SOIL FROST AND SNOWMETAMORPHISM-SIMULATIONS FOR THE BALTEX-REGION WITH A COMPLEX HYDRO-THERMODYNAMIC SOIL-VEGETATION-SCHEME

N. Mölders\textsuperscript{1}, I. Majhi\textsuperscript{1}, Anna Kliouchnikova\textsuperscript{2}, H. Elbern\textsuperscript{2}

\textsuperscript{1}Geophysical Institute, University of Alaska Fairbanks, 903 Koyukuk Drive, P.O. Box 99775-7320, Fairbanks, AK 99775-7320, USA
\textsuperscript{2}FV Rheinisches Institut für Umweltforschung an der Universität zu Köln e.V., Aachener Straße 201-209, 50931 Köln

molders@gi.alaska.edu; http://www.gi.alaska.edu/~molders/deklim.de
he@eurad.uni-koeln.de; http://www.uni-koeln.de/eurad-project/deklim.de

Key words: soil frost, snow metamorphism, data assimilation

1. Introduction

Frost and snow are the most common terrestrial surface conditions in the BALTEX region from October to mid-May. Snow-metamorphism and the depth of snow regulate soil freezing with implications for soil hydraulic properties and water supply to the atmosphere. A snow-cover results in a more stable stratification of the atmospheric boundary layer (ABL) and a reduced vertical exchange of trace gases. Isolated soil surfaces surrounded by snow can lead to substantial sensible heat fluxes, convection, and enhanced vertical mixing in the ABL, especially when solar radiation is significant. The strong spatial contrast in the energy budget of snow-covered and snow-free areas may generate appreciable advection of moisture and heat. Thus, the timing and duration of seasonal snow-cover influence climate conditions, and air-quality.

Soil frost restricts the mobility of soil-water, and infiltration. Moisture stored in frozen soils in winter can contribute to the peak of spring floods. Another important aspect of permafrost and the adjacent dynamic layer is the local equilibrium between the ice, gaseous, and liquid phase of water. Slight changes in heat diffusion and conduction caused by a change in snow thickness or water fluxes affect all three water phases in the soil and the soil temperature simultaneously. Any change in soil temperature results in freezing or thawing and a release of latent heat or consumption of energy, again altering soil temperature.

Due to the complex interaction between the soil water phases and soil temperature initializing frozen or partly frozen is extremely difficult and inadequate initialization may cause tremendous errors. The aim of our activity is to develop tools to simulate soil frost and snow metamorphism processes for mesoscale models and to assimilate soil temperature and moisture conditions to initialize these models.

2. Progress report

The hydro-thermodynamic soil-vegetation scheme (HTSVS) has been further developed for including soil freezing/thawing (frost) and snow-metamorphism (Mölders et al. 2003). The soil frost module was evaluated by means of lysimeter and soil temperature data. HTVS with both modifications (soil frost and snow metamorphism inclusion) has been evaluated against WINTEX and ATLAS data. This evaluation is still ongoing. The preliminary version of HTVS with soil frost and snow metamorphism processes has been integrated into the PennState/NCAR Mesoscale Meteorological Model MM5 in a two-way coupled mode. A
hierarchy of simulations with and without the frost module and with and without the snow module showed the influence of snow and frost on weather.

First results indicate that the snow-permafrost processes have a demonstrable impact on the surface thermal and hydrological regimes and on the near-surface atmospheric conditions even on the short (synoptic) timescales. The presence of snow results in a highly stable stratification. In cloud-free areas, the enhanced loss of radiant energy, and cooling of the air over snow lead to a positive feedback to relatively colder, drier conditions. In cloudy areas, a positive feedback to warmer, moister conditions develops over snow. An example of soil frost prediction is exhibited in Fig. 1.

Snow influences atmospheric humidity and temperature, which causes differences in wind speed and direction relative to snow-free conditions. As these differences propagate into the pressure field, sea level pressure is lower by more than 1.2 hPa in the simulations with snow. The effect of frost is an order of magnitude smaller.

Frost has a notably greater impact in cloud-free than cloudy areas. Frost without snow-cover reduces the water supply to the atmosphere, leading to cooler, drier conditions relative to no frost. When snow is present, frost enhances the insulating effect of snow in cloudy areas, but reduces it in cloud-free areas.

After development the assimilation procedure is under testing for the two most important modules used in HTSYS. The first module is the one in which the coupled equations for soil temperature and moisture within the soil are solved. These equations include among other terms the soil heat and moisture fluxes as well as the soil frost term. Both total energy and water fluxes in the soil strongly depend on soil moisture and temperature within the soil thus the information available about e.g. soil moisture can help assimilation algorithm to correct soil temperature and vice versa. As the constant boundary conditions for soil moisture and temperature at the bottom used in the model do not prevent the assimilation algorithm from correcting them, the beneficial impact of variational assimilation is clearly visible. The assimilation procedure for this module has been built and testing it is ongoing. The preliminary results of identical twin experiments show the ability of the procedure to assimilate the observations of soil moisture and temperature within the soil successfully starting from more than 25°C distortion of reference initial values, thereby also bridging the frost point.

Preliminary results show that initialization without data assimilation can lead to unrealistic soil heat and moisture and, hence, surface fluxes. Starting with zero ice content, for instance, would warm the soil due to the release of latent heat, and there would be no ice at the lower boundary because of the constant soil conditions at the bottom of the soil model. An upward-directed moisture flow would establish, resulting in a permanent source of energy as the soil-water transports heat. Therefore, we expect that as soon as the data assimilation for initialization of the soil moisture and temperature states will be implemented and tested, the full package (soil frost, snow metamorphism, and data assimilation) will lead to a great improvement of predicting the surface energy and water fluxes in the BALTEX area.

3. Future work

The offline evaluation of the modified HTSYS by WINTEX and ATLAS data and the improvement of the soil frost and snow metamorphism parameterizations will be ongoing. The next step is to evaluate 3D-simulations with the MM5 with the inclusion of soil frost and snow metamorphism processes by means of observational data.

Another next step is to implement the data assimilation tool in MM5. This step will include intensive tests for the optimal length of the assimilation interval. As the relaxation procedure from initially misspecified soil temperatures and humidity is of parabolic nature, a certain
spin up time will be required in practice. With improved consolidation further real case assimilation experiments will be conducted.

4. Disclaimer
The work is within the proposed time frame. No work with relevance of changes in our proposed activity has come to our knowledge.

References

Presentation of the activities

Internet

-http://www.gi.alaska.edu/~molders/deklim.htm

Seminars and Workshops


Extended Abstracts


Reports

Conferences

Fig. 1: Offline evaluation of predicted soil frost. Results shown are after 2030 days of simulation without restart for a site close to Leipzig (modified after Mölders et al. 2003)