A multi-layer snow cover scheme for numerical weather prediction and climate models

MeteoSchweiz COSMO

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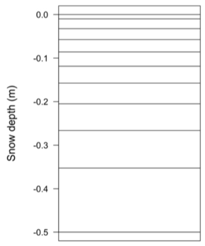
Introduction

The seasonal **snow cover strongly influences boundary layer processes** such as turbulence and radiation. Therefore, knowledge of the current state of the snow cover on the ground is of paramount importance for **numerical weather prediction (NWP) and climate models**. Currently, most NWP models use **simplified – typically one snow layer – snow cover schemes**, which are in general **not capable to simulate snow cover formation, evolution** and melt with adequate accuracy. Within the framework of the COSMO consortium (Consortium for Small-scale Modelling) we are developing a **new multi-layer snow cover scheme** for the regional weather forecasting and climate model **COSMO** and the global model **ICON** (Icosahedral Nonhydrostatic). Here we present the initial model setup and initial results.

Methods

Layering:

- Fixed number of layers (default 10).
- Fixed top layer thickness of 1 cm.
- Minimum aloud layer thickness (2.5 mm).
- Each layer consists of ice, water and air (volumetric fractions) and changes are calculated.



Heat Equation:

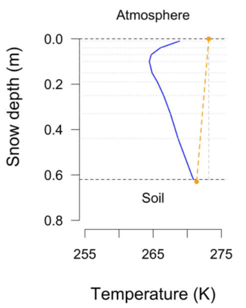


Fig. 1: Temperature profiles. Blue multi-layer scheme, orange single layer scheme. The one-dimensional heat equation is solved for a combined column of snow and soil layers with varying thickness. A set of linear equations results, which is then solved using the Thomas-Algorithm

Phase changes & water transport:

- Adapted from SNOWPACK.
- 'Hypothetical' temperature is calculated.
- Mass & energy changes are determined.
- Excess water (max. 0.08 Vol %) is transported down (bucket model).

$$\Delta T = T_s - T_{melt}$$

$$\Delta\theta_w = \frac{c_s \theta_i \rho_i \Delta T}{L_f \rho_w}$$

$$\Delta\theta_i = \frac{\rho_w \Delta\theta_w}{\rho_i}$$

$$Q_{pc} = \Delta\theta_i \rho_i L_f$$

$$L_f = 334\frac{J}{kg}$$

Settling & Re-meshing

- Layer thickness can change to due changes in volumetric ice content as well as overburden stress.
- Layer depth is re-calculated every timestep ensuring numerical stability (re-meshing).
- Mass and energy are conserved on new grid.

New snow density:

$$\rho_{HN} = 10^{c}$$

$$c_1 = 3.28 + 0.03 \cdot TA - 0.36 - 0.75 \times \cdot \arcsin(\sqrt{RH}) + 0.3 \cdot log_{10}(VW)$$

$$c_2 = 3.28 + 0.03 \cdot TA - 0.75 \cdot \arcsin(\sqrt{RH}) + 0.3 \cdot log_{10}(VW)$$

c_1 for TA ≥ -14 °C; c_2 for TA < -14 °C, RH is set constant to 0.8 (80%) and wind speed lower limit is set to 2 m s^{-1}

Results I - Verification

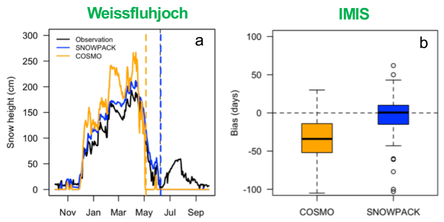


***Fig. 2: a)** Measured (black) and simulated snow height for a SNOWPACK simulation using COSMO output (blue) and the implemented single-layer snow scheme of COSMO (orange). The COSMO simulation (orange) becomes snow free to early compared to the measurement. **b)** At all IMIS stations the ground in COSMO is snow free about a month too early. A sophisticated snow cover scheme (SNOWPACK) while using the same input can reduce this bias significantly.*

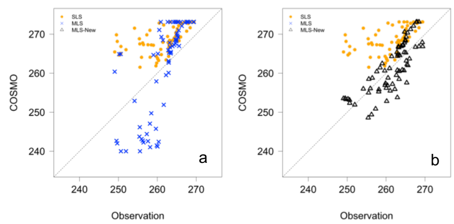


***Fig 3: a)** Comparison of observed (Weissfluhjoch) and forecasted snow surface temperature. Closed orange circles show the single-layer snow cover scheme (too warm) and blue crosses show the multi layer scheme (too warm during the day too cold during the night. **b)** Black triangles show the snow surface temperature forecasted with the multi-layer scheme using alternative parametrizations for albedo and turbulent flux calculations. Dashed line shows the 1:1 relationship.*

Results II – Validation (New Snow)

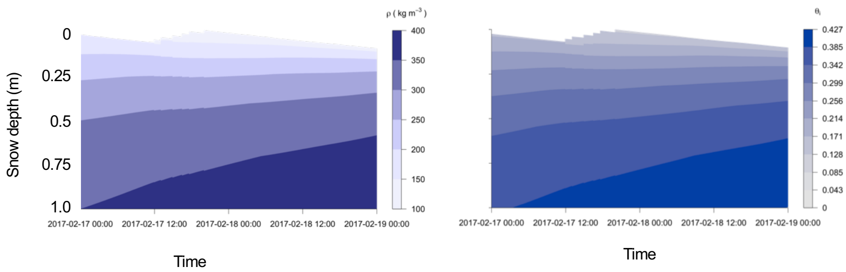


***Fig. 4: Left:** Snow cover density as predicted with the multi-layer snow cover scheme for a 48-hour forecast starting mid February 2017. **Right:** Corresponding volumetric ice content as predicted with the new scheme for the same period. New snow density is calculated (compare methods) and resulting new snow amounts added to the snow cover. Consequently a new mesh is calculated resulting in a new layering.*

Results III – Validation (Melting)

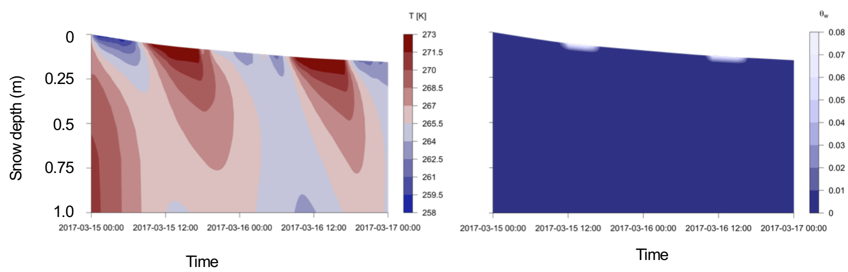


***Fig. 5: Left:** Snow cover temperature as predicted with the multi-layer snow cover scheme for a 48-hour forecast starting mid March 2017. **Right:** Corresponding volumetric water content as predicted with the new scheme for the same period. The holding capacity of water for the individual layers is limited to 8 Vol. %. Melting occurs in the top layers and water is transported down accordingly.*

Conclusions

- **Successful implementation** of a new multi-layer scheme (limited SNOWPACK version) into the numerical weather prediction model COSMO.
- At this stage the scheme **solves the 1D heat equation** for up to ten snow layers and computes **phase changes, water transport** as well as **settling**.
- The new scheme shows **improved scores for the snow surface temperature**, but tends to be too cold during the night – **adjustments to turbulent flux parameterizations required**.
- Future work will include further consolidation of the code and a **pre-operational test phase** during winter season 2019-2020 as well as the **implementation** of the multi-layer scheme into **ICON**.