EFFECT OF STRONG METEOR SHOWERS ON AEROSOL VERTICAL PROFILES

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Abstract: The aerosol measurements have been carried out at Kolhapur (16°42′N, 74°14′E) by using twilight technique. Newly designed Semiautomatic Twilight Photometer was operated during the period 1 January 2009 to 30 December 2011 to study the vertical distribution of the mesospheric aerosol number density per cubic decimeter (dm^3). Here after aerosol number density per cubic decimeter (dm^3) is abbreviated as 'AND'. In the present study vertical distribution of AND during strong meteor showers days is discussed. In the present work an attempt is made to calculate the mesospheric aerosol number density per cubic decimeter (AND) using Twilight Sounding Method (TSM), for the first time in India. The dust particles during strong meteor showers intrude in the Earth's atmosphere below 120 Km. The dust particles of strong meteor showers penetrate the lower atmosphere and also act as cloud condensation nuclei (CCN).

Key Words: aerosols, remote sensing, meteor showers, twilight technique, mesosphere, Earth's atmosphere, clouds

I. INTRODUCTION

Atmospheric aerosols are the suspended particles (fine solid or liquid droplets) in the air. Depending upon the source size of aerosols varies from 10^{-3} to 10^{2} µm. Particles larger than 100 µm cannot remain suspended in air for long periods. Dust, smoke, mist, fog, haze and smog are various forms of common aerosols. Aerosols are of considerable interest in atmospheric science. Aerosols play a vital role in altering the radiation budget of the earth's atmosphere. Aerosols determine what fraction of the solar radiation incident at the top of the atmosphere reaches the earth's surface and what fraction of the thermal radiation emitted from the earth escapes to the space. These two processes essentially determine the earth's climate. Aerosols are closely related to the atmospheric chemistry and atmospheric electrical conductivity due to the complex indirect consequences connected with aerosol induced cloud and precipitation processes.

The consequences arising from an increased aerosol concentration remain extremely difficult to understand because vertical distribution of aerosols in atmosphere is strong functions of their sources, sinks and their residence times. One of the major natural sources of aerosols is meteor showers. A meteoroid is a small rocky or metallic body travelling through space. Meteoroids are range in size from small grains to meter-wide objects. Most are fragments from comets or asteroids, while others are debris ejected from bodies such as the Moon or Mars. Most meteors are smaller than a grain of sand, so almost all of them disintegrate and never hit the Earth's surface. When such an object enters the Earth's atmosphere at a speed typically in excess of 20 km/s, produces a streak of light. This phenomenon is called a meteor. A series of many meteors appearing seconds or minutes apart, and appearing to originate from the same fixed point in the sky, is called a meteor shower.

Thus a meteor shower is the result of an interaction between a planet, such as Earth, and streams of debris from a comet or other source. Most meteoroids burn up when they enter the atmosphere. The left-over debris is called meteoric dust or just meteor dust. Meteor dust particles can persist in the atmosphere for up to several months. These particles might affect climate, both by scattering electromagnetic radiation and by catalyzing chemical reactions in the upper atmosphere. Many tons (around 15,000 tons) of meteor dust enter in the Earth's atmosphere each year.

Meteors typically occur in the mesosphere. Mesosphere is the third main layer of the Earth's atmosphere located about 50 to 85 kilometers above the Earth's surface. The mesosphere lies above the maximum altitude for aircraft and below the minimum altitude for orbital spacecraft. It has only been accessed through the use of sounding rockets. The rockets are used to carry instruments from above the surface of the Earth, the altitude generally between weather balloons and satellites (the maximum altitude for balloons is about 40 kilometers and the minimum for satellites is approximately 120 kilometers). As a result, it is the most poorly understood part of the atmosphere. In the present work an attempt is made to calculate the mesospheric aerosol number density per cubic decimeter (AND) using Twilight Technique, for the first time in India.

The aerosol measurements have been carried out at Kolhapur (16°42′N, 74°14′E) by using newly designed Semiautomatic Twilight Photometer during the period 1 January 2009 to 30 December 2011 to study the vertical distribution of the mesospheric aerosol number density per dm^3 (cubic decimeter). Here after aerosol number density per dm^3 is abbreviated as 'AND'. In the present study vertical distribution of AND during strong meteor showers days is discussed.

II. ISTRUMENTATION

The instrument, semiautomatic twilight photometer, is newly designed, developed and installed at Shivaji University, Kolhapur, Maharashtra, India. The system is a ground based passive remote sensing technique used to monitor the vertical distribution of the atmospheric aerosols. It is a simple and inexpensive but very sensitive technique and hence can be operated continuously for monitoring the day-to-day variability of the aerosols, at any place. The twilight photometer setup operated manually is used by several workers in all over the world to study the vertical distribution of atmospheric aerosol particles which is a strong function of their sources, sinks and their residence times. All this study is reviewed by Jadhav et al. [1] which is mainly on the stratospheric aerosols. However, during the course of this study the system is suitably modified to improve the sensitivity of the system.

The semiautomatic twilight photometer consists of a simple experimental set up. It comprises of a pleno-convex lens of diameter 15 cm having a focal length of 35 cm. A red band pass glass filter peaking at 670 nm with a half band width of about 50 nm is used. The red filter of 1.2 cm diameter and an aperture of 0.6 cm diameter are placed at the focal length of convex lens, provides approximately 1^0 field of view [(Aperture diameter/Focal length of lens) X57= (0.6cm/35cm) X 7=0.9771 degree]. A photomultiplier tube (PMT-9658B) is used as a detector. The PMT requires high voltage supply (700 V). The output signal (current) of the PMT, used for detecting the light intensity during the twilight period, is very low. It is of the order of nano to microamperes. The amplitude or strength of this low signal is amplified by using a newly designed fast pre-amplifier. The more details regarding the instrument and Fast pre-amplifier were given elsewhere, [2], [3]. The amplifier output recorded by the digital multimeter, Rishcom-100, having an adapter can store the data automatically for every 10 seconds in the form of date, time and intensity in Volts. During evening, the twilight photometer is operated for a time spell of ~90 minutes after the local sunset and during morning it is operated ~90 minutes before the sunrise.

Some noticeable features of the Semiautomatic Twilight Photometer are: Augmented efficiency of the system, Improvement in height resolution, Increased duration of operation of the system, Visibility of the small fine-scale features in the profiles derived by this system, A lot of upgrading in the sensitivity of the system, Amplified Signal to noise ratio, Drastically reduction in the white noise of the system, Better accuracy in measurement and recording the data, Amplified Signal to noise ratio. Hence it is able to give the information of aerosols in the atmosphere from 6 km to 350 km.

III. BASIC PRINCIPLE OF TWILIGHT TECHNIQUE

Figure 1 shows the twilight phenomenon schematically. The twilight sounding method (TSM) is analogous to the method of rocket sounding. When the sun is within 0-18º below the horizon, the lower part of the atmosphere comes under the Earth's shadow while the upper part is sunlit. The boundary between the illuminated and shadowed parts is monotonously shifting up during the evening twilight and down during the morning twilight.

In this technique, the solar radiation scans the Earth's atmosphere during the enhancement of the twilight, and the light received from any part of the sky is due primarily to the light scattered by illuminated by molecules and the particles of interest. It is assumed that bulk of the scattered light comes to an observer from the lowest, and therefore densest, layer in the sunlit atmosphere at the time of measurement. The contribution of the rest of the atmosphere above this layer can be neglected due to an exponential decrease of air density with increasing altitude. The height of this lowest layer (twilight layer) increases with increasing earth's shadow height. The lower atmospheric layers now submerged in shadow, no longer contribute to the sky brightness, and the scattered light comes more and more from the higher altitudes, which are still illuminated by direct sunlight.

The method for calculating the earth's geometrical shadow height (h) is given by Shah [4]. Thus the earth's geometrical shadow height (h) is defined as the vertical height from the surface of the earth, of a point where the solar ray grazing the surface of the earth meets the line of slight. Therefore,

$$h = R\,(\sec[\delta] - 1) \qquad \text{..... (1)}$$

Here, R is radius of earth and δ is sun's depression.

In following the method of Shah [4], it is assumed that the red twilight comes from a distance of 6 km. The raw data consists of intensity 'I' and time't'. The shadow heights were computed for zenith sky observations, and the raw data was utilized for the analysis of '1/I (dI/dh)' value, where 'I' is the observed intensity, 'dI' and 'dh' are the differences in intensities and shadow heights respectively observed at time 't' and 't+dt'.

As the sun sinks below the horizon, the effective height of the Earth's shadow rises and scattering takes place to higher levels. Most of the light received at the ground will be the primary scattered light by the particles for the solar depression less than 6-7 deg [4]. Therefore,

$$\frac{1}{I}\frac{dI}{dh} = \frac{d\log I}{dh} \qquad \text{..... (2)}$$

The effect of the Rayleigh scattering component on the value of '1/I (dI/dh)' has been studied by [5]. Variations in the vertical profiles of the molecular density were very small and their effect on the observed intensity was nearly constant, hence the variations in the value of – (1/I) (dI/dh) can be assumed to be mainly due to changes in aerosols density. Thus,

$$\frac{1}{I}\frac{dI}{dh} = \frac{d\log\,(\text{aerosol number density})}{dh} \qquad \text{..... (3)}$$

This Logarithmic gradient of the intensity cannot give the information about the aerosol number density. Therefore an empirical formula stated in the following equation is derived by the actual Lidar observations and the Photometric observations. Thus,

Aerosol number density per cm^3 =
$\text{Antilog}_{10}\ \{10['1/I\ (dI/dh)']-1\}$ ….. (4)

The mesospheric aerosol number density per cubic decimeter (dm^3) i.e. AND is calculated by using equation-5. The details regarding the calculation of AND were given elsewhere, [6].

$$AND = 1000\,(\text{Antilog}_{10}\ \{10['1/I\ (dI/dh)']-1\}) \qquad \text{….. (5)}$$

IV. RESULTS AND DISCUSSION

The meteor showers are divided into four types strong, medium, weak and irregular according to a scale developed by Robert Lunsford. The strong meteor showers are those having Zenith Hourly Rate (ZHR) normally ten or better. In astronomy, the Zenithal Hourly Rate (ZHR) of a meteor shower is the number of meteors a single observer would see in an hour of peak activity if the radiant is located exactly overhead and a very dark night. The rate that can effectively be seen is nearly always lower and decreases the closer the radiant is to the horizon. Actual counts rarely reach this figure as the zenith angle of the radiant is usually less and the limiting magnitude is usually lower. ZHR is a useful tool when comparing the actual observed rates between individual observers as it sets observing conditions for all to the same standards.

Table-I shows strong meteor showers. The dates shown in the table are accurate for 2009. The date's will 'move' based upon the year in the Leap year cycle.

The vertical distributions of the dust particles (aerosols) during strong meteor showers were studied. The profiles of AND against shadow, heights (h) obtained during strong meteor activities days were plotted. Some of them are showed in the Fig. 2 to 5. In all these figures the Y-axis represents altitude in 'km' and X-axis stands for corresponding AND. Many of such graphs studied and results were noted. The results acquired reveal that the dust particles during strong meteor showers intrude in the Earth's atmosphere below 120 km. These dust particles penetrate the lower atmosphere and also contribute to additional scattering in the atmosphere. After these meteor activities clouds were observed. Hence the particles of strong meteor showers act as cloud condensation nuclei (CCN).

A. Vertical profiles of AND during 'Quadrantids' activities

Figure 2 shows vertical profiles of AND during 'Quadrantids' activities. At the morning of 3 January 2010, one broad intense peak as shown in fig.2 (a) was noticed form 45 to 75 km, having peak particle number density about 700 particles per dm^3. On the next day two intense peaks were noticed at 67 km and 45 km having maximum particle density 624 and 1981 particles per dm^3 respectively as shown in fig.2 (b). This indicates that all the particles entered in the mesosphere collected in these narrow layers. On the subsequent day these layers moved down to 27 km having peak particle density 3086 particles per dm^3 and combined with Junge layer as shown in fig.2 (c). This study reveals that many of the particles entered in the mesosphere due to the 'Quadrantids' activities were descended to lower levels. Larger quantity of dew drops and cumulous clouds were observed on 6 January 2010.

B. Vertical profiles of AND during 'Lyrids' activities

Figure 3 shows vertical profiles of AND during 'Lyrids' activities. At the evening of 22 April 2009, many broad intense peaks as shown in fig.3 (a) were noticed form 35 to 105 km, having peak particle number density about 400-1100 particles per dm^3. On the next day at morning sky was full of cumulus clouds and dew drops were also observed.

The fig.3 (b) shows two broad peaks peaking at 53.61km and 64.52km with particle number density about 648 and 601 particles per dm^3 respectively at the morning of 22 April 2010. At the evening of the same day 75% sky was covered by cumulous clouds.

C. Vertical profiles of AND during 'Eta Aquarids' activities

Figure 4 shows vertical profiles of AND during 'Eta Aquqrids' activities. At the morning of 5 May 2010, three broad intense peaks as shown in fig.4 (a) were noticed at 30km, 31km and 46 km, having peak particle number density about 2462, 1650 and 835 particles per dm^3 respectively. On the morning of the next day all the three peaks observed with decreased altitudes and increased aerosol concentration. This implies that entire pattern slide downwards with the speed of 6km/12hours as shown in the fig.4 (b). The evening profile of 6 May 2010 showed intense peak at 20.73km with 3983 particles per dm^3. This layer was combined with the Junge layer. (The stratospheric aerosol layer was first measured in the late 1950s using balloon-borne impactors [7] and is often called the Junge layer, although its existence was suggested 50 years earlier from twilight observations [8]). The aerosol density of the layer at 30 km was decreased up to 1974 particles per dm^3 and the peak at 40 km was almost unnoticed. On the morning o 7 May 2010 the 85% sky was full of cirrocumulus clouds.

D. Vertical profiles of AND during 'Delta Aquarids, Perseids, Orinids' activities

The TSM data collection at Kolhapur is generally not possible during ~mid-May to ~mid-October in any year because of the prevailing southwest summer monsoon conditions (rains and extensive cloud cover). This being a passive technique, clear sky conditions are preferable for obtaining the vertical profiles of aerosols. Thus data coverage is for the period ~mid-October of any year to ~mid-May of the succeeding year. Hence during the activities of 'Delta Aquarids, Pewrseids and Orinids', study of vertical profiles of AND was impossible for all the three years.

E. Vertical profiles of AND during 'Geminids' activities

For all the three years viz. 2009, 2010, and 2011 sky was totally full of cirrostratus clouds during the 'Geminids' activites. Hence no data coverage, no vertical profiles of AND and no results.

F. Vertical profiles of AND during 'Leonids' activities

Figure 5 shows vertical profiles of AND during 'Leonids' activities. At the morning of 17 November 2011, many broad intense peaks as shown in fig.5(a) were noticed form 55 to 110 Km, having peak particle number density about 200-400 particles per dm^3. On the next day one intense peak was noticed in between 66-70 km having maximum particle density 824 particles per dm^3 as shown in fig.5 (b). This indicates that all the particles entered in the mesosphere collected in this narrow layer. On the subsequent day also downward shifting of this layer was noticed with maximum particle density 1630 particles per dm^3 at 31 km as shown in fig.5(c). This was another aerosol layer formed above the stratospheric aerosol layer or Junge layer. Same on following day this layer moved down to 27 km having peak particle density 3086 particles per dm^3 and combined with Junge layer as shown in fig.5(d). This study reveals that many of the particles entered in the mesosphere due to the 'Leonids' activities were descended to lower levels. These particles served as cloud condensation nuclei (CCN). The final result of this was that, high level clouds were observed on 21 November 2011.

The results acquired by this study are in good agreements with earlier workers [9, 10, 11, 12, 13, 14, and 15]. All the earlier workers reported the vertical distribution of aerosols in terms of logarithmic gradient of intensity. In this study the attempt is made to study the vertical distribution of aerosols in terms of AND at the first time.

In the present work, newly designed Semiautomatic twilight photometer, is used for aerosol measurements over Kolhapur (16°42′N, 74°14′E). The efficiency of the system is increased by adopting multiple pre-amplifier configuration which improves signal to noise ratio by factor of ten and this fact is responsible for measuring low level intensity by photometer. Therefore the duration of operation of the system has been increased to 90 minutes as compared to 45 minutes obtained by earlier system. As a result the system now can yield a reasonable qualitative picture of the vertical distribution of aerosols from about 6 km to a maximum of 350 km. This gives an opportunity to monitor the aerosols not only up to stratospheric levels but also at the mesospheric and thermospheric levels. Thus the sensitivity of the system is improved a lot.

Another one main advantage of the semiautomatic twilight photometer is improvement in height resolution. This is achieved due to high rate of sampling, as data is stored for every 10secs, as compared to 30secs in earlier system. The height resolution is .03km, 0.15km, 0.29km, 0.51km, 0.76km, and 0.91km for 6km, 10km, 20km, 50km, 100km, and 150 km respectively. Due to this improvement in height resolution, the small fine-scale features, which are not visible in the profiles derived by earlier workers, are visible in the profiles derived in the present study.

In this system it is possible to avoid the manual errors viz., error in time and oversight in noting down the readings from the digital-multimeter used by earlier workers, because as stated above Rishcom-100 has an adapter which stores the data automatically for every 10secs. Thus accuracy in measurement and recording the data is increased in this system.

V. SUMMARY AND CONCLUSIONS

The measurements using the twilight technique presented in this paper suggests the following,

a) The semiautomatic twilight photometer yields a reasonable qualitative picture of the vertical distribution of mesospheric aerosol number density per cubic decimeter (AND/ dm^3).
b) The main aim of this study is to demonstrate the measurement capabilities offered by semiautomatic twilight photometer and it is the first attempt in India made by the author to estimate mesospheric aerosol number density per cubic decimeter (AND/ dm^3).
c) The dust particles during strong meteor showers intrude in the Earth's atmosphere below 120 km. These dust particles penetrate the lower atmosphere and also acts as Cloud Condensation Nuclei (CCN).

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Figure captions:

Fig.1: Schematic diagram of twilight phenomenon
Fig.2: Influx of Quadrantids Meteor showers
Fig.3: Influx of Lyrids Meteor showers
Fig.4: Influx of Eta Aquarids Meteor showers
Fig.5: Influx of Leonids Meteor showers

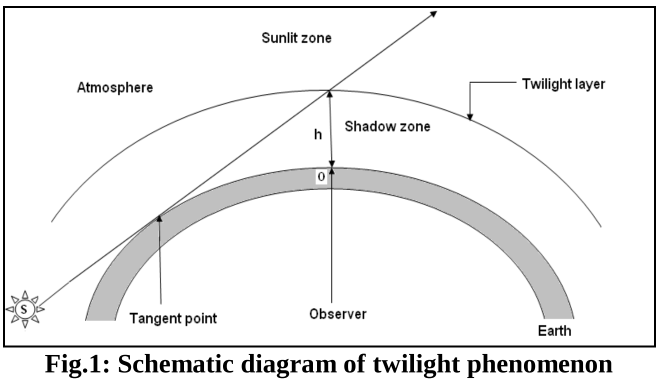


Fig.1: Schematic diagram of twilight phenomenon

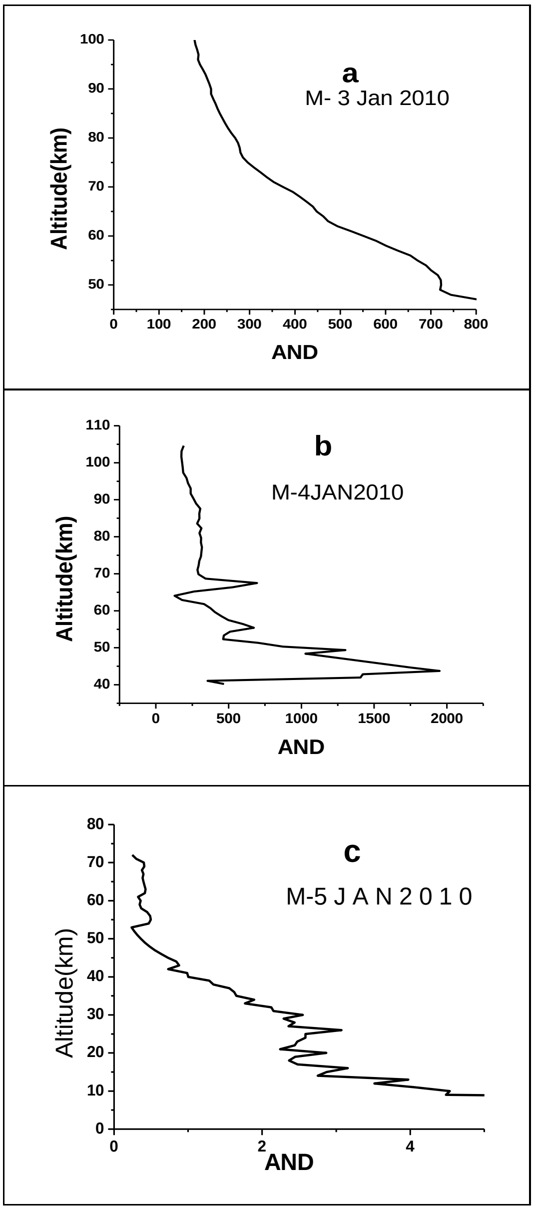
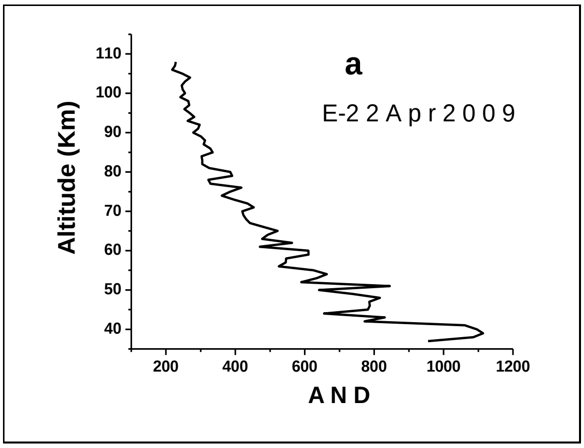


Fig.2: Influx of Quadrantids Meteor showers



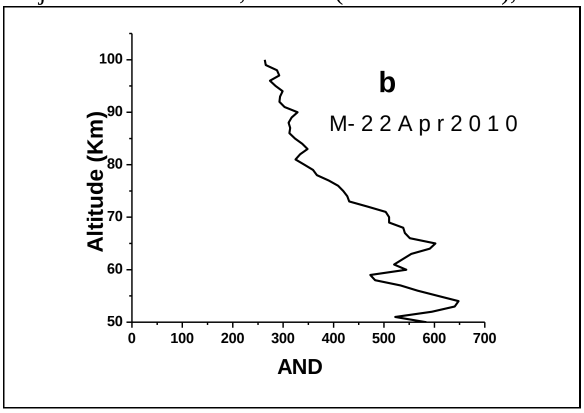


Fig.3: Influx of Lyrids Meteor showers

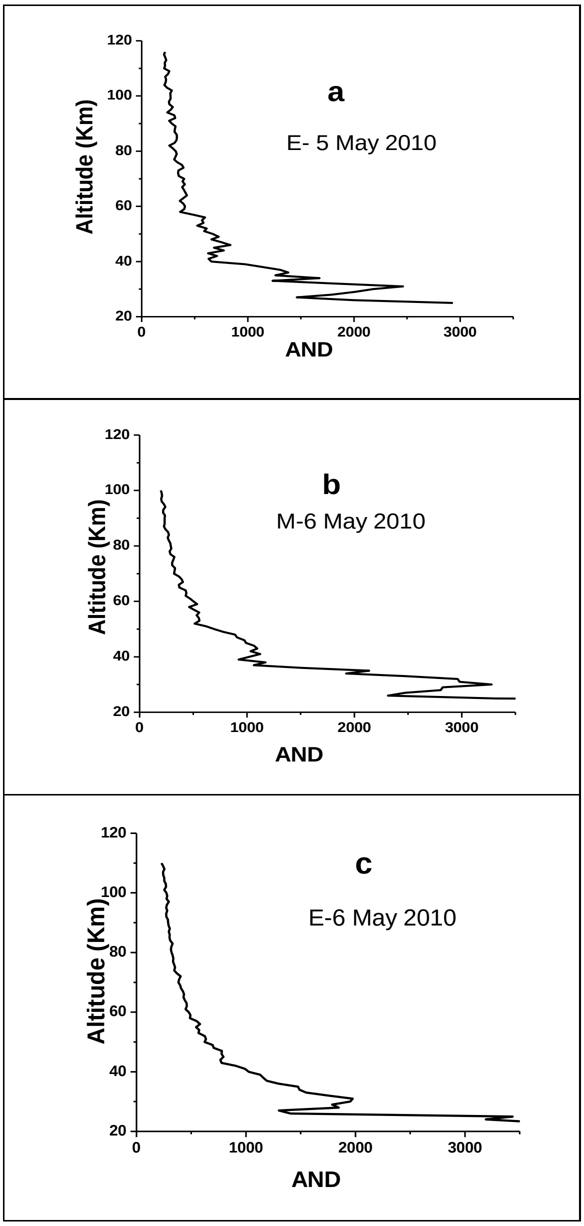


Fig.4: Influx of Eta Aquarids Meteor showers

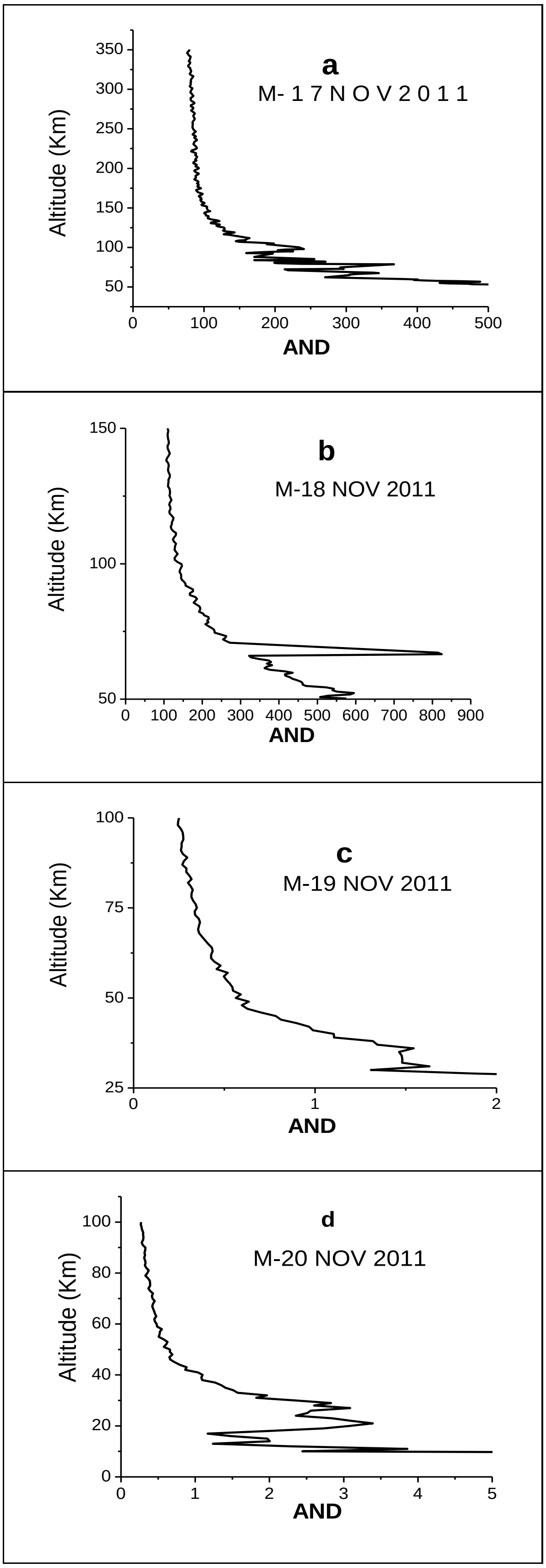


Fig.5: Influx of Leonids Meteor showers

TABLE-I: STRONG METEOR SHOWERS

Name	***Peak dates***	***ZHR***
Quadrantids	3 January	120
Lyrids	22 April	18
Eta Aquarids	6 May	60
Delta Aquarids	28 July	20
Perseids	12 August	100
Orionids	21 October	23
Leonids	17 November	15
Geminids	14 December	120