On the relationship of power lines outages caused by thunderstorms with Forbush decreases of cosmic rays

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Abstract. It is known that power lines outages often occur during thunderstorms. Here are the results of comparing of power lines outages in Yakutia from 2012 to 2018 with the database of Forbush-Storm events. This database contains information on geomagnetic storms and Forbush-decreases of cosmic rays from 1996 to 2018. There are 3 classes of the events: if these two ground-based manifestations of solar wind disturbances occur simultaneously (Forbush with Storm, F+S) or separately (Forbush without Storm, F-S and Storm without Forbush, S-F). For 7 years in the summer time, 73 power lines outages associated with thunderstorms were recorded. It is shown that in 56 cases these outages occurred simultaneously with (F-S) class, 16 – with (F+S) class, and only in 1 case lightning outages were not associated with Forbush-Storm events (-F-S). In 19 cases of (S-F) class, not a single lightning outage was recorded. This means that lightning outages on power lines are mainly associated with decreases in the cosmic rays intensity, and during geomagnetic storms, power transmission disruptions occur when storms are simultaneous with Forbush-decreases of cosmic rays. Apparently, this indicates the significance of the effect of cosmic rays on atmospheric electricity, and it is more significant than the effect of geomagnetic storms.

1. Introduction
It is usually assumed that outages on power lines during thunderstorms occur due to sudden jumps in the geomagnetic field in time (dB/dt) [1–2]. Sharp fluctuations of the geomagnetic field – geomagnetic storms and substorms – produce distributed electric fields, which leads to powerful geomagnetically induced currents (GIT) in technology conductors. In GIT power systems, they lead to dangerous effects: saturation of transformers, their overheating and destruction; generation of parasitic harmonics of alternating current; disruption of standard protective relays and, as a consequence, disconnection of power lines; fluctuations in active and reactive power in the power system and, as a consequence, to false operation or failure of automation and relay protection, massive power supply disruptions in load nodes [3]. The resulting currents reach values of tens of amperes. According to [4], the main cause of accidents on power lines are GIT generated in conductive materials during magnetic storms. In this case, geomagnetic storms, as a rule, should lead to thunderstorms and related outages on power lines. But this is not always so.
It was noted in [5] that the Dst index of the geomagnetic field, whose sharp decreases are a sign of geomagnetic storms, has a positive relationship with the number of thunderstorms, but there is evidence of an increase in the number of thunderstorms on days without the manifestation of magnetic storms. And according to [6], a negative correlation of thunderstorm activity with the parameters of solar activity and a positive correlation with the flow of galactic cosmic rays (GCR) was found. It was also found [7–10] that GCR can be one of the factors influencing the formation of clouds and associated cyclones, thunderstorm activity and other climatic phenomena, which are the main source of ionization in the stratosphere and troposphere.

In [11–13], similar mechanisms of the influence of GCR on cloud cover, on the transparency of the atmosphere, on the control of thunderstorm activity, and even on the initiation of lightning discharges was described. In this regard, it is important to understand what is still more significant for thunderstorms – geomagnetic storms or cosmic rays.

2. Data analysis

We compared an amount of power lines outages caused by thunderstorms (further thunderstorm outages) in Yakutia from 2012 to 2018 with the database of Forbush-Storm Classification (FSC) [14]. This database contains information on geomagnetic storms and Forbush-decreases in galactic cosmic rays (GCR) from 1996 to 2018. There are 3 classes of the events: if these two ground manifestations of solar wind disturbances occur simultaneously (Forbush with Storms, F+S) or separately (Forbush without Storms, F-S and Storms without Forbush, S-F).

Figure 1 shows a sheet from the database of Forbush-Storm Classification (FSC) [14]. Columns B–F contain information about geomagnetic storms (date, day in a year, an hour of storm beginning, main phase of the storm duration $\Delta T$, geomagnetic index Dst amplitude $\Delta$Dst, in nT), columns G–I show information about Forbush-decreases (date, an hour of Forbush beginning, magnitude of CR decrease, in %), columns J–L show class of events: Forbush without Storms (F-S), Forbush with Storms (F+S), Storms without Forbush (S-F).

Data on thunderstorm outages in summer time of 2012 to 2018 in one of the regions of Yakutia were provided by Yakutskenergo. 73 thunderstorm outages were recorded for 7 years under investigation. There can be from one to several power lines outages during any thunderstorm, table 1 shows an example of comparing FSC data and thunderstorm outages in summer 2017. 1st column shows the date of the event, 2nd column – the FSC class, 3rd column – the number of thunderstorm outages during this and the next day, 4th column – the intensity of the geomagnetic storm (the Earth's magnetic field decrease in the main phase of the storm, in nanoTesla) and/or the Forbush-decrease of GCR intensity (in %). The last column contains a note, special data. For example, in the given example on July, 19 the event was attribute to class Forbush-decrease.
without a geomagnetic storm (F-S), but the storm began a day later, on July, 20, i.e. maybe this event can be attributed to the class (F+S).

| Date   | Class | Number of thunderstorm outages | Intensity of GMS (nT) and FD (%) | Note                      |
|--------|-------|--------------------------------|---------------------------------|---------------------------|
| June, 16 | S-F   | --                             | 61 nT                           |                           |
| June, 22 | F-S   | 2                              | 3%                              |                           |
| June, 25 | F-S   | 2                              | 2%                              |                           |
| July, 02  | F-S   | 7                              | 7%                              |                           |
| July, 08  | F+S   | 1                              | 44 nT +1%                       |                           |
| July, 10  | F-S   | 1                              | 1%                              |                           |
| July, 16  | F+S   | 8                              | 115 nT +8%                      | At July, 20 GMS 43 nT     |
| July, 19  | F-S   | 1                              | 1%                              |                           |
| August, 03 | F+S  | 2                              | 67 nT +2%                       |                           |
| August, 14 | F-S  | 3                              | 3%                              |                           |
| August, 16 | F-S  | 1                              | 1%                              |                           |
| August, 22 | S-F  | --                             | 54 nT                           |                           |
| August, 31 | S-F  | --                             | 109 nT                          |                           |

Table 1 shows that there were 10 days with 28 thunderstorm outages, from 1 to 8 per day, in 2017. 6 geomagnetic storms (GMS) and 10 Forbush-decreases (FD): 7 events (F-S), 3 events (F+S), and 3 events (S-F) were observed in this summer of 2017.

One can see that 3 dates – July, 8, July, 16 and August, 3, assigned to the class (F+S), are accompanied by thunderstorm outages. Moreover, during 2 from that 3 dates – on July, 8 and August, 3 – geomagnetic storms were moderate, Forbush-decreases were small, and there were only 1 and 2 power lines outages on these days. On July, 16 there was a large geomagnetic storm and a large decrease in the CR intensity – and 8 power lines outages.

On 7 dates – June, 22 and 25, July, 2, 10 and 19, August, 14 and 16 Forbush without storms (F-S) were observed, and on July, 2 there was an intense Forbush-decrease of GCR intensity, 7%. During all these days there were from 1 to 3 thunderstorm outages, and on July, 2, an intense Forbush-decrease were accompanied by 7 thunderstorm outages in a day.

Three dates were attributed to the FSC events looked as a geomagnetic storm without Forbush-decrease (S-F) – on June, 16, August, 22 and 31, two moderate storms and one large storm. None one of them were accompanied by power lines outages.

A similar analysis was carried out for the summer time of each year from 2012 to 2018.

3. Results and discussion

The summary data of the events analyzed for all 7 years are given in Table 2. For each FSC class, “yes” means the number of days when thunderstorm outages occurred during the Forbush-Storm event, “no” means that there is no such coincidence. For example, one can see that in 2012 there were 7 days with thunderstorm outages, 5 events took place during (F-S) class, 2 – during (F+B) class. There were 2 events of class (S-F), and both of them were not accompanied by power lines outages.

In common, Table 2 shows that from the 73 cases thunderstorm outages during summer 2012–2018 under the analyze, most of them (56) occurred during Forbush-decreases without geomagnetic storms, i.e. during class (F-S) registration. There are 16 cases associated with the Forbush-decreases with storms class (F+S), and only in 1 case of thunderstorm outage is not associated with Forbush-storm events (this class of events is designated (-F-S)). Moreover, in 19 events of geomagnetic storm registration without Forbush-decrease – events of class (S-F) FBC,
not a single thunderstorm outage was recorded. This indicates a significantly more important role of the intensity of GCR in comparison with geomagnetic storms for the generation of thunderstorms and related power lines outages.

Table 2. The comparison of power lines outages caused by thunderstorms with the Forbush-Storm classification.

| Years | F-S | F+S | S-F | -S-F | Number of thunderstorm outages |
|-------|-----|-----|-----|------|------------------------------|
|       | Yes | No  | Yes | No   | Yes | No   |                              |
| 2012  | 5   | 2   | 2   |      | 7   |      |                              |
| 2013  | 5   | 1   | 5   |      | 6   |      |                              |
| 2014  | 15  | 2   | 1   |      | 17  |      |                              |
| 2015  | 9   | 5   | 4   |      | 14  |      |                              |
| 2016  | 4   | 2   | 2   | 1    | 7   |      |                              |
| 2017  | 7   | 3   | 3   |      | 10  |      |                              |
| 2018  | 11  | 1   | 2   |      | 12  |      |                              |
| Sum   | 56  | 16  | 19  | 1    | 73  |      |                              |

Apparently, this indicates that the occurrence of thunderstorms and related outages on power lines depend more on the intensity of cosmic rays than on geomagnetic storms. This is consistent with the conclusions of [7–10]. One of the possible physical mechanisms of such an effect was described in [11–13]: “The different charges necessary for the emergence of a thunderstorm cloud are formed by cosmic rays and radioactive elements in the air and soil. At the stage of mature and disintegration of a thunderstorm cloud, the main generator of dissimilar charges necessary for the formation of a strong electric field in the cloud and lightning are the lightning itself, in the highly branched and ionized traces of which huge amounts of dissimilar ions are formed. Lightning discharges in clouds are initiated by broad atmospheric showers (SHAL) formed by cosmic rays of extra high energies (ε>10^{14} eV)”. The relation of GCR with atmospheric phenomena is not limited by clouds, they control thunderstorm activity and initiate lightning discharges, affect atmospheric circulation, weather and climate, and in general, the processes of formation and development of baric systems of moderate and high latitudes [10].

Also, the fulfilled studies show the usefulness of using the Forbush-Storm classification of the events [14] to understand the impact of space weather on terrestrial processes.

4. Conclusions
This paper presents the results of a comparison of thunderstorm outages on power lines for the summer of 2012–2018 with Forbush-decreases of GCR and geomagnetic storms based on the Forbush-Storm classification of the events. The results are the following:

1. Most of the thunderstorm outages on power lines occur on days when there are Forbush-decreases of GCR (56 out of 73).

2. During geomagnetic storms thunderstorm outages on power lines occur if these geomagnetic storms occur simultaneously with Forbush-decreases of GCR (16 out of 73).

Taking into account the data presented here will help to assess the geoeccological risks from the effect of interplanetary disturbances on ground systems.

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