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The use of the Joss-type disdrometer for the derivation of Z-R relationships

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Abstract. Fourteen rainfall events have been recorded and analysed by the RD-69 (Joss-type) Disdrometer. The range of drop diameters that can be measured spans from 0.3 mm to 5.0 mm. The current position of the instrument was chosen after taking into account: a) the quiet surroundings, since high acoustic noise levels will impair the measurement of small drops, b) the effect caused by strong winds, producing turbulence at the edges of the transducer, c) the prevention from flooding and d) the resonance and splashing by raindrops. This instrument measures the raindrop size distributions continuously and automatically having the ability to transform the vertical momentum of an impacting raindrop into an electric pulse, whose amplitude is a function of the drop diameter. The knowledge of drop size distributions in rain is of importance in radar meteorology, precipitation physics, microwave propagation etc. and can be used for the estimation of other hydrometeorological parameters, such as rainfall rate R, liquid water content in a given volume W, radar reflectivity factor Z, etc. To calculate a drop size distribution, the distribution of drops of the diameter corresponding to size class i per unit volume must first be calculated from the data for every drop size class. Different Z-R relationships were derived and compared with the one describing the disdrometer data for the specific event, as well as, all rainfall events.

1 Description of the joss-type disdrometer RD-69

The RD-69 (Joss-type) Disdrometer, an instrument for measuring raindrop size distributions continuously and automatically has the ability to transform the vertical momentum of an impacting raindrop into an electric pulse whose amplitude is a function of the drop diameter. According to the principal of operation, the Disdrometer measures the size distribution of raindrops falling on the sensitive surface of the transducer. From the measurements the actual drop size distribution in a volume of air may be easily calculated. The range of drop diameters that can be measured spans from 0.3 mm to 5.0 mm. Drops smaller than 0.3 mm cannot be measured due to practical limits of the measuring principle and are usually of minor importance in applications for which the instrument is intended. Drops larger than 5.0 mm are very rare because of drop breakup due to the instability of large drops.

The RD-69 Disdrometer for raindrops consists of three main units (Distromet LTD, 1997):

- The transducer which is exposed to the rain
- The processor and
- The analog to digital converter - adapter, Analyser ADA – 90

The transducer consists of an electromechanical unit and a feedback amplifier. A conical styrofoam body is used to transmit the mechanical impulse of an impacting drop to a set of two moving coil systems. At the impact of a drop the styrofoam body together with the two moving coils moves downwards and a voltage is induced in the sensing coil. This voltage is amplified and applied to the driving coil such that a force counteracting the movement is produced. As a consequence the excursion is very small and it takes very little time for the system to return to it's original resting position and therefore to get ready for the next impact of a drop. The amplitude of the pulse at the output of the amplifier is a measure for the size of the drop that caused it.

The second unit the processor serves three functions:

- It supplies power to the transducer
- It processes the signal from the transducer
- It contains circuits for testing the performance of the instrument.

The signal processing circuit consists of a noise reduction filter, a dynamic range compressor and a signal recognition circuit. The noise reduction filter is an active bandpass filter,

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Fig. 1. The installation of the Disdrometer RD-69 on the roof of the Water Resources building.

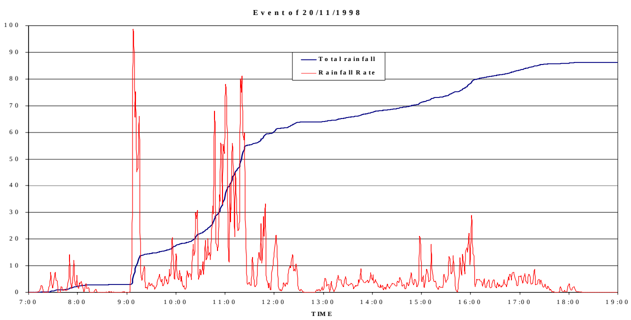

Fig. 2. The total rainfall and the rainfall rate for the event of 20-11-1999.

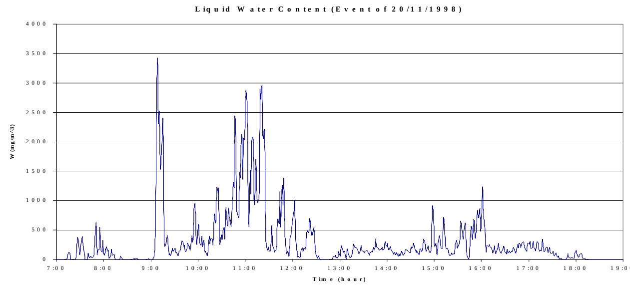

Fig. 3. The water liquid content for the event of 20-11-1999.

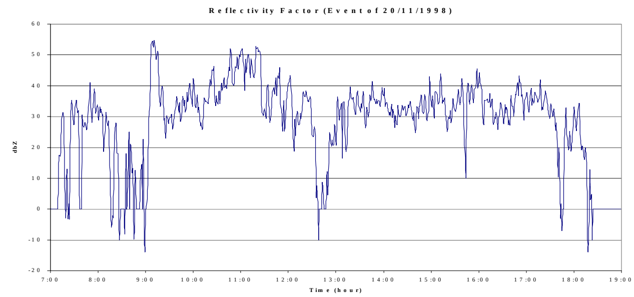

Fig. 4. The reflectivity factor for the event of 20-11-1999.

whose frequency response is designed to give an optimum ratio between the signal from raindrops and the signal from acoustic noise affecting the transducer. The dynamic range compressor consists of an amplifier with a voltage dependent feedback network to adjust the amplitude response of the system to the desired characteristic. The signal recognition circuit can distinguish between the signal pulses caused by drops hitting the transducer and the more uniform oscillations caused by acoustic noise. In this case a gate passes the pulse to a pulse standardiser, which produces a constant pulse duration without changing the peak amplitude of the original pulse.

The analog to digital converter – adapter, Analyser ADA – 90, is designed to be used as an interface between the RD-69 Disdrometer and a computer. The ADA – 90 accepts the drop size pulses from the transducer, converts them into a digital code, which is then transmitted in serial form to the computer. The ADA – 90 consists of three main building blocks (Distromet LTD, 1997):

– A peak detector circuit

– A nonlinear A to D converter

– And a parallel to serial converter / transmitter

As soon as the amplitude of a pulse at the input exceeds the triggering threshold for the conversion (0.157 V nominally) a conversion cycle is initiated. The conversion is completed 0.4 ms after the start of the A to D converter and the contents of the converter register are transmitted to the computer.

1.1 Installation of the RD-69 Disdrometer

The Disdrometer RD-69 was installed on the roof of the Water Resources Department of NTUA as shown in Fig. 1 and has been operated since November 1997. In order to operate the RD-69 Disdrometer, the transducer was installed taking into account the following conditions (Mimikou and Baltas, 1999):

– The Transducer was set up in quiet surroundings, since as high acoustic noise levels will impair the measurement of small drops. Signals caused by acoustic noise are suppressed by the instrument, but drop signals not exceeding the level of the noise will be suppressed together with the noise signal. Drop signals exceeding the noise signal will be measured with full accuracy. The presence of acoustic noise therefore causes a reduction in the number of small drops measured.

– The transducer was mounted with its top at ground elevation reducing the effect caused by strong winds, producing turbulence at the edges of the transducer.

– The transducer was set up in order to be prevented from flooding

– The transducer was set away from objects which can resonate when hit by raindrops, as well as, from surface where the drops can splash.

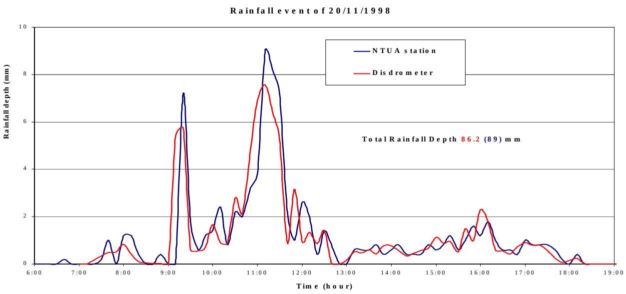

Fig. 5. The hyetograph measured by the NTUA station against the one estimated by the Disdrometer for the event of 20-11-1999.

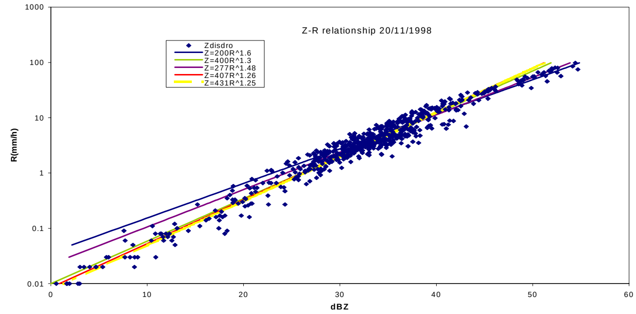

Fig. 6. A number of Z-R relationships against the data derived by the Disdrometer for the event of 20-11-1999.

2 Estimation of hydrometeorological parameters

A rain drop size distribution is commonly represented by the function $N(D)$, the number concentration of rain drops with the diameter D in a given volume of air. Because of the complicated processes involved in the formation of precipitation the function $N(D)$ largely varies and cannot be given in a simple form (Baltas and Mimikou, 1994). In many cases however a drop size distribution can be approximated by an exponential law and the following parameterisation can be used to characterise it:

$$N(D) = N_0 \exp(-\Lambda * D) \tag{1}$$

where N_0 is the number concentration of drops with diameter 0 on the exponential approximation and Λ is its slope.

In many practical cases where knowledge of the whole drop size distribution is not necessary, other quantities derived from the drop size distribution like rainfall rate R, liquid water content in a given volume W, radar reflectivity factor Z, etc. can be used.

To calculate a drop size distribution the quantity $N(D_i)$, the number density of drops of the diameter corresponding to size class i per unit volume must first be calculated from the data for every drop size class according to the following formula:

$$N(D_i) = \frac{N_A(D_i)}{AtV(D_i)\Delta D_i} \tag{2}$$

where N_A is the number of drops measured in drop size class i; D_I is the average diameter of the drops in class; A is the size of the sensitive surface of the Disdrometer; t is the time interval for one measurement (1 minute); $V(D_i)$ is the fall velocity of a drop with the diameter D_i; ΔD_i is the diameter interval of drop size class.

The quantities R, W, and Z are calculated using the following formulae:

$$R = \frac{\pi}{6} * \frac{3.6}{10^3} * \frac{1}{At} \sum_{i=1}^{20} N_A(D_i) D_i^3 \tag{3}$$

$$W = \frac{\pi}{6} * \frac{1}{At} \sum_{i=1}^{20} \frac{N_A(D_i)}{V(D_i)} D_i^3 \tag{4}$$

$$Z = \frac{1}{At} \sum_{i=1}^{20} \frac{N_A(D_i)}{V(D_i)} D_i^6 \tag{5}$$

To calculate N_0 and Λ, an exponential drop size distribution having the same values for W and Z as the measured distribution is assumed, the following formulae are used:

$$N_0 = \frac{1}{\pi} * \left(\frac{6!}{\pi}\right)^{4/3} * \left(\frac{W}{Z}\right)^{4/3} * W \tag{6}$$

$$\Lambda = \left(\frac{6!}{\pi} * \frac{W}{Z}\right)^{1/3} \tag{7}$$

In situations with heavy rain the dead time of the disdrometer may become a source of error in the measurements. After a drop hits the instrument a following drop can only be registered after a certain time which depends on the size of the first and of the following drop. This time is necessary for the decay of the mechanical oscillations in the transducer, after it has been hit by a drop. The following empirical function was developed for calculating a correction for this dead time:

$$N_{i\,\mathrm{corr}} = N_i * \exp\left[\frac{0.035}{T} * \sum_{D_k=0.85\,D_i}^{D_{k\,max}} N(k) * \ln \frac{D_k}{0.85(D_i - 0.25)}\right] \tag{8}$$

N_i is the number of drops in size class i without correction; $N_{i\,\mathrm{corr}}$ is the number of drops in size class i with correction; T is the sampling time in seconds

A drop in size class k causes a dead time for all channels i, where

$$D_k = 0.85 * D_i \tag{9}$$

The application of the dead time correction depends on the size of the diameter of the drops and the intensity of them.

Table 1. A number of rainfall events recorded last year

A/A	Date	Total Rainfall Depth (mm)
1	12/11/1998	25.02
2	13/11/1998	15.34
3	20/11/1998	86.24
4	03/01/1999	8.62
5	14/01/1999	8.41
6	29/01/1999	1.64
7	31/01/1999	4.89
8	040/3/1999	3.41
9	16/03/1999	69.06
10	19/03/1999	2.91
11	24/03/1999	3.09
12	29/03/1999	18.81
13	30/03/1999	9.06
14	01/04/1999	3.77

3 Results

Fourteen rainfall events from November 1998 to April 1999, shown in Table 1, have been recorded and analysed. The previously mentioned hydrometeorological parameters are estimated by applying the dead time correction technique. Representatively, in Fig. 2, one can observe the rainfall rate and the total rainfall for the event of November, 1999, while in Figs. 3 and 4 one can observe the water liquid content and the reflectivity factor. Figure 5 shows the comparison between the rainfall estimated by the disdrometer and the rainfall measured by the NTUA meteorological station. This event has a total rainfall height of 89 mm as measured by the NTUA station and 86.2 mm as estimated by the disdrometer. From statistical analysis it has been derived that it was a rainfall event with a 25-year return period. As it can be seen, there is a small deviation in the time of occurrence and the height of the peaks. This is mainly due to the different location of the two instruments, which are located at a distance of 1 kilometer apart.

A number of known Z-R relationships are plotted against the data estimated by the disdrometer, as representatively shown in Fig. 6. The relationship for the specific event derived is $Z = 407R^{1.26}$, whereas for all events is $Z = 431R^{1.25}$. The Z-R relationships were derived, in order to be used for the conversion of radar reflectivities to rainfall rates (Brandes, 1974).

4 Conclusions and additional remarks

The conclusions arising from the research efforts presented in this report can be summarised as follows:

1. A Joss-type disdrometer has been installed and operated since November 1997 at the NTUA. Fourteen rainfall events have been recorded and analysed and the results were compared against the ones estimated by the NTUA station.

2. The previously mentioned hydrometeorological parameters were estimated based on the drop size distribution. Also different Z-R relationships were derived and compared with the one describing the disdrometer data for all rainfall events. The Joss-type distrometer already installed is planned to be operating in comparison with the WSR-74 C-band radar located in the mountain of Imitos.

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