WCCAP Report: Nephelometer Workshop 2007

The nephelometer workshop was conducted parallel with the absorption photometer at the WCCAP facilities at the Leibniz Institute for Tropospheric Research in March 2007

List of scientist and station personnel participated in the workshop:

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List of instrumentation (nephelometer and absorption photometers) calibrated and compared during the workshop

Instrument class	Instrument type	
Nephelometer Measured quantity: scattering coefficient	A- TSI, multi-wavelength	14
	B- TSI, single-wavelength	2
	C- Ecotech, multi-wavelength	1
	D- Ecotech, single-wavelength	3
	E- Radiance Research	2
Absorption photometer Measured quantity: Absorption coefficient	F- MAAP	8
	G- PSAP, multi-wavelength	4
	H- PSAP, single-wavelength	8
	I- PSAP, home made	4
	J- Aethalometer, multi-wavelength	4
	K- Aethalometer, single-wavelength	3
Reference absorption	M- Photoacoustic absorption photometer	2
	N- Extinction cell, home made (difference of extinction and scattering)	1
		56

Outline of the the workshop

1) Calibration with CO2
2) Assumptions and non-idealities
3) Effect of non-idealities of illumination
4) Correction schemes
5) Ambient comparison

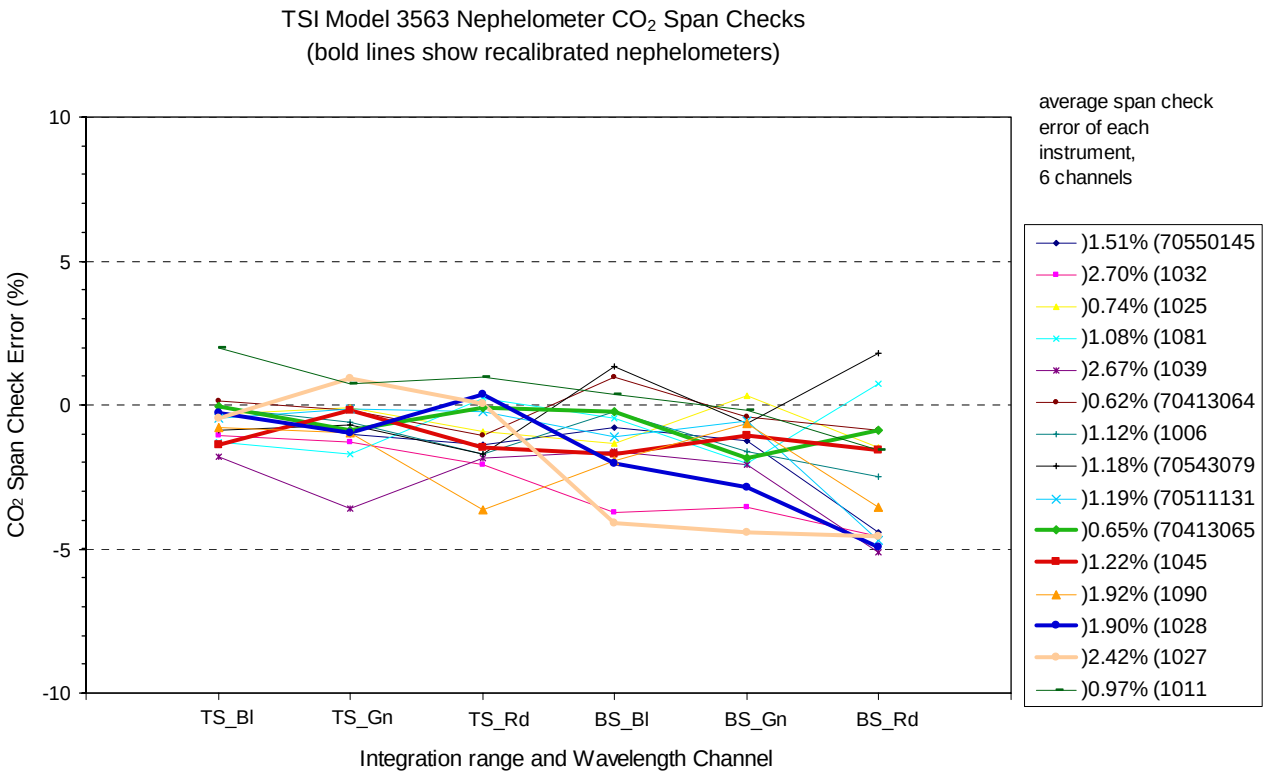
Experiments performed during the workshop

TSI model 3563, 3 wavelength, 14 units
Radiance Research model 903, single wavelength, 3 units
Ecotech model 9003, single wavelength, 3 units, and new 15LED source
Ecotech Aurora 3000, 3 wavelength, 1 unit (3 prototype light sources)

1. CO2 test of calibration (span) in terms of light scattering coefficient
2. Goniometer measurements of light source intensity as a function of angle
   a) TSI, difference compared to previous measurements (3 light sources)
   b) Radiance Research, new (3 light sources)
   c) Ecotech, new (1 light source)
3. Intercomparison of nephelometers measuring ambient aerosol scattering coefficient

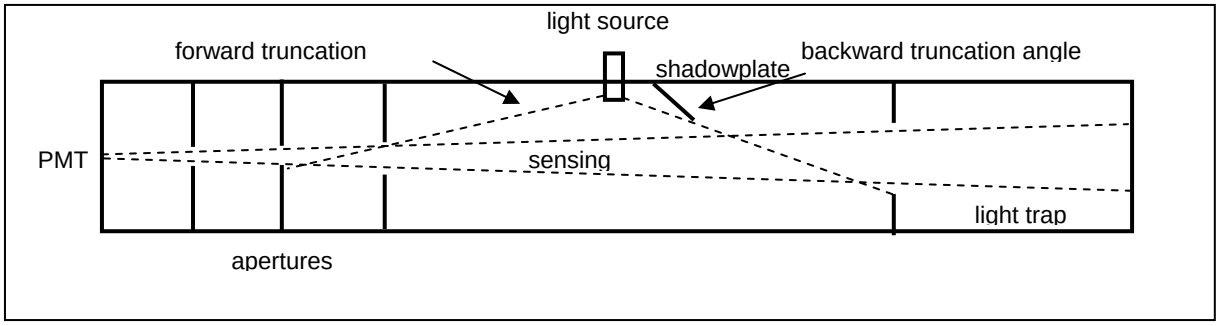
Results

Comparison span check – previous and during workshop



Illumination assumptions and non-idealities

- Forward and backward truncation angles of illumination of sensing volume
- Lambertian light source, sine function
- Light source small cf. length of sensing volume



Schematic of TSI nephelometer geometry, Anderson et. al, J. Geophys. Res., 1996

Practical limits

Truncation angles: forward ca. 7°, backwards ca. 10°
Illumination function: sine ± 1% RMS weighted average
Source/sensing length: ca. 5%

Illumination statistics

Manufacturer	TSI	Ecotech	Radiance Research
Truncation			
forward	7°	9°-18°	7°
backward	170°	157°-172°	170°
Illumination			
Source	incandescent	LED	xenon flash lamp
Opal glass	near cosine	near cosine	near cosine
Tuned LED array		rough cosine	
Illumination	40 nm bandwidth	8 nm bandwidth	40 nm bandwidth
wavelength	450 nm	460 nm	
	550 nm	525 nm	535 nm
	700 nm	670 nm	

TSI Nephelometer

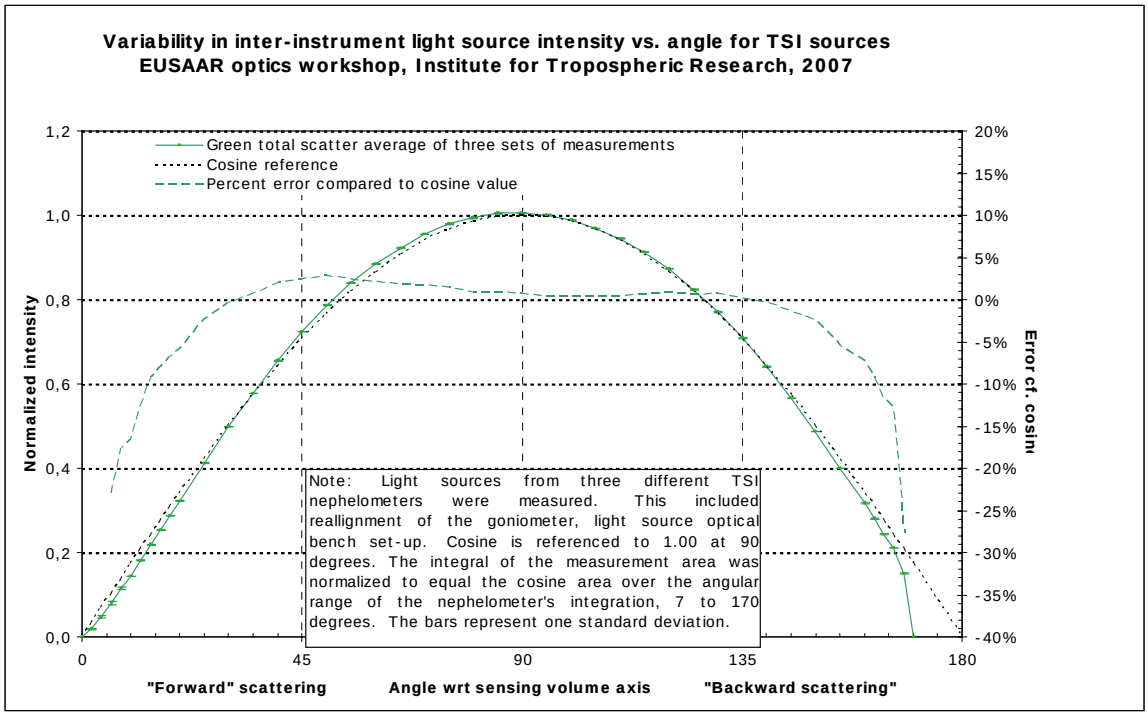


Figure 1: Angular illumination functions: average of three TSI nephelometer light sources

Figure 1 shows the measured cosine function (green line) against the ideal function (dotted line). The dashed line represents the error compared to the ideal cosine.

Radiance Research Nephelometer

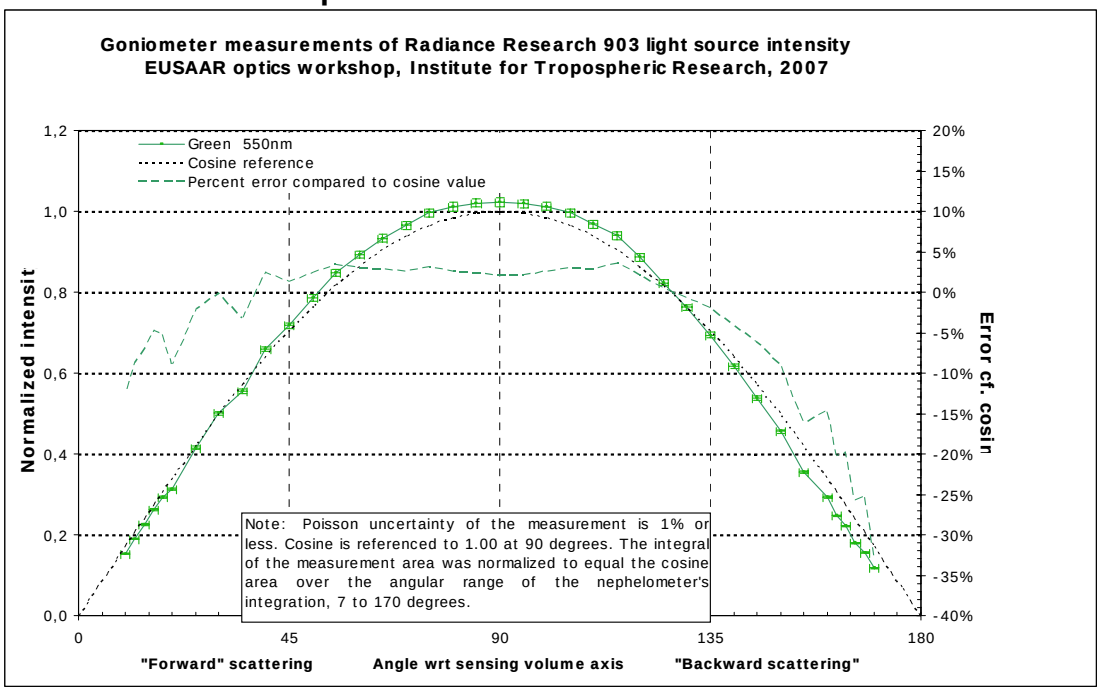


Figure 2: Angular illumination functions: Radiance Research nephelometer light source

Figure 2 shows the measured cosine function (green squares) against the ideal function (dotted line). The dashed line represents the error compared to the ideal cosine.

Ecotech Nephelometer

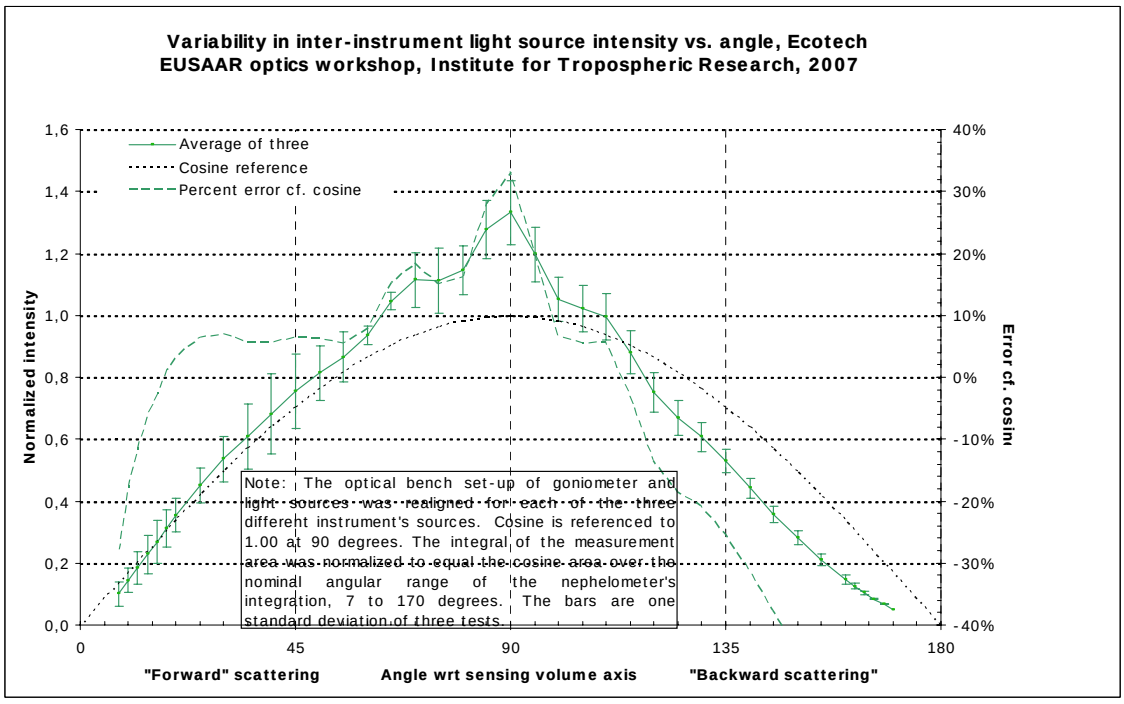


Figure 3: Angular illumination functions: Ecotech 1-wavelength nephelometer light source

Figure 3 shows the measured cosine function (green line) against the ideal function (dotted line). The dashed line represents the error compared to the ideal cosine. Ecotech modified the light sources after the workshop in March twice.

Ecotech nephelometer		
Model 9003 1-wavelength	In production	7 LED
Aurora 1000 1-wavelength	Prototype1	15 LED
Aurora 3000 3-wavelength	Prototype 2	3-time 15 LED
	Prototype 2a	3-time 15 LED (retuned)
	Prototype 3	Single High-Power LED, opal glass

After the first modification (increasing the number of LEDs) following improvement was achieved.

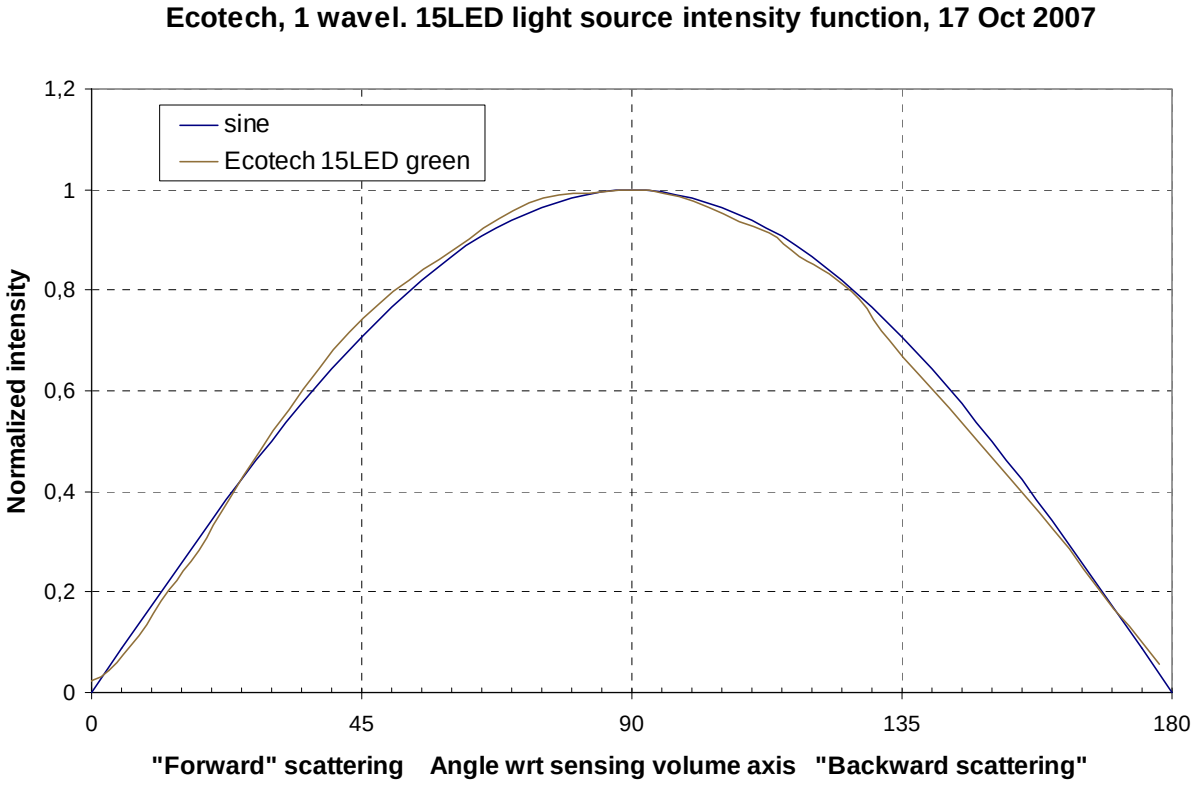


Figure 4: Angular illumination functions: Ecotech 1-wavelength nephelometer light source with 15 LED after retuning

The angular function of Ecotech light source was significantly improved after the number of LED was increased and the optimum tuning of the individual intensities was found (Fig. 4).

The next step was to simplify the light source using instead of the 15 LEDs one High_power LED and an opal glass (ideal diffuser) to achieve a Lambertian distribution (cosine function) of the illumination. As plotted in Fig. 5, the cosine illumination (green line) is almost identical compared to the ideal curve (dotted line).

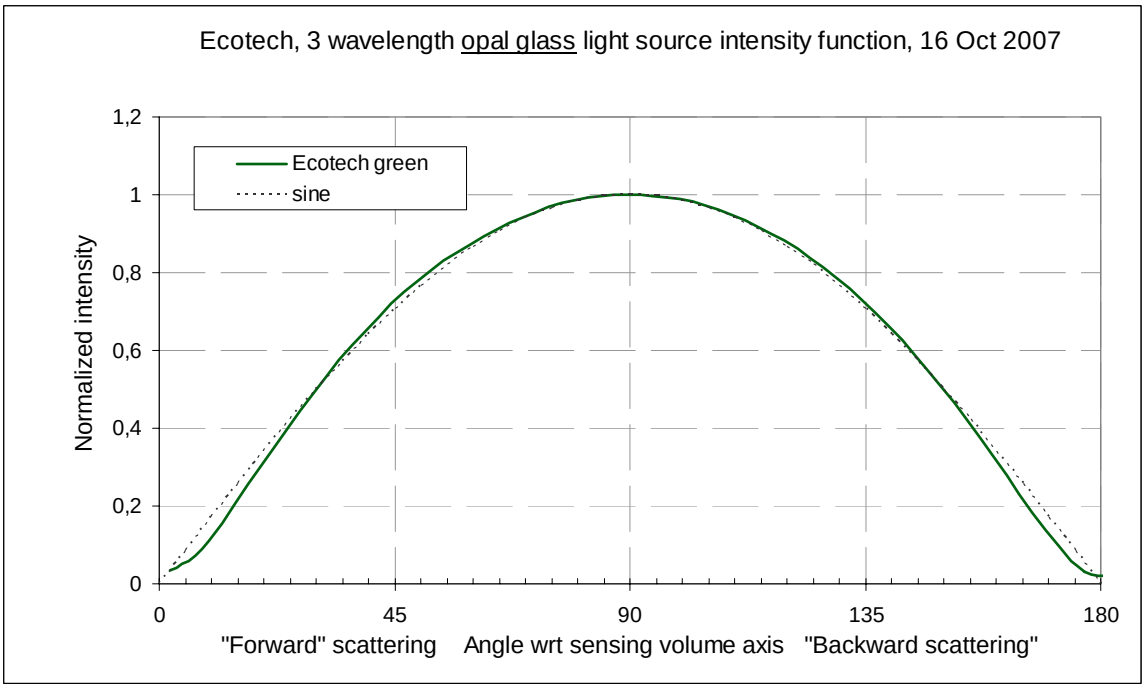


Figure 5: Angular illumination functions: Ecotech 3-wavelength nephelometer light source with one High-Power LED and an opal glass as diffuser

Truncation Error

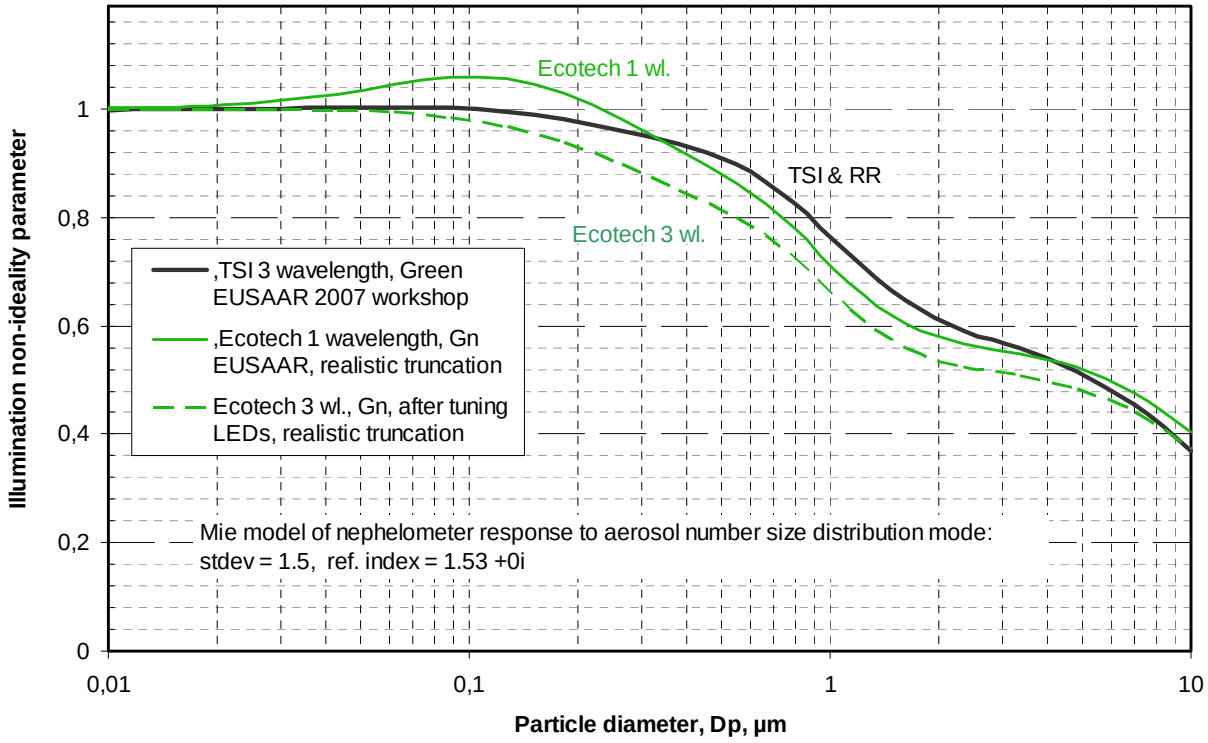


Figure 6: Calculated truncation error for the different nephelometers using a lognormal aerosol size distribution with a standard deviation of 1.5 as input for the Mie-model

As plotted in Fig.6, the truncation error increases with increasing mode diameter of the size distribution. The value One represents the ideal scattering coefficient. The black line represents the TSI and Radiance Research nephelometers with almost identical illumination functions. The green solid and dashed lines are the truncation errors of the 7-LED and the tuned 15-LED versions of the Ecotech nephelometer, respectively. Due to the shift towards forward scattering of the 7-LED version, the scattering coefficient is too high in the accumulation mode range. With increasing size, the measured scattering decreases, because larger particle scatter more and more in forward direction. Since the TSI and Radiance Research measure from 7° compared to the Ecotech nephelometer starting at larger angles, the Ecotechs have a higher truncation error for larger particles.

Ambient measurements

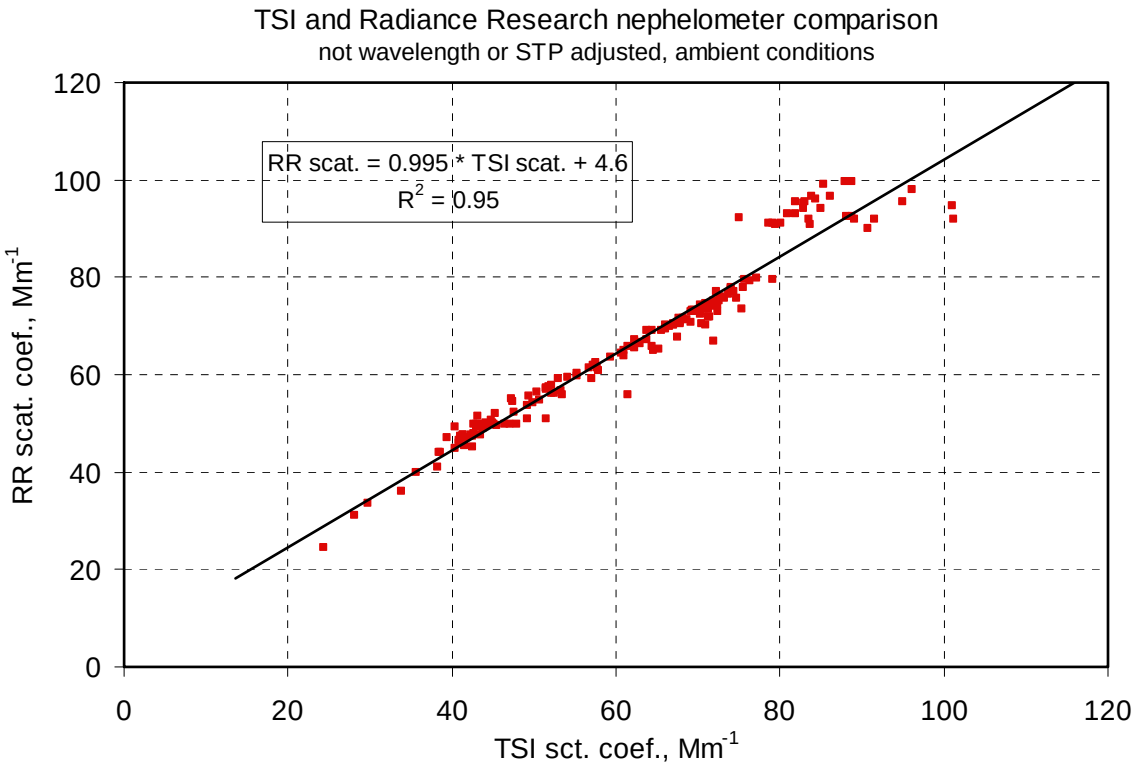


Figure 7: Correlation between the TSI and the Radiance Research nephelometers for ambient aerosol

In Figure 7, the correlation between the TSI and the Radiance Resaerch nephelometer is shown. The slope is almost One and the correlation coefficient is with R2=0.95 almost ideal. There is thus no difference using these instruments beside the lower detection limit.

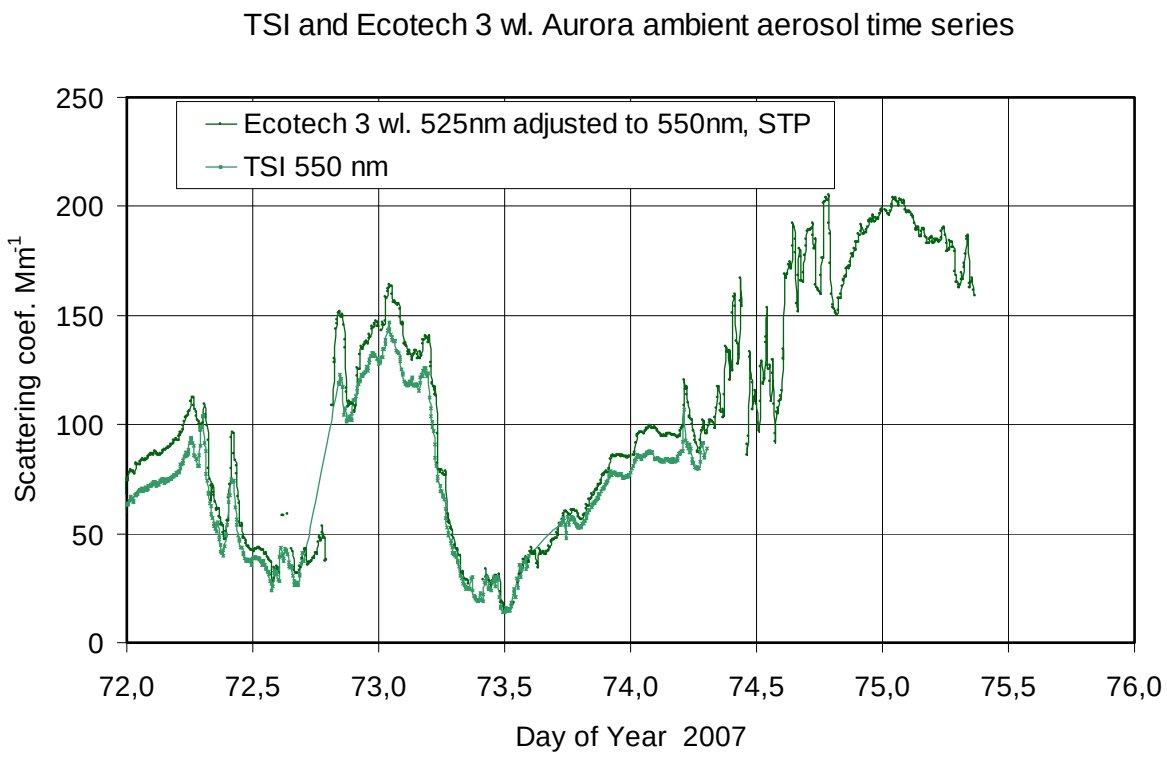


Figure 8: Comparison between the TSI and the Ecotech (7-LED version) nephelometers for ambient aerosol

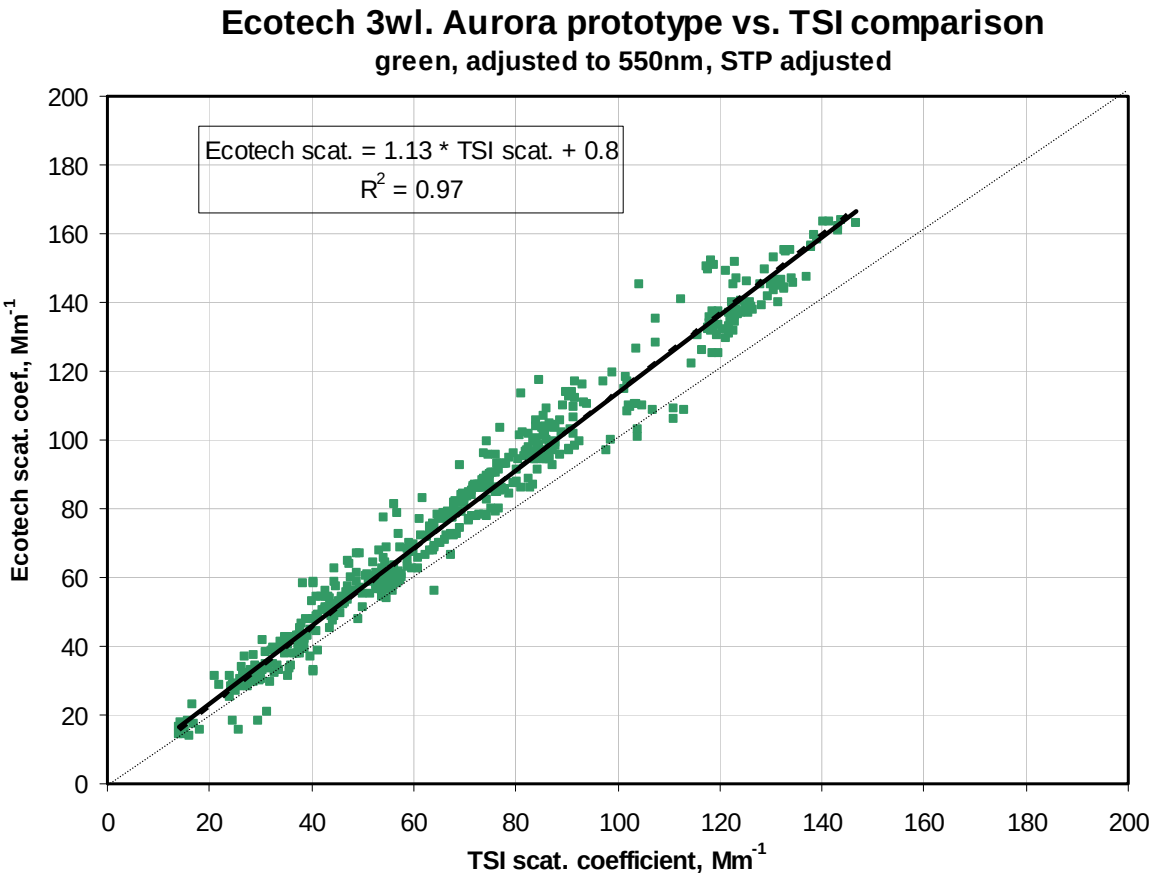


Figure 9: Correlation between the TSI and the Ecotech (7-LED version) nephelometers for ambient aerosol

In Figure 8, a time series of the measured scattering coefficient of the TSI and the Ecotech 7-LED nephelometers are shown for ambient aerosol. Due to the shift in illumination towards forwards scattering, the Ecotech nephelometer overestimates the scattering coefficient. The correction between both instruments is plotted in Figure 9 showing the same trend. While the correlation is very high (R2=0.97), the slope is 1.13 confirming the measured illumination function.