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Explicit representation of groundwater process in a global-scale land surface model to improve the prediction of water resources

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Groundwater is the most important freshwater resource and its relevance can be viewed in two aspects; a pervasive and seemingly abundant storage of freshwater and a consistent source of surface water in dry season in form of base runoff, which is nothing but a groundwater reservoir discharging into rivers. For proper estimation of groundwater resources in current and future climate conditions, explicit physically-based representation of groundwater process is necessary in models. Traditionally, global land surface models (LSMs) mainly focused on energy balance at land surface and often they have simplified runoff scheme largely neglecting the groundwater process. In this study, an explicit shallow groundwater representation was integrated into a LSM, Minimal Advanced Treatments of Surface Interaction and Runoff (MATSIRO).

The coupled model was applied in global-scale to evaluate the role and relevance of explicit groundwater representation on the prediction of groundwater-based freshwater resources. Three aspects of concern were seasonal variation of discharge, simulation of low flow, and estimation of net groundwater recharge. The results were compared with a commonly used approach in land surface modeling, in which gravity drainage from unsaturated soil column is assumed to be base runoff. The results showed that groundwater representation significantly improved the partitioning of runoff into surface and sub-surface component, and subsequently seasonal variation of discharge in majority of 20 major river basins of the world. In the prediction of monthly river discharge, the model with explicit groundwater representation out-performed the model with gravity drainage in 18 out of 20 target river basins. The most significant improvements were in river basins of semi-arid regions (e.g., Darling, Orange, and Zambezi river basins), and the river basins with marked dry season (e.g., Ganges and Mekong river basins) where upward capillary flow from groundwater reservoir to unsaturated soil column is substantial. Under such conditions, the gravity drainage assumption over-predicted net drainage flux from unsaturated zone to groundwater reservoir and consequently base runoff was over-predicted. Furthermore, using MATSIRO with groundwater representation, direct groundwater runoff from coastal region to ocean was estimated to be 5788 $km^3/year$ which is around 15 % of estimated global total runoff. Also, comparison of daily flow duration curves showed that the prediction of low flow, with probability of exceedance $\geq$ 90 %, was also enhanced with explicit representation of groundwater process. Finally, global groundwater recharge was predicted to be 31789 $km^3/year$. If the water table is in equilibrium condition, long-term mean groundwater recharge should be of similar magnitude to long-term mean base runoff. Multi-model ensemble mean base runoff from second phase of Global Soil Wetness Project (GSWP-2) is 30200 $km^3/year$. Due to lack of validation data for groundwater recharge on global scale, the estimation close to GSWP-2 multi-model ensemble mean base runoff can be assumed to provide first order approximation. Region-wise, humid regions (e.g., Amazon and Congo river basins) have the largest net groundwater recharge. The net groundwater recharge is small for arid and semi-arid regions mainly because of small precipitation input, high evaporative loss, and strong upward flux from saturated zone (groundwater reservoir) to unsaturated zone.

With enhanced prediction of monthly river discharge, low flow in daily temporal scale, and net groundwater recharge, the MATSIRO land surface model with explicit representation of groundwater process can be used in global-scale water resources assessment under current and future climate conditions.