ISSN 2229-5518

# Investigating the radiant sources of meteors

Anamol Mittal, Dr. K. Kishore Kumar

**Abstract**— The results obtained in the present study, which are related to basic meteor phenomenon such as meteor velocity distribution, height distribution and annual variability of meteors are discussed. An attempt is also made to identify the peak radiant sources of the observed meteors. The results are found to be consistent with the present understanding of the meteor phenomenon. Further studies are required to estimate the orbits of the meteors using single station observations. The important outcome of the present study is the algorithm for estimating the radiant sources using azimuth, zenith angle observations of meteor radar.

**Index Terms**— Astronomy, earth sciences, entrance velocity distribution, meteor wind radar, meteors, radiant sources, Thumba

## 1 INTRODUCTION

People have always wondered about the worlds that lie beyond the boundaries of sky, the purpose of our existence, whether the existence of earth is a result of some higher purpose or just a lucky coincidence? Well, answers to these questions are not known and beyond the reach of present technology. One such question asks: Where do the meteoroids (most commonly known as falling stars) come from and how is their distribution in solar system related to the formation of planets and other solar system bodies? You may find answers to these questions as you proceed through the report.

### 1.1 Some Fundamental concepts:

1. Equinox: Equinox is the intersection of the planes of the earth's equator and the earth's orbit, the ecliptic.

   The time when the Sun crosses the plane of the earth's equator, making night and day of approximately equal length all over the earth land occurring on about March 21 (vernal equinox) and Sept. 22 (autumnal equinox). [1]
2. Local Meridian: The Local Meridian is an imaginary Great Circle on the Celestial Sphere that is perpendicular to the local Horizon. It passes through the North point on the Horizon, through the Celestial Pole, up to the Zenith, and through the South point on the Horizon.

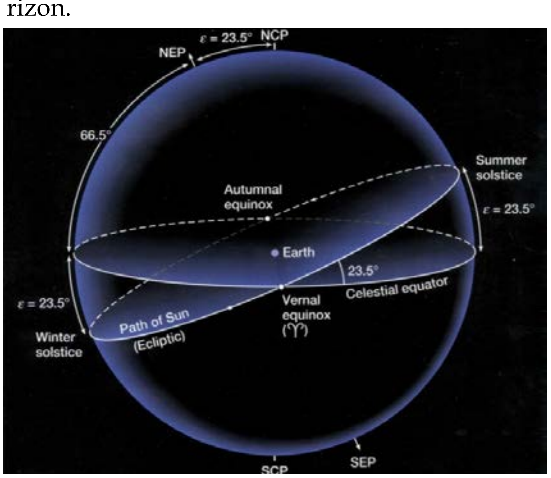



Figure 1: Representation of Equinox
Source:https://victoriastaffordapsychicinvestigation.files.wordpress.com/

3. Epoch: In astronomy, an epoch is a moment in time used as a reference point for some time-varying astronomical quantity, such as the celestial coordinates or elliptical orbital elements of a celestial body, because these are subject to perturbations and vary with time.[2]

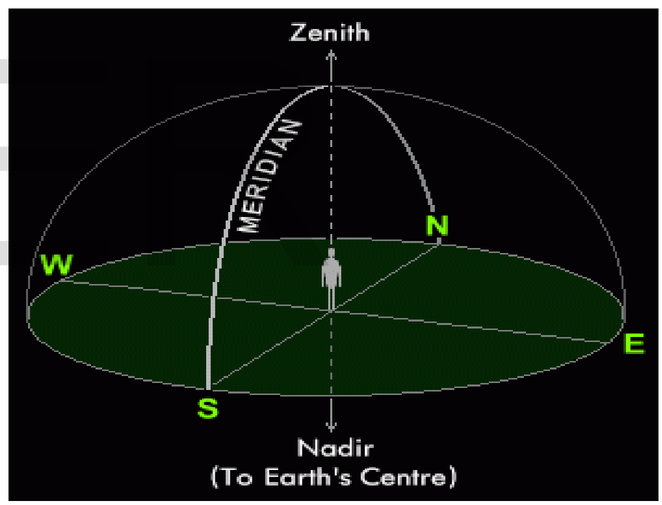



Figure 2: Representation of meridian
Source: http://www.aenigmatis.com/

### 1.2 Horizontal coordinate system:

The horizontal coordinate system is a celestial coordinate system that uses the observer's local horizon as the fundamental plane. It is expressed in terms of azimuth and altitude (or elevation) angle. [3]

4. Azimuth: The vector from an observer (origin) to a point of interest is projected perpendicularly onto a reference plane; the angle between the projected vector and a reference vector on the reference plane is called the azimuth.

5. Zenith distance: Zenith refers to an imaginary point directly "above" a particular location, on the imaginary celestial sphere. Therefore Zenith distance is the

angular distance from Zenith to the point of interest with center being the observer.

6. Altitude (Alt): Sometimes referred to as elevation, is the angle between the object and the observer's local horizon.
   Alternatively, zenith distance, the distance from directly overhead (i.e. the zenith) may be used instead of altitude. The zenith distance is the complement of altitude (i.e. 90°-altitude).

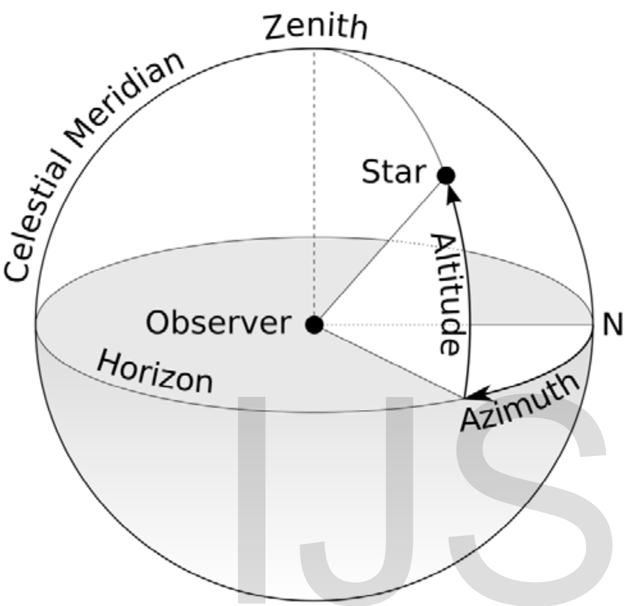



**Figure 3: Horizontal coordinate system**
**Source:https://en.wikipedia.org/wiki/Horizontal_coordinate_system**

## 1.3 Equatorial coordinate system

7. Hour Angle: Hour angle is defined as the angular distance on the celestial sphere measured westward along the celestial equator from the meridian to the hour circle passing through a point.[4](Note: an object's hour Angle indicates how much sidereal time has passed since the object was on the local meridian).

8. Declination: Declination's angle is measured north or south of the celestial equator, along the hour circle passing through the point in question.[4]

9. Right ascension: It is the angular distance measured eastward along the celestial equator from the vernal equinox to the hour circle of the point in question.[4]

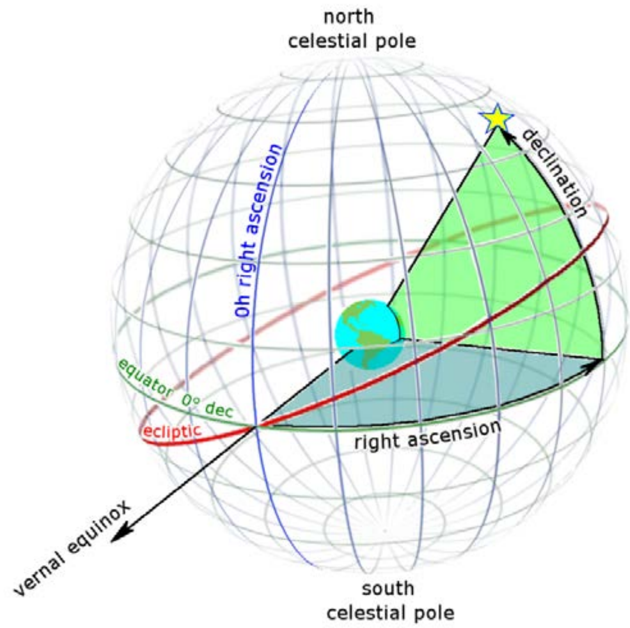



**Figure 4: Equatorial coordinate system**
**Source: https://en.wikipedia.org/wiki/Right_ascension**

In astronomy, we are usually concerned about the location of stars and other celestial objects. Since number of days in a month, days in a year, etc. are not constant over time, so we cannot rely upon these parameters. In order to have a well-defined and systematic unit system which does not change over time, we define some entirely new terms and concepts to help measure the exact position of a celestial object.

## 1.4 Time Depictions

10. Julian date: The Julian Day Count is a uniform count of days from a remote epoch in the past (4714 BCE November 24, 12 hours GMT). At this instant, the Julian Day Number is 0. It is convenient for astronomers to use since it is not necessary to worry about odd numbers of days in a month, leap years, etc. Once you have the Julian Day Number of a particular date in history, it is easy to calculate time elapsed between it and any other Julian Day Number. Note that the Julian day at the beginning of any day always gives you a half day extra. That is because the Julian Day begins at *noon*, Greenwich time.

11. Sidereal time: Sidereal time (star time) is a "time scale that is based on the Earth's rate of rotation measured relative to the fixed stars"[5] rather than the Sun.

Common time on a typical clock measures a slightly longer cycle, accounting not only the Earth's axial rotation but also for the Earth's annual revolution around Sun of slightly less than 1 degree per day. This creates a vacancy for a timescale which removes all the complications of Earth's orbit around sun, and just focuses on how long does the earth takes to spin 360 degrees with respect to the stars. Hence, sidereal time scale was invented.
Note: A mean sidereal day is 23 hours, 56 minutes, 4.0916 seconds 0.99726958 mean solar days), the time it takes the Earth to make one rotation relative to the vernal equinox.

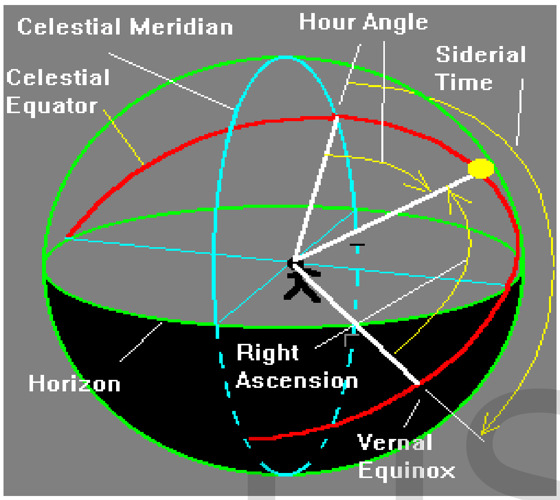



Figure 5: Representation of sidereal time and equatorial coordinate system.
http://plato.acadiau.ca/

12. Local Sidereal time (LST): Local Sidereal Time indicates the Right Ascension on the sky that is currently crossing the Local Meridian. So, if a star has a Right Ascension of 05h 32m 24s, it will be on your meridian at LST=05:32:24.

    More generally, the difference between an object's RA and the Local Sidereal Time tells you how far from the Meridian the object is.
    For example, the same object at LST=06:32:24 (one Sidereal Hour later), will be one Hour of Right Ascension west of your meridian, which is 15 degrees. This angular distance from the meridian is called the object's Hour Angle.

13. Greenwich mean sidereal time (GST): Greenwich mean sidereal time indicates the right ascension on the sky that is currently crossing the Greenwich meridian. It is related to Local sidereal time by the equation:
    GST= LST+ Longitude of the observer
    Note: Longitude=+ve (East) and -ve (West)

## 1.5 Basic definitions of Meteors and Meteoroids

14. Meteoroids: They are small chunks of rocks floating in outer space with speeds of about 20 km/sec on an average.

    Meteoroids occurring in the solar system may have many sources, of which mainly are: asteroids, comets, and ejections from planetary impacts of asteroids.
15. Meteoroids' Orbits: Meteoroids may travel in elliptical as well as circular orbits around the sun. Some meteoroids travel in clusters which are remnants of comets orbiting sun in elliptical orbits while rest of them travel in different speeds in different orbits, called as sporadic meteoroids.

16. Meteors: When a meteoroid enters the earth's atmosphere, a sudden streak of light is produced and this phenomenon is called meteor. The streak of light is caused by the intense heating produced by the air friction on meteoroid's surface upon entry into the earth's atmosphere. Commonly, this streak of light is called as a falling star. Meteor may be classified into two categories:
    - Sporadic meteors: Sporadic meteors originate from random chunks of dust floating around the Sun. Their occurrence is random.
    - Shower meteors: Shower meteors originate from dusts left by the comets as they orbit around the Sun in their elliptical orbit. The dust spreads out along the comet's orbit and forms an elliptical trail of debris that passes around the sun and crosses the orbits of planets.Meteor shower occurs when Earth passes through the trail of debris during its yearly orbit around sun.

17. Radiant position of meteor: The radiant or apparent radiant of a meteor shower is the point in the sky, from which (to a planetary observer) meteors appear to originate.[6]
    Meteor showers get their names from the constellation in where their radiant is located. Perseids come from Perseus, hence the name Perseids. [7]

## 1.6 Objectives of the present study

The present study aims at bringing out the salient features of meteor activity over Thumba using radar ob-

ISSN 2229-5518

servations in terms of variability of meteor counts at diurnal and annual scales, their height distribution and meteor entrance velocity distribution. The present study also aims at developing an algorithm to trace back the meteor radiant sources using the radar observations.

## 2. Introduction to meteor wind radar

**2.1 Meteor radar at Thumba:** We have recorded specular meteor radar data by SKiY-Met (all-sky-interferometric meteor radar) at Thumba, Thiruvananthapuram, India, at $8.5167^{o}$ N, $76.8667^{o}$ E which is working round the clock to record meteor activity. Electromagnetic pulses are radiated by a transmitter at a frequency of 35.25 MHz which detects the meteor trails occurring at 70-110 Km height range.Radar studies the way in which the meteoroids manifest themselves through generation of ionization trails. When meteoroids collide with the atmosphere at the entry velocities, they give rise to ionization trails that contain a large number of ions and electrons in small, confined space. The ionization results from shock heating and high energy collisions between meteoroids and the atmosphere. Two ways can be used to observe the reflected radiation: back-scatter or forward scatter. In the former, the transmitter of the radio waves is located at the same position as the receiver, and the technique was called radio echo in its early days. In the second method, the transmitter and the receiver are separated by a great distance. The SKiYMET radar uses the back-scattering method.

The meteor radar system is a multi-channel coherent receiver pulsed radar utilizing state-of-the-art software and computing techniques to acquire, detect, analyze and display meteor entrance events. Various calculations are performed in real-time on the detected meteor echoes. The results of these calculations can provide information about the nature of the meteor, such as the orbit and speed of travel on entering the atmosphere. The instrument detects a sufficient number of meteor echoes throughout the day to obtain a comprehensive picture of the wind field. Analysis of the decay time of the meteor trail allows the determination of absolute measurements of mesospheric temperatures. Table 1 depicts the specifications of the meteor radar systems used for the present study.

| | |
|---|---|
| • Operating frequency: | • 35.25 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) |
| • Bandwidth | • ~1.5 MHz |
| • Sensitivity | • -107 dBm |
| • Dynamic range | • 62-122 dB |
| • TX antenna | • Four circular polarized 3-element Yagi (crossed elements) at the corners of a square |
| • RX antenna | • Five circular polarized 2-Element Yagi (crossed elements) spaced to form an interferometer |

**Table 1: Specification of Meteor Radar at Thumba**

A single three-element Yagi antenna is used for transmission, and five two-element Yagi antennas are used for reception. The radar electronics are housed in an equipment building adjacent to the antenna system.This allows interferometry to be performed to determine the position of the meteor trial in the sky, without ambiguities in the angle of arrival. Various calculations are performed in real-time on the detected meteor echoes. The radar provides azimuth, zenith angle and radial velocity of the meteor trials. These information are used do derive horizontal wind velocity in the 80-100 km region of the atmosphere. The zenith and azimuth angle information can be used to locate the radiant sources of the meteors in the celestial co-ordinates. By measuring the time decay of the meteors the radar also provides the temperature information at ~90 km altitude.

**2.2 Angular Distribution of Meteors:**Figure 6 shows the angular distribution of meteors on a typical day. This is what radar exactly sees at any given point of time. The azimuth and zenith are plotted as polar coordinates. The units for azimuth and zenith are radians.The concentric circles represent constant zenith distance. A meteor void region can be observed in this figure at $0-180^{0}$ (East-west) and $90-270^{0}$ (North-South) plane. This is due to a special transmitting scheme that has been worked out to avoid the echoes from Equatorial elctrojet (EEJ,) which is a well-known E-region phenomenon in the height region of 100-110 km in the equatorial ionosphere. Four transmitting antennas at the corners of square are employed for this purpose. One pair of antennas will be transmitting out of phase with the other such that a null field will be formed at the overlapping region of the beams thus avoiding echoes from EEJ region.

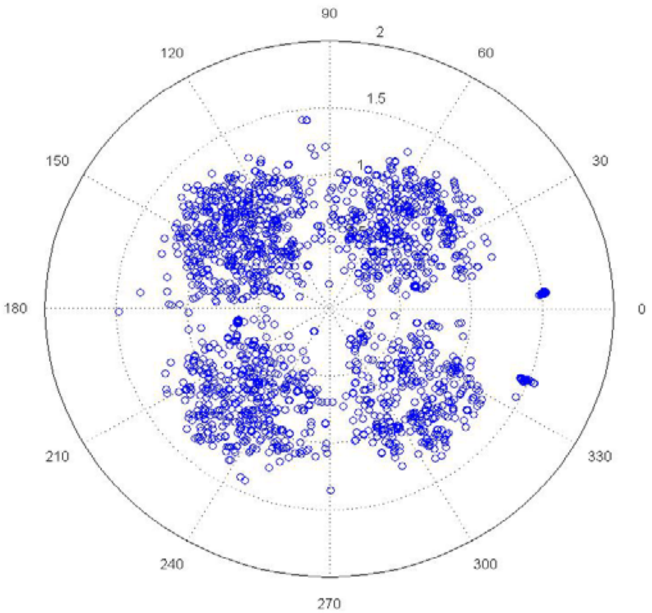



Figure 6: Angular distribution of meteors as seen by the radar

**2.3 Zenith and Azimuth gridding of meteor echoes:** The Azimuth and Zenith as seen by the radar can be gridded to study the angle of arrival statistics of the meteor echoes. An algorithm is developed to grid the metoer observations with respect to their azimuth and zentith angle. Figure 7.1 and 7.2 depicts the azimuth and zenith gridded metor echo statistics on two typical days viz., 2014/11/02 and 2013/11/02 respectively. The grpah was generated keeping x-axis as Azimuth and y-axis as Zenith. The random shifts in the position of maxima denotes the randomness of occurrence of the meteors. It may be also noted that the number of meteors occuring per day varies dramatically because of the presence of different meteor showers.

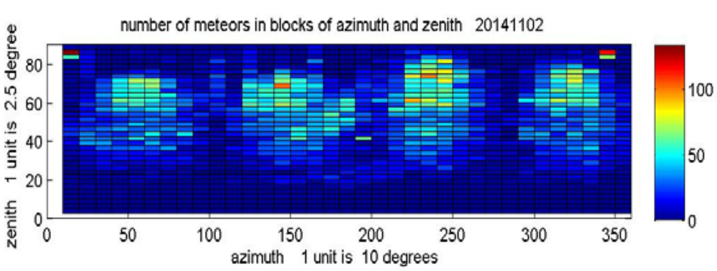



Figure 7.1: Azimuth and Zenith of different meteor activity as seen by the radar on 2014/11/02

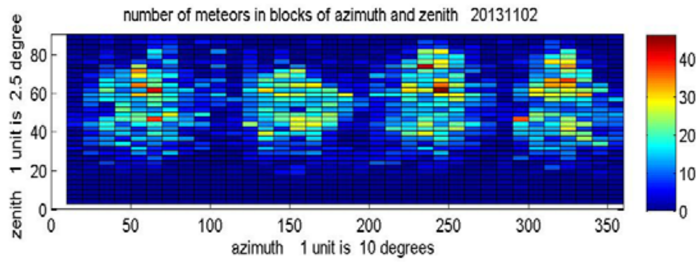



Figure 7.2: Azimuth and Zenith of different meteor activity as seen by the radar on 2013/11/02

**<u>3.1 Data</u>**

Meteor radar observations over Thumba during the years 2004-2014 are used for the present study. As mentioned in the previous section, the present meteor radar provides the three –dimensional distribution of meteor events in terms of zenith angle, azimuth angle and height. As the meteor enters into the Earth's atmosphere, it leaves a plasma trail from which radar signals are backscattered. However, detection of meteor trails is a function of radar frequency and power. So, radar operating at particular frequency may not detect all the meteors entering into the Earth's atmosphere. But can provide relative measurements of meteor flux entering into the Earth's atmosphere. An algorithm is developed using MATLAB to process the meteor radar observations and to derive the data products such as meteor flux, height distribution, diurnal and annual variation, meteor entrance velocity distribution and radiant sources.

**<u>3.2 Introduction to MATLAB:</u>**

MATLAB (MATrixLABoratory) is a high level language and interactive environment used by millions of scientists and engineers worldwide. It lets you explore and visualize ideas and collaborate across disciplines including signal and image processing, communication, control systems and computational finance.

Basically, we have used MATLAB to do various calculations which are described in a detailed way under the topic 'methodology' and to generate various depictions related to the present topic in order to help the readers visualize the key aspects of the output. Every plot which is incorporated in this report is generated by MATLAB.

Key features of MATLAB that made us use this software while making this report are:

1. **<u>Acquiring Data</u>**: MATLAB lets you access data from files, other applications, databases, and external devices. You can read data from popular file formats such as Microsoft Excel; text or binary files; image, sound, and video files; and scientific files such as MPD and HDF. File I/O functions let you work with data files in any format.

2. **Analyzing Data**: MATLAB lets you manage, filter, and preprocess your data. You can perform exploratory data analysis to uncover trends, test assumptions, and build descriptive models. MATLAB provides functions for filtering and smoothing, interpolation, convolution, and fast Fourier transforms (FFTs).
3. **Visualizing Data**: MATLAB provides built-in 2-D and 3-D plotting functions, as well as volume visualization functions. You can use these functions to visualize and understand data and communicate results. Plots can be customized either interactively or programmatically.

**3.3 Methodology:**

Detailed description about the methodology applied to the problem statement (to estimate the radiant sources) is presented below:

**1: Data gathering from the radar system-**

The SkiYMET radar is gathering data on a regular basis since 2004. Meteor processed data (MPD) files are obtained from the radar which contains information like azimuth and zenith of particular meteor detection and several other parameters such as height, range, meteor entrance velocity, radial velocity and signal to noise ratio. The obtained azimuth is the horizontal angle measured anti-clockwise from theEast baseline.

**2: Conversion of the acquired azimuth and zenith distance into right ascension and declination-**

(i) The Julian date of the date of observation was calculated by the formula[8]:

a = year/100
b = a/4
c = 2-a+b;
d = 365.25*(year+4716)
e= 30.6001*(month+1)
JD= date+c+d+e-1524.5

Where,
Year= year.
Month= month number of the year.
Date= day in the month.
JD= Julian day number for the date of observation.

Note: Julian day may be calculated directly in newer versions of MATLAB using the function 'julianday()'.

(ii) Number of Julian centuries of 36525 days from the epoch J2000.0 to the date of the observation:

T= (JD-2451545)/36525

(iii) Greenwich mean sidereal time:

Greenwich means sidereal time (degrees) at 0h UT:

GST*=100.46061837+36000.770053608*T+0.000387933*(T)^2;

Corrected Greenwich mean sidereal time for the time of detection:

GST=GST*+(hr*15.041+min*0.25068+sec*0.0041781)*1.0027337909;
Where,
hr= hour
min= Minute
sec= Second

This value is reduced to the range of 0 to 360 by adding or subtracting 360 from GST. The final value is the Greenwich mean sidereal time for the time of detection (in degrees). This value can be divided by 15 if the output is needed in hours.

(iv) Local Sidereal time:

LST= GST+lon
Where,
LST= Local Sidereal time.
GST= Greenwich mean sidereal time.
lon= Longitude of the observer, taken east as positive (+ve) and west as negative (-ve).

(v) Conversion cosines used to deduce the value of hour angle, declination and right ascension:

c_x=cos(lat)*sin(alt)-sin(lat)*cos(alt)*cos(az)
c_y=-cos(alt)*sin(az)
c_z=sin(lat)*sin(alt)+cos(lat)*cos(alt)*cos(az)

Where,
Lat= Latitude of the observer, north taken as positive and south as negative.
Alt= Altitude of the observed meteor= 90- zenith distance.
Az= Azimuth of the observed meteor measured eastwards from the north baseline.

(vi) Hour angle:

H= $\tan^{-1}$(c_y/c_x)
H_d=h*180/pi

Where,
H= hour angle (in radians).
H_d= hour angle (in degrees).

(vii) Declination:

Del= $\sin^{-1}$ c_z
Del_d=Del*180/pi;

Where,

ISSN 2229-5518

Del= Declination (in radians).
Del_d= Declination (in degrees).

(viii) Right ascension:

Alpha=LST-H_d

The value of alpha is reduced to the range of 0 to 360 by adding or subtracting 360. Alpha may be divided by 15 if the desired output is in decimal hours.

Where,
Alpha= right ascension (in degrees)

Note: Majority of the methodology is influenced by the scientific report presented by (czasz, 2008)

## 4. Results and Discussions

As discussed in earlier sections, meteor radar observations of meteor trails are extensively used in the present study. MATLAB algorithms are developed for accessing the meteor information as well as to process the data. The following are the important results brought from the present analysis.

### 4.1 Meteor entrance Velocity distribution:

Velocity with which a meteoroid enters the Earth's atmosphere characterises various parameters such as the rate of decay, the intensity of streak of light and the time upto which it is sustained in Earth's atmosphere. It becomes imporatnt to stduy the distribution of the meteors' entarnce velocity. The data sets as gathered from the radar with dates ranging from 2008/12/01 to 2008/12/31 is processed and a velocity distribution is generated as shown in figure 8.. The graph clearly indicates that maximum numbers of meteors occur at the range of velocity 26 ±5 Km/s while the peak velocity is around 65 Km/s. Almost similar velocity distribution is observed in most of the months (figure not shown) and the distribution shown in figure 8 can be generalized.



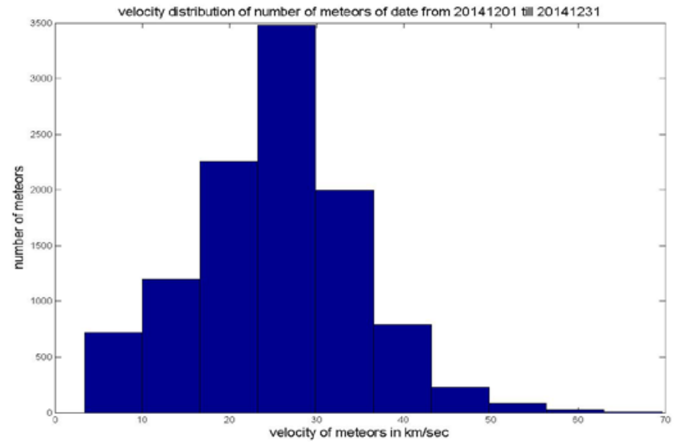



Figure 8: The velocity distribution of meteoroids entering into the Earth's atmosphere during the time period between 2014/12/01 to 2014/12/31

### 4.2 Height Distribution:

Data sets of an entire year (2014) are processed to quantify the height distribution of meteors occurring in the range of radar. An algorithm was developed to segregate the meteors according to their height of occurrence and the same is used to construct the height distribution and the same is shown in figure 9.1 and 9.2 for the years 2014 and 2011 respectively.

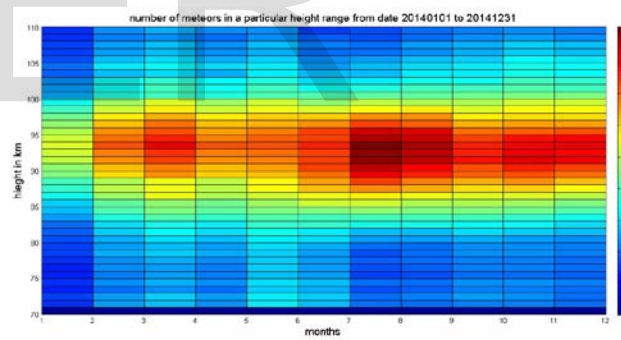



**Figure 9.1: The height distribution (in Km) of meteors occurring in different months in the year 2014**

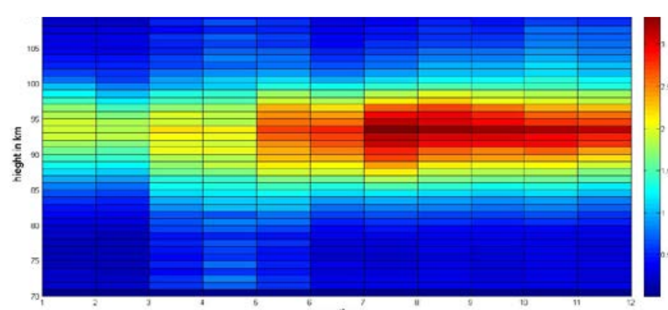



**Figure 9.2: The height distribution (in Km) of meteors occurring in different months in the year 2011**

From these two figures, it evident that the majority of meteors occur at the height range of 95 ± 5 km. The variation of height is caused by difference in mass, velocity and several different parameters, which include the frequency of the radar. The height at which meteor vaporizes varies with its mass m and velocity V and theories have been developed which relate rate of evaporation to m, V, other physical properties of the meteor and properties of the upper atmosphere. [9] The height distribution depicted in these two figures thus provides important information on nature of meteors such as mass, velocity including the background upper atmospheric conditions.

**4.3 Diurnal variation:**

As mentioned earlier, to study the number meteors observed during a day, MPD files are analyzed. An algorithm is developed to get the hourly counts in the height region of 70-110 km and a diurnal variation of meteor count on a typical day is shown in the figure 10. It is very interesting to note that meteor counts exhibit a strong diurnal variation. It can be observed that peak in meteor counts are observed during the local dawn and minimum is observed during local dusk. Note that the time in x-axis is given in UT and the conversion of local time is LT=UT+5:50 Hrs

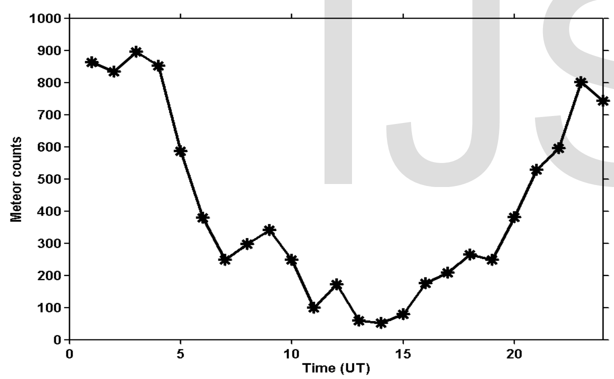
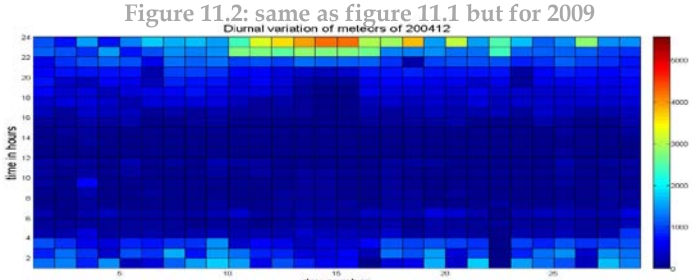
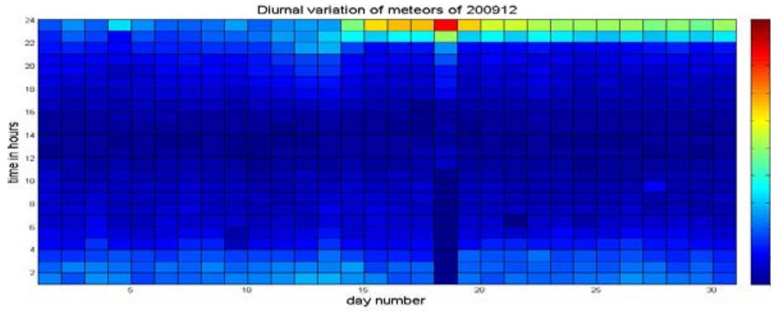



Figure 10: Diurnal variation of meteor count on a typical day

For further strengthening the observed feature of diurnal variation of meteor counts, diurnal variation of meteor counts are constructed using entire month of meteor radar observations. Figures 11.1, 11.2 and 11.3 show the monthly diurnal variation of meteor counts during the years 2004, 2009 and 2011.

Figure 11.2: same as figure 11.1 but for 2009



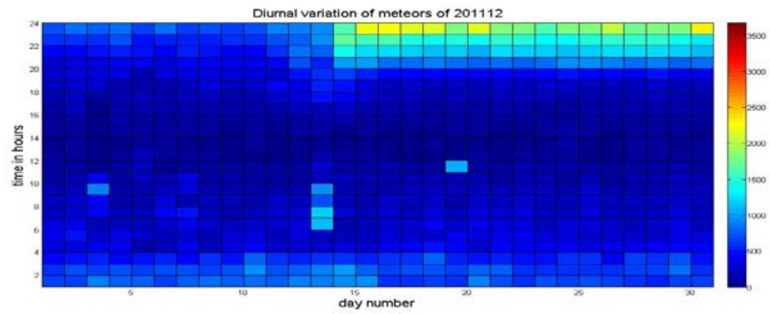




Figure 11.3: same as figure 11.1 but for 2011

From figure 10 and 11 it is clear that maximum number of meteors are observed during local sunrise time and minimum during local dusk time. The increased number of meteors during the day numbers 12-20 is due to the Gemini meteor shower occurring during the month of December. This is due to the ramming phenomenon of Earth against the outer space environment. It is held responsible together by rotation and revolution of the Earth around the Sun. When Earth rotates on its axis, remember it is also revolving around the Sun; time for maximum meteor activity is also the time when direction of observation coincides with the direction of velocity of revolution of the Earth around the Sun.This phenomenon is illustrated in figure 12.

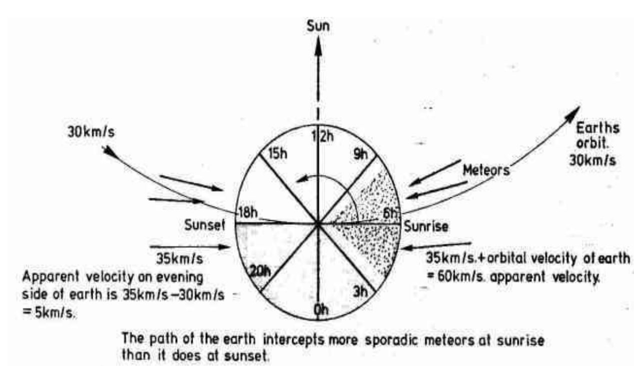



Figure 12: Illustration to show the reason behind diurnal variation of meteor counts

## 4.4 Annual variation of meteor counts and identification of showers:

After studying the diurnal variations, the meteor counts are averaged daily to study and the annual variations and to characterize the meteor showers. The radar observations during the year 2007 are used for the present analysis. Figure 13 shows the day-to-day variation of meteors counts during the January – December 2007. It is very exciting to note the periodic variation of the meteor counts, which show a low meteor activity during January to May, a peak activity during Jun-August and again a low activity during rest of the year. This pattern seems to be consistent during all other years. A peak meteor count of ~18,000 is observed during 23 June 2007. Several peak activities are observed throughout that year, which are labeled as A, B…etc in the figure 13.

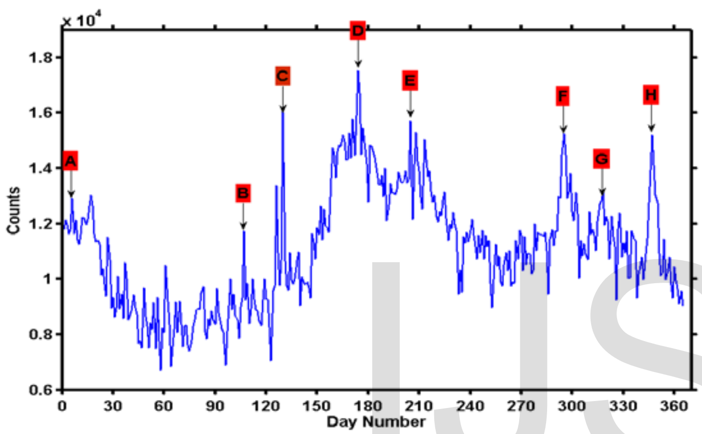



Figure 13: Day-to-day variation of meteor counts during January-December 2007 (The peaks shown in the figure corresponds to the well-known meteor showers)

A- Delta Cancrids, B- Lyrids, C- Eta aquarids, D- Sagittarids, E-Perseids F-Orionids, G- Leonids and H- Geminids.

There are several other meteor showers, however, the above mentioned are best seen from our latitudes. Some of the meteor showers are best viewed from other latitudes. These observations shown in the figure 13 are very useful in modelling as well as predicting the meteor showers. This information is also useful in characterizing the parental bodies of these meteors such as asteroids and comets. The effect of small meteoroids on objects in the space environment and space weather also can be assessed using these observations. The annual variation of meteor counts are verified for all the other years right from 2004 to 2014 and found consistent pattern. However, there is variation in number of meteors from one year to other.

## 4.5 Radiant Sources:

It is very imporatnt to locate the radiant sources of the meteor showers in the sky in order to identify their parental bodies such as comets and asteriods. Howvere, it is difficult to identify the radiant sources using single station observations. In recent years, a metho is developed to identify the radiant sources using single station data and the procedure is outlined in the data and methodlogy section of this report. An algortithm is developed to locate the sourece radiant of the observed meteor showers and this is the major contribution of the presetn study. For demonstarting the performance of the algorithm, the Geminid shower is chosen, which occurduring December 12-17 every year with right asension and declation 7 hr and $29^0$ respectively.

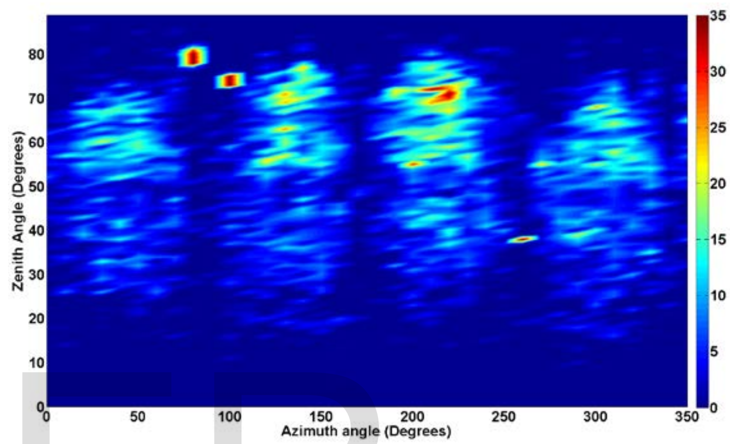



Figure 14: Azimuth-zenith distribution meteor counts on 14 December 2014

From figure 14, one cannot infer any information on the movement of the Geminid shower over the radar site. We have applied the procedure described in section 3 to estimate the right ascension and declination of the observed meteors with respect radar frame of reference. A number of other parameters are needed to estimate these two quantities such as latitude, longitude, Julian date and local sidereal time. One more important requirement is the azimuth angle supplied to the algorithm is to be with respect to North. The present meteor radar provides azimuth angles with respect to East. We have rotated the azimuth plane and adjusted the angles with respect to North. Figure 15 shows the right ascension and declination section of the Geminid shower obtained using the present algorithm for the year 2014. It is to be remembered that the parameters estimated are with respect to radar frame of reference and it has to be projected in to the celestial sphere co-ordinate system to get true right ascension and declination. Figure 15 clearly shows the movement of the radiant source over the radar site. The algorithm was applied to all the Geminid showers right from 2004 to 2014 and it is noted that the results are consistent from one year to another, which confirms the consistence of the algorithm.





Figure 13: Day-to-day variation of meteor counts during January-December 2007 (The peaks shown in the figure corresponds to the well-known meteor showers)

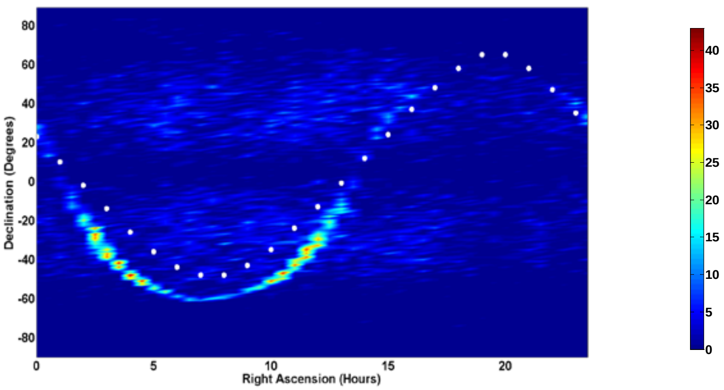



Figure 15: Right ascension and declination section of the Geminid shower obtained using the present algorithm for the year 2014. The

To further validate the algorithm, the theoretical prediction of radiant source over the radar site is obtained in the literature and is shown in figure 15 as white dots. It is very interesting to note the movement the radiant source is obtained using the present algorithm is agreeing well with the theoretical prediction thus validating the present algorithm. We have also verified the algorithm for other meteor showers such as Quadrantids, Perseids, Orionids and Leonidas and found consistent results. In most of the shower periods a sinusoidal pattern is obtained as shown in figure 15, but on in the absence of meteor showers the pattern was random. As mentioned earlier, the right ascension and declination depicted in figure 15 have to be projected in the celestial sphere to quantify their radiant source, which will be undertaken in near future.

## 5. Concluding remarks and suggestions

### 5.1. Conclusions

A study has been carried out to explore the astronomical aspects of the meteors using the meteor radar observations over Thumba. The data collected during the years 2004-2014 have been used for present study. MATLAB algorithms have been developed to process the data and to study the real-time meteor parameters such as meteor counts and meteor entrance velocity. The meteor observations are analyzed to get the diurnal variation of meteor counts, their height distribution, entrance velocity distribution and annual cycle of meteor counts. An algorithm is also developed to estimate the right ascension and declination of the radiant source of the meteors. Following are the important outcome of the present study.

(1) Almost all the diurnal variations of meteor count observed during the study period show similar pattern with peak counts at local dawn and minimum during dusk hours. The Earth's orbital motion around the Sun is identified as reason for the observed diurnal variation in the meteor counts.

(2) The day-to-day variation in the meteor counts are also constructed, which showed minimum meteor activity during January-May and September - December. A well-defined peak activity is observed during the months of June-August. Some of the peaks observed during the study period are associated with some of the known meteor showers.

(3) The height distribution of meteor counts has shown their peak at ~ 95 ± 5 km. However, it is noted that the height at which meteor counts peak is a function of radar operating frequency.

(4) The meteor entrance velocity distribution have shown that the meteor entrance velocity ranges from 10-60 km/s

(5) An algorithm was developed to identify the radiant source by estimating the right ascension and declination of the observed meteor. The algorithm was tested during the period of Geminid shower, which shown consistent results. However, further extension of the present study is needed to project the observed right ascension and declination into the celestial sphere system.



### 5.2. Suggestion

We are recommending the following suggestions to improve the present study,

(1) Along with meteor radar observations, simultaneous spectrometers can be operated to study the nature of the meteor .i.e. the constituents of meteors by observing the spectral lines they emit

(2) Commercial telescopes can be deployed at the radar site to view the meteor trails.

(3) The present algorithm can be improved by further including the convolution function as defined in (J. Jones, 2005). An attempt will be made soon in the future to improve the results of this report and locate the radiant position with a precision of a degree per day.

**Acknowledgement**

ISSN 2229-5518
The author would like to thank Dr. Anil Bhardwaj for his support and guidance.

## References


1. http://www.thefreedictionary.com/vernal+equinox
2. Soop, E. M. (1994). Handbook of Geostationary Orbits. Springer. ISBN 978-0-7923-3054-7.
3. https://en.wikipedia.org/wiki/Horizontal_coordinate_system
4. Hour angle- ^U.S. Naval Observatory Nautical Almanac Office (1992). P. Kenneth Seidelmann, ed. *Explanatory Supplement to the Astronomical Almanac*. University Science Books, Mill Valley, CA. p. 729. ISBN 0-935702-68-7.
5. National Institute of Standards and Technology [NIST], Time and Frequency Division. "Time and Frequency from A to Z." http://www.nist.gov/pml/div688/grp40/enc-s.cfm
6. Earth Observatory Glossary: Radiant on NASA.gov
7. http://www.nasa.gov/pdf/741990main_ten_meteor_facts.pdf
8. http://quasar.as.utexas.edu/BillInfo/JulianDatesG.html
9. (Greenhow, 1960), http://adsabs.harvard.edu/full/1960MNRAS.121..174G