



## Intercomparison of Quadrupole Aerosol speciation chemical monitors

**Project No.:** ACSM-2016-1-15

### Basic information

**Location of the quality assurance:** SIRTa, Lab 705

**Delivery date:** February 26<sup>th</sup>, 2016

**Setup in the laboratory:** February 29<sup>th</sup>, 2016

**Comparison and calibration period:** from March 3<sup>rd</sup> to March 14<sup>th</sup>, 2016

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## 1.0 Overview of the intercomparison.

The UHEL instrument passed the quality standards required as part of the ACTRIS2 network. These requirements include:

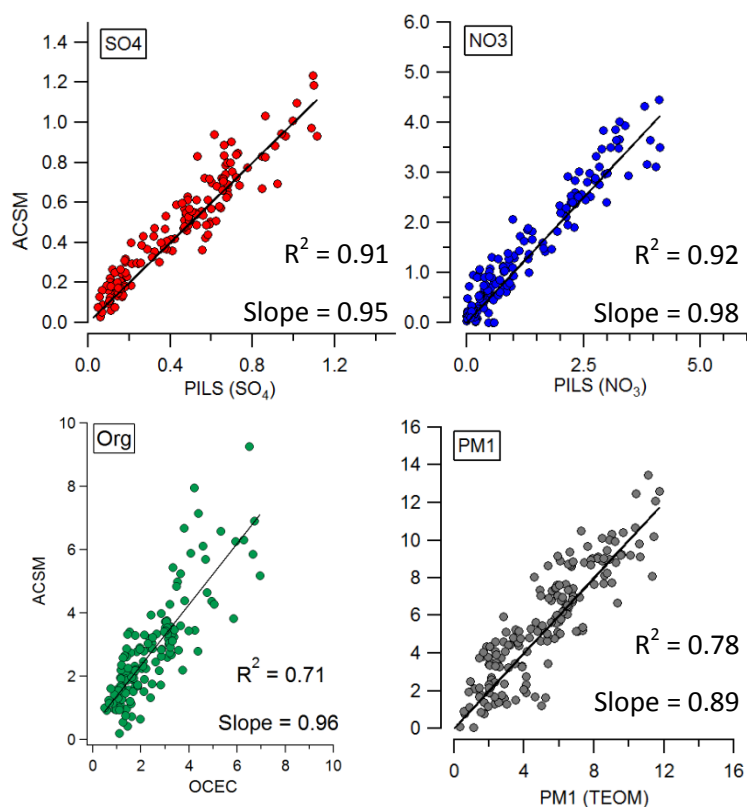
- 1) That the instrument performance is within the acceptable limits evaluated using the Z-score method by ISO 5725-2 compared with the median of all instruments.
- 2) The instrument performance was within  $\pm 30\%$  of the reference instrument.

From March 3<sup>rd</sup> to March 14<sup>th</sup> the UHEL QACSM participated in the ACMCC ACTRIS-2 workshop. The workshop consisted of an entrance intercomparison test and a final intercomparison check. In addition to these ambient measurement intercomparisons, there were a number of different calibrations performed. The calibrations included monodisperse (300 nm) ammonium nitrate and ammonium sulfate solutions, and polydisperse mixtures of ammonium nitrate and ammonium sulfate.

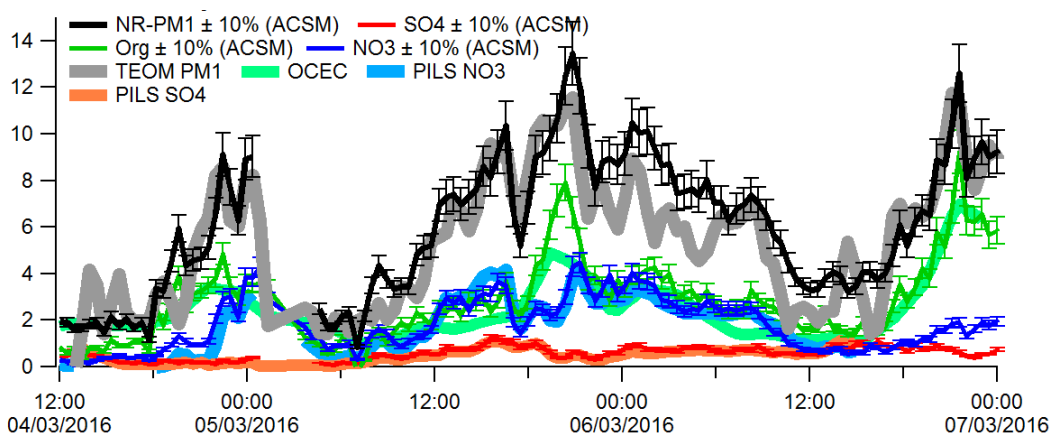
The report is divided into six main sections. The first section shows the status of the reference instruments in the week prior to the measurements period. The second section includes instrumentation on the laboratory setup, and the list of instruments used for the calibration. The third section outlines the error estimation for the ACSM instruments. In the final sections, we show the pre and post intercomparison results as a function of chemical species as well as the calibration results and the optimum settings that were determined for this instrument.

## 2.0 Reference instrument

The reference instrument was chosen to be the SIRTa instrument. This instrument participated in the previous ACSM intercomparisons and it has not been moved from the site since mid-2013. The instrument is regularly maintained and calibrated by the ACMCC staff. In order to validate this instrument's performance it is compared with several other collocated instrumentation at the site. These instruments include a particle into liquid sampler (PILS (PM1) for inorganic anions ( $\text{SO}_4^{2-}$ ,  $\text{NO}_3^-$ ), and cations ( $\text{NH}_4^+$ ). A sunset OCEC sampler for total OM. A TEOM-FDMS for total number concentration of submicron particles (PM1) measurements.



**Figure 2.1. Comparison of SO<sub>4</sub> measured by the SIRTA instrument with PILS-SO<sub>4</sub> measurements made at the site, NO<sub>3</sub> measured by the ACSM compared with that measured by the PILS-NO<sub>3</sub>, Organic measured by the SIRTA instrument compared with that of the OCEC instrument, and Total PM<sub>1</sub> measured by the ACSM compared with that from the TEOM instrument.**



**Figure 2.2. Time series comparison of of SIRTA organic, SO<sub>4</sub> and NO<sub>3</sub> species, with co-located online sampling instrumentation.**

The reliability of the SIRTAs instrument as a reference instrument was determined using comparisons with co-located external instrumentation for inorganic  $\text{SO}_4^{2-}$  and  $\text{NO}_3$  species as well as with  $\text{PM}_{10}$  species (Fig. 2.1, 2.2). Over the pre-calibration period we observe that the ACSM instrument agreed very well with the external instrumentation giving slopes ranging between 0.89 and 0.98, and correlations  $R^2 > 0.78$  for all species. The supplementary measurements PILS were not chosen as reference instruments since they do not technically measure the same particle types and differences in the measurements could be due to different particle types (refractory vs non-refractory,  $\text{PM}_{10}$  vs  $\text{PM}_{2.5}$ ) being measured rather than varying instrument performance.

### 3.0 Error estimation

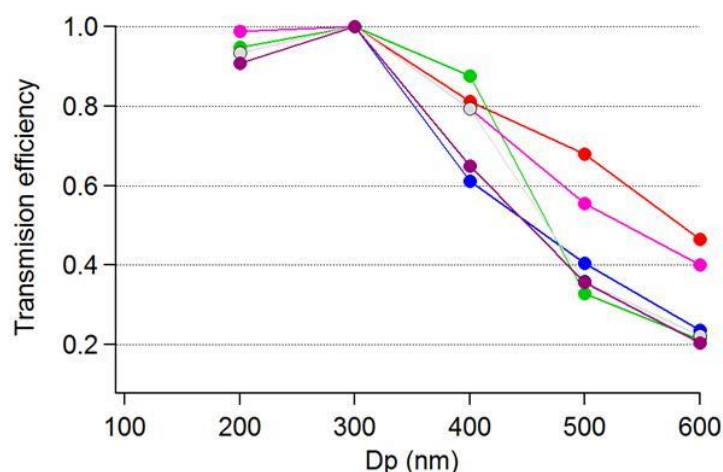
An error of 30% was used as the acceptable variation of a test instrument compared with the reference instrument. This error was estimated from a combination of tests performed during the intercomparison campaign. This is a first estimate and further analysis and tests will be performed to provide more accurate error calculations.

The first parameter that was taken into account for the error calculation was the error associated with calibrations (Error 1): reproducibility of the calibration using the same operator and the same calibration set-up. We calculated the calibration repeatability to be 24% between different operators (comparing the previous noted calibration values with those values obtained at the ACMCC), however repeatability of calibrations performed during the ILC exercise by the ACMCC staff and using the same set up were up to 14%. The second identified source of error was the efficiency with which aerosol particles are transmitted through the aerodynamic inlet (Transmission efficiency (TE)) (Error 2). We show in Figure 3.1 the TE for 5 different ACSM instruments measured for diameters from 200 nm up to 600 nm. The maximum variability associated with these measurements was calculated to be 25%. The final source of error that was taken into account is the variability in the chemical dependent collection efficiency (CDCE, Middlebrook et al., (2012) (Error 3). This was calculated independently for each instrument, the variability among these values under the same ambient sampling conditions was 5%.

Combining these errors using Eq 1 gives us a maximum error of 29%, these agrees well with previous estimates of aerodyne AMS instruments (30%) (Middlebrook et al.,

2012, Bahreini et al., 2009). Further analysis will be made to improve these estimates.

$$\sqrt{\sum Error1^2 + Error2^2 + Error3^2} \quad (Eq.1)$$



**Figure 3.1 Transmission efficiency measured for five different instruments from diameters of 200 nm up to 600 nm.**

#### 4.0 Pre-calibration intercomparison

Instruments were installed as shown in Figure 4.1. There were four different tables, each containing three to four instruments. Each table had its own inlet, fitted with a PM 2.5 cyclone. Relative Humidity (RH) was measured at each inlet and never increased above 30%. Most instruments were fitted with an additional nafion dryer. All sampling lines were composed of ½ inch copper tubes and were the same length for each instrument. All instruments sampled 3 l/min from the main inlet line, this flow was controlled by external sample line flow pumps.

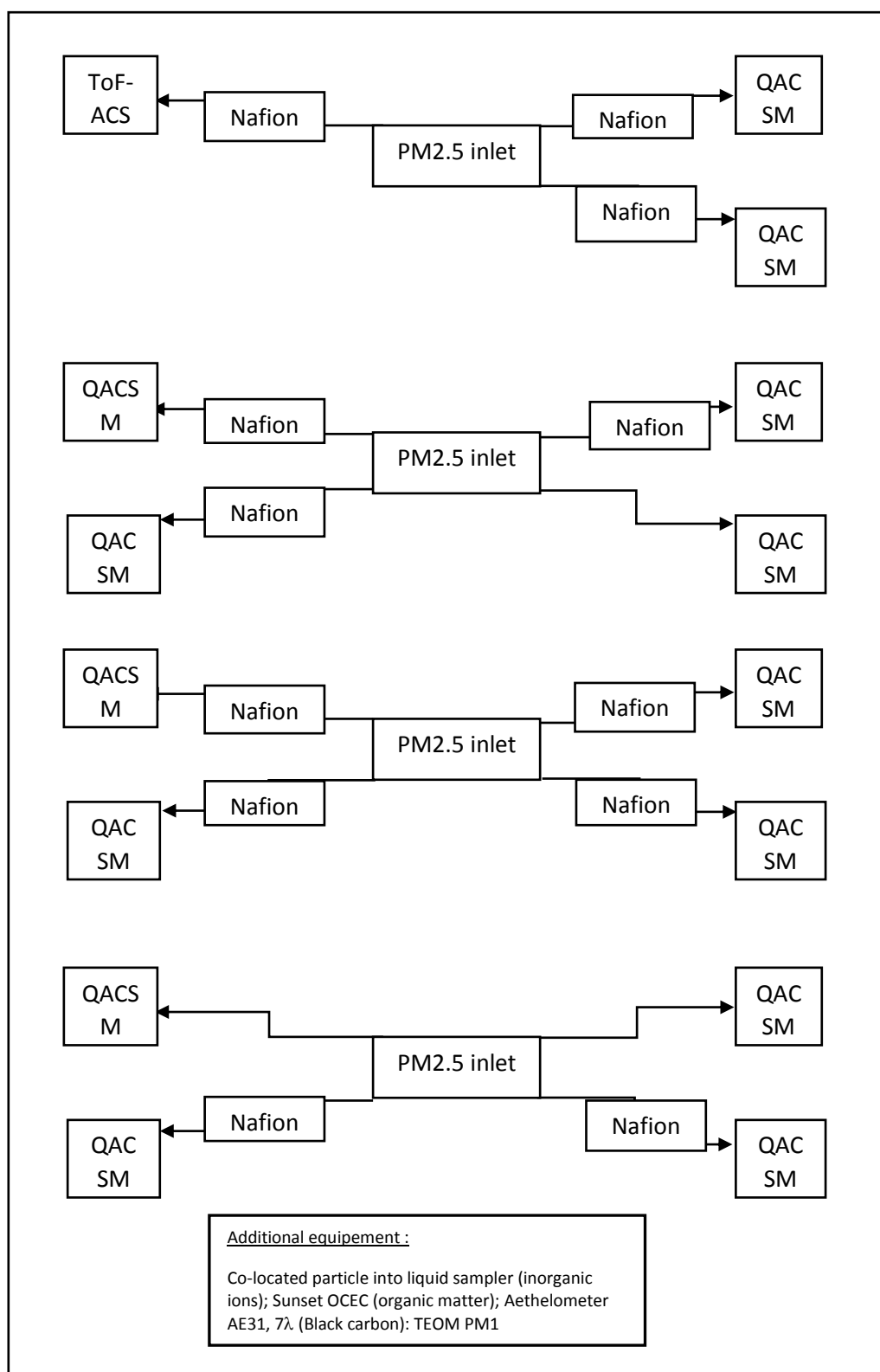


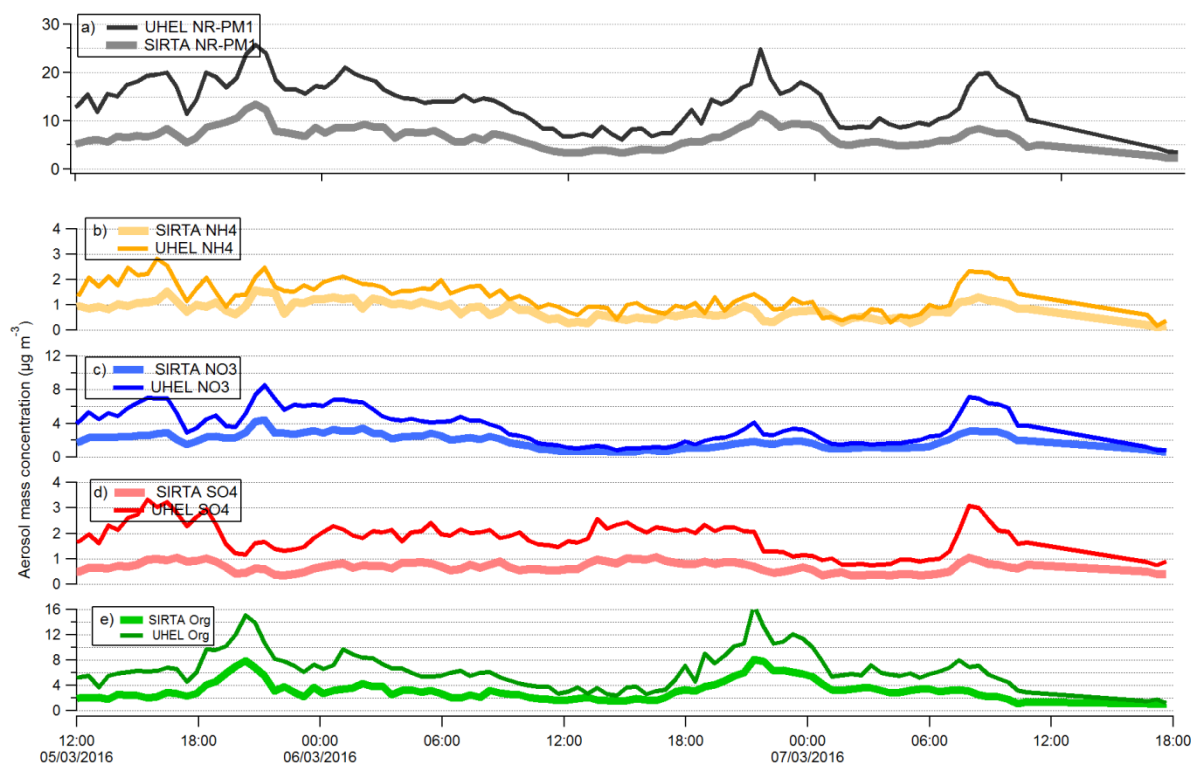
Figure. 4.1 Instrument set up during the intercomparison at the ACMCC.

Instruments were installed at their respective tables and turned on and left sampling at the station from the 4<sup>th</sup> to the 7<sup>th</sup> of March 2016. The UHEL instrument settings and calibration values are listed in table 3.1.

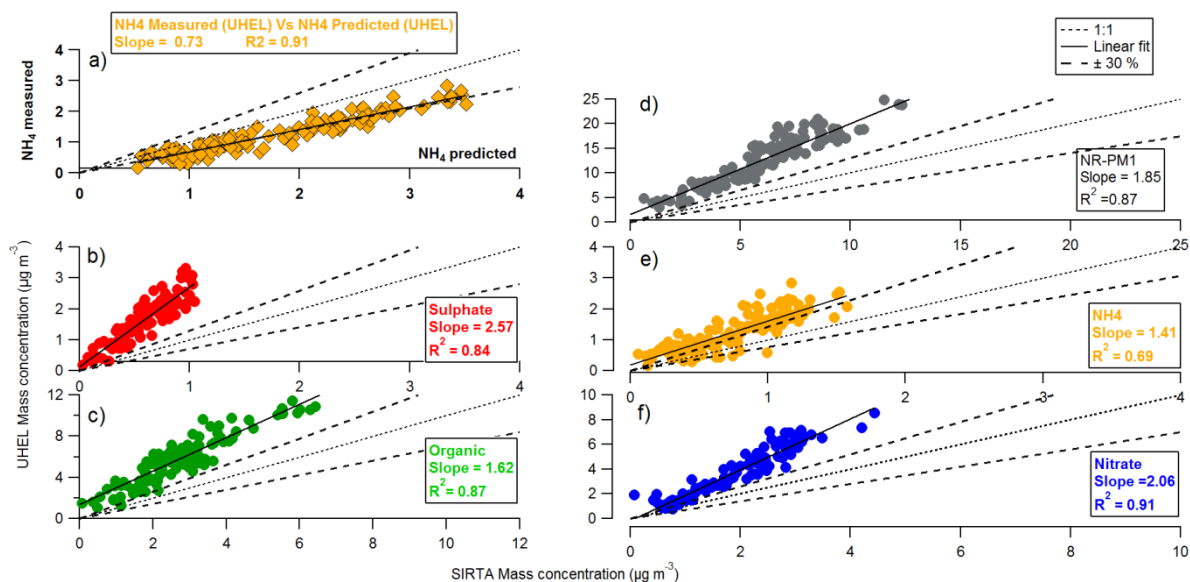
The instrument showed good agreement with the temporal trends of SIRTA reference instrument for total mass concentration, nitrate and organic (Fig. 4.2 and 4.3). However, the absolute concentrations of were largely overestimated by the UHEL instrument with slopes of  $>1.5$  for all species (Fig 4.3). The  $\text{NH}_4$  measured vs predicted show a relatively good agreement but is slightly underestimated with a slope of 0.73 suggesting that the combination of the RF  $\text{NO}_3$  and relative ionization efficiency (RIE) used for the  $\text{NH}_4$  are not suitable for this instrument.

<i>Lens pressure</i>	XXX
<i>Detector V</i>	2131
<i>Recent calibration</i>	
<i>NO3 IE</i>	$4.09 \times 10^{-11}$
<i>NH4 RIE</i>	6.16
<i>SO4</i>	1.2
<i>ACSM DAQ version</i>	2.019
<i>Scan range (amu)</i>	10 – 200
<i>ACSM igor version</i>	6.34

**Table 3.1. UHEL instrument settings prior to calibrations.**



**Figure 4.2.** Comparison of a) total NR-PM1 mass concentration and of each of the individual species measured by the ACSM, as well as the individual chemical species b)  $\text{NH}_4$ , c)  $\text{NO}_3$ , d)  $\text{SO}_4$ , e) Org.



**Figure 4.3.** a)  $\text{NH}_4$  measured vs  $\text{NH}_4$  predicted for UHEL instrument, and comparison of the UHEL instrument with the Sirta instrument for b)  $\text{SO}_4$ , c) Org, d) Total NR-PM1 mass concentration, e)  $\text{NH}_4$ , and f)  $\text{NO}_3$ .



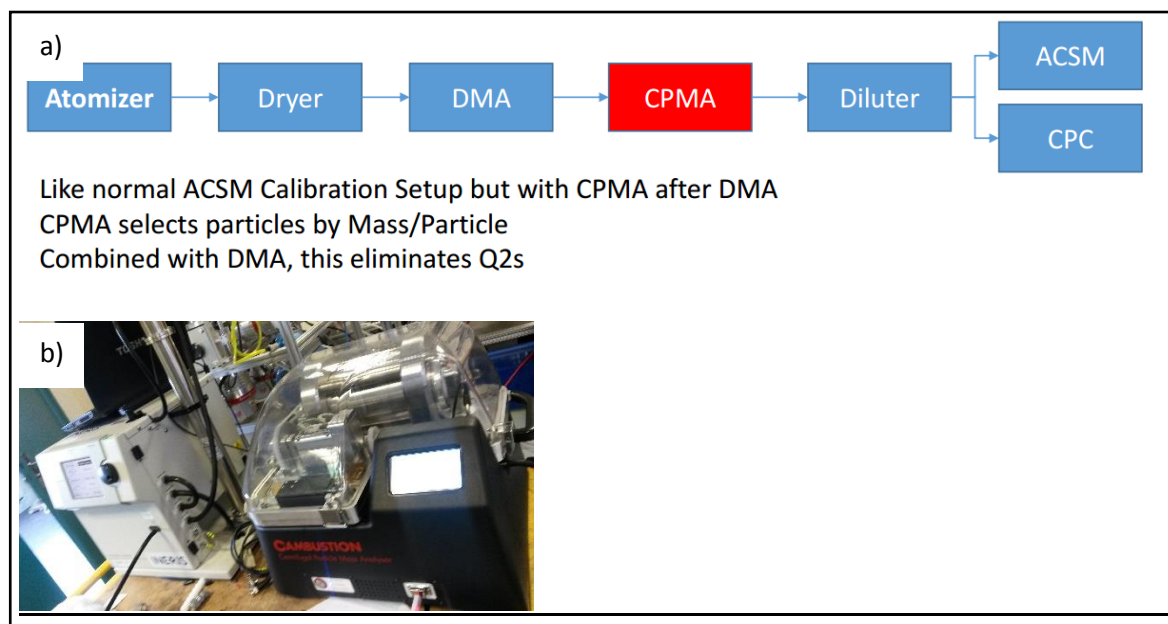
## 5.0 Calibrations

A series of calibrations were performed on each individual instrument. These included: 1) A monodisperse (300 nm) solution of Ammonium nitrate,

2) A monodisperse (300 nm) solution of Ammonium sulfate,

3) Mixtures of Ammonium Sulfate and Ammonium Nitrate (ratios 2:1, 1:2).

The calibration set up for 1) and 2) are illustrated in Fig. 5.



**Figure 5.0: a) Schematic showing Calibration set-up, b) Photo showing the DMA (TSI) and the Centrifugal particle mass analyzer (CPMA).**

The calibration set up included a differential mobility analyzer (DMA, TSI®) to select particles of diameter 300 nm. This DMA was calibrated prior to use, using 300 nm polystyrene latex spheres (PSL). The aerosol particles were then passed into a Centrifugal particle mass analyzer (CPMA) that separates particles by their actual mass and removes doubly charged aerosol particles. These particles are then passed simultaneously into the ACSM and into a condensation particle counter (CPC) (Fig. 5.0).

The response factor (RF) for the ammonium nitrate aerosol particles was calculated using a single salt solution of ammonium nitrate. This was calculated for each instrument and the corresponding ammonium ionization efficiency. The RF is applied to the raw ACSM signal to obtain quantitative information. This value is determined from a known quantity of a known chemical species that enters into the instrument.

The RIE is a chemical dependent value that is applied to different species, and is determined both from the single salt solutions of ammonium nitrate and ammonium sulphate. From these solutions we can calculate a RIE for ammonium and for sulphate.

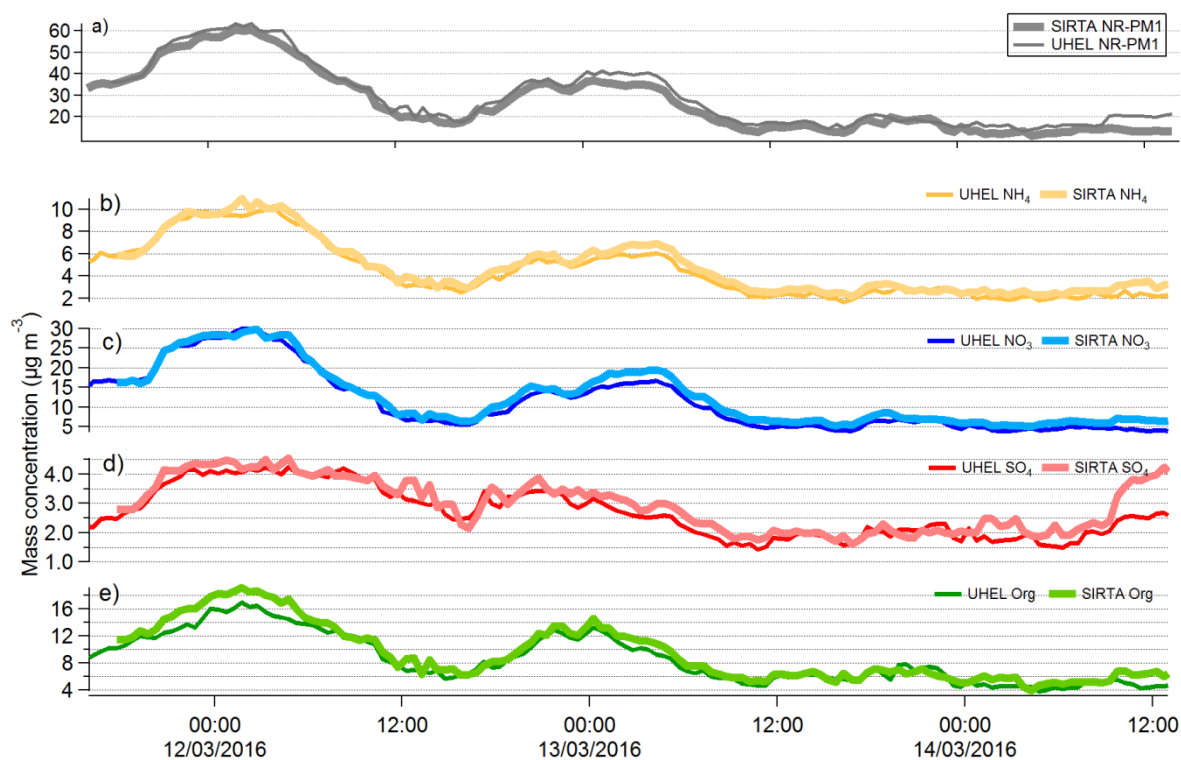
Serial #	RFNO <sub>3</sub>	RIENH4 STD	RIESO4 STD	RIESO4 MIX	RIENH4 MIX
UHEL					
Original	<b>4.09e-11</b>	6.16	1.2	-	-
Calibrated	<b>3.77e-11</b>	4.03	0.93	<b>1.48</b>	<b>4.36</b>

**Table 5: Calibration values for the UHEL instrument for each calibration method. Bold green highlights the recommended values.**

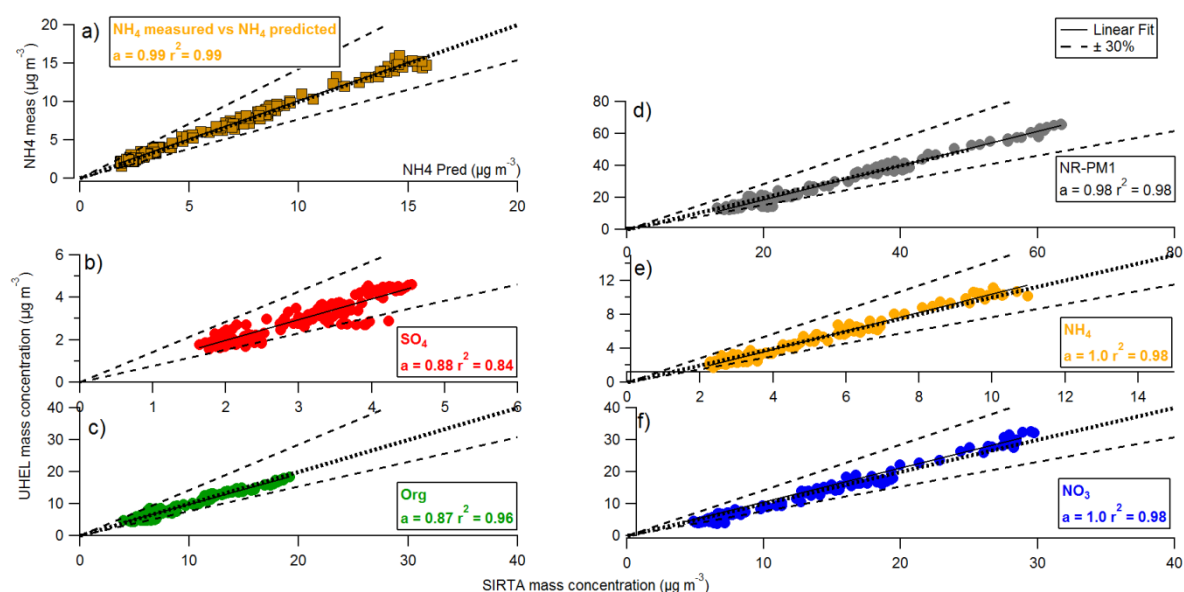
The third calibration, which is a relatively new method, uses mixtures of ammonium nitrate and ammonium sulfate. This calibration provides a verification of the RIE ammonium but also the RIE sulfate. This calibration method provides a more robust method to calculate the RIE ammonium since it is determined from two different compounds. It is advised in the future that the mixture calibration is performed at the site. The up to date calibration values are listed in Table 5.

### 5.1 Post-calibration intercomparison

Once all instruments were calibrated they sampled ambient air for a period of three days, from the 12<sup>th</sup> to the 14<sup>th</sup> of March (Fig. 5.1). This exercise is necessary to verify that all instruments were working correctly, and that these instruments compared well with the reference instrument at the site.



**Figure 5.1. Comparison of UHEL with reference instrument for a) Total PM, b) Ammonia, c) Nitrate, d) sulphate, and e) Organic.**



**Figure 5.2. a)  $\text{NH}_4$  measured vs  $\text{NH}_4$  predicted for UHEL instrument, and comparison of the UHEL instrument with the Sirta instrument for b)  $\text{SO}_4$ , c) Org, d) Total NR-PM1 mass concentration, e)  $\text{NH}_4$ , and f)  $\text{NO}_3$ .**

The post-calibration intercomparison period showed good temporal agreement between UHEL instrument and the SIRTa instrument, with total NR-PM<sub>1</sub> having a slope of 1, and a correlation of  $R^2 = 0.98$  (Fig. 5.2 d)). There was an improvement in all the linear correlations after calibration.

## 5.2 Determining instrument performance

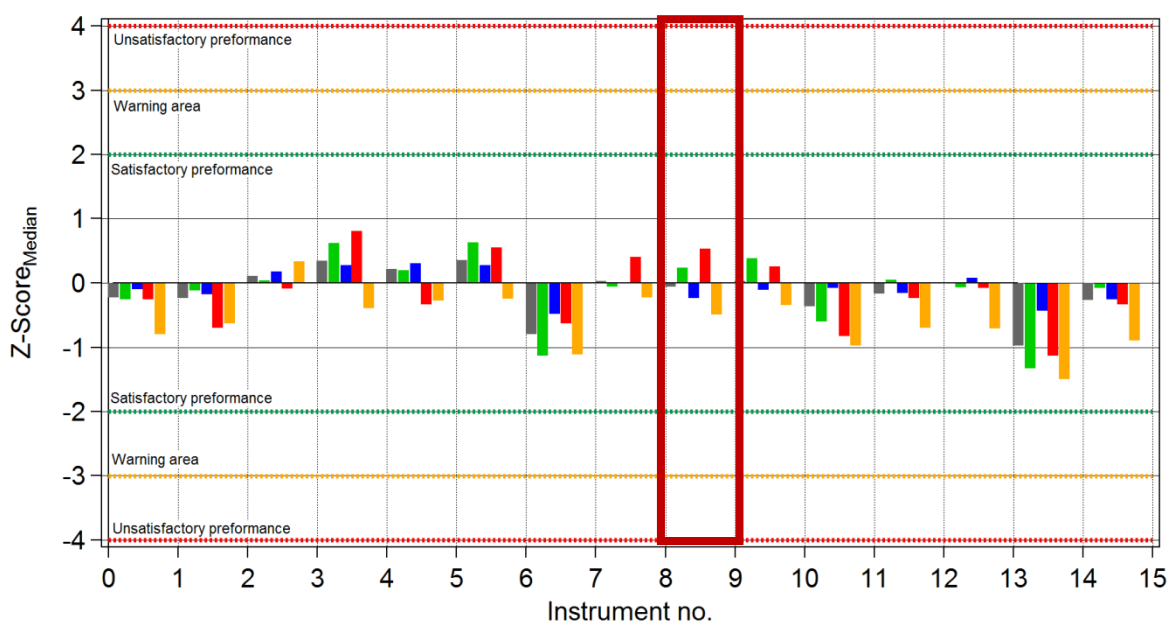
In order to determine whether instruments can be considered to meet the requirements of ACTRIS sampling, we chose to use two independent methods to evaluate each instrument. The first of these methods was to compare each instrument to the reference instrument. The test instrument was deemed to be within acceptable limits if the data points were within  $\pm 30\%$  of the reference instrument values (see section 3.0). The UHEL instrument, falls well within these limits and can therefore be considered to have passed the intercomparison (Fig. 5.2). Variability in the OA has been documented in previous studies (Crenn et al., 2015, Frohlich et al., 2015, Pieber et al., 2016), and continuing efforts are being invested to better understand the artefacts associated with these signals.

The second method chosen was the Z-score analysis following the standards defined by the international standard organization (ISO). These methods were initially validated in the first ACTRIS1 ACSM intercomparison (Crenn et al., 2015). This method has been evaluated according to ISO 5752-2 and provides a means to evaluate instrument performance relative to a reference instrument and to the median of all instruments participating in the intercomparison. This method has been applied to other European intercomparison exercises (JRC technical intercomparison reports). This approach evaluates if the variations in the different instruments from the reference value fall within a defined criterion. This will allow us to highlight any problems with the Q-ACSM instruments. The Z-score was calculated from the different instruments according to ISO 5752-2 (2005) (Eq.2).

$$Z_i = \frac{X_i - X^*}{\sigma_*} \quad \text{Eq. 2}$$

According to this test, instrument performance is considered acceptable when values fall between 2 and -2 (indicated by the green lines in Figures 5.3). Values falling between 2 and 3, may need to be examined. Figure 5.3 shows the z-score calculated for each instrument using the median of all instruments as the reference. The UHEL

instrument is no. 9 (red rectangle). It shows that this instrument is within excellent agreement with the reference instrument.



**Figure 5.3: Z-score calculation for each species measured by the ACSM for each instrument that participated in the intercomparison. These values are compared with the reference instrument Sirta. The red rectangle highlights the UHEL instrument.**

## 6.0 Conclusion

This instrument arrived in operating condition to the site, but the previous calibration values used resulted in this instrument largely overestimating the reference instrument. After calibration, all values fell within the  $\pm 30\%$  range of the reference instrument. Evaluating instrument performance using the z-score method (ISO 5752), showed that this instrument fell within the acceptable limits of good instrument performance in comparison with all participating instruments.

New corrections and up to date fragmentation tables will be developed by the calibration center and made available in the coming months. These will be shared amongst the ACTRIS community.

## 7.0 References

Crenn, V., Sciare, J., Croteau, P. L., et al., (2015), *Atmos. Meas. Tech.*, 8, 7239-7302, doi:10.5194/amtd-8-7239-2015.

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Fröhlich, R., Crenn, V., Setyan, A et al., (2015), **Atmos. Meas. Tech.**, 8, 2555-2576, doi:10.5194/amt-8-2555-2015

Middlebrook, A.N., R. Bahreini, J. L. Jimenez, and M. R. Canagaratna (2012) *Aerosol Sci. Tech.*, 46:258–271.

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