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Influence of current atmospheric circulation on interannual oscillating variations in spatial distribution of lightning activity in North Asia

Lena D. Tarabukina[1a], Nina K. Kononova[b], Vladimir I. Kozlov[a]
[a]Shafer Institute of Cosmophysical Research and Aeronomy of SB RAS, 31 Lenina Ave., Yakutsk, Republic of Sakha (Yakutia), Russia 677980; [b]Institute of Geography of RAS, 29 Staromonetnyi Ln., Moscow, Russia 119017

ABSTRACT

The interannual related fluctuations of lightning activity in two vast regions located on the West Siberian Plain and in the Amur and Sungari River valley were attempted to be explained by the atmospheric circulation change in northern hemisphere defined by method of B.L. Dzerdzeevskii. The elementary circulation mechanisms facilitating high lightning activity in both regions simultaneously and separately were found.

Keywords: Lightning, thunderstorm, atmospheric circulation, North Asia

1. INTRODUCTION AND METHODS

The mechanism of thundercloud forming and lightning activity is still under discussion. The long-term observations and synoptic analysis play the significant role. The circular macro processes last by long period epoch[1]. Therefore, in order to confirm complete relation of the considered processes, it is necessary to update the solution of this problem in the modern period. With the advent and development of technologies for instrumental localization of lightning discharges, thunderstorms have become actual in many regions of the world. Temporal variations in lightning activity are most often studied either in some relatively small regions, or as a long-term averaging of the seasonal series. In the paper the region of Northern Asia (60-180 East, 40-80 N) was considered, the data of the multi-station radio system of the World wide lightning location network (WWLLN) were used for the analysis of lightning activity. The detector in Yakutsk[2] was included in the network in 2009. The operation of the system is based on the receiving of radio signals radiated by lightning discharge, atmospheric, and the analysis of the arrival time of wave packets (TOGA) in the VLF frequency range (6-22 kHz) to at least 5 nearest stations[3]. The number of network stations has been increasing since 2009, which leads the detection efficiency (DE) growing. According to estimates[4] in 2012, the lightning detection efficiency of the cloud-to-ground and cloud-cloud types was on average 11-15%, and DE of lightning strokes with current of more than 100 kA was about 30%. To reduce the effect of DE changes on the results, the number of lightning strokes in the selected regions was represented as a ratio to the total amount over the whole territory, and the variations in the increments of the ratio values from year to year were considered.

To describe the atmospheric circulation the method developed by B.L. Dzerdzeevskii for the northern hemisphere[5]. The everyday state of atmospheric circulation is associated to elementary circular mechanism (ECM) with some certain dynamic scheme of cyclones movements and anticyclones stabilization. The classification consists of 41 ECM, 13 types and 4 general groups: zonal, northern meridional and southern meridional circulation and the disturbance of zonal circulation. By means of ECM the meteorological state is analyzed comprehensively and interconnected in a scale of whole northern hemisphere. The data on ECM have deep archive and is available on the website www.atmospheric-circulation.ru.

2. RESULTS

2.1 Lightning activity

There are two vast regions where the lightning density is higher than on surroundings in 10-100 times. The first region so called by us as western is on territory of 45-60 N, 60-90 E over West Siberian plain. The second region so called by us as eastern is between rivers Sungari and Amur. The maximum activity of second region is near to 127 E between Lesser

[1] tarabukina@ikfia.ysn.ru; phone +7 (4112) 390-484; ikfia.ysn.ru

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Khingan Range and Stanovoy Range. According with continuous observations in 2009-2017 the lightning activity in both regions changes in association with each other[6]: the coefficient of linear correlation of annual total sum increment of lightning strokes variations is -0.94. The atmospheric processes that form high lightning activity in these areas are very different. The thunderstorms in western region are formed usually by the western air mass transfer: the cyclones move from north-western and south-western directions[7]. The lightning activity in eastern region is defined by Far Eastern monsoon[8]. There are 1-3 periods of severe thunderstorms. There are periods of lightning activity decrease preceding that peaks.

2.2 Atmospheric circulation

We compared lightning number in two regions of high lightning activity with monthly variations in some climate indices as west pacific and polar index (http://www.cpc.ncep.noaa.gov/data/teledoc/telecontents.shtml). The strong positive and negative phases of west pacific index are consistent with zonal and meridional variations in the location and intensity of the North Pacific region including the East Asia region. The Polar Index is associated with strength of circumpolar vortex. We expected its relation with lightning activity in western region (West Siberia). However, the correlation of summer monthly variations was not sufficient and was below 0.3 absolute value. The general type of atmospheric circulation in 2009-2016 is meridional northern according to Dzerdeevskii method (fig.1). In summer, the meridional processes dominate over zonal types (both southern and northern types). In the beginning (June) and at the end (August) of summer the main circulation group was south meridional in 2013, 2014, and 2016. In July, the meridional northern group was main excepting 2010. The zonal circulation group occurs often in July in comparison to other months. The variation of days associated with four general groups of circulation did not show any correlation with lightning activity interrelation between two regions. Therefore, the variation of individual ECM was considered further.

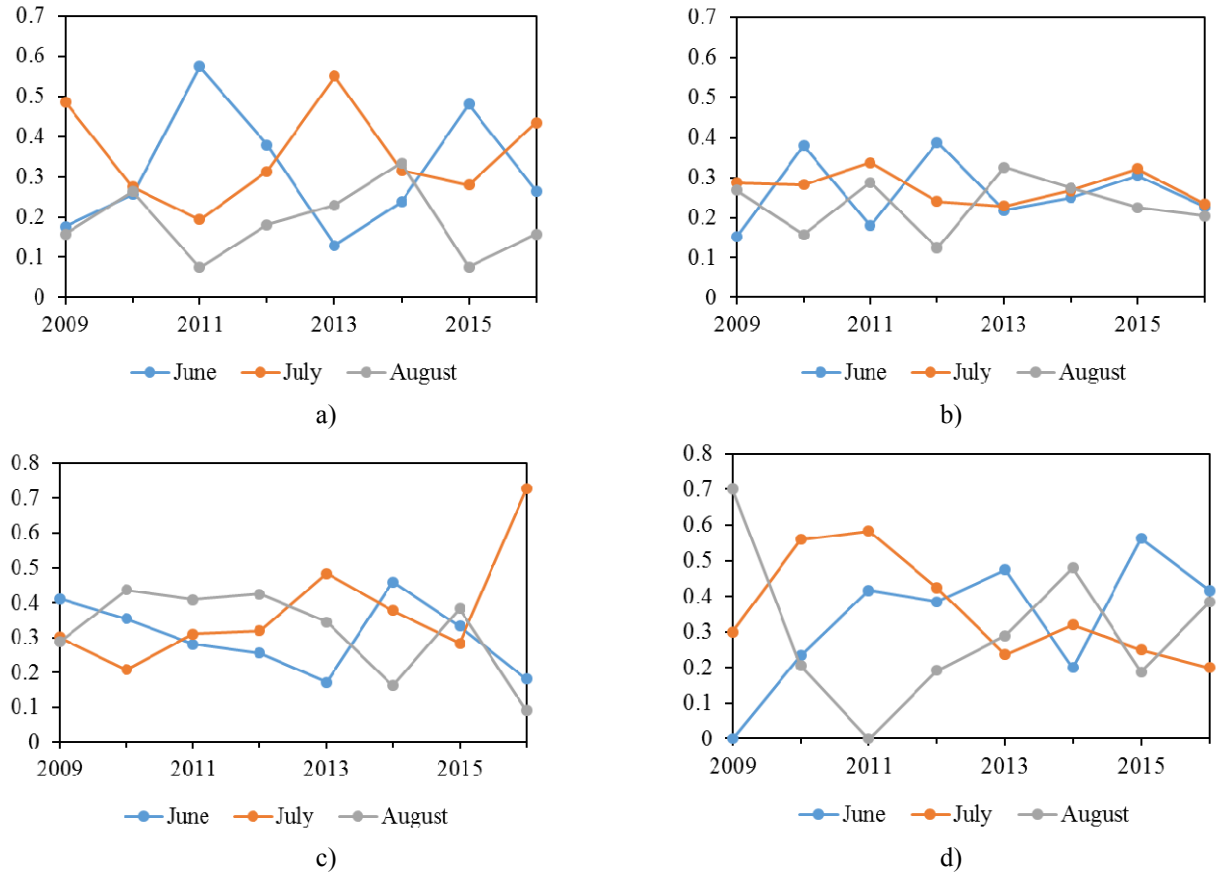


Figure 1. Monthly ratio of lightning stroke number in a) western, b) eastern regions, and monthly ratio of number of days associated with ECM grouped by general circulation type c) meridional north, and d) meridional south to summer total number.

2.3 ECM and severe thunderstorms

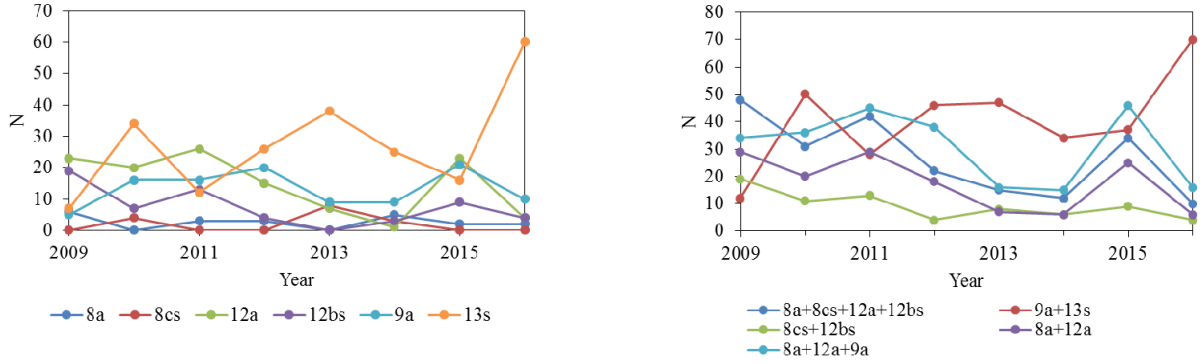
In summer in 2009-2015, the ECM of 8 and 12 types are very frequent. That ECM are responsible for southern outlets in both considered regions and therefore for severe thunderstorms. The ECM 9a (of meridional northern group) and ECM 13s (meridional southern group) are also frequent. During the days of these ECM, the cyclone develops in Siberia and thunderstorms occur on cold fronts of northwestern and southern cyclones. In 2016, the main circulation type changed to meridional southern: the days with ECM 13s lasted about 1/3 of summer days. The ECM 8a, 8cs, 12a, and 12bs of meridional northern group is associated with lightning number in eastern region greater than number in western region: the number of days with the largest lightning number in eastern region is >2 times greater than number of days with largest lightning number in western region (table 1). The ECM 8a is associated with the absence of blocking processes in Asia; the zone of low pressure occurs along Asian northern latitudes; the southern cyclones move from Mediterranean Sea and along Far Eastern coast[9]. The ECM 8cs is associated with blocking process oriented eastward of Western Siberia and southern cyclones move to Far East from Mongolian branch of polar front. The ECM 12a is associated with arctic air transfer over Siberia that spreads as a wide zone southward. The southern outlets are over other parts of northern hemisphere. The ECM 12bs has similar structure as ECM 8cs with high-pressure area over Siberia and low-pressure area over Far East. The arctic air mass moves westward in Asia, and southern outlets trajectories are shorter.

Table 1. The number of days associated with selected ECM and severe thunderstorms in 2009-2016 (June-August)

ECM	**2a**	**3**	**4b**	**6**	**8a**	**8cs**	**9a**	**10b**	**12a**	**12bs**	**13s**
Days number	14	50	17	24	21	15	106	23	119	59	218
Number (1) of days when ratio of daily lightning stroke number in eastern region to stroke number in western region <=1	11	23	7	12	3	4	43	9	26	16	104
Number (2) of days when ratio of daily lightning stroke number in eastern region to stroke number in western region >1	3	27	10	12	18	11	63	14	93	43	114
Ratio of days number (1) to number (2)	0.27	1.17	1.43	1	6	2.75	1.46	1.56	3.58	2.69	1.1

To find the factors of high lightning activity, seasonal variations in lightning strokes number of two large-scale regions of increasing lightning activity and ECMs associated with days of local peaks and days of reduced activity were considered separately. Every year the days of high lightning activity were selected by ~0.7 level of summer maximum, and days of low activity were selected by 0.1 level of maximum. In 2009-2016 for western region the 27 days of high lightning activity were selected (2-6 days each season). The ECM facilitated thunderstorms development in western region were ECM 9a and 13s (7 and 9 events correspondingly). The other lightning activity peaks were associated with ECM 12a and 12bs (2 days), 2a, 2b, 3, 4a, 6, 10a, 10b (1 day). During these selected days of high lightning activity in western regions, the lightning activity in eastern region is relatively low (26 days). The 40 days of severe thunderstorms in eastern region were selected: 2-10 each season, the mode value – 4. The 12 days are associated with ECM 13s, 8 days – with ECM 9a, 6 days – ECM 12a, 5 days – ECM 8a, other days – ECM 3, 12bs (3 days each), 9b, 8ds, 7as (1 day). The daily lightning number in eastern region was greater than lightning number in western region during 38 days and greater than 2 times during 30 days. Therefore, while the lightning activity is high in one of the regions the lightning activity in another region is relatively low. Most of the days of high lightning activity in eastern region associated with defined ECM had an arctic air masses invasion to Western Siberia and the atmospheric blocking forming. The days with polar

anticyclone absence (ECM 9a, 13s) were associated with southern cyclone outlets over both regions. However, the correlation between the frequency of individual ECM or groups of selected ECMs (fig. 2) with change of lightning activity dominance in considered regions was not sufficient (table 2). The statistical relation of atmospheric circulation and lightning activity is still under consideration.



a) b)

Figure 2. The number of days with selected ECM (a) and group of ECM (b) in summer.

Table 2. Correlation coefficient between variations of summer days number associated with ECM and groups of selected ECM and variation of total lightning number in eastern and western regions with high lightning density

ECM	8a	8cs	12a	12bs	9a	13s	8a+8cs+12a+12bs	9a+13s	8cs+12bs	8a+12a
In western region	-0,08	-0,06	-0,71	-0,58	-0,07	0,65	-0,76	0,61	-0,74	-0,7
In eastern region.	-0,49	0,36	0,09	-0,37	0,5	-0,09	-0,1	0,08	-0,23	-0,02

3. CONCLUSION

The variations of lightning number in two regions on West Siberian plain and in Amur and Sungari rivers valley were found to correlate negatively. The atmospheric circulation peculiarities were suggested to explain this relation because the atmospheric blocking in Western Siberia developed involving air masses from summer monsoon in Russian Far East[9]. The 13s and 9a ECM classified by B. L. Dzerdzeevskii often enhanced lightning activity in both regions. However, during summer peaks of lightning activity in those regions the lightning daily number in one of those regions was much bigger than the daily number in other region. The 8a, 8sc, 12a, and 12bs ECM of north meridional group more often facilitated lightning activity in Russian Far East than in Western Siberia. Generally, in 2009-2015 observed dynamic structure of lightning activity was associated with the dominance of northern meridional circulation. In summer of 2016, the atmospheric circulation was determined by southern meridional type that influenced on lightning activity in North Asia where the total lightning number in western region was greater than the total number in eastern region.

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