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Characteristics of thunderstorm centers during the development of mesoscale convective systems over the south of Western Siberia

Tatyana S. Koshikova[1a], Michael S. Kartavykh[b], Konstantin N. Pustovalov[a,b], Petr M. Nagorskiy[a], Ilya D. Churilov[b]
[a]Institute of Monitoring of Climatic and Ecological Systems of the Siberian Branch of the Russian Academy of Sciences, 10/3 Akademichesky Ave., Tomsk, Russia, 634055;
[b]National Research Tomsk State University, 36, Lenina Ave., Tomsk, Russia, 634050

ABSTRACT

In this work, estimates of thunderstorm activity during the passage of mesoscale convective complexes (MCC) in the south of Western Siberia for 2016–2019 were obtained. When analyzing the trajectories of the MCC movement, it was revealed that it passes from the southwest to the northeast. The duration of the thunderstorm activity generated by the MCC is on average about 9 hours. At the same time, the duration of thunderstorm activity less than 4 hours was not noted. average area of a thunderstorm center ~ 5700 km^2. The average distance covered by a thunderstorm is ~ 470 km. According to WWLLN, the number of lightning strikes is ~ 530.

Key words: mesoscale convective system, thunderstorm, instability index, ERA5 reanalysis

1. INTRODUCTION

Climate change, and, as a consequence, an increase in the number of dangerous meteorological phenomena have a large impact on the environment and on human activities. According to statistical data, in Russia 40% of all cases of dangerous meteorological phenomena are related to the zones of active convection formation[1]. With the development of deep convection, circulations of the "micro" and "meso" scale are often generated, posing a significant danger to the population and economic infrastructure, since they are associated with intense rainfall and floods, hail and squall wind intensifications. In particular, such systems include mesoscale convective systems (MCC). MCC is a complex of cumulonimbus clouds, united by a common anvil, and a lifetime of about 16 hours, in some cases – more than a day[2]. MCCs are found in different regions[2-4], including Western Siberia[5].

The development of MCC is always accompanied by intense thunderstorm activity. The main sources of information about thunderstorm hazard are: 1) visual and auditory meteorological observations; 2) counters of lightning discharges; 3) active radio engineering methods; 4) passive radio engineering systems for direction finding of thunderstorms; 5) satellite observations. At present, a system of the World Wide Lightning Local Network (WWLLN) has been formed, which includes a large number of modern stations located around the world and registering a radio pulse from lightning discharges in the range of 3–30 kHz.

The aim of this work is to assess the characteristics of thunderstorm centers associated with mesoscale convective systems over the south of Western Siberia.

2. USED DATA AND ITS PROCESSING

The study was carried out in the south of Western Siberia, which is conventionally located between 50 and 60 ºN. and 70 and 90 ºE, for the warm period (April–September) of the year. We selected the cases of the passage of the MCC in the south of Western Siberia for the period 2016–2019. The MCC was deciphered visually on the basis of an the RGB-composites created from the Terra, Suomi NPP, and Aqua satellites data[6]. To analyze the characteristics of thunderstorms associated with the selected MCC cases, we used WWLLN data posted hourly in the KMZ format[7]. These files, containing the coordinates of lightning strikes around the world in 1 hour, were assembled in a day, and then converted into TXT files.

[1]takosh_10@mail.ru; phone +7 3822 491-565; fax +7 (3822) 492-681; imces.ru

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Further, in the MATLAB software environment, maps were constructed for each of the selected MCC cases based on the data of channel 26 of the MODIS spectroradiometer (files MOD021KM/MYD021KM[8]) and the coordinates of lightning discharges according to WWLLN data. Lightning discharges were divided into groups, each of which corresponded to a unique color of the marker on the map, depending on the time of their registration (with a step of 1 hour) relative to the time of the satellite image (t_0): [t_0–6 ÷ t_0–5]; [t_0–5 ÷ t_0–4]; [t_0–4 ÷ t_0–3]; [t_0–3 ÷ t_0–2]; [t_0–2 ÷ t_0–1]; [t_0–1 ÷ t_0]; [t_0 ÷ t_0+1]; [t_0+1 ÷ t_0+2]; [t_0+2 ÷ t_0+3]; [t_0+3 ÷ t_0+4]; [t_0+4 ÷ t_0+5]; [t_0+5 ÷ t_0+6].

At the next stage, the coordinates of lightning discharges were digitized, the location of which corresponded to the position of the MCC at time t_0, as well as their extrapolated position t. The digitized data were saved in the form of mat-files, on the basis of which the quantitative parameters of thunderstorm centers were calculated: duration of thunderstorm activity (*T*); number of lightning strikes (*N*); the area of the thunderstorm center (*S*); complete displacement of the thunderstorm (*L*); lightning discharge density (ρ). Next, the statistical characteristics of the calculated parameter values were calculated.

To assess the convective potential over the south of Western Siberia during the development of mesoscale convective systems the K-index data (*KI*) from ERA5 reanalysis (ECMWF)[10], which has a spatial resolution of 0.25×0.25°and a temporal resolution of 1 hour was used. *KI* is calculated by the equation:

$$KI = (T_{850} - T_{500}) + TD_{850} - (T_{700} - TD_{700}).$$

Values of *KI* characterizes the degree of convective instability of the air mass, which is necessary for the occurrence and development of thunderstorms. The values of the *KI* index in the range of 25–30 ºC indicate that the state of the atmosphere is weakly unstable. At values of 30–35 ºC, the state of the atmosphere is unstable and the probability of a shower is high, and thunderstorms are also possible with a low degree of probability. *KI* values in the range 35–40 ºC indicate a highly unstable state of the atmosphere and the presence of a potential for the development of thunderstorms with a shower, and at values of the index above 40 ºC the atmosphere is extremely unstable and thunderstorms with heavy rainfall and hail are inevitable. As a result of studies[9], it was found that the use of the *KI* index is most promising for the development of methods for forecasting thunderstorm activity over Siberia.

3. MAIN RESULTS

In the course of the study, maps were constructed illustrating the thunderstorm activity associated with the passage of the MCC, and maps of the distribution of *KI*. Below in Figures 1, 2 there are 2 typical cases of satellite images of the MCC.

In the first case, the MCC moving in the Altai Territory in a northeastern direction, according to Figure 1, has the shape of an oval. The ratio of its major and minor semiaxes is approximately 1:1.5. The discharges observed 1–2 hours before the moment of the satellite image are characterized by a high density. At the time of the satellite image, the intensity of the discharges increases and remains at its maximum for another hour after the satellite flyby. The *KI* value at the moment of the satellite's passage is observed at 30 ºC, which indicates the transition of the atmosphere from a weakly unstable state to an unstable one. At the same time, the maximum value of the index was an hour later and reached 33 °C. Comparing the data obtained, we can conclude that the maximum instability of the atmosphere occurs at 07:00 UTC.

In the second case (see Fig. 2) the MCC also moves in a northeasterly direction. The ratio of its major and minor semiaxes is ~ 1: 1.5. The discharges observed 1–2 hours before the moment of the satellite image are characterized by high density and intensity, while the discharges observed 1–2 hours after the satellite flyby have a much lower intensity. This can be explained by the fact that the MCC has already passed the stage of maximum development and is beginning to fade. This is confirmed by the *KI* analysis at the indicated time points. The maximum value of the index, in the MCC area, was recorded at 03:00 UTC, and reached 35 °C 3 hours before the satellite flyby. This indicates a highly unstable state of the atmosphere. At the moment of the satellite pass, the value of *KI* = 34 ºC, with this value, the state of the atmosphere is no longer characterized by strong instability.

For the investigated thunderstorms, a statistical analysis of the characteristics was carried out (see Table). Thunderous activity over the south of Western Siberia lasts an average of 9 hours. Thus, the MCCs over the south of Western Siberia, as a rule, exist 7 hours less than the MCCs in the tropical zone[2,3]. The number of lightning strikes is 530 on average. The minimum value of *N* (at *P* = 5%) is 170 digits, and the maximum (at *P* = 95%) is 2400 digits. The area of the thunderstorm center is on average about 5700 km^2.

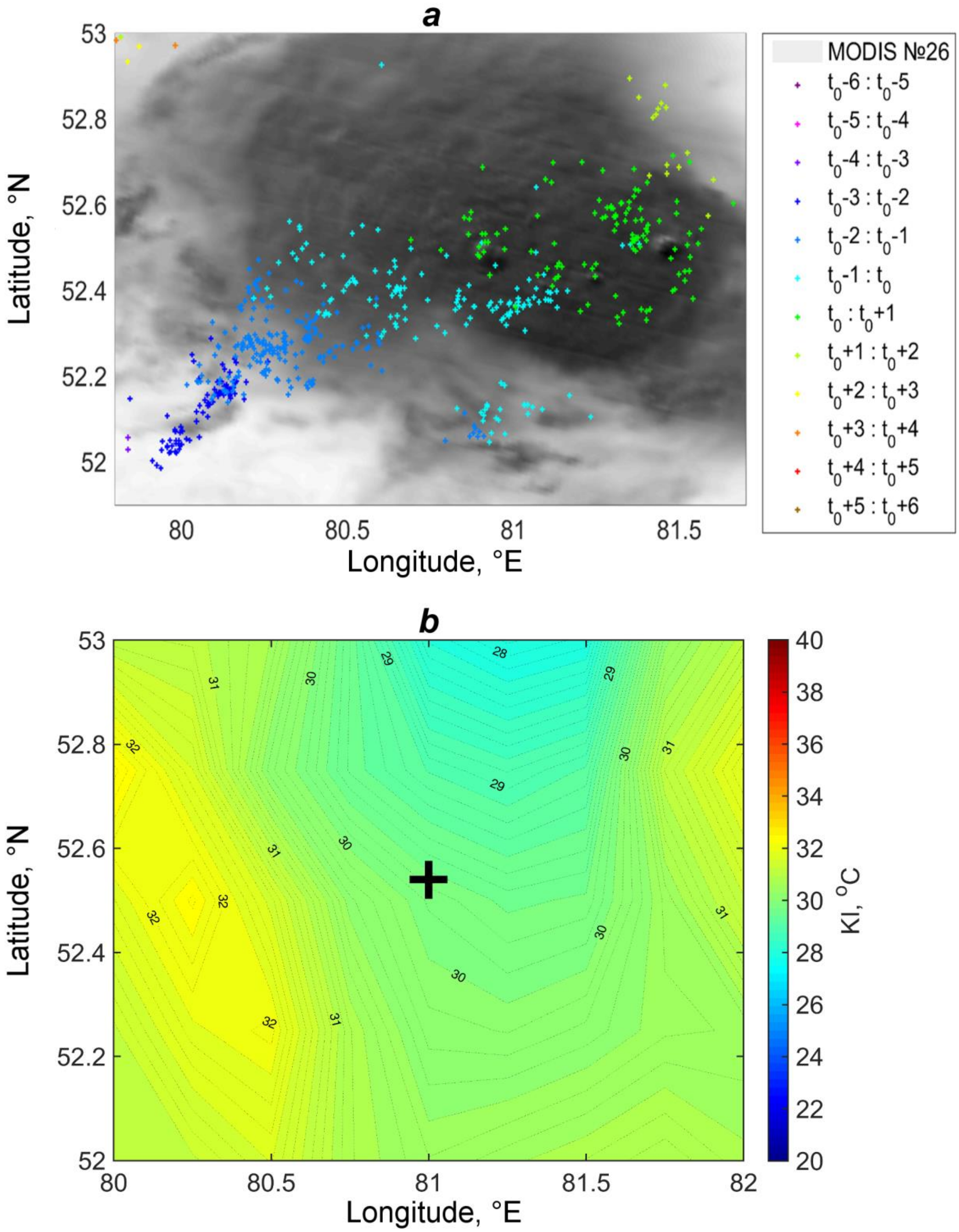

Figure 1. Satellite image of the MCC and coordinates of lightning discharges for one-hour time intervals (± 1–6 h relative to the time of the satellite image) (*a*), the distribution of the instability index *KI* for July 22, 2017, the time of flight 06:00 UTC (*b*).In figure *b*, the cross symbolically denotes the center of the MCC.

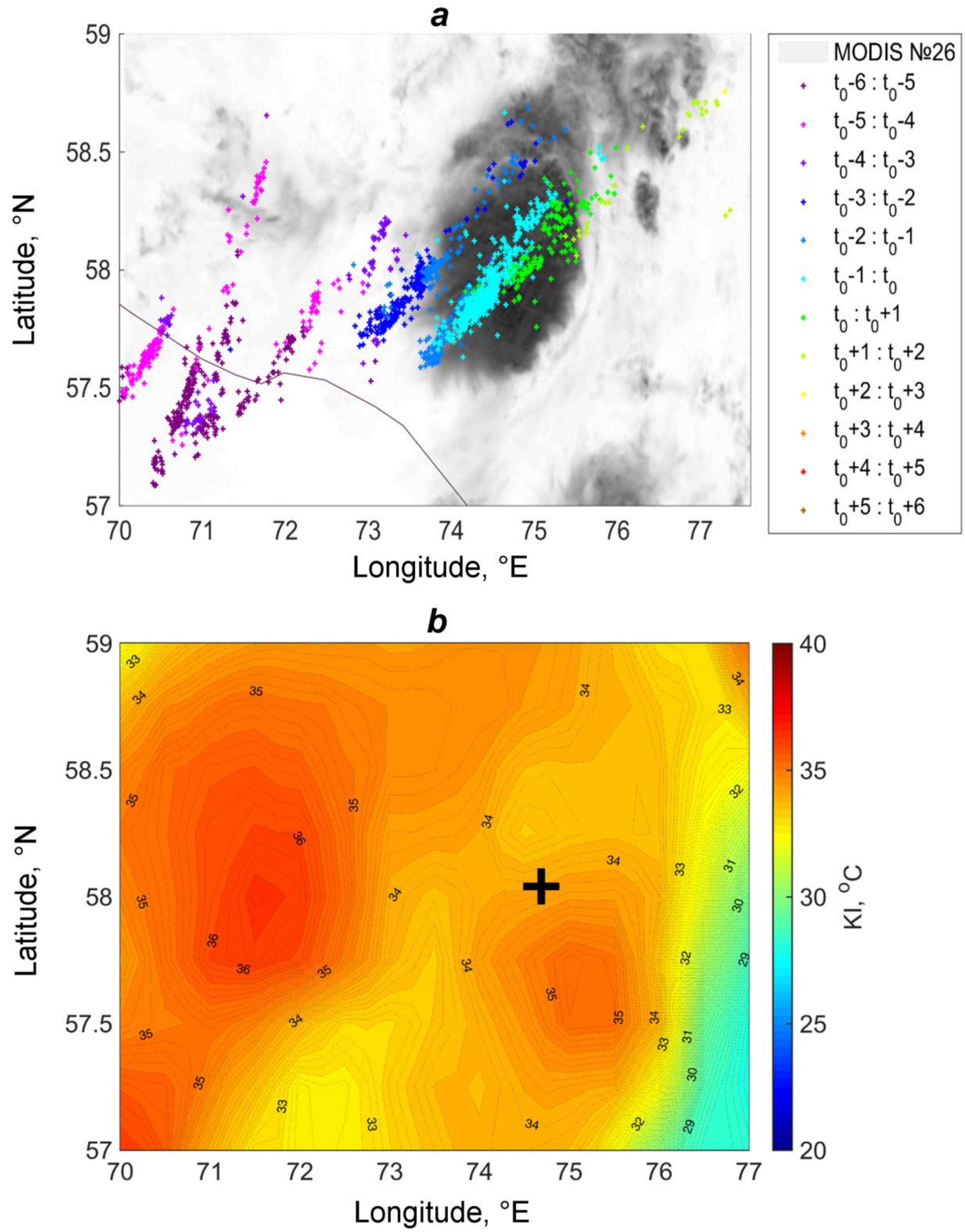

Figure 2. Satellite image of the MCC and coordinates of lightning discharges for one-hour time intervals (± 1–6 h relative to the time of the satellite image) (*a*), the distribution of the instability index *KI* for 03.08.2017, the time of flight 06:20 UTC (*b*). In figure *b*, the cross symbolically denotes the center of the MCC.

Table. Statistical characteristics of some parameters of thunderstorm centers: the duration of thunderstorm activity (*T*, hours); the number of lightning flashes (*N*); the area of thunderstorm center (*S* , km²); the displacement of thunderstorm center (*L*, km); the density of lightning flashes (ρ, flashes/km²).

	Median	Interquartile range	Percentiles			
			5	25	75	95
T, hours	9	6.25	4	5.25	11.5	12
N	528	1290	171	294	1590	2360
S, km²	5690	13600	719	1840	15400	38300
L, km	477	388	162	217	605	1030
ρ, flashes/km²	0.12	0.20	0.02	0.07	0.28	0.35

Typical *S* values vary in the range of 1850 – 15400 km², but cases of thunderstorm centers with an area of more than 38000 km² have also been recorded. The average distance covered by a thunderstorm over the south of Western Siberia is 470 km. The minimum value of *L* (at *P* = 5%) is 160 km, and the maximum (at *P* = 95%) is 1050 km. Typical values of the density of lightning flashes vary in the range 0.07÷0,28 flashes/km², and the average density of lightning discharges is ~ 0,12 flashes/km². The calculated values are so small because the density of discharges per km² was calculated not for a year, but for the analyzed case.

Next, a map of the MCC movement trajectories was built, reconstructed from the coordinates of lightning according to WWLLN data (see Fig. 3).

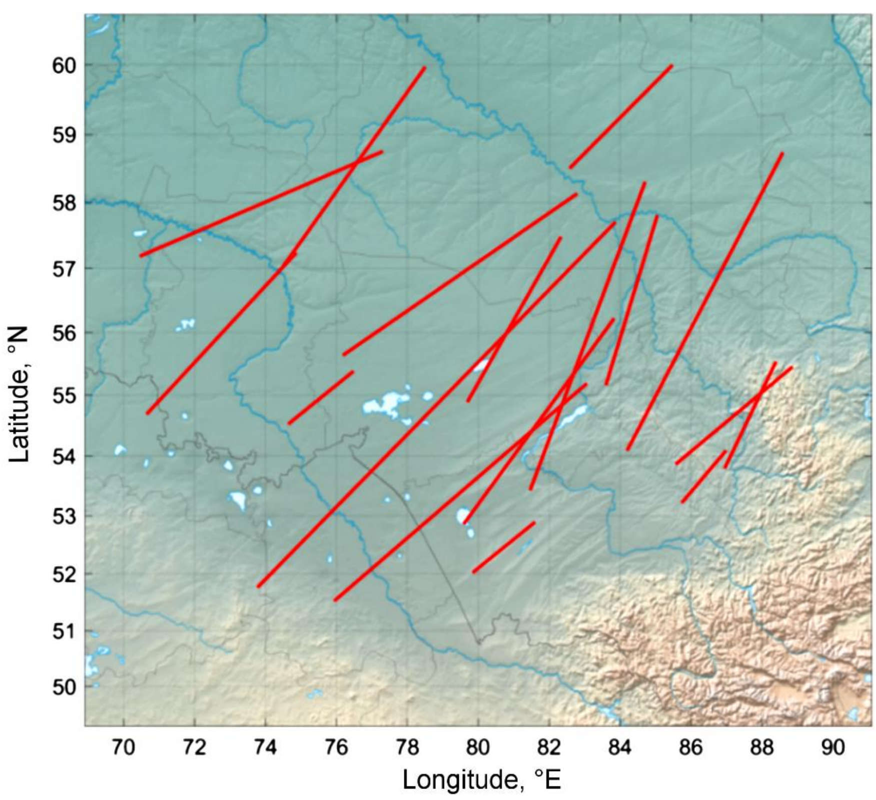

Figure 3. Map of the trajectories of the MCC over the south of Western Siberia.

Analyzing the map, it can be seen that the movement of mesoscale convective systems occurs from the southwest to the northeast. This direction of movement is due to meridional transport and southern cyclones constantly extending to the south of Western Siberia. The active formation of MCC occurs over a well-heated steppe zone, which includes a large number of shallow water bodies. The formed MCCs due to the meridional transfer move to the north of the study area.

CONCLUSION

A comprehensive assessment of thunderstorm activity was carried out during the passage of the MCC over the territory of the south of Western Siberia for the period from 2016 to 2019.

At the stage of maximum development of MCC, lightning discharges are characterized by high density and intensity. The movement of mesoscale convective systems occurs in the direction from southwest to northeast.

The total duration of thunderstorm activity generated by the MCC is on average about 9 hours. The duration of thunderstorm activity less than 4 hours was not noted. The area of the thunderstorm center associated with the MCC is, on average, ~ 5700 km^2. The average distance covered by a thunderstorm is ~ 470 km. The density of lightning flashes within a thunderstorm is ~ 0.12 flashes/km^2. The number of lightning flashes is ~ 530.

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