Plasma density over Svalbard during the ISBJØRN campaign

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Abstract. In 1997, reliable operation of the EISCAT Svalbard Radar (ESR) was achieved and a rocket launching facility at Ny Ålesund on Svalbard (79°N, 12°E) (SVALRAK) was established. On 20 November, 1977, the first instrumented payload was launched from SVALRAK. Although the payload configuration had been flown many times previously from Andøya Rocket Range on the Norwegian mainland, this presented an unprecedented in situ determination of positive ion density over Svalbard. Simultaneously, ESR measured similar density profiles but in a higher altitude regime. We have combined the ESR measurements with ion-osonde data to establish a calibration and subsequently combined the ground-based and in situ determined profiles to give a composite positive ion density profile from the mesosphere to the thermosphere.

Key words: Ionosphere (polar ionosphere; instruments and techniques)

Introduction

Until the end of 1997, the instrumentation on Svalbard (80°N, 16°E) has not been adequate for the reliable and regular measurement of plasma density in the lower ionosphere. The EISCAT Svalbard Radar (Wannberg et al., 1997) has been troubled by two problems: (1) above E-region heights, the incoherent scatter spectra have exhibited anomalous behaviour relative to those obtained from similar instruments at lower latitude; (2) in the lower thermosphere and below measurements have been impeded by "clutter" or interference (the exact cause being unclear at the time of writing). Here, we attempt to circumvent these problems by combining

incoherent scatter measurements with those of an ionosonde and rocket-borne positive ion probe. This kind of combination of instrumentation has been presented earlier by Hall et al. (1985) but for data from the north of Norway. The period we shall examine is the evening of the 20 November, 1997, although we shall briefly review the state of the ionosphere on the previous day.

The ISBJØRN I payload was flown on 20 November at 1732 UT and successful measurements were made in the height interval 50–71 km (Thrane et al., this issue). The positive ion probe (Blix et al., 1990), as the name suggests, determines the positive ion density, and this should not be confused with the electron density. In particular, at the time of year we shall present data from here, there is a strong likelihood that there was a significant negative ion content at least up to the upper mesosphere. The ESR system was directed at low elevation (45°) and scanned in azimuth. The pointing directions were 265°, 270°, 285°, 300°, 315°, 330° and 345° with a dwell time of 2 min at each position. It is important to be able to visualise the geometry of the combined experiment in order to assess the assumptions regarding homogeneity and stationarity that will be implicit in our conclusion. Figure 1 shows a 3-dimensional view: Svalbard is seen from the southwest with horizontal axes indicating distance in kilometers from ESR; the vertical axis indicates altitude in kilometers; the parabola indicates the measured trajectory of ISBJØRN I; the straight line extending from ESR is a typical beam (azimuth 300°) and is dotted in the region where clutter/interference makes measurements useless (see later); the dotted line on the ground indicates the footprint of the ESR beam. In Fig. 1, note that ESR measures at much longer ranges than indicated here, but we have chosen not to extend the plot upwards to the left for clarity. Figure 2 shows a plan view of the information in Fig. 1, and in particular, the points on the ESR beam where it intersects selected altitudes. Systems of the configuration of ISBJØRN I are usually expected to attain higher altitudes in which case one can
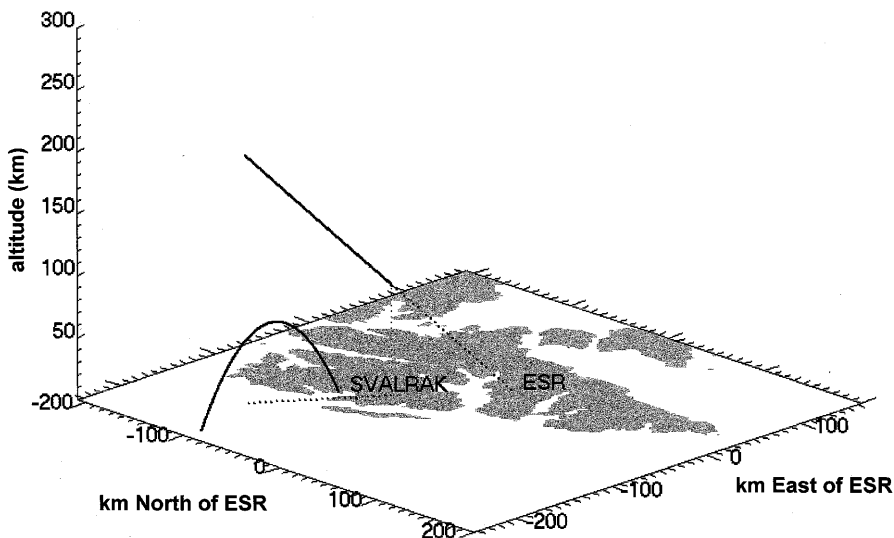

Fig. 1. Three-dimensional representation of the measurement geometry. The "floor" depicts Svalbard seen from the southwest with *horizontal axes* indicating distance in km from ESR. The *vertical axis* indicates altitude in km; the parabola indicates the measured trajectory of ISBJØRN I. The *straight line* extending from ESR is a typical beam (azimuth 300°) and is *dotted* in the region where clutter/interference makes measurements useless (see text). The *dotted line* on the *ground* indicates the footprint of the ESR beam. Landmasses are *grey*; sea is left *white*
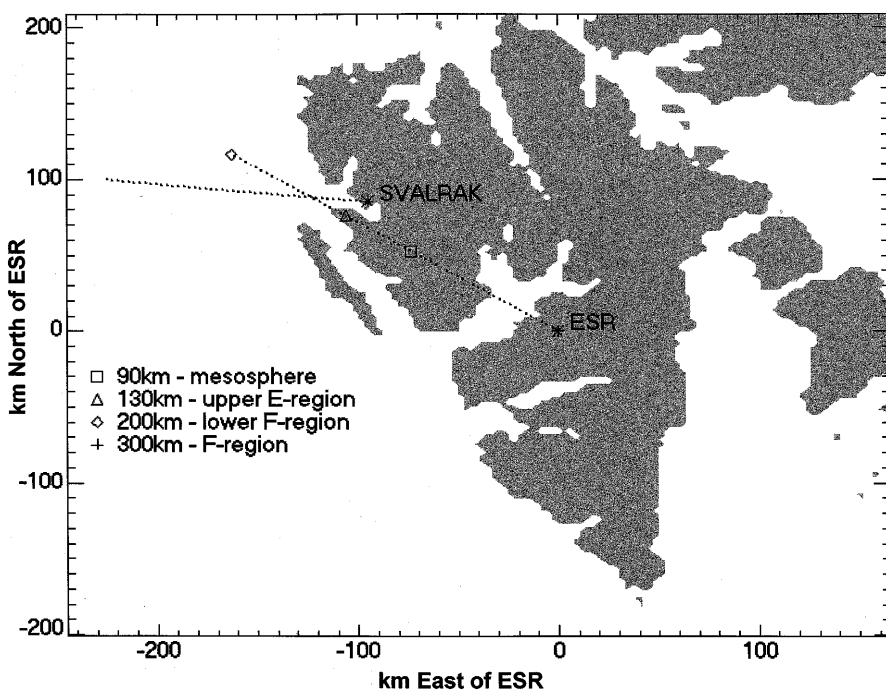

Fig. 2. Two-dimensional representation of the measurement geometry. This is essentially a plan view of the previous figure, but indicates intersections of the ESR beam with selected altitudes. The apogee of ISBJØRN I was 70 km and is this represented by the *mid-point* of the *line* extending *west* from SVALRAK

see that the ESR measurement volume and the payload trajectory could be arranged to be very close. In our case, there was a spatial separation of around 100 km between the payload apogee and the lowest ESR volume. We shall see that conditions were geomagnetically quiet and that ESR failed to detect any substantial spatial structure in the plasma density during the period in question, and we shall use this as part of our justification for presenting a composite ion density profile. While such plasma density measurements are commonplace at, for example, the EISCAT mainland site (69°N, 19°E), a database of such soundings does not, as yet, exist for Svalbard. Thus although this work will not present new physics, it is intended to contribute to establishing the status quo for the ionosphere at 80°N, 16°E.

ESR measurements

While it is unfortunate that there are difficulties in measuring at low altitude (i.e. under 85 km as we shall see) with ESR and therefore determining true height profiles, pointing the radar at a 45° elevation allows for a convenient portrayal of the results. In Figs. 3 and 4, we show the average electron density for the two periods of operation 1645–2300 UT on 19 November, 1997, and 1409–2010 UT on 20 November, 1997. The figures show plan views of the observed region with axes indicating horizontal distance from the ESR site. Since the elevation was very nearly 45°, the horizontal range from ESR is equal to the altitude. Stating that these are plots of electron density is, however, not quite true; equivalent electron densities have been calculated from
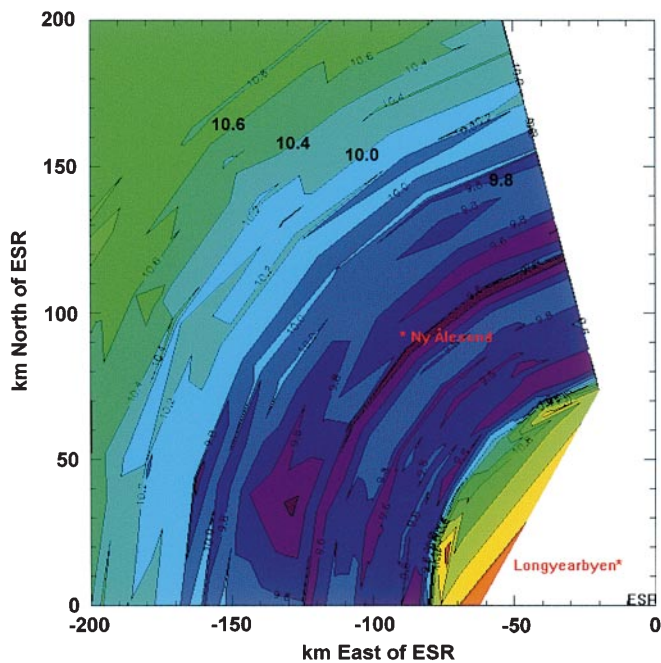
Fig. 3. Average electron density (or rather backscattered power calculated as electron density assuming scattering process is incoherent scatter) for 19 November, 1997. *Axes* denote horizontal distance from ESR. The radar operated at an elevation of 45° such that the *horizontal range* on the plot is identical to the measurement altitude. Period of measurement was 1645-2300 UT. Contours are labelled in $\log_{10}$(electrons per m^3)

the backscattered power assuming the scattering process to be that of classical incoherent scatter (Lehtinen and Huuskonen, 1996). No account has been taken for possible presence of negative ions, a factor which may affect the signal especially below 95 km. Little is known
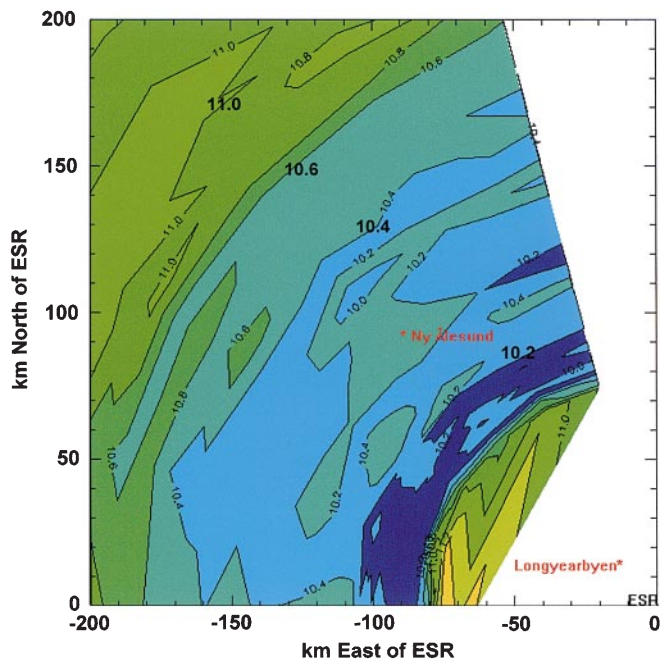
of negative ion concentration at such high latitudes and this in itself would be a worthy continuation of this kind of investigation. More importantly, though, clutter or interference of some kind manifests itself below 85 km as can be clearly seen by the "trough" in density at this horizontal range; All signals/closer to the radar than 85 km must be construed as artefact. It is interesting to note that this 85 km limit is independent of azimuth and this raises the question as to whether ESR is indeed affected by ground clutter, which we would expect to exhibit azimuth dependence. In the figures, we have attempted to show the average nature of the degree of ionisation on these two days. Obviously short-term variations may have occurred which we have subsequently averaged out. In practice, some sporadic E had been observed on 19 November, but this was less prevalent on 20. The conditions otherwise varied little as can be confirmed by that absence of significant geomagnetic activity depicted by Fig. 5, in which the two panels show the magnetometer records (*z*-component) for Ny Ålesund (location of SVALRAK) for the two days in question. Furthermore, note that the ionosphere is not sunlit during this period. The solar (10 cm) flux was 86.5 on the launch day, with a mean *Ap* of 2. Obviously, the individual soundings at 2 min resolution that have been averaged to construct Figs. 3 and 4 are also available, and in particular that nearest in time and space to ISBJØRN I; we shall defer presentation of this individual sounding until later.
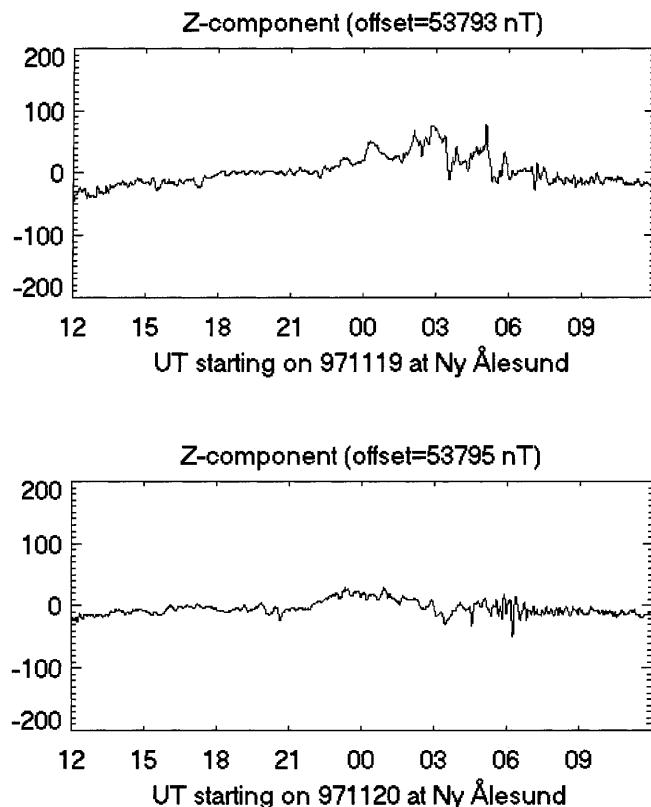

Fig. 5. *Z*-component magnetometer records for Ny Ålesund for 19 (*top*) and 20 (*bottom*) November, 1997. On each day, the record starts at 12 UT and extends for a 24-h period

Fig. 4. As for Fig. 3 but for 20 November, 1997. Period of measurement was 1409-2010 UT

ISBJØRN measurements

As described, the current flowing through the positive ion probe may be combined with the probe cross section to estimate the positive ion density. To illustrate the nature of this current we show the probe results in Fig. 6. Although plotted on a logarithmic scale (because the fluctuation amplitude tends to increase exponentially with height due to the increasing plasma density), we see that there is essentially a linear increase of positive ion
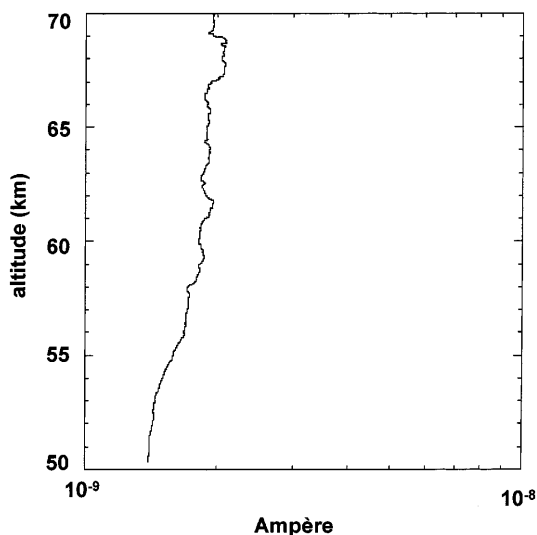
density through the height range of the observation. The reliability of the calculation has been established by, for example, Hall *et al.* (1985). Had electron density been measured in situ by the same payload, the difference between this and the positive ion probe would have represented the negative ion density (in order to preserve quasi neutrality of the gas). The fluctuations in the signal may be used to determine turbulence parameters, but we shall not address this kind of physics here. The resulting positive ion densities were determined to be $2 \times 10^9 \, \text{m}^{-3}$ at 50 km increasing almost linearly to $2.4 \times 10^9 \, \text{m}^{-3}$ at 70 km. The uncertainties due to instrumental noise and ion capture cross section amount to a factor 2.

Composite results

While we have considerable confidence in the ion probe determinations of ion density, ESR calculations depend on a "system constant" to establish absolute values of plasma density. Furthermore, the nature of ESR operation, which entailed real-time transfer of plasma parameters onto the Internet in order to contribute to launch criteria for ISBJØRN I, precluded recording of uncertainties. We have attempted to circumvent this problem, however, by introducing ionosonde data (University of Leicester ionosonde) and scale the ESR profiles accordingly. Some minutes prior to launch, a sporadic E (Es) layer had been observed but as ISBJØRN I attained apogee this had faded and only a remnant remained. The ionogram subsequent to the ISBJØRN I flight is shown in Fig. 7. In the usual way (e.g. Hargreaves, 1992) we may convert the ionogram
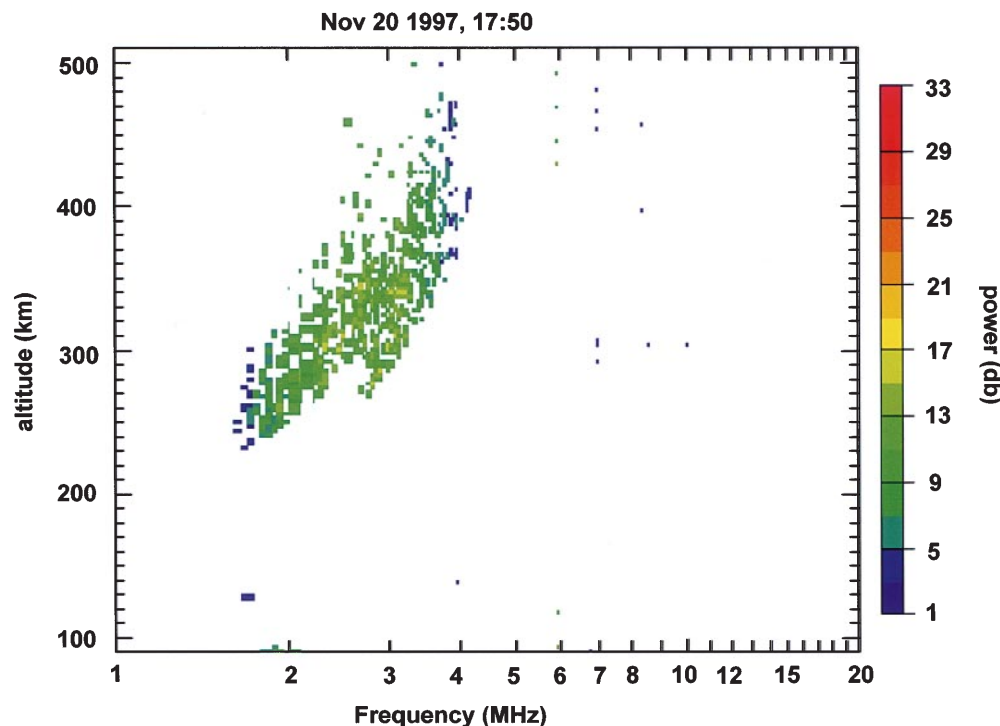

Fig. 6. Positive ion probe current for ISBJØRN I. The absolute units are unimportant; the general increase in current from 55 to 70 km corresponds to a linear increase in electron density from $2 \times 10^8 \, \text{m}^{-3}$ to $7 \times 10^8 \, \text{m}^{-3}$

Fig. 7. Ionogram for 1750 UT on 20 November, 1997. The small area of signal at about 125 km virtual height is considered to represent the remnants of an Es layer observed some 25 min earlier. The same feature is visible on the preceding ionogram at 1735 UT (not included here). The *colour coding* denotes signal strength

critical frequencies to electron densities, which in turn indicate 5×10^{10} m^{-3} at 260 km and 1.4×10^{11} m^{-3} at 380 km. Further to our discussion on the stationarity of the ionosphere during the evening of 20 November, we have noted little change in the F-region critical frequency, although a degree of variable Es was present.

Figure 8 depicts measurements from all three instruments on the same axes. The average of the factors required to scale the ESR plasma density profile to the ionosonde measurements was then determined, along with the standard deviation. The former was used to scale the ESR profile while the latter was used to determine a somewhat simplistic uncertainty. The identification of a minimum height of 85 km for useful observations by ESR at the time of the experiment via Figs. 4 and 5 and Hall (1997), leads to the rejection of data below 85 km. The reader is asked to recall that the ESR measurements presented here were accumulated as a result of a telescience service to the launch of ISBJØRN I and future D-region investigation will entail a more stringent approach to error treatment. Furthermore, future combination of ionosonde soundings with ESR profiles will help to determine the ESR system constant with more confidence rendering the inclusion of ionosonde measurements unnecessary. Nevertheless, it is hoped that the results presented here are of use to future ESR operations as a reference. Combining the ionosonde data with the ESR profile in this way and interpolating between the ion probe profile and the incoherent profile we arrive at Fig. 9. The profile in Fig. 9 may either be interpreted as a positive ion density profile, or, if we assume no negative ions, an electron density profile. It is tempting to identify the ledge at around 90 km as the negative ion shelf, but the authors feel this is a dangerous interpretation with so
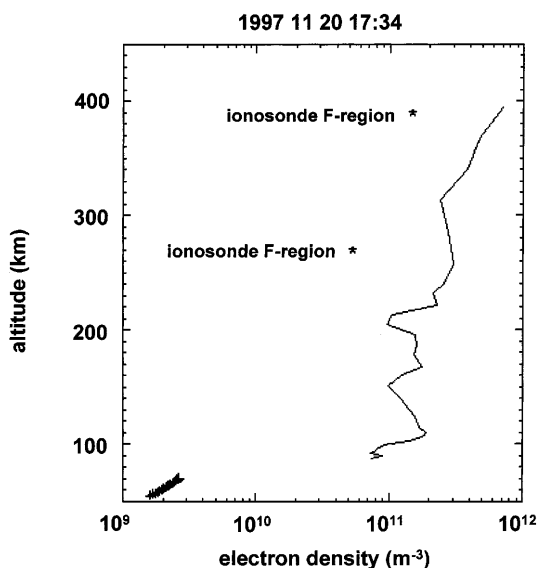

Fig. 9. Final composite plasma density profile for ISBJØRN I launch. See text for details

little data. It is conceivable that future investigation could establish negative ion density in ways similar to Hall *et al.* (1985), or Hall *et al.* (1998).

Conclusion

Despite not fully understood problems with ESR for measurements in the mesosphere, and the unexpectedly low apogee of the ISBJØRN I payload, we have determined a profile for positive ion density through the mesosphere and up to the F-region for the evening of 20 November, 1997, over Svalbard. We have determined, to some degree, the minimum measurement altitude for ESR at the time of writing and also the relation between electron densities indicated by the ESR standard analysis and ionosonde measurements. Although only an exploratory investigation has been reported here, it is of value for future measurements, both ground-based and in situ. The need to understand and alleviate the problems of low altitude ESR measurements have been identified, as has the need for combined in situ and ground-based measurements for mapping the negative ion presence in the mesosphere and lower thermosphere at high latitude.

Fig. 8. All plasma density measurements for the launch of ISBJØRN I on 20 November, 1997. The *solid line* represents the ESR measurement; the *dotted line* represents the ISBJØRN I measurement and the *two stars* the ionosonde measurement
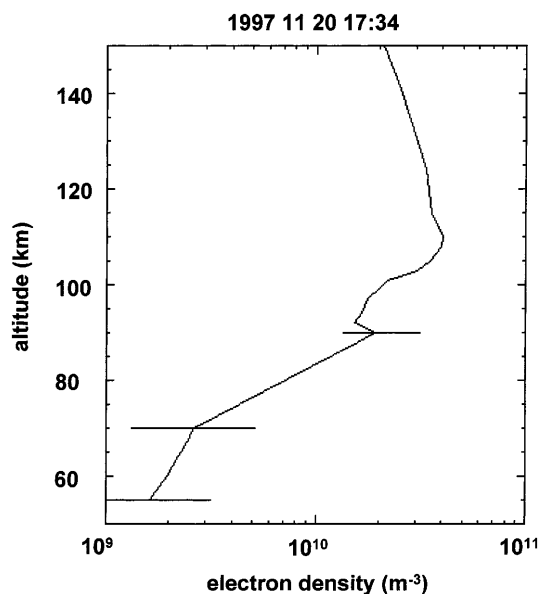
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