Soil freezing in a SVAT

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ABSTRACT

Soil moisture changes are generally due to external forcing (precipitation, evaporation, etc.) as well as internal forcing (gravitational force, capillarity, transpiration, etc.). Freezing/thawing effects must be taken into account, especially in those region where air temperature goes below 0 °C for several consecutive days.

A wrong or imperfect soil temperature and moisture estimation leads to errors in the boundary layer estimation (temperature, convection, etc.). Moreover soil properties (hydraulic conductivity, thermal capacity, etc.) may change during the freezing/thawing transient stage, leading to variations in the hydrological balance.

Comparisons with observations highlight the importance of the correct soil freezing/thawing parameterisation to correctly estimate the energetic and hydrological balances in the surface layer.

PURPOSE

- numerical modelling of the freezing/thawing processes in the soil
- better estimation of the soil water content in cold regions
- better estimation of the PBL

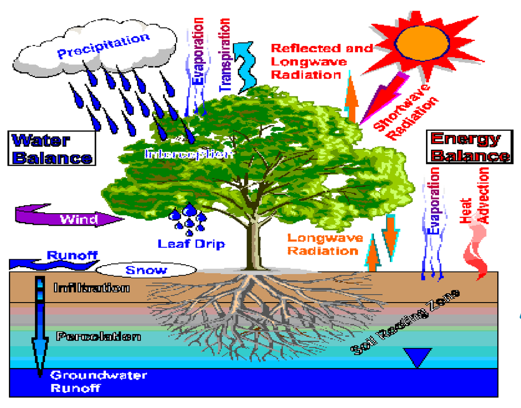


Fig. 1. The physical mechanisms at the soil-atmosphere interface.

AVAILABLE DATA

Synthetic data created on purpose

Field campaigns:

1. Brookings, SD USA - FLUXNET network
2. Falkenberg, DE EU – EOL NCAR

Source:

http://www.fluxnet.ornl.gov/fluxnet/

http://www.eol.ucar.edu/

LSPM – SVAT scheme

The **L**and **S**urface **P**rocesses **M**odel (**LSPM**) is a 1-D multilayer model computing energy, momentum and water exchanges between atmosphere and land. The processes in LSPM are described in terms of physical fluxes and hydrological state of the land.

The physical processes:

- Radiative fluxes;
- Momentum flux; sensible and latent heat fluxes; partitioning of latent heat into canopy, soil and snow components;
- Heat transfer in a multi-layer soil or lake

The hydrological processes:

- Evapotranspiration processes;
- Snow accumulation and melting;
- Rainfall, interception, infiltration and runoff;
- Soil hydrology, including water transfer in a multi-layer soil

Freezing/thawing parameterization

Three main parameterizations have been included in LSPM:

1) energy vs temperature (Schrodin et al.)

$\Delta E = (\rho c)\,\Delta z\,(T_{pre}-T_0)$ (> 0 melting; < 0 freezing) **Available energy for phase change**

$\Delta W_{l,max} = -\Delta W_{i,max} = \Delta E/(L_f \rho_w)$ **Max possible change of liquid water (ice) $W_{l,max}(W_{i,max})$**

$T = T_0 + (\Delta W_i - \Delta W_{i,max})(L_f\,\rho_w)/(\rho c\,\Delta z)$

2) thermal-capacity vs temperature (Viterbo et al.)

$$(\rho C)_s \frac{\partial T}{\partial t} = \frac{\partial}{\partial z}\left(\lambda_T \frac{\partial T}{\partial z}\right) + L_f \rho_w \frac{\partial \eta_i}{\partial t} \qquad \eta_i = f(T)\sigma_v \eta_f$$

$$f(T) = \begin{cases} 0 & T > T_1 \\ 0.5\left[1 - \sin\left(\frac{\pi(T - 0.5T_1 - 0.5T_2)}{T_1 - T_2}\right)\right] & T_2 \le T \le T_1 \\ 1 & T < T_2 \end{cases}$$

3) n. 2 modified

As the n. 2 but different definition of the soil ice: $\eta_i = f(T)\eta - \eta_{min}$

LSPM setting

Synthetic data:

6 layers (dm) 2,4,8,16,32,64 ΔT = 60 sec Initial η_w = 0.4 m^3/m
Initial T = 1°C Soil type = silty clay Soil porosity η_s=0.492 m^3/m^3
Wilting point η_{wi}=0.283 m^3/m^3 Field capacity Ψ_{fc}= 0.4 m
Vegetation type = short grass

Brookings (USA) campaign

6 layers (cm) 4,12,20,44,84,172 ΔT = 60 sec Initial η_w = 0.4 m^3/m^3
Initial T = 1°C Soil type = silt loam Soil porosity η_s=0.485 m^3/m^3
Wilting point η_{wi}=0.179 m^3/m^3 Field capacity Ψ_{fc}= 0.36 m
Vegetation type = short grass

Falkenberg (DE) campaign

4 layers (cm) 6,10,20,40 ΔT = 60 sec Initial η_w = 0.4 m^3/m^3
Initial T = 1°C Soil type = sandy and loam Soil porosity η_s=0.35 m^3/m^3
Wilting point η_{wi}=0.4 m^3/m^3 Field capacity Ψ_{fc}= 0.23 m
Vegetation type = short grass

RESULTS

FIRST TEST synthetic data

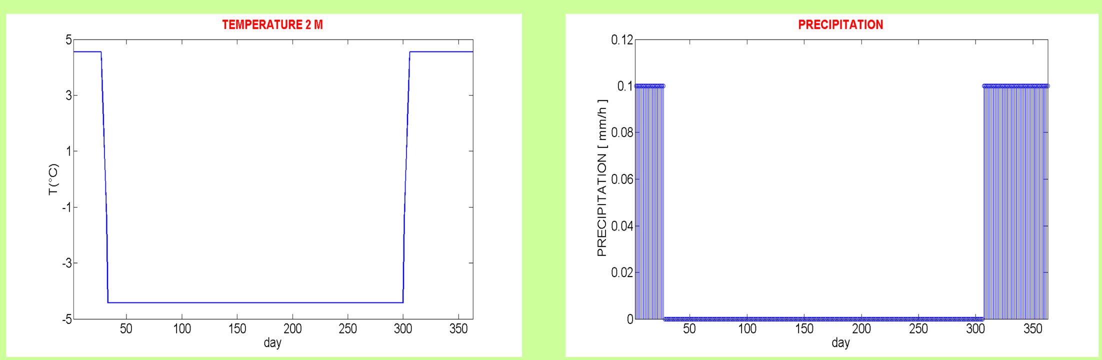


Fig. 1. Synthetic data created on purpose for the first test.

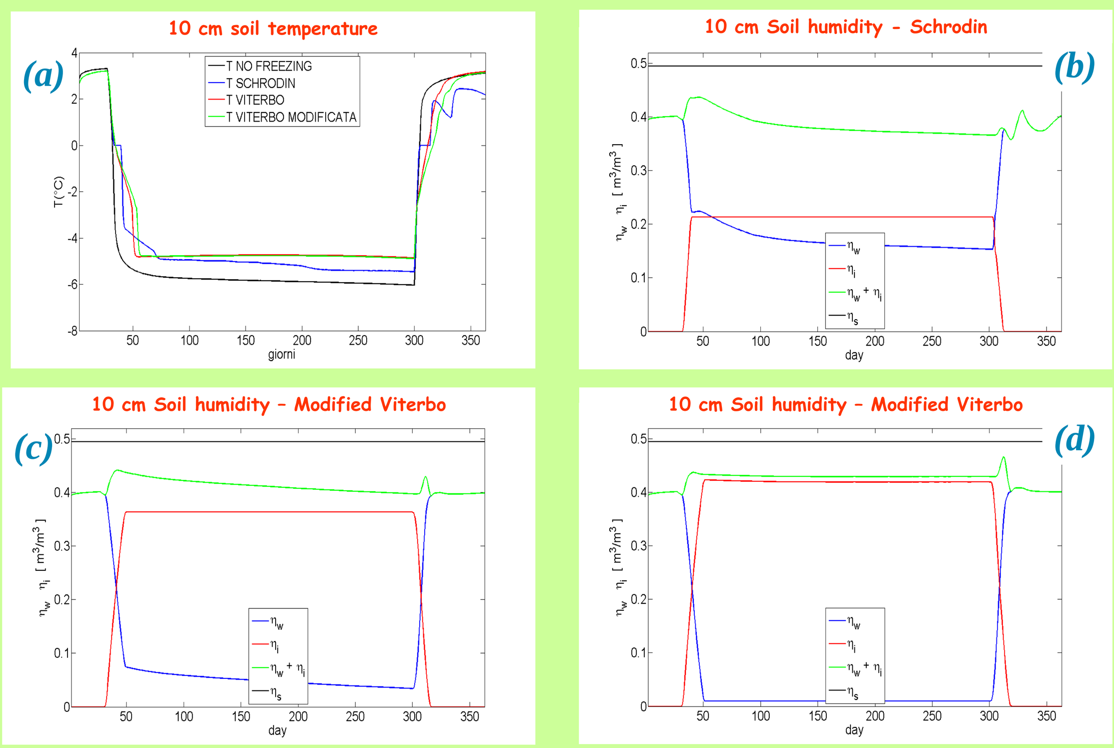


Fig. 2. Soil temperature (a) and moisture (volumetric) as simulated by the different parameterizations: Schrodin (b), Viterbo (c) and Viterbo modified (d).

SECOND TEST field campaign data

1) Brookings campaign

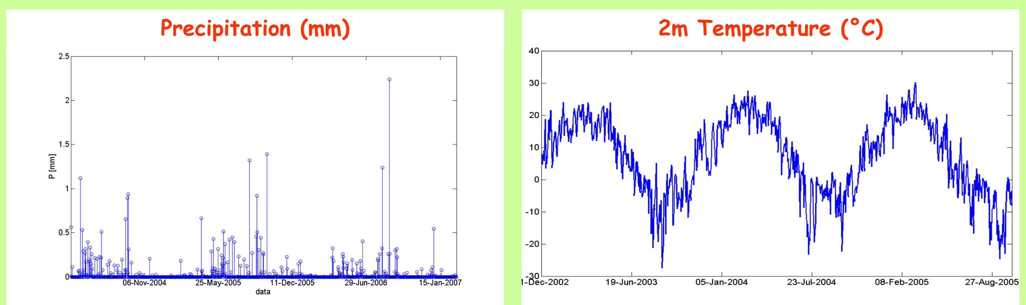


Fig. 3. Atmospheric and boundary conditions

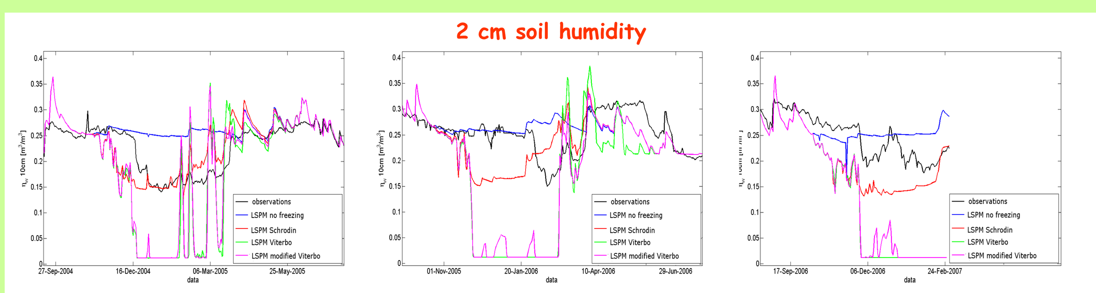


Fig. 4. Volumetric soil moisture for the three different parameterisations and without considering the soil freezing (notice the possible underestimation of snowfall).

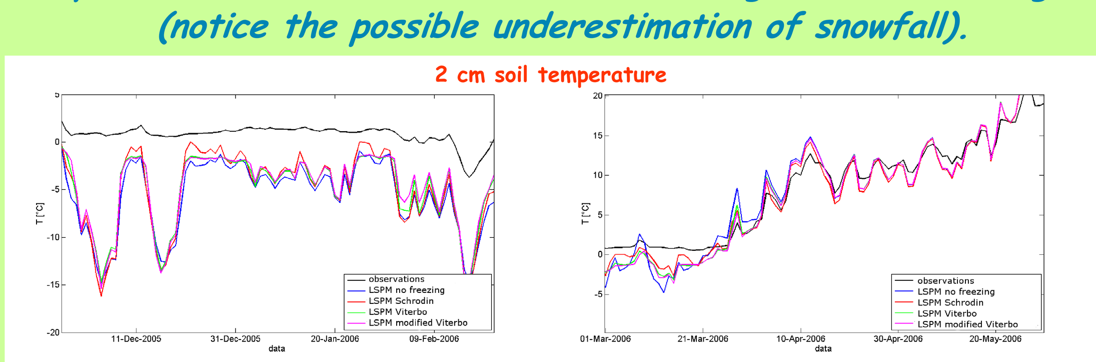


Fig. 5. Soil temperature for the three different parameterisations and without considering the soil freezing.

2) Falkenberg campaign

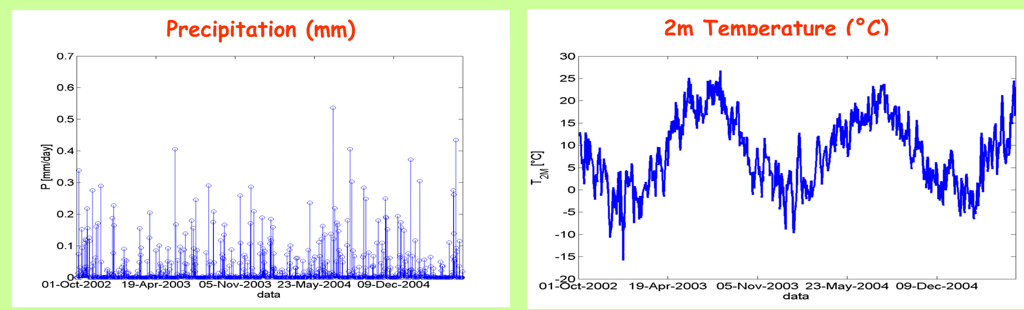


Fig. 6. Atmospheric and boundary conditions

a)

b)

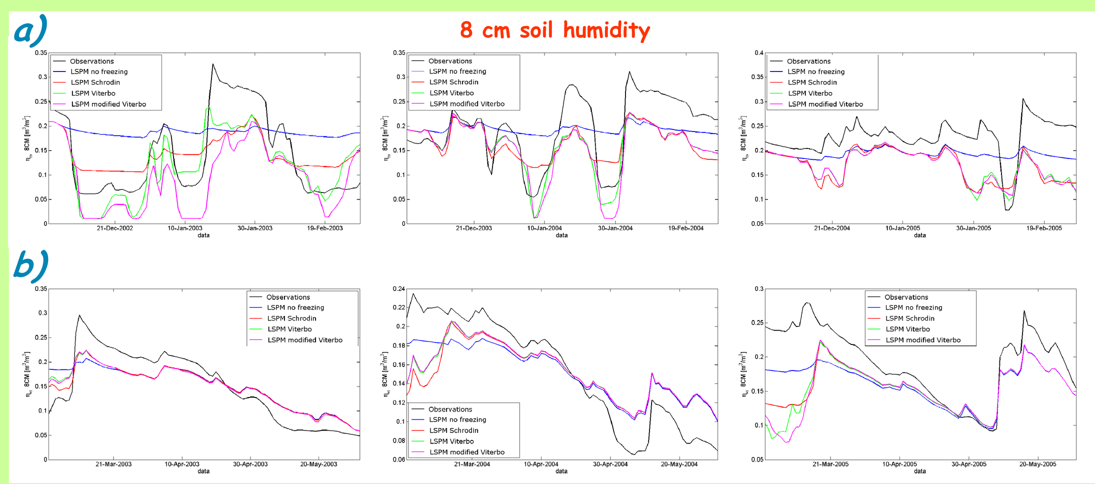
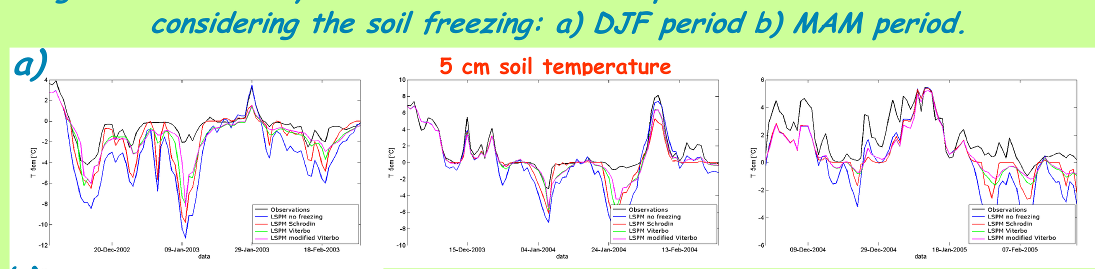


Fig. 7. Soil humidity for the three different parameterisations and without considering the soil freezing: a) DJF period b) MAM period.

a)



b)

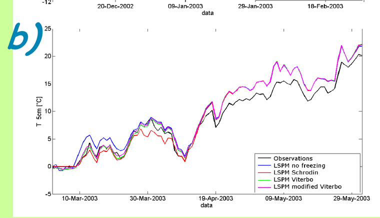


Fig. 8. Soil temperature for the three different parameterisations and without considering the soil freezing: a) DJF period b) MAM period.

Conclusions and future developments

In this work we implemented and tested some freezing parameterizations in the LSPM SVAT scheme.
Our analysis on synthetic data, as well as on campaign experimental data, do not show easily which is the best parameterization. The reason lies mainly in the rough precipitation data used as LSPM boundary conditions, especially regarding the snowfall.
Nevertheless, all the three parameterizations are able to catch the freezing and thawing period observed in the two campaigns.
A guided campaign with forced and artificially created boundary conditions could help in finding out the best parameterization and to give other suggestions for the numerical implementation of the thawing/freezing physical mechanism.
Another future improvement may be the inclusion of the soil properties change induced by the freezing/thawing process.

Acknowledgements

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References

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