École des Pontes ParisTech

Cours Mesures Environnementales :

Disdromètres et mesure de pluie

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Chair "Hydrology for Resilient Cities"
(*sponsored by Veolia*)

(EU Climate KIC)

(*EU INTER-REG NWE*)

Ecole des Ponts ParisTech, 18 mars / 6 mai 2015

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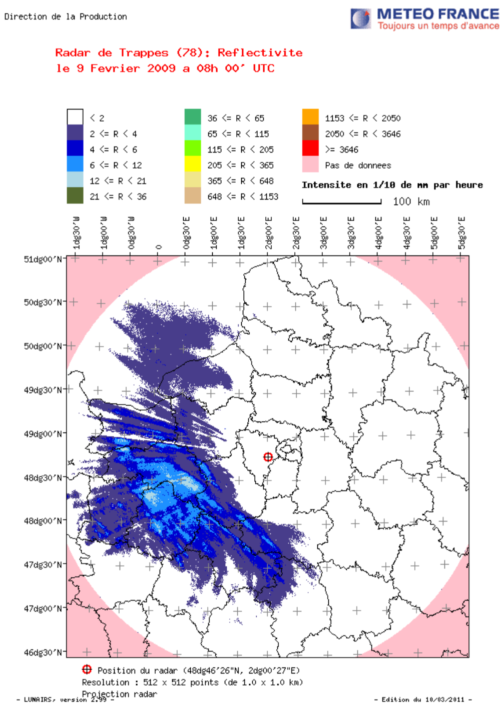
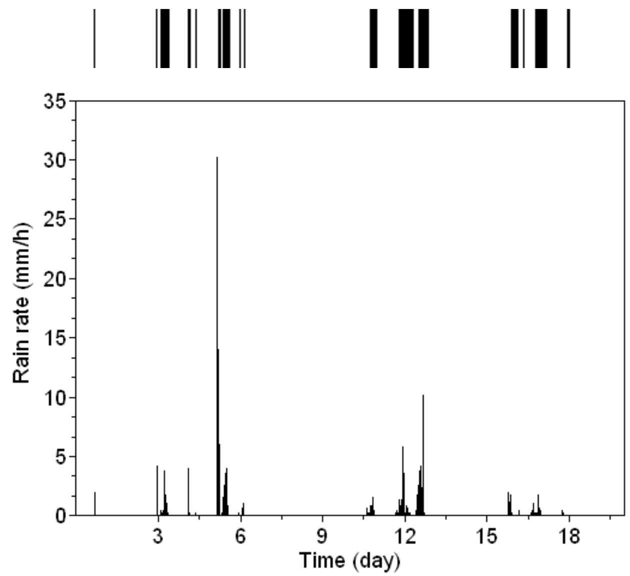
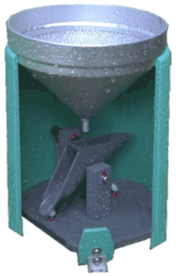

Direction de la Production
METEO FRANCE
Toujours un temps d'avance
Radar de Trappes (78): Reflectivite
le 9 Fevrier 2009 a 08h 00' UTC
< 2
2 <= R < 4
4 <= R < 6
6 <= R < 12
12 <= R < 21
21 <= R < 36
36 <= R < 65
65 <= R < 115
115 <= R < 205
205 <= R < 365
365 <= R < 648
648 <= R < 1153
1153 <= R < 2050
2050 <= R < 3646
>= 3646
Pas de donnees
Intensite en 1/10 de mm par heure
100 km
Position du radar (48dg46'26"N, 2dg00'27"E)
Resolution : 512 x 512 points (de 1.0 x 1.0 km)
Projection radar


Rain rate (mm/h)
Time (day)

How to measure rainfall ?

(+ a need to dvp a theoretical representation at the same time !)

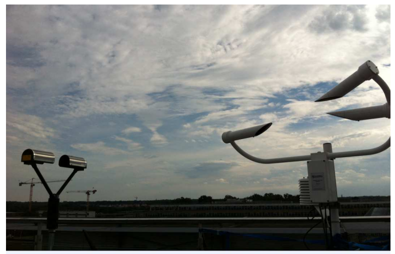
Rain gauge



Weather radars

Disdrometers

1D



2D

3D

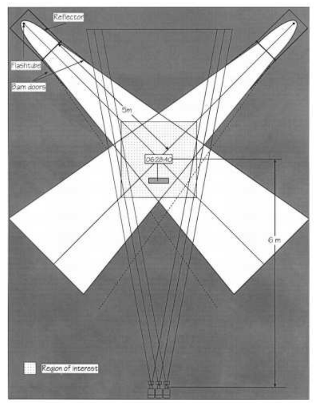


Fig. 1. Geometry of the different optical elements.

(From operational to research tools)

Outline

How do they work ?

PWS100 (Campbell Scientific)
Parsivel^2 (OTT)

What do they measure and how to relate it to relevant physical quantities?

Data analysis

Examples of applications

Example of optical limitations
Small scale rainfall variability
Retrieving radar properties

PWS 100 (Campbell Scientific)

Hardware configuration

Estimation of *v* and *d* for a liquid hydrometeor

Estimation of v and *d* for a solid hydrometeor

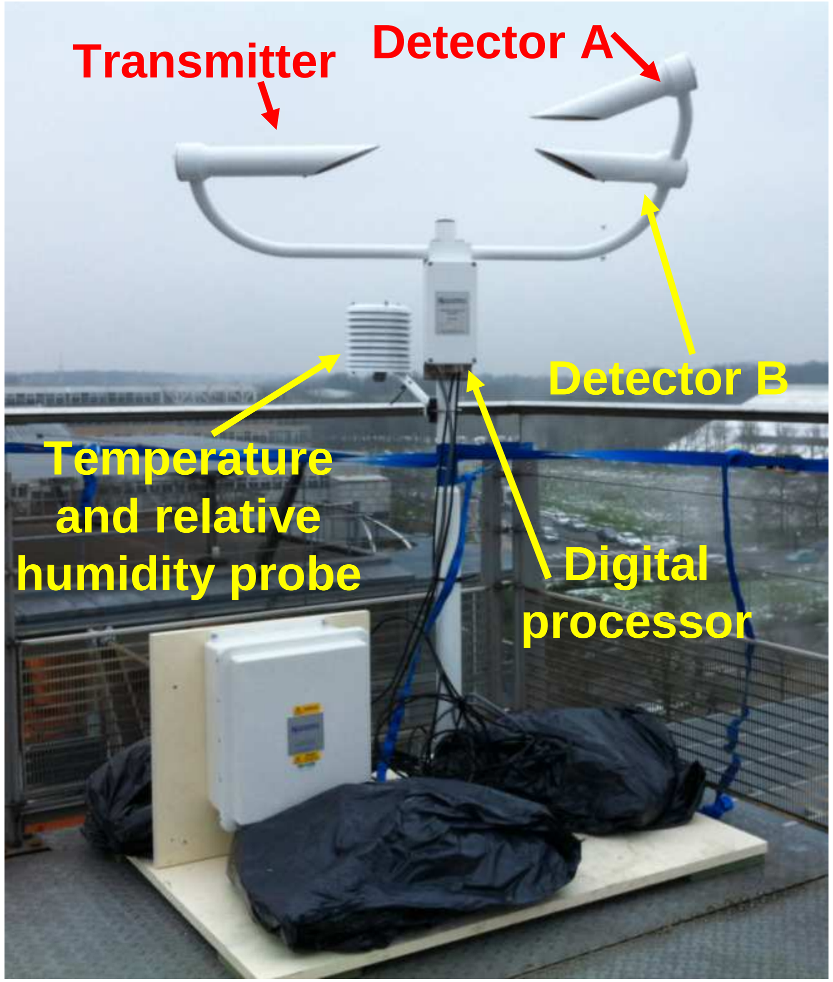
Distribution of size and velocity

Particle classification

References:

- PWS100 User's manual
- PWS100 Leaflet (http://www.campbellsci.co.uk)
- Ellis R A et al, 2006, New Laser Technology to Determine Present Weather Parameters, Meas. Sci. Technol., 17 1715-1722

Hardware configuration



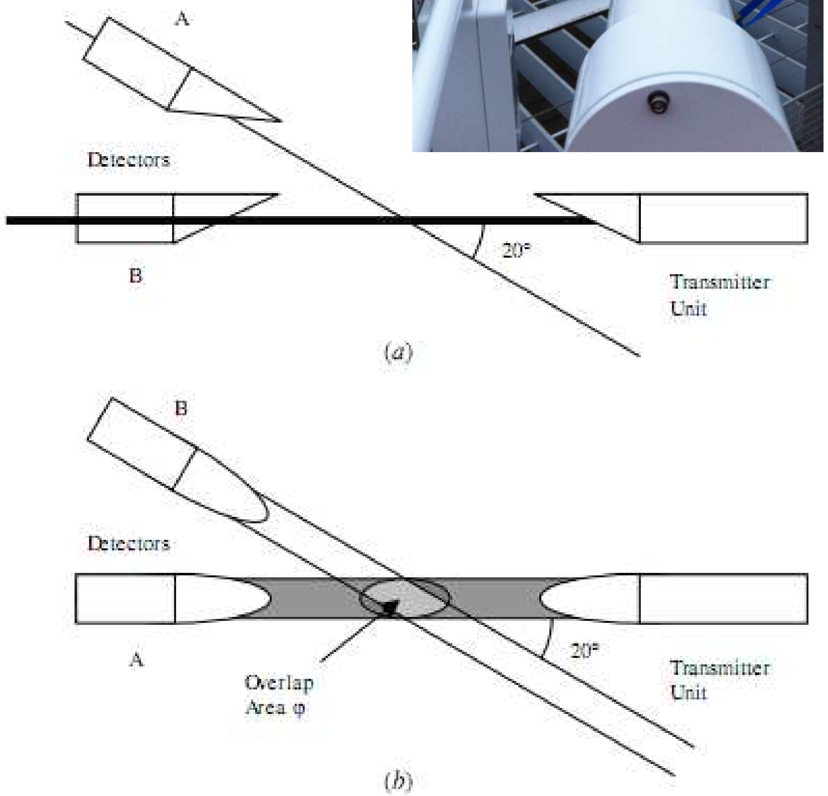
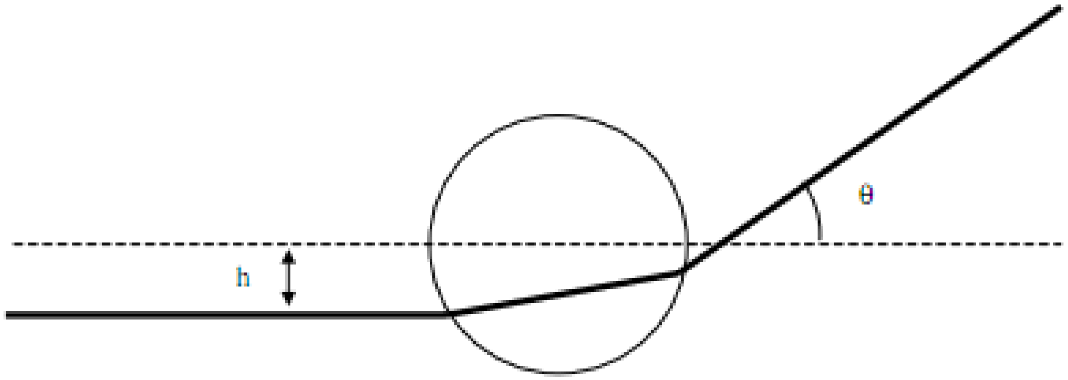


Figure 2. Transmitter and detector arrangement in (*a*) side view and (*b*) plan view.

Estimation of *v* and *d* for a liquid hydrometeor

Time delay between the two detectors

Refraction through a spherical drop :



$$h = \frac{rn\sin(\theta/2)}{\sqrt{1+n^2-2n\cos(\theta/2)}}$$

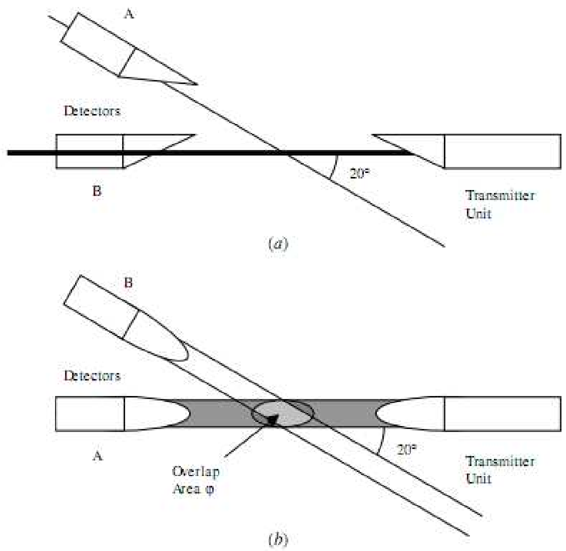


Figure 2. Transmitter and detector arrangement in (*a*) side view and (*b*) plan view.

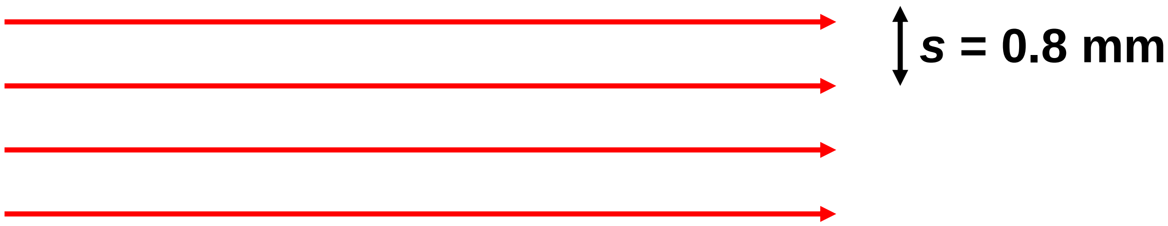
The signal reaches detector A slightly before detector B :

$$\Delta t_{AB} = \frac{h}{v}$$

Estimation of *v* and *d* for a liquid hydrometeor

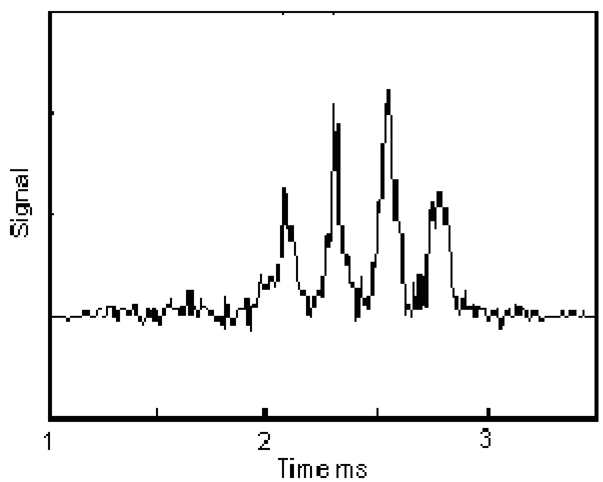
Periodic signal

Laser beam made of 4 sheets :



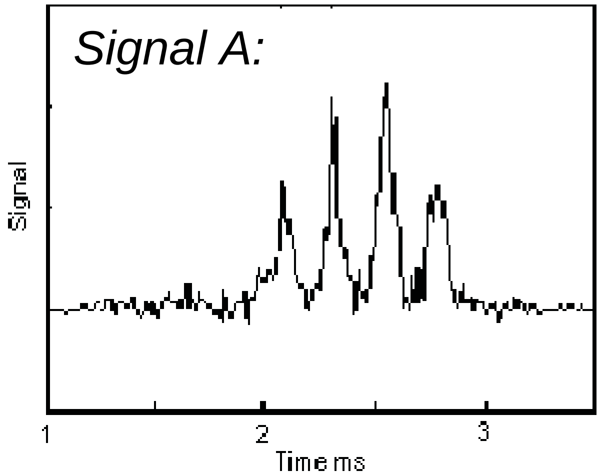
Periodic signal
($\Delta t_A = \Delta t_B$) received by
both detectors

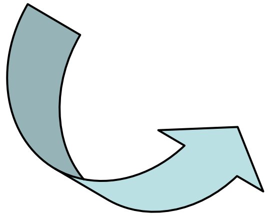
$$v = \frac{s}{\Delta t_A} = \frac{s}{\Delta t_B}$$



Estimation of *v* and *d* for a liquid hydrometeor

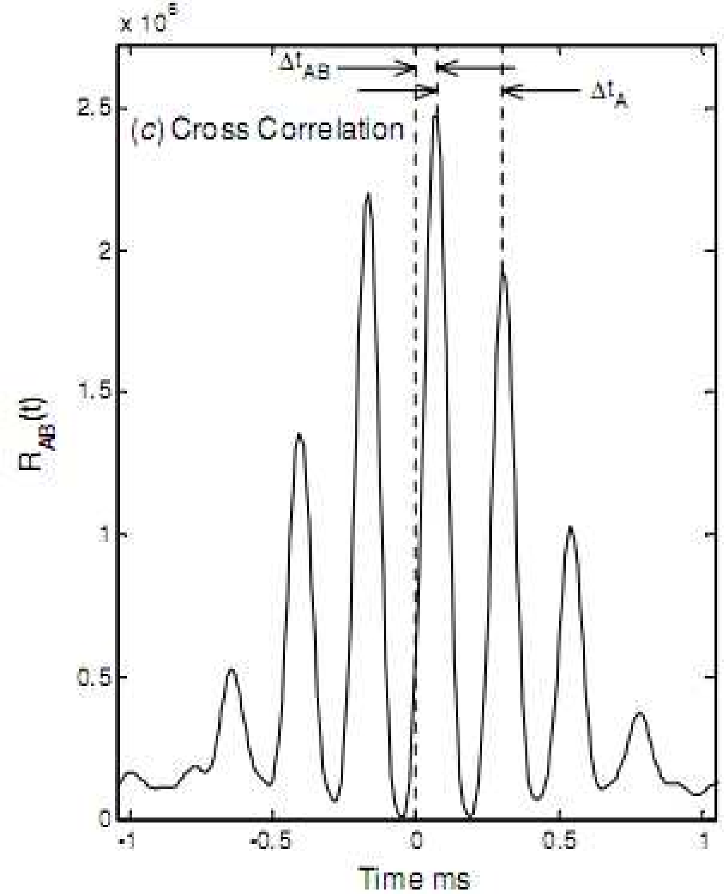
Estimation of $\Delta t_A = \Delta t_B$ and Δt_{AB}





Cross correlation:

$$R_{AB}(t) = \int_{-\infty}^{+\infty} I_A(\varepsilon) I_B(\varepsilon - t)\, d\varepsilon$$



$$d_p = \frac{2s\Delta t_{AB}\sqrt{1+n^2-2n\cos(\theta_D/2)}}{\Delta t_A n \sin(\theta_D/2)}$$

$$v = \frac{s}{\Delta t_A} = \frac{s}{\Delta t_B}$$

Estimation of *v* and *d* for a liquid hydrometeor

What about non-spherical drops ?

The authors (Ellis et al., 2006) of the paper basically assume that it is a good approximation to interpret the measured diameter as the equivalent diameter of a spherical particle. I will simply quote their justification:

"It is noted that as the drop becomes more oblate (they discuss a classical formula for shapes by Beard and Chuang, 1987) the optical power of the surfaces becomes greater but their separation also increases and this reduces the total power of the lens. For small deviations from spherical these two effects almost compensate for each other."

Distribution of size and velocity

34 classes of size

Particle diameter class		
Class	Diameter [mm]	Class width [mm]
1	=>0.00	0.1
2	=>0.10	0.1
3	=>0.20	0.1
4	=>0.30	0.1
5	=>0.40	0.1
6	=>0.50	0.1
7	=>0.60	0.1
8	=>0.70	0.1
9	=>0.80	0.1
10	=>0.90	0.1
11	=>1.00	0.2
12	=>1.20	0.2
13	=>1.40	0.2
14	=>1.60	0.2
15	=>1.80	0.2
16	=>2.00	0.4
17	=>2.40	0.4
18	=>2.80	0.4
19	=>3.20	0.4
20	=>3.60	0.4
21	=>4.00	0.8
22	=>4.80	0.8
23	=>5.60	0.8
24	=>6.40	0.8
25	=>7.20	0.8
26	=>8.00	1.6
27	=>9.60	1.6
28	=>11.20	1.6
29	=>12.80	1.6
30	=>14.40	1.6
31	=>16.00	3.2
32	=>19.20	3.2
33	=>22.40	3.2
34	=>25.60	74.4

34 classes of velocity

Particle speed class		
Class	Speed [m/s]	Class width [m/s]
1	=>0.00	0.1
2	=>0.10	0.1
3	=>0.20	0.1
4	=>0.30	0.1
5	=>0.40	0.1
6	=>0.50	0.1
7	=>0.60	0.1
8	=>0.70	0.1
9	=>0.80	0.1
10	=>0.90	0.1
11	=>1.00	0.2
12	=>1.20	0.2
13	=>1.40	0.2
14	=>1.60	0.2
15	=>1.80	0.2
16	=>2.00	0.4
17	=>2.40	0.4
18	=>2.80	0.4
19	=>3.20	0.4
20	=>3.60	0.4
21	=>4.00	0.8
22	=>4.80	0.8
23	=>5.60	0.8
24	=>6.40	0.8
25	=>7.20	0.8
26	=>8.00	1.6
27	=>9.60	1.6
28	=>11.20	1.6
29	=>12.80	1.6
30	=>14.40	1.6
31	=>16.00	3.2
32	=>19.20	3.2
33	=>22.40	3.2
34	=>25.60	74.4

At each time step : a 34 x 34 matrix with the number or particles for each class

Particle classification

The parameters used in the analysis are:

- Size
- Velocity
- Ratio of signal peak height to signal pedestal height
- Temperature
- Relative humidity
- Wet bulb temperature

Nine possible types:

- Drizzle
- Freezing
- Drizzle,
- Rain,
- Freezing rain,
- Snow grains,
- Snowflakes,
- Ice pellets,
- Hail
- Graupel

Fuzzy logic algorithm:

$$S_t = \prod_p S_{p,t}$$

Score for given particle type (t)

Score for each parameter (p) for a particle type (t) (from reference tables)

When a particle is detected:
- The parameters are estimated
- S_t is computed for each type
- The particle is affected the type for which it has the greatest score

Parsivel^2 (OTT)

Hardware configuration

Estimation of *v* and *d* for a liquid hydrometeor

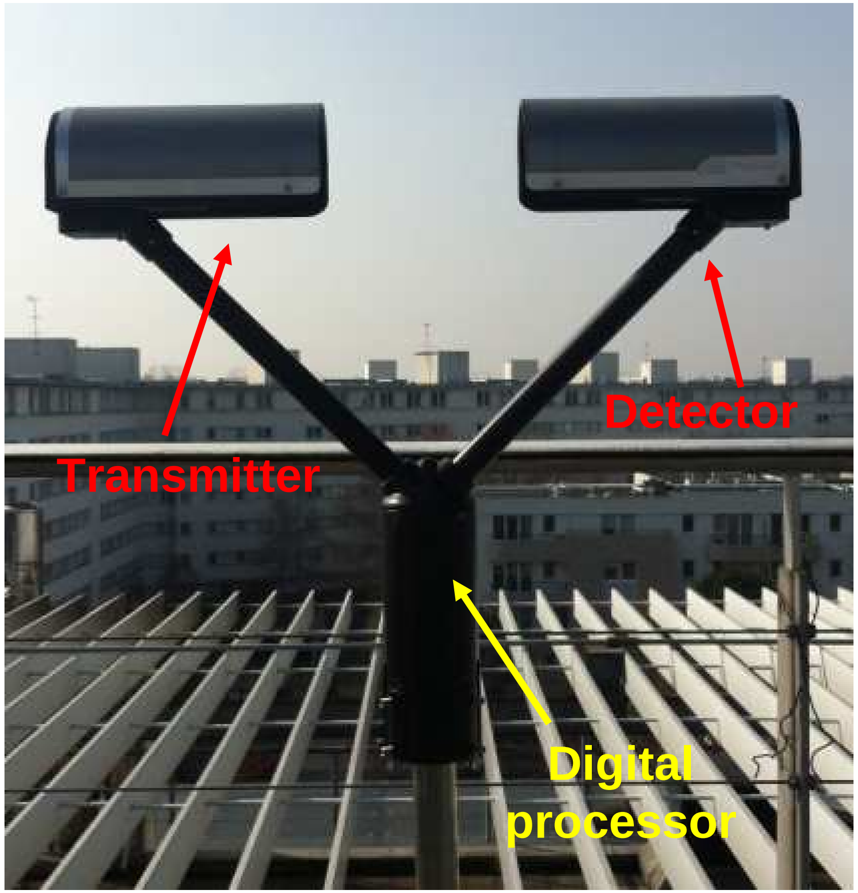
Distribution of size and velocity

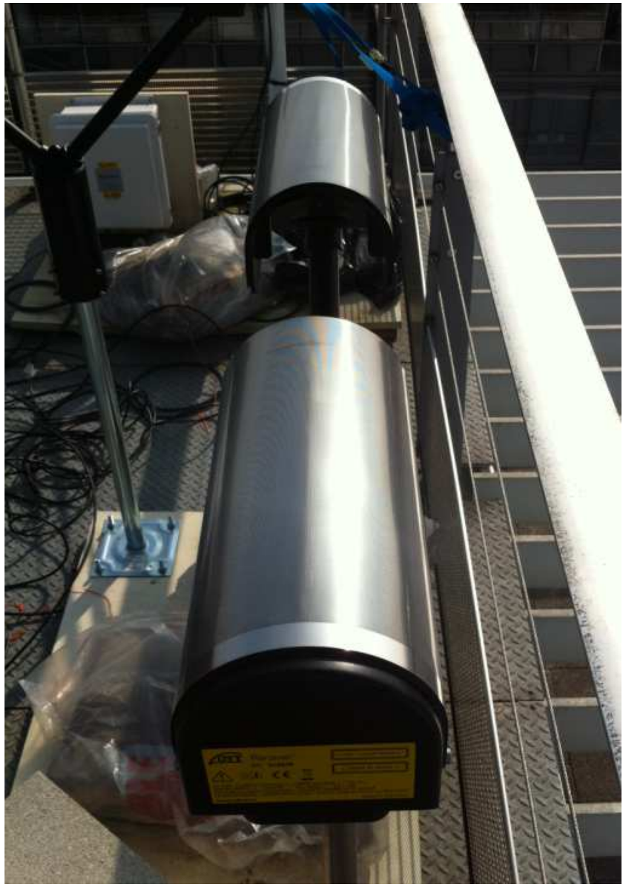
Particle classification (same principle as PWS100)

References:

- Parsivel2 User's manual
- Loffler-Mang, M. and J. Joss, *An Optical Disdrometer for Measuring Size and Velocity of Hydrometeors.* Journal of Atmospheric and Oceanic Technology, 2000. **17**(2): p. 130-139.
- Battaglia, A., et al., *PARSIVEL Snow Observations: A Critical Assessment.* Journal of Atmospheric and Oceanic Technology, 2010. **27**(2): p. 333-344.PWS100

Hardware configuration





Estimation of *v* and *d* for a liquid hydrometeor

Received signal

Hydrometeor falls through the sampling area :

→ Laser beam partially occluded

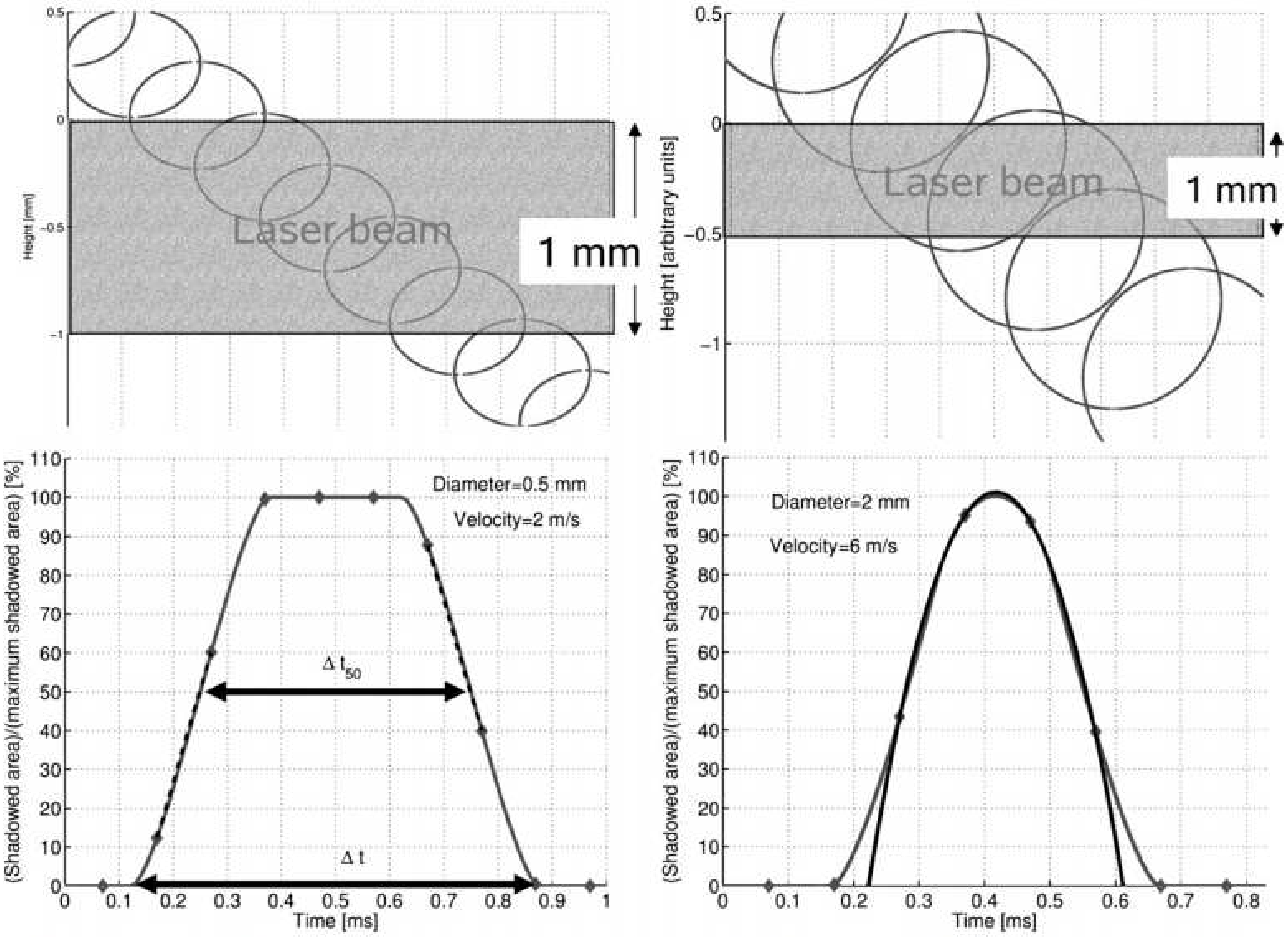


FIG. 2. Schematic diagram showing the influence of the size and of the velocity of two particles passing through the PARSIVEL beam on the output voltage. The diamonds represent the discrete PARSIVEL 10-kHz samples; continuous lines indicate the effective continuous signal produced by the particle dimming, normalized to its peak value F_{max}. (left) A 0.5-mm-diameter sphere (the small deformation is due to graphical problems) falling at 2 m s^{-1}. The dashed line is shown to exemplify the technique adopted to compute Δt_{50} (by linear interpolation). (right) A 2-mm-diameter sphere falling at 6 m s^{-1}. The black continuous line is shown to exemplify the technique adopted to estimate the maximum signal (by parabolic interpolation).

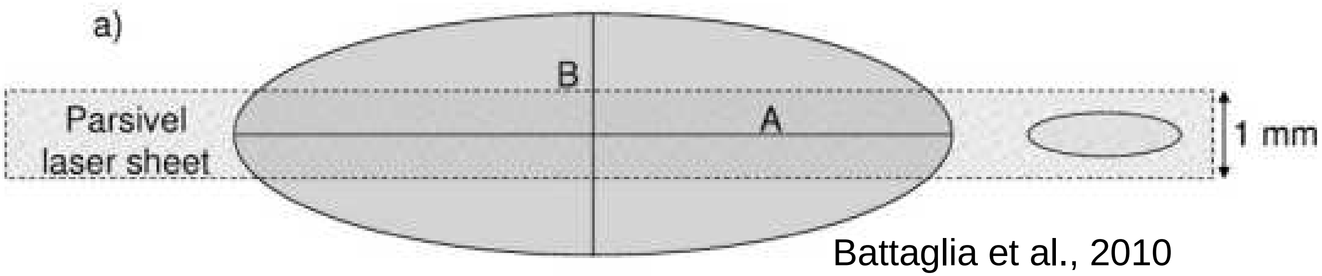
Warning : actually discrete measures !

Battaglia et al., 2010

Estimation of *v* and *d* for a liquid hydrometeor

Assumptions on the oblateness of falling rain drops

Horizontally oriented oblate spheroid



Battaglia et al., 2010

Axis ratio :

$$a_r^{PAR} = \frac{B}{A}$$

Equivolumic diameter : D_{eq}^{PAR}

$$Vol = \frac{4}{3}\pi A^2 B = \frac{\pi}{6}\left(D_{eq}^{PAR}\right)^3$$

Relation between axis ratio and equivolumic diameter:

→ All geometrical features related to D_{eq}^{PAR}

Axis ratio model for Parsivel:

$$a_r^{PAR} = \begin{cases} 1 & D_{eq}^{PAR} \le 1mm \\ 1.075 - 0.075 D_{eq}^{PAR} & 1mm \le D_{eq}^{PAR} \le 5mm \\ 0.7 & 5mm \le D_{eq}^{PAR} \end{cases}$$

Estimation of *v* and *d* for a liquid hydrometeor

Assumptions on the oblateness of falling rain drops

Small drops (D < 1 mm) are spherical, but biggers one are more elliptical (due to air friction)

Axis ratio = vertical / horizontal

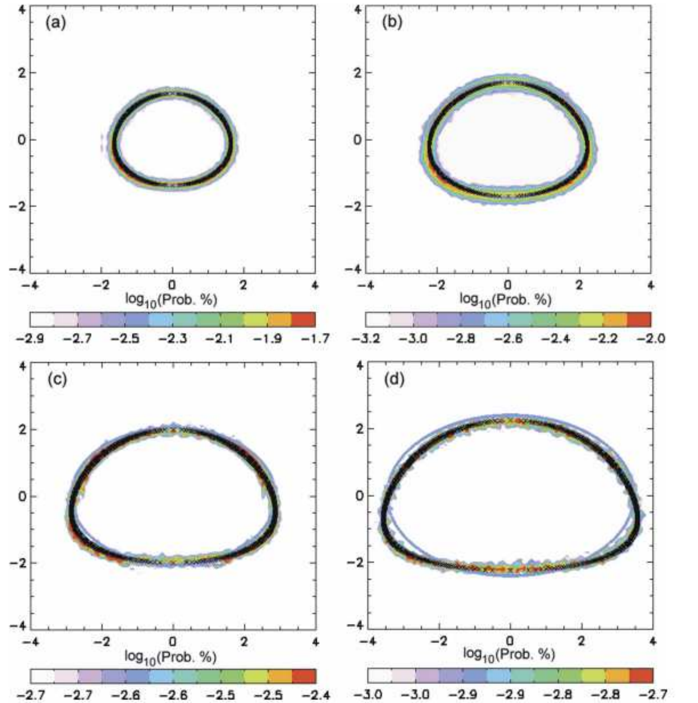
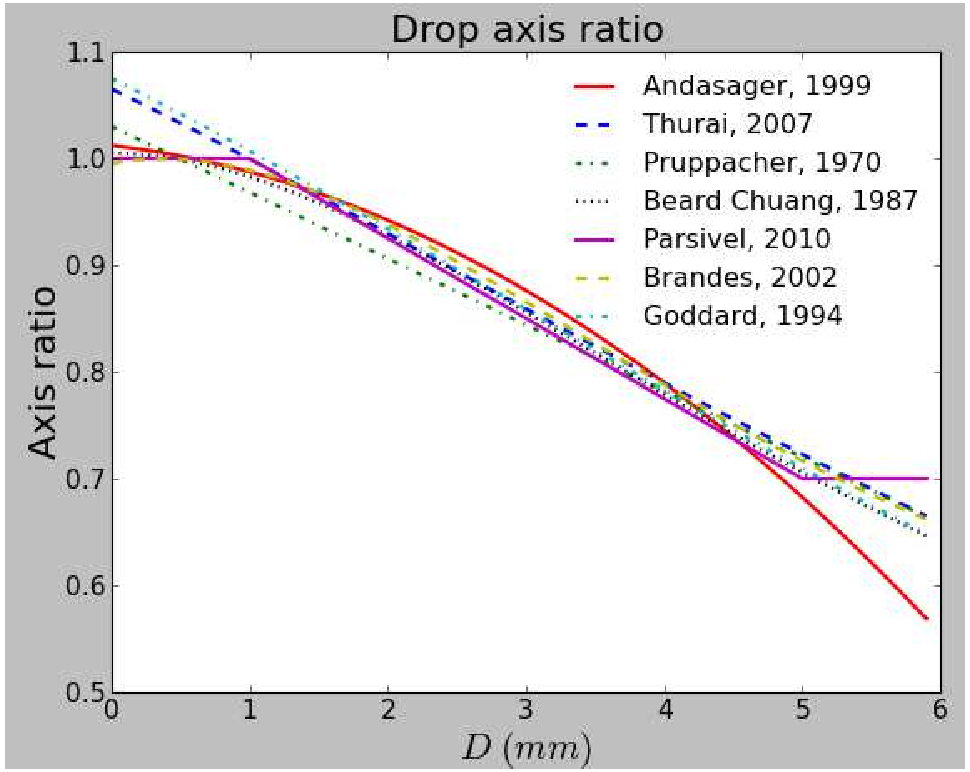


FIG. 1. Drop shapes given in terms of probability contours on a log scale indicated in color for (a) 3–3.25, (b) 4–4.25, (c) 5–5.25, and (d) 6–6.25 mm, the probability values being normalized with respect to the total number of pixels for all the drop contours in that diameter interval. Superimposed in black is the curve given by the fitted Eq. (1) obtained by modifying the shapes given in Wang (1982). Light blue curve shows the approximated oblate spheroid shapes whose axis ratios are from Thurai and Bringi (2005).

Thurai et al. 2007



Estimation of *v* and *d* for a liquid hydrometeor

How to compute the size ?

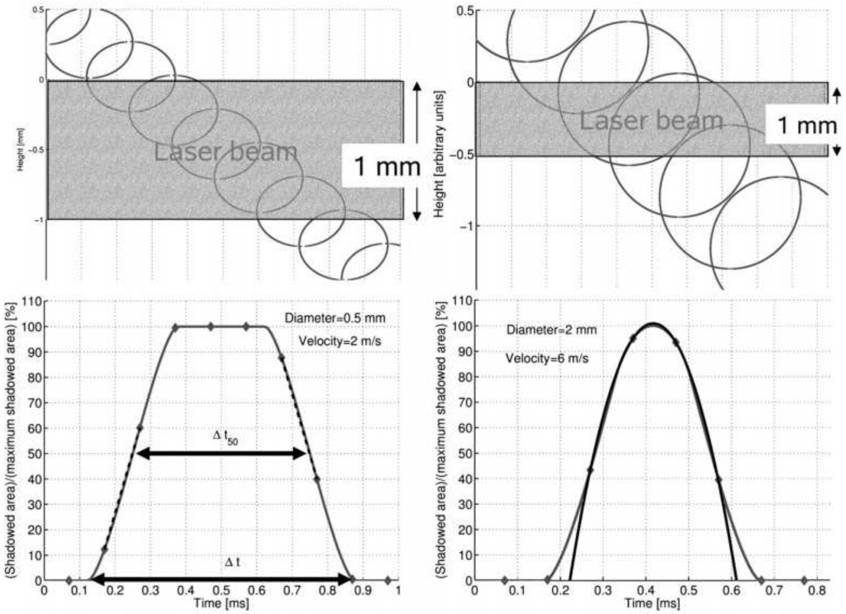
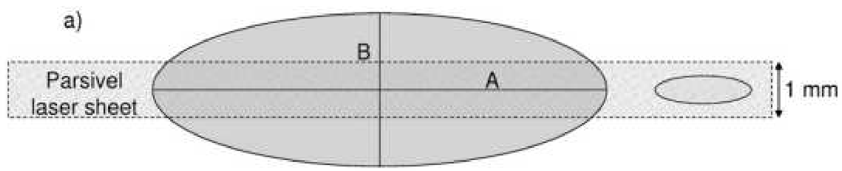


FIG. 2. Schematic diagram showing the influence of the size and of the velocity of two particles passing through the PARSIVEL beam on the output voltage. The diamonds represent the discrete PARSIVEL 10-kHz samples; continuous lines indicate the effective continuous signal produced by the particle dimming, normalized to its peak value F_{max}. (left) A 0.5-mm-diameter sphere (the small deformation is due to graphical problems) falling at 2 m s^{-1}. The dashed line is shown to exemplify the technique adopted to compute Δt_{50} (by linear interpolation). (right) A 2-mm-diameter sphere falling at 6 m s^{-1}. The black continuous line is shown to exemplify the technique adopted to estimate the maximum signal (by parabolic interpolation).



F_{max} = maximum shadowed area

$$F_{\max} = \begin{cases} \pi AB & B \le \dfrac{h}{2} \\ 2AB\left[\arcsin\left(\dfrac{h}{2B}\right) + \dfrac{h}{2B}\sqrt{1-\left(\dfrac{h}{2B}\right)^2}\right] & B > \dfrac{h}{2} \end{cases}$$

$$F_{max} \longrightarrow D_{eq}^{PAR}$$

(*A* and *B* determined by D_{eq}^{PAR})

Estimation of *v* and *d* for a liquid hydrometeor

How to compute the velocity ?

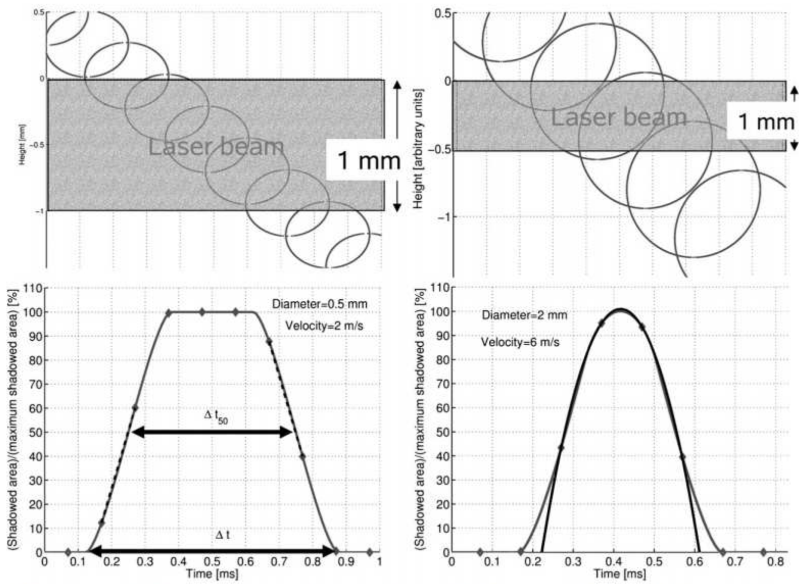


FIG.2. Schematic diagram showing the influence of the size and of the velocity of two particles passing through the PARSIVEL beam on the output voltage. The diamonds represent the discrete PARSIVEL 10-kHz samples; continuous lines indicate the effective continuous signal produced by the particle dimming, normalized to its peak value F_{max}. (left) A 0.5-mm-diameter sphere (the small deformation is due to graphical problems) falling at 2 m s^{-1}. The dashed line is shown to exemplify the technique adopted to compute Δt_{50} (by linear interpolation). (right) A 2-mm-diameter sphere falling at 6 m s^{-1}. The black continuous line is shown to exemplify the technique adopted to estimate the maximum signal (by parabolic interpolation).

Height in the vertical direction

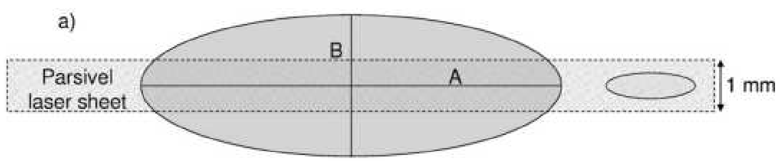
Laser beam width

$$v_{eff} = \frac{H + h}{\Delta t}$$

Duration over which the signal is affected

Assumption on drop shapes :

$$H = H_{est}^{PAR} = 2B = D_{est}^{PAR}\left(a_r^{PAR}\right)^{2/3}$$



Estimation of Δt : $\Delta t = f\left(\Delta t_{50}\right)$

Duration during which the intensity of the occlusion is greater than half of the maximum one

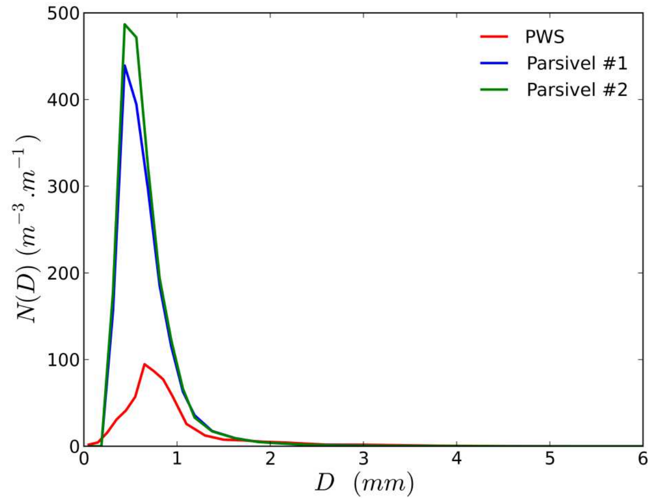
Drop size distribution and physical quantities

***N*(*D*) in mm^{-1}.m^{-3}** — ***N*(*D*)d*D* is number of drops with *D*<Diam.<*D*+d*D* per unit volume**

Interpretation of DSD (Jameson, A.R. and A.B. Kostinski, 1998):

- Computed for few min → reflects physical processes at stake (coalescence, collision, break-up)

- Computed over events or more → a formal relationship

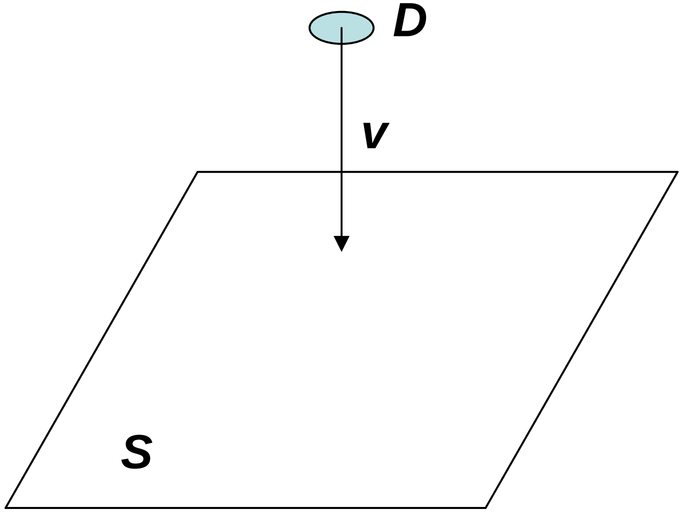


Two standard forms :

- Exponential: $$N(D) = N_0 e^{-\Lambda D}$$ (Marshall-Palmer 1948)

- Gamma distribution : $$N(D) = N_0 D^{\mu} e^{-\Lambda D}$$ (a dependency between μ (shape parameter) and Λ (slope)))

N(*D*) and rain rate



$$R = \frac{\textit{Rainfall depth during dt}}{dt}$$

$$\textit{Rainfall depth during dt} = \frac{\text{Volume}}{\text{S}} = \frac{\int_{D_{\min}}^{D_{\max}} \overbrace{\frac{4}{3}\pi\left(\frac{D}{2}\right)^{3}}^{\textit{Volume of drops}} \overbrace{v(D)S\,dt}^{\textit{Volume from which the drops falling reach S during dt}} \overbrace{N(D)dD}^{\textit{Nb of drops per unit vol}}}{S}$$

N(*D*) and rain rate

Hence we have:

$$R = \frac{4}{3}\pi \int_{D_{\min}}^{D_{\max}} N(D)v(D)\left(\frac{D}{2}\right)^3 dD$$

With *N*(*D*) in mm^{-1}m^{-3}, *v*(*D*) is m.s^{-1}, *D* in m d*D* in mm and *R* in m.s^{-1}

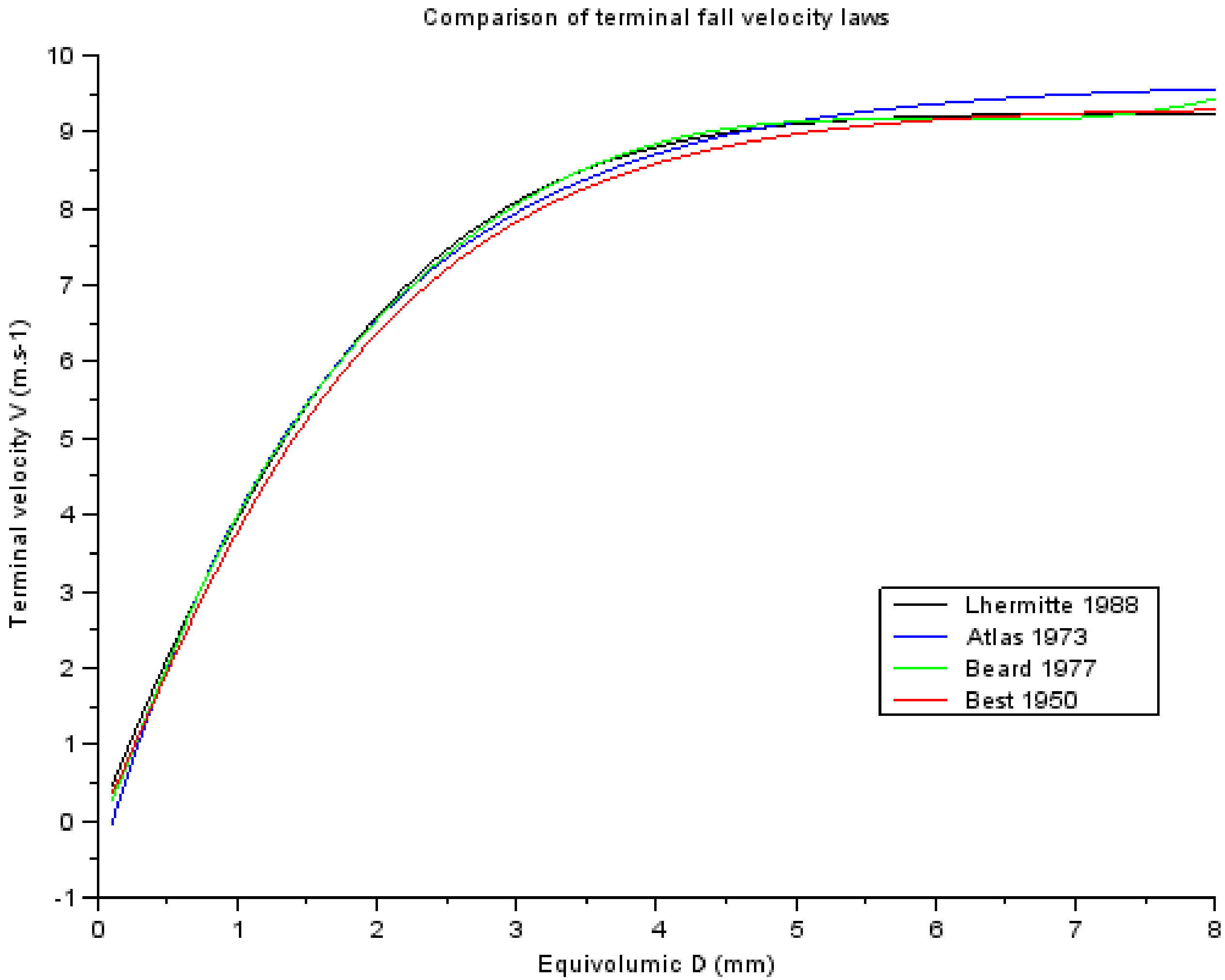
With more standard unit :

$$\boxed{R = 6\pi 10^{-4} \int_{D_{\min}}^{D_{\max}} N(D)v(D)D^3 dD}$$

With *N*(*D*) in mm^{-1}m^{-3}, *v*(*D*) is m.s^{-1}, *D* in mm d*D* in mm and *R* in mm.h^{-1}

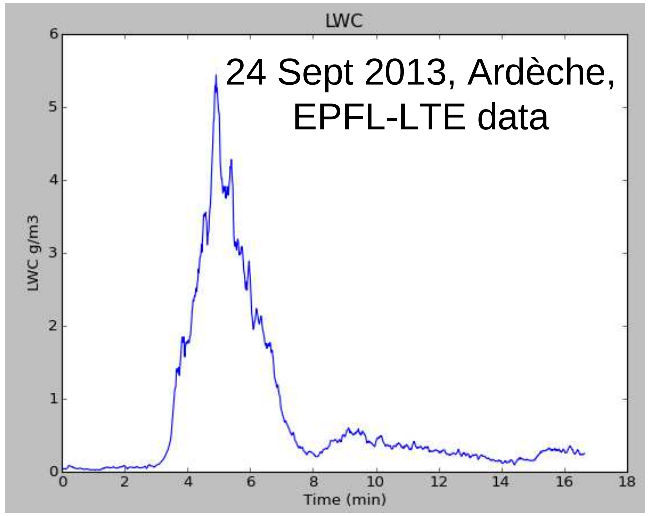
N(*D*) and rain rate

Terminal fall velocity of raindrops



$N(D)$ and other physical quantities

ρ_l (g.m^{-3}) (Liquid water content)



$$\rho_l = \rho_w \frac{1}{10^9} \frac{4}{3} \pi \int_{D_{\min}}^{D_{\max}} N(D) \left(\frac{D}{2} \right)^3 dD$$

With ρ_l in kg.m^{-3}, $N(D)$ in mm^{-1}m^{-3}, $v(D)$ is m.s^{-1}, D in m dD in mm

Radar parameters:

- Horizontal and vertical reflectivity:

radar wavelength (cm)

$$Z_{h,v} = \frac{\lambda^4 10^6}{\pi^5 \left| \frac{m^2 - 1}{m^2 + 1} \right|} \int_{D_{\min}}^{D_{\max}} N(D) \sigma_{B;h,v}(D) dD$$

$$Z_{dr} = 10 \log_{10} \left(\frac{Z_h}{Z_v} \right)$$

complex refractive index of water

(in cm^2) backscattering cross session at horizontal and vertical polarization

- K_{dp}

$$K_{dp} = \frac{1800\lambda}{\pi} \int_{D_{\min}}^{D_{\max}} \mathrm{Re}\left[S_{hh}(D) - S_{vv}(D) \right] N(D) dD$$

The real part of the forward scattering amplitude at horizontal/vertical polarization (Mishchenko et al., 1996)

Data retrieved from measurements

Over each time step Δt

For each time step Δt the number $n_{i,j}$ of drops per class of diameter D_i (with extend ΔD_i) and velocity v_j (with extend ΔD_j).

The sensing area of the disdrometers is S. Some authors suggest to take into account an effective sampling area which varies with size:

$$S_{eff}(D_i) = L\left(W - \frac{D_i}{2}\right)$$

Where L and W are respectively the length and width of the sensing area.

Snapshot of output message from Parsivel²

```
40:20000

41:20000

50:00000213

51:000209

90:-9.999;-9.999;02.213;02.051;00.425;-9.999;-9.999;-9.999;-9.999;-9.999;-9.999;-9.999;-9.999;-9.999;-9.999;-9.999;-9.999;-9.999;-9.999;-9.999;-9.999;-9.999;-

91:00.000;00.000;00.000;00.000;00.000;00.000;00.000;00.000;00.000;00.000;00.000;00.000;00.000;00.000;00.000;00.000;00.000;00.000;00.000;00.000;00.000;00.000;0

93:000;000;000;000;000;000;000;000;000;000;000;000;000;000;000;000;000;000;000;000;000;000;000;000;000;000;000;000;000;000;000;000;000;000;000;000;000;000;00

94:0000;0000;0000;0000;0000;0000;0000;0000;0000;0000;0000;0000;0000;0000;0000;0000;0000;0000;0000;0000;0000;0000;
```

Data retrieved from measurements

How to compute *N*(*D*)?

$N(D_i)\,\Delta\,D_i$ = nb of drops of in the class *i* per unit volume
The contribution to this by an individual drop is :

$$\frac{1}{Volume} = \frac{1}{S v_j \Delta t}$$

$N(D_i)\,\Delta D_i$ is the sum of the contribution of all the drop in class *i* observed during Δt.

$$\boxed{N(D_i) = \frac{1}{S_{eff}(D_i)\Delta D_i \Delta t}\sum_j \frac{n_{i,j}}{v_j}}$$

Remark: if v_j not available as for JW disdrometers, it is possible to use a standard model

Data retrieved from measurements

How to compute R ?

Method 1: with the computed DSD

$$R = 6\pi 10^{-4} \sum_i N(D_i) v(D_i) D_i^{\,3} dD_i$$

velocity affected to all the particle of size D_i.

Method 2: directly from the spectrum

$$R = \frac{\pi}{6\Delta t} \sum_{i,j} \frac{n_{i,j} D_i^{\,3}}{S_{eff}(D_i)}$$

With $N(D)$ in mm^{-1}m^{-3}, $v(D)$ is m.s^{-1}, D in mm dD in mm and R in mm.h^{-1}

Measures from the roof of the ENPC building

OTT Parsivel^2
(occulted light)
(Available since October 2013)

Campbell Scientific PWS100
(scattered light)
(Available since March 2013)

+ rain gauge

+ radar data
(C-band, Trappes,
Météo-France)

Installed with the help of
S. Botton team (ENSG)

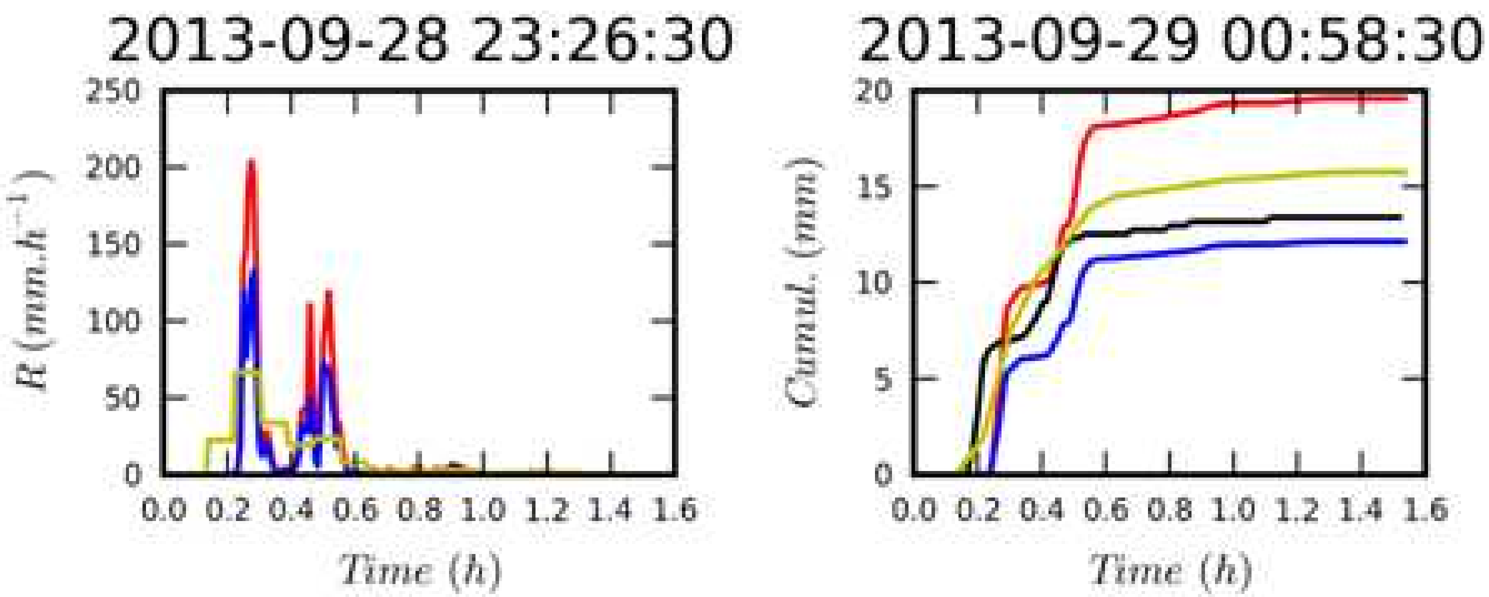
Data analysis

Scilab script :
disdro_data_analysis_student.sci

1) **Implement both methods of computing a rain rate for the PWS100 and the Parsivel²**
2) **Compare the obtained results (various methods and the two devices)**

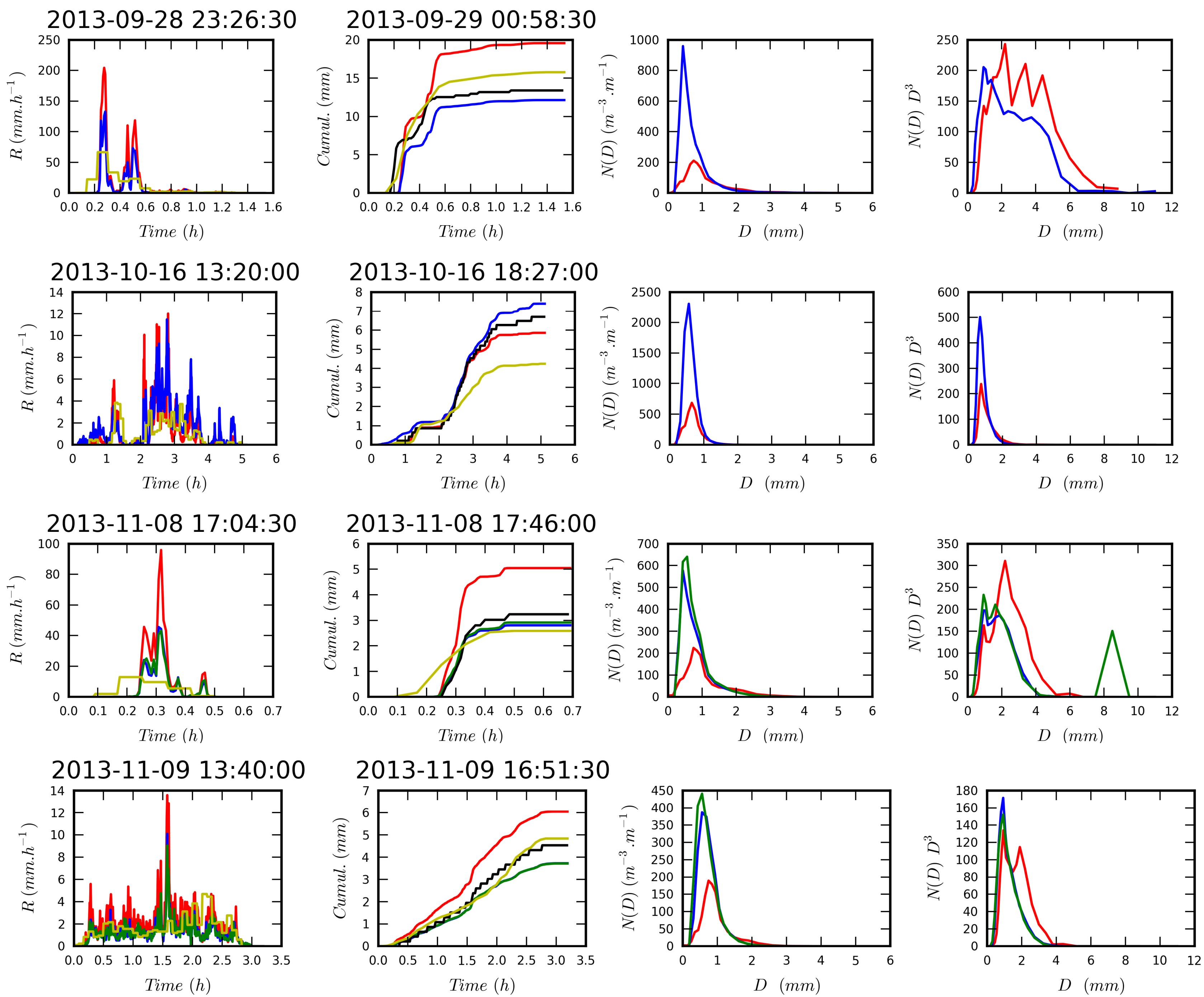
Measures from the roof of the ENPC building

Illustration for a typical event



PWS
Parsivel #1
Parsivel #2
Rain gauge
Radar

Total cumulative depth :
PWS vs. Pars 1 and Pars 2 vs. rain gauge:
PWS = 145 mm
Pars1 = 93 mm
Pars2 = 94 mm
Rain gauge = 99 mm

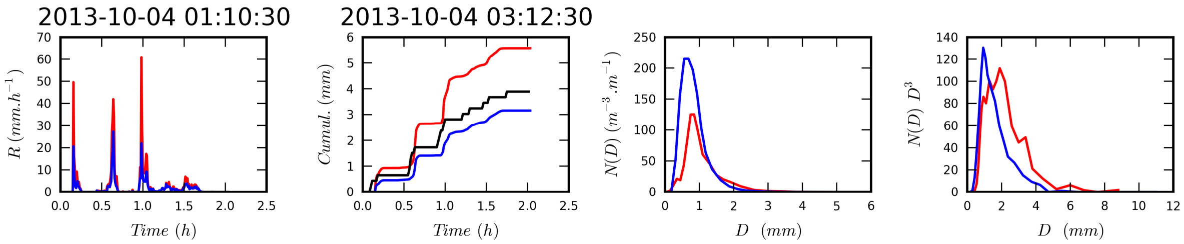

2013-09-28 23:26:30
2013-09-29 00:58:30
2013-10-16 13:20:00
2013-10-16 18:27:00
2013-11-08 17:04:30
2013-11-08 17:46:00
2013-11-09 13:40:00
2013-11-09 16:51:30
R (mm.h^{-1})
Cumul. (mm)
N(D) (m^{-3}.m^{-1})
N(D) D^3
Time (h)
D (mm)

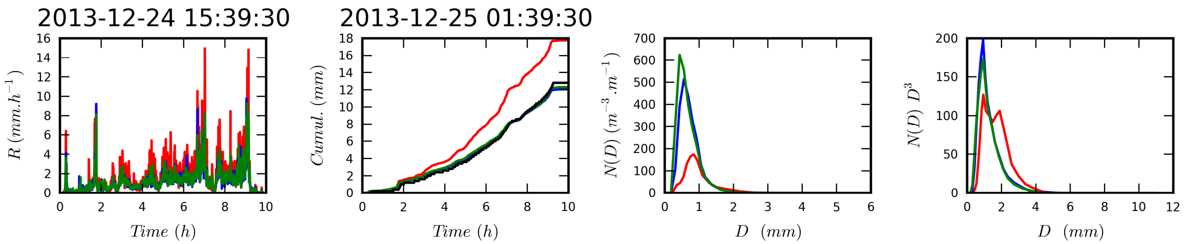
Measures from the roof of the ENPC building

Effects of large (>2mm) drops

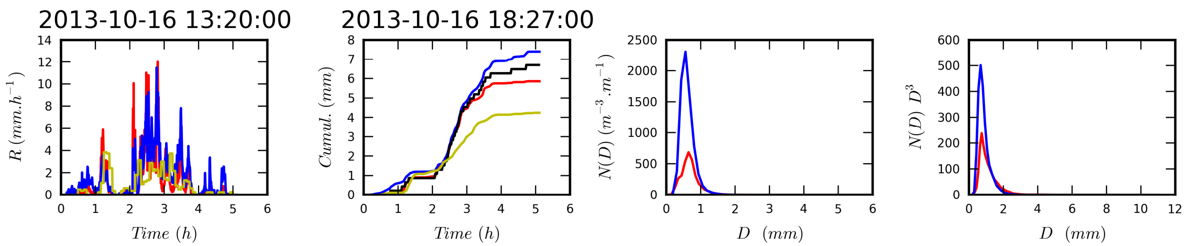
PWS100 seems to overestimate them

When great influence on rain rate → great differences





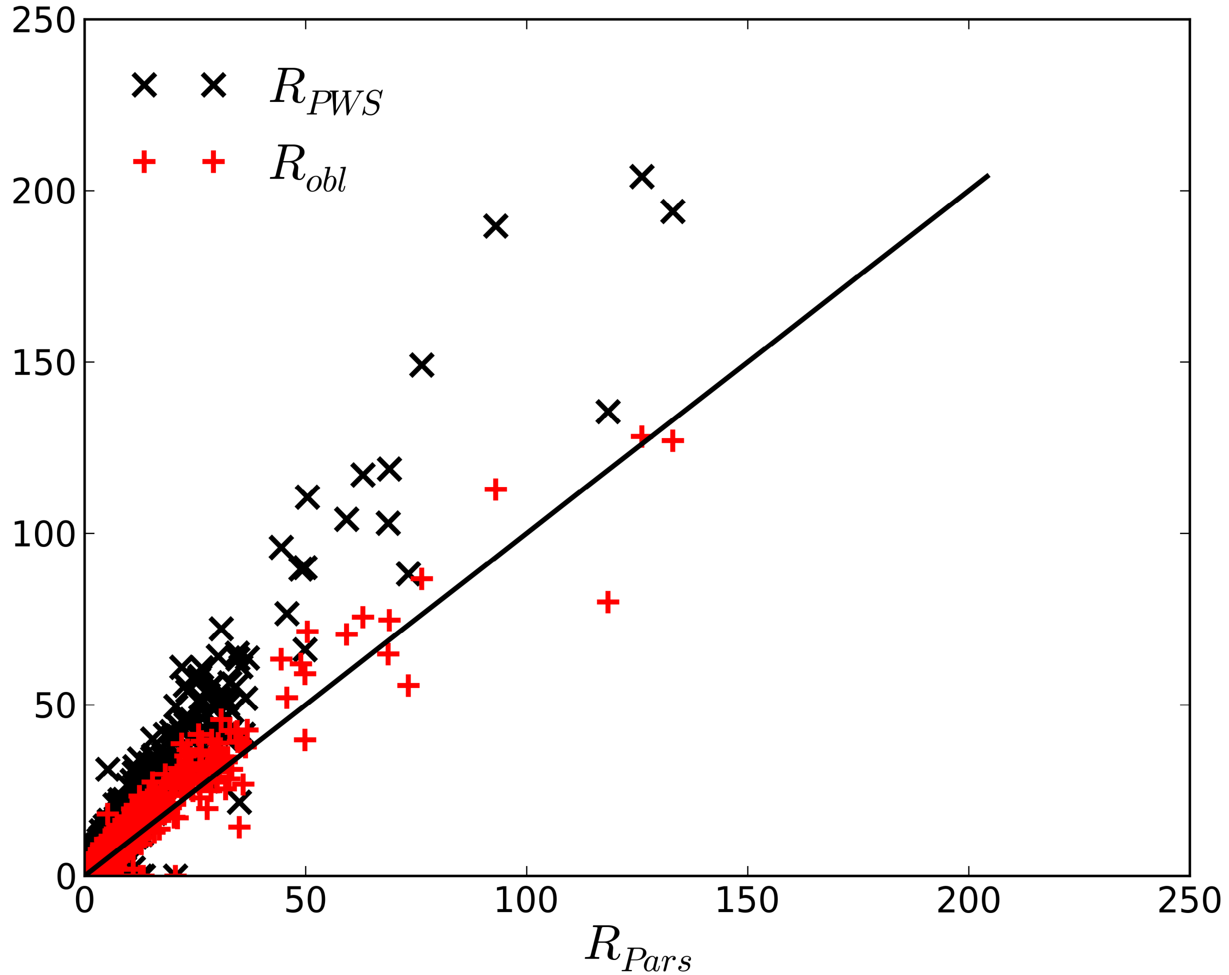
When small influence → lower differences between devices



Correction for drop oblatness

Drop oblateness poorly taken into account in the PWS100 software

→ Suggestion of a correction :



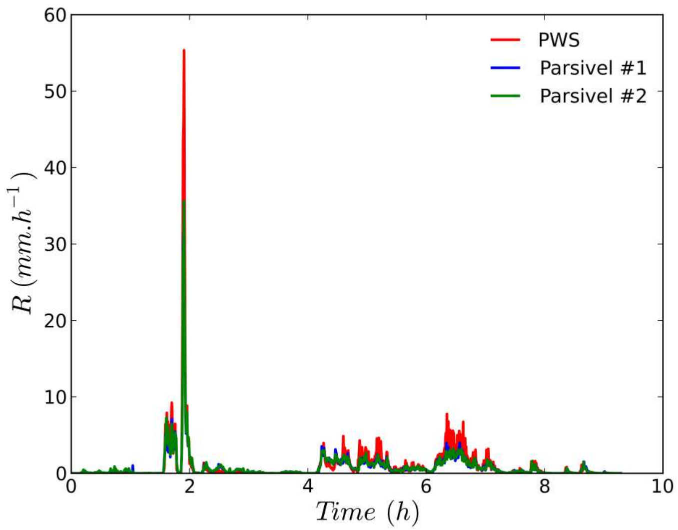
→ Measurements are comparable

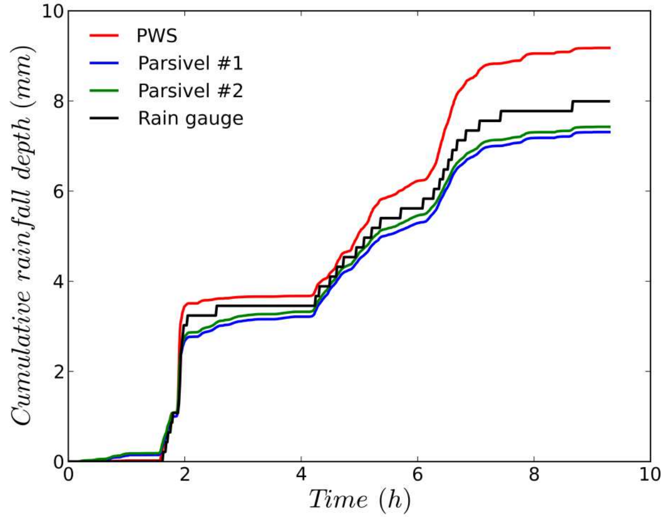
→ Better agreement of PWS100 with rain gauges

→ PWS100 (less noisy than Parsivel) can now be used for ground validation

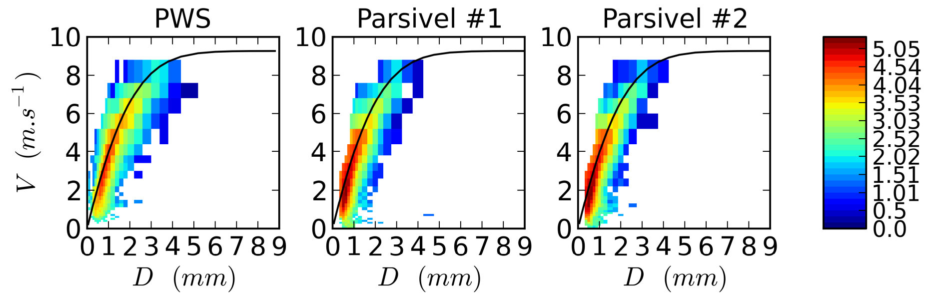
Measures from the roof of the ENPC building

Parsivel² overestimation of small drops

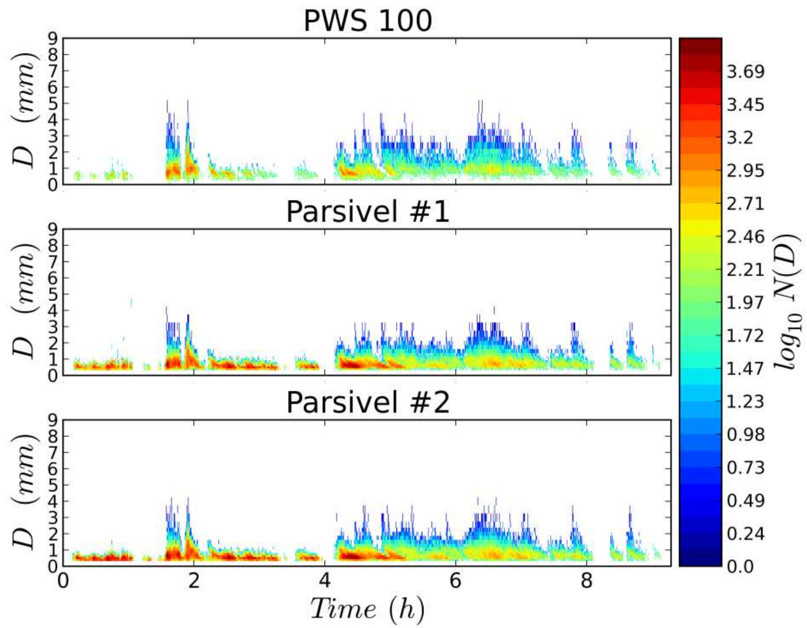




Visible on *N*(*D*) and also on size/velocity maps :



Also during the whole event :



Example of measurement issues

Non homogeneity of the laser beam

More or less occluded light according to the position of the drop in the laser beam

Study carry out with Thies disdrometer (functioning similar to Parsivel[2])

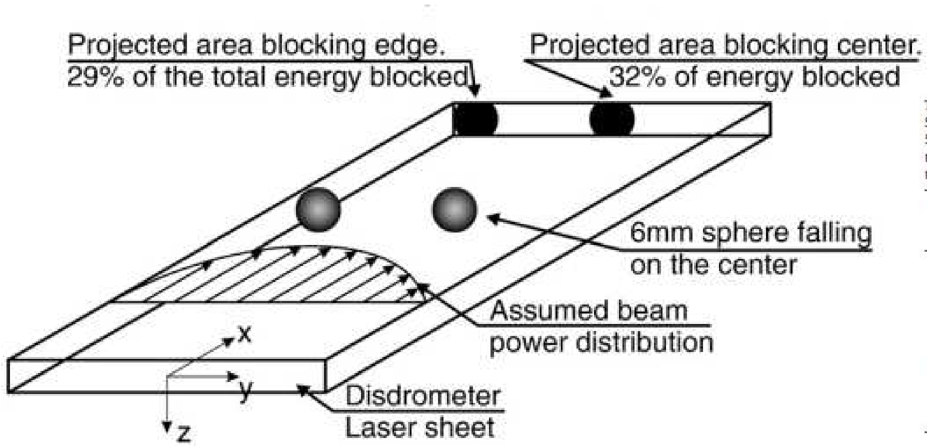


Table 3
Summary of simulation results showing how drops of 2 mm, 3 mm, 4 mm, 5 mm and 6 mm would be seen if they fall on the edge of the beam opposed to falling on the center assuming an assumed Gaussian beam pattern with the tails removed at 25% and 75%.

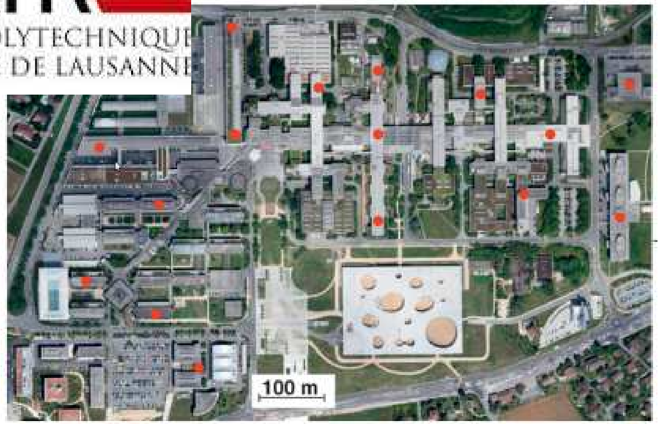
Diameter	Position	Estimated diameter (mm)	Variation amplitude (mm)	Blocked power
2	Center	2.14	0.34	11%
	Edge	1.80		9%
3	Center	3.22	0.48	16%
	Edge	2.74		14%
4	Center	4.29	0.57	21%
	Edge	3.72		18%
5	Center	5.36	0.63	27%
	Edge	4.72		24%
6	Center	6.41	0.67	32%
	Edge	5.75		29%

Fig. 3. Simulation schematics performed to estimate the error on the diameter measurement caused by an assumed Gaussian beam pattern with the tails removed at the 25th percentile and 75th percentile. Only the two extreme cases are shown, when a sphere falls on the edge of the beam, intercepting the beam with the least amount of energy opposed to a sphere falling on the center, where it intercepts the largest amount of energy. For complete results refer to Table 3.

It propagates to rain rate estimation with differences of 10 to 25 % found

Frasson, R.P.d.M., L.K. da Cunha, and W.F. Krajewski, *Assessment of the Thies optical disdrometer performance.* Atmospheric Research, 2011. **101**(1-2): p. 237-255.

Testing the Z-R relationship



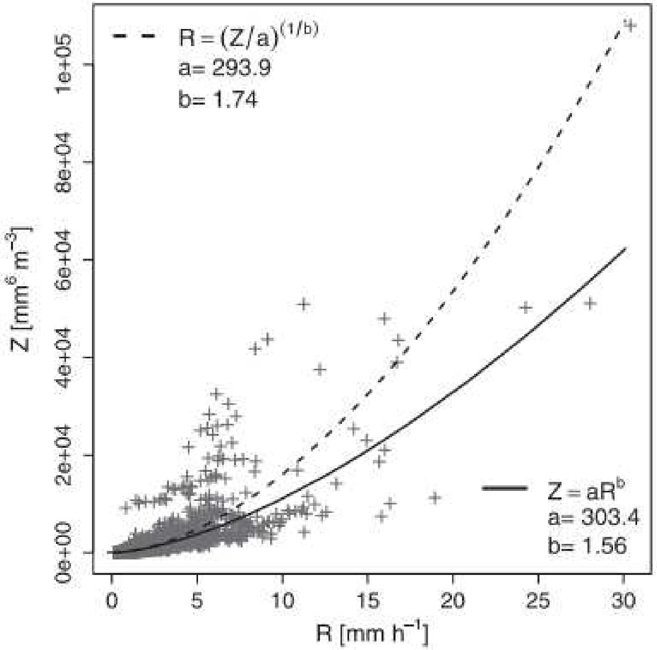
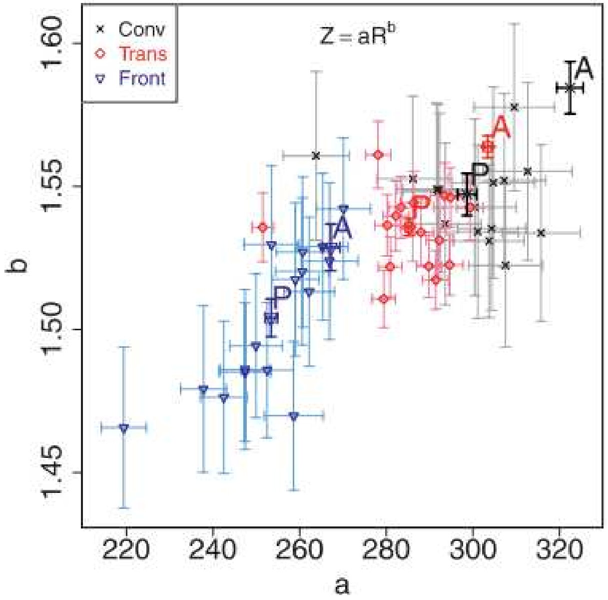


FIG. 2. The Z_A–R_A scatterplot and the fitted Z_A–R_A (solid line) and R_A–Z_A (dashed line) relationships for the transitional rainfall type at C band and at a 60-s temporal resolution.

For each station :

$$R = 6\pi 10^{-4}\int_{D_{\min}}^{D_{\max}} N(D)v(D)D^3\,dD,$$

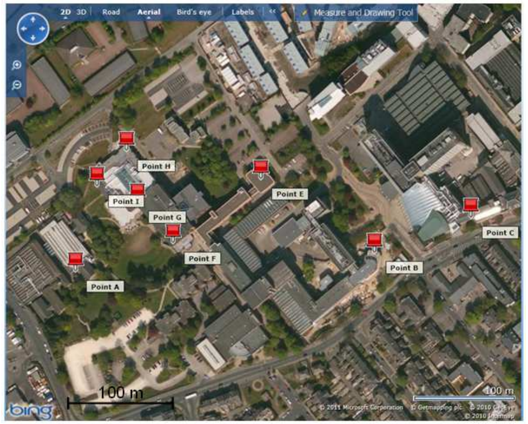
$$Z_h = \frac{10^6\omega^4}{\pi^5\left|\frac{m^2-1}{m^2+2}\right|}\int_{D_{\min}}^{D_{\max}}\sigma_{B_h}(D)N(D)\,dD$$



Jaffrain, J. and A. Berne, *Influence of the Subgrid Variability of the Raindrop Size Distribution on Radar Rainfall Estimators.* Journal of Applied Meteorology and Climatology, 2012. **51**(4): p. 780-785.

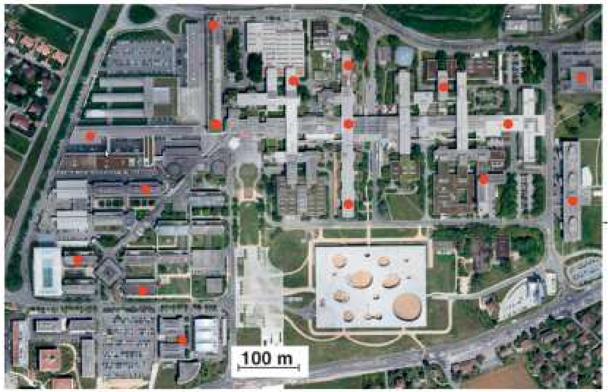
Validation of a Universal Multifractal downscaling process with the help a dense network of disdrometers or rain gauges

8 x 2 rain gauges, 0.2 mm



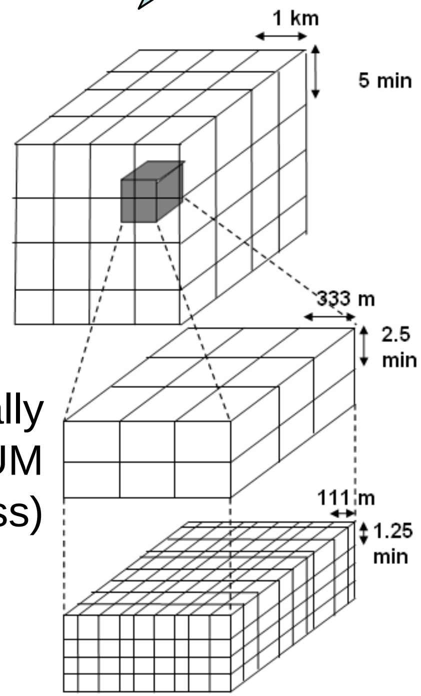
Coll. with A. Schellart, Bradford U. Campus (UK)

16 PARSIVEL® disdrometres, 1 min



Coll. with Alexis Berne EPFL Campus (Switzerland)

Aggregation to 1km x 5 min



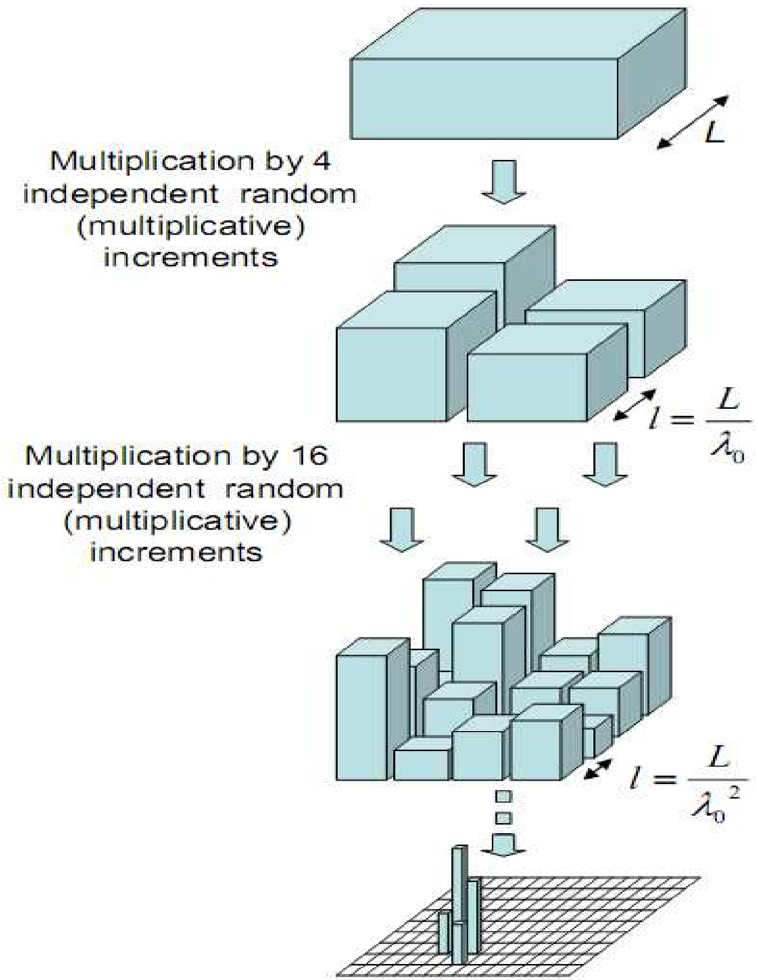
Downscaling (stochastically continuing the underlying UM cascade process)

Generation of the output of 2187 x 2187 virtual point measurements with observation scale of 46 cm x 1 min

Universal Multifractals

Theoretical framework

Based on the assumption that rain is generated through a cascade process



Multifractal fields

Resolution

$$\lambda = \frac{L}{l}$$

Singularity **Codimension function**

$$\Pr(\varepsilon_\lambda \geq \lambda^\gamma) \approx \lambda^{-c(\gamma)}$$

$$\langle \varepsilon_\lambda^{\,q} \rangle \approx \lambda^{K(q)}$$

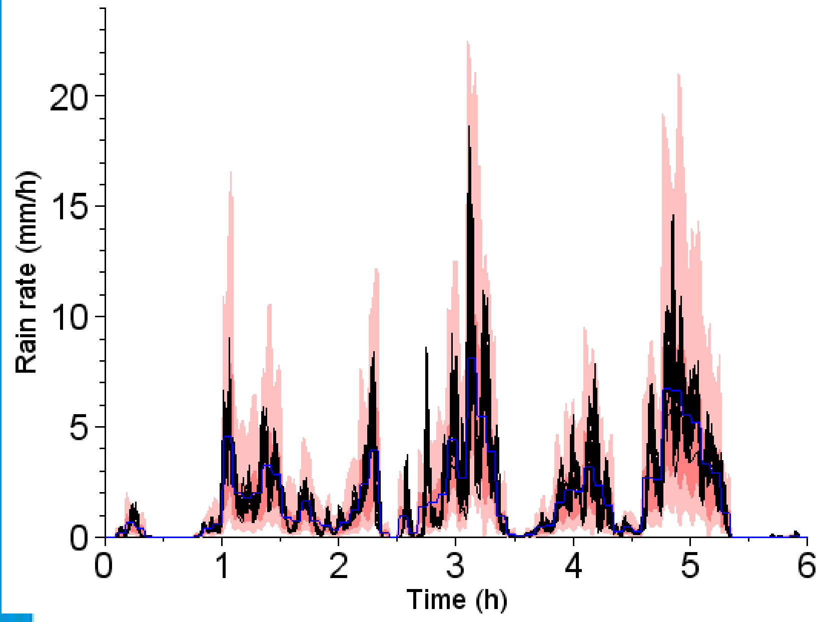
Moment order **Scaling moment function**

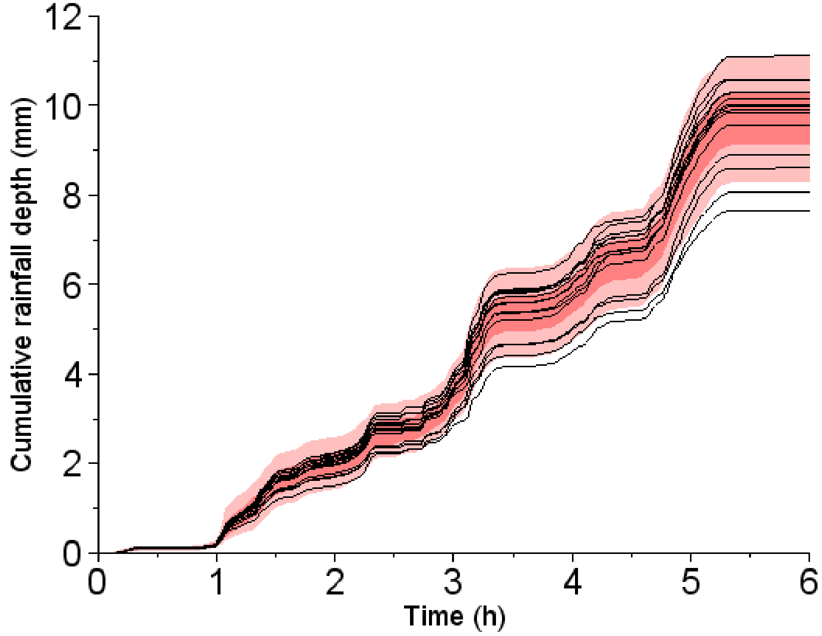
$K(q)$ $\xleftrightarrow{\textbf{Legendre transform}}$ $c(\gamma)$

Validation of a Universal Multifractal downscaling process with the help a dense network of disdrometers or rain gauges.

Results for 6 June 2009 in Lausane

16 disdrometers measurements + uncertainty range (75% and 95% quantile)





Gires, A., et al., *Influence of small scale rainfall variability on standard comparison tools between radar and rain gauge data.* Atmospheric Research, 2014. **138**(0): p. 125-138.