PRELIMINARY IONOSPHERIC AND AIRGLOW RESULTS OF PROJECT ISAAC

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Abstract: The research vessel S. A. Agulhas undertook a voyage in the region of the South Atlantic Anomaly during June/July 1983. In the present paper a preliminary analysis of the ionospheric and airglow observations made from the ship is given. It was found that the ionization density in the *F* layer in the Anomaly is larger at its maximum near noon than that at a station at a comparable latitude outside the Anomaly, but that its minimum value at night is considerably smaller.

Particle types of sporadic *E* ionization were encountered much more frequently at night in the Anomaly than outside, auroral, particle, flat and retardation types all being observed, the auroral type reaching a critical frequency for the ordinary ray of 7 MHz on one occasion.

391.4 nm airglow was observed to coincide with particle sporadic *E* traces on two occasions, but on one night this airglow emission was observed in the absence of sporadic *E* ionization. It is concluded that there is definite evidence that particles play a more important part in ionizing the *E* region in the Anomaly than at comparable latitudes elsewhere.

1. Introduction

It has been recognized for many years that the atmosphere over the South Atlantic Ocean may show unusual aeronomic phenomena because of the precipitation of charged particles there. Gledhill (1976) has reviewed attempts to measure these effects. Since then the publication by Gledhill and Hoffman (1981) of the results of four years of measurements in the South Atlantic Anomaly by the satellite Atmosphere Explorer-C has given a quantitative basis for the prediction of the magnitude of the expected effects. As a result of such estimates, Project ISAAC (International South Atlantic Anomaly Campaign) was undertaken in June/July 1983, with the cooperation of groups in Argentina, Brazil, Chile, France, Japan, the U.K., the U.S.A. and South Africa.

The present paper is a composite of two read at the SCAR Workshop on Energetics and Dynamics of the Middle and Upper Atmosphere at High Southern Latitudes, held at Bremerhaven in September 1984. It reports the preliminary results of the ionospheric and airglow measurements made on the research vessel S. A. Agulhas during the ISAAC cruise.

2. Observations

The S. A. Agulhas carried a Barry Research Vertical Incidence Chirpsounder, modified for microcomputer control, and three digital tilting-filter airglow photometers, measuring 391.4, 557.7 and 630 nm radiation respectively in the zenith. She left Cape Town at 0900 UT on 29 June 1983 (1100 S. A. Standard Time) and sailed directly to Gough Island (40°S, 10°W), arriving at 0600 UT on 4 July. She sailed again at 0830 UT on 5 July and went directly to a point at 30°S, 45°W, where she turned and followed a course to a point at 42°S, 38°W. Here the homeward voyage was commenced, the track leading to Inacessible Island (37°S, 13°W), back to Gough Island and from there to Cape Town on a more southerly route than that of the outward journey, arriving at 1300 UT on 22 July. The route, with dates indicated, is shown in Fig. 1, which also shows the regions of high energy electron precipitation observed by GINZBURG *et al.* (1962) from a Soviet satellite and of lower energy electron precipitation delineated by GLEDHILL and HOFFMAN (1981).

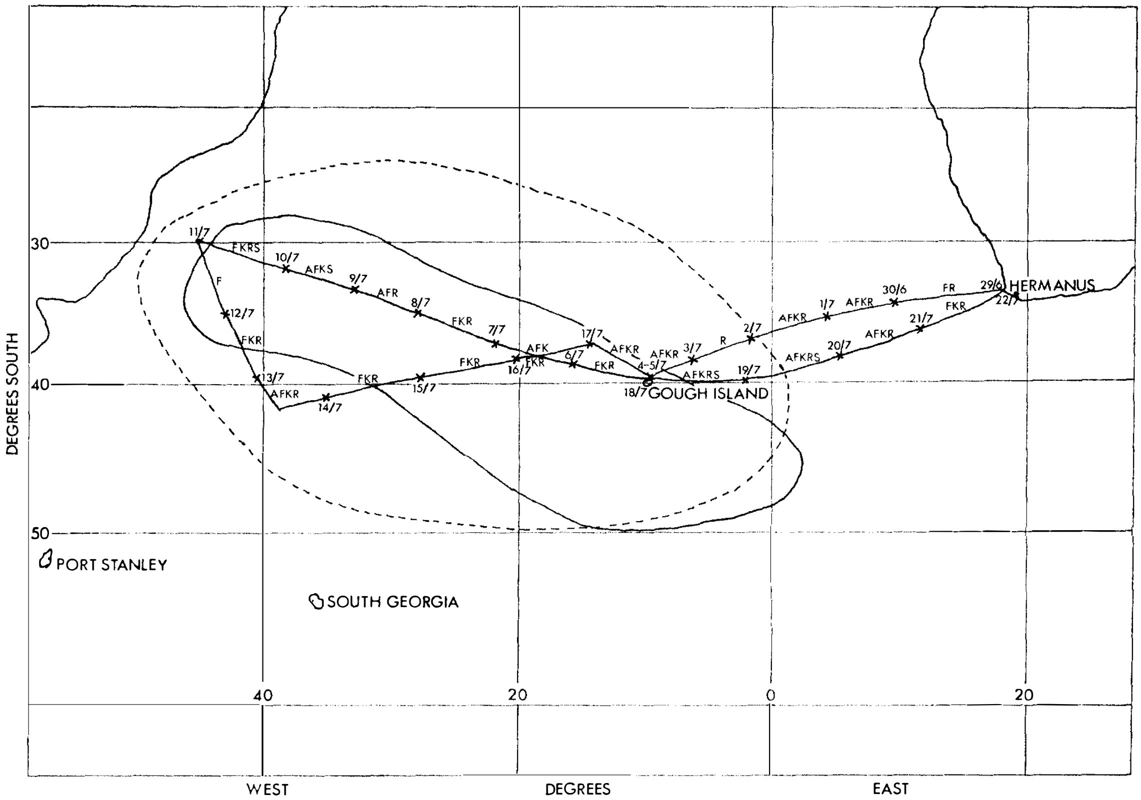

Fig. 1. The South Atlantic Ocean, showing the contours indicating the regions of precipitation of high energy (---) and low energy (—) electrons preivously reported and the route taken by the S. A. AGULHAS during Project ISAAC. The ship's noon position is indicated for each day of the voyage, as well as the sporadic E types observed during the nights.

Ionograms were recorded photographically at 15 min intervals throughout the cruise, except for two short periods in the vicinity of Gough Island when the antenna had to be lowered to allow loading and unloading operations to be carried out. In all, 2128 ionograms were recorded, only 56 being lost in the above way, and during urgent radio transmissions to and from the ship.

The airglow photometers were operated on 14 nights, some of which were cloudy and of little value. From 15 July onwards recordings were curtailed by moonrise. The data on five nights were good, and on three of these significant 391.4 nm airglow was observed, in association with particle type sporadic E ionization.

The ship also carried a 30 MHz riometer, supplied by Prof. P. H. STOKER, of Potchefstroom University, but the ambient noise level on the ship unfortunately made the records useless.

3. Ionosphere

3.1. The F region

Figure 2 shows the maximum and minimum values of f_oF_2 recorded on each day of the cruise (circles) and, for comparison, the corresponding values for Hermanus (34°S, 19°E), which lies at roughly the mean latitude of the cruise. It is seen that the maximum f_oF_2, near noon is practically always greater than that at Hermanus, the average being (8.95±0.15) MHz for the ISAAC values and (8.29±0.08) for Hermanus. The lowest f_oF_2 recorded, in the early morning, shows the opposite behaviour, with the ISAAC values consistently lower than those for Hermanus. The low early-morning values observed on the S. A. AGULHAS, often well below 1.5 MHz, were one of the immediately striking phenomena on the cruise. The mean ISAAC figure is (1.70± 0.06) MHz, while that for Hermanus is (2.24±0.05) MHz.

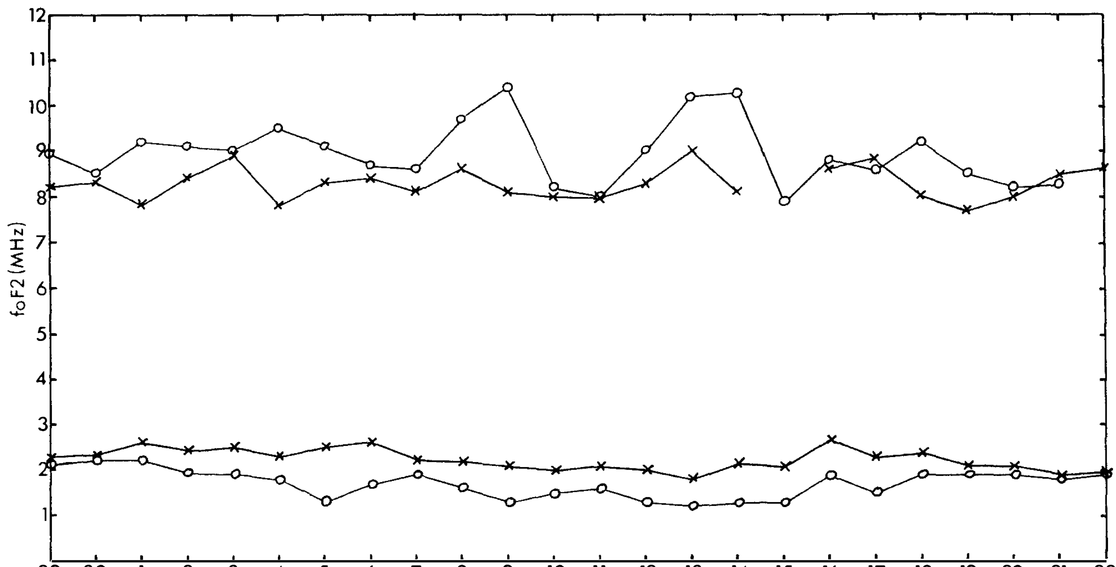

Fig. 2. The maximum and minimum values of f_oF_2 recorded on each day of the cruise (circles) and the corresponding values for Hermanus (crosses).

The higher values of f_oF_2 during the daytime are in accordance with the expectation that the precipitating electrons would leave some energy in the F region as they pass through. This is not what is shown by the minimum nighttime values, however. We are at present unable to explain this striking effect in the F region of the Anomaly.

3.2. The E region

In view of the hardness of the electron spectrum it was anticipated that the main ionospheric effect would be to produce particle-type sporadic E layers, especially at night, when the normal solar ultraviolet and X-ray flux is absent. This expectation was amply confirmed by the ionograms. Sporadic E ionization of the particle produced types a, auroral type; k, particle type; r, retardation type, was observed on 16 of the 22 nights of the campiagn, surprisingly including the nights when the ship was in the vicinity of Cape Town, usually regarded as lying outside the Anomaly. Figure 1 indicates the ship's positions and the types of sporadic E observed during the voyage. The period 12–16 July was especially interesting, showing f_oE_s values as high as 8 MHz.

To illustrate the results of the campaign in respect of the sporadic E region, we show f-plots in Fig. 3 for the E layer only.

The ordinary ray critical frequencies, f_oE_s, are indicated by dots on the lower portion of each section of the figure and the sporadic E types are shown at the top. The usual convention is used: A, K and R as above, and also S (slant type) and F (flat type), which is often, though not necessarily, due to particle precipitation.

There are many striking features of the plots. In the first place, the prevalence of sporadic E ionization of particle origin is far greater than at comparable latitudes elsewhere. The crosses in Fig. 3 indicate the critical frequencies of sporadic E ionization at Hermanus during the periods concerned. The very much smaller frequency of occurrence is typical of all the nights of the campaign. All the sporadic E ionization observed at Hermanus was f-type.

It is also evident that auroral type E_s appears when f_oE_s reaches its peak values, usually when it exceeds 3 MHz. There is an especially intense period of a-type E_s between 2200 UT on July 13 and 0015 on July 14 (Fig. 3E), with the maximum f_oE_s reaching 7 MHz. On some occasions two types of particle-produced E_s were present simultaneously, *e.g.* 1915 to 2030 UT on June 30, (Fig. 3A), 2215 to 2300 UT on July 13, (Fig. 3E), etc. These were visible on the ionograms as distinct traces.

We deduce from the above that there was a large amount of particle-induced sporadic E ionization on most nights of the voyage, much more than would be expected at comparable latitudes outside the South Atlantic Anomaly, as is shown by the Hermanus comparison. Although the geographic distribution of particle sporadic E was more widespread than anticipated, even occurring close to Cape Town, the Hermanus values show that it fell off rapidly to the east of the Anomaly. The next stage in this analysis is to compare our results with those obtained by our colleagues at Port Stanley, in Argentina, Brazil and Chile, to the west of the Anomaly.

4. Airglow

The three tilting-filter photometers counted photons, usually over a 16-s period, at each of a number of steps as the filter was tilted to scan across the spectral line. The number of steps was variable, and was chosen to give the best resolution of the wanted emission against the background, consistent with a reasonable duration of each cycle. The dark count was checked at the end of each cycle. In general, a complete scan took 10 min, with a reset time of 1 min. The output was registered digitally on a printer and also on strip chart.

The filters and photometers were carefully calibrated against a standard lamp,

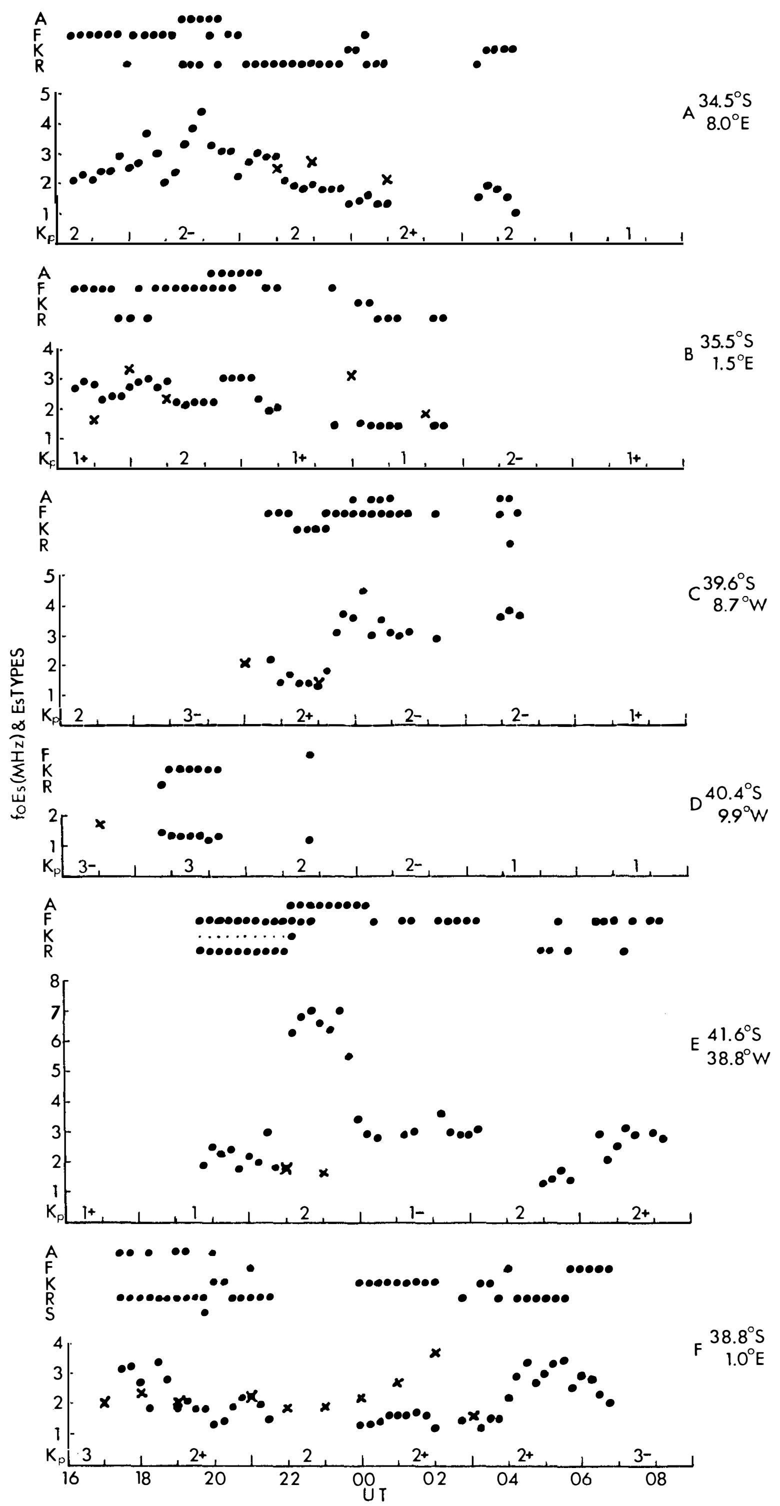

Fig. 3. *Values of f_oE_s observed on the S. A. AGULHAS (dots) and at Hermanus (crosses). The upper panels indicate the E_s types, while the three hourly Kp-indices are shown above the abscissa axes. The ship's midnight position is shown on the right hand side of each section. The dates are: A, June 30/July 1; B, July 1/2; C, July 3/4; D, July 4/5; E, July 13/14; F, July 19/20.*

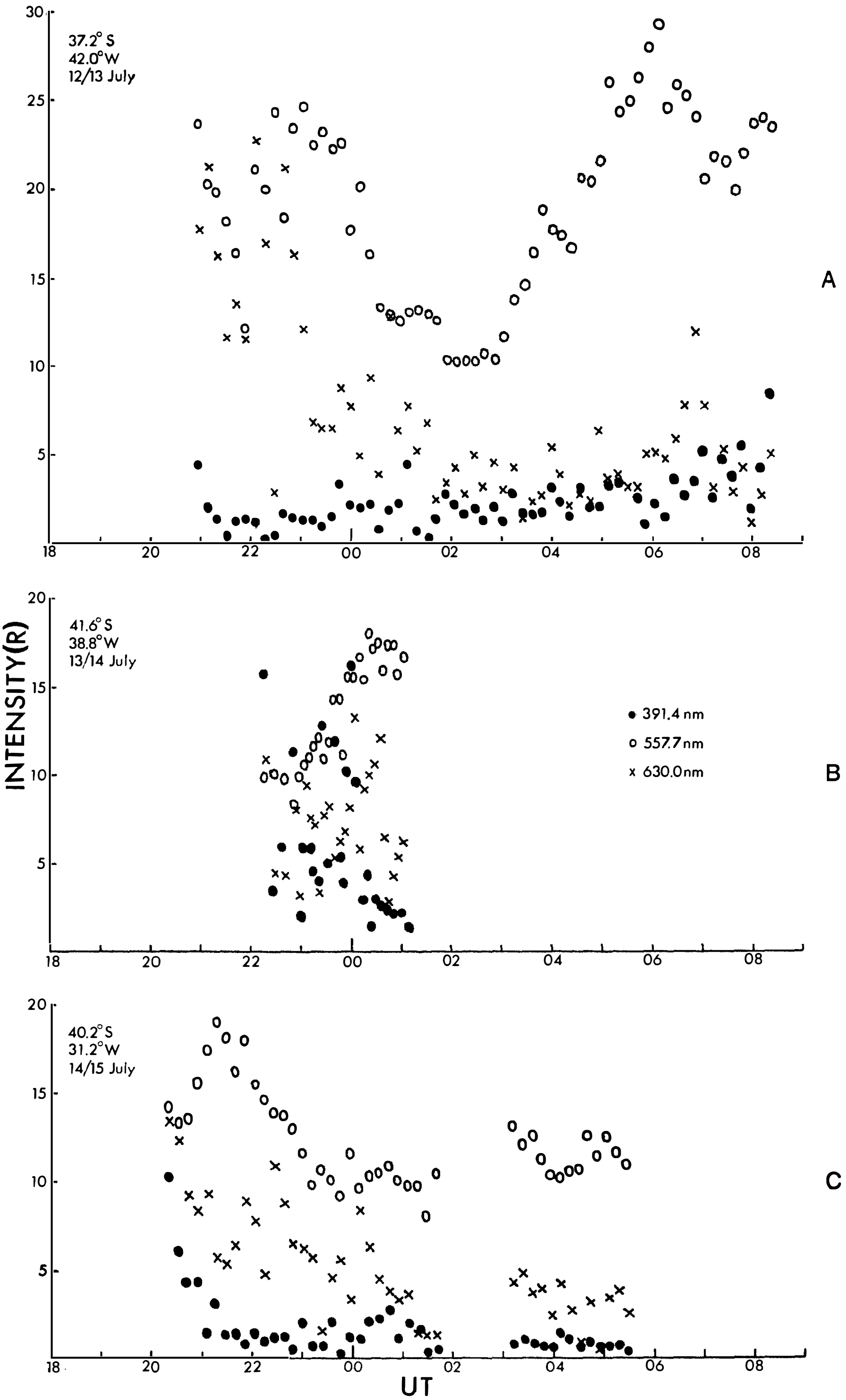

Fig. 4. The intensity of airglow 391.4 (dots), 557.7 (circles) and 630.0 (crosses) emissions as observed on the ship, accompanied by the dates and the ship's midnight position.

using a magnesium oxide coated screen and against low-brightness sources which had been calibrated at the International Workshops in Edinburgh and Lindau. The filters were calibrated at all tilt angles used in the experiments. Filter characteristics at normal incidence were as follows:

391.4 nm, bandwidth 1.7 nm, peak transmission 30%,
557.7 nm, bandwidth 0.5 nm, peak transmission 28%,
630.0 nm, bandwidth 0.8 nm, peak transmission 48%.

Since the N_2^+ radiation at 391.4 nm has such a high excitation energy from the ground state of N_2 (18.75 eV) it is a good diagnostic for particle precipitation at night. In this preliminary analysis we shall therefore place our emphasis on this emission. Of the five nights, during which reliable airglow records were possible in good visibility, only three showed significant intensities of 391.4 nm emission. The figures for these nights are shown in Fig. 4. The values for the intensities of 557.7 and 630 nm intensities are also included. We may dispose of these at once by noting the very low intensities, which are compatible with the small values of f_oF_2 observed with the ionosonde. We shall return to the discussion of these emissions in a later paper.

The larger values of the intensity of the 391.4 nm radiation are shown in Fig. 4B, between 2217 UT on July 13 and 0015 UT on July 14. Unfortunately, data are not available before 2217, when the intensity was already high. These peak values coincide exactly with the maximum in f_oE_s noted in the previous section, confirming charged particle precipitation as the source of the sporadic E ionization.

The peak in 391.4 nm intensity at about 0110 UT on July 13 (Fig. 4A) is much smaller and does not appear to coincide with any sporadic E ionization, but the comparable one at about 0100 UT on July 15 (Fig. 4C) agrees well with the sporadic E layer observed by the ionosonde.

The quantitative aspects of the relationships between ionization, airglow and energy input by precipitating electrons are at present being investigated. An interesting preliminary result is that the average level of 391.4 nm emission observed during the campaign, when weather and moon permitted observations to be made, was about 2 rayleighs. Using TORR and TORR's (1984) modification of KASTING and HAYS's (1977) expression relating precipitated energy density to N_2^+ emission, this corresponds to 2.4×10^{-3} erg cm^{-2} s^{-1}, which compares favourably with the value in the area of the ISAAC cruise of about 3–3.5×10^{-3} erg cm^{-2} s^{-1} found by GLEDHILL and HOFFMAN (1981).

The results of the ISAAC cruise support the conclusion of GLEDHILL and HOFFMAN (1981) that the intensity of electron precipitation in the Anomaly is *less* during magnetically disturbed periods than it is when Kp is low. On all the occasions shown in Fig. 3 Kp was 3 or less. During four periods, not shown, it reached 4 (July 7), 5 (July 12/13), 4+(July 16/17) and 5−(July 17/18). Auroral type E_s was not observed during any of these periods. The mean f_oE_s for the 460 nighttime ionograms when Kp was 3 or less was (2.23 ± 0.05) MHz and that for the 76 values when Kp exceeded 3 was (1.62 ± 0.09) MHz.

Acknowledgements

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