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Plasmaspheric refilling phenomena observed by the Intercosmos 24 satellite

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Abstract—The ion density, ion composition and electron temperature have been measured onboard the Intercosmos 24 satellite. Local increases of light ion density accompanied by electron temperature enhancements and simultaneously observed VLF wave phenomena are interpreted as a manifestation of the refilling ion fluxes within the plasmasphere.

INTRODUCTION

One of the important problems, hitherto unsolved, of the interaction between the ionosphere and magnetosphere is the problem of refilling of plasmaspheric flux tubes emptied during geomagnetic storms. A significant effort has been made to model the early stage of refilling, including large-scale plasma flows, and small-scale plasma processes (e.g. Singh *et al.*, 1986; Rasmussen and Schunk, 1990; Guiter and Gombosi, 1990). There is as yet no satisfactory experimental proof of this stage of the plasmaspheric refilling process.

The early stage of refilling is followed by a stationary refilling process. The upward H^+ and He^+ fluxes from the ionosphere are expected at the time the equatorial densities of light ions are lower than their equilibrium values. The corresponding light ion trough is a common feature in the outer ionosphere.

In the lower collisional regions, the light ion velocities and fluxes have been measured on the Isis 2 satellite (Hoffman and Dodson, 1980). The region in-between the low latitude edge of the ionospheric light ion trough and the equatorial plasmapause has been found to exhibit the largest fluxes, albeit with lower velocities than in the auroral and polar cap regions. At higher altitudes, where the plasma density is lower, a variety of spacecraft effects have made measurements of flows of the thermal plasma component exceedingly difficult. There has been significant observational progress on this subject with measurements from the DE 1 satellite (e.g. Sojka *et al.*, 1983; Chandler and Chappell, 1986). The first direct observations of light ion flows along the magnetic field lines at high altitudes in the plasmasphere were reported by Chandler and Chappell (1986). Typical velocities have been found to be of the order of a few hundred metres per second. Higher-speed (up to 1 km s^{-1}) flows observed in the outer plasmasphere appear to be associated with the refilling process. In such cases, large variations with L in the parallel ion velocities were observed. The presumption that the refilling process could be more intensive in some latitudinally narrow zone inside the outer plasmasphere was first formulated by Wrenn *et al.* (1984). These authors reported measurements of the velocity distribution of thermal protons at high altitudes in the magnetosphere and plasmasphere onboard the GEOS 1 satellite. They found a thin zone of intensive filling where the scattering and heating of ionospheric H^+ ions was maximised within the broader region where protons were flowing upwards with weak pitch-angle scattering and heating.

In the ion composition measurements made by the Intercosmos 24 satellite, 'local' increases of density of light ions H^+ and He^+ have been observed in narrow L-intervals within the plasmasphere during periods following magnetospheric substorms. Their occurrence in satellite records shows very good correlation with simultaneously observed subauroral electron temperature enhancements and VLF noise plasmaspheric emissions. The purpose of the present short paper is to show that these 'local' increases could reflect more intensive transport of light ions between the ionosphere and plasmasphere during plasmaspheric refilling. Different behaviour of H^+ and He^+ ions in the lower (up to 600 km) night ionosphere is mentioned, and this is consistent with this hypothesis.

OBSERVATIONS

The experimental base for studying the ionospheric manifestations of ionosphere–plasmasphere coupling in this paper are the data on cold plasma parameters and wave phenomena monitored by the instruments on the Intercosmos 24 satellite (launched in September 1989 with orbital parameters 500/2500 km altitude and 83° inclination). This involves namely measuring the ion composition with a Bennett-type mass spectrometer in combination with electron temperature measurements using the radiofrequency method, and broad-band observations of wave phenomena by means of an electric and magnetic antenna.

The HAM-5 mass-spectrometer is based on the three-stage Bennett type analyzer with the electron multiplier at the output. The sensitivity in the broad-scale mode is about 1 ion/cm^3, the mass resolution M/dM is about 30 for the 10% level. The HAM-5 mass-spectrometer has been working in two principal modes: (a) measuring of the full spectrum up to a.m.u. 65 (in about 6 s), (b) measuring of the number (for example 8) of selected peaks. The time required to measure one peak is about 0.1 s; the peaks to be measured have been selected periodically (once per minute) using mode (a). In this paper, we discuss the date set from an 8-month period (December 1989–July 1990) obtained from the HAM-5 mass-spectrometer working in mode (b).

During plasmaspheric refilling periods, 'local' increases of density of H^+ and He^+ ions have been observed in narrow L-intervals in the plasmasphere, often within the light ion trough. These light ion density variations occur in all local time sectors. An example of this phenomenon in the morning outer ionosphere (up to 2400 km) is given in Fig. 1. The ion concentrations display a quiescent variation with a slow decrease of light ion density towards higher latitudes at a time when the magnetosphere is already disturbed, but before the main phase of the storm with the sudden commencement (Fig. 1a). The situation changes dramatically soon after the ssc (Fig. 1b). The

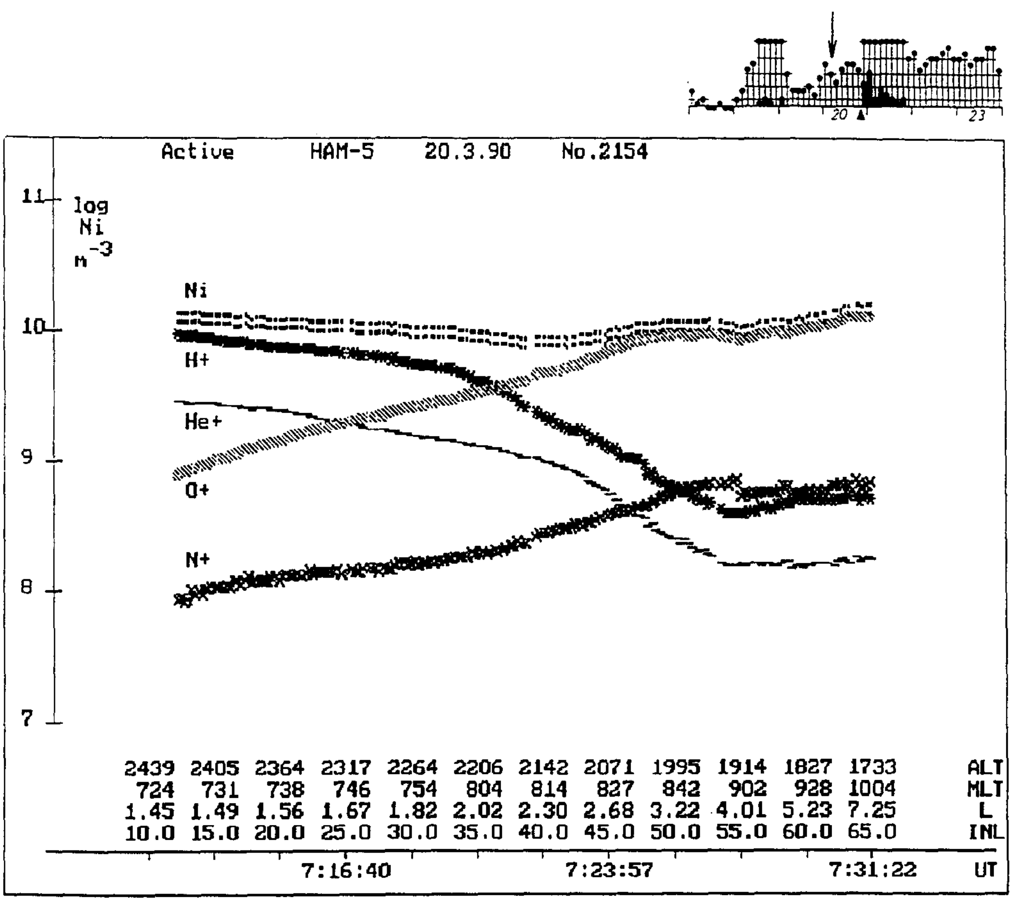

Fig. 1(a).

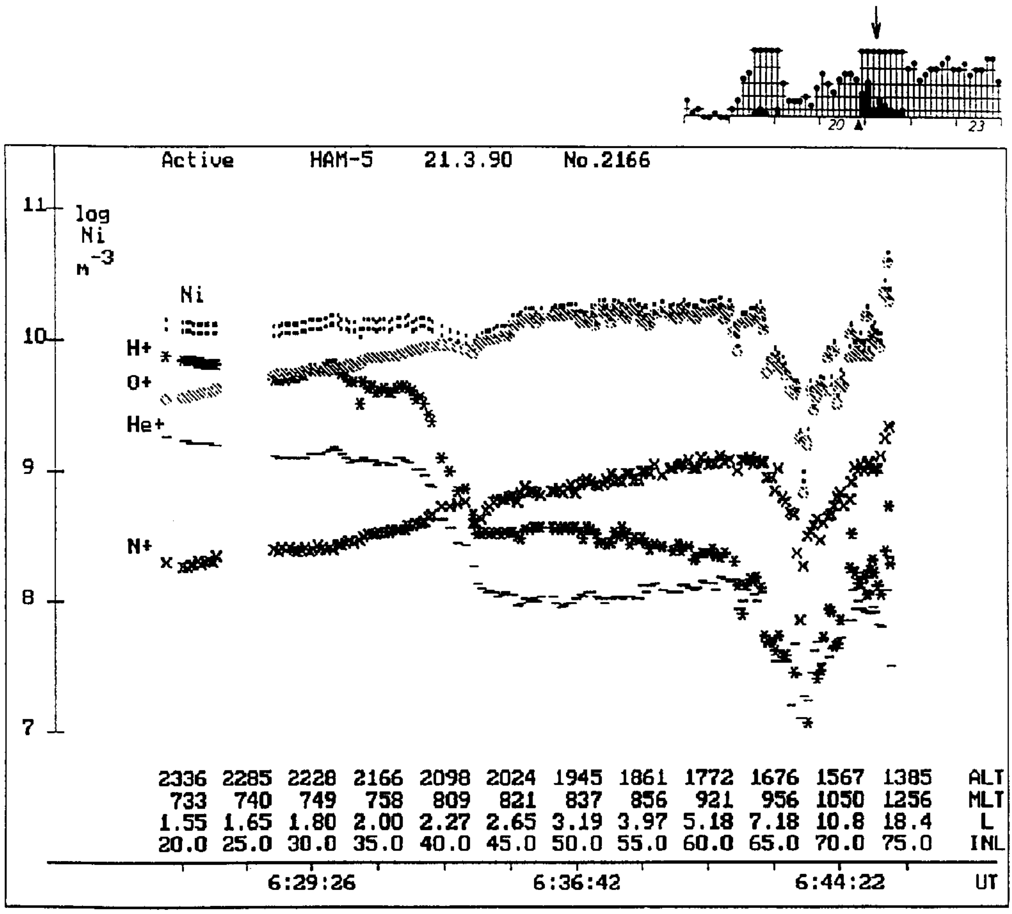

Fig. 1(b).

light ion density decreases abruptly by more than one order in a narrow L-interval around 2.1. The main ionospheric trough can also be clearly seen close to $L = 7$. During the period of quieting (Fig. 1c) the light ion trough begins to refill slowly. A distinct 'local' increase in the density of H^+ and He^+ ions, even reflected in a local increase of the total ion concentration, appeared within the light ion trough in a narrow L-interval close to $L = 2.5$.

At low ionospheric altitudes (up to 600 km) during the night, only latitudinal variations in He^+ density are observed depending on varying magnetospheric activity (abrupt decrease of the He^+ density deep within the plasmasphere at the onset of the substorm, 'local' increases of He^+ during the recovery phase). The H^+-concentration does not display larger local variations. An example is given in Fig. 2.

The temperature of thermal electrons T_e and electromagnetic wave phenomena were also recorded onboard the Intercosmos 24 satellite. The electron temperatures were measured using the method of the floating radio frequency probe (change of the floating potential on applying rf voltage with a frequency of ~ 50 kHz) by three planar probes oriented along the satellite velocity vector—T_{ex}, perpendicular to the orbital plane—T_{ey} and towards the zenith—T_{ez}. In cases of simultaneous measurements, in the same L-intervals as the 'local' increases of light ion density, the subauroral T_e enhancements and noise VLF plasmaspheric emissions which are believed to be the manifestation of plasmasphere–ionosphere coupling, were often observed. The example given in Fig. 3 is typical of the noon local time sector. In the situation of 'partial' quieting shown in Fig. 3b, the process of interaction between the plasmasphere and ionosphere is already reflected in the variation of the electron temperature (subauroral T_e peak) and in the occurrence of VLF emissions, but it is still not clearly

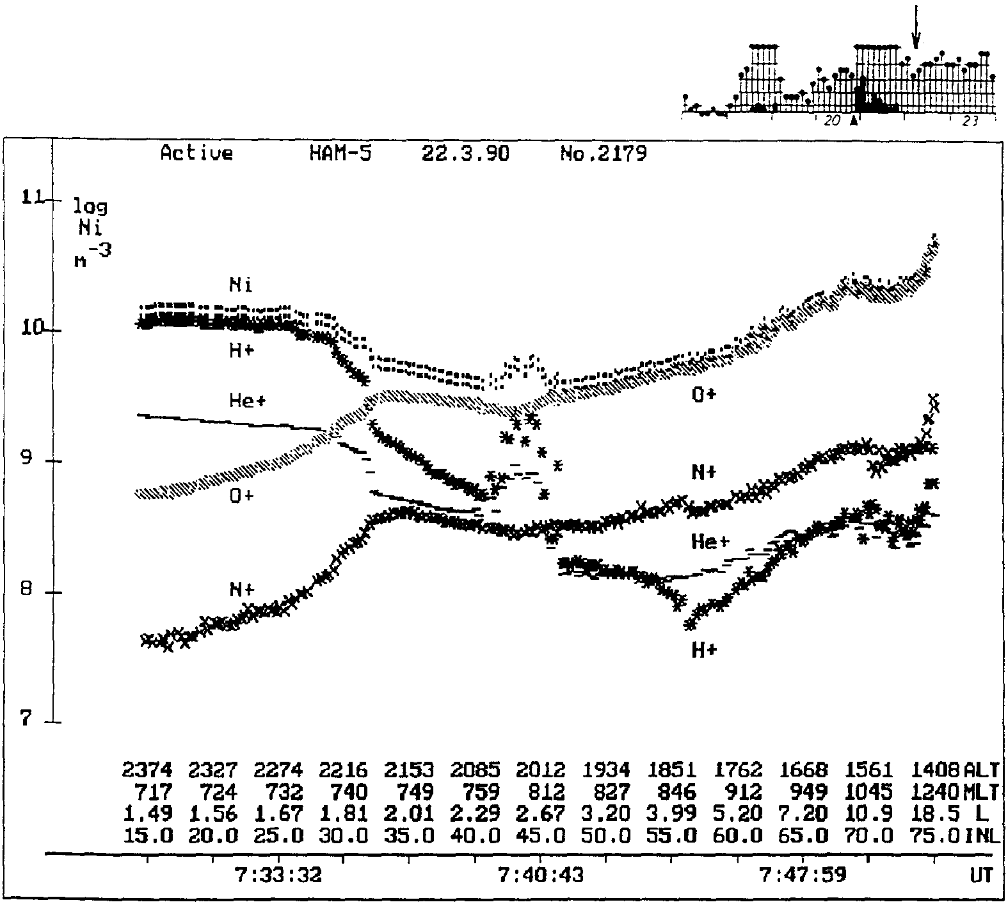

Fig. 1. Response of the morning ionosphere at altitudes of 1700–2400 km to the development of a larger geomagnetic disturbance (which followed soon after a smaller disturbance) before the main phase with the sudden commencement (Fig. 1a), soon after the ssc (Fig. 1b) and during the period of quieting (Fig. 1c).

reflected in the behaviour of the ion densities. During the phase of developed refilling (Fig. 3c) the 'local' changes of light ion densities are the same, or very similar to the changes of the electron temperature, frequently even in minute details.

DISCUSSION

During periods following magnetospheric substorms, enhancements in the latitudinal profile of electron temperature have been observed in the subauroral region of the ionosphere. These subauroral T_e peaks (and the related SAR arcs) have been demonstrated to be a symptom of the transfer of magnetic stormtime energy from the magnetosphere to the ionosphere (e.g. Kozyra *et al.*, 1986; Brace *et al.*, 1988). The mechanisms responsible for this energy transfer have not been fully resolved, but the magnetospheric source of ionospheric heating appears to be located in the equatorial region, where the ring current and plasmasphere overlap. As noted by Horwitz *et al.* (1986), the plasmaspheric ion temperatures and ionospheric T_e are often highly correlated in their latitudinal structure, which implies not only a considerable structure in the heat sources through adjacent flux tubes, but efficient heat conduction coupling of the ionosphere and plasmasphere along particular flux tubes.

The possibility of some connection of the process of refilling of the flux tubes with the ionospheric subauroral T_e peaks has already been suggested by Wrenn and Raitt (1975) and Wrenn *et al.* (1984). Recently, the assumption has been formulated that refilling of the plasmasphere from below brings the

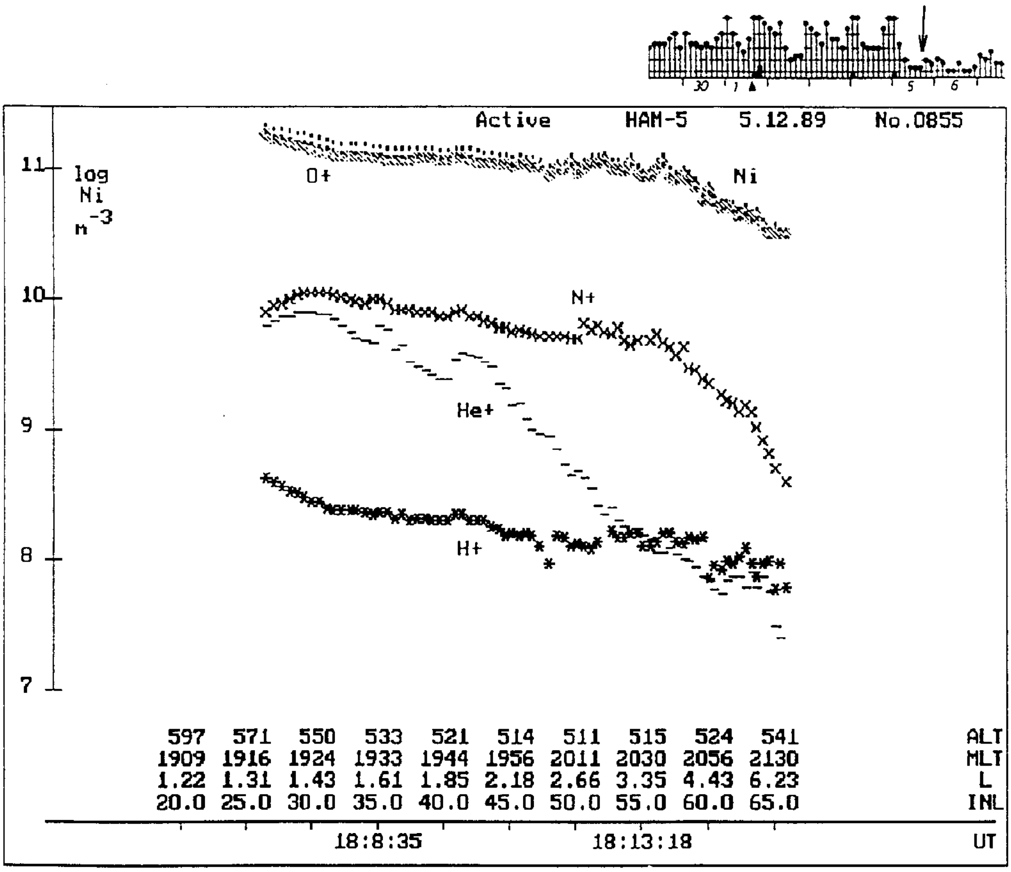

Fig. 2. Latitudinal variation of the ion composition in the evening ionosphere at smaller altitudes during the refilling period after the disturbance. The heavy ions and H^+ ions do not display larger local changes, whereas two 'local' peaks can be clearly observed in the He^+ concentration.

thermal ionospheric plasma into Coulomb contact with the ring current energetic particles, which sustains ionospheric heating on the affected L-shells during the refilling process (e.g. BRACE *et al.*, 1988). As OLSEN *et al.* (1987) reported, in the equatorial region, where the ring current and plasmasphere overlap, thermal H^+ and He^+ ions are heated by wave–particle interactions. The process forms a latitudinally thin zone where a small electrostatic potential barrier at the latitudinal edges of the equatorial trapped region can be present, which serves to reflect field-aligned light ions away from the equator back toward the ionosphere. This may have important implications for understanding how the plasmasphere refills.

In the outer plasmasphere region conditions are favourable for the excitation of many species of waves. One kind—VLF noise quarter-gyrofrequency emissions—occur only during the recovery periods following magnetospheric substorms (BOŠKOVÁ *et al.*, 1990, 1992). Their occurrence in satellite records shows very good correlation with simultaneously measured subauroral T_e enhancements. It is shown that the region where they are observed at low altitudes could be connected along magnetic field lines with the equatorial region of their origin. Their generation seems to be associated with the existence of a mechanism within the equatorial plasmasphere which accelerates thermal plasmaspheric electrons along geomagnetic field lines and thus, perhaps, with the process of refilling (e.g. SINGH *et al.*, 1986).

The observed close correlation of 'local' increases of light ion density, subauroral T_e enhancements and the occurence of VLF noise plasmaspheric emissions indicates that these light ion density variations are not only isolated ionospheric phenomenon. They could reflect a part of the complex process of plasmasphere–

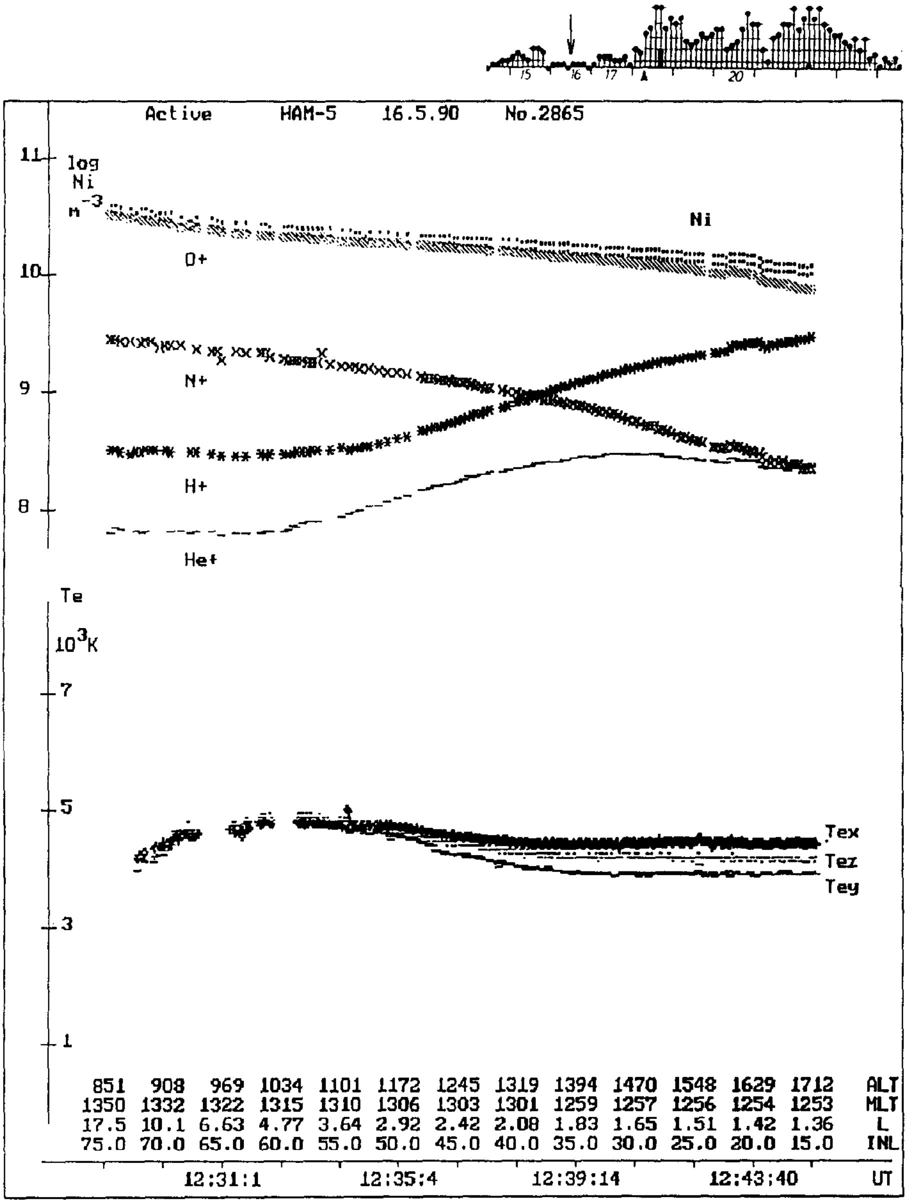

Fig. 3(a).

ionosphere coupling. We are suggesting that these 'local' increases of light ion density could be interpreted as a manifestation of a more intensive transport of light ions during the plasmaspheric refilling.

The different behaviour of H^+ and He^+ ions observed at low ionospheric altitudes during the night is consistent with this hypothesis. The H^+ ions are probably strongly bound by the familiar charge-exchange reaction to the O^+ ions, which significantly predominate in this region. The He^+ ions at lower ionospheric altitudes appear to be a very sensitive indicator of processes of interaction between the ionosphere and plasmasphere.

CONCLUSION

(1) During plasmaspheric refilling periods 'local' increases of density of H^+ and He^+ ions are detected

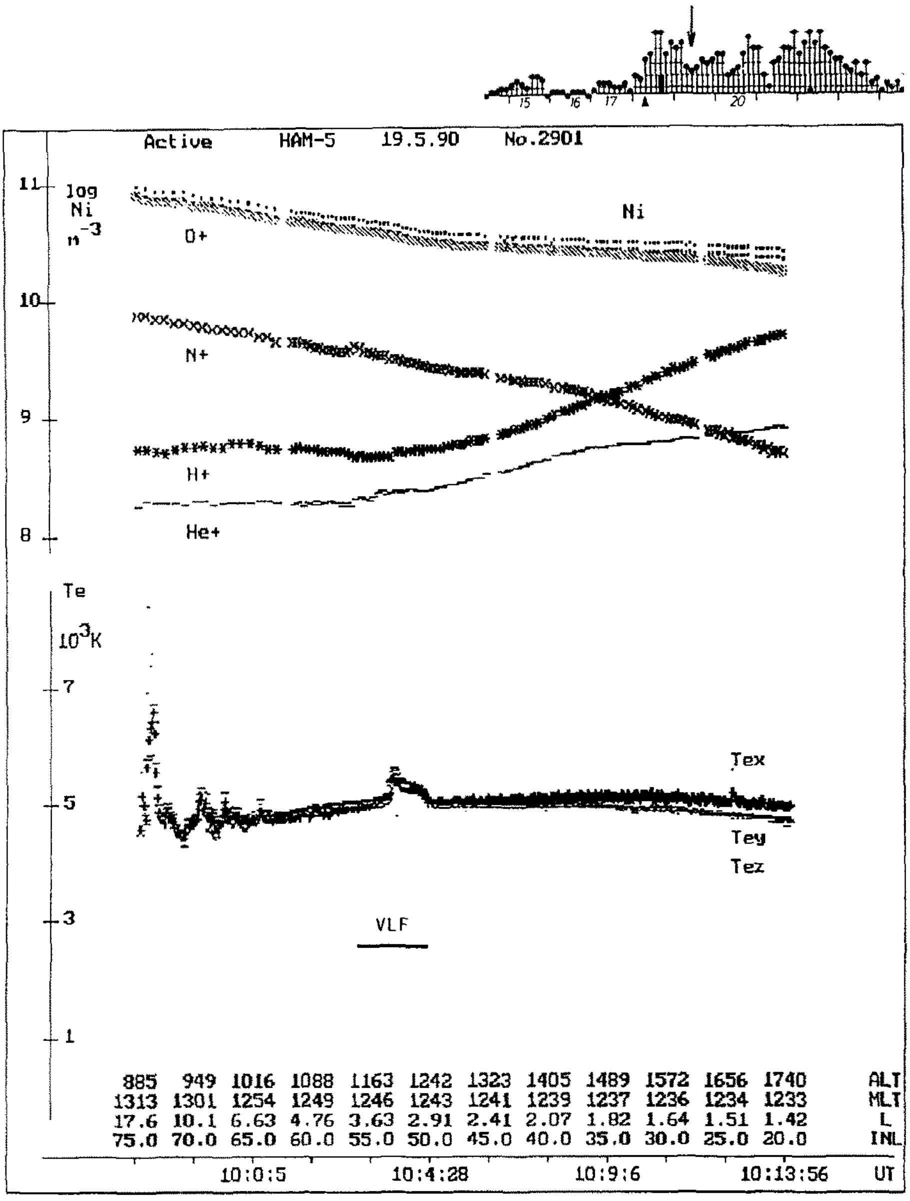

Fig. 3(b).

in narrow L-intervals within the plasmasphere. Subauroral electron temperature enhancements and VLF noise plasmaspheric emissions are frequently observed in the same L-intervals. We are suggesting that these 'local' increases of light ion density could be interpreted as a manifestation of variations in the refilling ion fluxes inside the plasmasphere. It is our opinion that the refilling process could be most intensive in these narrow L-intervals.

(2) At low ionospheric altitudes (up to 600 km) during the night, latitudinal variations only in He^+ density are observed, depending on the changing magnetospheric activity. The H^+ ions are probably strongly bound by the charge-exchange reaction to the O^+ ions. The He^+ ions at lower ionospheric altitudes appear to be a very sensitive indicator of the processes of interaction between the ionosphere and plasmasphere.

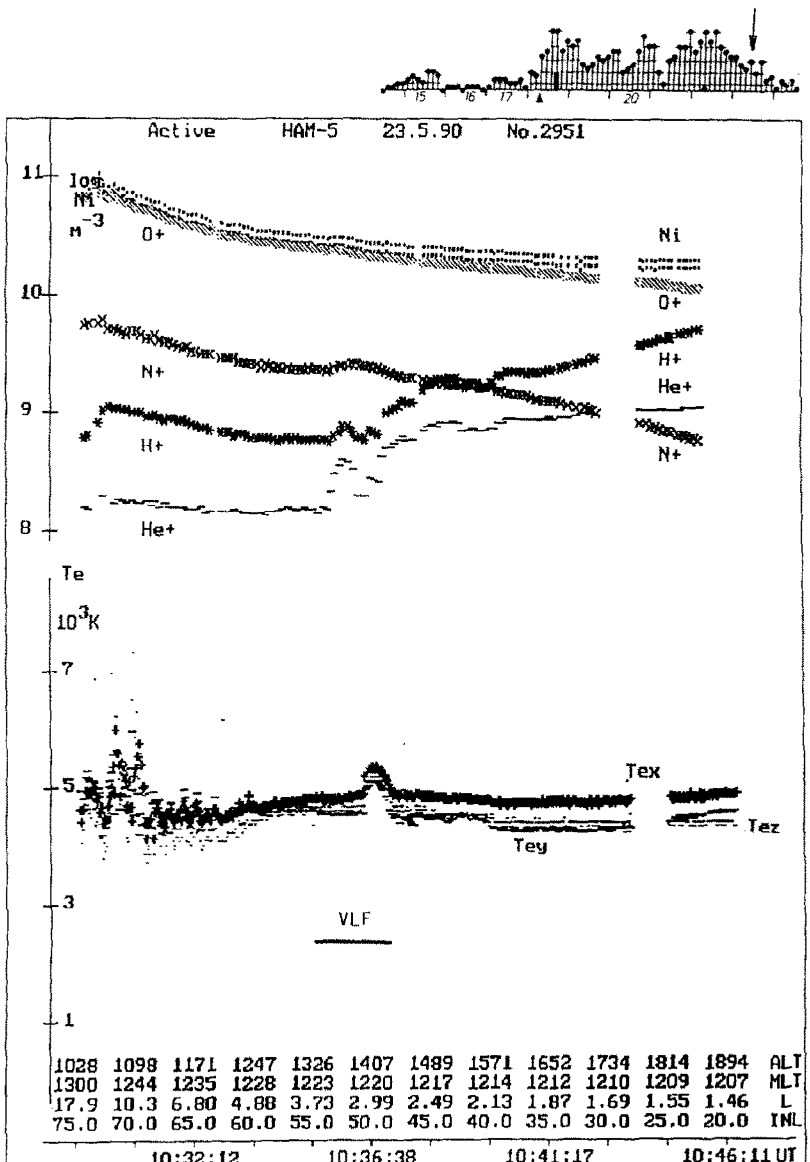

Fig. 3. Variations of plasma parameters (ion composition and electron temperature) in the noon local time sector at altitudes of 900–1900 km covering the period from magnetic quiescence (Fig. 3a), through the main phase of the disturbance with the sudden commencement and its partial quieting (Fig. 3b), to the developed phase of refilling which followed after another smaller disturbance (Fig. 3c). The horizontal line sections indicate the occurrence of the noise plasmaspheric VLF emissions.

REFERENCES

Bošková J., Jiříček F., Lundin B. V., Shklyar D. R. and Tříska P.	1990	*Ann. Geophys.* **8,** 755.
Bošková J., Jiříček F., Smilauer J. and Tříska P.	1992	*Studia geophys. geod.* **36,** 257.
Brace L. H., Chappell C. R., Chandler M. O., Comfort R. H., Horwitz J. L. and Hoegy W. R.	1988	*J. geophys. Res.* **93,** 1986.
Chandler M. O. and Chappell G. R.	1986	*J. geophys. Res.* **91,** 8847.
Fok M.-C., Kozyra J. U., Warren M. F. and Brace L. H.	1991	*J. geophys. Res.* **96,** 9773.
Guiter S. M. and Gombosi T. I.	1990	*J. geophys. Res.* **95,** 10,427.
Hoffmann J. H. and Dodson W. H.	1980	*J. geophys. Res.* **85,** 626.
Horwitz J. L., Brace L. H., Comfort R. H. and Chappell C. R.	1986	*J. geophys. Res.* **91,** 11,203.
Kozyra J. U., Brace L. H., Cravens T. E. and Nagy A. F.	1986	*J. geophys. Res.* **91,** 11,270.
Olsen R. C., Shawhan S. D., Gallagher D. L., Green J. L., Chappell C. R. and Anderson R. R.	1987	*J. geophys. Res.* **92,** 2385.
Rasmussen C. E. and Schunk R. W.	1990	*J. geophys. Res.* **95,** 6133.
Singh N., Schunk R. W. and Thiemann H.	1986	*J. geophys. Res.* **91,** 13,433.
Sojka J. J., Schunk R. W., Johnson J. F. E., Waite J. H. and Chappell C. R.	1983	*J. geophys. Res.* **88,** 7895.
Wrenn G. L. and Raitt W. J.	1975	*Ann. Geophys.* **31,** 17.
Wrenn G. L., Sojka J. J. and Johnson J. F. E.	1984	*Planet. Space Sci.* **32,** 351.