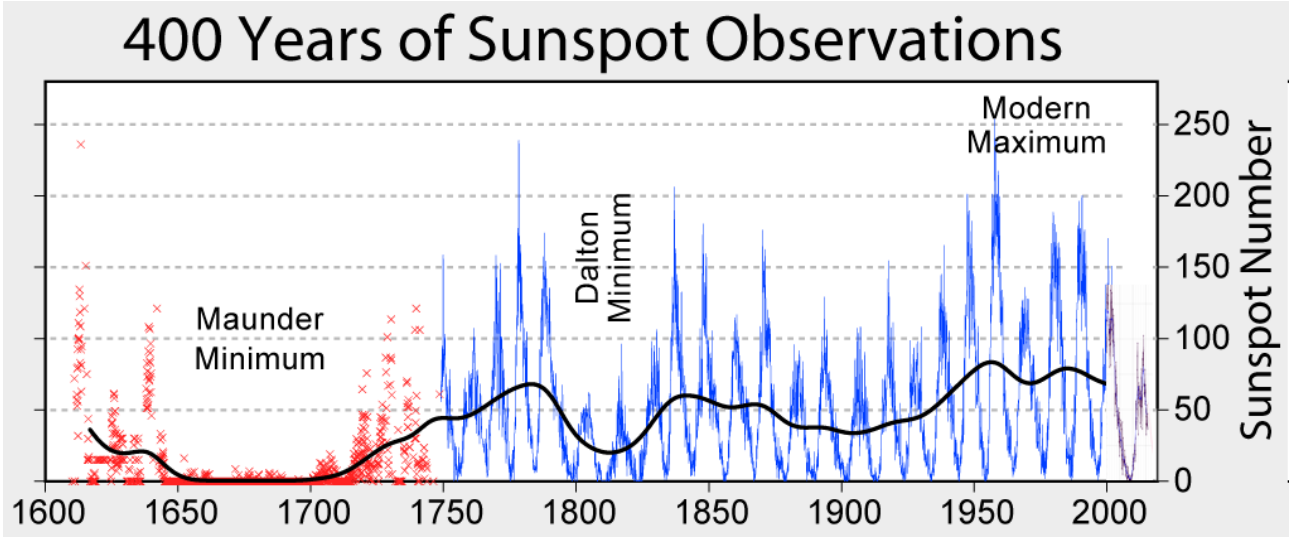


Source: Moreno-Chamarro et al., 2017

Little Ice Age (early 14th century–1850)

- **Possible causes**:
  - reduced solar activity (1260–1330, 1390–1560, 1645–1715)
  - increased volcanic activity (1257 - Samalas, 1815 - Tambora)
  - change in the sea circulation and the extension of sea ice in the Atlantic to the south





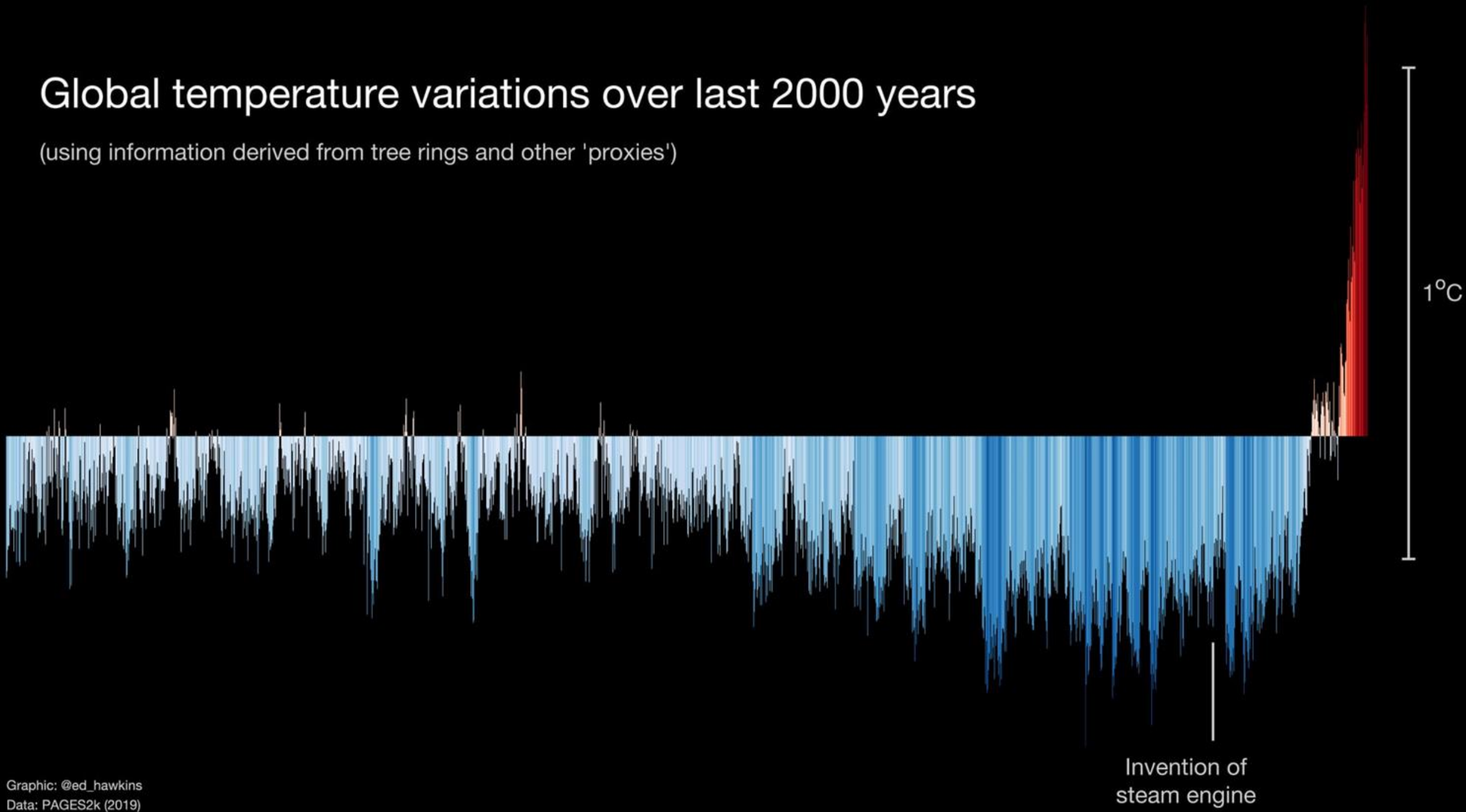
Source: mozaweb.com, wikipedia.org, 2019

Current climate change (1970s–present)

- **The biggest** current **environmental problem**
- Caused primarily by **enhanced of the greenhouse effect** through the increase in greenhouse gases emitted by the burning of fossil fuels and land use change
- Acceleration of air temperature rise since the 1970s
- 1988: Climate change seen as a major public, political and environmental issue (testimony of J. Hansen before the US Senate)

Global temperature variations over last 2000 years

(using information derived from tree rings and other 'proxies')



Graphic: @ed_hawkins
Data: PAGES2k (2019)

Question of the day

How can we prove that recent climate change is exceptional and when significant climate changes occurred?

Literature and sources

- Huhtamaa, H., Helama, S., Leijonhufvud, L., Charpentier Ljungqvist, F. Combining the archives of nature and society: Tree rings and tithes. Past Global Changes Magazine, 28(2), 50-51 (2020)
- Masson-Delmotte et al. (2021): IPCC, 2021: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change Cambridge, Cambridge University Press, 3949 p.
- White, S., Pei, Q., Kleemann, K., Dolák, L., Huhtamaa, H., Camenisch, C. New perspectives on historical climatology. WIREs Climate Change, 14(1), e808 (2022) https://wires.onlinelibrary.wiley.com/doi/abs/10.1002/wcc.808

Thank you for your attention