Study of aerosol content based on spectrophotometric observations: A comparison with long-term extinction profile from photometric observations

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Abstract. Spectroscopic observations of standard stars (spectrophotometric) have been carried out at Bosscha Observatory ITB (latitude= 6°49′28″ S, longitude= 107°36′56″ E, altitude=1310 m) using the Celestron C-11 reflector (D=11 inches, F/10.0), equipped with NEO R-1000 spectrograph (Resolution of 1000), and ST-8XME CCD camera to deduce total atmospheric extinction curve. Spectrograms were reduced with the long-slit task in the Image Reduction and Analysis Facility (IRAF). The total extinction curve obtained from observation is decomposed into three main components, i.e. Rayleigh scattering, Ozone and water vapor absorptions, and extinction by aerosol. The extinction profile by Aerosol serves as an important indication on size and distribution of particulates as the main constituent of atmospheric pollutant. This pollutant can be resulted from natural process or anthropogenic activities. The behavior of atmospheric extinction over Bosscha Observatory based on long-term astronomical photometric database (1982-1993) was previously studied by one of us in 1993. In this study we analyze new data and study the dynamics of atmosphere by comparing our recent result with that from long-term photometric observations to indicate variation of degree of atmospheric turbidity, particulate size and its distribution over the atmosphere. We recommend that long-term regular based spectrophotometry at an Observatory is imperative as an effective means to gain our insight on atmospheric dynamic.

1. Introduction

Atmospheric extinction shows degree of air transparancy and can be used as an indicator of sky and air qualities above an observing site. Three sources of extinction in the Earth’s atmosphere are important for ground-based stellar photometry, i.e. Rayleigh scattering by air molecules, aerosol scattering and ozon absorption [1]. Each component has its own dependency on altitude and wavelength. In total atmospheric extinction varies with observation site and time.

Study of atmospheric extinction over Lembang were carried out on 1982-1993 using photoelectric photometer attached to GOTO 45 cm (F/12) reflector and the Bamberg 37 cm (F/18) refractor at Bosscha Observatory. This study revealed variability of atmospheric extinction [2]. There was no significant variation except after the eruption of Mount Galunggung on 1982 because of injected volcanic ashes onto the atmosphere [3].
Atmospheric extinction is the reduction of intensity of incoming radiation as a result of absorption and scattering in the Earth’s atmosphere. Absorption process causes photon to be annihilated and transferred its energy to the absorbing molecules. Scattering of light causes change in the direction of motion and energy of photon (and particle) [4].

Aerosol scattering is caused by particulates and droplets with various sizes, i.e., air molecules $(10^{-4} \mu m)$, haze particles $(10^{-2} - 1 \mu m)$, fog and cloud droplets $(1 - 10 \mu m)$ and dust grains (cosmic dust, volcanic ash, combustion products, organic particles released by trees and plants, sea salt). The amount of aerosol scattering depends on the size and distribution of particulates. Scattering by small spherical particles with size of the order of the wavelength of light, is inversely proportional to $\lambda$. This is widely known as Mie scattering. The larger particles cause scattering which is independent of the wavelength. As for general aerosol in lower atmosphere, the actual size distribution of the particles of various shapes roughly results in a $\lambda^{-1}$ scattering [4].

At the higher part of atmosphere, Rayleigh scattering caused by air molecule is a well known process and treated as a standard scattering whose amount is proportional to $\lambda^{-4}$ [6].

2. Method
Spectrophotometric observations were conducted on June 2019 by observing spectrophotometric standard star, $\alpha$ Lyr (HR7001), at several airmasses, using Celestron C-11 reflector (11 inches, F10.0), equipped with NEO R-1000 spectrograph ($R=1000$), and ST-8XME CCD Camera [5]. Mathematical expression of airmass [4] which depends on zenith distance is given by equation (1) and (2).

\[
X = \sec(z), \quad z \leq 60^\circ \\
X = \sec(z) - 0.0018167(\sec z - 1) - 0.02875(\sec z - 1)^{2} - 0.0008083(\sec z - 1)^{3}, \quad z > 60^\circ
\]

The obtained spectograms were then pre-processed and reduced with longslit task within Image Reduction and Facility (IRAF). Flux calibration process was implemented to derive the total extinction curve, $A(\lambda,h)$. The obtained extinction curve deduced from the observation were then compared to the extinction curve based on long-term photometric database. Both curves were then decomposed into three main elements, Rayleigh scattering, Ozone absorptions, and extinction by Aerosol. Total extinction is expressed in equation (3).

\[
A(\lambda,h) = A_{Ray}(\lambda,h) + A_{Oz}(\lambda) + A_{aer}(\lambda,h)
\]

Atmospheric extinction caused Rayleigh scattering [1] is given by an empirical formula, expressed in equation (4) [1].

\[
A_{Ray}(\lambda,h) = 9.4977 \times 10^{-3} \left(\frac{1}{\lambda}\right)^{4} \left[\left(\frac{n-1}{n-1}_{\lambda=1}\right)^{2}\right] \times \exp\left(-\frac{h}{7.996}\right)
\]

We assume atmospheric pressure of 760 torr at $h = 0$ km and refraction index, $n$, as given in equation (5)

\[
\frac{(n-1)_{\lambda}}{(n-1)} = 0.23465 + \frac{1.076 \times 10^{2}}{146 - (\frac{\lambda}{\lambda})^{2}} + \frac{0.93161}{41 - (\frac{\lambda}{\lambda})^{2}}
\]

The ozone absorption bands [6] are empirically expressed in the equation (6).

\[
A_{Oz}(\lambda) = 1.11 \times 0.25 \times 2.5 \times (1210 \times \exp(-131(\lambda - 0.26)) + 0.055 \times \exp(-188(\lambda - 0.59)^{2})
\]
Then, by using equation (3), the extinction by Aerosol solely, can be deduced. In the above equations, \( h \) is given in km, while \( \lambda \) is expressed in \( \mu m \). \( \lambda = 1 \) in equations (4) and (5) means 1 \( \mu m \).

3. Results and Discussion

Figure 1 shows the extinction curve deduced from observation on June 2019. The total extinction curve is at range \( 0.298 \leq k_\lambda \leq 0.883 \) for \( \lambda = 4253.9 - 6964.6 \) \( \AA \). Figure 2 shows the mean extinction curve based on photometric observation on 1982 – 1993 [2]. The mean extinction curve at range \( 0.071 \leq k_\lambda \leq 0.393 \) for \( \lambda = 4250.0 - 7000.0 \) \( \AA \).

For both observational data, total extinction curves are shown by black solid line. The decomposed components, Rayleigh scattering is shown by blue dashdotted, Ozone absorption is shown by green dotted and Aerosol scattering is shown by red dashed. Extinction profile on June 2019 shows significant enhancement as compare to the previous two decades.

Rayleigh scattering and Ozone absorption for a particular place on the earth are well studied and the amounts are almost constant. Then, from the decomposition of total extinction curve, one can deduce the aerosol component and, moreover its change. As shown in Figure 1 and Figure 2, the increased level of total atmospheric extinction is thought to be caused by the enhancement of aerosol component.

Aerosol is emitted directly by wind and in-situ formation in the lower atmosphere. Aerosols is a condensation of gases. It comes from direct emission by wind, growth by nucleation, condensation and coagulation, and eventually deposit directly onto the Earth surface in the form of rain. In the atmosphere, aerosol may cause several environmental effects, and in a high concentration is hazardous to human respiratory system. Aerosol absorbs and scatters visible radiation, limiting visibility, and causes climate change [7]. Aerosol are mostly composed of particulates, such as sea salt, bacteria, algaes, protozoas, fungi, viruses, pollens, sand, dust, volcanic ashes. Reminiscent of fuel combustion, anthropogenic activity, biomass combustion
are among main contributors toward the increase amount of aerosol in the lower atmosphere. The major amount of particulates in the atmosphere are sea salt and dust that were brought naturally by winds. In the urban site, increasing anthropogenic activities emits big amount of particulates on to the atmosphere, both from direct emission or through the gas-to-particle formation [8].

Based on the this observation compared to long-term photometric observation on 1982-1993, the increase of total extinction curve was thought to be caused by the increasing aerosol content in atmosphere. There was one natural cause, i.e. eruption of Mt. Galunggung in 1983 that significantly altered the extinction profile in 1982 [3]. Since 1990-s the population of Lembang city has been increasing significantly. This impacted on increasing human being needs such as transportation, land clearing for housing, and other anthropogenic activities. This are thought to increase significantly amount of aerosol. Further study on aerosol chemical composition, would lead to a better assessment of air pollutant in the area around the Observatory.

4. Concluding remarks
Spectrophotometric observation is a useful technique with standard astronomical equipments to study aerosol and its dynamic in the lower atmosphere. The increase of atmospheric extinction from this study was indicated to be caused by injected aerosol to the atmosphere by increasing human activities rather than natural causes. It will be imperative to conduct spectrophotometry on a regular basis along with chemical analysis of sample of floating aerosol in the lower atmosphere to gain insight into the variation of aerosol (diurnal, seasonal and annual). This study should be suitable to be conducted at the observing station such as astronomical observatory or weather stations covering a wide area.

Conflicts of interest
There are no conflicts to declare.

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