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Marina V. Luksha
Belarusian State University, Faculty of Geography and Geoinformatics, Minsk
Belarus
maril2010@mail.ru
ORCID: 0000-0002-0462-4625

Aliaksei A. Novik
Belarusian State University, Faculty of Geography and Geoinformatics, Minsk
Belarus
novika@bsu.by
ORCID: 0000-0002-9416-6313

FEATURES OF SYNOPTIC PROCESSES OF WINTER THUNDERSTORMS ON THE TERRITORY OF THE MINSK REGION IN A CHANGING CLIMATE

CHARAKTERYSTYKA SYNOPTYCZNYCH PROCESÓW BURZ ZIMOWYCH NA TERYTORIUM OBWODU MIŃSKIEGO W ZMIENIAJĄCYM SIĘ KLIMACIE

***Abstract*:** The analysis of the occurrence of thunderstorms in the cold season of the year (from October to March) revealed their relationship with aerosynoptic conditions on the example of the Minsk-2 airfield for the period from 1989 to 2020. The determination of these relationships is necessary to make a qualitative forecast of thunderstorms as one of the hazardous weather phenomena for aviation. Using of surface analysis maps and the determination of the dominant air masses and stages of baric formations makes it possible to identify the presence of warm (with the air temperature above 0°C) and moist air mass from the south or southwest as well as to note the displacement of intensively deepening North Atlantic or southern cyclones in the stage of a young cyclone. Taking into account the dynamic factor allows us to estimate the displacement of the main and secondary active cold fronts with speeds of more than 30 km/h. Cold fronts with waves and occlusions that provide the rise of warm and humid air of the lower troposphere. Analysis of the aerological diagram makes it possible to determine the presence of convective instability in the atmosphere, characterized by vertical temperature gradients significantly greater than humid-adiabatic. The study of the situation at the level of 700 mb and 500 mb makes it possible to identify the presence of low-jet streams and positive vorticity indicating the rise of an air parcels. The study of the situation at the level of 300 mb makes it possible to determine the influence of a powerful jet stream of the western quarter, which enhances convective processes. The results obtained can be used to replenish the methodological base on the forecasting of hazardous convective phenomena in Belarus, as well as in the development of recommendations for the forecast of thunderstorms in the cold season of the year in the operational work of weather forecasters.

Key words: Hazardous convective phenomena, winter thunderstorms, synoptic conditions, aerological conditions, aviation forecasts
Słowa kluczowe: niebezpieczne zjawiska konwekcyjne, burze zimowe, synoptyczne warunki, warunki aerologiczne, prognozy lotnicze.

Introduction

The forecast of convective phenomena of the cold season of the year (from October to March) is a typical problem faced not only by civil, but also by aviation forecasters in the course of their operational activities. In particular, in the conditions of the modern period of global climate warming, expressed primarily in the increase in winter temperatures [Belgidromet… 10.2021], there is an increase in the number of cases of this hazardous phenomena.

According to the definitions existing in the scientific literature, winter (snow) thunderstorms include thunderstorms in which, instead of heavy rain, heavy snow, freezing rain or ice/snow grains fall. Due to the increase in winter temperatures, thunderstorms are most often accompanied by heavy shower in liquid form. In this regard, according to the authors, it is important to supplement the definition of "winter thunderstorms" by including liquid precipitation.

Winter thunderstorms are quite rare. Favorable conditions for the formation of thunderstorms on the territory of Belarus mainly develop during the warm season of the year (99% of them occurs from April to September) [Belgidromet… 09.2021].

Unfortunately, by now, the problem of forecasting winter thunderstorms has not received wide coverage in literature and science, both in Belarus and abroad. There is a small number of Russian (Yusupov Y., Kostinsky A.) [Yusupov; Post-science…], Belarusian (Malchik M.K.) [Malchik], Spanish (J. Montagna, F. Fabro) [Montanya, Fabro] and American (Patrick Market, Angela Oravets, David Gade, Sam Schwartz, etc.) authors [Patrick, Thundersnow!] who studied the processes of formation of winter (snow) thunderstorms for various conditions and territories. However, the lack of developed algorithms and methods for predicting such rare but very hazardous convective phenomena as winter thunderstorms and associated heavy shower, and squally wind strengthening, confirms the relevance of the chosen problem, in particular in the field of high-quality meteorological support of aviation, on which the safety, regularity and efficiency of flights depend. In addition, the absence of a well-formed aviation and meteorological school in Belarus and the insufficient coverage of the issue under consideration abroad makes it necessary to replenish the methodological base on forecasting hazardous convective phenomena of the cold season.

In this regard, one of the important tasks of work is determining the aerosynoptic conditions for the occurrence of thunderstorms in the cold season. The possibility of forecasting these hazardous convective phenomena is statistical processing of data on the number of cases of observed thunderstorms and their accompanying phenomena (heavy shower and squally wind) from October to March for the territory of the airfield Minsk-2 for periods of round-the-clock observations. Establishing links between hazardous convective phenomena of the cold season of the year and surface synoptic and high-altitude aerological conditions under which they were observed, can develops scientific recommendations for the forecast of thunderstorms in the cold season of the year.

Methods of Research

The study was carried out in several successive stages: collecting of initial data, analysis of the information received, search for relationships and patterns, development of recommendations for the forecast of hazardous weather events in the cold season.

The sampling stage of the initial data can be divided into three stages:

a) selection of the number of cases of hazardous convective phenomena of the cold season of the year on the example of winter thunderstorms and their accompanying phenomena;
b) selection of relevant surface meteorological data in the form of surface analysis maps, when the detected cases of winter thunderstorms were noted;
c) selection of relevant high-altitude meteorological data from aerological charts, when the detected cases of winter thunderstorms were noted.

To select the number of cases of hazardous convective phenomena of the cold season of the year, data from actual aviation and meteorological observations conducted at the Minsk-2 airfield in the period from October to March 1989 to 2020 were used.

The choice of the Minsk-2 airfield as an object of the studied territory is due to the large factual material collected on this airport over a long period of observations, as well as the importance of such studies for aviation.

It is no coincidence that 1989 was chosen as the beginning of the sample, since it was from this year that the longest period of warming began in Belarus for the entire time of instrumental observations over the past 130 years, which is characterized by a particularly sharp increase in winter temperatures. Over the past 30 years, the average annual temperature in the country has increased by 1.2°C, and the temperature in the period January-March increased by 2°C or more compared to the climatic norm [Belgidromet… 10.2021; Podgornaya 9].

Sampling of the initial data in the form of cases of hazardous convective phenomena of the cold season of the year was carried out by working with the AB-6 weather diaries, which are compiled by the meteorological technicians of the AMSC of the 1st category Minsk, located at the Minsk-2 airfield.

The purpose of this sampling stage was to search for cases of hazardous convective phenomena in the cold season of the year (October-March), namely: winter thunderstorms, intense heavy shower (snow, rain, snow grains); squally wind.
The accompanying meteorological conditions were also recorded: the speed and direction of the wind, the type of precipitation and visibility in them, the air temperature near the earth and its change, the baric trend.

The next stage of the sampling was the analysis of maps of surface meteorological conditions selected for the same date and synoptic period when cases of occurrence of hazardous convective phenomena of the cold season of the year were noted. The analysis of maps of surface meteorological conditions was carried out on the basis of archival data of the Belgidromet (1989–2003) and the Internet portal Wetter3 – aktuelle Wetterkarten (2004–2019) [Wetter3], as well as a partially preserved electronic database of maps of the 1st category AMSC Minsk (2020).

During the analysis of maps of surface meteorological conditions, the actual synoptic situations near the earth were determined, in which winter thunderstorms were observed, namely:

- baric formations, stages of their development;
- the presence of frontal sections, their displacement trajectories and development trends.

The third stage of the sample was the analysis of meteorological conditions by altitude using aerological diagrams for the same date and synoptic period when cases of hazardous convective phenomena of the cold season of the year were noted. Aerological diagrams were obtained as a result of reanalysis of ERA 5, using the free thundeR Internet platform (1989–2020) [11].

Based on the results of the analysis of aerological diagrams, the high-altitude weather conditions of the formation of winter thunderstorms were determined, in particular:

- air temperature and dew point deficit on 850 mb;
- wind direction and speed at the level of 700 mb, 500 mb, 300 mb;
- the level of condensation and the level of convection characterizing the power of the convective cloud.

The next stage of the study was the analysis of the information received: the correlation of cases of hazardous convective phenomena of the cold season of the year with the aerosynoptic situations in which they were observed.

Based on the results of the above-described analysis of the initial information, the interrelationships between hazardous convective phenomena and the aerosynoptic conditions of their formation were determined, and the main patterns of occurrence of hazardous convective phenomena in the cold season of the year were established.

In the next steps, these relationships and patterns were used as the basis for the recommendations of the forecast of such convective phenomena hazardous for aviation and rare in the cold season of the year, as winter thunderstorms and accompanying phenomena in the form of intense heavy shower and squally wind.

Thus, the following methods were used in the performance of the work: a statistical method for processing long-term series of meteorological data; a method for synthesizing and analyzing initial aerosynoptic information; a method of observations and personal experience in the field of aviation meteorology; modeling synoptic situations for predicting hazardous convective phenomena of the cold season.

Results and Discussion

The study analyzed the recurrence of winter thunderstorms (October–March) at the Minsk-2 airfield over the past 32 years (1989–2020), as well as the accompanying phenomena and the connection with the ground-level synoptic situation. The results of this analysis are presented in Table 1.

Based on the analysis of the initial information, it was found that over the past 32 years, 17 cases of winter thunderstorms have been observed at the Minsk-2 airfield (1 in January, 3 in February, 4 in March, 8 in October, 1 in November). For comparison, in the period from 1936 to 1976 (for 40 years), only 2 cases of winter thunderstorms were observed in the nearby city of Minsk [Malchik]. Thus, the number of winter thunderstorms has increased by about 7 times since the beginning of the warming period.

The formation of winter thunderstorms over the Minsk-2 airfield during the period under review was associated with the passage of atmospheric fronts: a cold front with waves (8 cases), a main cold front (1 case), a secondary cold front (1 case) and a warm-type occlusion front (7 cases). Thunderstorms on cold fronts were observed in the afternoon (from 12 to 18 UTC – 5 cases) or in the evening (from 18 to 20 UTC – 4 cases), and on occlusion – at night (from 00 to 03 UTC – 3 cases) or in the morning (from 08 UTC – 2 cases). One case of a winter thunderstorm on the cold front was recorded at night – from 00 to 02 UTC and 2 cases on the occlusion front – from 17 to 20 UTC.

At the same time, as a rule, winter thunderstorms were observed near the peak of wave disturbances on cold fronts with waves and near the point of occlusion on occluded fronts. Figure 1 shows the actual surface synoptic situations in which thunderstorms of the cold season of the year 2020 were observed, associated with a cold front with waves and an occlusion.

Table 1.

Surface meteorological conditions for the occurrence
of winter thunderstorms at the Minsk-2 airfield for the period from 1989 to 2020

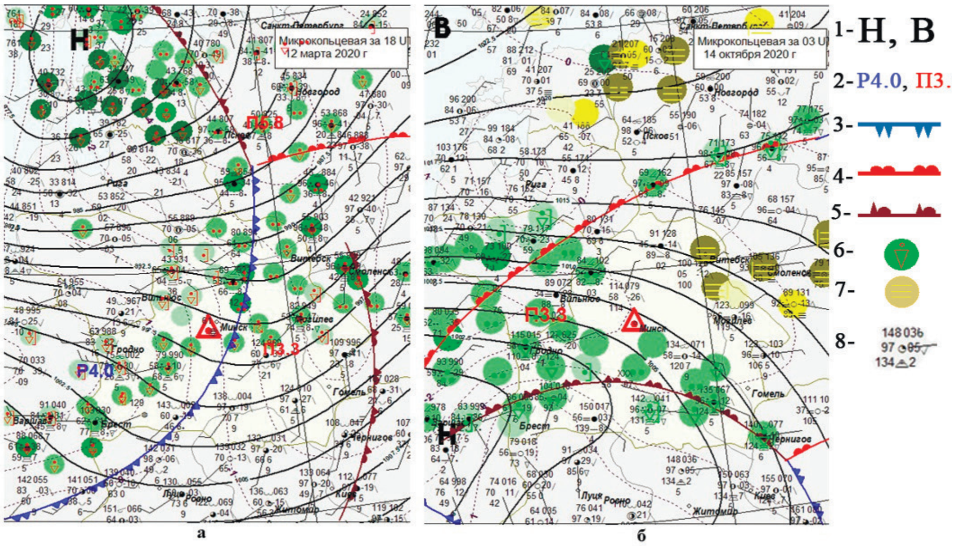
Tabela 1.

Powierzchniowe warunki meteorologiczne dla zdarzenia zimowych burz na lotnisku Mińsk-2 w latach 1989–2020

Date	Time, UTC	Synoptic situation	Wind		Baric trend, hPa/3h		Air temperature, °C		The phenomenon accompanying a thunderstorm	Visibility in precipitation, m
			Before front	After front	Before front	After front	Before front	After front		
26.01.1990	17.36–17.55	Occlusion	190° 3m/s	220° 5–9m/s	+1.8	+0.7	+6.4	+4.8	shower rain	3800
27.02.1990	19.46–20.42	Cold front with waves	190° 4m/s	290° 3–7m/s	-1.4	+1.6	+3.0	+0.2	shower snow	400
07.03.1990	13.17–13.39	Secondary cold front	300° 5-8m/s	320° 9–12m/s	+0.3	+3.6	+2.1	+1.0	shower snow	300
19.10.1996	19.40– 21.00	Occlusion	000° 0m/s	000° 0m/s	-0.6	-0.9	+11.4	+10.7	shower rain	2500
27.02.2002	16.51–18.00	Cold front with waves	150° 3m/s	290° 6–16m/s	-3.5	+4.4	+5.3	+1.,8	shower rain	2500
03.10.2003	08.08–08.30	Occlusion	200° 1m/s	210° 3m/s	+0.3	+0.3	+10.7	+9.9	shower rain	2300
31.10.2004	00.30–01.00	Occlusion	170° 2m/s	180° 3m/s	-1.0	+0.1	+12.1	+11.6	shower rain	2700
15.03.2005	15.13–15.23	Cold front with waves	240° 4–9m/s	300° 7–12m/s	-1.7	+2.2	+2.7	-0.3	shower snow	100
03.10.2006	01.10–02.42	Cold front with waves	210° 1m/s	230° 3–8m/s	-0.4	+0.7	+12.7	+11.5	shower rain	1600
23.02.2008	01.03–01.41	Cold front	220° 3–8m/s	280° 3–18m/s	-4.0	+3.0	+5.0	+37	shower rain	550

Date	Time, UTC	Synoptic situation	Wind		Baric trend, hPa/3h		Air temperature, °C		The phenomenon accompanying a thunderstorm	Visibility in precipitation, m
			Before front	After front	Before front	After front	Before front	After front		
12.03.2008	15.31–15.39	Cold front with waves	170° 3m/s	230° 3–8m/s	-2.3	-0.5	+7.9	+5.7	shower rain	1700
08.10.2009	18.06–18.38	Cold front with waves	180° 2m/s	340° 9–13m/s	-3.2	+2.2	+17.7	+11.2	shower rain	2800
10.11.2010	08.50–09.06	Occlusion	150° 3m/s	170° 5–8m/s	-0.6	+0.4	+6.8	+3.7	shower rain	3800
07.10.2011	18.14–18.54	Cold front with waves	000° 0m/s	280° 3–6m/s	-1.1	+1.1	+3.0	+0.2	shower snow	400
06.10.2012	18.31–19.30	Cold front with waves	000° 0m/s	350° 4–7m/s	-3.4	-1.2	+2.1	+1.0	shower snow	300
12.03.2020	16.54–17.28	Cold front with waves	200° 8m/s	270° 11–24 m/s	-4.4	+3.4	+11.4	+10.3	shower rain	2500
14.10.2020	03.45–04.07	Occlusion	060° 3–6m/s	100° 3–6m/s	-2.9	+1.0	+5.3	+1.8	shower rain	2500

Source: archival data of the Belgidromet (1989–2003), the Internet portal Wetter3 – aktuelle Wetterkarten (2004–2019), electronic database of maps of the 1st category AMSC Minsk (2020).
Źródło: dane archiwalne Belgidromet (1989–2003), portal internetowy Wetter3 – aktuelle Wetterkarten (2004–2019), elektroniczna baza map I kategoria AMSC Mińsk (2020).



Symbols: 1 – low and high pressure centers, 2 – baric tendency of pressure growth and drop, 3 – cold front, 4 – warm front, 5 – occlusion front, 6 – heavy precipitation, 7 – fog, 8 – surface sediment in the KN-01 code.

Fig. 1. Surface synoptic situation associated with winter thunderstorms: a – cold front with waves; b – occlusion
Ryc. 1. Powierzchniowa sytuacja synoptyczna związana z burzami zimowymi: a – front zimny z falami; b – okluzja
Source: comp. own based on 1st category map archive AMSC Minsk (2020).
Źródło: oprac. własne na podst. archiwum map I kategorii AMSC Mińsk (2020).

The frontal sections had displacement velocities of more than 30 km/h and were associated with troughs oriented from south to north or southwest to northeast, as part of deep Scandinavian cyclones with a pressure in the center of 965–985 gPa, and southern cyclones with a pressure in the center of 995–1005 gPa.

The wind at the ground had the direction of the southern component with an average speed of 3–5 m/s before the front passed. The passage of the fronts was accompanied by an increase in wind to 9–13 m/s and a turn to the southwest in the case of an occluded front, or west, northwest in the case of a cold front. Only 2 cases of wind strengthening above 15 m/s were noted. Also, large pressure gradients were almost always observed, which indicates high displacement rates of air masses.

Five thunderstorms were observed at an air temperature of +5 – 0 and less than °C, two thunderstorms – at a temperature of +5 – +10 °C, 10 thunderstorms at a temperature of +10 – +15 °C.

Table 2.

Aerological conditions for the formation of winter thunderstorms at the Minsk-2 airfield for the period from 1989 to 2020

Tabela 2.

Warunki powietrzne powstawania zimowych burz na lotnisku Mińsk-2 w latach 1989–2020

Date	Time UTC	Convective cloud power		AT-850		AT-700, wind direction and speed	AT-500, wind direction and speed	AT-300, wind direction and speed
		Condensation level, m	Convection level, m	Temperature °C	Deficit °C			
26.01.1990	17.36–17.55	700	3500	-0.3	2.0	240° – 80 km/h	240° 160 km/h	280° – 180 km/h
27.02.1990	19.46–20.42	600	2600	-3.3	1.4	250° – 80 km/h	240° – 120 km/h	240° – 130 km/h
07.03.1990	13.17–13.39	600	4600	-7.7	4.5	320° – 80 km/h	330° – 220 km/h	330° – 220 km/h
19.10.1996	19.40– 21.00	700	5300	+5.0	1.3	160° – 40 km/h	160° – 50 km/h	200° – 60 km/h
27.02.2002	16.51–18.00	700	5100	-0.2	0.0	240° – 100 km/h	240° – 110 km/h	240° – 150 km/h
03.10.2003	08.08–08.30	300	5300	+4.8	1.1	220° – 25 km/h	160° – 60 km/h	200° – 160 km/h
31.10.2004	00.30–01.00	600	5500	+9.7	2.5	240° – 80 km/h	240° – 120 km/h	240° – 170 km/h
15.03.2005	15.13–15.23	300	2000	-7.0	2.0	270° – 80 km/h	280° – 90 km/h	270° – 140 km/h
03.10.2006	01.10–02.42	500	5900	+6.7	5.0	260° – 70 km/h	260° – 80 km/h	260° – 150 km/h
23.02.2008	01.03–01.41	700	2600	+0.5	0.0	270° – 120 km/h	260° – 180 km/h	260° – 240 km/h
12.03.2008	15.31–15.39	500	2400	+0.2	05	250° – 80 km/h	240° – 120 km/h	250° – 110 km/h
08.10.2009	18.06–18.38	300	8700	+10.7	0.3	250° – 90 km/h	250° – 120 km/h	250° – 160 km/h
10.11.2010	08.50–09.06	400	3800	+6.5	2.7	200° – 60 km/h	200° – 70 km/h	220° – 120 km/h

Date	Time UTC	Convective cloud power		AT-850		AT-700, wind direction and speed	AT-500, wind direction and speed	AT-300, wind direction and speed
		Condensation level, m	Convection level, m	Temperature °C	Deficit °C			
07.10.2011	18.14–18.54	800	2800	+5.1	0.2	220° – 80 km/h	230° – 100 km/h	220° – 130 km/h
06.10.2012	18.31–19.30	800	5400	+5.5	0.0	250° – 110 km/h	260° – 120 km/h	250° – 190 km/h
12.03.2020	16.54–17.28	700	3100	+3.3	0.4	260° – 120 km/h	260° – 120 km/h	270° – 200 km/h
14.10.2020	03.45–04.07	900	4300	+9.8	2.0	150° – 70 km/h	160° – 80 km/h	210° – 110 km/h

Source: a product of its own development based jn result of reanalysis of ERA 5 from the free thundeR Internet.
Źródło: oprac. własne na podstawie wyników ponownej analizy ERA 5 w thundeR Internet (wolny dostęp).

All thunderstorms were accompanied by precipitation: at high temperatures in the form of heavy shower rain with reduced visibility from 550 to 3800 meters, at temperatures near zero – heavy shower snow with visibility from 100 to 400 meters.

After determining the altitude situation, the analysis of meteorological conditions at various levels was carried out using aerological diagrams obtained using the free thunder Internet platform [ThundeR]. At the same time, special attention was paid to the analysis of the levels of 700 mb, 850 mb, 500 mb, 300 mb. The results of the analysis are presented in Table 2.

From the aerological data it can be seen that cumulonimbus clouds, with which winter thunderstorms were associated, had a lower limit of about 300–900m, and an upper limit of 2000-8700m, depending on the temperature background.

At the level of 850 mb, in almost all cases, a ridge of warm and humid air is observed, which then changes into a trough of cold. The temperature range at this level ranges from -7.7 to +10.7 °C, depending on the prevailing air mass. At the 700 mb level, there is an increase in the south and south-westerly wind to the jet stream criteria (100 km/h). The analysis of this level shows the greatest vertical velocities and the greatest rise of the air parcel in the current situation [8]. At the level of 500 mb, in most cases, winds of the southern, south-westerly direction with speeds of more than 100 km/h are observed, which indicates the presence of a jet stream. At the level of 300 mb in all cases, with the exception of 19.10.2006, there is a jet stream of the south-westerly direction with speeds from 100 to 240 km/h. Jet streams and divergence, which are observed at this level, intensify the storm and create a wind share, so that the tops of the thundercloud will sometimes fly over layered cumulus clouds [Patrick].

In addition, the location of the area with thunderstorms near the jet stream axis on 300 mb indicates that the cyclone is gaining its activity [Thundersnow!].

Conclusion

Based on the analysis of existing information on actual winter thunderstorms using ground-level synoptic and high-altitude aerological data, a number of important patterns have been identified, which form the basis of scientifically based recommendations for making forecasts of aerosynoptic conditions for the occurrence of thunderstorms and their accompanying phenomena of the cold season, for example, the Minsk-2 airfield:

- the use of a surface synoptic situation with the determination of the dominant air masses and the stages of baric formations makes it possible to identify the presence of warm (with an air temperature above 0°C) and moist air mass from the south or southwest, as well as to note the displacement of intensively deepening North Atlantic or southern cyclones in the stage of a young cyclone;
- taking into account the dynamic factor allows us to estimate the displacement of the main and secondary active cold fronts with speeds of more than 30 km/h, cold fronts with waves and occlusion fronts, which provide the rise of warm and humid air of the lower troposphere;

- analysis of the aerological diagram makes it possible to determine the presence of convective instability in the atmosphere, characterized by vertical temperature gradients significantly greater than humid-adiabatic;
- investigation of the situation at the level of 700 mb and 500 mb makes it possible to identify the presence of low-jet streams and positive vorticity indicating the rise of an air parcel;
- studying the situation at the 300 mb level makes it possible to determine the influence of the powerful jet stream of the western quarter, which enhances convective processes.

Based on the results of step-by-step implementation of the points of this recommendation, it is possible to determine the aerosynoptic conditions favorable for the formation of winter thunderstorms. At the next stage, it is necessary to use additional computational methods for predicting convective phenomena that have already been built for the specific city or airfield under consideration.

It should also be noted that since a thunderstorm is a local mesoscale phenomenon, it is important to use operational radar data for the purposes of nowcasting, in combination with numerical weather forecast models.

Thus, the results of the study of aerosynoptic conditions for the occurrence of hazardous convective phenomena of the cold season, in the form of scientifically-based recommendations for automated forecasts of the year on the example of the Minsk-2 airfield, can be used for operational purposes not only in the field of aviation and meteorological support, but meteorological information of the population.

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Streszczenie

Analiza występowania burz w zimnej porze roku (od października do marca) ujawniła ich związek z warunkami aerosynoptycznymi na przykładzie lotniska Mińsk-2 z okresu od 1989 do 2020 roku. Ustalenie tych zależności jest konieczne do sporządzenie jakościowej prognozy burz jako jednego z niebezpiecznych zjawisk pogodowych dla lotnictwa. Wykorzystanie map analizy powierzchni oraz wyznaczenie dominujących mas powietrza i stadiów formacji barycznych pozwala na identyfikację obecności ciepłych (o temperaturze powietrza powyżej 0°C) i wilgotnych mas powietrza od południa lub zachodu oraz zwraca uwagę na przemieszczenie intensywnie pogłębiających się cyklonów Północnego Atlantyku lub południowego w stadium młodego cyklonu. Uwzględnienie czynnika dynamicznego pozwala na oszacowanie przemieszczeń głównego i wtórnego aktywnego frontu zimnego z prędkościami powyżej 30 km/h, frontu zimnego z falami i okluzjami, które zapewniają unoszenie się ciepłego i wilgotnego powietrza dolnej troposfery. Analiza wykresu aerologicznego pozwala na stwierdzenie występowania niestabilności konwekcyjnej w atmosferze, charakteryzującej się pionowymi gradientami temperatury znacznie większymi niż wilgotno-adiabatyczne. Badanie sytuacji na poziomie 700 mb i 500 mb pozwala na zidentyfikowanie występowania prądów niskostrumieniowych oraz dodatniej wirowości, wskazującej na wzrost przesyłek lotniczych. Badanie sytuacji na poziomie 300 mb pozwala na określenie wpływu silnego prądu strumieniowego zachodniej części, który wzmaga procesy konwekcyjne. Otrzymane wyniki mogą posłużyć do uzupełnienia bazy metodologicznej prognozowania niebezpiecznych zjawisk konwekcyjnych na Białorusi, a także na opracowanie zaleceń dotyczących prognozowania burz w zimnych porach roku w pracy operacyjnej prognostów pogody.