

# **Lecture VI**

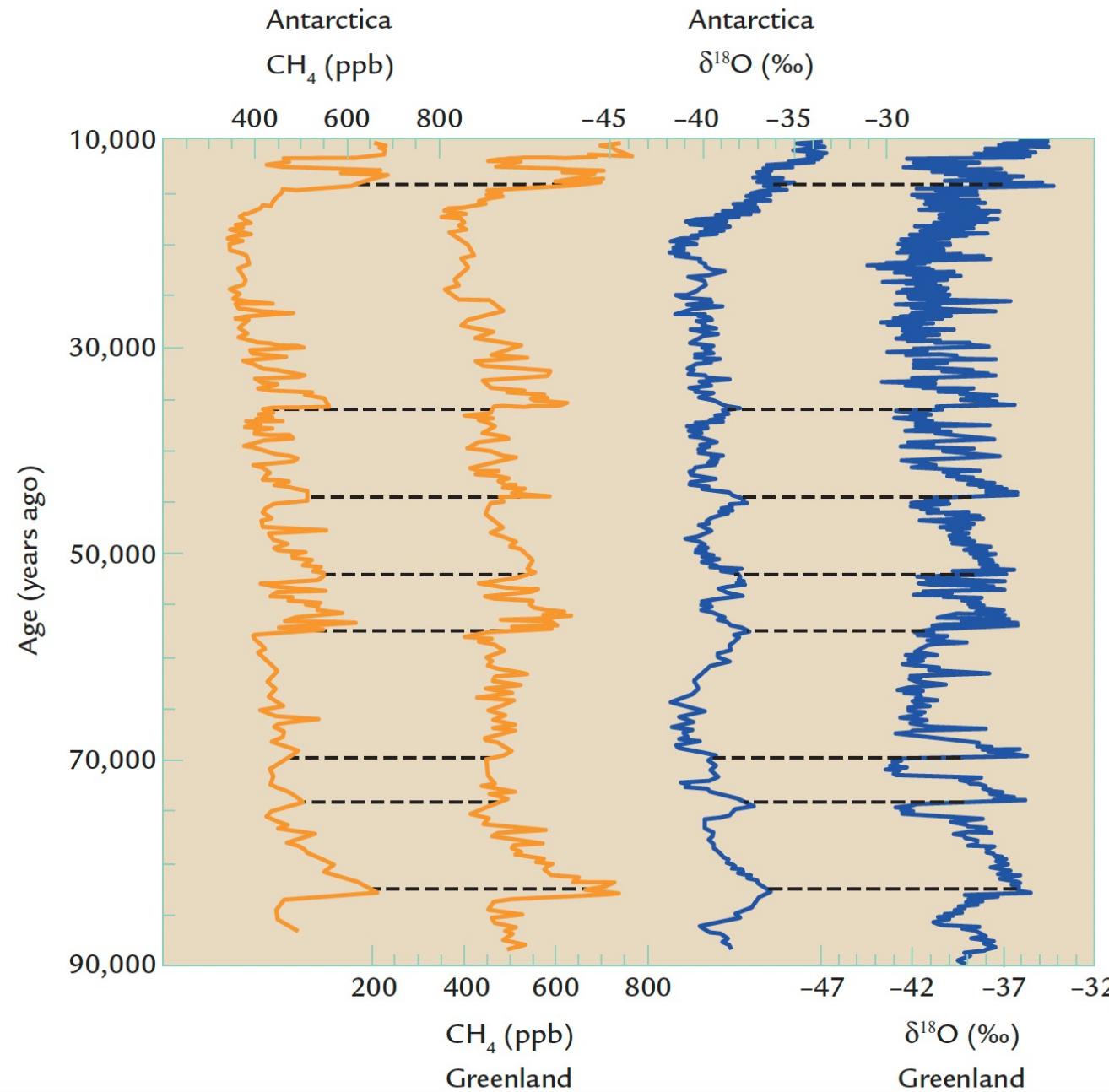
# **Historical and Future**

# **Climate Change**

From Part V of Ruddiman book and other sources as cited

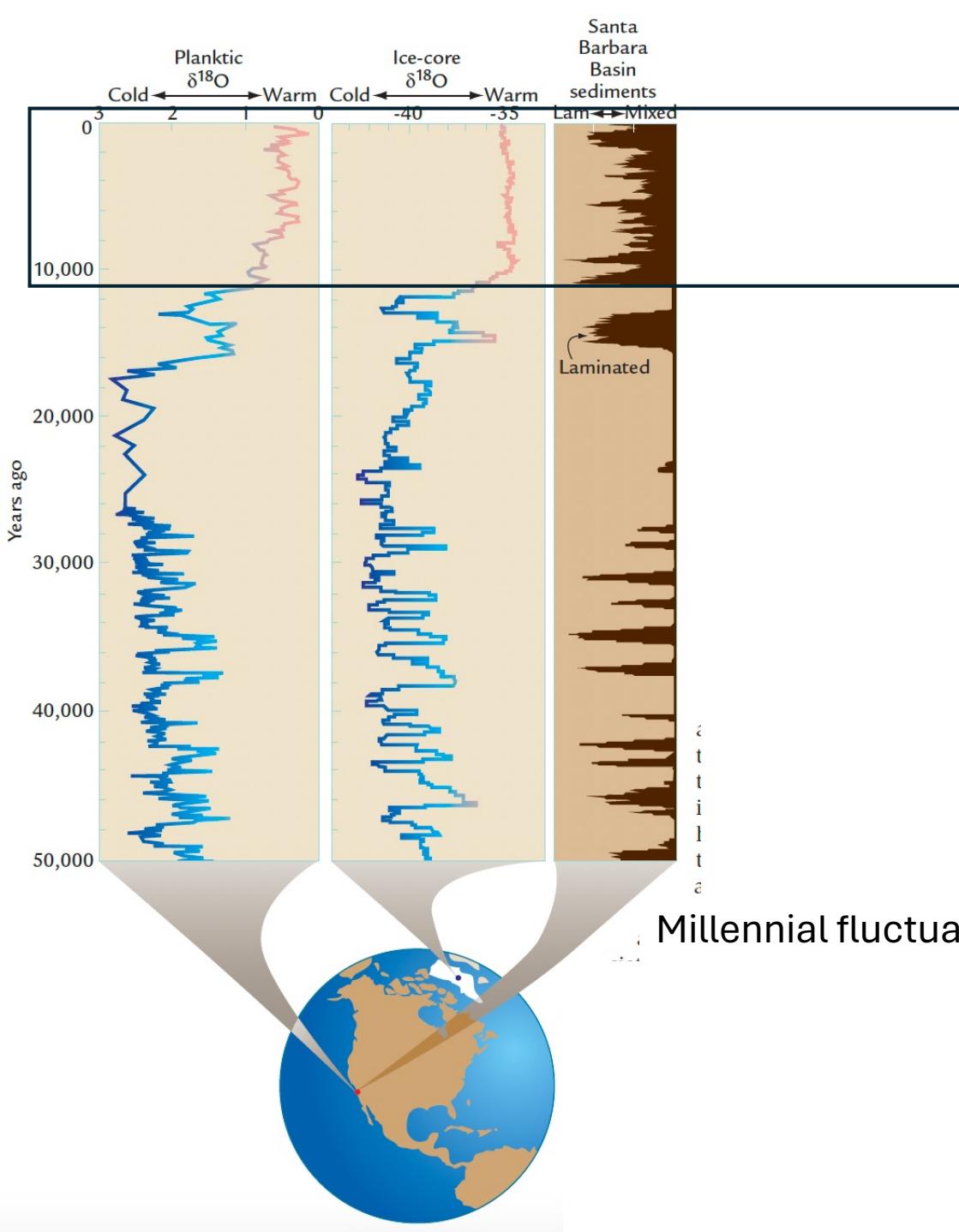
# *Millennial Oscillations of Climate*

- A few thousand years, they are called millennial oscillations.
- The oscillations were largest when glacial ice sheets existed in the Northern Hemisphere and much smaller or absent during interglacial climates like the current one.
- The oscillations are largely random, rather than cyclic.
- They could be driven by internally generated fluctuations in the margins of northern hemisphere ice sheets that alter conditions in and around the North Atlantic Ocean, with the signal then propagated southward through the atmosphere, or they could result from more complex interactions between the Northern and Southern Hemispheres linked to the redistribution of ocean heat.



**FIGURE 15-8**  
**Opposed millennial oscillations in Antarctic and Greenland ice**

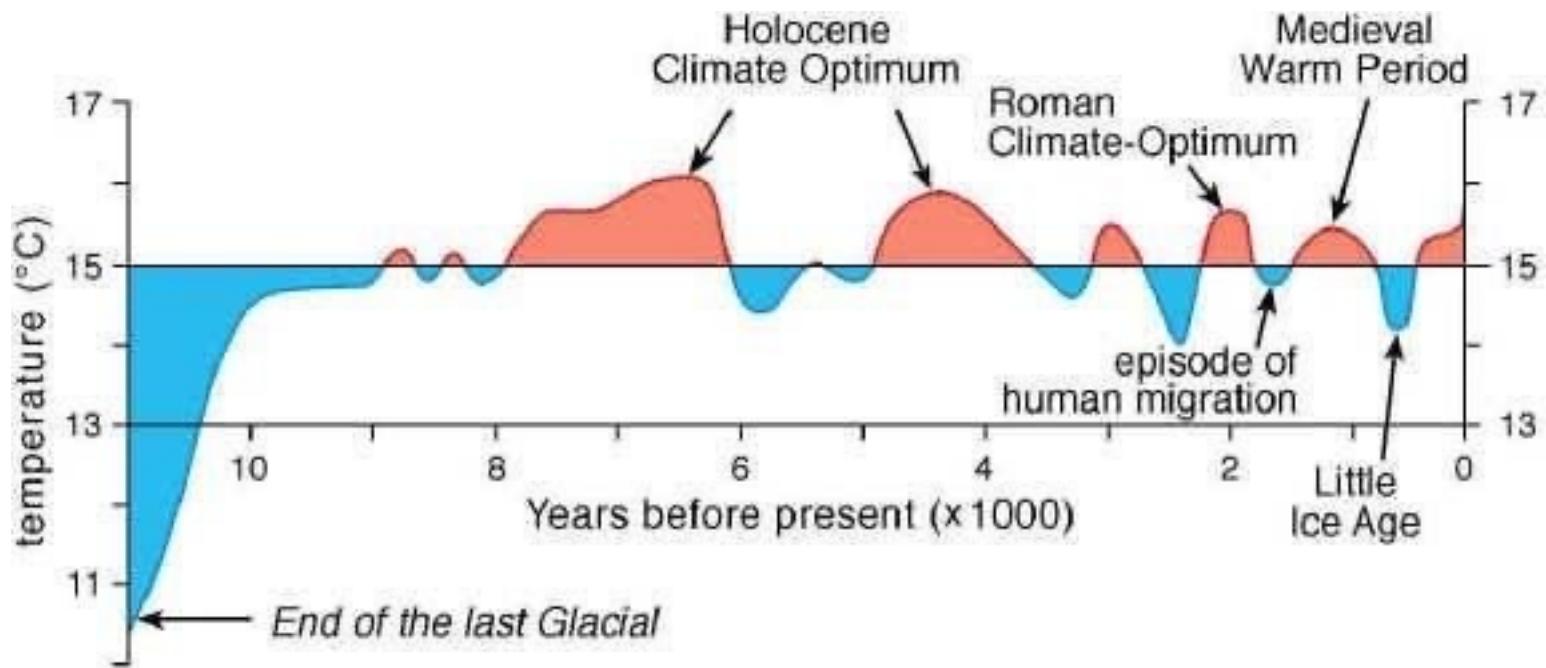
Records from Antarctic and Greenland ice that are correlated based on common variations in methane trends show that Antarctica tends to be warm (more positive δ<sup>18</sup>O values) when Greenland is cold (more negative δ<sup>18</sup>O values). (ADAPTED FROM T. BLUNIER AND E. J. BROOK, "TIMING OF MILLENNIAL-SCALE CLIMATE CHANGE IN ANTARCTICA AND GREENLAND DURING THE LAST GLACIAL PERIOD," SCIENCE 291 [2001]: 109-12.)



# The HOLOCENE

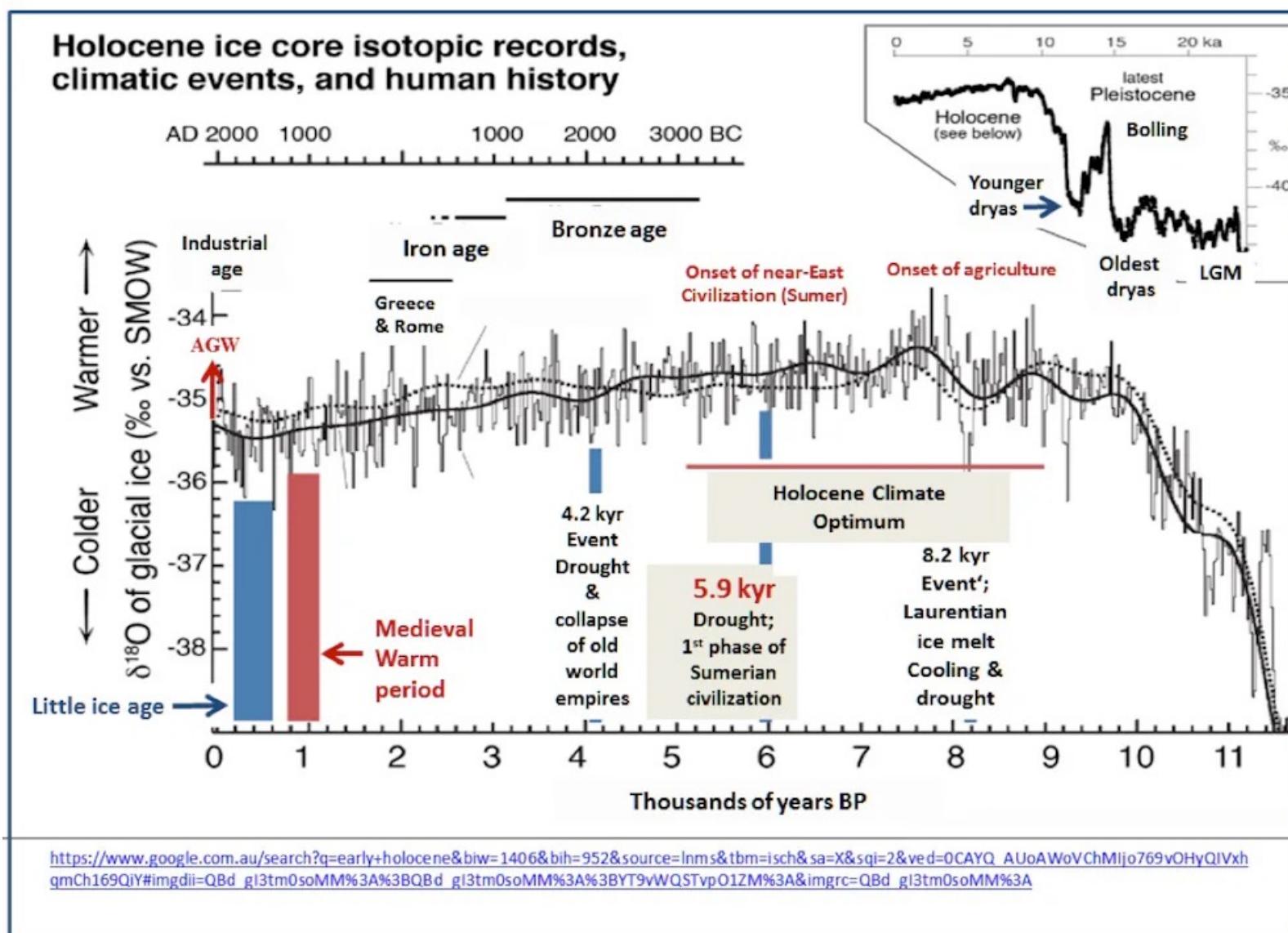
Period	Epoch	Age	Numerical age (Ma)	Key climatic features
Quaternary	Anthropocene	to be named	present	Marked upturns in CO <sub>2</sub> (~1965 CE) and temperature (~1975 CE)
	Holocene	L Meghalayan	~1950 CE	Initial CO <sub>2</sub> and temperature upturns (~1850 CE)
		M Northgrippian	0.0042	Short regional drying event
		E Greenlandian	0.0082	Short global cooling event; start of slight upturn in CO <sub>2</sub>
	Pleistocene	L to be named	0.0117	Onset of current interglacial
		M Chibanian	~0.129	Last Glacial Maximum (0.02 Ma)
		E Calabrian	0.774	Change to 100 ka glacial-interglacial periodicities (0.8 Ma)
		Gelasian	1.80	40 ka glacial-interglacial periodicities
			2.58	Intensified Northern Hemisphere glaciation (~2.7 Ma)
	E – Early; M – Middle; L – Late			

# Holocene temperature changes



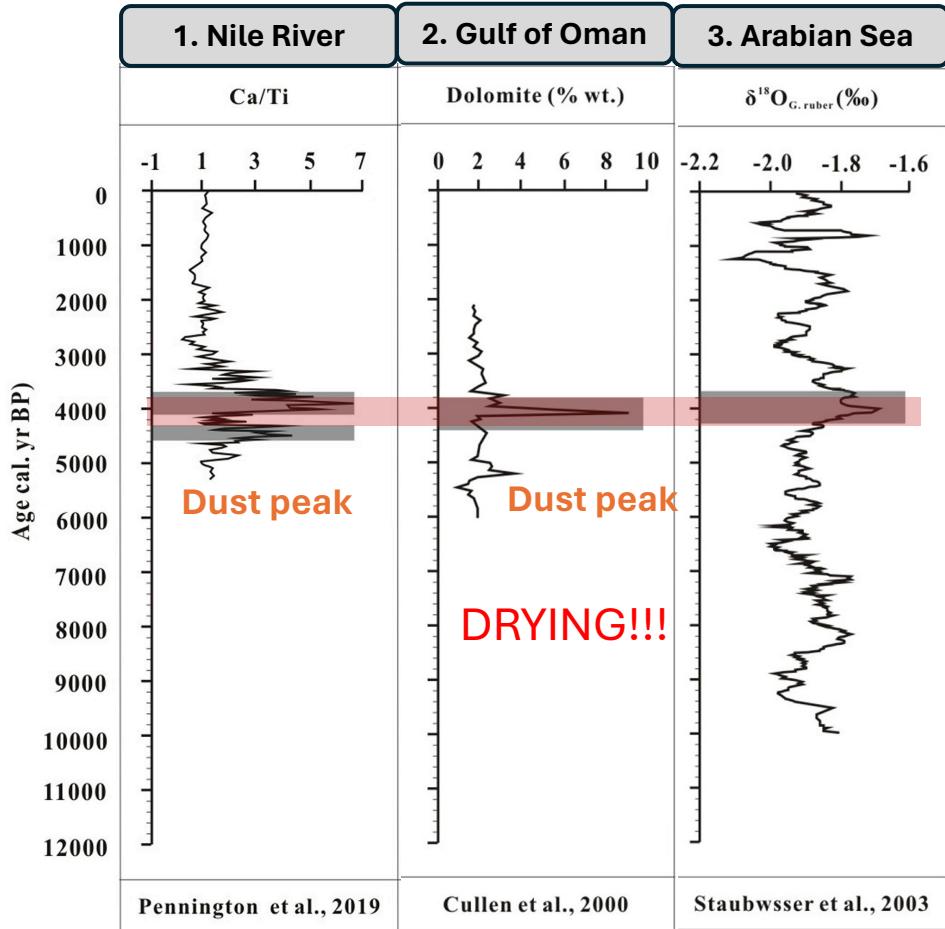
*Average near-surface temperatures of the northern hemisphere during the past 11,000 years (after Dansgaard et al., 1969, and Schönwiese, 1995)*

# Holocene climate and civilization changes



By Andrew Gilkson, for  
The Conversation

# The '4.2 kiloyear' drying event

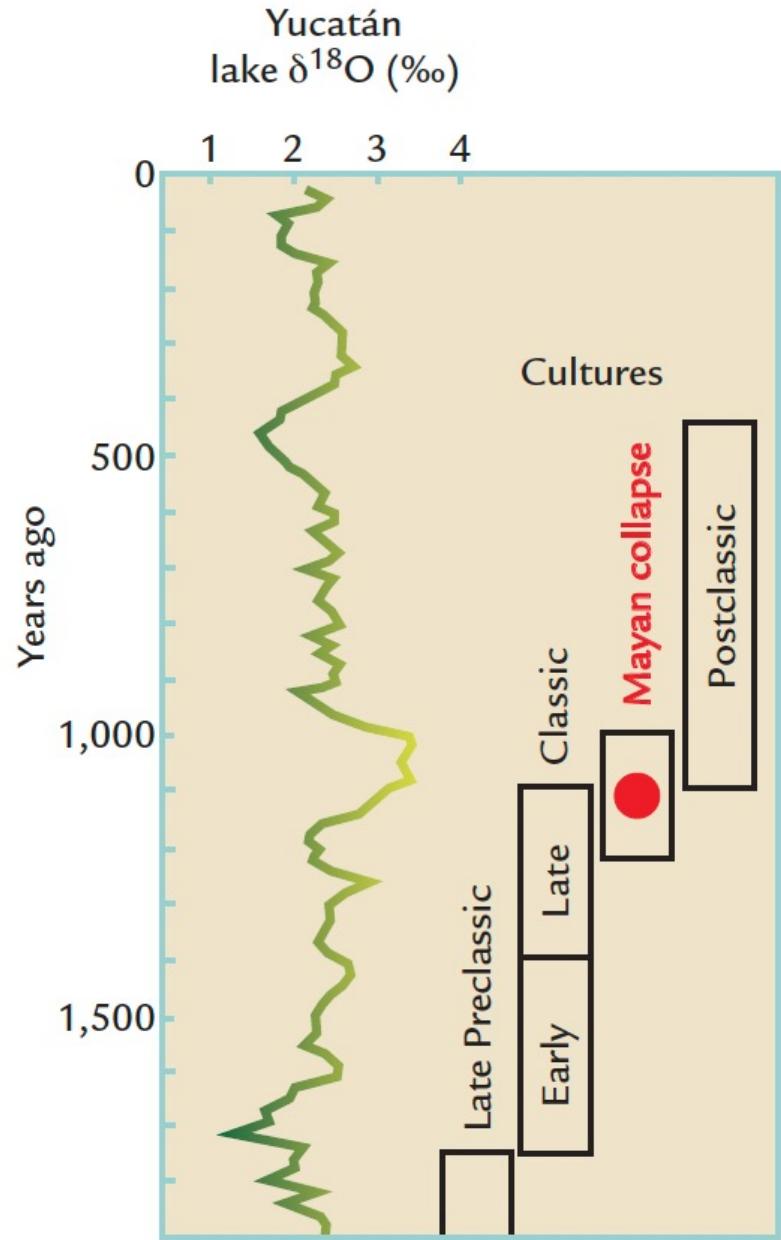


**Collapse/ deurbanization of the Bronze Age Indus Valley, Mesopotamian and Egyptian Civilization is linked with the 200-year drying at ~4200 years before present.**

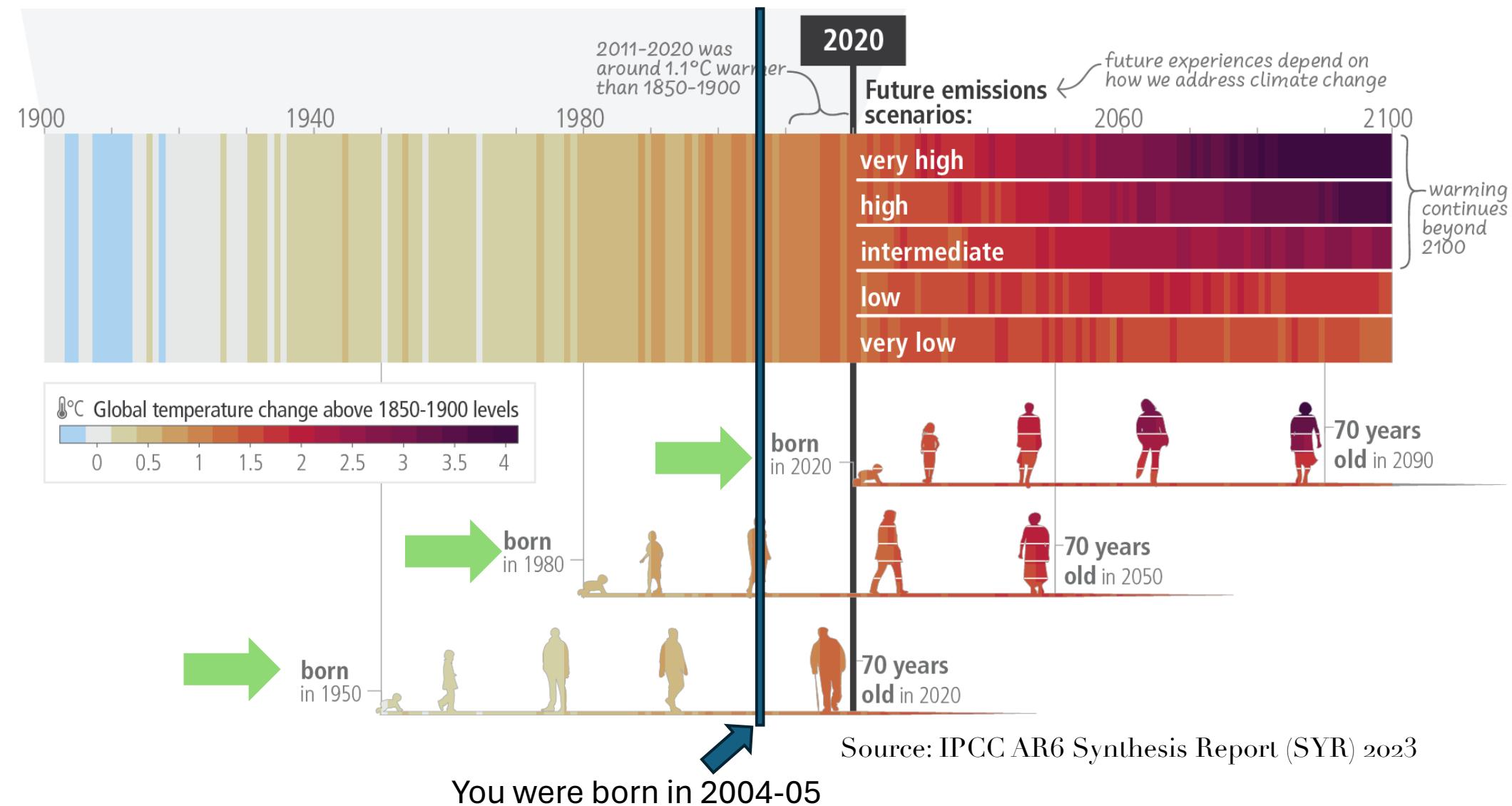
# Collapse of Maya civilization

## Did drought destroy Mayan civilization?

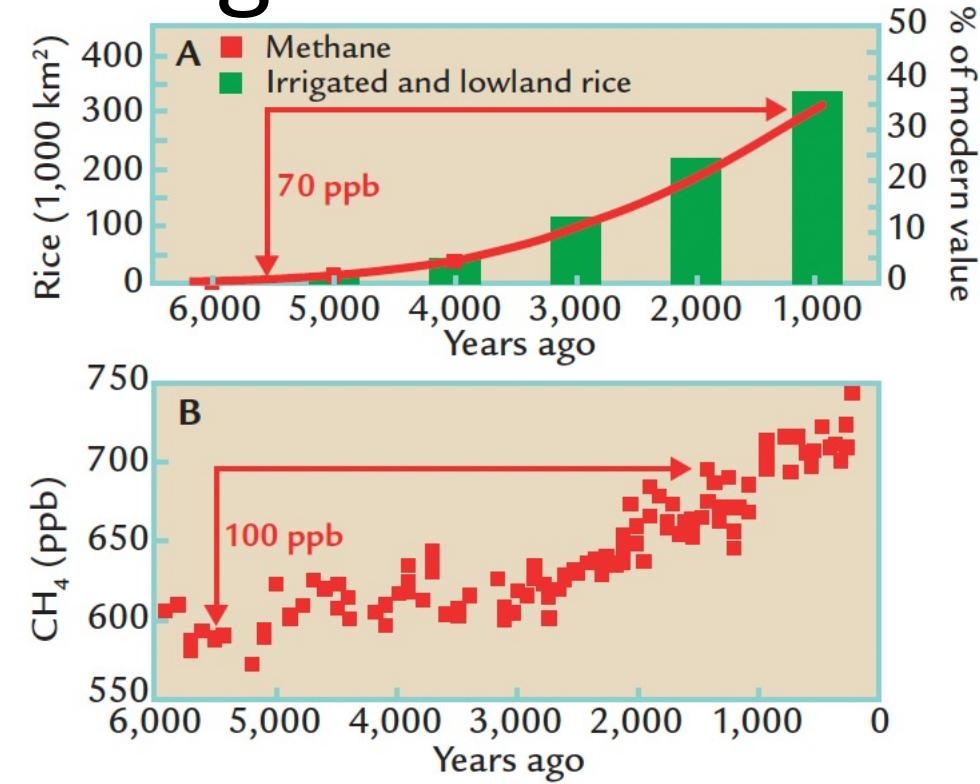
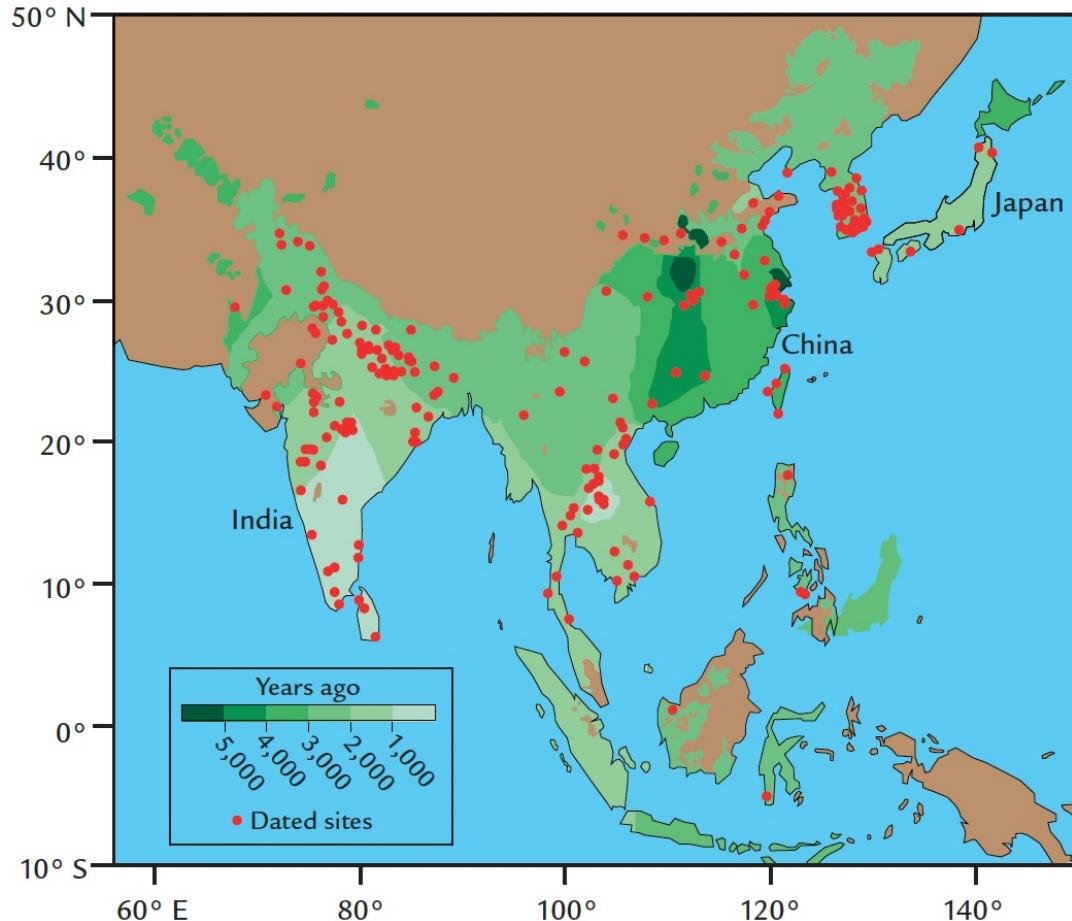
Lake sediments indicate periods of prolonged drought during the time that Mayan civilization disappeared. (ADAPTED FROM J.H. CURTIS, D. A. HODELL, AND M. BRENNER, "CLIMATIC VARIABILITY ON THE YUCATAN PENINSULA (MEXICO) DURING THE PAST 3,500 YEARS, AND IMPLICATIONS FOR MAYA CULTURAL EVOLUTION," QUATERNARY RESEARCH 46



# Temperature changes across generations



# Rice production and climate change



**FIGURE 16-16**

## Rice irrigation and methane

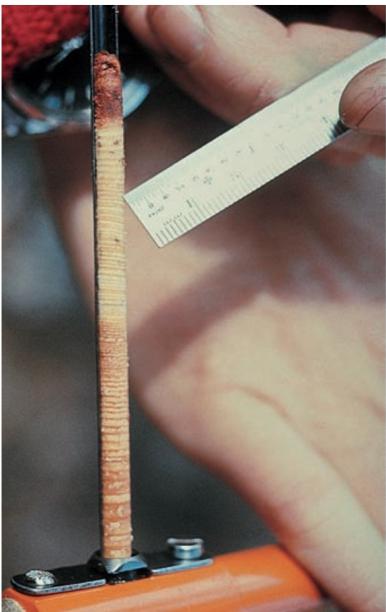
The increasing area of irrigated rice fields emitted greater amounts of methane that contributed to the observed  $\text{CH}_4$  increase in ice cores. (ADAPTED FROM D. Q. FULLER ET AL., "THE CONTRIBUTION OF RICE AGRICULTURE AND LIVESTOCK TO PREHISTORIC METHANE LEVELS: AN ARCHAEOLOGICAL ASSESSMENT," *THE HOLOCENE* 25 [2011]: 743–759, DOI:10.1177/0959683611398052.)

# Climate Changes During the Last 1,000 Years

**Coring for tree ring studies** To study tree rings, scientists drill into trees at sites where trees are under moderate stress because of cold or dryness (A). The cores extracted (B) are small in diameter compared to the trees (C). (COURTESY OF G. C. JACOBY, LAMONT-DOHERTY EARTH OBSERVATORY OF COLUMBIA UNIVERSITY.)



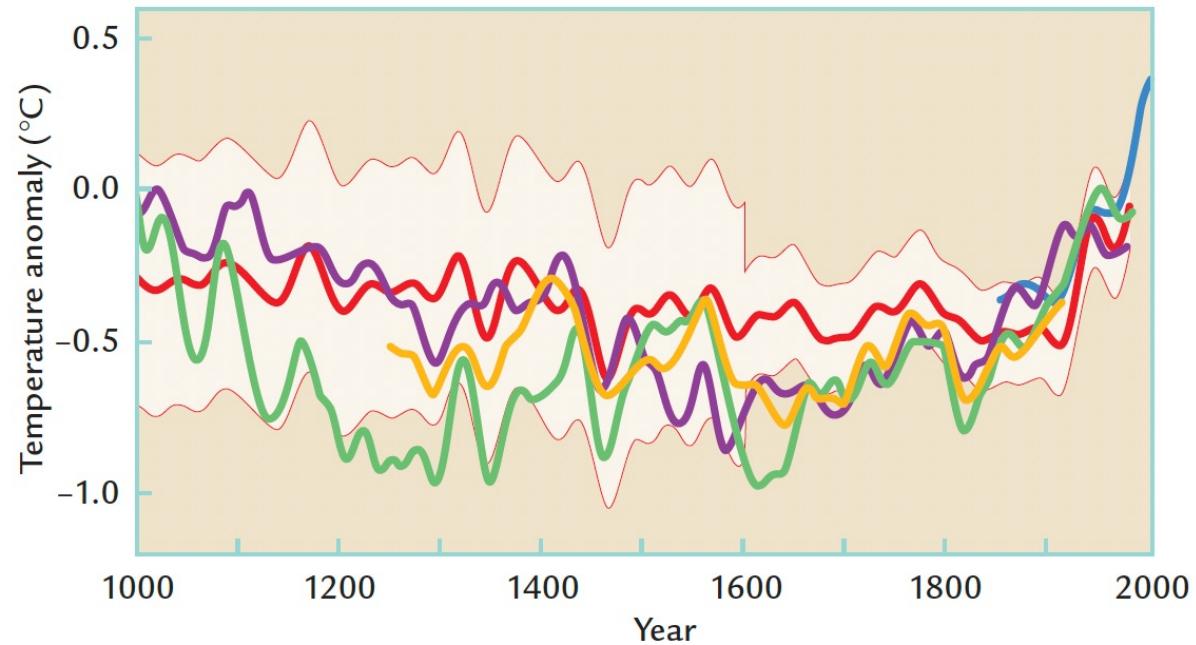
A



B



C

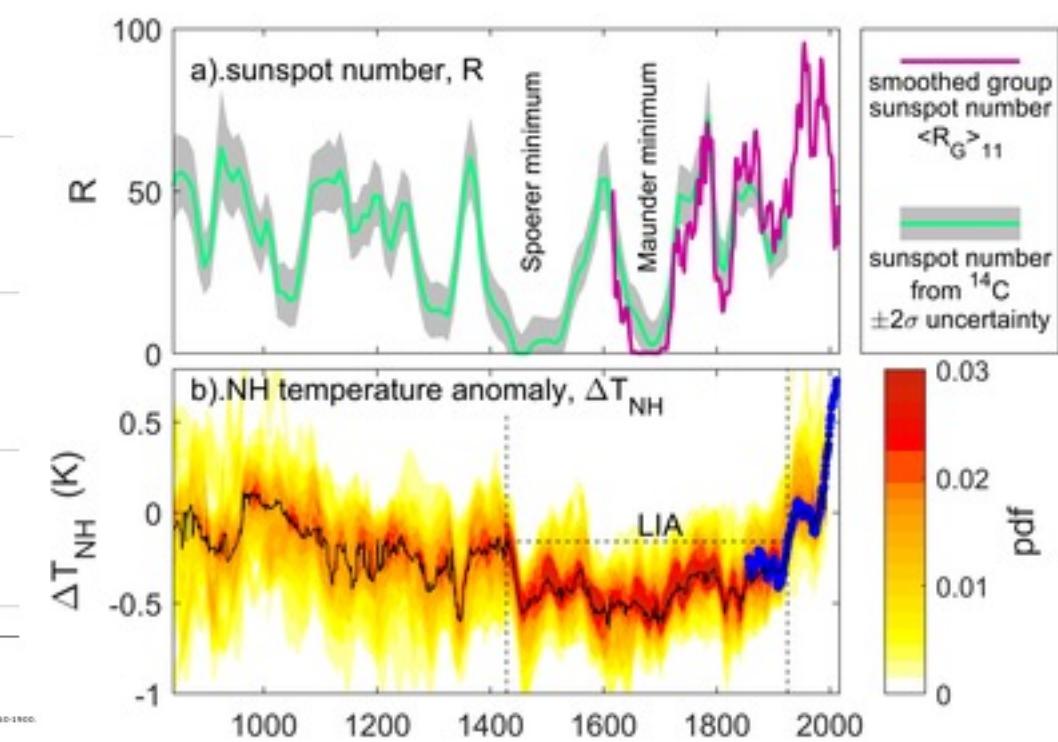
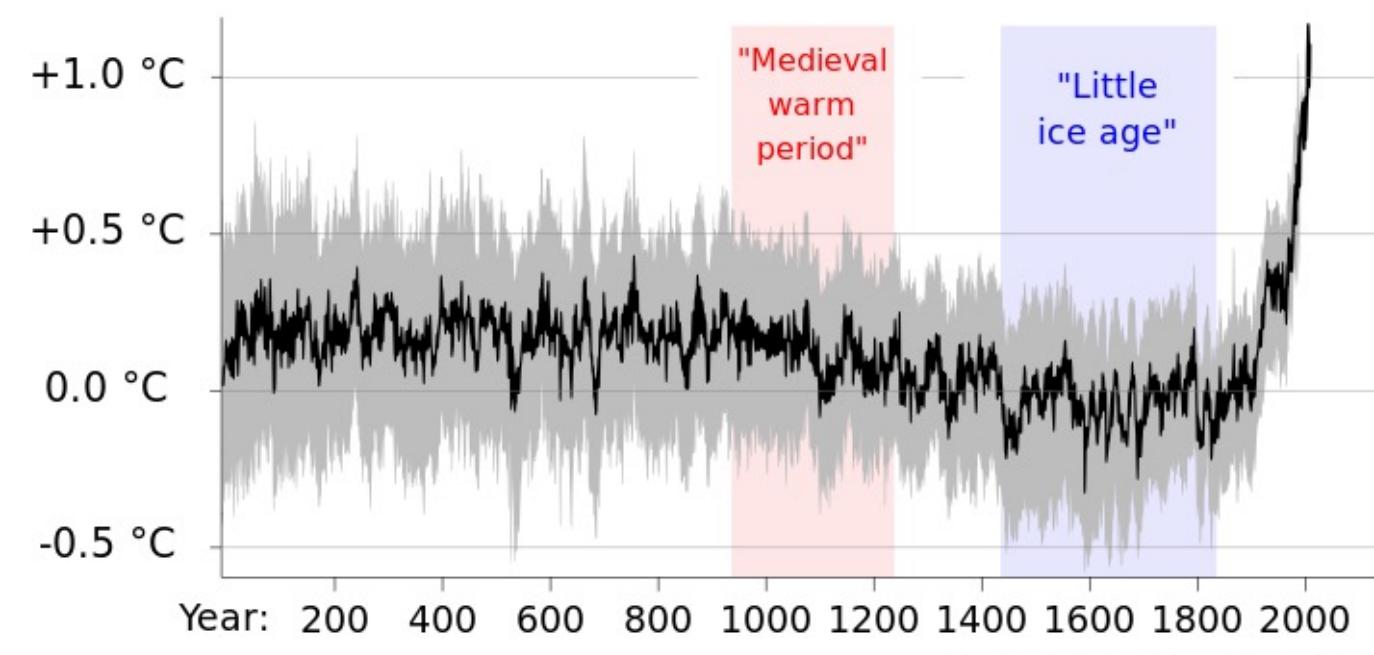


## Northern hemisphere temperatures during the last millennium

High-resolution climatic reconstructions spanning all or part of the last millennium show a small gradual cooling for the first 900 years, followed by a large and abrupt warming in the twentieth century. Light shading indicates uncertainty in estimated temperature of reconstruction shown in red.

# Little Ice Age and Medieval Climate Anomaly

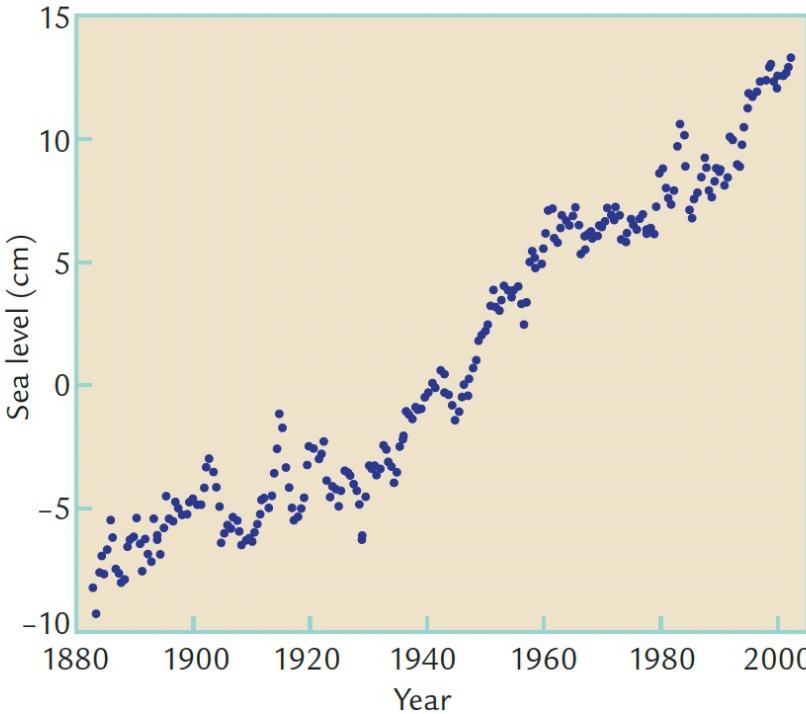
Global Average Temperature Change



Source: PAGES2k consortium, *Nature Communications*

PDF available here: [https://epic.awi.de/id/eprint/32886/1/PAGES2k\\_NGEO\\_inpress.pdf](https://epic.awi.de/id/eprint/32886/1/PAGES2k_NGEO_inpress.pdf)

# Climatic Changes Since 1850

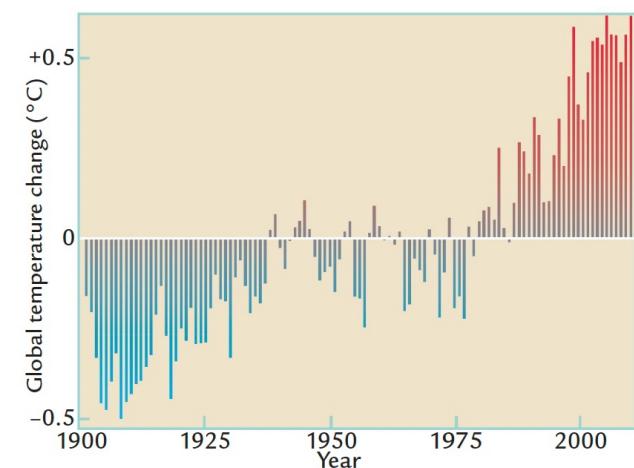
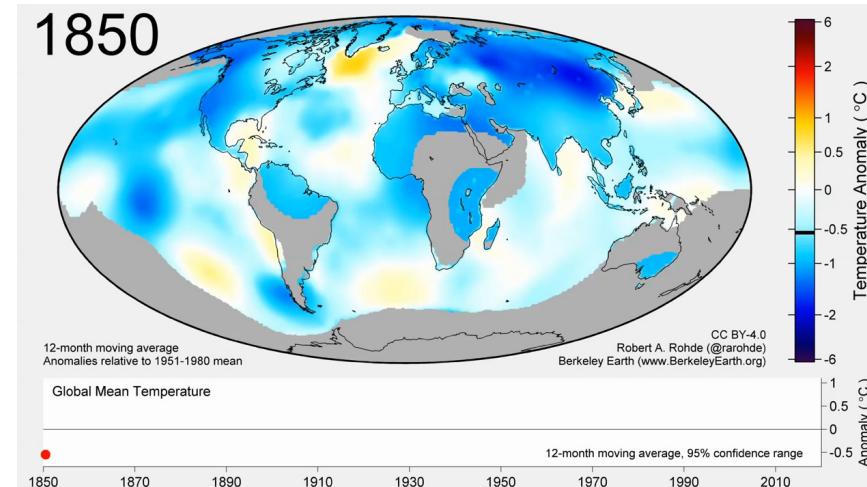
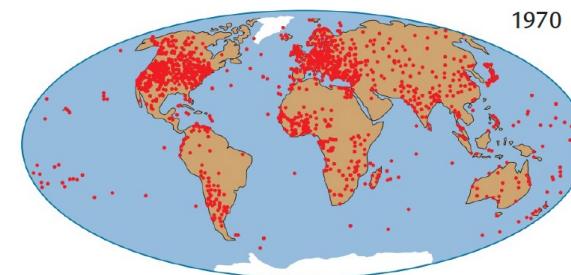
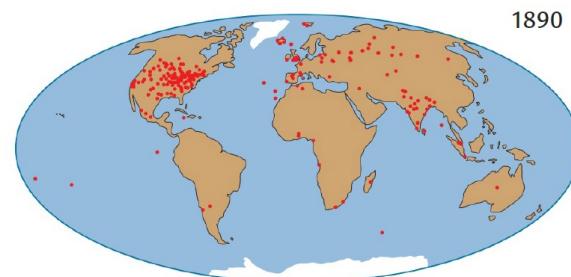


**FIGURE 18-7**

**Global rise in sea level during the twentieth century**

Sea level rose by  $\sim 17$  cm during the 1900s because land ice has melted and seawater has warmed and expanded. (ADAPTED FROM S. JEVREJEVA ET AL., "NONLINEAR TRENDS AND MULTIYEAR CYCLES IN SEA LEVEL RECORDS," JOURNAL OF GEOPHYSICAL RESEARCH 111 [2006]: DOI:10.1029/2005JC003229.)

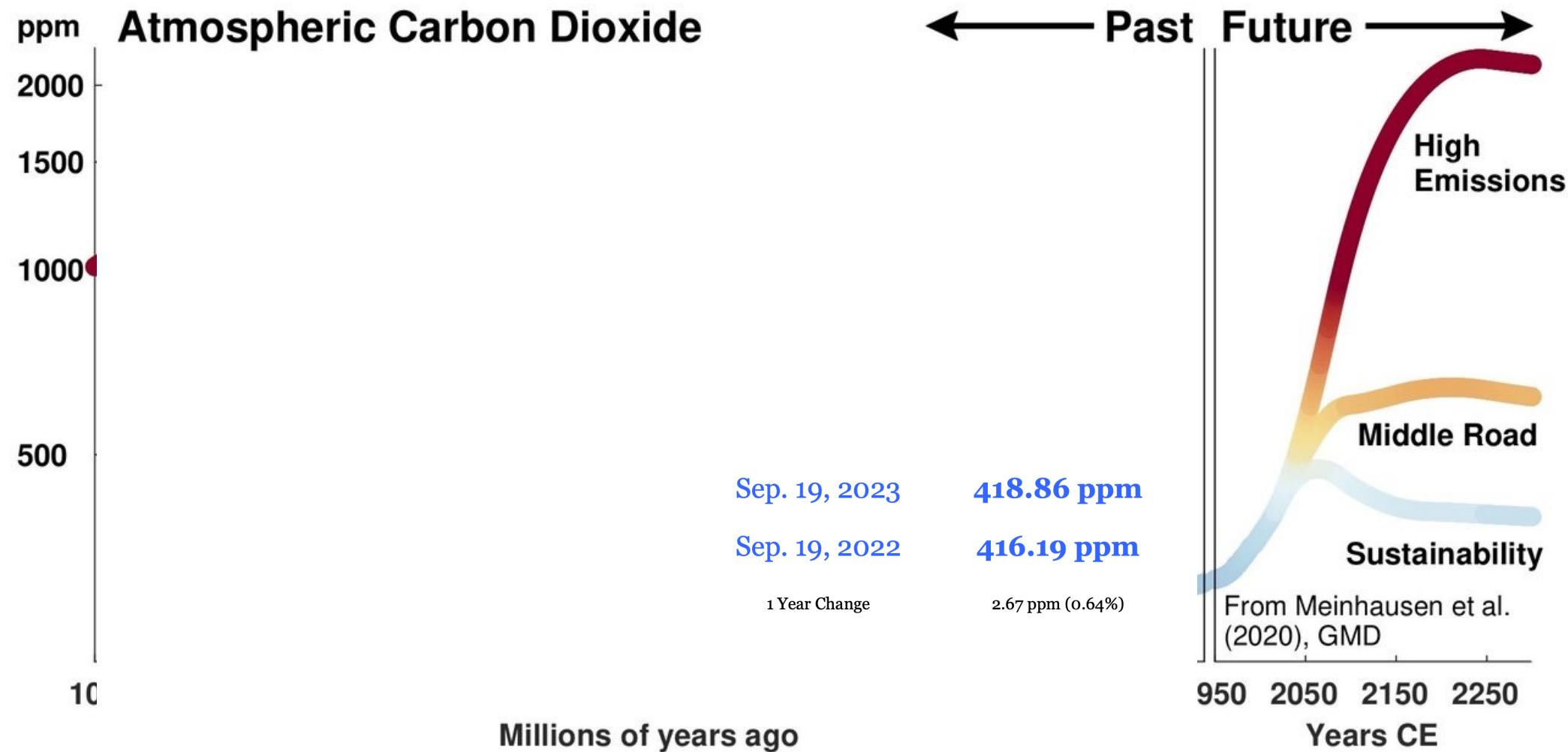
Increasing temperature monitoring stations



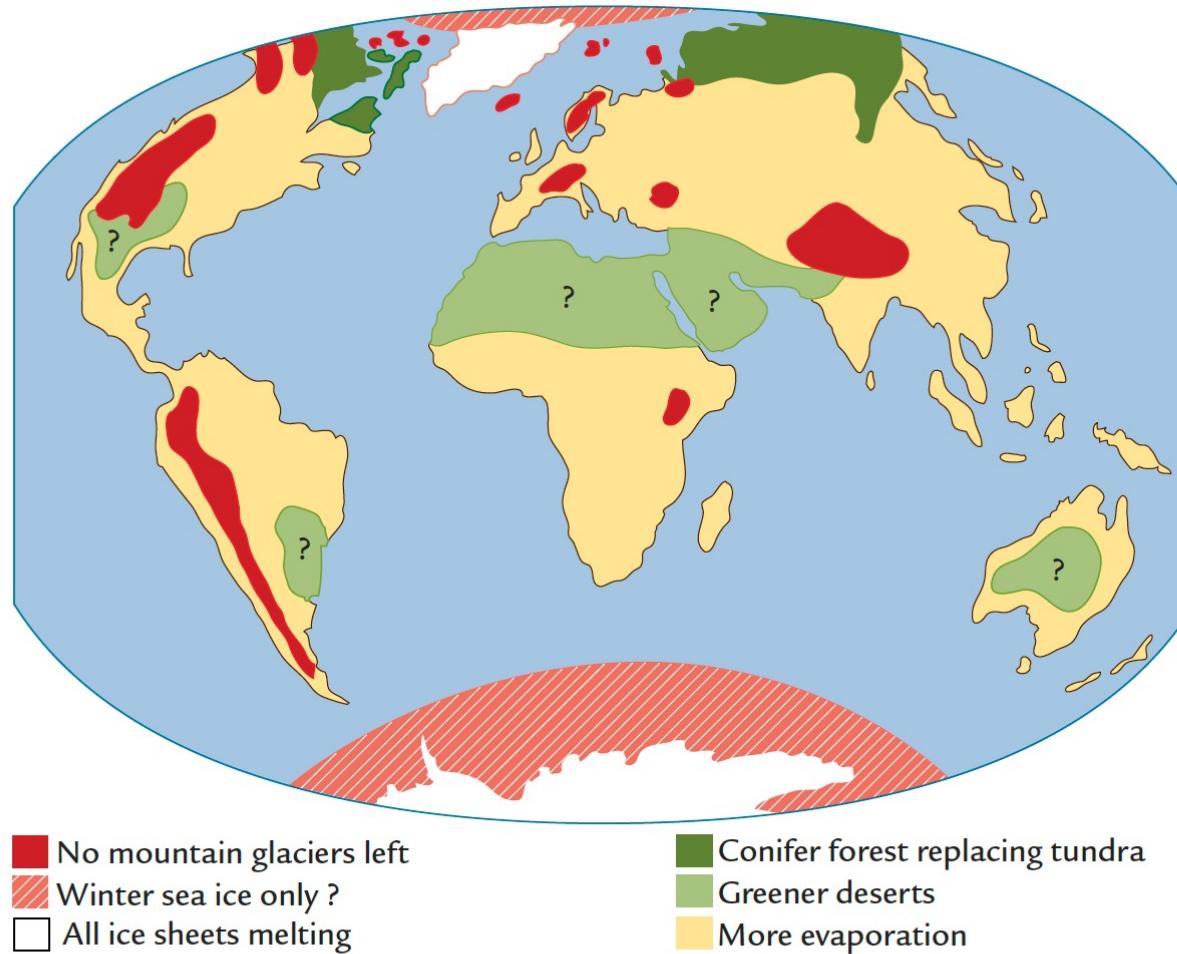
**FIGURE 18-9**

**Change in surface temperature since 1900**

# Analogues to future climate changes



# What does the future looks like?



**FIGURE 20-5**  
**The  $3 \times \text{CO}_2$  world**

The  $3 \times \text{CO}_2$  world that may come into existence in two or three centuries will be a disequilibrium world of fast- and slow-responding parts of the climate system.