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Long-term changes and future of snow in the Czech Republic
(Dlouhodobé změny a budoucnost sněhové pokrývky v České republice)

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Abstrakt: Příspěvek se zaměřuje na tři oblasti související s monitoringem parametrů sněhové pokrývky v České republice: automatické sněhoměrné stanice, vyhodnocování zásob vody ve sněhu a na změny ve sněhové pokrývce v České republice od roku 1961 do současnosti a její budoucí vývoj do roku 2100. Automatická sněhoměrná stanice je měřící zařízení schopné v reálném čase měřit a zaznamenávat vodní hodnotu celkové sněhové pokrývky (*SVH*) a v reálném čase celkovou výšku sněhové pokrývky (*SCE*). V současnosti se síť těchto stanic skládá ze 17 stanic schopných měřit výšku i vodní hodnotu a 50 automatických stanic měřících pouze výšku sněhové pokrývky. Do roku 2025 by se měla síť rozrůst o dalších 23 automatických sněhoměrných stanic. Data ze sněhoměrných polštářů poskytují důležitá data pro vyhodnocování zásob vody ve sněhu, které probíhá v týdenním kroku. Sněhová pokrývka a zejména zásoby sněhové vody jsou důležitou součástí hydrologické bilance množství vody v České republice. Vyhodnocování zásob vody ve sněhové pokrývce je také důležitou službou pro podniky povodí, pro které jsou tyto informace zásadní pro manipulace na vodních dílech. V Českém hydrometeorologickém ústavu (CHMI) vypočítáváme zásoby sněhové vody jednou týdně, ale zvyšující se počet automatických stanic v kombinaci s modelovými výpočty nám umožní odhadovat zásoby vody v denním kroku. Ve střední Evropě se vlivem klimatické změny spojené především s růstem teploty vzduchu mění i parametry týkající se sněhové pokrývky. Sníh je pro toto území důležitou součástí srážek a odtoku a má poměrně unikátní postavení i jako zdroj pitné vody pro obyvatelstvo.

Klíčová slova: klimatická změna – sněhová pokrývka – vodní hodnota sněhu – zásoby vody ve sněhu – automatická sněhoměrná stanice

Abstract: The paper focuses on three topics related to the monitoring of snow cover in the Czech Republic: automatic snow stations, evaluation of water reserves in snow and changes and evolution of snow cover in the Czech Republic from 1961 to 2100. Automatic snow station is a measuring mechanism, which can measure and record the snow water equivalent (*SWE*) and the total snow depth (*SD*) in real time. Nowadays there is a network of 17 complete stations (*SWE* and *SD*) and 50 snow depth automatic stations and a plan to build 23 more by 2025. Data from snow pillows are an important input for every week evaluation of water reserves in snow. Snow cover and especially the snow water supplies are an important part of the hydrological balance of water quantity in the Czech Republic. The evaluation of water reserves in a snow cover is also an important service for the state-owned water supply companies, for which this information is essential for the handling of waterworks. In the Czech Hydrometeorological Institute (CHMI) we calculate snow water reserves once a week, but the increasing number of automatic stations in combination with model calculations will allow us

to estimate water reserves in daily steps in the future. In Central Europe, due to climate change, the parameters related to snow cover are changing. Snow is an important component of precipitation and runoff for this area and has a rather unique position as a source of drinking water.

Keywords: climate change – snow cover – snow water equivalent – snow water supplies – automatic snow station

1. Introduction

Capturing data in the field is important for both research (climate change) and determination of water reserves in the snow. In addition to modelling and remote sensing, measured values are among the basic input data for assessment of snow characteristics. The evaluation of snow cover parameters, in particular snow water equivalent (*SWE*), is an important part of the hydrological balance of water quantity in the Czech Republic. There are unequivocal evidences that the air temperature is rising and the proportion of precipitation in the form of snow is decreasing in winter, thus reducing the ability of snow cover to form. Potential water resources are shrinking. Moreover, trends have been accelerating in recent years. In the future, we expect further deterioration of snow cover parameters in the Czech Republic. The intensity of these changes will mainly depend on the future development of the climate. The PERUN project focuses on the research of climatic extremes, drought and the consequences of climate change in the Czech Republic. Climate research is focused on this region with high horizontal resolution (PERUN 2023).

2. CHMI Snow station network

Stations measuring snow are distributed throughout the Czech Republic in lowland and mountainous areas. These include simple rain gauge stations with volunteer observers, as well as professional stations and observatories. Reliable and dense network of stations is due to demographic change mainly in mountain areas supplemented by automatic measurement of snow water equivalent (*SWE*) and snow depth (*SD*).

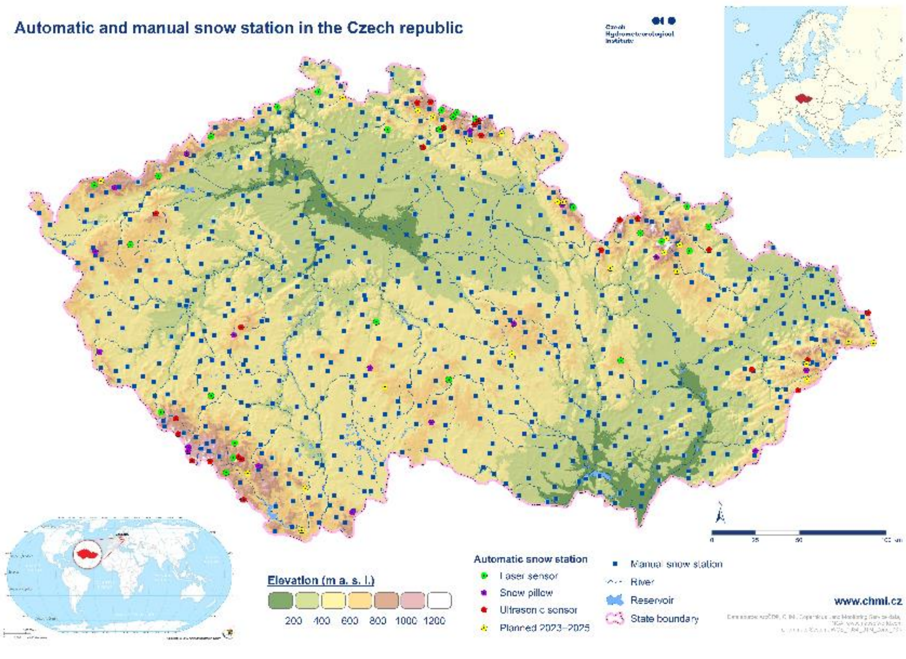

Fig. 1 Automatic and manual snow station in the Czech Republic 2023 with plan by 2025.
Obr. 1 Automatické a manuální sněhoměrné stanice v České republice 2023, plánované do roku 2025.

An automatic snow station is a measuring device capable of measuring and recording the water value of the total snow cover (*SWE*) and the total snow cover depth (*SD*) in real time. The weight of the snow on the measuring device is the equivalent of the water contained in the snow cover, i.e. *SWE*. It is obtained by measuring the hydrostatic pressure inside the antifreeze-filled bag (snow pillow) on which the snow cover lies. The total snow cover depth is measured above the weighed area of the station. Ultrasonic sensors are used to obtain the value of the total snow depth, i.e. *SD*. Simple type of station only measures snow depth using ultrasonic or laser sensor. As part of the snow cover monitoring, the station is supplemented by the measurement of other meteorological elements.

2.1 Snow pillow station network

Construction of the network began in 2006 by testing two types of stations, focusing on the technical functionality of the stations and the factors influencing the measurement accuracy.

Fig. 2 Automatic snow station – snow pillow type
Obr. 2 Automatická sněhoměrná stanice typu sněhoměrný polštář

The installed stations differed in the principle of *SWE* measurement, construction and size of the measured area. The obtained data were compared with manual control measurements using weight snow gauges according to the valid methodology of the CHMI. Better results and maintenance have led to network expansion used snow pillows since 2009. Snow pillow is the PVC bag filled with a mixture of antifreeze and water, where the change in hydrostatic pressure caused by the weight of the snow cover is sensed. Pressure sensors are installed outside the bag in the shaft. Older types have one pressure sensor, new types have two pressure sensors to check the possible failure. The temperature of the bag, to check the frost, is measured in contact above and below the bag itself. The bag has a square shape with an area of 9 m^2, or a circular one with an area of 7.065 m^2. It is placed on a sand and embedded at ground level. The bag is covered with geotextile, silage UV stable foil and a 3–5 cm thick layer of gravel. It is separated from the surrounding soil by a plastic curb. The measured area of the station is not defined in any way and the snow cover passes from/to the measured area of the station without interruption. A simple fencing is installed around the station. The station includes a mast structure in the shape of an inverted letter L. It houses a recording unit, an ultrasonic sensor, an air temperature sensor, alternatively a sensor to measure wind speed and direction, alternatively a sensor to measure relative humidity. The height of the mast structure is variable according to the installation location and the assumed maximum snow height (min. height is 2.3 m). The ultrasonic sensor measures the height of the snow cover, which is located above the measuring area of the station. The ultrasonic sensor is protected by a radiation cover to eliminate the error due to sunlight and is equipped with an automatic temperature correction, which eliminates the dependence of the propagation speed of sound in the air on the air temperature. For newer types of stations, the air temperature measured in the body of the ultrasonic sensor is recorded in the registration unit to verify the temperature independence of the sensor. Nowadays there is a network of 17 complete stations (*SWE* and *SD*) and a plan to build 3 more by 2025. They are deployed regularly especially in highlands and mountainous areas as seen on Fig. 1.

2.2 Factors influencing measurement accuracy (SWE)

During the testing of the automatic stations the factors that fundamentally influence the accuracy of the measurement were described. They can be divided into two groups: (a) factors influencing the accuracy of the measurement of the water value at the point and its explanatory value for the wider surroundings (natural, technical) (b) specific factors influencing the accuracy of the measurement. The most important natural factor influencing the accuracy of the water value measurement at a point is the right choice of the location. It must be selected well in advance and the distribution of snow cover must be regularly monitored during the various phases of the winter season (accumulation, melting). The climatic conditions of the location (prevailing wind directions, length of sunshine) and their possible change in the environment must be taken into account. Technical factors influencing the accuracy of measurements include, in particular, poor installation, insufficient instrument care, lack of calibration, and the quality of measuring sensors. In Central Europe with regular temperature fluctuations in the winter season, the most important specific factor affecting the accuracy of the measurement is the formation of snow bridges. During the regular melting and freezing periods of the snow cover, firn and ice layers are formed, causing the distribution of pressure over a wider area than the defined area of the measuring station. Another important factor is the side friction in the snow layer at the boundary of the measuring station's edge and the surrounding area. This is due to the different melting rates on the measuring area and the surrounding soil, where there is a difference in the speed of snow layer settling and side friction at the boundary. These two phenomena causes a change in the pressure on the snow pillow and thus a measurement error. In recent years, the melting, freezing and accumulation periods has become more frequent and more data control is needed.

2.3 Snow depth station network

The network of snow pillows was followed by other projects in 2015–2021. Extension of the network automatic snow stations measuring the depth of snow suitably complemented this existing network. Part of the project was installation of 40 new stations for measuring the depth of snow cover, which are distributed within the scope of all CHMI branches. Thirty snow stations are a part of already existing climatological or rain gauge stations, here it was mostly the installation of a laser sensor (see Fig. 3) and 10 stations with ultrasonic sensors were erected in the most problematic mountains regions (see Fig. 4).

Fig. 3 and 4 Automatic snow station – laser type (SHM31, left) and ultrasonic type (right).
Obr. 3 a 4 Automatická sněhoměrná stanice – laserová (vlevo) a ultrazvuková (vpravo).

CHMI has also long worked with professional organizations that operate snow stations and meet measurement standards. Data obtained from 10 stations are available in the database and further utilized. In 2023, a new project was launched, which will improve the snow pillow network and further expand the network of automatic snow stations (Fig. 1).

3. Evaluation of snow cover, snow depth and snow water equivalent

There are several reasons why there is an effort to continuously refine the calculation of snow water storage throughout the winter season. Due to the risk of long-term droughts and in general due to climate change in Central Europe, there is a growing demand for more accurate water storage calculations for the state water companies. Due to the increased frequency of melting periods in all altitudinal zones during the whole winter season, the staff of the state-owned water supply companies need to have the most accurate information available and also as soon as possible. The Flood Warning and Forecaster Service of the CHMI has similar requirements for more accurate water supply calculations as well as shorter calculation intervals.

3.1 Methodology for obtaining input data to improve interpolation

The snow water storage is calculated in a weekly step on Monday during the whole winter season from the beginning of November until the end of April. The weekly calculation step is due to the fact that the snow water equivalent is measured at manual weather stations only every Monday.

The calculation of water storage is performed using a special interpolation method in the GIS and among the most important and the most numerous input data belong measured values from manual weather stations. In recent years, the number of stations entering the calculation has stabilized at a total of 600. This number consists of 435 selected verified manual stations, 67 automatic snow stations and about 100 auxiliary stations. An auxiliary station in this case is a station where the snow cover parameters are measured only a few times per winter season and the remaining Monday values are calculated according to an established empirical relationship with the nearest surrounding regularly measured stations. Auxiliary stations are mainly located in places with insufficient density of regular measuring stations or in areas where interpolation of snow water value is problematic due to specific relief. The measurement of snow water equivalent can sometimes be difficult due to the specific density and structure of the snow layer and the accuracy of manual measurements may be affected. Similarly, the accuracy of automatic snow station measurements is in some cases affected by natural, technical and physical factors. For these reasons, data from all mentioned stations are checked in detail before starting the interpolation. The data from the automatic stations are checked continuously every day at 7 a. m. and measured values are checked by manual onsite measurements during problematic periods in the winter season. An important control for the manual measurements is the expert estimates of snow density intervals (the ratio of snow water equivalent to snow depth), which are determined each week for three different altitude areas (100–600 m a. s. l., 601–900 m a. s. l. and 901–1600 m a. s. l.). In problematic situations, snow density intervals are also determined for specific regions of the country or for individual mountain ranges. Another important element of the data control is the calculated snow water equivalent (*SWEC*). Theoretical values of *SWEC* are calculated using an empirical formula for all meteorological and climatological stations in a daily step. The last control element is data from selected profile measurements. These are detailed measurements in long transects in the Jizerske hory Mountains and Giant Mountains and at CHMI professional stations, whose values are taken as representative for the region.

3.2 Using satellite imagery and ground observations to define the extent of snow cover

For a good interpolation of *SWE* data it is also necessary to determine the zero isochion (snow line with zero value) for individual regions of the Czech Republic as accurately as possible. For the calculation of snow water reserves the territory of the Czech Republic is divided into 9 regions, in case of problematic situations 27 regions are used. For each region, a zero snow line value is determined to avoid erroneous interpolations where the water value was calculated even in areas where snow cover did not occur. Several sources are used to determine the zero isochion. Firstly, data are obtained from the NSIDC (*National Snow and Ice Data Center, University of Colorado*) portal, where images from daily MODIS satellite flybys over central Europe are archived. The selection of satellite images for snowline position analysis is based mainly on the date of acquisition and the amount of cloud cover. One representative image is selected for each week of the observation period. Suitable images are selected due to the Monday ground measurements of the CHMI either on the same day or at the earliest possible previous date. The transformed image is then imported into the ArcGIS as a classified raster, from which the classes "snow cover", "area without snow cover" and "cloud cover" are essential for the purpose of zero isochion. Unfortunately, the accuracy of images depends on the level of cloud cover. Other important sources for determining zero isochion are webcams (cameras of the CHMI, commercial cameras, cameras of amateur meteorologists, etc.) and, of course, records of snow cover measurements at meteorological stations and, last but not least, observations of amateur meteorologists.

3.3 Main outputs of the water storage in the snow cover evaluation

The checked data from manual, automatic and auxiliary stations and the zero isochion data in each region are the input database of weekly GIS calculation whose main purpose is to evaluate the water storage in snow cover as efficiently as possible, especially for flood protection, modelling flow forecasts and water management purposes. The current water storage is evaluated in the GIS for the whole country (see Fig. 5), individual 14 administrative regions and 6 main altitude zones, but also for nearly 80 selected catchments and waterworks. Another output is an assessment report of the weather trend in the week preceding the calculation of the water storage and a forecast of the meteorological situation in the coming week. Among important outputs belong naturally also maps of snow water equivalent and snow depth.

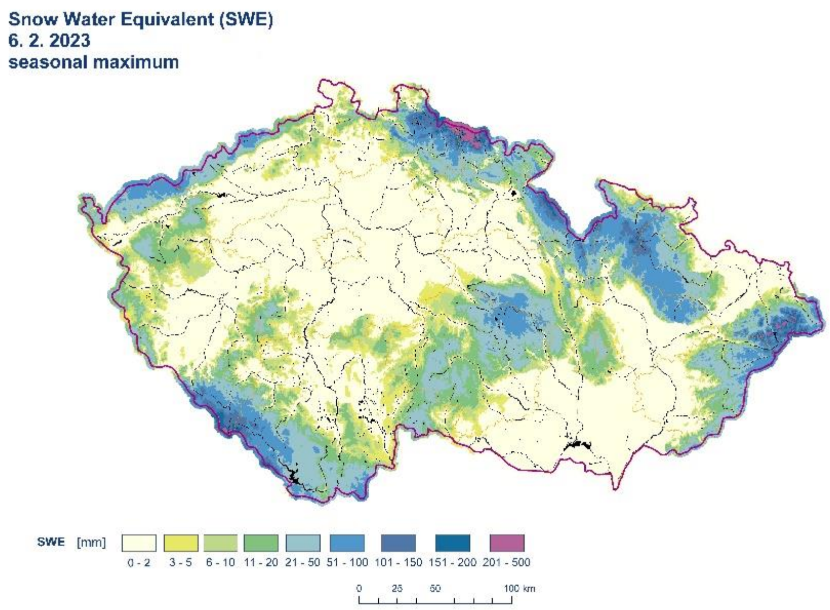

Fig. 5 Snow water equivalent February 6 2023.
Obr. 5 Vodní hodnota sněhu dne 6. února 2023.

The last output is a comparison of the current water storage with other winter seasons since 1970, or with the maximum, average and minimum storage volumes in a particular week of the season in selected basins of the country.

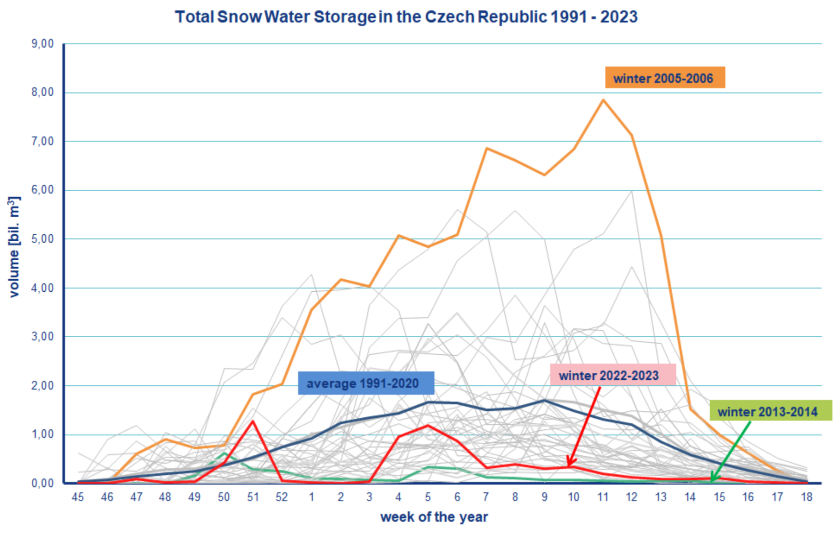

Fig. 6 Total snow water storage in the Czech Republic 1991–2023.
Obr. 6 Zásoby vody ve sněhu v České republice za období 1991–2023.

Other efforts of the snow water equivalent calculation are moving toward daily-step of evaluation. With more frequent floods or mid-week precipitation episodes, it is important for water management to have accurate information at the day step. Research in this area focuses on model calculations based on measurements of meteorological elements (air temperature and humidity, precipitation, speed and direction of wind). The model calculations can be checked by automatic snow stations. There is an assumption that the number of automatic snow stations will increase constantly in the future.

4. Climate change in Czechia

Europe's climate is characterized by significant regional variability due to the continent's location in the northern hemisphere and the influence of the surrounding seas and oceans, respectively the adjacent Asian continent and the Arctic. The main influence on Europe's climate has atmospheric circulation and its temporal and spatial changes. Climate change is already affecting Europe in various forms, depending on the region (European Parliament, 2023). As there is a sufficiently dense network of long-term measuring meteorological stations in the Czech Republic, supplemented by a number of remote sensing measurements, the analyses of change trends are significantly more accurate than similar global analyses (Ministry of the Environment of the Czech Republic 2015). Long series of meteorological measurements and observations, which are the result of many years of daily work of professional or even voluntary observers, are extremely valuable not only for evaluation, analysis or creation of homogeneous series of selected characteristics, but also especially for knowledge of climate variability and estimation of its development in the future.

4.1 Air temperature

The average annual air temperature in the Czech Republic has an upward trend of 0.3 °C in 10 years, increasing by an average of 2.1 °C over the measurement period 1961–2022 (see Fig. 7). The long-term temperature average (normal) for the period 1961–1990 is 7.5 °C, for the period 1981–2010 7.9 °C and for the period 1991–2020 8.3 °C (see Fig. 8). The warmest year was recorded in 2018, when the average air temperature reached 9.6 °C. In addition to the years 2013 and 2021, the eight previous years (2013–2022) are in the top ten warmest years recorded in the Czech Republic.

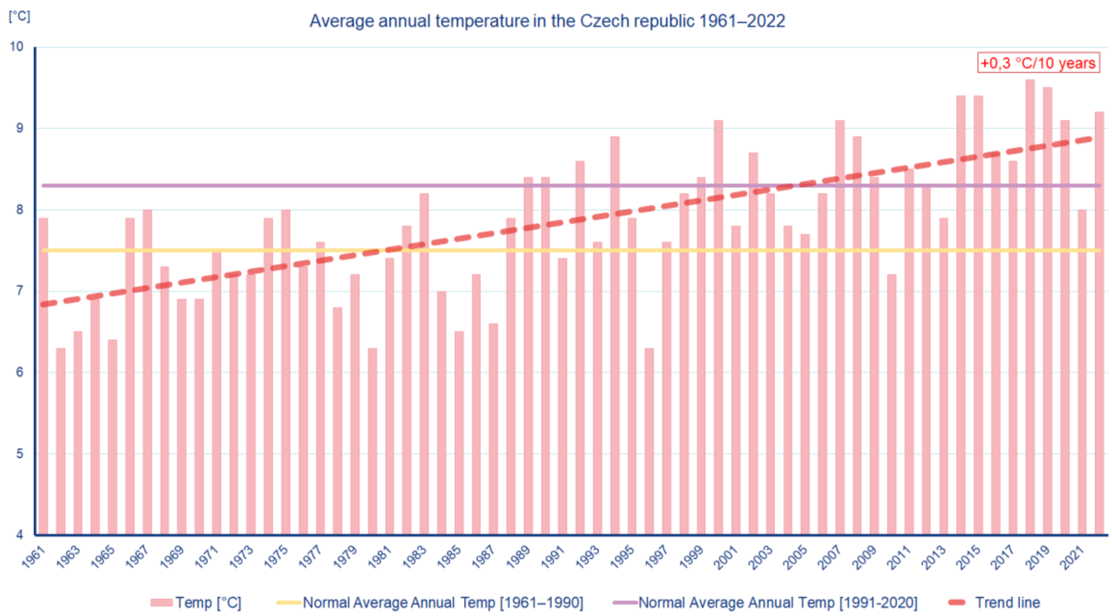

Fig. 7 Average annual temperature in the Czech Republic 1961–2022.
Obr. 7 Průměrná roční teplota vzduchu v České republice za období 1961–2022.

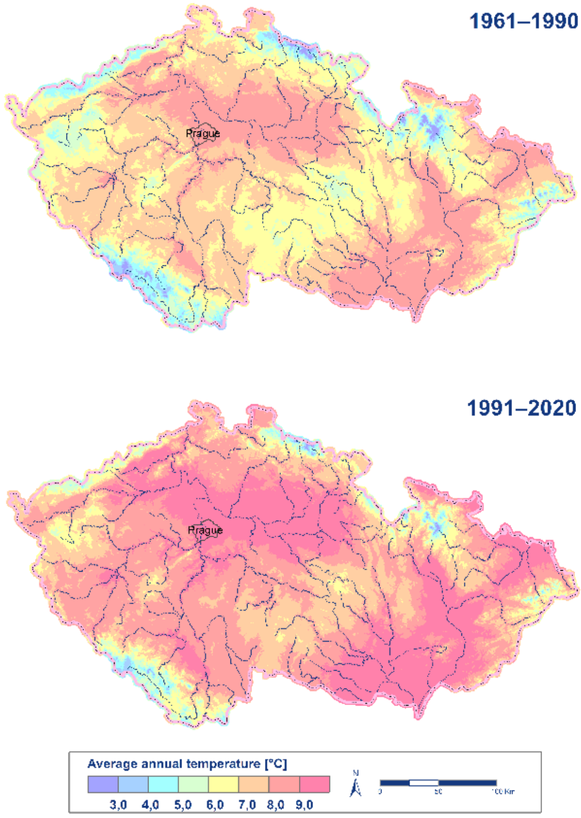

Fig. 8 Average annual temperature normal 1961–1990 and 1991–2020.
Obr. 8 Normály průměrné roční teploty vzduchu v České republice za období 1961–1990 a 1991–2020.

4.2 Precipitation and Snow

The average annual precipitation in the Czech Republic for the period 1961–1990 is 674 mm, for the period 1981–2010 686 mm and for the period 1991–2020 684 mm. Annual precipitation totals show no significant trend. But increasing air temperature indicates a change in the type of precipitation in winter from snow to rain and thus a smaller water supply in snow cover, which will be available at the beginning of spring. In order to express the respective status and changes, the ratio of the seasonal amount of new snow (measured in cm) and the total precipitation in mm, *S/P*, was used in this contribution. The ratio of new snowfall to total precipitation (*S/P* ratio) is an important metric that is widely used to detect and monitor hydrologic responses to climate change over mountainous areas. Changes in the S/P ratio over time have proved to be reliable indicators of climatic warming (Dong a Yi 2022). Data from the cold part of the year in the Czech Republic (November–April) were evaluated. The results showed that the *S/P* ratio recorded a noticeable decrease in the period 1991–2020 compared to the period 1961–1990 (see Fig. 9, Tab. 1). On average, this was from 0.40 to 0.31, i.e. by 21% (Prochazka et al. 2022).

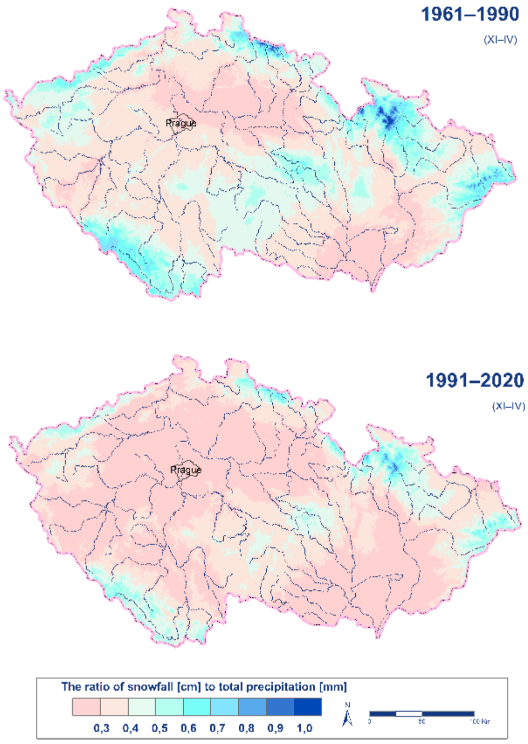

Fig. 9 The ratio of snowfall to total precipitation during the period 1961–1990 and 1991–2020.
Obr. 9 Poměr úhrnu nového sněhu a srážek v České republice za období 1961–1990 a 1991–2020.

Tab. 1 The ratio of new snowfall [cm] to total precipitation [mm] during the period 1961–1990 and 1991–2020.
Tab. 1 Poměr úhrnu nového sněhu [cm] a srážek [mm] v České republice za období 1961–1990 a 1991–2020.

		The ratio of new snowfall [cm] to total precip. [mm]	
Elevation (m a. s. l.)	**Area of Czechia (%)**	**1961–1990**	**1991–2020**
≤ 250	14	0.27	0.20
251–500	52	0.36	0.28
501–750	28	0.47	0.39
751–1000	5	0.63	0.52
≥ 1001	1	0.79	0.65

The increase in air temperature and the decrease in the *S/P* ratio make it likely that there will be a gradual decrease in the total amount of new snow. On Fig. 10 is the apparent decrease in the average annual total of new snow for each normal period. The year-round decrease between the periods 1961–1990 and 1991–2020 is 40 cm.

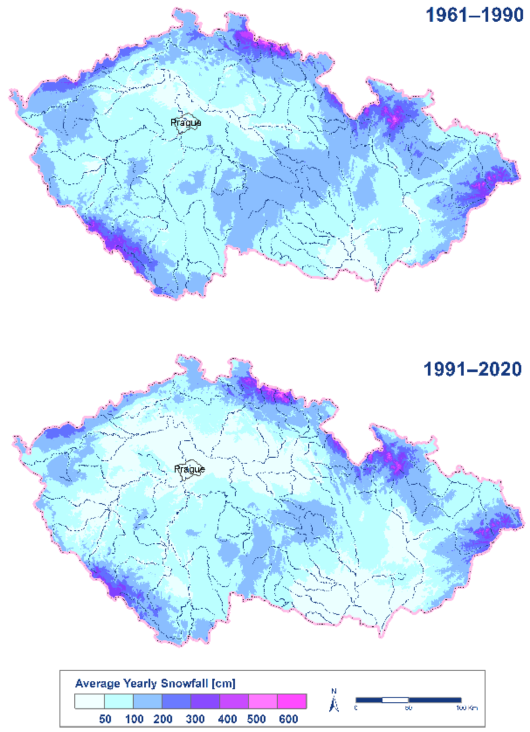

Fig. 10 30-Year Snowfall Normals in the Czech Republic 1961–1990 and 1991–2020.
Obr. 10 Normály úhrnu nového sněhu v České republice za období 1961–1990 a 1991–2020.

The following graph (see Fig. 11) shows the course of the maximum annual depth of snow at four selected mountain stations in the Czech Republic for the period 1961–2022. Linear trends show decreases in snow depth for all stations in Czechia.

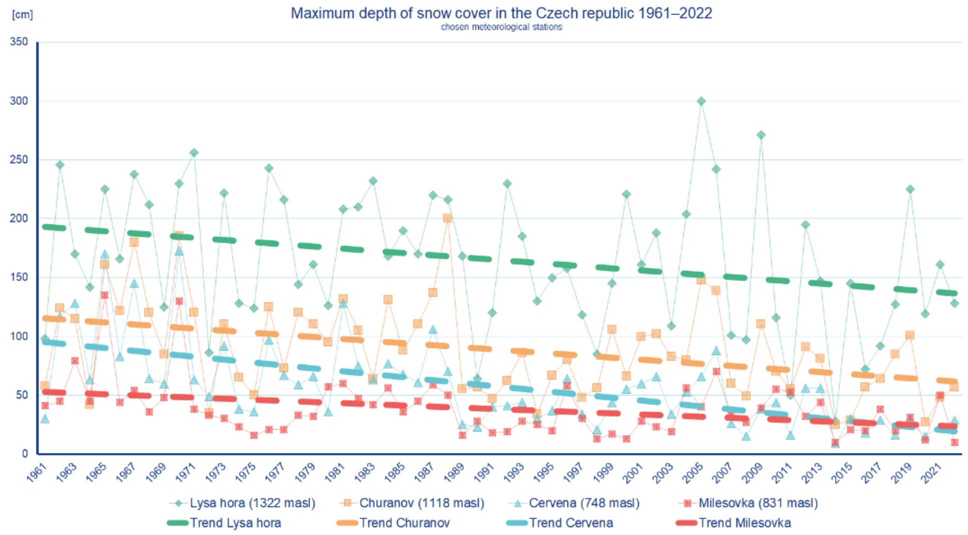

Fig. 11 Maximum depth of snow cover in the Czech Republic 1961–2022 (4 chosen stations).
Obr. 11 Maximální výška sněhové pokrývky na 4 vybraných stanicích v ČR (1961–2022).

The number of days with snow cover, i.e. days in which snow cover of at least 1 cm was recorded, has also been demonstrably decreasing. In the period 1961–1990, an average of 70 days with snow cover were recorded on the territory of the Czech Republic, during the period of years it was only 54 days on average per year (Fig. 12).

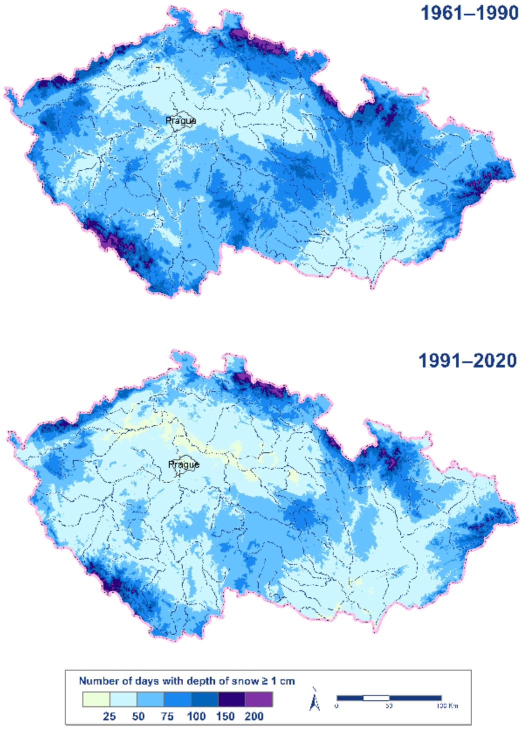

Fig. 12 Number of days with depth of snow ≥ 1 cm during the period 1961–1990 and 1991–2020.
Obr. 12 Počet dnů s celkovou výškou sněhové pokrývky ≥ za období 1961–1990 a 1991–2020.

5. Future - climate projection

5.1 Climate change scenario

The base of the climate change scenario in the Czech Republic is formed by the outputs of the regional climate model ALADIN-CLIMATE/CZ at a resolution of 2.3 km (Brozkova et al. 2019; ALADIN 2023). The climate scenario estimates were prepared on the basis of the calculation of the model ALADIN-CLIMATE/CZ by the Bias correction method (Räty et al. 2014). The model calculation is prepared for the period 1990–2014 (25 years) in the historical calculation mode and for the period 2021–2100 under the scenario SSP5-8.5 (IPCC 2021). The data for the following GIS analyses are outputs from the Project SS02030040 PERUN - Prediction, evaluation and research of the sensitivity of selected systems, impact of drought and climate change in the Czech Republic (PERUN 2023). Scenario SSP5-8.5 was chosen as the primary within the project solution and data are already available for it.

5.2 Results

Table 2, Figures 13 and 14 show that according to the scenario of very high greenhouse gas emissions SSP5-8.5, the trend of rising air temperatures will continue in the Czech Republic. Compared to the current climate, by 2040 it will warm by 1.3 °C in the winter months. The annual average air temperature will increase by 1.1 °C. By 2100 the average annual air temperature will increase by 4.6 °C compared to the current climate. Minimal annual temperature will increase by 4.6 °C, in winter season by 4.8 °C.

Tab. 2 Average annual, maximal and minimal temperature 1991–2100 (2021–2100 according to the scenario of very high greenhouse gas emissions SSP5-8.5)
Tab. 2 Průměrná roční, maximální a minimální teplota vzduchu za období 1991–2100 (2021–2100 dle scénáře SSP5-8.5)

	Annual			**Winter season**		
Period	**Tavg (°C)**	**Tmax (°C)**	**Tmin (°C)**	**Tavg (°C)**	**Tmax (°C)**	**Tmin (°C)**
1991–2020	8,3	12,9	3,8	−1,0	2,2	−3,9
2021–2040	9,4	14,2	4,9	0,3	3,5	−2,7
2041–2060	9,7	14,5	5,3	0,1	3,1	−2,8
2061–2080	11,1	15,9	6,6	1,7	4,9	−1,2
2081–2100	12,9	17,8	8,4	3,9	7,2	0,9

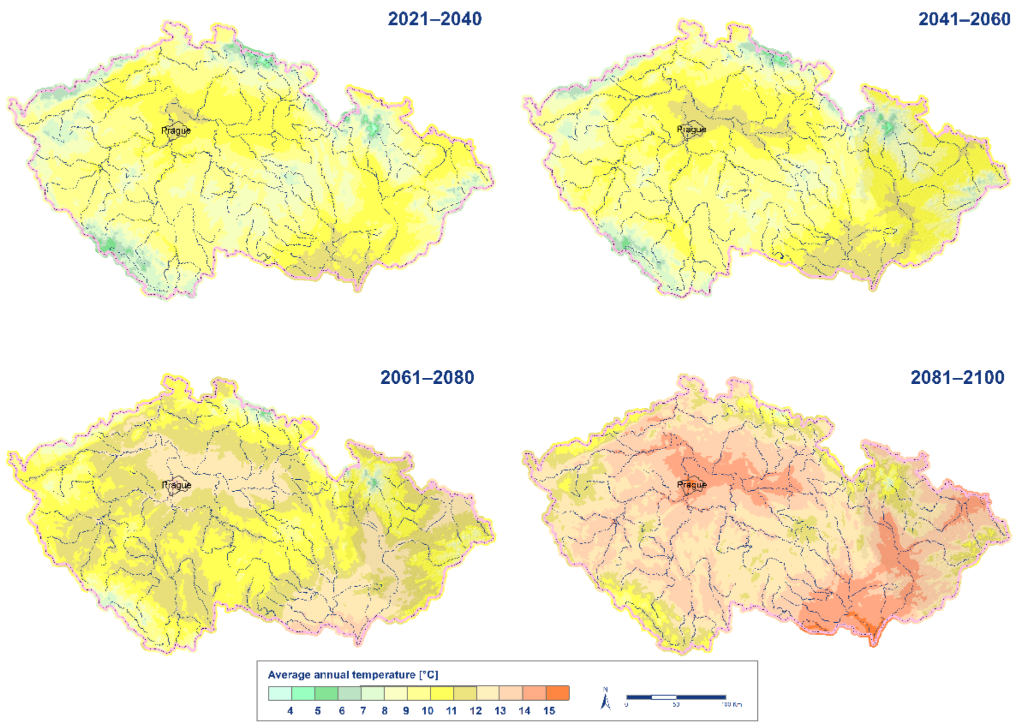

Fig. 13 Average annual temperature in the Czech Republic 2021–2100 (BIAS correction).
Obr. 13 Průměrná roční teplota vzduchu v České republice za období 2021–2100 (BIAS korekce).

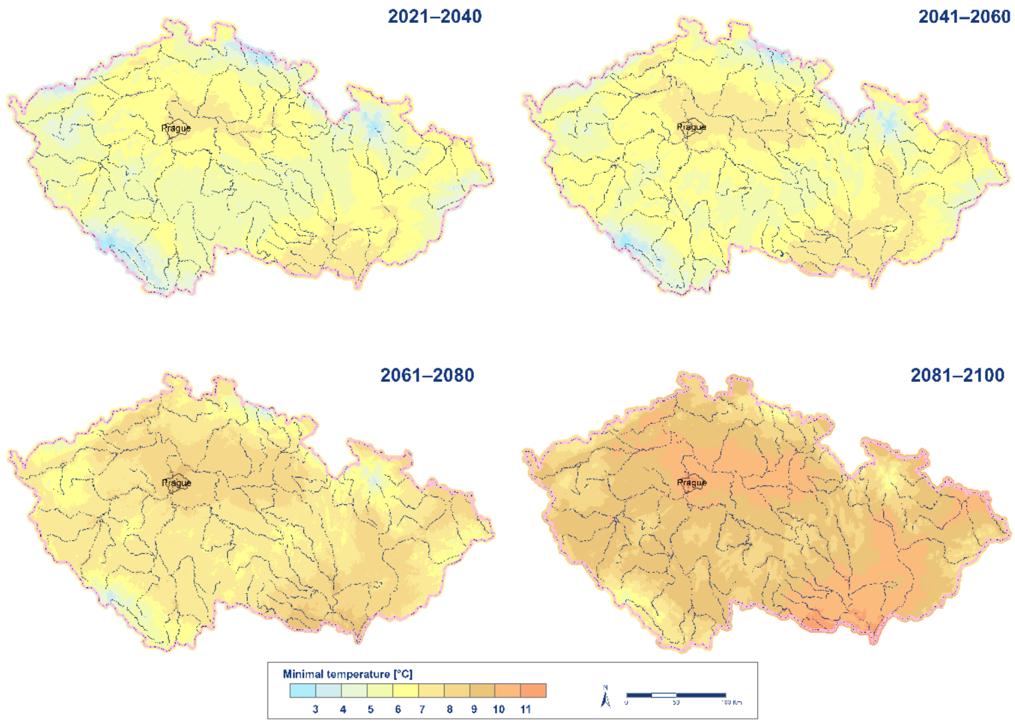

Fig. 14 Minimal temperature in the Czech Republic 2021–2100 (BIAS correction).
Obr. 14 Minimální teplota vzduchu v České republice za období 2021–2100 (BIAS korekce).

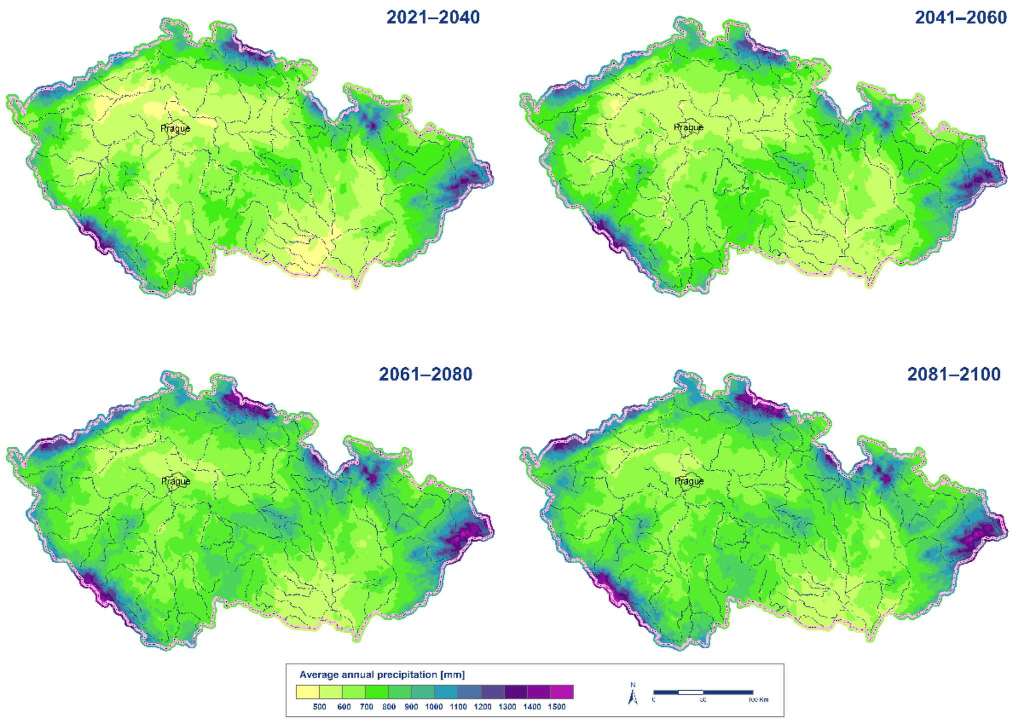

Fig. 15 Average annual precipitation in the Czech Republic 2021–2100 (BIAS correction).
Obr. 15 Průměrný roční úhrn srážek v České republice za období 2021–2100 (BIAS korekce).

6. Conclusion

Extension of the network contribute to better quality data interpolation, which is used in the hydrological forecasting service and, of course, for the calculation of snow cover water reserves for selected basins and water reservoirs. In general, especially in the last twenty years, the total volume of water storage in snow cover has been decreasing. Since 1980, four of the five worst winter seasons have been recorded in the last 20 years (2013–2014, 2019–2020, 2015–2016 and 2006–2007). On the other hand, three snowrich winters have also occurred in this period (2005–2006, 2009–2010 and 2004–2005). Moreover, the 2005–2006 winter season, with its 84 bil. m^3 of total volume, was the richest volume ever since 1980. Nevertheless, the trend is clear - fewer days with snow cover, decreasing snow depth maximum and increasing thaws during the whole winter season, even in the highest parts of the mountains (see Fig. 6). Among the main manifestations of climate change in the Czech Republic by 2100 based on scenario SSP5-8.5 is increasing air temperature in all seasons. The above mentioned outcomes of the climate change scenario also outline that precipitation totals will not decrease, rather they will increase slightly. However, what will change in relation to the rising air temperature is the change in the state and further the seasonal and temporal distribution of precipitation. It can be assumed that despite the fact that the amount of precipitation will be equal or higher, the share of precipitation in the form of snow will be lower and thus the ability to create and store snow cover will be decreased. This can negatively affect the water reserves in the snow, the soil moisture at the beginning of the growing season, as well as the amount of surface and subsurface water at the beginning of spring. Thanks to higher air temperatures, faster and greater evaporation of water from the landscape can also be assumed. According to the very high greenhouse gas emission scenario SSP5-8.5, the trend of rising air temperature will continue. By the end of the century, the average annual air temperature will increase by 4.6 °C compared to the current climate. Annual precipitation totals in the Czech Republic have a statistically insignificant trend. According to the scenario SSP5-8.5, we observe an increase by 2100 in precipitation totals in all seasons and an increase of 14% in the annual average (see Fig. 15). Given the above mentioned trend of air temperature, it can be assumed that the nature of precipitation will change.

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References

BROZKOVA, R., BUCANEK, A., MASEK, J. SMOLIKOVA, P. TROJAKOVA, A., 2019. New high-resolution operational configuration of the ALADIN model. *Meteorological Bulletin*, **72**, 5, 129–139, ISSN 0026-1173.

DONG, W., YI, M., 2022. Seasonality and variability of snowfall to total precipitation ratio over high mountain Asia simulated by the GFDL high-resolution AM4. *Journal of Climate*, **35**(17), 5573–5589. https://doi.org/10.1175/JCLI-D-22-0026.1

EU measures against climate change | News | European Parliament, 2023. Dostupné z: https://www.europarl.europa.eu/news/en/head-lines/society/20180703STO07129/eu-measures-against-climate-change

Flood warning and forecaster service of the CHMI – information about water storage in snow cover, 2023. Dostupné z: https://www.chmi.cz/files/portal/docs/poboc/CB/snih/aktual.htm

HAMR – a systematic tool to resolve the impacts of drought in the Czech Republic (including snow monitoring), 2023. Dostupné z: https://hamr.chmi.cz/hamr-JS/zasoba_snih.html

IPCC, 2021. Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 3−32. https://doi.org/10.1017/9781009157896.001

IPCC, 2022. Climate Change 2022 - Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press. Cambridge University Press, Cambridge, UK and New York, NY, USA, 3056 pp., https://doi.org/10.1017/9781009325844

NOLIN, A. W., SPROLES, E. A., RUPP, D. E., CRUMLEY, R. L., WEBB, M. J., PALOMAKI, R. T., MAR, E., 2021. New snow metrics for a warming world. *Hydrological Processes*, **35**(6), 1–13. https://doi.org/10.1002/hyp.14262

Ministry of the Environment of the Czech Republic, 2023.Strategy for Adaptation to Climate Change in the Czech Republic. Dostupné z: http://www.mzp.cz/C1257458002F0DC7/cz/zmena_klimatu_adaptacni_strategie/$FILE/OEOK-Adaptacni_strategie-20151029.pdf

PERUN - Prediction, evaluation and research of the sensitivity of selected systems, impact of drought and climate change in the Czech Republic, 2023. https://www.perun-klima.cz/

PROCHAZKA, J., LIPINA, P., SUSTKOVA, V., TESAR, M., 2022. Changes in the ratio of new snow and seasonal precipitation in mountain and foothill regions of the Czech Republic. Water Management in the Landscape 2022. Dostupné z: https://www.chmi.cz/files/portal/docs/reditel/SIS/nakladatelstvi/assets/sbornik-abstraktu-trebon_2022.pdf

RÄTY, O., RÄISÄNEN, J., YLHÄISI, J. S., 2014. Evaluation of delta change and bias correction methods for future daily precipitation: intermodel cross-validation using ENSEMBLES simulations. *Clim Dyn*, **42**, 2287—2303. https://doi.org/10.1007/s00382-014-2130-8

ALADIN, 2023. Dostupné z: https://www.umr-cnrm.fr/aladin/