ORCHIDEE-TECHNICAL REPORT

REPORT ON THE ROLE OF LITTER IN THE WATER FLUXES: HOW EXISTING MODELS REPRESENT LITTER?

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1. Introduction

The role of evaporation and evapotranspiration from land surfaces on the climate dynamic is known for several decades (Monteith 1976, Kelliher, 1993). But the role of litter as a controlling factor of water fluxes within the continuum soil-vegetation-atmosphere has been largely neglected in particular in models aiming at reproducing water fluxes from natural ecosystems (Petroupolos et al., 2009). Litter may substantially impact the hydrology. In particular, litter limits water loss by evaporation (Ogée et al., 2001), intercepts rainfall (Bristow et al., 1986) and reduces thermal amplitude at daily time scale (Park et al., 1998). Nevertheless, the litter dynamic makes complicating the development of models including litter since, the size, the albedo and other characteristics of litter may change during the year. Nevertheless, the importance of litter in hydrology induced the development of models representing litter, in particular for agroecosystems (Gonzalez-sosa et al., 1999 ; Findeling et al., 2003 ; Dahiya et al., 2007). The first models representing litter first considered litter as an opaque layer unable to store water or energy (Van Baven and Hillel, 1975). But since Van Baven and Hillel (1975), different approaches has been developed that can be classified in three categories:

(i) Models that do not explicitly represent litter but estimate parameters (soil resistance or conductance) with data obtained in systems where litter was present.

(ii) Models that explicitly represent litter as a new layer in the continuum soil-vegetation-atmosphere.

(iii) Models that only add a resistance parameters for litter to reduce evaporation.

I will, in the following sections, present some details of each philosophy used to represent litter but it must be noted that, to my knowledge, all the hydrological models representing litter are 1-D models but one (Sakaguchi and Zeng, 2009).

2. Models that do not explicitly represent litter.

These models are probably the less interesting in our situation since they considered that the soil resistance is due to a part of litter and a part of soil. However, they do not split explicitly the resistance parameter in two terms, they just estimate the resistance parameter on sites where litter was present (Baldocchi et al., 2000 ; Baldocchi et al., 2001 ; Dahiya et al., 2007).

Baldocchi et al., (2000) and Baldocchi et al., (2001) defined the soil resistance using the Camillo and Gurney (1986) equation firstly defined for bare soils.

(1) $R_{soil} = 4104 \times (w_s - w_g) - 805$

where w_s is the saturated volumetric water content and w_g represents the near surface volumetric water contents of the soil. In their case, they considered that the litter was totally dry and fixed w_g to zero. Therefore the litter representation is quite simple. Nevertheless with this simple scheme associated with a thermal stratification including litter to calculate soil surface aerodynamic resistance they showed that litter thickness could change the partitioning of solar energy into sensible, latent and soil heat flux.

Dahiya et al., (2007) used the Van Genuchten, (1980) equations to estimate the soil water retention curve and the hydraulic conductivity function. Then they optimized the parameters of the Van Genuchten, (1980) equations using different treatment for the same site: with or without much and with or without tillage. Therefore, they finally obtained four sets of parameters with very different values. For example, the differences of saturated hydraulic conductivity between treatments with mulch and control ranged between -97% and +40% depending on the depth and on the methodology used to optimize the parameters. They finally showed that their model parameterized with data obtained without mulch was not able to reproduce the water fluxes of crops where mulch is applied.

These approaches are probably not adapted to a land surface model but they underlined the importance of litter in the water exchanges between land surface and the atmosphere and they also showed that the parameters values could considerably change if litter is considered.

3. Models that explicitly represent litter as a new layer in the continuum soil-vegetation-atmosphere.

Another approach proposed in the literature to represent the effect of litter on water fluxes is to explicitly add layers with their own parameters values aiming at representing litter. The models using this approach moved from the soil-vegetation-atmosphere continuum to the soil-litter-vegetation-atmosphere continuum. To my knowledge, the great majority of models representing litter effects on hydrology used this method (Gonzalez-sosa et al., 1999 ; Findeling et al., 2003 ; Findeling et al., 2007 ; Ogée et Brunet, 2002 ; Schaap and Bouten, 1997 ; Dufrêne et al., 2005 ; Haverd and Cuntz, 2010 ; Bristow and Campbell, 1986 ; Bussière and Cellier, 1994).

They were generally quite successful to represent the water fluxes within the continuum soil-litter-vegetation-atmosphere. For instance, Gonzalez-sosa et al., (1999) and Gonzalez-sosa et al., (2001) using the same model on the same sites, a grassland in the southwest of France, but at different periods observed a decrease of 4-10% for evaporation when litter is explicitly represented. They also observed that soil evaporation decreased but transpiration increased compared to simulations with no litter. Finally they showed that the temperature profiles were considerably modified with colder averages and smaller amplitude for soil temperature. Findeling et al., (2003), using data coming from cropland in la Tijana's station in Mexico and in the Avignon's station in France, also observed better agreements between data and model outputs if a litter layer is explicitly represented but they also showed that their formalism did not improve the soil water and temperature evolution under both low and strong wind regimes. Ogée and Brunet (2002), compared their model outputs with data coming from a pine forest in southwest of France over a two years period. They obtained quite good agreements for soil and litter moisture and temperature as well as for the turbulent fluxes measured above the floor when litter was represented. Without explicit litter representation, the model was not able to successfully represent all the model outputs in the same time. Haverd and Cuntz (2010) reported that their model was better in reproducing evaporation and the associated isotopic signature in a tall Eucalypt forest in south-eastern Australia when litter was represented. Bristow and Campbell (1986) reduced evaporation by 36% with an explicit representation of litter in Pullman USA over a two years period. Finally, Bussière and Cellier (1994) reproduced quite well the soil water content profile of a sugar canes cropland in Guadeloupe with a model with explicit representation of litter.

Furthermore, Dufrêne et al., 2005, showed that the net ecosystem exchange calculated by the CASTANEA model was not sensitive to modification of parameters related to litter hydrology. Finally, it must be noted that Schaap and Bouten (1997), assuming an isothermal litter layer was also able to reproduce evaporation in a Douglas fir stand in the central Netherlands during two months.

The addition of new layer aiming at representing litter as a new component of the soil-vegetation-atmosphere continuum with its particular parameters seems to be a successful way to improve the water fluxes for very different ecosystems. Nevertheless, any of the models presented here has been evaluated for a long-term period. Moreover, they generally used the same sites to calibrate and validate their models.

4. Models that only add a resistance parameters for litter to reduce evaporation.

I found only two studies that add a resistance to reduce evaporation (Park et al., 1998; Sakaguchi and Zeng, 2009). Park et al., (1998) defined the resistance as following:

(2) $r = \frac{F(\theta)}{D_{atm}}$

where *r* is the litter resistance to vapor diffusion, *F(θ)* is the resistance of the litter layer to water vapor diffusion from the interior of the litter layer to its surface and D_{atm} is the molecular diffusivity of water vapor. *F(θ)* is expressed as functions of the litter layer thickness and its water content following eq. (3)

(3) $F(\theta) = F1(\theta_{sat} - \theta)^{F2}$

(3-1) $F1 = A \times THK^{B}$

(3-2) $F2 = C \times THK^{D}$

where θ_{sat} is the saturated water content of litter, θ the litter water content, *THK*, the litter thickness and *A*, *B*, *C* and *D* are coefficients.

With this scheme they were able to reduce evaporation by 47% and 61% for two different time periods compared to a model without litter resistance and therefore better reproduce water fluxes from a secondary mixed-forest in Nagoya, Japan.

Sakaguchi and Zeng, (2009) is the only study I found that aimed to add a litter resistance to evaporation in a land surface model. In their case, they used CLM 3.5 and presented another relation to define litter resistance *r*:

(4) $r = \frac{1}{0.004 \times u_*} \times (1 - e^{-L^{eff}})$

where u_* is the friction velocity and L^{eff} is the effective litter area index (i.e. the litter area index non recovered by snow). L^{eff} is calculated as following:

(5) $L^{eff} = L \times [1 - \min(f^{snow}, 1)]$

where L is the litter area index and f^{snow} is the effective snow cover of the litter layer given as:

(6) $f^{snow} = \frac{d_{snow}}{0.05}$

where d_{snow} is the depth of snow and 0.05 is assumed to be a typical depth of the litter layer. Finally, Sakaguchi and Zeng, (2009) assumed that L is equal to one.

A global simulation was performed by the authors and they showed that the effect of litter resistance on evaporation globally reduce by 11% the evaporation. They also showed that the part of soil evaporation in total evapotranspiration might increase or decrease depending on the biome (Fig. 1)

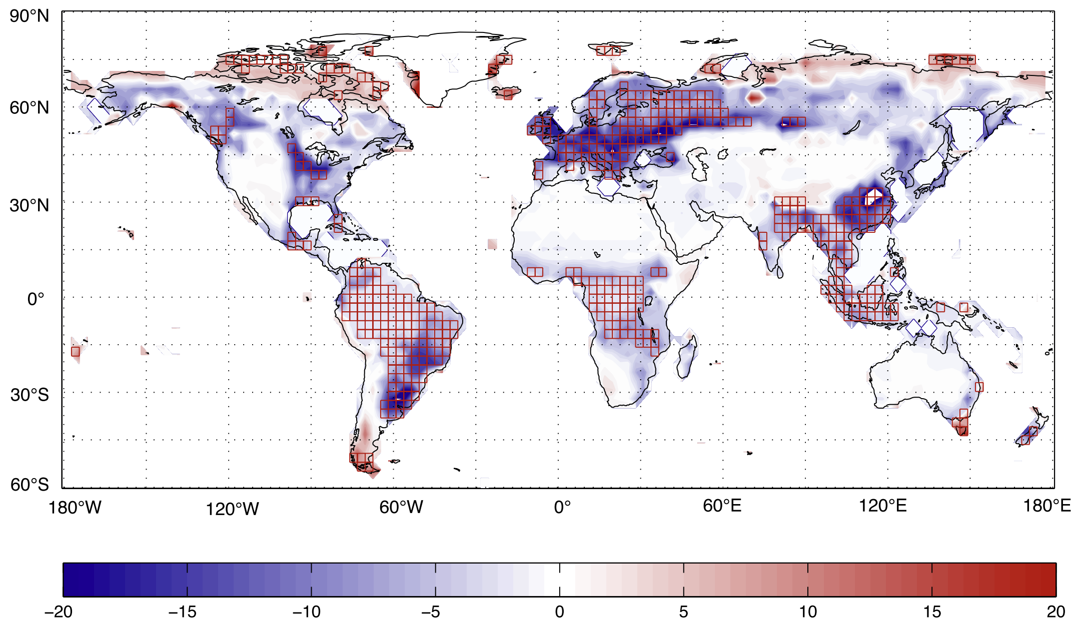

Figure 1: Difference between the new formulations (with litter resistance) and the control CLM3.5 (without litter resistance) in soil evaporation percentage (Es%) of the total ET. Red boxes indicate the grid boxes where the difference is statistically significant at the 95% confidence level based on the t test for 5 years of monthly outputs. Sakaguchi and Zeng, (2009).

5. Conclusion.

From the mini-review performed here, it seems that three different approaches exist to represent the effect of litter on water fluxes and in particular on evaporation. The first one, calibration of existing parameters using data obtained on sites where litter was present, is probably the less adapted to land surface model since the parameters are site dependants. The second one, an explicit representation of litter acting as a new layer in the continuum soil-vegetation-atmosphere, seems very promising. Indeed, with this approach the water fluxes are always better represented but also the temperature profiles, the daily thermal amplitude and the energy fluxes. However, this solution needs non-negligible developments and might not be a short-term solution to reduce evaporation in ORCHIDEE. Finally, the last solution, adding a litter resistance function to reduce evaporation, is probably the most adapted to ORCHIDEE. It seems not very difficult to implement in the model and could solve some of the problems discussed during the previous technical meetings. Moreover, this approach has already been implemented in a land surface model with interesting results.

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