

## RADAR OBSERVATIONS OF PLASMA DEPLETIONS IN THE IONOSPHERE\*

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*Received September 26, 2006*

The F region trough is a well-known feature of the transition zone between the mid-latitude and high-latitude ionosphere. Studies of the trough have started more than 30 years ago, however, the understanding of the trough formation or occurrence is still ambiguous, due either to limited spatial extent or to restricted time of observations. Some of the trough properties have been established using satellite tomography (see companion paper [1]). However, the satellite tomography gives information about the electron density only, while incoherent scatter radar observations can provide data about other ionospheric parameters, so that they are a very useful tool for the detailed study of an event. Tomography is suitable for long-term and/or statistical investigations, while incoherent scatter results can be utilized when particular cases are analysed in detail, for instance to identify the possible mechanisms of the trough generation. Here we present some radar images of the density trough together with coincident results for the ion vertical velocity and temperature data.

*Key words:* ionospheric trough, incoherent scatter radar.

### 1. INTRODUCTION

The depletions that are observed in the F region are known as ionospheric troughs. Some general information about the trough can be found in the companion paper [1]. Satellite based investigations are very useful for the study of the long-term behaviour of the trough, or of its general properties. On the other hand, the understanding of the mechanisms that contribute to the formation of the trough require data about other ionospheric parameters, which can be provided by the radars. EISCAT is a scientific association is an international research organisation operating three incoherent scatter radar systems in Northern Scandinavia and Svalbard (see details <http://www.eiscat.com/about.html>).

\* Paper presented at the National Conference on Applied Physics, June 9–10, 2006, Galați, Romania

Rom. Journ. Phys., Vol. 53, Nos. 1–2, P. 5–12, Bucharest, 2008

The trough formation is attributed to several mechanisms, among which the plasma convection, neutral wind effects, precipitation and heating are the most active. The trough can be the result of one or more of these processes. Nightside troughs form at the stagnation line, where westward convection is balanced by the eastward corotating plasma. Dayside troughs could form when the dayside high density plasma is replaced by the depleted plasma brought by the convective transport from the night side. A high ion velocity could result in heating, which in turn increases the ion loss and eventually leads to a depleted density. More details about the trough formation can be found in [2], [3] or [4].

## 2. OBSERVATIONS

The incoherent scatter (IS) radar is a powerful ground based technique for the study of the Earth's ionosphere. Based on the fact that an electromagnetic wave is transmitted to the ionosphere and receives a returned 'echo' [5]. The high-power energy is scattered by the electrons in the ionospheric plasma, which are themselves controlled by the much slower, massive positive ions. The scattered signal is detected by a large antenna and a sensitive receiver system. The frequency spectrum of the received signal provides information about the electron density, the electron and ion temperature, the plasma composition and its velocity. From these results, for some particular cases, many further ionospheric and upper atmospheric parameters can be deduced, like the ion composition, electric field strength, conductivity and current, Joule and particle heating rates, neutral air temperature, composition and wind speed, fluxes of heat and plasma along the Earth's magnetic field lines and, with additional information from the plasma lines, electric current density in the direction of the magnetic field and part of the spectrum of supra-thermal electrons [5, 6]. Of course, there are some limitations to this powerful method of ionospheric sounding. The main one is the fact that the profiles of plasma parameters at a single instant of time are aligned to the radar beam. Another inconvenience is the fact that the incoherent scatter radars are extremely expensive [5, 6].

The troughs have been identified in the latitude-altitude profiles of the electron density obtained when the radar antenna was scanning the upper atmosphere in a north-south plane, covering a wide band of latitudes between about  $60^\circ$  and  $75^\circ$  N. Figs. 1–4 present images where the trough can be observed at different times of the day, during different seasons. Besides the electron density, we have included the ion velocity and the ion and electron temperatures. In order to help the reader to identify the trough and the values of different parameters at the corresponding locations, the two edges of the trough are highlighted by two vertical dotted lines. We note that the plots are not very clear because the results obtained initially from the EISCAT measurements are

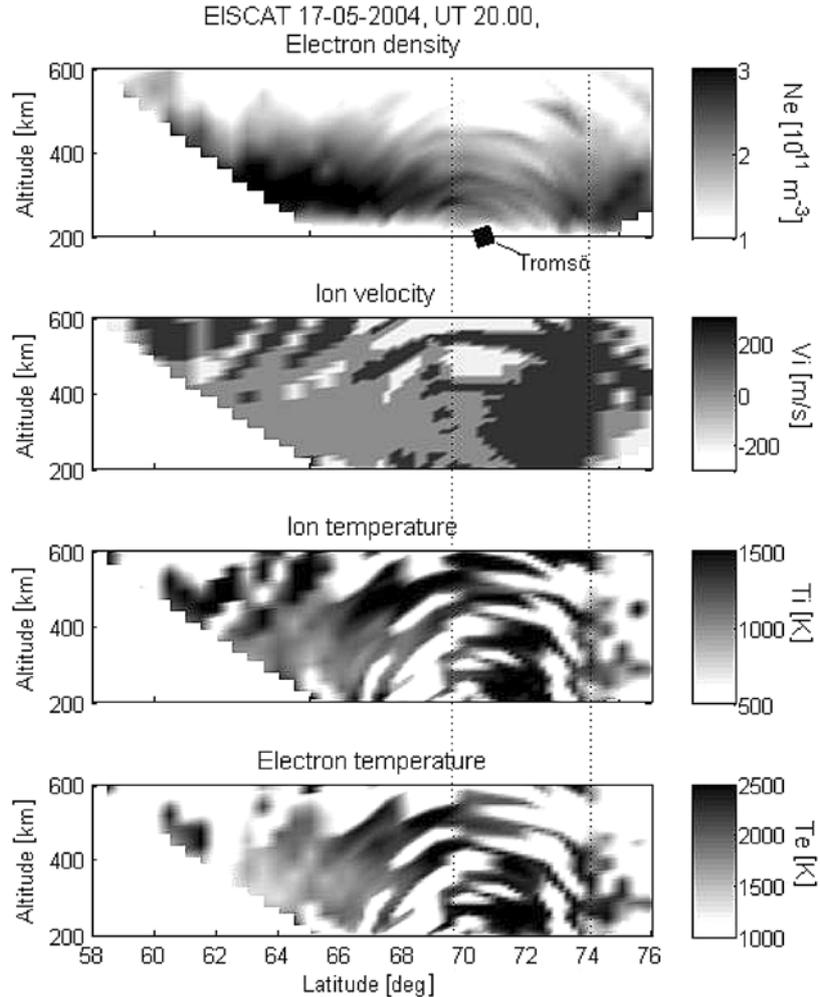


Fig. 1 – Electron density, ion vertical velocity, ion and electron temperatures for 17.05.2004, UT 20.00h. Positive ion velocity is upward. The small diamond in the upper plot shows where the location of the antenna receiver is (Tromsø). The position of the trough is delimited with the two vertical dotted lines.

interpolated in order to obtain a finer latitude-altitude grid. However, they can be used in order to achieve an idea about the local conditions in the ionosphere at the time of the trough occurrence.

A first glance at the plots will show that the behaviour of plasma is not identical in all cases. This, in fact, was the reason to select these particular plots, i.e. to show that at different times and seasons the plasma parameters show different behaviour, which is the result of the fact that the troughs are produced by different mechanisms.

Fig. 1 shows a summer trough whose position is between 70 and 74 degrees, at evening hours. As shown in [4], at summer the trough is located at higher latitudes than during other seasons. The density decrease is relatively important, from more than  $3.5 \cdot 10^{11} \text{ m}^{-3}$  to less than  $10^{11} \text{ m}^{-3}$ . The second plot shows the upward motion of the ions, which coincides almost exactly with the trough location. Also, the last two plots show a localized increase of both the ion and electron temperatures. The mounting ions might indicate the upwelling of plasma, which leaves a more molecular plasma whose recombination time is shorter. Due to the increased temperatures, the ion loss rate is higher and the plasma gets locally neutralized. The result is the formation of the observed trough.

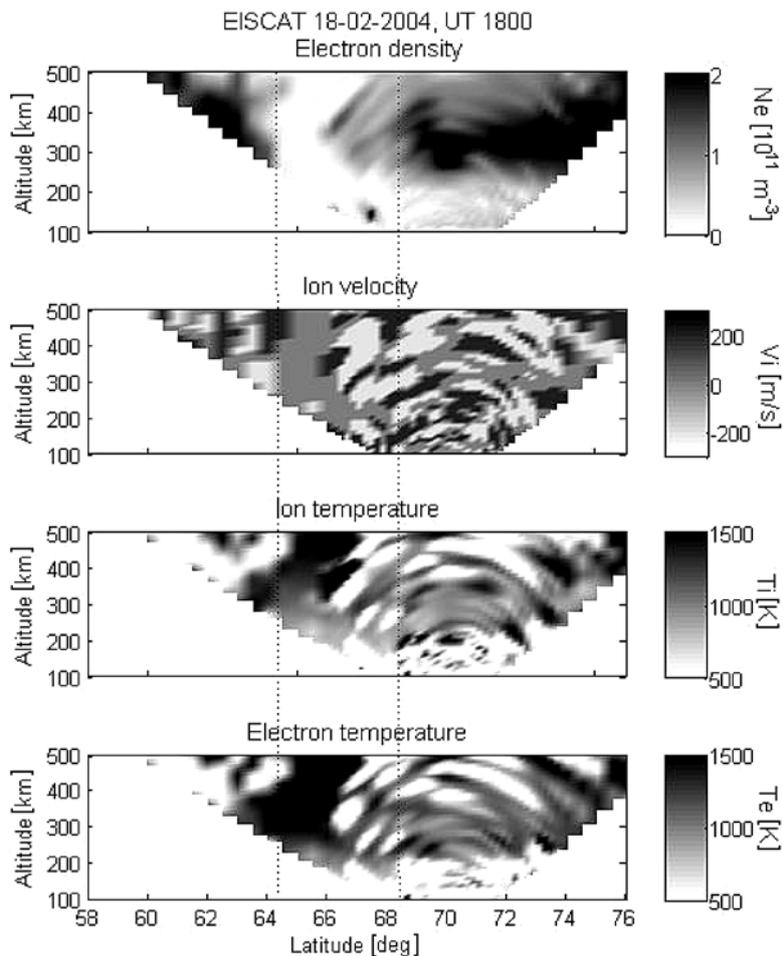


Fig. 2 – Electron density, ion vertical velocity, ion and electron temperatures for 18.02.2004, UT 18.00h. The same details as in Fig. 1.

Fig. 2 shows another trough, occurring during dark hours, in winter. Its location is at lower latitudes and is in line with the well-known fact that generally, the troughs form at lower latitudes at later times of day [2–4]. The depletion is even more accentuated and better defined than in the previous case. The ions in the trough are at rest, as the second plot shows. They seem to have a more turbulent motion outside the trough, contrary to the previous case, when the ions were descending outside the trough. This could be an indication of the plasma stagnation, occurring on the dusk side, where the westward convection is balanced by the eastward movement of mid latitude plasma corotating with the Earth. Of course, information about the horizontal movement of the ions would

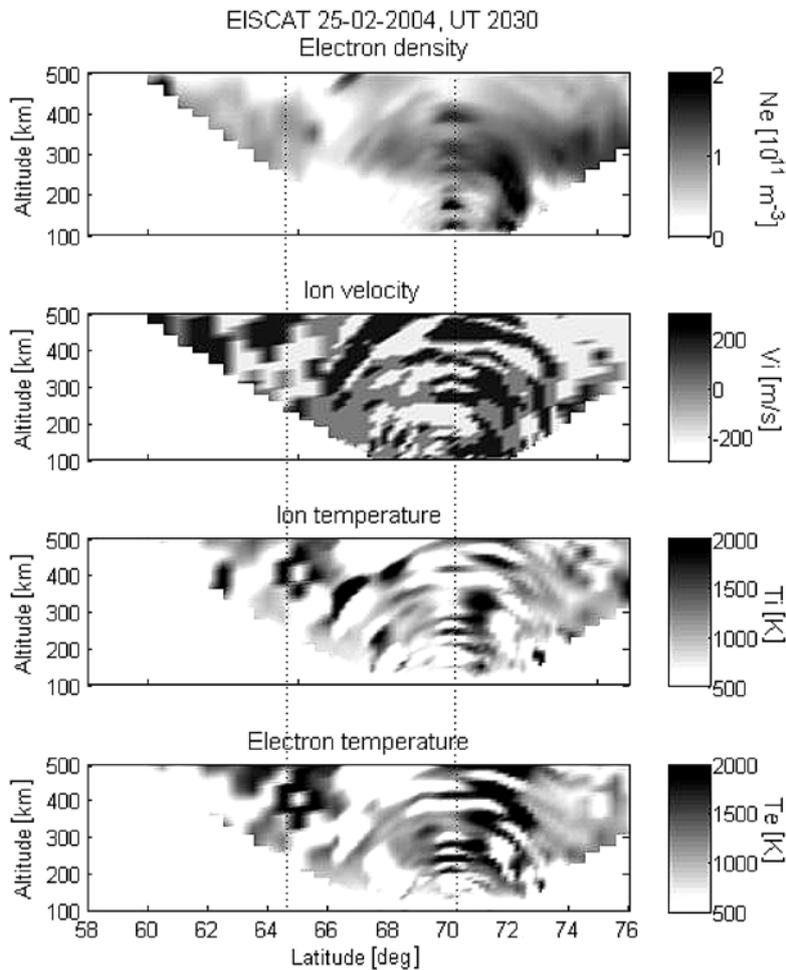


Fig. 3 – Electron density, ion vertical velocity, ion and electron temperatures for 25.02.2004, UT 20.30h. The same details as in Fig. 1.

be particularly useful to check this hypothesis. However, this shows that this particular trough is in fact a very good exponent of the night-time troughs forming at the stagnation line. Moreover, the temperatures are both increased, which contributes also decreasing the ion density in the favour of the neutral one.

In Fig. 3 we see another winter time trough, observed again at evening hours, at latitudes which are pretty much the same as for the previous trough. Although less obvious, the ion velocity plot shows, as in the previous case, that they are most likely at rest. This time, however, there is no difference between temperatures inside and outside the trough. A temperature increase is noticed towards North that coincides with a relatively abrupt increase of the density.

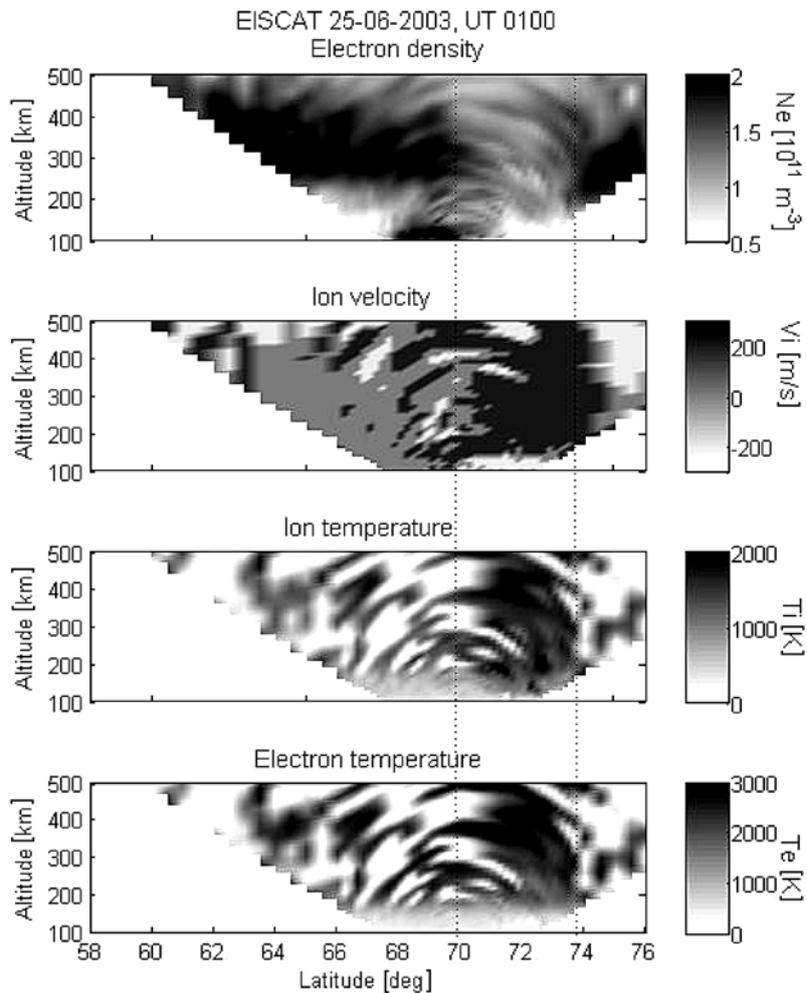


Fig. 4 – Electron density, ion vertical velocity, ion and electron temperatures for 25.06.2003, UT 01.00h. The same details as in Fig. 1.

This is probably the result of precipitating particles and most likely from the northern wall of the trough, as for instance, was observed by [7]. Most likely, the trough formation was initiated by the natural decay of plasma during night. Although some differences exist between the troughs seen in Figs. 2 and 3, they are small and, together with the fact that the observation time is the same, allow us to infer that troughs forming at evening during winter are the result of the decay of plasma being at rest and also lacking photoionization.

Finally, a last example shows again a summer trough, occurring at night. We must note that at this particular time the Sun is at its lowest height above the horizon during the polar summer season. A trough is seen, at high latitudes, as in Fig. 1. A clear upward movement is seen in the corresponding ion velocity plot, together with increases in both ion and electron temperatures. All these characteristics are similar to the other summer trough, including the fact that outside the trough the ions have no vertical movement. As in the previous case, there is a marked temperature increase. Together with the clear upward movement of the ions, this can be interpreted as frictional heating, which results in an accelerated rate of ion recombination and, further, to the decrease of the plasma density and formation of the trough.

Based on the similarities between the two summer troughs, we conclude that in summer time, the troughs form due to the frictional heating of the ions generated by their upward movement.

### 3. CONCLUSIONS

We have studied here some particular cases when the ionospheric trough was observed in incoherent scatter radar images. Besides the electron density, we have included in our study the ion velocity and the ion and electron plasma temperatures derived also from the same radar measurements.

We have selected two winter and two summer troughs. A first important observation is that the plasma parameters seem to have the same characteristics for the summer, respectively, winter troughs. Their location is similar, (low latitudes during winter, high latitudes during summer) and also the same variation is seen in the temperatures. More important, the ions behave similarly inside and outside the troughs observed in similar seasons. A second conclusion is that, during the time of the trough observation, the plasma parameters behave differently in summer and during winter. This is a clear indication of the fact that the formation mechanisms of the trough are different during summer and winter.

We have presented here only four cases, which are definitely too few to draw general conclusions. A more extensive study, including also information about the horizontal movement of ions, is required in order to better understand the formation mechanism of the trough and their prevalence during certain seasons.

*Acknowledgements.* Grant (project No 51465) from the Academy of Finland and support from Space Institute at the University of Oulu is gratefully acknowledged. We thank I. Virtanen for his programming efforts. EISCAT is an International Association supported by Finland (SA), France (CNRS), the Federal Republic of Germany (MPG), Japan (NIPR), Norway (NFR), Sweden (NFR) and the United Kingdom (PPARC).

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