A robust widening of the Hadley cell from the LGM to the future climate

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The width and intensity of the Hadley cell (HC) in the past, present and future climates are examined by analyzing the four sets of the equilibrium simulations archived for the Coupled Model Intercomparison Project phase 5 (CMIP5). They are the Last Glacial Maximum (LGM), the pre-industrial (PI), and the extended concentration pathway 4.5 (ECP4.5) and 8.5 simulations (ECP8.5). While the LGM represents the latest cold period of the Ice Ages about 21,000 years before the present, the latter two represent the 23rd century. In terms of multi-model ensemble-mean surface air temperature, the LGM is about -4.4°C colder than the PI condition. In contrast, the ECP4.5 and ECP8.5 are about 3.0°C and 9.0°C warmer than the PI condition. For these simulations, the poleward edge of the HC is identified by the zero-crossing latitude of 500-hPa mass stream function (Ψ500) or the location of maximum sea-level-pressure (SLP) in the subtropics.

The HC width exhibits a systematic widening from the LGM to the PI, and to the ECPs especially when detected by Ψ500. This trend is robustly found in both hemispheres but stronger in the Southern Hemisphere than in the Northern Hemisphere. More importantly, the widening of the HC is linearly related with the surface air temperature change. Based on Ψ500 metric, 10°C warming of global-mean surface air temperature is associated with about 5° widening of the HC. The HC intensity also exhibits a systematic weakening from the LCM to the ECPs. This is particularly evident in the Northern Hemisphere. In the Southern Hemisphere, only a weak hint of the HC weakening is found. A simple scaling analysis revealed that the widening and weakening of the HC is largely explained by the enhanced subtropical static stability in response to the increases of greenhouse gas concentrations.

Key words: Hadley cell, LGM, future climate