Analysis of the Mass Calculation Algorithm of the Grimm 1.108 Laser Aerosol Spectrometer

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In order to do a particle count and mass measurement, the Grimm laser aerosol spectrometer takes in an air stream of 1.2l/min or 0.012m^3/s with a pump and guides it through the measurement chamber. The minimum measurement interval is 6s. When a particle spectrum is measured that is dominated by large particles the large diameter bins of the differential mass data (dM-data) will also be populated with mass contributions. However, when the mass concentration of large particles is not high, the statistical behavior of particle counting events generates measurement intervals where none, one, or only few particles are counted. Therefore, when the individual dM bins are sorted for increasing values, the mass contributions of single counts become visible after the zero mass assignments of the zero counts. When the mass distribution is very low at small diameters and a long measurement is analyzed, the transition from zero counts to single counts can be observed even down to small diameters which can be used to extract the mass assignments to single count events. In the measurement analyzed for this purpose (see fig. 2 to 4), the zero events could be identified down to the 0.65um size bin. For this purpose, a measurement was taken at a location well-known for high traffic induced PM-Values in Stuttgart city (measured at the curb of the Cannstatter Strasse near Neckartor) during a warm September afternoon when the background PM-values from residential and office heating units were still low.

A similar approach of analysis as for the dM-data can be done for the differential count data (dC-data). According to construction, the effective measurement volume is 0.12l for a 6s interval. To calculate the counts per liter, a registered scattering pulse therefore need to be multiplied by 1/0.12=8.33 . However, the analysis shows that the Grimm is assigning the counts per liter per physical pulse according to the following scheme:

d [um]	0.65	0.8	1	1.6	2	3	4	5	7.5	10	15	20
cnt/m^3 per physical pulse	50	50	50	10	10	10	10	10	10	10	10	10

Obviously, the higher numbers account for particle loss that is size dependent.

The mass that will be assigned per registered pulse can be extracted to be as follows:

d [um]	0.65	0.8	1	1.6	2	3	4	5	7.5	10	15	20
mass [ug/m^3]	0.03	0.1	0.15	0.08	0.21	0.58	1.24	3.32	9.12	26.6	73	213

When now the assigned mass per m^3 is divided by the assigned counts per m^3, the mass assigned to each differential count in a size bin can be calculated:

d [um]	0.65	0.8	1	1.6	2	3	4	5	7.5	10	15	20
mass/ cnt [ug]	6.00E -07	1.00E -06	3.00E -06	8.00E -06	2.10E -05	5.80E -05	1.24E -04	3.32E -04	9.12E -04	2.66E -03	7.30E -03	2.13E -02

According to theory, the differential mass for an ideal sphere can be calculated per differential count dC according to the following equation, depending on the size d:

$$dM/dC=\pi/6*\rho*d^3 \quad (1)$$

with ρ being the density of the bulk material the particle consists of. From the analysis of the Grimm data, it becomes obvious that the software follows this theory strictly, except for a correction factor a. It is therefore assumed that the instrument actually performs the mass calculation according the following equation:

$$dM/dC=a*\pi/6*\rho_0*d^3 \quad (2)$$

with ρ_0 assumed to be the standard density of $1g/cm^3$. When the factor a is determined to minimize the root mean square error of 1-(actual mass /equation result), the correction factor can be determined to be a=4.3 from the given data set in the experiment. The compare ratio expressed as:

compare ratio = actual mass/equation (2) result

becomes fairly close to 1 and does not show any deterministic behavior versus the particle size. This compare ration is shown in fig. 1 for the values extracted from the experimental data set.

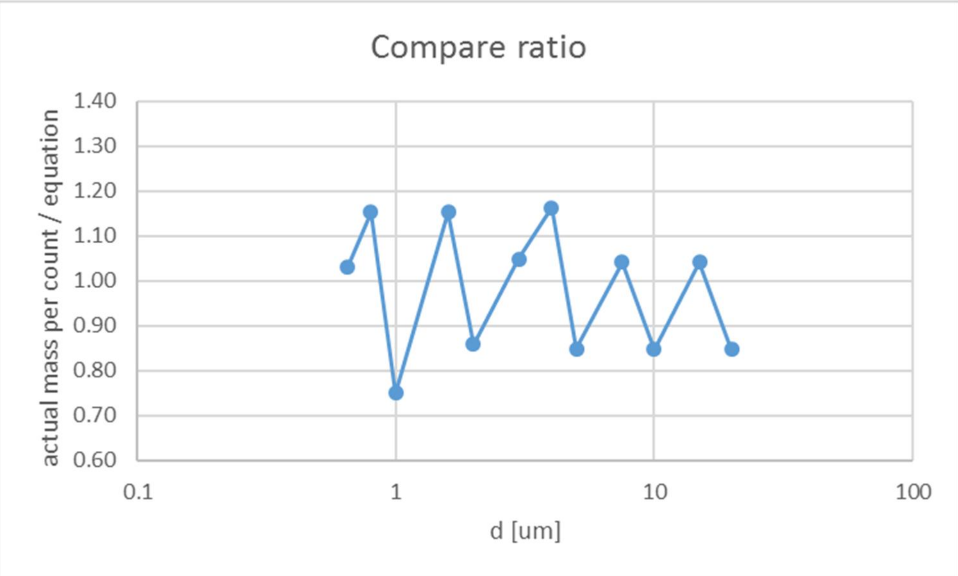

Fig. 1: Error ratio between actual measurement and equation result for the example data

Therefore, it is justified to assume that the instrument is really implementing the equation model (2) to assign the differential mass dM available in the dM-file to what is available as differential count dC in the dC-file.

In addition to this finding, we can also determine the expected average rate of counts in each bin that only contains single counts in the smallest measurement interval of 6s. This is mainly the case for the 10um, 15um and the 20um size bin at low differential particle concentrations. Assumed the differential mass contribution would be $10ug/m^3$ for the 20um size bin, the counts per $1m^3$ volume would be

$10ug/m^3$ / 2.13E-2 ug/cnt = $470cnt/m^3$=0.47cnt/l

Since 10 counts/l are assigned for a physical pulse count assigned to this bin in one measurement interval in the available measurement volume, we can assume that the effective volume is 0.1l .

As a consequence, the average count per measurement interval for this volume is:

0.47cnt/l * 0.1l = 0.047cnt

Therefore, the average count rate for 20um particles is:

r(20ug) = 0.047cnt/(6s) = 0.0078cnt/s

The average time between the arrival of two 20um particle is then

T(20um) = 1s/0.0078 = 127.7s = 2.13min

Similarly, the average time between two consecutive 10um particle events at a particle mass contribution of 10ug/m^3 would be:

T(10um) = 16s

This calculation shows, that the time between single large particle events can be fairly long. If particle concentration has to be calculated from such sparse events with enough statistical certainty, an averaging time for a significant number of events has to be provided, making large particle measurements at low particle concentrations with the Grimm 1.108 or a comparable instrument pretty slow.

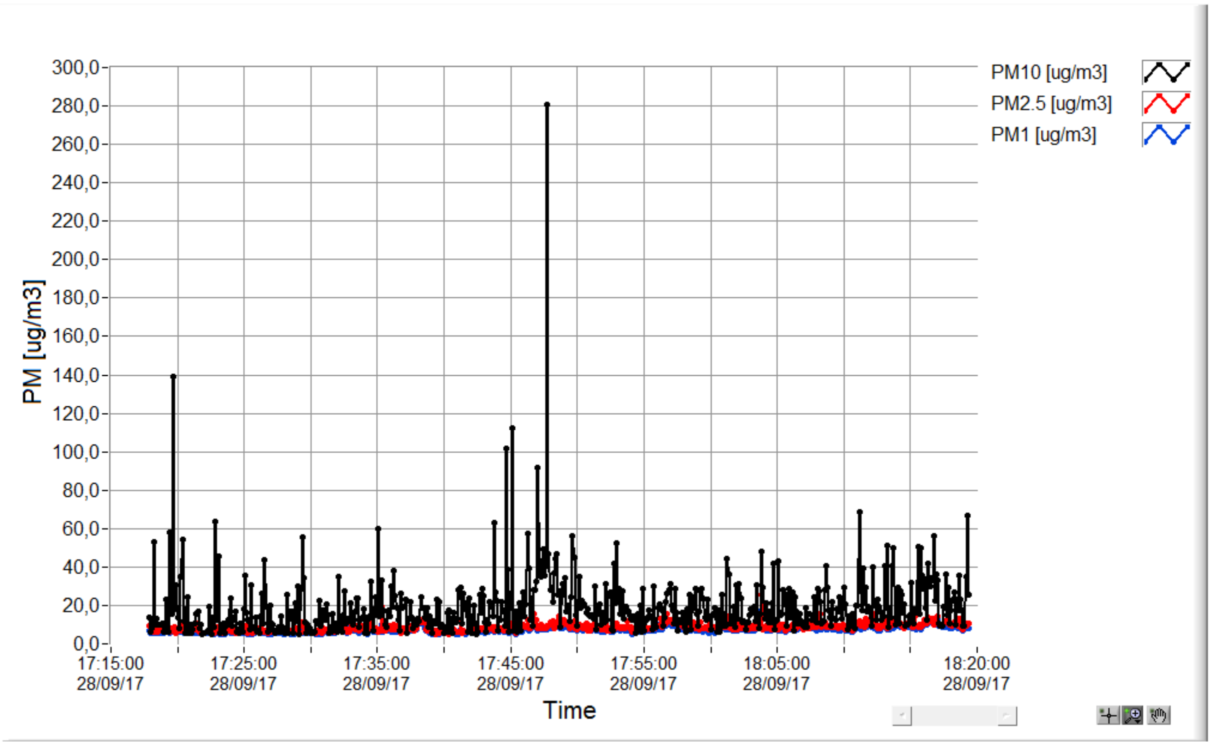

Fig. 2 PM10 and PM2.5 results of the example measurement near a high traffic loaded road in Stuttgart downtown

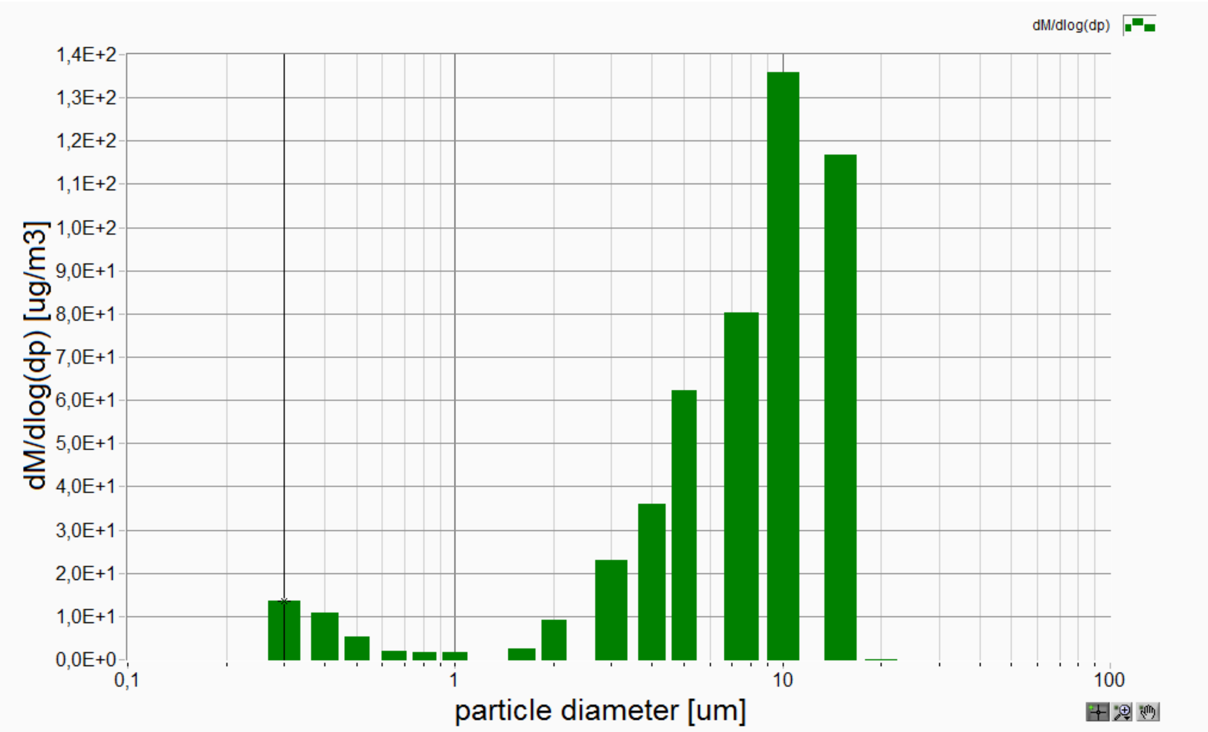

Fig 3: Typical mass distribution versus size during the measurement for an average over 10 measurement intervals of 6s

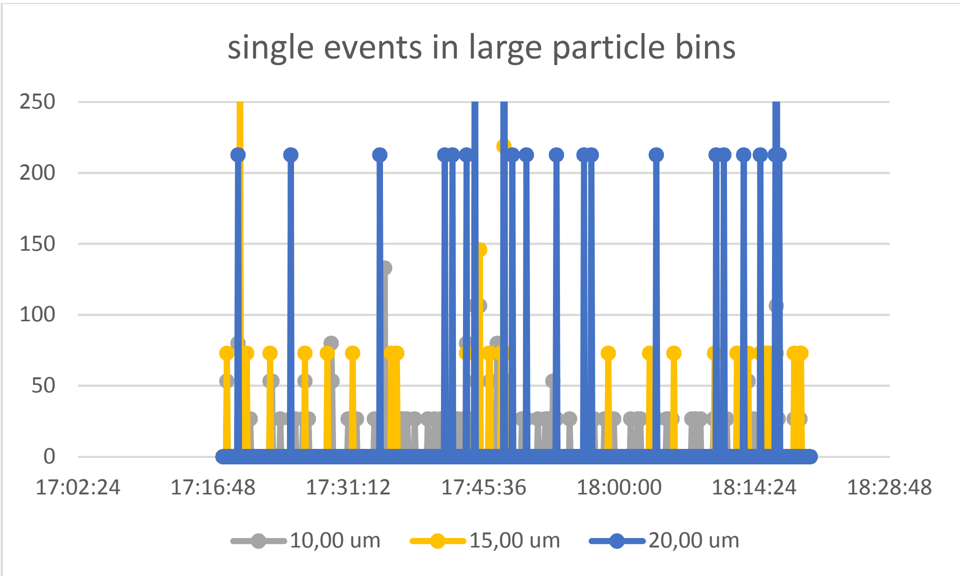

Fig. 4: single particle events in the large bins

Finally, to validate the results for the whole experiment, the differential mass data obtained from the measurement over 1h hour under equal conditions (see also fig. 2) were averaged across the whole measurement duration and was compared with the average of the calculated differential mass using equation 2 from the full set of count data. For this experimental data set a good agreement was found (see fig. b). However, due to the limited sample set, the factor a had to be slightly corrected to a=5.6 to really minimize the error ratio between measured and calculated data.

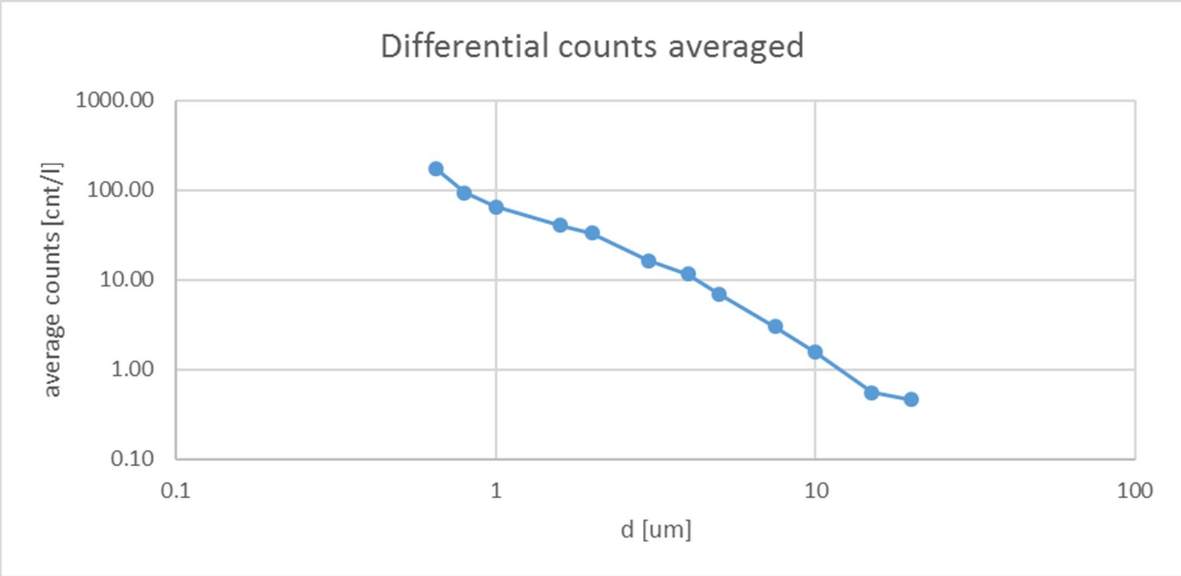

Fig. 5a: Averaged differential counts from the measured data set

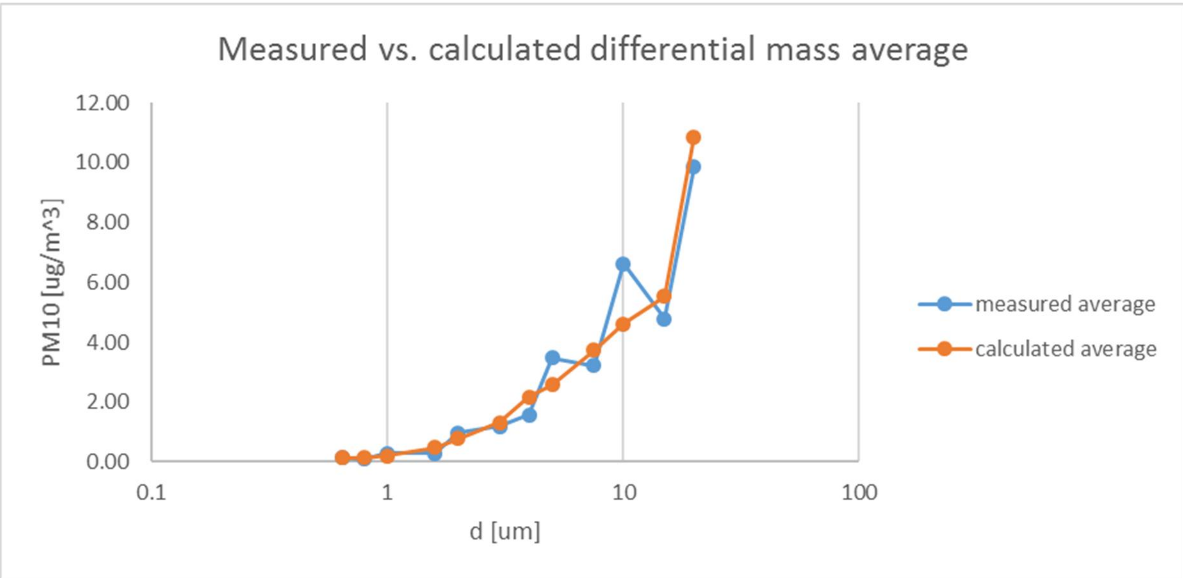

Fig. 5 b: Comparison of measured differential mass vs. differential calculated from differential counts for the measured data set (factor a=5.6)

Literature

/1/ Portable Laser Aerosolspectrometer and Dust Monitor Model 1.108/1.109; Grimm Aerosol Technik GmbH; Version V2-4 (24-10-14)