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CORRELATION BETWEEN INTENSITIES OF AURORAL ABSORPTION AND PRECIPITATED ELECTRONS*

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ABSTRACT

Particle detectors on the Alouette I satellite and on rockets have been used to study the correlation between the intensity of electrons with energies greater than 40 keV and the intensity of auroral radio-wave absorption. The average relationship between the intensity of precipitated electrons and the amount of absorption is in approximate agreement with that expected from theory. For the same electron flux a day-to-night absorption ratio of about a factor of two is suggested by the measurements.

INTRODUCTION

Various groups have studied h.f. and v.h.f. radio-wave absorption in the ionosphere by different ground-based methods. Some of the temporal and spatial characteristics of the different types of absorption have been determined, but these ground-based measurements have not, in general, given definite results as to the nature of the incident radiation that causes the absorption, or about the height distribution of the absorbing layers. With the aid of rockets and satellites, these problems are being investigated. With rockets, the maximum absorption at high latitude is found to be in the range of 60–90 km. Assuming that the absorption is caused by energetic particles originating above (say) 1000 km, it can be shown that electrons must have energy of the order of 40 keV to penetrate to this region and protons must have greater than about 0.6 MeV. Recent rockets and satellites have been instrumented with particle counters covering these energy ranges and hence their data are suitable for comparison with radio-wave absorption measurements.

Using data from the Alouette I satellite, McDiarmid *et al.* (1963, 1964) have shown that there is statistical agreement between the frequency of occurrence of precipitated electrons and auroral absorption. They compared the percentage of satellite passes during which the flux of these electrons was above a given threshold with the percentage of time during which auroral absorption was greater than 1 dB and 0.5 dB. The latter observations were made by Hartz *et al.* (1963) and Holt (1963). In addition, Maehlum and O'Brien (1963), using Injun I data, studied the relation between trapped electrons and auroral absorption. Their observations will be discussed later.

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The present study was undertaken to determine in more detail the relation between auroral absorption and energetic electrons, using satellite and rocket data. The satellite data used were from Alouette I which moves in a nearly circular orbit at an altitude of 1025 km and with an inclination of 80°. Reduced data were available from the time it was launched in late September, 1962, till May, 1963. Rocket data were available from several flights of Black Brant II rockets launched at Fort Churchill. The absorption measurements were made using 30 Mc/s riometers at several Canadian stations and at College, Alaska.

DESCRIPTION OF DATA

The charged-particle detectors on board the Alouette I satellite have been described previously by McDiarmid *et al.* (1963). The details of significance to the present work concern the Anton 223 Geiger counter which is sensitive to electrons with energies greater than 40 keV. The counter has an angular aperture of 4.5° and is inclined at 10° to the spin axis of the satellite. The particles of most interest to this study are the precipitated electrons, i.e. those with pitch angles less than 45° to the local magnetic field, which are lost in the atmosphere at altitudes below 100 km where they could cause absorption. For comparison, trapped electrons are also considered. They have pitch angles in the range 90 ± 20° and mirror at altitudes between 700 and 1000 km. Particles having essentially one pitch angle are observed at any one time, but the changing orientation of the satellite allows all pitch angles to be sampled in a period of about two weeks. Particle counts are recorded at 10-second intervals corresponding to about a $\frac{1}{2}°$ latitude interval. Three data samples, centered on the time the satellite crossed the L shell defined by the midpoint of the riometer antenna pattern at 100 km, were averaged to give a data sample over a latitude interval comparable to the beam width of the riometer antennas. Satellite passes selected were those within 5° longitude of each riometer station. The few passes during which there was a flux of protons in the 1 to 7 MeV range were excluded.

Details of the riometer stations are given in Table I. For the Canadian stations, the absorption in decibels was measured at the time the satellite crossed the L shell of the station. College riometer records were obtained for some satellite passes; however, for much of the time only hourly tabulations

TABLE I

Details of the riometer stations—geographic coordinates, invariant latitude at the stations, frequencies of riometers, and antenna orientations

	Ottawa	Val d'Or	Cape Jones	Churchill	Prince Albert	College
Lat.	45.4	48.2	54.6	58.8	53.2	64.7 °N
Long.	75.9	77.8	79.6	94.2	105.9	147.7 °W
Λ	58.3	61.0	66.9	70.2	60.5	64.2 °N
Freq.	30	30	30	30	30	27.6 Mc/s
Ant.	Polar	Polar	Polar	Polar	Polar	Zenith

were available and an interpolated value was used. Additional riometers were included for detailed study of individual passes, viz. Ottawa (zenith antenna), Cape Jones (south and zenith), and Churchill (zenith).

RESULTS

Examples of the data are shown in Figs. 1 to 3. At the top of each figure are intensities of precipitated electrons for 10 second or $\frac{1}{2}$° intervals. At the bottom, absorption in decibels is shown over the antenna beam widths which are indicated approximately. The absorption is not corrected for the obliquity of the antennas. The data are plotted against the invariant latitude Λ defined by $\cos^{-1}\sqrt{(1/L)}$. In Fig. 1 there is seen to be an association between the

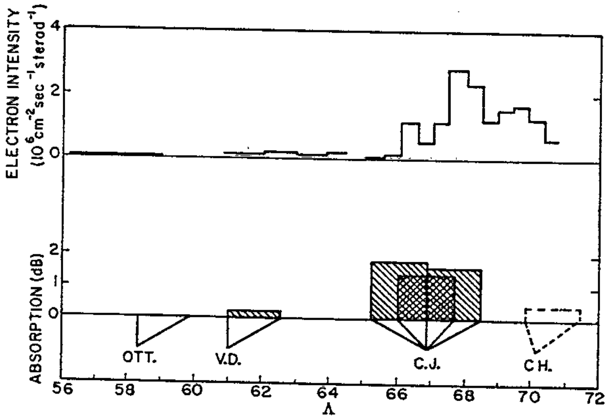

FIG. 1. Latitude variation of auroral absorption and precipitated electrons detected by the satellite at 1000 km on the L shell corresponding to each latitude. The cross-hatched regions represent absorption at stations which are within 5° of longitude of the satellite, while the dashed lines refer to stations which differ by more than 5° of longitude from the satellite. Stations are listed in Table I.

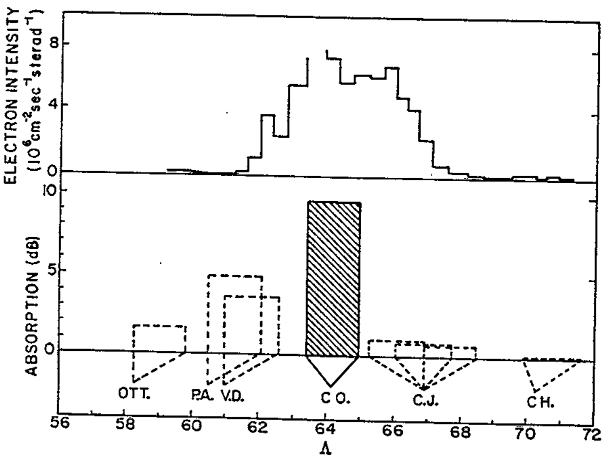

FIG. 2. Latitude variation of auroral absorption and precipitated electrons detected over College. (Dotted lines represent absorption at eastern stations.)

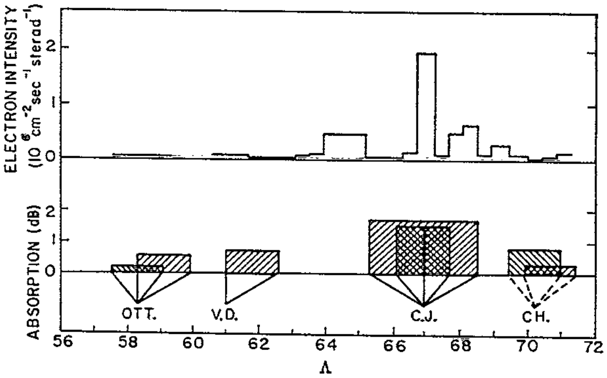

FIG. 3. Irregular electron flux detected by satellite passing over riometer stations.

precipitated electrons and the absorption; there is precipitation detected over the Cape Jones riometers when absorption was recorded and very little over the other stations, which showed a very low level of absorption. The second example (Fig. 2) shows the pass over College for which the most intense absorption was recorded during the interval studied. In this case, the absorption at the time of the pass was obtained. A point of interest here is the absorption at the other riometer stations (dotted) far to the east of the pass. Examples such as this suggest that the precipitation may extend for great distances in the east–west direction. Most passes showed a fair correlation, but Fig. 3 shows an example where the agreement is less obvious. There are orders of magnitude variation in the electron counts with no corresponding latitude variations in the absorption. In addition, there is some absorption recorded at Ottawa and Val d'Or although only a very low particle count is observed overhead.

It is difficult to provide an explanation for these discrepancies. If the observational techniques were more directly comparable, it would be possible to draw some conclusions. As it is, the particles are sampled over short time and space intervals along the line of flight whereas the riometer integrates absorption over wide antenna beam widths and a longer time period. With such an arrangement, it is not possible to distinguish between temporal and spatial fluctuations of the particles, or to determine to what extent the absorption follows them.

Figure 4 shows a summary of the observations—one point for each pass over each station. Open circles indicate that the ionosphere at 100 km over the station was sunlit, and closed circles, that it was in darkness. Both precipitated (4(*a*)) and trapped (4(*b*)) electrons are shown for comparison. (One pass included in 4(*a*) has a pitch angle greater than 45°. It has 5.9-dB absorption with a pitch angle of 48°.) Note that the particle detector counts either trapped or precipitated electrons, but not both simultaneously. In Fig. 4(*a*), the absorption $\geqslant 0.1$ dB is plotted according to the scale, but the intensity measurements below 5×10^3 cm^{-2} sec^{-1} sterad^{-1} correspond to low counting

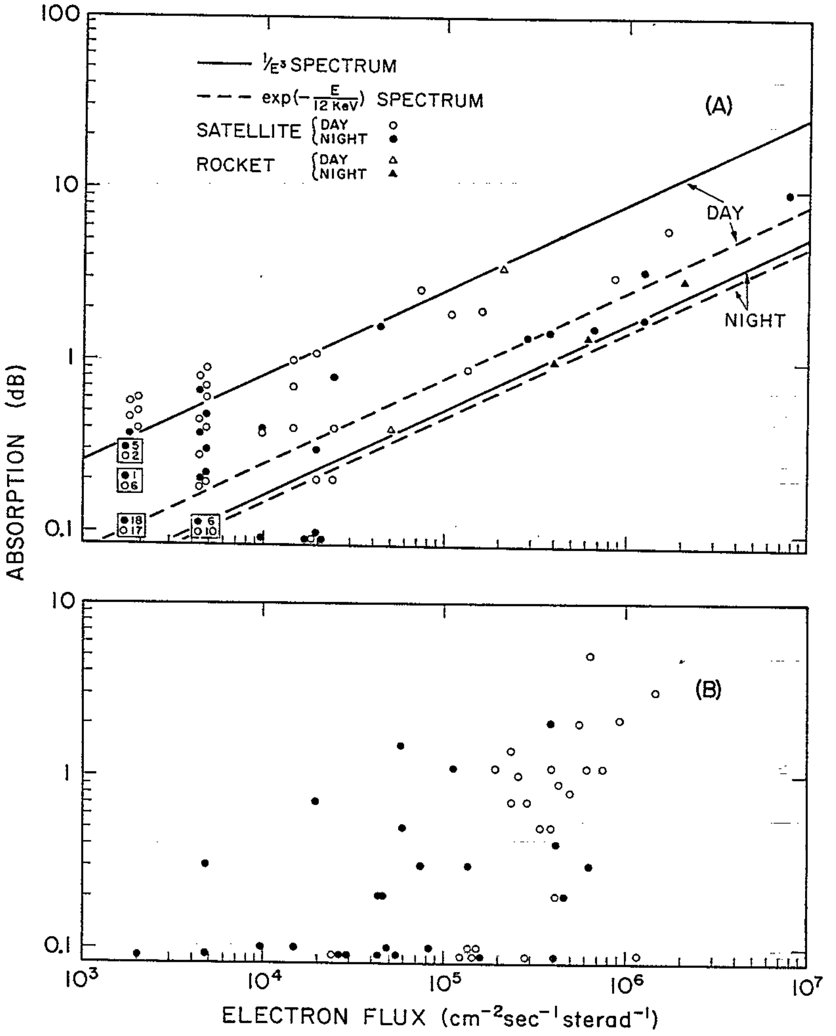

FIG. 4. Variation of absorption with electron flux for both precipitated (A) and trapped (B) electrons.

rates, for which the background correction is large, and hence the particle intensities as given by these points should be regarded as upper limits. A large number of passes, having both low absorption and low precipitated intensity, are grouped in boxes in the lower left corner of Fig. 4(*a*). This grouping of points does confirm that without an appreciable influx of electrons, there is very little absorption and vice versa. Absorption $\geqslant 0.2$ dB is present for all cases where the precipitated flux is greater than 2×10^4 cm^{-2} sec^{-1} sterad^{-1} and the absorption tends to increase with increasing flux.

Also shown in Fig. 4(*a*) are five measurements of electron flux obtained in rockets at altitudes around 100 km during times of auroral absorption at Fort

Churchill. Although the spread in the points is considerable, it can be seen that the measurements at 100 km are in reasonable agreement with the satellite measurements at 1000 km.

For trapped electrons at 1000 km (Fig. 4(*b*)), there are very few low fluxes. With higher fluxes, the absorption varies from zero to a level comparable with that produced by precipitation. This may be interpreted as a variation in the angular distribution of the particle flux at the satellite height; i.e. no absorption with a large trapped flux is consistent with marked anisotropy, while an absorption level comparable with that produced by precipitated electrons suggests an isotropic distribution. The observation differs from that of Maehlum and O'Brien (1963), who concluded that there was a high correlation between trapped and precipitated electrons during the disturbances they studied.

The present interpretation is consistent with rocket measurements of particle pitch angle distributions (McDiarmid and Budzinski 1964) which showed that in the auroral zone at altitudes above 100 km, angular distributions occur having varying degrees of isotropy ranging from almost complete isotropy in the pitch angle range 0 to 90° to essentially no isotropy over any appreciable pitch angle range (i.e. a distribution peaked near 90°).

The spread in the points for precipitated electrons shown in Fig. 4(*a*) may be due to a dependence of the absorption on day–night changes in the ionosphere or on variations in the spectrum of the electrons, or it may reflect a spatial variation in the incoming particle flux which the riometer averages out. The theoretical curves shown in Fig. 4(*a*) show the range of variations that might be expected from day–night effects and from different spectra. The curves, which were calculated assuming an isotropic angular distribution over the upper hemisphere, refer to day and night conditions and to two assumed energy spectra—a relatively hard differential spectrum of the form $1/E^3$ and a relatively soft spectrum of the form $e^{-E/12\ \mathrm{keV}}$. The calculated absorption is plotted against the directional intensity above 40 keV in the respective spectra.

The calculations for the $1/E^3$ spectrum use the ionization rates versus height given by Rees (1963) for an isotropic angular distribution, while for the $e^{-E/12\ \mathrm{keV}}$ spectrum, values of the ionization rate versus height as measured in a recent rocket flight (McDiarmid and Budzinski 1964) are used. The daytime calculations use the recombination coefficients given by Crain (1961) while the nighttime calculations use the coefficients found during the rocket flight mentioned above, which may or may not be typical of nighttime conditions.* For a given particle flux above 40 keV the absorption profiles are calculated using values of absorption per km per electron per cm^3 at a frequency of 27.6 Mc/s given by Holt (1963); these are then integrated over height to give the results shown in Fig. 4(*a*).

The calculated absorption versus intensity shows a relatively strong dependence on spectrum during the day, but very little dependence at night. This is

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*Crain has dealt in detail with the limitations of the assumptions underlying the use of an effective nighttime recombination coefficient.

because the nighttime recombination coefficients used become very large at altitudes below 83 km, and hence there is very little contribution to the absorption from below this height whatever the spectrum. If the effective nighttime recombination coefficient used, which it is emphasized is based on a single rocket flight, is not typical of nighttime conditions, then the day–night difference may not be as large as that calculated and the dependence on the nighttime spectrum may be appreciably greater than that shown in Fig. 4(*a*).

Particle spectrum measurements are not available at present from Alouette I and hence it is not possible to measure the dependence of the absorption on particle spectrum, and because of this and the fact that the number of data points is rather small, not very much can be said from the measurements about the dependence of absorption on day–night conditions. However, there appears to be a significant difference between the day and night points in Fig. 4(*a*); for instance, if it is assumed that the absorption (in dB) varies as $\sqrt{N}$ (N is the flux in particles cm^{-2} sec^{-1} sterad^{-1}), then the median line through the daytime points (using only those corresponding to fluxes appreciably above the background) in Fig. 4(*a*) is given by

$$\text{absorption} = 4 \times 10^{-3} \sqrt{N},$$

while the median line through the nighttime points is given by $2 \times 10^{-3} \sqrt{N}$.

SUMMARY

The statistical correlation between auroral absorption and precipitated electrons of energies greater than 40 keV has been confirmed with individual satellite passes. There is considerable spread in the measurements, but for a given particle flux the intensity of absorption falls approximately in the range expected. A moderate day–night difference is observed, but until simultaneous particle spectrum measurements are made it will not be possible to separate either day–night or spectrum dependences or to determine if all of the spread in the present measurements is caused by such dependences. For instance, it may be that the use of a narrow-beam riometer would give a significantly better correlation with the particle measurements.

The association between absorption and trapped electrons differs from the precipitated electrons in a manner that suggests that the angular distribution of the electron flux may vary from isotropic to a high degree of anisotropy.

ACKNOWLEDGMENTS

We wish to thank Professor R. Parthasarathy of the Geophysical Institute of the University of Alaska for providing the copies of the College riometer records.

NOTE ADDED IN PROOF: Geometrical correction factors for the obliqueness of the signals received by the riometer antennas have been provided by Dr. H. J. A. Chivers. This correction converts the measured absorption, for a particular riometer, to the equivalent absorption if all the signals received by the antenna traversed the absorbing layer at 90°. If these corrections were applied to the data used in this study the absorption values would be decreased; in particular, the absorption of the points in Fig. 4 would be reduced to about 0.65 of the value given. This would change the median lines quoted such that the daytime absorption would be represented by $2.6 \times 10^{-3} \sqrt{N}$ and the nighttime absorption by $1.3 \times 10^{-3} \sqrt{N}$ leaving the day–night ratio essentially unaltered.

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