**ON VARIATION OF SEVERAL CLIMATOLOGICAL CHARACTERISTICS AT AERODROMES IN THE RUSSIAN FEDERATION IN 2001-2015**

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**Abstract**

*Variation for several aeronautical climatologically characteristics were studied on the basis of hourly (half-hourly) meteorological terminal observations at 51 aerodromes of the Russian Federation in 2001-2015. For every aerodrome extreme temperature, wind and gusts, QNH were analyzed. Using data of three consecutive 5-year periods the variation of number of days with temperature values below -300C and above 300C, wind speed ≥10ms-1, gusts ≥15ms-1 were considered. Occurrence frequency of significant weather effecting on takeoff and landing (fog, blizzard, freezing precipitation, thunderstorm) is explored. Results for aerodromes with positive or negative trends of occurrence frequency of weather phenomena in 2001-2015 are exhibited.*

**Introduction**

The aeronautical climatological information required for the planning of flight operations should be prepared in the form of aerodrome climatological tables and aerodrome climatological summaries [4,5]. Amongst others, these tables and summaries contain the data on average and extreme values of temperature, QNH, on the occurrence frequency and duration of significant weather affecting airplane landing, take-off and terminal services operations.

Depending on terminal location such weather phenomena as fog, blizzard, icing, dust storm, thunderstorm etc may be considered as significant weather. According to ICAO recommendation, aeronautical climatological information should be based on the observations performed during at least 5-year [5]. Currently, the states with developed technological opportunities for acquisition, collecting, storage, processing of data can update the climatological information regularly and automatically.

In 2006 the guideline document, “The requirements for compilation of aerodrome climatological description” was published in Russia. This document describes the procedures for data collection, storage device recording and processing. But the reality is as follow: automated system for acquisition, collecting, storage of information is installed not in every Russian airport, producing of digital archive from paper record book makes it more difficult for the formation of climatological description. For this reason, climatological information was out of date in some Russian airports.

Meantime, in 2014 in framework of WMO Commission on Aeronautical Meteorology, a new expert team on Aviation, Science and Climate (ET-ASC) was established. One of the issues of ET-ASC is formulating a recommendation for aerodrome climatological description formation in the context of climate change and climate changing [3]. In order to implement recommendation, it is necessary for preliminary evaluation of the real changing of aerodrome climatological parameters and how large the variations are.

The paper contains information on several climatological characteristics variation at 51 aerodromes of the Russian Federation in 2001-2015.

**Data**

As previously mentioned, not every aerodrome has the digital archive of weather data. Even under the existence of such archives, there are, as a rule, digital tables (AV-6) based on terminal observations. The main shortcoming of these data is an absence often of information on significant weather for aviation.

Alternatively, one can suggest the database (DB) of terminal observations on the basis of METAR that contains information on atmosphere parameters and significant weather. Such DB is established in the Aeronautical Meteorology Department of the Russian Hydrometeorological Research Centre. It consists of hourly or half-hourly observations in the large airports located in the European and Asian parts of former USSR. Among others, DB contains data on wind (direction, speed, gusts), visibility, air temperature, dew point, QNH, clouds (coverness, ceiling), significant weather (in principal and intermediate time of observation). Information from terminal report is not free of shortcomings too. The major shortcoming is the rounding for temperature, pressure and wind parameters.

Currently, DB METAR contains information for 45 large aerodromes in the European part and for 41 aerodromes in the Asian part of former USSR in 2001-2015; DB is increasing further. For this current research one can choose the observations at 51 Russian aerodromes. Table 1 contains data on number of observations.

The terminal observations in this table are without gaps only.

The purpose of this study is to analyze the occurrence frequency and duration of significant weather – fog, blizzard, thunderstorm, tornado, as far as special ranges for temperature and wind parameters. The stated characteristics have been calculated for three consecutive 5-year periods (2001-2005, 2006-2010, 2011-2015), i.e. the minimum periods to get aeronautical climatological information. It is important to detect the monotonic trends for occurrence frequency of some parameters and to study interannual variation of extreme values for several atmosphere parameters (temperature, QNH, wind speed and gusts).

**Atmospherе parameters**

In the first place, it is a temperature, described in Table E of climatological description [4]. It should be noted that temperature values are rounded to 1 Celsius degree. Impact of temperature on take-off and landing should be considered particularly for extreme value. Very low temperatures make aerodrome operations difficult. In January 2017, “Christmas frost” (below -300C) resulted in cancelation or delay of about hundred flights just in Moscow airports (<http://www.interfax.ru/moscow/544427>). At high temperatures (as a rule, above +300C) the takeoff parameters (from Aircraft Flight Manual) are restricted. Air density decreases under increased temperature, therefore, an [ascensional power](http://www.multitran.ru/c/m.exe?t=235675_1_2&ifp=1&s1=ascensional%20power) generated on takeoff decreases too. For this reason aircraft weight restrictions arise. For a Boeing 737-800 aircraft, it was found [12] that the number of weight-restriction days from May to September will increase by 50%–200% at four major airports in the United States by 2050–70 under the RCP8.5 emissions scenario [13]. These performance reductions may have a negative economic effect on the airline industry.

For each of the 51 aerodromes yearly the extreme values for maximum and minimum temperature have been analyzed. It is found that there are no trends for temperature extremes at each aerodrome. However, 15-year period is rather a short time distance to evaluate climate change effect. Therefore, it is important to clarify, how global warming trend is expressed at absolute temperature extreme values. International airports, as a rule, are located close to settlements where meteorological observations have been made for many years. On the basis of this information, the places with temperature extreme values overtopping in the 21st century have been found.

It was detected that during very hot summer 2010 in the European part of Russia (EPR) the temperature absolute maxima were renewed from Anapa to St.-Petersburg (Fig.1). This was confirmed by terminal observations too. In 2010, absolute maxima of temperature were overtopped as well as in the Asian part of Russia (APR) – in Ulan-Ude, Khabarovsk and Bratsk. At the same time, in the early 21st century some absolute minima of temperature were renewed. It is most noticeably in the south of the EPR (in Mineralnye Vody, Anapa, Astrakhan); in the APR – in Barnaul, Khabarovsk, Tiksi.

On the basis of terminal data during three consequential 5-year periods, the occurrence frequency of days with Т≥+300С and Т≤–300С (conditionally named as “hot” and “very cold”) is investigated. An analysis revealed monotonic trend in the number of days (ND) with such extreme temperature just at three aerodromes in the EPR. So, in Arkhangelsk in 2001-2005, 2006-2010, 2011-2015, ND decreased consequently (3.8, 3.4, 2.6 days per year, respectively), in Syktyvkar ND increased (7.6, 9.4, 11.0 days a year, respectively). It is important to note: for the first time since the beginning of 21st century, in 2012 at Mineralnye Vody aerodrome, extremely low temperatures (Т≤–300С) were recorded for 2 days.

Hot and very cold day variations occur more often in the Asian part of Russia. Increase of ND with Т≥+300С during three 5-year periods was observed in western area of the APR: Barnaul(8.6, 8.8, 11.6), Ekaterinburg (8.0, 10.4, 11.4) and Tyumen (9.2, 9.6, 11.0) and in Far East - Nikolaevsk-on-Amur (1.8, 2.2, 5.0). By contrast, the decrease of hot days

occurred Eastern Siberia: in Chita (25.6, 17.6, 13.2), in Magadan (0.8, 0.02, 0) as well as increase of very cold days: in Yakutsk (111.2, 115.8, 116.4), Ulan-Ude (38.2, 45.8, 47.0), and in Blagoveshchensk (20, 21.0, 23.6).

*Wind* and *wind gust* are important factors which affect aircraft take-off and landing. Wind speed impact on the takeoff run required and the landing distance. This influence is very significant even under 10 m/s and can lead hazardous effect. Crosswind complicates aircraft handling because of appearance of turning and rolling moments. In the Aircraft Flight Manual for every aircraft type, the ultimate requirements (related to crosswind, headwind and tailwind) have been described. Wind gust means wind shear that is very dangerous on takeoff and landing procedures because of possible buckling and control failure. ND with wind speed V ≥10 m/s were investigated as well as the number of reports (NR) with wind gust ≥15 m/s. It seems more appropriate methodically to use NR instead of ND because wind gust is short-time.

Monotonic trend of occurrence frequency for ND with V ≥10 m/s (Fig.2 b, green arrows), were detected at ~1/3 of all aerodromes (16 of 51), according to evaluation on the basis of 5-year periods. ND with V ≥10 m/s increased at aerodromes located not far from Russian southern borders (Rostov-on-Don, Astrakhan, Chelyabinsk, Barnaul) as well as in Yakutiya (Yakutsk and Neryungri). Occurrence frequency decrease for such days were recorded at aerodromes of the northern EPR (Arkhangelsk and Syktyvkar), in Middle Volga region (Nizhniy Novgorod and Samara), in East Siberia (Blagoveshchensk, Ulan-Ude), in Kemerovo and Omsk.

Trends of occurrence frequency of NR with wind gust ≥15 m/s (fig.2 b, red arrows) were noted at 11 aerodromes (21.5% of total amount). At 7 of 11 aerodromes, NR with gusts more than 15 m/s enhanced in Yakutiya (Neryungri, Mirny, Tiksi), Far East (Nikolaevsk-on-Amur, Yuzhno-Sakhalinsk) as well as in Arkhangelsk and Sheremetyevo (Moscow). Both increase of ND with V ≥10 m/s and NR with gust ≥15 m/s occurred at Rostov and Yakutsk aerodromes. At Arkhangelsk aerodrome increase of strong gust frequency was compensated for decrease ND with strong wind. At Murmansk aerodrome, NR with gust ≥15 m/s decreased.

If we consider extreme pressure from terminal observations, it means extreme QNH, that is atmosphere pressure adjusted to sea level. Air Traffic Control passes the QNH to pilots on clearing them to descend below the [transition level](https://en.wikipedia.org/wiki/Transition_level), as part of [air traffic control](https://en.wikipedia.org/wiki/Air_traffic_control) clearance, on request of the pilot or when the QNH changes. A denoted QNH in climatological description should be accurate to the decimal place. Absolute maximum of QNH during 2001-2015 – 1068 hPa – was recorded at Novosibirsk aerodrome (2010), absolute minimum – 952 hPa – at Syktyvkar aerodrome (2011). Analysis of available maximum and minimum QNH values (rounded to the whole number) didn’t suggest any significant trends in 2001-2015 at all Russian aerodromes.

**Significant weather**

Below were the results which came up for aerodromes with monotonic trends of occurrence frequency of weather affected takeoff, landing, and terminal services operations (according to consequent 5-year data).

*Fog* is one of the main causes leading to visibility reduction. Visibility in conjunction with ceiling defines the complexity of takeoff and landing conditions. For this reason, aeronautical climatological description provides details such as fog occurrence frequency (diurnal and annual variations) and fog continuous duration. It should be noted that the last factor for the defined area is taken into account during aerodrome design phase because of the intention to minimize flight delays caused by low visibility. As a rule, for a 5-year period NR with fog does not exceed several hundred events, sometimes – several tens. In November 2006, maximum fog duration in the European part of Russia was registered in Saratov airport for 77 hours. As for the Asian part of Russia, the most long-term fogs were observed in Yakutsk airport. In January 2006 a similar fog event lasted for 165 hours.

Geographical distribution of trends of fog occurrence frequency in 2001-2015 is presented in Fig.3,a. it can be clearly noted that the fog frequency decreased mainly at EPR aerodromes (in Moscow, Syktyvkar, St.-Petersburg, Volgograd, Astrakhan), as well as at aerodromes in East Siberia (Tiksi, Yakutsk, Ulan-Ude) and in Vladivostok. Increase of fog occurrence frequency was typical for West Siberia and Southern Ural. In 2011-2015 as compared to 2001-2005, fog event number at Moscow aerodromes Vnukovo and Sheremetyevo decreased 2.1-fold, at Tiksi aerodrome – 2.6-fold (Table 2). At the same time the average fog event duration increased at some aerodromes of Volga region, in Vnukovo, (Moscow), Pulkovo (St.-Petersburg) and at aerodromes of Yakutiya ( in Yakutsk – by an average 2.5 h). In Pulkovo airport (St.-Petersburg) both average and maximum fog event duration increased.

There was a maximal increment in the number of days with fog in 1.6-fold between 2011-2015, as compared to what was recorded between 2001-2005, at aerodromes in Arkhangelsk and Barnaul . Besides, in Arkhangelsk the increase of maximum fog duration was registered (more than twofold during 15 years); in Blagoveshchensk both maximum and average fog duration increased. In contrast, in Chalyabinsk the growth of fog occurrence frequency was compensated, to some degree, by reduction of event duration.

Trends of ND with *blizzard* (Tabl.3) leading to visibility down in cold months occurred in 43% of all aerodromes, mainly the trend was negative. The most significant negative trend was detected at aerodromes of the EPR, especially in Domodedovo and in Syktyvkar – 4.5-fold and 3.1-fold respectively (Table 3). Positive trend of ND with blizzard was registered at just three aerodromes – in Stavropol, Nikolaevsk-on-Amur and Kemerovo (1.4-, 1.7-, 2,2-fold, respectively).

*Glaze* is an ice accretion on runway and at the aircraft surface, it can negatively affect takeoff and landing because of decrease of runway surface friction and increase of aircraft weight. Glaze is caused by freezing precipitation (FP); its occurrence leads to flight delays due to runway snow removal and aircraft deicing procedures. Therefore, information on glaze should be an important aspect of aeronautical climatological description (Table 4). In this paper ND with glaze and glaze event duration were analyzed. It was found that maximum FP occurrence frequency was observed in the European part of Russia – in Mineralnye Vody airport (freezing drizzle, mainly), in the Asian part of Russia – in Omsk airport and in Chelyabinsk (the Urals, the middle between European and Asian parts). The longest FP event was registered in Mineralnye Vody in February 2011 (68 hours, since 10 UTC 24.02 till 5.30 UTC 27.02), in Omsk in 2007 (37 hours, since 18.30 UTC 31.10 till 7.30 UTC 02.11).

Taking into account previous results [10], one can notice that maximum of FP event duration in Mineralnye Vody airport was overtopped in 21 century (44 h according to 1986-1995 data). As compared to former observations, maximum FP duration increased in Moscow airport Vnukovo (21.5 h in 2010 vs 17.5 h during 1986-1995). Unfortunately, former aeronautical climatological information was computed just for airports in Moscow, Nizhny Novgorod and Mineralnye Vody.

Monotonic trends of FP episodes between 2001-2015 which were recorded mainly at the aerodromes of the EPR, these trends were predominantly negative (Fig.3c). The most significant decrease of FP events (more than 3-fold) was observed at Voronezh and Syktyvkar aerodromes. No FP events in Bratsk were detected in 2011-2015, although 20 episodes there were just in 2001-2005 . FP frequency increase took place just in the south of the EPR – at Simferopol and Stavropol aerodromes (1.6- and 1.4-fold, respectively).

*Thunderstorm* is hazardous weather for aviation; its approach leads to revise of airport activities. It should be noted that thunderstorm in METAR is coded “at aerodrome” as well as “in the vicinity” (VC). However, “aerodrome vicinity” concept is difficult to define from an observer’s point of view. According to Federal Aviation Rules [7], “at aerodrome” means “at a radial distance 0 - 8 km from aerodrome reference point”; definition of “aerodrome vicinity” from [2] is interpreted as “a space at a radial distance 8-16 km from aerodrome reference point”. For lightning detectors (at Moscow aerodromes, for example) “near vicinity” means the ring between circles with radius of 9 and 19 km from installation point. Generally, at Russian aerodromes the observers define «in vicinity» rather roughly based on local orienting points. This leads to significant differences between events “at aerodrome” and “in vicinity” So, at Sochi aerodrome the observer sees a wide sector of sea view without orienting points, and number of thunderstorm “at aerodrome” differs from the same “in vicinity” by a factor of 4. For this reason, it was decided that we consider thunderstorms just “at aerodrome”.

Fig.3 shows mainly a decrease of number of days with thunderstorm at aerodromes of the EPR. Nevertheless, two Moscow aerodromes with highest capacity – Sheremetyevo and Domodedovo – were characterized by increase of thunderstorm activities – by 1.3- and 1.2-fold, respectively (Table 5). The most growth of thunderstorm occurrence frequency was detected in Surgut (4.2-fold). The most decrease of number of days with thunderstorm occurred in Vladivostok and Rostov-on-Don (9- and 7-fold, respectively).

As very hazardous weather as *tornado* is*,* was considered outside of other significant weather. Tornado can be experienced typical for vicinity of Sochi aerodrome only, but not every year (see Fig.3). the number of tornado events has reduced in the last few years (2 events in 2011-2015 vs 19 in 2006-2010 and 16 in 2001-2005).

Occurrence frequency of *squalls* (typically “in vicinity” too) is much more. Maximum number of squalls is observed in the south of the European part of Russia. So, at aerodrome Simferopol 45 squalls were registered between 2001-2015 (25 of them – in 2006-2010). Most long-term periods with squalls, accompanying very intense thunderstorms, were registered at Nizhniy Novgorod aerodrome, especially in 2006 (in June, 18 the squalls were detected every half-hour for 7 h, in September, 2 – for 4.5 h).

**Conclusion**

On the basis of hourly (half-hourly) terminal observation data at 51 aerodromes in Russia between 2001-2015, some variations of several parameters from aeronautical climatological description were studied. Aerodromes with monotonic trends for ND with extreme temperature, wind speed and gusts affecting takeoff and landing were found. In comparison with three consequent 5-year periods, one can detect some trends of occurrence frequency and duration of significant weather such as fog, blizzard, freezing precipitation, thunderstorms at several aerodromes.

According to research, such trends occur at ~25-40% aerodromes, more often – located in European part of Russia. On the whole, at each aerodrome of the EPR, except for Anapa and Sochi, at least one of similar trends was observed. In spite of global warming process, between 2001-2015 a decrease of hot days at some aerodromes as well as an increase of very cold days at others were detected. The change of wind conditions at Russian aerodromes is characterized by heterogeneity. As for significant weather for landing, take-off , and terminal services operations (apart from thunderstorms), one can observe negative trends in its occurrence frequency, especially in the European part of Russia.

We can record multiple climatic variations at some aerodromes. So, at the Moscow aerodrome Domodedovo occurrence frequency of thunderstorm increased, the same occurrence frequencies of fogs, blizzard and freezing precipitation decreased. At Yakutsk aerodrome, apart from renewing of absolute temperature maximum in 2011, the number of very cold days increased as well as occurrence frequency of days with thunderstorms and with wind speed ≥10 m/s. The number of days with fog decreased, but duration fog was up by ~2 h. One can note the decrease of occurrence frequency of fog, blizzard, thunderstorm at aerodromes Pulkovo (St-Petersburg) and Vostochny (Ulan-Ude).

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| --- | --- | --- | --- | --- | --- | --- | --- |
| **№** | **City/Aerodrome** | **ICAO code** | **Report number** | **№** | **City/Aerodrome** | **ICAO code** | **Report number** |
| 1 | Anapa /Vityazevo | URKA | 198541 | 26 | Tiksi | UEST | 133984 |
| 2 | Arkhangelsk/Talagi | ULAA | 191578 | 27 | NorilskAlykel | UOOO | 155774 |
| 3 | Astrakhan/Narimanovo | URWA | 251186 | 28 | Surgut | USRR | 253179 |
| 4 | Volgograd/Gumrak | URWW | 255466 | 29 | Mirny | UERR | 165524 |
| 5 | Voronezh/Chertovitskoye | UUOO | 192992 | 30 | Yakutsk | UEEE | 216905 |
| 6 | Kazan | UWKD | 249792 | 31 | Magadan/Sokol | UHMM | 157585 |
| 7 | Krasnodar/Pashkovskiy | URKK | 254502 | 32 | Tyumen/Roshchino | USTR | 252364 |
| 8 | Mineralnye Vody | URMM | 259013 | 33 | Yekaterinburg/ Koltsovo | USSS | 258107 |
| 9 | Moscow/Sheremetyevo | UUEE | 257943 | 34 | Chelyabinsk/Balandino | USCC | 224749 |
| 10 | Moscow/Vnukovo | UUWW | 259045 | 35 | Omsk/ Centralny | UNOO | 258882 |
| 11 | Moscow/Domodedovo | UUDD | 259745 | 36 | Krasnoyarskк/  Yemelyanovo | UNKL | 256439 |
| 12 | Murmansk | ULMM | 243943 | 37 | Novosibirskк/Tolmachevo | UNNT | 258882 |
| 13 | Nizhniy Novgorod/Strigino | UWGG | 244800 | 38 | Kemerovo | UNEE | 252496 |
| 14 | Nizhnekamsk/Begishevo | UWKE | 242232 | 39 | Barnaul | UNBB | 256997 |
| 15 | Rostov-on-Don | URRR | 255865 | 40 | Novokuznetsk/Spichenkovo | UNWW | 245634 |
| 16 | Salekhard | USDD | 197323 | 41 | Abakan | UNAA | 258210 |
| 17 | Samara/Kurumoch | UWWW | 257841 | 42 | Bratsk | UIBB | 257821 |
| 18 | St.-Petersburg/Pulkovo | ULLI | 278170 | 43 | Neryungri/Chulman | UELL | 172949 |
| 19 | Saratov/Centralny | UWSS | 258370 | 44 | Irkutsk | UIII | 257737 |
| 20 | Simferopol | URFF | 256454 | 45 | Chita/Kadala | UIAA | 180541 |
| 21 | Stavropol/Shpakovskoe | URMT | 240920 | 46 | Ulan-Ude/ Vostochny | UIUU | 240316 |
| 22 | Sochi | URSS | 253819 | 47 | Nikolaevsk-on-Amur/Nikolaevsk | UHNN | 167143 |
| 23 | Syktyvkar | UUYY | 197597 | 48 | Blagoveshchensk/ Ignatyevo | UHBB | 187986 |
| 24 | Ulyanovsk/Vostochny | UWLL | 222315 | 49 | Khabarovsk/Novy | UHHH | 259824 |
| 25 | Ufa | UWUU | 257515 | 50 | Vladivostok/Yakovichi | UHWW | 204171 |
|  |  |  |  | 51 | Yuzhno-Sakhalinsk/Khomutovo | UHSS | 198157 |

***Note. No aerodrome name if it coincides with city name***

**Table 1.** Number of METAR reports at aerodromes of the Russian Federation [1] (left – European part, right – Asian part) in 2001-2015.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **№** | **City** | **Number of episodes for 5 year** | | | | **Maximum/average duration, h** | | |
| **2001-2005** | **2006-2010** | | **2011-2015** | **2001-2005** | **2006-2010** | **2011-2015** |
| **Decrease of episode number** | | | | | | | | |
| 1 | Astrakhan | **388** | **287** | **240** | | 19/**2.37** | 18.5**/2.92** | 25.5/**3.39** |
| 2 | Volgograd | **561** | **487** | **384** | | 62.5**/3.82** | 37.5**/4.41** | 47.0**/4.94** |
| 3 | Moscow, Sharemetyevo | **237** | **165** | **110** | | 15/1.97 | 19.5/2.22 | 18.5/2.21 |
| 4 | Moscow, Vnukovo | **376** | **324** | **175** | | 44.5/**2.01** | 17/**2.27** | 20.5/**2.41** |
| 5 | Moscow, Domodedovo | **581** | **554** | **351** | | 38/1.73 | 17/1.43 | 18/1.77 |
| 6 | St.-Petersburg | **295** | **262** | **210** | | **10.5/1.69** | **12.5/1.72** | **17/1.92** |
| 7 | Syktyvkar | **281** | **273** | **200** | | 10/1.65 | 12/1.84 | 10.5/1.59 |
| 8 | Tiksi | **315** | **238** | **122** | | 7.5**/1.10** | 17**/2.28** | 17**/2.38** |
| 9 | Yakutsk | **521** | **479** | **428** | | 71.5**/7.08** | **165/8.84** | 140**/9.58** |
| 10 | Ulan-Ude | **101** | **66** | **60** | | 10.5/1.87 | 11/3.15 | 13.5/2.82 |
| 11 | Vladivostok | **576** | **356** | **327** | | 17.5/2.30 | 14.5/2.84 | 15/2.79 |
| **Increase of episode number** | | | | | | | | |
| 1 | Arkhangelsk | **180** | **226** | **285** | | **7/**1.57 | **11.5/**1.75 | **16/**1.70 |
| 2 | Salekhard | **165** | **241** | **254** | | 17.5/2.44 | 18.5/2.44 | 16.5/2.78 |
| 3 | Ulyanovsk | **119** | **128** | **148** | | 16/2.62 | 33/2.62 | 16/2.32 |
| 4 | Norilsk | **417** | **469** | **516** | | 27.5/3.11 | 18.5/2.78 | 35.5/2.88 |
| 5 | Chelyabinsk | **173** | **185** | **257** | | 25**/2.17** | 33**/2.07** | 15**/1.76** |
| 6 | Kemerovo | **154** | **170** | **229** | | 14.5/2.63 | 28.5/2.34 | 19/2.50 |
| 7 | Barnaul | **153** | **172** | **243** | | 15.5/2.24 | 27/2.60 | 16/2.23 |
| 8 | Blagoveshchenck | **122** | **143** | **169** | | **7.5/1.95** | **10.5/2.24** | **14/2.63** |

**Table 2.** Number and duration of episodes with fog for 5-year periods at aerodromes of the Russian Federation (red – positive trend, blue – negative trend)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **№** | **City** | **2001-2005** | **2006-2010** | **2011-2015** |
|  |  | **Negative trend** | | |
| 1 | St.-Petersburg | 27.6 | 15 | 11.8 |
| 2 | Nizhni Novgorod | 40.4 | 14.6 | 14.2 |
| 3 | Moscow, Vnukovo | 19.0 | 8.4 | 8.2 |
| 4 | Moscow, Domodedovo | 26.0 | 9.8 | 5.8 |
| 5 | Ufa | 17.0 | 10.8 | 9.0 |
| 6 | Samara | 24.4 | 16.2 | 15.6 |
| 7 | Simferopol | 4.6 | 3.8 | 2.4 |
| 8 | Voronezh | 29.8 | 26.8 | 22.2 |
| 9 | Volgograd | 24.0 | 15.6 | 14.2 |
| 10 | Rostov-on-Don | 18.6 | 9.2 | 7.4 |
| 11 | Krasnodar | 4.0 | 2.0 | 1.0 |
| 12 | Arkhangelsk | 27.8 | 19.8 | 19.8 |
| 13 | Salekhard | 56.4 | 43.8 | 37.8 |
| 14 | Blagoveshchenck | 7.6 | 4.6 | 2.4 |
| 15 | Khabarovsk | 8.2 | 6.8 | 4.8 |
| 16 | Yuzhno-Sakhalinsk | 36.4 | 26.8 | 26.7 |
| 17 | Vladivostok | 10.6 | 8.6 | 6.4 |
| 18 | Ulan-Ude | 9.6 | 6.2 | 3.8 |
| 19 | Syktyvkar | 35.2 | 19.8 | 11.4 |
|  |  | **Positive trend** | | |
| 1 | Stavropol | 9.6 | 12.6 | 13.8 |
| 2 | Nikolayevsk-on-Amur | 13.4 | 18.2 | 23.0 |
| 3 | Kemerovo | 3.4 | 4.0 | 7.6 |

**Table 3.** Number of days (5-year averaged) with blizzard   
at aerodromes of the Russian Federation

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **№** | **City** | **Number of episodes** | | | | **Maximum duration, h** | | |
| **2001-2005** | **2006-2010** | | **2011-2015** | **2001-2005** | **2006-2010** | **2011-2015** |
| **Decrease of episode number** | | | | | | | | |
| 1 | Astrakhan | **91** | **51** | **33** | | 15.5 | 9.5 | 13 |
| 2 | Volgograd | **125** | **98** | **88** | | 20 | 18 | **39** |
| 3 | Moscow, Domodedovo | **142** | **139** | **99** | | **6.6** | **10.5** | **18.5** |
| 4 | Samara | **53** | **47** | **38** | | 7 | 5 | 7 |
| 5 | St.-Petersburg | **40** | **24** | **21** | | 7 | 3.5 | 5.5 |
| 6 | Saratov | **120** | **98** | **78** | | 15 | 11 | 16.5 |
| 7 | Syktyvkar | **204** | **117** | **75** | | 7.5 | 31 | 8.5 |
| 8 | Rostov-on-Don | **160** | **96** | **89** | | 13.5 | 12 | 19 |
| 9 | Voronezh | **194** | **119** | **66** | | 14.5 | 15.5 | 8 |
| 10 | Surgut | **37** | **29** | **15** | | 3.5 | 4 | 5 |
| 11 | Chelyabinsk | **31** | **22** | **17** | | 11.5 | 7.5 | 15.5 |
| 12 | Bratsk | **20** | **2** | **0** | | 3 | 6.5 | 0 |
| **Increase of episode number** | | | | | | | | |
| 1 | Simferopol | **37** | **48** | **61** | | 12 | 18 | 10.5 |
| 2 | Stavropol | **78** | **80** | **110** | | 17.5 | 16.5 | 22.5 |

**Table 4.** Number and duration of episodes with freezing precipitation for 5-years periods at aerodromes of the Russian Federation (red – positive trend, blue – negative trend)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **№** | **Город** | **2001-2005** | 2006-2010 | 2011-2015 |
|  |  | **Negative trend** | | |
| 1 | St.-Petersburg | 9.8 | 7.4 | 6.6 |
| 2 | Kazan | 16.4 | 13.6 | 11.4 |
| 3 | Simferopol | 24.4 | 21.0 | 16.4 |
| 4 | Voronezh | 26.8 | 12.4 | 10.8 |
| 5 | Rostov-on-Don | 73.4 | 12.2 | 10.2 |
| 6 | Krasnodar | 23.4 | 11.4 | 10.2 |
| 7 | Salekhard | 1.0 | 1.2 | 4.0 |
| 8 | Vladivostok | 24.6 | 5.2 | 2.8 |
| 9 | Ulan-Ude | 9.8 | 8.2 | 6.8 |
| 10 | Krasnoyarsk | 23.6 | 12.8 | 9.6 |
| 11 | Syktyvkar | 9.2 | 7.2 | 6.6 |
|  |  | **Positive trend** | | |
| 1 | Moscow, Sharemetyevo | 11.2 | 11.4 | 15.0 |
| 2 | Moscow, Domodedovo | 20.6 | 22.4 | 24.0 |
| 3 | Ufa | 4.2 | 5.2 | 13.8 |
| 4 | Yakutsk | 4.6 | 5.2 | 8.2 |
| 5 | Surgut | 2.2 | 7.6 | 9.2 |
| 6 | Yekaterinburg | 8.2 | 10.8 | 15.0 |

**Table 5.** Number of days (5-year averaged) with thunderstorm at

aerodromes of the Russian Federation 

**Figure 1.** Aerodromes nearby the settlements where absolute extremes of temperature (red is maximum, blue is minimum) were overtopped in 21st century.

|  |
| --- |
| **а** |
| **б** |

**Figure 2.** Aerodromes with trends in occurrence frequency ( arrow up – positive trend, arrow down – negative trend) of a) ND with Т≥+300С (red) and ND with Т≤-300С (blue).; b) ND with wind speed ≥10 m/s (green) and NR with gusts ≥15 m/s (red).

|  |
| --- |
| a |
| **b** |
| **c** |
| **d** |

**Figure 3.** Trends (red is positive, blue is negative) in occurrence frequency of ND with a) fog, b) blizzard, c) freezing precipitation d) thunderstorm at aerodromes of the Russian Federation between 2001-2015.

**Figure 4.** Tornado events in vicinity of the Sochi aerodrome in 2001-2015.

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