Challenges in modelling the Last Glacial Cycle:

Implications for marginal seas

Eduardo Zorita Institute of Coastal Research, Helmholtz-Zentrum Geesthacht, Germany

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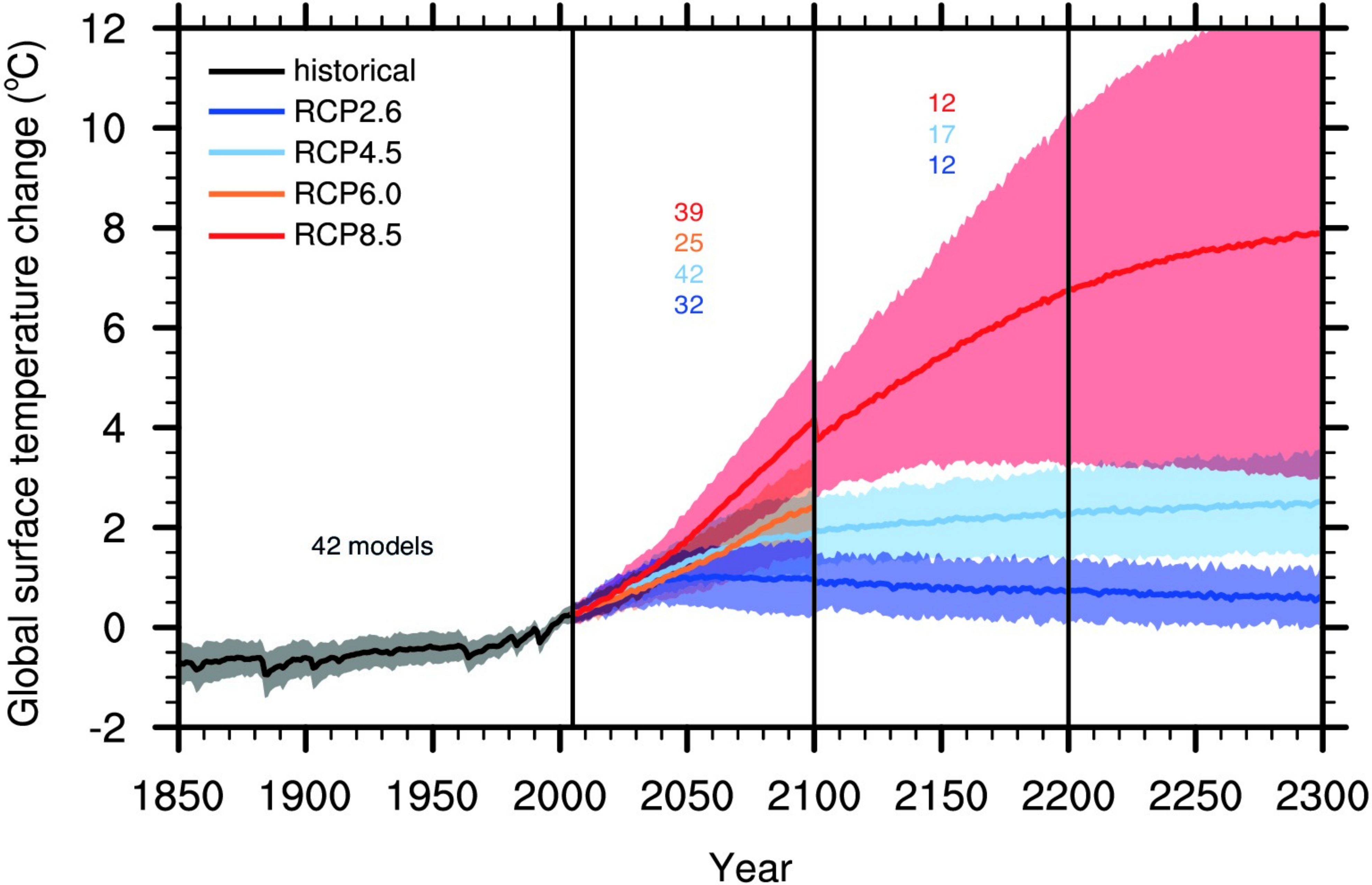
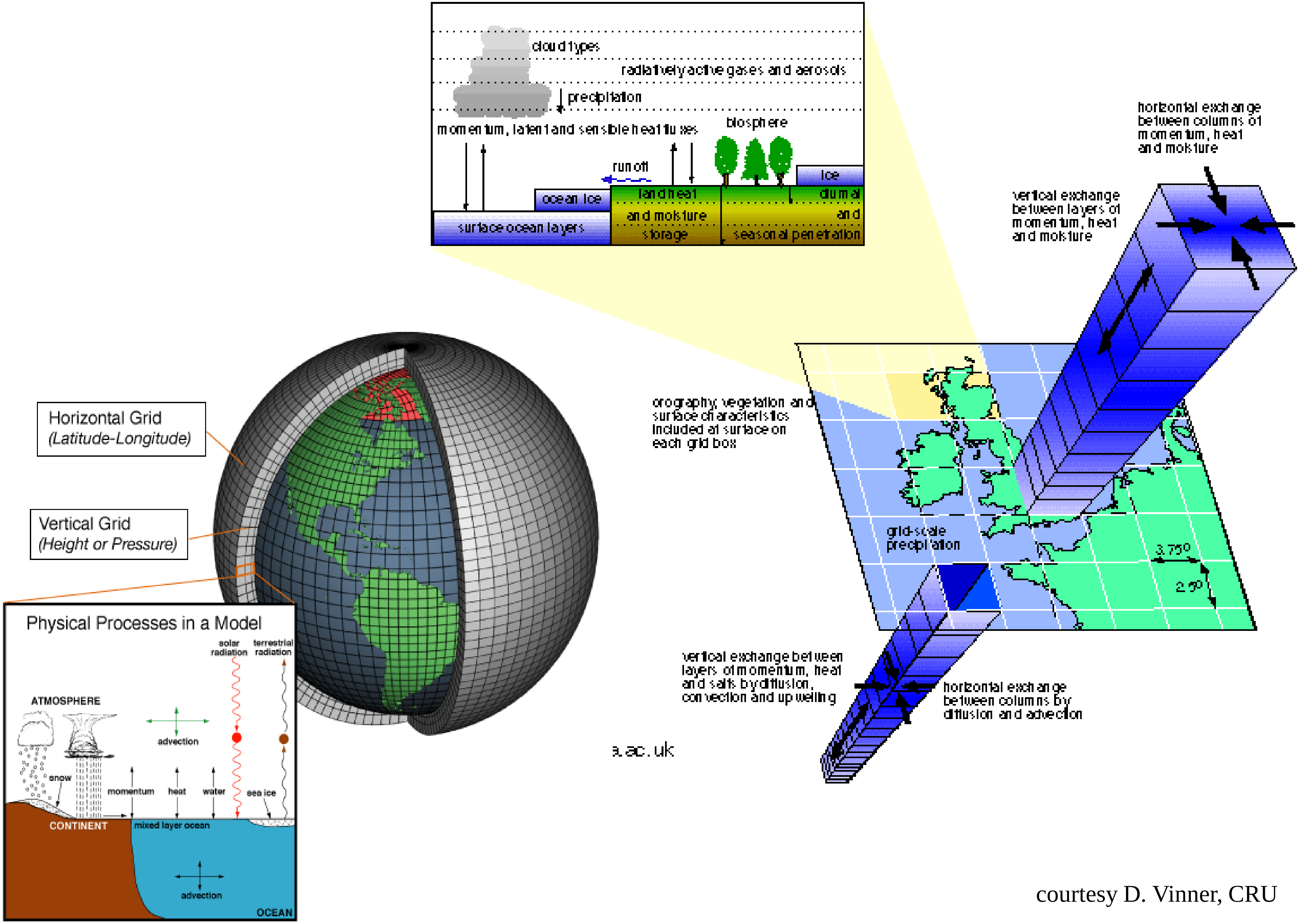
Helmholtz-Zentrum Geesthacht
Centre for Materials and Coastal Research

1) Climate simulations may disagree quite strongly.
Use output of several models when possible !



Structure of a General Circulation Model

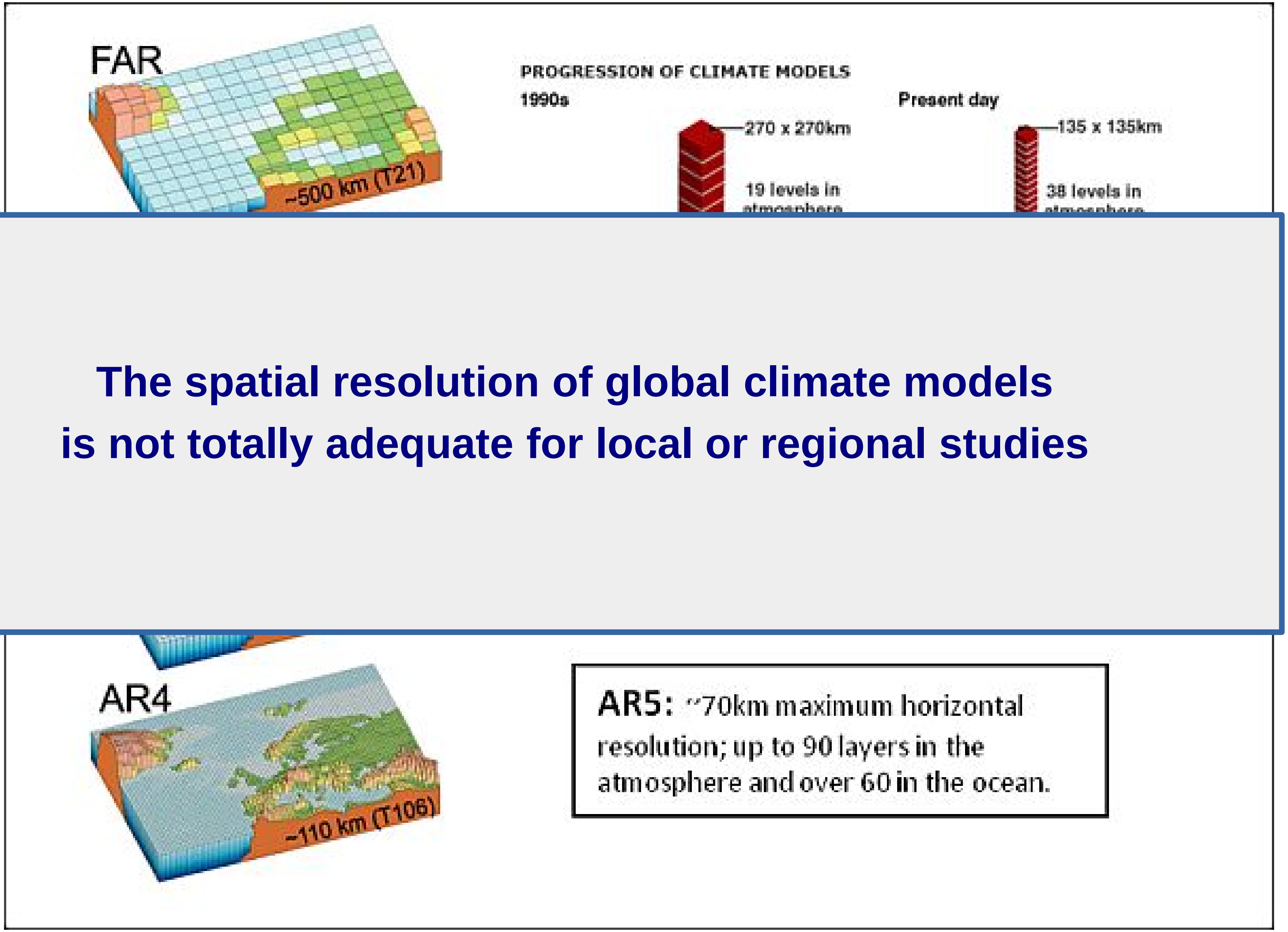


courtesy D. Vinner, CRU

Improvement in spatial resolution of global climate models

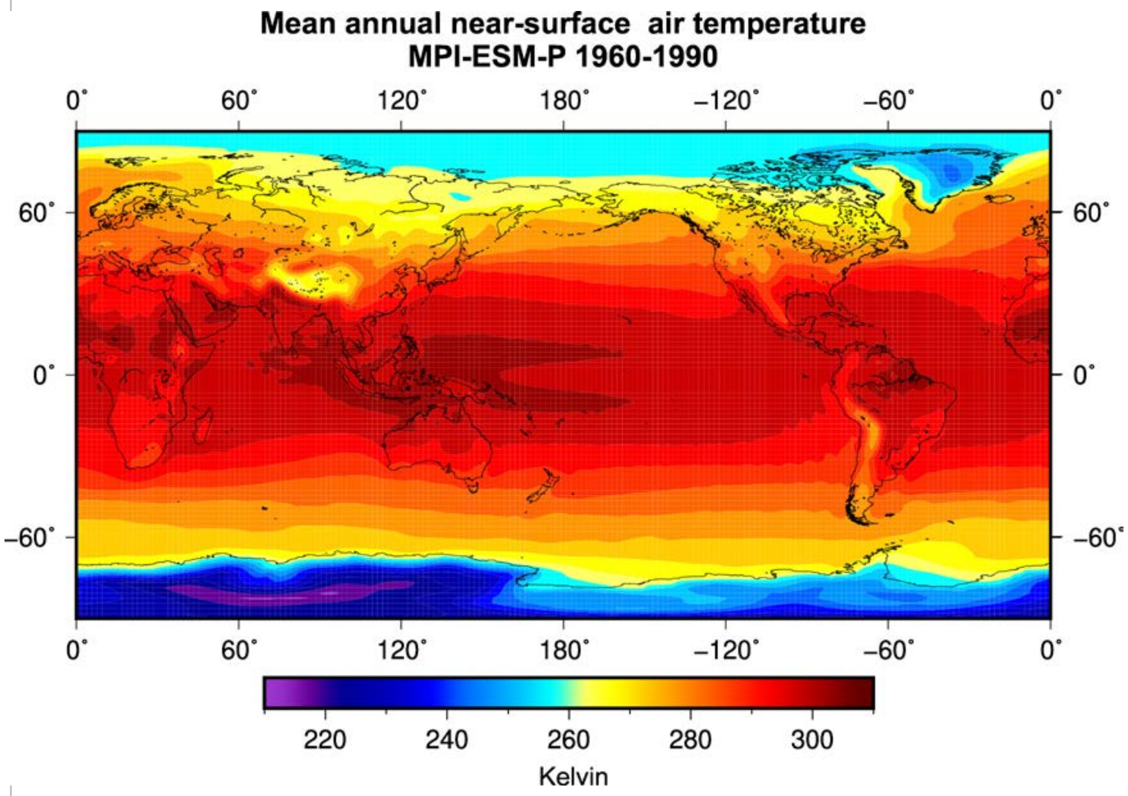
First Assessment Report ~1990

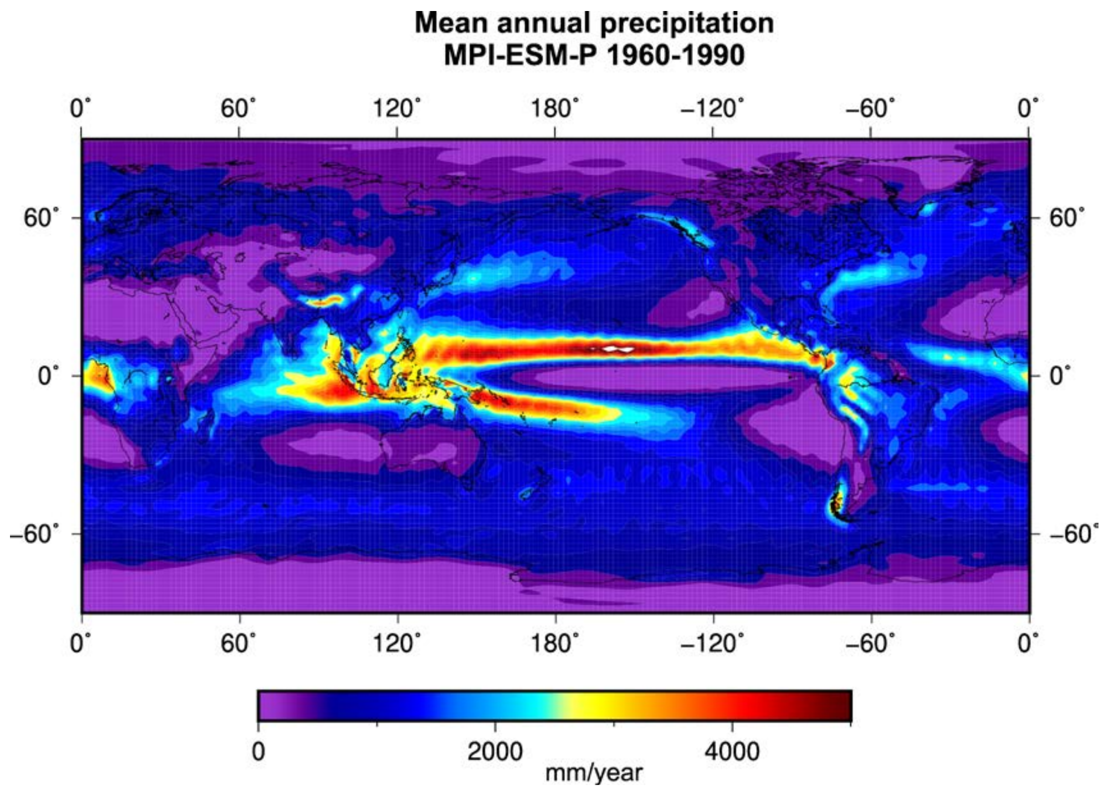
Fourth Assessment Report ~2007



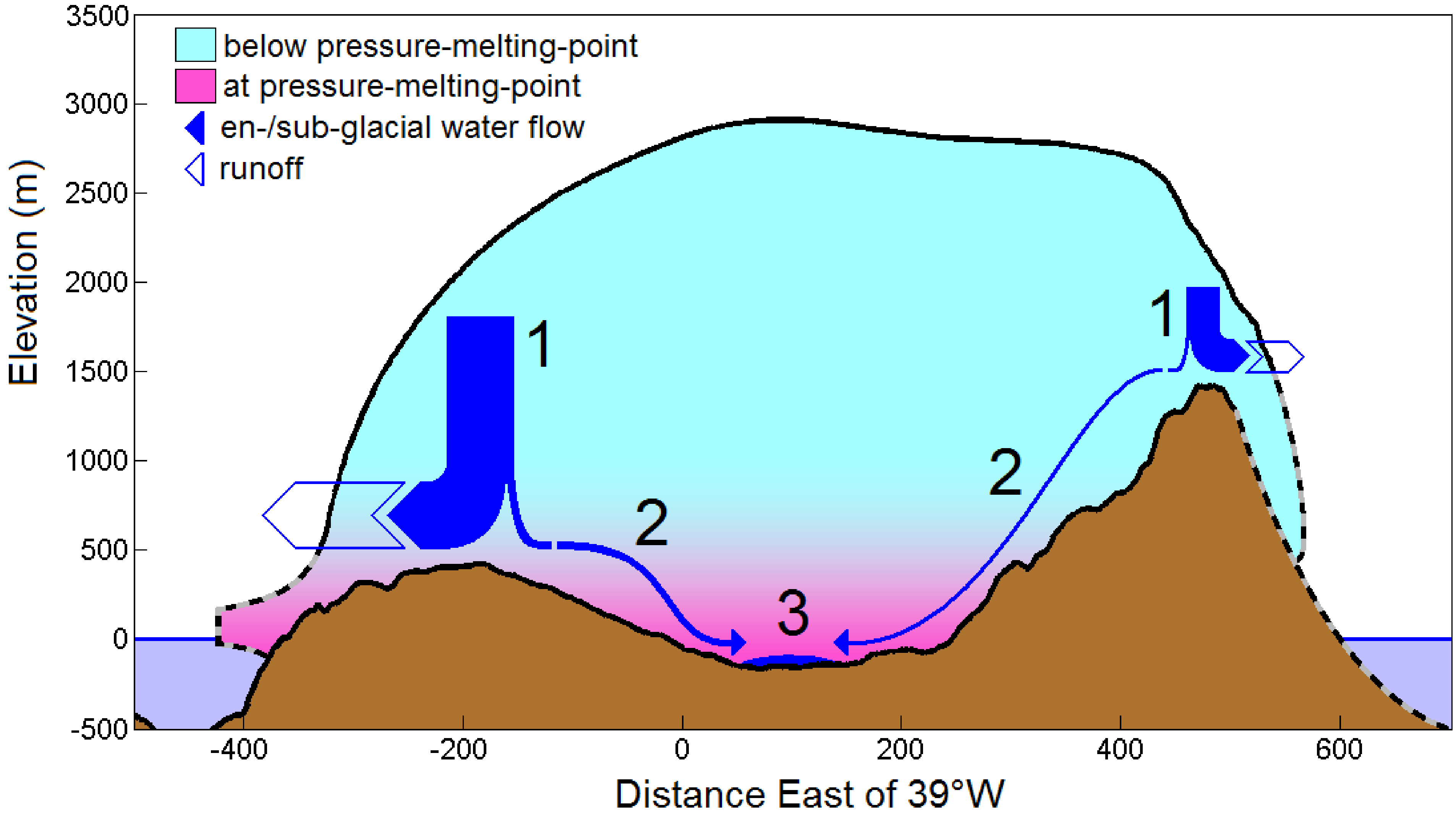
The spatial resolution of global climate models is not totally adequate for local or regional studies

Quite realistic simulations, but...

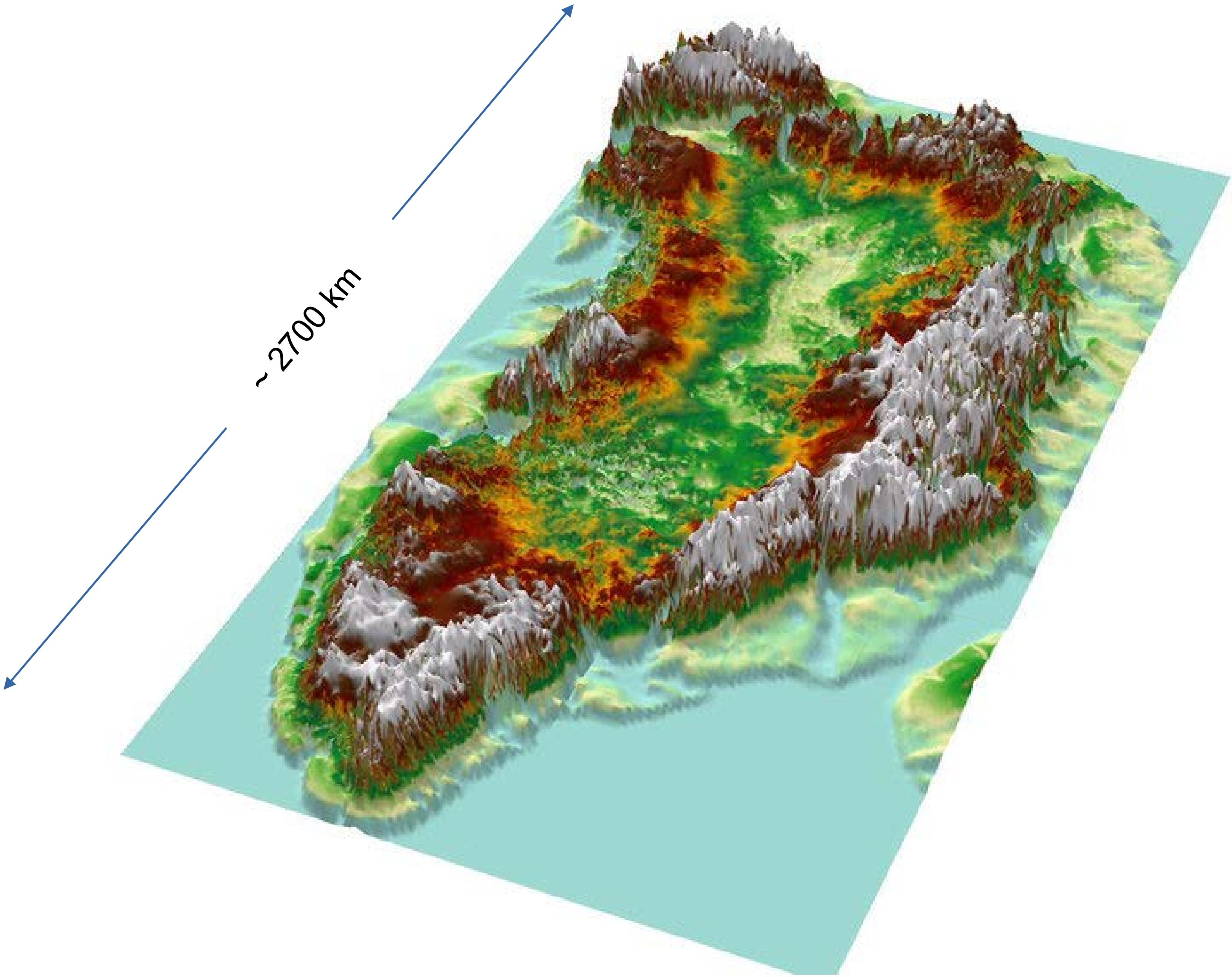




The weak (missing) link of present climate models: land ice dynamics



Greenland topography beneath the ice sheet



Take home message for user of climate model data:

Present global climate models

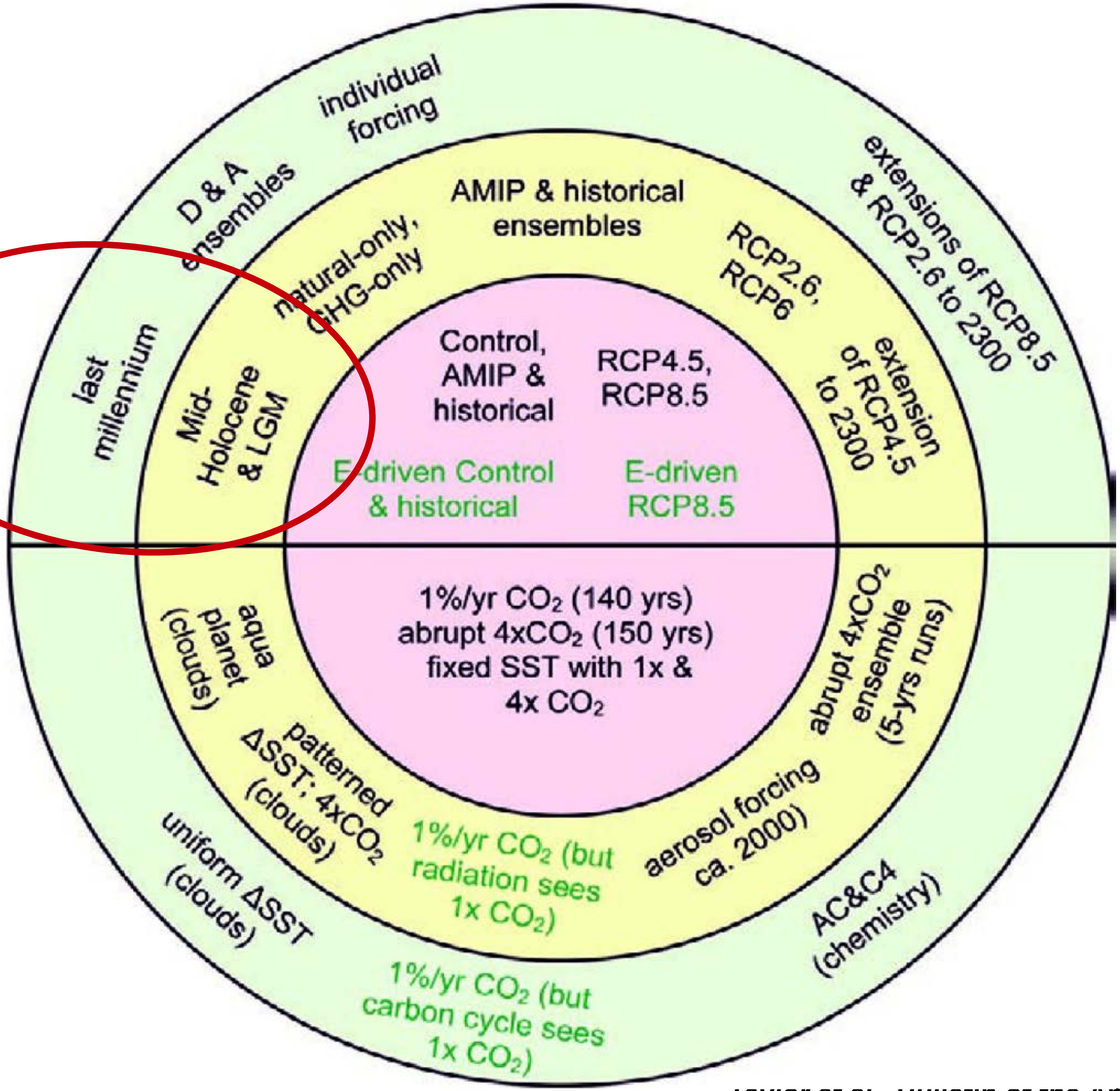
DO NOT simulate land-ice dynamics

(with very few non-operational exceptions)

The Climate Model Intercomparison Project 5 simulation scheme: different modelling groups providing simulations under the same protocol

~ 2013

No transient simulations

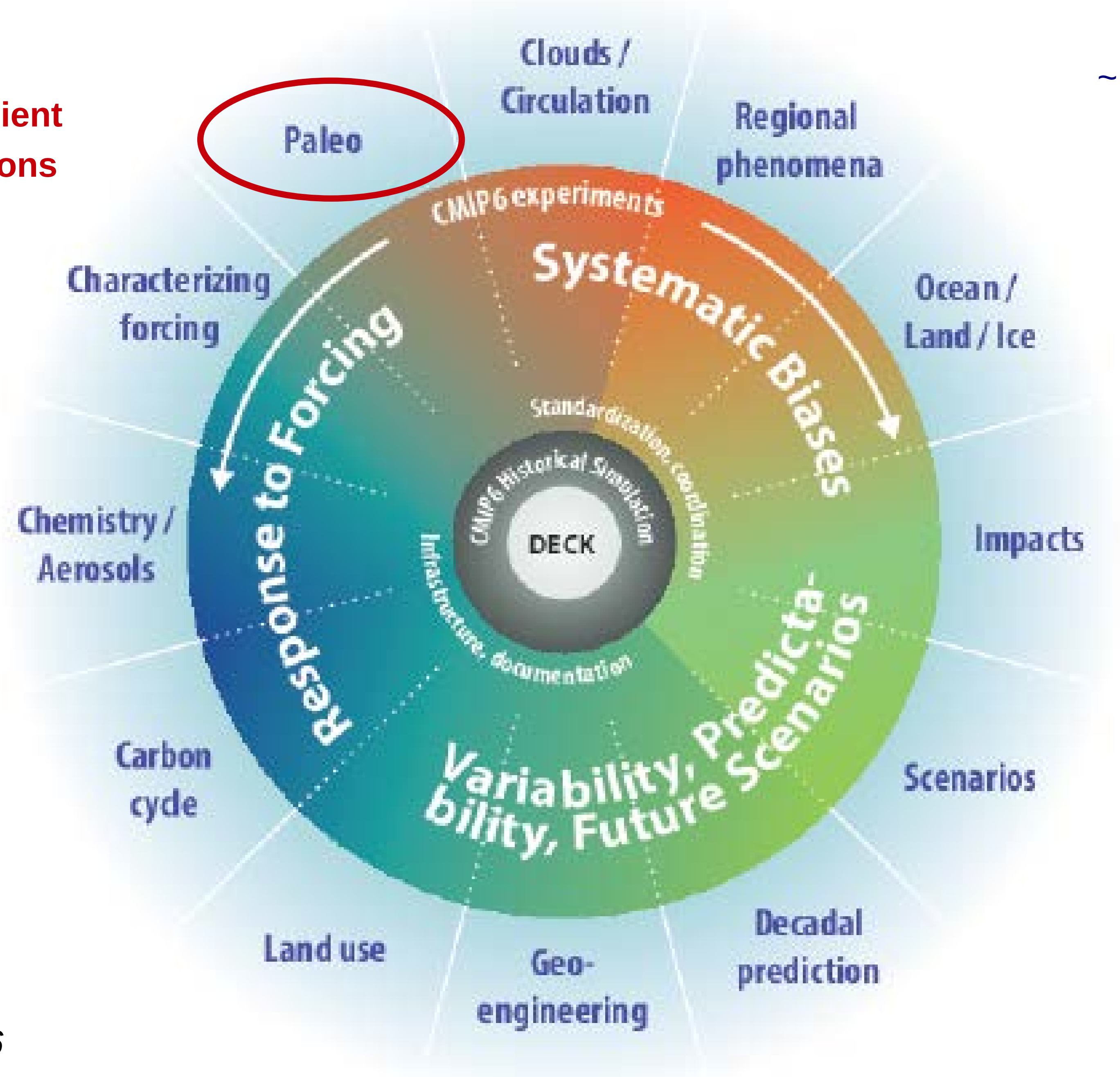


Taylor et al., Bulletin of the American Meteor. Soc (2012)

The CMIP6 simulations scheme
Climate Model Intercomparison Project

No transient simulations

~ 2020

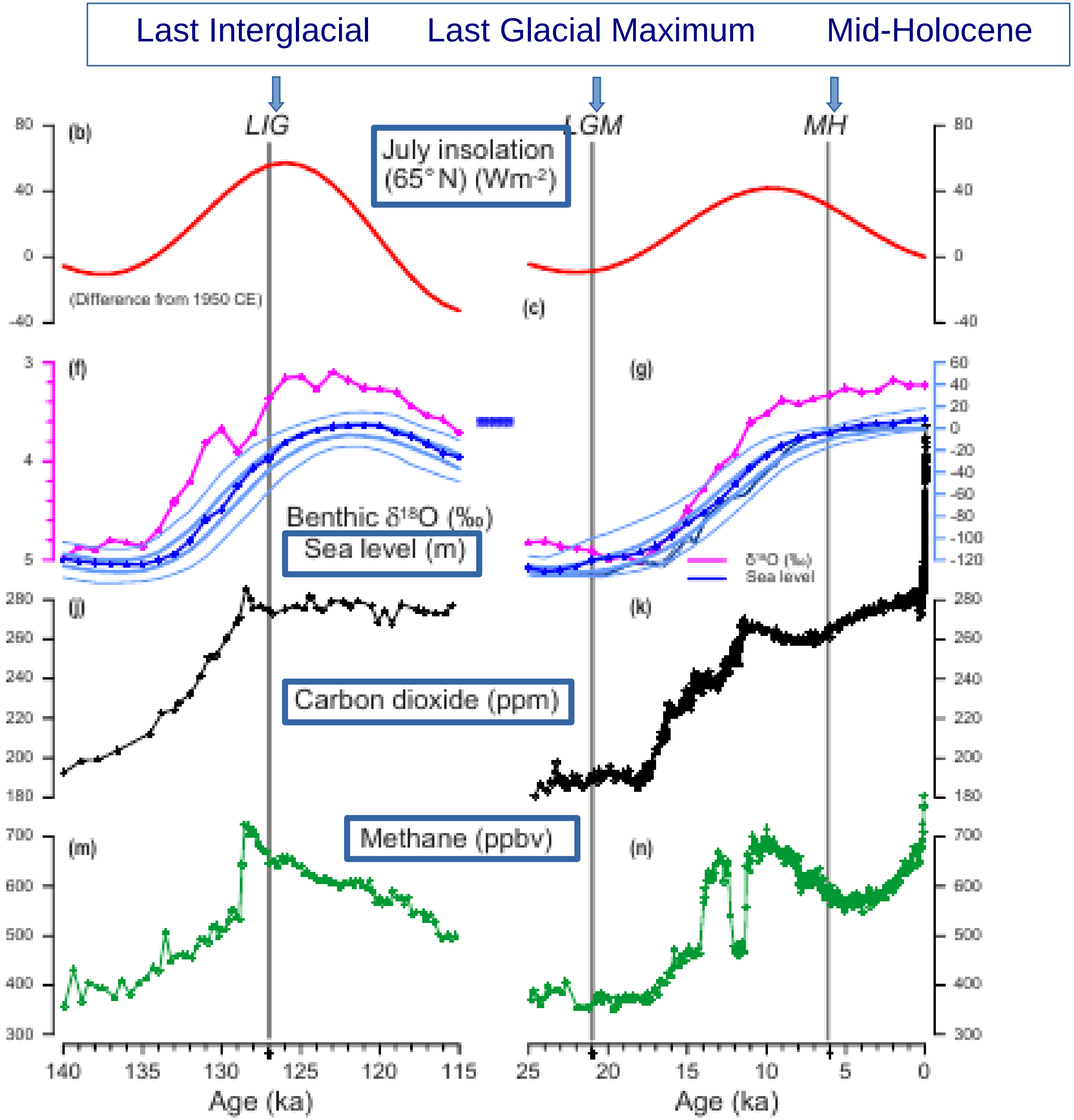


Eyring et al., 2016

Paleo climate simulations in the Climate Model Intercomparison Project 6

Period	Purpose
Last millennium (*past1000*) 850–1849 CE	(a) Evaluate the ability of models to capture reconstructed variability on multi-decadal and longer timescales. (b) Determine what fraction of the variability is attributable to "external" forcing and what fraction reflects purely internal variability. (c) Provide a longer-term perspective for detection and attribution studies.
mid-Holocene (*midHolocene*) 6 ka	(a) Evaluate the model response to known orbital forcing changes and changes in greenhouse gas concentrations against palaeodata that describe major temperature and hydrological changes. (b) Establish relationships between changes in mean state and variability
Last Glacial Maximum (*lgm*) 21 ka	(a) Evaluate how the model performs with ice-age boundary conditions against palaeodata. (b) Provide empirical constraints on global climate sensitivity.
Last Interglacial *(lig127k)* 127 ka	(a) Evaluate climate model performance during a period of Northern Hemisphere warmth and a sea-level high stand. (b) Establish the impacts of this climate on sea ice and ice sheets.
mid-Pliocene Warm Period (midPlioceneEoi400) 3.2 Ma	(a) Evaluate the Earth system response to a long-term CO_2 forcing analogous to that of the modern. (b) Establish the significance of CO_2-induced polar amplification for the stability of the ice sheets, sea ice, and sea level.

External forcings and 'time slice' simulations in CMIP6

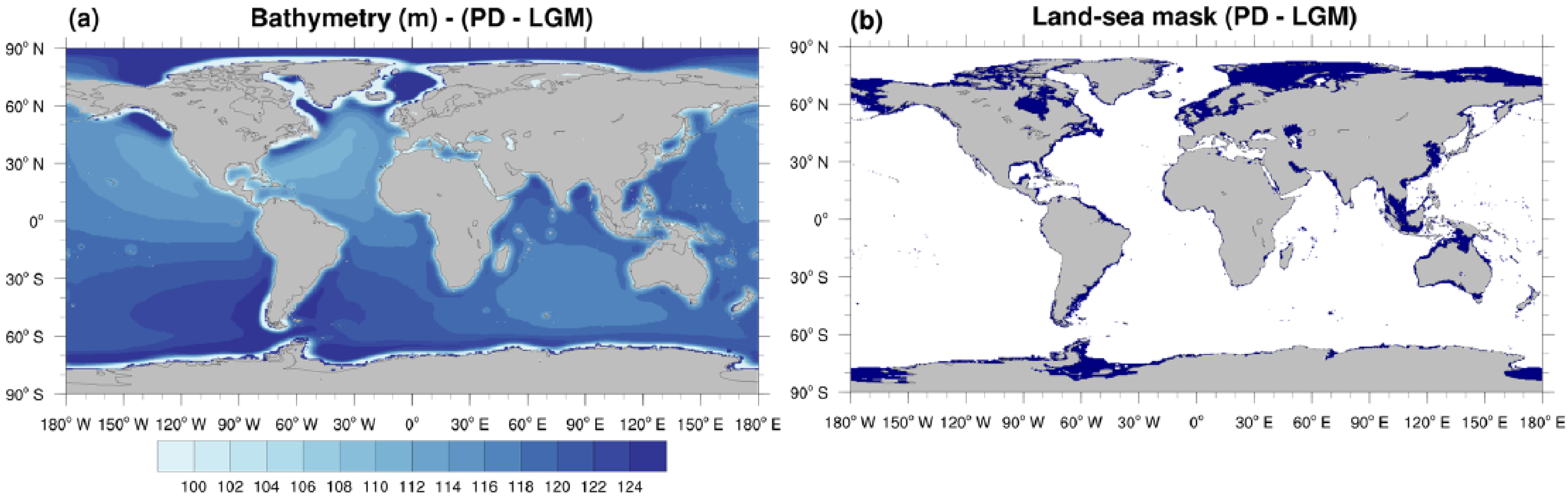


Kageyama et al., 2018

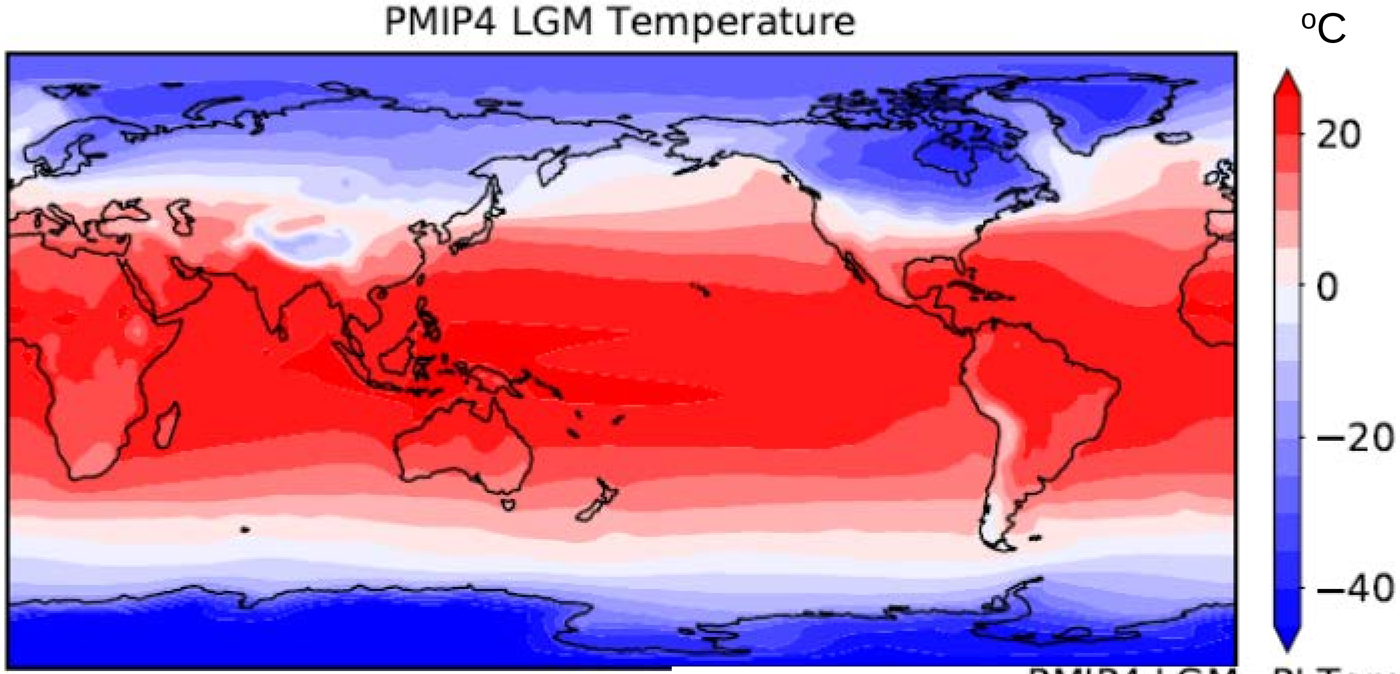
The Last Glacial Maximum: Ice Sheets

The Last Glacial Maximum: Ocean bathymetry and land-sea mask

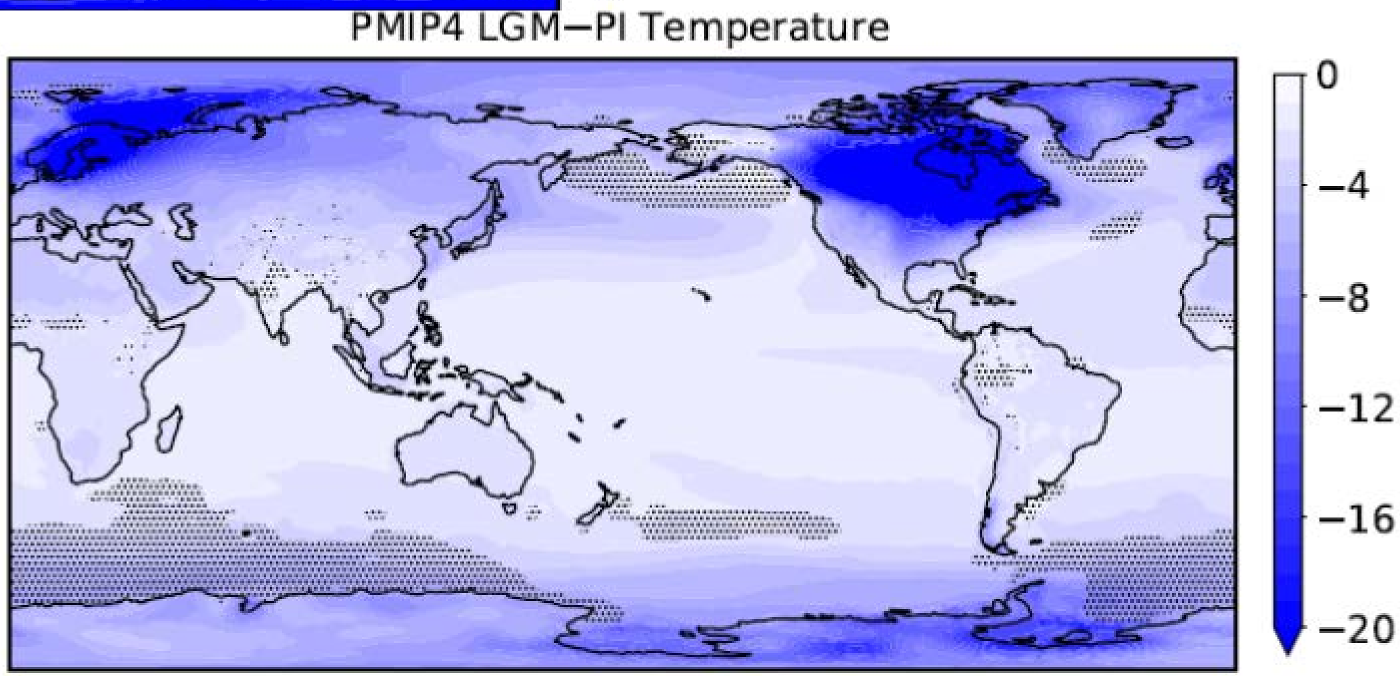
Differences to present day



Simulated temperature at the Last Glacial Maximum (20 thousand years before present)



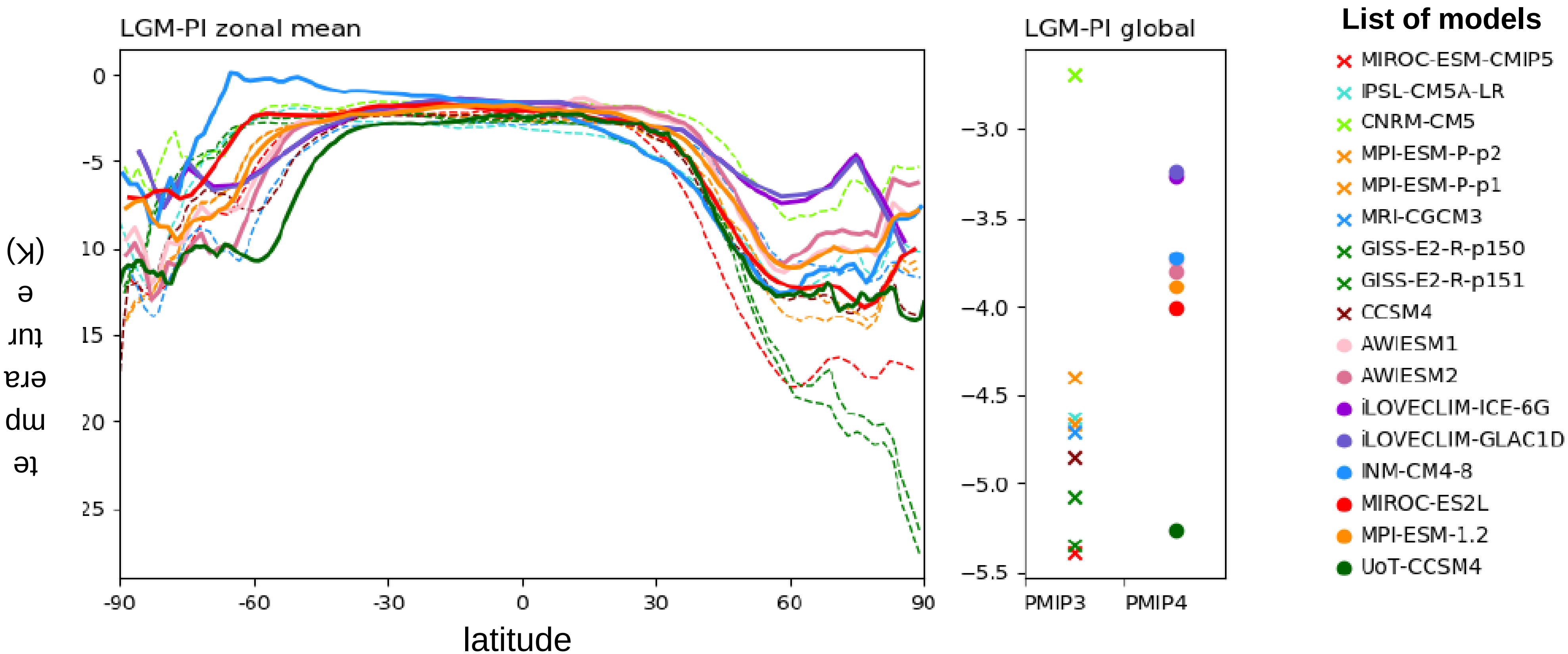
Stippling indicates the regions where models do NOT agree



Temperature difference between LGM and today

Kageyama et al., 2019

Differences between Last Glacial Maximum and recent temperature averaged in the west-east direction

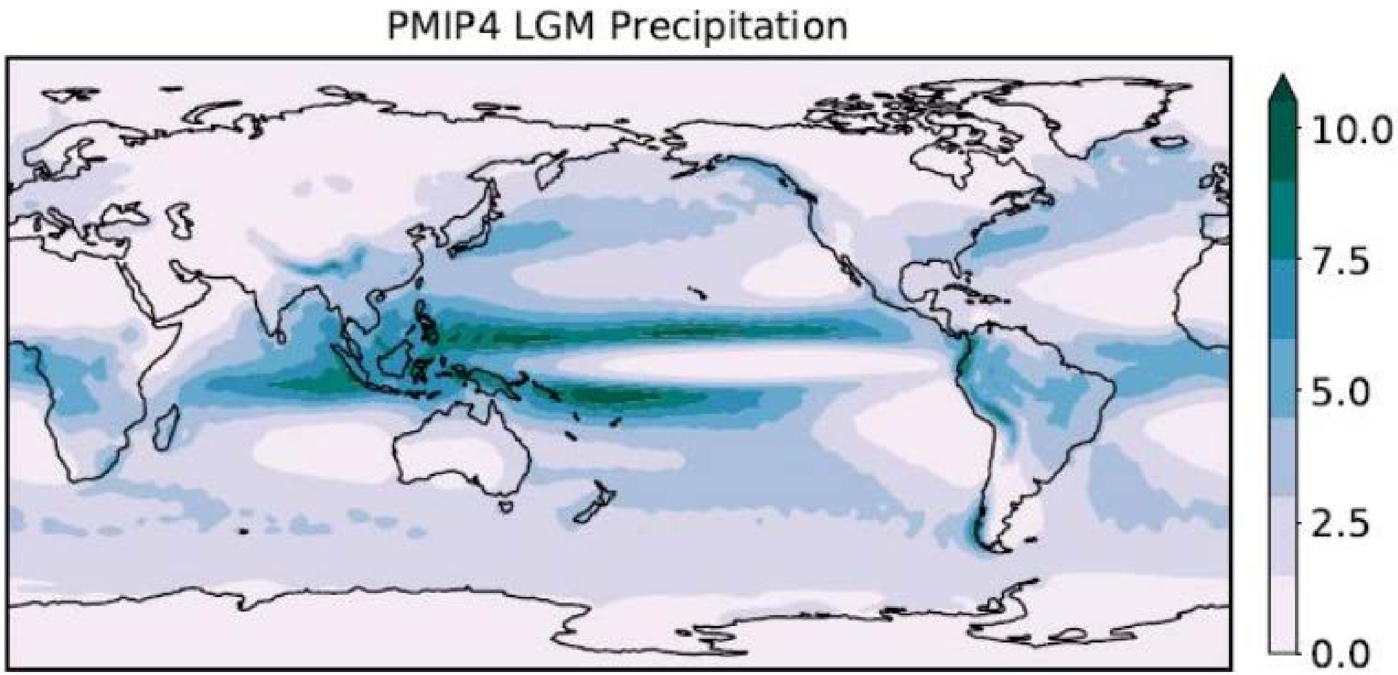


South Pole North Pole

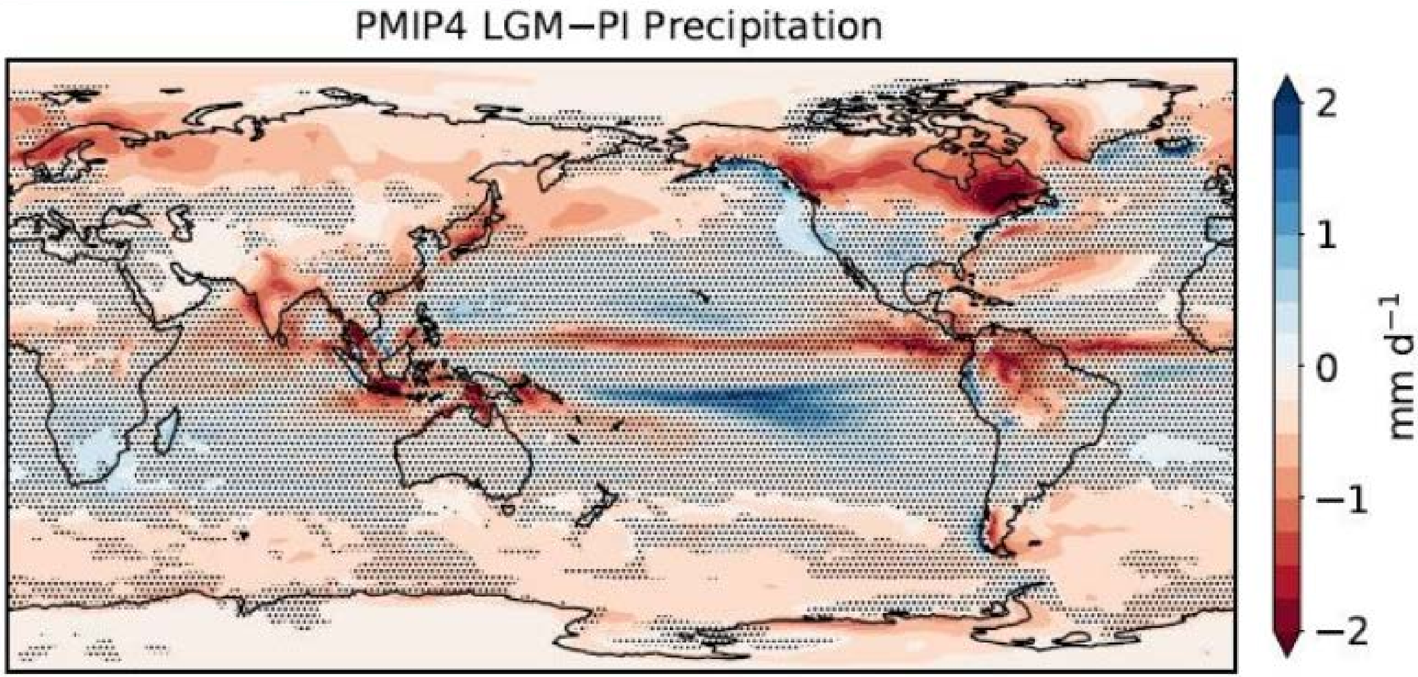
Kageyama et al., 2019

When possible, use data from several models

Simulated precipitation at the Last Glacial Maximum



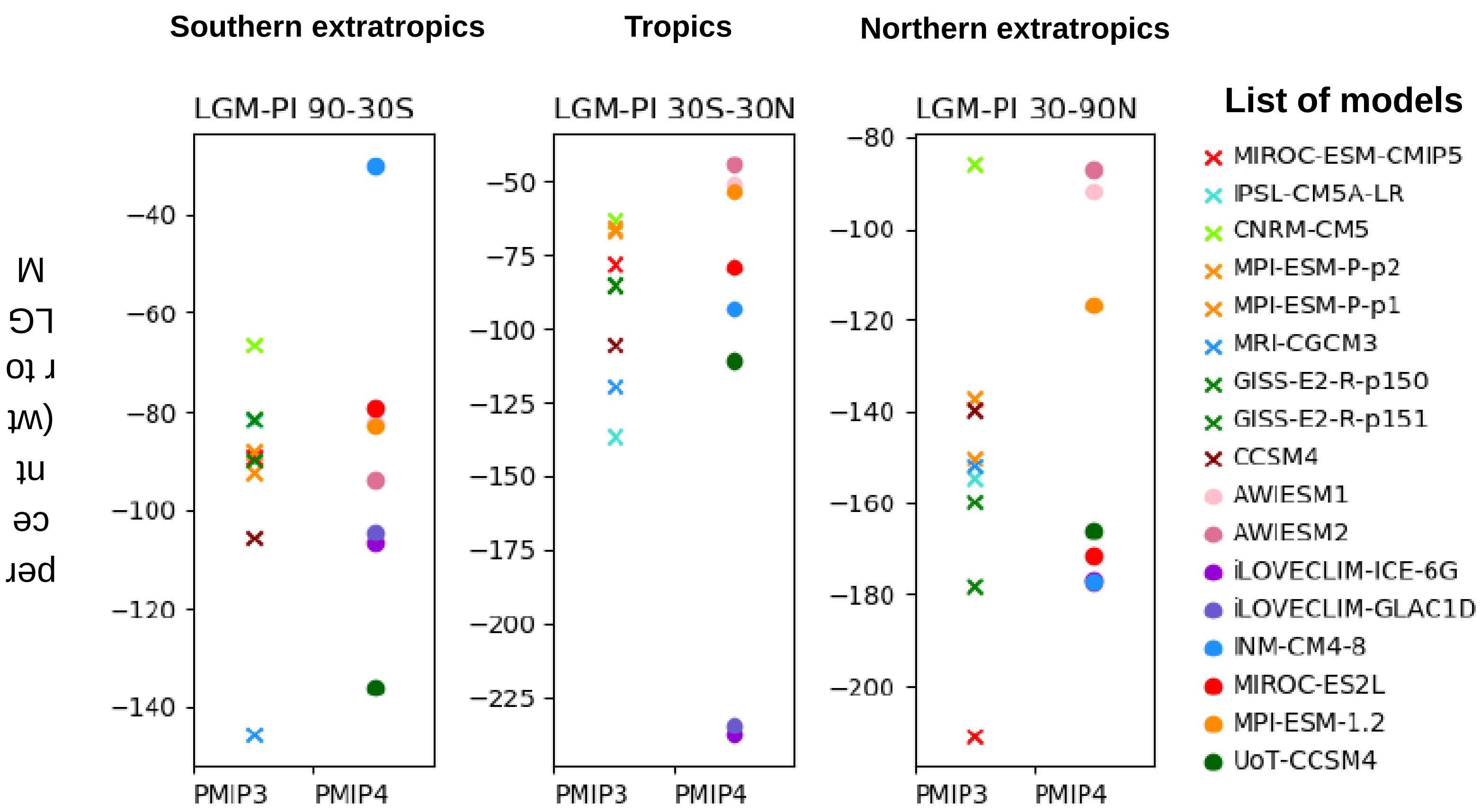
Stippling indicates the regions where models do NOT agree



Precipitation difference between LGM and today

Kageyama et al., 2019

Differences between Last Glacial Maximum and recent precipitation averaged in the west-east direction



Kageyama et al., 2019

The Trace-21ka transient simulations

Transient climate simulations of the deglaciation 21–9 thousand years before present (version 1) – PMIP4 Core experiment design and boundary conditions

Ruza F. Ivanovic[1], Lauren J. Gregoire[1], Masa Kageyama[2], Didier M. Roche[2,3], Paul J. Valdes[4], Andrea Burke[5], Rosemarie Drummond[6], W. Richard Peltier[6], and Lev Tarasov[7]

Boundary condition	Description
Initial conditions (pre-21 ka)	Recommended (optional) to use either: – Last Glacial Maximum (LGM; 21 ka) equilibrium simulation, including +1 psu global ocean salinity – Transient orbit and trace gases (26–21 ka) and all other boundary conditions fixed as per equilibrium LGM See Table 1 for details. The method must be documented, including information on the state of spin-up
Insolation	
Solar constant	Preindustrial (e.g. $1361.0 \pm 0.5\,W\,m^{-2}$)
Orbital parameters	Transient, as per Berger (1978)
Trace gases	Adjusted to the AICC2012 age model (Veres et al., 2013):
Carbon dioxide (CO_2)	Transient, as per Bereiter et al. (2015)
Methane (CH_4)	Transient, as per Loulergue et al. (2008)
Nitrous oxide (N_2O)	Transient, as per Schilt et al. (2010)
Chlorofluorocarbon (CFC)	0
Ozone (O_3)	Preindustrial (e.g. 10 DU)
Ice sheet	Transient, with a choice of either: – ICE-6G_C reconstruction (references in text) – GLAC-1D reconstruction (references in text) How often to update the ice sheet is optional
Orography and coastlines	Transient. To be consistent with the choice of ice sheet. Orography is updated on the same time step as the ice sheet. It is optional how often the land-sea mask is updated, but ensure consistency with the ice sheet reconstruction is maintained
Bathymetry	Keep consistent with the coastlines and otherwise use either: – Transient data associated with the chosen ice sheet; it is optional how often the bathymetry is updated – Preindustrial bathymetry
River routing	Ensure that rivers reach the coastline It is recommended (optional) to use one of the following: – Preindustrial configuration for the model – Transient routing provided with the ice sheet reconstruction (if available) – Manual/model calculation of river network to match topography
Freshwater fluxes	At participant discretion. Three options are *melt-uniform*, *melt-routed* and *no-melt* (see text). It is recommended (optional) to run at least one Core simulation with a scenario consistent with the chosen ice sheet reconstruction to conserve salinity (e.g. as provided). See text for full details (Sect. 2.5)
Other (optional)	
Vegetation and land cover	Prescribed preindustrial cover or dynamic vegetation model
Aerosols (dust)	Prescribed preindustrial distribution or prognostic aerosols

Ivanovic et al, 2016

A transient Trace21ka simulation: external forcings (prescribed by the researcher)

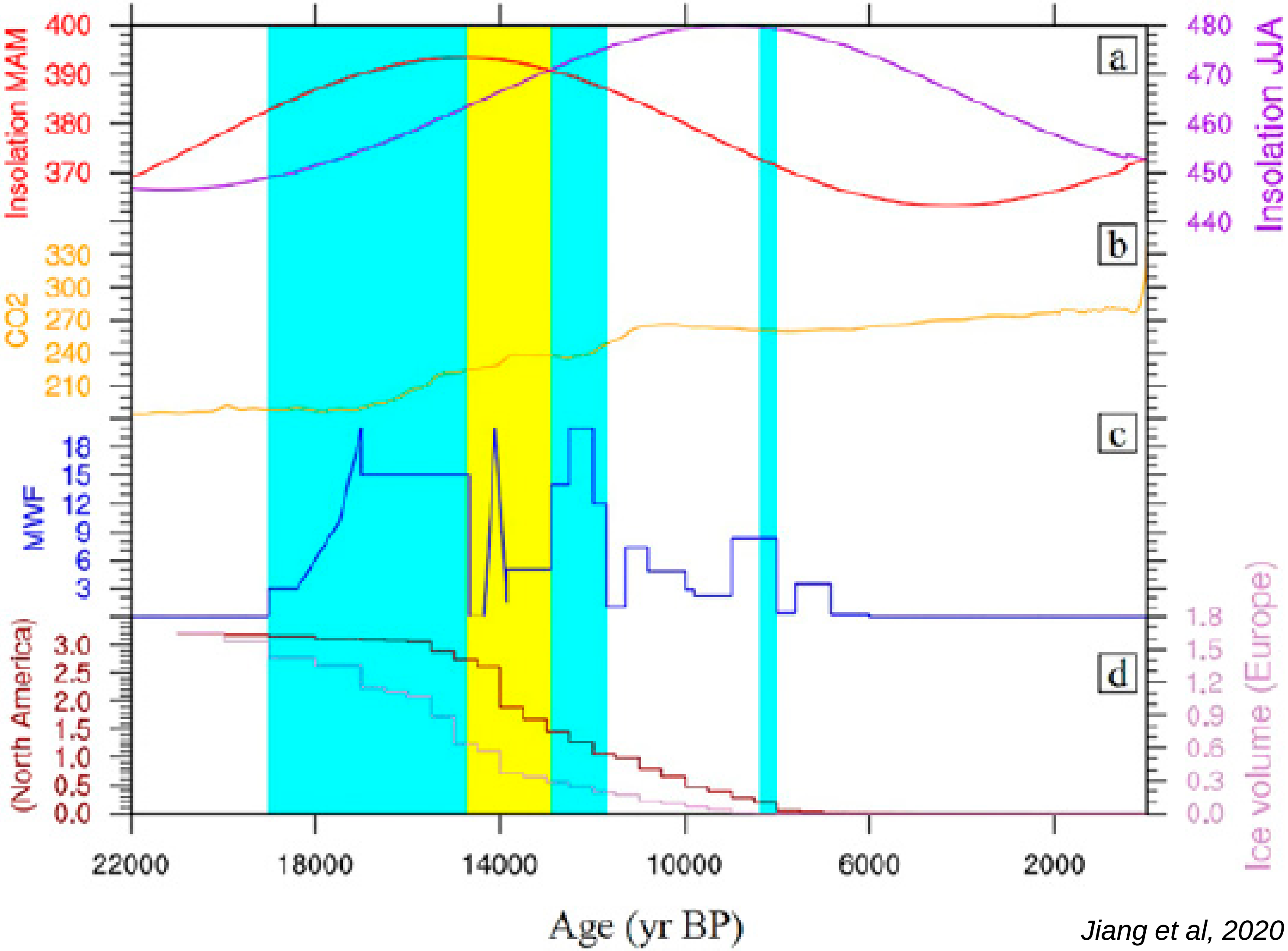
Climate Model : CCSM3

Insolation at 45N in boreal spring
(example for the whole insolation field)

Atmospheric CO_2

Melt Water Flux

North American Ice Sheet



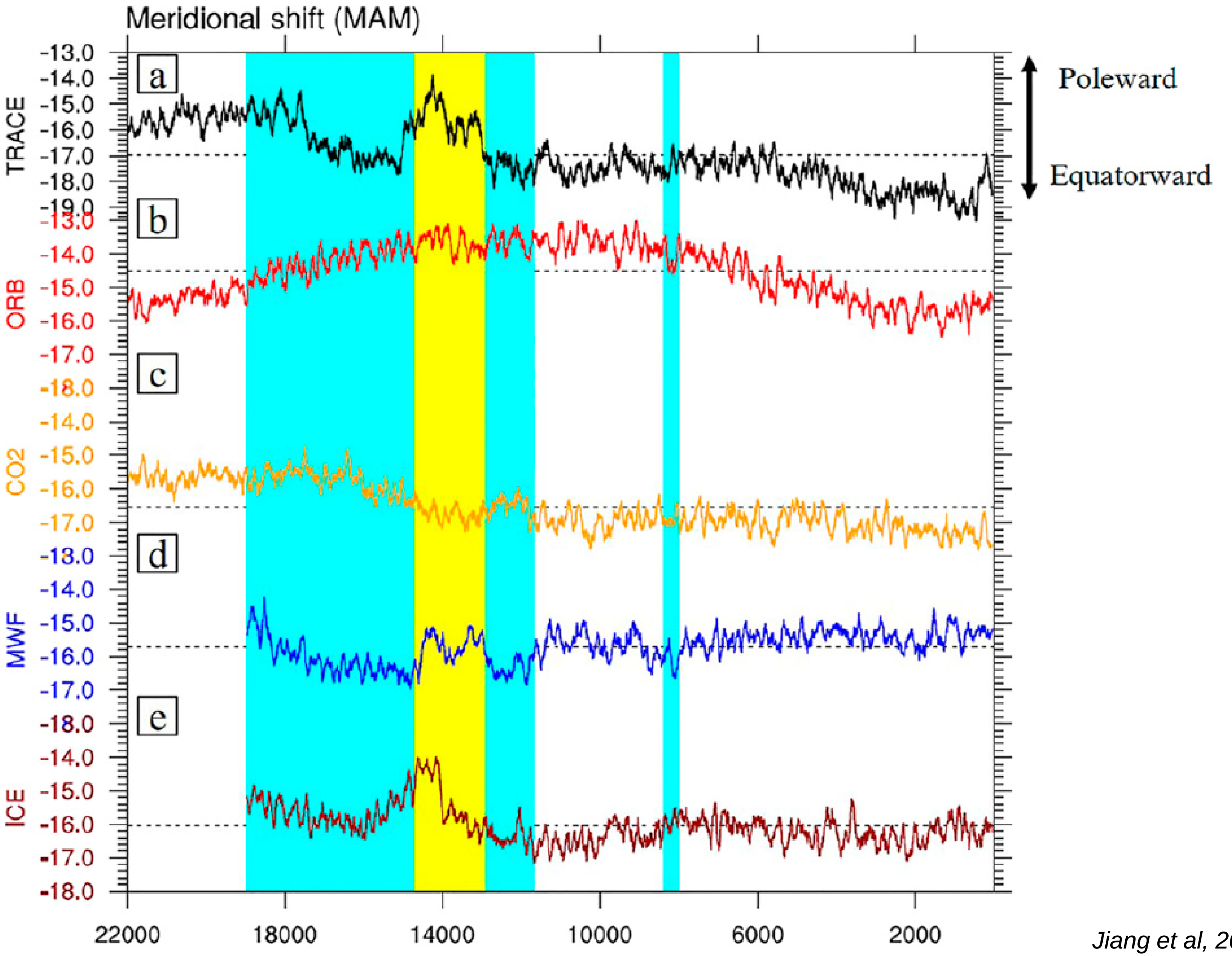
Jiang et al, 2020

Example of a transient Trace21ka simulations: westerly winds over Central Asia

All forcings

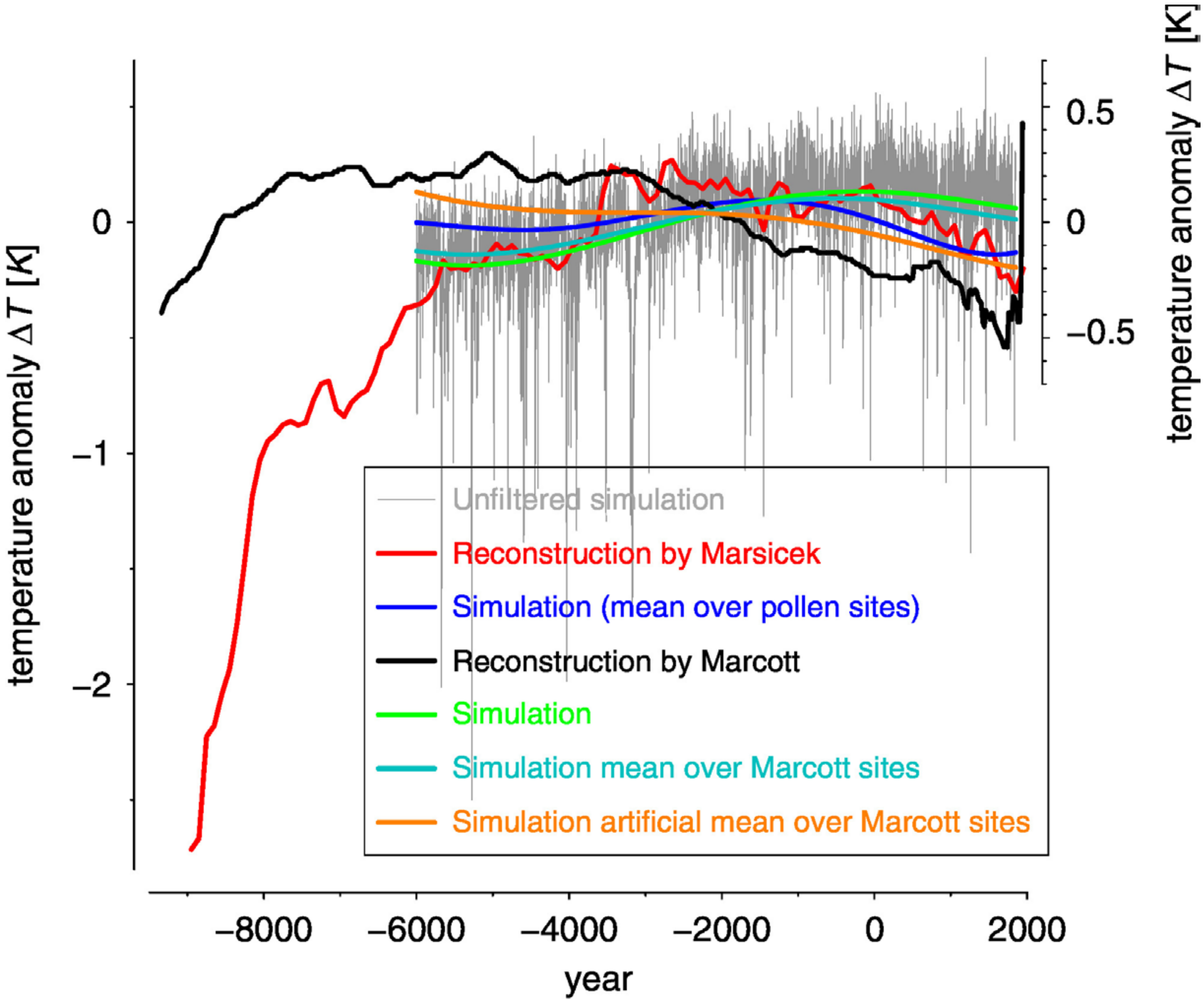
Only orbital forcing

GHG only



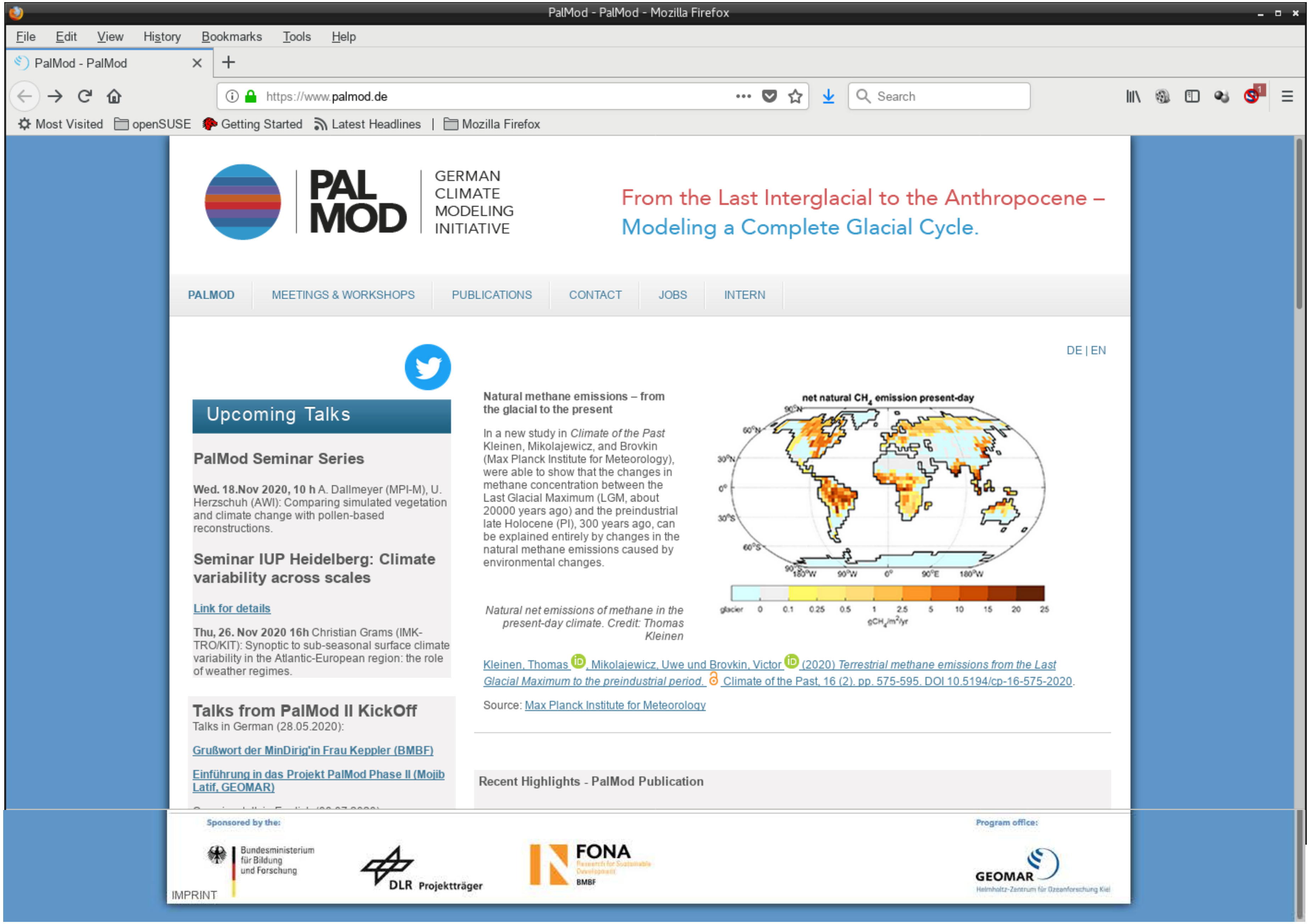
Jiang et al, 2020

The Holocene conundrum:
reconstructions (and models) disagree



Bader et al, 2020

The Palmod Project - First transient simulation of the Last Glacial Cycle with an Earth System Model



The Palmod Project : First transient simulation of the Last Glacial Cycle with an Earth System Model

Objective

- Use a state-of-the-art Earth System Model,
- With a reasonable spatial resolution (~100 km),
- With interactive carbon cycle, terrestrial and marine,
- With interactive land-ice (thermo-)dynamics,
- With interactive geo-elasticity !!,
- with the only external forcing being the orbital forcing,
- **to simulate the past 130 k years of Earth’s climate**

Final thoughts

- Earth System Models may help to interpret large networks of proxy records in a physically consistent manner . Do use the large data sets provided by CMIP5 and CMIP6 !
- Different models may, however, provide diverging pictures. Critical stance is always needed
- When focusing on small scales (a few hundreds of km), simulations may be perfectly wrong
- This is specially true in regions with complex topography or coastlines
- Trust more the large-scale characteristics a much less the local features