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The Variation of Ionospheric TEC During Solar Eclipse on March 20, 2015

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Abstract

This study aims to investigate the variation of Total Electron Content (TEC) during the solar eclipse on 20 March 2015. For this purpose, TEC values obtained from five different GPS receivers [(morp, onsa, mar6, mets, tro1)] are examined for determining the ionospheric variation during the time of solar eclipse using percentage deviation calculation from mean values. To determine the impact of the solar eclipse, the TEC changes during the geomagnetically quiet (March 30) and the disturbing (March 19) days, as the reference days, are also studied. As a result of the examination, a behavior similar to a sunset in TEC values is observed in all stations when the percentage deviation calculations are considered. It is concluded that there is a decrease in morp, mets, mar6, onsa, and tro1 stations due to the solar eclipse by 16.45%, 6.53%, 7.99%, 8.12%, and 7.22%, respectively. There is an increase in TEC values on both reference days. However, the percentage of increase in the disturbing day is higher than the quiet day. It can be stated that the decreases in the ionospheric TEC at these five stations with eclipse size greater than 80% are due to the eclipse.

Keywords: GPS-TEC, Solar eclipse, Ionosphere, Percentage deviation,

1. Introduction

The main source of ionization in the atmosphere is the sun. Therefore, a possible solar eclipse provides an opportunity to examine the causes of serious changes in the atmosphere. A solar eclipse, it reduces sun rays and plasma flux entering the earth's atmosphere. The atmosphere responds to these changes during the daytime by modifying the electrodynamics processes and the ionization source of their species at night-like. The effects of the solar eclipse on the ionosphere have been studied since the early 1900s [1, 2]. Ionospheric components are disturbed due to solar eclipse, many researchers have been conducted on the ionospheric response to solar eclipses, and different models, theories, and observations have been made [3-10]. The effect of the solar eclipse over the earth's atmosphere is similar to the short interval after sunset and so the effects in both cases are also expected to be similar [11]. It provides a potential for the investigations of important events such as photoionization and dynamic processes (such as atmospheric waves, acoustic gravity waves, energy, and momentum exchange) in the ionosphere due to sudden changes in solar ionizing radiation [6, 12, 13].

The dynamic processes during an eclipse significantly depend on changes in daily, solar and geophysical variations. Changes in neutral gas release and photoionization cause sudden perturbation of the natural structure of the ionosphere. Further, observation and investigation of the ionospheric structure during a solar eclipse have contributed to the understanding of transport, dissociation, diffusion, collision, and chemical processes as well as radio propagation. Experimental and theoretical research results have been compared to the derivation rate of electron production and loss of ionization[14, 15]. The ionosphere has various effects on many phenomena, especially radio wave communication. Radio waves are affected by electrons in the ionosphere Therefore, it is necessary to continuously monitor the change of ionospheric electron density. TEC refers to the total number of electrons in the beam path between the receiver and the transmitter [16-18]. TEC is a very useful parameter to determine the effect of space weather on the ionosphere, particularly satellite communications and satellite navigation[19]. TEC values are measured in TECU units and 1 TECU = 10^{16} el/m^2.

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In this study, TEC values obtained from five Global Position System (GPS) stations connected to the International GNSS System (IGS) network were used to investigate the effect of the solar eclipse. TEC values obtained for five different GPS stations (see Table 1) where the solar disk size was above 80% during the solar eclipse that occurred on 20 March 2015 were analyzed by using the percentage deviation calculation. To examine the effect of the eclipse more clearly, the same calculations were made for two different days from March of the same year as disturbed (March 19) and quiet (March 30), and the results were compared. Section 2 gives detailed information about the background conditions. Section 3 indicates the material and method. Sections 4 and 5 present the Discussions of results and Conclusions.

2. Background Conditions

The first contact of the total solar eclipse that occurred on March 20, 2015 occurred in the Central Atlantic Ocean, north of the equator, at 07:40:52 UT, and its final contact was in Central Asia at 11:50:13 UT. The largest eclipse occurred at 09:45:39 UT at a location with coordinates 64.43°N, 6.65°W. Most of the total eclipse path was over the North Atlantic Ocean and ended above the Arctic Ocean (Figure 1). As a result, an eclipse was seen in most of Europe, such as the United Kingdom (morp station), Sweden (onsa and mar6 station), Finland (mets station) and Norway (tro1 station) (see Table 2 for eclipse characteristics at these locations).

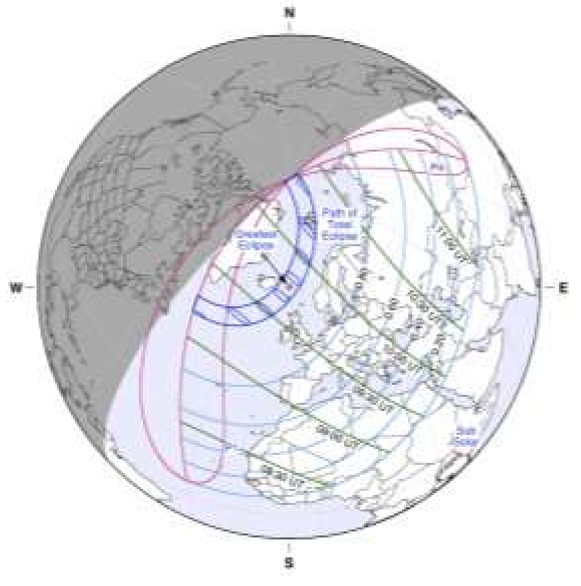

Figure 1. Eclipse geometry at sea level. (A) Schematic (credit: National Aeronautics and Space Administration (NASA)) of the solar eclipse on 20 March 2015 at the Earth's surface. The path of the total solar eclipse is denoted by the strip bounded by dark blue curves, while paths of the partial (0.80, 0.60, 0.40, and 0.20 magnitude) eclipse are plotted with light blue curves. The progression of the greatest eclipse is marked by green curves with time stamps (Universal Time, UT) ("Eclipse map/figure/table/predictions courtesy of Fred Espenak, NASA/Goddard Space Flight Center, from eclipse.gsfc.nasa.gov.").

The geomagnetic situation for the three days considered in this study is shown in Table 1. When the hourly changes of the geomagnetic kp and dst indices are examined, the kp value is 3,0 and the dst value is -50 nT at the eclipse hours (~ 08: 30-11: 15 UT) on March 20, and these values indicate that there is a moderate storm. On March 19 at the same time (~ 08: 30-11: 15 UT) the kp value is 5,0 and the dst value is -65 nT, and there is a moderate geomagnetic storm on this day. On March 30, at the same time (~ 08: 30-11: 15 UT), the kp value is 0,7 and the dst value is -12 nT, and these values indicate that the ionospheric environment is quiet. Kp and Dst values were taken from NASA's https://omniweb.gsfc.nasa.gov/form/dx1.html website for the day of the eclipse.

Table 1. Geomagnetic variation on March 19, 20, and 30, 2015.

	19.Mar.15		20.Mar.15		30.Mar.15	
Hours	**kp**	**dst**	**kp**	**dst**	**kp**	**dst**
0	4,3	-88	4,7	-64	1,7	-19
1	4,3	-83	4,7	-69	1,7	-15
2	4,3	-75	4,7	-63	1,7	-13
3	4,0	-69	3,0	-56	2,0	-13
4	4,0	-73	3,0	-53	2,0	-11
5	4,0	-73	3,0	-52	2,0	-9
6	3,7	-69	4,7	-58	0,7	-7
7	3,7	-61	4,7	-55	0,7	-7
8	**3,7**	**-60**	**4,7**	**-52**	**0,7**	**-6**
9	**5,0**	**-65**	**3,0**	**-50**	**0,7**	**-7**
10	**5,0**	**-63**	**3,0**	**-49**	**0,7**	**-13**
11	**5,0**	**-66**	**3,0**	**-55**	**0,7**	**-15**
12	4,3	-67	2,7	-48	0,3	-11
13	4,3	-71	2,7	-44	0,3	-8
14	4,3	-72	2,7	-43	0,3	-11
15	3,0	-68	2,3	-44	0,3	-12
16	3,0	-61	2,3	-50	0,3	-13
17	3,0	-59	2,3	-54	0,3	-13
18	2,3	-60	3,3	-53	0,7	-15
19	2,3	-58	3,3	-49	0,7	-15
20	2,3	-59	3,3	-47	0,7	-15
21	3,7	-58	4,3	-45	1,7	-17
22	3,7	-55	4,3	-45	1,7	-19
23	3,7	-58	4,3	-54	1,7	-17

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3. Materials and Methods

TEC values for the stations given in Table 2 were obtained by using the IONOLAB TEC/STEC software provided by the ionosphere research laboratory (IONOLAB) at the Electrical and Electronics Engineering Department of Hacettepe University [17, 19, 20]. With this software, one can generate IONOLAB-TEC and IONOLAB-STEC with their RINEX data. The IONOLAB-TEC software processes RINEX files in both RINEX 2 and RINEX 3 formats. How to obtain TEC values with this software is explained in the http://www.ionolab.org/downloads/ionolabtec/README.txt file.

The vertical TEC used in this study is estimated from line-of-sight TEC (STEC) values using a simple mapping function and correlated to an ionospheric piercing point (IPP) latitude and longitude, assuming compression of the ionosphere. It was found that the four different mapping functions for the single-layer model (SLM) at various heights best fit the Chapman profile and that the best fit in terms of least squares is obtained when the ionospheric pierce point is set to 428.8 km. Thus, the IPP is determined as 428.8 km in the IONOLAB-TEC software.

The percent deviation calculation for the studied station is made by subtracting the TEC values, when the solar disk is maximum, from the mean TEC value at the beginning and end of the solar eclipse. Then, the percentage deviation is taken and multiplied by 100 as follows:

$$Dev\ (\%) = \frac{TEC_{ME} - TEC_{M}}{TEC_{M}} \times 100 \qquad (1)$$

Here, $TEC_M = (TEC_{BE} + TEC_{EE})/2$ is given and TEC_{BE} and TEC_{EE} are the TEC values at the beginning and end of the eclipse and $\mathrm{TEC}_{\mathrm{ME}}$ is the TEC value at the maximum of the eclipse.

4. Results and Discussion

The variation of the TEC values calculated for the five stations located in the upper latitude region of the northern hemisphere on March, 19, 20, and 30, 2015 is shown in Figure 1. It is seen that the TEC values on the day of the solar eclipse on March 20, 2015, decreased at all stations except the tro1 station during the eclipse. However, the TEC values of the tro 1 station expected to increase during these hours are stable.

It was observed that TEC values did not decrease at all stations at the same hours on March 30, 2015, which was taken as the quiet reference day. On March 19, 2015, which was chosen as the disturbed reference day, there was no decrease in TEC values at all stations at the same time. Thus, it can be stated that the decrease in ionospheric TEC on March 20, 2015, occurred as a result of the solar eclipse.

The beginning, maximum, and ending times of the solar eclipse are given in Table 2 for morp, onsa, mar6, mets, and tro 1. The maximum obscuration rates of the solar eclipse in these stations are 91.07%, 84.00%, 84.55%, 78.17% and 95.33%, respectively. More detailed information can be seen in Table 2.

While the usual behavior of TEC values tends to decrease from sunset to sunrise, they tend to increase after sunrise. However, TEC values exhibit an unusual change in a situation such as a solar eclipse and a geomagnetic storm. During a solar eclipse, TEC values begin to decrease during daylight hours since the sun, which is the main source that ionizes the ionosphere, does not affect the ionosphere like when there is no solar eclipse. It can be said that the TEC values return to normal daily distribution with the decrease in the magnitude of the solar eclipse after the maximum disc. This variation is very similar to TEC behavior at sunrise. When the percent deviation values obtained by Equation 1 for five different stations are examined, it is seen that there is a decrease of 16.45% in morp station, 6.53 in mets station, 7.99% in mar6 station, and 8.12% in onsa station, and 7.22% in tro1 station. The decrease in TEC values during the eclipse has been reported in many studies in the literature [21-25].

Also, Chernogor et al. (2019) examined the electron density change over Kharkov for this eclipse using Incoherent Scatter Radar (ISR) and they stated that the electron density values decreased by 18.5% and 16.5% at lower altitudes (190 and 210 km) [1]. Although Ne and TEC values are different parameters, the results are similar to the results obtained in this study.

Besides, it is seen that the ionospheric TEC values increased at all stations on both the days of geomagnetic disturbed, 19 March 2015, and quiet, 30 March 2015, without an eclipse. However, the percentage increase in TEC values on disturbing days is higher than on quiet day. When the longitudes of the stations used in the present study are compared with the percentage deviation change, it can be stated that the difference decreases on the day of the eclipse (March 20) when traveling from west to east.

Table 2. Information about studied stations and results of percentage deviation.

IGS Station code	Country	Lat.		Lon.		Magnitude	Obscuration	Start of SE (UT)	Max of SE (UT)	End of SE (UT)	Deviation (%)		
		Geog.	Geom.	Geog.	Geom.						March, 19	March, 20	March, 30
morp	UK	55.21N	57.01N	-1.68W	85.38W	0.921	91.07%	08:29	09:35	10:44	2,95	-16,45	0,10
onsa	Sweden	57.39N	56.87N	11.92E	99.54E	0.865	84.00%	08:43	09:51	11:01	9,84	-8,12	3,37
mar6	Sweden	60.59N	59.04N	17.26E	106.40E	0.869	84.55%	08:53	10:00	11:08	3,59	-7,99	1,66
mets	Filland	60.22N	57.55N	24.40E	112.57E	0.819	78.17%	08:59	10:07	11:15	6,72	-6,53	1,62
tro1	Norway	69.66N	67.21N	18.94E	115.54E	0.955	95.33%	09:04	10:08	11:13	6,39	-7,22	1,32

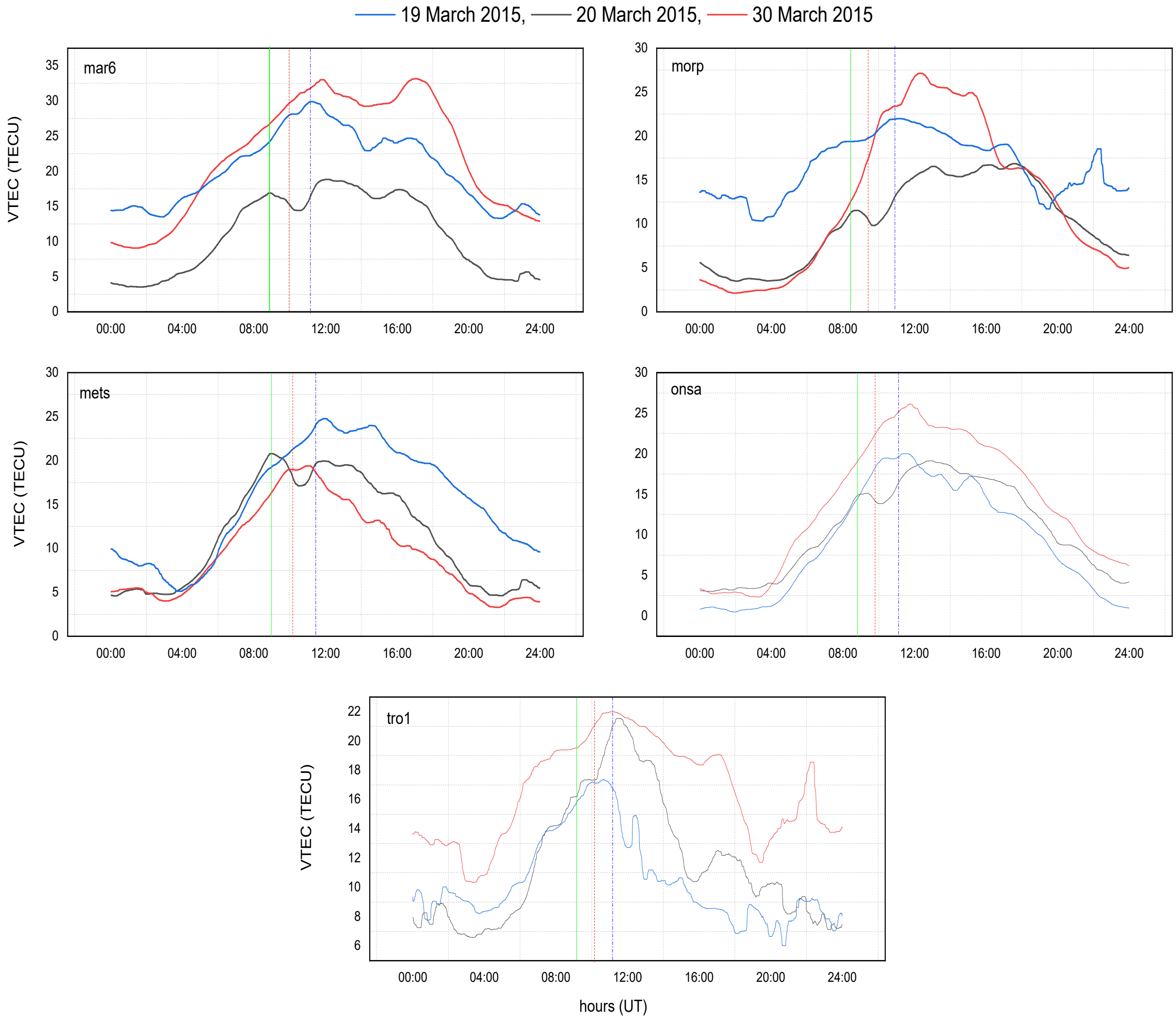

Figure 2. Temporal variation of TEC values on March, 19, 20, and 30, 2015 at five IGS stations. Black, blue and red lines indicate on March, 19, 20, and 30, 2015 days, respectively. The vertical lines show the beginning (green), maximum(red), and ending(blue) time of the solar eclipse for all stations.

5. Conclusion

The present study investigates the change of TEC during the solar eclipse on 20 March 2015. For this purpose, TEC values obtained from five different GPS receivers are examined at the beginning, the maximum solar disk and normalization time of solar eclipse used the percentage deviation method. Also, a disturbed (March, 19) and quiet (March, 30) day with no eclipse in the same month is chosen as the reference to identify the source of the changes during the eclipse.

TEC values obtained from all stations examined is showed a similar distribution during sunset with the onset of the solar eclipse. TEC values are decreased with the onset of the solar eclipse and this decrease continued until the magnitude of the eclipse is maximized. After the maximum eclipse size, it is seen that TEC values increase with a decrease in the magnitude of the solar eclipse. With the complete disappearance of the solar eclipse, TEC values return to normal daily distribution in a very short time. As a result of the investigations, it can be stated that the decreases in ionospheric TEC are due to the total solar eclipse, even though March 20, 2015, was a disturbing day.

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Author's Contributions

Ramazan Atıcı: Presented the main idea of the article, and managed the data editing and writing processes.
Selçuk Sağır: Applied the method and interpreted the results.

Ethics

There are no ethical issues after the publication of this manuscript.

References

[1]. Chernogor, L.F., I.F. Domnin, L.Y. Emelyanov, ve M.V. Lyashenko, 2019. Physical processes in the ionosphere during the solar eclipse on March 20, 2015 over Kharkiv, Ukraine (49.6° N, 36.3° E). *Journal of Atmospheric and Solar-Terrestrial Physics*. **182**:1-9.

[2]. Eccles, W.H., 1912. Effect of the eclipse on wireless telegraphic signals. . *Electrician* **69**:109–116.

[3]. Rishbeth, H., 1968. Solar eclipses and ionospheric theory. *Space Science Reviews*. **8**(4):543-554.

[4]. Curto, J., B. Heilig, ve M. Pinol, 2006. Modeling the geomagnetic effects caused by the solar eclipse of 11 August 1999. *Journal of Geophysical Research: Space Physics*. **111**(A7).

[5]. Zhang, X., Z. Zhao, Y. Zhang, ve C. Zhou, 2010. Observations of the ionosphere in the equatorial anomaly region using WISS during the total solar eclipse of 22 July 2009. *Journal of Atmospheric Solar-Terrestrial Physics*. **72**(11-12):869-875.

[6]. Chukwuma, V.ve B. Adekoya, 2016. The effects of March 20 2015 solar eclipse on the F2 layer in the mid-latitude. *Advances in Space Research*. **58**(9):1720-1731.

[7]. Pietrella, M., M. Pezzopane, ve A. Settimi, 2016. Ionospheric response under the influence of the solar eclipse occurred on 20 March 2015: Importance of autoscaled data and their assimilation for obtaining a reliable modeling of the ionosphere. *Journal of Atmospheric Solar-Terrestrial Physics*. **146**:49-57.

[8]. Atıcı, R., S. Sağır, L.Y. Emelyanov, ve M. Lyashenko, 2021. Investigation of Ionospheric Electron Density Change During Two Partial Solar Eclipses and Its Comparison with Predictions of NeQuick 2 and IRI-2016 Models. *Wireless Personal Communications:*1-13.

[9]. Yaşar, M., 2021. The solar eclipse effect on diffusion processes of O++ O2→ O2++ O reaction for the upper ionosphere over Kharkov. *Thermal Science*,(00):7-7.

[10]. Yaşar, M., 2021. The change of diffusion processes for O++ N2→ NO++ N reaction in the ionospheric f region during the solar eclipse over Kharkov. *Thermal Science*,(00):6-6.

[11]. Adekoya, B.ve V. Chukwuma, 2016. Ionospheric F2 layer responses to total solar eclipses at low and mid-latitude. *Journal of Atmospheric and Solar-Terrestrial Physics*. **138**:136-160.

[12]. Shagimuratov, I.I., G.A. Yakimova, N.Y. Tepenitsyna, I.I. Efishov, ve L.M. Koltunenko, 2018. Effects of the Solar Eclipse of March 20, 2015 on the Total Electron Content over Europe. *Russian Journal of Physical Chemistry B*. **12**(3):568-575.

[13]. Maurya, A.K., M.N. Shrivastava, ve K.N. Kumar, 2020. Ionospheric monitoring with the Chilean GPS eyeball during the South American total solar eclipse on 2nd July 2019. *Scientific reports*. **10**(1):1-10.

[14]. Davis, C.J., M. Lockwood, S. Bell, J. Smith, ve E. Clarke, 2000. Ionospheric measurements of relative coronal brightness during the total solar eclipses of 11 August, 1999 and 9 July, 1945. in *Annales Geophysicae*. Springer.

[15]. Davis, C.J., E. Clarke, R. Bamford, M. Lockwood, ve S. Bell, 2001. Long term changes in EUV and X-ray emissions from the solar corona and chromosphere as measured by the response of the Earth's ionosphere during total solar eclipses from 1932 to 1999. in *Annales Geophysicae*.

[16]. Klobuchar, J.A., 1987. Ionospheric time-delay algorithm for single-frequency GPS users. I*EEE Transactions on Aerospace Electronic Systems*,(3):325-331.

[17]. Arikan, F., C. Erol, ve O. Arikan, 2004. Regularized estimation of vertical total electron content from GPS data for a desired time period. *Radio Science*. **39**(6).

[18]. Atıcı, R., 2018. Comparison of GPS TEC with modelled values from IRI 2016 and IRI-PLAS over Istanbul, Turkey. *Astrophysics and Space Science* **363**(11):231.

[19]. Arikan, F., C. Erol, ve O. Arikan, 2003. Regularized estimation of vertical total electron content from Global Positioning System data. *Journal of Geophysical Research: Space Physics*. **108**(A12).

[20]. Nayir, H., F. Arikan, O. Arikan, ve C. Erol, 2007. Total electron content estimation with Reg-Est. *Journal of Geophysical Research: Space Physics*. **112**(A11).

[21]. Borchevkina, O., I. Karpov, ve A. Karpov, 2017. Observations of Acoustic Gravity Waves during the Solar Eclipse of March 20, 2015 in Kaliningrad. *Russian Journal of Physical Chemistry B*. **11**(6):1024-1027.

[22]. Shagimuratov, I., G. Yakimova, N.Y. Tepenitsyna, I. Efishov, ve L. Koltunenko, 2018. Effects of the Solar Eclipse of March 20, 2015 on the Total Electron Content over Europe. *Russian Journal of Physical Chemistry B*. **12**(3):568-575.

[23]. Galakhov, A.ve O. Akhmetov, 2017. Transverse resonance in the high-latitude section of the Earth–ionosphere waveguide during the solar eclipse of March 20, 2015. *Geomagnetism and Aeronomy*. **57**(5):618-623.

[24]. Alizadeh, M.M., H. Schuh, S. Zare, S. Sobhkhiz-Miandehi, ve L.-C. Tsai, 2020. Remote sensing ionospheric variations due to total solar eclipse, using GNSS observations. *Geodesy and Geodynamics*. **11**(3):202-210.

[25]. Hoque, M.M., D. Wenzel, N. Jakowski, T. Gerzen, J. Berdermann, V. Wilken, M. Kriegel, H. Sato, C. Borries, ve D. Minkwitz, 2016. Ionospheric response over Europe during the solar eclipse of March 20, 2015. *Journal of Space Weather and Space Climate*. **6**:A36.