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INVESTIGATION OF CIRCUMTERRESTRIAL SPACE BY MEANS OF INCOHERENT SCATTER RADAR

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The results of investigations of ionosphere by means of the Kharkov incoherent scatter radar are presented. The measurements realized jointly with Massachusetts Institute of Technology (Haystack Observatory) and Cornell University (Arecibo Observatory) made it possible to reveal the longitudinal and latitudinal variations of topside hydrogen ion behavior. Ionosphere observations in Kharkov during the solar eclipse on August 11, 1999 first have been carried out up to 1500-km altitude. They have shown the significant changes in state of the F region and topside ionosphere including hydrogen ion concentration, plasma fluxes, that is the evidence of significant infringement of plasma exchange processes between ionosphere and protonosphere.

The parameters of ionized part of circumterrestrial space, i.e., the ionosphere are measured by means of satellites, rockets and ground-based radio physical methods. One of the most informative and accurate methods is the method of incoherent scatter. This method makes it possible to measure simultaneously and with high accuracy the basic parameters of ionosphere plasma: electron concentration N_e, electron and ion temperatures T_e and T_i, vertical velocity of plasma V_z, ionic composition in the altitude range from 100 up to some thousand kilometers.

The incoherent scatter method is based on the scattering of radiowaves on the thermal fluctuations of electron density. Since the effective reflecting surface of ionosphere plasma volumes that are sounded is usually extremely small the signal-to-noise ratio is equal to a few percents. Therefore, the high potential radio devices, i.e., incoherent scatter radars are necessary for determination of plasma parameters of such small signals. The unique incoherent scatter radar has been created near Kharkov city. Radar is equipped with one of the largest in the world zenith parabolic 100-m diameter antenna, with power transmitter device that has the peak pulse power in order of 4 MW and average power about 100 kW, high-sensitive receiver, which noise temperature is about 100 K and high-speed digital correlator. The techniques of measurement and processing of the scatter signal for signal-to-noise ratio less than 0.1 are elaborated.

There are eight observatories in the world: four in America and in other ones in Ukraine, Russia, Japan, Northern Europe, that carry out ionosphere investigations by means of incoherent scatter radars. The coordinated ionosphere observations are performed in accord with the International Geophysical Calendar.

The joint ionosphere measurements together with Massachusetts Institute of Technology (Haystack Observatory) and Cornell University (Arecibo Observatory) enabled revealing the longitudinal and latitudinal variations in behavior of topside hydrogen ions [1].

Figure 1 illustrates longitudinal comparison of the topside hydrogen ion behavior from simultaneous observation results obtained by radars of Millstone Hill (42.6 N and −71.5 E) and Kharkov (49.7 N and 36.3 E) on February 13-14, 1996. The two panels placed above show plots of the H^+ fraction at several topside altitudes as a function of local time. The Kharkov data clearly show much greater concentrations of H^+ ions in comparison with Millstone's observations at nearly identical altitudes.

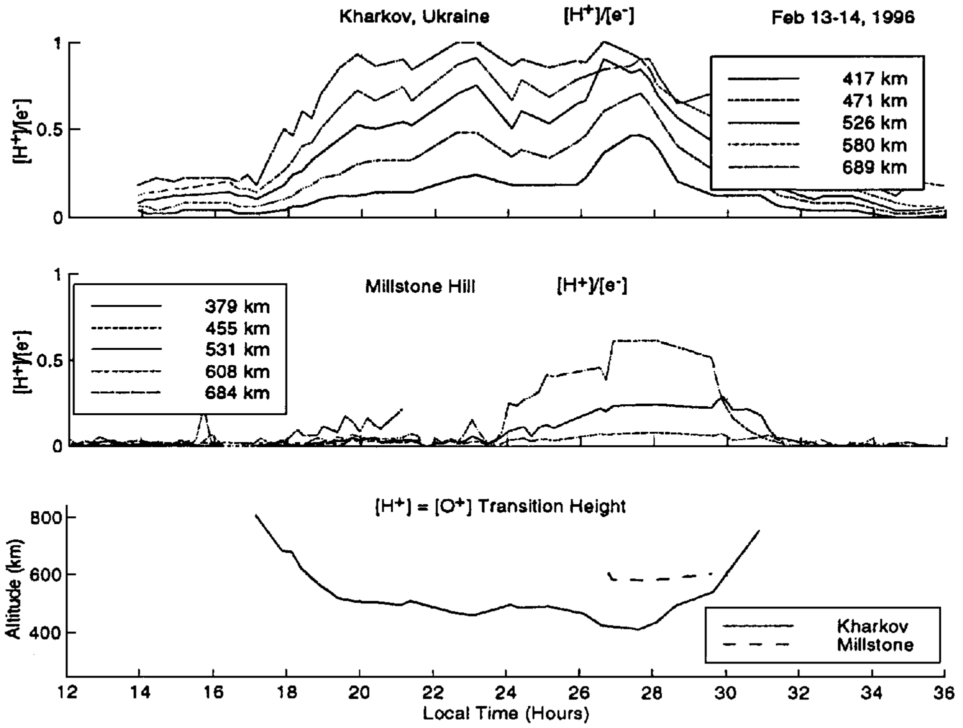

Figure 1. Comparison of observed topside H^+ ion fractions and the O^+/H^+ transition altitude from Kharkov and Millstone Hill data, showing significant longitudinal light ion variations

The bottom panel plots the altitude at which $[H^+] = [O^+]$. It is the important altitude of transition between ionosphere and protonosphere. Below this altitude the charge-exchange chemical processes dominated, above it diffusion and transport prevailed. In this quiet ionosphere, the Kharkov data show transition occurred at 450 to 500 km for most of night. On the contrary, the O^+/H^+ transition for Millstone Hill does not even decrease below 600 km until 0300 LT, and then only for 2 hours. This shows evidence of significant variations of longitudinal topside hydrogen ion.

The observed high concentrations of H^+ ions over Kharkov compared to ones over Millstone Hill can be possibly explained by the following reasons:

- the noncoincidence of the geodetic and geomagnetic poles and as a result the magnetic flux tube for Kharkov (geomagnetic latitude is 45.4 N, $L = 1.9$) has higher values of H^+ ion density than the magnetic flux tube for Millstone Hill (geomagnetic latitude is 53 N, $L = 3.2$) because of their different geometric sizes;
- the influence of additional ionosphere heating due to conjugate photoelectron energy input from Southern hemisphere. The point is that for Millstone Hill the conjugate ionosphere region occurs beyond the Southern polar circle, where the sun does not set in February, while in Kharkov the additional heating from the conjugate region (that occurs near Madagascar island) is absent at night.

Investigations during the period of more than solar activity cycle show that in summer electron temperature decreases near noon at solar activity maximum while that is not observed at solar minimum. Increasing of heat transfer due to large values of electron density N_e causes this fall of T_e.

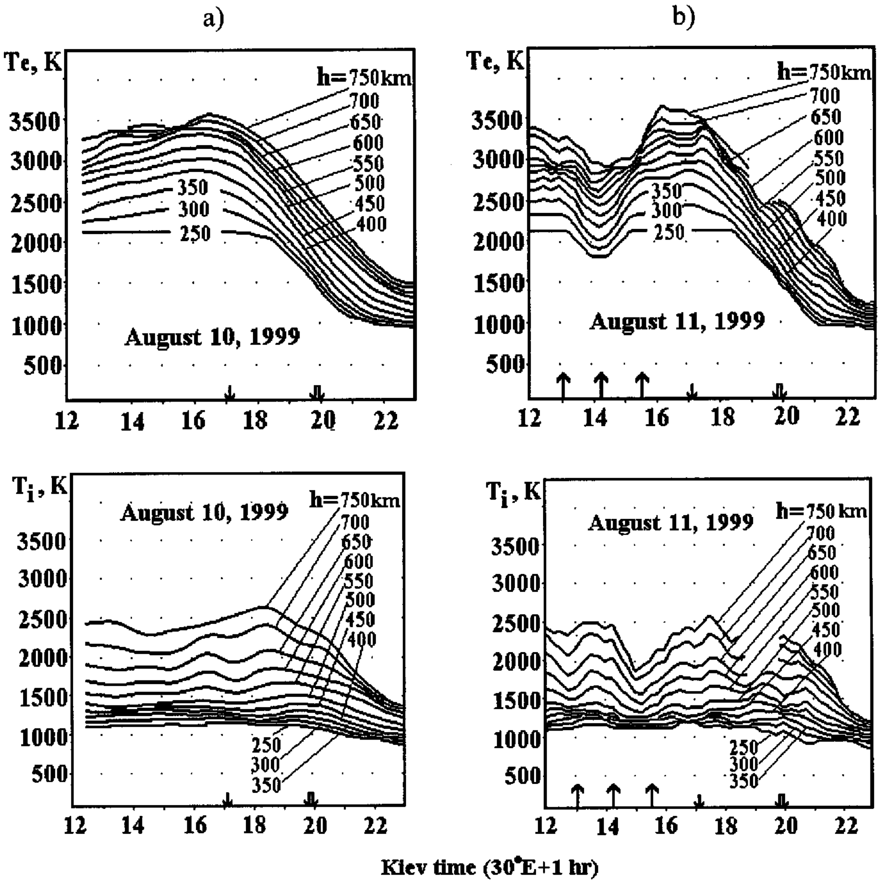

Figure 2. Time variations of electron T_e and ion T_i temperatures at the constant altitudes: a) on the control (preceding) day; b) on the eclipse day. The upward arrows mean the momentum of the first contact, maximum and last contact of eclipse; the downward arrows mean the sunset at Kharkov (double) and conjugate region (single)

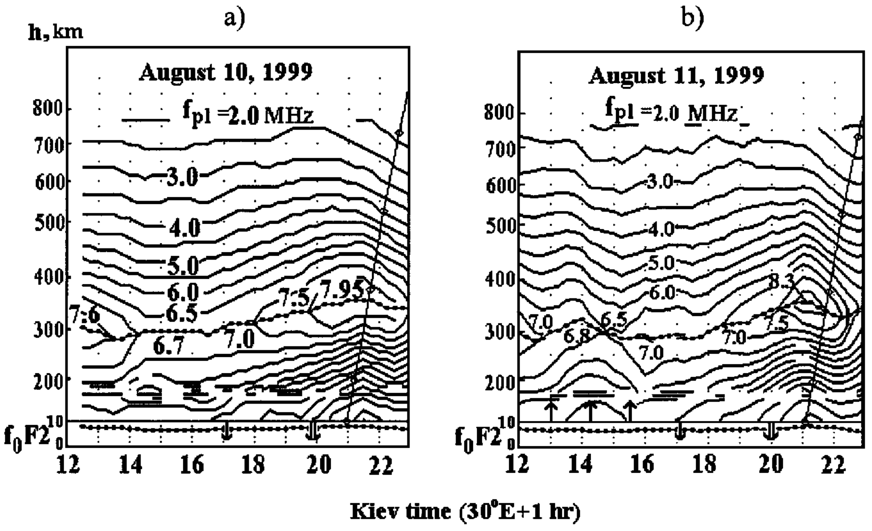

Figure 3. Contours of constant plasma frequency in the F region of the ionosphere as functions of height and time: a) on the day preceding the eclipse; b) on the eclipse day

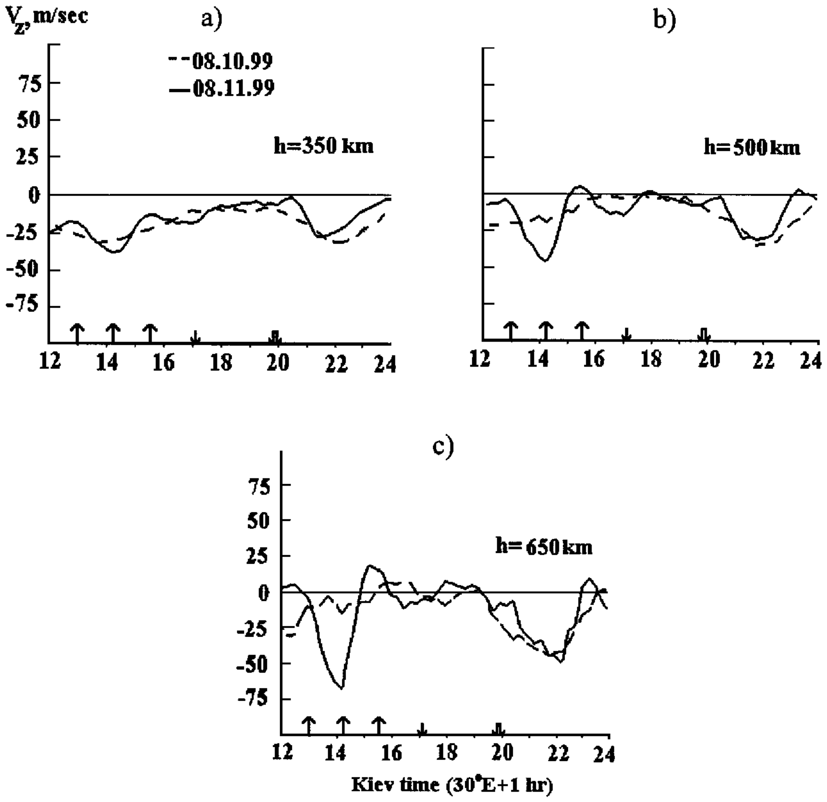

Figure 4. Time variations of vertical plasma velocity on control and eclipse days at altitudes of 350, 500, 650 km

The ionosphere effects of solar eclipse on August 11, 1999 were first observed by the Kharkov radar up to 1500 km. Investigations have shown the significant changes of ionosphere behavior [2].

At Kharkov the eclipse occurred during the period 1257—1529 according to Kyiv time with the maximum phase at 1413, when the disk of the sun was 83 % obscured on the earth's surface.

Eclipse caused the decrease of electron temperature by the value of ≈ 500—600 K at all altitudes with almost similar rapidity. The changes of T_e are centered at the time of eclipse maximum, following closely the variation of solar radiation flux. The ion temperature decreases together with the amplitude, which increases with altitude, but in contradistinction to the electron temperature there is a delay of the ion temperature change relative to the eclipse commencement. For low altitudes the fall of the ion temperature T_i is restricted from below by the value of neutral temperature T_N (Fig. 2).

During the eclipse, the decrease of incident flux of solar radiation leads to increase of losses rate. It causes the significant infringements of equilibrium between processes of production, losses and plasma transfer, which is described by the equation of continuity: $\frac{\partial N}{\partial t} = q - \beta N - \frac{\partial}{\partial z}(N_{V_z})$, where q is the rate of photoionization, β is the coefficient of linear losses, and V_z is the plasma vertical velocity. This infringement of equilibrium causes increase of downward plasma diffusion from upper F region to balance of the loss processes. As a result the electron density of the F layer peak did not change significantly (Fig. 3).

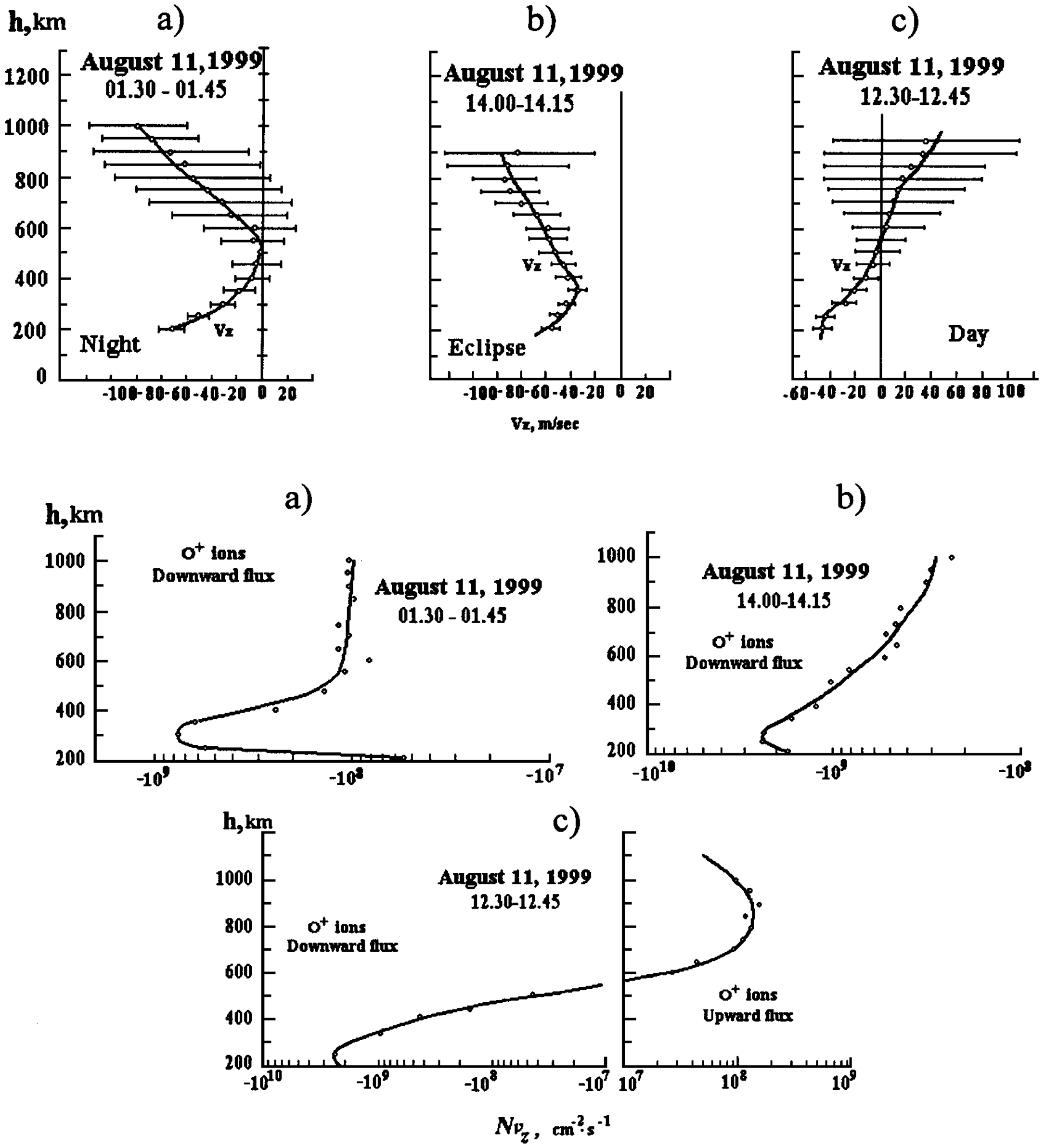

Figure 5. Altitude variations of vertical velocity of O^+ ions and the O^+ flux: a) at night, b) at the eclipse maximum time, c) in the daytime, before eclipse commencement

The downward plasma movement is confirmed by the significant increase of the downward vertical velocity of *F* region plasma, and at the altitude above sim 650 km V_z oscilating during the eclipse (Fig. 4). Figure 5 shows that during the eclipse maximum the altitude profiles of vertical velocity of O^+ ions and the O^+ flux have changed their shape and became similar to the nighttime profiles.

Figure 6 shows that increase of downward plasma diffusion from upper *F* region leads to increase of the specific percentage concentration of the hydrogen ion at maximum obscuration by value up to 40 % at low heights and decrease of the transition altitude, where $N(O^+) = N(H^+)$, to about 120 km.

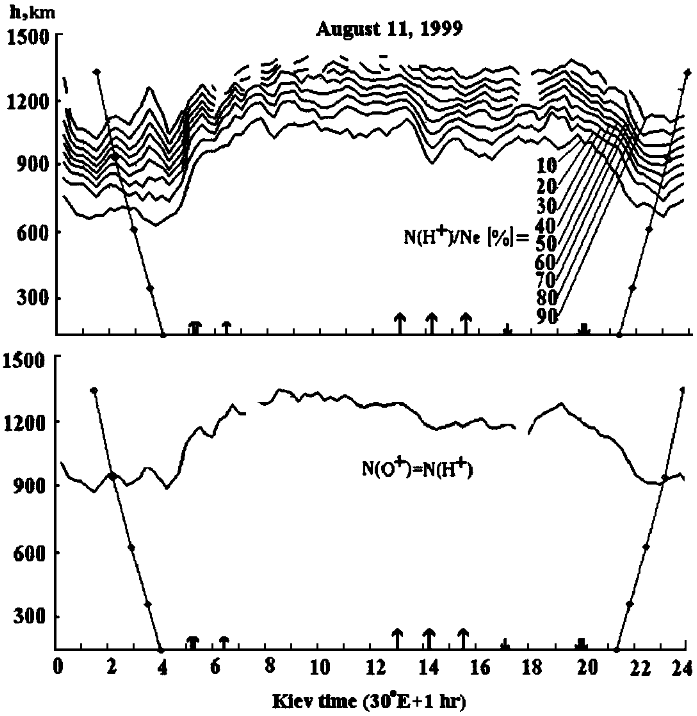

Figure 6. Altitude-diurnal variations of the percentage of H$^+$ ions and the topside transition height, where $N(O^+) = N(H^+)$, on the eclipse day

This change in the ionosphere behavior is the evidence of the significant infringement of plasma exchange processes between ionosphere and protonosphere during the solar eclipse.

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