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Solar-Terrestrial Relations and Physics of Earthquake Precursors

Estimation of anthropogenic impact on lightning activity over urbanized areas of Northeast Asia

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Abstract. The anthropogenic influence on lightning activity is revealed by an increase in the density of lightning stroke in the places with accumulation of artificial products in air and by an additional period of one week in temporal variations. In this study, a comparative analysis of the density of lightning strokes within the city (with a resolution of 0.25 degrees along longitude-latitude) and the surrounding areas (up to 0.5 degrees around the city center cell). The observations were carried out using the World Wide Lightning network (WWLLN), one of the sensors of which was installed in Yakutsk in 2009. We selected cities within the territory of 60-180E, 40-80N. Selected cities in Siberia and Russian Far East have a population of more than 50 thousand – 57 cities. Due to the high population density in the North-Eastern China, we selected only large cities with a metropolitan population of more than 400 thousand people – 26 cities. The urban effect could be revealed in about 20% of cities. The 4-, 7-, 25-day period was found in variations of lightning number around cities.

1 Introduction

The local anthropogenic effect on meteorology in urban areas is a widely speculated subject. The effect may be found in temperature enhancement on few tenths of degree in lowest layer of atmosphere over urban areas of major cities [1-3]. It is known as "heat island" and is well studied in terms of its dependence on area and population density in city [1]. Besides the thunderstorm could be influenced by thermodynamics peculiarities over urban areas, the air pollution is also often examined [2, 3]. The aerosol concentration augmentation and air composition change was defined as a general factor influencing on cloud microphysics and air conductivity and thus on the enhancement of lightning activity [2, 3]. With growth of the particulate matter concentration, the positive flash rate reduces as it was found in regions close to tropical zone [2, 4]. Another anthropogenic factor might be a spatial distribution of elevated constructions [5, 6]. One can find other possible factors and its description of influence mechanisms in [6].

The anthropogenic effect was found in major cities with huge population [1]. The dependence on population density was well explained by the simulation of produced heat, for example, in [1, 7]. However, the size of urbanized area was found to be less influencing factor on total cloud-to-ground lightning rate, as well as PM10 (particulate matter), although

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the last does influence on positive flash rate [8]. In smaller cities, the urban effect in lightning activity was slighter than in major cities, especially at mid-latitudes [8]. Lightning activity dependence on urban effect was studied mostly in tropical latitudes [2].

The long-term observation of very low frequency pulses in Yakutia resulted strong weekly period in lightning activity in Yakutia. It was explained by the anthropogenic effect of the “weekend” [9]. The effect was confirmed worldwide [10].

This study considers lightning activity in rather low populated cities of Siberia and large cities of Northeastern China at midlatitudes and its surrounding areas.

2 Equipment

We tested lightning activity in the territory of 40-80 N and 60-180 E. The lightning stroke number in areas was estimated by the WWLLN data. The WWLLN sensor was installed in Yakutsk in 2009 [11]. The WWLLN has about 60 stations over the world. The lightning location method is based on the difference of very low frequency lightning signal arrival time to at least five sensors [12]. The WWLLN detects both cloud-to-cloud and cloud-to-ground lightning strokes, the detection depends on current of lightning stroke. The system often selects signals of strong lightning strokes: the estimated detection efficiency was more than 25% for lightning currents more than 40 kA and about 15% for any type of lightning strokes in 2012 [13, 14]. The accuracy of stroke location is tens of kilometers. Hutchins et al. [15] concluded that WWLLN detection efficiency was enough to be detect any thunderstorm.

This preliminary analysis was based on the lightning density that was counted on area of 0.5-degree radius around city center. The area was estimated with the spherical approximation of the Earth. The rural localities were selected as rectangular areas surrounding cities by the 0.5-degree disposition from city area. Such width of selected area allows to examine whole metropolitan area despite of city population and its spread. But since the center area has diameter of more than hundred kilometers, the peak lightning density in small urban area will be distributed to its 1-degree area. That’s way we conditioned lightning activity to be sufficiently greater than in surrounding areas in this preliminary study. The lightning density was corrected on maps of relative detection efficiency [14] every hour and integrated for interval of hour, day, and month.

It includes 57 largest cities in Russian Siberia and 26 largest cities of China. The population of 8 cities of 26 selected in China are greater than population in largest city in Siberia. The smallest city in Russia that was considered in this paper had more than 50 thousand population. The data were obtained from the website [16] with data based on official census in 2010 and estimation in 2017.

3 Lightning density in cities and surrounding areas

3.1 Spatial distribution

The estimated spatial distribution of mean 10-years lightning density has approximately two areas of maximum (fig. 1). The first area is around Western and Central Siberia (47-52 N, 60-90 E). The second area is above Russian Far East and southern regions of Eastern Siberia (40-55 N, 90-120 E). The maximum of lightning density is spread in North Asia as a linear zone at midlatitudes with the disposition to the East. Note that most of cities in North Asia are in the zone of high lightning activity, perhaps due to mild climate of midlatitudes. The cities located in region with low lightning density are to the north of considered territory (over land to 140 E) – Norilsk and Yakutsk. A lot of cities in Siberia were established close to river. As was showed in Yakutsk, lightning stroke often terminates to bank of a river or hills along the river [17]. One can note that the location of Russian cities doesn't match with peak values in lightning density. The location of Chinese large cities and some Russian cities close to Amur River better overlaps the areas with peak lightning density.

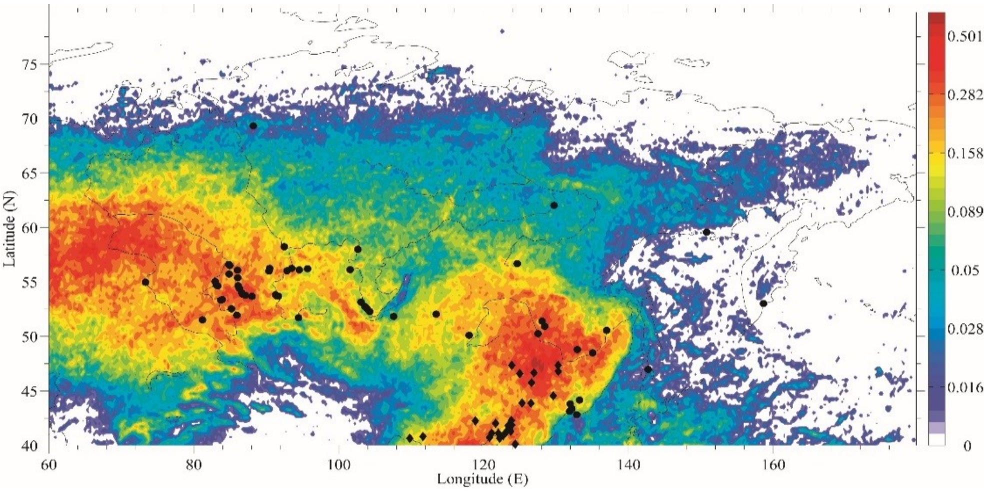
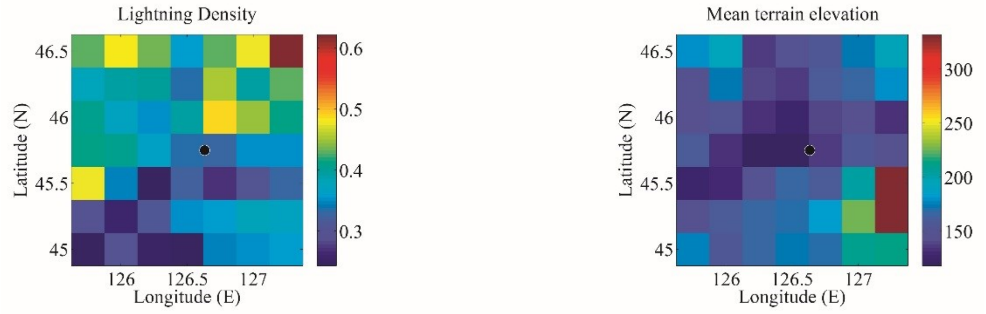
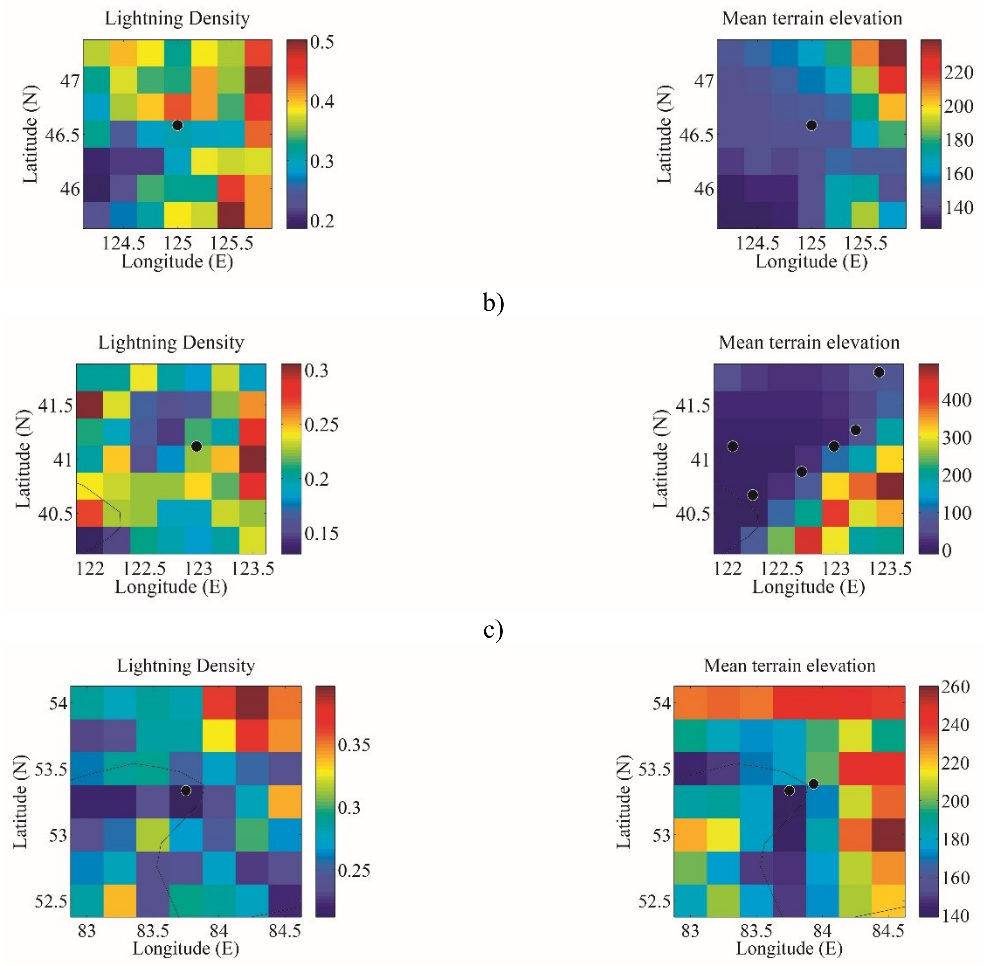


Fig. 1. The mean lightning density in 2009-2018 corrected on relative detection efficiency in logarithmic scale (stroke/km^2·month). The spatial resolution is 0.25 of degree. Siberian cities are marked by black circles; Chinese cities are marked by black diamonds.

However, both small cities in Russia and very large cities in China showed irregular dependence in mean lightning density considering 0.25-degree spatial resolution. To evaluate the causes that might contribute irregularities in dependence, we analyzed lightning density in locality around every city with common diameter of 1.75 degree (7x0.25 degree). Peak lightning activity in selected areas was associated mostly (~60%) with terrain irregularities as highlands, vast swamps and interfluve, with a probability decreasing correspondingly (fig. 2c-d). The high lightning density in a vicinity or inside urban territories (that were ~30% of cities) was driven by orographic peculiarities there more probably. On flat localities (with no highlands, river interfluve, lakes, vast swamp areas etc.) in less than 10% of cities, lightning activity was difficult to be explained by other causes than the urban effect (fig. 2a-b). The high lightning density in a 0.25-degree vicinity probably was formed by the displacement of polluted air masses caused by major direction wind, as was showed in similar study to Atlanta [18]. It was confirmed by the comparison with mean season rose of wind by meteorological observations [19, 20]. The orographic effect is concluded to have stronger influence on lightning activity than urban effect.



a)



b)

c)

d)

Fig. 2. The samples of high lightning density (stroke/km2) in summer 2009-2018 (left chart) and mean terrain elevation (m) (right chart) in the urban areas of: a) Harbin (China), b) Khabarovsk (Russia), c) Anshan (China), d) Barnaul (Russia). The black circles mark city center. The right chart contains all big cities around.

3.2 Statistical analysis

We tested variations in lightning density with hour time-resolution in 9 areas included urban region in the center of them. The variation in center area was compared to maximum of 8 surrounding areas. The number of hours when lightning density in central area around were greater than density in surroundings in average was only about 12.6±2.9% from number of hours with nonzero lightning density in any of 8 surrounding areas in each summer in 2009-2018 (maximum reached 22-24%) both in Siberia and China regions. The number of hours, when lightning activity was only in central area and was absent in surrounding areas, was about 5% out of number of hours with lightning activity in any of 9 areas. The minimum of lightning activity was in the coastal cities of Russian Far East (Magadan, Yuzhno-Sakhalinsk, Petropavlovsk-Kamchatsky) and coastal cities in Northeastern China (Dalian, no lightning strokes during summer of 2009-2018). It is explained by the conditions of thunderstorm forming process [21]. The percentage of lightning activity in urban area of that cities was highest (about 20%), perhaps due to smaller size of sample. Khabarovsk had the highest percentage among Russian major cities. On average among all cities, the lightning density greater 2 times in city than the density in surrounding areas both in Russia and China every summer 2009-2018. The ratio as parameter of urban effect was chosen to reduce the influence of atmospheric circulation as general factor of variation. We neglect the differences between meteorological state driven by changing circulation in central area and surrounding areas. The annual number of lightning activity hours in surrounding areas almost uniformly variated with annual number of lightning activity hours in central areas. However, the percentage of total hours when lightning density is greater than in central area varied in range of 3-58%, with median value – 9%.

The dependence of lightning activity total duration on urban population are nonuniform (fig. 3). The ratio of intense lightning activity in urban area for small cities are widely distributed around 12%. Some threshold of minimum ratio with city population increasing can be noted (fig. 3). However, the sample of major cities was small in Russian Siberia.

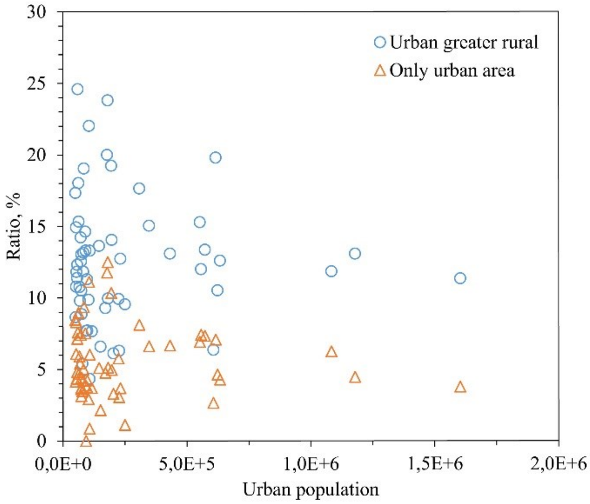


Fig. 3. The ratio of number of hours with lightning density greater in city area to the number of hours of lightning activity in surrounding area (marked by circles). The percentage of lightning activity only in central area (marked by triangles).

3.2 Week variation of lightning activity

The spectrum of hourly variation in lightning density over city area was obtained by the simple fast Fourier transformation. The length of time series includes only summer season in 2009-2018 (2208 hours). The complication of these time series is that lightning activity in such small selected areas as city area was often less 20% of the full time. The general form of spectrum was pink noise – amplitude decrease with increasing period. The more frequent peak periodicities were around 4 day, 6-9 (mean – 7) days, 14-15 days, about 25 days, both in cities in Russian Siberia and Northeastern China. These periods can be associated with meteorological phenomena. The city population did not influence on determination of periodicity in this study. The mean density spectrum normalized on maximum for every city had definite 4-days component for Russian cities. For Chinese cities, the mean normalized spectrum was rather stable without clear peaks. While presented in logarithmic scale, it could be linearly fitted with the slope steeper in areas surrounding city than in city area from about 7 days to 20 days on average (fig. 4).

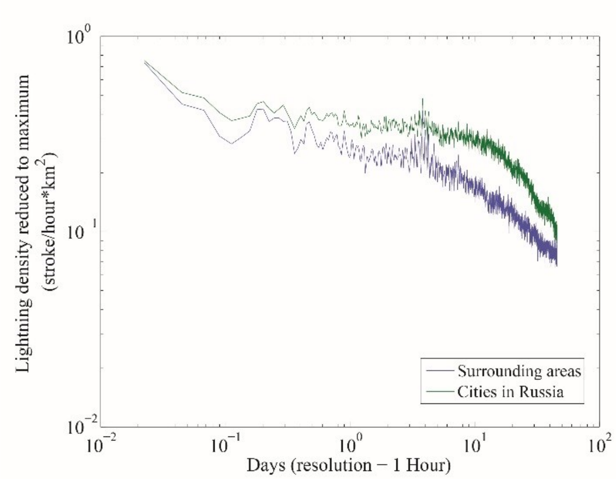


Fig. 4. The mean normalized spectrum of lightning density variation in 57 cities and surrounding areas in Russia in summer of 2018.

4 Conclusions

The anthropogenic effect in city climate is an important problem that is carefully studied through various approaches. The enhance of lightning activity above the urban area was found mostly in tropical regions and over major cities at midlatitudes. The selected cities are in the regions of high lightning density in North Asia. Only 3 of 57 cities in Siberia has population more than 1 million people and in Northeastern China 15 cities had more than 1 million people. But the amount of people didn't influence on lightning activity in urban areas much by rough estimation. The ratio of hours number when lightning density was higher in urban area was distributed around 12% of the whole lightning activity duration in selected area around. In detailed consideration of mean lightning activity pattern in 60% of cities the peak lightning density was associated with orographic peculiarities mostly. However, the cause of peak density in about 30% of cities could have an anthropogenic source displaced by wind (the general direction was obtained by meteorological data) besides orographic effect. Only cities on flat terrain allow to detect anthropogenic effect with higher probability. The mean spectrum showed the general periods of 4, 7, 14, 25 days, especially for Russian cities.

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