# SNOWPACK: where do we stand today?

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ABSTRACT: We present both snow depth and precipitation driven simulations of the snow cover at Weissfluhjoch, 2540 m a.s.l., near Davos, Switzerland. We performed simulations with the latest release of SNOWPACK. A confirmation of the robustness of the simulations is the high agreement between modeled and measured depth of snowfall HN(24) over 24 hours.

KEYWORDS: snow, snow settlement, snow-cover modelling.

## 1 INTRODUCTION

The Swiss snow-cover model SNOWPACK is presently used in many applications from snow sports and engineering to climate change assessment but also for avalanche warning. The core routines are packed in a library that also serves as the basic module for the land surface scheme Alpine3D. The separate application MeteoIO handles all input data in both applications. These components, including a visualization tool, are available as open source packages (models.slf.ch).

Since 2002, the year three papers describing the model in detail appeared (for example, see Lehning et al., 2002), SNOWPACK evolved in many respects. Based on newly acquired data sets, we updated the parameterizations of the density of new snow (see Schmucki et al., submitted) or of the albedo. We also revisited some concepts of the model such as snow settlement: we now divide the stress applied to the snow into a purely static overburden and a stress rate dependent term that allows mimicking the relaxation behavior of new and older snow. In addition, we adapted the temperature dependence of viscosity to cover a large temperature range from about -70 °C up to the melting point (Groot et al., 2013). Finally, we maximized the accuracy of both mass and energy balance. This is necessary for implementing advanced water transport equations such as the recent solver for the Richards equation (Wever et al., 2013).

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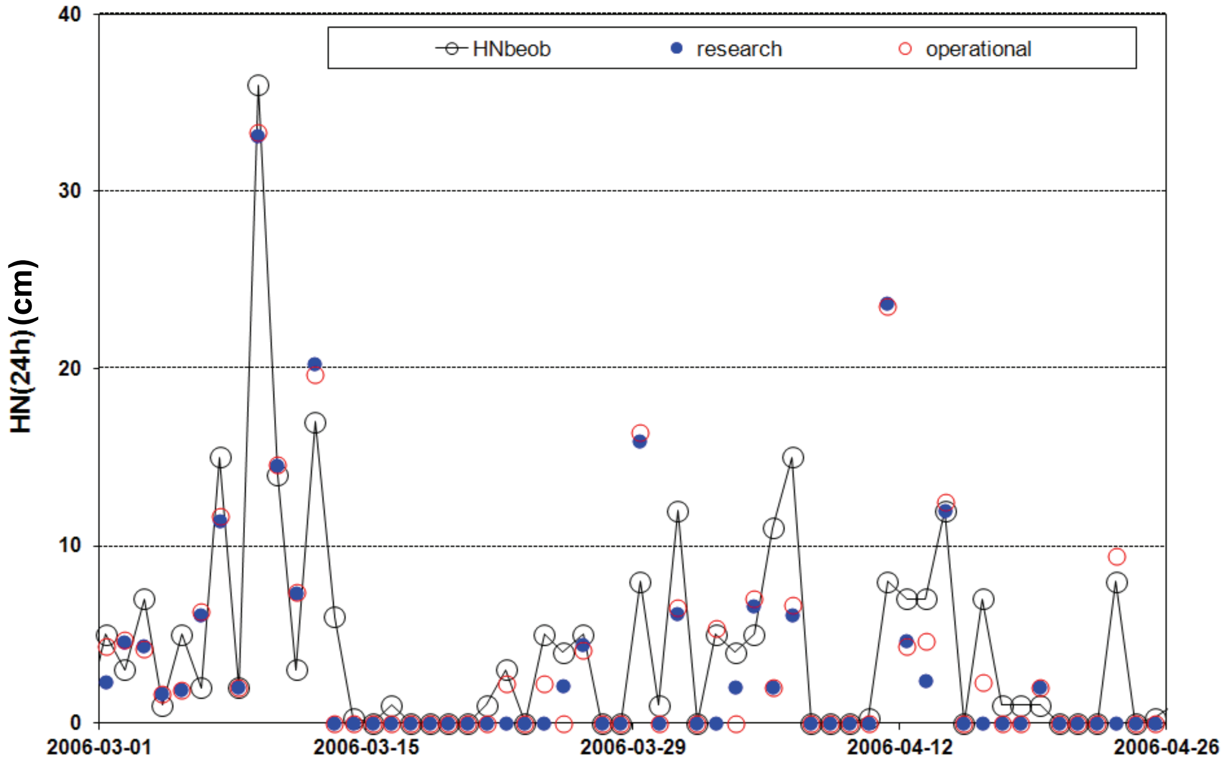
## 2 MODEL AND DATA

We used the latest release of SNOWPACK and MeteoIO, 3.1.0 and 2.3.0, respectively, to produce the simulations shown below. The input data from the Automatic Weather Station WFJ2 located in the SLF study plot at Weissfluhjoch, 2540 m a.s.l., were read from the SLF database. We used the ground temperature, the snow surface temperature, the reflected incoming short wave radiation, and the height of snow to drive the model. However, whenever the snow surface temperature gets above -1.0 °C, the model switches from Dirichlet to Neumann boundary conditions at the snow surface: air temperature, relative air humidity, and wind speed then allow computing the turbulent fluxes, and incoming long wave radiation is parameterized assuming clear sky conditions as cloudiness is unknown. In addition, we run the simulations either in research or operational mode. The latter corrects for settlement errors reflected in erroneous values of the modeled snow depth compared to measurements; that way we expect to minimize errors on the depth of snowfall. This is how we run operationally snow-cover simulations for the Swiss avalanche warning service.

## 3 RESULTS AND DISCUSSION

Figure 1 shows modeled and measured snow depth for two winter seasons, namely 2005/06 and 2009/10. We only present the results obtained in research mode as they are more instructive. During the accumulation period, the model captures quite well snow depth changes due to settlement. Discrepancies may often be due to erosion events not or not fully captured by the model. The most prominent error seen at the beginning of the season 2005/06 is first due to a missed erosion event, but we also suspect that our albedo parameterization


Figure 1. Modeled (red) and measured (blue) snow depth in centimeters for two winter seasons at Weissfluhjoch. Here we run SNOWPACK in research mode such that errors during settlement periods are apparent.



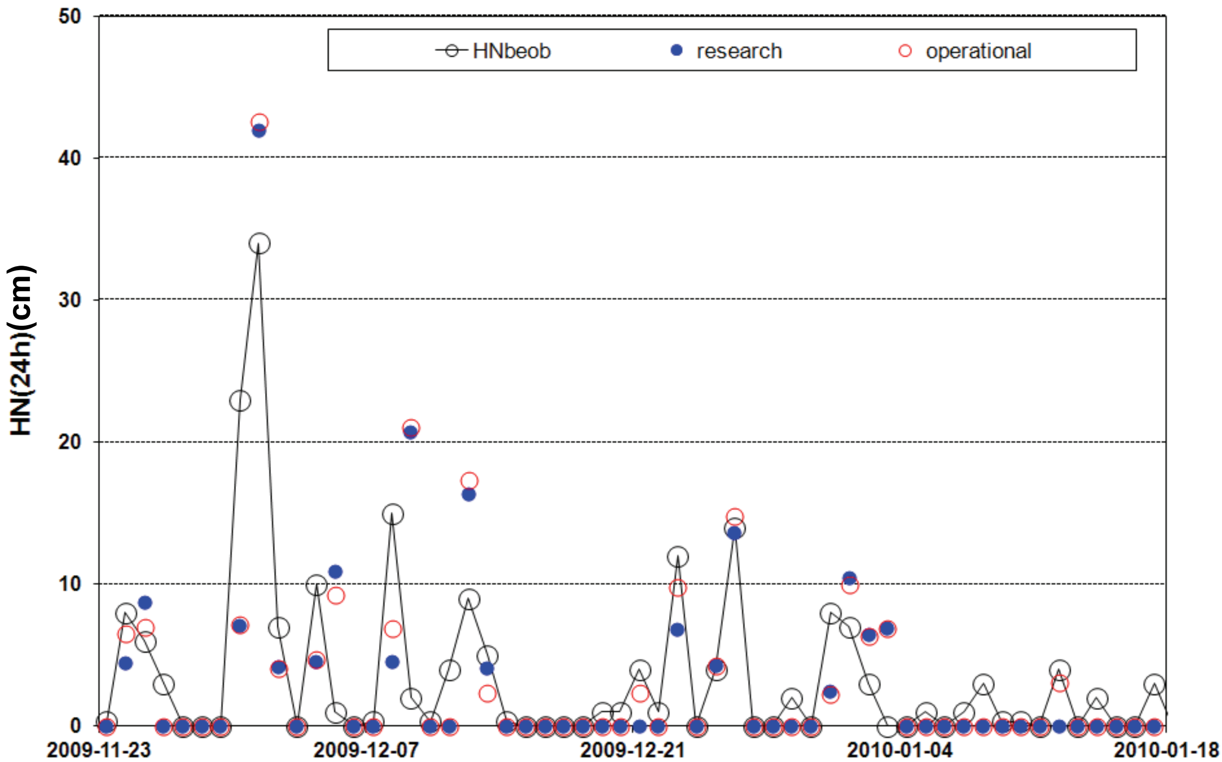




Figure 2. Comparison of calculated and measured depth of snowfall HN(24h) in centimeters. The open circles represent the daily measurements performed around 07:00 hours. The filled blue circles are the results of a simulation in research mode while the red circles are the operational results.

yields too high values during that period, reducing the net flux of shortwave radiation into the snowpack.

Based on the above, we would expect to also calculate satisfyingly the depth of snowfall. Figure 2 compares modeled and measured daily depth of snowfall HN(24h) at 07:00 hours. We focus on one period each for the winter seasons considered and show simulation results for both the research and operational modes to better assess the capability of the model. Note that snow surface temperature was rarely above -1 °C during these two periods. While almost no snowfall event is missing in operational mode, only a few are in research mode. However, the model reproduces all important snowfalls and in those cases, both modeled depths of snowfall match well observations. Furthermore, except one case in April 2006, measured depth of snowfall is captured within ±10 cm, with even less difference between the two modes themselves.

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