

WP3- NA3: In-situ chemical, physical and optical properties of aerosols

Deliverable D3.11: Standardized protocol for CCN measurements

This document provides a standardized protocol for long-term cloud condensation nuclei (CCN) measurements using a cloud condensation nuclei counter (CCNC) at aerosol monitoring stations such as those of the ACTRIS research infrastructure networks. The ultimate aim of defining standardized operations procedure (SOP) is to provide homogeneous data sets of high-quality CCN measurements to the world data centre for aerosols. The resulting SOP is the product of intense scientific exchange and discussions between the CCNC users among the ACTRIS partners as well as other CCNC experts. Any feedback for improvements of this SOP can be directed to the authors Martin Gysel (martin.gysel@psi.ch) and Frank Stratmann (frank.stratmann@tropos.de).

Table of Contents

1 CCNC types and operation modes	2
2 Standard calibration procedure	2
2.1 Temperature sensor calibration	2
2.2 Flow rate calibration	3
2.3 Supersaturation calibration	3
2.3.1 <i>Experimental approach for the empirical calibration</i>	3
2.3.2 <i>Köhler theory for ammonium sulphate</i>	4
2.3.3 <i>Data analysis approach for the supersaturation calibration</i>	4
2.4 OPC calibration	5
3 Standard operation procedure (SOP)	5
3.1 Standard operation mode.....	5
3.2 Standard operation parameters	6
3.3 Routine instrument maintenance.....	7
4 Data analysis approaches	7
4.1 Relevant temperature readings and conditions for stable supersaturation	7
4.2 Treatment of diffusion losses.....	8
4.3 Filtering and flagging of bad data	8
4.4 Specific data analysis steps for polydisperse measurements	9
4.4.1 <i>Interpolation to the target supersaturation</i>	9
4.5 Specific data analysis steps for monodisperse measurements	9
4.5.1 <i>Inversion of the raw data</i>	9
4.5.2 <i>Interpolation to the target supersaturation</i>	9
5 File formats for data reporting	10
6 Acknowledgements	10
7 References	10

1 CCNC types and operation modes

Several research groups have developed their own CCNC instruments based on different operation principles. However, the continuous-flow streamwise thermal-gradient CCNC (Roberts and Nenes, 2005; Lance et al., 2006) from Droplet Measurement Technologies (DMT, Boulder, USA), is the only commercially available instrument. Most ACTRIS partners and other research groups that investigate the CCN properties of aerosols use the DMT-CCNC. This SOP contains instructions that generally apply for CCN measurements using any CCNC type as well as instrument specific aspects that specifically refer to the DMT-CCNC. Users of other CCNC types are expected to be expert CCNC operators that are able to address specific quality assurance aspects of their particular CCNC instrument in an appropriate manner.

The supersaturation applied in the DMT-CCNC is traditionally varied by variation of the temperature gradient along the droplet activation column at a constant air flow rate. Alternatively, it is possible to vary the air flow rate at a constant temperature gradient (Moore and Nenes, 2009). However, the latter approach needs modifications to the software, and ideally also the hardware of the DMT-CCNC if the flow is scanned. Furthermore, the calibration of the supersaturation is more complex. For these reasons the traditional approach of stepping the temperature gradient at constant flow rate is addressed in this SOP and recommended for basic CCNC users.

CCN measurements of ambient aerosols are commonly done in two different ways. The basic approach is a direct measurement of the CCN number concentration of the whole polydisperse aerosol sample by simply using the CCNC as is (Fig. 1a). A more advanced approach is to measure the CCN number size distribution by operating the CCNC downstream of a differential mobility analyser (DMA) that is scanned or stepped across the relevant size range (Fig. 1b). A condensation particle counter (CPC) can be included in the experimental setup of monodisperse CCN measurements in order to additionally determine the CCN active fraction of particles as a function of particle size. The SOPs are defined for both experimental approaches – polydisperse and monodisperse CCNC measurements – as either of them has its specific advantages and disadvantages.

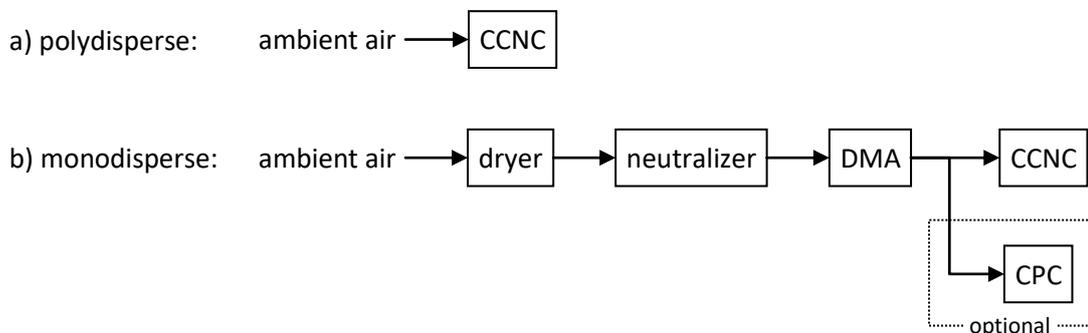


Figure 1: Experimental setup for a) polydisperse and b) monodisperse CCN measurements.

2 Standard calibration procedure

This section provides an overview of mandatory and optional instrument calibrations that are necessary to ensure high quality of the CCN measurements. **The target accuracy in supersaturation is $\pm 10\%$ (relative) at supersaturations above $SS=0.2\%$ and $\Delta SS \leq 0.03\%$ (absolute) at lower supersaturations.** Maximal intervals for checking/repeating the different calibration steps are also indicated below. Longer calibration intervals may be possible if proper instrument performance is permanently verified with comparing the measurement parameters of all data points against the output of the sophisticated CCN instrument model from Anthanasios Nenes' research group (Lathem and Nenes, 2011; Raatikainen et al., 2012). This model can be downloaded from the following web page (<http://nenes.eas.gatech.edu/>).

2.1 Temperature sensor calibration

The temperature gradient applied across the activation column of the CCNC is one of the main factors determining the supersaturation. However, effects of temperature reading uncertainties on the resulting supersaturation are accounted for by the empirical supersaturation calibration of the CCNC (see Sect. 2.3). Nevertheless, Figure 2 gives an example where the temperature regulation is not well

adjusted, i.e. that one or several activation column temperatures are not regulated to their nominal setpoints but rather stabilise slightly off their respective target temperatures (in a reproducible manner). The main problem of such offsets is that it becomes more difficult to use the actual temperature readings to assess whether the activation column has settled at the target supersaturation (target temperature gradient).

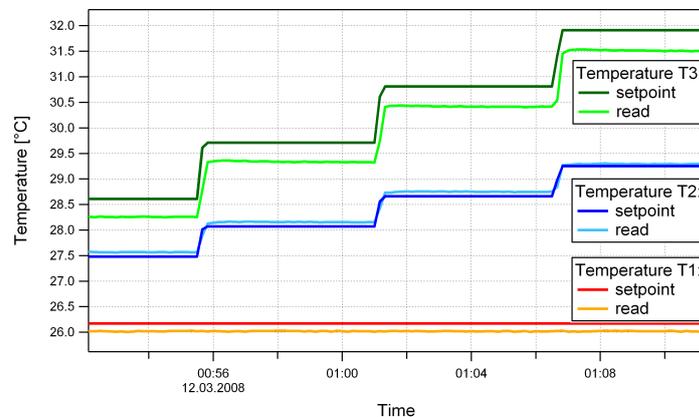


Figure 2: Example of badly adjusted temperature regulation. The actual column temperatures stabilise with an offset to the setpoint temperature.

Recommendations:

- No calibration of the temperature sensors beyond the standard factory calibration is required.
- Differences between setpoint temperatures and corresponding actual temperature readings (when stabilised) should be minimised. DMT provides instructions to fix potential temperature regulation offsets. The supersaturation calibration of the CCNC must be repeated after this adjustment.

2.2 Flow rate calibration

The total flow rate through the CCNC column has a direct influence on the resulting supersaturation and the aerosol sample flow rate must be known to calculate CCN number concentrations. Accuracy of the instruments internal measurements of the total and aerosol sample flow rates is thus crucial for accurate CCN measurements.

Recommendations:

- The total flow rate at the CCNC inlet should frequently be checked, at least every 6 months.
- The sample flow rate should be checked every 6 months. This can be done according to the instructions given in the CCNC operator manual. Alternatively, a careful check of the plateau value of the activated fraction observed during calibration also reveals whether the sample flow rate is correctly measured (the activation plateau for larger particle diameters must be at unity if both CPC and CCNC work correctly).

2.3 Supersaturation calibration

2.3.1 Experimental approach for the empirical calibration

The supersaturation in the activation column of the DMT CCNC is empirically calibrated using the experimental setup shown in Fig. 3 and pure salt particles with well-known CCN activation behaviour. The goal of this calibration is to determine the relationship between the temperature gradient across the activation column and the resulting supersaturation. The critical diameter for CCN activation at a fixed supersaturation can be determined with “D-scans”, i.e. by applying a fixed temperature gradient in the CCNC while scanning/stepping the sizes selected by the DMA. Alternatively, the critical supersaturation for CCN activation of particles with a well-defined size can also be determined with “S-scans”, i.e. by selecting a constant particle size with the DMA while stepping the supersaturation (temperature gradient) applied in the CCNC.

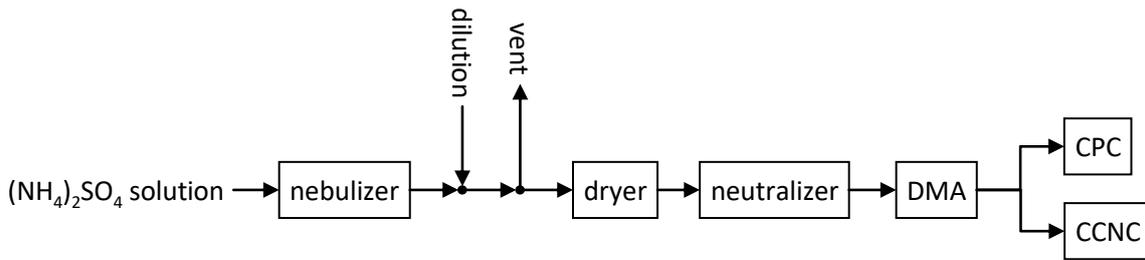


Figure 3: Experimental setup for the calibration of a CCNC.

Recommendations:

- Ammonium sulphate, $(\text{NH}_4)_2\text{SO}_4$, should be used as calibration standard (see also Sect. 2.3.2). Use MilliQ water and as pure as possible ammonium sulphate for preparing the calibration solution (concentration should be around 0.1 g L^{-1}). (Do not use ammonium bisulphate, sulphuric acid or sodium chloride.)
- The calibration setup shown in Fig. 3 should be used. The approach chosen for diluting/venting the sample air may be adapted. Correct size selection by the DMA must be verified with certified polystyrene latex (PSL) size standards. The relative humidity in the DMA must be $\leq 20\%$.
- The CCNC must be calibrated at the typical ambient pressure of the monitoring station.
- D-scans or S-scans can be applied for the supersaturation calibration.
- Particle number concentrations larger than 2000 cm^{-3} should be avoided during calibration in order to minimise water vapour depletion effects on the maximal supersaturation and the droplet growth kinetics (see Lathem and Nenes, 2011).
- Supersaturation calibrations should be performed at least every 6 months.

2.3.2 Köhler theory for ammonium sulphate

Ammonium sulphate, $(\text{NH}_4)_2\text{SO}_4$, and sodium chloride, NaCl, are most commonly used as calibration standard for the CCNC. Ammonium sulphate is recommended in Sect. 2.3.1 as a calibration standard because its thermodynamic properties are well known and because the ammonium sulphate particles are almost spherical. Key properties of aqueous ammonium sulphate solutions required for calculating the critical supersaturation as a function of particle diameter using Köhler theory (e.g. McFiggans et al., 2006) are: water activity, surface tension and density of the solution as a function of solute concentration. Many more or less reliable models and parametrisations of these properties are available in literature (e.g. Rose et al., 2008). It is recommended in Sect. 2.3.1 that the same thermodynamic data for aqueous ammonium sulphate solutions are taken by all CCNC users to calculate equilibrium vapour pressures with Köhler theory. For this purpose, a lookup-table containing the critical supersaturation of ammonium sulphate particles as a function of dry diameter and temperature has been made available on the internet:

<http://www.actris.net/LinkClick.aspx?fileticket=Ay zv Qgom QXk%3d&tabid=5081&mid=17174&language=en-GB>

This lookup-table is essentially based on the Köhler theory implementation described in Gysel et al. (2002) and it has been verified against the Aerosol Diameter Dependent Equilibrium Model (ADDEM; Topping et al., 2005). The code for calculating this look-up table can also be obtained in Wavemetric's Igor Pro Software (contact: martin.gysel@psi.ch).

2.3.3 Data analysis approach for the supersaturation calibration

This section lists several aspects that are considered to be crucial to retrieve an accurate CCNC supersaturation calibration curve from the raw calibration data acquired according to the instructions above.

Recommendations:

- The plateau value corresponding to activation of all particles at larger diameters/high supersaturation should be at 1.0 ± 0.1 . Higher or lower values indicate a malfunction of the CCNC (or CPC).

- A sophisticated inversion of the raw calibration data to account for the effects of the finite DMA transfer function and/or multiply charged particles is not required (multiply charged particles can easily be identified in the raw measurement of a homogeneous aerosol).
- A sigmoid or error function is recommended to fit the observed activation ratio (CCN number concentration divided by the CPC number concentration) as a function of particle diameter in order to retrieve the critical diameter from a D-scan at a fixed supersaturation. Accounting for multiply charged particles is done by setting the baseline of the fit function to the plateau value of the activation ratio in between the activation steps of doubly and singly charged particles. The maximum value of the fit function is set to the plateau value of the activation ratio observed at the particle diameters above the activation step of the singly charged particles (should be 1.0 ± 0.1). The half rise position and width of the fit function remain the only free fit parameters, where the half rise position represents the critical diameter for CCN activation. (Retrieving the critical supersaturation from an S-scan at a fixed particle diameter is done in an equivalent manner.)
- Theoretical size- and temperature dependent critical supersaturation values of ammonium sulphate for the evaluation of the calibration measurement should be taken from the lookup-table provided in Sect. 2.3.2). Other thermodynamic models that agree within 2% (relative) with the lookup-table are also acceptable. (Note: the thermodynamic model used by the manufacturer deviates more than this tolerance from the reference theory. Furthermore, the supersaturation calibrations are made at around 840 mbar, which is lower than the ambient pressure at most monitoring stations. Relying on the manufacturers CCNC calibration thus needs additional efforts to ensure that it fulfils the quality standards defined at the beginning of Sect. 2).
- The theoretical supersaturation values from the lookup-table should be taken for the temperature $T_{\text{act}} = 0.5(T_1 + T_2)$, where T_1 and T_2 are the temperatures at the top and centre of the activation column wall, respectively (see Sect. 4.1 for details).
- The calibration curve should be established between the supersaturation and the temperature gradient. The supersaturation is inferred from the observed critical diameter (D-scans) or critical supersaturation (S-scans) of the calibration particles. The temperature gradient is defined as $\Delta T = 2(T_2 - T_1)$. See also in Sect. 4.1 for the reasons of choosing this particular definition of ΔT as well as a recommendation concerning the use of nominal temperature setpoint values versus actual temperature readings.
- Normally, a linear calibration curve (with non-zero axis intercept) should be applied when relating critical supersaturation to temperature gradient. Small deviations from linearity can occur and may be accounted for with non-linear calibration curves if needed. However, strong deviations from linearity may indicate potential problems (e.g. bad humidifier performance).

2.4 OPC calibration

The optical particle counter (OPC) in the CCNC instrument can, besides the mere counting, also be used to determine the size of the activated droplets, in order to investigate the droplet growth kinetics. However, this is beyond the scope of CCN monitoring activities.

A systematic drift in time of the resulting droplet sizes would most likely indicate a drift of the supersaturation calibration. It is sufficient to look at relative droplet size changes to identify such drifts.

Recommendations:

- The calibration of the OPC for accurate optical sizing is optional.

3 Standard operation procedure (SOP)

3.1 Standard operation mode

The CCNC can be operated in different manners and with different experimental setups (see Sect. 1). The station operators are essentially free in their choice of operation mode but the following recommendations should be considered.

Recommendations:

- No recommendation is made regarding the preferred experimental setup for the CCN measurement. Both polydisperse CCN number concentration or monodisperse CCN number size distribution measurements can be done.
- The traditional approach varying the supersaturations by stepping the temperature gradient at constant flow rate is recommended for normal CCNC users.
- The stepping temperature gradient approach is recommended for basic CCNC users to vary the supersaturation. Expert CCNC users can apply the scanning flow rate approach to vary the supersaturation, but careful quality assurance using a detailed modelling of the instrument behaviour for all calibration and ambient sample measurements will be required (Lathem and Nenes, 2011; Raatikainen et al., 2012).

3.2 Standard operation parameters

This section indicates appropriate ranges for several user-selectable CCN instrument parameters. Standard supersaturation settings and measurement cycle durations are also defined in order to make measurements from different monitoring sites easily comparable.

General recommendations:

- The standard total flow rate is 0.5 L min^{-1} . Other flow rates between a minimum of 0.2 L min^{-1} and a maximum of 1 L min^{-1} may be chosen. However, very low total flow rates may result in enhanced diffusion losses (see Sect. 4.2). The maximal possible flow rate is limited by droplet growth rate. It must be ensured that the activated CCN grow to detectable droplet sizes in the OPC.
- Ratio of sample to total flow rate: the standard value is 1:10. Flow ratios in the range between 1:7 and 1:12 still provide valid CCN measurements.
- Often turbulence in the sample flow line creates a great deal of noise in the sample and sheath flows, especially if the CCN picks off a much faster flow line or if the flow in the sample stack is turbulent due to high winds. A remedy for this is to have the CCN sample line flow through a large diameter line or mixing vessel to remove pressure fluctuations from the line. The default flow rate PID values are optimized for fast control of the flow proportional valve. The flow stability can be increased by optimizing the instrument PID values for a slower response in the DMT Service Tab. Refer to the DMT manual on how to optimize these values.
- Instrument temperatures: It should be ensured that the temperature at the top of the activation column (T_1) is below the inlet temperature (T_{inlet}). Furthermore, T_1 should remain "constant" within a band of $\sim 10^\circ\text{C}$ width and T_1 should also remain below 30°C .
- Enough time should be given at each supersaturation setpoint to ensure good counting statistics during the interval with fully stabilised column temperatures (see also Sect. 4.3).
- The total CCN number concentration measured at the highest supersaturation of 1.0% should be compared with the integrated DMPS/SMPS particle number concentration in order to check the plausibility of the measurements. This should be done at least on a monthly basis.

Specific recommendations for polydisperse CCN measurements:

- Common supersaturations should be: $SS = 0.1, 0.2, 0.3, 0.5$ and 1.0% . The highest supersaturation of 1.0% is mainly required for the plausibility check against the DMPS/SMPS as described in the general recommendations (see above). It may be skipped from the regular supersaturation cycles but intermittent measurements at $SS = 1.0\%$ are required.
- A finer resolution of the supersaturation spectrum may be chosen if possible and desired: $SS = 0.1, 0.15, 0.2, 0.25, 0.3, 0.35, 0.4, 0.5, 0.7,$ and 1.0% .
- When using the scanning flow CCNC operation mode: at least 2 temperature gradients are needed to cover the whole SS-range from 0.1 to 1.0% . The lower supersaturation range (0.1 - 0.5%) should permanently be covered, while measurements at high supersaturation are only intermittently done.
- The duration of a complete measurement cycle covering the whole supersaturation spectrum should be one hour or shorter.

Specific recommendations for monodisperse CCN measurements:

- The experimental setup for monodisperse CCN measurements must include a dryer, neutralizer, DMA and CCNC as shown in Fig. 1b (the CPC is optional). The neutralizer is crucial in order to account for the charging probability of singly charged particles and to correct for interferences from multiply charged particles (see also Sect. 4.5.1).
- The DMA should be operated as outlined in the SOP for size distribution measurements (Wiedensohler et al., 2012).
- Monodisperse measurements should be done as D-scans, i.e. stepping/scanning the diameter range at a fixed supersaturation.
- The diameter range to be covered during the D-scans should be 40-300 nm (or from zero activation to 300 nm). Covering diameters larger than 300 nm is appreciated but not mandatory. Stopping D-scans at a largest diameter of 300 nm implies that independent size distribution measurements (DMPS/SMPS) have to be used to estimate the number concentration of CCN above 300 nm if they give a substantial contribution (this may be the case at low supersaturation).
- Common supersaturations should be: $SS = 0.1, 0.2, 0.3, 0.5$ and 1.0% . The highest supersaturation of 1.0% is mainly required for the plausibility check against the DMPS/SMPS as described in the general recommendations (see above). It may be skipped from the regular supersaturation cycles but intermittent measurements at $SS = 1.0\%$ are required.
- The duration of a complete measurement cycle covering the D-scans at all supersaturations should be 1 to 1.5 hours.

3.3 Routine instrument maintenance

Instructions for the routine maintenance of the CCNC instrument are for the most part available elsewhere.

Recommendations:

- The maintenance instructions provided in the manufacturer's latest CCNC operator manual should be followed. The manual (DOC-0086; Rev I-2 or later) can be downloaded at: <http://www.dropletmeasurement.com/resources/manuals-and-guides.html>
- A CCNC SOP for the Global Atmosphere Watch (GAW) program is currently in preparation. The instrument maintenance guidelines that will be provided in this document should also be followed.
- Treating the activation column with a weak bleach solution to clean it from bacteria may occasionally be needed (once a year or less often).
- Addition of a weak antibacterial agent to the supply water during normal CCN operation to prevent growth of bacteria in the activation column is not recommended as an influence on the resulting supersaturation cannot be excluded.

4 Data analysis approaches

4.1 Relevant temperature readings and conditions for stable supersaturation

The temperatures of the activation column in the CCNC are needed in several steps of the data analysis. It is important that the appropriate temperature readings are chosen in each step.

Recommendations:

- It has been shown in Fig. 2 that differences between the nominal temperature setpoints and the actual temperature readings may remain even after full stabilisation of the activation column. It is possible to use either nominal temperature setpoint values or actual temperature readings to relate temperature gradient with supersaturation. However, it is crucial to consistently use the same of the two alternatives for evaluating the calibration data and the ambient measurements. Choosing the nominal setpoint temperature values makes it easier to exactly apply the target supersaturation (as the CCNC software also works with nominal temperatures), while it is more difficult to assess whether the target supersaturation is reached within a given tolerance, i.e. whether the column temperatures are sufficiently close to their target values. It is the other way round when using actual temperature readings.

- The Köhler theory, which is used to calculate the critical supersaturation of the calibration particles and to derive hygroscopicity parameters from CCN measurements, is temperature dependent. The relevant temperature in this context is the temperature at the position in the activation column where the growing particles cross the critical activation threshold. This value is typically somewhere between the temperatures at the top (T_1) and the centre (T_2) of the activation column wall. It is recommended to use $T_{act} = 0.5(T_1 + T_2)$ for the Köhler theory calculations (see also Sect. 2.3.3).
- The supersaturation in the CCNC is essentially proportional to the temperature gradient across the wall of the activation column along the cylinder axis. The instrument calibration curve thus relates the supersaturation to the temperature gradient expressed as $\Delta T = 2(T_2 - T_1)$. The temperature gradient across the top half of the activation column wall normally determines the relevant supersaturation. When working with nominal temperature setpoints, the ΔT value provided in the raw data files can directly be used as is. When using actual temperature readings, the temperature gradient should be calculated as $\Delta T_{meas} = 2(T_{2,read} - T_{1,read})$. Note: a slightly smaller temperature gradient is actually applied across the bottom half of the activation column wall. This is controlled by the software parameter “%TG” which is defined such that $(T_3 - T_1)/(1-\%TG) = \Delta T$. “%TG” is normally set to 7% and should not be changed to maintain optimal instrument performance.

4.2 Treatment of diffusion losses

Diffusion losses occur in the CCNC for particles with small diameters. Figure 4, which is taken from Rose et al.(2010), illustrates how the size-dependent diffusion loss factor can be estimated from the supersaturation measurements. Correction of the diffusion losses for polydisperse CCN measurements would only be possible if independent particle number size distribution measurements were available. However, diffusion losses should introduce only a minor bias in the total CCN number concentration measured with a CCNC, unless the dominant number fraction of CCN is very small.

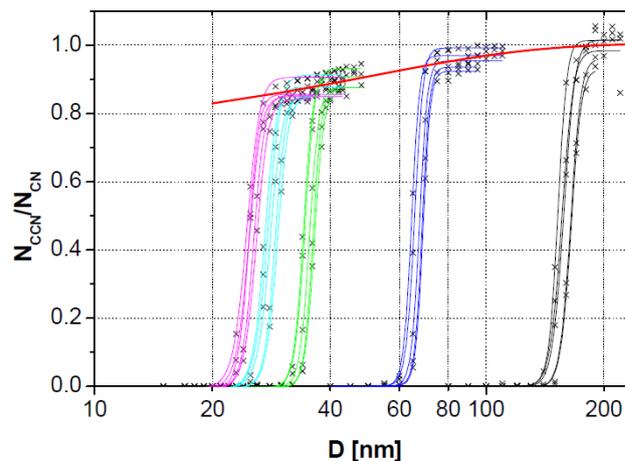


Figure 4: Activation ratios (N_{CCN}/N_{CN}) as a function of dry particle diameter observed during ammonium sulphate calibration of a CCNC (different colours indicate different supersaturations). The drop of the maximal activation ratio (red line) below unity at small particle diameters indicates diffusion losses in the CCNC (relative to the detection efficiency of the reference CPC). This figure is taken from Rose et al. (2010).

Recommendations:

- Diffusion losses in the CCNC can be ignored for ambient measurements at atmospherically relevant supersaturations.

4.3 Filtering and flagging of bad data

Some important parameters that should be used for filtering or flagging of bad data are listed here.

Recommendations:

- The CCNC needs some time to stabilise after supersaturation setpoint changes when applying the normal temperature gradient stepping mode. The duration required for reaching the new target supersaturation depends on several factors such as the size and sign of the temperature gradient

change. The flag “TempsStabilized” provided in the raw data files does reliably indicate all periods when the supersaturation deviates from its target value but it does not reliably indicate whether the target supersaturation is reached. Consequently, “TempsStabilized” should not be used as the single parameter to filter periods with unstable supersaturation. Additional filtering of a fixed interval after the supersaturation setpoint changes is recommended instead. The appropriate duration of this interval for each step in the applied supersaturation cycle should initially be assessed. More sophisticated flagging based on the actual temperature readings may be applied by expert users.

- The flow rates in the CCNC may occasionally be disturbed, e.g. if other processes on the PC cause a high CPU usage. Data points where the total flow rate deviates more than 5% from the target flow rate should be filtered. This should be done with the raw data in the 1-s time resolution format.
- Ambient measurements with CCN number concentrations larger than 5000 cm⁻³ should be flagged as vapour pressure depletion effects reduce the relevant supersaturation (Lathem and Nenes, 2011).

4.4 Specific data analysis steps for polydisperse measurements

4.4.1 Interpolation to the target supersaturation

Often, the CCN measurements are not conducted exactly at the target supersaturation values defined in Sect. 3.2. However, direct comparisons of data sets from different times or stations are only possible if they are available at the same supersaturation.

Recommendations:

- Interpolation of the CCN number concentration measurements to the nearest target supersaturations, as defined in Sect. 3.2, is required before reporting the measurement results to data centres.
- Simple linear interpolation (extrapolation) of the CCN number concentration as a function of supersaturation should be used.
- Any results where the actual supersaturation is more than 20% (relative) off the nearest target supersaturation should be reported as “missing data”.

4.5 Specific data analysis steps for monodisperse measurements

4.5.1 Inversion of the raw data

Interferences from multiply charged particles may have a substantial influence on the raw data of monodisperse CCN size distribution measurements. Fortunately, it is possible to account for these interferences in a quantitative manner.

Recommendations:

- An appropriate data inversion algorithm must be applied to the raw data of monodisperse CCN number size distribution measurements. The data inversion can for example be done in the same manner as for standard particle size distribution measurements using a DMPS/SMPS. The inversion algorithm must account for size dependent transfer probability of the DMA, for the charging probability of singly charged particles and correct for the interferences of multiply charge particles. This is only possible if a neutraliser is included in the experimental setup (see Sect. 3.2).
- It is not required to invert the smearing of the size distribution caused by the finite width of the DMA’s transfer function.
- The results from monodisperse CCN measurements should be reported as CCN number size distribution (rather than activated fraction as a function of particle size).

4.5.2 Interpolation to the target supersaturation

Often, the CCN measurements are not conducted exactly at the target supersaturation values defined in Sect. 3.2. However, direct comparisons of data sets from different times or stations are only possible if they are available at the same supersaturation.

Recommendations:

- Interpolation of the CCN number size distribution measurements to the nearest target supersaturations, as defined in Sect. 3.2, would in principle be desirable. However, an appropriate

interpolation approach has not yet been identified. For this reason, particular care should be taken to conduct monodisperse CCN measurements as close as possible to the target supersaturations.

5 File formats for data reporting

Easy access to all available quality-assured data sets of atmospheric aerosol properties is very important for atmospheric and climate research. Submission of the ambient CCN measurements to the world data centre for aerosols (WDCA; <http://www.gaw-wdca.org/>) is thus a crucial step in implementing the CCN monitoring activities in the ACTRIS research infrastructure network. The file formats for reporting the CCN data to the WDCA have been defined. They are described in full detail on the WDCA web page:

- Regular annual data reporting (level 2):
<http://www.gaw-wdca.org/SubmitData/RegularAnnualDataReporting/CloudCondensationNucleusCounterregular/tabid/3260/Default.aspx>
- Advanced reporting, level 0:
<http://www.gaw-wdca.org/SubmitData/AdvancedDataReporting/Level0/CloudCondensationNucleusCounterlevel0/tabid/5000/Default.aspx>
- Advanced reporting, level 1:
<http://www.gaw-wdca.org/SubmitData/AdvancedDataReporting/Level1/CloudCondensationNucleusCounterlevel1/tabid/5001/Default.aspx>

6 Acknowledgements

We would like to express our particular thanks to all CCNC users among the ACTRIS partners as well as to Anne Jefferson, John Ogren, Thanos Nenes who provided valuable input for this document.

7 References

- Gysel, M., Weingartner, E., and Baltensperger, U.: Hygroscopicity of aerosol particles at low temperatures. 2. Theoretical and experimental hygroscopic properties of laboratory generated aerosols. *Environ. Sci. Technol.*, **36**, 63-68, doi:10.1021/es010055g, 2002.
- Lance, S., Medina, J., Smith, J. N., and Nenes, A.: Mapping the operation of the DMT Continuous Flow CCN counter. *Aerosol Sci. Technol.*, **40**, 242-254, doi:10.1080/02786820500543290, 2006.
- Latham, T. L. and Nenes, A.: Water vapor depletion in the DMT continuous-flow CCN chamber: effects on supersaturation and droplet growth. *Aerosol Sci. Technol.*, **45**, 604-615, doi:10.1080/02786826.2010.551146, 2011.
- McFiggans, G., Artaxo, P., Baltensperger, U., Coe, H., Facchini, M., Feingold, G., Fuzzi, S., Gysel, M., Laaksonen, A., Lohmann, U., Mentel, T. F., Murphy, D. M., O'Dowd, C. D., Snider, J. R., and Weingartner, E.: The effect of physical and chemical aerosol properties on warm cloud droplet activation. *Atmos. Chem. Phys.*, **6**, 2593-2649, doi:10.5194/acp-6-2593-2006, 2006.
- Moore, R. H. and Nenes, A.: Scanning flow CCN analysis - A method for fast measurements of CCN spectra. *Aerosol Sci. Technol.*, **43**, 1192-1207, doi:10.1080/02786820903289780, 2009.
- Raatikainen, T., Moore, R. H., Latham, T. L., and Nenes, A.: A coupled observation - modeling approach for studying activation kinetics from measurements of CCN activity. *Atmos. Chem. Phys.*, **12**, 4227-4243, doi:10.5194/acp-12-4227-2012, 2012.
- Roberts, G. C. and Nenes, A.: A continuous-flow streamwise thermal-gradient CCN chamber for atmospheric measurements. *Aerosol Sci. Technol.*, **39**, 206-221, doi:10.1080/027868290913988, 2005.
- Rose, D., Gunthe, S. S., Mikhailov, E., Frank, G. P., Dusek, U., Andreae, M. O., and Pöschl, U.: Calibration and measurement uncertainties of a continuous-flow cloud condensation nuclei counter (DMT-CCNC): CCN activation of ammonium sulfate and sodium chloride aerosol particles in theory and experiment. *Atmos. Chem. Phys.*, **8**, 1153-1179, doi:10.5194/acp-8-1153-2008, 2008.

- Rose, D., Nowak, A., Achtert, P., Wiedensohler, A., Hu, M., Shao, M., Zhang, Y., Andreae, M. O., and Pöschl, U.: Cloud condensation nuclei in polluted air and biomass burning smoke near the mega-city Guangzhou, China - Part 1: Size-resolved measurements and implications for the modeling of aerosol particle hygroscopicity and CCN activity. *Atmos. Chem. Phys.*, **10**, 3365-3383, doi:10.5194/acp-10-3365-2010, 2010.
- Topping, D. O., McFiggans, G. B., and Coe, H.: A curved multi-component aerosol hygroscopicity model framework: Part 1 - Inorganic compounds. *Atmos. Chem. Phys.*, **5**, 1205-1222, doi:10.5194/acp-5-1205-2005, 2005.
- Wiedensohler, A., Birmili, W., Nowak, A., Sonntag, A., Weinhold, K., Merkel, M., Wehner, B., Tuch, T., Pfeifer, S., Fiebig, M., Fjåraa, A. M., Asmi, E., Sellegri, K., Depuy, R., Venzac, H., Villani, P., Laj, P., Aalto, P., Ogren, J. A., Swietlicki, E., Williams, P., Roldin, P., Quincey, P., Hüglin, C., Fierz-Schmidhauser, R., Gysel, M., Weingartner, E., Riccobono, F., Santos, S., Grüning, C., Faloon, K., Beddows, D., Harrison, R., Monahan, C., Jennings, S. G., O'Dowd, C. D., Marinoni, A., Horn, H.-G., Keck, L., Jiang, J., Scheckman, J., McMurry, P. H., Deng, Z., Zhao, C. S., Moerman, M., Henzing, B., de Leeuw, G., Löschau, G., and Bastian, S.: Mobility particle size spectrometers: harmonization of technical standards and data structure to facilitate high quality long-term observations of atmospheric particle number size distributions. *Atmos. Meas. Tech.*, **5**, 657-685, doi:10.5194/amt-5-657-2012, 2012.