International Journal of Electronics and Applied Research (*IJEAR*) **Vol. 2, issue 2, December 2015**
Published Online (*http://eses.co.in/ESES Journal)* **ISSN 2395-0064**

Expansion of Earthquake (EQ) time Equatorial Anomaly: an index of precursor as seen in major Nepal EQ of April 2015

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Abstract

The application of Electromagnetic methods in the research field of EQ precursor study with aims of identifying signature of an impending EQ and its epicenter, needs new approaches and techniques, because even with the available volume of work and reports on these aspects, the problem remains still a challenging one. The paper addresses such aspects in case of the Nepal EQ of April , 2015 (epicentre at 28.266N and 84.463 E),of magnitude M= 7.9, by examining through analysis of global Total Electron content (TEC) data for detection of precursive anomaly signature in the Earthquake time Equatorial Anomaly (EEA), a feature observed to develop at the equator and in the longitude sector of the epicentre. Significant that, along with the EEA, a remarkable increase in TEC develops days before the impending earthquake persisting even to late night hours at the epicentre, a location just outside the normal equatorial anomaly belt . This feature is associated with the expansion of Earthquake time Equatorial Anomaly Crest (we call EEAC). The explanations of such phenomena are sought in pumping process of ionization density mainly by ExB drift, where E is the earthquake modified electric field. Possible additional sources working for growth & development of EEA and EEAC are also suggested.

Key Words: Earthquake; Global TEC; Appleton Anomaly Crest; Nepal EQ; Electric field

1. Introduction

A significant number of works related to earthquake (EQ) time ionospheric study, show possible modifications of atmospheric parameters prior to and during an earthquake event [Davies and Baker 1965; Calais and Minster , 1995; Ruzhin and Depueva, 1996]. The magnitude of such changes may vary with latitude, longitude of the epicentre position as well as on the solar geomagnetic status of the earthquake time [Depueva et al., 2007; Devi et al., 2008; Oyama et al ., 2011; Devi et al., 2011(a); Liu et al. , 2013; Devi et al., 2014; Smirnov et al., 2015]. Equatorial anomaly factor takes a key role in such changes specially when the epicentre lies near to the equator and at low latitudes [Depueva and Ratanova, 2001; Devi et al., 2001; Devi et al., 2004; Devi et al., 2011(b)] . In case of an EQ with epicentre at mid latitude, the equatorial anomaly effect may not be very effective but there are still evidences of growth of Earthquake time Equatorial Anomaly (EEA), significantly at the longitude zone of a mid- latitude EQ epicentre [Devi et al., 2012; Devi et al., 2013; Ryu et al., 2014; Ryu et al., 2016]. Such modifications of anomaly prior to mid latitude EQs are also shown through model computation by Karpov et al., [2013]. However, in such cases, the sources and physics involved in one event to the other being highly variable, the EQ precursor study is still a challenging problem especially in anomaly crest locations.

The Nepal EQ of M = 7.9 that struck 77 km northwest of Nepal's capital Kathmandu at 0611 hrs GMT on 25 April 2015, with epicentre at 28.266°N and 84.463° E , a location just above the normal equatorial anomaly crest , is expected to exhibit prominently the effects of any change in the physical and dynamical status of the equatorial anomaly caused by a massive earthquake and therefore possible prediction parameters for identifying the epicentre would be sharply on focus. With this background and aims, Global Total Electron Content (TEC) data are examined to look for growth and development of EQ time equatorial anomaly, a feature associated by Devi et al., [2012; 2013] in prediction of Japan EQ of March 2011.

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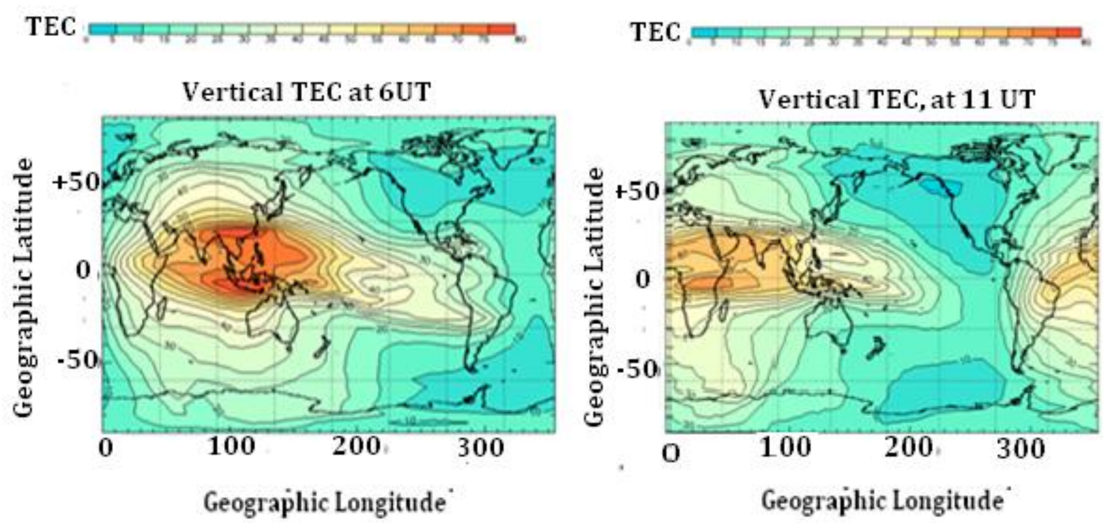
2. Analysis and result.

2.1 Global TEC features prior to Nepal EQ of April 25

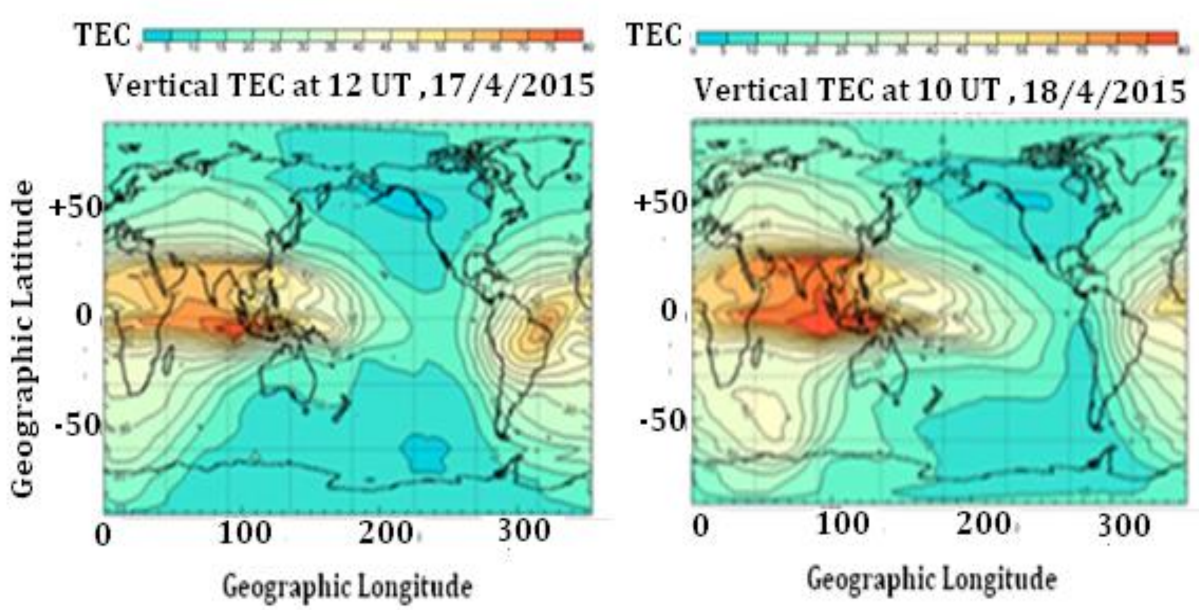
The Global TEC maps are analyzed on routine basis and appearance of anomalous features specially growth of Earthquake time Equatorial Anomaly (EEA) is examined as a possible prelude to an EQ. The analysis shows that Normal Equatorial Anomaly (NEA) (i.e., Appleton Anomaly) develops during daytime, and its position shifts from east to west longitude zone as day advances. As an example, one can note from Figure 1(a), the presence of NEA in 90°E -100°E longitude zone at 6 UT (i.e. local noon/post noon hours) and at 11 UT (local noon/post noon hours) in the 30° E - 40° E longitude sector (Figure 1b) .



(a) (b)

Figure 1. Displays development of Normal Equatorial Anomaly (a) around 90°°E -100 °E longitude at 6UT (during local day hours and (b) at 11 UT (local day hours) in & around 20° E to 30° E longitude , weeks before the massive Nepal EQ of April 2015.

But from early part of April-2015, an anomalous TEC zone starts appearing at 90°E-100°E longitude more significantly at 12 UT i.e., during the night sector and we present in Figure 2(a) formation of such an intense TEC contour on April 17^{th} in this longitude sector and 10°S to 15°S latitude zone. The growth of such strong density zone around the equatorial region significantly at the epicentre longitude was also found to appear prior to the massive Japan EQ of March 2011 .This observation was noted and reported by Devi et al., [2012; 2013] and this phenomenon is termed by them as Earthquake time Equatorial Anomaly (EEA) . The EEA feature as shown in Figure 2 (a) for April 17 had grown stronger on April 18 [(Figure 2(b)] and along with this development, also an intense density zone appeared during afternoon to evening hours at about 25 ° N latitude and 80°E -90 °E longitude, just above the normal equatorial anomaly crest location. This strong density as it appears at the anomaly crest zone synchronously with the development of Earthquake time Equatorial anomaly, we call this formation as Earthquake time Equatorial Anomaly Crest (EEAC).



(a) (b)

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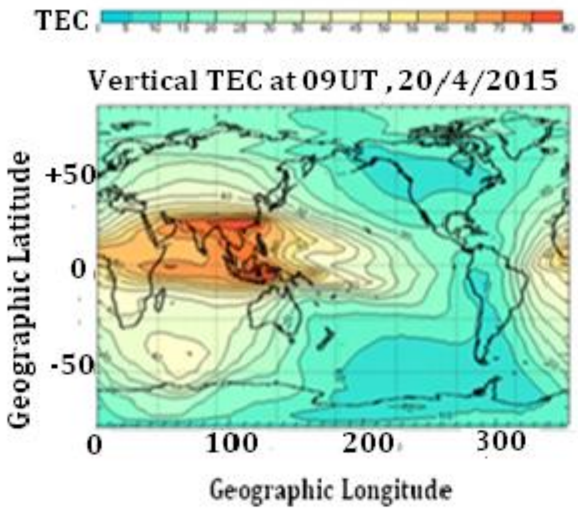

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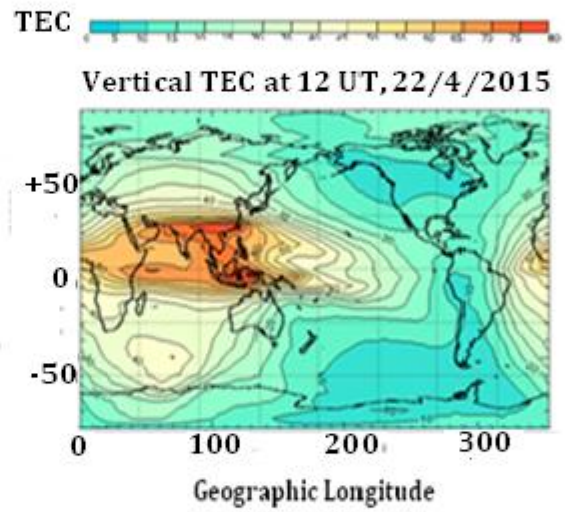
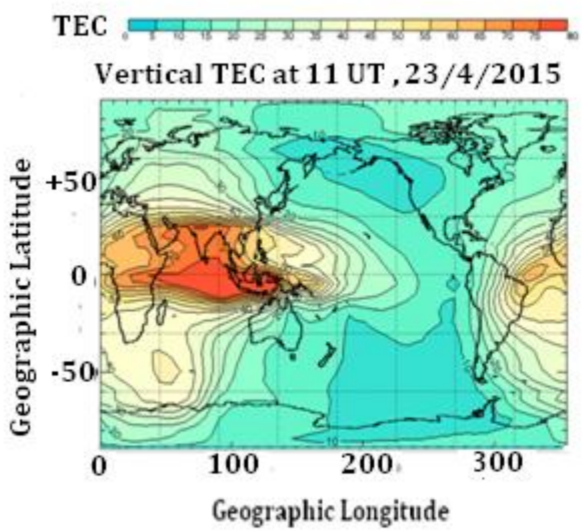
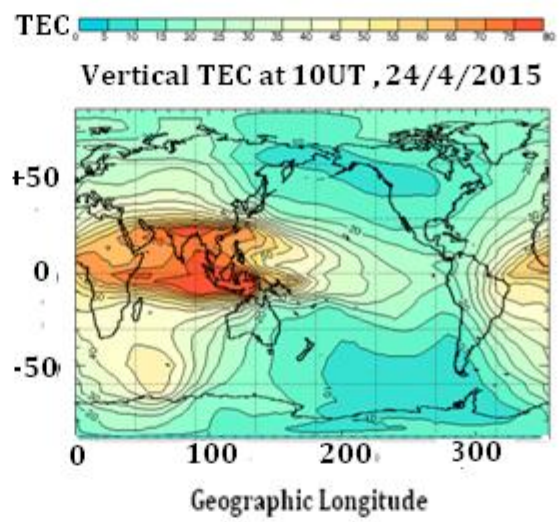


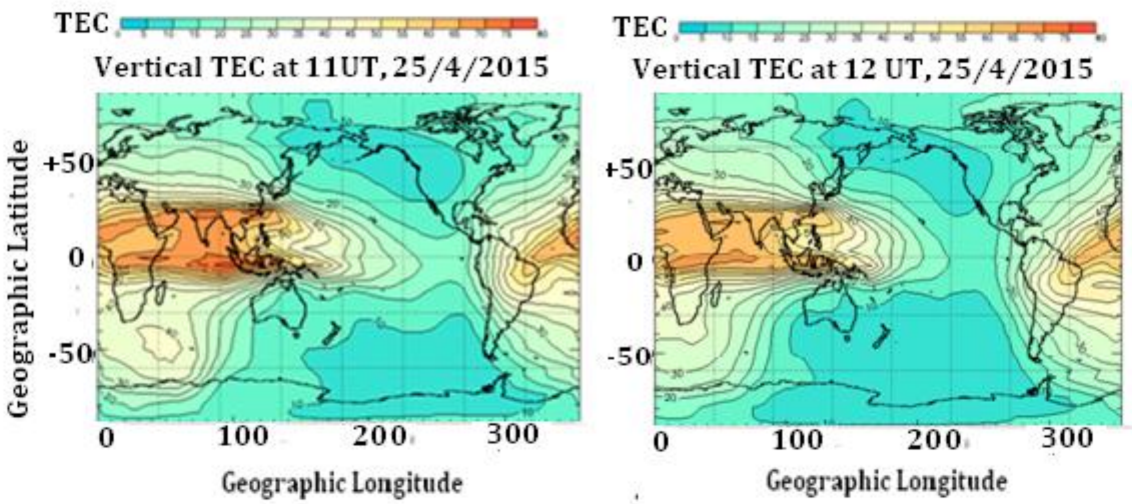
(d)



(e)



(f)



(g) (h)

Figure 2 . Dispalys develoment of (a) EEA on April 17 , i.e., 9 days prior to the massive Nepal EQ and (b-g) EEA and EEAC features from April 18 to 24 , just prior to the occirrence of the earthquke. . The dissipation of the EEA and EEAC are seen on April 25 (h)..

It is also observed that strength of EEA becomes so strong in some of the days that its effect was visible up to 10°N latitude [Figures 2(b), 2(e) and 2(f)]. Along with this strong EEA signature, the EEAC too appeared in the TEC maps with full strength till April 24th. The intensity of both EEA and EEAC decreases from April 25 [Figure 1(h)] and disappears after that . Based on the growth and development process of EEA and EECA from April 18 to 24, an EQ is predicated to occur on April 25th, on basis of the approach of Devi et al., [2013]. But to identify the epicene location, it is essential to estimate the magnitude of EEA and EEAC. For addressing this aspect the following procedures are adopted:

(i) The maximum latitudinal spreads of EEA and EEAC (areas where EEA and EEAC converge are examined as the first index

(ii) Longitudinal spread within the maximum latitudinal range is then defined

(iii) TEC value within the anomaly latitude-longitude zone is marked

The magnitudes of EEA and EEAC are finally determined by the following approach:

For evaluation of EEA, the increase in TEC value within this anomaly zone (as defined in the items (i, ii and iii above), with respect to the ones prevailing in the Normal Equatorial Anomaly (NEA), is calculated. The EEAC strength is determined from the increase in TEC value within the EEAC anomaly zone (as defined in items i, ii and iii above), with respect to average value of TEC at the particular defined areas.

The EEA and EEAC strengths so determined are expressed in grades (arbitrary unit) from 0.5 to 10, for EEA and 0.5 to 15 for EEAC, with 40 TEC U as minimum value of the TEC and 80 TECU, as the maximum in the anomaly zone. The result of analysis is presented in Figure 3 where EEA and EEAC magnitudes are plotted from April 18 to April 25. One can note that both the anomalies start increasing from April 21 to reach maximum on April 24.

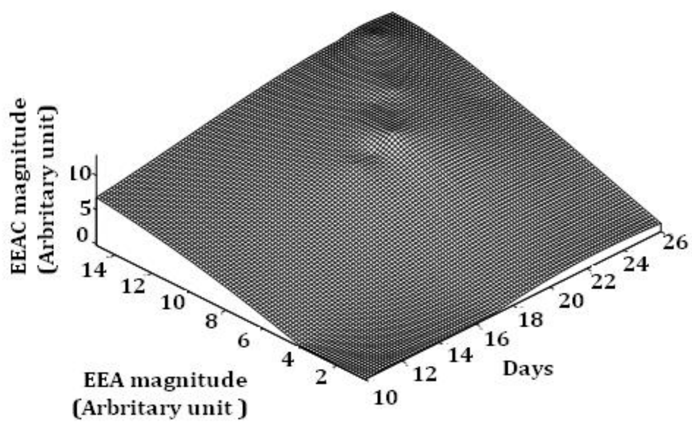


Figure 3. Displays the strength of EEA and EEAC from April 18 -24 , 2015 .

The occurrence of the EEAC is a rare event, because the anomaly effect needs to be strong enough to make a high TEC zone beyond the normal anomaly crest and especially in the night sector. To identify the most likely position of the development of the EEAC, the latitudinal and longitudinal coverage of the EEAC is evaluated from the day of its appearance to its disappearance and percentage of occurrence of EEAC at a particular latitude/longitude zone is calculated from the total number of EEAC cases observed. The results as displayed in Figure 4, show that EEAC was developed within 80° E to 118° E longitude and 21°N to 30° N, but the highest frequency of occurrence is at the latitude zone of 27°N-28° N and a longitude region spreading from

84°E to 87° E. The analysis thus suggests a possible earthquake at 25°N - 28°N latitude and 80°E -87° E longitude, interestingly coinciding with the epicentre location of the Nepal EQ. Thus the approaches adopted through EEA and EEAC may well be adopted as preludes to an impending EQ.

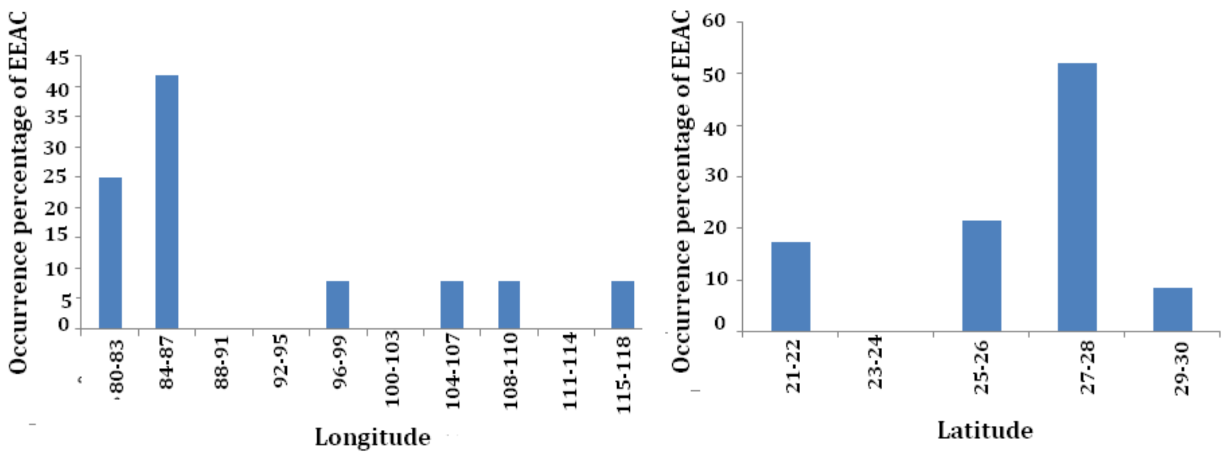


Figure 4 . Presents latitudinal and longitudinal spreads of the EEAC. The EEAC is observed within 21° N to 30 °N, but with highest frequency of occurrence within 27° N -28 ° N . Similarly the longitudinal spread goes from 80°E to 118°E with maximum frequency of occurrence in the zone.84°E- 87° E.

3. Discussions

This paper focuses a few features seen on TEC prior to the major EQ of Nepal the epicentre of which lies in the sub Himalayan region. The analysis shows that there are enhancements on TEC (i) at the equatorial anomaly (-5°N to 10°N Latitude) & the epicentre longitude zones and (ii) at the anomaly crest station around the epicentre latitude /longitude of Nepal EQ. Such increase in TEC days before a seismic event at equatorial and low latitude stations can be associated with seismogenic electric field above the epicenter, which is explained by many workers [Depueva & Ruzhin 1995; Devi et al., 2001; Devi et al 2004], through generation of a local up-drift /down drift of plasma by EXB process . Karpov et al., [2013] have shown that the electric fields of several mV/m can be generated by EQ preparatory processes and such situation may result to magnification of already existing equatorial anomaly effect which can dump the density at higher latitudes beyond the normal anomaly crest zone .Devi et al., [2004] have also detected development of strong anomaly prior to the massive 8.1 earthquake over Ahmadabad (23.36 °N, 70.33° E) while analyzing foF2 data. This process seems to be effective in the Nepal EQ when strong anomaly effect enhances the TEC at a region just outside the Normal Equatorial Anomaly Crest. The simultaneous growth of strong EEA in the latitude zone of -5° N to 10° N and near the epicentre longitudes suggests coupling process between development of EEA and EEAC. The intense EEA at the night sector that was observed in presence of mid latitude earthquakes from TEC global data was suggested by Devi et al., [2013] to be due to the result of westward E-field enhanced by the EQ induced processes that propagates density to lower latitudes from mid latitude epicenter through downward drift. The increase in TEC at this longitude zone is further enhanced by EM focusing effect generated at the EEA location due to the presence of the distortion of earth magnetic field in this sector [Devi et al., 2013].

But the source of development in EEA and EEAC during the day hours as seen in this EQ, (presented in Figure 5, as one of such cases) might be sought again in the EQ time E field at the epicentre or enhancement of already existing E field due to modification of conductivity at the upper atmosphere through generation EQ induced waves. The additional E field will generate an extra H component in the near equatorial region enhancing the electrojet strength within 10° N latitude. This process will increase ionospheric current through the three conductivity processes and further augments the anomaly and pushes the plasma beyond the normal anomaly crest zone. The very strong anomaly noticed especially on 23rd and 24th April, just prior to the EQ of 25th could be associated with such factor.

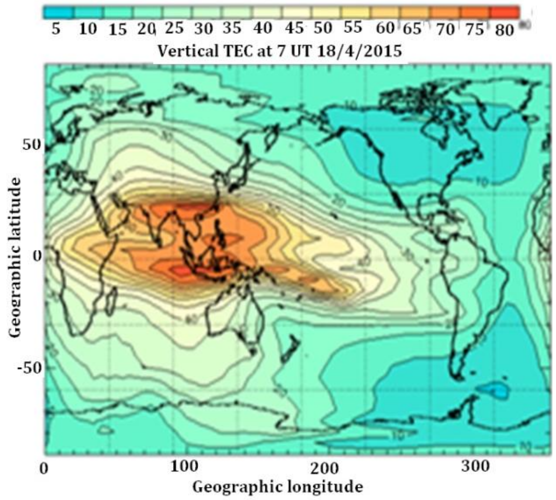


Figure 5. Dispalys develoment of day-time EEA and EEAC prior to the occrrence of Nepal EQ

One of such mechanisms of generation of current and field over a seismic area in the atmosphere - ionosphere circuit is through charged aerosols emitted by the lithospheric gases which are then injected into the atmosphere. Magnitude of such current / electric filed is expected to get amplified over a thickly populated aerosol environment, when epicentre lies in such a zone as in the case of Nepal EQ. Analysis of aerosol distribution pattern from MODIS data over the epicentre region (Sub Himalayan zone), shows (Figure 6a) thick layers of aerosol during vernal Equinoxial months (i.e. March April and early May). The aerosol intensity goes down during summer with the onset of Monsoon and interesting enough to note that during Autumnal months of September and October the strength of aerosol also goes low as is seen from Figure 6(b). Under such background environment, one can expect significant contribution of aerosols in enhancement of EQ induced E field over the epicenter area of Nepal EQ that occurred in vernal Equinoxial month. This process could increase the electrojet strength augmenting the anomaly phenomenon.

There is also possibility of increasing the ionization density at the equatorial zone when the stations are connected by a fault line by emission of radon from lithosphere near to the epicenter especially in major EQ as of Nepal. Such radon emission enhances the electron density in the ionosphere and also modulates the E-field [Pulinets 2009; Freund 2009] through generation of

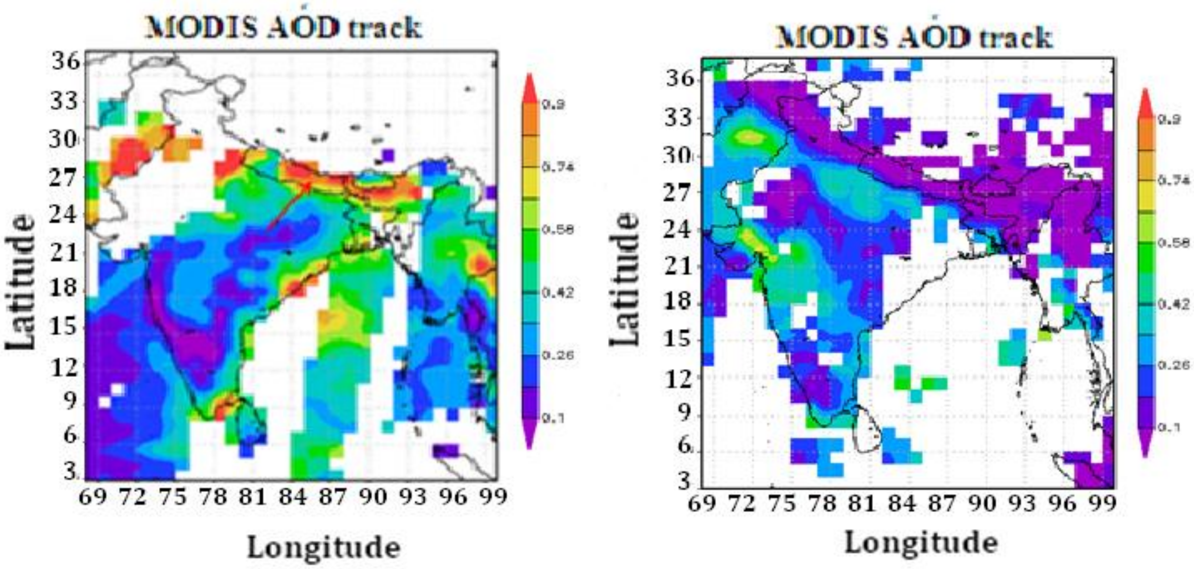


Figure 6. Dispalys AOD track received from MODIS, for (a) Vernal equnoxial months and (b) Autumnal equnoxial season . Thick aerosol layers along the Sub Himalaayn region is significant during Vernal Equnoial seasn. The colour bar shows the srength of AOD.

ionospheric current. This process could further modulate the Anomaly process and, strengthen the equatorial anomaly, as seen during April 23 and 24, 2015.

Further, it is also important to bring the conjugate status of EEAC and the EEA developed during the Nepal EQ. One may explain such association through electric current generated between the fault and ionosphere [Sorokin and Hayakawa 2013] , which might drive ionospheric current both vertically and horizontally resulting to drift of anomaly both in vertical and horizontal directions along the fault lines as observed in this case .

6. Conclusion

The TEC global data prior to and during the very strong earthquake over Nepal show presence of Earthquake time Equatorial Anomaly (EEA) , as well as growth of intense density at the epicentre location of 28 °N that lies just outside the normal Appleton anomaly crest zone suggesting widening of Earthquake time Equatorial Anomaly Crest (EEAC) . Development of EEA is observed to be so strong that intense TEC zone is detected up to 10 °N, and anomaly crest is expanded even during night hours. The development of EEA and EEAC are tried to explain by east ward (daytime) and westward E-field (night time) which are enhanced by the EQ preparatory processes leading to strong ionospheric current and hence electro jet strength. Contribution of EQ time emission of radon in the density enhancement may also be a factor, but justification needs further study related to measurements of radon especially around high seismic lines. These are the future courses of study.

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