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WHAT CAN WE LEARN FROM ARCHIVE RECORDS OF SNOW AVALANCHES IN THE TATRA MOUNTAINS?

Abstract. The aim of studies was to summarize all available published records of snow avalanche events in the Tatra Mountains in a form of a geodatabase and assess the usefulness of compiled information for analyses of long-term changes in snow avalanches characteristics. The systematic study of various sources from Poland and Slovakia resulted in geodatabase including about 3406 avalanche events, of which 2033 were registered in the Polish and 1373 in the Slovakian parts of the Tatra Mountains. The geodatabase comprises information about location, type and size of the avalanche, time of the event, source of the information as well as information about rescue missions, number of injured and fatalities. The snow avalanches causing the accidents are well documented. The rest of the avalanches were registered only as a result of the researches lasting from one up to maximum 11 winters or sporadic observations. In the Polish part of the High Tatra Mountains most of the avalanches were reported (681 events) in the Białka Valley, especially the Mięguszowieckie Szczyty ridge. In the Slovakian part of the Tatra Mountains most of the records came from the Žiarska Valley (222 events), especially the Tri kopy ridge. Although the records are unsystematic, the collected information can be used, if processed with caution, to analyse the certain aspects of the avalanche activities. The geodatabase was designed and developed in the way that allows future improvements by adding new records, either recent or historical ones.

Keywords: Snow avalanches, historical records, avalanche accidents, the Tatra Mountains

INTRODUCTION

Snow avalanches are one of the main factors that shape the landscape and pose a serious threat to both human life and infrastructure in the mountainous regions (Keylock 1997). Snow avalanches, rapid movements of huge masses of snow usually happen on a slope with inclination 25–50° (McClung, Schaerer 2006; Sekiguchi et al. 2005), where considerable amount of snow is accumulated (Schweizer et al. 2003) and specific weather conditions lead to the changes of snow structure (Kłapa 1959). The movement of snowpack is triggered by various factors e.g. wind, changes in weather conditions, additional pressure caused by new snowfall (Schweizer et al. 2003), presence of people (Schweizer, Lütschg 2001) and earthquakes (O'Leary, Ranger 1968;

Podolskiy et al. 2010). Although snow avalanches are highly energetic processes, very often they leave little mark in the landscape. Most of the avalanches constitute only snow movement on the slope and they can be left unnoticed in the landscape in the following spring or summer after the snow melts down. The wet type of avalanche is the exception – it can erode the slope and leave the mark in the relief (Gardner 1983; Ackroyd 1986). Moreover, the frequent avalanching in one gully can modify the shape of cones in the runout zone (Jomelli, Francou 2000; Luckman 1978; Lempa et al. 2015). Significantly different situation can be observed, when an avalanche reaches the forest or dispersed trees above the treeline. All kinds of avalanches have the ability to change the course of the treeline (Bebi et al. 2009; Walsh et al. 1994; Czajka et al. 2012; Kaczka et al. 2015; Spyt et al. 2016) and injure individual trees (Lempa et al. 2016; Šilhán, Tichavský 2017), which comprise the long-lasting fingerprint. The occurrence, magnitude and type of snow avalanches are difficult to predict since an avalanche can be triggered by several factors which are influenced by relief and weather conditions (Perla, Martinelli 1976; Schaerer 1977; Feer, Schaerer 1980; Luckman 1992; McClung, Schaerer 1985; Smith 1995; Smith, McClung 1997a,b; Weir 2002; Maggioni, Gruber 2003). The complexity of triggering factors makes the snow avalanches particularly dangerous in the mountainous regions where human presence is permanent. The disastrous events causing thousands of casualties happened when the avalanches reached the settlements, either permanent or temporary (Huascarán-Ancash, Peru, May 31th 1970: 20,000 deaths; Marmolada, Italy, December 13th 1916: 10,000 deaths; Huascaran Avalanche, Peru, January 10th 1962: 4,000 deaths). The most tragic avalanche accidents in the Tatra Mts. happened in the Mengusovská Valley in January 20th 1974 (12 deaths) and in the Rybi Potok Valley (Białka Valley) in January 28th 2003 (8 deaths). The first snow avalanches in the Tatra Mountains were reported in the context of the accidents that happened to the iron miners in the mid of the 19th century (Stolarczyk 1915) in the Polish Tatra Mountains. Probably the first reported avalanche victim in the Slovakian Tatra Mountains was a hiker Ján Mahlar who lost his life in 1888 (www.hzs.sk). From that period most of the snow avalanche accidents and mountain rescue services interventions have been related to tourist activities (Fig. 1). This is a typical scenario in most of the European mountains (the Carpathians, in most cases in the Alps, the Caucasus, the Pyrenees). Therefore, it can be presumed that the increase of winter sports popularity (Zweifel et al. 2006) may lead to the higher number of cases when tourists and mountain rescue service employees would be in danger because of snow avalanches. Every year the number of visitors in the Tatra Mountains is higher and nowadays almost all avalanche accidents involve tourists and/or skiers. Although only 15% of annual tourist traffic in the Polish part of the Tatra Mountains falls on winter months (Pociask-Karteczka et al. 2007), it is still over 200 000 (2002) up to 600 000 tourists per year (2016). On the other hand, since 1980 the highest parts of the Slovakian Tatra Mountains

Fig. 1. The search of the tourists caught by snow avalanche as part of a rescue operation performed by the Tatra Volunteer Search and Rescue (TOPR) in the Hala Kondratowa in 1935 (Author unknown)

have been excluded from legal tourism during the whole winter and spring (from November until June).

The temporal dynamics of snow avalanches are influenced by the changes of climate (Martin et al. 2001; Lazar, Wiliams 2008; Castebrunet et al. 2014) and modifications of land use. These affect the long-term trends of avalanches' characteristics such as number of events, size, type and seasonality (Castebrunet et al. 2014; Lavigne et al. 2015). The decrease of winter solid precipitation (Falarz 2001, 2002; Żmudzka 2011; Ustrnul et al. 2015) accompanied by the increase of winter and spring temperature (Żmudzka et al. 2015) result in general reduction of avalanches in the Tatra Mountains (Gądek et al. 2016), whereas the reports from the other mountains emphasize the lack of direct link (Schneebeli et al. 1997; Bader, Kunz 2000; Eckert et al. 2010). In addition, the creation of national parks in Slovakia (1949) and Poland (1955) lead to introducing of a strict policy of natural protection. It has resulted in a reforestation, including the highest parts of the subalpine and mugo pine zones. The denser and higher forest and dwarf mountain pine thicket stabilize the snow cover (McClung 2001) and increase the roughness of surface (Kajimoto et al. 2004) reducing the probability of avalanching even more.

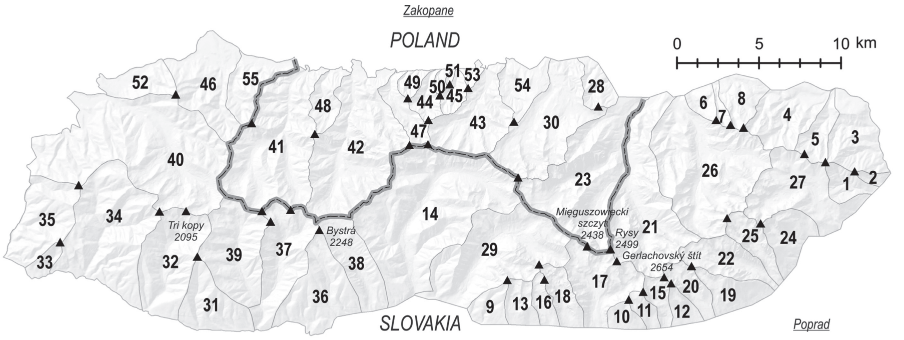
The aim of this study was to summarize all available records of snow avalanche events for the Tatra Mountains in a form of a geodatabase and assess the usefulness of compiled information for analyses of long-term changes in snow avalanche characteristics.

GEOGRAPHICAL SETTINGS

The Tatra Mountains occupy an area of 785 km^2, mostly in Slovakia (77.7%) and partly in Poland (22.3%) (Radwańska-Paryska, Paryski 1995). The highest peak, Gerlachovský štít (2655 m a.s.l.) is located in the Slovakian part, whereas Rysy (2499 m a.s.l.) is considered as the highest peak of Poland. The Tatra Mountains are young mountains of the Alpine orogeny. Although the Tatra Mountains are significantly smaller than the Alps, their landscapes are generally alike due to the similarities in geology and distinct features of post-glacial relief. The Tatra Mountains form a barrier for the air circulation and the local weather is influenced mainly by the polar marine (65%) and polar continental (25%) air masses (Niedźwiedź et al. 2015). The mean annual temperature ranges from about 6°C at the foothills (600–650 m a.s.l.) to –4°C on the highest peaks of the Tatra ridge (Hess 1965; Niedźwiedź 1992). Mean annual precipitation changes with altitude reaching 1890 mm at the tops of the ridges. The number of days with snow cover in the Tatra Mountains is about 100 at the foothills and almost 300 on the highest peaks (Hess 1965). The relief and local climate create suitable conditions for snow avalanche formation. In total, 3770 avalanche tracks were identified in the Tatra Mountains (Rączkowska et al. 2016) using geomorphological methods.

MATERIALS AND METHODS

The information about avalanche events from all available sources (described in detail in the next chapter) were collected and put together in a form of a geodatabase. It includes reports about the date and location of avalanche events, name of the source and other accessible data e.g. size, type, number of casualties are included in the geodatabase. Afterwards, the simple spatiotemporal analyses were performed using the ArcMap 10.2.2 software for the whole Tatra Mountains and for 55 main valleys following the geographical division proposed by Z. Radwańska-Paryska, W. Paryski (1995), (Fig. 2). Only the Białka Valley was split in two parts due to the location in two countries. The avalanche records derived from different sources were compared with the map of known snow avalanche tracks recently developed by M. Žiak, M. Długosz (2015) and Z. Rączkowska et al. (2016), (Fig. 3). The information about the tourist activities (tourist paths and number of visitors) were obtained from



	Tatra region	Country	Valley: Polish	Valley: Slovakian	Area [km^2]	Altitude [m a.s.l.] Max	Altitude [m a.s.l.] Min	The highest peak	The amount of avalanche paths
1	Belianske Tatra Mts	Slovakia	Czarna Rakuska	Čierna Rakúska	4.5	1947	877	Bujačí vrch	6
2		Slovakia	Huczawy Bielskiej	Belanská Hučava	1.2	1488	779	Faixova	0
3		Slovakia	Kotliny	Kotliny	12.7	1947	760	Bujačí vrch	6
4		Slovakia	Bielskiego Potoku	Belej	13.2	2152	867	Havran	29
5		Slovakia	pod Koszary	dolina pod Košiare	5.5	2012	866	Jatky	17
6		Slovakia	Międzyścienna	Medzistenná	3.0	1890	949	Muráň	0
7		Slovakia	Nowa	Nowá	1.5	1999	947	Nový vrch	10
8		Slovakia	Hawrania	Havrania	6.5	2152	924	Havran	29
9	High Tatra Mts	Slovakia	Bielańska	Bielanská	4.4	2494	1195	Kriváň	4
10		Slovakia	Wielkiej Huczawy	Veľkej Hučavy	2.9	2285	1482	Tupá	6
11		Slovakia	Stwolska	Štôlska	2.6	2538	1477	Končistá	12
12		Slovakia	Stos	Hromadná	3.1	2601	1380	Kotlový štít	18
13		Slovakia	Ważecka	Važecká	4.7	2494	1501	Kriváň	27
14		Slovakia	Cicha Liptowska	Tichá	52.3	2301	974	Svinica	220
15		Slovakia	Batyżowiecka	Batizovská	3.6	2654	1454	Gerlachovský štít	70
16		Slovakia	Furkotna	Furkotská	3.3	2413	1547	Veľké Solisko	29
17		Slovakia	Mięguszowiecka	Mengusovská	15.2	2560	1344	Vysoká	143
18		Slovakia	Mlynicka	Mlynická	5.8	2428	1471	Hrubý vrch	69
19		Slovakia	Sławkowska	Slavkovská	7.1	2476	1291	Bradavica	54
20		Slovakia	Wielicka	Velická	5.3	2654	1407	Gerlachovský štít	76
21		Slovakia	Białej Wody	Bielovodská	29.3	2638	955	Zadný Gerlach	364
22		Slovakia	Staroleśna	Veľká Studená	9.9	2476	1140	Bradavica	183
23		Poland	Białki	Bielovodská	34.6	2499	955	Rysy	298
24		Slovakia	Łomnicka	Skalnatá	8.2	2632	1135	Lomnický štít	63
25		Slovakia	Małej Zimnej Wody	Malá Studená	6.2	2632	1155	Lomnický štít	151
26		Slovakia	Jaworowa	Javorová	39.1	2627	990	Ľadový štít	358
27		Slovakia	Kieżmarska	Kežmarskej Bielej Vody	20.0	2632	895	Lomnický štít	127
28		Poland	Filipka		4.8	1489	940	Gęsia Szyja	3
29	HT/WT	Slovakia	Koprowa	Kôprová	32.7	2494	974	Kriváň	233
30		Poland	Suchej Wody	Suchej vody	24.5	2301	943	Svinica	108
31	Western Tatra Mts	Slovakia	Tarnowiecka	Trnovská	11.4	2184	862	Baranec	23
32		Slovakia	Żarska	Žiarska	20.0	2184	869	Baranec	116
33		Slovakia	Dolina Szankowa	Šanková dolina	2.5	1566	789	Babky	0
34		Slovakia	Jałowiecka	Jalovecká	33.0	2184	783	Baranec	125
35		Slovakia	Sucha Sielnicka	Suchá Sielnická	15.3	1805	692	Sivý vrch	3
36		Slovakia	Bystra	Bystrá	16.9	2248	910	Bystrá	44
37		Slovakia	Raczkowa	Račkova	17.5	2248	885	Bystrá	65
38		Slovakia	Kamienista	Kamenistá	11.7	2248	998	Bystrá	44
39		Slovakia	Jamnicka	Jamnícka	19.1	2194	953	Jakubina	86
40		Slovakia	Zuberska	Studená	57.5	2178	789	Baníkov	150
41		Poland	Chochołowska		35.1	2137	914	Jarząbczy Wierch	113
42		Poland	Kościeliska		31.3	2176	904	Starorobociański Wierch	149
43		Poland	Bystrej		16.9	2005	924	Kopa Kondracka	76
44		Poland	Strążyska		3.7	1894	894	Giewont	8
45		Poland	Białego		2.9	1762	910	Długi Giewont	6
46		Slovakia	Bobrowiecka Orawska	Bobrovecká	17.4	1663	785	Bobrovec	4
47		Poland	Małej Łąki		5.7	2096	922	Małołączniak	19
48		Poland	Lejowa		5.6	1829	910	Kominiarsk Wierch	2
49		Poland	za Bramką		2.1	1447	897	Łysanki	0
50		Poland	ku Dziurze		1.0	1377	894	Sarnia Skała	0
51		Poland	Spadowiec		0.4	1267	904	Łomik	0
52		Slovakia	Błotna	Blatná	7.4	1687	795	Osobitá	0
53		Poland	nad Capkami		1.2	1378	902	Krokiew	0
54		Poland	Olczyska		7.7	1704	879	Kopa Magury	2
55		Slovakia	Cicha Orawska	Tichá	9.5	1663	828	Bobrovec	0

Fig. 2. Characteristics of the study area

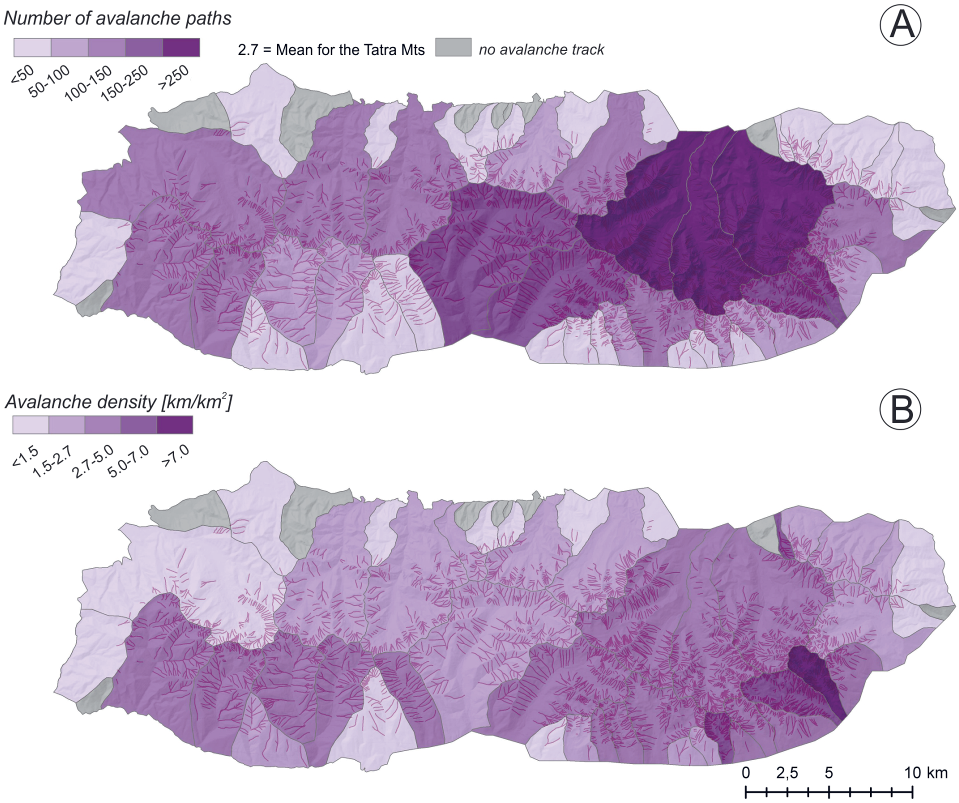


Fig. 3. (A) The map of the potential avalanche tracks based on the research of M. Žiak (2012) and M. Žiak and M. Długosz (2015) and (B) density of the avalanche tracks in 55 studied valleys (see Fig. 2 for detailed information). Violet lines – potential avalanches tracks after M. Žiak and M. Długosz (2015)

the tourist map 1: 25,000 and records about the number of sold tickets at the entrance to the Tatra National Park. The distinct differences between the organization of the collecting, keeping and sharing the records about snow avalanches in Poland and Slovakia were the main reason why several analyses were performed as a kind of compression between part of the Tatra Mountains which lay in these two countries.

THE SOURCES OF THE RECORDS OF SNOW AVALANCHES IN THE TATRA MOUNTAINS

The geodatabase was established based on various available sources, such as publications in bulletins, quarterlies, conference papers, scientific articles, newspapers, popular science magazines, as well as printed or on-line chronicles.

Since the same avalanche events and monitoring were sometimes reported in different sources, their reports were crosschecked and verified. The percentage division of avalanche sources used to build database is presented in Figure 4. In total, the information about avalanche events was derived from 1159 and 1335 sources, in the Polish and Slovakian parts of the Tatra Mountains, respectively.

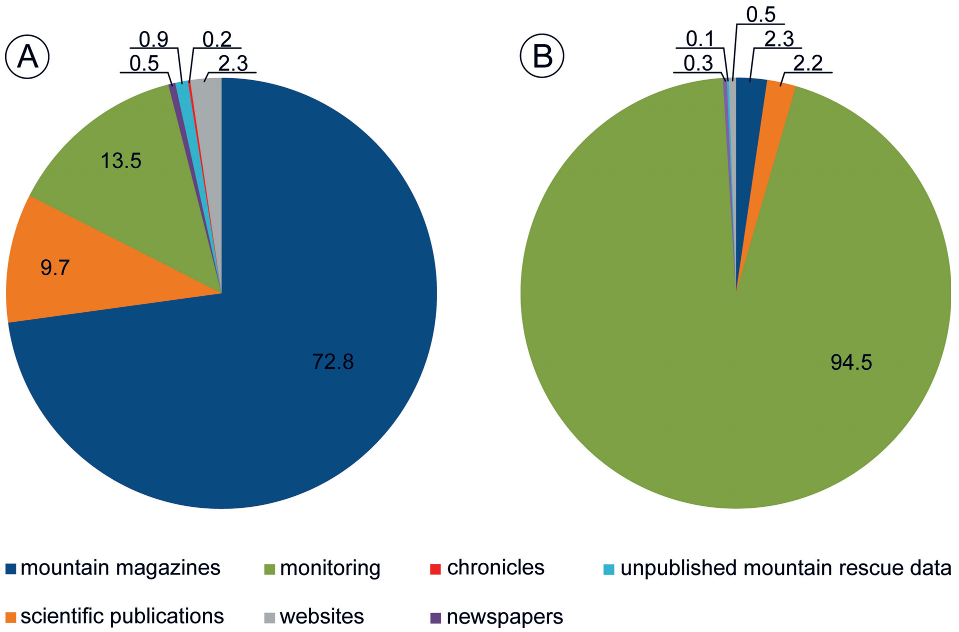


Fig. 4. The percentage structure of the sources employed in geodatabase. (A) Poland and (B) Slovakia

The information about the oldest snow avalanches in the Polish Tatra Mountains can be found in the parish chronicle of Zakopane (Stolarczyk 1915) and death records in Kościelisko Village.

The avalanche events in the Polish Tatra Mountains were reported mostly in the popular science magazine entitled "Wierchy" (~15.7%) which has been issued yearly since 1923 by the *Polish Cultural Tatra Society*. Nearly 77% of the information about avalanche events described in "Wierchy" magazine was based on the reports from the Polish Mountain Rescue Services, including TOPR (Tatra Volunteer Search and Rescue) and GOPR (Mountain Volunteer Search and Rescue). Worthy of note are articles written by M. Kłapa (1959) and M. Kłapowa (1969). Moreover, the chronicle "Wołanie w górach" (Jagiełło, 2002) describes around 6% of avalanche events. The magazine "Taternik" of the Polish Mountaineering Association, one of the longest issued magazines informing about the various mountain related matters, reported about 2% of avalanche events since year 1907. The unique source of avalanche records constitutes "Pamiętniki Towarzystwa Tatrzańskiego" issued by the *Polish Cultural Tatra*

Society over the period 1876–1920 and 1992–2003. However, the particular attention should be focused on issues written in 1910 by M. Zaruski (<1%), who concentrated on avalanches in the Rybi Potok Valley (Białka Valley) and described them in detail. Moreover, articles written by K. Chomicz in the 1960s (1962, 1964) provide complex information about snow and avalanches (~1%). The information about the avalanche events were also reported in the newspaper "Ilustrowany Kuryer Codzienny" in 1940s (<1%). Around 2% of the information comes from different websites and about 1% from the reports provided on the TOPR website.

K. Grósz described one of the earliest avalanche events in the Slovakian Tatra Mountains in an article published in 1916 (~2%). The more recent events have most often been reported by the Slovakian Mountain Rescue Service – *Horská záchranná služba* (20%) in a form of yearly issued volume since 2004/2005 winter. The avalanches in the Slovakian Tatra Mountains are also mentioned in the records found in the Polish sources described above.

Monitoring in the Polish Tatra Mountains have been conducted by M. Kłapowa and reported in the "Wierchy" magazine in 1969 (~43%). The results of this stream of permanent avalanche observations are one of the most valuable sources of information although author did not provide information about each encountered event. Instead a generalized picture, e.g. number of avalanches per month in given location, is provided. Recent monitoring was reported in the bulletin "Biuletyn Śniegowy dla Tatr Polskich" for 2012–2014 period, issued by the Institute of Meteorology and Water Management (~14%). The avalanche conditions in 2004–2006 period was described in the article about snow conditions in the Polish Tatra Mountains written by A. Fiema et al. (2007a, b) (~8%). Z. Rejowska (1948) in the magazine "Taternik" reported about 8% of avalanche observations. In the Slovakian Tatra Mountains nearly 75% of observations have been conducted and reported by the Mountain Rescue Service *Horská záchranná služba* since 2004/2005 when the monitoring of snow avalanches was initiated.

The information about snow avalanches was also presented in a cartographic form almost from the beginning of the research on avalanches in the Tatra Mountains. The research performed at the Wysokogórska Stacja Klimatologiczna Instytutu Geograficznego UJ in the Pięć Stawów Polskich Valley in 1928–1930 (Leszczycki 1929a, b, c, 1931; Milata 1937) was summarised on the map of avalanches in the area (Pawlik 1931). The information about snow avalanche hazard was included in a winter ski map of the Polish Tatra Mountains scale of 1: 20 000 (WIG, 1934). The manuscript map of avalanches based on the monitoring in the Polish Tatra Mountains conducted by M. Kłapowa 1959–1967 was created in 1976. The cadaster of the snow avalanches was developed by L. Milan (1981) and later the map of the potential avalanche tracks in the Slovakian Tatra Mountains was created by M. Žiak (2012). The similar technique was applied for the Polish part and resulted in the map of potential snow avalanche tracks (Ž i a k, D ł u g o s z 2015). The usefulness of these records was limited since they mostly focus on the spatial distribution of the avalanches and do not provide information about timing of the particular events.

THE RECORDS OF THE SNOW AVALANCHE EVENTS

The snow avalanche geodatabase includes about 3406 avalanche events, of which 2033 were registered in the Polish and 1373 in the Slovakian parts of the Tatra Mountains.

Although people have traversed the Tatra Mountains for centuries, the first information was recorded in the mid of the 19th century (S z c z e p a ń s k i 1933), whereas more systematic information has been collected since the 1900s (Z a r u s k i 1908, 1909, 1910, 1911, 1913; G r ó s z 1916). The number of records steadily piled up in the 20th and 21st centuries (Fig. 5). During the first three decades of the 20th century information about 52 snow avalanches was archived

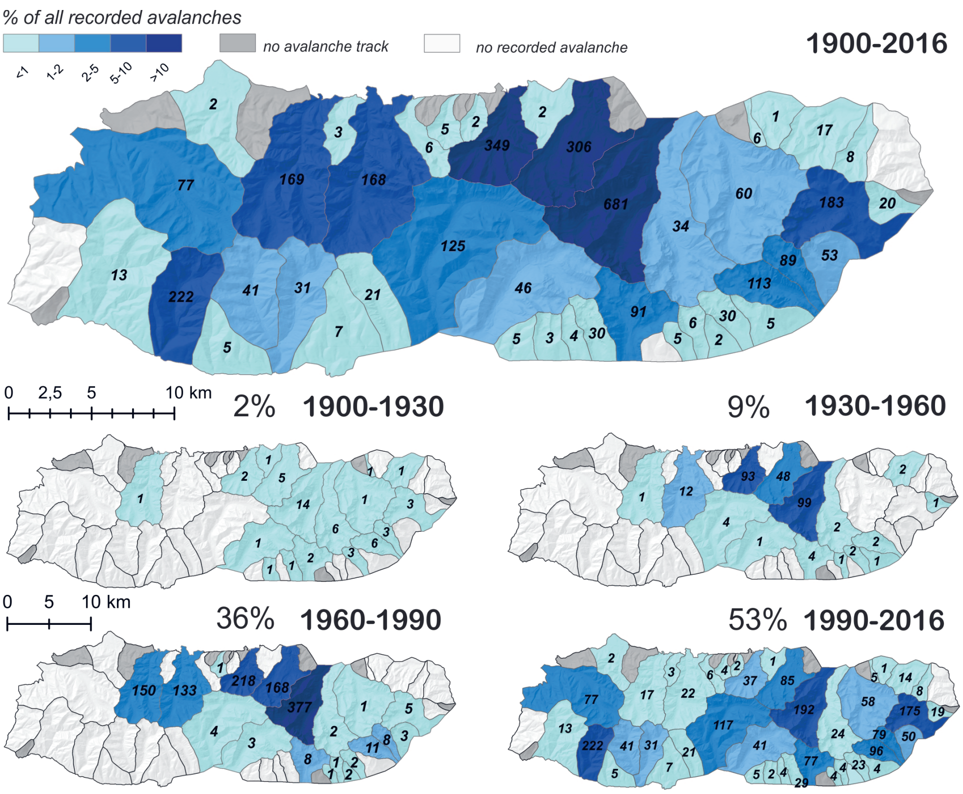


Fig. 5. The avalanche events reported in the 1900–2016 period and analysed in four periods (the number above the map shows the percentage of the records in the particular period in comparison with all 3047 recorded events)

coming mainly from the High and Belianske Tatra Mountains. Most of the avalanches (14) recorded at that time occurred in the Białka Valley, including 567 avalanches observed in one day by M. Zaruski (1910), however counted in the geodatabase as a one event. The four valleys, i.e. the Białka Valley, Bielovodská Valley, Veľká Studená Valley and Sucha Woda Valley constitute the region where most of the avalanches (60%) were observed in 1900–1930 period. Very few (10%) pieces of information were collected on avalanches in the Western Tatra Mountains. There is one report about the avalanches in the Chochołowska and Olczyska Valleys, two reports from the Bystra Valley and only one record from the Kôprová Valley on the southern side of the main ridge of the Tatra Mountains. The low number of records can be attributed to the initial stage of the scientific investigation (Zaruski 1910, 1911, 1913; Grósz 1916; Leszczycki 1929a, b, c, 1931; Milata 1937, 1947; Pawlik 1931). Also this was a period when the formal mountain rescue services in Poland and Slovakia were established (1909 and 1913, respectively) and the archives from the first decade could be incomplete. During the next period (1930–1960), the Tatra Mountains became very popular tourist destination and development of the infrastructure was continued despite the major pause during the Second WW. Moreover, the first long-lasting avalanche monitoring was conducted at that time. This resulted in heavily increased number of reported avalanches (from 52 to 273). However, the main locations where the highest number of avalanches was observed remained the same – the Białka Valley (99 reported avalanches) and the Sucha Woda Valley (48). The biggest increase in the amount of the information occurred in case of the Bystra Valley (from 2 to 93 in 1900–1930 and 1930–1960 period, respectively). The Kościeliska Valley is the next place in the Western Tatra Mountains, where relatively high number of observations was performed. These valleys were and are the most popular tourist destination (Pociask-Karteczka et al. 2007). The number of avalanches in the Slovakian side of the Tatra Mountains remained almost the same for the first three decades of the 20th century.

The 1960–1990 period is characterised by subsequent rise in number of avalanches in the Polish Tatra Mountains and very slow increase of the number of observations in the Slovakian side. The largest number of accounts came again from the Białka Valley (377), Sucha Woda Valley (168) and Bystra Valley (218). The number of observations increased also in the Kościeliska Valley (133) and Chochołowska Valley (150). In the Slovakian part of the Tatra Mountains it slightly increased (maximum 11 in the Veľká Studená Valley) but stayed at the same level as in previous periods. During the last, marginally shorter period (26 years), the total number of reported avalanches (1628) is higher than during the previous 90 years (1423). This abrupt increase of the number of records is solely an effect of the monitoring projects carried out in Poland and Slovakia during some years at the beginning of the 20th century (Poland: 1947/1948, 1959–1967, 2004–2006, 2012–2014; Slovakia: 2004-until now, published to 2015). The systematic observations improved the knowledge about the avalanche activity in the Western and Belianske Tatra Mountains. New data has changed the picture of the avalanches due to the high number of avalanche records form the Žiarska Valley (222), Studená Valley (77), Jamnícka Valley (41) and Račkova Valley (31) where no avalanches had been reported before.

The described dataset is not sufficient to perform an analysis of temporal changes of snow avalanche events. However, by pooling together all the records it is possible to identify the places of high avalanche activity (Fig. 6). Half of the all observations in the Polish part of the Tatra Mountains took place in twelve locations, among which 7 is placed in the Białka Valley. The highest number of avalanches was reported from the slopes of the Mięguszowieckie Szczyty ridge. The similar analyses performed for the Slovakian part of the Tatra Mountains revealed that 20 locations account for 47% of the records (Fig. 6), among which the slopes of the Tri kopy Mountain in the Žiarska Valley (Fig. 7) are the location where snow avalanches are the most active.

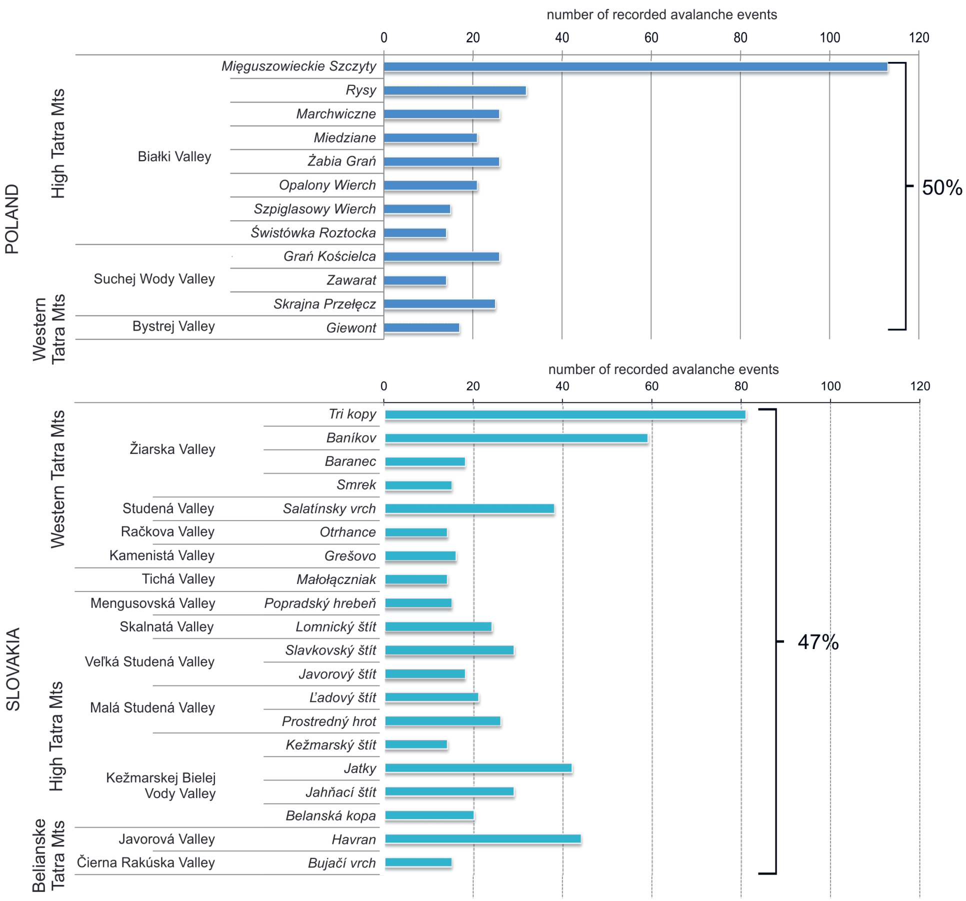


Fig. 6. The frequency and spatial distribution of avalanche events during 1900–2016

Fig. 7. The snow avalanches in the Žiarska Valley at 07.04.2009 (Photo P. Gavlák, http://hiking.sk/hk/ar/1158/lavina_storocia_v_ziarskej_doline.html)

The avalanches pose a threat for people who appear on the path of the snow movement. The cross-points of the avalanche tracks and hiking trials help to identify the potentially dangerous places (Fig. 8). Taking into account the differences in the density of the tourist trails in the Polish (1.3 km/km^2) and Slovakian (0.8 km/km^2) Tatra Mountains, the relative number of avalanche tracks passing the tourist trials is similar (1.4 avalanches/km^2 and 1.2 avalanches/km^2, respectively). The Białka Valley seems to be the crucial area. This valley is very popular among tourists and at the same time the high number of cross-points (117), avalanche tracks (298) and recorded events (681) occurred there. These result in a relatively high number of recorded accidents and casualties (Fig. 9). On the other hand, the Mengusovská, Bielovodská, Malá Studená and Veľká Studená Valleys are cases, for which the number of cross-points does not correspond with the number of accidents caused by avalanches. This demonstrates the complexity of the snow avalanche hazard. Nevertheless, not all the tourist trails are equally popular among winter tourists and not all of the victims were on the trail when snow avalanche caught them. The records of the accidents are the most complete among all information about the avalanches and they have already been extensively studied (Krąż, Balon 2012; Quirini-Popławski 2007; Vojtek 2005).

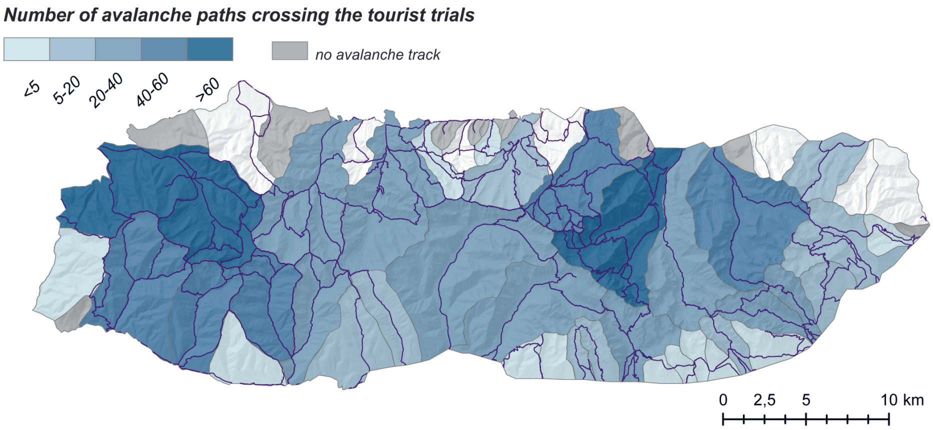


Fig. 8. The number of avalanche tracks crossing the tourist and hiking trails where avalanche events were recorded

The considerable number of collected records, characterized by the precise dates of the avalanche events stretching over 100 years, provides an opportunity to study the seasonality of the snow avalanche activity. The figure 10 shows the time when 2347 analysed avalanche events happened. The fully comprehensive picture of the seasonality based on the daily data is hard to create due to the unsystematised observations, however, little changes of the seasonality can be observed over 1900–2016 period (Fig. 10a). The use of monthly totals of the events, not only allows including 805 more events (less precisely dated) but also shows the temporal pattern of the avalanching. March is the month when avalanches are the most frequent in the entire Tatra Mountains. In the Polish part also in April and May a lot of avalanches happened, whereas in the Slovakian Tatra Mountains, the number of avalanches diminishes fast towards spring. The next noticeable difference concerns the higher frequency of snow avalanche activity at the end of autumn/beginning of winter (October-December) registered in the Slovakian than in the Polish records. These temporal differences between Slovakian and Polish Tatra Mountains are related to slope orientation and difference in solar radiation.

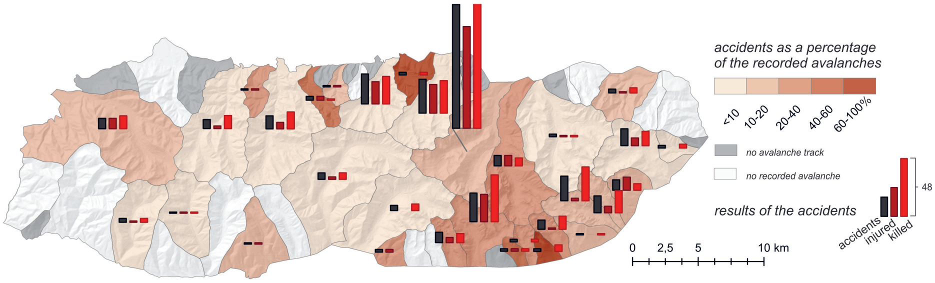


Fig. 9. The number of mountain rescue services interventions during 1900–2016 period

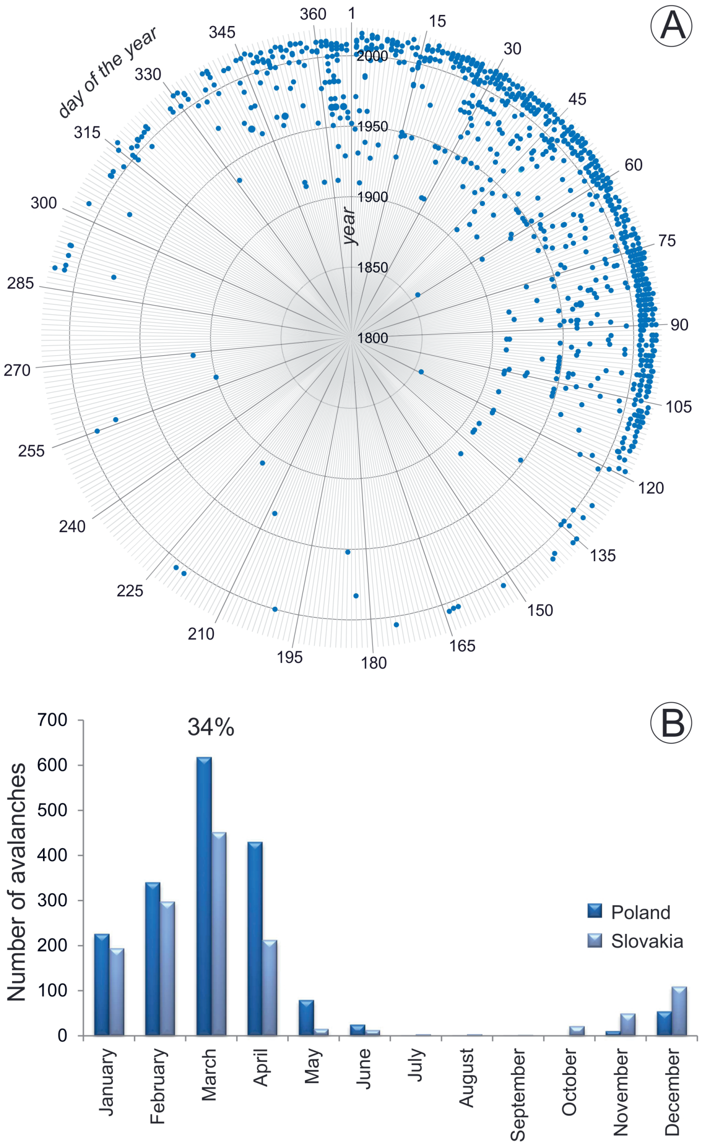


Fig. 10. The temporal variability of the snow avalanches activity. A – daily resolution, B – monthly resolution

CONCLUSIONS

1. The geodatabase includes the records about 3406 snow avalanches described by the location of the avalanche, time of the event, source of the information and if available also type and size of the avalanche, as well as information about rescue missions, number of injured and fatalities.

2. Although the geodatabase resulted from detailed queries authors are aware that some records can be missing. Therefore the geodatabase was designed and developed in the way that allows future improvements by adding new recent records and complementing the historical ones.
3. Due to the archives kept by mountain rescue services in Poland and Slovakia, the snow avalanches causing the accidents are well documented for full period of 20th and 21st centuries. The rest of the avalanches were registered only as a result of the researches lasting from 1 up to maximum 11 winters.
4. The Polish part of the High Tatra Mountains, especially the Białka Valley is the place where most of the avalanches were reported (681 events). The highest number of observations consider the slopes of the Mięguszowieckie Szczyty ridge. In the Slovakian part of the Tatra Mountains most of the records concern the Žiarska Valley (222 events), especially the Tri kopy ridge.
5. The unsystematic nature of the reports and monitoring as well as fragmented archives result in rather patchy picture of the history of the snow avalanches in the Tatra Mountains. This shows that better understanding of the dynamics of the snow avalanches requires the systematic and permanent monitoring. Still, the collected information can be cautiously used to analyse certain aspects of the avalanche activities.
6. The demonstrated incompleteness of the historical records creates the need of using the methods based of proxies such tree rings or geophysical modelling to reconstruct the past snow avalanche activity. The historical records play a crucial role in calibration and verification of such methods (Chrustek et al. 2013; Lempa et al. 2015; Gądek et al. in print).

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