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Hadley circulation extent and strength in a wide range of simulated climates

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Understanding the Hadley circulation (HC) dynamics is crucial because its changes affect the seasonal migration of the ITCZ, the extent of subtropical arid regions and the strength of the monsoons. Despite decades of study, the factors controlling its strength and extent have remained unclear. Here we analyse how HC strength and extent change over a wide range of climate conditions from the Last Glacial Maximum to future projections. The large climate change between paleoclimate simulations and future scenarios offers the chance to analyse robust HC changes and their link to large-scale factors.

The HC shrinks and strengthens in the coldest simulation relative to the warmest. A progressive poleward shift of its edges is evident as the climate warms (at a rate of 0.35°lat./K in each hemisphere). The HC extent and strength both depend on the isentropic slope, which in turn is related to the meridional temperature gradient, subtropical static stability and tropopause height. In multiple robust regression analysis using these as predictors, we find that the tropical tropopause height does not add relevant information to the model beyond surface temperature. Therefore, primarily the static stability and secondarily the meridional temperature contrast together account for the bulk of the almost the total HC variance. However, the regressions leave some of the northern HC edge and southern HC strength variance unexplained.

The effectiveness of this analysis is limited by the correlation among the predictors and their relationship with mean temperature. In fact, for all simulations, the tropical temperature explains well the variations of HC except its southern hemisphere intensity. Hence, it can be used as the sole predictor to diagnose the HC response to greenhouse-induced global warming. How to account for the evolution of the southern HC strength remains unclear, because of the large inter-model spread in this quantity.