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Estimating the impact of irrigation and groundwater pumping on regional hydroclimate using an Earth System Model

Yusuke Satoh[1], Yadu Pokhrel[2], Hyungjun Kim[1], and Tokuta Yokohata[3]
[1]Korea Advanced Institute of Science and Technology, Moon Soul Graduate School of Future Strategy, Daejoen, Korea, Republic of (yusuke.satoh@kaist.ac.kr)
[2]Michigan State University, East Lansing, United States of America
[3]National Institute for Environmental Studies, Tsukuba, Japan

Irrigation is an anthropogenic forcing to the Earth-system that alters the water and heat budgets at the land surface, leading to changes in regional hydro-climate conditions over a range of spatiotemporal scales. These impacts of irrigation are anticipated to escalate in the future due to increased food demand and the pervasive effects of climate change. Thus, it is imperative to better understand the nature, extent, and mechanisms through which irrigation affects the Earth's system. However, despite its increasing importance, irrigation remains a relatively nascent component in the Earth-system modeling community, necessitating advancements in modeling and a deepened understanding.

Our research aims to improve the quantitative understanding of the impacts of irrigation and groundwater use as anthropogenic drivers on regional climate and environmental changes. To this end, we developed an improved Earth-system modeling framework that is based on MIROC-ES2L (Hajima et al 2020 GMD) coupled with hydrological human-activity modules (Yokohata et al. 2020 GMD). This model enables the simulation of a coupled natural-human interaction including hydrological dynamics associated with irrigation processes. Employing this Earth-system model, we carried out a numerical experiment in T85 spatial resolution, utilizing an AMIP style set-up. Here, our ensemble simulation allows for statistical quantification of the irrigation impact differentiating them from the uncertainties arising due to natural variability.

Through our investigation, we have identified specific regions and seasons where irrigation exerts a discernible influence on regional hydro-climate. Notably, our results show substantial disparities—larger than or comparable to inter-annual variability—between simulations incorporating and excluding the irrigation process, particularly in heavily irrigated regions such as Pakistan and India. Our model demonstrates that the introduction of moisture into the soil through irrigation alters the hydrological balance of the land surface, consequently influencing the overlying atmosphere. Conversely, we found significant uncertainty in the impact estimate for some regions, even those heavily irrigated, such as the central United States and eastern China, indicating the challenges of robustly estimating irrigation impacts with limited samples. This underscores the necessity for an appropriate statistical approach to evaluate the impact of irrigation, considering the inherent variability. Furthermore, our study delves into estimating

regional variations in the contributions of groundwater and surface water use to these impacts. Emphasizing the importance of a more nuanced understanding of regional characteristics in irrigation impact assessments, our research underscores the significance of coupled earth system models in comprehending and predicting the intricate interplay between human activities and the Earth's climate system.