

Report for the period November 2010-October 2012

Operation of SCINDA Receiver at the University of Calcutta and analysis of data for Space Weather Studies

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The SCINDA receiver has been operational at the Institute of Radio Physics and Electronics, University of Calcutta, Calcutta, India since November 2006. A grant of US\$4945.00 was received in November 2010. A dedicated broadband internet connection is operational from the government-run Bharat Sanchar Nigam Limited (BSNL) since October 2008. An on-line UPS is being used to prevent data loss due to disruption of power.

Data from the SCINDA receiver is available to the Satellite Beacon Group of this Institute in the post-processed form. It had earlier been utilized for studying some Space Weather events which occurred during July 2009 and June 2010. It is important to note that this period coincides with the longest recorded benign solar activity epoch. However some cases of large bite-outs in Total Electron Content (TEC) and associated fluctuations in carrier-to-noise ratios of GPS links from Calcutta (22.58°N, 88.38°E geographic; magnetic dip: 32°N) were recorded on October 8, 2009 and March 13, 2010 which had been reported in *Paul et al. [J. Geophys. Res., 2011]* and the case of September 25, 2008 in *Das et al. [Ind. J. Radio Space Phys., 2012]*.

Equatorial ionospheric phenomena like i) the Equatorial Ionization Anomaly (EIA) covering a major part of the day and extending till around 21:00LT and ii) equatorial ionospheric irregularities generated primarily over the magnetic equator in the post-sunset hours introduce significant perturbations on transionospheric satellite communication and

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14. ABSTRACT The SCINDA receiver has been operational at the Institute of Radio Physics and Electronics, University of Calcutta, Calcutta, India since November 2006. Data from the SCINDA receiver is available to the Satellite Beacon Group of this Institute in the post-processed form. It had earlier been utilized for studying some Space Weather events which occurred during July 2009 and June 2010. It is important to note that this period coincides with the longest recorded benign solar activity epoch. However some cases of large bite-outs in Total Electron Content (TEC) and associated fluctuations in carrier-to-noise ratios of GPS links from Calcutta (22.58°N, 88.38°E geographic; magnetic dip: 32°N) were recorded on October 8, 2009 and March 13, 2010 which had been reported in Paul et al. [J. Geophys. Res., 2011] and the case of September 25, 2008 in Das et al. [Ind. J. Radio Space Phys., 2012].			
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navigation links. Characterization of the daytime gradients of EIA, identification of suitable precursors to onset of Equatorial Spread F (ESF) along with the capability of mapping the irregularities from their inception over the magnetic equator to their subsequent movement towards the northern crest of the EIA and beyond require spatially distributed multi-technique tracking capabilities at a high resolution. The present report utilizes i) ionization density distribution using C/NOFS data available from <http://cindispace.utdallas.edu> ii) IGS data recorded at Bangalore and Hyderabad available from the SOPAC website <http://sopac.ucsd.edu> iii) RTI maps from the MST radar operational at Tirupati iv) geostationary VHF amplitude scintillation using geostationary satellite beacon from FLEETSATCOM (FSC - 250MHz, 73E) from Calcutta v) SCINDA data from Calcutta and vi) GPS data from a meridional chain of stations located at Calcutta, Baharampore and Siliguri operated during September 2011. These results were presented at COSPAR-2012 held at Mysore, India.

Figure 1 shows the locations of the stations and zones of coverage from each station on a map of India. Figure 2 shows the locations of the three stations involved in the meridional campaign against the backdrop of a schematic plot of EIA and magnetic field lines. Significant increase of scintillation activity have been noted on geostationary FLEETSATCOM (250MHz) and MTSAT (1.6GHz), and GPS during the equinoxes of February-April (38 nights of L-band scintillations with $S_{4max} \geq 0.6$) and August-October 2011 (22 nights of L-band scintillations with $S_{4max} \geq 0.6$) in comparison to the unusually low solar activity period 2008-2010. The three GPS stations were operated more-or-less along the 88°E meridian at Calcutta (IRPE, CU) (22.58N 88.38°E geographic; magnetic dip: 32N), Baharampore (K.N. College) (24.09N 88.25°E geographic; magnetic dip: 34.73N) and Siliguri (North Bengal University) (26.72N 88.39°E geographic; magnetic dip: 39.49N) during September 2011 on a campaign mode. This configuration of stations provided the ability to track equatorial ionospheric irregularities over the subionospheric swath of $14^\circ\text{-}34^\circ\text{N}$ extending from the magnetic equator through the northern crest of the EIA to locations beyond the northern crest. This report presents some representative cases of events.

Figure 3 shows the ionization density distribution over the magnetic equator for April 6, 2011 using the C/NOFS data. Presence of irregularities are noted over the geographic latitude

range 5.1° - 11° N and geographic longitude range 73.7° - 103.1° E during 16:09-16:17UT. Figure 4 shows the TEC and S_4 plot for April 6, 2011 using data from two IGS stations at Bangalore and Hyderabad. Pronounced secondary enhancements in TEC are noted from both the stations during 14:00-18:00UT associated with nearly saturated scintillations ($S_{4\max} \sim 1$) from Bangalore. Figure 5 shows the RTI map available from the MST radar for the event on April 6, 2011. Three distinct plumes may be observed starting from around 19:26LST and continuing till about 01:38LST with maximum heights of 500km. Figure 6 shows the variation of S_4 on different GPS satellite vehicles and geostationary MTSAT (SV129, L1) as a function of local time (Zulu time) observed from Calcutta on April 6, 2011. On this night, SV4, 11, 13, 17, 23, 24 and 129 (MTSAT) exhibited intense ($S_4 \geq 0.6$) to saturated scintillations during 14:00-16:00LT. As saturated scintillations were observed on FSC (350-km subionospheric point: 21.10° N, 87.25° E geographic) during 14:05-14:35UT and MTSAT (350-km subionospheric point: 21.03° N, 93.87° E geographic) during 14:31-17:21UT as shown in Figure 7, a longitudinal distribution of irregularities may be understood. Figure 8 shows the TEC bite-out observed on SV23 link from Calcutta during 13:54-14:21UT. The amplitude of the bite-out was nearly 20 TEC units resulting in 3.2m range error at GPS L1. The SCINDA S_4 data at Calcutta were combined with data from Baharampore and Siliguri at elevation greater than 15° to map the spatial distribution of the impact zone of the equatorial irregularities for the night of April 6, 2011 over the period 14:00-18:00UT which is shown in Figure 9. It is noted that the intensity of scintillations maximize during 15:00-16:00UT with the northern extent of the affected region stretching to 23° N.

The GPS meridional campaign in September 2011 involved the three stations located at Calcutta, Baharampore and Siliguri, situated more-or-less along the 88° E meridian. TEC measured at Calcutta, Baharampore and Siliguri above an elevation of 50° were combined to generate the map over the subionospheric latitude range 20° - 28° N and subionospheric longitude swath 86° - 90° E. Figure 10 which shows the TEC map at 10:00UT for September 23, 2011 indicates the poleward gradient of TEC to be sharper (11 TECU/deg) than the equatorward gradient (3 TECU/deg). Poleward gradients calculated on different days of the period August 31-September 29, 2011 were combined to understand the correlation with occurrence of post-sunset scintillations on GPS links near the crest of the EIA. Figure 11 shows the result of the

correlation where it is found that occurrence of scintillations at Calcutta with $S_4 \geq 0.4$ on GPS links is strongly associated with poleward TEC gradients in excess of 8TECU/deg. On this date, a number of GPS links, namely SV9, 15, 18, 21 and 29 were affected as observed on SCINDA from Calcutta during 14:00-18:00UT. The northern extent of the equatorial irregularity belt on this day was found to be nearly 28°N.

Transionospheric satellite communication and navigation links operating primarily at L-band are frequently subjects to severe degradation of performances arising out of ionospheric irregularities which usually drift from west-to-east in the post-sunset hours. Proxies to L-band scintillations may be identified using the much simpler and inexpensive VHF measurements across spaced aeriels. Various characteristic features of equatorial ionospheric irregularity bubbles, namely, the drift and characteristic velocity may be correlated with L-band scintillation indices for identifying a possible tool for forecasting L-band scintillations.

VHF spaced receiver data have been recorded at Calcutta using the geostationary FLEETSATCOM (FSC, 250 MHz, 73°E; 350 km subionospheric point: 22.12°N lat., 87.25°E long.) since August 2010. After the unusually prolonged bottom of the solar cycle spanning 2006-2010, scintillation activity dramatically picked up during the equinoxes of 2011. While the autumnal equinox of 2010 witnessed only a few cases of intense VHF scintillations, 47 cases of intense ($S_4 > 0.6$) were recorded at VHF during the vernal equinox of 2011 and 38 cases of intense ($S_4 > 0.6$) L band scintillations. The present report shows the results of correlation between VHF spaced areal measurements and L-band scintillation indices for February-March, 2011 (mean sunspot number varies between 29.6 to 55.8). Figure 12 shows fluctuations in the VHF carrier amplitudes recorded using the east antenna during the post-sunset hours of March 28, 2011. Figure 13 shows the corresponding calculated 1-minute S_4 index at VHF. Nearly saturated scintillations were observed during the periods 14:45-15:00 UT, 15:15-15:50 UT and finally from 16:50-17:45 UT. In the local post-midnight period, the intensity of scintillations was reduced significantly. The corresponding drift and characteristic velocities were calculated using the method of Full Correlation Analysis. A number of GPS links were affected on March 28, 2011 including SV 11, 13, 17, 23 and 24. As majority of communication and navigation links operate at L-band, forecasting the intensities of L-band scintillations using VHF as a proxy would

be extremely helpful from the system perspective. Accordingly GPS satellites with 350-km subionospheric points lying within latitude swath of 20.12° - 22.12° and longitude 86.25° - 88.25° were selected around that of FSC. Figure 14 shows the VHF drift velocity and S_4 of GPS SV 13 link as a function of UT on March 28, 2011. The red colour denotes the S_4 at L-band and the blue one is the drift velocity at VHF link. When the maximum S_4 of nearly 1.5 was observed at SV13 link at 17:32 UT, the satellite was not in the selected latitude and longitude swath as mentioned earlier. Figure 15 shows the correlation between drift velocity at VHF and S_4 at L-band of the month of February-March, 2011. From the graph it is clear that S_4 in L-band also increased with the increasing drift velocity at VHF. Figure 16 shows variation of decorrelation time at VHF with S_4 at L-band for the same months. The decorrelation times were calculated from VHF amplitude scintillations across spaced aerials.

The severity of these events in terms of depletions in TEC resulting in range errors during low solar activity periods and magnetically quiet conditions raises serious questions on their impact during the ensuing solar maximum period at equatorial latitudes. It is strongly felt that the SCINDA observations at Calcutta should be continued during the present solar cycle for characterization of these case studies for potential use in prevention of severe outages of satellite-based transionospheric communication and navigation links.

The expenditure incurred so far during the period ending October 2012 has been INR 200374.00 with a balance of INR 15883.00. In order to sustain the continuous recording and uploading of the SCINDA data, rental for the broadband internet connection has to be continued, storage media for archiving the data and batteries for the online UPS procured and other contingent expenses met.

Expenditure incurred during the period November 2010-October 2012 for the project 'SCINDA'

Amount Received in November 2010: US\$4945.00 = Rs.2, 16,257.00

Expenditure till October 2012: Rs.2,00,374.00

Balance Amount: Rs. 2,16,257-2,00,374.00=Rs.15, 883.00

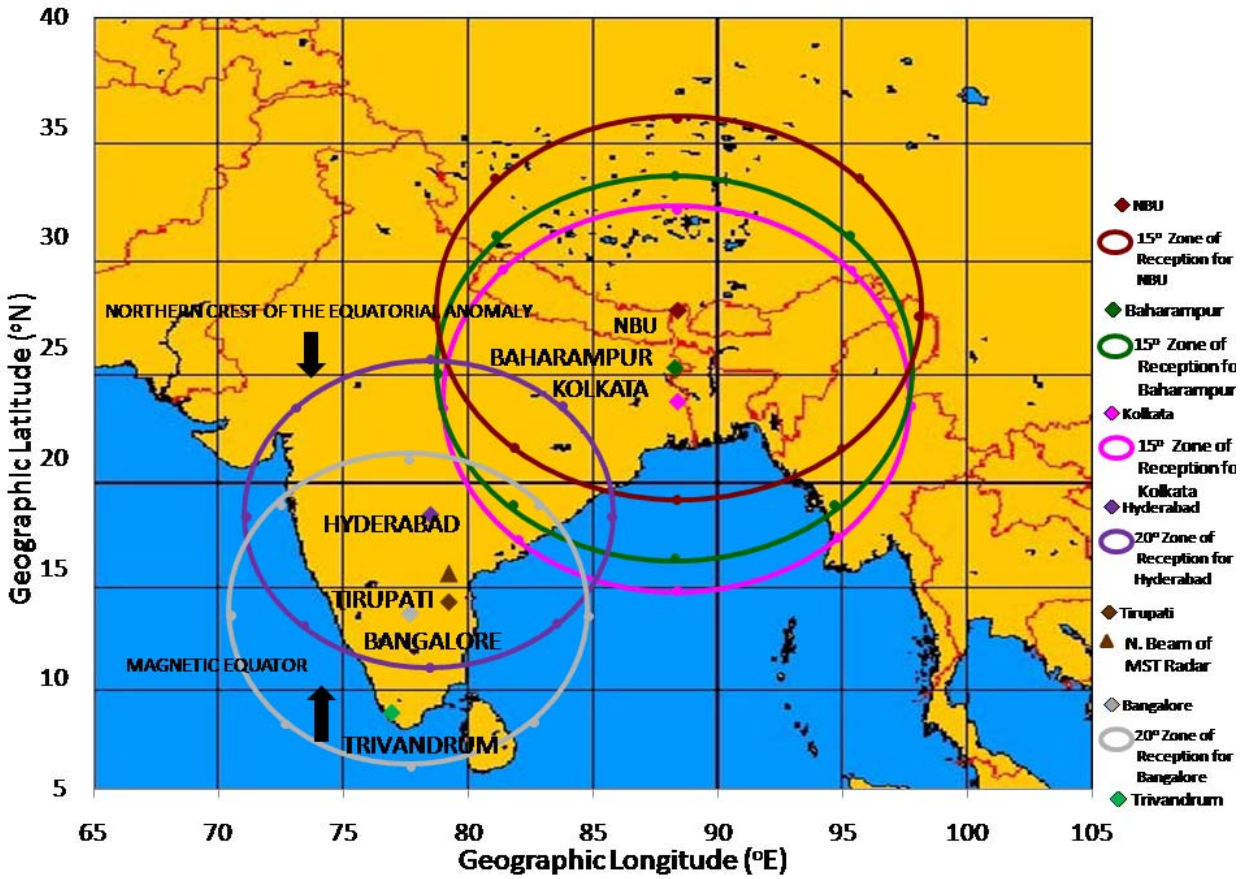


Figure 1

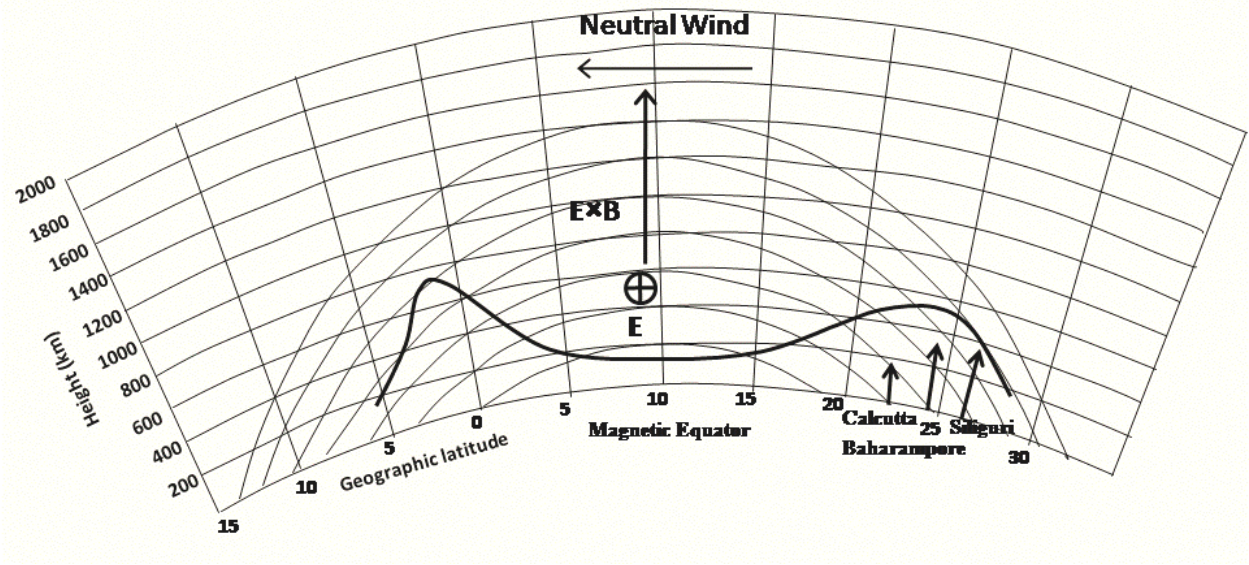


Figure 2

April 6, 2011

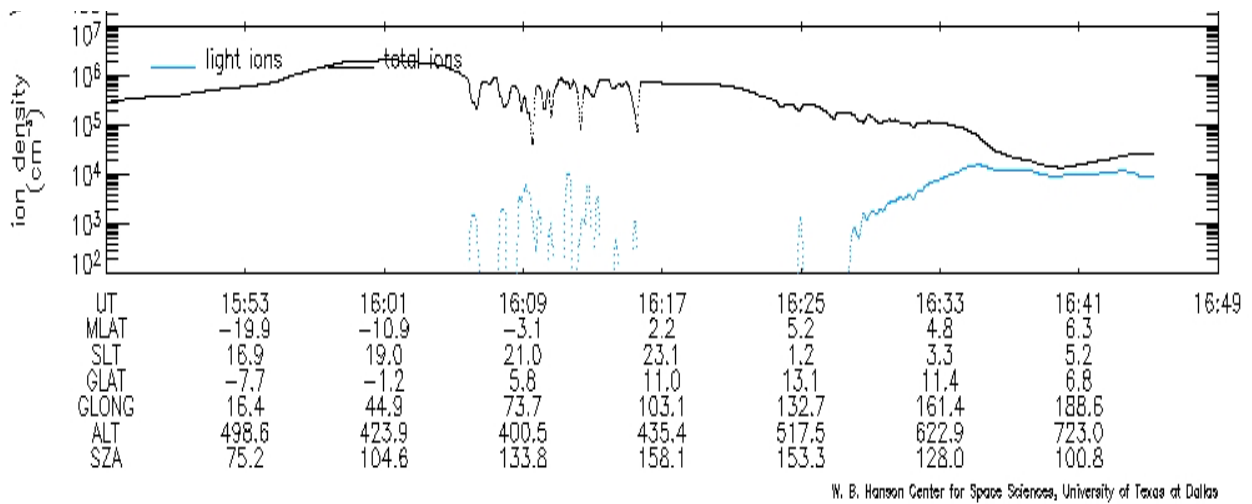
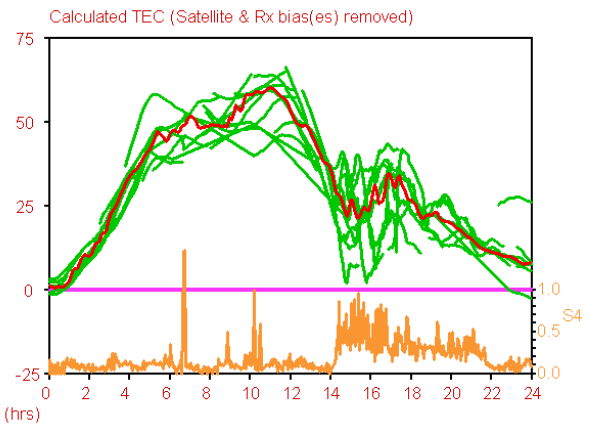
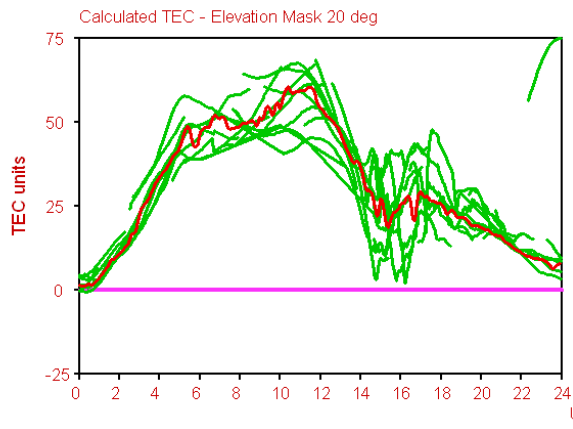


Figure 3

Date: 2011/04/06 (DoY: 096) Station: ban2 - Bangalore,India



Date: 2011/04/06 (DoY: 096) Station: hyde - Hyderabad (located in central part of India),INDIA

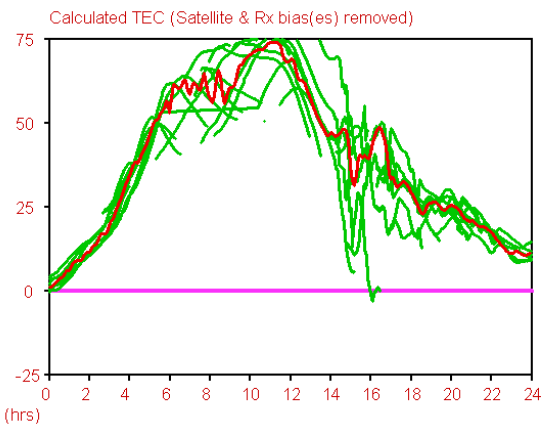
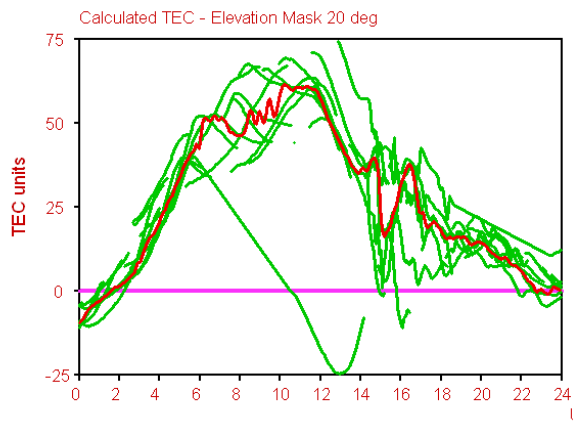


Figure 4

Str: Tirupati (13.5N 79.2E geographic)

Range Time SNR Plot

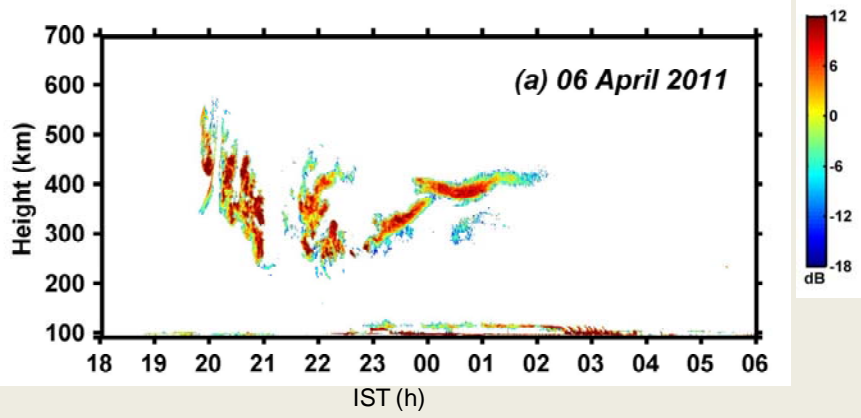


Figure 5

GPS S₄ & Elevation Angle – Calcutta Evening of 06 Apr 2011 (Day 096)



SSN: 41

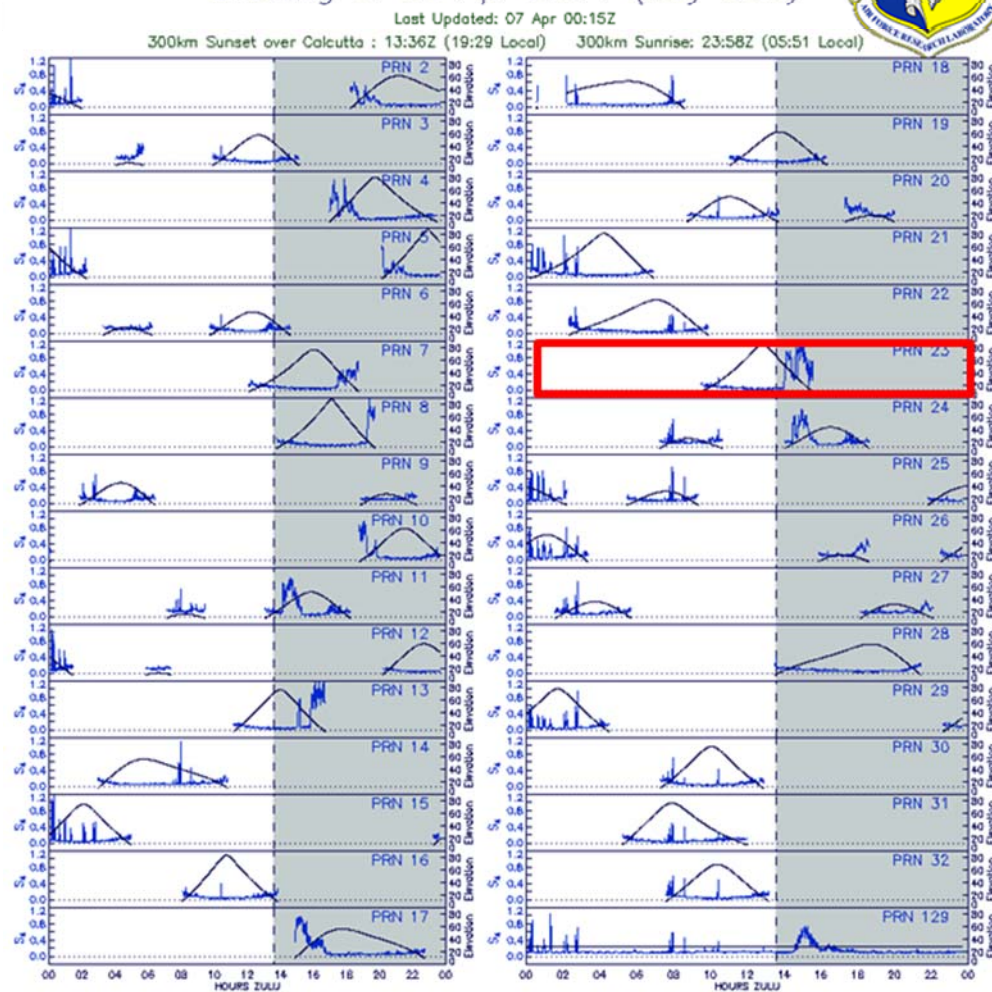
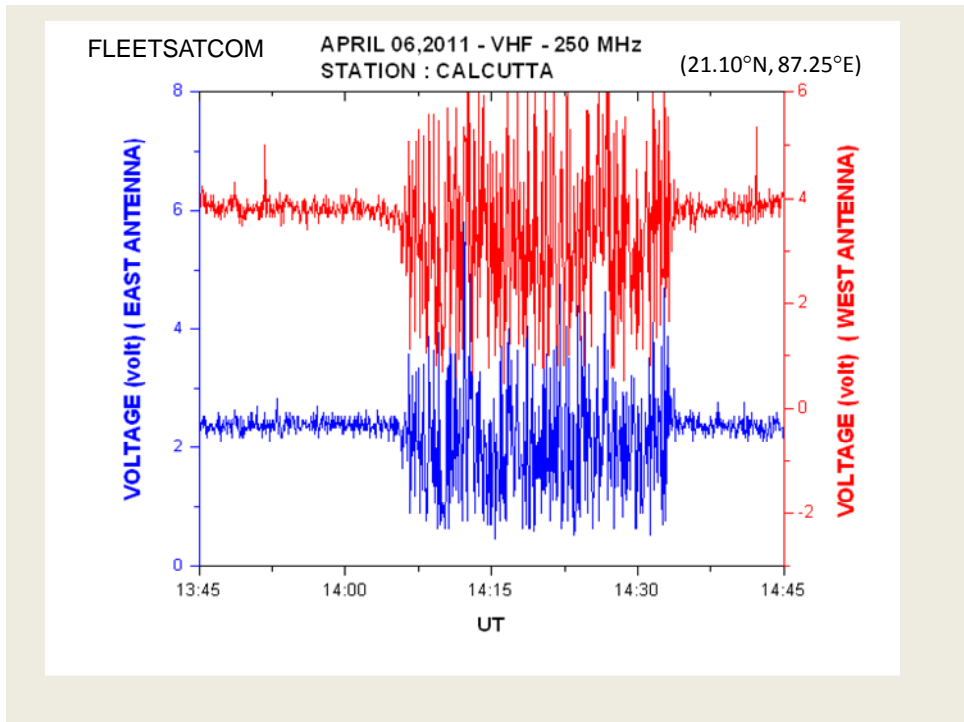


Figure 6



MTSAT/ L1 / (350-km subionospheric point from Calcutta 21.03°N, 93.87°E)

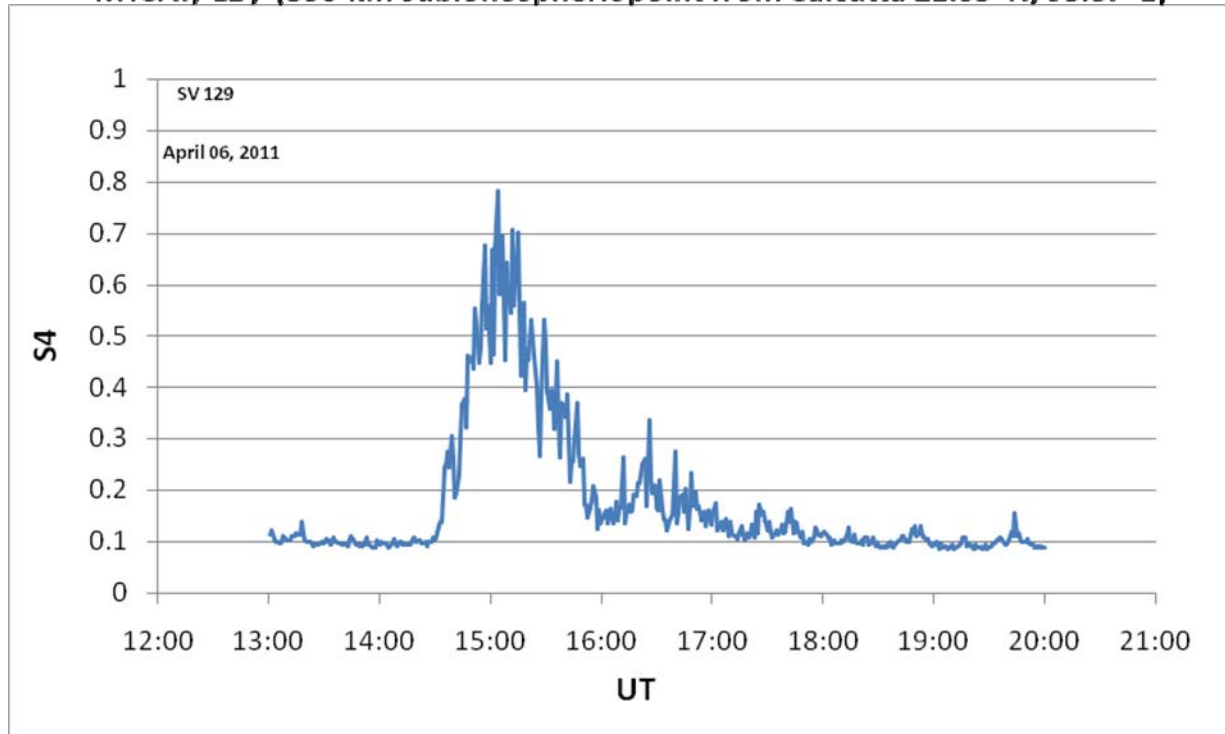
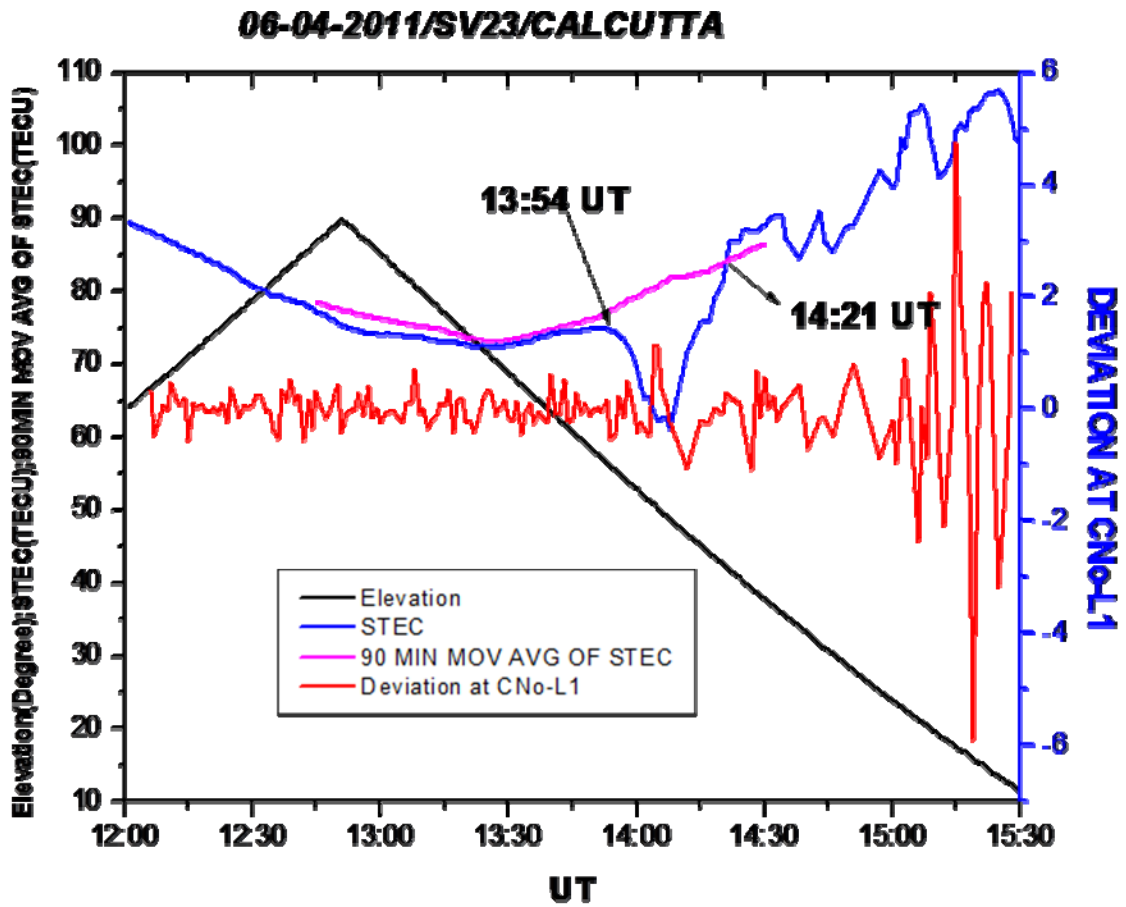


Figure 7



TEC bite-out ~20 TECU results in ~3.2m range error at L1

Figure 8

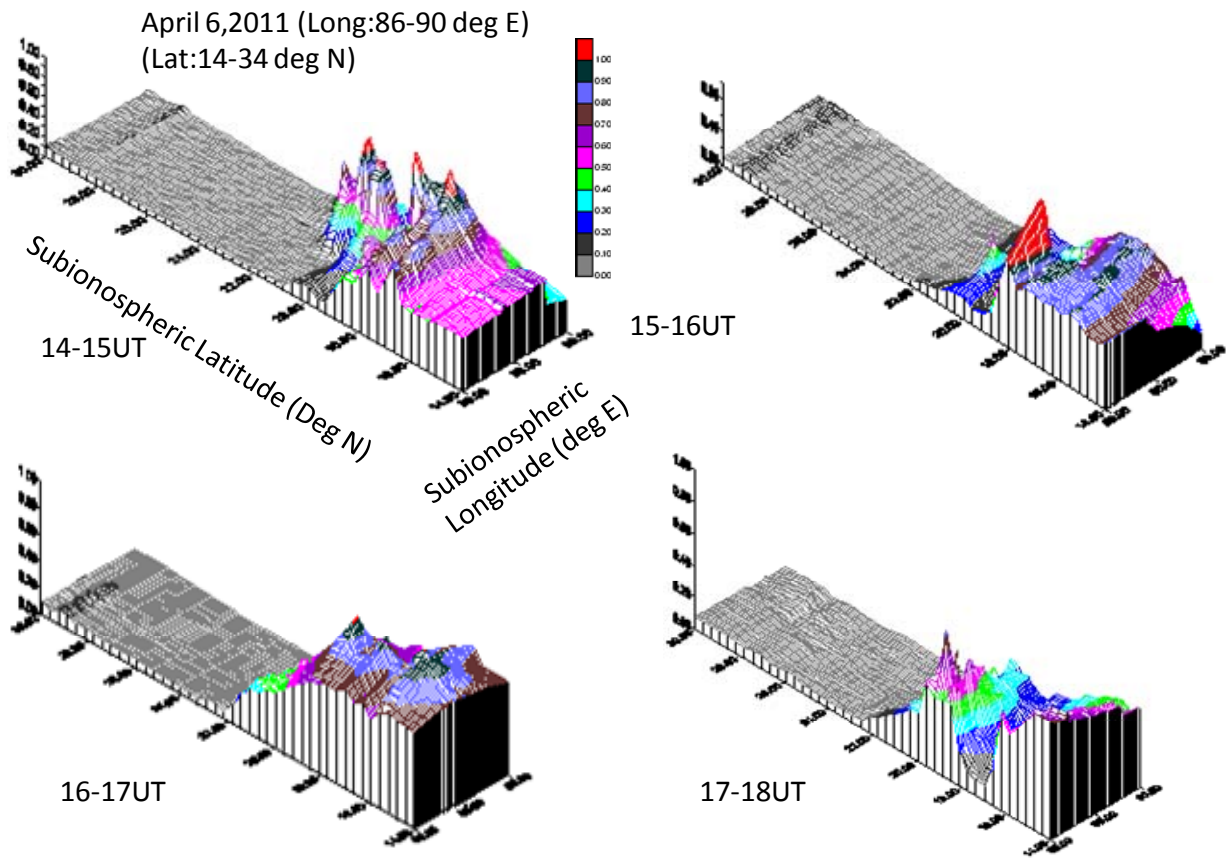


Figure 9

TEC Contours (Elv>50°) 10:00 UT
Subion. Lat.: 20°-28°N Subion. Long.: 86°-90°E
September 23, 2011 SSN: 59

Stns:
Calcutta
Baharampore
Siliguri

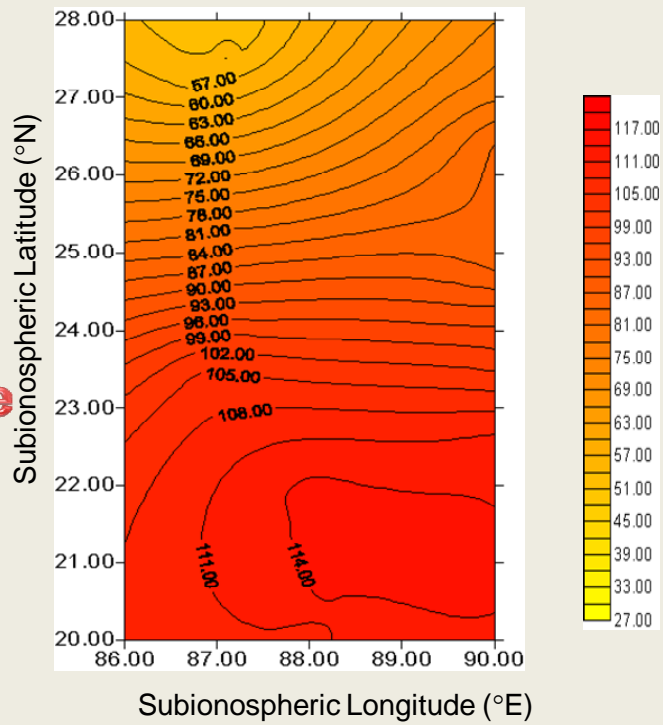


Figure 10

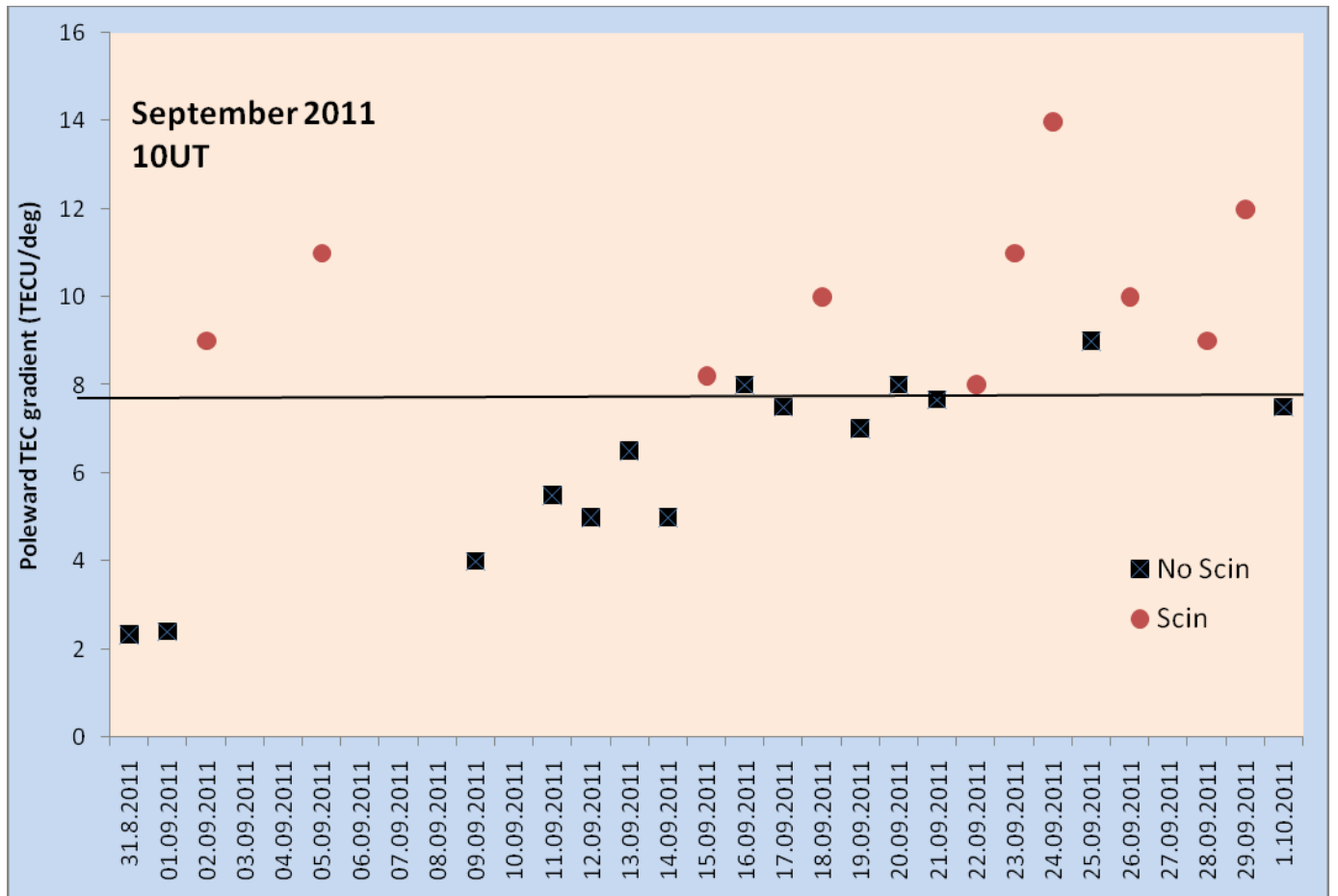


Figure 11

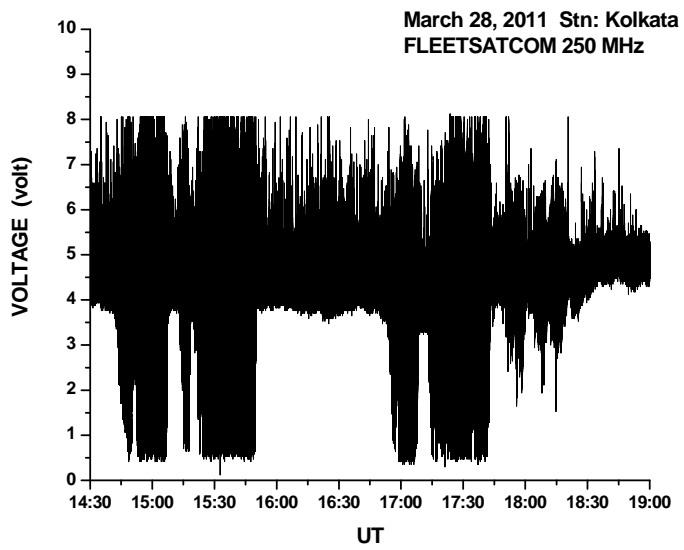


Figure 12

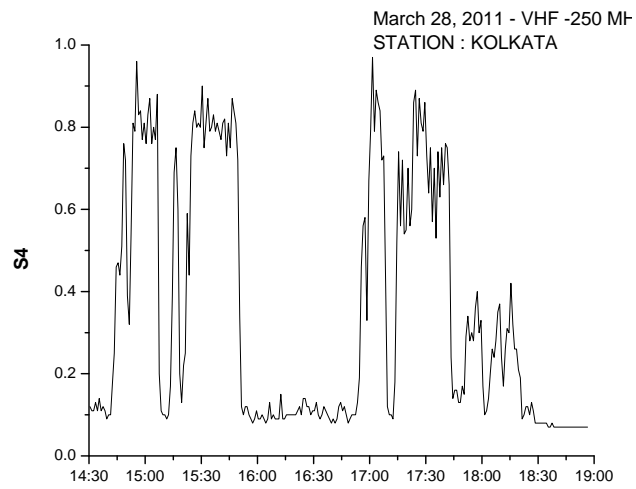


Figure 13

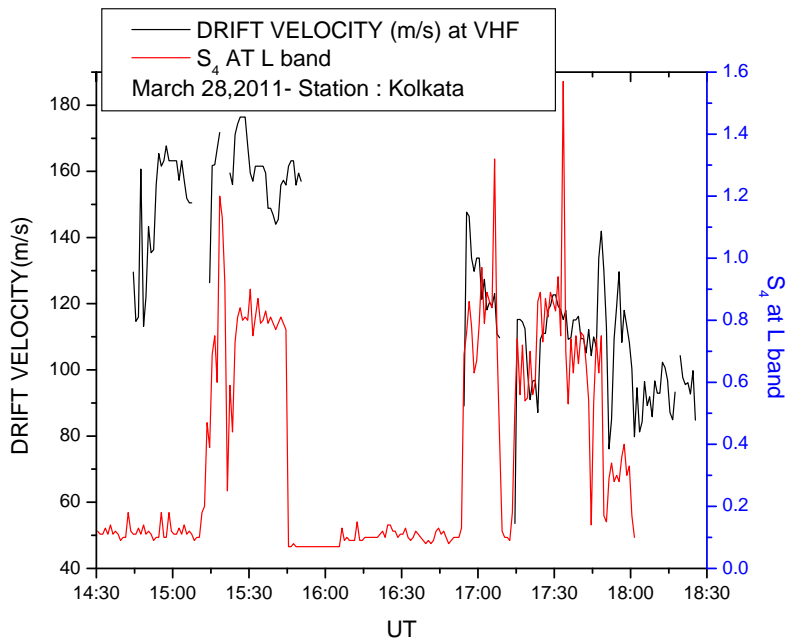


Figure 14

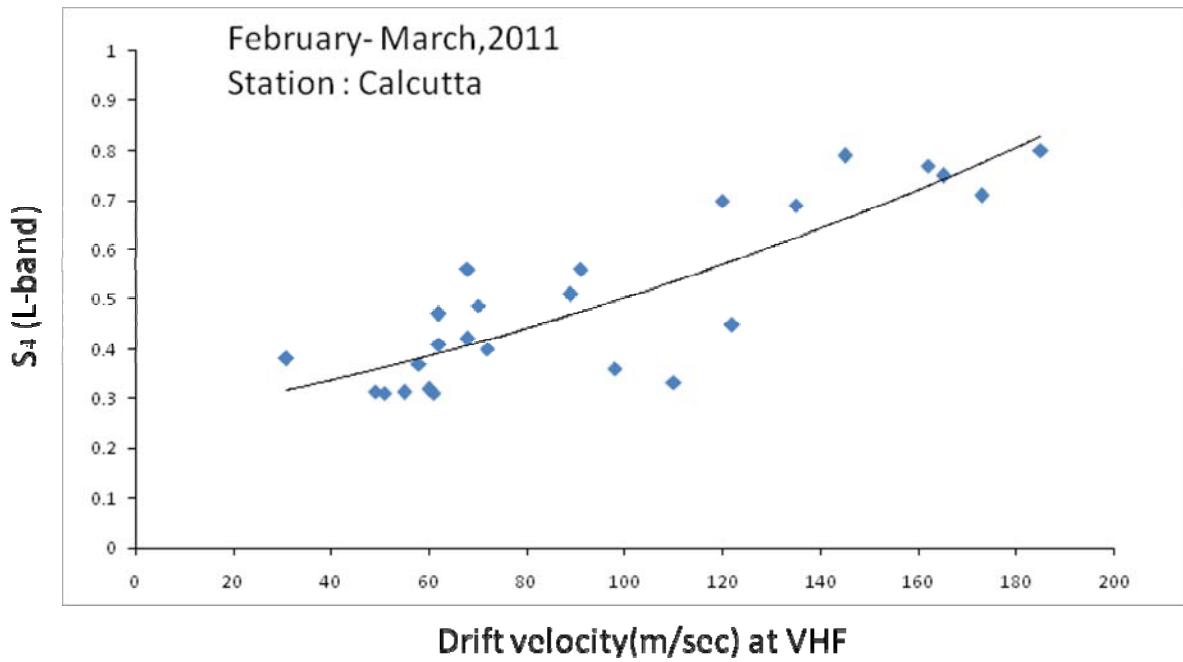


Figure 15

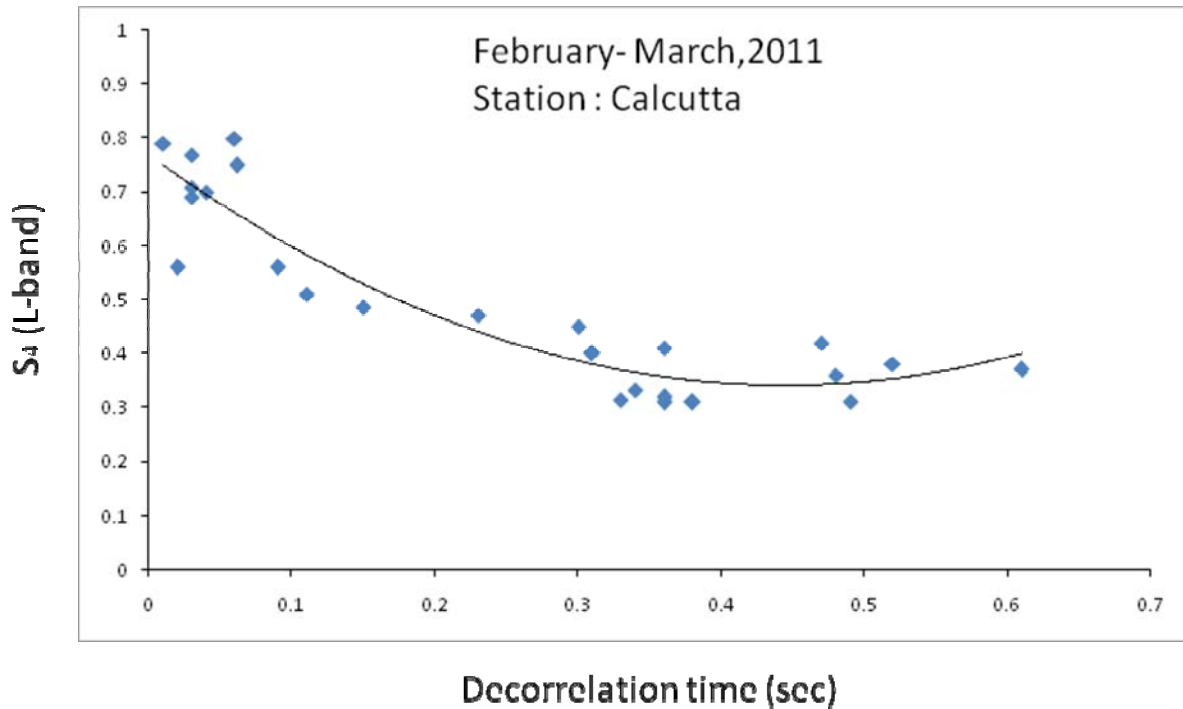


Figure 16

Journal Publications (2010-2012)

1. Characteristics of L-band (1.5GHz) and VHF (244 MHz) amplitude scintillations recorded at Kolkata during 1996-2006 and development of models for the occurrence probability of scintillations using Neural network, A. Das, A. DasGupta and **S. Ray**, *J. Atmos. Sol. Terr. Phys.*, 72, 685-704, 2010.
2. Characteristics of the Equatorial Ionization Anomaly in Relation to the Day-to-Day Variability of Ionospheric Irregularities around the Post-Sunset Period, **A. Paul** and A. DasGupta, *Radio Sci.*, 45, RS6001, doi:10.1029/2009RS004329, 2010.
3. Characteristics of SBAS grid sizes around the northern crest of the equatorial ionization anomaly, **A. Paul**, A. Das and A. DasGupta, *J. Atmos. Sol. Terr. Phys.*, 73, 1715–1722, 2011.
4. Characteristics of intense space weather events as observed from a low latitude station during solar minimum, **A. Paul**, B. Roy, S. Ray, A. Das and A. DasGupta, *J. Geophys. Res.*, 116, A10307, doi:10.1029/2010JA016330, 2011.
5. Response of the equatorial ionosphere to the total solar eclipse of 22 July 2009 and annular eclipse of 15 January 2010 as observed from a network of stations situated in the Indian longitude sector, **A. Paul**, T. Das, S. Ray, A. Das, D. Bhowmick and A. DasGupta, *Ann. Geophys.*, 29, 1955–1965, 2011.
6. Impact of equatorial ionospheric irregularities on transionospheric satellite links observed from a low latitude station during the minima of solar cycle 24, T. Das, B. Roy, A. DasGupta and **A. Paul**, *Ind. J. Radio Space Phy. (Special Issue on Low-latitude upper atmosphere-ionosphere-plasmasphere system in a record low solar minimum in Asian sector)*, 41, 2, 247-257, 2012.

7. Das, A., and **A. DasGupta**, Precursors of Equatorial Spread F observing GPS TEC data from different GAGAN stations in India, *Adv. Space Res.*, 50, 167-181, 2012.

Conference Presentations (2010-2012)

1. Characteristics of SBAS Grid Sizes Around the Northern Crest of the Equatorial Ionization Anomaly, A. Paul, A. Das and A. DasGupta, International Beacon Satellite Symposium (BSS-2010), Universitat Politècnica de Catalunya, Barcelona, Spain, June 7-11, 2010
2. GPS Phase Scintillations, A. DasGupta and A. Paul, International Beacon Satellite Symposium (BSS-2010), Universitat Politècnica de Catalunya, Barcelona, Spain, June 7-11, 2010
3. Characteristics of Intense Space Weather Events as Observed with GPS from a Low Latitude Station, A.Paul and A. DasGupta, 12th Solar Terrestrial Physics (STP-12) meeting of the Scientific Committee on Solar Terrestrial Physics (SCOSTEP), Berlin, Germany, July 12-16, 2010
4. Ionospheric Phase and amplitude scintillation effects on GNSS in the low latitudes, A.Paul, Workshop on Science Applications of GNSS in Developing Countries, International Centre for Theoretical Physics (ICTP), Trieste, Italy, April 11-27, 2012
5. Characterization of the effects of Equatorial Ionospheric Irregularities on Satellite-Based Navigation Around the Northern crest of the Equatorial Ionization Anomaly in the lead-up to the solar maximum, A. Paul, B.Roy, A.Das, T.Das, S.Ray and A.DasGupta, COSPAR-2012, Mysore, India, July 14-22, 2012