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Cite as: AIP Conference Proceedings **1531**, 384 (2013); https://doi.org/10.1063/1.4804787
Published Online: 10 May 2013

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Columnar Aerosol Characterization Over Scandinavia and Svalbard

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Abstract. An overview of sun photometer measurements of aerosol properties in Scandinavia and Svalbard was provided by Toledano et al. (2012) thanks to the collaborative effort of various research groups from different countries that maintain a number of observation sites in the European Arctic and sub-Arctic regions. The spatial coverage of this kind of data has remarkably improved in the last years, thanks, among other things, to projects carried out within the framework of the International Polar Year 2007-08. The data from a set of operational sun photometer sites belonging either to national or international measurement networks (AERONET, GAW-PFR) were evaluated. The direct sun observations provided spectral aerosol optical depth (AOD) and Ångström exponent (AE), that are parameters with sufficient long-term records for a first characterization at all sites. At the AERONET sites, microphysical properties derived from inversion of sun-sky radiance data were also examined. AOD (500nm) ranged from 0.08 to 0.10 in Arctic and sub-Arctic sites whereas the aerosol load was higher in more populated areas in Southern Scandinavia (average AOD about 0.10–0.12 at 500 nm). On the Norwegian coast, aerosols showed larger mean size than in continental areas. Columnar particle size distributions and related parameters were used to evaluate aerosol volume efficiencies. The aerosol optical depth characterization revealed that the seasonal patterns in the high Arctic (with the typical hazy spring), in the sub-Arctic region and Southern Scandinavia are all different. The clean continental, polluted continental and maritime aerosols constitute the three main aerosol types, although persistent (Asian) dust was also detected in Svalbard.

Keywords: Aerosols, Arctic, AERONET, GAW, Scandinavia.
PACS: 93.30.Li, 92.60.H-, 42.68.Wt, 42.68.Jg

INTRODUCTION

An overview of sun photometer measurements of aerosol properties in Scandinavia and Svalbard was provided by Toledano et al. [1] thanks to the collaborative effort of various research groups from different countries that maintain a number of observation sites in the European Arctic and sub-Arctic regions. The data from a set of operational sun photometer sites belonging either to national or international measurement networks (AERONET, GAW-PFR) were evaluated, with the aim of evaluating the columnar aerosol properties, their spatial variability across Scandinavia and seasonality. The aerosol optical depth (AOD) and the Ångström exponent (AE) from direct sun observations are the only parameters with sufficient long-term records for a first characterization at all sites. At the AERONET sites, microphysical properties derived from inversion of sun-sky radiance data were also examined.

The spatial coverage of this kind of data has remarkably improved in the last years, thanks to projects carried out within the framework of the International Polar Year 2007-08, like POLAR-AOD, POLARCAT, etc. [2]. Thanks to this, it is now possible to evaluate the aerosol properties both in the Arctic and in those areas that are in the way of polluted air masses that are transported into the Arctic. Unfortunately there is a lack of absorption data (e.g. single scattering albedo data) from these ground-based sun photometer measurements, which in general are not available for AOD (440nm) less than 0.4 (after AERONET quality assurance criteria). Only in specific events it is possible to investigate the absorption properties and their transformations during transport, e.g. [3].

SITES AND INSTRUMENTATION

The list of utilized observation sites is given in Table 1. They were all analyzed, however only those with the longer datasets will be shown in the results section. Note that in some cases the sites were unfortunately discontinued. The amount of available data is shown by the number of measurements months (Table 1). Two of the

Radiation Processes in the Atmosphere and Ocean (IRS2012)
AIP Conf. Proc. 1531, 384-387 (2013); doi: 10.1063/1.4804787

sites, Ny-Ålesund and Norrköping_1995, have remarkably long datasets. Also note that most of the sites are part of the ground-based aerosol monitoring networks AERONET [4] and GAW [5].

TABLE (1). List of sun photometer sites in the European Arctic sector and Scandinavia. List of institutions: Andoya Rocket Range (ARR); Alfred Wegener Institute for Polar and Marine Research (AWI); European Space Agency (ESA); Finnish Institute of Marine Research (FIMR); Finnish Meteorological Institute (FMI); Goddard Space Flight Center (GSFC); Joint Research Centre (JRC); Norwegian Institute for Air Research (NILU); Polish Academy of Science (PAN); Swedish Meteorological and Hydrological Institute (SMHI); Swedish National Space Board (SNSB); Stockholm University (SU); University of Valladolid (UVa); World Radiation Center (WRC).

Site	Institution	Coordinates	Network	Instrument	Start	End	N.months
Hornsund	GSFC,PAN	77.0N, 15.6E	AERONET	Cimel	2004	-	38
Longyearbyen	GSFC	78.2N, 15.6E	AERONET	Cimel	2003	2004	10
Ny_Ålesund	AWI	78.9N, 11.9E	Polar-AOD	SP1A	1991	-	114
Ny_Ålesund	NILU,WRC	78.9N, 11.9E	GAW-PFR	PFR	2002	-	50
Andenes	UVa,NILU,ARR	69.3N, 16.0E	AERONET-RIMA	Cimel	2002	-	46
Kiruna	SMHI	67.8N, 20.4E	GAW-PFR	PFR	2007	-	34
Sodankylä	FMI	67.4N, 26.6E	GAW-PFR	PFR	2004	-	48
Birkenes	NILU, UVa	58.4N, 8.3E	AERONET-RIMA	Cimel	2009	-	14
Gotland	SMHI	57.9N, 19.0E	AERONET	Cimel	1999	2004	34
Gustav_Dalen_Tower	JRC	58.6N, 17.5E	AERONET	Cimel	2005	-	34
Helsinki	FMI	60.2N, 25.0E	AERONET	Cimel	2008	-	20
Helsinki_Lighthouse	JRC, FIMR	59.9N, 24.9E	AERONET	Cimel	2006	-	30
Hyytiälä	FMI	61.8N, 24.3E	AERONET	Cimel	2008	-	25
Jokioinen	FMI	60.8N, 23.5E	GAW-PFR	PFR	2004	-	42
Kuopio	FMI	62.9N, 27.6E	AERONET	Cimel	2008	-	25
Norrköping_1995	SMHI	58.6N, 16.2E	-	SPM2000	1995	-	166
Norrköping	SMHI,ESA,SNSB	58.6N, 16.2E	GAW-PFR	PFR	2007	-	46
Palgrunden	ESA, SU, SNSB	58.8N, 13.2E	AERONET	Cimel	2008	-	16
SMHI[a]	SMHI	58.6N, 16.2E	AERONET	Cimel	2001	2006	22
Visby	SMHI	57.7N, 18.4E	GAW-PFR	PFR	2007	-	48

The Sun photometers listed in Table 2 are instruments operating routinely in the sites above. They are extensively described elsewhere [4-7]. All of them perform direct sun observations, from which the optical thickness of the atmosphere is derived. The AERONET Cimel also performs sky radiance scans (almucantar and principal), which allow the retrieval of a set of optical and microphysical properties via inversion algorithms [8, 9].

TABLE (2). Summary of sun photometer characteristics.

Instrument	PFR	Cimel	SP1A	SPM2000
Spectral range	368-862 nm	340-1640 nm	350-1065 nm	368-778 nm
N. channels	4	9	17	3
Sun (sampling period)	1 min	5-15 min	1 min	1 min
Sky radiance	no	every 1h	no	no
Temp. stabilized	yes	no	no	yes
AOD uncertainty	0.01	0.01-0.02	0.01	0.01-0.02

RESULTS

Seasonal Characterization of Aerosol Optical Depth and Ångström Exponent

We evaluated multi-annual monthly means of aerosol optical depth (AOD) and Ångström exponent (AE) at the investigated sites (Table 1). However only the most representative sites (in terms of data amount and location) are shown in the following discussion. The first result of the analysis is the difference in the AOD seasonal patterns, which made us classify the sites in three groups: Svalbard, northern Scandinavia and middle-southern Scandinavia. These seasonal patterns can be observed in Figure 1.

The well-known Arctic haze season in spring followed by a very clean summer is observed at the Svalbard sites [2]. Over northern Scandinavia, about 67-70ºN (sub-Arctic), the seasonal pattern is conditioned by the site location and background aerosol, as shown by the different AE, which are lower for sites closer to the ocean and higher inside the continent. Therefore it is not as uniform as in Svalbard. The arrival of transported aerosols to this area is episodic and not persistent.

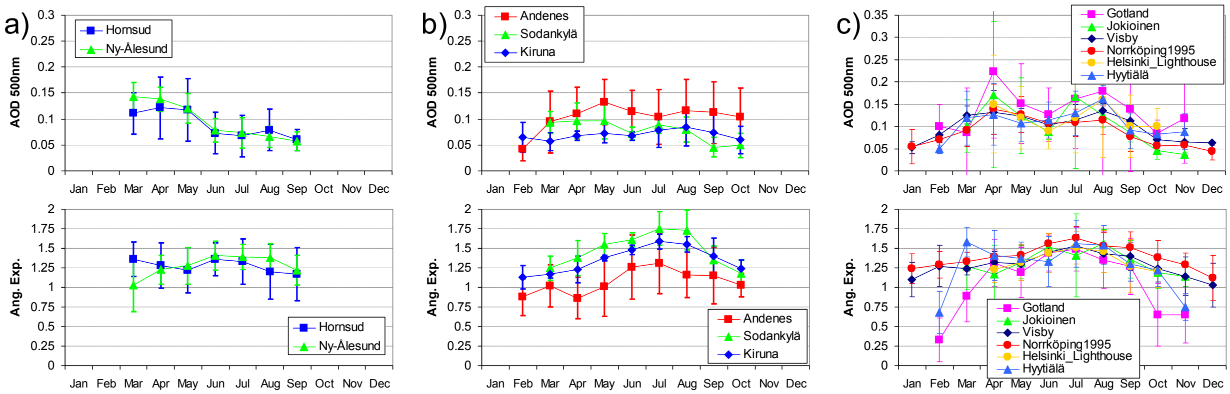

FIGURE 1. Multi-annual monthly means of aerosol optical depth (500 nm) (top panels) and Ångström exponent (bottom panels) at the sites located in (a) Svalbard; (b) northern Scandinavia; (c) southern Scandinavia. The operation period for each site is listed in Table 1. Error bars give standard deviation within the month.

As for the southern sites, the AOD exhibits higher values and the European and Eurasian air masses determine the seasonality of AOD and AE. Winters are clean, and there are two AOD peaks along the year, the first one in spring (likely due to agricultural fires and biomass burning in Eastern Europe), and the other one in summer. The AOD peaks are associated to high Ångström exponents, indicating fine particle predominance which is typical for both urban/industrial pollution and biomass burning.

The aerosol types are identified in the AE-AOD plot shown in Figure 2. The spring months at Ny-Ålesund exhibit AOD (500 nm) > 0.1 and AE between 0.8 and 1.5 (Arctic haze, [5]). In Norrköping, the presence of polluted aerosols is observed, with monthly mean AOD (500 nm) above 0.15 and high associated AE above 1.3, which corresponds to the AOD peak in spring and summer.

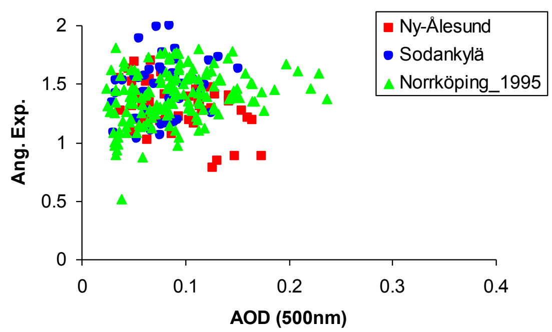

FIGURE 2. Scatter plot of the Ångström exponent versus the aerosol optical depth (500 nm) monthly means at Ny-Ålesund (Svalbard), Sondankylæ (Finland) and Norrköping (Sweden).

Aerosol Microphysical Properties

The strong retrieval restrictions (AERONET level 2.0) and the reduced sampling of the sky radiances, make the number of these data very small. These plots indicate clear fine mode predominance in the volume size distributions for almost all sites and months. The average fine mode fraction of the size distribution ranges from 0.50 at Gotland up to 0.73 at Ny-Alesund. At Hornsund (Svalbard), the fine mode concentration had a clear gradient, being higher in May and April and lower during summer. The southern site better data coverage is Gotland, where the fine mode has the highest mean concentrations. The coarse mode, likely due to sea salt, has stable concentration along the year.

Columnar particle size distributions and related parameters were also used to evaluate aerosol volume efficiencies, as can be seen in [1].

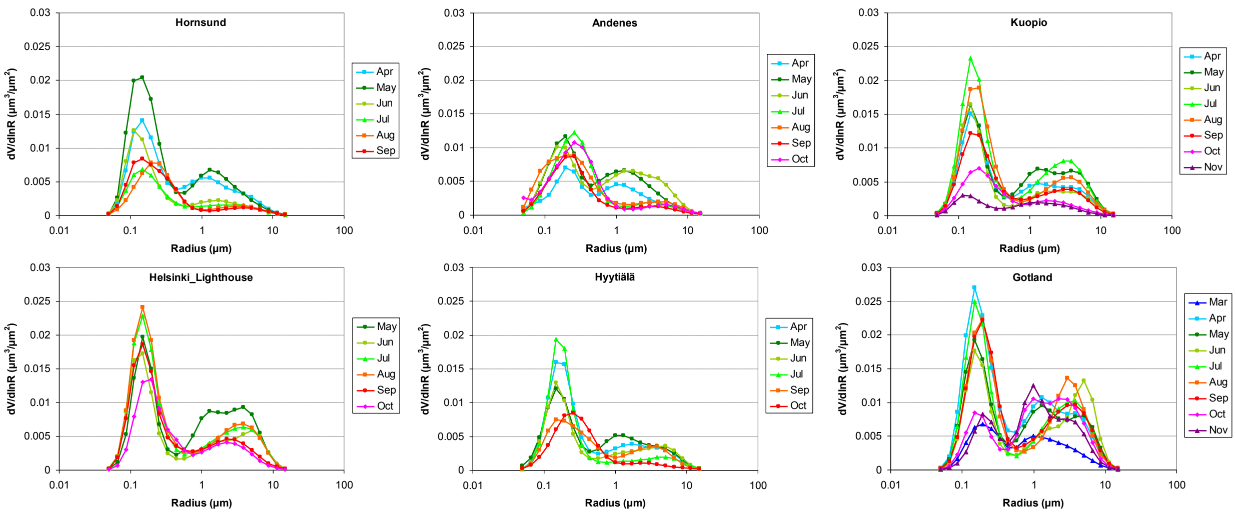

FIGURE 3. Multi-annual monthly means of aerosol particle size distribution at 6 representative sites in Svalbard and Scandinavia. Note that winter months are missing for most of the sites.

CONCLUSIONS

AOD (500nm) ranged from 0.08 to 0.10 in Arctic and sub-Arctic sites whereas the aerosol load was higher in more populated areas in Southern Scandinavia (average AOD about 0.10–0.12 at 500 nm). On the Norwegian coast, aerosols showed larger mean size than in continental areas.

The aerosol optical depth characterization revealed that the seasonal patterns in the high Arctic (with the typical hazy spring), in the sub-Arctic region and Southern Scandinavia are all different. The clean continental, polluted continental and maritime aerosols constitute the three main aerosol types, although persistent (Asian) dust was also detected in Svalbard.

ACKNOWLEDGMENTS

We gratefully acknowledge the provision of data and the collaboration in the analysis by all the groups and institutions involved in the study, especially to M. Gausa, K. Stebel, V. Aaltonen, S. Blindheim, C. L. Myhre, G. Zibordi, C. Wehrli, S. Kratzer, B. Håkansson, T. Carlund, G. de Leeuw and A. Herber. We thank the AERONET, PHOTONS, RIMA and WRC staff for their scientific and technical support. Financial support was provided by: the Spanish CICYT (CGL2008-05939-CO3-01/CLI, CGL2009-09740 and CGL2011-13085-E); the Norwegian Research Council for POLARCAT-Norway; and the Swedish National Space Board and ESA for Norrköping and Palgrunden sites. The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement Nr. 262254 [ACTRIS].

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