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Optical observations of meteoric dust in the middle atmosphere during Leonid activity in recent years 2001–2003 over India

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[1] Twilight photometric technique has been used in order to demonstrate that the middle atmosphere can be perturbed by the presence of tiny particles delivered after an encounter with cometary dust trails like the one produced by 55P/Tempel-Tuttle. The presence of meteoric dust in the atmosphere from the Leonid activity that occurred from 2001 to 2003 was detected by the twilight photometer operated at Pune (18.5°N, 73.9°E), India. The November 2001 and 2002 Leonid storms, and the 2003 November outburst, caused significant enhancements of dust from just above the mesopause to the lower stratosphere. The present study shows the formation of meteoric dust layers at mesospheric levels and their subsequent descent to lower altitudes. The enhanced stratospheric layers are observed 4 to 8 days after the peak meteor activity. **Citation:** Padma Kumari, B., J. M. Trigo-Rodríguez, A. L. Londhe, D. B. Jadhav, and H. K. Trimbake (2005), Optical observations of meteoric dust in the middle atmosphere during Leonid activity in recent years 2001–2003 over India, *Geophys. Res. Lett.*, *32*, L16807, doi:10.1029/2005GL023434.

1. Introduction

[2] Meteoric dust is being continuously delivered to the terrestrial atmosphere from comets and asteroids. It is important to quantify the order of magnitude of the dust influx produced by unusual high-activity meteoric events in order to decipher its possible contribution to atmospheric and climate physical processes. The past encounters of the Earth with dust trails associated with 55P/Tempel-Tuttle presented an opportunity to study the magnitude of dust input during meteor storm and outburst conditions. Since these conditions are unusual and extreme they will provide an excellent opportunity to try and constrain the influx of debris from extraterrestrial sources and their behavior in the middle atmosphere. When the Earth intercepts a dust trail, thousands of particles ranging from tens of microns to several centimeters enter the terrestrial atmosphere at high velocity. Meteoroids from 55P/Temple-Tutle dust trails enter the Earth's atmosphere with an average geocentric velocity of 70.6 km/s. At this high velocity the original meteoroids are not expected to retain their original morphology, but instead survive as quenched, molten silicate spheres [*Rietmeijer and Jenniskens*, 2000]. Consequently, the resulting mass delivered to the atmosphere and surviving ablation is not well known. Recently, *Trigo-Rodríguez et al.* [2004a] estimated the mass influx of Leonid particles during past Leonid outbursts and storms, from the dependence of the size distribution and relative abundance of large particles. If large particles dominate the dust trail (as the 1998 outburst) the released mass would be on the order of several metric tons, whereas trails composed of fine dust particles would be one or two orders of magnitude lower depending on the intensity and extension of the high-activity level [*Trigo-Rodríguez et al.*, 2004a]. Small spheres or condensates of metal rich particles are produced during ablation of high-velocity meteoroids [*Rietmeijer*, 2002a, 2002b]. Another approach to this problem is the measurement of cosmic dust collected in different terrestrial environments; the recent estimate of the terrestrial mass accretion rate for meteoroids of all sizes is (49–56) × 10^6 kg/yr [*Love and Brownlee*, 1993]. Consequently, the Leonid input would be significant compared with the daily average for the Earth from all sources, i.e., ~85 × 10^3 kg.

[3] On the rare occasions when Earth intercepts a dust trail a meteor storm is produced [*Jenniskens*, 1996]. Approximately every 33.3 yr the return to perihelion of comet 55P/Tempel-Tuttle makes it possible for the Earth to intercept dust trails associated with this comet. Leonid storms produce the strongest meteor rates visible at Earth [*Brown and Arlt*, 2000]. The recent storms associated with the last 55P/Tempel-Tuttle return to perihelion have been reasonable-well predicted [*McNaught and Asher*, 1999, 2001; *Lyytinen and Jenniskens*, 2003].

[4] On Nov. 18, 2001, the Earth crossed the 1866 dust trail, the intensity of which was reinforced by the presence of the 1669 and 1767 dust trails. So the Leonid annual shower turned into a meteor storm as had been predicted [*McNaught and Asher*, 1999, 2001]. A very strong shower peak of ~3400 meteors/hr was reported in 2001 [*Arlt et al.*, 2001]. Again on Nov. 19, 2002, the Earth intercepted two 55P/Tempel-Tuttle dust trails [*McNaught and Asher*, 2002]. As a consequence, two strong peaks were observed in 2002 with typical spatial number densities of ~3000 particles heavier than 6 × 10^{-6} g in a cube with 1000 km-long edges [*Trigo-Rodríguez et al.*, 2004b]. On November 2003, the Earth did not cross any dust trails, but two meteor outbursts occurred on Nov. 13 and Nov. 19 as predicted [*Vaubaillion et al.*, 2003].

[5] Here we present the detection of an important input of Leonid ablation debris in the atmosphere during Nov. 2001, 2002 and 2003. We used the twilight photometric technique, a distant atmospheric sounding method used in the past for

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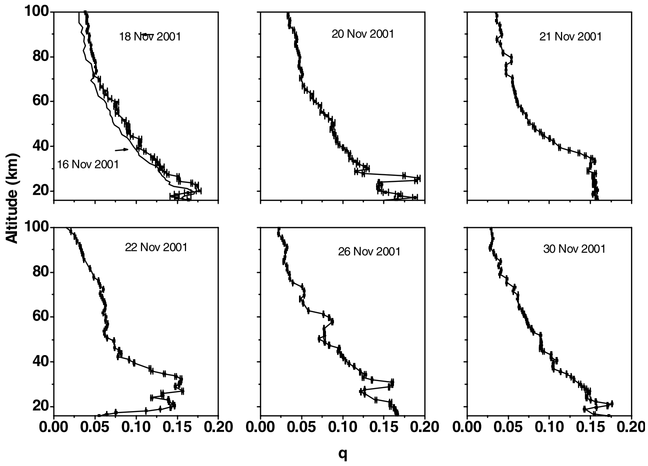

Figure 1. Logarithmic gradient of evening twilight intensity (q) curves for Nov. 2001. The Leonid storm took place on Nov. 18. Nov. 16 shows the atmospheric condition before the storm. Although the profiles on 18 and 20 do not show any dust layers at high altitudes they show enhanced values compared to 16. The profiles on 21 and 22 show dust accumulation below 40 km. On 26, high altitudes still seem to be perturbed with small layer enhancements, and finally on 30 no enhancements are seen. (The threshold level of detection of photometer is 0.001 ± 2×10^{-5} particles/cc at high altitudes and 1 ± 2×10^{-2} particles/cc at low altitudes).

monitoring the influx of meteoric dust in the upper and middle atmosphere [*Link*, 1975; *Mateshvili et al.*, 1999, 2000; *Padma Kumari*, 2004]. The twilight observations were carried out at Abastumani Astrophysical Observatory, Georgia (42.8°N, 41.8°E) during Quadrantid, η Aquarid, Perseid, Orionid, Geminid and Leonid meteor showers. All these meteor events showed an enhancement of the atmospheric scattering ability [*Mateshvili et al.*, 1999, 2000]. In the present study, a twilight photometry technique has been used for the first time from a ground station located in Pune (India) to monitor meteor dust in the middle atmosphere.

2. Methodology

[6] The twilight photometer consists of a simple experimental setup. It comprises a telescopic lens, a red filter peaking at 660 nm and a photomultiplier tube as a detector. The scattered light from the zenith sky is gathered from a 1° field of view. A more detailed description of the instrumentation and methodology is given elsewhere [*Padma Kumari*, 2004]. The dominating mechanism of formation of twilight sky brightness is light scattering in the sunlit layers of the atmosphere. The most important circumstance, which gives an altitudinal sounding ability to the twilight event, is that only a comparatively thin layer of air above the Earth's shadow contributes maximum to the sky brightness at every instant (see *Rozenberg* [1966] for more details). The most effective way of retrieving the aerosol layer is by the logarithmic gradient of intensity [*Mateshvili and Rietmeijer*, 2002] i.e.,

$$\mathbf{q = -d(\log I)/dh}$$

where I is measured twilight intensity obtained in relative units and h is the effective height of the Earth's shadow computed using the recorded time of observation from Earth's simple geometry [*Padma Kumari*, 2004]. The effect of Rayleigh scattering on the value of q, studied by *Bigg* [1956], is nearly constant and it does not give any structure on the q profile, and thus, I is assumed to be directly proportional to aerosol number density. The estimated uncertainty in the measurements should increase with altitude (as the signal gets smaller), but to avoid this, the signal level is kept constant through out the experiment by changing only the exposure area of the telescopic lens, and maintaining the output in the range 2 to 12 V. During this process no instrumental function is changed [*Padma Kumari*, 2004]. Hence, the error in measurement is ~1–2%. The photometer-derived profiles are compared with that of lidar and the comparison is found to be very good [*Padma Kumari et al.*, 2004].

3. Results and Discussion

[7] The vertical profiles of the logarithmic gradient of twilight intensity (q) obtained on 16, 18, 20, 21, 22, 26 and 30 November 2001, are shown in Figure 1. The horizontal bars in each profile represent the error in the measurements. Although the profiles on 18 and 20 do not show any enhancements at high altitudes except a narrow layer in the lower stratosphere, they show somewhat enhanced values at these high altitudes compared to the values on Nov. 16 (before Leonid storm) and Nov. 26 and 30 well after the Leonid storm. On Nov. 21, it is likely that dust particles from higher levels descended to lower ones and accumulated at altitudes below 40 km. On Nov. 22, a broad layer is observed from the tropopause to 40 km with a peak at 30 km. On Nov. 26, the higher altitudes still seem to be perturbed with small layer enhancements at about 30 km, 58 km and 70 km, indicating a further influx of meteoric dust. Finally, on Nov. 30 no enhancements are seen except for a small peak at ~20 km.

[8] In the year 2002, the vertical profiles were obtained during the evening twilights of Nov. 18, 25, 27 and 29 (Figure 2). No significant enhancements are observed at higher altitudes in the profile obtained on Nov. 18 because the observations were performed hours before the two Leonid storms. On Nov. 25 an evident enhancement in the profile was observed from 40–55 km indicating the presence of dust layer in this altitude range. During the following days this dust layer descended to lower altitudes. In fact, the profile on Nov. 27 shows a prominent dust layer in the lower stratosphere (20–30 km). This stratospheric layer is found to decrease in intensity on Nov. 29 and, in general, no additional enhancements were observed.

[9] Despite the lower intensity of the Leonid meteor shower in 2003, the results were interesting. The vertical profiles obtained from Nov. 13 to Nov. 28, 2003 are shown in Figure 3. The profile obtained on the evening of Nov. 13 shows no obvious enhancements at high altitudes, but a stratospheric layer peaking between 20–30 km is very prominent. In the early morning of Nov. 14, the Leonid outburst peak is observed over East Asia, and on the morning of Nov. 16, a broad enhancement from 55 to 80 km peaking at ~65 km appears in the profile. On the

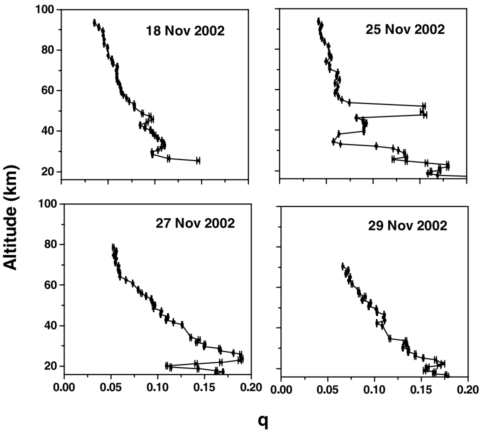

Figure 2. Logarithmic gradient of evening twilight intensity (q) curves for Nov. 2002. The Leonid storm took place on Nov. 19. Nov. 18 shows the atmospheric condition well before the storm. After the storm, Nov. 25 shows an enhanced layer from 40–55 km. This layer is descended to lower stratosphere by Nov. 27 and finally no enhancements are seen on Nov. 29.

morning of Nov. 17, the dust layer descended to lower altitudes, peaking between 35 and 55 km with peaks at ~40 and ~50 km. It seems that the layer in the profile of Nov. 16 while descending in the atmosphere broke up in two distinct dust layers. It would be produced under the influence of prevailing physical conditions in this atmospheric region. One possibility is that the dust particles were formed by a double population of different sizes (e.g. remaining ablation fragments and smaller condensates) that would be redistributed under the effect of turbulence or other physical processes. Such redistribution would be the cause of the observed differences in the intensity of both dust layers between Nov. 16 and 17. Another Leonid outburst took place on Nov. 19. This other outburst was a real independently observed phenomenon [*Vaubaillion et al.*, 2003]. As a result a broad enhancement was observed on the morning of Nov. 20 between 65 and 95 km, peaking at ~ 80 km. On the morning of Nov. 25, another enhancement was observed from 20 to 50 km. Finally, on the evening of Nov. 28 no additional enhancements were seen at high altitudes, except for a narrow layer at ~20 km. The pioneering work by *Mateshvili et al.* [2000] during the 1998 and 1999 Leonid meteor showers showed the formation of meteoric dust layers in addition to an overall enhancement of atmospheric turbidity by using the same technique.

[10] During atmospheric deceleration, Leonid meteoroids are ablated in the upper atmosphere. As a consequence of ablation, a column of ionized elements produces the luminous phenomenon known as meteors. Typical beginning and ending heights for visual Leonid meteors are respectively 120 and 90 km [*Trigo-Rodríguez et al.*, 2002]. Small meteoroid fragments survive ablation [*Borovička and Jenniskens*, 2000]. Previously, *Mateshvili et al.* [2000] estimated the particle diameters to range from 0.02 to ~22 μm. The presence of layers at different altitudes and their evolution as a function of time supports the idea that ablation of Leonid meteoroids produces particles in a wide range of sizes as previously observed by *Mateshvili et al.* [1999, 2000].

[11] The appearance of different layers suggests that large objects that probably formed from incompletely melted materials several tens of microns in size were released. As a consequence of compaction during heating, ablation can create dense particles. Even fluffy, low-velocity meteoroids may melt and become dense spheres [*Love and Brownlee*, 1990]. The dense particles may form as condensates of meteor vapor, appearing as dust layer at higher altitudes, which can be detected as an enhancement in the twilight vertical profile. This dust layer slowly descends to lower altitudes and disappear within a few days as seen in Figures 1, 2, and 3. Probably, simple sedimentation alone cannot account for the observed rapid clearing of the upper atmosphere, but dynamics and poorly understood processes such as coagulation or electrostatic charging of the particles might also play a significant role.

[12] Finally, it is interesting to note that the detection of the meteoritic contribution was made possible by the present quiescent condition of the middle atmosphere. For example, such detection would not nave been possible after the volcano Mt. Pinatubo erupted in the Philippines in 1991, which produced a large impact at stratospheric altitudes. The stratospheric aerosol depth following the Pinatubo eruption increased by about 2 orders of magnitude, making difficult to study the meteoritic contribution to the atmospheric aerosol. Since then, there have been no major volcanic eruptions. The stratosphere is presently in a quiescent condition. Satellite observations during the volcanically quiescent period have shown an increase in the background stratospheric aerosol layer [*Thomason et al.*,

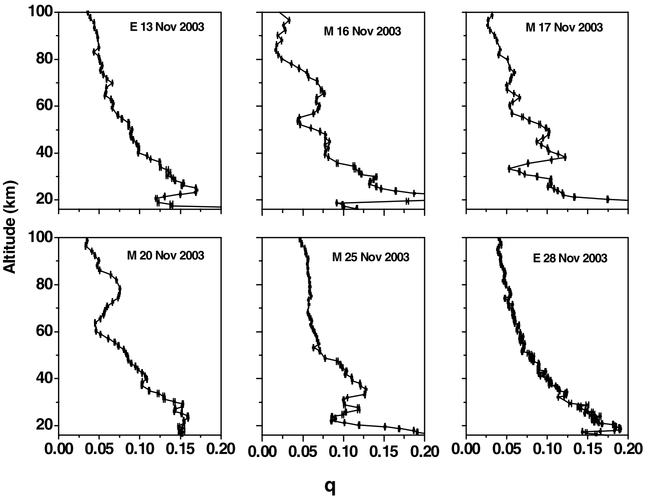

Figure 3. Logarithmic gradient of morning (M) and evening (E) twilight intensity (q) curves for November 2003. The Leonid outburst took place on the early morning of Nov. 14 over East Asia. Nov. 13 shows the atmospheric condition well before the outburst. After the outburst enhanced layer is seen on 16 morning and is descended by ~20 km on 17 morning. Again a broad enhancement seen between 65–95 km on 20 morning is due to another Leonid outburst on 19. This layer is descended to lower altitudes by 25 Nov. and finally no enhancements are seen on 28 Nov.

1997]. But, there has been considerable uncertainty as to whether this increase is caused by anthropogenic activity or if the trend is influenced by volcanic eruptions. From our data it is evident that the meteoric dust particles, after high meteor activity, may contribute significantly to the physico-chemical processes taking place at stratospheric altitudes.

4. Conclusions

[13] The twilight photometric technique is a useful tool for monitoring the influx of meteoric dust qualitatively in the middle atmosphere and its subsequent descent to lower altitudes. Our data show that the higher altitudes were highly perturbed after the Leonid meteor activity of 2001, 2002 and 2003. In general, 4 to 8 days after the peak meteor activity, an enhanced stratospheric layer was detected between 20 and 30 km and, sometimes, between 20 and 40 km. This layer seems to be a short-lived feature probably caused by rapid settling of ablation products of Leonid meteoroids. A couple of weeks after the meteor activity, the atmosphere recovers its normal dust distribution profile although a dust layer at 30 km altitude can persist for more time. Consequently, under the present or future quiescent periods, study of the meteoric contribution to the atmospheric aerosol layers makes sense in order to improve our knowledge of its influence on atmospheric chemistry, dynamics, and reflectivity changes.

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