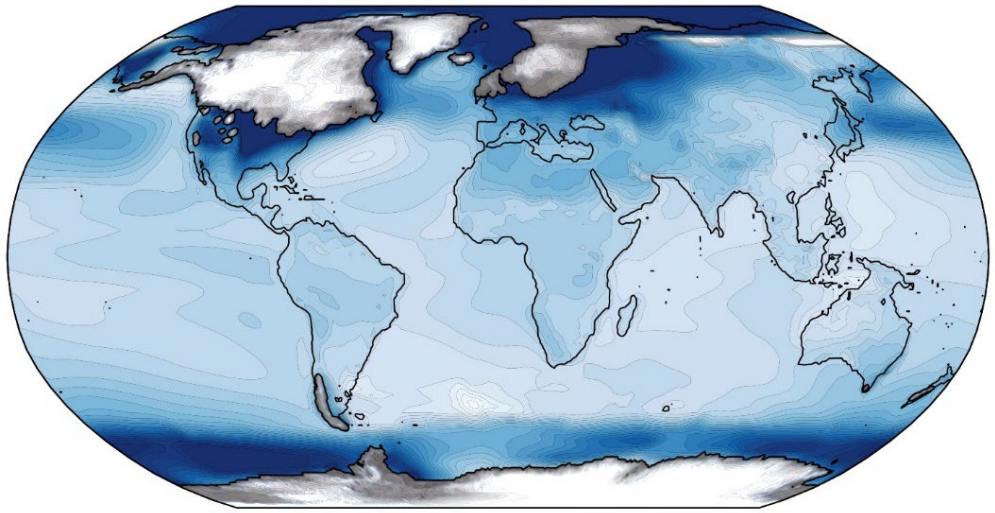
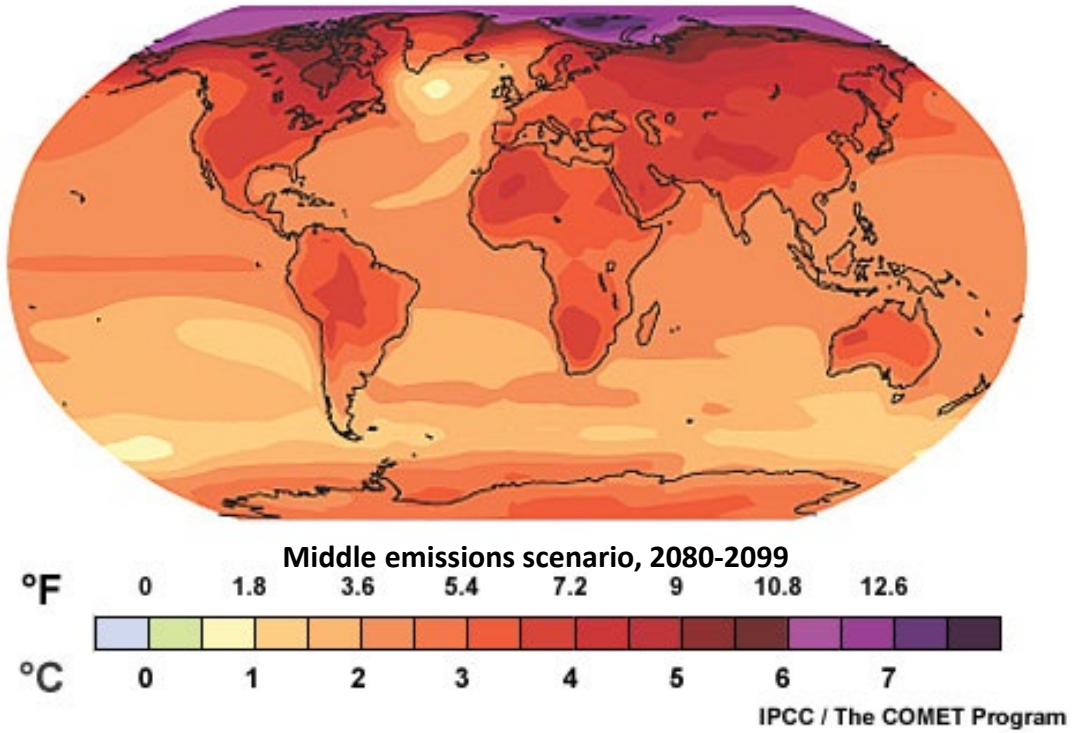
INQUA

From the Theory of Ice Ages to IPCC climate projections





María Fernanda Sánchez Goñi
EPHE, PSL University, Paris
UMR EPOC, Université de Bordeaux

École Pratique des Hautes Études | PSL Research University Paris | cnrs | Université de Bordeaux | EPOC

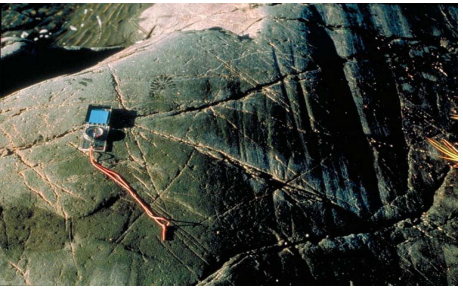
Th Quaternary Era: the last 2.58 million years

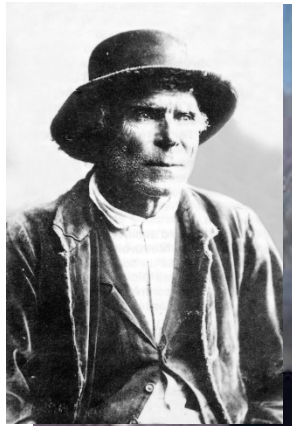
The Quaternary Era: the last 2.58 million years

- The natural evolution of the climate system at global scale and its regional impacts
- How the climate is now diverting from the natural climate trend
- The issues that still remain in climate projections due to:

    - limits in the reconstructions of past climates
    - limits of models in simulating regional climates

The Theory of Ice Ages

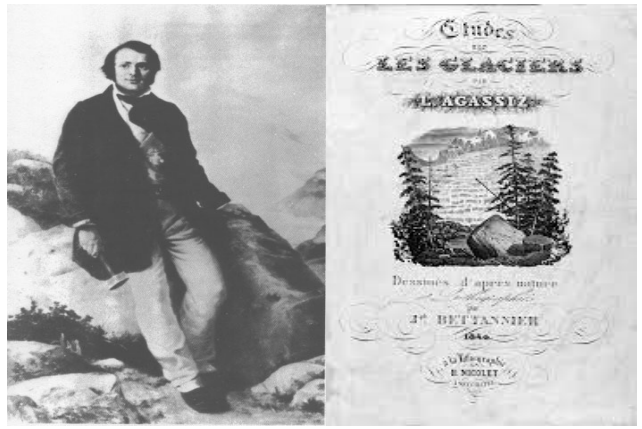




Jean-Pierre Perraudin
(1815)

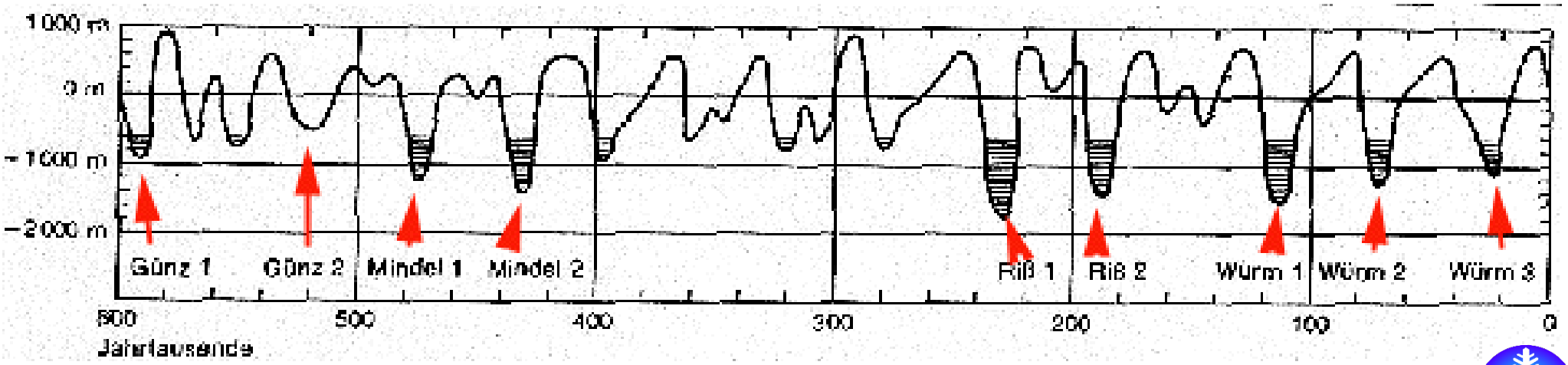
Ignace Venetz
(1816-1829)

Jean de Charpentier
(1834)

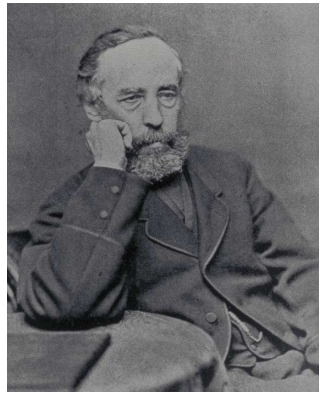


Louis Agassiz
(1840)

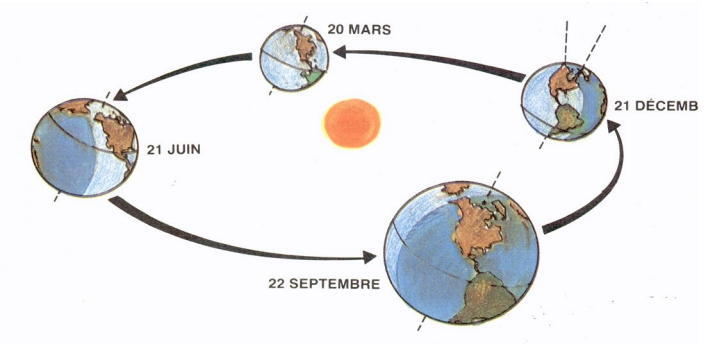
Succession of glacial-interglacial periods (Penck & Bruckner, 1909)

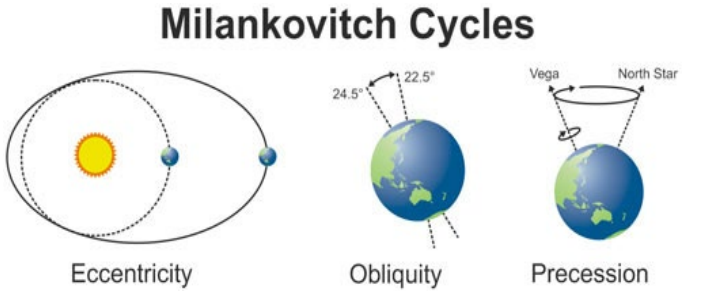


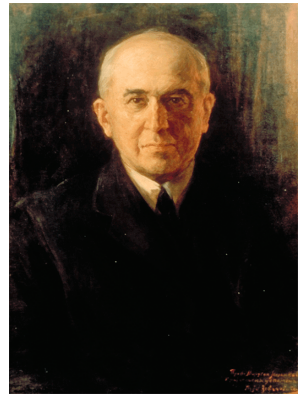
The Astronomical Theory of Ice Ages



James Croll
(1875)

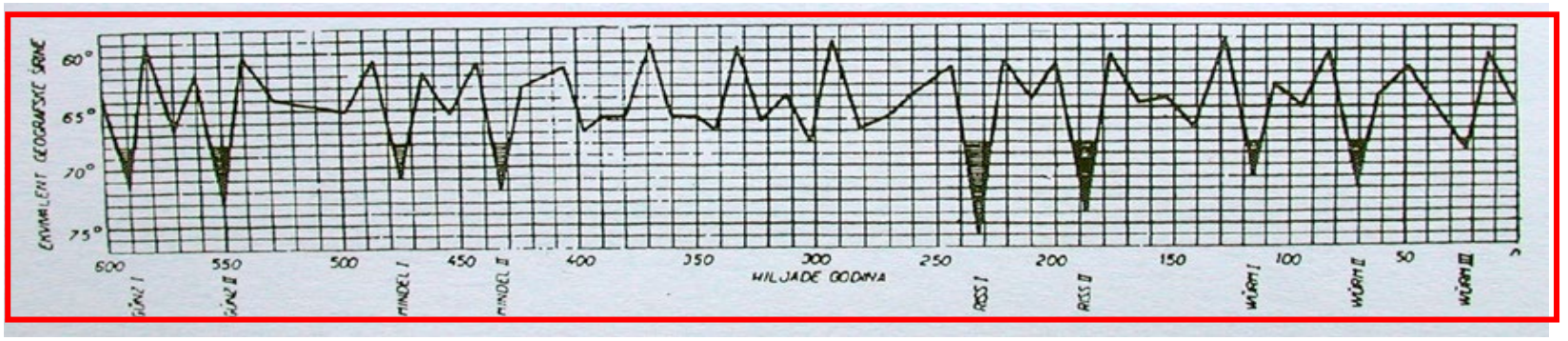


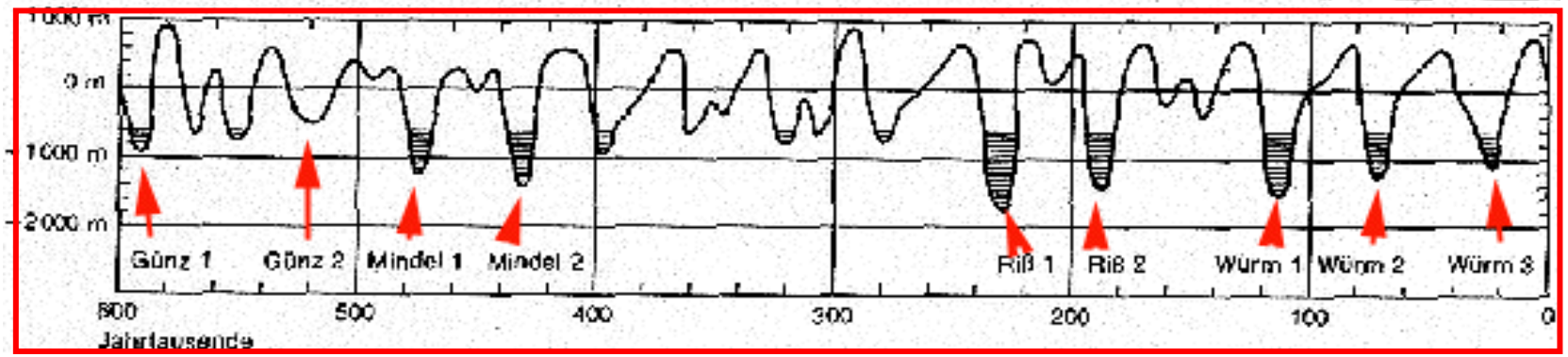




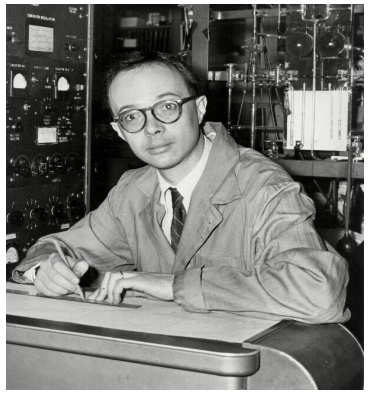
Milutin Milankovitch
(1912-1914)

Insolation 65°N in summer by Milankovitch (adapted from W. Köppen & A. Wegener, 1924)

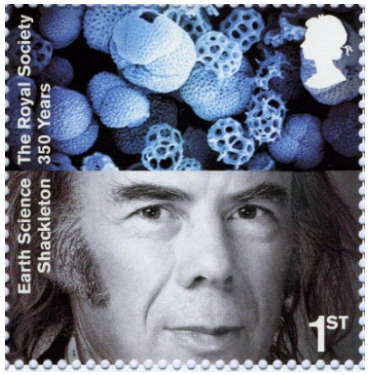




The Quaternary Era: orbital-scale climate changes

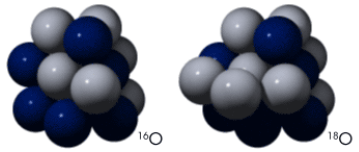


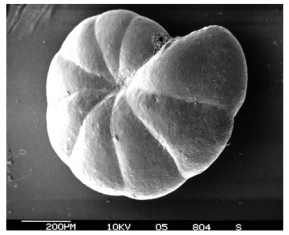
Cesare Emiliani (1955)

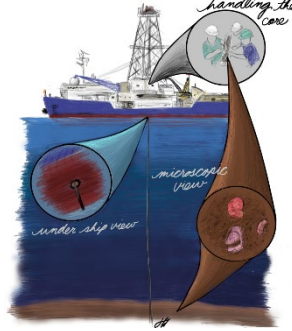


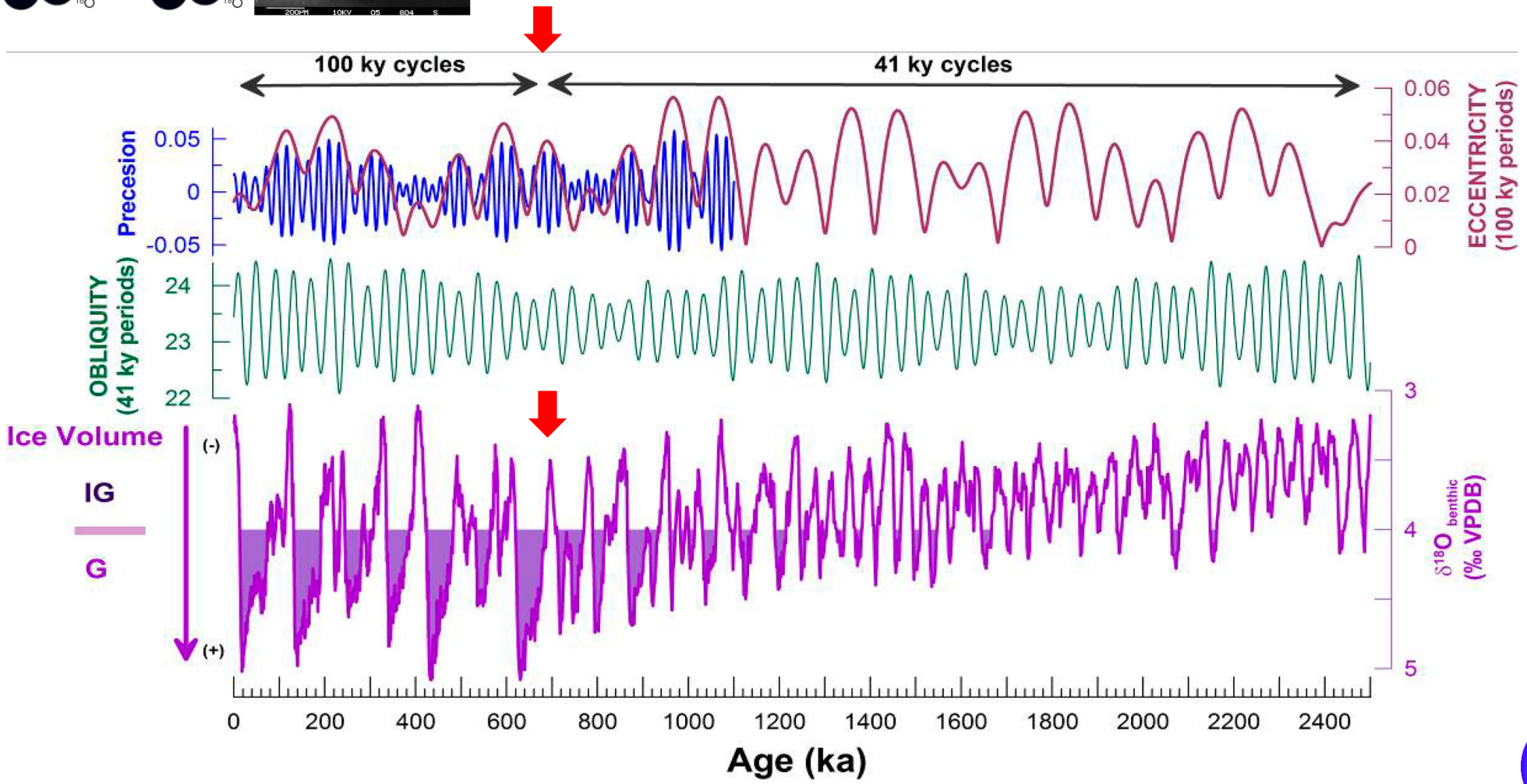
Nick Shackleton (1973)

$CaCO_3$









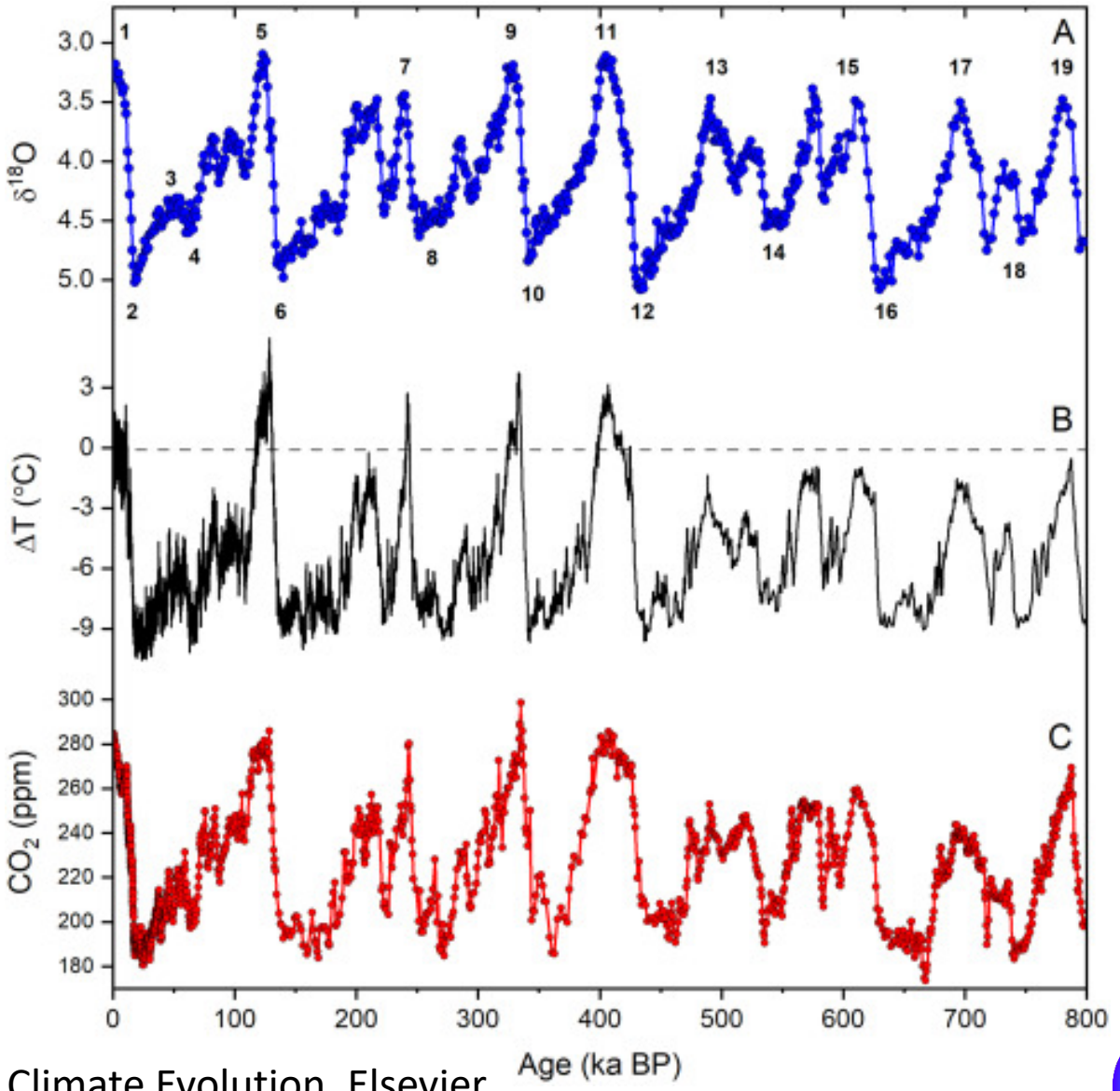
The Quaternary Era: orbital-scale climate changes

Ice volume

Claude Lorius (1985, 1990)

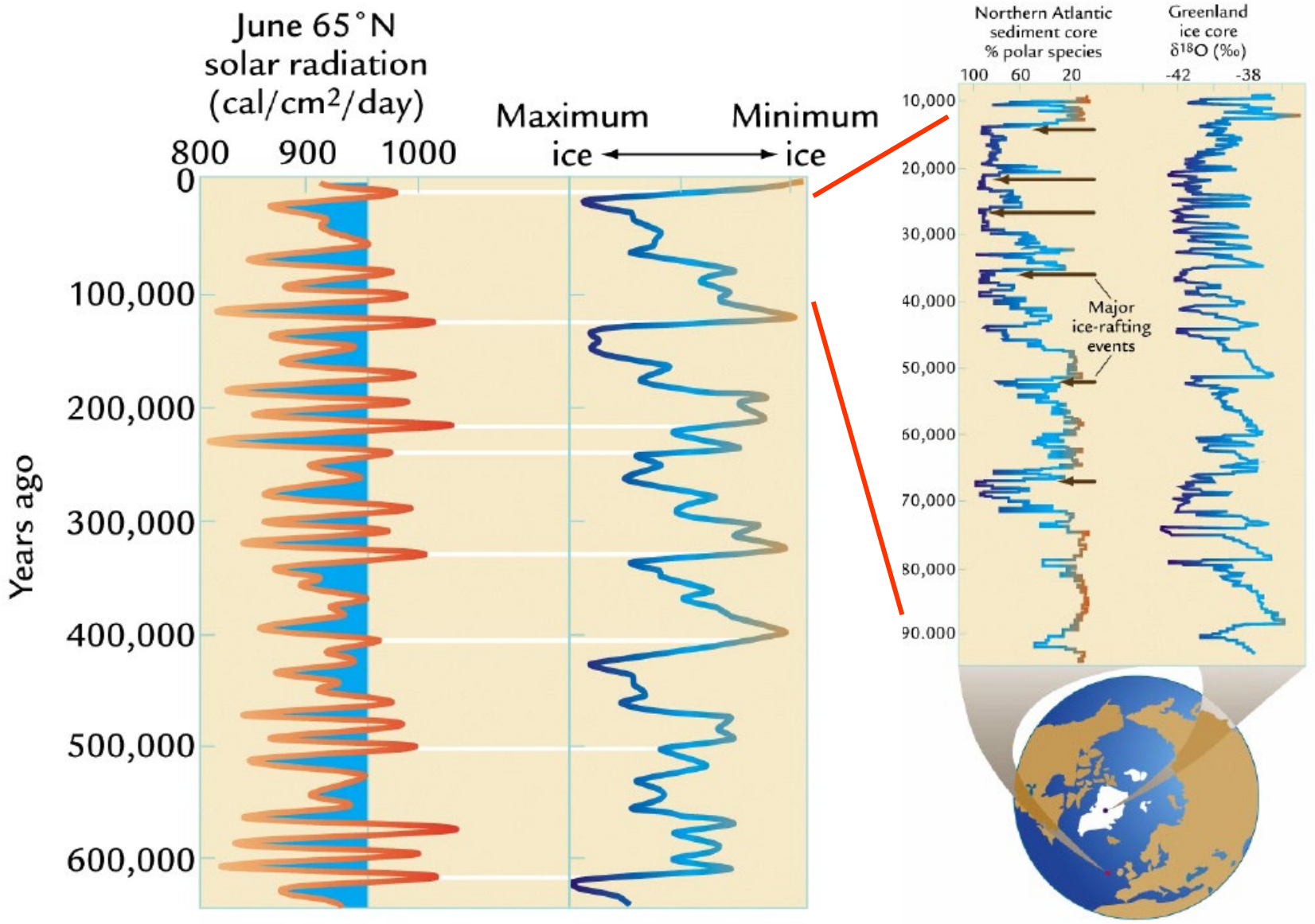
Antarctic temperature

Atmospheric CO2 concentration



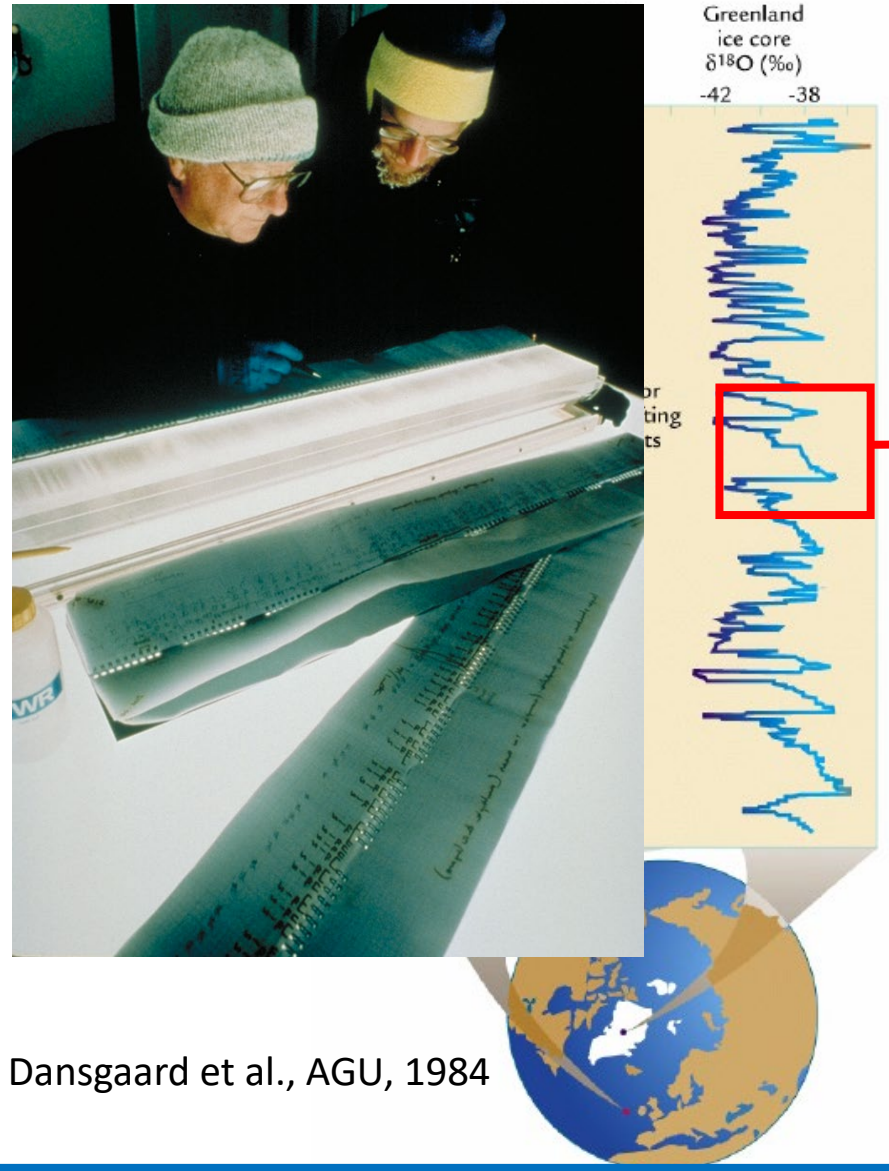
Wilson et al., 2022, Antarctic Climate Evolution, Elsevier

The Quaternary Era: millennial-scale climate changes



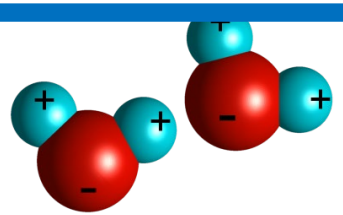
Ruddiman, Earth's Climate, 2001

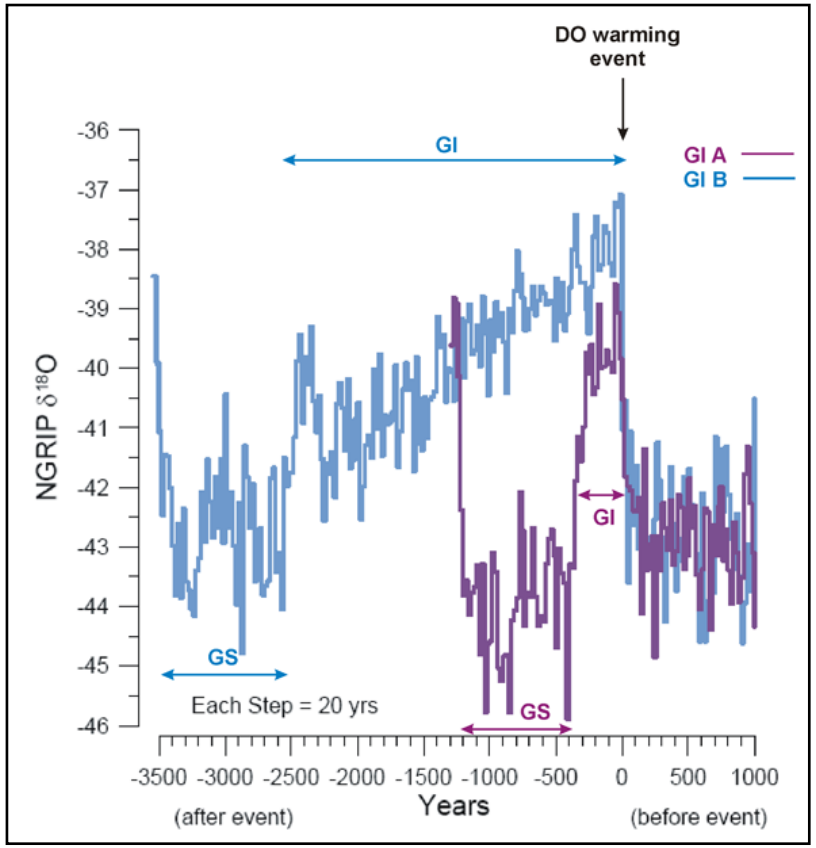
Dansgaard-Oeschger cycles: 1000-2000 years



Dansgaard et al., AGU, 1984

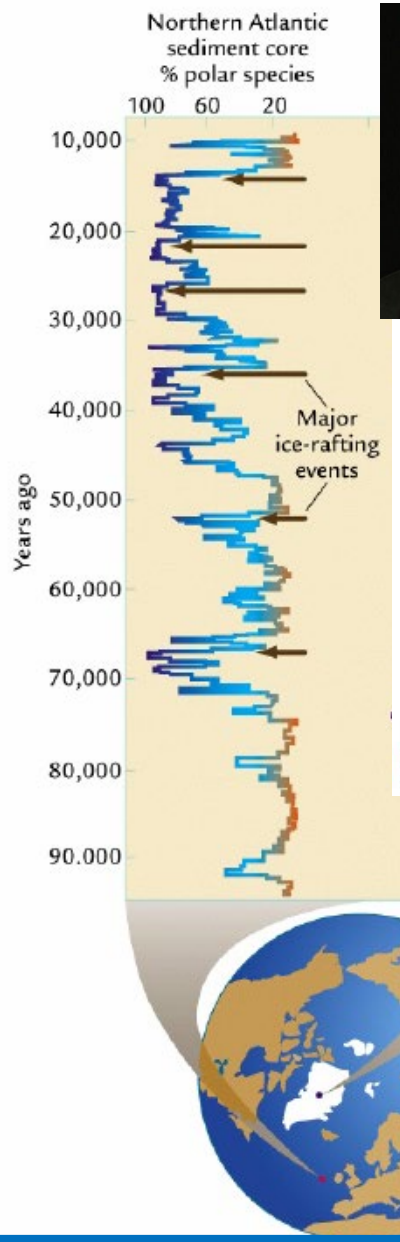
H_2O $\delta^{18}O$



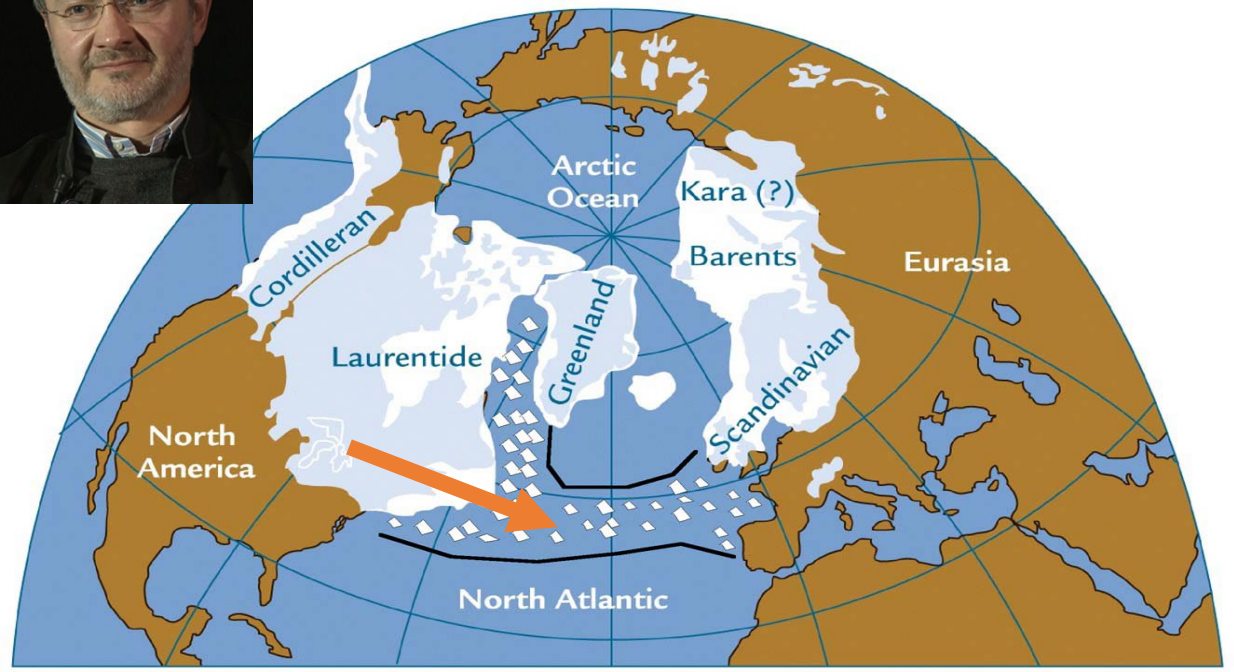


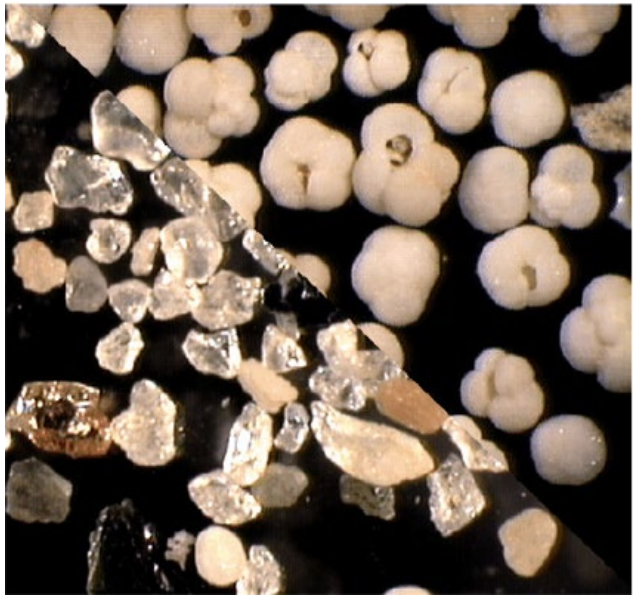
Sanchez Goñi and Harrison, QSR, 2010

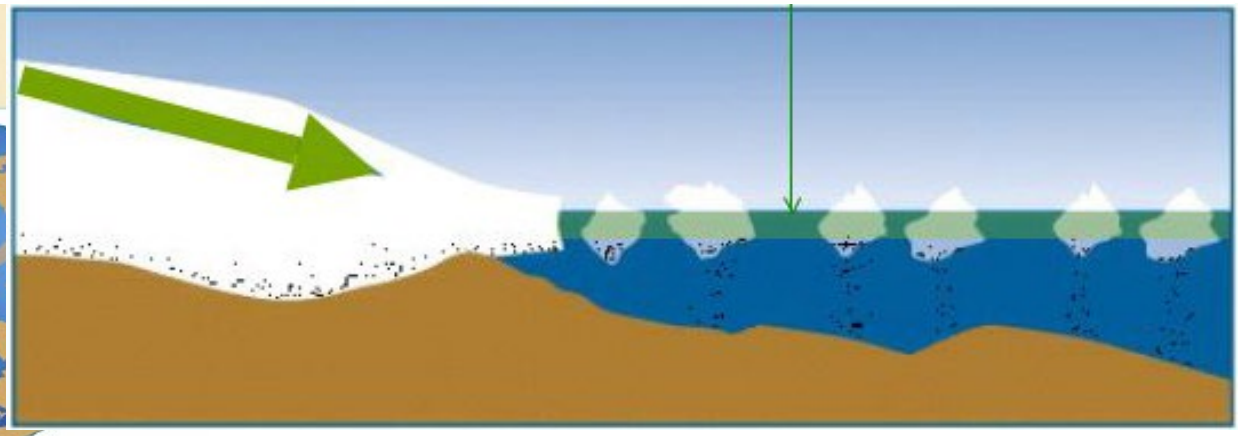
Heinrich events: 7.000-10.000 years



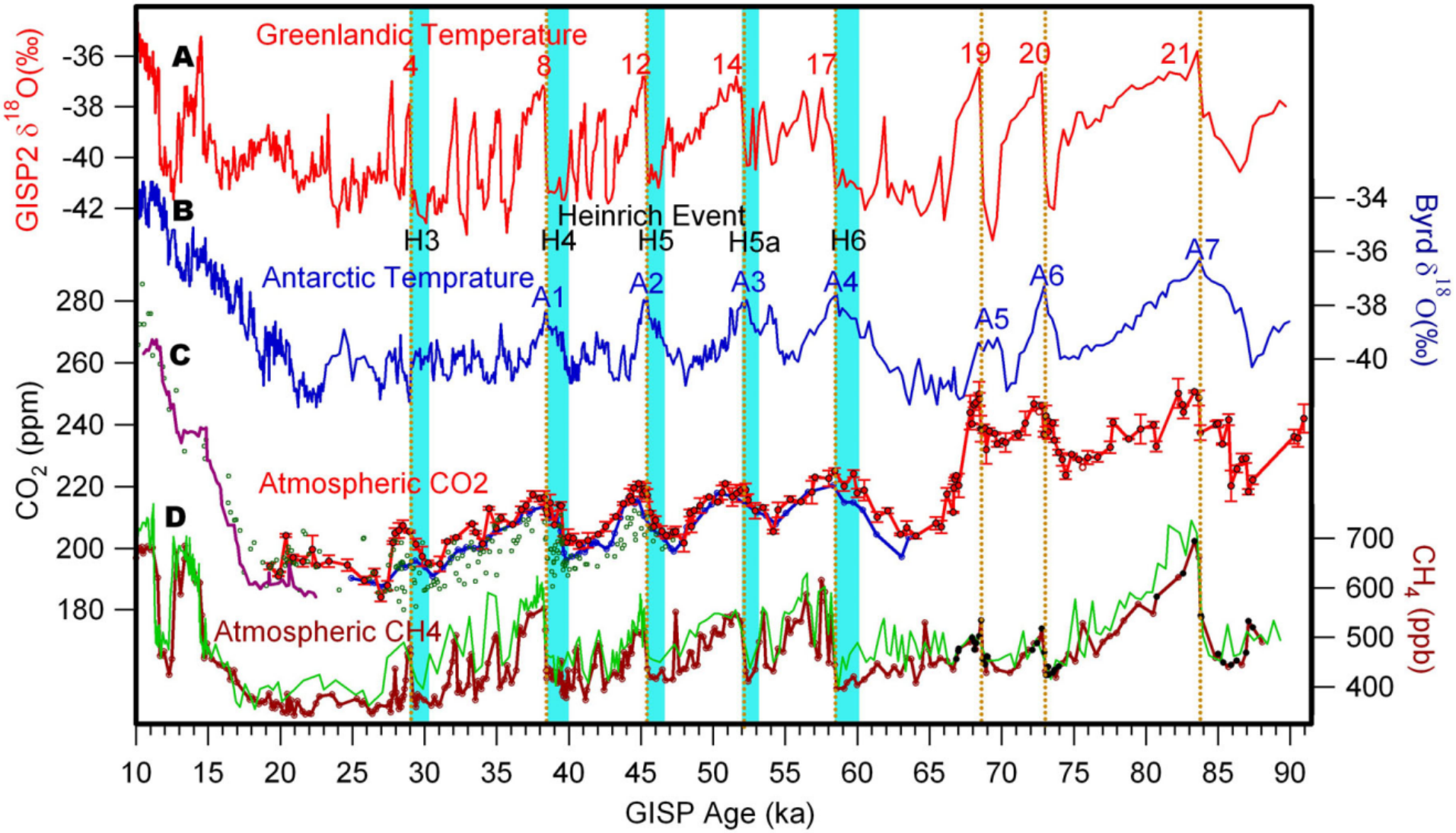
Heinrich, QR, 1988







The Quaternary Era: millennial-scale climate changes



Ahn & Brook, Science, 2008

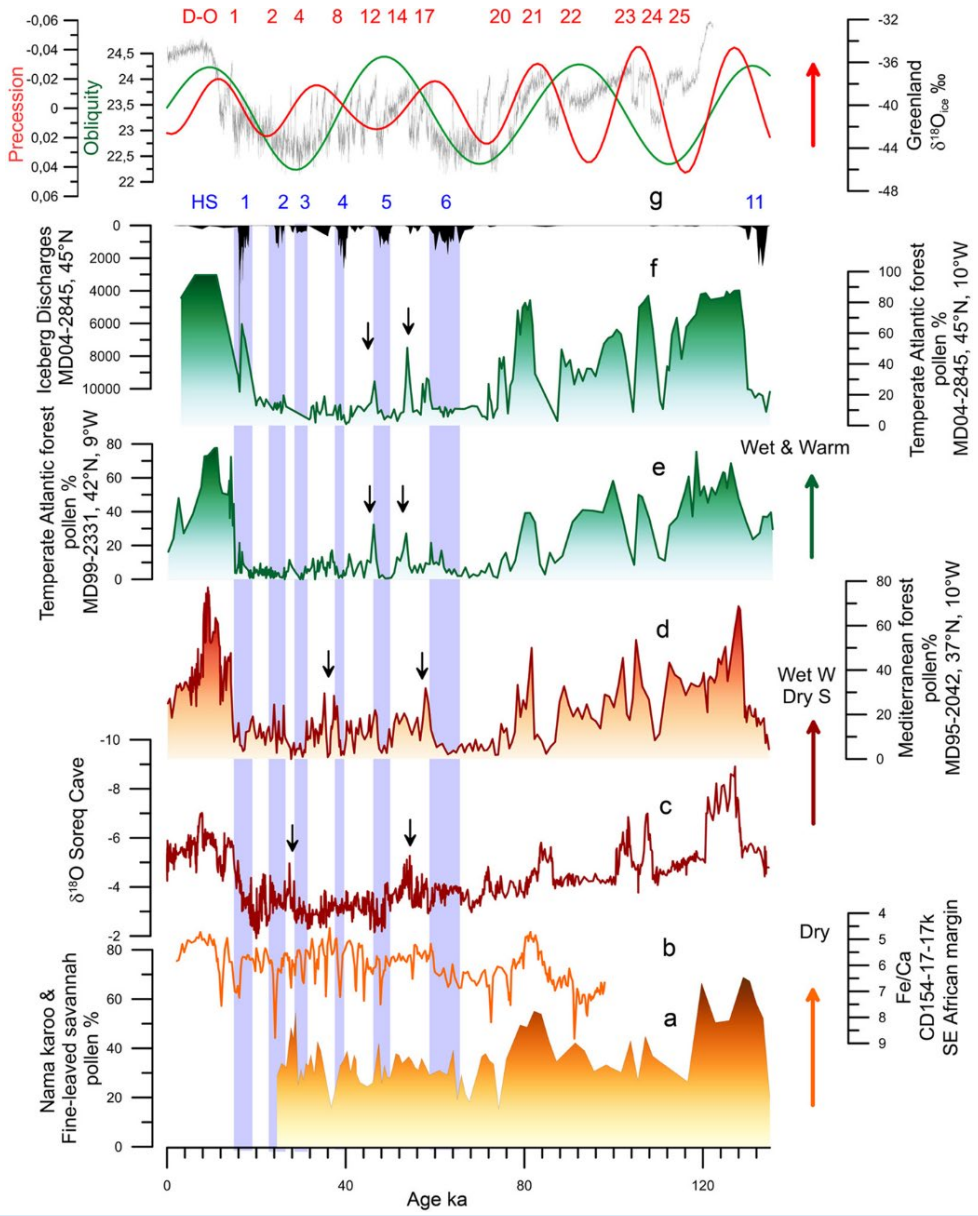
The Quaternary Era: millennial-scale vegetation changes

Cold phases

Centro-European steppe

Mediterranean steppe

Fynbos



Warm phases

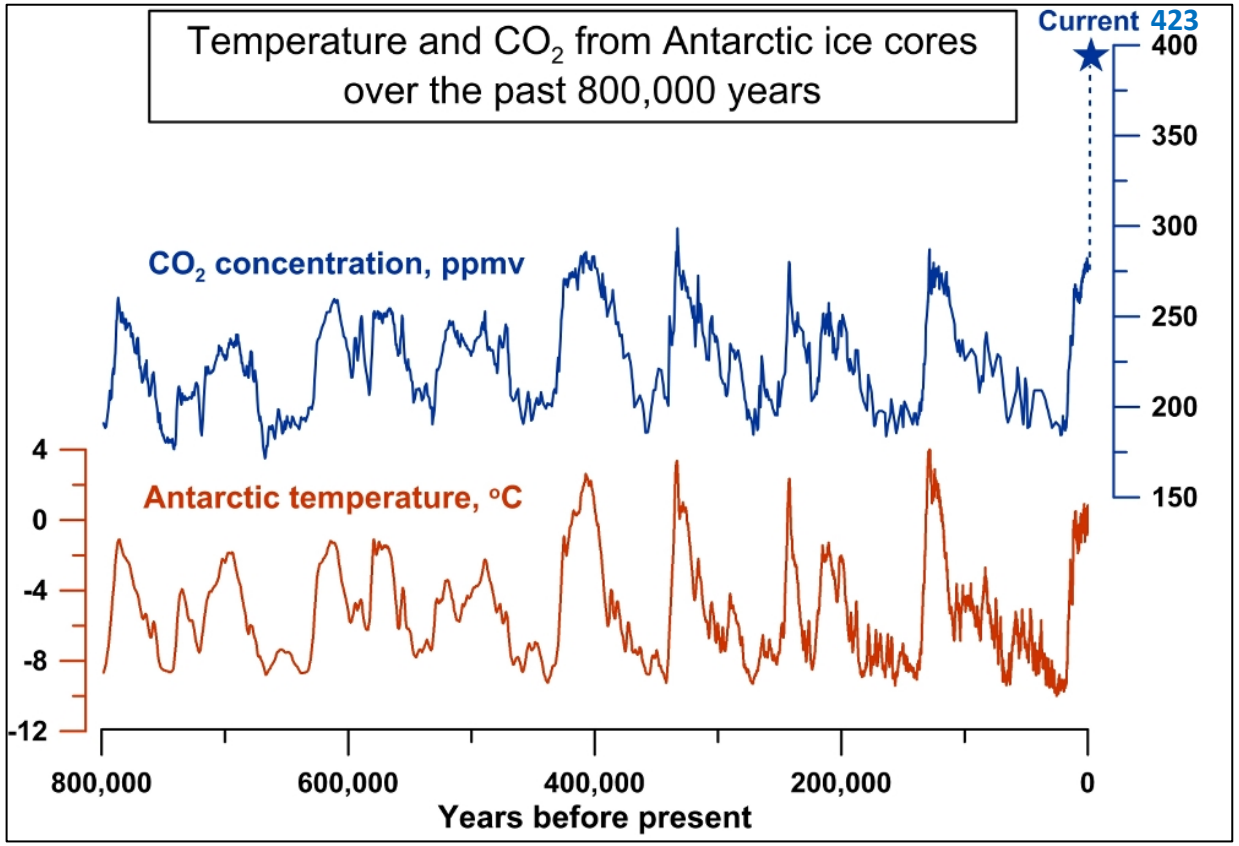
Temperate and humid forest

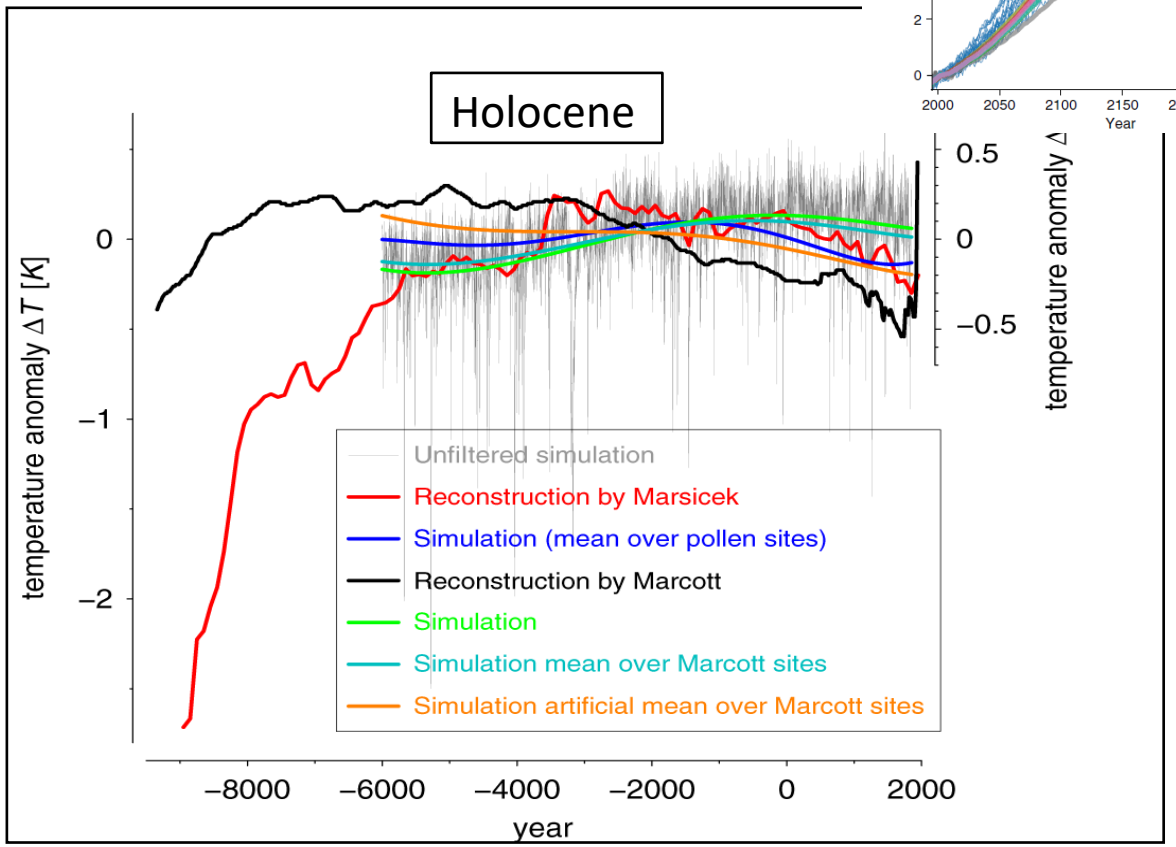
Mediterranean forest

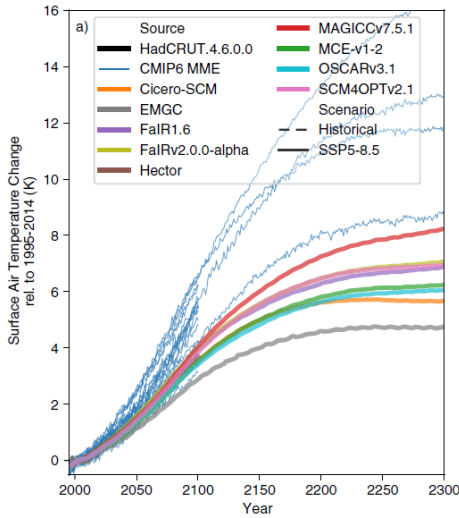
Nama-karoo

Sanchez Goñi, EHS, 2020

From the Quaternary Era to the future



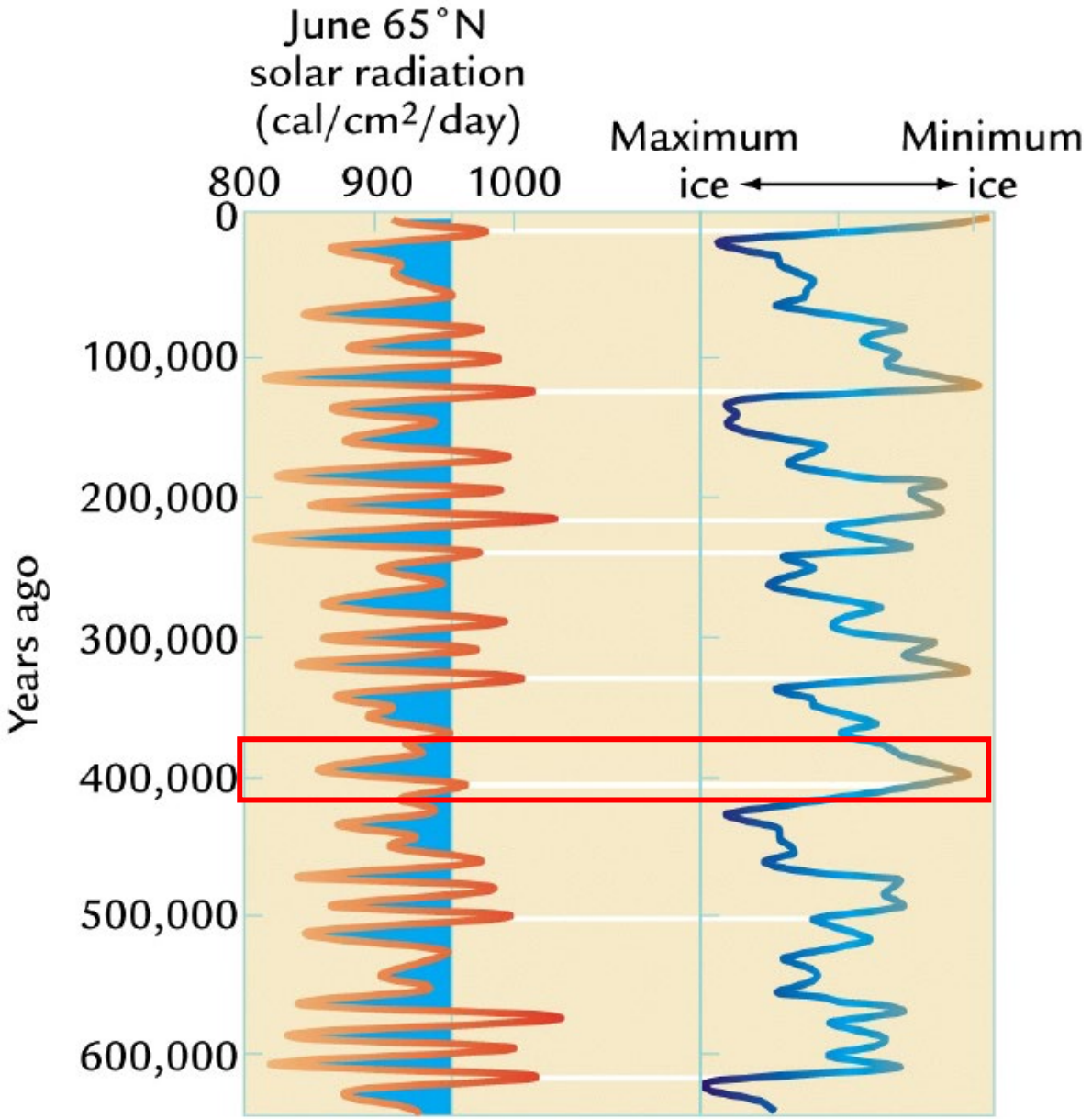




Nicholls et al., 2021, Earth's Future

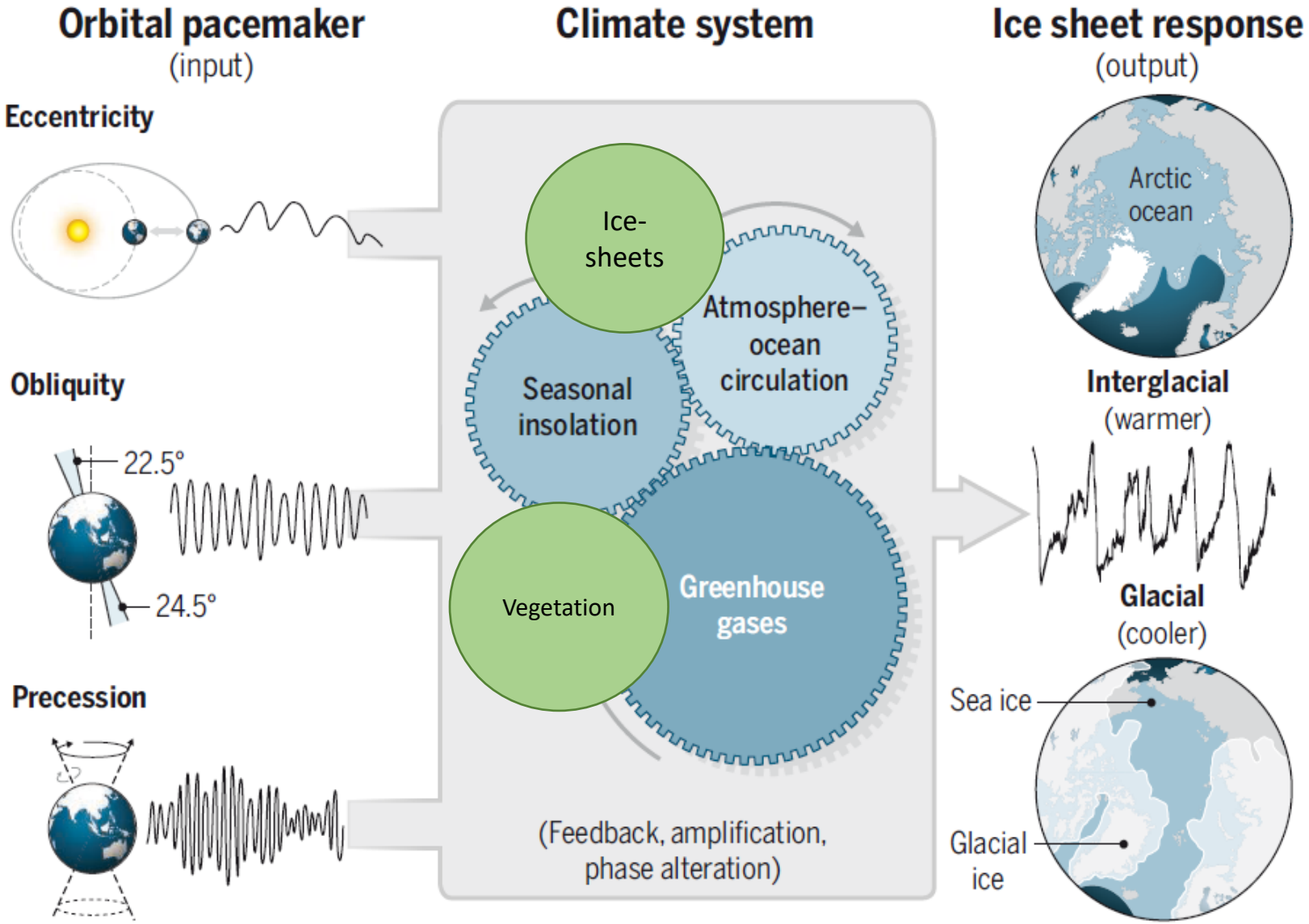
Bader et al., 2020, Nat. Comm.

The non-linearity of the climate system



Ruddiman, Earth's Climate, 2001

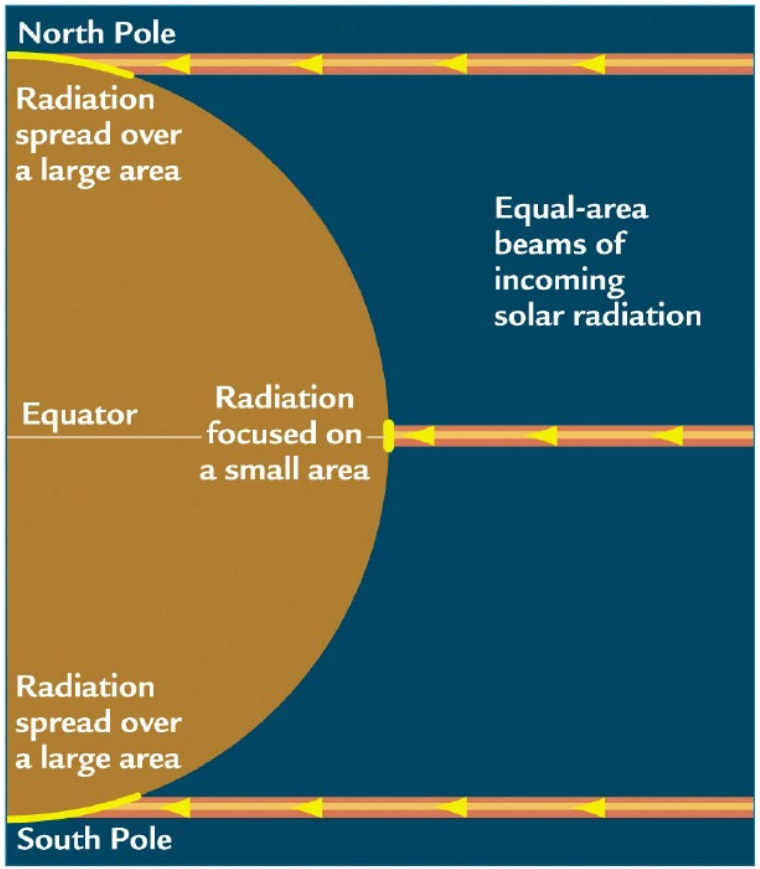
The non-linearity of the climate system

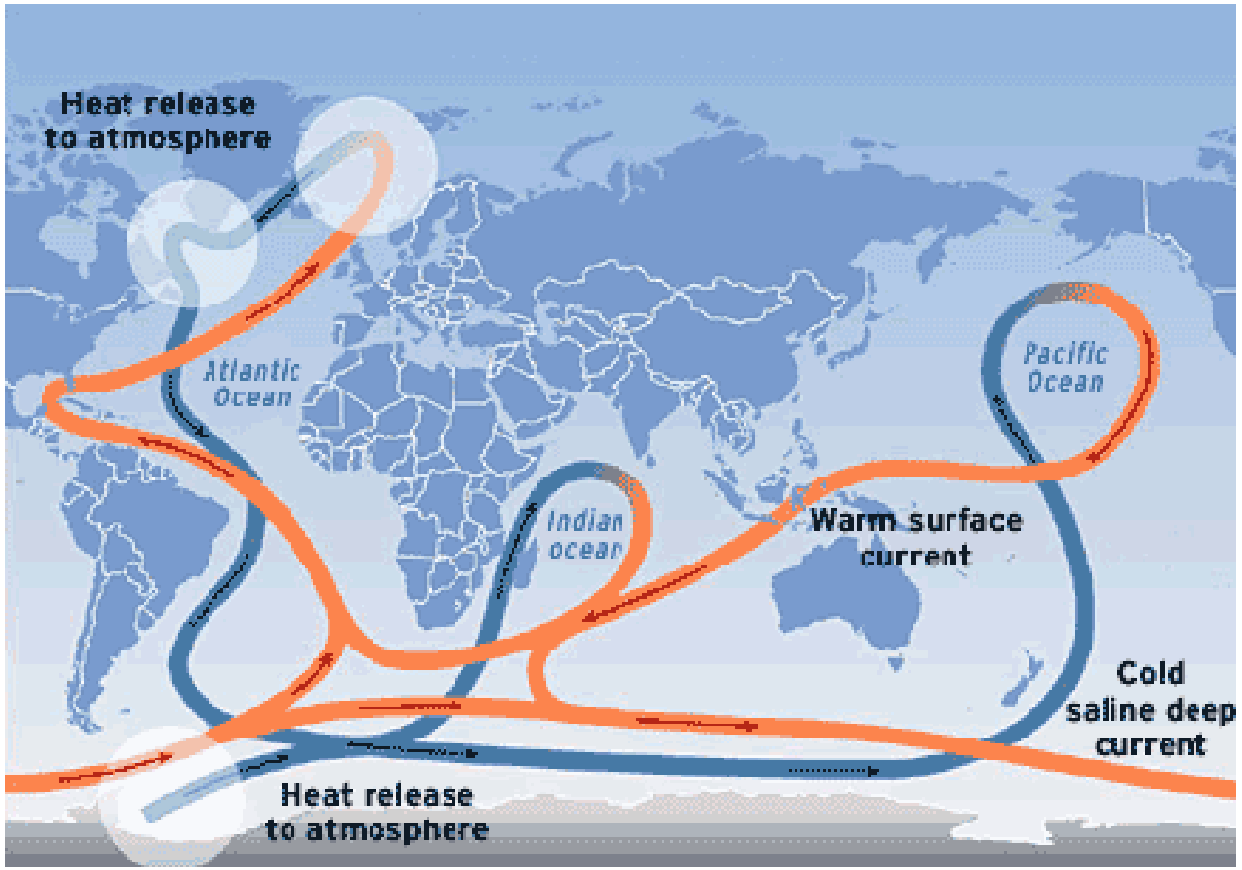


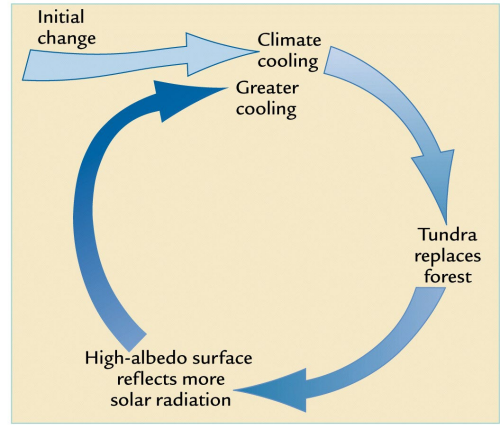
And the millennial-scale variability

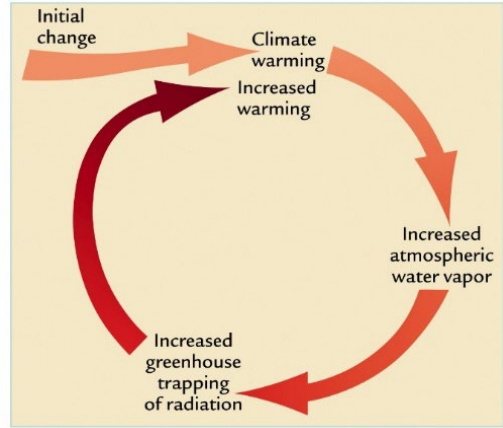
Hodell, Science, 2016, modified

The non-linearity of the climate system

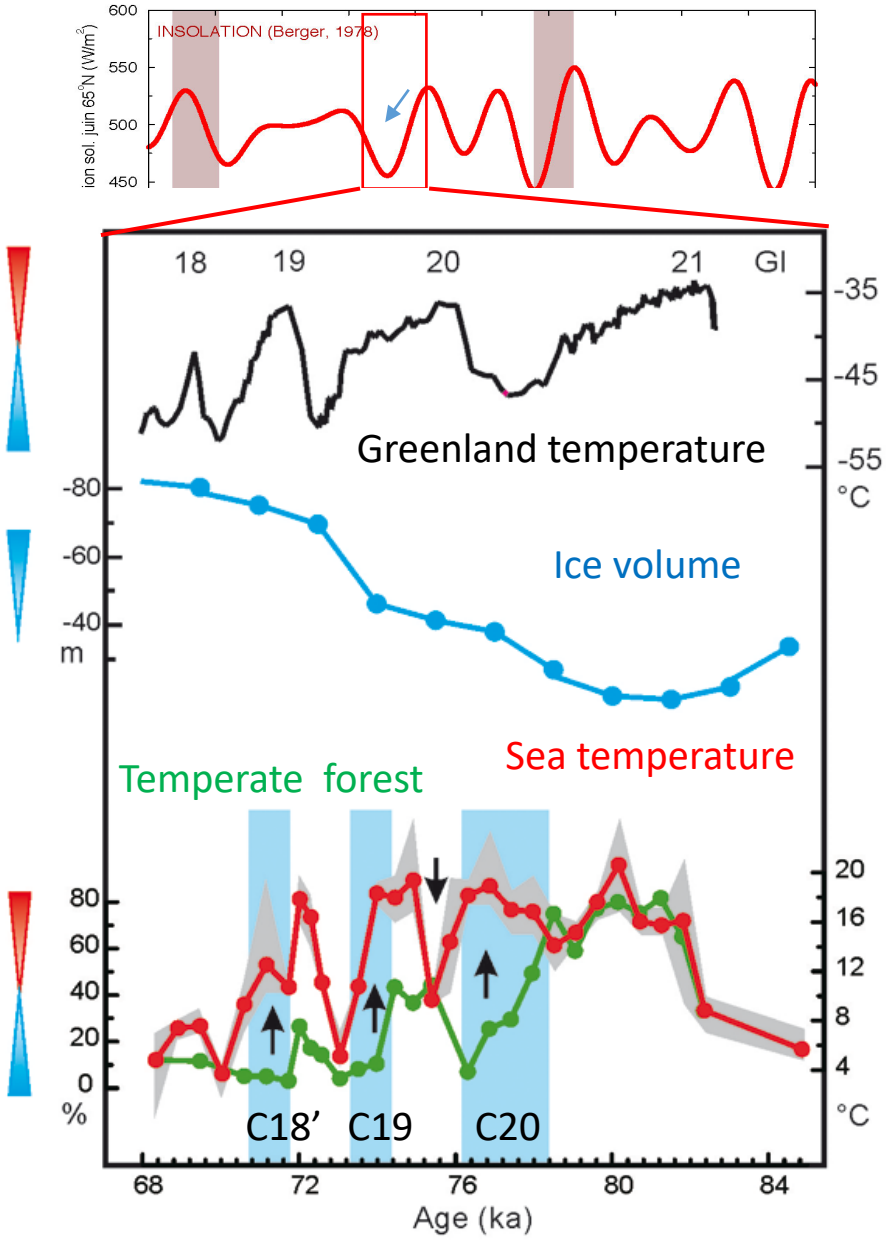


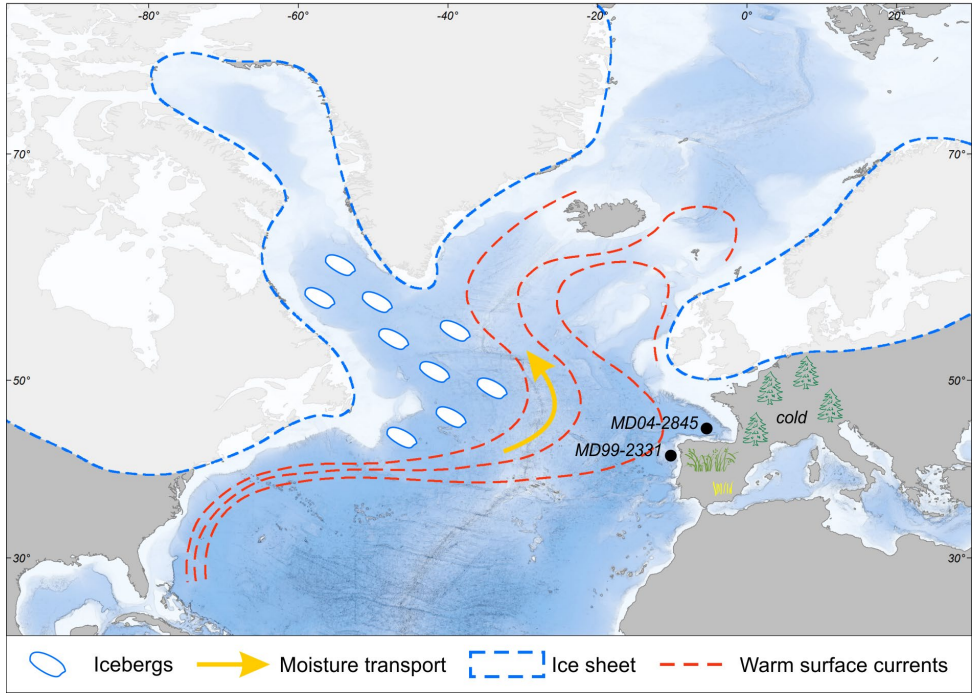


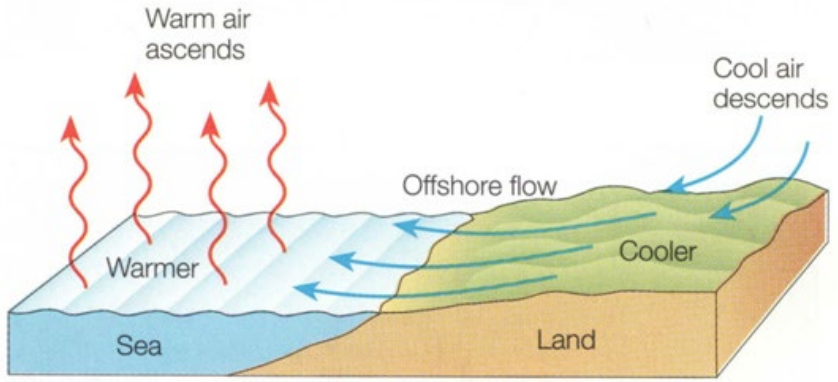




The non-linearity of the climate system: the last glaciation (80-70 ka)



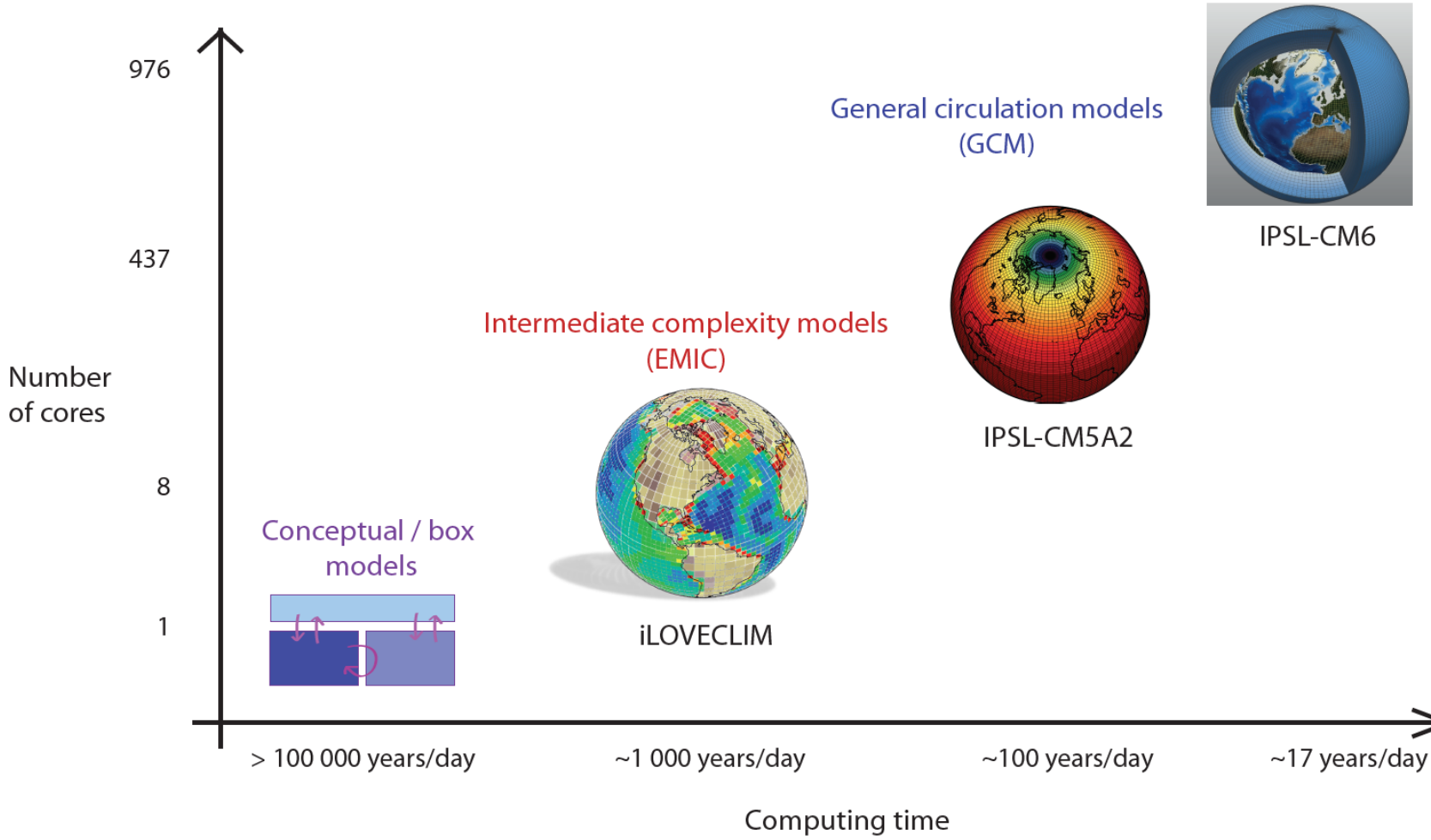




Sanchez Goñi et al., *Nat. Geosci.*, 2013

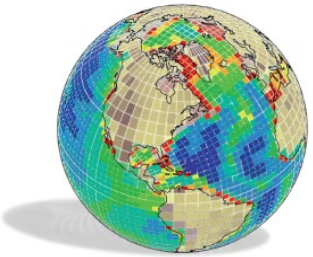
Development of climate models

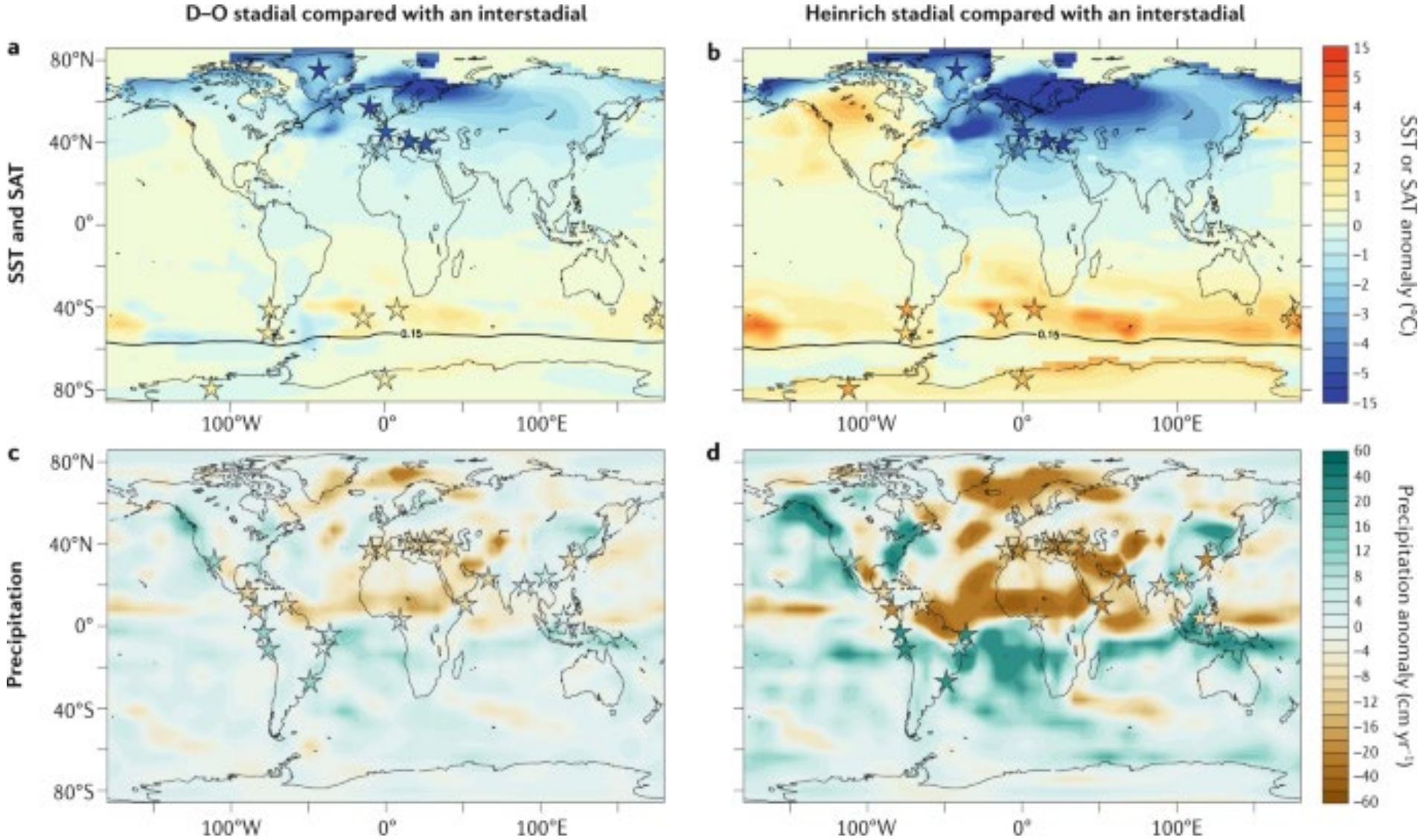
- Identify the role of the different feedback mechanisms that explains the observed climatic response reconstructed by data
- Evaluate whether these reconstructions are physically realistics



The Quaternary Era: regional impacts of rapid cooling

Intermediate complexity models (EMIC)

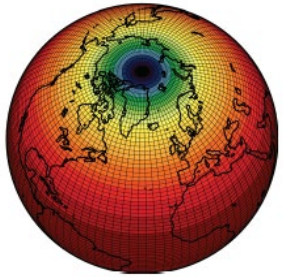




Menviel et al., 2020 Nat. Rev. Earth&Env.

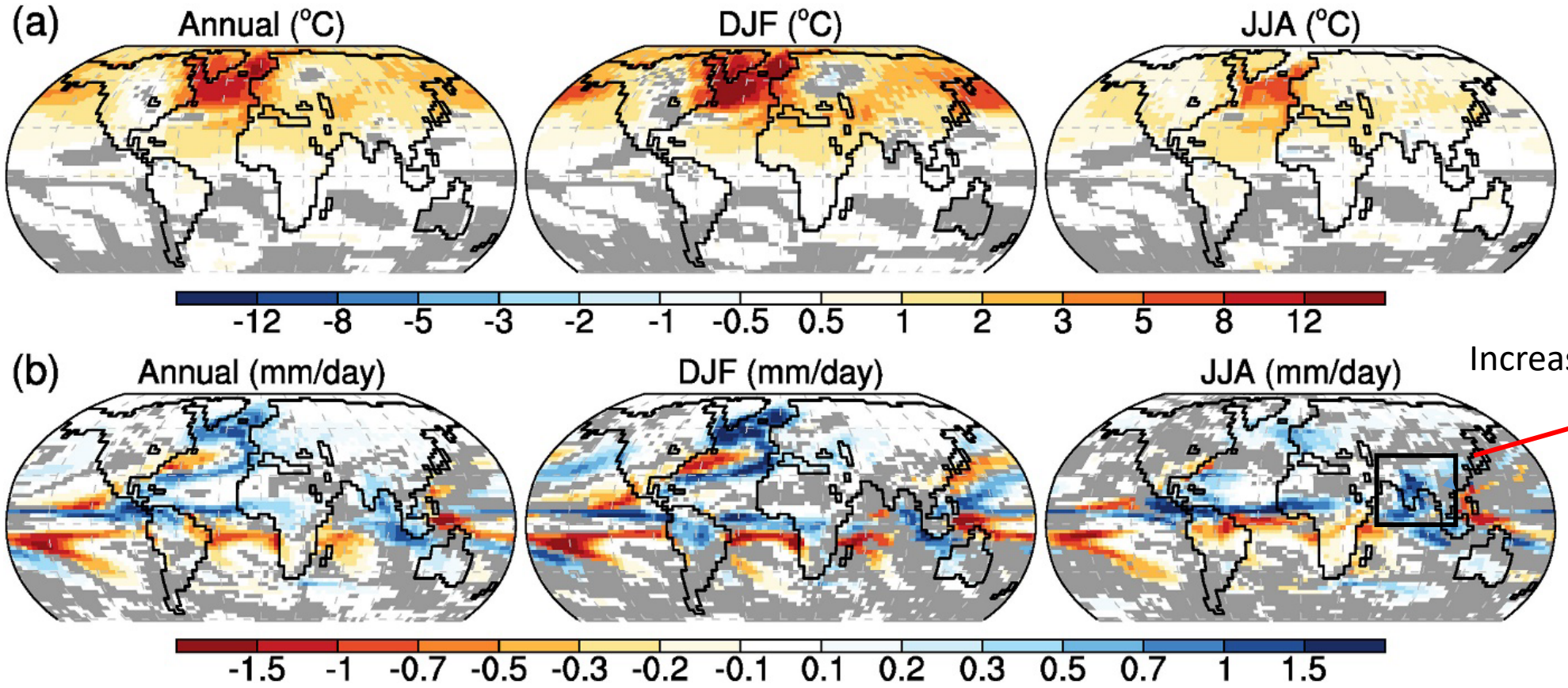
The Quaternary Era: regional impacts of rapid warming

General Circulation Model (GCM)



IPSL-CM5A2

Differences between average GI (warm) and GS (cold)



Increase summer precipitation

Gray shade means no robust responses

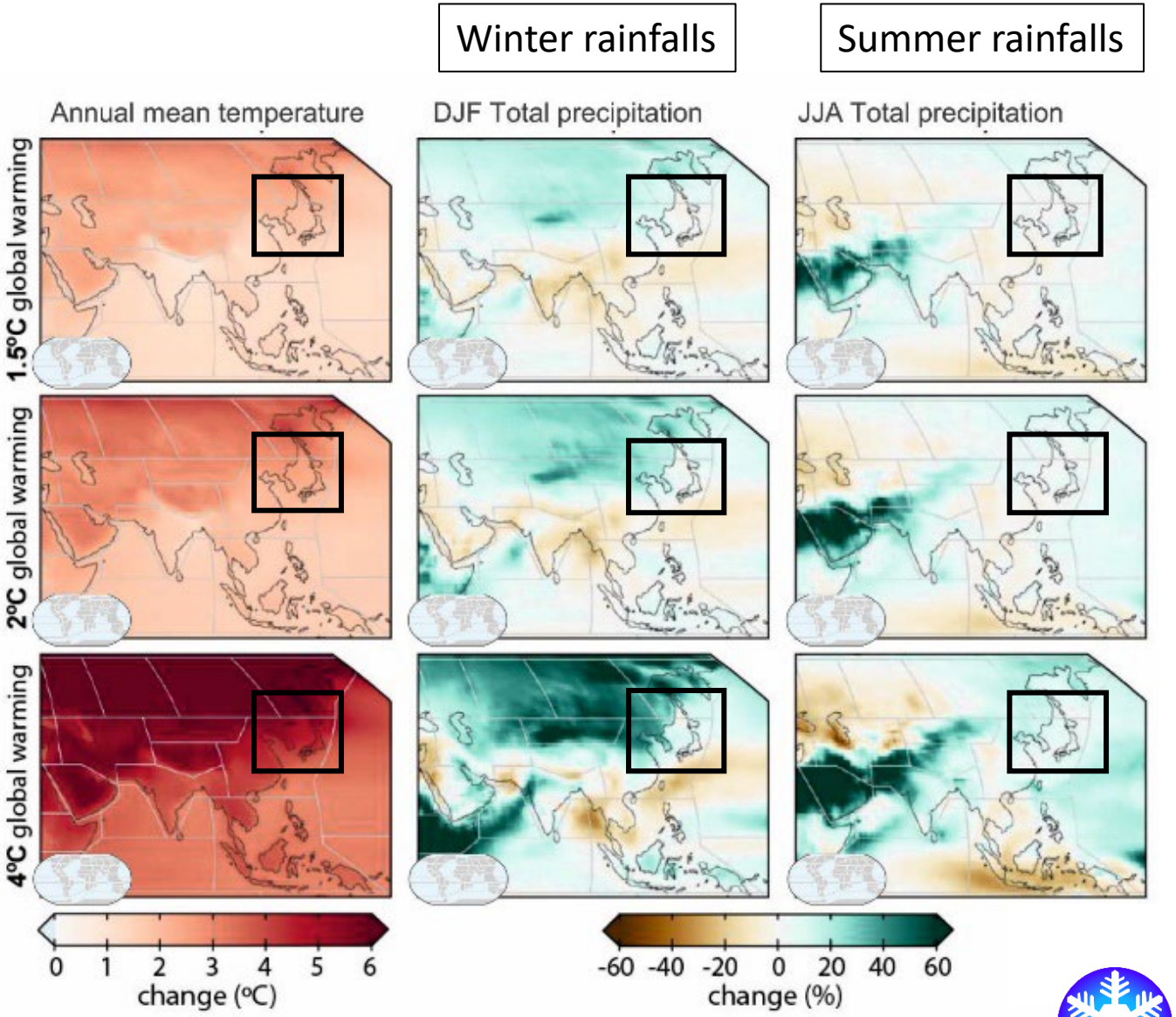
Izumi et al., 2023, QSR

East Asia monsoon projections

- Seasonal paradox in East Asia proposed by numerical simulations for the end of the century
- Increase in the speed and intensity of the hydrological cycle during winter time

This paradox strongly questions on:

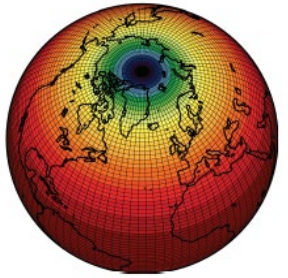
(1) the reliability on the numerical simulations
(2) the drivers controlling the regional and seasonal precipitation patterns in East Asia



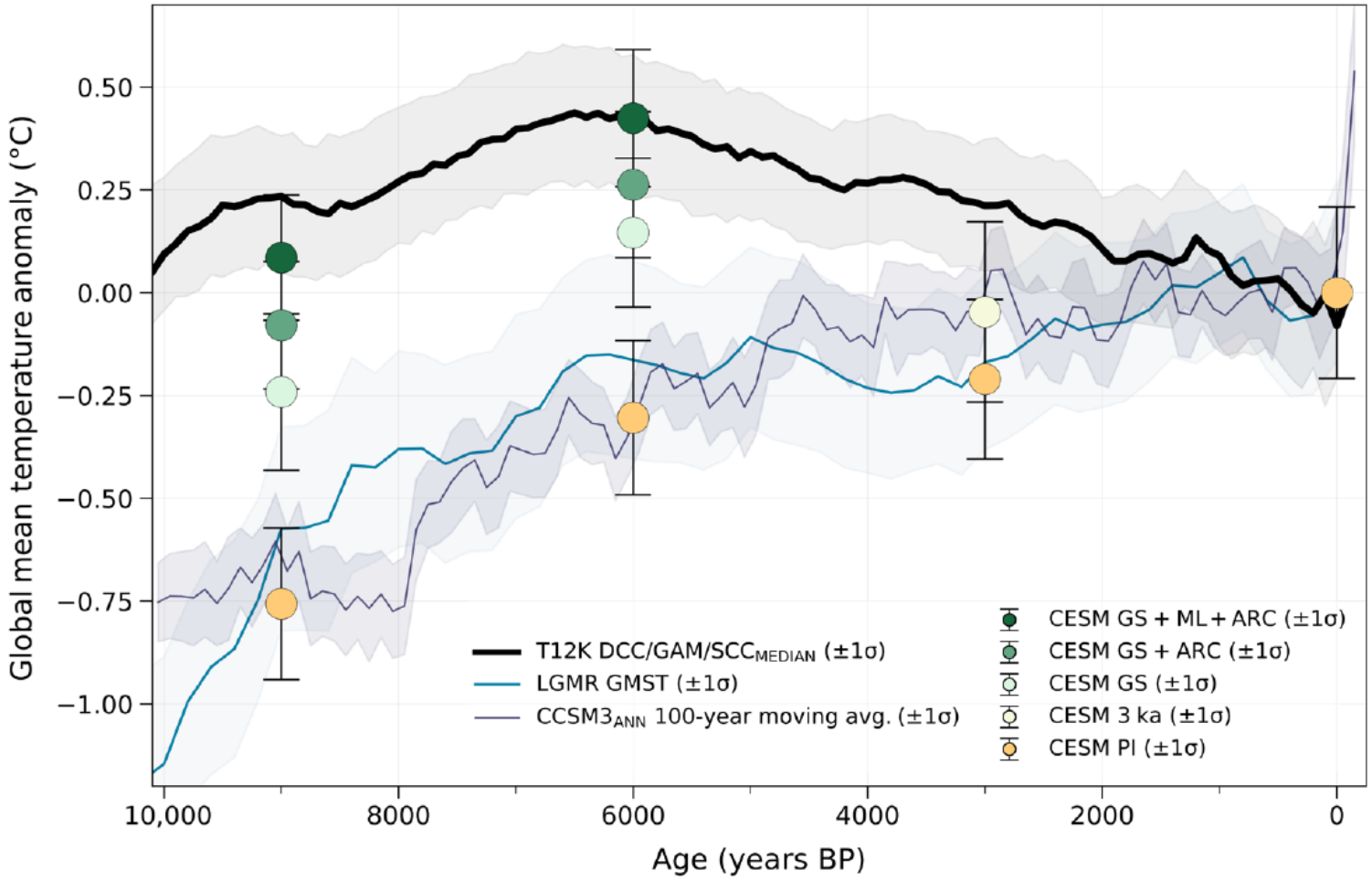
IPPC 6th Assessment Report, 2022

The Holocene temperature conundrum

General Circulation Model (GCM)

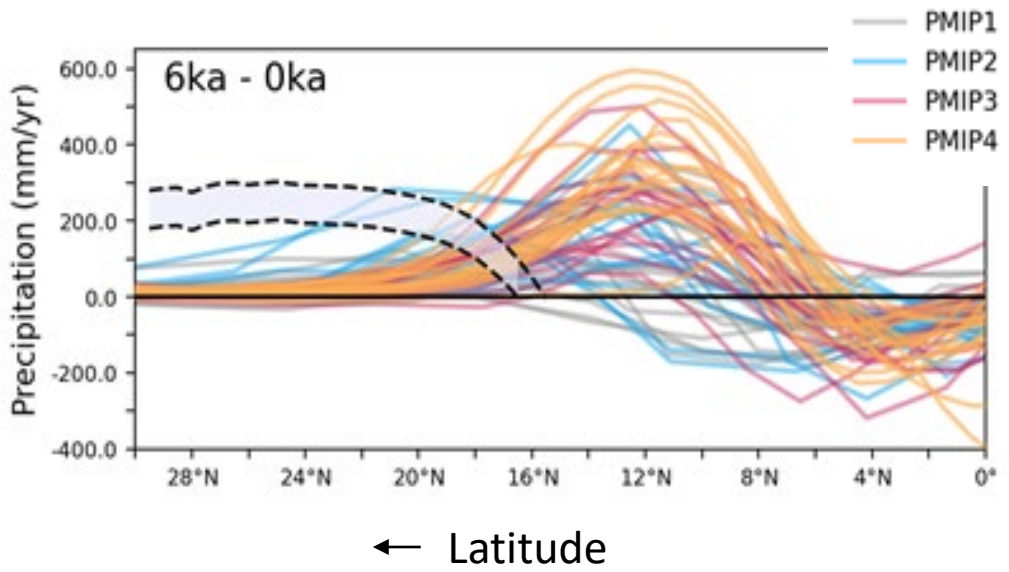


IPSL-CM5A2



Thompson et al., Sci. Adv., 2022

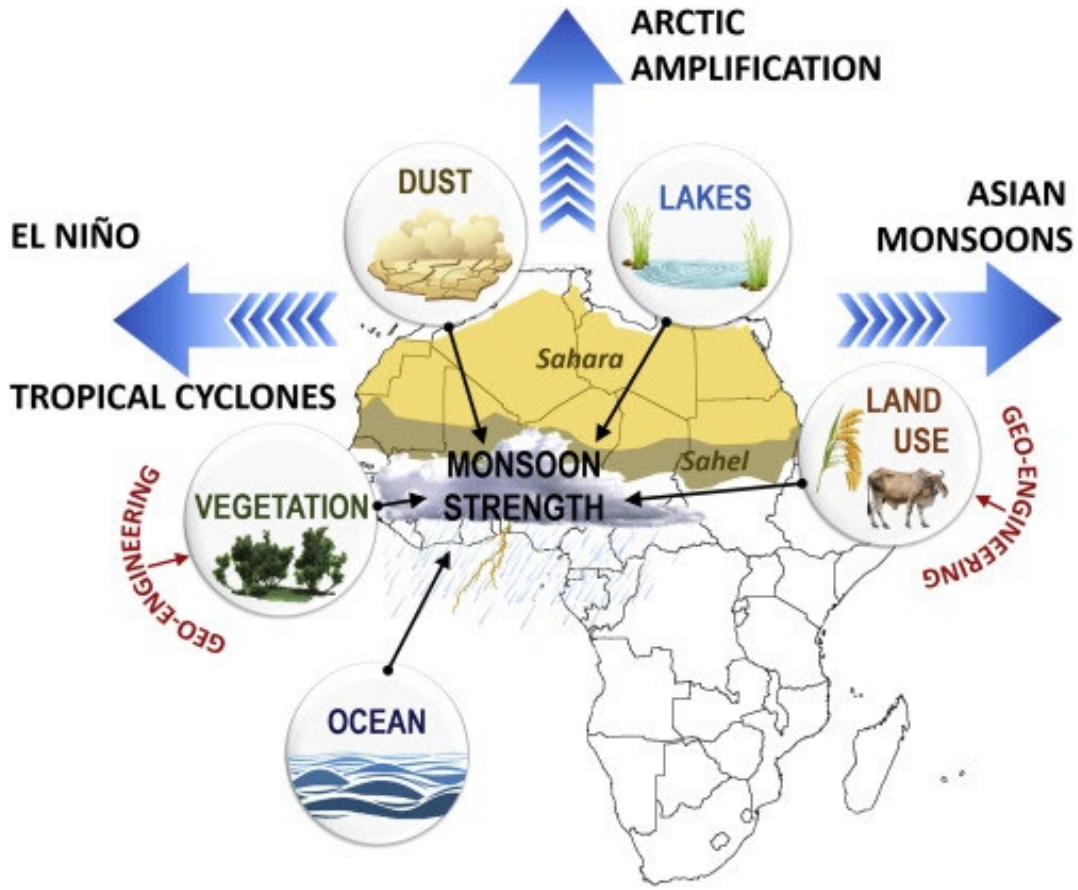
Multi-model approach: the African « nightmare »



Brierley et al. CP, 2020, WG1 AR6 (2021, chap. 3), Braconnot et al. PAGES, 2021

- Northward shift still underestimated (data: 17°N)
- Results more consistent between 8°N and 16°N
- BUT new simulations with interactive vegetation ~OK (ex: Dallmeyer et al. 2021)

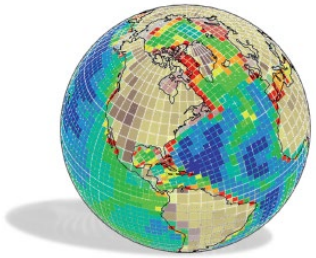
- Model deficiencies : atmospheric physics, coupling with land surface (vegetation, soil etc..)
- Balance between different effects still unclear

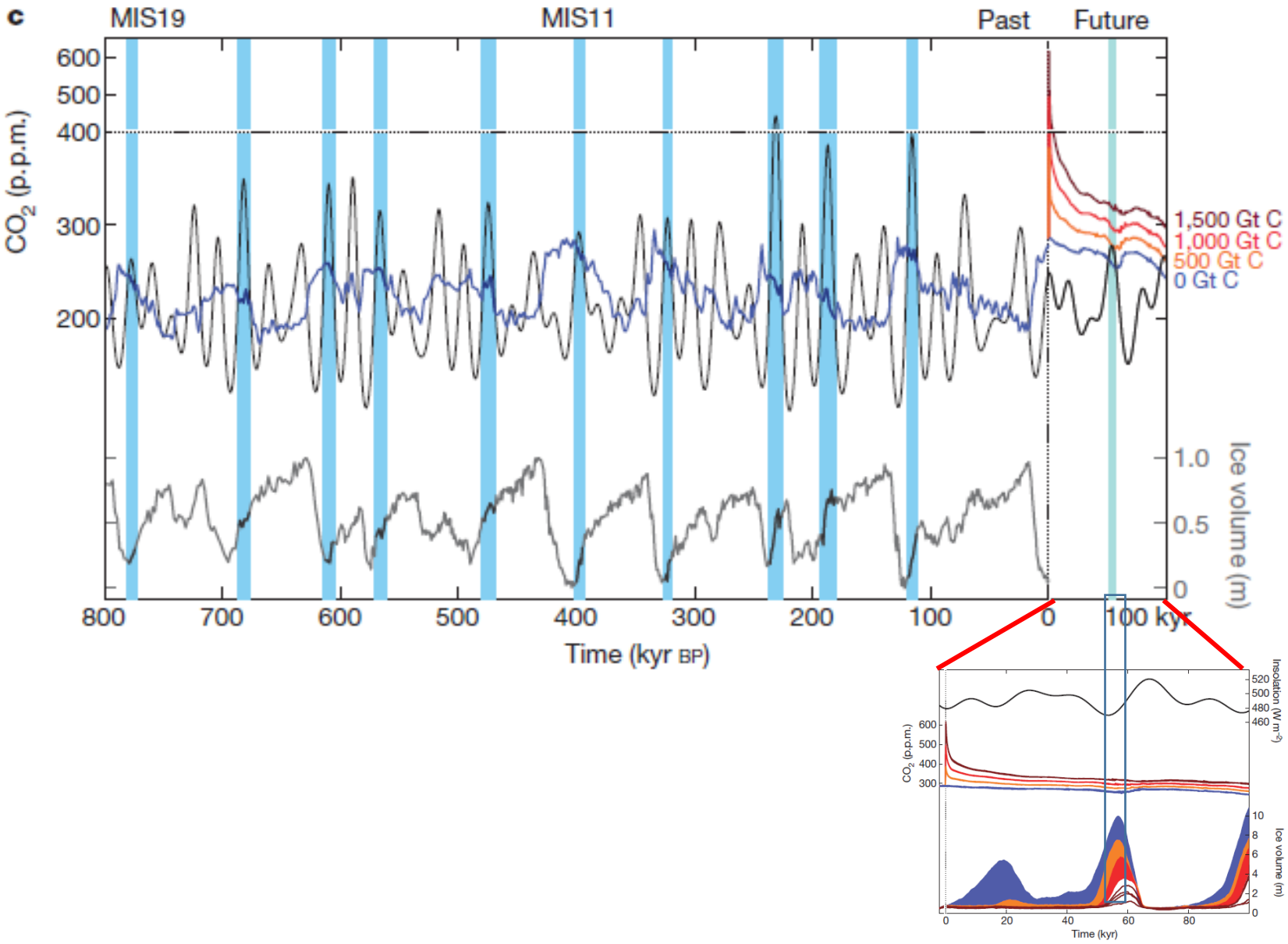


Pausata et al. 2020

The prediction of the next glacial inception

Intermediate complexity models (EMIC)



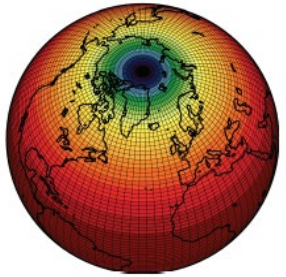


- Low-resolution atmosphere
- Low-resolution ocean
- SICOPOLIS ice-sheet module, only NH
- Simple vegetation module

Ganopolski et al., 2016, Nature

Multi-model approach: Sea level evolution

General Circulation Model (GCM)



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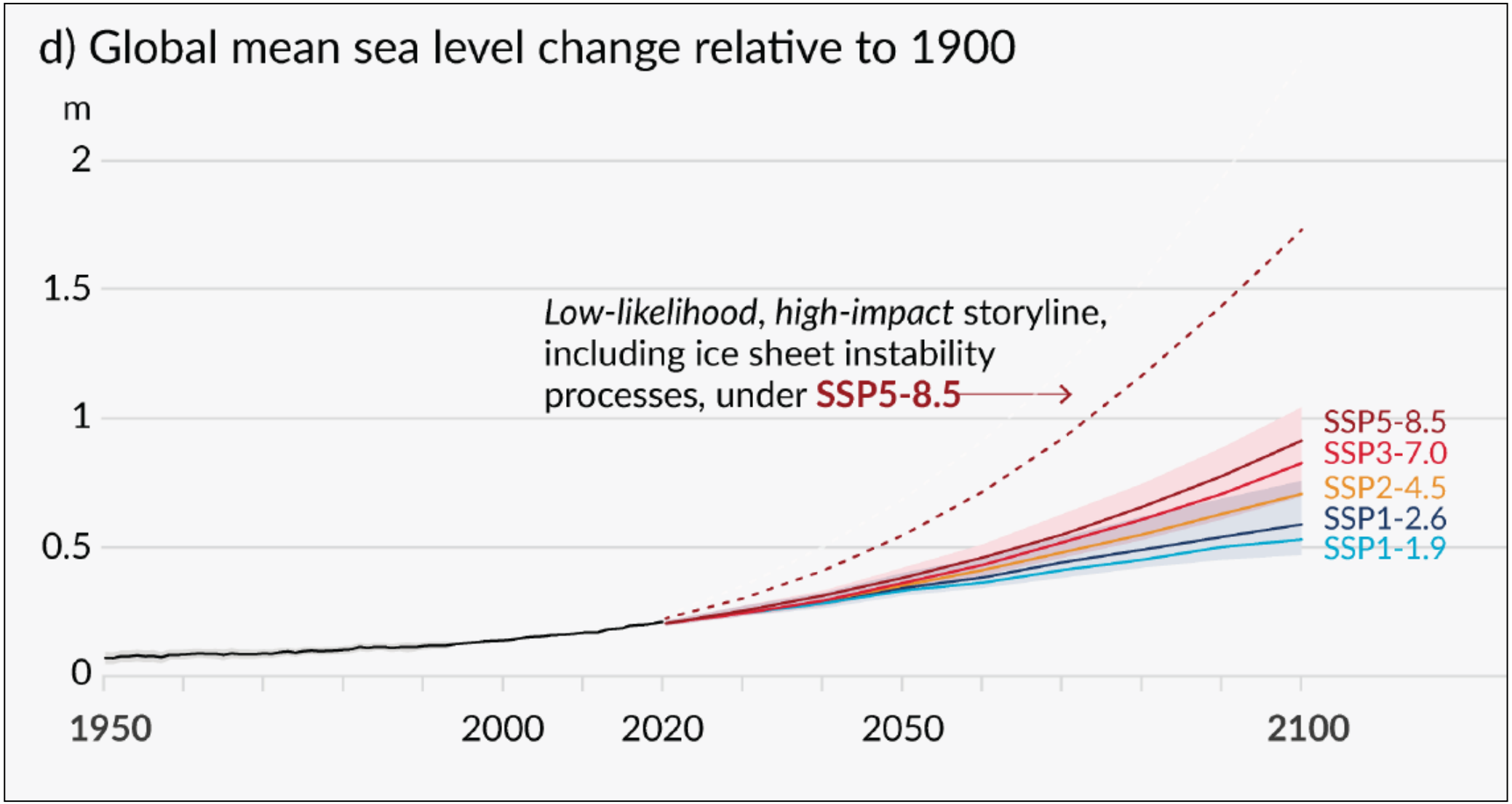
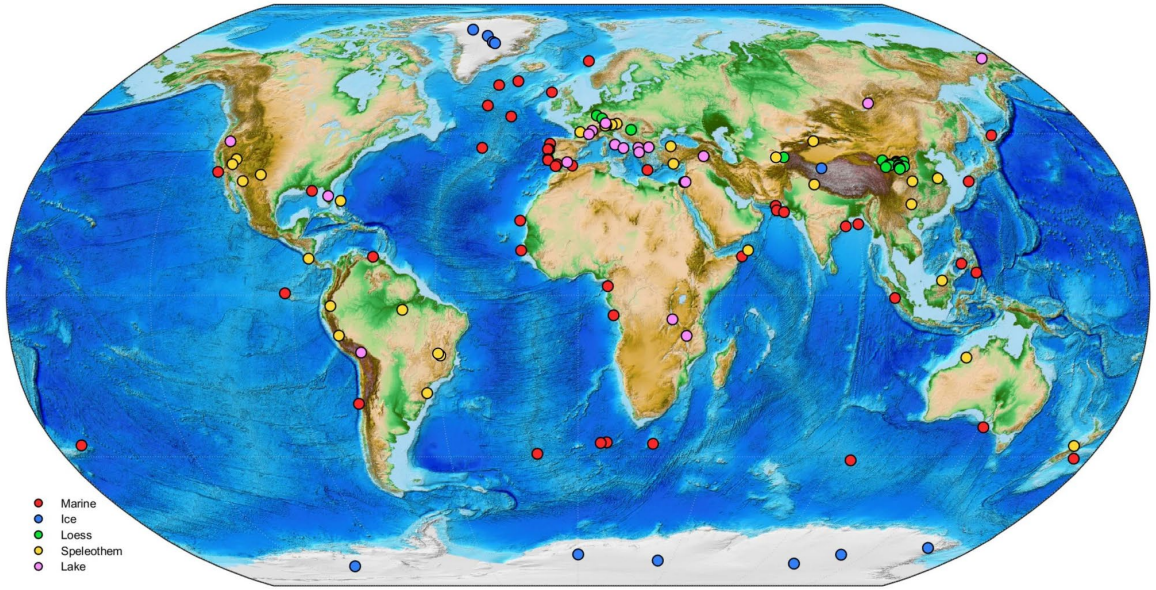


IPPC 6th Assessment Report, 2022

Conclusion

Uncertainties in data reconstructions and model simulations, inconsistent climate responses from different models, and the mismatch between simulated and reconstructed past climates highlight:

- the difficulty in modelling regional and global responses to past climate changes
- the necessity to improve data coverage, methodologies, and uncertainties
- the necessity to improve models:
  more systematic use of paleoclimate information for model tuning and model development



These issues have strong implications for future climate modeling (projections of sea level rise, the timing of glacial inception and the regional impact of global climate change…)

Conclusion

Basic research on the Quaternary is still needed and requires a long-term perspective to understand the climate system and improve climate projections

More than that…
Quaternary studies are crucial to identify the biological and cultural mechanisms behind human evolution since the emergence of our genus *Homo*, *c.* 2 million years ago

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