

6.8 RELATIVISTIC MAGNETOSPHERIC ELECTRONS: LOWER IONOSPHERIC CONDUCTIVITY AND LONG-TERM ATMOSPHERIC VARIABILITY

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Long-term (1979-88) observations of relativistic electrons in the earth's outer magnetosphere show a strong solar cycle dependence with a prominent intensity maximum during the approach to solar minimum (1983-85). This population therefore closely corresponds to the presence of high-speed solar wind streams emanating from solar coronal holes. Using a numerical code, we have calculated the precipitating electron energy deposition in the earth's upper and middle atmosphere. Observed events (typically persisting several days) would have maximum effect in the 40-60 km altitude range with peak energy depositions $> 110 \text{ keV/cm}^3\text{-s}$. We suggest that this electron population could play an important long-term role in modulating lower D-region ionization and middle atmospheric ozone chemistry. We describe methods of observing middle atmospheric and lower ionospheric effects of the electrons including balloon, riometer, and space-based ozone sensor systems. A particularly promising approach may involve the monitoring of global Schumann resonance modes which are sensitive to global changes in the properties of the earth-ionosphere cavity. Present work indicates that Schumann resonance properties are moderately correlated with the flux of precipitating relativistic electrons thus offering the possibility of continuously monitoring this aspect of magnetosphere-atmosphere coupling.

Figure 1. (Following page) Summary of measurements in the 3 - 5 and 5 - 7 MeV energy range for S/C 1979-053 and S/C 1982-019, with data shown as the daily flux averages (electrons/cm²-s-sr-MeV). This highly compressed format shows the long-term behavior of the relativistic electron components from 1980 to 1988. The 5 - 7 MeV channel has been offset downward by one decade in flux for clarity of presentation. No background rate has been subtracted from the counting rates used. Thus, one can observe the smooth, systematic variation of the minimum flux level in each of the energy channels. As discussed previously [Baker et al., *J. Geophys. Res.*, 91, 4265, 1986; Baker et al., *Geophys. Res. Lett.*, 14, 1987] we attribute the minimum count rate in each channel to a galactic cosmic ray component which escapes elimination by the SEE particle analysis system. As shown in our previous analysis, the background variation is plausibly associated with the several hundred MeV/nucleon cosmic ray flux. A variety of analyses and comparisons with other concurrent measurements shows that the large, spiky enhancements above this background level are due almost exclusively to relativistic electron enhancements.

A notable feature of the data is that there were very few significant electron enhancements (i.e., peaks well above background) during 1980. In contrast from late 1981 through early 1986 there were numerous, intense electron spikes. In 1984 and 1985, these increases were particularly intense and frequent -- so much so as to give almost a continuous presence at 6.6 R_E. By late 1986, the relativistic electron flux was waning and individual enhancements were not nearly as large as during 1982-85. A detailed comparison with average solar wind properties shows that relativistic electron enhancements tend to occur only following the passage of solar wind streams $V \geq 600 \text{ km/s}$. thus, the entire run of SEE data is consistent with the earlier findings that very high-energy electrons occur only on the declining edges of high speed solar wind stream structures.

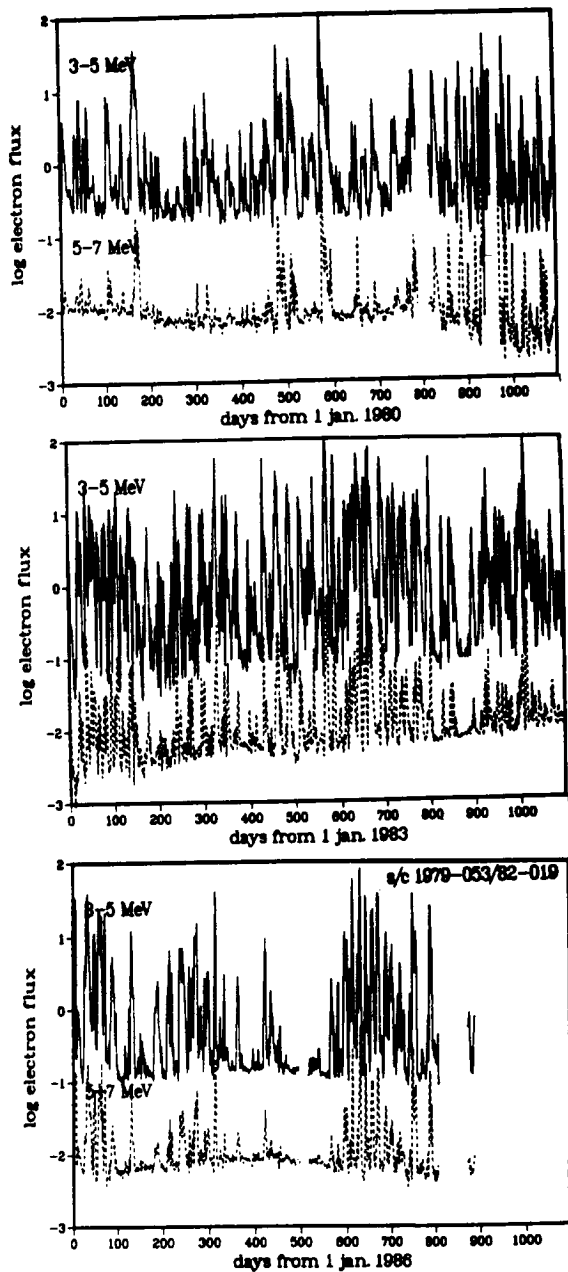


Figure 1.

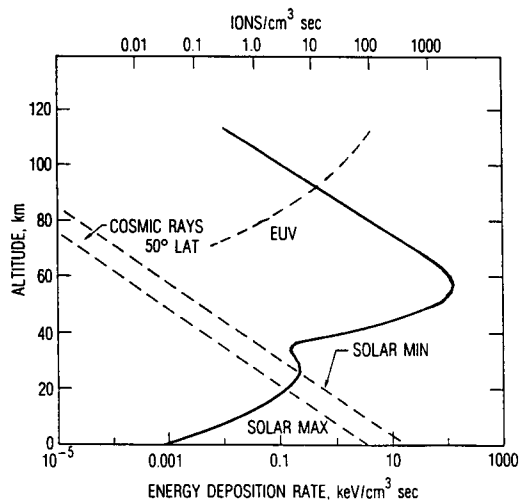


Figure 2. The principal loss mechanism for relativistic electrons in the earth's radiation zone is precipitation into the atmosphere. Normal auroral electron precipitation is confined to a fairly narrow latitudinal band (inv. latitude $\sim 68 - 72^\circ$) i.e., the auroral oval itself. Furthermore, the 20 - 100 keV auroral electrons penetrate only down to ~ 100 km altitude before they are stopped. Unlike these low-energy electrons, multi-MeV electrons are very penetrating. In fact, the ≥ 1 MeV electrons examined here are capable of penetrating down to the lower D region and into the upper stratosphere. The Bremsstrahlung X-rays that such electrons produce when interacting with atmospheric constituents can penetrate even more deeply, and both the primary electrons and the secondary photons can be significant ionization sources.

In order to quantify energy deposition aspects, we have used a numerical transport code to study the interaction of relativistic electrons with earth's atmosphere and ionosphere. The code provides a realistic 1-D representation of vertical atmospheric densities and cross sections. We take as input the measured electron spectrum at $6.6 R_E$ for a particular relativistic electron enhancement, viz., a modest event observed in mid-June 1980. We characterize the high-energy component of this event (≥ 1 MeV) with a spectral from $dJ/dE = 10^3 \exp(-E/587 \text{ keV})$ and use this spectrum in the model atmosphere code. The figure shows the results of this calculation and illustrates energy deposition rate versus altitude. The solid curve shows our estimate of the relativistic electron energy deposition. This calculation shows the very large energy deposition rate in the 40 - 70 km altitude range that occurs during the peak of an electron precipitation event. This deposition is due to the primary electron energy loss. The secondary peaks at ~ 25 km altitude are due to the Bremsstrahlung energy deposition. Even this photon deposition is fairly significant.

For comparison purposes, we have included the energy deposition rates for galactic cosmic rays (both at solar maximum and at solar minimum) at 50° geomagnetic latitude. Near the upper part of the figure we also show the other significant source of ionizing radiation, i.e., the solar extreme ultraviolet (EUV). As can be seen from the figure, at mesospheric and upper stratospheric heights, the relativistic electron energy deposition is dominant during the peak of a multi-MeV precipitation event. Since we are discussing ionizing radiations here, we can use the standard value of 35 eV per ion pair to estimate the ion production rate. We show this scale along the top of the figure. We see that the peak rate is $1000 - 3000 \text{ ions (cm}^3\text{-s)}^{-1}$ at ~ 50 km altitude.