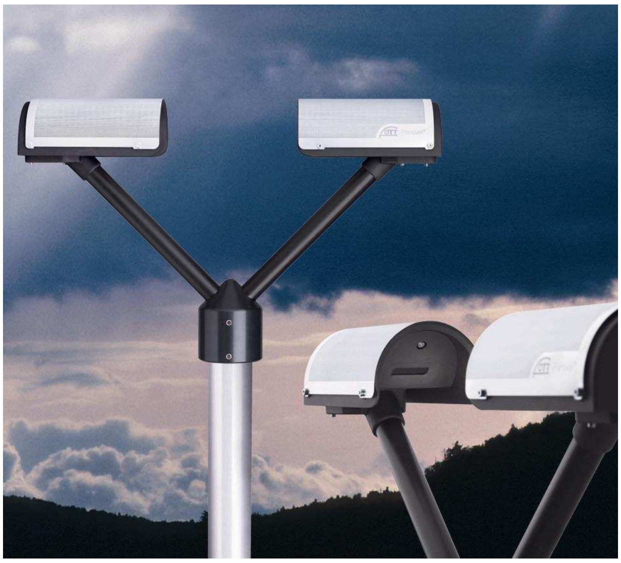
OTT PARSIVEL® - ENHANCED PRECIPITATION IDENTIFIER FOR PRESENT WEATHER, DROP SIZE DISTRIBUTION AND RADAR REFLECTIVITY - OTT MESSTECHNIK, GERMANY

Kurt Nemeth[1], Martin Löffler-Mang[2]

[1] OTT Messtechnik GmbH & Co. KG, Kempten (Germany)

[2] HTW, Saarbrücken (Germany)



1. Introduction

OTT Parsivel®: Laser based optical Disdrometer for simultaneous measurement of PARticle SIze and VELocity of all liquid and solid precipitation. This state of the art instrument, designed to operate under all weather conditions, is capable of fulfilling multiple meteorological applications: present weather sensing, optical precipitation gauging, enhanced precipitation identification, and functions as a disdrometer for spectrum classification, visibility and radar reflectivity. Parsivel® can be operated as a reliable unattended sensor for automatic weather stations and /or as a PC based instrument for scientific or meteorological applications. The comparison of radar reflectivity between Parsivel® and weather radar shows positive results and radar reflectivity data produced by Parsivel® can even be considered as an alternative data source. Parsivel® can support and improve significantly the quality based information of a weather radar with ground based enhanced precipitation data.

1.1. Background and basic meteorological applications

The design requirements for the instrument lead to a universal Commercial Off-The-Shelf (COTS) piece of equipment, which meets the meteorological and hydrological requirements of the sensor specification according to WMO and NWS guidelines and regulation as a laser-optic enhanced precipitation identifier and present weather sensor.
The patented extinction method for simultaneous measurements of particle size and velocity of all liquid and solid precipitation employs a direct physical measurement principle and classification of hydrometeors.
The instrument provides a full picture of precipitation events during any kind of weather phenomenon and provides accurate reporting of precipitation types, accumulation and intensities without degradation of performance in severe outdoor environments. Parsivel® operates in any climate regime and the built-in heating device minimizes the negative effect of freezing and frozen precipitation accreting critical surfaces on the instrument.
Parsivel® can be integrated into an Automated Surface/ Weather Observing System (ASOS/AWOS) as part of the sensor suite. The derived data can be processed and included into transmitted weather observation reports and messages (WMO, SYNOP, METAR and NWS codes).

1.2. Performance, accuracy and calibration procedure

The new generation of Parsivel® disdrometer provides the latest state of the art optical laser technology. Each hydrometeor, which falls through the measuring area is measured simultaneously for size and velocity with an acquisition cycle of 50 kHz. It is subsequently classified into 32 classes of sizes and velocities. The basic measuring ranges from 0 to 20 m/s and 0.2 to 25 mm cover all natural precipitation types from drizzle, rain, mixed form, ice pellets , hail through to snow. Parsivel® determines the exact precipitation type by internal spectrum signature comparison, using particle size and velocity distribution information. The implemented signatures for all natural precipitation types are based on investigation and expertise on the relationship of hydrometeors by Locatelli, Hobbs and Gunn-Kinzer. Even drops registering parabolic form in different signature classes will be corrected in shape in order to correlate to their ideal sphere and will be matched to their single water equivalent. Border events will be considered and corrected by statistical methods.
The adjustable measuring interval from 10 seconds to 60 minutes coupled with fast data signal processing performance and features enable Parsivel® to provide real-time and highly accurate intensity and accumulated precipitation data.

Long-term stability is maintained by automatic compensation of temperature and alteration effects. That is done during the event of no precipitation, based on radiometric methods and algorithms.
Each instrument gets calibrated on the unique calibration bench, which simulates high-precision reference particle sizes (0.5, 1.0, 2.0 and 4.0 mm) and velocity (intensity ranges up to 1800 mm/H) using a rotating disc. Due to the inhomogeneous laser beam and its signature the extinction accuracy in any spot of the measuring area is low. The calibration process determines the laser performance signature and transfers the correction coefficients automatically into the connected on-line instrument. Once calibrated, no further calibration is required. Simple maintenance procedures such as cleaning the optics and performance checks of the laser path will be prioritised and reported to the user as service tasks to be carried out in the short and medium term.
The calibration bench in the Meteorological Services laboratory can be used as a quality inspection after a two-year period and guarantees deployed instruments in any automatic weather observation network are suitably verified.

Figure 1 Parsivel® Calibration bench

The accuracy, reliability, and long life expectancy with an Mean Time Between Failure of 7 years make the Parsivel® suitable as an unattended enhanced precipitation identifier, optical precipitation gauge, present weather sensor, disdrometer for particle distribution and radar coefficient.
The accuracy of rain rate meets the WMO recommendation of +-5% and is based on highly accurate particle measuring performance using the patented extinction principle with a statistical accuracy performance of better than +-2%.
The performance and accuracy of the radar reflectivity as output data is related to particle diameter and statistically represents the precipitation event in a certain time period.
The radar reflectivity accuracy of +-20%, real time precipitation intensity and accumulation with +-5% make the instrument suitable for weather radar data adjustments and as input for water discharge modelling software for flood warning systems.

2. Comparison with Weather Radar

2.1. Radar reflectivity in the case of rain

Conventional precipitation radars measure the radar reflectivity η, which is the total backscatter cross-section of all scatters divided by the pulse volume V_P. If the Rayleigh approximation is valid and the individual particles are assumed to be spherical with a diameter D_k, η can be written as

$$\eta = \frac{1}{V_P} \sum_{V_P} \sigma_k = \frac{\pi^5 |K|^2}{\lambda^4 V_P} \sum_{V_P} D_k^6 \qquad (1)$$

where λ is the wavelength and $|K|^2 = |(\varepsilon_r - 1)/(\varepsilon_r + 2)|^2$ is the dielectric factor ($\varepsilon_r = n^2$; ε_r relative permittivity, n complex index of refraction).
The equivalent radar reflectivity factor Z_e is defined as

$$Z_e = \frac{\lambda^4 \eta}{\pi^5 |K_w|^2} \qquad (2)$$

where $|K_w|^2$ is the dielectric factor for water, indicating that the scatterers are expected to be water spheres.
Rain K in equation (1) is identified by K_w. Therefore, the estimate of the radar reflectivity factor from measured drop size distributions, Z_M, can be expressed as the sixth moment of the drop size distribution with respect to the volume, $N(D_V)$:

$$Z_M = \int N(D_V) D_V^6 dD_V \qquad (3)$$

Because raindrops with a volume equivalent diameter, D_V, larger than 1 mm are oblate rather than spherical, the backscatter cross-sections of these particles differ from those of spheres with the same volume. The difference depends on the departure from the spherical shape and the spatial distribution of their orientation. The error in estimating Z_e with (3) (when assuming the drops are spherical with a diameter equal to D_V) is not considered a predominant source of error compared to other uncertainties when comparing radar measured Z_e to estimates from ground measurements of drop size distributions. Therefore, (3) can be accepted to be a good estimate of Z_e.

In the case of Parsivel® the integral can be evaluated as a sum over discrete measured size classes by:

$$Z_M = \sum_i \frac{n_i D_i^6}{tFv_i} \qquad (4)$$

where n_i = number of measured drops in class *i* during time t , D_i = mean diameter in class *i*, F = area, and v_i = mean velocity of drops in class *i*. The denominator tFv_i is necessary because the drops are counted by area and time and have to be transferred to a volume distribution. Here t was chosen as 30 s.

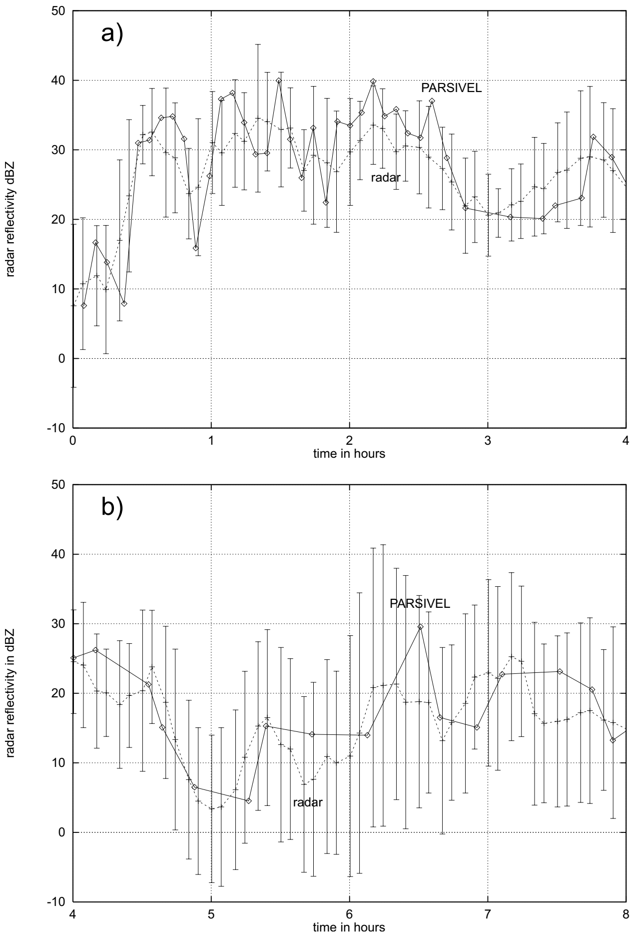


Figure 2a) Time series of the radar reflectivity factor in dBZ during a rain event, 6th of May 1999, 00:00 - 04:00 CEST, comparison of measured (C-Band Radar, dashed line) and estimated data from drop size spectra (Parsivel®, solid line); additionally, the error bars represent the standard deviation of the area average of the radar data. b) same as a), but for the period 04:00 - 08:00 CEST.

Reflectivity data in dBZ are presented for the early hours of the 6th of May 1999 (Figs. 2a and 2b) derived (i) from drop size distributions obtained by the optical disdrometer Parsivel® and (ii) from radar data. The Parsivel® was mounted on a platform in the Forschungszentrum Karlsruhe, 20 m to the side and 15 m below the antenna of the C-band radar ($\lambda =$ 5.4 cm). Parsivel® can be connected directly to a weather radar site and installed in proximity of the radar in order to provide differentiated radar support data for calibration purpose a reasonable comparison, the radar signals were averaged over a complete azimuth scan on the lowest elevation (0.4 degrees) in the nearest range gate (1.5 to 2 km) using the following procedure:

A volume scan was performed every 5 minutes, then the spatial average and standard deviation of the innermost scan-circle were calculated. The average was taken as an estimate of the radar-measured five-minute averaged reflectivity at the radar site. The spatial standard deviation provides an indication of the uncertainty of that estimate.
From the drop size distribution measured with Parsivel®, Z_M was calculated every 30 s with (4) and then averaged over five minutes.

During the 8 hours of measurement, Z_e (radar) attained values between 5 and 40 dBZ. The spatial standard deviation of the radar data (error bars), which also serves as a measure for the spatial homogeneity of the rainfall, ranged from 10 to 40 dBZ (minimum at 0:30 hours, maximum at 6:15 hours). From 3:30 hours its level increased from 15 dBZ to the maximum and then came to rest at a level of approximately 25 dBZ. The compared data agree reasonably well when taking the error bars into account, since most differences between radar means and Parsivel® estimates range from 0 to ± 5 dBZ and do not exceed 10 dBZ. Point measurements are compared with volume data!

2.2. Estimation of radar reflectivity from snow measurements

In the case of snow it is also possible to calculate some radar reflectivity factors from the measured snow size spectra, but many more aspects have to be taken into account. For readers who are interested in such estimations a special paper treats this subject:

M. Löffler-Mang and U. Blahak, „Estimation of the Equivalent Radar Reflectivity Factor from Measured Snow Size Spectra”. J. Appl. Meteorol., Vol. 40, No. 4, pp. 843-849, April 2001.

3. Enhanced Weather Radar Performance

3.1. Spatial Weather Radar and required improvements

Flash Floods may cause significant harm to infrastructure and human life, especially where communities with a region size below 100 square km located on streams and small rivers are concerned. The problem is always that these relatively small regions are not covered by supra-regional and central flood forecasting authorities and are neither considered as individual measuring spots nor for warning messages.

The spatial weather radar measurements are established and will be enhanced in the near future. Weather radar data are provided for government users like water authorities and water-related associations in conjunction with research and modelling of flash flooding and water discharge. In Germany, nearly the entire country's area is covered by the weather radars of the German Weather Service (DWD). Weather radar data, historical precipitation database KOSTRA, and precipitation intensity and accumulation data are the main input parameters for highly sophisticated modelling software for water discharge. This can even be applied for non-monotone structured areas and other topographically clustered sub-regions with high topographic resolution and for a not sufficient coverage of water level and precipitation measuring sites.

The main problem is currently that weather/precipitation radar's measurement triggering level starts from a level of 1 to 2 km due to topographic form of valleys and hills and measures the limited radar reflectivity over ground as quality based information and not as quantified data. For the exact determination of active precipitation for water discharge (for example solid precipitation can be considered as non-direct impact input data) the quantified rain rate and intensity on ground is required. It is mandatory to trace and extrapolate precipitation from the falling process until reaching the ground and to evaluate the transmission from vertical radar reflectivity "Z" to rain rate "R". Various groups around Europe are investigating and researching this key relationship in order to work out appropriate discharge models.
The method is almost to correlate the spatial information and three-dimensional distribution from the radar scan with measured precipitation data from the ground with delays of hours in offline mode and only in some exceptions with no delay in online mode. The disadvantage of this method is reflected in failing to consider or only partially considering the different types of precipitation and the height of the melting snow / rain layer, which leads to significant overestimation of the rain rate.

Often, it is exactly the precipitation events with a zero temperature zone between 1000 and 2000 metres over sea level that lead to flooding in mid-level mountain areas. As this is the altitude level in which the radar normally measures, it is important to obtain information relating to the bright band. With the height information of the bright band it is possible to consider and to compensate for the over-estimation in the bright band itself and the under-estimation in the snow.

3.2. Conclusion and next practical steps

The realization of the enhancement should be considered in two project phases. First the value for Z shall be extrapolated to ground by profile correction method. This can be achieved by a climatologic estimation by considering the ground temperature, by measuring with vertical radar or from data from the precipitation radar itself (by continuous scan of a high resolution profile). The local topography, the height and the altitude of melting layer have to be considered for the basic correlation and first step. The second step considers the adjustment and calibration of weather radar data from the correlation of a ground based precipitation network and distribution of precipitation data
The adjustment of the weather radar with precipitation data input leads to a precise and overall precipitation data network. Regional weather forecasts and high water early warning system can be improved significantly by the combination and correlation of spatial weather radar and ground based enhanced precipitation data (radar reflectivity, intensity and accumulated precipitation).

Scientific Essays

1. Löffler-Mang, M., and J. Joss, 2000: An optical disdrometer for measuring size and velocity of hydrometeors. J. Atmos. Ocean. Tech., 17, 130-139.
2. Löffler-Mang, M., and U. Blahak, 2001: Estimation of the equivalent radar reflectivity factor from measured snow size spectra. J. Appl. Meteor., 40, 843-849.
3. Jitze P. van der Meulen, 2003: Exploratory actions on automatic Present Weather observations; Final Report with recommendations EUMETNET
4. Yuter, S. E., D. Kingsmill, L. B. Nance, and M. Löffler-Mang, 2006: Observations of precipitation size and fall speed characteristics within coexisting rain and wet snow J. Appl. Meteor, published January 2006

OTT MESSTECHNIK GmbH & Co. KG
Ludwigstraße 16
87437 Kempten · Germany
Tel. 0831/5617-0
Fax 0831/5617-209
E-Mail: info@ott-hydrometry.de

www.ott-hydrometry.com