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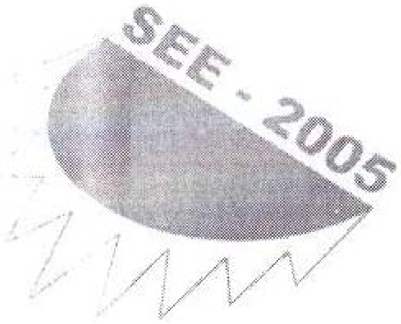
International Symposium

Solar Extreme Events

Fundamental Science and Applied Aspects

Nor-Amberd, Armenia
26 - 30 September 2005



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Foreword

From September 26 to 30, 2005, 75 scientists and students from 11 countries attended the second conference on Solar Extreme Events (SEE-2005) at Nor Amberd, Armenia.

Investigation of Solar Extreme Events is important for several reasons:

- It provides unique information about violent processes in the solar corona, including mechanisms of particle acceleration and Coronal Mass Ejection (CME);

- The study of propagation of huge amounts of solar plasma in the interplanetary space can shed light on its interactions with Interplanetary Magnetic Field (IMF) and ambient population of the Galactic Cosmic Rays (GCR);

- Interplanetary shocks and CMEs, along with solar particle and electromagnetic emissions, trigger various dynamic processes in the Earth's magnetosphere, causing global geo-effective events, including geomagnetic storms, heating of the upper atmosphere, changes in the electrodynamic properties of ionosphere, and creation of geomagnetically-induced surface currents. All this constitutes Space Weather (SW) conditions that change dramatically with SEE development.

- Space Weather can have a negative impact on the performance and reliability of space-borne and ground-based technology systems and endanger human health and life. It is of paramount importance to establish accurate methods for monitoring and forecasting SW disturbances and to identify the mechanisms of various SW effects.

The solar extreme events of October-November 2003, known as the Halloween events, have provided us with valuable information we can use to achieve better understanding of space weather. The SEE-2004 symposium in Moscow in July 2004 focused on comprehensive discussions of solar/heliospheric and magnetospheric aspects of these events. The data obtained onboard numerous satellites and from ground-based observatories were presented, discussed and interpreted both from experimental and theoretical points of view. Meetings during the COSPAR Assembly (Paris, July 2004) and the European Cosmic Ray Symposium (Florence, September 2004) revealed the substantial interest of the scientific community in the Halloween events as well as its continuous efforts to understand them in detail. New attempts to develop analytical techniques to incorporate data from space-borne and surface instruments have created new perspectives for understanding and forecasting the consequences of SEEs.

In 2004 several extreme events from the end of July to mid-November provided new examples of severe Geospace Storms and Forbush decreases. However, the 23rd solar cycle reserved its most severe events for the descending phase. The Ground Level Enhancement (GLE) from the event of January 20, 2005 , the largest one in nearly half a century, caused gigantic count rate increases on the neutron monitors of South Pole. The event displayed very complicated behavior, revealing diversity of particle acceleration mechanisms and the importance of numerous factors influencing particle transport, composition and event geo-effectiveness. The analysis of these events is underway; it will provide an extremely interesting basis for the understanding of SEEs and their effects.

The aims of SEE-05 were twofold:

(1) To provide a wide forum for discussion of recent Solar Extreme Events and their impact on technological systems and human environment, and

(2) To discuss directions of future research,
while promoting cooperation between groups with different research interests from different countries.

The scientific program was divided into three major areas:

- Energetic processes on the Sun during extreme events
- Magnetospheric response to solar extreme events
- Violent conditions of space weather
  and possibilities for its forecasting.

The conference sessions consisted of invited talks and contributed papers presented at poster sessions. High-quality invited talks were given by Vahe Petrossian, Igor Veselovsky, Riho Nymmik, Vladimir Kuznetsov, Galina Bazilevskaya. Leonid Lazutin, Yuri Stozhkov, Yuri Yermolaev, Erwin Flueckiger, John Bieber, Anatoly Belov, Michail Panasyuk, Frank Jansen andYasushi Muraki. The review talks highlighted how the Sun affects heliosphere and the Earth's environment, putting particular emphasis on energetic particle storms, solar eruptions producing these storms and their impact on Earth.

The conference reports demonstrated that integrated information about the consequences of Extreme GLEs and Geomagnetic Storms, including spectral forms, amplitudes and anisotropies of ion fluxes in the vicinity of Earth, strength and direction of the interplanetary Magnetic Field and the state of the magnetosphere, is indispensable for testing solar ion acceleration and propagation models as well as for early diagnostics of the expected impact of violent solar eruptions on technology.

New types of particle monitors, measuring secondary cosmic ray fluxes with inherent correlations are necessary for establishing world-wide networks for Space Weather forecasting. The International Heliophysical Year should provide an excellent opportunity for establishing these networks as well as involve participation of developing countries and, of course, European Space Weather initiatives.

The conference site was located near experimental facilities of Aragats Space Environmental Center (ASEC). The operation of ASEC monitors was demonstrated to the conference participants. In addition, the data base of solar extreme events detected by ASEC monitors was available in the computer class. The prototype detectors developed by Cosmic Ray Division of Alikhanyan Physics Institute (the conference host) were demonstrated during the poster sessions. It is planned to use these detectors for the new Space Weather network. Participants from Croatia, Bulgaria and Costa Rica expressed a wish to become a part of the new network by installing detectors in their countries. Negotiations concerning the formal aspect of this cooperation are underway.

The conference was supported by COSPAR, International Science and Technology Center (ISTC), National Foundation of Science and Advanced Technologies and WEB limited.

We thank Andranik Oganesyan, Veronika Moiseenko and Arthur Reimers for their help in preparing the volume of the SEE-2005 proceedings.

Ashot Chilingarian, Mikhail Panasyuk

August, 2005

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Regional Middle Latitude Ionospheric D-region during of 14–24 April 2002 Magnetic Storm Period

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Using a partial reflection technique, there were experimentally investigated the electron density, N, changes in the middle latitude ionospheric D-region during the 14 – 24 April 2002 magnetic storm. During the solar proton events, spe, increase by more than 50 – 100% in the electron density in the lower D-region of the ionosphere (~70 – 80 km) was observed for several tens of minutes. There were made estimations of the ionization rate. On the basis of the experimental data of electron density changes over the proton precipitation periods, corresponding fluxes were estimated, being $\sim 10^6 - 10^7 m^{-2} sec^{-1}$.

Introduction

Solar flares, being an indicator of processes influencing the geomagnetic field and near-the Earth plasma conditions, are very important for geophysicists. There are three main kinds of solar radiation, which particularly influence processes in the upper atmosphere and lead to appearing different phenomena: X-ray radiation, protons having energy of 1–100 MeV, and low energy plasma [1,2]. Commencement of magnetic storms, which – as known – occurs some time after flares on the Sun, is, as a rule, accompanied by flares of the X-ray (XRA), optic (FLA) ranges, by precipitations of protons (SPE) and electrons into the Earth ionosphere. These periodical events go on over tens of hours to 5 – 20 days (sometimes even more) depending on a value (class) of the magnetic storm. Energy electrons of $\varepsilon \geq 40$ KeV, precipitating out of the radiation belts, are a sufficient source of additional ionization of the middle latitude D-region of the ionosphere (up to the latitudes of ~ 45 – 60°) at the heights of z □ 80 – 100 km (see, e.g., [3 – 7]). Moreover, over the periods of solar flares and magnetic storms, satellite measurements often show higher (by a few magnitude orders) – comparing with those obtained under undisturbed conditions – values of proton fluxes. Such proton fluxes penetrate down to the lower ionospheric D-region heights (z □ 55 – 75 km), possibly causing considerable changes in this ionospheric part ionization [7 – 9]. Nevertheless, there are great difficulties in measuring fluxes of the precipitating charged particles at the middle latitudes and in obtaining correct estimations of their energy contributions at $z < 90 - 100$ km when using the satellite measurements conducted at considerably higher altitudes ($z > 200$ km). Investigating of magnetic storms and their influence on a near-Earth plasma state is urgent due to their great scientific and applied interest. Each magnetic storm is accompanied by a whole complex of phenomena in near-Earth plasma, being in its turn a unique phenomenon. As a rule, each magnetic storm has, besides general features, some specific feature characteristics, which – in their turn – cause corresponding characteristic changes in the atmospheric and ionospheric parameters.In a comparatively wide range, there are studied reactions of the upper ionosphere (mainly F-region) to magnetic storms at both middle and high latitudes. There is a large list of the publications (see, for instance, [5, 6, 10 – 14]). Nevertheless their investigating, modeling and predicting are far from the final stage. Responses of the middle latitude ionospheric D-region to the magnetic storms are of a complicated and ambiguous character. Statistics of the events (a number of reliable experiments) do not so far allow to determine many peculiarities of the response. Possible effects of the magnetic storms on the middle latitude ionospheric D-region have been studied not well: there are only incidental experimental investigations (see, for instance, [3, 7]). A role of the precipitating proton fluxes during the magnetic storm in the high latitude ionospheric D-region have been studied rather well [1–2]. Their possible effects in the middle latitude ionospheric D-region have been studied not well: there are only sporadic experimental investigation results (see, for instance, [3, 7, 15–16]). Therefore there is necessity of going on with the experimental investigations and of obtaining information in order to study this problem, which is important both for a purely theoretical aspects and for a solution of a whole number of practical tasks in radio communications, radio navigation, internet systems and others. Observing of every magnetic storm allows to widen the information on complicated and many-sided physical processes accompanying the storm.

The given paper shows experimental investigation results obtained by means of a radar of partial reflections (PR) of electron density variations in the middle latitude ionospheric D-region in vicinity of Kharkiv during the magnetic storm on 14 – 24 April 2002.

General information

The solar and geomagnetic data were obtained from the URL http://solar.sec.noaa.gov/weekly/. Geophysical conditions when carrying out the investigations were as follows: a geomagnetic storm began on 17 April and lasted up to 24 April. In Boulder, according to the USGS magnetometer data, a sudden storm commencement (SSC) in the geomagnetic field was recorded on 17 April at 11:09 UT (57 nT).A greater than 10 MeV proton event began at geo-synchronous orbit on 17 April at 15:30 UT, reached the peak of 24 pfu at 15:40 UT on 17 April, than ended at 00:35 UT in April 18. And a greater than 10 MeV proton event began on 21 April at 02:25 UT and ended on 26 April at 07:15 UT (peak flux of 2520 pfu on 21 April at 23:20 UT). The time dependences of the proton and electron fluxes, and also Hp-component of the geomagnetic field are shown in Fig. 1. The proton plot contains the five-minute averaged integral proton flux (protons/cm^2 sec^{-1} sr^{-1}) as measured by GOES-8 for each of the three energy thresholds: greater than 10, 50, and 100 MeV. The electron plot contains the five-minute averaged integral electron flux (electrons/cm^2 sec^{-1} sr^{-1}) with energies grater than 2 MeV at GOES-8. The *Hp* plot contains the five-minute averaged magnetic field H-component in nanoteslas as measured by GOES-8. The *H*-component is parallel to the spin axis of the satellite, which is nearly parallel to the Earth's rotation axis.

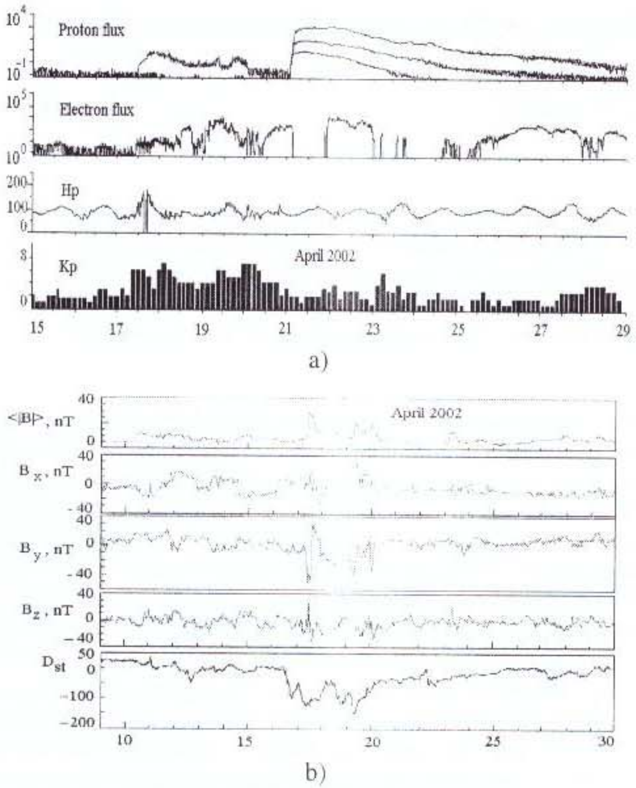

Fig. 1. Temporal dependences of proton and electron fluxes, Hp-component of the geomagnetic field, Kp index (a), and the interplanetary magnetic field and the D_{st} - indices, obtained by means of the "ACE" satellite(b).

The temporal variations in the interplanetary magnetic field and in the D_{st} - indices, obtained by means of the "ACE" satellite situated 1.5 mln km from the Earth, are shown in Fig. 2. The minimum value of the D_{st} –index was $D_{st\ min}$=155. As known [17], this index describes a disturbance degree of the geomagnetic field, which in its turn describes intensity of the magnetic storms. Over a storm period, the magnetic activity indices of A_{pmax} and K_{pmax} were 62 and 7, respectively. According to one of the classifications, the magnetic storm considered belongs to the strong and very strong ones [18]. The energy E_m and the power P_m of such magnetic storms are ~ 6.5 10^{15}J and ~ 7.5 10^{11} w, respectively. The E_m value is convenient to be estimated using the minimum $D_{st\ min}$ value [19]:$E_m=1.5\ E_M(D^*_{st}/B_0)$, where $E_M \approx 8\cdot10^{17}$ J is the dipole geomagnetic field energy near the Earth surface, B_0=3 10^{-5} T is the geomagnetic field induction value at the equator; the corrected D_{st} value is$D^*_{st}=D_{st}-bp^{1/2}-c$. Here b=5 10^5 nT/(Jm^3)$^{-1/2}$, c = 20 nT, $p = N_p m_p v^2_{sw}$; N_p and m_p are the density and mass of protons, v^2_{sw} is the solar wind velocity. The magnetic storm energy estimated by $E_m=1.5\ E_M(D^*_{st}/B_0)$, under $D^*_{st\min} \approx 220$ nT, was $\approx 6\ 10^{15}$J, the maximum power value (on 19 April) being $\approx 5.5\ 10^{11}$ w (Δt = 3 hours).

Instrumentation, Methods of Data Acquisition and Processing

The probing of the ionospheric D-region was performed with the Kharkiv V. Karazin National University MF radar [20] located at the Kharkiv V. Karazin National University Radio-Physical observatory.The specifications for the facility are as follows: operating frequencies f = 2.31 MHz, sounding pulse length τ =25 micros, repetition rate F = 1 per second, peak pulse power $P \approx$ 100 kw, antenna gain $G \approx$ 40. The amplitudes of signal plus noise of the ordinary and extraordinary polarizations, A_{sno}, A_{snx}, respectively, were digitized at a rate of 1 per second and recorded on magnetic tapes. In order to determine the signal amplitudes A_o, A_x, two samples of noise amplitudes A_{no}, A_{nx} were acquired within each interpulse interval. The measurements of A_{sno}, A_{snx} and A_{no}, A_{nx} were made within an altitude range of 60–126 km. The estimates of the mean squared signal amplitudes $<A^2_{o,x}>$ and noise $<A^2_{no,nx}>$ were made using 60 samples of the signal and 120 samples of the noise obtained over 60-s intervals. The estimate statistical errors have not exceed 10%. Using $<A^2_{o,x}>$, their ratio, $R = <A^2_x> / <A^2_o>$, was calculated and used further to obtain the electron density against height and time profiles, $N(z, t)$, (z is the altitude, t is time) by applying the differential absorption technique of [21] and the methods of [22]. To obtain the $N(z)$ profiles, we also used the model electron-neutral molecule collision frequency profile, $\nu(z)$, of [23]. The $N(z)$ profiles were estimated over intervals of 10 min during the entire observation period with an error of not more than 30%. The $N(t)$ plots appear down-shifted by ~5 min because of the 10-min averaging. The dates of the experiments are presented in Table 1. The measurements of $A_{sno}(z,t)$, $A_{snx}(z,t)$ and $A_{no}(t)$, $A_{nx}(t)$ were made before some days, during and after the magnetic storm. The comparison was made with the data obtained by the same equipment as that used on the magnetically quiet days (the control days). Controlling over the ionosphere state was carried out by means of an ionosonde.

TABLE 1
Information of the experiments.

Date	Data Acquisition Time Interval (UT)
April 10, 2002	01:27:00 – 18:10:00
April 16 – 17, 2002	20:05:10 – 21:00:00
April 24, 2002	01:30:00 – 18:30:00
April 25, 2002	04:25:00 – 14:45:00
May 03 – 04, 2002	21:15:00 – 11:25:00

Experimental results

In the April 17, 2002 experiment, after 12:55 UT, the strong partial reflection signals were intermittently observed in the z = 72–78 km altitude range over 10–25 min intervals (the signal-to-noise ratio was more than 3). It should be emphasized that in the absence of disturbances, signals from this altitude interval are usually absent or their levels are significantly lower than the noise levels. With regard to the electron density during these disturbed intervals, it increased by more than 100% (see $N(t)$ at a few z = *constant* in Figure 2). At this time, approximately after 12:00 UT, the GOES-8 satellite measurements exhibit a significant increase in the fluxes of more than 1, 10, 30, and 100-MeV protons. It should be noted that in the z = 81–90 km altitude range the electron density variations are less pronounced because the ionization at these altitudes is produced by the solar UV and X-ray radiations and is not affected by the protons. The more than 2 MeV electrons measured by the GOES-8 satellite to precipitate from the Van Allen radiation belts approximately after 11:00 UT produce a peak in ionization at even lower altitudes.

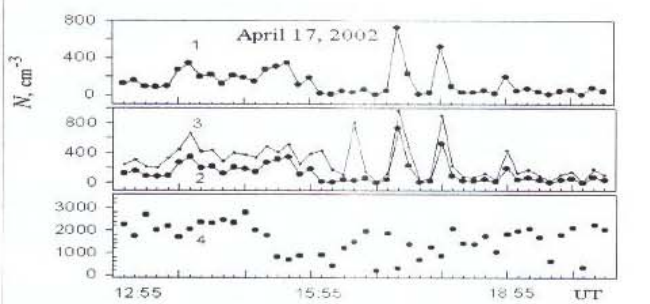

Fig. 2 Electron density against time for selected altitudes during April 17, 2002 (curve 1 for 72 km, 2 for 75 km, 3 for 78 km and 4 for 84 km).

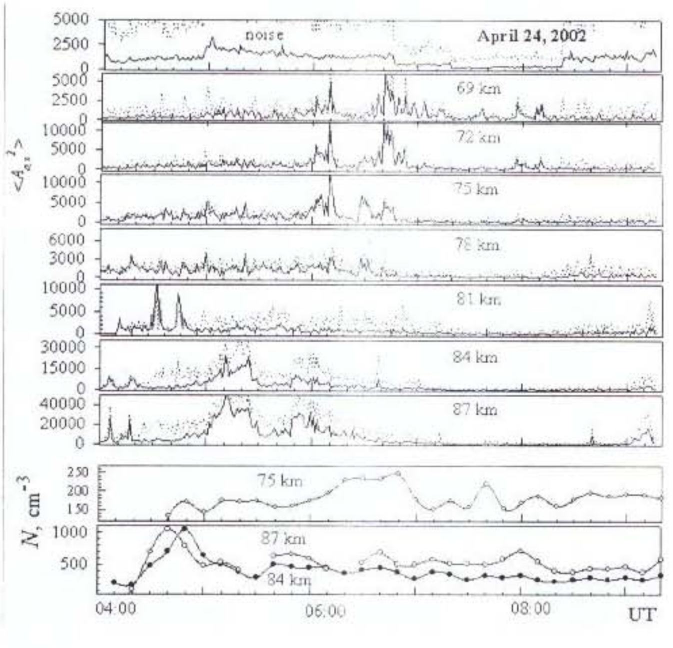

Fig. 3. Height-time dependences of one-minute averaged intensities of partial reflection signals $A_{o,x}(z,t)$ and noise $A_{n\ o,x}(t)$ and changes in the electron density in the middle latitude lower ionosphere D-region, obtained in the experiment of 24.04.2002 during proton precipitations.

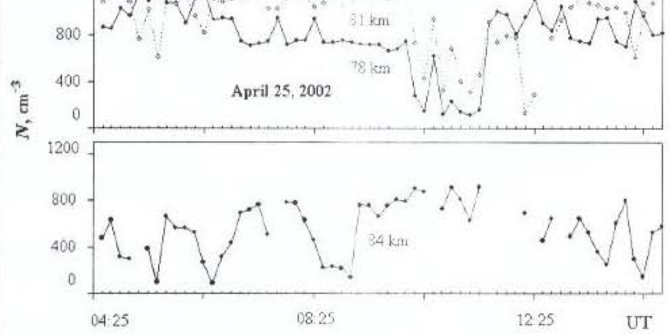

Fig. 4. Height-time dependence of the electron density in the D-region, obtained in the experiment of 25.04.2002

In the April 24 experiment (note that the precipitations of protons having $\varepsilon > 10$ MeV started on 21.04.2002 and went on till 26.04.2002) about 5–10 min after the *spe* commencement over 50–60 min within 69–75 km, there were recorded intensive signals (at $z > 78$ km there were no intensive PR signals), which were not observed before the event (the $< A^2_{o,x} >$ values became tens of times larger). The electron density within this height interval increased by about 50% over this period (see Fig. 3). At $z = 84$, 87 km over this time interval, the changes in the electron density corresponded to the typical diurnal variation. The *N(z)* increase at 04:20–05:00 UT being related to the high-energy electron precipitation after the magnetic storm. In the April 25 experiment, PR signals from the ionization irregularities within 84–93 km had weak intensity. Electron density values succeeded to be reconstructed within 78–84 km. An example of the *N(z)* variations at $z = 78$–84 km is shown in Fig. 4. From the beginning of the experiment and till about 10:00 UT, the *N(z)* values at $z = 78$–81 km exceed about 1.5–3 times the typical values under such conditions. This seems to have been caused by proton precipitations lasting, as noted earlier, till about 07:15 UT. At $z = 84$ km after about 09:10 UT, the*N(z)* values have a typical diurnal character under undisturbed conditions. Note also that over the growth period of the PR signal intensities and for about an hour after, the intensity of the noise and its dispersion decreased with a following recovery of the typical diurnal variation.On April 10 and May 3–4, 2002, experiments, which are characteristic of the undisturbed conditions, the features noted above were not detected.

Proton Modeling Results. Discussion

Using the methods from [7], on the basis of a mechanism for precipitation of the high energy particles (electrons, protons), we estimate the proton flow parameters. Using the electron density magnitudes under the undisturbed N_0- and disturbed N-conditions, there were estimated ionization rates of $q_0 = \alpha_0 N_0^2$, $q = \alpha N^2$. If the energy distribution of particles (which is unknown for the ground observations) is neglected, then the flow density of the particle power, $P_1 \approx 2\varepsilon_i \Delta z \Delta q$, where $\Delta q = q - q_0$; $\varepsilon_i = 35$ eV is the energy lost in one ionization act, Δz is the height range where the flow of the particles of the given energy ε is absorbed. On the other hand, the P_1 parameter is connected with the particle flow *p*: $P = \varepsilon p$ When having P_1, one can estimate the power and energy of the particles precipitating over the area *S*: $P = P_1 S$, $E = P \Delta T$, where ΔT is the precipitation duration. The methods of estimating the particle flow parameters consist in calculating the Δq value, the P_1, *p*, *P* and *E* values being calculated as well.In calculations based on the *N(z, t)*, it was assumed that $\Delta t = 1.2 \times 10^3$ sec and $S = 10^{14}$ m^2. For convenience of making estimates, we set $\Delta z = 10$ km.

TABLE 2
The proton flux parameters

Date	April 17, 2002	April 24, 2002
z, km	75	75
N_0, m^{-3}	1.1×10^8	1.6×10^8
N, m^{-3}	3.0×10^8	2.5×10^8
q_0, m^{-3}s^{-1}	1.2×10^5	2.6×10^5
q, m^{-3}s^{-1}	9.0×10^5	6.3×10^5
P_1, J m^{-2}s^{-1}	2.6×10^{-6}	1.2×10^{-6}

p, $m^{-2}s^{-1}$	0.9×10^{6}	4.0×10^{5}
P, W	2.6×10^{8}	1.2×10^{8}
E, J	1.0×10^{13}	4.8×10^{12}

The modeling results for the experiments discussed are presented in Table 2. They correspond in a good manner to the known data on the proton fluxes obtained experimentally and theoretically during disturbances having different natures (see, for instance, [7]). Unfortunately, there is no possibility of correct comparing the proton flux values obtained with those obtained over the observation period in the satellite measurements. This is caused by the fact that there are no reliable methods of recalculating proton fluxes, obtained in the satellite measurements at $z > 200$ km, into their values for the lower ionosphere considered. In the April 17, 2002 experiment, as mentioned above, the proton precipitation occurred. The effects appeared during the 13:45–14:15 UT interval after the SSC at 11:07 UT and with time delays of no less than a 30 min after the beginning of the solar proton event at 15:30 UT. From an increase in N at 72–75 km by a factor of 1.5–3 that was observed during the 13:45–14:15 UT interval and after 16:25 UT by a factor of up to 7, it follows that the ~10–20 MeV proton energy flux $p \approx 10^{7}$ m^{-2} s^{-1}. In the April 24, 2002 experiment, the proton flux was $p \approx 4.0\times10^{5}$ m^{-2} s^{-1} (Table 2).

Conclusions

Using the PR technique, in Kharkiv there were carried out observations of the middle latitude ionospheric D-region responses to the strong magnetic storm on 17–24 April, 2002. The magnetic storm was accompanied by intense proton precipitations. Though the main magnetosphere-ionosphere processes occur, as a rule, at the polar latitudes, information on strong disturbances of the electron density in the middle latitude lower ionosphere is of great importance owing to few such investigations available. Over the proton precipitation periods (according to the GOES satellite measurements), the strong PR signals were intermittently observed in the $z = 72$–78 km altitude range over 10–25 min intervals (the signal-to-noise ratio of more than 3). The data on the electron number density is inferred from the MF radar measurements and an error does not exceed ~30%. The information on proton fluxes is inferred from the experimental electron density data by using a 2-ion chemical scheme.

After the SSC at 11:07 UT on April 17, 2002, an increase in N by a factor of 1.5 – 3 in the 72 – 78 km altitude range was observed to last for 10 – 15 min, and after the solar proton event at 16:25 UT increases in N by a factor of up to 7 were intermittently observed till ~19:00 UT. The corresponding ~10–20 MeV proton energy fluxes were $p \approx 10^{7}$ m^{-2} s^{-1}.

On April 24, 2002, an increase in the electron density by 50% was observed to last for 45–50 min in the 72–78 km altitude range, and the proton flux was estimated to be $p \approx 4.0\times10^{5}$ m^{-2} s^{-1}.

In the April 10, 2002 and May 3 – 4, 2002 experiments, during quiet conditions, the features mentioned above were not detected.

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