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# IONOSPHERIC EFFECTS DURING THE TOTAL SOLAR ECLIPSE AT HIGH LATITUDES ON 20 MARCH 2015

S.M. Cherniakov, V.A. Tereshchenko, O.F. Ogloblina, E.B. Vasiliev, A.D. Gomonov

*Polar Geophysical Institute, Murmansk, Russia*
*e-mail: sergeich@pgi.ru*

**Abstract.** The medium-wave facility of partial reflections of the Polar Geophysical Institute (the observatory "Tumanny", 69.0N, 35.7E) has observed behavior of the lower high-latitude ionosphere during the 20 March 2015 total solar eclipse. There were several effects during the eclipse. On the height 60–80 km the ionosphere has shown the effect of a "short night", but at the higher altitudes local enhanced electron concentration regions were revealed and the behavior of the electron concentration had a wave-like form. The periods and behavior of waves during the eclipse were also calculated using data of the riometer at the obs. "Tumanny". It can be explained by influence of acoustic-gravity waves which originated after cooling of the atmosphere by the lunar shadow during its supersonic movement along the earth surface and the electron concentration change during the eclipse.

## 1. Introduction

The physical phenomena occurring during solar eclipses in the ionosphere are of interest as conditions of development of eclipses are known and it gives an opportunity to check the existing hypotheses and techniques of researches. Studying of solar eclipses gives useful information for specification of physical processes in the atmosphere and creation of more exact ionospheric models is promoted.

Observations of ionospheric effects of solar eclipses have begun right after putting into operation of vertical sounding stations of the ionosphere [*Schafer, Goodall*, 1932]. Early studies considered reaction of the ionosphere to a solar eclipse as the behavior of the environment during a short night. In the early seventies Chimonas and Hines [*Chimonas, Hines*, 1970] have assumed that during a solar eclipse the atmospheric gravity waves caused by supersonic passing of the lunar shadow across the Earth's surface and cooling of the atmosphere because of reduction of sunlight in the field of the shadow have to be observed. In the next years researchers have received confirmation of existence of the similar effect [*Sauli et al.*, 2007]. However it should be noted that the problem of definition of appearance of the acoustic-gravity waves caused by a solar eclipse isn't trivial one as in the ionosphere practically there are always wave processes caused by various sources that can complicate reliable definition of their appearance.

Further researches have shown that physical processes in the ionosphere during solar eclipses are more various and depend on many factors: time of day, season, degree of near-earth space disturbances, etc. All this belongs to the region *D*, the most difficult and least of all the studied part of the ionosphere [*Belikovich, et al.*, 2003; *Tereshchenko, et al.*, 2011a]. Experimental studies of the region *D* are complicated because of rather low values of the electron concentration, complexity and variety of the processes happening at these heights, absence of sufficient experimental base and difficulties when receiving exact and reliable measurements of sizes which can be used for understanding of the happening processes.

The majority of researches of a response to solar eclipses concern behavior of the ionosphere at the heights more than 100 km. Influence of eclipses on the lower ionosphere is investigated much less. The method of partial reflections was applied to studying of reaction of the lower ionosphere to a solar eclipse [*Belrose et al.*, 1970; *Belrose et al.*, 1972; *Benediktov, et al.*, 1978; *Belikovich, Goncharov*, 1994]. Interesting data on profiles of the electron concentration during a solar eclipse were obtained by means of rockets [*Kane*, 1969; *Faire*, 1970]. In the work [*Haug et al.*, 1970] results of comparison of simultaneous observations of the partial solar eclipse on May 20, 1966 in Greece by the partial reflections facility and during starts of rockets are considered.

Effects of solar eclipses in the equatorial ionosphere where they often occur are rather well studied. Reaction of the ionosphere at the middle latitudes was investigated less as in the region they were more rare. Despite rather simple nature of behavior of the middle-latitude ionosphere, still there is no standard theory of its reaction on solar eclipses. More it belongs to the polar ionosphere where the numerous ionospheric disturbances proceeding in the auroral zone can have a significant effect on the received results. Behavior of the polar ionosphere during solar eclipses was investigated rather seldom [*Tereshchenko et al.*, 2001; *Belikovich et al.*, 2008; *Tereshchenko et al.*, 2011b; *Tereshchenko et al.*, 2012]. Therefore observations of the ionospheric phenomena of solar eclipses by the method of partial reflections in the lower ionosphere of high latitudes are of interest.

## 2. Equipment and parameters of the eclipse

The partial reflections facility of the Polar Geophysical Institute (PGI) for research of the lower ionosphere consists of the transmitter, the receiver, the transmitting and receiving phased array and the automated system of data collection. It is located at the observatory "Tumanny" (69.0N, 35.7E) in the Murmansk region. Key parameters of the partial reflections facility and the technique of signals processing are specified in the work [*Tereshchenko et al.*, 2003]. Technical characteristics of the radar: working frequencies – 2.60-2.72 MHz; transmitter power in an impulse – about 60 kW; impulse duration – 15 microsec; sounding frequency – 2 Hz. The phase array consists of 38 couples of crossed dipoles, occupies the space of $10^5$ $m^2$ and has directional pattern width on the level of half power about 20°. Two circular polarizations are taken alternately which amplify by the direct amplification receiver with the band of 40 kHz. Registration of amplitudes of signals can be done in the range of heights of 30-240 km. A height step of data records is 0.5·n, where n = 1, 2, … .

The solar eclipse on March 20, 2015 at the observatory "Tumanny" was partial one with phase maximum of the eclipse 0.855 which took place at Tm=10:20:06 UT. The sun height over the horizon at the time of the greatest phase of the eclipse was h = 20.5°. The eclipse has begun at T1 = 9:15:48 UT. The end of the eclipse was at T4 = 11:23:58 UT [*Astronomical year-book*, 2014].

At the beginning of March, 2015 on the Sun there were several powerful X-ray flares. As a result of the processes happening on the Sun the magnetic storm has begun on the Earth on March 17, 2015. After March 17 the magnetic field of the Earth has begun to calm down. Variations of the geomagnetic field according to the data of the geophysical observatory "Loparskaya" of the Polar Geophysical Institute (68.63N, 33.28E) in the day of the eclipse on March 20, 2015 and in the control day on March 19, 2015 are given in Fig. 1 [*PGI Geophysical data*, 2015]. The geomagnetic situation at the period of the eclipse was weakly disturbed one (Kp = 5 - 3 5 - 3 3-2+ 3+ 4+, ∑=28).

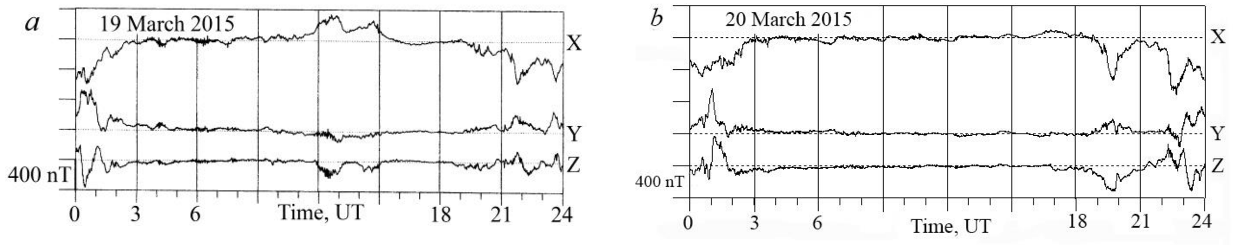

**Figure 1.** Geomagnetic field variations in the observatory "Loparskaya"

For separation of periodic signals in the considered data the digital bandpass elliptic filter (Kauer's filter) of the package of application programs of the MATLAB programming language was used. Feature of this elliptic filter is a steep decline in the amplitude characteristic. The bandpass elliptic filter is described by the following parameters: the size of pulsations of the amplitude-frequency characteristic (AFC) in a bandwidth, Rp, dB; the size of suppression of a signal in the rejection band, Rs, dB; an order of the filter, N; the cut-off frequency, fp. In the case of the bandpass filter the fp parameter is described by two frequencies of fp1 and fp2 and the filter makes a signal filtration in the bandwidth from fp1 to fp2. We used the following parameters of the bandpass elliptic filter: N = 8, Rs = 40 and Rp = 0.1. The cut-off frequencies were set at the each case of calculation. For the analysis of spectral components of data it was used the Morlet wavelet.

## 3. Results of observations

In Fig. 2 the behavior of amplitudes of ordinary and extraordinary waves and the electron concentration in the period of the March 20, 2015 eclipse is shown: in Fig. 2, a, b - amplitudes of ordinary (*Ao*) and extraordinary (*Ax*) waves, in Fig. 2, c – the electron concentration (*Ne*). The continuous line in the bottom of drawings has put eclipse time.

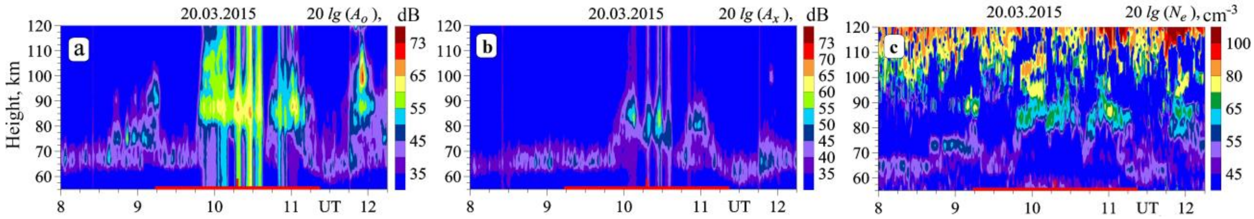

**Figure 2, a-c.** Amplitudes of ordinary (**a**), extraordinary (**b**) waves and the electron concentration (**c**)

Amplitudes of ordinary and extraordinary waves during the eclipse have experienced essential change at all heights. Heights of reflection have risen by 20-25 km, and amplitude has increased by 25-30 dB. The height of the electron concentration maximum has risen by 20-25 km. In the electron concentration and amplitudes of waves wave manifestations are noticeable.

In Fig. 3 the profiles of the electron concentration (PEC) in the control day on March 19, 2015 (at the left) and during the eclipse on March 20, 2015 (on the right) are shown. The first profile (09:15 UT) shows PEC before the eclipse. The second PEC (10:04 UT) is drawn in fifty minutes after the beginning of the eclipse and fourteen minutes prior to the eclipse maximum. It shows reduction of the electron concentration at all heights, but the greatest change takes place at the heights of 73-81 km. Here the electron concentration has decreased more than ten times. The third profile (10:34 UT) is drawn in fifteen minutes after the eclipse maximum. PEC shows increase in the electron concentration at the heights over 73 km, and at the heights of 68-72 km shows reduction. At the same time at the height of 85 km the local maximum of the layer is formed. The fourth PEC (11:11 UT) is drawn ten minutes until the end of the eclipse. Lower than 80 km the profile of the electron concentration is similar with the PEC before the eclipse, i.e. it has returned to the initial state. Higher than 80 km the electron concentration has increased and at the height of 83 km the local maximum was created. The fifth PEC (12:05 UT) is drawn for the ionosphere after the eclipse. It is visible that it has returned to the condition of the ionosphere before the eclipse. The behavior of PEC in general corresponds to approach of "short night", i.e. reduction of the ionizing radiation during the eclipse.

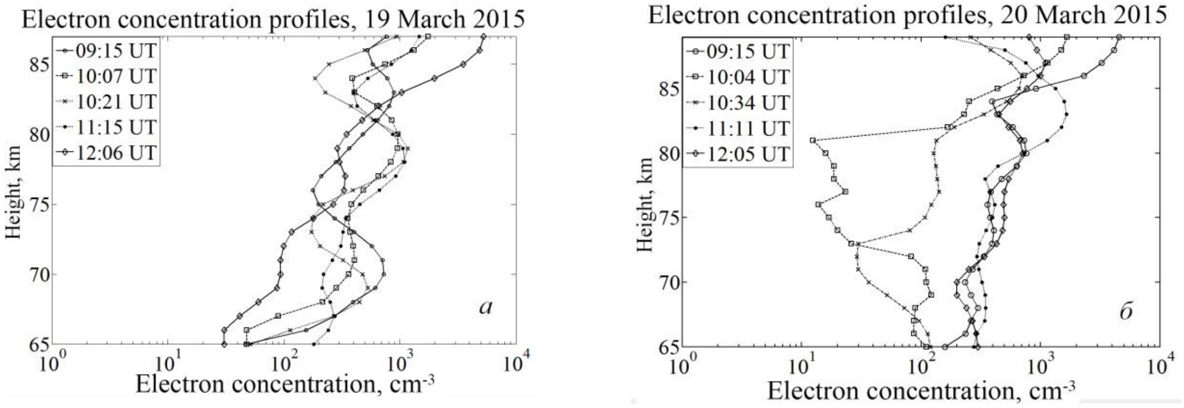

**Figure 3**. The electron concentration profiles in the control day on March 19, 2015 (at the left) and during the eclipse on March 20, 2015 (on the right)

In Fig. 4 the behavior of the electron concentration at the heights of 68 km and 90 km is shown. Letters B, M and E are designated the beginning, the maximum and the end of the eclipse, respectively (these designations are identical ones in all subsequent figures). A geometrical eclipse function represents the ratio of an open part of the solar disk unscreened by the Moon disk to the full disk of the Sun. It changes from one (1.0) before an eclipse and to zero (0) at a total eclipse. As an ionization function during an eclipse depends on an open part of the solar disk, one may say, that the behavior of an ionization function during an eclipse is similar to behavior of an eclipse function. Since an eclipse function is normalized value, it can be adjusted to a profile of the electron concentration at the chosen height and we can compare their behavior. The shaped line has shown behavior of the reduced eclipse function. Actually this is the comparison of behavior of an ionization function and a profile of the electron concentration at the chosen height.

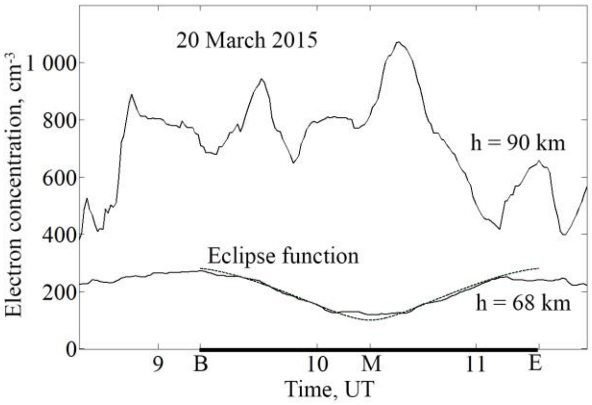

**Figure 4.** Temporal profiles of the electron concentration at the heights of 68 km and 90 km during the solar eclipse on March 20, 2015

By consideration of behavior of the electron concentration at different heights it has turned out that during the eclipse the good consent of behavior of a temporal profile of the electron concentration with the reduced eclipse function was observed only at some heights. In Fig. 4 changes of the temporal profile of the electron concentration at the height of 68 km during the eclipse well corresponds to changes of the profile of the reduced eclipse function (i. e. an ionization function). During the eclipse typical temporal profiles of the electron concentration were profiles for which it was impossible to define a minimum of the electron concentration at the eclipse maximum. The example of it is the profile of the electron concentration at the height of 90 km (Fig. 4). The similar behavior of profiles of the electron concentration is caused, probably, by wave processes at various heights of the lower ionosphere.

The typical periods of Brunt–Väisälä frequencies in the atmosphere are equal 5-10 minutes depending on a condition of the atmosphere [*Brunelli, Namgaladze*, 1988]. Therefore in the electron concentration and amplitudes of ordinary and extraordinary waves presence of wave processes with the periods from 10 to 80 minutes (internal gravity waves) has been analyzed. For the analysis of the obtained data the digital bandpass elliptic filter which parameters have been described above was used.

For examples, we consider the data of calculation of the periods of wave manifestations in the electron concentration for heights of 68 km ("short night") and 90 km (wave processes). The filtered electron concentration and its wavelet-spectrum for heights of 68 km (at the left) and 90 km are given in Fig. 5 (on the right).

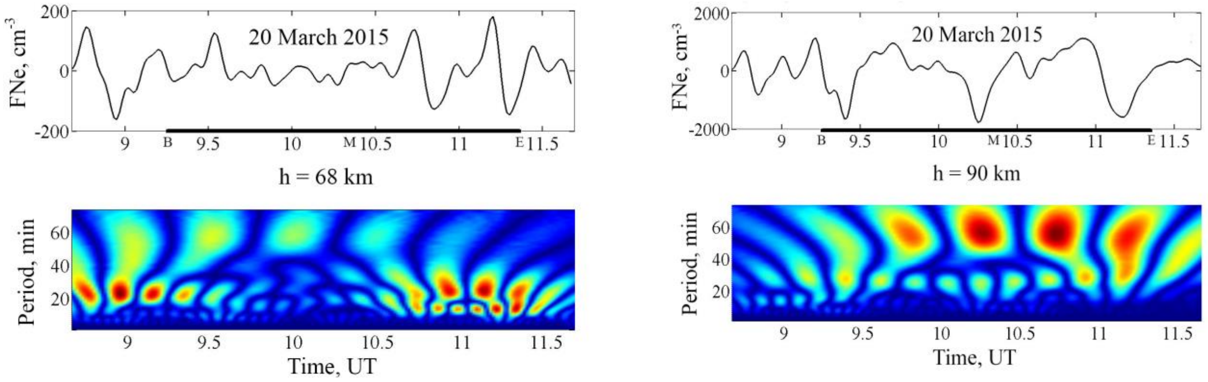

**Figure 5.** The filtered electron concentration (upper) and its wavelet-spectrum (bottom)

At the beginning of the eclipse in the electron concentration at the height of 68 km waves with the periods of 23 and 57 minutes have been seen. The wave with the period of 57 minutes was gradually weakened and by the end of the eclipse has disappeared. The wave with the 23 minutes period also weakened to the eclipse maximum, but at the same time at 9:30 UT has begun to transform to two weak waves with the periods of 18 and 28 minutes. At the eclipse maximum waves with the periods of 18 and 28 minutes have begun to transform to the waves with periods of 23 and 37 minutes, respectively. At 10:40 UT the wave with the period of 23 minutes transformed to two waves with the periods 14 and 28 minutes. At the same time the wave with the period of 37 minutes began to transform to the wave with the period of 28 minutes. , and the wave with the period of 14 minutes has amplified. By the end of the eclipse all waves have weakened.

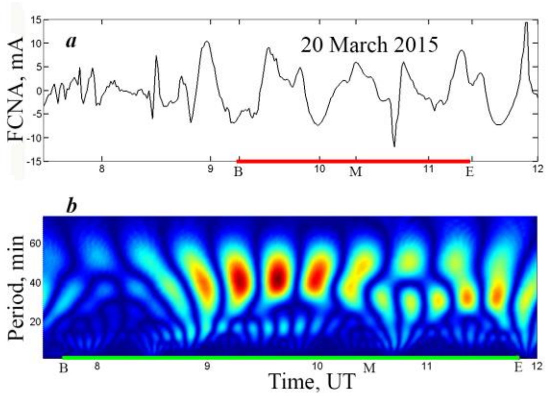

**Figure 6.** (**a**) the filtered data of cosmic noise absorption level according to the riometer measurements, (**b**) the wavelet-spectrum of the filtered data

At the height of 90 km at the beginning of the eclipse the wave with the period about 46 minutes had appeared. At approach to the maximum of the eclipse, the period of the wave had begun to increase till 57 minutes, at the same time its intensity also increased. After the eclipse maximum intensity and the period of the wave began to decrease. Before the eclipse the stronger wave was the wave with the period of 27 minutes. At approach to the eclipse maximum the amplitude of the wave decreased, but after the maximum it increased the intensity. Moreover, the wave period after the maximum began to increase continuously and by the end of the eclipse its period and the decreasing period of the wave of 57 minutes passed into one period about 46 minutes.

At the height of 68 km waves with the smaller periods of 10-30 min were more intensive ones. At the same time at the eclipse maximum these waves decreased on amplitude, and then increased again.

At the same time with observations by the facility of partial reflections, measurements of cosmic noise absorption with use of a standard riometer were carried out. In Fig. 6, *a* the filtered data of cosmic noise absorption level with the periods from 6 to 90 minutes, and in Fig. 6, *b* the wavelet-spectrum of the filtered data are shown. The continuous line in the bottom of Fig. 6, *a* is the eclipse time in the place of observations (observatory “Tumanny”) and in the bottom of Fig. 6, *b* is the time of the eclipse on the Earth (the specified times show emergence and leaving of a penumbra from the Earth's surface).

Before the eclipse over observatory “Tumanny” two waves with the periods of 18 and 46.5 min have appeared. At approach to the eclipse maximum at the observatory “Tumanny” the wave with the period of 46.5 min has begun to weaken and at the eclipse maximum has transformed on two waves with the periods of 28.5 and 51.5 min, but then gradually their periods have begun to change. They have again come to the end of the eclipse to the one period, smaller, than prior to stratification, and equal 36.5 min. The wave with the period of 18 min at approach to the eclipse maximum has disappeared.

## 5. Conclusion

Results of observations of ionospheric effects of the March 20, 2015 total solar eclipse in the lower ionosphere of high latitudes according to the data of the partial reflections facility and the riometer located at the observatory “Tumanny” of the Polar Geophysical Institute (Murmansk region) are given. In general in the lower ionosphere during the eclipse maximum reduction of the electron concentration was noticeable, at the same time local increases in the electron concentration were noted. During the eclipse the changes of the electron concentration had wavy character. During the eclipse some waves transformed to two waves and united to one. Suppression of waves of the smaller periods in the field of reduction of the electron concentration at approach to the eclipse maximum was noted. Similar behavior has also cosmic noise absorption fixed by the riometer. These changes at the place of observations can be caused by passing of the acoustic-gravity wave generated by cooling the atmosphere during the supersonic passing of the lunar shadow across the Earth's surface, by changing of the electron concentration caused by the solar eclipse and vertical movements.

## References

Astronomical year-book for 2015 (2014). SPb.: IAA RAS. 683 p. (in Russian)

Belikovich V.V., Goncharov N.P. (1994) Research of the D-region of the ionosphere by means of artificial periodic irregularities, Geomagnetism and Aeronomy, V. 34, No. 6, 84-95. (in Russian)

Belikovich V.V., Vyakhirev V.D., Kalinina E.E., Tereshchenko V.D., Chernyakov S.M., Tereshchenko V.A. (2008) Ionosphere response to the partial solar eclipse 29.03.2006 according to observations in Nizhny Novgorod and Murmansk, Geomagnetism and Aeronomy, V. 48, No. 1, 98-103. (in Russian)

Belikovich V.V., Vyakhirev V.D., Kalinina E.E., Tereshchenko V.D., Ogloblina O. F., Tereshchenko V.A. (2003), Research of the D-region of the ionosphere by the method of partial reflections at middle latitudes and in the auroral zone, Radiophysics and Quantum Electronics, V. 46, No. 3, 181-191. (in Russian)

Belrose J.S. (1970) Radio wave probing of the ionosphere by the partial reflection of radio waves (from heights below 100 km), J. Atmos. Terr. Phys., V. 32, № 4, 567–596.

Belrose J.S., Ross D.B., McNamara A.G. (1972) Ionization changes in the lower ionosphere during the solar eclipse of 7 March 1970, J. Atmos. Solar-Terr. Phys., V. 34, N 4, 627-640. doi: 10.1016/0021-9169 (72)90150-X.

Benediktov E.A., Vyakhirev V.D., Goncharov N.P., Grishkevich L.V., Ivanova V.A. (1978) Variations of electron concentration in the D-region of the ionosphere, Radiophysics and Quantum Electronics, V.21, No. 3, 348-351. (in Russian)

Brunelli B. E., Namgaladze A.A. (1988) Physics of the ionosphere. M.: Science. 528 p.

Chimonas G., Hines C.O. (1970) Atmospheric gravity waves induced by a solar eclipse, J. Geophys. Res., V. 75, N 4, 875.

Faire A.C. (1970) Rocket Density Measurements at Eglin, Florida, Nature, V. 226, № 5251, 1110-1111.

Haug A., Jespersen M., Kane J.A., Thrane E.V. (1970) Electron densities measured by the partial reflection method compared with simultaneous rocket measurements, J. Atmos. Terr. Phys., V. 32, № 6, 1139-1142.

Kane J.A. (1969) D-region electron density measurements during the solar eclipse of May 20, 1966, Planet. Space Sci., V. 17, N 4, 609-616.

PGI Geophysical data (2015) / ed. by V. Vorobjev [et al.], Murmansk, Apatity: PGI, 87 p.

Sauli, P., Roux S.G., Abry P., Boška J. (2007) Acoustic-gravity waves during solar eclipses: detection, characterization and modeling using wavelet transforms, J. Atmos. Sol.-Terr. Phys., V. 69, N (17-18), 2465-2484.

Schafer J.P., Goodall W.M. (1932) An effect of the recent solar eclipse on the ionized layers of the upper atmosphere, Science, V. 11. DOI: 10.1126/science.76.1976.444-a.

Tereshchenko V.D., Poltev E.K., Ovchinnikov N.A., Tereshchenko V.A., Ogloblina O.F., Vasilyev E.B. (2011a) To determination of the lower ionosphere parameters from observations of differential absorption and phase measurements of partial reflections of radio waves, Propagation of radio waves. XXIII All-Russian scientific conference (Yoshkar-Ola, on May 23-26, 2011.). Collection of scientific reports: in 2 V. - Yoshkar-Ola: Mar STU. V. 1, 267-270. (in Russian)

Tereshchenko V.D., Tereshchenko V.A., Chernyakov S.M. (2011b) Ionospheric effects of a partial eclipse of the Sun on June 1, 2011 in Murmansk according to the method of partial reflections, riometer and magnetic data, Proc. of the XVII regional conference on propagation of radio waves, St. Petersburg, on November 15-17, 2011 SPb: Physics department of SPbSU, 17-21. (in Russian)

Tereshchenko V.D., Tereshchenko V.A., Cherniakov S.M., Ogloblina O.F. (2012) Experimental researches of wave disturbances in the polar lower ionosphere during the partial solar eclipse on 1 June 2011, Physics of Auroral Phenomena, Proceeding of the XXXV Annual Seminar, 28 February – 2 March, 2012, Apatity, Russia. Apatity: KSC RAS, PGI, 115-118.

Tereshchenko V.D., Vasilyev E.B., Ovchinnikov N. A., Popov A.A. (2003) The medium wave radar of the Polar Geophysical Institute for research of the lower ionosphere, Techniques and methods of geophysical experiment, Apatity: KSC RAS, 37-46. (in Russian)

Tereshchenko V.D., Vasilyev E.B., Yakimov M.V., Tereshchenko V.A., Ogloblina O.F., Tarichenko M.A. (2001) Radar observations of the lower polar ionosphere during a partial solar eclipse on August 11, 1999, Radar research of environments, Proc. of the XVI-XIX All-Russian symposiums. Is. 2, SPb: Mozhaisky MSA, 347-352. (in Russian)