

Spatiotemporal Response of Ionosphere to the Geomagnetic Storm of March 2013

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ABSTRACT

Storms perturb the geomagnetic field. This perturbation affects the ionosphere. This study investigates how the ionosphere responded to the March 2013 storm. Diurnal variations in TEC from March 16 to March 20 at 24 stations across Africa were used to analyze the storm's behaviour and the ionosphere's response in the African sector.

The storm occurred between 17 and 18 March 2013. There was an initial enhancement of TEC across the stations on March 17. The enhancement was more pronounced in the low- and mid-latitude stations than the EIA station. The low- and mid-latitude stations experienced a rise in TEC of about 20 percent in most stations; ULDI (49.0 percent) had the highest enhancement. On March 18, TEC values were reduced across all stations, with stations such as RABT (-44.6 percent), ABPO (-39.49 percent), and ULDI (-34.4 percent) showing the highest depletion rates. RABT and ABPO are low-latitude stations, while ULDI is a mid-latitude station. The depletion continued on March 19 except at NKLK (25.54 percent), RABT (9.65 percent), MAL2 (7.33 percent), MBAR (7.17 percent), and DAKR (5.2 percent), which had various rates of enhancement. These stations are closer to the EIA crest or in the northern hemisphere. The depletion in the recovery phase of the storm is due to DDEF. The study shows that storms affect the midlatitude region more than the EIA region. Also, the EIA crest recovers better after storms than places closer to the equator and the midlatitude region.

Keyword: spatiotemporal variation, TEC, Geomagnetic storm, Africa

INTRODUCTION

There is an electrically conducting region in the Earth's upper atmosphere that affects the propagation of radio waves (Rabiu et al., 2007; Atsuki et al., 2023). This region is called the ionosphere. The parameter used to study the effect of ionospheric variation on radio systems is total electron content (TEC) (Leonard et al., 2004; Oladosu et al., 2019). TEC is the amount of electron density along the path of radio propagation (Rastogi & Klobuchar, 1990). Ionospheric variation mainly depends on solar activity.

The active regions of the Sun consist of bipolar magnetic fields, which are associated with the number (Weber et al., 2023). The magnetic field within the Sun has a toroidal orientation and moves in directions that are opposite to those of the Sun's equator (McClintock et al., 2014; Li, 2018; Muñoz-Jaramillo et al., 2021). Increased Sun activity increases the ejection of energetic particles into interplanetary space; this includes extreme ultraviolet, X-ray, proton, solar flare, and coronal mass ejection (CME) emissions (David, 2015; Pulkkinen, 2007). This creates a co-rotating region that injects energy into the thermosphere-ionosphere coupling, thus affecting the electron density and dynamics in the ionosphere (Uga et al., 2024). This affects the dynamics of the Earth's magnetic field, causing a perturbation of the field. The perturbation of the magnetic field is called a geomagnetic storm. Storm-time variation of the ionosphere at low and mid-latitude is influenced by electrodynamic processes and the neutral wind circulation in the thermosphere (Oyeyemi et al., 2024). The effect of a geomagnetic storm on the ionosphere can be either positive or negative (Pandey et al., 2025).

Geomagnetic storms weaken the equatorial plasma fountain, thus causing a drastic storm-time TEC variation (Nirvikar & Pandey, 2007). TECs in the equatorial ionization anomaly (EIA) region are depleted during storms (Rama Rao et al., 2006). EIA regions are areas where there is a push of plasma due to the interaction between the electric field and magnetic field. This push is called the equatorial plasma fountain. Africa has the most developed equatorial plasma fountain. The ionosphere plays a crucial role in radio propagation, satellite communication, and navigation systems; thus, its response to geomagnetic storms is very important to space weather research. This response is complex and varies with solar cycle, latitude, season, and location (Akala et al., 2013). This study investigates how the ionosphere within the African sector was affected by the geomagnetic storm of March 2013.

METHODOLOGY

Total electron content (TEC) data from IGS and NIGNET stations were used. This covers 24 stations across Africa. The data were processed using the GPS_TEC application developed by Gopi. Five days of TEC data were used to investigate the storm. To study all the phases of the storm. A diurnal analysis was done using universal time.

The disturbance effect was analyzed using

$$\Delta\text{TEC}\% = \frac{\Delta\text{TEC} - \Delta\text{TEC}_{\text{previous day}}}{\Delta\text{TEC}_{\text{previous day}}} \times 100\%$$

Table 1. List of stations and their location

s/n	station	latitude	longitude	city	country	s/n	station	latitude	longitude	city	country
1	mal2	-12.42	111.86	Malindi	Kenya	13	mbar	-10.22	102.36	Mbarara	Uganda
2	clbr	-4.30	80.09	Calabar	Nigeria	14	unec	-3.25	79.37	Enugu	Nigeria
3	abuz	-0.62	79.75	Zaria	Nigeria	15	bkfp	0.72	76.62	Birnin Kebbi	Nigeria
4	abpo	-29.19	116.26	Antananarivo	Madagascar	16	zamb	-26.26	98.4	Lusaka	Zambia
5	hnus	-42.35	82.1	Hermanus	South Africa	17	hrao	-36.32	94.6	Kruger sdrp	South Africa
6	harb	-36.31	94.7	Pretoria	South Africa	18	dear	-40.01	118.85	De Aar	South Africa
7	adis	0.17	110.47	Addis Ababa	Ethiopia	19	nklg	-8.04	81.05	Libreville	Gabon
8	ulag	-3.03	75.45	Lagos	Nigeria	20	mfig	-36.25	92.5	Mafeking	South Africa
9	cggg	-1.04	81.9	Toro, Bauchi	Nigeria	21	dakr	2.35	51.91	Dakar	Senegal

10	wind	-33.16	84.6	Windhoek	Namibia	22	futy	-1.33	84.31	Yola	Nigeria
11	sbok	-39.03	82.85	Springbok	South Africa	23	sutm	-41.09	84.7	Sutherland	South Africa
12	rabt	23.28	69.23	Rabat	Morocco	24	uldi	-38.2	97.4	Ulundi	South Africa

Latitudinal Variation of the stations

EIA region: ± 17

Low latitude: $\pm 17 - \pm 30$

Mid latitude: $\pm 30 - \pm 60$

Table 2: Geomagnetic parameters

date	Dst (nT)	Solar-wind speed (km/s)	IMF Bz (nT)
March 16	-25	551	-6
March 17	-132	767	-20
March 18	-96	702	-5
March 19	-45	500	-4
March 20	-42	711	-7

The geomagnetic data were obtained from the Omni website.

Result

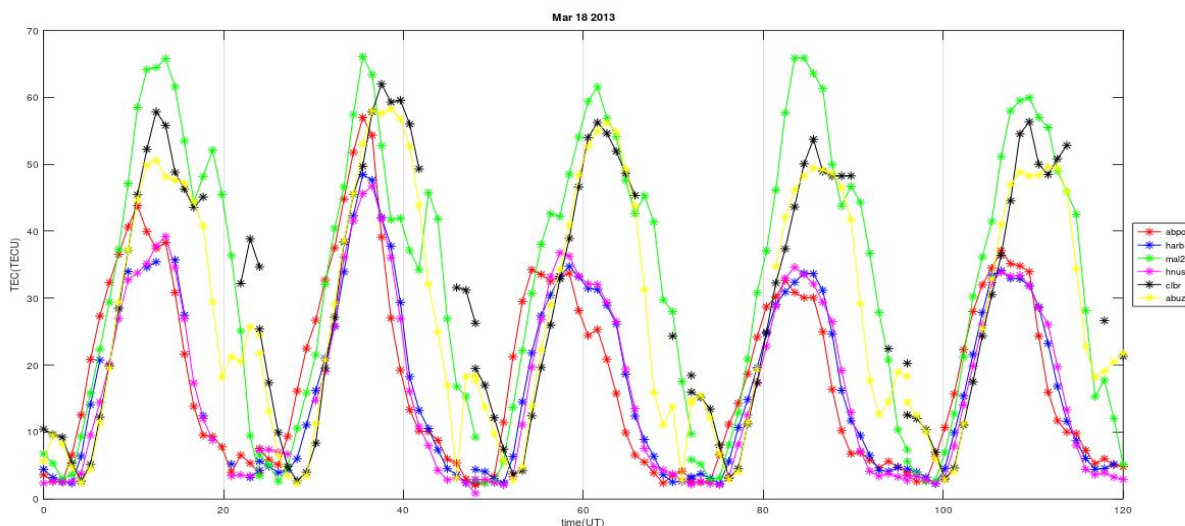


Fig1: Diurnal Variation of TEC at ABPO, HARB, MAL2, HNUS, CLBR, ABUZ from 16th to 20th March 2013.

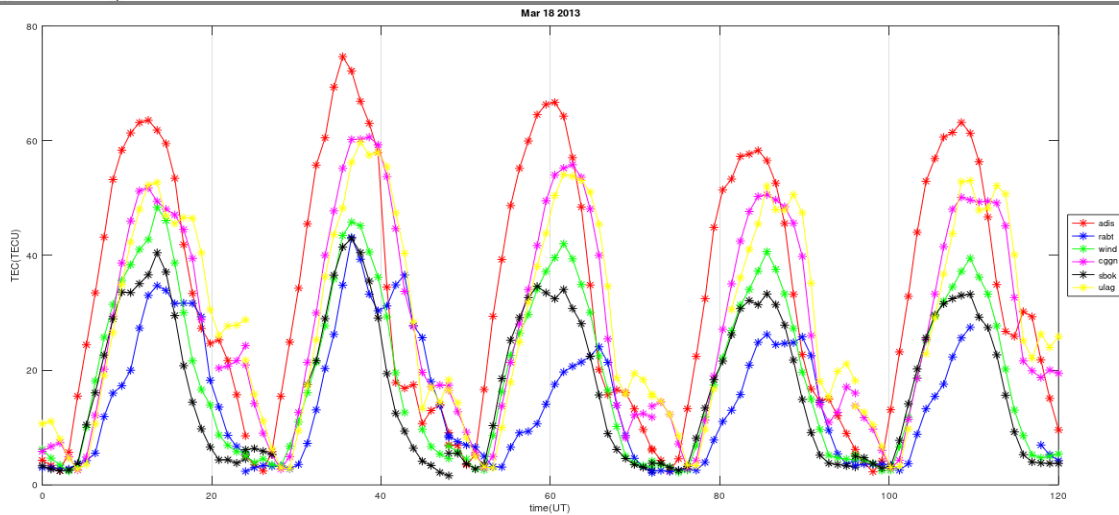


Fig2. Diurnal Variation of TEC at ADIS, RABT, WIND, CGGN, SBOK and ULAG from 16th to 20th March 2013.

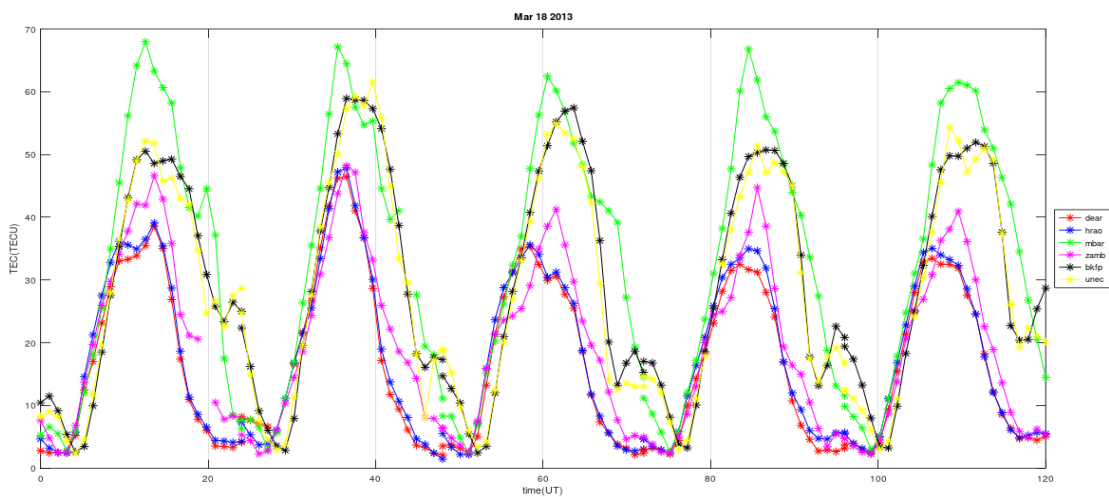


Fig.3 Diurnal Variation of TEC at DEAR, HRAO, MBAR, ZAMB, BKFP and UNEC from 16th to 20th March 2013.

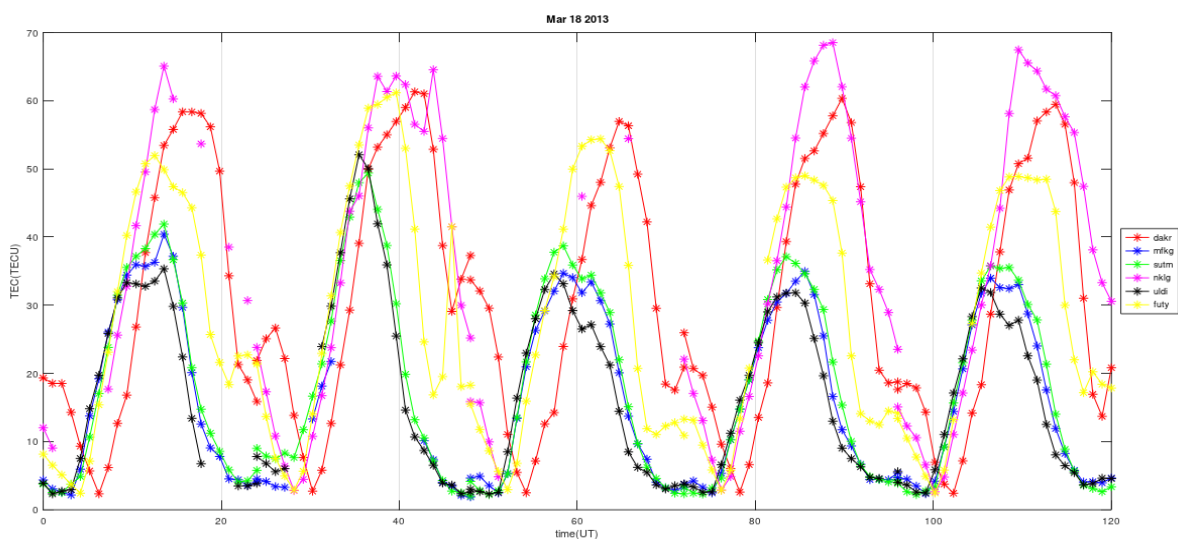


fig 4. Diurnal Variation of TEC at DAKR, MFKG, SUTM, NKLK, ULDI and FUTY from 16th to 20th March 2013.

This study investigates the response of the ionosphere across the African sector to the March 2013 storm. On March 17, a solar wind of about 767 km/s and IMF Bz of -20 nT causes a storm of -132 nT. This storm occurs during the night hours of March 17 through March 18. The storm is studied through three phases: The pre-storm phase (March 16 & 17), the main storm (March 18), and the recovery phase (March 19 & 20). The study showed TEC enhancement from March 16 to March 17 across all the stations except WIND (-4.82 percent), MBAR (-1.4 percent), and NKLG (-0.63 percent). A percentage enhancement of over 20 percent was observed at ABPO (30.01 percent), RABT (24.4 percent), HRAO (22.81 percent), DEAR (20.0 percent), HARB (35.03 percent), HNUS (20.5 percent), SUTM (20 percent), and ULDI (49 percent). These stations are in the mid-latitude region, except ABPO and RABT, which are in the low-latitude region. Most stations in the EIA region experience enhancement between 5 and 17 percent. On March 18, there was TEC depletion across all stations, but the percentage depletion varies across the stations. High TEC depletions were observed at RABT (-44.6 percent), ABPO (-39.49 percent), ULDI (-34.4 percent), and HARB (-28.46 percent). ADIS (-12.31 percent), NKLG (-15.5 percent), FUTY (-11.28 percent), and UNEC (-10.59 percent) are stations within the EIA region. During the recovery phase on March 19, stations such as ADIS (0.170 N), ABUZ (0.620 S), CGGN (1.40 S), UNEC (3.250 S), and BKFP (0.720 N) show continuous depletion from March 18. DAKR (2.350 N), NKLG (8.040 S), MBAR (10.220 S), MAL2 (12.420 S), ZAMB (26.260 S), and RABT (23.280 N) showed a certain percentage of enhancement. While all the stations in the midlatitude, such as WIND (33.160 S), HRAO (36.320 S), SBOK (39.030 S), ULDI (38.20 S), DEAR (40.010 S), and SUTM (41.090 S) showed further depletion on March 19. Big latitudinal and longitudinal differences occur across sectors while investigating ionospheric response to storms (Imtiaz et al., 2020; Shahzad et al., 2023; Luo et al., 2026). Wan et al. (2025) observed varying responses to storms (the American sector experienced a positive response while the Asian sector experienced a negative response).

This study shows an enhancement throughout most of the study areas to the storm on the day the storm commenced. Aa et al. (2024) and Wan et al. (2025) explained that equatorward neutral wind from Joule heating pushes plasma along magnetic field lines upward into higher altitudes, thereby reducing downward diffusion. While depletion on March 18 and the recovery phase in most stations are due to the disturbance dynamo electric field (DDEF), according to Tahir et al. (2024) and Barad et al. (2025), DDEF is usually more prominent in the recovery phase. This explains the continued depletion of TEC experienced on March 19 (recovery phase of the storm investigated in this study).

Stations in the northern hemisphere show enhancement during the recovery phase compared to stations in the southern hemisphere, where depletion continued in the recovery phase. This study is in line with Aol et al. (2023), who observed higher TEC in the northern hemisphere than the southern hemisphere. St Patrick's Day storm shows inverse hemispheric asymmetries across different regions; this is partly due to thermospheric composition changes and nondipolar geomagnetic field geometry Astafyeva et al. (2015).

The rate of enhancement experienced at low- and mid-latitude stations was higher than the enhancement at the EIA region station. This might be due to the plasma fountain within the EIA region, responsible for high TEC within the EIA region; thus, the rate of enhancement will be reduced. TEC at mid-latitude is mainly controlled by extreme ultraviolet radiation and neutral wind, while the plasma fountain controls TEC at the EIA region Oladosu et al., 2019.

During the pre-storm enhancement, TEC peak values within the EIA region range between 59.24 TECU at BKFP and 74.82 TECU at ADIS, while at low latitude it was between 43.39 TECU at RABT and 56.93 TECU at ABPO, and at mid-latitude the range was between 43.39 at SBOK and 52.33 at ULDI. The highest TEC value was observed within the EIA region, which is mainly due to the plasma fountain.

CONCLUSION

The March 2013 storm had both positive effects, as observed in the March 17 enhancement due to PPEF, and negative effects of TEC depletion, as observed on March 18 across the study area due to the effect of the DDEF. The study shows a strong latitudinal variation across the station. The rate of the response is mainly

controlled by the plasma fountain in the EIA and the neutral solar wind in the midlatitude. During storms, TEC in midlatitude is more affected than in the low-latitude and EIA regions.

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