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- Longitudinal swath of reduced or no L band scintillations over India

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Characteristics of postmidnight L band scintillation in the transition region from the equatorial to midlatitudes over the Indian longitude sector using COSMIC, C/NOFS, and GPS measurements

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Abstract Occurrence of L band scintillations around midnight and postmidnight hours have not been well studied and reported from the higher equatorial latitudes in the transition region from the equatorial to midlatitudes over the Indian longitude sector. The present paper reports cases of postmidnight L band scintillation observations by COSMIC during March 2014 over the Indian longitude sector. GPS S_4 measurements from the International Global Navigation Satellite Systems Service station at Lucknow (26.91°N, 80.96°E geographic; magnetic dip: 39.75°N) corroborate occurrence of postmidnight scintillations. The *F* region vertical upward velocities around the magnetic equator during evening hours have been used to understand the possibility of impact of irregularities generated over the magnetic equator at latitudes north of 30°N. Postmidnight L band scintillations at latitudes greater than 30°N without corresponding premidnight scintillations present interesting scientific scenario and give rise to suggestions of (1) any coupling mechanism between the equatorial and midlatitudes through which irregularities seeded in the midlatitudes may affect transionospheric satellite links at low latitudes or (2) irregularity generation at midlatitudes not connected with equatorial instabilities. Long-term analysis of S_4 at L band measured by COSMIC over the Indian longitudes during March 2007–2014 exhibits a well-defined longitude swath around 75–83°E of reduced ($0.2 < S_4 < 0.4$) or no scintillations which may be attributed to the longitudinal variability of scintillation occurrence following the global four-cell pattern of ionospheric activity.

1. Introduction

The equatorial ionosphere covering the latitude regime 5–40°N and 65–100°E geographic encompasses the geophysically sensitive Indian longitude sector which presents some of the highest total electron content values in the world coupled with intense amplitude and phase scintillations on transionospheric satellite links typically during postsunset to local midnight. Although significant scientific researches have been performed on characterizing this region of the ionosphere, new hitherto unknown facts continue to emerge from this sector. Morphology of postsunset equatorial ionospheric irregularities and scintillations from the Indian region has been extensively studied over the past six decades [*Aarons*, 1982; *Basu et al.*, 1980, 1988; *Rastogi and Klobuchar*, 1990; *DasGupta et al.*, 2004]. Intense amplitude scintillations at VHF and L band are normally observed in the premidnight hours over the Indian subcontinent, while weak or moderate scintillations are sometimes found during postmidnight hours. The irregularities are formed over the magnetic equator in the postsunset hours and extend in both horizontal and vertical directions. *Anderson and Haerendel* [1979] had investigated in detail the motion of depleted magnetic flux tubes in the equatorial ionosphere. Bubbles are actually depleted magnetic flux tubes. Evidence of depleted flux tubes are available from Atmospheric Explorer and SROSS-C2 observations of deep plasma bite-outs at ±10–20° dip latitudes [*McClure et al.*, 1977; *Paul et al.*, 2002] and from observations of dark bands in 6300 A° airglow intensity which are oriented in the north-south direction [*Weber et al.*, 1980; *Mukherjee et al.*, 1998; *Mukherjee*, 2002; *Sinha et al.*, 2001]. Using topside sounder data from Alouette 2 and ISIS 1, *Dyson and Benson* [1978] also found that the bubbles extend for great distances along geomagnetic field lines.

The Indian subcontinent essentially covers the equatorial zone in the South Asian longitudes. While the magnetic equator touches the southern tip of the peninsula near Trivandrum, the northern crest of the equatorial ionization anomaly (EIA) passes near Calcutta. While a lot of emphasis have been given to satellite observations of the ionosphere south of the northern crest in the geophysically sensitive Indian longitude sector, very few and isolated studies have been conducted north of the northern crest of the EIA. In the absence of adequate ground-based measurements from locations north of the northern crest of EIA in the Indian longitude sector, satellite-based measurements of scintillation occurrences could provide valuable information from this geophysically sensitive region of the Earth.

Recent efforts have been made to study occurrence of L band scintillations around midnight and postmidnight hours using GPS measurements from two stations, Calcutta (22.58°N, 88.38°E geographic; magnetic dip: 32°N) situated near the northern crest of the EIA and Siliguri (26.72°N, 88.39°E geographic; magnetic dip: 40°N) located beyond the northern crest of the EIA in the Indian longitude sector [*Das et al*., 2014].

Proper understanding of the phenomena of equatorial spread *F* (ESF) and scintillations needs development of accurate models of the small- and medium-scale irregularities associated with them. These issues could be addressed using ground- or satellite-based measurements [*de La Beaujardière et al*., 2004] for detection of ESF or irregularities. The large-scale structures associated with scintillations (~300–400 m for L band and 800 m–1 km for VHF) are essentially field-aligned. However, the smaller-scale structures are bifurcated as observed by all-sky images [*Kelley*, 2009] and Global Ultraviolet Imager (GUVI) Thermosphere-Ionosphere-Mesosphere Energetics and Dynamics (TIMED) images [*Henderson et al*., 2005]. The seeding mechanism affecting the bifurcation is sensitive to local conditions which are not well understood. Earlier studies of the equatorial scintillations have established the longitudinal morphology [*Aarons*, 1982, 1993; *Basu and Basu*, 1985].

The Constellation Observing System for Meteorology, Ionosphere, and Climate (COSMIC/FORMOSAT-3) was launched on 15 April 2006 as a joint venture between the United States and the Republic of China (Taiwan) [*Anthes et al*., 2008]. The sensors on board the six satellite constellation make routine observations of the ionosphere. Every COSMIC satellite carries onboard three instruments for studying the ionosphere, namely, GPS Occultation Experiment (GOX), Tiny Ionospheric Photometer (TIP), and Tri-Band Beacon (TBB). The present study used the GOX S_4 index measurements to study irregularity characteristics and scintillation occurrence over the Indian longitude sector during 2007–2014 with special emphasis on March 2014 because of postmidnight L band scintillation activity.

Since the emphasis behind the present study was to understand midnight and postmidnight L band scintillation occurrence in the Indian longitude sector, particularly in the less explored transition region from the equatorial to the midlatitudes, it was necessary to validate COSMIC observations with ground-based data. Data from the International Global Navigation Satellite Systems Service (IGS) station at Lucknow (26.91°N, 80.96°E geographic; magnetic dip: 39.75°N) located beyond the northern crest of the EIA were utilized to study L band scintillation occurrence particularly during postmidnight period.

It is important to note that the present paper does not attempt to provide a morphological study of L band scintillation occurrence over the Indian longitude sector but presents a statistical overview using COSMIC measurements over the Indian longitude sector coupled with GPS S_4 measurements from Lucknow with a primary focus on midnight and postmidnight scintillation observations. In spite of coordinated observations from COSMIC and GPS during March 2014, an exact correlation between S_4 indices measured by the two may not be obtained mainly due to the different measurement techniques and geometry of the raypath.

Day-to-day variability of scintillations in the equatorial region have been extensively studied using different techniques, like images at 135.6 nm from the Global Ultraviolet Imager (GUVI) which showed a distinct longitudinal variation in its occurrence [*Basu et al*., 2009]. The present paper also reports longitudinal variability of scintillation occurrence over the Indian longitude sector in the light of the global wave number four-cell pattern.

Since development of ionospheric irregularities is subject to rapid uplifting of the *F* region ionosphere over the magnetic equator during the evening hours, the vertical upward ion velocities obtained from the Communications/Navigation Outage Forecasting System (C/NOFS) satellite are used to study the ionospheric dynamics around the magnetic equator during evening to midnight time period.

2. Data

The COSMIC GPS Occultation Experiment (GOX) data used in this study were downloaded from the COSMIC Data Acquisition and Analysis Center Web site (http://cosmic-io.cosmic.ucar.edu/cdaac/login/cosmic/) recorded during

2007–2014 over the Indian subcontinent broadly covering the latitude and longitude swath of 5–40°N and 65–100°E. The recorded files contain the S_4 index calculated from the 1 Hz L band data corresponding to each observation and occultation of the GPS satellites observed by COSMIC. These files contain information on the position (latitude, longitude, and altitude) and universal time of the COSMIC satellite making the observations. The maximum and minimum values of the S_4 index and the S_4 calculated over a 9 s interval are reported in these files [*Dymond*, 2012]. The 1 Hz S_4 measurements correspond to the Cartesian coordinates of the COSMIC satellite and GPS satellites in the geocentric fixed coordinate system. In the present paper, the maximum value of S_4 calculated over a 9 s interval and the associated position information have been used. Maximum S_4 values were filtered, and those greater than 0.2 were selected. To ensure that only *F* region scintillations are considered, S_4 values that occurred within the altitude range of 200–500 km were retained. The S_4 values were binned into two categories, 13:00–19:00 UT and 19:00–23:00 UT, to consider local premidnight and postmidnight hours over the Indian subcontinent. It should be noted that March 2014 was magnetically quiet with *Kp* values varying from 0 to 4. The monthly mean sunspot number for March 2014 was 128.7.

In order to provide further corroboration of postmidnight L band scintillation observations in the transition region between the equatorial and midlatitudes, scintillation observations from the IGS station at Lucknow (26.91°N, 80.96°E geographic; magnetic dip: 39.75°N) have been used. The station at Lucknow was selected as it lies beyond the northern crest of the EIA and hence could provide information on the transition zone between the equatorial and midlatitudes. It is important to note that there are very few or nonexistent ground-based measurements over the latitude range of 30–35°N, primarily because of terrain and logistic issues. Thus, satellite-based studies can effectively fill-up this void and thereby provide new information. S_4 index measured on different GPS satellite vehicle links at 30 s interval during 13:00–23:00 UT of March 2014 have been obtained from the IGS station at Lucknow available on the website http://sopac.ucsd.edu. An elevation mask of 20° has been used while analyzing the data to eliminate the effects of multipath. Although S_4 measurements have been used from COSMIC as well as GPS, a point-to-point correspondence is not expected primarily due to different measurement techniques and effect of geometry.

The C/NOFS satellite was launched in April 2008 into a low-inclination (13°) orbit, with perigee of 400 km and apogee of 850 km. It is a U.S. Air Force mission to forecast ambient plasma densities and irregularities in the equatorial ionosphere [*de La Beaujardière et al.*, 2004]. Instruments on the satellite measure electric fields, plasma characteristics, neutral winds, and the strength of scintillation-producing irregularities. The upward ion velocity V_z is provided by C/NOFS at 1 s resolution on the website http://cindispace.utdallas.edu. The downloaded data are filtered to cover the Indian longitude sector 65–100°E. Positive values of V_z indicate upward direction.

3. Results

Figure 1a shows a map of the Indian subcontinent with the magnetic equator passing near the southern tip of the peninsula over Tirunelveli (8.73°N, 77.70°E geographic; magnetic dip: 3.26°N), Calcutta (22.58°N, 88.38°E geographic; magnetic dip: 32°N), located in the anomaly crest region, and the station at Lucknow (26.91°N, 80.96°E geographic; magnetic dip: 39.75°N) located beyond the northern crest of the EIA. Figure 1b shows the tracks of the COSMIC satellites over India during March 2014. It is important to note that a large number of passes of COSMIC were available, particularly north of 30°N geographic latitude which coincides with the major region of interest in the present paper. Figure 2 shows the scintillation occurrence map as observed by COSMIC over the Indian subcontinent for weak scintillations ($0.2 \leq S_4 < 0.4$) in Figure 2a, moderate scintillations ($0.4 \leq S_4 < 0.6$) in Figure 2b, and strong scintillations ($S_4 \geq 0.6$) in Figure 2c during 13:00–19:00 UT of March 2014. The color scale on the right indicates different levels of scintillations at varying latitudes and longitudes. Figure 3 shows the corresponding scintillation occurrence map from COSMIC for the postmidnight period of 19:00–23:00 UT.

From Figure 2, it is found that majority (53 cases out of 68) of intense scintillation ($S_4 \geq 0.6$) events observed by COSMIC during 13:00–19:00 UT of March 2014 occurred over the latitude region 20–40°N while only 15 cases were found within the range of 5–20°N. Out of the 53 cases of intense scintillations noted between 20 and 40°N, 36 occurred at latitudes north of 30°N. It is important to note that observations of L band scintillations at locations well beyond the northern crest of the EIA are very few in the Indian longitude sector.

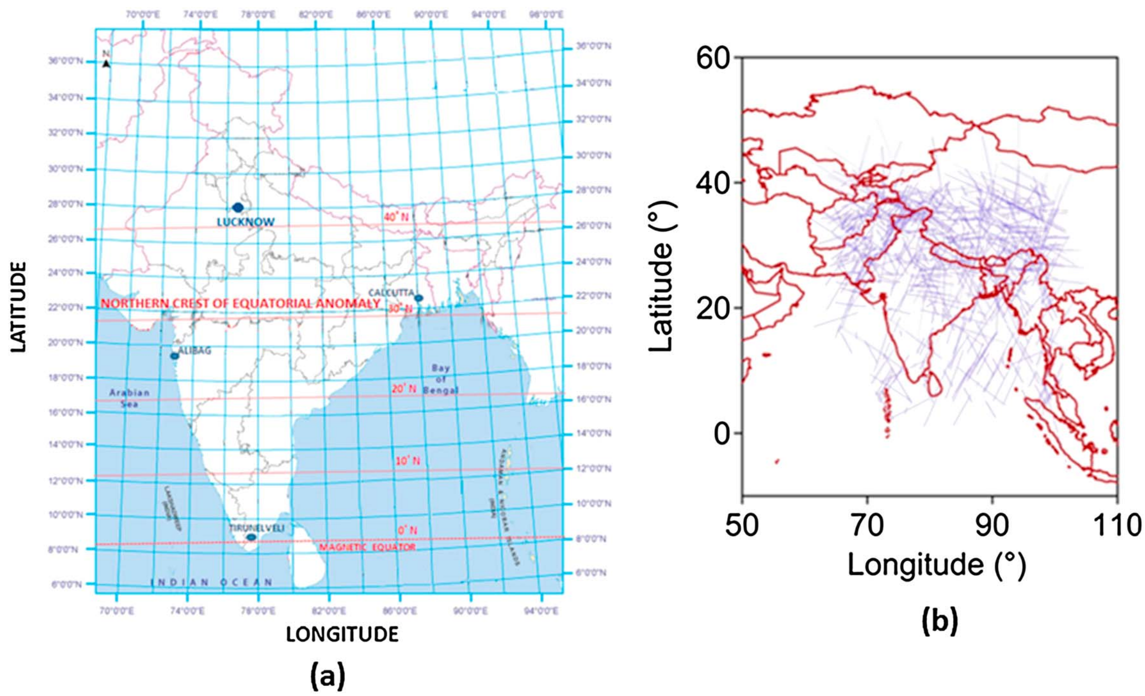

Figure 1. (a) Map of India showing the magnetic equator, northern crest of the equatorial ionization anomaly (EIA), and the station at Lucknow (b) tracks of COSMIC satellites over India during March 2014.

During the postmidnight hours (19:00–23:00 UT), nine cases of intense scintillations ($S_4 \geq 0.6$) were found between the latitudes of 20 and 40°N, of which seven occurred at latitudes greater than 30°N as seen from Figure 3. On further analyzing these seven cases, it was found that they occurred between 19:00 and 20:00 UT and were confined to heights of 234–341 km. Further, five of them occurred over the longitude swath 67–75°E.

These cases also show a pronounced longitudinal confinement with 36 cases of intense scintillations observed between 85 and 100°E during the premidnight hours 13:00–19:00 UT. However, only seven such cases were noted between 75 and 80°E in the premidnight period and none during the postmidnight hours.

Postmidnight scintillations were observed by COSMIC on 1, 3, 4, 5, 7, 8, 9, 12, 13, 14, 15, 16, 27, 29, and 30 March 2014. Such observations at latitudes greater than 30°N were noted on 1, 4, 7, 8, 9, 12, 13, 14, and 15 March 2014. Out of these cases, premidnight scintillations in the same region (latitude > 30°N) were observed on all the above dates with the exception of 8 and 9 March 2014. Observations of scintillations by COSMIC during early evening hours (13:00–15:00 UT) at locations around the magnetic equator (~10–12°N geographic latitude in the Indian longitude sector) are noted only on 8 March 2015 (13:47 UT, 12.56°N geographic latitude, 95.75°E geographic longitude). This suggests that the cases of postmidnight scintillations observed by COSMIC on 8 and 9 March 2014 at latitudes north of 30°N may not owe its origin to ionization density irregularities generated over the magnetic equator in the early evening hours which elongate with the progress of the night along the highly conducting geomagnetic field lines to off-equatorial latitudes.

Figure 4a shows the variation of S_4 index ($S_4 > 0.2$) measured on different GPS SV links from Lucknow as a function of 350 km subionospheric latitude and longitude during 13:00–19:00 UT (premidnight hours), while Figure 4b shows the corresponding plot for 19:00–23:00 UT (postmidnight) over the entire month of March 2014. It could be seen from Figure 4a that the majority of scintillation cases were confined within 20–26°N, although there were some events which occurred at subionospheric latitudes greater than 30°. During postmidnight period (19:00–23:00 UT), it is interesting to note cases of GPS scintillations with S_4~0.4 around 32°N which are sufficiently away from the northern crest of the EIA and the region of equatorial electrojet. From these figures, a longitude swath of reduced or no scintillations could be identified around 75–78°E during premidnight period and 75–80°E during postmidnight hours.

Figure 5 shows the maximum z component of ion velocity (V_z + ve upward) obtained from C/NOFS during the evening to midnight time interval of 17:00–24:00 magnetic local time (MLT) over 65–100°E covering the

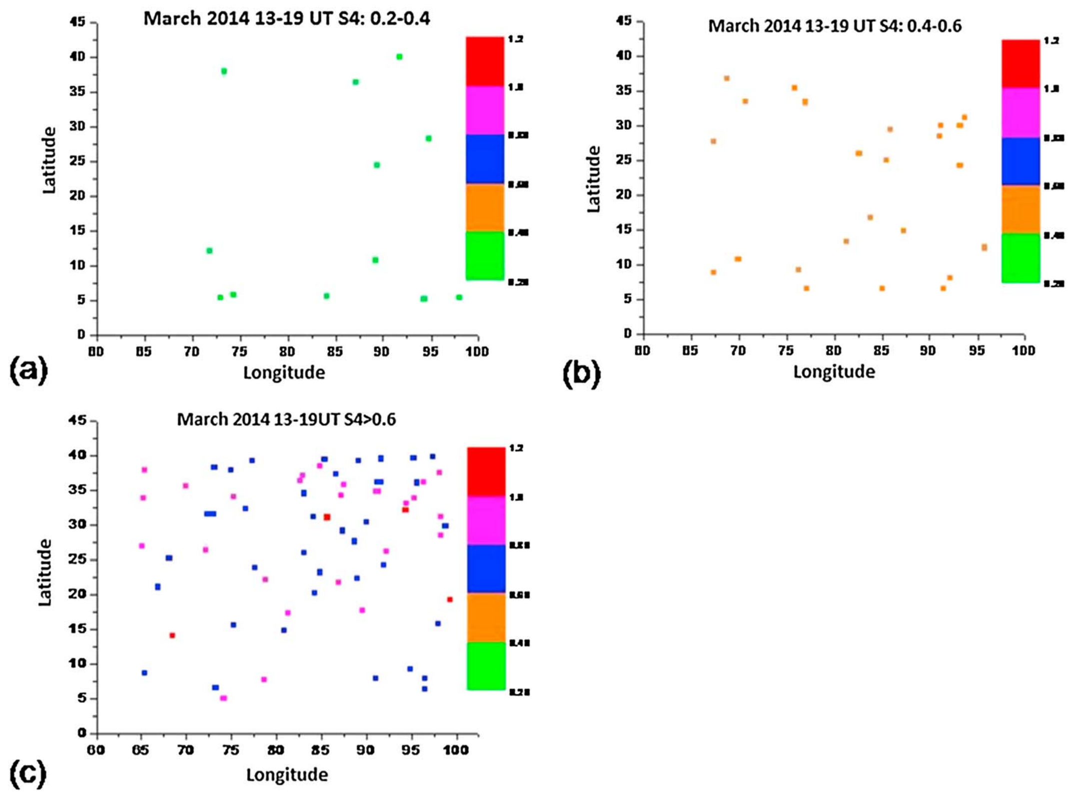

Figure 2. Scintillation occurrence map as observed by COSMIC over the Indian subcontinent for (a) weak scintillations ($0.2 \le S_4 < 0.4$), (b) moderate scintillations ($0.4 \le S_4 < 0.6$), and (c) strong scintillations ($S_4 \ge 0.6$) during 13:00–19:00 UT of March 2014. The color scale on the right indicates different levels of scintillations at varying latitudes and longitudes.

Indian longitude sector at different magnetic latitudes (MLATs) in Figure 5a and different magnetic local times (MLTs) in Figure 5b on different days of March 2014. The black dots correspond to dates of scintillation observation by COSMIC, while the crosses represent nonscintillation dates. It is interesting to note that cases of scintillation correspond to maximum V_z occurring at higher MLAT as shown in Figure 5a. A clear distinction between the *F* region vertical velocity for scintillation and nonscintillation cases could be identified around 100 m/s. Occurrence of maximum V_z during 19:00–21:00 MLT is found to cause scintillations as evident from Figure 5b. On 9 March 2014, the maximum value of V_z was found to be 177 m/s at 19:42 MLT over the magnetic equator. Corresponding to this date, there was no premidnight scintillations at latitudes greater than 30°N but there was postmidnight scintillation observations by COSMIC in this region.

Maps of scintillation occurrences over the Indian longitude sector observed by COSMIC were made for the month of March during 2007–2014 covering extremely low to high solar activity period. Figures 6 and 7 show maps of S_4 at different latitudes and longitudes over the Indian subcontinent for the periods of 13:00–19:00 UT and 19:00–23:00 UT, respectively. The color scales shown on the right indicate the levels of scintillations. It is important to note that in almost all the figures, a zone of low ($0.2 < S_4 \le 0.4$) or nonexistent scintillation ($S_4 < 0.2$) activity, marked with a box, is found over the longitude swath 75–83°E.

4. Discussions

It is important to note that occurrence of L band scintillations during postmidnight hours is rare and has not been extensively reported in literature from the Indian longitude sector [*Das et al.*, 2014]. Such effects are usually recorded at locations around the northern crest of the EIA like Calcutta [*Ray and DasGupta*, 2007]. However, the present study reports occurrences of L band scintillations mainly during 19:00–20:00 UT from COSMIC and GPS measurements at latitudes between 30°N and 40°N using COSMIC GPS radio occultation and ground-based GPS records.

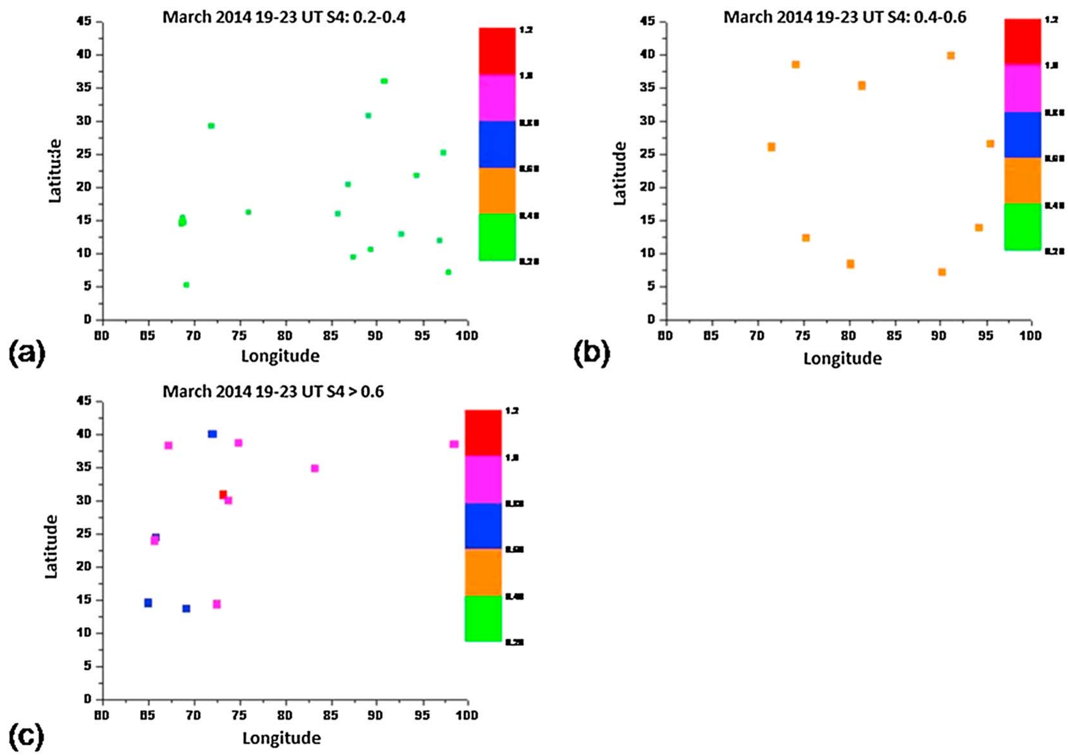

Figure 3. Scintillation occurrence map as observed by COSMIC over the Indian subcontinent for (a) weak scintillations ($0.2 \leq S_4 < 0.4$), (b) moderate scintillations ($0.4 \leq S_4 < 0.6$), and (c) strong scintillations ($S_4 \geq 0.6$) during 19:00–23:00 UT of March 2014. The color scale on the right indicates different levels of scintillations at varying latitudes and longitudes.

Scintillation observation at latitudes beyond the northern crest of the EIA in the equatorial region around midnight and postmidnight hours is an outstanding problem that has not been properly addressed so far. Observation of postmidnight L band scintillation by COSMIC at latitudes greater than 30°N without corresponding premidnight scintillations in this region is a new observation which is difficult to explain on the lines of present understanding of equatorial ionospheric processes. Vertical upward ion velocities measured by C/NOFS during early evening to midnight time interval indicate that on dates when postmidnight scintillations occurred over the Indian longitude sector of 65–100°E, vertical upward ion velocities were higher (>100 m/s) at magnetic latitudes of −10°N to 5°N around the magnetic equator. Thus, stronger uplift of the *F* region ionosphere over the magnetic equator will force the irregularities to move to higher off-equatorial latitudes with a finite time delay between occurrence of scintillations near the magnetic equator and off-equatorial locations. It is important to note that maximum upward ion velocities are mainly confined within the time interval of 19:00–21:00 MLT on scintillation dates. One of the most intriguing observations was noted on 9 March 2014 when maximum V_z values of 177 m/s were noted at 19:42 MLT at magnetic latitude of 0.26°N. However, on this date no premidnight scintillations were noted by COSMIC at latitudes greater than 30°N, although there were postmidnight scintillation observations in this region. On 8 March 2014, maximum V_z value of 129 m/s was found at 21:16 MLT. On this date, COSMIC observed scintillations during early evening hours between the magnetic equator and the northern crest of the EIA (10–20°N), but there were no premidnight scintillations north of 30°N, although there were postmidnight scintillations in this region.

Similar results were reported earlier from spread *F* and scintillation studies in the Indian region covering a solar cycle [*Chandra and Rastogi*, 1972]. Occurrence of strong equatorial spread *F* (ESF) was reported during postmidnight periods of June solstices of low sunspot number years from low-latitude stations like Ahmedabad (magnetic dip: 33.38°N) and Taipei (magnetic dip: 35.72°N) [*Rastogi and Kulkarni*, 1969; *Huang and Yeh*, 1970]. VHF scintillation studies from India have shown that the equatorial belt of scintillations in the Indian region is narrowest during June solstices of low sunspot number years [*Banola et al*., 2010].

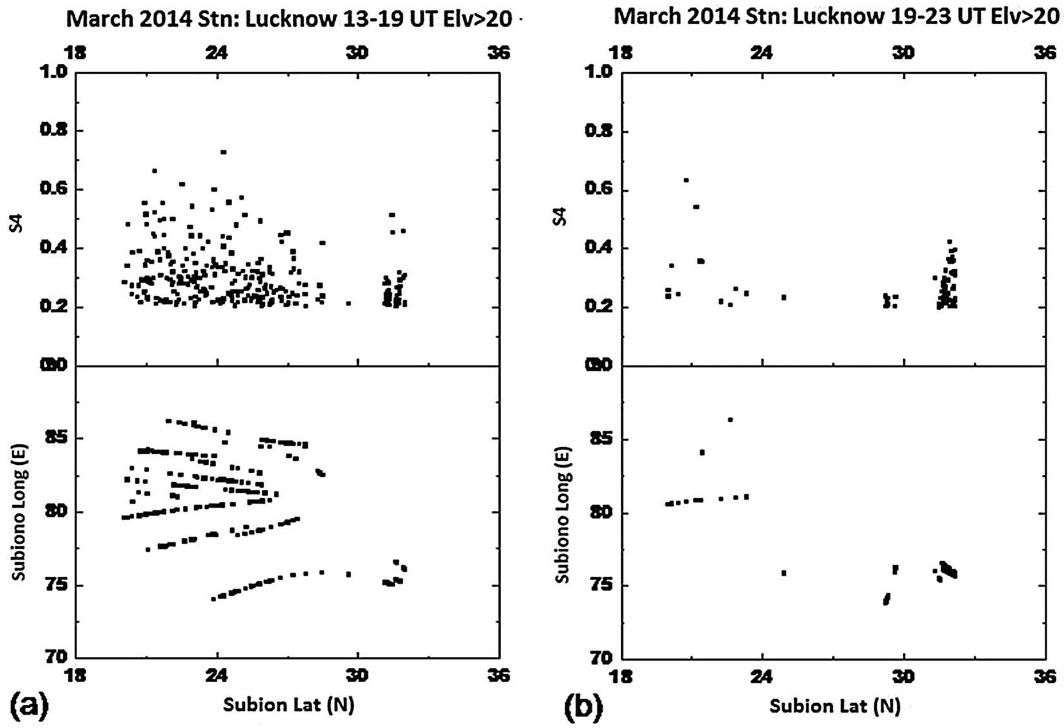

Figure 4. Variation of S_4 index measured on different GPS SV links from Lucknow as a function of 350 km subionospheric latitude and longitude during (a) 13:00–19:00 UT and (b) 19:00–23:00 UT for March 2014.

It has been suggested that coupling between mesoscale traveling ionospheric disturbance (MSTID) at low to middle latitudes and the equatorial *F* layer leads to growth of equatorial plasma bubbles [*Krall et al.*, 2011]. This coupling is most pronounced when the wave vector is perpendicular to the geomagnetic field and is nonexistent if the MSTID occurs at such high latitude so as not to influence the bottomside *F* layer. ESF may be triggered when the MSTID affects field lines corresponding to the bottomside *F* layer. It has also been proposed that traveling ionospheric disturbances could be one of the major sources of the nonequatorial scintillation events [*Candido et al.*, 2011; *Das et al.*, 2014]. Very low values of background electron densities present during these midnight and postmidnight scintillation observations in the transition region between

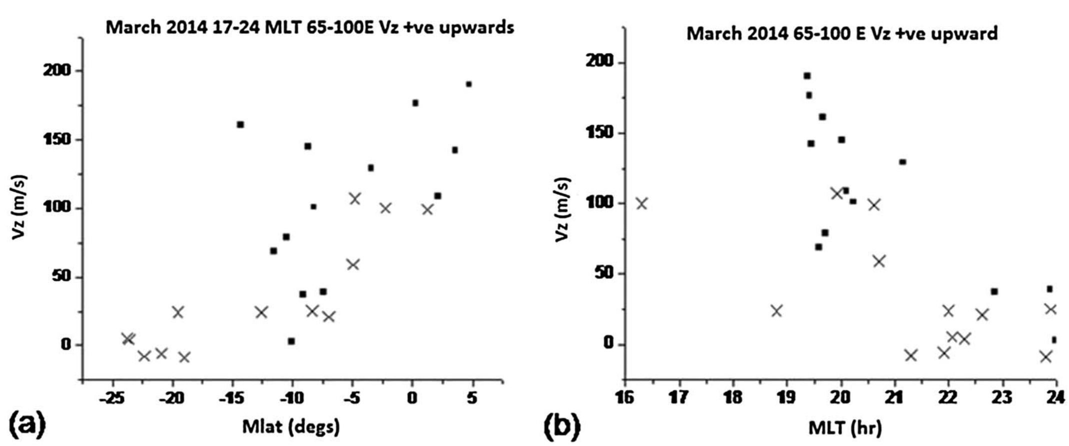

Figure 5. Maximum *z* component of ion velocity (V_z + ve upward) obtained from C/NOFS during 17:00–24:00 MLT over 65–100°E at different (a) magnetic latitudes (MLATs) and (b) different magnetic local times (MLTs) on different days of March 2014. The black dots correspond to dates of scintillation observation by COSMIC, while the crosses represent nonscintillation dates.

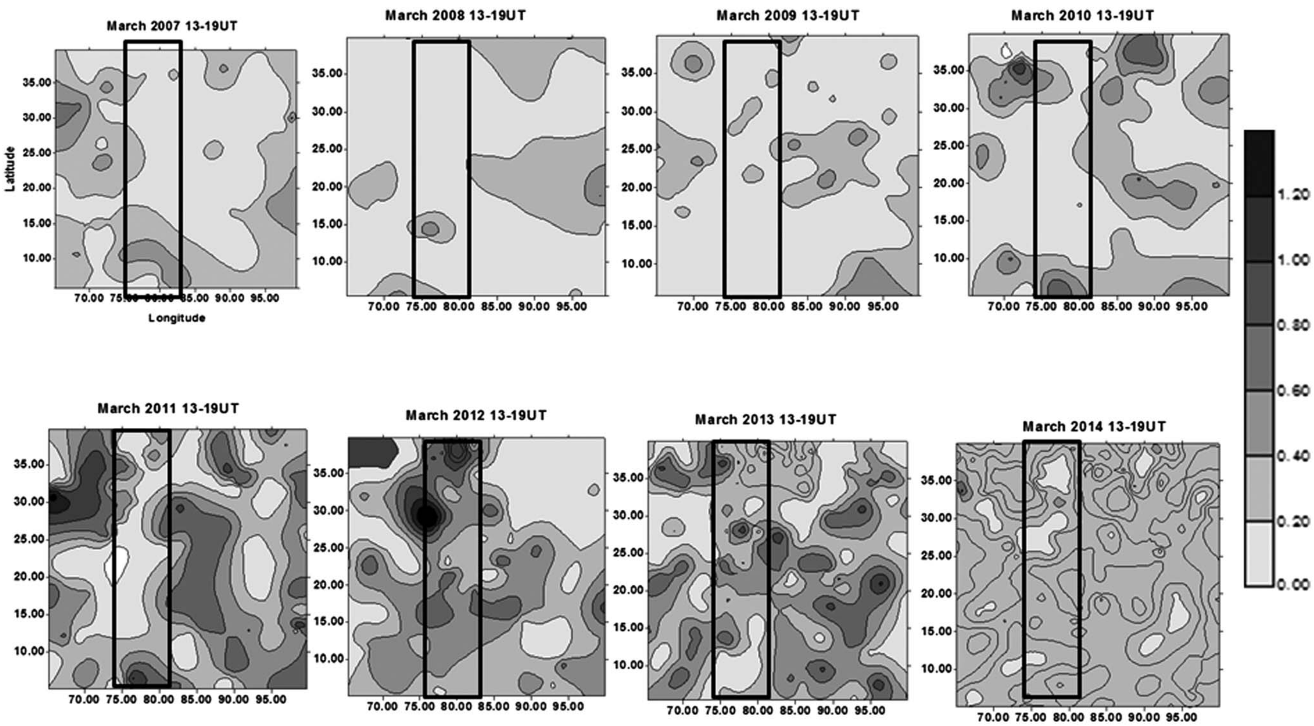

Figure 6. Maps of S_4 at different latitudes and longitudes over the Indian subcontinent for the period of 13:00–19:00 UT of the month of March for 2007–2014. The color scale indicating levels of scintillation is shown. All scintillation levels with $S_4 > 0.6$ are shown in black.

the equatorial and midlatitudes could be associated with ionospheric irregularities of midlatitude origin. Observations of plasma depletions by C/NOFS on consecutive orbits indicate a slow growth rate during premidnight hours, which may eventually reach the satellite altitude around midnight or postmidnight period [*Yokoyama et al*., 2011a, 2011b]. The role of the equatorward thermospheric wind which is responsible for the midnight temperature maximum may be important in creating a favorable condition for the growth of Rayleigh-Taylor instability around midnight. Postmidnight ionization depletions near the magnetic equator could be generated by polarization electric fields associated with ionospheric instability mechanism occurring in the midlatitudes [*Miller et al*., 2009] under magnetic quiet conditions. Present understanding of the physics behind ionospheric irregularities indicate prereversal vertical rise of the *F* layer, atmospheric gravity waves, and gravity wave manifestation as large-scale wave structure as possible triggering mechanisms. During solar minimum period, when gravity wave perturbations play the dominant role for instability growth over prereversal enhancement, onset of scintillations may be delayed to late evening or postmidnight hours [*Li et al*., 2011; *Abdu*, 2012]. However, it is important to note that the cases presented in this paper occurred under moderate-to-high solar activity conditions when the background ionospheric conditions necessary for seeding of ionospheric irregularities may not be dominated predominantly by gravity waves.

Transionospheric satellite signals at L band are affected by ionospheric irregularities of 300–400 m scale sizes primarily during local postsunset to midnight time interval. Thus, observations of scintillations at off-equatorial latitudes and locations beyond the northern crest of the EIA during postmidnight hours are often attributed to local generation of smaller-scale irregularities [*Li et al*., 2012]. Further, observations of L band scintillations during postmidnight hours may not be attributed to decaying irregularities or "fossil" bubbles. It has been suggested that remains of irregularities generated in the midlatitudes may move equatorward which may be feasible only when the equatorial electrodynamics becomes weak, as is the case during postmidnight hours [*Das et al*., 2014]. The weak strength of the equatorial electrojet during midnight and postmidnight periods is supposed to be conducive for movement of irregularities from higher latitudes toward the northern crest of the EIA [*Yokoyama et al*., 2011a, 2011b; *Miller et al*., 2009; *Das et al*., 2014]. However, these suggestions need further observations from ground-based continuous measurements over the latitude swath 20–40°N to establish any coupling mechanism between equatorial low and middle latitudes.

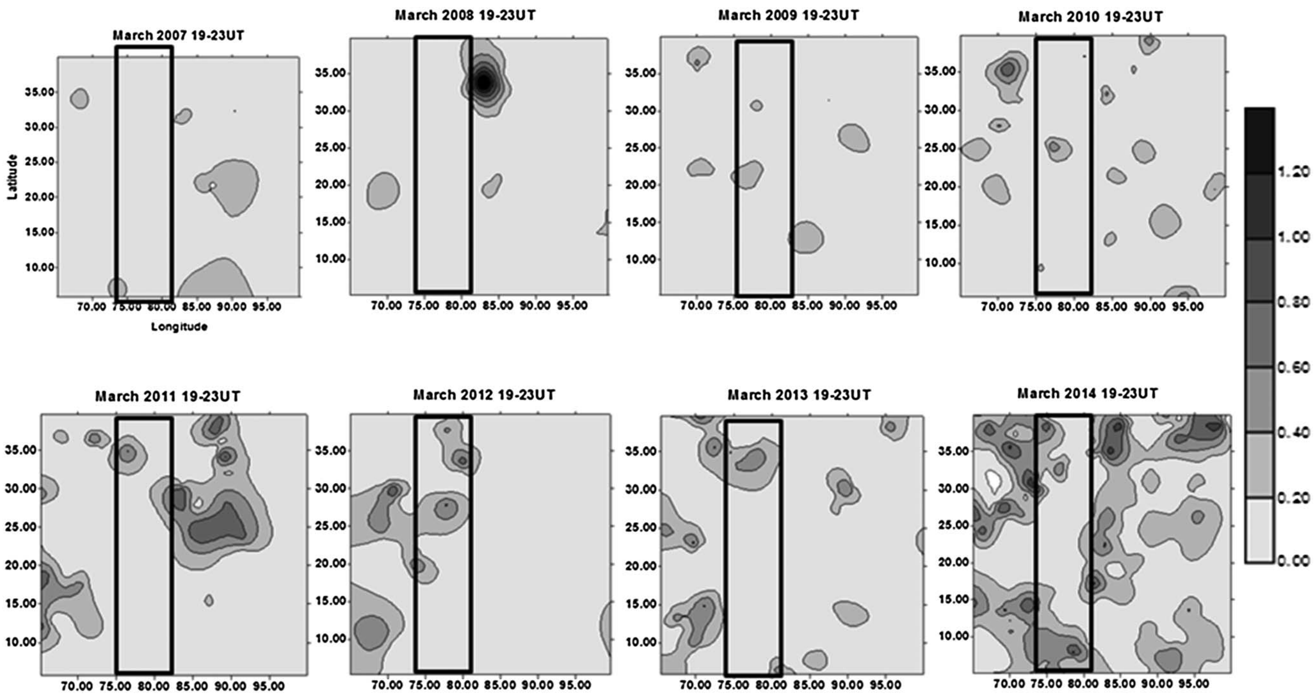

Figure 7. Maps of S_4 at different latitudes and longitudes over the Indian subcontinent for the period of 19:00–23:00 UT of the month of March for 2007–2014. The color scale indicating levels of scintillation is shown. All scintillation levels with $S_4 > 0.6$ are shown in black.

The results over the extended period of 2007–2014 indicate existence of a zone of weak or no scintillation covering the longitude swath 75–83°E over India for major part of the 8 year observation. This result is in good correspondence with the global four-cell pattern of longitudinal variability of the ionosphere [*Immel et al.*, 2006]. Observations of equatorial postsunset ionosphere through O^+ airglow measurements using the IMAGE FUV and TIMED GUVI have shown longitudinal wave number four-cell pattern in magnetic latitude and *F* region peak ion density at a particular local time [*Sagawa et al.*, 2005; *Henderson et al.*, 2005]. Observations with OGO-4 satellite have exhibited this pattern to be invariant in space over many days around the equinoctial period under magnetic quiet conditions during high sunspot number years [*England et al.*, 2006]. However, to the best of our knowledge, occurrence of a longitude swath of reduced ionospheric scintillation activity in the Indian longitude sector has not been reported earlier.

Acknowledgments
COSMIC scintillation data are available from the COSMIC Data Analysis and Archive Center (http://cdaac-www.cosmic.ucar.edu/cdaac/). C/NOFS CINDI data are provided through the auspices of the CINDI team at the University of Texas at Dallas (http://cindispace.utdallas.edu). IGS data are available from the website http://sopac.ucsd.edu. One of the authors (A.P.) acknowledges the support provided through scholarship under the Erasmus Mundas Leaders program of the European Union.

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