OBSERVATION AND MODELING THE VERTICAL VARIABILITY OF THE SINGLE SCATTERING PROPERTIES DURING ARCTIC HAZE

J. Lisok[1], M. Chilinski[1], K.M. Markowicz[1], P. Makuch[2], T. Petelski[2], C. Ritter[3], T. Zielinski[2]

[1]Institute of Geophysics, University of Warsaw, Warszawa, Poland

[2]Institute of Oceanology, Polish Academy of Sciences, Sopot, Poland
[3]The Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research, Potsdam, Germany

Abstract
The aim of this research was to estimate vertical variability of aerosol single scattering properties measured in high latitudes during the episodes of strong Arctic Haze. Hence, a field campaign was carried out between 15.03-29.04.2014 in Longyearbyen and NyAlesund in Spitsbergen, Svalbard. During the campaign the data from ground-based remote sensing and in-situ measurements were collected. In addition, numerical simulations of vertical profiles of aerosol optical properties obtained from Navy Aerosol Analysis and Prediction System (NAAPS) was calculated. Subsequently all of data were compared to determine the compatibility of the measurements.

1. INTRODUCTION[1]

Regarding climatological conditions of aerosol optical properties, Arctic is believed to be one of the cleanest environments on Earth (Graversen et al., 2008) with an average aerosol optical depth equals to 0.045 and annual variability reaching 0.015 at 500nm referring to NAAPS calculations. The vertical profiles of extinction coefficient of aerosol components are mostly consisted of sea salt, sulphate and dust which occurs at 0, 1, and 7km levels respectively (Samset et al.,2013). However, the most important component for the study is soot, which appears in a whole troposphere (Sharma et al., 2013; Samset et al.,2013). Hence, soot is believed to be one of the main elements of Arctic haze (IPCC, 2013).

[1] *Corresponding author address*: Justyna Lisok, Institute of Geophysics, Faculty of Physics, University of Warsaw, Pasteura 7, 02093 Warsaw, Poland, e-mail: jlisok@igf.fuw.edu.pl

Arctic haze is a phenomenon of enhanced pollution conditions which occur in Arctic every year during spring season (Shaw, 1995; IPCC, 2013). It is believed that polluted air masses appear due to long-range transport from anthropogenic sources, which are situated in the middle latitudes (Graversen et al., 2008). The phenomenon has a significant impact on the seasonal and temporal climate properties in Arctic, interacting with radiative shortwave and longwave fluxes (Ramanathan and Carmichael, 2008; Bond et al., 2013). Hence, the very region was proven to have one of the highest radiative forcing levels (Ramanathan and Carmichael, 2008). Moreover, the uncertainties in the exact relations exist due to insufficient knowledge level on the vertical stratification of aerosols with strong regards to absorbing ones (Sharma et al., 2013). It's believed, that levels of black carbon lying over 5 km are the most significant, where up to 75 per cent of total radiative forcing was measured (Samset et al., 2013). In addition, a strong necessity for further studies and observation network are essential for understanding climate responses to air pollution (Samset et al., 2013; Zarzycki and Bond, 2010). The following studies has been carried out under Polish-Norwegian Research Programme entitled 'Impact of absorbing aerosols on radiative forcing in the European Arctic' in order to enhance knowledge on vertical stratification of aerosols which have a significant role in climate change.

2. METHODOLOGY

In order to contribute a new knowledge on aerosols properties in Arctic the field campaign was carried out during spring season (16.03-29.04.2014) in Spitsbergen, which is one of

islands situated in a range of Svalbard Archipelago. Figure 1 represents three field sites NyAlesund (78°55′N, 11°56′E), Longyearbyen (78°13′N, 15°33′E) and Hornsund (77°00′N, 15°33′E), where measurements were provided. NyAlesund represented a reference station relatively free of local emission sources, hence most of equipment was placed there (tab. 1). Remote sensing data were collected by two Ceilometers: CHM15k (ÿ: 1064 nm) pointed into the sky over an angle of 30 degrees and CL-51 (ÿ: 910 nm) pointed vertically. In addition, data from Lidar KARL (ÿ: 355, 532,1064 nm) were gathered. Hence, complementary data from ceilometers and lidar were supposed to give an answer of atmospheric conditions both in low and middle troposphere.

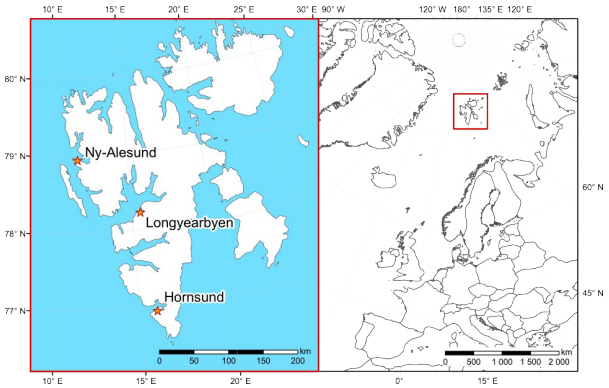

Fig. 1. Research areas, where measurements were provided during spring field campaign carried out under iAREA grant (3-4.2014). In the right cartoon red rectangle shows a placement of Svalbard on the map of Europe. Left panel represents three research sites.

Tab. 1. Equipment measuring optical properties of the atmosphere in research areas during field campaign in Spitsbergen.

NyAlesund	Longyearbyen
Aethalometer (AE-31)	Aethalometer (AE-31)
Nephelometer (TSI 3563)	Nephelometer (Aurora 4000)
Photoacoustic Extinctiometer (PAX) α 532, 870 nm	Photoacoustic Extinctiometer (PAX) α 532 nm
Sun Photometers Microtops II	Sun Photometers Microtops II
Particle Measurement Systems (CSASP-100HV)	
Laser Aerosol Spectrometer (3340)	
Lidar (KARL)	
Ceilometer (CHM15k, CL-51)	
Micro-Aethalometer (AE51)	

Together with remote sensing the in-situ measurements were provided. Scattering and absorbing properties of the atmosphere were collected by means of Aethalometer (AE-31) in both stations – NyAlesund and Longyearbyen. The instrument operates in seven wavelengths ÿ: 370, 470, 520, 590, 660, 880 and 950 nm. Scattering properties were provided by

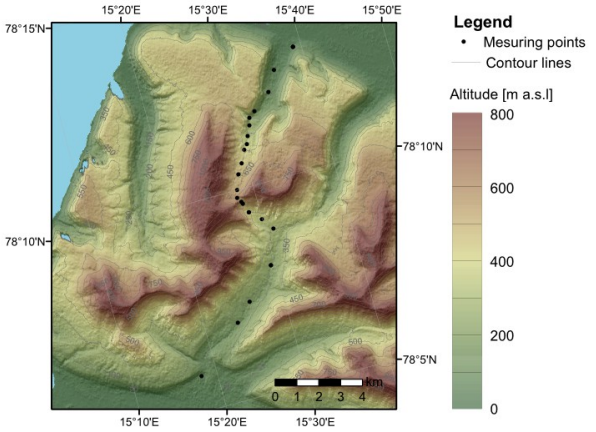

Fig. 2. Measurements of aerosol optical properties with sun photometer Microtops II along route through two valleys. Black circles represents an example of measurements points from 06.04.2014.

Nephelometer (TSI 3563) at ÿ: 450, 550, 700 nm and Polar Nephelometer (Aurora 4000) at ÿ: 450, 525, 635 nm. Integrated measurements of both absorption and scattering properties were determined by two Photoacoustic Extinctiometers in NyAlesund operating at ÿ: 532, 870 nm respectively and one (532 nm) in Longyearbyen. The size and particle type were additionally provided in NyAlesund by Particle Measurement Systems (CSASP-100HV) and Laser Aerosol Spectrometer (3340). Hornsund is a polish polar station in a south-western part of Spitsbergen included in Aerosol Robotic Network (AERONET). We used data from CIMEL 8N-EDPS9 in order to compare our results with other measurements on Svalbard.

Apart from continuous measurements also periodic ones were carried out during clear sky conditions, where aerosol optical properties were

sampled by means of Sun Photometers Microtops II. Collected data might be divided into two groups: stationary discrete measurements, which were provided next to the station building – as well as vertical profiles ranging from 0m a.s.l. to 660m a.s.l. They were taken during snow mobile trips along route via two different valleys located in SW-NE direction with a saddle in the middle (fig. 2.).
Furthermore, several methods were used due to data processing. Extinction profiles were retrieved from Ceilometer (CL-51) by means of Klett-Fernald Sasano method (Klett, 1981). with a 30 min time averaging. We have calculated extinction coefficients from in-situ measurements obtained from parallel Aethalometers and Nephelometers measurements. Data were removed from errors which occurred during clean air conditions and smoothed by means of consecutive average. In addition, extinction was retrieved from Microtops II aerosol optical depth profiles. The final aerosol optical depth data from Microtops II were obtained from 5 measurements per point by averaging them. A standard time resolution for this series of data is 15 min.

3. RESULTS

In this section we provide a short review of in-situ single scattering properties collected during spring field campaign '14 in a reference station – NyAlesund, Spitsbergen. Fig. 3 and 4 represent black carbon concentration (ng/m^3) derived from Aethalometer AE-31, scattering coefficient (Mm^{-1}) and Angstrom exponent both measured by Nephelometer TSI as well as meteorological conditions from Alfred Wegener Institute's station in NyAlesund. Additionally extinction coefficient was recalculated from the mentioned measurements (km^{-1}).

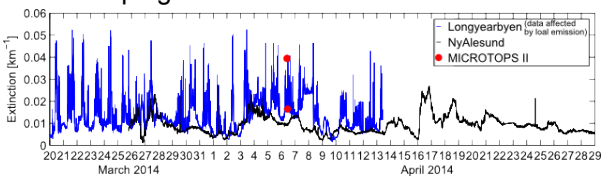

Fig. 3. Extinction coefficient retrieved from measurements during field campaign - Spitsbergen 2014. Blue line represents Longyearbyen, which is highly affected by a local emission, black line refers to NyAlesund measurements, red dots symbolises retrieved extinction from vertical profiles of aerosol optical depth by means of Microtops II.

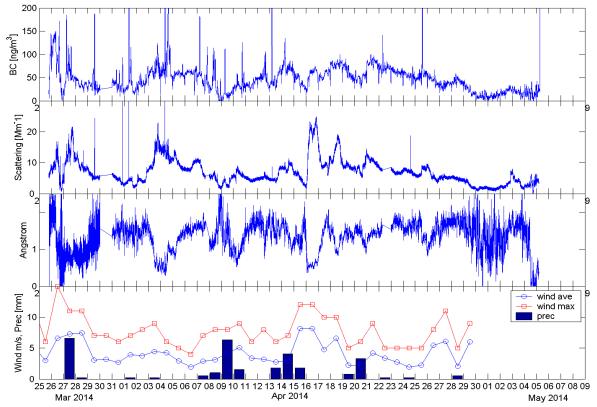

Fig. 4. Aerosol optical properties as well as meteorological data in NyAlesund during the field campaign.

Data can be divided into a few periods regarding the extinction fluctuations (fig. 3.). The first one occurred on 26-27th of March, where the aerosol extinction coefficient was changing from 0.01 to 0.015 km^{-1} at the beginning of 26th. After that, it decreased within two hours to the values near 0. During 27th extinction came back to the level of 0.02 km^{-1}. At the beginning of the period the black carbon concentration (fig. 4) was relatively high (150 ng/m^3) but gradually decreased to values near 0 till the night hours of the next day. Later, the coefficient reached values between 50 and 70 ng/m^3 with a few extremal peaks. In addition, the shape of scattering curve (fig. 4) seems to be similar to the black carbon concentration curve. Firstly, scattering was equal to 0.015 km^{-1}, then decreased to 0 and during 27th it rose to 0.01 – 0.02 km^{-1}. In the period, Angstrom exponent was changing from 2 to 1 level with a high standard deviation. In the first day a wind speed was rising from 4 m/s to 6m/s being the reason of lowering the level of all coefficients. On the 27th the wind speed stabilized while the snowfall occurred (5mm).
The next period can be found between 28th of March and 2th of April where extinction coefficient decreased below 0.01 km^{-1} level. In the time both: black carbon and scattering coefficients were equal to 30 ng/m^3 and 0.008 km^{-1} respectively so operated below the noise ratio. On the 30th some

problems with equipment occurred, consequently there are no measurements at that time. The average amount of Angstrom exponent was equal to 1.4 however the value of standard deviation was high.

Next period occurred during 3th till 7th of April where extinction value was relatively high (0.01-0.02 km^{-1}) and some days with possible Arctic haze appeared (fig. 3). What is more, black carbon concentration persisted on a level of 50 ng/m^3 while scattering values were the highest in the first 3 days (0.015 km^{-1}) then dropped to 0.01 km^{-1} (fig. 4). Firstly, large particles predominated (Angstrom ~ 0.5) as a result of local sea salt emission. Later, the Angstrom exponent increased, so more smaller particles appeared most likely after a few days of dry weather.

During 8th and 13th of April the extinction coefficient persisted on a low level (average 0.07 km^{-1}) (fig. 3) while black carbon concentration gradually rose from values near 0 to 60 ng/m^3 with an peak equals to 90 ng/m^3 (12.04) (fig. 4). Scattering coefficient was evenly low (0.06 km^{-1}) with a little decrease at the beginning of the period. Firstly, small particles in superiority were observed (8-9th), between 9th and 10th larger aerosols appeared. During 11-13th the Angstrom exponent went back to relatively high values (1.5). In the first few days the precipitation occurred which washed out the atmosphere, later a light wind (4 m/s) possibly lead to advection of smaller particles (fig. 4).

On 14th extinction coefficient slightly rose (0.01 km^{-1}) regarding level occurring in the earlier period. On 15th dropped down to the values near 0. Both black carbon concentration and scattering followed the trend of extinction – beginning with 60 ng/m^3 and 0.009 km^{-1}, ending with 25 ng/m^3 and 0.002 km^{-1} respectively. The average value of Angstrom exponent was equal to 1.3 with a high standard deviation reaching from 1 to 1.6. The observed wash out was caused by the occurrence of the precipitation (4 and 3 mm) in the two days.

The period between 16th and 18th was characterised by a relatively high extinction coefficient reaching 0.015-0.02 km^{-1}. Black carbon concentration persisted between 60-70 ng/m3 while the scattering value reached the highest observed level (0.022 km^{-1}) during the field campaign. Then, the scattering coefficient reduced to 0.009 km^{-1} and went back to 0.018 km^{-1} on the other day.

The last period between 19th and 29th of April represents the time of calm and stable conditions regarding the extinction coefficient fluctuations. Its average value was equal to 0.01 km^{-1} with small rise during 21th and 25th. Black carbon concentration gradually dropped from 60 to 20 ng/m^3. The same trend occurred for scattering coefficient, which was equal to 0.009 km^{-1} at the beginning, then decreased to the level of 0.005 km^{-1} at the end of the period. The particles suspended in the air were rather small with a few exceptions, where a precipitation occurred (20th , 25th as well as 26th) in a reference to the Angstrom exponent (1.4).

4. CASE STUDY

During the field campaign a few events of aerosol advection were observed, which might be considered as Arctic haze conditions. In addition to the general description of the optical properties presented in section 3, some examples of the possible aerosol transport will be included in the following section.

The widest variety of data were sampled during the event, which occurred on 6.04.2014. The in-situ and remote sensing data (fig. 6) were gathered. Moreover, we have done additional measurements by collecting the vertical profiles of aerosol optical depth by means of Microtops II (fig. 5). According to the fig. 5a the profile can be split between two valleys with different properties. Between 9 UTC and 10:30 UTC we were moving along the Longyearbyen town and then up to the mountain saddle via glacier. Generally speaking, the higher we drove, the smaller aerosol optical depth as well as bigger aerosols were measured. The data collected from 0 to 300m a.s.l. had a high value of aerosol optical depth (0.09-0.105) and relatively higher Angstrom exponent (0.8-1) due to presence of the town in a close distance where a local production of smaller particles was occurring.

The only exception from the rule mentioned earlier might be seen between 450 and 500m a.s.l., where a higher aerosol optical depth was measured (0.097-0.099). The phenomenon can be

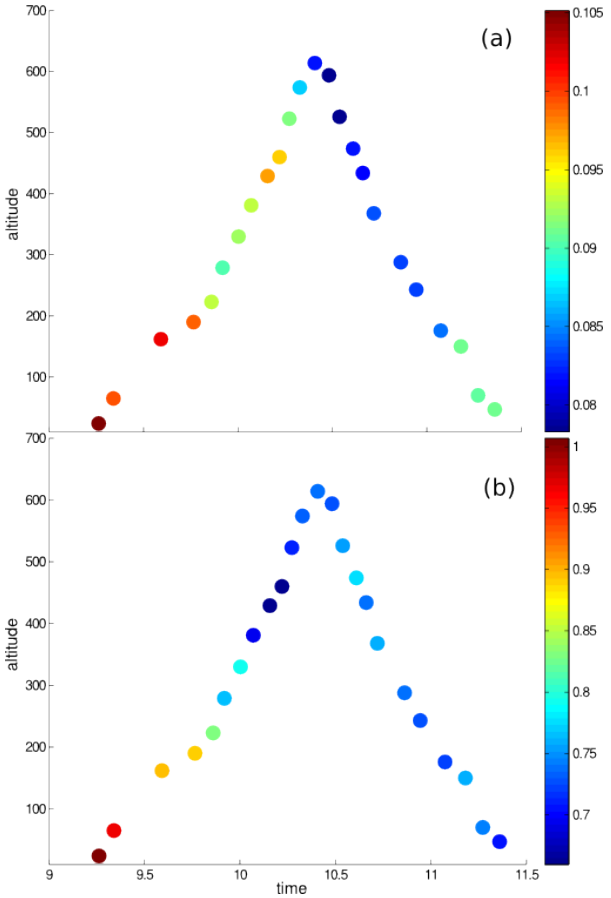

Fig. 5. Vertical profiles of the aerosol optical depth (a) and Angstrom exponent (b) measured by means of two MICROTOPS II instruments during 6.04.2014.

explained by the occurrence of blizzard next to the glacier surface. The presence of the phenomenon can be confirmed by a low amount of Angstrom exponent (0.6). After crossing the saddle a gradual increase of aerosol optical depth was measured (from 0.08 to 0.092) with a small variability of Angstrom exponent (0.7-0.8) which can be connected with a wind directed up to the valley from the ocean area.

In the same time the vertical profiles of extinction coefficient were sampled from ceilometer (fig. 6). The highest value of extinction occurred at the 0 m.a.s.l. (0.03km^{-1}). It was decreasing to the level of 600m.a.s.l. Then, a thin layer of enhanced extinction properties was measured at the 650 m a.s.l., which can be connected with aerosol transport - hence, with possible Arctic haze event. Moreover, some further study must be done before creating wider conclusions.

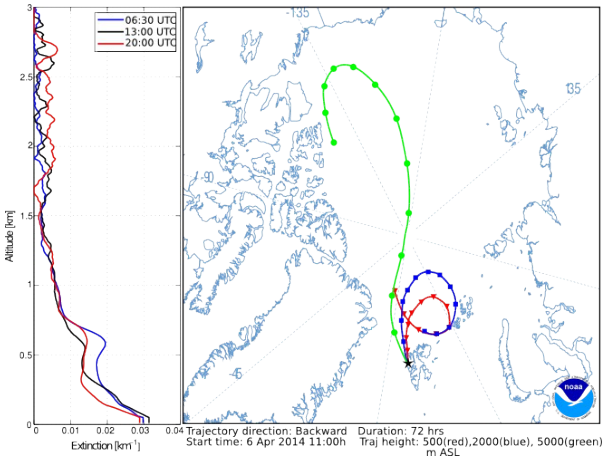

Fig. 6. Vertical profile of extinction coefficient [910nm] from Ceilometer(CL-51) and back trajectories from HYSPLIT model on 6.04.2014.

Above the mentioned altitude the coefficient was decreasing and changing into instrument noise after the 1.5km. Regarding the HYSPLIT back trajectories (fig. 6) the air masses, which occurred in Spitsbergen on 6.04.2014, came from the ocean area situated 100-200 km north from the field of study.

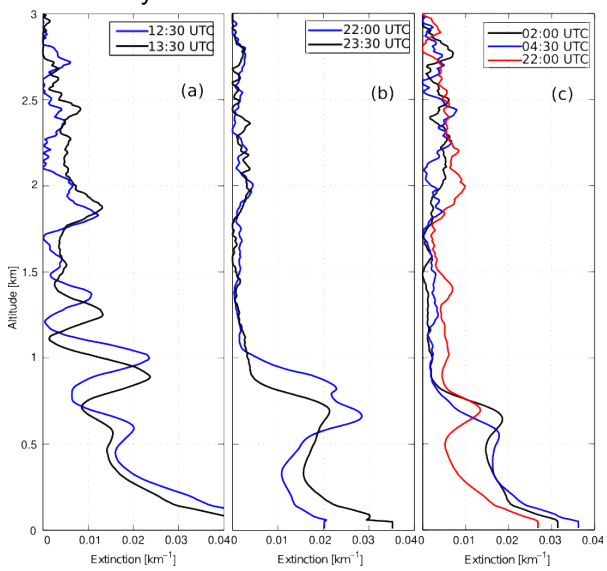

Fig. 7. Vertical profiles of extinction coefficient [910nm] from Ceilometer(CL-51) from 7.04.2014 (a), 11.04.2014 (b) and 12.04.2014 (c).

In the figure 7 some additional vertical profiles are shown from a few further possible aerosol events taken in 7.04.2014, 11.04.2014 as well as 12.04.2014. As we can see, ceilometer measurements showed layers with increased extinction values between 0.5 and 1 km. They are

believed to be connected with a sea salt transport due to the altitude of appearance.

5. CONCLUSION

During iAREA field campaign, which was carried out between 15.03-29.04.2014 in NyAlesund and Longyearbyen (Spitsbergen), a typical strong spring advection of Arcitc Haze was not observed. However, some small events of enhanced aerosol optical depth values were measured. The remote sensing as well as mobile measurements were collected Regarding ceilometer data, thin layers of mentioned aerosol occurred usually at 0,5km and 1km. They are believed to have been mostly consisted of sea salt. The reason for such a small amount of Arctic Haze advection during 2013/2014 season might be strongly connected with weather anomalies: enhanced snow conditions during previous summer as well as higher mean temperature during winter. There is a strong need for further processing of collected data to create wide conclusions.

6. ACKNOWLEDGMENTS

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