

Monitoring of lightning activity in Yakutia with four long-range lightning detector systems

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Abstract. Long-term lightning observations can make a significant contribution to regional lightning climatology. The Yakutsk observatory has three one-point detectors with 480 km and 1200 km estimated radius of detection and one station included in the world wide lightning location network (WWLLN). The one-pointed detectors show the presence and direction on a thundercloud, while the WWLLN one locates the distance. A regular region with the highest lightning density is located in the southern part of Yakutia and formed by the Far Eastern monsoon. A second region with usually high lightning density is the western part of Yakutia, between the Lena and Vilyui Rivers. A mountain influence on the movement of a thundercloud is clearly traced in the northern and north-eastern regions of Yakutia. The lightning activity season lasts from late May to early September, and its duration slightly tends to increase. The available annual and seasonal variations in the lightning number show some quasi-oscillations with a period of 2-4 years.

1. Introduction

The thundercloud and lightning forming process remains the subject of discussion. Long-term observations make a significant contribution to the solution of this problem. Information about the regions of high lightning activity is also needed for practical use, for instance, protection against lightning, forest wildfires, induced currents on pipelines, etc. The development of technology allowed the instrumental observations to be more effective in locating and counting lightning strokes. The lightning locating systems (LLSs) based on a very low frequency (VLF) radio wave receiving method are widely distributed, providing significant quality of lightning data. There are many LLS networks around the world. In Russia the networks concentrate mostly in the European part. The only network that covers the most part of Russia is the “Vereya” network [1]. It is used for forest protection and has closed access to its data. However, maintaining the network is quite expensive and difficult in a region with a low-level infrastructure. That is why observations with one-pointed LLSs are still actual in some rural or low-populated regions, such as Yakutia. The first instrumental observation of lightning activity in the south-western part of Yakutia was made by A. Philippov by means of so-called lightning counters in the 1970-1980s. The lightning density and mean annual pattern was obtained by an Optical Transient Detector installed on a satellite Microlab-1 in 1995-2000 [2]. The lightning activity over the whole territory of Yakutia has been studied by ShICRA SB RAS since the 1990s [3]. The climatology obtained for the ten-year period of observations was presented in [3-4]. This paper presents the current state of ShICRA’s study on the lightning activity.



2. Instruments

The detection of VLF pulses radiated by a lightning stroke has been conducted in Yakutia since the 1990s by means of a lightning direction finder constructed by ShICRA SB RAS [3]. The direction finder is located at a place that is free from technical noise at a distance of 27 km from Yakutsk. Assuming on the early samples that the frequency of cloud-to-cloud (intercloud, intracloud) lightning stroke pulses is a bit higher than that of cloud-to-ground lightning stroke pulses, the lightning stroke type is determined by the frequency range of statistics. The radius of detection was evaluated as being 1200 km. However, because of the amplitude threshold set for long-range detection, the range and azimuth of pulses of lightning strokes that terminated to ground closer than ~100-200 km are not located by this detector. The ShICRA detector is used for a few scientific tasks in winter and summer in different modes. That is why the amplitude threshold is changed two times per year. Due to uneven mode switching, as well as technical failures, the representativeness of a continuous series of data is reduced at the beginning and end of the summer season. More details about the lightning direction finding method can be found in [3].

The instrumental base was updated by relatively short-range lightning detectors of the Boltek Corporation. A Stormtracker device (<http://www.boltek.com/downloads/stormtracker-pci>) was installed in Yakutsk in 2009. It detects lightning strokes and has a mode to identify flashes by clustering a few strokes (most often 2 strokes). The effective radius is up to 480 km (300 miles). However, the signals of lightning discharges that terminated close enough (< 30-60 km) to the detector have a waveform cut due to the amplitude threshold that leads to a range defining error. Since the detector is in the city, the noise background is not low. Therefore, the number of signals in a range of 0-60 km is often several times higher than the number of signals received from longer distances. The detector has not been modified, except for the software update in 2012. The spectrum of each signal is analysed automatically. The analysis results are the following parameters of lightning pulse: time (resolution ~ microseconds), azimuth, distance, amplitude of signal, wavelength, type (cloud-to-ground /CG, cloud-to-cloud /IC, compact intracloud discharge, noise) of a lightning stroke and its polarity. Signals with a defined range of 0 km were considered as an error and were not counted by us. The geographic coordinates were defined in post-processing considering the Earth as a sphere.

The second Boltek-produced detector LD-250 (<http://www.boltek.com/product/ld250-long-range-detection-kit>) was installed in Oktemcy locality at ~50 km distance from Yakutsk in July 2014. It has the same detection range as the Stormtracker. One more LD-250 was also installed in Neryungri city in southern Yakutia in 2013. However, this detector is not considered in this paper due to limited hours of its work (9 am – 23 pm). The output data have the same format as the resulting files of Stormtracker except that the LD-250 does not determine the type and polarity of a lightning stroke. The geographic coordinates are determined in the same way as for Stormtracker data.

All above-described LLSs have similar design: the receiving antenna (a rod and two loop antennas) is connected through the amplifier and analog-to-digit converter to the laptop. The ShICRA's detector has loop antennas of several times larger radius than the rod antenna length. And the Boltek detectors have two small loop antennas covered in a block and certified cable as a whip antenna. The time synchronisation is made by GPS-clocks with an accuracy of hundreds of nanoseconds.

In 2009, the detector in Yakutsk was included in the World wide lightning location network (WWLLN). The construction of the Yakutsk detector is presented in [5]. The technology of lightning location is fully described in [6]. To identify the lightning stroke its signal must be detected at least at five stations. Currently there are about 60 stations around the world. The WWLLN detects IC strokes as many as CG strokes. The detection efficiency (DE) of lightning strokes without the type difference was estimated as 11-15%, on average, in 2012 [7]. The network better detects powerful discharges that can be produced by a lightning current of more than 40 kA (the DE of such lightning strokes was ~30% in 2012). The WWLLN detects every thunderstorm sufficiently. Hutchins et al. showed that the number of thunderstorm clusters did not change while the number of lightning strokes per cluster increased with increasing DE [8]. The azimuth and distance of lightning stroke to the Yakutsk station were determined by considering the Earth as a sphere.

These LLSs mostly detect lightning strokes with a strong current or strokes that are relatively close to the detector range. The type of lightning stroke is not identified except for the Stormtracker device: the VLF broadband receivers provide detection signals from both CG and IC strokes. The most powerful component of the CG stroke is a return stroke that radiates signals with high magnitude in comparison with IC strokes and other components of the CG strokes. Thus, the number of CG stroke signals is greater than the number of signals of IC strokes detected by LLSs based on the VLF method. However, the IC strokes occur more frequently, on average, more than 3.5 times [9]. The radiation of IC strokes per each 10 kHz is about 10% [10]. Therefore, the LLS detects rather even numbers of IC and CG strokes.

3. Results

A linear latitudinal dependence on the average lightning number is noted. As expected, the lightning density decreases northward. There are three regions of high lightning activity that can be seen on the map of average density of lightning strokes. Thunderstorms occur most frequently in the southern part of Yakutia. The thunderstorm season starts earlier and ends later in southern Yakutia. This region is influenced by the Far East monsoon activity.

The second region with intense lightning activity is the western area of the valley between the Lena and Vilyui Rivers. The third region forms are influenced by the mountain chain that prevents free spread of clouds and facilitates convection. These three regions of high lightning activity can be noted on annual maps resulting from observations in 2009-2017. In comparison with significantly better located WWLLN data (a distance error is tens of kilometers), the ShICRA's detector demonstrates the day of a thunderstorm and the azimuth of its location rather accurately (Figure 1). The azimuth to other relatively small regions with high lightning density in north-western Yakutia is also distinguished by the ShICRA's detector. However, the determined distance to the thunderstorm deviates widely, which could be seen in the north-eastern direction, for example. This type of error is specific for the one-point LLS. The data of the Stormtracker and LD-250 have the same type of error in distance determination.

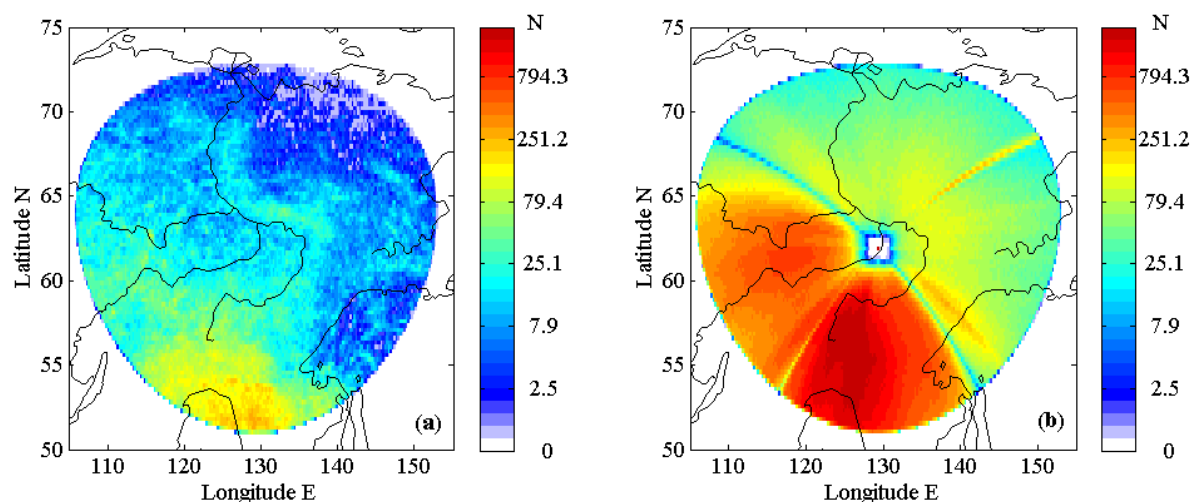


Figure 1. Map of mean lightning stroke number in summer in: a) 2009-2017 obtained by WWLLN data, b) 2011-2016 obtained by ShICRA's detector data. The color scale is logarithmic.

The Stormtracker and LD-250 are used to define lightning activity in Central Yakutia. The LD-250 detects a less number of lightning strokes than the Stormtracker, perhaps because the amplitude threshold in the Stormtracker receiver is lower. The lightning activity in Central Yakutia also depends on the orography, and the density along the floodplain is higher.

The variation of the annual lightning number in Yakutia oscillates with a period of 3 years (Fig. 2). However, the periodicity was disrupted in 2017 when the lightning stroke number had abruptly increased more than 2 times compared to the value in 2016. The variations resulting from the WWLLN and ShICRA's detector observations are similar, and the correlation coefficient is about 0.9. Intense lightning activity was in 2011, 2014-2015, and 2017. The same years of severe thunderstorms were for the central part of Yakutia (Figure 2). However, the correlation between variations by the WWLLN and Stormtracker data is about 0.5. The Stormtracker lightning number is greater than the number defined by the WWLLN because of its specification. A notable difference was in 2013. It is interesting to note that the interannual variation by the Stormtracker data correlates with the variation of the total number in the region of very high lightning activity with center in the valley of the Amur and Sungari Rivers: the correlation coefficient is 0.74. This could mean some influence of the monsoon circulation on the cyclone activity over Yakutia.

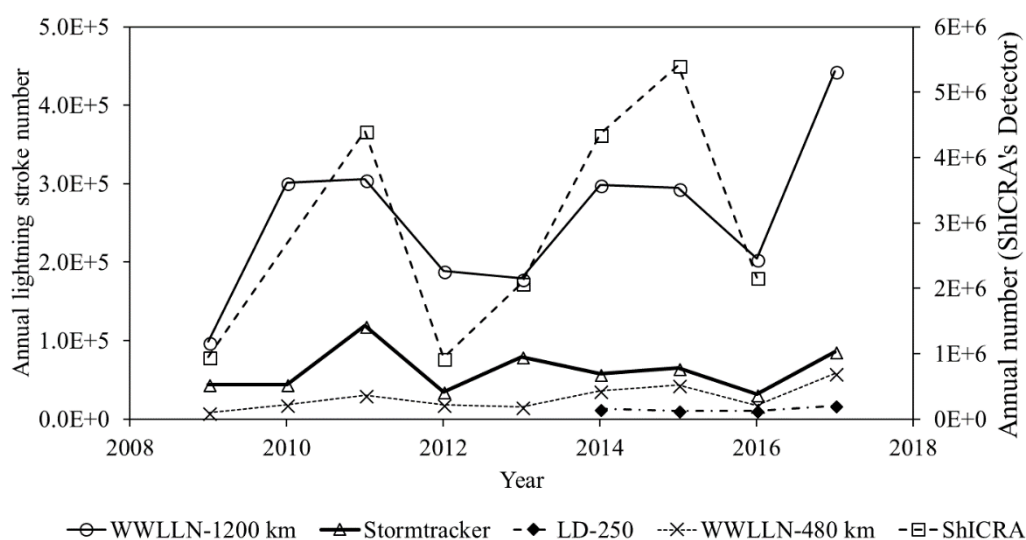


Figure 2. The annual lightning number detected by four sensors in Yakutia.

The thunderstorm season in the whole territory of Yakutia lasts from May to September. The thunderstorm season in Central Yakutia starts around the second decade of May and ends in August or at the beginning of September. The date of the season beginning varied within 2 weeks besides 2015 when a thunderstorm occurred in the first decade of May. The last day with thunderstorm in Central Yakutia tends to the second decade of September. Its duration tends to be prolonged (Figure 3). Although the number of days with thunderstorm varies without a significant increasing trend.

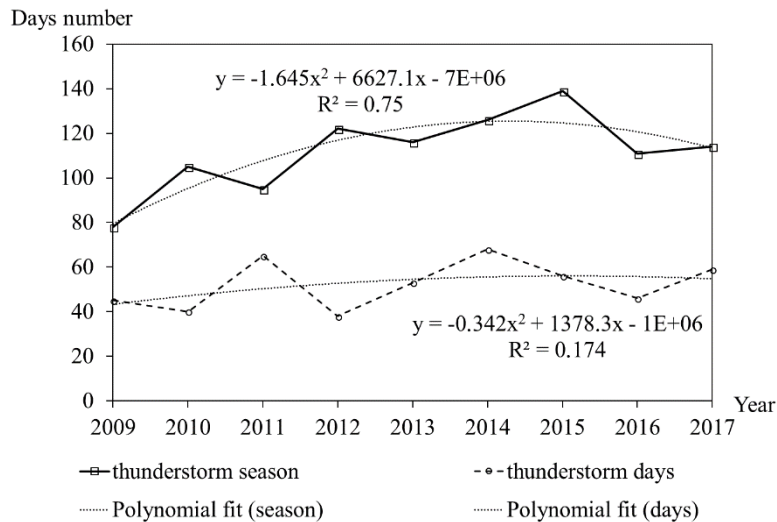


Figure 3. The thunderstorm activity season duration and the number of days when at least one lightning stroke was detected.

The seasonal variations obtained by all LLSs have a similar form. However, the absolute values differ between all LLS observations. The WLLN data show almost two times less than daily lightning stroke number obtained by the Stormtracker and less than 10 times than the ShICRA's detector data according to these detector areas. The correlation coefficient between the seasonal variations by the Stormtracker and LD-250 data was 0.76 ± 0.23 , although the absolute daily number had almost a 3 times difference. The seasonal variation often has 1-3 periods of severe thunderstorm. These periods offset from the beginning of summer to midsummer from year to year. The first peak is often in the second decade of June, the second peak at the beginning of July, and the third one in last decade of July or at the beginning of August. The stability of the seasonal variation form confirms the results of observations of the radio noise component obtained at a frequency of 8.7 kHz in 1979-2006 [11]. The offset of the peak lightning activity through the summer season is also noted in the variation of the monthly lightning stroke number. The monthly number of lightning strokes shows a quasi-oscillation with a period of 3 years. Although the number in July was expected to have the highest value, the lightning stroke number in June dominated in 2012-2013, 2016, and the August lightning number was high in 2011 and 2014 (Figure 4). If severe thunderstorms are associated with cyclonic fronts for Yakutia region, the lightning activity peaks may indicate at least two periods of intense cyclonic activity every summer and periods of low lightning activity after peaks may be related to a cold arctic air mass inflow.

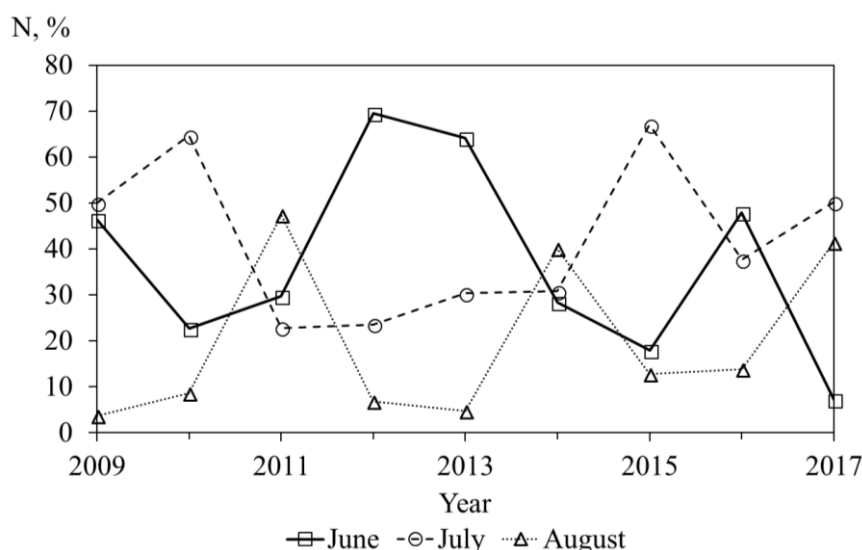


Figure 4. The ratio of monthly lightning stroke number to total summer lightning number.

The peak days are characterized by the number of lightning strokes 10 times greater than the mean daily number. Some quasi-oscillation was noted in the variation of the date difference between two seasonal peaks.

The mean daily variation in the lightning stroke number is a standard half-wave with a maximum around 15-20 LT by any LLS observation. There is some offset of the maximum to nighttime in August or the end of the thunderstorm season.

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