Indian Journal of Radio & Space Physics
Vol 42, December 2013, pp 397-403

Characteristic feature studies of integrated field intensity of sferics at North-East India

S Barui[1], S S De[1,$,*], D K Haldar[1], Suman Paul[1], G Guha[1], P Hazra[2] & A Ghosh[1]

[1]Centre of Advanced Study in Radio Physics and Electronics, University of Calcutta, Kolkata 700 009, India

[2]Electronics & Communication Engineering, Narula Institute of Technology, Agarpara, Kolkata 700 109, India

E-mail: de_syam_sundar@yahoo.co.in

Received 17 August 2011; revised 18 April 2013; re-revised received and accepted 6 November 2013

Some studies on the variations of integrated field intensity of sferics (IFIS) at 9 kHz are carried out at Mirik (lat 26.9°N, long 88.2°E), a hilly place of North-East India, under different seasonal conditions during January - December 2011. The recorded data are analyzed and interpreted. During locally clear days and nights, IFIS provides a regular behaviour, i.e. field strength remains constant but decreases gradually after the onset of rain. During short period showers, IFIS exhibits a sudden rise and gradual fall. An irregular variation in IFIS is observed with the coverage of roof height cloud mass.

Keywords: ELF-VLF sferics, Integrated field intensity of sferics (IFIS), Atmospheric noise

PACS No.: 92.60.Ta; 92.60.Pw

1 Introduction

Thunderstorms generate and separate electrical charges, whereas lightning neutralizes electrical charges. Simultaneous processes are operating within the environment of convective clouds that affect cloud electrification[1]. Charging of thunderclouds may be initiated by inductive or non-inductive processes.

An inductive process needs pre-existing electric field to induce charges on a particle so that when it rebounds from another charge, the field gets enhanced. Within the atmosphere, the fair weather electric field resulting from positive charges in the atmosphere and negative charges on the ground could be considered as the pre-existing field[2]. Satellite and air-borne instruments demand some other processes of charging.

Non-inductive processes are based on collisions between graupel particles and cloud-ice particles and on the selectivity to transfer charge of a certain polarity to other particles. Here, charge transfer occurs when ice crystals collide with simulated graupel particles within a cloud of super cooled water droplets[3]. In a thundercloud, the smaller ice-crystals are charged positively and move upward and the larger graupel particles are charged negatively which descend relative to the smaller particles[3,4]. This physical situation depends on the prevailing conditions of temperature, liquid water content and their mixing within the thunderstorm. Also, changing of solid particles can involve tribo-electric charging, charging by fracto emission and photoelectric charging[5].

The negatively charged graupel particles become larger in size by accumulating the water droplets and fall down under the action of gravity with huge negative charges. During the downward journey, the graupels carry negative charges within it up to the ground surface[3]. Some of these negative charges are released as negative space charge in the lower zone of thundercloud that forms some stratification of charge centers. Due to convection, negative and positive charge centers mixed up randomly and produce discharge phenomena in the form of lightning[4,6]. Due to the updraft, the upper part of the thundercloud with positively charged regions goes upward up to the lower ionospheric height and joins the global electric circuit, thereby, introducing itself as the generator.

Sferics are trapped between lower boundary of the ionosphere and ground; and propagate over long distances through the Earth-ionosphere waveguide with very less attenuation. The source-detector distance, transmission conditions in the atmosphere, nature of dielectric properties in the medium and type of discharge can primarily affect the amplitude and waveforms of the sferic signals[7]. Propagation of long range radio waves below 60 kHz is the Earth-ionosphere waveguide problem. VLF atmospherics from thundercloud is studied extensively[8]. The effects of geophysical events in the records of sferics or transmitted sub-ionospheric signals could be observed and analyzed. The atmospherics are significant with regard to electrical phenomena in different types of cloud during meteorologically active periods. IFIS measurements are expected to provide different features for the study of ionospheric propagation[9]. Lightning activity may be taken as an agent for global temperature change[10]. Long term changes in lightning activity can be found through their effects on global electric circuit as known from Schumann resonance[10,11] as well as through remote sensing of lightning source region[12]. Such observations can give the outcome of global change.

ELF-VLF sferics are mainly produced during lightning discharge by cloud to ground (CG) discharges[13,14]. CG strokes have much longer discharge path, i.e. larger current moments that produce more ELF sferics[15-17].

It is difficult to study the characteristics of ionospheric D-region because of low electron densities (~10^9 m^{-3}) and high electron-neutral collision frequencies (~10^6 s^{-1}). But VLF waves are reflected from the D-region and for this, VLF waves are treated as a tool to explore information regarding this region[7,18]. Studies with tweeks to investigate the D-region of ionosphere have also been performed by many researchers[19-22].

The three centers of global lightning activities are located at South Africa, Central and South America, and South Eastern Asia. Local meteorological condition, seasonal condition and geographic locations are much affected by thunderstorm activities. During meteorologically active periods, the impulse-like lightning signals (sferics) have important significance in regard to electrical phenomena occurring in different types of clouds. IFIS measurement provides different signatures in the study of ionospheric propagation[23,24]. The attenuation of signal in ELF range is very less, which is as low as 10 dB or less per 10 km (Ref. 25).

The electrical status of cloud is the decisive factor of atmospheric radio noise due to sferics. The experimental study of ELF-VLF sferics in the North-Eastern part of India is scanty. The growth and decay of electrical activity in thundercloud over hilly places are still to be studied in detail. During the local monsoon and local thunderstorms, IFIS characteristics are modulated and the nature of modulation varies from one place to the other and also with latitude[26]. During the months of April and May, short duration severe thunderstorms occur mainly in the Eastern and North-Eastern part of India as well as in Bangladesh. The storms are mainly due to the formation of low pressure region during the summer season. The wind speeds are within the range 60 - 95 km h^{-1}. Moreover, there are more precipitations from cumulonimbus clouds having durations of 10-20 min (Ref. 27).

The purpose of this work is to investigate the nature of variation of IFIS with short duration, which is peculiar event in the North-Eastern part of India. To explore it, the IFIS at frequency 9 kHz are recorded at Mirik during 01 January - 31 December 2011. Here, the outcome of the study of the measurements of lightning characteristics during tropical thunderstorms at Mirik is reported. It is found that VLF electromagnetic waves are generated primarily by CG discharge produced by overhead cumulonimbus cloud. Some specific characteristics observed in the diurnal variation of IFIS are also reported. Different types of cloud are observed during the measurements.

The geographical position of Mirik is suitable for IFIS investigations from local cloud discharges as well as from the distant three sources at Australia, Japan and Africa. It is one of the hill stations of India with a big natural lake. Mirik is situated at an altitude of 1767 m from the sea level. Maximum temperature is 29° C in summer and 13° C in winter. Average rainfall is ~280 cm annually. The location of Mirik is in between the base of the Himalayas and the Bay of Bengal. The position is quite good to explore various characteristics of thunderstorms. The experimental site is situated in the plane area at a distance of few km from the nearest town, free from any type of industries, and dense locality. So, the occurrences of man-made and other industrial noise are not possible. There are no other observations conducted along with this experiment. The power supply system for the receiver is thoroughly checked and no fault or any leakage was detected. It is very prone to rainy weather, even in winter. The features of IFIS are, therefore, expected to be somewhat different from the worldwide average.

2 Experimental setup

The schematic diagram of the experimental arrangement is shown in Fig. 1. The voltage induced

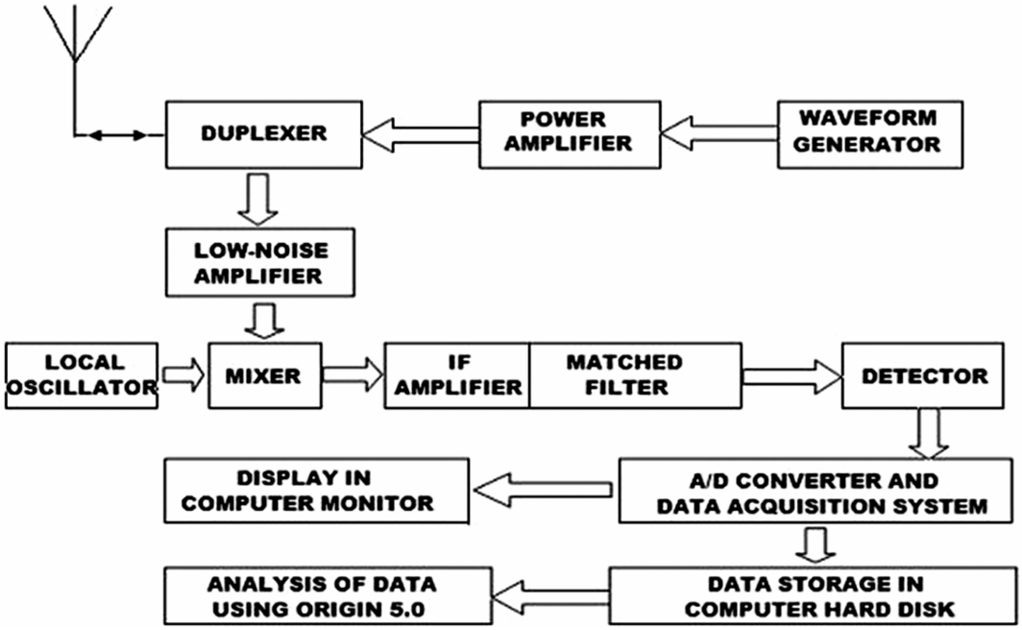

Fig. 1 — Schematic diagram of ELF-VLF receiver at Mirik

in a 2 m long vertical antenna made of copper wire has been amplified using AC amplifier with 60 dB gain. The output of the AC voltage is interfaced with a computer through a buffer having bandwidth 1-20 kHz. An automatic gain control circuit is used to adjust the range of the amplifier. Data are stored in a computer via radio-sky-pipe data acquisition system. White atmospheric radio data have been collected during 01 January - 31 December 2011 under different physical situations, e.g. clear sky, rainfall, presence of roof height clouds, etc.

3 Observations

The average diurnal variations of the IFIS at 9 kHz during 01 January - 31 December 2011 are presented in Fig. 2. The signal strength (intensity level) starts to decrease from midnight and goes on decreasing till the minimum is reached at around 08:00 hrs IST. Up to midday, the signal strength remains low. During afternoon, the signal strength increases and attains maximum towards the evening. After sunset, the signal strength decreases slightly and remains almost constant till midnight. The maximum value is found during the afternoon when the discharge of intra-cloud (IC) is high. This observation is similar to those obtained at plane land during clear days.

Figure 3 depicts the mean level of atmospherics in a clear day on 23 March 2011, where steady signature over the main part of the day is seen. The present record is devoid of incidents like rain, shower, thunderstorm and cyclone[28]. The strength is almost 4 dB lower compared to the average of 4 days observations. This situation is rare in Mirik during mid March to June. It is interesting to note that during the midnight from 22:00 hrs to 02:00 hrs IST of 12 August 2011, the noise level exhibited sudden fall followed by the effects of recovery. The average duration of this type of fading in atmospheric noise is about 10-15 minutes. Figure 4 represents four such fadings. The lowest value is about 2.5 dB whereas the highest is around 5 dB.

During the onset of overhead shower, the atmospheric radio noise level decreases rapidly to a very low value. The level recovers after the end of the rain. Two such events are shown in Fig. 5 caused on 25 July 2011. Left side of the figure corresponds to rain at the midday, whereas the right side is due to the rain at the late midnight (dawn). The duration of midday rain was about 25 min while during nighttime, it was around 15 min. It is noted that the amount of fall in atmospheric radio noise related to midday rain is about 2 dB, which is about 3 dB related to nighttime rain.

During pre-midday and midday hours on 16 September 2011, the cloud height at Mirik was very low (may be called ‘roof-height’ clouds). Quite a good number of high buildings were covered by cloud masses (cloud masses are formed by liquid droplets or frozen crystals made of water as well as different aerosols suspended in the atmosphere, i. e. the total mass of cloud ice in the mixed phase region of the storm, with little size dependence). The day was almost dark. The atmospheric level was not steady. The atmospheric radio noise showed anomalous zig-zag variations of nearly 2 dB (Fig. 6).

The average seasonal variations of IFIS at 9 kHz over Mirik during 01 January - 31 December 2011 are presented in Fig. 7. It showed maximum level during July-August, whereas it attained normal level throughout the year.

In the present analysis, only those attenuations are considered which are related to rain. Analyses of LF signals by considering large data of rain and its relative abundance would reveal the optimum condition for the attenuation of LF wave by a heavy shower. The observational results are the manifestations of electrical status of the precipitating cloud over Mirik.

4 Discussion

The occasional sudden fall in atmospherics (Fig. 2) during clear nights may be due to the propagational effects. VLF radio waves are mostly scattered during daytime from different layers of the ionosphere. Although the reflections of those waves during nighttime gets more concentrated due to absence of D-layer and the merging of ionospheric F_1-F_2 layer. The presence of fair weather condition in the atmosphere and the reduction of the aerosol particles at midnight period affect the value of the signal strength at the receiver. As a result, the signal strength increases and attains its maximum value usually at late midnight (dawn). At night, E-region is occasionally perturbed due to the formation of

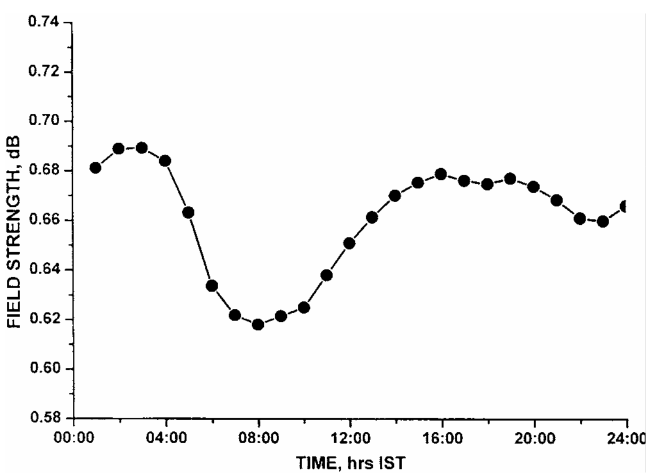

Fig. 2 — Average variations of integrated field intensity of sferics at 9 kHz over Mirik during 01 January - 31 December 2011

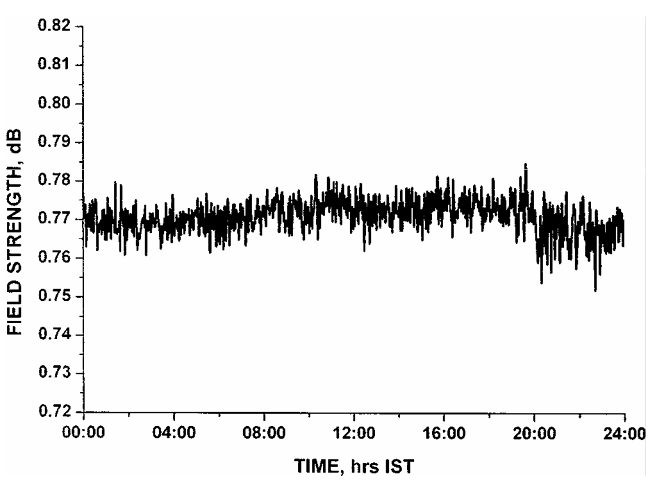

Fig. 3 — Diurnal variations of atmospherics at 9 kHz over Mirik on a typical clear day on 23 March 2011

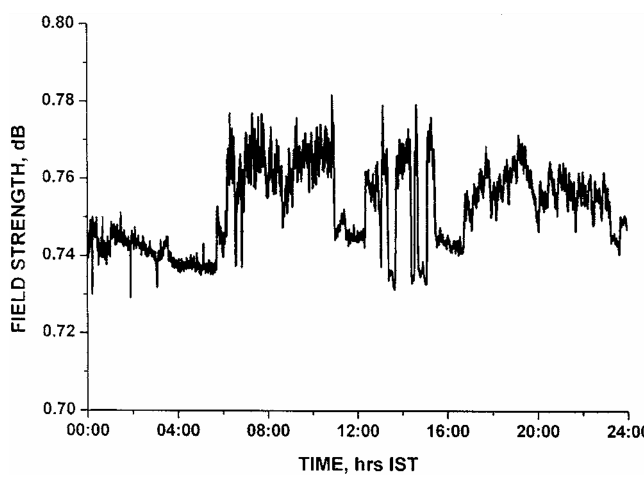

Fig. 4 — Occasional sudden fall of atmospheric signals at 9 kHz on 12 August 2011

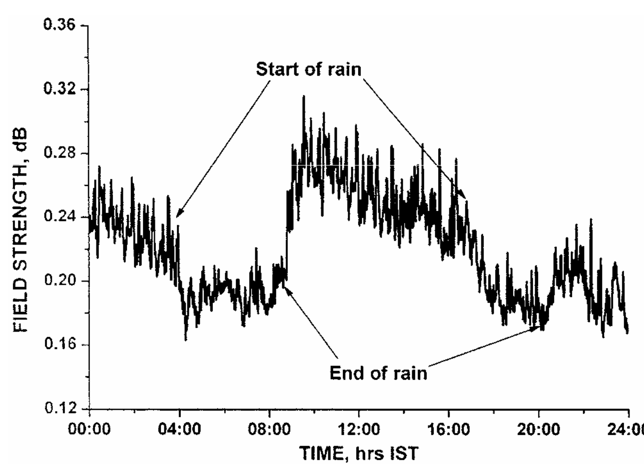

Fig. 5 — Fall in sferics field strength with the onset of rain at late midnight (dawn) and also at the beginning of night (dusk) on 25 July 2011

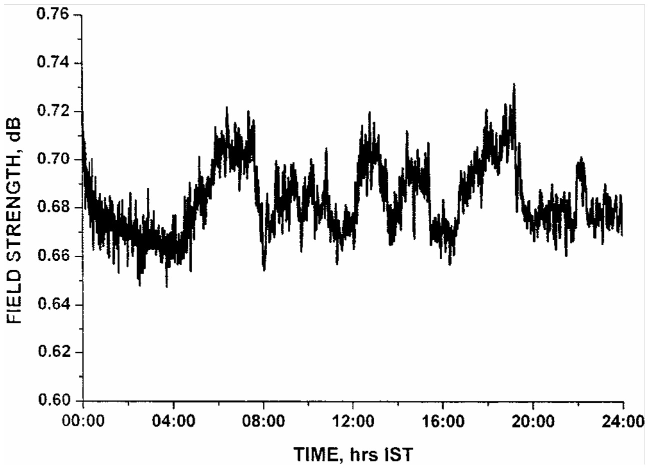

Fig. 6 — Anomalous zig-zag variation of atmospheric signals at 9 kHz on 16 September 2011 with the appearance of roof-height clouds

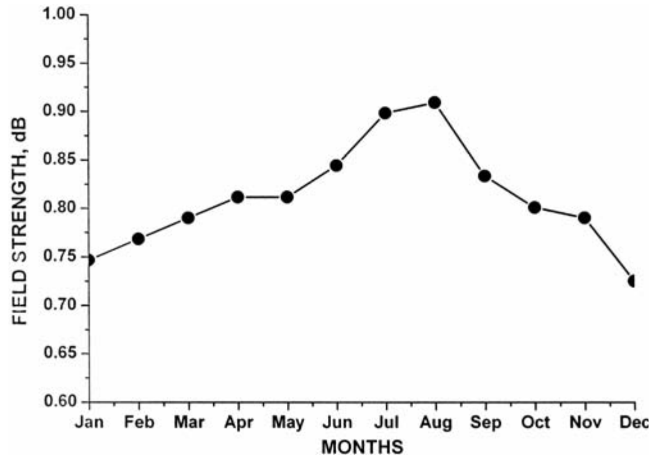

Fig. 7 — Seasonal variations of integrated field intensity of sferics at 9 kHz over Mirik during 01 January - 31 December 2011

sporadic-E (E_s) layer. During midnight, E_s layer is expected to cause scattering of radio waves so that the magnitude of Poynting vector decreases and as such attenuation is observed. The signal returns back to its normal value when the E_s-layer passes through the reflecting zone of E-layer.

The fall in atmospheric radio noise with the onset of rain (Fig. 5) is due to drainage of charge from upper region of cloud to the lower region, thereby, lowering the potential difference between top and bottom of cloud. As a result, the rate of IC discharges decreases. This signature may be due to the fading of atmospherics with the onset of shower.

A small linear displacement of roof height cloud is associated with its large angular displacement with respect to receiver's point of view. In a hilly place, appearance of roof height cloud is an occasional phenomenon. Also, mesoscale convective system (MCS) might be present near the observation site. The heaps of cloud masses passed over the receiver in the direction of wind velocity. The approach of cloud mass increases the noise level. Gradually, the angular distance went on increasing and the noise level decreased. The zig-zag variation is due to the passage of the sequence of different clouds through the overhead receiver. In the MCS system, these types of features are also possible.

July-August is the most effective months of monsoon season in West Bengal. During monsoon season, the occurrences of the thunderstorms and lightning are increased significantly. Also, the location of the Asia-Australia thunderstorm centre is nearer to Mirik than the other thunderstorm regions. So, the influences of these affect more in the value of the 9 kHz signal over Mirik (Fig. 7).

It is seen that the nighttime level of IFIS is typically 10 dB greater than the daytime level. At night, ELF-VLF signals are reflected from the lower E-region due to the absence of D-region. After sunrise, the electron density beneath the E-region increases. The deflection height decreases with time due to the gradual formation of D-region. Constructive interference would occur between different modes. The ELF-VLF signal level somewhat decreases due to well known sunrise effect[18,29]. During all the seasons, the ELF-VLF sferic signals are highest in a day in the afternoon and late afternoon period. During clear day, IFIS remains steady. The daily maximum and daily minimum of average IFIS are highest during monsoon[30]. Daily minimum usually occurs around 08:30 to 10:00 hrs IST. After the onset of the rain, IFIS decreases appreciably and then gradually increases to its previous level when the rain would cease. Some anomalous variation of IFIS is observed with the coverage of roof-height cloud mass.

The electrical conductivity of the middle atmosphere changes by many orders of magnitude from troposphere to mesosphere. The electrical properties of the atmosphere depend on the density of neutral particles, the density of the ionospheric particles and the presence of geomagnetic field. Atmospheric electrical conductivity increases with height.

The lightning activity is mostly marked in the surrounding of the inter-tropical convergence where the troposphere reaches its maximum height and the convection is most energetic. In these regions, IC lightning plays the key role in the effective lightning activities. These sources may excite higher transverse electric and transverse magnetic modes[31]. Because of different locations of the lightning centers, the influences of global thunderstorm activity zones are different for which the annual intensity variations at different latitudes are not same.

Satellite observations show great variability in the longitudinal distribution of thunderstorm activity centres along with their temporal and seasonal variations. Observations of global lightning distribution during January 1998 - February 2005, taken from LIS (Lightning Imaging Sensor), NASA[32], confirm that the thunderstorm activity in Himalayan region is more prominent than Asia-Australia region. The global variations of thunderstorm activity centers change the source-receiver distance which may be the reason for seasonal and temporal variations in the amplitude of sferics[33].

5 Conclusion

Variations of IFIS at 9 kHz have been recorded at a hilly place of North-East India for a period of one year. The outcome of the analyses showed some unusual characteristics and are reported here. These types of investigations have been carried out for the first time at the Eastern and North-Eastern part of India. Looking towards the anomalous characteristics, it is convinced that prolonged data for several years should be taken continuously at this place to justify the nature of variations of IFIS. Further investigation in this area is contemplated in the near future.

Acknowledgement

The authors acknowledge the support from Indian Space Research Organisation (ISRO) for carrying out this research through S K Mitra Centre for Research in Space Environment, University of Calcutta, Kolkata, India. They are thankful to the Director, S K Mitra Centre for Research in Space Environment, University of Calcutta. They also gratefully acknowledge the suggestions and comments of the learned reviewers which helped to improve the content of this manuscript.

References

1 Stolzenburg M & Marshall T C, Charge structure and dynamics in thunderstorms, *Space Sci Rev (USA)*, 137 (2008) 355.
2 Brooks I M & Saunders C P R, An experimental investigation of the inductive mechanism of thunderstorm electrification, *J Geophys Res (USA)*, 99 (1994) 10627.
3 Berdeklis P & List R, The ice crystal-graupel collision charging mechanism of thunderstorm electrification, *J Atmos Sci (USA)*, 58 (2001) 2751.
4 Baker M & Nelson J, A new model of charge transfer during ice-ice collisions, *Appl Phys (Germany)*, 3 (2002) 1293.
5 Saunders C P R, Charge separation mechanisms in clouds, *Space Sci Rev (USA)*, 137 (2008) 335, doi: 10.1007/s11214-008-9345-0.
6 Jungwirth P, Rosenfeld D & Buch V, A possible new molecular mechanism of thundercloud electrification, *Atmos Res (UK)*, 76 (2005) 190.
7 Tomko A A & Hepner T, Worldwide monitoring of VLF-LF propagation and atmospheric radio noise, *Radio Sci (USA)*, 36 (2001) 363.
8 Rakov V A & Uman M A, *Lightning: Physics and effects* (Cambridge University Press, Cambridge), 2003, pp 67-93.
9 Ferguson J A, Ionosphere model variation at VLF and LF, *Radio Sci (USA)*, 30 (1995) 775.
10 Williams E, The Schumann resonance: A global tropical thermometer, *Science (USA)*, 256 (1992) 1184.
11 Nickolaenko A P, Hayakawa M & Hobara Y, Long-term periodical variations in global lightning activity deduced from the Schumann resonance monitoring, *J Geophys Res (USA)*, 104 (1999) 27585.
12 Watkins N W, Bharmal N A, Clilverd M A & Smith A J, Comparison of VLF sferics intensities at Halley, Antarctica, with tropical lightning and temperature, *Radio Sci (USA)*, 36 (2001) 1053.
13 Burke C P & Jones D L, An experimental investigation of ELF attenuation rates in the Earth-ionosphere duct, *J Atmos Terr Phys (UK)*, 54 (1992) 243.
14 Barr R, Jones D L & Rodger C J, ELF and VLF radio waves, *J Atmos Sol-Terr Phys (UK)*, 62 (2000) 1689.
15 Teer T L & Few A A, Horizontal lightning, *J Geophys Res (USA)*, 79 (1994) 3436.
16 Siingh D, Singh R P, Singh A K, Kumar S, Kulkarni M N & Singh A K, Discharge in stratosphere and mesosphere, *Space Sci Rev (UK)*, 169 (2012) 73, doi: 10.1007/s11214-012-9906-0.
17 Neubert T, Rycroft M, Farges T, Blanc E, Chanrion O, Arnone E, Odzimek A, Arnold N, Enell C-F, Turunen E, Bösinger T, Mika Á, Haldoupis C, Steiner R J, van der Velde O, Soula S, Berg P, Boberg F, Thejll P, Christiansen B, Ignaccolo M, Fu¨llekrug M, Verronen P T, Montanya J & Crosby N, Recent results from studies of electric discharges in the mesosphere, *Surv Geophys (USA)*, 29 (2008) 71, doi: 10.1007/s10712-008-9043-1.
18 Clilverd M A, Watkins M W, Smith A J & Yearby K H, Diurnal and annual variations in 10 kHz radio noise, *Radio Sci (USA)*, 34 (1999) 933.
19 Maurya A K, Singh R, Veenadhari B, Kumar Sushil, Cohen M B, Selvakumaran R, Pant P, Singh A K, Siingh D & Inan U S, Morphological features of tweeks and nighttime D region ionosphere at tweek reflection height from the observations in the low-latitude Indian sector, *J Geophys Res (USA)*, 117 (2012) 1, doi: 10.1029/2011JA016976.
20 Singh R N, Singh R P, Singh U P & Singh A K, Some features of low latitude second and third harmonic tweeks, *Indian J Radio Space Phys*, 21 (1992) 377.
21 Kumar S, Dixit S K & Gwal A K, Propagation of tweek atmospherics in the Earth-ionosphere waveguide, *Nuovo Cim (Italy)*, 17C (1994) 275.

22 Singh A K & Singh R P, Propagation features of higher harmonic tweeks at low latitude, *Earth Moon Planet (Netherlands)*, 73 (1996) 277, doi: 10.1007/BF00115886.

23 De B K, Pal M, De S S, Bera R, Adhikari S K, Guha A & Sarkar S K, Studies on the integrated field intensity of ELF-VLF sferics at Tripura, India, *Indian J Radio Space Phys*, 34 (2005) 408.

24 De S S, De B K, Adhikari S K, Sarkar B K & Guha A, Study of amplitude spectrum of VLF sferics and vertical electric field at Kolkata, *Indian J Radio Space Phys*, 35 (2006) 187.

25 Cummer S A, Modeling electromagnetic propagation in the Earth-ionosphere waveguide, *IEEE Trans Antenna Propag (USA)*, 48 (2000) 1420.

26 Thomson N R & Clilverd M A, Solar cycle changes in day time VLF sub-ionospheric attenuation, *J Atmos Sol-Terr Phys (UK)*, 62 (2000) 601.

27 Storm: Severe thunderstorms observations and regional modelling, *http://www.imd.gov.in/SciencePlanofFDPs/storm/ genesis.html*.

28 Kumar P P, Power spectrum analysis of sferics from lightning, *Indian J Radio Space Phys,* 21 (1992) 149.

29 De S S, De B K, Bandyopadhyay B, Guha G, Paul S, Bhowmick A, Haldar D K, Chattopadhyay G & Sanfui M, Studies on the Variations of ELF Atmospherics over Kolkata, *Bulg J Phys (Bulgaria)*, 37 (2010) 37.

30 Saunders C P R, Keith W D & Mitzeva R P, The effect of liquid water on thunderstorm charging, *J Geophys Res (USA)*, 96 (1991) 11007.

31 Magunia A, The thunderstorm-driven diurnal variation of the ELF electromagnetic activity level, *J Atmos Terr Phys (UK),* 58 (1996) 1683.

32 The lightning imaging sensor, *http://thunder.nsstc.nasa.gov/ bookshelf/pubs/LIS_ICAE99_Print.pdf*.

33 Christian H J, Blakeslee R J, Boccippio D J, Boeck W J, Buechler D E, Driscoll K T, Goodman S J, Hall J M, Koshak W J, Mach D M & Stewart M F, Global frequency and distribution of lightning as observed from space by the optical transient detector, *J Geophys Res (USA)*, 108 (2003) 4005, doi: 10.1029/2002JD002347.