Signal outages during geomagnetic storms from the northern crest of the equatorial anomaly in the Indian longitude sector

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Introduction

- Degradation of performance of GNSS during geomagnetic storms is a topic which has been studied for almost two decades.

- The first storm reported to have affected GPS was the storm of 22 October 1999 [*Basu et al.,J. Geophys. Res.,* 2001b], when the Wide Area Augmentation System (WAAS) parameter Grid Ionospheric Vertical Error (GIVE) exceeded a value of 6m.

- During the superstorms of 29 and 30 October 2003, 20 November 2003 and 8 November 2004, the localizer performance with vertical guidance service level of WAAS were unavailable for the entire WAAS coverage region for varying periods of time, with full or partial coverage loss in excess of 10h [*Doherty et al.,GPS Solut.,* 2004; *Basu et al.,J. Geophys. Res.,* 2008].

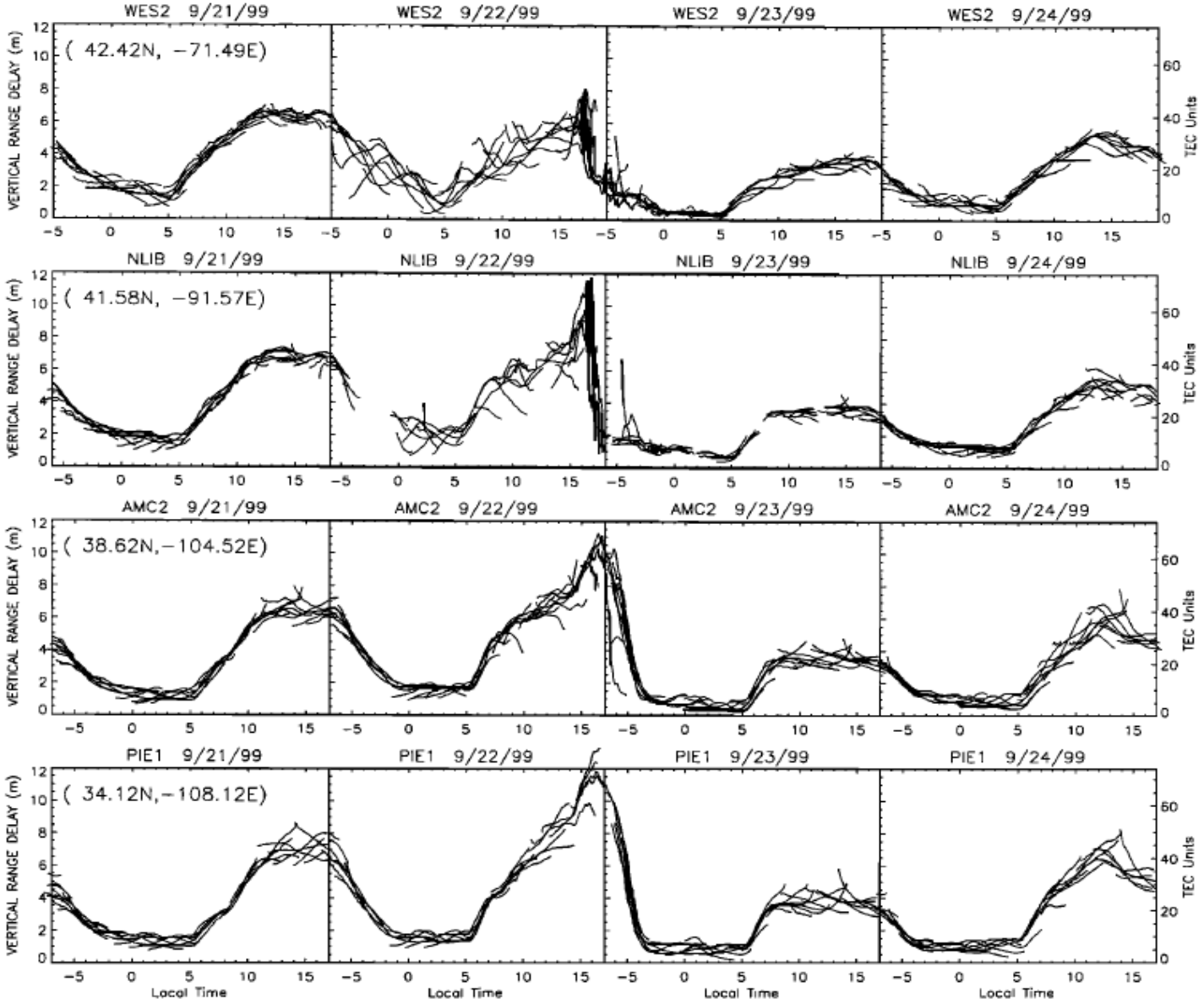


Figure 5. Range delays recorded at four stations in the International GPS Service for Geodynamics (IGS) network, namely, Westford, Massachusetts (WES2), North Liberty, Iowa (NLIB), Colorado Springs, Colorado (AMC2), and Pietown, New Mexico (PIE1), during September 21–24, 1999. Range delay can be related to TEC at 1.575 GHz by noting that a 6.15 TEC units change causes a 1-m range delay.

Basu et al., J. Geophys. Res., 2001

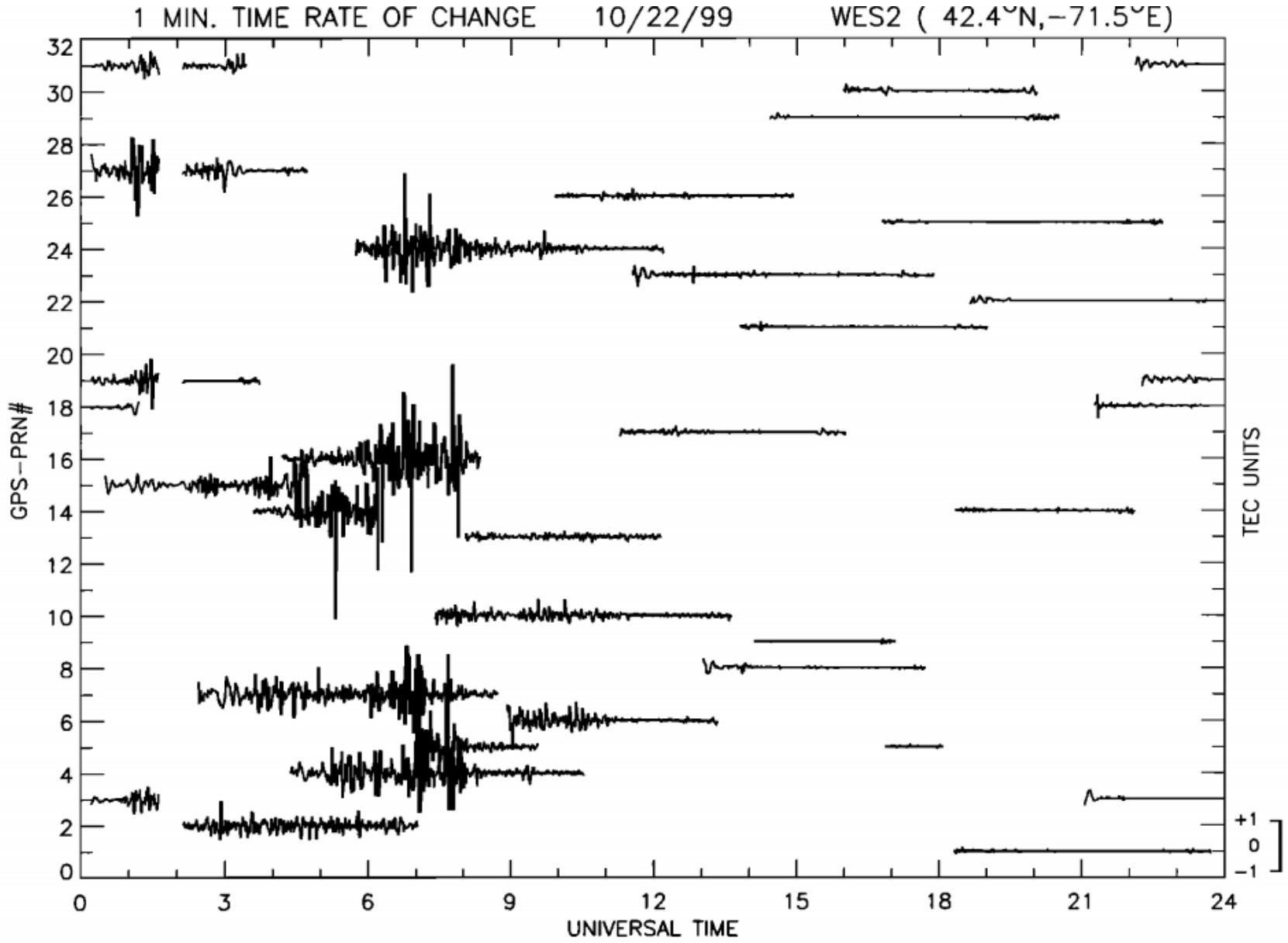
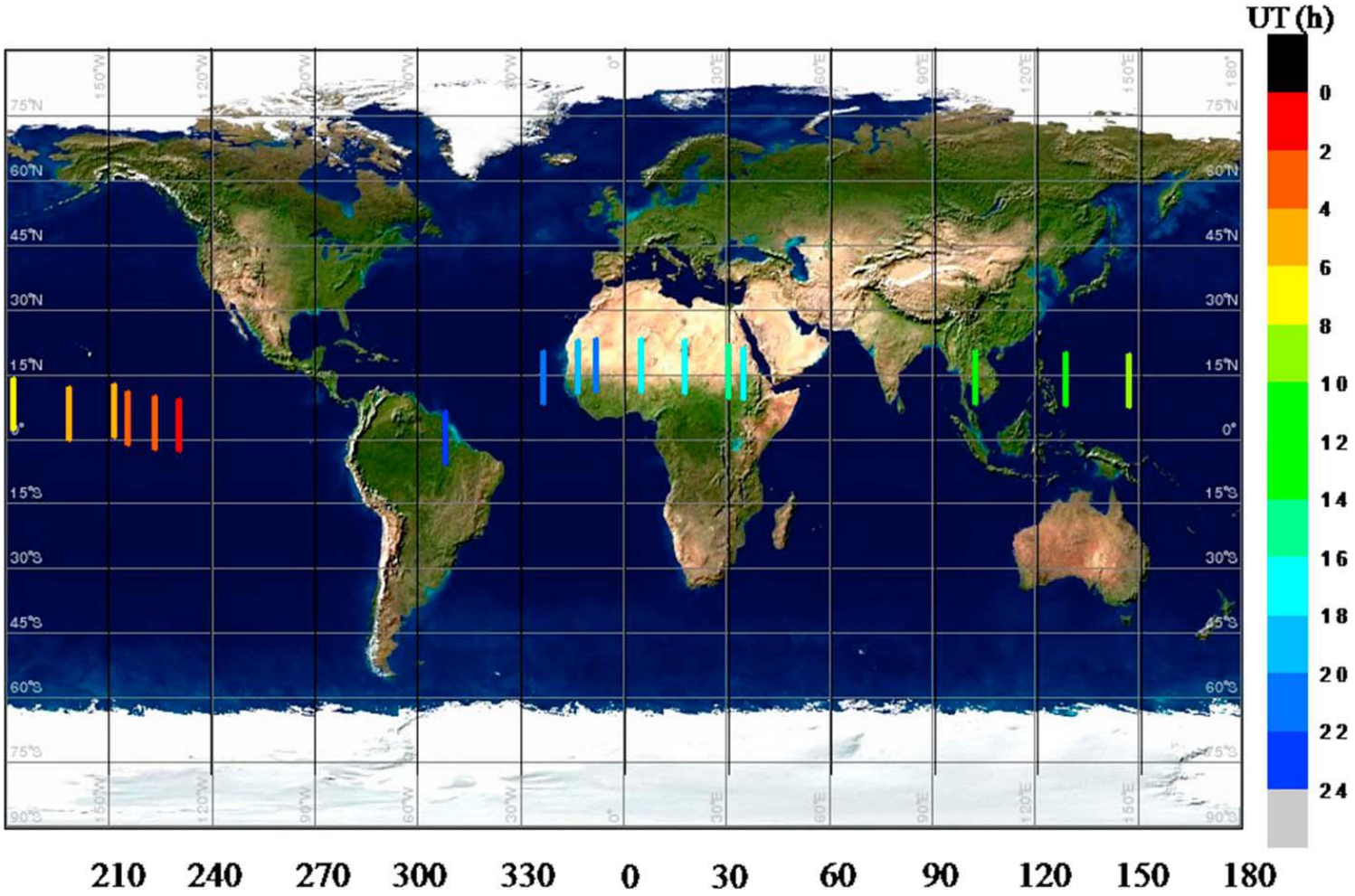


Figure 13. Same as in Figure 4 but for October 22, 1999.

Basu et al., J. Geophys. Res., 2001



World map showing the occurrence of ESF for 17 intense storms. The positions of the color bars indicate the longitude at which ESF occurred for the first time, and the colors of the bars indicate the UT interval during which the Southward IMF Bz crossed -10 nT. [Ray et al, Radio Sci, 2015]

Ray et al., Radio Sci., 2015

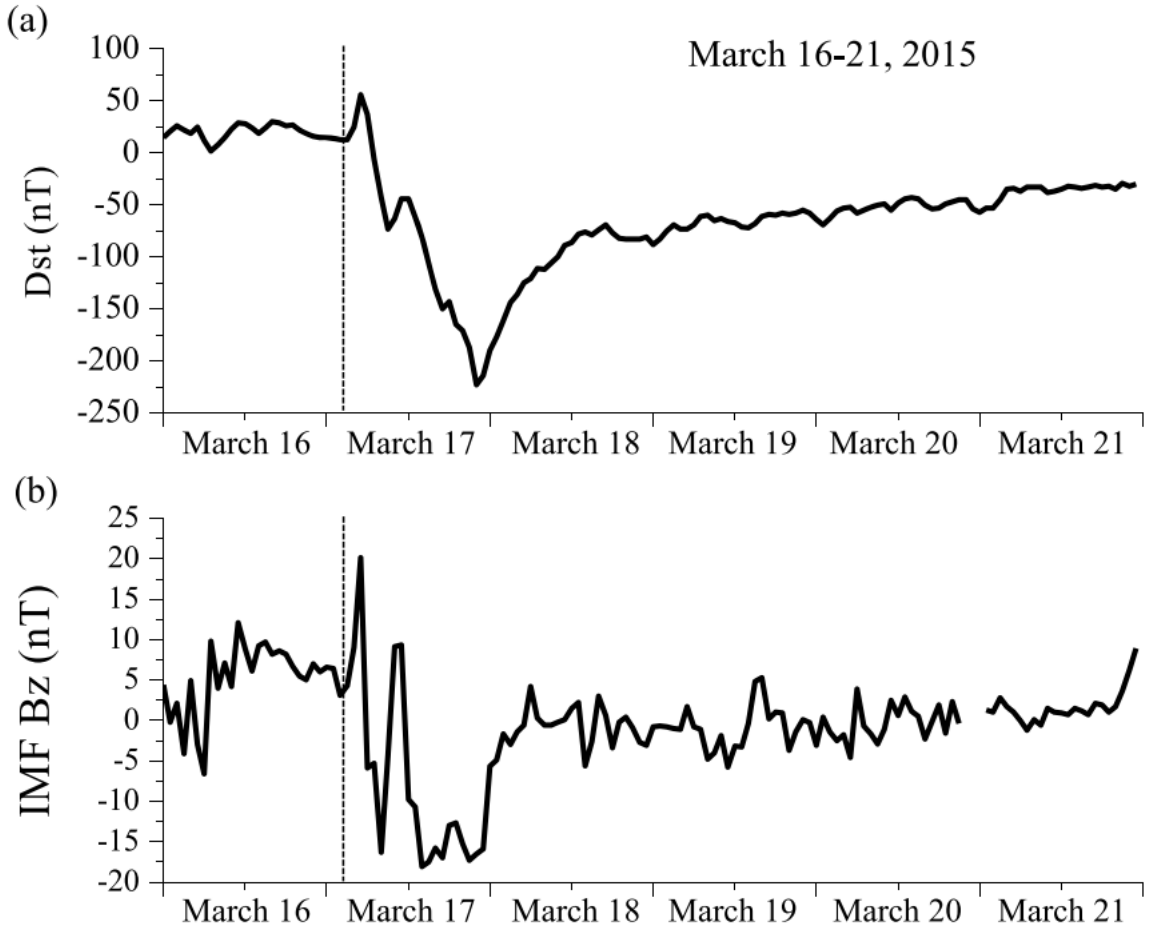


Figure 2. Variation of the (a) *Dst* index and (b) IMF B_z during 16–22 March 2015. The dotted lines show the time of storm commencement in each plot.

Ray et al., *JGR*, 2017

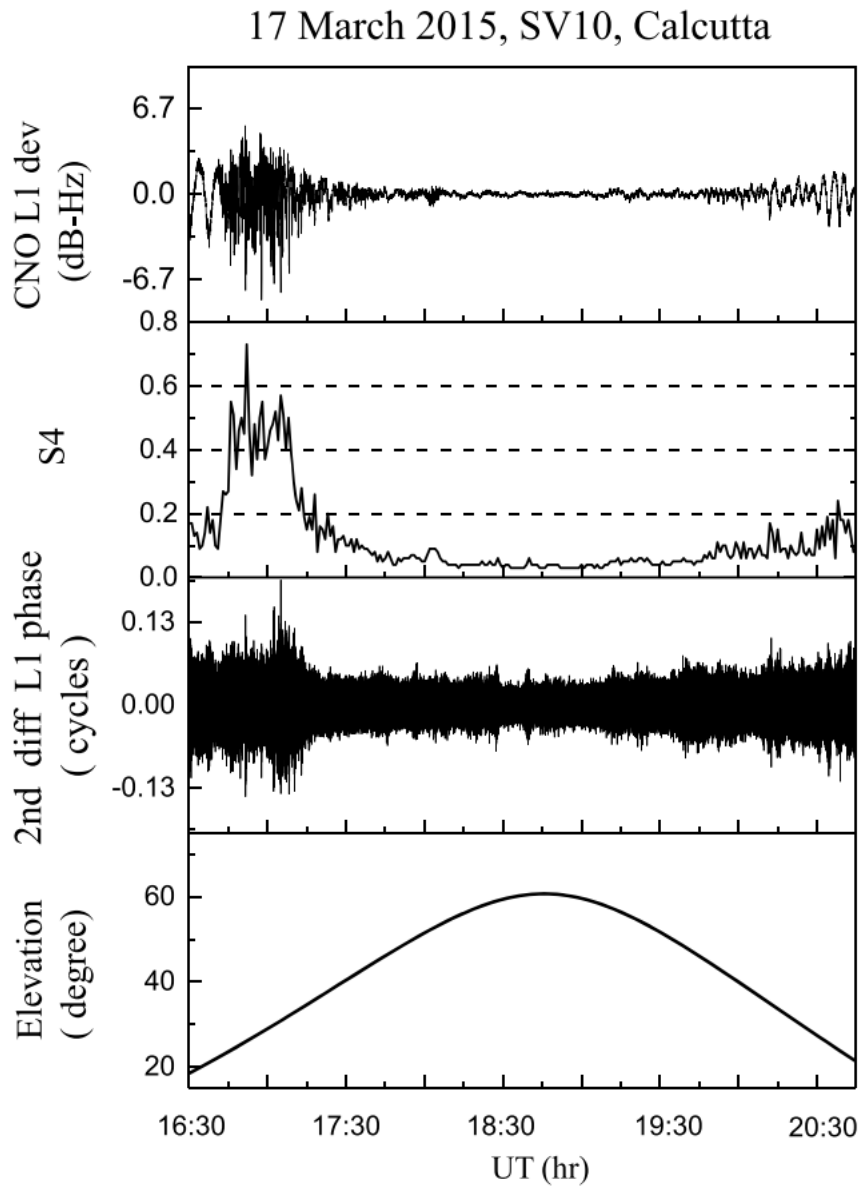


Figure 4. CNO deviations for scintillations observed from Calcutta on SV10, S4, second difference of phase, and satellite elevation angle variations during 16:30–20:45 UT of 17 March 2015.

Ray et al., *JGR*, 2017

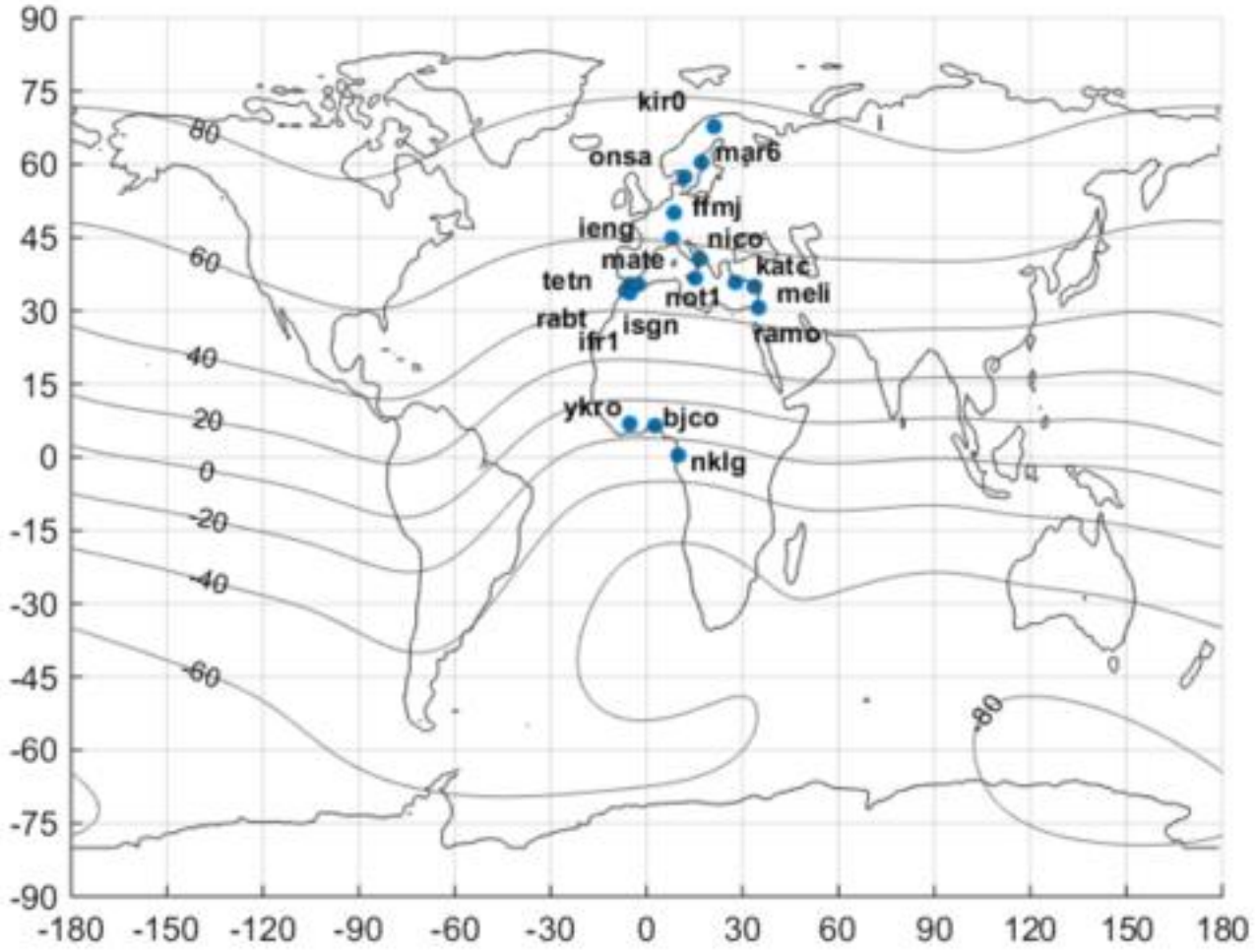


Fig. 1. Locations of the stations on a world map from which GNSS TEC have been used.

Paul et al., *Adv. Space Res.*, 2017

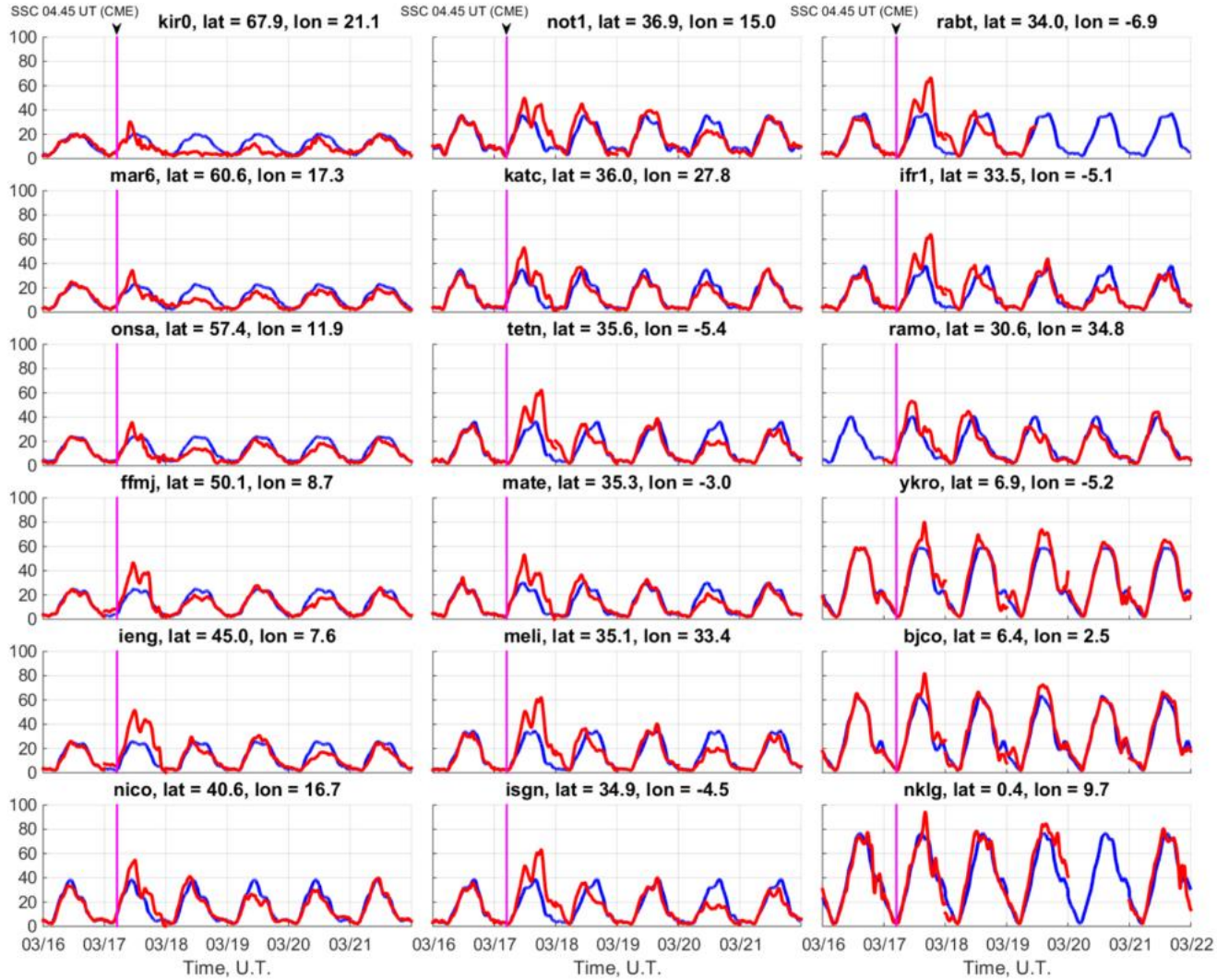


Fig. 3. Variation of the VTEC recorded at the 18 stations as a function of Universal Time (UT) for the period March 16–22, 2015. The 3 panels each represent six stations and the stations have been ordered by latitude. The blue line shows average VTEC values computed for 3 geomagnetic quiet days before the storm while the red curve indicates daily VTEC values. The time of storm sudden commencement (SSC) is indicated by the pink vertical line at 04:45 UT. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Paul et al., Adv. Space Res., 2017

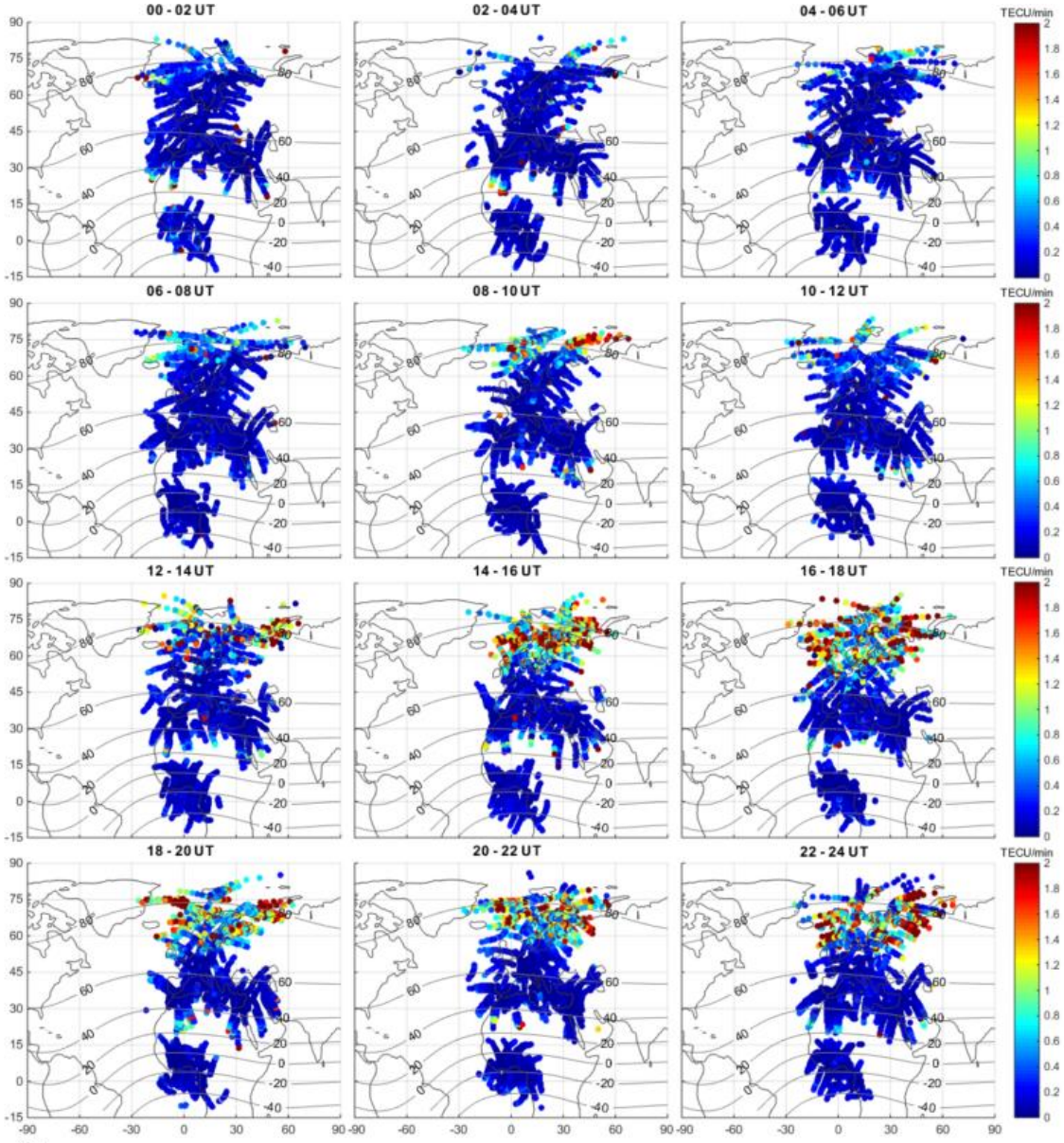


Fig. 4. ROTI values calculated for 2 h bins from 00:00 to 24:00 UT of March 17, 2015 on a world map. The colour points on the figures indicate ROTI values ranging from 0 to 2 TECU/min.

Paul et al., Adv. Space Res., 2017

While the earlier storms were intense or superstorms, the focus of the present work is to highlight the impact of less intense geomagnetic storms on transionospheric satellite links during 2012-2014 within the framework of the present phase of the SCINDA project at University of Calcutta.

Data

The storms under study occurred during

1. 29 September – 02 October, 2012
2. 07-11 October 2012
3. 14-17 July 2012
4. 15-19 February 2014

The maximum negative Dst for each storm is between -100nT to -150nT.

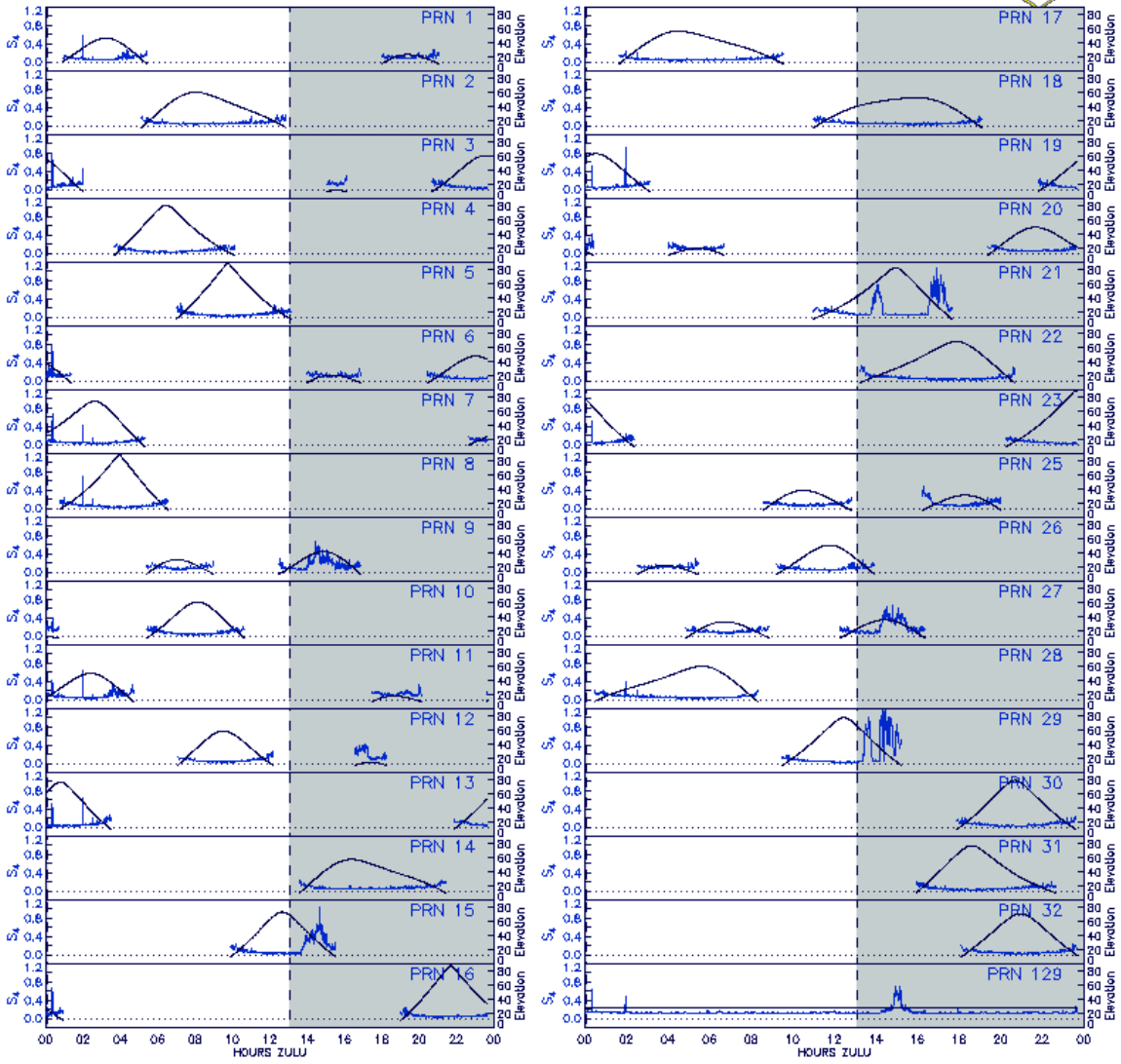
- 50Hz carrier phase data from a dual frequency GPS receiver located at Calcutta (22.58^{o}N, 88.38^{o}E, 32^{o}N magnetic dip) under the **SCIntillation Network Decision Aid (SCINDA)** program was analyzed.

- The data is available to authorized users at the URL **http://capricorn.bc.edu/scinda/users/india/kolkata/**

GPS S_4 & Elevation Angle – Calcutta
Evening of 02 Oct 2012 (Day 276)

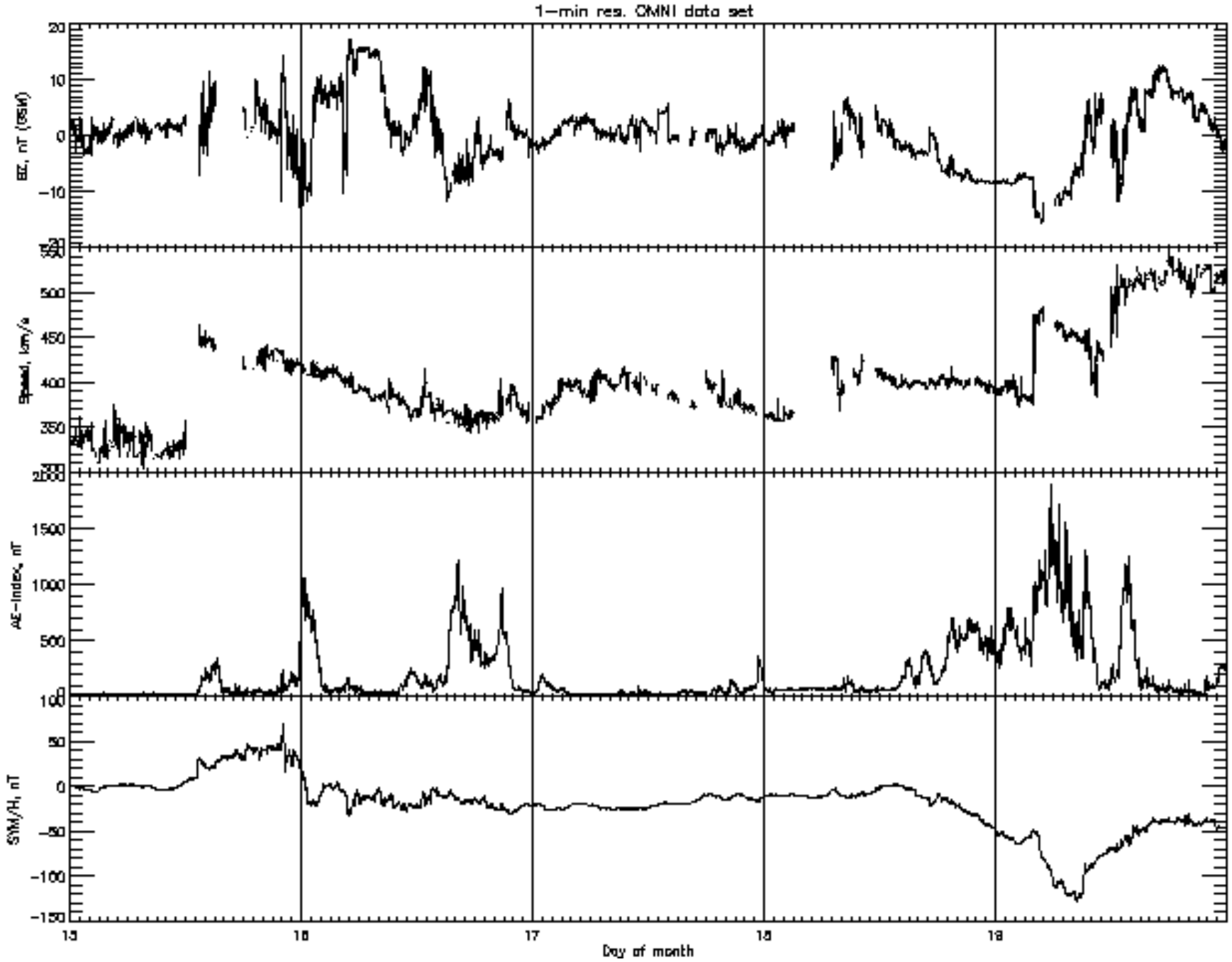
Last Updated: 02 Oct 23:45Z

300km Sunset over Calcutta : 13:03Z (18:57 Local) 300km Sunrise: 00:03Z (05:56 Local)



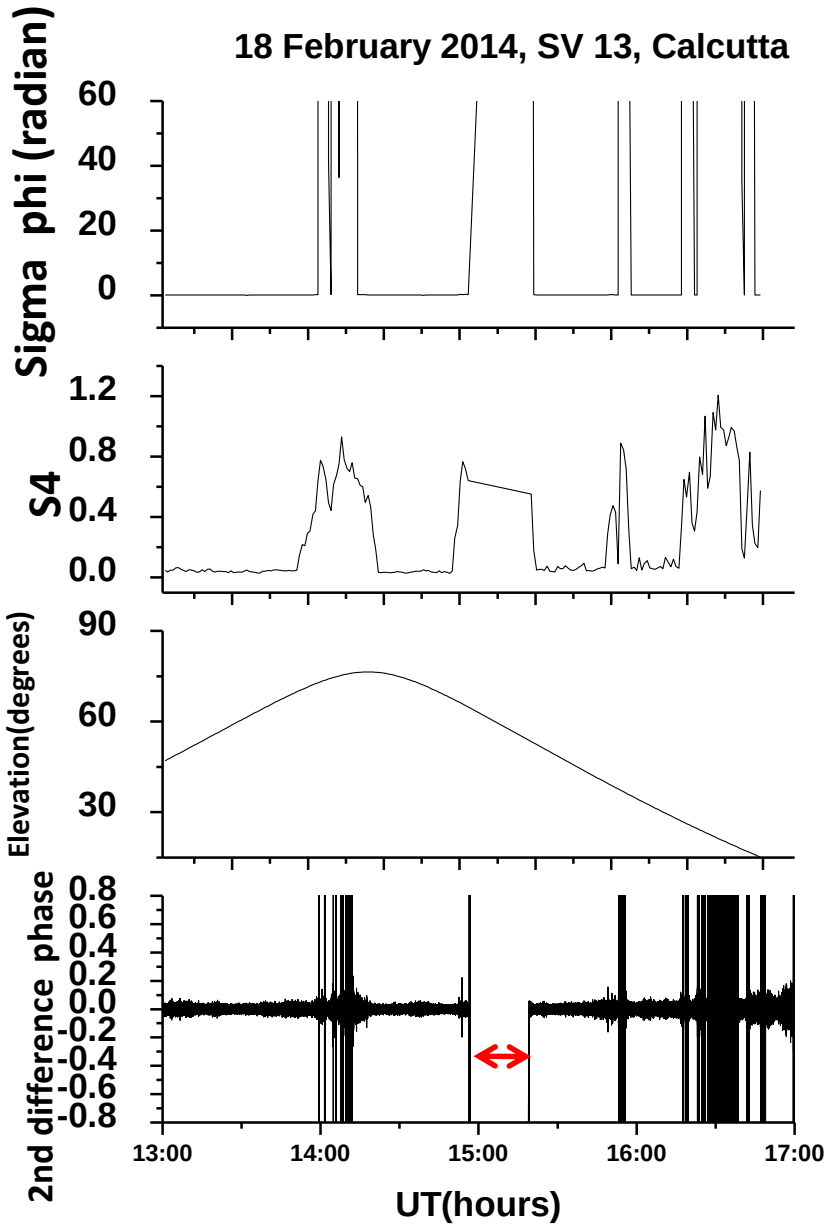
15-19 February 2014

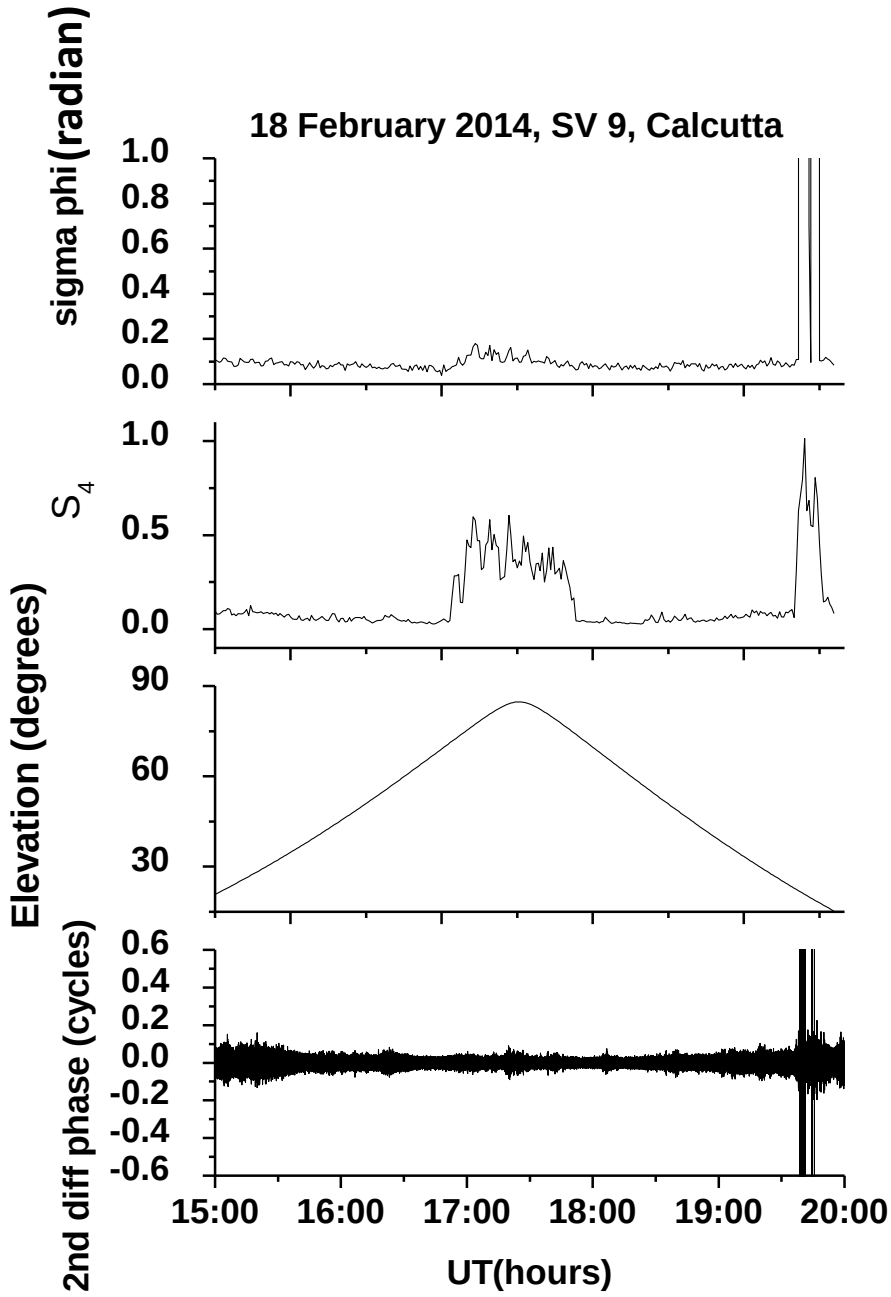
15-19 Feb 2014

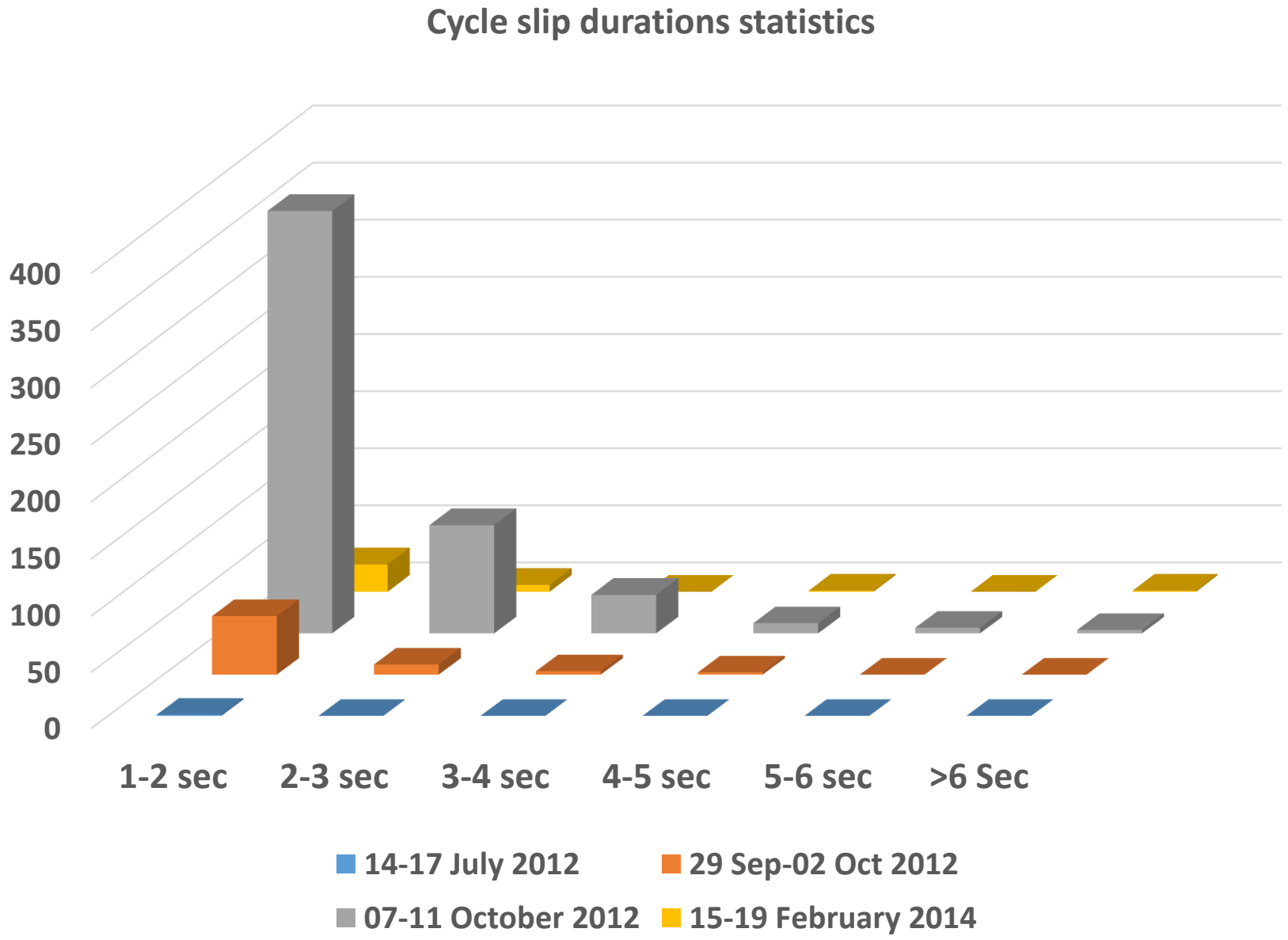


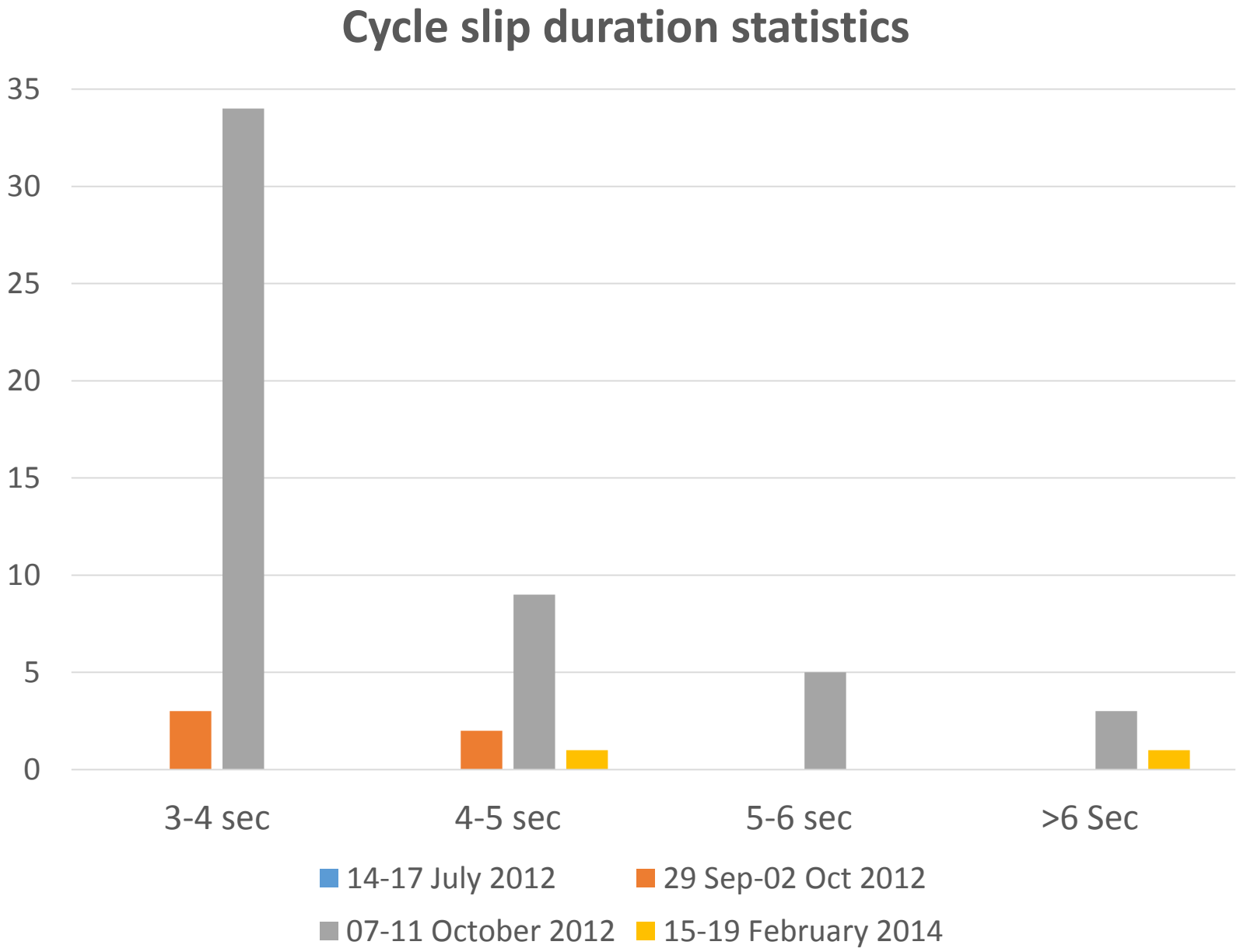
Source:- https://omniweb.gsfc.nasa.gov/form/dx2_adv.html

14:56:43.00 to **15:19:11.00 UT**
at GPS L1




18 February 2014, SV 9, Calcutta
sigma phi (radian)
1.0
0.8
0.6
0.4
0.2
0.0
S_4
1.0
0.5
0.0
Elevation (degrees)
90
60
30
2nd diff phase (cycles)
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
15:00
16:00
17:00
18:00
19:00
20:00
UT(hours)


Cycle slip durations statistics
400
350
300
250
200
150
100
50
0
1-2 sec
2-3 sec
3-4 sec
4-5 sec
5-6 sec
>6 Sec
14-17 July 2012
29 Sep-02 Oct 2012
07-11 October 2012
15-19 February 2014


Cycle slip duration statistics
35
30
25
20
15
10
5
0
3-4 sec
4-5 sec
5-6 sec
>6 Sec
14-17 July 2012
29 Sep-02 Oct 2012
07-11 October 2012
15-19 February 2014

ICAO specified level of compliance of GPS measurements for aeronautical Approach with Vertical Guidance (APV)

Signal-in-space performance requirements for APV approach operations [*ICAO, 2006]*

Requirements	**APV I**	**APV II**
Horizontal accuracy (95%)	16 m (52 ft)	16 m (52 ft)
Vertical accuracy (95%)	20 m (66 ft)	8 m (26 ft)
Integrity	1–2x10-7/app.	1–2x10-7633 /app.
Time-to-alert (TTA)	10 sec	6 sec
Continuity	1–8x10-6/15 sec	1–8x10-6 /15 sec
Availability	0.99–0.99999	0.99–0.99999
Horizontal alert limit (HAL)	40 m (130 ft)	40 m (130 ft)
Vertical alert limit (VAL)	50 m (164 ft)	20 m (66 ft)

Conclusions

- **50Hz phase data from the SCINDA receiver at Calcutta, located near the northern crest of the equatorial anomaly in the Indian longitude sector, have been analyzed during 4 geomagnetic storms with maximum negative Dst is between -100nT to -150nT occurring during sunspot number maximum years 2012-2014.**

- **It has been observed that during the storm of February 15-19, 2014, a cycle slip of duration 22m 28s was observed by the satellite SV 13, during the local early evening hours (14-15UT, 20-21LT) of February 18th . Corresponding to this event, patches of saturated amplitude (max S4 ~ 1) and phase scintillation (max $\sigma\phi$ > 1) have been observed.**

- **This event corresponded in time to the beginning of main phase of the storm subsequent to the southward turning of IMF Bz at 1326 UT on February 18. For Calcutta, 13-15UT corresponds to the dusk sector. The prompt penetration electric field (PPEF) strengthens at this hour, enhances the vertical EXB drift at low latitudes, causing upward rise of F-layer and formation of plasma bubbles which result in scintillations in amplitude and phase.**

- **For Approach with Vertical Guidance II (APV II) the ICAO requirement for Time –to-Alert (TTA) is 6s. During the four storms analyzed, two storms showed loss of lock for durations greater than 6s on three occasions. The occurrence of loss of lock for 22m on February 18 is rather alarming as far as GNSS users are concerned.**

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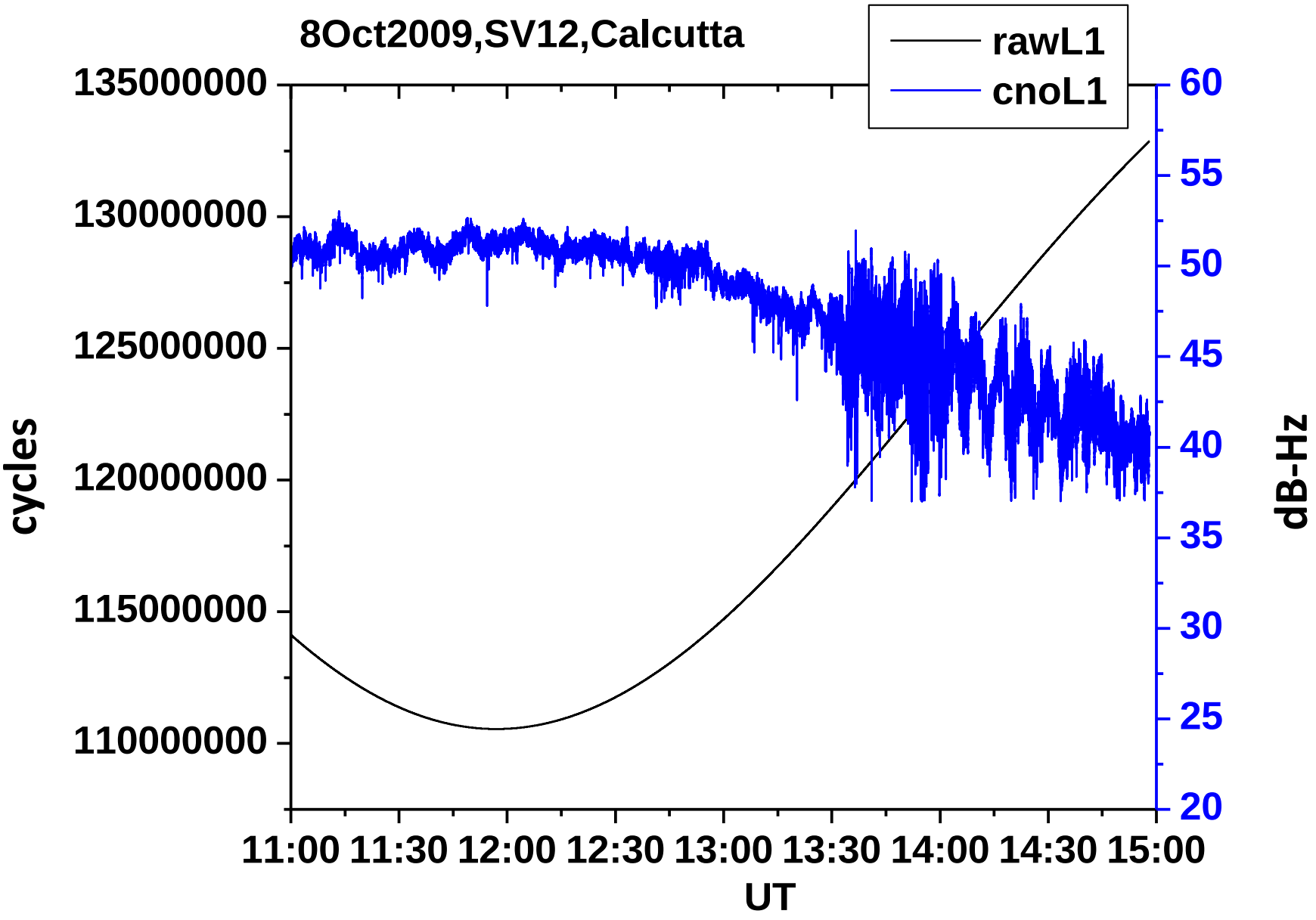
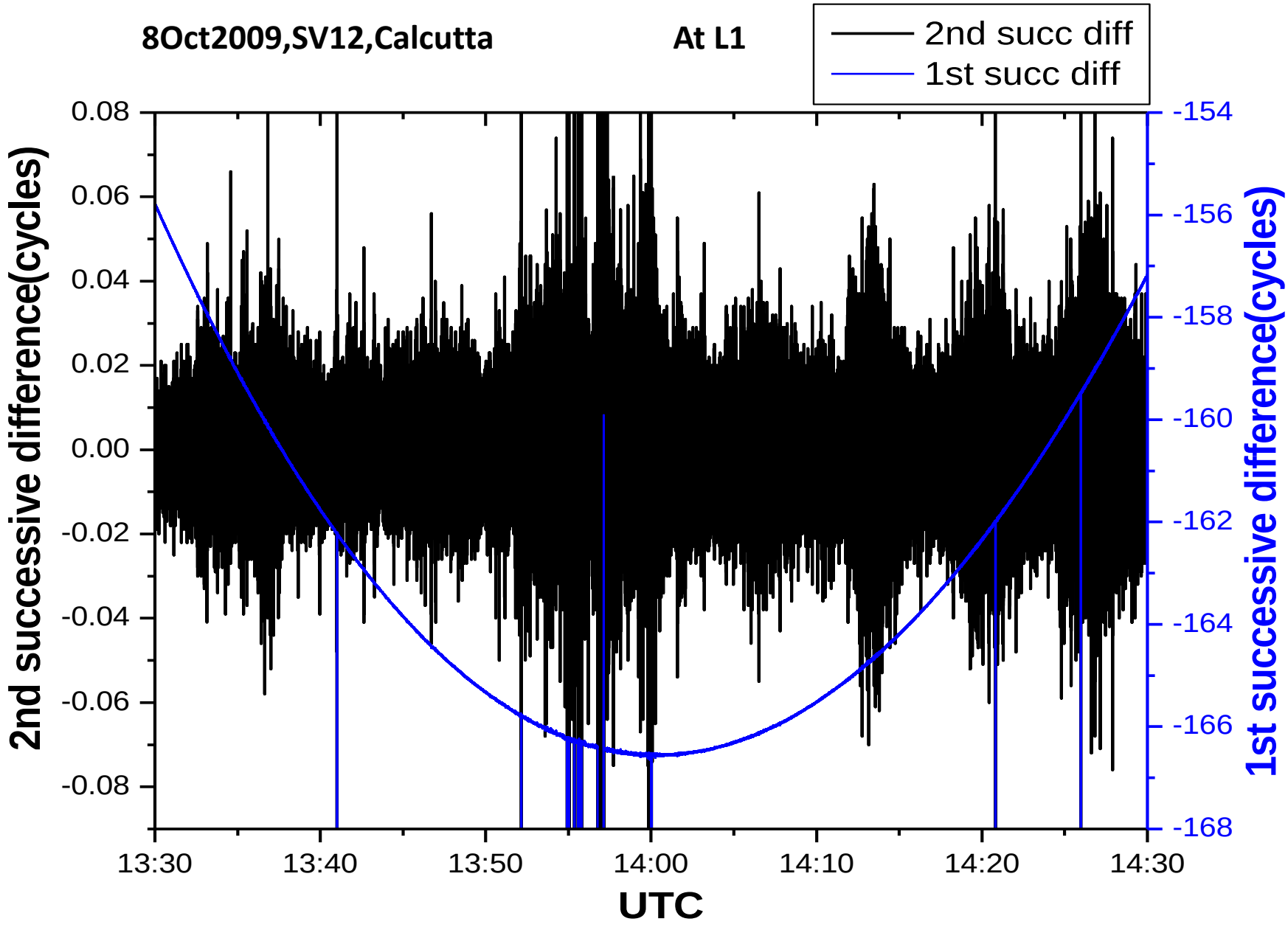
The Co-Authors.

THANK YOU


8Oct2009,SV12,Calcutta
rawL1
cnoL1
135000000
130000000
125000000
120000000
115000000
110000000
cycles
60
55
50
45
40
35
30
25
20
dB-Hz
11:00
11:30
12:00
12:30
13:00
13:30
14:00
14:30
15:00
UT


8Oct2009,SV12,Calcutta
At L1
2nd succ diff
1st succ diff
2nd successive difference(cycles)
1st successive difference(cycles)
UTC
0.08
0.06
0.04
0.02
0.00
-0.02
-0.04
-0.06
-0.08
-154
-156
-158
-160
-162
-164
-166
-168
13:30
13:40
13:50
14:00
14:10
14:20
14:30