



## **Northern Hemisphere monsoon response to mid-Holocene orbital forcing and greenhouse gas-induced global warming**

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Precipitation and circulation patterns of Northern Hemisphere monsoons are investigated in Coupled Model Inter-comparison Project phase 5 simulations for mid-Holocene and future climate scenario rcp8.5. Although both climates exhibit Northern Hemisphere warming and enhanced inter-hemispheric thermal contrast in boreal summer, changes in the spatial extent and rainfall intensity in future climate are smaller than in mid-Holocene for all Northern Hemisphere monsoons except the Indian monsoon. A decomposition of the moisture budget in thermodynamic and dynamic contributions suggests that under future global warming the weaker response of the African, Indian and North American monsoons results from a compensation between both components. The dynamic component, primarily constrained by changes in net energy input over land, determines instead most of the mid-Holocene land monsoonal rainfall response. Our results highlight that mean surface warming and inter-hemispheric contrast in surface warming are poor indicators of the monsoonal precipitation response. Rather, the monsoon response is constrained by the integrated energy balance, which accounts for changes at the surface as well as at the top of the atmosphere. This explains why the mid-Holocene does not represent an analogue for future warming.