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Model performance in simulating the Global Monsoon: Skill evolution across CMIP generations

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Improving projections of future changes in the global hydrological cycle is essential in order to understand the potential impacts of climate change and develop appropriate strategies of mitigation and adaptation to their socio-economics implications. This improvement requires a rigorous global climate model (GCM) evaluation, considering that several models often misrepresent fundamental processes of the global climate system. Recently, monsoons have been seen not just as independent systems that modulate the regional hydrology and climate but as a dominant global mode referred to as the Global Monsoon (GM). The GM is tied to global atmospheric circulation processes such as seasonal precipitation variations, the migration of the Inter-Tropical Convergence Zone (ITCZ), and the variability of the Hadley and Walker cells. Additionally, it can be seen as the response of the climate system to the annual solar radiation cycle. In this context, it is essential to consider not only regions with a marked seasonal change in the direction of surface winds but also the variation of precipitation in the tropics and subtropics. Reliable representations of its main characteristics are crucial for global simulations and climate change projections.

This work assesses the ability of 64 GCMs part of three generations of the CMIP (phases 3, 5 and 6) simulating the most relevant characteristics of the global monsoon. Emphasis was placed on the GM domain and the two main modes of annual variation of precipitation and surface winds, referred to as Solstitial and Equinoctial modes. The GM wind domain and GM precipitation domain are well captured in most of the GCMs, and CMIP6 models show a significant improvement especially over the Asian-Australian monsoon (AAM) region. In order to evaluate the main modes of variability, we used projections of the model simulations onto the first two multivariate empirical orthogonal functions (MV-EOF) from observations. As a result, we find that in general, model performance is higher simulating the Solstitial mode compared to Equinoctial mode, but it has improved for both modes across the CMIP generations in terms of spatial variability and magnitude. Despite this, a regional analysis shows that performance over some regions, such as South America, does not exhibit significant improvement neither for the monsoon domain nor the annual variation modes.

We also considered the annual and seasonal mean of precipitation and surface winds, and we

observed a notable improvement across CMIP generations to reproduce their spatial patterns of variability. However, biases of magnitude remain significant, mainly for global precipitation. Finally, it is relevant to point out that dispersion among GCMs was considerably reduced within CMIP6 and that we do not find a direct relationship between model performance and horizontal resolution.