A study of hailstorms in the South of Western Siberia

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Abstract. The paper presents the mapped spatial distribution of the maximum hail days in the period 1966–2016 and the number of hailfall with different diameters and hail frequency from 2015 to 2018. The territories most affected by hail are identified, the key factor is orography. Hail with an annual frequency of occurrence is observed mainly in regions with an altitudes of more than 300 m asl which influenced by the southern mountains of Siberia. The characteristics of convective clouds (height and cloud top temperature, thickness of the cloud, temperature at the condensation level) are presented according to upper-air sounding and satellite measurements. An assessment of synoptic processes on days with hail has shown an increase share of intra-mass processes, in particular, mesoscale convective systems (MCS) in the summer.

Introduction
Climate changes in the world and particularly in Russia are characterized by an increased frequency of hazardous weather phenomena [1–2], which significantly affect the various socio-economic spheres of the regions. There has been an enlargement in the number of convective-related heavy precipitation and hail events over many areas.

According to Roshydromet, heavy precipitations, strong wind, hail, blizzards and abnormally cold weather cause the most damage. For example, in 2016, the total losses from convective hazardous phenomena exceeded 2 billion rubles, a significant contribution to which is made by the severe hail observed in Western Siberia. So, it can be noted a great hail that fell in the Republic of Altai on July 28, 2014, with loss of approximately 50 million rubles. In 2017, a hailfall was responsible for the crop damage over an area of 702 hectares in the Altai Territory with insured damage of 13.24 million rubles. In 2018, a hail event on June 28 in the Novosibirsk Oblast led to economic losses to be around 95 million rubles.

Based on the information published in the Roshydromet reports, a time series of the number of cases with the hazardous event “severe hail” (hail of 20 mm and greater) in the Siberian Federal District was compiled (Figure 1).
Figure 1. The number of cases with the hazardous phenomenon "severe hail" in Russia (1), Siberian Federal District (2) and their ratio (3)

Severe hail frequency on the territory of Siberia in relation to the overall frequency in Russia in some years can reach 33%. Note hail is not a common convective weather phenomenon in Siberian Federal District. Regarding the entire territory of Russia, highly exposed to hail hazard is Ciscaucasia regions and the North Caucasus, where the dynamics of the hail have been studied in sufficient detail [3]. In the last 30 years, there has been a reduction the occurrences of hail in the mountains, while in plains such events have become more frequent. Detailed studies of hail activity in other territories of Russia are less presented in the scientific publications. The change in the physical characteristics of a hailfalls under changing climate has been analyzed in [4], where particular attention is given to the fact that the overall frequency of hail events varies slightly from 1960 to 2014 with an increasing of the number of days with large-sized hail since 1990s.

The study of the hail characteristics is essential for several reasons. As for meteorologists, climatological information is important to improve the understanding of atmospheric processes that lead to the formation of hail. Geographers need understand the impact of surface features and properties on hail. Economists and insurers need to correctly estimate the insurance in specific hail events. In the construction sector, heat insulation of structures or power supply systems, for example, solar thermal systems are most vulnerable to hail. The main wastage fell on the agricultural sector and was characterized by crop damage [5].

The study is aimed to assess the spatial and temporal structure of hail, in addition with the characteristics of convective clouds, including the temperature and humidity structure on days with registered cases of hail over several selected regions of Siberian Federal District geographically located in southeast part of Western Siberia.

Methods and data
Hail is produced in deep convective storms that are characterized by strong updrafts, large supercooled liquid water contents, high cloud tops, and a sufficient lifetime [6, 7]. Hail-bearing thunderstorms are usually highly-organized convective systems in terms of multicells, mesoscale convective systems (MCS), or supercells. A hailstone has a density comparable to that of solid ice and occurs in spheroidal, conical, or generally irregular shape.

Following World Meteorological Organization (WMO) for recording of current and past weather at and around a station [8], number 96 is applicable for great hail and hail with thunderstorm is encoded by 99. For aviation purposes, the WMO technical guidelines suggest the code "GR" (formed from the French word grêle) for significant hail with a diameter of 5 mm or greater, notably to differentiate it from other forms of solid precipitation [5]. In this study, we turned to the WMO recommendation and took into consideration hail with a diameter of 5 mm or greater fallen on the ground.
There are several approaches to investigate the distribution of hail, including the evaluation of its diameter. Since the 1960s, a registration network called “hailpad” has been utilized in many countries [9]. In Russia, a method of visual registration of hail with an instrumental measurement of its dimensions has been adopted for the work of the national observational network.

The study involved data on the average multイヤear and maximum (per year) hail days, calculated on the basis of observation at 127 meteorological stations for the climate normal period 1966 to 2016. Upper-air data was used for temperature-humidity structure in the summer from 1995 to 2018, carried out at 00 and 12 UTC on days when hail was recorded in the area of observation stations up to 150 km (available at http://www.weather.uwyo.edu). To study the repeatability of hail processes depending on the hailstones diameter, we took the database of weather reports (WAREP) with events for 127 meteorological stations in 2015–2018. A cloudiness characteristic has been identified based on satellite information for 2007–2018.

To determine the cloudiness parameters, the Level-1b AVHRR radiometer data (available at http://www.rpocpod.ru) has been taken. The accuracy of the decoded thematic cloud products has been estimated using the NOAA AWG algorithm [10]. In addition, collections of cloud products (06_L2) by MODIS were used (available at https://modis-atmos.gsfc.nasa.gov/products/cloud).

**Hailstorm characteristics**

Within reference area (50–62 °N, 74–94 °E), a technical officer (observer) at weather station register an individual hail event rather rarely, on average, 1–4 days per season. In general, hail falls around 5–10 days per year across the territory of the south-east of Western Siberia. Figure 2 shows the distribution of the hail frequency and the maximum recorded diameter of hail near observation network sites for 2015–2018. In total, 306 cases of hailfalls were recorded near weather stations located within area under study. Of these, in 55% of cases hailstone size did not exceed 5 mm, in 35% – 6 to 10 mm and in 10% of cases the hailstone measured 10 mm. Hailstone larger than 16 mm has been recorded in 13 cases (in 2018–8, 2016–2 and 2015–3).

![Figure 2. A hail frequency and the maximum recorded hailstone size from 2015 to 2018 for southern Western Siberia](image)

The duration of hailfall less than 10 minutes was recorded in 83% of cases, while in 55% of cases hail lasted up to 5 minutes. The durable hail (from 30 minutes to an hour) has been noted in 2% of
cases. The mode of duration is 3 minutes with an arithmetic mean value equal 7 minutes for the territory. Comparison the characteristics of hail under climate change with the period 1936–1965 has demonstrated a tendency to double the number of days with a prolonged hail (30–60 minutes), as well as a hail with diameter greater than 10 mm.

Note that hail with a diameter of less than 10 mm had a short duration generally. Only in 20% of cases, the hail lasted more than 10 minutes, whereas hail greater than 10 mm in 25% of the cases lasted more than 10 minutes, which often led to the formation of a hail layer on the underlying surface up to 10–15 cm.

In general, within area under investigation the maximum hail days per season is unevenly distributed (Figure 3). In the northern part of the territory (more than 54 N), to which Tomsk Oblast predominantly lies, the maximum number of days with hail greater than 5 mm per season does not exceed 5 days.

The highest number of days with hail is observed along the borders of the Altai Territory, which is explained by the contribution of forced convection processes on the windward slopes of the South-Siberian Mountains (including the Salair Ridge, Kuznetsky Alatau and Altai foothills). The average long-term number of days with a hail with diameter exceeds 5 mm reflects the dependence of the spatial distribution to a greater degree on the orographic factor. Thus, this characteristic varies over the territory from 0.2 to 2.6 days with hail per year. At the same time, hail with annual frequency of occurrence is observed mainly in areas with an altitude of more than 300 masl. The maximum hail frequency is recorded on the western slopes of the Kuznetsk Alatau (Central Rudnik station, height 495 m) and in the foothills of Altai (Shebalino station, height 862 m). The area of boosted hail days in the Ob reservoir is also highlighted. Hypothetically, this is due to the available extra moisture source of water vapor in the development of convective clouds but it requires demanding research.

Weather situations that favor thunderstorms and hail formation in the south of Western Siberia are most often associated with the passage of cold catafronts and occluded fronts. Based on satellite

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**Figure 3.** The maximum number of days with hail for 1966–2016
remote sensing data selected for the period 2007–2018 it has been ascertained that in convective clusters formed along occluded front, there can simultaneously exist several convective cells capable of producing hail. Therefore, the cases of almost concurrent hail precipitation in 3–9 points have become frequent. The share of *Cumulonimbus* hail clouds amounted to 68%.

The contribution of intra-mass clouds, in particular, mesoscale convective systems (MCS), to days with convective hazardous phenomena has 32%. On average, 21 days with MCSs paired with hail was recorded. On all recorded days with the MCSs, thunderstorms were observed in 100%, including thunderstorms and hail (10%), within the radius of formation and passage of the MCSs according to the ground network. MCSs usually generate over the underlying surface, where in the middle troposphere an updraft is observed, due to mesoscale wind convergence. This is conducted, inter alia, the increasing frequency of prolonged heat waves [1], when the underlying surface warms over 30–35 °C.

Next, we analyzed the temperature-humidity structure of the troposphere and assessed the characteristics of convective cloudiness pursuant to upper-air observations (Table 1). It was revealed that in the summer convective season over the territory of Western Siberia, the top of *Cumulonimbus* producing hail reaches an isobaric surface of 200 hPa. The condensation level on days with hail in all months is 200 meters lower for *Cumulonimbus*, observed in the north of the studied region (58 °N) compared to same type of convective clouds, which are formed to the south (55 °N); the maximum differences between them are observed in August and close to 500 m. The thickness of hail clouds exceeds 4 km, increasing to the south, and in July – to 7 km. During the hail season a threshold air temperatures of the sub-cloud layer of hail clouds varies from 7–11 °C in the north to 8–12 °C in the south of the study area. Notice that during periods of abnormally hot weather, large hailstones larger than 15 mm are greater often formed, this fact does not contradict the physical prerequisites for the formation of hail, but this requires additional thought and hypothesis generation.

**Table 1.** Characteristics of convective clouds in days with hail over southeastern part of Western Siberia for the period 1995–2018

| Cloud characteristic | Kolpahevo (58.30 °N 82.88 °E) | Novosibirsk (54.90 °N 82.92 °E) |
|----------------------|-------------------------------|---------------------------------|
|                      | Jun   | Jul  | Aug | Jun   | Jul  | Aug |
| Temperature at the level of condensation, °C | 7.0   | 11.0 | 8.0 | 8.0   | 12.5 | 7.0 |
| Cloud-base height, m | 1,300 | 1,300| 1,300| 1,500 | 1,300| 1,300|
| Cloud-top height, m | 5,400 | 7,100| 6,000| 6,000 | 8,500| 7,000|
| Cloud thickness, m  | 4,100 | 5,800| 4,700| 5,500 | 7,200| 5,700|

Satellite remote sensing of high resolution allows assessing the characteristics of cloudiness in more detail and approximately in time to the beginning of the phenomenon. Within the reference area (50–62 °N, 74–94 °E), the AVHRR thematic products of cloud interpretation were considered. The scan time of the study area by the radiometer should have been as close as possible to hailfall occurred in May-August for 2015–2018. The event was taken as an event with a discrepancy in time of hailfall and passage of satellite equipped with AVHRR, no longer than 1 hour. Under this condition, 84 cases were picked. The average values of the cloud formed above 10, 11, and 11.5 km for June, July, and August, respectively. The cloud top temperature varies between -55 and -50 °C for the summer months.

The consistency in assessment of determining the cloud top height has shown that there is an underestimation of the values (82 %) retrieved by upper-air sounding comparing with the satellite measurement (approximately 500–4,500 m). Such discrepancies in the results are directly related to the spatial-temporal differences between the time of hail detection by the ground-based station network and upper-air observations. The percentage of hail precipitation cases that are close in time to upper-air sounding is small, and is less than 3.5 and 23 % for the period 00 and 12 UTC respectively.
With the distance of the site of hail fall from the observation point, this percentage is at least halved. Therefore, it is more consequential to use satellite sensing data for the diagnosis of hail processes.

**Summary**

The first in-depth hail climatology in the south-east of Western Siberia, Russia, based on various source of information, is described. Despite the fact that the study on the climatology of hail is based on insuffciently long time series, we made an attempt to map of the frequency and intensity of hail. Extension of the time series will allow clarifying this distribution. The study present the spatial distribution of the maximum and average number of days with hail over the period 1966–2016 and the number of cases with hail depending on the diameter and frequency of occurrence for 2015–2018.

The orography factor in the hail frequency has notable impact. The territories most affected by hailstones correspond to the zone of influence of the southern mountains of Siberia (Kuznetsk Alatau, Salair ridge and the foothills of the Altai). The enlarged numbers of days with hail near the Ob reservoir area is also highlighted.

By analyzing observational data from upper-air sounding on days with hail we found that the cloud base height of Cumulonimbus formed in the north of the studied region (about 58 °N) is 200 meters lower than for the same type of cloud in the south (55 °N), and the maximum difference up to 500 m is noted in August. The thickness of the hail clouds exceeds 4 km, increasing to the south, and by July it can reach 7 km. The threshold air temperatures of the sub-cloud layer vary during the hail season in the range of 7–11 °C in the north and 8 to 12 °C in the south of area under investigation.

On the basis of satellite information, it was found that 68% frontal Cumulonimbus clouds produced hail. The contribution of intra-mass cloudiness, in particular, mesoscale convective systems, on days with hazardous convective phenomena amounted to 32%. The average values of the top height of clouds from which hailstones fell reached 10,000–11,000 m. The cloud top temperature varied -55 to -50 °C.

The consistency in assessment of determining the cloud top height has shown that there is an underestimation of the values (82 %) retrieved by upper-air sounding comparing with the satellite measurement (approximately 500–4,500 m). Such discrepancies in the results are directly related to the spatial-temporal differences between the time of hail detection by the ground-based station network and upper-air observations.

The implementation of being actively developed numerical weather prediction (NWP) models for thunderstorms and hail into operational practice requires refining the predictor’s parameterization, and this in itself is a difficult task. Such a difficulty in describing cloudiness and precipitation in climate models and large-scale weather forecast models also lays in the fact that they in most models is a sub-grid process that differs in regions.

Therefore, the study of parameters of convective clouds, generating hazardous convective phenomena in different geographical areas, contributes not only to the improvement of regional weather forecasts, but also to an understanding of the physical processes occurring in such clouds accompanied by thunderstorms and hail. The results are beneficial for designing and enhancing the NWP of thunderstorms, heavy rain, hail and strong wind etc.

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**References**

[1] Stocker T F, Qin D, Plattner G-K, Tignor M, Allen S K, Boschung J, Nauels A, Xia Y, Bex V and Midgley P M (eds.) 2013 *Climate Change 2013: The Physical Science Basis* (Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA).

[2] Kattsov V M et al 2014 *Second Roshydromet assessment report on climate change and its consequences in Russian Federation, Moscow* (Federal service for hydrometeorology and environmental monitoring).
[3] Abshaev M T, Abshaev A M, Malkarova A M 2012 *Estimation of antihail projects efficiency considering the tendency of hail climatology change* (Proceedings of the 10th WMO Scientific Conference on Weather Modification. World Meteorological Organization) 1-4.
[4] Allen J, Tippett M 2014 *The characteristics of United States hail reports 1955–2014* (Electron. J. Severe Storms Meteorol) 10 (3) 1-31.
[5] Punge H J, Kunz M 2016 *Hail observations and hailstorm characteristics in Europe* (A review, Atmospheric Research) 176-177 159-184.
[6] Pruppacher H R, Klett J D 2010 *Microphysics of Cloud and Precipitation* (Kluwer, Academic Publisher, Dordrecht).
[7] Houze R A 2014 *Cloud dynamics* (International Geophysics Series, Academic Press, San Diego) 104.
[8] WMO, *Manual on codes, international codes*, vol. I.1, part A – alphanumeric codes. Tech. Rep. WMO-No. 306 World Meteorological Organization, 2011.
[9] Vinet F 2001 *Climatology of hail in France* (Atmos. Res.) 56 (1-4) 309–323.
[10] Kostornaya A A, Saprykin E I, Zakhvatov M G, Tokareva Y V 2017 *A method of cloud detection from satellite data* (Russ. Meteorol. Hydrol.) 42 (12) 753-758. DOI: 10.3103/S1068373917120020.