Measuring and modelling changes in the firn at Colle Gnifetti, 4400 m a.s.l., Swiss Alps

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Alpine cold firn provides mountain glaciers with a buffer against mass losses from a warming climate. It also plays a central role in ice core studies, thanks to its preserved depositional stratification and proximity to European anthropogenic sources of atmospheric emissions. Ongoing degradation towards a temperate regime is expected to critically alter cold firn, but to this day limited knowledge exists of its unfolding and consequences. Field monitoring and physical modeling efforts are then important to improve quantitative understanding of cold firn processes and evolution.

Colle Gnifetti (4450 m a.s.l.), in the Monte Rosa range, is a prominent site for cold firn research. Featuring remarkably low accumulation rates, it allows a longer temporal coverage of ice cores than any other alpine cold firn site. As such, it has received a great deal of scientific attention over almost 50 years, leading to a unique long-term archive of glaciological measurements.

This thesis presents the first deployment of a high-resolution, fully coupled energy balance and firn model at Colle Gnifetti. The model is driven by the long-term hourly weather series measured at the nearby Capanna Margherita weather station (4560 m a.s.l.), corrected and supplemented by other high-altitude stations in the region.

The peculiar surface accumulation regime of Colle Gnifetti, dominated by wind scouring and melt consolidation, is replicated with a three-phase anomaly model, including a mean long-term accumulation grid, an annual anomaly time series and a hourly down-scaling algorithm. After tuning from in situ observations of previous field campaigns, the coupled model is used to simulate surface conditions and firn evolution – at hourly resolution and down to 20 m depth – between 2003 and 2018. A trend of annual melt increase, amounting to 4 mm w.e. yr-2 and on the edge of statistical significance, is found over the simulated period. Comparison of modeled firn temperatures to 25 measured borehole profiles demonstrates a close match, with mean deviations of 2 °C and negligible bias; simulated melt amounts are found to be consistent with the results of previous investigators, thereby validating the use of the model for alpine cold firn research.

Results from a brief field campaign on Colle Gnifetti are also presented: they include the first set-up installed on site to monitor and report firn temperatures in real time. Thermal tracking of meltwater infiltration after melt events reveals generally shallow refreezing depths, exceeding 0.5 m only during extreme heat waves.

The main recommendations formulated for future research are the model implementation of a physical – rather than parametrized – approach to water percolation, and the long-term installation of a firn monitoring station.

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