REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden, to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED** *(From - To)*
18-02-2015	Final	13 Feb 2013 – 12 Feb 2015

4. TITLE AND SUBTITLE Operation of SCINDA Receiver at the University of Calcutta	**5a. CONTRACT NUMBER** FA238613-1-4014
	5b. GRANT NUMBER Grant AOARD-134014
	5c. PROGRAM ELEMENT NUMBER 61102F
6. AUTHOR(S) Dr. Ashik Paul	**5d. PROJECT NUMBER**
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) University of Calcutta 92 Acharya Prafulla Chandra Road Calcutta 700009 India	**8. PERFORMING ORGANIZATION REPORT NUMBER** N/A
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) AOARD UNIT 45002 APO AP 96338-5002	**10. SPONSOR/MONITOR'S ACRONYM(S)** AFRL/AFOSR/IOA(AOARD)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S) AOARD-134014

12. DISTRIBUTION/AVAILABILITY STATEMENT

Distribution A: Approved for public release. Distribution is unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

The SCINDA (AFRL's Scintillation Network Decision Aid) station at Calcutta (22.58°N, 88.38°E geographic; magnetic dip: 32°N) is situated in the geophysically sensitive Indian longitude sector virtually underneath the northern crest of the Equatorial Ionization Anomaly (EIA). The nearest SCINDA station on the west is located at Rajkot (22.50°N 70.78°E geographic) and on the east at Manila (14.58°N 121°E geographic). The station at Calcutta thereby forms an important link between the above two widely separated longitude sectors. The report summarizes some of the important research conducted during the period 2013-2014 using the SCINDA data.

15. SUBJECT TERMS

Space weather, Ionospheric Irregularities, scintillation

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON** Ingrid J. Wysong, Ph.D.
U	U	U	SAR	5	**19b. TELEPHONE NUMBER** *(Include area code)* +81-3-5410-4409

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

Report Documentation Page

Form Approved
OMB No. 0704-0188

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
18 FEB 2015	**Final**	**13-02-2013 to 12-02-2015**

4. TITLE AND SUBTITLE
Operation of SCINDA Receiver at the University of Calcutta

5a. CONTRACT NUMBER
FA2386-13-1-4014

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER
61102F

6. AUTHOR(S)
Ashik Paul

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
University of Calcutta,92 Acharya Prafulla Chandra Road,Calcutta 700009,India,IN,70009

8. PERFORMING ORGANIZATION REPORT NUMBER
N/A

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
AOARD, UNIT 45002, APO, AP, 96338-5002

10. SPONSOR/MONITOR'S ACRONYM(S)
AFRL/AFOSR/IOA(AOARD)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
AOARD-134014

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

The SCINDA (A F R L ??? s S c i n t i l l a t i o n N e t w o r k D e c i s i o n A i d) station at Calcutta (22.58 N, 88.38 E geographic; magnetic dip: 32 N) is situated in the geophysically sensitive Indian longitude sector virtually underneath the northern crest of the Equatorial Ionization Anomaly (EIA). The nearest SCINDA station on the west is located at Rajkot (22.50 N 70.78 E geographic) and on the east at Manila (14.58 N 121 E geographic). The station at Calcutta thereby forms an important link between the above two widely separated longitude sectors. The report summarizes some of the important research conducted during the period 2013-2014 using the SCINDA data.

15. SUBJECT TERMS
Space weather, Ionospheric Irregularities, scintillation

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**Same as Report (SAR)**	**5**	

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

Principal Investigator: Dr. Ashik Paul
Institute of Radio Physics and Electronics
University of Calcutta
ashik_paul@rediffmail.com
ashikpaul@aol.in

Co-Investigator: Dr. Sarbani Ray
Institute of Radio Physics and Electronics
University of Calcutta
sarbanir@yahoo.com

The SCINDA GPS receiver has been operational at the Institute of Radio Physics and Electronics, University of Calcutta, Calcutta, India since November 2006. 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.

The SCINDA station at Calcutta (22.58°N, 88.38°E geographic; magnetic dip: 32°N) is situated in the geophysically sensitive Indian longitude sector virtually underneath the northern crest of the Equatorial Ionization Anomaly (EIA). The nearest SCINDA station on the west is located at Rajkot (22.50°N 70.78°E geographic) and on the east at Manila (14.58°N 121°E geographic). The station at Calcutta thereby forms an important link between the above two widely separated longitude sectors.

The following section briefly discusses some of the important research conducted during the period 2013-2014 using the SCINDA data.

The equatorial ionosphere is characterized by (i) large values of Total Electron Content (TEC) and sharp latitudinal gradients of TEC, (ii) steep temporal variation of TEC, (iii) large diurnal variation of TEC and (iv) post-sunset secondary enhancement of TEC. These features cause major limitations in accuracy of standard ionospheric TEC models in this region. Three artificial neural network (ANN) based models have been developed based on real time low latitude TEC data along three longitudes 77°E, 88°E and 121°E in the region between the magnetic equator and locations beyond the northern crest of the Equatorial Ionization Anomaly (EIA) to predict the vertical TEC values. These models have shown more accurate predictions than other standard ionospheric TEC models like International Reference Ionosphere (IRI), Parameterized Ionospheric Model (PIM) and NeQuick. The longitudinally separated models have been used to find any longitudinal differences in TEC along the equatorial regions. The causes behind the longitudinal differences in TEC and its diurnal variations in these regions have been explained in terms of the geomagnetic declination and inclination angle along with the role of the zonal wind [*Sur and Paul*, *Adv. Space Res.,* 2013; *Sur and Paul*, URSI-GASS, 2014].

(i) Multistation and multi-technique observation of equatorial ionospheric irregularities from locations over the magnetic equator through the northern crest of the Equatorial Ionization Anomaly (EIA) and beyond is one of the important objectives of the Indian CAWSES program. For this purpose, multistation observational campaign was conducted during September 2011, April 2012 and September 2012 involving GPS TEC and S_4 from Calcutta situated virtually underneath the northern crest of the EIA, and GPS S_4 measurements from Siliguri, located beyond the northern crest of the EIA. Intense amplitude scintillation observations have been noted around midnight and post-midnight hours on certain GPS links located north of Siliguri with no scintillation patches during pre-midnight period. Satellite links experiencing scintillations from Siliguri were unaffected at Calcutta. Day-to-day variability have been noted in the maximum northern observation of GPS scintillations at different S_4 levels from both Calcutta and Siliguri. Simultaneous observations from Siliguri and Calcutta indicate that post-midnight GPS amplitude scintillations are possibly associated with interaction of traveling ionospheric disturbances from mid-latitudes towards the equator, with transionospheric GPS links contrary to early evening hours when such movement are usually from over the magnetic equator towards the northern and southern crests of EIA. Information related to the variabilities of latitudinal extent of scintillation observations along 88°E meridian at different times during 13-19 UT and different levels of intensities of scintillation could provide useful to information for transionospheric satellite link design and Satellite-based Augmentation System (SBAS) [*Das et al.*, *J. Atmos. Sol. Terr. Phys.*, 2014].

(ii) The pole ward gradient of the Equatorial Ionization Anomaly (EIA) introduces more intense propagation effects on transionospheric satellite links in comparison to the equator ward gradient. Characterization of the pole ward gradient was performed during March-April, August-October, 2011 and March-April, 2012 using GPS TEC recorded from a chain of stations located more-or-less along the same meridian (88.5°E) at Calcutta, Baharampore, Farakka and Siliguri. The pole ward gradients calculated on magnetically quiet days at elevation in excess of 50° at 14:00, 15:00 and 16:00 LT were found to have a strong correlation with GPS S4 observed from Calcutta during post-sunset-to-mid-night hours. A threshold value of pole ward TEC gradient is calculated above which there is a probability of scintillation at Calcutta with S4 ≥0.4 [*Das et al.*, *Ann. Geophys.*, 2014].

(iii) Transionospheric satellite navigation links operate primarily at L-band and are frequently subject to severe degradation of performances arising out of ionospheric irregularities. Various characteristic features of equatorial ionospheric irregularity bubbles like the drift velocity, characteristic velocity, decorrelation time and decorrelation distance can be determined using spaced aerial measurements at VHF. These parameters measured at VHF from Calcutta have been correlated with L-band scintillation indices and GPS position accuracy parameters for identifying possible proxies to L-band scintillations. Good correspondences have been observed between decorrelation times and distances at VHF with GPS S_4 and PDOP during periods of GPS scintillations (S_4>0.3) for February-April 2011, August-October 2011 and February- April 2012. A functional relation has been developed between irregularity drift velocity measured at VHF and S_4 at L-band during February-April 2011, and validation of measured S_4 and predicted values performed during August-October 2011 and February-April 2012. Significant improvement in L-band scintillation prediction and consequent navigational accuracy will result using such relations derived from VHF irregularity measurements which are much simpler and inexpensive [*Das et al.*, *Radio Sci.*, 2014].

Journal Publications during 2013-2014

1. Comparison of standard TEC models with a Neural Network based TEC model using multistation GPS TEC around the northern crest of Equatorial Ionization Anomaly in the Indian longitude sector during the low and moderate solar activity levels of the 24th solar cycle, D. Sur and A. Paul, *Adv. Space Res.*, 52, 810-820, 2013.
2. Impact of Space Weather events on satellite-based navigation, B. Roy, A. DasGupta and A. Paul, *Space Weather*, 11, 680–686, doi:10.1002/2013SW001001, 2013.
3. Characteristics of equatorial ionization anomaly (EIA) in relation to transionospheric satellite links around the northern crest in the Indian longitude sector, A. Das, K. S. Paul, S. Halder, K. Basu, and A. Paul, *Ann. Geophys.*, 32, 91-97, doi:10.5194/angeo-32-91-2014, 2014
4. Observation of ionospheric irregularities around midnight and post-midnight near the northern crest of the Equatorial Ionization Anomaly in the Indian longitude sector: Case studies, T. Das, K.S. Paul and A. Paul, *J. Atmos. Sol. Terr. Phys.*, http://dx.doi.org/10.1016/j.jastp.2014.05.001, 2014.
5. Effects of transionospheric signal decorrelation on GNSS performance studied from irregularity dynamics around the northern crest of the EIA, T. Das, B. Roy and A. Paul, *Radio Sci.*, http://dx.doi.org/10.1002/2014RS005406, 2014.

Important conference papers during 2013-2014

1. Impact of intense Space Weather events on SBAS guided navigation, A.Paul, B.Roy and A.DasGupta, International Beacon Satellite Symposium (BSS-13), University of Bath, Bath, UK, July 8-12, 2013.
2. Prediction of ESF Generation during intense geomagnetic storms, S. Ray and B. Roy, International Beacon Satellite Symposium (BSS-13), University of Bath, Bath, UK, July 8-12, 2013.
3. Identification of seeding mechanism of equatorial ionospheric irregularities using the Giant Meterwave Radio Telescope, T.Das, S. Ray, A. Datta and A. Paul, Metre Wavelength Sky Conference, NCRA-TIFR, Pune, December 9-13, 2013

4. Impact of Multiple Frequency Scattering on GNSS Performance under adverse ionospheric conditions, A. Das and A. Paul, 40th COSPAR Scientific Assembly, Moscow, Russia, August 2-10, 2014
5. Proxies to GNSS signal outages from irregularity dynamics around the northern crest of the Equatorial Ionization Anomaly, T. Das and A. Paul, 40th COSPAR Scientific Assembly, Moscow, Russia, August 2-10, 2014
6. Performance Analysis of Artificial Neural Network based TEC Models at Different Longitudes in the Low Latitude Region, D. Sur and A. Paul, 31st General Assembly of URSI, Beijing, China, August 16-23, 2014
7. Frequency Diversity Techniques applied to GNSS under adverse ionospheric conditions, A. Das and A. Paul, 31st General Assembly of URSI, Beijing, China, August 16-23, 2014