VARIATIONS OF THE MID-LATITUDINAL IONOSPHERE DRIVEN BY SPACE WEATHER

BY

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CONCEPT OF THE STUDY

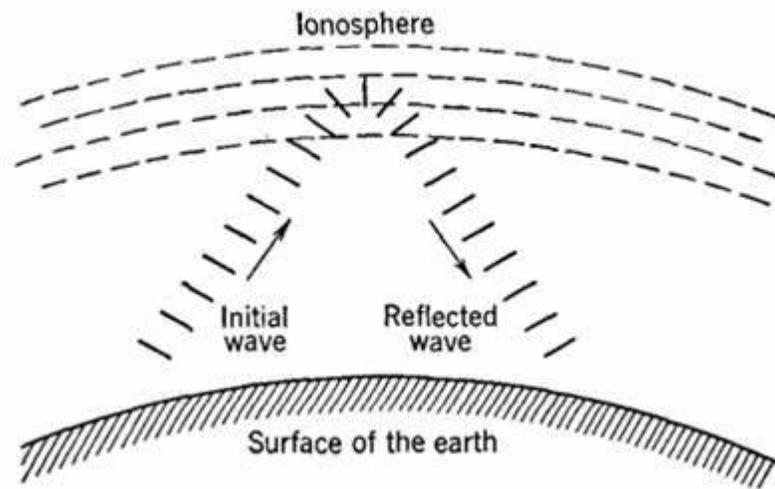➢ Propagation of radio and communication signals varies with the condition of the ionosphere

Figure 1: Propagation of radio waves via the ionosphere
(https://vias.org/albert_ecomm/aec12_radio_wave_propagation_007.html)
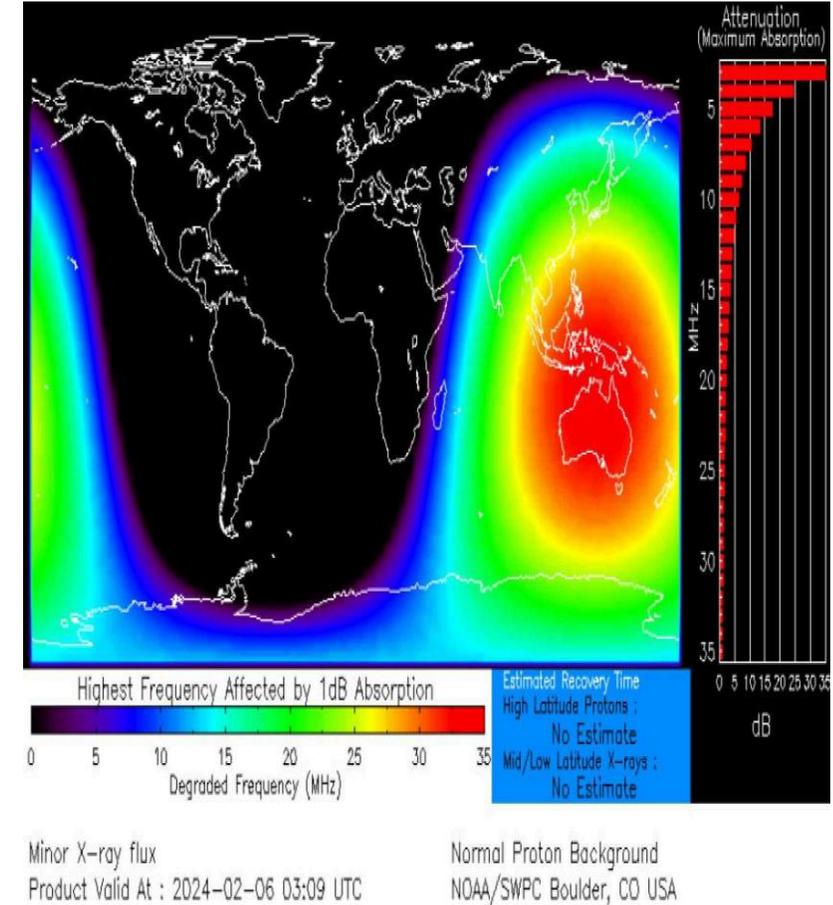
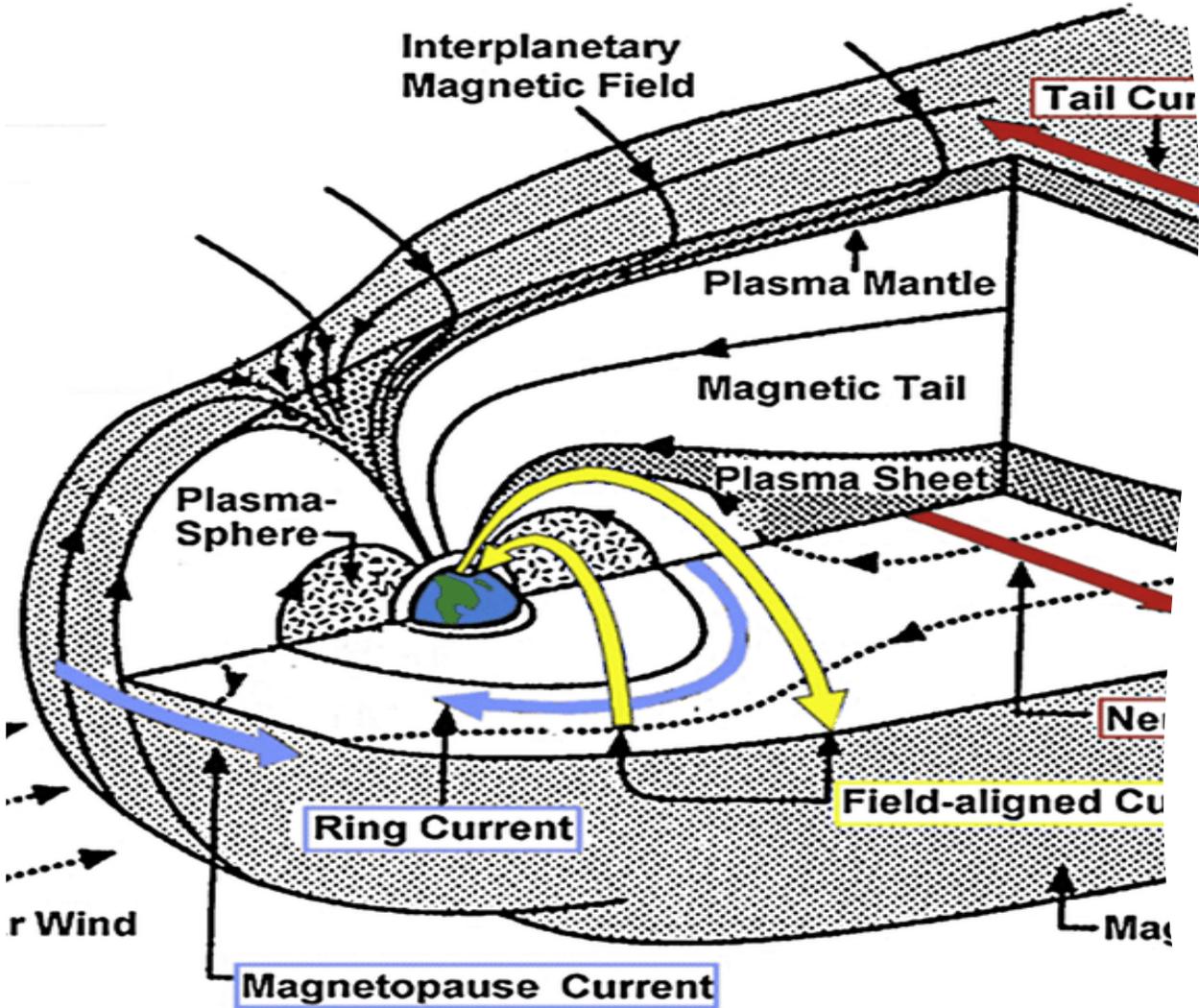

Figure 2: Radio blackouts on 19 may 2022 (Source: National oceanic & atmospheric administration

DEFINITION OF TERMS

SUN AND SOLAR WIND:

➤ Fusion reaction of hydrogen in the suns core, together with its differential rotation

➤ Creates the suns magnetic field which are released into interplanetary space with the solar wind.

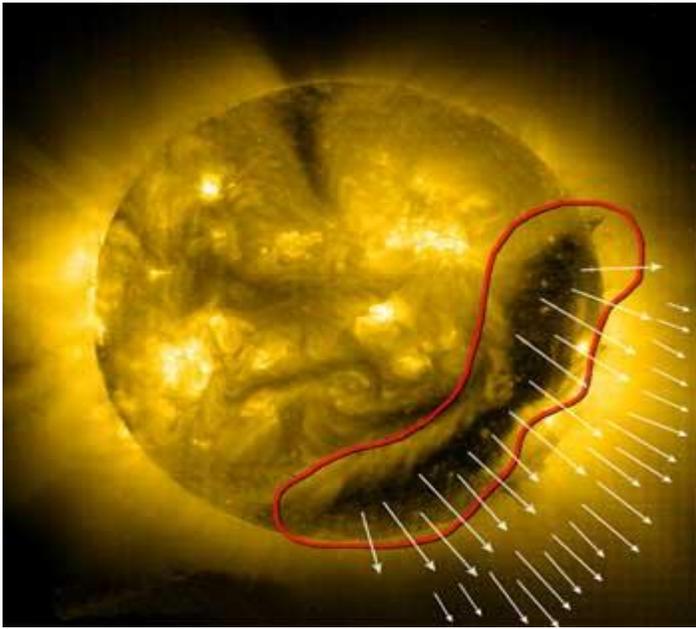Fig. 3: A sketch of the magnetosphere in Kivelson and Russel (1995)

MAGNETOSPHERE:

➢ a region of space surrounding Earth and distinguished by four currents depending on flow of charged particles (Maltsev and Ostapenko, 2000):

1. Magnetopause current

2. Ring current

3. Magnetotail current

4. Field aligned current

Figure 4: GM storm from CIR

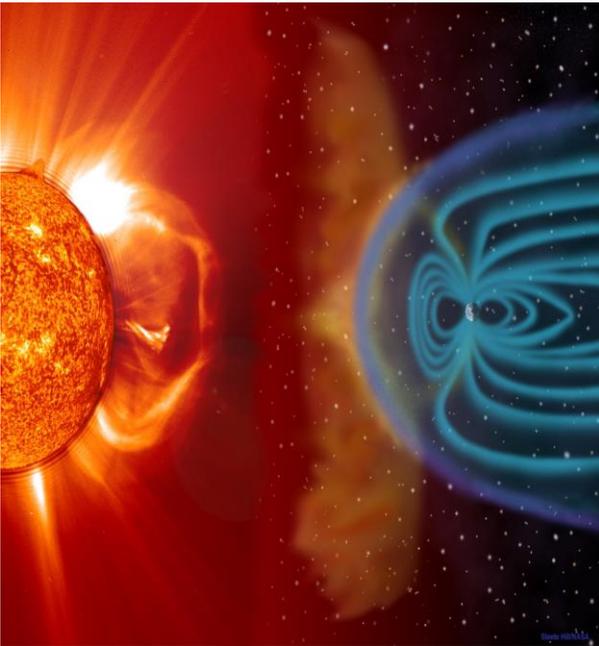Figure 5: GM storm from CME (European Space Agency)

SOURCES OF GEOMAGNETIC STORMS (GMs)

➤ Corotating interaction regions (CIRs) are associated with gradual storms – frequent during declining phase

➤ Coranal mass ejection (CMEs) are associated with sudden geomagnetic storms – Solar maxima

➤ Associated with different types of magnetic field on the sun.

➤ Their contributions to geomagnetic activity strongly depend on the 11-year solar cycle (Legrand & Simon, 1981).

DISTURBANCE STORM TIME & INTENSITY LEVELS

➢ Dst index - Measures the strength of the ring current around earth
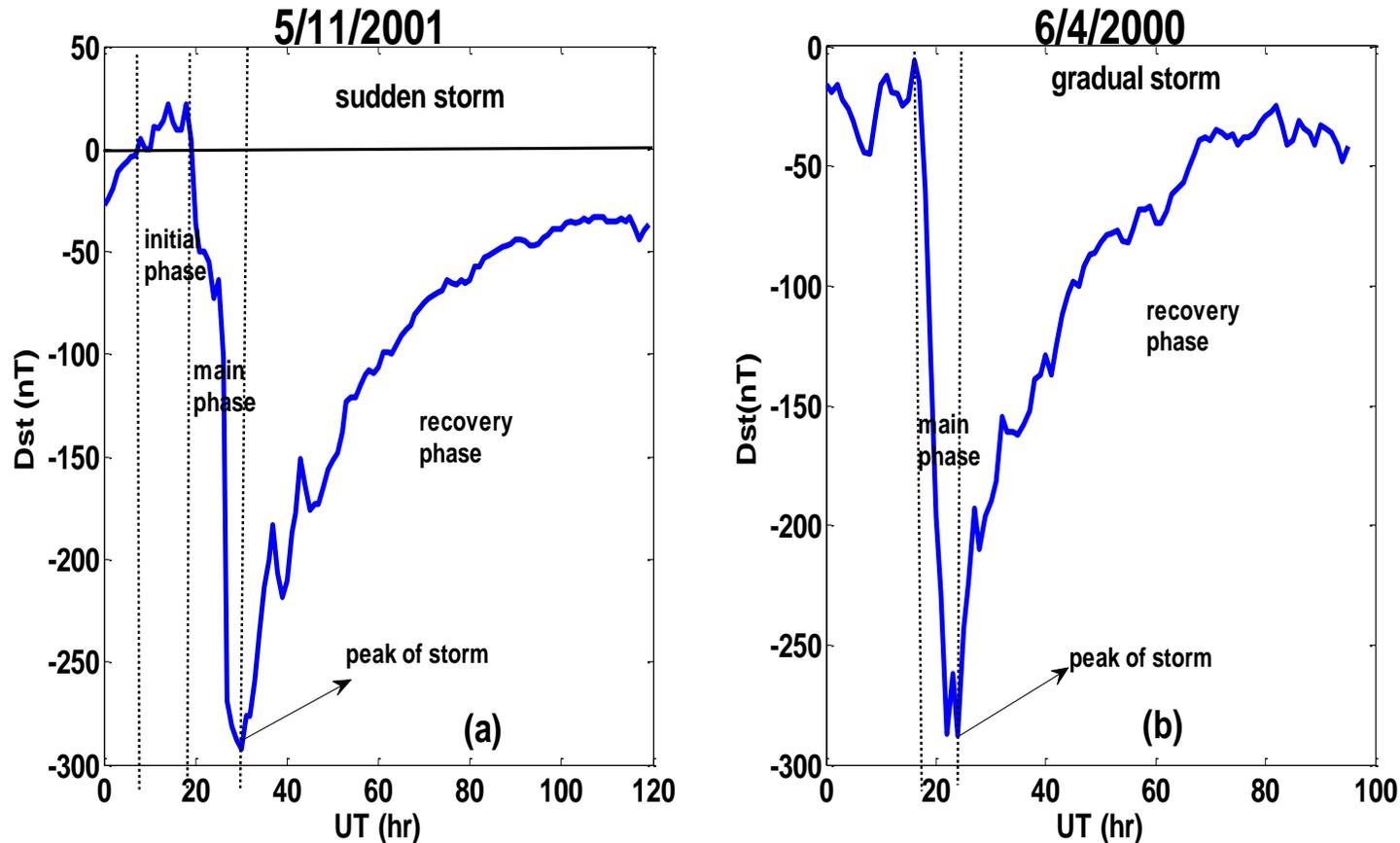

Figure 6: Schematic of sudden & gradual geomagnetic storms

Table 1: Definition of geomagnetic activity intensity levels (Echer et al., 2006)

Level	Dst, (nT)
Intense	Dst ≤ -100
Moderate	-50 ≥ Dst < -100
Weak	-30 ≥ Dst < -50
Quiet	Dst > -30

IONOSPHERE

➢ A region within the upper atmosphere where large concentrations of ions and free electrons exist.

Figure 7: Layers of earths atmosphere (https://ar.inspiredpencil.com/pictures-2023/ionosphere-layers-atmosphere)
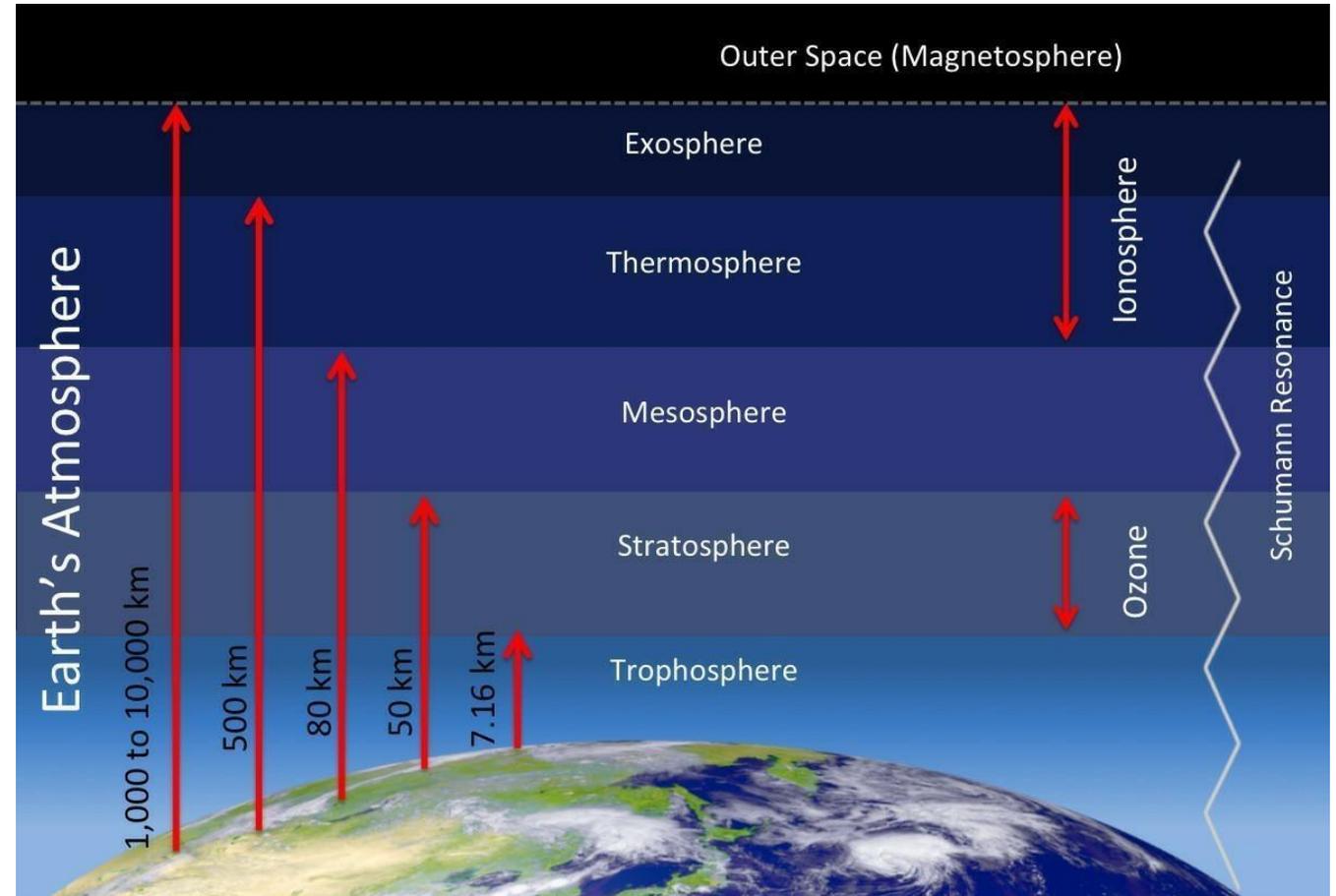
LAYERS OF THE IONOSPHERE

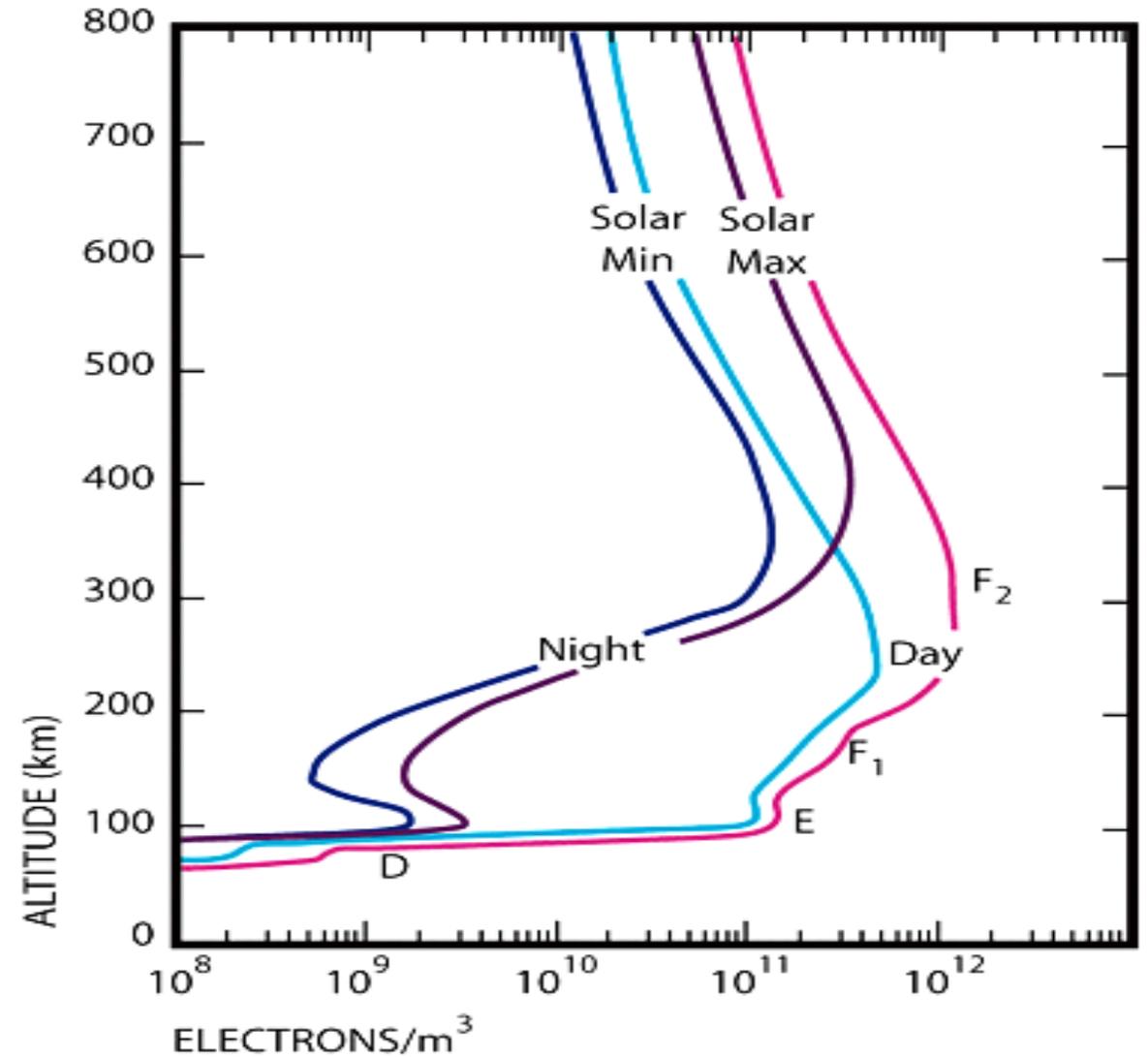➢ It is divided into D, E, F1 & F2 layer which are distinct in daytime.

Figure 8: Layers oaf the ionosphere (Lanzerotti et al. 2007)

MEASUREMENT OF TOTAL ELECTRON CONTENT (TEC)

➢ Ionization and density varies with height

➢ Critical freq. of each layer is related to density (Ne) by

$$foF2 = 9*\sqrt{Ne} \qquad\qquad 1.1$$

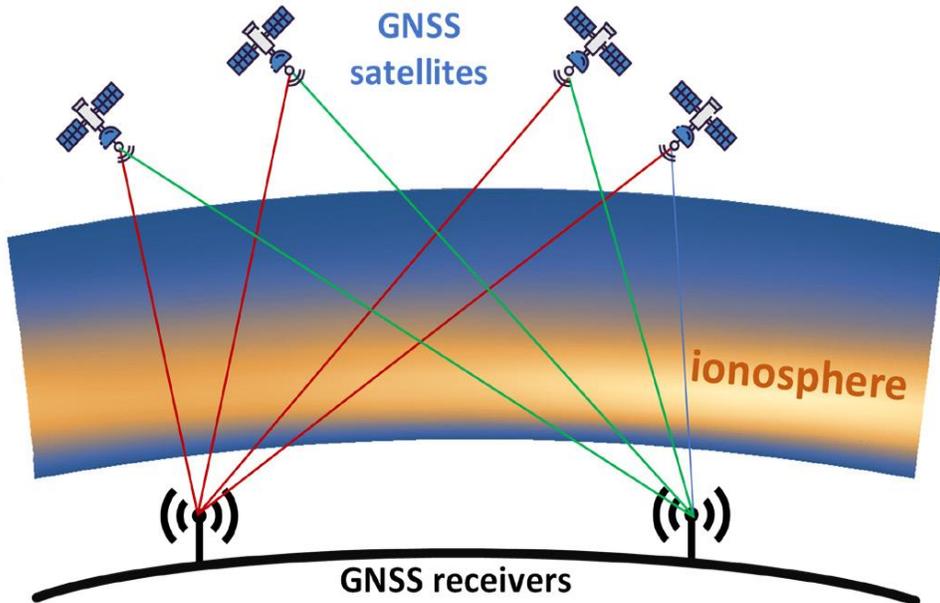where Ne is maximum electron density per m3 and fo is in Hz

➢ TEC - A measure of the number of electrons of the ionosphere in a unit cross-section column above an observatory.
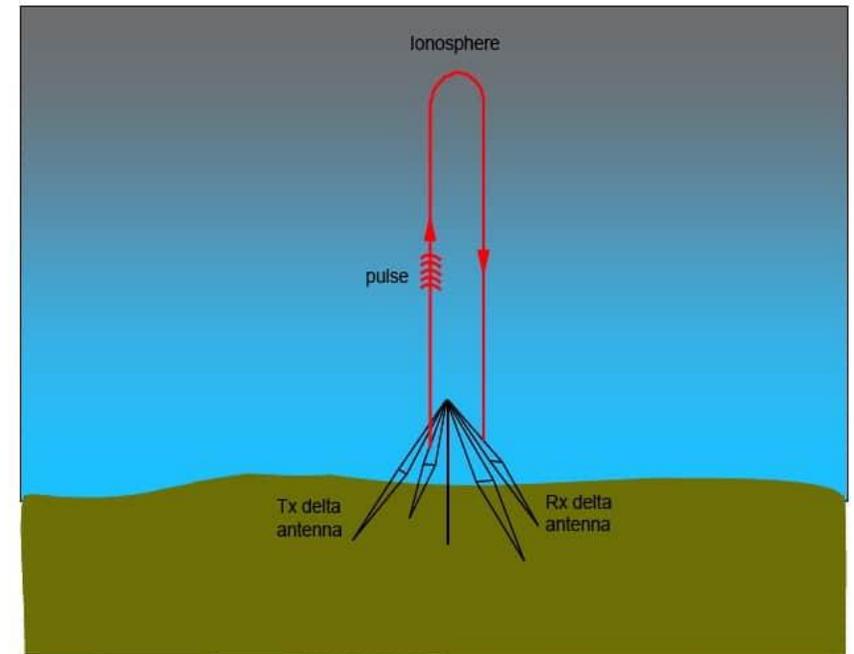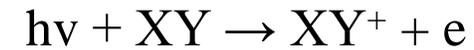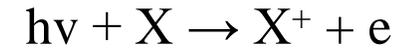
$$1 \text{ TEC unit} = 1016m^{-2}$$

Figure 9: Measurement of TEC using GNSS receivers in Naumov et al. 2024

Figure 10: Measurement of TEC using ionosondes in Australian Bureau of meteorology
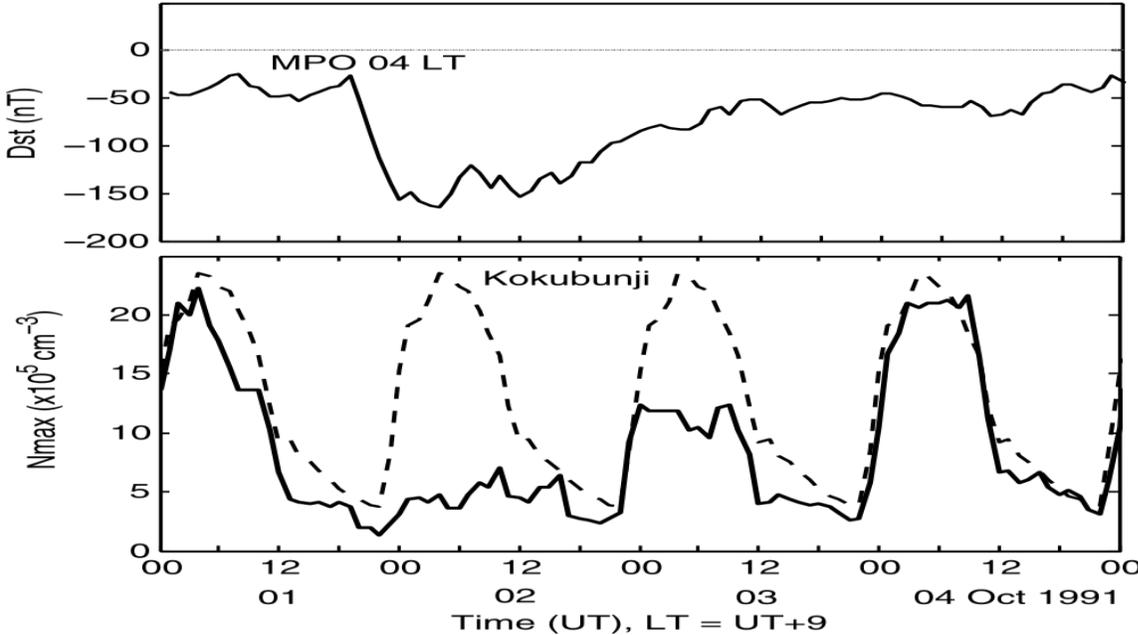
Figure 11: (bottom) Example of a negative ionospheric storm at Kokubunji during (top) the geomagnetic storm of 2-4 October 1991 in Lekshmi et al. (2011)

Figure 12: (bottom) Example of a positive ionospheric storm at Kokubunji during (top) the geomagnetic storm of 22-25 October 1999 in Lekshmi et al. (2011)

IONOSPHERIC STORMS

➢ Are increase (positive storms) or decrease (negative storms) of f0F2 or TEC.

➢ Positive storms – enhancement of ionization

$$hv + X \rightarrow X^+ + e$$

$$hv + XY \rightarrow XY^+ + e$$

➢ Negative storms – enhancement of recombination process

$$X^+ + e \rightarrow X + hv$$

$$XY + e \rightarrow X^* + Y^*$$

EFFECTS OF IONOSPHERIC STORMS

source: swc.nict.go.jp

PURPOSE OF THIS PHD PROJECT

➢ Variations of TEC during GMs in relation to

• local time, seasons, severity of the geomagnetic storms,

• the type of storms (sudden or gradual) and the phase of the solar cycle

➢ identification of +, - ionospheric storms

• estimate their strength during geomagnetic storms.

➢ estimation of the standard deviation of the measured TEC

LITERATURE REVIEW

➢ A summary of TEC patterns during GMs are :

1. Variations in the peaks of positive & negative ionospheric response with latitude.

2. positive storms are more pronounced in winter and negative storms are more pronounced in summer.

3. Well defined positive phase for daytime storms

4. Negative phase depth linked to severity of storms.

TEC DATA

➢ between January 2015 and December 2019, corresponding to the decreasing phase of solar cycle 24.

➢ National Network of Permanent GNSS Stations (ReNEP), (https://renep.dgterritorio.gov.pt/).

TABLE 2: COORDINATES OF GNSS RECEIVERS

Location	Latitude	Longitude
Lisbon (Cascais)	38.7N	9.14W
Azores (Furnas)	37.8N	25.4W
Madeira (Funchal)	32.7N	16.9W

METHODS OF DATA ANALYSIS

➢ Average of the five quietest days

$$\overline{TEC_{QD}} = \frac{1}{5}\sum_{i=1}^{5} TEC_i \qquad\qquad (1.2)$$

➢ Standard deviation of the quiet day TEC values

$$\sigma = \text{SD} = \sqrt{\frac{1}{24}\sum_{H=0}^{23}(TEC_{QD}(H) - \overline{TEC_{QD}})^2} \qquad\qquad (1.3)$$

METHODS OF DATA ANALYSIS CONTD.

➢ Variations of TEC during geomagnetic storms

$$\Delta TEC = TEC - TECQD \qquad\qquad (1.4)$$

➢ σ = SD – Used to determine the values of ΔTEC that was statistically significant.

TABLE 3: SELECTED TABLE OF GEOMAGNETIC STORMS

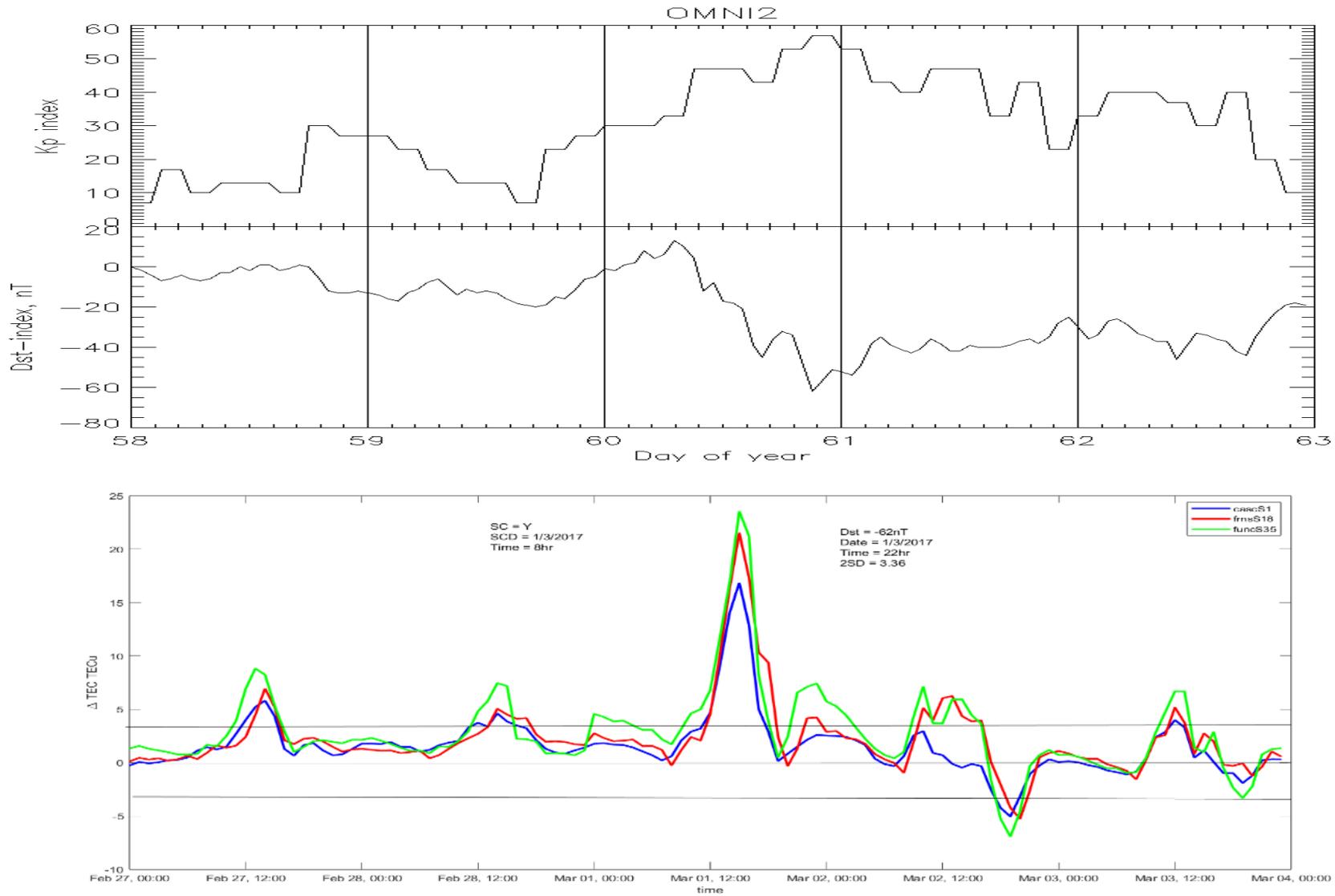| S/N	Storm dates	SSC (Y/N)?	Storm commencement time UTC	Storm Dst minimum, UTC	Dst min, nT	Kp max	Ionospheric response (type, max amplitude in TECu & SD, synchrony: Y/N)
1.	01.03.2017	Y	01.03.2017 8h	01.03.2017 22h	-62	6-	+ 16-23 TECu (9-13 SD) Y
2.	27.03.2017	Y	26.03.2017 22h	27.03.2017 17h	-71	6+	+ 10-13 TECu (4-5 SD) Y
3.	27-28.05.2017	Y	27.05.2017 22h	28.05.2017 8h	-146	6+	-/+ 10 – 12 TECu (5 – 6 SD) Y

RESULTS

Figure 13: Plots of Dst index (top) and change in TEC (bottom) for 27.02.2017 - 03.03.2017
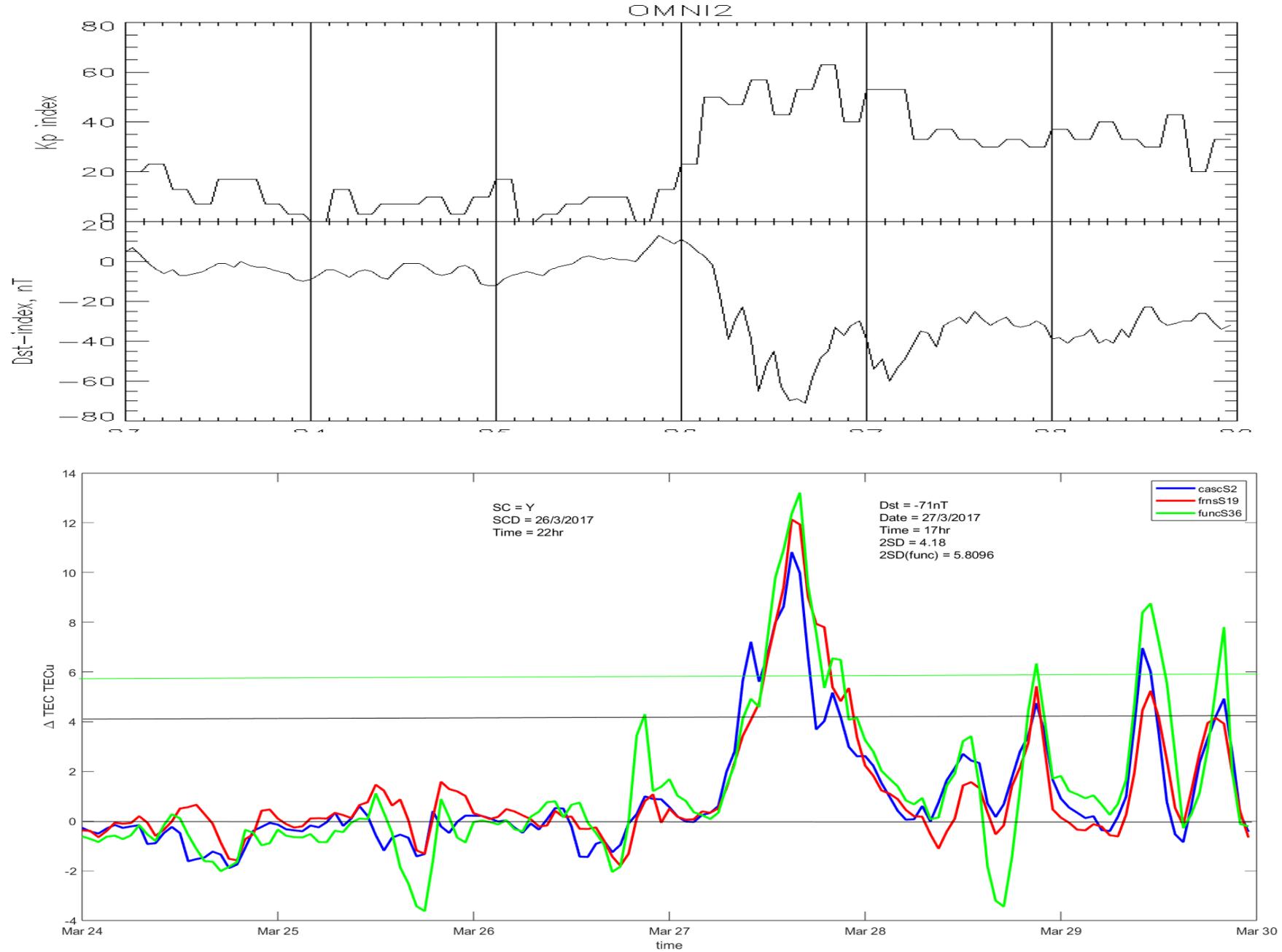
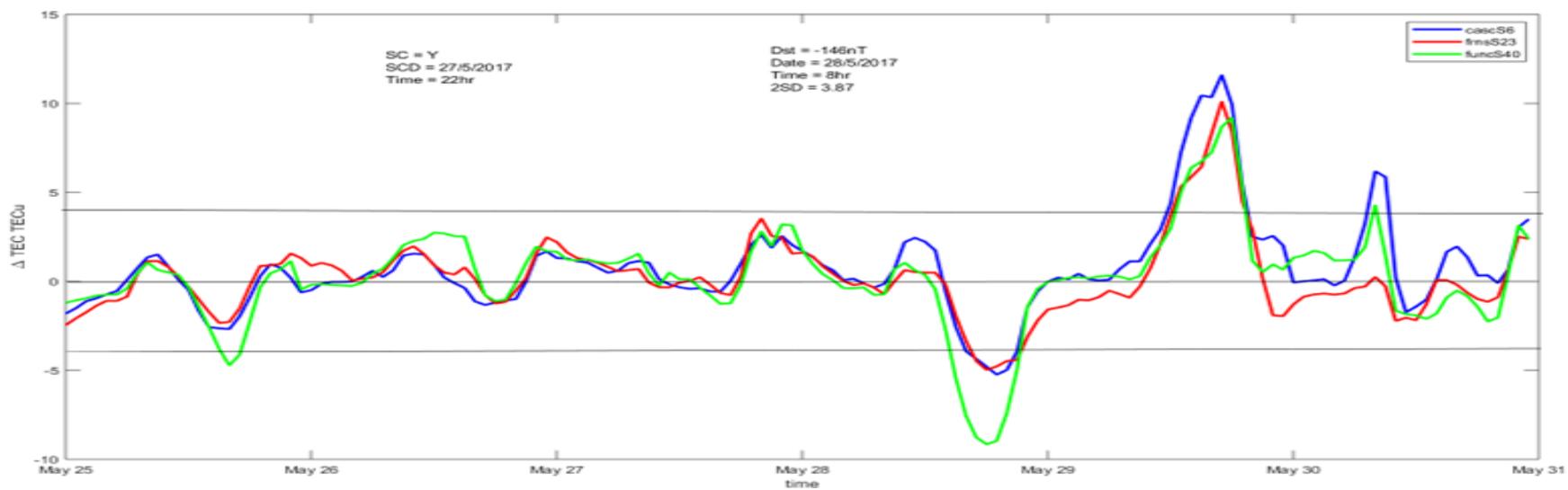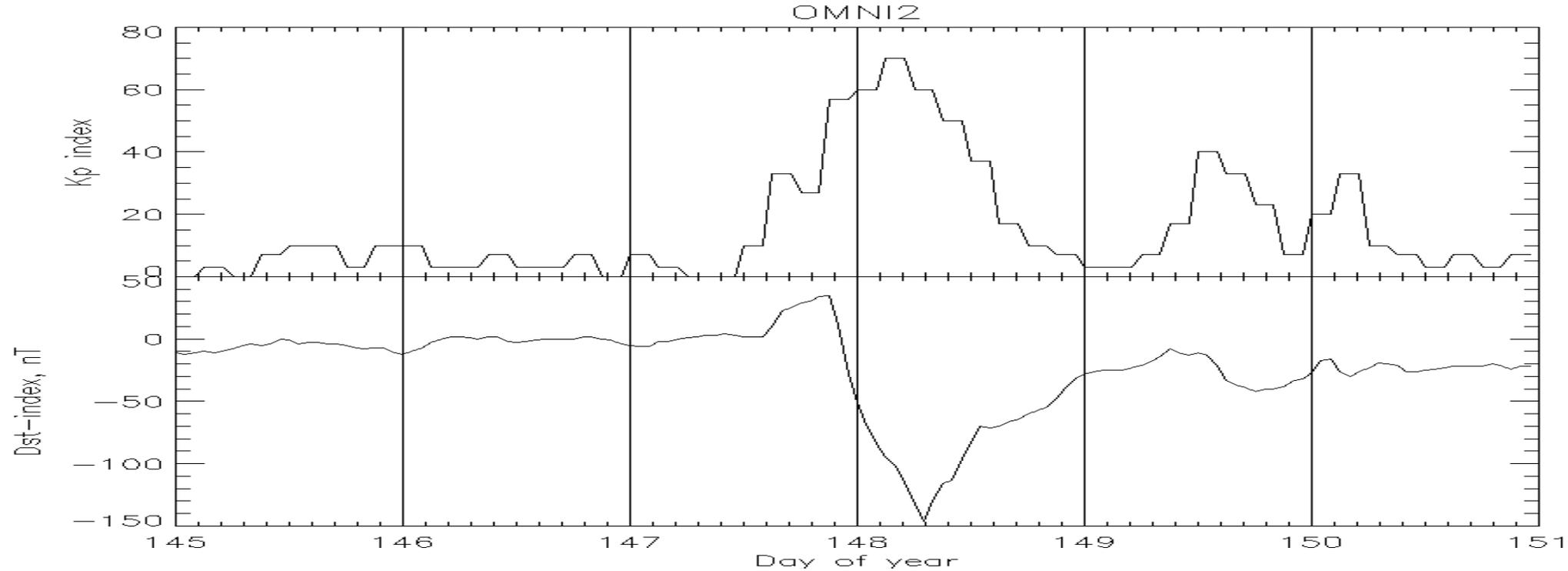Figure 14: Same as Figure 7 but for 24.03.2017 - 29.03.2017

Figure 15: Same as Figure 7 but for 25.05.2017 - 30.05.2017

CONCLUSION

➤ All three stations had ionospheric response

➤ Further discussions of other geomagnetic storms would be able to reveal effects of

➤ seasons, onset & severity of GMs.

➤ Also, modelling could be done to reveal the solar wind & IMF drivers of

ionospheric storms