Chapter I.5
An Introduction to Rain Gauges and Disdrometers

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1 Introduction

Rainfall plays a key role within the hydrological cycle. Its accurate and spatially revolved quantitative measurement is one of the main current challenges within the hydro-meteorological community (Marzano et al., 2002). Several techniques may be enumerated for this purpose: local direct instrumentation (such as rain gauges and disdrometers), ground-based remote instrumentation (such as microwave radars and radiometers), and satellite-based remote instrumentation (such as microwave radars, microwave radiometers, infrared sensors). The synergy between all these instruments, with their advantages and drawbacks, is fundamental for a better comprehensive analysis of the rainfall field space-time features. For example, the measurement of hydrometeor size distributions from disdrometers can provide a powerful opportunity to directly investigate the microphysical properties of thunderstorms and allow a comparison from retrievals performed, for example, by polarimetric radars (Vulpiani and Marzano, 2008).

In this chapter an introduction to the main ground-based instruments to measure raindrop size distribution and rain will be given. Rain gauges and disdrometers will be described to provide a useful overview of the local in situ measurements, often used to calibrate and validate rainfall estimates derived from radar observations.

1.1 Rain Gauge

Any instrument which is able to collect and measure the rainfall intensity can be regarded as a pluviometer (or rain gauge) (Ahrens, 2004). The standard pluviometer, which was invented by the English scientist Robert Hooke around the second half of 1600, consists of a funnel connected to a measuring tube for registering the level

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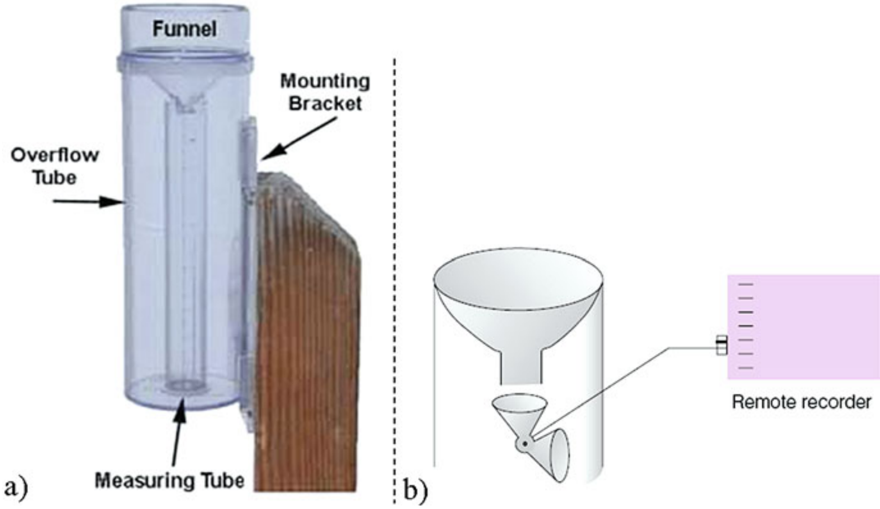

Fig. I.5.1 Two types of pluviometers. **Panel a** standard rain gauge; **panel b** balance rain gauge

of rain (see left panel of Fig. I.5.1). The area of the funnel is larger than that of the measuring tube and, as a consequence, a good degree of precision of the order of 0.1 mm can be achieved. In order to obtain the accumulated rain R_{acc} expressed in mm/m^2 (i.e., the conventional unit) the measure of the volume of water W (l) has to be normalized as follows:

$$R_{acc} = \frac{W}{A}, \qquad (1)$$

where A is the area of the funnel tube expressed in m^2 and its inverse is often referred as pluviometric factor. Therefore, if the pluviometer measure 1 l of water (i.e., 1 dm^3 = 0.001 m^3) with $A = 1$ m^2, through Eq. (1), a height of 1 mm will be observed on the measuring tube. The measured (m) rain rate R_m expressed in mm/h indicates the level of rain observed after an hour.

Another type of pluviometer, shown on the right panel of Fig. I.5.1, uses a balance to gather the rain. The balance is composed of a couple of little bins which are fixed to each other and they are free to oscillate around an horizontal axis. When one bin accumulates a given quantity of water its increased weight produces the discharge of the accumulated water and the second bin takes the place of the first and the cycle goes on. Every time that the two bins rotate, the quantity of water discharged is registered on a roll of paper. The sum of each registration, provides, according to some proportions, the quantity of rain fallen. This type of pluviometer is often used in the automatic meteorological stations even though the tendency to underestimate the rain quantity has been noticed for intense rainy events. This is due to the loss of water during the bin rotations.

In addition, it should be mentioned that other types of pluviometers use weighing systems where the weight of the gathered water is associated to the rain fallen expressed in millimeter.

1.2 Disdrometer

The microphysics of hydrometeors, their composition, their shape, their size, and their statistical distribution are the key parameters to characterize the precipitation phenomena and their knowledge is very important in order increase the accuracy of estimations obtained by weather radars.

Since around 1977 the measurements of the distribution of the size of raindrops are possible thanks to an instrument called impact disdrometer which was invented by J. Joss and A. Waldvogel and for this reason it is often labeled as Joss & Waldvogel Disdrometer (JWD) (Joss and Waldvogel, 1977). More recent progresses in this field have been yielding a more sophisticated instrument than the JWD. In 1990, the Joanneum Research Center of Graz (Australia), in collaboration with the European Space Agency/European Space TEchnology Centre (ESA/ESTEC) invented the 2D video disdrometer (2DVD).

In the following, instrumental details about the two types of disdrometer mentioned above are given together with a mathematical formulation of the measured quantities. Eventually, section ends with an example on how distrometer observations are converted into quantity of interest for microphysical meteorological studies such as water content, drop concentrations, and mean drop diameter.

1.2.1 Instrument Details

The fundamentals that describe these two instruments are quite different. The JWD is based on the transduction of the mechanical momentum, which is indicted by the impact of a hydrometer on the area of the sensor (A) and to an electrical energy, whereas the 2DVD takes a picture of the shadow that an hydrometeor causes when it goes through two perpendicular beams of light. A schematic view of both the JWD and the 2DVD is shown in Fig. I.5.2.

In detail, the 2DVD is composed of two cameras which are perpendicular to each other and two illumination devices which are positioned in front of each camera. For reasons that will be clear later, both the cameras and the illuminators do not lie on the same horizontal plane but they are spaced of about 6.18 mm. The two beams of light, generated from the illumination devices, overlap defining a sensed area or also called virtual measuring area A. Every particle which goes through A is registered as a shadow from the two cameras. Therefore, the optical signal, collected from the cameras, is transduced into an electrical signal whose intensity is related to the particle sizes. Unlike the JWD, the 2DVD allows the measure of the shape of the hydrometeors exploiting the fact that two pictures, of the same particle, are taken from a different angle of view (i.e., shifted by 90°). In addition, since the vertical

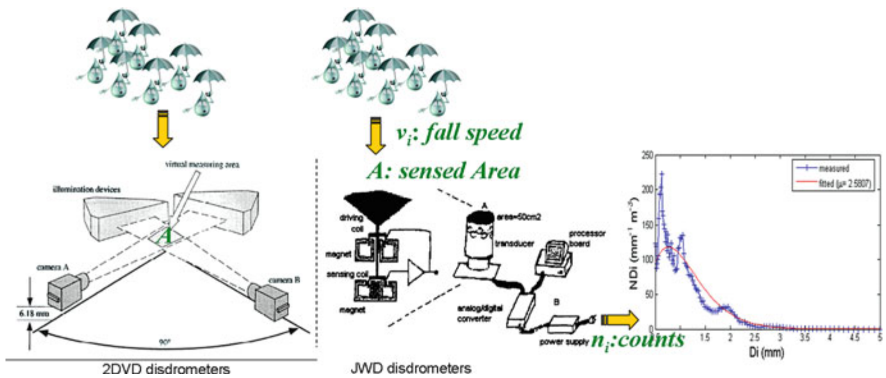

Fig. I.5.2 *Left panel*: components of the 2D video disdrometer. *Middle panel*: components of Joss-Walvogel disdrometer. *Right panel*: an example of the output of a disdrometer expressed in $mm^{-1} \cdot m^{-3}$ (instead of counts)

distance between the cameras is known, the vertical fall velocity of drops can also be obtained. More details about this instrument can be found in Hanesch (1999).

On the other hand, the JWD (see middle panel of Fig. I.5.2) is composed of a conical section in which the drops impact producing the downward movement of the conical section between two coils. The first coil registers the amplitude of the displacement of the conical section, whereas the second one contrasts this downward displacement restoring the initial position of the conical section. From this brief exposition it is clear that, unlike the JWD, the 2DVD disdrometer allows to retrieve some important quantities for meteorological applications, such as the vertical fall velocity and the shape of a drop (i.e., its axis ratio).

Both the JWD and the 2DVD, when used for obtaining the RSD, produce, at their output and at the discrete instant t (s), the counts (n) of drops for each interval of diameters as shown in the right panel of Fig. I.5.2. From the JWD and the 2DVD counts, the measured raindrop size distribution (RSD) can be calculated using the following equation:

$$N_{\mathrm{m}}(D_i, t) = \frac{n_i(t)}{A \cdot \Delta t \cdot v_i \cdot \Delta D_i} , \qquad (2)$$

where the subscript "m" indicates a measured quantity, D_i (mm) is the central rain drop diameter of the "channel" c_i which has been computed as mean value between the drop diameters D_{ci} and $D_{ci+1}, N_{\mathrm{m}}(D_i,t)$ ($mm^{-1}.m^{-3}$) the number of rain drops per unit of volume in the channel c_i at the discrete instant t, $n_i(t)$ the number of drops rekoned in the ith channel at the instant t, A (m^2) the sensor area, Δt (s) the sample period, v_i ($m \cdot s^{-1}$) is the rain drop fall speed of a rain drop whose diameter is D_i, and ΔD_i (mm) is the ith channel width. A typical parameter setup to calculate $N_{\mathrm{m}}(D_i, t)$ from Eq. (2) for a JWD disdrometer are: $A = 0.005$ m^2, $\Delta t = 10$ s, $\Delta D_i = D_{ci+1} - D_{ci}$ for i ranging from 1 to $n_c = 104$ with minimum and maximum diameters equal to 0.5 and 5 mm, respectively, uniformly spaced in a logarithmic scale. On the contrary, for a 2DVD disdrometer the maximum and minimum detectable range of diameters is, respectively, 0.1 and 10 mm, whereas the sensed area is equal to 0.010 m^2.

The speed v_i, in Eq. (2), can be described by models of terminal velocity of rain drops as, for example, that proposed by Atlas and Ulbrich (1977), which approximated form is reported here:

$$v_i = 3.78 \cdot D_i^{0.67} \,. \tag{3}$$

In the past, starting from measurement experiments of Gunn and Kinzer (1949), exact but relatively complex analytical expressions have been semi-empirically established for various rain regimes (Foote and Toit, 1969; Beard and Pruppacher, 1969; Wobus et. al., 1971; Beard, 1976).

From Eqs. (2) and (3), the computation of the measured rain rate R_m (mm/h) is straightforward through the moments of $N_m(D_i,t)$ of order 3.67, as specified by

$$R_m(t) = 3.78 \cdot \frac{\pi}{6} \cdot m_{3.67}(t) \,, \tag{4}$$

where $m_n(t)$ is the general expression of $N_m(D_i,t)$ moment of order n and can be calculated from disdrometer measurements as

$$m_n(t) = \int_0^\infty D^n \cdot N(D,t) \cdot dD = \sum_{i=1}^{n_c} D_i^n \cdot N_m(D_i,t) \,.\, \Delta D_i. \tag{5}$$

In Eq. (5), the third term underlines the discrete nature of the measured RSD, whereas the extremes of the integral point out the untruncated range of diameters (Montopoli et al., 2008a, 2008b).

1.2.2 Particle Size Distribution

Modeling the size distribution of particles is a hard task but, at the same time, very important in order to retrieve some key quantities for characterizing precipitations such as water content and rain rate. In the following, we will refer to the drop size distribution (DSD), instead of the more general definition of particles size distribution (PSD) when the particles are supposed to be precipitating whereas the acronyms RSD will indicate the raindrop size distribution. The major difficulty in modeling the DSD is due to its high variability and to the fact that a given size of hydrometeors can be associated to different drop concentrations for the same rain rate intensity. Disdrometer, before introduced, surely is needful to model DSDs.

Recently, many studies (e.g., Tokay et al., 2002 and Testud et al., 2001) have demonstrated that a gamma distribution can be a valid alternative to the more consolidated Marshall e Palmer distribution, based on an exponential function, to describe DSD. Gamma distribution assumes the following form:

$$N(D, \mathbf{p}) = N_w \cdot f(\mu) \cdot \left(\frac{D}{D_\mathrm{m}}\right)^{\mu} \cdot \exp\left[-(4+\mu) \cdot \frac{D}{D_\mathrm{m}}\right], \tag{6}$$

where $N(D,\mathbf{p})$ ($\mathrm{m}^{-3}\cdot\mathrm{mm}^{-1}$) is the number of drops per unit volume per unit size interval, D (mm) is the sphere-equivalent drop diameter, N_w ($\mathrm{m}^{-3}\cdot\mathrm{mm}^{-1}$), μ, and D_m (mm) are the intercept, the shape, and the mass-weighted mean diameter parameters, respectively, and $f(\mu)$ takes the following form:

$$f(\mu) = \frac{6}{4^4} \cdot \left[\frac{(4+\mu)^{(4+\mu)}}{\Gamma(4+\mu)}\right], \tag{7}$$

where Γ is the complete gamma function. In general, the parameters N_w, μ, and D_m can be retrieved using the moments of the RSD (e.g., Ulbrich and Atlas, 1998),

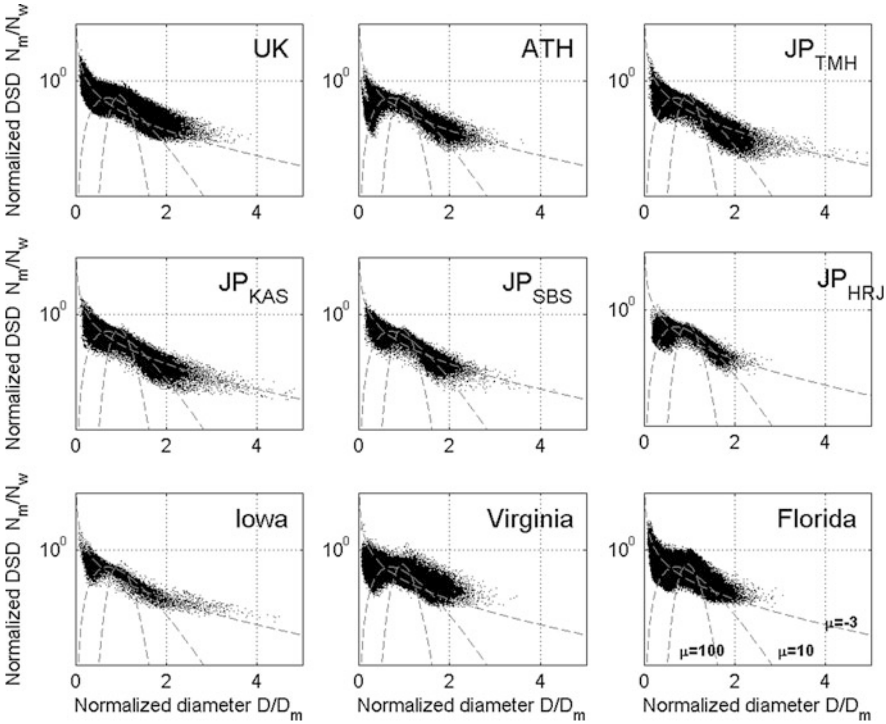

Fig. I.5.3 *Black dots* indicate the scaled RSD ($N_\mathrm{m}(D)/N_\mathrm{w}$) vs normalized diameter (D/D_m) for all the RSD data sets. *Gray-dashed lines* indicate the normalized gamma distributions for values of μ equal to –3 and 10 and 100 as shown in the *lower right corner* formalized in Eq. (5), such as, for example, the second, the third, the fourth, and the sixth. The mass-weighted mean diameter D_m is calculated as the ratio between the fourth and the third empirical moments of the RSD:

$$D_m = \frac{m_4}{m_3} \,. \tag{8}$$

The generalized intercept parameter N_w is also computed from the fourth to third moment of the RSD and can be derived from

$$N_w = \frac{256}{6} \cdot \frac{m_3^5}{m_4^4} \,, \tag{9}$$

where the moment m_n of order n is expressed by Eq. (5).

Typical shapes of DSD are shown in Fig. I.5.3 for different regions where distrometer were located (USA: Virginia, Iowa, and Florida; Japan: Kitaashigara Hiratsuka and Shibusawa; Greece: Athens; UK: Chilbolton).

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