P2.10 BOUNDARY LAYER PROFILES OF AEROSOL SIZE DISTRIBUTION OBTAINED BY KITES AND A TETHERED BALLOON DURING THE ARCTIC OCEAN EXPEDITION (AOE-2001)

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1. INTRODUCTION

The remote summer Arctic provides a unique environment to improve our understanding of the cloud mediated effect of natural aerosol on climate. The lack of anthropogenic aerosol sources and the relatively low transport of polluted air from mid-latitude sources during the summer months make the high Arctic a simplified system for the study of the origin and fate of natural aerosols.

A Tethered Lifting System (TLS) developed by researchers at the Cooperative Institute for Research in the Environmental Sciences (CIRES) at the University of Colorado was used to profile the boundary layer and lower troposphere during the Arctic Ocean-2001 expedition aboard the Swedish icebreaker Oden. Profiles of basic meteorological variables and aerosol concentration were obtained from July through August, both from the pack ice during two short-term measurement stations and during a three-week drift when Oden was anchored to an ice floe located close to the North Pole.

A description of the TLS is given, as well as details of the lightweight meteorological and aerosol instruments used to collect particle data. Data from field calibrations of the aerosol instrument versus research grade condensation particle counters (CPC) are also presented.

Aerosol profiles obtained with the system are compared to those measured concurrently from instrumentation on board a helicopter, results from a series of profiles are used to demonstrate the ability of the system to observe changes occurring in the boundary layer, and preliminary profiles of low-resolution size spectra are also shown.

2. THE TETHERED LIFTING SYSTEM

The TLS incorporates both parafoil kites and aerodynamic tethered balloons as lifting platforms for complementary wind regimes to enable operations in winds from 0 to 20 m s^{-1}(Balsley, 1998).

During the transit portion of the voyage, and during periods of higher winds during the ice drift, either a 7.4 m^2 or a 13 m^2 parafoil kite were used to lift the payloads. The smaller kite was used when boundary layer winds, as determined by radiosonde launches or remote sensing data, exceeded 12 m s^{-1}, to reduce the tether tension and enable more efficient operation of the TLS. Both parafoil kites performed well, although heavy icing on the bridle lines would occasionally limit their use for extended periods.

During the three-week ice drift, when on board storage space was available, a 21 m^3 aerodynamically-shaped tethered balloon was also used for profiling. Due to the thickness of the balloon material (0.15 mm) it was able to maintain its helium with only small “top-offs” once a week. This reduced the amount of helium needed to operate the balloon for the extended experiment.

The kite and balloon platforms were used with equal frequency during the campaign to collect well over 100 vertical profiles, with more than 50 of those including measurements with the aerosol instrument. Flights were conducted to altitudes as high as 2400 m, but were usually limited to 1000-1500 m to allow for more frequent profiles through the altitudes of most interest.

A 1-kW electric winch was used to raise and lower the TLS platforms and instrument packages. Power for the winch was provided by either a direct AC line from the icebreaker or from an inverter powered by a series of car batteries. Over 3000 m of braided Veteran was used as the tether, providing a breaking strength over 400 kg with a diameter of less than 2.5 mm. The small (130 kg) winch could provide a maximum pull of 200 kg tension and a top line speed of 1 m s^{-1}, allowing round-trip flights of the system up to 1000 m to be conducted in under one hour. Tether icing occurred on occasion and was manually removed from the tether as it was reeled in. This proved to be a nuisance, slowing the profiling process, and would sometimes limit the number of profiles that could be obtained in a given day, but was by no means a “show stopper.”

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3. METEOROLOGICAL AND AEROSOL PAYLOADS

During the AOE campaign a combination of three different scientific payloads were flown on the TLS: a Basic Meteorological Payload (BMP), an Aerosol Payload (AP), and a high-resolution 3D wind payload. The high-resolution 3D wind payload is described in the companion paper (#7.5).

The BMP provides 1 Hz measurements of pressure (Motorola MPX4115A), temperature and humidity (Vaisala Humitter 50Y), wind speed (CIRES pitot tube), wind direction (Precision Navigation Vector 2XG), along with support measurements of pitch and roll (AOSI 2-axis tilt sensor). These data are logged on board using a datalogger with Compact Flash storage (Onset Computer Corp. Tattletale model 8). The BMP provided support meteorological and altitude data for the AP, and data for calibration of similar sensors on the newly developed 3D wind payload.

The AP was designed specifically for the AOE project to measure particle concentrations in 4 size ranges. It consists of a TSI PortaCount+ (PC+) condensation particle counter, a set of 3 solenoid valves to switch between 4 inlets, and an on board datalogger/controller.

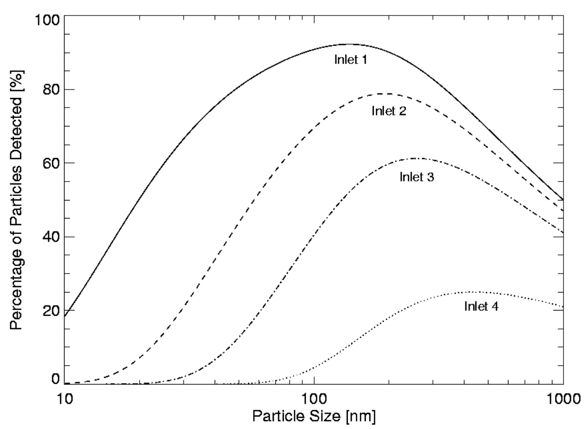

Fig. 1. Theoretical response curves for the four different inlets to the PortaCount+. Inlet 1 passes directly to the PC+, while Inlets 2-4 pass through Particle Size Selectors with 2, 5, and 17 diffusion screens, respectively.

One of the four inlets (inlet 1) is connected directly to the PC+ to give a particle count over the full range of the of 20 nm to over 1 μm. The other three inlets are passed through TSI Particle Size Selectors (PSS) with varying numbers of diffusion screens, to selectively capture smaller size particles, and effectively raise the lower cutoff limit of that inlet. In an attempt to create size bins to help identify the various particle size modes expected in the high Arctic, the PSSs were outfitted with 2 (inlet 2), 5 (inlet 3), and 17 (inlet 4) diffusion screens, giving the theoretical size response for each of the four inlets shown in Fig. 1. The solenoid valves were automatically switched every 5 seconds to divert flow sequentially between each of the four inlets, producing a low-resolution (4 channel) size spectrum every 20 seconds. The 5 second per channel timing was selected to allow sufficient time for the inlet tubes to flush and the sensor readings to settle.

The entire system is housed in a styrofoam container to provide insulation and vibration absorption, and is powered by a set of 16 AA NiMH batteries. Weight of the system is under 3 kg and it has sufficient battery capacity for over 5 hours of continuous operation.

4. CALIBRATION

Calibration runs of the TLS AP took place during the transit into the pack ice. Data are compared with aerosol systems operated continuously on board Oden during the experiment by researchers from the Institute for Tropospheric Research in Leipzig, Germany. Total particle concentrations for sizes between 3-800 nm were measured using a TSI 3025 Ultrafine Condensation Particle Counter (UCPC), and size spectra were determined using a Differential Mobility Particle Sizing (DMPS) system (Birmili, 1999).

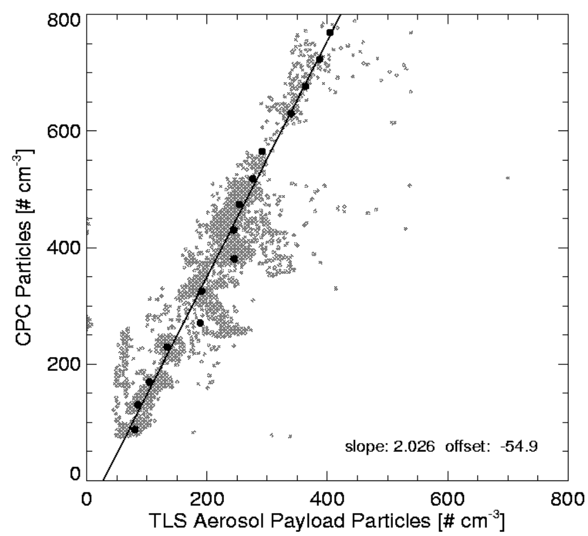

Fig. 2. Scatter plot of calibration data comparing the TLS AP and the CPC. The gray points show the raw data from the three calibration runs, and the black points represent bin-averaged data used to calculate the weighted least squares fit (black line).

For the calibration runs, the AP was suspended from a mast on the 4th deck of the Oden, roughly 5 m below the CPC inlet, but otherwise operated in the same manner as when suspended from the TLS. Total particle counts from the TLS Aerosol Payload are plotted against the adjusted UCPC counts for data from three different calibration runs made under a wide range of atmospheric conditions. Since the TSI 3025 can detect particles down to 3 nm, as opposed to the aerosol payload, which has a lower detection limit of 20 nm, additional data from the 3-20 nm bins of the DMPS output were subtracted from the

UCPC data. These data are then bin-averaged and fit to produce the calibration used for operational profiling with the TLS AP (see Fig. 2).

The TLS Aerosol Payload data is also compared to a concurrent airborne profile made using a TSI 3010 CPC flown on board the *AS 350B Equrille* helicopter used during the AOE campaign. Unfortunately, most of the helicopter profiles were made at large distances from the ship and the TLS site, and for this flight was between 45 and 80 km from the ship during the profile shown (see Fig. 3). While there is excellent agreement between the particle concentration profiles at upper levels, differences in the lower level boundary layer structure correspond to differences in particle concentrations at those levels. The moist level above the mixed layer in the TLS profile corresponds to an enhanced particle

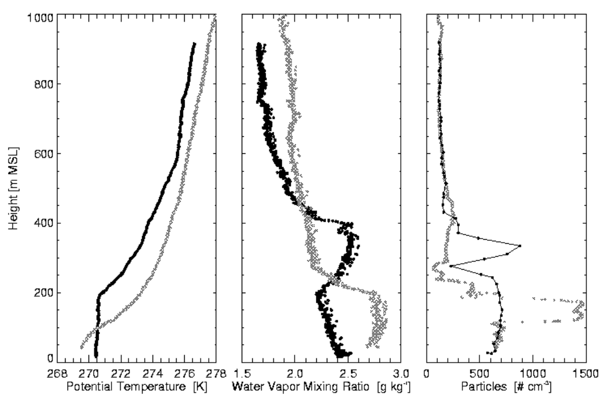

Fig. 3. Potential temperature, water vapor, and particle concentration for TLS (black) and helicopter (gray) profiles obtained on 13 Aug. 2001.

concentration layer, which is also seen in the helicopter profile, but is roughly 200 m lower with no discernible mixed layer beneath it.

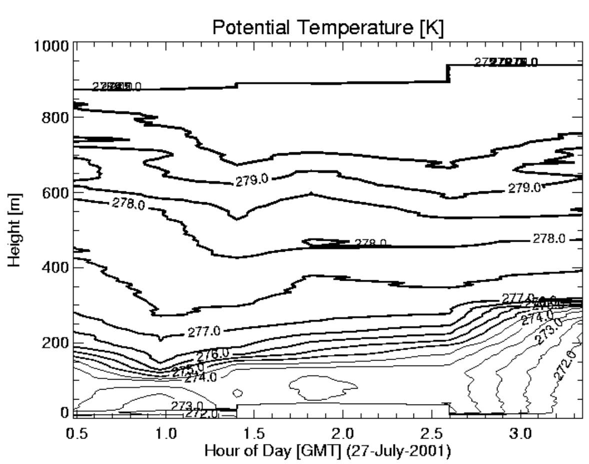

Fig. 4. Contours of potential temperature produced from six TLS profiles with the BMP.

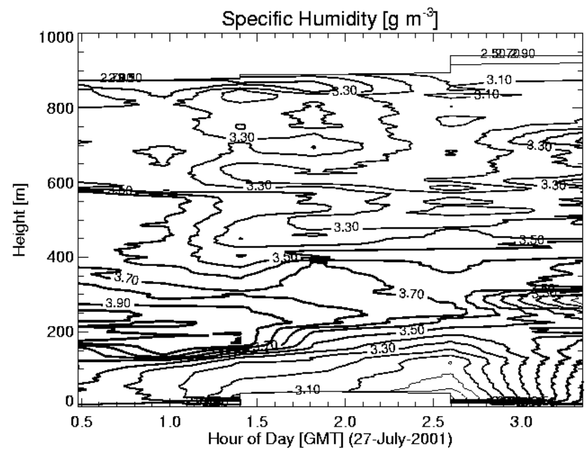

Fig. 5. Contours of specific humidity produced from six TLS profiles with the BMP.

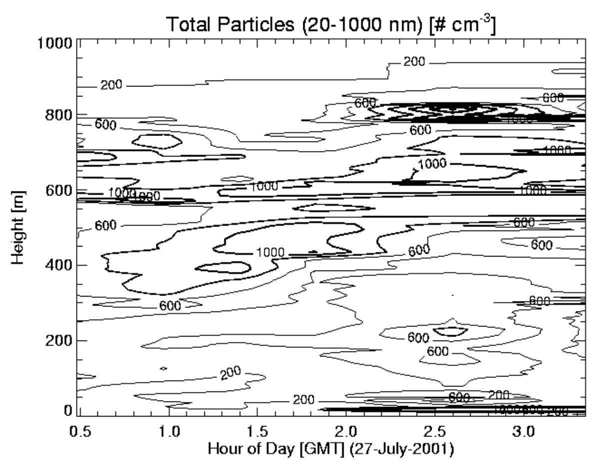

Fig. 6. Contours of particle concentration produced from six TLS profiles with the Aerosol Payload.

5. RESULTS

Preliminary results from the AOE campaign are presented to demonstrate the capability of the TLS and AP to make repeated profiles of the boundary layer and observe changes in aerosol structure. The series of contour plots (see Figs. 4-6) are constructed from 6 TLS profiles with the BMP and AP measured over 3.5 hours on 27 July 2001. The contours on each plot are labeled and drawn with increasing thickness to indicate increasing values.

In addition to the total particle concentration, relative changes in different particle size ranges can also be deduced from the Aerosol Payload data. Combinations of the four inlet channels are used to obtain a low-resolution size spectrum. Taking the difference of

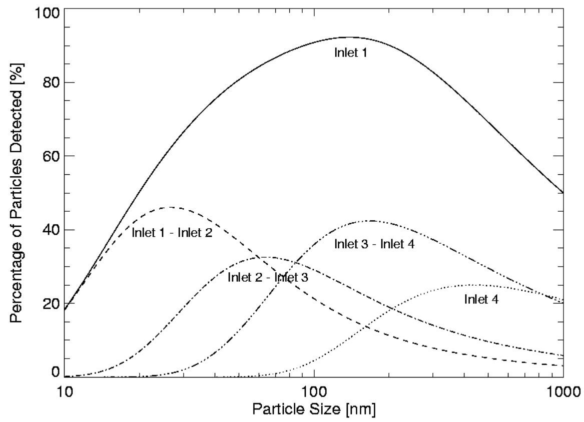

Fig. 7. The theoretical particle size response functions for the total particle counts (solid line, inlet 1), and four combinations of the four inlet channels.

consecutive inlet channels, along with inlet 4 on it's own, four distinct, but overlapping, size ranges are produced (see Fig. 7).

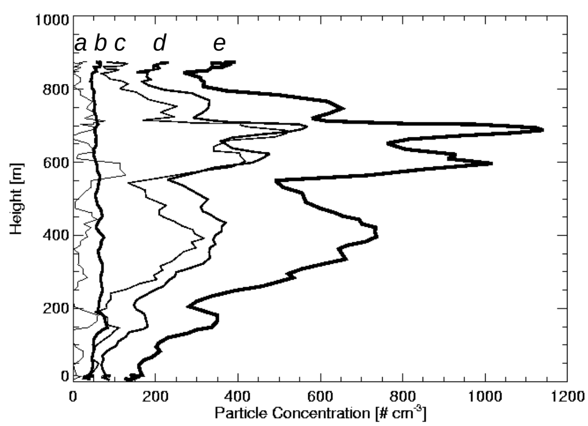

*Fig. 8. Total particle concentration and concentrations of four size bins created from the differences of the measurements from the four Aerosol Payload inlets. The inlet combinations used to create each curve are labeled at the top of the plot: (**a**) inlet 1 - inlet 2 (finest particles), (**b**) inlet 4 (largest particles), (**c**) inlet 2 - inlet 3, (**d**) inlet 3 - inlet 4, and (**e**) inlet 1 (total particles).*

While additional work will be undertaken to invert this data to produce more clearly defined size ranges, the data can be used as it is to qualitatively analyze the rough particle size spectra as a function of altitude and/ or time. Fig. 8 shows an example TLS profile with the AP made on 27 July 2001. It is one of the profiles used to create the contour plots shown in Fig. 4-6. Noticeable in the plots are similarity between the two central size bins (**c** and **d**) and the total particle concentration (**e**), the relatively constant concentration of the largest particles with height (**d**), and the relatively low and sporadic concentrations of the smallest particles (**a**).

While additional data analysis and continued development are needed to improve the AP system, its utility has been clearly demonstrated when used in conjunction with the TLS, especially for work in remote areas such as the Arctic.

ACKNOWLEDGMENTS

The authors would like to acknowledge the assistance of the scientists and crew of the icebreaker Oden during the AOE-2001 campaign, and both the Meteorological Institute of Stockholm University and the Swedish Polar Secretariat for funding this project.

Dr. Jensen would also like to thank Dr. John Birks of the University of Colorado for loaning the TSI PortaCount+ used during the project.

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