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Peculiarities of Thunderstorms' Occurrences on the Border of the Western Siberia Plains and Altai Mountains

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Abstract:

Mountains of Altai are characterized by the greatest elevation in the Siberian region, creating an obstacle for Western air masses transfer. This fact determines the diversity of micro-climatic conditions. Complex climatic and geomorphologic factors create the variety of storms in certain regions of the mountainous country. At the same time, the climate and the weather in the mountains of Altai is the product of processes of general atmospheric circulation. Any economic activity feels the risk during storms. The airport on the territory of the Altai Republic which receives a lot of passengers, especially in the summer, operates

again. Therefore, it is rational to conduct the study of the relationship of thunderstorm activity with cyclonic activity, which was the purpose of the study, on the Northern slopes of the Altai, where the airport and the weather station are situated. The results of the study allowed identifying the periods of thunderstorms' manifestation on the border of the plains of Western Siberia and the Altai Mountains, as well as their confinement to the frontal phenomena.

Keywords: thunderstorm; air mass circulation; mountainous country; atmospheric front; correlation.

JEL Classification: Q54 ; Q50 ; Q51.

Introduction

Interest in the thunderstorm is fluctuating. In some periods, an illusion arises that everything is known, which is replaced by the discovery of new phenomena, the introduction of new facts into the scientific circulation that require reflection and further research (Rutjes *et al.* 2016, 12202).

The first information about thunderstorms is known from the works of Anaxagoras and other ancient philosophers (Arabadji 1960, 17). V.I. Arabadzhi examined the evolution of ideas about the occurrence and development of thunderstorms in his monograph, several chapters of which he devoted to the evolution of thunderstorm activity (Arabadji 1960, 32). Studies of thunderstorms, their geographical distribution, protection from lightning, and other issues continues today (Gijben *et al.* 2017, 195; Mecikalski and Carey 2016, 129; Guo and Zhang 2017, 120; Ruml *et al.* 2017, 27). This is due to the features' identification of thunderstorms' manifestation in various physical and geographical conditions. Works point to the complex interaction of atmospheric processes and the underlying surface (Ershova *et al.* 2012, 13; Konstantinova 2013, 8; Kocheeva 2002, 7; Krechetova 2007, 17). These and other works are devoted to the study of the Western Siberia and Kazakhstan territories (Alekhina 1979, Gorbatenko 2003, Ershova *et al.* 2012, Konstantinova 2013, Kocheeva 2002, Krechetova 2007).

The results of studying the temporal and spatial distribution of thunderstorms in the Altai mountains (within the Altai Republic (AR)) are presented in (Belikova *et al.* 2013, Dmitriev *et al.* 2011, Kocheeva 2002, Krechetova 2007, Krechetova *et al.* 2013). However, there is yet no analysis of the relationship between the manifestation of thunderstorms and cyclonic activity for this area.

The Altai Republic is located within a mountainous country, the northern part of which is located on the border with the Western Siberia plains. The thunderstorm activity is manifested most intensively in this part of the AR (Belikova et al. 2013, 27; Dmitriev *et al.* 2011, 51; Kocheeva 2002, 15; Krechetova 2007, 5; Krechetova *et al.* 2013, 110). The location of the "Civil Aeronautical Meteorological Station (AMSG), a specialized agency (airdrome meteorological office) that performs meteorological support for civil aviation" allows us to study the relationship of thunderstorm activity and cyclonic activity with the subsequent (later) practical significance of these studies (Guo and Zhang 2017).

It is known that a thunderstorm is associated with the presence of a strong instability of air stratification at high moisture content. A general background for the emergence and development of thunderstorms in sufficiently large areas is created by macroprocesses. Macrocirculation conditions determine the pathways of cyclones, in which, in general, conditions favorable for the thunderstorms' occurrences are formed. However, in each specific area these conditions are realized in different ways, depending on the characteristics of a particular territory (Ershova *et al.* 2012, 10; Konstantinova 2013, 7; Krechetova 2007, 12). The purpose of this work is to identify the relationship of circulation processes in the atmosphere with the emergence of thunderstorms on the boundary of the plains of Western Siberia and the mountainous country. For this purpose, the analysis of long-term data on the forms of atmospheric circulation available to AMSG Gorno-Altaisk and the Gorno-Altaisk Center of Hydrometeorology and Monitoring of Environment (CHME) for 2006-2015 was carried out.

Figure 1. The position of the Altai Republic (AMSG Gorno-Altaisk)

Source: https://everipedia

1. Materials and methods

The archival data of observations at the AMSG Gorno-Altaisk, as well as the data recorded during the work of one of the authors at this station were used in the work. During processing of primary data, more than 5000 values were collected, which are grouped in 120 tables. The sample for this period was: 207 values for thunderstorms, 605 values for the formation and passage of fronts (Table 1).

Table 1. Repeatability of atmospheric fronts (fragment of original table)

Year	2006	2007	2008	…	2013	2014	2015
	Days						
High-altitude trough	14	13	14		12	27	24
Surface through	1	2	1		4	14	4
Low altitude cyclone trough	15	10	7		-	5	4
Occlude	22	14	11		5	9	10
Cold front	23	11	18		7	7	12
Secondary cold front	5	1	3		1	1	5
Warm front	18	6	11		5	4	2
Secondary warm front	1	1	1		-	-	2

*Note**: Calculations were made in the programs: Exel STATISTICA.

2. Results and discussion

The location of the study was chosen based on the publications' analysis (Belikova, Krechetova, Kocheeva *et al*. 2013, 27-28; Gorbatenko 2003) which presented the results of the spatial distribution of thunderstorms' study for the entire territory of the Altai Republic. They were based on data from visual observations of 14

hydrometeorological stations (HMS) of the Gorno-Altaisk Center of Hydrometeorology, which amounted to more than 13,500 thunderstorms in 1955-2011 (Kocheeva 2002, 2; Krechetova *et al.* 2013, 109).

The analysis carried out in showed that on the territory of the Altai Republic, thunderstorm activity is characterized by a pronounced periodization (Belikova *et al.* 2013; Kocheeva 2002; Krechetova 2007). Statistical analysis made it possible to identify five HMS groups within the republic, where the number of thunderstorms is statistically different. Use of instrumental data allowed confirming the results obtained on the data of the hydrometeorological service (Belikova *et al.* 2013, 28; Krechetova *et al.* 2013, 112). During the regionalization, were identified three areas: with small, medium and high thunderstorm activity. Meteorological stations were established, where against a background of any thunderstorms' intensity their number is always greater than in adjacent territories. Such areas were classified by the authors as cluster of cells of thunderstorm (Dmitriev *et al.* 2011, 89; *Belikova et al.* 2013, 28; Kocheeva 2002, 10-11; Krechetova *et al.* 2013, 112).

AMSG Gorno-Altaisk is located on the border of the Western Siberia plains and the Altai Mountains. For our study, this is the most convenient point of observation and the source of the necessary data.

In light of the set goal, it was important to consider the characteristics of atmospheric circulation in the thunderstorm (summer) season in the northern Altai, where the study area is located. Here, on the border of the mountains and plains of Western Siberia, an extremely important role in the formation of weather conditions is played by the transfer of air masses from other regions of the Earth during the general circulation of the atmosphere (Ratna *et al.* 2017, 67).

Areas of advected air masses' formation are the Arctic seas, the Atlantic Ocean, the European part of Russia, Western and Eastern Siberia, and Central Asia. Latitudinal, or zonal, circulation is the transfer of air from the west, south-west, north-west. Meridional circulation stops air transport from the west and ensures the dominance of arctic or tropical air masses – cold and dry from the north, hot and dry from the south (Sukhova 2009, 50).

In the process of moving air masses under the influence of the underlying surface, air properties change, in spite of this, arctic air brings cold snap, tropical – strong warming, Atlantic – precipitation.

With the change in the type of air masses, the weather changes dramatically. Under the influence of the underlying surface, the advected air mass transforms into a local moderate continental air mass. The most active transformation of air properties occurs in anticyclone weather, frontal phenomena stop this process. During the cyclones' passage, the weather types (the warm front, the airmass, the cold front) are successively replaced (Sukhova 2009, 51).

As the underlying surface warms up in Central Asia, cyclonic activity on the polar front intensifies, where Iran's tropical air and the still cold continental air of Siberia interact. Formed cyclones with high energy rise to the north and north-east. Mass outlets of warm air cause warming, but the arrival of fresh Arctic air again leads to the restoration of low temperatures. Invasion of the Arctic air occurs only from the north and north-west. By April, incursions of continental Arctic air from Eastern Siberia have completely ceased, since the conditions for its transfer – the crests of high pressure of the East Siberian anticyclone – disappear (Sukhova 2009, 53).

The weather is very unstable in May. Another important role in the climate is the intrusion of Arctic air entering the rear of the cyclones of the Arctic front. Advection of cold air also occurs along the eastern periphery of anticyclones, the centers of which are above the European part of Russia. When the sedentary anticyclone is situated above Eastern Siberia, the dry air from the south heated over Central Asia spreads along the western periphery and the weather becomes warm. However, the warm sunny weather is soon replaced by cold and overcast with drizzling rain, with snowfalls in the highlands. In May the amount of precipitation increases by 2-3 times compared to April. The summer is characterized by the most stable weather. The greatest amount of precipitation falls during this time. The transfer of air masses from the west is suspended when a high-pressure crest approaches from the southwest of the Azores anticyclone. In the northern regions of the mountainous country, there are active frontal phenomena (Sukhova 2009, 54).

Thus, air masses that come from the Atlantic and the Arctic, Central and Central Asia, Europe and Eastern Siberia and other regions during the general circulation appear in the observation zone of the hydrometeorological station at the "Gorno-Altaisk" airport. During all seasons of the year, cyclonal processes prevail. Under the influence

of relief and features of the general circulation local winds of the fohn type formed in the valley of the Katun river, playing an important climate-forming role (Sukhova 2009, 56).

Analysis of the frontal phenomena (Tables 1 and 2) showed a large range of variability during the study period.

Table 2. Mathematical characteristics of some frontal phenomena for 2006-2015

Statistical indicator	High-altitude trough	Surface trough	Occlude	Cold front	Warm front
Average	15,6	4,2	11,8	11,8	7,8
Standard deviation	8,8	3,9	5,2	5,6	5,6

The revealed regularity corresponds to those features that are formed in the above-considered circulation specificity in combination with the station's geographic location.

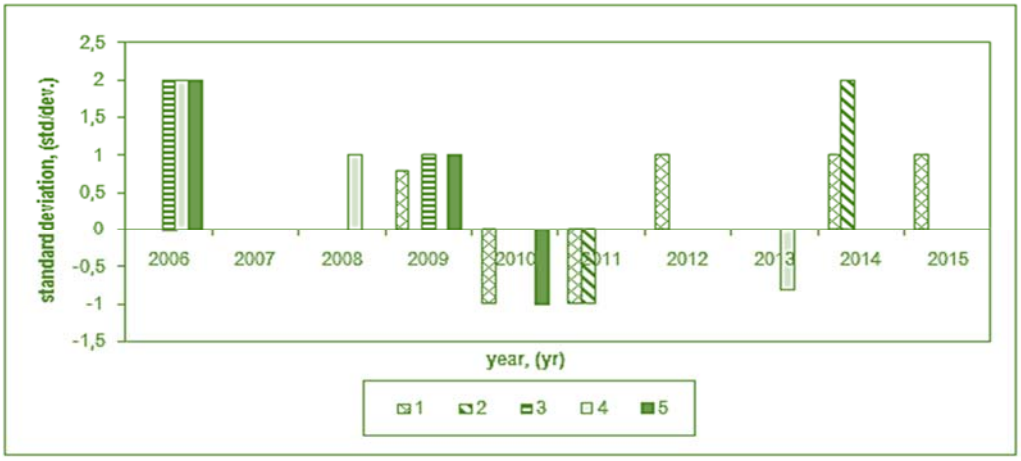
The representation of the calculated standard deviation in the graphical form (Figure 2) allows us to present the character of the temporal distribution of the number of frontal phenomena characterized by significant deviations from the average values.

The greatest number of considered frontal phenomena was recorded in 2006 and 2014. They account for more than 30% of abnormal deviations in the number of cold, warm, and occlude fronts. It is established that their number is statistically significantly higher than the average values. Excess in the amount of two values of the standard deviation of the corresponding characteristics of natural processes most often indicates the anomalous nature of these events.

At the same time, there are years when the number of frontal phenomena fluctuates near the average value. This determines that the magnitude of the standard deviation of these years is not shown on the graph (Figure 2).

It should be noted that about 70% of the deviations in the number of frontal phenomena occur in the positive spectrum. In this respect, 2006 is indicative, when three of the five phenomena considered are characterized by an increased number of manifestations, and their magnitude exceeds two standard deviations (Figure 2). In the structure of frontal phenomena the predominance of the high-altitude trough is manifested – 37.5%, against a background of a relatively equal number of deviations of the remaining frontal phenomena, shown in Figure 2 (12-19%). 2010 and 2011 excel, when the number of manifestations of the high-altitude trough is significantly reduced – by more than one standard deviation. In mathematical analysis, such a situation is not treated as an anomaly, but not taking it into account, when studying natural phenomena, would be wrong.

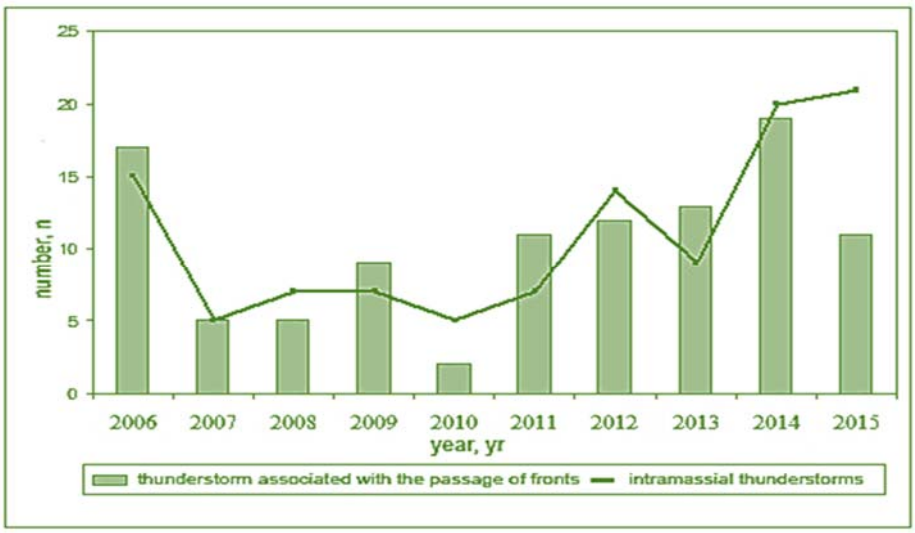
Figure 2. Distribution and magnitude of the standard deviation of the number of frontal phenomena: 1 - high-altitude trough; 2 - surface through; 3 - occlude; 4 - cold front; 5 - warm front



The ratio of the thunderstorms number associated with the passage of atmospheric fronts and air mass thunderstorms is shown in Figure 4. There is a clear trend towards an increase in the number of thunderstorms

from 2010 to the present. Attention is drawn to the manifestation of a 1-2-year cycle (or its trend) in the distribution of air mass storms (Figure 3).

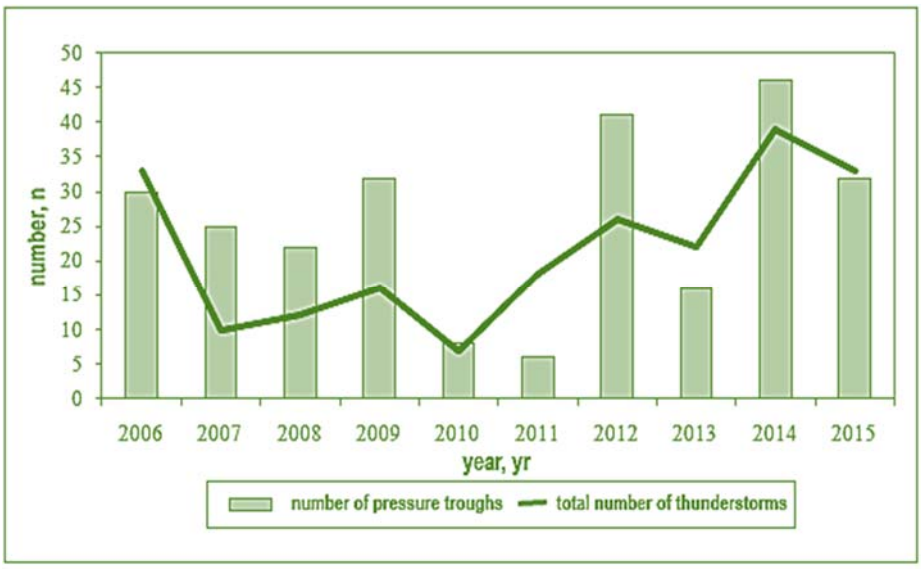
Figure 3. Number of thunderstorms that were registered at the station at the "Gorno-Altaisk" airport



Thunderstorms associated with the passage of atmospheric fronts are characterized by a more complex distribution in time. Although the general trends coincide in two cases (Figures 3, 4).

Analysis of the available data shows that not only the situation's stabilization in the atmosphere leads to a decrease in thunderstorm activity, but also an anomalously small number of some frontal phenomena (Figures 2-4). An increase in instability creates favorable conditions for the thunderstorms' formation (Figure 4; Tables 1, 2). It should be noted that the spread of the total number of thunderstorms is slightly less than the number of days of surface's and altitude's troughs existence. This is characterized by the standard deviation of these values: 10.8 and 13.1, respectively.

Figure 4. Number of thunderstorms recorded at the station at Gorno- Altaisk airport and the number of troughs



Troughs have horizontal axes, which are a line of convergence of air currents for the valley. Convergence of air currents to the axis of the trough leads to the development of ascending air movements and the formation of clouds and precipitation. The axis of the trough is a convenient place for meeting air masses of various properties, *i.e.* for the formation and exacerbation of atmospheric fronts (Gijben *et al.* 2017).

The correlation coefficients between the number of thunderstorms and the number of days with different circulation patterns vary widely. The highest value – 0.75 is established for air mass thunderstorms and the number of days with a high-altitude trough. This connection is confirmed using nonparametric statistics' methods.

Conclusions

At present, against the background of studies of varying degrees of the thunderstorms' manifestation, interesting regional aspects continue to be revealed.

In general, a large amount of factual material has been accumulated on the territory of the Altai Republic, but there are regional peculiarities that cause differences in their manifestation. In the foothills of the Altai Republic – on the border of the mountains and Western Siberia plains, the number of thunderstorms associated with the passage of atmospheric fronts varies from 2 to 19 for the period 2006-2015. The number of air mass thunderstorms varies from 5 to 21. Their average values differ slightly 10.4 and 11, respectively.

In the total volume of frontal phenomena, the altitude trough is most often manifested. The cold front and the occlude are characterized by the same average values (Table 2). It is established that these processes contribute to the formation of thunderstorms in the studied territory to the greatest degree.

At the same time, a decrease in the number of lightning events shows a correlation with a decrease in the number of trough manifestations and the passage of the warm front.

During the study, a tendency to 1-2 years of periodization in the manifestation of thunderstorms in the study area was revealed. It is combined with features noted back in 1980 for other territories (Agarkov *et al.* 1980).

Thus, qualitative and quantitative assessments have shown the connection between the formation and manifestation of thunderstorms with some frontal phenomena at the boundary of the Western Siberia plains and the Altai Mountains. At the same time, there are phenomena that cannot be linked uniquely and directly with the dynamics of the thunderstorms' number. This gives grounds for further search for the factors of influence not only on the northern macroslope of the Altai Mountains, but also in the inland regions of the mountainous country.

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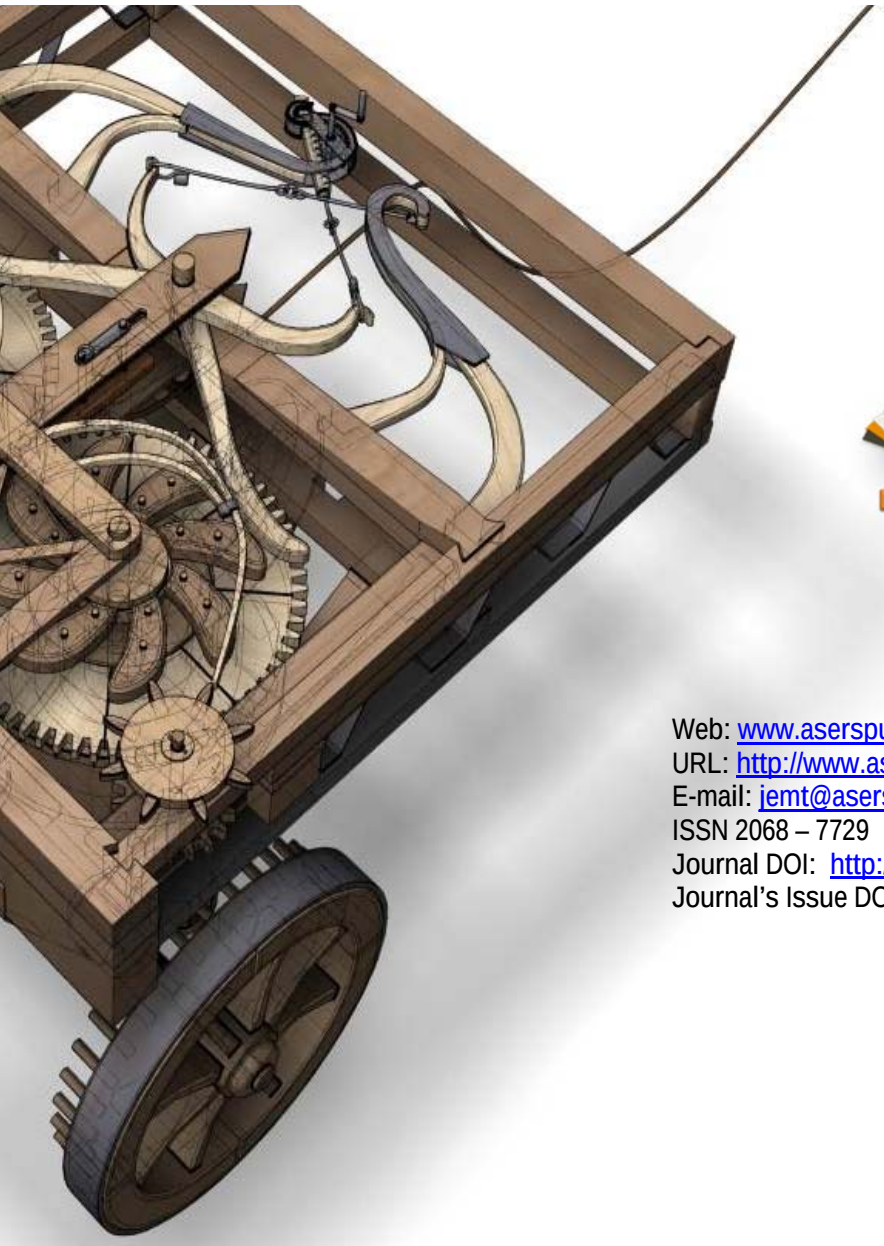

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