J.Ind.Geophys. Union, 24(3) (2020), 25-31

Measurement of Maxwell's current density from a tropical station during severe lightning disturbances and fair-weather days of 2019

C.P. Anil Kumar*, N. Venkatesh, C. Panneerselvam and C. Selvaraj
Equatorial Geophysical Research Laboratory, Indian Institute of Geomagnetism, Krishnapuram, Tirunelveli-627 011, India.
*Corresponding author: cpanil@iigs.iigm.res.in

ABSTRACT

A study of the global electric circuit can help us to understand the electrical environment of the Earth's atmosphere. This approach provides a good frame work for exploring interconnections and coupling of various regions of the Earth's upper atmosphere. With the aim of understanding the behaviour of air-Earth current system during severe meteorological disturbances, we carried out observations of Maxwell's current (air-earth current) for a short period during lightning hours and fair weather days of 2019 at an equatorial station Tirunelveli (8.7^0 N, 77.8^0 E), located in southern part of India. Unusual lighting activity was noted during the peak summer of 2019 over this location and corresponding electric variability in air-earth current amplitude and phase charge in electric field were measured. During fair weather days, the current density is only a few pico amps; however, a tenfold increase in the current density was noted during disturbed weather conditions. Our analysis indicates that a rise in temperature led to enhanced convection during mid-day hours, which in turn, contributed to source activity. Possibly, this is the first report that brings out that the rise in temperature is covariant to source activity. We found the wind flow to be moderately southwesterly during the period of observation.

Keywords: Global electric circuit, Atmospheric electricity, Maxwell's current density, Lightning disturbances, Tirunelveli

INTRODUCTION

Notable experiments were carried out by Lord Kelvin during 1860s (Aplin and Harrison, 2013). Since then a new regime of geophysics termed as "Atmospheric Electricity" started. In 1902, Kennelly suggested that an electrical conducting layer existed in the upper part of the atmosphere and was called "electrosphere" (now known as the "ionosphere") (Rycroft et al., 2012). Kennelly further suggested that a spherical capacitor is formed between the Earth's surface and the aforesaid conducting layer in the upper atmosphere. Several measurements have shown that the actual value of the average potential of the ionosphere is above about 250 kV and it fluctuates on a temporal and spatial scale on fair-weather days, mainly due to worldwide lightning activity (Kasemir, 1955; Chaimers, 1967; Kamra, 2001; Raina, 2002; Panneerselvam et al., 2007; Anil Kumar et al., 2009, 2017; Rycroft et al., 2012). Fair weather day in atmospheric electricity studies, is defined as a day without rainfall, having wind speed less than 5 m/s and cloud coverage less than 3 octas. During the fair weather, the electric potential gradient is expressed as:

$$F = \frac{dV}{dh}, \qquad F = -\frac{\sigma}{\varepsilon_o} \qquad \dots (1)$$

where V is the potential; F, the potential gradient; h, the vertical distance from the Earth's surface, σ, the conductivity and ε_o, the -permittivity of free space. Electrometers have been widely used to measure this potential difference between the conductor and the Earth's surface (Rycroft et al., 2012 and references cited therein). Further, during fair weather, the diurnal variation of the air-earth current shows, significant variations mostly due to the change of space charge of the lowest layers of the atmosphere. Space charges are carried by small ions, large ions, dust particles, clouds, precipitation charges, etc. Overall process can be taken to be a pileup of charges due to conductivity gradient. Next, the density of space charge 'ρ' is related to the potential gradient as $\varepsilon_o \frac{dF}{dh} = -\rho$ (Rycroft et al., 2012 and references cited therein). While long-term investigations agree well with the Carnegie curve, (Ralph Markson, 1978), short-term investigations have indicated considerable deviations from this standard curve (Clayton and Polk, 1977; Jeeva et al., 2016). Several attempts have been made to study atmospheric electrical parameters under different meteorological, geophysical and space-weather conditions in the context of the Indian subcontinent (Monohar and Kandalgaonkar, 1995; Kamra et al., 1997; Dutta and Bhattacharya, 2004; Kar et al., 2004: Panneerselvam et al., 2007, Anil Kumar et al., 2009, 2013). Monohar and Kandalgaonkar (1995) studied the effects of thermal power plant emissions on atmospheric parameters. Kamra et al. (1997) investigated the effects of relative humidity on the electrical conductivity of marine air. Datta and Bhattacharya, (2004) shed light on the air-earth current during severe meteorological disturbances. Panneerselvam et al. (2007) studied the diurnal variation of atmospheric Maxwell current over a low latitude station Tirunelveli. Over the same tropical station, Anil Kumar et al. (2009) reported the measurement of atmospheric conduction current density using improvised Wilson's plate antenna. Next, Anil Kumar et al., (2013) investigated the behaviour of atmospheric electric parameters and micro-meteorological process during the solar eclipse of 15 January, 2010.

With the objective of understanding the characteristics of the air-earth current systems during severe meteorological disturbances associated with lightning, we carried out measurements of Maxwell's current for a short period during lightning hours on 23 May, 2019 and 29 May, 2019 over a low latitude station Tirunelveli. This laboratory has a history of two decades of studies in atmospheric electricity over the Indian subcontinent. Unusual lighting activity was noted on the aforesaid days of the peak summer over Tirunelveli and corresponding electric variability in the air-earth current amplitude and the measured phase change. We also present the averaged pattern of the current density on fair weather days of 2019.

INSTRUMENTATION AND METHODS

We have carried out measurements of the air-earth current and electric field over Tirunelveli using a horizontal long wire antenna (HLWA) and an electric fill mill (EFM). Tirunelveli is located 30 m above the mean sea level (AMSL) and is close to the southern tip of peninsular India. Observational site is chosen for being pollution-free and has less convective activity, thereby allowing non-masking of global electrical signals. Further, this site is in the non-radioactive zone and has a flat landscape with no multi-storied buildings or trees near HLWA. Weather measurements were done using a co-located Automatic weather station (AWS). We indigenously developed sensors, filters and electrometers used in this study and the observations were carried out after a proper calibration of the setup for the air-earth current studies. A detailed description of the experimental set up is given below.

HLWA experimental setup

One, among the common ground-based sensors used for the air-earth current measurements is the HLWA (Kasemir, 1955; Kasemir and Ruhnke, 1959; Ruhnke, 1965; Raina, 2002; Panneerselvam et al., 2007). An advantage with this long-wire antenna is that it allows the suppression of local disturbances by averaging the vertical current over a larger area. HLWA, when placed in the atmosphere closely follows the electrical current variations of the air-earth environment after the initial net charge on the antenna leaks off. When the antenna is shorted to the ground through a resistor, it picks up a certain amount of current, proportional to the Maxwell current density (Ruhnke, 1965). In this study, we use this technique for the air-earth current measurements. HLWA is comprised of a long tinted copper wire antenna of length 144 m and 3 mm diameter. It is horizontally fixed 1 m above the ground by means of isolated masts that are electrically separated using Teflon rods. It is worth mentioning here that the feedback resistance of the electrometer should be always smaller than the resistance of the electric source measured for current measurement of using this antenna. We set the RC time constant of the HLWA electrometer circuit as per scientific requirements. Figure 1 presents the circuit diagram of this electrometer using Op-Amp AD 549. Under controlled conditions, we carried out the calibration of this electrometer using Keithley calibration instruments and the I-V characteristics are linear. Next, a buffer stage (LM308) is connected to the electrometer output. Output signals are filtered by a low pass filter (3 dB) and the filtered signal is fed to 12 bit high resolution Windows based data logging system. We have used 1 min and ½ hourly averaged of data for analysis.

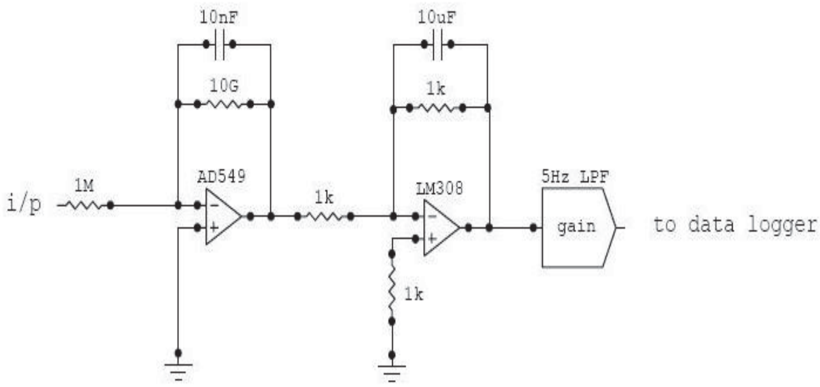

Figure 1. HLWA Electrometer Circuit

Current measurements using HLWA

Assuming that the electric field lines are converging and falling straight onto the copper wire, the total current collected by HLWA can be split into three components viz. (i**)** conduction current, J_{cd}, (ii) convection current, J_{cv}, and (iii) displacement current, J_d (due to a time-varying electric field) (Chaimers, 1967). Next, the current density is estimated using the following static effective area formulation proposed by Tammet et al., (1996):

$$S = \frac{hC}{\varepsilon}, \qquad \ldots(2)$$

Where, Є= dielectric constant of air, C = capacity of the antenna, h = height of the antenna above ground. As such, the effective area of HLWA is estimated to be ~158 m^2. Next, the total current density was estimated by dividing the measured current by this effective area of the antenna.

EFM measurements

An atmospheric electric field is one of the key parameters in the global electric circuit. Electric field mill (EFM) is a specialized electro-mechanical instrument used for measuring the strength of the electric field in the atmosphere. In order to measure the vertical electric fields over Tirunelveli, an EFM, made up of non-magnetic stainless steel was deployed facing upward. EFM device is based on the principle of electrostatic induction and primarily consists of two electrodes. Figure 2 presents the schematic of EFM installed at Tirunelveli. One of them is exposed to the atmospheric electric field and has rotating vanes due to which shielding and unshielding of the field takes place. When the sensor is alternately exposed and shielded from the electric lines of force, the surface charge induced on the sensor is a time varying function of the electric field. Thus, the induced electric current, which flows to secondary sensor electrodes, is proportional to the strength of the electric field. Higher electric field develops whenever there is a remarkable difference in the overhead electric potential. Next, a charge amplifier measures the charge collected in the secondary electrode and output is transferred to the measuring device through a multiplexer. Further details of the EFM are available at http://www.boltek.com.

AWS measurements

Meteorological parameters like wind speed, wind direction, temperature and humidity were done with AWS, installed about 100 m away from HLWA and EFM, with a 1 second sampling rate. We carried out visual scanning of sky conditions for cloud coverage less than 3 octas overhead during daytime. It is worthy to mention here that moderate southwesterly winds blow over this station during April-May.

RESULTS AND DISCUSSION

Table 1 presents the list of fair weather days over Tirunelveli during 2019. Figure 3 presents the general pattern of diurnal behaviour of ambient electric field (measured by EFM) and air-earth current density (measured by HLWA) during the fair weather days of 2019. Electric field variations are shown in the top panel; the bottom panel represents the current density measurements. A minimum in both ambient electric field and current density can be noted about 0300 h UT. Next, two peaks in current density can be seen during 1800-1900 h and 2100-2200 h. Electric field variations are marked by a gradual increase beyond 1500 h, followed by a peak about 2200 h.

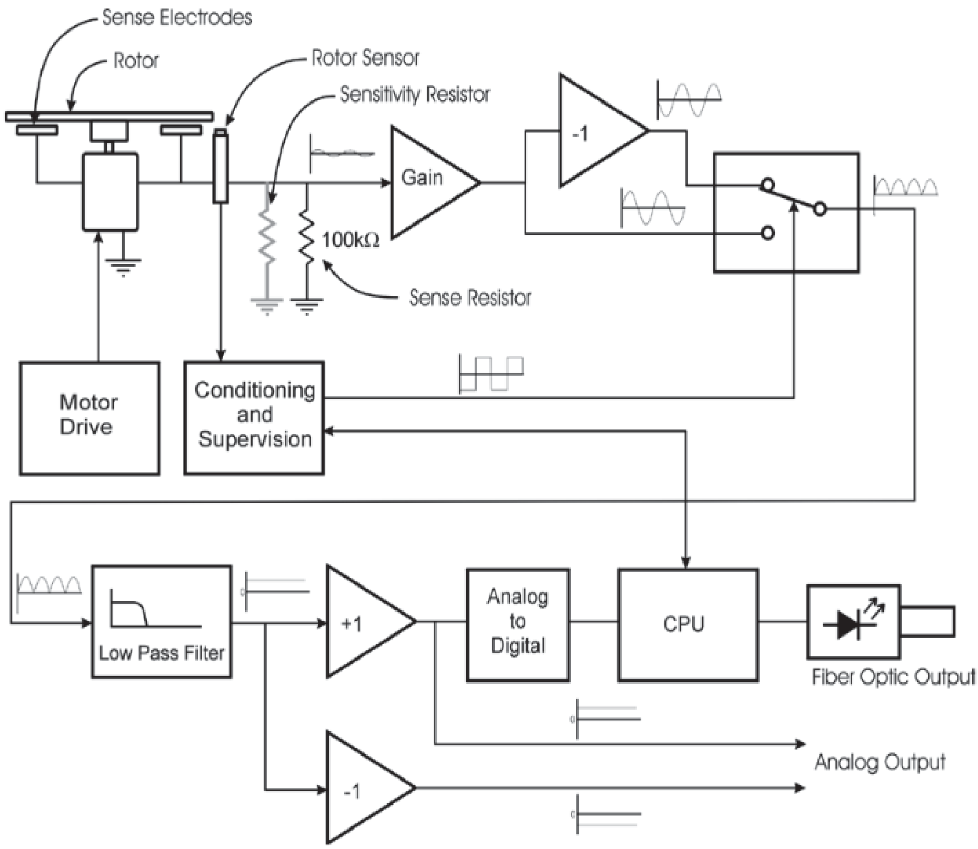

Figure 2. Schematics of EFM installed at Tirunelveli

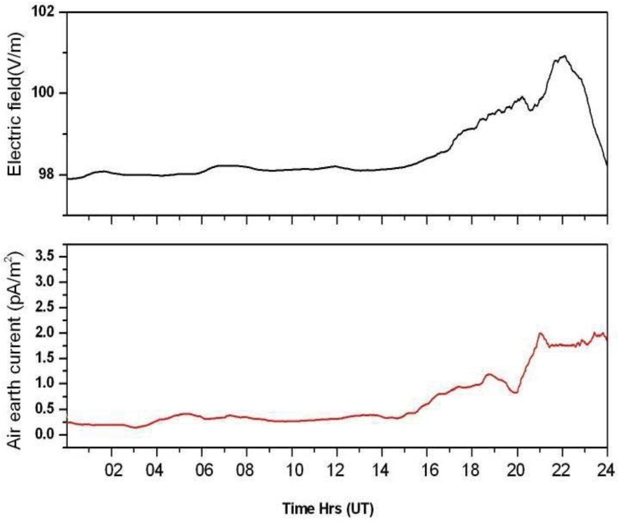

Figure 3. General behaviour of electric field (top panel) and air-earth current (bottom panel) observed at Tirunelveli on the fair weather days.

Table 1. List of fair-weather days during 2019

Fair weather	Jan -2019	Feb-2019	March -2019	April-2019
Wind speed less than 5m/s. No precipitation. Cloud coverage is Less than 3 octas.	Jan-09 Jan-10 Jan-11	Feb-14 Feb-15 Feb-24 Feb-25 Feb-26 Feb-27	Mar-01 Mar-05 Mar-06 Mar-09 Mar-25 Mar-26 Mar-27 Mar-28	April-10

Figure 4 presents the behaviour of the air-Earth current, measured by HLWA on 23 May 2019 (represented by a black curve) during 1300 – 1400 h IST. In the context of atmospheric electricity, 23 May represents a disturbed weather day. Also shown in red in the figure is normal variability of the same on the fair-weather day of 10 April 2019. On fair-weather day, current variability is limited to ~ 0.2 – 0.3 nA. However, the range of variability is notably enhanced on 23 May and is from ~ – 0.32 nA to 0.15 nA. Observed variations on 23 May clearly points towards a reversal of polarity under the presence of thunder clouds.

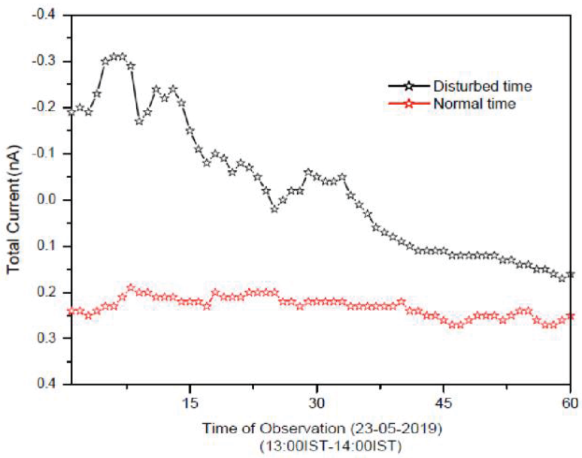

Figure 4. Behaviour of air-earth current noted on 23 May 2019 (black curve) during 1300 – 1400 h IST using HLWA. On this day, unseasonal lightning activity was observed. Red curve represents the variation of air-earth current on a fair-weather day of 10 April 2019.

During the fair weather day the total current was positive without many perturbations. On 23 May, marked peaks in atmospheric current variations can be noted during 1300 – 1315 h and about 1330 h, in contrast to nearly steady variations observed on the fair-weather day of 10 April. Unusual variation of air-earth current observed on 23 May under the presence of clouds has been linked to their electrical influence on atmospheric electricity. On this day, electrified cumulus clouds were seen moving overhead during 1300 – 1400 h. Furthermore, its polarity reversal points towards a significant role of negative ions associated with the thunderclouds in influencing atmospheric electricity. It is well known that the negative ions are released from the bottom of a thundercloud to the Earth's surface during disturbed weather conditions (Datta and Bhattacharya, 2004). Under the presence of electrified clouds, an average upward current of 1000 Amps per cloud is released into the ionosphere that charges the global electric circuit (GEC) to a potential difference of + 250 kV with respect to the Earth's surface (Kamra, 2001). From lightning observations, few hundreds of thunderstorms occur per minute worldwide. Each one acts as a current source and the associated current density/field changes in GEC are seen in about 18 minutes or less depending upon the separation of the source region and observing site. Thus the return current is triggered over the observing site is higher than that noted over the fair weather region. Study of such changes due the tropical cumulus clouds by Datta and Bhattacharya, (2004) indicates a ten to hundred fold increase in current density during disturbed weather conditions, when compared with that noted during the fair weather conditions viz. ~ few pico amps. We have limited our measurements to 1400 h because the experiment switched off due to severe lightning and thunder storm intensification, followed by rain for a few minutes (a normal practice to protect the highly sensitive electrometers and measuring devices when the ambient electric potentials reach above 3kV).

Figure 5 presents AWS measurements of some meteorological parameters from 25 to 29 May, 2019 that corresponds to disturbed weather conditions. On these disturbed days, diurnal variation of temperature, humidity, wind speed and direction are shown from bottom to top panels. Due to some technical glitch, AWS observations could not be carried out on 23 May. On each day, temperatures are seen to attain a maximum around noon hours. Such a temperature maximum coincides with the minimum of humidity and strong wind speeds; thereby, indicating an enhancement in convection activity during noon hours. Furthermore, the wind direction was moderately southwesterly during this time. Overall, combined behaviour of meteorological parameters points towards the important role of atmospheric dynamics in defining atmospheric electricity.

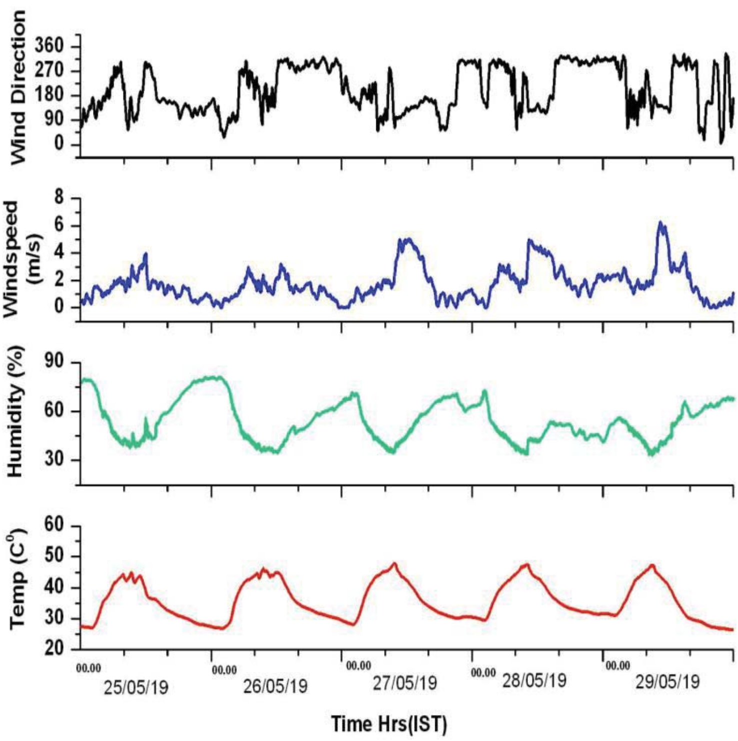

Figure 5. AWS measurements of temperature, humdity, wind speed and direction on 25 – 29 May 2019.

Figure 6 presents the behaviour of ambient electric-field and current density (shown in the top and bottom panels, respectively) on the disturbed day of 27 May, 2019. Compared to fair weather days, an enhancement/increase in air-earth current density and ambient electric field can be seen, which coincides with the maximum in convection activity in the lower atmosphere. Owing to this, we suggest that increased convection, in turn, boosts the local dynamo.

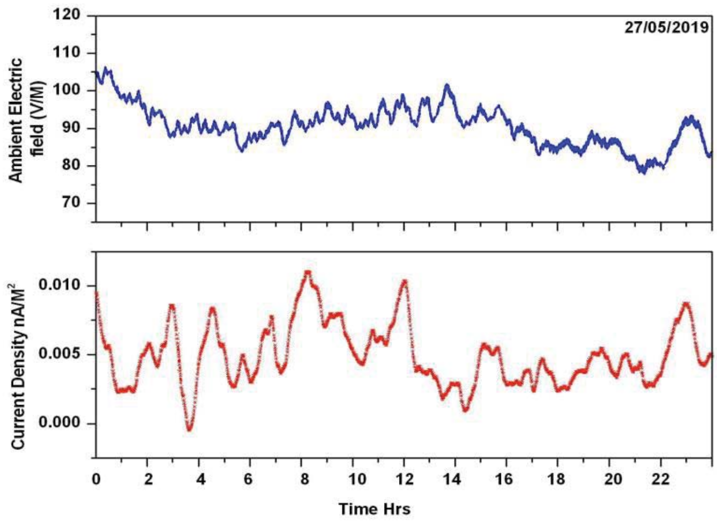

Figure 6. Behaviour of electric field (top panel) and current-density (bottom panel) on a maximum in convection activity in the lower atmosphere day of 27 May 2019.

Unusual variation in the horizontal and vertical electric field during a day has been linked to the behaviour of mixing layer (the atmosphere layer from the ground up to which turbulence is present). As the sun heats up, the lower atmosphere beginning morning hours, the thickness of this mixing layer starts increasing and becomes greater as the day progresses. As the solar heating decreases from the noon hours to evening, the lower layers of air observing fair-weather cools down more rapidly. Such cooling produces temperature inversion layer up to a few hundred meters and is dependent upon spatial extent of open location and amount of aerosols present/moving therein. Over this station, Panneerselvam et al. (2003, 2007) and Anil Kumar et al. (2009, 2013), have studied the effects of dynamics on the atmospheric electric parameters.

CONCLUSIONS

The present laboratory has a history of two decades in atmospheric electricity studies over the Indian subcontinent. Using an indigenously built electrometers and sensors, the measurements of Maxwell's current were carried out over a low latitude station Tirunelveli (8.7^0 N, 77.8^0 E), India. We present in this study, limited observations of air-earth current density and electric field measurements, during unusual lighting and strong convection activity during May 2019. On fair weather days, two peaks are seen in diurnal variation of current density during 1800-1900 h and 2000-2100 h, respectively; while, electric field variations are marked by a gradual increase beyond 1500 h followed by a peak about 2200h, UT. Corroborative study of current density and electric field measurements, with AWS measured meteorological parameters during disturbed days of 23 and 27 May 2019, clearly indicate towards the important role of lightning and convection activity in modifying atmospheric electricity. As such, we interpret that an increased convection boosts up the local dynamo which in turn, lead to changes in current density and electric field over this tropical station.

ACKNOWLEDGMENTS

The authors are grateful to the Director, Indian Institute of Geomagnetism, Navi Mumbai for constant support and Ministry of Science and Technology, Government of India, for the financial assistance. The authors thank the referees for evaluating the paper and for their valuable suggestions.

Compliance with Ethical Standards

The authors declare that they have no conflict of interest and adhere to copyright norms.

REFERENCES

Anil Kumar, C.P., Panneerselvam, C., Nair, K.U., Jeeva, K., Selvaraj, C. and Gurubaran, S., 2009. Measurement of atmospheric conduction current density from a tropical station using improvised Wilson's plate antenna, Earth Planets Space, 61, 919-926.

Anil Kumar, C.P., Gopal Singh, R., Selvaraj, C., Nair, K.U., Jayakumar, H.J., Vishnu, R., Muralidas, S. and Balan, N., 2013. Atmospheric electric parameters and micro meteorological process during the solar eclipse on 15 January, 2010., J. Geophys. Res. (Atmos) 118, 5098-5104, doi:10. 1002/jgrd.50437.2013.

Anil Kumar, C. P., Balan, N., Pannerselvam, C., Jeni Victor, N., Selvaraj, C., Nair, K.U., Elango, P., Jeeva, K., Akhila., J.C.

and Gurubaran, S., 2017. Investigation of the Influence of Galactic Cosmic Rays on Clouds and Climate. Proc. Indian National Sci., Acad/, 83, 631-644, doi: 10.16943/ptinsa/2017/49028, 2017, ISSN 2454-9983.

Aplin, K.L. and Harrison, R.G., 2013. Lord Kelvin's atmospheric electricity measurements. Hist. Geo. Space Sci., 4 (2), 83–95.

Chaimers, J.A. 1967. Atmospheric electricity, Pergumon press, New York, 34-38.

Clayton, M. and Polk, C., 1977. Electrical Process in Atmospheres, Proc. 5th Int. Conf. on Atmospheric Electricity (Ed) Garmisch Partenkirchen, Dolezalek, H., and Steinkopt, R., 440-451.

Datta, T. and Bhattacharya, A.B., 2004. Atmosphericelectrical field in relation to severe meteorological disturbances. Ind. J. Radio and Space Phys., 33, 374- 383.

Jeeva, K., Gurubaran, S., Williams, E.R., Kamra, A.K., Sinha, A.K., Guha, A., Selvaraj, C., Nair, K.U. and Ajay Dhar, 2016. Anomalous diurnal variation of atmospheric potential gradient and air-earth current density observed at Maitri, Antarctica. J. Geophys. Res, Atmos., 121(12), 12593-12611, doc: 10/1002/2016JDO25043.

Kamra, A.K., Deshpande, C.G. and Gopalakrishnan, V., 1997. Effect of relative humidity on the electrical conductivity of marine air. Q. J. R. Meteorol Soc. 123, 1295- 1302.

Kamra, A.K., (Edt), 2001. Cloud physics and atmospheric electricity frontiers, Vol-II, pages 696-875.

Kar, S.K., Bhattacharya, A.B. and Yuei-An Liou, 2004. Solar effects on terrestrial radio communication disturbances and associated tropospheric and ionospheric variations. Ind. J. Phys. 78(B), 151- 163.

Kasemir, H.W., 1955. Measurement of the air-earth current density, in Proc. Conf. Atmos. Electricity, Geophys. Res. Pap., 42, 91-95, Air Force Cambridge Res., Cent., Bedford.

Kasemir, H.W. and Ruhnke, L.H., 1959. Antenna problems of measurements of the air-earth current, Recent advances in atmospheric electricity edited by L.G.Smith, PP 137-147, Pergamon, New York.

Monohar, G.K. and Kandalgaonkar, S. S., 1995. Study of thermal plant emissions on atmospheric parameters., Ind. J. Radio & Space Phys., 24, 297-307.

Panneerselvam, C., Selvaraj, C., Jeeva, K., Nair, K. U., Anil Kumar, C. P., and Gurubaran S., 2007. Diurnal variation of atmospheric Maxwell current over the low latitude continental station, Tirunelveli. Earth Planets Space, 59(5), 429–435.

Panneerselvam, C., Nair, K.U., Jeeva, K., Selvaraj, C., Gurubaran, S. and Rajaram, R., 2003. A comparative study of atmospheric Maxwell current and electric field from a low latitude station Tirunelveli, Earth Planets Space, 55, 697-703.

Raina, B.N., 2002. Surface measurements of the components of air-earth current density. Cloud Physics and Atmospheric Electricity Frontiers, Vol. II, 973-988

Ralph Markson, W., 1978. Solar modulation of atmospheric electrification and possible implications of the sun –weather relationship, Nature, 273, 103-109.

Ruhnke, L.H., 1965. Area averaging of atmospheric electric currents, J. Geomagn. Geoelectr., 21, 453–462.

Rycroft, M., Nicoll., K.A., Aplin, K.L. and Harrison, R.G., 2012. Recent advances in global electric circuit coupling between the space environment and the troposphere, J. Atmos. and Solar Terr. Phys., 90-91, 298-311.

Tammet, H., Israelsson, S., Knudsen, E. and Tuomi, T.J., 1996. Effective area of a horizontal long-wire antenna collecting the atmospheric electric vertical current J. Geophys. Res., 101, D23 29, 671-682.

Received on: 17.03.2020; Revised on: 29.06.2020; Accepted on: 06.07.2020