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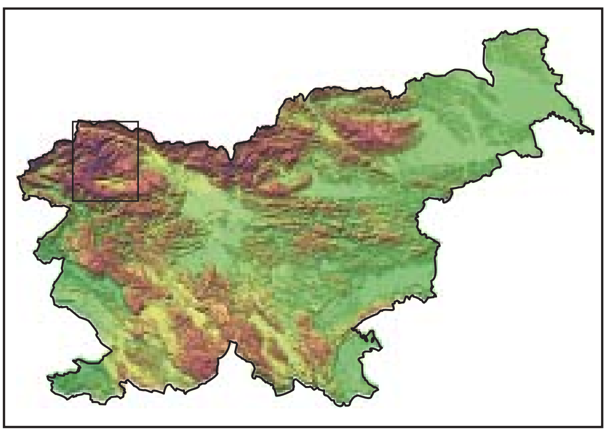
MEASURING WINTER PRECIPITATION WITH SNOW COVER WATER ACCUMULATION IN MOUNTAINOUS AREAS

VODNATOST SNEŽNE ODEJE KOT KAZALEC KOLIČINE PADAVIN V GORSKEM SVETU

Matej Ogrin

Deep snow cover, has due to several heavy snowfalls on Vojsko (1067 m), almost covered the meteorological station (photograph: Matej Ogrin).
Snežna odeja je zaradi obilnih sneženj konec februarja in v začetku marca 2004 skoraj povsem prekrila meteorološko postajo na Vojskem (1067 m) (fotografija: Matej Ogrin).



Measuring winter precipitation with snow cover water accumulation in mountainous areas

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ABSTRACT: Precipitation variability in mountainous regions is much bigger, than it is possible to conclude from data of a few meteorological stations in this area. There are big differences between windy sides, lee sides and the valleys. During winter, when snow precipitation prevails, snow accumulates on ground as snow cover, which enables us to see the variability of precipitation on small scale. Results of researching snow cover give us more precise data and show us new facts about precipitation variability in Julian Alps and their surroundings and in Karavanke.

KEY WORDS: water accumulation of snow cover, snow cover, precipitation, relief, local climate, Julian Alps, precipitation variability.

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1 Introduction

Snow cover is one of the most remarkable phenomena in moderate altitudes during the winter time. During the snowfall, landscape turns white, nature falls asleep.

Snow cover is not rare in the lowlands of the central Europe. However, usually it does not last very long. Even in cold winters there are periods without snow cover. At higher elevations, such as mountains, plateaus and high alpine valleys, snow cover lies longer and many times continuously for several months. The reasons for this are lower air temperatures and heavier precipitation. During this period, snow cover accumulates from one snowfall to another and snow cover is usually deepest at the end of the accumulative season, which is in early or middle spring. In Slovenia snow cover is, especially due to intensive precipitation, deepest in the Julian Alps and the sub-alpine areas surrounding them.

High precipitation in this area occurs when a humid, south-western wind blows. In winter and early spring most of it falls as snow. Annual precipitation in the Julian Alps and their sub-alpine surroundings is between 2000–4000 mm. Although the annual precipitation decreases towards the east, even the most eastern part of the Slovenian Alps (Pohorje), gets around 1500 mm of precipitation per year.

2 Starting point

As snow accumulates from one snowfall to another, it is at a certain depth deep enough to keep the water which runs from the surface of snow cover towards the floor within it. Water entering the snow cover could be a result of the thawing snow which occurs due to high temperature, or it could be rainwater, which enters snow cover during the rain.

If snow cover is cold enough (the temperatures of the inner layers must be below the freezing point), water penetrating through it freezes. Otherwise it stays within snow cover in a liquid state and we say that the snow is wet.

The colder a winter is, and the less thaws there are, the smaller the depth of snow which is still sufficient to keep the thawing water inside can be. Snow also evaporates but the amount of water which evaporates from snow is very small. It is negligible especially in wintertime, when temperatures are low (Vrhovec 2000). The amount of water, accumulated in snow cover is water accumulation of snow cover (WASC).

During its time being snow cover changes through many processes. Thawing, sinking and transformation are the most important ones. The depth of snow cover also changes. It changes not only when it snows but also when no precipitation occurs. Snow sinks gradually in days after heavy snowfall, even more than 20 cm per day. So it can be seen that the depth of snow cover changes constantly and the data of snow cover depth are useful only when they are simultaneously collected. As mentioned above, the water amount within snow cover does not change if snow cover is deep enough. So when we want to describe precipitation, the data about the amount of water in snow cover do not change daily and are therefore much more useful than the data about depth of snow.

When there is strong wind, the rain gauges in mountains can be an unreliable source of precipitation data. Strong wind causes eddies in their surroundings and snow is blown away. Consequently, the data of snow precipitation are much underestimated. Besides, at the windy sides of the slopes, wind carries the falling snow horizontally, sometimes, close to the ridges, even uphill.

According to the fact that the rain gauges of the national observing service are rather scarcely located and that they are especially in mountainous areas insufficient and during snowfall also useless, our task was to get more reliable data of precipitation. Therefore, we measured the WASC in the western part of the Slovenian Alps in winter months.

Continuous and systematical monitoring of WASC is not developed in Slovenia. Some individual researches were made by Vrhovec and Sluga (Sluga 2000; Vrhovec 2000). They were made in the area of the Julian Alps on the Komna plateau and in the Triglav Lakes Valley. Tomaž Vrhovec also lead terrain classes for students of meteorology, where they met this method of measuring WASC.

We made some researches in the area of the Julian Alps, Karavanke Mountains and Trnovski gozd dinaric plateau during the winter 2003–2004. This winter was due to often heavy snowfall almost ideal for such researching.

3 Weather conditions in the winter 2003–2004

Permanent snow cover formed in the Slovenian Alps, at the altitude of above 1000 m, on 21st December. Before that date it had snowed several times, but due to high temperatures snow did not stay permanently. The exception was snow at the elevations of above 2000 metres and in shady sides. Since that date snow cover stayed in mountains until late spring.

In the heavy snowfall at end of December (29th–31st December) 1–2 metres of snow fell in the Julian Alps. In the Karavanke Mountains and the Kamnik and Savinja Alps up to 70 cm of snow fell, further east, on the eastern Pohorje, only about 10 cm of snow fell.

Next heavy snowfall appeared from 17th to 19th January, so that on 19th January the depth of snow cover measured at the monitoring stations in the western Slovenia was: Kredarica (2515 m) 250 cm, Vogel (1510 m) 210 cm, Vojsko (1067 m) 95 cm and Rateče (865 m) 50 cm.

Figure 1: Areas of research.

Figure 2: The Ravne alp on 4th January 2004 (photograph: Matej Ogrin).

Figure 3: The Ravne alp on 27th March 2004 (photograph: Matej Ogrin).

Until 19th February mostly dry and periodically warm and cold weather with very little precipitation prevailed in the mountains. Therefore, the deep snow cover transformed, sunk and on sunny slopes it also thawed. On the slopes with slightly southern exposition, in flat areas and shady sides the snow cover was deep enough to retain the thawing water within the inner layers. In clear weather, with dry air and temperatures above 0 °C, snow cover evaporates. The used latent heat from snow cover intensely decreases the temperature of snow cover surface, which is why the loss of water from snow cover as a result of evaporation is almost negligible.

At the end of this mostly dry period there were still around 120–180 cm of snow left in the Julian Alps at the altitude of 1500 m, and at the altitude of 2500 m there were around 270 cm of snow left. In the Karavanke Mountains and the Kamnik and Savinja Alps the depth of snow cover at the elevations of about 1500 m was only 40–70 cm.

The period from 21st to 23rd February was the only time since 21st December 2003 that it rained during precipitation also at the altitude of above 1500 m. At that time there were 180 cm of snow on Vogel and on 21st and 22nd February 87 mm of rain and snow fell. According to the depth of snow we presume that most of the rain water and thawing water from this period retained in the snow cover. The highest temperatures in this period were from 0–4 °C.

On 23rd February changeable weather with frequently heavy snowfall began. From that day, until 8th March, the whole of Slovenia, except the sea side region called Primorska, got a lot of snow. In the mountains of western Slovenia from 1–2 metres of snow fell, and on 29th February the snow cover on Vojsko was 215 cm and in Rateče 125 cm deep. At the elevations of above 1000 m, the deepest snow cover formed a week later, after the snowing on 8th March. The next day, 320 cm of snow were measured on Vogel and on Kredarica 430 cm. Since that date the depth of snow cover did not increase, the reason for this being the sinking of snow. However, until 7th April, when WASC in the alpine and also in the sub-alpine areas started to decrease, two more big snowfalls appeared. The first was from 22nd to 26th March.

In general, the mean air temperatures in January, February and March, which almost corresponds to the time of accumulation of snow cover, were according to data of Slovenian environmental agency, very close to the average. In Rateče (865 m), the mean air temperature for the period January–March 2004 was –2.2 °C, which is only 0.1 °C colder than the average of the period 1961–1990. On Kredarica (2515 m), the mean air temperature for the period January–March 2004 was –7.9 °C, which is normal (0.1 °C above the average) for the period 1961–1990. On Kredarica February and March were warmer than the average (+1,7 °C, and +0.7 °C) and January was 2.1 °C colder than the average.

In Rateče March was normal (0.2 °C below average), January was 0.7 °C colder and February 0.8 °C warmer than the average. It can be seen from the temperatures above that the temperatures in the mountains were rather normal, except in January and February in high alpine areas.

4 Measurements and results

The observations and measurements of snow cover were made from 13th March to 4th April 2004. In this period the snow cover on most of the observation spots was deep enough, so that the thawing water stayed within the inner layers of snow.

The locations where the measurements were taken on the Trnovski gozd dinaric plateau, on 13th March, the western Karavanke Mountains and the Julian Alps on both sides of the Upper Sava Valley (the Pod Špik cirque, 1410 m), on 16th and 17th March, the Lower Bohinj mountains, on 27th and 28th March, the Fužina plateau, on 3rd and 4th April 2004.

The method of measuring was a method of taking samples from each layer of snow. First it was necessary to identify all the layers. The samples were taken with two different cylinders without the top and the bottom (like a tube) with a volume 0.173 and 0.385 litres. A hole was dug into the snow to reach the floor, so that the total snow profile was seen. We took the sample from each layer and weighed it. On the basis of the weight and the volume the density of the snow sample ($\rho = m/V$) was obtained. For each layer it can be presumed that the density within this layer does not change. However, if the layer was big enough and if it was likely that the density from the upper part of one layer differed from the lower part, two samples of this layer were taken. This means that actually a new layer was »made«. Thus we cannot always conclude the number of snowfalls from the number of layers. This makes sense, because during a long snowfall (2 and more days), when, for instance, the Genova cyclone passes Slovenia in the warm sector, when the south-western winds prevail, snow contains more water than later, after a cold front passes the mountains and the temperatures fall. Since the cold air contains less moisture than the warm, the snow is lighter and its density is much smaller.

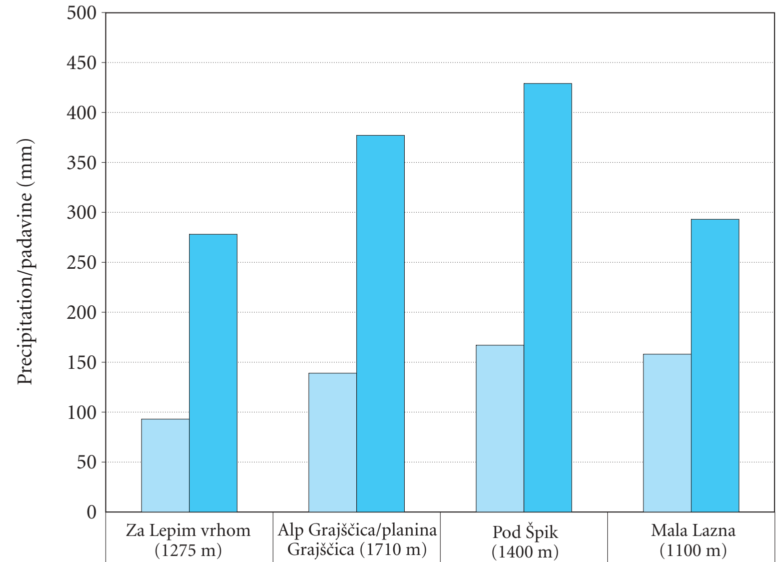
After the samples had been taken from each layer and the density had been calculated (with measuring the height of each layer) the mass of the virtual column of snow was calculated:

$$m = \rho \cdot V \qquad (1)$$

where:
m … mass (kg)
ρ … density (kg/m^3)
V … volume (m^3)

For each layer we can say that the mass of snow (kg) is equal to mass of water (kg) if we neglect the mass of air in snow. Because the density of water is 1 kg/dm^3 and also 1 dm^3 = 1 l, for each layer we can say that 1 kg of snow per square meter is equal to 1 l of water per square meter (l/m^2). If we spread 1 l of water in a box with surface 1 m^2, we obtain height of 1 mm. This means, that 1 l of precipitation per square meter is equal to a layer of rainwater with height of 1 mm.

Figure 4: Snow profile, where all layers of snow cover can be identified. The avalanche shovel is 20 cm wide (photograph: Miha Pavšek).



	Za Lepim vrhom (1275 m)	Alp Grajščica/planina Grajščica (1710 m)	Pod Špik (1400 m)	Mala Lazna (1100 m)
After/po 23. 2. 2004	93	139	167	158
Winter/zima 2003/2004	278	377	429	293

Figure 5: Water accumulation between 14th to 17th March 2004 in the western Karavanke Mountains (Za Lepim vrhom, 1275 m, alp Grajščica, 1710 m), on the cirque Pod Špik (the Julian Alps, 1400 m) and in Mala Lazna on the Trnovski gozd dinaric plateau (1100 m). The black columns show the total water accumulation and the white ones show water accumulation after 23rd February 2004. Measurements at location Za Lepim vrhom were taken at hunting hut.

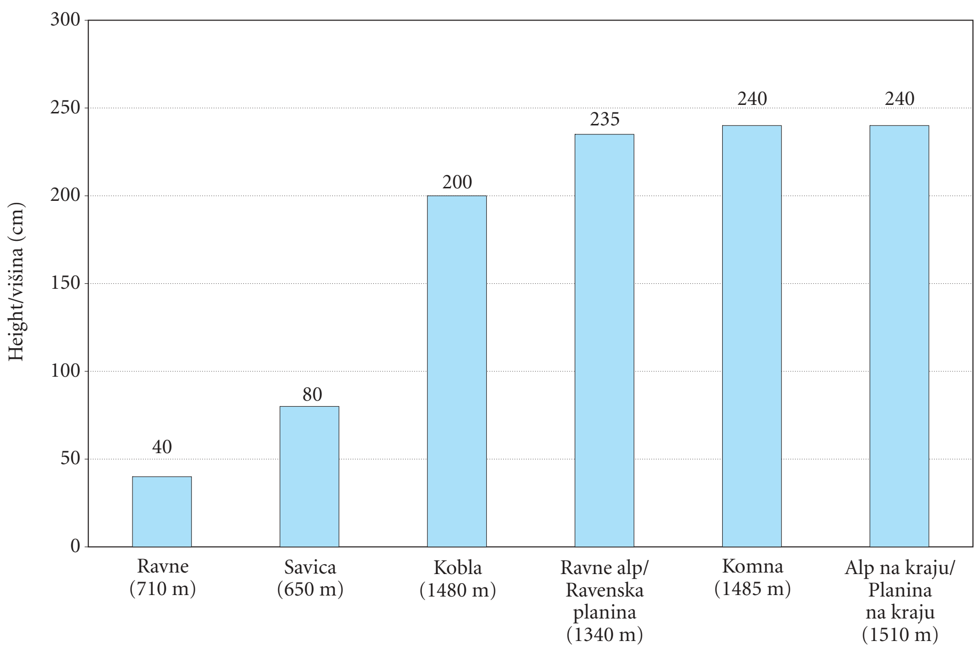


Figure 6: Snow depth on 27th and 28th March 2004.

Altogether 9 profiles were dug on different spots. In addition, the depth of snow cover was measured with a snow probe on many spots. If we know the depth of snow cover and if we presume that the average density from a snow profile, which was dug in the surroundings, is the same, we can also estimate the differences in precipitation in smaller areas.

The monitoring of data about the depth of snow and water accumulation in snow cover enables us also to see the differences in precipitation in a mountainous area where a monitoring network is rare and insufficient. However the sampling spot must be selected correctly and must fulfil the following conditions. The sampling spot must be:
- protected from wind so that no erosion or accumulation effects can be detected (Sluga 2000),
- on a flat terrain;
- open from forest or relief topography;
- protected from avalanche deposition (Sluga 2000).

In the Slovenian Alps many alpine pastures and meadows lie on the elevations of between 1000 and 2000 m and many of these pastures are flat enough, without forest and protected from wind. So these pastures can be used as a good measuring spot. The following pastures were used: Alp Blato, Alp V lazu, Ravne Alp and Alp Grajščica.

The method of comparing precipitation was in winter 2003–2004 used for the snowfall which accumulated from 23rd February. Frequent snowfall at low temperatures at the end of winter and the start of spring made it easier to measure the differences. Before the snowing started, on 21st February, rain with desert sand had fallen and had coloured the old snow yellow-brown, so it was not hard to determine all the layers after this date.

Figure 5 shows different water accumulation of snow cover in the southern sub-alpine area of the Julian Alps (the Trnovski gozd dinaric plateau), in the northern part of the Julian Alps (Pod Špikom) and in the western Karavanke Mountains (Za lepim vrhom, Alp Grajščica), which are located a little more northwards than the Julian Alps.

After 23rd February the WASC is greatest on the spot Pod Špik (167 mm) and in Mala Lazna (158 mm), then come Alp Grajščica (139 mm) and the sampling spot near the hunting hut under Lepi vrh (93 mm).

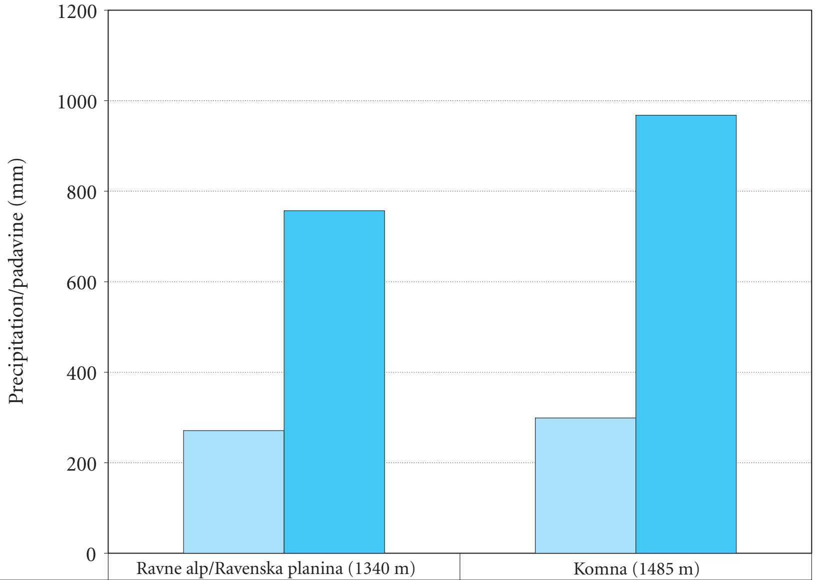
These data indicate that even at small distances (all sampling spots, except Mala Lazna, are within a distance of 7 km), the intensity of precipitation changes noticeably.

The differences could be explained with a trend of decreasing precipitation from the south-western parts of the Julian Alps towards the interior and the northern parts. The most intense precipitation in the Slovenian Alpine areas falls when the south-western winds prevail. Consequently, the warm and humid air ascents at ridges and condensation begins. Frontal precipitation is reinforced by orographic ascenting. Often snowfall begins much earlier before the cold front passes a mountain area.

The decrease of precipitation is not equable, the reason for this being variable mountainous topography with deep valleys and high ridges following each other. After each ridge the air descends and consequently precipitation decreases as well. Later, when the air flows and rises over the next ridge, it grows again. However, the increase is usually smaller than at the ridge before.

This is also the reason, why the WASC decreases from cirque Pod Špik towards Karavanke, and there, when the air climbs the Karavanke Mountains, it rises again.

If we look at the total WASC, we see that Mala Lazna received less precipitation than the Alp Grajščica. However, we must be cautious because the sampling spot Mala Lazna lies at only 1100 m and we cannot say that no melting water ran off during the thaws before 23rd February. At the end of March 2004 the measures were taken also in the Lower Bohinj Mountains.



	Ravne alp/Ravenska planina (1340 m)	Komna (1485 m)
After/po 23. 2. 2004	271	299
Winter/zima 2003/2004	757	968

Figure 7: Comparison of WASC between the Ravne alp (1340 m) and Komna (1485 m).

Figure 6 shows the distribution of snow cover on different spots in Bohinj. It is important to note that the measurements were taken in a 30 hours lasting period. This is important because on the days before the measuring, 70 cm of snow fell. During the measuring which took place in the morning on 27th March, the snow cover sunk for 8 cm. Since the measurements on the Komna and the Alp Pri kraju were taken on 28th March, it can be presumed that at the time when the snow depth on the Ravne alp was measured, the snow cover on the Komna and the Alp Pri kraju was at least 15 cm higher.

Although in general the depth of snow increases with elevation, it is not always the case. On Ravne (710 m) the snow depth was smaller than at Savica (650 m), although Savica lies at a lower elevation. In this case

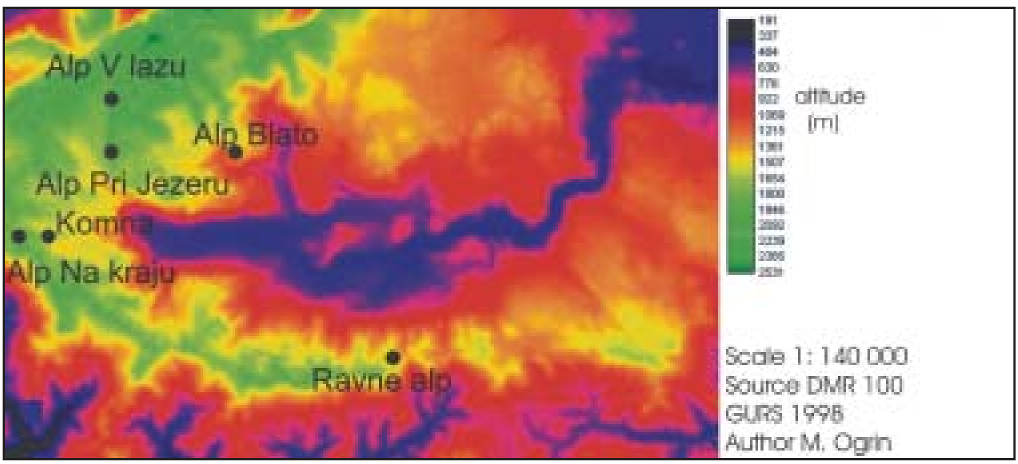


Figure 8: Location of measuring spots in Bohinj.

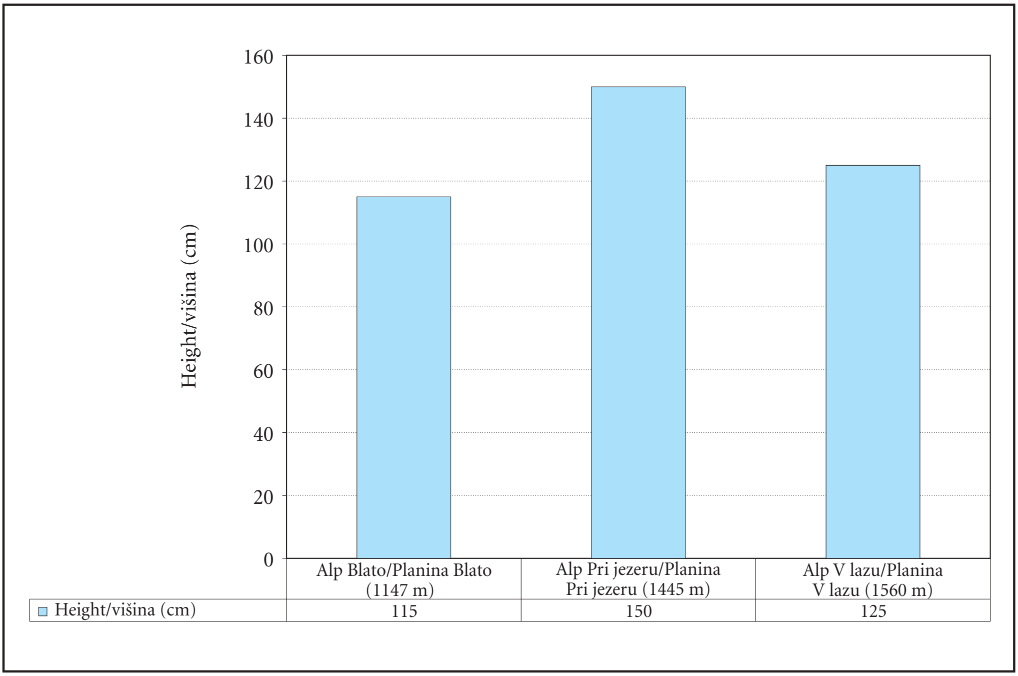


Figure 9: Depth of snow cover on 3rd and 4th April 2004 on the measuring spots on the Fužina plateau.

the position of a place is more important. Ravne is a village on a small flat plateau above the Bohinj basin, usually above the temperature inversion, with very small northern exposition. The duration of solar radiation is longer than in Ukanc, where Savica is located. Ukanc is a place at the end of the Bohinj basin, hidden under the walls of the Komna plateau, with very high southern horizon, which is formed by the Lower Bohinj Mountains (1500–2000 m). The temperature inversion in Ukanc is strong, lasts long and the solar radiation is very small. In this case the morphology of a place and especially its surroundings are much more important than its elevation.

Figure 7 confirms that the Lower Bohinj Mountains get a lot of precipitation during the whole year and this is also one of the most humid areas in Slovenia. The Ravne alp lies on the eastern part of the Lower Bohinj Mountains, the Komna plateau lies in the western part of this mountain chain.

The amount of precipitation that accumulated from 21st December to 27th March on the Ravne alp was 757 mm and on the Komna 968 mm, and since 23rd February, 271 mm on the Ravne alp and 299 mm on the Komna. In both cases it can be seen that the Ravne alp got less precipitation than the Komna. This indcates that precipitation decreases along the ridge of the Lower Bohinj Mountains from the Komna towards the Ravenska alp, and further to the east.

Big differences are obvious if the graph 1 and the graph 3 are compared. The Alp Grajščica and the Pod Špik cirque get much less precipitation. The dates between both measurements differ for 12–14 days, when one bigger snowfall passed the Slovenian mountains, which added around 112 mm of precipitation on Vogel and around 70 mm of precipitation in Rateče. So it can be seen that most differences between the stations on the graph 1 and the graph 3 occur mostly due to different location and not due to time difference.

At the beginning of April the measurements on the Fužina platea plateau were taken. The Fužina plateau lies north of the Bohinj basin, and according to the estimates and data available, it gets less precipitation than the Lower Bohinj Mountains, which are in the southern part of the Bohinj basin. The measurements were taken on 3rd and 4th April. They were taken at the following locations: the Alp Blato (1147 m), the

Alp Pri jezeru (1445 m) and the Alp V lazu (1560 m). On 3rd and 4th April the temperatures at the elevations of around 1500 m were above 0 °C, the snow cover was wet through all the layers and the water started to run off from the snow cover. However, it is estimated that except on the Alp Blato, the run off until this date was negligible, the reason for this being deep snow and low temperatures on the previous days.

Although the measurements were taken within 24 hours, the sinking of the snow cover was smaller than on 27th and 28th March because the snow cover was old and much better transformed. The estimates are that during the measurements the snow sunk for around 5 cm.

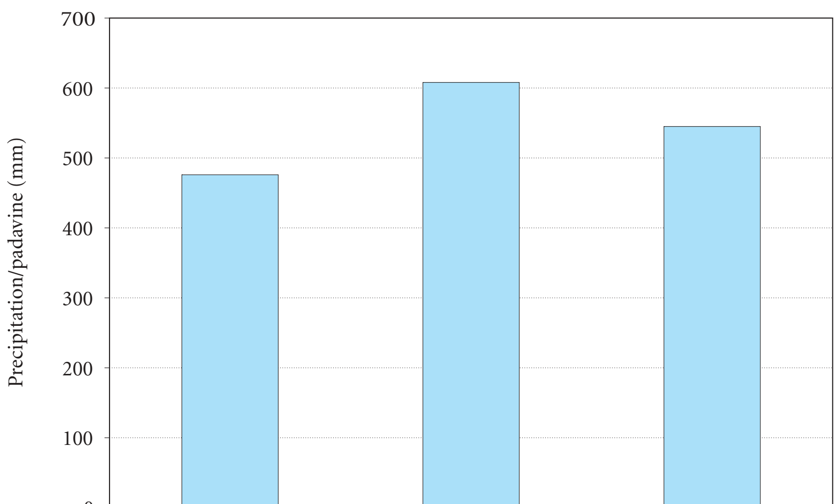
The snow cover was deepest on the Alp Pri jezeru, where it was still 150 cm deep.

The Alp V lazu had 125 cm of snow and the Alp Blato 115 cm of snow. It can be noticed that the highest snow cover was at the second highest measuring spot. This could be explained with the location of the measuring spots. The Alp V lazu gets more solar radiation than the Alp Pri Jezeru. The location of the measuring spot of The Alp Pri jezeru lies in a small concave relief shape where temperature inversion is frequent, although not deep and strong. Snow transforms and thaws slowly, so it also sinks slowly. Part of this difference could also indicate that due to its location about 2 km north into the interior of the Julian Alps, the Alp V lazu gets less precipitation.

Figure 10 shows the differences between the water accumulation in the snow cover at the beginning of April 2004 on three measuring spots on the Fužina alps. Similar to the previous graph, the Alp Pri jezeru took the first place, the Alp V lazu the second and the Alp Blato the third.

On the measuring spots the snow cover accumulated from 476 to 608 mm of precipitation.

If we compare these values with the Komna and the Ravne alp, we see that the difference is big although the measurements were taken only a week later. During this week no precipitation occurred and, as written above, the temperatures were low enough (in the first half of the week the temperatures were around



	Alp Blato/Planina Blato (1147 m)	Alp Pri jezeru/Planina Pri jezeru (1445 m)	Alp V lazu/Planina V lazu (1560 m)
Precipitation/padavine (mm)	476	608	545

Figure 10: WASC on the measuring spots on the Fužinarska planota plateau.

or below 0 °C, on the last two days the temperatures at the altitude of 1500 m rose to around 5 °C), so that the run-off was negligible.

This leads us to the conclusion that the only reason for the differences in precipitation between the Lower Bohinj Mountains and the Fužina plateau is the decline of orographic effect. Still, it must be noted that this effect is still big.

The same effect could be the reason for the differences between the Alp V lazu and the Alp Pri Jezeru, because the Alp V lazu is located app. 2 km towards the north. However, these results must be tested in the following winters. The results for Alp Blato are less representative, because, due to lover elevation and higher temperatures, some water from the snow cover ran off.

5 Comparison between the precipitation data from pluviometers and the precipitation data from snow cover

In the Julian Alps precipitation is measured at many stations. However, only few are located in the mountains. Most of the spots are in valleys, bellow 1000 m except Vogel (1515 m) and Kredarica (2515 m), which are located above 1500 m. It is clear that such a rare network of stations cannot describe real conditions, even if the pluviometers measured precipitation without errors.

The measured amount of precipitation in the Slovenian mountains is smaller than the real one (Pristov et al. 1998). We get much closer to the real values if we multiply the measured amount with the correction factor, which could be calculated in different ways.

In Slovenia precipitation is measured with Hellman's pluviometers. The experiments showed, that at low temperatures and in windy conditions (> 5 m/s), when light and dry snow falls, this pluviometers measure

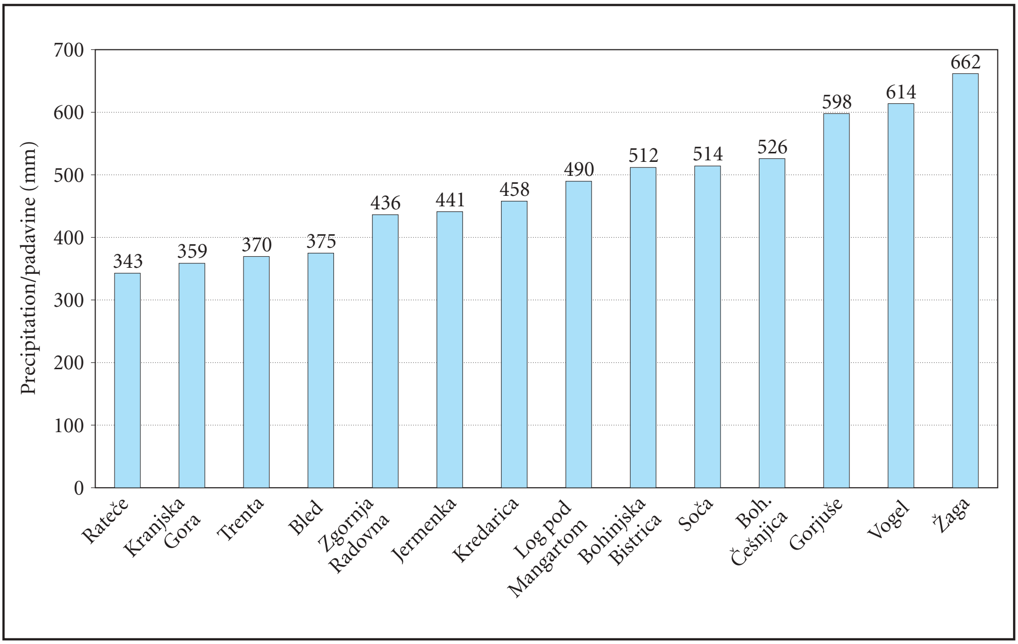


Figure 11: Precipitation amount in the Julian Alps in the period from 21st December 2003 to 3rd April 2004 as measured by ARSO (2004).

only 22–87% of precipitation (Kolbezen and Pristov 1998). Due to the fact that snow flakes are lighter and are thus easier to carry by wind than rain drops, the errors in the periods when precipitation falls mainly as snow are expected to be even bigger.

Some Slovenian meteorologists have made some researches to get better values or estimates about the precipitation in the Slovenian mountains. Considering only windy conditions did not bring to a solution. Besides, if the river run-off is taken into account, the precipitation estimates are too high, so the conclusions were made that specific conditions of the Slovenian Alps must be considered (Pristov et al. 1998).

The annual precipitation measured at the stations in the Julian Alps was corrected with a correction factor. Each station had its own factor. Errors are bigger when it snows, because wind carries snowflakes much easier than raindrops. Stations in valleys were corrected for about +4%, which is not a lot.

Bigger differences appear at higher elevations, especially when a station is exposed to windy conditions. On Vogel (the station lies in the Lower Bohinj Mountains), the correction factor is +9%, and on Kredarica +61% (Pristov et al. 1998).

Such a difference is a consequence of strong winds, which prevail during rainy or snowy weather, and it is also a consequence of bigger part of snow precipitation than at lower elevations.

However, it is not only elevation that influences errors that occur while measuring precipitation. Very important are also the mycro-relief and topography of the surroundings where precipitation is measured (Pristov et al. 1998).

In winter time most precipitation above 1500 m falls as snow, so the values measured with pluviometers are even less precise.

Table 1: Different methods were used to get the precipitation on spots along the Lower Bohinj Mountains from 21st December 2003 to 27th March 2004.

Ravne[1] alp	Komna[1]	Komna[2]	Vogel[3]	Vogel[4]
757	968	620	611	953

1 WASC in the period 21. 12. 2003–27. 3. 2004.

2 Estimated precipitation for the same period. Estimation was calculated, presuming that the ratio the Komna – Vogel stays the same. We multiplied the value on Vogel (measured with pluviometer) with the ratio factor (the Komna corr. / Vogel corr.). The corrected values were calculated by Pristov et al. (1998).

Precipitation (Komna) = [Precipitation (Vogel$_{(ARSO)}$) · (Precipitation (Komna$_{corr.}$)] / Precipitation (Vogel $_{corr.}$).

3 Precipitation for the same period measured with pluviometer.

4 Estimated precipitation on Vogel, calculated from WASC in the same period as on the Komna. The value was obtained with the ratio factor (the Komna corr. / Vogel cor.)

Precipitation (Vogel) = [WASC (Komna) · (Precipitation Komna$_{corr.}$] / Precipitation (Vogel $_{corr.}$)

The upper table shows that the values given by pluviometers and the values measured from the snow cover differ very much. With regard to the values of WASC, pluviometers measured only 64% of precipitation.

If the estimated (on the basis of the measured precipitation with pluviometers) precipitation on the Komna and WASC are compared, it can be seen that the snow cover contained 348 mm (56%) more water than the value from pluviometer.

Precipitation on Vogel could be calculated also in a different way, it could be calculated from the WASC on the Komna but with the assumption that the ratio Vogel–Komna does not change. The value for Vogel that we get on the basis of this calculation is 953 mm.

The value Komna[2] was calculated in a similar way. This value was calculated presuming that the ratio between the corrected values for Komna and Vogel remains the same and the precipitation measured in a pluviometer was taken as the basis.

On Vogel no snow profile was dug, but if we consider that the precipitation increases from the Ravne alp towards the Komna, it is clear that the precipitation on Vogel must be at least higher than 757 mm. This indicates that the values in the pluviometer on Vogel are noticeably too low.

Different data for the same spots show problems when dealing with precipitation in alpine areas, especially in winter.

Values measured from snow cover contain errors as well. Nevertheless, these errors should be much smaller comparing with errors which appear at pluviometers in mountains when it snows and when strong winds blow. Such a situation is actually very normal for a mountainous area. The errors that occur at measuring WASC could be successfully avoided with repeating sampling and with precise definition of different layers within the snow cover. The more snow profiles we obtain, the better results we can get.

The differences between pluviometers and WASC are not small, and our research indicates that the pluviometer on Vogel measured only 64% of WASC value if we neglect errors occurring when sampling water accumulation. It can be also concluded that values measured from WASC are more reliable, especially if it is considered that in the period of snow accumulation almost no rain fell (less or equal to 10% of all precipitation on Vogel).

6 Differences between the measuring spots

Are the differences measured in the winter 2003/2004 typical for this area? Do they indicate some relations between some parts of Slovenian mountains?

In the winter 2003–2004 most of precipitation in the Julian Alps and the surroundings appeared under the influence of south-western winds, when cyclons passed Slovenia mainly from the west towards the east, from the southwest towards the northeast or from the west towards southeast. After a cold front had passed Slovenia, there was often the north-eastern wind that blew in lower parts of troposphere. However, above this cold air, warm and humid south western or south eastern winds continued to blow. This type of weather is typical for this area. However, in many years of the last decade other weather types prevailed. We are not going to discuss these changes, we just want to note that distribution of precipitation in a mountainous area, depends very much on the winds which prevail during the »bad weather« situations. So the relations described below are actually the results of a meteorological situation when most of precipitation falls at western or south-western winds.

6.1 Rateče, Pod Špik cirque, the Alp Grajščica

As the first example we can show relations between Rateče, the Pod Špik cirque and the Alp Grajščica. We compared the precipitation measured in Rateče at the meteorological station (865 m) with the precipitation which accumulated in the mountains not very far from Rateče. The distance from Rateče to the Pod Špik cirque is 9 km. Both spots have also different location. The Pod Špik cirque lies close, beneath the massif of the Špik's group on its northern side and the precipitation there is strongly influenced by the orographic effect which occurs when humid air at south-western winds ascents the Špik's massif.

Rateče lies on northern part of the Upper Sava Valley, relatively far from the orographic obstacles of the Julian Alps. It is also important that the direction of the Julian Alps massif turns to the south at Rateče in to Tamar valley. Air, which at south-western winds passes the massif, descends above the Upper Sava

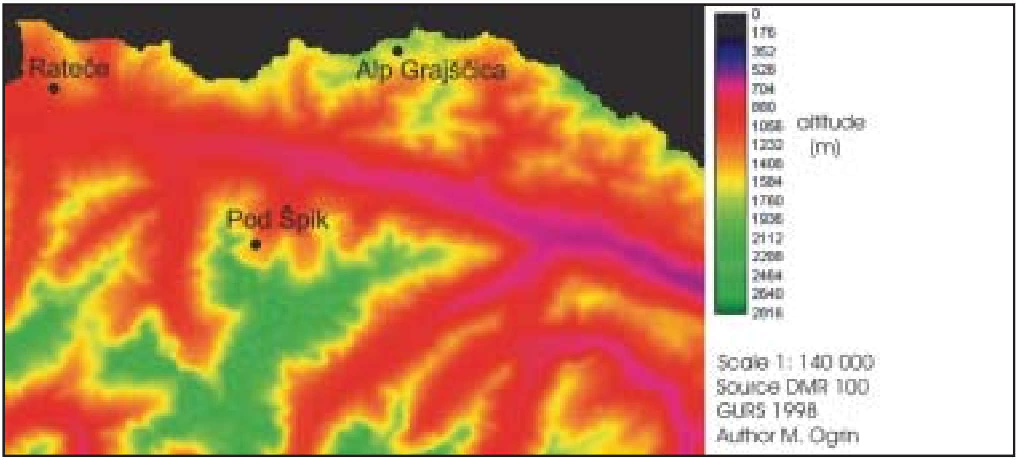


Figure 12: Location of measuring spots.

Valley, so that Rateče is less under the influence of orograpfic effect. The air starts to ascent the Karavanke Moutains but this effect is weaker than at the Julian Alps.

When the south-western wind blows it happens frequently that a cloud window, which indicates that orographic effect is weaker, appears above Rateče.

Since Rateče lies relatively low (865 m) in a valley with weak winds, the data measured with pluviometers are more precise. At the annual level, the correction factor for precipitation is 4% (Pristov et. al 1998).

Table 2: Precipitation in period from 21. 12. 2003 to 14. 3. 2004.

	Rateče[1]	The Pod Špik	The Alp Grajščica
Total	284[1]	429	377
Since 23. February	108[1]	167	139

[1] Corrected value with factor 1.04

Table 3: Precipitation ratios between sampling spots.

	Total	Since 23rd February	21st December–23rd February
Pod Špik cirque – Rateče[1]	1.51	1.55	1.48
Alp Grajščica – Rateče[1]	1.33	1.29	1.35
Pod Špik cirque – Alp Grajščica	1.14	1.20	1.10

[1] Corrected value with 1.04

The measured data were corrected with the annual factor 1.04 because the correction factor is not known only for winter time. However, in the valleys with usually weak winds we presume that the correction factor in winter does not differ much from the annual one.

The results of WASC in the Pod Špik cirque showed that 429 mm precipitation fell since the start of snow accumulation. The pluviometer in Rateče measured 284 mm (the measured value is 273 mm) of precipitation and the total accumulation on the Grajščica was 377 mm. Since 23rd February the values are smaller, 164 mm, 108 mm and 139 mm. It is interesting that the ratios between measuring spots do not differ much if we compare the total precipitation with the one from 23rd February to 14th March, or if we compare it to the one from 21st December to 23rd February.

6.2 Alp Grajščica – Pod Špik cirque

On the Alp Grajščica (1710 m), which lies in western Karavanke Mountains between Murnovec (1866 m) and Kresišče (1839 m) total WASC was 377 mm, which is 88% of WASC in cirque Pod Špik. After 23rd Feb the WASC on Alp Grajščica was 83% of WASC in the Pod Špik cirque.

It is interesting, that the ratios between the stations don't differ much. In both periods, (21. 12. 2003–23. 2. 2004 and 23. 2. 2003–14. 3. 2004) bigger amount of precipitations remains on the same stations.

Ratios of total precipitation show, that in the Pod Špik cirque fell 51% more precipitation than in Rateče, on Alp Grajščica 33% more than in Rateče and in the Pod Špik cirque 14% more precipitation than on Alp Grajščica.

6.3 Komna – the Ravne alp

Table 4: Precipitation ratios between sampling spots Komna and Ravne Alp.

	Total	Since 23rd February	21st December–23rd February
Komna – The Ravne alp	1.28	1.10	1.38

The ratio the Komna / the Ravne alp is in both cases > 1. However, the differences are bigger than in the previous examples. The distance from the Komna to the Ravne alp is about 14 km, which is quite a lot. Along the ridge of the Lower Bohinj Mountains we do not have enough information to explain these differences more precisely. Further researches are necessary to get more detailed information about the precipitation along the ridge.

7 Conclusion

The results of our research show variability of precipitation in wintertime in some parts of the Julian Alps, Trnovski gozd dinaric plateau and the Karavanke Mountains. The errors that occur at measuring WASC are much smaller if the sampling spot is chosen correctly, if all the different layers within the snow cover are identified and if the samples are taken correctly. The values must be verified with the repetition of measuring (taking two or more different samples). It can be seen that the values measured from the snow cover are noticeably higher than the ones measured with pluviometers.

The main reason must be the errors that appear at collecting precipitation with pluviometers when it snows and when strong winds blow, which is often the case in mountainous areas. The estimates on Vogel show that the pluviometer measured only about 64% of the whole precipitation which fell in the winter 2003–2004. However, these researches must continue in order to get more data and relations about the total precipitation in wintertime.

The precipitation ratios between some parts of north-western Slovenia in the winter 2003–2004 showed a close similarity. The ratios are close to each other and they all indicate the decrease of precipitation from the Julian Alps northwards towards the Karavanke Mountains and also decrease of precipitation in the Upper Sava Valley.

The ratios along the Lower Bohinj Mountains ridge are not so similar, although all of them indicate the decrease of precipitation along the ridge towards the east. But in order to obtain more detailed conclusions, more researches would be necessary, especially due to the bigger dimensions of the ridge, compared to researches in the mountains above Upper Sava valley.

These results show precipitation conditions and ratios only between some parts and in situations when above the mountains the south-western winds prevail or when a cyclon from the North Mediterranean passes Slovenia towards the east. It must not be concluded that it is at all situations with precipitations like that. On the other hand it is true that the main part of the annual precipitation is brought by the western or south-western circulation.

It is presumed that in summer precipitation variability is more unpredictable. The reason is convective precipitation, which is very common in the Slovenian mountains, and a smaller part of frontal or orographic precipitation. In summer the values from pluviometers are also more precise and of course there is no snow cover which would accumulate the precipitation.

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Vodnatost snežne odeje kot kazalec količine padavin v gorskem svetu

UDK: 911.2:551.578.4(234.323.6)
COBISS: 1.01

IZVLEČEK: Spremenljivost padavin v gorskem svetu je bistveno večja, kot jo zaznajo redke padavinske in meteorološke postaje. Do velikih razlik prihaja zlasti med privetrnimi, zavetrnimi ter dolinskimi kraji. Pozimi, ko prevladuje sneženje, se padavine akumulirajo na tleh v obliki snežne odeje in tako dobimo vpogled v padavinske razmere v gorskem svetu. Ta vpogled nam nudi natančnejšo sliko in odkriva nove zakonitosti v razporeditvi padavin v Julijskih Alpah in njihovem predgorju ter v Karavankah.

KLJUČNE BESEDE: vodnatost snežne odeje, snežna odeja, padavine, relief, lokalna klima, Julijske Alpe, spremenljivost padavin.

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Vsebina

1 Uvod

Snežna odeja je pojav, ki v zmernih in višjih geografskih širinah najbolj zaznamuje najhladnejši letni čas. Pokrajina se odene v belo, rastline in tudi nekatere živali obmirujejo, pokrajina je mirna, spokojna.

V srednji Evropi snežna odeja po nižinah ni redek pojav, čeprav je res, da praviloma ne traja zelo dolgo, še pogosteje pa ne leži neprekinjeno več mesecev. Povsem drugače pa je v gorskem svetu, kjer sta trajanje in količina snežne odeje bolj izrazita. Vzrok za to so nižje povprečne temperature zraka in večja količina padavin v vzpetem svetu. Slednje je zelo značilno tudi za svet Julijskih Alp in njihovega predgorja. Tam se ob vlažnih jugozahodnih vetrovih izločajo velike količine padavin, ki znašajo letno 2000–4000 mm. Tudi ostali gorati svet Slovenije prejme razmeroma veliko padavin. Čeprav količina proti vzhodu precej pojema, prejme letno celo Pohorje približno 1500 mm padavin.

2 Izhodišče

V hladni polovici leta, zlasti pozimi in spomladi, velik del padavin v gorah pade v obliki snega. Sneg se kopiči iz sneženja v sneženje in pogosto se zgodi, da od določenega trenutka, ko preseže določeno-kritično debelino, vsebuje vso vodo, ki je padla v določenem daljšem obdobju. Pogoj za to je, da je snežna odeja tako debela, da procesi taljenja ob visokih temperaturah in morebitna deževnica ne prodrejo skozi snežno odejo oziroma se vsa voda zadrži v snežni odeji. To pomeni, da snežnica, ki se stali na površini (ali deževnica) v plasteh snežne odeje ponovno zmrzne oziroma ne pronica v tla. S tem pa se poveča gostota snežne odeje in zmanjša njena debelina. Kritična debelina snežne odeje je odvisna od vremenskih razmer. Manj kot je močnih odjug in dežja, tanjša je. Snežna odeja tudi izhlapeva, vendar je ta proces ob nizkih temperaturah v primerjavi s taljenjem in odtekanjem v naših gorah zanemarljiv (Vrhovec 2000). Vodnatost snežne odeje (v nadaljevanju: VSO) je količina vode, ki jo vsebuje snežna odeja.

Snežna odeja se ves čas preobraža, seseda in ob temperaturah nad 0 °C tudi tali. Zato se spreminja praktično vsak dan. Po obilnih sneženjih se dnevno sesede tudi za več kot 20 cm. Kljub vsemu pa ob zgoraj omenjenih pogojih velika večina vode ostane v snežni odeji.

To dejstvo nam lahko koristi pri ugotavljanju padavin v gorah na določenem območju v izbranem obdobju. Podatki o debelini snežne odeje so uporabni le, če so bili izmerjeni istočasno. VSO ob omenjenih pogojih ostaja nespremenjena, zato so podatki o VSO za preučevanje količine padavin toliko bolj uporabni in zanesljivi.

Dežemeri ob močnem vetru, ki je v gorah ob padavinah pogost, spremenijo vetrovne razmere v svoji okolici tako, da se ujame vanje precej manj padavin, kot bi se jih sicer. Ob močnem vetru je na privetrnih straneh gora praktično nemogoče meriti padavine, saj letijo vodne kapljice in snežinke pod zelo majhnim kotom glede na podlago, včasih celo vodoravno in v okolici grebenov za krajši čas tudi navzgor.

Glede na dejstvo, da je mreža gorskih padavinskih postaj pri nas redka in da je zlasti ob sneženju kakovost podatkov, dobljenih iz dežemerov zelo vprašljiva, je preučevanje vodnatosti snežne odeje kot kazalca padavin lahko zelo koristno in uporabno.

V Sloveniji nihče ne opravlja sistematičnega preučevanja vodnatosti snežne odeje. Nekaj raziskav sta naredila Vrhovec (2000) in Sluga (2000), ki sta raziskovala na območju Vogla, Komne in doline Triglavskih jezer. S tem načinom ugotavljanja vodnih razmer so se srečavali študenti meteorologije na terenskih vajah pod vodstvom Tomaža Vrhovca. Avtor članka se je februarja 2004 pridružil tem terenskim vajam in kmalu zatem sam opravil terenske meritve na območju Julijskih Alp, Zahodnih Karavank in Trnovskega gozda. Razmere za tako merjenje so bile v zimi 2003–2004 skoraj idealne.

3 Vremenske razmere v zimi 2003–2004

Snežena zima se je leta 2003 v našem sredogorju začela 21. decembra. Tedaj je padlo do približno 30 cm snega. Pred tem je sicer nekajkrat snežilo, a so odjuge pobrale večino snega. Zlasti Karavanke so bile skorajda brez snega, razen v osojah, kjer ga je ležalo nekaj centimetrov. Od tega dne je snežna odeja pokrivala sredogorje in visokogorje vse do pozne pomladi.

Snežna odeja se je močno odebelila v dneh od 28. 12. do 31. 12., ko so se nad zahodno Slovenijo pojavljale obilne padavine. V Julijskih Alpah je snežilo do dna dolin, v sredogorju in visokogorju je zapadlo približno 150 cm snega, v Posočju blizu dva metra. Proti vzhodu so padavine slabele, meja sneženja je bila večinoma nad 1200 metri. V Karavankah in Kamniško-Savinjskih Alpah je padlo do 70 cm snega. Snežna odeja je bila po poslabšanju vremena v Julijskih Alpah na višini 1500 m debela do 160 cm, višje pa do 200 cm, v Karavankah in Kamniško-Savinjskih Alpah pa do 100 cm. Zanimivo je, da je v tem poslabšanju ponekod na Pohorju padlo le približno 10 cm snega.

Od 17. do 19. januarja je v dveh poslabšanjih vremena naše gore ponovno zasnežilo precej na debelo. 19. januarja je snežna odeja na Kredarici merila 250 cm, na Voglu 210 cm, v Ratečah 50 in na Vojskem 95 cm.

Večjega poslabšanja vremena potem ni bilo vse do 21. februarja. Vmes je bilo tudi daljše obdobje zelo toplega vremena, ko je bila temperatura na 1500 m nekaj dni približno 9 °C. Snežna odeja se je preobražala in sesedala, zlasti na prisojah in v nižjih legah pa tudi hitro talila. V jasnem vremenu s temperaturami nad lediščem in ob nizki relativni vlagi snežna odeja tudi izhlapeva. Latentna toplota, ki se porablja za izhlapevanje, znižuje temperaturo snežne odeje, zato ostaja sneg pozimi na osojnih in ravnih legah suh ali zmrznjen tudi pri pozitivnih temperaturah in je izhlapevanje zanemarljivo. V Julijskih Alpah je ostalo na 1500 m od 120–180 cm, na višini 2500 m pa do 270 cm snega. V sredogorju Karavank in Kamniško-Savinjskih Alpah ga je bilo precej manj, le 40–70 cm.

Pomembno je, da sneg na prisojah po daljšem toplem in sončnem obdobju marsikje povsem izgine, na strminah pa splazi. Razlike med snežnimi razmerami na prisojah, osojah in ravnimi območji so vse večje. Snežno odejo merimo na ravnih tleh, kolikor je v gorah temu kriteriju sploh moč ustreči.

Od 21. do 23. 2. je bilo edino poslabšanje v zimi 2003–2004, ko je tudi v sredogorju padla večja količina dežja. Po podatkih ARSO je 21. februarja na Voglu deževalo in snežilo, skupno je padlo 59 mm padavin, od tega 5 cm snega. Naslednji dan so izmerili 28 mm dežja. 23. februarja dopoldne je sprva še deževalo, sredi dneva pa že snežilo. Ta dan je padlo 75 mm padavin, od tega večina kot sneg, saj se je snežna odeja odebelila za 60 cm. V teh dneh je na Voglu padlo skupaj 162 mm, od tega 65 cm snega. Ker je bila snežna odeja na Voglu ob deževju debela 180 cm, lahko privzamemo, da se je večina deževnice zadržala v snežni odeji in je bil odtok zelo majhen ali zanemarljiv.

Slika 1: Območja raziskave.
Glej angleški del prispevka.

23. februarja se je začela tako imenovana druga zima, ki je prinesla obilo snega v gore in tudi v nižine. V nižinah je zima trajala do druge polovice marca. V več vremenskih poslabšanjih se je v gorah snežna odeja hitro debelila in dosegla pod približno 1000 m največjo debelino 29. februarja, ko je bilo na Vojskem 215 cm, v Ratečah pa 125 cm snega.

Zimsko vreme se je nadaljevalo. Večje sneženje 8. marca je bilo zadnje, ko je obilno snežilo tudi po nižinah. Tedaj so na Voglu namerili 320 cm snega, na Kredarici 430 cm, na Vojskem 175 in v Ratečah 115 cm.

Zimsko vreme se je po 14. marcu preselilo v sredogorje, kjer si je snežna odeja spet opomogla v dneh od 22. do 26. marca, ko je v Julijskih Alpah padlo do 70 cm snega, drugje pa večinoma pod 50 cm.

6. in 7. aprila je na zahodu in severu Slovenije nad nadmorsko višino 1300 m spet zapadlo 40–80 cm snega. To je bilo zadnje večje vremensko poslabšanje z večjo količino snežnih padavin v sredogorju.

Meseci januar, februar in marec skoraj v celoti zaobjamejo obravnavano obdobje. Vsi trije meseci so imeli povprečne temperature zelo blizu povprečnih vrednosti. Po podatkih ARSO je bila v Ratečah (865 m) povprečna mesečna temperatura v obdobju januar–marec –2,2 °C, kar je 0,1 °C hladneje od povprečne vrednosti v obdobju 1961–1990. Na Kredarici (2515 m) pa je bila povprečna mesečna temperatura v istem obdobju –7,9 °C, kar je za 0,1 °C nad dolgoletnim povprečjem 1961–1990. Mesečne povprečne temperature so nekoliko bolj odstopale. Na Kredarici sta bila februar in marec toplejša od povprečja (1,7 °C; 0,8 °C), januar pa je bil hladnejši (–2,1 °C). V Ratečah je marec malenkostno odstopal od povprečja (–0,2 °C), januar je bil prehladen (–0,7 °C) in februar toplejši od povprečja (0,8 °C). V visokogorju so bile temperaturne razmere nekoliko bolj podvržene odstopanjem, medtem ko je v nižjih legah odklon manjši od ene stopinje.

Slika 2: Ravenska planina 4. januarja 2004 (fotografija: Matej Ogrin).
Glej angleški del prispevka.

Slika 3: Ravenska planina 27. marca 2004 (fotografija: Matej Ogrin).
Glej angleški del prispevka.

4 Meritve in rezultati

Preučevanje prerezov snežne odeje ne da le vpogleda v vodnatost stolpca snežne odeje. Omogoča tudi ugotavljanje razlik v količini padavin na različnih mestih. To je za gorski svet zelo uporabno, saj do sedaj znani podatki temeljijo na meritvah z dežemeri, ki so zlasti pozimi precej neuporabni, merilnih mest pa je malo. Če je mesto vzorčenja izbrano pravilno, velja da je zapadla količina snega enaka količini padavin. Nove plasti snega se sprva še lepo ločijo od starih. Razlika v vsebnosti vode omogoča primerjavo izdatnosti padavin na različnih lokacijah. Vzorčno mesto mora biti:
- zaščiteno pred vetrom tako da ta ne odnaša ali nanaša snega (Sluga 2000);
- na ravnih tleh;
- na neporaslem območju in dovolj oddaljeno od reliefnih preprek (balvanov, sten) in
- zunaj dosega snežnih plazov (Sluga 2000).

V zimi 2003/2004 smo to metodo preizkusili na primeru padavin, ki so padle od 23. 2. do konca marca. Tedaj se je začelo daljše obdobje s pogostimi in obilnimi sneženji, delo pa je močno olajšalo dejstvo, da je 21. februarja nad nas med rahlim dežjem ob južnih vetrovih prineslo puščavski pesek. Pesek je rumeno obarval površino stare snežne odeje, kar je olajšalo razpoznavo različnih plasti.

Merjenje vodnatosti snežne odeje ni potekalo skozi vso zimo. Meritve so bile opravljene med 13. marcem in 4. aprilom. Merjenja so potekala na naslednjih lokacijah: Trnovski gozd (13.marec), Zahodne Karavanke in Špikova skupina (16. in 17. marec), Spodnje Bohinjske gore (27. in 28. marec) in Fužinarske planine (3. in 4. april).

Snežno odejo smo vzorčevali z dvema valjema prostornine 0,173 in 0,385 l. V snežni odeji smo naredili prereze od površine do tal. Nato smo ugotovili različne plasti v prerezu snežne odeje in vzeli iz vsake plasti vzorec snega. S pomočjo tehtanja in znane prostornine ($\rho = m/V$) smo izračunali gostoto snežne odeje v posamezni plasti. Privzeli smo, da se gostota znotraj plasti ne spreminja. Če je plast zelo debela (več kot 40 cm), lahko vzamemo več vzorcev in ugotovimo znotraj nje nove plasti. To je uporabno zlasti, ko je dolgotrajno sneženje posledica prehoda sredozemskega (genovskega) ciklona. Takrat pada sprva, ob toplih jugozahodnih vetrovih, gost, tudi moker sneg. Ko hladna fronta preide območje, pada v hladnejšem zraku bolj suh in rahel sneg. Za večjo natančnost smo postopek opravljali z dvema valjema in vzorčenje po potrebi ponovili. Izmerili smo tudi višino vsake plasti in tako dobili stolpec snežne odeje, ki je bil enak višini celotne snežne odeje. Količino vode smo izračunali na naslednji način:

$$m = \rho \cdot V \tag{1}$$

kjer je:
m … masa (kg)
ρ … gostota (kg/m3)
V … prostornina (m3)

Za vsako plast velja, da je masa snega (kg) enaka masi vode (kg), če zanemarimo maso zraka v snegu. Ker je gostota vode enaka 1 kg/dm^3 in ker je 1 dm^3 enak 1 l, velja za vsako plast snega, da je 1 kg snega na 1 kvadratnem metru površine (kg/m^2) enako litru vode na kvadratnem metru površine (l/m^2). Če liter vode razlijemo npr. po kvadru s površino spodnje ploskve 1 m^2, ugotovimo, da 1 l padavin na kvadratni meter ustreza plasti deževnice z debelino 1 mm.

Tako smo izmerili 9 prerezov na različnih lokacijah. Poleg tega smo na več mestih z lavinsko sondo merili debelino snežne odeje na 5 cm natančno in dobili hkrati tudi podatke o skupni višini snežne odeje.

Slika 4: Prerez snežne odeje, v katerem so lepo vidne posamezne plasti. Lavinska lopata je široka 20 cm (fotografija: Miha Pavšek).
Glej angleški del prispevka.

Slika 5: Vodnatost snežne odeje (VSO) od 14. do 17. marca 2004 v Zahodnih Karavankah (planina Grajščica, 1710 m in Za Lepim vrhom), v krnici Pod Špikom (1400 m n. m.) in v Mali Lazni (1100 m n. m.) na Trnovskem gozdu. Temni stolpci kažejo VSO od začetka akumulacije 21. decembra 2003, svetlejši pa VSO od 23. februarja 2004. Meritve Za Lepim vrhom so bile opravljene pri lovski koči.
Glej angleški del prispevka.

Slika 5 kaže podatke o vodnatosti snežne odeje na južnem predgorju in na severu Julijskih Alp in v Zahodnih Karavankah. VSO po 23. februarju je različna in sicer znaša največ Pod Špikom (167 mm) in v Mali Lazni (158 mm). Sledi merilno mesto na planini Grajščici (139 mm) in merilno mesto pri koči za Lepim vrhom (93 mm). Iz omenjenih razlik je očitno, da se tudi na majhnih razdaljah (razen Male Lazne, so merilna mesta oddaljena med seboj manj kot 7 km) količina padavin močno spreminja. Razlike lahko pojasnimo s splošnim upadanjem količine padavin od južnega predgorja Julijskih Alp proti severu. Orografske padavine so posledica prevladujočih jugozahodnih vetrov ob poslabšanjih vremena. Najobilnejše padavine nastopijo ob kondenzaciji, ki nastopi zaradi prisilnega dviganja vlažnega zraka prek gorskih grebenov. Padavine se pojavijo že pred prihodom fronte, frontalne padavine pa se zaradi tega učinka še dodatno okrepijo. Količina padavin se na privetrni strani grebenov na poti proti notranjosti Julijskih Alp nekoliko poveča. V zavetrju, od grebena Špikove skupine proti severu nad Zgornjesavsko dolino pa upade. Ko se vlažen zrak nato spet dviga ob Karavankah, količina padavin spet nekoliko naraste. Prirastek je manjši kot na grebenih Julijskih Alp.

Podoben je vrstni red pri celotni vodnatosti, kjer je Mala Lazna na tretjem mestu. Če upoštevamo samo vodnatost do 23. marca (od skupne VSO odštejmo VSO po 23. februarju), pa celo na zadnjem. To pripisujemo močni februarski odjugi, ko se je snežna odeja predvsem v nižjih legah hitro talila in je voda iz nje pospešeno odtekala. Konec marca smo opravili meritve tudi v Spodnjih Bohinjskih gorah.

Slika 6: Višina snežne odeje 27. in 28. marca 2004.
Glej angleški del prispevka.

Slika 6 kaže na razporeditev višine snežne odeje na različnih mestih v Bohinju. Nad nadmorsko višino 1300 m je bilo ob začetku meritev 27. marca zjutraj približno 70 cm novega snega, ki pa se je hitro sesedal. Na Ravenski planini se je snežna odeja tega dne dopoldne v treh urah sesedla za 8 cm. Ocenjujemo, da se je v celem dnevu sesedla vsaj za 15 cm. Ker smo na Komni merili šele naslednje jutro ocenjujemo, da je bila višina snežne odeje dan prej na Komni vsaj 15 cm višja.

Snežna odeja z višino praviloma narašča, kar pa se ni pokazalo ob primerjavi merilnih mest Ravne (710 m) in Savica (650 m). V tem primeru je precej bolj pomembna lega merilnih mest, saj leži Savica v zatrepu Bohinjske kotline (Ukanc) s pogosto temperaturno inverzijo in majhno osončenostjo. Ravne ležijo sicer na nekoliko osojni pobočni terasi, a z bistveno večjo količino prejetega sončnega sevanja. Marca pa so Ravne tudi že nad inverzno plastjo, saj ležijo približno 200 m nad dnom Spodnje Bohinjske doline.

Slika 7: Vodnatost snežne odeje na Ravenski planini (1340 m) in na Komni (1485 m).
Glej angleški del prispevka.

Slika 7 potrjuje znano dejstvo, da so Spodnje Bohinjske gore eno najbolj namočenih območij Slovenije. Od 21. decembra do konca marca je na tem območju padlo 757 (Ravenska planina) oziroma 968 mm padavin (Komna). Od 23. februarja pa 271, oziroma 299 mm. V obeh primerih vidimo, da je na Ravenski planini, ki leži vzhodno od Črne prsti VSO nekoliko manjša. Sklepamo, da količina padavin vzdolž grebena Spodnjih Bohinjskih gora postopoma pada proti vzhodu oziroma jugovzhodu.

Razlike so opazne tudi pri primerjavi slik 5 in 7, kjer smo na podobni nadmorski višini (Planina Grajščica, Pod Špikom) namerili bistveno manjšo vsebnost vode. Med obema meritvama sta minila približno 2 tedna, vmes je bilo le eno večje poslabšanje s sneženjem. Sodeč po podatkih ARSO je takrat na Voglu padlo 120 in v Ratečah 69 mm padavin. Večji del razlik VSO med Voglom in Ravensko planino ter Pod Špikom in Grajščico je posledica različne lege glede na jugozahodne vetrove in s tem različne intenzitete padavin.

V začetku aprila smo opravili meritve na Fužinarskih planinah (Blato, 1147 m; Pri jezeru, 1453 m; V lazu, 1560 m). Fužinarske planine ležijo severno od Bohinjske kotline in prejmejo manj padavin kot greben Spodnjih Bohinjskih gora. 3. in 4. aprila so tudi v sredogorju prevladovale temperature nad 0 °C, snežna odeja je bila ojužena in premočena do tal. Zaradi taljenja je VSO upadala. Razmere pokažeta sliki 8 in 9.

Slika 8: Merilna mesta v Bohinju.
Glej angleški del prispevka.

Snežna odeja se je v tem obdobju sesedala, sesedanje pa je bilo počasnejše kot 27. in 28. marca, saj sneg ni bil svež. Meritve so potekale 24 ur. V tem času je bilo po naši oceni sesedanje manjše od 5 cm. Snežna odeja je bila najdebelejša na planini Pri jezeru (150 m). Na planini v Lazu je merila 125 cm in na planini Blato 115 cm. Zanimivo je, da je bila snežna odeja najdebelejša na planini Pri jezeru in ne na planini V lazu. Nepričakovana razlika je posledica mikroklimatskih razmer. Merilno meto na planini Pri jezeru je v senčni legi v kotanji južno od planinske koče. Zaradi manjše osončenosti in lege v majhni kotanji, se je snežna odeja počasneje preobražala in talila. Merilno mesto na planini V lazu je na sončni legi sredi planine.

Slika 9: Višina snežne odeje na Fužinarskih planinah.
Glej angleški del prispevka.

Slika 10 kaže razlike v vodnatosti v začetku aprila 2004 na treh Fužinarskih planinah. Podobno kot na sliki 7, je bila tudi tu največja vodnatost na planini Pri jezeru, sledi ji planina V lazu in nato planina Blato. Tedaj je na izbranih merilnih mestih snežna odeja še vedno vsebovala 476–608 mm padavin. V primerjavi s stanjem na Komni in Ravenski planini je razlika velika, čeprav je med meritvama minil le teden dni. Večji del razlike pripisujemo manjši količini padavin. V tem tednu se je stalila le manjša količina snega in odtekla kot snežnica, saj je bilo večji del tedna še hladno s temperaturami pod ali približno 0 °C. Ozračje se je ogrelo šele 1. in 2. aprila.

Manjša višina snežne odeje na planini V lazu v primerjavi s planino Pri jezeru je morda tudi posledica upadanja količine padavin proti osrednjemu delu Julijskih Alp. Za potrditev te domneve bi potrebovali več meritev.

Slika 10: Vodnatost snežne odeje na Fužinarskih planinah.
Glej angleški del prispevka.

5 Primerjava podatkov o količini padavin s postaj ARSO in preračunanih iz vodnatosti snežne odeje

Slika 11: Količina padavin izmerjenih na postajah ARSO v obdobju od 21. decembra 2003 do 3. aprila 2004 (ARSO).
Glej angleški del prispevka.

Slika 11 kaže količino padavin, ki so jo izmerili na opazovalnih postajah mreže ARSO v Julijskih Alpah v obdobju od 21. decembra 2003 do 3. aprila 2004. Te vrednosti ne izražajo povsem resničnega stanja, saj prihaja pri merjenju padavin do določenih napak. Praviloma so izmerjene količine padavin v Sloveniji manjše od dejanskih. Dejanske vrednosti dobimo, če pomnožimo izmerjene padavine s t. i. korekcijskim faktorjem, ki ga izračunamo na več načinov (Pristov in sodelavci 1998). V Sloveniji uporabljajo Hellmanove dežemere, ki v vetrovnih razmerah ob nizkih temperaturah (ko pada suh sneg) zajamejo le 22 % padavin, medtem ko ujamejo pri dežju 87 % padavin. (Kolbezen in Pristov 1998). Z metodo ugotavljanja pravih količin padavin so se ukvarjali tudi slovenski meteorologi, vendar so ugotovili, da zgolj upoštevanje pravih vetrovnih razmer v okolici dežemerov ne da točnih rezultatov. (Pristov in sodelavci 1998). Dobljene vrednosti so bile previsoke predvsem v gorskem svetu, sodeč po primerjavi z bilanco odtokov. Potrebno je upoštevati tudi specifične razmere v visokogorju. (Pristov s sodelavci 1998; Kolbezen in Pristov 1998).

Korekcijski faktor je za vsako padavinsko postajo nekoliko drugačen. (Pristov s sodelavci 1998). Dolinske postaje dobijo na letni ravni približno 4 % več padavin, kar je razmeroma malo. Večje razlike so v sredogorju, kjer je ocenjena razlika pri Voglu na +9 %, še precej večja pa je v visokogorju, saj znaša na Kredarici kar +61 %.

Na korekcijski faktor pa ne vpliva le nadmorska višina, temveč tudi oblika površja ter izpostavljenost merilnega mesta in okolice (Pristov s sodelavci 1998). Pozimi tudi v sredogorju prevladuje sneženje, zato so izmerjene količine še bolj podcenjene.

Preglednica 1: Količina padavin v obravnavanem obdobju vzdolž grebena Spodnjih Bohinjskih gora, pridobljena z metodami, opisanimi v opombah.

Ravenska planina[1]	Komna[1]	Komna[2]	Vogel[3]	Vogel[4]
757	968	620	611	953

[1] VSO v obdobju 21. 12. 2003–27. 3. 2004.

[2] Izračunana vrednost padavin v obravnavanem obdobju po metodi razmerij glede na Vogel. Razmerje korigiranih vrednosti Komna/Vogel v obdobju 1961–1990 je pomnoženo s količino padavin, ki so jo izmerili na meteorološki postaji Vogel v obdobju 21. 12. 2003–27. 3. 2004. Korrigirane vrednosti je izračunal Pristov s sodelavci (1998).

padavine (Komna) = [padavine ($Vogel_{ARSO}$) · padavine ($Komna_{kor.}$)] / padavine ($Vogel_{kor.}$).

[3] Izmerjena količina padavin na postaji ARSO v obdobju 21. 12. 2003–27. 3. 2004.

[4] Ocenjena vrednost padavin, ki izhaja iz razmerja $Komna_{kor.}$ / $Vogel_{kor.}$, pri čemer izhajamo iz vrednosti, dobljenih z merjenji vodnatosti snežne odeje na Komni.

padavine (Vogel) = [VSO (Komna) · padavine ($Komna_{kor.}$)] / padavine ($Vogel_{kor.}$).

Preglednica 1 pokaže, da se vrednost v obravnavanem obdobju na Voglu in iz te ocenjena količina padavin na Komni, precej razlikujeta od VSO, ki smo jo namerili na Komni. Vrednosti dobljene z izračunom, ki temelji na podatkih meteorološke postaje Vogel, znašajo le 64 % vrednosti, dobljene z merjenjem VSO. Povedano drugače: na Komni smo z metodo merjenja VSO dobili 348 mm padavin več, kot če bi izhajali iz izmerjene vrednosti na meteorološki postaji na Voglu.

Količino padavin na Voglu lahko izračunamo tudi drugače. Če privzamemo, da se razmerje med količino padavin na Voglu in Komni ohranja, lahko na podlagi VSO na Komni ocenimo količino padavin na Voglu. Izračunana vrednost 953 mm je občutno višja od izmerjene vrednosti na opazovalni postaji ARSO.

Vrednost Komna[2] (preglednica 1) smo izračunali iz količine padavin, ki so jo izmerili na meteorološki postaji Vogel. Ponovno smo privzeli, da se razmerje med količino padavin na Voglu in Komni ohranja.

Iz razlik Komna-Ravenska planina bi lahko sklepali, da se količina padavin vzdolž grebena Spodnjih Bohinjskih gora počasi znižuje proti vzhodu. To pomeni, da je na Voglu VSO presegala tisto na Ravenski planini. Izmerjene vrednosti na meteorološki postaji na Voglu ARSO pa so za 146 mm manjše kot na Ravenski planini.

Različni podatki za iste postaje v zgornji preglednici so lep primer težav, s katerimi se srečujemo pri merjenju količine padavin v gorskem svetu. Tudi podatki, dobljeni iz vodnatosti snežne odeje, imajo določeno napako, zato je poleg natančnosti nujna večkratna ponovitev meritev na različnih lokacijah. Vseeno pa gre bolj zaupati podatkom, dobljenim z izračunom VSO, kot pa izmerjeni količini padavin, o čemer govorijo podatki, dobljenih iz ostalih prerezov snežne odeje, ki smo jih izkopali in izmerili njihovo vodnatost. Prerez na planini Pri Jezeru je bil opravljen 27. marca, vseboval pa je približno enako količino padavin (608 mm) kot je bila, po podatkih ARSO, izmerjena količina padavin na Voglu (611 mm). Na obeh mestih se je snežna odeja formirala na isti dan. Glede na večkrat potrjeno dejstvo, da je greben Spodnjih Bohinjskih gora precej bolj namočen od Fužinarskih planin (na letno prejeme približno 500 mm več) so te vrednosti argument več, da so izmerjene količine padavin pozimi precej pocenjene.

Razlike med podatki, dobljenimi na meteorološki postaji Vogel in podatki, ki smo jih dobili s pomočjo VSO, so velike. V obravnavanem obdobju je dežemer na Voglu ujel 64 % količine padavin, izračunane s pomočjo VSO.

Če so padavine večinoma v obliki snega in so izpolnjeni drugi omenjeni pogoji, dobimo z metodo VSO bolj zanesljive podatke o količini padavin v gorskem svetu.

6 Razmerja med posameznimi merilnimi mesti

Oglejmo si še, ali so razlike, ki smo jih namerili med posameznimi mesti odraz bolj ali manj stalnih razmer v namočenosti gorskih predelov ali so zgolj slučajne.

V zimi 2003–2004 je večina padavin v Julijskih Alpah in okolici padla med vremenskimi poslabšanji, ki so prihajala z jugozahoda ali zahoda.

Sekundarni cikloni so Slovenijo prešli od zahoda proti vzhodu, jugozahoda proti severovzhodu ali pa so od zahoda proti jugovzhodu. Ko je ciklon s hladno fronto prešel Slovenijo, so v nižjih plasteh ozračja pogosto zapihali severovzhodni vetrovi, medtem ko je zgoraj vztrajal topel in vlažen jugozahodnik ali jugovzhodnik.

Tak tip poslabšanj je v Sloveniji običajen, vendar se v zadnjih letih uveljavljajo tudi drugi vremenski vzorci. V tem prispevku ne bomo navajali možnih vzrokov za te spremembe, radi bi le opozorili, da je razporeditev padavin v gorskem svetu močno odvisna od prevladujočih vetrov ob vremenskih poslabšanjih.

6.1 Rateče, Pod Špikom, Planina Grajščica

Kot prvi primer smo analizirali razmere v Ratečah (865 m), Pod Špikom (1400 m) in na planini Grajščici (1710 m). V Ratečah smo vzeli podatke meteorološke postaje ARSO, na ostalih dveh lokacijah pa smo izmerili VSO. Poleg oddaljenosti, ki znaša 9 km, kažeta postaji nekaj razlik v legi glede na orografske pregrade. Krnica Pod Špikom je pod grebenom Špikove skupine. Sklepamo, da padavine, ki se ob prehodu tega grebena bistveno okrepijo, tod še ne oslabijo.

Rateče so na drugi strani Zgornjesavske doline, zato je oslabitev padavin onstran orografske pregrade Julijskih Alp v Ratečah izrazitejša kot v krnici Pod Špikom. Dviganje zraka severno od Rateč pa ponovno povzroči povečanje količine padavin proti najvišjim delom Karavank. Znak spuščanja zraka nad Ratečami je tudi okno v oblačnosti, ki se pojavi, ko nad tem območjem piha jugozahodnik.

Slika 12: Merilna mesta.
Glej angleški del prispevka.

Preglednica 2: Količina padavin v obdobju 21. 12. 2003–14. 3. 2004.

	Rateče[1]	Pod Špikom	Planina Grajščica
skupaj	284[1]	429	377
obdobje po 23. februarju	108[1]	167	139

[1] Korigirano s količnikom 1,04.

Preglednica 3: Razmerja v količini padavin med merilnimi mesti.

	skupaj	23. februar–14. marec	21. december–23. februar
Pod Špikom – Rateče[1]	1,51	1,55	1,48
Grajščica – Rateče[1]	1,33	1,29	1,35
Pod Špikom – Grajščica	1,14	1,20	1,10

[1] Korigirano s količnikom 1,04.

Količino padavin, izmerjeno v Ratečah, smo korigirali s korekcijskim faktorjem, ki znaša 1,04 (Pristov in sodelavci 1998). Verjetno je korekcijski faktor za padavine v obliki snega nekoliko drugačen, vendar ga ne poznamo. Ker so na dnu doline v Ratečah močni vetrovi med sneženjem razmeroma redki, ocenjujemo, da napaka zaradi upoštevanja samo celoletnega faktorja ni pomembna.

Preglednici 2 in 3 kažeta, da je v obdobju 21. 12. 2003–14. 3. 2004 Pod Špikom padlo 429 mm padavin, na Planini Grajščica 377 mm in v Ratečah 284 mm. Po 23. 2. so bile v enakem vrstnem redu zabeležene naslednje vrednosti: 167 mm, 139 mm in 108 mm.

6.2 Grajščica – Pod Špikom

Na Planini Grajščici, ki leži približno 1710 m visoko v zahodnih Karavankah nad Martuljkom, med Murnovcem (1866 m) in Kresiščem (1839 m), je snežni stolpec celotnega obravnavanega obdobja vseboval 377 mm padavin, kar znaša 88 % količine, ki smo jo v snežni odeji izmerili pod Špikom. Od 23. 2. pa je količina na Planini Grajščici znašala 83 % tiste pod Špikom.

Zanimivo je, da se razmerja med posameznimi postajami ne razlikujejo veliko. V prvem obdobju (21. 12. 2003–23. 2. 2004) in drugem obdobju (23. 2. 2003–14. 3. 2004) se večja količina pojavlja na istih merilnih mestih.

Razmerja celotnih padavin nam pokažejo, da je padlo Pod Špikom 51 % več padavin kot v Ratečah, na Planini Grajščici 33 % več kot v Ratečah in Pod Špikom 14 % več padavin kot na planini Grajščici.

6.3 Komna – Ravenska planina

Preglednica 4: Razmerje v količini padavin med Komno in Ravensko planino.

	skupaj	23. februar–27. marec	21. december–23. februar
Komna – Ravenska planina	1,28	1,10	1,38

Razmerje količine padavin na Komni in Ravenski planini je v obeh terminih večje od 1. Vseeno pa so razlike med obdobjema večje kot v preglednici 3. Razdalja med Komno in Ravensko planino je približno 14 km, kar je za razgiban gorski svet veliko. Prav tako je podatkov o količini padavin vzdolž grebena Spodnjih Bohinjskih gora premalo, da bi lahko te razlike točneje pojasnili. Vsekakor bodo potrebne nadaljnje raziskave.

7 Sklep

Raziskava se je osredotočila na razlike v zimski količini padavin na območju Trnovskega gozda, Julijskih Alp in Zahodnih Karavank. Vrednosti VSO so opazno večje od vrednosti, ki jih zabeležijo dežemeri. Podatki o vodnatosti snežne odeje so zanesljivejši kot podatki o količini padavin, ki jih zabeležijo redki dežemeri. Napake pri merjenju VSO močno zmanjšamo, če pravilno izberemo merilna mesta in vzorčenje ponavljamo.

Glavni razlog za napake meritev pri dežemerih so vetrovne razmere, ki se pojavljajo ob padavinah v gorskem svetu. Rezultati kažejo, da je v zimi 2003/2004 dežemer na Voglu zabeležil le 64 % padavin, ugotovljenih na podlagi VSO.

Razmerja količine padavin med posameznimi merilnimi mesti v gorskem svetu severozahodne Slovenije so v zimi 2003–2004 pokazala veliko podobnost. V obeh obdobjih so si zelo podobna in nakazujejo padec količine padavin od juga proti severu ter oslabitev padavin nad Zgornjesavsko dolino.

Razmerji količine padavin vzdolž grebena Spodnjih Bohinjskih gora se nekoliko razlikujeta od razmerij v Zgornjesavski dolini in njeni okolici, čeprav kažeta na padec vzdolž grebena proti vzhodu. Za natančnejše poznavanje padavinskih razmer vzdolž grebena bodo potrebne nadaljnje in podrobnejše meritve.

Rezultati raziskave so bili osredotočeni le na nekaj območij v gorskem svetu. V času meritev je večino padavin prinesla zahodna do jugozahodna cirkulacija zraka. Zato so rezultati uporabni le za predstavitev razmer ob takem tipu vremena, ki pa je tod prevladujoč.

Upravičeno domnevamo, da je spremenljivost padavin poleti še večja. Razlog so konvekcijske padavine, ki so v gorskem svetu Slovenije zelo pogoste in manjši delež padavin, ki so posledica prehoda ciklonov. Poleg tega so vrednosti, ki jih izmerimo z dežemeri poleti zanesljivejše.

8 Literatura

Glej angleški del prispevka.