ACTRIS Intercomparison Workshop for Integrating Nephelometer and Absorption Photometers

The intercomparison workshop for absorption photometer was the conducted from Feb. 18 to Feb. 22, 2013, and the integrating nephelometer intercomparison workshop took place from Feb. 25 to Mar. 1, 2013.

In the following, the participating ACTRIS partner and associate partner institutes as well as the individual participants are listed.

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1 Participants

Table 2.1: Participant list

ACTRIS intercomparison workshop: Absorption photometer and nephelometer			
Participant list ACTRIS WP3 workshop Feb. 18 - Mar 01, 2013, TROPOS, Leipzig			
First name	**Family name**	**Institution**	**short form**
Aalto	Pasi	University Helsinki	UHEL
Backman	John	University Helsinki	UHEL
Briel	Bjoern	Deutscher Wetterdienst	DWD
Coz Diego	Esther	Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas	CIEMAT
Dos Santos	Sebastiao	Joint Research Centre	JRC
Drinovec	Luca	Aerosol d.o.o.	AEROSOL
Flentje	Harald	Deutscher Wetterdienst	DWD
Hervo	Maxime	Université Blaise Pascal Clermont-Ferrand	UBP/CNRS
Karlsson	Hans	Stockholm University, Department of Applied Environmental Science	ITM
Laborde	Marie	Aerosol consulting ML / Ecotech	ECOTECH
Mocnik	Grisa	Aerosol d.o.o.	AEORSOL
Mogo	Sandra	Universidad de Valladolid	GOA-UVA
Monahan	Ciaran	National University of Ireland, Galway	NUIG
Mueller	Thomas	Leibniz Institute for Tropospheric Research	TROPOS
Nadezda	Zikova	Institute of Chemical Process Fundamentals AS CR, v.v.i.	ICPF
Pandolfi	Marco	Agencia Estatal Consejo Superior De Investigaciones Cientificas	CSIC
Sciare	Jean	Laboratoire des Sciences du Climat et de l'Environnement (LSCE)	SIRTA CORSICA
Smejkalova-Holubova	Adela	Czech Hydrometeorological Institute	CHMI
Titos	Gloria	Centro Andaluz de Medio Ambiente - Universidad de Granada	CEAMA
Todor	Arsoff	Institute for Nuclear Research and Nuclear Energy, Bulgarian Academy of Sciences	BEO
Tuch	Thomas	Leibniz Institute for Tropospheric Research	TROPOS
Virkkula	Aki	University Helsinki	UHEL
Vratolis	Stergios	National Centre for Scientific Research "Demokritos"	NCSR-D
Wiedensohler	Alfred	Leibniz Institute for Tropospheric Research	TROPOS

2 Absorption photometer intercomparison

2.1 Organization and experimental setup

2.1.1 Organization of runs

Because of the multitude of instruments and different types of instruments not all instrument could be compared in a single run. Therefore, the instruments were divided in subgroups. For a better comparison each experiment for a subset of absorption photometers was done together with a 'reference set'. A reference set consists of a MAAP and a nephelometer. Two reference sets were available and were compared before the workshop. The experimental runs were organized in in several steps:

I	First intercomparison of instruments of the same type	Several runs with • ambient air • filtered particle free air
II	Inspection	• Cleaning measurements chamber and inlets • Flow check and calibration if necessary • Calibration of temperature and pressure sensors if necessary
III	Second intercomparison of instruments of the same type	Several runs with • ambient air • filtered particle free air
IV	Intercomparison of selected instruments of different types	Several ambient air runs.

2.1.2 Experimental setups

Several types of absorption photometer were compared. Table 3.1 gives an overview of instruments. Because of the multitude of instruments the setup changed little from experiment to experiment. The experimental setups consist of several compounds:

inlet	• ambient air inlet without size cut
aerosol dryer	• aerosol was dried using silica dryers • humidity was check in reference nephelometer
aerosol flow splitting	• low flow instruments (< 3 lpm, PSAP& Aethalometer): aerosol splitters for submicrometer particles • high flow instruments (6 lpm, MAAP): mixing chamber
reference instruments	• two sets of MAAP + TSI 3565 nephelometer. The MAAP with serial number 32 (from the Melpitz field station) was used as reference for all intercomparison runs of MAAPs.

Table 2.1: List of instruments

Institution	**MAAP**	**Aethalometer**			**PSAP**	
		AE22	AE31	AE33	Radiance research	other types
ISAC	x					
CIEMAT				x		
CEAMA			x			
PSI	x[(a)]		x[(a)]			
JRC	x		x			
NILU						iPSAP
FMI (associate partner?)			x			
UHEL	x				x	
TROPOS 32	x					
TNO	x					
NUIG	x					
FORTH			x			
NCSRD			x			
DWD	x				x	
BEO						
CHMI			x			
AEROSOL				x		
CSIC	x					
SIRTA			x			
CORSICA			x			
ECOTECH						
ULUND				x		
NOAA						CLAP
ITM						iPSAP
ISSEP		x				
UPAC					x	CLAP
GOA-UVA					x	

[(a)] Intercomparison again TROPOS instruments after the workshop

2.2 Intercomparison of MAAPs

MAAPs were divided in two subsets. Description of measurements, inspection and summary of results are given below.

During the workshop MAAP PSI was in use for a field campaign. An intercomparison to instrument MAAP TROPOS was done from March 18 to 20.

Results of MAAP intercomparison before inspection

Description: Two sets of MAAP were compared using the mixing chamber. The instruments were operated as they arrived. The only data processing was to correct all BC concentrations to STP conditions if necessary.

Set 1: Instruments: CSIC, UHEL, JRC, NUIG, TROPOS, ISAC

Observations: a) UHEL and CSIC are too low and too high, respectively. In both cases the reasons was a wrong flow.

b) The noise of Instruments JRC and CSIC is higher than for the other instruments

Set 2: Instruments: JRC, DWD, ISCA, CEAMA, TNO, TROPOS

Observations: a) Instrument CEAMA is too low compared to the average. The reason was the flow wrong flow.

b) The noise of Instruments JRC and CSIC is much higher compared to the other instruments (see paragraph in section 'Inspection')

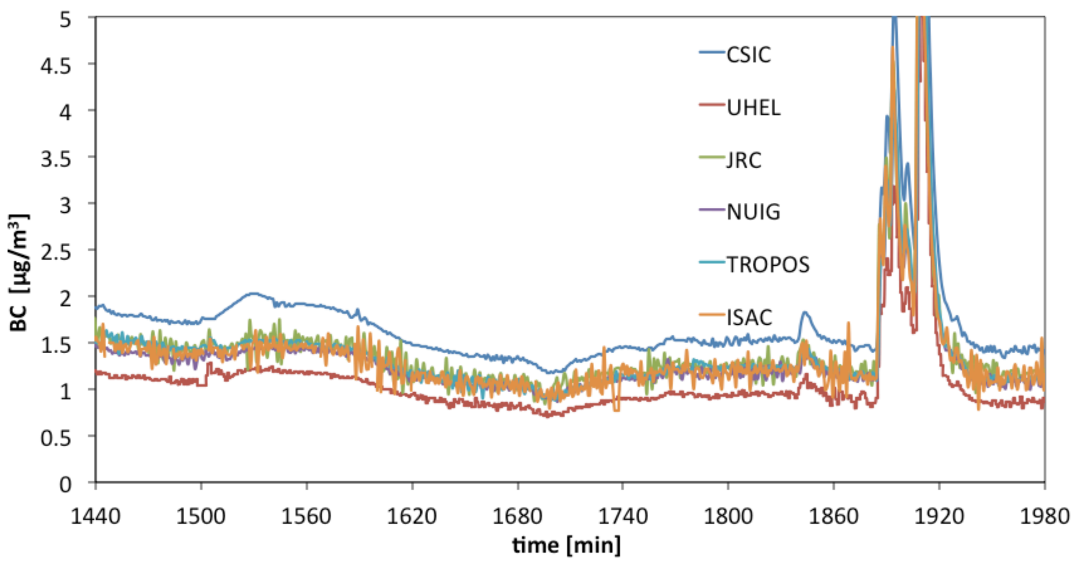

Figure 2.2.1: Intercomparison of MAAPs in set 1.

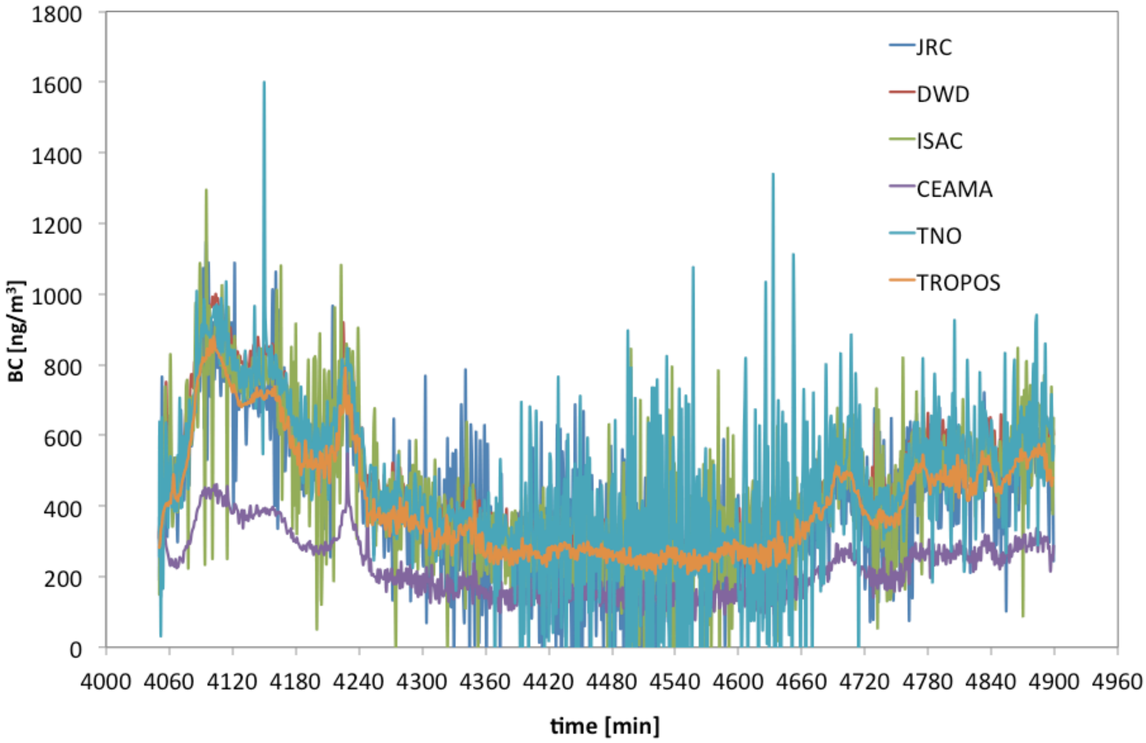

Figure 2.2.2: Intercomparison of MAAPs in set 2.

<u>Inspection of MAAPs</u>

Table 2.2.1: Observations of instrument during inspection.

Institute	service	flow deviation	T & P sensors	other observations
CEAMA	cleaned	-49%	ok	
CSIC		+23.9%	ok	
DWD		-1.38%	ok	
UHEL	cleaned, yellowish pollen inside	-18.6	ok	
ISAC		-2.5%	ok	high noise level
JRC	cleaned	+0.2%	ok	high noise level
NUIG		-2.3%	ok	
TNO	cleaned	-1.28%	ok	reflecting edges in sensor head were blackened
TROPOS 32		+1.5%	ok	
PSI	cleaned, dust in inlet and measurement chamber	+1.7%	ok	

Investigation of high noise of MAAPs JRC and CSIS

a) More test were undertaken for finding the reason for the higher noise.

b) Fluctuations in flow (measurement of mass flow, pump, flow regulation) can be excluded.

c) The noise was not correlated to raw intensities recorded by MAAP (using the scientific data format PF12).

d) No explanation for high noise was found.

Results of intercomparison after instrument inspection

Description: Two subsets of MAAP were compared using the mixing chamber for high flow instruments. All instrument were operated with a flow of 10 lpm. Recorded BC concentrations data are corrected STP conditions.

Subset 1: Instruments: CSIC, UHEL, JRC, NUIG, TROPOS, ISAC

Subset 2: Instruments: JRC, DWD, ISCA, CEAMA, TNO, TROPOS 32

Observations: a) Instrument CEAMA is too low compared to the average. The reason was found to be a wrong flow.

b) The noise of Instruments JRC and CSIC is much higher compared to the other instruments (see paragraph in section 'Inspection')

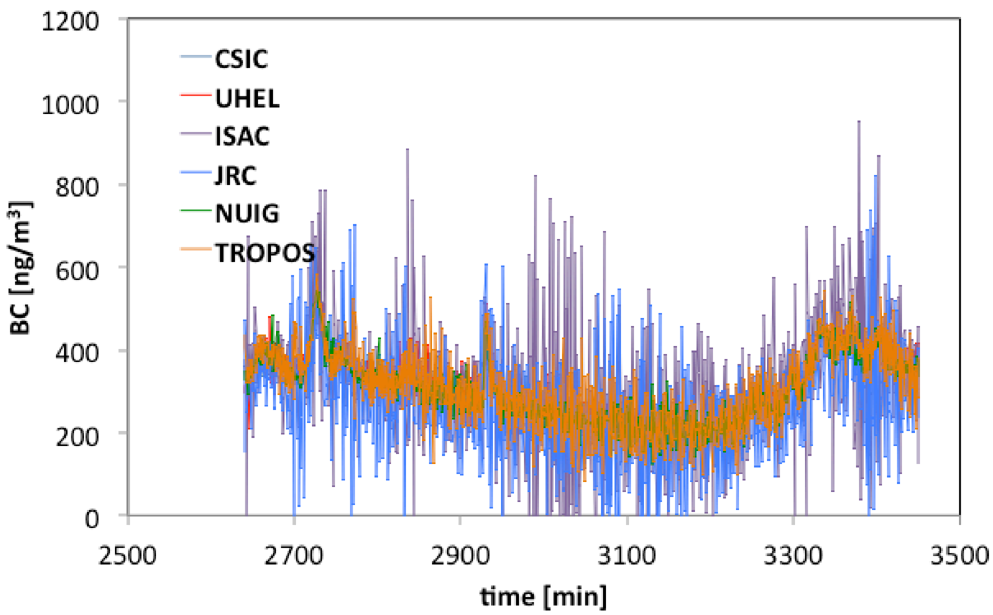

Figure 2.2.3: Intercomparison of MAAPs in set 1 after inspection.

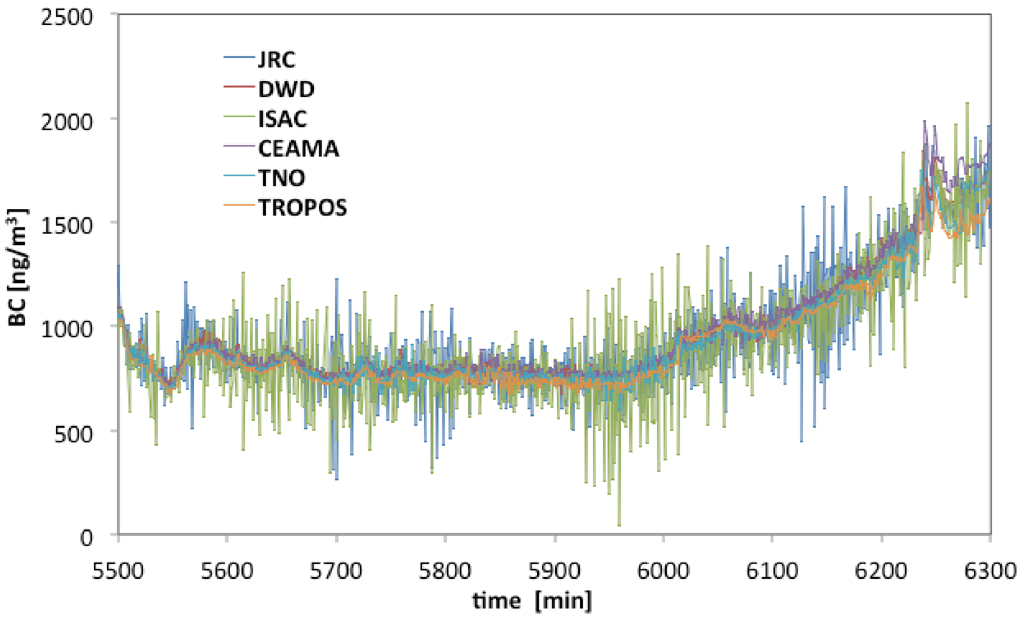

Figure 2.2.4: Intercomparison of MAAPs in set 2 after inspection.

<u>Summary of MAAP intercomparison</u>

Noise: The noise was measured with filtered and is given as double standard deviation (95% confidence interval). For noise tests the flows were set to 6 lpm.

Relative sensitivity: The relative sensitivity of individual instruments is defined as the values of the instrument compared to the average of all instrument in the subset, and is calculated by a linear fit of a correlation plot. The relative sensitivity is given as the deviation in per cent compared to the reference set.

Comparison to previous workshops:

Compared to results from previous workshops (EUSAAR + GAW) the unit to unit variability of relative sensitivities hasn't changed. The noise of individual instruments has significantly increased.

Table 2.2.2: Relative sensitivities and noise for individual MAAPs.

Institute	serial number	rel. Sensitivity			noise (2σ) in ng/m³
		subset 1	subset 2	compared to TROPOS	
CEAMA	43		3.2%		
CSIC	81	-2.6%			
DWD	13		1.9%		
FMI	88	0.4%			35
ISAC	80	-1.5%	-3.1%		124
JRC	118	(14.7%)(1)	-0.3%		102
NUIG	30	-3.8%			36
TNO	85		-1.5%		
TROPOS 32	32	5.6%	-3.8%		19
PSI	11			2.0%	44

(1) Because of low concentrations and the high noise of the JRC MAAP the result is not meaningful.

2.3 PSAP intercomparison

All PSAP were run in parallel at the same manifold. Description of measurements, inspection and summary of results are given below. Different types of PSAPs were used:

a) The commercial single spot, three wavelength instrument from Radiance Research:
Specifications: wavelengths: 467 nm, 530 nm and 660
Instruments: UHEL (SN 103), GOAUVA (SN 96), DWD (SN 104)

b) The commercial single spot, single wavelength instrument from Radiance Research:
Specifications: wavelength: 565 nm
Instruments: UPAC (SN15)

c) The multi spot, single wavelength instrument developed at ITM (iPSAP)
Specifications: wavelength 532 nm
Instruments: ITM (iPSAP4), NILU (iPSAP15)

d) The multi spot, there wavelength instrument (CLAP) developed at NOAA
Specifications: 466nm, 529 nm, 654 nm
Instruments: UPAC (SN 10.024), NOAA (SN 10.023)

Table 2.3.1: Results of instrument inspection and settings.

Instrument	flow deviation at 1lpm,	spot diameter / remark	Instrument settings:
RR-GOAUVA (SN96)	-9%, flow adjusted	4.9 ±0.1/ sharp	Filter Area=17.81 A=0.866 B=1.317
RR-DWD (104)	-1.9%, flow adjusted	4.8 ±0.1/ sharp	Filter Area=17.81 A=0.865 B=1.317
RR-UHEL (103)	-0.7%, flow adjusted	4.9 ±0.1/ sharp	Filter Area=19 A=1.023 B=1.556
RR-UPAC (15)	problems with mass flow meter ?	5.1 ±0.3 / diffuse, diameter of 'central spot'	"Manufacturer build in data" Spot size=17.83 A=0.71 B=1.0796
ITM	(1)	3.1 ±0.1/ sharp, difficult to measure	
NILU	(1)	-	
CLAP 1002023	+3%	5.0 ±0.1/ sharp	
CLAP 100.024	+2%	5.0 ±0.1/ sharp	

(1) More investigations needed, since the instrument changes flow depending on aerosol concentration.

Radiance Research intercomparison after inspection and flow calibration

Instruments: UHEL (SN 103), GOAUVA (SN 96), DWD (SN 104), UPAC (SN 15)

Data processing:

Data of all instruments were processed similar. Mass flows are calibrated and particle light absorption coefficients are referenced to STP conditions. For comparison the STP corrected raw data are shown (no further loading and scattering correction). A spot correction was not applied, since measurement of since the spot sizes is subjective what easily can lead to errors of 5% in spot area.

Expected sensitivities:

Because of different settings the instruments have different loading corrections factors. The loading corrections for the PSAP compared to the original PSAP (without Bond correction) is as follows.

GOAUVA and DWD settings are similar to the original PSAP including the Bond loading correction factor of 1.22. (Values are lower compared to original PSAP)

UHEL has a different correction factors consisting of loading and spot size of about 1.35 (Values are lower compared to original PSAP).

UPAC has correction factor of 1.0 (older instrument, constant loading correction factors).

Results: Intercomparison results are shown in Figure 3.3.1 and summarized in Table 3. 3.1. GOUAVA and DWD PSAP differ less than 4%. This is in the normal uncertainty of instruments.

UHEL instead is 5% lower compared to GOAUVA and DWD. This is partly explained by the larger loading correction factors. Considering the larger loading correction, values for the similar to DWD PSAP. Considering the correction factors this instrument is within the range of uncertainties.

UPAC PSAP measured at a different wavelength. The wavelength difference can explain a smaller value compared to the other PSAP of 6%. The difference of 28% can not be explained by the different correction factors. Applying the additional Bond loading correction factor of 1.22 would increase the difference up to 50%. A huge leak can be excluded, since the zero measurement was quite ok. The flow in the data was unusually constant at 1.00 slpm without any deviation during the experiment time. That could be an indication for an error in the flow measurement. The flow was check with a gilibrator and was found to be 0.95 slpm. The spot on the filter is larger and blurred, what makes a measurement difficult. The flow meter and the p-rings of the instruments need to bee checked. Probably the blurred spot explains the smaller values.

UPAC (SN 15) was not used for calculating averages.

Actions required: UPAC (SN 15) needs service.

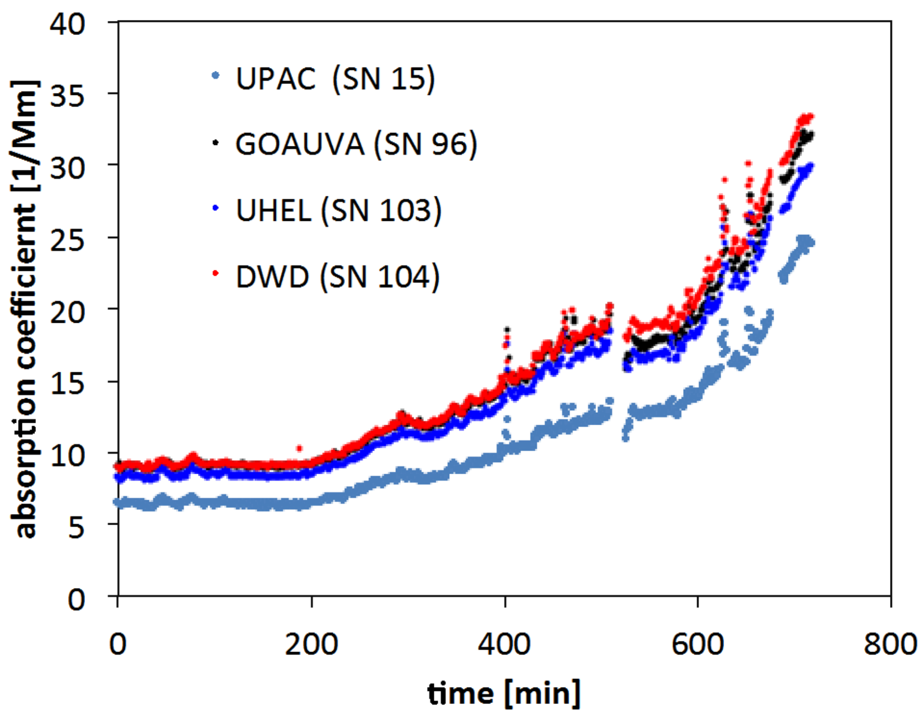

Figure 2.3.1: Intercomparison of Radiance Research PSAPs for the green wavelength.

<u>ITM-PSAP intercomparison</u>

Instruments: GOAUVA (SN 96), iPSAP5, iPSAP15

Data processing: Data of all instruments were processed similar. Mass flows are calibrated and particle light absorption coefficients are referenced to STP conditions. For ITM-PSAPs a loading correction similar to the original correction for Radiance Research PSAP was applied. Additionally the Bond correction was applied to make it comparable with the Radiance Research PSAP.

Results: Correlation of ITM design PSAP versus Radiance research

a) iPSAP4 vs. GAOVA: slope =1.279, intercept =0.98, R2=0.77

a) iPSAP15 vs. GAOVA: slope =1.775, intercept =0.25, R2=0.73

Concluding remark: Differences between the ITM design PSAP and Radiance Research PSAP are not understood. Further actions are required. For time reasons this can not be accomplished during instrument intercomparison workshops.

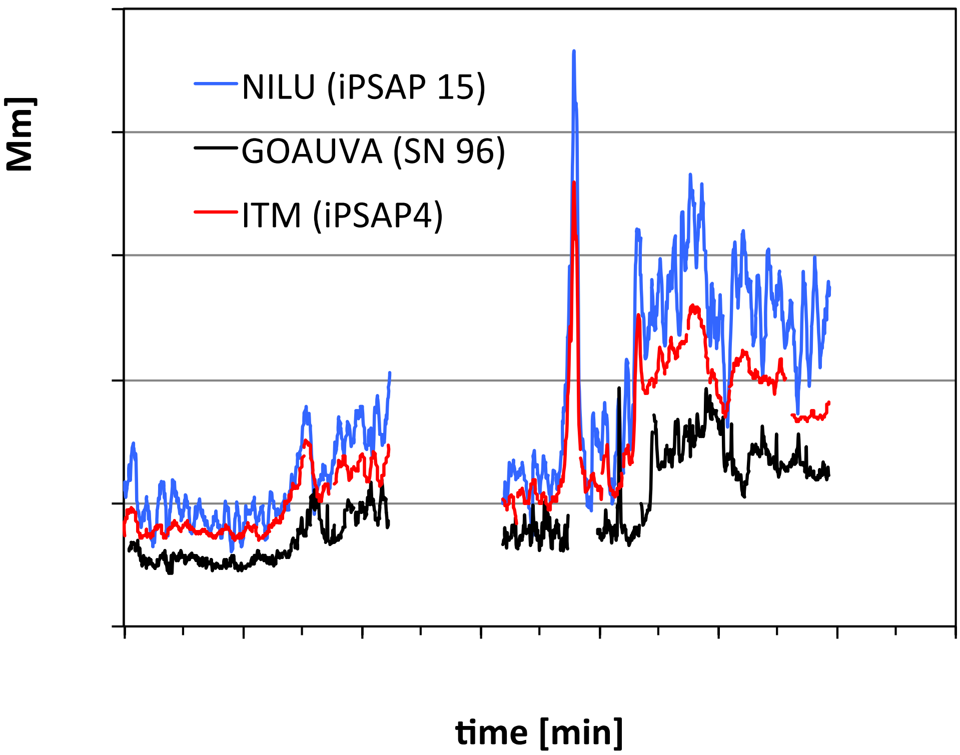

Figure 3.3.2: Intercomparison of ITM design (iPSAP) and a Radiance Research PSAP.

<u>CLAP-PSAP intercomparison</u>

Instruments: CLAP 100.23, CLAP 100.024, PSAP (SN103)

Data processing: Flow deviations to reference flow meter (Gilibrator) is smaller 2%. Shown are raw data, to avoid differences because of different corrections.

Observations: CLAP 100.023 was very noise, because of a noise power supply. Compared to CLAP 100.024 the values were on average 5% higher, but this deviation is very uncertain. Because of the high noise no data for CLAP 100.0023 are shown. After the workshop it could be shown that the main unit of CLAP 100.023 was working well.

Results: Correlation of CLAP100.024 versus Radiance Research PSAP SN 103:

a) slopes are 1.005, 0.993 and 0.912 for Blue, Green and Red.

a) Coefficients of determination (R^2) are about 0.8 for all wavelengths.

Concluding remark: The larger deviation of the red wavelength can not be explained. Values for the blue and green wavelengths agree well for CLAP 100.024 and PSAP SN103

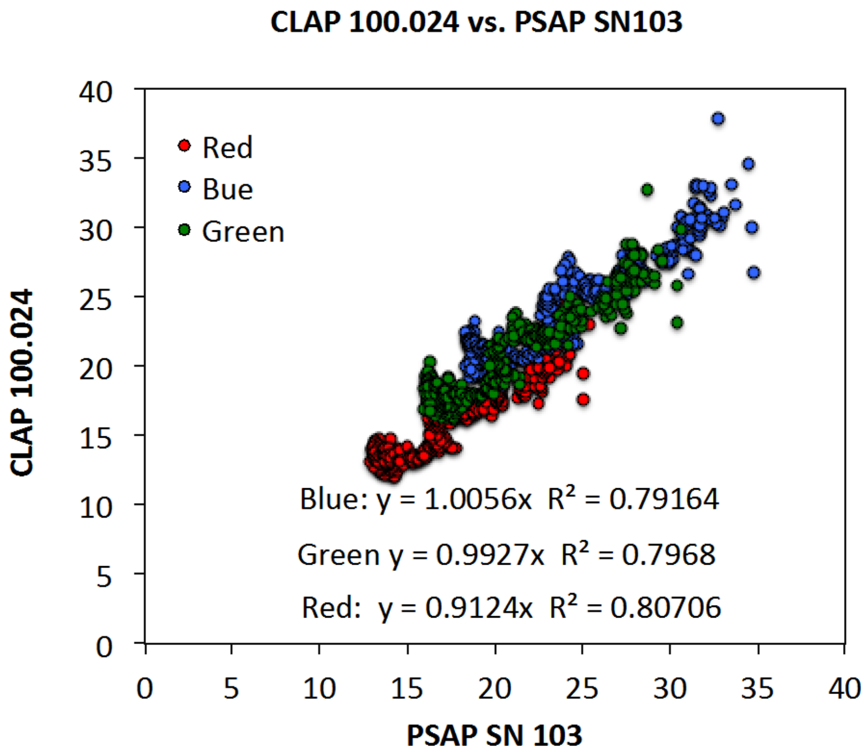

Figure 2.3.3: Intercomparison of CLAP 10.024 and PSAP SN 103.

Summary of PSAPs

Table 2.3.2: Relative sensitivities of PSAPs compared to reference set. The relative sensitivity if given as per cent deviation to the reference set.

Instrument	rel. sensitivity			reference set
	Blue	Green	Red	
RR-GOAUVA (SN96)	0.1%	0.7%	3.5%	avg. of SN96, SN103, SN104
RR-DWD (104)	0.4%	4.6%	2.9%	avg. of SN96, SN103, SN104
RR-UHEL (103)	-4.4%	-5.4%	-6.5%	avg. of SN96, SN103, SN104
RR-UPAC (15)		-27.8%		avg. of SN96, SN103, SN104
ITM		slope=27.9% intercept=0.98		SN96
NILU		slope=77.5% intercept=0.25		SN96
CLAP 10.023	0.5%	-0.8%	-8.8%	RR SN103

Table 2.3.3: Noise (double standard deviation) of PSAPs for 1 min averaging time.

Instrument	noise in 1/Mm		
	Blue	Green	Red
RR-GOAUVA (SN96)	0.146	0.158	0.194
RR-DWD (104)	0.124	0.13	0.136
RR-UHEL (103)	0.08	0.076	0.094
RR-UPAC (15)		0.138	
iPSAP4=ITM		0.116	
iPSAP15		0.066	
CLAP 10.024	0.48(1)	0.48(1)	0.22(1)

(1)The noise in the three channels was correlated. A possible explanation could be an unstable flow. To remove the correlated part for each wavelength the average of the three wavelengths was subtracted. The noise from a characterization at NOAA was about 0.3, 0.32 and 0.35 for 1 minute averaging time.

2.4 Aethalometer intercomparison

Table: 3.4.1: Instrument types, spot configuration and mean ratio.

Instrument	type	mean ratio	spot size
AER	AE33	-	-
ULUND	AE33	-	-
CIEMAT	AE33	-	-
CEAMA	AE31	0.85	extended
FMI	AE31	1	standard
CHMI	AE31	1	standard
NCSR-D	AE31	1	standard
JRC	AE31	1	extended
SIRTA	AE31	-	-
FORTH	AE31	1	standard
CORSICA	AE31	-	-
ISSEP	AE20	0.85	extended

Technical description: AE20: double wavelength 370 and 880 nm

AE31: 7-wavelengths 370, 470, 520, 590, 660, 880, 950 nm

AE33: dual spot, 7-wavelengths 370, 470, 520, 590, 660, 880, 950 nm

Experimental: Two sets of instruments:

Set 1: CIEMAT, REF, LUND, CEAMA, FMI, CHMI

Set 2: CIEMAT, Ref, ULUND, NCSRD, JRC, SIRTA

Rel. sensitivity was calculated from correlation plots of individual instruments and the reference MAAP (TROPOS 137). For Aethalometers the 880 nm BC channel was compared to the BC concentration of MAAP at 670.

Aethalometer flows were set to 4 lpm and the MAAP flow was set to 8 lpm. The volume reference for all instruments was set to the standard conditions (T=20C, P=1013 hPa).

Intercomparison before inspection

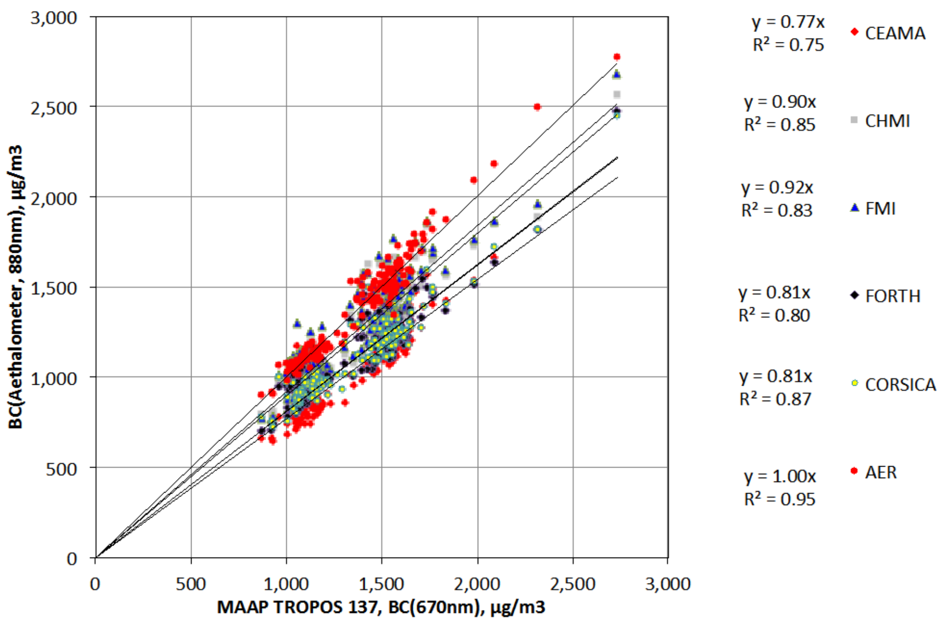

Figure 3.4.1: Intercomparison of Aethalometers in set 1. Plotted are BC concentrations from Aethalometers at 880 nm versus BC from MAAP at 670 nm.

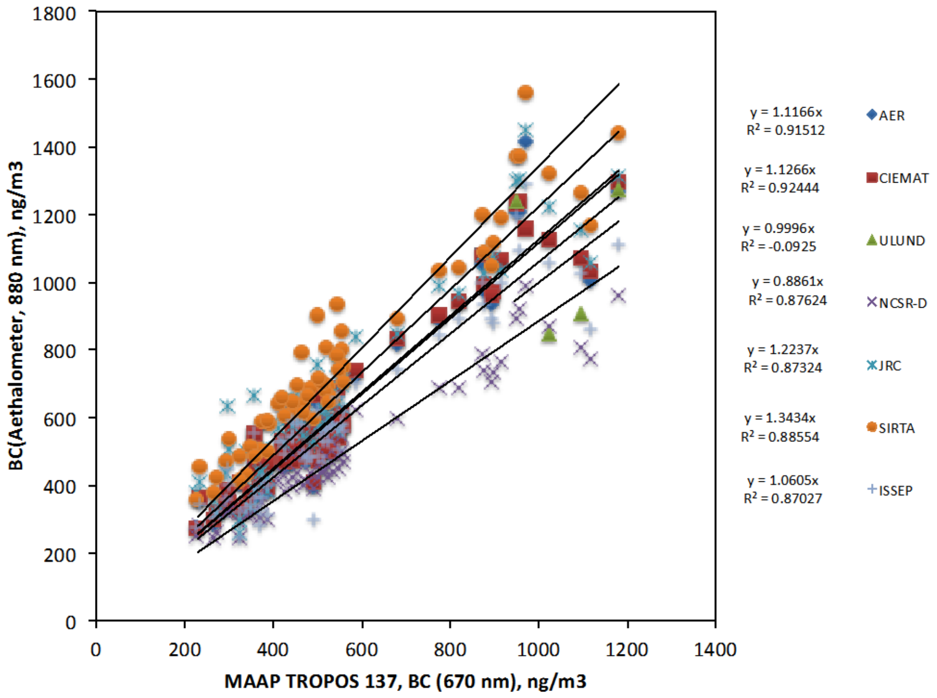

Figure 3.4.2: Intercomparison of Aethalometers in set 2. Plotted are BC concentrations from Aethalometers at 880 nm versus BC from MAAP.

Table: 3.4.2. Intercomparison results before inspection. The relative sensitivity is given as percent deviation compared to MAAP.

	set	AE33			AE31								AE22
		CIEMAT	AER	ULUND	CEAMA	FMI	CHMI	NCSR-D	JRC	SIRTA	FORTH	CORSICA	ISSEP
rel.sens.	1	8	0%		-23%	-8%	-10%				-9%	-19%	
R^2			0.95		0.75	0.83	0.85				0.8	0.87	
rel.sens.	2	12%	12%	8%				-11%	22%	34 %			6%
R^2		0.92	0.91	0.89				0.8	0.87	0. 89			0.87
averages		8%			-4%								6%

<u>Inspection</u>

Aethalometers inspection was done according to service

AE31 FMI:	Cleaning optics, flow check
AE31 FORTH:	Send for repairing to Aerosol d.o.o.
AE31 CORSICA:	Send for reparing to Aerosol d.o.o.
AE31 SIRTA:	Flow calibration
AE31 CEAMA:	
AE31 CHMI:	
AE31 NCSR-D:	
AE31 JRC:	
AE20 ISSEP:	
AE33 CIEMAT:	
AE33 AER:	
AE33 ULUND:	

Intercomparison after inspection

Table: 3.4.1.3. Intercomparison results after inspection. The relative sensitivity is given as as percent deviation compared to MAAP.

	set	AE33			AE31						AE20
		CIEMAT	AER	ULUND	CEAMA	UHEL	CHMI	NCSRD	JRC	SIRTA	ISSEP
rel.sens.	1	11%	8%	5%	19%	13%	11%				
R^2		0.83	0.83	0.81	0.82	0.84	0.81				
rel.sens.	2	12%	10%	5	%			-0.9%	24%	31%	1%
R^2		0.83	0.82	0.81				0.82	0.70	0.62	0.73
avg.		8.5%			15%						1%

Conclusions of Aethalometer intercomparison:

Relative sensitivities before and after inspection can vary. The reasons could not be explained in detail for all instruments. One explanation also could be that the ambient aerosol might have changed between the two runs. The average sensitivity for AE31 changes from -4% to 15%. For AE33 the average sensitivity does not show such a change and amounts 8% and 8.5%, respectively. In calibration experiments (see Deliverable WP3 / D3.16) it was found, that AE33 is less sensitive to changes of the aerosol type, specifically the particle number size distribution of the absorption fraction.

AE33 Aethalometers show overall variability (all runs, all sets) of about 10% compared to MAAP. In Contrast the AE31 show a much higher variability of up to 40% (CEAMA -32% to 19%). Results show here are the relative dependence compared to MAAP. The MAAP is not reference instrument for absolute values. The use as a ‘reference’ is because of the low unit to unit variability (c.f. Table 3.1.2.2). Therefore a more experiments like that presented in Deliverable WP3 / D3.16 are necessary.

The results for AE31 are similar to results of previous workshops (GAW and EUSAAR).

Wavelength dependence:

Data: The wavelength dependence was investigated from runs after instrument inspection. The BC concentration was normalized to the concentration of the 880 nm channel.

Observation: The BC concentration shows a wavelength dependence with higher values for smaller wavelengths. This can be an indication for organic carbon. Furthermore it can be seen, that the AE33 instruments have a stronger wavelength dependence. The conversion factors of the AE31 for calculating the BC concentration from the optical attenuation are 39.5, 31.1, 28.1, 24.8, 22.2, 16.6, 15.4 for the wavelength 370, 470, 520, 590, 660, 880, 950. The values for the AE33 are smaller by a constant factor of 2.13.

Actions required: Investigation of the different wavelength dependences of AE31 and AE33. It is not clear if that is an artefact of the instruments or result of the present aerosol during the workshop.

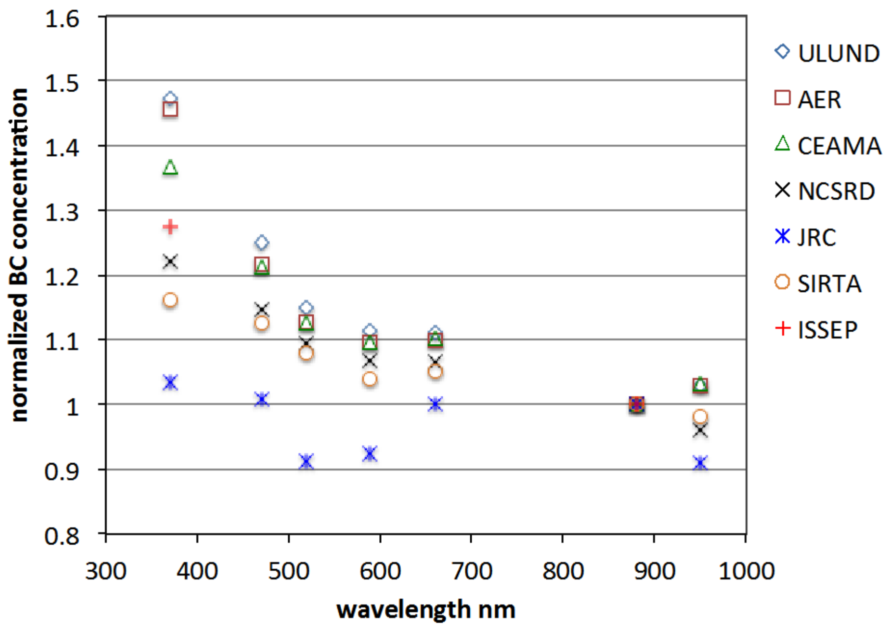

Figure: Spectral run of normalized BC concentration for set 2.

3 Integrating nephelometer intercomparison

3.1 Organization and experimental setup

The instruments were split in several subgroups. Integrating nephelometers from manufacturers TSI and Ecotech were compared in separately.

Two integrating nephelometers of type TSI 3563 were designated as reference instruments. The reference instruments (TROPOS 1027 and TROPOS 1025) were compared before the workshop The sensitivity of TROPOS 1025 compared to TROPOS 1027 for total scattering (ts) and backscattering (bs) is: -3.1% (blue, ts), -2.7% (green, ts.), -4.9%(red, ts), -15.6% (blue, bs) -14.3% (green, bs), -16.4% (red, bs). Several calibrations confirmed that the backscattering coefficient is significantly lower for TROPOS 1025.

The steps for performing the intercomparison experiments are shown in Table 4.1.1. Because of the multitude of instruments the setup changed little from experiment to experiment. The experimental setups consist of several compounds shown in Table 4.1.1. A an overview of all instruments is given in Table 4.1.3

Table 4.1.1: Steps for performing integrating nephelometer intercomparison.

I	First intercomparison of instruments of the same type	Several runs with • ambient air • filtered particle free air
II	Inspection	• Cleaning measurements chamber and inlets • Calibration of T and P sensors if necessary
III	Second intercomparison of instruments of the same type	Several runs with • ambient air • filtered particle free air Use of a reference sets.

Table 4.1.2: Component of the experimental setup.

inlet	• ambient air inlet without any size cut
aerosol dryer	• aerosol was dried using silica dryers • humidity was check in the reference integrating nephelometer
aerosol flow splitting	• manifold for Ecotech integrating nephelometers or mixing chamber with 8 output ports for TSI 3563 integrating nephelometers
reference instruments	• integrating nephelometers of type TSI model 3563

Table 4.1.3: List of integrating nephelometers.

Institution	**TSI**	**Ecotech**			
	model 3563	Model 9003	Aurora 1000	Aurora 3000	Aurora 4000
SIRTA 060511		x (blue)			
SIRTA 030382		x (green)			
ULUND				x	
CIEMAT				x	
ISAC		x			
CSIC				x	
ECOTECH					x
NCSR-D				x	
FORTH			x		
TROPOS					x
BEO	x (1)				
CEAMA	x				
CORSICA	x				
DWD	x				
FMI	x				
GOA-UVA	x				
CHMI	x				
JRC	x				
UBP	x				
NUIG	x				
PSI(1)	x(1)			x(1)	
TNO	x				
TROPOS 1025	x				
TROPOS 1027	x				
UHEL	x				
UPAC	x				

(1) Instruments not available during workshop. The intercomparison was performed after workshop against the instruments from TROPOS.

3.2 Intercomparison of integrating nephelometers of type TSI model 3563

Instruments:

All integrating nephelometers from brand TSI are of type TSI model 3565. These instruments measure total and back- scattering coefficients at the three wavelengths 450, 550 and 700 nm.

Experimental runs:

Run 1: test aerosol: ambient air, 25/26. Feb.
instruments: JRC, CEAMA, TNO, CHMI, NUIG, TROPOS 1027

Run 2: test aerosol: ambient air, 26. Feb.
instruments: UBP, UHEL, DWD, CORSICA, TROPOS 1027

Run 3: test aerosol: filtered air, 27. Feb.
instruments: UBP, UHEL, DWD, CORSICA, TROPOS 1207

Run 4: test aerosol: ambient air, 27/28 Feb.
instruments: DWD, JRC, UPAC, NUIG, UBP, TROPOS 1027

Run 5: test aerosol: filtered air, 28 Feb.
instruments: DWD, JRC, UPAC, NUIG, UBP, TROPOS 1027

Run 6: test aerosol: ambient air 28 Feb. to 1. Mar.
instruments: UBP, CHMI, TNO, NUIG, CORSICA, TROPOS 1027

Noise tests using filtered air

Instrumental noise was determined by filtered air. Data were recorded with one minute time resolution. The noise is defined as the double standard deviation (2σ) of the data.

Table 4.2.1: Noise of TSI 3565 integrating nephelometers, ts=Total scattering, bs=backscattering, red=700nm, gree=550nm, blue=450nm.

Instrument	ts, blue	ts, green	ts, red	ts, blue	ts, green	ts, red
BEO	0.348	0.223	0.231	0.235	0.166	0.206
CEAMA	0.781	0.445	0.409	0.362	0.195	0.339
CORSICA	0.762	0.323	0.484	0.338	0.251	0.398
DWD	1.164	0.499	1.320	0.996	0.327	0.875
FMI	1.306	0.422	0.477	0.806	0.285	0.484
GOA-UVA	-	-	-	-	-	-
CHMI	0.582	0.315	0.326	0.392	0.171	0.203
JRC	0.393	0.193	0.190	0.259	0.126	0.139
UBP	0.753	0.441	0.388	0.354	0.298	0.347
NUIG	0.553	0.343	0.583	0.422	0.367	0.478
PSI	3.994	1.661	0.820	3.229	1.260	0.833
TNO	0.662	0.416	24.38	0.4667	0.282	3.471
TROPOS 1027	0.545	0.414	1.201	0.601	0.305	1.214
UHEL	0.537	0.298	1.118	0.428	0.262	0.967
UPAC	0.355	0.232	0.245	0.232	0.135	0.211

Span check

Span checks were performed with CO2 prior to servicing instruments. The result is given as the relative deviation relative deviation to the theoretical value of Rayleigh scattering coefficients of CO_2.

Table 4.2.2: Span check results. The relative deviation is given in per cent deviation from the theoretical value. A positive value means that the integrating nephelometer gives too high values.

	ts, blue	ts, green	ts, red	ts, blue	ts, green	ts, red
BEO	-	-	-	-	-	-
CEAMA	3.1 %	1.0 %	0.5 %	4.7 %	3.5 %	2.9 %
CORSICA	1.3 %	-0.5 %	2.2 %	0.1 %	-0.9 %	-0.5 %
DWD	5.6 %	1.6 %	6.4 %	-1.5 %	-6.7 %	-10.5 %
FMI	2.0 %	3.6 %	10.9 %	-6.7 %	-1.9 %	9.0 %
GOA-UVA	-	-	-	-	-	-
CHMI	3.3 %	2.3 %	3.4 %	7.1 %	4.9 %	7.1 %
JRC	4.15 %	0.5 %	-2.1 %	2.6 %	0.9 %	-5.8 %
UBP	-11.7 %	-16.0 %	-31.4 %	-4.4 %	-6.7 %	-19.0 %
NUIG	-1.4 %	5.3 %	7.7 %	-4.6 %	3.5 %	9.5 %
PSI	6.0 %	-7.6 %	-15.8 %	-10.6 %	-12.1 %	-14.8 %
TNO	-1.7 %	0.3 %	72.1 %	0.0 %	-1.5 %	32.1 %
TROPOS 1027	-2.2 %	-1.2 %	-1.6 %	-3.0 %	2.3%	2.6 %
UHEL	2.6 %	3.0 %	0.6 %	4.8 %	2.2 %	2.5 %
UPAC	3.4 %	5.3 %	0.4 %	3.6 %	3.9 %	-2.0 %

Instruments inspection

FMI: Span check stopped because the lamp connector was very hot and getting burnt.

UBP: Span check for all wavelengths too low? Instrument needed to be cleaned.

PSI: Span check for most wavelength too low. A possible reason could be that the instrument was calibrated at Jungfraujoch at low pressure. Temperature and pressure sensors were compared at room temperature and were found to be ok.

TNO: Red channel too high! The background was too high in the red. Possibly the background is drifting? Reasons could not be found. The Instrument cell was clean. In the light trap 'metallic' particle were found. After cleaning the background did not change. Multiplier voltages are ok. In summary, the reasons could not be found.

BEO: Both temperature sensors measure to high values of about 5K. Sensors were not recalibrated. Sensors should be checked again when instrument is back at the station.

Black baffle inside the detection unit was loose and blocked partly. This obviously happened during transportation. For fixing the baffle the whole detection unit was disassemble. Therefore the instrument had to be recalibrated. Therefore an initial span check was not possible.

GOA-UVA: Cell had a mechanical damage and the multiplier for red was not working. For testing the multiplier was replaced by multiplier of different type. Multiplier should be replaced by a new one of the same type. Intercomparison with other TSI nephelometers was not possible.

NUIG: The temperature in the first experiments in the instruments was 20K too high and the scattering coefficients were much lower. Correction of the temperature and pressure can explain the differences. The problem was an almost blocked blower for cooling the light source and cell. After cleaning the temperature in the cell was ok. The blue backscattering coefficients were still about 10% lower. The other channels are ok.

CHMI: Instrument needed to be cleaned.

DWD: Instrument needed to be cleaned.

<u>Instrument intercomparison results</u>

The intercomparison runs were done with subsets of instruments (see overview of experimental runs). The relative sensitivity of individual instruments compared to the average of instruments was calculated for each run. Table 4.2.3 gives relative sensitivities compared to the average of all instrument in that subset. Beside the relative sensitivity of the instrument also the intercept of the linear correlation is given if the span of values is high enough. If the date are relatively close together, the intercept is not reliable and just the slope is given. Instruments, which deviate more the 10% from the average, were excluded from the calculating the average.

Table 4.2.3: Instrument comparison results. Per cent relative sensitivities compared to the average of the subset of instruments. In brackets the intercept in Mm^{-1} is given

		total scattering			backscattering		
experiment	instrument	450 nm	525 nm	635 nm	450 nm	525 nm	635 nm
run 4	DWD	4.61 % (-1.97)	2.05 % (-0.75)	8.23 % (-0.13)	-5.58 % (-0.61)	-7.21 % (-0.16)	-0.33 % (-0.06)
run 4	JRC	0.59 % (0.72)	5.22 % (-0.82)	2.62 % (-0.13)	-1.37 % (0.25)	3.61 % (-0.07)	3.62 % (0.16)
run 4	UPAC	2.60 % (-0.78)	2.59 % (-0.26)	-3.26 % (-0.46)	0.43 % (-0.07)	0.75 % (-0.16)	-5.23 % (-0.04)
run 4	TROPOS 1027	2.26 % (-0.57)	2.41 % (-0.31)	-1.77 % (0.92)	10.44 % (0.42)	11.8 % (0.36)	6.69 % (0.15)
run 6	UBP	2.90 % (-0.30)	0.08 % (-0.19)	1.07 % (0.53)	4.95 % (-0.01)	1.13 % (0.01)	0.63 % (0.22)
run 6	CHMI	4.25 % (0.30)	1.22 % (0.47)	3.16 % (0.68)	6.71 % (-0.03)	1.52 % (0.09)	-0.40 % (0.27)
run 4	TNO	-6.41 % (0.26)	-5.53 % (0.26)	-5.96 % (-3.67)	-11.25 % (0.22)	-7.85 % (0.01)	-7.54 % (-0.41)
run 4	NUIG	-2.50 % (0.30)	-0.20 % (-0.27)	1.38 % (0.71)	-9.60 % (-0.06)	-4.93 % (-0.16)	-0.70 % (0.03)
run 4	CORSICA	-1.63 % (-0.42)	1.42 % (-0.60)	1.60 % (0.59)	-5.06 % (0.12)	-2.47 % (-0.01)	0.56 % (0.13)
run 1	CEAMA	-6.45 % (5.20)	-5.92 % (3.17)	-6.18 % (2.37)	-5.75 % (0.33)	-4.27 % (0.15)	-9.88 % (0.52)
-	BEO[1,3]	+5.7 %	+1.1 %	+3.7 %	0.0 %	-5.3 %	-0.4 %
run 2	UHEL[4]	-1.44 % (-0.08)	-1.80 % (0.27)	-2.70 % (-0.11)	0.55 % (0.19)	0.19 % (-0.01)	-0.29 % (-0.04)
-	PSI[3]	-4.8 % (-0.02)	-6.4 % (-0.1)	-11.1 % (-0.4)	-5.1 % (-0.4)	-7.6 % (-0.2)	-14.5 % (-0.1)
-	GOA-UVA[2]	-	-	-	-	-	-
-	FMI[2]	-	-	-	-	-	-

(1) Because of less variation in the aerosol concentration the data for intercomparison were concentrated in a point cloud. Therefore the correlation line had to be forced through the origin.

(2) No data available because of technical problem with instruments

(3) Intercomparison after workshop. Reference instrument was TROPOS 1027.

(4) Intercomparison before instrument inspection.

3.3 Ecotech integrating nephelometers

Types of instrument

M9003: Total scattering only and single wavelength instruments.

Aurora3000: Total and back-scattering multi-wavelength instrument. The wavelengths are 450, 525, and 635 nm.

Aurora4000: Polar multi-wavelength instrument. The wavelengths are 450, 525, and 635 nm. Total and backscattering coefficients are be measured by setting a variable shutter to 0° and 90°. This is similar to the total and backscattering measurement mode of the Aurora3000. Additionally any other angle between 0° and 90° is possible. This polar technique was not used and only total and backscattering coefficients were evaluated.

Overview of intercomparison runs

Run 1: Instruments not cleaned and not calibrated: CNR, ECOTECH, ULUND, SIRTA 060511, SIRTA 030382. Reference is the average of ECOTECH and ULUND since data from the other instruments were not reliable.

Run 2: Instruments not cleaned and not calibrated: CIEMAT, NCSR-D, FORTH, CSIC. Reference is the average of CIEMAT and NCSR-D since data from the other instruments were not reliable.

Run 3: Instruments cleaned and calibrated: CIEMAT, NCSR-D, FORTH, ECOTECH

Run 4: Cleaned and calibrated: CIEMAT, NCSR-D, ECOTECH, ULUND un-calibrated but cleaned.

Run 5: Instruments cleaned and calibrated: ULUND, CIEMAT, NCSR-D, ECOTECH

Run 6: Instruments cleaned and calibrated: CSIC, FORTH, SIRTA 060511, SIRTA 030382, TROPOS, ISAC

Run 7: Instruments cleaned and calibrated: CSIC, FORTH, SIRTA 060511, SIRTA 030382, TROPOS

Run 8: Instruments cleaned and calibrated: CSIC, CIEMTA, TROPOS

Run 9: Instruments cleaned and calibrated: CSIC, SIRTA 030382, TROPOS, NCSR-D, ECOTECH, CIEMTA (recalibrated)

Run10: Instruments cleaned and calibrated: CSIC, FORTH, , SIRTA 060511, SIRTA 030382, TROPOS

Run11: Instruments cleaned and calibrated: CSIC, SIRTA 030382, TROPOS, NCSR-D, ECOTECH, CIEMTA (recalibrated)

Run12: Instruments cleaned and calibrated: CSIC, FORTH, SIRTA 060511, SIRTA 030382, TROPOS

Instrument inspection

SIRTA 060511: Instrument was much lower compared to other instrument during initial intercomparison. A leak through zero port was found. The leak only appears using an external pump, and an automatic zero was not possible. After initial intercomparison run1 the instrument was calibrated and cleaned. The following intercomparison went fine.

SIRTA 030382: Instrument was much lower compared to other instrument during initial intercomparison. Leak through zero port was found (as for SIRTA 060511), and o-ring on light source was broken. No suitable spare o-ring was present. Another too long o-ring was cut and glued; this is not a long term solution. After calibration the next intercomparison went fine.

ULUND: Leak test failed, a small leak present. Instrument was opened and cleaned. Bugs were found in cell. After reassembling the leak test was ok. The leak probably was just from a screw not been tied enough.

CIEMAT: Initial intercomparison was ok. Leak test passed.

NCSR-D: Initial intercomparison was ok. Leak test passed.

ISAC: Initial intercomparison failed. Instrument was too low. Leak found I light source. The o-ring was broken and replaced (similar as for instrument SIRTA 030382). Cell was full of pollen and and a dead moth. Instrument was cleaned and calibrated. Following intercomparison was ok.

MONTSENY: Instrument during first intercomparison too low. Leak found at and cap of cell mayby because of a damaged o-ring. O-ring could not be replaced, therefore the outside of the cell was sealed. That is not a long term solution. After full calibration the next intercomparison was ok.

ECOTECH: Intercomparison ok.

TROPOS: Nothing to comment

ECOTECH: Nothing to comment

FORTH: Nothing to comment

PSI : Nothing to comment

Instrumental noise:

No runs with filtered air long enough to derive the instrument noise were performed.

Intercomparison of instruments before and after inspection

Instruments were compared before and after inspection. The inspection included a possible recalibration. Results for the individual instruments are shown in Table 4.3.1 and 4.3.2.

Table 4.3.1: Instrument intercomparison **before inspection and calibration**. Per cent relative sensitivities compared to the average of the subset of instruments. In brackets the intercept in Mm^{-1} is given.

run	instruments	total scattering			backscattering		
		450 nm	525 nm	635 nm	450 nm	525 nm	635 nm
run 1	SIRTA 060511 (1)	-12					
run 1	SIRTA 030382 (1)		-108				
run 1	LUND (1)	1.25	2.1	3.9	-	-	-
run 1	ISAC (1)		-36				
run 2	CIEMAT	1.28 (-2.04)	-1.07 (1.05)	-1.37 (1.73)	-	-	-
run 2	CNSR-D	-1.28 (2.04)	1.07 (-1.05)	1.37 (-1.73)	-	-	-
run 2	FORTH		-48 (19)				
run 2	CSIC	-74 (28)	-78 (33)	-79 (34)			
-	TROPOS	-	-	-	-	-	-
run 1	ECOTECH (1)	-1.25	-2.1	-3.9	-	-	-

(1) Because of less variation in the aerosol concentration the data for intercomparison were concentrated in a point cloud. Therefore the correlation line had to be forced through the origin.

Table 3.2.3.2: Instrument intercomparison **after inspection and calibration**. Per cent relative sensitivities compared to the average of the subset of instruments. In brackets the intercept Mm^{-1} is given. Results are averages for several intercomparison runs.

Run	instrument	total scattering			backscattering		
		450 nm	525 nm	635 nm	450 nm	525 nm	635 nm
runs 7, 8	SIRTA 060511	0.94 % (-1.70)					
runs 7 , 8	SIRTA 030382		1.02 % (-1.82				
runs 4, 10, 12	LUND	1.04 % (-0.02)	1.02 % (1.14)	1.02 % (2.25)	0.97 % (-0.34)	0.95 % (0.09)	0.98 % (2.40)
runs 8,10	ISAC		1.02 (-5.35)				
runs, 3, 4, 8, 9, 11	CIEMA	0.97 % (1.75)	0.93 % (-0.91)	0.94 % (1.67)	0.96 % (-0.34)	0.94 % (-0.30)	0.89 % (0.19)
runs 3, 4, 9, 11	CNRS-D	0.96 % (0.65)	0.94 % (2.69)	0.98 % (0.35)	0.92 % (0.62)	0.95 % (-0.03)	0.93 % (0.15)
runs 7, 10	FORTH		0.98 % (-2.7)				
runs 7, 8, 9, 11	CSIC	0.99 % (-1.16)	1.00 % (-1.89)	1.04 % (-2.07)	1.02 % (-0.51)	1.03 % (-0.68)	1.08 % (-0.58)
runs 7, 8, 9, 11	TROPOS	1.03 % (-2.52)	0.98 % (3.27)	0.99 % (0.90)	1.03 % (-0.29)	0.95 % (0.23)	1.01 % (-0.50)
run 11	ECOTECH	6.28 % (-1.71)	3.2 % (-0.21)	-7.93 % (0.42)	8.74 % (0.13)	0.92 % (-0.25)	1.39 % (0.12)
	PSI	-10.7 % (1.4)	-7.1 % (-0.13)	6.8 %[(1)] (-1.85)	-2.9 % (-0.06)	2.2 % (-0.54)	-1.8 % (-0.34)

[(1)] Compared after workshop to TSI model 3565 (TROPOS 1025). Note that the nephelometer TROPOS 1025 was about 10% lower for total scattering in the red. That explains the apparent larger relative sensitivity of the PSI integrating nephelometer for total scattering in the red channel.

3.4 Comparison of Ecotech and TSI integrating nephelometers

For comparison of TSI and Ecotech integrating nephelometers, the scattering and backscattering coefficients wee adjusted to STP conditions. Furthermore the truncation errors of Ecotech and TSI integrating Nephelometers were corrected for (Müller et al. 2010). The data of the TSI integrating nephelometers were adjusted to the wavelengths of the Ecotech integrating nephelometer using the scattering Ångström exponent. The relative sensitivity of the average of Ecotech integrating nephelometers compared to the TSI integrating nephelometers is summarized in Table 4.4.1. Values of Ecotech and TSI instruments differ significantly. The scattering Ångström exponent of the Ecotech and TSI integrating nephelometers are 1.02 and 1.21, respectively. A loss of large particles due to sample line losses could explain the lower scattering coefficients and higher values for the Ångström exponent of the TSI nephelometers. However, a gradual decrease of Ångström along the manifold was not found for the Ecotech nephelometers. Possibly the TSI integrating nephelometers was sucking cleaner air form the lab through a leak. **For unknown experimental errors this comparison failed.**

Table 4.4.1: Relative sensitivity of Ecotech integrating nephelometers to TSI integrating nephelometer TROPOS 1025. Values are corrected for truncation, temperature and pressure, and wavelength.

	total scattering			back scattering		
	blue (450 nm)	green (525 nm)	red (635 nm)	blue (450 nm)	green (525 nm)	red (635 nm)
rel. sens. of Ecotech compared to TSI (TROPOS 1025)	+8.5%	+12.9%	+23.1%	+17.5%	+16.2%	17.6%

To exclude losses in the sampling lines the TSI integrating nephelometer (TROPOS 1025) and one Ecotech integrating nephelometer (TROPOS) were compared at the end of the workshop using the mixing chamber. The test aerosol in this case was ammonium sulphate. In this experiment a good agreement between TSI and Ecotech integrating nephelometers for total scattering coefficient was found. However, for backscattering coefficients the Ecotech integrating nephelometer shows higher values. Table 4.4.2 shows the results compared to data from a similar experiment published in Mueller et al. (2011). This test confirms the comparability between TSI model 3565 and Ecotech4000 nephelometers for total scattering coeffcients. For backscattering coefficients the difference can be up to 16% .

Table 3.2.4.2: Relative sensitivity of Ecotech integrating nephelometers compared to TSI integrating nephelometers.

	total scattering			back scattering		
	blue (450 nm)	green (525 nm)	red (635 nm)	blue (450 nm)	green (525 nm)	red (635 nm)
Ecotech vs. TSI during ACTRIS 2013	-1.9 %	+1.1%	+0.5%	+5.2%	-10.5%	16.2%
Ecotech vs. TSI from Mueller et al. (2011)	-4%	-2%	-5%	-7%	1%	11%

References:

Bond, T. C., Bussemer, M., Wehner, B., Keller, S., Charlson, R. J., and Heintzenberg, J.: Light absorption by primary particle emissions from a lignite burning plant, Environmental Science and Technology, 33, 3887-3891, 1999.

Ogren, J. A.: Comment on "Calibration and Intercomparison of Filter-Based Measurements of Visible Light Absorption by Aerosols", Aerosol Sci. Tech., 44, 589-591, 2010.

Müller, T., Laborde, M., Kassell, G., and Wiedensohler, A.: Design and performance of a three-wavelength LED-based total scatter and backscatter integrating nephelometer, Atmospheric Measurement Techniques, 4, 1291-1303, 2011.