Temperature and precipitation distribution changes in response to global warming – results from transient simulations of the Last Deglaciation from a hierarchy of climate models

Elisa Ziegler, Christian Wirths, Heather Andres, Lauren Gregoire, Ruza Ivanovic, Marie-Luise Kapsch, Steffen Kutterolf, Uwe Mikolajewicz, Julie Christin Schindlbeck-Belo, Matthew Toohey, Paul J. Valdes, Nils Weitzel, and Kira Rehfeld

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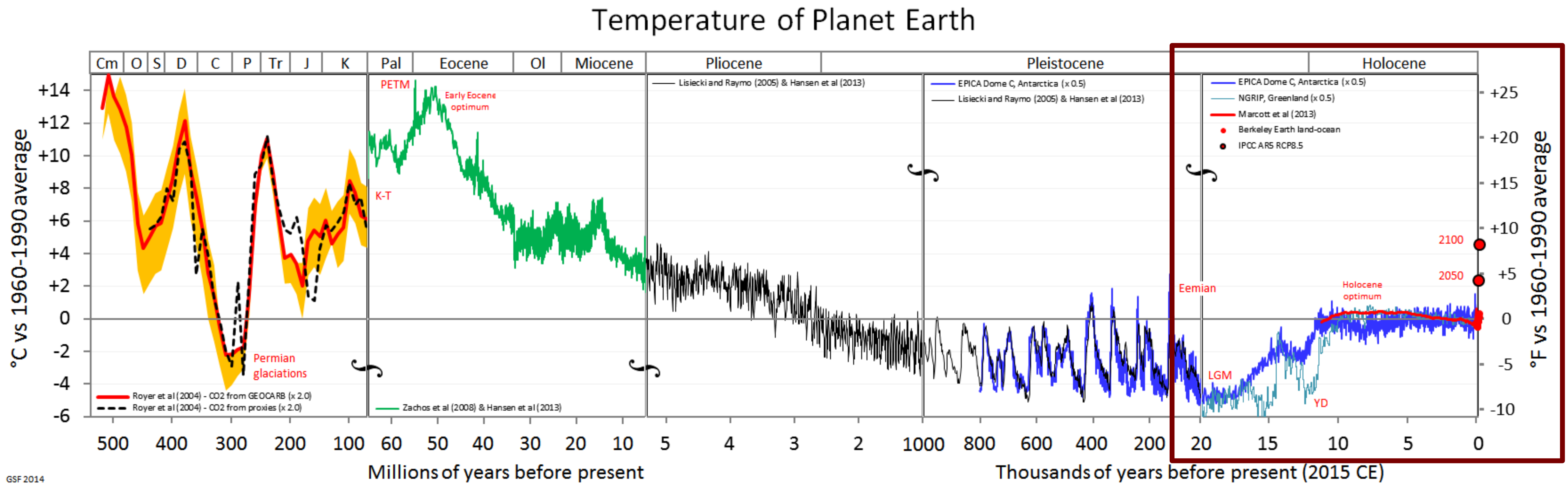
Consider past climate changes...



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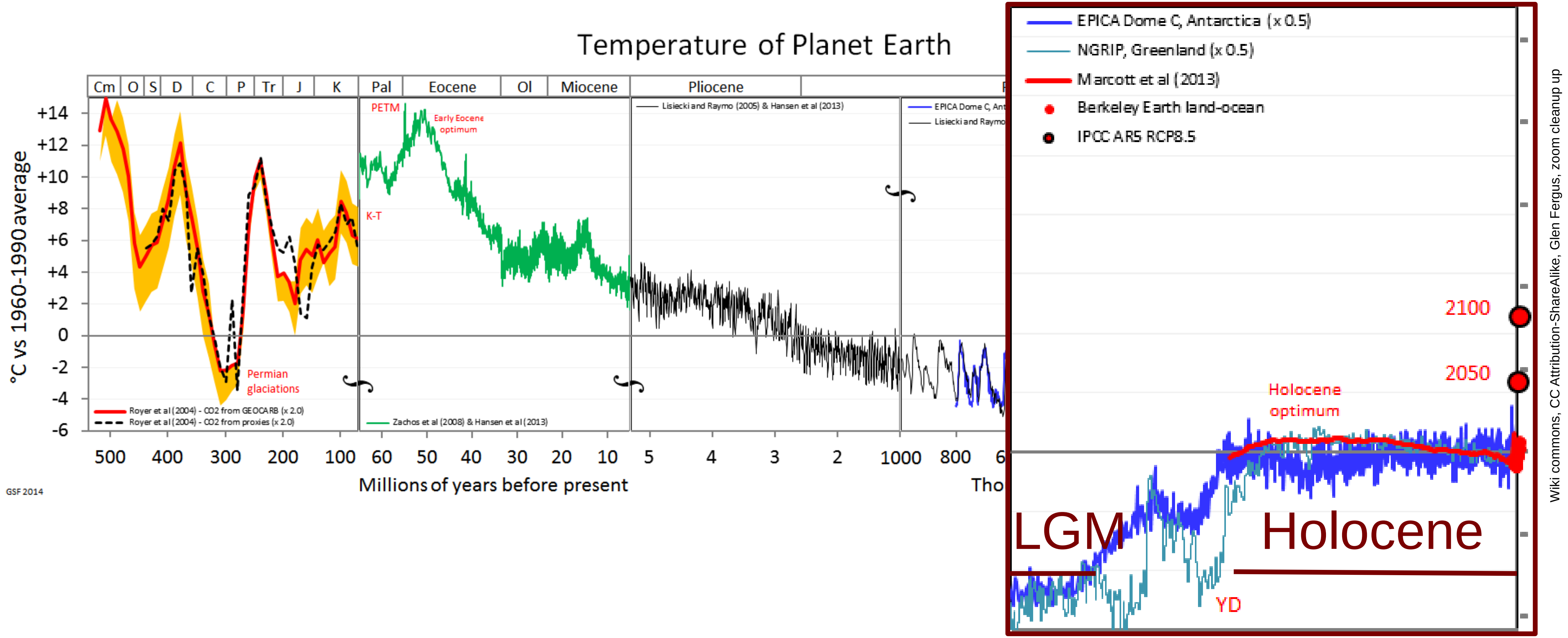
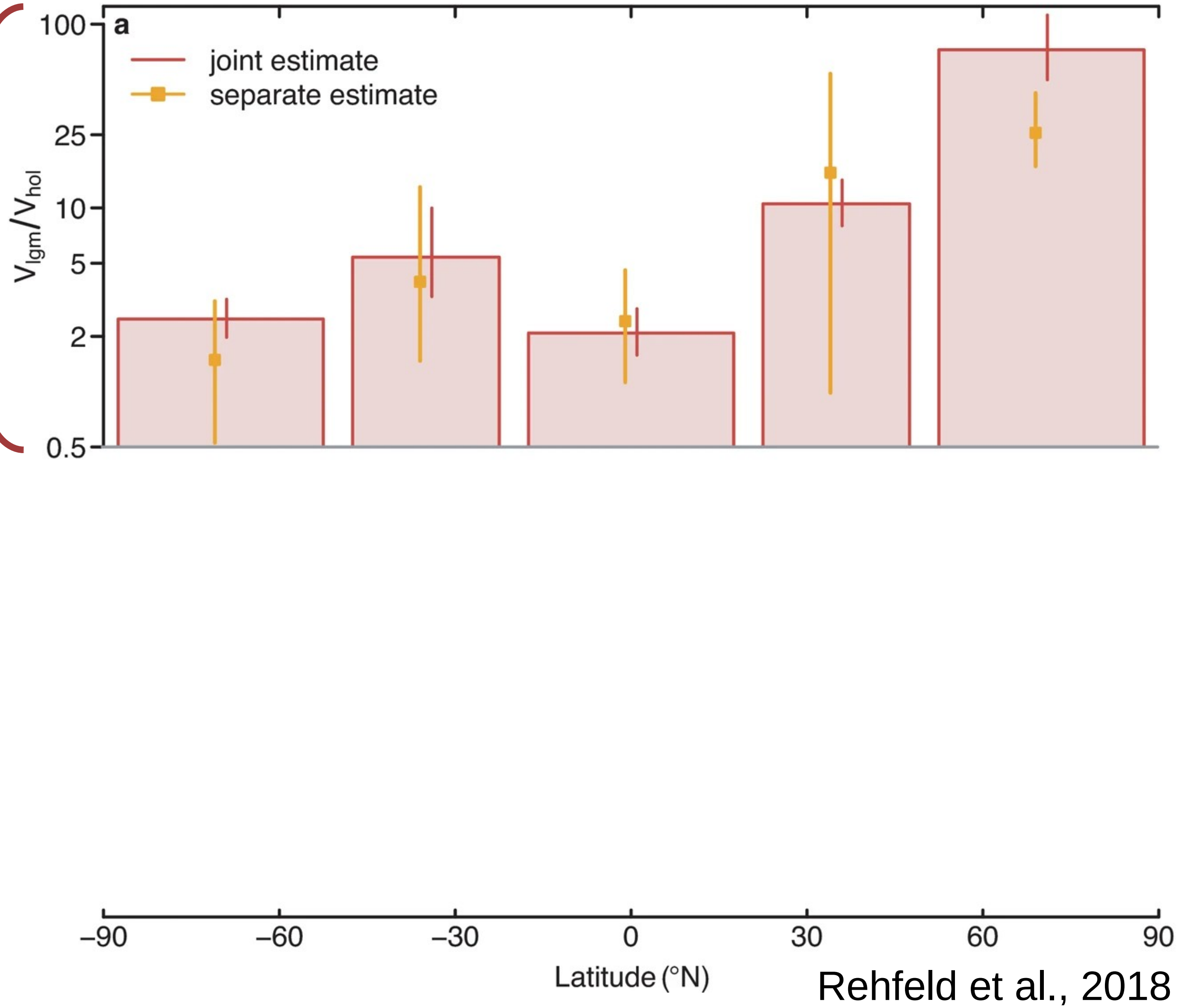


...to learn about what to expect in the future.

Limited agreement on past changes in variability

Proxies:
up to 100× higher variance during LGM than Holocene



Rehfeld et al., 2018

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Proxies:
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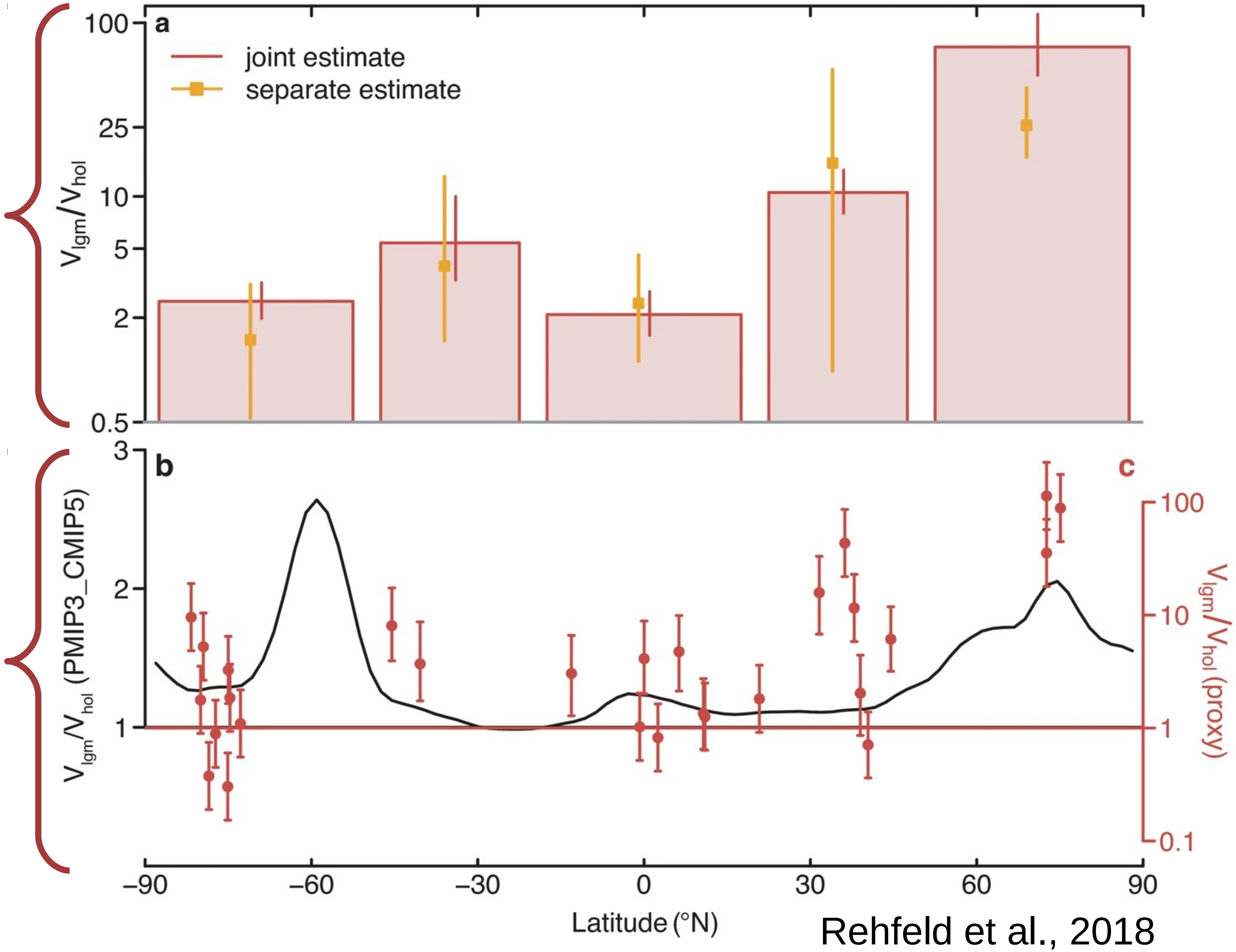
Models:
variance only up to 3× higher



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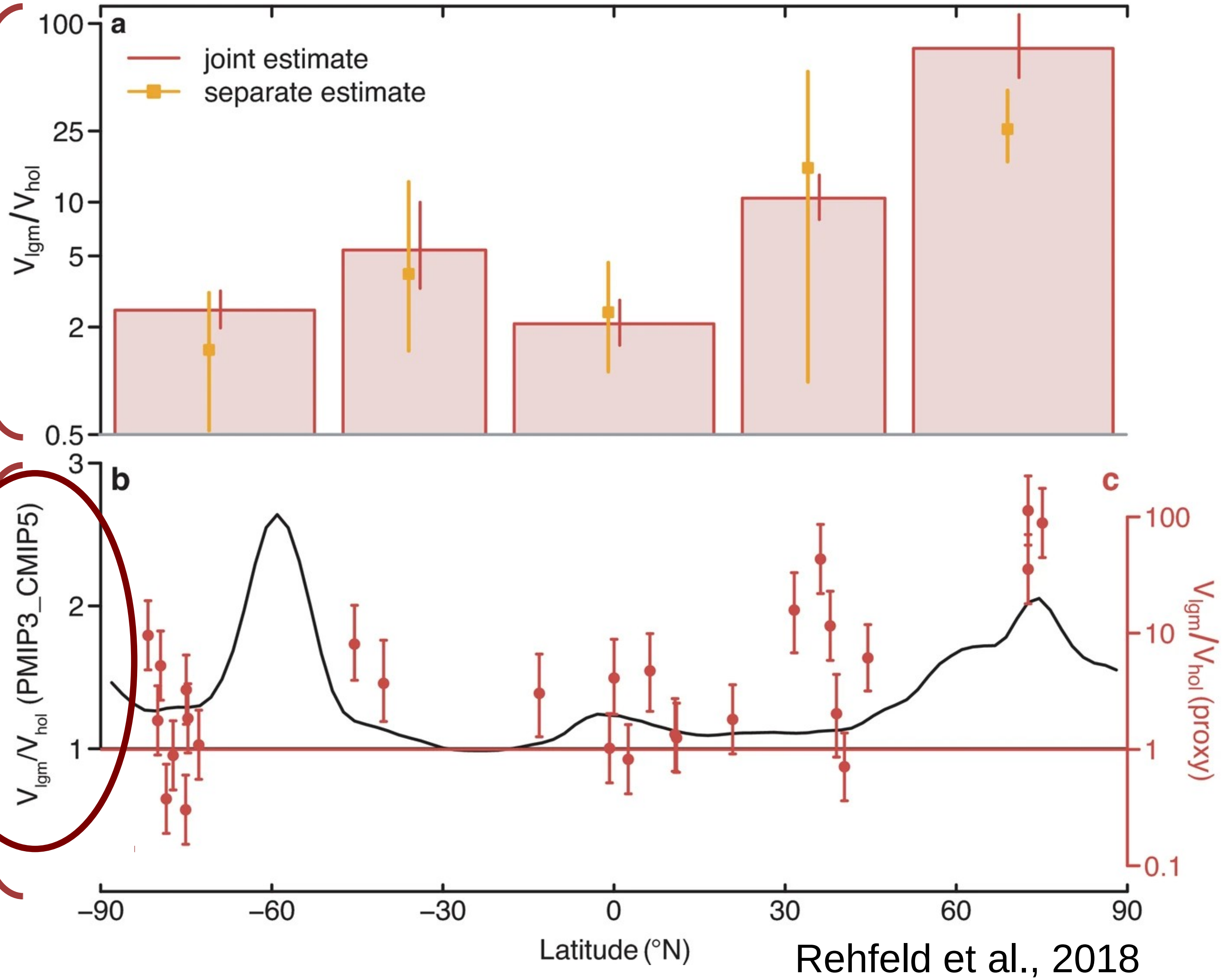
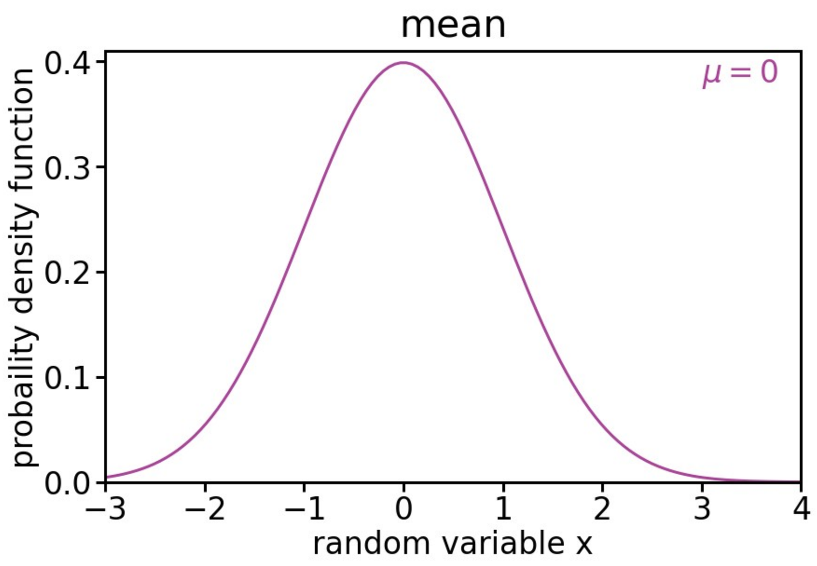


Rehfeld et al., 2018

When the mean climate changes,



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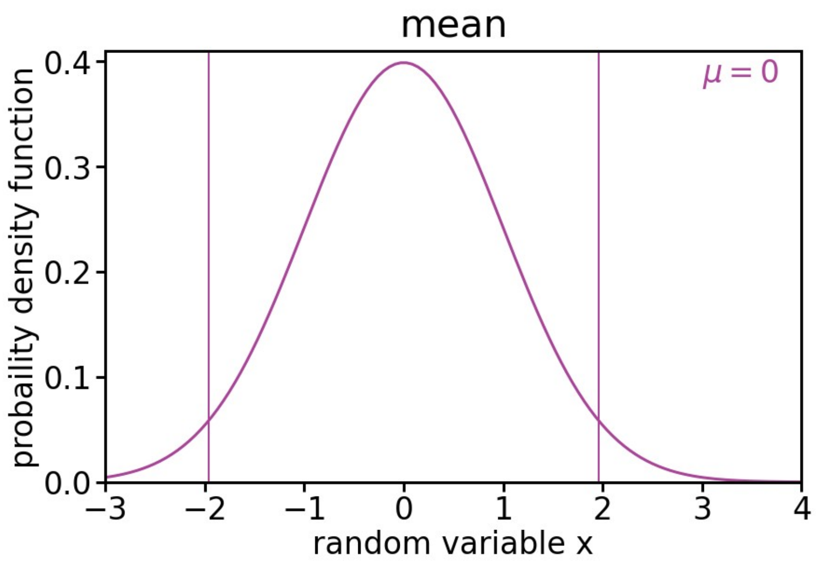

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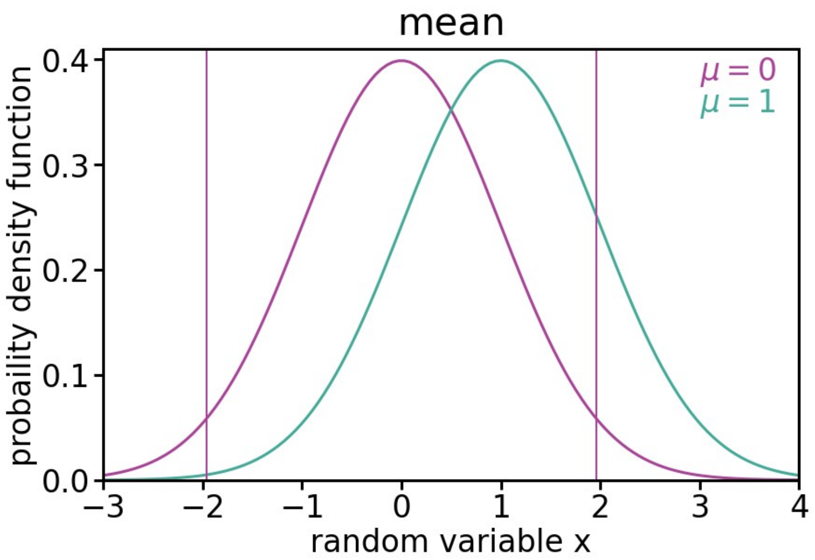
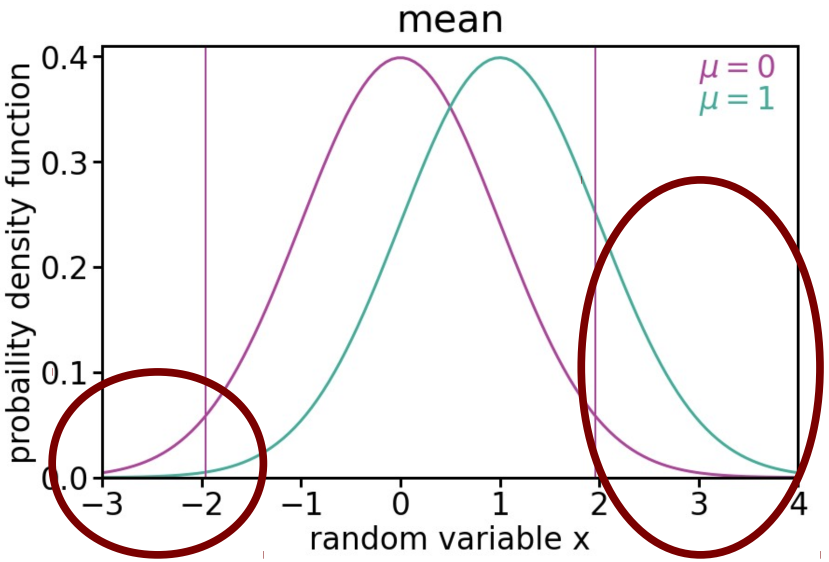


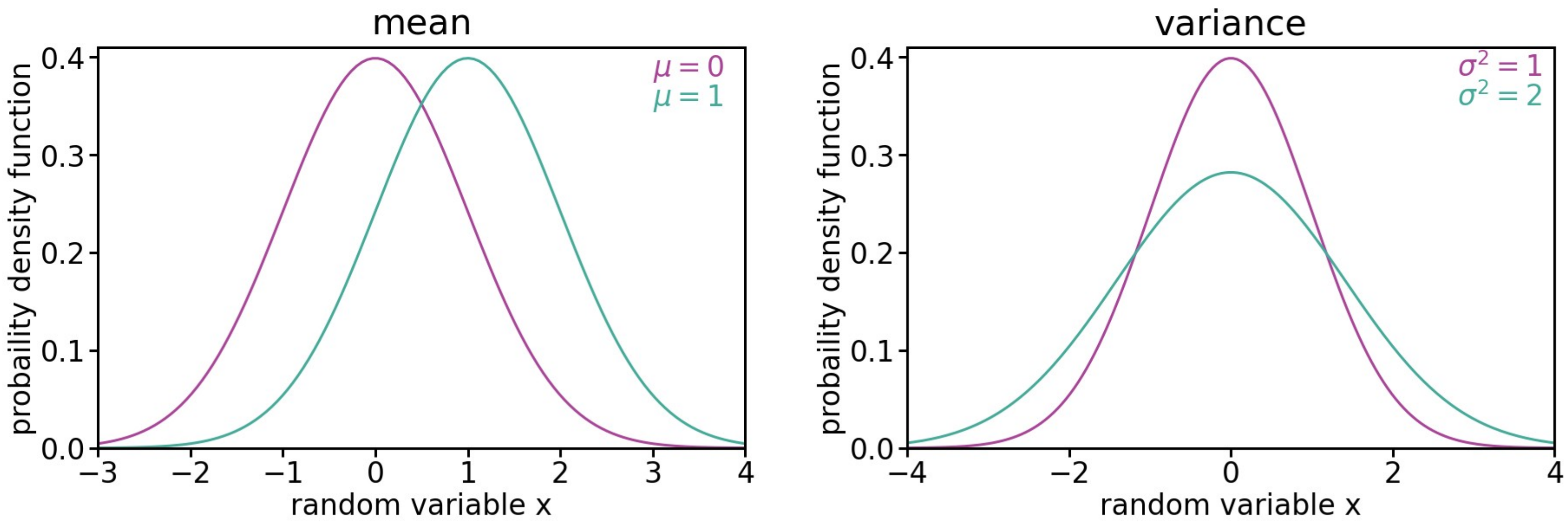
When the mean climate changes, so do the extremes



less extremes

more extremes

As do higher moments, i.e. variance



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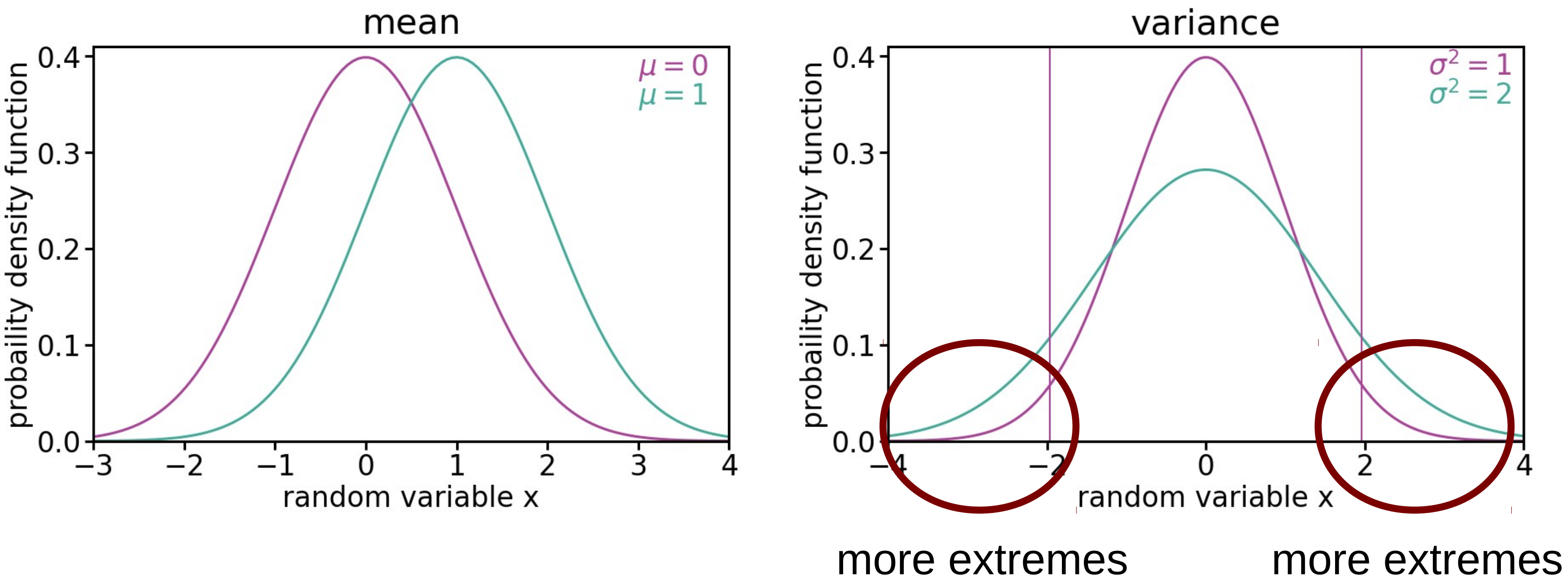
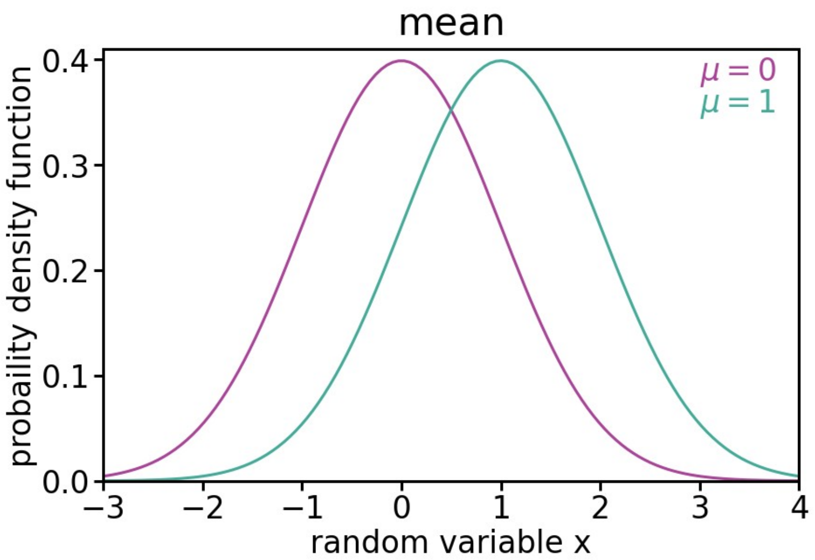
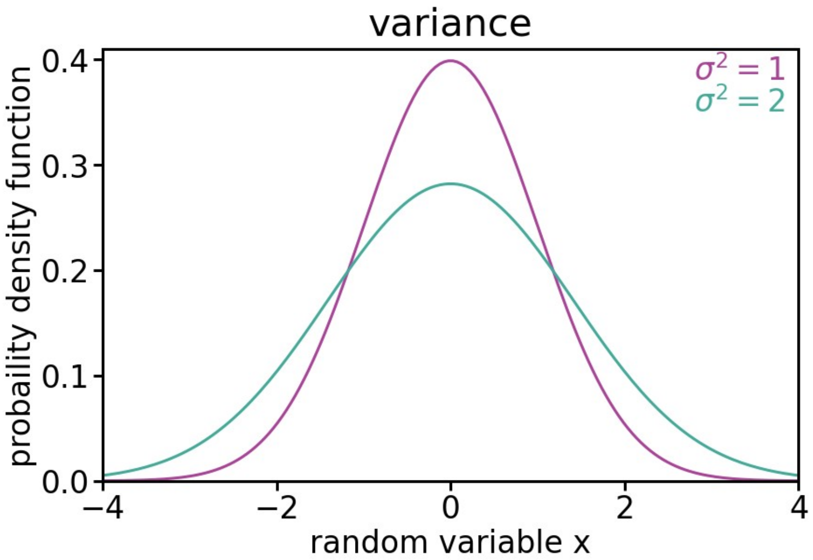
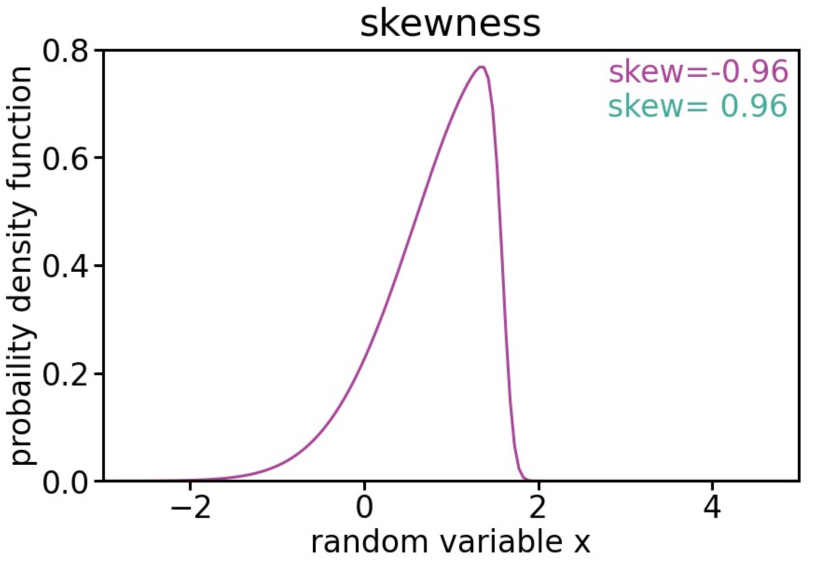


As do higher moments, i.e. skewness



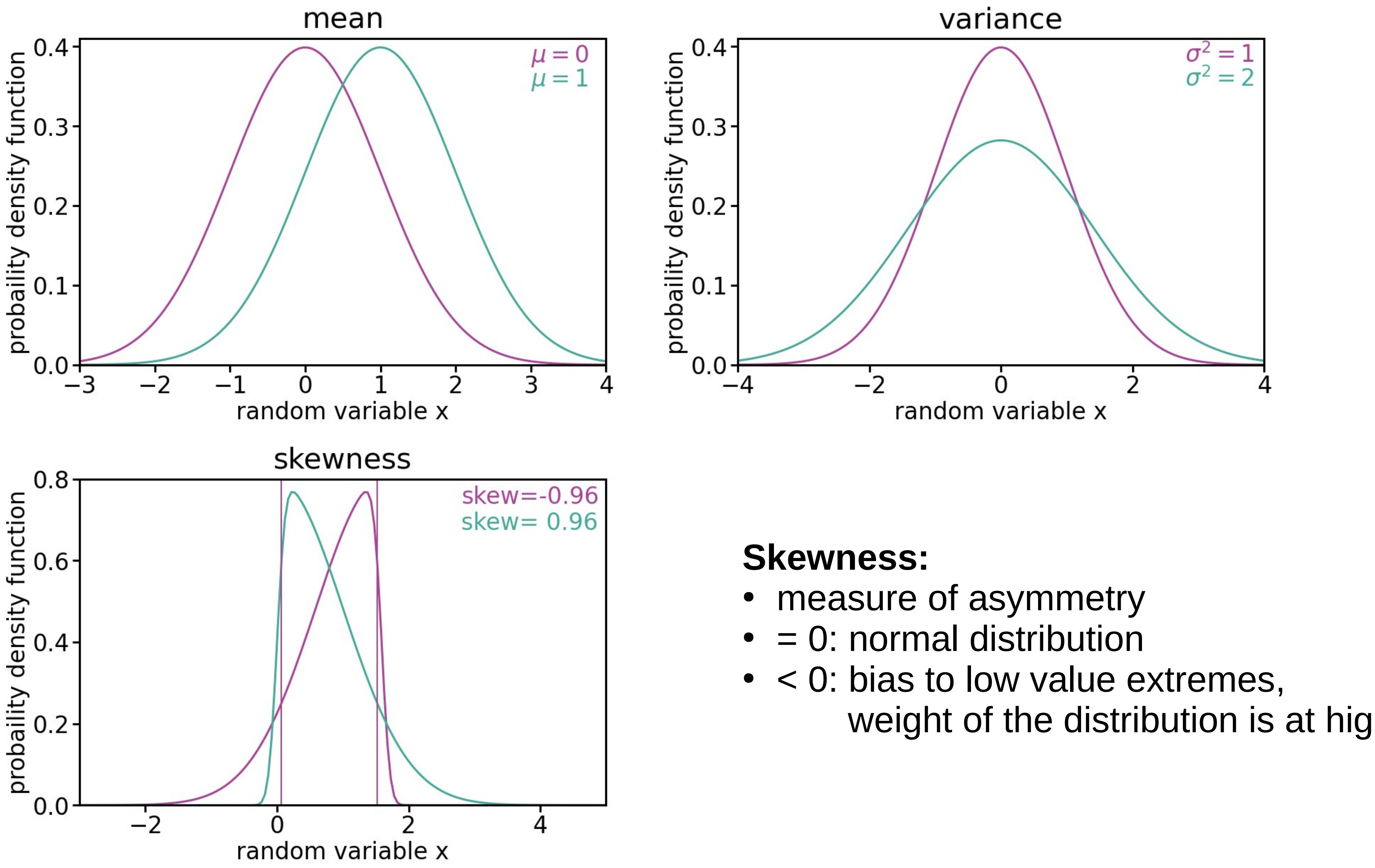




Skewness:

- measure of asymmetry
- = 0: normal distribution
- < 0: bias to low value extremes,
  weight of the distribution is at higher values

As do higher moments, i.e. skewness



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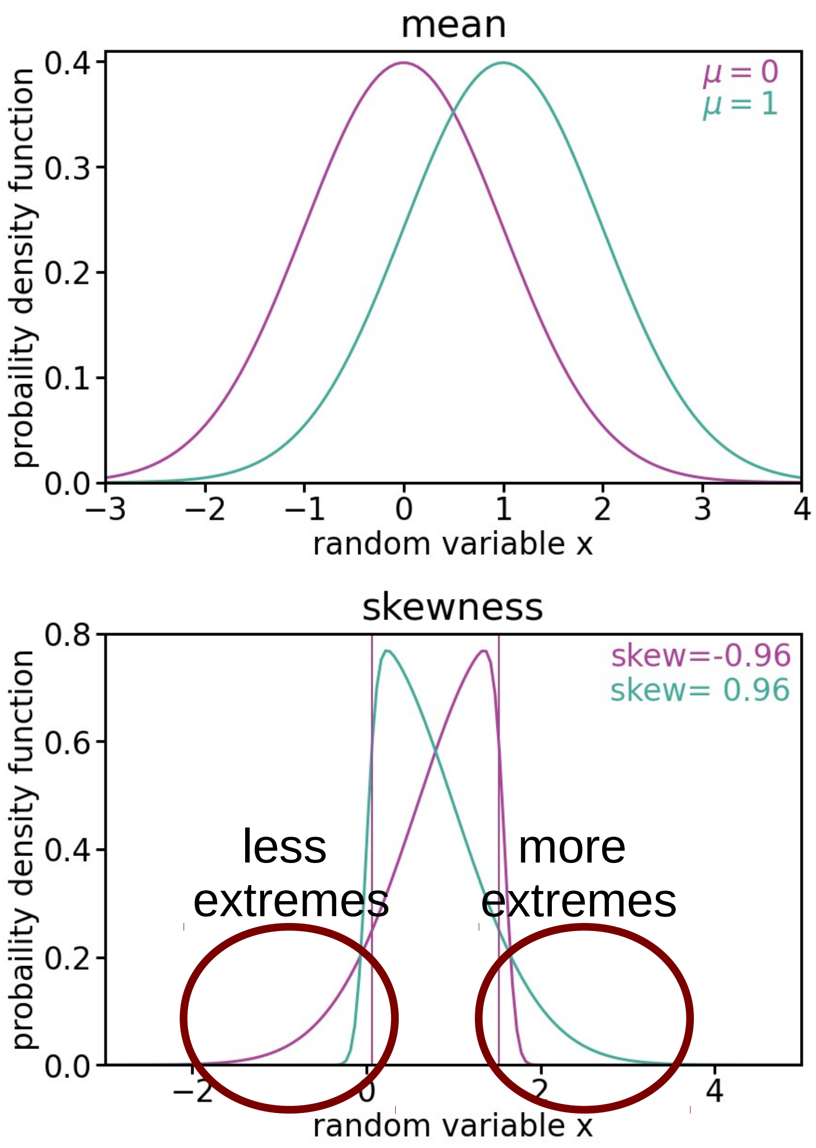

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- measure of asymmetry
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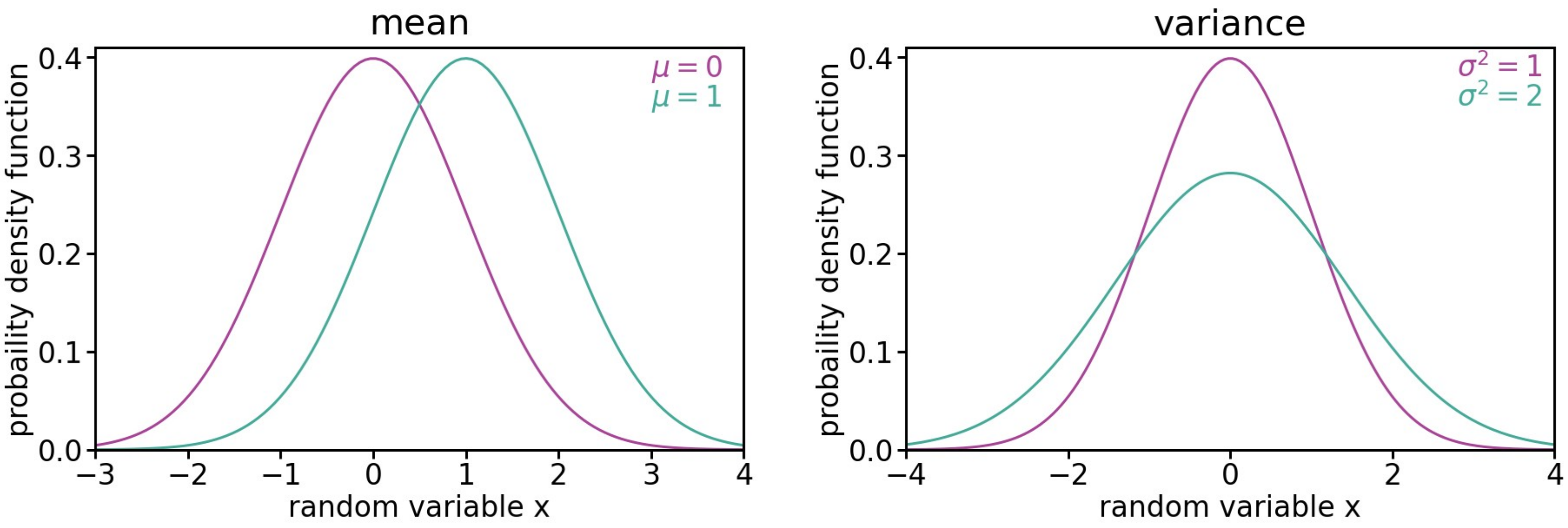
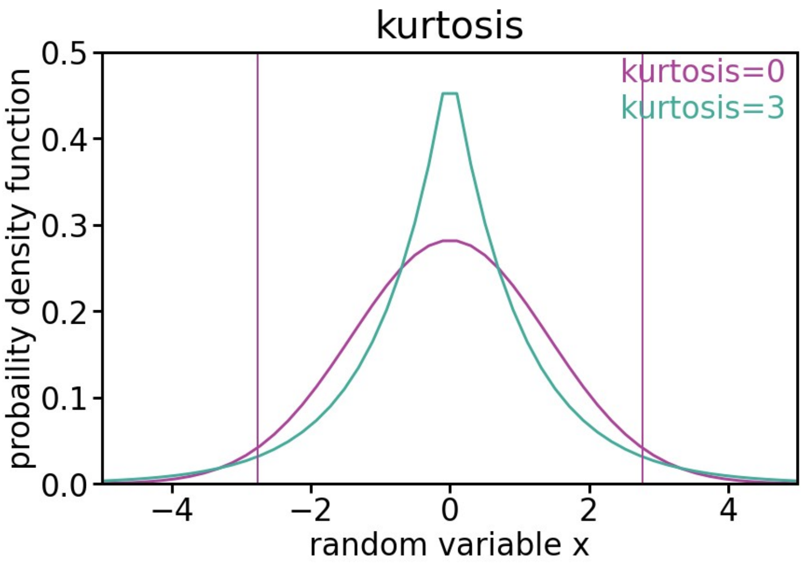
As do higher moments, i.e. kurtosis



(Excess) kurtosis:

- measures heaviness of the tails
- = 0: normal distribution
- > 0: fat tails, more extremes



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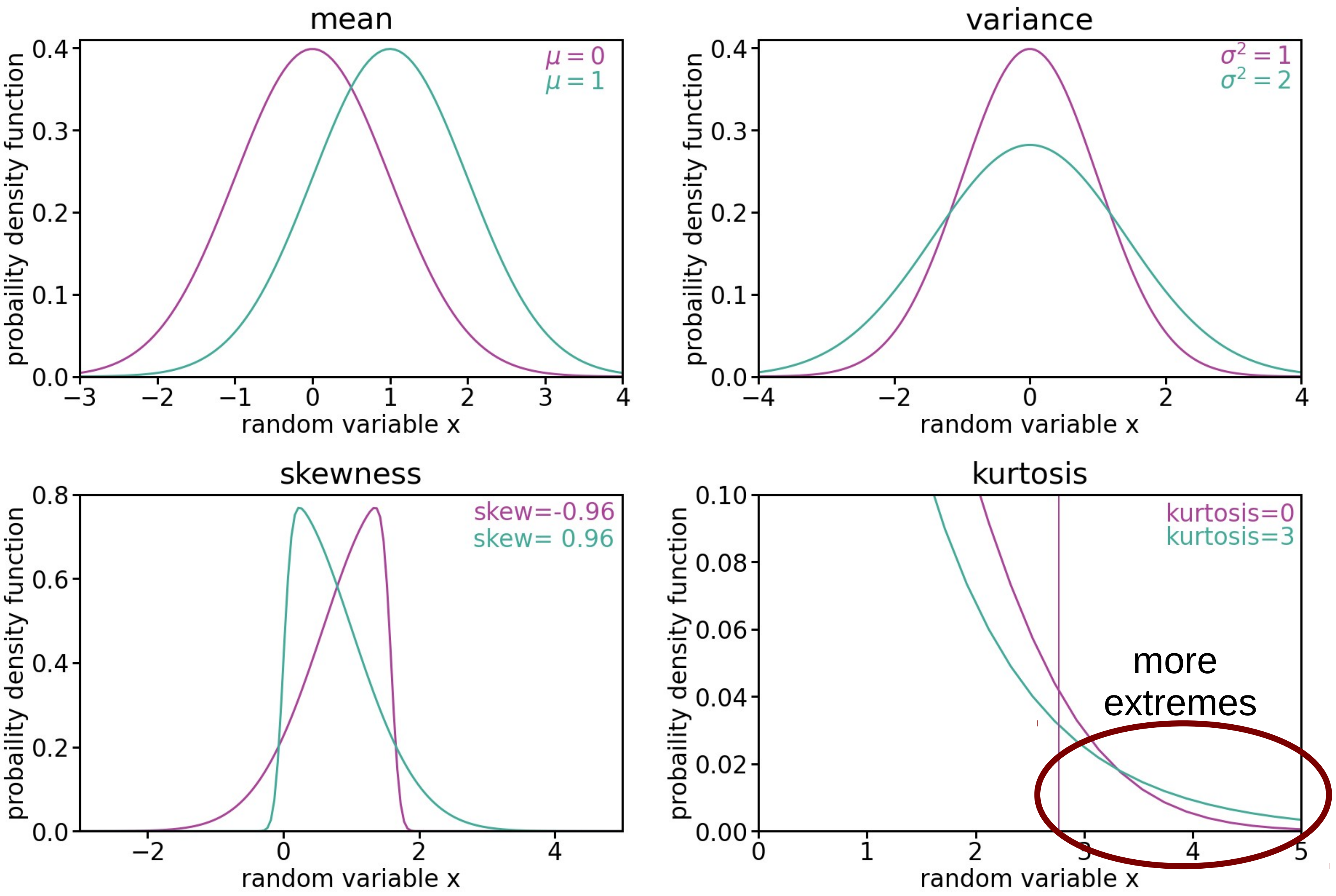
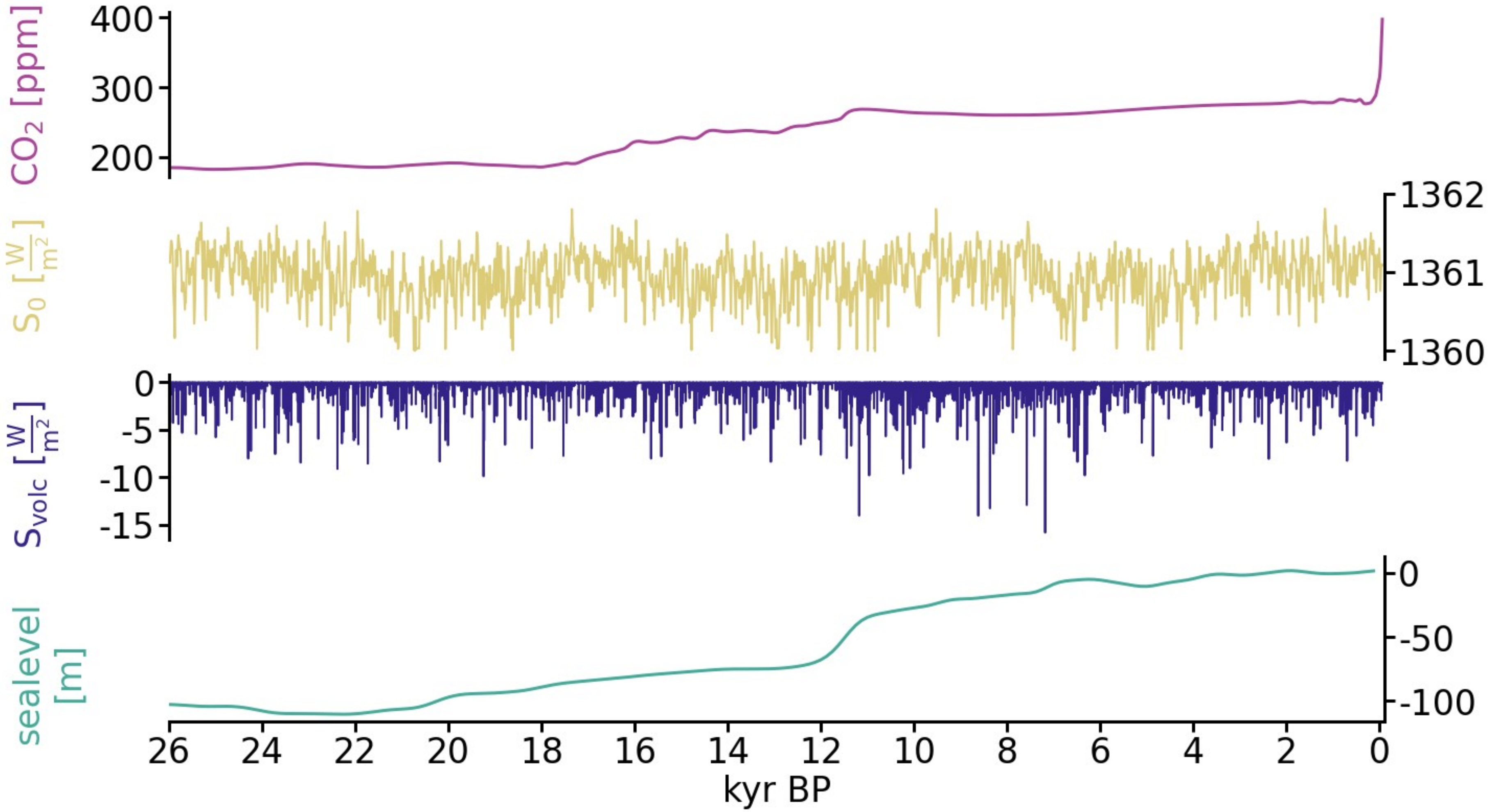


So how do the distributions of temperature & precipitation change under global warming?

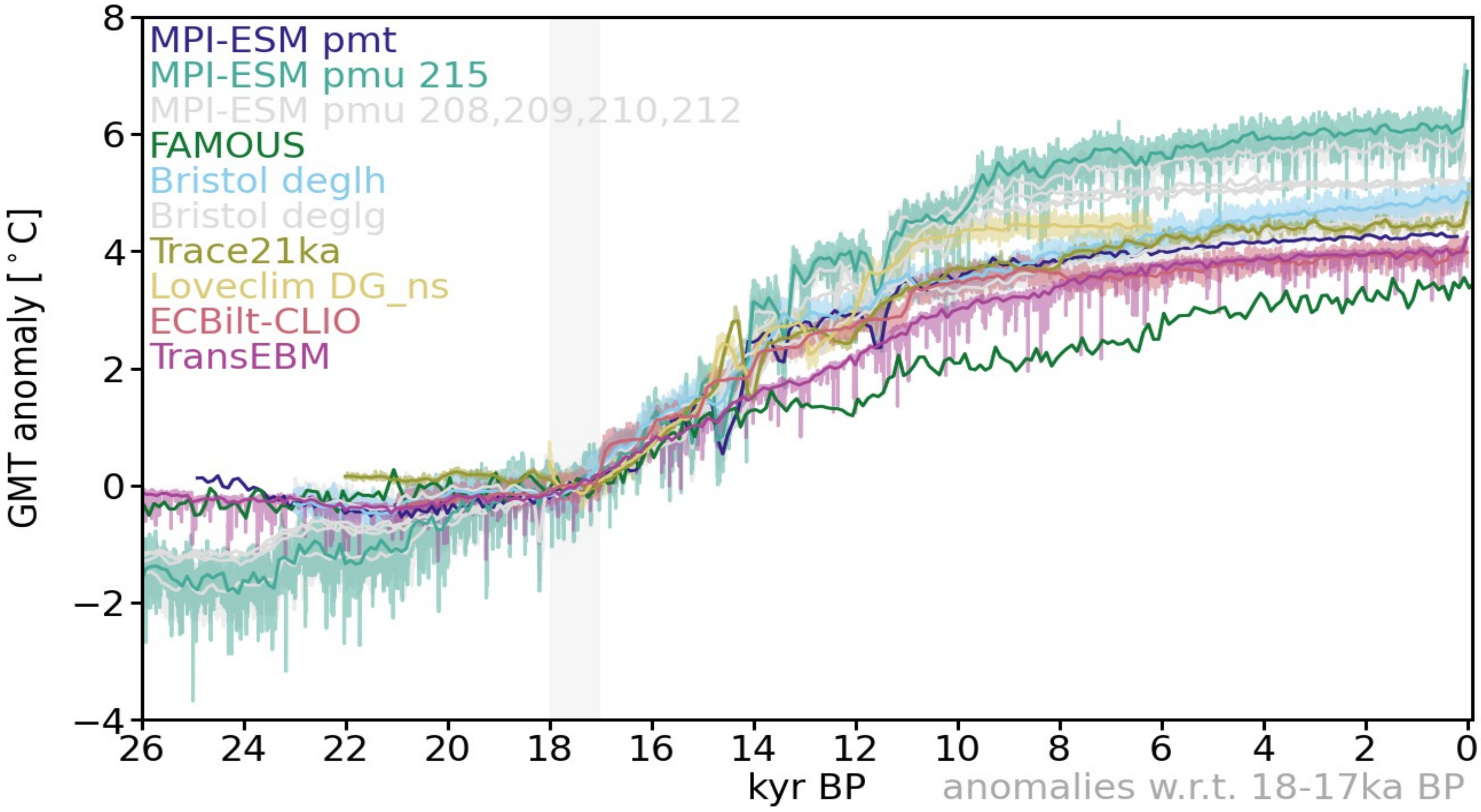
Analyze transient simulations of the Last Deglaciation from models of varying complexity

Forcings from LGM to present day



volcanic: Schindlbeck-Belo, Kutterolf, Toohey, pers. comm., CO_2: Köhler et al. 2017, sealevel: Grant et al. 2012 , solar: surrogate from Steinhilber et al. 2009

Global means in transient Deglacial simulations



3-7° GMT increase since LGM

Models: MPI-ESM pmt Kleinen et al. 2020, pmu Kapsch et al, pers. comm., FAMOUS Smith & Gregory 2012, Bristol Gregoire, Ivanovic & Valdes, pers. comm., Trace21k He 2010, Loveclim DG_ns Menviel et al. 2011, ECBilt-CLIO Timm&Timmermann 2007, TransEBM forcing: CO_2: Köhler et al. 2017, orbital: Berger 1978, meltwater: assimilated from SSTs Jonkers et al. 2020, ice: Argus et al. 2014 & Peltier et al. 2015, volcanic: Schindlbeck-Belo, Kutterolf, Toohey, pers. comm., solar: surrogate from Steinhilber et al. 2009

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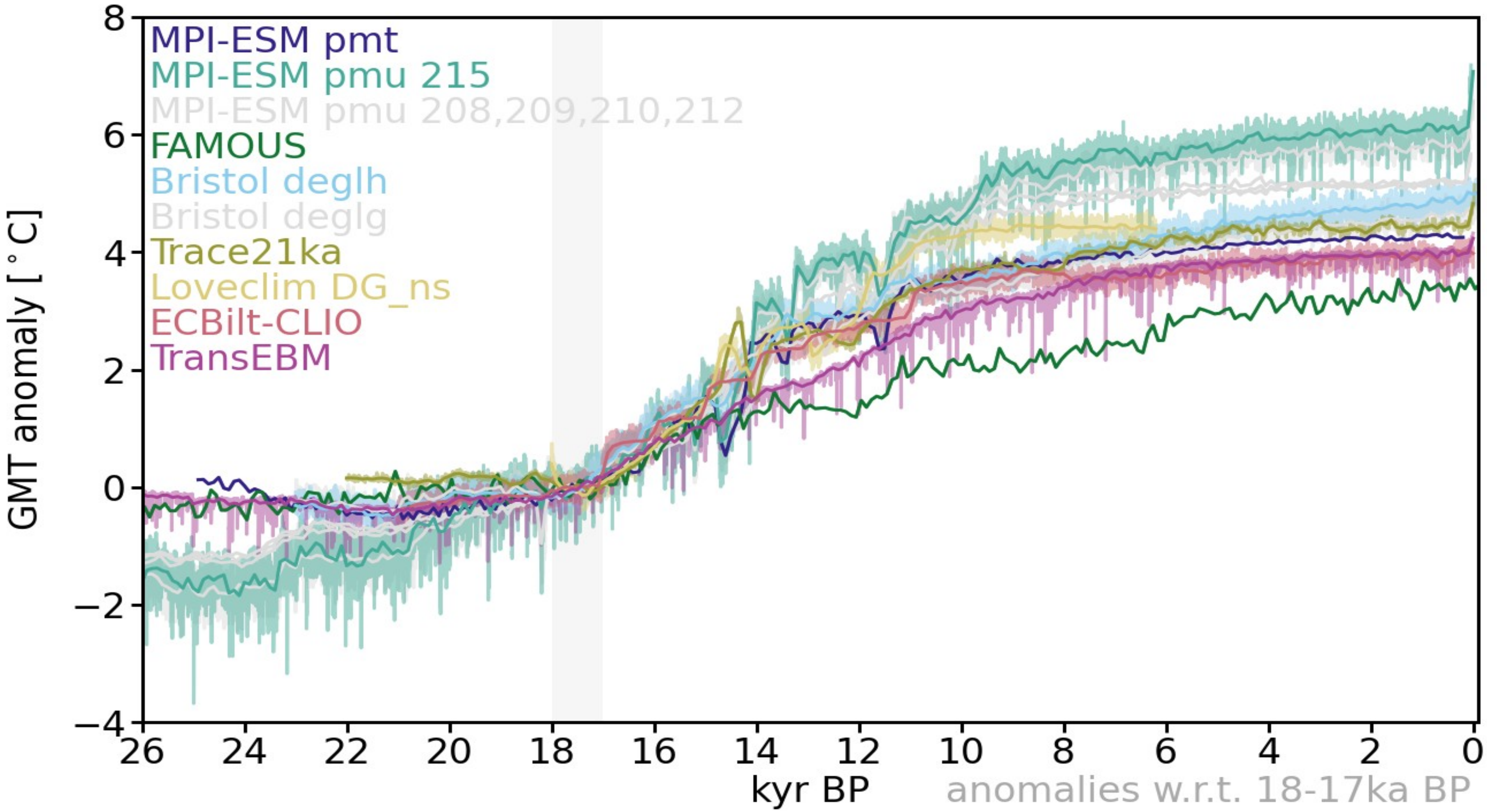

3-7° GMT increase since LGM

Here, 3 example simulations

- LGM 23-19 ka, Deglaciation 19-8 ka, Holocene 8-0 ka BP
- separate linear detrending of periods
- resolution: T21, 100 yr

⇨ Centennial changes

TransEBM experiments

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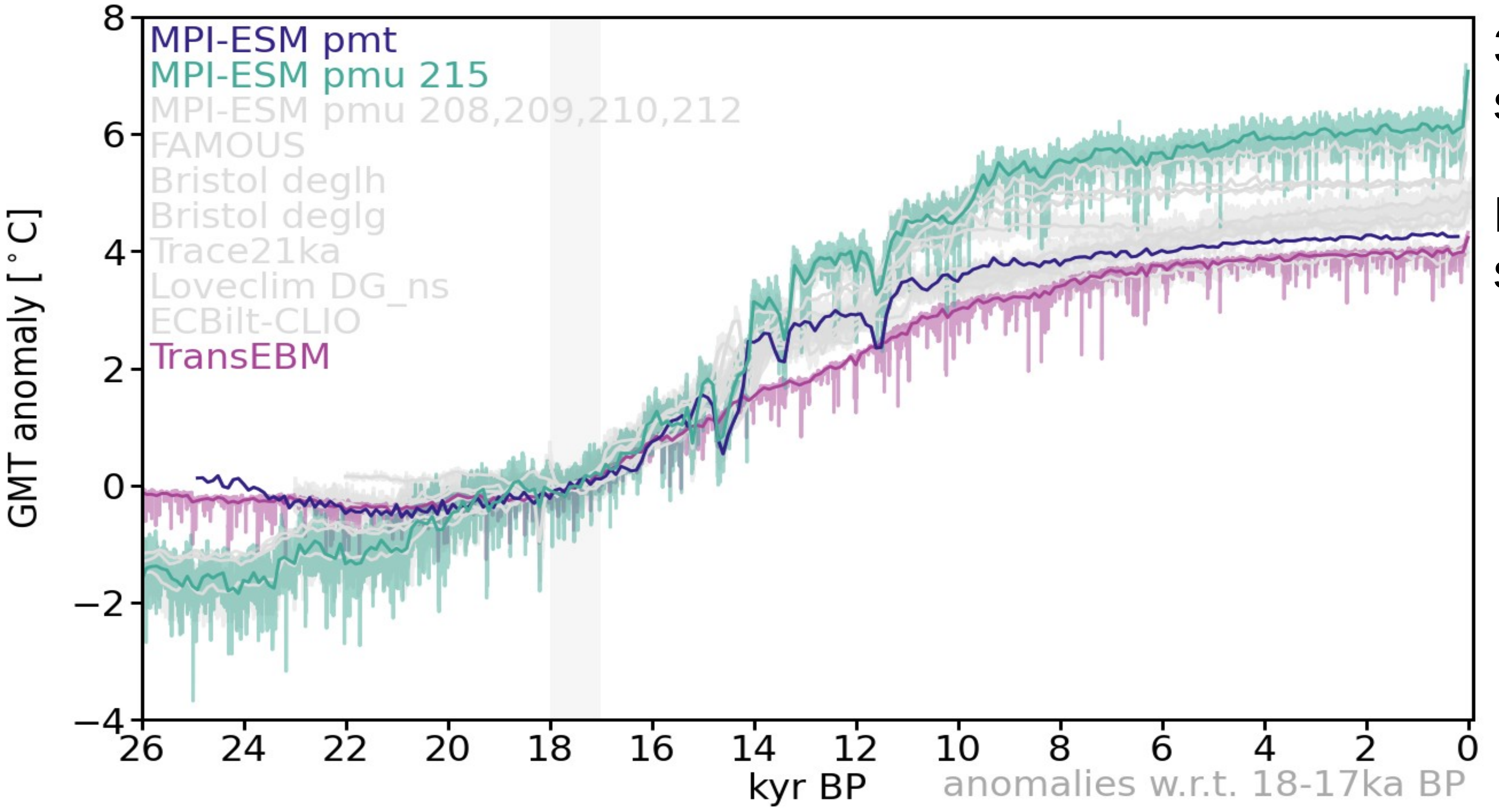

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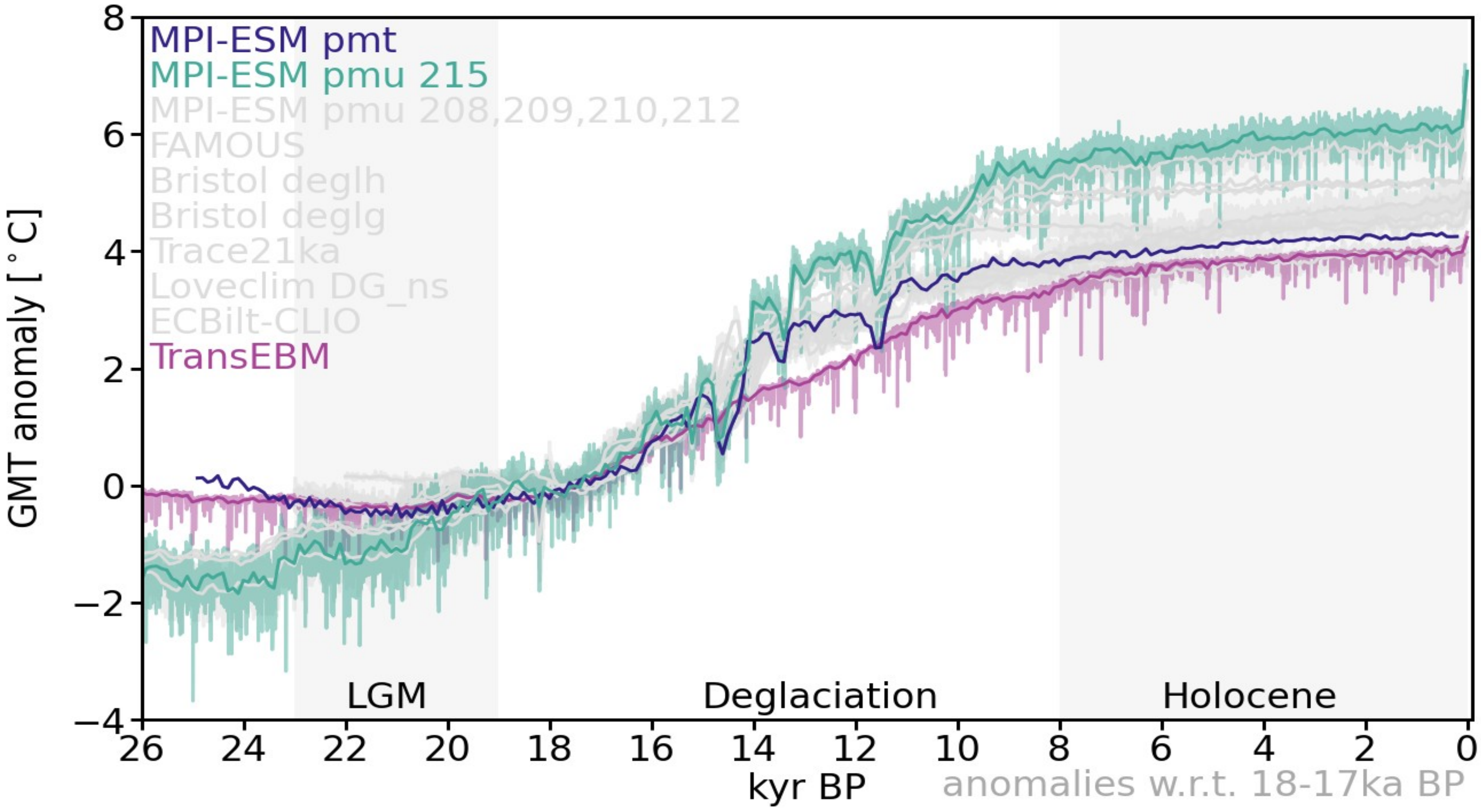

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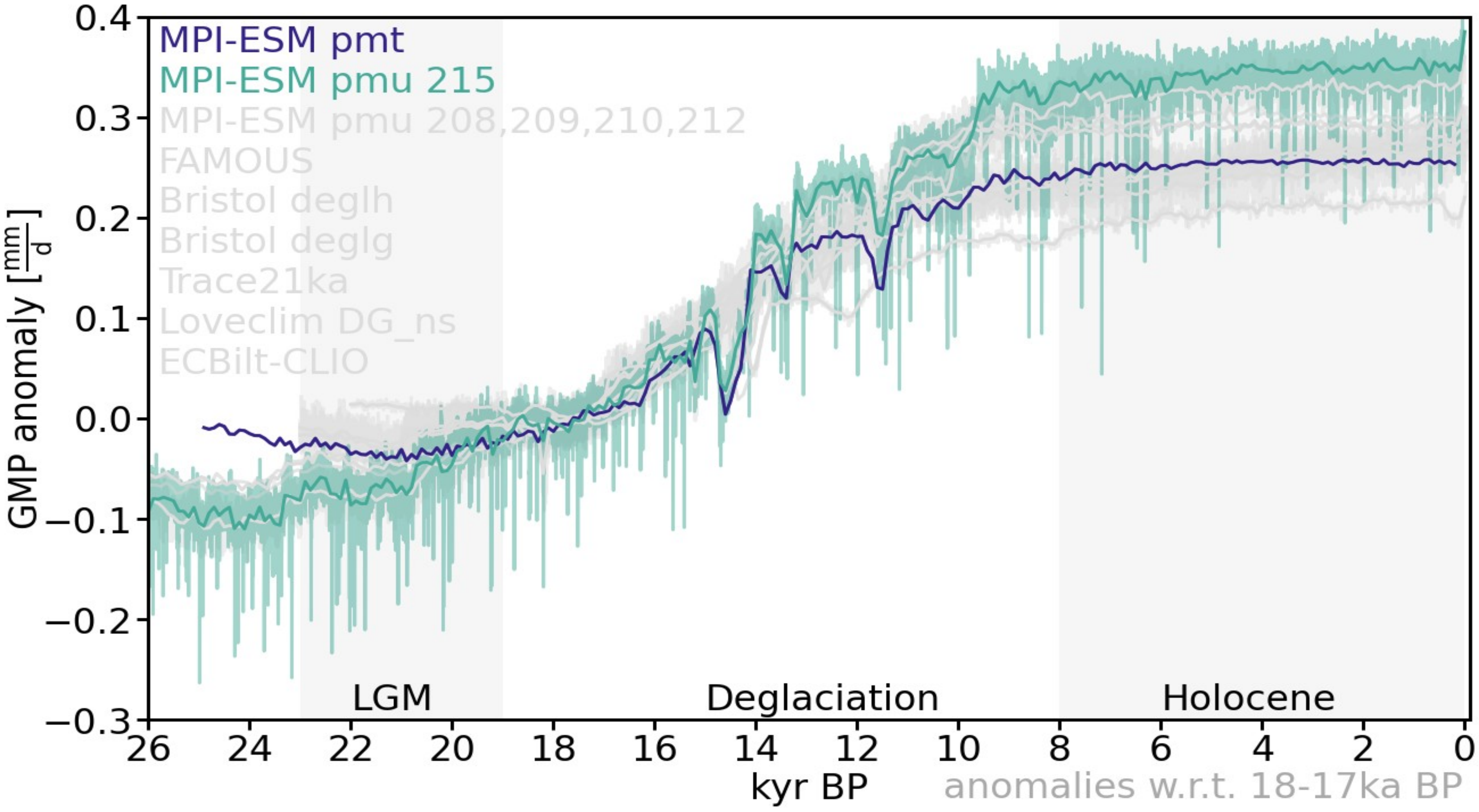

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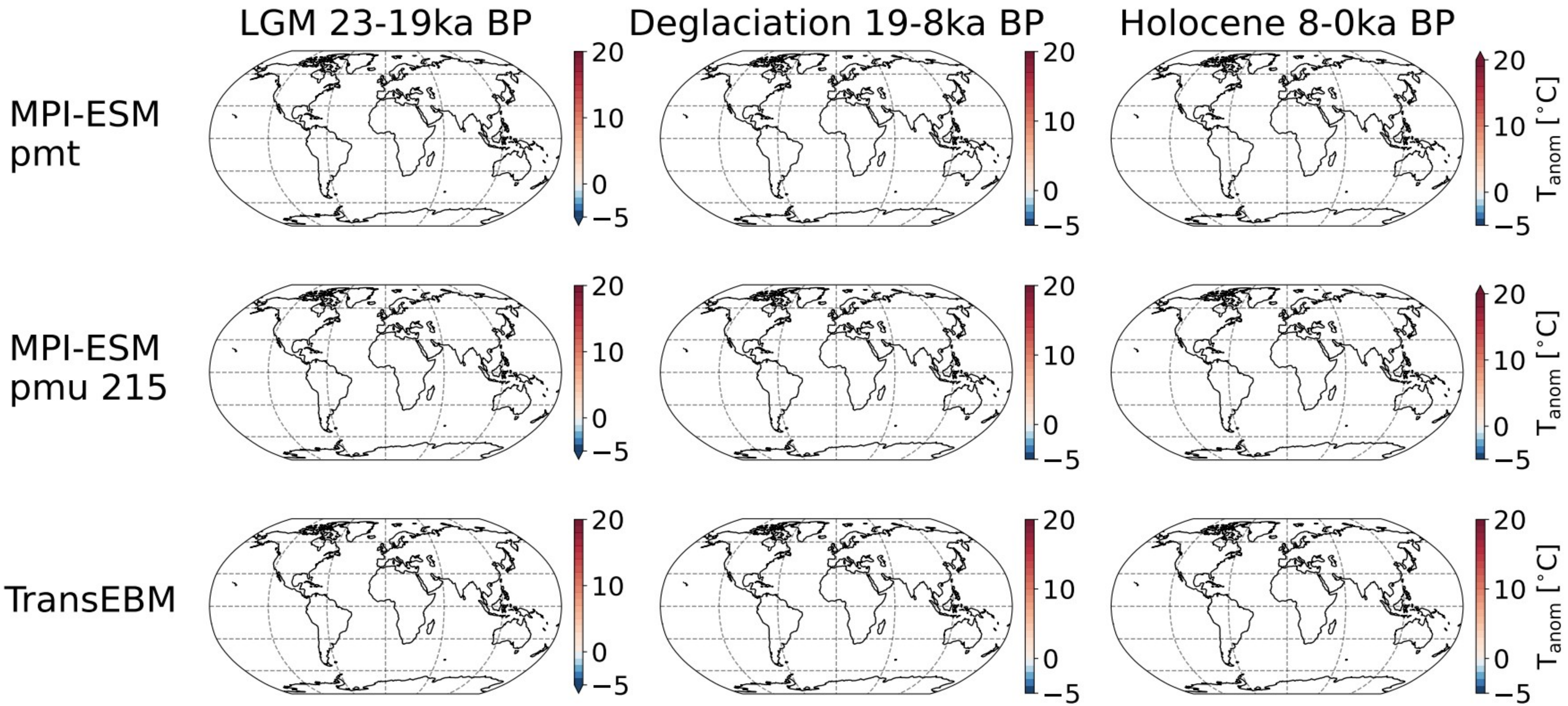
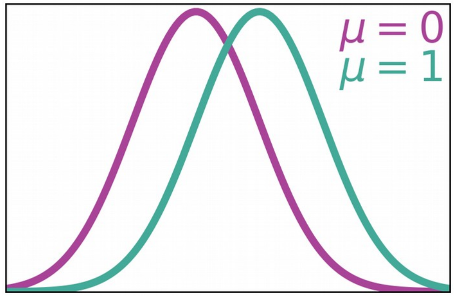
Temperature mean:



anomalies w.r.t. 18-17ka BP



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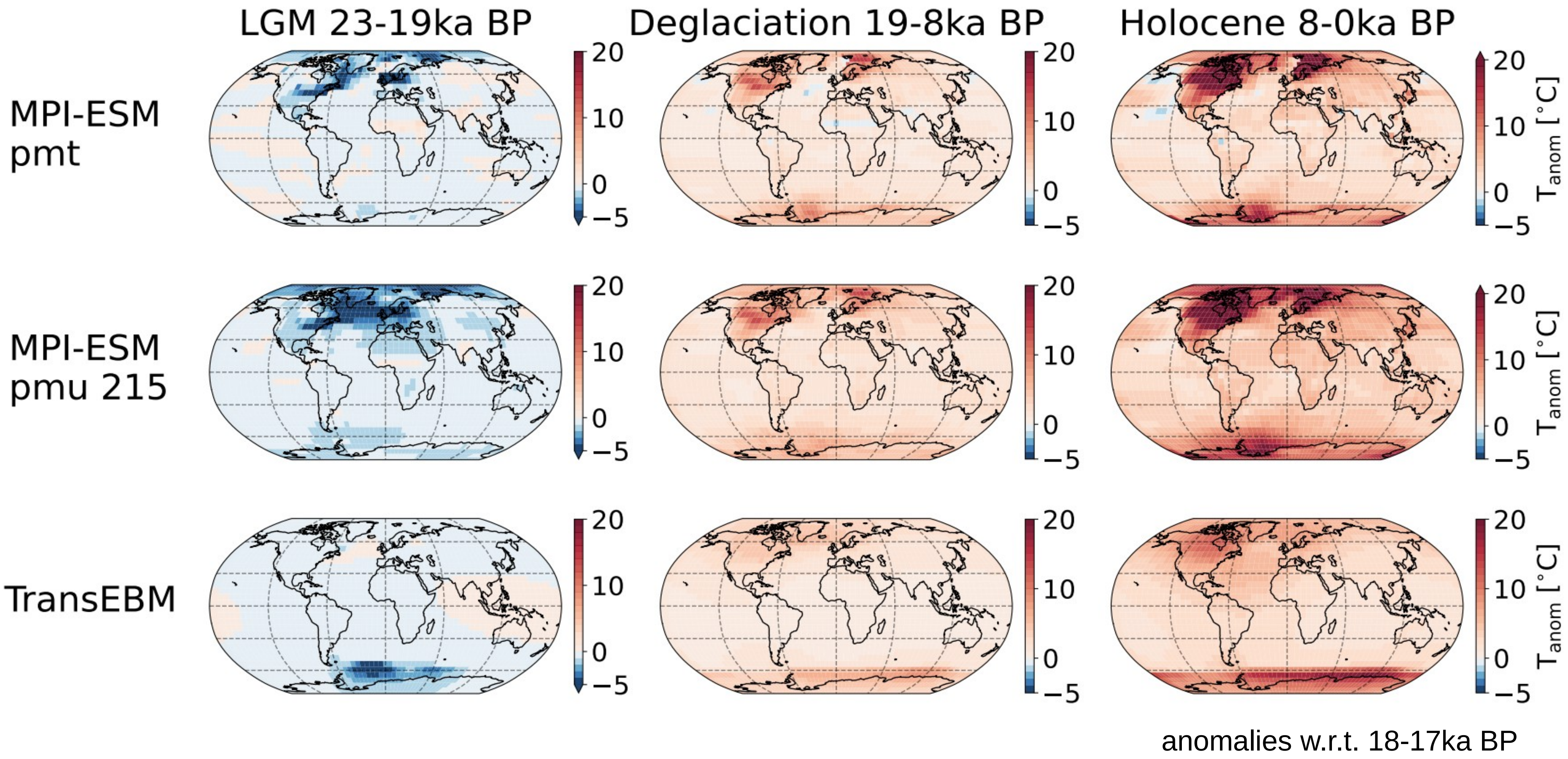
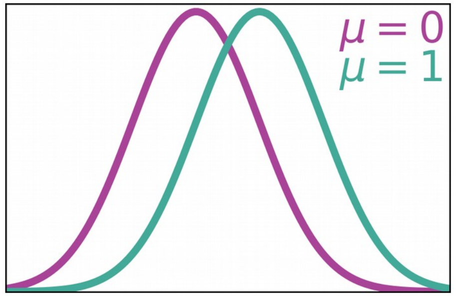
Temperature mean: warming across simulations





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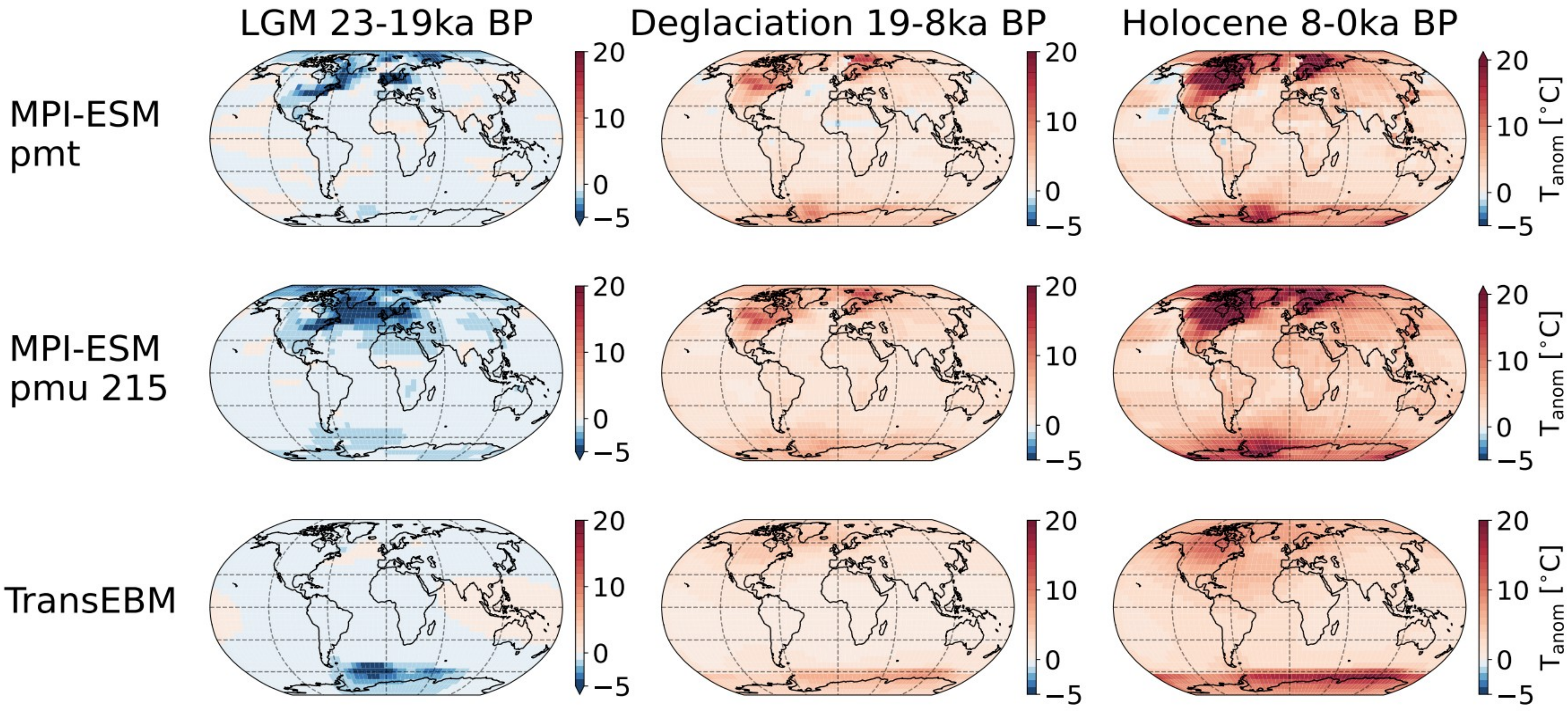
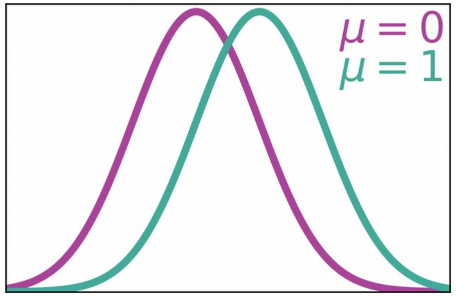


- degree of change varies

anomalies w.r.t. 18-17ka BP



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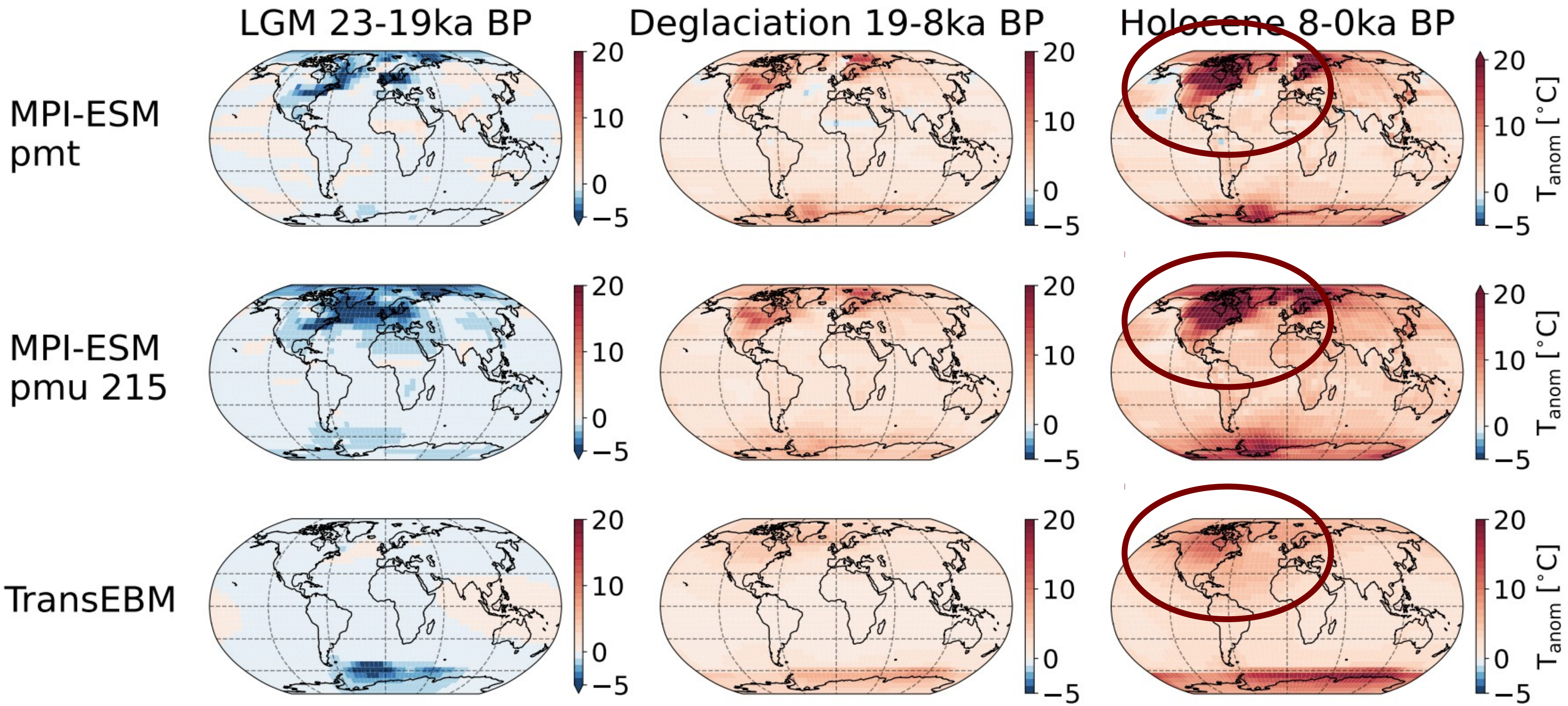
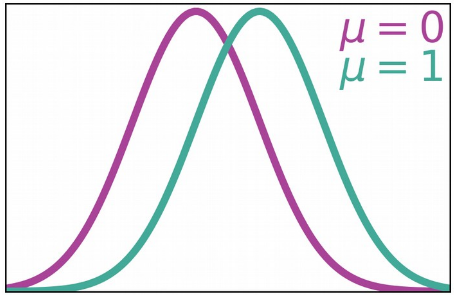


anomalies w.r.t. 18-17ka BP

- degree of change varies

Regional:
- large warming in (northern) high latitudes



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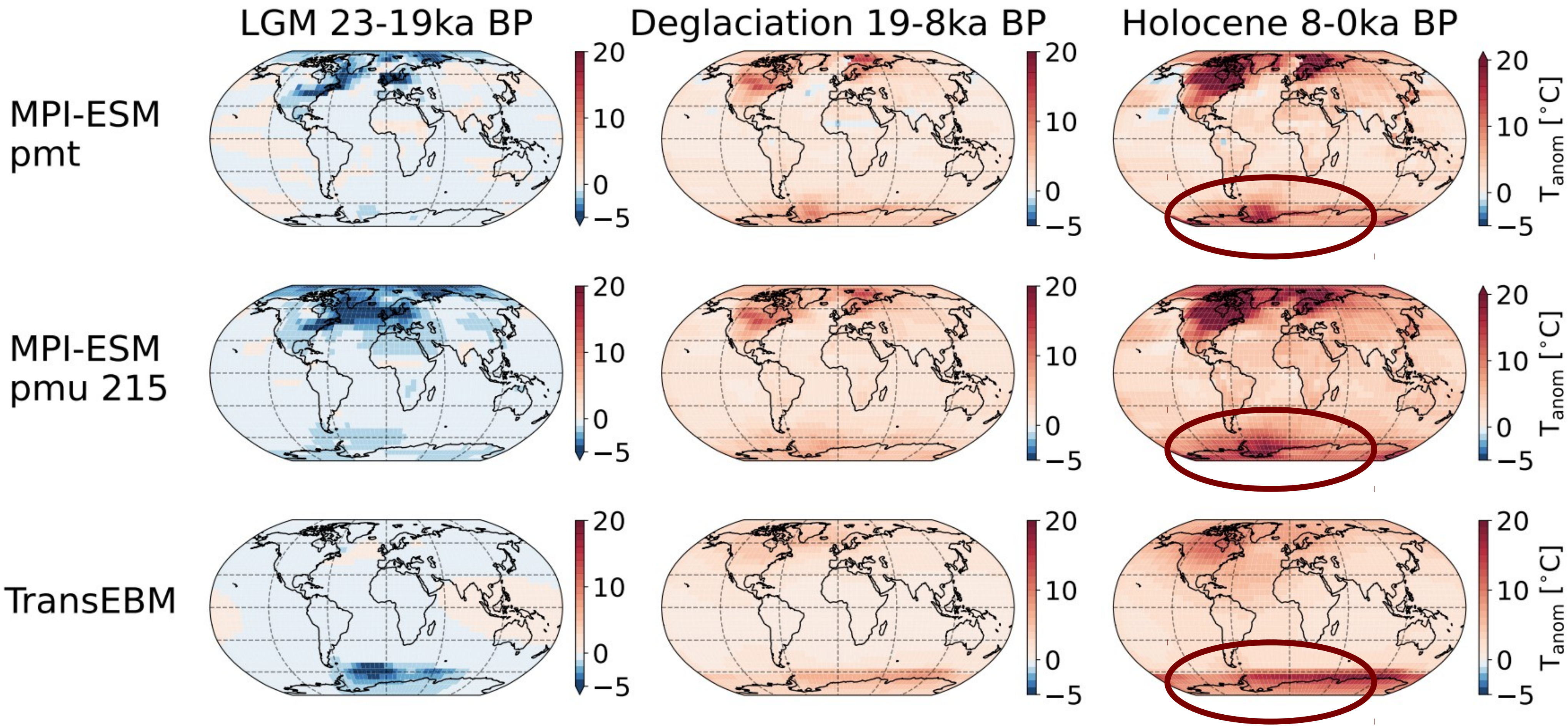
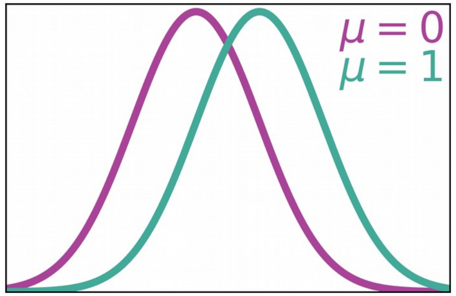


anomalies w.r.t. 18-17ka BP

- degree of change varies

Regional:

- large warming in (northern) high latitudes
- effect of changing ice



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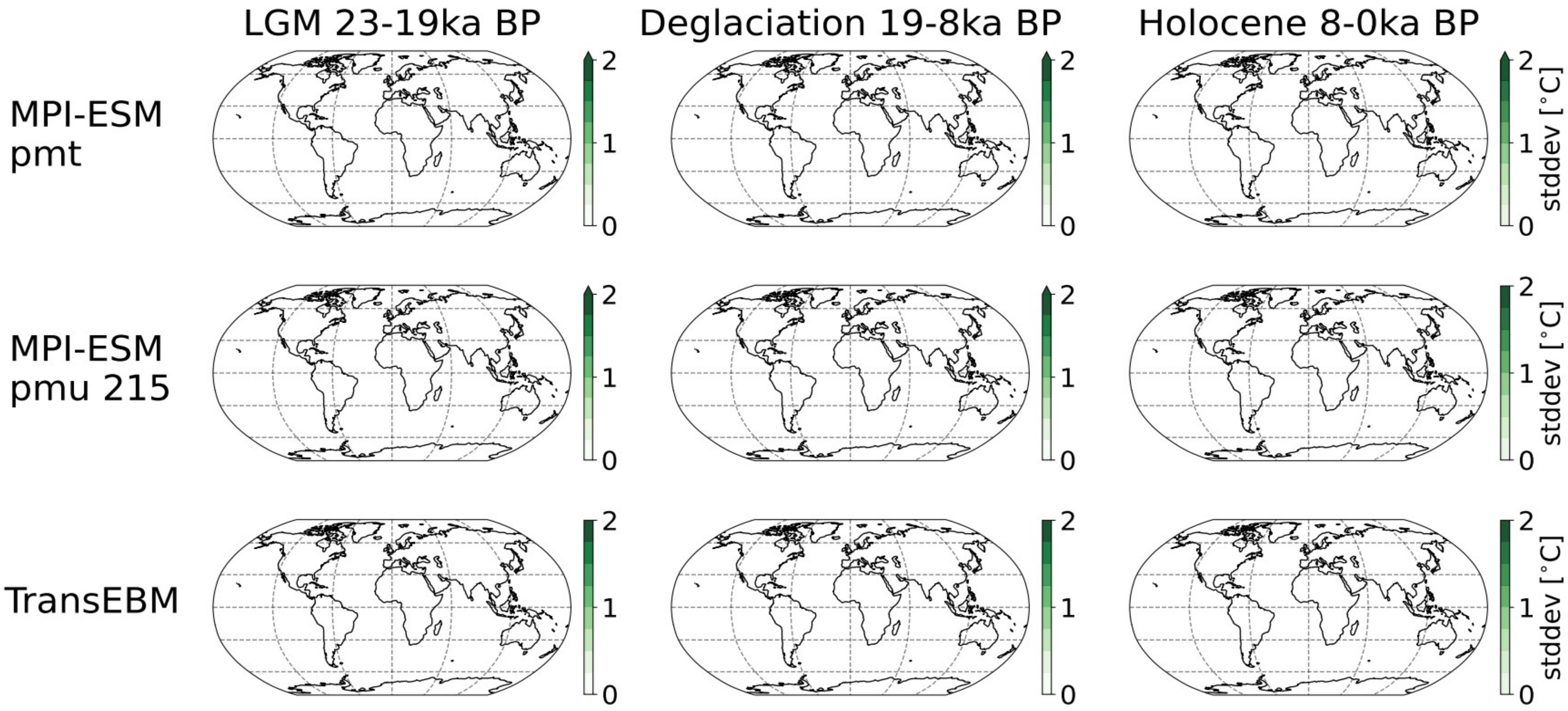
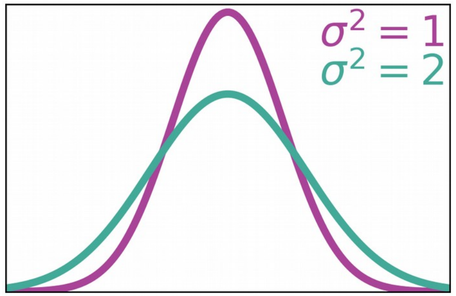
Temperature standard deviation





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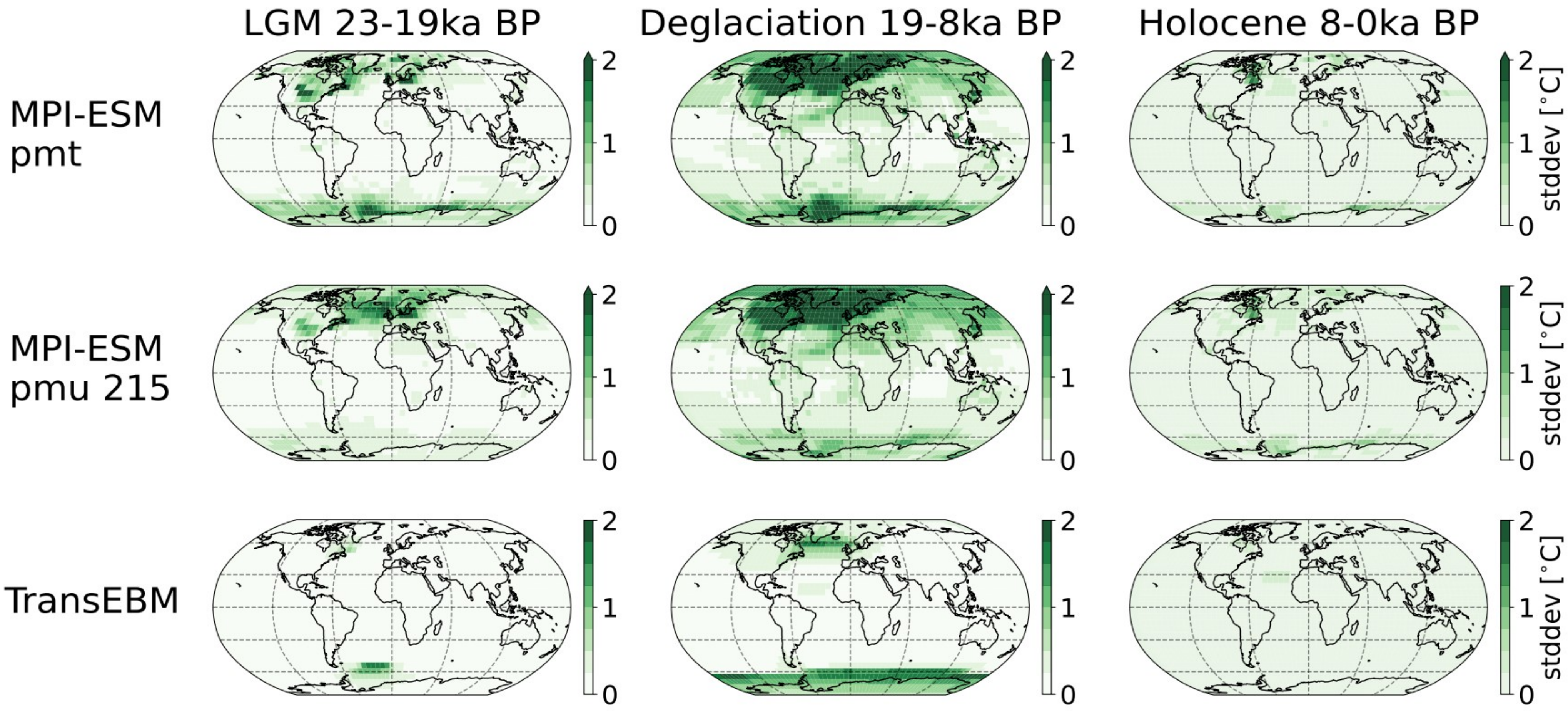
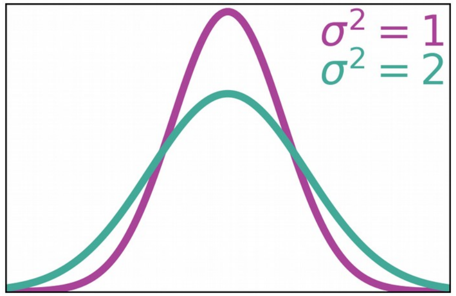
Temperature standard deviation decreases towards Holocene





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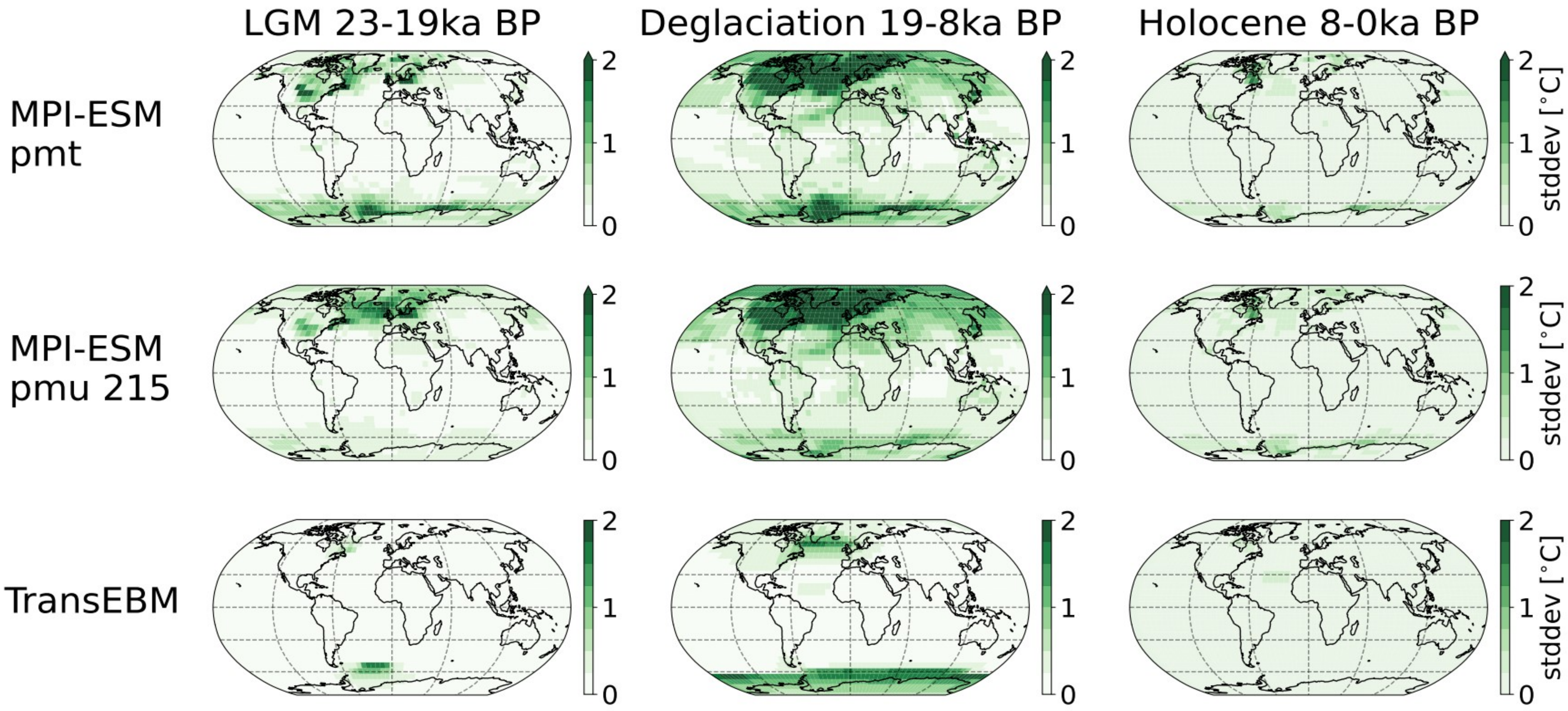
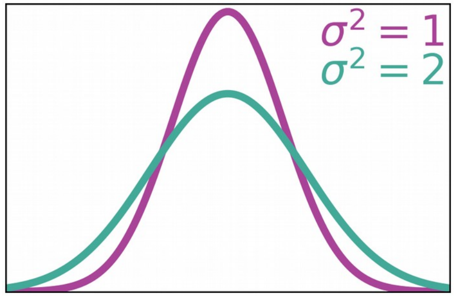


- Deglaciation highest
- Holocene lowest



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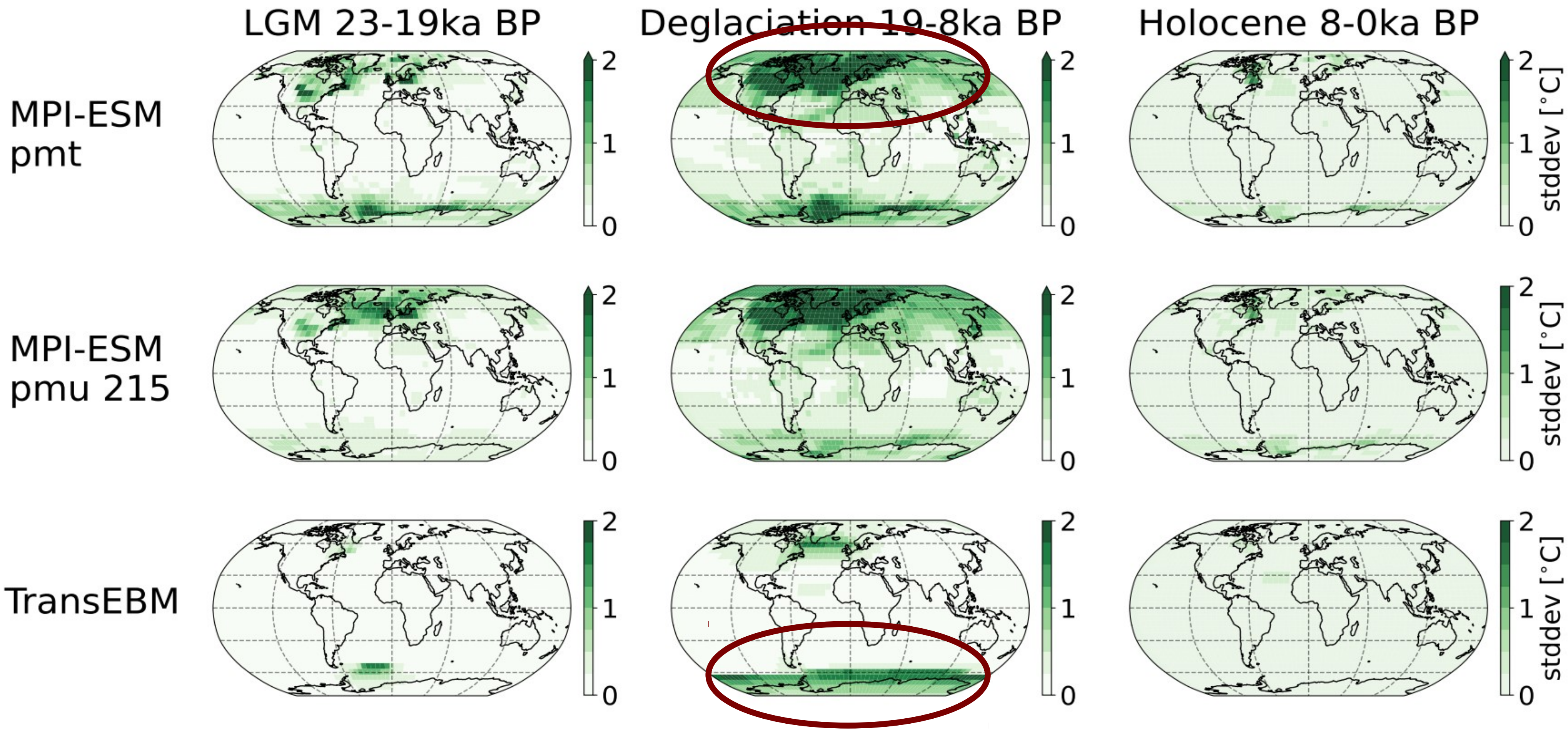
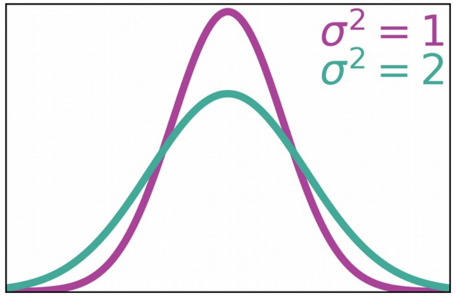


- Deglaciation highest
- Holocene lowest

Regional:

- largest in (northern) high latitudes



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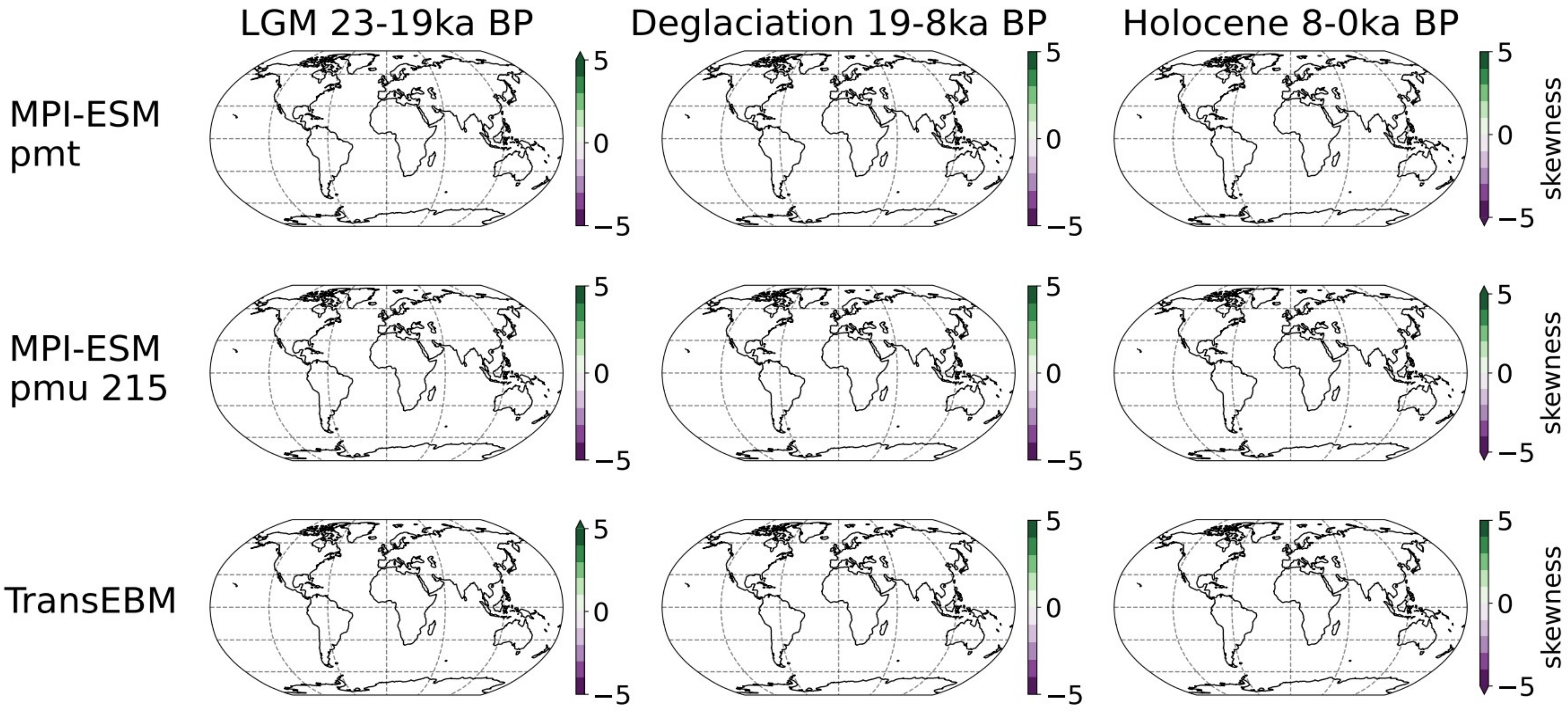
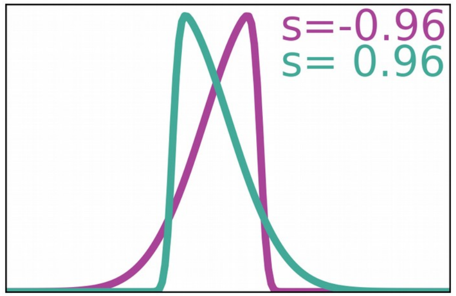
Temperature skewness





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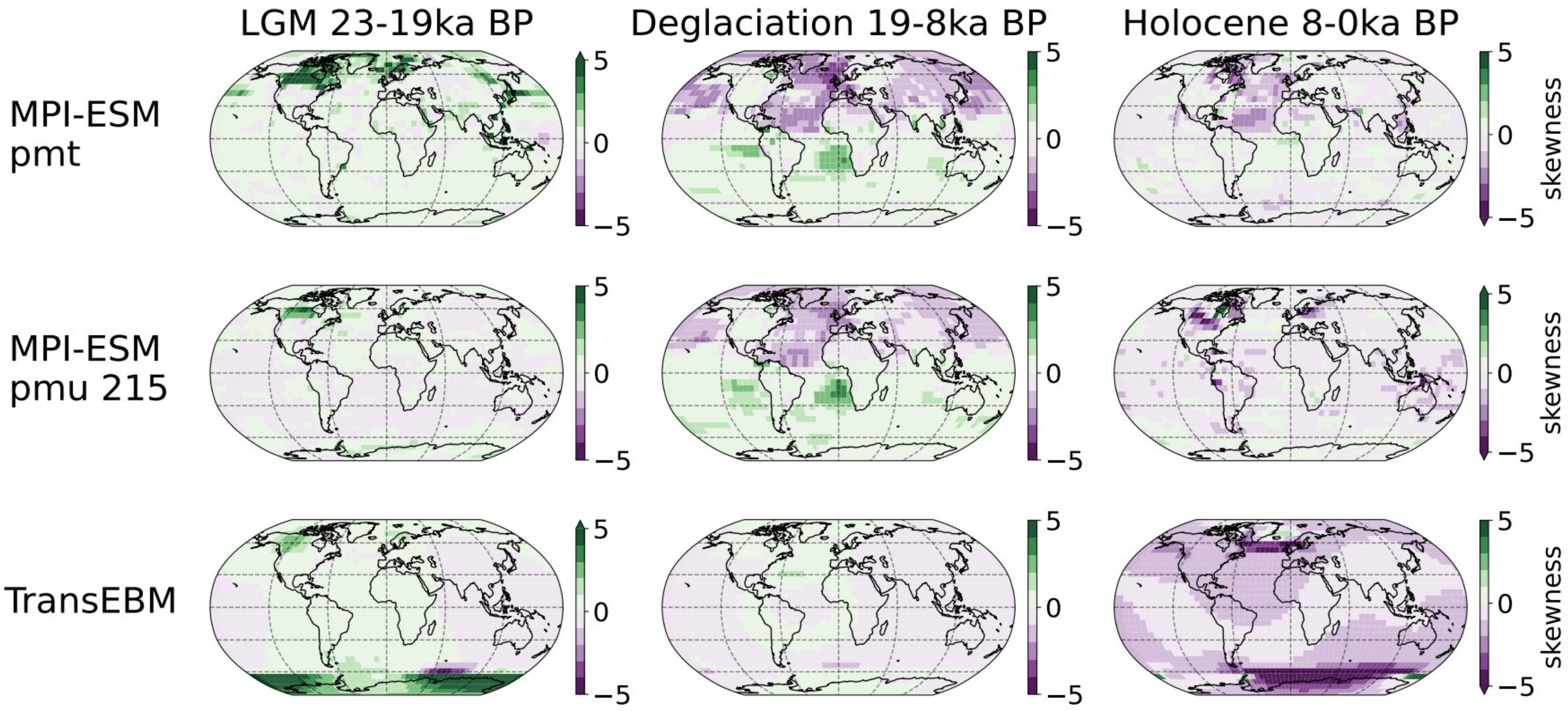
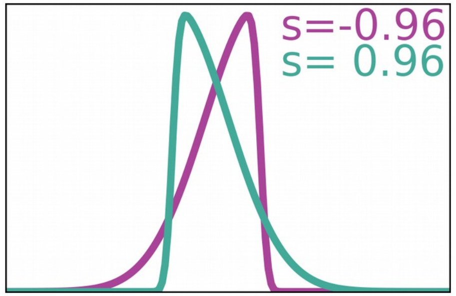
Temperature skewness decreases with warming





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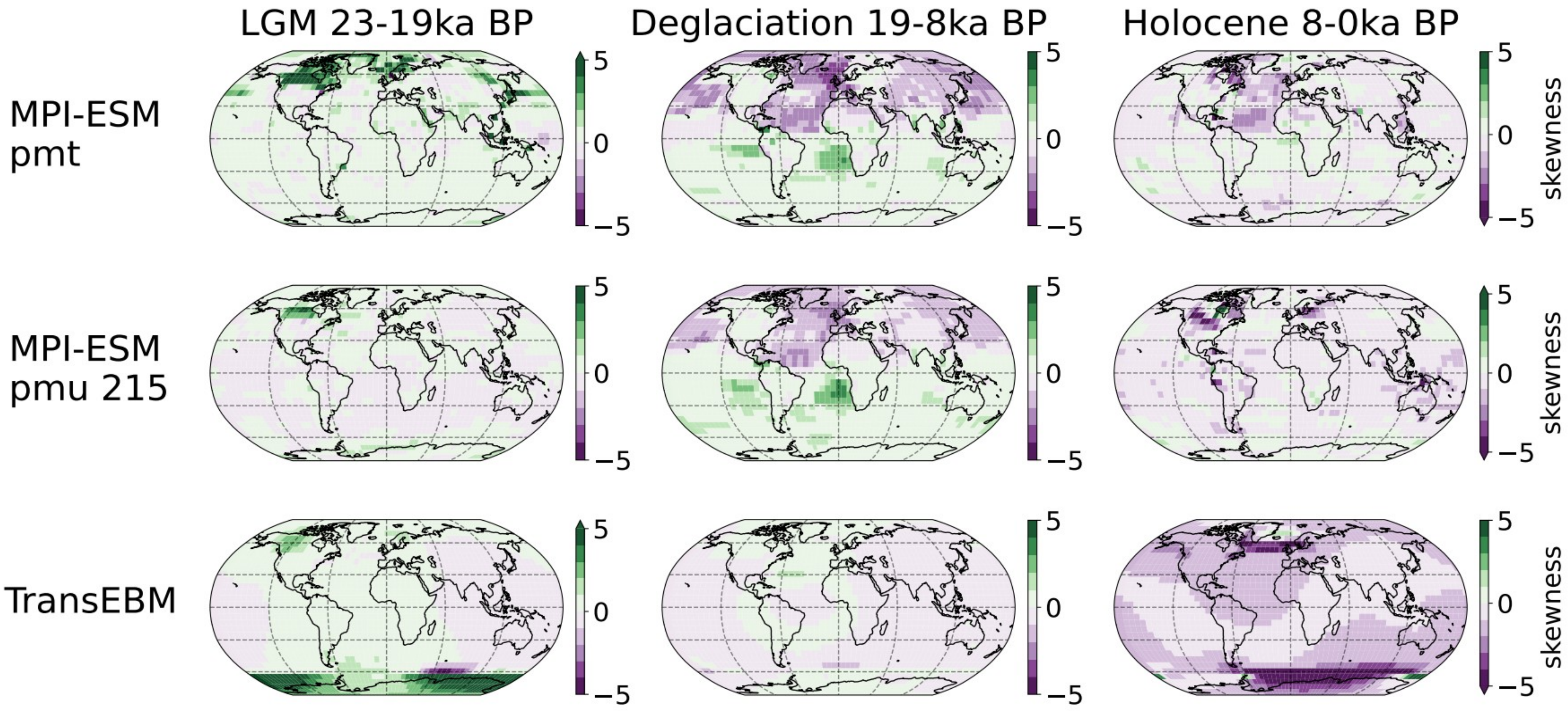
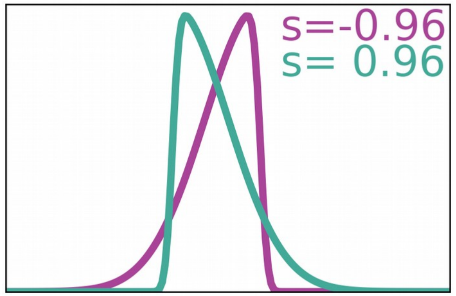


- with warming: more often negative skew



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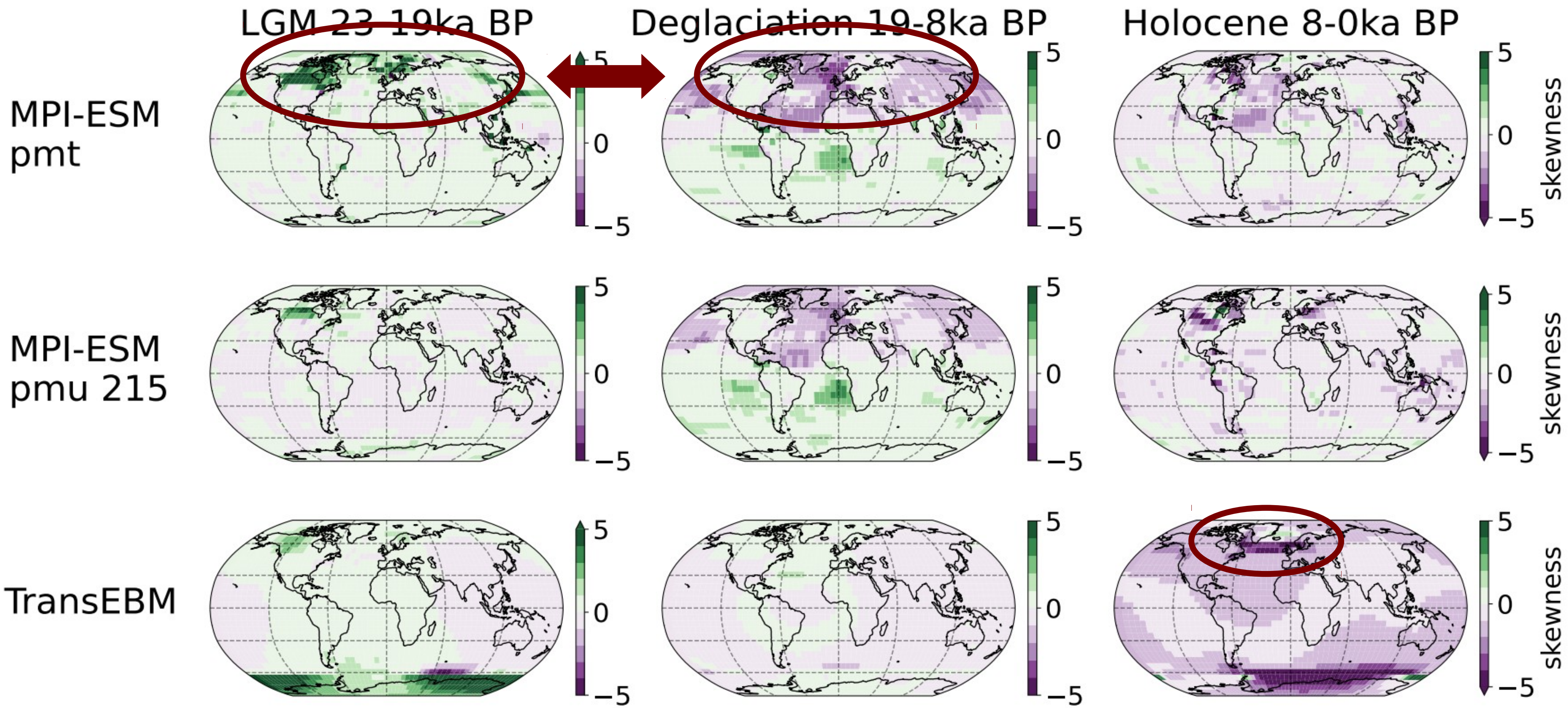
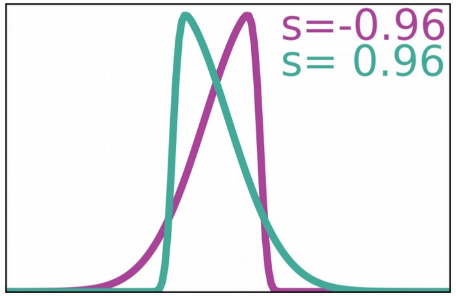


- with warming: more often negative skew

Large changes in response to:

- ice changes
- freshwater forcing



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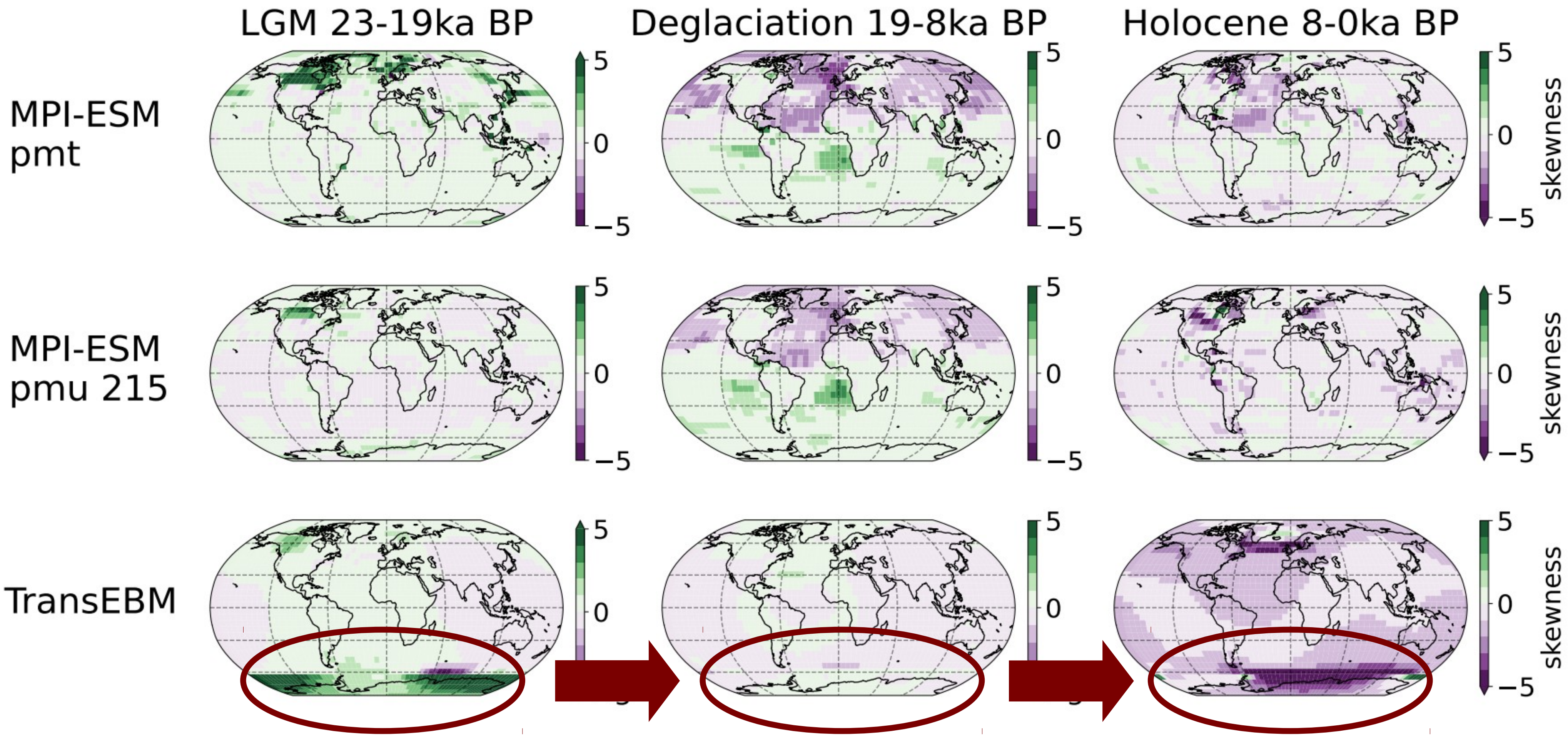

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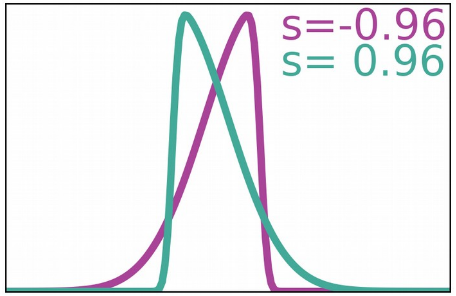

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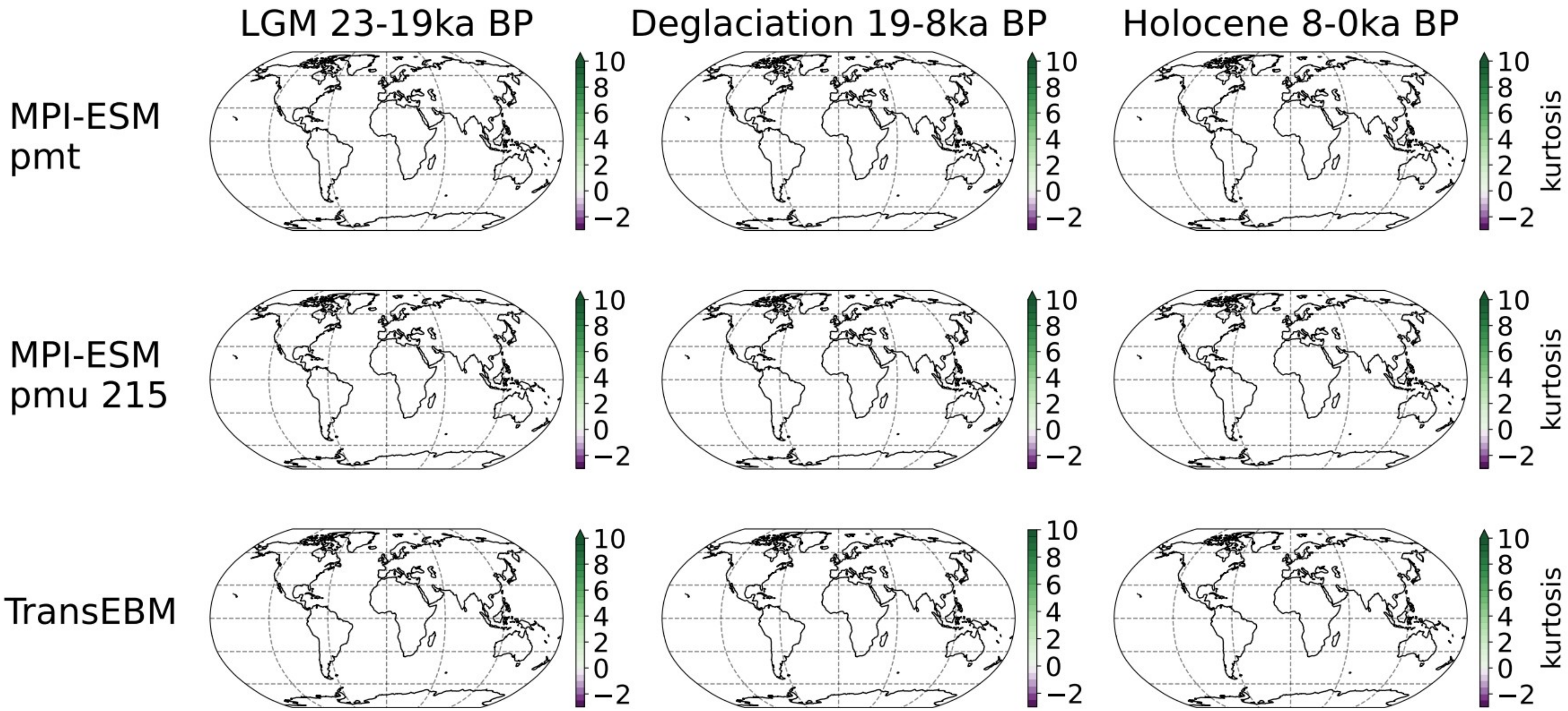
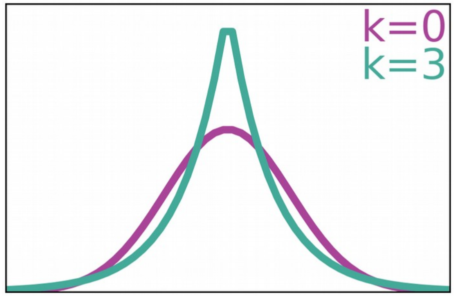
Temperature kurtosis





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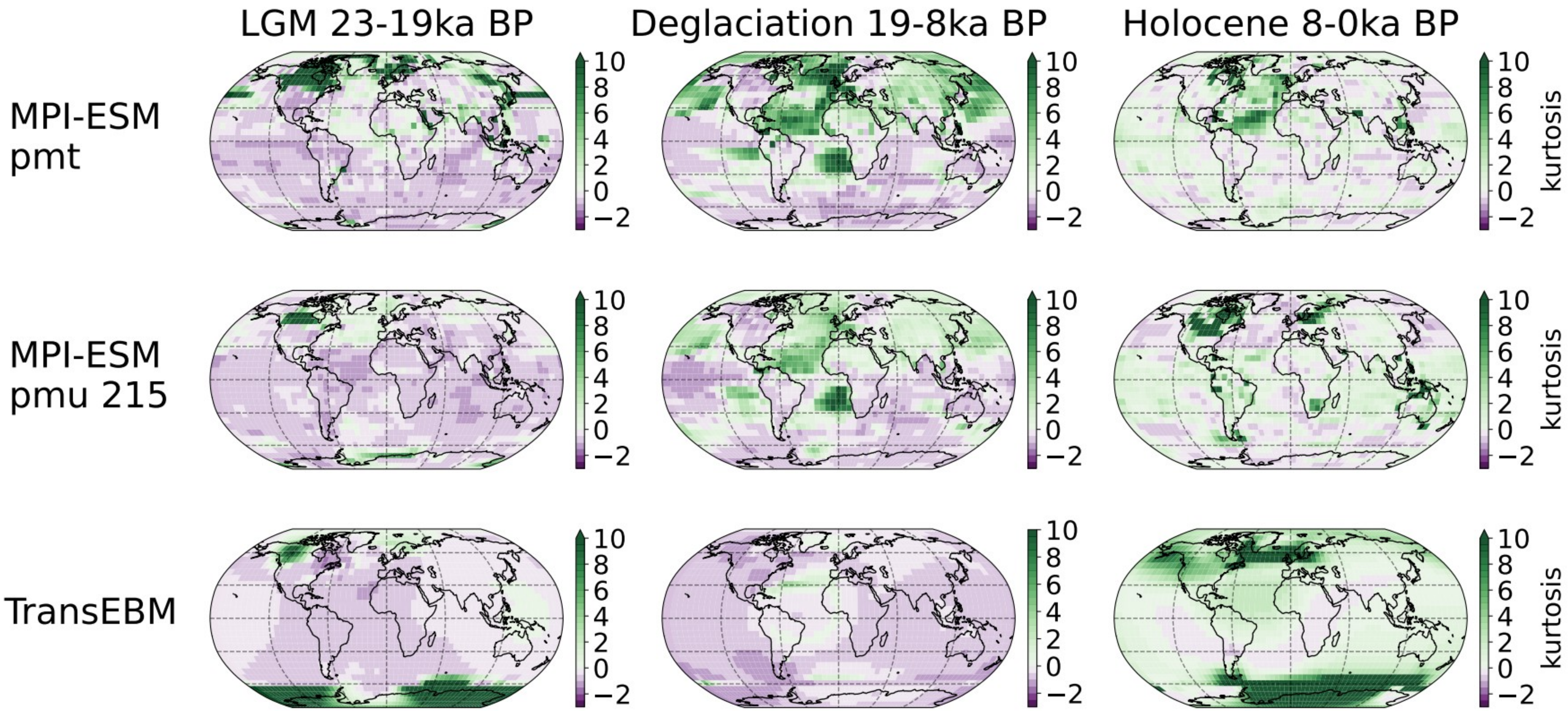
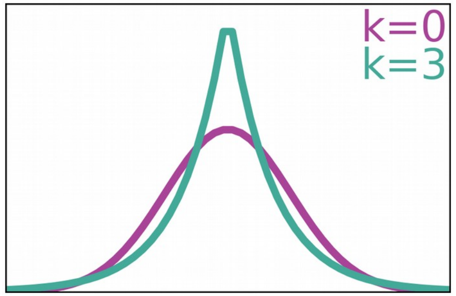
Temperature kurtosis increases with warming





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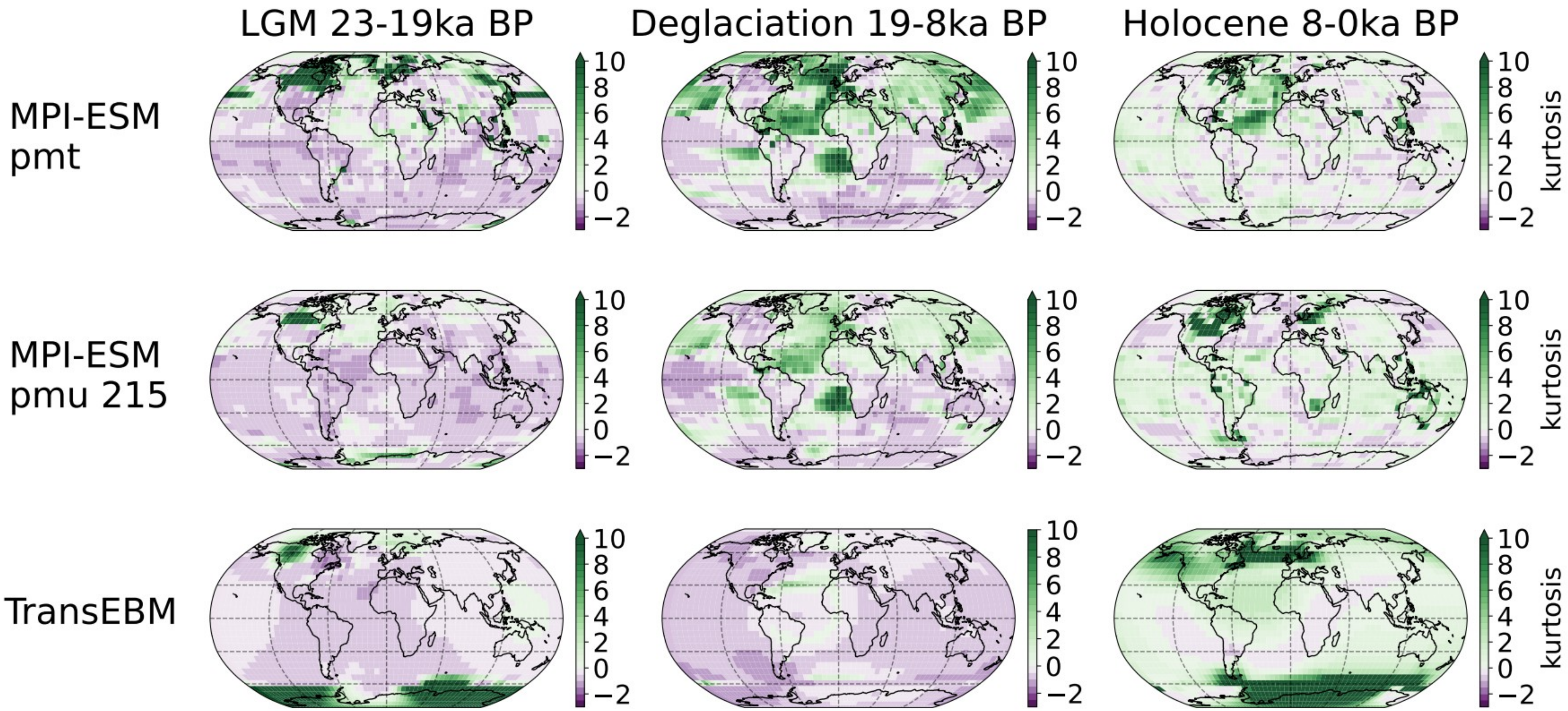
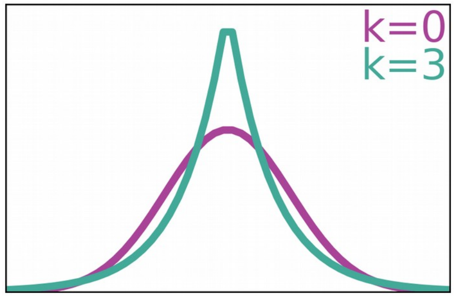


- Holocene: more often positive kurtosis
- differing trends in LGM vs. Deglaciation



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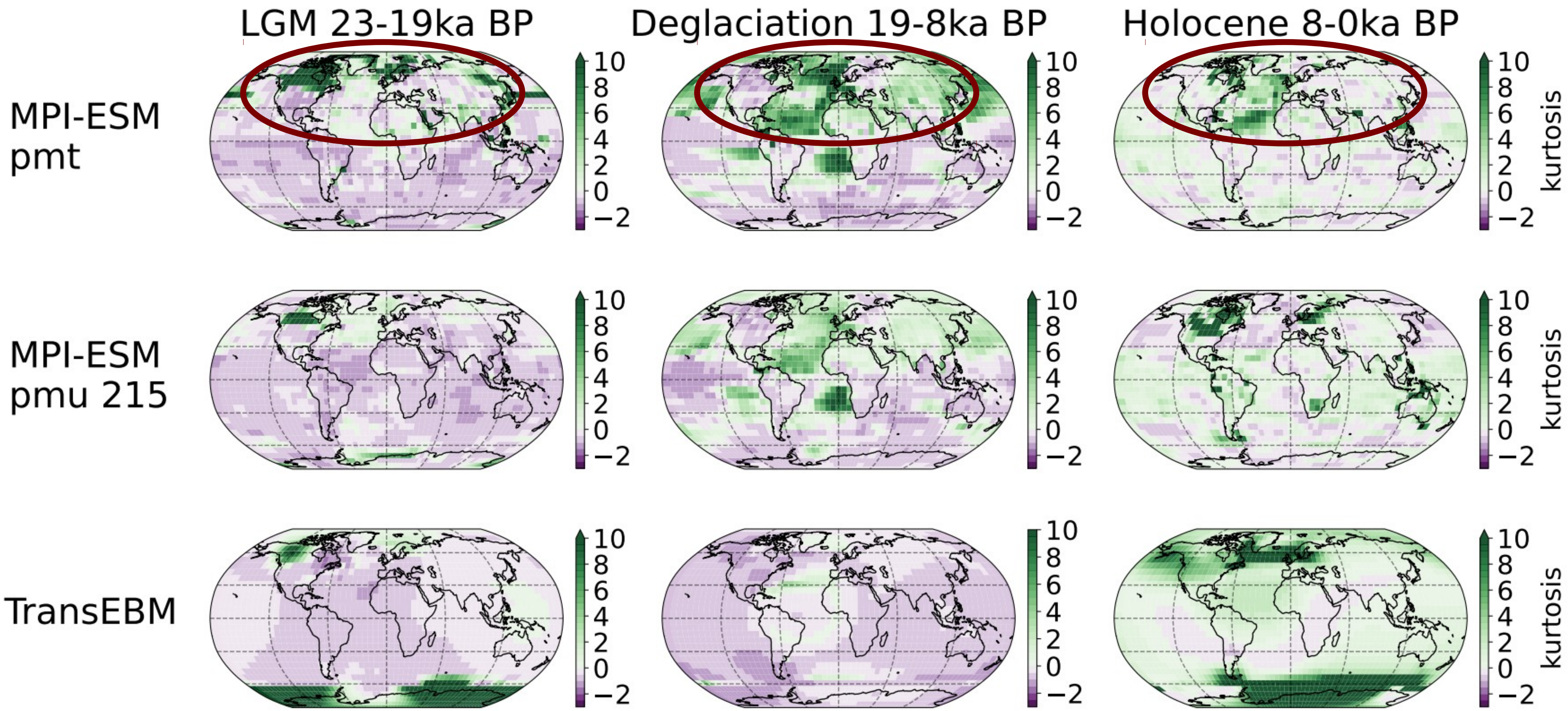

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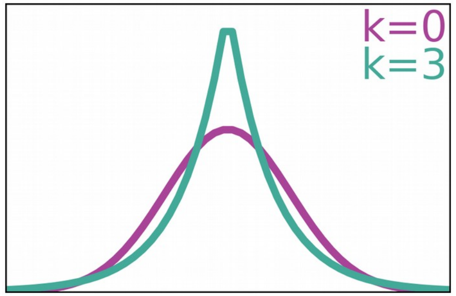

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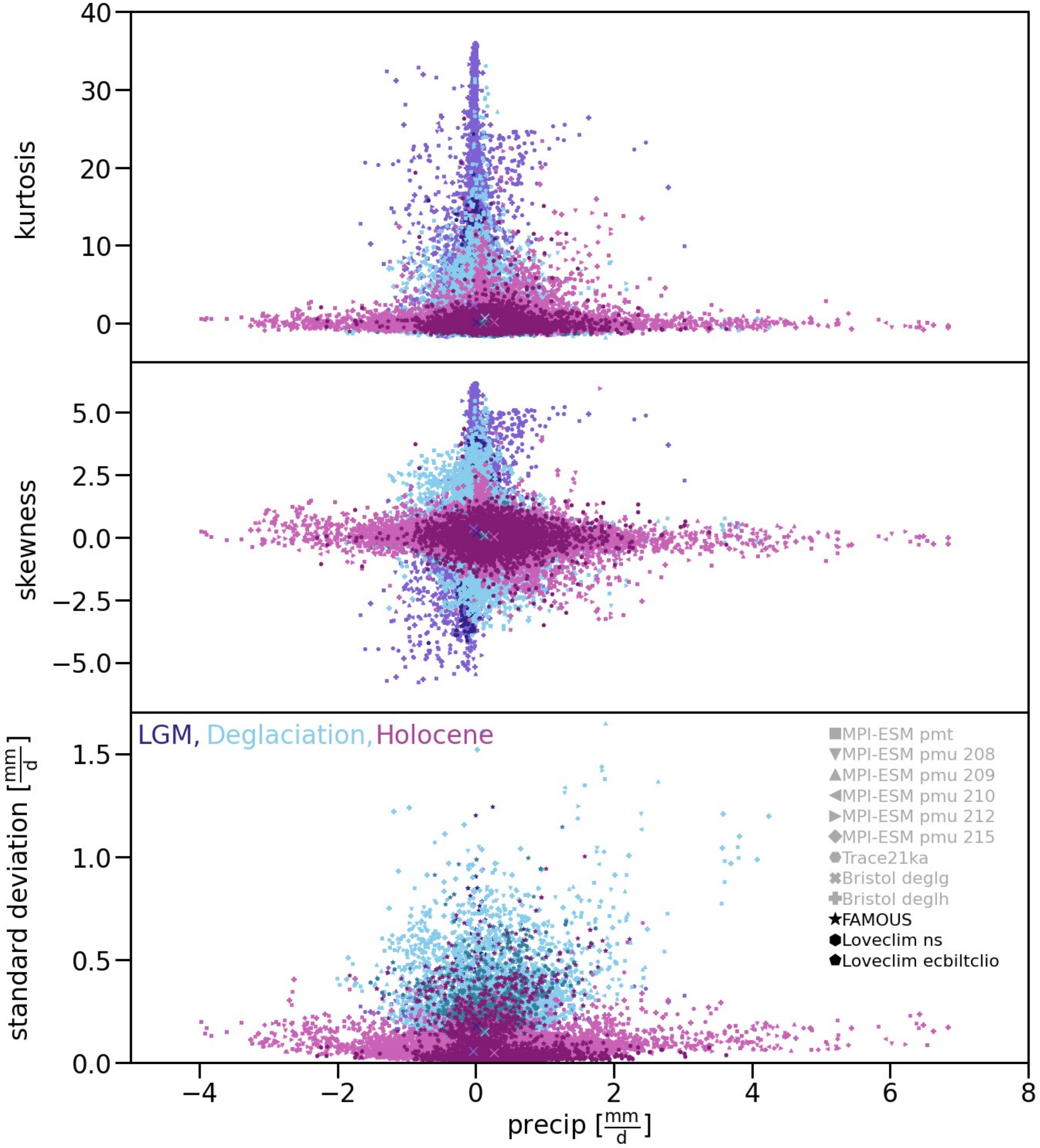
Overall for temperature



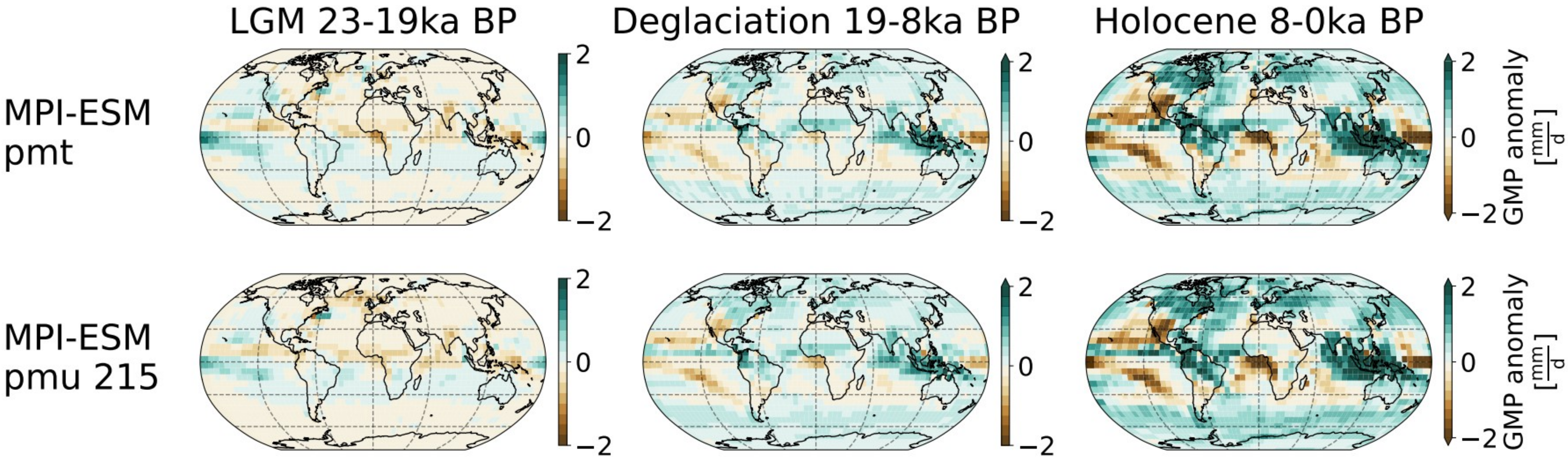
Overall for temperature

With warming:

- high variance while warming, before settling in low variance state
- trend towards negative skewness
- trend towards positive kurtosis

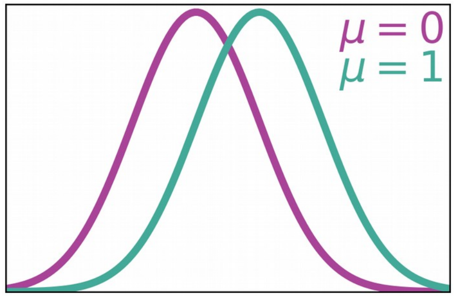
⇨ weight of distribution moves to higher temperatures (“normalizing” what used to be extreme), formerly common cold values part of lower temperature tails

Precipitation mean: wetting across simulations



anomalies w.r.t. 18-17ka BP

Across ensemble
- increase in precipitation towards the Holocene
- especially in tropical regions, Europe and the area of the Laurentide ice sheet over North America



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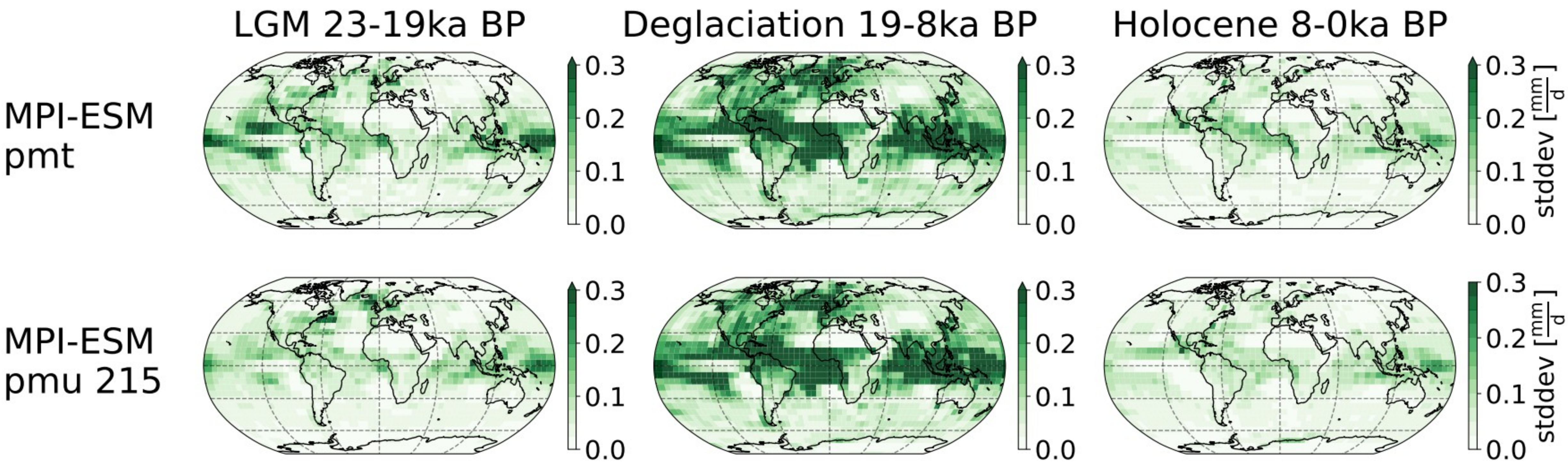
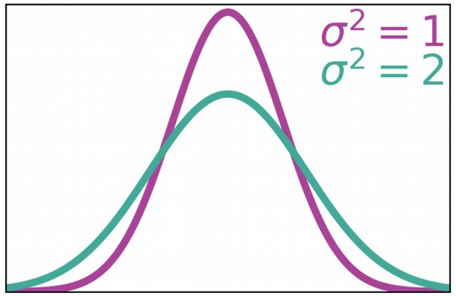
Precipitation standard deviation increases during Deglaciation



Across ensemble
- increase in standard deviation during the Deglaciation, in particular in the tropics
- LGM & Holocene: similar or lower values during LGM



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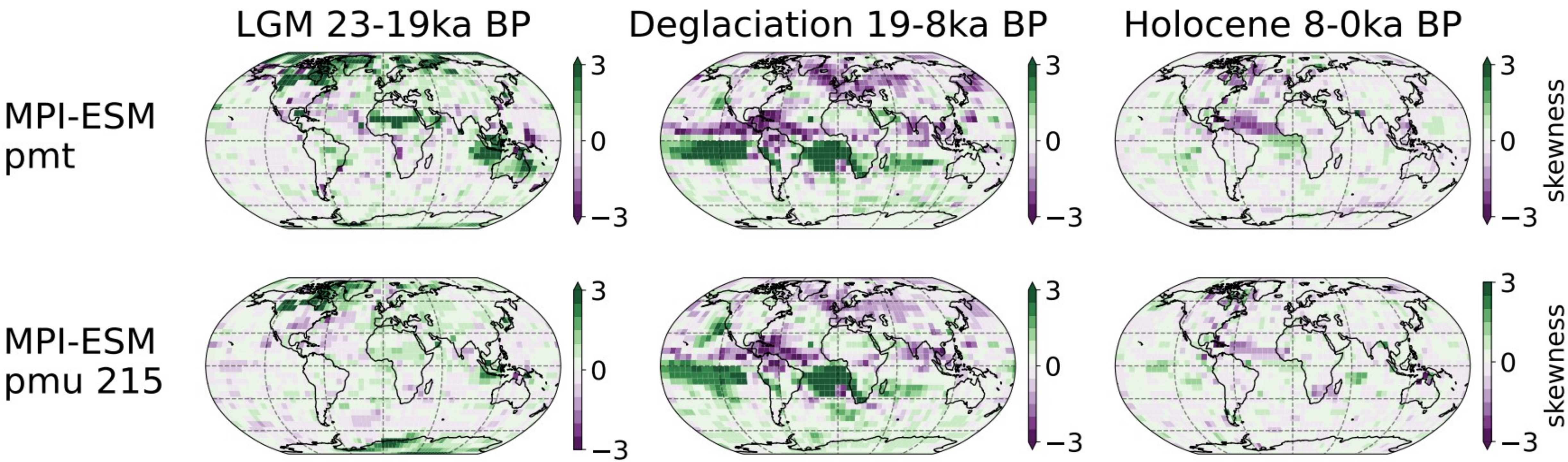
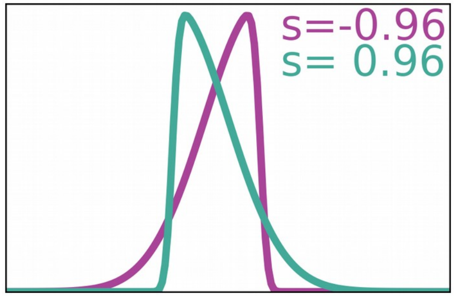
Precipitation skewness decreases with warming



Across ensemble:

- more negative skew with warming
- suggesting a tendency towards dry event outliers in a long tail
- and an overall shift to higher values
- the degree of change varies between simulations & some extreme shifts during Deglaciation



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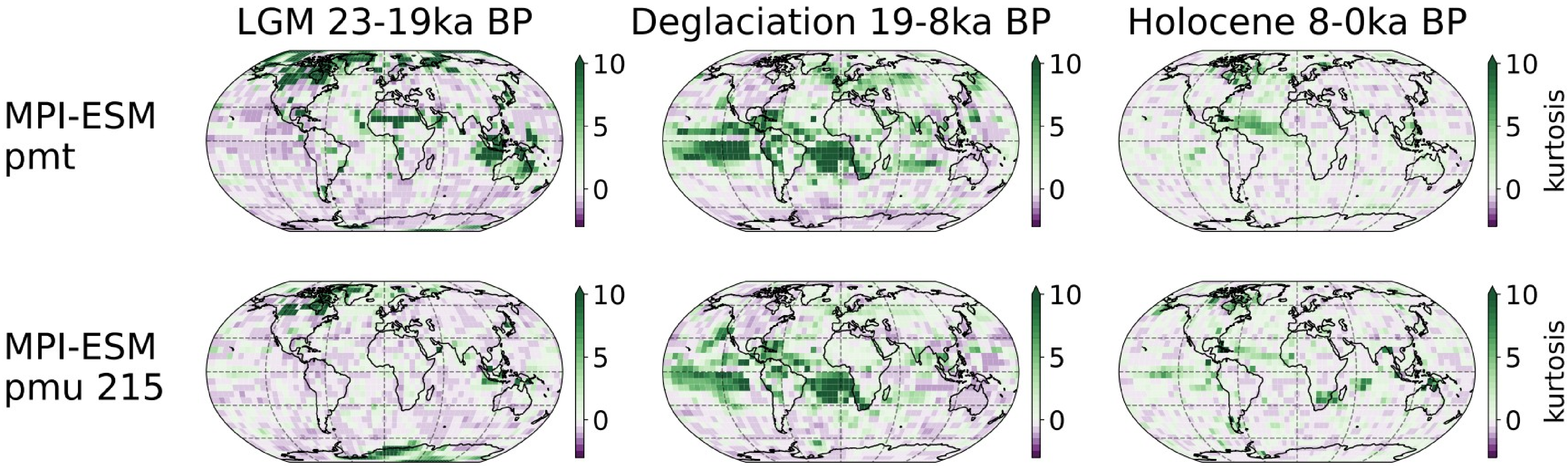
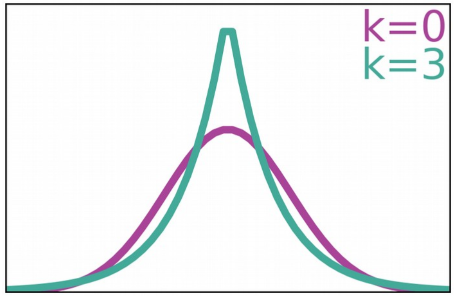
Precipitation kurtosis: increase towards the Holocene



Across ensemble:

- from Deglaciation to the Holocene more often positive kurtosis
- suggesting more extreme centuries in response to the increase in overall precipitation
- but exceptions exist
- no clear patterns when comparing the LGM with Deglaciation or Holocene



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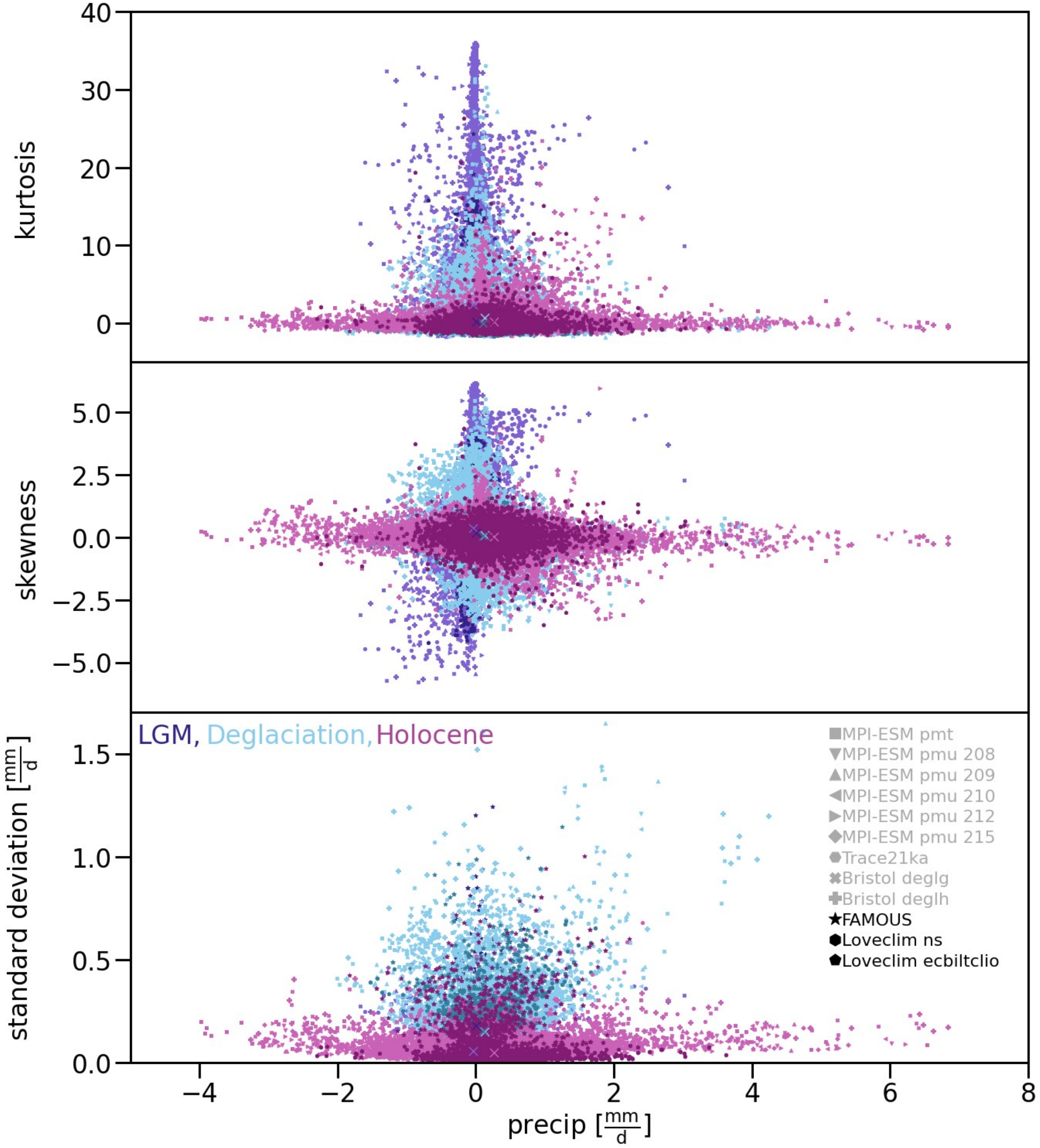
Overall for precipitation



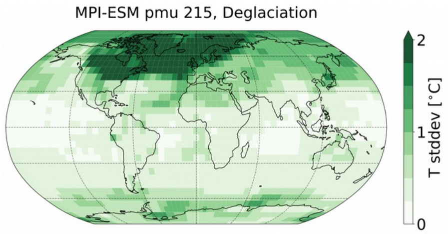
Overall for precipitation

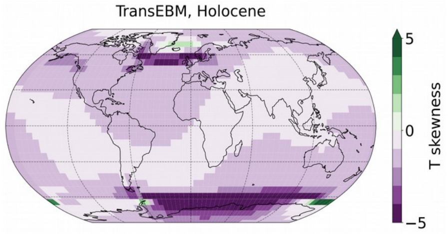
With warming:
- increase of variance with warming
- trend towards negative skewness
- trend towards positive kurtosis
- but large regional differences

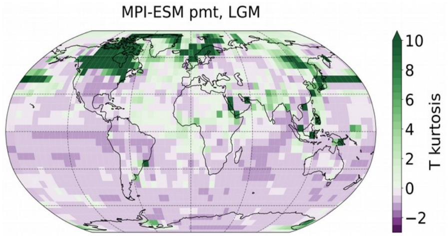
⇨ weight of distribution moves to higher, previously extreme amounts of precipitation, but regionally dryness gets more pronounced

Warming changes the distributions of temperature and precipitation

While the degree of change varies, there are patterns on the **centennial** scale:







Variance:
- lower Holocene temperature variance than during LGM
- similar or higher precipitation variance
- overall higher Deglacial variance

Skewness:
- more often negative with warming
- suggesting longer low-value tails and more data at high values

Kurtosis:
- more often positive with warming
- suggesting fatter tails and thus more extremes

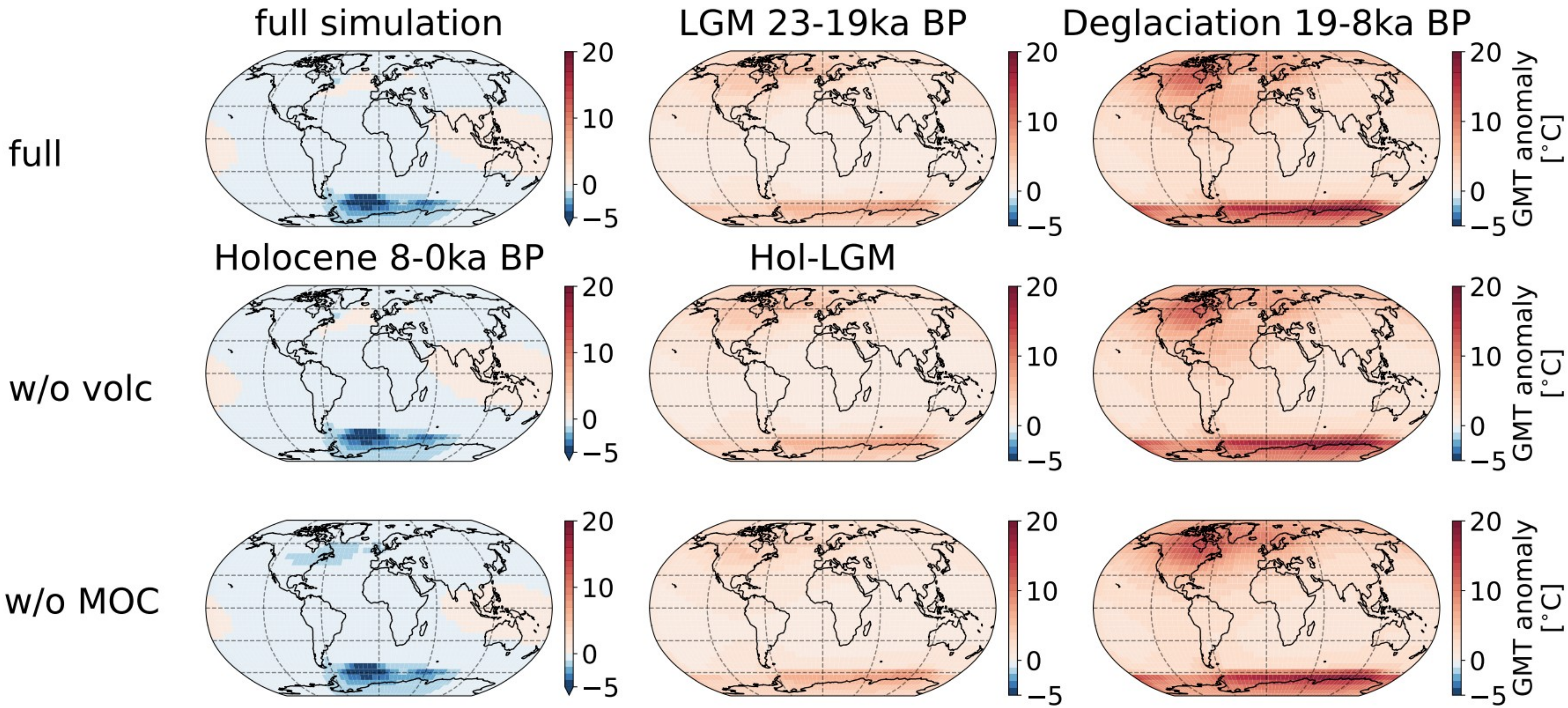
Deviations from normal distribution!

Changes seem related to freshwater forcing and that of changing ice sheets

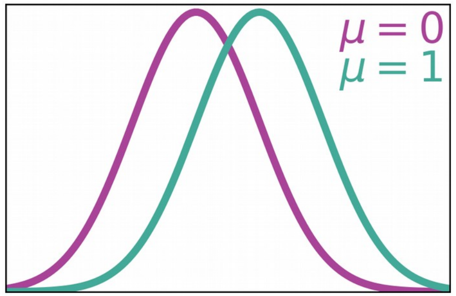
Examine sensitivity experiments

Compare to proxies

Temperature mean in TransEBM sensitivity experiments



anomalies w.r.t. 18-17ka BP



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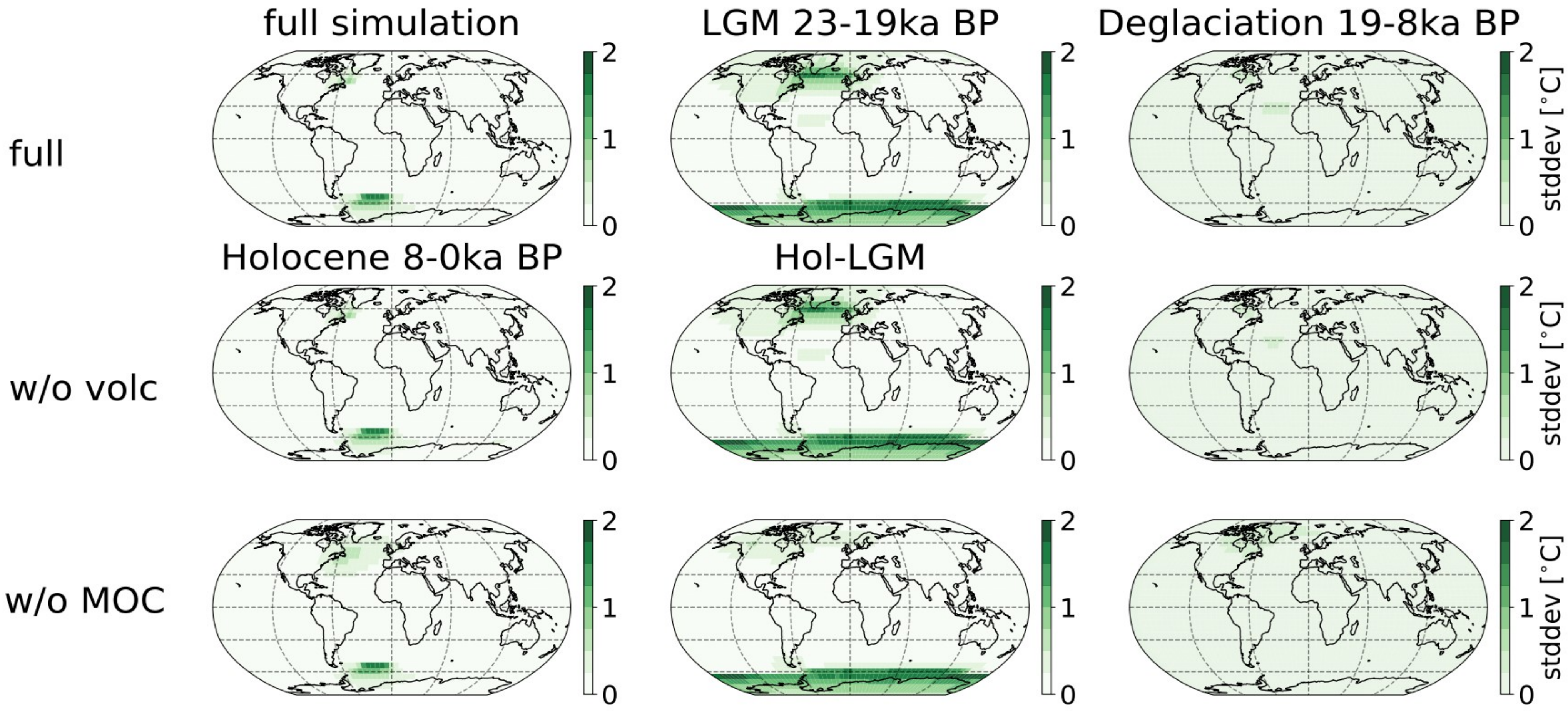
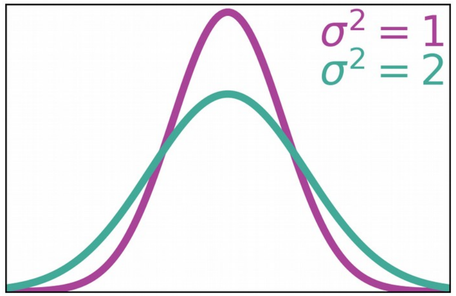
Temperature standard deviation in TransEBM sensitivity experiments





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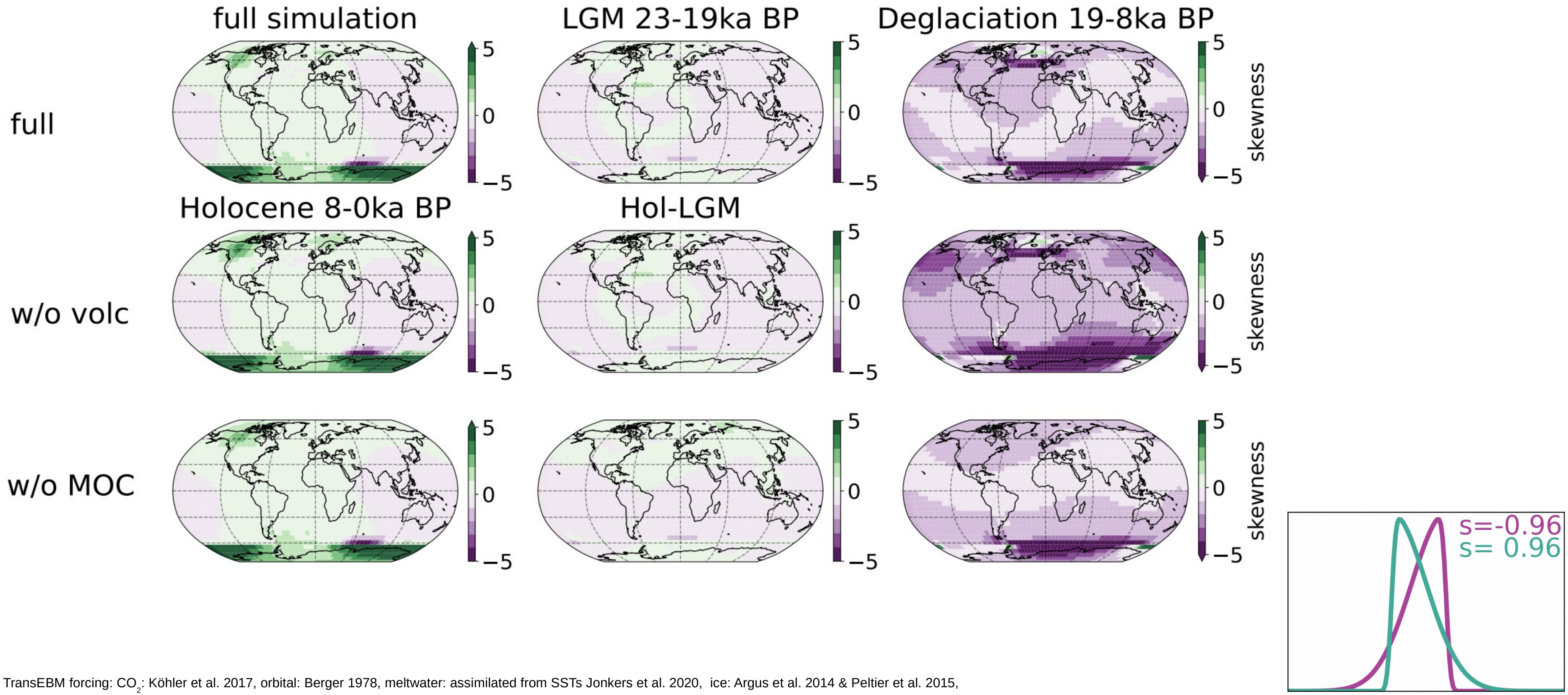
Temperature skewness in TransEBM sensitivity experiments



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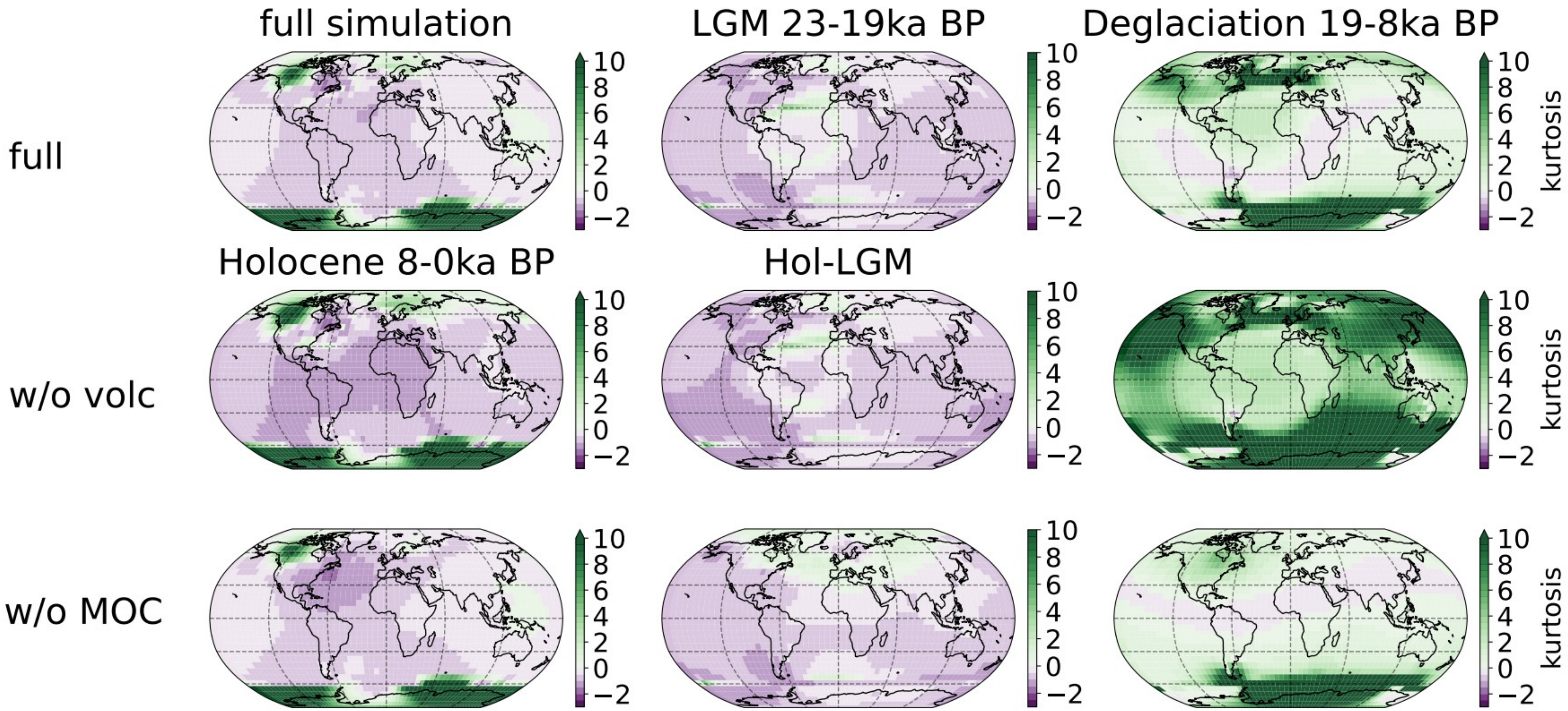
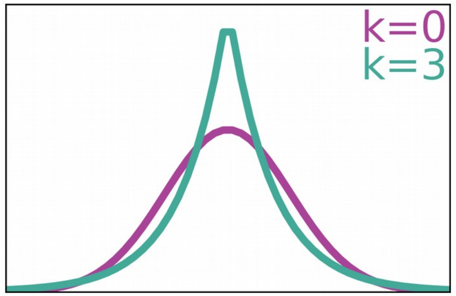
Temperature kurtosis in TransEBM sensitivity experiments





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