The D-region ionosphere during the solar minimum as seen by the EISCAT Svalbard continuous 1-year IPY radar experiment

Antti Kero[1], ***Carl-Fredrik Enell***[1], ***Lassi Roininen***[1], ***Thomas Ulich***[1], ***Esa Turunen***[2], ***Ingemar Häggström***[2], ***Pekka T. Verronen***[3], and ***Sanna-Mari Salmi***[3]

[1] Sodankylä Geophysical Observatory/University of Oulu, Tähteläntie 62, FI-99600 Sodankylä, Finland, antti.kero@sgo.fi

[2] EISCAT Scientific Association, Kiruna, Sweden

[3] Finnish Meteorological Institute, Helsinki, Finland

Abstract

The EISCAT Svalbard Radar (ESR) was operated in a continuous mode during the International Polar Year (IPY), starting on 1 March 2007 and ending on 29 February 2008. The radar experiment was dedicated to ensure good coverage also in the ionospheric lower E and D regions, in addition to covering the more standard experiment target, the ionospheric F peak, and reaching into the topside ionosphere. By using this unique continuous dataset gathered during the solar minimum, we show that anomalous variability of the quiet daytime electron density in the D region can be explained by the varying NO concentration.

Our focus is especially on September–October 2007, where the quiet daytime electron density suddenly increased by a factor of 7–10. This enhancement, most clearly seen at sunsets, lasted for several days. Using a detailed chemistry model we can show that an enhanced nitric oxide density explains the electron density at 92 km. This finding might provide aims to estimate NO from various quiet daytime electron density measurements in the upper mesophere-lower thermosphere.

1 Introduction

While the ESR IPY data in the altitude range 100-500 km have been extensively used, for example in a major initiative in high latitude ionospheric modeling supported by funding from the International Space Science Institute in Berne, Switzerland; the low altitude IPY data have not yet been utilised. We present analysis of the ionospheric D-region data, where backscattered power measurements, with 3 km range resolution and 2.25 km steps, start from the altitude of 45 km as shown in Fig. 1. The data is subject to sea and/or tropospheric clutter, which is variable with season/day up to 65 km. However, normally data is usable for altitudes higher than 70 km. The ISR experiment does not have sufficient frequency resolution for advanced Doppler and spectral width determinations, but we demonstrate how using a detailed coupled neutral and ion-chemistry model [1], one can deduce the effect of neutral atmospheric variability, possibly related to preceding precipitation events, in the daytime electron density estimated from the backscattered power data.

2 NO^+ dominant polar ionosphere during the solar minimum

In Fig. 2, the electron density measurements are shown at a single altitude as a function of UT and season, i.e. each column of pixels represents one single day at 92 km. The choice of this particular altitude is somewhat arbitrary, but representative for the NO^+ dominant ionosphere, which is mainly caused by photoionisation of NO by the solar Lyman-α radiation. The diurnal variability of photoionisation is clearly visible in the data as transients during the sunrise and the sunset times. As expected, the photoionisation also has a clear seasonal cycle; the strongest D-region is found during polar day and the weakest during polar night, where only a few hours around local noon are affected by scattered sunlight.

On top of this background electron density, which is due to photoionisation, energetic particle precipi-

978-1-4244-6051-9/11/$26.00

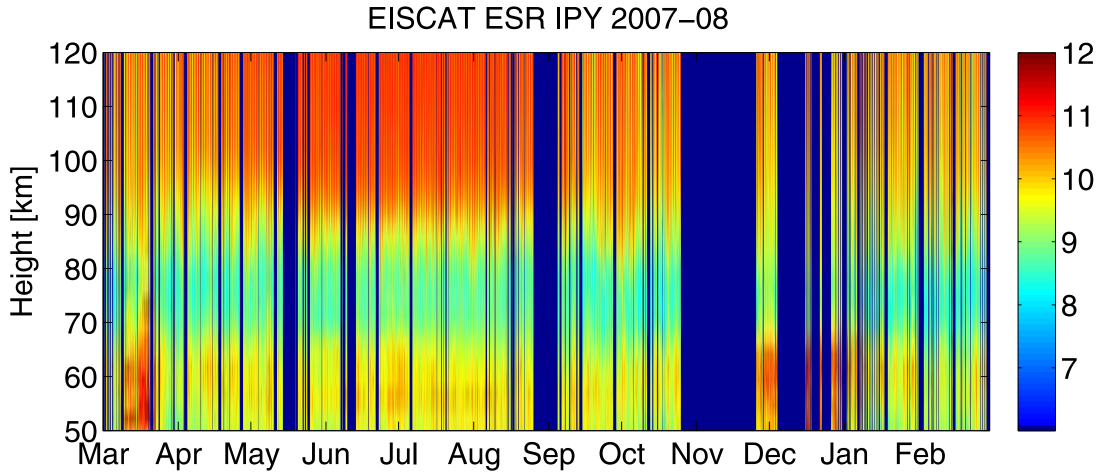


Figure 1: Electron density (base ten logarithm of m^{-3}) based on the backscattered power detected by EISCAT Svalbard Radar (ESR) during the 1-year IPY run.

tation events are capable of increasing the electron density instantaneously by several orders of magnitude. Probably due to magnetospheric configuration, these events seem to favor especially the morning sector when the ESR station is usually located inside the cusp region, according to a study by Newell et al., 2004 [2]. The ionisation due to precipitation events differs from photoionisation by its sporadic occurrence, statistically following geomagnetic activity and *magnetic* local time rather than season and local time.

Apart from the slowly varying seasonal cycle, there are sudden transients also in the background electron density. These are most clearly visible around the sunsets, since the sunrises are somewhat masked by the precipitation events. Here we focus on the sudden elevation of the background electron density during September-October 2007, highlighted in Fig. 2. The electron density is elevated by a factor of 7–10 during the last days of September, and the enhanced level remains for several weeks, at least until the data gap on 11–13 October 2007.

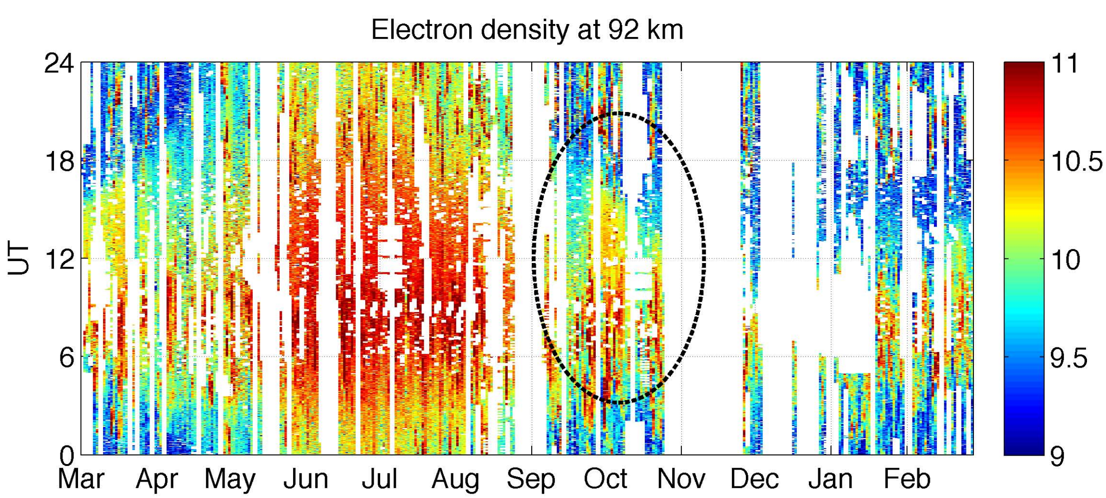
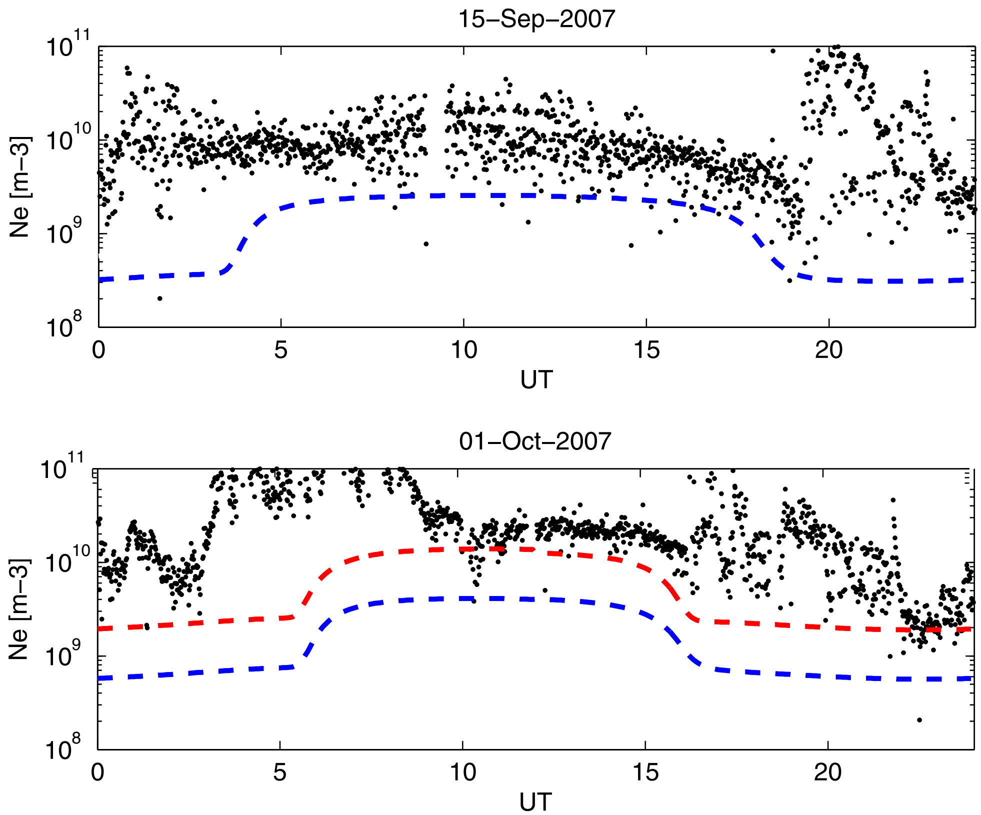


Figure 2: Electron density (base ten logarithm of m^{-3}) at 92 km. Anomalous background electron density variation during September-October 2007 is highlighted.



1

Figure 3: Electron density from ESR (black dots) vs. SIC model simulations. Blue lines represent the SIC model initialisation runs and the red line (lower panel) is calculated with the initial NO concentration increased by a factor of 10.

The key feature worth noting is that the background electron density follows the daily sunset times rigorously, both before and after the transient. This indicates that the sudden intensification of the ionosphere is, indeed, due to enhanced photoionisation, and not caused by precipitation of the moment. However, since the energetic particle precipitation is known to produce NO [3], the enhanced level of photoionisation might be caused by *preceding* precipitation events during the geomagnetic storm in late September 2007.

The measured electron densities are compared to Sodankylä Ion and Neutral Chemistry model SIC simulations in Figure 3 for the dates before and after the anomalous electron density enhancement. The SIC model is a detailed time-dependent ion and neutral chemistry model combining 36 positive ions, 28 negative ions and 15 neutral species via several hundreds of reactions [1]. The model needs as input parameters the neutral background atmosphere, here taken from the MSIS model [4], and the fluxes of various ionisation sources, such as electromagnetic radiation, energetic particle precipitation and cosmic rays. In the simulations presented in this study, the neutral atmosphere is predisposed only to the spectrum of solar irradiance [5].

In practise, the SIC model must first be initialised to a dynamic chemical equilibrium by modelling the same day repeatedly until the concentrations of active chemical species, such as NO, are converged sufficiently. Electron densities corresponding to these initialisation runs are shown as blue dashed lines in Fig. 3. The red dashed line in the lower panel represents the electron density prediction for a case where the starting value of the NO concentration is increased by a factor of 10 from the initialised level.

As shown in Fig. 3, the SIC model is in fairly good agreement with the lowest values of the electron densities on 15 September 2007, underestimating slightly the floor level of the data, but capturing correctly the sunset feature visible around 18 UT. In the case of 1 October 2007, the SIC model used with 10 times higher NO level (red line), again, slightly underestimates the floor of the enhanced electron density but shows a clear concurrence in the sunset. These findings indicate that the enhanced electron density detected by ESR in October 2007 is due to intensified photoionisation, despite the fact that the solar irradiance entering the polar atmosphere is decreasing during local autumn. The intensification, however, can be explained by an NO concentration increased roughly by one order of magnitude.

3 Conclusions

The 1-year IPY experiment conducted by ESR reveals new perspectives on the polar D-region ionosphere during solar minimum. To demonstrate the scientific potential of this unique dataset, we focused on just one aspect, the anomalous background electron density variation in autumn 2007. It turned out that while the intensity of the solar irradiance generally decreases in autumn, the background electron density suddenly increases in the last days of September 2007. According to our analysis, this can be explained by an enhanced NO concentration, probably related to the preceding ionisation events during the geomagnetic storm. This finding might provide aims to estimate the NO concentration from various quiet daytime electron density measurements. However, this requires more investigation, most importantly an independent experimental verification of the relation between NO and the electron density in the upper mesophere-lower thermosphere.

4 References

1. Verronen, P. T., "Ionosphere-atmosphere interaction during solar proton events", *Ph.D. thesis*, Finnish Meteorological Institute, Helsinki, Finland, URL http://ethesis.helsinki.fi/, ISBN: 951-697-650-6, 2006.

2. Newell, P. T., J. M. Ruohoniemi, and C.-I. Meng, "Maps of precipitation by source region, binned by IMF, with inertial convection streamlines," *J. Geophys. Res.*, 109, A10206, 2004, doi:10.1029/2004JA010499.

3. Turunen, E., P. T. Verronen, A. Seppälä, C. J. Rodger, M. A. Clilverd, J. Tamminen, C. F. Enell and Th. Ulich, "Impact of different precipitation energies on NOx generation during geomagnetic storms.", *J. Atmos Sol.-Terr. Phys.*, doi:10.1016/j.jastp.2008.07.005

4. Hedin, A. E., "Extension of the MSIS Thermospheric Model into the Middle and Lower Atmosphere", *J. Geophys. Res.*, 96, 1159–1172, 1991.

5. Tobiska, W., Woods, T., Eparvier, F., Viereck, R., Floyd, L., Bouwer, D., Rottman, G., and White, O., "The SOLAR2000 empirical solar irradiance model and forecast tool", *J. Atmos. Sol.-Terr. Phys.*, 62, 1233–1250, 2000.