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IONIZATION PROCESSES IN THE LOWER IONOSPHERE DURING THE GEOMAGNETIC STORM ON 16–17 DECEMBER 1971

by

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Abstract

The ionization processes in the lower ionosphere during the geomagnetic storm on 16–17 December 1971 are studied using satellite and riometer measurements from the northern auroral zone and polar cap regions. The magnetic storm activity was characterized by sudden storm commencement on 16 December at 1904 UT. Another sudden storm commencement was observed at 1418 UT on 17 December. During the storm, auroral absorption (AA) events and a weak polar cap absorption event were in progress. The different ionization processes are discussed in the paper.

1. *Introduction*

The great majority of absorption events seen during a magnetic storm in the auroral zone are auroral absorption (AA) type processes. If other processes are to be analyzed, one must necessarily first be able to recognize the usual AA events. This can be done by analyzing the latitudinal, longitudinal and temporal behavior of the events together with their relations to other phenomena, such as magnetic activity. After this, the other absorption events can be distinguished from the background of the AA events. In the present case, different absorption events due to the injection of energetic solar protons are examined.

The basic morphological features of AA events are well known. An AA event begins in the night-time sector, with clear relationship to the substorm onset, at L-values of 6 or less depending on the level of magnetic activity. From the onset area the event spreads in all directions, the most pronounced spreading being toward the morning sector of the auroral zone and toward the pole (BERKEY *et al.*, 1974, RANTA *et al.*, 1981).

The situation becomes more complex when other types of absorption such as polar cap absorption (PCA) and absorption events related to sudden storm commencement (SCA) occur simultaneously with AA events. This is the case with the storm studied here. This storm was partly studied earlier by SHUMILOV *et al.* (1977b) using observations from five Soviet riometer stations, but that study was limited to a rather narrow longitudinal sector. In the present study the main part of the storm is analyzed by using the whole riometer station network in the auroral zone and polar cap areas in the Northern Hemisphere in order to get a better idea of the spatial and temporal development of the events. This broader scope allows an identification of the types of absorption and the related particle precipitation phenomena in a more uniform way. The total number of stations used is 19 and the coverage of the auroral zone and polar cap regions is as good as can be achieved. One must keep in mind, however, that, because of the sea areas in the Northern Hemisphere, the coverage is less complete than it should be for this kind of analysis, and some unavoidable ambiguities remain.

2. *Observations*

The measured cosmic noise absorption for the 19 stations is presented in Fig. 1. Table 1 lists the locations and the measuring frequencies of the stations, and the location of the riometer chains is also seen in Figs. 4 and 5. The analysis covers the period from 1600 UT on 16 December 1971 to 1700 UT on 17 December 1971, during which occurred the main parts of a very strong and complex magnetic storm with two sudden storm commencements and a PCA event.

Figure 2 shows the intensity of solar protons at energies exceeding 10 MeV in the interplanetary space measured onboard Explorer 434 (Solar Geophysical Data No. 329) and the proton intensity in the geostationary orbit of satellite ATS-1 measured in the energy range from 5 to 21 MEV (Solar Geophysical Data No. 338).

In Figure 3 the magnetic variation and magnetic indices are shown for the auroral zone and low latitudes (UAG report No. 56). The sudden commencements occurred at 1908 UT on 1 December 1971 and 1418 on 17 December 1971.

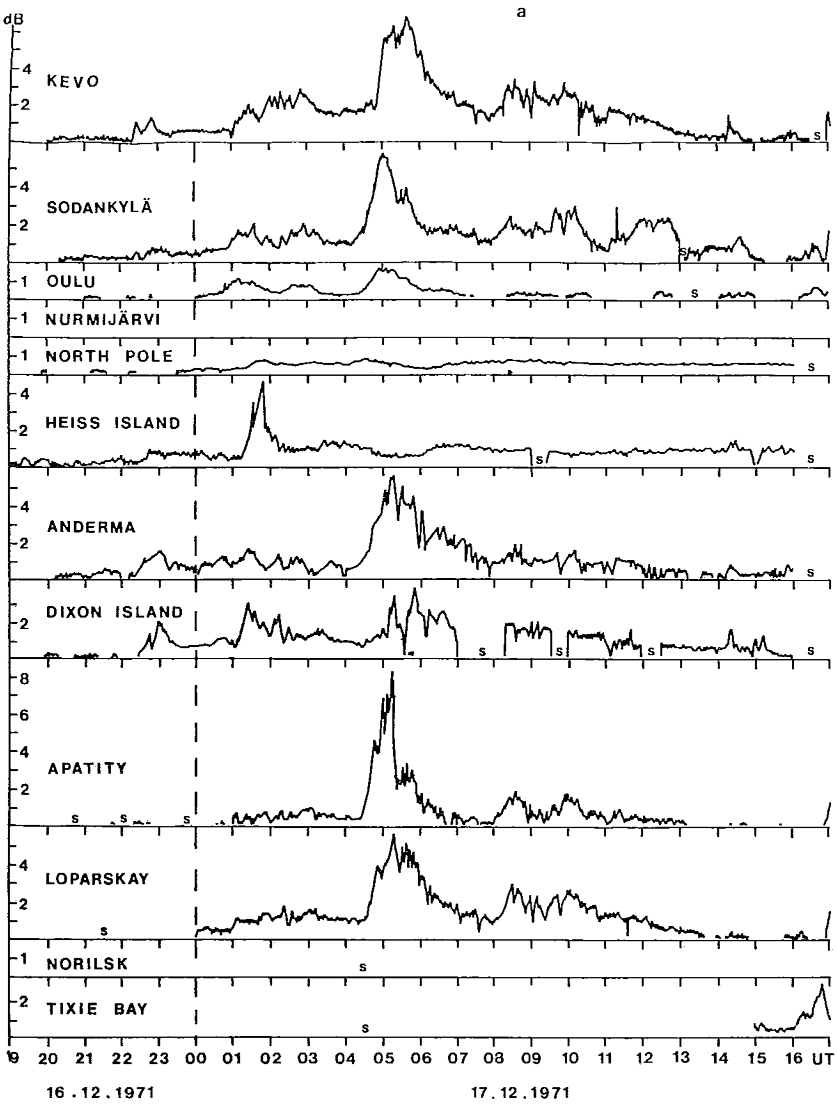

Fig. 1a. Variation of ionospheric absorption according to riometer measurements in the Northern Hemisphere, 16–17 December 1971.

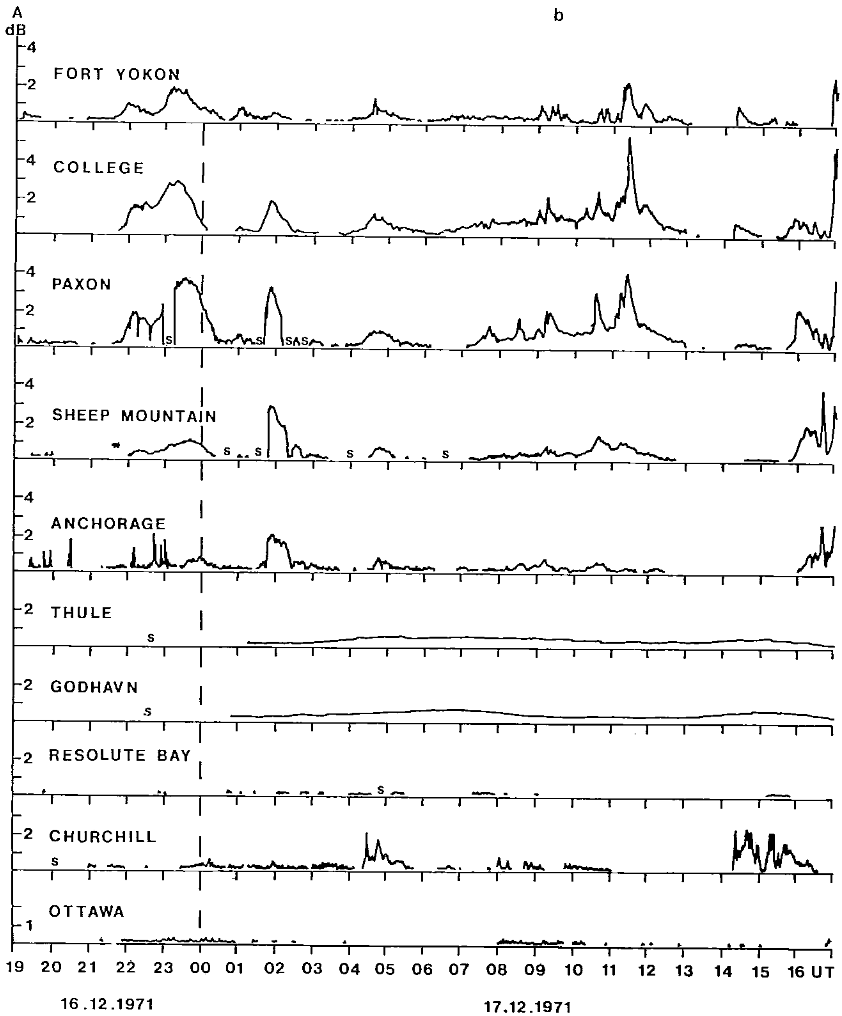

Fig. 1b. Variation of ionospheric absorption according to riometer measurements in the Northern Hemisphere, 16–17 December 1971.

Table 1. List of riometer stations.

Station	freq. MHz	geogr. coord.	
Kevo	27.6	69.75°N	27.01°E
Sodankylä	27.6	67.41	26.40
Oulu	27.6	65.06	25.48
Nurmijärvi	27.6	60.51	24.65
Loparskaya	32.0	68.37	33.18
Apatity	30.0	67.60	33.30
Heiss Island	32.0	80.70	56.20
Dixon Island	32.0	73.55	80.57
Norilsk	32.0	69.40	88.10
Tixie Bay	32.0	71.60	128.10
Anderma	30.0	63.90	137.50
North Pole	30.0		
Fort Yokon	30.0	66.60	214.80
College	30.0	64.86	212.15
Paxon	30.0	63.04	214.50
Sheep Mountain	30.0	61.82	212.50
Anchorage	30.0	61.20	210.15
Thule	30.0	77.51	290.71
Resolute Bay	30.0	74.70	265.10
Churchill	30.0	58.80	265.90
Ottawa	30.0	54.40	284.30
Godhavn	30.0	69.26	306.49

The cosmic noise absorption measured by four riometer chains in the Northern Hemisphere at 1400 UT on 17 December 1971 is presented in Fig. 4 and that at 0200 UT on 17 December 1971 in Fig. 5, as a function of latitude.

3. *Description of the absorption events*

The riometer data from Thule, Godhavn, North Pole and Heiss Island (Fig. 1b) indicate the onset of weak PCA at about 23–24 UT on 16 December. Because the absorption values in this PCA event are only of the order of 0.5 dB, a very careful analysis of the riometer data was needed. The satellite data indicate an increase in proton flux at the same time as absorption was observed by riometers, indicating that the PCA event was in progress, although its intensity was near the lower limit of detectability. The given interpretation receives support from the quantitative agreement between the measured values and the values estimated from the available proton flux data using the formula of Adams and Masley (1966). The PCA event can also be recognized in the data from Kevo, Sodankylä, Dixon Island, Anderma

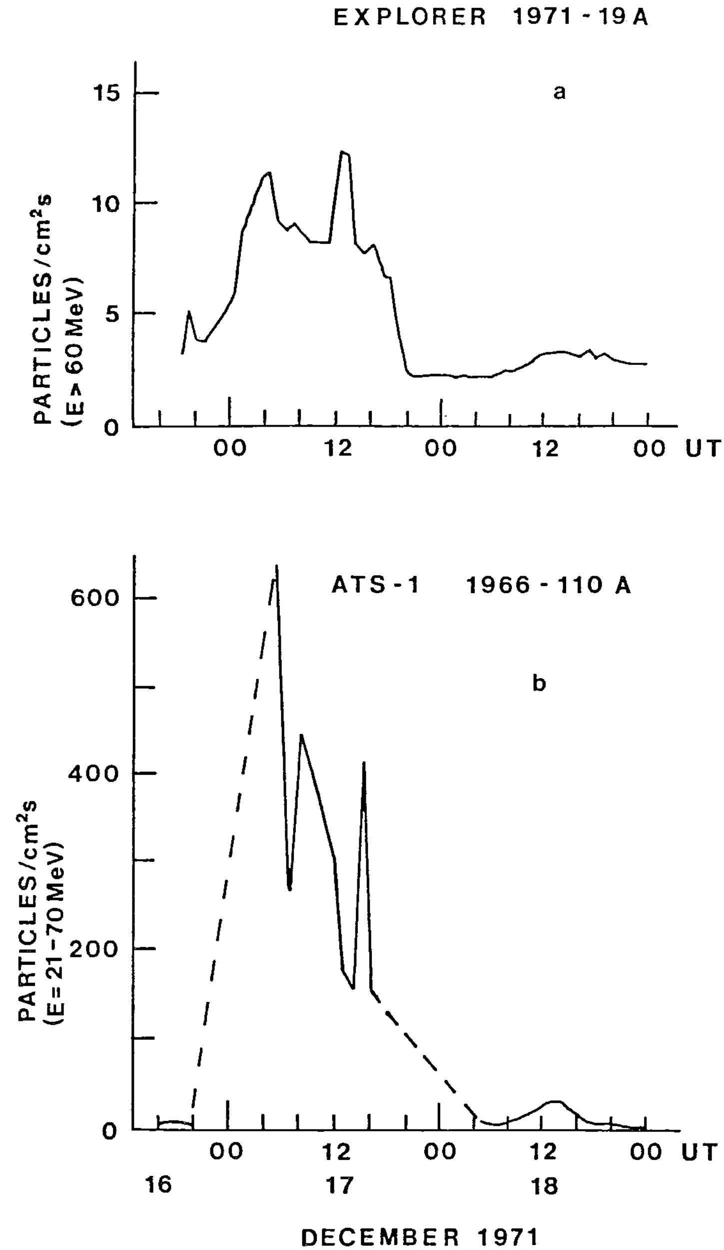

Fig. 2. The measured proton fluxes on 16–18 December 1971.
a) by satellite Explorer (Solar Geophys. Data 329)
b) by satellite ATS-1 (Solar Geophys. Data 338)

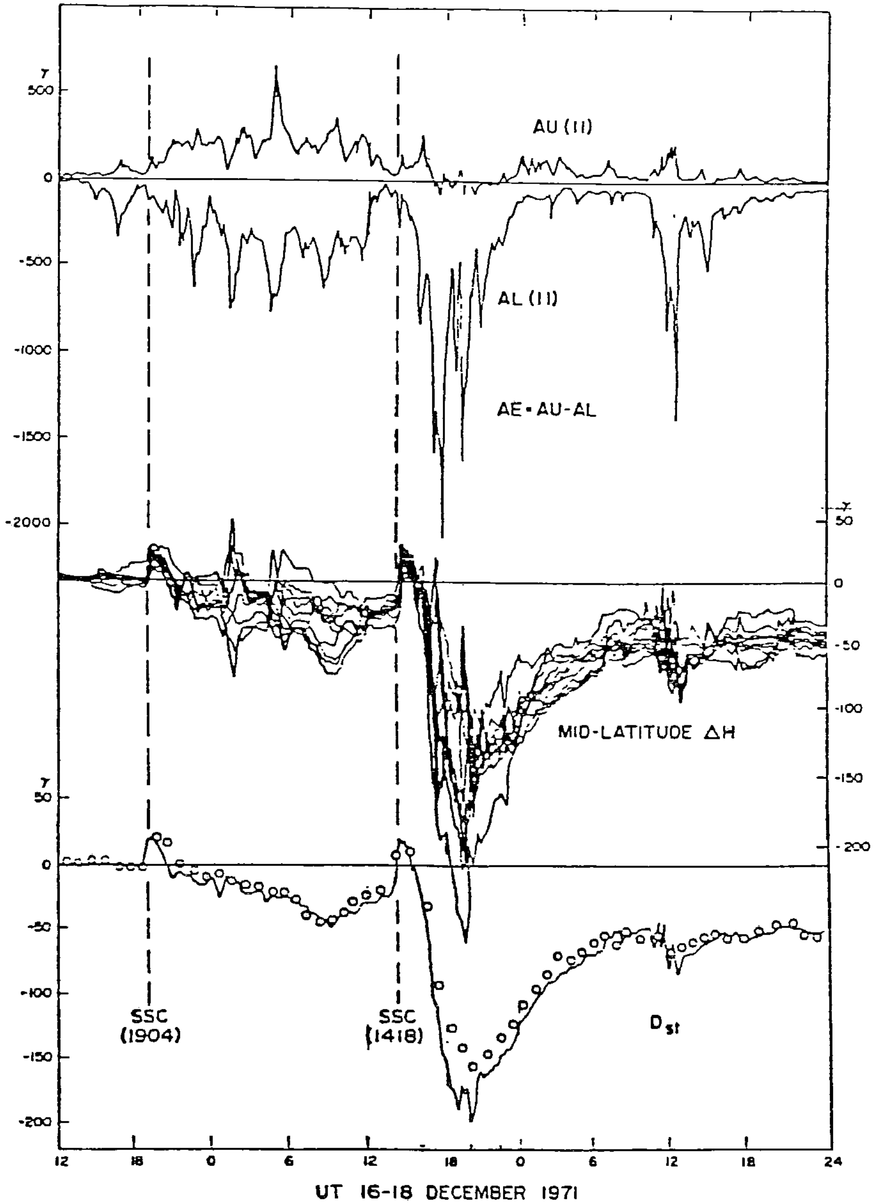

Fig. 3. The auroral electrojet indices, the superposed *H*-component records from ten mid-latitude observatories and the DST index (UAG).

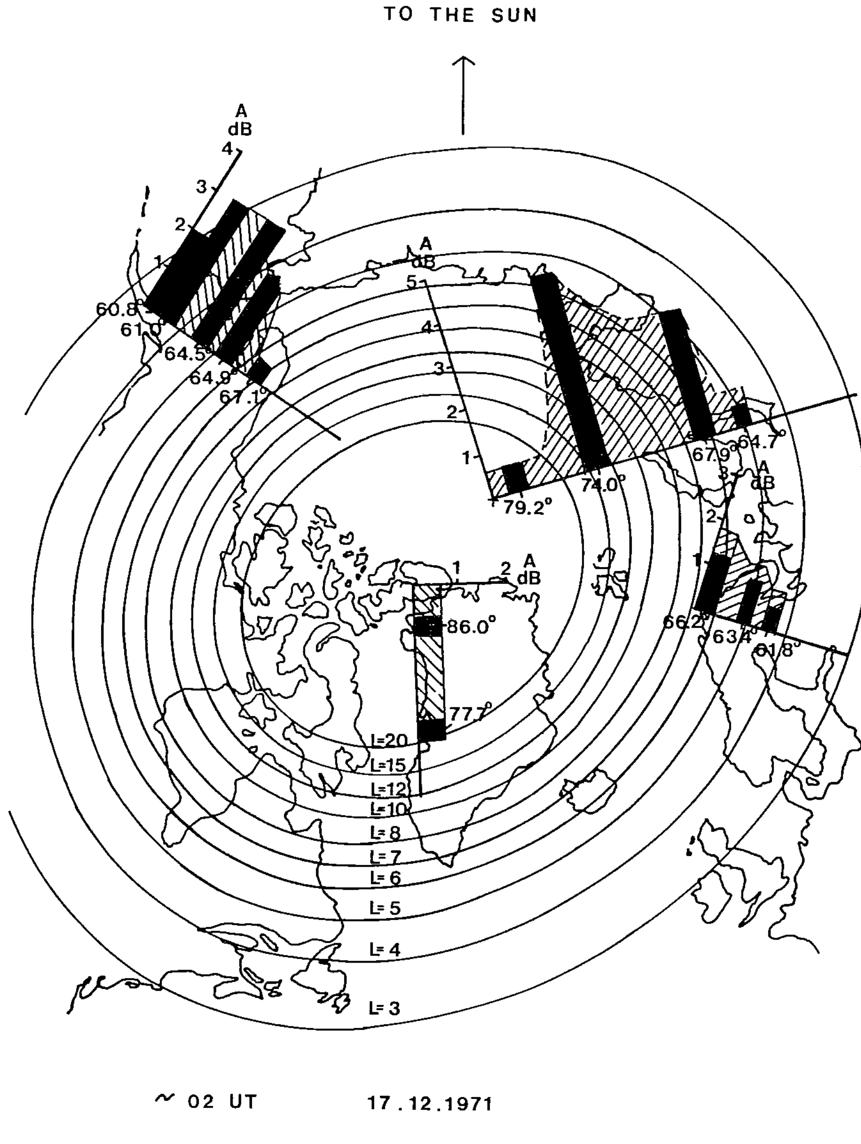

Fig. 4. Schematic figure for the variation of absorption on 17 December 1971 at about 02 UT.

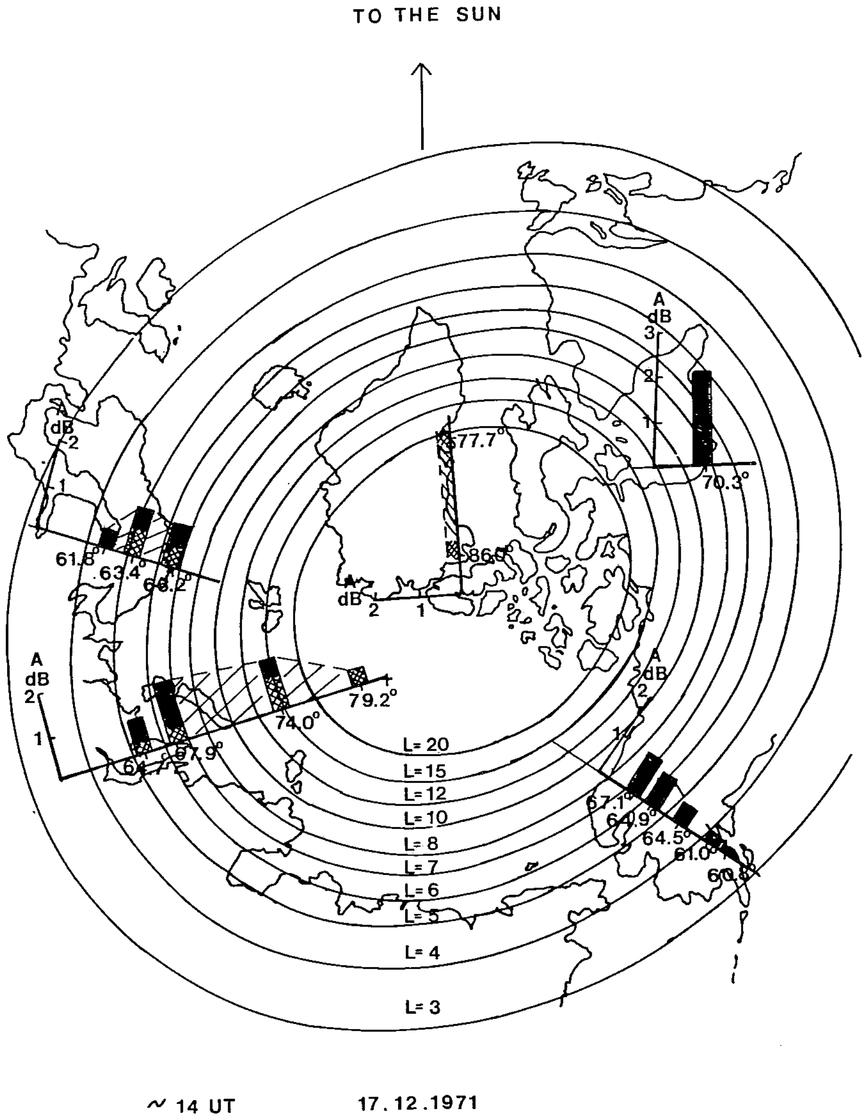

Fig. 5. Schematic figure for the variation of absorption on 17 December 1971 at 14 UT.

and Loparskaya, and it was perhaps seen in Fort Yokon and College, too.

The AA and SCA parts of the analysis are a little more complicated. The first SSC (sudden storm commencement) at 1904 on 16 December did not cause any clear SCA event. The only indications of the possible existence of SCA come from the weak absorptions of the order of 0.2 dB at Fort Yokon and Heiss Island. It cannot be clearly concluded that those events are related to SSC and, moreover, a typical SCA should occur at much lower L-values (HARTZ, 1963).

The first AA event is related to the magnetic substorm having onset at about 22 UT. The AE index maximum is at about 23 UT and the recovery lasts to about 2320 UT. The onset region is not clearly seen because the Scandinavian riometer chain is too much to the east. Otherwise the AA event is typical. The absorption maximizes in the Alaskan sector, where values of about 3 dB were recorded.

The second absorption event has a time coincidence with the AE index maximum at about 02 UT on 17 December and can be seen in the Alaskan, Scandinavian, and Soviet sectors. It contains rather peculiar features. The absorption measured by the chain Heiss Island, Dixon Island, and Anderma does not exhibit the usual AA type of features. Heiss Island is located at L-value about 14 and shows an absorption maximum over 4 dB, which can be compared with the 2 dB absorption at Dixon Island and that of 1.8 dB at Anderma. This latitudinal distribution of absorption is not usual for an AA event. The Alaskan sector also shows abnormal behavior, displaying a sharp onset and decay during the beginning phase of the PCA event. Since this is seldom seen during a normal AA event, we present also an other explanation for this event, which is discussed later.

The next two substroms commenced at about 04 UT and 09 UT on 17 December. These were accompanied by quite typical AA events, which are not considered further here.

The sudden commencement at 1418 UT caused a clear SCA, which was seen in Fort Yokon (1 dB), College (0.8 dB), Paxon (0.5 dB), Heiss Island (0.5 dB), Dixon Island (1.3 dB), Anderma (0.7 dB), Kevo (0.5 dB) and Sodankylä (0.4 dB). It was probably also measured in Apatity. The values are measured from the existing background absorption level. Some of the features of this event are similar to the normal SCA event (ORTNER *et al.* 1962), but it also has very interesting differences. The highest absorption values are obtained at relatively high L-values, as at Fort Yokon, Dixon Island and Kevo, but the normal SCA event occurs at much lower L-values, about L = 4–5. There was also a separate and very different event related to this SSC and seen at Churchill. A rather intensive absorption event rising to about 2 dB values commenced immediately after the SSC and behaved similarly in some respects to the substorm – related absorption events in the morning. One could consider it as a substorm-type absorption assuming that the substorm commenced immediately after the SSC. However we consider another explanation as well, discussed later, because the AE index behavior does not support the existence of an SSC-triggered substorm.

4. *Discussion*

The absence of the SCA event during the first SSC is probably related to the fact that the ring current system was very weak at that time, as can be seen from the simultaneous Dst values. Thus there was no suitable plasma population for the formation of a typical SCA event. According to SHUMILOV and ROMANDRUCK (1975), the appearance of an SCA event depends on the level of the Dst index before the SSC, because there must be a suitable plasma population in the magnetosphere to allow ring current formation and thence SCA-related precipitation upon compression of the magnetosphere during the SSC.

In connection with the second SSC, at 1418 UT, a clear SCA event occurred in the zone, that contained by the stations Kevo, Dixon Island and Fort Yokon; but no SCA-type absorption was seen inside the polar cap (*c.f.* Fig. 5). This SCA occurred at abnormally high L-values and differs essentially from those studied by BOROVKOV and SHUMILOV (1978). In a typical case the SCA inside the polar cap, is proportional to the pre-existing level of absorption as presented in Fig. 6.

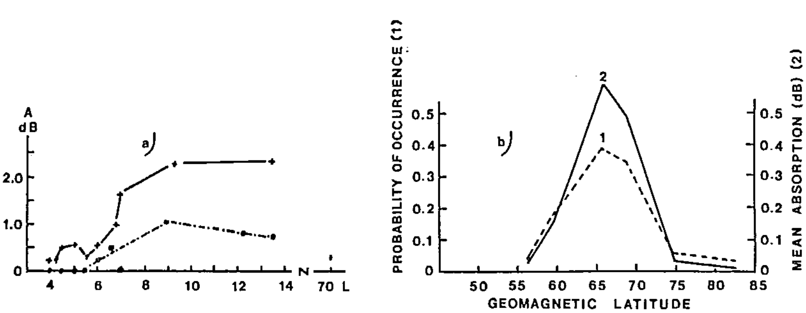

Fig. 6a. Increase of absorption caused by penetration of additional flux of solar protons during SSC on 13 June 1968 along axis L values. Absorption before SSC (o), additional absorption at the time of SSC (+). BOROKNOV, SHUMILOV, 1978.

Fig. 6b. The latitudinal distribution, amplitude and appearance frequency of electron SCA (HARTZ, 1963).

The SCA events can then be explained satisfactorily in terms of the betatron acceleration of solar protons already trapped in the magnetosphere. One possible way of explaining the present event is to assume direct solar proton penetration into the poleward boundary region of the auroral zone instead of acceleration of the magnetospheric particles in the SSC-related magnetospheric compression. This penetration would depend on good coupling between the magnetosphere and the interplanetary space. The tendered explanation thus requires that good coupling conditions existed and that either an energetic proton population arrived simultaneously with the low energy plasma causing the SSC or the rapid magnetospheric deformation caused favorable penetration conditions for an existing high energy proton flow. Both processes could take place together, of course. There is some indication that, simultaneously with the plasma front causing the SSC, a new energetic proton population did appear; for this could explain the event seen at Churchill (L-value 8). At that time Churchill was near the assumed cusp region location. This explanation of the Čhurchill event is also supported by the good temporal coincidence with the ATS-1 data and the duration of the event, and with the good quantitative agreement between the measured absorption of about 2 dB and the absorption of about 1.8 dB estimated from the available information on the proton flux and the formula given by POTEMRA and LANZEROTTI (1971).

The unusual behavior of the absorption at about 02 UT on 17 December is likewise probably, due to localized proton precipitation. Such precipitation sometimes occurs in the cusp region, the auroral zone, and the polar cap during the beginning phase of PCA, as was the geophysical situation at that time (MYNDS *et al.*, 1974, DURNEY *et al.*, 1972, KREMSER *et al.*, 1977, PEREJASLOVA, 1982). During the anisotropic phase of PCA there may be peaked absorption in the cusp region and in the auroral zone but not necessarily in the polar cap. This would seem to be the situation during this event. At that time Heiss Island was near the assumed cusp peak region (see Fig. 6 in PERESJALOVA 1982) and thus the high absorption at that station is related to the cusp region proton penetration. The corresponding absorption peaks seen in the Alaskan sector are PCA-related auroral zone peaks. The steep equatorward edge of these phenomena is typical and seen also in the satellite data (HYNDS *et al.*, 1974).

5. *Conclusions*

In the present analysis an attempt was made to identify the different absorption phenomena during a complicated magnetic storm, when practically all particle precipitation-based absorption events measurable by riometer were temporarily active.

Among the several usual AA events were a weak PCA and an SCA event. The present analysis suggests that, by using the network of riometer stations covering the active areas in one hemisphere, it is possible, even in the case of complicated phenomena, to separate processes to at least some degree on the basis of their behavior in time and space, and to use the information obtained to reveal the different particle precipitation processes.

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