E region ionization enhancement over northern Scandinavia during the 2002 Leonids

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Abstract

Intensive E-region ionization was observed with the EISCAT UHF radar during the 2002 Leonids meteor shower. The levels of the geomagnetic disturbance were low during the event. Thus the ionization cannot be explained by intensive precipitation. The layer was 30-40 km thick, so it cannot be classified as a sporadic E-layer (often associated to ions of meteoric origin). These are typically only about km-wide. Incoherent scatter radars have never so far reported any notable meteor shower-related increases in the average background ionization. The 2002 Leonid storm flux, however, was so high that it, if any, might be able to induce such an event. Whether meteors in general can cause such an excess E-region ionization during an intensive shower is discussed. The University of Leeds CABMOD model is used to estimate deposition rates of individual meteors and to relate the results to the predicted Leonid flux values in free space and observed ionization on November 19, 2002.

1. Introduction

The nighttime ionization of the atmosphere originates from different sources such as photoionization and auroral precipitation. Various instabilities, irregularities, tides and waves also carry around ionization, provided by weak particle precipitation from space. Meteors ionize continuously around the globe. Most of this ionization occurs within the ionospheric E region overlapping the meteor zone. The sporadic meteoroid influx is continuously present, but has various periodic behaviours, such as the daily apex maximum during the local morning hours and antapex minimum at evening. Shower meteors associated with comets often have a larger-size population and are thus optically more spectacular than the sporadics, while the latter contain much higher fluxes at small masses [1]. An excess ionizing effect of the shower meteors has been discussed [2], but not observed earlier.

Meteor trails are expanding cylindrical columns of ionization following an ablating meteoroid entering the Earth's atmosphere. In this process the region of ionized gas formed around the meteoroid expands almost instantaneously to a so-called initial radius. Two trains of meteors of size 10 μg (corresponding to a radius of 100 μm for a density of 2000 kg m^{-3}) will meet after 4 minutes at 115 km altitude due to molecular diffusion, and even faster if turbulent diffusion is assumed [3]. Thus the ionization spreads quite fast uniformly throughout the lower part of the ionosphere around the Earth. We investigate whether meteors caused the intensive E region ionization during the Leonid maximum in 2002.

2. The Leonids 2002

The re-entry of the 33-year period comet 55P/Tempel-Tuttle, which had caused a spectacular meteor storm in 1833, raised high expectations in 1998 and the following years. The comet was known to have a lot of remnants around its orbit from the earlier Sun passes. Modellers did forecasts of the occurrence and intensity of the dust trails ejected from the comet in 1767 and 1866, and these agreed very well with the observations [4]. The 1767 trail was the one most visible for Western European observing conditions. Earth passed through it around 0400 UT on November 19 and highly increased meteor activity was reported from 0330 to 0530 UT. The ZHR reached some 2400 at its best [5]. The EISCAT UHF radar observed an intensive E-layer extending up to 140 km altitude between 0300 and 0630 UT. The elevation angle of the Leonid radiant for the EISCAT UHF radar site in Tromsø rose to its maximum height at about 43° at 0500 UT.

3. Observations

The experiment described in this paper was run on the 930 MHz EISCAT UHF radar near Tromsø, Norway. An ordinary ionospheric observing mode was employed for studying whether some excess ionization could be distinguished. In the Swedish special program the radar was pointing into zenith, thus differing from usual common program runs. The measurements extended from 95 km beyond 400 km altitude. The altitude resolution was 0.9 km over the whole

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measurement range, but in the analysis gradually changing from 3 km in the E region to 20 km in the F region. The standard autocorrelation function arc1 mode, mostly used for auroral arc studies, was employed for the UHF radar.

Figure 1 shows the EISCAT UHF electron density data as 1-minute integrated electron density profiles every half an hour between 0130 UT and 0630 UT. Electron density values up to 3.4 x 10^{11} m^{-3} were recorded. The density profiles show a blunt-ended layer form similar to the ones produced in simulation studies on meteoric matter deposition in the atmosphere [2,6].

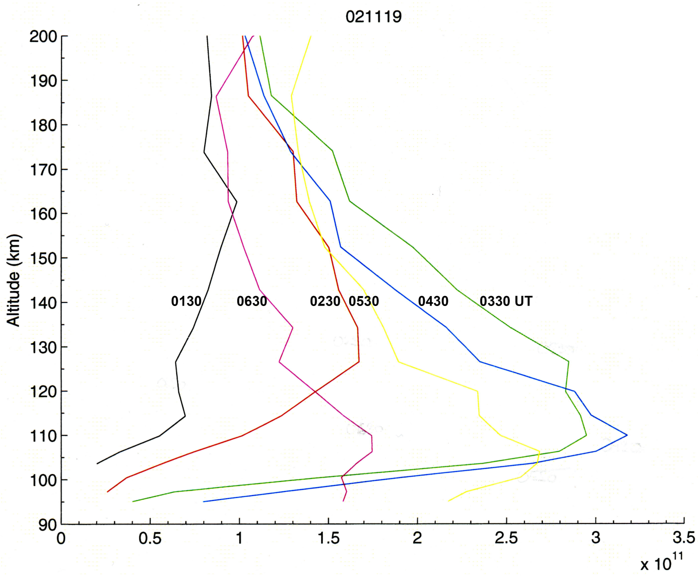

Figure 1. 1-minute integrated electron density profiles at half hour intervals from the EISCAT UHF observations over Tromsø during the Leonid storm.

Many strong optical meteors were seen above the EISCAT location in Northern Scandinavia during the 1767 burst. Table 1 shows some local statistics over the region. One of these Leonids were observed at two stations of the optical imager ALIS network and analyzed in detail [7].

Table 1. Strong visual Leonids during the meteor shower.

Time of occurrence [UT]	0320	0330	0340	0350	0400	0410	0420
Number of Leonids	2	3	4	4	7	3	1

4. Meteoroid Material Deposition and Ionisation

In this section we will estimate from predicted Leonid flux values in space how much the meteoroids could induce excess ionization in the ionospheric E region. We used Leonid flux forecasts for 1998-2001 [8] for the meteoroids, since we did not find any estimated or observed flux values for the 1767 trail in 2002. Especially the observed 1999 Leonid storm values from the 1899 trail are comparable to the 2002 ZHR values of more than 2500 for the 1767 trail [5]. Thus we call this case for 1999/2002. We also use an established relationship between a specific sized meteoroid and the line density, which it is expected to leave in its trail [9].

The common description of the process maintaining the ionospheric ionization in the E region is the momentary electron density governed by the continuity equation balancing between the ion production term and the ionization loss. Here we assume the meteoroids as the source. We will calculate the ionization production for a 40 μm meteoroid. It is estimated to leave a line density of 10^{10} electrons per meter of trail length behind it [9]. If we assume a 30 km long trail, it will include about 3.0×10^{14} electrons. The flux of such meteoroids for the 1999/2002 case was about 2 $m^{-2}h^{-1}$ [8]. The EISCAT UHF radar beam volume has a diameter of about 1 km and the ionization extends about 30-40 km in altitude. Thus the area for meteoroid hits coming in some 40° elevation angle would be about 30 km^2. The number flux on the radar area is thus 6×10^7 h^{-1}. These trails include a total of 1.8×10^{22} electrons produced within one hour. Estimating the radar volume to be a 30 km long cylinder with 1 km diameter, we get the excess electron density of 7.5×10^{11} m^{-3}. Thus the ion production within one hour related to the most intensive predicted Leonids fluxes calculated with this rough model is about twice the observed density of 3.4x10^{11} m^{-3}. In this analysis, however, any variations along the meteoroid path are ignored.

A more detailed analysis can be done by estimating deposition rates of individual meteors by employing the University of Leeds CABMOD model [10] and relating the results to the predicted Leonids flux and observed ionization on November 19, 2002. Due to the high speed of the Leonids, all the evaporating atoms will ionize [10] and the electron production rate can be assumed to be equal to the ablation rate. The initial density of the Leonid meteoroids is a parameter which is not definitely known. The estimates vary between 400 to 2000 kg m^{-3}. In general the ablation peak maximum altitude varies several kilometres for different density meteoroids with otherwise similar parameters, being higher up for lower densities. A density of 2000 kg m^{-3} was proposed by Williams [11]. Rietmeijer [12] got the same result from several estimates of radius and density.

In the present modelling, we assume a chondritic composition and a density of 2000 kg m^{-3} for the meteoroids. The atmospheric density profile, necessary to solve the differential equations describing the change to the velocity of the meteoroid in time, is taken from the MSIS-model for the latitude, longitude and time of year. The ablation profiles of the different compounds are calculated starting at 500 km altitude, where sputtering dominates the mass loss until the meteoroid melts and ablation begins in the lower E region (depending on the mass, velocity and zenith angle). Figure 2 shows two examples of the output of the CABMOD model.

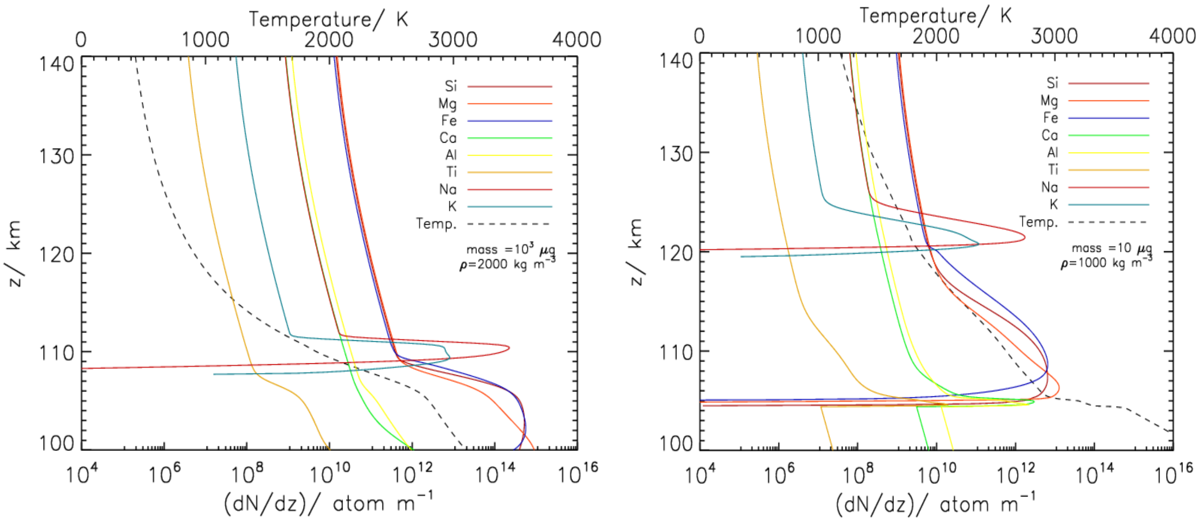

Figure 2. Two examples of the predicted elemental ablation profiles as a function of the altitude (zenith angle of the radiant = 49°). Left-hand panel: meteoroid mass = 1000 μg, density = 2000 kg m^{-3}. Right-hand panel: meteoroid mass = 10 μg, density = 1000 kg m^{-3}. Note that deposition occurs at higher altitudes for smaller meteoroids, as well as those with lower density.

Results from different CABMOD runs appropriate for this study are shown in Table 2. The result refers to a single particle, given mass, velocity = 71 km s^{-1} (for the Leonids) and radiant zenith angle = 49° (for Tromsø radar station).

Table 2. Rates of ablation at 120 and 130 km, and the total rate at the altitude where the Na ablation rate is a maximum, for four different Leonid meteoroids of different masses, arriving from 49° zenith angle over the EISCAT UHF radar.

Meteor Mass [μg]	Atoms/m at 120 km	Atoms/m at 130 km	Atoms/m at Na_{Max}	Altitude at Na_{Max} [km]
1	4 x 10^8	2 x 10^8	6 x 10^{10}	122
10	10^{12}	6 x 10^8	10^8	120
100	2 x 10^{10}	10^{10}	6 x 10^{12}	117
1000	2 x 10^{10}	2 x 10^{10}	2 x 10^{14}	110

The numbers in Table 2 can be related to the 40 μm (about 1 μg) meteoroid used in the calculation above. It was estimated to leave a line density of 10^{10} electrons per meter of trail length left behind it. The results from the CABMOD model show that the ionization at 120 km of height can be explained clearly by the ablation of particles with mass close to 10 μg. At 130 km altitude, the rate of electrons production is 2×10^{10} electron m^{-1}. Particles with a mass of 10^3 μg would produce ionization at this altitude. The last column shows the altitude where the produced ionization would maximize corresponding to sodium ablation for different size particles.

5. Summary

A strong and thick ionization layer was observed in the ionospheric E region with the EISCAT UHF radar over the Northern Scandinavia simultaneously with the 2002 Leonid maximum caused by the trail ejected from the comet 55P/Tempel-Tuttle in 1767. The geomagnetic activity was low, so the event was not caused by strong precipitation. Many unusually strong Leonids were observed at the same time period over the region. Despite theoretical predictions, enhanced ionospheric ionization has not been observed with incoherent scatter radars earlier.

Calculations based on the estimated Leonid fluxes in free space conclude that ionization of the order of magnitude of the observed peak electron density of 3.4×10^{11} m^{-3} can be reach in the ionospheric E region. Simulations with the CABMOD model estimating deposition rates of individual meteors and relating them to the flux also show that ionization up to 130 km altitude can be produced by the continuous inflow of fast meteoroids.

6. Acknowledgements

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