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UNCERTAINTY ANALISYS OF DISDROMETER MODEL PARSIVEL^2 FOR RAINFALL AMOUNT

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Joint Research Report of INPE-CCST, INPE-CPTEC, UFSC-EMC-LEPTEN/LABSOLAR, IFSC-Florianópolis and UFSC-INE-LAPIX/INCOD

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HIDROCAM - Avaliador de hidrometeoros utilizando câmeras de alta velocidade na superficie, para validar imagens de RADAR meteorologico.

ANALISE DE INCERTEZAS DO DISDRÔMETRO MODELO PARSIVEL^2 PARA QUANTIDADE DE CHUVA

RESUMO

O presente trabalho descreve a análise de incertezas do disdrômetro PARSIVEL^2 instalado no Instituto Federal de Educação (IFSC) de Florianópolis SC, Brasil. Além de atender as normas ISO, a análise tem como objetivo realizar uma comparação estatística com um protótipo e uma metodologia ainda em desenvolvimento de um disdrômetro que utiliza câmera.

ABSTRACT

The present work describes the uncertainty analysis of a PARSIVEL^2 disdrometer deployed at Federal Educational Institute (IFSC) in Florianopolis SC Brazil. This analysis was performed in order to comply with ISO technical recommendations and also to made a statistical comparison with a camera based disdrometer (CD). The CD prototype is still under development and the disdrometer will be used for its validation.

LIST OF FIGURES

Pág.

LIST OF TABLES

Pág.

LIST OF ABBREVIATIONS

CCST	–	Earth Terrestrial Systems Center
IFSC	–	Federal Institute of Education
INPE	–	Brazilian Institute of Space Research
ISO	–	International Organization for Standardization
NASA	–	National Aeronautics and Space Administration
NIST	–	American National Standards Institute
SC	–	Santa Catarina State, Brazil
WMO	–	World Meteorological Organization

1 Introduction

The present work will make the uncertainty analysis of PARSIVEL^2 disdrometer. Equipment is deployed at Federal Educational Institute (IFSC) in Florianópolis SC Brazil (LAT = -27.593368, LONG = -48.541531), co-allocated to a standard meteorological station. A picture illustrating the deployment site could be observed on figure 1.1.

The objective of this study are to use disdrometer data to validate a camera-based disdrometer and made a preliminary study of radar precipitation data comparison. By the end of this work it will be obtained equations to evaluate sensor uncertainty for rainfall amount to made statistical validations of data.

Figure 1.1 - PARSIVEL^2 site overview.

2 Materials and Methods

2.1 Disdrometer Rain Amount Uncertainty Analysis

Uncertainty is an important analysis of measurement activity. Several standards like (NIST, 1994)[1], (ISO, 2010)[2], (NASA, 2010) and so on, have been defined to establish a common ground of mathematical and statistical concepts to be considered on that analysis. Current section will describe the *type b* uncertainty analysis according to (ISO, 2010), for rainfall amount and intensity used in the present work. The first step is the definition of measurement process. The rainfall amount estimated by measurement is described by equation 2.1. A typical result of one minute disdrometer data in a local rainfall event is illustrated on figure 2.1.

$$RR = 6\,\pi\,10^{-4} \int_{D\_min}^{D\_max} D^3\,\nu\,(D)\,N\,(D)\,dD \tag{2.1}$$

Where:

- RR: is the rainfall amount in mm,
- D: is the average class particle diameter in mm,
- $\nu\,(D)$: is the particle velocity as a function of average D class,
- $N\,(D)$: is the number of particles as a function of average D class,
- dD: is the width of diameter class as a function of D.

The rainfall amount is considered in the present work an indirect measurand, resultant of a *multivariate relationship* associated from different characteristics (CASTRUP, 2004). To estimate RR uncertainty it will be considered a discretized version as described on equation 2.2, and then a summation of classes according to data presented by PARSIVEL[2] manual (HYDROMET, 2011).

$$\begin{gathered} G = f\left(D_0, \nu\left(D_0\right), N\left(D_0\right), \delta\left(D_0\right)\right) \\ RR_0 = 6\,\pi\,10^{-4}\,D_0^3\,\nu\,(D_0)\,N\,(D_0)\,\delta\,(D_0) \end{gathered} \tag{2.2}$$

[1]NIST-American National Standards Institute
[2]ISO-International Organization for Standardization

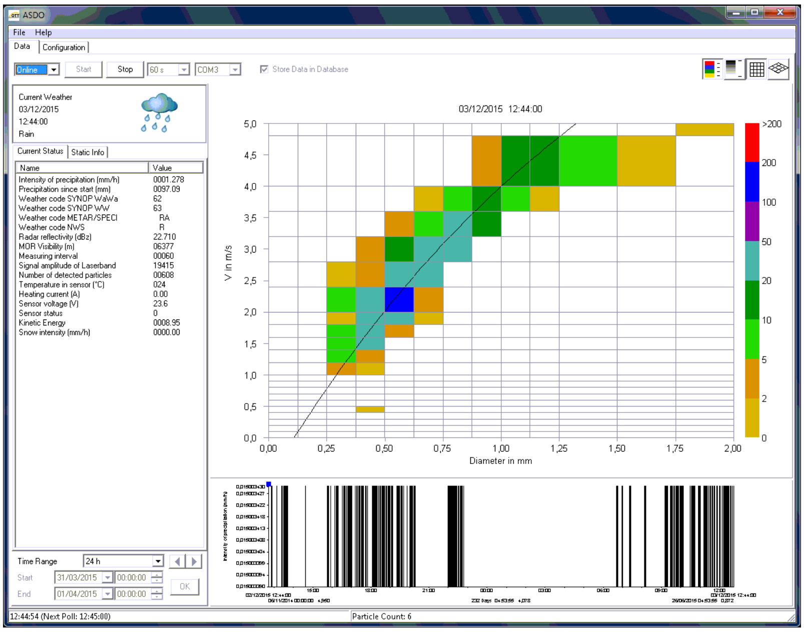

Figure 2.1 - Typical data sample obtained from PARSIVEL[2].

Where:

- f: is a derivable and continuous function relating G with input variables,
- G: is the combined mathematical relation to be determined by indirect measurement,
- RR_0: is the true or nominal rainfall amount,
- D_0: is the true or nominal class particle diameter in mm,
- $\nu(D_0)$: is the true or nominal particle velocity as a function of average D_0 class,
- $N(D_0)$: is the true or nominal number of particles as a function of average D_0 class,
- dD_0: is the true or nominal class spread as a function of D_0,

The analyses will be developed for one class as a generic case and then, will be extended to the other particle diameter classes. From that point of view we have two approaches. The first one is to determine the sources of errors and develop the expression described on equation 2.3 by expanding, multiplying, rearranging and simplifying the multivariate terms.

$$RR_0 + \epsilon_{RR} = 6\,\pi\,10^{-4}\left(D_0 + \epsilon_D\right)^3\left(\nu_0\left(D_0\right) + \epsilon_{\nu(D)}\right)\left(N\left(D_0\right) + \epsilon_{N(D)}\right)\left(dD_0 + \epsilon_{dD(D)}\right) \tag{2.3}$$

Where:

- ϵ_{RR}: is the estimation of error of RR,
- ϵ_D: is the estimation of error of D,
- $\epsilon_{\nu(D)}$: is the estimation of error of $\nu\left(D\right)$,
- $\epsilon_{N(D)}$: is the estimation of error of $N\left(D\right)$,
- $\epsilon_{dD(D)}$: is the estimation of error of $dD\left(D\right)$.

The second one is to use a general expression described on equation 2.4 (ALBERTAZZI; SOUZA, 2008, chap.7.4), that takes into account the correlation coefficient among the variables is known.

$$u^2\left(G\right) = \sum_{i=1}^{n}\left(\frac{\partial f}{\partial X_i}\right)^2 u^2\left(X_i\right) + 2\sum_{i=1}^{n-1}\sum_{j=i+1}^{n}\frac{\partial f}{\partial X_i}\frac{\partial f}{\partial X_j}u\left(X_i\right)u\left(X_j\right)r\left(X_i, X_j\right) \tag{2.4}$$

Where:

- $u^2\left(G\right)$: is the square of combined uncertainty to be determined,
- $\frac{\partial f}{\partial X_i}$: is the partial derivative of f related to input variables X_i, also known as sensitivity coefficient, associated to variables X_i,
- $u\left(X_i\right)$: is the standard uncertainty of i_{th} is the variable that is being combined,

- $r(X_i, X_j)$: is the estimated correlation coefficient between variables X_i and X_j.

The equation 2.2 partial derivatives relative to particle diameter, speed, number (or count) and class spread are determined respectively on equations 2.5, 2.6, 2.7 and 2.8.

$$\frac{\partial f}{\partial D} = 3D^2 \delta(D) \nu(D) N(D) \tag{2.5}$$

$$\frac{\partial f}{\partial \nu(D)} = D^3 N(D) \delta(D) \tag{2.6}$$

$$\frac{\partial f}{\partial N(D)} = D^3 \nu(D) \delta(D) \tag{2.7}$$

$$\frac{\partial f}{\partial \delta(D)} = D^3 \nu(D) N(D) \tag{2.8}$$

The partial derivatives are the sensitivity coefficients that determine the relative contribution of errors for rainfall amount. All input variables are aleatory because of the random errors associated to the measuring values. The combination of the four aleatory variables has to consider their statistical dependencies. D and ν have some physical dependency between then, according to the empirical relation obtained by (GUNN; KINZER, 1949). The other variables N and δ are related to the measuring process and presents no correlation among the other ones. From the general expression presented on equation 2.4 we substitute the variables for RR according to equation 2.9.

$$
\begin{aligned}
u^2(G) = &\left(\frac{\partial f}{\partial D}\right)^2 u^2(D) + \left(\frac{\partial f}{\partial \nu(D)}\right)^2 u^2\nu(D) + \left(\frac{\partial f}{\partial N(D)}\right)^2 u^2 N(D) \\
&+ \left(\frac{\partial f}{\partial \delta(D)}\right)^2 u^2\delta(D) \\
&+ 2\frac{\partial f}{\partial D}\frac{\partial f}{\partial \nu(D)} u(D)\, u(\nu(D))\, r(D, v) \\
&+ 2\frac{\partial f}{\partial D}\frac{\partial f}{\partial N(D)} u(D)\, u(N(D))\, r(D, N(D)) \\
&+ 2\frac{\partial f}{\partial D}\frac{\partial f}{\partial \delta(D)} u(D)\, u(\delta(D))\, r(D, \delta(D)) \\
&+ 2\frac{\partial f}{\partial \nu(D)}\frac{\partial f}{\partial N(D)} u(\nu(D))\, u(N(D))\, r(\nu(D), N(D)) \\
&+ 2\frac{\partial f}{\partial \nu(D)}\frac{\partial f}{\partial \delta(D)} u(\nu(D))\, u(\delta(D))\, r(\nu(D), \delta(D)) \\
&+ 2\frac{\partial f}{\partial N(D)}\frac{\partial f}{\partial \delta(D)} u(N(D))\, u(\delta(D))\, r(D, \delta(N(D)))
\end{aligned}
\tag{2.9}
$$

Where:

- $r(D, N(D)) = r(D, \delta(D)) = r(\nu(D), N(D)) = r(\nu(D), \delta(D)) = r(D, \delta(N(D))) = 0$, because the coefficient of correlation between these variables are zero.

After removing the zero coefficients of correlation from equation 2.9, we have the results on equation 2.10. It is important to notice that equation 2.10 could also be obtained from general expression described on equation 2.4 described by (ALBERTAZZI; SOUZA, 2008, chap.7.4).

$$u^2(G) = \left(\frac{\partial f}{\partial D}\right)^2 u^2(D) + \left(\frac{\partial f}{\partial \nu(D)}\right)^2 u^2 \nu(D) + \left(\frac{\partial f}{\partial N(D)}\right)^2 u^2 N(D)$$
$$+ \left(\frac{\partial f}{\partial \delta(D)}\right)^2 u^2 \delta(D) + 2\frac{\partial f}{\partial D}\frac{\partial f}{\partial \nu(D)} u(D)\, u(\nu(D))\, r(D, v) \quad (2.10)$$

The correlation coefficients $r(D, v)$ are determined empirically. A detailed description of output data is described on table 2.1. It is important to notice that particle velocity is obtained by empirical relation obtained by (GUNN; KINZER, 1949) on equation 2.11 also used by PARSIVEL^2 whose graph is illustrated on figure 2.2. That approach is considered satisfactory for the present case use. As could be noticed, $\nu(D)$ is considered highly correlated to particle diameter.

$$\nu(D) = 9.65 - 10.3\, e^{-0.6D} \quad (2.11)$$

Calculate $r(D, \nu(D))$ from equation 2.11 is a coarse approximation. The estimation of $r(D, \nu(D))$ will be obtained from average particle diameter and speed described on table 2.1. To improve the results, it was obtained four different $r(D, \nu(D))$ from average D and $\nu(D)$ values, for every one of four distinct uncertainties described on table 2.1 as follows.

- classes 1 to 10 $r_{1-10}(D, \nu) = 0.996$
- classes 11 to 15 $r_{11-15}(D, \nu) = 0.996$
- classes 16 to 20 $r_{16-20}(D, \nu) = 0.985$
- classes 21 to 25$r_{21-25}(D, \nu) = 0.947$
- classes 26 to 30 $r_{26-30}(D, \nu) = 0.734$
- classes 31 to 32 $r_{31-32}(D, \nu) = 0.734$

The PARSIVEL^2 presents a partial correlation for classes 26 to 32, and should be properly considered on that equation. Solid precipitation has partial correlation too

$r_{31-32}(D,\nu) = 0.734$. Replacing the partial derivatives determined on equations 2.5, 2.6, 2.7 and 2.8 and $r(D,\nu(D))$ leads to equation 2.12.

$$\begin{aligned} u^2(G) = {} & \left(3\,D^2\nu(D)\,N(D)\,\delta(D)\right)^2 u^2(D) + \left(D^6 N(D)\,\delta(D)\right)^2 u^2\nu(D) \\ & + \left(D^3\nu(D)\,\delta(D)\right)^2 u^2 N(D) + \left(D^3\nu(D)\,N(D)\right)^2 u^2\delta(D) \\ & + 2\left[3\,D^2\nu(D)\,N(D)\,\delta(D)\right]\left[D^3 N(D)\,\delta(D)\right] u(D)\,u\nu(D)\,r_n(D,v) \end{aligned} \tag{2.12}$$

Simplifying equation 2.12 results into equation 2.13, that should be used to determine the standard uncertainty for every class, using the coefficients presented on table 2.1.

$$\begin{aligned} u^2(G) = {} & 9\,D^4\nu(D)^2 N(D)^2\delta(D)^2 u^2(D) + D^6 N(D)^2\delta(D)^2 u^2\nu(D) \\ & + D^6\nu(D)^2\delta(D)^2 u^2 N(D) + D^6\nu(D)^2 N(D)^2 u^2\delta(D) \\ & + 6\,D^5\nu(D)\,N(D)^2\delta(D)^2 u(D)\,u\nu(D)\,r_n(D,v) \end{aligned} \tag{2.13}$$

After obtaining the uncertainty for every class they have to be summed again to determine the overall uncertainty of rainfall amount by the final expression described on equation 2.14.

$$\begin{aligned} u^2(G) = {} & 6\,\pi\,10^{-4}\sum_{i=1}^{32}\sum_{j=1}^{32}\sum_{n=1}^{32} 9\,{D_i}^4\nu_j(D_i)^2 N_{i,j}(D_i)^2\delta_i(D_i)^2\,u_n^2(D_i) \\ & + {D_i}^6 N_{i,j}(D_i)^2\delta_i(D_i)^2\,u_n^2\nu_j(D_i) \\ & + {D_i}^6\nu_j(D_i)^2\delta_i(D_i)^2\,u_j^2 N_{i,j}(D_i) + {D_i}^6\nu_j(D_i)^2 N_{i,j}(D_i)^2\,u_n^2\delta(D_i) \\ & + 6\,{D_i}^5\nu_j(D_i)\,N_{i,j}(D_i)^2\delta_i(D_i)^2\,u_n(D_i)\,u_n\nu_j(D_i)\,r_n(D_i,v_i) \end{aligned} \tag{2.14}$$

Where:

- i: is the number of D classes
- j: is the number of $\nu(D)$ classes
- n: is the number of the uncertainty of grouped category considered

The uncertainty values presented on table 2.1 are considered expanded uncertainties $U(X)$. To obtain the standard uncertainties $u(X)$ it is necessary to divide the expanded uncertainty by t-Student coefficient $t_{\alpha,\nu}$ according to the confidence level and the number of degrees of freedom. When there is neither information about the number of degrees of freedom nor its error distribution, they are considered to be infinite, with normal distribution and $t_{\alpha,\nu} = 2$. Using data from table 2.1, the standard uncertainty for diameter $u_n(D)$ is obtained as follows.

- classes 1 to 10 $u_{1-10}(D) = \dfrac{U_{1-10}(D)}{t_{0.95,\infty}} = \dfrac{0.075}{2} = 0.0375$
- classes 11 to 15 $u_{11-15}(D) = \dfrac{U_{11-15}(D)}{t_{0.95,\infty}} = \dfrac{0.125}{2} = 0.075$
- classes 16 to 20 $u_{16-20}(D) = \dfrac{U_{16-20}(D)}{t_{0.95,\infty}} = \dfrac{0.25}{2} = 0.125$
- classes 21 to 25 $u_{21-25}(D) = \dfrac{U_{21-25}(D)}{t_{0.95,\infty}} = \dfrac{0.5}{2} = 0.25$
- classes 26 to 30 $u_{26-30}(D) = \dfrac{U_{26-30}(D)}{t_{0.95,\infty}} = \dfrac{1}{2} = 0.5$
- classes 31 to 32 $u_{31-32}(D) = \dfrac{U_{31-32}(D)}{t_{0.95,\infty}} = \dfrac{1.5}{2} = 0.75$

The standard uncertainty for particle velocity $u_n\nu(D)$ is obtained as follows.

- classes 1 to 10 $u_{1-10}\nu(D) = \dfrac{U_{1-10}\nu(D)}{t_{0.95,\infty}} = \dfrac{0.1}{2} = 0.05$
- classes 11 to 15 $u_{11-15}\nu(D) = \dfrac{U_{11-15}\nu(D)}{t_{0.95,\infty}} = \dfrac{0.2}{2} = 0.1$
- classes 16 to 20 $u_{16-20}\nu(D) = \dfrac{U_{16-20}\nu(D)}{t_{0.95,\infty}}) = \dfrac{0.4}{2} = 0.2$
- classes 21 to 25 $u_{21-25}\nu(D) = \dfrac{U_{21-25}\nu(D)}{t_{0.95,\infty}} = \dfrac{0.8}{2} = 0.4$
- classes 26 to 30 $u_{26-30}\nu(D) = \dfrac{U_{26-30}\nu(D)}{t_{0.95,\infty}} = \dfrac{1.6}{2} = 0.8$
- classes 21 to 32 $u_{31-32}\nu(D) = \dfrac{U_{31-32}\nu(D)}{t_{0.95,\infty}} = \dfrac{3.2}{2} = 1.6$

Table 2.1 - Particle classes for speed, velocity and derived uncertainty and correlation coefficients.

	Diameter [mm]				velocity [m/s]				
Class	Min-max	average	spread	uncert.	Min-max	average	spread	uncert.	r(D,v)
1	0.0005-0.1245	0.062	0.125	± 0.075	0.000-0.150	0.050	0.100	± 0.050	0.996
2	0.1245-0.2495	0.187	0.125	± 0.075	0.100-0.200	0.150	0.100	± 0.050	
3	0.2495-0.3745	0.312	0.125	± 0.075	0.200-0.300	0.250	0.100	± 0.050	
4	0.3745-0.4995	0.437	0.125	± 0.075	0.300-0.400	0.350	0.100	± 0.050	
5	0.4995-0.6245	0.562	0.125	± 0.075	0.400-0.500	0.450	0.100	± 0.050	
6	0.6245-0.7495	0.687	0.125	± 0.075	0.500-0.600	0.550	0.100	± 0.050	
7	0.7495-0.8745	0.812	0.125	± 0.075	0.600-0.700	0.650	0.100	± 0.050	
8	0.8745-0.9995	0.937	0.125	± 0.075	0.700-0.800	0.750	0.100	± 0.050	
9	0.9995-1.1245	1.062	0.125	± 0.075	0.800-0.900	0.850	0.100	± 0.050	
10	1.1245-1.2495	1.187	0.125	± 0.075	0.900-1.000	0.950	0.100	± 0.050	
11	1.2500-1.5000	1.375	0.25	± 0.125	1.000-1.200	1.100	0.200	± 0.100	
12	1.5000-1.7500	1.625	0.25	± 0.125	1.200-1.400	1.300	0.200	± 0.100	
13	1.7500-2.0000	1.875	0.25	± 0.125	1.400-1.600	1.500	0.200	± 0.100	
14	2.0000-2.2500	2.125	0.25	± 0.125	1.600-1.800	1.700	0.200	± 0.100	
15	2.2500-2.5000	2.375	0.25	± 0.125	1.800-2.000	1.900	0.200	± 0.100	
16	2.5000-3.0000	2.75	0.5	± 0.25	2.000-2.400	2.200	0.400	± 0.200	0.985
17	3.0000-3.5000	3.25	0.5	± 0.25	2.400-2.800	2.600	0.400	± 0.200	
18	3.5000-4.0000	3.75	0.5	± 0.25	2.800-3.200	3.000	0.400	± 0.200	
19	4.0000-4.5000	4.25	0.5	± 0.25	3.200-3.600	3.400	0.400	± 0.200	
20	4.5000-5.0000	4.75	0.5	± 0.25	3.600-4.000	3.800	0.400	± 0.200	
21	5.0000-6.0000	5.5	1	± 0.5	4.000-4.600	4.400	0.800	± 0.400	0.947
22	6.0000-7.0000	6.5	1	± 0.5	4.600-5.600	5.200	0.800	± 0.400	
23	7.0000-8.0000	7.5	1	± 0.5	5.600-6.400	6.000	0.800	± 0.400	
24	8.0000-9.0000	8.5	1	± 0.5	6.400-7.200	6.800	0.800	± 0.400	
25	9.0000-10.0000	9.5	1	± 0.5	7.200-8.000	7.600	0.800	± 0.400	
26	10.0000-12.0000	11	2	± 1	8.000-9.600	8.800	1.600	± 0.800	0.734
27	12.0000-14.0000	13	2	± 1	9.600-11.200	10.400	1.600	± 0.800	
28	14.0000-16.0000	15	2	± 1	11.200-12.800	12.000	1.600	± 0.800	
29	16.0000-18.0000	17	2	± 1	12.800-14.400	13.600	1.600	± 0.800	
30	18.0000-20.0000	19	2	± 1	14.400-16.000	15.200	1.600	± 0.800	
31	20.0000-23.0000	21.5	3	± 1.5	16.000-19.200	17.600	3.200	± 1.600	
32	23.0000-26.0000	24.5	3	± 1.5	19.200-22.400	20.800	3.200	± 1.600	

(a) SOURCE: PARSIVEL^2 manual pages.
(b) The authors grouped classes 26 to 32 to calculate $r(D, v)$ because they are all solid particles whose speed varies around 1%, as illustrated on figure 2.2.

The standard uncertainty for class spread $\delta(D)$ is the half of resolution of spread divided by $t_{0.95,\infty} = 2$ because its error distribution is considered normal with infinite degrees of freedom, and determined as follows.

- classes 1 to 10 $u_{1-10}(D) = \dfrac{U_{1-10}\delta(D)}{t_{0.95,\infty}} = \dfrac{0.075}{2} = 0.0375$

- classes 11 to 15 $u_{11-15}(D) = \frac{U_{11-15}\delta(D)}{t_{0.95,\infty}} = \frac{0.125}{2} = 0.075$
- classes 16 to 20 $u_{16-20}(D) = \frac{U_{16-20}\delta(D)}{t_{0.95,\infty}} = \frac{0.25}{2} = 0.125$
- classes 21 to 25 $u_{21-25}(D) = \frac{U_{21-25}\delta(D)}{t_{0.95,\infty}} = \frac{0.5}{2} = 0.25$
- classes 26 to 30 $u_{26-30}(D) = \frac{U_{26-30}\delta(D)}{t_{0.95,\infty}} = \frac{1}{2} = 0.5$
- classes 31 to 32 $u_{31-32}(D) = \frac{U_{31-32}\delta(D)}{t_{0.95,\infty}} = \frac{1.5}{2} = 0.75$

The standard uncertainty for number of particles $u_n N\,(D)$ is the half of resolution (or digital increment $= 0.5$) divided by $\sqrt{3}$, because its error distribution is considered uniform as described on equation 2.15.

$$u_n N\,(D) = \frac{0.5}{\sqrt{3}} = 1.1547 \qquad (2.15)$$

All uncertainties where placed in a table 2.2, to make easier implement RR using equation 2.14.

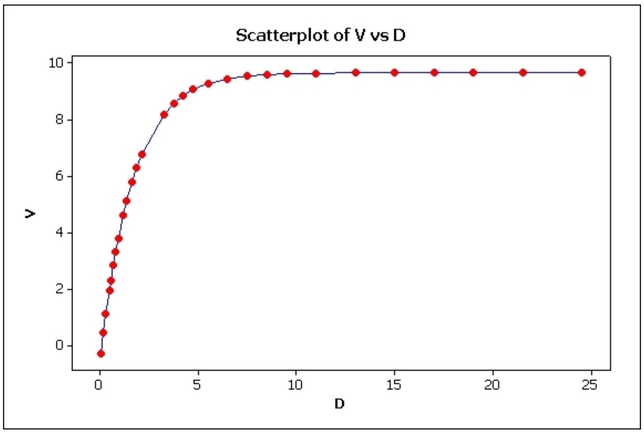

Figure 2.2 - Speed and velocity data used to derive the correlation coefficients.

From PARSIVEL^2 manual it was obtained the following technical data.

Table 2.2 - Squared standard errors determined for RR for particle diameter, velocity, spread and correlation coefficients.

Class	D	$u^2(D)$	$\nu(D)$	$u^2\nu(D)$	$\delta(D)$	$u^2\delta(D)$	r(D,v)
1	0.062	0.0375	0.050	0.050	0.125	0.0375	0.996
2	0.187	0.0375	0.150	0.050	0.125	0.0375	0.996
3	0.312	0.0375	0.250	0.050	0.125	0.0375	0.996
4	0.437	0.0375	0.350	0.050	0.125	0.0375	0.996
5	0.562	0.0375	0.450	0.050	0.125	0.0375	0.996
6	0.687	0.0375	0.550	0.050	0.125	0.0375	0.996
7	0.812	0.0375	0.650	0.050	0.125	0.0375	0.996
8	0.937	0.0375	0.750	0.050	0.125	0.0375	0.996
9	1.062	0.0375	0.850	0.050	0.125	0.0375	0.996
10	1.187	0.0375	0.950	0.050	0.125	0.0375	0.996
11	1.375	0.0750	1.100	0.100	0.250	0.0750	0.996
12	1.625	0.0750	1.300	0.100	0.250	0.0750	0.996
13	1.875	0.0750	1.500	0.100	0.250	0.0750	0.996
14	2.125	0.0750	1.700	0.100	0.250	0.0750	0.996
15	2.375	0.0750	1.900	0.100	0.250	0.0750	0.996
16	2.75	0.125	2.200	0.200	0.500	0.125	0.985
17	3.25	0.125	2.600	0.200	0.500	0.125	0.985
18	3.75	0.125	3.000	0.200	0.500	0.125	0.985
19	4.25	0.125	3.400	0.200	0.500	0.125	0.985
20	4.75	0.125	3.800	0.200	0.500	0.125	0.985
21	5.5	0.250	4.400	0.400	1	0.250	0.947
22	6.5	0.250	5.200	0.400	1	0.250	0.947
23	7.5	0.250	6.000	0.400	1	0.250	0.947
24	8.5	0.250	6.800	0.400	1	0.250	0.947
25	9.5	0.250	7.600	0.400	1	0.250	0.947
26	11	0.500	8.800	0.800	2	0.500	0.734
27	13	0.500	10.400	0.800	2	0.500	0.734
28	15	0.500	12.000	0.800	2	0.500	0.734
29	17	0.500	13.600	0.800	2	0.500	0.734
30	19	0.500	15.200	0.800	2	0.500	0.734
31	21.5	1	17.600	1.6	3	1	0.734
32	24.5	1	20.800	1.6	3	1	0.734

- Particle size measuring range for liquid precipitation $0.2 \ldots 5\,mm$.
- Particle size measuring range for solid precipitation $0.2 \ldots 25\,mm$.
- Particle speed measuring range for solid precipitation $0.2 \ldots 20\,m/s$.
- Accuracy of liquid precipitation $\pm 5\,\%$ (it will be considered the repetitive-

ness with infinity degrees of freedom).

- Accuracy of solid precipitation $\pm 20\,\%$ (it will be considered the repetitiveness with infinity degrees of freedom).

The particle diameter D and speed $\nu\left(D\right)$ are described in $32 \times 32 = 1024$ different classes, each one with an average occurrence and class spread. The amount of particles on every class is obtained by $\left[D, \nu\left(D\right)\right]$ index.

2.2 Conclusions

The mathematical relationships necessary for evaluation of rainfall amount uncertainty were developed during this work. The results comply with ISO, WMO, ABNT, etc. recommended *type b* uncertainty assessments. The next steps of current research will be to apply the developed equations on data monitored to aggregate *type a* allowing further comparisons and evaluation of precipitation forecasting in the Florianópolis region.

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