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MEASUREMENT OF PARTICLE SIZE DISTRIBUTION IN AMBIENT AIR USING THE ELECTRICAL AEROSOL SPECTROMETER OF TARTU UNIVERSITY

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MEASUREMENT of PARTICLE SIZE DISTRIBUTION in AMBIENT AIR USING the ELECTRICAL AEROSOL SPECTROMETER of TARTU UNIVERSITY

1.0 Purpose and applicability

This SOP contains the protocol for performing measurements of particle size distribution in outdoor air for the EU-multicenter study ULTRA-2. The spectrometer is an original full electrical aerosol instrument developed at the University of Tartu for atmospheric aerosol studies in ambient conditions.

2.0 Definitions

EAS Electrical Aerosol Spectrometer of Tartu University

Aerosol particle size fractions by EAS:

Fraction	Lower boundary (nm)	Upper boundary (nm)	Geometric mean diameter (nm)
NC13	10.0	17.8	13.3
NC24	17.8	31.6	23.7
NC42	31.6	56.2	42.2
NC75	56.2	100.0	75.0
NC130	100.0	177.8	133.4
NC240	177.8	316.2	237.1
NC420	316.2	562.3	421.7
NC750	562.3	1000	749.9
NC1300	1000	1778	1334
NC2400	1778	3162	23714
NC4200	3162	5623	4217
NC7500	5623	10000	7499

Main particle size ranges in ULTRA2 study:
$NC_{0.01-2.5}$: total particle number concentration (cm^{-3}) in the size range between 0.01 - 2.5 μm
$NC_{0.01-0.1}$: particle number concentration (cm^{-3}) in the size range between 0.01 - 0.1 μm
$NC_{0.1-1.0}$: particle number concentration (cm^{-3}) in the size range between 0.1 - 1.0 μm
$NC_{1.0-2.5}$: particle number concentration (cm^{-3}) in the size range between 1.0 - 2.5 μm

Sub particle size ranges:
$NC_{0.01-0.03}$: particle number concentration (cm^{-3}) in the size range between 0.01 - 0.03 μm
$NC_{0.03-0.1}$: particle number concentration (cm^{-3}) in the size range between 0.03 - 0.1 μm
$NC_{0.1-0.5}$: particle number concentration (cm^{-3}) in the size range between 0.1 - 0.5 μm
$NC_{0.5-1.0}$: particle number concentration (cm^{-3}) in the size range between 0.5 - 1.0 μm

OP: operating procedure

3.0 References

Mirme, A. Electrical Aerosol Spectrometry, Ph.D. Thesis, University of Tartu, Tartu, 1994.

Kikas, Ü., Mirme, A., Tamm, E., Raunemaa, T. Statistical characteristics of aerosol in Baltic Sea region. J. Geophysical Research, vol. 101, no. D14, pp.19319-19327.

4.0 Discussion

N.A.

5.0 Responsibilities

N.A.

6.0 Equipment and Materials

6.1 EAS

6.1.1 Operation principle of EAS.

Electrical Aerosol Spectrometer (EAS) is an instrument for measuring aerosol particle size distribution in broad size range in ambient conditions.
EAS utilises electrical method in full size range (0.01 – 10.0 μm). The aerosol is sucked into the EAS, the particles are charged electrically in a corona type discharge and analysed by a multichannel electrical mobility classifier. The particle charge fluxes of the mobility classes are measured electrometrically. The size distribution is derived using the calibration data.

6.1.2 The construction

EAS system consists of a sensor unit, connected to a controlling computer via RS232 interface.
The sensor unit has two measurement paths, both starting with a charging unit followed by mobility analyzers.
The air is driven by a built in electronically controlled blower supplied with a filter unit.
The transmission of the commands from the computer and data transfer is performed by a built in controller supplied with a command decoding and data communicating circuitry.
The principal units of EAS are:
particle chargers,
analyzers,
Electrometric amplifiers,
high voltage supplies,
the blower,
decoder-communicator,
controller.

6.1.3 Software

The EAS system is controlled and also verified by software.
All units are controlled by computer commands.

Also all units have built in sensors monitoring their operation parameters, i.e. the charging currents, the voltages and air flow.

The basic instrument data such as available operation modes, the list of operation commands and respective operation parameters of the units are provided in the EAS configuration file. That also includes the calibration data of electrometric channels.

Particular settings for the current measurement such as operation modes used, interface and timing settings also EAS calibration data file names and output file formats are listed in EAS initialisation file.

6.1.4 EAS operation

The measurement is designed to avoid any need of human assistance.
The computer is configured to automatically to start the measurement program after power on and initialisation. The program with the information on EAS initialisation is included in AUTOEXEC.BAT file.
The computer loads the program, reads from the initialisation file the starting information, loads the settings and calibration files as indicated in initialisation file and starts the measurement.
Basic measurement cycle consists of a measurement period and of an offset period following each other. The actual aerosol particle measurement is performed during measurement period when EAS is in measurement mode meaning that the aerosol particles are charged, analyzed and measured. During offset period EAS is in offset mode, when the charging is off, there is no signal from aerosol and measured are the offset levels of the channels. That gives a bias to calculate the pure signal of aerosol and to assess the errors.

Measurement starts the operation with the system test i.e. with the offset mode.

An operation cycle consists of periodical reading of the data from electrometric channels, that has 10 second period normally, followed by the system checking, which means the reading of operation parameters of the EAS principal units.
The data are transferred to the computer with parity bit and checksum checking.
The cycle performs the pre-processing of the electrometric data according to configuration file and storing them into the computer memory.

The operation parameters are also processed and stored. In addition they are tested against the expected values in configuration file and if a discrepancy is discovered a “beep” sound is issued and the name of respective parameter is displayed on computer screen.

The basic measurement cycle has 5 minutes period normally. The cycle starts with turning on measurement mode. After elapsing a certain time (defined in initialisation file, 2/3 of the cycle time normally) the program turn to an offset mode, the aerosol does not reach the electrometric channels and the statistical parameters of the channels are tested. The respective processing is performed after the end of the cycle i.e. in the beginning of next cycle.

The data are stored periodically on the disk. The storing period is independent from the other cycles and synchronized with the full hour period. The storing is performed when all the data are statistically processed. The transforms before the storing are performed according to the formats in initialisation file.

As a rule each data file contains the starting and end times and the respective mean values of storing period and the standard deviations of the mean values. Also the mean operation parameters are stored of both, the measurement and offset times.
The storing ends with calculating the disk free space and displaying the result on the screen.

The program enables without interrupting the measurement process, at almost any time to call to the screen the lists of operation parameters, the settings, the results of electrometric channel readings and last calculated, averaged or saved aerosol distribution data of all formats.

6.1.5 Monitoring the data on the computer screen

The measurement process and verification, the information on measured data can be followed on the computer screen.

The screen has several data fields. The central part of the screen is used for displaying the data. the format of the data can be selected by pressing a keyboard button highlighted in the menu right side on the screen, or function keys according to the bottom line on the screen. The disk free space is displayed on the top right of the screen, Also the current data display mode and settings are displayed there.

The top line of the screen presents the course of current measurement process. Each data reading cycle (every 10 seconds normally) starts with displaying the current computer time and measurement mode. If data processing for the other cycles are in progress the respective messages will appear.

A message “WARNING:” followed by the list of respective parameters will appear if The EAS verification program has found one or more parameters out of the designated range.

The data screen (central part of the screen) has a format:

the title of the currently displayed data with the measurement time, mode and scale settings on the top,

followed by the printout of respective measurement data as selected from the menu in the right side of the screen. The data starting from direct readings of the channels up to particle volume concentration distribution can be printed on the screen.

The size distributions are summed with the last line presenting the estimate of total concentration, mean size and the distribution width. The EAS Verification parameters can also be displayed (Supplementary channels, in the menu).

Function keys allow to select between the data of basic cycle (10 second aerosol distribution) averaged data or saved data. The measurement settings can also be verified by pressing a function key.

For safety reasons the measurement can be terminated only by pressing several keys in fixed sequence within one basic cycle time.

The key labeled as DosShell enables to temporary stop the measurement and download the stored data. It is on responsibility of the servicing person to continue the measurement with inserting a command EXIT after downloading the data.

6.3 Paper materials

a. Field forms to record parameters of EAS.
b. Laboratory forms to record data acquisition
c. etc.

7.0 Procedures

7.1 Pre-measurement service and testing

EAS sensing unit is disassembled and cleaned.

The position and the length of corona needles are checked and changed or corrected if needed.

EAS is assembled together and the operation parameters of the units are checked in all operation modes externally in parallel with monitoring by a computer program.
Air flows are checked with an external flowmeter in parallel with the built in one.

The EAS system is tested with laboratory aerosol side by side with another aerosol instrument e.g. CPC, an aerosol electrometer, another EAS.

The system does run continuously in the lab during one week. After that the parameters are checked again against known instrument.

All unnecessary files are deleted from the hard disk of the computer.
It should be calculated about 150 kB of disk space per day. A backup copy of all needed files is made.

7.2 Starting the measurement

It is assumed that the software has been installed and the computer has been set in correct mode.

- Install EAS at the location. EAS should be installed vertically on a firm, nonvibrating surface. The temperature should not exceed the range from -20 to +30 degrees of Celsius. The humidity is not limited. The water droplets and rain should be avoided by appropriate screening.
- Install the computer according the manual. The distance from EAS is determined by the length of the data cable and can be up to 100 m.
- Connect the aerosol inlet to EAS, check manually the tightness. Connect the sampling tube. The tube should prevent the rain droplets or water to get into the EAS and should have low pressure drop (a metal tube 3 – 8 cm of diameter, the length determined by sampling height of measurements). The pressure difference between EAS inlet and the room should not exceed 5 mm of water at EAS operation. Check aerosol flow of EAS by EAS flowmeter.
- Connect the power cables.
- Connect the data cable between the computer respective serial port and EAS.
- Turn power on of both the computer and EAS.
- Wait and follow the computer screen.

Messages about loading the program, the initialisation and configuration files, calibration data should appear.
The measurements starts with the signing on message on the screen.
Next a normal measurement screen should appear with displaying an empty fraction number concentration.

- The measurement goes on in normal way if the messages line is regularly (10 sec period) displaying the messages and there is no warning messages. The warning message and “beep” sound should appear about twice in an averaging (5 minutes) period when the measurement mode is changed. That enables to check the functioning of EAS even when the computer monitor is off. If the warning is issued more often, write down the displayed parameters and consult the responsible person (E-mail address mirme@ut ee).

The warning means that the system may get polluted and the data need more careful checking. However the warning information is stored on the disk and the discrepancy will be discovered later anyway and low quality data will be rejected. The purpose of early informing is to reduce the possible loss of the measurements.
The screen starts to display the aerosol distribution after finishing the first averaging cycle (about 5 minutes). The distribution should be close to normal. The total concentration (last line on data screen) can be compared to other instruments e.g. CPC. However the noise and the errors may still be elevated since electrometric channels may need more time for warm up (30 minutes).

7.3 Bidaily maintenance of EAS

Normally EAS does not need any maintenance.
However to avoid the data loss because of hanging the computer program depending on the quality of local power supply it is safe to listen to the beep sound or take a look on the screen.

- If the beep is issued and the warning appears about twice per 5 minutes and not every 10 seconds the system is operating normally.

- If there is frequent warning, write down the message and inform via E-mail.

- If the computer has stalled with an computer error message on screen write down the message and restart the computer buy pressing Reset button. Continue as Starting the measurements.

- If there is a signing on message on screen, check the cable connection with EAS and power on of EAS, the indicators are in front of EAS. Switch both, the computer and EAS off and then on. Proceed to Chapter 7.2.

7.4 Biweekly service of EAS

- Check the free disk space on right top of the screen.

- Verify the computer time (appears on message line every 10 seconds), with the official measurement time (should be a special clock in the cabin).

- Verify the computer date in the title of data screen. That is important since some computers may not to change the date when hanging.

- Write into the diary the date the official time and the computer time.

- It is wise to download all collected data to a floppy disk. That can be done without interrupting the measurement as follows.
- Press DosShell key.
- Insert a floppy disk.
- Type insert a command “copy MMDDYY.* a:”. MM stands for the month, DD for day and YY for year you want to copy.
- The computer copies the data to the disk and informs you.
- Copy the days needed. A disk fits about 10 to 12 days of data.
- Insert command “exit” if there is enough free space on the disk and the time difference is less that 5 minutes (half of measurement period). EAS continues the measurements normally.

- If the disk space is short, delete the data files downloaded earlier (do not delete the files just downloaded, you can do that next time after making backup copies). Insert exit if the clock was OK.

- Date and time can be corrected by inserting the DOS commands “date” and “time” and typing on request the correct values.

- Make a remark in diary about the correction.

- After correcting the date or time the program may not continue operating correctly. Restart the computer by pressing reset button. Act as starting the measurement.

7.5 Indicators of malfunctioning of EAS

Normally EAS can operate many months without any problem since it does not contain critical to pollution or consumable parts.

- Occasional beep sound does not mean malfunctioning. Some parameters are noisy and may be well in the range in average.

However some theoretical cases can be figured as follows

- EAS is not working

Indicator: Not any beep sound, computer is hanging with an error message on the screen.
Action: restart the computer.

Indicator: Not any beep sound, computer is displaying signing on message.
Action: check the power on, check the cables, restart the computer.

- No data saved

Indicator: free disk space is low, not all data saved.
Action: delete some not needed data files, restart the computer.

- EAS is polluted

Indicator: Often issued beep sound, unusual aerosol distribution, high error estimates.
Action: consult via E-mail, cleaning EAS.

- An unit in EAS is down

Indicator: regular beep sound, the respective parameter is close to zero or far out of range.
Action: consult via e-mail, EAS needs fixing the unit.

In all cases do not switch EAS off before consulting. The EAS system is rather complex with parallel channels. In many cases the indicated malfunctioning may mean only some increase in error level, but the data may be still useful.
*The exception is if there is a smoke coming out from EAS or from the computer.

8.0 Analytical procedures

8.1 Averaging of hourly and daily mean size distributions

The processing is made using a special computer program that transforms the primary EAS data format to fraction concentration format (Chapter 2.) and ULTRA2 format, with verification the operation parameters. The software has been tested in ULTRA1 study.

8.2 Calculation of particle number concentrations

Number concentrations of the total spectrum are primary calculated as fraction concentrations (Chapter 2). Additionally, for ULTRA2 the following size ranges are calculated:

Main particle size ranges:
$NC_{0.01\text{-}2.5}$: total particle number concentration (cm^{-3}) in the size range between 0.01 - 2.5 μm
$NC_{0.01\text{-}0.1}$: particle number concentration (cm^{-3}) in the size range between 0.01 - 0.1 μm
$NC_{0.1\text{-}1.0}$: particle number concentration (cm^{-3}) in the size range between 0.1 - 1.0 μm
$NC_{1.0\text{-}2.5}$: particle number concentration (cm^{-3}) in the size range between 1.0 - 2.5 μm

Sub particle size ranges:
$NC_{0.01\text{-}0.03}$: particle number concentration (cm^{-3}) in the size range between 0.01 - 0.03 μm
$NC_{0.03\text{-}0.1}$: particle number concentration (cm^{-3}) in the size range between 0.03 - 0.1 μm
$NC_{0.1\text{-}0.5}$: particle number concentration (cm^{-3}) in the size range between 0.1 - 0.5 μm
$NC_{0.5\text{-}1.0}$: particle number concentration (cm^{-3}) in the size range between 0.5 - 1.0 μm

8.3 Comparison of total number concentration and CPC counts

The graphical comparison is made using logarithmic scatterplot of EAS $NC_{0.01\text{-}2.5}$ versus NC by PC. The statistical characteristics, Geom. Mean Ratio (GMR) and Geom Std. Dev. (GSR) of total concentrations are assessed.

8.4 Convolution to particle volume and volume distributions

The convolution is made using a computer program used in ULTRA1. The concentration is presented in micrograms per m^3 assuming particle mass density equal to 1 g/cm^3.

8.5 Calculation of particle volume concentrations

Main particle size ranges:
$VC_{0.01\text{-}2.5}$: total particle volume concentration in the size range between 0.01 - 2.5 μm
$VC_{0.01\text{-}0.1}$: particle volume concentration in the size range between 0.01 - 0.1 μm

$VC_{0.1\text{-}1.0}$: particle volume concentration in the size range between 0.1 - 1.0 μm
$VC_{1.0\text{-}2.5}$: particle volume concentration in the size range between 1.0 - 2.5 μm

Sub particle size ranges:
$VC_{0.01\text{-}0.03}$: particle volume concentration in the size range between 0.01 - 0.03 μm
$VC_{0.03\text{-}0.1}$: particle volume concentration in the size range between 0.03 - 0.1 μm
$VC_{0.1\text{-}0.5}$: particle volume concentration in the size range between 0.1 - 0.5 μm
$VC_{0.5\text{-}1.0}$: particle volume concentration in the size range between 0.5 - 1.0 μm

9.0 Attachments

Figure 1. EAS field diary
Figure 2. EAS data acquisition diary

Figure 1. **EAS field diary**

Official		EAS			CPC	
Date	Time	Date	Time	Concentration	Count	Remarks

Figure 2. **EAS data acquisition diary**

Date	Time	Retrieved files	Verification remarks