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NOTE

Equatorial Ionospheric Anomaly as Precursive Parameter of Earthquake and Geomagnetic Storm: Global and GPS-derived TEC as inputs

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Abstract

The paper discusses the possible adaptation of Equatorial Ionospheric Anomaly (EIA) as a precursive parameter of an Earthquake (EQ) and Geomagnetic storm (GMS). A few case studies with EQ and GMS imprinted features on equatorial/low latitudes Total Electron Content (TEC) derived from global Maps and GPS are presented. While EQ preparatory processes trigger the growth of strong earthquake time Equatorial Anomaly (EEA) and expansion of the anomaly crest (EEAC), the GMS effects are observed to disintegrate the EIA strength. Possible adaptations of these parameters in prediction studies are brought into discussion along with the system physics involved.

Keywords: EIA, EEA, Earthquake, Geomagnetic Storm, precursors

1. Introduction

The growth and development processes of Geomagnetic Storms (GMS) are complex with the emission of strong solar flares and with the evolution of strong SN, the consequence effects are visible from the near-earth environment to the ionosphere and beyond. The EQ is of lithospheric origin in a complex environment between the earth's interior status and fault zone and generates involved dynamics in the atmosphere through multi-system coupling processes that link the lithosphere to the ionosphere and beyond. Considering the nature of the contribution of both the phenomena to atmosphere, it is expected to have a unique or common parameter to work on in associating the growth of these two hazards, thus identifying a possible precursor. In search of EQ preludes, at present, there are a number of methods adopted where the electromagnetic (EM) approaches [Devi et al., 2001; Liu et al., 2001; Ouzonov and Freund, 2004; Depueva et al., 2007; Oyama et al., 2008; Liu et al., 2010; Oyama et al., 2011; Devi et al., 2010 a,b; Devi et al., 2012, Devi et al., 2015 a,b; Devi et al., 2018, Devi et al., 2020]are considered to be effective. One of the phenomena we now consider here is the Equatorial Ionospheric Anomaly (EIA) a feature to be examined in association with the growth of EQ and GMS.

It is more than seven decades since the existence of the EIA and the anomaly belt were discovered by Appleton (1946) and the significance of the phenomena gradually spread not only in understanding ionosphere density modulation features but now its implications also reached hazard-related issues like in Earthquake involved precursive studies. This anomaly is well represented by two peaks of electron density or in Total Electron Content (TEC) around ± 15° geomagnetic latitudes and a trough at the equator (Figure 1). Also, this phenomenon is mainly through the contributions of dumping of plasma from the equator to the low latitude stations through the EXB vertical drift process where E is the eastward ionosphere electric field and B is the earth magnetic field component [Anderson and Klobuchar, 1983; Balan and Bailey, 1995; Anderson et al., 2002; Anderson et al., 2009; Horvath and Lovell, 2013; Balan et al., 2018]. Other sources are neutral wind and gravity wave-induced plasma distributions, but the E-field is the most significant component here. The Anomaly is a daytime phenomenon and any deviation from the normal pattern is an anomaly in the "Equatorial Anomaly ". We will look for this phenomenon by following the EM approaches [Liu et al., 2002; Devi et al., 2004; Depueva et al., 2007; Devi et al. 2011; Devi and Barbara, 2012; Devi et al., 2013; Liu et al., 2014; Ryu et al., 2014; Devi et al., 2015a; Ryu et al.2016; Devi et al., 2018; Devi et al 2019; Oyama et al., 2016,2019,2020; Devi et al., 2022] with extension to GMS environment to identifying EIA-EQ-GMS precursive relation.

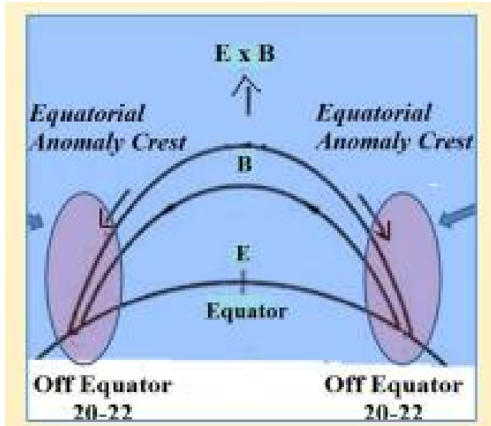


Figure 1: Equatorial Ionospheric Anomaly: density from the equator is pumped to off equatorial zone

2.0 Analysis

In Figure 2, a Global TEC map is displayed where we note the effect of EIA as a decrease in density at the equator and high at off equatorial zone. The GPS-derived TEC over Guwahati a low-latitude station also shows the EIA effect with a sudden increase in TEC after the normal daytime density peak, as imprinted in its profile (Figure 3).

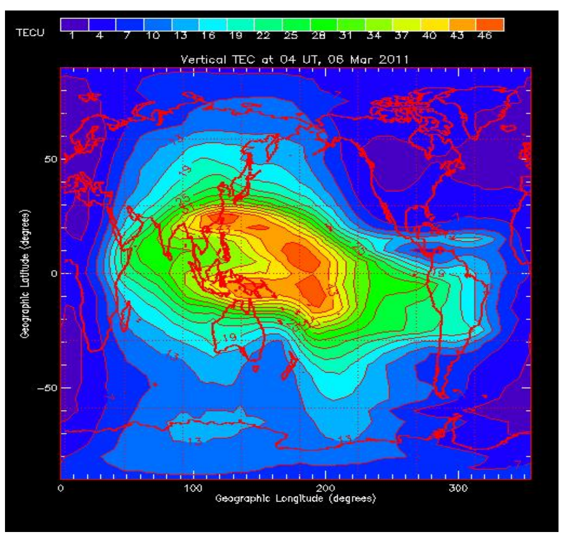


Figure 2: Global TEC map where the effect of EIA as a decrease in density at the equator and high at off equatorial zone is clear.

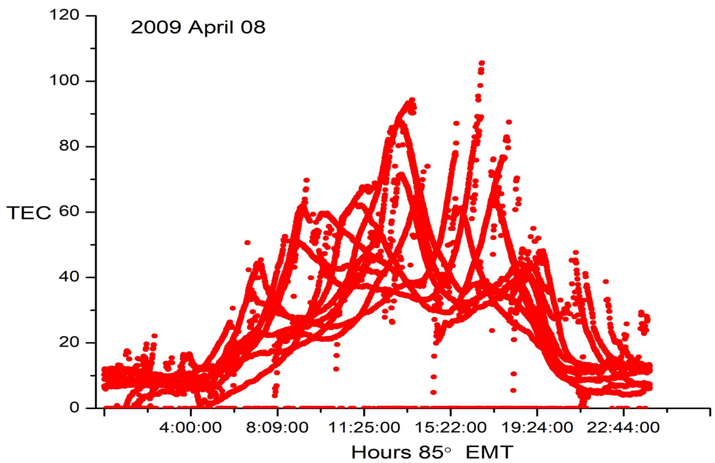


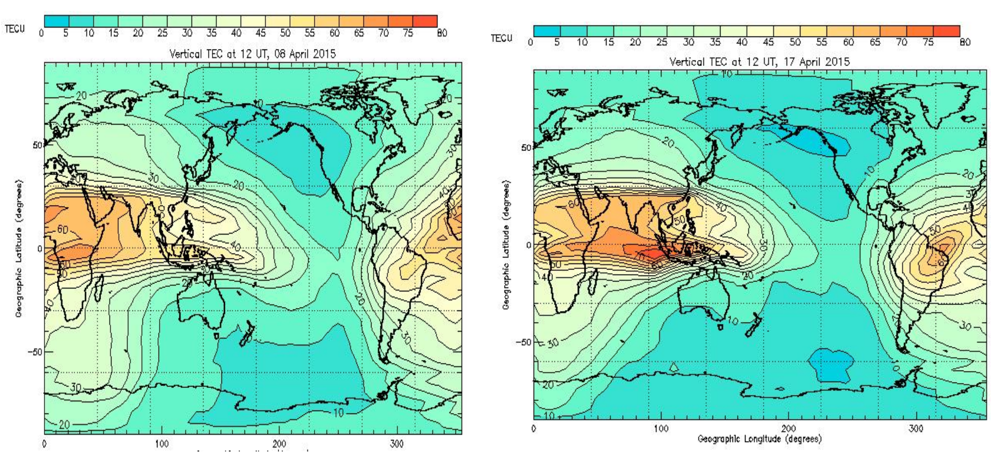
Figure 3. GPS-derived TEC over Guwahati; The Increase in TEC after the noon peak is the EIA effect.

2.1: EQ time EIA Signature

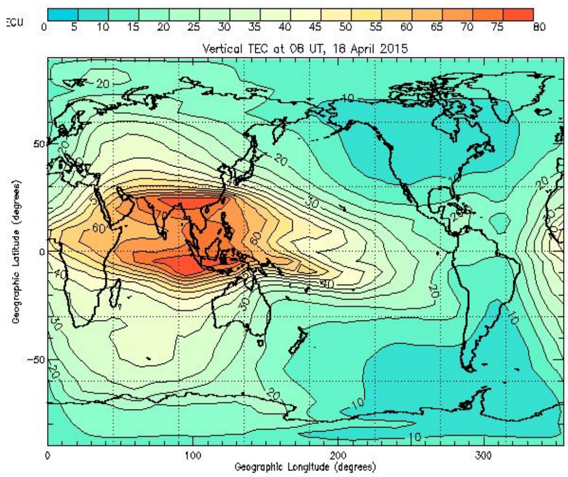
We present here a few EQ time TEC profiles to identify EIA features imprinted therein.

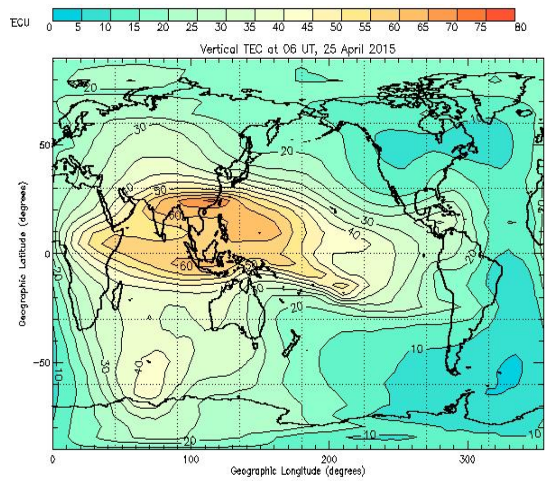
(1) Nepal EQ of April 2015.

We start with the Nepal EQ of April 2022, 2015, of M=7.8, with the epicenter at 28°13′48″N 84°43′52″E / 28.230°N 84.731°E, a location above the equatorial anomaly crest. The TEC profiles from weeks before to the day of the event are displayed in Figure 4, in search of EQ time EIA signature.



(a) (b)





(c) (d)

Figure 4: Nepal EQ time TEC profiles : (a) Normal EIA during daytime (note development of anomaly at 20 °E longitude), (b) Nighttime development of strong TEC at epicenter longitude, (c) Same as of (b) but daytime. Note the presence of high TEC even up to the epicenter latitude (beyond the normal crest zone), (d) Anomaly started disappearing after the event.

Figure 4(a) displays a normal daytime EIA at the day longitude when no anomaly was seen at the epicenter longitude (dusk period). But a week before the EQ we see the development of a strong density zone at the epicenter longitude and at the 10° s of the equator. We call it an Earthquake Ttime Equatorial Anomaly (EEA). The Anomaly gets stronger as the days approach the event and we note the expansion of the Crest to the epicenter latitude (we call Earthquake time Equatorial Anomaly Crest, EEAC) along with the presence of EEA during this period (Figure 4c). The anomaly started losing strength on the EQ day (Figure 4d). The diurnal variation of EEA and EEAC strength a week before the event (Figure 5) clearly shows how around the epicenter zone anomaly grows in strength.

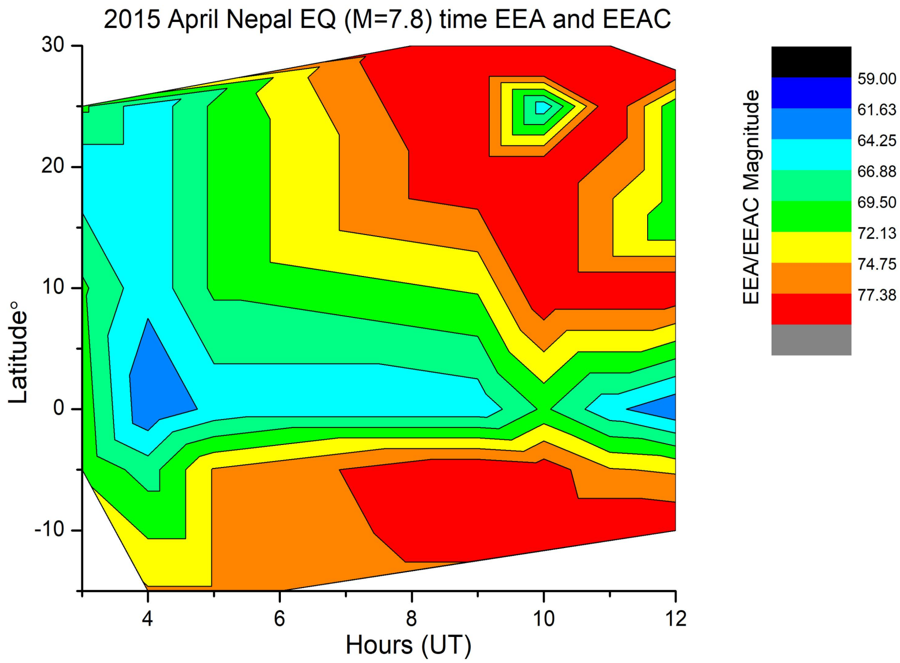
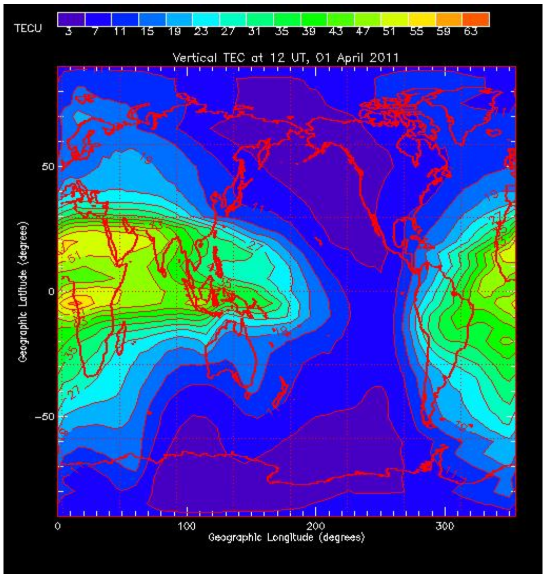
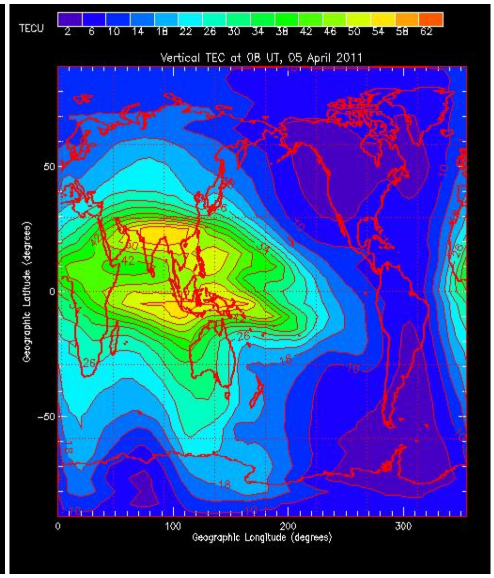


Figure 5: Development of strong EEA and EEAC: average features of the week before the Nepal EQ

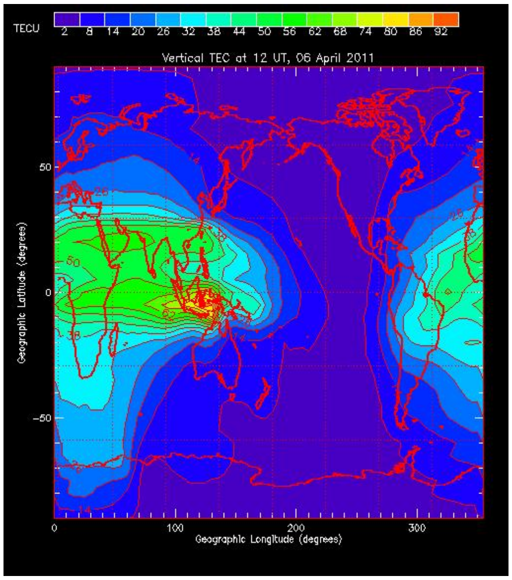
(2) The next case we present is for Japan EQ of M=7.1 that occurred at 2300 JPT on April 7 2011 at epicenter 38.253°N 141.640°E. The TEC profiles before, during, and after this event are presented in Figure 6. We selected this event to look for possible EQ time EIA growth in a low mid-latitude epicenter and we note that as in low latitude epicenters, in this event too the TEC profiles before 6 days of the event carry a normal EIA feature at the day longitude and no EEA at the epicenter longitude did develop. But EEA started appearing at the epicenter longitude two days before the EQ, got strengthened a day before the event, and (Figure 6c) lost energy after the EQ.



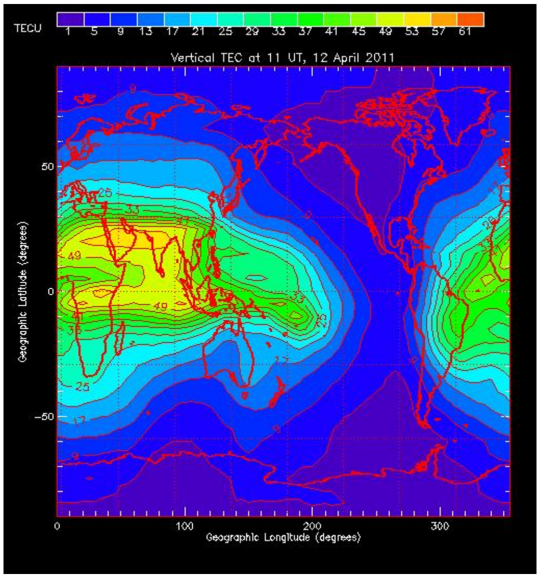
(a)



(b)



(c)



(d)

Figure 6: Development process of EQ time Anomaly during Japan EQ of April 2011 ;(a) No EEA 6 days before the event; (b & c) formation of EEA 2 days &1 day to EQ; (d) Anomaly started losing strength after the event.

Finally what comes out is that EEA develops at the Longitude of the epicenter a week to days before an EQ and EEAC develop at the latitude of the epicenter and the EQ gets triggered at the waning phase of these phenomena. Thus EEA /EEAC are strong preludes to an EQ. We observed such features during the Tohoku EQ of Japan on March 11, 2011 [Devi and Barbara 2012], and also during Indonesia EQs [Devi et al., 2013]

Now we extend this study in search of EIA- GMS associations.

2.2 EIA-GMS Association: A Few Case Presentations

Case 1: April 2023 is a strong GMS event with the Main Phase (MP) of DST value going beyond -200 nT as displayed in Figure 7.

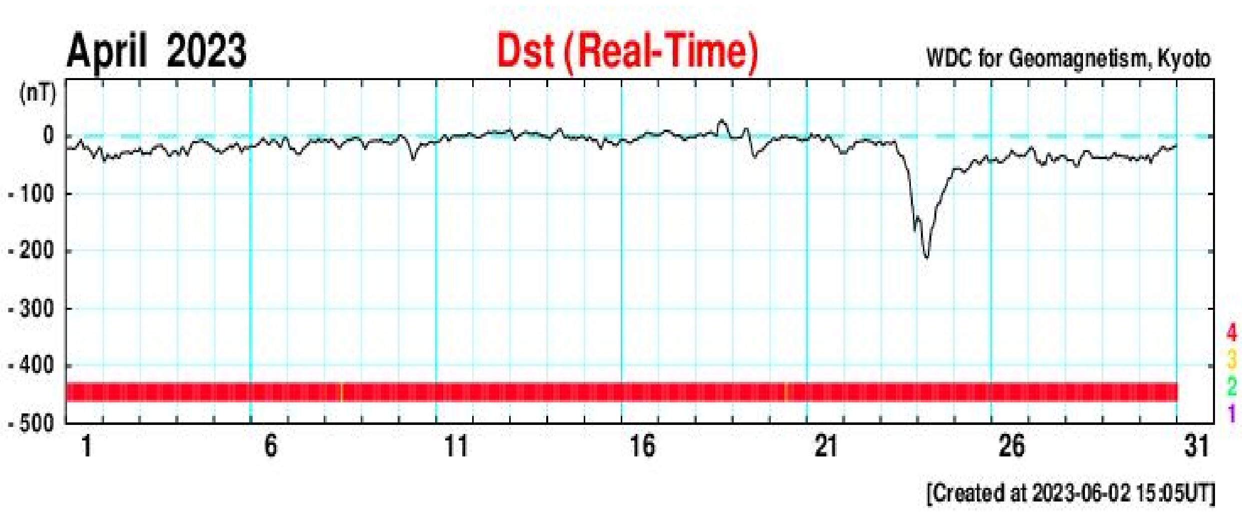
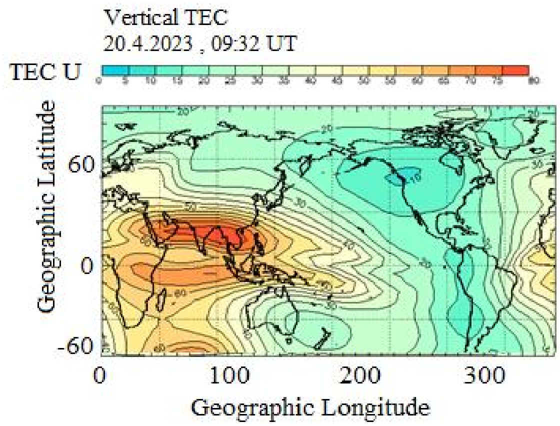
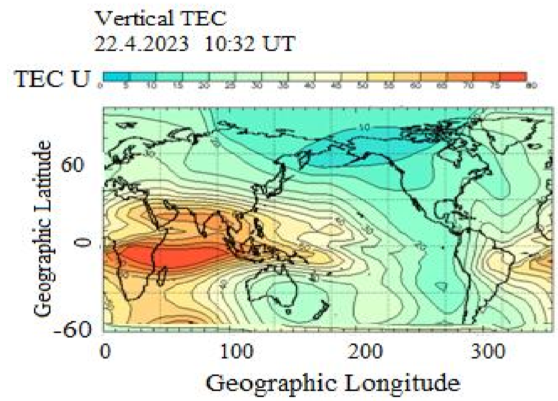


Figure 7: Dst profile displaying the development of a strong GMS with the main phase on April 24, 2023

Global TEC profiles present strong EIA features as usual in the equinoctial month of April 2023 (Figures 8 a,b) but the EIA gets dissipated during the main phase (Figures 8 c,d) while reappearing in strength after the MP of the storm (Figure 8 e), unlike EQ time EEA character no EIA developed during dusk.



(a)



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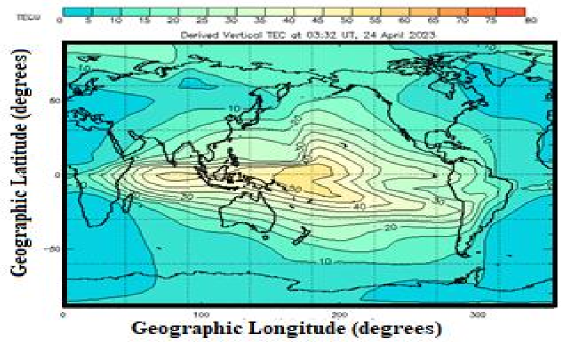

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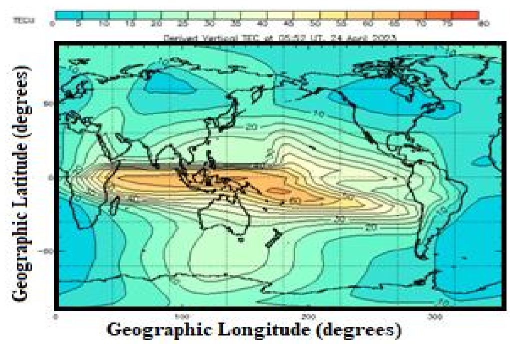
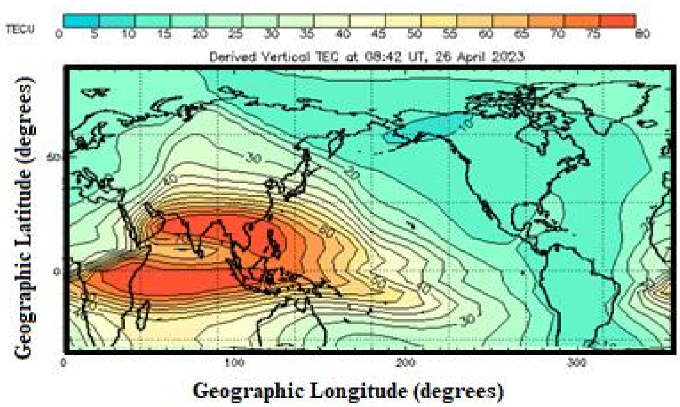


(d)

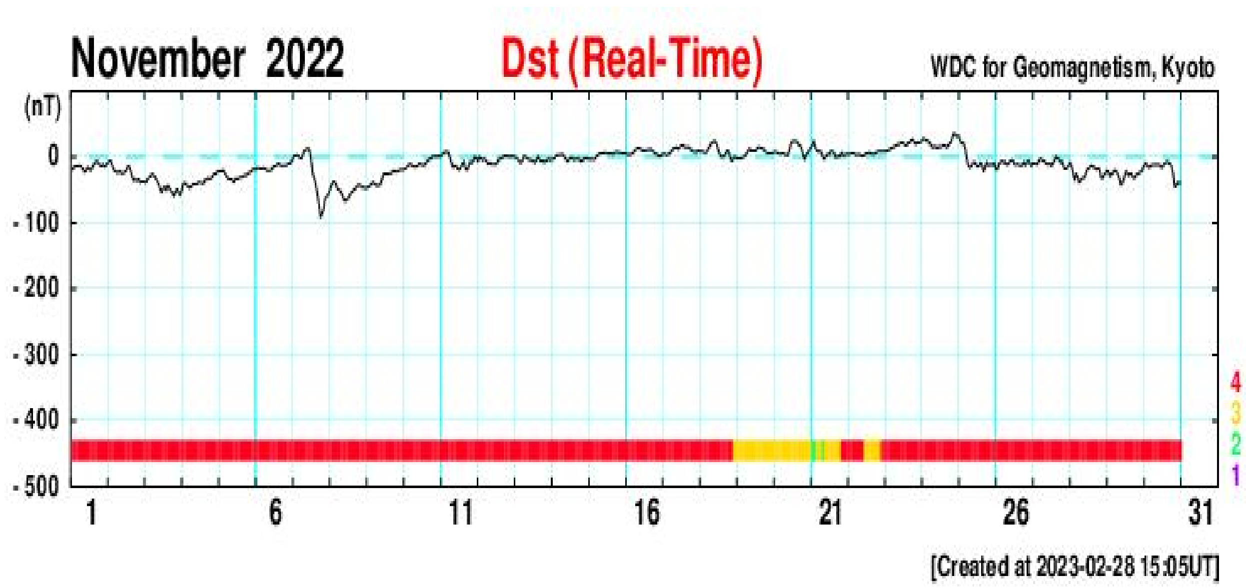


(e)

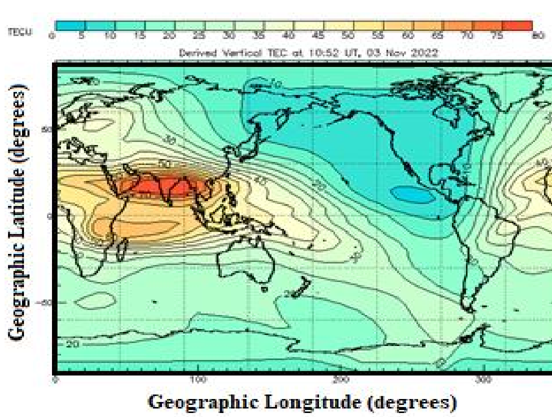
Figure 8 : (a,b) strong EIA features as usual in the equinoctial month of April 2023; (c,d) the EIA gets dissipated during the Main Phase; (e) reappearing in strength after the MP of the storm.

Case 2: November 2022 GMS, moderately strong main phase in November 7/8:

This is a moderate GMS event with DST swings to -100 nT (Figure 9a). The presence of EIA with usual strength before the GMS (Figure 9 b,c), the disappearance of the same at the MP (Figure 9 d), and the reappearance of the EIA (Figure 9e) after the event of Nov.2022 GMS, is clear as displayed by the respective TEC profile.



(a)



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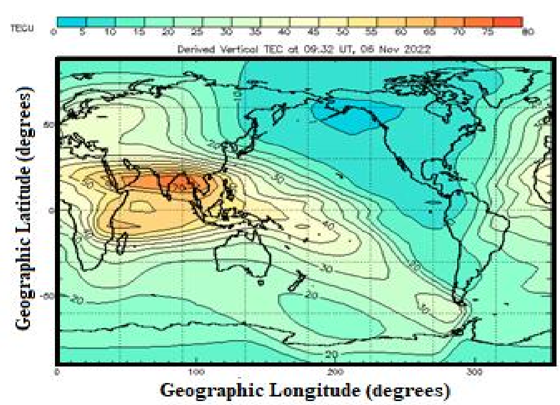

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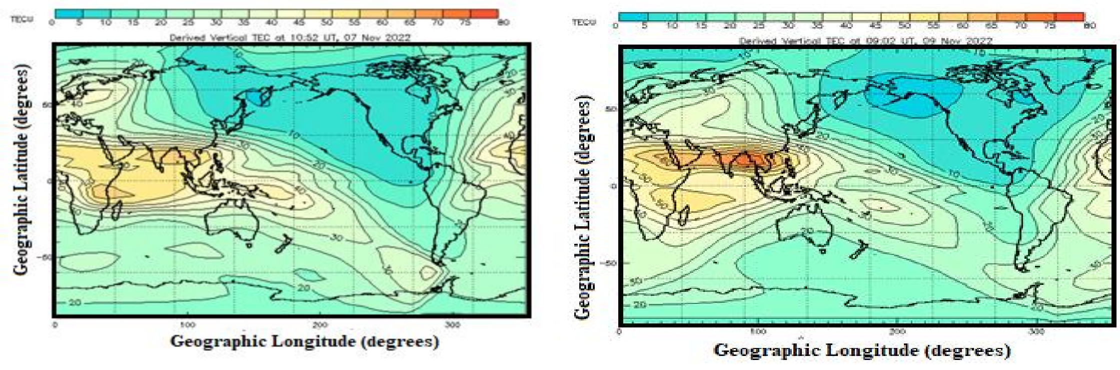


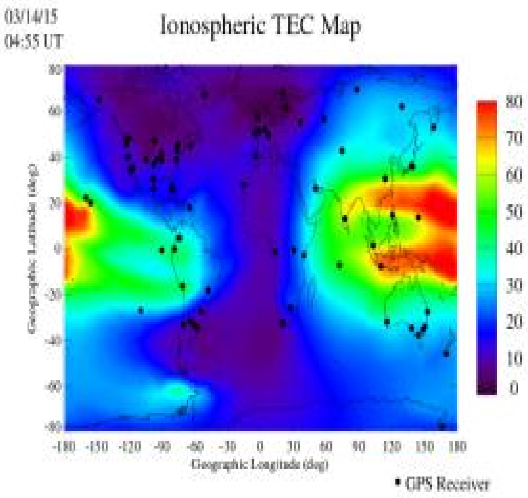
(d) (e)

Figure 9: (a) Dst profile with MP goes to -100 nT on November 7, 2022 ; (b,c) TEC profiles present EIA of usual strength before the MP ; (d) Disintegration of EIA at the MP and (e) regrowth of EIA after the MP.

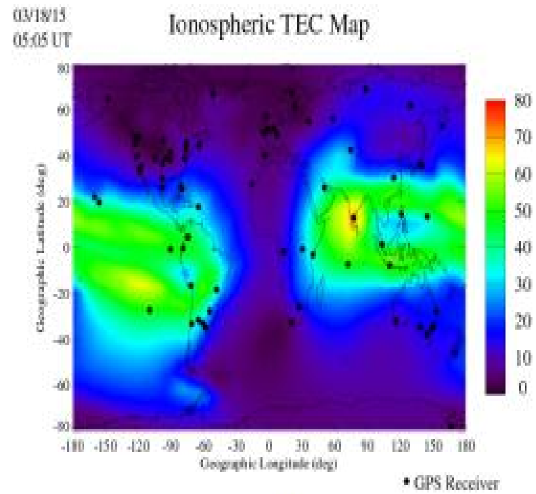
Case 3: March 2015 GMS strong Main Phase on 17/18

The first super geomagnetic storm of solar cycle 24 occurred on “St. Patrick's Day” (17/18 March 2015 Figure 10). The source of the storm can be traced back to the solar event on 15 March 2015. The Global TEC profiles show that the normally developed EIA (Figure 11a) gets inhibited on MP of the storm (Figure 11b).

Figure 10: Dst profile of March 2015 with strong GMS event on 17/18 March



(a)



(b)

Figure 11: Daytime EIA strong as in Equinoxial months before the GMS, (b) disappearance of EIA at the main phase

What we finally obtain is that

- EQ triggers strong EIA manifested as EEA and EEAC week to days prior to the EQ and the event gets triggered at the waning phase of these phenomena.
- GMS does not trigger EIA but distorts the features and may inhibit the growth of the anomaly at the MP.

Thus looking into profile features and temporal and spatial growth features, EIA/EEA/EEAC can be adopted as a precursive parameter of EQ and GMS. However, more observations are planned for GMS-related studies covering mid-latitudes.

3.0 Discussion

The growth process of EIA is controlled by the ionospheric E field, resulting in EXB drift leading to the pumping of plasma from the equator to low latitude. During an earthquake, the EQ-induced E field acts in a similar way to enhance the EXB drift process augmenting the anomaly [Depueva and Rotanava 2001; Devi et al., 2004; Depueva et al., 2007; Devi et al., 2010a; Freund (2011); Devi et al., 2013; Ryu et al.2014; Fan et al., 2015; Ryu et al.2016; Devi et al., 2018; Oyama et al., 2019, Oyama and Devi 2020].

Similarly, one of the sources generally associated with storm time density modulation is the storm time electric field, which penetrates directly to low latitudes (Fejer et al., 1979), this disturbance dynamo electric fields (DDEFs) is westward during daytime and manifests itself like ExB/B^2. This process of charge movement thus acts in a reverse mode of operation with respect to that generally working where the east-ward electric field enhances the vertical drift and pushes plasma from the equator to high latitudes. Therefore the resultant storm-induced modification in density depends on the effect of both the electric fields eastward/westward processes and as we see a weakening of EIA results in this process. However, there are reports of enhancements in EIA by storm-induced E-field [Tsurutani et al., 2004; Mannucci et al., 2005; Lin et al., 2005; Abdu et al., 2012]. But unlike their results, a strong decrease in EIA strength is observed in all the case studies here that cover mainly equator to low latitude features. In the future, we plan to extend this observation to the Midlatitude epicenter and relevant effects on EIA.

4.0 Conclusion

Thus, we see that EEA and EEAC have distinct characteristics with growth in epicenter longitude (EEA) and latitude (EEAC), and also the precursor features are more or less translated as the strengthening of EEA /EEAC (week to days before the EQ) and the event gets triggered just at the waning phase of these phenomena. But GMS being a Global event such features are not distinct but inhibition of EIA at the main phase is significant. In the future, a few more cases with midlatitude density profiles be included in the study. Further, it is proposed to have Nanosatellite measurements of E and H fields covering EQ and GMS events to finalize the role of the EQ-induced E field and storm-penetrated E field towards these changes in EIA and to implement these parameters in precursive model framing.

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