Atmospheric aerosol measurements over CSIR-Paardefontein vicarious calibration site using LIDAR

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Abstract. In order to calibrate Earth Observing (EO) hyper-spectral and multi-spectral imager system using the vicarious calibration approach, it is essential to know the history and current status of aerosol loading and atmospheric properties over the calibration site. The background atmospheric condition and aerosol loading act as inputs to the radiative transfer code (RTC) in order to simulate the top of atmosphere (TOA) radiance. Atmospheric aerosol and properties have a major effect on the transmission of solar radiation from the sun to the surface and on the return path back to the sensor and they can also degrade the spatial image characteristics (e.g., the contrast of an object observed against a background). A LIDAR (Light Detection and Ranging) measurement campaign at the Council for Scientific and Industrial Research (CSIR) Paardefontein test range (25° 29'4.79"S, 28°22'51.25"E) was planned and executed to evaluate aerosol loading on the 30^{th} to the 31^{st} August 2010. In this site, a large test targets will be constructed for use during vicarious calibration and validation of data products from EO hyper-spectral and multi-spectral imaging system. In this paper, the temporal and spatial variations of aerosol extinction coefficient and fluctuation of Aerosol Optical Thickness (AOT) retrieved from the CSIR-National Lacer Centre mobile LIDAR will be presented. The AOT obtained from CSIR-NLC LIDAR was compared to the AOT measured by the Multi-angle Imaging SpectroRadiometer (MISR). The temporal and spatial evolution of the aerosol extinction coefficient shows that the aerosol loading was found to be unstable over the site during the measurement period. The AOT measured by the CSIR-NLC mobile LIDAR is in good agreement with the AOT measured by MIRS.

1. Introduction

For the scientific community to obtain remote sensing data from the hyper-spectral and multi-spectral imager system of highest quality, the continuation and consolidation of radiometric calibration is essential. The primary objective of the radiometric calibration is to determine accurate relationship between the incident spectral radiance and the instrument output [3]. Different approaches are employed for absolute radiometric calibration of hyper-spectral and multi-spectral imager systems, (1) laboratory radiometric calibration (Pre-flight); (2) on board radiometric calibration; (3) inter-sensor radiometric calibration, and (4) vicarious calibrations using natural uniform targets. Vicarious calibration is an absolute radiometric calibration approach that is independent of the approach used for pre-flight and on-board radiometric calibrations. Three vicarious calibration methods (the reflectance based, the irradiance based (also known as improved reflectance based) and the radiance based method) have been developed by the Remote Sensing Group (RSG) at the University of Arizona in the late 1980's and the rely on the measurements of the following parameters (either the surface reflectance or the surface leaving radiance) and atmospheric characterization (aerosol optical thickness, ozone and column water vapour) performed over a selected calibration site at the same time the satellite over pass the calibration site. These parameters are used as inputs into a Radiative Transfer Code (RTC) to compute the Top of Atmosphere (TOA) spectral radiance over the selected test site [1]. The solar radiation passes through the atmosphere from the sun to the earth surface and from the earth surface (calibration site) back to the earth observation (EO) hyper-spectral and multi-spectral imaging system. The atmosphere contains air molecules (ozone, H_2O, etc) and particulate matter (haze, dust, fog, and cloud droplets) also known as aerosols suspended in the air that absorb and scatter solar radiation from the sun to the surface as well as degrading the surface reflected solar radiation reaching the EO hyper-spectral and multi-spectral imaging system. Atmospheric aerosols (directly and indirectly) play a major role in many atmospheric process (e.g. Earth's radiation budget, air quality and visibility, clouds, precipitation and chemical processes in the troposphere and stratosphere). Aerosols affect the radiation budget directly by scattering and absorbing solar and thermal infrared radiation and indirectly by changing the cloud microphysics, albedo and precipitation. Aerosols greatly affect the top of atmosphere (TOA) and they also degrade image characteristics (e.g., the contrast of an object observed against a background) [2]. Furthermore, scattering and absorption of solar radiation by aerosols become the dominant factor in the boundary layer near the earth's surface (the troposphere), especially under low visibility conditions [8] caused by haze, dust, etc.

Atmospheric aerosol characteristics (optical and microphysical) can be retrieved from analyses of the solar radiation scattered or attenuated from by the atmosphere using instruments on the ground, a ship, an aircraft or a satellite [2]. In this study, we used the ground-based technique (active technique) that is not based on the solar light but on the lidar signal transmitted to the atmosphere and reflected back by atmospheric aerosol in the signal path. In general, the lidar can quantify and characterize the atmospheric aerosol concentration, optical depth, nitrogen, temperature, ozone, and water content, which are important when calibrating multi-spectral images using vicarious calibration technique. The lidar can also be used to quantify and characterize cloud position, thickness, and other general cloud properties, which are important for an improved understanding of the earth-radiation budget, global climate change, and scintillation[3].

2. Methods

2.1. Instrumentation

The primary objective of the ground mobile lidar system [4] developed at the National Laser Centre (NLC) of the CSIR, is to measure aerosol, water vapour and ozone at the lower atmosphere, troposphere. The system is comprised of three subsystems (see 1), namely a laser transmitter, optical receiver and a data acquisition system that are custom-fitted into a van using a shock absorber frame.

The system uses a neodymium-doped yttrium aluminium garnet (Nd:YAG) laser, transmitting 150 mJ pulses of the second harmonic (532 nm) into the atmosphere at 10 Hz. For reception, the LIDAR uses a Newtonian telescope configured with a 406 mm diameter primary mirror for the collection of back-scattered light at the laser wavelength (aerosol return). For data acquisition, the CSIR-NLC LIDAR system uses a LIDAR transient digitizer which

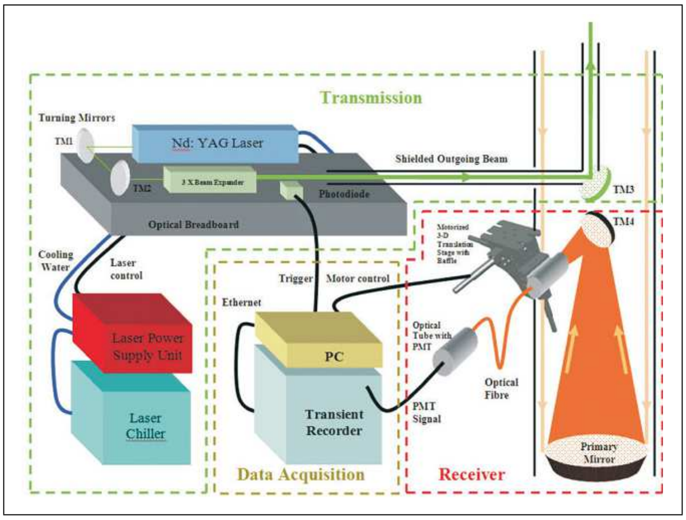

Figure 1: Detailed system block diagram showing all the CSIR-NLC mobile LIDAR components [4].

Figure 2: The CSIR-NLC mobile LIDAR system.

measures and records the analog and photon-count signals simultaneously. Additional details on the configuration of the CSIR-NLC mobil LIDAR (shown in 2) system can be found in [4] and [3]. The system is capable of providing aerosol backscatter measurements up to 40 km with a 10 m vertical height resolution.

2.2. Retrieval technique

To retrieve the altitude profiles of aerosol extinction $\alpha(r)$ or backscatter coefficient $\beta(r)$ from a backscattered LIDAR signal, the solution to the LIDAR equation (Equation 1) is required. The lidar equation can written as [5]:

$$P(r) = P_0 \frac{c\Delta t}{2} A\eta \frac{[\beta_a(r) + \beta_m(r)]}{r^2} e^{-2\int_0^r [\alpha_a(r)+\alpha_m(r)]\mathrm{d}r} \tag{1}$$

where $P(r)$ is the instantaneous received power at time t, P_0 is the transmitted power in watts at t_0, c is the speed of light, Δt is the laser pulse width, A is the area of the receiving mirror, η is the overall system efficiency, $r = \frac{c(t-t_0)}{2}$ is the range, $\beta_a(r)$ and $\beta_m(r)$ are the volume backscattering coefficients $\beta(r)$ for the aerosol and the air molecule components of the atmosphere, respectively and $\alpha_a(r)$, $\alpha_m(r)$ are the corresponding volume extinction coefficients $\alpha(r)$. The extinction coefficient profile $\alpha(r)$ is the most important parameter for atmospheric studies [2] because the aerosol optical thickness (AOT) obtained from $\alpha_a(r)$ is used as one of the input to RTC to calculate TOA radiance.

The solution to Equation 1 is obtained using different inversion techniques. The most widely used successful retrieval techniques are outlined in [6]. The inversion technique is not a straightforward process since there are two unknown variables, the aerosol extinction and backscatter coefficient. To determine either the aerosol extinction or the backscattered coefficient, a definitive relationship between these two variables was assumed and the molecular contributions to the backscattering and extinction coefficient was estimated using a reference model atmosphere (Mass Spectrometer - Incoherent Scatter - MSISE-90 Model). The aerosol extinction profile was retrieved following the LIDAR inversion method [5]. The obtained aerosol extinction coefficient was then integrated with height to obtain the AOT, which is an indicator of the aerosol loading in the vertical column of the atmosphere and also an input to the radiative transfer code used to calculate the Top of Atmosphere (TOA) radiance..

3. Observations

The CSIR-NLC mobile LIDAR was deployed at the CSIR Paardefontein test range on the 30^{th} August 2010 and 31^{st} August 2010, respectively, to assess the temporal and spatial evolution of LIDAR backscatter signal(analog data and raw photon count data). Figure 3 (a) and (b) and (c) and (d) shows the temporal and spatial evolution of the analog data and raw photon count data on the 30^{th} August 2010 and 31^{st} August 2010, respectively. Measurements were conducted for approximately two hours each day and no cloud observed in the height time LIDAR backscattered signal returns for both the analog data and raw photon count data.

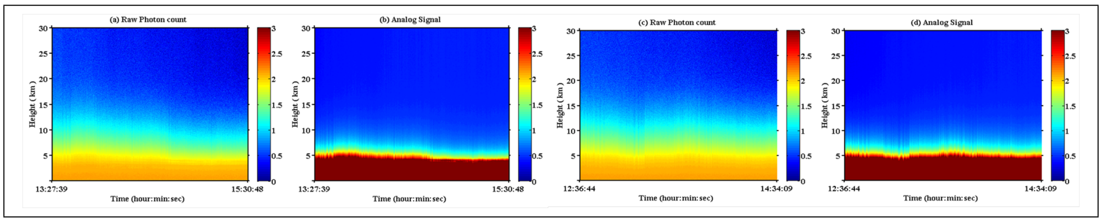

Figure 3: Height-time-colour map of the LIDAR signal (a) and (c) raw photon count signal and (b) and (d) analog signal measured on the $30th$ August 2010 and $31st$ August 2010 respectively

The analog and photon count data were merged or 'glued' together into a single return signal in order to increase the dynamic range of the backscatter signal and improves the signal to noise ratio (SNR). The analog and photon count signals were glued together after performing the appropriately scaling, dead time correction and range correction. Figure 4 shows the glued photon count results for the analog and photon count data (shown in Figure 3 (a) and (b)) measured on the 30^{th} August 2010.

Figure 6 shows the corresponding "glued" signal for the analog and photon count data measured on the 31^{st} August 2010. The glued signal allows us to use the analog data in the strong signal regions and the photon count data in the weak signal regions [8]. It can be observed in Figure 4 and 6 that the combined (glued) signal reveals a better picture of the structure of the atmosphere in comparison to the analog signal and the raw photon count. It was found in [3] that the analog form of the signal is more accurate for the lower height region in comparison to the upper height region and that the photon count data is more accurate in the upper height region. The embedded images in Figure 4 and 6 shows height time colour map of the lidar signal gather on the 30^{th} and 31^{st} August 2010, respectively in the lowest part of the troposphere (below 2.5 km). It can be observed that this region is the most active region in the troposphere and its rate of fluctuation was observed to be in the order of minutes. The change in this layer might be due to absorption of the sun's energy by the surface that heats the lower levels of the atmosphere, hence the rapid change with time in the lowest part of the atmosphere. This support the argument that in the boundary layer (troposphere) near the earth's surface, the scattering and absorption of solar radiation by aerosols is higher, especially under low visibility conditions caused by haze, dust, etc. Furthermore, the top of the PBL altitude was within a 1.3 2.5 km range during the lidar measurement periods.

The LIDAR inversion technique was applied to the returned LIDAR signal (shown in Figure 4 and 6) to determine the extinction coefficient α. Figure 5 shows the 10 minutes averaged height profile of the aerosol extinction coefficient retrieved from LIDAR signal returned on the 30th and 31st August 2010. Different height profiles for measurements on the same day are observed.

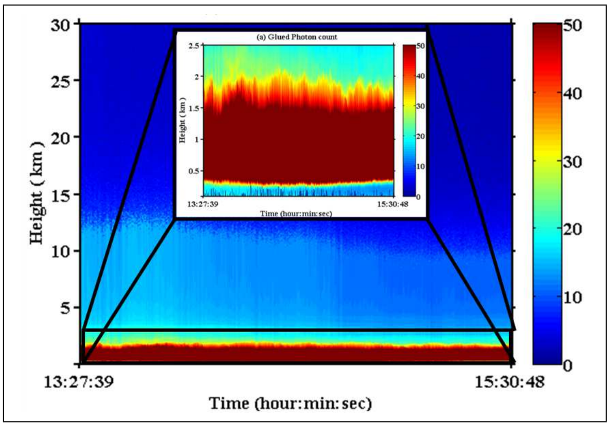

Figure 4: Height-time-colour map of LIDAR signal (glued analog and photon count) returns for the 30*th* August 2010.

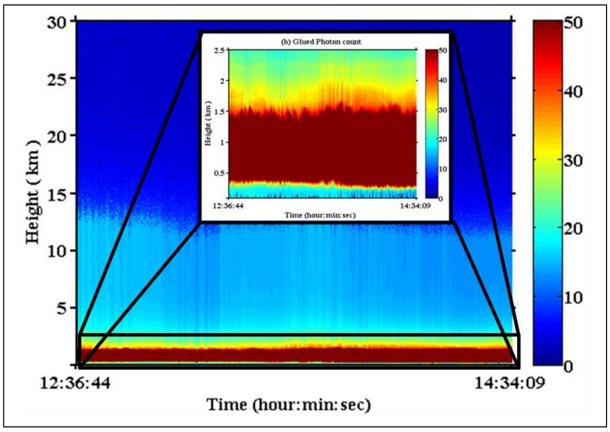

Figure 6: Height-time-colour map of LIDAR signal (glued analog and photon count) returns for the 31*st* August 2010

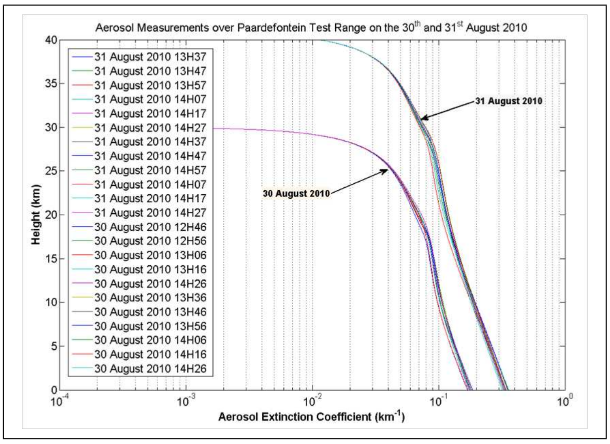

Figure 5: Aerosol extinction coefficient retrieved from LIDAR returned signal for the 30^{th} and 31^{st} August 2010.

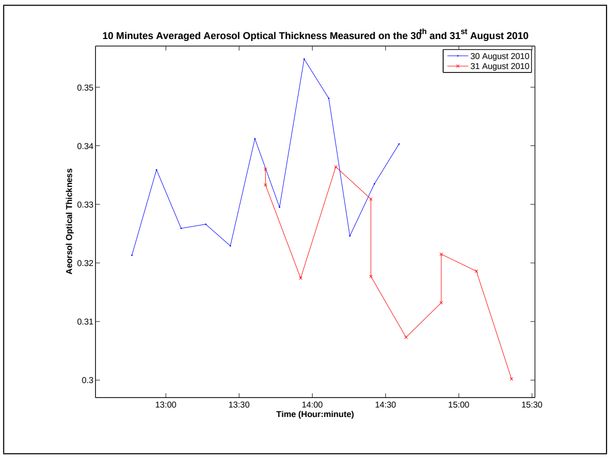

Figure 7: AOT obtained from CSIR-NLC mobile LIDAR on the 30^{th} and 31*st* August 2010

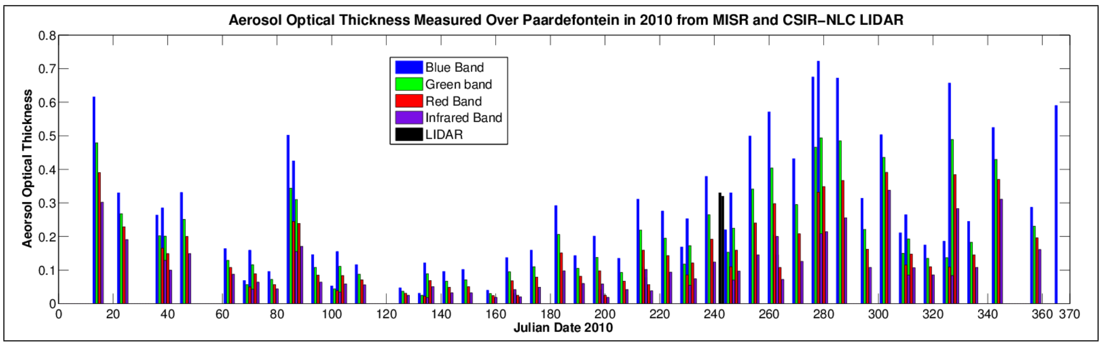

Figure 8: AOT measured by MISR and average AOT obtained from CSIR-NLC mobile LIDAR in the Green band.

The temporal evolution of the aerosol extinction coefficient shows that the aerosol loading was found to be unstable over the site during the measurement period. This is due to the change in the aerosol loading resulting from the change in humidity, temperature, etc. The AOT (shown in Figure 7) was calculated by integrating the 10 minutes aerosol extinction coefficient shown in Figure 5 for the 30^{th} and 31^{st} August 2010, respectively. The averaged AOT was 0.33 ± 0.011 and 0.32 ± 0.012 for the 30^{th} August 2010 and 31^{st} August 2010, respectively. It can be observed in Figure 7 that there is a temporal and spatial fluctuation of aerosol loading over the CSIR Paardefontein test range.

The AOT obtained using the LIDAR was compared to AOT data retrieved from Multi-angle Imaging SpectroRadiometer (MISR) on the footprint of Latitude, 25°S to 26°S and 28°E to 29°E Longitude. The data available was measured in the Blue (443 nm), Green (555 nm), Red (670 nm) and Infrared (865 nm) spectral band. Figure 8 shows the annual AOT measured using MISR in the spectral bands mentions above and the CSIR-NLC mobile LIDAR operats in the 532 nm wavelength. Note, the CSIR-NLC mobile LIDAR operate in the wavelength between the Blue and the green band. The measured AOT by the CSIR-NLC LIDAR is 0.33 ± 0.011 and 0.32 ± 0.012 for the 30^{th} August 2010 and 31^{st} August 2010, respectively. It is shown in [9] the AOT decreases with an increase in wavelength and the data obtained from the CSIR-NLC LIDAR during the measurement period are in good agreement with AOT measured by MISR.

4. Conclusion and future works

Aerosol optical properties were measured using CSIR-NLC LIDAR over CSIR Paardefontein test range and it was found that the aerosol extinction coefficient varies with altitude and time. The measured aerosol extinction coefficient was integrated with height to get the aerosol optical thickness. The AOT data obtained from the CSIR-NLC LIDAR was compared to the measured AOT from MISR and were found to be in good agreement. The annual AOT, Ozone and water vapor content over the CSIR Paardefontein Vicarious calibration site should be evaluated to determine the best time to perform vicarious calibration on the site currently been developed.

5. Acknowledgement

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