THE MINIMUM TEMPERATURES IN THE WINTER 2006/07 IN SLOVENIAN FROST HOLLOWS AND COLD BASINS

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Abstract
The members of Slovenian Meteorological Forum, Department of Geography at University of Ljubljana and Slovenian Forestry Institute started to measure temperatures in Slovenian frost hollows and cold basins in 2004. The measurements, which improved during the period 2004–2006, continued also in the winter 2006–2007, all together, in more than 30 frost hollows and cold basins Alpine, Dinaridic and even Submediterranean areas. Although the winter 2006/2007 was very mild, minimum temperatures in frost hollow Hribarice fell below − 35 ˚C.

Key words: minimum temperatures, frost hollows, cold basins, winter 2006/2007, nocturnal cooling, Slovenia.

MINIMALNE TEMPERATURE V SLOVENSKIH MRAZIŠČIH V ZIMI 2006/07

Izvleček
Člani Slovenskega meteorološkega foruma, Oddelka za geografijo Univerze v Ljubljani in Gozdarskega inštituta Slovenije smo v letu 2004 pričeli z meritvami v slovenskih mrazišči. Mreža meritev se je v obdobju 2004–2006 razširila, z meritvami pa smo nadaljevali tudi v zimi 2006/2007. Meritve so potekale v več kot 30 mrazišči dinarskega, alpskega in tudi submediteranskega sveta. Kljub mili zimi 2006/2007, so temperature v mrazišču Hribarice padle pod − 35 ˚C.

Ključne besede: minimalne temperature, mrazišča, zima 2006/2007, nočno ohlajanje, Slovenija.

1. INTRODUCTION

In the last years, researches of temperature conditions in Slovenian frost hollows and cold basins have brought new knowledge on this field. Previously, most of the researches in Slovenia focused on the researching of ecological conditions in frost hollows: Gams (1972, 1974), Zavadlav (1974), Majdič (1973), Ogrin, Krevs (1995), or they focused on air pollution-related problems in cold air pools in valleys and basins: Petkovšek, Rakovec (1975), Petkovšek (1971). The last researches focused more on topographical climatological conditions (Ogrin 2000). As a further step, researches continued in successful collaboration between Department of Geography (Ogrin D., Ogrin M.) at University of Ljubljana, Slovenian Forestry Institute (Sinjur I.) and Slovenian Meteorological Forum (Vertačnik G., Ortar J., Gustinčič M., Debevc K., Trošt A., Logar T.) and they brought us to conclusions that temperature in some Alpine frost hollows during winter time quite often fall below − 30 ˚C, in some extreme cases even below − 40 ˚C (Ogrin, Ogrin 2005; Sinjur, Ogrin 2006; Sinjur et al. 2007). In the winters of 2004/2005 and 2005/2006, temperatures below − 40 ˚C were measured twice. On January 25, 2006, the lowest temperature ever recorded in Slovenia was measured. On the Lepa Komna Alpine karst plateau, in the frost hollow Mrzla Komna the temperature fell to − 41,7 ˚C.

In other Alpine countries, research of temperature conditions in some Alpine frost hollows such as Grünloch /Austria/ also went on in last years (Whiteman et al. 2004). Very known Alpine frost hollows are also Funtensee /Germany/, Glattalp /Switzerland/, Lago di Fosses and Campo Lussi /both Italy/.

2. METHODOLOGY

The measurements from the period 2004–2006 continued also in the winter 2006–2007 in more than 30 frost hollows and cold basins in the Julian Alps, the Karavanke mountains, the Pohorje, Dinaric karst plateaus Snežnik and Trnovski gozd, the Dinaric region of Notranjska and, also, in the Slovenian Istria. We used analogous Thermo Schneider alcohol minimum thermometers and Dallas semiconductor digital thermometers which are also data loggers. They are named also i-buttons.

Analogous minimum thermometers were used in the cold basins of the Notranjska region. According to the provider, the instrument error is ± 0.3 ˚C and the resolution 0.5 ˚C. The range of measurement is − 40 ˚C to + 40 ˚C. In Alpine frost hollows, where temperatures can fall much lower, we used similar thermometers with a measurement range down to − 50 ˚C or even − 60 ˚C. The advantage of alcohol minimum thermometers is a small error in comparison to digital thermometers, especially at temperatures below − 30 ˚C. The disadvantage is that we can only measure current temperature and minimum temperature in one period, so the data cannot be stored and we cannot see the dynamics of temperature changes in time. Digital thermometers we used are also data loggers, so they could give us the insight into the processes of nocturnal cooling and the formation or degradation of cold air pool. Their disadvantage is a relatively big error of measurements. At − 30 ˚C, the error is from − 0.7 to + 1.2 ˚C and at − 40 ˚C, the error rises to the interval from − 0.9 to + 1.6

˚C. The minimum limit value for the measurement range is − 40 ˚C, which is the biggest disadvantage of digital thermometers. In some higher frost hollows, the measurements were carried out with both kinds of thermometers. The resolution of digital thermometers can be set to 0.1 or 0.5 ˚C. In most cases, we chose the resolution of 0.5 ˚C, because lower resolution enables more memory for the data logger and a longer period of measurements, which was set on 85 days.

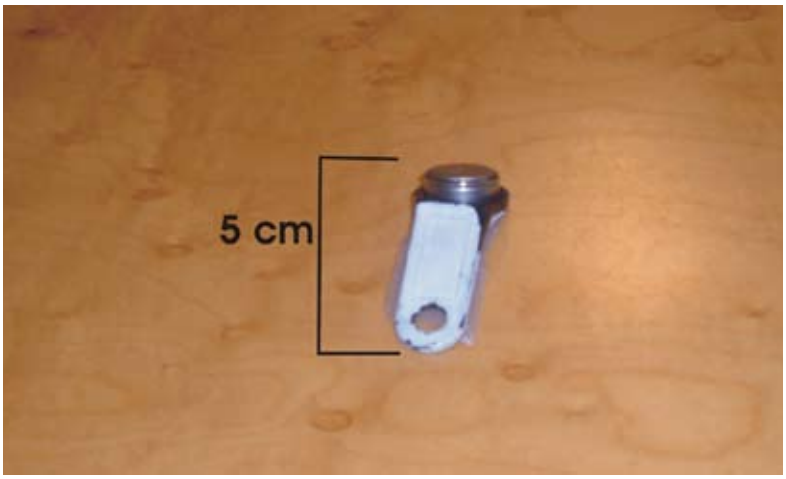
All the measurements were taken from 1.5 to about 3 m above the surface. In the lowlands, we had no problems with the setting of the height of measurements because snow cover during the winter 2006/2007 was very poor and, except for a day or two in the last decade of March 2007, it did not exceed 50 cm. The only exception was in the frost hollow Najen in the Planica valley where the snow cover was deeper (about 1 m) during the winter. There we put the thermometer about 2.5 m above the ground.

In the mountains, problems with snow cover were bigger. In some parts, snow cover was deeper than 2 m, so from the experience of previous winters, we had to prepare a special equipment to keep the thermometer and the shield high enough. We prepared special wooden or metal poles, which were set on the basic carriers. The height of the measurements changed daily due to the changing of the snow cover height. In some cases, wind accumulation brought also additional snow which caused even more problems. Nevertheless, thermometers were almost all the time at least 1,5 m above the surface.

Figure 1: A radiation shield for a digital thermometer (Photo: I. Sinjur).

Figure 2: A radiation shield for an alcohol thermometer (Photo: M. Ogrin).

Figure 3: A digital thermometer, known also as i-button on a white clip (Photo: M. Ogrin).



The research focused on temperature minima, which usually appear during morning hours. If conditions are not ideal, they can appear also earlier in the night. When measuring temperature, it is also very important what kind of radiation shield we use. The World Meteorological Organization declared a Stevenson screen as a reference standard for mea-

suring temperature. For temperature measurements in the mountains and at many different locations we did not use Stevenson screens, the reason for this being financial and logistical problems, but we made adequate low cost radiation shields. As for nocturnal temperatures, minimum temperatures in the Stevenson screen were 0.3 °C higher than in our shields for digital thermometers (Sinjur, Vertačnik 2007), and the temperatures measured with our alcohol thermometer in a special radiation shield were 0.8 ˚C lower than in the reference Stevenson screen.

3. RESULTS

3.1 Weather in the winter 2006/2007

The article describes the period from December 1, 2006, to March 31, 2007. We took a period of meteorological winter and also March, which is also considered as a winter month due to low average temperatures. Table 1, showing comparison of the average temperature between December to March on Kredarica (2515 m) and Krvavec (1740 m), confirms this statement. These are the highest meteorological stations in the Slovenian mountains. Kredarica lies in the central part of the Julian Alps in the northwestern part of Slovenia, while Krvavec is located in the Kamnik and Savinja Alps in the northern part of Slovenia.

Table 1: Average monthly temperatures (˚C) on Krvavec (1740 m) and on Kredarica (2515 m) during the reference period 1971–2000.

	$T_{avg.\ (1971–2000)}$ Dec (˚C)	$T_{avg.\ (1971–2000)}$ March (˚C)
Kredarica (2515 m)	− 6.0	− 6.6
Krvavec (1740 m)	− 2.6	− 2.1

Source: Oddelek za geografijo 2006.

The winter 2006/2007 was extremely mild in the Alps and consequently it was also a 'green' winter, especially in lowlands. In Slovenia, December was very warm at first. Even on Kredarica, the compact snow cover disappeared and the ground was only partly covered with snow. This happened for the very first time since the beginning of measurements on Kredarica in 1955. On December 9, after a cold front had passed Slovenia, the snow line dropped below 1000 m. Afterwards a short colder period began and it lasted for five days. The first clear night after the cold front was the night on December 12. Then the conditions for intensive nocturnal cooling in December 2006 were the best in most of the frost hollows. On December 15, warm advection began and warm weather lasted until December 18. On December 18, the temperatures fell again and this was a start of a mainly dry type of weather in the mountains which lasted until December 30. Only on the first days, the temperatures were around the average, but soon warm advection began and above 1500 m the temperatures were around or above 0 ˚C. Since December 9, there was permanent snow cover in the Slovenian Alps until the late spring in May or June 2007.

Snow cover is very important for temperature conditions in frost hollows and cold basins because of special physical characteristics. White surface of snow reflects most of incoming solar radiation and emits almost as blackbody in the long-wavelength infrared part of spectrum. Consequently, in clear and sunny weather the equilibrium temperature on snow surface is much lower than on other types of ground. This explains unusually low daily temperatures in clear and calm weather. Beside this, very low thermal conductivity minimizes heat flux from the ground to the atmosphere, which enables very quick cooling of the air during evening hours and extremely low nocturnal temperatures.

Average December temperatures in the mountains were 2 to 3 ˚C above the average in the reference period (this means the period 1971–2000). In Rateče (865 m), which lies in the Upper Sava valley on the border between the Karavanke mountains and the Julian Alps in the very northwestern part of Slovenia, the average December temperature was − 0,7 ˚C, on Vogel (1515 m) in the southern part of the Julian Alps it was 1.2 ˚C, on Krvavec (1740 m) 0.6 °C and on Kredarica (2515 m) − 3.1 ˚C (ARSO 2007).

January 2007 was, relatively, the warmest month of the winter, which means that the positive anomaly from the average temperature was the biggest. From January 1 to January 21, the weather was very warm. During this period southwestern winds prevailed. On January 22, very unsettled weather with frequent precipitation began and the temperatures went slowly lower and lower. On January 24, after a cold front had passed Slovenia, winter weather began and lasted until the last days of January. On January 26 and 27, good conditions for nocturnal cooling in the frost hollows and cold basins appeared again. Although the last week of January was much colder than the previous ones, the average January temperatures were very much above the average. On Kredarica, the average daily temperature was below the average for only six days and the average January temperature was − 3.6 ˚C, which is 3.6 ˚C warmer than the average of the reference period. In Rateče, the average January temperature was 0.1 ˚C, which is 4 ˚C warmer than the average of the reference period. On Krvavec, January was 2.9 ˚C warmer than the average (ARSO 2007).

Table 1: The average monthly temperatures (˚C) for the period December 2006 – March 2007 at some Slovenian mountain stations and means of the reference period 1971–2000 (in the brackets).

	$T_{avg.}$ Dec 2006	$T_{avg.}$ Jan 2007	$T_{avg.}$ Feb 2007	$T_{avg.}$ Mar 2007	$T_{avg.}$ Dec 2006 – Mar 2007
Rateče (864 m)	− 0.7 (− 3.1)	0.1 (− 3.9)	0.7 (− 2.1)	3.1 (1.4)	0.8 (− 1.9)
Kredarica (2515 m)	− 3.1 (− 6.0)	− 3.6 (− 7.2)	− 5.5 (− 8)	− 5.7 (− 6.6)	− 4.5 (− 7.0)
Krvavec (1740 m)	0.6 (− 2.6)	− 0.9 (− 3.8)	− 1.8 (− 4)	− 0.9 (− 2.1)	− 0.8 (− 3.1)
Vogel (1510 m)	1.2	0.6	− 0.2	0.4	0.5

Source: ARSO 2006.

In February 2007, mild weather continued. During the whole month not even a single strong cold front passed Slovenia. However, there was a lot of unsettled weather, which is also called 'Atlantic' type of weather. The positive anomaly of temperature was smaller than in January, but it was still high. In Rateče, the average February temperature was

0.7 ˚C, which is 2.8 ˚C warmer than the average. On Kredarica, the average temperature in February 2007 was − 5.5 ˚C, which is 2.5 ˚C above the average, and on Krvavec the February temperature was 2.2 ˚C higher than the average (ARSO 2007). Due to the unsettled weather with frequent precipitation, conditions for nocturnal cooling in the frost hollows and cold basins were unfavourable and the lowest temperatures did not fall as low as in January or December. Additionally, temperature extremes did not appear on the same date, which also proves the changeability of the weather. The lowest temperatures appeared on February 4, 5, 17, 18 and 20.

Early spring weather started already in March and lasted until March 19. Until this date, the temperatures were similar to the average of April. On March 19, a strong cold front passed Slovenia and in most places in the lowlands, the highest snow cover of the winter 2006/2007 was measured. From 10 to 40 cm of snow fell in most of the Slovenian interior lowlands. In most of the Slovenian frost hollows and cold basins, the best conditions for nocturnal cooling in March appeared in the morning of March 22. In general, March 2007 was warmer than the average, although the positive anomaly was smaller than in the period December 2006 – February 2007. In Rateče, the positive anomaly of average March temperature was 1.7 ˚C, on Krvavec 1.2 ˚C and on Kredarica only 0.9 ˚C (ARSO 2007).

Table 2: Monthly air temperature (˚C) anomaly for the period December 2006 − March 2007 from corresponding means of the reference period 1971−2000.

	Anomaly (˚C) Dec 2006	Anomaly (˚C) Jan 2007	Anomaly (˚C) Feb 2007	Anomaly (˚C) Mar 2007	Average anomaly (˚C)
Rateče (864 m)	2.4	4	2.8	1.7	2.7
Kredarica (2515 m)	2.9	3.6	2.5	0.9	2.5
Krvavec (1740 m)	2	2.9	2.2	1.2	2.1
Average	2.4	3.5	2.5	1.3	2.4

Source: ARSO 2006.

We see that during the period of research the average monthly temperatures were much higher than usually. On average, the temperatures in this period were 2.4 ˚C higher than in normal winters.

Table 3: Monthly air temperature (˚C) and its anomaly from the corresponding means of the reference period 1971−2000 in Rateče and on Kredarica.

	$T_{avg.}$ Dec 2005 (˚C)	Anomaly (˚C)	$T_{avg.}$ Jan 2006 (˚C)	Anomaly (˚C)	$T_{avg.}$ Feb 2006 (˚C)	Anomaly (˚C)	$T_{avg.}$ Mar 2006 (˚C)	Anomaly (˚C)
Rateče	− 5.7	− 2.6	− 6.2	− 2.3	− 3.2	− 1.1	− 0.2	− 1.6
Kredarica	− 9.8	− 3.8	− 8.8	− 1.6	− 9.6	− 1.6	− 7.6	− 1.0

Sources: ARSO 2006, Oddelek za geografijo 2006.

If we compare average temperatures of the winter 2006/2007 with the winter 2005/2006, when we measured the lowest temperature ever measured in Slovenia, we see that in Rateče the average anomaly in the period December − March was 4.6 ˚C and on Kredarica 4.5 ˚C higher, which explains a lot about the conditions in frost hollows and cold basins during the winter 2006/2007.

3.2 The minimum air temperatures in the winter 2006/2007

Table 4: The minimum air temperatures (˚C) in the frost hollows of the Julian Alps in the winter 2006/2007 measured with digital thermometers.

	T min (˚C) December	Tmin (˚C) January	Tmin (˚C) February	Tmin (˚C) March	$T\ min_{abs}$	Date
Fužine plateau						
Planina Ovčarija alp (1633 m)	− 31	− 29.5	− 27.5	− 31	− 31	12.12.2006 and 22.3.2007
Vrtec (1634 m)	− 26.5	− 29.5	− 26.5	− 30	− 30	22.3.2007
Kriški podi						
Srednje Kriško jezero lake (1935 m)	− 24.5	− 22.5	No data	No data	− 24.5[1]	11.12.2006
Hribarice						
Hribarice (2306 m)	− 35	− 36.5	No data	− 28.5[2]	− 36.5	26.1.2007
Pokljuka plateau						
Medvedova konta (1310 m)	− 27	− 32	− 26.5	− 24.5	− 32	27.1.2007
Planina Javornik alp (1298 m)	No data	− 27.5	− 24.5	− 25.5	− 27.5	27.1.2007
Komna plateau						
Luknja (1430 m)	− 20	− 30.5	− 23	− 15.5[3]	− 30.5	27.1.2007
Krošnja (1448 m)	− 25.5	− 32.5	− 25.5	− 27.5	− 32.5	27.1.2007
Planina Govnjač alp (1455 m)	− 26	− 31.5	− 24.5	− 15[3]	− 31.5	27.1.2007
Mrzla Komna (1592 m)	− 30.5	− 29.5 [4]	− 26.5	− 31	− 31	22.3.2007
Planina Poljanica alp (1602 m)	− 26.5	− 22.5	− 22	− 22.5	− 26.5	11.12.2006
Planica valley						
Najen (1010 m)	No data	− 21	− 18	− 17	− 21	27.1.2007

[1] *Measurements only until 24 January 2007.*

[2] *Measurements started on March 17, 2007.*

[3] *Measurements only until March 19, 2007.*

[4] *Measurements were taken 75 cm above the ground (snow cover).*

Source: Slovenski meteorološki forum 2007.

Although the winter 2006/2007 was very mild, the lowest temperatures in the frost hollows fell relatively low, as shown in Table 5. That is because for low temperatures, only

a few hours of calm and clear weather during the night is needed, and this is possible also in very mild winters.

Table 5: The minimum air temperatures (˚C) in the frost hollows of the Dinaric plateaus Trnovski gozd and Snežnik during the winter 2006/2007 measured with digital thermometers.

	T min (˚C) December	Tmin (˚C) January	Tmin (˚C) Februar	Tmin (˚C) March 2007	T min $_{abs}$ (˚C)	Date
Trnovski gozd plateau						
Smrekova draga (1130 m)	− 13.8	− 20	− 14.1	− 16.3	− 20	27.1.2007
Snežnik plateau						
Velika Padežnica (1200 m)	− 22.5	− 28	− 21.5	− 9.5	− 28	27.1.2007

Source: Slovenski meteorološki forum 2007.

Figure 4: The lake Srednje Kriško jezero. On January 24, a snow avalanche destroyed the temperature station at the bottom of the frost hollow (Photo: M. Ogrin).

In the Julian Alps, the measurements are shown from 12 frost hollows on the Fužine plateau, the Kriški podi, the Hribarice, the Pokljuka plateau, the Komna plateau and the Planica valley. All the temperatures were measured with digital thermometers with the resolution of 0.5 ˚C. In eight cases, the lowest temperature fell to − 30 ˚C or lower. At the Srednje Kriško jezero lake, the temperature measurements were taken only until January 24. On this day, a snow avalanche destroyed and buried the temperature station. From among the measured values the frost hollow Hribarice is with − 36.5 ˚C from January 26, 2007, by

far the coldest. This is the highest frost hollow, where measurements were taken in Slovenia so far. It lies at an elevation of 2306 m. It is also interesting that the minimum was measured a day earlier than in the lower frost hollows. Also the second coldest value, − 35 ˚C, which was measured on December 11, 2006, appeared a day before than at lower elevations. This is because after a cold front passes Slovenia, especially in winter, dry air at higher elevations comes easily and earlier, while at lower elevations cloudiness and moisture remain a day or sometimes even longer.

If we take a look at the meteorological conditions on January 26, 2007, we see that on that day under the elevation of 2000 m the sky was still covered with low clouds. However, the area of Hribarice was already above the upper cloud line. During the day of January 26, also the sky cleared slowly at lower elevations and in the following night in many lower frost hollows and cold basins the best conditions for nocturnal cooling appeared. At the same time the wind started to blow at higher elevations, so a cold air pool could not form on the Hribarice.

This confirms also the fact that on January 27, among the frost hollows on the Komna plateau, the ones with a lower elevation and a smaller sky view factor (the Planina Govnjač alp, Luknja, Krošnja) had lower minima than the Mrzla Komna, which is more than 100 m higher and also a more open. Usually, the Mrzla Komna is colder if conditions are the same. In Luknja, Krošnja and the Govnjač alp − 30.5 ˚C, − 32.5 ˚C and − 31.5 ˚C were measured this morning and on the Mrzla Komna − 29.5 ˚C.

Figure 5: The Planina Ovčarija alp is one of the coldest frost hollows in the Slovenian Julian Alps (Photo: J. Ortar).

On the Mrzla Komna and also on the Planina Ovčarija alp, the minimum of the winter was − 31 ˚C. In both, this temperature was measured on March 22, 2007. The same temperature was measured in the Planina Ovčarija alp on December 12, 2006. On this very night, the lowest temperature on the Mrzla Komna was − 30.5 ˚C.

The same January minimum was measured in both frost hollows. It was on January 27, when the temperature fell to − 29.5 ˚C. Also in February, both had the lowest temperature on the same date. On the Planina Ovčarija alp − 27.5 ˚C and on the Mrzla Komna − 26.5 ˚C were measured. The temperatures in both frost hollows were very similar and they were also measured on the same date. In January and February 2007, very similar minimum temperatures appeared also in Vrtec. However, in December 2006 the minimum was significantly higher. The Planina Poljanica alp is located near Mrzla Komna at an elevation of 1602 m. We noticed that although it has very similar properties as the Mrzla Komna and is also very close to it, the minimum temperatures were significantly higher. The only explanation is its location under the mountain Kal (2001 m). We think that downslope wind from the southern slope of Kal disturbs nocturnal cooling in the Planina Poljanica alp.

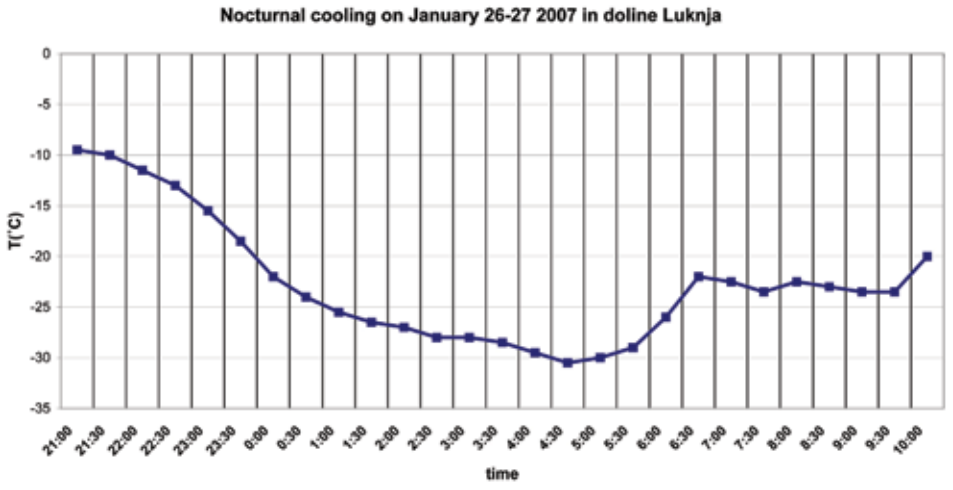
Figure 6: The Planina Javornik alp is a large Alpine pasture with small frost hollows, where winter temperatures often fall below − 30 ˚C (Photo: M. Ogrin).

A special group of Alpine frost hollows are the ones on the Pokljuka plateau. It is a karst plateau at an elevation between 1100 and 1400 m. It has a lot of concave relief depressions, such as uvalas, or dolines. In some of them which are more open and not so steep are also Alpine pastures (the Planina Kranjska dolina alp, the Planina Velika Raven alp, the Planina

Klek alp). The Planina Javornik alp is one of the most known, it is also a big Alpine pasture with shallow frost hollows, where cold air pools form daily. The deepest frost hollow is the uvala called Medvedova konta, which is almost symmetrical and 61 m deep with the bottom at 1310 m. The plateau itself is a generator of cold air, but cold air pools in these frost hollows are even more resistant and intensive. The Medvedova konta uvala is known for the strongest inversions because it is deepest and, except on the bottom, covered with dense spruce forest, which also prevents the wind from blowing the cold air out of the frost hollow. In summer time, when no snow cover appears, cold air blows also from small holes on the karst ground, which also generates a cold air pool. However, this effect is impossible in winter due to snow cover and also because the ground (and the air within) are warmer than the outside temperature in the Medvedova konta. In the winter 2006/2007, the lowest temperature in the Medvedova konta was − 32 ˚C, surprisingly 0.5 to 1 ˚C lower than on higher and presumably colder frost hollows on the Komna.

The frost hollow Najen in the Planica valley is very interesting for researches of frost hollows in valley bottoms. A concave relief shape is a result of moraine accumulation (Ogrin, Krevs 1995). Its elevation of 1010 m is quite low for Alpine frost hollows. But according to some field measurements, this is not the only very cold place of the Planica valley. Very similar temperatures were measured also in the lowest part of the valley on the Rateško polje plain near the Ledine lake. On January 16, 2005, at 7:45 the temperature in Najen was − 20.8 ˚C. About 40 minutes later − 20.5 °C were measured on Rateško polje plain. In the morning of January 30, 2005, − 24.3 ˚C were measured in Najen and about 30 minutes later − 25.2 °C were measured on the Rateško polje plain. In the winter 2006/2007, there were no measurements on the Rateško polje plain.

Figure 7: Nocturnal cooling in the Velika Padežnica (1200 m) from January 26 to January 27, 2007.



Source: Slovenski meteorološki forum 2007.

The Smrekova draga on the Trnovski gozd plateau is a well known frost hollow and it is famous for vegetation inversion. This phenomenon is also a result of a synergy between radiative cooling and a cold air flow from the karst underground when the ground is not under the snow cover. The minimum, which was measured on January 27, was − 20 ˚C. In the last three years, since the beginning of our measurements of temperatures in Smrekova draga, we noticed that due to the frequent bora wind, which is a very common wind for Dinaric plateaus in Slovenia, this frost hollow did not have very low minima during cold advection. In such situations a strong bora wind on area of Smerkova draga disturbs the cold air pool formation very efficiently.

The Velika Padežnica is one of the largest and most famous frost hollows on the Snežnik plateau. It is a large uvala with cultivated pasture in the bottom and also a hunter's hut. The measurements in the Velika Padežnica have been taken since November 2005. During the winter 2006/2007 the lowest temperature was − 28 ˚C. It was measured on January 27. In Fig. 7, we see that on that very night nocturnal cooling was disturbed twice during the night and conditions were far from ideal.

Figure 8: A smoke plume trapped within the temperature inversion in the Velika Padežnica. The morning summer sun still did not mix the cold air pool (Photo: M. Ogrin).

In the winter 2006/2007, we started with measurements also on the Pohorje mountains. We found a concave depression, which could have some signs of a frost hollow. It is a small valley named Radovna, between Mizni vrh and Travni vrh at an elevation of 1220 m. The main ridge of the Pohorje is flat on its top and there are some shallow depressions, which are not a result of karst processes because there are no limestone or dolomite. We call them

nivation hollows (Ogrin et al. 2007). From these hollows the water runs off on the surface. Its way out of the frost hollow was made by erosion and not by corrosion as is the case in other frost hollows in the Julian Alps (except Najen) and Dinaric plateaus. This means that cold air can also flow out of the Radovna what worsens the conditions for effective nocturnal cooling. During the period of research, the minimum temperature was − 16 ˚C, which is far from the values in other frost hollows.

Table 7: The minimum temperatures (˚C) in the frost hollows of the Slovenian Istria and on the Pohorje in the winter 2006/2007 measured with alcohol minimum thermometers.

	Elevation (m)	T_{min} (˚C)	Period of measurements	Date (presumably)
Slovenian Istria				
Zalipnik	755	− 8.5	26.11.2006 – 9.2.2007	
Movraška vala*	170	− 10.5	1.12.2006. − 13.2.2007	28.12.2006
Upper Rižana Valley	60	− 8.5	16.12. − 28.12.2006	28.12.2006
Malinska	360	− 9.5	16.12. − 28.12.2006	28.12.2006
Pohorje				
Radovna	1220	− 16.0	20.1. − 1.5.2007	

** Measured partly with an alcohol minimum thermometer and partly with a digital thermometer.*
Source: Oddelek za geografijo 2007.

Table 8: The minimum temperatures (˚C) in the cold basins of the Notranjska region in the winter 2006/2007.

	Elevation (m)	28.11. 2006 – 18.12.2006	18.12.2006 – 13.1.2007	13.1.2007 – 2.2.2007	2.2.2007 – 20.2.2007	20.2.2007 – 11.3.2007	11.3.2007 – 4.4.2007	$T_{min\ abs}$ (˚C)
Loško polje	570	− 8.0	− 5.5	− 14.0	− 7.5	− 3.5	− 7.5	− 14.0
Babno polje	750	− 10.5	− 15.0	− 20.0	− 12.5	− 8.0	− 8.0	− 20.0
Bloke plateau	720	*	− 12.5	− 18.0	− 7.5	2.0	− 5.0	− 18.0
Retje	705	− 9.0	− 16.0	− 20.0	− 10.5	− 4.5	− 9.0	− 20.0
Podpreska	740	− 9.0	− 12.0	− 18.0	− 7.0	0.0	− 4.0	− 18.0
			20.1. − 30.1.					
Rakitna	785	*	− 20.5		*			− 20.5

* No measurements
Sources: Oddelek za geografijo 2007; Slovenski meteorološki forum 2007.

The cold basins of the Notranjska region belong to a special group. They are mostly poljes, larger and deeper depressions with more or less flat bottoms and higher surroundings. The only exception is the Bloke plateau which is mostly made of dolomitic rocks. These cold basins are much larger than the Alpine frost hollows. However, their elevations are much

lower, between 570 and 785 m. All the poljes have been inhabited for centuries and local people are used to low nocturnal temperatures in all seasons of the year. The most famous among them is Babno polje, which is also known as "Slovenian Siberia". This is so because on the Babno polje there is a meteorological station and it is known as the coldest station within the national network of Slovenian meteorological stations. After all, − 34.5 ˚C which is the officially lowest temperature ever measured in Slovenia, was measured on the Babno polje. It was on February 15 and 16, 1956, and on January 13, 1986. The meteorological station on the Babno polje is located at its edge, about 10 m above the lowest part of the polje bottom. As a result, minimum temperatures at the bottom of the polje can be about 5 ˚C lower than at the meteorological station. Our temperature station was set at the polje bottom. But the measurements in other poljes, such as Retje, Podpreska or Rakitna also showed similar or even bigger potential for nocturnal cooling. In the winter 2005/2006, Podpreska was the coldest among these poljes and, in the winter 2006/2007, the coldest cold basin of the Notranjska region was Rakitna.

However, the Babno polje is still the coldest place with a meteorological station within the national observation network in Slovenia. The thanks go to Mr. Dušan Ule, who has been observing the weather in this unique part of Slovenia for decades. Due to the very mild weather in the winter 2006/2007, the cold basins in the Notranjska region did not have very low temperatures. The lowest temperature, − 20.5 °C, was measured in Rakitna polje. It was probably measured on January 27, 2007. The measuring period in Rakitna lasted for only 11 days but this was the coldest period of the winter 2006/2007. Probably during the same morning, − 20 ˚C were measured in the Babno polje and Retje and − 18 ˚C were measured on the Bloke plateau and in Podpreska. On the Loško polje, only − 14 ˚C were measured. In comparison with the winter 2005/2006, the absolute minima were 6 to 10 ˚C higher. But in the winter 2004/2005, on March 1, 2005, − 36 °C were measured on the bottom of the Babno polje and on January 24, 2004, − 32 ˚C were measured.

4. CONCLUSION

The weather during the winter 2006/2007 was extremely mild, which reflected also at temperature minima in the Slovenian frost hollows and cold basins. Compared with the winters 2004/2005 and 2005/2006, the minima did not reach − 40 ˚C. Although for extreme minimum temperatures a very short period, sometimes even one night, is enough, in the winter 2006/2007 there was not any. The best conditions for nocturnal cooling appeared in the night from January 26 to January 27, 2007. And at higher elevations they appeared one night earlier. Very good conditions appeared in some frost hollows and cold basins also in the morning on March 22, 2007. In the frost hollows of the Komna plateau and on the Fužine plateau, the temperatures fell to − 30 or to − 32 ˚C, and on the Hribarice (2306 m) the temperature fell even lower, down to − 36.5 ˚C, which is the absolute minimum measured in Slovenia in the winter 2006/2007. But conditions were still far from ideal!

When searching for the coldest spot in Slovenia, we found some new candidates beside the Mrzla Komna, for example, the Planina Ovčarija alp, Krošnja and Hribarice. In some cases also the Medvedova konta can be very cold, although a bad sky view factor and a lower

elevation are a handicap for this frost hollow. Due to bad conditions for nocturnal cooling during the winter 2006/2007, a good and relevant comparison between the frost hollows and cold basins was not possible. Due to its high elevation, a new dimension is opened by the frost hollow Hribarice. It is among the highest known frost hollows in the Alps and when there is calm and dry winter atmosphere, the minima around − 50 °C are possible.

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MINIMALNE TEMPERATURE V ZIMI 2006/07 V SLOVENSKIH MRAZIŠČIH

Povzetek

Člani Slovenskega meteorološkega foruma, Oddelka za geografijo FF Univerze v Ljubljani in Gozdarskega inštituta Slovenije smo v letu 2004 pričeli z meritvami v slovenskih mraziščih. Glavni cilj teh meritev je osvetliti temperaturne razmere na dnu mrazišč, saj so to z vidika temperature precej ekstremne lege, ki so bile v Sloveniji le delno preučene pred nekaj desetletji. Mreža meritev se je v obdobju 2004−2006 razširila, z meritvami pa smo nadaljevali tudi v zimi 2006/2007. Meritve so potekale v več kot 30 mraziščih Julijskih Alp, Karavank, Pohorja, Snežnika, Trnovskega gozda, Notranjske in slovenske Istre.

Meritve so del sistematične mreže in v nekaterih mraziščih potekajo neprekinjeno, ponekod pa le pozimi. Merilni inštrumenti so digitalni registratorji (T gumbki) in analogni minimalni alkoholni termometri, sevalno zaščito pa jim zagotavljajo posebej prirejeni zakloni, postavljeni približno 2 m nad tlemi.

Čeprav je bila zima 2006/2007 zelo mila, so v redkih nočeh z ugodnimi pogoji za izrazito nočno ohlajanje temperature padle pod − 30 ˚C. Tako smo v najhladnejših mraziščih Komne in na Fužinskih planinah izmerili absolutne temperature med − 30 in − 32,5 ˚C, v večini primerov pa je bila najnižja temperatura izmerjena 27. januarja 2007 zjutraj. V zimi 2006/2007 smo prvič opravljali meritve tudi v mrazišču Hribarice, ki je zaenkrat najvišje odkrito mrazišče v Sloveniji, saj leži na nadmorski višini 2306 m. To mrazišče je opravičilo predvidevanja, saj smo v njem 26. januarja 2007 izmerili celo − 36,5 ˚C, kar je vsaj 3,5 ˚C hladneje kot v mraziščih Komne in Fužinskih planin, ki so doslej veljala za najhladnejša. Očitno je, da je to mrazišče zaradi nadmorske višine zelo verjetno najhladnejše do sedaj odkrito mrazišče v Sloveniji, le zelo mila zima pa je preprečila tudi precej nižje temperature. Izkazalo se je tudi, da absolutni minimumi v Hribaricah pogosto nastopijo dan prej kot v nižje ležečih mraziščih, kar je povezano z zgodnejšo razjasnitvijo po prehodu hladne fronte v visokogorju kot pa v nižjih legah.

V obravnavanem obdobju smo presenetljivo nizke temperature izmerili tudi v mrazišču Medvedova konta na Pokljuki, ki leži 200−300 m nižje kot večina mrazišč na Komni in Fužinskih planinah. Minimalna temperatura je bila tam − 32 ˚C.

Kraška polja na Notranjskem so imela v obravnavanem obdobju mile minimume, ki so bili med − 14 ˚C in − 20 ˚C, kar je v primerjavi z zimama 2004/2005 in 2005/2006 višje za 10−15 ˚C, v opazovanih mraziščih slovenske Istre pa je bil izmerjen minimum − 10,5 ˚C.