Contribution of Meteor Flux in the Occurrence of Sporadic-E over Arabian Peninsula

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Abstract: Sporadic-E (Es) is generally associated with a thin-layered structure present in the lower ionosphere mostly consisted of metallic ions. This metallic ion layer is formed when meteors burn in the upper atmosphere resulting in the deposition of free metal atoms and ions. Many studies have attributed to the presence of Es due to metallic ion layer, specifically during the nighttime. Using data from a network of meteor monitoring towers and a collocated digital ionosonde radar near Arabian Peninsula, in this paper, we are reporting our observations of Es together with the meteor count. It has been observed that the presence of Es and the meteor count data have no correlation in time, both diurnally and seasonally, leading us to conclude that presence of meteors is not the main cause for the presence of Es over Arabian Peninsula.

Key words: Sporadic-E, Meteor Flux, foEs, Ionosphere

1 Introduction

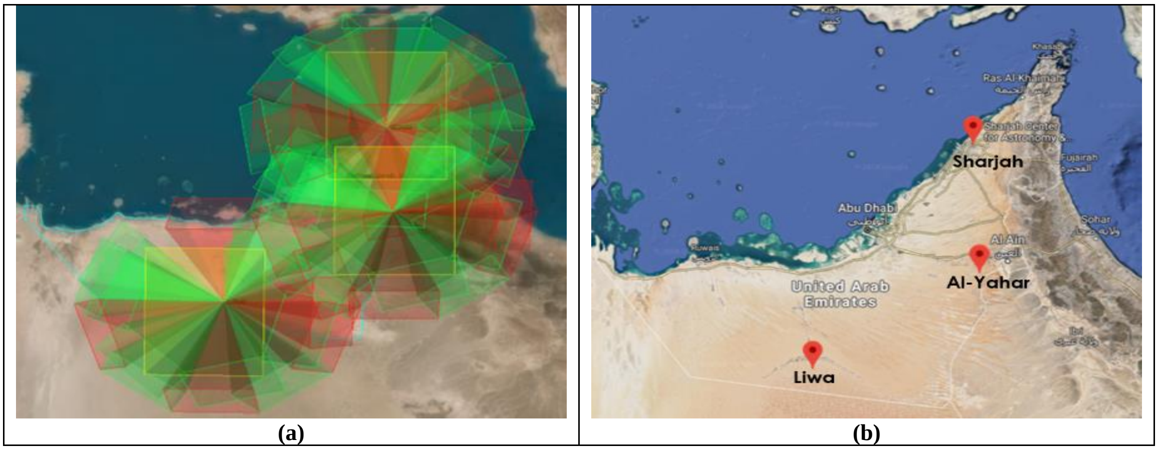
Meteors are visible appearance of extraterrestrial dust, generally known as meteoroids. They appear in the sky when meteoroids ablate in the Earth's atmosphere. Meteors can be categorized as being either part of a shower, or of the background meteor flux. There is a vast amount and variety of meteoroid material entering the atmosphere every day (Ceplecha et al., 1998), and its deposition is highly variable spatially as well as temporally. These variations are attributed to the inconsistency of the meteoroid material density surrounding the Earth, seasonal changes of atmosphere and the Earth's movement around the Sun, the methods of observing them such as geographical location of the observing site and geometrical factors related to the observing instruments' capability and position of sources etc. This extraterrestrial influx changes the metallic composition of the Earth's atmosphere and lower ionosphere. This happens when meteors burn in the dense atmosphere, resulting in the heating and deposition of free metal atoms and ions (Ceplecha et al., 1998). It is now a well-established fact that, permanent ionized metal layer in lower ionosphere, at around 90-130 km altitude, is due to the ablation of meteors in that region (Plane et al., 2015). Meteor observations can be performed with radio (Stober and Chau, 2015; Lima et al., 2015; Yi et al., 2016) as well as with visual means (Vitek and Nasyrova, 2018; Kozlowski et al. 2019; Fernini et al., 2020). Detection using visual cameras can only be performed during night compared to radio-based observations which can be performed throughout the day and is suitable for estimation of total meteor activity. A combination of multiple types of observations may also be used (Brown et al., 2017).

Kopp, (1997) showed that the thin-layered structured sporadic-E layer (Es) in the Earth's ionosphere, lying between the altitude range of 90-130 km, is mostly consisted of ionized metal atoms FeC, MgC and NaC. In mid-latitudes, the so-called 'windshear' theory is thought to be the mechanism responsible for this formation (Whitehead, 1989). Therefore, the intensity and occurrence of Es is expected to be proportional to the amount of metal ion content at the lower ionosphere and its chemical processes, as well meteorological processes in the lower ionosphere (Feng et al., 2013; Yu et al., 2015). The nature of Es observed globally has been a function of many factors such as geographical latitude, observing instruments' sensitivity of the viewing system etc. For example, Es can be observed at almost all times at some geographical locations around the globe (Shaikh et al. 2020); thus, making the term 'sporadic', misleading.

In this paper we are reporting the observations of Es and the meteor counts simultaneously observed during nighttime over the Arabian Peninsula region. A constant and well-established presence of Es has been reported with a consistent count of meteor also present throughout the 1-year observation period (May 2019 – April 2020), reported in this work.

2 Data and Methodology

The meteor counts for this study has been obtained in collaboration with the UAE Meteor Monitoring Network (UAEMMN) project (Fernini et al., 2020). The project aims to detect the occurrences of meteors in the region above the United Arab Emirates. The project collects data through three strategically located towers, each of which are fitted with 17 cameras (see table 1). Following a simulation using Systems Tool Kit software (STK: https://www.agi.com/products/stk) as shown in Fig 1a, towers' locations have been selected as illustrated in Fig 1b using © Google Maps. The three towers, located at Sharjah, Al-Yahar and Liwa, scan the entire UAE sky for meteor incidents (Fig 1a). Each of the three UAEMMN towers employs the use of the UFOCapture Software developed by SonotaCo (SonotaCo, 2005) to detect meteor occurrences. The software can detect movements from the feed of the cameras on the towers. If a movement or action is detected, it writes the video of the action to the hard disk of the computer, from a few seconds before the action is recognized to a few seconds after the action is completed. During the night, the bright streaks produced by a meteor burning up in the atmosphere allows the software to easily detect movements from the sudden changes in pixel values.



(a) **(b)**

Figure 1: (a) Sky coverage simulation by all cameras using Systems Tool Kit (STK). (b) Location of the towers pinpointed on the UAE map using © Google Maps.

Two other software, UFOAnalyzer and UFOOrbit, also developed by SonotaCo (SonotaCo, 2007a; SonotaCo, 2007b), are used to calculate parameters that define the meteorite. UFOAnalyzer can calculate the direction and elevation of the meteorite occurrence. If the meteorite is detected by two or more sites, UFOOrbit can calculate the orbit of the meteorite. Fig 2 shows a radiant map obtained as the result of analyses by the software. The radiant map shows the radiant points on a sinusoidal projection map of the observed meteors, which is defined as the point in the sky from which the path of the observed meteor begins. The figure shows result of two stations of the UAE Meteor Monitoring Network (Sharjah and AL-Yahar stations) obtained during the period between May 2019 and April 2020. The result show different meteor groups such as Geminids, South Taurids and Alpha Capricornids to name a few, as well as some sporadic meteors. The radiant velocity is color coded as shown in the figure. By locating the radiant maps, the network ensures its accuracy in terms of linking a meteor to its respective shower.

Instruments	Geographical Lat.	Geographical Long.	Specification
Sharjah Digital Ionosonde	25.285381°N	55.464417°E	Freq. Range = 1-30 MHz
Sharjah Meteor Monitoring Tower	25.235611°N	55.539645°E	CCD Cameras
Al-Yahar Meteor Monitoring Tower	24.285922°N	55.463625°E	CCD Cameras
Liwa Meteor Monitoring Tower	23.104722°N	53.754828°E	CCD Cameras

Table 1: Location of the instruments used to generate data for this study

The data recorded by the towers are manually analyzed and filtered to ensure accuracy (Fernini et al., 2020). The UAEMMN towers record possible meteor occurrences and, can sometimes record airplanes and noise but these occurrences can be filtered manually by looking at the recorded video (Fernini et al., 2020). Airplane occurrences can be quite common at the Sharjah Tower, as it is in the midst of two busy airports. This is a potential advantage over the other radio frequency-based radar systems which may incorporate these observations as legitimate. The critical frequency of the sporadic-E layer (foEs) of the ionosphere is obtained from the ionosonde collocated with Sharjah meteor tower. The ionosonde records one ionogram every

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15 minutes, and it has been in operation since May 2019. All ionogram-derived parameters used in this study have been manually scaled. All the data used in this study is available from SWI Lab, (2020).

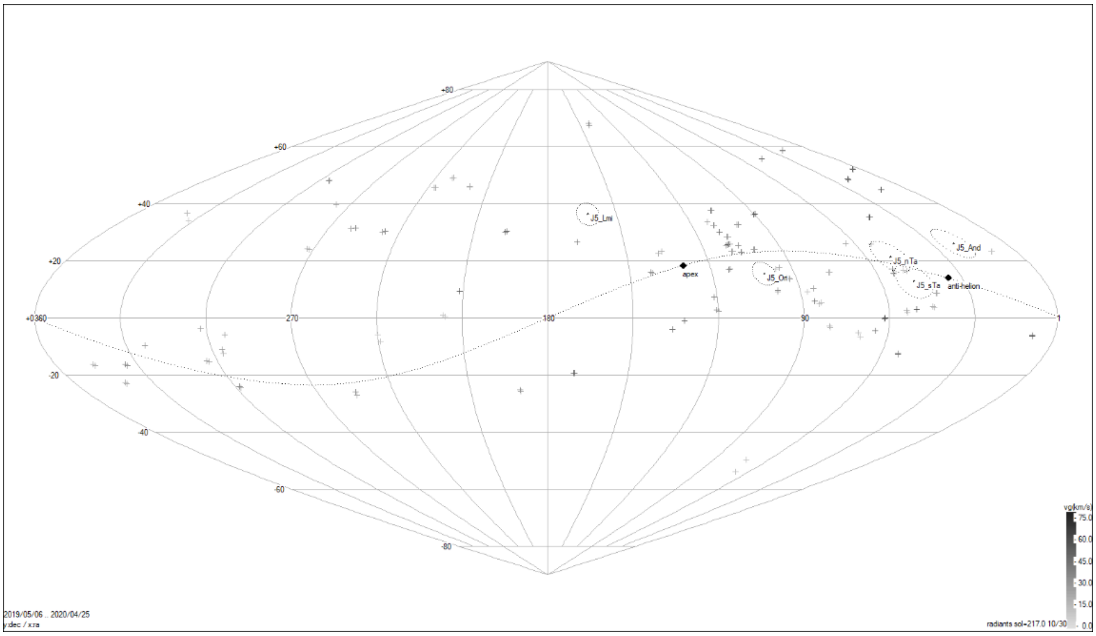


Figure 2: A radiant map of meteor observations by the Sharjah and Al-Yahar stations during the period May 2019 – April 2020

3 Discussion

Fig 3 shows the observation of Es and meteor count. A constant presence of Es can be observed throughout the year and all hours of the day. An important point to note here is that this observation was performed during a time when the solar activity was low. The average F10.7 solar radio flux value during 1-year observational period was recorded as 69.43. Only geomagnetically quite days with average daily Kp value less than 3 were selected for the analysis. It is expected that the Es observations would be stronger as solar cycle 25 get stronger in coming years. Fig 3(b) shows the hourly meteor count for the whole 1-year observational period. No observations were recorded during the daytime.

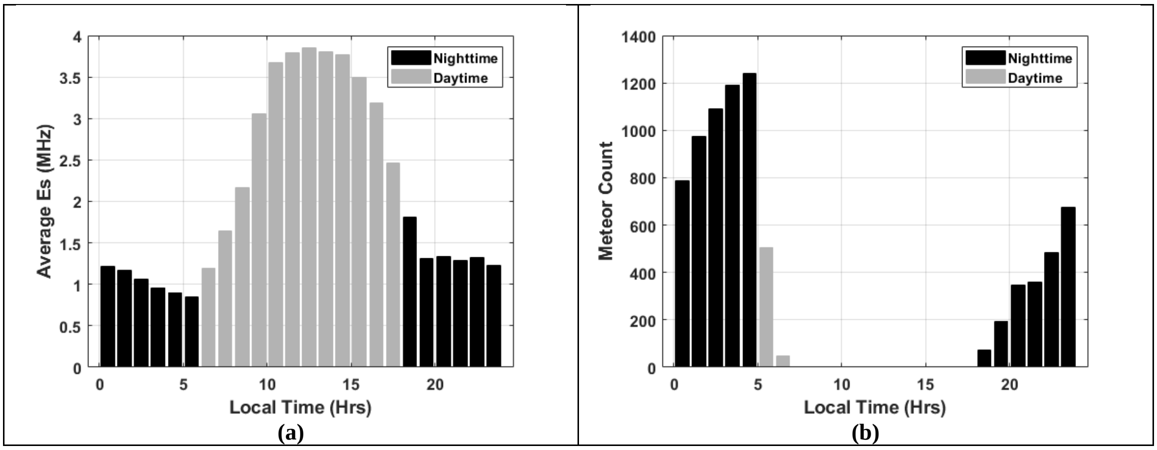
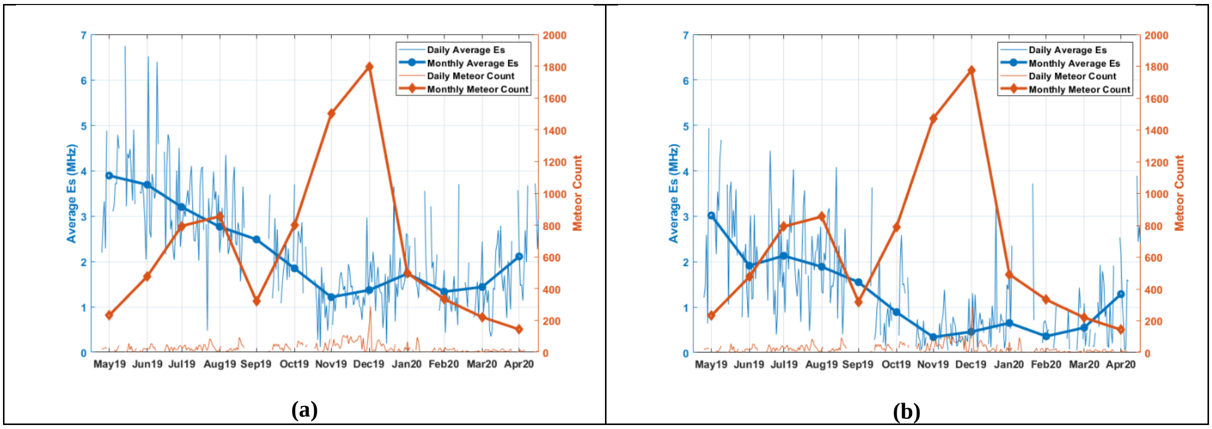


Figure 3: Simultaneous monitoring of meteors and Es over arabian peninsula from May 2019 – April 2020. (a) Hourly average of Es occurences recorded using ionosonde, (b) Hourly metero count

Fig 4 is a comparison between the daily and monthly meteor counts with daily and monthly averages of Es occurrences. 4(a) shows all daily observations (24 hours) and 4(b) provides observations for nighttime, only. The trend of monthly averages of Es clearly shows a rise in summer months and a decline in the autumn and winter months. At the other end, the meteor monthly count shows an opposite trend with larger number of meteors observed during November - December 2019 and very low numbers in the Spring and Summer months. Both 4(a) and 4(b) shows very similar trend for Es averages. The difference is in the intensity of the Es which is greater when all observations are considered due to the inclusion of daytime Es observations. The meteor count is same in both cases since we have only observed meteors through visual cameras during the nighttime.



(a) **(b)**

Figure 4: Daily and monthly averages of Es and meteor count over Sharjah. (a) Including all observations (24 hours), (b) Nightime observations only

The observations presented in Fig 4 are inconsistent with Younger et al. (2009) who reported meteor flux data observed by radars installed at Esrange (68oN), Ascension Island (8oS) and Rothera (68oS). They showed that, for high latitudes, there is a clear annual cycle present where maximum count rate is observed in summer. Whereas for low latitude Ascension Island, the maximum count rates were observed for both solstices (summer and winter). Similar observations were also reported by Singer et al. (2004) using a meteor radar situated at the ALOMAR observatory (69oN), and Haldoupis et al. (2007) from European latitudes.

There have been other studies that correlate meteor activity with the Es seen in ionograms, examples of which include Chandra et al. (2001), Haldoupis et al. (2007), and Ellyet and Goldsborough (1976). There are also numerous studies whose results are inconclusive. This may be because plasma density abnormalities may exist which may cause ionograms to record scatter echoes beyond the foEs. The abnormalities are caused by plasma instabilities due to the various electrodynamic processes in the ionosphere. Meteoric activity may provide metallic ions to the ionosphere, but they may not be displayed in ionograms if the conditions are unfavorable. This may be why a good correlation between meteor activity and Es is not seen (Chandra et al., 2001). Fig 4 show differences between the variations in foEs and meteor counts observed both at small and large timescales. Es may be affected by differences in climatology and wind dynamics. Visual meteor counts may not include all meteors. The metallic ions deposited by a meteor in the ionosphere may not be proportional to the meteoric activity as well. The exact relationship between metallic ion densities and meteoric activity is not known, and transportation of metallic ions by neutral winds is also not accounted for. Due to these uncertainties, the incongruous relationship between foEs and visual meteors count is not unexpected, however, they are not enough to explain the incongruity.

Constellation	Hourly Dates	Rate	Speed (km/s)	Shower Name	Quantity from the UAEMMN towers
Capricorn	Jul 3 – Aug 15	5	41	Capricornids	6
Perseus	Aug 10 - Aug14	40	60	Perseids	2
Taurus	Nov 01 – Nov 07	8	30	Taurids	10
Gemini	Dec 10 – Dec 13	50	35	Geminids	17
Monocerous	Dec 5 – Dec 20	15	35	Monocerotids	2

Hydra	Dec 03 – Dec 15	3	58	Hydrids	4

Table 2: Meteor showers observed by UAEMMN network

One can expect to see a meteor entering in the Earth's atmosphere every 10 minutes or so, but there are predictable times during the year when the Earth's atmosphere is full of them, and these are referred to as meteor showers (Kronk, 2014). These showers occur monthly with some meteor showers more pronounced than others, depending on their parents' progenitors (Collins, 2020). We can see about 30 meteor showers during the year. Since the meteors in each shower seem to come from a certain point in the sky, the shower is named after the constellation from which the meteors come. The Quadrantids, the Perseids, and the Geminids are the most prominent of all the meteor showers. Table 2 is showing the data obtained from the UAEMMN network about the meteor showers. The data is taken from the same one-year study period used in this work. We can clearly observe that most meteor showers occurred from the period from August to December resulted in significant increase in the numbers of visual meteors observed in UAE (see Fig 4). However, it seems quite understandable here that not all those meteor showers contributed to the presence of Es in UAE since Es observations were higher in summer than during the winter months.

Es may not be observed if the period of meteoric activity does not provide long lived metallic ions in the background plasma density. However, under favorable conditions, the meteoric debris consisting mostly of metallic ions could be converged to form sharp layers of ionization lead to density gradients responsible for ionospheric irregularities and spreading of the echos in the ionograms. Since the ionospheric background conditions considerably vary with latitudinal region, simultaneous observations from different geographical regions would be needed to confirm a certain meteoric activity and its linkage with the appearance of Es. Therefore, a thorough analysis using the systematic analysis of past data taken simultaneously from different latitudinal regions yield a better picture on the role of meteoric activity in the E-region ionization.

4 Conclusion

In this paper, using simultaneous observations of foEs and the meteoric influx (meteor count rates through visual cameras) show no diurnal or seasonal dependence over Arabian Peninsula. We report the seasonal observations of Es simultaneously taken with the visual count observations from a geographical region which has not been reported before. However, no attempt was made to link the simultaneous observation of Es and meteor influx in detail. It is shown that the annual variation of both observations, on average, has no correlation on monthly basis having linear correlation coefficients less than -0.35 (negative 0.35) for both full day and nighttime observations (see Fig 5).

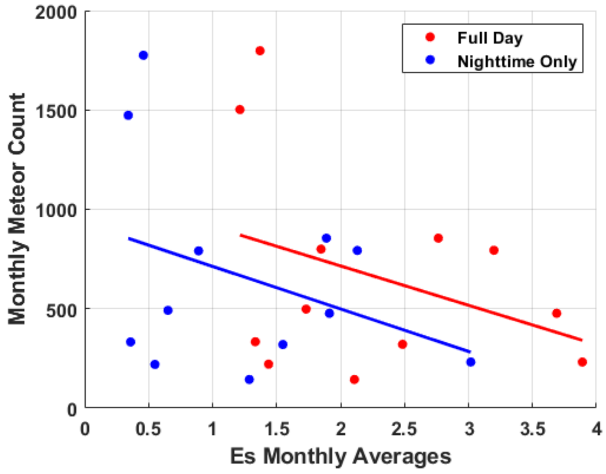


Figure 5: Relaitonship betweeen Es monthly average and monthly meteor count observed at Sharjah.

Our one-year observations clearly show that the Es observations are not dependent on the presence of meteor flux since the meteor count trend, which is peaking in winter and declining in summer, is found to be uncorrelated to the trend observe for Es averages (see Fig 4). Such results have not been reported in the literature and do not comply with frequently reported studies which established a strong seasonal correlation between daily meteor counts with daily averages of Es occurrences, as mentioned in the references above. It is also important to note that this study, unlike many of the previous studies, used visual observations for observing meteors. Since the data is manually checked and verified from the recoded visual data, unlike for radio based radar observations where false observations' rate is very high, the study is likely to provide a real picture since there is a very little chance of having false data. Nevertheless, the authors believe that a more detailed study is required to fully investigate and properly identify the Es seasonal dependence on the meteor influx in the region around Arabian Peninsula.

Data Availability

All data used in this work is available from the dataverse of SWI Lab and acquired and managed by Sharjah Academy for Astronomy, Space Sciences and Technology (see reference SWI Lab, (2020)).

Author Contribution

Muhammad Mubasshir Shaikh: Conceptualization, Investigation, Data Curation, Writing – Original Draft.
Govardan Gopakumar: Investigation, Software, Data Curation, Writing - Review & Editing.
Aisha Abdulla Alowais: Software, Writing - Review & Editing
Maryam Essa Sharif: Software Writing - Review & Editing
Ilias Fernini: Writing - Review & Editing

Competing Interests

The authors declare that they have no conflict of interest.

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