Physical and isotopic characteristics of snowpack in NW Slovenia

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ABSTRACT: Snowpack is a reflection of different environmental factors, joining all three spheres: atmo-, hydro- and geosphere. Orographic diversity of Slovenia influences the climate and also snowpack characteristics in alpine part of Slovenia that differ of those in the other parts of the Alps. To improve our knowledge about characteristics of snowpack and to combine avalanche and snow hydrology research in Slovenia we started with more detail investigations in winter 2010/11. Physical characteristics of snowpack in combination with stable oxygen isotope analysis were determined at different locations (i. e. frost hollows, clearing, forest and slopes) for the first time in NW Slovenia. In the paper preliminary results of the on-going investigations on some snow characteristics (i. e. snow depth, snow temperature, SWE and isotopic composition of oxygen) obtained during three winter seasons from 2010 until 2013 are presented. All three winter seasons were close to the normal regarding the mean air temperatures with larger temperature anomalies in cold and windy February 2012. Due to dry conditions in the beginning of 2012 was snow cover very thin and dry, snowpack metamorphism slow and wind created snowdrifts and slabs. Snow was melted fast during very mild March 2012. On the contrary, snow cover was deep and wet snowpack metamorphism influenced the snowpack characteristics in winter 2012/13. Altogether 32 snow pits were investigated. Observed changes in profiles show high variability during particular winter, in space and also in particular snow profile.

KEYWORDS: Snowpack characteristics, oxygen isotopes, alpine watershed, NW Slovenia

1 INTRODUCTION

The characteristics of snow, such as snow depth, layer thickness, density, temperature, hardness, water content, grain size and shape are important in snow and avalanche research (Pavšek, 2002). Considerable data on relating these characteristics to physical processes in snow cover is collected and is practically used. The snow hydrology is mainly focused on snow water equivalent (SWE) determination, where spatial and temporal variability in SWE is recognised as an important factor for hydrological balance estimation (Holko et al., 2009).

Recently, the stable isotopes of water are used as a tool to trace the water flow and to estimate the residence time of water in a catchment. Snow melt is one of the water sources with specific isotopic content. However, the isotopic content of snow melt differs from those of the snowfalls (Sokratov and Golubev, 2009, Lechler and Niemi, 2012; Dietermann and Weiler, 2013). Moreover, the construction of the isotopic profile is determined by mass transfer in the pore space of snow and mass exchange between the snow cover and the atmosphere.

The spatial and temporal variability of the snow cover and the snow melt is especially complicated in the regions with complex orography and high spatial variability in snow accumulation and environmental conditions, such as Slovenian alpine watersheds. Detailed snow structure investigations are mainly performed in heavy snow regions as the part of avalanche research, while otherwise snow stratigraphy and physical processes in snow cover are not focused on. The processes of isotopic content evolution are closely linked to the same physical processes in snow as those, responsible for snow avalanches formation. However, for regions with highly variable snow cover as in Slovenia, not many details on snow cover evolution

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(including the isotopic content change) are known.

Snow cover in Slovenia is a regular but in space and time highly variable phenomenon. Despite the negative consequences observed in winters with a lot of snow (up to 7 m) and severe droughts as a consequence of lack of snow (e. g. winter 2011/12), the snow patches behaviour in terms of varying accumulation and melt due to complex orography is poorly understood. In addition, despite more than 30 years of application of isotopes in hydrological investigations in Slovenia environmental isotopes were only rarely used in mountain areas in the past and were not used in snowpack investigations. That is why it is studied recently into more detail, and should improve not just water balance, but also snow physics understanding.

2 MATERIALS AND METHODS

Determination of physical characteristics of snow in combination with sampling of snow for stable oxygen isotope analysis was performed for the first time in NW Slovenia during winter 2010/11 (Vreča et al., 2011, 2012). Five snow pits were investigated in January, February and April 2011 at two alpine plateaus in Julian Alps (i.e. Komna and Pokljuka) at altitudes of about 1300 and 1600 m a. s. l. Selected locations are at different altitudes, have different climatic conditions and are situated in the recharge areas of two important Slovene karstic aquifers. Sampling was performed at Komna (1 snow pit) in a frost hollow while other 4 snow pits were investigated at Pokljuka at two locations with different canopy structures (i. e. clearing and forest stand). Snowpack was characterised according to international UNESCO-IHP snow classification (Fierz et al., 2009). Samples for determination of stable oxygen isotopic composition of snow were collected at different intervals from the surface to the bottom of snow profile. For comparison of different sampling techniques we performed sampling at thicker (6 to 33 cm) and thinner (2 to 3 cm) intervals.

We continued with snow investigations in winter 2011/12 but sampling was limited due to low precipitation amount and other meteorological conditions. Sampling was performed again in Julian Alps at Komna and Pokljuka in January, February and March 2012. In addition, snow sampling was performed in March 2012 at Kredarica, the highest meteorological station in Slovenia (2514 m a. s. l.). For comparison with Julian Alps investigations were expanded in winter 2011/12 also to Karavanke (frost hollow Sklede), N Slovenia. All together seven snow pits were investigated. Physical characteristics were determined only partly and sampling for isotope analyses was performed only at selected depths.

Finally, in winter 2012/13 sampling was expanded to more locations and twenty snow pits were investigated in Julian Alps (Komna, Pokljuka, Kredarica, Vršič) and in Karavanke (Kofce, Kepa) where basic snowpack characteristics were determined and samples for isotope analyses were collected at selected depths (Figure 1). Sampling started in December 2012 and was performed due to long snow cover also during the spring until May 2013.

Figure 1. Snow sampling at Kofce in March 2013 (photo courtesy of Miha Pavšek)

The oxygen stable isotopic composition ($\delta^{18}O$) in collected samples is determined on isotope ratio mass spectrometer (i.e. IsoPrime with MultiFlow-Bio module or on Varian MAT 250) at the Jožef Stefan Institute by means of water-CO_2 equilibration technique. All measurements are carried out against laboratory standards that are periodically calibrated against international standards recommended by the IAEA. The conventional δ notation is used and values are reported as per mil (‰) deviations from the V-SMOW standard. Measurement precision is better than ±0.1‰ for $\delta^{18}O$. Due to high and long snow cover in winter 2012/13 are analyses of samples collected from 8 snow pits still in progress.

3 RESULTS AND DISCUSSION

In this paper we present preliminary results of the on-going investigations and will focus only on snow depth, snow temperature measured at different snow depths, SWE and isotopic composition of oxygen. In winter 2010/2011 varied snow depth of investigated pits between 19 and 118 cm, snow temperature was close to 0°C and SWE was between 92 and 239 mm. Detail profiles showed considerable changes in isotopic composition through the profiles (up to 10 ‰) and also a difference between the profiles on clearing and in the forest (Vreča et al., 2013). The differences are related to different climate conditions at clearing and in the forest. In profiles on clearing we observed irregular isotope profiles reflecting different precipitation events. Ice crust as a consequence of fast snow melt event preserved below prior isotopic composition of snow and above it reflected changing conditions during few days snow precipitation event (Vreča et al., 2012). In profiles in forest a monotonically decrease in $\delta^{18}O$ with depth and a change in isotopic composition was observed indicating a phase changes due to the influence of snow sublimation and vapour diffusion through the snow pack (Vreča et al., 2012). The isotopic composition of oxygen recorded in investigated snow pits ranged from -19.0 to -8.5‰.

Winter 2011/12 was considerably different than 2010/11. Largest temperature anomaly occurred in a very cold and windy February 2012 (Cegnar, 2012a) and a very mild March 2012 (Cegnar, 2012b) and snow rapidly melted. The average air temperatures at Kredarica were -12.6 and -2.7°C in February and March 2012, respectively, and differed considerably from long-term averages (-8.7 and -7.1°C for February and March 1961-1990). Winter 2011/12 was also very dry, snowpack metamorphism was slow and wind crated snowdrifts and slabs. Consequently the snow characteristics were considerably different and only few snow pits were analysed. Snow depth of investigated pits in Julian Alps varied between 8.5 and 55 cm, snow temperature from -10°C to close to 0°C and SWE was between 23 and 177 mm. A deeper pit (200 cm) was investigated at Kredarica where temperature varied between -5 and -1°C. In Karavanke pits varied snow depth between 46 and 70 cm and temperature variations were between -2.7 and -0.4°C. SWE was not determined. Due to different climate conditions (Cegnar, 2012a, 2012b) and especially lower air temperatures in February 2012 much lower minimum values of isotopic composition of oxygen was observed than in 2010/11 and different changes in isotopic signal with snow depth were characteristic. In most profiles an increase in $\delta^{18}O$ to the bottom of the profile was observed while at Kredarica an irregular isotope profile with no evident trend was recorded. The isotopic composition of oxygen in investigated snow pits ranged from -25.4 to -7.5‰.

Results for winter 2012/13 are reported only for 12 of 20 investigated pits that were sampled until the end of February 2013 varied snow depth between 20 and 150 cm, snow temperature from -26°C to close to 0°C and SWE, which was not measured in all pits, between 56 and 420 mm. Isotopic composition of oxygen varied considerably and ranged from -29.0 to -9.1‰. The lowest isotope values were observed at Pokljuka in surface layer of profiles at clearing and forest stand investigated in December 2012 and are related to low air and snow temperatures. During the sampling period which stopped in May 2013 wet metamorphism influenced the snowpack characteristics considerably and numerous individual layers with varying properties were formed. All results will be inspected into more detail when we finish with isotope analyses and considering in evaluation of obtained data also parameters.

4 CONCLUSION

First results on physical characteristics of snow in combination with stable oxygen isotope analysis that were performed during last three winters in Slovenian Alps indicate relations between snow stratigraphy and climate variability, micro locations complexity, snow melting and alpine watersheds. Snowpack characteristics vary in space and time and depend mostly on air temperature, wind, relative humidity and precipitation (snow and rain) events. The rain events during warmer periods as well as additional load, a consequence of drifted snow and from the trees falling snow cause heterogeneity in snowpack (Fierz et al., 2009). During water percolation and subsequent refreezing solid ice layers or lenses are formed. Heterogeneities in snow profiles cause problems in representative snow sampling, blur the climate signals stored in snowpack, significantly impacts the SWE and snowpack stability on steep slopes. Therefore, investigations should be continued and widened in order to get long-term and thus more comparable and reliable results.

Further work will focus on evaluation of all obtained results and particularly on estimation of isotopic composition of snow melt water which contributes to groundwater recharge. It is known that snow metamorphism, and particularly seasonal sublimation can amount from 5 to 40% in continental interior causing also an increase in snowpack $\delta^{18}O$ values. Such shifts can lead also to underestimate of the contribution of winter season precipitation to the groundwater recharge (Lechler and Niemi, 2011).

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