



Transient Simulations and other Model Priors

August 22, 2023 – 10-11 AM

Two main ways of investigating past climate



Proxy records



Model simulations

For Paleo DA, we also need: proxy system models and the equations of data assimilation.

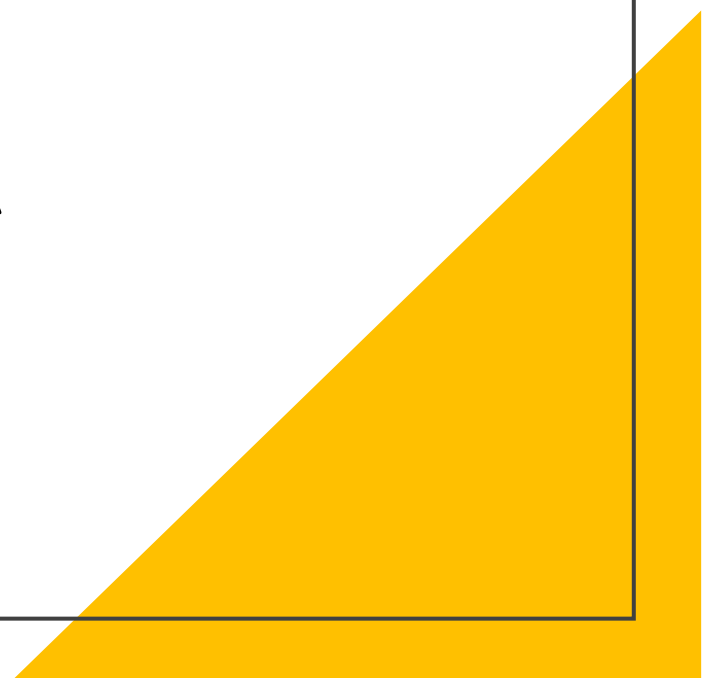
This talk
will cover:

Part I: The Role of Model
Simulations in Paleo DA

Part II: A Quick Introduction to
Climate Models

Part III: What Simulations are
Out There?

Part I: The Role of Model Simulations in Paleo DA



Question: What is the role of a model prior in paleoclimate data assimilation?

What role does a model play in paleo DA?

A model simulation is used to make the “prior,” which is our starting point for offline paleo DA.

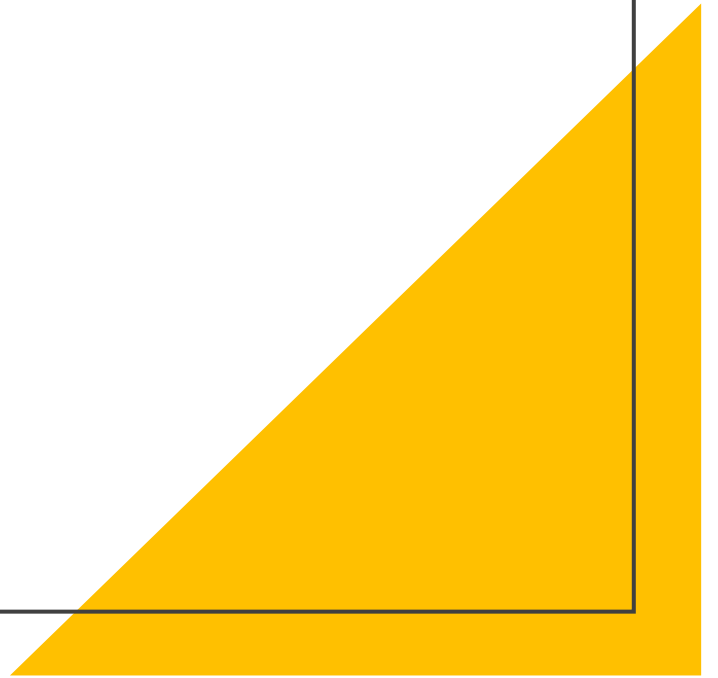
A model prior:

Provides an initial range of climate states

Quantifies the covariance between locations, seasons, and variables

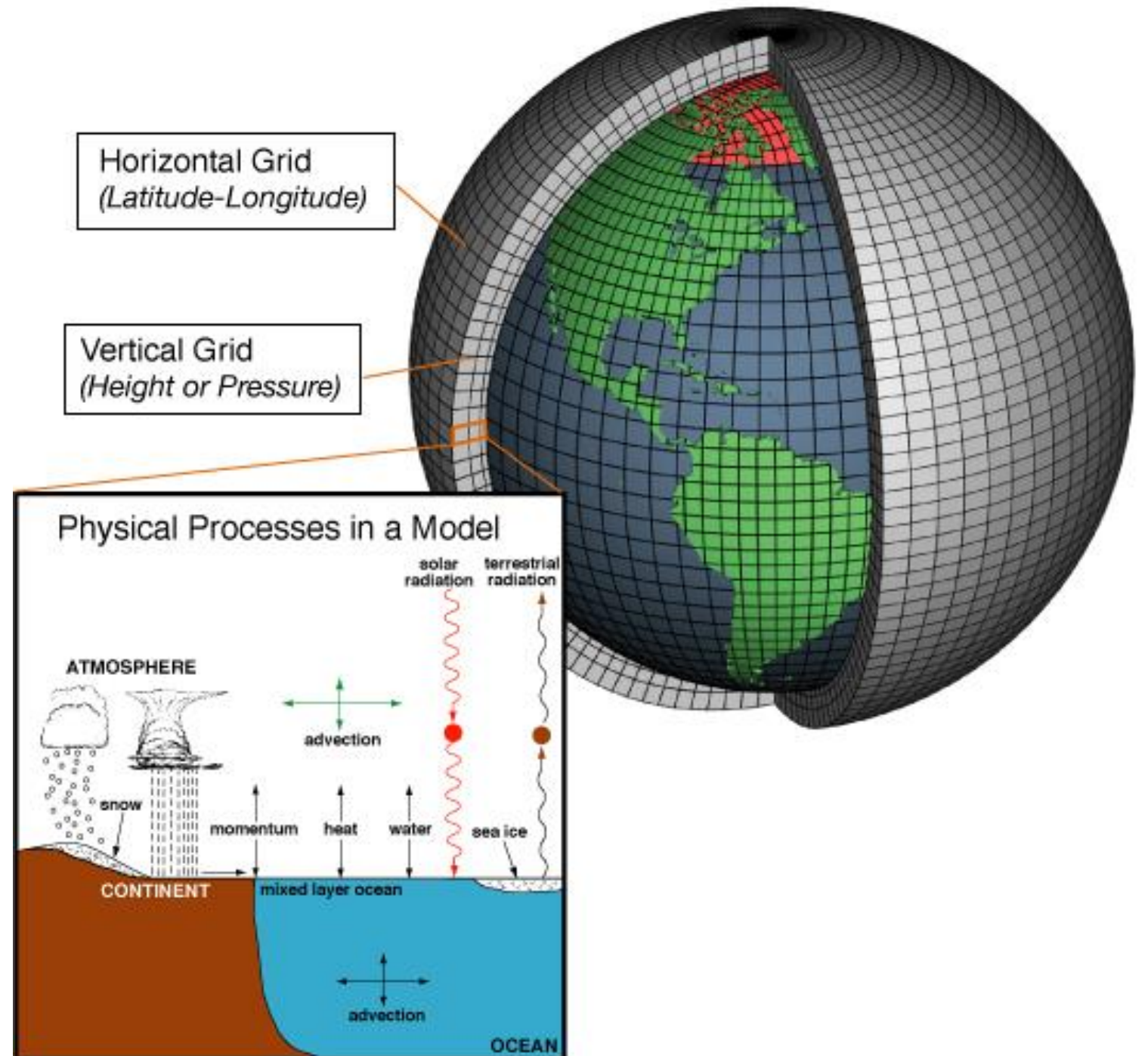
Part II:

A Quick Introduction to Climate Models



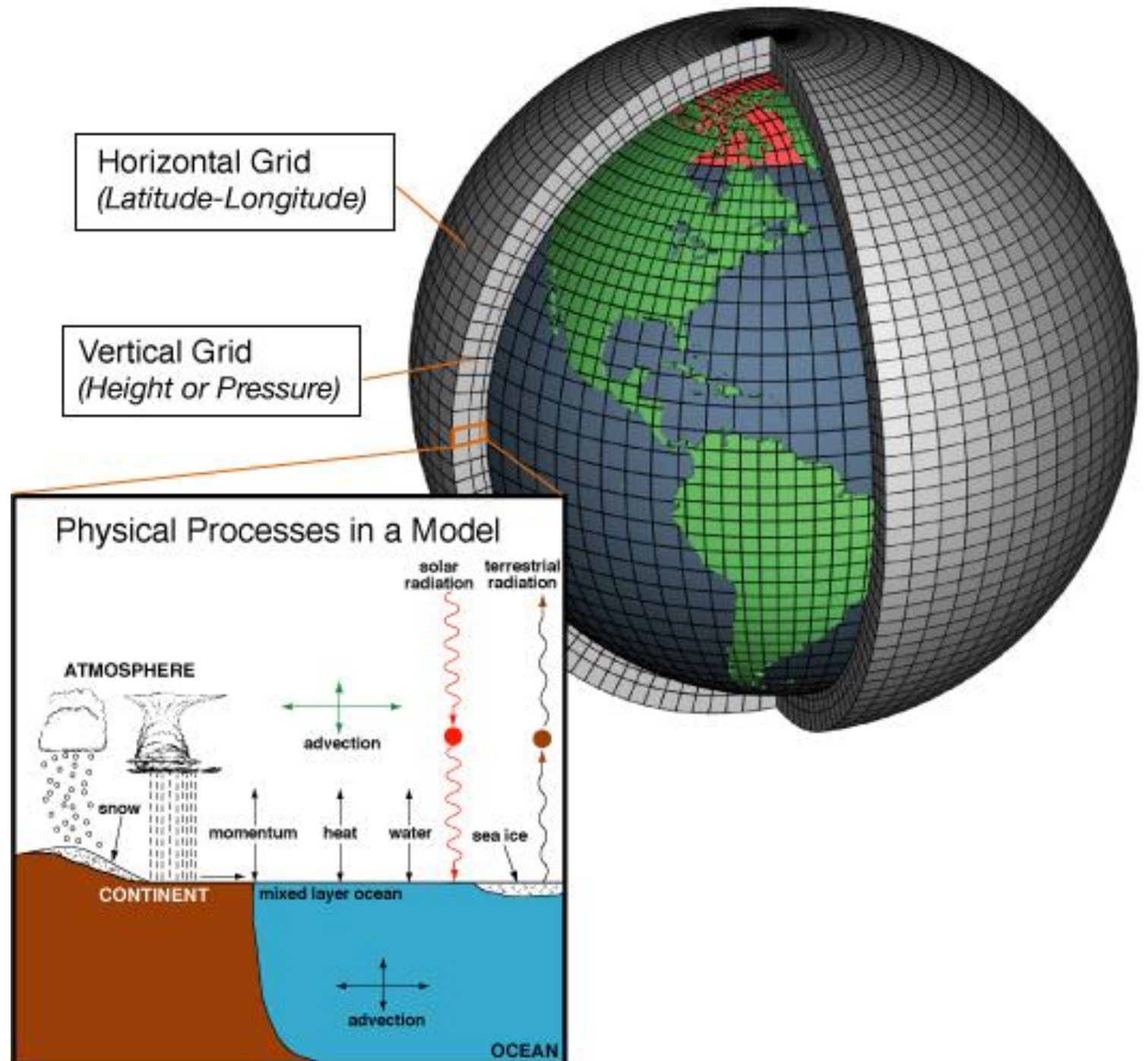
Climate Models

Climate models quantify our mathematical understanding of the climate system.



Uses for climate models

- Simulate the past and present
- Make predictions of the future
- Run idealized experiments
- Do data assimilation!

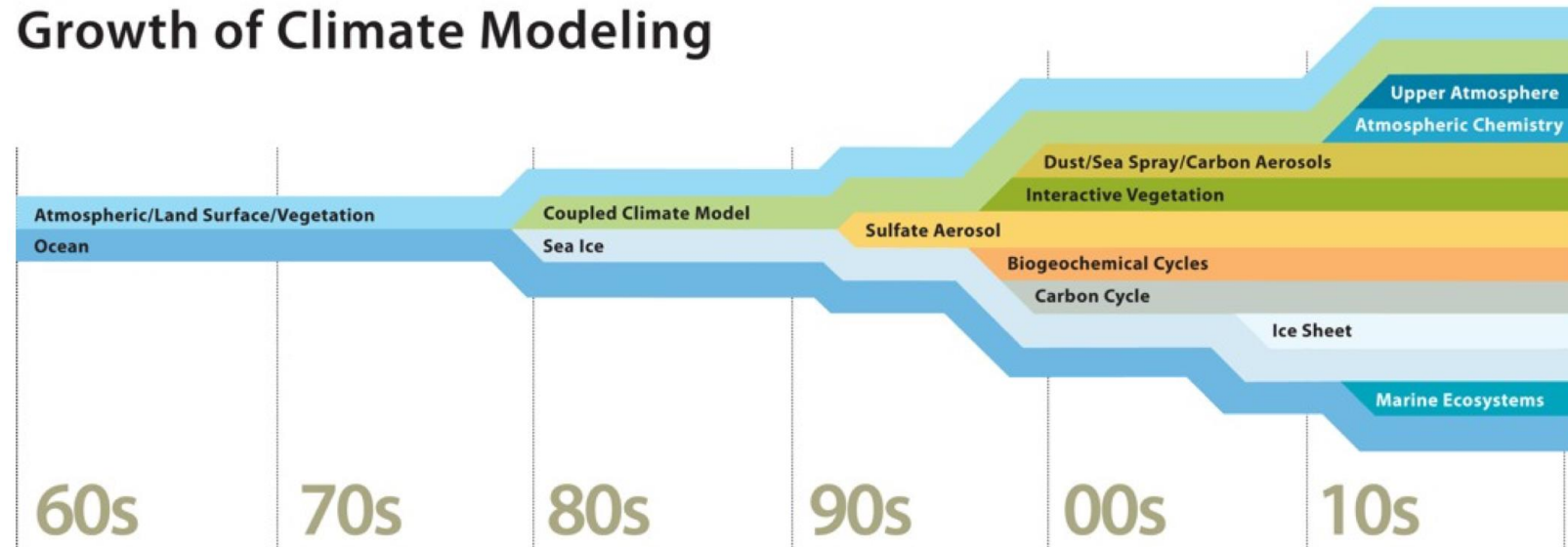


Model components and coupling

Components of a Climate Model

<https://www.ucar.edu/ucar/>

Growth of Climate Modeling



Today's climate models incorporate a **huge amount of processes** and their interactions to reproduce what we experience as climate in increasingly fine detail

EMICs, GCMs, and ESMs

Different models have different levels of complexity:

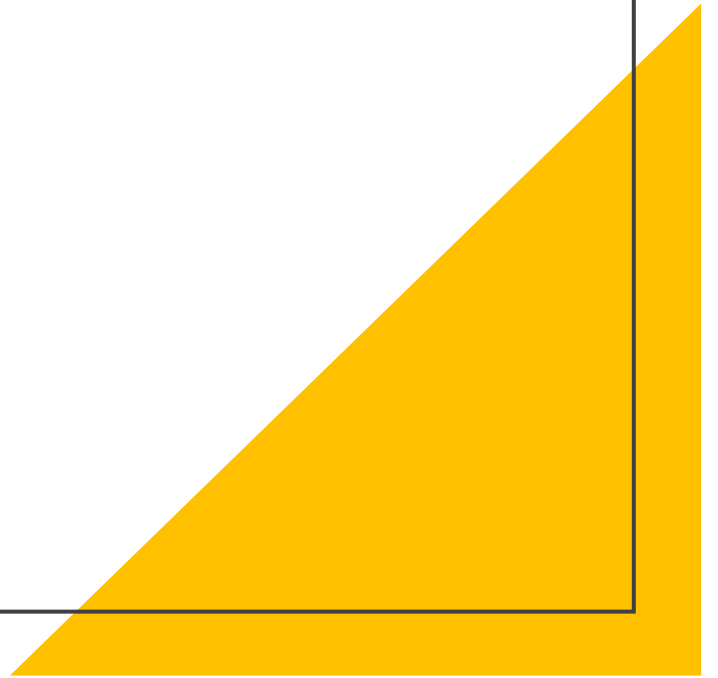
- **Earth system Model of Intermediate Complexity (EMIC)** – A less complex model.
- **General Circulation Model (GCM)** – A typical modern climate model.
- **Earth System Model (ESM)** – Compared to GCMs, ESMs may have more complex chemistry/biology/etc.

Also, different models can have different features: isotopes, dynamic vegetation, etc.

Discussion: Have you used climate simulations in your research? If so, how have you used them?

Part III:

What Simulations are Out There?



Equilibrium vs. transient simulations

Equilibrium simulations:

- Constant forcings
- Run until simulations approach equilibrium

Transient simulations:

- Changing forcings
- Run over the time period of interest

What simulations are out there?



There are *lots* of simulations out there!

When looking for a simulation, think about:

What time period / scenario am I interested in?

Is the chosen model good at simulating what I'm interested in?

Is a simulation available?

Many simulations have been made available (or are available on request).

What simulations are out there?

Some paleo simulations are listed at <https://pmip4.lsce.ipsl.fr/doku.php/wg:ptof:models:>

- **PMIP4/CMIP6 Equilibrium Simulations**

- **piControl** (Preindustrial): *The control run that all the climate changes can be calculated from*
- **abrupt4xCO2** (Instantaneous quadrupling of carbon dioxide): *An idealized global warming experiment (primarily included for calculating the climate sensitivity)*
- **midHolocene** (6,000 yrs ago): *Useful for identifying impacts of orbital forcing*
- **lgm** (The last glacial maximum at 21,000 yrs ago): *The archetypal cold climate state*
- **lig127k** (Last Interglacial, 127,000 yrs ago): *Peak of the warm period prior to last glaciation*
- **Eoi400** (Pliocene, 3,205,000 years ago): *warm conditions before any Northern Hemisphere glaciation (minimal continental drift)*
- **DeepMIP** (Eocene & Paleocene, 50-60 million yrs ago): *Warm climates with carbon dioxide concentrations similar to end of century projections (continents drifted, PMIP-only)*

- **PMIP4/CMIP6 Transient Simulations**

- **1pctCO2** (Carbon dioxide concentrations increase by 1% per year): *An idealized global warming experiment (primarily included for calculating the transient climate response)*
- **historical** (1850CE onwards): *Free-running simulations of industrial era (so climate variability's phase/sign does not match observations, but its statistics should)*
- **past1000** (last millennium, 850CE onwards): *Free-running simulations seeing 1000+ years of climate forcings*
- **LDv1** (last deglaciation, 21,000 years ago to present): *Very-long simulation that encompasses all forcings (PMIP-only)*

- **Other Transient Simulations** *There are several other long palaeoclimate simulations that may be useful*

- ☞ **TraCE** This simulation runs from 22,000 years before present (22ka) to 1990 CE as well as single-forcing sensitivity simulations of varying lengths. Contact ✉ [Bette Otto-Bliesner](#)
- ☞ **iTraCE** This simulation runs from 22,000 years before present (22ka) to around 11ka as well as single-forcing sensitivity simulations of varying lengths. It also includes isotopes. Contact ✉ [Bette Otto-Bliesner](#)
- ☞ **MPI** Simulations with both fast and slow forcings from 8000ka-present. Contact ✉ [Johann Jungclauss](#).
- ☞ **Kiel** Simulations of both the Holocene and the Eemian exist for the Kiel model. Contact ✉ [Vyacheslav Khon](#).
- ☞ **AWI** Slowly a simulation from the Last Glacial to present is being created. Contact ✉ [Gerrit Lohmann](#)
- ☞ **IPSL** Several simulations from 6000ka to present have recently been performed in France. Contact ✉ [Pascale Braconnot](#) and Olivier Marti.
- ☞ **FAMOUS** An old simulation of the last glacial cycle with accelerated-forcing. Contact ✉ [Robin Smith](#)
- ☞ **EC-Earth3** Simulation from about 8ka, I think. Contact ✉ [Qiong Zhang](#)
- ☞ **CESM1.2.1** Simulation from 11.7 onwards. Contact Zhiping Tian and ✉ [Dabang Jiang](#)
- ☞ **HadCM3** A set of transient sensitivity simulations since the deglacial. There are also series of equilibrium simulations of HadCM3 run over the last glacial cycle. A version of these does exist with water isotopes. Contact ✉ [Paul Valdes](#)
- ☞ **GISS** There are a series of equilibrium simulations of GISS-E2-1-G run during the Holocene, potentially with water isotopes. Contact ✉ [Allegra LeGrande](#)

The Coupled Model Intercomparison Project (CMIP):

- The same experiments run on a collection of different models.
- Useful for exploring a range of simulations for particular time periods.
- Useful for a wide variety of paleoclimate research

Other simulations:

- Lots of simulations have been run outside of the PMIP/CMIP framework.
- Here are some long transient simulations
- Read papers to find others (look for the data availability section)

• PMIP4/CMIP6 Equilibrium Simulations

- **piControl** (Preindustrial): *The control run that all the climate changes can be calculated relative to*
- **abrupt4xCO2** (Instantaneous quadrupling of carbon dioxide): *An idealized global warming experiment*
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• PMIP4/CMIP6 Transient Simulations

- **1pctCO2** (Carbon dioxide concentrations increase by 1% per year): *An idealized global warming experiment*
- **historical** (1850CE onwards): *Free-running simulations of industrial era (so climate change is due to natural and anthropogenic forcings)*
- **past1000** (last millennium, 850CE onwards): *Free-running simulations seeing 1000 years of natural climate variability*
- **LDv1** (last deglaciation, 21,000 years ago to present): *Very-long simulation that ends in the present*

• Other Transient Simulations There are several other long palaeoclimate simulations

- 🌐 **TraCE** This simulation runs from 22,000 years before present (22ka) to 1990 CE
- 🌐 **iTraCE** This simulation runs from 22,000 years before present (22ka) to around 2100 CE
- 🌐 **MPI** Simulations with both fast and slow forcings from 8000ka-present. Contact [Maurice](#)
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Terminology: CMIP vs. PMIP

Simulations of the present and future



- **CMIP**: Coupled Model Intercomparison Project (currently CMIP6)
- **PMIP**: Paleoclimate Modelling Intercomparison Project (currently PMIP4)

Simulations of the past



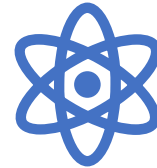
What sort of simulations make a good prior?



Cover the time period of
interest



Long enough



Contain the needed
variables (e.g., $\delta^{18}\text{O}$ if you
want to use isotopes)



And more!

Simulations
used in data
assimilation
priors

LMR

CCSM4 last millennium simulation

PHYDA

CESM Last Millennium Ensemble
(LME)

LGMR

A collection of iCESM simulations
(0, 3, 6, 9, 12, 14, 16, 18, and 21 ka)

Holocene
Reconstruction

HadCM3 and TraCE-21ka transient
simulations

Let's look at:

CMIP simulations

A thick, hand-drawn orange line that spans the width of the text "CMIP simulations" below it.

The Coupled Model Intercomparison Project (CMIP)

CMIP is an effort to conduct the same simulations with a large variety of climate models, to see how robust the results are.

Most recent release:
CMIP6/PMIP4.

Individual models have biases.
Using the multi-model mean is often an improvement.

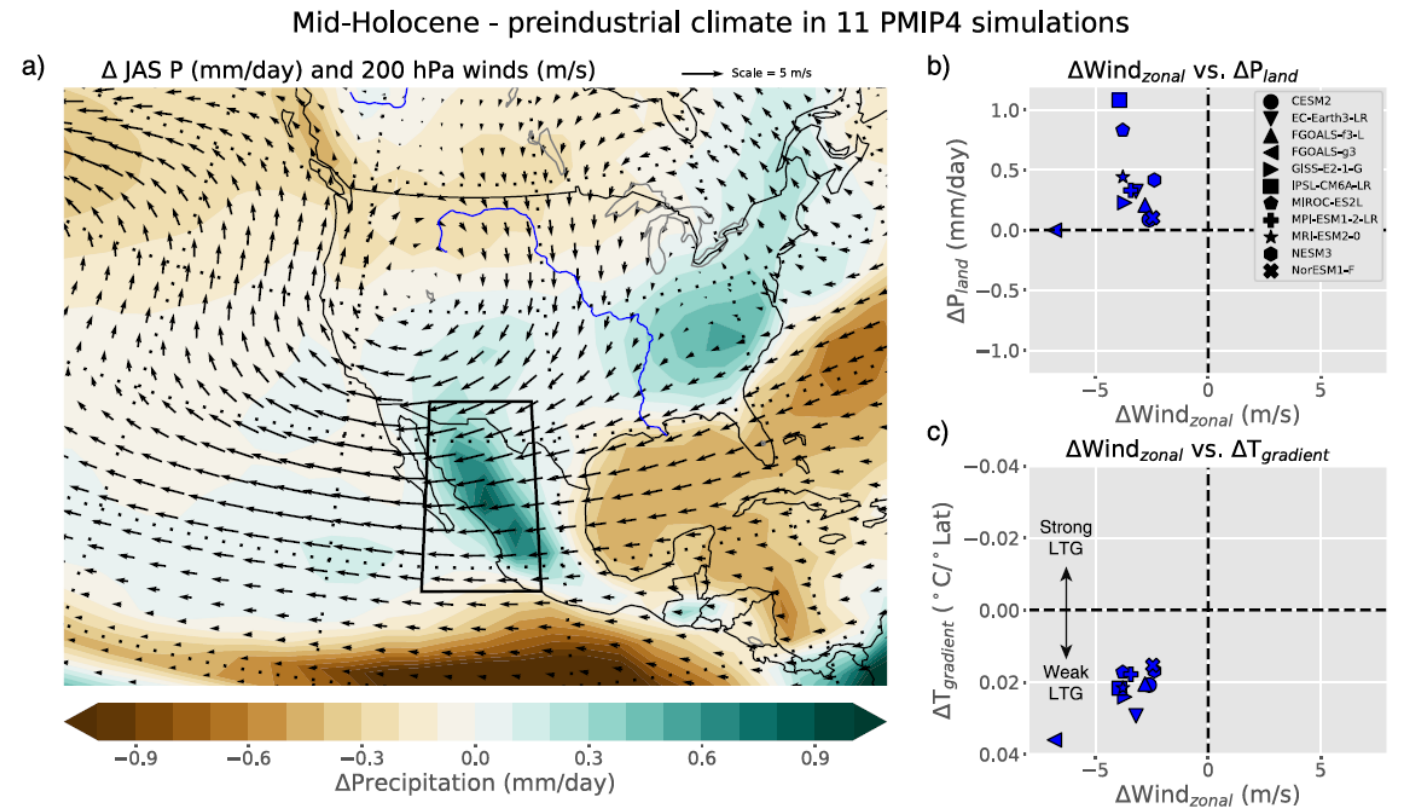


Figure 3. Change (Δ) in Mid-Holocene (6 ka) Paleoclimate Modelling Intercomparison Project phase 4 (PMIP4) modeled July-September (JAS) precipitation (P) and winds relative to preindustrial. (a) Eleven-model mean JAS precipitation (colors) and wind anomalies (vectors). Increased JAS monsoon region precipitation and easterly wind anomalies (weaker westerlies) occurred during the mid-Holocene. (b) Relationship between land JAS monsoon region precipitation change (y-axis) and JAS monsoon region zonal wind change (x-axis) during the mid-Holocene relative to preindustrial conditions. Nearly all 11 PMIP4 models show stronger mid-Holocene precipitation coincided with reduced zonal winds. (c) Relationship between the latitudinal temperature gradient (y-axis) and zonal winds (x-axis). In all models a weaker Latitudinal Temperature Gradient corresponds with weaker zonal winds.

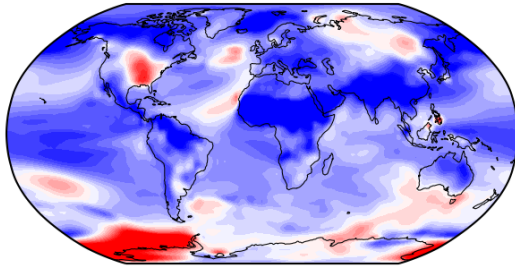
An example of PMIP model analysis: changes in the North American monsoon in 11 PMIP4 models (Routson et al., 2022).

How much similarity is there in CMIP6 simulations?

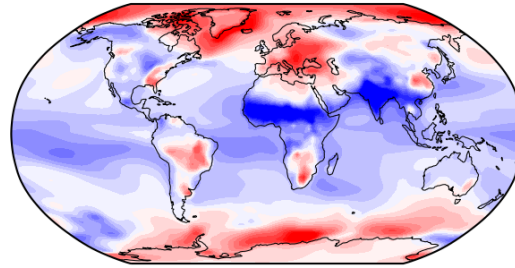
Let's look at mid-Holocene anomalies in 13 CMIP6 models.

Change in annual-mean surface air temp (° C) for MH-PI in CMIP6 models

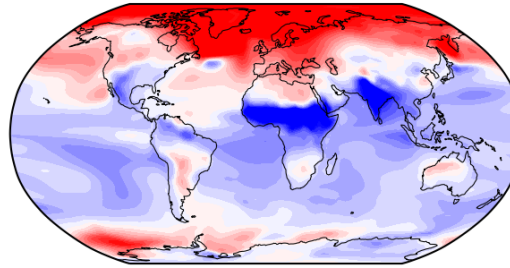
AWI-ESM-1-1-LR



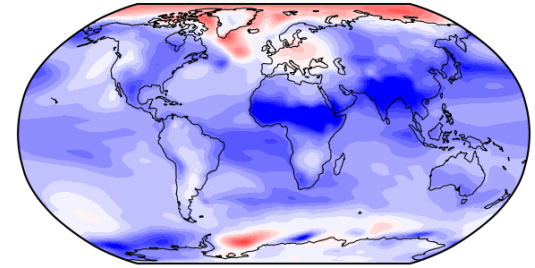
CESM2



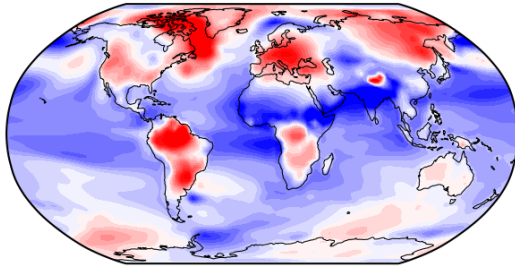
EC-Earth3-LR



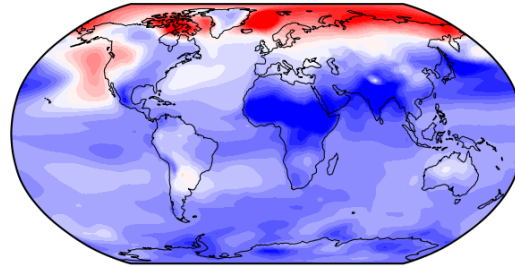
FGOALS-f3-L



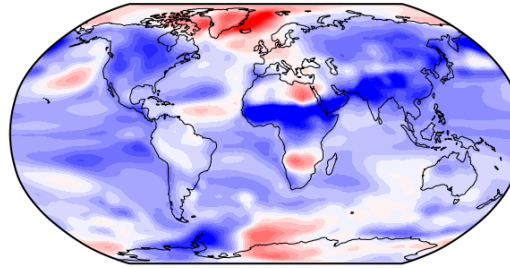
FGOALS-g3



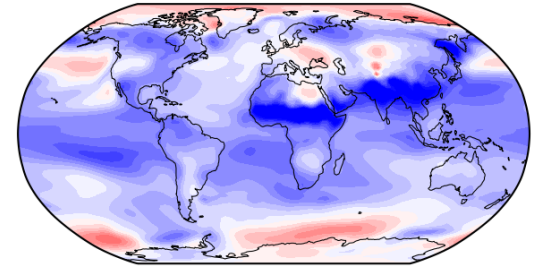
GISS-E2-1-G



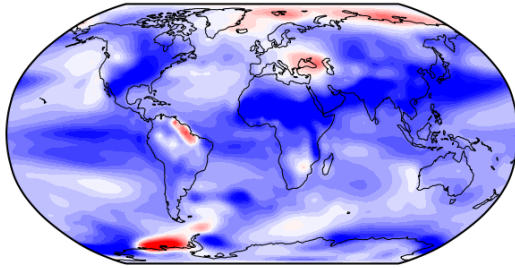
INM-CM4-8



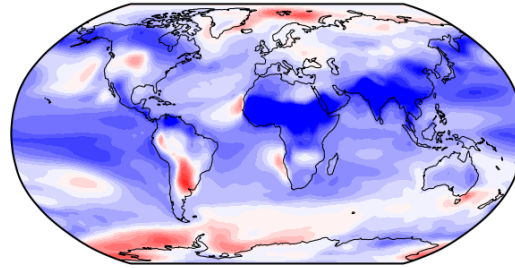
IPSL-CM6A-LR



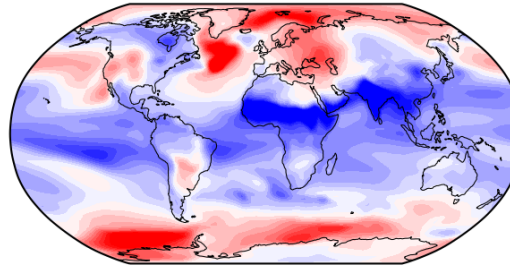
MIROC-ES2L



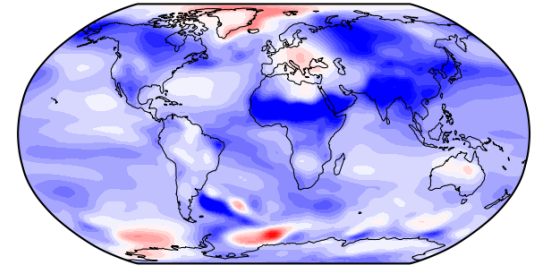
MPI-ESM1-2-LR



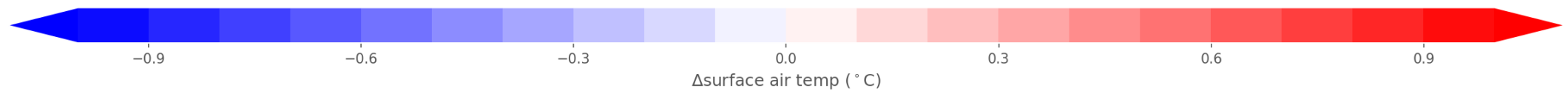
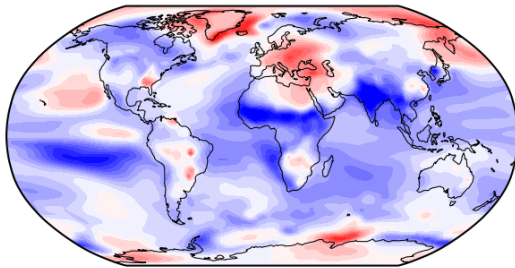
MRI-ESM2-0



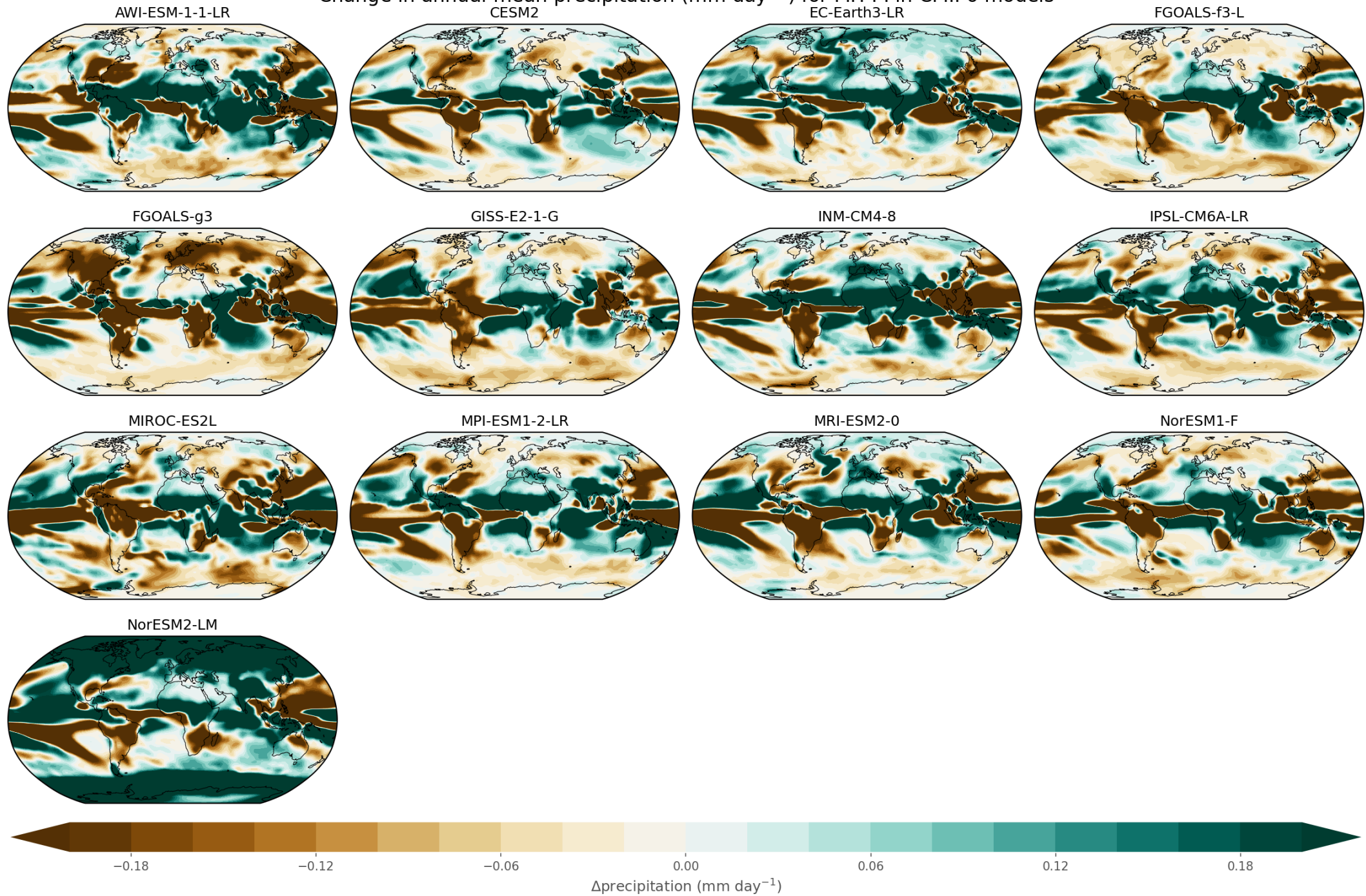
NorESM1-F



NorESM2-LM



Change in annual-mean precipitation (mm day⁻¹) for MH-PI in CMIP6 models



Downloading CMIP simulations

You can easily *create an account* and download CMIP model results.

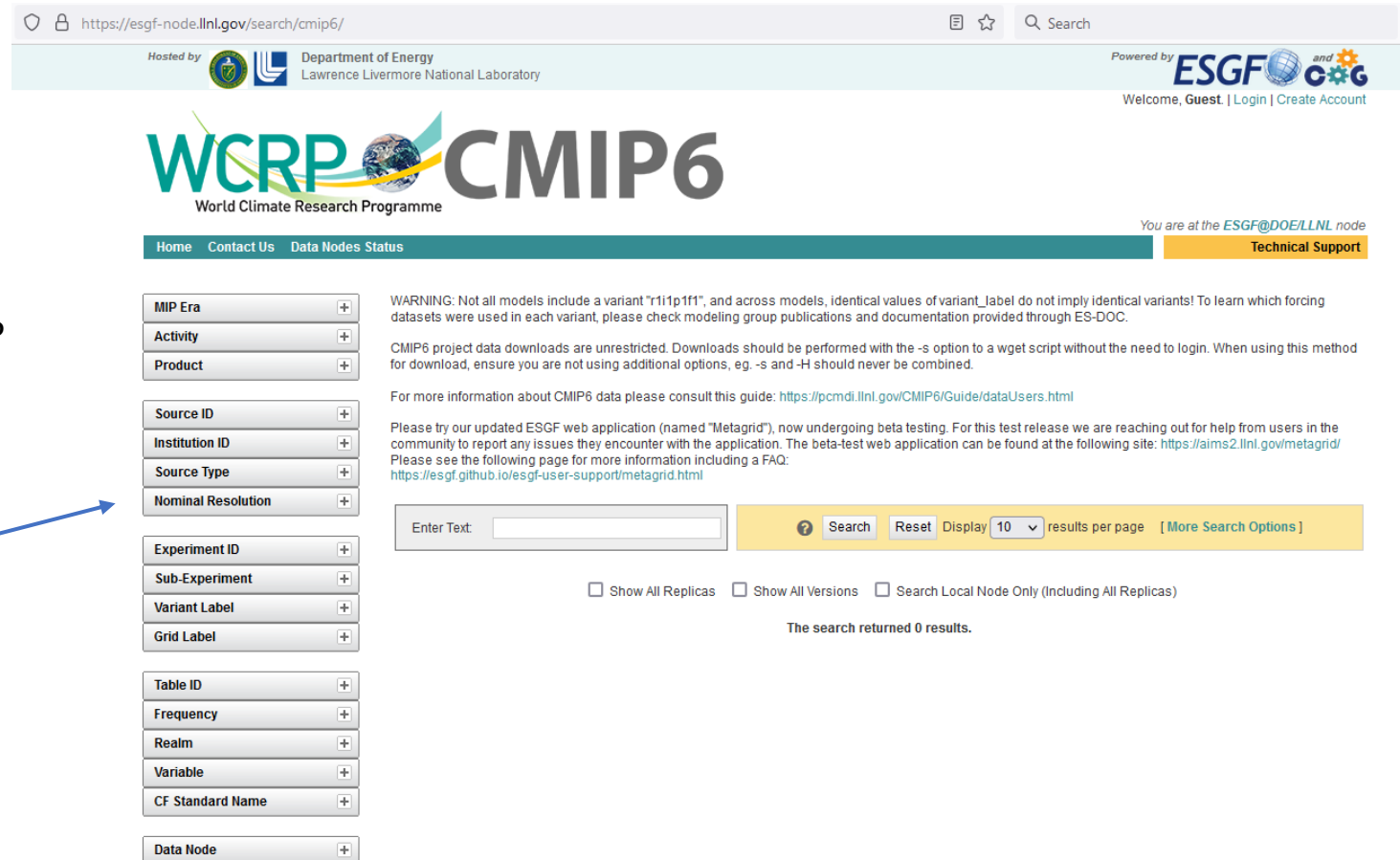
A guide for getting started:
<https://pcmdi.llnl.gov/CMIP6/Guide/dataUsers.html>

One of the ESGF data portals: <https://esgf-node.llnl.gov/search/cmip6/>

I usually start by filtering by:

- Experiment ID
- Realm
- Variable

Models are useful for lots of types of paleoclimate research.



The screenshot shows the ESGF CMIP6 search interface. At the top, the URL is <https://esgf-node.llnl.gov/search/cmip6/>. The page is hosted by the Department of Energy, Lawrence Livermore National Laboratory, and is powered by ESGF and Google. The main header features the WCRP CMIP6 logo and a navigation bar with links to Home, Contact Us, Data Nodes, and Status. A sidebar on the left contains a list of filterable fields: MIP Era, Activity, Product, Source ID, Institution ID, Source Type, Nominal Resolution, Experiment ID, Sub-Experiment, Variant Label, Grid Label, Table ID, Frequency, Realm, Variable, CF Standard Name, and Data Node. The main content area displays a warning about dataset variants, information about data downloads, and a link to a guide. Below this is a search bar with a text input field, a search button, a reset button, and a display options dropdown set to 10 results per page. There are also checkboxes for 'Show All Replicas', 'Show All Versions', and 'Search Local Node Only (Including All Replicas)'. The search results section indicates 'The search returned 0 results.'

Let's look at:

Transient simulations



Transient simulations

Transient simulations are useful for studying climate changes through time.

CMIP includes last millennium transient simulations, but there are more (and longer!) simulations outside of CMIP.

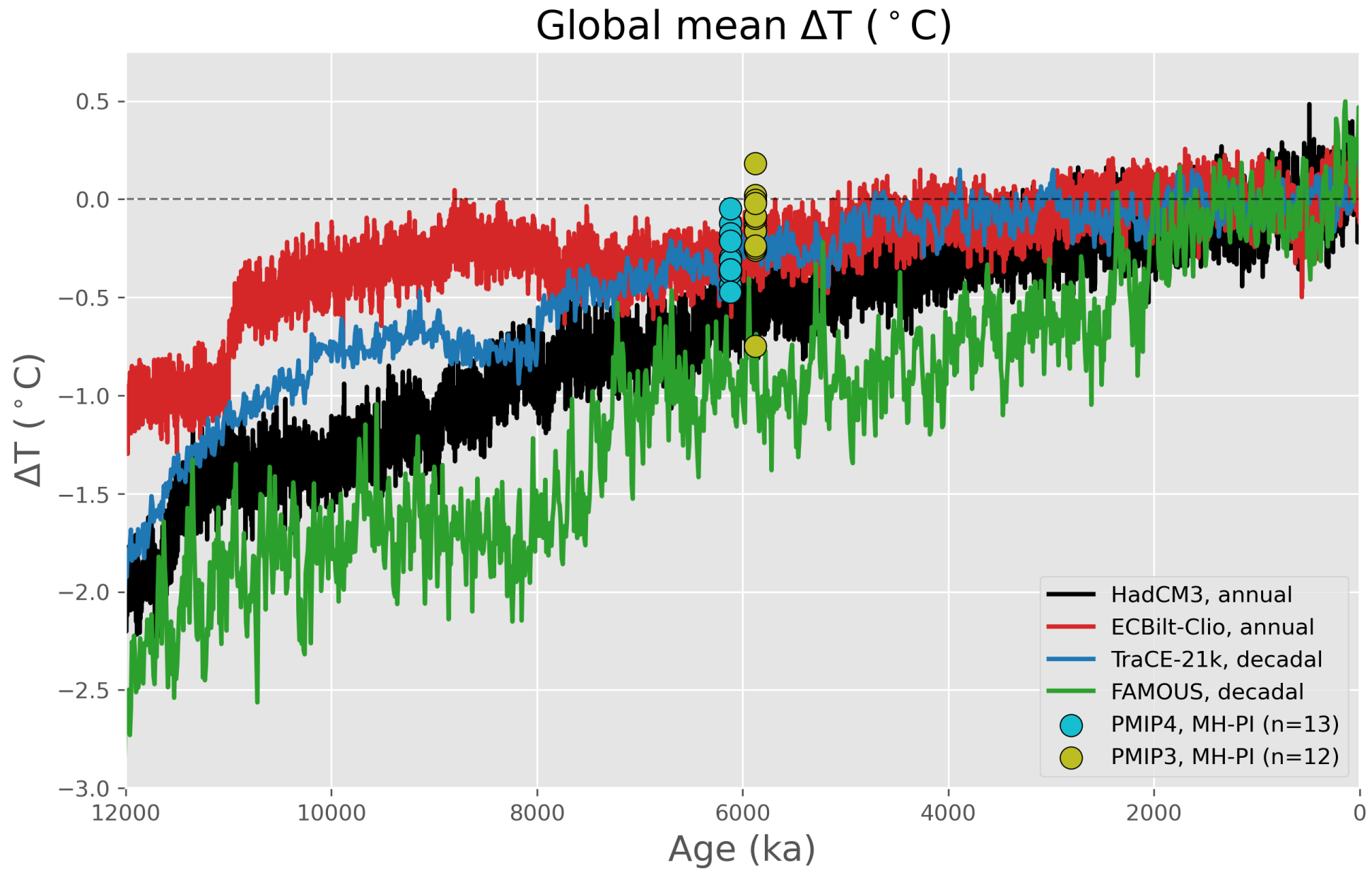
Long transient simulations are rare, since they take a lot of resources to complete, but some are available.

Transient simulations

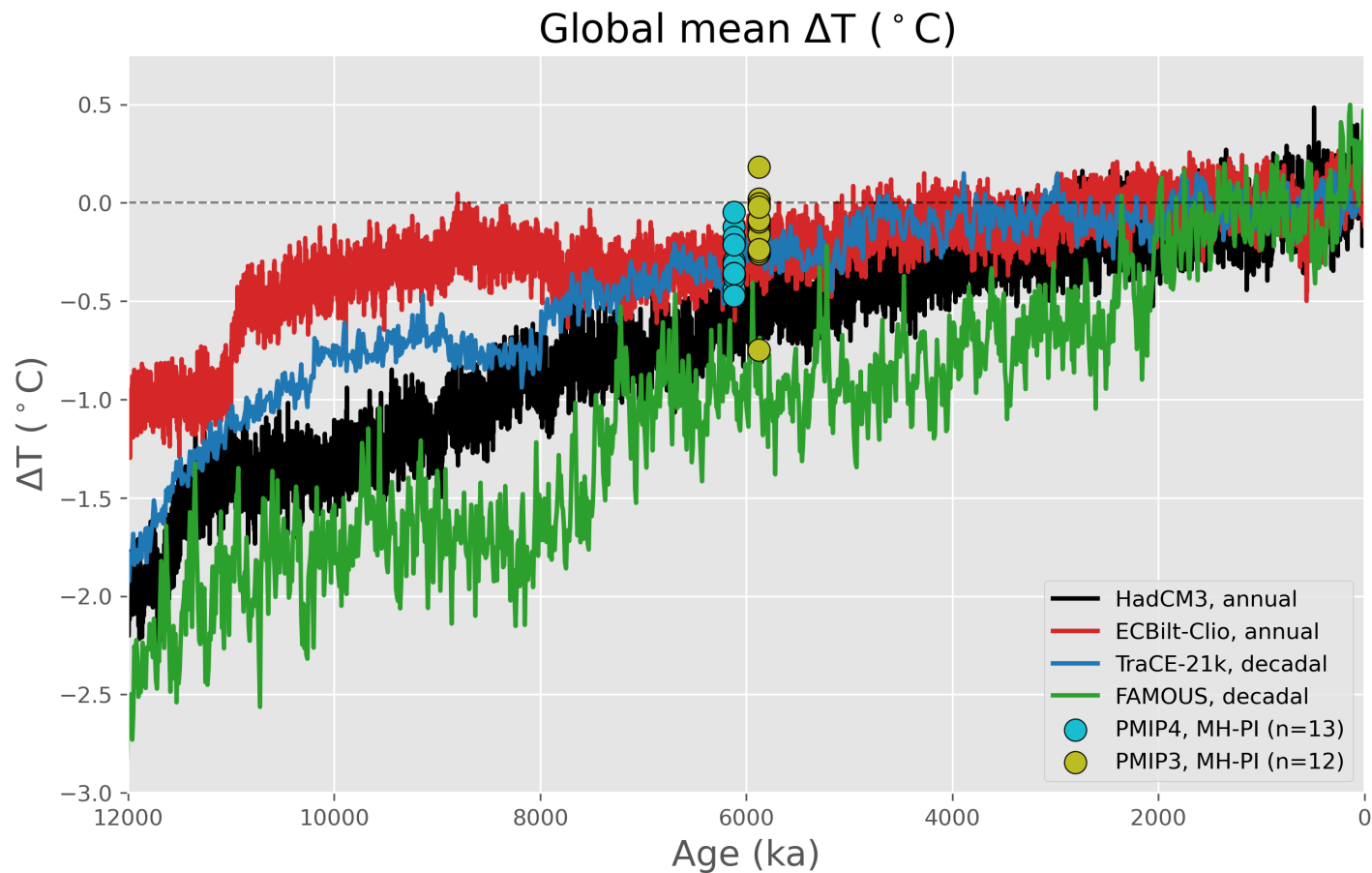
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And for the period 850-2005, the CESM Last Millennium Ensemble (LME) is one place to start:
<https://www.earthsystemgrid.org/dataset/ucar.cgd.cesm4.cesmLME.html>.

Let's compare few transient simulations with CMIP.



Question: What observations can you make?



To some extent, climate models disagree with each other and with proxy records.

Past climate can be explored using models, proxy records, or both.

Data assimilation is a way of synthesizing information from proxy records and models.

You can use models in your research!

Lots of model data is freely available:

- If you'd like to explore PMIP/CMIP output (LGM, mid-Holocene, etc.), you can make an account at ESGF.
- Other simulations can be found online (CESM LME, TraCE, iTRACE, etc.)
- You can try to request simulations from the people who ran them.
- When in doubt, look for the “Data Availability” section at the end of papers.

Simulations can be **analyzed directly, compared to proxy data**, or used for **data assimilation**.

Thoughts/questions?