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Analysis of Ionospheric Anomalies due to Space Weather Conditions by using GPS-TEC Variations

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Outline

I- Aim of the Study

In this study;

Effects of space weather conditions on ionospheric TEC changes are examined.

II- Ionosphere

The atmospheric layer surrounding the Earth is composed of 99% Nitrogen (N_2) and Oxygen (O_2) and Carbon Dioxide (CO_2) and other gaseous structures (Rishbeth and Garriott, 1969; Ratcliffe, 1972; Kelley, 1989).

The atmosphere of the Earth is divided into various layers depending on the activity of the Sun, the gravity and magnetic field of the Earth, the temperature and the degree of ionization.

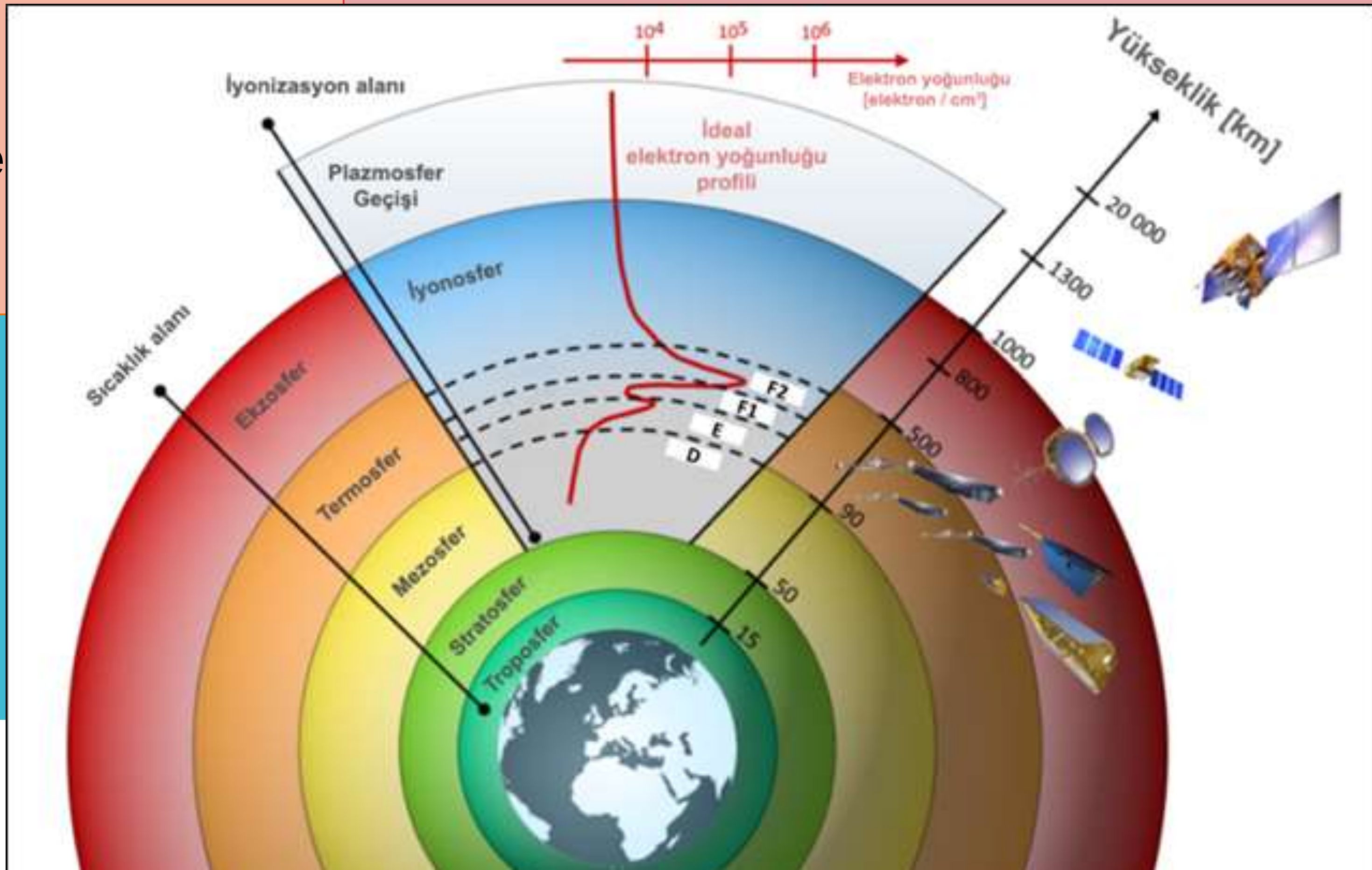
II- Ionosphere

Depending on the temperature

- troposphere,
- stratosphere,
- mesosphere,
- thermosphere
- exosphere.

Depending on the ionization,

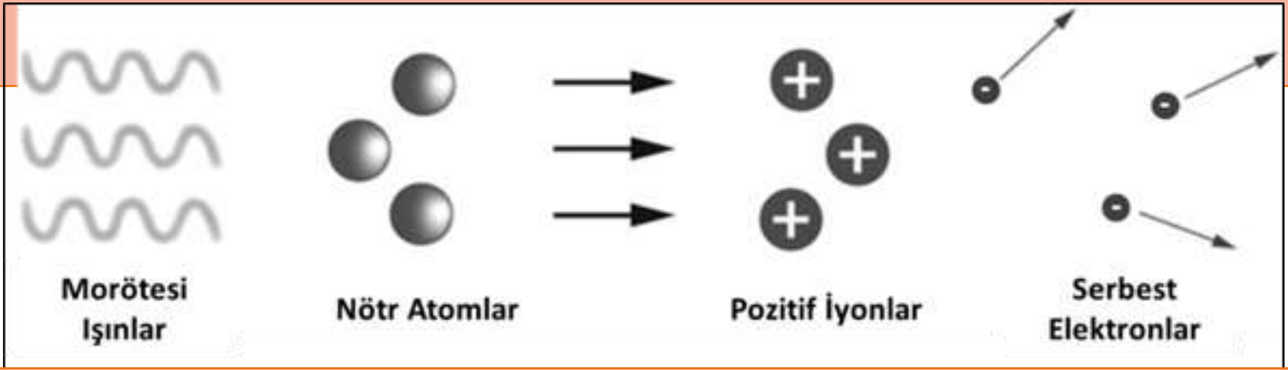
- neutral ionosphere up to 70 km,
- magnetosphere from 70 km to 1000 km.



II- Ionosphere

The Photoionization

Daytime Extreme ultraviolet (EUV) rays and X-rays emitted from the sun multiply atoms and molecules that are gaseous in the atmosphere, resulting in the formation of positively charged ions and negatively charged free electrons, ie, photoionization (Ratcliffe, 1972; Zolesi and Cander, 2014).

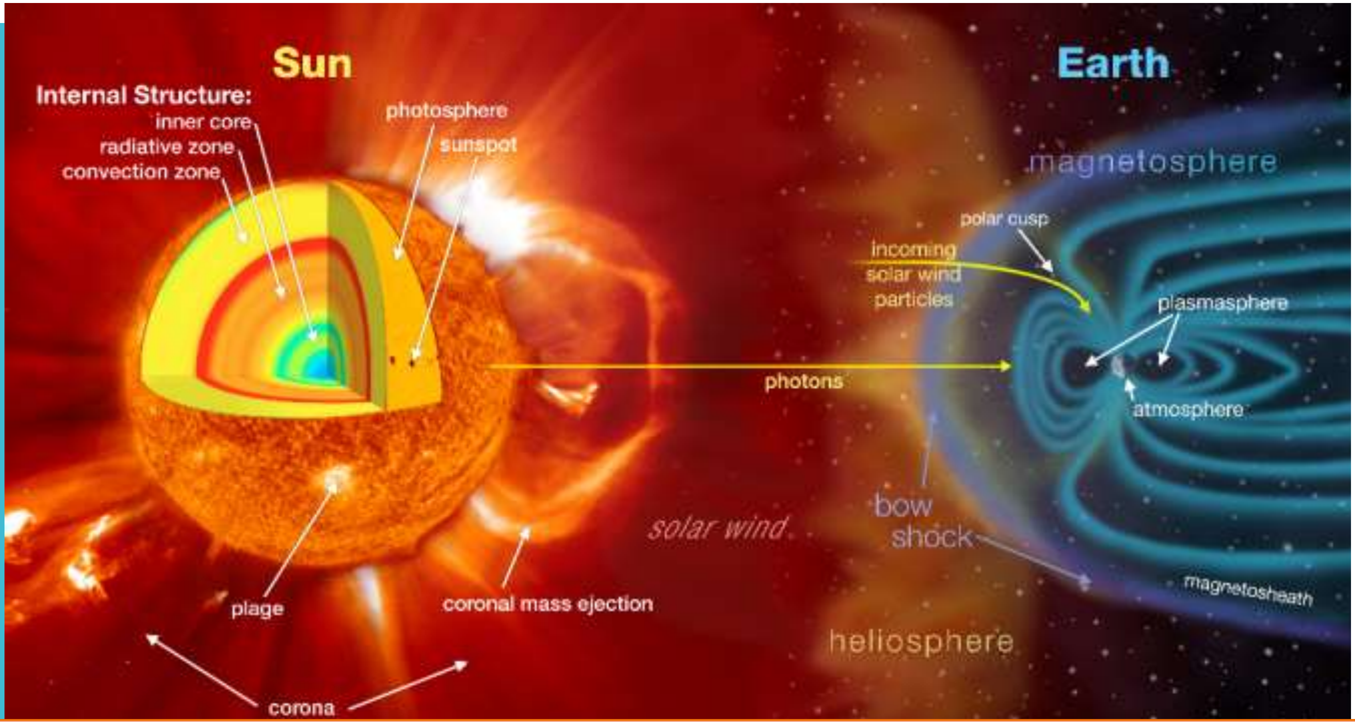


In the hours when the sun is not visible, ions and electrons recombine to form neutral atoms and molecules, which causes backward inverse processes in the ionosphere.

III- Space Weather Conditions

Due to solar and / or geomagnetic activity, time-dependent changes in the Solar System, including the magnetosphere, ionosphere, and thermosphere conditions, form the space weather conditions. Solar activities can affect Earth's space weather conditions in three different ways.

III- Space Weather Conditions



The first is the CME-Coronal Mass Ejections, which radiates hot plasma to the outer space,

The second is the high-velocity plasma released from the coronal mass ejections forming the solar winds,

The third is the Solar bursts with the magnetic energy released with intense radiation.

III- Space Weather Conditions

The influence of the ionosphere layer causes major changes such as changing the density distribution in the ionosphere, increasing or decreasing the TEC values, and impairing the current balance in the ionosphere (Komjathy, 1997).

In order to model these changes in the ionosphere, it is necessary to define the solar activity and / or geomagnetic indices and determine the solar and geomagnetic effect levels. In order to interpret the solar and geomagnetic activities that cause the change in the ionosphere, indices called as variables of space weather conditions are used.

III- Space Weather Conditions

- **Solar Activity Indices**
  - SFI- Solar Flux Index **(F10.7)**
  - EUV- Extreme Ultraviolet Flux Index, (**EUV 0.1-50 nm** and **EUV 26-34 nm**)

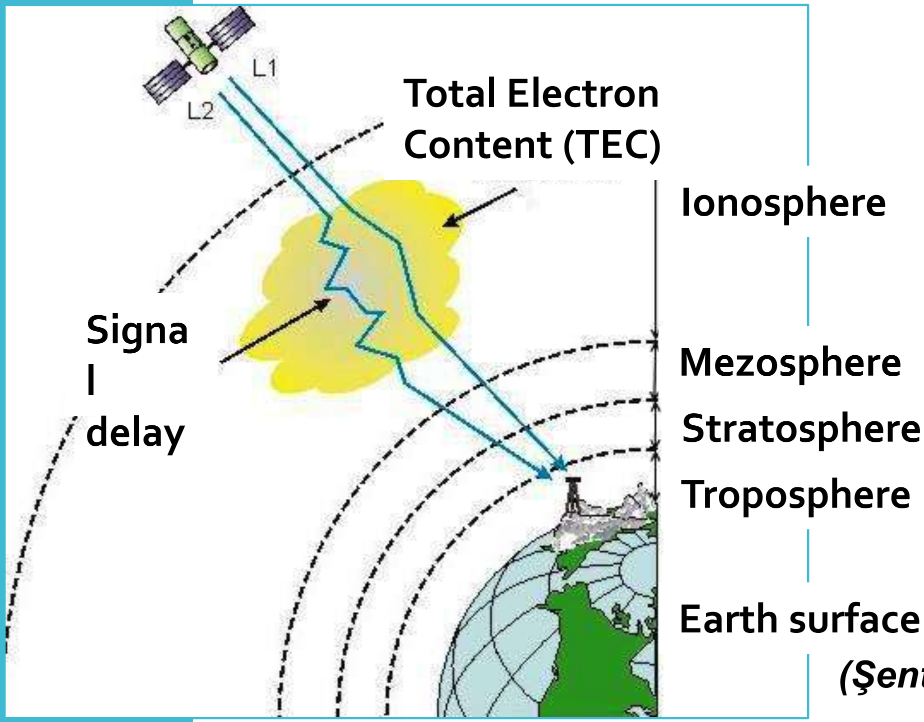
- **Geomagnetic Storm and Geomagnetic Activity Indices**
  - Geomagnetic Storm Index **(Kp)**
  - Geomagnetic Activity Index **(Dst)**

- **Magnetic Field Changes**
  - Magnetic Field Indices **(Bx, By ve Bz)**

- **Plasma Density and Particle Flux Indices**
  - Proton Density **(Np/cm3)**
  - Proton Flux **(>1, >2, >4, >10, >30 ve >60 MeV)**

IV- Estimating GPS-TEC Variation and Analysis

GPS signals are delayed when passing through the ionosphere.



(Şentürk and Çepni, 2014)

The ionosphere structure reflects the waves at frequencies of 30 MHz and below.

The signals at 50 MHz and above can pass through the ionosphere, but are subject to attenuation and delay in the ionosphere *(Schaer, 1999).*

IV- Estimating GPS-TEC Variation and Analysis

Vertical Total Electron Content (VTEC)

Leveling (Smoothing) coefficient B^m, Φ_4 combined with STEC values;

$$STEC_u^m(n) = \frac{1}{A}\left(\frac{f_1^2 f_2^2}{f_2^2 - f_1^2}\right)\left(B^m - \Phi_{4,u}^m(n) - \left(DCB^m + DCB_u\right)\right)$$

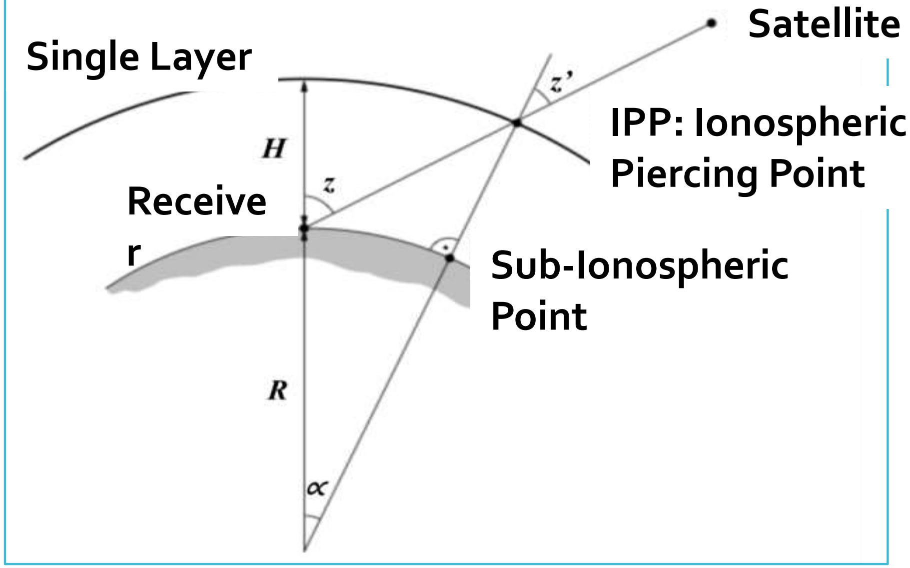
Calibrated STEC variations can be obtained by eliminating satellite and receiver DCBs, from the each satellite and receiver arc

VTEC variations (*Klobuchar, 1986*), can be obtained by single-layer ionosphere model **with mapping function**

$$M\left(z_m(n)\right) = \frac{STEC_u^m(n)}{VTEC_u^m(n)}$$

$z_m(n)$: receiver and satellite zenith angle

IV- Estimating GPS-TEC Variation and Analysis



$M(z)$ mapping function:

$$M(z) = \frac{1}{\cos z'} = \frac{1}{\sqrt{1 - \sin^2 z'}}\ , \qquad \sin z' = \frac{R}{R+H} \sin(\alpha z)$$

z': (IPP) zenith angle at the point where the signal path from the receiver to the receiver is located in the ionosphere; R: Radius of the world (6378.137 km);α=0.9886 The scale factor of the improved thin-layer projection function; H: Height of ionospheric thin layer (350 km) *(Mannucci v.d., 1993; Schaer, 1999)*

IV- Estimating GPS-TEC Variation and Analysis

The hourly VTEC values can be obtained by fitting second degree polynomial surfaces to the IPP points on each station with the calibrated VTEC values at these points. (*Durmaz ve Karslioglu, 2014*):

$$VTEC(\varphi_{IPP}, s_{IPP}) = a_0 + a_1\varphi_{IPP} + a_2 s_{IPP} + a_3\varphi_{IPP}^2 + a_4\varphi_{IPP}s_{IPP} + a_5 s_{IPP}^2$$

φ_{IPP} and s_{IPP}: Spherical coordinates of IPPs in the sun-fixed reference system
a_0, a_1, a_2, a_3, a_4 ve a_5 : Polynomial surface coefficients

An hourly VTEC variations are obtained by the obtaining polynomial surface coefficients and the positions of each station in the sun-fixed spherical coordinate system.

IV- Estimating GPS-TEC Variation and Analysis

VTEC anomalies affected by ionospheric changes can be calculated according to the moving median (MM) method between quartiles (*Liu vd., 2009*);

- **Lower quartiles (LQ) and upper quartiles (UQ) are obtain.**
- **VTEC values are determined in the normal distribution with mean (m) and standard deviation (σ), MM, LQ and UQ values are determined at m and 1.34σ confidence interval (*Klotz ve Johnson, 1983*).**
- **Lower Boundary (LB) values LB = MM – 1.5(MM – LQ)**
  Upper Boundary (UB) values UB = MM + 1.5(UQ – MM)
- **Positive anomaly variations are over the upper boundaries**
- **Negative anomaly variations are below the lower boundaries**

If the anomalies found within one day are higher or lower than the limit values of more than one third, the day is considered abnormal day. *(Liu v.d., 2009).*

V- What We Do?

In this study;

- **The continuity of the GPS observations belonging to the IGS stations was checked,**

- **The index values of the space weather conditions investigated,**

- **Relation between the space weather condition indices and ionospheric TEC variations were examined.**

VI- Findings

- Analysis result of Space Weather Conditions,
- Calculation of Ionospheric TEC variations,
- Analysis of space weather condition with ionospheric TEC variations,

SPACE WEATHER CONDITION INDICES DATA

The space weather conditions have been studied to determine the quiet days of the ionosphere.

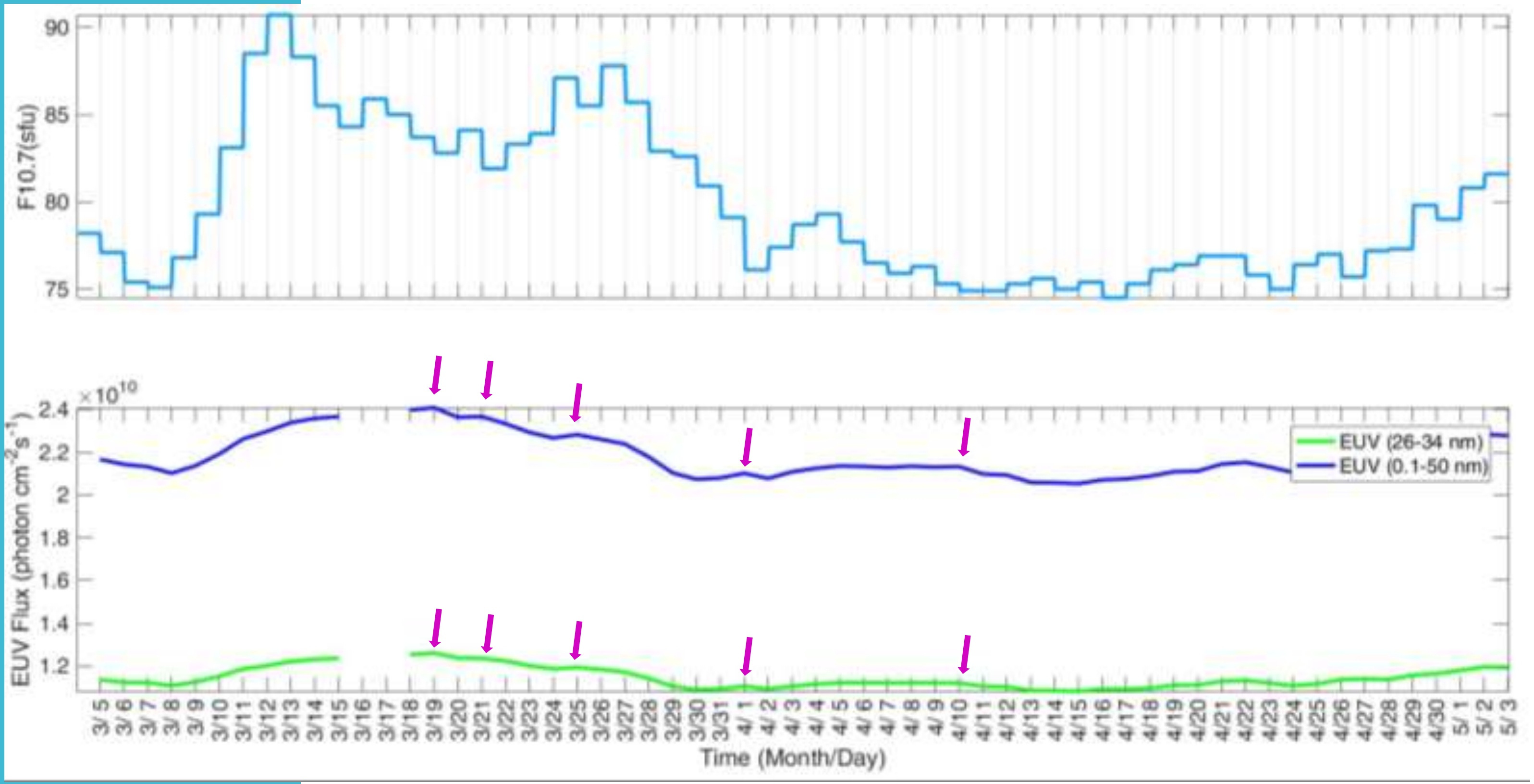
In this study, the indices of space wearther conditions;

- Solar flux indices (F10.7cm ve EUV 0.1-50nm, EUV 26-34nm),
- Geomagnetic storm and geomagnetic activity (Kp ve Dst),
- Magnetic field indices (Bx, By ve Bz),
- Plasma density index (proton density)
- Particle flux indices (proton akısı >1, >2, >4, >10, >30 ve >60 MeV)

Totally 15 indices were used.

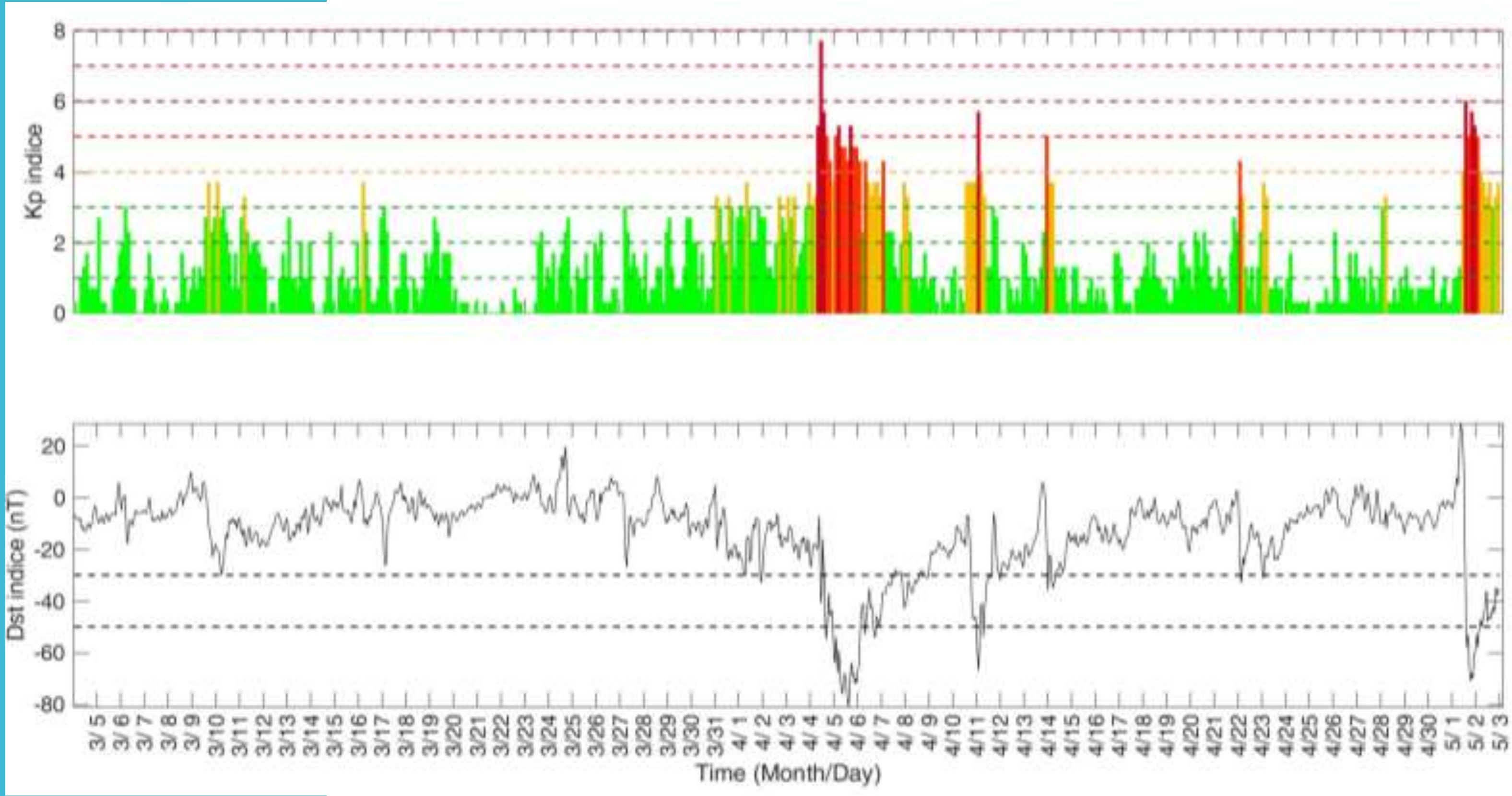
ANALYSIS OF SPACE WEATHER CONDITIONS

Analysis of the solar activity (SA) indices (F10.7cm and EUV 0.1-50nm, EUV 26-34nm) (F10.7 limit value 150 sfu; EUV peak)



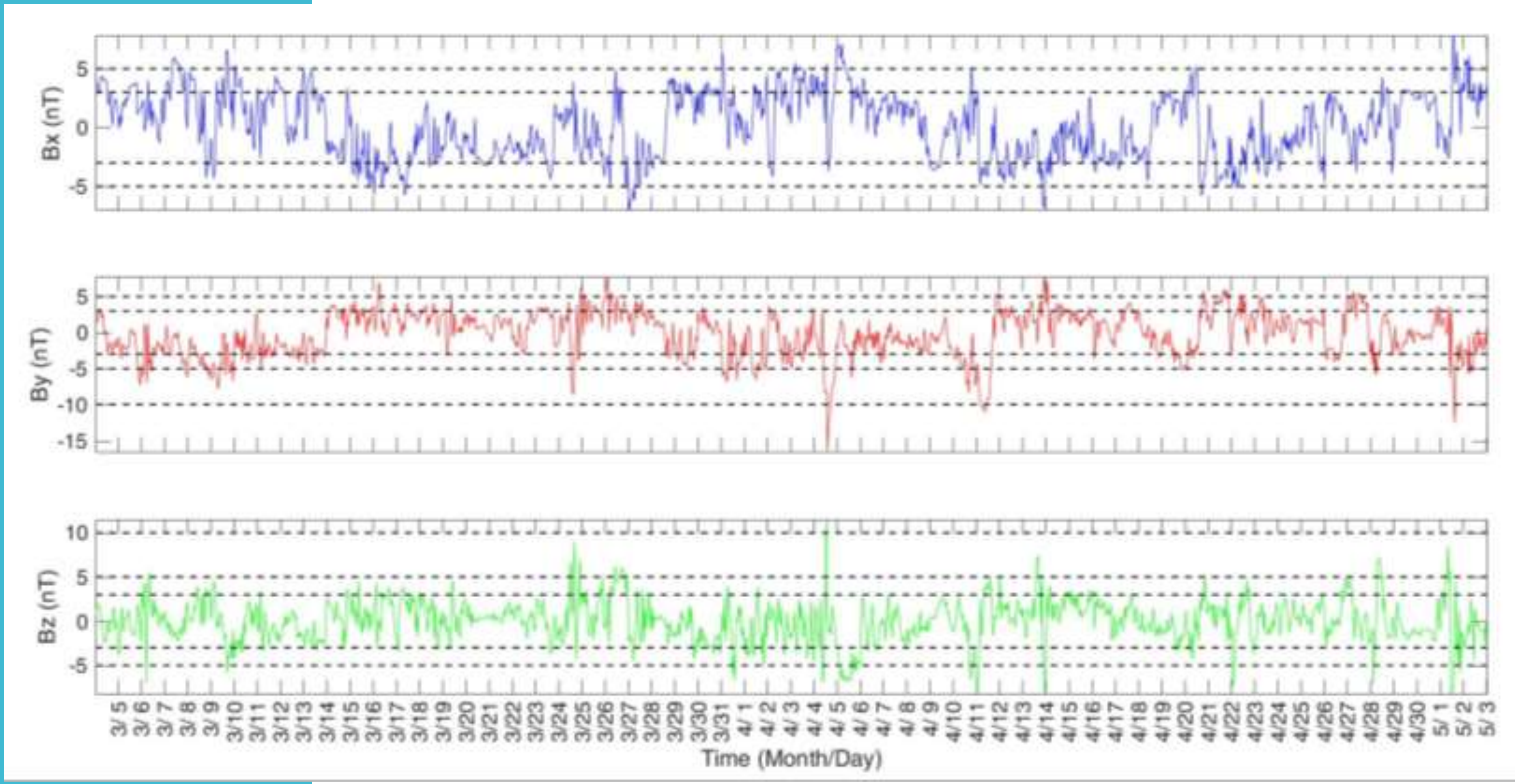
ANALYSIS OF SPACE WEATHER CONDITIONS

Geomagnetic Storm (GS) and Geomagnetic Activity (GA) indices (Kp and Dst),



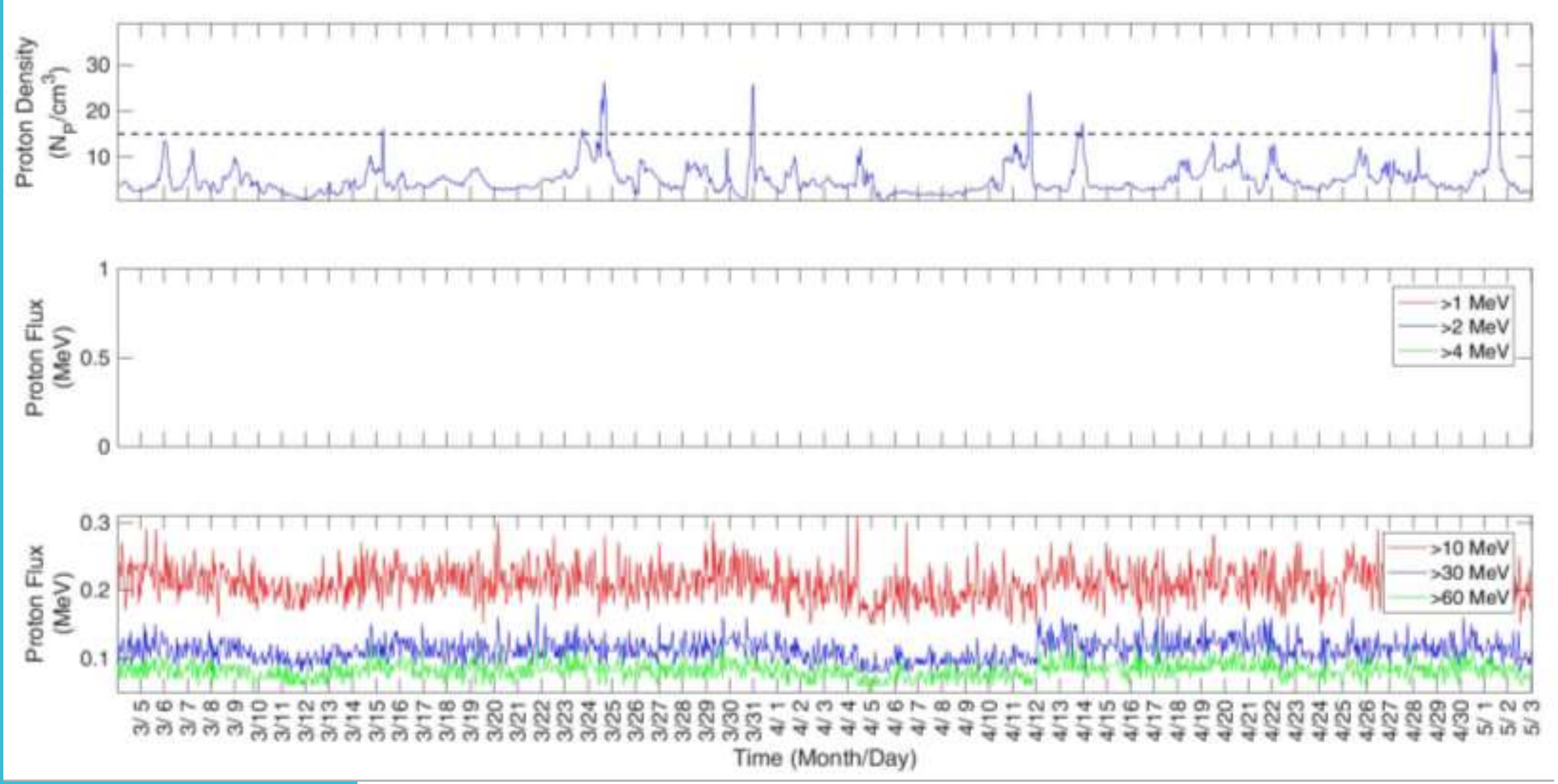
ANALYSIS OF SPACE WEATHER CONDITIONS

Magnetic Field (MF) Indices (Bx, By and Bz),



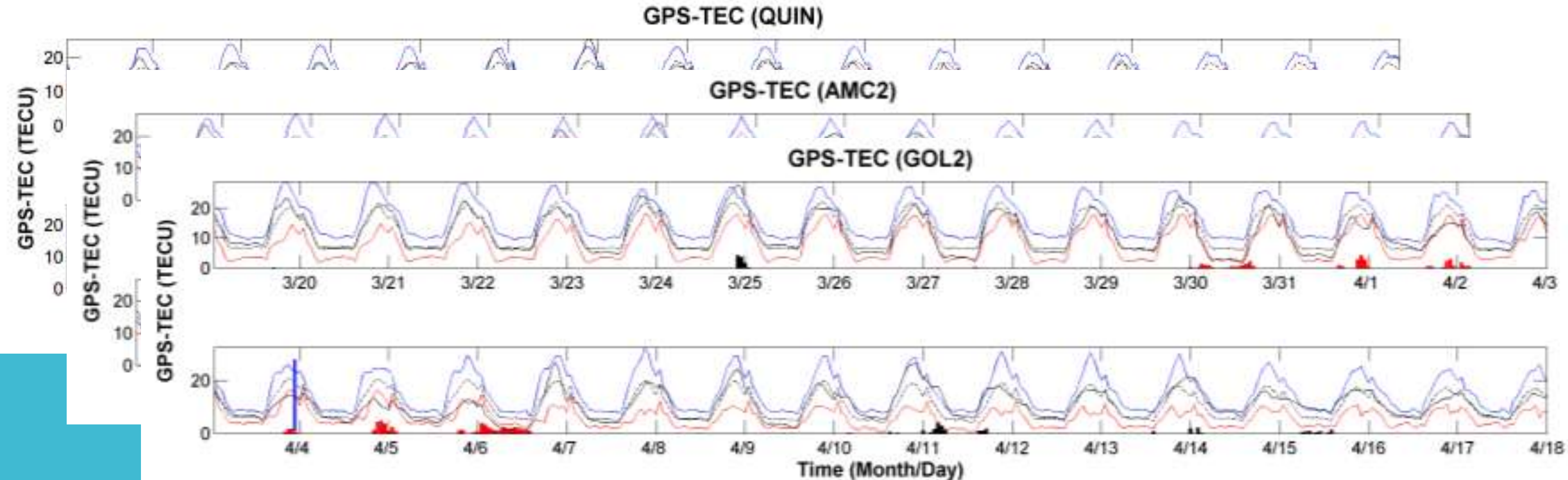
ANALYSIS OF SPACE WEATHER CONDITIONS

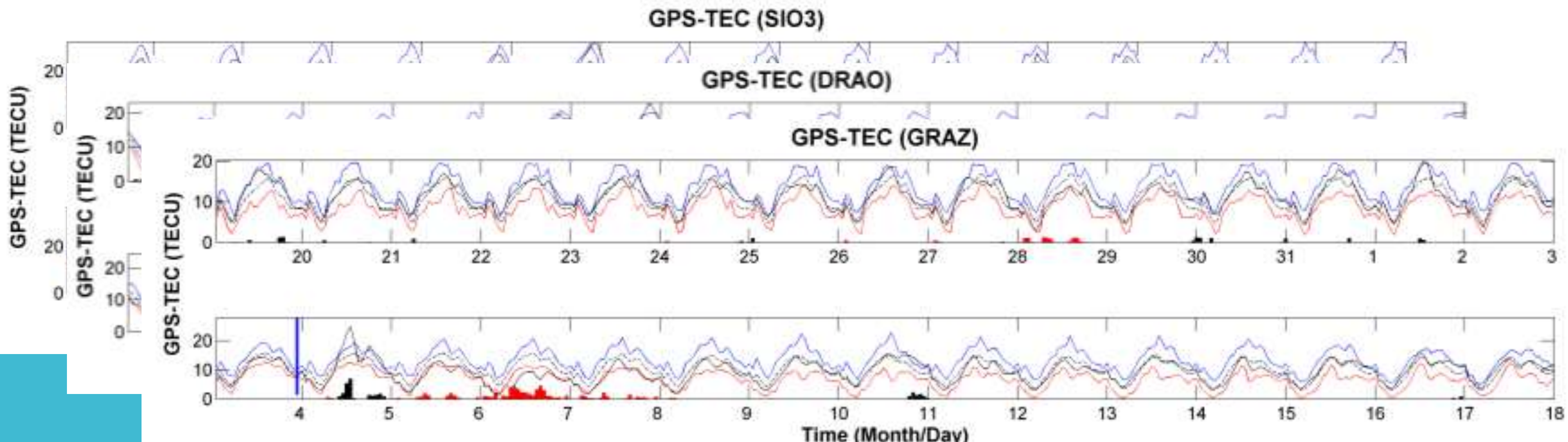
Plasma Density (PD) and Particle Flux (PA) indices (proton density and six different energy scale proton flux)



ANALYSIS OF SPACE WEATHER CONDITIONS

	Time (Month/Day)	3/20	3/21	3/22	3/23	3/24	3/25	3/26	3/27	3/28	3/29	3/30	3/31	4/1	4/2	4/3	4/4	4/5	4/6	4/7	4/8	4/9
GA	F10.7		+				+		+									+				+
	EUV(.1-50nm)		+				+							+				+				+
	EUV(26-34nm)		+				+							+				+				+
GA GS	Kp																	+	+	+		
	Dst (nT)																	+	+	+		
MF	Bx (nT)								+					+				+	+			
	By (nT)						+	+	+					+	+			+	+			
	Bz (nT)						+		+					+				+	+			
PD	N_p					+	+															
PF	>1MeV																					
	>2MeV																					
	>4MeV																					
	>10MeV																					
	>30MeV																					
	>60MeV																					
	DECISION	Q		Q	Q					Q	Q	Q	Q			Q					Q	





Upper Bound
GPS-TEC Variations
Median Values
Lower Bound
Negative Anomaly
Positive Anomaly

SPACE WEATHER CONDITIONS AND ANALYSIS OF IONOSPHERIC VTEC VARIATIONS

24 March positive abnormal day (plasma density)

25 March positive abnormal day (Solar activity, magnetic field and plasma density)

1 April abnormal day (Solar activity and magnetic field)

2 April negative abnormal day (magnetic field)

5 April negative abnormal day (Solar activity, geomagnetic storm, geomagnetic activity and magnetic field)

6 April negative abnormal day (geomagnetic storm, magnetic field)

7 April negative abnormal day (geomagnetic storm and geomagnetic activity)

Negative abnormal days (Occured under the quiet space weather conditions. The source must be researched.

	Time MM/DD	3/20	3/21	3/22	3/23	3/24	3/25	3/26	3/27	3/28	3/29	3/30	3/31	4/1	4/2	4/3	4/4	4/5	4/6	4/7	4/8	4/9
	KARAR	S		S	S					S	S	S	S			S					S	
Percentage Change of VTEC (%)	SIO3														33.3			37.5		62.5		
	GOL2												58.3							58.3		
	QUIN											33.3			41.7				54.2			
	AMC2						33.3							33.3	45.8	37.5		41.7	95.8	50.0		
	DRAO					33.3	66.7							50.0	66.7	70.8			91.7	58.8		
	GRAZ																	50.0	45.8	87.5	58.3	

Thanks For Your Attention…