Pergamon

Adv. Space Res. Vol. 20, No. 6, pp. 1165–1168, 1997

Printed in Great Britain
0273-1177/97 $17.00 + 0.00

PII: S0273-1177(97)00766-7

JOINT IMAGING RIOMETER–INCOHERENT SCATTER RADAR OBSERVATIONS: A FOUR-DIMENSIONAL PERSPECTIVE ON ENERGETIC PARTICLE INPUT TO THE AURORAL MESOSPHERE

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ABSTRACT

The application of the cosmic noise absorption technique using riometers has markedly improved in recent years with the introduction of systems with multiple narrow beams ('imaging' riometers). One such instrument, using 49 beams, has been operating at Kilpisjärvi, Finland, since September 1994. The beam pattern encompasses the location of the EISCAT incoherent scatter radar facility, offering prospects for studies using simultaneous joint observations. The radar can monitor the height and time variation of electron density in the D-region while the imaging riometer data provide the horizontal distribution of energetic charged particle precipitation. The latter is essential in order to correctly identify whether variations in the radar measurements are truly temporal, or actually spatially-confined structures moving through the radar beam. We present examples of such joint observations, and discuss the advantages of this approach compared with the capabilities of the two individual techniques alone.

INTRODUCTION

The precipitation of energetic charged particles into the Earth's auroral regions is highly variable in both space and time. The flux-energy distribution of the particles adds a further degree of complexity to this picture. Interpreting measurements as a function of these variables, within a proper context, is one of the challenges of modern space geophysics.

The cosmic noise absorption technique, using riometers, detects auroral precipitation events when the particle population contains significant electron fluxes with energies of several 10's keV or more (Collis *et al.*, 1984). We consider here the consequences of energetic electron precipitation in association with auroral events. (Proton (PCA) precipitation merits a separate study.) Statistical analyses of absorption events from networks of riometer stations have helped build up a picture of the large-scale energetic particle precipitation at auroral latitudes. However, the wide antenna beam of a standard riometer, subtending approximately 100 km horizontally in the D-region, means that small-scale features cannot be accurately monitored. The introduction of systems using multiple narrow beams (imaging riometers, IRIS) has improved the application of the technique in recent years (Detrick and Rosenberg, 1990). The relatively small beam-widths, and relatively large number of beams (~13°, and 49, respectively, for the Kilpisjärvi IRIS considered below), allow images of the horizontal distribution of radio absorption to be constructed. For the Kilpisjärvi system the spatial coverage is 240 km square at 90 km altitude (a commonly assumed height for the peak of the absorbing layer). IRIS measurements alone provide no height-dependent information. For this, we turn to high resolution

D-region electron density profiles from incoherent scatter radar. In the present paper we combine simultaneous observations from both techniques.

INSTRUMENTS, OBSERVATIONS, RESULTS

The Imaging Riometer at Kilpisjärvi

A 49-beam IRIS was installed at Kilpisjärvi, Finland (69.05°N, 20.79°E) in August 1994 (Hargreaves *et al.*, 1996). The system operates at 38.2 MHz and measures the cosmic radio noise power in each beam direction every second. Kilpisjärvi is 83 km from the transmitter site of the EISCAT incoherent scatter radar, which is well within the IRIS field-of-view (Collis and Hargreaves, 1996).

The EISCAT Incoherent Scatter Radar

The EISCAT incoherent scatter radar facility (69.6°N, 19.2°E) is capable of routine measurements of D-region electron density with altitude resolutions of typically 1-3 km and time resolutions 5-10 sec. The flux-energy distributions of the precipitating charged particles that produce the observed electron density profiles can be estimated using several algorithms (e.g. Hargreaves and Devlin, 1990; Fujii *et al.*, 1995). Quantitative tests of these 'inversion techniques' give some confidence as to their reliability (Fujii *et al.*, 1995). Their application rests on assumptions for the neutral atmosphere, for the detailed ion chemistry of the D-region (or suitable bulk parameters), and for an energy degradation model for the incoming particles. Interpreted in this way, the observed electron densities yield an implied downward energetic particle flux within an approximately 1 km^2 column (i.e. the radar beamwidth).

Joint Observations

IRIS operates continuously, while EISCAT gathers data during discrete operations totalling about 1500 h per year. These are split equally between common programmes and special programmes (see Collis and Hargreaves, 1996). For the present study we utilise results from a special programme in May 1995 that measured electron density in the altitude range 56-141 km with 1 km resolution every 5 sec. The radar beam was aligned along the geomagnetic field direction, intersecting the D-region some 20 km south of the transmitter site. The observing interval from 1130 to 2130 UT covered the local afternoon and evening sector, the latter time being magnetic midnight at EISCAT.

Figure 1 shows the electron density measurements from the radar. Although the details of precipitation patterns vary from day to day, the behaviour in Figure 1 may be considered rather typical for this time sector. Up to about 13 UT there were occasional density enhancements maximising at about 93 km, similar to those described by Collis *et al.* (1996), but virtually no D-region ionisation in the early afternoon. In the evening the precipitation intensified with rapid variations, seen also in radio absorption, Figure 2. We cannot explore details here, but concentrate on a few key points only.

By itself, EISCAT furnishes spot measurements of the energy input within the radar beam. Broader-scale estimates require information on the spatial extent and lifetimes of the precipitation features, which are provided by IRIS. Figure 3 illustrates two examples. The daytime event (a) was rather weak. The observed densities have to be corrected for the photo-ionised component to estimate the precipitating electron flux-energy spectrum. In addition, the measurements have significant statistical uncertainties for weak events. As a result, the inversion to particle flux is somewhat uncertain, particularly for high energies (corresponding to low altitudes where the electron density was small). Although the radar detected this feature for about 10 minutes, the IRIS observations revealed that it was actually a long-lived, slowly equatorward-drifting patch that moved through the radar beam. More accurately, the precipitation showed co-rotating characteristics similar to those reported for another event at the same local time by Collis et al. (1996). With the assumption that the particle spectrum did not change significantly with time, which seems a reasonable inference based on

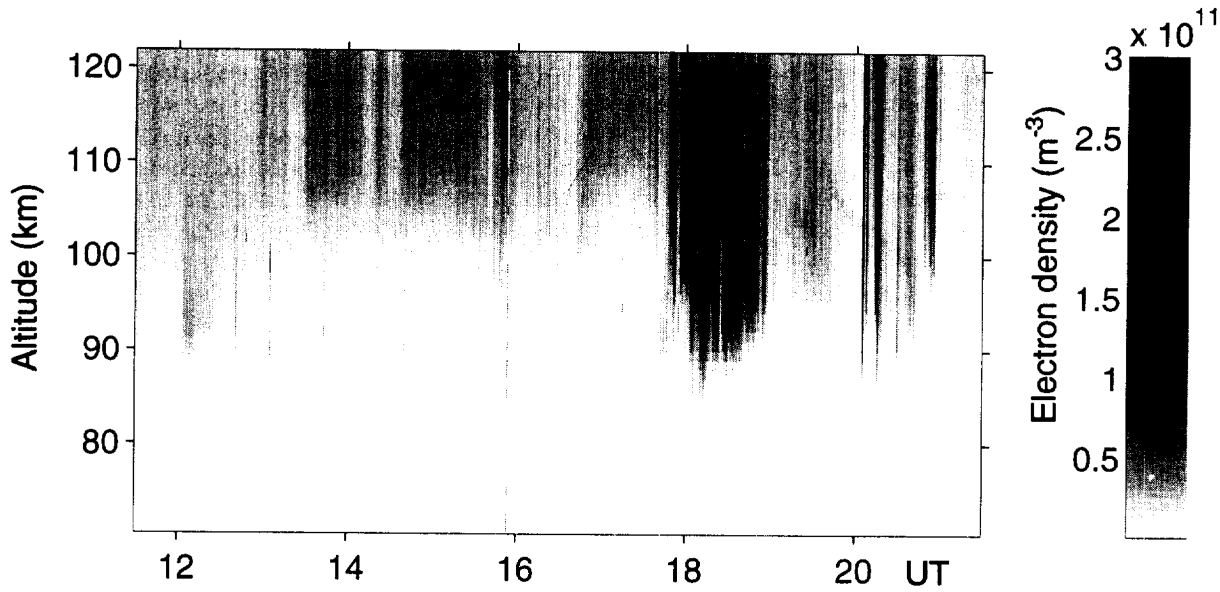

Fig. 1. Electron density measurements from EISCAT in the afternoon and evening sector.

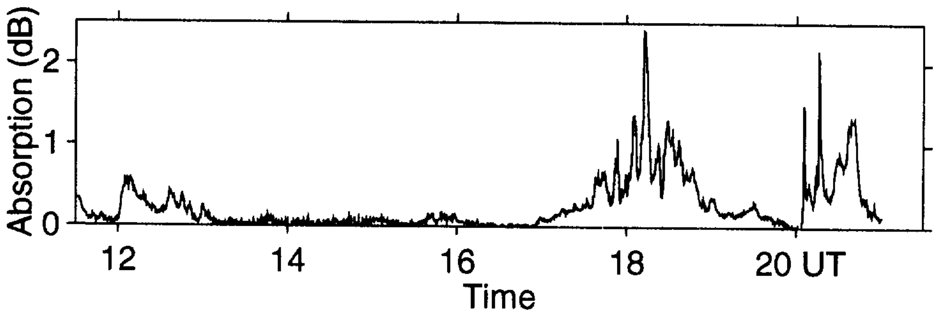

Fig. 2. IRIS observations of radio absorption in one of the beams close to EISCAT.

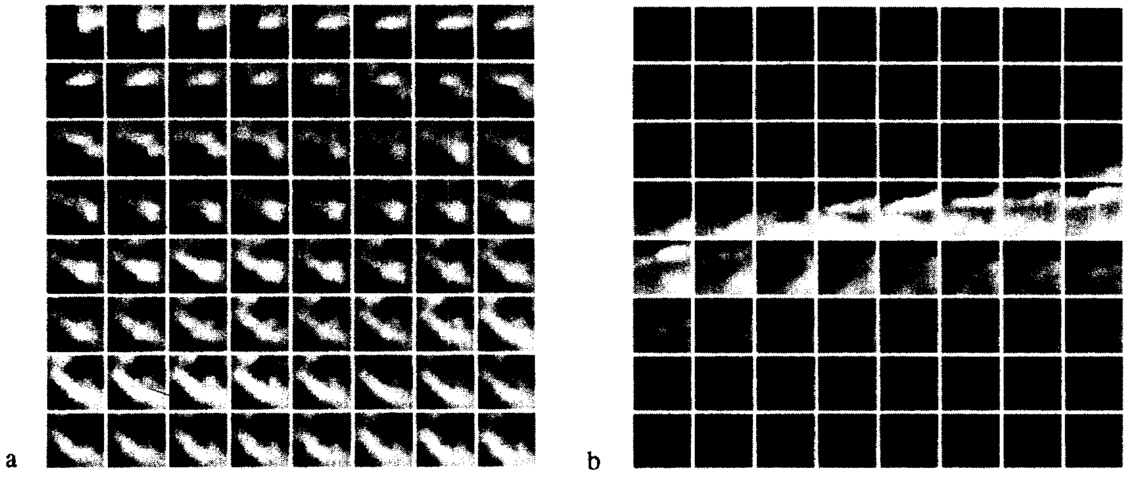

Fig. 3. IRIS absorption images 31 May 1995. Each image is 240 km square. Time increases left to right then down the page. (a)1200-1232 UT (30-s data), white=0.7dB, (b) 2000-2005:40 UT (10-s data), white=2.0dB.

the observations, the IRIS data can be readily converted into space-time maps of energy input for this event. Preliminary estimates for the main precipitation region are of the order of 10^6 J s^{-1}.

The substorm onset shown in Figure 3b was very different from the daytime event. The precipitation region expanded rapidly polewards across the IRIS field of view and showed dynamic changes on time scales of a few seconds with very localised structure. The most intense absorption was slightly east of EISCAT so the measured electron densities would underestimate the maximum energy input. Nevertheless, the densities were large and corrections for measurement noise and photo-ionisation were insignificant. Knowing the absorption recorded by the IRIS beam closest to EISCAT, together with the maximum recorded by any of the 49 beams, it is possible to estimate the maximum energy deposition by simply scaling the observed electron densities by the ratio of the two absorption measurements (implicitly assuming that the electron energy spectrum is the same). In this case the ratio was about 5, implying electron densities at the maximum some five times larger than observed by EISCAT. The implied peak energy input was of the order of 10^8 J s^{-1}, which is considerably more than for the daytime event but the integral effects over the event lifetimes are comparable because of the persistence of the daytime event.

SUMMARY

Simultaneous joint observations by incoherent scatter radar and imaging riometer are a powerful tool for investigations of energetic particle effects on the D-region. The general principles of this technique have been illustrated using examples from the EISCAT radar and the 49-beam IRIS at Kilpisjärvi, 83 km from the radar transmitter site. The radar is capable of high-resolution measurements of the electron density profile, from which the particle flux-energy distributions can be computed. The IRIS observations provide the spatial context within which to interpret the radar data, revealing, for example, the spatial extent and dynamics of precipitation regions.

ACKNOWLEDGEMENTS

EISCAT is supported by Finland (SA), France (CNRS), Germany (MPG), Japan (NIPR), Norway (NFR), Sweden (NFR) and the UK (PPARC). The Kilpisjärvi IRIS facility is funded by PPARC and operated in collaboration with Sodankylä Geophysical Observatory.

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