ATMOSPHERIC AEROSOL LOAD MORPHOLOGICAL CLASSIFICATION AND RETRIEVED VISIBILITY BASED ON LIDAR BACKSCATTER MEASUREMENT

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ABSTRACT

In this paper, the tropospheric aerosol load morphological classification and its impact on temporal variation of visibility are investigated using a continuous 23-hour single channel CSIR-NLC mobile LIDAR backscatter measurement. The trajectory of the air mass that arrived at the measurement site (Pretoria, 25° 44' S; 28° 11' E), was traced back using on-line HYSPLIT model. The visibility range has been calculated and presented, using average aerosol extinction co-efficient profile and assuming that the atmosphere is homogeneous. The results show that the measurement site is loaded predominantly in the middle and upper troposphere by a transported hazy air-mass.

1. INTRODUCTION

Aerosols are produced by natural and anthropogenic activities. Atmospheric aerosols play an important role in many atmospheric processes. Although, they are a minor constituent of the atmosphere, they have an appreciable influence on the Earth's radiation budget, air quality, visibility, clouds, precipitation, and chemical processes in the troposphere and stratosphere [1]. Their occurrence, formation processes, impacts, residence and evolution time, the physicochemical atmospheric processes, transport, dynamics and source, as well as the resulting climate-relevant optical properties of aerosols are subjected to vary especially in the troposphere because of widely different sources and meteorological processes. In order to understand the above properties in the troposphere, the morphological classification of the atmospheric aerosol load is important. The aerosol load morphological profile is important in determining the light-scattering properties, source apportionment or source matching, transport and dynamic characteristics of the aerosol. Therefore, a vertically resolved measurement of aerosol optical properties, such as LIDAR backscatter and extinction coefficient altitude profiles is ideal. Further, the visibility parameter (which in general is defined as the maximum distance at which an object can be identified by human eyes) can also be quantified using the aerosol extinction co-efficient.

In this paper, we present the results obtained in terms of the aerosol load morphological classification and determined temporal variation of visibility pattern from CSIR-NLC-LIDAR.

2. DATA AND METHOD

A mobile LIDAR system is being developed at the Council for Scientific and Industrial Research (CSIR) National Laser Centre (NLC), Pretoria (25° 44' S; 28° 11' E), South Africa. The system is currently employed for atmospheric remote sensing including aerosols, clouds, boundary and mixed layers and other meteorological applications [2]. The LIDAR is operated at 532 nm wavelength and is capable of providing backscatter information from ground to 40 km with the range resolution of 10 m.

The CSIR-NLC mobile LIDAR was operated for 23 hours from 16 October 2008, 14h UTC to 17 October 2008, 13h UTC at the University of Pretoria, Pretoria, South Africa. Here, we use the datasets obtained in the above experiment to determine the atmospheric aerosol load morphological classification in the troposphere and also for retrieving the temporal evolution of visual range.

In general, retrieval of the aerosol backscatter and extinction coefficient profiles is based on the LIDAR signal inversion and the Fernald (1984) method, which was suitably adopted for the CSIR-NLC LIDAR [2].

The present morphological classification of aerosol load profile is made based on the LIDAR extinction co-efficient at 532nm by determining the total aerosol optical depth (τ) in the troposphere (from 0.3 to 18 km) and optical depth profile (Δτ) at range-interval of 3 km. The visual range is determined using the Koschmeider equation and the extinction co-efficient profile information. We also assume a plane parallel homogenous atmosphere in the range-interval of 1 km [3].

In addition, we use the Hybrid Single-Particle Lagrangian Integrated Trajectories (HYSPLIT) model developed by US, NOAA; Air Resources Laboratory (http://www.arl.noaa.gov/HYSPLIT.php). To derive the air trajectory arrived at the measurement site, we basically use the 24 hr traced back-trajectory analysis.

3. RESULTS

Figure 1 shows the temporal evolution of total optical depth derived from the hourly averaged aerosol extinction profile. Here, the extinction profiles are integrated from 300 m to 18 km since we are concerned with the troposphere aerosol loading. Initially, the aerosol load profiles are screened for every 3 km intervals (Figure 2). The appearance of cloud is observed from 3-6 km (22:15 hrs to 05:15 hrs). Thereby, the optical depth shown in Figure 1 is overlapped both with and without considering the 3-6 km region of the troposphere. The profile excluding the 3-6 km region from 22:15 hrs to 05:15 hrs indicates the background aerosol information. The values found from sunset to early sun-rise (18:15 hrs to 03:15 hrs) are in the range of 0.094 to 0.11 with a mean value of 0.1. Before sunset and after early sun-rise periods, (before 18:15 hrs to after 03:15 hrs) the optical depth is in the range of 0.028 to 0.084 with a mean value of 0.049.

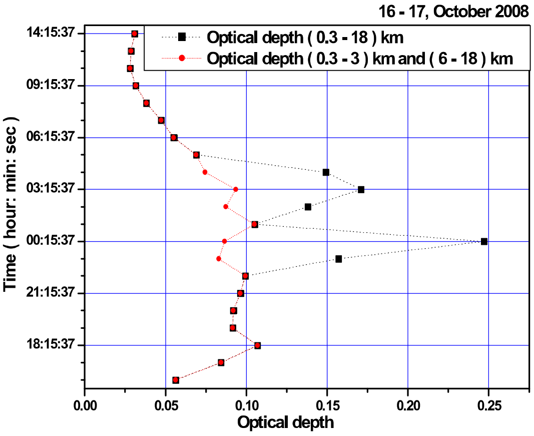

Fig.1: Temporal evolution of optical depth (τ) derived for the troposphere height region from 0.3 to 18 km.

The above results indicate that during the 23 hour measurement, the Pretoria atmosphere has a greater loading of transported polluted air during the night time. On the other hand, during 22:15 hrs to 05:15 hrs the 3-6 km profile shows large values of optical depth in the range of 0.15 to 0.25 with a mean value of 0.18. This is due to the appearance of middle level cloud. The HYSPLIT model was run for such a height region (3-6 km) and for 24 hours air mass back-trajectory. Results indicate that, the cloudy air mass which has an average vertical thickness of 2.5 km and which loaded the height region (3-6 km), had originated from the southern part of South Africa and Botswana.

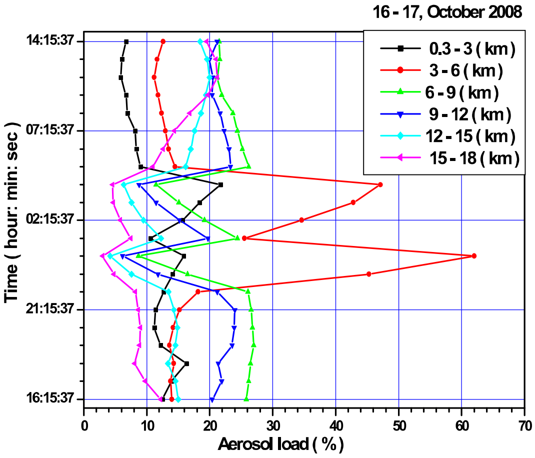

Fig. 2: Temporal evolution of the aerosol load at height interval of every 3 km.

Apart from 22:15 hrs to 05:15 hrs, when dominant clouds were present in the 3-6 km region, Figure 2 indicates that the maximum aerosol load occurred in the 6-9 km and 9-12 km height regions and the highest value of τ occurred at 18:15:37 LST,. Here, almost 50% of the tropospheric τ (which is an indirect indication of aerosol load) contributed from the 6 to 12 km height region which is the middle troposphere. The backward air trajectory analysis for this height region (6-12 km) using the HYSPLIT model indicates that the air mass transported from Namibia and the Atlantic Ocean passed through the southern part of South Africa and Botswana (see Figure 3). When comparing Figure 1 with Figure 2, the integrated optical depth shows a lower value for 17 October 2008 (10:15 LST) and the aerosol load profile indicates that during this time, almost 62 % of the tropospheric τ is contributed from the 9 to 18 km height region. The back-trajectory analysis also indicates a similar kind of air-mass transport as noted for the 6-12 km height region. Figure 2 shows the 66.4 percentile of the extinction coefficient which takes place in the 6 km to 18 km range interval.

This confirms that the Pretoria atmosphere (troposphere) was predominantly loaded from the middle and upper troposphere during the 23-hour measurement.

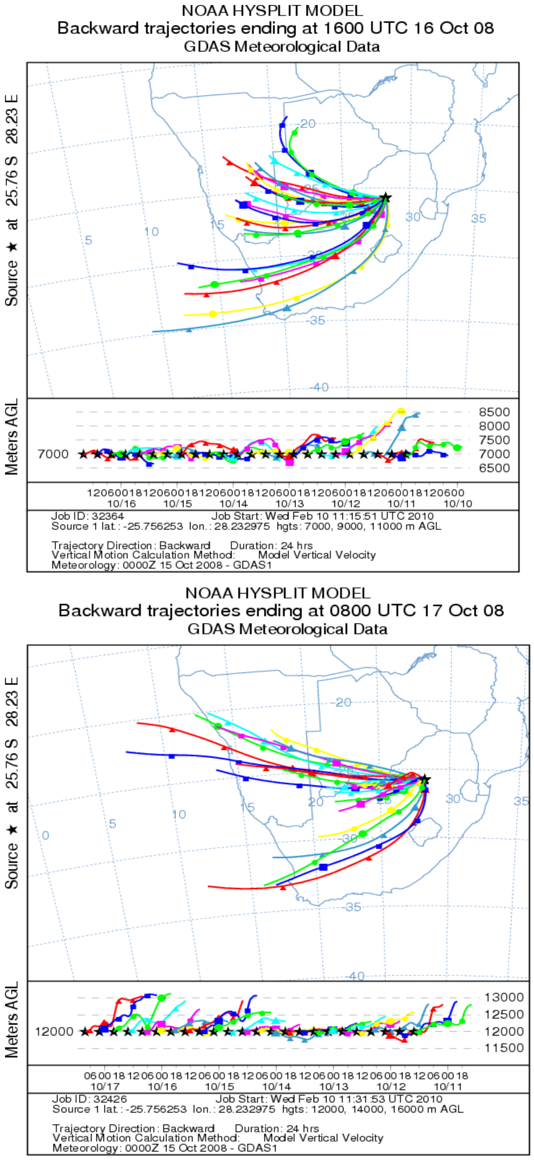

Fig. 3: The 24-hours air mass back-trajectory ending point at Pretoria on October 16 and 17, 2008, 16 UTC and 08 UTC.

In the visibility range calculation we utilized the standard value for the Koschmieder constant (3.92) and the average aerosol extinction profiles (km^{-1}) for every 6 km interval. In the absence of particles, the visual range of a Rayleigh atmosphere is more than 200 km due to scattering of air molecules at 532 nm. In fact, under such conditions, the visibility of most distant objects near the surface would be limited by the curvature of the earth. In general, the visibility degradation is caused by the presence of different forms of aerosol particles, such as dust, fog, smog, smoke and haze. Thus correlating temporal variability of atmospheric aerosol load morphological classification in the troposphere (Fig. 2) shows that the troposphere is significantly loaded from the middle and upper part (during the 23-hour measurement in average 66.4 % of atmospheric aerosol load takes place in the height range between 6 km and 18 km) and Figure 4 shows the temporal evolution of the average visibility range for every 6 km interval. It clearly indicates that the visibility (transparency of the atmosphere) degradation in the middle and upper part of troposphere is caused due to higher aerosol particles load (dust, smoke, and haze) and hydrometeors in the middle and upper part of troposphere.

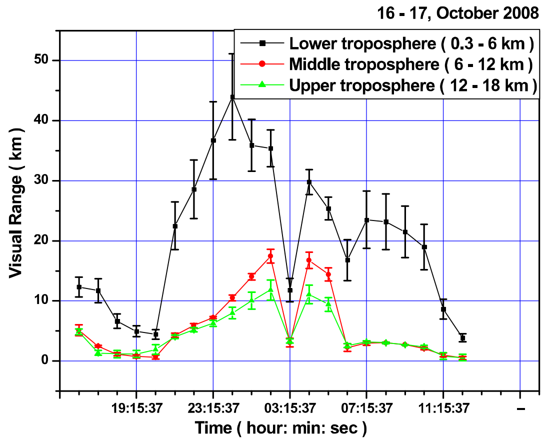

Fig. 4: Temporal variation of mean visual range in lower, middle and upper part of troposphere.

Also the higher standard deviation of visibility in the lower part of the troposphere shows the effect of drag force and other dynamical, transport mechanisms which are highly active. This might be due to different sources, sink mechanisms and meteorological processes in the lower part of the troposphere.

The average visual range values over cloudy and cloudless conditions over all parts of the troposphere indicate higher values of visibility from sunset to early sun-rise (18:15 hrs to 03:15 hrs). Later, a clear decline of visibility toward the daytime (before 18:15 hrs to after 03:15 hrs), is evident from Figure 4. Those results indicate that the overall aerosol dynamical activities, loading processes and the influence of solar radiation on meteorological processes increase during the daytime on the whole part of the troposphere.

Based on the international definition of fog, mist, and haze, the visibility pattern can be used to classify the atmosphere into fog (< 1 km), mist (>1<2 km) and haze (>2<5 km) [4]. It is clear from Figure 4 that during the daytime, the average values of visual range in the middle and upper part of the troposphere are between 2.46 ± 0.33 and 2.38 ± 0.32 respectively. We can conclude, based on the trajectory analysis and the obtained average visibility values, that the Pretoria atmosphere (middle and upper part of the troposphere) is predominantly loaded by the wind-blown hazy air-mass transport from Namibia and Atlantic Ocean which passed through southern part of South Africa and Botswana.

4. CONCLUDING REMARKS

The visualization of the atmospheric aerosol optical depth and HYSPLIT air mass back-trajectory analysis from sunset to early sun-rise and visa versa indicates that the Pretoria atmosphere (middle and upper part of the troposphere) has a higher aerosol load at the night time. By the polluted air mass originated from the southern part of South Africa and Botswana.

Aerosol load morphological classification during the 23-hour measurement shows 66.39 ± 18.34 % of the mean aerosol loading is present in the range interval of 6 km – 18 km. This indicates that the middle and upper troposphere has the highest mean loading with the longest residence time. The temporal variation of visibility and the high standard deviation in the lower part of the troposphere indicates that the lower part of the troposphere is affected by drag force and other dynamical and transport mechanisms which actively evolve with time.

In the near future, by adding other channel, 2-D scanner and with observations at different places, we plan to retrieve microphysical properties of aerosols, and to investigate the transport mechanisms and particulate matter (aerosols) distribution over South Africa. This will enable us to classify local and external source regions, determine aerosol characteristics in relation with atmospheric condition, and to study the direct and indirect impact of atmospheric aerosols on the local and global climate change.

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