Formation of intense thunderstorms in Yakutia in periods of frequent atmospheric blocking in Western Siberia

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Abstract. The variation of lightning strokes number in Yakutia were found to depend on the atmospheric blocking forming in Western Siberia. The correlation between total summer lightning stroke number in area of 1200 km radius around Yakutsk and frequency of atmospheric blocking in July at longitude of 70±5°E (Western Siberia) was -0.8. The total lightning number in Yakutia 1200-km radius area correlated with frequency of atmospheric blocking in July at longitude of 125±5°E (valley of Amur and Sungari Rivers) with coefficient of 0.56. The interannual variation of total lightning stroke number in Central Yakutia has been found to be linearly related to lightning activity in the eastern part of North Asia (valley of Amur and Sungari Rivers) of monsoon origin.

Introduction
Lightning activity in Yakutia with small population and very large territory might be the frequent cause of technical structure damages and forest fires. There were events of lightning strokes caused damage to power facilities, telecommunications and induced currents on trunk pipelines transporting hydrocarbons produced in the High North ([1, 2, 3]). Every year, regular fires cause great damage on forests in Russia, especially in Yakutia that has low population density (except for its central part). Solovyev and Kozlov [4] found that the number of fires in Yakutia due to lightning activity could be 49-88% of the total number of forest fires. For this reason, the variation of regional lightning activity and its forming factors ought to be carefully studied.

The early patterns of lightning activity in Northeastern Siberia was obtained using the results of meteorological observations [5] and measurements by simple spherics (electromagnetic pulse radiated by lightning return stroke) counter [6]. There is a network on the south latitudes of Russia – from its central part to the east coast [7]. The network has one sensor in Yakutsk. But the data access is closed,
and the network does not cover most part of Yakutia territory. Continuous instrumental observations of lightning activity in Yakutia have been conducted by the scientific group of ShICRA SB RAS since 1993 [8]. The observation on lightning activity and its climatology in the eastern part of Russia are developed at the fast pace in Kamchatka territory [9] and in the Buryat Republic [10].

Due to changes of atmospheric circulation epoch and development of instrumental methods for observing thunderstorm events, it is necessary to update the meteorological analysis of the conditions for the formation of dangerous natural phenomenon, lightning activity.

As it was shown in [11], there are “seesaw” interannual fluctuations in the spatial distribution of summer precipitation in Siberia. According to [12] the annual mean precipitation in summer in Western Siberia varied in antiphase with precipitation in Eastern Siberia. In [12], such oscillations were explained by atmospheric blocking. A similar “seesaw” effect was observed in interannual variations of thunderstorms in the regions of Siberia [13].

**Instruments and methods**

The variations of daily number of lightning strokes were evaluated by using lightning locating systems (LLS) that detect radio pulses of a very low frequency (VLF) range (sferics) emitted by lightning discharge. The data were obtained by the following LLS: World wide lightning location network (WWLLN), a single-point long-range azimuth finder, single-point device “StormTracker” (Boltek Co.). The sensor installed in Yakutsk was included in WWLLN in 2009. The design of the sensor is presented in [14] and consists of 1.5m-height rod antenna, broadband amplifier, sound card of laptop. The network consists of more than 50 sensors around the world [15]. Due to VLF range of detection (the propagation distance is more than 6000 km), the network covers the whole area of interest: Siberia and northeastern part of Asia. It detects better the sferics produced by powerful lightning strokes [16]. The network does not recognize the lightning type (cloud-to-ground, CG; intercloud/intracloud, IC). As the number of IC lightning strokes during thunderstorm is considered to be much higher than the number of CG lightning strokes (on average about two-three times) [17], the network detects rather equal number of IC and CG strokes. The detection efficiency allows sufficiently identifying every thunderstorm occurrence in Yakutia, especially last two years due to increasing number of sensors in Eurasia [18]. The single-point long-range azimuth finder had been working since early 2000s until 2016. It had a rod antenna and two large magnetic loop antennas placed as cross relatively to each other and oriented to north-south and east-west to identify the direction of sferics. The estimating radius of its detection was 200-1200 km in summer. The inner limit of radius was caused by typical technology of single-point LLS. The sferics of close lightning strokes have largest amplitude that exceeds the threshold and cause errors in stroke locating. It had two modes of detection: monitoring of local thunderstorm activity in summer and sufficiently far thunderstorms in winter. The amplitude threshold was changed two time per year. As the date of mode switch was varied from year to year, the representative data period was about from June 10 to August 31. The data were missed in 2010 due to technical support problems.

The days with intense thunderstorms were selected by the level of 0.7 of the maximum daily number of lightning strokes for the summer season, and the days with the minimum number of lightning were selected by the level of 0.3.

To describe the atmospheric circulation of the Northern Hemisphere, the classification of B.L. Dzerdzeevskii was used. The four groups of circulation are distinguished: zonal (an anticyclone on the North Pole, southern outlets, no blocking), disturbance of zonal circulation (high pressure on the Pole, one blocking over the Hemisphere), northern meridional (2-4 blocking and 2-4 southern cyclone outlets), southern meridional (cyclonic activity on arctic front especially regeneration of southern cyclones). The groups include 13 types and 41 elementary circulation mechanism (ECM) [19]. Each ECM corresponds to a certain dynamic scheme of the movement of cyclones and anticyclone localization. The data are updated every year and are available on the website [20].
Meteorological conditions were described basing on ERA-interim reanalysis data. The blocking process is a combination of an Arctic anticyclone with a subtropical zone of low pressure, as a result of which the movement of cyclones from west to east is blocked. Depending on the configuration of the pressure field, there are two main types of blocking [21, 22]: monopole and dipole. The monopole blocking (Omega, Ω) is a strengthened high-pressure area, at the base of which atmospheric low-pressure areas are located on both sides. The dipole blocking (Rex) consists of a blocking anticyclone in the northern part of the blocking region and a cyclone in the southern part. The blockings were identified by the method based on [21, 22], by analysis of inverting gradient of the geopotential heights at the level of 500 hPa and the field of potential temperature. The effect of blockings formed in the longitude range of 70 ± 5°E and 125 ± 5°E on lightning activity was considered. The blocking condition was calculated for the latitude range of 40-60°N each year in July.

Results
According to the data of the WWLLN, the total number of lightning strokes in Yakutia (the whole area and its central part) was significantly high in 2011, 2014, 2015 and 2017 in comparison with other years (Figure 1). The most intense lightning activity was in 2017 over the whole area of Yakutia. The increase in the number of stations in the network and therefore increasing efficiency of detection could cause the positive trend of the annual number of spherics in 2009-2017. In the Central part of Yakutia of 480-km radius around Yakutsk city, the mean density of lightning strokes was $3.6 \times 10^{-3}$ stroke/(km² months.), the average was 1.5 times higher than this indicator in the whole territory of Yakutia is $2.3 \times 10^{-3}$ stroke/(km² month.). According to the standard map of the mean density of lightning strokes estimated from early meteorological observations [23], there are three zones in Yakutia with average values of less than 1 stroke /((km² year) in the North of the region to 2 strokes/(km² year) in its southern part.

![Figure 1](image-url)

**Figure 1.** The total number of lightning strokes within the area of 480-km and 1200-km radius around Yakutsk (62N, 129.7E)

The spatial distribution of lightning strokes density in Yakutia is non-uniform. Lightning activity in the southern part of Yakutia is influenced by severe cyclones located in the valley of the Amur and Sungari rivers. The intense lightning activity in that eastern part of Asia is driven by the summer monsoon [24]. Lightning activity in the rest territory of Yakutia is subject to orographic effect. The mountain ranges obstruct movement of thunderclouds: the Verkhoyansk Range (along the Aldan River and lower course of the Lena River) and the Momsky ridge.

Thunderstorm season in Central Yakutia often begins in the second or third decade of May and continues to the end of August or early September. The date of thunderstorm season beginning varied
within 2 weeks. The date of the season ending in 2015 shifted later; it caused an increase in season duration. The number of thunderstorm days was not correlated with the duration of the season: the correlation coefficient was 0.2.

The variations in total lightning number in Central Yakutia were found to correlate with the lightning activity changes in region of Amur and Sungari rivers valley, driven by the summer East Asian monsoon: the correlation coefficient was 0.74 for period of 2009-2017. As in the central part of Yakutia, the annual increments of the total number of lightning strokes over the whole region correlated (0.56) with the similar variations observed in the southeastern part of North Asia and negatively correlated (-0.84) with the variations in Western Siberia (Figure 2a).

One could note that intense thunderstorms often developed at the boundary between the cyclone and anticyclone and due to the cut-off cyclone activity. We found several ECMs identified by B.L. Dzerdzeevskii method that were associated with severe thunderstorms in Yakutia: 13s (southern circulation group), 12a, 12bs, 9a, 8a, 10b (northern meridional group), 3, 6 (zonal circulation over Eurasia). In general, severe thunderstorms in Yakutia corresponded to the cyclones of the southwestern and western directions (~ 81% of cases of intense thunderstorms), the other intense thunderstorms were associated with the northwestern direction. The southern cyclone outlet over the Pacific Ocean and from the Mongolian branch of the polar front contributes to the invasion of arctic air into outlet’s rear and the formation of a blocking process over Western Siberia and central part of Siberia. In July 2013 (the month was featured by frequent blockings in Siberia, Figure 2b), the paths of cyclones in the eastern part of North Asia during long-term blocking in Western Siberia had a general meridional component developing over southwestern Yakutia and passing Central Yakutia further to the north, as was shown in [25]. However, in general, the probability of intense thunderstorms decreases due to the restriction of the paths of cyclones movement, and hence lightning activity decreases during the season. For example, it happened in the 20th of July 2013, when a long blocking anticyclone filled the area to the northwest of Yakutia (Figure 3, 4). The movement of cyclones from the west and northwest corresponds to the western flow of air masses, that prevails in the years of low frequency of blockings. Low frequency of blocking corresponds to an increase in the frequency of ECM 13s in 2017, during which cyclonic activity was formed at northern latitudes, and the western flow prevails in Western Siberia.
Figure 2. a) Total number of lightning strokes by WWLLN data in July in three regions: 1 - 120-130 E, 40-55 N; 2 - 65-75 E, 47-62 N; 3 - 1200 km around Yakutsk. b) The relative frequency of atmospheric blocking for the following longitudinal intervals: 1 - 120-130 E; 2 - 65-75 E. The number of lightning strokes in July in Yakutia - line 3

Summary
The intense thunderstorms in Central and South Yakutia generally occur due to the warm outlets from south and south-west (~81% of days with daily lightning stroke number higher than 0.7 level of season maximum). The formation of cyclones moving from south and south-west is associated with East Asia monsoon activity. Lightning activity in Yakutia was found to negatively correlate with blocking frequency in Western Siberia (~0.8). The outlet of the southern cyclone over the Pacific Ocean and from the Mongolian branch of the polar front contributes to the arctic air mass flow in its rear and the formation of a blocking process over Western Siberia.

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Figure 3. Lightning stroke distribution (each stroke is marked by cross, based on WWLLN data). Geopotential height at 850 hPa level (ERA-Interim) is showed by lines with gradient coloring. The wind vector at level of 850 hPa is marked by arrows. The 20th of July 2013

Figure 4. The cloud cover as a product of observation by Modis detector on Aqua/Terra satellites on 20th of July 2013. The region of 60-180 E, 40-80 N

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