THE DEVELOPMENT OF A NETWORK OF AUTOMATIC SNOW STATIONS IN THE CZECH REPUBLIC IN RELATION TO CLIMATE CHANGE AND OTHER FACTORS

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ABSTRACT: Over the past two decades, the Czech Hydrometeorological Institute (CHMI) has gradually expanded its manual snow monitoring network with automatic snow-measuring stations. Since 2006, several technologies have been evaluated, particularly snow pillows for measuring snow depth and snow water equivalent (SWE). The resulting network now covers major mountain and highland regions beyond the primary climatological stations and has been further complemented by automatic snow depth sensors.

Network development has been driven by the need to maintain reliable long-term datasets for water management, compensate for the declining number of observers in mountain regions, and adapt to climate change, which is shifting suitable monitoring sites to higher elevations. Station locations were selected according to representativeness, wind exposure, vegetation, terrain, and accessibility.

CHMI currently operates 60 standalone automatic snow stations, and this network is supplemented by 46 additional lasers and ultrasonic snow depth sensors located at meteorological stations.

Long operational experience demonstrate that representative site selection is more important for obtaining reliable SWE observations than the choice of measurement technology itself.

Future work will focus on integrating historical and automated observations to ensure consistent long-term SWE datasets.

KEYWORDS: Automatic snow station, snow water equivalent, meteorological data supplementation, climate change, station site selection

1. INTRODUCTION

Over the past twenty years, CHMI has started a new era of snow measurement. Until then, the core of snow measurement was manual and depended mainly on volunteer observers, but also on professional staff at professional stations. More than 800 rain gauge stations (also snow measurement sites) were distributed throughout Czech Republic. In response to demographic changes, particularly the decline in the permanent population of mountainous regions, and the increasing demand for automation, a program was initiated to gradually modernize and expand the snow monitoring network not only in mountain areas. The main motivation was to rescue snow datasets, which are used for various purposes in climatology, hydrological, and forecasting services.

2. TEST SITE HYDROLOGICAL EXPERIMENTAL BASE THE JIZERA MOUNTAINS

A detailed hydrological research program was established in the mountainous region of northern Czechia during the 1980s. Snow monitoring has always been an integral part of this research. For this reason, an experimental project aimed at testing instruments for automated snow measurements was launched in the 1990s.

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2.1 Origins and interruption of the project

The first project, initiated in 1996, included the installation of three automatic snow stations ("snow pillows"). The stations were supplied by Sommer GmbH through international aid. At that time, however, neither an operational methodology nor a sustainable maintenance framework had been established, and the cost of servicing the stations proved prohibitively high. Consequently, the project was gradually discontinued, and the stations were removed from the operational monitoring network. Despite its limited lifespan, **the project provided valuable experience that laid the foundation for the successful implementation of automated snow monitoring in the years that followed.**

2.2 New project, new visions

The second project started in 2006 and was led by hydrological staff with support from climatologists. Two types of snow pillows were built at the elevation of 775 m a.s.l. near a climatological station. Observations were conducted weekly. The principle of measuring snow water equivalent (SWE) and snow depth is relatively straightforward. It is based on weighing the snowpack over a predefined surface area, while snow depth is measured above the same area. Two sizes were selected, with measurement areas of 16 m² and 9 m². The first station (16 m²) was a prototype developed for this test site. The steel platform was supported by four load cells, which continuously measured the weight of the overlying snowpack.



Figure 1: The test site 775 m a.s.l., the Jizera Mountains (2006).

The platform was surrounded by a perimeter frame (fence) to isolate (cut) the snowpack within the defined measurement area. The second station was a well-known system based on a "pillow" filled with a non-freezing mixture of glycol and water and the weight of snowpack was measured by pressure sensor(s).

The stations were in an open area to the east of the climatological station. The site is sheltered by trees to the east and south, whereas it is exposed to the north, towards the water reservoir, and only partially sheltered to the west.

Selecting a suitable location for the stations was challenging because a sufficiently large, level area was required. Considering the prevailing north–south wind direction, the site was not ideal for snow measurements. However, no more suitable location was available within the study area. It gave us the first experiences and started filling the methodology for the next projects.

After three years of testing, the systems were evaluated against several criteria, including measurement accuracy, maintenance and servicing requirements, and the ease of dismantling and relocation. **Based on the evaluation, the snow pillow system with pressure sensors was selected for operational deployment under Central European climatic conditions, and two additional monitoring sites were subsequently established.**

3. DEVELOPMENT OF THE AUTOMATIC SNOW MONITORING NETWORK AND SITE SELECTION CRITERIA

3.1 Development of the automatic snow monitoring network

Following the pilot phase, the network was gradually expanded from 2009 through a series of national projects, which enabled the progressive deployment of snow pillow stations throughout the Czech Republic. During the following decade, snow pillow type stations (16) were gradually installed in the major mountain and upland regions beyond the existing climatological station network. Because the network developed gradually, there was no pressure for rapid deployment. This allowed each site to be evaluated over a period of two to three years against predefined selection criteria before installation.

Following the successful deployment of snow pillow stations, the next phase focused on automating snow depth measurements. As snow depth remained the last manually observed snow variable, a nationwide modernization project was carried out between 2017 and 2021. In collaboration with the regional climatology branches of CHMI, automatic snow depth sensors were installed at existing climatological stations, and additional stations were established in previously unmonitored regions. This significantly improved the spatial coverage and operational efficiency of the national snow monitoring network.

The most recent phase of network development has focused on meeting the operational requirements of partner organizations, particularly river basin authorities and mountain rescue services. **New stations have been installed in locations where improved snow information supports flood forecasting, water resources management, and public safety.**

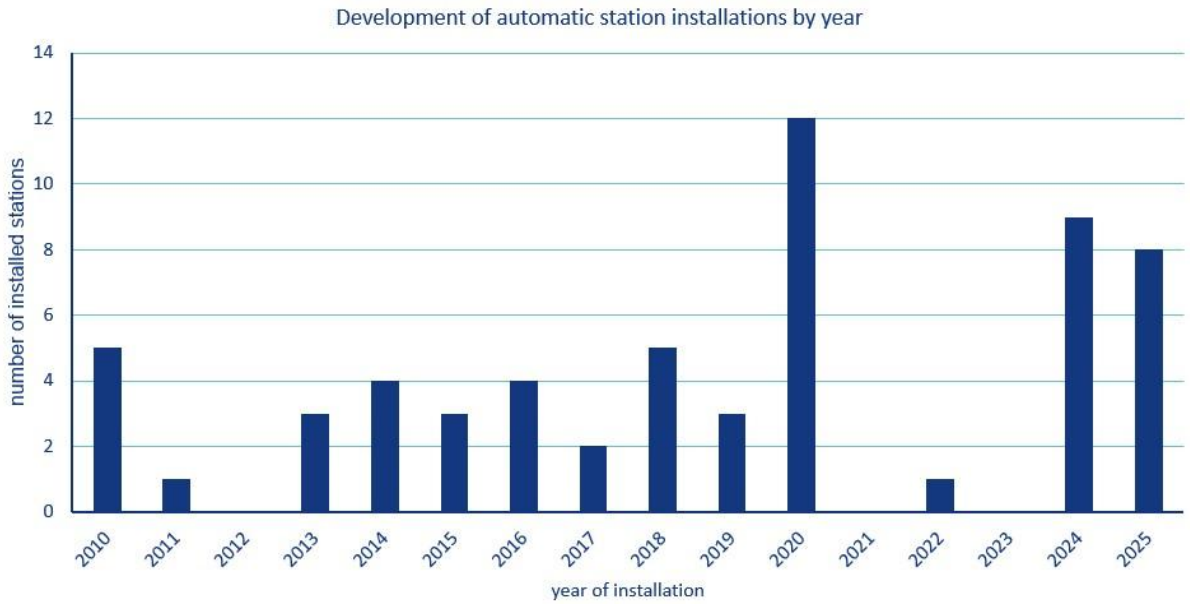


Figure 2: Development of the standalone automatic snow station network

A well-considered development of the network is expected to continue in the coming years. Future efforts will focus on improving the spatial coverage and long-term sustainability of ground-based snow observations. Despite the rapid development of remote sensing and modelling techniques, in-situ measurements will remain the primary reference source for snow monitoring, model calibration, and the validation of satellite products.

3.2 Site selection criteria

The primary objective of an automatic snow monitoring station is to provide representative observations of snow conditions within a catchment for hydrological analyses and snow water resource assessment. Site selection should therefore follow these principles:

Representativeness – The station should represent the snow conditions of the target catchment, geomorphological unit, or landscape type rather than local anomalies.

Elevation – Stations should preferably be located above 500 m a.s.l., corresponding to the main snow accumulation zone in Czechia. The selected elevation should reflect the average elevation of the monitored catchment.

Topography – Flat terrain is preferred. If this is not possible, a gently sloping and uniformly inclined site should be selected. Convex and concave landforms that promote snow removal or accumulation should be avoided.

Slope and Aspect – Steep slopes (>5°) and strongly north- or south-facing slopes should be avoided because they influence snow accumulation and melt, reducing representativeness.

Snow Climate – The site should have a sufficiently long and reliable snow season, based on historical observations or climatological analyses, with adequate snowfall frequency, snow cover duration, and seasonal snow depth.

Wind Exposure – Locations exposed to strong winds should be avoided to minimize snow redistribution and measurement bias.

Vegetation and Land Cover – Stations should be installed in open areas, preferably on maintained grassland, with minimal influence of surrounding vegetation.

Anthropogenic Influences – The site should be sufficiently distant from buildings, roads, forests, and other obstacles that may affect snow accumulation or create local microclimatic effects.

Table 1: Recommended criteria for selecting automatic snow station sites (2022).

Criteria	*Recommended threshold*
Elevation	> 500 m a.s.l.
Snow cover duration	30–40 days with SD > 1 cm
Significant snow depth	≥ 5 days with SD > 20 cm
Annual snowfall	≥ 60 cm
Maximum snow depth	> 25 cm
Maximum SWE	> 50 mm

The following graph (see Figure 3) shows the evolution of the annual maximum snow depth at three selected stations in the Krkonose Mountains since the beginning of the 21st century. The linear trend indicates an extreme decline in snow across all elevations in the Krkonose region.

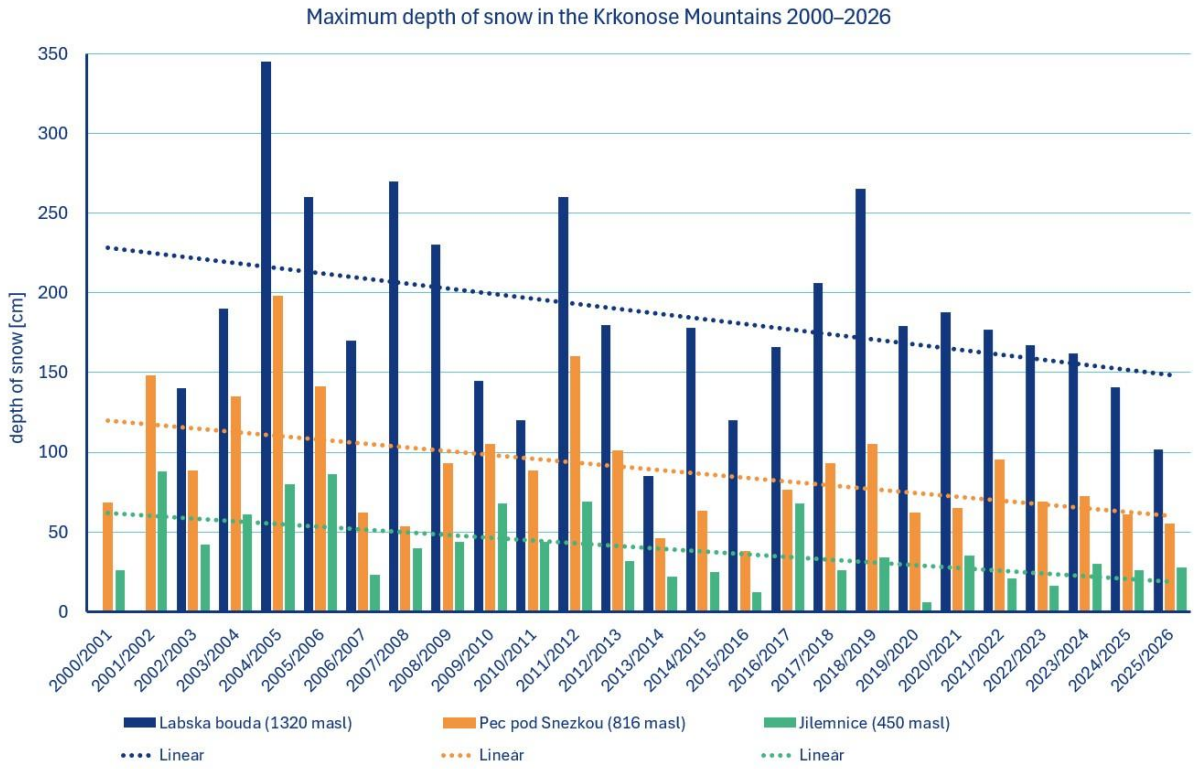


Figure 3: Maximum depth of snow at three different stations in the Krkonose Mountains.

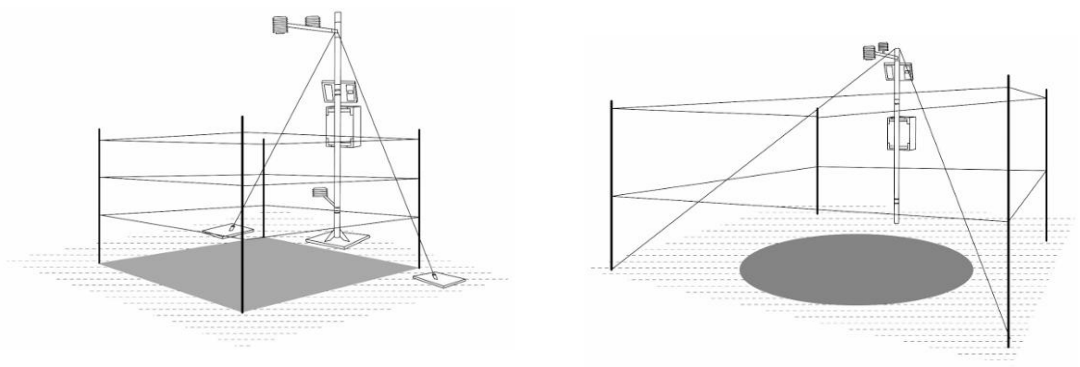


Figure 4: Two types of automatic snow stations (pillows) operated by CHMI



Figure 5: Automatic snow stations located on volunteer observers' properties and in open terrain

3.3 Lessons learned from 20 years of operating

Nearly twenty years of operational experience have shown that **measurement accuracy depends more on-site conditions than on the sensor technology itself**. Representative site selection is therefore the most important prerequisite for reliable measurements.

The largest measurement uncertainties are caused by natural processes within the snowpack rather than by sensor malfunction. The most important is **snow bridging**, when ice layers formed during repeated melting and refreezing redistribute the snow load outside the pillow, and **side friction**, which develops along the boundary between the snow pillow and the surrounding snowpack. These processes may temporarily affect the measured SWE, particularly during winters with frequent freeze–thaw cycles, which are typical of Central Europe.

Regular maintenance, continuous quality control, and comparison with manual observations remain essential for ensuring long-term data consistency. Operational experience demonstrates that high-quality SWE observations result from the combination of appropriate site selection, careful installation, and systematic data validation rather than from measurement technology alone.

Table 2: Lessons learned from 20 years of practice.

Lessons learned	*Recommendation*
Site selection	Assess sites for 2–3 winters before installation.
Local conditions	Prioritize exposure, terrain, vegetation, and access.
Snow bridging	Check SWE after freezing–thaw periods.
Wind exposure	Avoid wind-exposed and redistribution-prone sites.
Maintenance	Inspect stations before and after the snow season.
Validation	Maintain manual reference observations.

The following map (see Figure 5) illustrates the spatial distribution of approximately 100 automatic and 400 manual stations that monitor snow cover parameters. Considering ongoing climate change, an elevation of at least 500 m above sea level is recommended for the installation of automatic stations.

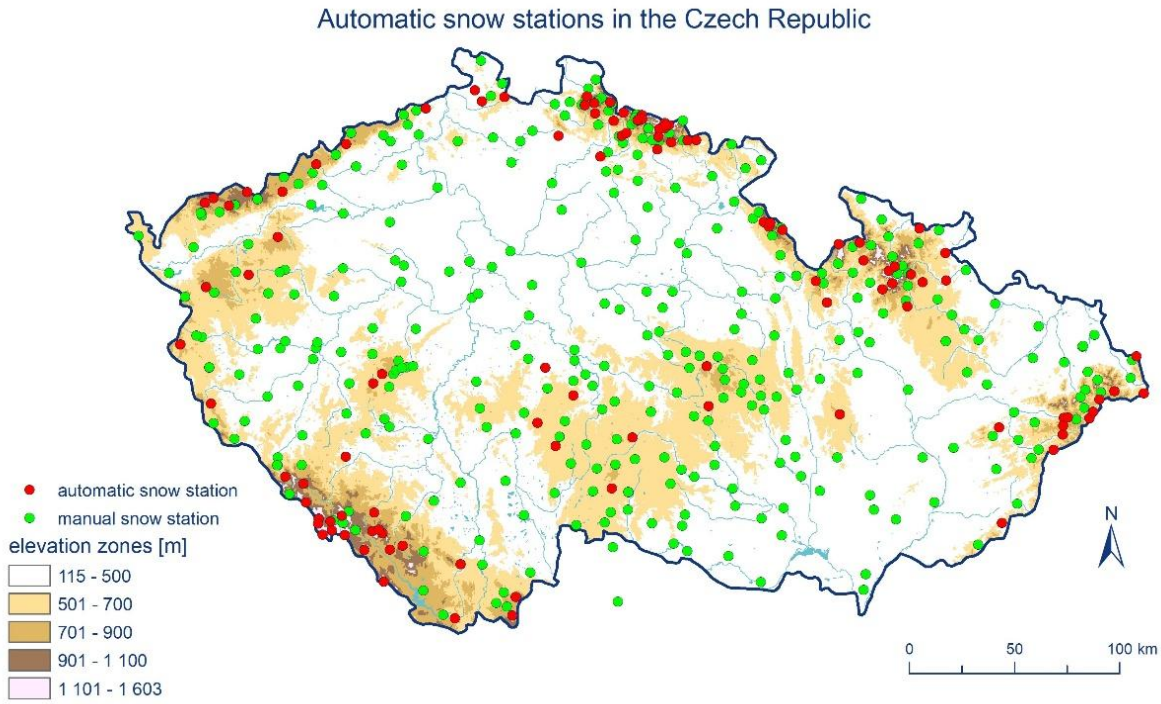


Figure 6: Automatic and manual snow stations in the Czech Republic in 2026.

4. VALIDATION AND MAINTENANCE

To ensure the long-term reliability of automatic snow observations, all stations are inspected regularly throughout the year. Routine maintenance includes verification of sensor performance, inspection of the station structure, power supply and data logger, assessment of the measuring area, and photographic documentation. Minor defects are corrected during field visits.

Winter inspections also include manual control measurements of snow depth (SD) and snow water equivalent (SWE). These measurements are performed both in the immediate vicinity of the station and along a representative snow course following a standardized CHMI methodology. The results are compared with automatic observations to verify measurement accuracy and identify potential systematic errors.

Different station types require specific inspection procedures. Snow pillow stations are checked for the condition of measuring surface and surrounding snowpack, while ultrasonic and laser sensors are verified using manual snow depth measurements. These regular inspections form an essential part of the quality assurance system and contribute to the long-term consistency of the national snow monitoring network.

To standardize field inspections, **CHMI uses the ESRI Survey123 platform**. The digital protocol enables field technicians to record inspection results, maintenance activities, manual validation measurements, pictures, and metadata directly on site using mobile devices. The collected information is transferred to the central database, ensuring traceability and consistent quality control across the entire monitoring network.

5. SUPPLEMENTING HISTORICAL SNOW DEPTH AND SNOW WATER EQUIVALENT DATA

In connection with the possibility of comparing measured data and calculating snow water equivalent before and after automation, it will also be necessary to focus on methods for supplementing historical data on snow depth and snow water equivalent for areas with automatic stations installed in the last 20 years.

As automatic snow stations were being added, particularly in mountainous and highland areas that had previously been more difficult to monitor, the resulting interpolation of snow depth and water equivalent was far more representative and better reflected the actual field conditions. Improving the availability of historical snow depth and snow water equivalent data could enable better long-term comparisons of snow cover conditions.
Currently, we are focusing on selecting the most suitable methods for supplementing historical data.
Out of several possibilities, we can highlight two methods that seem particularly suitable.

1) Prediction using machine learning

Machine learning methods generally aim to use available training data to find a function that best generalizes the statistical relationships between features and the predicted value. In our case, the features are observations from surrounding stations, which are available even for the period we want to predict. To train the predictive model, we used the Random Forest algorithm, which provides a nonlinear prediction function. This algorithm is universal, fast, does not pose a risk of overfitting, and has often proven effective for similar types of tasks.

2) The Missing Values program

Another option for supplementing historical data is the Missing Values program, which works with the CHMI climatological database CLIDATA. The suitability of this method is assessed using the mean squared error and data correlation. When the parameters are set appropriately, it can provide a reliable alternative for further climatological analyses, including machine learning applications. The program estimates missing values of the observed variable based on spatial relationships with surrounding stations.

In simple terms, the missing value is calculated using linear regression between the measured value and station elevation.

6. CONCLUSION AND FUTURE RECOMMENDATIONS

Over the past two decades, CHMI has developed a standalone automatic snow monitoring network covering the major mountain and highland regions of the Czech Republic. Long-term experience has shown that **representative site selection is one of the key factors affecting data quality**. Elevation, terrain, wind exposure, vegetation and local snow conditions should therefore be considered together when selecting new sites.

Automation does not eliminate the need for field observations. Regular maintenance, manual control measurements and systematic data validation remain essential for maintaining reliable long-term SD and SWE records.

Future development should focus on **filling spatial and elevation gaps, maintaining representative ground observations, integrating in-situ data with models and remote sensing, and reconstructing historical SD and SWE series**. Site-selection criteria should also be periodically reassessed as climate change modifies the spatial and altitudinal distribution of seasonal snow cover.

The future challenge is not simply to increase the number of automatic stations, but to maintain a representative, sustainable and quality-controlled monitoring network.

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REFERENCES

Bercha, S., 2018. Automatic snow measuring stations network in CHMI [online]. In: Snow conference Abstracts – Towards a better harmonization of snow observations, modeling and data assimilation in Europe. Budapest: COST Action ES1404 Harmosnow, https://harmosnow.eu/snowconference/abstracts-v4.pdf.

CLIDATA. Professional Climatological Database, https://www.clidata.cz/, last access: 7 August 2026.

CHMI. Flood Warning and Forecasting Service – snow daily data, https://hydro.chmi.cz/hpps/snh?key=map&sx=1722724.5&sy=6415123.5&sz=2, last access: 7 August 2026.

Holub, M., Fryc, T., Bercha, S., Nemec, L., 2026. Snow depth prediction in mountainous regions. Mountain meteorological conference in the Krkonose Mountains Proceedings 2026, Spindleruv Mlyn, The Czech Republic.

Jirak, J., Bercha. S., 2026. Regular monitoring of snow cover in the Krkonose Mountains and its application in estimating snow water storage. Mountain meteorological conference in the Krkonose Mountains Proceedings 2026, Spindleruv Mlyn, The Czech Republic.

Jirak, J., Bercha. S., Vajskebr, V. 2022. Planned development of ASNS: automatic snow measuring stations. Workshop – 25th Gathering of Snow Specialists Proceedings 2022, Spindleruv Mlyn, The Czech Republic, http://www.uh.sav.sk/sk-sk/Veda-a-v%C3%BDskum/Konferencie/Stretnutia-sneh%C3%A1rov.

Kaminková. A., Sustkova, J., Lipina, P., 2026. Reconstruction of snow depth time series in the Jeseniky and Kralicky Sneznik Mountains. Mountain meteorological conference in the Krkonose Mountains Proceedings 2026, Spindleruv Mlyn, The Czech Republic.

PERUN, Climate change scenarios for the Czech Republic by 2100, https://www.perun-klima.cz/scenare/, last access: 7 August 2026.

Sustkova, V., Bercha, S., Jirak, J., 2023. Long-term changes and future of snow in the Czech Republic. International Snow Science Workshop Proceedings 2023, Bend, Oregon.

Sustkova, V., Bercha, S., Jirak, J. 2024. Snow data management with the usage of geographical information system. International Snow Science Workshop Proceedings 2024, Tromsø, Norway.