Equatorial and low latitude Ionospheric Response to Some of the Space Weather Events over Indian region

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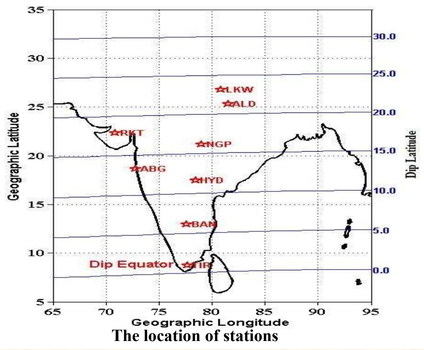
Objective:

The main objective of this work is to understand the ionospheric response to the super geomagnetic storm of the current solar cycle-24 that occurred on the **17th march 2015** and Dst reached its minimum value (-228 nT). We used Equatorial Electrojet (EEJ) strength, CADI ionosondes at Tirunelveli (8.73° N, 77.70° E, geom: 0.32^0 N) and Allahabad (25.45°N, 81.85°E; geom: 16.5^{0}N) and GPS TEC from Indian stations during 16-18 March 2015 to characterize contrasting characteristics of this geomagnetic storm. The observations showed significance increase of h'F (virtual height) ~560 km and upward (vertical) drift of ~70 m/s over Tirunelveli followed by intense Equatorial spread F (ESF) irregularities in ionosonde, the ESF was so intense that its signatures are sowed in Allahabad ionosonde on the storm day as compared to other days due to the eastward penetrating electric fields. EEJ showed EEJ/CEJ signatures and TEC observations showed increase of ~20 TECU followed by storm onset. Suppression of anomaly crests on the subsequent day of the storm possibly suggests the role of disturbance dynamo effect. Another interesting feature is the periodic oscillations in hpF2 (peak height) and h'F (virtual height).

Data sets

The list of stations along with instruments

Station	Instrument	Geographic latitude	Geographic longitude	Geomagnetic latitude
Tirunelveli (TIR)	CADI ionosonde, SCINDA GPS receiver	8.73^{0}N	77.7^{0}E	0.23^{0}N
Bangalore (BAN)	IGS GPS station	12.97^{0}N	77.59^{0}E	4.44^{0}N
Hyderabad (HYD)	CADI ionosonde, IGS GPS station	17.36^{0}N	78.47^{0}E	^{0} 8.76
Nagpur (NGP)	GNSS receiver	21.14^{0}N	79.08^{0}E	12.42^{0}N
Rajkot (RKT)	SCINDA GPS receiver	22.30^0 N	70.93^{0}E	14.21^0
Allahabad (ALD)	CADI ionosonde	25.43^{0}N	81.84^{0}E	16.48^{0}N
Lucknow (LKW)	IGS GPS station	26.85^0 N	80.92^{0}E	17.69^0 N



The location of stations

A brief introduction of geomagnetic storm

A geomagnetic storm is a temporary disturbance of Earth's magnetosphere that occurs when there is a very effective exchange of energy from the solar wind or cloud of magnetic field into the space environment surrounding Earth. These storms result from variations in the solar wind or cloud of magnetic field that produces major changes in the currents, plasmas, and fields in Earth's magnetosphere.

A geomagnetic storm has mainly three distinct phases:

1. **The initial phase**
2. **The main phase**
3. **The recovery phase**

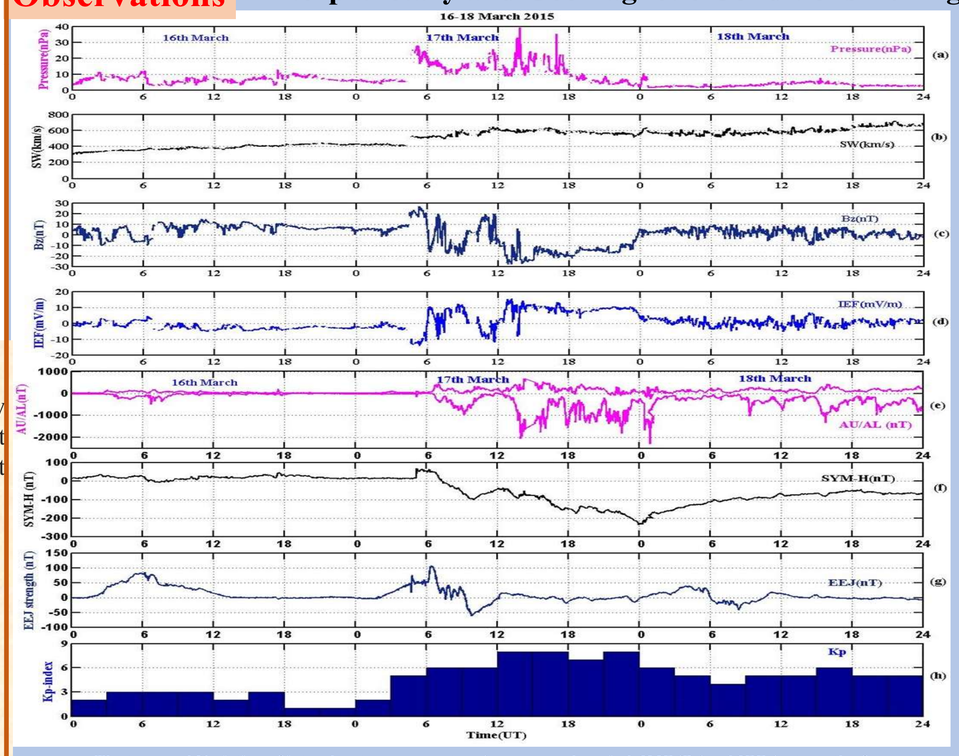
During the geomagnetic storms time electric field in the equatorial ionosphere could be primarily affected by the two processes:

(1) the solar wind-magnetosphere dynamo, associated with prompt or direct penetration (PPEF) of the magnetospheric convective electric field [Senior and Blanc, 1984],

(2) the ionospheric disturbance dynamo (DDEF), due to global thermospheric wind circulation associated with Joule heating at high latitude [Blanc and Richmond, 1980]

Observations

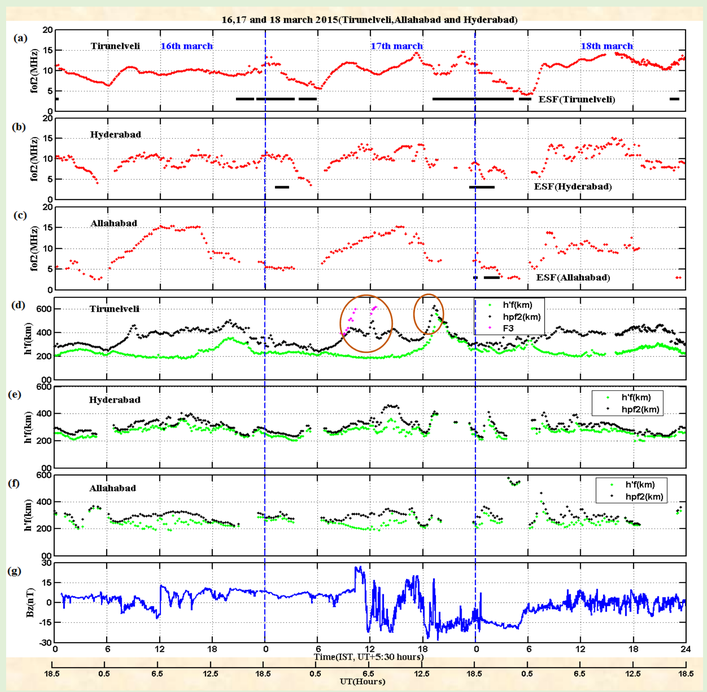
Interplanetary and Geomagnetic Conditions During 17–18 March 2015



The temporal Variation of interplanetary parameters (pressure, solar wind, IMF (Bz)and IEFy), strength of EEJ(nT), and geomagnetic indices (AU/AL(nT),SYM-H(nT) and Kp)

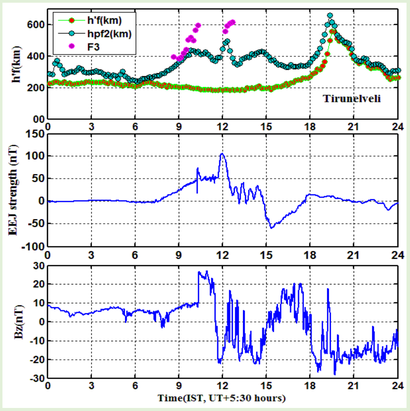
- **This Geomagnetic storm is strongest geomagnetic storm of the current solar cycle-24 where Dst reached of -228 nT**
- **During this geomagnetic storm a CME hit the Earth's magnetic field on March 17th at approximately 04:30 UT**
- **Initially the impact was a low intensity G1-class (Kp=5) geomagnetic storm and after the storm intensified G4-class (Kp=8)**
- **During storm time solar wind pressure varied between ~20-30 nPa, average solar wind speed was ~500-600 km/sec,**
- **Interplanetary Magnetic field varied between ± 25 nT, Interplanetary electric(IEF) varied between ± 10mV/m,**
- **Auroral electrojet activity AE (AU/AL) indices sows the multiple fluctuation during the onset of storm time which is indicates the substorm activity**
- **Equatorial electrojet (EEJ) reached ~ -100 nT and counter Electrojet (CEJ) ~50 nT**

Ionosonde Observations

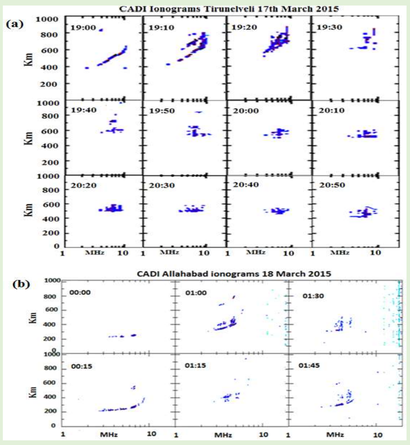


The temporal variations of ionospheric F region density in terms of foF2 in MHz (red) for (a) Tirunelveli, (b) Hyderabad, and (c) Allahabad. h'F in km (green) and hpF2 in km (peak height) (black) for (d) Tirunelveli, (e) Hyderabad, and (f) Allahabad, respectively, during 16–18 March 2015.

- **Virtual height increases maximum ~560 km at Tirunelveli**
- **F3 layer occurring → prompt penetration electric field**
- **The intense spread F generated → strong pre reversal enhancement (PRE).**
- **fof2,h'f and hpf2 show the Oscillatory behavior → the neutral winds.**

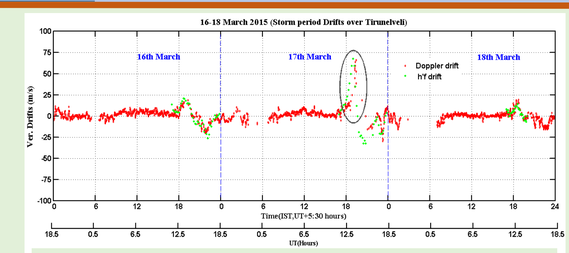


Virtual height on 17th March over Tirunelveli

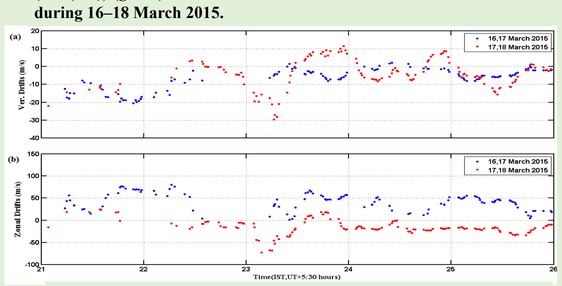


Ionograms of intense Equatorial spread F (ESF) over the Tirunelveli and Allahabad on 17th -18th March 2015 (night)

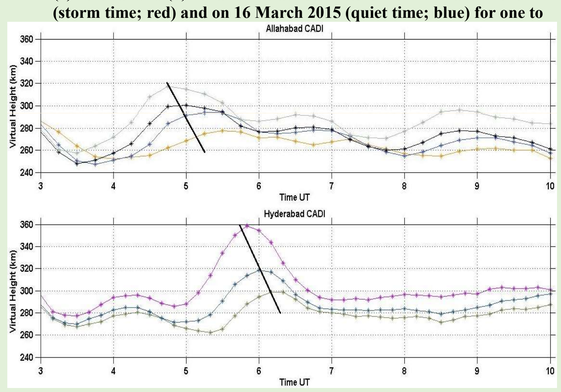
- **The variation of Doppler drifts and h'F drifts over Tirunelveli obtained from CADI ionosonde during the storm time**
- **Vertical Doppler plasma drift (red) and h'F drift (green) shows the same magnitude of drift evening time → ~70 m/sec Due to the prompt penetration electric field (PPEF)**
- **Simultaneous observations of CADI isodensity profile at Allahabad (5-8MHz) and Hyderabad (5-7 MHz)**
- **This representing the Traveling Ionospheric Disturbances (TIDs) during recovery Phase. It's possible that TIDs could have propagated to low latitude from high latitude Due to the Joule Heating.**



The Doppler vertical drifts (red) and rate of change of virtual height (h'F (km)) (green) over Tirunelveli as obtained from CADI ionosonde during 16–18 March 2015.

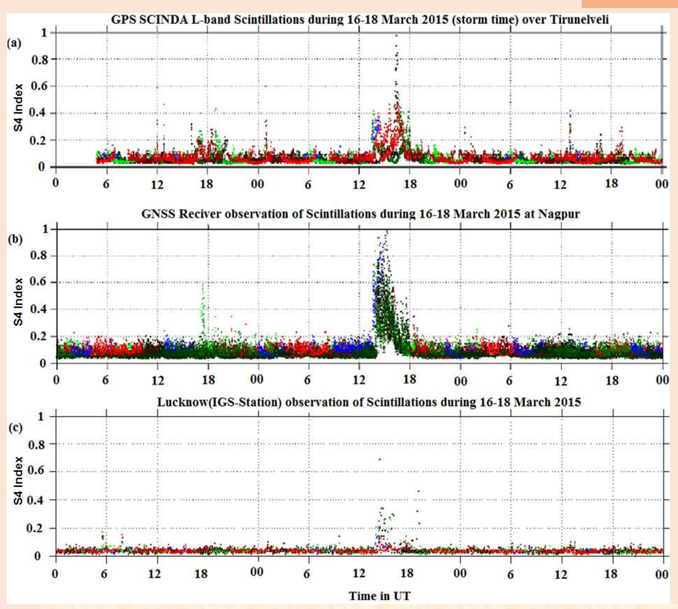


(a) vertical and (b) zonal drifts at 15.5–20.5 UT on 17 March 2015 (storm time; red) and on 16 March 2015 (quiet time; blue) for one to

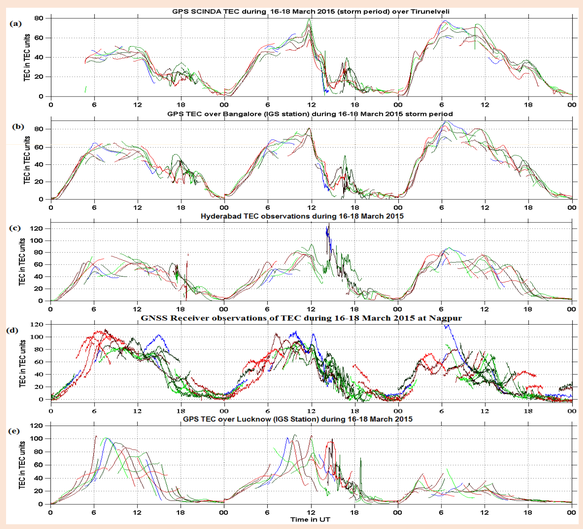


The variation of isodensity at (a) Allahabad (5–8 MHz) and (b) Hyderabad (5–7 MHz) stations, respectively. The black line indicates variation of phase velocity

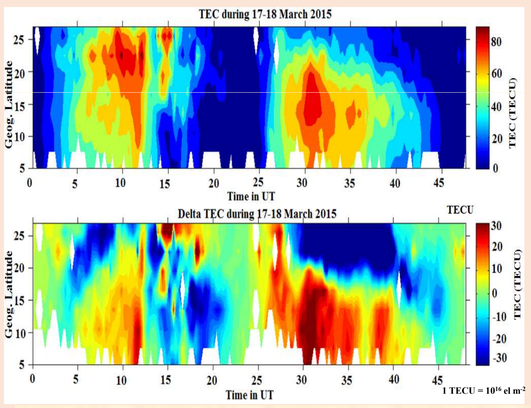
GPS/GNNS Receiver Observations



The GPS L band scintillations over (a) Tirunelveli, (b) Nagpur, and (c) Lucknow stations for the days 16–18 March 2015, respectively. Different colors indicate different PRNs



Temporal variation of GPS/GNSS vertical TEC from equator to beyond anomaly crest zone, namely, Tirunelveli (TIR), Bangalore (BAN), Hyderabad (HYD), Nagpur (NGP), and Lucknow (LKW), respectively, from top to bottom during 16–18 March 2015



(a) The latitudinal and temporal variations of TEC (vertical) during 17–18 March 2015. (b) The delta TEC during 17–18 March 2015 after subtracting quiet day TEC (here it is 16 March)

Summary and Conclusions

- **Evidence of EEJ/CEJ signatures during the super geomantic storm time**
- **Prereversal enhancement (PRE) drifts went upto 70 m/s during storm time as obtained from the CADI Doppler drift measurements in association with virtual height of 560 km on 17 March 2015 over Tirunelveli (magnetic equator) due to the direct prompt penetration electric field**
- **This PRE drifts are enhanced due to the prompt penetration of eastward electric fields in association with undershielding effect.**
- **F3 layer occurrence at Tirunelveli during main phase of the storm possibly indicates the electric field fluctuations due to Prompt penetration electric fields**
- **Oscillatory behavior in density, hpF2 and h'F during recovery phase which could be due to storm induced meridional neutral wind perturbations at the Tirunelveli and Allahabad**
- **Feature of the traveling ionospheric disturbances (TIDs) propagation to equatorward possibly associated with disturbance meridional wind surge during recovery phase**
- **Very strong L band scintillations observed at the Tirunelveli and Nagpur**
- **Enhanced EIA during main phase and suppression of both EIA density and its latitudinal extension during recovery phase**