Possible Effect of Stratospheric QBO on The Ionospheric E-Region Current Densities

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ABSTRACT

It is known that ionospheric winds cause the ions to drift in the geomagnetic field. This drift set up a current which produces ground-level geomagnetic field variations. In this study, the relationship between stratospheric QBO and the ionospheric E- region current densities (J_x and J_y) for low latitudes (01.22 N, 103.55 E) have been statistically investigated using the multiple regression model. Also the effect of F10.7 solar flux index was included in the investigation. As a result of the investigation using the multiple regression model, it was determine that an increase/a decrease of 1 s.f.u in the F10.7 solar flux caused an increase/a decrease of 1.5×10^{-2} A/km and 2.5×10^{-2} A/km on J_x and J_y current density, respectively. On the other hand, an increase/ a decrease of 1 m / s in the QBO caused a decrease/ an increase of 3×10^{-3} A/km and 4×10^{-3} A/km on J_x and J_y current densities, respectively.

Keywords: Ionospheric current densities, stratospheric QBO, F10.7 Solar flux, multiple regression

İyonosferik E Bölgesi Akım Yoğunlukları Üzerinde Stratosferik QBO'nun Olası Etkisi

ÖZ

İyonosfer rüzgarlarının, iyonların jeomanyetik alanda sürüklenmesine neden olduğu bilinmektedir. Bu sürüklenme, yer seviyesinde jeomanyetik alan değişimleri üreten bir akım oluşturur. Bu çalışmada, stratosferik QBO ile düşük enlemde (01.22 K, 103.55 D) iyonosferik E- bölgesi akım yoğunlukları (Jx ve Jy) arasındaki ilişki çoklu regresyon modeli kullanılarak istatistiksel olarak incelenmiştir. Ayrıca F10.7 Güneş akısı indisinin etkisi de araştırmaya dahil edildi. Çoklu regresyon modelini kullanılarak yapılan araştırmanın bir sonucu olarak, F10.7 Güneş akışında 1 s.f.u luk artma/azalma, Jx ve Jy akım yoğunlukları üzerinde sırasıyla 1.5×10^{-2} A/km ve 2.5×10^{-2} A/km'lik bir artma/azalmaya neden olduğu görülmüştür. Öte yandan, QBO' da 1 m / s 'lik bir artma/azalma, Jx ve Jy akım yoğunluklarında sırasıyla 3×10^{-3} A / km ve 4×10^{-3} A / km'lik bir azalma/artmaya neden olduğu görülmüştür.

Anahtar Kelimeler: İyonosferik akım yoğunlukları, stratosferik QBO, F10.7 Güneş akısı, Çoklu regresyon.

INTRODUCTION

Ionosphere, which starts nearly at 50 km elevation from the ground and stretches up to 1000 km, is upper layer of the atmosphere. Ionosphere is also a natural plasma that is ionized mostly by the Sun. In this respect, it is a conductive layer. The conductivity of ionospheric medium is extremely important in terms of radio communication, space-weather condition forecasts, and satellite positioning system, because all of these measurements are made via electromagnetic wave, and for this reason, conductive medium affects some characteristics of electromagnetic wave such as reflection, refraction and damping. In this context, it is important to know the conductivity of ionospheric plasma, and current and current density, which depend

on conductivity [1-5].

Ionospheric current density shows different characteristics depending on the geomagnetic field of the Earth and on the latitudes. For this reason, ionospheric research is analyzed separately for each hemisphere as equatorial region -low latitude- (0-30), middle latitude (30-60) and high latitude(60-90) regions. Equatorial region is generally a complex region with internal effects coming from below (thunders, stratospheric QBO-Quasi Biennial Oscillation, sudden stratospheric heating, earthquakes, atmospheric waves, etc.) and external effects coming from above (the Sun, galactic and cosmic rays, the medium among planetary, etc.) [1, 2, 6-10]. Lastovicka et al. (2006) reported that meteorological processes dominate the region below 90 km and that external forces are predominant at altitudes above 90 km. It was also stated that in the mesosphere lower thermosphere, both processes affect approximately the same extent.

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In order to explain this complexity to some extent, the relationship between the ionospheric current densities (Jx and Jy) and the stratospheric QBO and F10.7 solar flux were investigated on the equator region (01.22 N, 103.55 E) for 22 solar cycles in the present study.

MATERIAL and METHOD

The charged particle in the ionospheric medium is moved by force as follows;

$$\mathrm{m}_\alpha \frac{\mathrm{d}\mathbf{V}_\alpha}{\mathrm{d}t} = -q_\alpha \left(\mathbf{E} + \mathbf{V}_\alpha \times \mathbf{B} \right) - \mathrm{m}_\alpha \nu_\alpha \mathbf{V}_\alpha \qquad (1)$$

where α can be used individually for electrons and ions, or for each alone ν_α is collision frequency for electrons and ions and m is mass. ν_α is particle velocity[1,4]. Then, by making the assumptions made by Özcan and Aydoğdu 2004 and by updating expressions for coordinates (01.22 N, 103.55 E), the following expressions were obtained.

$$J_{\Sigma x} = B\Sigma_1 U_x - B\frac{\Sigma_2}{\sin I}U_y + \Sigma_1' E_x - \frac{\Sigma_2'}{\sin I}E_y \quad (2)$$

and

$$J_{\Sigma y} = B\frac{\Sigma_2}{\sin I}U_x + B\frac{\Sigma_1}{\sin^2 I}U_y + \frac{\Sigma_2'}{\sin I}E_x + \frac{\Sigma_1'}{\sin^2 I}E_y \,(3)$$

Where σ_1 and σ_2 is denoted Pedersen and Hall

conductivities and *I* is dip angle (17.48º) and *B* is approximately 0.5 Gauss (see Ozcan and Aydoğdu, 2004 for details).

$$\Sigma_1 = \int_{h_1}^{h_2} \frac{\nu_i}{\omega_{ci}} \sigma_1 \mathrm{d}h \,, \qquad \Sigma_2 = \int_{h_1}^{h_2} \frac{\nu_i}{\omega_{ci}} \sigma_2 \mathrm{d}h$$

$$\Sigma_1' = \int_{h_1}^{h_2} \sigma_1 \mathrm{d}h, \qquad \Sigma_2' = \int_{h_1}^{h_2} \sigma_2 \mathrm{d}h,$$

RESULT and DISCUSSION

The relationship between ionospheric E- region current densities (J_x and J_y) obtained with the help of IRI (International Reference Ionosphere) and Equations (2) and (3) and the stratospheric QBO data taken from http://www.geo.fu-berlin.de/met/ag/strat/ and the relation between F10.7 Solar flux taken from https://omniweb.gsfc.nasa.gov were examined by using statistical multiple regression model. In addition, in order to see the effect of the directions of the QBO wind, Dummy$_{eastern}$ and Dummy$_{western}$ were added to the model. The examination was made for 22. Solar cycle (01/1987-01/1997). The statistical model consisted of two stages. In the first one, the stationary of the dependent (Jx and J_y) and independent (F10.7 Solar flux and QBO) variables was analyzed. In the second one,

the regression coefficients between the variables were obtained (for detailed information about the model, please see Reference 10 and 11).

In Table 1, the results of unit root test applied with three separate tests for dependent and independent variables are shown. In order for the variables to be stationary, the test results given in the upper part of the table must be bigger than the McKinnon (1996) critical values given in the lower part of the table as an absolute value. Since stationary is important for the statistical model used, the stationary of the variables was sought according to at least 2 test results. In this respect, the Jx, Jy and F10.7 solar flux variables are stationary according to ADF and KPSS tests, the QBO variable is stationary according to ADF and PP tests.

Table 1. Unit root test results of variables

Variables			
	ADF	PP	KPSS
Jx	-4.32	-2.34	0.23
Jy	-4.55	-2.76	0.23
QBO	-5.21	-3.79	0.05
F10.7	3.16	-2.63	0.23
The level of significance	MacKinnon	[1996]	critical values
1%	-4.05	-4.05	0.21
5%	-3.45	-3.45	0.14
10%	-3.15	-3.15	0.11

After the stationary of the variables was determined, the following regression equation was established for Jx and Jy current densities and the regression coefficients in the equation were obtained.

Jx= β1(F10.7)+ β2 (QBO)+ β3(Dummy$_{western}$)+ β4(Dummy$_{eastern}$)+ε   (4)

Jy= β1(F10.7)+ β2 (QBO)+ β3(Dummy$_{western}$)+ β4(Dummy$_{eastern}$)+ε   (5)

In Table 2, the results of the regression coefficients obtained with the regression equations defined with the Equations 4 and 5 are shown. According to reference values given in the two lines at the lowest part of the table, The ARCH LM test results being bigger than 0.05, and the Durbin Watson test results being between 1.5 and 2.5 show that the equations and their results that were established for both current densities are correct.

It is possible to claim that both of the Jx and Jy current densities are affected by QBO and F10.7 solar flux by looking at the Adj. R^2 value (0.90 and 0.91 respectively). This value is consistent with the solar radiation indices reported by Özgüç et al. in 2008 for

ionosphere F2 region critical frequency (foF2) definition, and with the model established for SSN, solar flux at 2800 MHz, and Mg II indices (0.99). While there is a positive relation between the F10.7 solar flux and current densities, a negative relation was detected between the QBO and current densities. A 1 s.f.u increase/decrease that occur in the F10.7 solar flux causes 1.5×10^{-3} A/km and 2.5×10^{-3} A/km increase/decrease on Jx and Jy, respectively. A 1 m/s increase/decrease in QBO, on the other hand, causes an decrease /increase of 3×10^{-3} A/km and 4×10^{-3} A/km on Jx and Jy, respectively. In addition, it is also seen that both the eastern and western directions of the QBO are effective on current densities as positive.

Similarly, in examinations made between the QBO and ionospheric parameters; it was reported that QBO was related in TEC (0.704) (Tang et al., 2015), between foF2 (0.64) (Chen, 1992); with foE 0.50 (Atıcı and Sagir); with foEs (between 0.58-0.94 range) (Cetin et al., 2017). In addition, Sagir et al. (2015) reported a positive relation between the directions of the QBO and NnD. In this respect, the present study is consistent with the previous ones.

Table 2. Regression coefficients

Coefficient	Jx	Jy
R^2	0.91	0.91
Adj. R^2	0.90	0.91
β_1	0.015	0.025
	(0.00)*	(0.00)*
β_2	-0.003	-0.004
	(0.00)*	(0.05)**
β_3	2.07	3.12
	(0.00)*	(0.00)*
β_4	2.10	3.20
	(0.00)*	(0.00)*
MA(1)	0.57	0.53
	(0.00)*	(0.01)**
Durbin Watson	1.85	2.07
ARCH. LM	0.95	0.89

CONCLUSION and SUGGESTION

It is known that Stratospheric QBO affects the ionosphere especially on the equatorial region [5, 6, 8, 10-14]. In the present study, the relation of QBO with the current density of the E-region of the ionosphere, which has a significant impact on satellite positioning, space weather forecast, and radio wave propagation were examined. In the examination, the effect of the Sun, which is the basic source of the formation of the ionosphere, was evaluated for 22. Solar cycle and with the help of F10.7 Solar flux indices, and was included in the related model. As a result of the examination, it was seen that QBO affected Jx and Jy in a negative way at a rate of nearly one-fifth and one-sixth of the F10.7 Solar

flux. For this reason, including the ionospheric current density, therefore the stratospheric QBO, in future studies that will be conducted on weather forecast, Global Positioning System, and radio wave propagation will contribute to obtain more accurate results.

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