Assessing groundwater-stream interactions influence on ORCHIDEE land surface model dynamics: parametrization and results for Little Washita watershed

A. Tootchi, A. Jost, A. Ducharne, T. Verbeke, Sorbonne Universités, UPMC Univ Paris 06, CNRS, EPHE, UMR 7619 METIS, 4 place Jussieu, 75252 Paris Cedex 05, France

Key words: Land surface models, Groundwater modelling, wetland hydrology

Introduction

Land surface is a complex medium embedding water dynamics at the interface of atmosphere and deep subsurface. Although streams morphology mainly follows topography, understanding basin hydrology requires much more than measurement of surface properties. To capture the integrated system, upland recharge zones, rivers, floodplains, low-lying wetlands and their interactions should be considered. Even though river water parallel to main channel can be measured at hydrometric stations, exchanged fluxes perpendicular to the thalweg, within the subsurface saturated/unsaturated layer and temporally flooded zones (like wetlands) could not be easily quantified. Yet, these hydrologic exchange flows comprise a significant fraction of streamflow. For example it is estimated that up to 30% of Amazon River's annual flow is exchanged with its surrounding floodplains [1].

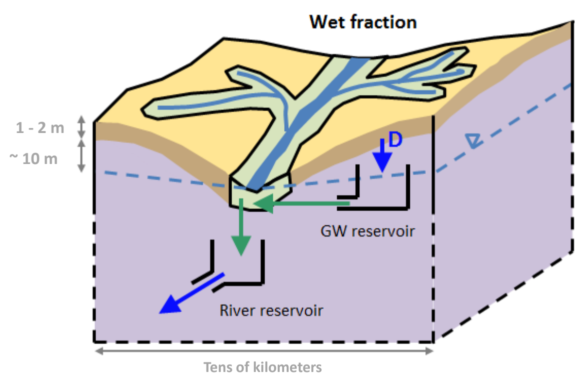

Figure 1: Flow exchanges in different directions within the groundwater/stream interface (Credit: Agnès Ducharne)

Parametrizing the water flow dynamics in different land features helps capturing most of the variation in groundwater/stream/atmosphere interactions. For instance, storage capacity reduces the variation in monthly mean runoff during winter and summer with a significant effect on surface temperature through sustained evaporation [2]. Also, the groundwater (GW) is shown to have a critical impact on energy and mass exchanges with the environment if located within the root zone and can affect rainfall persistence [3, 4, 5, 6]. In many land surface models (LSM), GW processes are not represented in detail and water infiltration is often freely drained at the bottom of the soil column or is trapped within it (in a no drainage situation) with no lateral movement. Advances have been made toward introducing GW and stream interaction (at regional scale) with encouraging feedbacks in improving base-flow and evapotranspiration [7]. In these developments, aquifer/streams fluxes are often formulized as proportional to hydraulic gradient between the river water and surrounding banks, adjusted to a coefficient based on river width and hydraulic conductivities of riverbed and aquifer.

Modelling framework

In the ORCHIDEE land surface model, the effect of GW on river discharge is described within the river routing scheme using a linear reservoir model to represent GW storage and delay, with no horizontal GW fluxes between grid-cells [8]. The GW parametrization is currently being improved, to describe the interactions between the water table and soil moisture, in a sub-grid fraction, defined as a function of topography and hydrogeological data. This improved model is called ORCHIDEE-GWF (GroundWater-fed Fraction) and builds upon recent developments to permit saturation into the soil column [9].

ORCHIDEE-GWF is also intended to be fed by a global wetland map at high resolution, such as the composite wetland map proposed by [10]. The latter is based on the overlap of floodplains and inundated areas (mostly derived from satellite imagery) with so-called scattered GW driven wetlands, identified from high-resolution indices of shallow water tables.

The idea of the modelling framework is to introduce a wetland fraction in each grid-cell, which corresponds to lowland fraction. This fraction is described as a separate hydrological element, with a separate water budget. The lowland fraction receives water input not only through rainfall infiltration and snowmelt, but also from the down-flowing runoff (upland fraction) of the grid-cell. The runoff includes both overland flow and GW flow, delayed by the corresponding lagging reservoirs of the routing scheme. The lowland fraction thus acts as riparian buffer zone, with increased soil moisture compared to upland fraction, allowing to build a water table within ORCHIDEE-GWF soil column (if climate is wet enough). The free bottom drainage is blocked and replaced by a lateral GW-stream exchange for the lowland fraction.

Expected results

We aim to test the ORCHIDEE-GWF first at the basin scale (Little Washita watershed in the USA, 600 km²) before global-scale deployment. This small watershed is chosen since [3] have shown the direct connection between aquifer and vegetation root uptake in areas where the water table is shallow (1-5 m). The results will be compared to observations and also modelling results of [3, 4] which include 3-D water exchanges. Through these simulations we expect to obtain better representation of latent heat fluxes at the basin scale along with improved seasonality variations caused by the introduction of riparian buffer zones. Another challenge is to adapt water dynamics parametrization for different scales, from small regional scales to global scale.

References

[1] Richey, J. E., Mertes, L. A., Dunne, T., Victoria, R. L., Forsberg, B. R., Tancredi, A. C., Oliveira, E. (1989). Sources and routing of the Amazon River flood wave. Global biogeochemical cycles, 3(3), 191-204.

[2] van den Hurk, B., Hirschi, M., Schär, C., Lenderink, G., van Meijgaard, E., van Ulden, A., & Jones, R. (2005). Soil control on runoff response to climate change in regional climate model simulations. Journal of Climate, 18(17), 3536-3551.

[3] Kollet, S. J., Maxwell, R. M. (2008). Capturing the influence of groundwater dynamics on land surface processes using an integrated, distributed watershed model. Water Resources Research, 44(2).

[4] Maxwell, R. M., Kollet, S. J. (2008). Interdependence of groundwater dynamics and land-energy feedbacks under climate change. Nature Geoscience, 1(10), 665-669.

[5] Fan, Y., Miguez-Macho, G., Jobbágy, E. G., Jackson, R. B., Otero-Casal, C. (2017). Hydrologic regulation of plant rooting depth. Proceedings of the National Academy of Sciences, 201712381.

[6] Bierkens, M. F., Van den Hurk, B. J. (2007). Groundwater convergence as a possible mechanism for multi-year persistence in rainfall. Geophysical Research Letters, 34(2).

[7] Vergnes, J. P., Decharme, B., Habets, F. (2014). Introduction of groundwater capillary rises using subgrid spatial variability of topography into the ISBA land surface model. J. of Geo. Res.: Atmospheres, 119(19)

[8] Ngo-Duc T, Laval K, Ramillien G, Polcher J, Cazenave A (2007) Validation of the land water storage simulated by Organising Carbon and Hydrology in Dynamic Ecosystems (ORCHIDEE) with Gravity Recovery and Climate Experiment (GRACE) data. Water Resour. Res., 43, W04427.

[9] Campoy, A., Ducharne, A., Cheruy, F., Hourdin, F., Polcher, J., Dupont, J. C. (2013). Response of land surface fluxes and precipitation to different soil bottom hydrological conditions in a general circulation model. J. of Geo. Res.: Atmospheres, 118(19).

[10] Tootchi, A., Jost, A., Ducharne, A. (in prep). Multi-source global wetland mapping: combining surface water imagery and groundwater constraints. To be submitted to HESS (Hydrol. Earth Syst. Sci)