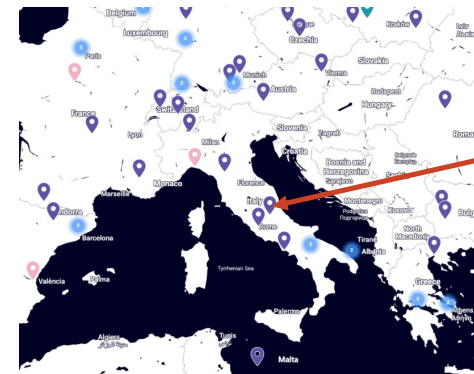


Laser disdrometer calibration. A light on standards in Europe PART I: theoretical framework



Authors: Mario Montopoli ^{4,1}, Elisa Adirosi⁴, Luca Baldini⁴, Luca Lanza⁵, Enrico Chinchella⁵, Cauteruccio Arianna⁵ and vital support from AQ-NF team ^{1, 2, 3}



L'Aquila NF

ACTRIS Cloud Remote Sensing Workshop June 2026 - D. Rossi, M. Montopoli and D. Cimini

Motivation

- **ACTRIS CCRES has recently established a laboratory procedure for laser disdrometer calibration (Kneifel et al., at LMU)**
- **Such procedure makes use of metal spheres as also suggested by the producers**
- **A recent publications from Chinchella et al. 2026 (<https://doi.org/10.1016/j.atmosres.2026.108865>) highlighted as water spheres behaves differently by metal ones in estimating the drop sizes.**
- **European regulations complete the framework**
 - **CEN^(*) Regulations and Standardization (CEN/TS 17445)**
 - **EN^(**) 18097:2025 (Hydrometry — Non-Catching Rain Gauges — Calibration):**
 - **CEN/TR 17993:2023 (Calibration and Accuracy of Non-Catching Precipitation Measurement Instruments)**

()CEN: European Committee for Standardization (CEN)*

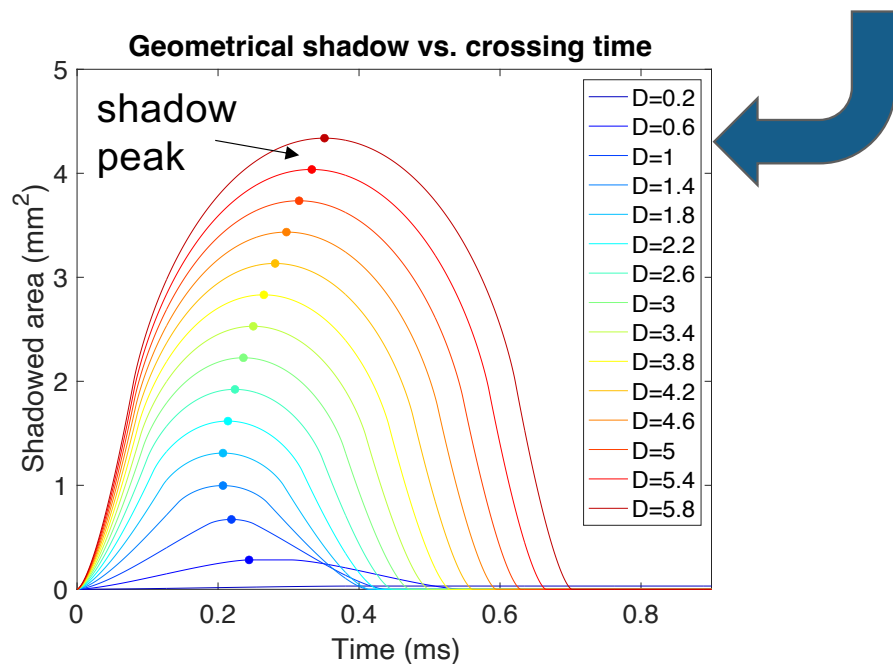
*(**) EN: European / Norm Standard document*

Outline

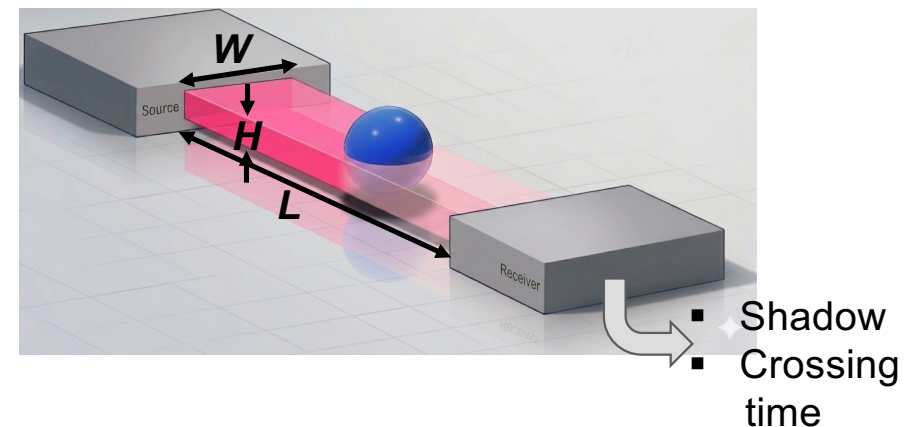
- PART I: Why a metal sphere should produce a different “disdrometer signal” wrt. a water sphere?**
- PART II: How to conduct a laboratory calibration experiment in agreement with CEN regulations?

Disdrometer: principle of measure

- **Operating principle:** It works based on the extinction principle; as a particle passes through the light beam, it creates a shadow, which is measured by the receiver in terms of intensity and time duration.
- **Measurement range:** The sensor can measure particle diameters from 0.2 to 25 mm and fall velocities from 0.2 to 20 m/s.
- **Size retrieval:** from the shadow peaks, the sphere size can be retrieved (the target variable in this presentation)



Shadowed area vs. crossing time by a metal sphere of diameter D passing through a $H=1$ (mm) altitude of disdrometer laser beam.



	L (mm)	W (mm)	H (mm)	λ (nm)
Thies-LPM	228	20	0.75	786
Parsivel2	180	30	1.00	650

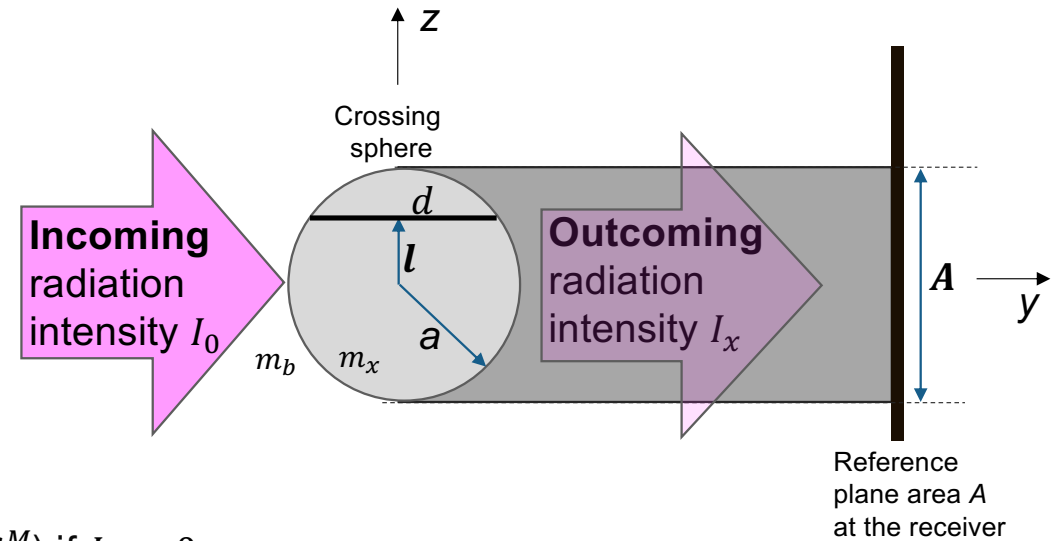
Shadow definition

• **Shadow** (S^x) can be defined as the area interested by a reduction of the radiation received (I_x) at the reference plane over the incoming one (I_0) :

$$S^x(t) = \int_A \left[1 - \frac{I_x(\mathbf{l}, t)}{I_0} \right] d\mathbf{l} \quad \begin{cases} = 0 \text{ (no shadow) if } I_x = I_0 \\ = A \text{ (geometrical shadow } S^M) \text{ if } I_x = 0 \end{cases}$$

x is the sphere's material ($x = M$ for metal, $x = W$ for water)

I_x : refracted intensity (Lambert-Beer law)



$$\alpha_x = \frac{2\pi}{\lambda} \text{Im}\{m_x\} \quad \text{specific attenuation coefficient (m}^{-1}\text{)}$$

$$m_x = n_x + jk_x \quad \text{complex refractive index of sphere of material x-th}$$

$$m_b = n_b + jk_b \quad \text{complex refractive index of the background}$$

Synthetic experiments

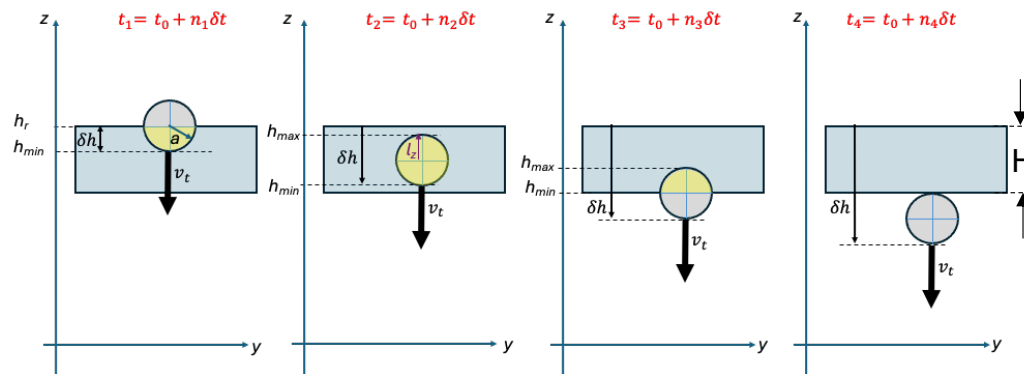
	Symbol	Units	LPM	PARSIVEL2
Laser beam height	H	(mm)	0.75	1.00
Laser beam wavelength	λ	(nm)	786	650
Refractive index of water	m_W	-	1.328+j0	
Refractive index of metal	m_M	-	2.5+j3	
Sphere's diameters	D	(mm)	from 0.2 to 6	
Sphere's fall velocity	v_t	(ms ⁻¹)	Gunn and Kinzer 1949	

Table 1: Simulated experiment parameters.

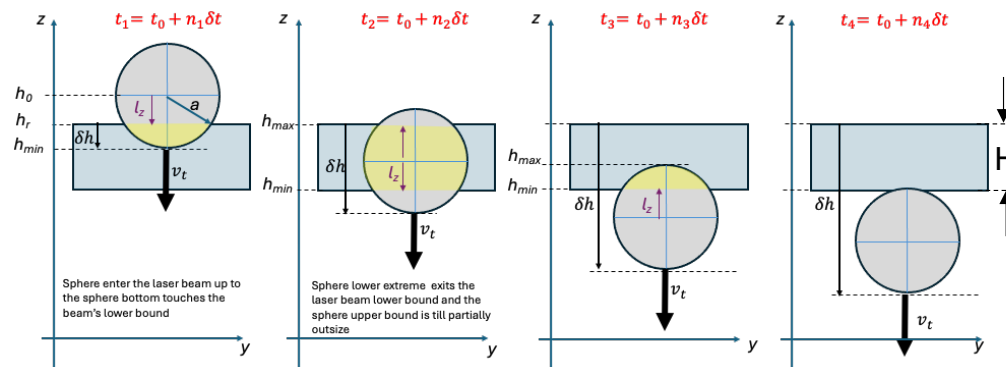
- Shadows are calculated for each particle type (x = Metal and x =Water spheres) and at each crossing time.
- No sampling issue are considered.

Falling spheres through a laser beam (side view)

Sphere diameter lower than beam height



Sphere diameter larger than beam height

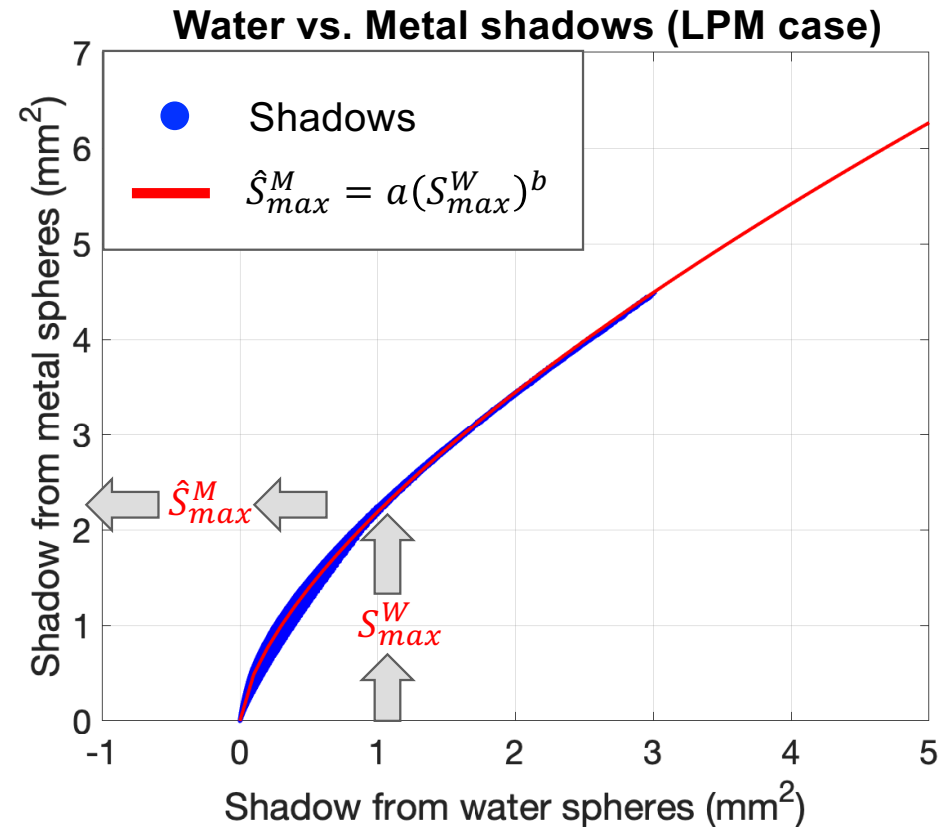


 Shaded geometrical area

Shadowed area: geometrical vs. refraction-guided

- Metal and water sphere shadows are highly correlated to each other

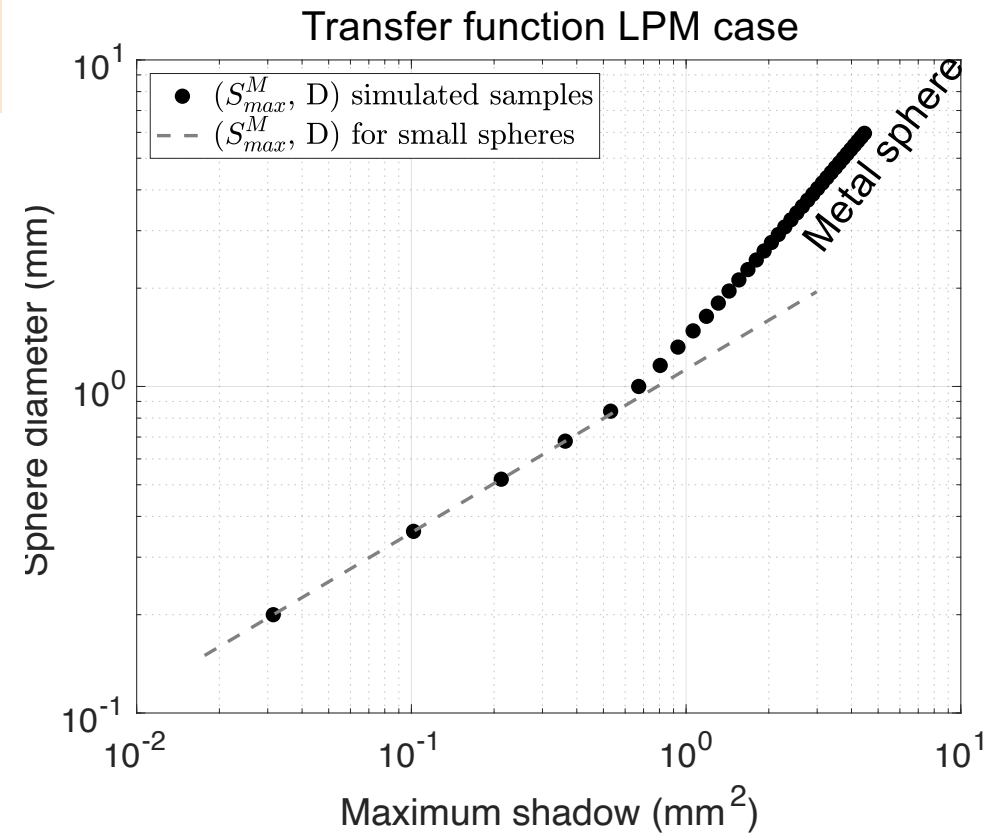
- Shadow from water spheres (S_{max}^W) can be transformed into that from metal sphere (\hat{S}_{max}^M) using regression coeff. a and b



The blue dots dispersion in the figure is due to the shadows over time while the sphere is crossing the laser beam.

Results: transfer function (from shadow to size)

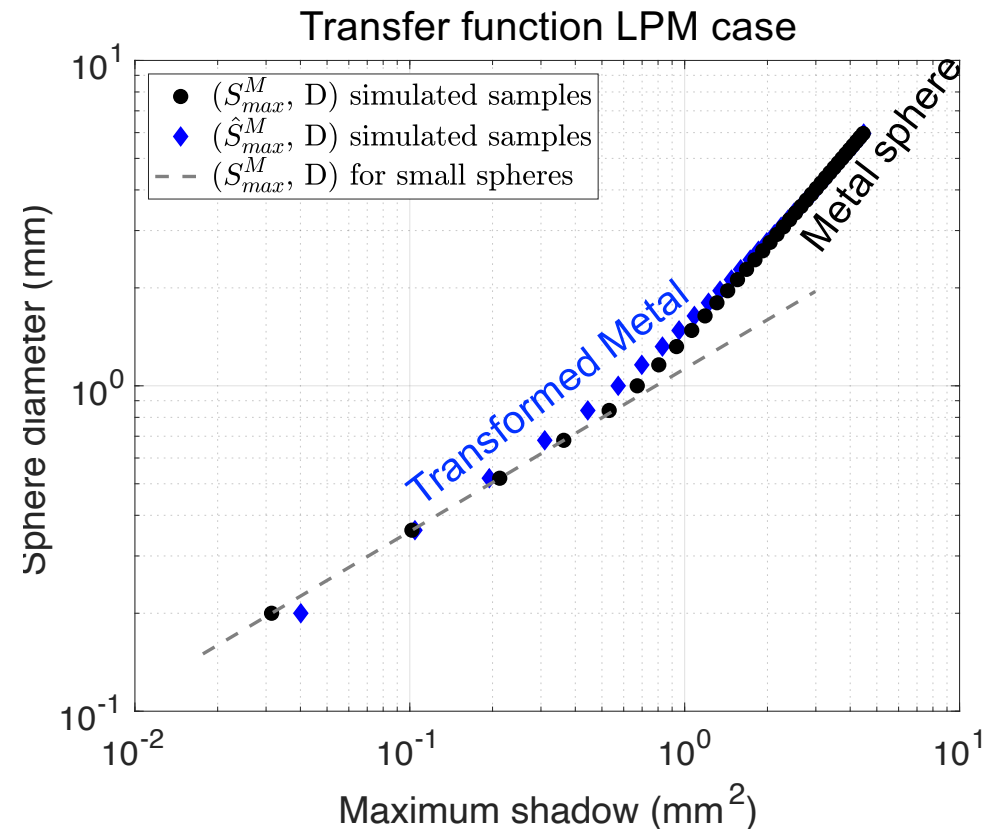
- The transfer function (TF) varies as a function of the shadow definition considered.



Results: transfer function (from shadow to size)

- The transfer function (TF) varies as a function of the shadow definition considered.

- TF of **transformed metal sphere** \neq TF of metal sphere



Results: transfer function (from shadow to size)

- The transfer function (TF) varies as a function of the shadow definition considered.

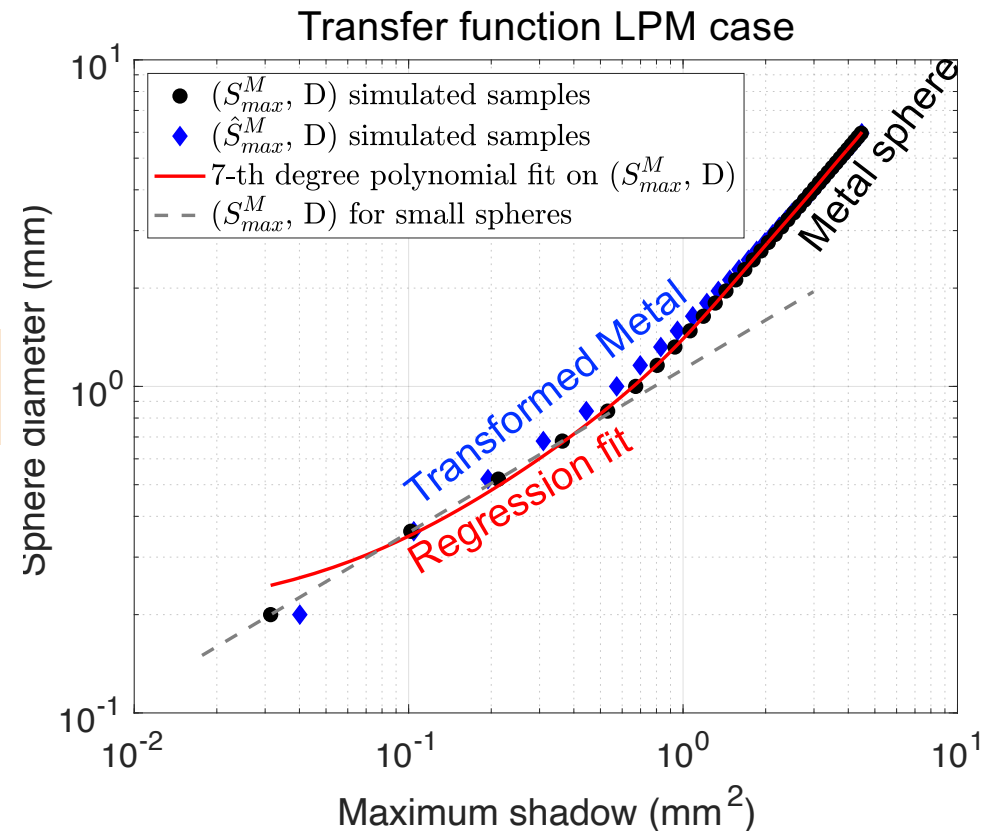
- TF of **transformed metal sphere** \neq TF of metal sphere

- Differences are further amplified if considering a polynomial regression:

$$\hat{D}^x = \sum_{k=1}^{N+1} p_k^M [S_{max}^x]^{(N-k+1)} \text{ with } N = 7$$

$x = M$ for metal sphere; $x = W$ for water sphere

- Reasonably, disdrometers might assume the transfer function associated to the geometrical shadow of metal spheres (solid red curve and p_k^M coeff.)



Results: transfer function (from shadow to size)

- The transfer function (TF) varies as a function of the shadow definition considered.

- TF of **transformed metal sphere** \neq TF of metal sphere

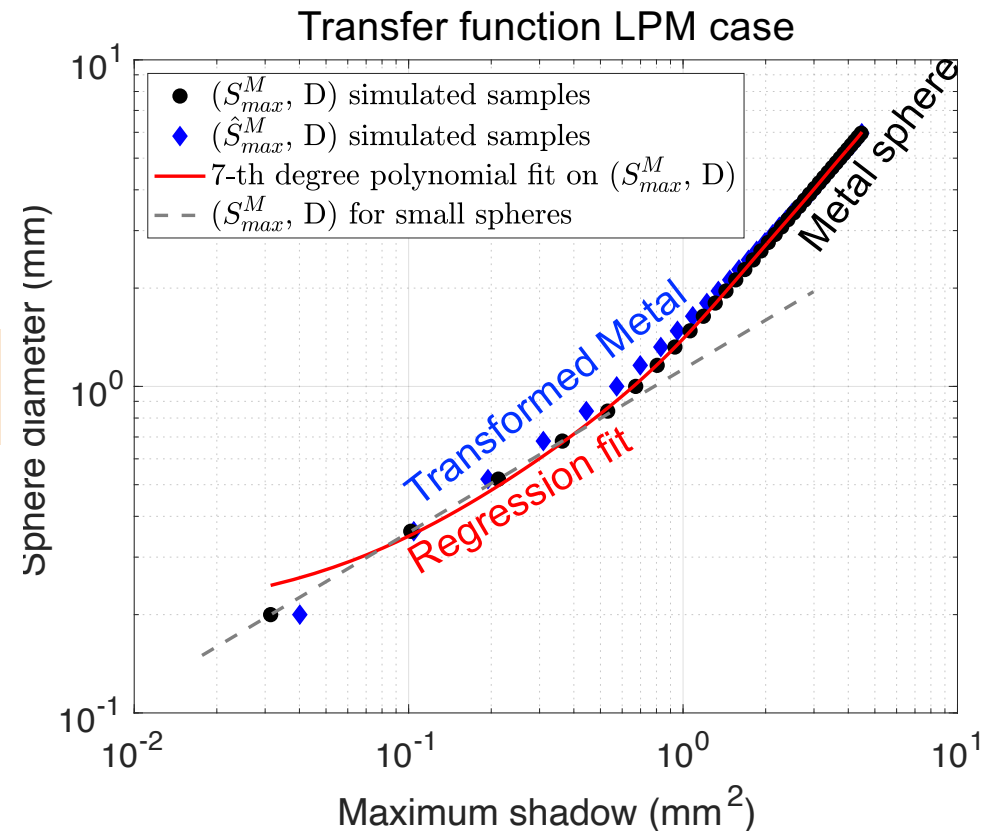
- Differences are further amplified if considering a polynomial regression:

$$\hat{D}^x = \sum_{k=1}^{N+1} p_k^M [S_{max}^x]^{(N-k+1)} \text{ with } N = 7$$

$x = M$ for metal sphere; $x = W$ for water sphere

- Reasonably, disdrometers might assume the transfer function associated to the geometrical shadow of metal spheres (solid red curve and p_k^M coeff.)

- It is therefore clear that calibration using metal spheres can produce calibration curves that differ from those obtained using water spheres, that is, the hydrometeor whose dimensions we wish to determine.



Diameter estimation errors: comparison with laboratory experiments

- Assumed disdrometer size-estimation-formula
(tuned on metal spheres)

$$\hat{D}^x = \sum_{k=1}^{N+1} p_k^M [S_{max}^x]^{(N-k+1)} \text{ with } N \text{ in } [3, 11]$$

- Relative error metric

$$e_D^x (\%) = \frac{\hat{D}^x - D}{D} 100$$

$x = M$ for metal sphere;

$x = W$ for water sphere

D = true diameter

p_k^M = estimation coefficients tuned on metal spheres

S_{max}^x = maximum shadow registered by the disdrometer
in response to particle x

Diameter estimation errors: comparison with laboratory experiments

- Assumed disdrometer size-estimation-formula (tuned on metal spheres)

$$\hat{D}^x = \sum_{k=1}^{N+1} p_k^M [S_{max}^x]^{(N-k+1)} \text{ with } N \text{ in } [3, 11]$$

- Relative error metric

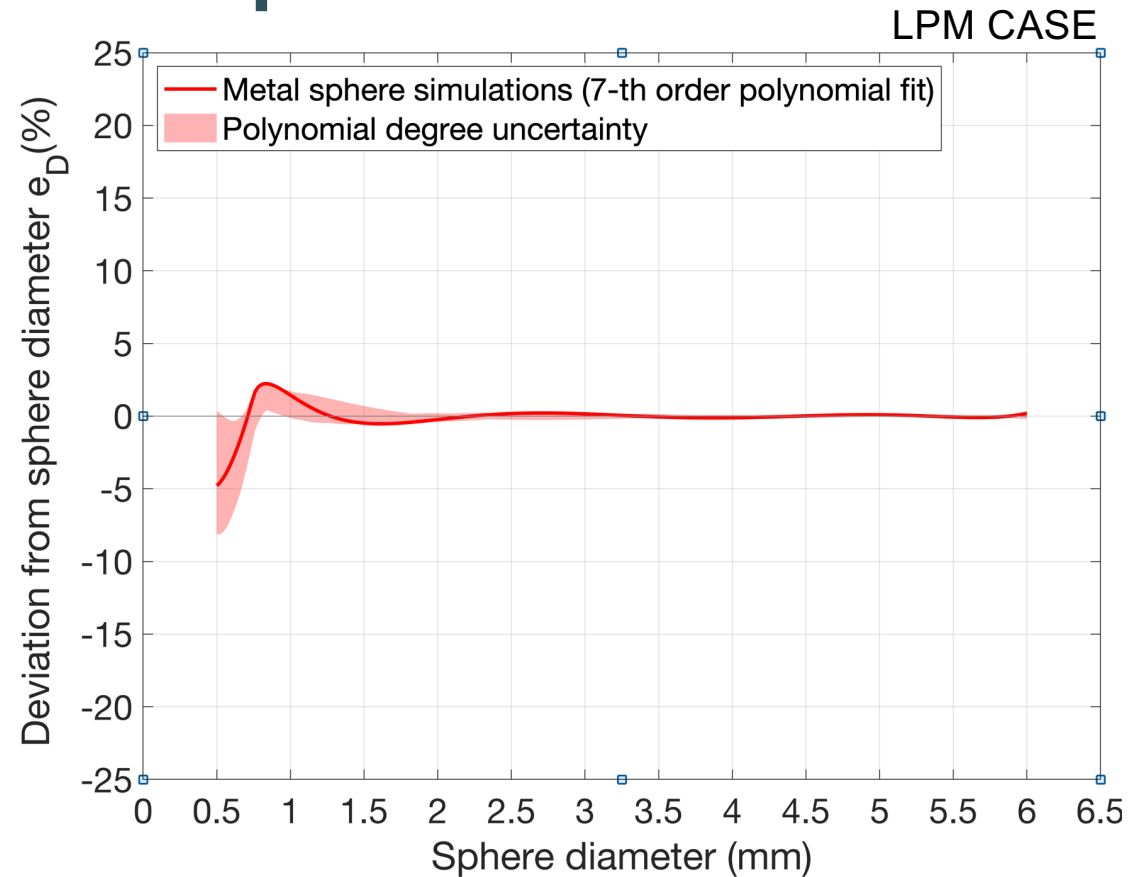
$$e_D^x (\%) = \frac{\hat{D}^x - D}{D} 100$$

$x = M$ for metal sphere;
 $x = W$ for water sphere

D = true diameter

p_k^M = estimation coefficients tuned on metal spheres

S_{max}^x = maximum shadow registered by the disdrometer in response to particle x



Diameter estimation errors: comparison with laboratory experiments

- Assumed disdrometer size-estimation-formula (tuned on metal spheres)

$$\hat{D}^x = \sum_{k=1}^{N+1} p_k^M [S_{max}^x]^{(N-k+1)} \text{ with } N \text{ in } [3, 11]$$

- Relative error metric

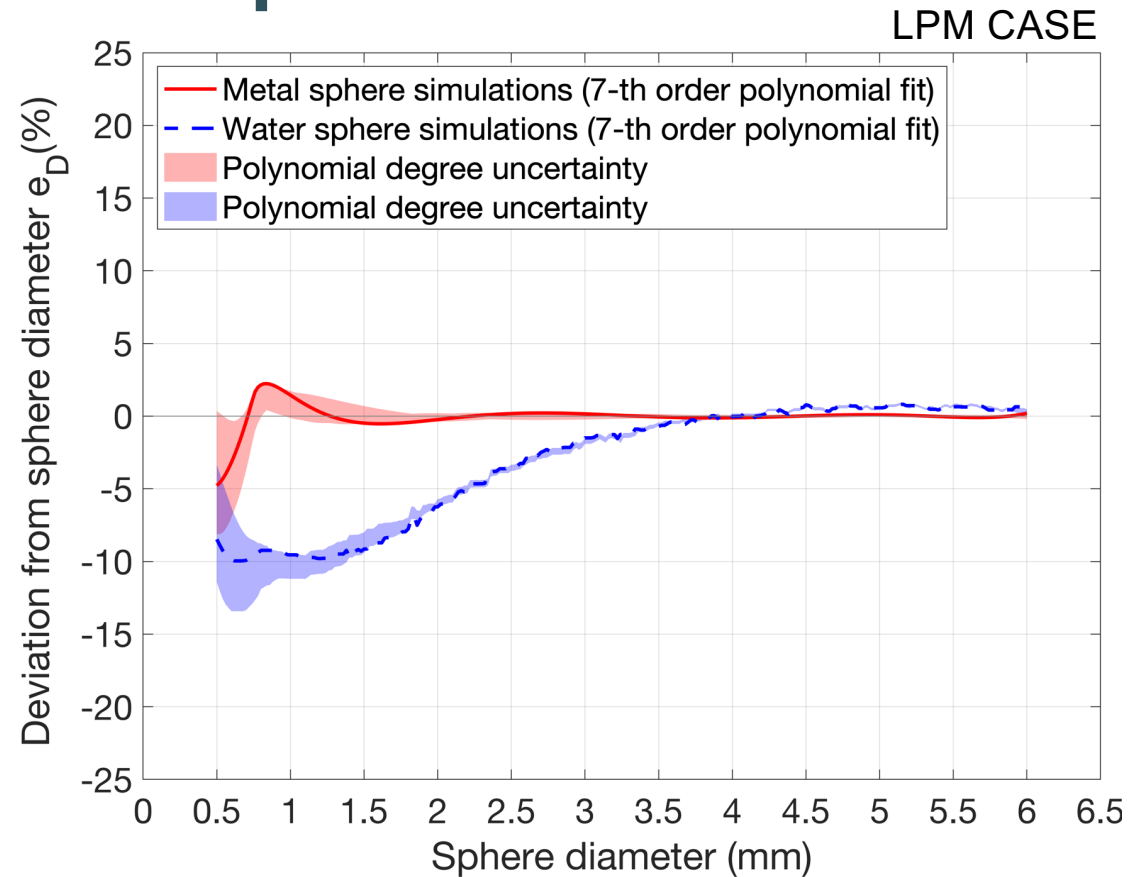
$$e_D^x (\%) = \frac{\hat{D}^x - D}{D} 100$$

$x = M$ for metal sphere;
 $x = W$ for water sphere

D = true diameter

p_k^M = estimation coefficients tuned on metal spheres

S_{max}^x = maximum shadow registered by the disdrometer in response to particle x



Diameter estimation errors: comparison with laboratory experiments

- Assumed disdrometer size-estimation-formula (tuned on metal spheres)

$$\hat{D}^x = \sum_{k=1}^{N+1} p_k^M [S_{max}^x]^{(N-k+1)} \text{ with } N \text{ in } [3, 11]$$

- Relative error metric

$$e_D^x (\%) = \frac{\hat{D}^x - D}{D} 100$$

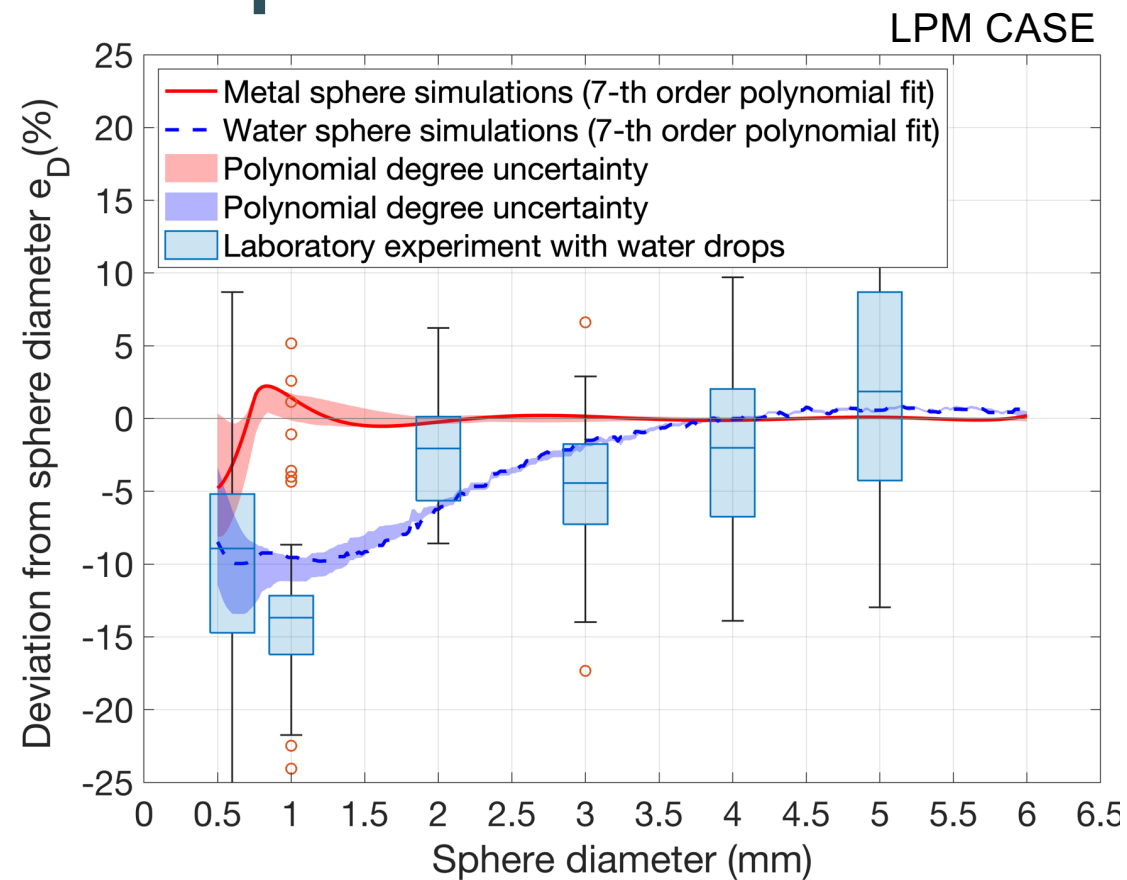
$x = M$ for metal sphere;
 $x = W$ for water sphere

D = true diameter

p_k^M = estimation coefficients tuned on metal spheres

S_{max}^x = maximum shadow registered by the disdrometer in response to particle x

Similar results are obtained for Parsivel2.



•Lab. experiment from Chinchella et al. 2026
 (<https://doi.org/10.1016/j.atmosres.2026.108865>)

Conclusions

- Geometrical shadow produced by metal spheres differs from that produced by water spheres (due to refraction)
- If shadow is defined as that produced by a metal sphere (i.e. purely geometrical shadow), but water drops are tested, some systematic size estimation errors can arise.
- Such size systematic errors underestimate smaller drops as -10% and converge toward zero for larger ones.
- These results seems to be confirmed by laboratory experiments.

Suggestions for the future

- Try checking with the disdrometer producer how really disdrometer transfer function is defined.
- Try defining an “universal” correction factor curve to adapt the metal sphere calibration into that of water
- Test the impact of size errors on Z and R in light rain regimes

