Geophysica (1995), 31, 23-36

Source Region of the Energetic Electron Precipitation Between L-Values 3 and 6

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(Received: November 1994; Accepted: February 1995)

Abstract

The ionization sources in the middle atmosphere between the L-values 3.3 and 6.0 have been studied using the cosmic noise absorption measurements. At L-values 4-6 during disturbed times the auroral electron precipitation of magnetospheric origin dominates in ionization and gives two maxima in the diurnal variation of the electron density, one in the morning hours and another one near midnight. During quiet times only one maximum in the ionization is seen in afternoon hours; it is likely due to the precipitation of energetic electrons from the radiation belts inside the plasmapause. At L-values 3.3-4.0 the main ionization source at these low altitudes is that due to H Lyman α. Owing to the seasonal variation of NO density, which is the main component to be ionized, both winter and autumn anomalies are observed; this means that there is enhanced electron density during the autumn and winter months. Since the variation of the electron density in the middle atmosphere at middle latitudes is not a function of the solar zenith angle (with the daytime maximum delayed about 3-4 hours) another ionization source must exist. We propose that the excess ionization in the middle atmosphere in the afternoon hours is caused by energetic electron precipitation from the radiation belt.

Key words: geophysics, ionosphere, magnetosphere, absorption

1. Introduction

Auroral electrons, solar H Lyman α -radiation and X-ray radiation together with energetic electrons from radiation belts, galactic cosmic rays, energetic solar protons and their associated brehmsstrahlung X-rays are significant sources of ionization in the middle atmosphere at altitudes of 60-100 km (*Reagan,* 1977; *Vampola* and *Gorney*, 1983). Measurements of this ionization can be made by sounding rockets, incoherent scatter technique and observing the attenuation of galactic radio noise received by riometers (*Little* and *Leinbach*, 1959; *Friedrich* and *Torkar*, 1983; *Collis et al.*, 1984; *Ranta et al.*, 1985).

In the auroral zone the dominating ionization source at those altitudes is auroral electrons which give two maxima in the diurnal variation of the electron density, one near midnight (around 22-01 LT) and one in the morning hours (around 07-14 LT). The auroral

Published by the Finnish Geophysical Society, Helsinki

zone is typically a few degrees in latitude wide and lie between about 60° and 75° geomagnetic latitudes. During disturbed times the morning maximum is seen earlier and during quiet times it is seen later (*Hargreaves*, 1966; 1969; *Berkey et al.*, 1974; *Ranta* and *Ranta*, 1977). During quiet times the night maximum may even disappear.

The ionization due to solar H Lyman α -radiation dominates at middle latitudes. On this basis one might expect the diurnal variation of the electron density to be a function of the solar zenith angle (solar zenith angle = an angle between the zenith and sun), causing the maximum in the electron density to occur near noon with some time lag due to the relaxation time (*Torkar* and *Friedrich*, 1983; *Lastovicka*, 1977, 1978). In addition, ionization due to the precipitation of energetic electrons from the radiation belts maximizes in the altitude range 70-90 km and may be comparable to the ionization due to direct solar H Lyman α -radiation. At night the electron precipitation may dominate over the ionization due to scattered H Lyman α -radiation (*Vampola* and *Gorney*,1983).

In this paper we study the variation of the electron density in the middle atmosphere at the middle and high latitudes using the cosmic noise absorption measurements (riometer measurements), which mainly respond to the electron density enhancements in the altitude range 60-100 km. To identify the main ionization sources, we examine the relation between the absorption data and the auroral electrojet index AE.

2. *Measurements*

From the Northern Hemisphere, the riometer absorption data for the year 1975 from six stations in Finland between L-values 3.3 and 6.0 were analyzed. The Finnish stations lie between geographic latitudes 60 and 70° N and at longitude of about 20° E and they cover the geomagnetic latitudes between 57° and 66° N. The stations are shown in Figure 1 and their coordinates are given in Table 1. The absorption values for the first minute of each hour were used. The method of data analysis and the derivation of the quiet day curve (QDC) are explained by *Ranta et al.*(1983). The absorption has been computed for the first minute of each hour from the formula

$$A = 10\log_{10} (Po/P)$$

where P is the received cosmic noise power and Po the cosmic noise under quiet conditions at the same sidereal time. The quiet day level has been determined separately for every month from a sidereal time-cosmic noise plot. The absorption data are divided into groups according to the magnetic activity level. The absorption values obtained for 1-hour average AE-values greater and less than the given value were then processed separately. LT-time is used. As the difference between LT and UT 2 hours is used.

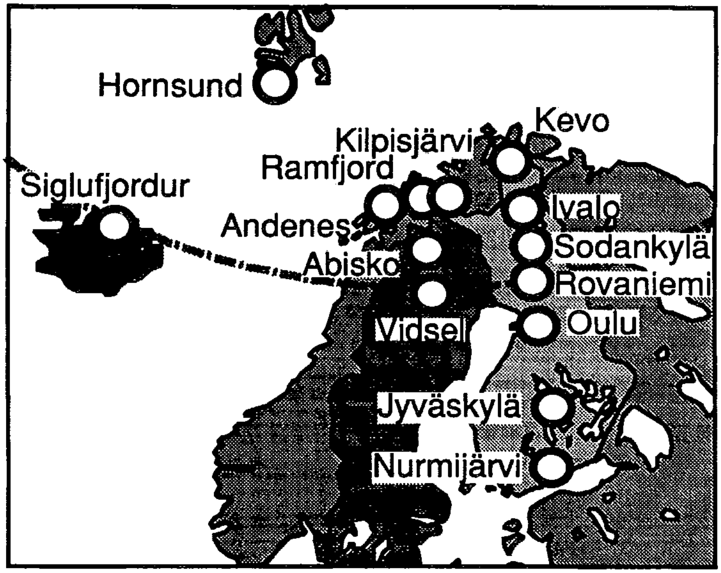


Fig. 1. Riometer stations. The data for Kevo (KEV), Ivalo (IVA), Sodankylä (SOD), Rovaniemi (ROV), Oulu (OUL), Jyväskylä (JYV) and Nurmijärvi (NUR) are used in this study.

Table 1. Riometer stations.

Station		geogr. coordinates		L-value	freq.
		lat.	long.		MHz
KEVO	KEV	69°45'N	27°01'E	6.0	27.6
IVALO	IVA	68°34'N	27°25'E	5.5	27.6
SODANKYLÄ	SOD	67°25'N	26°24'E	5.1	27.6
ROVANIEMI	ROV	66°34'N	25°50'E	4.8	27.6
OULU	OUL	65°06'N	25°59'E	4.3	27.6
JYVÄSKYLÄ	JYV	62°24'N	25°40'E	3.7	27.6
NURMIJÄRVI	NUR	60°31'N	24°39'E	3.3	27.6

3. *Results*

The diurnal variation of the absorption as a function of the local time (LT) is shown in Figure 2 for six Finnish stations in the year 1975 between the L-values of 3.3 and 6.0. The lower part presents the behaviour of the absorption during quiet periods, when AE<40 and the upper part during the disturbed period, when AE>40. In these periods the diurnal variation is more or less similar for all the stations, when AE<40: absorption begins to increase at about 10 LT, reaches a maximum at 15-16 LT and returns to normal at 19 LT. During the more disturbed periods at the southernmost stations, shown in the upper part of Figure 2, when L<4, the daytime maximum occurs at the same time as during the quiet periods between 15-16 LT. Going to the north, in the northernmost station, at Kevo, the maximum is seen at about 11 LT. At Ivalo the maximum occurs at 13 LT and at Rovaniemi at 13-14 LT.

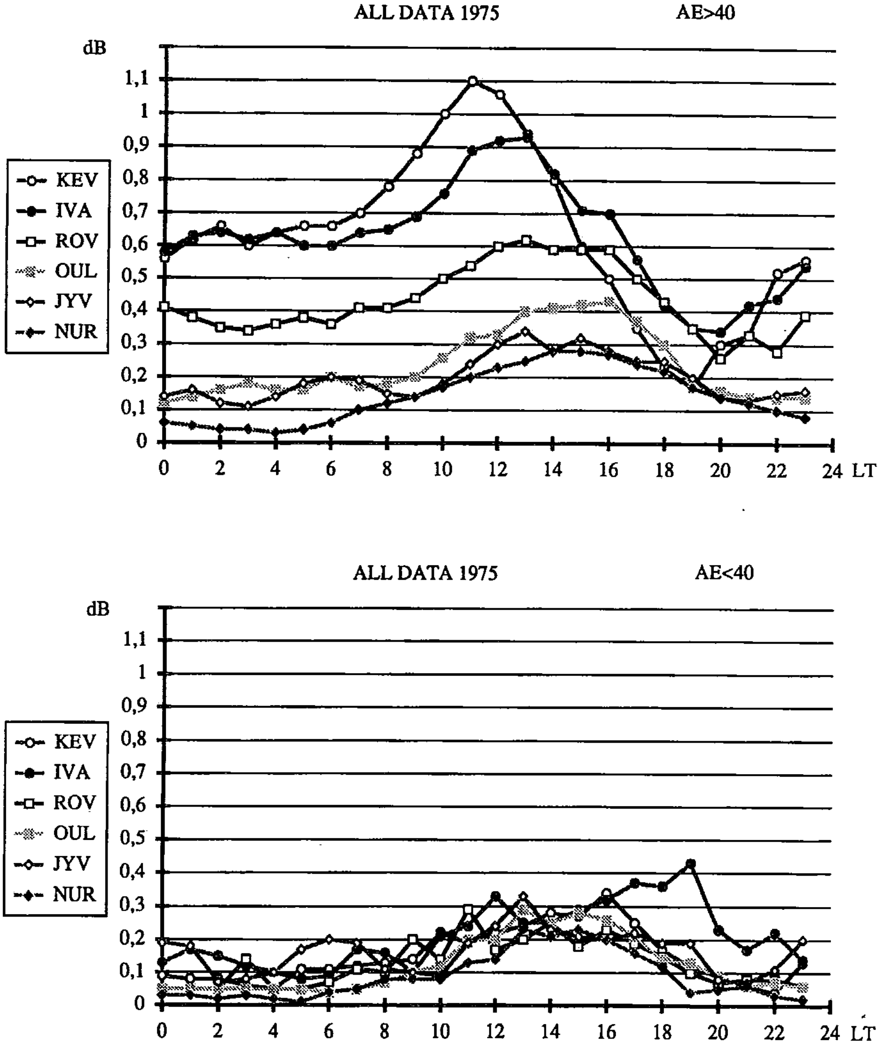


Fig. 2. The mean diurnal variation of the ionospheric absorption in the year 1975 for six Finnish riometer stations for AE values greater and less than 40.

Figure 3 presents the mean diurnal variation of the absorption at Kevo in the year 1975 for AE-values greater and less than 40, 80, 140, 220, 300 and 400. The absorption data for AE values greater than the given index are shown in the upper part of the figure and those for AE values less than the index in the lower part. This method of grouping the data to increasing activity reveals a maximum between about 12 and 13 LT and clearly show the absorption to be due to auroral electrons. In two cases, when AE<80 and 40, the daytime maximum is seen between 13 and 15 LT indicating that in these cases the cause to the ionization is the precipitation of the energetic electrons from the radiation belts.

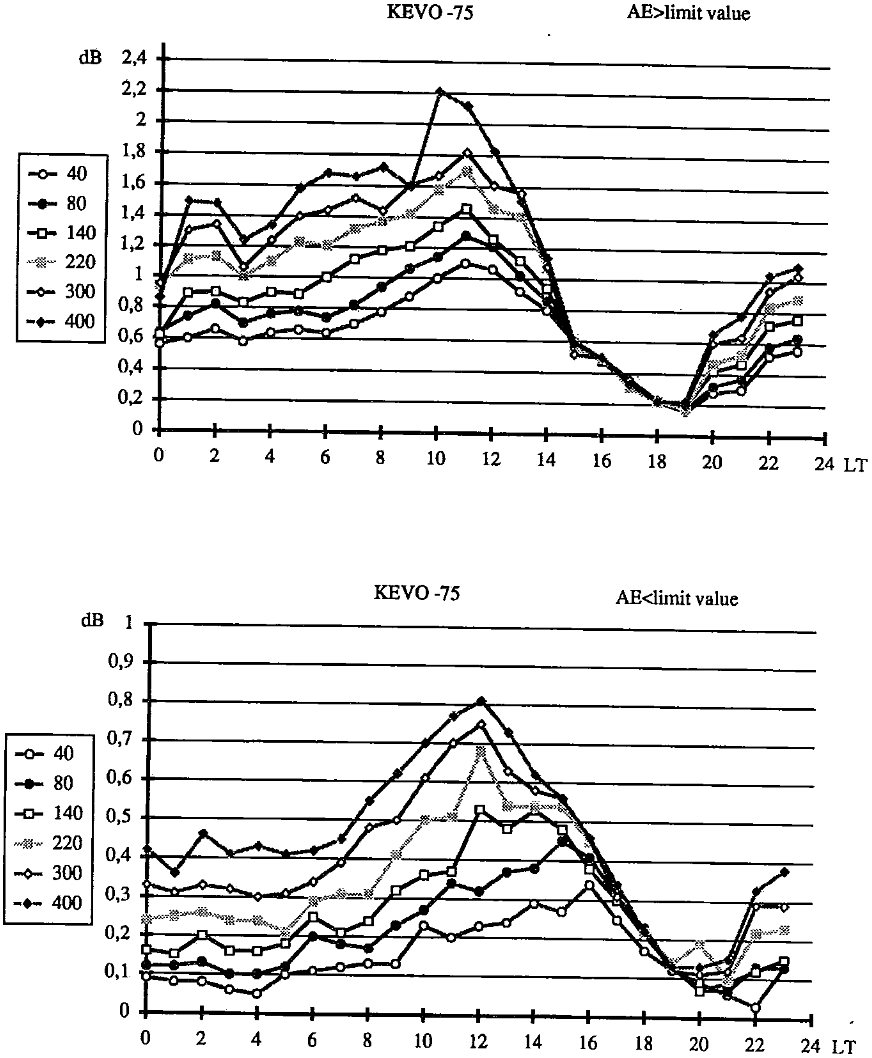
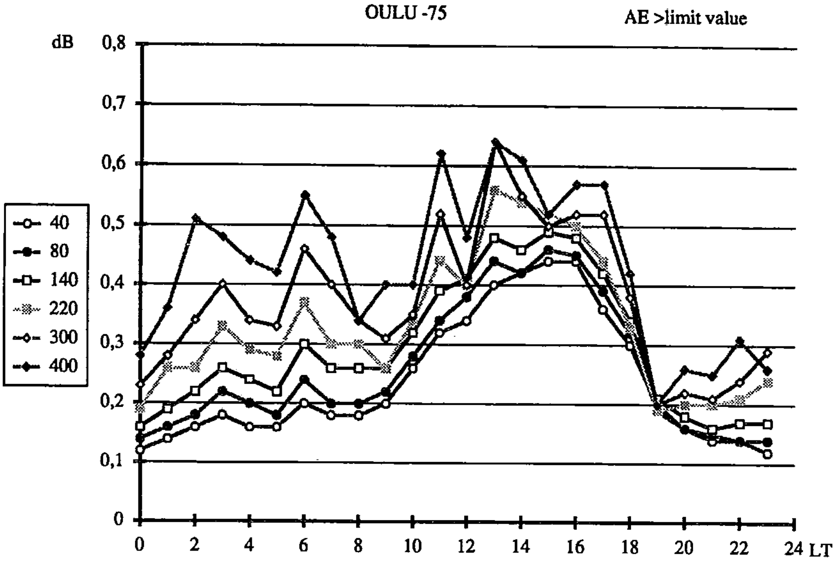


Fig. 3. The mean diurnal variation of the ionospheric absorption for Kevo in the year 1975 for AE values greater and less than 40, 80, 140, 220, 300 and 400.

Figure 4 shows the mean diurnal variation of absorption for Oulu for the year 1975, the absorption data grouped as decribed above with different AE-index values. Here the maximum of absorption is consistently seen in the afternoon, even during very disturbed periods indicating that at this lower latitude (L=4) the ionization caused by auroral electrons occurs so seldom that it does not affect the mean behavior of absorption. Only in the cases, when AE>220, 300 or 400, there is the increased absorption during the night and morning hours.



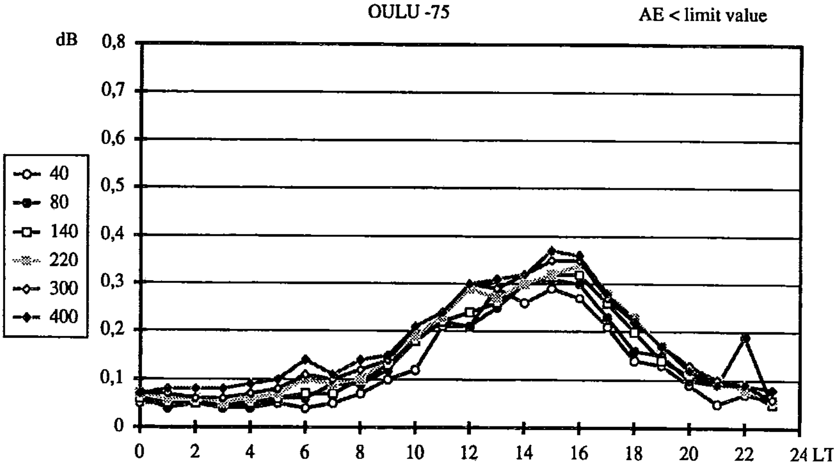


Fig. 4. The mean diurnal variation of the ionospheric absorption for Oulu in the year 1975 for AE values greater and less than 40, 80, 140, 220, 300 and 400.

Figure 5 shows the corresponding results for Nurmijärvi (L-value 3.3). As in Oulu the auroral electrons do not influence the mean ionization in the middle atmosphere.

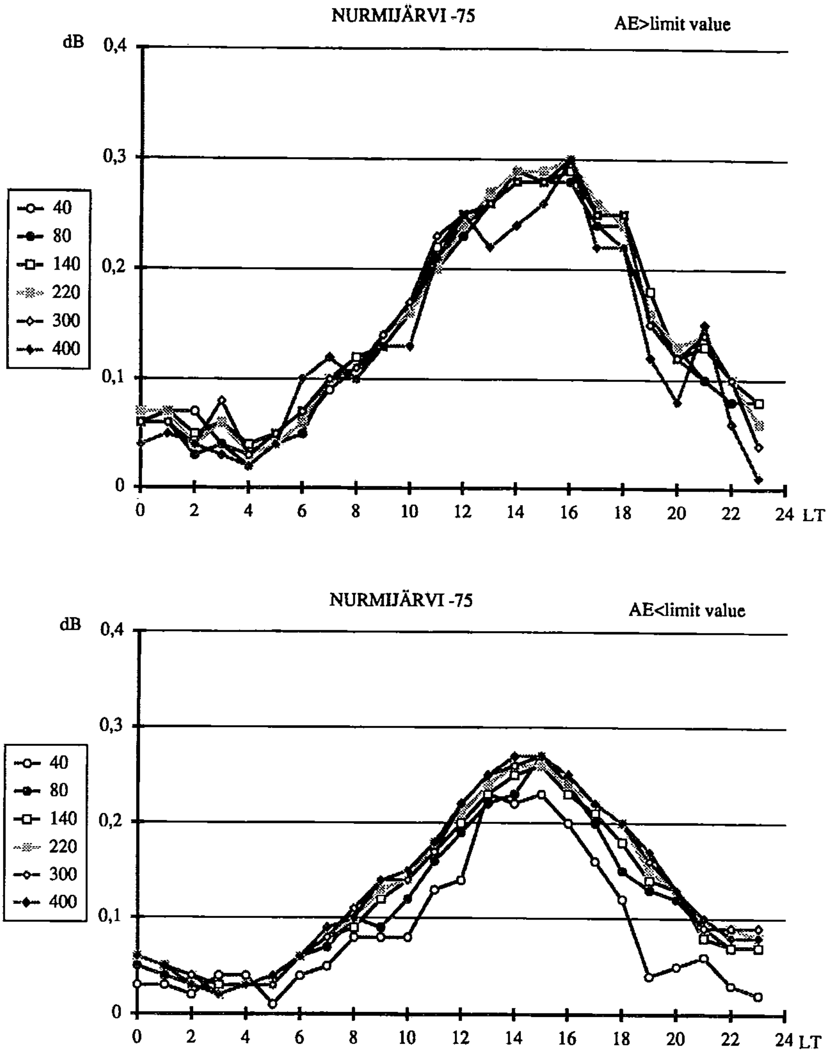


Fig. 5. The mean diurnal variation of the ionospheric absorption for Nurmijärvi in the year 1975 for AE values greater and less than 40, 80, 140, 220, 300 and 400.

Two stations, Nurmijärvi and Oulu, were selected for a study of the diurnal variation of the absorption during the different seasons, Figures 6 and 7. The AE-index value 140 was chosen as the dividing point for the "quiet time" and "disturbed time". Evidently the

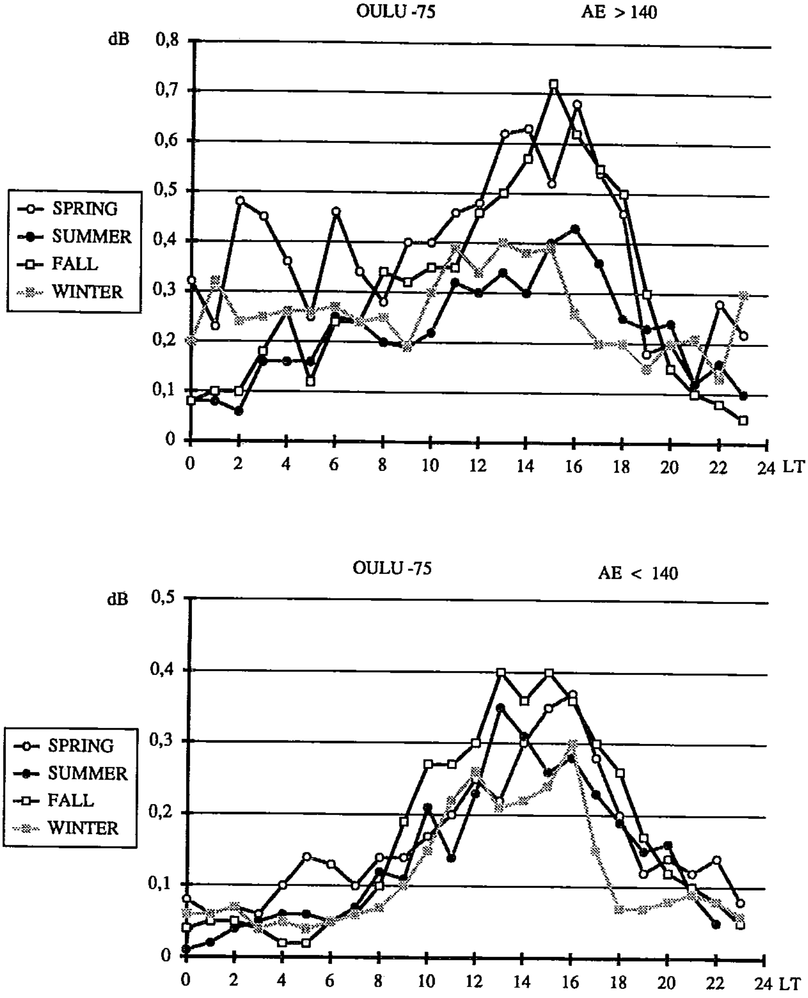


Fig. 6. The mean diurnal variation of the ionospheric absorption for Oulu in the year 1975 during different seasons for AE values greater and less than 140.

absorption at Nurmijärvi does not depend on magnetic activity, but the absorption values at Oulu tend to be a little higher during the disturbed times. At Nurmijärvi the greatest absorption is seen in the summertime and the absorption is about twice as great in autumn as spring. An increase of the absorption in the springtime begins after the noon. The differences between seasons are not so clear at Oulu as at Nurmijärvi. However absorption values during the equinoxes are a little higher than in winter- and summertime. During all seasons the maximum absorption at Oulu is located in the afternoon hours whereas at Nurmijärvi it is located in the afternoon during the equinoxes and the summer, and around noon in the winter.

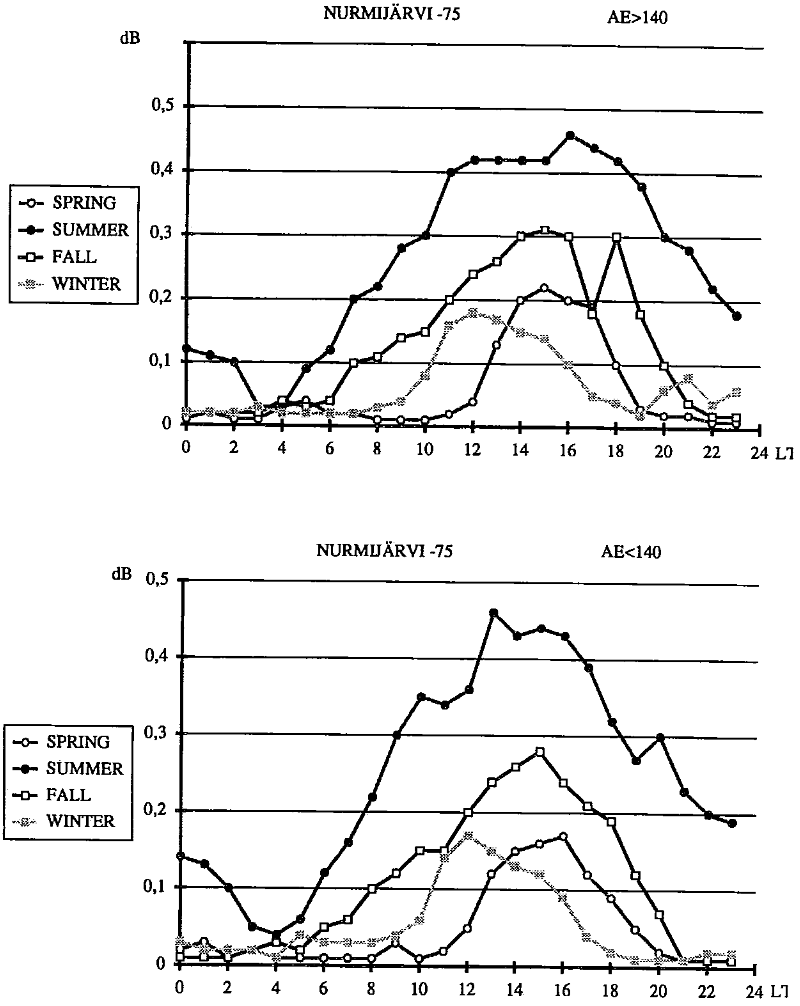


Fig. 7. The mean diurnal variation of the ionospheric absorption for Nurmijärvi in the year 1975 during different seasons for AE values greater and less than 140.

The daily maximum absorption values for six stations as a function of AE are presented in Figure 8. In two southernmost stations no dependence is seen between the absorption values and AE-indexes. At Oulu the absorption values are only a little higher when AE>220. In the more northern stations the absorption values increase as a function of AE-indexes.

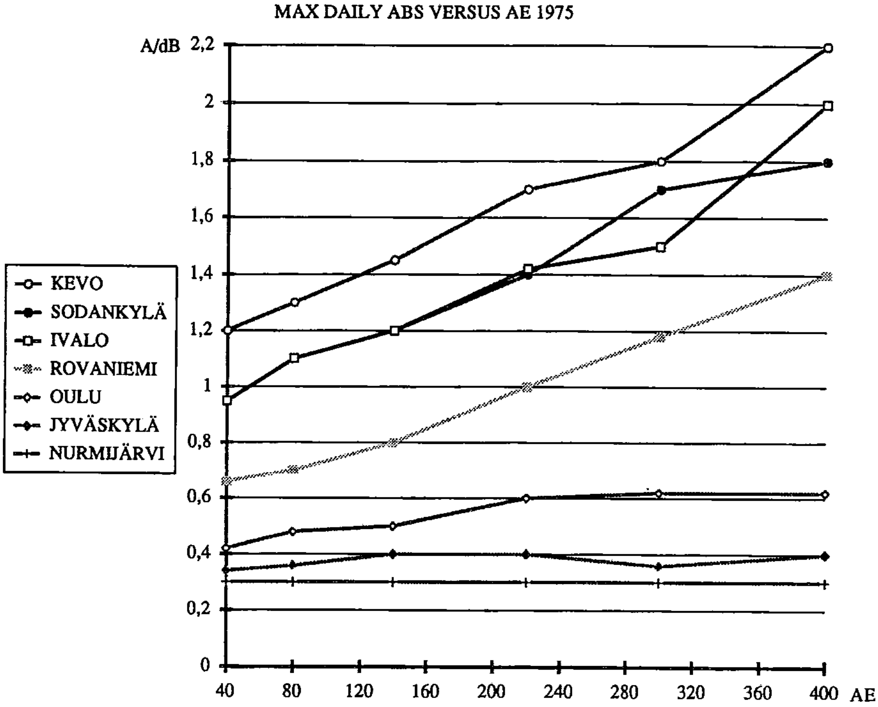


Fig. 8. The maximum daily absorption as a function of daily average AE values for six Finnish riometer stations in the year 1975.

4. *Discussion*

The results indicate that during quiet periods both at high and middle latitudes (L-values of 3.3-6.0) the ionization in the middle atmosphere maximizes about 3-4 hours after the noon. One exception is in the wintertime at middle latitudes where the maximum absorption is seen near noon. For the maximum to be seen at high L-values 5-6, the magnetic activity must be very low, AE<40, so that the ionization by auroral electrons is not so dominating that the afternoon side maximum is observable. (The auroral zone in the morning and night time hours locates north of the northernmost stations Kevo, when AE<40). During disturbed times at high latitudes the maximum in ionization shifts to the morning hours, but at middle latitudes the absorption does not depend much on magnetic activity. Because the ionization does not follow the solar zenith angle one may conclude that it is not entirely caused by direct solar radiation. The time lag of 3-4 hours is not explained by atmospheric relaxation time. Probably the source of this excess ionization is energetic electron precipitation from the radiation belt from the so-called bulge region, which may extend to high L-values during very quiet condition, Figure 9. The reason that the ionization is not seen in the wintertime could be that the electrons causing the ionization are so energetic that the ionization is seen below 70 km. At these heights during sunset periods the negative ions are formed decreasing the electron density.

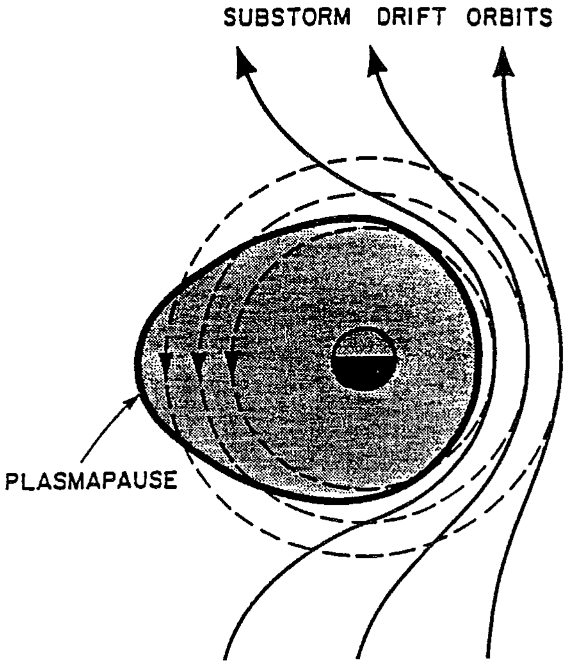


Fig. 9. Simplified model of the drift of medium energy (10-100 keV) electrons in the equatorial plane, for magnetically disturbed (solid curves) and quiet (dashed curves) periods (*Thorne et al.*, 1974).

During quiet conditions high-energy electrons (E>40keV) are trapped inside the (nearly) dipolar magnetic field of the inner magnetosphere, forming the radiation belt. The electron population in the equatorial plane has been monitored by satellites showing higher fluxes for electrons with lower energies and verifying the existence of the slot region, i.e. a region of low particle fluxes with minimum fluxes between L=3 and L=4 (dependent on particle energy) and with the depth of the minimum increasing with increasing electron energy. It is generally accepted that pitch angle diffusion by resonant interaction with plasmaspheric hiss is the dominant loss process for geomagnetically trapped electrons for 2<L<5. Mainly ELF plasmaspheric hiss has been taken into consideration, but recently it has been shown that VLF-hiss also plays a considerable role, overcoming difficulties with the slow rates of pitch-angle diffusion at intermediate pitch-angles. Plasmaspheric hiss is continuously observed throughout the plasmasphere over a band of frequencies several hundred Hz wide, centered at several hundred Hz. The hiss is generated at the steep gradient of cold plasma density, the plasmapause, by cyclotron resonance with medium energy electrons and it is propagated into the plasmasphere. Therefore , the total wave amplitude and the distribution of wave energy and also the effectness of the pitch-angle diffusion process depends on the density distribution of the cold plasma, especially at the position of the plasmapause. During quiet conditions the density inside the plasmasphere is great. The loss process leads to a continuous, L-dependent precipitation of high-energy electrons into the ionosphere (*Wagner* and *Ranta*, 1983).

Vampola and *Gorney* (1983) studied the precipitation of the energetic electrons in the middle atmosphere using satellite measurements and they found the average energetic electron precipitation during quiet times to be a function of L-value with maximum at L-values between 4 and 5. Comparing the ionization rates for different sources, they concluded that the electron precipitation can be an important ionization source in the 70 to 80 km range, where it even competes with the direct H Lyman α -ionization during daytime and is one order higher than the ionization caused by scattered H Lyman α -ionization during nighttime.

The comparison of absorption values for different seasons at Nurmijärvi and Oulu, shows for Oulu virtually no seasonal variation, but there are clear differences at Nurmijärvi. The maximum absorption at Nurmijärvi is seen during the summertime indicating that ionization due to H Lyman α -radiation dominates. The absorption is about twice as high in autumn as in spring, a phenomenon discussed by *Ranta et al.* (1983) as the autumn anomaly. One possible cause of the autumn anomaly, which is seen regularly every year at mid-latitudes, is the seasonal variation in the NO density. The wintertime absorption around noon is comparable to that in springtime, a phenomenon called winter anomaly. The term winter anomaly has been used to indicate increased electron density in the lower ionosphere during certain winter days, winter anomaly days. The term is also used to indicate increased electron density during the winter months compared with the values at the same solar zenith angle during other seasons as the term is used in this study. On winter anomaly days the electron concentration is enhanced between 75 and 95 km altitude due to increased NO density. Why the ionization caused by the energetic electrons from the radiation belts is not seen at middle latitides during the winter months is not known.

We may now summarize the ionization sources at L-values between 3.3 and 6.0 in the middle atmosphere as follows:

1. At L-values 4-6

a) During disturbed times the auroral electron precipitation of magnetospheric origin dominates in ionization and gives two maxima in the diurnal variation of the electron density, one in the morning hours and another one near midnight.

b) During quiet times only one maximum in the ionization is seen in the afternoon hours, possibly due to the precipitation of energetic electrons from the radiation belts inside the plasmapause.

2. At L-values 3.3-4.0

a) The main ionization source is the direct solar radiation. Owing to the seasonal variation of NO density, which is the main component to be ionized, both winter and autumn anomalies are observed, it means the enhanced electron density during the autumn and winter months.

b) Since the variation of the electron density in the middle atmosphere at middle latitudes is not a function of the solar zenith angle, but the daytime maximum is delayed about 3-4 hours, another ionization source must exist. We propose that the excess ionization in the middle atmosphere in the afternoon hours is caused by energetic electron precipitation from the radiation belt.

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