ATMOSPHERIC TURBIDITY MEASUREMENTS USING A 355NM-532NM LIDAR AND A SUNPHOTOMETER IN MANILA, PHILIPPINES

Edgar Vallar*[1], Ernest Macalalad[3], Michael Lajara[2], and Ma. Cecilia Galvez[1]
[1]Associate Professor, Physics Department, De La Salle University
2401 Taft Ave., Manila, 1004, Philippines; Tel: +63-2-5360229
Email: edgar.vallar@dlsu.edu.ph

[2]Physical Sciences Department, De La Salle University,
Dasmariñas, Cavite, 4115, Philippines

[3]Ph.D. Student, Institute of Space Science, National Central University,
300 Jhongda Rd., Jhongli, Taoyuan, 32001, Taiwan

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ABSTRACT: Real-time measurements of atmospheric turbidity were conducted in Manila, Philippines using the De La Salle University (DLSU) 355nm-532nm Mie LIDAR and Middleton SP02 4-channel sunphotometer. The DLSU Mie LIDAR system and the Middleton SP02 Sunphotometer are currently housed in the Science & Technology Research Center of DLSU, Manila, Philippines. DLSU is located in the center of Manila and is approximately 900 meters from Manila Bay. The DLSU LIDAR mainly consists of a 20-Hz, Q–Switched Nd:YAG laser and 20-cm diameter, 800-mm focal length Newtonian telescope. The SP02 Sunphotometer is a 1.25-kg commercial 4-channel Sunphotometer with center wavelengths at 368nm, 500nm, 675nm and 862nm (10-nm bandwidth). The sunphotometer was attached to a homemade tracker mount that tracks the sun and gets data automatically throughout the day. DLSU LIDAR researchers built LabView-based VI's for both the LIDAR and the sunphotometer enabling automatic data acquisition and processing. A detailed description of both systems can be found in www.dlsu-lidar.tk. The optical depth was determined from the data of each instrument. The Ångström turbidity law was then utilized to obtain the atmospheric turbidity. Typical values of turbidity vary from 0.0 to 0.5. For clean, clear, turbid and very turbid atmospheres, the turbidity values are 0.0, 0.1, 0.2 and 0.4, respectively. Experiments were conducted last 2010 January 08, 12 and 22. The average turbidity up to 400 meters horizontal range from the LIDAR site was determined. The LIDAR derived turbidity values were 0.184, 0.23, and 0.0295, respectively for the three dates. The corresponding sunphotometer values are 0.191, 0.235, and 0.0280, respectively. The January 08 and 12 values show a turbid atmosphere while the January 22 value indicates a relatively clear atmospheric condition.

1. INTRODUCTION

Metropolitan Manila (14°33'57" N and 120°59'38" E), home of about 20% of the country's population, is situated adjacent to Manila Bay (where maritime aerosols originate) and is flanked by several industrial/commercial sites along with urban settlements plus some agricultural communities (where continental and urban aerosols come from). These aerosols pose a severe threat to the health of people working and residing in Manila.

LIDAR and sunphotometry are two remote sensing techniques that provide real-time and accurate measurements of atmospheric turbidity along with minimizing the influence of humans in the measurement process. The Ångström turbidity coefficient (B) can be determined using a LIDAR and a sunphotometer. Typical values of B vary from 0.0 to 0.5. For clean, clear, turbid and very turbid atmospheres, B has values of 0.0, 0.1, 0.2 and 0.4 respectively (Brooks D. 2000; Keogh WM and Blakers AW. 2004; Macalalad EP. 2006). Thus, a large B means that the atmosphere is turbid.

2. DLSU LIDAR AND SUNPHOTOMETER

This work utilized both the 355nm and 532nm channels of the DLSU Mie LIDAR system along with the Middleton SP02 Sunphotometer which are currently housed in the Science & Technology Research Center of DLSU, Manila, Philippines. DLSU is located in the center of Manila and is approximately 900 meters from Manila Bay.

The LIDAR mainly consists of a 20-Hz, Q–Switched Nd:YAG laser and 20-cm diameter, 800-mm focal length Newtonian telescope. The SP02 Sunphotometer is a 1.25-kg commercial 4-channel Sunphotometer with center wavelengths at 368nm, 500nm, 675nm and 862nm (10-nm bandwidth). The sunphotometer was attached to a homemade tracker mount that tracks the sun and gets data automatically throughout the day. DLSU LIDAR researchers built LabView-based VI's for both the LIDAR and the sunphotometer enabling automatic data acquisition and processing. A detailed description of both systems can be found in www.dlsu-lidar.tk.

3. METHODOLOGY

LIDAR and sunphotometer data were obtained last 2010 January 08, 12, and 22. For January 08 & 12, the LIDAR was positioned to be 15° from the vertical while, for January 22, the LIDAR was oriented at 23° from the vertical. Background/offset removal was performed for both datasets. "Cloud-screening" was also done on the sunphotometer data. Fernald's inversion method was employed on the LIDAR data and a value of 30 was assumed for the extinction-to-backscatter ratio.

After pre-processing, data for each channel of the sunphotometer at a given Sun-position is inverted to obtain the total optical depth $\tau(\lambda)$ using

$$\tau(\lambda) = \frac{1}{m(\theta)} \ln\left[\frac{V_0(\lambda)}{V(\lambda)R^2}\right] \tag{1}$$

$m(\theta)$ corresponds to the airmass, R is equal to 1 AU (astronomical unit), V_o is the calibration constant and V is the voltage signal. The aerosol optical depth $\tau_a(\lambda)$ is derived by subtracting the Rayleigh, ozone and water vapor optical depths from the total optical depth (Schimd B and Wehrli C. 1995; Ingold T. 2000).

For the LIDAR, the aerosol optical depth at each wavelength is determined from the extinction coefficient profile $\sigma(z)$ through

$$\tau_a(\lambda) = \int_0^R \sigma(z)dz \tag{2}$$

The Ångström turbidity coefficient (*B*) can be derived the aerosol optical depth $\tau_a(\lambda)$ using the Ångström turbidity law which is given by

$$\tau_a(\lambda) = B\lambda^{-\alpha} \tag{3}$$

Taking the natural logarithm of both sides of Eqn. 3 yields

$$\ln \tau_a(\lambda) = \ln B - \alpha \ln \lambda \tag{4}$$

By plotting [LN $\tau_a(\lambda)$] along the y-axis and [ln λ] along the x-axis along with determining the best-fit line for the dataset, the turbidity coefficient *B* is derived from $e^{\text{y-intercept}}$. This procedure is performed separately on the LIDAR data and the sunphotometer data to gather the turbidity coefficient for each instrument.

4. RESULTS

The atmospheric turbidity (*B*) was determined for January 08, 12 and 22 up to about 400 meters horizontal range from the LIDAR site. This location gives the edge of the so-called "DLSU area" which was the main focus of the study. This area has two busy main streets intersecting each other and always has lots of vehicles (public [buses, jeeps, motorcycles] and private).

Figure 1 provides the comparison of the time variation of the turbidity coefficient (*B*) between the LIDAR and the sunphotometer. For January 08, the LIDAR average *B*-value is 0.184 while, for the sunphotometer, it is 0.191. This yields a 3.73% difference. The LIDAR and sunphotometer B_{ave} for January 12 was 0.23 and 0.235, respectively. This produces a 2.15% difference. Lastly, for January 22, an average *B*-value of 0.0295 was obtained from the LIDAR, while an average value of 0.0280 was achieved for the sunphotometer. It has a 5.22% difference. The turbidity coefficient values for January 08 and 12 represent turbid atmospheres while the January 22 value indicates a relatively clear atmosphere.

However, there is greater variability in the LIDAR *B* compared with the sunphotometer *B*. This may be partly due to the sunphotometer having more sample averages compared to the LIDAR which makes the former more stable. The sunphotometer is also a column-integrated measurement unlike the LIDAR which is spatially resolved. Thus, it may happen that *B* has a range or location dependence since there is an inherent altitude variation of aerosol concentration.

5. CONCLUSION

Real-time measurements (up to 400 meters horizontal range from the LIDAR site) of atmospheric turbidity (*B*) were successfully conducted last 2010 January 08, 12, and 22 in Manila, Philippines using the DLSU 355nm-532nm Mie LIDAR and Middleton SP02 sunphotometer (368nm, 500nm, 675nm and 862nm). The *B*-values indicate turbid atmospheric conditions last January 08 and 12 while a relatively clear atmosphere was found last January 22.

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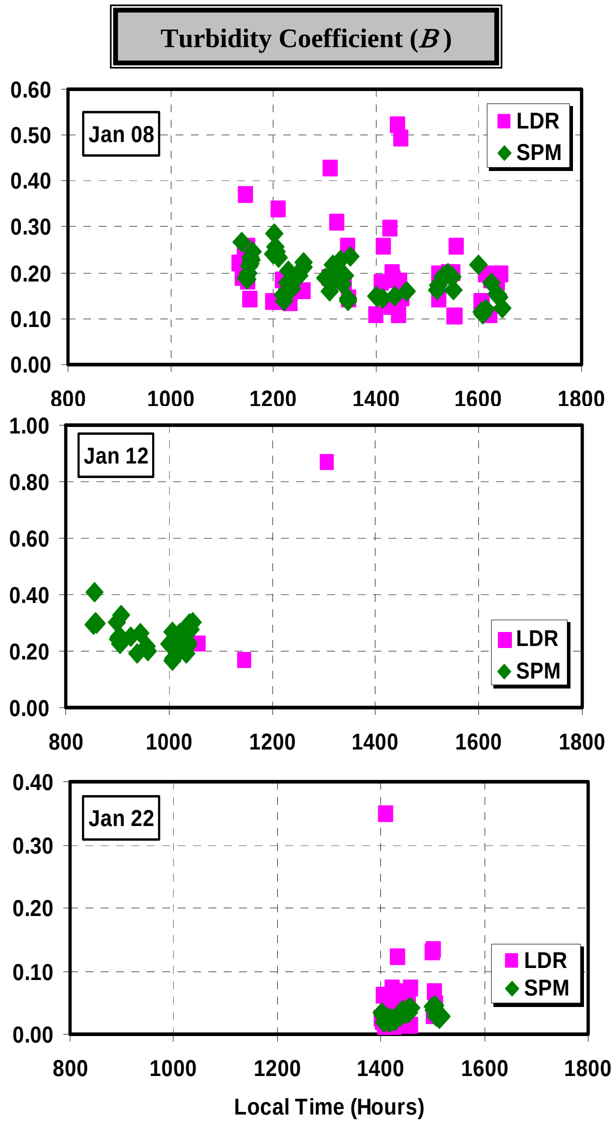

Figure 1. Comparison of LIDAR- and Sunphotometer-derived time variation of turbidity coefficient (*B*) for experiment dates 2010 January 08, 12, and 22.