Paleoclimate Applications with CESM: Past climates inform our future

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NCAR

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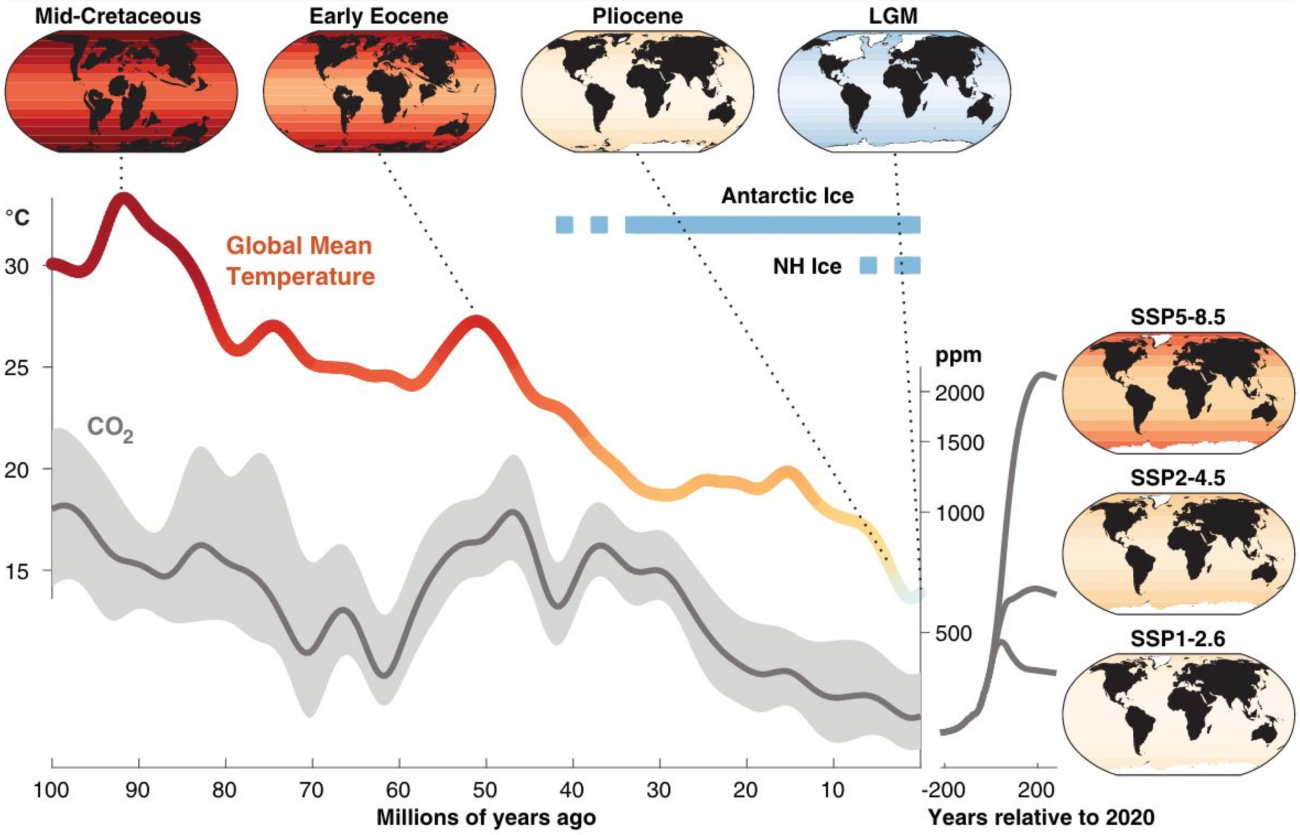
Outline

- Why do we study paleoclimates with CESM?
- What is proxy data?
- Example applications and capabilities of paleoclimate simulations
  - Water isotope tracers
  - Low-resolution climate ensembles
  - High-resolution extreme weather phenomena
- How do you modify CESM for paleoclimate simulations?
- Resources for paleoclimate applications of CESM & Paleoclimate Working Group

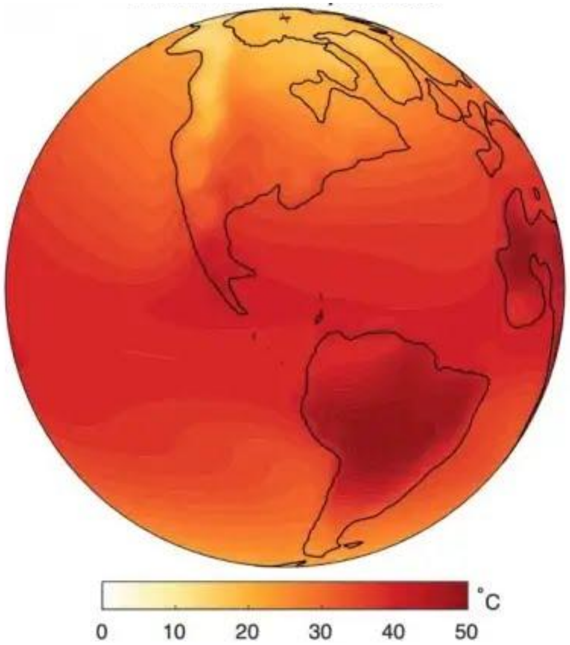
Past climates provide only real data for future high CO_2 scenarios



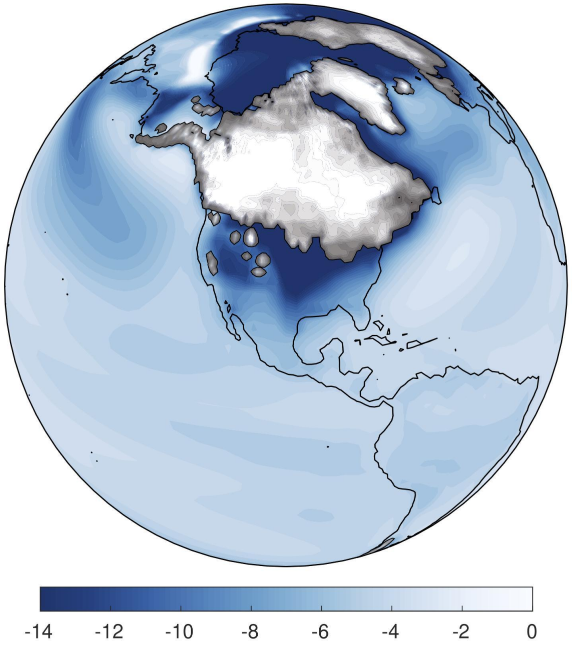
Tierney et al. (2020), *Science*

Past extreme climate states

High CO_2 (>1000 ppm)
Early Eocene Climatic Optimum (~50 Ma)



Low CO_2 (~180 ppm)
Last Glacial Maximum (~21 kya)



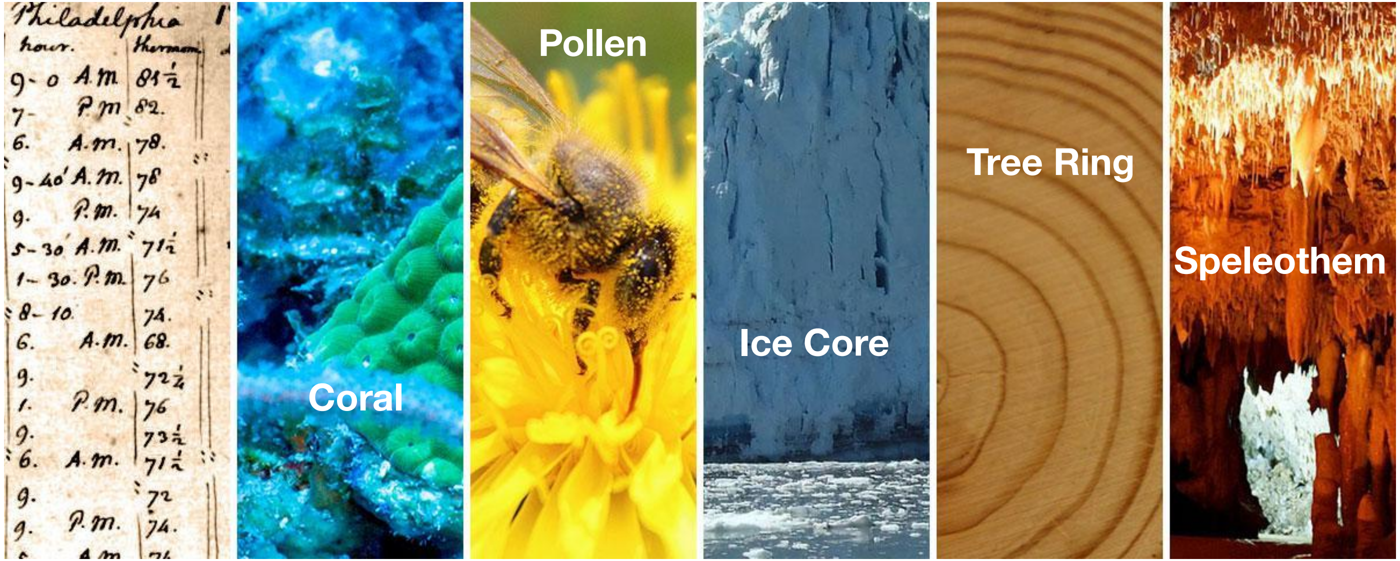
Proxies: real-world climate data beyond the record of direct measurements

Proxies can be physical, chemical, or biological measurements related to…

Air temperature
Precipitation
Atmospheric CO_2

Ocean-atmosphere circulation
Ice sheets

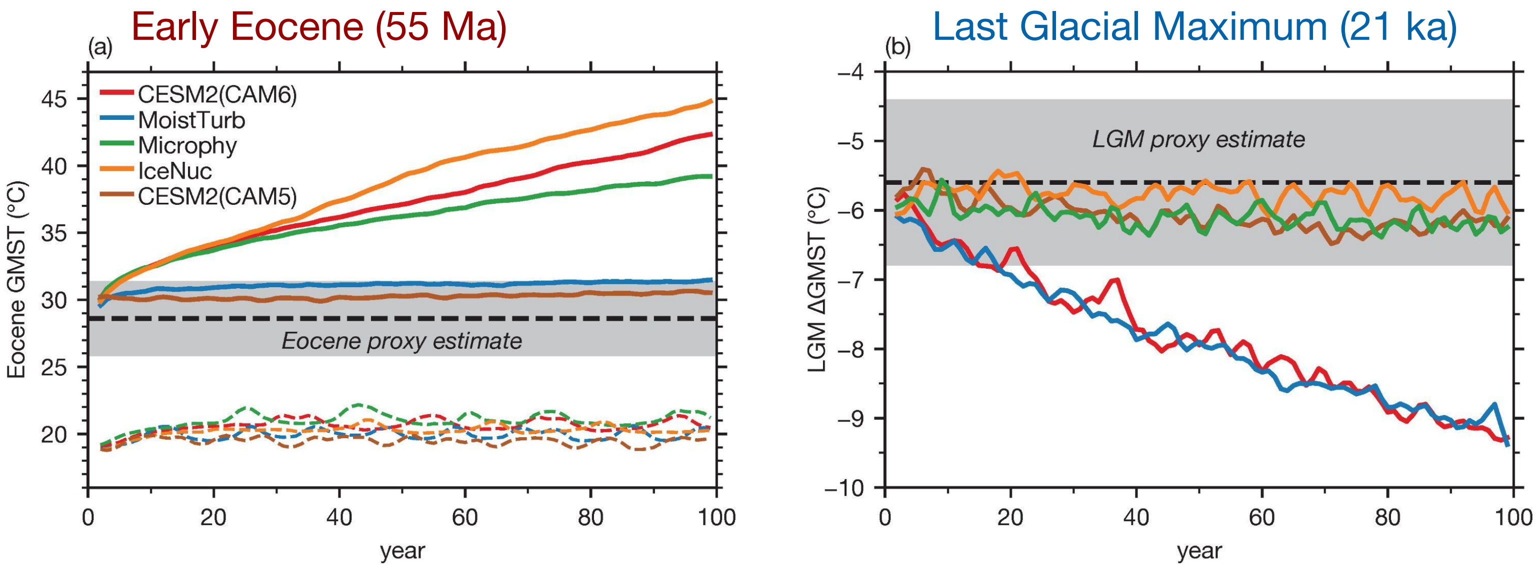
Ocean temperature
Salinity
Sea level



Picture Credit: NOAA

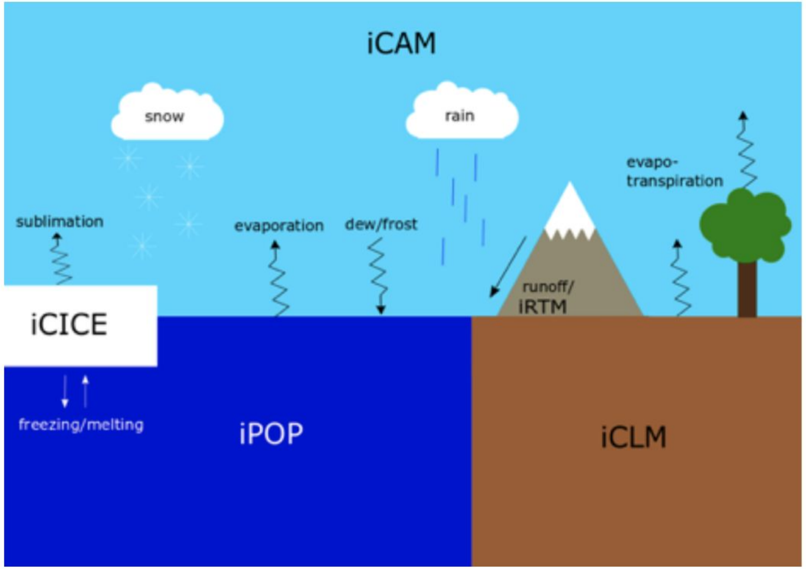
Past climates provide out-of-sample testing of modeled processes

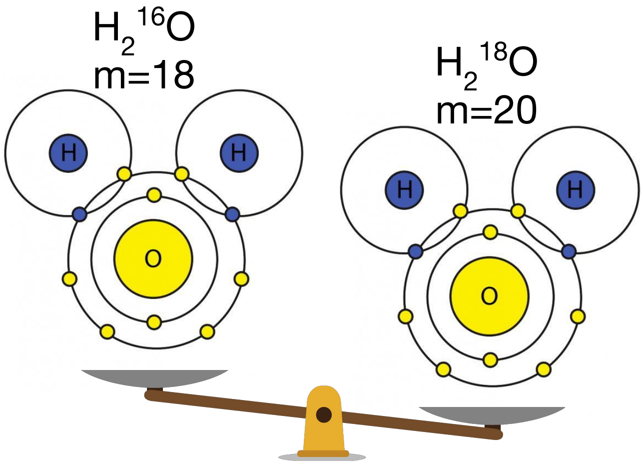
CESM2 overestimates past extreme warming & cooling, adjustments to the cloud schemes bring temps within proxy range but dependent on climate state



Water isotope tracers throughout the hydrologic cycle of CESM (iCESM)

Water isotope tracers help erode the "language barrier" that exists between climate models and proxy data





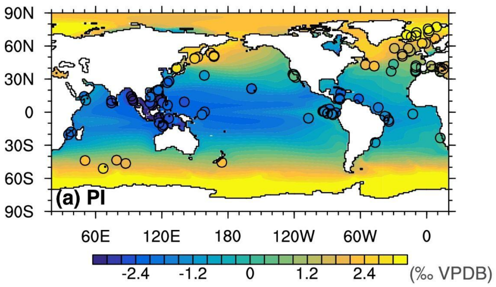
Speleothems, ice cores, foraminifera

Water isotope tracers vastly improve proxy-model comparisons

Late Holocene
(4 kya–present)

From **iCESM** to **proxy** space:

$\delta^{18}O_{seawater}$ & **SST** → planktic foram model → **$\delta^{18}O_{calcite}$**



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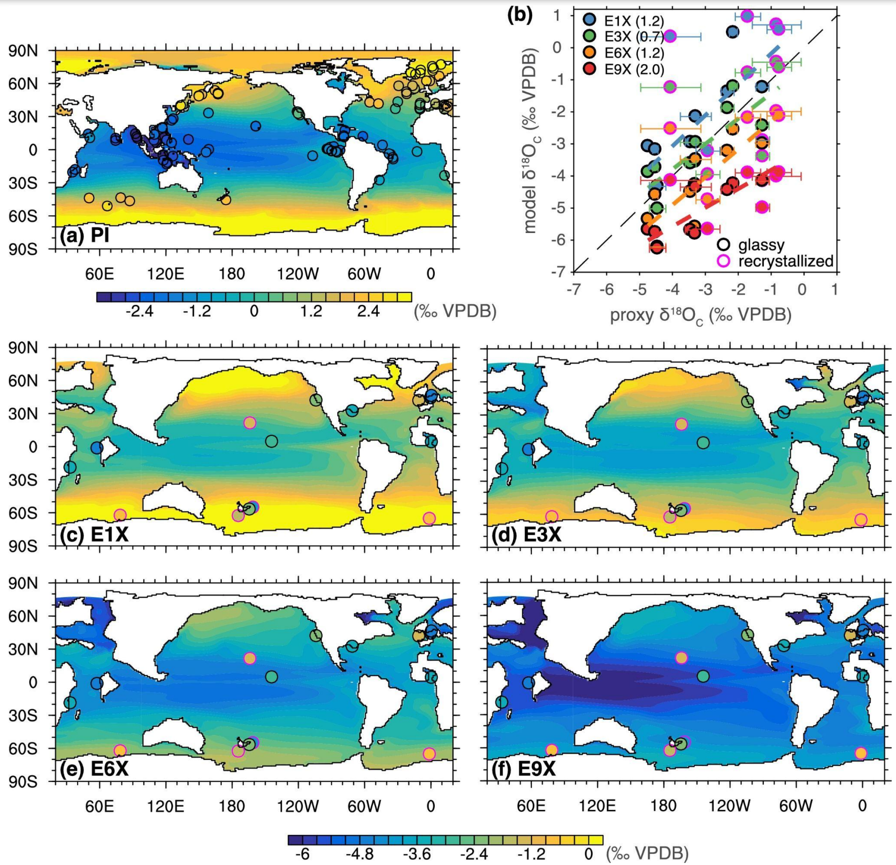
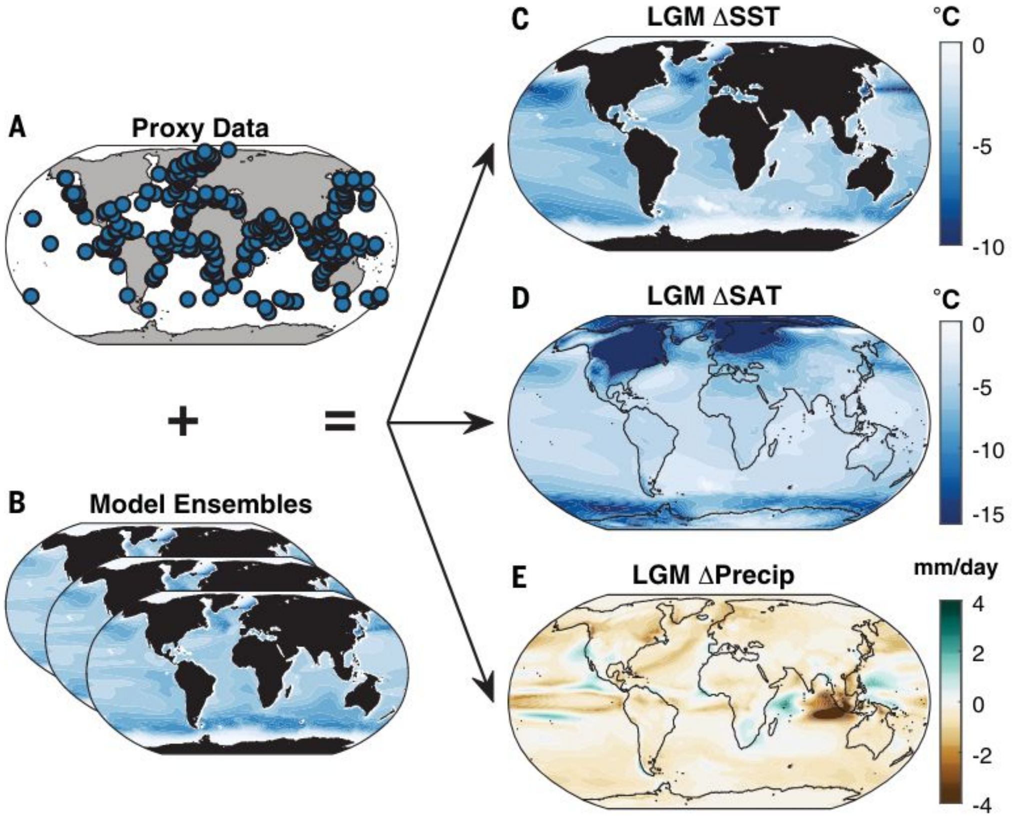
Early Eocene (55 Ma)
with different CO_2 levels

Low-resolution (≥100 km) simulations can build ensembles of past climate states that help reduce uncertainty in boundary conditions and forcings (like CO_2)



Simulation ensembles assess uncertainty & improve paleoclimate reconstructions

Data assimilation can be used to produce climate field reconstructions that leverage the strengths of climate model ensembles and proxy data



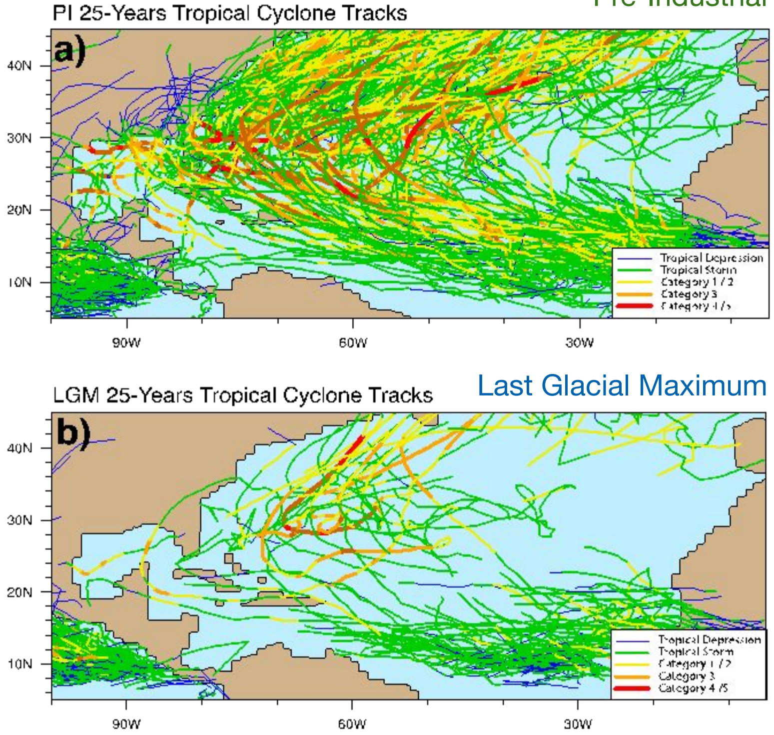
High-resolution enables past-to-future assessment of rainfall extremes

Precipitation & $\delta^{18}O_p$

Credit: Jiang Zhu (NCAR)

Pre-Industrial

Last Glacial Maximum



Credit: Clay Tabor, UConn

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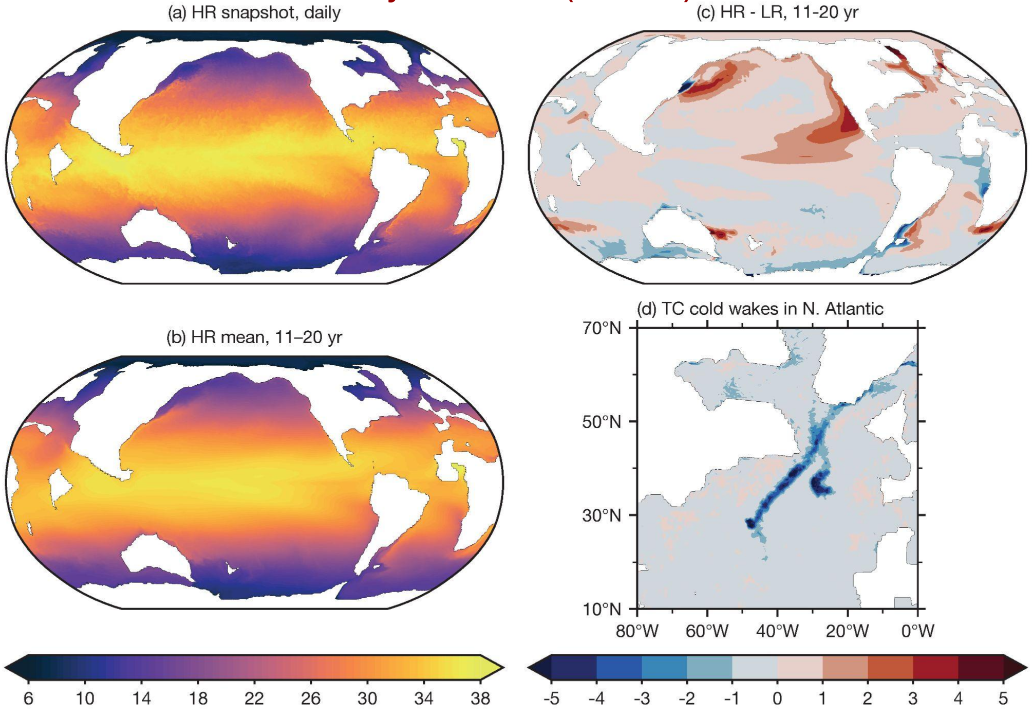


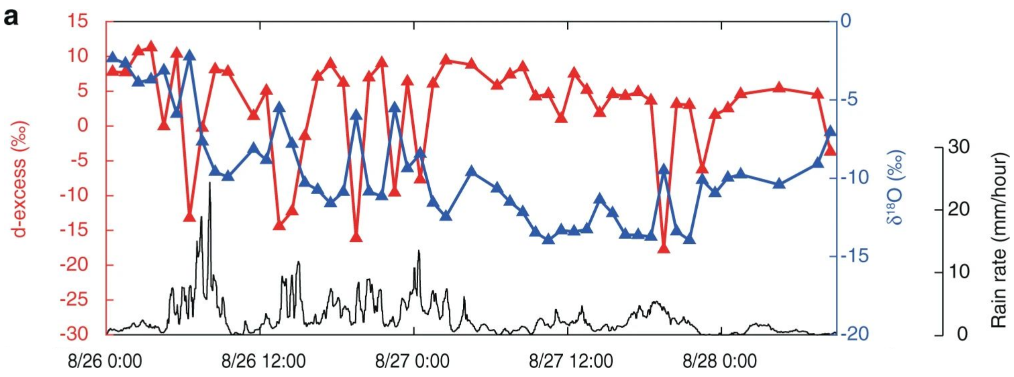
High-resolution proxy records enable the study of paleotempestology

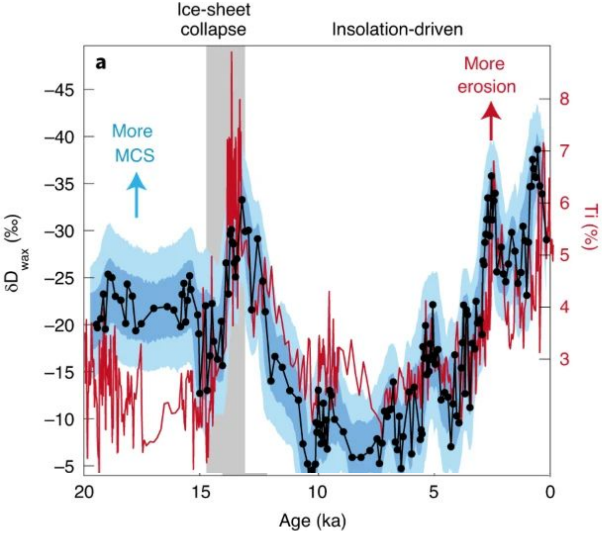
Multiproxy reconstructions can provide strong evidence for past changes in extreme precipitation events

(e.g., tropical cyclones or mesoscale convective systems)

Hall’s Cave, TX (20 kya–present)

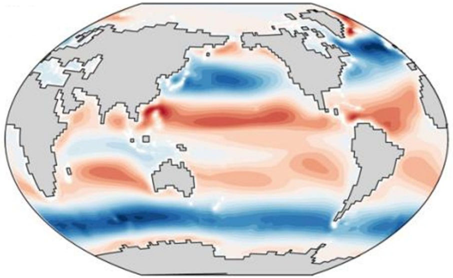
Hurricane Harvey moving over Austin, TX (2017)





Developing paleoclimate simulations is highly interdisciplinary

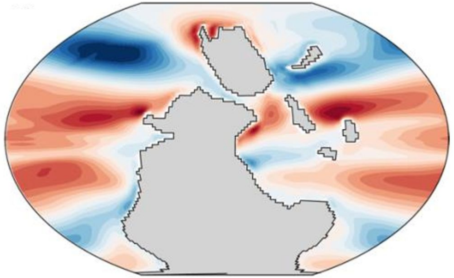
“Out-of-box” default
pre-industrial case



Now you know some cool things we can study with CESM…
but how do we get there?

???

Deep-time
paleoclimate case



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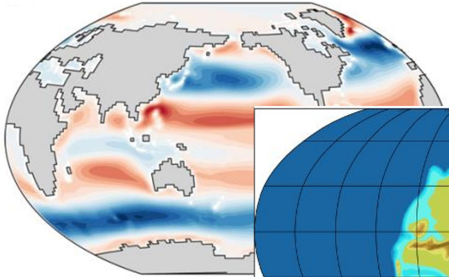
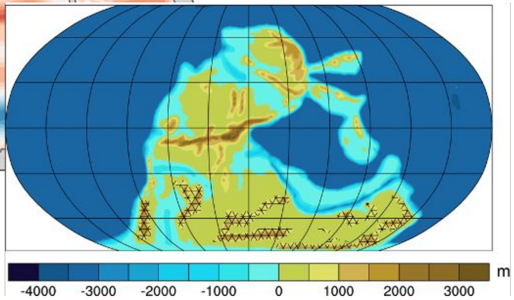


Paleogeography
Topography, sea level, bathymetry



Scotese (2021), *AREPS*

Deep-time
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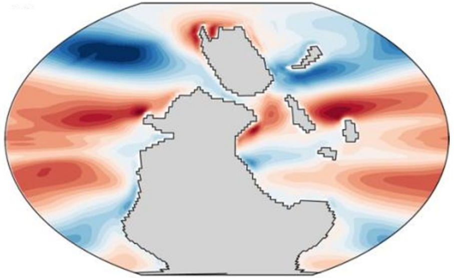

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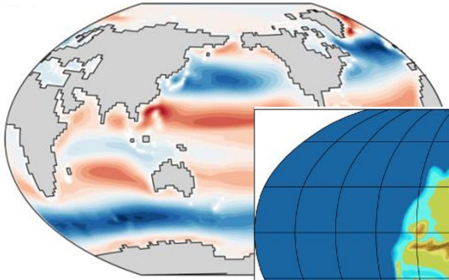

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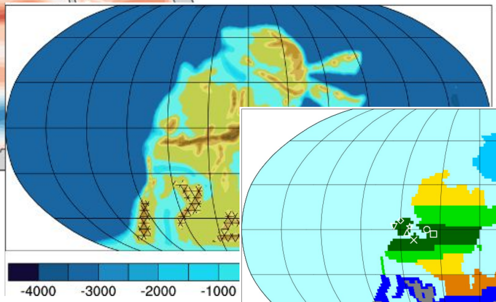
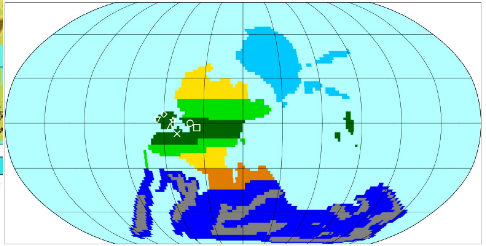


Scotese (2021), *AREPS*

Land surface cover
Vegetation, land ice, rivers



Wilson et al. (2017), *New Phytologist*
Matthaeus et al. (2021), PNAS

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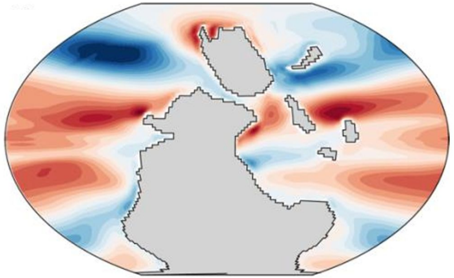

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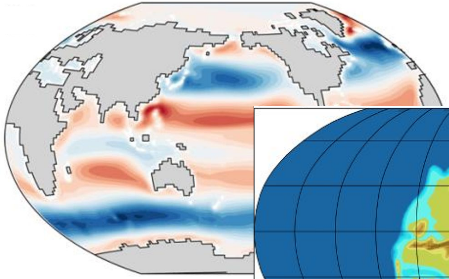

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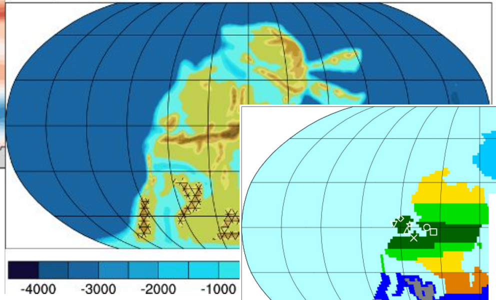

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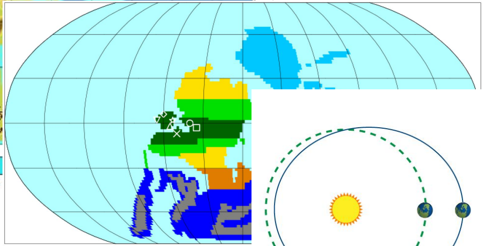
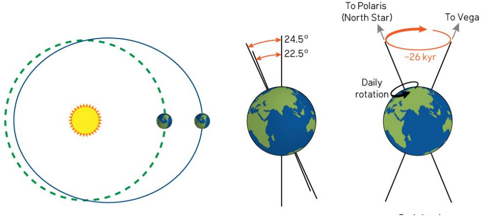


Wilson et al. (2017), *New Phytologist*
Matthaeus et al. (2021), PNAS

External forcing
Orbital configuration, solar luminosity



Gough (1981), *Solar Physics*

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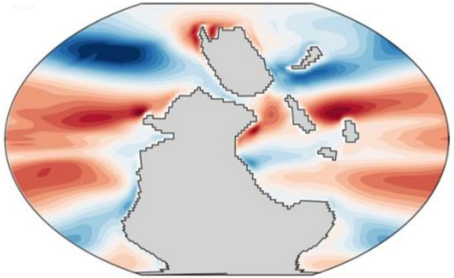

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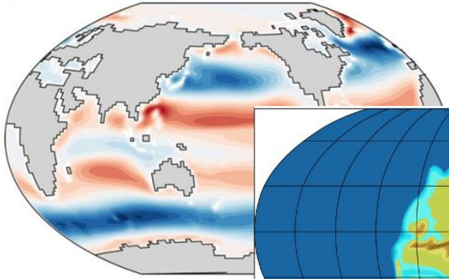

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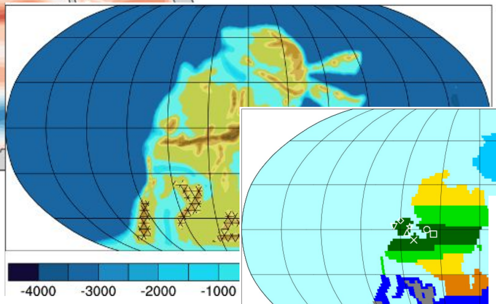

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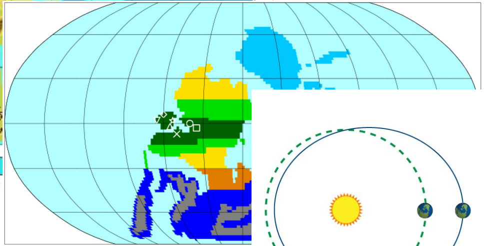

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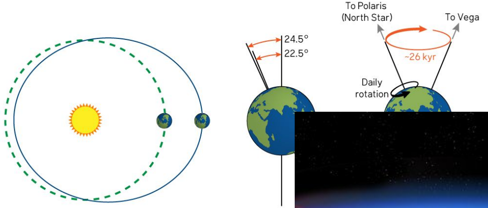

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Atmospheric composition
GHGs, aerosols

Heavens et al. (2012), *JAMES*
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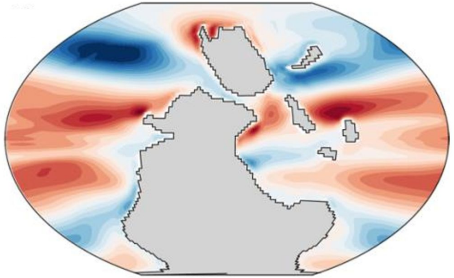

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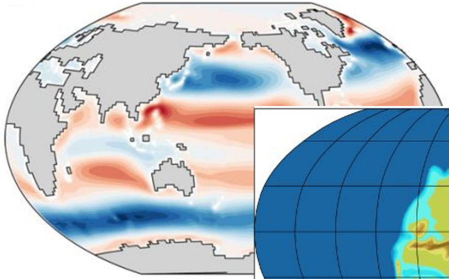

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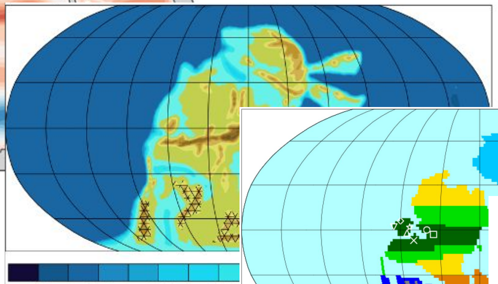

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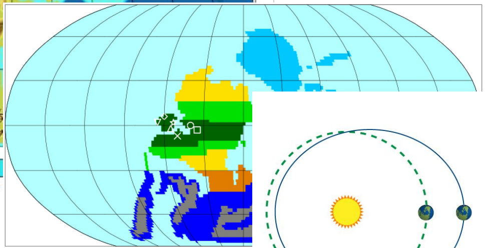

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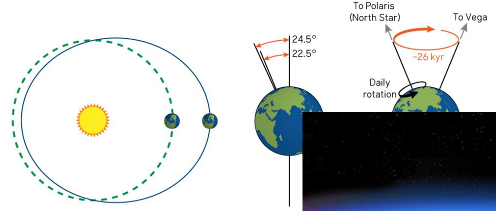

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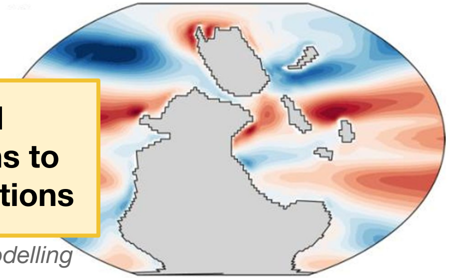
Potential modifications to parameterizations

Deep-time
paleoclimate case



Tseng et al. (2016), *Ocean Modelling*

Resources: Paleoclimate with CESM & Paleoclimate Working Group

- Start from available CESM simulations before creating a new one
- Subscribe to Paleoclimate mailing list: ccsm-paleoclimate@cgd.ucar.edu
- Post & engage with Paleoclimate section of DiscussCESM forum
- Attend Paleoclimate Working Group meetings in winter and summer