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EURAMET comparison 1282
Comparison of condensation particle counters

FINAL REPORT

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EURAMET 1282:
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EXECUTIVE SUMMARY

Aerosol particle number concentration has recently featured in vehicle emission legislation and is becoming increasingly important in other areas such as ambient air monitoring. Number concentration measurements are also often integral to particle size distribution measurements, such as when using a Mobility Particle Size Spectrometer.

The draft ISO standard ISO/DIS 27891 [1] describes a calibration procedure for Condensation Particle Counters (CPCs - the usual type of instrument for measuring particle number concentration in the size range from a few nanometers to a few micrometers) either by reference to an aerosol electrometer, or to a reference CPC. The DIS refers to the role of NMIs in providing certification for both reference aerosol electrometers and reference CPCs.

The aim of this comparison was to compare the results of different laboratories' measurements of particle number concentration using CPCs (in cm^{-3}).

The comparison took place at the Leibniz Institute for Tropospheric Research (TROPOS) in October 2013 as part of the EMRP project ENV02 PartEmission (Automotive combustion particle metrics), Deliverable 1.2.2.

Because this is the first multi-NMI comparison of CPCs, EURAMET participants were joined by other participants with strong metrological expertise in this area.

The comparison included aerosol particle concentrations between about 100 and 20,000 cm^{-3}, and aerosol particle sizes from 13 to 100 nm, using aerosol particles composed of unsintered silver, sintered silver and soot. The results show discrepancies between instruments with a relatively high (23 nm) 50% cut-off size, even at aerosol particle sizes well above the cut-off size. Apart from this, the results showed that for the full concentration range, and sizes between 23 and 100 nm, agreement to ±10% between reference laboratories is currently achieved.

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1. INTRODUCTION

Aerosol particle number concentration has recently featured in vehicle emission legislation and is becoming increasingly important in other areas such as ambient air monitoring. Number concentration measurements are also often integral to particle size distribution measurements, such as when using a Mobility Particle Size Spectrometer.

The draft ISO standard ISO/DIS 27891 [1] describes a calibration procedure for Condensation Particle Counters (CPCs - the usual type of instrument for measuring particle number concentration in the size range from a few nanometers to a few micrometers) either by reference to an aerosol electrometer, or to a reference CPC. The DIS refers to the role of NMIs in providing certification for both reference aerosol electrometers and reference CPCs.

Although not strictly a chemical measurement, the comparison belongs in the Gas subcommittee of TC-MC because of the similarity to gas concentration measurements, following the precedent of earlier projects 893 (workshops to establish “Metrology infrastructure for airborne nanoparticles”) and 1027 (“Comparison of combustion particle number concentration and size”).

The aim of this comparison was to compare the results of different laboratories’ measurements of particle number concentration using CPCs (in cm^{-3}).

The comparison took place as part of the EMRP project ENV02 PartEmission (Automotive combustion particle metrics), Deliverable 1.2.2.

Because this is one of the first multi-NMI comparisons of CPCs, EURAMET participants were joined by other participants with strong metrological expertise in this area.

2. OPERATION OF THE COMPARISON

2.1. PARTICIPANTS

The 8 participating laboratories in the EURAMET comparison were:

- NPL – United Kingdom (co-ordinating laboratory)
- TROPOS (Leipzig Institute for Tropospheric Research) – Germany, the hosts
- Tampere University of Technology (TUT), in collaboration with MIKES – Finland
- METAS - Switzerland
- PTB - Germany
- JRC-IET – EU
- AIST – Japan
- APSL (US Army Primary Standards Laboratory) – USA

2.2. PARALLEL EXERCISES

Three distinct exercises were carried out during the week.

(i) A comparison of the participants’ ability to calibrate their CPCs in the “plateau” (size- and particle composition-independent) region of their operation, using a range of particle size, material and concentrations.

(ii) An investigation of the detection efficiencies of the participants' CPCs at particle sizes below the plateau region, using a range of particle size, material and concentrations. This is known to depend on the particle size and composition in subtle ways that make comparisons between different laboratories and particle sources difficult. In this context, several models of CPC with different size characteristics were used, while one participant (PTB) brought two different models of CPC (see Table 1 below).

(iii) As part of a separate deliverable within EMRP project ENV02, non-metrological organisations also took measurements, to demonstrate the suitability of the procedures for wider dissemination of traceability for these measurements.

Only the first of these is reported in detail in this report, though some other data are also included, for convenience.

2.3. PROCEDURE

The comparison was held at the Leipzig Institute for Tropospheric Research (TROPOS) in Germany during the week 14-18 October 2013.

Because transportable measurement standards for aerosols are not easily available, participants brought their CPCs and any associated equipment to TROPOS. The CPCs were connected to a common aerosol source using pipework designed to minimise differences between the ports, taking into account different diffusive losses due to the different flow rates of the CPCs by adjusting the length of the conductive tubing to each CPC, according to theoretical calculations. A length of 70 cm was used for the 1 l/min instruments, and aerocalc software used to determine equivalent loss lengths for the other instruments.

Two types of airborne particle generator were used for the comparison, with three distinct types of particle being produced. A ceramic furnace condensation-type aerosol generator was used to produce Ag particles. These were usually sintered to produce more spherical particles, but on some runs unsintered particles were used, to assess the effect of particle morphology. The second generator was a miniCAST (Series 5200) generating soot particles.

All measuring equipment was operated by people from the relevant participant laboratories, with the exception of the APSL equipment, which was operated on their behalf by TROPOS.

Several different commercial designs of butanol CPC were used, as set out in Table 1.

Lab	CPC model	Flow rate (l/min)	Approximate 50% cut-off size
NPL	TSI 3775	0.3	4 nm
TROPOS	TSI 3772	1.0	10 nm
MIKES-TUT	Airmodus A20	1.0	7 nm
METAS	Grimm 5412	0.6	5 nm
PTB (1)	TSI 3772	1.0	10 nm
PTB (2)	TSI 3790	1.0	23 nm
JRC	TSI 3790	1.0	23 nm
APSL	TSI 3772	1.0	10 nm
AIST	TSI 3772	1.0	10 nm

Table 1: Participants' CPCs

Particle sizes were selected within the nominal range 6 to 100 nm, and the concentration range was between around 100 and 20 000 particles cm^{-3}.

Aerosol particle size was characterised by a Mobility Particle Size Spectrometer (MPSS). Accurate assignment of size to aerosol particle distributions is a complex topic in itself, and was not a central aspect of the comparison. The comparison was primarily concerned with the ability of the participants to measure the particle number concentration of the aerosol, while the different sizes were used to indicate limitations of the CPCs and the experimental design.

Further details of the procedure followed are given in the Protocol (Appendix 1), and of the equipment and methods used by the participants in the Results Proformas (Appendix 2).

2.4. COMPARISON RUNS

There were 52 designated runs, described in Table 2 below.

In summary:

Runs 1 - 22 were of sintered Ag particles, of sizes from 6 to 60 nm and concentrations between 100 and 20,000 cm^{-3}.

Runs 23 – 32 were of unsintered Ag particles, of sizes 23 or 41 nm and concentrations between 100 and 20,000 cm^{-3}.

Runs 33 – 52 were of soot particles, of sizes from 23 to 100 nm and concentrations between 100 and 20,000 cm^{-3}.

2.5. REPORTING OF RESULTS

As described in the Protocol (Appendix 1), final results were sent via email using the agreed Proformas (Appendix 2), to allow for recalibration of equipment after its return to the home laboratory.

Participants decided whether particle size was within the plateau region of their CPC, and estimated their own measurement uncertainties independently, with rationales explained on the Proformas.

Run	Nominal particle size (nm)	Nominal concentration cm-3	Particle material
1	60	20000	sintered Ag
2	60	10000	sintered Ag
3	60	5000	sintered Ag
4	60	1000	sintered Ag
5	60	100	sintered Ag
6	41	20000	sintered Ag
7	41	10000	sintered Ag
8	41	5000	sintered Ag
9	41	1000	sintered Ag
10	41	100	sintered Ag
11	26	20000	sintered Ag
12	26	10000	sintered Ag
13	26	5000	sintered Ag
14	26	1000	sintered Ag
15	26	100	sintered Ag
16	13	20000	sintered Ag
17	13	10000	sintered Ag
18	13	5000	sintered Ag
19	13	1000	sintered Ag
20	13	100	sintered Ag
21	6	10000	sintered Ag
22	6	1000	sintered Ag
23	41	20000	unsintered Ag
24	41	10000	unsintered Ag
25	41	5000	unsintered Ag
26	41	1000	unsintered Ag
27	41	100	unsintered Ag
28	23	20000	unsintered Ag
29	23	10000	unsintered Ag
30	23	5000	unsintered Ag
31	23	1000	unsintered Ag
32	23	100	unsintered Ag
33	100	20000	soot
34	100	10000	soot
35	100	5000	soot
36	100	1000	soot
37	100	100	soot
38	80	20000	soot
39	80	10000	soot
40	80	5000	soot
41	80	1000	soot
42	80	100	soot
43	41	20000	soot
44	41	10000	soot
45	41	5000	soot
46	41	1000	soot
47	41	100	soot
48	23	20000	soot
49	23	10000	soot
50	23	5000	soot
51	23	1000	soot
52	23	100	soot

Table 2: Description of each run.

3. RESULTS

3.1. REPORTED RESULTS

The full set of reported results for the comparison is given in Table 3.

	NPL		TROPOS		MIKES-TUT		METAS		PTB (1)		PTB (2)		JRC		AIST		APSL	
Run	conc cm-3	u/c (k=2)	conc cm-3	u/c (k=2)	conc cm-3	u/c (k=2)	conc cm-3	u/c (k=2)	conc cm-3	u/c (k=2)	conc cm-3	u/c (k=2)	conc cm-3	u/c (k=2)	conc cm-3	u/c (k=2)	conc cm-3	u/c (k=2)
1	20740	873	21034	716	19820	287			18475.3	1332.0	17877.9	1290.0	17275.5	1816.6	20163	456	20628	681
2	10819	456	10701	381	10444	186			9667.6	697.1	9069.5	654.4	8873.5	953.8	10430	236	11148	368
3	5179	218	5140	271	4983	145			4690.5	338.4	4278.0	308.8	4173.7	458.8	4980	118	5407	178
4	1100	46	1066	27	1034	71			996.6	71.9	851.3	61.5	830	87.8	1050	25	1170	39
5	113	5	110	6	108	6			100.6	7.3	87.7	6.4	85.4	10	108	2.9	121.1	4
6	21909	922	22046	517	20856	302			19316.5	1392.6	15761.5	1137.1	13535		21242	480	21684	716
7	11570	487	10706	245	11174	198			10361.5	747.0	8260.9	596.0	7068.1		11166	252	11890	392
8	5126	216	5021	111	4930	143			4609.3	332.3	3507.3	253.1	2925.2		4937	117	5411	179
9	1062	45	1029	23	997	68			952.3	68.7	700.7	50.6	577.8		1018	24	1135	37
10	159	7	153	7	150	8			141.7	10.3	101.4	7.4	81.6		151	4	169.1	5.6
11	19236	809	18751	420	18556	268			16506.2	991.1	4345.1	261.0	2342.9		19044	1358	19132	631
12	10618	447	10212	266	10220	181			9207.6	552.8	2388.0	172.3	1279.5		10480	747	10934	361
13	5348	225	5087	114	5116	149			4663.1	280.0	966.6	69.8	532.8		5274	378	5596	185
14	1202	51	1138	134	1129	77			1051.6	63.2	177.5	12.9	102.1		1179	85	1279	42
15	140	6	134	16	135	7			123.5	7.5	13.7	1.0	8.6		138	10	149.7	4.9
16	24054	1012	22985	433	22773				17839.6	1071.1	0.0	0.0	0		30122	19162	20192	
17	13058	551	12325	854	12704				10140.3	611.2	0.0	0.0	0		16899	10751	11739	
18	5957	251	5585	145	5822				4758.1	285.7	0.0	0.0	0		7730	4918	5829	
19	1025	43	958	35	987				794.5	47.8	0.0	0.0	0		1311	834	939.4	
20	106	5	99	8	105				80.6	4.9	0.0	0.0	0		134	85	96.5	
21	8733	368	5788	179	7914				1088.4	65.5	0.0	0.0	0				1927	
22	649	27	394	15	587				35.6	2.2	0.0	0.0	0				100	
23	20743	873	20770	532	20210	293			18468.4	1331.4	15639.9	1128.4	10863.6		20088	454	20598	680
24	11059	465	10803	299	10738	191			9874.5	711.9	8261.3	596.1	5932.5		10651	241	11320	374
25	5279	222	5158	98	5088	148			4758.2	343.1	3925.5	283.3	2873.4		5079	121	5574	184
26	1225	52	1184	46	1153	79			1100.7	79.4	908.8	65.6	682.2		1174	28	1304	43
27	98	4	94	6	93	5			90.0	6.5	73.8	5.4	55.8		94	2.5	105	3.5
28	21377	899	21213	380	20736	300			18563.6	1113.3	4154.5	249.5	2517.8		21409	1526	21021	694
29	11345	477	11143	202	11070	196			10022.8	601.1	2311.1	138.8	1407		11371	811	11672	385
30	5366	226	5190	98	5209	151			4764.9	285.8	1125.7	67.7	689.6		5383	386	5619	185
31	1136	48	1088	23	1076	74			1012.5	60.8	277.8	16.7	175.8		1136	81	1208	40
32	116	5	111	6	112	6			103.7	6.3	31.9	2.0	20.3		116	8.4	123.9	4.1
33	26090	1098	26497	546	25075	362	24150	320	23183.1	1672.5	23767.2	1714.7	19323.2	2012.1	25191	569	24644	813
34	13438	565	13191	535	12947	229	12600	165	12038.3	868.6	12007.9	866.3	10157.2	1053.9	12911	292	13146	434
35	6949	292	6764	130	6640	193	6590	90	6248.9	450.9	6145.5	443.4	5288	545.9	6664	158	6937	229
36	1444	61	1390	61	1348	92	1391	18	1302.4	94.0	1268.3	91.6	1097.7	120.4	1378	33	1475	49
37	99	4	95	5	94	5	94.6	1.3	92.5	6.7	90.4	6.6	76.4	9.4	94	2.5	101.7	3.4
38	22372	943	22587	1132	21745	318	22260	300	20114.9	1451.8	20272.2	1463.2	18927.9	2092.4	21769	492	21354	705
39	12826	541	12618	635	12422	223	12680	170	11608.1	838.1	11428.8	825.3	10019.1	1131.3	12350	279	12612	416
40	6203	261	6066	160	5941	173	6020	80	5561.8	401.5	5385.4	388.8	4745.9	503.1	5951	141	6231	206
41	1314	55	1279	37	1231	84	1268	17	1189.6	85.9	1138.3	82.2	1007.6	105.4	1255	30	1356	45
42	153	6	149	8	146	7	149	2	138.0	10.0	133.4	9.7	117.1	13.5	146	3.9	158.7	5.2
43	21038	886	21166	666	20491	298	20160	380	18716.6	1350.6	16423.1	1185.2	12976.4		20441	462	20214	667
44	10907	459	10764	256	10554	187	10380	200	9792.4	706.5	8401.5	606.2	6530.9		10529	238	10870	359
45	4938	208	4800	103	4731	138	4720	90	4442.3	320.5	3740.6	269.9	2906.5		4757	113	5022	166
46	1380	58	1337	32	1292	88	1325	25	1245.6	89.9	1025.8	74.1	799.8		1322	32	1427	47
47	108	5	105	6	103	5	104.5	2	97.3	7.1	80.3	5.8	62.1		104	2.8	112.4	3.7
48	22993	967	23043	527	22365	323	22350	570	20163.2	1210.6	7508.7	450.8	5703.4				21859	721
49	11570	487	11299	193	11264	200	11235	290	10256.7	615.8	3742.1	224.7	2091.9				11465	378
50	5700	240	5530	125	5512	160	5570	145	5084.9	305.3	1801.4	108.2	974.1				5792	191
51	1376	58	1325	33	1297	89	1347	35	1226.2	73.7	430.7	25.9	239.2				1421	47
52	95	4	92	5	91	5	89	2.3	83.7	5.1	28.6	1.8					98.6	3.3

Table 3: Reported results.

The numbers given a yellow background are those that were designated by the participants as being away from the plateau of their CPC. These data are not considered further in this report.

It is notable that while TROPOS and PTB consider that their TSI 3772 instruments are reporting valid results for the 13 nm particles (Runs 16 – 20), AIST and APSL do not.

As explained in the Results Proforma in Appendix 2, the METAS instrument required repair at the start of the comparison, and was only able to participate from the third day (run 33). The AIST data for runs 48 to 52 were inadvertently not recorded.

3.2. PRELIMINARY ASSESSMENT

A preliminary assessment of the results showed that while there was generally good agreement, the two TSI 3790 CPCs (JRC and PTB 2) gave significant lower results than the other instruments, even at particle sizes considered to be in their plateau region. These results are presented in the charts below, but their results are not taken into account when calculating the comparison reference values.

The data from the three laboratories reporting for the 13 nm particles (Runs 16 – 20) - NPL, TROPOS and PTB 1 – also showed significantly more variation, which can be attributed to the size being close to the edge of the plateau region, especially for the TSI 3772 instruments used by TROPOS and PTB.

3.3. COMPARISON REFERENCE VALUE

Independent measurements of particle number concentrations, using an aerosol electrometer, were supplied by TROPOS. However, high accuracy traceable values of particle number concentration also require detailed knowledge of the presence of multiply-charged particles, which will be increasingly significant at the higher particle sizes used, and experimental measurements of these were not available.

The comparison reference value is taken simply to be the mean of the results reported as being "on plateau", with the exception of the cases mentioned in Section 3.2.

3.4. GRAPHICAL PRESENTATION OF RESULTS

Selected results are presented graphically in 9 Figures:

Figure 1: 60 nm sintered Ag at a range of concentrations (Runs 1 – 5)
Figure 2: 26 nm sintered Ag at a range of concentrations (Runs 11 - 15)
Figure 3: 41 nm unsintered Ag at a range of concentrations (Runs 23 – 27)
Figure 4: 23 nm unsintered Ag at a range of concentrations (Runs 28 – 32)
Figure 5: 100 nm soot at a range of concentrations (Runs 33 – 37)
Figure 6: 41 nm soot at a range of concentrations (Runs 43 – 47)
Figure 7: 23 nm soot at a range of concentrations (Runs 48 - 52)
Figure 8: 20,000 cm^{-3} sintered Ag at a range of sizes (Runs 1, 6, 11, 16)
Figure 9: 20,000 cm^{-3} soot at a range of sizes (Runs 33, 38, 43, 48)

In all cases the y-axis shows percentage difference from the comparison reference value.

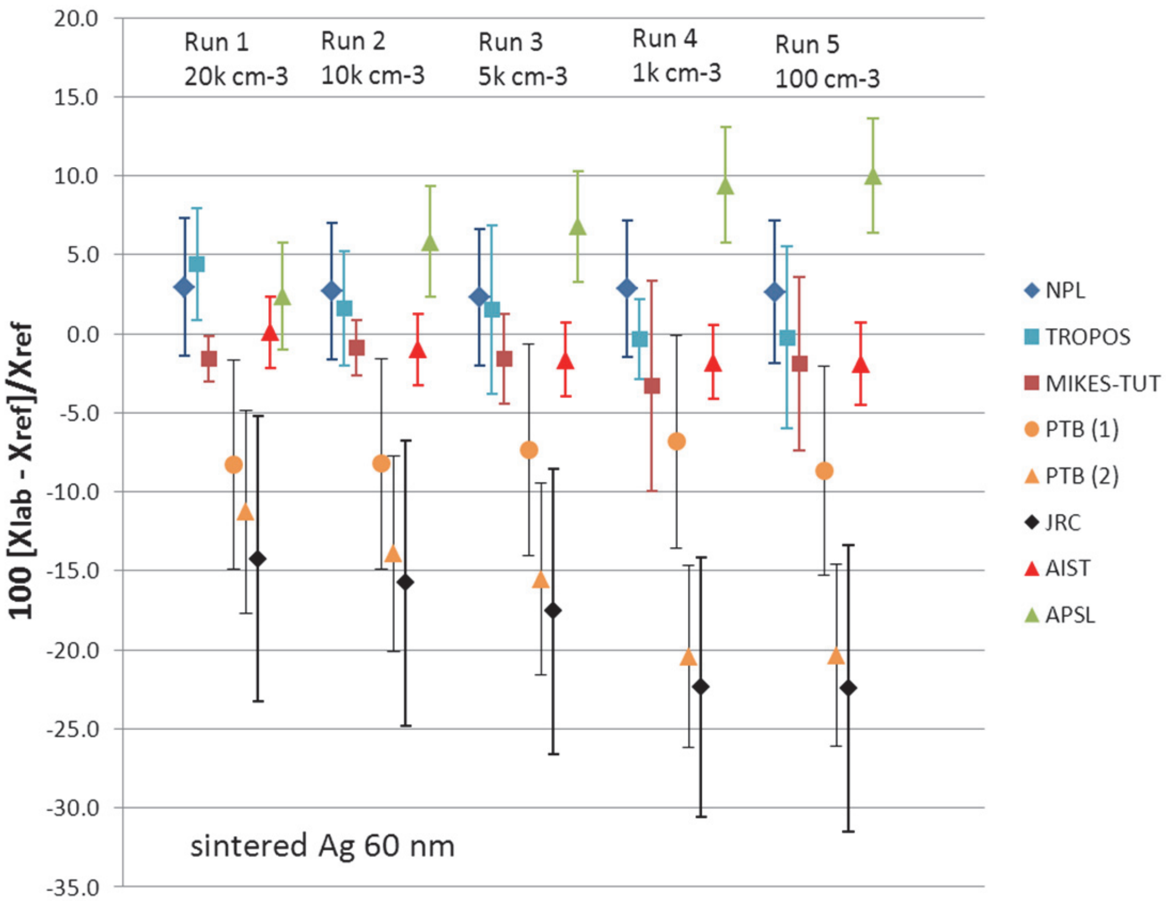

Figure 1: 60 nm sintered Ag at a range of concentrations (Runs 1 – 5)

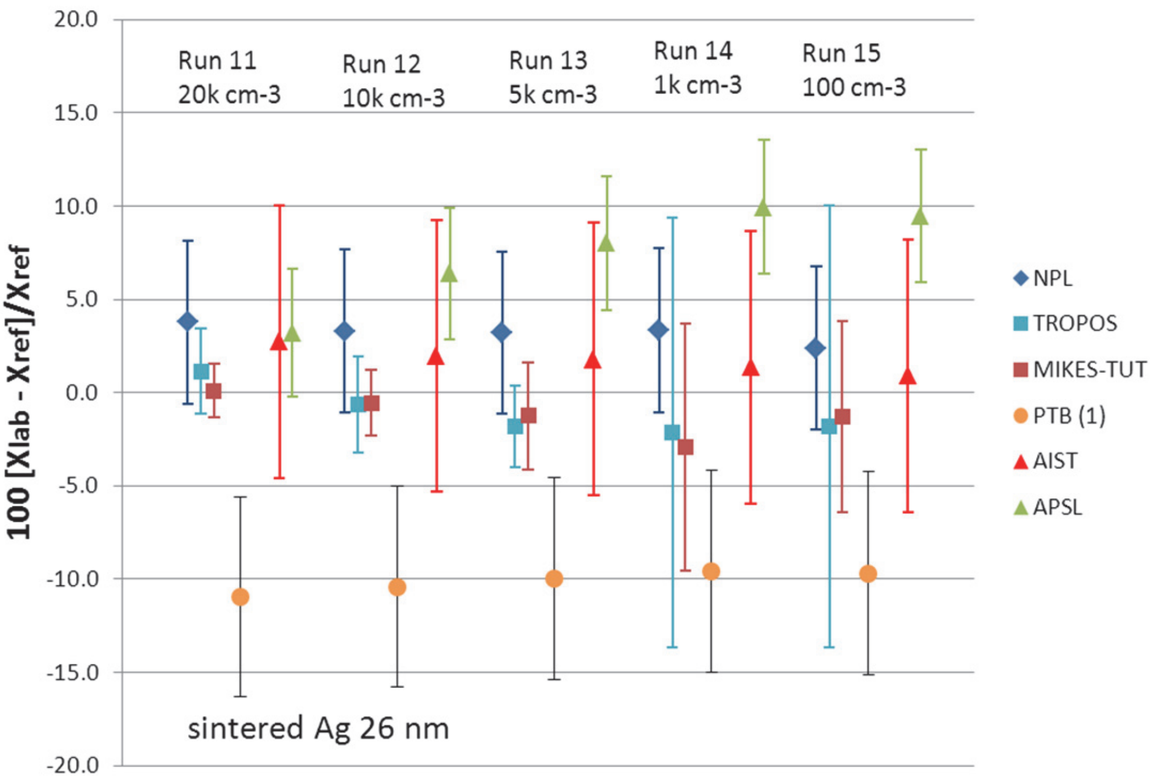

Figure 2: 26 nm sintered Ag at a range of concentrations (Runs 11 - 15)

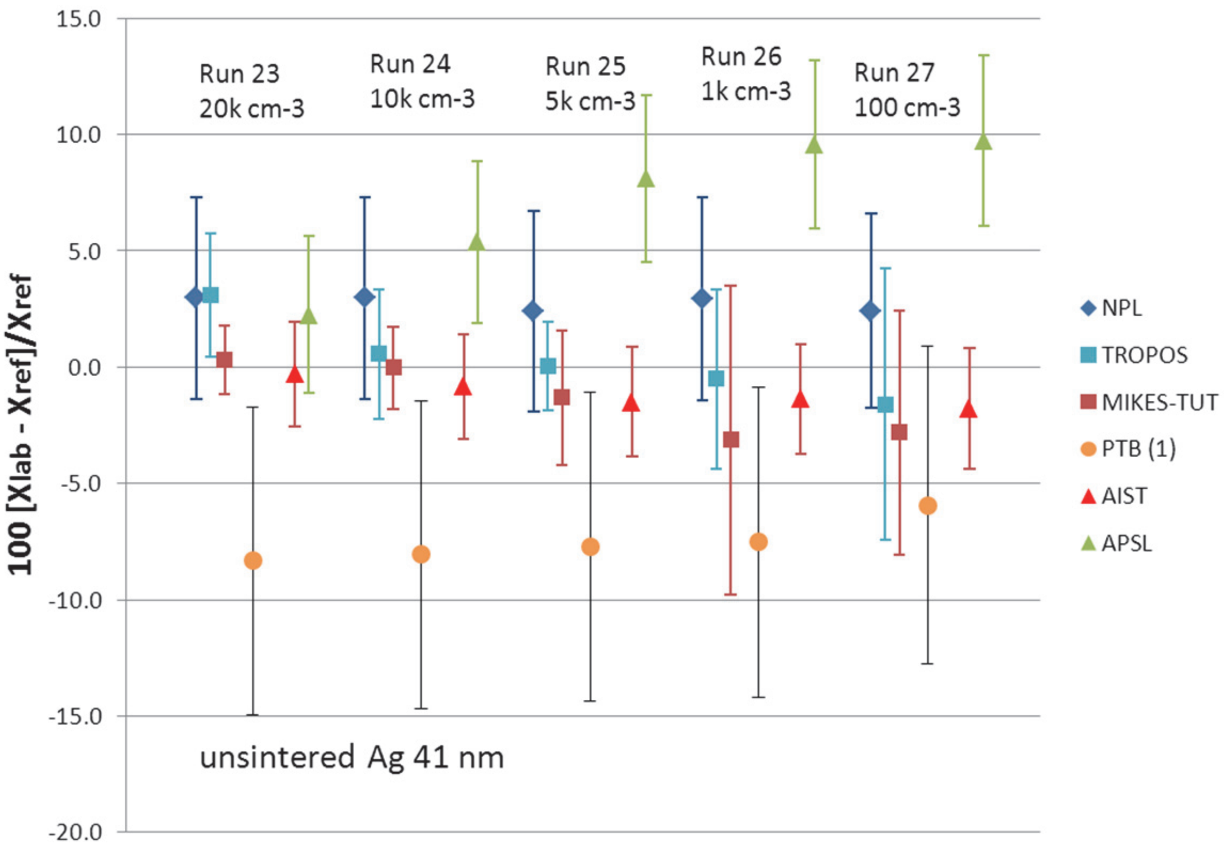

Figure 3: 41 nm unsintered Ag at a range of concentrations (Runs 23 – 27)

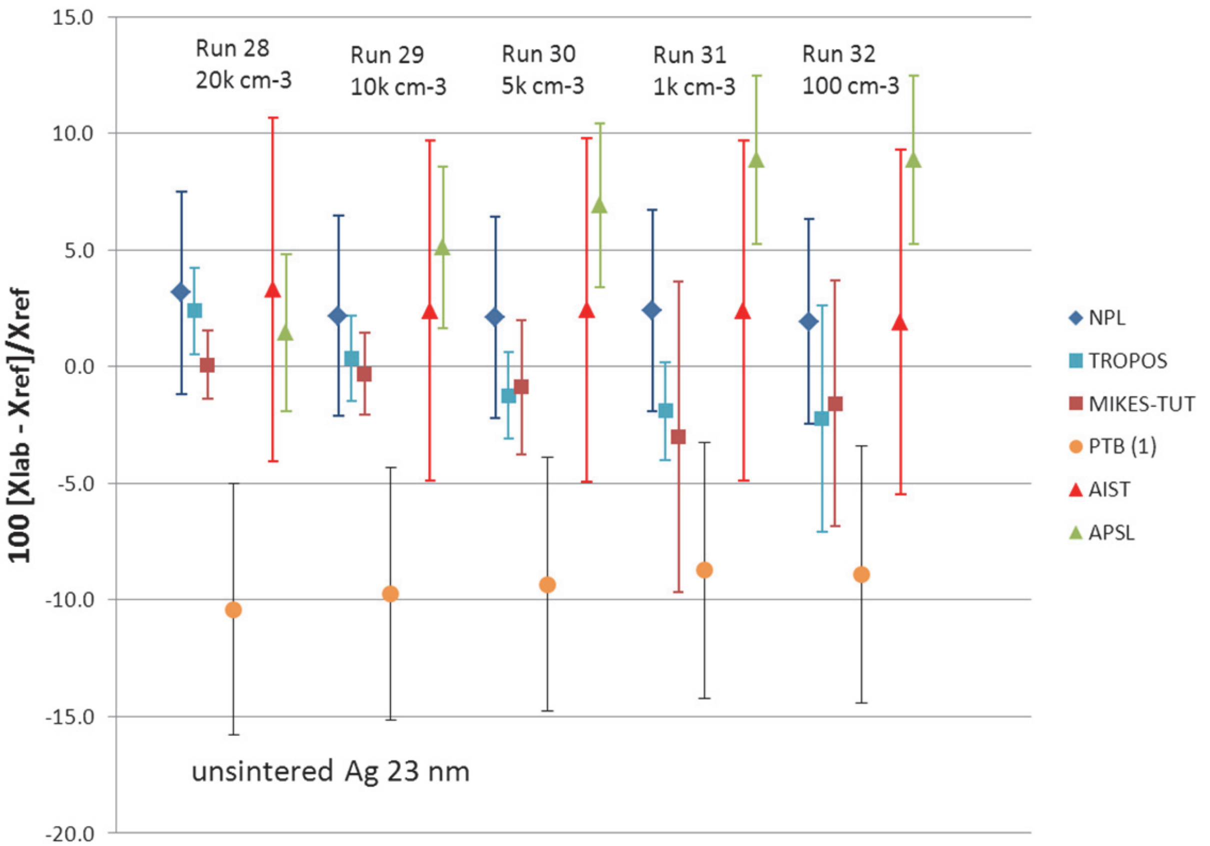

Figure 4: 23 nm unsintered Ag at a range of concentrations (Runs 28 – 32)

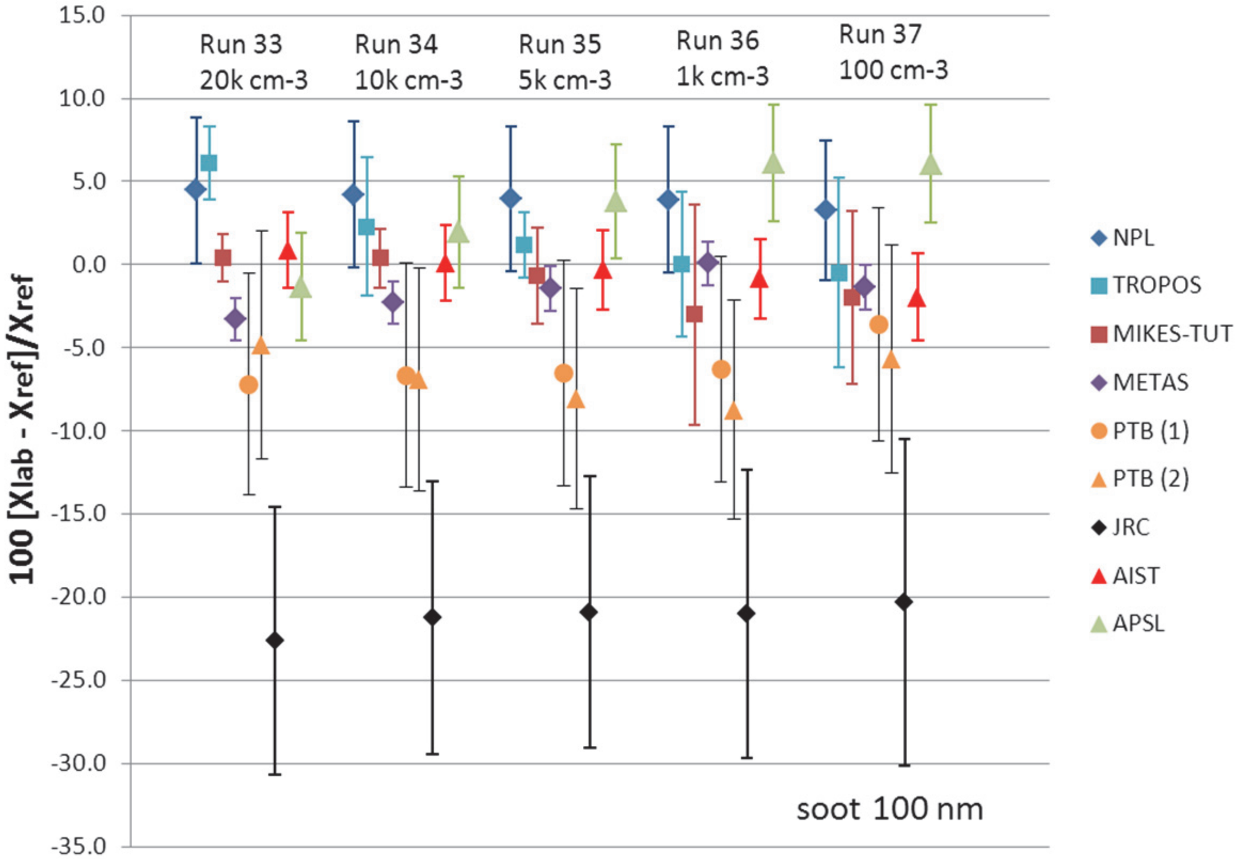

Figure 5: 100 nm soot at a range of concentrations (Runs 33 – 37)

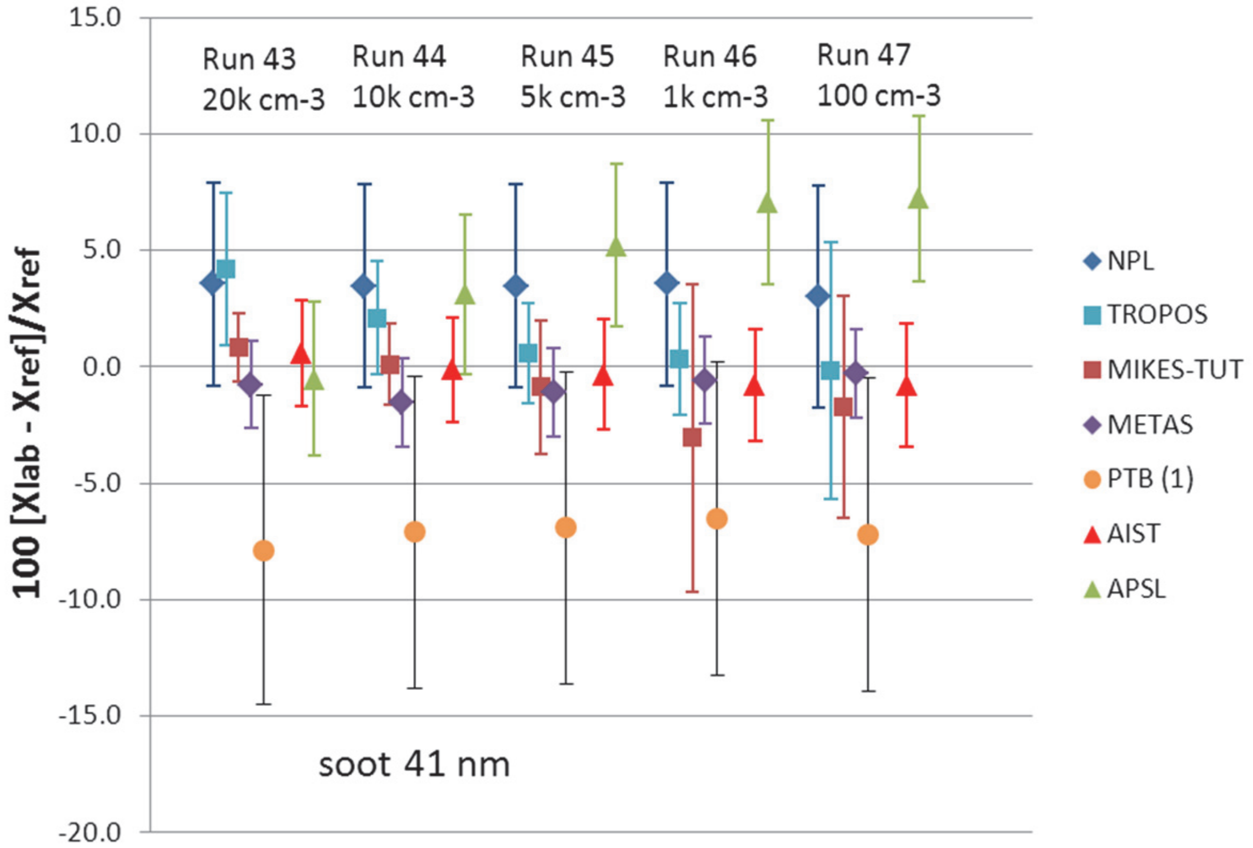

Figure 6: 41 nm soot at a range of concentrations (Runs 43 – 47)

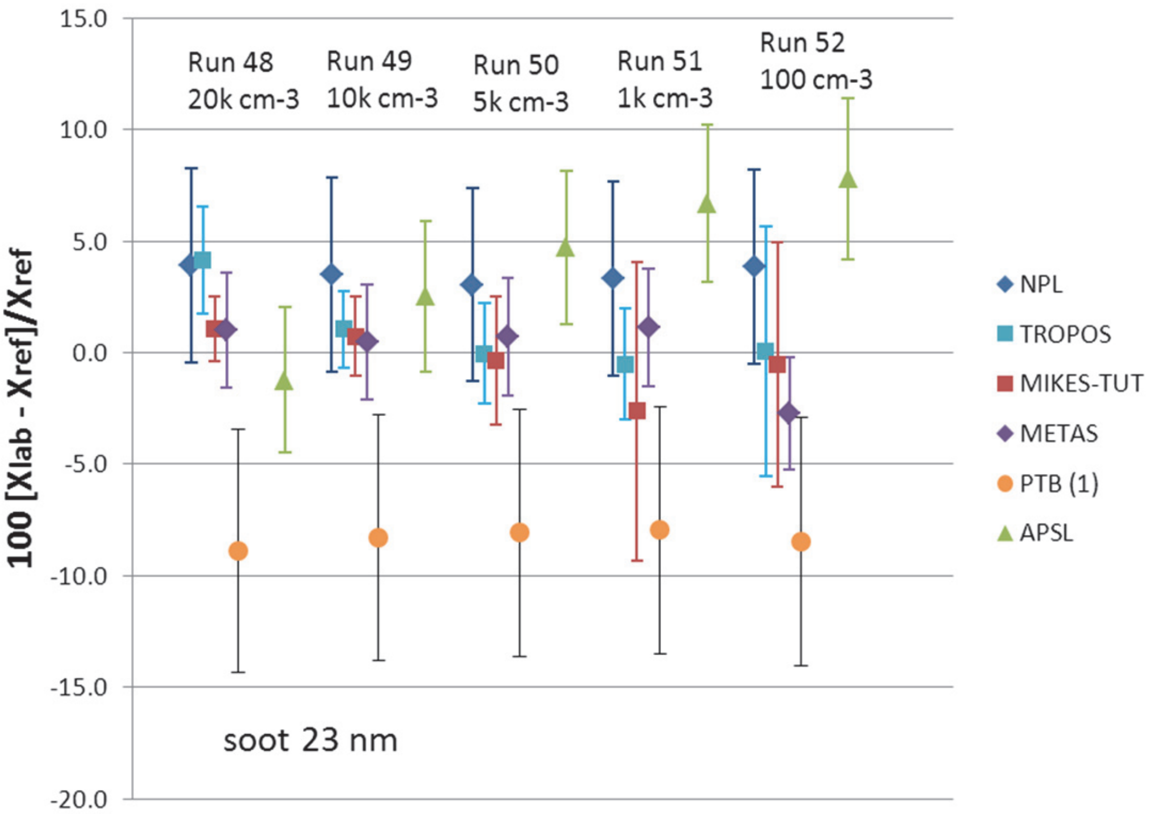

Figure 7: 23 nm soot at a range of concentrations (Runs 48 - 52)

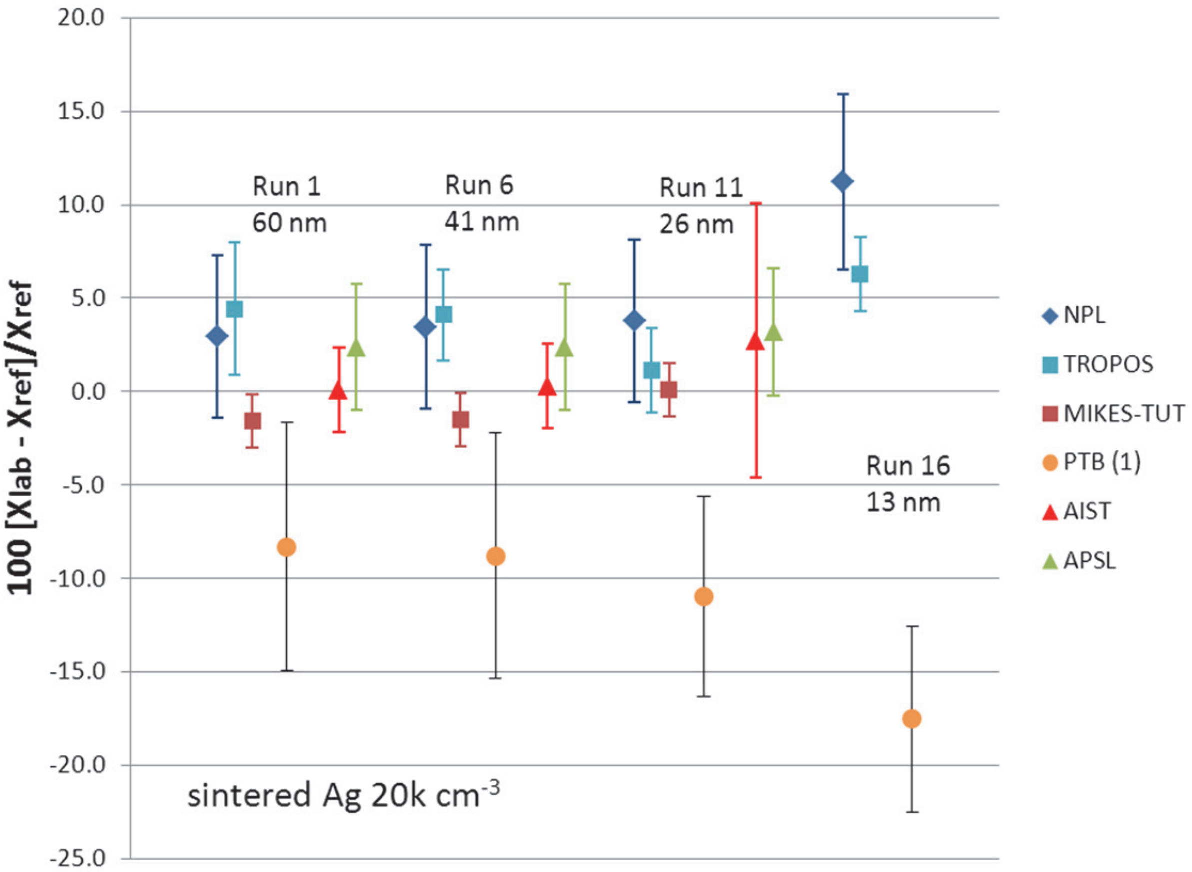

Figure 8: 20,000 cm^{-3} sintered Ag at a range of sizes (Runs 1, 6, 11, 16)

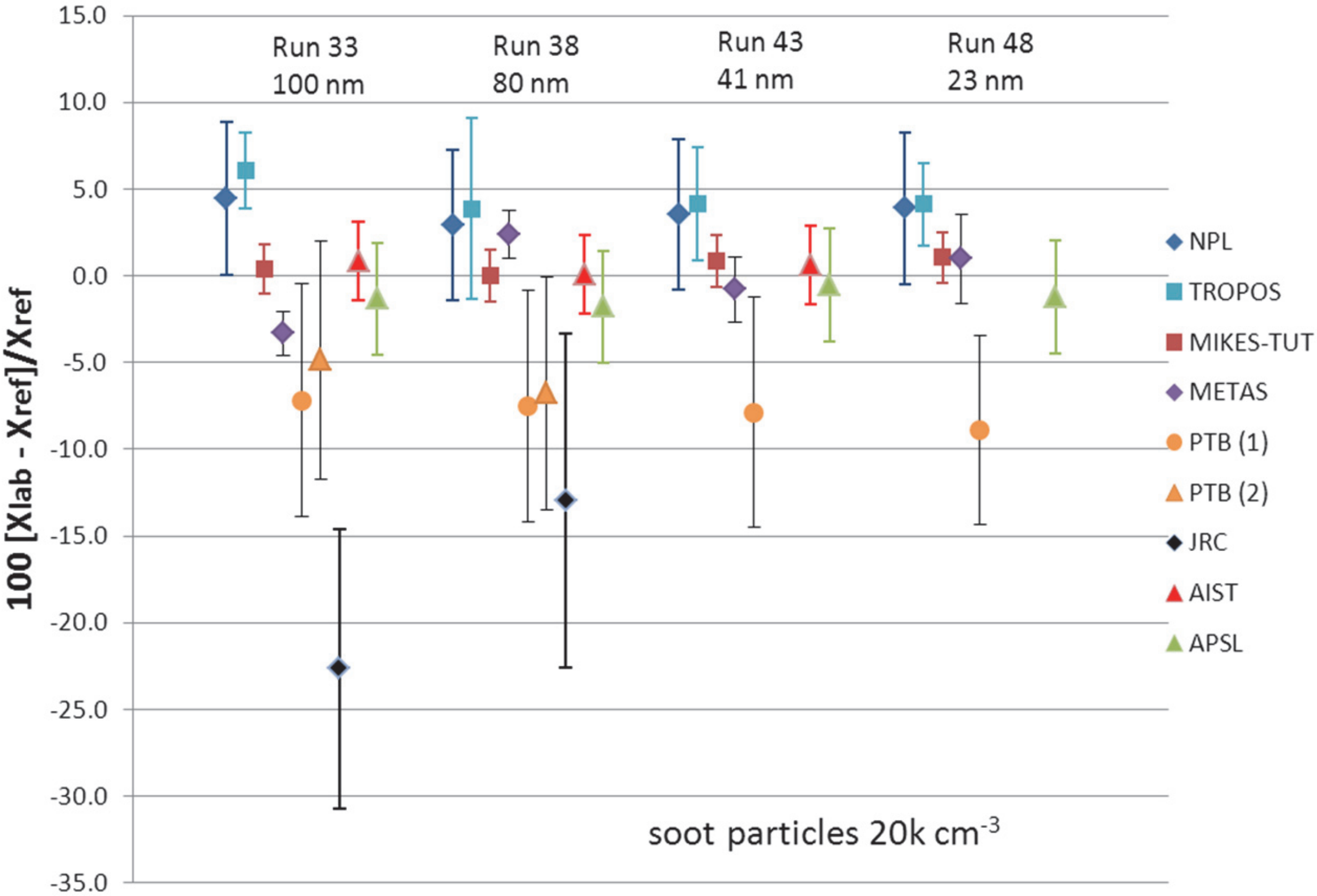

Figure 9: 20,000 cm^{-3} soot at a range of sizes (Runs 33, 38, 43, 48)

4. DISCUSSION AND CONCLUSIONS

4.1. SUMMARY OF RESULTS

In general terms, two aspects of this type of measurement are examined by this comparison: firstly, the ability of the participants to calibrate their CPCs in the “plateau” region of CPC operation; and secondly, the range of particle size, concentration and material over which the calibration is valid.

4.1.1 Plateau region

With 100 nm soot, the largest particle size used (which should be most comfortably in the plateau region of the CPCs), there is agreement, with the exception of the JRC results, at the level of about ±7% (Figure 5). This level of agreement holds across the full range of concentrations, between 100 and 20,000 cm^{-3}. The exception was from one of the TSI 3790 instruments with a relatively high 50% cut-off size of 23 nm, whose results are in contrast to those of the similar instrument PTB(2).

With 60 nm sintered silver, the largest silver particle size used, the two TSI 3790 instruments underread by similar amounts, while agreement between the other instruments was similar to the 100 nm soot case, at about ±10% (Figure 1).

4.1.2 Effect of particle size, concentration and material

With the understandable exception of the TSI 3790 instruments at sizes below 80 nm, the level of agreement was consistent at about ±10% over the full range of concentrations used (100 to 20,000 cm^{-3}), and for each of the three particle materials (unsintered silver, sintered silver, and soot), for sizes down to 23 nm (Figures 2, 3, 4, 6, 7 and 9).

Agreement at 13 nm particle size, for the three participants who reported it, is less good, as expected because of the proximity to the 50% cut-off size (Figure 8).

4.2. SUPPORTED CMC CLAIMS

It is proposed that this comparison can be used to support CMC claims for condensation particle counter calibrations in the range 100 to 20,000 cm^{-3}.

5. REFERENCES

[1] ISO/DIS 27891: Aerosol particle number concentration — Calibration of condensation particle counters

APPENDICES

APPENDIX A1 – EURAMET 1282 PROTOCOL

EURAMET 1282

Comparison of Condensation Particle Counters

Coordinating Laboratory: NPL, UK
Host: TROPOS, Leipzig, Germany

Protocol (final version)

Background

Aerosol particle number concentration has recently featured in vehicle emission legislation and is becoming increasingly important in other areas such as ambient air monitoring. Number concentration measurements are also often integral to particle size distribution measurements, such as when using a Differential Mobility Analyzer System.

Condensation Particle Counters (CPCs) are the usual type of instrument for measuring particle number concentration in the size range from a few nanometers to a few micrometers. These instruments have a large size range over which they have constant detection efficiency for nanoparticles of all compositions (the "plateau" region), and an instrument and particle-material dependent drop in detection efficiency at low sizes. The drop in detection efficiency at large sizes is of much lower importance, as the number of larger particles is negligible.

Calibration of CPCs can be done via comparison with a reference CPC or a reference aerosol electrometer. Procedures for doing this have been set out in ISO/DIS 27891. The DIS refers to the role of NMIs in providing certification for reference aerosol electrometers and reference CPCs.

Although not strictly a chemical measurement, the comparison belongs in the Gas subcommittee of TC-MC because of the similarity to gas concentration measurements, following the precedent of earlier projects 893 (workshops to establish "Metrology infrastructure for airborne nanoparticles"), 1027 ("Comparison of combustion particle number concentration and size"), and 1244 ("Comparison of aerosol electrometers"), which took place in March 2013 as part of the same EMRP project, ENV02 PartEmission.

The aim of this comparison is twofold:

(1) to compare the accuracy of different laboratories' measurements of particle number concentration in the plateau region of their CPC, as in a traditional metrological comparison, and

(2) to measure the detection efficiencies of the CPCs at sizes below the plateau region using a selection of common particle sources. In this case there are no "correct"

answers, and the aim is to provide information to the participants.

As in the EURAMET 1244 comparison of aerosol electrometers, EURAMET participants are being joined by other participants with expertise in this area.

Comparison protocol

The comparison will be held at TROPOS in Leipzig, Germany, during the week 14-18 October 2013.

Participants will be responsible for the transport of their instruments to and from Leipzig, and for their setting up and operation. This includes the independent calibration of the CPCs and any flow meters used and the collection of data. Butanol can be provided by TROPOS if necessary.

The electricity supply at Leipzig is 230V 50Hz with CEE 7/4 socket (plug type F). Participants must provide their own electrical adaptors if necessary.

Participants will sample the test aerosol (particles+nitrogen) at flow rates that have been arranged individually (in the range 0.3 to 1.5 litre/min (at 25°C and 101.3 kPa)), with diffusion losses compensated by differing lengths of sample tubing. Participants are expected to take readings every second. Participants' CPCs must connect to ¼-inch TSI conductive tubing. The outlet connection of each CPC (i.e. connection to the vacuum line, if needed) should be either a ¼" Swagelok tube connector or a ¼" tube. Participants must provide their own adaptors if needed.

Particles will be mainly evaporated/condensed Ag nanoparticles between 6 nm and 60 nm in size, both sintered and not sintered, and CAST generated soot particles between 23 nm and 100 nm in size. Where possible, there will be 5 target concentrations between 100 and 20,000 particles cm^{-3}.

The measurement period for each run will last for 10 minutes, with a "clean air" interval between runs lasting 5 minutes.

Particle number concentrations are to be reported at standard conditions (25°C and 101.3 kPa, as in the Tampere comparison). Data on the sample temperature and pressure will be supplied.

The schedule for the week is expected to be:

	Monday	Tuesday	Wednesday	Thursday	Friday
	14.10.	15.10.	16.10.	17.10.	18.10.
08:00		Ag 26 nm sintered	Cast 100 nm	CPC cut-off	Packing of CPCs
09:30	Instrument setup	Ag 13 nm sintered	Cast 80 nm	Ag not sintered	If needed
11:00		Ag 6 nm sintered	Cast 41 nm	Ag sintered	
12:30	Lunch break	Lunch break	Lunch break	Lunch break	
	13:30 meeting				
13:30	60 nm Ag sintered	Ag 41 nm not sintered	Cast 23 nm	additional measurements	
15:00	41 nm Ag sintered	Ag 23 nm not sintered	CPC cut-off - CAST	Data evaluation	
16:30		Meeting, data evaluation		Packing of the CPCs	
		setup Cast measurements			
20:00			Joint Dinner		

The brown colored runs are to be reported as "plateau" comparison runs, even though some sizes will be well below the plateau region. Results that are clearly below the plateau region will be evaluated separately in the EURAMET report.

The blue colored runs are for the information of the participants, and will not be formally reported on the proforma (below).

On each day, some time will be reserved for data processing.

Reporting of the results

The final results are to be reported, with volume corrected to standard conditions, on the pro-forma sheets attached. It is expected that these will be submitted by participants after they have returned to their laboratories to allow subsequent checks on the equipment.

Participating laboratories should specify the method and calibration procedure used for the comparison in detail. They should also state the route through which the calibration procedure provides traceability to the SI.

The expanded uncertainty for each measurement in the plateau region should also be calculated. Information should be provided about how the uncertainty budget was calculated.

NPL and TROPOS together will be responsible for collecting and reporting measurement results.

Points of contact:

General contacts and reporting of the results for the comparison

paul.quincey@npl.co.uk
tuch@tropos.de

APPENDIX A2 – PARTICIPANTS RESULTS PROFORMAS

EURAMET 1282 – Comparison of Condensation Particle Counters TROPOS 14-18 October 2013

Results Proforma

Participant laboratory and people involved:

NPL
Paul Quincey
Dimitris Sarantaridis

Model / origin of CPC:

TSI CPC 3775

Method of flow control:

Volumetric – critical orifice.

Calibration methods and traceability:

CPC: Calibrated against reference FCE (GRIMM FCE model: 5.705). Reference FCE calibrated using a voltage source (Keithley 213), a 1 GΩ standard resistor (Welwyn) traceable to NPL primary standards of resistance, and a voltmeter (HP 3458A) traceable to NPL primary standards of voltage.

Flow meter (model MKS 1179A): Calibration performed by determining mass loss from a cylinder of synthetic air during a measured time interval. Traceability to NPL mass standards.

Components included in the uncertainty calculation:

1. CPC random uncertainty: standard deviation of the mean concentration measured for every 5 min run.

2. CPC flow rate random uncertainty.

3. CPC calibration uncertainty.

4. Temperature correction uncertainty.

5. Pressure correction uncertainty.

Run designation	Was the particle size in the plateau region for the CPC? (Y/N)	Result (particles cm^{-3} at 25°C and 101.3 kPa)	Measurement uncertainty (95% confidence) (cm^{-3}) –
1	Y	20740	873
2	Y	10819	456
3	Y	5179	218
4	Y	1100	46
5	Y	113	5
6	Y	21909	922
7	Y	11570	487
8	Y	5126	216
9	Y	1062	45
10	Y	159	7
11	Y	19236	809
12	Y	10618	447
13	Y	5348	225
14	Y	1202	51
15	Y	140	6
16	Y	24054	1012
17	Y	13058	551
18	Y	5957	251
19	Y	1025	43
20	Y	106	5
21	N	8733	368
22	N	649	27
23	Y	20743	873
24	Y	11059	465
25	Y	5279	222
26	Y	1225	52
27	Y	98	4
28	Y	21377	899
29	Y	11345	477
30	Y	5366	226
31	Y	1136	48
32	Y	116	5
33	Y	26090	1098
34	Y	13438	565
35	Y	6949	292
36	Y	1444	61
37	Y	99	4
38	Y	22372	943
39	Y	12826	541
40	Y	6203	261
41	Y	1314	55
42	Y	153	6
43	Y	21038	886
44	Y	10907	459
45	Y	4938	208
46	Y	1380	58
47	Y	108	5
48	Y	22993	967
49	Y	11570	487
50	Y	5700	240
51	Y	1376	58
52	Y	95	4

Date results submitted: 27 November 2013

EURAMET 1282 – Comparison of Condensation Particle Counters TROPOS 14-18 October 2013

Results Proforma

Participant laboratory and people involved:
TROPOS
Thomas Tuch

Model / origin of CPC:
3772 CPC, TSI Inc. Condenser temperature set to 18 deg. C

Method of flow control:
1 L/min critical orifice

Calibration methods and traceability:
CPC counting efficiency calibrated at concentrations > 1000 cm^{-3} with aerosol electrometer and flow meter. Traceability to SI units is through the ampere and mass flow rates.

CPC linearity calibrated at high and low concentrations with dilution proportionality test, and validated at high concentration against aerosol electrometer linearity test.

Components included in the uncertainty calculation:
Three components are included in the uncertainty calculation of concentration measurements with the CPC. The type B uncertainties in CPC counting efficiency and CPC inlet flow rate are taken from the CPC and flow meter calibration certificates, respectively. The type A uncertainty is calculated as the standard deviation of the data set of concentrations for each measurement.

Date results submitted: 27 November 2013

Filled proformas are to be sent to: paul.quincey@npl.co.uk and tuch@tropos.de by 29 November 2013.

Run designation	Was the particle size in the plateau region for the CPC?	Result	Measurement Uncertainty (95% confidence)
		cm^{-3} @ 25°C and 101.3kPa	cm^{-3} @ 25°C and 101.3kPa
1	Yes	21033.6187	715.83741
2	Yes	10701.4443	380.664824
3	Yes	5140.4965	271.30036
4	Yes	1065.52001	27.0392315
5	Yes	109.824874	6.34697358
6	Yes	22046.2198	517.407169
7	Yes	10706.4481	244.608602
8	Yes	5020.68826	111.326571
9	Yes	1028.60729	23.0811577
10	Yes	152.658777	6.95194503
11	Yes	18751.29	420.352892
12	Yes	10211.9194	265.500166
13	Yes	5087.0279	114.306397
14	Yes	1138.45881	134.006107
15	Yes	134.261096	16.208722
16	Yes	22985.2208	433.424256
17	Yes	12324.6265	853.667088
18	Yes	5585.10769	145.401504
19	Yes	957.56735	34.6145932
20	Yes	99.4068516	8.15869039
21	No	5787.91577	179.268947
22	No	394.314735	15.417165
23	Yes	20769.8331	532.115766
24	Yes	10802.5196	299.243924
25	Yes	5157.51019	97.879878
26	Yes	1184.16239	45.7687753
27	Yes	94.1713163	5.57322075
28	Yes	21212.8464	379.809054
29	Yes	11142.653	201.823385
30	Yes	5190.37185	98.2639699
31	Yes	1088.25017	23.4291725
32	Yes	111.262924	5.53201125
33	Yes	26496.5926	546.461093
34	Yes	13191.1926	534.681693
35	Yes	6764.10492	130.259092
36	Yes	1390.20641	60.9446649
37	Yes	95.4016635	5.46257587

38	Yes	22587.3308	1131.8229
39	Yes	12618.1738	634.746781
40	Yes	6065.85754	160.085385
41	Yes	1279.47844	37.1950856
42	Yes	148.741406	7.84466999
43	Yes	21165.6555	665.721529
44	Yes	10763.7623	256.320292
45	Yes	4800.39418	103.001055
46	Yes	1337.05504	31.8543124
47	Yes	104.63314	5.79540621
48	Yes	23042.6835	527.493059
49	Yes	11299.478	192.682593
50	Yes	5529.51982	125.142516
51	Yes	1325.15107	33.057828
52	Yes	91.5220643	5.12167837

Date results submitted: 27th November 2013.

EURAMET 1282 – Comparison of condensation particle counters TROPOS 14-18 October 2013

Results Proforma (4th December 2013)

Participant laboratory, and people involved:

Tampere University of Technology (TUT), Aerosol physics laboratory, Jaakko Yli-Ojanperä
Mikes, Thermal and mass group, Richard Högström

Model / origin of CPC:

Airmodus A20 single flow butanol CPC

Method of flow control:

critical orifice just before the outlet of the CPC

Calibration methods and traceability:

The CPC has been calibrated using the Single Charged Aerosol Reference (SCAR) at Tampere University of Technology. The SCAR is a Faraday cup aerosol electrometer based number concentration standard.

Faraday cup aerosol electrometer calibration and traceability:

The current measurement function of the electrometer was calibrated with a current source based on a high value reference resistor and a direct voltage source. Traceability of the reference resistor is based on a calibration chain starting from MIKES Quantum-Hall resistance standard. Traceability of the Fluke 5440B direct voltage source is based on a calibration chain starting from MIKES Josephson direct voltage standard

Mass flow meter calibration and traceability:

The flow meter was calibrated against the LFE calibration system. The operation of the LFE is based on laminar flow elements (molbloc, DH Instruments) and it is calibrated against the dynamic weighing system (DWS1). The operation of the DWS1 is based on dynamic gravimetric weighing of a gas vessel. Therefore, mass flow measurements are traceable to the definitions of mass and time.

The electrometer and the mass flow meter were calibrated before the campaign and the CPC was calibrated after the campaign.

Components included in the uncertainty calculation:
Electrometer calibration correction, type B.
Flow meter calibration correction, type B.
Standard deviation of the measured concentration (CPC), type A
CPC calibration correction, type B

Run designation -	Was the particle size in the plateau region for the CPC? (Y/N)	Result (particles cm^{-3} at 25°C and 101.3 kPa)	Measurement uncertainty (95% confidence) (cm^{-3}) – only necessary for results in the plateau region.
1	Y	19819,5	287,4
2	Y	10443,5	185,9
3	Y	4982,8	145,3
4	Y	1033,6	70,8
5	Y	108,1	5,5
6	Y	20855,8	301,9
7	Y	11174,0	198,1
8	Y	4930,2	143,3
9	Y	997,3	68,3
10	Y	150,5	7,7
11	Y	18555,6	268,5
12	Y	10220,2	181,1
13	Y	5116,3	148,7
14	Y	1129,4	77,3
15	Y	135,0	6,9
16	N	22772,8	
17	N	12703,9	
18	N	5821,6	
19	N	986,9	
20	N	104,6	
21	N	7914,2	
22	N	586,8	
23	Y	20209,9	292,6
24	Y	10738,0	190,6
25	Y	5087,7	147,9
26	Y	1152,8	79,0
27	Y	93,3	4,8
28	Y	20735,8	299,7
29	Y	11070,0	196,1
30	Y	5208,6	151,4
31	Y	1076,2	73,7
32	Y	111,6	5,7
33	Y	25075,2	362,5
34	Y	12947,3	229,4
35	Y	6640,0	193,0
36	Y	1347,6	92,3
37	Y	94,2	4,8
38	Y	21745,2	318,0
39	Y	12421,8	222,8
40	Y	5941,0	172,8
41	Y	1231,1	84,3
42	Y	145,7	7,4
43	Y	20491,0	297,7
44	Y	10554,2	187,1
45	Y	4730,9	137,5
46	Y	1291,7	88,5

47	Y	103,3	5,3
48	Y	22364,9	323,3
49	Y	11263,5	199,5
50	Y	5511,6	160,2
51	Y	1297,4	88,9
52	Y	90,9	4,6

Date results submitted:

4 December 2013

EURAMET 1282 – Comparison of Condensation Particle Counters TROPOS 14-18 October 2013

Results Proforma

Participant laboratory and people involved:

METAS, Felix Lüönd

Model / origin of CPC:

METAS Grimm 5412, S/N 54121103

Method of flow control:

Internal pump and flow controller, flow was continuously monitored by an external mass flow meter (Vögtlin Red-y smart series, S/N 150874) at the exhaust of the CPC. A cold trap was used downstream of the CPC exhaust to prevent butanol vapour from influencing the flow measurement.

Calibration methods and traceability:

The flow meter was calibrated against the corresponding METAS primary standard in 2012. The corresponding calibration data were used to correct the measured flow. As the calibration was done with air, a correction factor of 1.002 was used to correct the flow readings obtained with nitrogen during the campaign. As the flow meter measures mass flow, no information about aerosol temperature and pressure during the measurements is required.

The CPC broke during transport to the campaign. Therefore, it was calibrated again after the campaign against the METAS primary standard for particle number concentration (TSI 3068B electrometer, S/N 70701106). This calibration also involved two mass flow meters calibrated against the METAS primary standard for flow in 2011. The electrical part of the electrometer was calibrated in 2013 against the METAS primary standard for small DC current (as low as 10 fA).

The calibration of the CPC was done according to the ISO 27891 draft with miniCAST particles at the sizes 10 nm, 23 nm, 41 nm, 80 nm, and 100 nm for concentrations < 10’000 cm-3. For each particle size, the counting efficiency of the CPC was measured in 6 repetitions. Each repetition included subtraction of the electrometer offset and a correction for multiply charged, larger particles. The uncertainty in the counting efficiency averaged over the 6 repetitions contains contributions from both the variability of the instrument readings recorded at 1 Hz frequency and from the variability of the counting efficiency between the individual repetitions (this results in a conservative estimate of the uncertainty because the two mentioned variabilities can partly have the same origin). Deviations from the ISO 27891 protocol in terms of the number of voltage levels taken into account in order to correct the measured concentrations for multiply charged particles were accepted when correction of a specific multiple charge level influenced the resulting counting efficiency by less than 1%. Small particle size or size selection in the far downslope of the initial size distribution reduced the number of required voltage levels usually to two or even one (i.e. no multiple charge correction at all, as in the case of 10 nm particles).

More detailed information about the calibration procedure and the uncertainty calculation can be given on request.

Components included in the uncertainty calculation:

- Variability (type A uncertainty) of the CPC reading during a 5 min measurement, i.e. standard deviation of the measured values divided by the square root of the number of 1s readings. However, the timing of the individual 5 min measurements was not always precise during the campaign. This leads to a higher uncertainty than just the one based on the standard deviation within the 5 min measurement in cases where the number concentration drifts with time. As in some runs with CAST aerosol the number concentration drifted, we estimated the uncertainty due to the timing of the measurement by estimating the variability of the mean concentration from a data window shifted by +- 1 min compared to the original window. We used the maximum of this variability due to timing uncertainty and the variability based on the 1s readings during the used 5 min measurement as an estimate for the uncertainty of the average CPC concentration.
- Uncertainty in flow measurement: This includes the variability (type A) of the flow measured during the used 5 min period of a measurement as well as a type B contribution from the calibration of the flow meter.
- Uncertainty in the counting efficiency of the CPC as determined during the calibration of the CPC against the reference electrometer.

The resulting particle number concentration C_{CPC} is given by

$$C_{CPC} = \frac{C_{meas}}{\eta_{CPC}} f_q$$

where

$$f_q = \frac{q_{nom}}{q_{meas}} \cdot A$$

with q_{nom} being the nominal volumetric flow rate of the CPC (0.6 lpm), q_{meas} being the flow measured by the mass flow meter (after correction according to the calibration of the flow meter), and A being a factor referring the flow measurements to standard conditions (A is a constant as no temperature or pressure measurements are involved). C_{meas} denotes the average measured particle concentration, and η_{CPC} is the counting efficiency of the CPC as determined in the calibration.

The relative uncertainties of the above mentioned influence quantities are added quadratically to obtain the relative uncertainty $u(C_{CPC})$.

Remarks:

- For the METAS Grimm 5412 CPC, data are only available from run 33 due to the CPC being under repair on October 14 and 15.
- For a particle diameter of 23 nm (runs 48 – 52), the METAS CPC has a detection efficiency of 96.9% which is only compatible with the 100% counting efficiency at sizes above 41 nm if uncertainties in the detection efficiency are taken at 95% confidence interval (k = 2). Nevertheless, given the high counting efficiency, 23 nm has been considered as part of the plateau region.
- After the campaign, the METAS 5412 CPC returned to Grimm for further tests which

had been postponed after repair due to the tight schedule of the campaign. According to the Grimm engineers, these tests did not alter the calibration of the CPC. Therefore, the later calibration performed at METAS is considered as valid and representative for the calibration during the campaign.

Run designation	Was the particle size in the plateau region for the CPC? (Y/N)	Result (particles cm^{-3} at 25°C and 101.3 kPa)	Measurement uncertainty (95% confidence) (cm^{-3}) – only necessary for results in the plateau region.
33	Y	24150	320
34	Y	12600	165
35	Y	6590	90
36	Y	1391	18
37	Y	94.6	1.3
38	Y	22260	300
39	Y	12680	170
40	Y	6020	80
41	Y	1268	17
42	Y	149	2
43	Y	20160	380
44	Y	10380	200
45	Y	4720	90
46	Y	1325	25
47	Y	104.5	2
48	Y	22350	570
49	Y	11235	290
50	Y	5570	145
51	Y	1347	35
52	Y	89	2.3

Date results submitted: 17th December 2013; with revised uncertainties 1st April 2014

EURAMET 1282 – Comparison of Condensation Particle Counters TROPOS 14-18 October 2013

Results Proforma

Participant laboratory and people involved:

PTB, Arne Kuntze (calibration at TROPOS), Anke Jordan-Gerkens (calibration at TROPOS), Andreas Nowak (data analysis)

Model / origin of CPC:
TSI 3772, CPC, temperature difference at 17°C

Method of flow control:
The flow is adjusted at 1 L/min about a critical orifice. The flow was checked frequently during the workshop against PTB blow flow meter. Currently, we don't have a traceable method, which monitored directly the flow of CPC.
After the workshop, the flow of CPC was calibrated against the primary standard for mass flow measurements at PTB. The calibration of the critical orifice was performed at standard conditions. For that reason, a constant factor was used to correct the particle concentration like:

$$N_{total} = \frac{f_{nominal}}{f_{calibration}} * N_{serial}$$

$f_{nominal} = 1{,}0$ l/min
$f_{calibration} = 1.007$ l/min

We also used the serial output of CPC for detection of the particle number concentration.

Calibration methods and traceability:
The CPC counting efficiency is calibrated at concentrations > 1000 cm-3 with aerosol electrometer (AE) based on a soot aerosol generated from MINI-CAST. For the AE the charging of capacity was measured against primary standard at PTB. The method is traceable for SI units F, V and s.

Components included in the uncertainty calculation:

Several parts were included in the calculation of the uncertainty budget:

1.) type A: based on the empirical uncertainty: $u(\bar{q}) = \frac{s_{p(q)}}{\sqrt{n}}$

2.) type B: based on several assumptions:
   a. for the uncertainty of flow calibration: u(flow) = 0,2 %
   b. for the bias of flow splitter at TROPOS: u (bias) = 3%
   c. for the uncertainty of the multiple charge correction: u(charge) = 2% for particle > 40 nm

Both types were combined to calculate the uncertainty budget following the Guide to the expression of uncertainty in measurement (GUM 5.1.1., JCGM 104:2009). The formula for non correlated input quantities was used:

$$u_c(y) = \sqrt{\sum_{i=1}^{N} \left(c_i * u(x_i)\right)^2}$$

sensitivity coefficient c_i= 1

Run designation	Was the particle size in the plateau region for the CPC? (Y/N)	Result (particles cm^{-3} at 25°C and 101.3 kPa)	Measurement uncertainty (95% confidence) (cm^{-3}) –
1	Y	18475.31	1331.984074
2	Y	9667.62	697.1168025
3	Y	4690.53	338.3774652
4	Y	996.60	71.89895973
5	Y	100.57	7.296436852
6	Y	19316.48	1392.578177
7	Y	10361.51	747.0262799
8	Y	4609.31	332.2971726
9	Y	952.31	68.68600047
10	Y	141.66	10.25447038
11	Y	16506.16	991.0769145
12	Y	9207.59	552.8430146
13	Y	4663.09	279.9977846
14	Y	1051.60	63.18693827
15	Y	123.51	7.469967125
16	Y	17839.61	1071.081905
17	Y	10140.32	611.2436855
18	Y	4758.10	285.6999173
19	Y	794.45	47.76376519
20	Y	80.59	4.89935353
21	N	1088.41	65.457954
22	N	35.59	2.204809356
23	Y	18468.42	1331.418684
24	Y	9874.46	711.9175773
25	Y	4758.24	343.0747818
26	Y	1100.66	79.41686272
27	Y	90.01	6.524886693
28	Y	18563.56	1113.311553
29	Y	10022.84	601.1343612
30	Y	4764.86	285.7949603
31	Y	1012.54	60.77562749
32	Y	103.65	6.280927096
33	Y	23183.08	1672.534942
34	Y	12038.32	868.5680083
35	Y	6248.90	450.8554801
36	Y	1302.43	94.03101672
37	Y	92.45	6.734035644
38	Y	20114.89	1451.841573
39	Y	11608.09	838.087499
40	Y	5561.76	401.4865876
41	Y	1189.63	85.87602797
42	Y	137.98	10.01044801
43	Y	18716.63	1350.63353
44	Y	9792.41	706.5211143
45	Y	4442.32	320.5251586
46	Y	1245.61	89.90393453
47	Y	97.25	7.062556813
48	Y	20163.16	1210.56712
49	Y	10256.71	615.8271789
50	Y	5084.92	305.343815
51	Y	1226.17	73.68361457
52	Y	83.74	5.081439808

Date results submitted: 10th January 2014; modified version with revised uncertainties 12th May 2014

EURAMET 1282 – Comparison of Condensation Particle Counters TROPOS 14-18 October 2013

Results Proforma

Participant laboratory and people involved:

PTB, Arne Kuntze (calibration at TROPOS), Anke Jordan-Gerkens (calibration at TROPOS), Andreas Nowak (data analysis)

Model / origin of CPC:
TSI 3790, EECPC

Method of flow control:
The flow is adjusted at 1 L/min about a critical orifice. The flow was checked frequently during the workshop against PTB blow flow meter. Currently, we don't have a traceable method, which monitored directly the flow of CPC.
After the workshop, the flow of CPC was calibrated against the primary standard for mass flow measurements at PTB. The calibration of the critical orifice was performed at standard conditions. For that reason, a constant factor was used to correct the particle concentration like:

$$N_{total} = \frac{f_{nominal}}{f_{calibration}} * N_{serial}$$

$f_{nominal}$ = 1,0 l/min
$f_{calibration}$ = 0.959 l/min

We also used the serial output of CPC for detection of the particle number concentration.

Calibration methods and traceability:
The CPC counting efficiency is calibrated at concentrations > 1000 cm-3 with aerosol electrometer (AE) based on a soot aerosol generated from MINI-CAST. For the AE the charging of capacity was measured against primary standard at PTB. The method is traceable for SI units F, V and s.

Components included in the uncertainty calculation:

Several parts were included in the calculation of the uncertainty budget:

1.) type A: based on the empirical uncertainty: $u(\bar{q}) = \frac{s_{p(q)}}{\sqrt{n}}$

2.) type B: based on several assumptions:
   a. for the uncertainty of flow calibration: u(flow) = 0,2 %
   b. for the bias of flow splitter at TROPOS: u (bias) = 3%
   c. for the uncertainty of the multiple charge correction: u(charge) = 2% for particle > 40 nm

Both types were combined to calculate the uncertainty budget following the Guide to the expression of uncertainty in measurement (GUM 5.1.1., JCGM 104:2009). The formula for non correlated input quantities was used:

$$u_c(y) = \sqrt{\sum_{i=1}^{N} \left(c_i * u(x_i)\right)^2}$$

sensitivity coefficient c_i= 1

Run designation	Was the particle size in the plateau region for the CPC? (Y/N)	Result (particles cm^{-3} at 25°C and 101.3 kPa)	Measurement uncertainty (95% confidence) (cm^{-3}) –
1	Y	17877.91	1289.959177
2	Y	9069.53	654.4480134
3	Y	4277.96	308.828773
4	Y	851.26	61.45812577
5	Y	87.70	6.365757049
6	N	15761.51	1137.134308
7	N	8260.90	596.0447579
8	N	3507.25	253.0629466
9	N	700.70	50.59418266
10	N	101.40	7.358206838
11	N	4345.13	260.9543148
12	N	2387.97	172.3335049
13	N	966.61	69.79030387
14	N	177.52	12.86236582
15	N	13.71	1.032584034
16	N	0.00	0
17	N	0.00	0
18	N	0.00	0
19	N	0.00	0
20	N	0.00	0
21	N	0.00	0
22	N	0.00	0
23	N	15639.91	1128.397461
24	N	8261.33	596.0785138
25	N	3925.47	283.2652942
26	N	908.78	65.61360216
27	N	73.80	5.371674294
28	N	4154.48	249.4880234
29	N	2311.10	138.8476063
30	N	1125.66	67.66346489
31	N	277.77	16.73905434
32	N	31.88	1.971386572
33	Y	23767.22	1714.726696
34	Y	12007.87	866.3105531
35	Y	6145.51	443.422032
36	Y	1268.25	91.57357679
37	Y	90.44	6.588780348
38	Y	20272.24	1463.177103
39	Y	11428.83	825.251206
40	Y	5385.38	388.7507268
41	Y	1138.25	82.15275825
42	Y	133.41	9.664713316
43	N	16423.06	1185.174981
44	N	8401.46	606.2085681
45	N	3740.61	269.889167
46	N	1025.84	74.05603333
47	N	80.31	5.842288745
48	N	7508.72	450.8388363
49	N	3742.06	224.6916359
50	N	1801.40	108.2185565
51	N	430.72	25.90306673
52	N	28.56	1.773249394

Date results submitted: 10th January 2014; modified version with revised uncertainties 12th May 2014

EURAMET 1282 – Comparison of Condensation Particle Counters TROPOS 14-18 October 2013

Results Proforma

Participant laboratory and people involved:
JRC, Francesco Riccobono

Model / origin of CPC:
TSI 3790

Method of flow control:
Critical orifice

Calibration methods and traceability:
CPC inlet flow measured twice a day with a primary bubble flow meter.
CPC counts based on calibration performed by the manufacturer's calibration service.

Components included in the uncertainty calculation:
Standard deviation of CPC concentration measured during one run
Uncertainty on the CPC inlet flow rate measurement
Uncertainty on temperature measurement
Uncertainty on pressure measurement
Uncertainty of the calibration of the CPC by the manufacturer

Run designation	Was the particle size in the plateau region for the CPC? (Y/N)	Result (particles cm^{-3} at 25°C and 101.3 kPa)	Measurement uncertainty (95% confidence) (cm^{-3}) – only necessary for results in the plateau region.
1	yes	17275.5	1816.6
2	yes	8873.5	953.8
3	yes	4173.7	458.8
4	yes	830.0	87.8
5	yes	85.4	10.0
6	no	13535.0	
7	no	7068.1	
8	no	2925.2	
9	no	577.8	
10	no	81.6	
11	no	2342.9	
12	no	1279.5	
13	no	532.8	
14	no	102.1	
15	no	8.6	
16	no	0.0	
17	no	0.0	
18	no	0.0	
19	no	0.0	
20	no	0.0	

21	no	0.0	
22	no	0.0	
23	no	10863.6	
24	no	5932.5	
25	no	2873.4	
26	no	682.2	
27	no	55.8	
28	no	2517.8	
29	no	1407.0	
30	no	689.6	
31	no	175.8	
32	no	20.3	
33	yes	19323.2	2012.1
34	yes	10157.2	1053.9
35	yes	5288.0	545.9
36	yes	1097.7	120.4
37	yes	76.4	9.4
38	yes	18927.9	2092.4
39	yes	10019.1	1131.3
40	yes	4745.9	503.1
41	yes	1007.6	105.4
42	yes	117.1	13.5
43	no	12976.4	
44	no	6530.9	
45	no	2906.5	
46	no	799.8	
47	no	62.1	
48	no	5703.4	
49	no	2091.9	
50	no	974.1	
51	no	239.2	
52	no	NaN (software failure)	

Date results submitted: 4th December 2013

EURAMET 1282 – Comparison of Condensation Particle Counters TROPOS 14-18 October 2013

Results Proforma

Participant laboratory and people involved:
U.S. Army Primary Standards Laboratory
Miles Owen

Model / origin of CPC:
3772 CPC, TSI Inc.

Method of flow control:
1 L/min critical orifice

Calibration methods and traceability:
CPC counting efficiency calibrated at high concentration with aerosol electrometer and flow meter. Traceability to SI units is through the ampere and mass flow rates.

PAO oil (emery oil) was used as the calibration material.

CPC linearity calibrated at high and low concentrations with dilution proportionality test, and validated at high concentration against aerosol electrometer linearity test.

Components included in the uncertainty calculation:
Three components are included in the uncertainty calculation of concentration measurements with the CPC. The type B uncertainties in CPC counting efficiency and CPC inlet flow rate are taken from the CPC and flow meter calibration certificates, respectively. The type A uncertainty is calculated as the standard deviation of the mean for each measurement.

Run designation	Was the particle size in the plateau region for the CPC?	Result	Measurement Uncertainty (95% confidence)
		cm^{-3} @ 25°C and 101.3kPa	cm^{-3} @ 25°C and 101.3kPa
1	Yes	20628	681
2	Yes	11148	368
3	Yes	5407	178
4	Yes	1170	39
5	Yes	121.1	4.0
6	Yes	21684	716
7	Yes	11890	392
8	Yes	5411	179
9	Yes	1135	37
10	Yes	169.1	5.6
11	Yes	19132	631
12	Yes	10934	361

13	Yes	5596	185
14	Yes	1279	42
15	Yes	149.7	4.9
16	No	20192	
17	No	11739	
18	No	5829	
19	No	939.4	
20	No	96.5	
21	No	1927	
22	No	100.0	
23	Yes	20598	680
24	Yes	11320	374
25	Yes	5574	184
26	Yes	1304	43
27	Yes	105.0	3.5
28	Yes	21021	694
29	Yes	11672	385
30	Yes	5619	185
31	Yes	1208	40
32	Yes	123.9	4.1
33	Yes	24644	813
34	Yes	13146	434
35	Yes	6937	229
36	Yes	1475	49
37	Yes	101.7	3.4
38	Yes	21354	705
39	Yes	12612	416
40	Yes	6231	206
41	Yes	1356	45
42	Yes	158.7	5.2
43	Yes	20214	667
44	Yes	10870	359
45	Yes	5022	166
46	Yes	1427	47
47	Yes	112.4	3.7
48	Yes	21859	721
49	Yes	11465	378
50	Yes	5792	191
51	Yes	1421	47
52	Yes	98.6	3.3

Date results submitted: 9 December 2013

EURAMET 1282 – Comparison of Condensation Particle Counters TROPOS 14-18 October 2013

Results Proforma

Participant laboratory and people involved:
NMIJ/AIST
Dr. Kenjiro Iida and Dr. Hiromu Sakurai

Model / origin of CPC:
TSI 3772

Method of flow control:
Critical orifice with external vacuum source

Calibration methods and traceability:
The CPC was calibrated against the primary, FCAE-based number concentration standard at AIST as reference, with sucrose (up to 30 nm), poly-alpha-olefin (30 nm to 50 nm) and polystyrene latex particles (100 nm). The charge concentration measurement by the primary FCAE standard has its SI traceability established for the current and volumetric flow rate measurements.

Components included in the uncertainty calculation:
- Uncertainty in the calibration by the primary standard of AIST, which was size and concentration dependent
- Uncertainty due to the variation of the detection efficiency between the measurement at TROPOS and the calibration at AIST
- Uncertainty due to the variation of the flow rate between the measurement at TROPOS and the calibration at AIST
- Uncertainty due to the difference in the particle type between the measurement at TROPOS and the calibration at AIST

Run designation	Plateau region for the CPC? (Y/N)	Result (particles cm^{-3} at 25 °C and 101.3 kPa)	Measurement uncertainty (95 % confidence) (cm^{-3}) – only necessary for results in the plateau region.
1	Y	20163	456
2	Y	10430	236
3	Y	4980	118
4	Y	1050	25
5	Y	108	2.9
6	Y	21242	480
7	Y	11166	252
8	Y	4937	117
9	Y	1018	24
10	Y	151	4.0
11	Y	19044	1358
12	Y	10480	747
13	Y	5274	378
14	Y	1179	85

15	Y	138	10.0
16	N	30122	19162
17	N	16899	10751
18	N	7730	4918
19	N	1311	834
20	N	134	85
21	N	no report because of nearly zero detection efficiency	
22	N	no report because of nearly zero detection efficiency	
23	Y	20088	454
24	Y	10651	241
25	Y	5079	121
26	Y	1174	28
27	Y	94	2.5
28	Y	21409	1526
29	Y	11371	811
30	Y	5383	386
31	Y	1136	81
32	Y	116	8.4
33	Y	25191	569
34	Y	12911	292
35	Y	6664	158
36	Y	1378	33
37	Y	94	2.5
38	Y	21769	492
39	Y	12350	279
40	Y	5951	141
41	Y	1255	30
42	Y	146	3.9
43	Y	20441	462
44	Y	10529	238
45	Y	4757	113
46	Y	1322	32
47	Y	104	2.8
48	Y	data not recorded	
49	Y	data not recorded	
50	Y	data not recorded	
51	Y	data not recorded	
52	Y	data not recorded	

Date results submitted: 2 January 2014