SnowMIP2: Implications for NWP Snow Schemes

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1. Introduction

The high albedo of snow, compared with other natural surfaces, has a large impact on the surface energy and mass balances of snow-covered regions and hence on atmospheric boundary layer development and the properties of overlying air masses. Exposed vegetation, however, can shade underlying snow and mask its albedo. Large areas of the Northern Hemisphere, and the source regions for continental Polar air masses in particular, have both forests and seasonal snow cover. It is important, therefore, that NWP snow schemes should be able to accurately represent both the high albedo of snow and masking by exposed vegetation. The consequences of failing to do so were highlighted by Viterbo and Betts (1999), who found that a positive bias in albedos over boreal forests in spring had been responsible for large cold biases through the lower troposphere at high northern latitudes in the operational ECMWF model prior to a revision of the snow albedo scheme inspired by observations made during the Boreal Ecosystem-Atmosphere Study (BOREAS; Betts and Ball 1997). The reduction in modelled albedo for forests with snow cover then led to an overestimation of snow sublimation, which was rectified by introducing a separate tile for snow under tall vegetation in the ERA-40 land surface model (Betts et al. 2001). A similar model revision (Essery and Clark 2003) was found to counteract the excessive sublimation and resulting underestimation of runoff predicted by the surface scheme of the Met Office climate model for the partially forested catchments of the Torne and Kalix rivers of northern Scandinavia in phase 2e of the Project for the Intercomparison of Land-surface Parameterisation Schemes (PILPS; Bowling et al. 2003).

Despite limitations that will be discussed later, field studies such as BOREAS and intercomparisons such as PILPS have been influential in the development of NWP surface schemes. This article presents some recent findings from the Snow Model Intercomparison Project (SnowMIP) on the simulation of forest snow processes.

2. The Snow Model Intercomparison Project

SnowMIP aims to evaluate the performance of snow models used in a wide range of applications by comparing simulated and observed snow properties. In situ meteorological data from field sites are supplied to participants who run their individual models and return results that are then compared with additional observations from the same sites. Two phases of SnowMIP have been completed to date. The first phase of SnowMIP involved 24 models making simulations for four sites with short vegetation that is completely buried by snow in the winter (Etchevers et al. 2004). The participating models included simple hydrological models, NWP land surface schemes and sophisticated snow physics models. No clear tendency for more sophisticated models to produce better simulations of snowmelt was found.

SnowMIP2 was commissioned as a working group of the International Commission on Snow and Ice (now the International Association of Cryospheric Sciences) and was subsequently also adopted as an activity of the GEWEX Global Land Atmosphere System Study. To investigate the influence of forest canopies on snow processes, five sites with paired forested and open plots were selected for use in SnowMIP2. The sites ranged in latitude from 40 to 62ºN and ranged in elevation from 180 to 2800 m above sea level. Selected results are shown in the next section for just two of these sites: the Swiss Federal Institute for Forest, Snow and Landscape Research site at Alptal (http://www.wsl.ch/staff/manfred.staehli/snow-alptal.ehtml) and the Environment Canada Boreal Ecosystem Research and Monitoring Sites (BERMS) in Saskatchewan (http://berms.ccrp.ec.gc.ca/e-main.htm). Amongst the SnowMIP2 sites, Alptal is generally the warmest and wettest and BERMS is generally the coldest and driest. Both have open areas and coniferous forests; the trees are spruce and fir of about 35 m height at Alptal and 12 – 15 m pine at the BERMS Old Jack Pine site. Meteorological data from the open and forested sites were supplied for model forcing over the winters of 2002 – 2003 and 2003 – 2004.

Most of the thirty-three models participating in SnowMIP2 account separately for the masses of intercepted snow in a forest canopy and snow on the ground beneath the canopy. With such a model structure, snow falling on a forest has to be partitioned into interception by the canopy and throughfall to the forest floor. Intercepted snow can remain in the canopy for some time and eventually either sublimate, melt or unload from the canopy. Solar radiation has to be partitioned into reflection and absorption by the canopy and transmission to the underlying snow. Thermal radiation at the snow surface has components from the canopy, determined by predicted canopy temperatures, and from the sky through canopy gaps. Turbulent fluxes transport heat and moisture between the snow and the canopy air space and between the canopy and the atmosphere. Energy absorbed at the snow surface has to be partitioned into energy used for warming, sublimating or melting snow. Each of these partitioning steps introduces uncertainty in the modelling of forest snow processes.

3. Selected Results

Results from SnowMIP2 have been presented by Rutter et al. (2009) and Essery et al. (2009), and work on analysing the performance of models in simulating forest and clearing snow processes is continuing. Summaries of model outputs can be downloaded from
http://xweb.geos.ed.ac.uk/~ressery/SnowMIP2/ results.html.

Snow depth can be measured automatically at sites using ultrasonic ranging, but simulations of snow depth are influenced by model parametrizations of both snow mass balance and snow compaction. SnowMIP has therefore concentrated on evaluating simulations of snow mass, which is commonly expressed in millimetres of snow water equivalent (SWE). Manual measurements of SWE were made at the Alptal and BERMS open and forested plots; Figures 1 and 2 show observations and simulations over two winters at each site. It is immediately apparent that there is a large spread between the model predictions. No group of models was found to perform consistently better than all others in simulating SWE at all sites. The median of the model ensemble matches the duration of snow cover quite well in most cases but underestimates the differences in maximum snow accumulation between open and forest plots.

The high temporal variability and high model range give very confusing plots if simulated albedos are plotted for every model individually. Instead, Figures 3 and 4 show maxima, minima, medians and interquartile ranges of simulated albedos for the open and forested plots at Alptal and BERMS, compared with observations for periods when they were available. A few models evidently still assign high albedos to forests in winter, even 10 years after the findings of Viterbo and Betts (1999) were published, and a few models have low albedos for the open plots due to underestimations of snow cover. Generally, however, the median of the model ensemble captures the difference between forested and open plots with snow cover well. The interquartile range of the albedo simulations for open sites is much larger at BERMS than at Alptal, where frequent snowfall events refresh the snow albedo. This confirms that the rate at which the albedo of a snow surface decreases over time is a large remaining source of uncertainty in snow models. The significance of this uncertainty will be reduced for forested areas due to the reduction in solar radiation reaching the snow surface beneath the forest canopy.

Because snow has a low thermal conductivity, soils beneath snow are insulated from low winter air temperatures. Figures 5 and 6 show simulations and observations of near-surface soil temperatures at Alptal and BERMS. Because of the wet soil and mild air temperatures, the soil temperature measured at the Alptal forest site decreases slowly towards 0ºC over the course of the winter. Some of the models predict sub-freezing temperatures, but the median of the models remains close to 0ºC while there is snow on the ground. At BERMS, low air temperatures and shallow snow lead to soil temperatures falling well below 0ºC. Most of the models predict soil temperatures that are too low, particularly for the forested plot, where observations show that the soil is not as cold as at the open plot. Soils beneath snow do not interact with the atmosphere directly, but soil temperature anomalies can affect NWP if they persist after the snow has melted or if they lead to soil moisture anomalies through influences on infiltration of melt water into the frozen soil. Accurate simulations of soil temperatures are of increasing importance as NWP begins to be called on to produce a greater range of products for a wider range of applications.

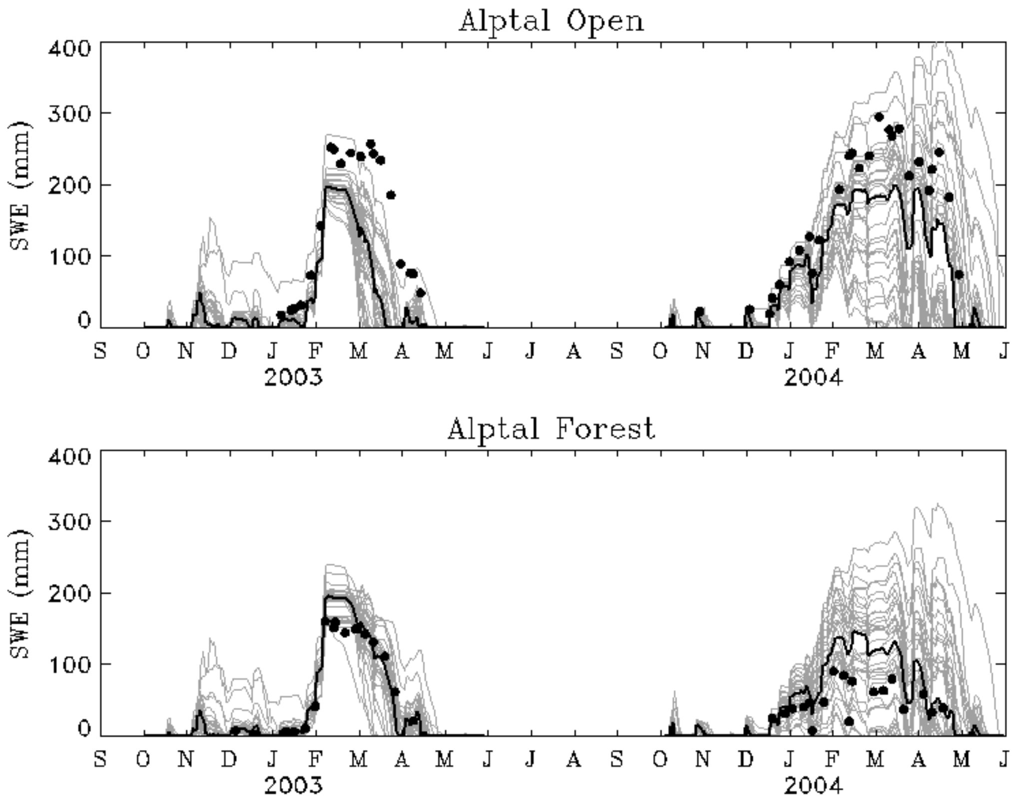

Figure 1. SWE for the Alptal open and forested plots. Grey lines are results from individual models, black lines are medians for all model simulations and black dots are observations.

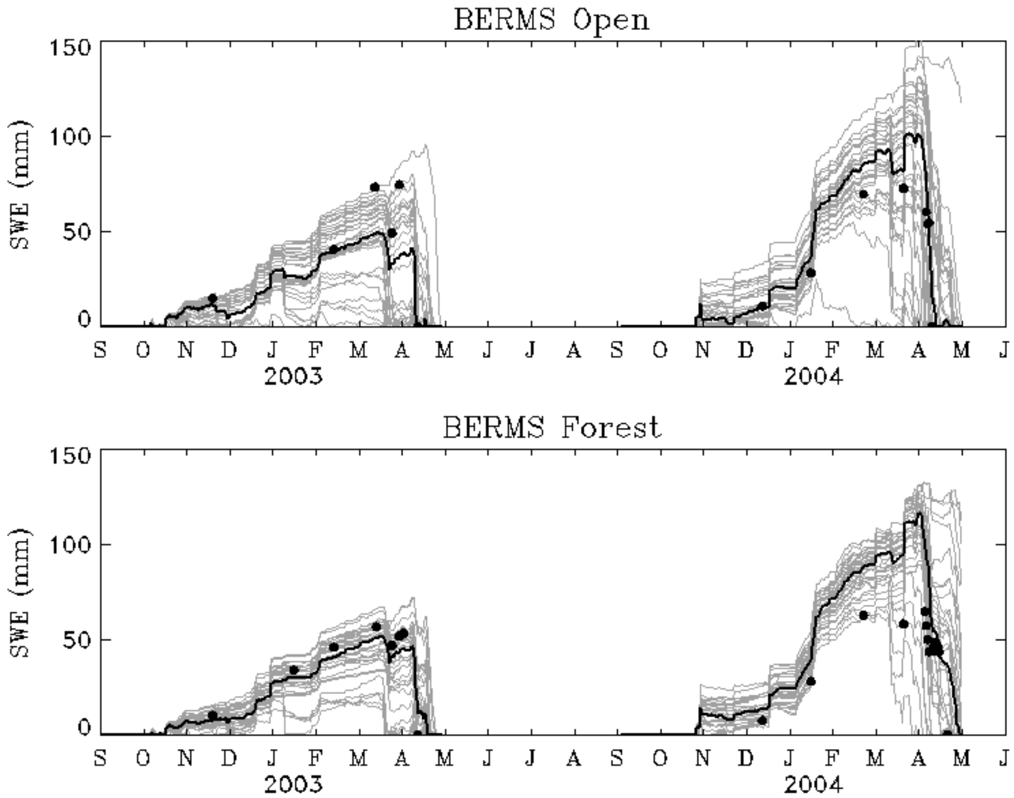

Figure 2. As Figure 1, but for BERMS.

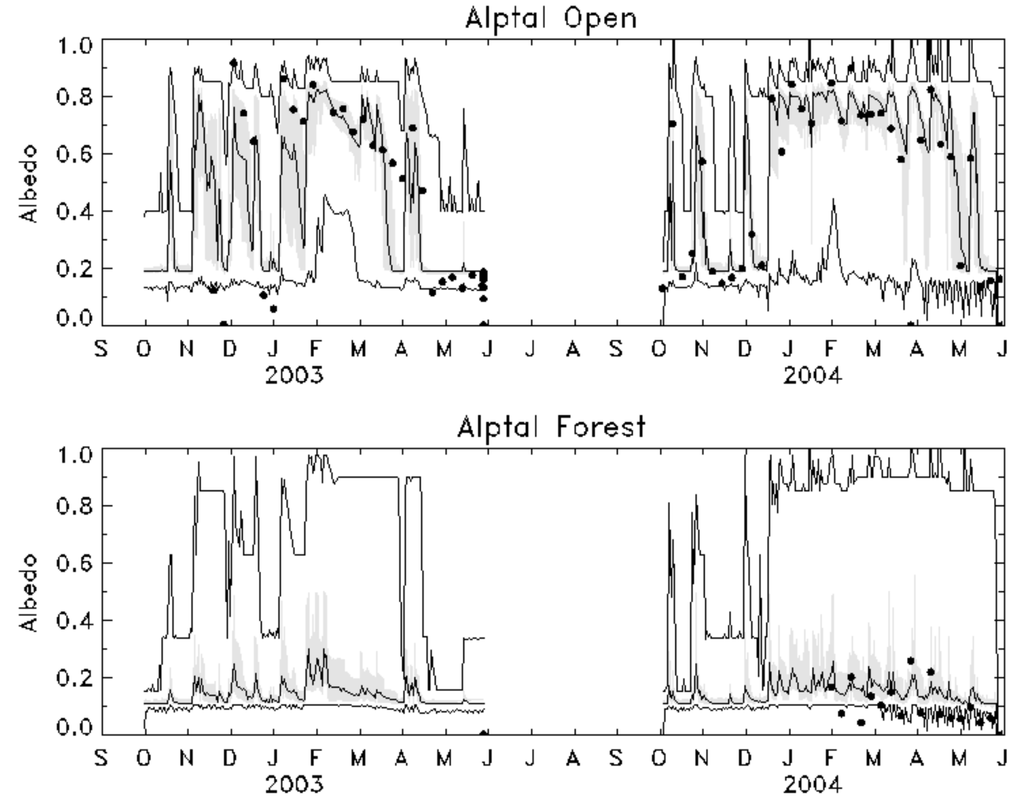

Figure 3. Albedo for the Alptal open and forested sites. Black lines are medians, maxima and minima of all model simulations, grey bands are interquartile ranges of the simulations and black dots are observations. Albedos were not measured at the forest site before February 2004.

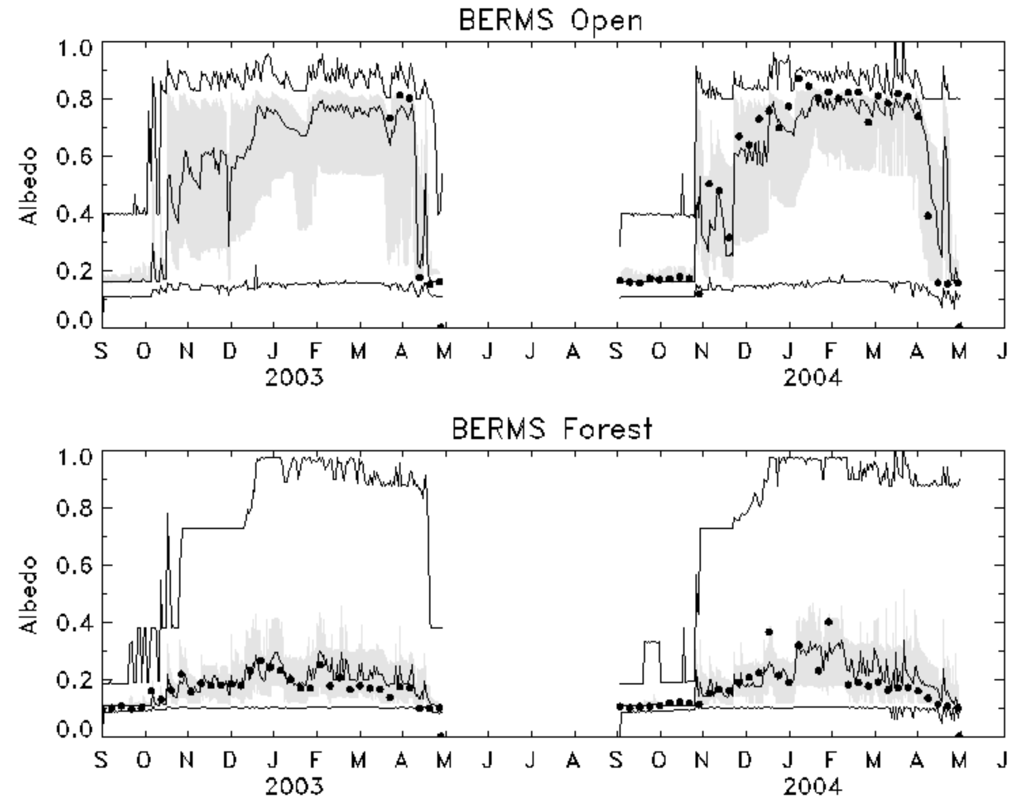

Figure 4. As Figure 3, but for BERMS. Albedos were not measured at the open site before March 2003.

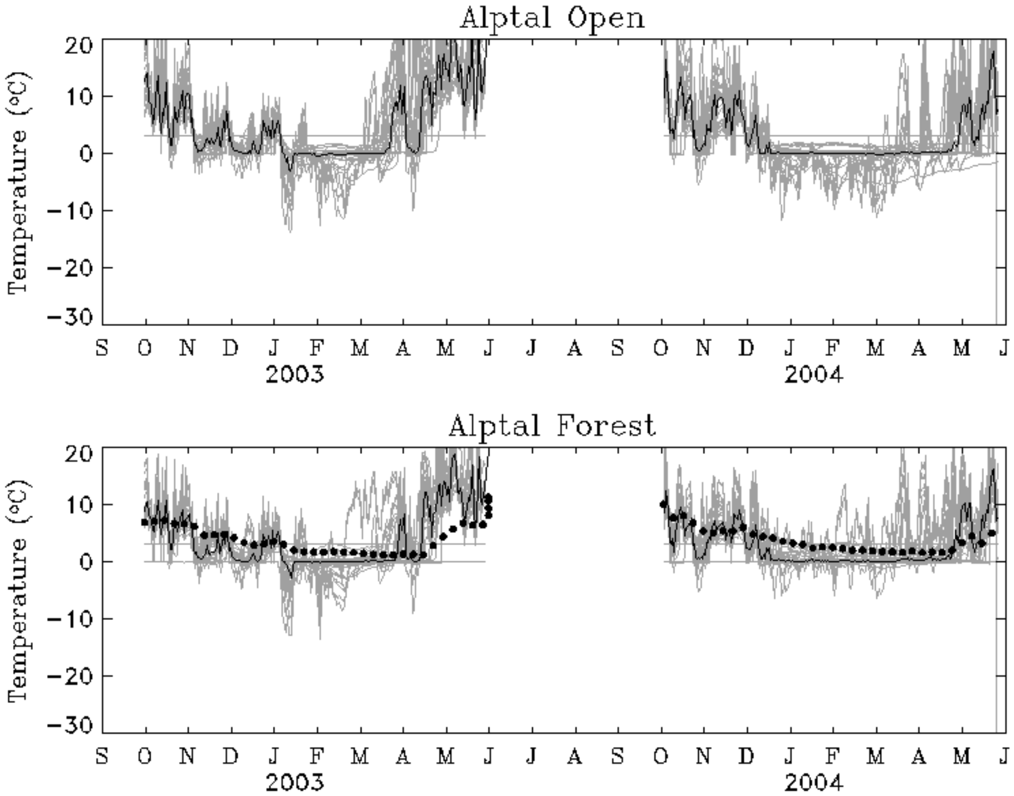

Figure 5. Near-surface soil temperatures for the Alptal open and forested plots. Grey lines are results from individual models, black lines are medians for all model simulations and black dots are observations. Soil temperatures were not measured at the open site.

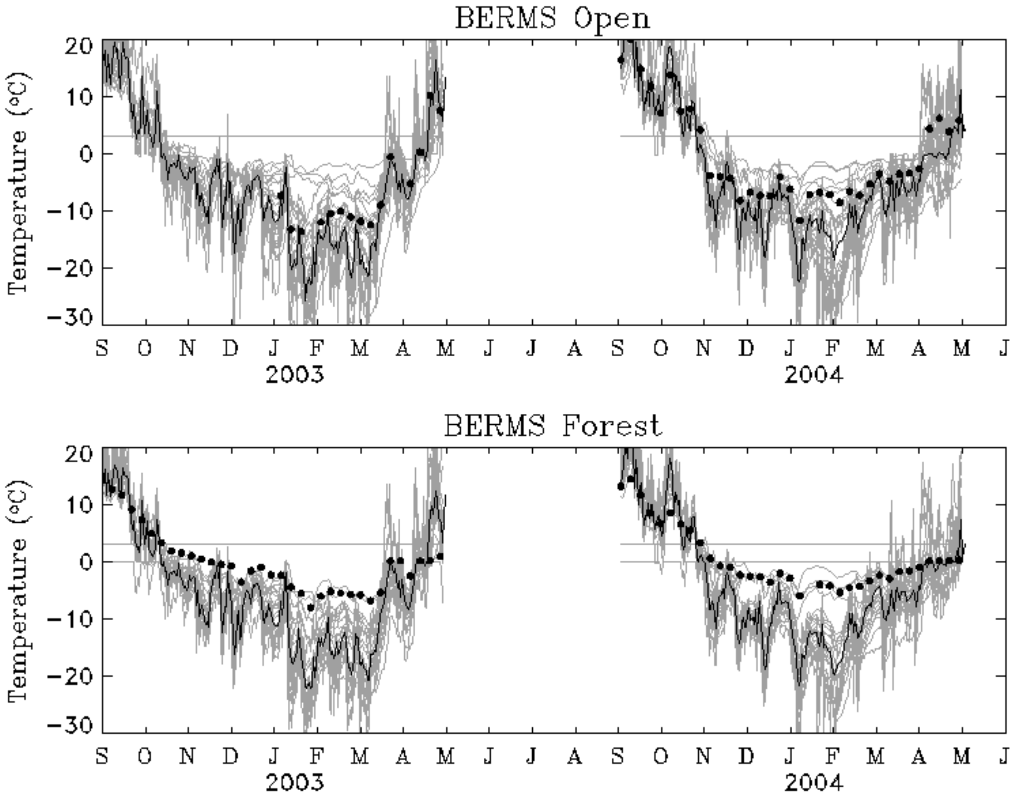

Figure 6. As Figure 5, but for BERMS. Soil temperatures were not measured at the open site before January 2003.

4. Discussion

The local, uncoupled simulations used in SnowMIP2 and many other studies have some limitations for assessing the performance of land surface schemes for NWP applications. On the scales of NWP model grids, the boreal regions are mosaics of evergreen and deciduous forests, clearings, wetlands, lakes and short vegetation in clearings, burnt areas and higher elevation parts of the landscape rather than homogeneous blankets of forest. An accurate representation of effective albedos on these scales requires not just good models for the albedos of snow and exposed vegetation but also accurate estimates of the fraction of forest cover. Roesch (2006) found large discrepancies in albedos for forest areas in IPCC AR4 climate simulations due to difficulties in determining the extent of snow albedo masking.

When coupled to an atmospheric model for NWP applications, a land surface scheme is driven by meteorological data provided by the atmospheric model and provides energy and mass flux boundary conditions for the atmospheric model. In uncoupled simulations, however, fluxes calculated by the land surface scheme do not influence the driving data, and surface-atmosphere interactions cannot be studied. Moreover, the use of meteorological data measured at a specific site is likely to underestimate the uncertainty in model predictions obtained when driving the surface model with forecast variables such as precipitation and air temperatures.

Despite these limitations, close involvement with field studies and participation in intercomparison studies have been found to be highly beneficial in the evaluation, understanding and improvement of the performance of NWP land surface and snow schemes. Results from SnowMIP2 have already been used to test the performance of new multi-layer snow schemes proposed for use in the Met Office and ECMWF models (Dutra et al. 2010).

5. References

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