Altitudinal and latitudinal asymmetry in diurnal variation of sporadic meteor flux observed over Thumba

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We present here latitudinal dependence of the diurnal variation of the sporadic meteor flux rate based on radar observations made from Thumba (8.5°N, 77°E), Darwin (12.5°S, 130.8°E), Buckland Park (34.4°S, 138.3°E) and Davis (68.6°S, 78.0°E). The most striking observation was the occurrence of a secondary peak at Thumba at 03:00 local time (LT) prior to the occurrence of the commonly observed morning peak at 06:00 LT at all altitudes. Surprisingly, the secondary peak was not observed at Darwin, which is a low-latitude station close to Thumba, but in the southern hemisphere. Further, we found that this secondary peak has a clear seasonal variation. In summer (winter), the primary (secondary) peak is larger than the secondary (primary) peak and they are comparable in the equinoxes. The observed diurnal rates also showed seasonal and latitudinal variabilities, which can be interpreted in terms of observing geometry of the sporadic meteor sources in the local sky. Our observations also suggest that there exists asymmetry in northern and southern hemisphere sporadic meteor flux.

Keywords: Meteor, meteor flux, sporadic, Thumba.

THE meteoroid flux into the Earth's atmosphere is either due to meteor showers or sporadic meteors. Only about one quarter of visually observable meteors are shower meteors and the rest consist of sporadic meteors coming from all directions and not connected to any specific known shower. However, some of these are considered to be part of an unknown shower. The shower meteors move in parallel paths and have radiants originating from a small area on the celestial sphere, whereas the sporadic meteors are dispersed and appear to have a broad distribution of radiants over the entire sphere. The main sources that were considered to be responsible for the sporadic meteors are the result of gradual evolution and diffusion of meteoroid streams under the radiation and gravitational effects of big planets and stars or collisions between the stream and dust cloud particles or particles evolved from the asteroid belt or from meteoritic streams. These sporadic meteors are more dispersed than the shower meteors and the radiants are assumed to be random and the sources are assumed to be more concentrated in the ecliptic[1,2].

Although radio observations of meteors have been made since the late forties and many aspects of meteor science matured in the sixties, it is only recently that a methodology was developed, using meteor radar interferometry, which led to the determination of the annual variability of meteoric input in both the northern and southern hemispheres. These studies have shown that the sporadic meteor flux is not constant throughout the globe. However, recent studies have shown that they are not random, but follow certain periodic diurnal and seasonal pattern[3–5]. The sporadic meteoroid is mainly concentrated in six sources: the helion and anti-helion sources, the north and south apex, and the north and south toroidal sources. Previous studies on sporadic meteors were focused on the behaviour of these six sources. Moreover, the latitudinal dependence of diurnal meteor rates showed that the rates are maximum/minimum in equatorial/polar latitudes respectively[6]. The high-power large-aperture Jicamarca radar in interferometric mode has been used to observe more than 3000 meteor echoes per hour and it was found that the radiant distribution of all the detected meteors is concentrated in relatively small angles centred around the Earth's apex with no appreciable inter-annual variability[3]. Several reports mainly concentrated on the origin of the sporadic meteor sources and also on the seasonal variations. Thus for a better understanding of the meteoric origin, it is important to know precisely the global annual, seasonal and diurnal variation of the meteor flux. The statistical determination of the annual variability of meteoric input in both the northern and southern hemispheres is a recent subject of interest. Although recent studies have shown that the meteor flux follows certain diurnal pattern[6], its latitudinal and seasonal dependences are not known precisely.

The present study shows the altitudinal and latitudinal dependence in the diurnal variations of the sporadic meteor flux based on observations made from Thumba (8.5°N, 77°E), Darwin (12.5°S, 130.8°E), Buckland Park (34.4°S, 138.3°E) and Davis (68.6°S, 78.0°E). Interesting results on the secondary peak in the meteor flux observed during the pre-sunrise hours and limited to Thumba have been analysed and discussed in terms of their origin.

An All-SKy interferometric METeor (SKiYMET) radar has been commissioned at Thumba, located in the southern part of India, to study the mesosphere and lower thermosphere (MLT) region dynamics through temperature and wind observations. This meteor radar operates at 32.25 MHz with a peak power of 40 kW. The present meteor radar system is a multi-channel coherent receiver pulsed radar utilizing advanced software and computing techniques to acquire, detect, analyse and display meteor

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Table 1. Specifications of SKiYMET Radar

Parameter	Specifications
Operating frequency	32.25 MHz
Peak power (solid-state transmitter)	40 kW
Maximum duty cycle	Up to 15%
Pulse width	Programmable between 1 μs and 200 μs (13.3 μs)
Pulse repetition frequency	Programmable between 1 Hz and 50 kHz (2144 Hz)
Band width	~ 1.5 MHz
Sensitivity	–107 dBm
Dynamic range	62–122 dB
Transmitting antenna	Four circular-polarized three-element yagi antenna (crossed elements) at the corners of the square
Receiving antenna	Five circular-polarized two-element yagi antenna (crossed elements) spaced to form an interferometer

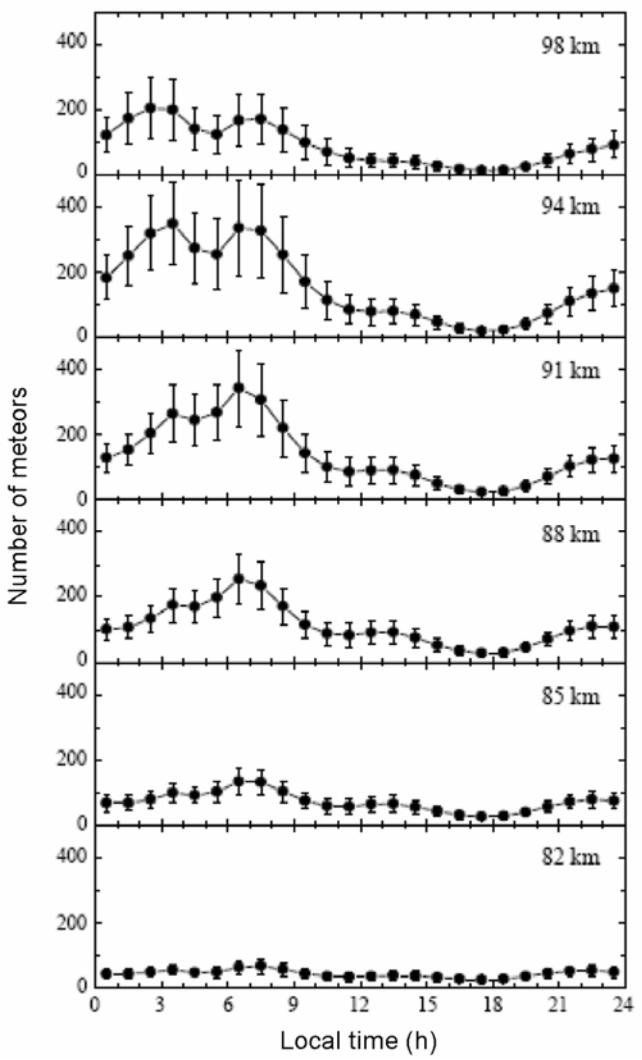

Figure 1. Mean meteor flux with local time at Thumba plotted for 82, 85, 88, 91, 94 and 98 km from bottom to top respectively. Vertical bars represent standard deviation.

occurrence events. A detailed description of this radar and the meteor detection algorithm is given elsewhere[7]. Detailed specifications of the Thumba SKiYMET radar are given in Table 1. For the present study, we used the meteor flux rate observed by this radar and the data used here correspond to the period of March 2006–February 2007.

To study the diurnal variations of the meteor count rates for different latitudes, we used observations from the Darwin meteor radar located in the northern part of Australia, the Buckland Park meteor radar located in the southern part of Australia and the Davis mesosphere–stratosphere–troposphere (MST) radar located in the Antarctic. The Darwin All-Sky interferometric meteor radar operates at 33 MHz, with a peak power of 7.5 kW. The Buckland Park All-Sky interferometric meteor radar[8] operates in the frequency range 30–60 MHz, with a peak power of 7.5 kW. The Davis MST radar[9] operates at 55 MHz with a peak power of 100 kW. Meteor data used for the present study correspond to the period of March–November 2006 and February 2007 for Darwin, March–May 2006 for Buckland Park and March 2006–February 2007 for Davis.

Figure 1 shows the mean diurnal variation of sporadic meteors detected at six heights (82, 85, 88, 91, 94 and 98 km) over Thumba. The entire dataset of March 2006–February 2007 has been used to calculate the diurnal pattern of the sporadic meteor flux. Total meteor count rates covering the height range 82–98 km were calculated after removing multiple detections and ambiguous detections of echoes. Unambiguous detections were only allowed and careful inspection was made to remove the contribution from shower meteors. As can be seen in Figure 1, the diurnal variation shows the maximum and minimum meteor flux rate to occur at ~ 06:00 LT and ~ 18:00 LT respectively, in 82–91 km altitude, which is consistent with earlier studies[3–5]. The hourly rate has a maximum of ~ 400 meteors per hour occurring at ~ 94 km.

We observed secondary peak occurring at Thumba at 03:00 LT at all heights and further, the secondary peak increased with increasing height. At ~ 94 km, the amplitude of the secondary peak was comparable to the primary peak (which usually occurs at 06:00 LT) and at ~ 98 km the secondary peak was larger than the primary

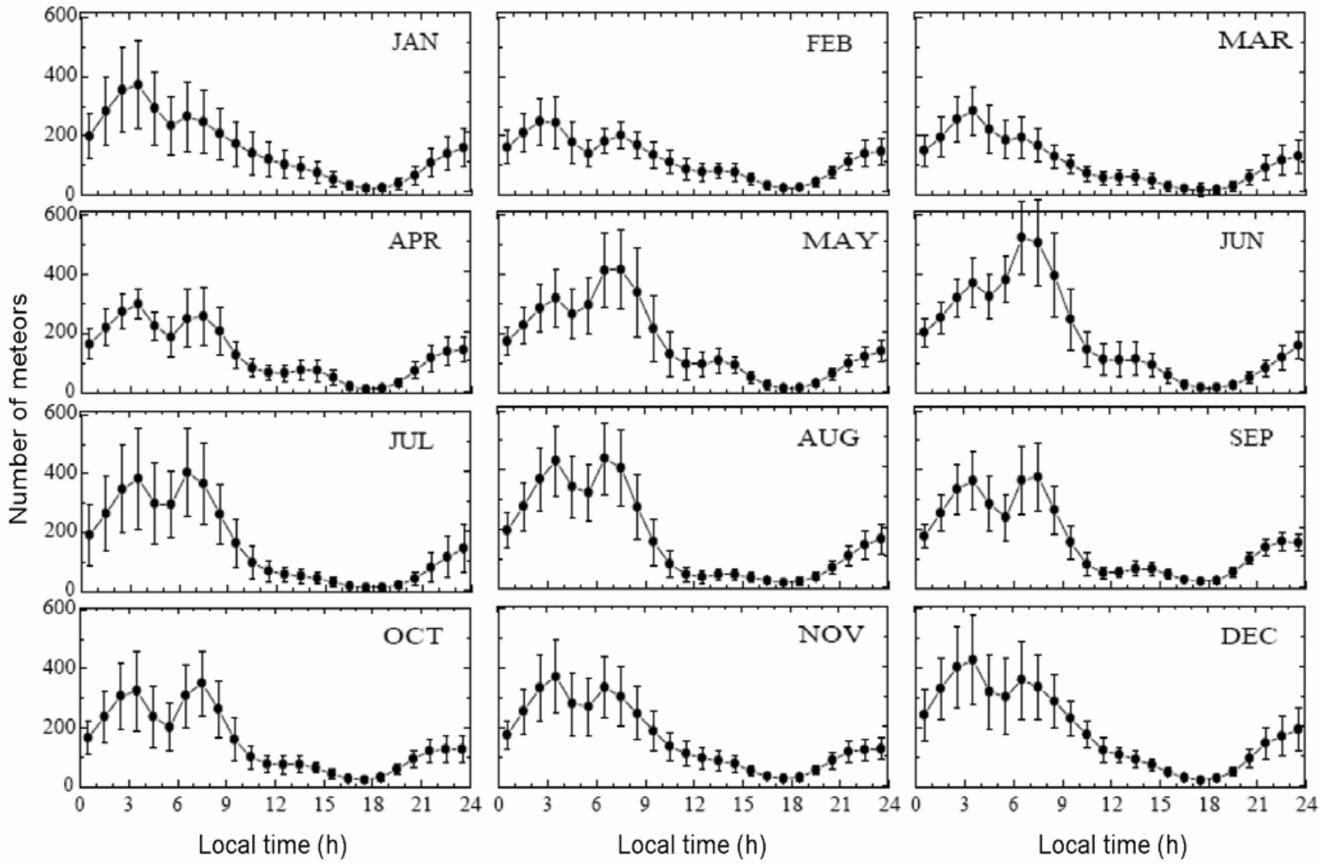

Figure 2. Mean meteor flux with local time plotted for each month in 2006. Vertical bars represent standard deviation.

peak. If the diurnal variation had to be driven solely by the orbital motion of the Earth about the Sun, the maxima and minima should occur at 06:00 LT and 18:00 LT respectively. However, our observations from Thumba showed secondary peak at 03:00 LT. The diurnal variation of meteor echoes was studied using a 50 MHz radar from Puerto Rico[10] and it was found that the peak of specular echoes occurs at 03:00 LT and that of non-specular echoes at 06:00 LT.

Figure 2 shows the monthly meteor rates at ~ 94 km in 2006 at Thumba. A clear inspection shows maximum and minimum meteor rates are at 06:00 LT and 18:00 LT respectively, apart from the dominant secondary peak at 03:00 LT, irrespective of the season. Seasonal behaviour of the secondary peak can be clearly seen from the figure.

During spring (March–May) and fall (September–November), the meteor flux distribution is comparable for both the peaks. However, there is an asymmetry in summer (June–August) and winter (December–February). In summer, the primary peak is larger than the secondary peak, whereas in winter the secondary peak dominates the primary peak. Monthly variation clearly shows that the minimum meteor rate is observed in March when the highest elevation of the Earth's apex in the Indian sector is the lowest compared to other seasons[11]. The primary peak contribution is dominant from May and it is evident till November. However, the secondary peak contributes more from November and lasts till April. The maximum difference between primary (secondary) peak and secondary (primary) peak can be observed in June (January). During some months both the peaks are comparable, whereas in other months one peak is dominant; however, in March there is no primary peak which shows the variability of the sporadic meteor sources.

To characterize seasonal variabilities in the two peaks, we have calculated the height ratio for the primary and secondary peaks at ~ 06:00 LT and 03:00 LT respectively. Figure 3 displays the height ratio normalized to that of 82 km for both the peaks. As seen from the figure, the primary peak at 06:00 LT maximizes around ~ 91 km except for summer, whereas the secondary peak maximizes above ~ 94 km for all seasons.

The width of the ratio increases above ~ 94 km and decreases below ~ 94 km from fall to winter. The width ratio has also some seasonal variation with winter (fall) showing maximum (minimum) above 94 km and minimum (maximum) below 94 km respectively. The maximum/minimum ratio of specular and non-specular meteor trails were ~ 8 and 30 respectively, from the same radar and observing volume[10]. The maximum/minimum ratio in

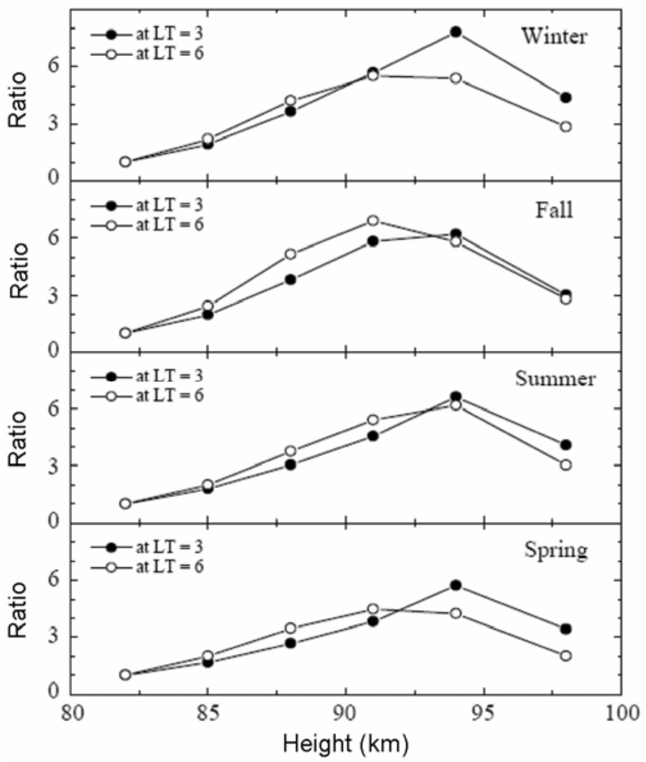

Figure 3. Maximum to minimum ratio plotted with height for four seasons, i.e. spring, summer, fall and winter, from bottom to top respectively. Solid and hollow circles show 03:00 LT and 06:00 LT values respectively.

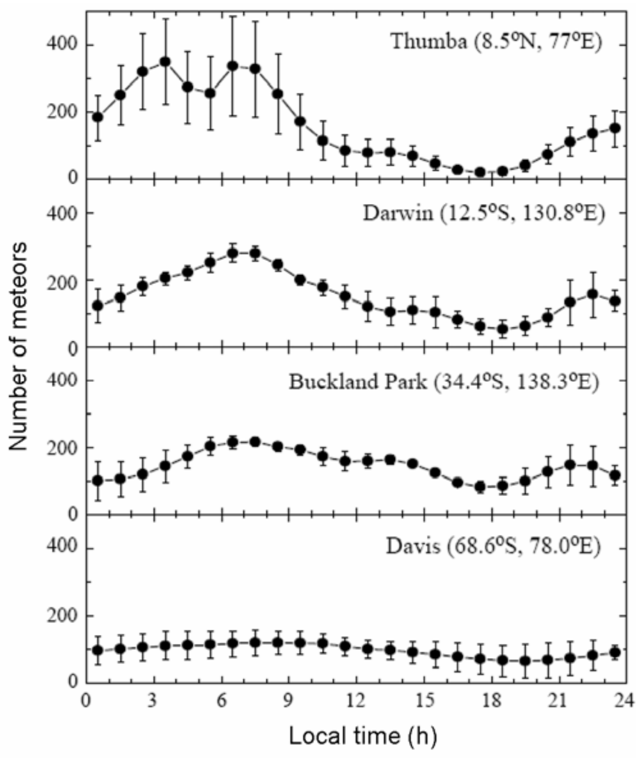

Figure 4. Mean meteor flux with local time plotted for Thumba, Darwin, Buckland Park and Davis respectively. Vertical bars represent standard deviation.

our observations was around ~ 8 for both the primary and secondary peaks.

In order to compare the occurrence of the secondary peak at different latitudes, we present observations from Darwin, Buckland Park and Davis along with those observed at Thumba (Figure 4). As seen from this figure, maximum and minimum meteor flux at Darwin, Buckland Park and Davis are observed at ~ 06:00 LT and ~ 18:00 LT respectively, which is also observed at Thumba. At polar latitudes, however, there exists very little diurnal variation. Meteor deposition rate is found to decrease with increasing latitude. Interestingly, the secondary peak, which is observed at 03:30 LT at Thumba, is not observed at other latitudes. The secondary peak has not been observed even at Darwin, which is also a low-latitude station similar to that of Thumba, but in the southern hemisphere. The secondary peak, which is dominant over Thumba, may assume importance due to its possible role in the E-layer plasma processes. This could include finding a relation between the metallic ion density from meteoric influx and the ionospheric parameters, such as sporadic-E activity and generation of plasma irregularities, at that time. Several studies in the past showed preliminary results suggesting that in the short term there is a more complex relation between them and it generally depends on atmospheric wave dynamics[10,12,13]. The secondary peak in the meteor flux in the pre-dawn hours reported here would provide an important input in understanding such a relationship.

Figure 5 shows seasonal variations of daily meteor rate plotted for altitudes of 82, 85, 88, 91, 94 and 98 km. Seasonal variation of the sporadic meteor flux shows a maximum in summer and minimum in the equinoxes, with a secondary maximum in winter showing a semiannual variability. In addition, it has been observed that the annual variations of meteor rates increase sharply as time progresses from spring equinox into summer, but decrease less abruptly from summer to fall and winter. This makes the variation asymmetric about the summer peak. Similar results were found in the equatorial measurements made by identical equatorial meteor radar in Ascension Island for about a total of 4 years, showing in general lower count rates undergoing a semiannual variability[14]. This exhibits maximum count rates in the summer and winter solstices and minimum count rates in the equinoctial months[14]. The present observations are consistent with earlier observations[4].

The sporadic meteor radiants are not random in space but directed towards the plane of the ecliptic, which thus explains that the summer (winter) maximum (minimum) is as a result of the Earth's tilt to the ecliptic plane[15]. But, our findings are in contrast to the earlier observations[15] which showed only one peak (we observed double peak with summer maximum and secondary maximum in winter).

The general diurnal pattern of the sporadic meteor flux is known to be due to the effect of the Earth's rotation and its motion around the Sun (~ 30 km/s). During dawn hours, the Earth's onward motion intercepts all the meteors moving in the opposite direction and even catches up a few slower meteors travelling in the same direction. During dusk hours, only those meteors travelling with a velocity much faster than the Earth's heliocentric velocity are able to enter the Earth's atmosphere. Therefore, the maximum meteor flux rate should be around 06:00 LT, whereas the minimum should be around 18:00 LT[4,5,10,11]. It is evident from the previous observations that the relative location of the meteoroid sources in the local sky has seasonal and latitudinal differences and there exists an asymmetrical meteor distribution in the northern and southern hemispheric poles[4]. The main contributor in meteor distribution is thought to be concentrated in the apex-centred particle population as observed at Jicamarca and Arecibo[4,16]. However, recent observations and models suggest that the main source seems to be the Earth's apex with ~ 30–60% contribution and the remaining mostly originates from the helion and anti-helion sources

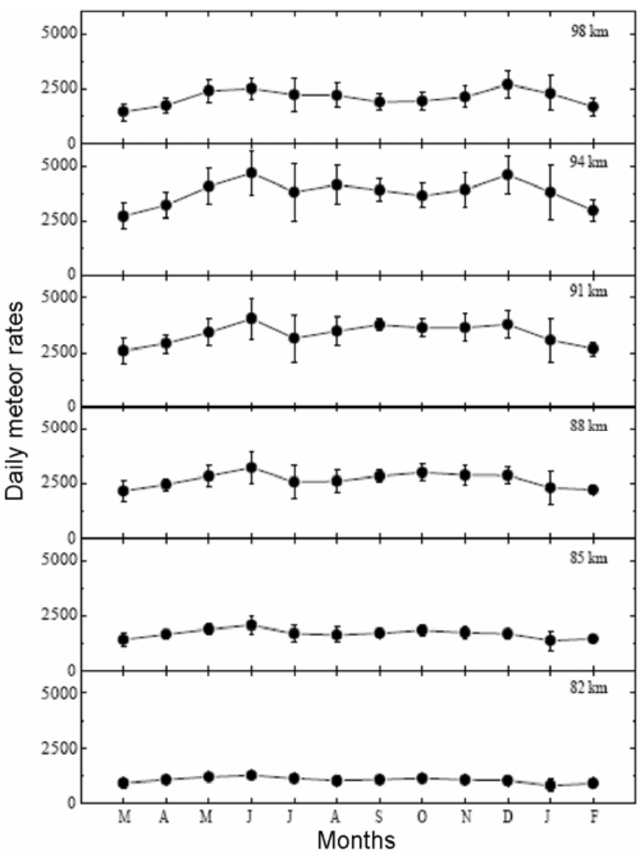

Figure 5. Seasonal variation of mean meteor flux plotted with day of the year. Vertical bars represent standard deviation.

with a small contribution from south and north toroidal sources[3]. It should also be noted that the small-scale features such as secondary peak in the diurnal meteor rate can be explained by the right combination of contribution from apex, helion and anti-helion sources.

The primary and secondary peaks observed in the diurnal variation of the sporadic meteor flux also have seasonal variation. During different seasons, we have different distribution patterns of primary and secondary peaks. The peak of the flux is reached early in the morning, decreasing sharply after the rate maximizes. The measured rates are high in January and February and then decrease until June. We observed the secondary peak in the meteor rate throughout the year with significant seasonal variation. During summer, the primary peak is larger than the secondary peak, indicating that at Thumba-like latitudes, the contribution due to anti-helion sources during this part of the year could be larger than that of the helion sources. During the autumn equinox, the distribution seems to be symmetric around ~ 06:00 LT followed by a more dominant secondary peak, suggesting a stronger contribution from the helion sources at equatorial latitudes. The seasonal and diurnal variability on the small-scale features of the meteor rates suggests that the contribution of the different meteor radiant distributions to the meteoric mass flux varies throughout the year.

Thumba is located in the northern hemisphere and Jicamarca is located on the southern hemisphere, and the minimum rate would be in spring (fall) in the northern (southern) hemisphere, however, the ratio of maximum daily rate between spring and fall is much less in Thumba. Hence, our observations suggest that there exists asymmetry in the northern and the southern hemisphere sporadic meteor flux. Darwin, a low-latitude station in the southern hemisphere, however, does not show secondary peak in the diurnal rate. This can be interpreted in terms of global asymmetry in the sporadic meteor flux. Also, the secondary peak in the diurnal meteor rate is not observed in any of the latitudes in the southern hemisphere (see Figure 5).

The asymmetry in the sporadic meteor flux can also be interpreted in terms of the meteor angle of arrival. The angle of arrival is variable at different latitudes, i.e. at higher latitudes, the average entry angle may not vary significantly whereas at lower latitudes, the average angle of arrival can be quite different throughout the day leading to the observed diurnal variability. This could be a possible reason for the observed asymmetry in the global sporadic meteor flux in the northern and southern hemispheres. However, simultaneous measurements from different radars around the globe are required to quantify the diurnal and seasonal variability of the sporadic meteor flux.

We have examined the secondary peaks observed at Thumba near the magnetic equator. They are compared with the observations at low, mid and high latitudes. Our observations can be summarized as follows:

(1) Occurrence of a secondary peak at Thumba occurring at 03:00 LT prior to the occurrence of the commonly observed morning peak occurring at 06:00 LT at all latitudes.
(2) This secondary peak has not been observed at Darwin, which is a low-latitude station close to that of Thumba, but in the southern hemisphere.
(3) The secondary peak has a clear seasonal variation. In summer (winter), the primary (secondary) peak is larger than the secondary (primary) peak, and they are comparable in the equinoxes.
(4) Recent observations and models suggest that the main source seems to be the Earth's apex with 30–60% contribution and the remaining mostly originates from the helion and anti-helion sources with a small contribution from the south and north toroidal sources.
(5) The apex-centred distribution is sufficient to reproduce the general large-scale diurnal trend in the meteor rate. However, the small-scale features such as secondary peak can be explained by the right combination of contribution from the apex, helion and anti-helion sources.

Based on the above observations and analyses, it is shown that the sporadic meteors show local time and seasonal dependence. This could include a search for establishing a relation between the metal ion density and the meteoric influx, and to study the relationship among Field Aligned Irregularities (FAIs), sporadic-E (Es) and meteor counts at shorter timescales. Several studies in the past have shown inconclusive results, suggesting that in the short term there is a more complex relation between sporadic-E and meteoric deposition. Sporadic-E at shorter timescales generally depends on atmospheric wave dynamics providing the favourable wind shears needed for Es formation. Such effects may also contribute to longer time scale sporadic-E variability, but on the average these short-term influences are reduced when it comes to long-term seasonal changes. It is evident that there are complicated electrodynamic processes occurring within the meteor trails for the generation of FAIs.

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