Airborne observations of Arctic tropospheric aerosols (ASTAR 2000) for validation of satellite and ground-based remote sensing

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1. Introduction

The polar regions are receiving increased attention in climate change scenarios obtained from climate models. Recently, large variations in many climate parameters have been found in the "Changing Arctic" (Morison et al., 1998). Warming of the air temperature near the surface is clearly observed, especially over the continent (Chapman and Walsh, 1993; Walsh and Chapman, 1998; Serreze, 2000), and thinning of sea ice in the 1990s is reported for a wide area of the Arctic Ocean (Rothrock et al., 1999).

Aerosols, together with clouds, are believed to have a strong impact on climate through the radiative effect with a large spatial variability; however, their 3-D distribution and interactions are still uncertain, especially in the polar regions. In the Arctic, concentrations of normal background aerosols are very low and optical thickness in the 500 nm is in the range 0.03 to 0.05 (Herber, 1996). However, strong seasonal variations in aerosol optical depth are known and the large spring increase is due to high concentrated layered aerosols called "Arctic Haze" (Shaw, 1995; Herber, 1996; Heintzenberg, 1989). This large spring maximum of aerosol loading is originated from anthropogenic sources surrounding the Arctic, and trapped a long time in the strong inversion layer over the Arctic Ocean without any effective removal process (Shaw, 1995). Though this is only a seasonal phenomenon, its radiative effect is not negligible, because solar radiation becomes effective just in this season after the long polar night and a large influence might be expected related to the melting and decay of sea ice. Many observational studies have been devoted to the Arctic Haze (Bodhaine and Dutton, 1993; Jaeschke et al., 1999); however, not so much has been done concerning the radiative effect yet.

A new cooperative project on aerosols in the Arctic, ASTAR 2000 (Arctic Study of Tropospheric Aerosol and Radiation) was conducted for March and April 2000 in and around Svalbard to investigate the 3-D behavior and radiative effects of tropospheric aerosols in the Arctic and their impact on climate. Airborne observations using a Dornier 228 aircraft and coordinated remote sensing, in-situ measurements and sampling of aerosols were done at the international research site, Ny-Ålesund, Svalbard (Fig. 1). At this site, scientists from several countries including German and Japanese scientists have already conducted ground based atmospheric science observations for about 10 years (Gernandt et al., 2000; Yamanouchi et al. 1996). Satellite measurements of SAGE-II (Stratospheric Aerosol and Gas Experiment) were also included as part of the ASTAR 2000 campaign. Finally, data will be used as input for regional climate model studies (HIRHAM) to estimate radiative forcing and discuss the climatic impact of aerosols in the Arctic atmosphere.

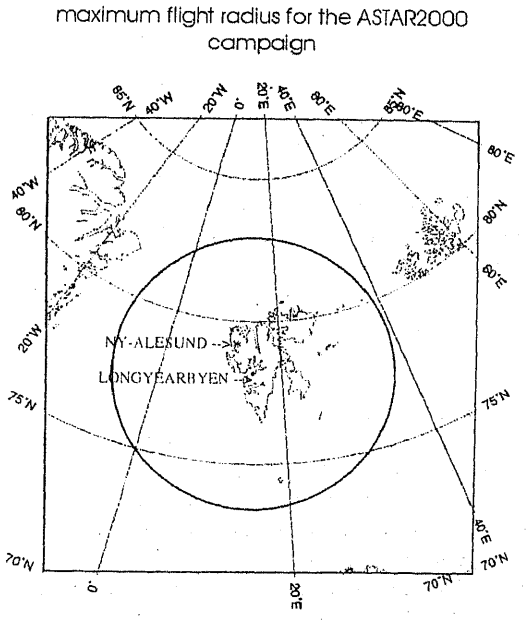

Fig. 1 Map showing the ground-based observation site, Ny-Ålesund, and base of airborne observation, Longyearbyen. Also shown is a circle with maximum flight radius.

2. Airborne observations

Airborne observations using Dornier 228 aircraft of Alfred-Wegener Institute for Polar and Marine Research (AWI) were the crucial experimental part of the project. A sunphotometer was used for the measurement of solar radiance to derive optical depth and extinction coefficients, and also for the measurement of sky brightness in the almucanter plane to derive the scattering phase function. The sunphotometer was installed in the plane on a solar tracker behind a quartz window, which was prepared specially for optical measurements. The sunphotometer was to be adjusted to the direction of the sun, 80 degrees apart from the plane heading and the solar height should be between 15 ° to 7 ° for the extinction measurement. By rotating the heading of the air plane 180 degrees, horizontal scan for brightness measurement in the same zenith angle was made. Downward and upward shortwave and longwave radiation fluxes was measured by broad band radiometers settled on the roof and bottom of the plane. In-situ measurements of aerosols were made; particle size distribution, absorption and scattering coefficients will be measured by optical particle counters (OPCs), a particle soot absorption photometer (PSAP) and an integrating nephelometer (IN), respectively. Aerosols were also sampled with a low volume filter sampler and aerosol impactor to conduct chemical analyses and electron microscope analyses.Air was introduced to the diffuser from the intake settled at the roof of the plane, and then guided to each instrument. Data from all the instruments were to be recorded in a central data recorder together with flight information and basic meteorological parameters such as pressure, temperature, relative humidity, dew point and wind velocity.

Using Longyearbyen airport (78 ° N, 15 ° S) as the operational base, 22 survey flights with about 80 flight hours were successfully conducted for the period from March 15 until April 25, 2000. Those flights were made in small target areas depending on the objective within about 500 km from Longyearbyen, as shown in Fig. 2. In the target area, a vertical profile from near the surface up to 8 km was measured with the level flight at 1 km altitude intervals.

3. Ground-based and in-situ observation

The airborne measurements were complemented by comprehensive ground-based measurements, providing such crucial aerosol parameters as phase fuction and absorption coefficients as a function of height. Coordinated ground-based remote sensing, in-situ measurements, sampling and balloon-borne observations of aerosols were performed at the surface, at the international research site, Ny-Ålesund (78.95 °N, 11.93 °E; Fig. 1).

In 1991, regular measurements of aerosols commenced at Ny-Ålesund. Since then observations have been improved and extended by newly developed instruments, such as sun and star photometers, to retrieve the aerosol optical depth and phase function in the visible and near infrared spectral range, the tropospheric Raman-lidar to measure extinction coefficients and depolarization as a function of altitude, and the Fourier transformed infrared spectrometer (FTIR) to calculate the aerosol optical depth in the IR spectral range by measuring emission spectra. Additional new systems are a micropulse lidar for backscatter measurement and sky radiometers for extinction and phase function measurements.

In-situ measurements were made by optical particle counters (OPCs), integrating nephelometer and particle mobility analyzer. Ground sampling of aerosols were done by high volume and low volume samplers and an aerosol impactor. Balloon-borne aerosol sonde with OPC was launched and a tethered balloon with OPC was used to obtain the vertical distribution of aerosol particle concentration in the atmosphere close to the surface. Supporting data included surface ozone measured by Dasibi ozone meter, precipitable water amount and liquid water content by microwave radiometer, precipitation by POSS, surface radiaitive fluxes by BSRN (Baseline Surface Radiation Network) radiometers and aerological soundings. At the Zepelin mountain station (470 m a. s. l.), in-situ measurements and samplings of aerosols were also made.

4. Results

Within ninteen profiles obtained by airborne observations, five was in a haze condition ($\tau > 0.1$) and another five was in a background condition ($\tau < 0.06$). Some profiles even without haze condition contained some layers with high concentration of aerosols. Fig. 2 is one of the extinction profile obtained in the haze condition with the largest total optical depth, $\tau = 0.18$, among the campaign. A high concentration layer between 3 km and 1 km was noticeable. In other 4 cases in a haze condition, the lower most layer was the extensive higest concentration layer.

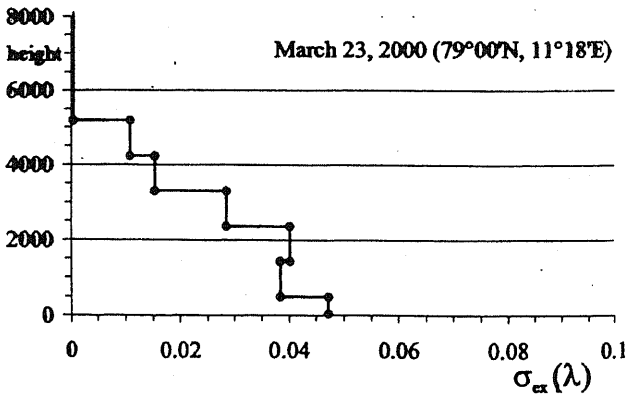

Fig. 2 Aerosol extinction (532 nm) profile obtained from airborne sunphotometer, March 23, 2000.

From the in-situ measurements on board airplane, scattering coefficients were measured by an integrating nepheloeter (IN), and absorption coefficients were measured by a particle soot absorption photometer (PSAP). Adding both coefficients, extinction coefficients were also estimated and the vertical profile was derived. Comparing both figures, similar extinction profiles are found qualitatively. However, quantitatively, extinction coefficients obtained from in-situ measurements are roughly half of those obtained from sunphotomter measurements. This discrepancy might partly be attributable to the correction factor of the in-situe instruments - air intake, diffuser, intake pipes and instruments theirselves, IN and PSAP. Anyway, we could obtain extinction profile using great differnt type of instruments within factor of two. From the electron microscope analysis of impacted samples, chemical constituents of aerosols were derived and found that aerosols in most of layers were made of sulpahate particles, but some upper layer were soot abundant for the profile of March 23.

From the ground-based in-situe measurements at Ny-Ålesund continuous record of aerosol parameters were obtained. The variation of scattering coefficients at three wavelength region during the campaign was examined. Roughly seen, there are three terms with high scattering coefficients, scattering coeficient (at 550 nm) > 0.01 km^{-1}. It was found that these high aerosol concentration at the surface occurred during northerly wind components, which corresponded to the typical meteorological condition with northery air flow from the Arctic airmass, looking at 500 hPa geopotential hight patterns of meteorological analysis, such as NCEP/NCAR.

Aerosol opticasl properties were retreived from the sky-radiometer measurements. Not only an optical depth, but also size distribution, complex refractive index and scattering phase function were obtained. Rather larger Ångstrom parameters were derived for the haze condition, which meant the higher abundunce of smaller particles. These results could also be estimated from physical parameters by in-situ measurents and compared.

Vertical distribution of aerosol extinction was estimated from ground-based lidar measurements. Using an lidar ratio estimated by fitting the total optical depth to the sunphotometer optical depth, an extinction profile was derived from backscatter coefficients measured by AWI lidar (Schumacher and Neuber, 2000). A good correspondence was seen with the airborne sunphotomter profile on March 23 (Fig. 3). Time height cross section of extinction coefficient were also estimated from micro-puls lidar, and growth and decay of thick aerosol layers were seen. However, some distortion of extinction profile was seen in noon time due to the contamination of solar radiation into the signal because of the inclined setting of the lidar. Some kind of correction needed to be made for these data.

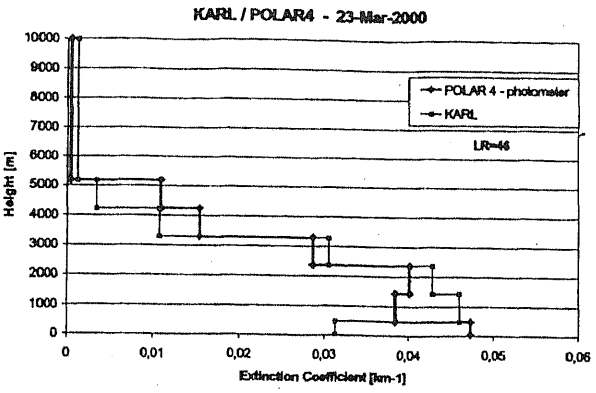

Fig. 3 Comparison of aerosol extinction profile measured by airborne sunphotometer (thick line) and by ground-based backscatter lidar (thin line) at Ny-Ålesund, Svalbard, March 23, 2000 (Schumacher and Neuber, 2000).

5. Satellite observations, meteorological analysis and model studies

SAGE-II (Stratospheric Aerosol and Gas Experiment) satellite observations of stratospheric aerosols are used to separate the tropospheric contribution from total atmospheric aerosol burden and provide information on spatial distributions in the Arctic region (McCormick, 1987). Also, satellite extinction measurement could be validated from airborne measurement data. A combination of all of these methods is recently used to obtain as much information as possible on temporal and vertical distributions of atmospheric aerosols and their optical properties. In the first comparison of extinction coefficients made for April 19, profiles between airborne measurments and satellite measurements provided an excelent correspondence (Fig. 4; Thomason and Burton, 2000).

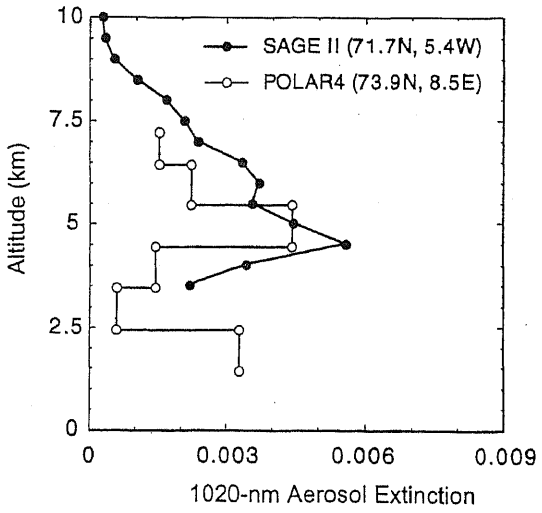

Fig. 4 Comparison of aerosol extinction profile (1020 nm) measured by airborne sunphotometer (white circle) and by SAGE-II measurement (black circle), near Svalbard, April 19, 2000 Thomason and Burton, 2000)

Atmospheric circulation patterns were examined using meteorological analysis data. Vertical profile of temperature and wind were estimated from NCEP/NCAR or ECMWF analysis and comparisons were made with the aerological soundings at Ny-Ålesund. Backward trajectories were calculated for the air parcel near the airborne obsrvation points. Some example shows a typical mid tropospheric air flow from north which originated from northern Siberia few days before.

For detailed model studies it is necessary to provide data on the temporal and spatial - in particular - vertical distribution of aerosols. Furthermore, optical parameters such as spectral optical depth, extinction coefficient, absorption coefficient, and phase function have to be measured. For all of these parameters a large number of different methods and instruments are used, including satellite information, like SAGE-II. There is not yet a clear understanding of the impact of tropospheric aerosols on radiative forcing processes in the Arctic. All these aerosol data will then be incorporated in to the HIRHAM Arctic regional climate model (Dethloff et al., 1996) for detailed model studies on the direct radiative forcing of Arctic tropospheric aerosols.

6. Concluding remarks

A five-week field capaign have provided a data set for the validation of satellite and ground-based remote sensing. Among 19 vertical profiles obtained by airborne measeurements, five profiles showed a haze condition ($\tau > 0.1$; 500 nm) with a layer of exetinction coefficient about 0.05 km^{-1} and another five showed a background condition ($\tau <$ 0.06). A good correlation was seen between the airborne measured extinction profile and ground-based lidar profile in several occasions; however, sometimes, it was dificult to compare both profiles due to the differnce in the target airmass. Also, a good correspondence of SAGE-II satellite extinction profile to airborne profile was found. These data set is of great value for the study of radiative properties of Arctic aerosols, which might have a substantial effect of radiative forcing to the Arctic climate.

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