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SPATIOTEMPORAL CHARACTERISTICS OF THE DECEMBER 1, 2023 GEOMAGNETIC STORM ON DATA FROM THE NHC OPTICAL COMPLEX AND THE IRKUTSK REGIONAL ASTRONOMICAL SOCIETY

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Abstract

The results of the December 1, 2023 strong geomagnetic storm studies are presented using images from citizen scientists in the Irkutsk region. Based on the method of frames georeferencing and stereometry, the spatial parameters of mid-latitude auroras were determined. The prospect of joint use of citizen scientists photographs and specialized optical instruments data for studying geomagnetic storms is discussed.

Keywords: auroras, geomagnetic storms, atmospheric glow, georeferencing, citizen scientists.

Introduction

Today there are many amateur photographers with a passion for astronomy who observe stars, planets, auroras and other events. One of the world's first known "citizen scientists" was farmer Bentley of the United States, who observed and cataloged over 700 auroras over a hundred years ago [*Silverman et al.*, 1983]. Relatively new optical phenomena in the upper atmosphere, such as STEVE [*Macdonald et al.*, 2018; *Gallardo-Lacourt et al.*, 2018] or "dunes" [*Palmroth et al.*, 2020], were originally discovered by citizen scientists. It is also worth mentioning Russian amateur scientists who have made significant contributions to the history of discoveries and observations in astronomy. For example, Engelhardt V.P., who built his own observatory with the largest telescope in the XIX century and described more than a dozen comets, asteroids and hundreds of nebulae [*Trifonov and Trifonova*, 2022].

Due to the solar activity approaching the maximum of the 11-year cycle, a sufficiently large number of geomagnetic storms accompanied by both polar and mid-latitude auroras (MAs) are observed on the Earth. The latter phenomenon was considered to be quite rare [*Mikhalev*, 2019], but since more sensitive instrumentation has appeared, it can be assumed that subvisual MA is a frequent geophysical phenomenon. And, most likely, it does not belong to the extremely rare observable ones, as it was supposed earlier [*Mikhalev*, 2019]. This is evidenced by the statistics of MA registration in the south of Eastern Siberia, in the Geophysical Observatory (GPO) of ISTP SB RAS (103°04`E, 51°48`N) from 2021 to the present. In 2021, the Optical Instruments of the National Heliogeophysical Complex (NHC), which includes Fabry-Perot interferometers, spectrometers, photometers, and all-sky cameras, were commissioned. From the moment of putting into operation to March, 2024, 38 MAs have been registered using the all-sky cameras of the GPO ISTP SB RAS. This amounts to an average of about 12 cases per year.

The paper considers the geomagnetic storm December 1, 2023, caused by the solar flare of M9.82 class, occurred on November 28, 2023. The averaged planetary index was Kp=7, which relates to the G3 level - a strong geomagnetic storm. The minimum Dst-index value was equal to -107 nTL (Fig.1). Meteorological conditions for optical observations were quite favorable on the night of 01.12.2023: mostly clear, with slight variable cloudiness, the Moon was waning. The authors in [*Mikhalev*, 2019] showed that there is dependence of the MA registration in the 630 nm auroral emission on the Dst-index. Figure 1 shows that the minimum value of Dst-index value was observed at 12.00-13.00 UT and the brightest red airglow at mid-latitudes was observed during the same time. In conformity with the classification adopted in [*Rassoul et al.*, 1993], MAs of this type can be attributed to type "d". Heavy particles with energies of 1-100 keV precipitating from the ring current during recharging cause at geomagnetic latitudes $\leq 40°$ low-latitude and at geomagnetic latitudes $\geq 40°$ mid-latitude auroras. Electron fluxes with energies $\leq$ 10 eV cause a phenomenon such as SAR arcs, and electron precipitations with energies ~10-1000 eV lead to MA of type "d" [*Rassoul et al.*, 1993].

The midlatitude aurora on December 01, 2023 was observed with all-sky cameras of the OI NHC. All-sky cameras are designed to record the spatial pattern of various emissions airglow intensity of the upper atmosphere. Brief technical characteristics: the FOV is 180 degrees, the direction is zenith. The cameras use interchangeable filters to register main emissions - OH, atomic oxygen with lines 557.7 nm, 630 nm, 427 nm, 865 nm, 589.3 nm. The transmission half-width of each interference filter is ~ 2 nm (except for the OH band), the exposure time is 55 s, for OH - 8 s.

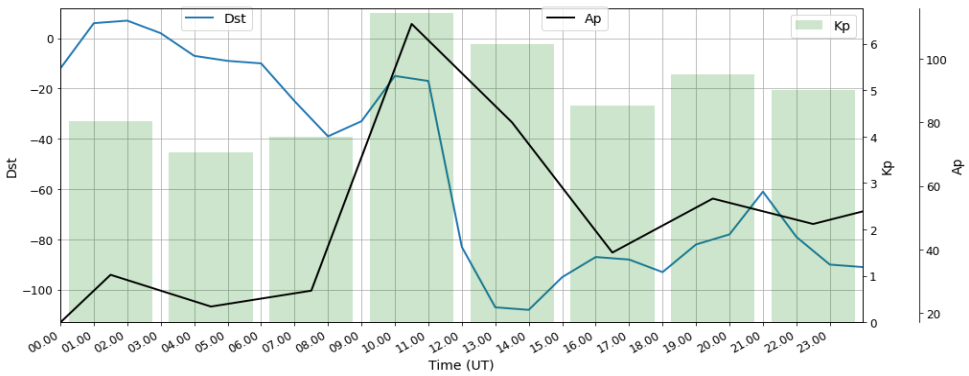
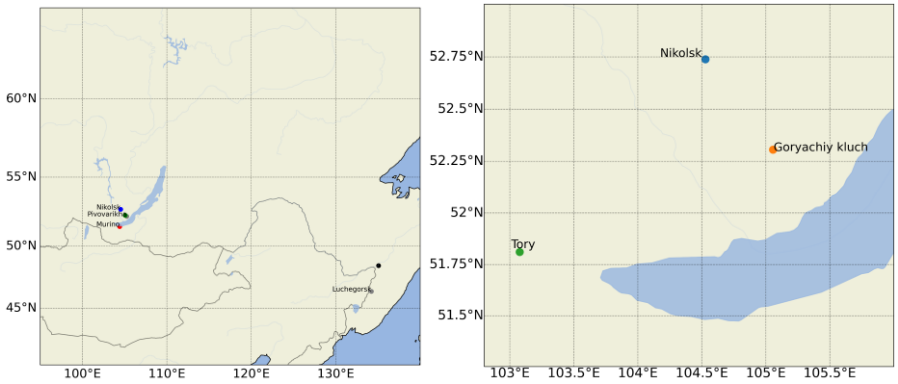


Figure 1. Dst, Ap, Kp indices behavior during geomagnetic storm December 1, 2023.

Representatives of the Irkutsk Regional Astronomical Society (IRAS) and citizen scientists performed observations with digital cameras and smartphones at several locations within the Irkutsk region and Primorsky Krai. Figure 2a shows the locations of the amateur and GPO ISTP SB RAS (Tory) observations. For the following analysis images with precise location information taken in one time interval were selected. Figure 2b demonstrates these observation points - Nikolskoye and Goryachiy Klyuch. The distance between them is about 72 km.



a) b)

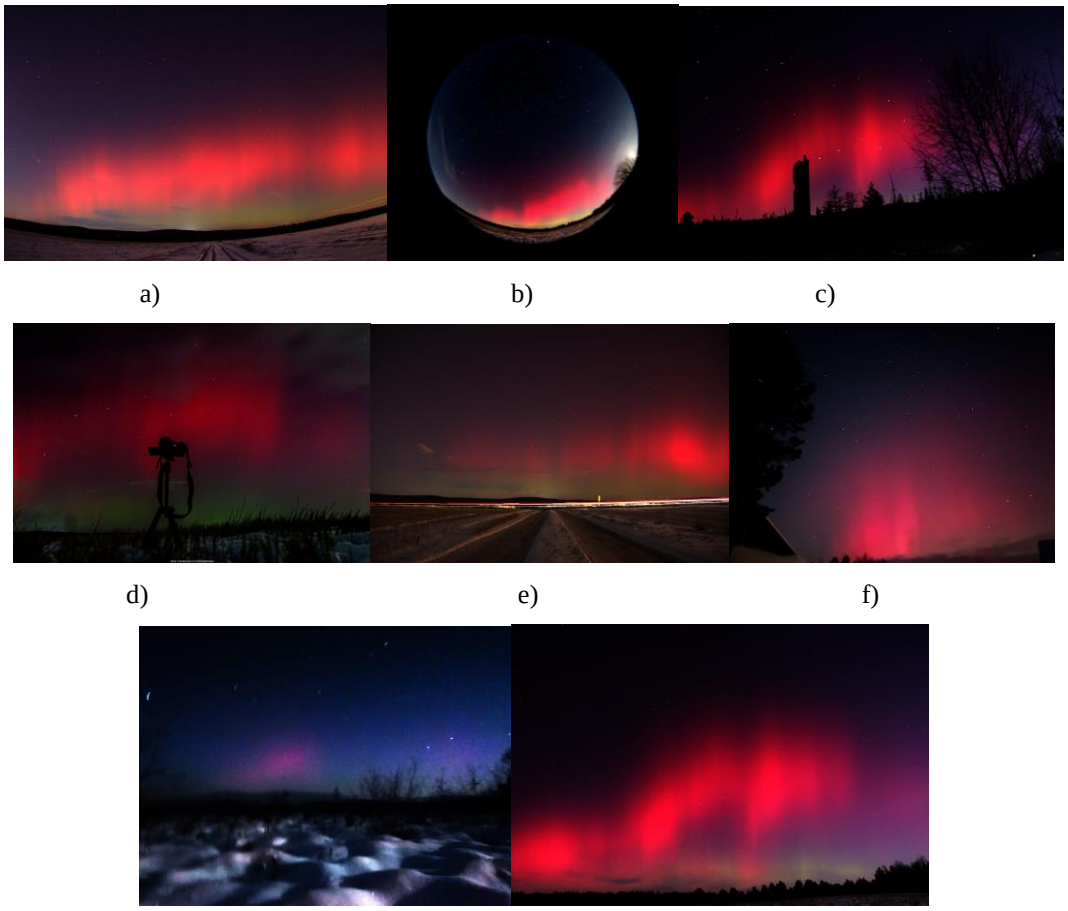
Figure 2. a) all observation points of the geomagnetic storm December 1, 2023; b) points for further analysis.

Some instructions for aurora imaging were developed by representatives of IRAS and ISTP SB RAS. The place of observation should be chosen far away from settlements and any illumination. It is also necessary to record the exact location and shooting time. The direction of sight should be chosen to the North. Among the important recommendations is the correct choice of sensitivity and exposure time. Fig. 3 shows examples of frames obtained during the geomagnetic storm December 1, 2023 at different observation points.

Discussion

The use of two or more spatially separated optical instruments makes it possible to obtain spatial parameters of the phenomena registered in the atmosphere. Since the geographical coordinates and exact time of the images are known, this made it possible to carry out a joint analysis of the images coinciding in time using stereometry. Additionally, the geographic image georeferencing technique [*Syrenova et al.*, 2021] was applied in the analysis to display the matched images and estimate the height of the aurora. Projections on the Earth's surface for the frames from Nikolsk and Goryachiy Klyuch were made for some set of heights. Then, the comparison was made by the stereovision method, when for some region of auroras there is a complete match at a certain altitude. Thus, it was determined the height of about 500 km, on that for the different images, the coincidence of the same “pillars” of airglow is observed. This is consistent with the altitude range of “a” or “d” type red auroras, which tend to be highlighted at much higher altitudes than the usual forms of polar lights [*Mikhalev et al.*, 2019]. The upper boundary of these MAs can reach a height of ~550 km [*Mikhalev et al.*, 2019].

For further analysis, all-sky camera images of the NHC were selected. Fig. 4a shows the projection of the NHC all-sky camera frame onto the Earth's surface. The aurora occupies about half of the frame with the southern boundary reaching about 54 degrees N. Fig. 4b shows the image of the camera with which observations were made in Nikolsk (Fig. 3h). It can be seen that the radiant structure of the aurora is clearly visible. In the meantime in Fig. 4a, the aurora

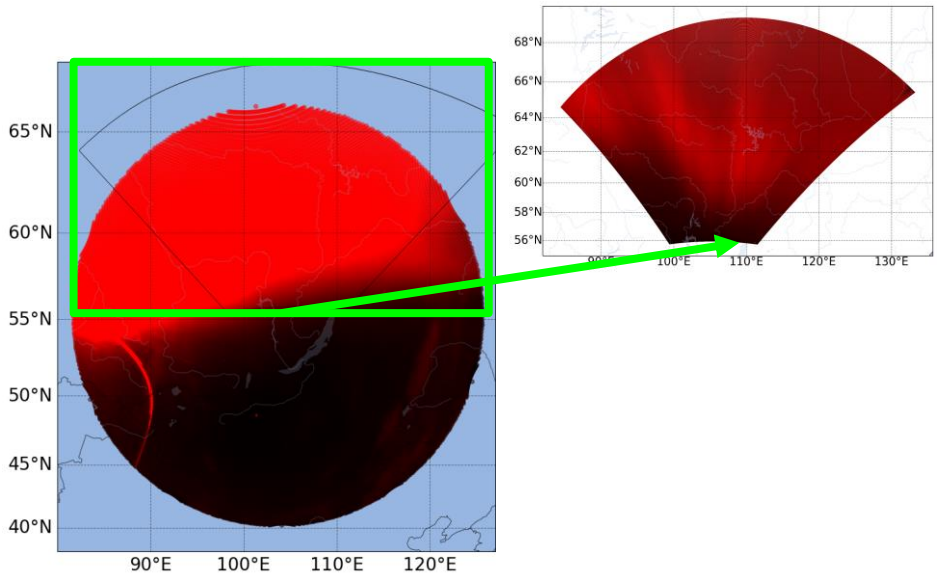


a) b) c)

d) e) f)

g) h)

Figure 3. Images of the northern horizon December 1, 2023 by citizen scientists at different observation points: a) - Maloe Goloustnoye - Y. Shevtsova, b) - Nikolsk - P. Nikiforov, E. Skaredneva, c) - Goryachiy Klyuch - Turkov, d) - Pivovarikha - M. Yakhnenko, e) - Pervomaysky - P. Kosarev, f) - Murino - E. Provilkov, g) - Luchegorsk - S. Yashnova, h) - Nikolsk - P. Nikiforov, E. Skaredneva.



a) b)

Figure 4. a) projection of the NHC all-sky camera frame on the Earth's surface for a height of 500 km. December 1, 2023, 13:41:00 UT, b) frame of the Nikolsk survey (by P. Nikiforov) at the same moment of time.

has the appearance of a broad diffuse band (homogeneous luminescence of the “veil” type). This difference between images in fig.4a and 4b in the aurora structure can be explained by the difference in the exposure time of the frames. At long exposure time, as on the all-sky camera - 55 seconds, such structures, changing in time, overlap each other and finally present a homogeneous glow. It should be noted that the southern boundary of the aurora coincides quite well in both images. It is clearly visible at the segment of 100-110 degrees East longitude.

The joint analysis of the obtained images showed that the digital camera data from citizen scientists are sufficiently informative for studying the events occurring in the atmosphere at different altitudes. Further involvement of more amateur photographers will make it possible to use more spatially separated observation points and, consequently, to improve the accuracy of the resulting MA characteristics and to get the latitudinal dependence of the aurora oval distribution.

Conclusion

With the growing interest in polar and mid-latitude auroras, citizen science observations can undoubtedly make a significant contribution to the study of space weather events. With real-time advance notification of upcoming MAs from space weather forecast sites (for example, https://wdc.kugi.kyoto-u.ac.jp/dst_realtime/index.html, https://xras.ru/magnetic_storms.html, https://www.swpc.noaa.gov/products/wsa-enlil-solar-wind-prediction) and from academic institutions such as ISTP SB RAS, it is possible to cover a larger observing space. The joint analysis of events with the data of observatories conducting monitoring observations seems to be relevant for improving the accuracy of determining the accuracy of characterizing the manifestations of geomagnetic storms.

Images of midlatitude auroras were obtained with the help of representatives of the Irkutsk Regional Astronomical Society and citizen scientists.

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