MPLNET UV LIDAR INTEGRATION: TESTS AND PRELIMINARY RESULTS OF FIRST INTERCOMPARISON AT NASA GSFC IN SPRING 2012


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ABSTRACT

The NASA Micro Pulse Lidar Network (MPLNET) is a federated network of Micro Pulse Lidar (MPL) systems designed to continuously measure aerosol and cloud vertical structure, day and night, over long time periods required to contribute to climate change studies and provide ground validation for models and satellite sensors in the NASA Earth Observing System (EOS). In spring 2012, twenty-one sites were active worldwide; in addition, numerous temporary sites have been deployed in support of various field campaigns. Most MPLNET sites are colocated with the NASA Aerosol Robotic Network (AERONET) sites. In this paper, we present some preliminary results of the first effort by MPLNET to integrate other commercial UV lidars than MPL systems in the network. This would provide more dense observations and, when possible, take advantage of different wavelengths to study aerosol optical and microphysical properties. A Leosphere ALS-450 UV lidar was operated next to the standard MPLNET lidar and AERONET sunphotometer at NASA Goddard Space Flight Center from March to May 2012. These two different lidars will be, when possible, jointly deployed in support of the NASA SEAC³RS field campaign in summer 2012, to study aerosol impacts in South East Asia (SEA).

1. INTRODUCTION

The characterization of the space-temporal distribution of aerosol properties to assess climate forcing and air quality at global scales rely on network measurements. In this framework, MPLNET [1], a member of the GALION lidar network of networks, has a key objective to provide the vertical component of this aerosol distribution utilizing a network of ground-based stations. Efforts were made in spring 2012 to integrate MPLNET with an additional commercial lidar with a different wavelength (355 nm) than MPL system (532-527 nm), produced by Sigma Space. The integration of a new instrument allows denser spatial observations, which benefit from the use of two different wavelengths. The purpose of this paper is to present the relative steps and results of the integration campaign that was held at GSFC in spring 2012. Moreover, a sensitivity study using two wavelengths to aerosol layer detection is also discussed.

2. MPLNET Lidar Network

The NASA MPLNET Lidar Network (MPLNET) is a federated network of ground based Micro Pulse Lidar (MPL) systems. The instruments are deployed worldwide providing continuous information on vertical structure of the atmosphere. Global measurements of aerosol and cloud microphysical and optical properties over a temporal period relevant to climate variations contribute to a better comprehension of their influence on radiative transfer and are therefore important in climate change studies. In addition, the network provides ground validation for models and satellite sensors in the frame of NASA Earth Observing System (EOS).

2.1 Network structure

Twenty-one elastic backscattering lidars in the VIS wavelength (532-527nm) are deployed and operational worldwide in MPLNET, both in Arctic and Antarctic regions, mid-latitudes, and tropics. To be part of the network, eye-safe (Hazard distance = 0 m) commercially available lidars should operate autonomously, under all meteorological conditions. MPLNET is based on a federated approach, allowing independent research groups to join the network and setup their own site. Data processing and data storage is centralized at NASA GSFC, enabling a common set of algorithms to be applied to all sites, ensuring continuity in the data. Single wavelength elastic backscattering lidars rely on critical assumptions to retrieve optical properties of aerosols [2] that affect measurement accuracy. The inversion of the lidar equation is greatly improved and simplified by the presence of a sunphotometer co-located with the lidar [3]. As consequence, when possible, the MPLNET sites are colocated with AErosol ROBotic NETwork (AERONET) [5] sun-photometers.

2.2 MPLNET data products

MPLNET has been providing quality near real time (NRT) lidar data through a public website since 2000 (http://mplnet.gsfc.nasa.gov) in NETcdf format.
MPLNET NRT data products include Level 1, 1.5a, 1.5b, 2.0 [7]. The data are acquired continuously, day and night, using a standard resolution (1 minute temporal, 75 m vertical) and are available in NRT (one hour to one day delay). The operational NRT products are not quality assured (no data screening).

3. UV LIDAR MPLNET INTEGRATION

In March 2012 a compact elastic backscattering UV lidar (model ALS450 [8] produced by LEOSPHERE) was deployed in the MPLNET site of NASA Goddard Space Flight Center (38 59’ 34” N 76 50’ 26” W Elev. 87m). The instrument was located few meters from the MPL lidar and AERONET sun-photometer.

3.1 Instrument calibration and principal technical characteristics of the two lidar systems

MPL and ALS450 lidars functioning principle consists in sending a laser pulse to the atmosphere. The backscattered signal is then collected and sampled into time-bin series to obtain a time-range intensity profile. Processing procedures applied to raw signals include background subtraction (MPL, ALS450), after pulse correction (MPL), blind reference subtraction (ALS450) or energy normalization (MPL). A complete description of instrument correction steps can be found in [8],[9]. A critical step for both lidars is the overlap correction, which represents a non-linear signal loss (MPL, coaxial configuration or ALS450, bистatic configuration) in the near range (0-5Km MPL, 0-350m ALS450). Full details on MPL overlap correction function can be found in [2], [10]. ALS450 overlap function was estimated through horizontal path measurements assuming a well-mixed atmosphere [11]. The measurements performed at GSFC show a full overlap of the ALS450 lidar at around 350m. Once correction steps are applied, the normalized relative backscattering (NRB) (Level 1 data product) is obtained from Eq. 1. NRB is depending on atmospheric parameters only, if we exclude the lidar constant C, taking into account of the optical efficiency of the system. The ALS450 is not normalized to the laser energy, as the system does not have an energy monitor channel. The NRB is represented in Eq. 1 as:

\[
NRB(r) = P(r)r^2 = C \left[ \beta_m(r) + \beta_p(r) \right] r^2
\]  

where \( \beta(r) \) is the volume backscattering coefficient (subscript m refers to molecular backscattering, p to particle backscattering), \( r \) is the range above the ground; \( T^2 \) is the round-trip optical transmission. Equation (1) is the baseline data product, stored daily in Level 1 NETcdf file for each MPLNET. The principal technical characteristics of the MPL and ALS450 lidars are summarized in Table 1.

Table 1. Principal instrument characteristic for MPL and ALS450 Lidar.

<table>
<thead>
<tr>
<th>Wavelength</th>
<th>MPL</th>
<th>ALS450</th>
</tr>
</thead>
<tbody>
<tr>
<td>527nm</td>
<td>355nm</td>
<td></td>
</tr>
<tr>
<td>PRF</td>
<td>2500 Hz</td>
<td>20Hz</td>
</tr>
<tr>
<td>Pulse energy</td>
<td>7 µJ</td>
<td>10500 µJ</td>
</tr>
<tr>
<td>Telescope diam.</td>
<td>20 cm</td>
<td>15 cm</td>
</tr>
<tr>
<td>Depolar.Channel</td>
<td>Yes*</td>
<td>Yes</td>
</tr>
<tr>
<td>Detection</td>
<td>Photoncounting</td>
<td>Analog/Photonic.</td>
</tr>
<tr>
<td>Eye-safe</td>
<td>Yes</td>
<td>EU Standards</td>
</tr>
<tr>
<td>Overlap</td>
<td>≈5000m</td>
<td>≈350m</td>
</tr>
</tbody>
</table>

*not the model currently deployed at GSFC
Both instruments are designed to operate autonomously and continuously. However, the ALS450 is operated on business hours, as at that period the instrument didn’t meet the eye-safety US requirements.

3.2 ALS450 integration and first results

To generate daily quicklooks of the ALS450 lidar, the first integration step consists in processing and converting its HDF5 [http://www.hdfgroup.com] output files into Level 1 data files [7]. The conversion algorithm reads and concatenates the provided hourly HDF into NETcdf format that is consistent with the MPLNET format. The uncertainty of NRB signal is fully characterized in [9] for MPL lidars. For ALS450 lidar, as the backscattered power is converted into analog signal, the uncertainty is defined as the reverse of the normalized variance of the electric signal:

\[
SNR_{ALS450} = \frac{S_l}{\sqrt{\sigma_I^2 + \sigma_k^2}}
\]  

where \( S_l \) it is the measured lidar signal converted in voltage and \( \sigma_I^2 \) and \( \sigma_k^2 \) are the variances of lidar signal and radiometric signal respectively [12]. Figure 1 shows an intercomparison between the ASL450 lidar and the MPL lidar expressed in terms of NRB for May 18th, 2012.

Figure 1. ALS 450 (upper) and MPL Lidar (lower) NRB on May 18th, 2012
4. MPLNET ALGORITHM VALIDATION IN THE UV AND SENSITIVITY STUDY

The integration of a UV lidar into the MPLNET increases its capabilities in assessing aerosol layer properties, deriving from the capability of having measurements at two different wavelengths (UV 355nm, VIS 532nm). In this section, the MPLNET algorithm, adapted to 355nm wavelength, is validated against an independent method (developed at GSFC) to retrieve aerosol optical properties at 355nm, and a sensitivity study on aerosol layer detection is also performed.

4.1 Level 1.5 data retrieval validation

The MPLNET original algorithm Level 1.5 retrieval was adapted to 355nm wavelength to invert Eq. 1. The key step in this operation is the calibration of the NRB signal to the atmosphere backscattering, removing any instrumental dependence [3]. This is accomplished retrieving the constant C value (Eq. 1) using a co-located sunphotometer measurement of the Aerosol Optical Depth (AOD) and U.S. Standard atmosphere data to calculate the expected molecular backscattering signal, above the boundary layer, in an aerosol free region. Then, the C value is continuously updated with co-located AOD measurement provided by AERONET. After the C value is calculated, the aerosol properties charactering Level 1.5a data are retrieved using an iterative method [4], which uses an independent measurement of column AOD (i.e. AERONET) as a constraint to retrieve particle backscattering coefficient ($\beta_p$), layer average extinction-to-backscattering ratio (LR) and optical depth profiles. The detailed MPLNET procedures to retrieve Level 1.5a data may be found in [3]. The preliminary results of the algorithm validation are shown in Figure 2. The particle backscattering coefficient profile at 355nm is retrieved with the adapted MPLNET algorithm (red line) and independently (blue line) during a field campaign at Dongsha Island on March 23rd, 2010. Cross-correlation coefficient (CC) is computed to assess discrepancies in shape between the two retrievals. For this case study, CC=0.92 (1 corresponds to 100% correlation, -1 signals completely uncorrelated). As clearly visible in Figure 2, the main differences arise in the first bins of the profile. This is due to the automatic overlap correction function applied by MPLNET algorithm and other near-range corrections. The average bias, estimating the total average absolute value of the difference between the two particle backscattering profiles on the column, is also evaluated, and the result gives 3.4 10e-7 m$^2$ sr$^{-1}$. This accuracy is far beyond the uncertainty (not reported in here) associated with particle backscattering coefficient profiles, making the retrieval consistent.

4.2 Sensitivity to aerosol layers detection

A parameter to determine instrument sensitivity to an aerosol layer is the aerosol scattering ratio (ASR), or the ratio of total over molecular backscattering coefficient [3]. This non-dimensional variable equals unity if the atmosphere is aerosol free. ASR is particularly indicated to assess the contrast (i.e. detection) of a certain aerosol layer with respect to the molecular backscattering. According to Rayleigh theory, the molecular scattering is stronger at shorter wavelengths (it is proportional to $\lambda^{-4}$). Measurements of ASR are used to derive volume backscattering profiles [13]. Lower sensitivity corresponding to lower ASR values introduces higher uncertainty in backscattering coefficient retrievals. During Eiafjallajökull eruption over Europe, the ash layer [14] was detected on depolarization channel, because the ash layer signature in parallel channel was barely visible. Figure 3 shows a simulation of R as a function of the particle backscattering coefficient. To get R=10 at 3.5km altitude, the color ratio, defined as the ratio of particle backscattering coefficient at 532nm over the particle backscattering coefficient at 355nm, should be of the order of 0.2.

![Figure 2. Validation of MPLNET algorithm at 355nm versus an independent method on particle backscattering coefficient retrieval vs altitude (1bin=75m) retrieval](image)

![Figure 3. Simulations of R (y axis) versus particle backscattering coefficient (x axis) at 355nm and 532nm at 3.5km altitude.](image)
integrated into MPLNET lidar network. The ALS450 output data (HDF files) are converted into Level 1 data (in the same format than the MPLNET) and NRB quicklooks are under test and will be soon available online. The Level 1.5 retrieval algorithm was modified to be used at 355nm wavelength and was validated against an independent method. The intercomparison result shows a cross-correlation of 0.92 and an average bias of 3.4 10e-7 m$^{-1}$ sr$^{-1}$ of the Level 1.5 backscattering coefficient profiles retrieved with the two different methods. The use of two wavelengths permits to better characterize and study the scattering properties of aerosol layers, clouds and precipitations.

5 REFERENCES