Degradation of Tomographic Estimations of Ionosphere during Geomagnetic Storms

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Degradation of Ionospheric Estimations during Geomagnetic Storms

Motivation:

- Space Weather effect perturbs the ionosphere. This, in turn, affects the estimation of the ionospheric electron density, using approaches, like tomography. The amount of degradation occurring in estimation needs to be quantified, as it may affect the related applications.

Objectives:

- To assess the degradation of the tomographic estimation of ionospheric electron density distribution during space weather driven geomagnetic storm

Approach:

- To find the accuracy of tomographic estimation, with respect to measured values
- To compare the estimation accuracy on a geomagnetic storm day with respect to a quiet day

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Tomography:

Tomography is the technique by which the distribution of any physical parameter can be estimated from the knowledge of some finite numbers of their path integrals

Here, tomographic estimation of ionospheric electron density distribution done in 3D space using TEC as input.

TEC is obtained from the GNSS receivers installed across India

Validation done using the unused TEC values and using ionosonde measurements of NmF2 at Delhi

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- Input TEC values obtained from GAGAN enabled GPS receivers of GAGAN ionospheric network installed across India
- 20° cut-off elevation is kept. It makes the IPP boundary at about 8° from the receivers in all sides
- Vertical TEC derived from GAGAN GIVD are additionally used
- From 0° to 35 ° N and from 70 °E to 85 °E and altitude up to 800 km is taken as the volume of interest

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- In our approach, the background density is obtained using the ***Modal decomposition*** technique
- **Spatial Electron Density:** Weighted Combination of linearly independent basis distribution functions that spans the space [$Ne = \sum_i \Psi_i X_I$]
- **Observation Equation:** Suitable bases with unknown weights integrated over definite paths and equated with measured TEC [$\underline{STEC} = \{ \int \underline{\Psi}\, dl \} * \underline{X} = A * \underline{X}$]
- **Snapshot period:** 15 minutes of snapshot period is used
- **Solution:** Weights of each base estimated [$\underline{X} = A^{-1} * \underline{TEC}$]
- **Estimation:** Using estimated weights and corresponding bases, TEC over any path may be determined [$Ne = \sum_i \Psi_i X_I$]

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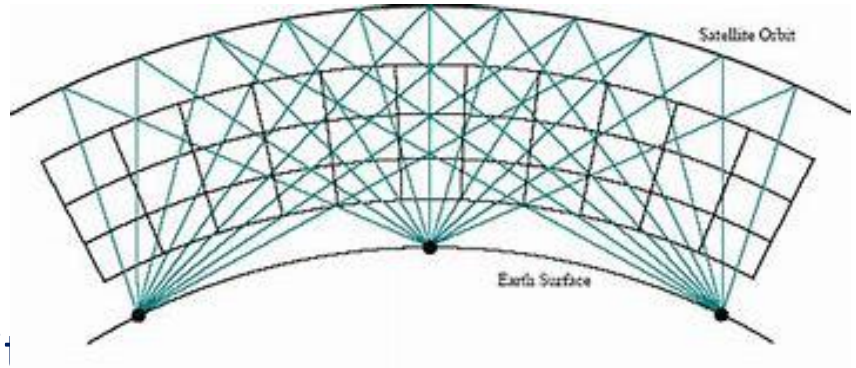
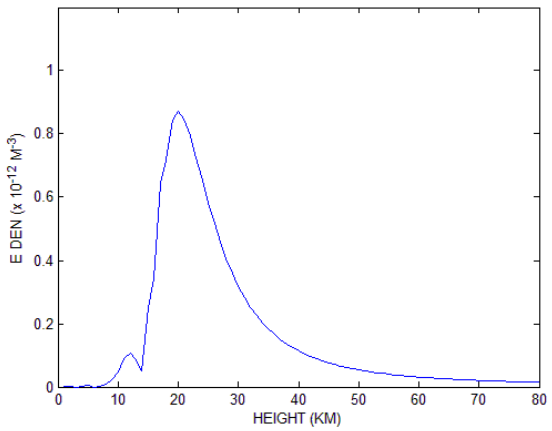
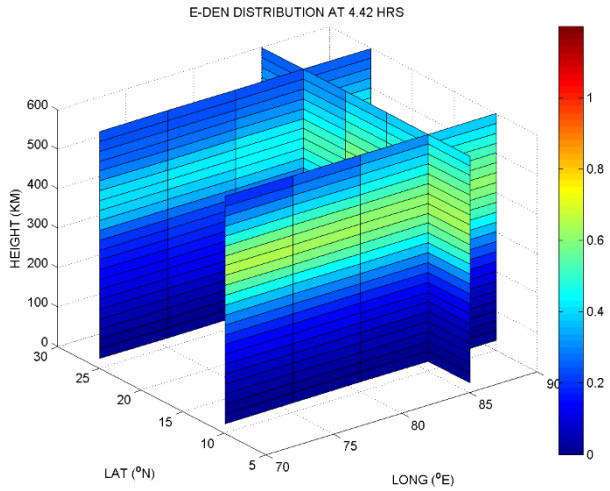
- The finer variations are obtained using conventional **Ray tomography.**

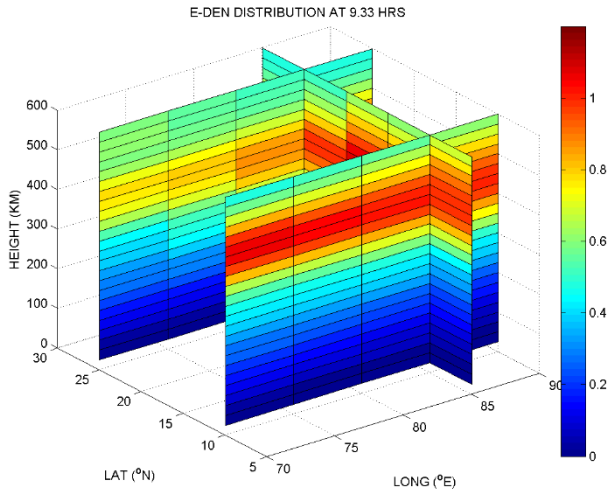
$$[\ x_j^{k+1} = x_j^k * \{\frac{T_m}{<A_i * x_i>}\}^{\lambda(\frac{A_j}{Amax})}\ ]$$

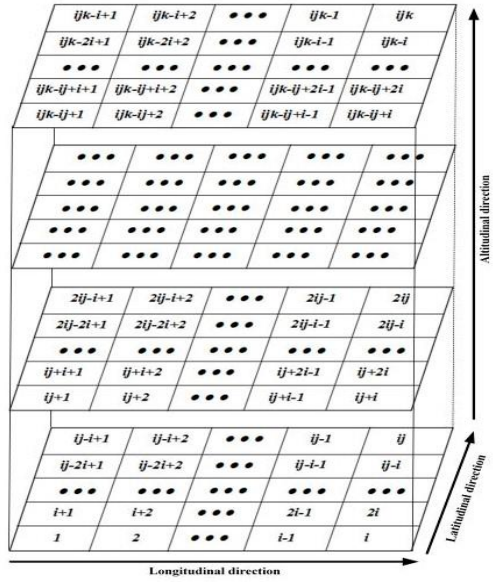
- MART algorithm is used for estimation of the density values.
- The values obtained after convergence is used as the final densit, values











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- Estimation is done for both quiet and geomagnetic storm day

  Quiet days chosen were 03 March, 2015 and 17 April, 2017

  Storm days chosen were 17 March, 2015 and 08 Sept, 2017

- Accuracy observed using two different means: Comparing TEC and comparing NmF2

  TEC values not used in tomographic estimation were used for finding accuracy

  NmF2 data obtained from Delhi Ionosonde used as reference values.

- Any change in accuracy between the storm day and quiet day are observed
- This is done to observe any degradation in accuracy

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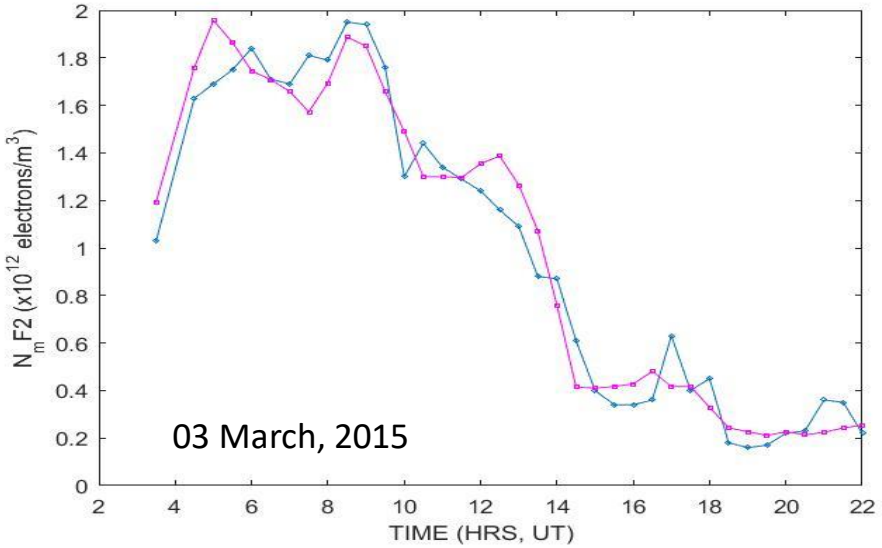
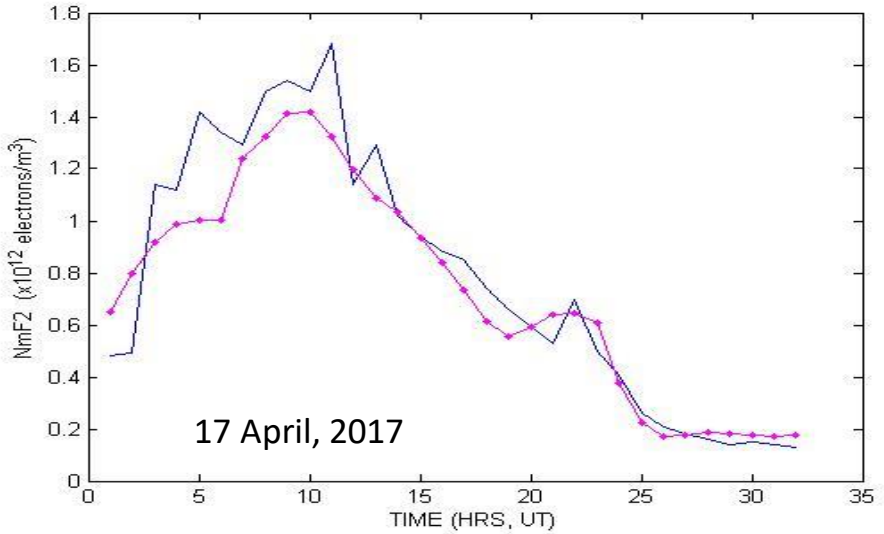
Results – Quiet Days

- On quiet days, the estimated NmF2 followed the actual measurements quite well.
- Both the days showed good conformance when compared with the ionosonde measured NmF2





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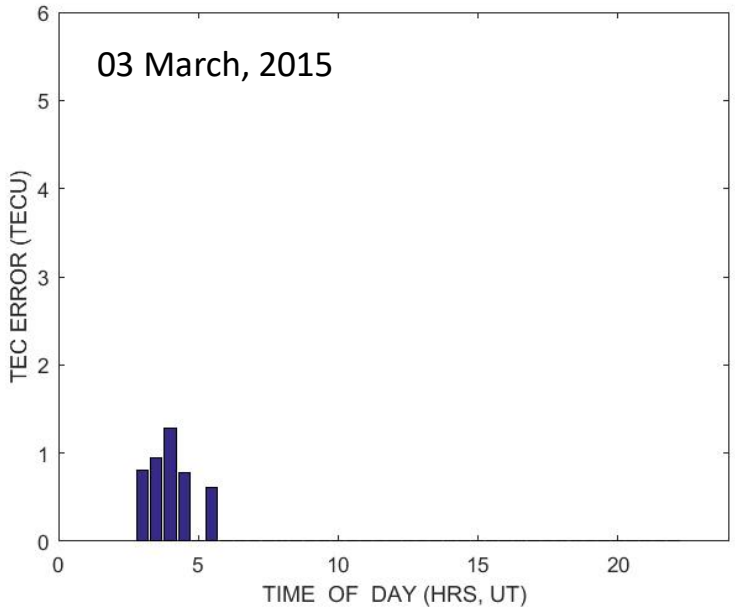
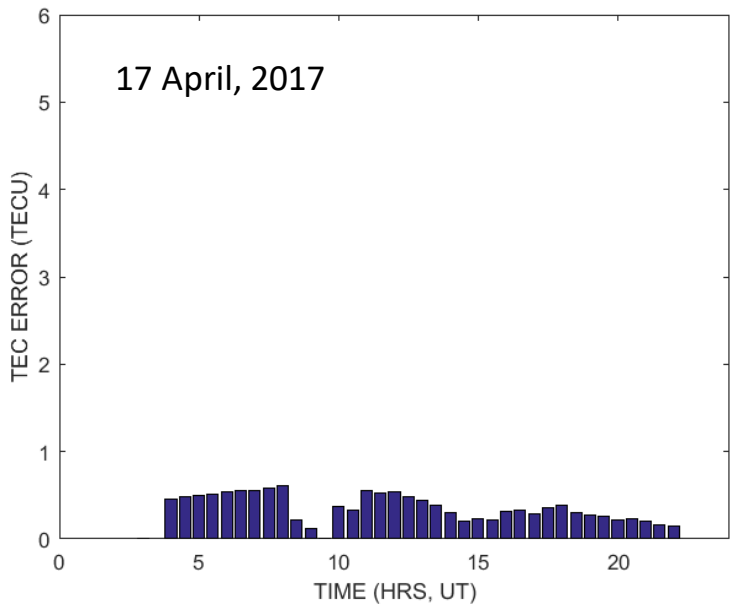
Results – Quiet Days

- On quiet days, the reconstruction of TEC was also quite accurate
- MART iterations round continued till, ε<0.1 TECU or #>50, whichever comes first
- Error shown as zero when the first condition was met





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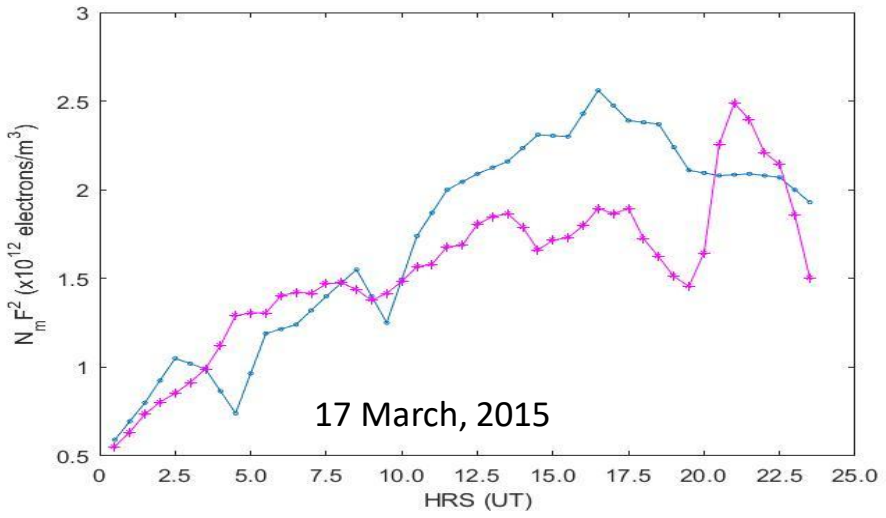
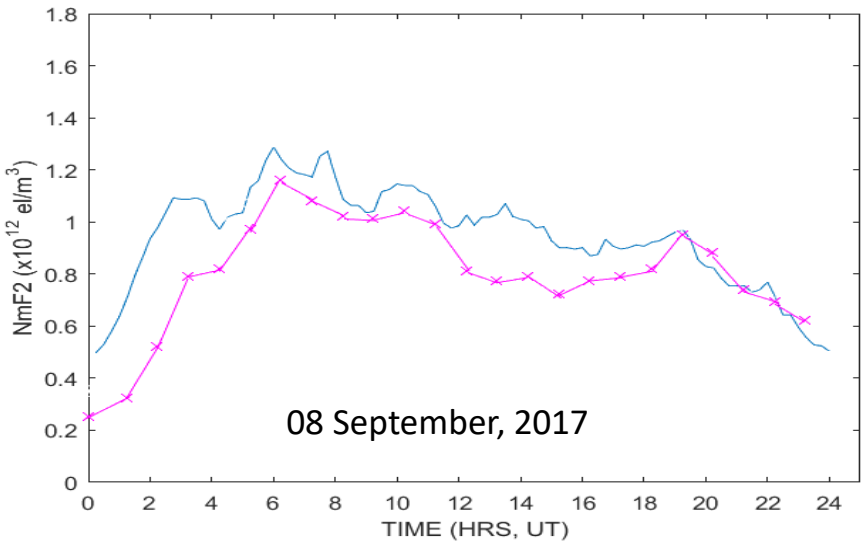
Results – Storm Days

- On storm days, the estimated NmF2 showed distinct deviation from the measured values.
- It is worth noting that the deviation started at





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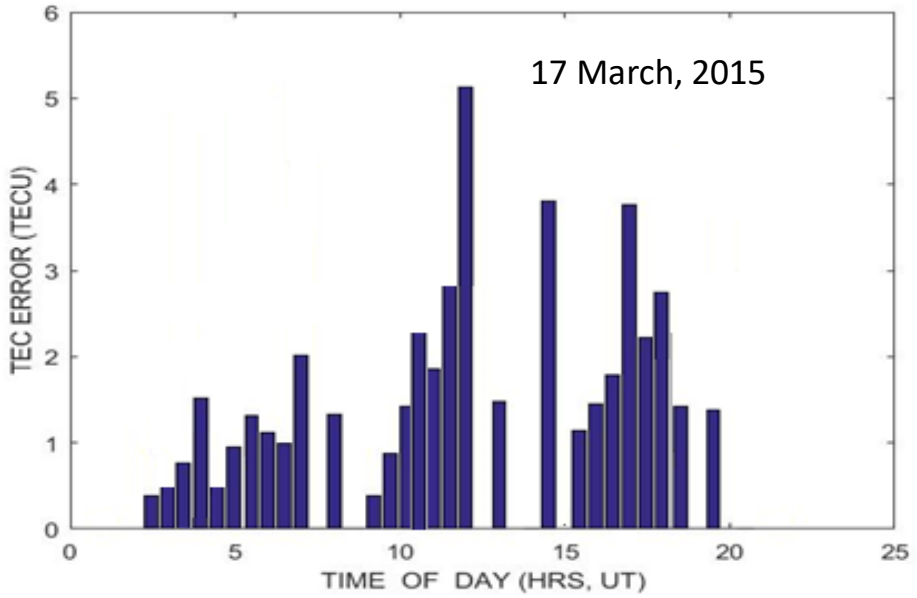
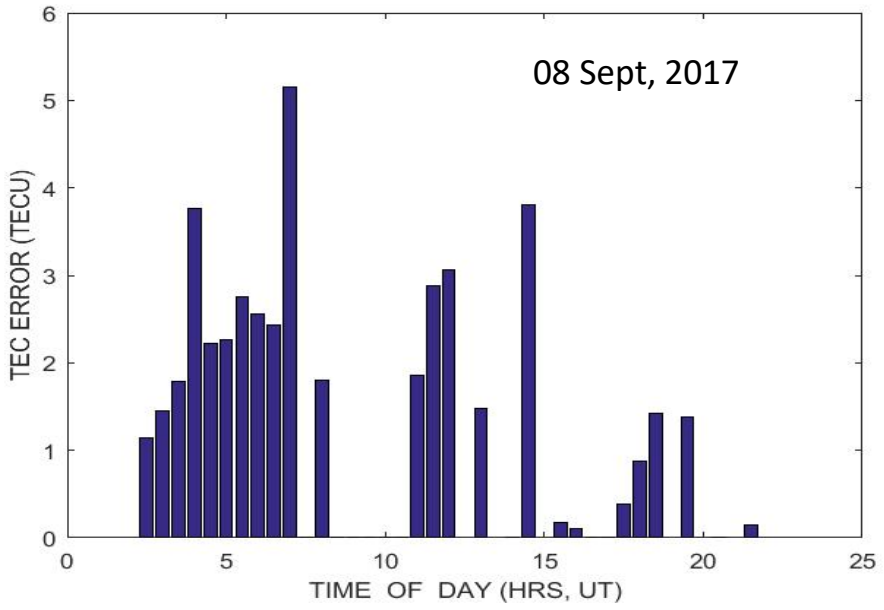
Results – Storm Days

- On storm days, the reconstruction of TEC showed large residual values
- Over certain period of times, the residues exceeded 4 TECU even after 50 iterations





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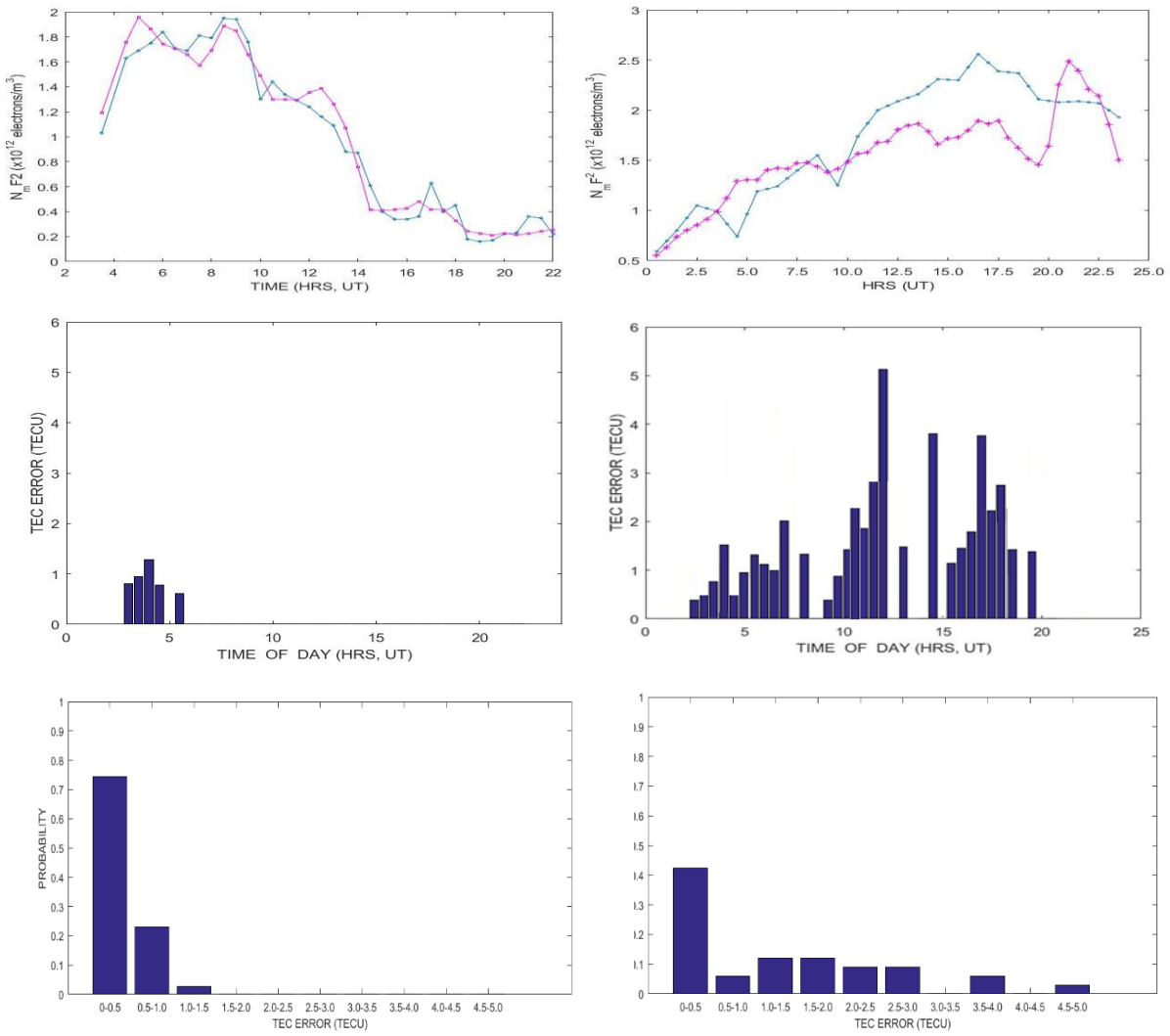
Results

- The estimation mean error for NmF2 was 0.008 (x 10^{12}) el/m^3 and the SD of the error was 0.12 (x 10^{12}) el/m^3
- In contrast on the storm day, the estimation mean error for NmF2 was 0.168 (x 10^{12}) el/m^3 and the SD of the error was 0.34 (x 10^{12}) el/m^3
- The estimation mean error for TEC was 0.42 TECU compared to 1.36 TECU on the storm day
- The SD for TEC estimation error for quiet day was 0.463 TECU compared to 1.39 TECU on the storm days



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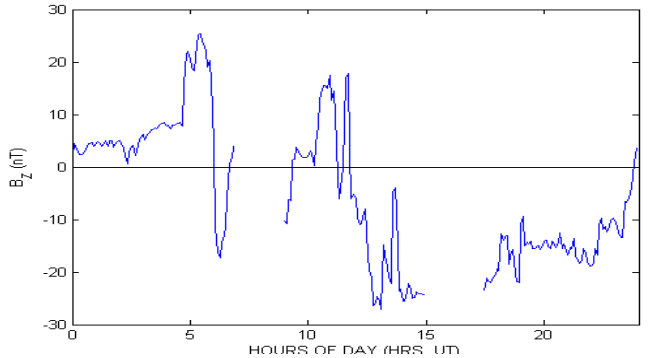
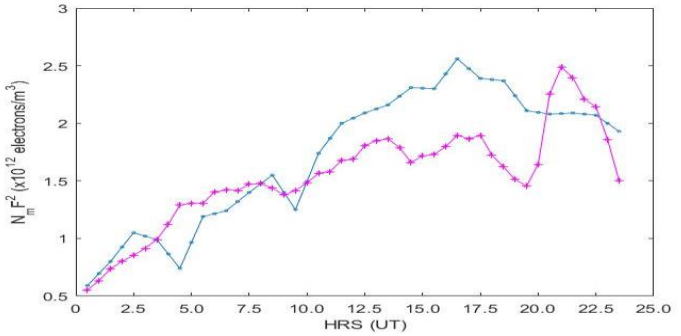
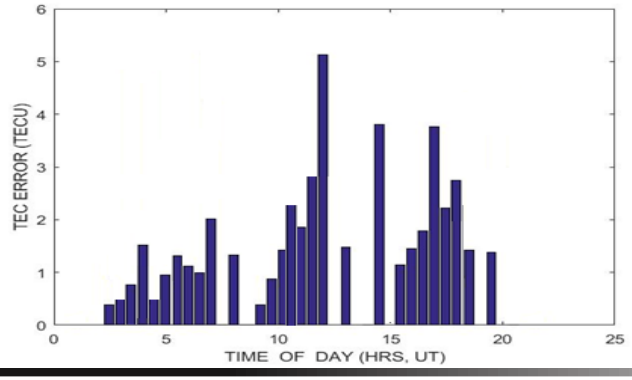
Discussions

- The abrupt transition of the IMF-Bz at ~ 1200 Hrs. is reflected in the deterioration of the tomographic estimation of the ionospheric electron density
- Possible reason being that the PPEF led to additional induced electric field leading to the atypical redistribution of the charge densities
- The degradation is the result of the irregularities generated in the ionosphere and the rapid fluctuations in the spatial and temporal profile of the electron density.







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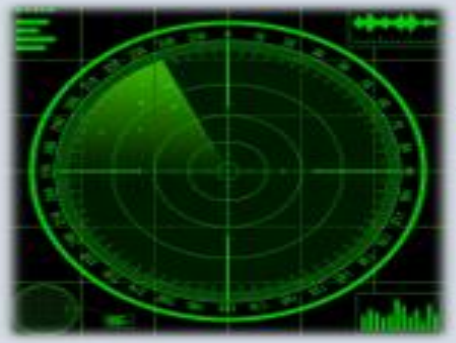
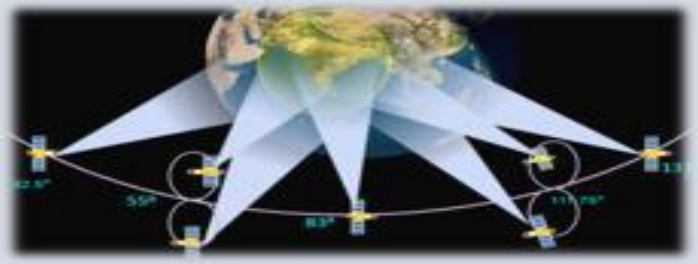
Final Outcome:

- Degradation of tomographic estimation of ionospheric electron density has been observed
- Statistically, the degradation is large on a super storm day
- Tomographic Estimation procedure has to be made more robust to improve performance during storm

Future plan:

- Improve the tomographic estimation procedure that can accommodate fast changing ionospheric electron density profile








Thank You