AEROSOL OPTICAL PROPERTIES FROM TROPOSPHERIC LIDAR AND SUN PHOTOMETER DURING THE GOA AEROSOL ARCTIC CAMPAIGNS 2005 AND 2006 AT ALOMAR

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1. INTRODUCTION

Tropospheric aerosols have an important role in our climate for their contribution to cloud formations and sunlight attenuation affecting critically the global radiative balance. Depending on various generating sources, tropospheric aerosols may vary greatly in both time and space. Several models for the study of the optical properties of the tropospheric aerosols have been developed. However, the optical properties of aerosols, governed by physical parameters such as particle density and size distribution, have not yet been well characterized in the Artic zone.•

In the Arctic, long term observations, especially in-situ and a few aerosol lidar measurements, are carried out at Ny-Ålesund/Svalbard (79°N) [Ritter (2004)].

The location of ALOMAR, north of the Arctic Circle and on an island, a few hundred meters from seashore and about 30 km off the continent, makes it ideal for investigations related to Arctic phenomena such as noctilucent clouds, polar stratospheric clouds and Arctic haze. For air masses from the north and north-west ALOMAR can represent a reference station for almost unpolluted, clear air. Air masses passing above ALOMAR with back-trajectories from the north-east transport continental air from the urban centres in northern Russia, whereas western and south- western back-trajectories have a strong maritime influence. ALOMAR's year-round capability is essential for long term studies to also include intra-annual variations.

Previous studies report synergetic use of Lidar and sun-photometer [Landulfo (2003), Müller (2003), Veselovskii (2006)]. The Lidar and sun–photometer can provide information regarding microphysical properties of the aerosols by combining observations at different optical wavelengths. We present the results of Artic campaigns during summertime in 2005 and 2006 with the simultaneous observations by Cimel sun photometer and Lidar, extending the former 2002 and 2003 campaigns conducted by the Group of Atmospheric Optics of Valladolid [Toledano (2006)].

2. INSTRUMENTS

2.1 The Sun-photometer

The Cimel Electronique CE-318 sun photometer is an automatic sun and sky radiometer, with spectral interference filters centered at selected wavelengths: 340, 380, 440, 500, 670, 870, 1020 and 1640 nm for aerosol measurements. The filter band pass has 2 nm FWHM in the UV and 10 nm FWHM for the visible and infrared regions. The Cimel sun photometer is the standard instrument of AERONET network [Holben (1998)]. Direct sun measurements are performed at these wavelengths (1.2º field of view) to determine aerosol optical depth (AOD) and another channel at 940 nm is used for water vapor content retrieval. Sky radiance measurements are acquired at 6 wavelengths (from 440 to 1640 nm) in the solar almucantar and principal plane (for details, see [Holben (1998), Holben (2001)], http://aeronet.gsfc.asa.gov; and http://www-loa.univ-lille1.fr/photons/). Inversion algorithms can then be applied to the sky and direct sun measurements to retrieve aerosol size distribution, single scattering albedo, phase function and complex refractive index [Dubovik (2000), Holben (1998)].

The Cimel sun photometer was calibrated at El Arenosillo within the Spanish Network for Aerosol Measurements (RIMA), in close collaboration with AERONET and according to the AERONET protocols. The direct sun channels were calibrated by inter-comparison with a master instrument. For the sky channels calibration an integrating sphere was utilized. This procedure yields to an estimated accuracy of 0.01-0.02 for the absolute AOD error (wavelength dependent) and 5% relative error for the radiance in the sky channels.

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The Cimel automatic sequence has been followed for the measurements. This sequence includes direct sun measurements at selected airmasses are between 7 to 2, and every 15 minutes when the airmass is below 2. Almucantar and principal plane sky radiance measurements are performed each hour. This schedule was enhanced by the implementation of extra direct sun measurements at airmasses higher than 7, in order to carry out 24 h sun direct measurements during the midnight sun period [Holben (2001)]. Three direct sun measurements are performed at each time (triplet) in order to reject cloud contamination. The data have been cloud-screened following the AERONET Standard Algorithm [Smimov (2000)].

2.2 The tropospheric Lidar

The newly setup tropospheric Lidar at ALOMAR, in operation since July 2005, is an aerosol backscatter lidar that provides elastic and inelastic atmospheric returns in the ultraviolet, visible and near infrared.

Since daytime capabilities are particularly relevant in the summer Arctic, the interference filters of the receiving optics are chosen rather narrow (0.2 nm). Crucial for the daylight capability is also the powerful laser (1020 mJ at 30 Hz repetition rate), which has been used before for a mesosphere system. Part of the original 1064 nm light is transformed into its second (532 nm) and third harmonics (355 nm). The light at the latter two wavelengths is linearly polarized. A refractive beam-widening telescope expands the outgoing beam to about 5 cm and reduces the beam divergence to less than 140 µrad. The telescope is a Newtonian type with a parabolic primary mirror (focal length 125 cm). The effective focal length of the lidar is reduced in the focal box to about 60 cm. Also in the focal box the spectral selection (<450 nm , 450-600 nm, >600 nm) and the selection of the parallel- (p) and cross-polarized components (s) at 532 nm are performed. The two wavelength bands <400 and >600 nm are guided via optical fibers to a spectral analyzer separating elastic and different inelastic channels. These spectrally (and by polarization) separated channels are then additionally filtered using narrow band interference filters, what minimizes crosstalk and background noise. Behind the filters the beam is focussed on photomultiplier tubes or an APD, and finally the electronic output is analyzed by a combination of one transient recorder and one photon counting device for each channel. At the moment only five detection channels are used (355o, 532p, 532s, 1064o and 387o), but the data acquisition electronics shall be extended to detect simultaneously three additional Raman channels (two H_2O Raman at 408 and 660 nm and one extra N_2 Raman at 608 nm).

During the reported period, the only Raman signal available was too weak to provide valuable extinction profile throughout the troposphere. Moreover, the altitude of full overlap was most of the time around 1400 m asl. Therefore the lidar data are presented here only to characterize the aerosol distribution [Frioud (2006)].

3. RESULTS

Figures 1 and 2 show the temporal evolution of spectral AOD for 550 nm and 1020 nm and the derived Ansgtröm exponents for the range of wavelengths 440/870 nm as suggested by the AERONET protocols, during the campaigns in summertime 2005 and 2006 respectively. We will analyze specific cases from each campaign.

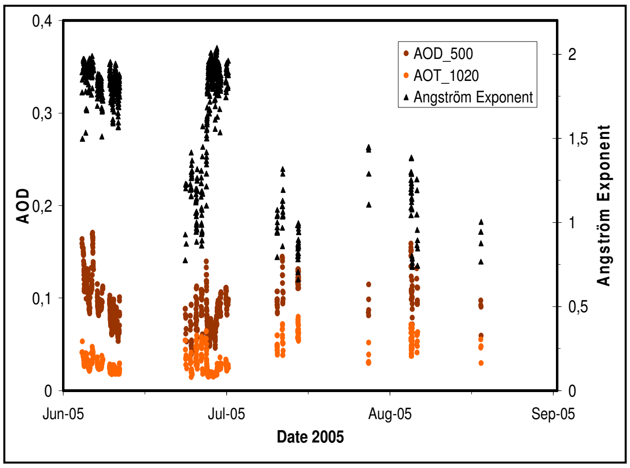

Figure 1. Series of Aerosol Optical Depth measured at two wave-lengths (500 nm and 1020 nm, left scale) and Ångström exponent (right scale) measured with CIMEL sun photometer at ALOMAR during summertime 2005.

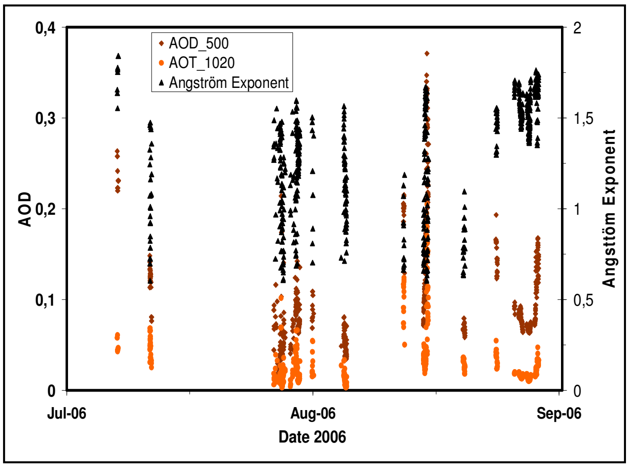

Figure 2. Same as Fig. 1 for summertime 2006.

3.1 *Observations from July 1 to 3, 2005*

The statistical results for aerosol optical depth and Ångström exponent for the first days of July 2005 give an average AOD of 0.048 with standard deviation (STD) of 0.008 at 500 nm and an average AOD of 0.013 (STD 0.003) at 1020 nm. The Ångström exponent is 1.86 (STD 0.09)(Fig. 3). During the end of June and beginning of July 2005, a stable high pressure system was centered between northern Scandinavia and the Svalbard archipelago, remaining almost for one week. A warm and dry air mass arrived at our site from the south east, with temperatures around 18-20ºC at noon. This is consistent with the mostly cloudless lidar observations (Figures 4-5, top panels) and the rather poor and stable aerosol stratification (bottom panels) observed above 1400 m asl (full-overlap lower altitude). According to the HYSPLIT back-trajectories (Fig. 6) air masses arriving above ALOMAR on July 2 have had a long residence time over sea. Moreover the lowest back-trajectory is fully confined to the Arctic. This is quite consistent with the low observed AOD values, while the very high values of Ångström exponent are rather surprising for such maritime back-trajectories.

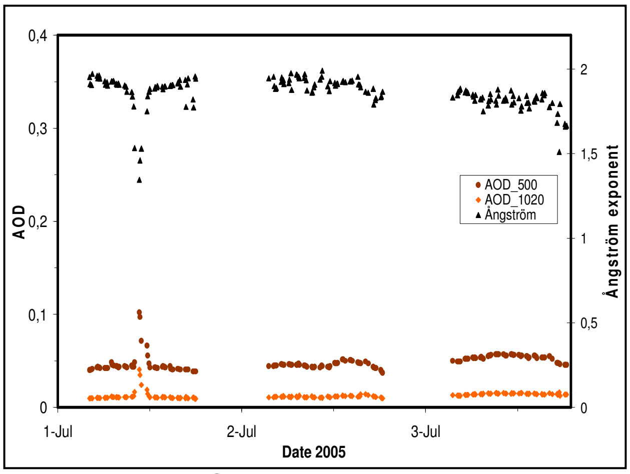

Figure 3. Aerosol Optical Depth measured at two wave-lengths (500 nm and 1020 nm) and Ångström exponent measured by CIMEL sun photometer at ALOMAR from July 1 to 3, 2005.

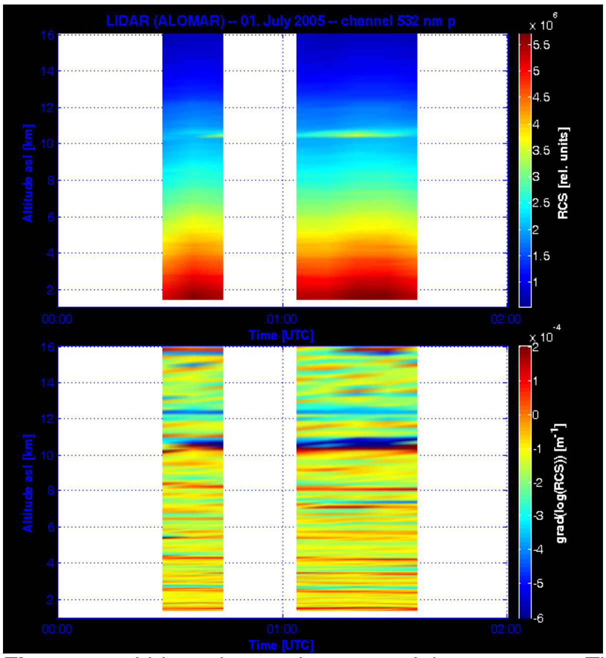

Figure 4. Lidar observations on July 1, 2005. The temporal resolution is 8 minutes. The top panel shows the time-series of range-corrected signals (RCS) for the 532 nm (p) channel. The bottom panel show the corresponding altitude log-derivative. In both panels, saturated colours are used

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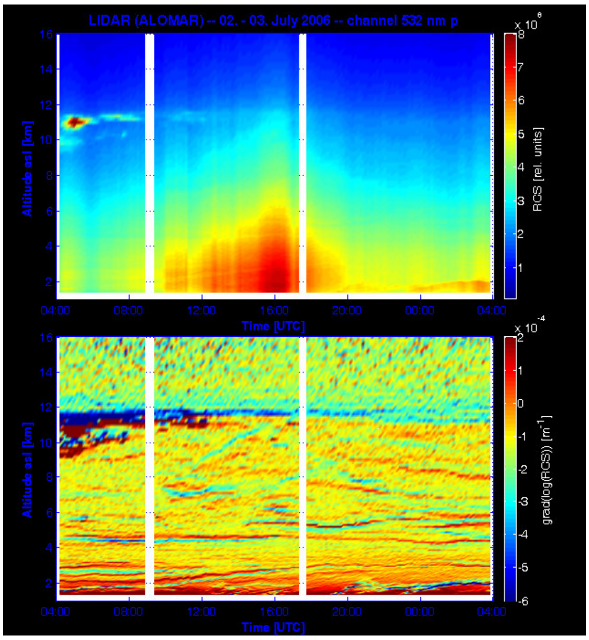

Figure 5. Diurnal cycles of Lidar observations from July 2 to 3, 2005. The conditions are the same as in Fig. 1.

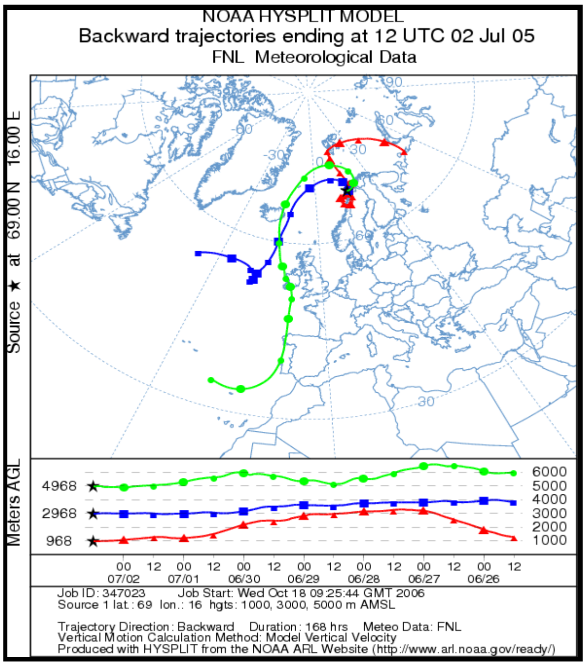

Figure 6. 7-days back-trajectories ending above ALOMAR on July 2, 2005 at 12h UTC.

3.2 *Observations on August 11 ,2005*

The AOD is higher than in the last period, with average value at 500 nm of 0.12 (STD 0.02) and 0.062 (STD 0.014) at 1020 nm. The average Angström exponent is 1.26 (STD 0.18) (Fig. 7). Unlike the case shown previously, the lidar observations (Fig. 8) show the presence of a strongly marked transition from aerosol rich to aerosol poor air parcels with increasing altitude (deep blue area in the bottom panel), what is consistent with higher AOD values. The back-trajectories (Fig. 9) present about five days residence time exclusively over land, what is consistent with higher AOD.

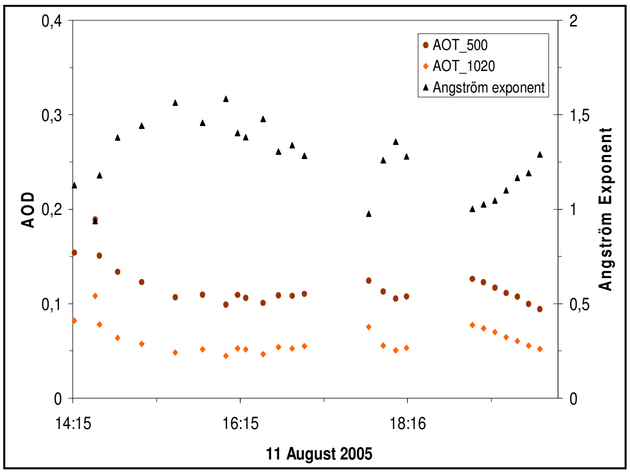

Figure 7. Aerosol Optical Depth measured at two wave-lengths (500 nm and 1020 nm) and Ångström exponent measured by CIMEL sun photometer at ALOMAR on August 11, 2005.

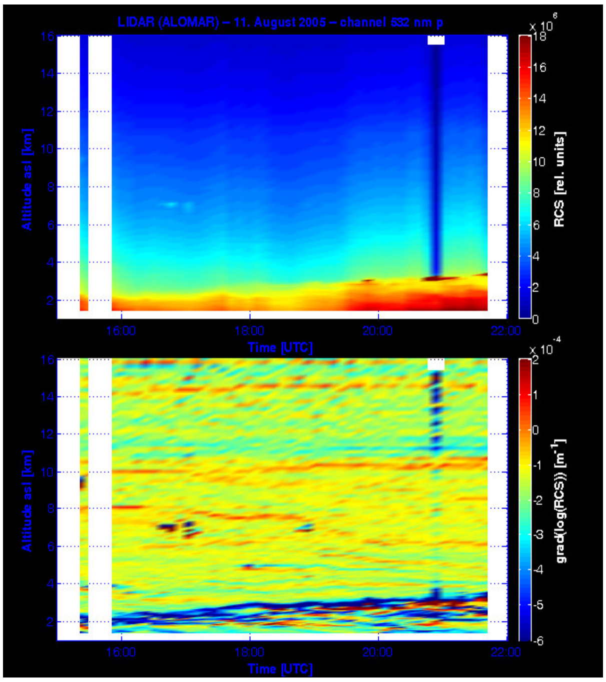

Figure 8. Lidar observations on August 11, 2005. The conditions are the same as in Fig. 1.

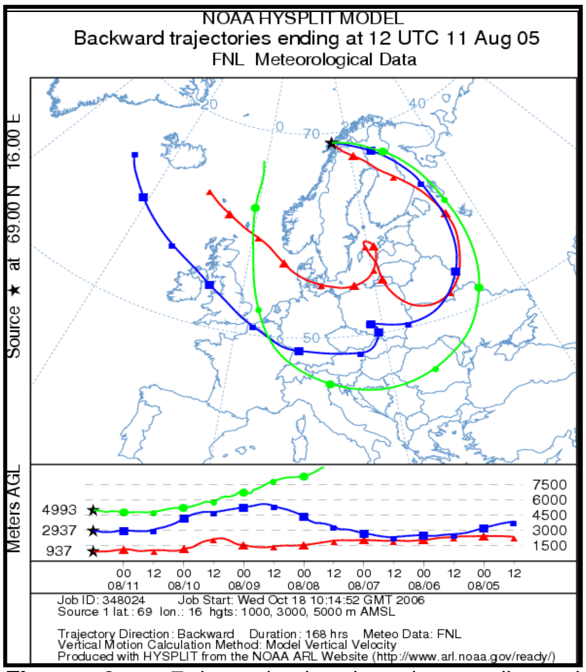

Figure 9. 7-days back-trajectories ending above ALOMAR on August 11, 2005 at 12h UTC.

3.3 *Observations on July 30, 2006*

As shown in Fig. 10, the average AOD at 500 nm is 0.081 (STD 0.041), the Ångström exponent is 1.13 (STD 0.28). The corresponding back-trajectories are shown in Figure 12. The air mass arrive from the southwest, thus we expect to have maritime aerosols with continental influence. The back-trajectory ending around 3000 m is pointing to the low troposphere of the very industrialized London area. This is consistent with the presence of a marked aerosol boundary around the same altitude (Fig. 11), as well as AOD values similar to the continental case on August 11, 2005.

3.4 Observations from August 27 to 29, 2006

The Cimel observations of aerosols at ALOMAR for these days have several similarities with the previously considered time series. The relatively small variation of AOD is consistent with the stable anticyclonic conditions prevailing in the region, while the AOD average values of 0.08 (STD 0.04) at 500 nm and of 0.02 (STD 0.03) at 1020 nm (Fig. 13) are quite typical for summertime at this location. The rather high values of the Ångström exponent are indicative of prevailing small particles. The 7-days back-trajectories (Fig. 15) are mostly confined over land, what is consistent with relatively high AOD and with the persistent presence of a marked aerosol layer transition between 2 and 3 km asl in the lidar time series (Fig. 14).

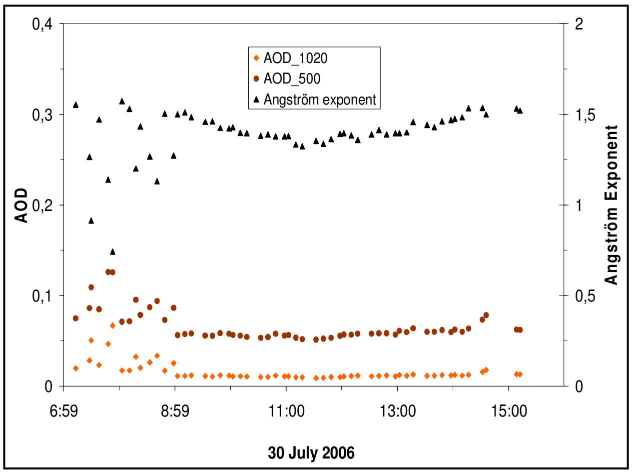

Figure 10. Aerosol Optical Depth measured at two wave-lengths (500 nm and 1020 nm) and Ångström exponent measured by CIMEL sun photometer at ALOMAR on July 30, 2006.

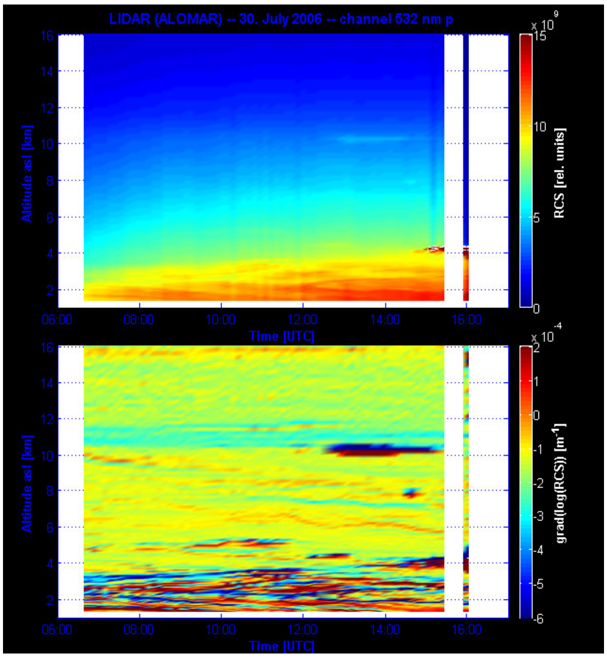

Figure 11. Time series of Lidar observations on July 30, 2006. The conditions are the same as in Fig. 1.

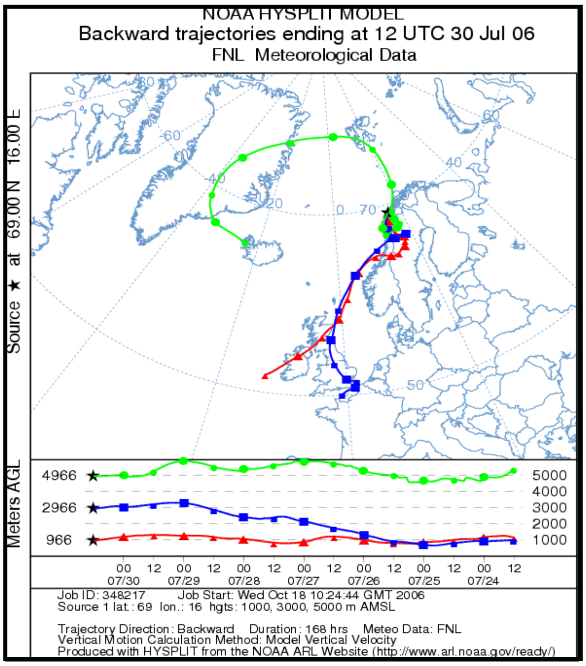

Figure 12. 7-days back-trajectories ending above ALOMAR on July 30, 2006 at 12h UTC.

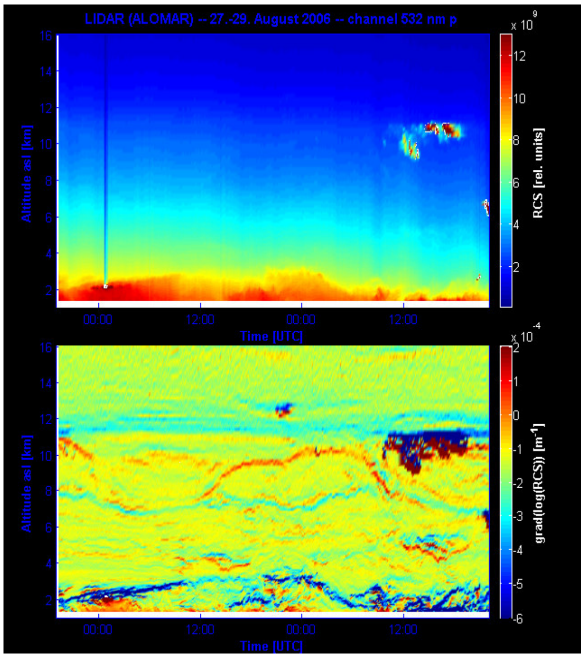

Figure 14. Diurnal cycles of Lidar observations from August 27 to 29, 2006. The conditions are the same as in Fig 1.

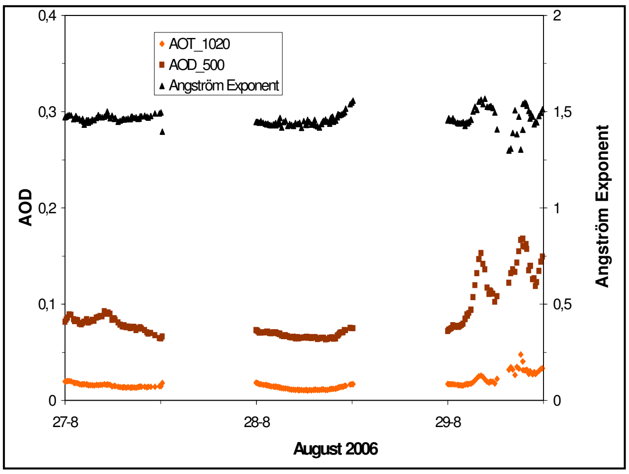

Figure 13. Aerosol Optical Depth measured at two wave-lengths (500 nm and 1020 nm) and Ångström exponent measured by CIMEL sun photometer at ALOMAR from August 27 to 28, 2006.

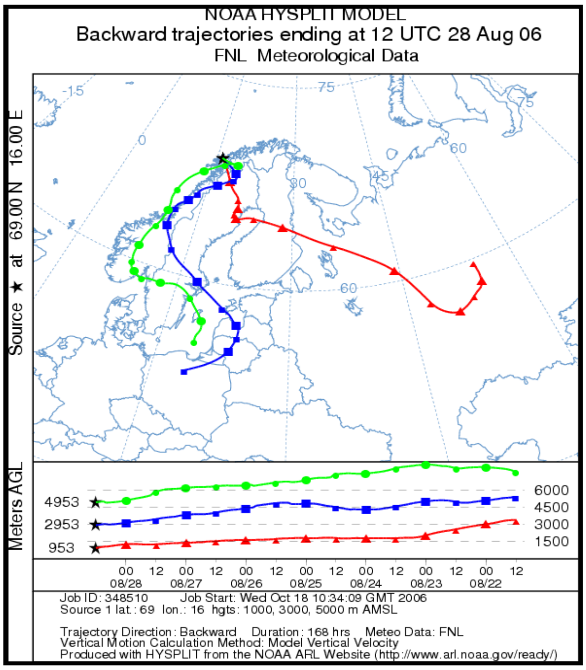

Figure 15. 7-days back-trajectories ending above ALOMAR on August 28, 2006 at 12h UTC.

4. CONCLUSIONS

As a continuation of the former campaigns of measurements at ALOMAR and the related study of the aerosols in the Arctic, the Group of Atmospheric Optics from Valladolid performed new measurement campaigns during the summers 2005 and 2006. In this paper we present case studies regarding the aerosol dynamics and characterization by the simultaneous and collocated measurements of a CIMEL sun photometer and a tropospheric backscatter lidar. The observed AOD variations are consistent with the Lidar observations and with the back-trajectories of air masses. The observed Ångström values are found to be quite typical for a remote continental location likely with low contribution of coarse maritime aerosols.

The interpretation of the high Ångström exponents even when air masses were expected to bring aerosols of maritime type is not clear yet. In situ analysis of particle size distribution and chemical analysis would be needed to help clarifying the likely origin of the predominant fine particles observed above ALOMAR. This issue shall be further investigated in upcoming campaigns.

As more data are available, the observed aerosol stratifications must also be further investigated, related both to the season and to the airmass origin. Since July 2006 a Cimel sun photometer operates at Alomar on a permanent basis. It may provide, together with the Lidar, a climatological approach to the aerosol properties in this Arctic region

5. ACKNOWLEDGMENTS

The ALOMAR ARI and eARI (Enhanced Access to Research Infrastructure) Projects, under the EU's 5th framework programme (RITA-CT-2003-506208), and CICYT (Acciones Especiales REN2001-5024-E; REN2002-12641-E/CLI) and REN 2002-00966/CLI provided the necessary funding and infrastructure for the campaigns. We thank the ALOMAR team for its help and dedication. We acknowledge the NOAA Air Resources Laboratory (ARL) for the provision of the HYSPLIT transport model and READY website, (http://www.arl.noaa.gov/ready.html) used in this publication. Supported by the Programme Alβan, the European Union Programme of High Level Scholarships for Latin America, scholarship No. E05D050718CO.

6. REFERENCES

Dubovik O. and King M., 2000: A flexible inversion algorithm for retrieval of aerosol optical properties from sun and sky radiance measurements. __*J. Geophys. Res.*, **105**(D16),20, 673–696.

Frioud, M., Gausa M., Stebel K., Hansen G., Myhre C., Singer W., Latteck R., De Frutos A., Cachorro V., Toledano C., Rodriguez E., 2006: Observation and characterization of aerosols above ALOMAR (69°N) by tropospheric Lidar, sun-photometer, and VHF radar, __*Proc. SPIE*, **6367**, 19–28, 2006.

Holben B., Eck T., Slutsker I., Tanré D., Buis J., Setzer A., Vermote E., Reagan J. and Kaufman Y., 1998: AERONET- a federated instrument network and data archive for aerosol characterization. __*Remote Sens. Environ.*, **66**,1–16.

Holben B., Tanre D., Smirnov A., Eck T., Slutsker I., Abuhassan N., Newcomb W., Schafer J., Chatenet B., Lavenue F., Kaufman Y., Vande Castle J., Setzer A., Markham B., Clark D., Frouin R., Halthore R., Karnieli A., O'Neill N., Pietras C., Pinker R., Voss K. and Zibordi G., 2001: An emerging ground-based aerosol climatology: Aerosol optical depth from AERONET. __J. Geophys. Res., 106, 12067–12097.

Landulfo E., Papayannis A., Artaxo P., Castanho A. D. A., de Freitas A. Z., Souza R. F., Vieira Junior N. D., Jorge M. P., Sánchez-Coyllo O. R. and Moreira D. S., 2003: Synergetic measurements of aerosols over São Paulo, Brazil using LIDAR, sunphotometer and satellite data during the dry season. __*Atm. Chem. Phys.*, **3**, 1523–1539.

Müller D., Mattis I., Wandinger U., Ansmann A., Althausen D., Dubovik O., Eckhardt S. and Stohl A. 2003: Saharan dust over a Central European EARLINET-AERONET site: Combined observations with Raman lidar and Sun photometer. __*J. Geophys. Res.,* **108** JD002918.

Ritter C., Kische A., Neuber, R., 2004: Tropospheric Aerosol characterized by a Raman Lidar over Spitsbergen, __*Reviewed and revised papers presented at the 22nd ILRC, 12-16 July 2004, Matera, Italy, ESA Publications Div.*, 459–462.

Smimov, A., Holben B. N., Eck T. F. and Dubovik O., 2000: Cloud-screening and quality control algorithms for the AERONET database. __*Remote Sens. Environ.*, **73**, 337–349.

Toledano, C., Cachorro V., Sorbías M., Vergaz R., Berjón A., De Frutos A., Antón M. and Gausa M., 2006: Aerosol optical depth at ALOMAR Observatory (Andøya, Norway) in summer 2002 and 2003. __*Tellus* **58**B, 218–228.

Veselovskii I., Whiteman D.N., Dubovik O., Kolgotin A. and Korenskii M., 2006: Comparison of aerosol microphysical properties retrieved from multi-wavelength lidar and sun photometer, *Reviewed and revised papers* *presented at the 23rd ILRC, 24-28 July 2006, Nara, Japan.*, 309–312.