2. Chowdappa, P. and ChandraMohanan, R., *J. Biosci.*, 1995, **20**, 637–649.
3. Ramakrishnan, K. and Thankappan, M., *South Indian Hortic.*, 1965, **13**, 33–34.
4. Chowdappa, P. and ChandraMohanan, R., *J. Plantn. Crops* (*suppl.*), 1993, **21**, 129–133.
5. Chowdappa, P., ChandraMohanan, R. and Ramanujam, B., *Indian Phytopathol.*, 1993, **46**, 92–93.
6. Chowdappa, P. and ChandraMohanan, R., *Trop. Agric.* (*Trin.*), 1996, **73**, 158–160.
7. Sarma, Y. R., Chowdappa, P. and Anandaraj, M., in *IPM System in Agriculture – Key Pathogens and Diseases* (eds Upadhyay, R. K. *et al.*), 2002, vol. 8, pp. 149–187.
8. Stamps, D. J., Waterhouse, G. M., Newhook, F. J. and Hall, G. S., Revised tabular key to the species of the *Phytophthora*, Mycological papers, 162, CAB International Mycological Institute, Kew, London, 1990, p. 28.
9. Kaosiri, T. and Zentmyer, G. A., *Mycologia*, 1980, **72**, 988–1000.
10. Oudemans, P. and Coffey, M. D., *Mycol. Res.*, 1991, **95**, 1025–1046.
11. Chowdappa, P. and ChandraMohanan, R., Proc. 7th International Congress on Plant Pathology, Edinburgh, Scotland, UK, 1998, p. 51.
12. Panbieres, A., Marais, A., Trentin, F., Bonnet, P. and Ricci, P., *Phytopathology*, 1989, **79**, 1105–1109.
13. Forster, H., Oudemans, P. and Coffey, M. D., *Exp. Mycol.*, 1990, **14**, 18–31.
14. Cooke, D. E. L. and Duncan, J. M., *Mycol. Res.*, 1997, **101**, 667–677.
15. Crowford, A. R., Bassam, B. J., Drenth, A., Maclean, D. J. and Irwin, J. A. G., *Mycol. Res.*, 1996, **100**, 437–443.
16. Lee, S. B. and Taylor, J. W., *Mol. Biol. Evol.*, 1992, **9**, 636–653.
17. Mueller, U. G., Lipari, S. E. and Milgroom, M. G., *Mol. Ecol.*, 1996, **5**, 119–122.
18. Neill, N. R., Van Berkum, P., Lin, J. J., Kuo, J., Ude, G. N., Kenworthy, W. and Saunders, J. A., *Phytopathology*, 1997, **87**, 745–750.
19. Raeder, U. and Broda, P., *Lett. Appl. Microbiol.*, 1985, **1**, 17–20.
20. White, T. J., Bruns, T., Lee, S. and Taylor, J., in *PCR Protocols – A Guide to Methods and Applications* (eds Innis, M. A., Gelfand, D. H., Sninsky, J. J. and White, T. J.), Academic Press, San Diego, 1990, pp. 315–322.
21. Brasier, C. M. and Griffin, M. J., *Trans. Br. Mycol. Soc.*, 1979, **72**, 111–143.
22. Harris, D. C., Cardon, J. A., Justin, S. H. F. W. and Passey, A. J., *Trans. Br. Mycol. Soc.*, 1984, **82**, 249–255.
23. Mchau, G. R. A. and Coffey, M. D., *Mycol. Res.*, 1994, **98**, 1035–1043.
24. Blaha, G., Hall, G., Warokka, J. S., Concibido, E. and Ortiz-Garcia, C., *Mycol. Res.*, 1994, **98**, 1379–1389.
25. Butler, E. J., *Agric. J. India*, 1906, **1**, 299–310.
26. Bhat, K. S. and Leela, M., *Indian Farm.*, 1968, **18**, 19–20.
27. Leonian, L. H., *Phytopathology*, 1922, **12**, 402–408.
28. Tsao, P. H. and Alizadeh, A., Proc. 10th International Cocoa Research Conference, Santo Domingo, 1988, pp. 441–445.
29. Uchida, J. Y. and Aragaki, M., *Phytopathology*, 1989, **79**, 1212.
30. Mchau, G. R. A. and Coffey, M. D., *Mycol. Res.*, 100, **99**, 89–102.

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A case study of twilight probing of the atmosphere during Leonid meteor shower 2001

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Twilight sounding method is used to retrieve the vertical distribution of the dust particles throughout the middle atmosphere. The photometry observations of the twilight sky brightness were carried out during the Great Leonid meteor storm of November 2001 at a tropical inland station Pune (18°32′N, 73°51′E), India. This experiment gave an opportunity to monitor height distribution of meteoric dust between 16 and 150 km. Normalization of the current set of data with a reference data set shows the evidence of influx of the fine meteor dust with a broad peak at around 80 km in the evening twilight of November 18, the day of meteor storm peak, and its subsequent descent to the lower stratosphere. The magnitude of enhancement of dust due to this meteor shower at the peak of distribution is about seven times the normal.

MANY observers, ever since the discovery of the twilight phenomenon, have shown that the characteristics of the light scattered downward by the atmosphere during the twilight period are sensitive indicators of the aerosol component of the atmosphere. The twilight variations that occur as the solar depression angle changes can be used to derive information on the vertical distribution of atmospheric aerosols[1].

The twilight sounding method, involving ground-based photometry of the twilight zenith sky brightness, can be used to derive the vertical distribution of dust particles intruding the Earth's atmosphere during the active meteor showers[2], volcanic eruptions[3,4] and also aerosols forming within the atmosphere. This method is based on the fact that the luminosity of the twilight sky at a given moment depends on the momentary height of the Earth's shadow. Bulk of the scattered light comes to an observer from a narrow atmospheric layer. The lower cut-off of this layer is determined by the shadow of the solid Earth. The contribution of the rest of the atmosphere above this layer may be neglected due to an exponential decrease of air density.

Bartusek *et al.*[5], in Australia, carried out simultaneous twilight and Lidar observations of the atmospheric aerosols. The results of his comparative study showed a good confirmation of the validity of twilight data. The earlier results of twilight sounding method showed that some

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finely dispersed matter, responsible for additional light scattering above and beyond that to be expected of a purely molecular atmosphere, was present at every height. In particular, a rapid rise of extra scattering above 70 km had been attributed by a number of authors to an enhanced abundance of dust particles of interplanetary origin at these altitudes[6]. This method was successfully used by Link in France in revealing aerosol of meteoric origin in the atmosphere[7]. He found that aerosol layers emerged at some heights between 60 and 120 km during the active periods of Librids, Orionids, and Geminids by showing a certain correlation between enhanced twilight scattering and the occurrences of these meteor showers. Also a significant rise of twilight sky brightness was observed in the period of maximum of Quadrantids[8], η-Aquarids[9] and Leonids[10]. The formation of several dust layers and their subsequent descent and dissipation were reported during these meteor showers. The ground-based results of Link were also confirmed by balloon-borne twilight measurements[11]. At Abastumani Astrophysical Observatory, Georgia (42.8°N, 41.8°E), twilight observations have been carried out for many years with the aim of investigating the distribution of the meteoric matter in the Earth's atmosphere during different meteor showers[2]. Their twilight measurements during the active periods of 1998 and 1999 Leonid meteor showers showed that large amounts of dust particles were injected into the atmosphere. They observed the formation of dust layers in addition to an overall enhancement of atmospheric turbidity. Thus, the twilight observations have revealed enhanced abundances of meteoric dust in the upper and middle atmosphere.

Leonid meteors are visible every year from about November 17 to 18. But during the year 2001, on November 18, the Earth ran into the dense ribbon of debris left behind by comet Temple-Tuttle during its 1767 orbit around the Sun. So the normal meteor shower turned into a meteor storm. Normal showers can have meteor rates of a few to several dozen meteors per hour whereas a storm can have 1000 meteors per hour and can go into tens of thousands per hour. The peak of the storm took place at around 10 : 30 UT on 18 November (http://www.astropix.com/HTML/F_COMETS/LEONID1.HTML).

The twilight photometer is being operated at a tropical inland station, Pune since November 2001. The clear sky conditions on November 18 helped us to take twilight measurements. An attempt has been made to monitor the influx of the great Leonid meteor storm dust by twilight method, for the first time in India. The preliminary results obtained were discussed and presented in this paper.

The twilight photometer, which is indigenously designed and developed at the Indian Institute of Tropical Meteorology, is being operated at Pune to retrieve the aerosol vertical profiles from about 6 km to a maximum of 150 km. A more detailed description of the instrument and the measurement technique were given elsewhere[4]. The scattered light gathered from 1° field of view by a convex lens is passed through a red filter peaking at 660 nm with a 50 nm half bandwidth to a photomultiplier tube (EMI 9798). The output from the photomultiplier tube is amplified by a fast pre-amplifier, whose output, which is proportional to the scattered intensity reaching the instrument, is measured. The measurements are made at every 30 s interval. The measured intensity (I) and the corresponding recorded time constitute the raw data. The recorded time is converted to Earth's shadow height (h), one of the main parameters of the twilight method, by our model, which includes the effects of atmospheric refraction and the correction that arises due to the strong attenuation of the lowest Sun rays by denser layers of the lower atmosphere.

The most significant problem of this method is the uncertainty of height determination, which cannot be obtained from measurements. The height resolution is not constant; it increases with increase in Earth's shadow height, from about 1.7 km at 20 km to 4 km at 100 km. But still it gives a good opportunity to monitor the aerosols in a wide range of altitudes, as it is less restricted in height.

The logarithmic gradient of the intensity, i.e. $q = -\mathrm{d}\log I/\mathrm{d}h$, is the most effective way of distinguishing the aerosol layers or to reveal the stratified structure of the atmospheric dust. In addition, q is not affected by an increased role of secondary scattering in the deep twilight that is important when considering intensity variations at high altitudes in the atmosphere[6]. At higher wavelengths, the role of Rayleigh scattering is very less as compared to Mie scattering. The variations in the vertical profile of molecular density are very small and hence the effect of Rayleigh scattering on the value of q, as studied by Bigg[12], is nearly constant. It does not give any structure on q curve and I is assumed to be directly proportional to aerosol number density.

The great Leonid meteor storm of 2001 observations were performed with the aid of twilight photometer described in the previous section. The observation sets, made use of in the present study are the evening twilights of November 13, 18, 20, 21, and 22. Due to weather conditions, the measurements from November 14 to 17 and 19 were noisy. A typical photometry curve of the twilight light intensity $I(h)$, as a function of height (h) of the Earth's shadow is shown in Figure 1. It shows the large range of decrease in scattered light intensity within 45 min following the local sunset. The lower atmospheric layers, submerged in shadow, no longer contribute to the sky brightness. The scattered light comes more and more from the higher layers, which are still illuminated by direct sunlight. As the air density decreases with height, the scattering coefficient also decreases and sunlight is scattered more weakly. As a result, sky brightness diminishes and so the illumination at the Earth's surface falls.

Within a short-term process, a temporal and spatial dynamic of the aerosol loading of the atmosphere may be described well enough in arbitrary units. A simple way to distinguish a rapidly evolving component of atmospheric aerosol brought in by meteor showers is to normalize the current set of data, $Ic(h)$, with a reference twilight set, $Ir(h)$. The reference set should be chosen as close as possible to the active period and should be free from dust particles. Here the twilight set of November 13 is selected as a reference set. Of course, November 13 is also not entirely free from dust particles because of the Taurid meteor shower, which occurs during 3–10 November. The ratio curves Ic/Ir of evening twilight measurements on November 18, 20 and 21, plotted from 16 to 150 km, are shown in Figure 2. It is noticed from the figure that on November 18, the day of intense meteor storm, there is an enhancement of scattered light intensity from the height range 30–120 km with a peak at about 80 km (solid line in Figure 2). At this altitude, the magnitude of enhancement is about seven times the normal. This broad peak may be due to the production of a large number of secondary particles as a result of fragmentation, ablation and condensation, which later fill up all levels of the middle atmosphere. The secondary particles may also be formed through condensation of evaporated dense meteor vapour in the trails of meteors and bolides, as discussed in detail by Hunten *et al.*[13], which may occur at any level.

An intensive descent of dust particles from mesosphere to stratosphere took place on the following days. An unexpected increase of the values above 120 km on November 20 as compared to November 18 may be due to further influx of meteor dust. On the 21st, the higher values between 50 and 100 km and lower values above 100 km as compared to November 20 may be due to subsequent descent of the dust. On November 21, a peak is seen in the lower stratosphere. Similar type of enhancements during Leonid showers of 1998 and 1999 have been shown by Nino Mateshvili *et al.*[2]. During the 1998 Leonid shower, they found two dust layers, one at 117 km and the other at 54 km, on the evening of November 20. These layers had descended to 93 and 30 km respectively on the morning of November 21. During 1999 Leonid shower, the maximum at 53 km was found to be very weak unlike on the evening of 20 November 1998. A weak maxima at 50 km and a better developed one at 40 km were seen on 22 November 1999. From their long-term observations carried out at Abastumani Observatory during different meteor showers, it was noticed that a layer at about 30 km is a rather frequent feature during meteor showers and is of short-lived nature. A similar feature is also seen in our observations (dashed curve in Figure 2).

Some signs of stratification began to develop by November 22. The vertical profiles of the logarithmic gradient of twilight intensities, dlog I/dh, of 13, 18, 22 and 23 November plotted from 16 to 100 km are shown in Figure 3. On November 13, which is not entirely free from dust, the values are higher but on November 18 some enhanced layered structures are seen at almost all levels indicating the influx of the meteor dust. On the 21st, the dust particles seem to accumulate from about 40 km and they even penetrate into the troposphere. On the 22nd a broad layer is observed from the tropopause to 40 km with a peak at around 25–30 km. There are so many evidences for the existence of meteoric matter in the lower stratosphere, which support our study.

When the Earth runs into the dense debris, left behind by the comet, it hits the Earth's atmosphere at high velocity, about 70 km/s, and the great energy from their speed causes them to burn up in the upper atmosphere, at a height of about 80–100 km. Very little is known about the fate of the evaporated material and its possible effects on the atmosphere. Much of the evaporated material

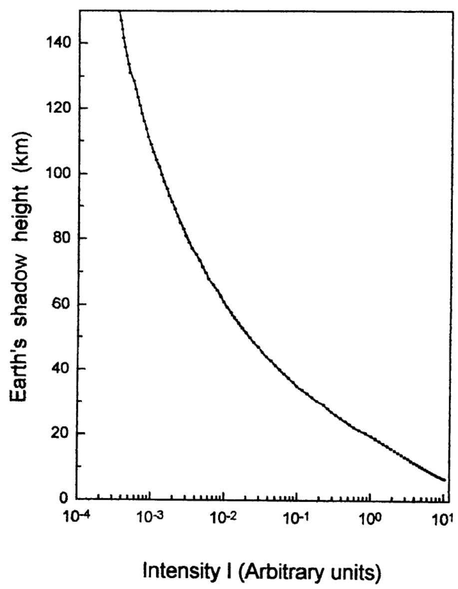

Figure 1. A typical photometric twilight light intensity curve.

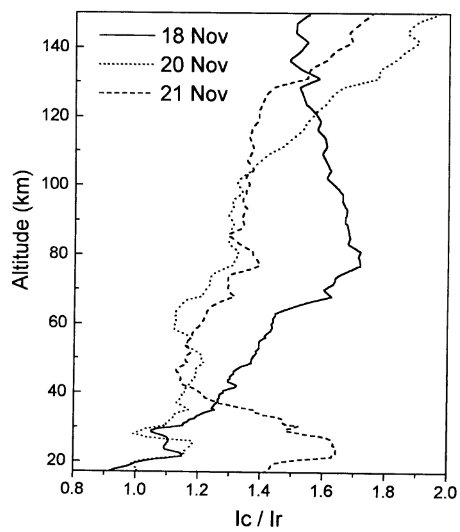

Figure 2. Ratio curves of current to reference twilight intensities for the evenings of 18, 20 and 21 November 2001.

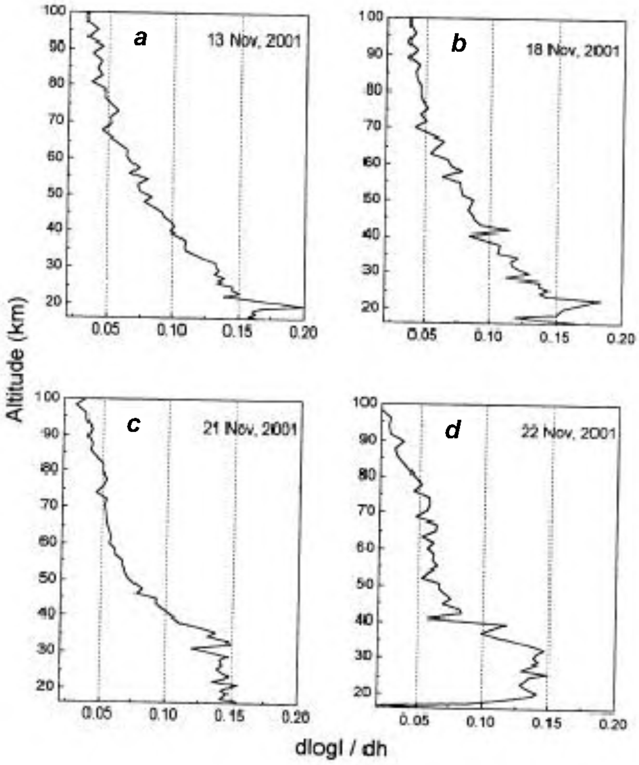

Figure 3. Logarithmic gradient of twilight intensity curves.

should quickly re-condense into a multitude of tiny particles as pointed out by Rosinski and Snow[14]. According to Hunten *et al.*[13], large number of these particles reaches 30 km where they interact with the stratospheric aerosol layer. He also calculated the interaction of stratospheric aerosol particles with meteoric debris, which suggests that meteors substantially perturb some properties of the layer above 25 km. In the stratosphere they serve as condensation nuclei for sulfates and in the mesosphere they act as a sink for metallic atoms and ions, as suggested by Hunten and Wallace[15] from their rocket measurements of sodium day-glow. Similar results have also been found in twilight measurements[16]. Also, presence of meteoritic material in the stratosphere was found by *in situ* measurements of chemical composition of individual aerosol particles at altitudes between 5 and 19 km using a laser ionization mass spectrometer mounted on the nose of a WB-57F high altitude research airplane[17]. The dust loading due to meteors is very small compared to the overall loading since the contribution due to natural and anthropogenic activities in the lower troposphere is maximum. However, meteoric dust particles may contribute significantly to the physico-chemical processes taking place at stratospheric–mesospheric altitudes. The role of heterogeneous chemistry is also significant and needs to be investigated from the experimental and modelling efforts.

The twilight sounding method gives a qualitative and in some aspects semi-qualitative information on the height distribution of the dust particles. Our twilight measurements during and after the Leonid meteor storm 2001, showed that all levels of the middle atmosphere are loaded with meteoric dust particles, perhaps both primary and secondary particles. The large enhancement in the twilight scattering on the day of the storm peak, at about 80 km, and its subsequent descent to lower levels of the atmosphere is clearly seen in the ratio curves. The formation of a broad layer in the lower stratosphere, due to dust accumulation, on the fourth day of the storm is explained by the logarithmic gradient of intensity. The main aim of this paper is to demonstrate the measurement capabilities offered by the twilight method, and it is the first attempt made by the authors to monitor the influx of the extra-terrestrial matter in the Earth's atmosphere.

1. Coulson, K. L., *Appl. Opt.*, 1980, **19**, 3469–3480.
2. Nino Mateshvili, Iuri Mateshvili, Giuli Mateshvili, Lev Gheondjian and Zurab Kapanadze, *Earth, Moon and Planets*, 2000, **82–83**, 489–504.
3. Ashok, N. M., Bhatt, H. C., Chandrasekar, T., Desai, J. N. and Vaidya, D. B., *J. Atmos. Terr. Phys.*, 1984, **46**, 411–418.
4. Nighut, D. N., Londhe, A. L. and Jadhav, D. B., *Indian J. Radio Space Phys.*, 1999, **28**, 75–83.
5. Bartusek, K. and Gambling, D. J., *J. Atmos. Terr. Phys.*, 1971, **33**, 1415–1430.
6. Iuri Mateshvili, Giuli Mateshvili and Nino Mateshvili, *J. Aerosol. Sci.*, 1998, **29**, 1189–1198.
7. Link, F., *Planet Space Sci.*, 1975, **23**, 1011–1012.
8. Link, F. and Robley, R., *Planet Space Sci.*, 1971, **19**, 1585–1587.
9. Mateshvili, G. G., Mateshvili, Yu. D. and Mateshvili, N. Yu., *Solar System Research*, 1997, **31**, 483–488.
10. Nino Mateshvili, Giuli Mateshvili, Iuri Mateshvili, Lev Gheondjian and Olga Avsajanishvili, *Meteor. Planet. Sci.*, 1999, **34**, 969–973.
11. Fechrenbach, M. and Link, F., *C. R. Acad. Sci.*, 1974, **B279**, 687–689.
12. Bigg, E. K., *J. Meteorol.*, 1956, **13**, 262–268.
13. Hunten, D. M., Turco, R. P. and Toon, O. B., *J. Atmos. Sci.*, 1980, **37**, 1342–1357.
14. Rosinski, J. and Snow, R. H., *J. Meteorol.*, 1961, **18**, 736–745.
15. Hunten, D. M. and Wallace, L., *J. Geophys. Res.*, 1967, **72**, 69–79.
16. Gault, W. A. and Rundle, H. N., *Can. J. Phys.*, 1969, **47**, 85–98.
17. Murphy, D. M., Thomson, D. S. and Mahoney, M. J., *Science*, 1998, **282**, 1664–1669.

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