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Upscaling runoff and evapotranspiration fluxes in the Little Washita watershed using physically-based hillslope models

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1. Introduction

Land Surface Models used in regional or global applications are built on coarse grid cells (0,2-2°) with 1D vertical fluxes. They neglect or over simplify hydrological processes occurring at finer scale. These processes, such as groundwater dynamics and stream-aquifer interactions are essential to predict evapotranspiration and runoff fluxes. Thus, **upscaling** these water fluxes from local to global scale is a challenging issue that we tackle here. To do so we consider the **hillslope scale** (Khan et al, 2014; Loritz et al, 2017), since it represents a first step in the reduction of fluxes dimensionality. In this study, we investigate the following question :

Using physically based models, can water balance from 3D catchment simulation be predicted by a single hillslope model ?

The approach consists in defining a representative hillslope of the catchment, and to use the drainage density in order to obtain the fluxes for the whole basin (Fig.1). The **Little Washita (LW) watershed** (Oklahoma, USA) is used as study site. LW hydrology is **simulated over 20 years (1993-2013)** using the **integrated code HydroGeoSphere** (Aquanty.com) for both 3D and 2D simulations.

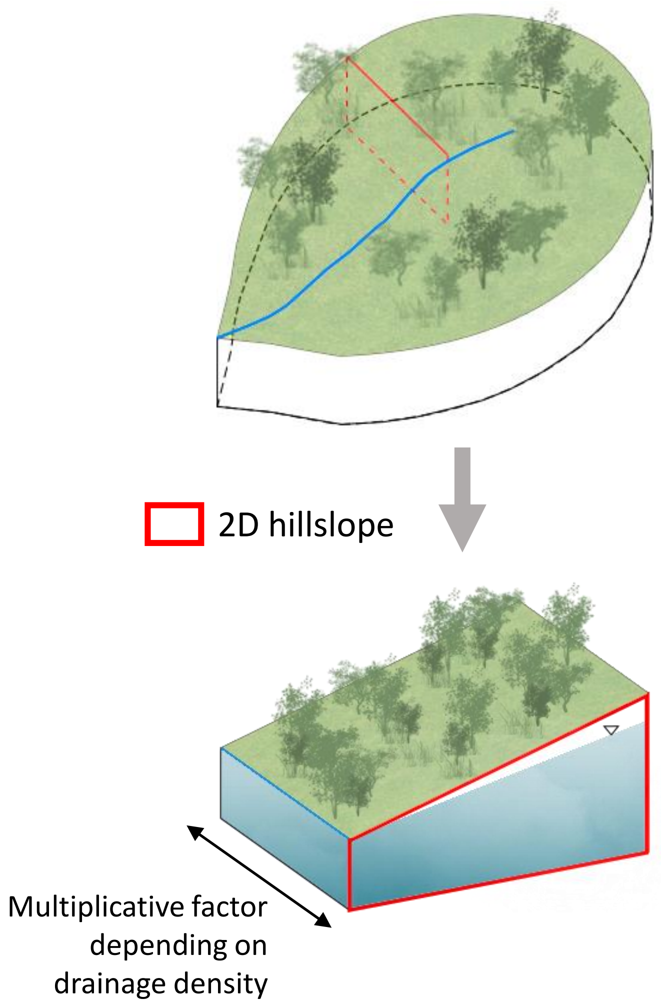
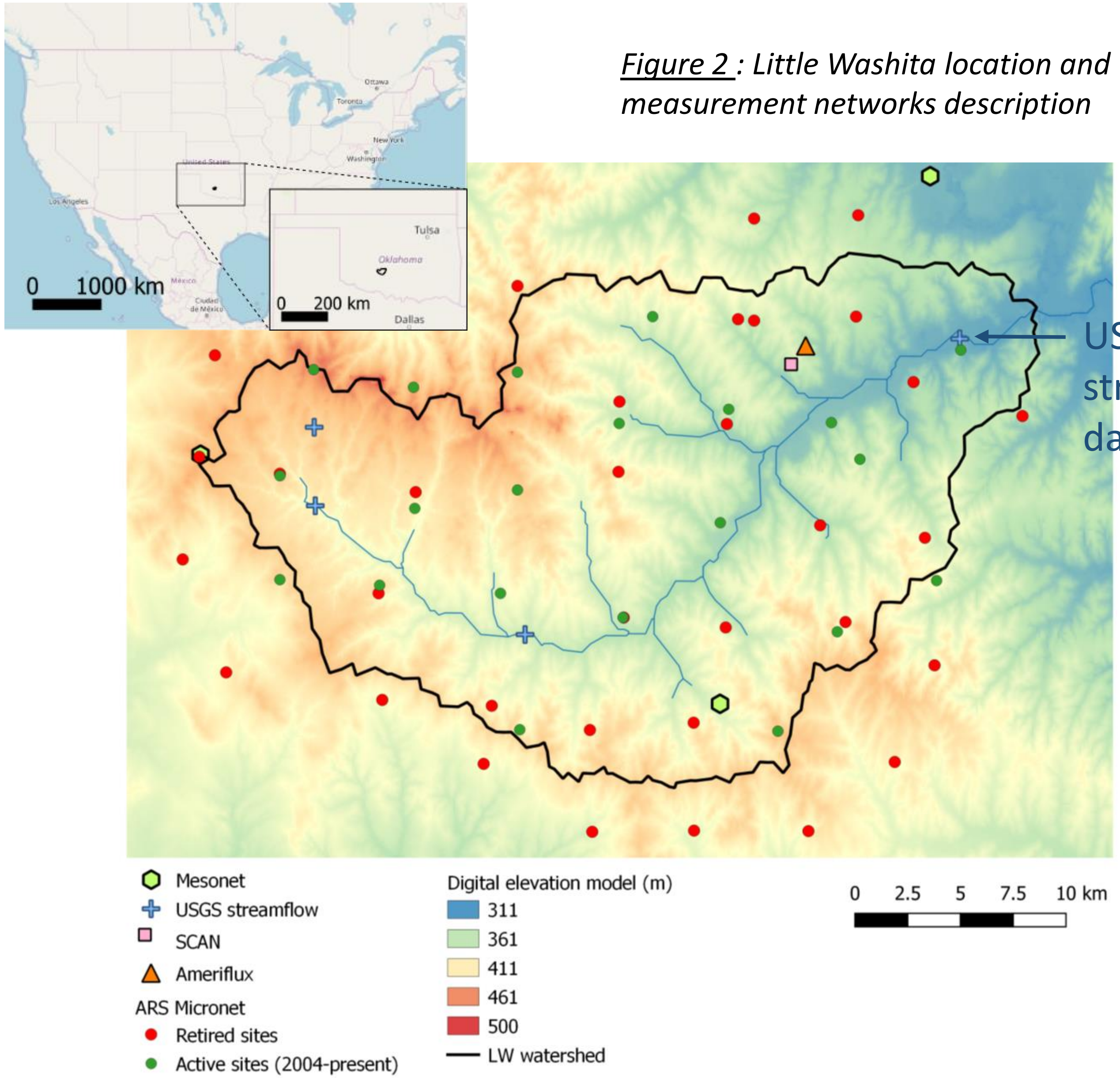


Figure 1 : Schematic of the hillslope modelling approach

2. Study area : the Little Washita watershed (Oklahoma, USA)

- The Little Washita (LW) is an **experimental watershed** that :
  - contains **several measurement networks** (Fig.2). It is « *an outdoor hydrologic research laboratory* » according to Starks et al., 2014.
  - is used as a study site for **many modelling studies** (Rigon, 2006; Kollet and Maxwell, 2008; Ferguson and Maxwell, 2010; Condon and Maxwell, 2014)
- Area : **610 km²**
- **Sub-humid climate** (Allen and Naney, 1991) :
  - Average annual rainfall : 740 mm
  - Average daily temperature for :
    - July : 34°C
    - January : -4°C
- Vegetation : **65 % grassland, 16% crops, 13% trees**. (Starks et al., 2014)

Figure 2 : Little Washita location and measurement networks description



USGS1 : streamflow data

3. Three-dimensional reference model

A 3D model is built using the integrated physically based code HydroGeoSphere (HGS, Aquanty.com). This model is used as the reference in order to evaluate the hillslope simulations (referred to as « REF 3D » later).

Some caracteristics of the reference model :

- Discretization :
  - spatial : 100m to 1000m horizontally
    1cm to 18m vertically
  - Temporal : max 86 400 sec (1day)
- Homogeneous geological medium parameters ($K_{sat} = 10^{-5}$ $m.s^{-1}$)
- Homogeneous meteorologic forcings (not spatialized) from NARR dataset (North America Regional Reanalysis)
- Spatialized vegetation, constant in time
- Critical depth boundary condition at the outlet
- Initialization by spinup strategy over one year

The model was calibrated over a year in order to fit the measured river discharge at the USGS1 station. Then, the hydrology is simulated over the 20 years period using the calibrated parameters. As we focus on decreasing model dimensionnality, the fit between measured and simulated data will not be tackled here.

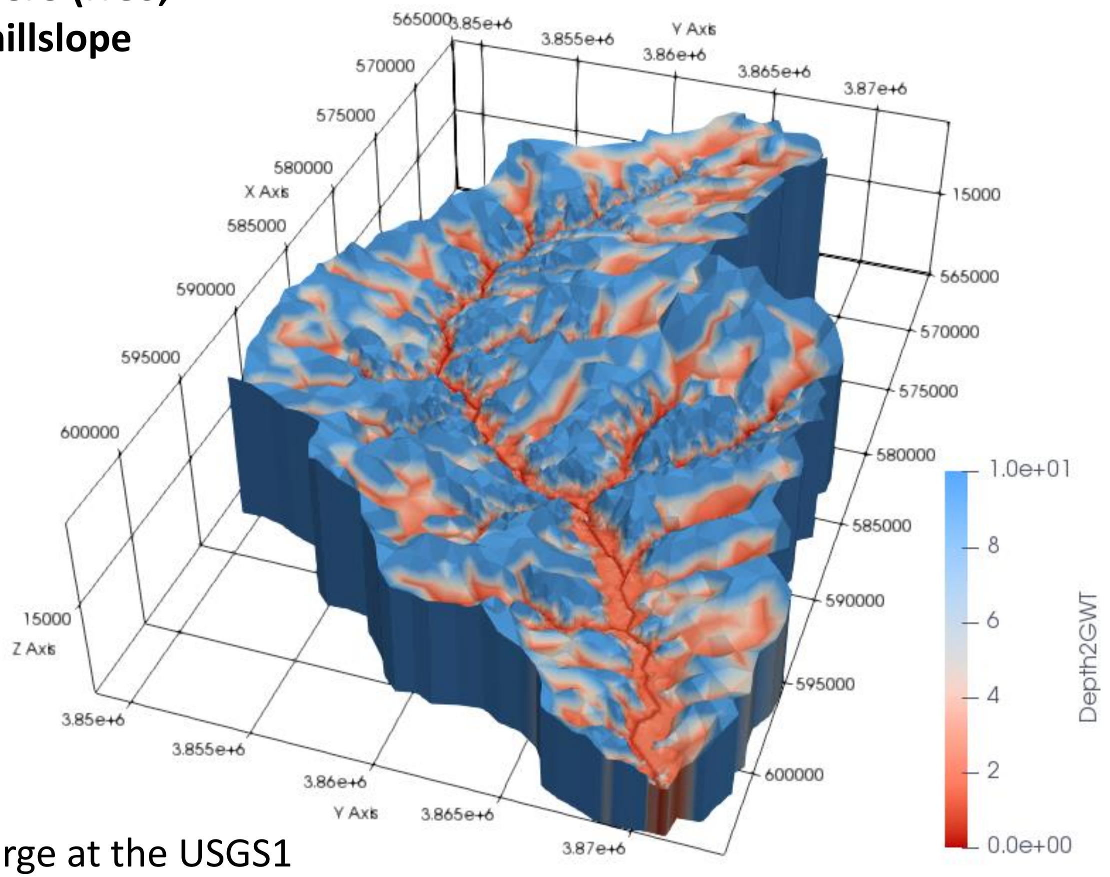


Figure 3 : 3D modelling – Depth to groundwater table (m)

4. Parametrization of the hillslope scale model

Hillslope model is also built using HGS. Some of its caracteristics are :

- In order to keep the hillslope parametrization as simple as possible, we consider a **linear soil surface and a flat base** (Fig.4).
- Spatial and temporal discretization are the same as in the reference model.
- An **equivalent vegetation** is defined by averaging the parameters according to the percentage of the basin surface each vegetation type occupies.
- The hillslope simulation is initialized the same way as the reference model and then runned over the same 20 years.

How sensible is the hillslope model to its geometry parameters L and γ ?

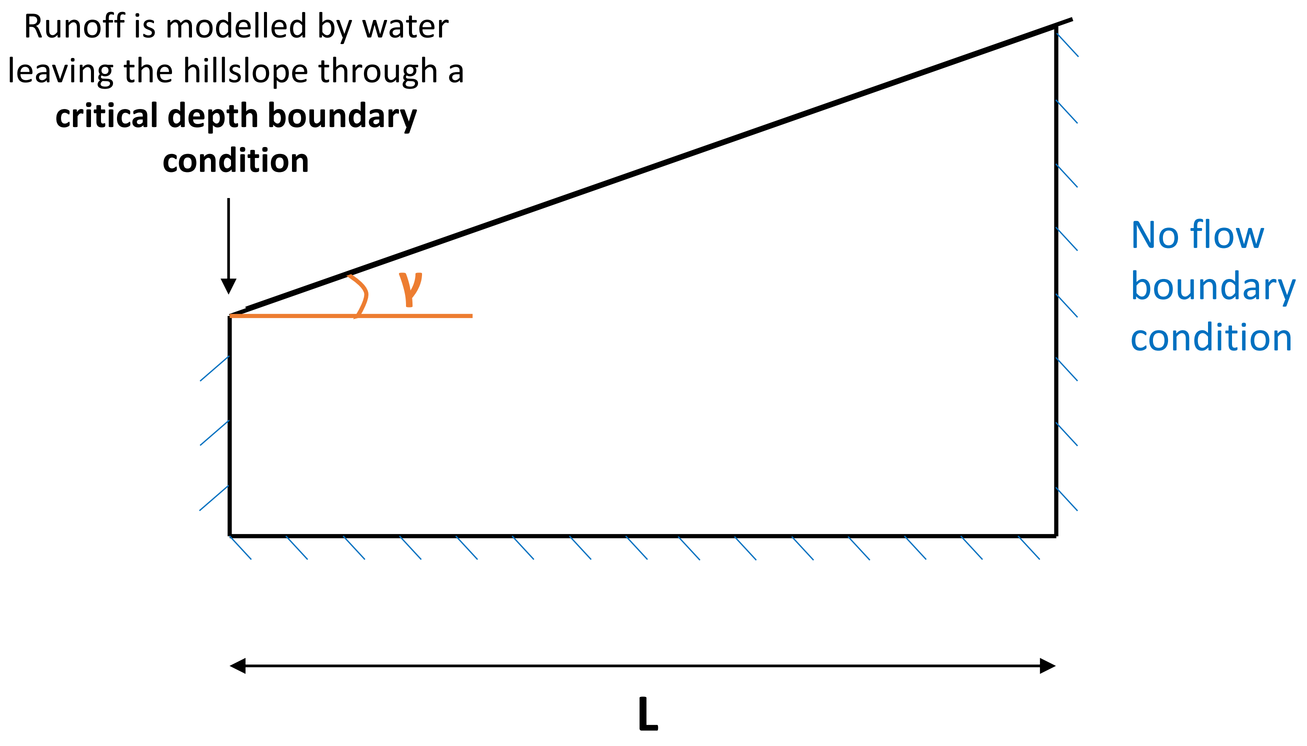


Figure 4 : Conceptual schema of the 2D hillslope model. Its geometry will be determined by both L and γ parameters.

4. Parametrization of the hillslope scale model

Sensitivity tests were conducted on both hillslope **length (L)** (Fig.5a) and **slope (tan(γ))** (Fig.5b) **:**

- Over the 20 years period, the negative variation in water storage leads to a decreasing river discharge. **Larger is L, slower is the river discharge decrease.**
- Steeper is the slope, larger is river discharge. This increase of river discharge with slope is constant over the period, which shows a **direct correlation between slope and river discharge.**
- The hillslope **evapotranspiration (ET) fluxes turned out not to be sensitive** to the geometry parameters.

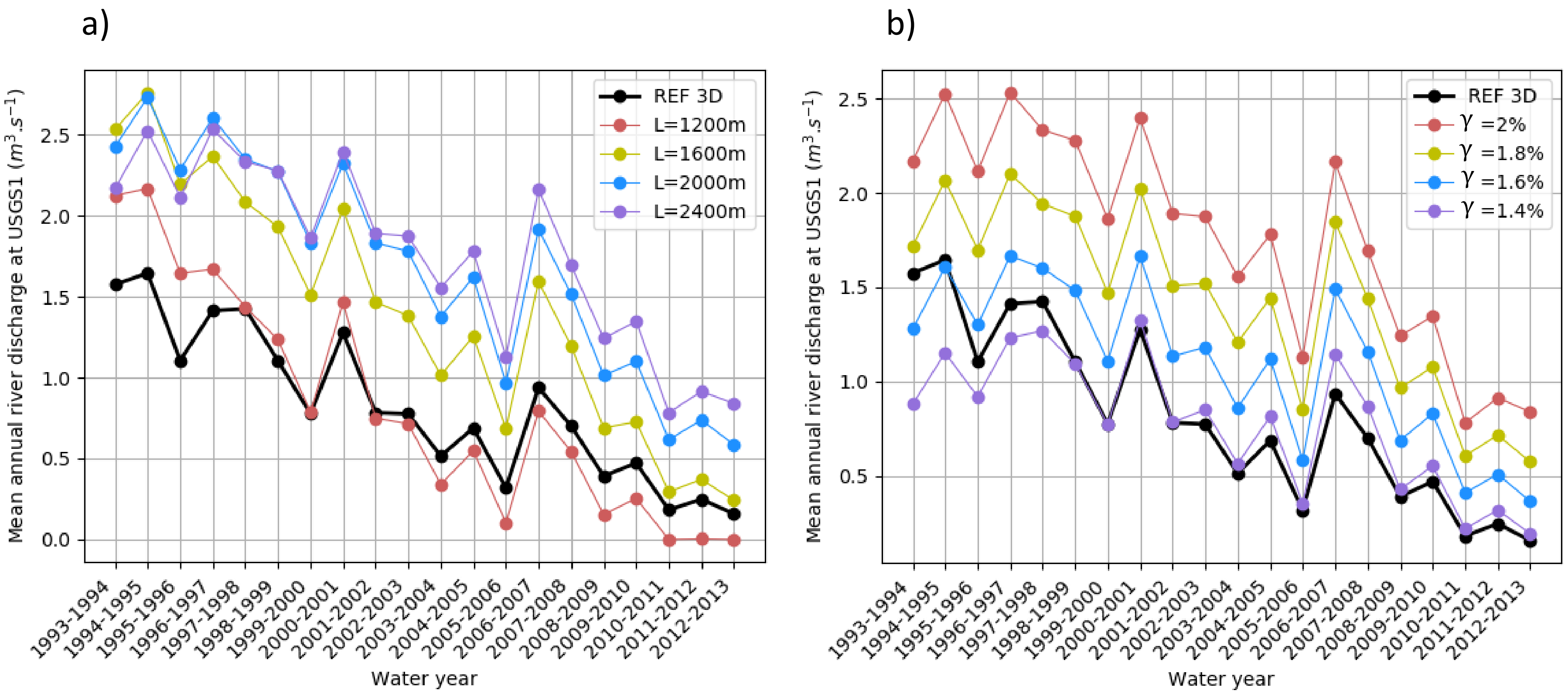


Figure 5 : River discharge sensitivity over the 20 years period to :

a) the hillslope length L (the parameter (tan(γ)) is set to 2%)

b) to the slope (tan(γ)) (the parameter L is set to 2400m).

5. Results

The sensitivity tests allow us to define the best hillslope geometry parameters in order to fit with the reference model : L=2200m and $(\tan(\gamma))$ =1,4%.

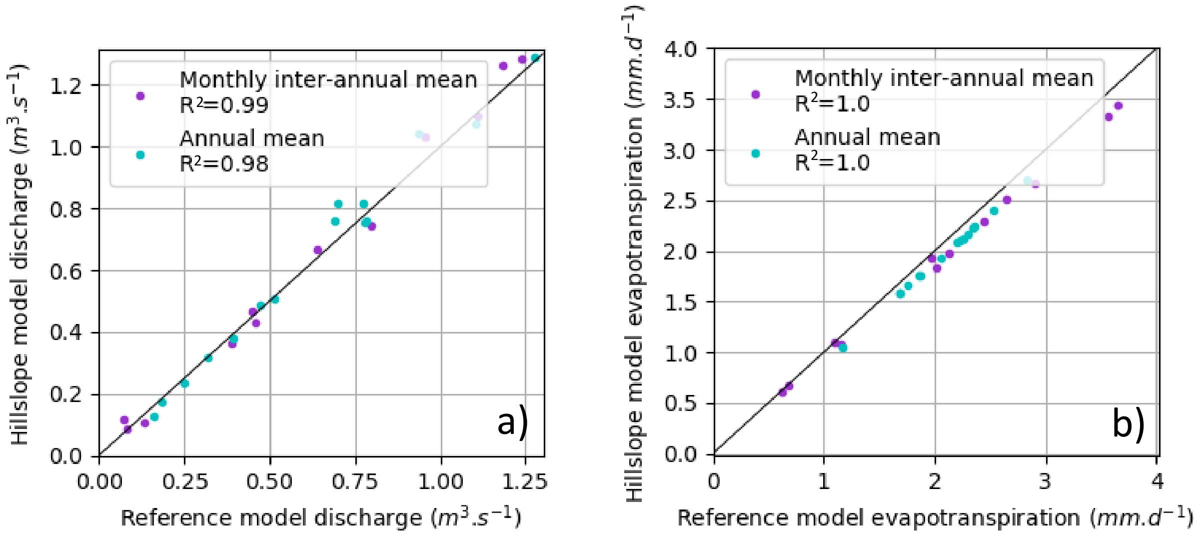


Figure 6 : Correlation between 2D and 3D simulated runoff (a) and evapotranspiration (b). Annually and monthly interannual averaged fluxes are shown here.

- 2D runoff and ET fluxes match well 3D fluxes when they are annually and monthly averaged (Fig.6). Nevertheless, ET is slightly underestimated by the 2D model (Fig.6b).
- At the daily timescale, the simulation of runoff peaks can be evaluated. It is shown that the peaks recession period is shorter with 2D model than with 3D model (Fig.7a). Regarding the ET, underestimation by the 2D model mostly occurs during the dry season (Fig.7b).

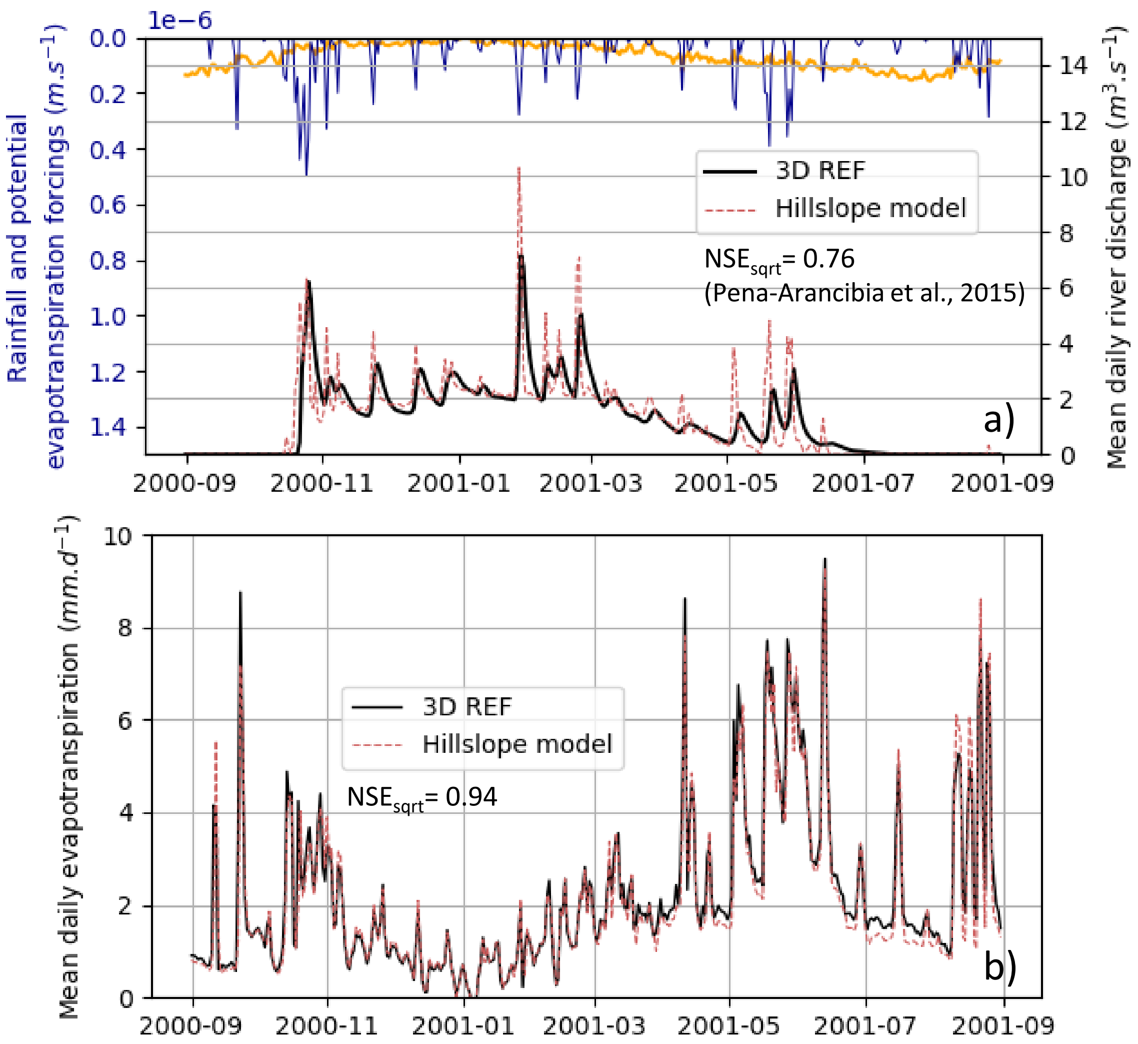


Figure 7 : Comparison of daily averaged fluxes for a water year (2000-2001) between 2D and 3D simulated runoff (a) and evapotranspiration (b).

6. Conclusion and perspectives

Take home message

Regardless of some minor differences between hillslope simulated fluxes and reference ones (runoff peak recession period, dry season evapotranspiration), **we show that water balance from three-dimensional Little Washita watershed simulation can be predicted by a single hillslope model.**

What's next ?

The next steps of this work are : (i) to develop a simplified hillslope analytical model that describes the hydrology of the hillslope; (ii) To upscale the 2D model to 1D soil column geometry, and (iii) to establish the relationships between the 3D and 1D hydrologic constitutive equations and parameters.