CHANGES IN THE FREQUENCY OF METEOROLOGICAL PHENOMENA IN SLOVAKIA BETWEEN CLIMATOLOGICAL NORMAL 1961 – 1990 AND 1991 – 2020

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The last three decades showed significant change in the daily, seasonal and annual course of various meteorological variables. Global warming affects physical processes in the atmosphere and analysis of long-term data for selected meteorological phenomena (MP) can supplement information about the response of land meteorological observation on climate changes. This study aims to analyze changes in frequency of selected MP in comparison of climatological normals (CLINOs) 1991 – 2020 and 1961 – 1990. We used 10 professional climatological stations for the purpose of this research. Investigated phenomena are fog, glaze, hail and thunderstorm. Results show decreasing trend in hail occurrence in 8 of 10 studied stations and also increasing trend in glaze incidence in 9 of 10 selected station. The highest increase in fog appearance is present on the mountain stations: Chopok and Lomnický štít. Both mountain stations, Chopok and Lomnický štít, recorded increase in thunderstorm activity as well. Detecting these changes may help to prevent the risk of natural hazards, possible damage on socio-economical activities and also could help to adapt on changing environment.

Posledné tri dekády zaznamenávame významnú zmenu v dennom, sezónnom a ročnom chode rôznych meteorologických premenných. Klimatická zmena a globálne otepľovanie ovplyvňujú fyzikálne procesy v atmosfére a my sme toho svedkami. Rozdielne správanie meteorologických javov (MP) je toho dôkazom. Táto štúdia má za cieľ analyzovať rozdiely v početnosti výskytu vybraných meteorologických javov pri porovnaní klimatologických normálov (CLINOs) 1991 – 2020 a 1961 – 1990. Pre účely výskumu sme vybrali 10 profesionálnych meteorologických staníc. Skúmanými javmi sú výskyt hmly, poľadovice, krupobitia a búrky. Výsledky ukazujú pokles vo výskyte krupobitia na 8 z 10 študovaných staníc a tiež nárast výskytu poľadovice na 9 z 10 sledovaných staníc. Najvyšší nárast výskytu hmly sme zo sledovaných staníc zaznamenali na horských staniciach – Chopku a Lomnickom štíte. Obe vysokohorské stanice, Chopok a Lomnický štít, zaznamenali taktiež nárast výskytu búrok na stanici. Detekcia týchto zmien môže pomôcť v prevencii rizika prírodných hrozieb, možných škôd na socioekonomických aktivitách a tiež môže pomôcť v adaptácii na zmenené podmienky prostredia.

Key words: meteorological phenomena, fog, glaze, hail, thunderstorm, climatological normal

INTRODUCTION

Present climate change affects various meteorological variables as air temperature, precipitation patterns and other. Changes are visible especially when longer period is taken into account. The research of meteorological phenomena changes in time and space is less frequent than most important basic meteorological variables like air temperature or precipitation. However, the research of the meteorological phenomena is important due to their potential negative impact on the society, especially particular sectors, e.g. impact of fogs and glaze on transport, impact of thunderstorms and hails on agriculture etc. Among the papers dealing with this kind of topic, the most frequent is the climatological analysis of thunderstorms, e.g. Kunz et al. (2009) in south-western Germany or Vose et al. (2014) in United States coastal regions. Sometimes the research of thunderstorm climatology is coupled with other phenomena, like hail (Allen et al., 2011), glaze and hail (Changnon, 1968). Further, we can mention works dealing with glaze and/or freezing rain climatology, e.g. Bezrukova et al. (2006) in Russia, Gay and Davis (1993) in south-eastern United States. Papers describing fog climatology or trends in fog occurrence are described e.g. by Avotniece et al. (2015) on the territory of Latvia or Cséplő et al. (2019) on Hungarian meteorological stations. In this paper we present the comparison of meteorological phenomena normals between present normal period 1991 – 2020 and previous normal period 1961 – 1990 in order to find out how the changing climate affects frequency and spatial distribution of meteorological phenomena.

MATERIAL AND METHODS

In this paper we present the comparison of meteorological phenomena normals between present normal period 1991 – 2020 and previous normal period 1961 – 1990. Meteorological normals serve as reference values of meteorological variables and can be used in monitoring, process of planning etc. Therefore the society can prepare for weather influences, climate oscillation, climate change etc. The Slovak Hydrometeorological Institute (SHMÚ) publishes meteorological normals in compliance with the methodology presented in the manuals of World Meteorological Organization (WMO 2017, 2018). The normal period 1991 – 2020 represents fourth generation of normal periods after periods 1901 – 1930, 1931 – 1960 and 1961 – 1990.

The data for creation of the normal values are extracted from meteorological database of SHMÚ, originally 78 stations which met the WMO criteria of completeness were processed for evaluation of meteorological phenomena (Národný klimatický program SR, 2023). For the purposes of this paper, we selected 10 stations (Fig. 1, Tab. 1) with emphasis on the presence of professional observation, that is only on part of the stations, distribution across the whole country and across various altitudes, from lowland stations e.g. Hurbanovo (115 m a.s.l.) up to mountain stations, e.g. Lomnický štít 2633 m a.s.l. Finally, we selected four meteorological phenomena for further analysis – fog, glaze, hail and thunderstorm. The selected meteorological phenomena belong to the group of dangerous meteorological phenomena. The occurrence of fog, i.e. the presence of small water droplets or ice crystals near the earth's surface, causing a decrease in horizontal visibility below 1 km, is dangerous for all types of transport. Glaze, a layer of ice on objects and the earth's surface, which was formed by the freezing of raindrops and drizzle, is limiting factor for infrastructure and transport routes. Another two phenomena are associated with storm activity. One of the destructive phenomena is the occurrence of hail, which can destroy harvest on fields or trees, and it is risk for people's health and human property. The storm phenomenon in our processing includes a storm at the station and also a remote storm. The storm, in addition to the already mentioned hail, is accompanied by atmospheric discharges, potentially strong winds and intense precipitation. It is dangerous for all kinds of human activity. In this article, only the number of days with the occurrence of individual phenomena was processed, i.e. their intensity was not evaluated, or multiple occurrences in one day. We digitised data from previous CLINO 1961 – 1990 (NKP SR, 2015) and subsequently processed the data from absolute frequency to average annual frequency and finally computed absolute and relative deviations between the two normal periods. We also used digital version of the newest CLINO 1991 – 2020 (NKP SR, 2023). Graphical outputs were created in ArcGIS Pro 3.1.2 software. Selected MP don't need any equipment to measure. Their observance depends strictly on subject dedicated to provide these observations. Slovak Hydrometeorological Institute (SHMÚ) provides 78 stations with MP observations. We chose just those 10 stations with professional staff to avoid possible gaps in observations because the majority of stations in the SHMÚ network have volunteer staff. However stations except Bratislava-letisko, Košice-letisko and Poprad have changed their period of observations from continuous 24 hour observations to limited period 06:30 till 21:00 CET. This change took place in 2000, thus this fact could affect some of the presented results for normal 1991 – 2010 (NKP SR, 2023).

Figure 1. Spatial distribution of selected climatological stations in Slovakia used for the comparison between CLINOs 1991 – 2020 and 1961 – 1990.

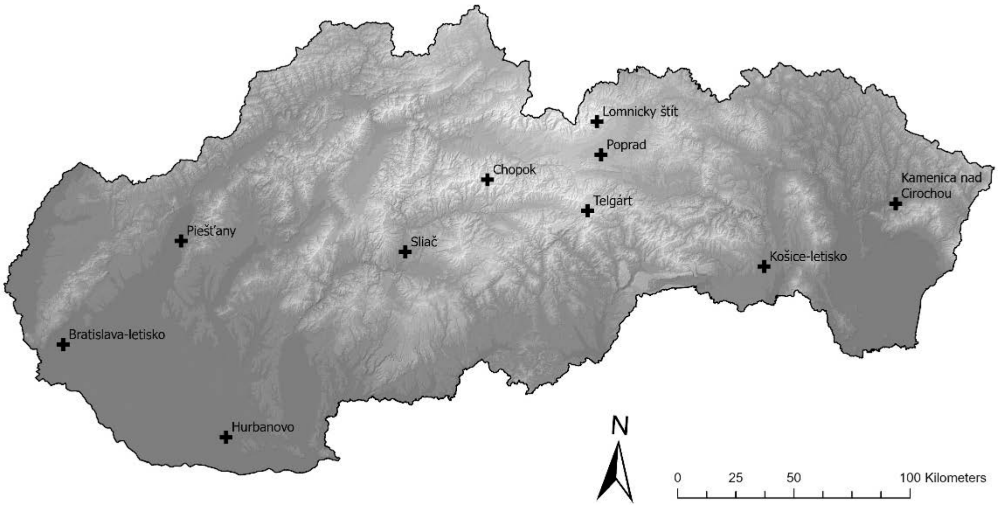


Table 1. Selected climatological stations in Slovakia used for the comparison between CLINOs and their coordinates and altitude.

number	indicative	station	x-sjtsk	y-sjtsk	elevation [m]	latitude	longitude
1	11816	Bratislava-letisko	-566058	-1278668	128	48.17028	17.20750
2	11826	Piešťany	-515344	-1234074	161	48.61306	17.83167
3	11858	Hurbanovo	-495941	-1318480	115	47.87250	18.19306
4	11903	Sliač	-418827	-1238812	310	48.6425	19.14194
5	11916	Chopok	-383440	-1207744	2005	48.94389	19.59222
6	11930	Lomnický štít	-336375	-1182764	2634	49.19528	20.21306
7	11934	Poprad	-334574	-1197046	693	49.06806	20.24944
8	11938	Telgárt	-340448	-1221138	900	48.84861	20.18917
9	11968	Košice-letisko	-264473	-1245053	229	48.67056	21.23861
10	11993	Kamenica nad Cirochou	-207790	-1218033	176	48.93472	21.99417

RESULTS AND DISCUSSION

Fog

Four of ten presented stations show decrease in fog occurrence, other six stations show increase. Decrease is present in western and central Slovakia except Bratislava-letisko station and in the easternmost station used in this analysis – Kamenica nad Cirochou. Most significant increase in terms of absolute numbers can be observed in the mountain stations – Chopok with increase of 28.6 days and Lomnický štít with increase of 25.8 days (Fig. 2) followed by Bratislava-letisko station (+18.5 days).

Figure 2. Absolute difference in number of days with fog in selected stations between CLINOs 1991 – 2020 and 1961 – 1990

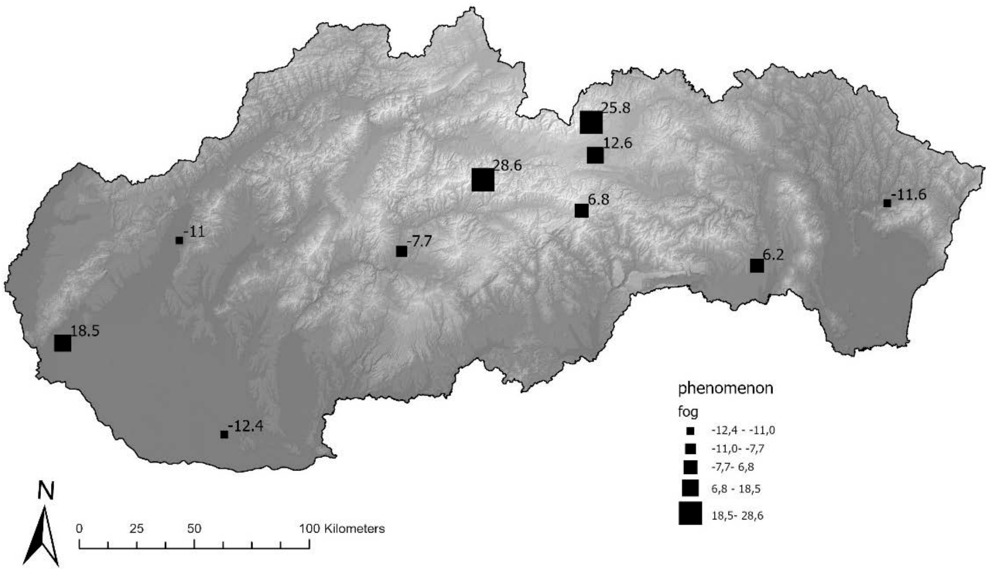
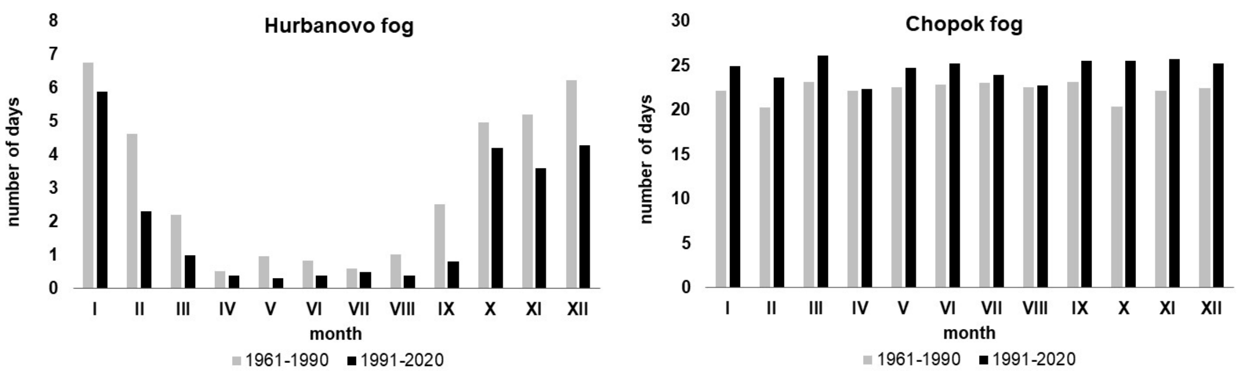


Table 2. Monthly change in number of days with fog between CLINOs 1991 – 2020 and 1961 – 1990 for selected stations.

indicative	station	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Year
11816	Bratislava-letisko	-0.2	-0.1	0.6	2.1	1.9	1.5	1.8	1.9	3.2	3.7	1.3	0.7	**18.5**
11826	Piešťany	-1.8	-0.9	-1.8	0.5	0.1	-0.7	-0.3	-0.2	-1.7	-0.7	-0.9	-2.4	**-11.0**
11858	Hurbanovo	-0.9	-2.3	-1.2	-0.1	-0.7	-0.4	-0.1	-0.6	-1.7	-0.8	-1.6	-1.9	**-12.4**
11903	Sliač	-0.7	0.9	-1.8	0.5	0.1	-1.4	-0.4	-2.0	-2.5	-0.6	0.2	0.0	**-7.7**
11916	Chopok	2.7	3.4	2.9	0.2	2.2	2.3	0.9	0.2	2.4	5.1	3.5	2.8	**28.6**
11930	Lomnický štít	1.9	2.2	2.3	1.7	2.7	2.0	1.9	2.0	2.6	3.6	1.6	1.3	**25.8**
11934	Poprad	2.4	-0.6	-1.1	0.1	0.8	2.0	2.5	1.9	1.2	1.0	1.5	1.1	**12.6**
11938	Telgárt	2.1	-0.6	0.7	-0.2	0.4	-0.4	0.2	0.1	0.0	1.0	1.4	2.1	**6.8**
11968	Košice-letisko	-0.9	-0.2	-1.5	0.5	1.2	0.8	1.2	0.4	1.9	2.3	0.1	0.3	**6.2**
11993	Kamenica nad Cirochou	-0.5	-0.4	-1.5	-0.3	-0.9	-1.0	-0.2	-3.9	-2.0	-0.1	0.6	-1.2	**-11.6**

Figure 3. The mean monthly number of days with fog in stations Hurbanovo and Chopok for CLINOs 1991 – 2020 and 1961 – 1990.



Glaze

We can see the increase of glaze phenomenon between normal periods on nine stations, only Chopok shows decrease. Highest absolute increase can be seen on Košice-letisko and Bratislava-letisko stations with 10.5 and 6.5 days per year respectively (Fig. 4, Tab. 3). Climate change can play role in increase of glaze phenomenon on the majority of the stations, with generally warmer temperature in winter months and suitable conditions for freezing rain and glaze formation. Absolute values for CLINOs 1991 – 2010 and 1961 – 1990 on the stations Bratislava-letisko and Košice-letisko are presented on Fig. 5 showing changes of the phenomena – in case of Bratislava-letisko, highest increase is present in January and December, in case of Košice-letisko, highest increase is present in January and February.

Figure 4. Absolute difference in number of days with glaze in selected stations between CLINOs 1991 – 2020 and 1961 – 1990.

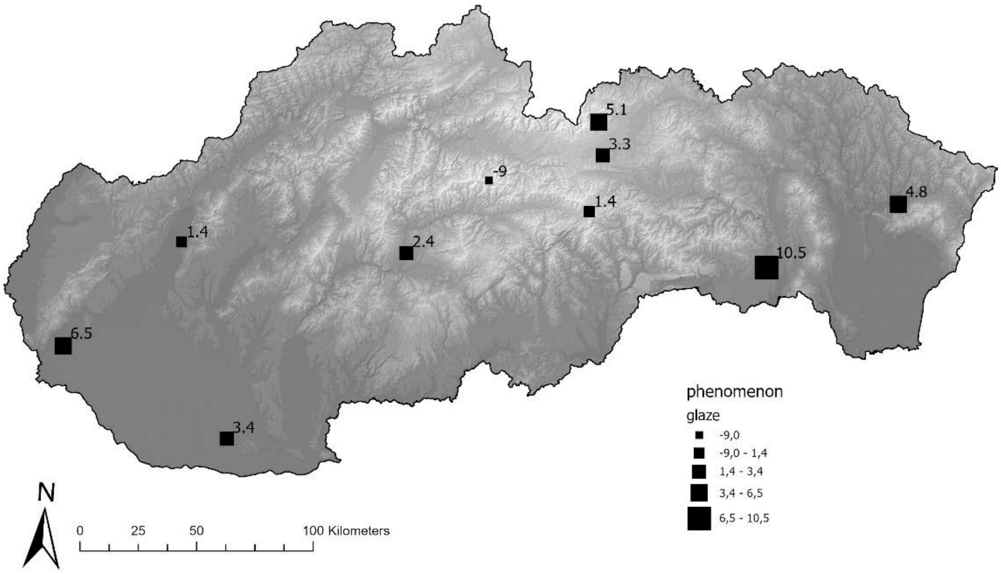
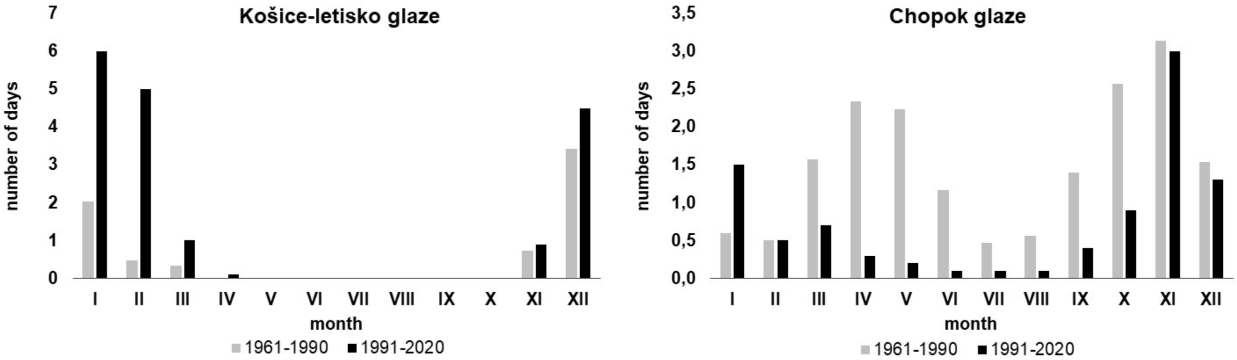


Table 3. Monthly change in number of days with glaze between CLINOs 1991 – 2020 and 1961 – 1990 for selected stations.

indicative	station	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Year
11816	Bratislava-letisko	2.4	0.8	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	2.6	**6.5**
11826	Piešťany	1.4	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.1	-0.1	**1.4**
11858	Hurbanovo	2.0	1.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.1	0.0	**3.4**
11903	Sliač	1.0	0.6	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	**2.4**
11916	Chopok	0.9	0.0	-0.9	-2.0	-2.0	-1.1	-0.4	-0.5	-1.0	-1.7	-0.1	-0.2	**-9.0**
11930	Lomnický štít	1.0	0.2	0.0	0.0	0.2	-0.1	0.1	-0.3	0.8	0.5	2.0	0.7	**5.1**
11934	Poprad	1.3	0.3	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.2	1.1	**3.3**
11938	Telgárt	0.4	0.2	-0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.1	-0.1	1.0	**1.4**
11968	Košice-letisko	4.0	4.5	0.7	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.2	1.1	**10.5**
11993	Kamenica nad Cirochou	1.9	1.7	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.5	**4.8**

Figure 5. The mean monthly number of days with glaze in stations Košice-letisko and Chopok for CLINOs 1991 – 2020 and 1961 – 1990.



Hail

The occurrence of MP hail is strictly connected with another convective cells, supercells and thunderstorms. Overall, we observed decreasing amount of hail incidence in 8 of 10 investigated climatological stations (Fig 6). Poprad is the only station with increase of hail (+0.1 days) and Piešťany station remains without change. The highest increase is in April and summer months at these stations in comparison between CLINOs 1991 – 2010 and 1961 – 1990 (Tab. 4). Station Poprad gained increase by 10.5% and Lomnický štít 7.6% per year in average. On the other hand, the highest decrease in days with hail appeared at the station Sliač with relative frequency value –57.1% in average. We could assume that increasing number of days with hail in the High Tatras Region are connected with prevailing wind direction from north-west, increasing trend in precipitation amount, convective situations and lower level of 0°C isotherm during spring and early summer months (Łupikasza and Szypuła, 2019). Decreasing amount of days with hail in the rest of selected stations could be explained by leeward effect of Tatras Mountains during prevailing north-west situations and different morphology conditions in lowland areas. Absolute values for CLINOs 1991 – 2010 and 1961 – 1990 on the stations Bratislava-letisko and Košice-letisko are presented on Fig. 7.

Figure 6. Absolute difference in number of days with hail in selected stations between CLINOs 1991 – 2020 and 1961 – 1990.

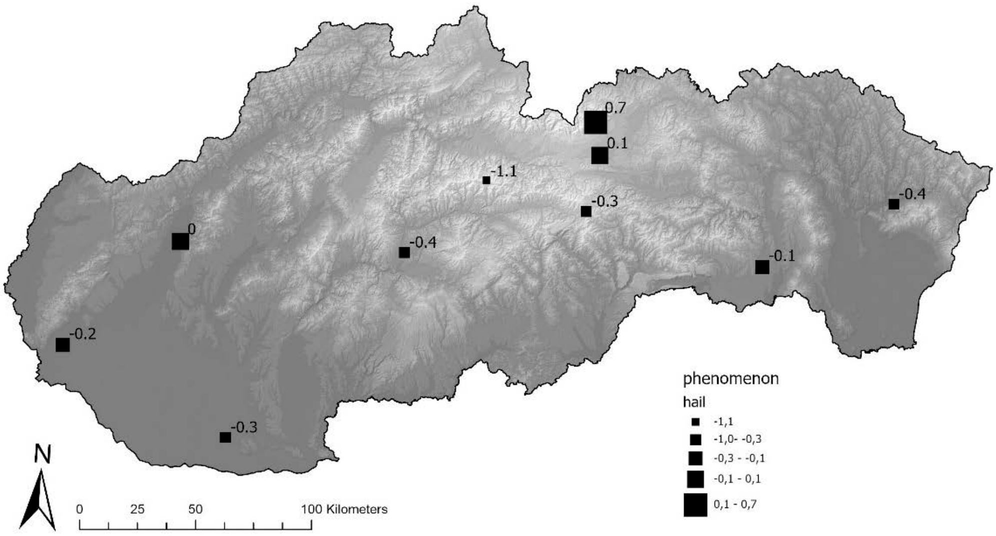
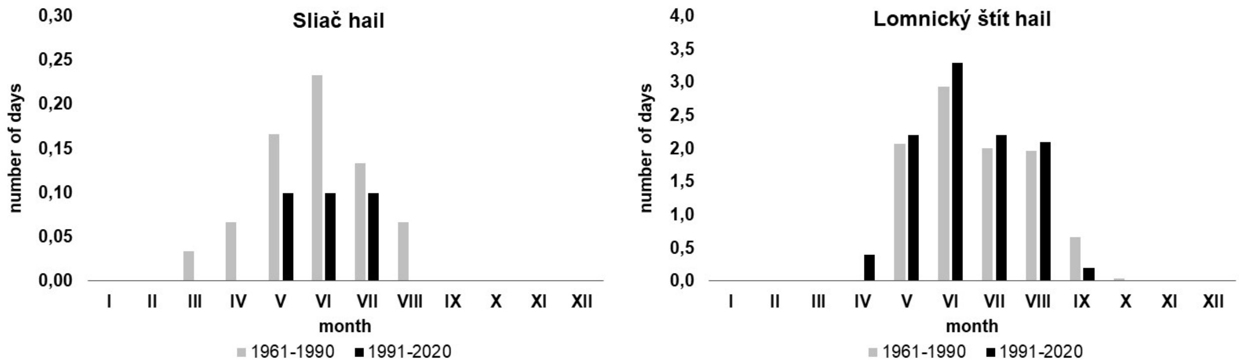


Table 4. Monthly change in number of days with hail between CLINOs 1991 – 2020 and 1961 – 1990 for selected stations

indicative	station	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Year
11816	Bratislava-letisko	0.0	0.0	-0.1	0.0	0.1	-0.1	0.0	-0.1	0.0	0.0	0.0	-0.1	**-0.2**
11826	Piešťany	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.0	-0.1	0.0	0.0	0.0	**0.0**
11858	Hurbanovo	0.0	0.0	0.2	-0.2	-0.2	-0.1	0.0	-0.1	0.0	0.0	0.0	0.0	**-0.3**
11903	Sliač	0.0	0.0	0.0	-0.1	-0.1	-0.1	0.0	-0.1	0.0	0.0	0.0	0.0	**-0.4**
11916	Chopok	0.0	0.0	0.0	0.2	-0.3	-0.1	-0.2	-0.1	-0.5	0.0	0.0	0.0	**-1.1**
11930	Lomnický štít	0.0	0.0	0.0	0.4	0.1	0.4	0.2	0.1	-0.5	0.0	0.0	0.0	**0.7**
11934	Poprad	0.0	0.0	0.0	0.0	-0.1	-0.2	0.3	0.1	-0.1	0.0	0.0	0.0	**0.1**
11938	Telgárt	0.0	0.0	0.0	0.1	0.2	-0.3	-0.1	-0.1	-0.1	0.0	0.0	0.0	**-0.3**
11968	Košice-letisko	0.0	0.0	0.0	0.2	0.0	0.0	-0.1	-0.1	-0.1	0.0	0.0	-0.1	**-0.1**
11993	Kamenica nad Cirochou	0.0	0.0	0.1	-0.1	0.0	-0.1	-0.1	-0.1	-0.1	0.1	-0.1	0.0	**-0.4**

Figure 7. The mean monthly number of days with hail in stations Sliač and Lomnický štít for CLINOs 1991 – 2020 and 1961 – 1990.



Thunderstorm

Various MP are strictly connected, and their incidence is usually synchronic. That is also an example of strong relationship between convective phenomenon and hail. Throughout our study we observed rising amount of days with thunderstorms at the same stations as it was for hail occurrence during CLINO 1991 – 2020 (Fig. 8, Tab. 5). The stations with highest increase of thunderstorms are situated in mountainous environment and characterized by higher altitudes, namely Lomnický štít (+5.1 days annually), Telgárt (+4.5 days annually) and Chopok (+3.2 days annually) (Fig. 9). Stations Poprad and Bratislava-letisko noticed increase by less than one day. When we looked at the correlation between altitude of station and rising amount of days with thunderstorm we found linear trend with $R^2 = 0.68$ and exponential trend $R^2 = 0.76$. Although it is relatively strong correlation it is necessary to study that relationship more precisely with higher amount of available stations. On the other hand, stations located in lowland areas noticed decreasing amount of thunderstorms in the new CLINO. Hurbanovo station (–6.1 days) and Piešťany (–7.6 days) observed the biggest drop in this MP. This can be caused by the change in observation regime from 24 hours to 6:30 CET till 21:00 CET in the year 2000 on these stations (NKP SR, 2023). Seasonal and monthly changes in thunderstorm regime are shown in Fig 9. Mountainous stations Lomnický štít and Chopok observed similar increase in number of days with thunderstorm during summer months June, July and August. The steepest increase appeared in July on the both stations where Lomnický štít peak gained +42.2% and Chopok 55.4% more days with thunderstorm. It is in agreement with Lukasová et al., where they found out the highest increase in precipitation in July (+45.5 mm) in comparison of CLINOs 1991 – 2010 and 1961 – 1990 on the Skalnaté pleso observatory situated under Lomnický štít. Lowland stations Hurbanovo and Piešťany observed the most significant decrease in May, June and August.

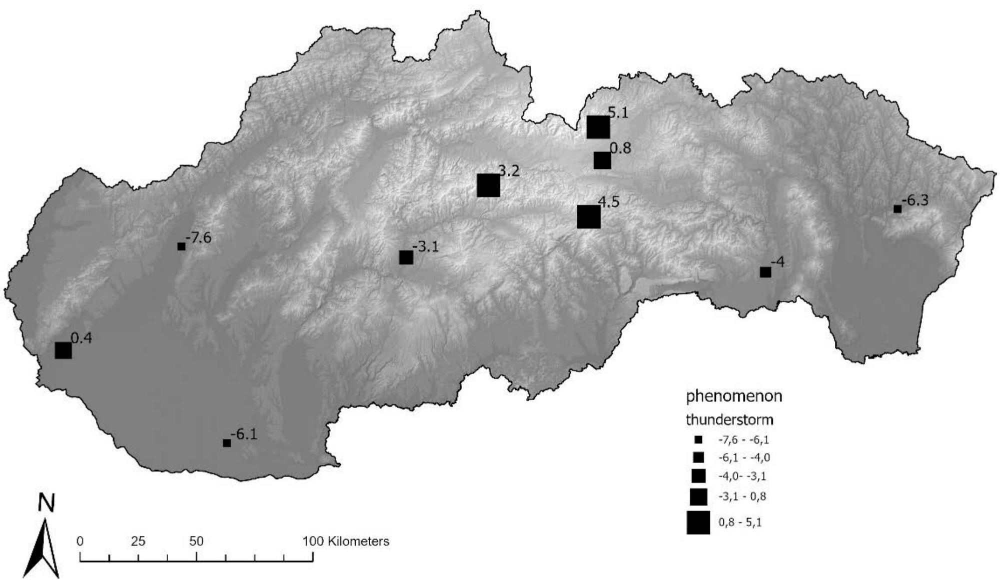
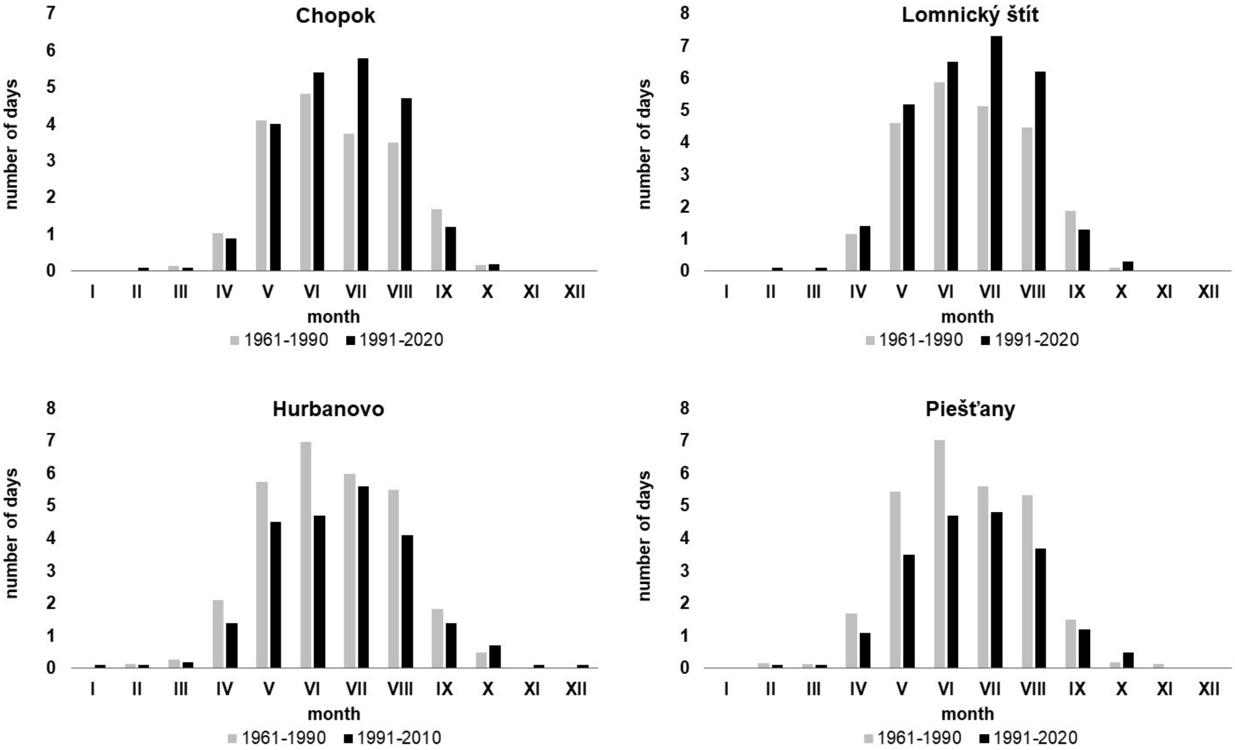


Figure 8. Absolute difference in number of days with thunderstorm in selected stations between CLINOs 1991 – 2020 and 1961 – 1990.

Table 5. Monthly change in number of days with thunderstorm between CLINOs 1991 – 2020 and 1961 – 1990 for selected stations.

indicative	station	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Year
11816	Bratislava-letisko	0.0	-0.2	0.2	0.0	-0.2	-0.8	1.4	-0.4	0.2	0.3	0.0	-0.2	**0.4**
11826	Piešťany	0.0	-0.1	0.0	-0.6	-1.9	-2.3	-0.8	-1.6	-0.3	0.3	-0.1	0.0	**-7.6**
11858	Hurbanovo	0.1	0.0	-0.1	-0.7	-1.2	-2.3	-0.4	-1.4	-0.4	0.2	0.1	0.1	**-6.1**
11903	Sliač	0.1	-0.2	-0.1	-0.3	-1.5	-1.5	1.1	-0.4	-0.3	0.2	-0.2	-0.1	**-3.1**
11916	Chopok	0.0	0.1	0.0	-0.1	-0.1	0.6	2.1	1.2	-0.5	0.0	0.0	0.0	**3.2**
11930	Lomnický štít	0.0	0.1	0.1	0.2	0.6	0.6	2.2	1.7	-0.6	0.2	0.0	0.0	**5.1**
11934	Poprad	0.0	0.0	0.1	0.1	-0.8	-1.0	1.8	0.9	-0.7	0.3	0.0	0.0	**0.8**
11938	Telgárt	0.2	0.1	-0.1	0.2	0.2	0.4	1.9	1.5	0.2	0.2	-0.1	0.0	**4.5**
11968	Košice-letisko	0.0	-0.1	-0.1	-0.2	-1.1	-0.9	-0.1	-1.0	-0.6	-0.2	0.1	0.0	**-4.0**
11993	Kamenica nad Cirochou	0.0	0.0	-0.3	-1.2	-1.4	-1.7	-0.3	-0.8	-0.6	-0.2	0.1	0.1	**-6.3**

Figure 9. The mean monthly number of days with thunderstorm in stations Chopok, Lomnický štít, Hurbanovo and Piešťany for CLINOs 1991 – 2020 and 1961 – 1990.



CONCLUSION

In this paper we analyzed 4 meteorological phenomena and changes in their frequency during the two last normal periods in the selected group of 10 meteorological stations. From that point of view, the main results of our study for CLINO 1991 – 2020 can be highlighted by following statements:

- Hail occurrence decreased in all studied stations exclusive of Poprad and Piešťany.
- The highest increase in days with thunderstorm appeared in mountainous stations, Lomnický štít, Chopok and Telgárt especially in summer months (June, July, August),
- Lowland stations Hurbanovo and Piešťany detected decrease in days with thunderstorm mainly in May, June, August.
- Correlation between altitude of station and rising amount of days with thunderstorm found linear trend with coefficient of determination $R^2 = 0.68$.
- The highest increase in relative frequency of fog is on Bratislava-letisko (41.7%) and Poprad (27.8%), the highest increase in absolute numbers is in the mountain stations (Chopok with 28.6 days and Lomnický štít with 25.8 days).
- Number of days with glaze recorded increase in all stations despite of Chopok, the highest relative increase was recorded on Sliač, 184.6% for normal 1991 – 2020, the highest absolute increase was recorded on Košice-letisko with 10.5 days per year.

All the results mentioned above needs more detailed research with higher amount of stations to prove these statements. Moreover, paper related to this topic are very rare for the territory of Slovakia although meteorological phenomena are really important if we want to look at the changing climate relations to other variables. Therefore we hope, that our paper will be useful for the future investigation of changes in frequency of meteorological phenomena.

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