Rainfall Amount and Intensity measured by the Thies Laser Precipitation Monitor

Eckhard Lanzinger[1], Manfred Theel[1], Herbert Windolph[2]

[1]Deutscher Wetterdienst (DWD)
TI23 b : Measuring Systems
Frahmredder 95
D-22393 Hamburg
Germany
email: eckhard.lanzinger@dwd.de

[2]Adolf Thies GmbH & Co. KG
Hauptstraße 76
D-37083 Göttingen
Germany
http://www.thiesclima.com

Abstract

The Laser Precipitation Monitor (LPM) manufactured by Thies is a Present Weather sensor based on an optical disdrometer. Thus rainfall amounts can be derived from the disdrometric information. The factory calibration process for the volume measurement is described and the resulting measurement uncertainty is given. In this paper rainfall amount measured by the LPM is compared with measurements of reference rainfall gauges such as a pit gauge. Rainfall intensities are evaluated in comparison with post-processed high resolution data of a Pluvio (OTT) weighing rain gauge.

Introduction

Facing an increasing number of extreme rainfall events in many parts of the world the measurement of rainfall intensity has become more important. In many cases it is not only a huge total rainfall amount that causes destruction to nature and buildings but high peaks of rainfall intensity during short periods of time. For the sufficient dimensioning of water run-off systems and canals it is crucial to have long time series of rainfall intensity measurements. In some cities sewage water systems are actively controlled in real time with rainfall intensity being the key input parameter in the run-off model [1].

The Laser Precipitation Monitor (LPM) is curently being introduced as a Present Weather sensor (PWS) in the observing network of the German Weather Service (DWD). In addition to the Present Weather information [2] the instrument is also capable to provide drop size spectra and rainfall intensities derived from these. This is an interesting feature for all real time applications such as on-line radar calibration because there should be no time delay of the output, due to the optical principle of measurement. Moreover it is a contactless measurement and hence does not suffer from many of the drawbacks known from catching type rain gauges, e.g. evaporation losses and water

retention in the funnel. Due to its low detection threshold of 0.001 mm/h the LPM could complement measurements of catchment type rain gauges in the low intensity range.

This investigation is a first step to quantify the accuracy of rainfall intensities and rainfall amounts measured by the LPM in a field intercomparison.

Experiment

All measurements used for this investigation were carried out at the weather station Wasserkuppe which is located in central Germany at an elevation of 950 m (asl). At this site a manned 24 h synoptic weather station and the reference field for the Global Precipitation Climatology Centre (GPCC [3]) are colocated. The latter is a German contribution to the World Climate Research Programme (WCRP) and to the Global Climate Observing System (GCOS).

Another part of the measurement field is dedicated to sensor field intercomparisons with its own data acquisition system designed for this purpose. Due to the centralised architecture of this system all data are recorded synchronously. The combination of a manned weather station and the test site allows intercomparisons of manual and automatic observations.

Laser Precipitation Monitor

The device is basically a laser disdrometer which measures the size and vertical velocity of precipitation particles falling through a thin laser light sheet of less than 1 mm thickness. The size of the area of detection is approximately 46 cm^2.

Figure 1: The Laser Precipitation Monitor manufactured by Thies. The square box contains the laser diode and all electronics. The receiver is mounted in a small enclosure opposite to it. In the lower left corner of the picture the Pluvio weighing rain gauge can be seen that served as an intensity reference for this intercomparison.

Every particle falling through this light sheet reduces the transmitted intensity with the signal amplitude being a measure for the particle diameter. The vertical velocity is derived from the signal duration by using the measured particle diameter and the known thickness of the light sheet. For the

Present Weather detection the type of precipitation is classified based on the size and velocity of the set of particles detected within a 1 minute time interval. The disdrometer determines the volume of every single particle by taking into account the asymmetric shape of droplets with a diameter larger than 1 mm [4]. Rainfall intensity is thus calculated by integrating the volumes of all single droplets detected within the past 1 minute time intervall.

The factory calibration comprises a determination of the geometrical shape and size of the laser light sheet and a calibration of the droplet volume measurement. The characteristics of the light sheet such as beam width and alignment are exactly measured by using an optical beam analyser. For the volume calibration an automated calibration bench is used. It consists of a precision dispensing pump with an accuracy of 0.3% and a droplet generator that is mounted on a 2D positioning system. Uniform droplets of about 3 mm diameter are falling through the light sheet at 15 equally distributed positions. At each position 30 droplets are measured. Based on the repeatability of disdrometer measurements at a fixed position the uniformity of the droplet diameters can be estimated to 2%.

The calibration process is carried out in two steps where the deviation of the mean volume from the reference is determined. After the first run the device is adjusted by setting appropriate calibration parameters. In a second run the adjustment is checked. The manufacturer has defined a maximum allowed tolerance of 2.2%. This is the measurement uncertainty for the volume measurement under laboratory conditions provided that a larger number of droplets is falling through equally distributed points of the light sheet. It does not apply to the volume measurement of a single droplet.

Figure 1 shows one of three LPMs installed in the test field. All three sensors were mounted in the same orientation, with the receiver looking to the North. Precipitation coming from South-West which is the prevailing wind direction during precipitation is thus not obscured by any parts of the instrument body.

Reference rain gauges

Figure 2 gives an overview of the GPCC part of the measurement field containing the reference rain gauges "Pit Gauge" (1) and "DFIR" (2) and some manual standard sensors (3).
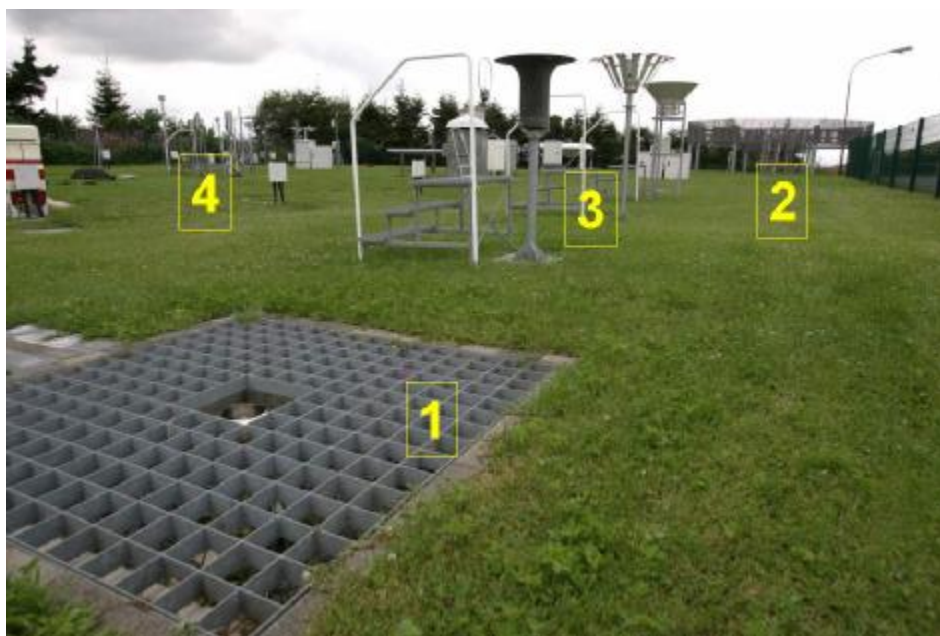

Figure 2: The intercomparison site Wasserkuppe (Germany). A Hellmann rain gauge installed in a pit (1) according to WMO recommendations [5] serves as the reference for the comparison of rainfall amounts. Further standard rain gauges (3) including a DFIR (2) are aligned beside. Three LPMs and the reference weighing rain gauge (4) are located some 20 m away from them.

Both reference gauges are installed according to WMO recommendations [5]. The 3 LPMs and the Pluvio weighing rain gauge that was used as rainfall intensity reference are some 20 m away from the pit gauge and can be seen in the background of the picture (4). For the evaluation of rainfall amounts the daily sums of the GPCC pit gauge were used.

When comparing rainfall intensities of several instruments on a 1-minute time scale we had to face the following problems:

a) The Pluvio rain gauge and the LPM calculate and update the output value for rainfall intensity every 60 s according to their own internal clocks, i.e. in general the instruments are not synchronised. It is therefore not possible to compare these values directly because rainfall intensity is a highly variable measure in time.

b) In addition to these general timing problems it is known [6] that the Pluvio's filter algorithms introduce a time delay in the intensity output which is larger than the considered 1-minute time scale.

c) Rainfall amount and intensities also vary spatially on the measurement field depending on the surrounding.

The last problem could not be influenced and has to be taken into account, when data is interpreted. The first two problems were solved by deriving the reference rainfall intensities with our own algorithm from the raw data of the Pluvio weighing rain gauge. These data are internally updated every 6 s and can be treated as instantaneous weight measurements of the collecting bucket. Thus the 1st derivative of the weight curve gives an instantaneous "rainfall intensity" which refers to the last 6 s. Integration over the last 10 values of this derivative curve gives the rainfall intensity according to WMO definition [7] and refers to the last 60 s.

Due to the influence of wind and the rain drops hitting the bucket the weight signal is rather noisy. In order to reduce noise while still preserving the peak height of maxima in the intensity curve we have used a Savitzky-Golay filter [8] implemented in the TISEAN software package [9]. It works as a running filter which fits an n-th order polynomial through a selectable number of data points. We found that a 3rd-order polynomial fit with a filter length of $\pm$ 10 data points gives good results, i.e. noise is significantly reduced while peak heights are preserved.

It has to be mentioned that the Pluvio rain gauge is installed at 200 cm height above ground and has no windshield. Wind losses of rainfall accumulation have to be considered.

Results

For this investigation data from a period of one year (Sept. 2005 until Sept 2006) were analysed. Only days with liquid precipitation events were considered. Moreover days with data gaps or malfunction of single instruments were also skipped.

Daily rainfall amounts

After filtering the data some 80 values of daily rainfall amounts remained in the data set. The mean deviations for several rain gauges with respect to the GPCC pit gauge are listed in Table 1. Obviously the manual rain gauges Hellmann, Canadian Nipher and Tretyakov agree better with the pit gauge than the Pluvio weighing rain gauge and the LPMs do. The Hellmann gauge is installed at a 4 m distance to the Pluvio gauge and reveals the known fact, that the Pluvio rain gauge accumulates less than a Hellmann rain gauge [10]. The comparison of the unshielded Hellmann gauge (at 200 cm height) and the pit gauge (also equipped with a Hellmann gauge) shows that wind induced accumulation losses average out at a value of about 3% - 4%. Interestingly the Canadian Nipher collected by 2 % more rain than the pit gauge.

Table 1: Mean differences of 80 daily rainfall amounts between several rain gauges and the reference pit gauge. Data was taken at the test and reference field Wasserkuppe (Germany) during Sept. 2005 and Sept. 2006.

Device / Gauge	Installation height [cm]	Mean deviation from Pit Gauge
Hellmann	200	-3.3 %
Pluvio	200	-5.6 %
Canadian Nipher	150	+2.0 %
Tretyakov	200	+1.8 %
LPM 3	200	+20.2 %
LPM 8	300	+15.0 %
LPM 9	200	+5.3 %

All LPMs measure significantly higher rainfall amounts than the reference pit gauge. LPM 9 shows a mean deviation of +5.3% whereas LPM 8 and LPM 3 consistently report +15.0% and +20.2% higher rainfall amounts than the pit gauge.

In Figure 3 the differences between the measurements of the LPMs and the pit gauge are displayed together with their corresponding linear fit curves. In the left-hand picture (half-logarithmic scale) the whole data set is displayed, also showing one outlier at a rainfall amount of 56 mm/day. This outlier has not been used for fitting the linear fit function. Nevertheless there seems to be a problem in the calibration of the LPMs because at least two devices (LPM 3 and LPM 8) consistently report 15% to 20% too high daily sums, whereas one (LPM 9) gives lower readings. This will be investigated in laboratory in the near future.

In the right-hand picture of Figure 3 a zoomed view (linear scale) of the range below 2 mm/day is given. Note that in this range clusters of points occur where the LPMs better agree to each other than to the reference. Furthermore in several cases the LPMs reported daily sums up to 0.2 mm/day when the observer indicated "rain" and the amount from the pit gauge was not measurable or zero. This proves that the LPM has a very low sensitivity threshold and is able to measure consistent and plausible values for smallest rainfall amounts.
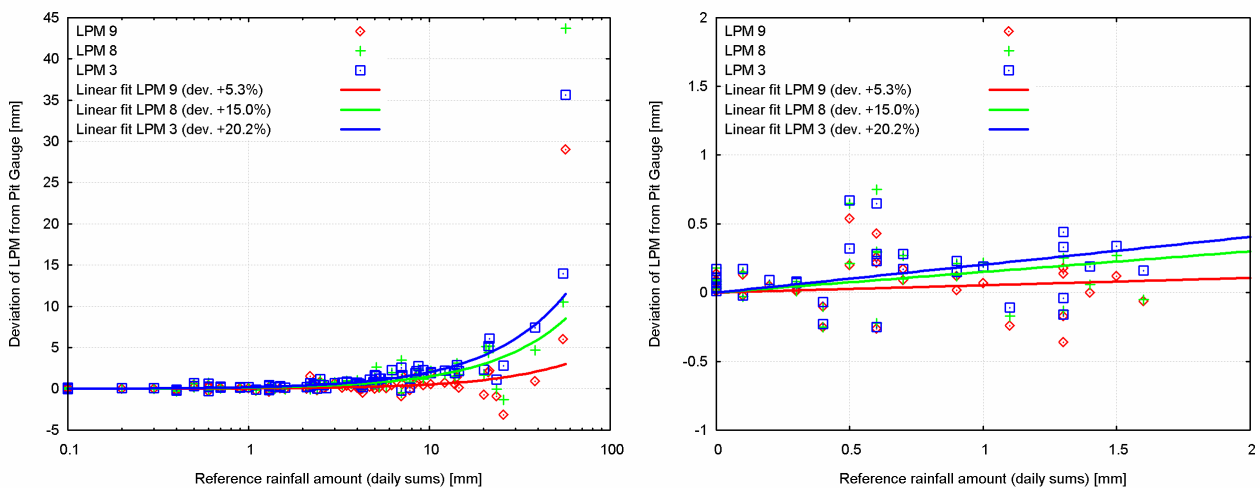

Figure 3: Differences of daily accumulation of the LPMs from the reference pit gauge and linear fit curves. The half-logarithmic picture on the left gives an overview showing also some outliers. The right picture gives a zoomed view of rainfall amounts less than 2 mm.

In Figure 4 the residuals of the linear fits are depicted (outlier not included) showing the spread of the values around the fit curve. Most values are within a ±1 mm band around the fit curve (which corresponds to *y=0* in this diagram).
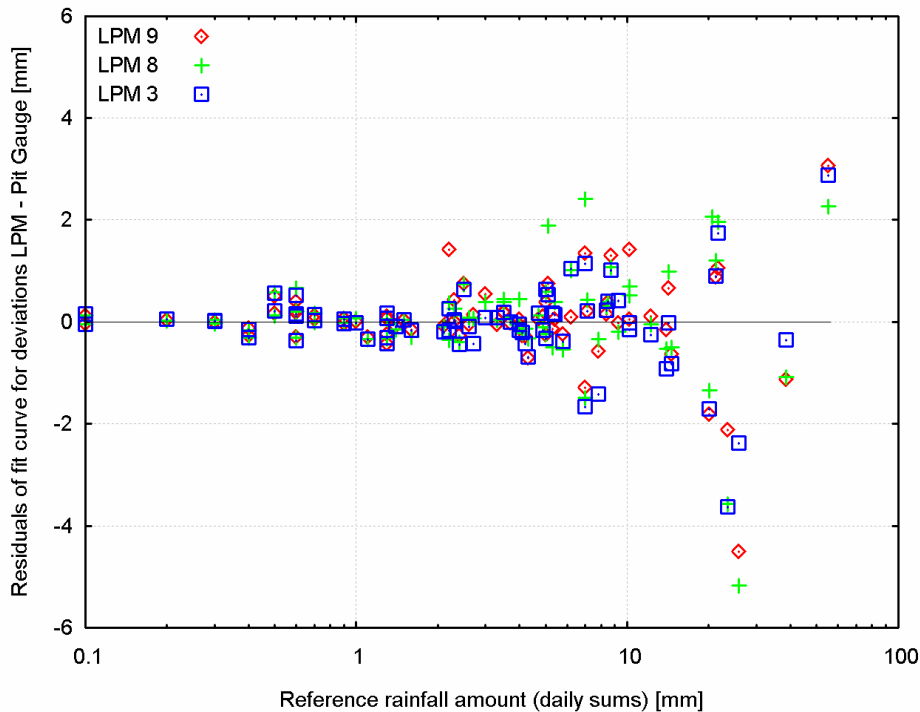

Figure 4: Residuals of the fit for the deviations (LPM – Pit Gauge).

Rainfall intensities

For the intercomparison of rainfall intensities data from the period 08/10 to 09/30 were selected. During periods without precipitation the noise level (1 σ) of the filtered reference data is between 0.1 mm/h and 0.8 mm/h with single spikes up to 2 mm/h.

A typical section of a time series is depicted in Figure 5, where all three LPMs (vertical bars) and the reference intensities (black curve) are plotted in one graph. The LPMs appear one after the other because they were not synchronised and calculate a new value every 60 s. The sampling rate of the reference curve is ten times higher, i.e. it is updated every 6 s.

It could be seen in many examples that the output of the LPM has no delay and truely calculates the sum for the last 60 s, as required by the WMO definition. Generally the LPMs follow well the reference curve, except for intensity peaks where they tend to overshoot. Obviously this overshoot behaviour is one reason for the LPM's tendency to accumulate higher rainfall amounts than the reference gauges. It is not likely that the Pluvio weighing rain gauge in combination with our filter algorithm provides too low peak intensities in this order of magnitude. One possible explanation could be two (or more) coincident particles in the light sheet that appear as one large particle. As the volume *V* is derived from the measurements of diameters *d* it is quite sensitive to systematic measurement errors (because $V \sim d^3$). The real reasons for this behaviour of the LPMs have to be thoroughly analysed in further studies of the particle size spectra.
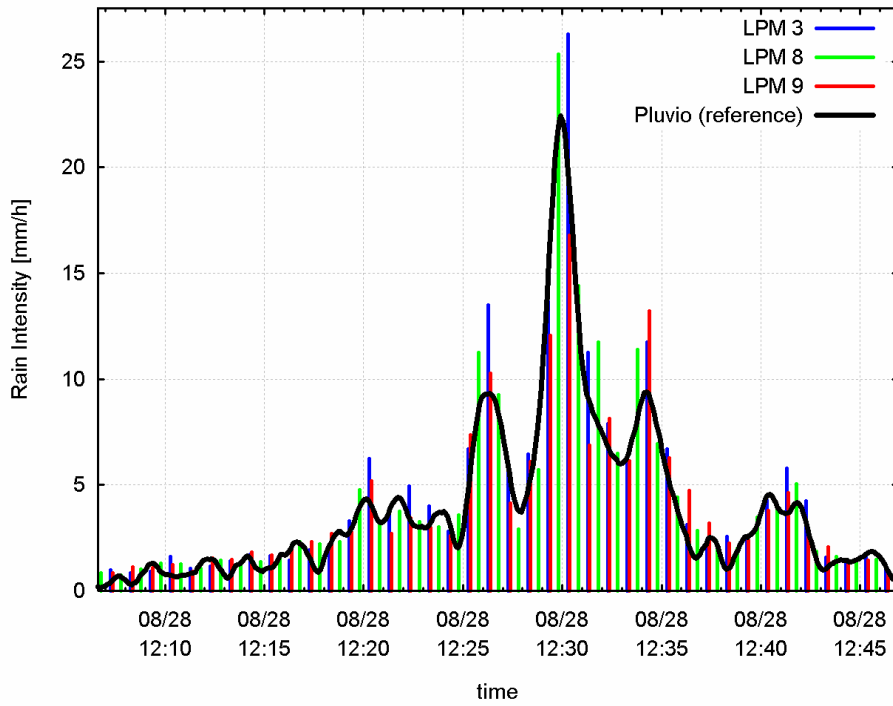
Figure 5: Coloured bars represent rainfall intensities of the LPMs, the black curve shows the reference intensities of the Pluvio weighing rain gauge.

Figure 6 shows a scatter plot of all reported intensities by LPM 9 during the selected days. A linear fit (through zero point) to these data gave a slope of 1.192, i.e. in the intensity range up to 75 mm/h the LPM 9 measured by 19.2% higher rainfall intensities than the reference. The corresponding deviation for LPM 3 is +37.2% and for LPM8 it is +31.2%. These figures reflect the same tendency to higher readings that can be seen in the deviations for daily rainfall amounts but they are significantly higher than those, because the overshoots increase with increasing intensities and thus increase the slope of the linear fit curve.
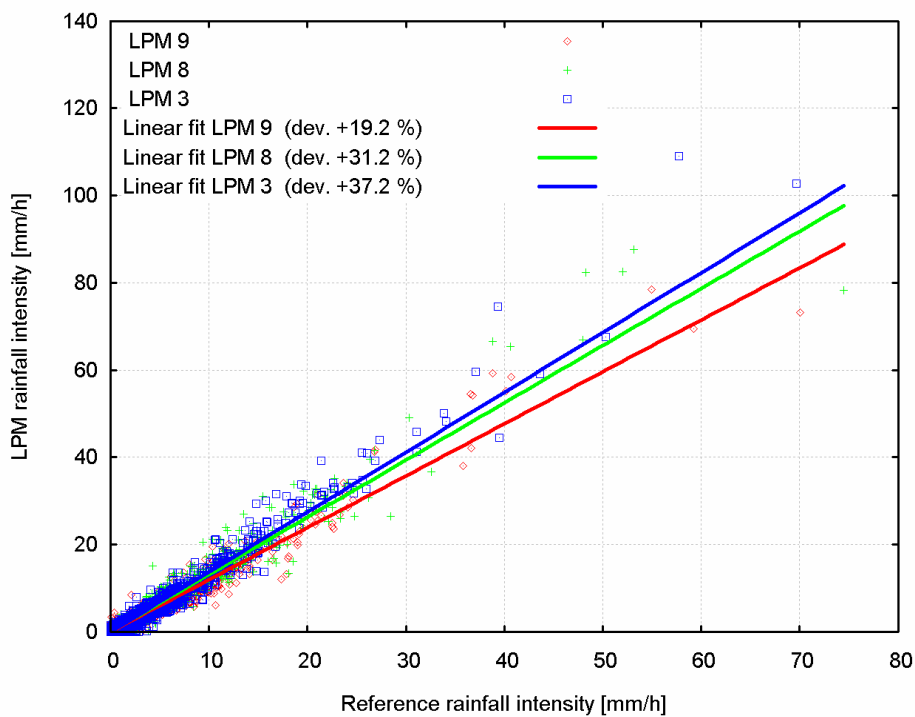

Figure 6: Rainfall intensity of the LPMs against reference rainfall intensity. The slope of the fit curve gives the relative deviation from the reference.

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Conclusions

The Laser Precipitation Monitor (LPM) has primarily been purchased as a Present Weather sensor for the observing network of DWD. This field intercomparison aimed at investigating its aditional capability to measure rainfall amounts and intensities.

It has been shown that the LPM generally measures larger rainfall amounts than the reference rain gauges. Among the three instruments under test LPM 9 gave significantly lower readings than LPM 8 and LPM 3 which agreed better to each other. Further tests in the laboratory will be performed in the near future to understand this behaviour.

The intercomparison of the measured rainfall intensities with the post-processed data of a Pluvio weighing rain gauge as the reference revealed that the LPM has a tendency to overshoot at the occurrence of intensity peaks which cannot yet be explained. An analysis of the corresponding particle size spectra could provide an indication.

The time response of the rainfall intensity measurement is very good which is a favourable feature for all real-time applications.

The LPM has a very low sensitivity threshold (0.001 mm/h) and reports even lowest rainfall intensities in a measurement range where catchment type rain gauges suffer from deficiencies such as evaporation losses and undercatch. Therefore the LPM complements catchment type rain gauges in the low intensity range.

The combined measurement of Present Weather information, particle size spectra and rainfall intensities could be of great benefit to many applications, e.g. Radar calibration. May this work contribute to further improvements of this technology.

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