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APPLIED RADIO PHYSICS: SPACE, ATMOSPHERE, AND EARTH'S SURFACE RESEARCH

INVESTIGATION OF VARIATIONS OF PARTIALLY REFLECTED SW SIGNALS AND RADIO NOISE IN THE MIDDLE LATITUDE D-REGION DURING THE SOLAR ECLIPSES

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The results of experimental studies performed with the help of the partial reflection technique near Kharkiv and of the analysis of effects in the variations of partially reflected SW signals and radio noises in the midlatitude lower ionosphere (D-region) during six partial solar eclipses are provided.

KEY WORDS: *partial reflection technique, partial solar eclipses, midlatitude lower ionosphere, air temperature, electron concentration, radio noises*

1. INTRODUCTION

The solar eclipse (SE) occurs quite seldom in a specific region, therefore, its observation provides for a unique opportunity to trace the dynamics of the near-Earth medium and specify the associated physical processes. During a specific eclipse the dynamic processes depend on the geographical situation, degree of disturbance of the Sun and near-Earth medium. A number of publications are related to the effects associated with the SE. The lower ionosphere (its D-region) response to SE still remains the least studied. Complexity and multiplicity of physical and chemical processes occurring at the said altitudes are making studying of the entire picture of the midlatitude D-region response to SE far more complicated. It should be added that total solar eclipses occur seldom in the middle latitudes, and the middle latitude ionosphere response to SE is masked by the influence of the processes in the auroral oval. Therefore, the problem of studying the SE effects in the ionosphere remains of fundamental importance. Its scientific value is represented both by further studying of the already revealed effects and by searching for other manifestations of the SE in the atmosphere, especially at the lower ionosphere altitudes. Regional particularities are of great importance for solving the purely practical problems.

The observations showed that SE are associated with a number of permanent effects in the ionosphere: decreasing of the electron concentration N and the temperature T of the medium, delays in decreasing of N with respect of the moment of occurrence of the eclipse maximum phase, as well as generation of the quasi-periodic (wave) disturbances in the ionosphere. At the same time, it should be taken into consideration that each SE possesses its own, individual particular features stipulated by different helio-geophysical and regional conditions reasoning a number of typical particularities in the lower ionosphere response parameters (see, for example, [1–4]). Experimental observations over the state of the midlatitude ionospheric D-region during significant partial SE in the daytime [1–3] are carried out with the help of the partial reflection technique (PR technique) at V. Karazin Kharkiv National University for quite a time already (starting from 1981). This paper provides the results of experimental studies performed with the help of the PR technique and of the analysis of effects in the variations of partially reflected SW signals and radio noises in the midlatitude lower ionosphere during six SE that occurred during different times of the day near Kharkiv, Ukraine on August 11, 1999; May 31, 2003; October 3, 2005; March 29, 2006; August 1, 2008 and March 20, 2015.

2. GENERAL INFORMATION ON THE EXPERIMENTS AND SOLAR ECLIPSES

The experimental studies were carried out near Kharkiv at the Radio Physical Observatory of V. Karazin Kharkiv National University with the help of the PR technique radar using the equipment [5]. During the observations the equipment parameters were the following – the transmitter pulse power $P = 150$ kW, the operating frequency $f = 2.31$ MHz, the probing pulse duration was 25 μsec, the pulse repetition rate $F = 1\ldots10$ Hz, the antenna gain ratio $G \approx 50$, and the investigated range of altitudes was 60…126 km. The altitude and time dependences of the amplitude of the mixture $A_{so,x}(z,t)$ of the PR signal $A_{o,x}(z,t)$ and radio noise $A_{no,x}(t)$ (where t is the time, the indices “o” and “x” correspond to normal and abnormal polarizations) were recorded during the experiments from 22 altitude levels starting from 60 km after every $\Delta z = 3$ km. The measurements were performed in continuous sessions with the duration from one to tens of hours. To separate the amplitudes of the PR-signals $A_{o,x}(z,t)$ there were also recorded the amplitudes of the radio noise $A_{no,x}(t)$ only (two samples within the frequency bandwidth of 50 kHz) during the periods of time preceding the probing pulse emission. The estimations of the average values of the intensities $< A^2_{x,o} >$ and noises $< A^2_{nx,no} >$ were performed on the basis of 60 realizations upon the time interval of 60 sec. Statistical error of the above estimates did not exceed 5%. The altitude and time dependences $< A_{x,o}^2 > (z,t)$ and $< A_{nx,no}^2 > (t)$ were calculated. Their smoothing with the help of the moving average method upon the intervals of 10...30 minutes with a 1…5-minute shift was additionally used for performance of the analysis. Based on the obtained values $< A_{x,o}^2 > (z)$ at the fixed altitudes with the step of $\Delta z = 3$ km it was calculated their ratio $R_{o,x}$ (the altitude profiles $R_{o,x}(z)$ were calculated on the averaging interval $\Delta t = 10$ minutes), which ratio was used subsequently for obtaining of the electron concentration profile $N(z)$ on the basis of the differential absorption technique [6]. The error in calculation of the profiles $N(z)$ did not exceed 30%. The algorithm of the fast Fourier transform on the time interval of 64 or 128 minutes was applied in order to estimate the periods of variations of $< A_{x,o}^2 > (t)$ or $N(t)$. The control over the state of the ionosphere was performed with the help of a standard ionosonde. The information about the space weather was taken from the World Data Centers with the access via the internet (http://www.sec.noaa.gov/). The atmospheric air temperature was measured at the altitude of 2 m over the surface of the Earth in Kharkiv, Ukraine using a standard thermometer after every 15…30 minutes (relative and absolute errors of temperature measurements were 0.3% and 0.1° correspondingly). Basic information about SE and the helio-geophysical conditions during the above-mentioned SE are provided in Tables 1 and 2. All the SE analyzed to be partial.

Maximum value of coverage of the Sun disk $A(t) = S / S_0$ (where S, S_0 are the area of the covered fraction of the Sun and the value of the function of its total area, correspondingly) was 0.77, and the minimum was 0.24 (ΣKp is the total daily value, P_p is the proton flux density, P_E is the electron flux density). Illumination of the surface of the Earth during the moments of maximum coverage of the Sun disk decreased by 1.3…5.2 times as compared with the background days. Decreasing of the near-surface atmosphere temperature that occurred within 1.2…1.7 hours during the SE amounted to 1.3…7.3 K as compared with the control days. During the partial SE on August 11, 1999 the measurements taken on August 10 and 12 were used as the reference ones. Minimum distance from the point of observation to the bandwidth of total SE with the width of 110 km was $R_{\min} \approx 900$ km. The moon shadow in the vicinity of the observation point glided along the surface of the Earth from the west to the east with the velocity of $\upsilon \sim 800$ mps. The geophysical situation during August 10 and 11 was quiet, the day of August 12 could be referred to the moderately disturbed days. Duration of the SE in the point of observations amounted to 2 hours 16 minutes. For the period of observations performed within 30.05–01.06.2003 during the SE of May 31, 2003 at the final stage of a small magnetic storm (MS) that occurred on May 29–30, the geophysical situation was not quiet. The values of the geomagnetic activity index K_p varied as follows: 29: 5-4-4-3-6-7-8-8, 30: 8-4-4-3-4-5-4-5, 31: 5-5 - 3-1-3-3-2-2.

TABLE 1: General information about the solar eclipses

Characteristics	11.08.1999	31.05.2003	3.10.2005	29.03.2006	01.08.2008	0.03.2015
Start of the SE (UT)	09:57	02:10	08:36	10:02	09:10	09:19
End of the SE	12:29	04:20	10:42	12:21	10:14	10:15
Time of maximum coverage of the disk	11:13	03:10	09:38	11:12	11:17	11:22
Maximum value of the Sun disk coverage function	0.73	0.64	0.24	0.77	0.44	0.45
Maximum decrease of illumination, times	3.9	3.6	1.3	5.2	2.6	2.8
Maximum value of the air temperature, degrees	32	20.5	18.5	14.5	32	9
Maximum decreasing of the air temperature, degrees	7.3	2.2	1.4	2.4	2.2	2.3

TABLE 2: Information about the helio-geophysical conditions during the observation periods

Date	**Characteristics**				
	A_p	$F_{10.7}$	ΣK_p	p_p	p^e
10–12.08.1999	7; 8; 10	127; 128; 123	11; 13; 16	(3.2; 1.3; 1.5)x10^5	(3.1; 1.9; 1.2)x10^6
30.05.–1.06.2003	49; 17; 19	117; 113; 112	37; 24; 22	(2.5; 8.0; 6.7)x10^5	0.05; 0.4; 1.8)x10^7
02–04.10.2005	13; 7; 4	75; 74; 83	22; 11; 4	1.5x10^4	(0.7; 1.3; 1.6)x10^8
28–30.03.2006	6; 4; 4	79; 82; 84	10; 13; 10	(1.6; 1.7; 1.6)x10^4	(4.5; 6.8; 3.5)x10^6
31.07–2.08.2008	13; 16; 17	96; 94; 97	13; 12; 13	(6.7; 6.9; 6.6)x10^4	(4.7; 4.5; 4.8)x10^6
19–21.03.2015	28;24;14	109; 113; 114	32;30;22	(7; 1.2; 0.9)x10^6	(5; 7.6; 7.9)x10^8

During the SE a very strong solar flare M3.9/2b, which was accompanied by the coronal mass ejection (CME), occurred in the visible region of the Sun 365 during the period of 05:13–06:38. LT. Duration of the SE in the point of observations was 2 hours, 10 minutes. During the partial SE of October 3, 2005 the observations were performed on 2–4.10.2003. (the reference measurements – on October 2 and 4). The geophysical situation was quiet during the period of observations; and the solar activity was low. The bandwidth of total SE had the width of about 100 km. Minimum distance from the point of observation to the bandwidth of total SE amounted to about 1000 km. The moon shadow velocity near the point of observation was about 750 mps. Duration of the partial SE in the point of observations was 2 hours 06 minutes. Observations during the SE of March 29, 2006 were performed on March 28–30. Data for the first and the third days were used as the reference ones. The geophysical situation was quiet during March 28–30. The solar activity was low during the period of observations. The bandwidth of total SE had the width of about 100 km. Minimum distance from the point of observation to the bandwidth of total SE amounted to about $R_{\min} \approx 900$ km. The moon shadow velocity near the point of observation was $\upsilon \approx 750$ mps. Duration of the SE in the point of observations amounted to 2 hours 18 minutes. During the SE of August 1, 2008 the observations were performed on July 31–August 2. Data for the first and the third days were used as the reference ones. The geophysical situation was quiet from July 31 to August 2. The solar activity was low during the period of observations. The bandwidth of total SE had the width of about 110 km. Minimum distance from the point of observation to the bandwidth of total SE amounted to about $R_{\min} \approx 4000$ km. The moon shadow velocity near the point of observations was about $\upsilon \approx 750$ mps. Duration of the SE in the point of observations amounted to 2 hours 16 minutes. It is important that these measurements were performed within one and the same month like in 1999. Substantial differences were represented by the fact that the extent of the Sun's disk coverage was by approximately 1.75 times higher during the SE of 1999. Moreover, during the period of SE on 11.08.1999 the solar activity was higher, and the geophysical situation was less quiet and proceeded to moderate disturbances of August 12, 1999. During the SE of March 20, 2015 the observations were performed on March 18–21. Data for the first, third and fourth days were used as the reference ones. The geophysical situation was quiet during March 19–21. The solar activity was relatively low during the period of observations. The bandwidth of total SE had the width of about 100 km. Minimum distance from the point of observation to the bandwidth of total SE amounted to about $R_{\min} \approx 950$ km. The moon shadow velocity near the point of observations amounted to $\upsilon \approx 750$ mps. Duration of the SE in the point of observations amounted to 2 hours 03 minutes. The specific feature of the SE on March 20, 2015 was that it happened at the background of the relaxing geospace storm that occurred on March 17–18, 2015.

3. OBSERVATION DATA PROCESSING RESULTS AND DISCUSSION

3.1 Atmospheric Temperature Variations

Figure 3 provides variations of the near-surface atmosphere temperature T_a during the days of SE and on the control days (blackened and non-blackened circles correspondingly).

It is evident that the SE of August 11, 1999 stipulated decrease of the temperature by 7.3°. The rate of decreasing and subsequent increasing of the values of T_a was comparatively low on that day: 11 and 5 degrees/hour correspondingly. On the background days of August 10 and 12 T_a varied with the rate of about 1 degree/hour in the middle of the day. As it is evident from Fig. 3 the value of T_a decreased by approximately 1.5–2° on the day of SE on May 31, 2003. On October 3, 2005 during the SE the air temperature continued increasing till approximately 09:30…09:40 same as before the SE. The increase of T_a ceased after occurrence of the phase of maximum coverage of the Sun disk. As compared with the background day of October 2 decreasing of T_a amounted to 1.3…1.4° by the end of SE. In approximately 15…20 minutes before the end of SE a comparatively fast temperature growth to the background values started within 15…20 minutes. The rate of increase of T_a was about 4 degrees/hour; during the background days that value amounted to about

1 degree/hour. During the SE of March 29, 2006 variations of T_a corresponded, in general, to the phases of SE. At maximum coverage of the Sun disk T_a decreased by 2.0…2.1°. By the end of SE it was restored to the background value. During the eclipse, the rate of decreasing of T_a was about 2 degrees/hour, and on the control day it did not exceed 1 degree/hour. During the SE of August 1, 2008 variations of T_a corresponded, in general, to the phases of SE. At maximum coverage of the Sun disk T_a decreased by 2.1…2.2°. By the end of SE it was not restored to the background value. During the SE of March 20, 2015 variations of T_a corresponded, in general, to the phases of SE. At maximum coverage of the Sun disk T_a decreased by 2.2…2.4°. By the end of SE it was restored almost to the background value. The rate of decreasing of T_a was about 2 degrees/hour during the eclipse. The rate of subsequent increase of T_a amounted to about 2 degrees/hour; on the background days that value was approximately 1 degree/hour. We admit that the meteorological situation on the control days was approximately the same as on the days of all the SE.

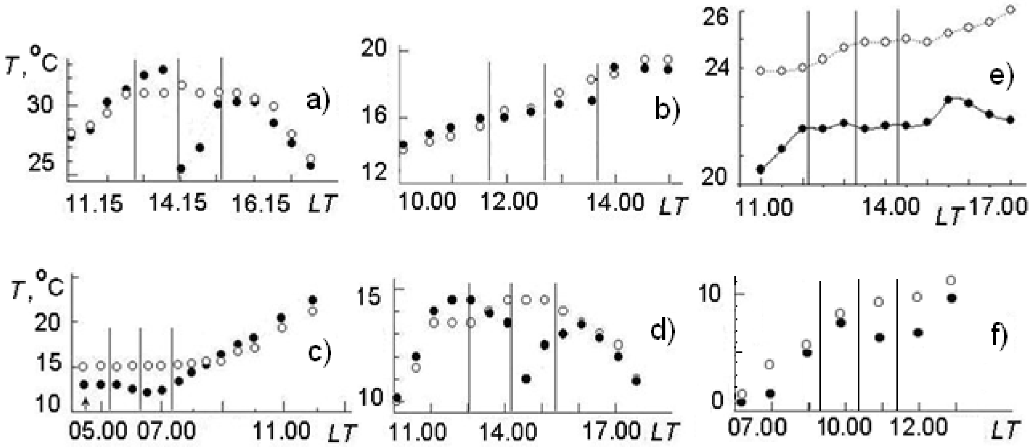

FIG. 3: Variations of the atmospheric temperature near the surface of the Earth during the periods of SE (blackened circles) and on the control days (non-blackened circles): a – on 11.08.1999, b – on 03.10.2005, c – on 31.05.2003, d – on 29.03.2006, e – on 01.08.2008, f – 20.03.2015. The moments of the start, maximum phase and end of SE are marked with vertical lines. The moment of the Sun rising over the surface of the Earth is marked with the arrow.

3.2 Variations of Partially Reflected Signals and Noises

Analysis of the considered experiments showed that the determined typical particularities in variations of the characteristics of the PR-signals and noises during the periods of all the SE turned out to be similar in most of the aspects. Therefore, further we shall consider them on the example of the SE of March 29, 2006.

3.2.1 Variations of average intensities of noises and PR-signals

Let us consider temporal variations of the average intensities (to put it shorter, hereinafter – the intensities) of noises and signals. On the day of SE, as it is evident from Fig. 4 (to save the space in the Figure we show them for one magnetoionic component only, the normal one) the intensity of noises $< A_{nx,no}^2 >$ started to decrease by the beginning of SE and decreased by ~ 1.4…1.8 times within ~ 40 minutes after it started; after that it started an inessential increase of the values of $< A_{nx,no}^2 >$ began within approximately 70 minutes, which changed subsequently for a substantially higher increase before late afternoon.

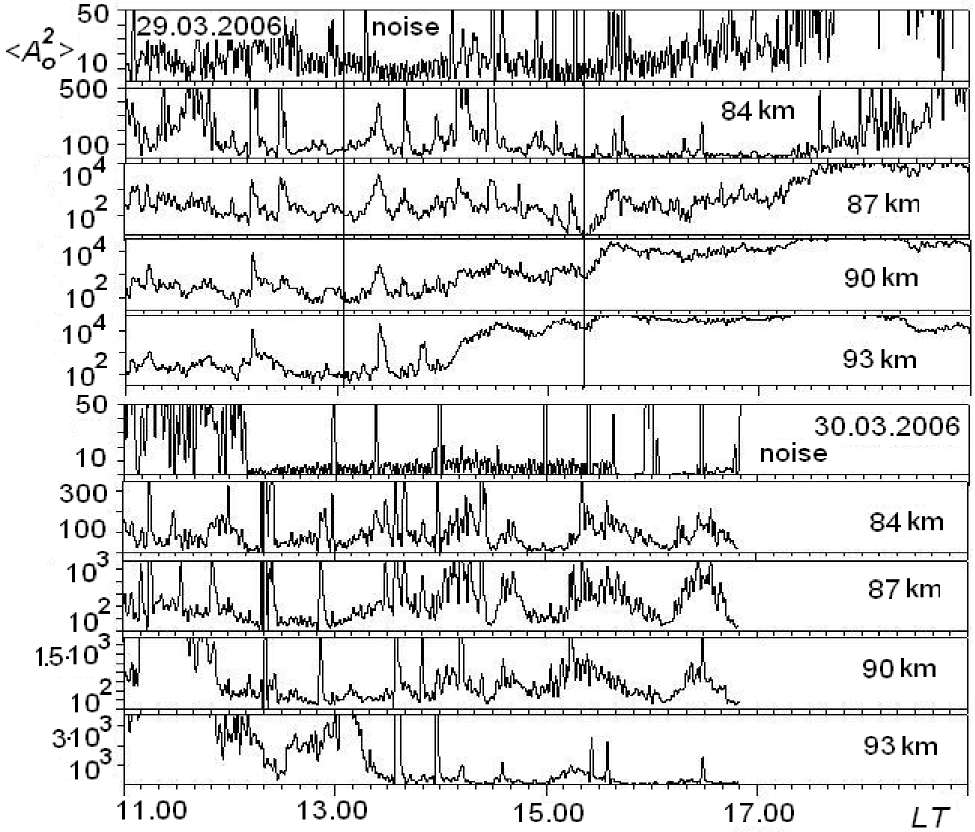

FIG. 4: Time and altitude variations of average intensities (in relative units) of the noise and PR-signal of normal polarization on March 29 and 30, 2006. Vertical lines denote conditional moments of the beginning and end of the SE. Averaging was performed upon the 1-minute interval.

We admit that during the period of SE on August 11, 1999, there occurred, on the contrary, increasing of the noise intensity and its dispersion by several times. That process started soon after occurrence of the moment of the eclipse and lasted for 20 minutes after the end of SE [1,3]. On the control day – March 30 – the intensity of noises varied inessentially during the same period of time as during the SE of March 29.

It is important to note that behavior of noises during all the experiments performed is, in general, similar to the described above and in [1,3] increasing of the intensity of the noises during SE. Apparently, the following effects are associated directly with the eclipse: 1) increasing of the noise intensity and its dispersion by several times. This process starts soon after occurrence of the eclipse and lasts for approximately 20 minutes after the end of SE; 2) increasing of average intensities of the PR-signal and the dispersion by several times at the altitudes of 81–87 km, which started soon after the first contact of the disks of the celestial bodies and lasted for tens of minutes after their last contact. Therefore, the behavior of noises can be explained same as in [1,3]. Increasing of the noise intensity and its dispersion after beginning of the eclipse can be explained in following way. The noise within the frequency bandwidth of the order of 2…3 MHz represents a superposition of the signals from the radio electronic means operating within this band. The solar eclipse is accompanied by decreasing of the electron concentration and absorption of radio signals in the ionosphere upon substantial areas with the typical dimension L of several thousand kilometers. Decreasing of the absorption results in increasing of the interference received by the main and side lobes of the PR radar antenna system pattern consisting of orthogonal vertical rhombuses. The same effect is revealed in a much stronger manner during the late afternoon time.

During the experiments performed on the day of SE there occurred an increase of average intensities of the PR-signal and its dispersion by single to hundreds of times at the altitudes of 81–96 km that started soon after the beginning of the SE and lasted for tens to hundreds of minutes afterwards (at the altitude of z < 87 km the increase of the values of $< A_{x,o}^2 > (t)$ changed for decreasing of the values of $< A_{x,o}^2 > (t)$ within approximately 2 hours after the end of the SE; after that there started a fast increase of the values of $< A_{x,o}^2 > (t)$ same as at z > 87 km). The same effect took place in other experiments too, it is similar to that described in [1,3]. The process explanation is provided *ibid.* And namely, it is known (see, for example, [7]) that $< A_{x,o}^2 > \propto \frac{\overline{\Delta N^2}}{\Omega_\pm^2 + \nu^2} \exp\{-4K_{x,o}\}$, where $\overline{\Delta N^2}$ is the intensity of the fluctuations N, $\Omega_\pm = \omega \pm \omega_L$, $\omega = 2\pi f$, $\omega_L = 2\pi f_L$, $f_L = f_B \cos\alpha \approx 1.3$ MHz, f_B is the gyrofrequency of the electrons, α is the angle between the vertical and the geomagnetic field inductance vector, ν is the rate of impacts between the electrons and neutrals, $K_{x,o}$ is the integral absorption coefficient of the PR-signal with X- and O-polarizations. The solar eclipse results in occurrence of the following processes: 1) decreasing of N and, thus, of $K_{x,o}$ as well; 2) decreasing of the gas temperature and, thus, of ν as well; and 3) variation and, under certain conditions, increasing of $\overline{\Delta N^2}$ (see [7]). All the above three factors can explain the increase of $< A_{x,o}^2 > (t)$. At the same time, the increase of dispersion of the intensities proves non-stationary mode of the processes as well as incomplete “deduction” of the noises. As it is already noted, dispersion of the noises also increased during the same time intervals.

On the control days the intensities of the PR-signal and its dispersion were subject to typical for the undisturbed conditions time and altitude variations for all the experiments considered above at the altitudes of 81…96 km.

3.2.2 Variations of the PR signal-to-noise ratio

Let us consider the example of time variations of the PR signal-to-noise ratio $s/n(z,t)$ provided in Fig. 5. Solid lines in the Figure are obtained with the help of the moving average method: the averaging upon 10 minutes and the shift upon 1 minute. Vertical lines denote the moments of beginning, maximal coverage and the end of SE. The averaging was performed upon the interval of 1 minute (marked with the points on the graph). Experimental data for March 28 and 30, 2006 are separated with a vertical line on the lower 5 diagrams.

The manner of behavior of such dependences turned out to be approximately equal within the entire D-region on the day of SE. We admit the following main particularities: 1) in about 10 minutes after the beginning of SE the values of $s/n(z,t)$ increased by tens to hundreds of times within several minutes and continued increasing during the entire period of the SE; 2) a comparatively smooth decreasing of $s/n(z,t)$ during several hours started after the end of the SE. Such variations of $s/n(z,t)$ appeared to be typical for all the considered experiments and they were not available on the control days. They are, apparently, associated with the eclipse. On the control days the manner of behavior of the value $s/n(z,t)$ was quite different as it can be seen, for example, from Fig. 5. In particular, an essential increase of $s/n(z,t)$ began by approximately one hour earlier than on the day of the solar eclipse of March 29, 2006.

3.2.3 Variation of the ratio between the intensities of abnormal and normal polarizations of the noises and PR-signals $R_{o,x}(z,t)$

Let us consider the time and altitude variations of the ratio between the intensities $R_{o,x}(z,t)$ (Fig. 6: the solid lines are obtained using the moving average method: averaging after 10 minutes, shifting after 1 minute).

Vertical lines denote the conditional moments of beginning, maximal coverage and the end of SE. The averaging was performed upon the interval of 1 minute (marked with the points on the graph). Experimental data for March 28 and 30, 2006 are separated with a vertical line on the lower 5 diagrams.

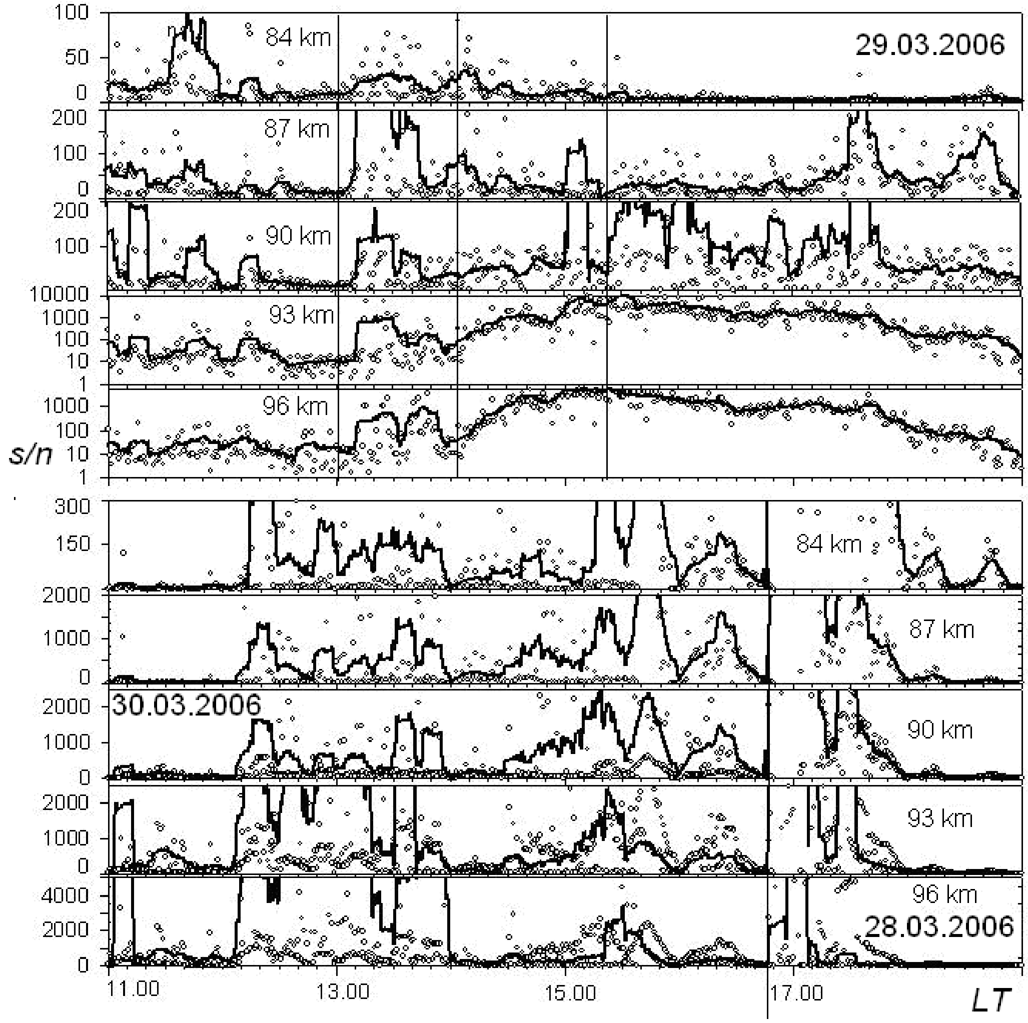

FIG. 5: Time and altitude variations of the PR signal-to-noise ratio of the normal polarization during the period of SE on March 28, 29 and 30, 2006

The following was typical for the ratio of the intensity of the noises: one day before the SE at approximately 13:00 $R_{o,x} \approx 0.3–0.5$ for the noise. After the period of time from 13:10 till 14:00 the above ratio increased up to 8…14 and continued during 4 hours. After 17:10 $R_{o,x} \approx 0.1…0.3$. On the day of SE, before the beginning of the eclipse the values of $R_{o,x}(z,t)$ amounted to ~ 0.8. In approximately 30 minutes after the beginning of covering the Sun disk the values $R_{o,x}(z,t)$ decreased by 1.5…2 times within several minutes and continued their smooth decreasing within approximately 2.5 hours. A slight increase of the values of $R_{o,x}(z,t)$ was observed after approximately 16 hours.

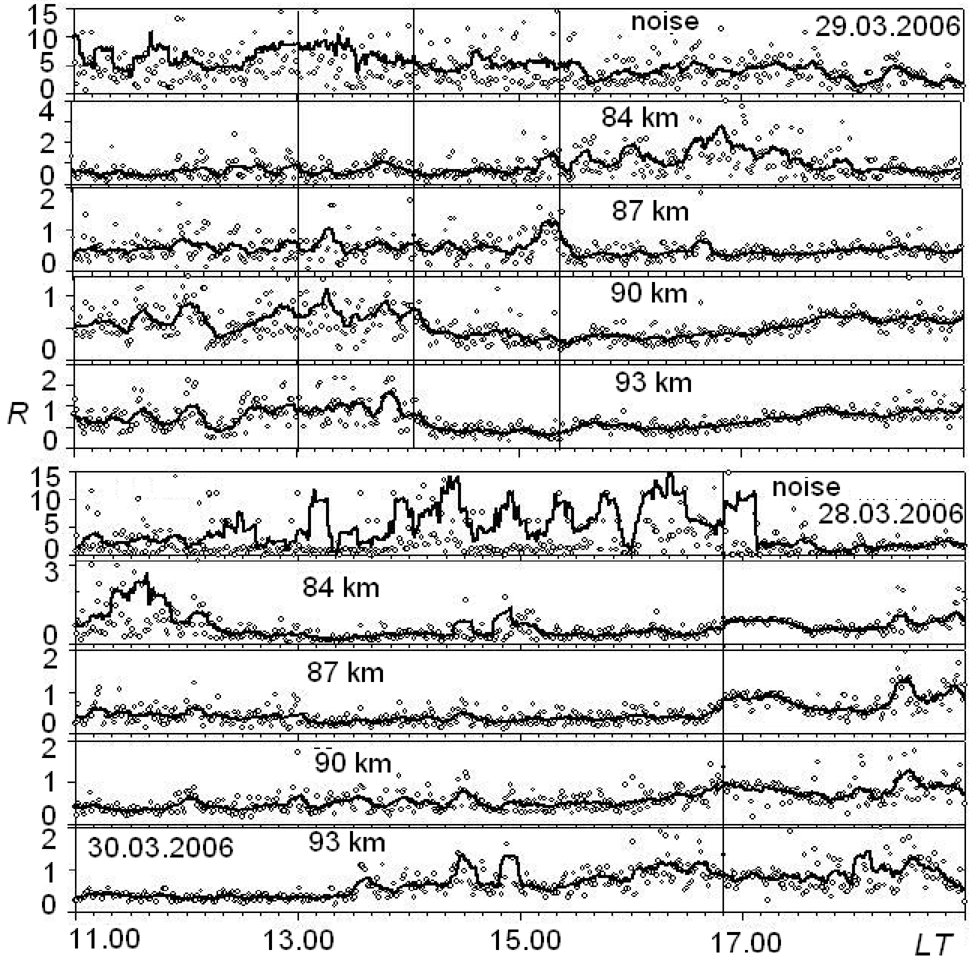

FIG. 6: Time and altitude variations of the ratio R between “x” and “o” polarizations of average intensities of the PR-signals and noises during the SE of March 28, 29 and 30, 2006

The following was typical for the ratio of the intensities of the PR-signals obtained on the day of SE: 1) at the altitudes of z < 87 km till 15:10 LT the value of $R_{o,x} \approx 0.5$. In 10 minutes before the end of SE the values of $R_{o,x}(z,t)$ increased by 3…4 times quasi-periodically with the period of about 50 minutes during approximately 150…160 minutes with further relaxation to the values of $R_{o,x} \approx 0.5$–0.7; 2) at the altitudes of z > 87 km after 55…60 minutes following the start of the SE (near the SE maximum) the values of $R_{o,x}(z,t)$ gradually decreased by about 2 times (the process lasted till the end of SE). Immediately after the SE a slight increase of the values of $R_{o,x}(z,t)$ was observed within several hours, which was typical for the undisturbed conditions as well. It is noteworthy that in this case the values of dispersion of the value concerned varied almost synchronously with its variation. On the control days – March 28 and 30 – the above described particularities of the time and altitude variations of intensities of the PR-signals were not observed.

Therefore, it was determined that all the considered experiments were characterized by a typical increasing of the ratio $R_{o,x}(z,t)$ by up to 3 times soon after the moment of occurrence of the eclipse at the altitude of 81 km accompanied with the increase of the dispersion σ_R^2 of the estimate of $R_{o,x}(z,t)$. After occurrence of the maximum eclipse phase the aforementioned parameters are decreased to their undisturbed conditions, and then – remain unchanged during approximately 2 hours. At the altitudes of 84 and 87 km the effect is similar in the qualitative terms although expressed weaker.

4. CONCLUSIONS

Comparative analysis performed for the SE effects in the near-surface atmosphere showed that the effects of the eclipse of August 11, 1999 could be considered as the most typical ones. The eclipse of October 3, 2005 occurred at about noon. The effects of the said SE generally resembled the effects of SE of August 11, 1999, however, they were expressed weaker. This is explained by a significant difference in the extent of coverage of the Sun disk A_{max} (0.24 and 0.73 correspondingly). The eclipses of March 29, 2006 and August 11, 1999 were very similar in terms of their parameters: the values of A_{ma} amounted to 0.77 and 0.73, the times of start and end of the SE were practically the same, and the moments of entering into the main phase differed by 1 minute. Temporal variations of the gas temperature in the near-surface atmosphere were close to the forecasted ones. They depended on the time of the day, the season and apparently, partially upon the cloud structure intensity. The largest variations of T_a occurred on August 11, 1999 (7.3°) at $A_{max} = 0.73$, the least ones – on October 3, 2005 (1.3°) at $A_{max} = 0.24$. The rates of variation of T_a: from 2 to 11 degrees/hour also varied substantially.

The associated with the solar eclipse variations of the parameters of PR-signals and radio noises within the middle latitude D-region, most of which are similar and observed during all of the periods of the observed SE, are determined and explained. It is determined that the typical processes last for 2…4 hours and are caused, primarily, by the cooling of atmospheric gas, decreasing of the ionization rate and further decreasing of the electron concentration.

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