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Changes in snowfall/precipitation-day ratio in Slovakia and their linkages with air temperature and precipitation

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Abstract: Knowledge on snowfall and precipitation variability is one of the most important information about climate changes. The presented study is based on daily data for precipitation totals and new snow cover depths and monthly air temperature from 29 meteorological stations in Slovakia. The aim is to determine to what extent the change of monthly air temperature mean affects the snowfall in the mountainous area of Slovakia. In order to achieve the aim of the research work, the snow days and precipitation days (SD/PD) ratio is calculated for the months from October to April and the trend is investigated. On the basis of correlation analysis it is determined that the main factor for changes in the SD/PD ratio is the mean monthly air temperature while precipitation plays an important role only for the stations with the altitude above 1300 m. Spatial distribution of the changes in the SD/PD ratio for the winter time (December – January – February) during the period 1981–2011 was investigated by cluster analyses. The results show that the stations are grouped according to their geographical location and relief of the territory.

Key words: snowfall, snow days, precipitation, air temperature

1. Introduction

Precipitation is a key element of climate which determines the availability of drinking water and the level of the soil moisture. Changes in precipitation could have a significant impact on society and on different aspects of man activity. Snowfall and snow cover in the mountainous areas are the main

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factors also for determining the development of winter sports and tourism. Knowledge about precipitation variability is therefore one of the most important information about climate changes. Meteorological observations show that there is an increasing of extremely weather events during the last decades. This is very likely connected with global climate change both due to natural processes and anthropogenic changes in the composition of the atmosphere and in land use.

Studies on precipitation variability show a decreasing trend of precipitation totals in the Central and Southern Europe and an increasing trend in the Northern Europe. The analysis of the trend of annual precipitation shows an increase of about 20% to 40% in many regions of the Northern hemisphere (*IPCC, 2007*). Despite of this the negative tendency in annual precipitation for the period 1979–2005 has been established in Central and Southern Europe.

Because of importance of the problem and the increasing interest in skiing and winter tourism, the variability of precipitation and snow cover in the mountainous area in Slovakia has received increasing attention in recent years and it was analyzed by many authors. The dependence of snow cover duration and solid precipitation on the altitude was investigated by *Vojtek et al. (2003)*. The authors pointed out the general tendency to decreasing of snow cover duration and solid precipitation occurrence in Slovakia but in the higher altitudes and the northern part of the country there is an opposite trend which is in coincidence with some studies about the Alps (*Beniston et al., 2003*). *Lapin et al. (2007)* pointed out that the variability and trend in snow cover are influenced not only by precipitation but also by air temperature. And this influence is related to the geographical position as altitude and topography. Similar results were showed by *Cazacioc (2007)* who studied the impact of temperature and atmospheric circulation on snow cover duration in Romania. According to *Krasteva and Koleva (2008)* snow pattern depends mainly on circulation conditions and the temperature conditions are decisive factor for the formation and persistence of the snow cover.

The aim of work is to determine to what extent the change of monthly air temperature mean affects the snowfall in the mountainous area of Slovakia. In order to achieve this aim the following tasks have been solved: 1) determination of the number of snowfall (SD) and precipitation (PD) days for the months from October to April at each of investigated stations; 2) estimation of the trend in the SD/PD ratio; 3) calculation of the correlation between the SD/PD ratio and air temperature means and precipitation totals; and 4) analysis of possible change of the SD/PD ratio according to alternative climate change scenarios for Slovakia up to the year 2100.

The results from this research could be useful for assessment of climate change impacts and especially impacts of precipitation and snowfall variability on winter sports, tourism, water resources or forestry sector.

2. Data and methods

The presented study is based on daily data for precipitation totals and new snow cover depths from 29 meteorological stations in Slovakia. These stations are situated mostly in the mountainous area of the country. Geographical distribution of the stations is shown in Fig. 1 (detailed information is in Table 1). According to the data availability the analysis is made for two periods: 1961–2011 (for 16 stations) and 1981–2011 (for all 29 stations).

The stations are grouped into three groups from the point of view of altitude as follows: 1) with altitude bellow 600 m a.s.l., 2) with altitude between 600 and 1000 m a.s.l., and 3) above 1000 m a.s.l. In order to determine the

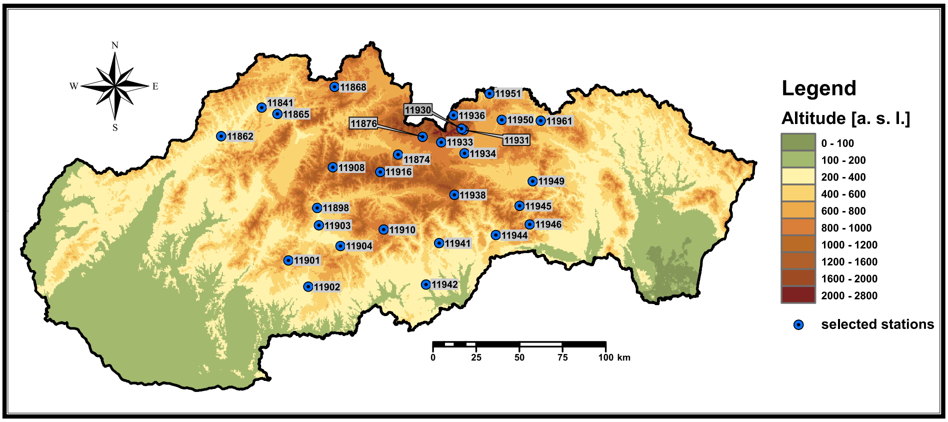


Fig. 1. Geographical distribution of meteorological stations used in the research.

Table 1. List of meteorological stations used in the research

Station number	Station	Altitude [a. s. l.]	Investigated period
11942	Rimavská Sobota	215	1961-2011
11862	Beluša	254	1961-2011
11841	Dolný Hričov, airport	309	1981-2011
11941	Ratková	311	1981-2011
11944	Rožňava	311	1981-2011
11903	Sliač, airport	313	1961-2011
11902	Bzovík	355	1981-2011
11865	Žilina	365	1981-2011
11904	Vígľaš - Pstruša	368	1981-2011
11949	Spišské Vlachy	380	1981-2011
11898	Banská Bystrica -Zelená	427	1961-2011
11951	Červený Kláštor	469	1961-2011
11945	Švedlár	477	1961-2011
11961	Plaveč	485	1961-2011
11950	Podolinec	573	1981-2011
11901	Banská Štiavnica	575	1981-2011
11946	Štós, kúpele	580	1981-2011
11908	Liptovská Osada	616	1981-2011
11874	Liptovský Hrádok	640	1961-2011
11934	Poprad, airport	694	1961-2011
11868	Oravská Lesná	780	1961-2011
11938	Telgárt	901	1961-2011
11876	Podbanské	972	1981-2011
11936	Tatranská Javorina	1013	1981-2011
11910	Lom nad Rimavicou	1018	1961-2011
11933	Štrbské Pleso	1322	1961-2011
11931	Skalnaté Pleso	1778	1961-2011
11916	Chopok	2005	1961-2011
11930	Lomnický Štít	2635	1961-2011

effects of mean air temperature change on snowfall, the monthly data for all investigated stations are used. All needed data were provided by the Slovak Hydrometeorological Institute in Bratislava (SHMI).

The studied area is typical of complex climate varying form moderately warm to moderately cold climate (according to Slovak national climatic classification). The lowest altitudes within the studied area are characterized by moderately warm climate, without regular long-lasting snow cover during the winter, while higher locations are characterized by moderately cold climate, which has regular snow cover during the majority of winter. Great variability of weather linked to the cyclonal activity is typical for the entire region. The highest regions, represented by three stations with the highest altitude have climate characteristic typical for mountain areas of medium latitudes.

Close to big ski resorts are several stations included in the analysis: stations Podbanské and Štrbské Pleso (ski resorts Interski and Solisko from 1350 m a.s.l. up to 1850 m a.s.l.) station Tatranská Javorina (ski resort Ždiar from from 1000 m to 1200 m), stations Skalnaté Pleso and Lomnický štít (ski resort Lomnické sedlo from 1700 m to 2200 m and ski resort Tatranská Lomnica from 800 m to 1700 m) and also station Chopok (ski resort Kosodrevina from 1100 m to 2000 meters, ski resort Jasná from 1200 m to 2000 m.)

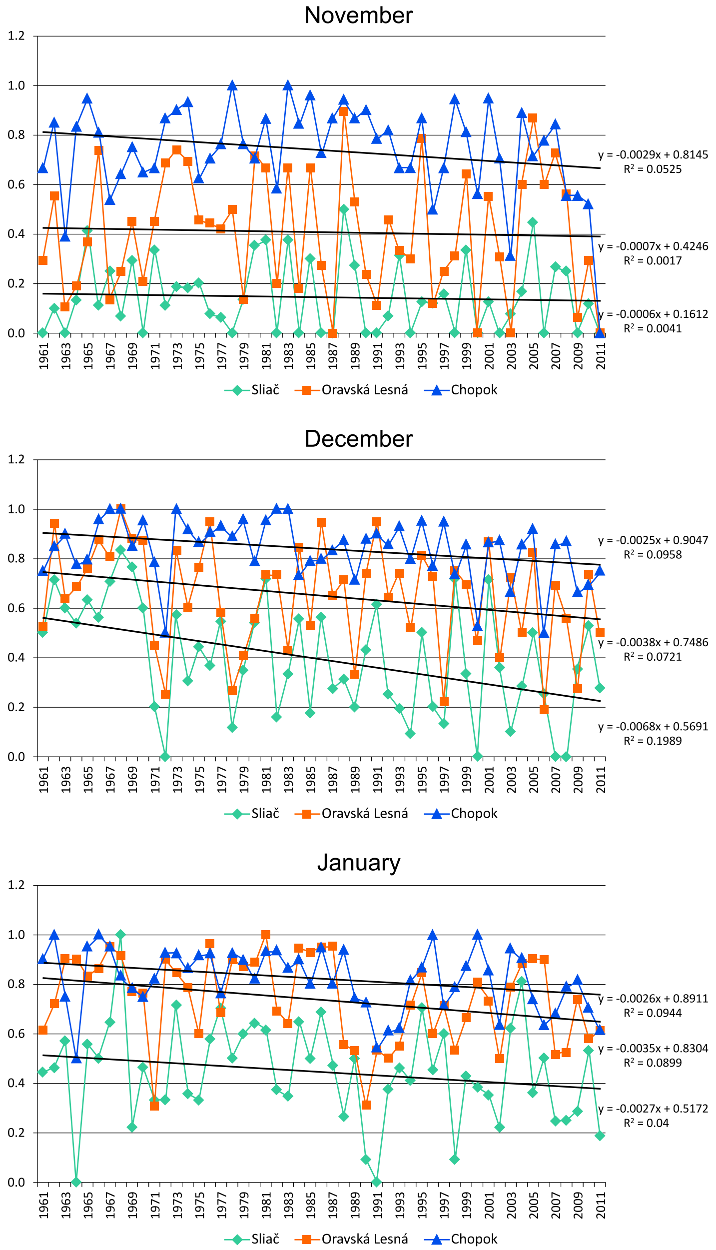
The snowfall/precipitation-days ratio (SD/PD) is computed following *Serquet et al. (2011)* methodology. The number of PD and SD is calculated for each of studied meteorological stations and for every month from October to April although at the stations with low altitude there are usually only few snowfall days in October and April. As the SD we consider all days with new snow which formed 1cm or more of new snow cover at the 7h MLT term even if precipitation totals for some of these days are less than one mm. Therefore the number of snowfall days is only some fraction of the number of precipitation days (with daily precipitation total one mm or more). After calculation of monthly number of snowfall and precipitation days the ratio between them for each station and each month is determined. The temporal changes in the SD/PD ratio are determined by linear regression for the periods 1961–2011 and 1981–2011. In order to estimate the effect of temperature change on snowfall days we calculated the correlation between SD/PD and monthly air temperature means and precipitation totals.

Cluster analysis has been applied in order to study spatial and geographical changes in the variability of the SD/PD ratio. This method gives us a tool for classifying the investigated meteorological stations according to the variability of snowfall and precipitation days. We have applied complete linkage and Euclidean distances for winter season (December – January – February) of the period 1981–2011.

3. Results and discussions

The trend of SD/PD for the period 1961–2011 is investigated on the basis of 16 stations because of availability of complete data series. This trend is negative for most of cases and the values of trend are higher during the winter months (December, January and February), Fig. 2. Similar results were found for Bulgarian mountains by *Petkova and Alexandrov (2012)* who show overall decrease in snow cover duration and maximum snow cover depth during the period 1931–2005. Positive tendencies in the SD/PD changes occur only at some stations in high altitude: (Lomnický Štít (2635 m a.s.l.) – December, January and February and Skalnaté Pleso (1778 m a.s.l.) – January and February but this trend is not statistically significant. On the other hand the negative trend at the stations Chopok (2005 m a.s.l.) and Telgárt (901 m a.s.l.) makes impression and it is statistically significant from December to March. The negative trend for station Chopok, which with its altitude of 2005 m also belongs to the group of the highest mountain stations may be caused by the fact that the most of precipitation at Chopok comes from humid air masses flowing from the southwest and south, including cyclones and frontal pressure waves advancing from the Mediterranean to the northeast. However at the stations Lomnický Štít and Skalnaté Pleso the most of precipitation usually comes from air masses advancing from the northwest and west. Station Chopok also lies more to the south so the influence of warm sector of cyclones or frontal pressure waves advancing from the southwest is more significant, resulting in increase of the portion of mixed and liquid precipitation in the total precipitation during the winter months.

From the first group of stations (with the altitude bellow 600 m a.s.l.) the positive but not statistically significant trend of SD/PD is observed only in a few cases: in February at the stations Švedlár (477 m a.s.l.) and Červený Kláštor (469 m a.s.l.) and in March at the stations Banská Bystrica – Zelená (427 m a.s.l.) and Sliač (313 m a.s.l.). This may be caused by generally more continental climate at stations Švedlár and Červený Kláštor, while at



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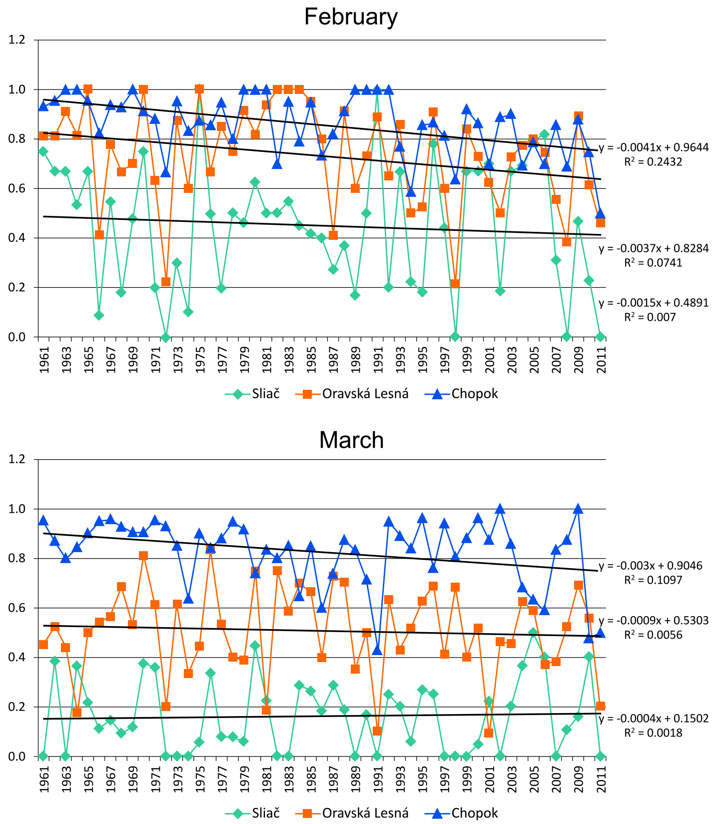

Fig. 2. Ratio of snow days and precipitation days and trend at selected stations for the period 1961–2011.

stations Banská Bystrica and Sliač this can be related to the higher amount of precipitation in the early spring.

There are only few cases with snowfall during April and October in average at the stations with the altitude bellow 600 m a.s.l. (Fig. 3), therefore we did not calculate the trend for these cases (more than 20% of days with no new snow cover in average). The stations with altitude above 600 m have a negative trend of SD/PD in April and October (Fig. 3).

The negative trend in the SD/PD ratio is determined for most of cases at all investigated 29 stations for the period 1981–2011. The main difference for the period 1981–2011 in comparison to the period 1961–2011 is the pos-

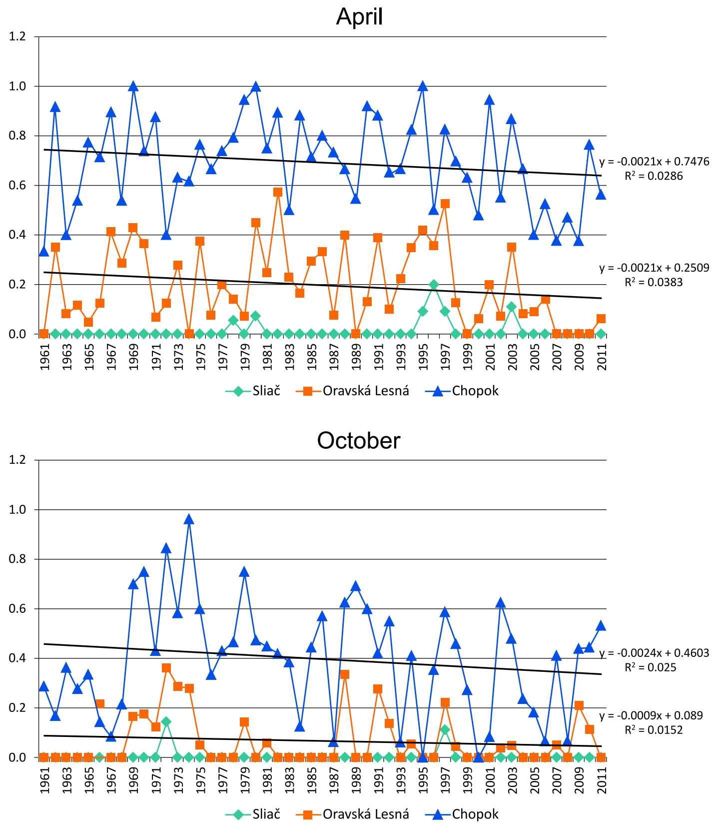

Fig. 3. Ratio of snow days and precipitation days and trend at selected stations for April and October for the period 1961–2011.

itive trend in March for most of stations. Nevertheless the most of stations with altitude above 600 m keep the negative trend of SD/PD in March for the period 1981–2011. All of investigated stations situated above 1000 m a.s.l. have a positive trend of SD/PD in January and February. The positive trend in February is observed also at some stations with altitude less than 600 m a.s.l. as Vígľaš – Pstruša, Ratková, Rožňava and Švedlár. According to the coefficient of determination the trend is statistically significant only in a very few cases. In these cases the continentality of climate mentioned earlier comes into play and at the end of the winter in some enclosed valleys where stations are situated, it causes more stable and colder climate.

The results from correlation analysis between monthly air temperature and the SD/PD ratio and between precipitation and the SD/PD ratio show that the changes in the SD/PD ratio are determined by air temperature means and only for the stations with altitude above 1300 m the correlation between SD/PD and monthly precipitation totals is well established. The correlation coefficients between the SD/PD and monthly air temperature for the period 1961–2011 are negative and for the stations with the altitude up to 1000 m the values are higher for November, December, March and April as for the stations situated in altitudes above 1000 m the highest values occur in January and February. Less significant relation between air temperature and the SD/PD ratio in the territories above 1000 meters in autumn months and in early winter (October, November, December) may be linked to the presence of temperature inversions frequently occurring in Central Europe in this time of the year[1]. This effect is strong and evident at lower altitudes in January and February and it is clearly expressed by the low correlation coefficient between SD/DP and air temperature at stations up to 600 meters. At the stations above 600 meters the trends of rising air temperature are evident and this causes noticeable decrease in the number of days with snow in January, February and March. The correlation between the SD/PD and monthly precipitation totals is positive but the correlation coefficients are statistically significant only for the stations with altitude above 1300 m. High altitude is therefore critical in this case, since during situations with high precipitation it guarantees temperature conditions below the freezing point which are necessary for the presence of snow.

For the period 1981–2011 we studied the correlation between SD/PD, temperature and precipitation at 29 stations (Table 2). The results are similar with those for the period 1961–2011. In low (up to 600 m a.s.l.) and middle (601–1000 m a.s.l.) altitudes the mean temperature affects the changes in the SD/PD mainly at the beginning and the end of the winter as well as in October and April. In the higher part of study area a statistically significant correlation between the SD/PD and air temperature is established for the January – April months nevertheless some stations with the

[1] Temperature inversions are caused by retaining layers of the atmosphere where there is temperature rise with the altitude, which is inconsistent with the standard conditions in the atmosphere. If in the analysed period and area, are these inversions presented very frequently, they can affect the average monthly air temperature.

Table 2. Correlation between air temperature and SD/PD ratio for the period 1981–2011

Station	Altitude [a. s. l.]	Correlation of temperature and SD/PD						
		X	XI	XII	I	II	III	IV
Rimavská Sobota	215	**-0.53**	**-0.72**	**-0.54**	0	-0.31	**-0.39**	**-0.57**
Beluša	254	**-0.68**	**-0.72**	**-0.52**	-0.32	**-0.37**	**-0.59**	**-0.71**
Dolný Hričov, airport	309	**-0.69**	**-0.64**	**-0.64**	**-0.44**	**-0.38**	**-0.66**	**-0.78**
Ratková	311	**-0.47**	**-0.5**	-0.48	-0.25	-0.3	-0.33	**-0.73**
Rožňava	311	**-0.51**	**-0.56**	**-0.61**	**-0.44**	-0.29	**-0.49**	**-0.75**
Sliač, airport	313	**-0.39**	**-0.63**	**-0.54**	-0.23	**-0.41**	**-0.58**	**-0.7**
Bzovík	355	**-0.56**	**-0.49**	**-0.5**	-0.2	**-0.5**	**-0.42**	**-0.68**
Žilina	365	**-0.62**	**-0.68**	**-0.72**	**-0.51**	-0.12	**-0.66**	**-0.76**
Vígľaš - Pstruša	368	-0.35	**-0.63**	**-0.68**	**-0.4**	-0.27	-0.43	**-0.7**
Spišské Vlachy	380	**-0.63**	**-0.6**	**-0.66**	-0.36	**-0.49**	**-0.67**	**-0.65**
Banská Bystrica, Zelená	427	**-0.54**	**-0.55**	**-0.65**	**-0.39**	-0.19	-0.36	**-0.72**
Červený Kláštor	469	**-0.72**	**-0.64**	**-0.81**	**-0.51**	-0.33	**-0.55**	**-0.43**
Švedlár	477	-0.28	**-0.54**	**-0.77**	**-0.52**	-0.09	**-0.59**	**-0.68**
Plaveč	485	**-0.42**	**-0.66**	**-0.6**	**-0.51**	-0.31	**-0.68**	**-0.65**
Podolinec	573	**-0.49**	**-0.56**	**-0.64**	**-0.71**	-0.3	**-0.77**	**-0.6**
Banská Štiavnica	575	**-0.5**	**-0.67**	**-0.65**	**-0.4**	-0.18	**-0.59**	**-0.57**
Štós, kúpele	580	**-0.46**	**-0.7**	**-0.68**	**-0.56**	**-0.4**	**-0.62**	**-0.65**
Liptovská Osada	616	**-0.61**	**-0.66**	**-0.69**	**-0.41**	**-0.33**	**-0.67**	**-0.45**
Liptovský Hrádok	640	**-0.45**	**-0.67**	**-0.61**	**-0.63**	**-0.37**	**-0.66**	**-0.53**
Poprad, airport	694	-0.31	**-0.63**	**-0.52**	**-0.68**	**-0.54**	**-0.68**	**-0.5**
Oravská Lesná	780	**-0.61**	**-0.56**	**-0.59**	**-0.73**	**-0.52**	**-0.66**	**-0.51**
Telgárt	901	**-0.52**	**-0.45**	**-0.54**	**-0.58**	**-0.59**	**-0.61**	**-0.6**
Podbanské	972	**-0.58**	**-0.55**	**-0.61**	**-0.72**	**-0.7**	**-0.61**	**-0.65**
Tatranská Javorina	1013	**-0.42**	-0.19	-0.5	**-0.74**	**-0.73**	**-0.65**	**-0.57**
Lom nad Rimavicou	1018	**-0.56**	**-0.55**	**-0.66**	**-0.63**	**-0.49**	**-0.45**	**-0.72**
Štrbské Pleso	1322	**-0.46**	-0.07	**-0.46**	**-0.7**	**-0.78**	**-0.65**	**-0.5**
Skalnaté Pleso	1778	-0.26	0.02	-0.21	**-0.63**	**-0.66**	**-0.65**	-0.07
Chopok	2005	**-0.39**	-0.1	-0.07	**-0.71**	**-0.58**	**-0.74**	**-0.38**
Lomnický Štít	2635	0.06	0.16	-0.18	**-0.36**	**-0.62**	**-0.53**	-0.33

Statistically significant coefficients are in Bold

altitude between 1013–1322 m show good correlation between the SD/PD and temperature for the October – December months as well. The most noticeable are high negative correlation values for the month of April and stations below 600 meters. In April also the most significant increases in air temperature at selected stations were recorded since 1981. In the high mountain areas this does not apply, because this period is just after the culmination of winter in these areas, therefore despite of the increase in air temperature since 1981, local conditions still cause precipitation to fall in the form of snow. The correlation analysis shows that for the period 1981-2011 precipitation totals are important for changes in the SD/PD at the stations in altitude above 1000 m. Only at a few stations with altitude lower than 1000 m correlation between the SD/PD and precipitation is statistically significant for the months from February to April. This tighter relationship may result from the geographic location of some of these stations and from the specific dependencies between monthly rainfall and number of days with snow.

Spatial distribution of changes in the SD/PD ratio for the winter time (December – January – February) during the period 1981–2011 was investigated also by cluster analyses. By means of complete linkage and Euclidean distances we clustered stations that had similar features during the period 1981–2011 in regards of changes in the SD/PD ratio (Fig. 4). The stations are classified into four groups. In two of the groups, three and four subgroups of stations are determined.

The first group of stations ("green" in Fig. 4) includes 15 stations divided in four subgroups as follows: 1) Rimavská Sobota and Bzovík; 2) Telgárt; Poprad and Spišské Vlachy; 3) Ratková, Rožňava, Vígľaš – Pstruša, Banská Štiavnica, Banská Bystrica – Zelená and Sliač, and 4), Beluša, Žilina and Dolný Hričov. The second group (Fig. 4, "blue") includes 10 stations situated mainly in altitude above 600 m. Three subgroups of stations are in this group: 1) Tatranská Javorina and Skalnaté Pleso; 2) Štrbské Pleso and Podbanské, and 3) Červený Kláštor, Štós – kúpele, Lom nad Rimavicou, Liptovský Hrádok, Plaveč and Oravská Lesná. Only two stations (Podolinec and Švedlár) are in the third group of stations (Fig. 4 "orange") and other two stations (Lomnický Štít and Chopok) are included in the fourth group (Fig. 4 "red").

The results of cluster analysis show that the main factor for including stations into a given cluster is geographical location, relief and distance between the stations.

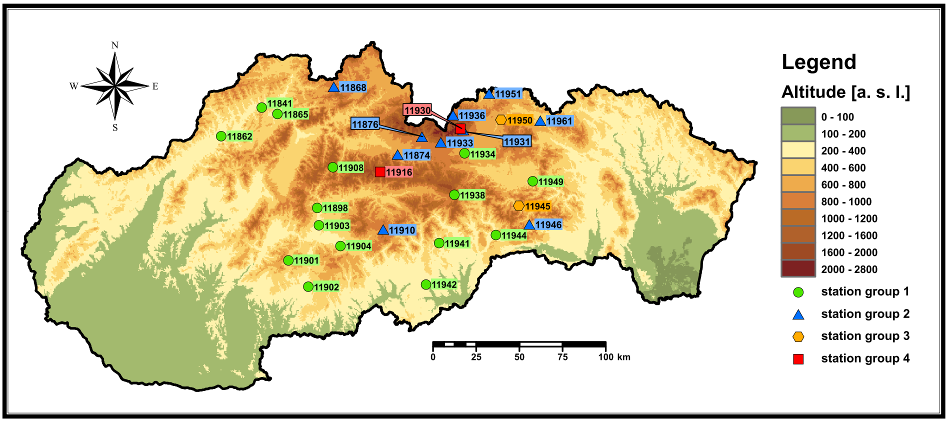

Fig. 4. Groups of stations according to the spatial distribution of the changes in SD/PD ration for the winter-time during the period 1981–2011.

4. Conclusion

The actuality of presented research is determined by the facts that snowfall and snow cover in the mountainous areas are one of the main factors for determining the development of winter sports and tourism. From the other side, these elements have also importance for availability of water resources and in general hydrologic balance as well.

The following conclusion can be pointed out on the basis of the investigation of the SD/PD ratio in the mountainous part of Slovakia for the period 1961–2011.

The trend of SD/PD for the period 1961–2011 is negative for most of cases and the values of trend are higher during the winter months (December, January and February). This negative trend in the SD/PD ratio is determined for most of cases at all investigated 29 stations for the period 1981–2011. The main difference for the period 1981–2011 in comparison to the period 1961–2011 is the positive trend in March for the most of stations.

There are only few cases with snowfall during April and October at the stations with the altitude bellow 600 m a.s.l. The stations with altitude above 600 m have a negative trend of SD/PD in April and October.

The results from the correlation analysis between monthly air temperature, precipitation and the SD/PD ratio show that the changes in the SD/PD ratio are determined predominantly by air temperature. Only for the stations with altitude above 1300 m the correlation between SD/PD and monthly precipitation totals is well established and statistically significant.

The results of cluster analysis of the winter-time SD/PD ratio for the period 1981–2011 show that the main factor for inclusion stations into a given cluster is the geographical location, relief and distance between the stations.

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