A Past2K run with CESM

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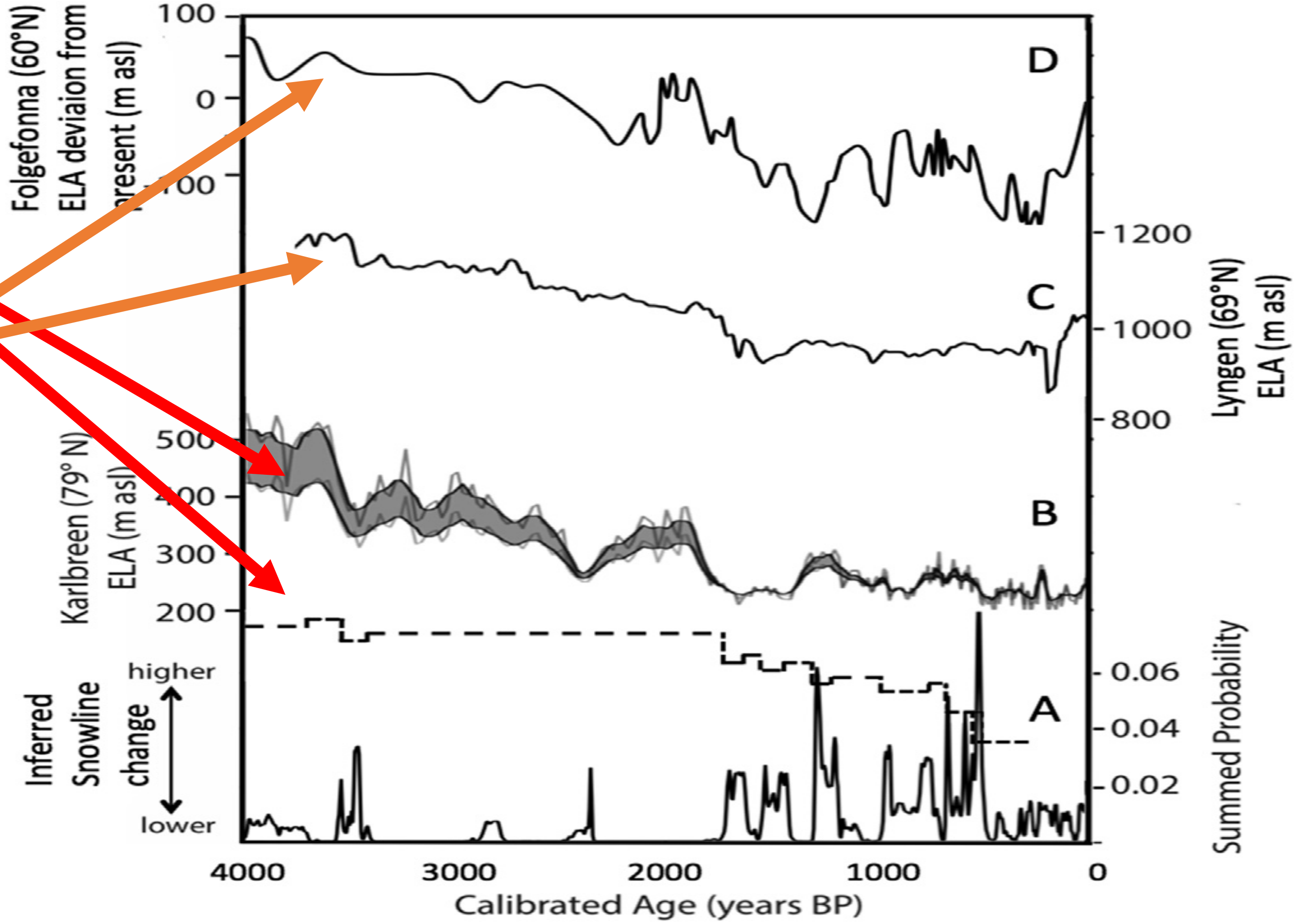
Synchronous snowline depression throughout the North Atlantic Arctic during the late Holocene



All four reconstructions show snowline descent (or ice expansion) between 4.0 and 3.5 ka, with additional stepped cooling early in the first millennium AD, and during the LIA (Miller et al. 2017, Guat. Sci. Rev.)

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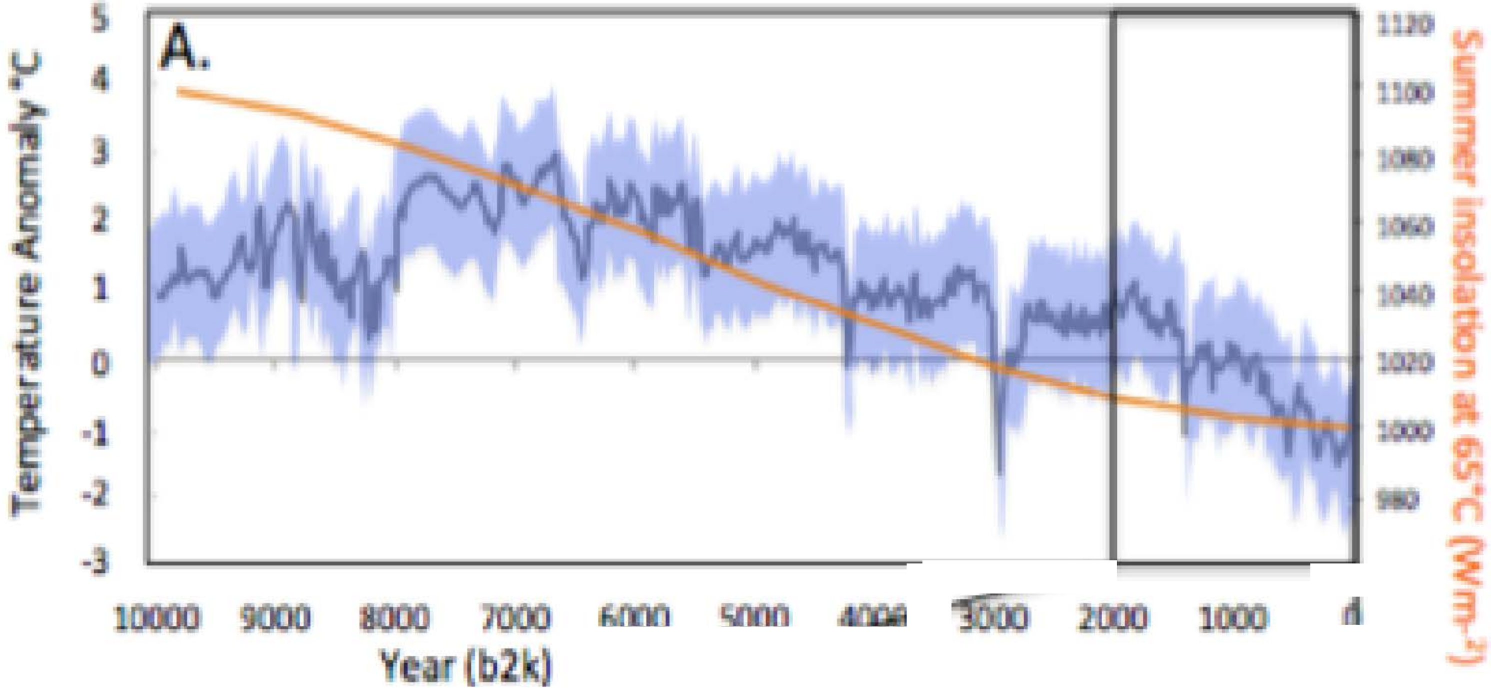
Common timing of snowline depression of similar magnitude throughout the North Atlantic Arctic

- Evidence across the North Atlantic Arctic, e.g. Svalbard, Norway, Greenland, Baffin Island, Arctic Canada (Anderson et al. 2008, Miller et al. 2012, 2013a, b)
- The onset of Neoglaciation is between 5.0 and 4.0 ka.
- The cryosphere expanded significantly between 4.0 and 3.5 ka.
- Minimal ice expanding occurred between 3.5 and 2.0 ka.
- Beginning early in the first millennium AD, snowline began a significant but irregularly paced decline. The rate of snowline lowering was faster than the preceding two millennia, and culminated in the Little Ice Age.
- Total snowline depression between 5.0 ka and the Little Ice Age is 300 – 500 m.
- Snowline descent identified with these reconstructions reflects persistent summer cooling.

Mechanisms leading to synchronous snowline depression throughout the North Atlantic Arctic

summer insolation and temperature anomalies over Iceland



Insolation decline?

- The greatest snowline lowering's occurred during the lowest rate of insolation decline.
- Only small snowline descent in the North Pacific Arctic through the late Holocene (~50 m over the past 5 ka) (Bedding et al. 2013, Pendleton 2015).

Mechanisms leading to synchronous snowline depression throughout the North Atlantic Arctic (Cont.)

Insolation decline

Insolation alone cannot explain the observed temporal and spatial patterns of snowline changes during the late Holocene.

Volcanic forcing

A compilation of volcanic forcing for the past 6 ka by Crowley indicates frequent eruptions about 5.0 ka (the time of initial Neoglaciation) and between 4.0 and 3.5 ka (an interval of widespread ice expansion). However, the Crowley reconstruction does not indicate frequent volcanism between 0 and 800 CE. Nevertheless, decadally repeated eruptions in the first millennium AD helps to explain the accelerated snowline depression in the past 2 ka.

Spatial distribution of sea ice

We hypothesize that sea ice plays a crucial role in lowering the summer temperature in the North Atlantic Arctic, leading to the reconstructed snowline lowering despite only a small insolation change.

Modeling experiments

We focus on the last 2 ka as this period has the most data and is of wide interest to the paleo community, e.g. PAGES 2K. It also allows the use of existing Last Millennium Ensemble (LME, Otto-Bliesner, 2016), which already covers the period from 850 CE to present day.

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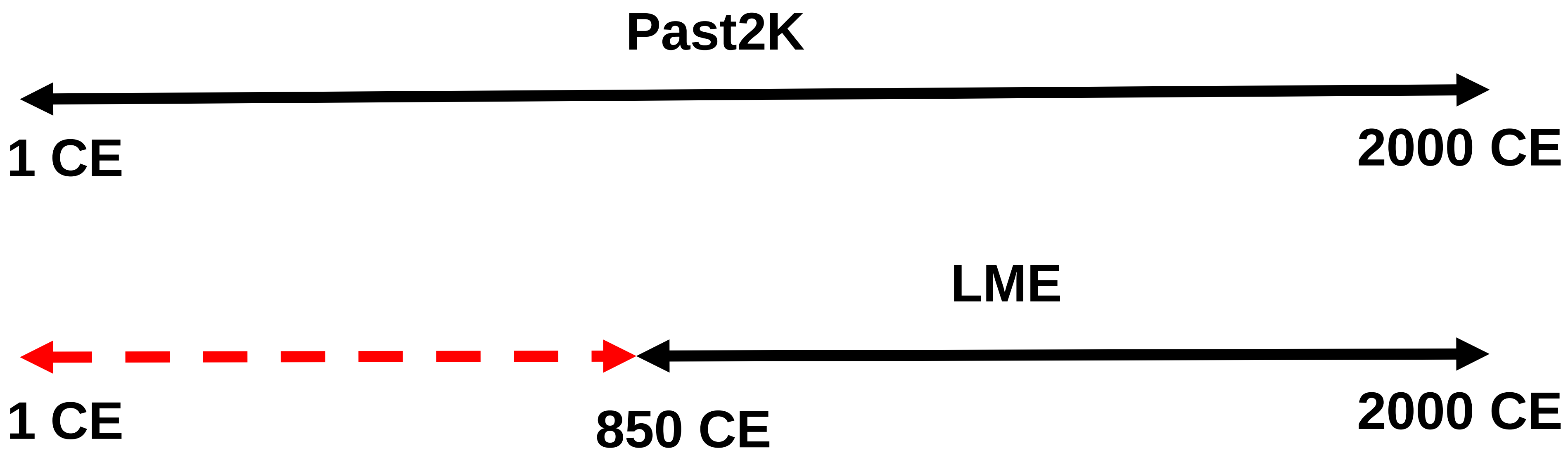


Forcing data?

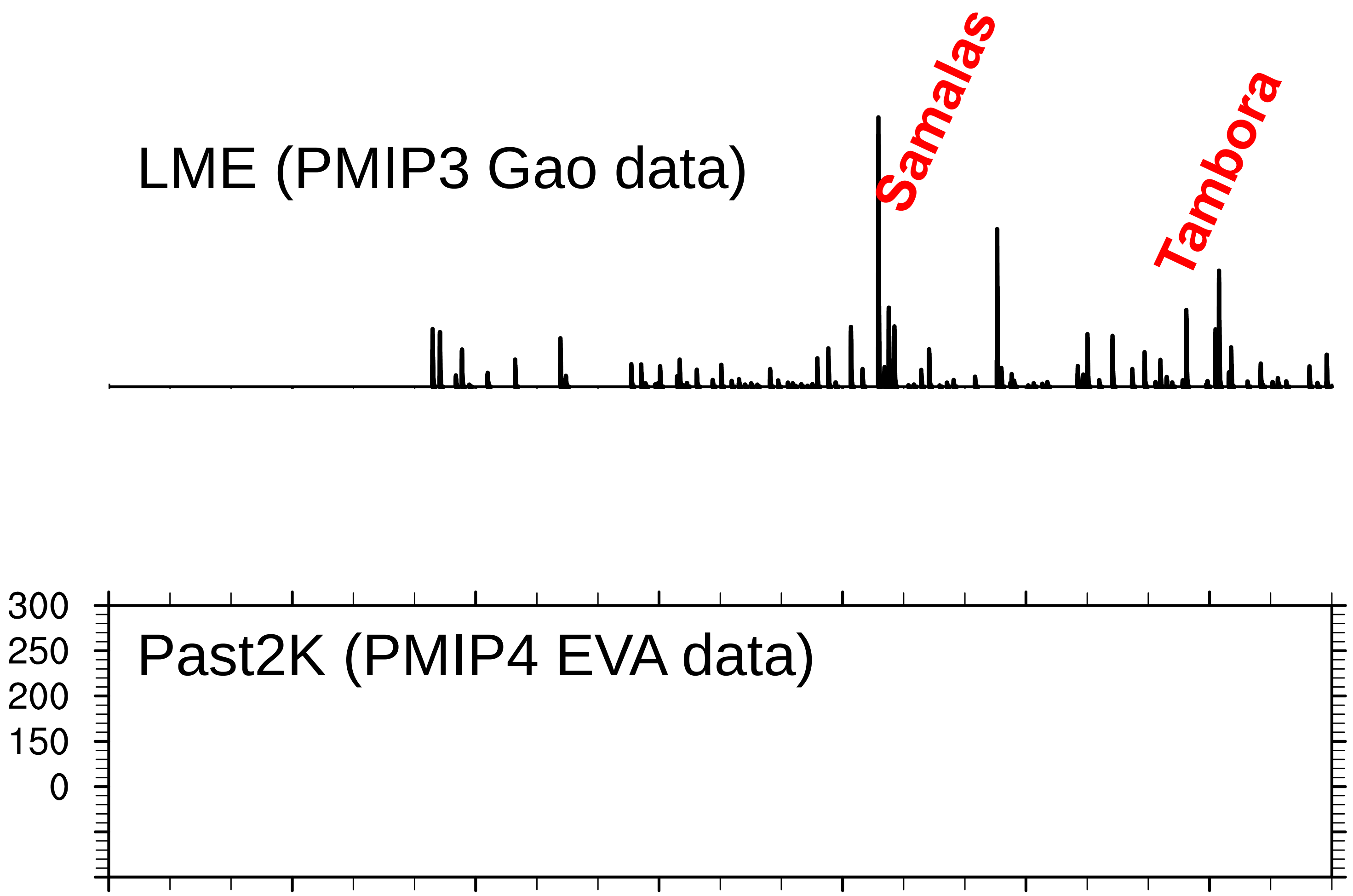
Data compiled by PMIP4 working group (Paleoclimate Modeling Intercomparison Project, Jungclaus et al. 2016) for natural forcings (i.e. solar irradiance, volcanic aerosol) and anthropogenic forcings (i.e. greenhouse gases, land cover/use)

PMIP4 volcanic sulfate aerosol forcing

- PMIP4 EVA data (Toohey et al. 2016, Geosci. Model Dev.) provides space-time distribution of volcanic aerosol mass, effective radius, and optical depth.
- CESM *reads in* space-time distribution of volcanic aerosol mass, *assumes* constant aerosol effective radius, and *computes* aerosol optical depth.

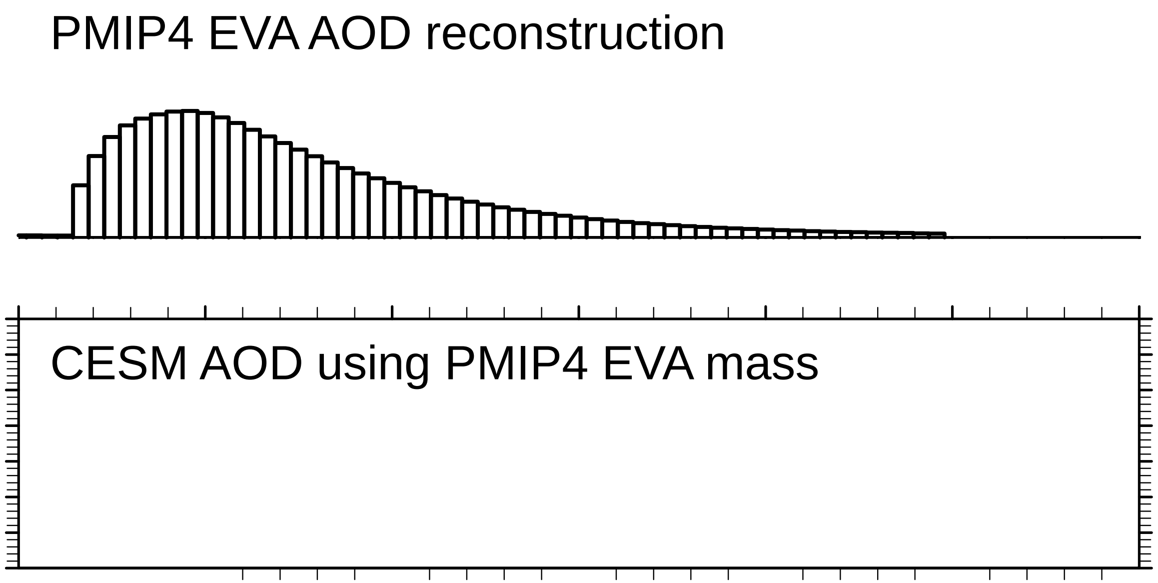
- A straightforward way of applying PMIP4 volcanic forcing is to provide PMIP4 aerosol mass data to CESM, but the goal is to constrain CESM simulation with PMIP4 aerosol optical depth.
- Aerosol optical depth is a measure of the extinction of the solar beam by dust and haze. Typically, higher loading of volcanic aerosol results in greater aerosol optical depth.

Global volcanic aerosol mass



PMIP4 data has a much weaker volcanic aerosol loading than LME Gao data for major eruptions.

Global mean volcanic aerosol optical depth (AOD) for Tambora



For CESM to match EVA AOD reconstruction, EVA aerosol mass needs to be increased by a factor of 1.67 before being fed into CESM.

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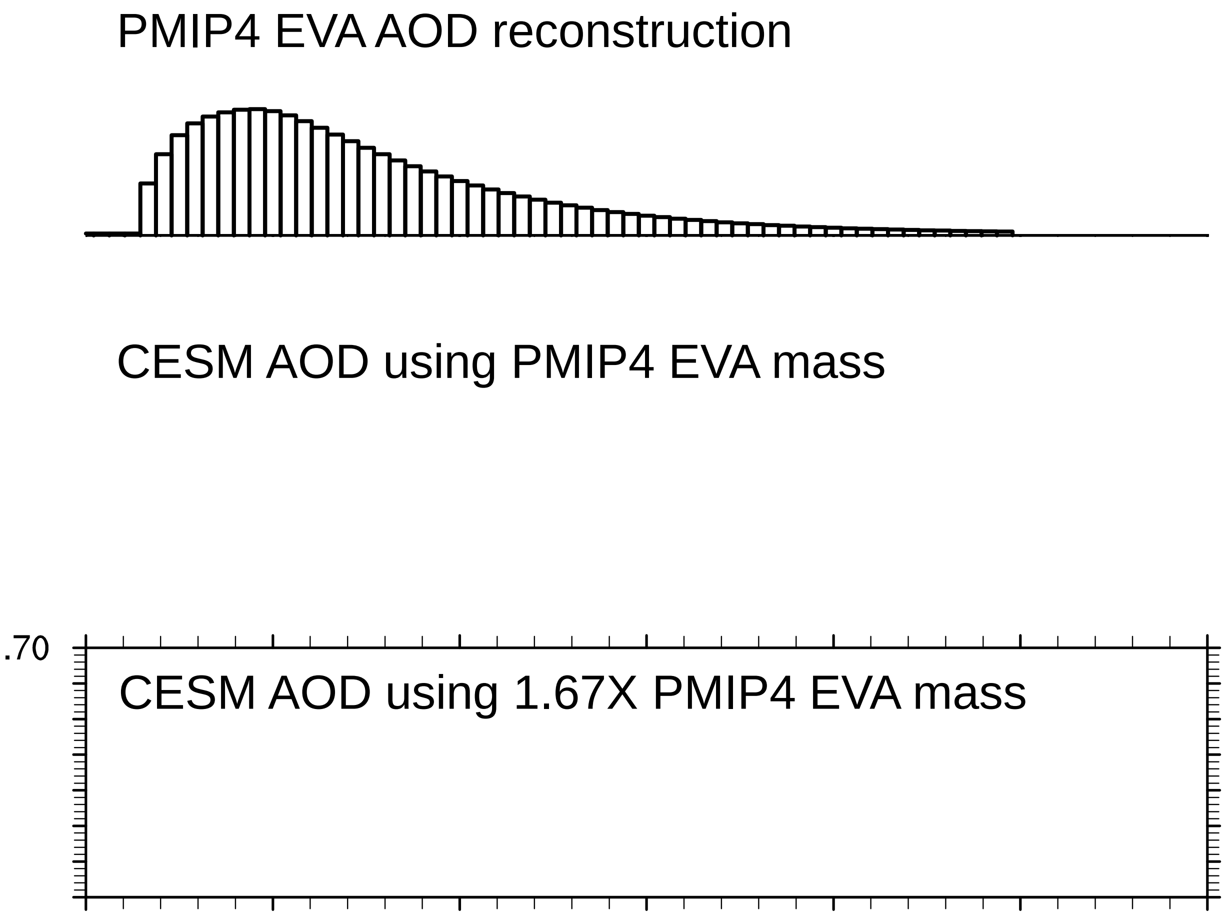

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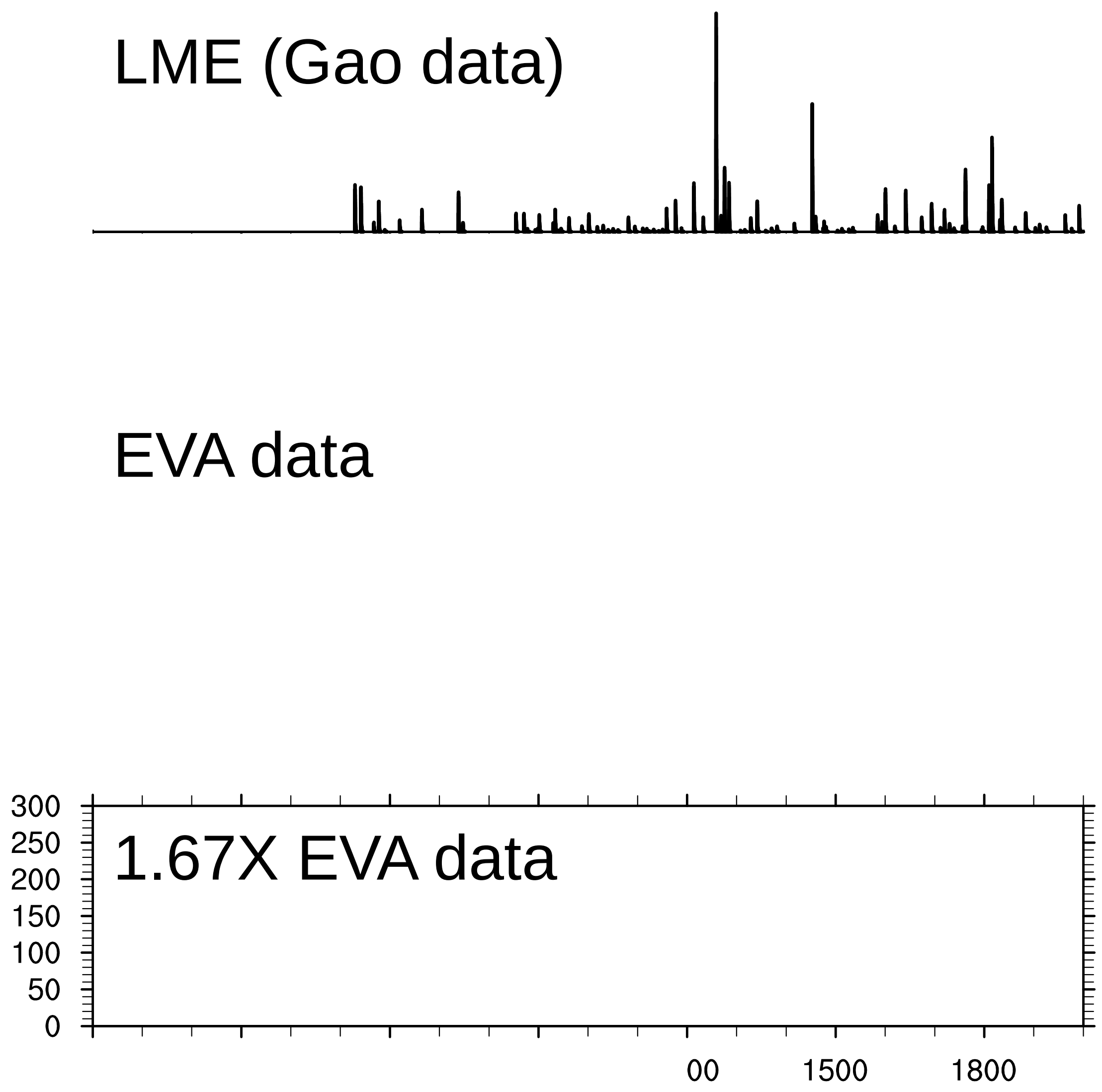
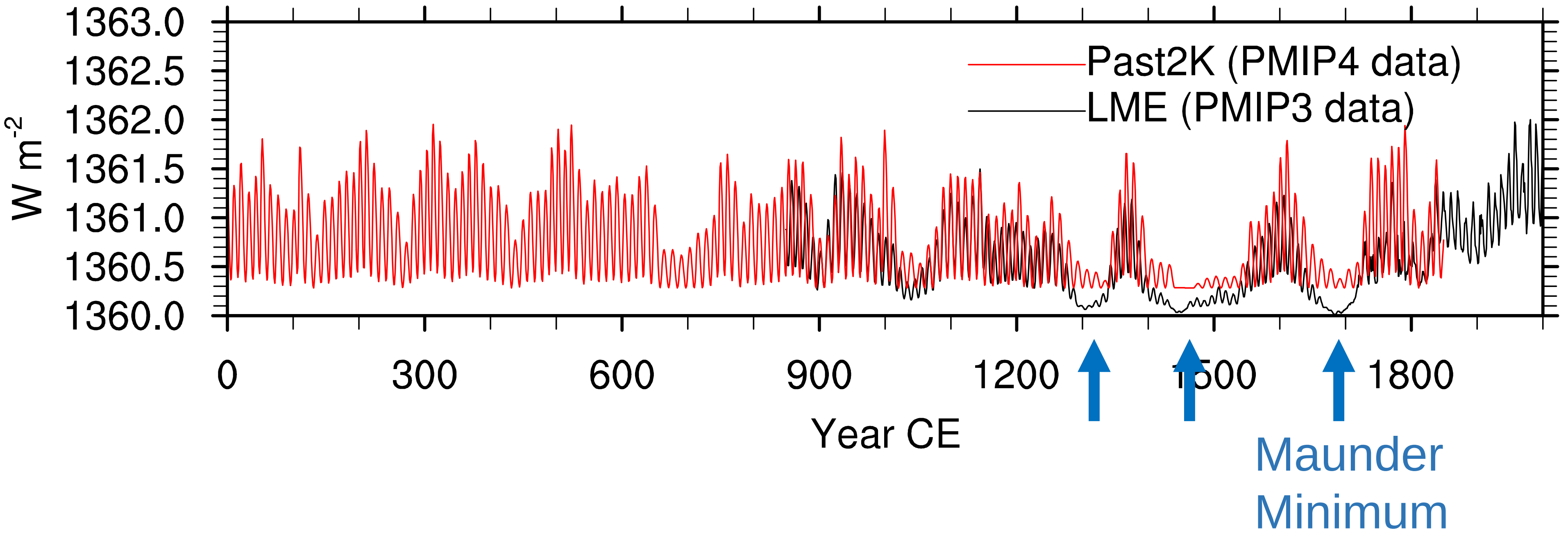
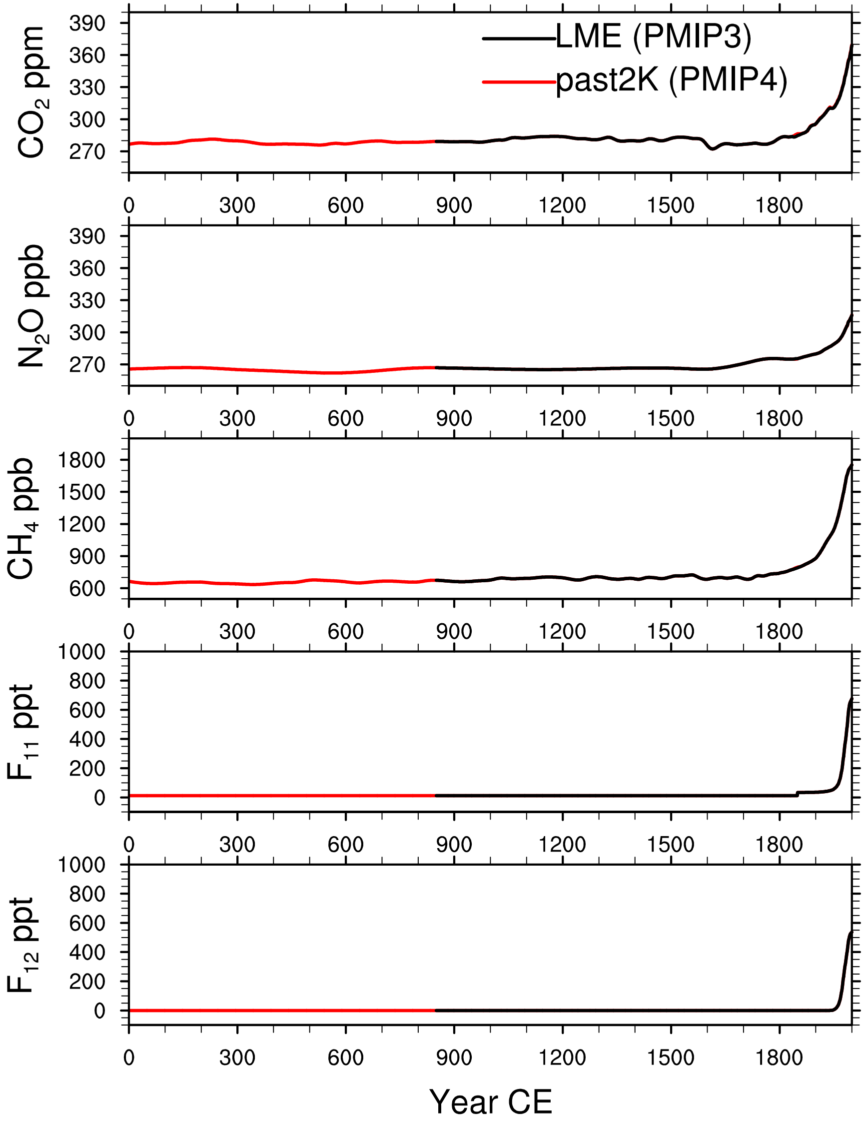
Global volcanic aerosol mass for Past2K run



Total Solar Irradiance for Past2K run

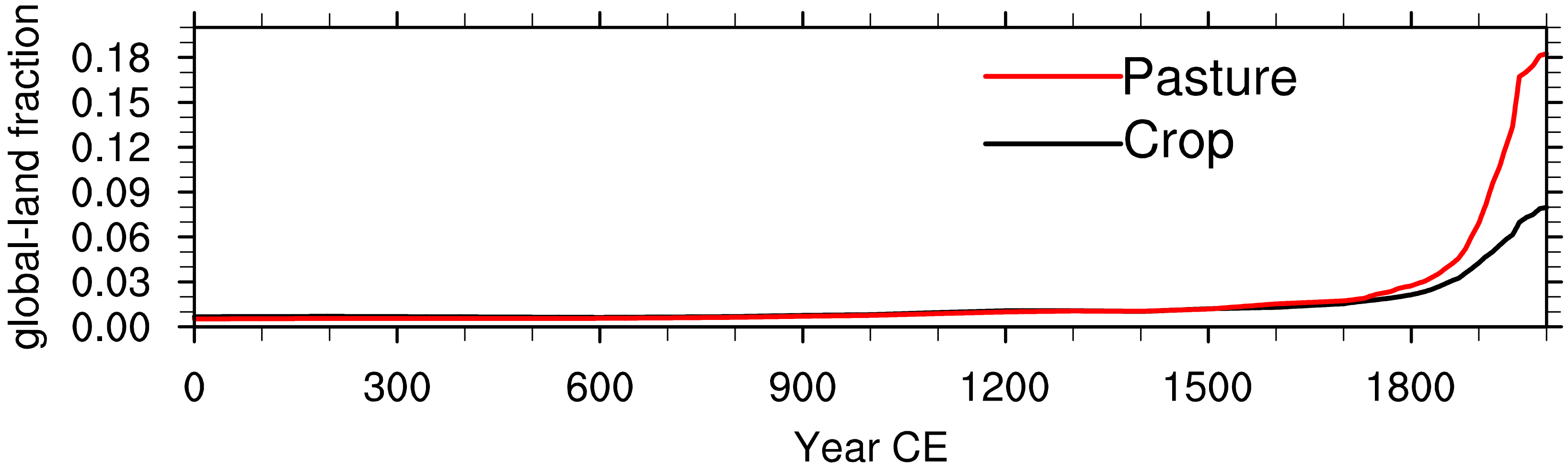


Greenhouse gas concentration for Past2K run



No obvious trend in CO_2, N_2O between 1 CE and 1600 CE, a slight increasing trend in CH_4.

PMIP4 land use/cover for Past2K run



- Cropland and pastureland changes are minimal between 1-850 CE.
- Use LME 850 CE land cover as baseline and apply PMIP4 cropland changes relative to 850 CE. Unlike LME runs, PMIP4 pasture changes are not applied to Past2K transient. This (non-)treatment of pasture changes presumably has limited impact on climate simulation over the North Atlantic Arctic due to the very small pastureland fraction there.

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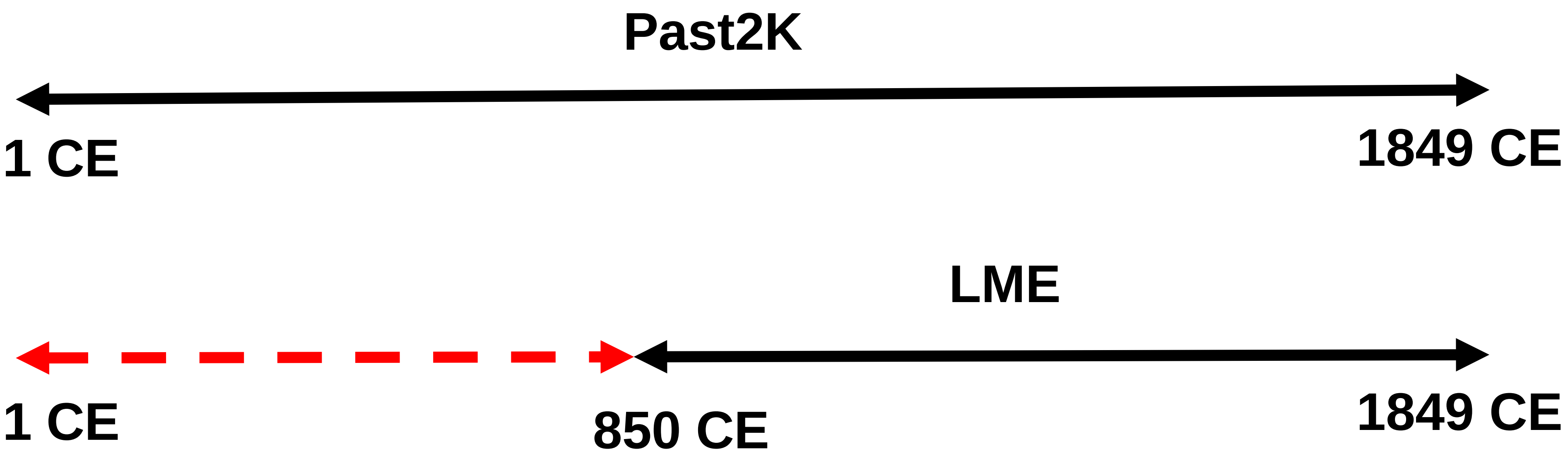
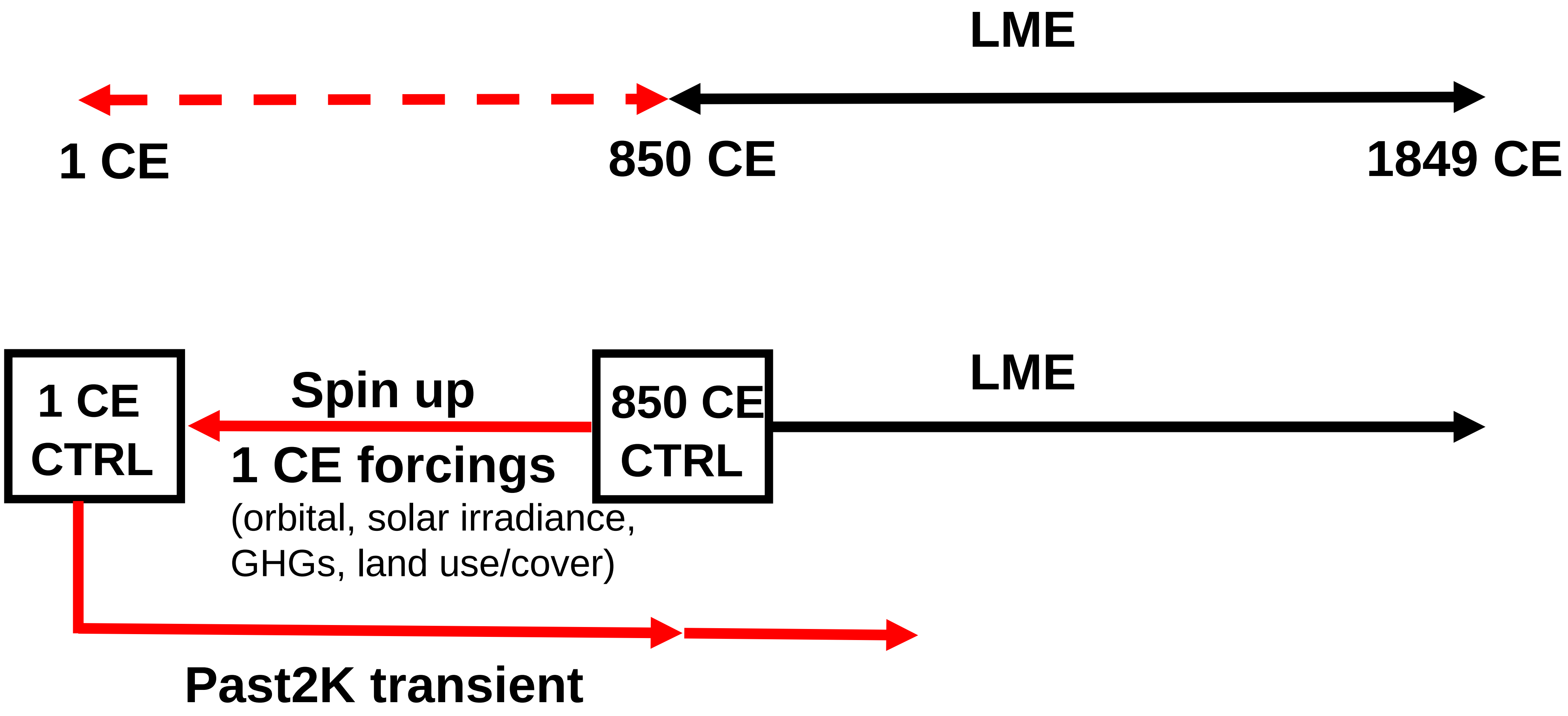


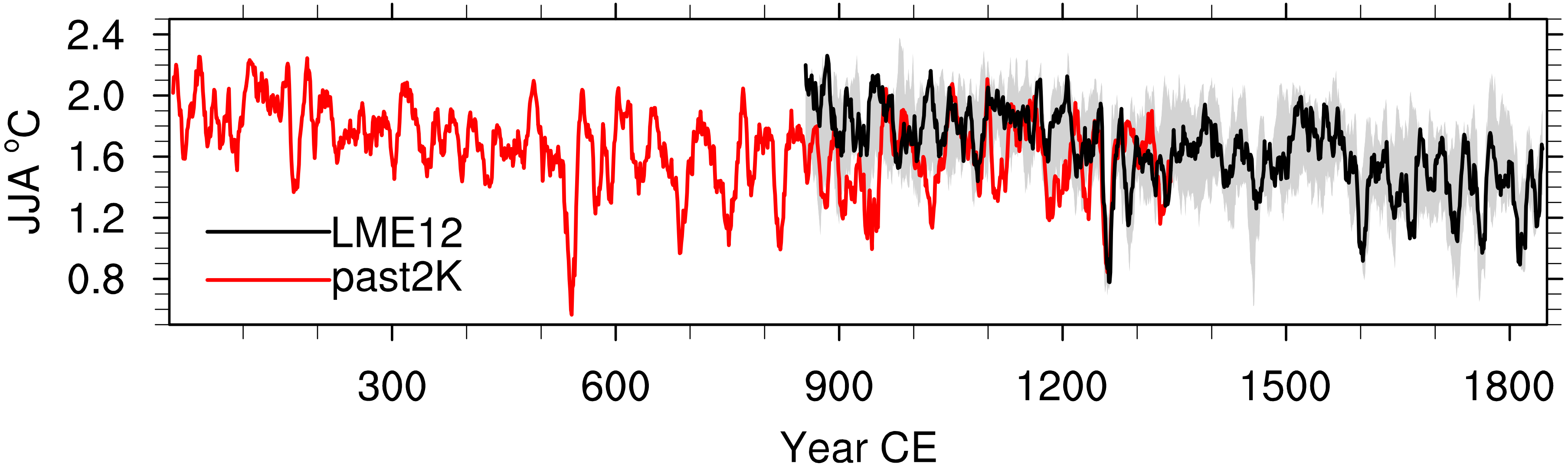
- Forcing data? PMIP4 forcings.
- Same version of CESM as used by LME.

A Past2K run with CESM



JJA 2-m air temperature in the North Atlantic Arctic

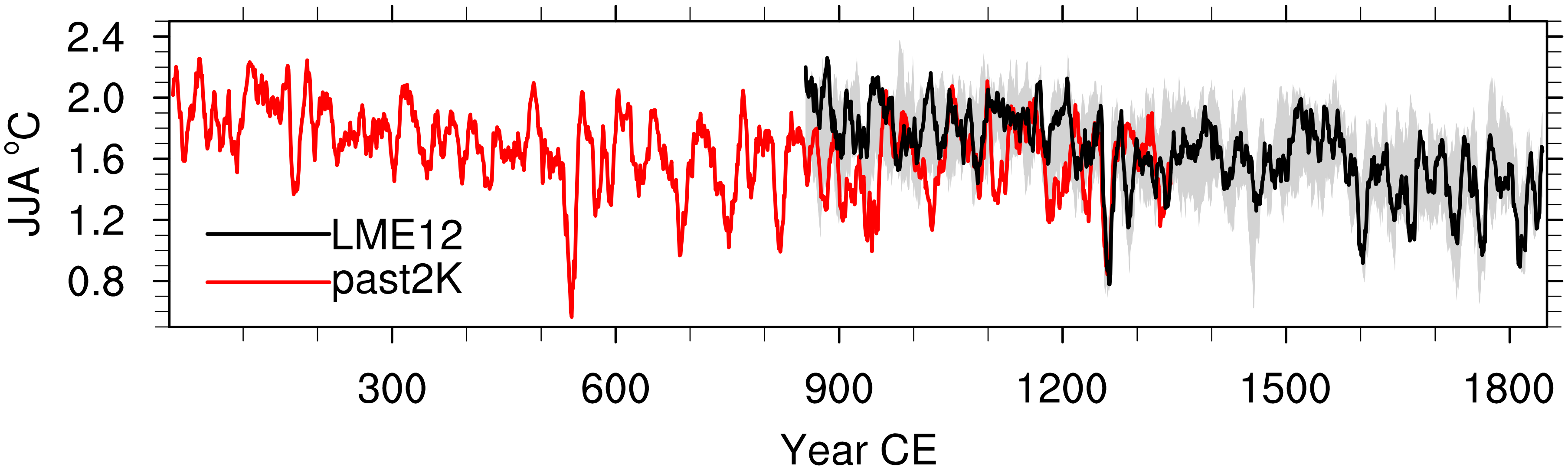
decadal
2-m air
temp



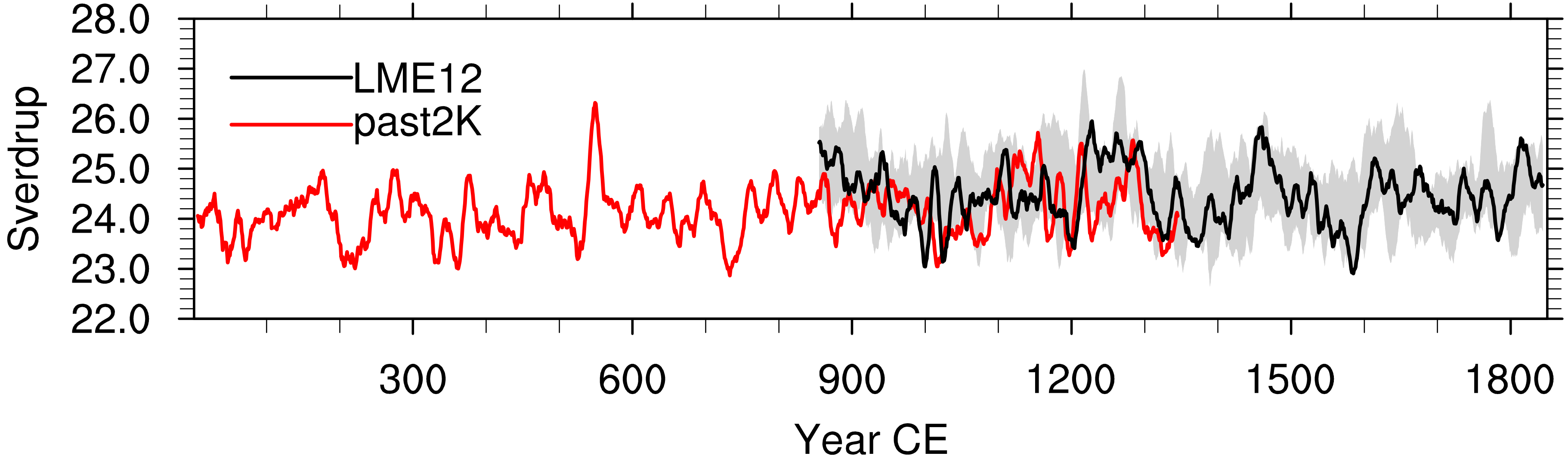
over land, 90W-60E, 60N-90N

JJA 2-m air temperature in the North Atlantic Arctic

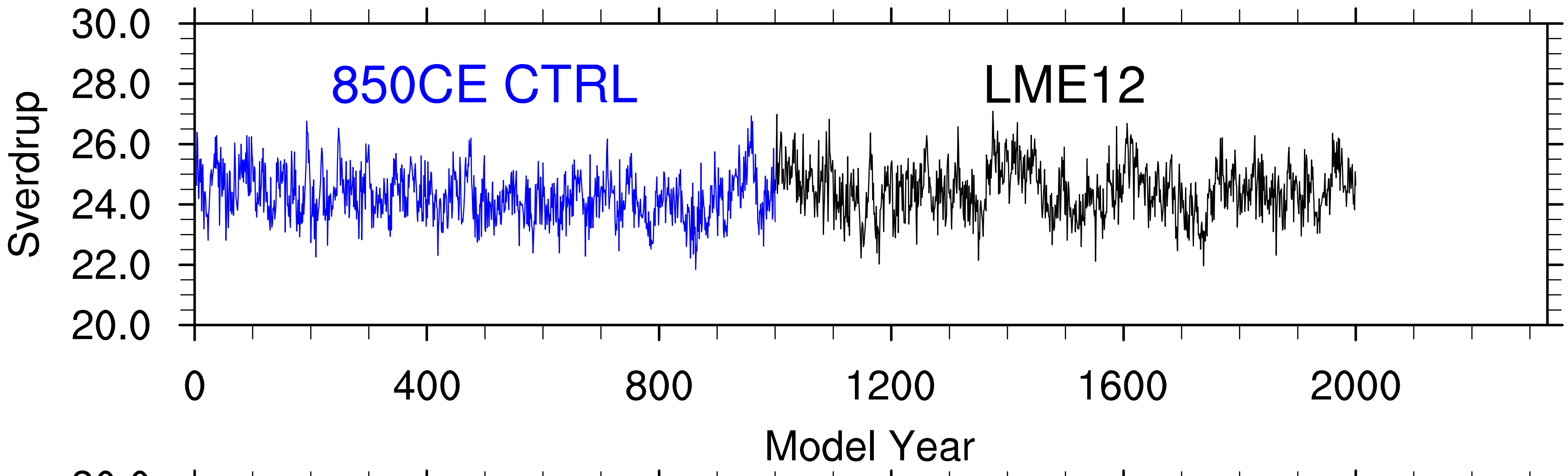
decadal
2-m air
temp



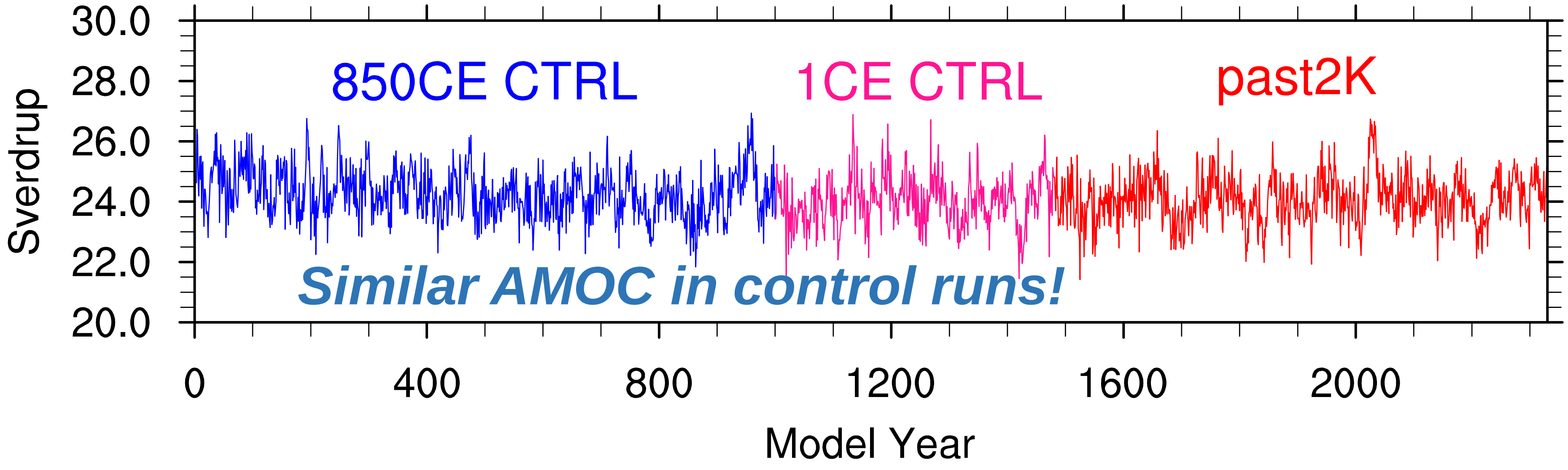
decadal
AMOC
(Atlantic
Meridional
Overturning
Circulation)



Annual AMOC



Sverdrup
30.0
28.0
26.0
24.0
22.0
20.0
850CE CTRL
LME12
0
400
800
1200
1600
2000
Model Year



Sverdrup
30.0
28.0
26.0
24.0
22.0
20.0
850CE CTRL
1CE CTRL
past2K
Similar AMOC in control runs!
0
400
800
1200
1600
2000
Model Year

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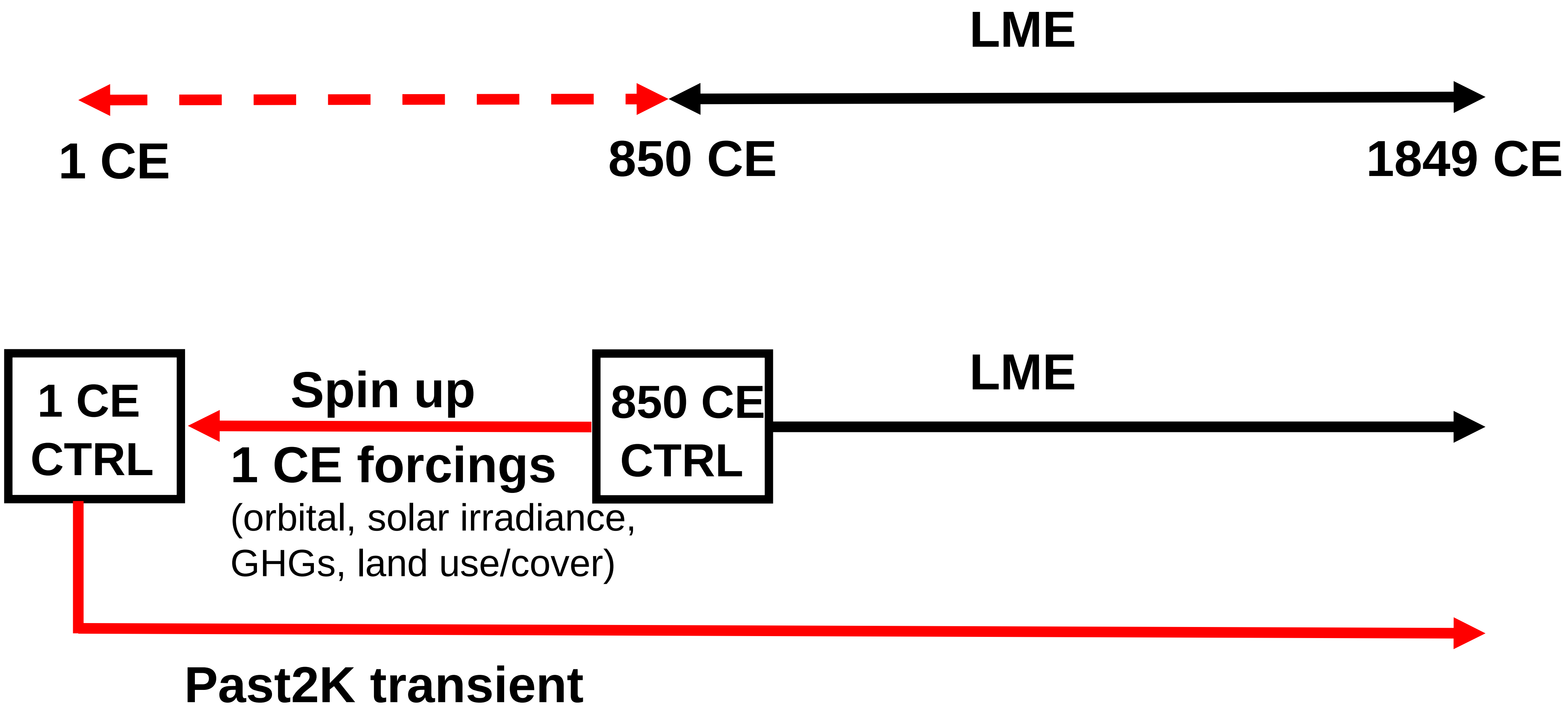
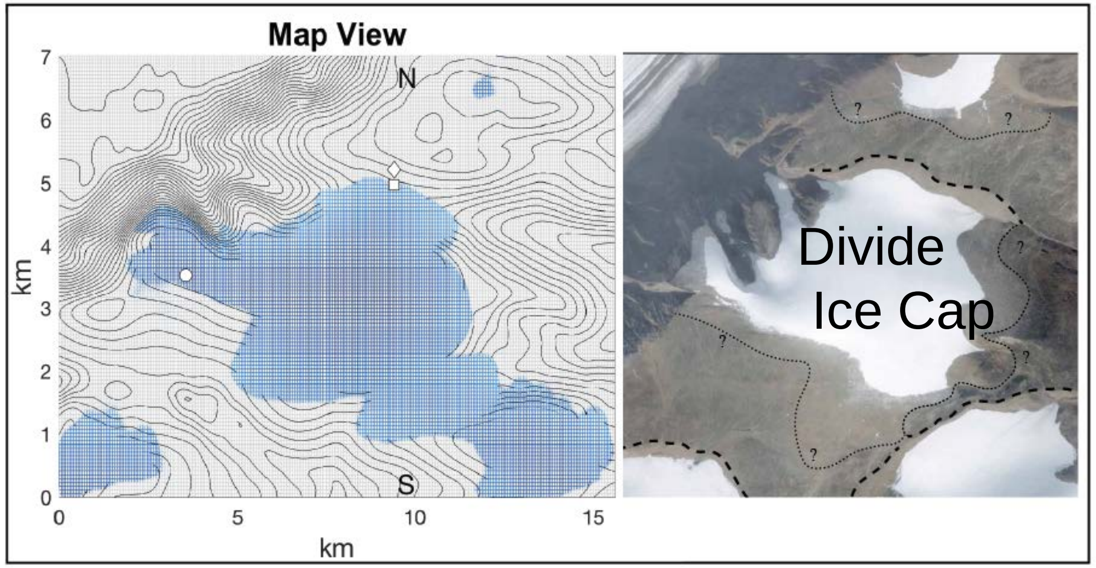
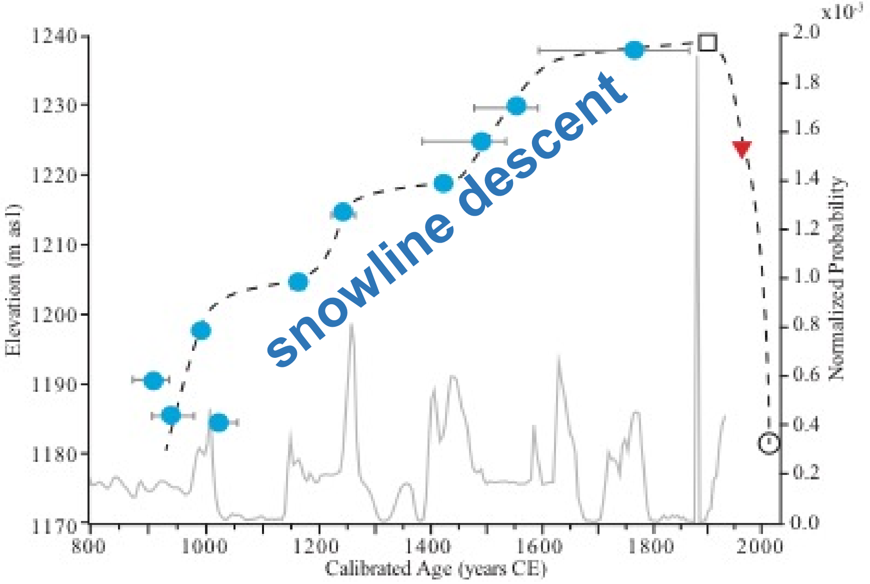


Data-model comparison using Past2K output

glacier model | Google map | snowline reconstruction





Using the spatial and temporal constraints on ice margin movement over the past 2 ka, glacier model can estimate the temperature changes required to reproduce the reconstructed advance and retreat cycle (Pendleton et al. 2017, Clim. Past, submitted).

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