THE HIGH-LATITUDE D-REGION DURING ELECTRON PRECIPITATION EVENTS

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The paper is concerned with the fluxes of energetic electrons entering the high-latitude atmosphere during auroral radio absorption events, and with their effect on the electron density in the auroral D region. We attempt to calculate the radio absorption during precipitation events from the fluxes of energetic electrons measured at geosynchronous orbit, and then consider the use of absorption measurements to indicate the magnetospheric particle fluxes, and the production rates and electron densities in the D region.

Although riometers have been operated at high latitudes since the International Geophysical Year of 1957-58, and despite a general acceptance that in the auroral zones they register the effects of energetic electrons which reach the D region during precipitation events, there has persisted a lack of hard evidence on the cause-and-effect relationships involved. It has not been clear, for example, which part of the electron spectrum causes most of the auroral radio absorption, or how exactly one can account for the absorption quantitatively from knowledge of the electron spectrum. Further, it has not been established whether radio-absorption measurements using riometers can serve to indicate the magnetospheric fluxes, the fluxes reaching the atmosphere, or the resulting electron density distribution in the lower ionosphere - though useful results from rockets have recently been published concerning the last point (Friedrich and Torkar, 1983; Miyazaki et al., 1981). Considering the advantages of the riometer technique as an auroral monitor (simplicity and continuity of operation, and suitability for use in a network), and an increasing tendency to combine riometer data with measurements from other ground-based techniques such as cameras and magnetometers in auroral studies, it would be a great advantage to have a more specific interpretation of riometer data. The comparison which we attempt here therefore has a practical aspect as well as the scientific one.

There are several links in the chain of events connecting magnetospheric particles with auroral radio absorption:

Particle fluxes at geosynchronous orbit
↓
Ionospheric particle precipitation
↓
Electron production rate
↓
Electron density profile
↓
Radio absorption profile
↓
Total radio absorption.

The ionospheric production rate has been calculated from the incoming spectrum of energetic electrons using the method of Rees (1963). The conversion of an electron-density profile to an absorption profile is straightforward given an appropriate neutral-atmosphere model, and the final integration to total absorption is trivial. Since there are uncertainties about the ionospheric loss rates linking production rate to electron density, we may be able to narrow the possibilities here; however, it turns out that there are also major effects in the relation between magnetospheric particles and those reaching the ionosphere.

Penman et al. (1979 a, b) attempted to calculate auroral radio absorption using particle data from the geosynchronous ATS-6. Those data included electron energies only up to 80 keV, and one result of the investigation was that although the 40-80 keV band was important in auroral absorption production, extrapolation of the spectrum suggested that the 80-160 keV band should also be important. Although reasonable agreement between calculated and observed absorption was obtained for some events, the smaller events presented greater difficulty.

The present study uses the medium-energy charged-particle spectrometer on GEOS-2, which covers the energy range 15-300 keV. The detector reception angle is rectangular, ± 2° by ± 3°, and the standard data processing sorts the fluxes into bins according to pointing angles (with respect to the geomagnetic field, whose orientation is known from the magnetometer) of 0° - 5°, then every 10°, up to 175° - 180°. There are 15 energy ranges, the energy being determined by pulse height analysis. The events studied were selected using the University of Lancaster riometer network in Scandinavia. To try to ensure that the GEOS footprint was close to the ground stations events were only used if there was similarity of time variation between the absorption event and the satellite particle flux, and if the absorption event was fairly uniform over the riometer network. The absorption was calculated from the measured 0° - 5° fluxes for 37 occasions between September 1978 and June 1979, two thirds of them during the winter months. The absorption measured at 30 MHz ranged between 0.1 dB and 6.0 dB. Initially, a height profile of the effective recombination coefficient, α_e, was assumed on the basis of published literature.

Calculations of the absorption assuming that the measured 0° - 5° flux is indeed the flux precipitated into the atmosphere give values that are about right for large events but are consistently over-estimates for the small events. Taking the ratio $R = A_{obs}/A_{calc}$, where A_{obs} and A_{calc} are respectively the observed and calculated absorption values, it is found that the variation of R with A_{obs} is well represented by a relation

$$R = 1.15 \tanh (A_{obs}/3.3).$$

The use of the function tanh is purely empirical and at this stage has no significance other than that it fits the data. The constant 1.15, whose value in any case depends on the magnitude of $\alpha_e(h)$, represents the fact that wide-beam riometer data tend to overestimate the true (or zenithal) absorption because of the obliquity of some of the received cosmic-noise signals. Its precise value is not germane to the present analysis. We note in passing that of the data points about one-third represent daytime (i.e. sunlit ionosphere) and two-thirds night (dark ionosphere), but the same procedure works equally well for both sets and it appears, therefore, that solar illumination has no significant effect.

It seems likely that the departure of R from a constant value stems from the assumption that the flux recorded by the GEOS detector within pointing angles 0° - 5° is the flux actually precipitated into the atmosphere. The theory of pitch-angle diffusion given by Kennel and Petscheck (1966) shows that there will be a distribution of pitch angles within and just outside the loss cone. Since the theoretical loss cone in our case is 2.6°, the detector will record particles outside the loss cone that do not reach the atmosphere. How serious this is depends on the pitch angle diffusion coefficient, D. If D is sufficiently large we have strong diffusion, with the loss cone re-filling rapidly and an almost uniform distribution of pitch angles. In this extreme the 0° - 5° flux indeed represents the flux in the loss cone. But if D is small, diffusion is weak and there will be a hole in the pitch-angle distribution, a depletion to which the ± 2° by ± 3° detector is relatively insensitive.

Calculations based on the Kennel and Petscheck theory have been carried out to predict the response of the detector as functions of pointing angle and diffusion coefficient, and by going back to the raw particle data examples have been found which tend to confirm that the loss cone is more depleted (relative to the region just outside the loss cone) for weak absorption events than for stronger ones.

For an α-type loss process the radio absorption should be proportional to the square root of the production rate. We therefore identify the term tanh $(A_{obs}/3.3)$ with $(F_p/F_m)^{1/2}$, where F_p is the flux precipitated (i.e. within the 2.6° loss cone) and F_m is the 0° - 5° measured flux. From this relation it is seen that F_p/F_m exceeds 50% if A_{obs} > 3 dB, but is only 10% if A_{obs} = 1 dB. To get the ratio over 90%, approaching an isotropic particle distribution therefore, the observed absorption must exceed 6 dB. Absorption events as large as this are infrequent. (During the whole IMS period of 4 years there were only about 35 events > 6 dB in Scandinavia). It seems, therefore, that most auroral absorption events occur under conditions of less than strong diffusion.

It is also possible to relate the magnitude of the absorption event to that of the diffusion coefficient. Values range between about 1×10^{-2} s^{-1} to 3×10^{-5} s^{-1} from strong to weak absorption events.

Having derived a method for calculating the radio absorption from particle fluxes measured at geosynchronous orbit, we now consider what absorption measurements using a riometer can tell us about magnetospheric particles and about D-region electron densities, and what reliance can be placed on such estimates. For this purpose the precipitating electrons are considered in energy bands 20-40 keV, 40-80 keV, 80-160 keV and 160-320 keV. Plots of the energy flux within a given band and over pointing angles 0° - 5° show the association with the measured radio absorption to be best for the 40-80 keV and 80-160 keV energy bands. The band 160-320 keV show no significant association, indicating that these particles do not usually produce much auroral absorption. For the 40-80 keV and 80-160 keV bands it appears that the measured auroral absorption provides a worthwhile indicator of the energy flux if the absorption exceeds 2 dB. Below that level it places an upper limit on the energy fluxes. Equations have been derived for these relationships, both for 0° - 5° and for trapped (85° - 95°) particles. No day-night difference is evident.

The procedure has been carried through to estimates of electron-ion production rates and electron densities, both as a function of height in the D region. As an example, the estimated production rate (Q) at 85 km is related to the 30 MHz absorption (A) by $Q = 4620\ A^2$, where Q is in cm^{-3} s^{-1} and A is in dB. The scatter of the data points suggests that a prediction using this formula would be correct to within a factor of 2 on 95% of occasions. In converting production rates to electron densities several profiles of the effective recombination coefficient, $\alpha_e(h)$, were tried, and the final choice (which is entirely consistent with published estimates of α_e) was influenced by reference to rocket data on D-region electron densities during auroral absorption events. The procedure eventually arrived at gives electron density profiles that agree reasonably well with the analyses of accumulations of rocket data by Friedrich and Torkar (1983) and by Miyazaki et al. (1981).

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REFERENCES

Friedrich, M. and K. M. Torkar (1983), J. Atmos. Terr. Phys., 4[illegible], [illegible]7.

Kennel, C. K. and H. E. Petscheck (1966), J. Geophys. Res., 71, 1.

Miyazaki, S., T. Ogawa and H. Mori (1981), Memoirs Nat. Inst. Polar Res. Japan., Special Issue No. 18, p. 304.

Penman, J. M., J. K. Hargreaves and C. E. McIlwain (1979a), Planet. Space Sci., 27, 445.

Penman, J. M., J. K. Hargreaves and C. E. McIlwain (1979b), Space Research, 19, 363.

Rees, M. H. (1963), Planet. Space Sci., 11, 1209.