A comparison study of two snow models using data from different Alpine sites

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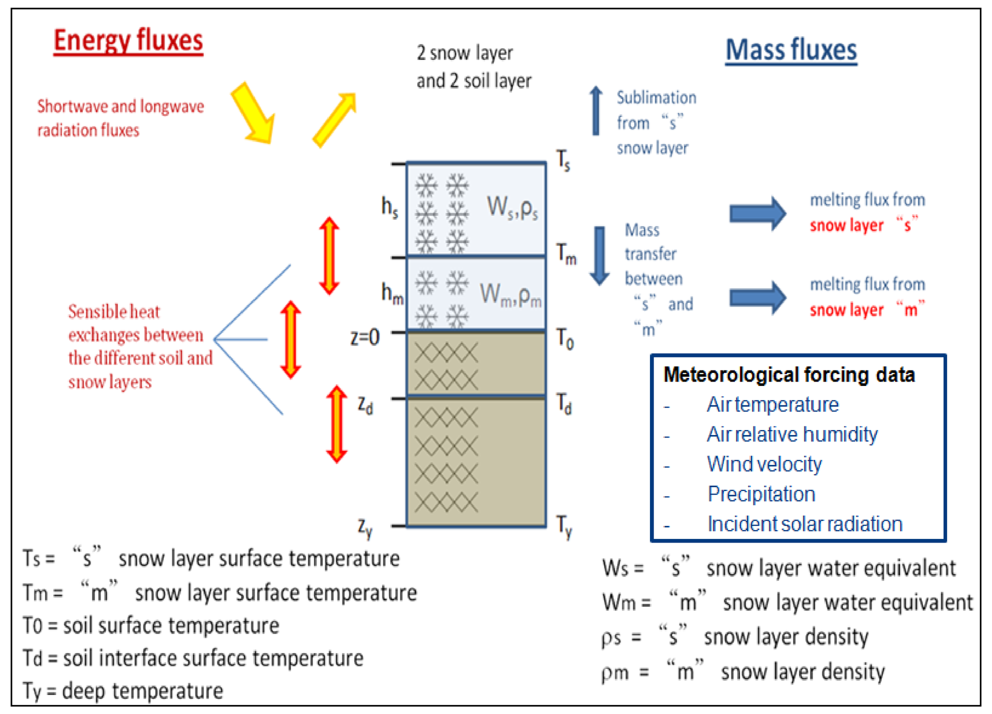
Introduction

The hydrological balance of an Alpine catchment is strongly affected by snowpack dynamics. Melt-water supplies a significant component of the annual water budget, both in terms of soil moisture and runoff, which play a critical role in floods generation and impact water resource management in snow-dominated basins. Several snow models have been developed with variable degrees of complexity, mainly depending on their target application and the availability of computational resources and data. According to the level of detail, snow models range from statistical snowmelt-runoff and degree-day methods using composite snow-soil or explicit snow layer(s), to physically-based and energy balance snow models, consisting of detailed internal snow-process schemes. Intermediate-complexity approaches have been widely developed. Nevertheless, an increasing model complexity does not necessarily entail improved model simulations. Here a multilayer energy balance snow module is presented. The model has been developed at CIMA Research Foundation for hydrological purposes. Snow observations supplied by three Alpine sites were used for the model calibration, whose methodology is here described. Preliminary results of a comparison analysis against the snow module developed at UPMC and IRSTEA are shown and discussed.

1. Multilayer energy balance snow model

The snow module of SMASH (Snow Multidata Assimilation System for Hydrology) has been developed at CIMA Research Foundation. The model consists of a multilayer snow dynamics scheme providing a complete assessment of snowpack state. It is physically based on mass and energy balances and reproduces the main physical processes occurring within the snowpack: accumulation, density dynamics, melting, sublimation, radiative balance, heat and mass exchanges.



Snow model scheme - Energy and mass fluxes between adjoining layers and atmosphere are shown.

Mass balance and snow density evolution

Snow mass balance evaluates the Snow Water Equivalent (SWE) of each layer accounting for snowfalls (*Froidurot et al. 2014*), melting rates, sublimation process and downward mass transfer.

$$SWE_{i,t+1} = SWE_{i,t} + Sf - Melt_i - subl_i \pm D_i$$

Snow density is updated considering both **snow compaction** and the **destructive thermal metamorphism** (*Anderson 1976*).

$$\frac{1}{\rho_{si}}\frac{d\rho_{si}}{dt} = \frac{\sigma_{si}}{\eta_{si}(T_{si},\rho_{si})} + \xi_i(T_{si},\rho_{si})$$

Energy balance and heat flows

The model estimates the ground heat flux, the radiation balance and the conductive heat fluxes among layers (Fourier law).

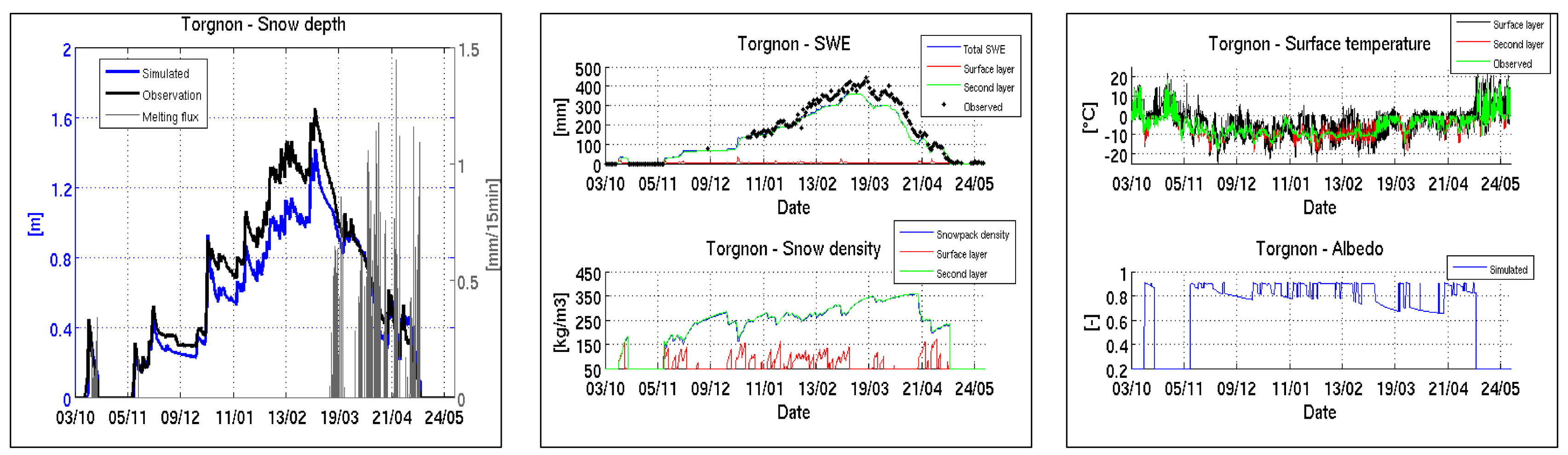
Energy balance: SMASH estimates ground heat flux, radiation balance and conductive heat fluxes between adjoining layers (Fourier law). The penetration of shortwave radiation into the snowpack is estimated after Anderson (1976).

$$R_{Sw\downarrow} = R_{Sw,inc} \cdot e^{-\nu z}$$

Turbulent heat fluxes: use of the bulk formulation. The turbulent transfer coefficient depends on the atmospheric stability depending on the Richardson number (*Caparrini et al. 2004*).

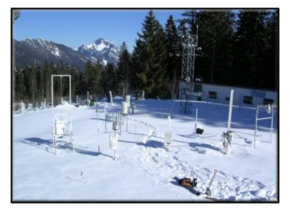
$$C_H = C_{HN}\psi_{stab}$$

Surface albedo: function of the snow age according to the parameterization proposed by *Wiscombe and Warren* (1980).



Snow model simulations at Torgnon site, winter season 2013-2014.

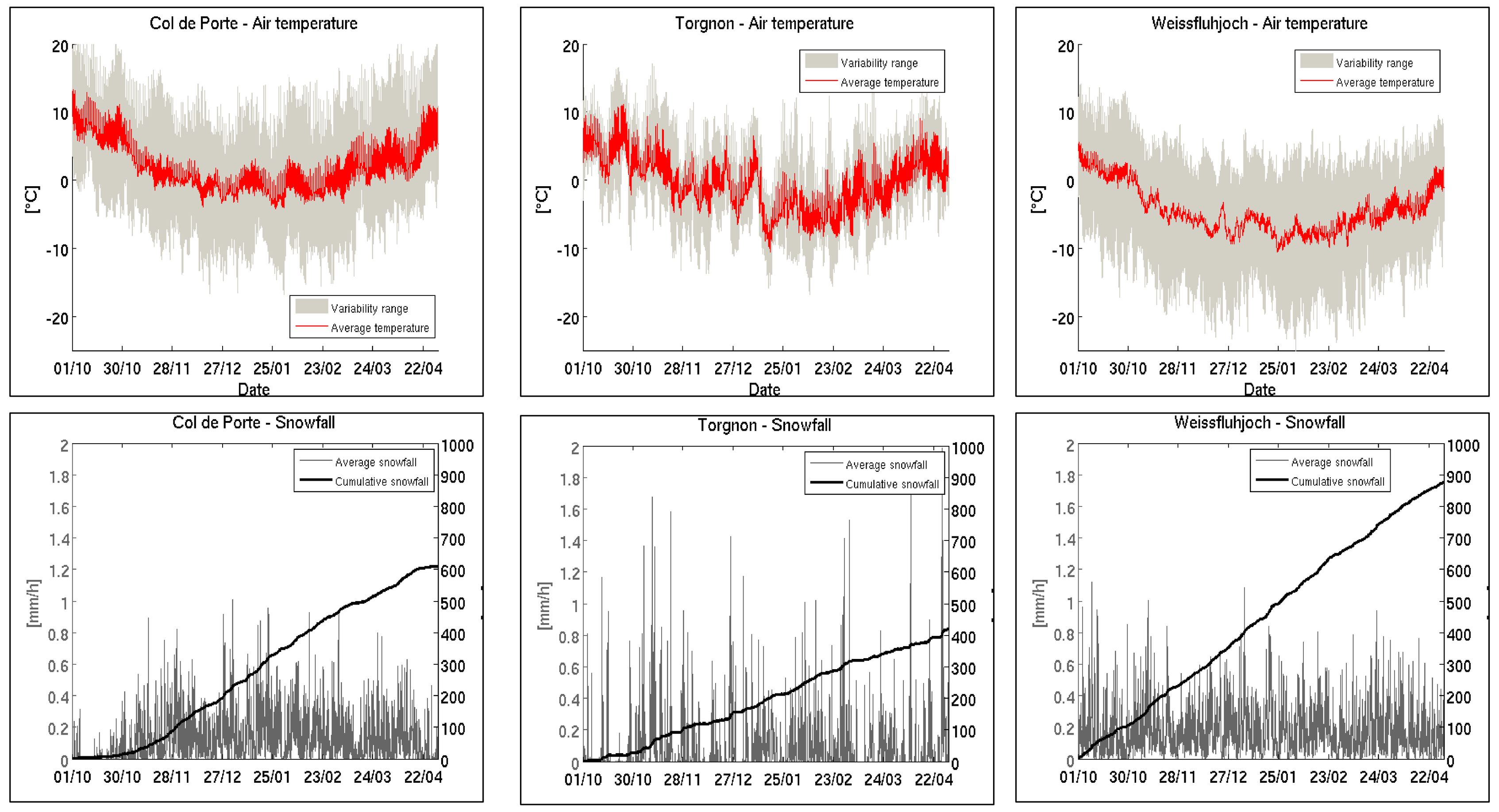
2. Datasets: 3 Alpine sites



***Col de Porte**, France*
1325 m a.s.l.
Period: 1993-2011

***Torgnon**, Italy*
2160 m a.s.l.
Period: 2012-2016

***Weissfluhjoch**, Switzerland*
2540 m a.s.l.
Period: 1996-2016

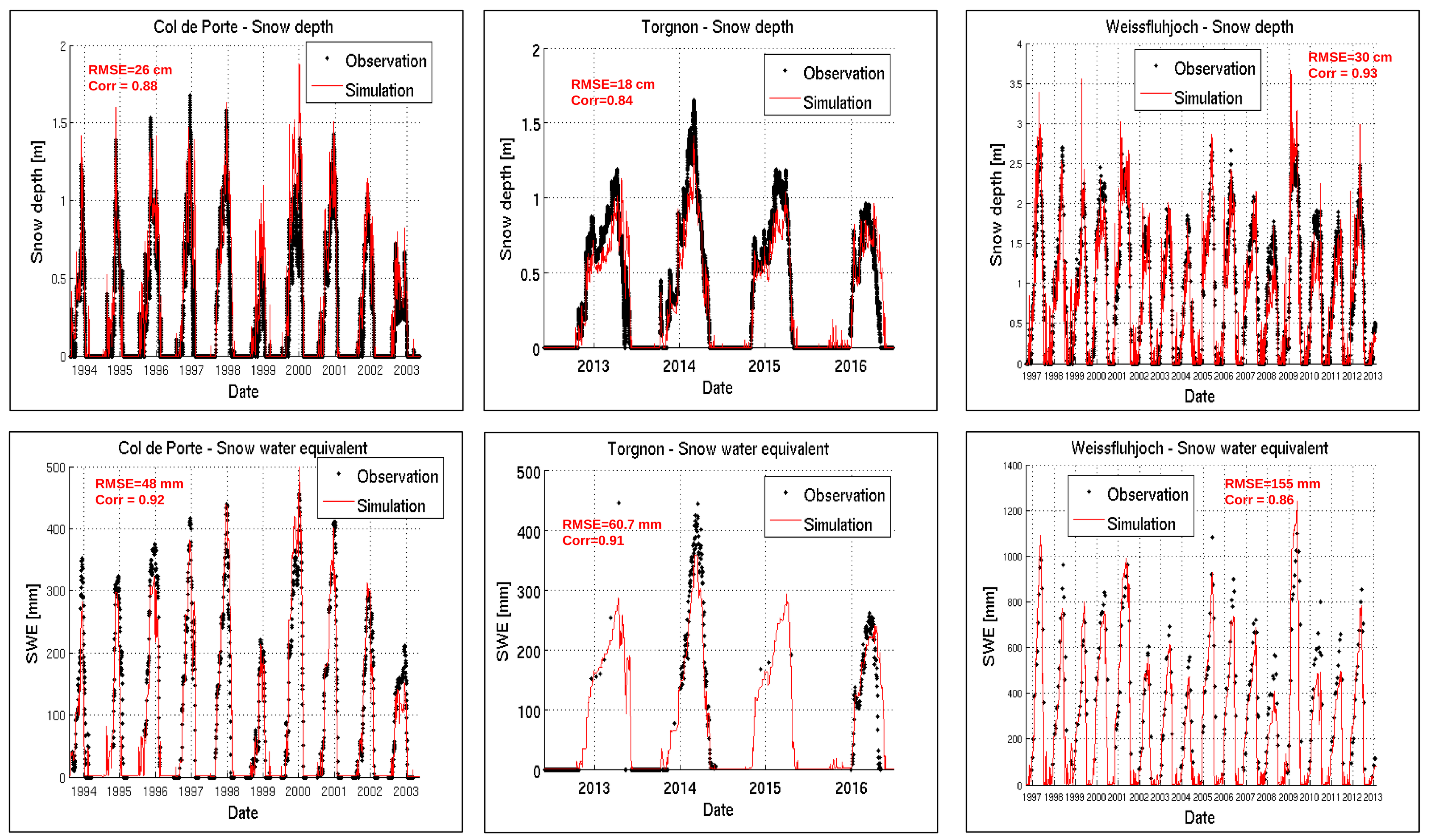


3. Model calibration

A preliminary sensitivity analysis has been performed to select the calibration parameters: snow roughness and snow viscosity. Several random combinations of parameters values have been tested (*brute force approach*) and the resulting Kling-Gupta Efficiency (KGE) coefficients have been analyzed.

$$KGE = 1 - \sqrt{(r-1)^2 + (\beta-1)^2 + (\gamma-1)^2}$$

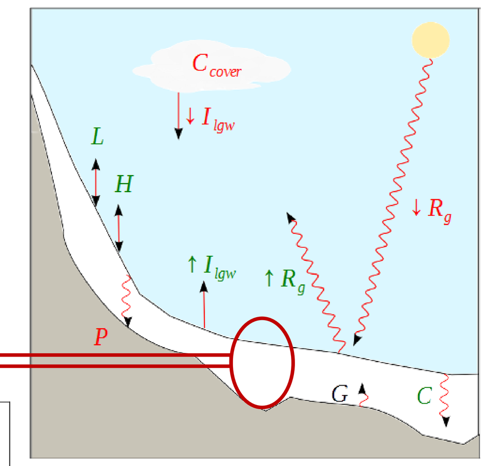
The KGE allows considering the correlation coefficient, the bias ratio and the ratio of variability.
Starting from the best parameters values, a combined calibration has been carried out (*jackknife method*) by searching for local KGE optima (*optimization criterion*).



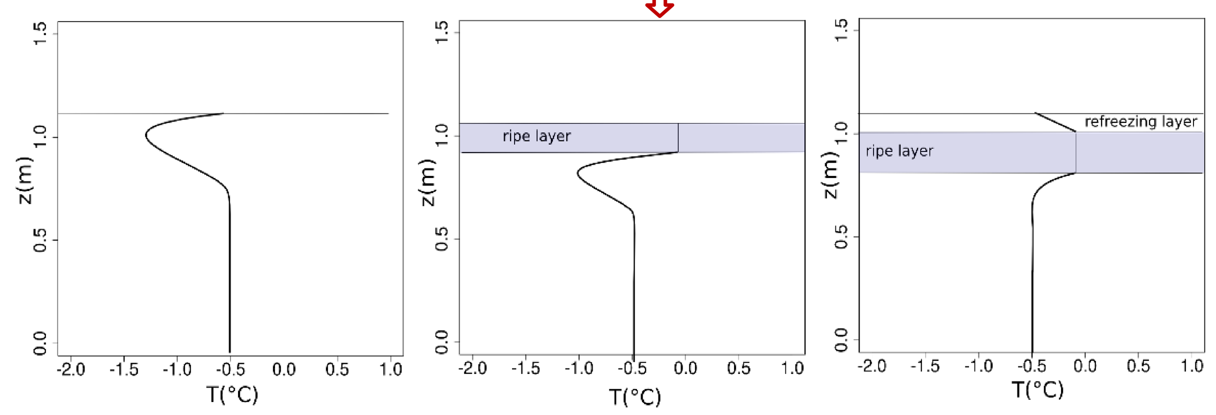
Calibration results – simulations of snow depth and SWE at the Alpine sites.

4. Comparison with the UPMC/IRSTEA snow model

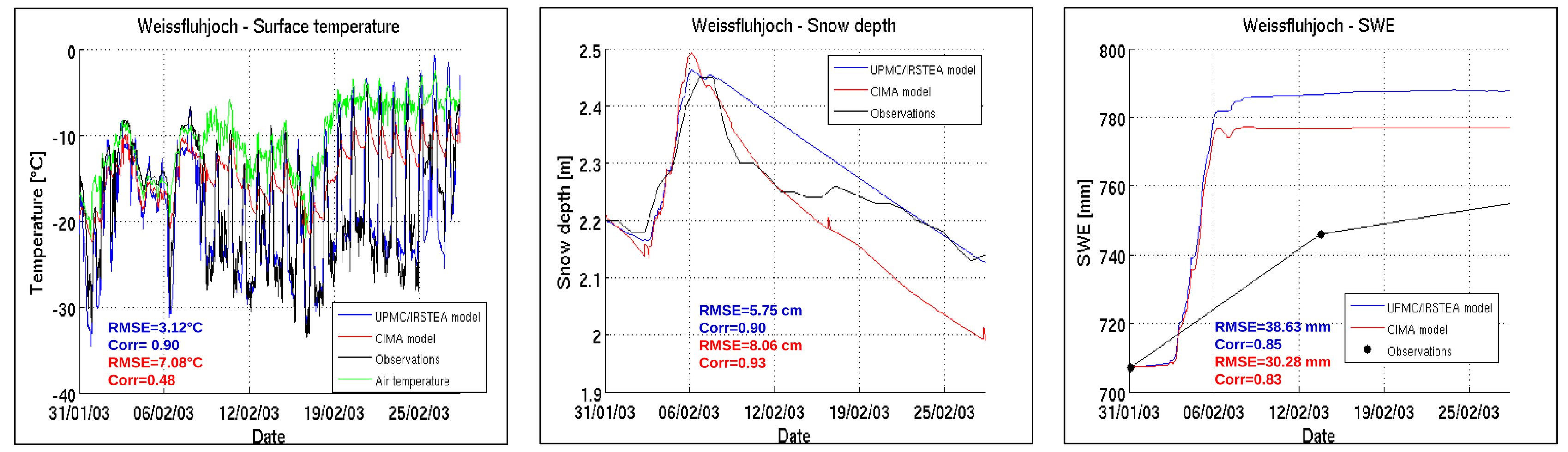
The new snow module under development at UPMC is a one layer model resolving analytically the heat and phase change equations. For now, the model is able to simulate the temperature profile inside a unique dry snow layer. Ongoing work includes taking melt and mass exchange between liquid water inside dry snow. Transition between dry, melting and refreezing snow configurations.



Energy balance fluxes taken into account in the model



The three configurations of the snowpack conduction: from left to right, pure conduction in dry snow, ripening of a surface layer (conducting to melt), and refreezing layer.



Snow models intercomparison at Weissfluhjoch site, 31 January 2003 – 28 February 2003.

The snow models catch the overall trend of the surface temperature. The monolayer model better simulates the daily thermal cycle with respect to the multilayer one, which does not succeed in properly reproducing the temperature range. In terms of snow depth, both models achieve a very good estimation during the accumulation phase. The multilayer model reveals a too fast snow compaction after the snowfall event. Both snow models are affected by a comparable overestimation of SWE with a good positive correlation with respect to the observations, even though only two measurements are available over the analyzed period (every 2 weeks).

5. Conclusion and perspectives

Despite of their different schemes and physical parameterizations, in this preliminary comparison analysis the two analyzed models have revealed comparable performances both in terms of energy and mass balances.
This analysis will be deepened by testing and comparing these snow modules at the three Alpine sites and over the whole available dataset period.
The main aim is to investigate the impact of the different modeling settings on the simulated snowpack processes and dynamics.

References

Anderson, E. A. (1976). A point of energy and mass balance model of snow cover. *NOAA Tech. Rep. NWS*, *19*, 1-150.

Caparrini, F., Castelli, F., & Entekhabi, D. (2004). Estimation of surface turbulent fluxes through assimilation of radiometric surface temperature sequences. *Journal of Hydrometeorology*, *5*(1), 145-159.

Froidurot, S., Zin, I., Hingray, B., & Gautheron, A. (2014). Sensitivity of precipitation phase over the Swiss Alps to different meteorological variables. *Journal of Hydrometeorology*, *15*(2), 685-696.

Wiscombe, W. J., & Warren, S. G. (1980). A model for the spectral albedo of snow. I: Pure snow. *Journal of the Atmospheric Sciences*, *37*(12), 2712-2733.