SYNERGETIC OBSERVATIONS BY GROUND-BASED AND SPACE LIDAR SYSTEMS AND AERONET SUN-RADIOMETERS: A STEP TO ADVANCED REGIONAL MONITORING OF LARGE SCALE AEROSOL CHANGES

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ABSTRACT

The paper presents the preliminary results of the lidar&radiometer measurement campaign (LRMC-2017), estimation of statistical relations between aerosol mode concentrations retrieved from CALIOP and ground-based lidar stations and case study of fire smoke events in the Eurasian regions

using combined ground-based and space lidar and radiometer observations.

1. INTRODUCTION

Coordinated lidar and radiometer sounding (LRS technique [1]) and related algorithms for processing combined lidar and radiometer data (LidAlm, POLIPHON, LIRIC, GARRLiC, SKYLIDAR, [2-6]) provides estimates of the key aerosol optical parameters, which determines the aerosol layer contribution in the equation of radiation transfer, as well as aerosol mode concentration profiles.

However, the low number of coincident lidar and sun-radiometer stations restricts the scope of LRS for monitoring atmospheric aerosol.

New version of Lidar&Radiometer Sounding (LRS) technique, named LRS-S, takes data of ground-based lidar stations, as well as satellite lidar (CALIOP) in the vicinity of AERONET radiometer stations to increase about ten times the number of sites suitable for control of aerosol parameters [7].

Combined Lidar&Radiometer measurement campaign (LRMC-2017) was started in 2017 with the aim to verify an ability to obtain information on aerosol concentration profiles over a large region from coordinated radiometer and ground-based and space lidar measurements. The first measurement period lasted from 15 to 31 of May, 2017. Additional measurements were carried out in 2017 and 2018.

This paper presents the preliminary results of collocated measurements of ground-based and satellite lidars in the vicinity of AERONET stations and observations of some aerosol events over Eurasian continent to assess the performance of LRS-S technique and expose significant features.

2. MEASUREMENT PROCEDURE

To date, 26 lidar stations of EARLINET, AD-Net and CIS-LiNet lidar networks associated with AERONET sun-radiometers sites submitted measurement data to the general database.

Three types of coordinated lidar and radiometer measurements were carried out in the frame of LRMC-2017 (Figure 1):

- R&L, coordinated sun-radiometer and multi-wavelength lidar measurements at the ground-based complex radiometer and lidar stations; R&L measurements provide local information about aerosol mode concentration profiles averaged over a time interval, $\Delta T \approx 30-60$ min;
- R&C, AERONET radiometer measurements and CALIOP sounding in the vicinity of AERONET station, $\Delta S \approx 100 km$; R&C measurements provide aerosol mode concentration profiles averaged over the trajectory segment $\Delta L \approx 100-200 km$.
- R&L&C, combined radiometer, ground-based lidar and CALIOP measurements in the vicinity of AERONET station.

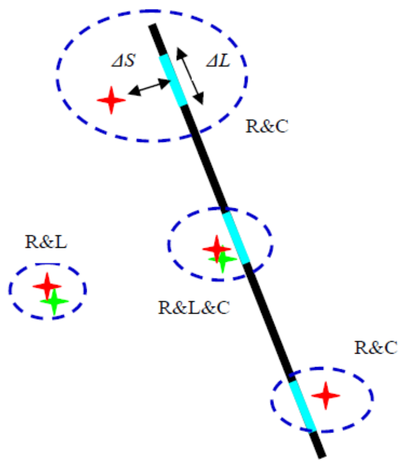


Figure 1. The scheme of measurement in the frame of LRMC-2017: black line is CALIOP ground track; blue segment is a part of trajectory of length, *ΔL,* used for retrieving aerosol parameters; *ΔS* is the distance between radiometer station and trajectory segment; red star is AERONET station; green star is multi-wavelength lidar system.

STUDYING OF STATISTICAL RELATIONS BETWEEN AEROSOL PARAMETERS

In general, the aerosol parameters retrieved from R&L and R&C measurements are different because they are calculated from different statistical ensembles of lidar data with the employment of time and/or space averaging procedures for R&L and R&C measurements, correspondingly. Coincidence of the results should be expected if the aerosol random field satisfies some conditions: horizontal spatial homogeneity and ergodicity.

Results of R&L&C measurements allow comparing the aerosol concentration profiles, $c_k^g(h)$ and $c_k^s(h)$, retrieved from ground-based and satellite lidar measurements to be compared. Index k is related to the aerosol mode.

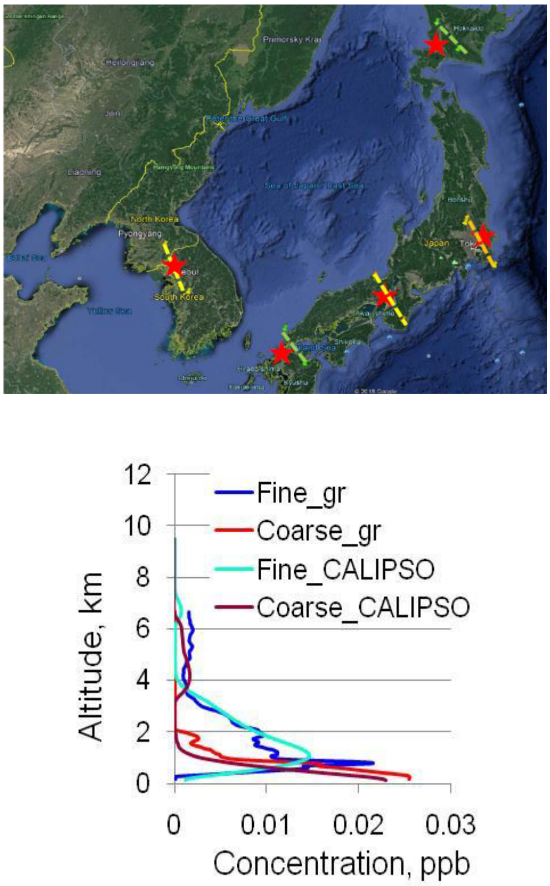


Figure 2. Implementation of R&L&C measurements at AD-Net stations: a) –scheme of measurements; b) – profiles of aerosol mode concentration in Fukuoka region from ground-based lidar measurements (gr) and satellite ones (CALIPSO); 17/05/2017; G(fine)=0.05, G(coarse)=0.1

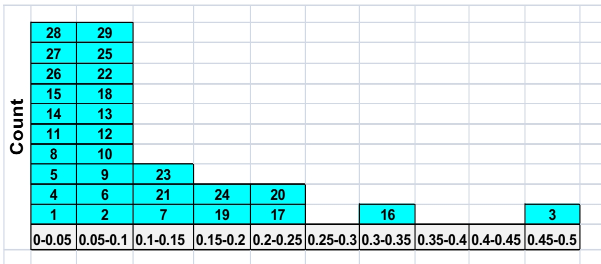
Differences between profiles $c_k^g(h)$ and $c_k^s(h)$ were numerically estimated by parameter G:

$$G\left(c_k^g, c_k^s\right) = \frac{\sum_i \left(c_k^g(h_i) - c_k^s(h_i)\right)^2}{\sum_i \left(c_k^g(h_i)\right)^2 + \sum_i \left(c_k^s(h_i)\right)^2}; \quad (1)$$

where $G\left(c_k^g, c_k^s\right) \in [0,1]$; if $G\left(c_k^g, c_k^s\right)$ equals 0 or 1, it means the complete coincidence of the profiles $c_k^g(h)$ and $c_k^s(h)$ or the localization of aerosol in non-coincident atmospheric layers, correspondently.

Figure 2 shows the implementation scheme of R&L&C measurements at AD-Net stations and results of retrieving aerosol concentration profiles in Fukuoka region.

Probability distribution of the parameter $G\left(c_t^g, c_t^s\right)$ for total (fine and coarse) aerosol particles concentration are shown in figure 3. Average value of parameter $G\left(c_t^g, c_t^s\right)$ for all measured ensemble of data is 0.11.



1- Athens *(EARLINET);* 2,3 - Barcelona *(EARLINET);* 4 - Granada *(EARLINET);* 5 - Hohenpeissenberg (*EARLINET); 6* - Madrid *(EARLINET);* 7- Finakalia *(EARLINET);* 8 - Lille *(EARLINET);* 9 - Potenza *(EARLINET),* 10 - Lecce *(EARLINET);* 11 - Bucharest *(EARLINET);* 12-15 - Evora *(EARLINET);* 16,17 - Haifa *(TROPOS);* 18,19 - Minsk *(EARLINET,CIS-LiNet);* 20 - Tomsk *(CIS-LiNet);* 21,22 - Teplokluchenka *(CIS-LiNet);* 23- Tsukuba *(AD-Net);* 24- Chiba *(AD-Net;* 25 - Osaka *(AD-Net);* 26 - Fukuoka *(AD-Net);* 27,28 - Sapporo *(AD-Net);* 29-Seoul *(AD-Net)*

Figure 3. Chart of probability distribution of the parameter $G\left(c_k^g, c_k^s\right)$ for the height profiles of the total concentrations of aerosol particles, retrieved from ground-based and satellite lidar measurements

CASE STUDY OF DUST AND FIRE SMOKE EVENTS IN THE EURASIAN REGIONS

Eurasian continent includes regions with advance infrastructure for monitoring of environment as well as uninhabited and inaccessible areas where only satellite observations are available. LRS-S technique is a potentially optimal tool for studying large scale aerosol changes and monitoring the aerosol transport over Eurasian area.

In the frame of LRMC-2017 campaign we tested the algorithm and new software package LIRIC-2 for retrieving aerosol mode concentration profiles for some aerosol events in 2017 – 2018:

- transport of fire smoke to European regions from North America and East Russian regions and Ukraine in August, 2018;
- fire smoke in Vietnam, April 2017;

Figures 6 demonstrate the examples of retrieved aerosol concentration profiles. Intercontinental transport of fire smoke in the free troposphere creates a wide layer of small aerosol particles with a maximum at an altitude of 3-6 km in the East European region (Fig. 6, a-c). Local fire spots pollute boundary layer in Bac-Lieu, Vietnam (Fig. 6, d).

SUMMARY

Implementation of LRS-S technique increases the number and geographical area of sites for monitoring of aerosol parameter profiles. Results of LRMC-2017 measurement campaign demonstrate that coordinated ground-based and satellite lidar and radiometer measurements with assimilation data of LRS-S observations for modeling aerosol transport are perspective research lines for development of regional large-scale aerosol monitoring.

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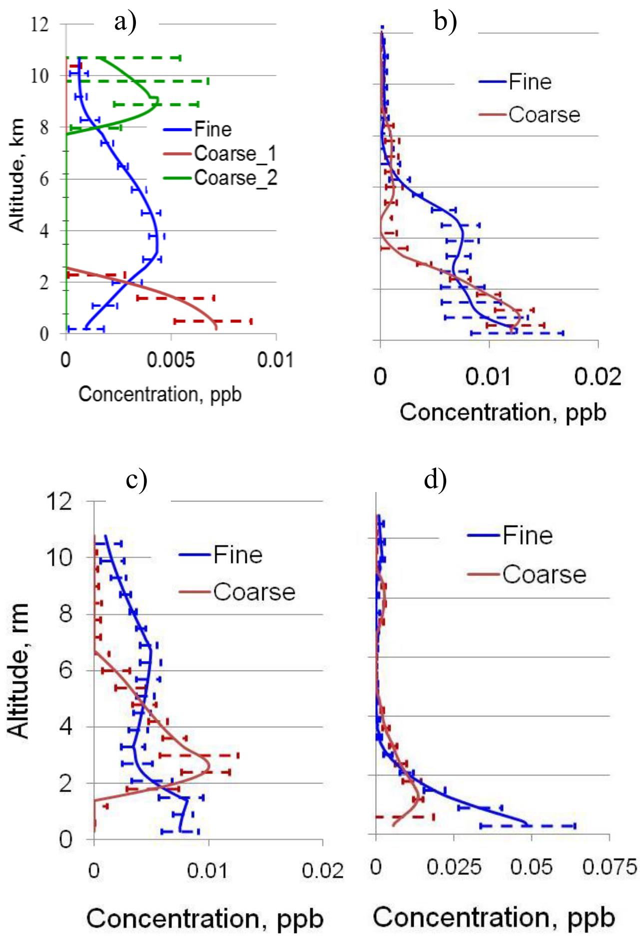

Figure 6. Profiles of aerosol mode concentration at: a)Belsk, Poland, 29/08/2018; b) Kyiv, Ukraine, 31/08/2018; c)Minsk, Belarus, 02/09/2018; d) Bac Lieu, Vietnam, 18/04/2017

REFERENCES

1. A. Chaikovsky, et al. Proceeding of SPIE, 4678, 257-268 (2002).
2. J. Cuesta, et al. Appl. Opt., 47, 4598–4611 (2008).
3. A. Ansmann, et all. Atmos. Chem. Phys., 12, 9399–9415 (2012).
4. A. Chaikovsky, et al. Atmos. Meas. Tech., No. 9, 1181–1205 (2016).
5. A. Lopatin, et al. Atmos. Meas. Tech., 6, 2065–2088 (2013)
6. R. Kudo, et al. Atmos. Meas. Tech., No. 9, 3223-3243 (2016)
7. Chaikovsky, et al. EDJ Web of Conferences, 176, 08007 (2018)