Quantifying the influence of volcanic forcing on water isotopes and climate in polar and alpine regions using HadCM3

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Abstract

The frequency of extreme weather events depends relatively more on climate variability than on average changes. This makes variability a crucial element to consider in future projections. Stable water isotopes such as δ18O extracted from climate archives, including ice-cores, have been used to reconstruct regional climate and evaluate climate simulations. These archives have shown that variability in the Holocene is much lower than that at the Last Glacial Maximum (LGM, 21 kyr ago). However, state-of-the-art climate models still fail to simulate this shift. Comparison is difficult, since paleoclimate equilibrium simulations are typically run for few centuries and do not yet incorporate water isotope tracers. Volcanic eruptions offer a unique testbed to analyse the link between regional archives and global climate since well reconstructed aerosol data from 800 CE onward allow the investigation of small and large-scale effects in time and space on the climate. Here, millenial simulations from the isotope-enabled version of HadCM3 forced by solar and volcanic reconstructions in pre-industrial, LGM and past-millenium scenarios were evaluated. We then analysed the influence of volcanic eruptions on climate and δ18O values in polar and alpine regions. This allowed us to test the dependency of isotope values on regional shifts in climatology as well as global anomalies using composite analysis of volcanic eruptions. We finally discuss the impact of these results on the climatic representation of polar and alpine ice-cores representing changes in global climate variability.

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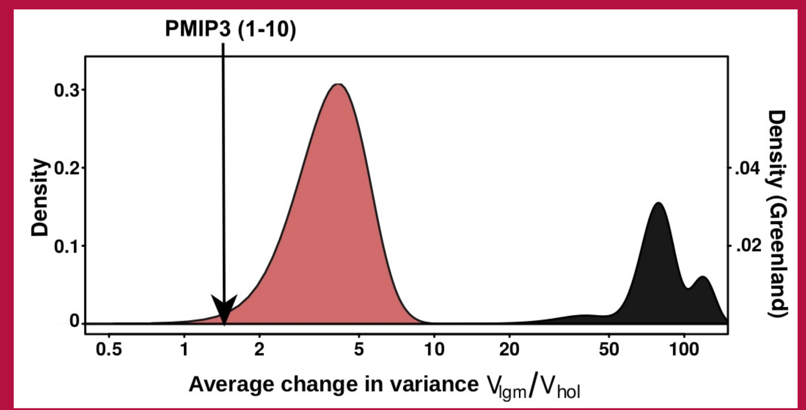
1 Motivation

Climate variability governs the probability of extreme events[1] and thus living conditions on Earth. How projected changes in mean climate will affect climate variability remains uncertain[2-5]. To this end, comparing the last glacial to the present interglacial can provide new insights. However, models simulate a lower change in variability during that period than reconstructions from proxies like δ^{18}O suggest[3,5]. Comparison is difficult, since paleoclimate equilibrium simulations are typically run for few centuries and do not yet incorporate water isotope tracers.

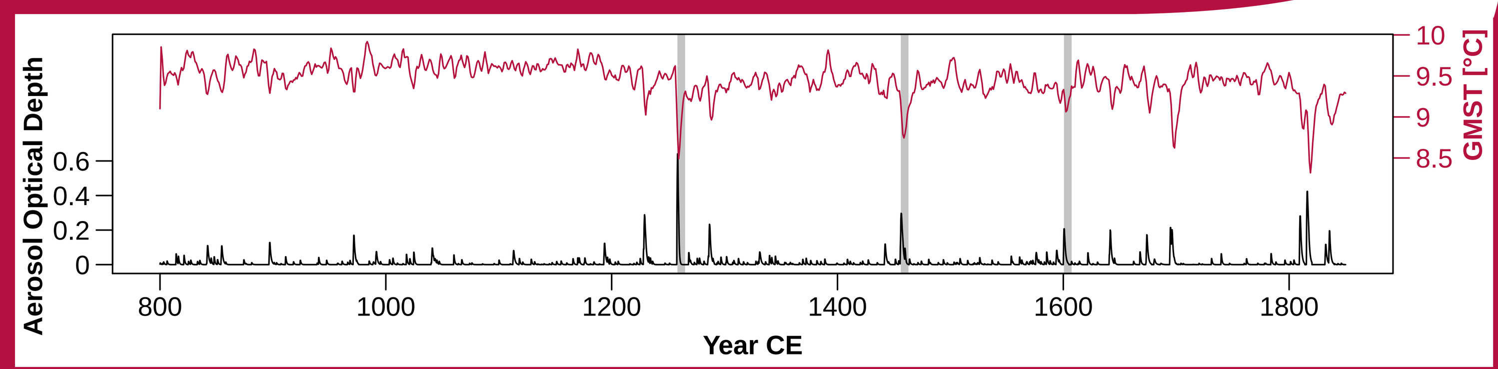


Variability change in proxy data from LGM to Holocene[3].

2 Data

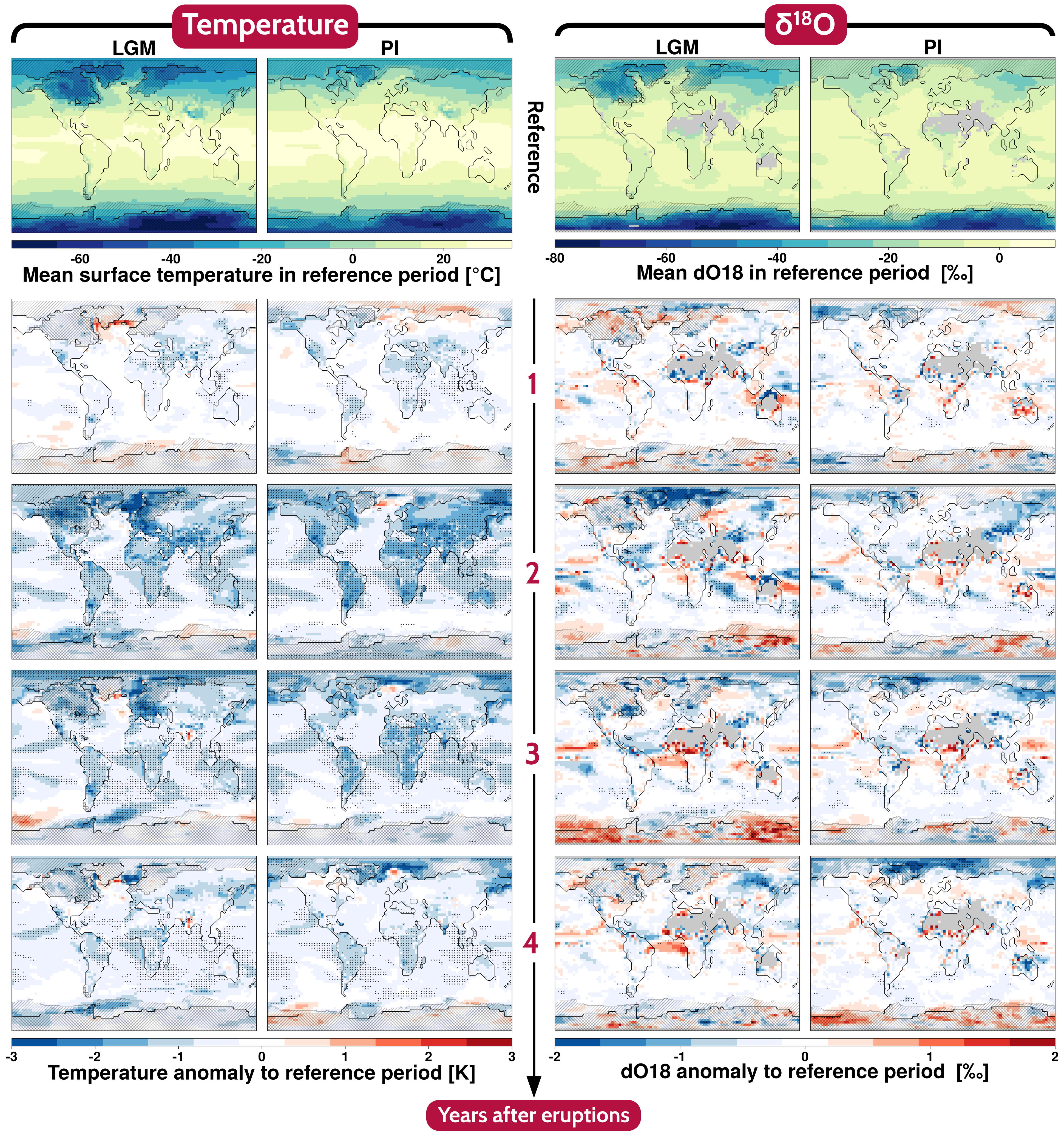
Model: Isotope-enabled GCM (HadCM3)[6]
Land/Ocean res.: 3.75°x2.5°/1.25°x1.25°, 19 Levels / 20 Levels
Input: Crowley 2008 (Volcanic)[7], Steinhilber et al. 2009 (Solar)[8], Land-Sea-Mask, Ice Shields, CO_2
Runs: (Un)forced LGM/PI (pre-industrial) (3 runs each)
Time: Output saved monthly for 1000+ years

Eruptions	
1257CE	Samalas
1455CE	Kuwae
1600CE	Huaynap.



Aerosol optical depth (AOD) from volcanic forcing shown with global mean surface temperature (GMST) taken from a forced LGM simulation. Vulcanoes later analyzed in 3 highlighted in gray.

3 What happens after a volcano erupts?

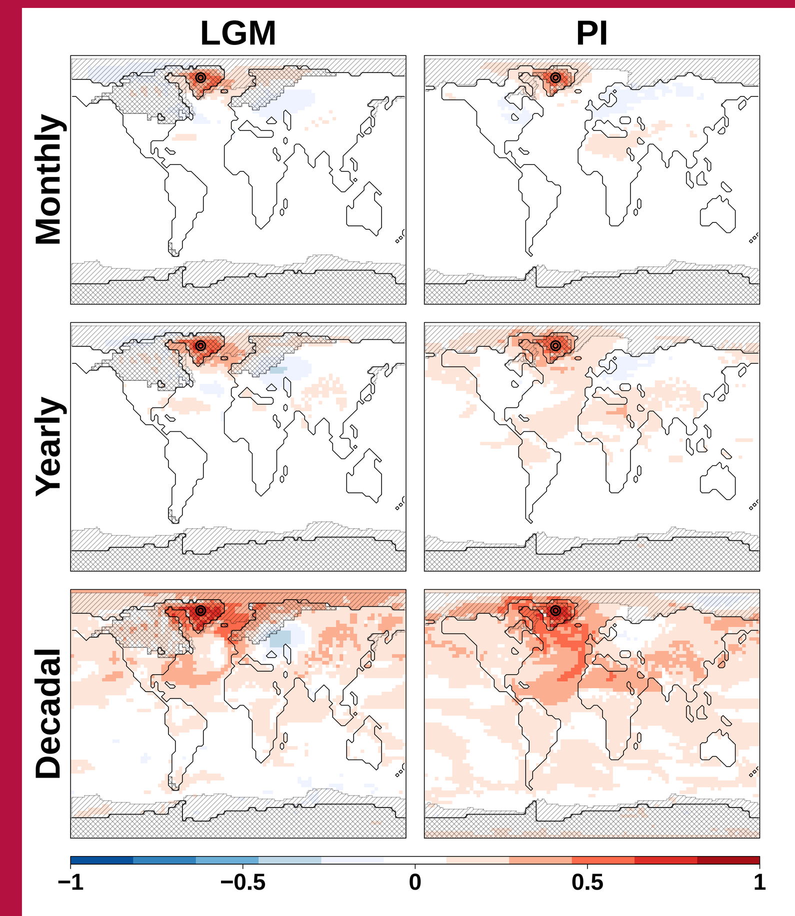


Surface temperature (TAS) and δ^{18}O anomalies averaged over 9 eruptions (from 3 simulations). Reference period is an average of the three years before each eruption. Gray values are not available due to an insufficient amount of precipitation. Hatched areas indicate ice shields and a greater or equal to 50% yearly coverage of sea ice. Dots indicate anomalies greater than 2σ (w.r.t. the reference period) and a greater than 60% same sign response rate.

➡ On short timescales, local δ^{18}O response may not be in line with TAS response

4 Results

- Volcanic eruptions resulted in GMST cooling with regional warming near sea ice edge
- δ^{18}O response around Antarctica different from TAS response
- δ^{18}O correlation with TAS is spatially limited but reaches global scales for longer timescales
- Even on decadal timescales, there are regional modes that govern δ^{18}O-TAS relationship



Pearson correlation coefficient for TAS time series at each grid box and δ^{18}O time series near NGRIP ice core drill site (Marked on map). Results shown are from forced simulations, unforced results are highly similar. When time series are smoothed to represent longer time scales (e.g., decadal instead of monthly data), correlation radius increases.

5 Conclusion

δ^{18}O is a powerful proxy for TAS, however on short time scales, regional modes are still not understood and a major source of uncertainty.

Outlook

- Test correlation between δ^{18}O and other climatic variables
- Test stationarity assumption

References

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This work used the ARCHER UK National Supercomputing Service (http://www.archer.ac.uk)

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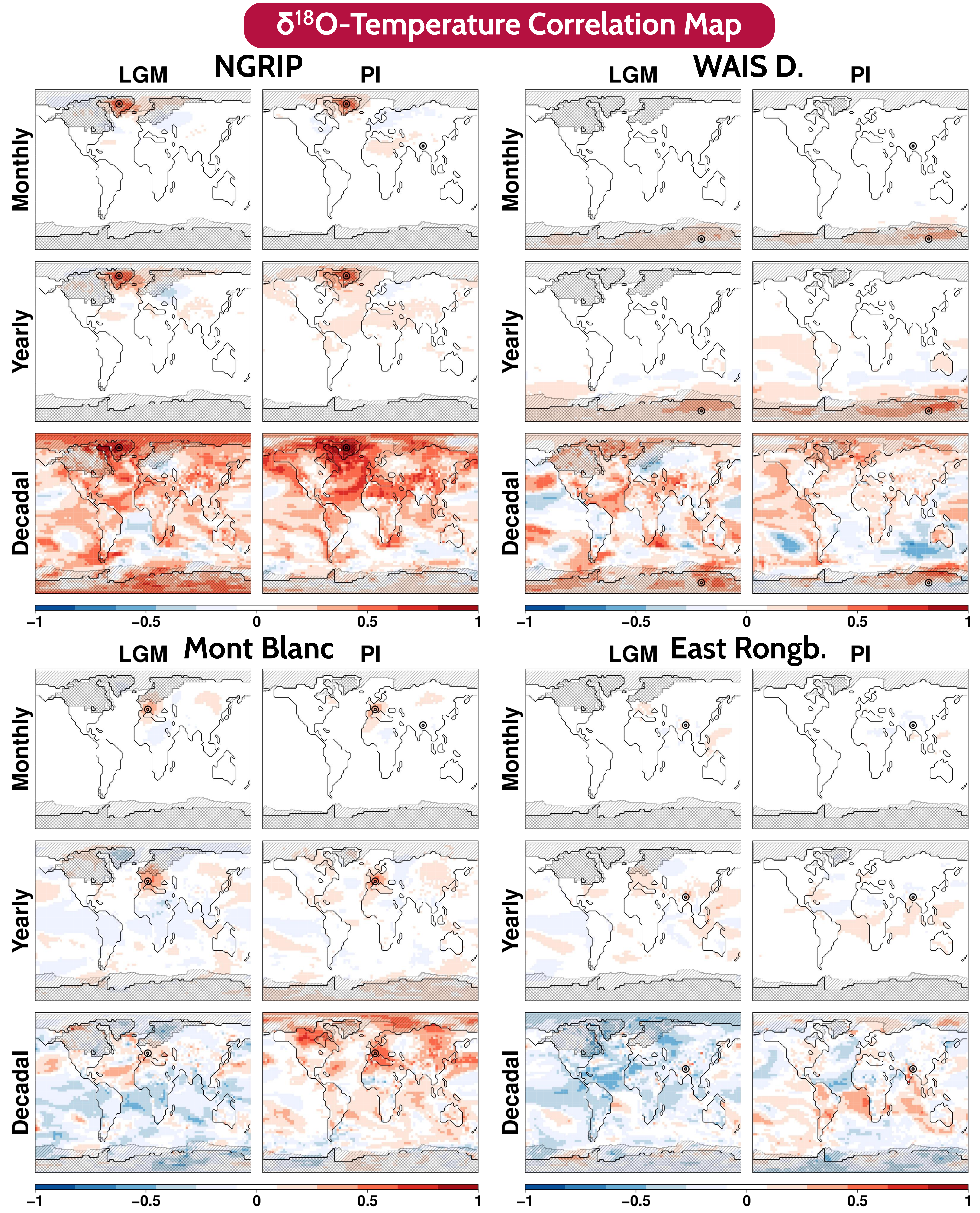
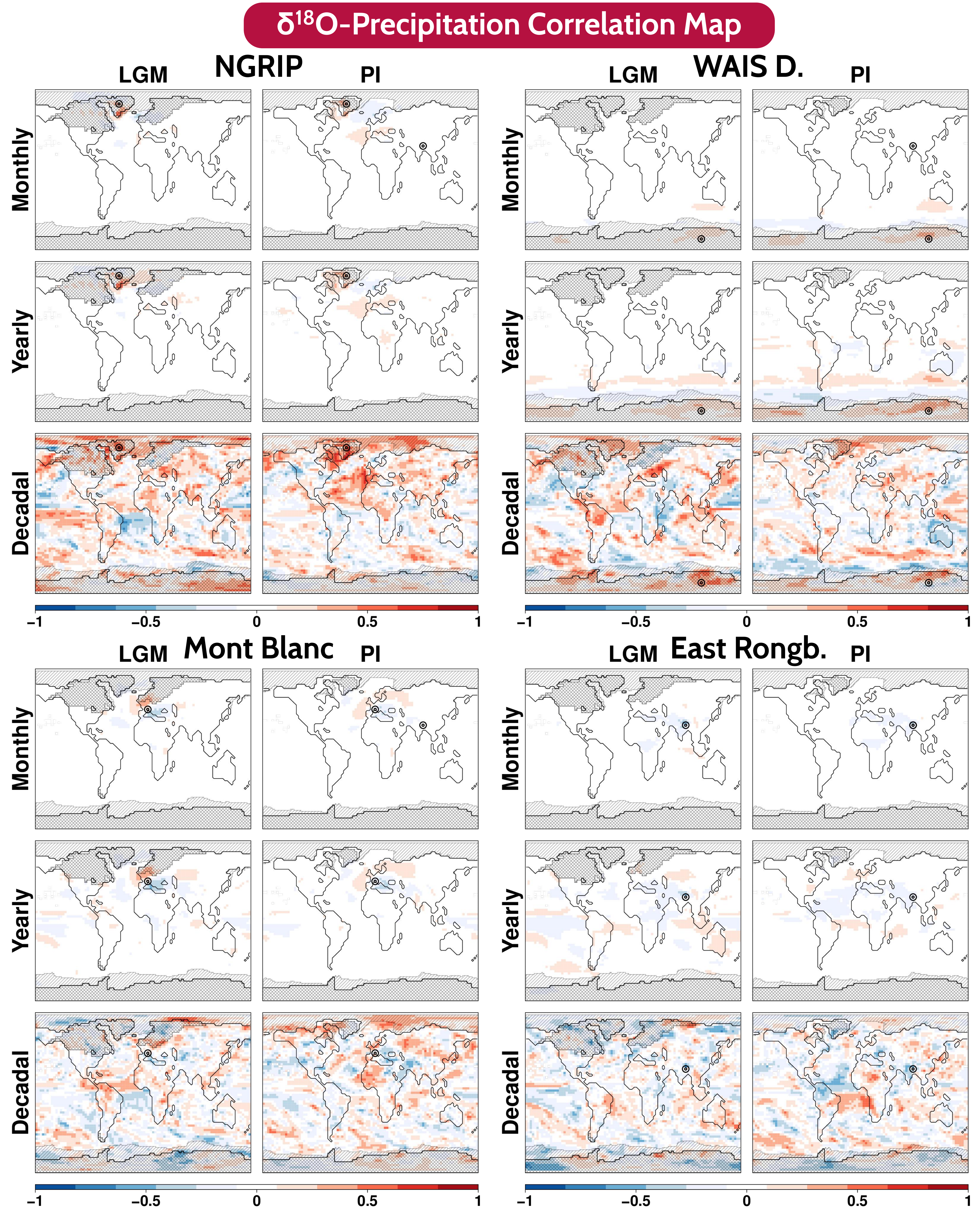
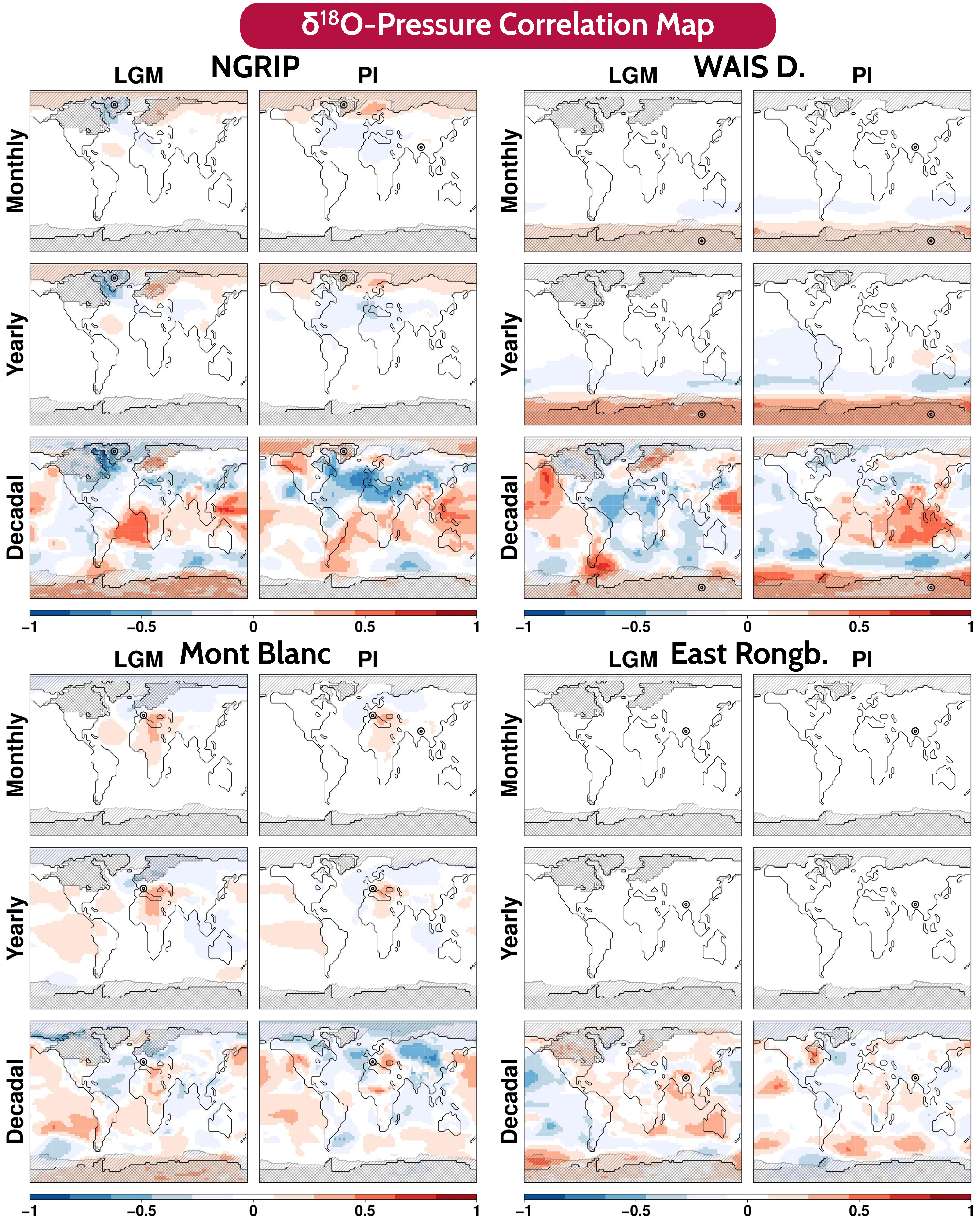
Additional plots



δ18O-Temperature Correlation Map
NGRIP
WAIS D.
Mont Blanc
East Rongb.
LGM
PI
Monthly
Yearly
Decadal
−1
−0.5
0
0.5
1


δ18O-Precipitation Correlation Map
NGRIP
LGM
PI
WAIS D.
LGM
PI
Monthly
Yearly
Decadal
Monthly
Yearly
Decadal
−1
−0.5
0
0.5
1
−1
−0.5
0
0.5
1
Mont Blanc
LGM
PI
East Rongb.
LGM
PI
Monthly
Yearly
Decadal
Monthly
Yearly
Decadal
−1
−0.5
0
0.5
1
−1
−0.5
0
0.5
1



δ18O-Pressure Correlation Map
NGRIP
WAIS D.
LGM
PI
Monthly
Yearly
Decadal
−1
−0.5
0
0.5
1
Mont Blanc
East Rongb.