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Comparative analysis of local and global atmospheric electric field at the Northern Pakistan

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ABSTRACT

Daily variations of the Atmospheric Electric Field (AEF) allow to observe separately the atmospheric electricity due to global and local factors. Observations of the AEF are made for three different sites of Pakistan during fair weather conditions. These three sites are Islamabad (ISB), Muzaffarabad (MZF) and Balakot (BKT). Analyses of the diurnal variations of the atmospheric electric field for these sites are discussed in this paper with respect to annual and seasonal behavior. Muzaffarabad and Balakot sites show two daily maxima and Islamabad site shows single maxima, characteristic of local influences, such as the aerosol, sunrise effect and "Austausch effect" or exchange layer effect. Later, these results are compared globally with land based measurements available in the literature and with the Carnegie curve. Local effects found to be dominant among these sites with respect to one another due to geographical location, climate and different meteorological parameters. This is the first different creation of the ISB-MZF-BKT database which will be very effective to improve the information of atmospheric electricity in the complex processes due to weather and climate. This database from Pakistan will be useful for the scientific community for further understating and investigation of the Global Electric Circuit (GEC).

1. Background

Earth's electrical phenomena have been studied during the past 150 years and mostly used to get information on the Global Electric Circuit (GEC). The global circuit concept given by Wilson (1921) is extremely useful for the understanding of electric current flow, and connection of this vertical flow with the clouds and climate (Williams and S.J.Heckman, 1993; Williams, 2003; Tinsley et al., 2007; Nicoll and Harrison, 2016). It is well established now that GEC is driven due to large scale charge separation in thunderstorms and electrified rain clouds, which distribute the large amount of current flow around the planet. GEC is also influenced by the energetic charged particles from space due to solar and cosmic activities (Bennett and Harrison, 2008; Williams, 2009; Rycroft et al., 2012). Atmospheric conductivity close to Earth's surface varies due to the ions produced by terrestrial radioactivity and cosmic rays (Israel, 1973; Harrison and Aplin, 2003; Bennett and Harrison, 2008).

Continuous studies and observation of the atmospheric electric field (AEF) from the globe can improve our understating regarding thunderstorm and the global atmospheric electric system, which may be varying within our changing weather and environment. Thunderstorm and lightning activities is the major sources for the maintenance of global circuit variation all around the world (Rycroft et al., 2000; Siingh et al., 2005; Victor et al., 2019). To understand different processes occurring in thunderstorm, study of the atmospheric electric field variation is very important. Especially, the high energy particles and their fluxes correlated with thunderstorm (Thunderstorm Ground Enhancement, TGEs). It helps better to understand the high energy processes and electrical structure of thunderclouds (Chilingarian et al., 2010, 2016; Chilingarian, 2018). Chilingarian (2018) claims that the flux of high energy particles lasts 1–10min with approximate energies up to 40 MeV and the lowers ones remain for more than 2 h with energy less than 3 MeV. Another area of current research related to atmospheric electricity is layer cloud properties. As layer clouds are electrically charged at their upper and lower boundaries (Nicoll and Harrison, 2016). A thunderstorm is defined as having three charged regions which are upper positive, middle negative and lower small positive (Williams, 1989), because of this tripolar structure in clouds, the atmospheric electric field changes near to the ground (Maitra et al., 2014). Still, it must be needed to made simultaneous measurements of AEF at different locations

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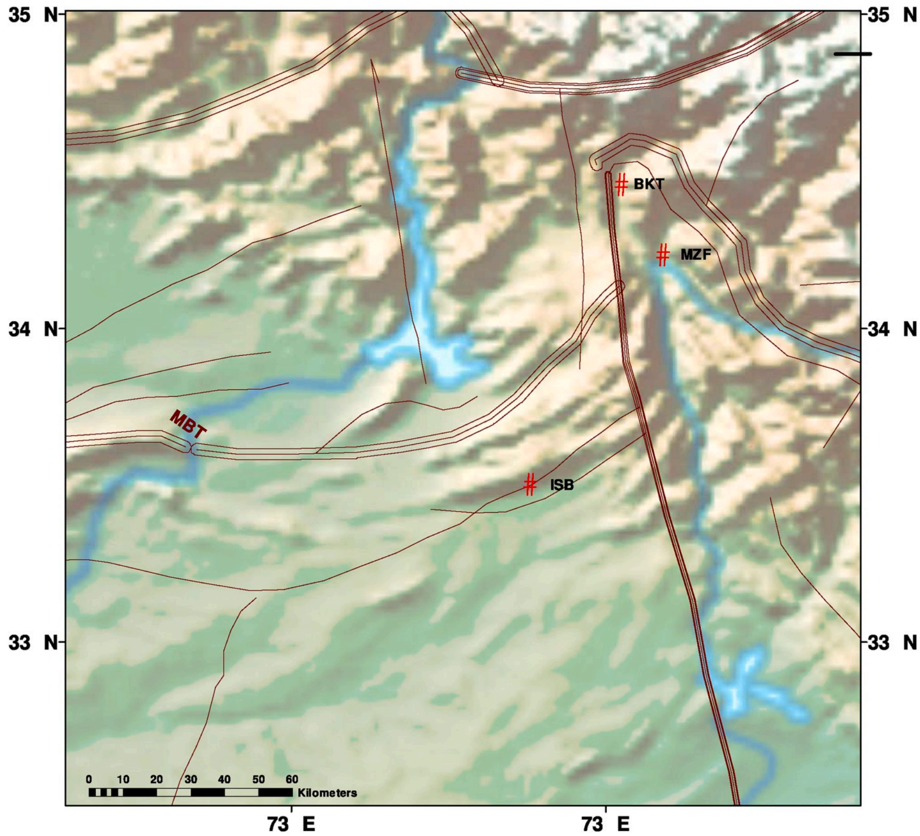


Fig. 1. Location map of ZEBRA electric field mills at the Northern sites of Pakistan.

around the globe to understand multiple processes related to global electric circuit.

The atmospheric electricity in fair weather is modulated by local effects like aerosol and meteorological parameters (Chalmers, 1967; Harrison and Carslaw, 2003; Bennett and Harrison, 2007). Mainly, the small ions (they have the ability to change) which become large ions due to the attachment with the aerosol and dust particles which reduces their mobility (Kamra et al., 1994; Harrison and Carslaw, 2003; De et al., 2013). Ion-Induced Nucleation (IIN) processes has also been considered as an active source for the formation of new particles in troposphere. A very detailed review paper on IIN is published by (Li et al., 2015). They described that aerosol nucleation events may significantly influence the Earth's climate (Kazil et al., 2010; Makkonen et al., 2012). The nucleation via gas-to-particle conversion is the largest source of atmospheric aerosol particles (Kulmala et al., 2013).

The conductivity decreases due to less mobility of ions which increases the atmospheric electric field (Dhanorkar and Kamra, 1997; Williams, 2003; Harrison and Carslaw, 2003; Deshpande and Kamra, 2004). High pollution due to anthropogenic aerosol, industries, and vehicles movement increases the AEF at urban sites and this is observed at many locations around the world (Chalmers, 1967; Sheftel et al., 1994; Bennett and Harrison, 2008; De et al., 2013) Meteorological parameters play important role in the rapid variation of the atmospheric electric field as a local effect (Bennett and Harrison, 2007). During rain clouds, rain showers, change in pressure and temperature, wind speed and wind direction, fog and relative humidity changes the AEF values (Xu et al., 2013; Xie et al., 2014; Smirnov, 2017).

Northern areas of Pakistan are seismically active, and after 2005 Kashmir Earthquake intensive studies has been started and still under going. The purpose behind this paper in a near future is to study and observe any type of anomaly or disturbance on the Earth's surface. Many studies regarding seismicity and before impending earthquakes have been done at these locations (Barkat et al., 2017; Asim et al., 2017a, b; Ahmed et al., 2018; Zafar et al., 2018; Tariq et al., 2019; Ahmad et al., 2019a). Time series analysis of soil radon has been studied previously and also for Pakistan too though still it is not universally accepted (Singh et al., 2017; Barkat et al., 2018). The proposed model of Lithosphere, Atmosphere, and Ionosphere coupling (LAIC) for the short term earthquake precursors explained by Pulinets and Boyarchuk (2004), stated that anomalies observed in the ionosphere over seismically active region could be due to the variation in the atmospheric electric field. Similarly in 2009, physical phenomenon of the vertical electric field generation over the active tectonic faults is explained by Pulinets (2009). He explained the air ionization and its facts. Natural radioactivity is one of the main source of production of ions in the Planetary Boundary Layer (PBL) of the atmosphere. These ions produces the air conductivity and which is further responsible for the fair-weather atmospheric electric current in the PBL (Hoppel et al., 1986). These are the evidences which explains the variation in atmospheric electric field is related to seismically active regions and could be relate to study the Earthquake precursors. For this, we are setting the base line of atmospheric electric field for Northern areas of Pakistan. As these are very first studies going on the atmospheric electric field for Pakistan and needed to observe critically at all the stations.

The locations of all three sites (ISB,MZF,BKT) lie in the hilly area and experiences a heavy rain and high seasonal effects. Recently, study on the atmospheric electric field is presented for two sites (Islamabad and Muzaffarabad) of Pakistan (Gurmani et al., 2018; Ahmad et al., 2019b). Present work is the extension and comparison by adding one more site at the Northern area of Pakistan. The analyzed data of the AEF shows a local effect possibly associated with atmospheric aerosol, meteorological parameters and geographical differences. In addition to this, an attractive comparison and contribution have been found globally.

A very recent study done by Nicoll et al. (2019), for almost 17 different sites and covering four continents, explains extremely well about the global atmospheric electricity and a reasonable comparison of

Table 1
Sunrise and sunset timings for Jan and July of all three sites.

	ISB(LT)		BKT(LT)		MZF(LT)	
	January	July	January	July	January	July
Sunrise	7:00	5:00	7:00	5:00	7:00	6:00
sunset	17:00	19:00	17:00	19:00	18:00	19:30

"Sunrise and Sunset timings"

Table 2
Total number of fair-weather days of all three sites for the studied period.

year	ISB	MZF	BKT
2015	160	148	200
2016	183	175	000
2017	189	131	195
Total	532	454	395

"Fair Weather days"

data due to local and global effect.

2. Measurement sites, instrumentation and extraction of fair-weather data

There are many different methods to measure the atmospheric electric field. Most common methods in old times were potential probes (Chalmers, 1967) and burning fuses (Israel, 1973), and still these methods are under use by many scientists at different stations. The most popular method nowadays is an electric field mill (EFM) which gives the opportunity of faster measurements with multiple options of meteorological conditions. An electric field mill is mounted outdoors, where it is well exposed to the atmospheric electric field. It typically consists of one or more electrodes which is alternately shielded and exposed sensor plates to atmospheric electric field.

For the present study, data is acquired from the EFM which is installed at different sites of Pakistan. The EFM is manufactured by Mission Instruments and named as ZEBRA field mill. The system were calibrated in the laboratory before installation and calibration repeated periodically for each EFM. The accuracy of the device for the electric field value is $\pm$ 5 % (for E $>$ 800 V/m).

The EFM is mounted at the rooftop of a single floor building for Islamabad site (approximately 7 m from the ground). Similarly, for Balakot and Muzaffarabad are also at rooftop but comparatively less height (Height of EFM for BKT and MZF from the ground is approximately 4 m). The rooftop values of AEF are higher as compared to the ground AEF values. So, all the systems are calibrated with respect to height by applying a reference field mill at the ground for few days (Rakov and Uman, 2003). A correction factor is calculated and applied to modify the present rooftop data for this study.

Fig. 1 shows the three locations where EFMs are mounted. Islamabad (ISB) and Balakot (BKT) has subtropical climate with four seasons. Balakot is more humid and rainy as compared to Islamabad. Climate of Muzaffarabad (MZF) is mild and generally warm in temperature. It is a city with a significant rainfall. The EFM site at Balakot is more quite place as compared to Islamabad and Muzaffarabad, and is covered by trees and hills (approximately 40 m). Islamabad and Muzaffarabad are more populated near the EFM site and vehicular traffic is also high. MZF station is installed on the mountain near the city(approximately 4 Km). The population of these three cities are approximately 1015 million, 96,000 and 30,000 for ISB, MZF and BKT respectively. The BKT sensor is located in the valley which is covered around hills and mountains (3–4 Km), so experience less sun and different environment. Its (BKT) one side is covered closely with large trees. The atmospheric electric field variation between three sites can provide useful information of local affects e.g. pollution transport. The sunrise and sunset timings for these stations of extreme winter(Jan) and summer (Jul) months are given in Table 1.

Fair weather days were obtained for each station that are defined meteorologically as fair days. Weather data of different meteorological parameters were provided by Pakistan Meteorological Department (PMD), and also simulated data of few missing parameters were obtained from meteoblue (www.meteoblue.com). Weather data is well compared and double checked from both sources to get fair days. Criteria of fair weather is fulfilled completely as in the literature and updated with respect to recently defined by Harrison and Nicoll (2018). There would be no low stratus cloud and up to three-eighths cumuliform cloud as long as there is no effect on AEF record. Wind speed less than 6 m/s, zero precipitation is preferred for all three stations. Atmospheric electric field amplitude range for all three station is different which could be due to local effect of geographic location. The AEF for Muzaffarabad, Balakot, and Islamabad is ranged from 40 to 500 V/m, 40–280 V/m and 40–400 V/m respectively.

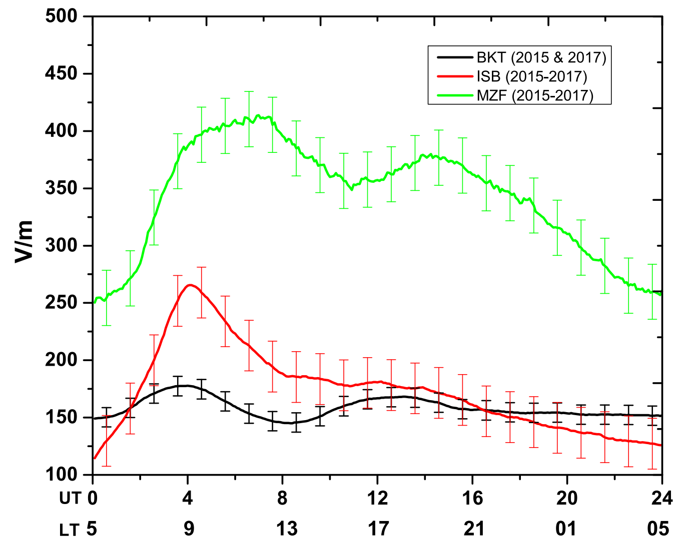


Fig. 2. Annual variation of atmospheric electric field of Islamabad, Balakot and Muzaffarabad. Error bar represents their corresponding standard deviations.

The geographic coordinates of Islamabad is at 33.75° N, 73.75° E. The coordinates of Muzaffarabad and Balakot are 34.36° N, 73.49° E and 34.54° N, 73.35° E, respectively. The presented data for Islamabad and Muzaffarabad is for the period of 2015, 2016 and 2017. In case of Balakot, the presented data is of two years (2015 and 2017). Due to some technical problems in the year 2016, data transmission was not complete and that is the reason why the data of year 2016 is not included in the present study. The elevation of ISB, MZF and BKT sites are 618 m, 1158 m and 1041 m respectively. The Aeriel distance between all three sites with respect to one another are: $ISB - MZF = 75.87km$ $ISB - BKT = 91.19km$ and $MZF - BKT = 24.07km$.

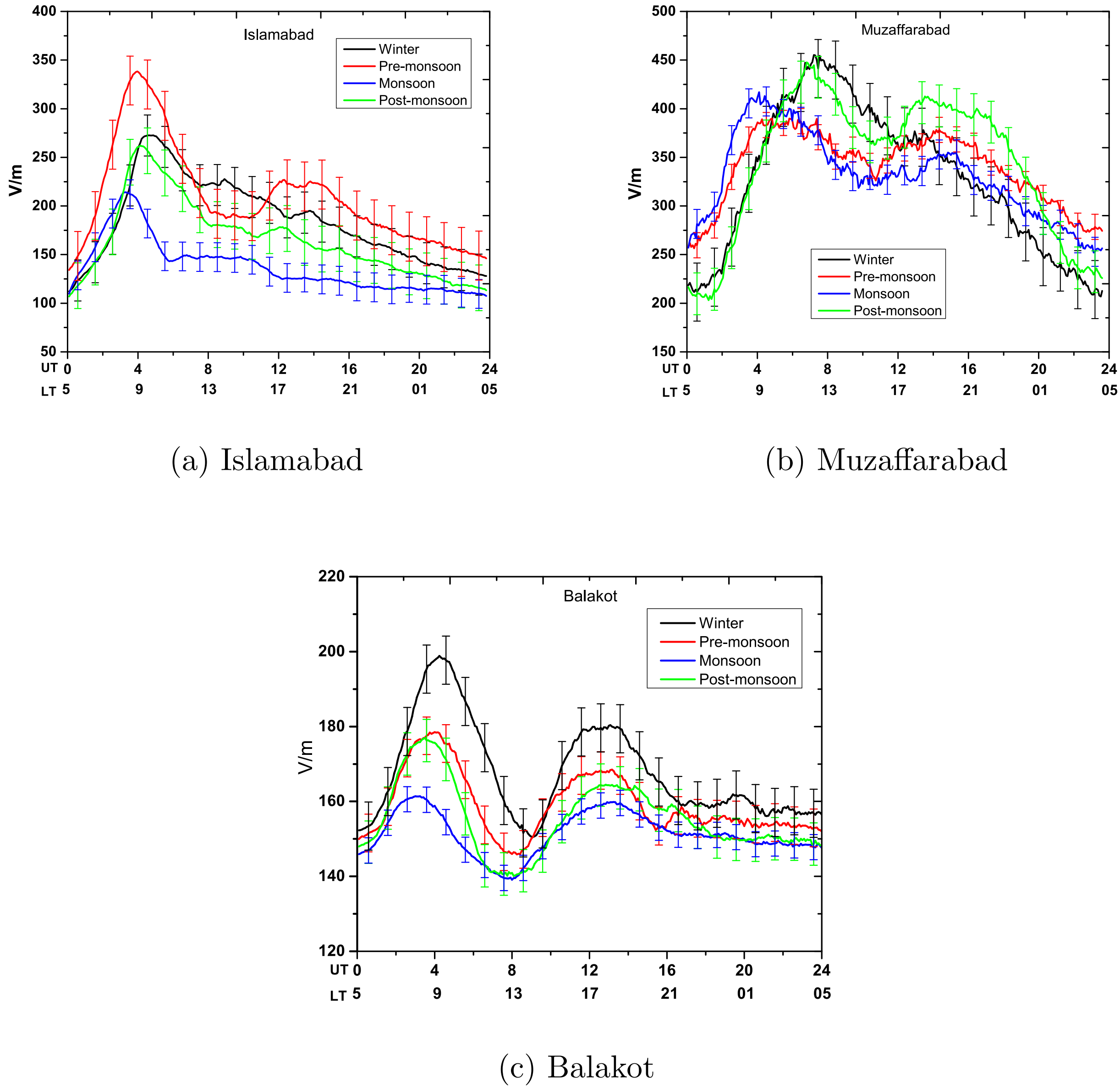
3. Results and discussion

We divide our results and discussion in two parts, one is local comparison of these three stations with respect to one another and their prevailing environment. The second comparison is with respect to the available studies done around the globe.

3.1. Local comparison

The diurnal variation of atmospheric electric field during fair weather days is an important key parameter in the research field of atmospheric electricity around the globe.

Selected fair weather days are presented in Table 2 for year 2015–2017. The similar method of data analysis is adopted for BKT as



(a) Islamabad (b) Muzaffarabad (c) Balakot

Fig. 3. Seasonal variation of atmospheric electric field of all three sites. Error bars represents their corresponding standard deviation.

have been done for ISB (Gurmani et al., 2018) and MZF (Ahmad et al., 2019b). For all three sites, data is received per minute then it is averaged over 5 min to observe the trend of each station for the selected period. Later, data is again averaged on hourly basis.

The diurnal annual variation of the atmospheric electric field of ISB, MZF and BKT is shown in Fig. 2. Single sharp peak is observed for Islamabad at 04:00 UT (very weak secondary peak at 14:00 UT) while clear double peaks are observed for Muzaffarabad and Balakot stations. The first maxima of MZF is at 06:30 to 7:00 UT (11:30–12:00 Local Time, LT) and the second maxima is around 13:30 to 14:00 UT (18:30–19:00 LT) which is just before the local sunset. In case of BKT, the first maxima (morning peak) is at 04:00 UT (09:00 LT) and second peak is at 13:00 UT (18:00 LT) before the local sunset. For Islamabad, the observed single peak is at 04:00 UT (09:00 LT). The time of first peak of BKT and ISB is same but differs from the MZF. The first peak of all three site is a late morning period (sunrise peak). Muzaffarabad curve is quite consistent with mountainous observatory (Yaniv et al., 2017). MZF has two maximum peaks with a delay of 1–2 h compared to BKT and ISB. As already mention, the sensor of MZF is located at the top of mountain far from the city center. The range of the annual average atmospheric electric field of MZF site lies from 250 V/m to 415 V/m (first maximum peak). The maximum peak value of the AEF of BKT is 180 V/m and for ISB is 270 V/m. Variations in the atmospheric electric field are always different at different land-based stations due to local effects(Yaniv et al., 2016). These sites, especially MZF site clearly shows “Austausch effect” or exchange layer effect around sunrise which can cause unmarked high values of the atmospheric electric field due to turbulent and convective mixing (Marshall et al., 1999; Yaniv et al., 2017; Nicoll et al., 2019). Differences in the peaks of the AEF for these three station are also due to anthropogenic pollution. ISB also has second peak which is obscured by the first peak and this can be related to the population difference discussed in section 2. Time shift in the first peak of MZF as compared to the ISB and BKT could be due to the sensor is located at the mountain near to the city. So, it take time that the aerosol particulates to arrive at the sensor. Similarly, a black carbon peak is observed at the same time (08:00–09:00 LT) for Karachi as of the AEF peaks are observed (Ghauri et al., 2019). For the twin-cities, Islamabad and Rawalpindi, increase in CO_2 is observed at different location of Islamabad city (Shahid et al., 2018, 2019).

For the present study, the diurnal data of the AEF is typically divided

Table 3
Annual Correlation coefficient of all stations with respect to one another.

Stations	ISB	MZF	BKT
ISB	1	–	–
MZF	0.768	1	0.279
BKT	0.645	–	1

"Correlation between all stations"

Table 4
Seasonal correlation coefficient of all stations with respect to one another.

Stations	Winter(ISB)	Winter(MZF)	Winter(BKT)
Winter(*ISB*)	1	–	–
Winter(*MZF*)	0.864	1	–
Winter(*BKT*)	0.650	0.321	1
Stations	Pre-monsoon (ISB)	Pre-monsoon (MZF)	Pre-monsoon (BKT)
Pre − *monsoon*(*ISB*)	1	–	–
Pre − *monsoon*(*MZF*)	0.358	1	–
Pre − *monsoon*(*BKT*)	0.783	0.034	1
Stations	Monsoon(ISB)	Monsoon(MZF)	Monsoon(BKT)
Monsoon(*ISB*)	1	–	–
Monsoon(*MZF*)	0.719	1	–
Monsoon(*BKT*)	0.31	0.161	1
Stations	Post-monsoon (ISB)	Post-monsoon (MZF)	Post-monsoon (BKT)
Post − *monsoon*(*ISB*)	1	–	–
Post − *monsoon*(*MZF*)	0.780	1	–
Post − *monsoon*(*BKT*)	0.405	0.266	1

into four seasons. The four seasons are; 1, winter (January, February & December) 2, pre-monsoon (March–May) 3, monsoon (June–August) 4, post-monsoon (September–November). All four seasons averaged over the mentioned period of each site is shown in Fig. 3.

The maximum atmospheric electric field values of ISB for winter and pre-monsoon are 275 V/m and 335 V/m which is around at 04:00 UT. Similarly, for MZF the maximum AEF value of winter and pre-monsoon are 450 V/m and 390 V/m respectively. The first maximum of MZF is observed at 07:30–08:00 UT during winter and pre-monsoon. In case of BKT, the maximum the AEF values for winter and pre-monsoon are 200 V/m and 180 V/m respectively at 04:00 UT. The first local morning peak for ISB and BKT is around the same time at 04:00 UT. But for MZF, the time for morning peak is little later for winter and post-monsoon. Values of post-monsoon and monsoon are found lower for all three stations due to heavy rainfall. The time for morning peak is also little earlier due to sunrise effect. During summer, the sunrise effect becomes earlier due to solar heating convection (Yaniv et al., 2017).

The maximum values of AEF during monsoon for ISB, MZF and BKT are 220 V/m, 400 V/m and 160 V/m respectively. Intense monsoon season is observed at all three stations and so the AEF value is very low. It could be due to the decreased aerosol concentration near the earth surface of to heavy rain (Adlerman and Williams, 1996; Sharma et al., 2003; De et al., 2013). The concentration of aerosol is decreased near earth surface by 40–75% than pre-monsoon and post-monsoon (Hyvärinen et al., 2011). Similarly, Adlerman and Williams (1996) observed that the aerosol concentration in air follows a regular seasonal variations. They explained well in detail about the seasonal variation and its behavior with respect to aerosol in all the seasons. Similar trend for seasonal variation of atmospheric electric field is observed at neighboring sites of Pune and Kolkata (Latha, 2003; De et al., 2013). Recently, Jana and Maitra (2019) discuss the electric field variation at tropical urban location with respect to the seasons. They compared their results even with the black carbon concentration and found a significant correlation in all the seasons. The AEF values of urban location are clearly affected by pollutants. Balakot results are very comparable with Kolkata results, having two peaks and not much difference in the values of first and second peaks.

A very clear secondary peak is observed in case of MZF and BKT but for ISB, a very weak secondary peak is observed in seasonal variations. The secondary peaks of MZF for winter, pre-monsoon, monsoon and post-monsoon are 370 V/m, 375 V/m, 352 V/m and 410 V/m respectively. Difference in timings for secondary peak is not significant, all peaks lie around 14:00 to 18:00 UT before the sunset. For BKT, the secondary peak values of winter, per-monsoon, monsoon and post-monsoon are 180 V/m, 168 V/m, 158 V/m and 164 V/m respectively. Time for secondary peak of BKT is around 12:30 to 13:00 UT which is early as this station is fully covered by mountains (early sunset due to mountains). In case of Islamabad, secondary peak is slightly at different position with respect to time which approximately lies from 12:00 to 12:30 UT.

Table 3 shows the correlation between each station with respect to one another. According to these numbers, the correlation of Islamabad is strong with Muzaffarabad and Balakot. The correlation coefficient is weak between MZF and BKT. Correlation coefficients with respect to seasonal variation are shown in Table 4. A strong correlation is observed in all the seasons between ISB and MZF except in pre-monsoon which could be due to local effects. As already mentioned (in section 2), MZF station is quite far from city center and installed at the top of mountain. Trend and the timings (around 04:00 UT) of the primary peak is similar of BKT and ISB but the seasonal correlation of AEF is very weak between these two. Again, a week seasonal correlation is found between MZF and BKT. Even these both stations are more close to each other as the aerial distances are mentioned in the above section.

Fig. 4 represents the variation of diurnal variation of maximum and minimum values of the atmospheric electric field with respect to time for all seasons. In case of hours of maximum, Islamabad and Balakot are close to each other, but Muzaffarabad is far away specially in winter and pre-monsoon. For hours of minimum, the case becomes opposite due to early second peak of Balakot. Islamabad and Muzaffarbad are more comparable in respect of minimum value hours. Balakot is very down at hour of minimum. These differences in the maximum and minimum time could be related to anthropogenic pollution as previously explained. Future aerosol measurements certainly will be very helpful to understand better our results.

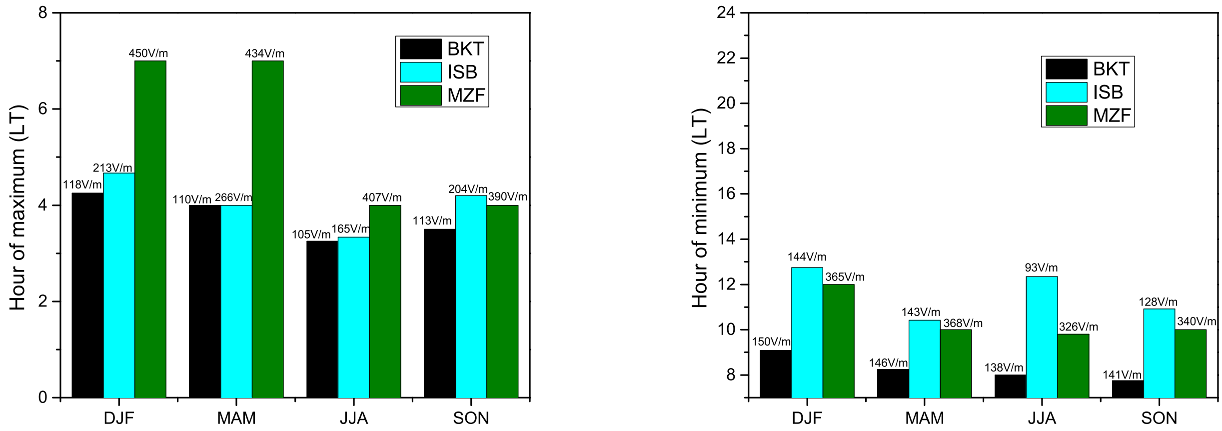
3.2. Global comparison

In this section, we compare our all three station results with the Carnegie curve and other land-based stations that studied the atmospheric electric field around the globe.

Annual variation of each month is shown in Fig. 5 for India and Pakistan. All stations are in Asia, where the monsoonal effect is very strong. Monthly trend of Kolkata and BKT station is almost similar.

Pre-monsoon values start decreasing in most of cases due to pre-monsoonal effect, and similarly post-monsoon values from October starts increasing before starting the winter (De et al., 2013; Ahmad et al., 2019b).

Fig. 6 clearly shows the difference between our land based sites and the Carnegie curve. A weak correlation is observed between all our sites and the Carnegie curve as expected. Typically, BKT and MZF clearly show two peaks, a late morning peak and afternoon peak. ISB shows strong morning peak and very weak secondary peak like a single maxima in the Carnegie curve. This is commonly found that the atmospheric



(a) Hours of maximum (b) Hours of Minimum

Fig. 4. Seasonal variation with respect to hours of maximum and minimum for all three sites, with their respective atmospheric electric field value at each bar.

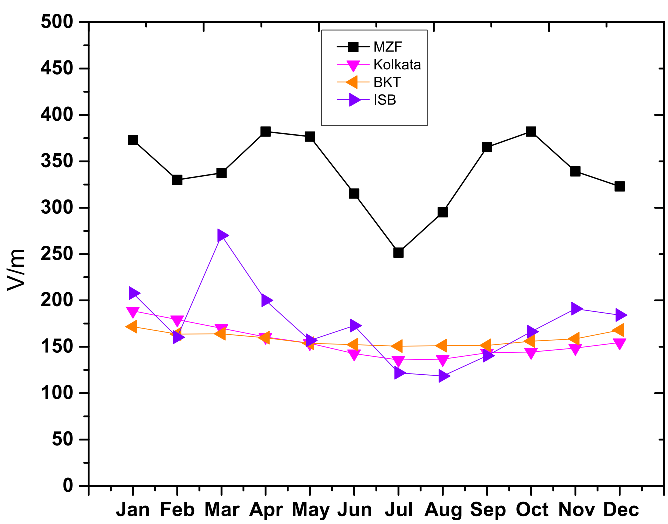


Fig. 5. Monthly variation of the atmospheric electric field of Pakistan sites and few more sites around the world.

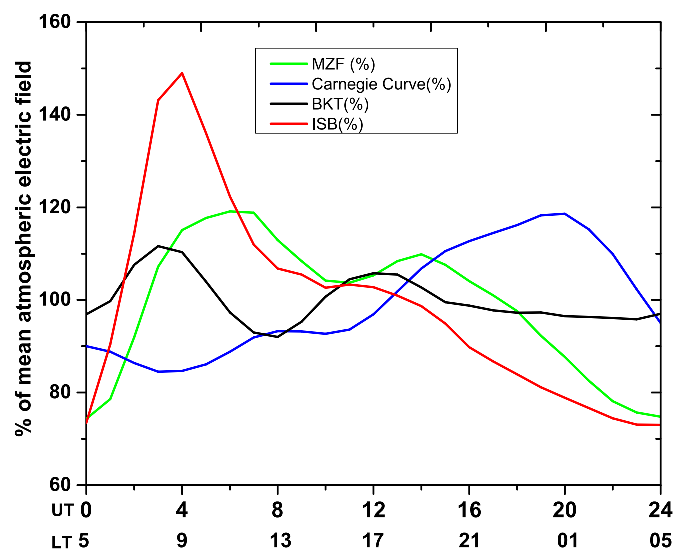


Fig. 6. Comparison of Carnegie curve and three sites (ISB, BKT, MZF) of Pakistan.

electric field values are different due to different locations and environment at land and ocean (De et al., 2013; Yaniv et al., 2017; Tacza et al., 2014; Jana and Maitra, 2019; Nicoll et al., 2019). First late morning peak is more related to Asia-Australia thunderstorm activity which includes sunrise effect and local aerosol effect. Similarly, in many land-based stations around the world, a clear deviation in the atmospheric electric field is observed (Latha, 2003; De et al., 2013; Yaniv et al., 2017; Jana and Maitra, 2019; Tacza et al., 2020). This is to be expected as the majority of these sites are continental and close to extremely populated areas where high concentration of aerosol pollution is found. To compare with the Carnegie curve, all the non-disturbed weather conditions are considered for the AEF values and only positive values are taken into account.

All the land-based measurements of the atmospheric electric field are compared in Fig. 7. Many curves show the morning peak, values of the AEF are comparable to one another around the mean plotted as a function of the local time of its respective site. A largest local effect has been found in all cases. The double peak is a clear indication of local influences on the atmospheric electric field which could be anthropogenic pollution, sunrise effect and seasonal effects. Typical trend of air pollution have been observed in land-based measurements, which follows an annual cycle with maximum in winter and minimum in summer due to the seasonal change and annual variation in emissions (e.g. less traffic during summer break and more usage of domestic heating in winter).

4. Conclusion and future work

The data analysis of the atmospheric electric field in three different sites in Pakistan is presented. The diurnal, seasonal and annual variation of the electric field for these three sites were obtained and analyzed. The differences in the daily variation were attributed mainly to local effects, in major proportion due to anthropogenic pollution. The Austausch process also contribute in the differences, mainly at the Muzaffarabad observatory where the results show a clear difference in amplitude values. For all stations, a double oscillation typical of polluted places is observed, which produce huge deviations from the Carnegie curve. For a seasonal comparison, it is observed an influence due to monsoon effect.

The effect of meteorological parameters and aerosol concentration on the atmospheric electric field need to be further studied individually. In a near future, we plan to work further on these parameters for the

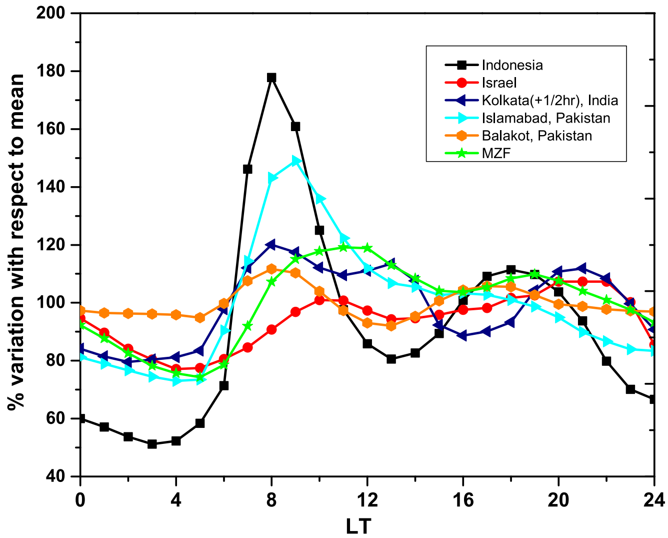


Fig. 7. Different land based measurements of atmospheric electric field.

each station of Pakistan. Once these parameters are correctly identified, we would be able to investigate several geophysical phenomena on the atmospheric electric field.

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