THE INVESTIGATION OF RELATIONSHIP BETWEEN SOLAR PARAMETERS AND TOTAL ELECTRON CONTENT MODELS AT MID-LATITUDE REGION

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Outline

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2. Statistical analysis method
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1. TEC MODELS

- **1.1. International Reference Ionosphere (IRI) Model**
- IRI model is an international project sponsored by the COSPAR and URSI.
- For given location, time and date, IRI provides monthly averages of the electron density, electron and ion temperature, and ion composition in the altitude range from 50 km to 2000 km. Additionally IRI includes Total Electron Content (TEC, a user cab select the starting and ending hight of the integral).

1.2. IONOLAB TEC MODEL

- IONOLAB (www.ionolab.org) service is presented by a leading research group that develops for imaging of ionosphere and space weather. The TEC estimation method of IONOLAB group, IONOLAB-TEC, is one of the most important contributions for ionospheric mapping and electron density reconstruction.

- The main goal of this study is to compare the sensitivity of IRI-2012 and IONOLAB-TEC models to the changes occurred on the sun at mid-latitude region.

2. STATISTICAL ANALYSIS METHOD

- In the present study, the multiple regression analysis method was used to determine the relationship between dependent (TEC values) and independent (solar parameters) variables.
- The multiple regression analysis consists of three stages namely, unit root test, co-integration test and regression model.
- The unit root test is used to investigate whether the variables is stationary or not.
- If the variables are stationary, then co-integration test is applied to determine whether a long-term relationship between the variables exists or not.
- After this stage, the regression equation sets up between the variables and it is investigated how the variables are connected to each other.

- The equation including the dependent variable is defined by adding a constant and a time trend as follows (Enders, 2008; Sagir et al., 2015):

$$\Delta y_t = \mu + \beta t + \delta y_{t-1} + \sum_{j=1}^{k} \alpha_j \Delta y_{t-j} + \varepsilon_t \quad (1)$$

3. RESULTS AND DISCUSSIONS

- To investigate the relationship between the variables, TEC values for coordinates (39.7 N; 32.76 E) of Ankara city of Turkey at universal time (UT) 12:00 and 24:00 during equinox months (March and September) of 2009 year were taken from the IONOLAB website (www.ionolab.org) and the IRI-2012 website (http://omniweb.gsfc.nasa.gov/vitmo/iri2012_vitmo.html).
- Similarly; the values of solar parameters (proton density, proton speed and F10.7 solar flux) were taken from OMNIWeb Data Explorer website (http://omniweb.gsfc.nasa.gov/form/dx1.html).

3.1. **Results obtained for the universal time 12:00**

- Table 1, 2 and 3 show the unit root test, co-integration test and regression model results of dependent (GPS-TEC and IRI-2012-TEC) and independent (solar parameters) variables on March and September equinox months of 2009 year.

Table 1. The unit root test results belong to dependent variables on equinox months for UT 12:00.

Dependent Variables	Stationary tests (March)			Stationary tests (September)		
	ADF	PP	KPSS	ADF	PP	KPSS
IRI-2012	-4.30	-4.42	0.18	-1.18	-1.19	0.18
GPS-TEC	-5.25	-7.32	0.50	-4.71	-7.03	0.45
D(IRI-2012)	-	-	-	-3.13	-3.08	0.63
The level of significance	McKinnon(1996) critical values					
			ADF	PP	KPSS	
1%			-4.27	-4.26	0.21	
5%			-3.55	-3.55	0.14	
10%			-3.21	-3.20	0.11	

Table 2. The unit root test results belong to independent variables for equinox months.

Independent Variables	Stationary tests (March)			Stationary tests (September)		
	ADF	PP	KPSS	ADF	PP	KPSS
Vp	-3.91	-2.57	0.09	-3.02	-2.26	0.07
Np	-3.83	-3.91	0.15	-3.22	-3.19	0.09
F10.7	-2.58	-2.51	0.16	-2.61	-2.22	0.09
D(Vp)	-4.58	-5.18	0.16	-4.23	-4.95	0.18
D(F10.7)	-7.40	-7.40	0.22	-3.87	-3.64	0.09
D(Np)	-	-	-	-6.01	-11.64	0.48
The level of significance	McKinnon(1996) critical values					
1%	-4.27	-4.26	0.21			
5%	-3.55	-3.55	0.14			
10%	-3.21	-3.20	0.11			

Table 3. The co-integration test results for IRI-2012 and GPS-TEC values on equinox months at 12:00 UT.

Regression Model	March equinox		September equinox	
	ADF	p-value	ADF	p-value
Model (IRI-2012)	-4.81	0.000	-5.60	0.000
Model (GPS-TEC)	-4.74	0.000	-5.39	0.000
The level of significance values	McKinnon(1996) critical			
1%		-2.65		
5%		-1.95		
10%		-1.60		

- After determining the stationarity of variables and detecting there is a long-term relationship between the variables, the following equations are derived by Eq. (1) depending on stationarity of the variables:
- For IRI-2012-TEC;
- $IRI\text{-}12.00 = c + \beta_0 (D(Vp)) + \beta_1 (Np) + \beta_2 D(F10.7) + \varepsilon$ (2)
- For GPS-TEC;
- $GPS\text{-}TEC = c + \beta_0 (D(Vp)) + \beta_1 (Np) + \beta_2 D(F10.7) + \varepsilon$ (3)

Table 4. Multiple regression analysis results for equinox months at 12:00 UT

	March equinox		September equinox	
TEC models	IRI-2012	GPS-TEC	IRI-2012	GPS-TEC
c	-0.0228	11.7581	-0.0517	14.3099
	(0.88)	(0.00)*	(0.11)*	(0.000)*
β_0 (Vp)	0.0006	0.0127	-0.0006	0.0196
	(0.00)*	(0.00)*	(0.05)**	(0.04)**
β_1 (Np)	-0.0113	-0.0862	-0.0047	0.078
	(0.00)***	(0.06)***	(0.08)***	(0.07)***
β_2 (F10.7)	0.0228	0.4136	0.0133	0.5757
	(0.03)**	(0.00)*	(0.03)**	(0.02)**
AR or MA	1.000	0.887	0.898	0.823
	(0.000)*	(0.000)*	(0.000)*	(0.000)*
R^2	0.99	0.65	0.68	0.65
Adj. R^2	0.99	0.58	0.57	0.55
Durbin Watson	1.685	1.661	2.149	2.071
Prob. (F-statistics)	(0.000)	(0.000)	(0.001)	(0.000)
Serial Cor. LM	(0.405)	(0.455)	(0.402)	(0.061)
White Hetero	(0.935)	(0.366)	(0.507)	(0.309)

*,**,*** represents the significant level at 1%, 5%, and 10%, respectively.

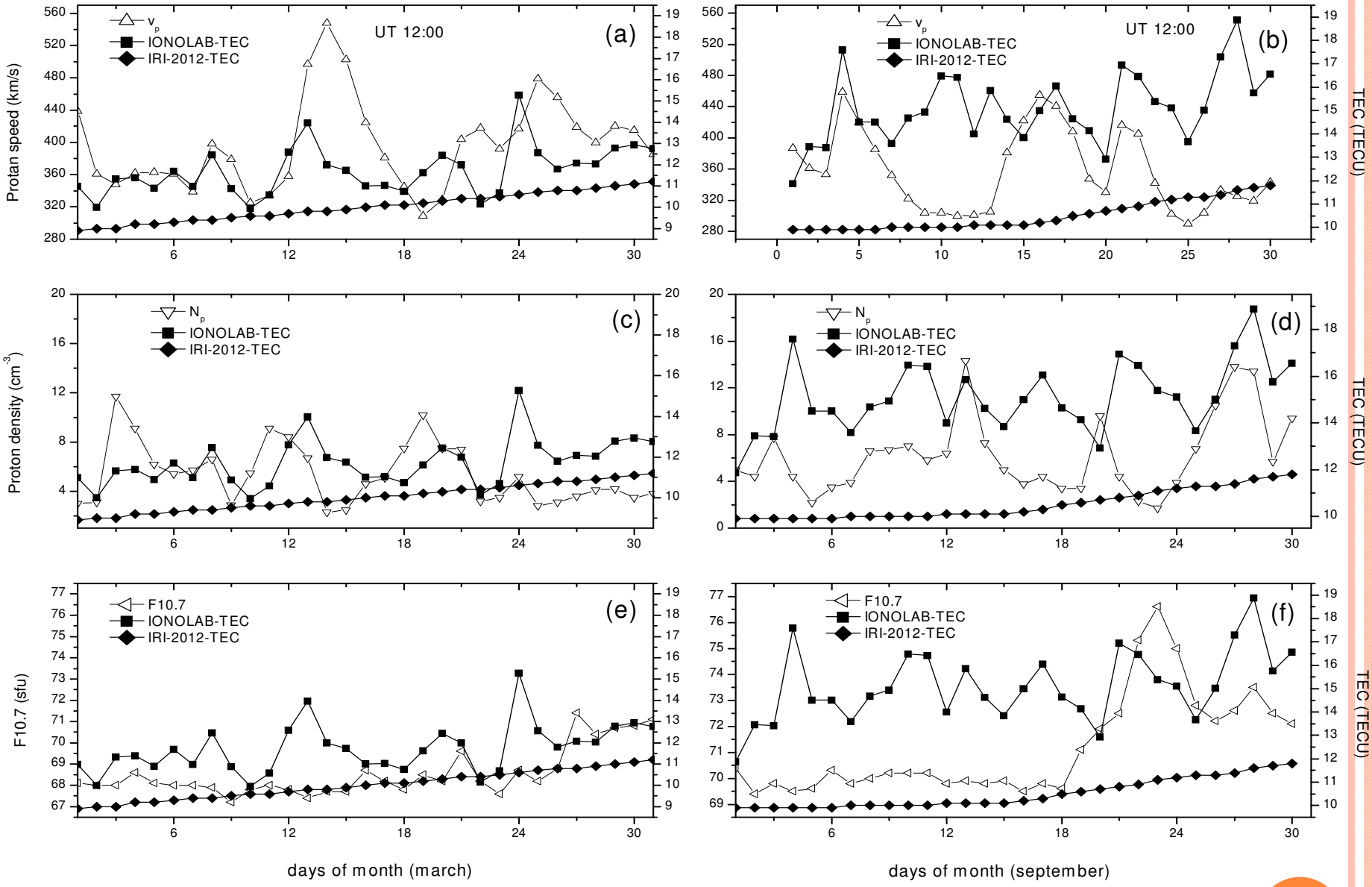

Figure 1 The variation of total electron content at mid-latitude region depending on solar parameters at 12:00 UT during March (left panel) and September (right panel) equinox months of 2009 year.

3.2. Results obtained for the universal time 24:00

- For 24:00 UT, it is made the same calculations as in 12:00 UT and our regression model results are given at Table 5.

Table 5. Regression analysis results for equinox months at 24:00 UT

	March equinox		September equinox	
TEC models	**IRI-2012**	**GPS-TEC**	**IRI-2012**	**GPS-TEC**
c	0.0296	9.7223	-0.0214	6.1149
	(0.12)	(0.00)*	(0.002)*	(0.000)*
β_0 (Vp)	0.0002	0.0101	-0.0006	-0.0036
	(0.08)***	(0.01)*	(0.03)**	(0.08)***
β_1 (Np)	-0.0067	-0.3628	-0.006	-0.0467
	(0.01)*	(0.00)*	(0.09)***	(0.100)***
β_2 (F10.7)	0.0296	0.5607	0.0249	0.4006
	(0.02)**	(0.00)*	(0.01)*	(0.00)*
AR or MA	-0.661	-0.927	-0.566	-0.941
	(0.01)*	(0.000)*	(0.01)*	(0.000)*
R^2	0.67	0.49	0.61	0.67
Adj. R^2	0.57	0.39	0.51	0.59
Durbin Watson	1.762	2.051	1.975	1.843
Prob. (F-statistics)	(0.000)	(0.003)	(0.001)	(0.000)
Serial Cor. LM	(0.084)	(0.882)	(0.884)	(0.461)
White Het.	(0.586)	(0.895)	(0.686)	(0.703)

*,**,*** represents the significant level at 1%, 5%, and 10%, respectively.

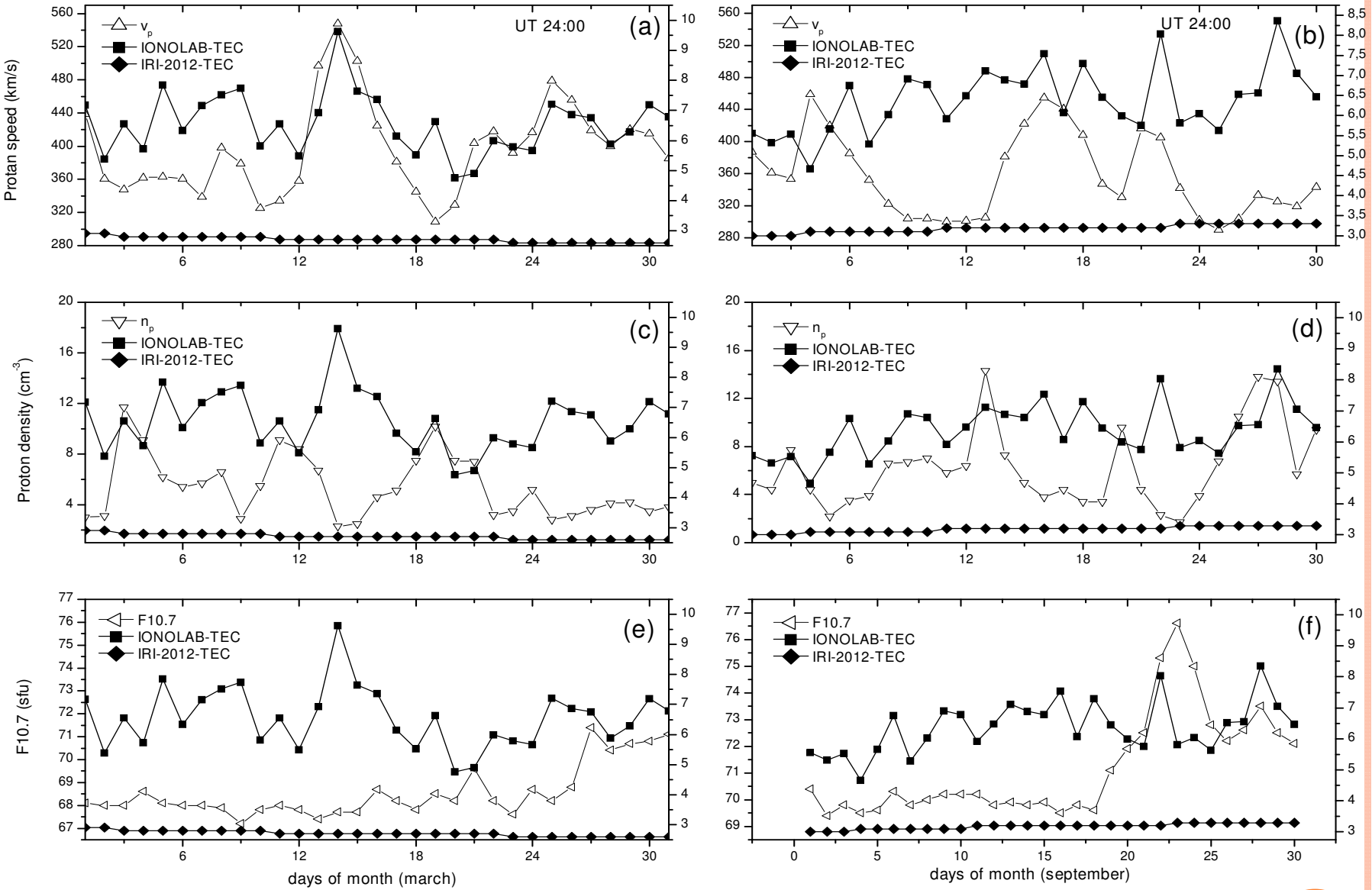

Figure 2. The variation of total electron content depending solar parameters at mid-latitude region for UT 24:00.

4. CONLUSIONS

- The following results are obtained by our multiple regression model;

1. It is observed that the independent variables have effect over the dependent variables on both March and September equinoxes.
2. The effecting coefficients of Vp and Np are greater at 12:00 UT than 24:00 UT for both IRI-2012 and IONOLAB-TEC models at both months. However, this situation is opposite for F10.7 solar flux values expect for IONOLAB-TEC on September month.
3. The order of effecting rates of independent variables on dependent variables is as F10.7>Np>Vp in all cases.
4. The Adj.R^2 values which are expressing the percentage of effecting of independent variables over the dependent variables are greater at 12:00 UT than 24:00 UT.
5. The effect on IONOLAB model of all three parameters is greater than IRI-2012 model for both each months and 12:00 and 24:00 UT.
6. While Np has a negative effect on dependent variables, F10.7 cm solar flux has a positive effect on dependent variables at all cases.

- We can conclude that IONOLAB-TEC values obtained for mid-latitude coordinates are more sensitive than IRI-TEC values to variations occurred in the sun.

THANK YOU FOR YOUR ATTENTION