International Civil Aviation Organization

THE SIXTH MEETING OF IONOSPHERIC STUDIES TASK FORCE (ISTF/6)

Bangkok, Thailand, 19 – 21 January, 2016

Agenda Item 4: Review of deliveries of Tasks and related Action Items

e) Task 5 - Iono Models

IONOSPHERIC GRADIENT ANALYSIS FOR GBAS USING TIME STEP METHOD

(Presented by India)

SUMMARY

This paper presents the technique adopted for estimation of ionospheric delay gradients for GBAS threat model along with detailed analysis and results. The Time Step method is useful in absence of multiple receivers at short baseline as single receiver is sufficient to estimate the ionospheric gradient. This technique has been employed for GAGAN TEC receivers as they are located at long baseline.

The working paper also presents the results of ionospheric gradients computed using the above technique. Significant gradients of the order of 500 mm/km have been observed.

1. INTRODUCTION

1.1 The ionospheric delay gradients, caused by plasma bubbles, produce significant ranging errors which are very crucial especially for implementation of GBAS. The occurrence of plasma bubbles is rare over mid latitude but is very frequent over the equatorial and low latitude region.

1.2 The characteristics of the plasma bubbles, especially the ionospheric gradient is pertinent for the development of Iono threat model for GBAS.

1.3 The GAGAN-TEC network established for characterizing the ionospheric behavior and development of ionospheric model for Indian SBAS- GAGAN, has been leveraged effectively for developing the GBAS threat model

2. DISCUSSION

2.1 The ionospheric delay gradient can be computed by using two techniques with the dual frequency receiver- Time Step method and Station-Pair Method. The Station-Pair method requires at least two receivers with short baseline (~5-50 km) while single receiver is sufficient for Time- Step Method.

2.2 Since the stations of GAGAN-TEC network have nominal baseline of ~500 km, it is not feasible to use Station-Pair method. Hence Time-Step method has been used for computation of iono delay gradients.

2.3 The software tool on MATLAB platform has been developed based on Time Step method to derive the iono gradients (mm/km) from the ISMR data format. The detailed description of the procedure is presented in Attachment I to this working paper.

2.4 The computation of iono gradients has been completed for all the days of year 2004 to 2013 (10 years) for almost all the stations of GAGAN-TEC network.

2.5 Based on manual screening of the gradients at Bangalore station, a total of 138 days have been identified from 2004 to 2013 (except 2011) having significant ionospheric activity with extreme gradients.

2.6 Large number of threat points exceeding the CONUS model gradient threshold of 425 mm/km has been observed at Bangalore. The detailed results are presented in the Attachment I to this working paper.

3. ACTION REQUIRED BY THE MEETING

3.1 The meeting is invited to do the following:

a) discuss the iono gradient estimation technique – Time Step method as appropriate methodology in absence of multiple short baseline stations;

b) note the results of the ionospheric gradients; and

c) discuss any relevant matters as appropriate.

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Ionospheric Gradient Analysis for GBAS using Time Step Method

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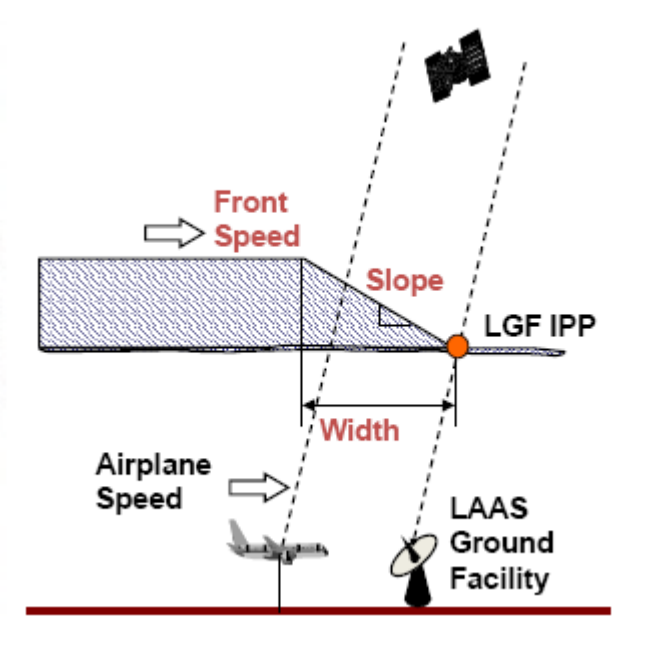
ICAO ISTF/6
19-21 January 2016
Bangkok, Thailand

Introduction

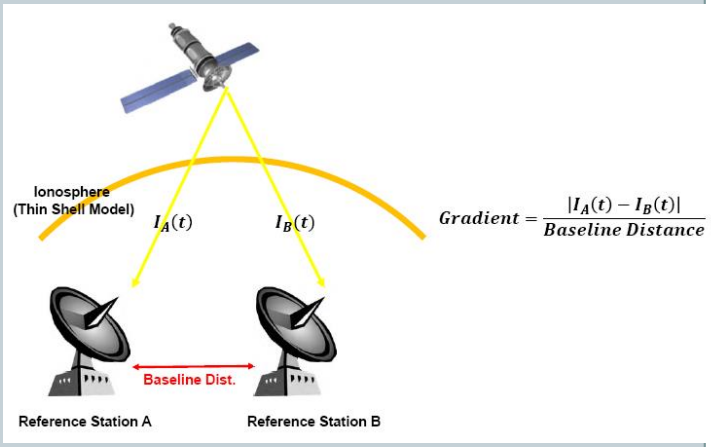
- Localized sharp spatial gradients in the ionospheric densities may result in safety hazard due to differences in corrections computed by the reference stations and actual ionospheric delay experienced by any aircraft.
- Ionospheric gradients are required for development of Iono Threat model for GBAS.

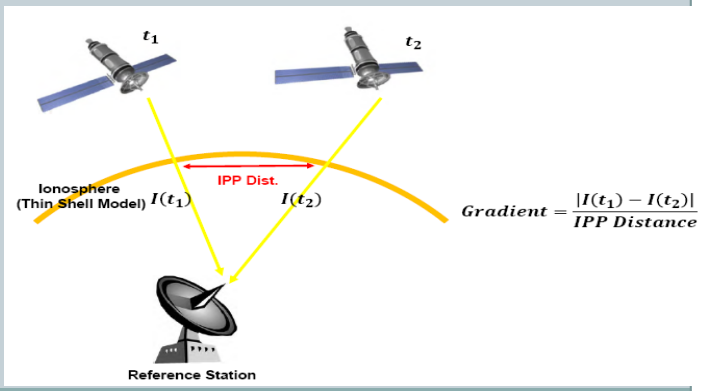


Computation of Iono Gradient

Ionospheric gradient can be calculated by using two methods with dual frequency receiver:

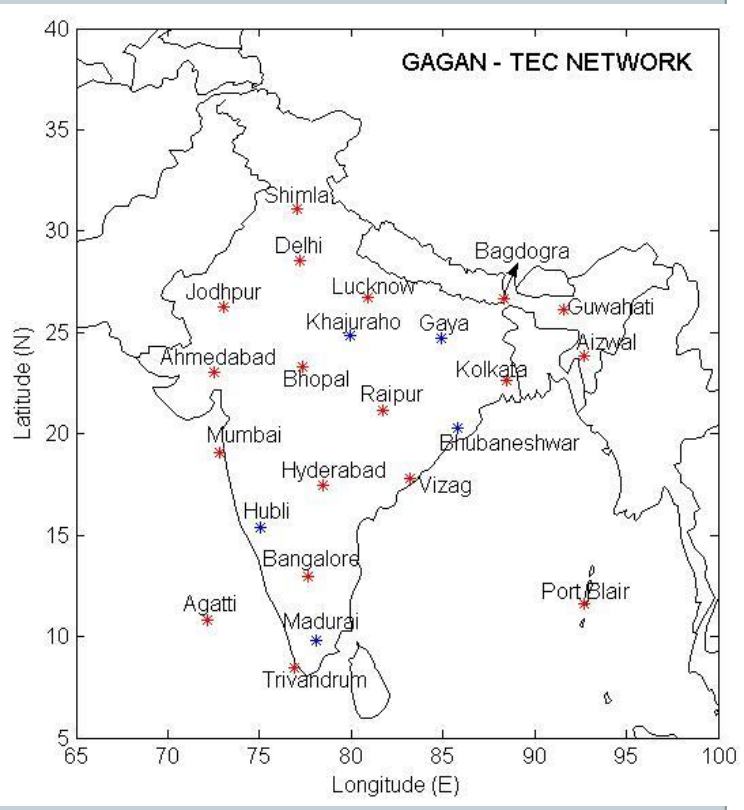
- Station-Pair Method
  - Provides spatial gradient
  - Requires multiple (at least 2) GPS stations at short baseline, less than 50 km
- Time-Step Method
  - Provides spatio-temporal gradient
  - Single receiver is sufficient





Calculation of Iono Gradient

- Station-Pair method is not feasible to compute iono gradient using GAGAN-TEC network as they are widely separated receivers (~500km baselines),
- Hence, the ionospheric gradients are calculated at each GAGAN TEC station using a 'Time-Step' method.



✓ Software tool in MATLAB has been developed to calculate the gradient from TEC data (ISMR) using Time-Step Method

Calculation of Iono Gradient- methodology

- 'Delta TEC' values, derived from carrier phase, at each 15 seconds interval are used for gradient computation.
- Elevation and azimuth information is interpolated for corresponding time interval.
- The Ionospheric Pierce Points (IPP) coordinates are computed at ionospheric shell height of 350km.
- Distance between each Ionospheric Pierce Point is calculated by converting the IPP coordinates into xyz Cartesian coordinates.
- Elevation mask angle is kept at 10 degree.
- The output file consists of – GPS WEEK, TOW, PRN, Gradient (mm/km), STEC, Elevation, Azimuth
- Provision to plot the gradients and corresponding Slant TEC if gradients exceeds certain threshold (100 mm/km). Useful for manual screening.

Gradient Analysis

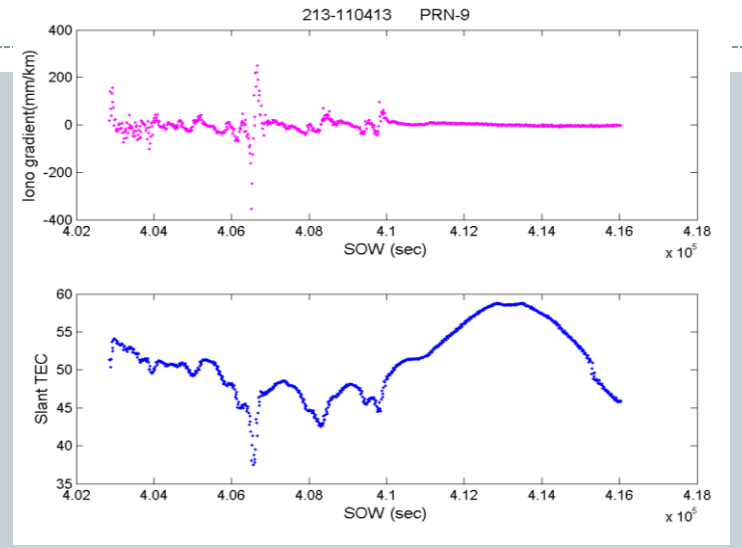
- ✓ The daily iono gradients have been generated for almost all the stations of GAGAN-TEC network from the year 2004 to 2013.
- ✓ The plots of gradient and corresponding STEC have also been generated for the days when gradient exceeds threshold of 100 mm/km.

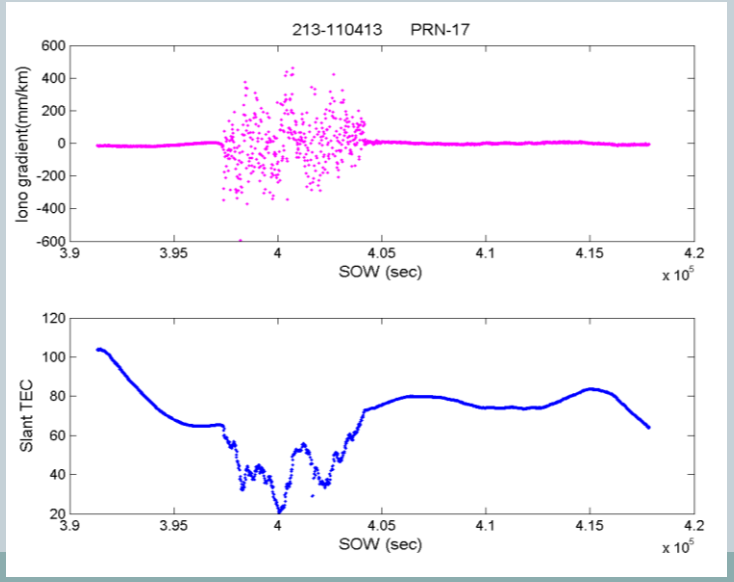
Identification of dates

- By manually screening the plots of gradients (> 100 mm/km) and STEC, the significant dates have been identified for Bangalore station, a low latitude station.
- A total of 138 days (59 days from 2004 to 2010 and 79 days from 2012 to 2013) have been identified experiencing significant iono activity at Bangalore.
- The elevation mask angle for data logging was 15° from 2004 to 2010 and it was set to 5° from 2012 onwards. Hence the days were segregated.
- The data of 2011 is not available from Bangalore. This period is mostly low solar activity period barring 2 months- Oct-Nov 2011.

Results of Iono Gradients

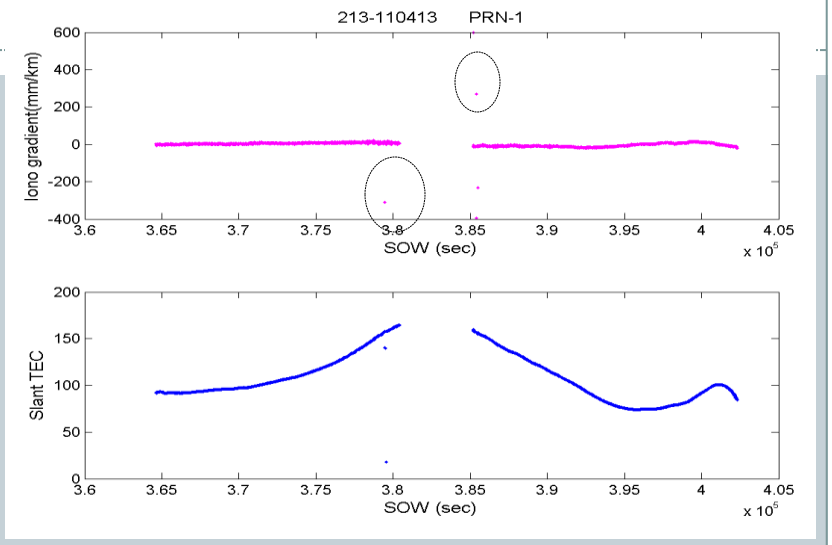
- Example plots of gradients along with slant TEC are shown here for different satellites on a single day (11 April 2013) for Bangalore (Rx ID – 213)
- Gradients exceeding 400 mm/km are observed during plasma depletions (bubbles).

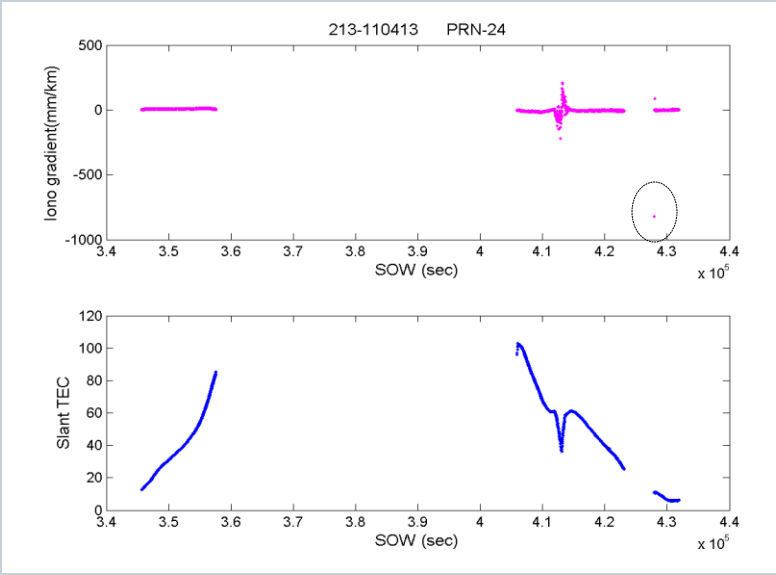




Results of Iono Gradients

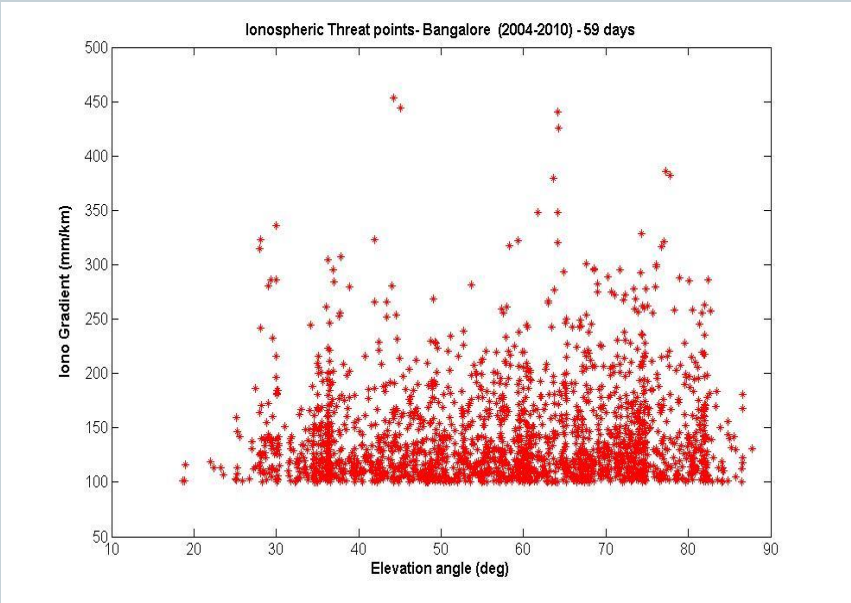
- Sometimes false values of gradients are included due to inherent incorrect data of ‘delta TEC’ as shown in these plots for same day (11 April 2013 but for different satellites).
- Gradient points close to 400 mm/km are visible although there is no irregularity in TEC.
- This may be due to cycle slips or unsettling of the phase lock loop.
- Manual screening is required to sort out these ‘false’ gradients.





Ionospheric threat points – 2004 to 2010

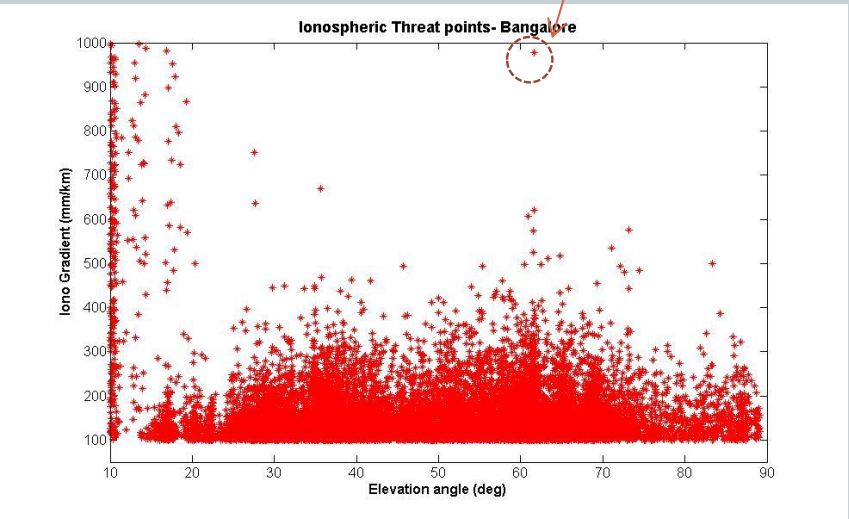
- Ionospheric gradient points for 59 identified days at Bangalore from 2004-2010 w.r.t. elevation angle.
- Only 4 points exceeds gradient of 400 mm/km.



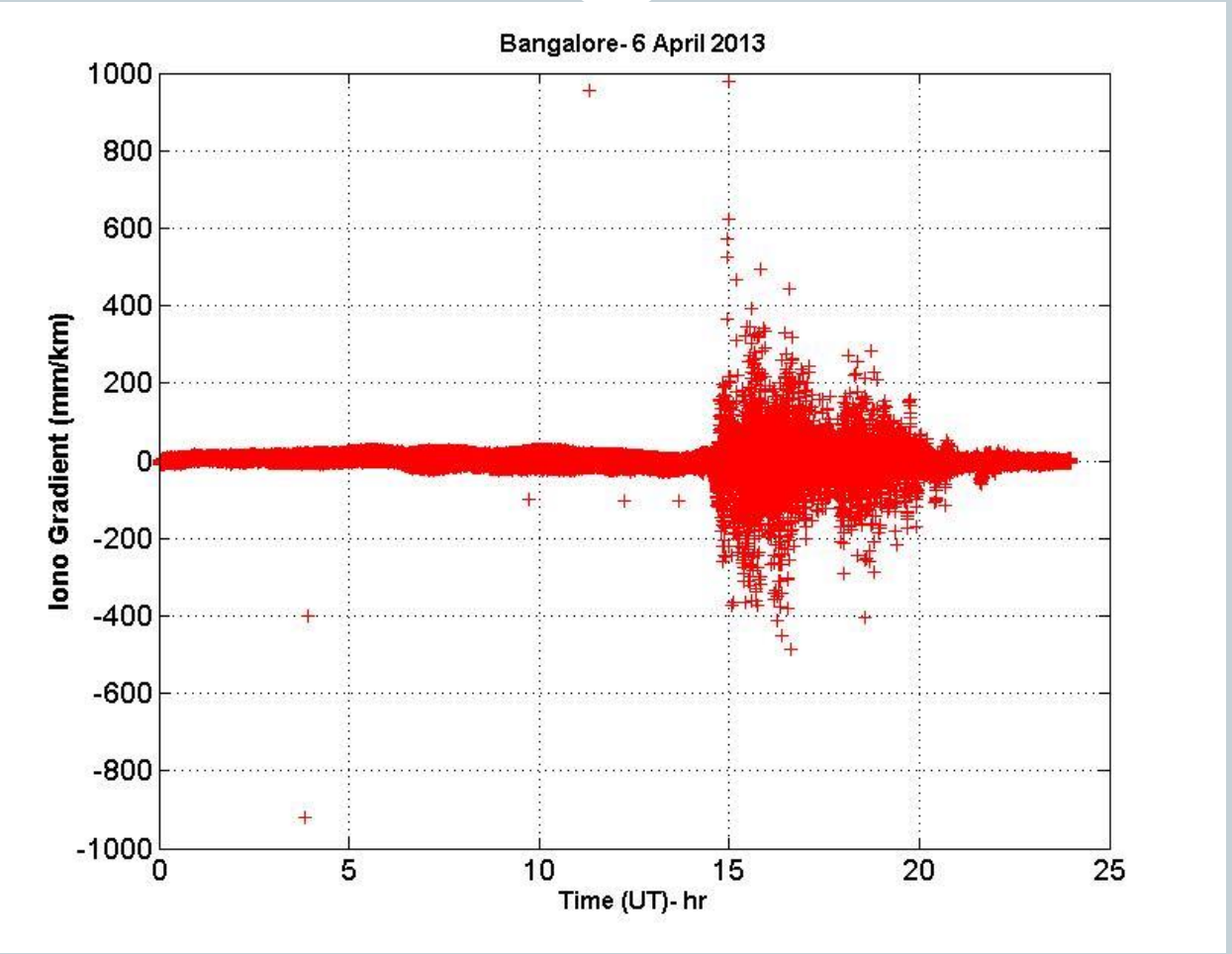
Ionospheric threat points – 2012 to 2013

- Results for 79 identified days at Bangalore from 2012-2013.
- Large number of points crossing the gradient of 400 mm/km.
- Low elevation gradients seems to be false gradients and needs to be verified manually.

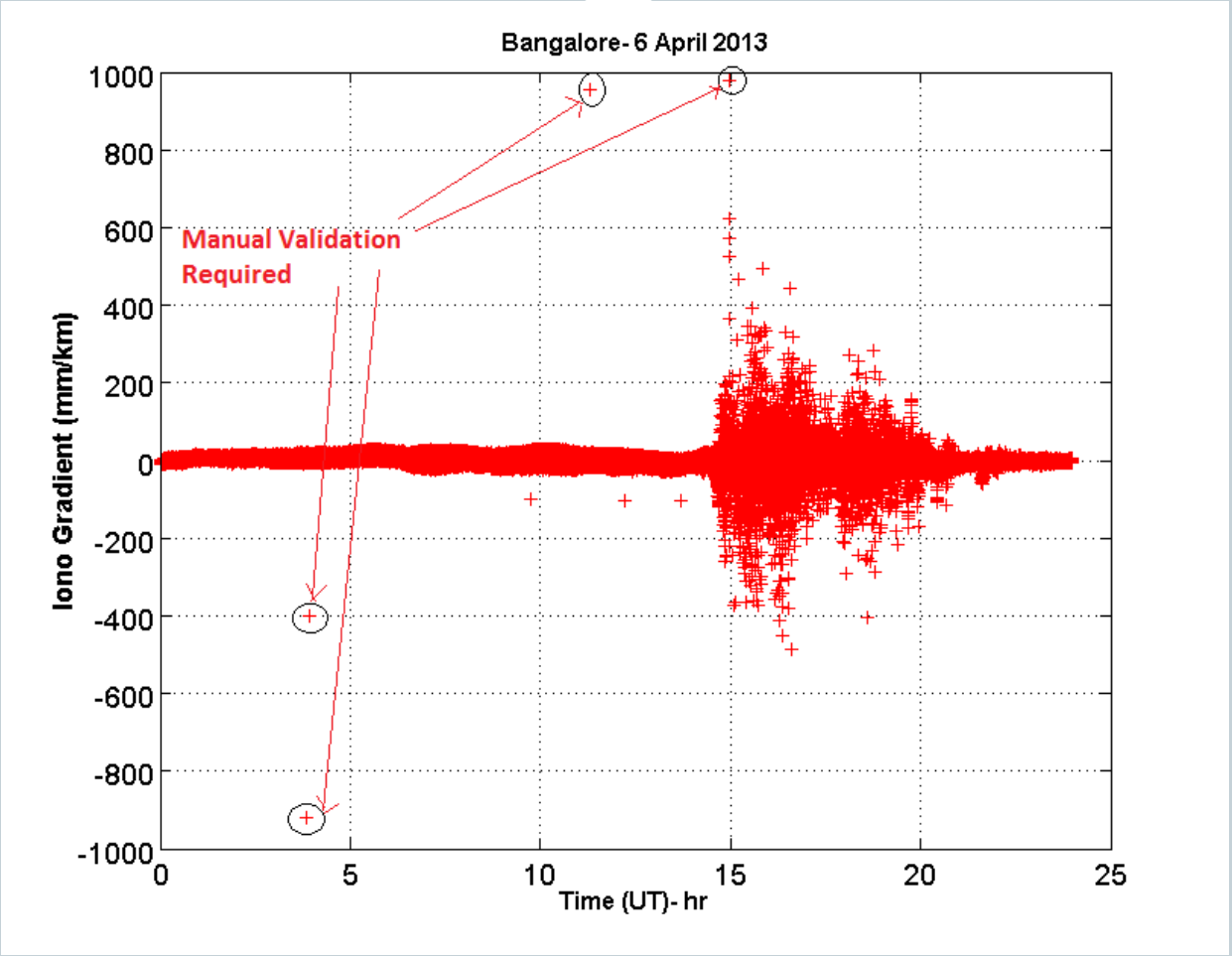
6 April 2013



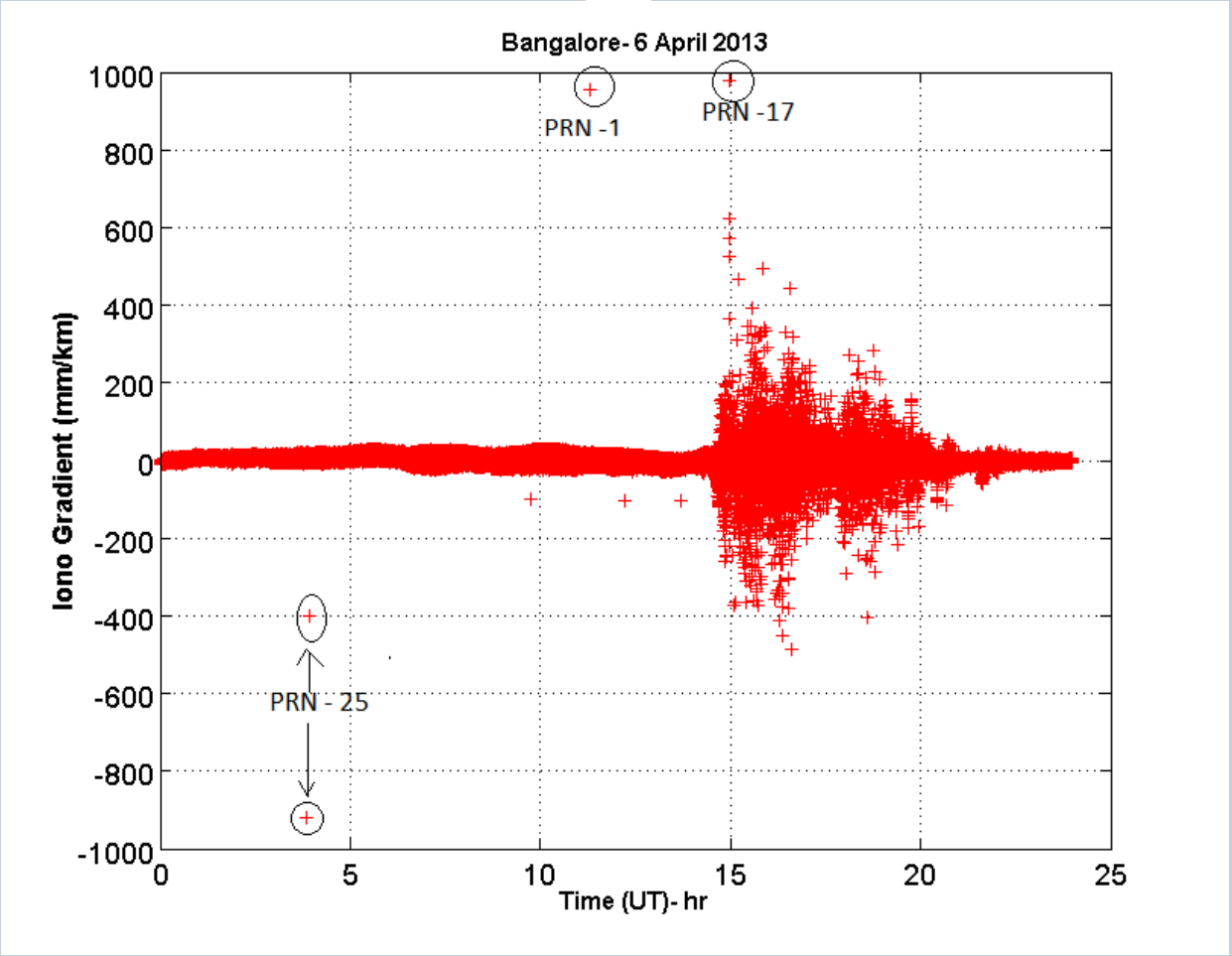
Gradient Verification- 6 April 2013



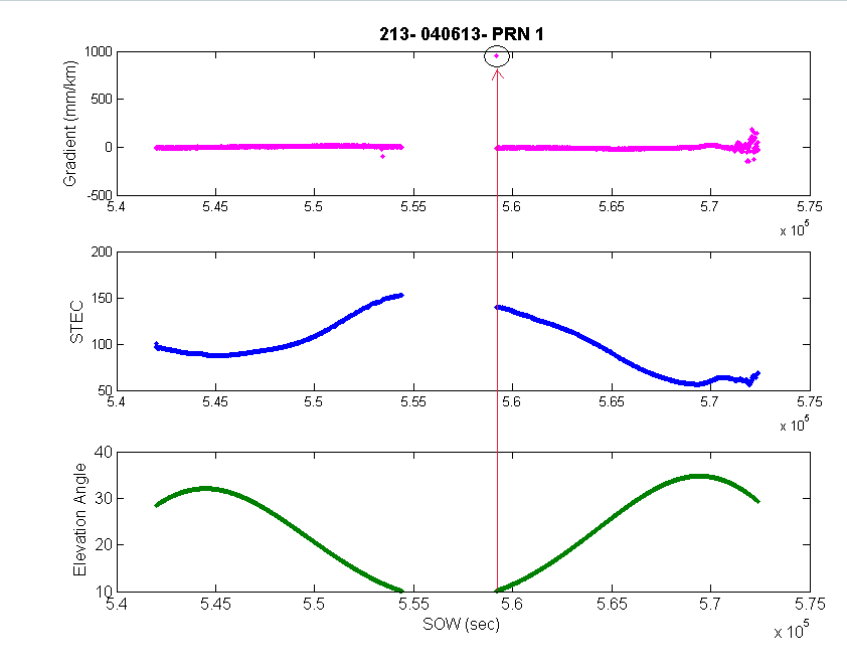
Gradient Verification- 6 April 2013



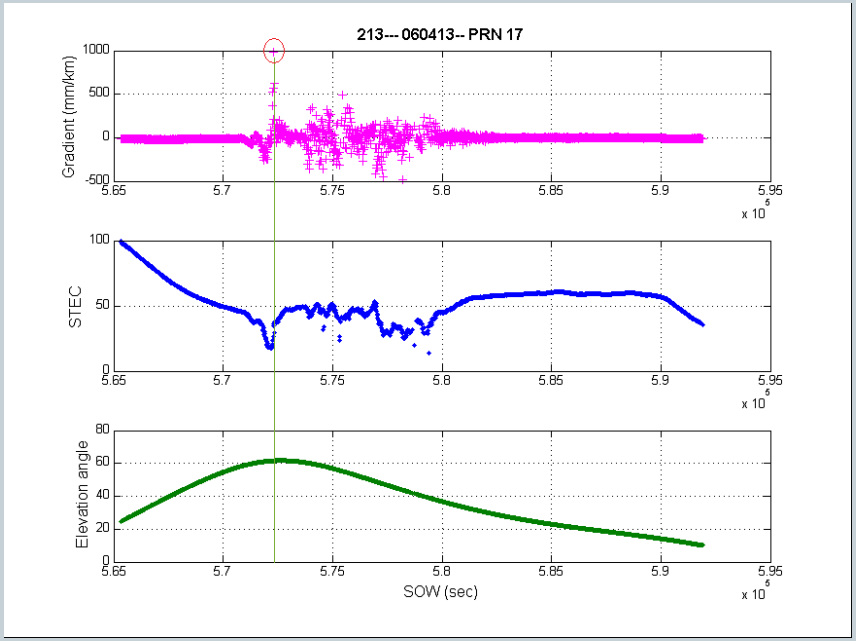
Gradient Verification- 6 April 2013



Gradient Verification- 6 April 2013



Iono gradient from PRN 1 is invalid



Iono gradient (955mm/km!)from PRN 17 seems to be valid point

Validation with Station-Pair method

- India has acquired the Long Term Ionospheric Anomaly Monitoring (LTIAM) tool from FAA through ISTF/ICAO.
- LTIAM utilizes Station-pair method to compute the Gradients.
- Trial run of LTIAM is completed successfully after some modifications.
- It can be used for further verification of identified threat points, if data from other sources is available.

Conclusion

- The MATLAB tool has been developed to derive the ionospheric gradients from ISMR data based on Time Step method.
- The daily gradients have been generated from almost all GAGAN-TEC stations.
- The plots of the gradients have been generated for days exceeding gradient threshold of 100mm/km.
- Total 138 days from 2004 to 2013 have been identified at Bangalore to be significant iono activity by manually screening the gradient plots.
- The dates are attached in Appendix A (59/79 days)
- The preliminary consolidated results indicate significant gradients exceeding 400mm/km.
- Further manual verification is required to validate the results, especially at low elevation angles.
- 'Station-Pair' method may also be used for verification, if data from other sources is available.