Enhanced Possibilities of PARSIVEL Disdrometer: Precipitation Type, Visibility, and Fog Type

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Abstract: The well known laser-optical disdrometer PARSIVEL (PARticle SIze and VELocity) already allows a number of different meteorological analyses. To mention only the most important ones these are drop and snow size distribution, fall velocity, energy distribution, precipitation intensity, radar reflectivity, and total amount of precipitation.

Besides these from the measured two-dimensional distribution of size and velocity the type of precipitation can be derived. This is possible due to the characteristic coherence of size and velocity for different hydrometeors such as rain drops (small to medium sizes, higher velocities), snow flakes (small to large sizes, low velocities), graupel (small to medium sizes, medium velocities), and hail (medium to large sizes, high velocities). Using this information PARSIVEL can be applied as present weather sensor.

Furthermore, with some small additional hardware and software PARSIVEL can also deliver a good estimation of visibility. This enhancement is reached by an additional laser diode and one or two additional detectors for scattered light within the existing housing. A combination of the scattered light intensity and the original extinction signal allows calculation of the visibility from meters to kilometers.

Finally, a more intelligent combination of the light scattered into different angles gives the possibility to distinguish between different types of fog. For example, the ratio of forward to backward scattered light for a fog consisting of water drops is significantly higher than that for an ice fog. Some similar consideration is valid for the discrimination between fog and dust particles.

The paper mainly deals with these enhanced possibilities. The fundamentals will be presented and first results will be shown as an experimental validation.

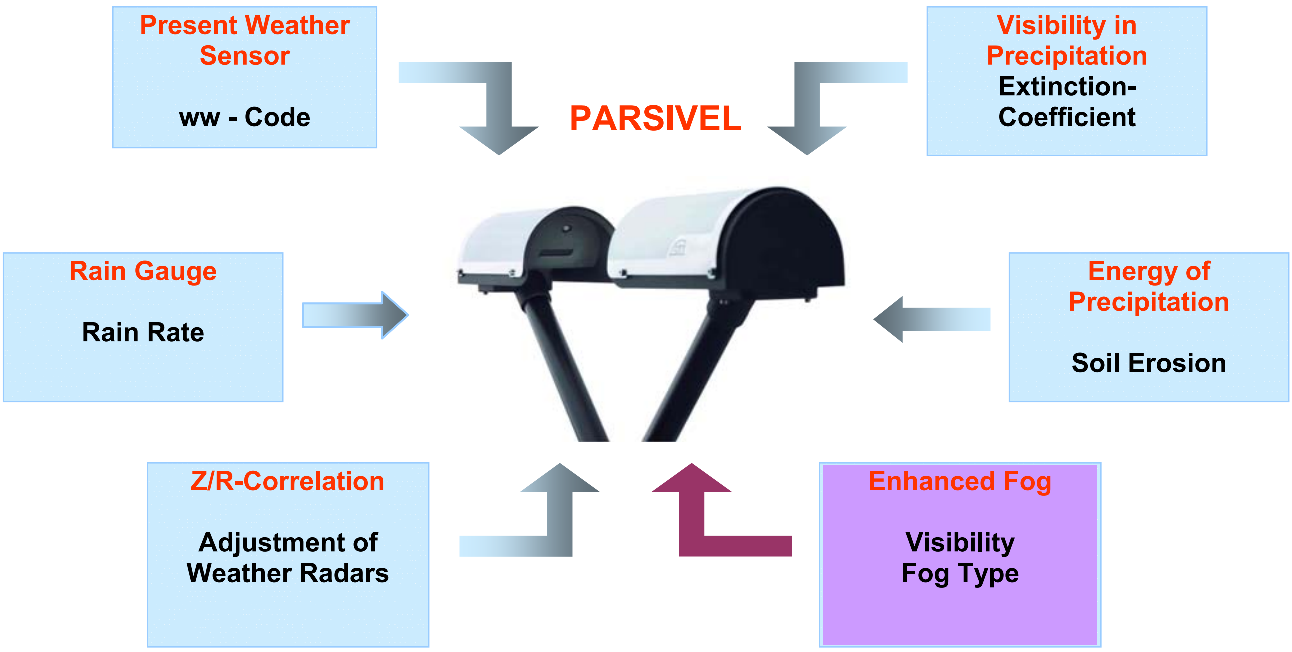

Fig. 1: The different features of the PARSIVEL sensor, including EF (Enhanced Fog)

Part I: Precipitation Type

Extinction measuring principle

The sensor's transmitter unit generates a flat, horizontal beam of light, which the receiver unit converts into an electric signal (Fig. 2A). This signal changes whenever a hydrometeor falls through the beam anywhere within the measurement area (Fig. 2B). The degree of dimming is a measure of the hydrometer's size, and together with duration of the signal, the fall velocity can be derived (Fig. 2C).

PARSIVEL detects and identifies 8 different precipitation types as drizzle, mixed drizzle/rain, rain, mixed rain/snow, snow, snow grains, freezing rain and hail.

The output data consist of 2D spectral distribution related to size and velocity of particles, rain accumulation and intensity, present weather reports, radar reflectivity, precipitation energy, and visibility.

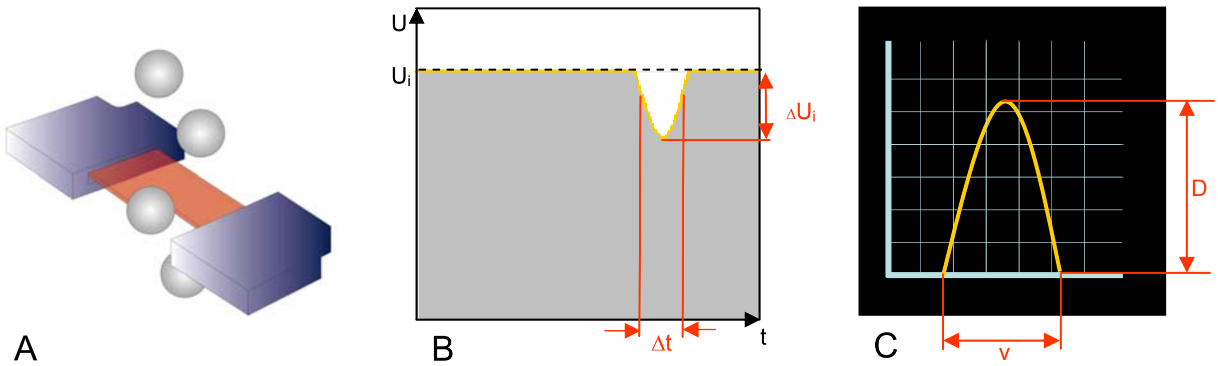

Fig. 2: Extinction measuring principle

Precipitation classification

The idea for precipitation classification is to make use of significant different fall velocities of different hydrometeor types. This is shown with the help of two examples: Figure 3 gives the characteristic 2D distribution of fall velocity over drop size for a 60min rain event.

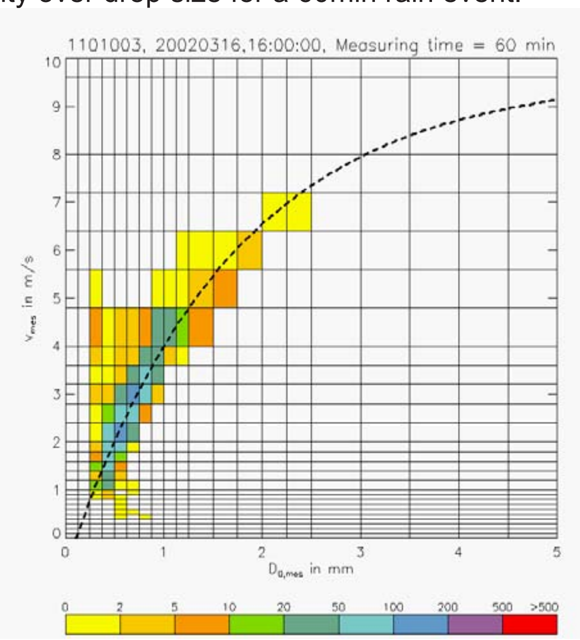

Fig. 3: Typical rain event

The dashed line in Fig. 3 represents the well-known empirical relation from Gunn & Kinzer (1949):

$$v(D) = 9.65 - 10.3 \exp(-0.6\ D)$$

with D in mm and v(D) in m/s. The colours in the 2D-array indicate the number of particles found in this specific size and velocity class. The blue and green fields with high drop numbers group, as expected, along the Gunn & Kinzer curve.

The second example shows a characteristic 2D distribution for a 60min snow event, see Fig. 4. The particles group mainly below the Gunn & Kinzer curve for rain. Especially the larger snow flakes show substantially lower fall velocities as the equivalent drops. This is in agreement with our expectations.

There is no single relation for fall velocity of snow because of the wide variety of densities and shapes. Locatelli and Hobbs (1974) give a large number of equations for several characteristic types of solid precipitation.

The precipitation type is automatically classified from the 2D distribution with the help of characteristic values from literature and a sophisticated decision tree.

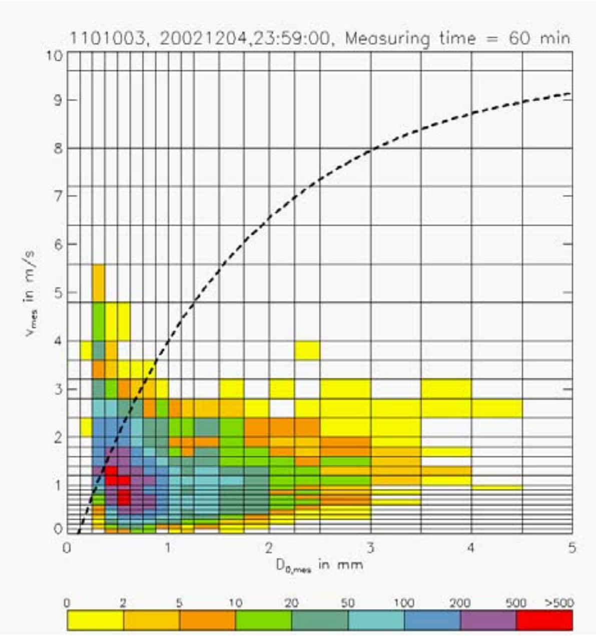

Fig. 4: Typical snow event

Furthermore, not only single type precipitation can be measured and classified, but also mixed precipitation. For example, wet snow flakes and rain drops in the melting layer exhibit two branches in the 2D distribution and clearly can be separated or individually evaluated, for more details see Yuter et al. (2006).

Part II: Visibility

Fundamentals

There are two principal optical mechanisms to estimate visibility in fog. On the one hand this is extinction of single particles (rain) or of a whole particle ensemble (fog). The signal is proportional to D^2, high stability of transmitted power is necessary, and the visibility is measured directly. On the other hand this is scattering by particles. Here the signal is proportional to D^4, the signal to noise ratio is good, and the visibility has to be calculated from the measured signal with some additional assumptions.
Let us look a little bit closer to the extinction method. Attenuation of the light by fog normally is described by an exponential law:

$$P(x) = P_0 e^{-\sigma_e x}$$

with following quantities

σ_e	extinction coefficient
x	beam length
P_0	transmitted power
P(x)	remaining power after path x

This law can be converted to the visibility S_n by taking the logarithm of the equation and by assuming a minimal contrast of 0.05:

$$S_n = \frac{-\ln(0{,}05)}{\sigma_e} = \frac{3}{\sigma_e}$$

Table 1 shows some corresponding values of visibility S_n, extinction coefficient σ_e, remaining power after 25cm beam length $P_{0,25}$, and signal strength in a receiver at this point.

S_n [m]	σ_e [1/m]	$P_{0,25}/P_0$ [%]	Signal [%]
5000	0,0006	99,99	0,01
1000	0,003	99,93	0,07
500	0,01	99,75	0,25
200	0,02	99,50	0,50
100	0,03	99,25	0,75
50	0,06	98,51	1,49

Table 1: Examples of visibility and receiver signal

At low visibilities (50m) there is sufficient signal strength of approx. 1.5% for reasonable measurements. But for higher visibilities the signal strength rapidly decreases below the typical noise level. This makes some enhanced fog measurement necessary.

PARSIVEL-EF

Figure 5 shows a sketch of PARSIVEL-EF (Enhanced Fog). It is obvious that the new system not only makes use of the already existing extinction path, but also consists of some additional scattering sensor barrier. In the front plates on one side a laser diode is included, on the other side a photo diode. They look at each other under some angle in forward scatter direction. In combining the information from existing extinction and from forward scattering PARSIVEL-EF should allow the estimation of visibility in the range up to 500m with reasonable accuracy (details follow in the next sub-chapter).

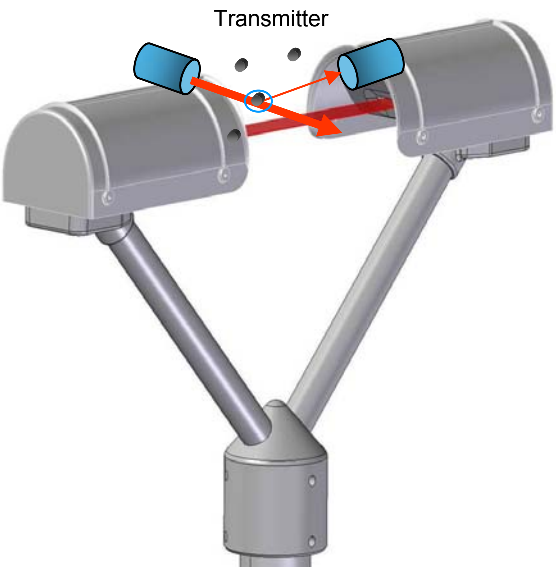

Fig. 5: Sketch of PARSIVEL-EF

A calibration of the new PARSIVEL-feature was done with the help of optical filters. Fog was simulated by a set of these filters with well-known attenuation and scattering properties.

Evaluation in fog chamber
An experimentation centre to test poor visibility conditions in fog has been developed at the Clermont-Ferrand Laboratoire des Ponts et Chaussees in charge of research on safety and visibility. It consists of an installation producing artificial fog in a laboratory that is 30m in length. This equipment makes it possible to study the factors that affect visibility in fog both day and night. Fog density is constantly controlled by means of a transmissiometer connected to data acquisition system.
The fog chamber is used for the development of European Research in collaboration with European partners, such as research institutes, departments of transport, or private companies. The fog room can be used also to demonstrate or to test the properties of prototypes of any sensor systems affected by fog.
Thanks to this offer of collaboration the visibility function of the new PARSIVEL-EF could be investigated in the fog chamber. The results of the calibration done by attenuation and scattering with optical filters were in acceptable agreement with the transmissiometer of the fog chamber. It can be stated that PARSIVEL-EF gives good visibility estimation in the range from 25m to 550m with an accuracy of +-100m.

Part III: Fog Type

Particle scattering
The scattering of light by particles (drops, ice crystals, soot particles, etc.) is a rather complicated process. It depends on particle shape, particle size, wavelength, and very strong on the scattering angle. For spherical particles the scattering field around the particle can be calculated by Mie-theory. For all other cases knowledge mainly comes from experiments.
Figure 6 shows the experimental set-up for measuring the scattering field around an ensemble of particles. In the middle of the picture there is a glass containment for the investigated particles. It is filled with fog consisting of water drops and can continuously be refilled by new drops from the above standing nozzle. The laser beam comes from the right side and passes through the glass. The detector is moved around the glass on the tape marks on the table and is just positioned at an angle of approx. 55° forward scattering. With this set-up the data are taken for a graph as shown in fig. 7.

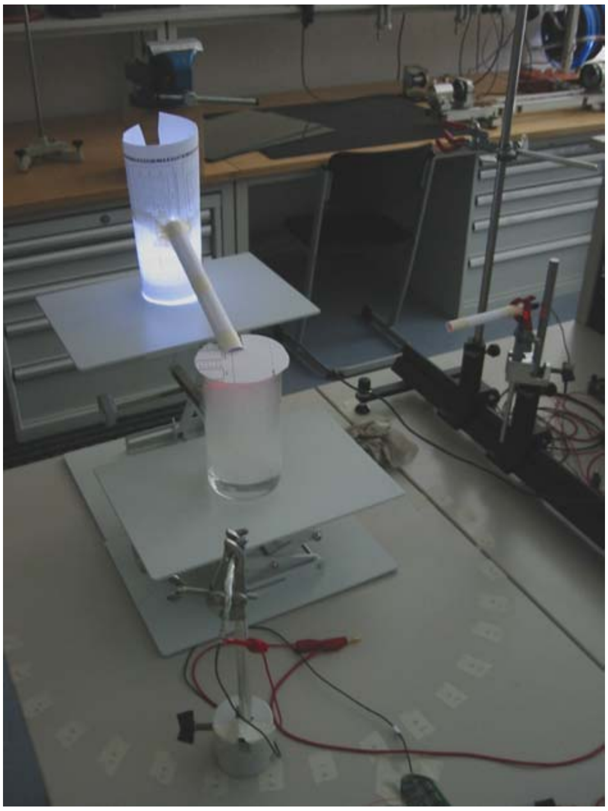

Fig. 6: Experimental set-up for scattering field

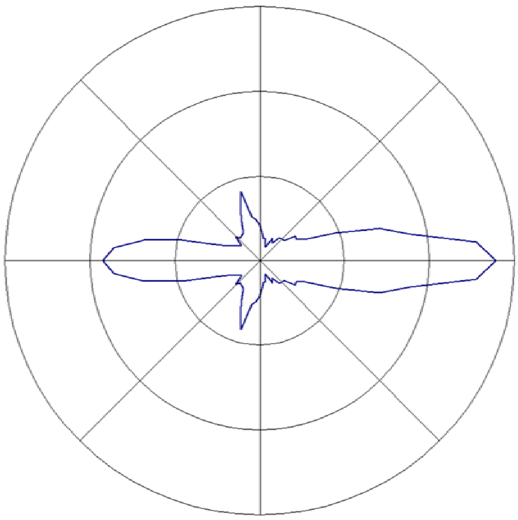

Fig. 7: Scattering intensity field around fog drops (laser beam from left side, drops in center)

Multi-detector system

Each particle type has its own characteristic scattering field around the particles. For example, fog particles show a smaller ratio between forward to backward scattering than smoke and dust particles.

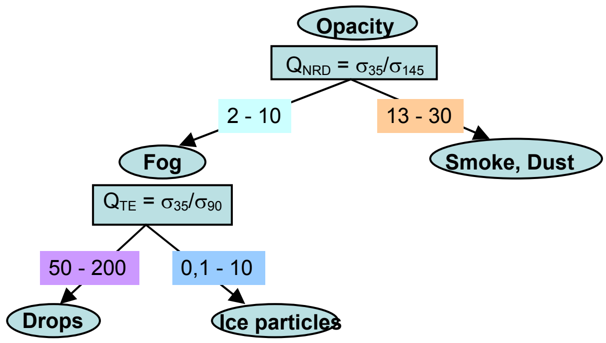

Fig. 8: Scattering ratio of different particles

Figure 8 gives special values taken from scattering simulations for different particle types. For discrimination between drops, ice particles, and dust/haze three angles are of main interest. These are approx. 35° forward scattering, 145° backward scattering, and 90° rectangular scattering.
Starting from a general opacity the ratio of σ_{35} to σ_{145} (i.e. forward to backward scatter intensity) has values between 2 and 10 for fog particles, whereas the values for smoke and haze particles are typically in the rang from 13 to 30.
Looking closer at the fog, the ratio σ_{35} to σ_{90} gives the possibility to discriminate between drops and ice particles. For drops this value is significantly higher (in the range from 50 to 200) compared to ice particles (0.1 to 10).
All values given in fig. 8 are only rough estimates and have to be verified before being used in the decision tree of a measuring device. But the medium-term idea is to integrate the necessary number of detectors within the PARSIVEL system, so that beneath the visibility also the fog type will be evaluated. This could be helpful to estimate the hazardousness of a special fog for example for traffic.

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