Testing a Dry Soil Layer scheme in SURFEX and Harmonie-Arome

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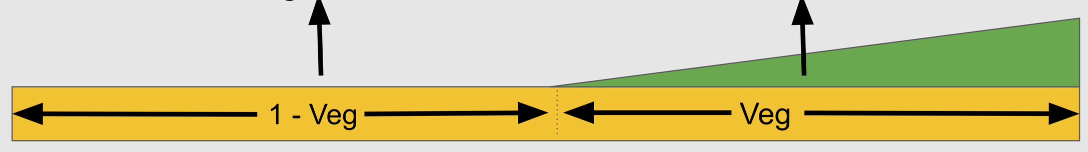
1. Introduction

Total evapotranspiration (ET) is a key variable in Land surface/Earth System models, which needs to be accurately simulated in order to avoid excessive biases in simulated energy, water, and carbon cycles. Models, which usually simulate ET by formulating resistance-based parameterizations for plant transpiration and direct evaporation from the soil and the plant canopy, often overestimate ET on semi-arid environments. A new soil evaporation resistance parameterization in which soil evaporation is approximated as water vapour diffusion through a dry soil layer (DSL) following [1] is available in SURFEX, and has shown good performance in offline tests for two semi-arid sites from the LIAISE field campaign [2]. Recent Harmonie-Arome (H-A) tests activating DIF and MEB ISBA settings have shown a degradation in near surface humidity variables, leading to an overall dry bias, specially in areas with contrasting seasons where the soil gets quite dry in late spring and summer. In this study we test the DSL parameterization in H-A experiments over Spain.

2. Current ET parameterization in SURFEX and inclusion of a Dry Soil Layer (DSL)

ISBA / ISBA DIF

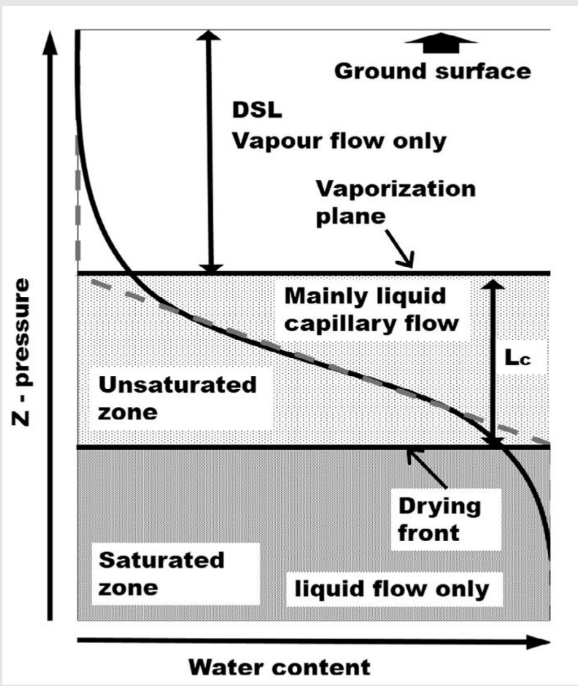
$$ET = E_g + E_{tr} = \ldots$$



$$\ldots = (1-veg)\frac{\rho_a(h_u q_{sat}(T_s)-q_a)}{R_a} + veg\frac{\rho_a(q_{sat}(T_s)-q_a)}{R_a+R_{stom}}$$

Schematic representation of a DIF ISBA patch (no MEB) when no snow is present, and expressions for soil evaporation and plant transpiration. The former is assumed to take place in liquid phase and only controlled by atmospheric resistance $R_a=(V_a C_H)^{-1}$, while transpiration includes plant's stomatal resistance (R_{stom}), which decreases with leaf area index (LAI) and SWI (see section 3).

DSL in ISBA / ISBA DIF and MEB



Balugani et al., 2018

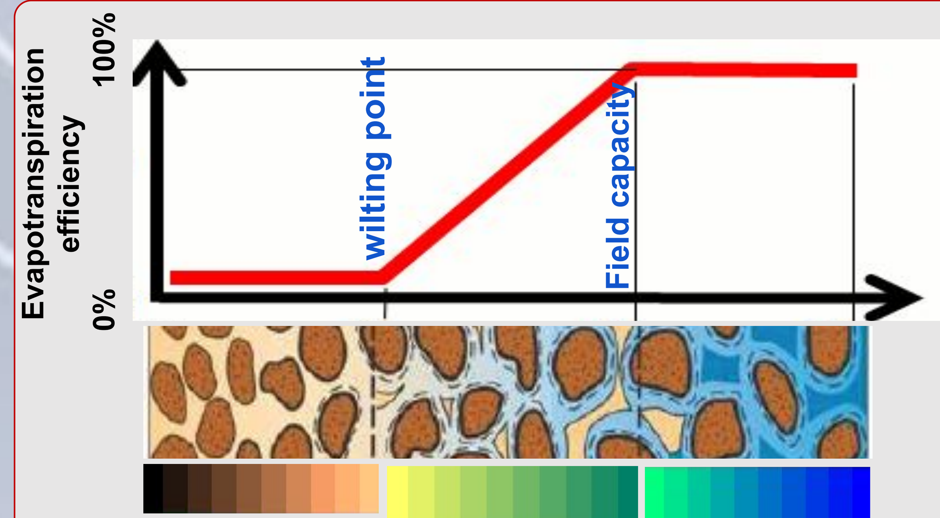
In arid and semi-arid areas, when the top soil humidity falls below a certain value (θ_{dsl}, a fraction K of the soil's porosity ϕ), a dry soil layer of depth *DSL* is formed when the liquid continuity through a soil profile is lost, and water transport is mainly in the gas phase [3]. We followed [1] for this implementation, where a soil resistance to evaporation R_{soil} is added to E_g by parameterizing *DSL* as a function of the top soil layer soil moisture (θ_{top}). Δz (maximum DSL thickness) is set to 1.5 cm, θ_{air} is an "air-dry" soil moisture, D_v the air diffusivity for water and τ the tortuosity. A similar implementation was done for the Multi-Energy Balance (MEB) ISBA option but not tested in this work.

$$E_g = (1-veg)\frac{\rho_a(h_u q_{sat}(T_s)-q_a)}{R_a+R_{soil}}$$

$$R_{soil} = \frac{DSL}{D_v \tau} \qquad \theta_{dsl0} = K\Phi$$

$$DSL = \begin{cases} \Delta z \frac{\theta_{dsl0}-\theta_{top}}{\theta_{dsl0}-\theta_{air}} & ;\theta_{top} < \theta_{dsl0} \\ 0 & ;\theta_{top} \gg \theta_{dsl0} \end{cases}$$

3. Soil moisture indexes



SMR (Soil Moisture Residue) closeness to evapotranspiration

SWI (Soil wetness index): evapotranspiration efficiency

FCE (Field Capacity Excess): degree of saturation

- These are used in Figure 2 to study the overall changes in soil moisture introduced by the DSL implementation.
- They consider the relative position of the absolute soil moisture with respect to their soil texture properties of each grid point (wilting point, field capacity and porosity)
- Transpiration is only possible when SWI>0 for the transpirative layers (soil layer 2 in SURFEX), and is maximum for SWI>1.

4. Testing DSL in H-A

- Model version: Harmonie-46h1_dev
- Domain: IBERIAxl_2.5, 65 levels, 2.5km
- Surface: 2 Patches, DIF+ES, SEKF
- MEB activated in PATCH2 (forests)
- Upper air assim: 3DVAR

- Coldstart in jan,1st 2022, 3h cycling
- +48h forecast after may, 1st
- Fig.1 shows verification for may.
- **DSL runs only activate the scheme for PATCH1 (low vegetation patch).**

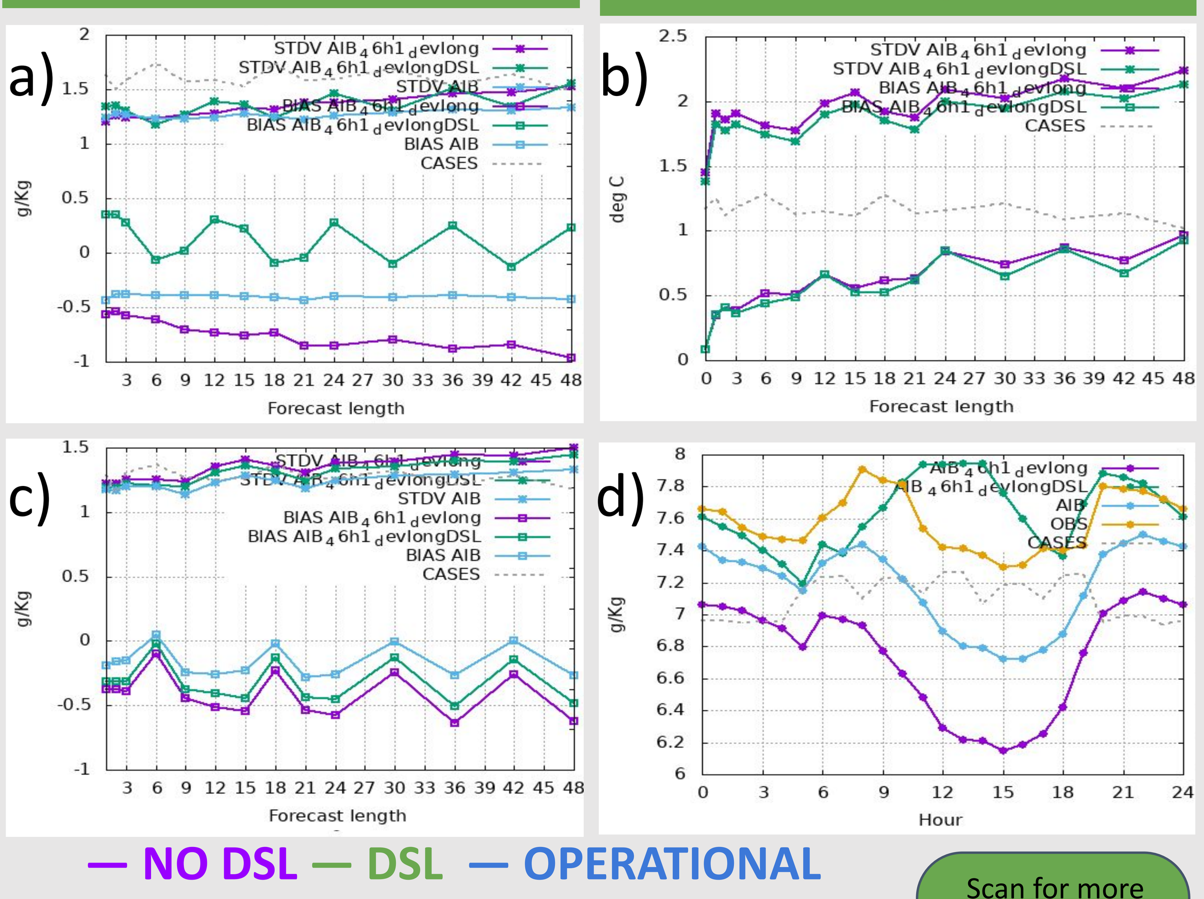


Figure 1. BIAS and STDV for Q2m and T2m over stations where the fraction of bare soil (1-*veg*) for PATCH1 is larger than 0.7 ((a) and (b)) or smaller than 0.4 (c), and diurnal cycle for Q2m for stations where (1-*veg*) > 0.7 for PATCH1 (d).

Scan for more verification results (hirlam users):

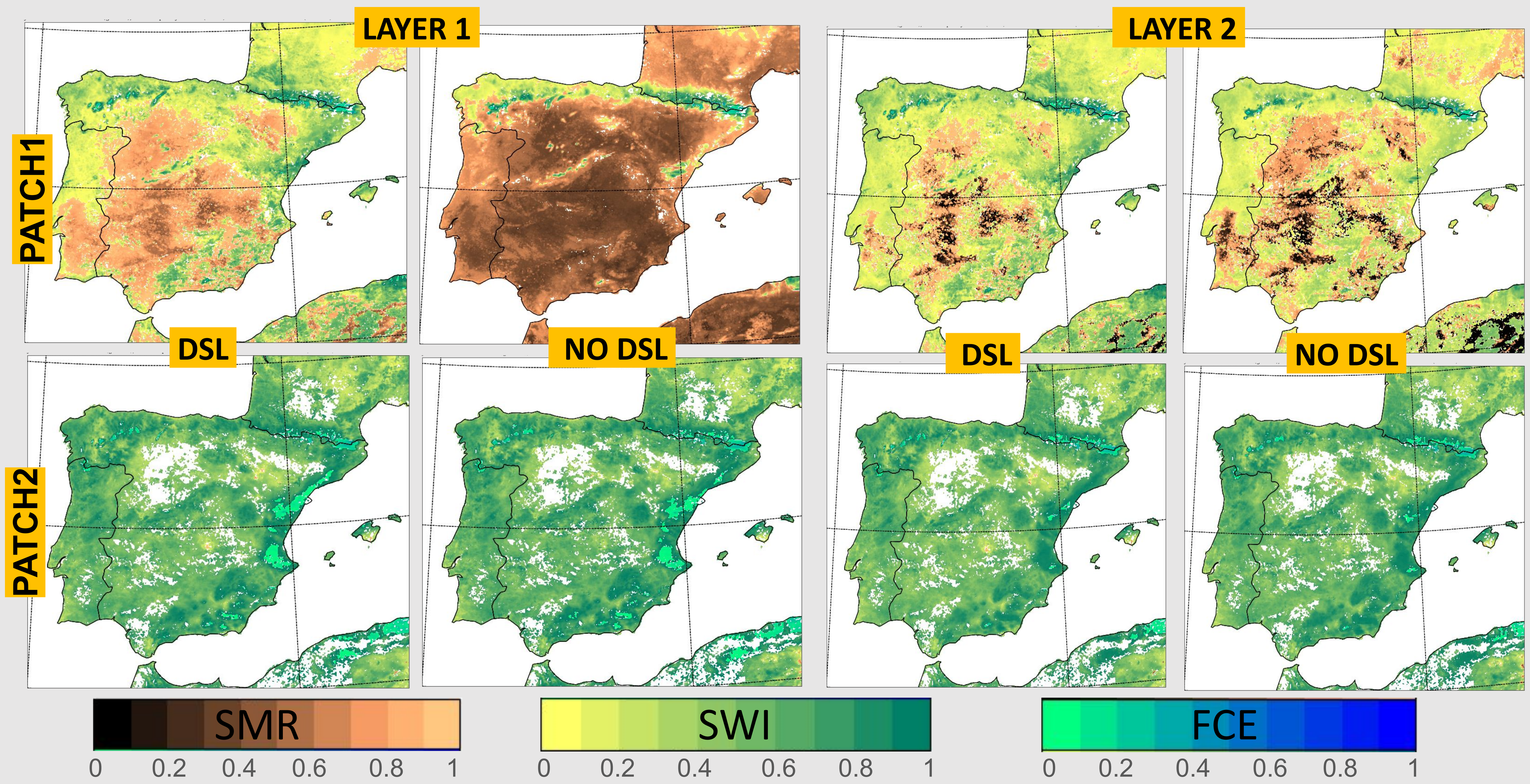


Figure 2. SMR, **SWI** and **FCE** indexes for both PATCHES and the two first DIF soil layers at the end of May'22 for the **DSL** and **NO DSL** simulations.

5. Discussion

In Fig. 1a,b&c, a clear benefit of activating the DSL scheme is shown for Q2m, with biases close to the operational configuration or even quite smaller for selection of stations with a low vegetation fraction (Fig. 1 a,b) , i.e. a large amount of bare soil directly exposed to the atmosphere for evaporation. The diurnal cycle (b) is clearly improved in the DSL run, although it appears to be about 3h out of phase with respect to observations and the remaining runs. Q2m is interpolated in SURFEX between the surface and the lowest atmospheric level values for each PATCH and then a final gridpoint value is obtained by patch-averaging. Analyzing the changes in Layer 1 soil moisture indexes (Fig. 2, the 4 leftmost figures) it is evident that after activating DSL, the decrease in E_g throughout the previous months strongly increase surface soil moisture in PATCH1. Therefore, Q2m increases due to the increase of the bottom values of the interpolation for PATCH1. The impact of the scheme is also seen in layer 2 (the transpirative layer in SURFEX), so that the areas active for transpiration are increased and their transpiration efficiency is larger. Meanwhile, soil moisture values in PATCH2 (where the DSL was not active) show that there is no apparent excessive soil evaporation or drying problem for layer 1 in the MEB patch, nor a lack of potential for transpiration in layer 2. This agrees with the low bias of Q2m in verifications for PATCH2 dominated areas (not shown but available in the QR code above).

6. Summary & outlook

- Excessive soil evaporation (E_g) in PATCH1 in H-A with new surface options (DIF, MEB) produces a dry bias in near surface humidity variables (Q2m, Td2m, HR2m…).
- The DSL scheme helps to reduce this bias by reducing E_g, keeping a more moist first soil layer.
- The second soil layer is also more moist, but the increase in plant transpiration (E_{tr}) during summer will be limited in crop areas, where the vegetation fraction *veg* (defined as a function of LAI in SURFEX) drops substantially in that season, leading to less *ET* (not shown).
- In order to reduce this decrease of *ET* during summer, which can reduce precipitation extremes in airmass convection, a different formulation for *veg* will be considered.

7. References

[1] Swenson, S. C., and D. M. Lawrence (2014), Assessing a dry surface layer-based soil resistance parameterization for the Community Land Model using GRACE and FLUXNET-MTE data, J. Geophys. Res. Atmos., 119, 10,299–10,312, https://doi.org/10.1002/2014JD022314

[2] Boone, A., M. Best, J. Cuxart, J. Polcher, P. Quintana, J. Bellvert, J. Brooke, G. Canut-Rocafort, J. Price, 2019: Land surface Interactions with the Atmosphere over the Iberian Semi-arid Environment (LIAISE). *Gewex News*, **29**(1), 8-10.

[3] Balugani, E., Lubczynski, M. W., van der Tol, C., & Metselaar, K. (2018). Testing three approaches to estimate soil evaporation through a dry soil layer in a semi-arid area. Journal of Hydrology, 567, 405–419. https://doi.org/10.1016/j.jhydrol.2018.10.018

8. Acknowledgements

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