Measurement uncertainty sources of optical present weather and visibility sensors

Limitations, challenges and improvements

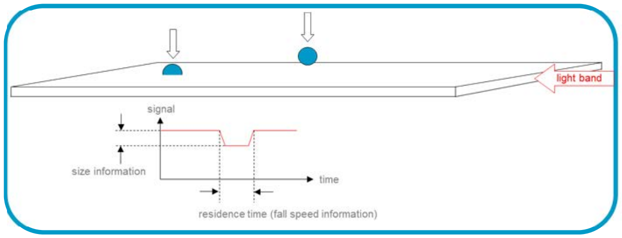
2018-10-10 / Klaus Heyn

VAISALA

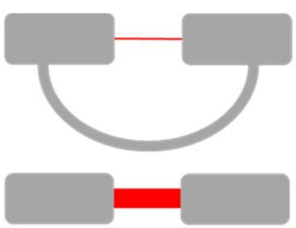
Conventional Measurement Concepts

Optical disdrometers utilize the optical attenuation behavior of precipitation particles.

The particle max. width and residence time are evaluated to determine the precipitation type.



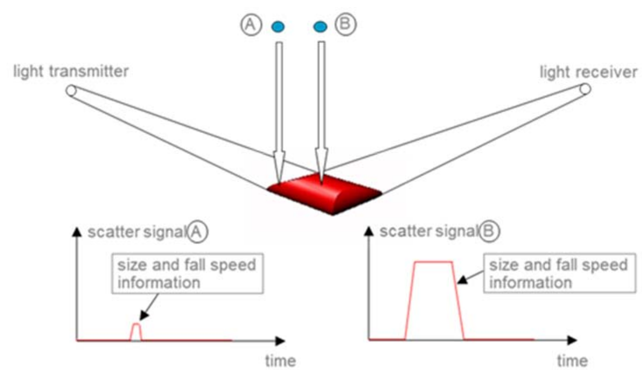
The optical transmitter generates a horizontal light band.



The optical receiver detects the signal changes when particles pass the light band.

Forward scatter sensors had originally been developed to exclusively determine visibility.

Precipitation particles that pass the measurement volume generate a sufficiently strong scatter signal "peak" and can be detected.



Due to the conical transmitter light beam the particle residence time and the detection sensitivity varies over the entire sample volume.

Several Weaknesses

Disdrometers can not determine the non-precipitation related EXCO.
➡ No full present weather and visibility reporting capabilities.

Insufficient small droplet detection capabilities limit the Drizzle, Ice Crystals and Snow Grains detections.

Precipitation type information is limited to particle signal strength and duration results.

Limited liquid / solid differentiation capabilities.

The utilization of additional information is unavoidable if a reliable precipitation detection and classification shall be achieved.

The Measurement Uncertainty Components

The measurement uncertainty of visibility and present weather sensors incorporates a significant amount of different influence factors.

Operational Disturbances

- Sun
- Snow clogging
- Spider webs
- Flying insects
- Shadowing by the mechanical structure

Physical Impacts EXCO / **Physical Impacts Precipitation**

Scatter resp. attenuation signal measurement

Physical Impacts EXCO:

- Measurement angle, value and tolerance
- Measurement wavelength
- Absorption

Physical Impacts Precipitation:

- Sample area size and definition
- Available particle signal dynamics
- Detection sensitivity distribution

A realistic measurement performance judgment needs to consider as many influence factors as possible.

General Influences

- Window dirt contamination
- Short and long term drifts
- SCU representative-ness

Comparison set-up Impacts

- Spatial homogeneity
- Measurement uncertainties of the reference sensors

Meteorological Impacts

- Representative-ness of “point” measurement
- Spatial differences

Measurement Uncertainty

It is not sufficient to state just one single aspect of this variety of impacts like the often utilized “scatter measurement accuracy” that only reflects how good the sensor responds to the SCU (Scatter meter Calibration Unit).

Field comparisons against reference sensors may cover most of the influence factors.

The Measurement Uncertainty Components

Details about the General Influences and the Operational Disturbances will not be part of this short presentation. Please see the extended abstract for further information.

General Influences
- Window dirt contamination
- Short and long term drifts
- SCU representative-ness

Operational Disturbances
- Sun
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A present weather sensor needs to incorporate a number of measures in order to reliably minimize the impact of the various operational influences and disturbances.
These must be capable to keep the measurement performance within the required borders for an untouched operation time of more than e.g. 90 days.

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The uncertainty components regarding the comparison set-up and the meteorological conditions that are common for all technologies are not subject-matter of this paper.

The Measurement Uncertainty Components

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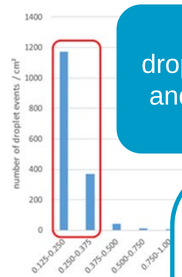
Available Particle Signal Dynamics - Small Precipitation Particles

With conventional technologies the small precipitation particle signals can not safely be differentiated from the unavoidable electrical noise spikes.

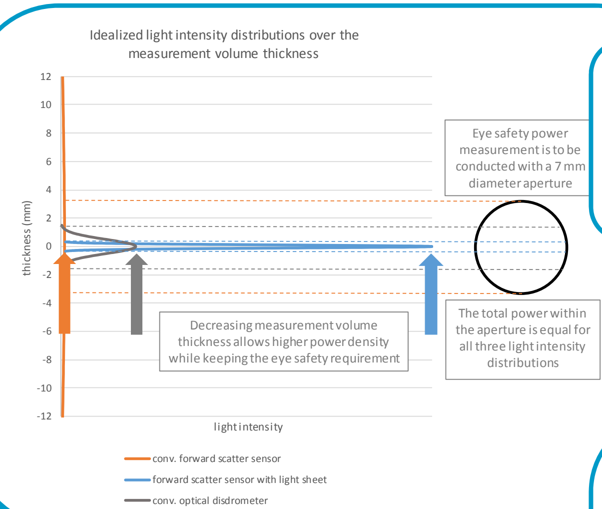
Exemplary drizzle event comparison:



The conventional disdrometer reported droplets in the 0.25 – 0.375 mm diameter class and above and underestimated the number of droplets in the 0.125 – 0.25 mm class.

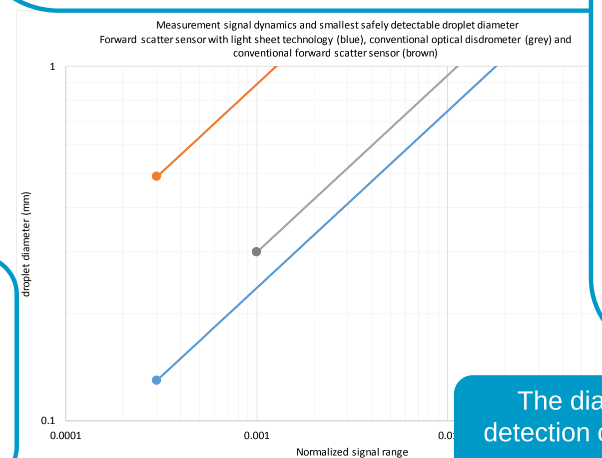
The high resolution reference identified Gamma distributed droplet sizes with diameters exclusively below 0.22 mm.

The small particles detection sensitivity is an essential precondition for all precipitation type differentiations since it defines how reliable the typically large number of very small particles in a precipitation event can be detected and identified (Ice Crystals, Snow Grains, Drizzle).



More light intensity is required within a significantly smaller cross-section when the small particle detection sensitivity shall be increased.

The diagram illustrates the impact of the sample volume thickness.



In order to overcome the limitations of conventional optical disdrometers and present weather sensors a significantly reduced sample volume thickness needs to be used in a forward scatter arrangement.

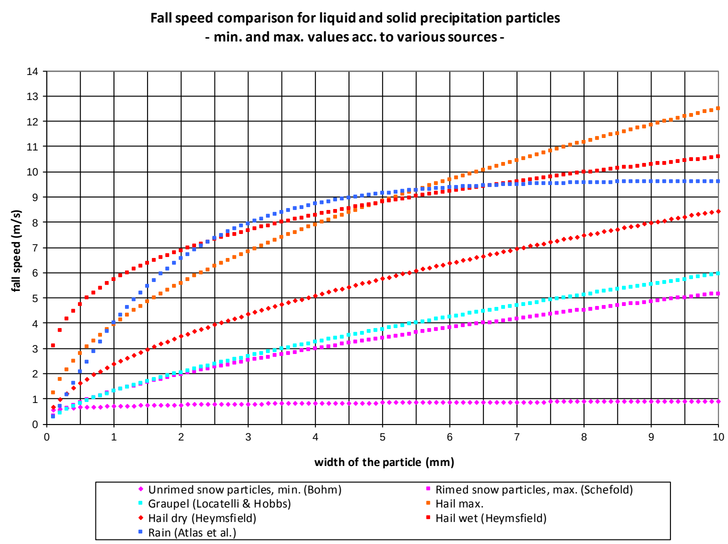
Exclusively such an arrangement allows a sufficiently sensitive and reliable small particles detection.

The diagram compares the small droplet detection capabilities for different technologies and sample volume thicknesses.

Conventional disdrometers need to base the liquid / frozen particle differentiation exclusively on size and fall speed information (typically supported by ambient temperature information).

A precipitation type determination that is exclusively based on size and fall speed incorporates significant uncertainties.

For various phenomena and especially for small particles the size and fall speed can be very similar.

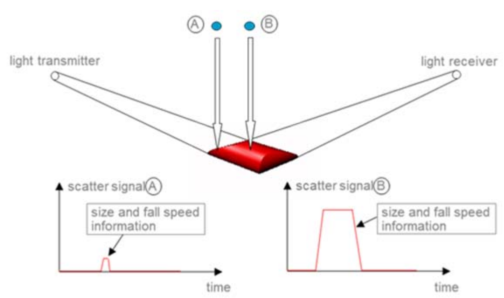


In order to decrease the precipitation type determination uncertainties the particle type differentiation should not only be based on size and fall speed.

When the scatter properties of each single particle that passes the sampling volume can be additionally taken into account the uncertainties will significantly reduce.

Conventional present weather sensors in forward scatter geometry provide normally a very poor size / fall speed information if at all.

The precipitation type determination capability is naturally very limited.



The uncertainties can be decreased when the scatter measurement from a conical measurement volume is combined with other information like a separate liquid water content measurement.

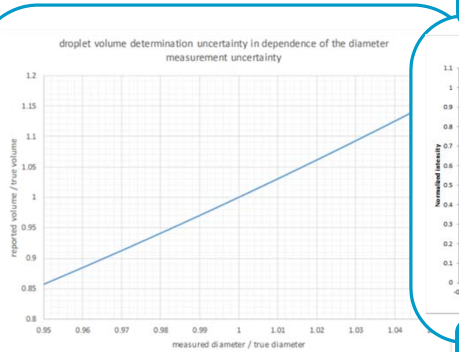
In order to allow single particle scatter properties evaluations, a present weather sensor should incorporate a high and homogenously distributed detection sensitivity in combination with a sufficiently high sampling and data processing speed.

These are as well the indispensable preconditions for a reliable identification and reporting of mixed precipitation.

Sample Area Size and Definition

Typically the detection sensitivity along the sampling area of conventional optical disdrometers is not homogenously distributed.

Diameter determination errors of 5% and more are expectable.

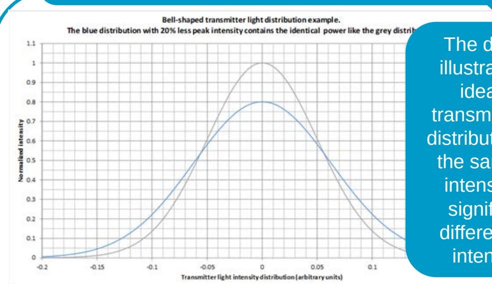


The diagram illustrates the droplet volume determination error in relation to the diameter measurement error.

Additionally the sampling area size is not very well defined (undercatch due to shadowing by the mechanical structure).

The sensitivity distribution for conventional present weather sensors is typically less even than for optical disdrometers.

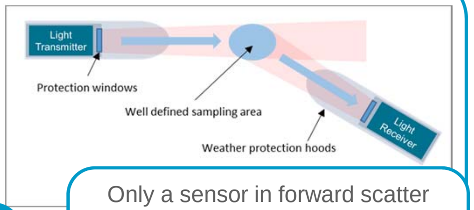
Sampling volume portions with lower transmitter intensity will scatter less signal towards the receiver which has a direct impact on the droplet size estimation.



The diagram illustrates two idealized transmitter light distributions with the same total intensity, but significantly different peak intensities.

The SCU based calibration adjustment utilizes the total transmitter light intensity and diffuses a defined portion into the receiver field of view.

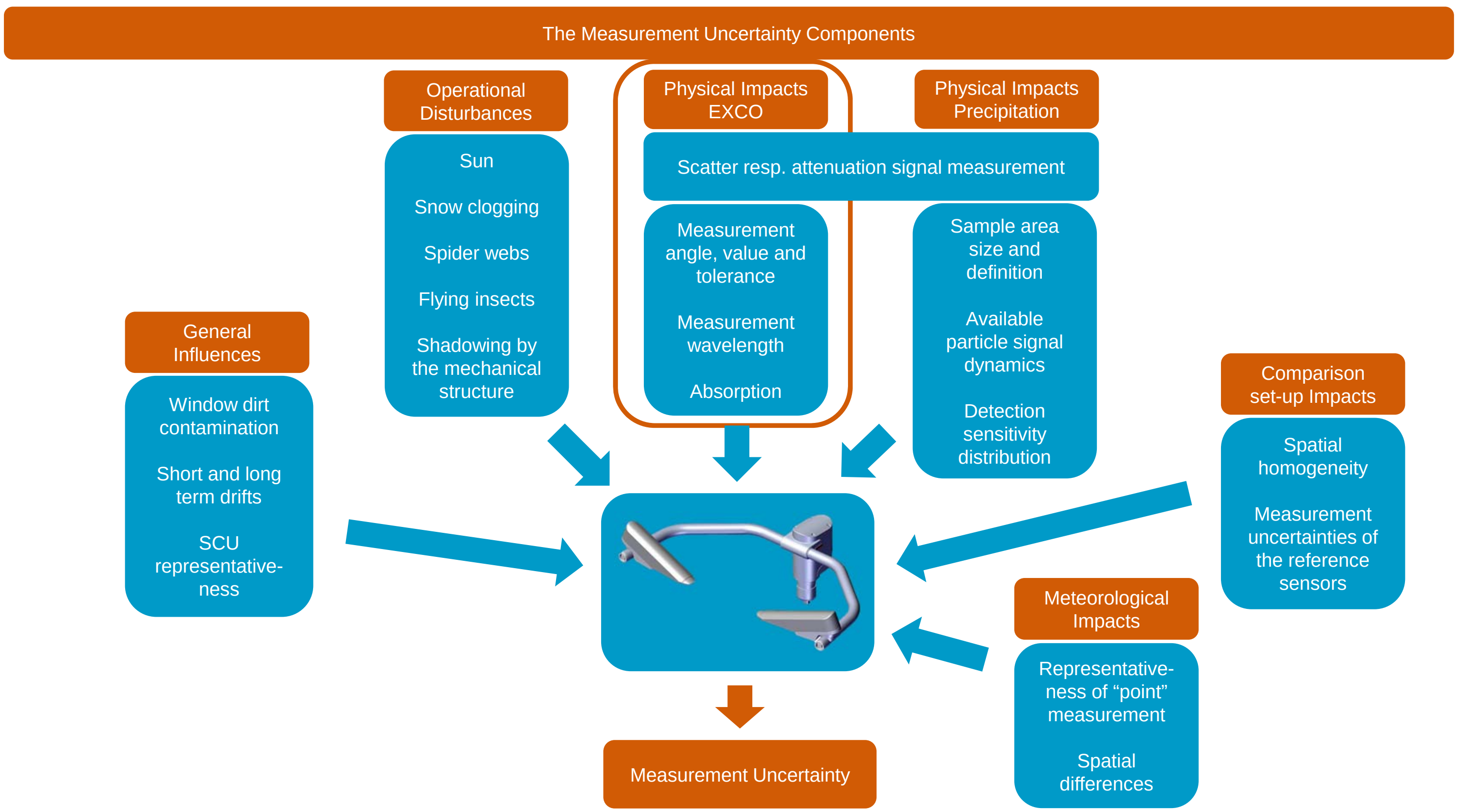
It will apply only correctly to the liquid water content determination when the transmitter light intensity distribution is sufficiently comparable from unit to unit. This is typically not the case.



Only a sensor in forward scatter geometry can provide a sampling volume that is sufficiently remote from any enclosure parts and the mechanical structure.

A visibility and present weather sensor should provide a clearly defined sampling area with a most even precipitation particle signal strength distribution.

A visibility and present weather sensor should allow a field calibration of both, visibility and precipitation intensity.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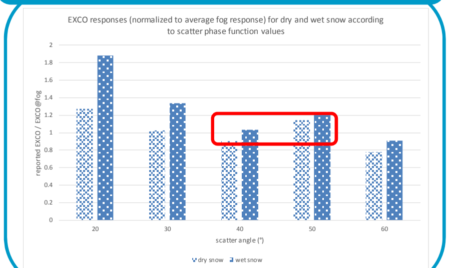
Measurement angle - value and tolerance

The optimal forward scatter angle of 42° provides the lowest achievable visibility measurement uncertainties for fog and snow.

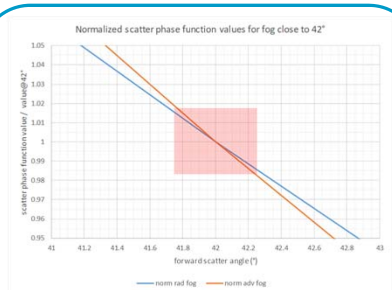


The figure illustrates the values of the scatter phase functions for wet and dry snow relative to average fog for different angles from 20° to 60°.

An angle between 40° and 50° obviously provides the best agreement.

For a representative calibration of the fog and snow responses a forward scatter angle of 42° is desirable.

The figure shows the radiation and advection fog scatter phase functions for an angle range from 41° to 43°.



If the fog response error after SCU calibration shall be kept below 2%, a forward scatter angle tolerance below +/-0.25° is mandatory.

Even the optimal forward scatter angle does not allow to apply the fog calibration directly to rain.

The figure exemplary illustrates the scatter signal strength overestimation for rain

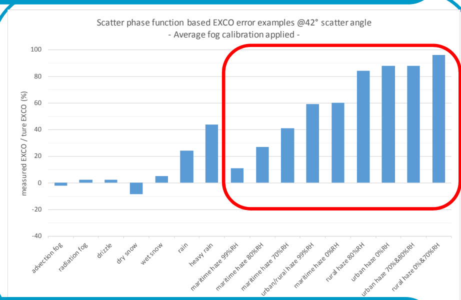
Conventional forward scatter sensors typically need to live with these measurement uncertainties since a dedicated calibration of the precipitation related EXCO portion is not resp. can not be applied.

Only a precipitation type, intensity and size distribution depending determination of the precipitation related EXCO portion allows to reduce the visibility measurement uncertainty in rain.

Measurement wavelength and Absorption

The expectable worst-case signal strength for dry rural haze is approximately 95% higher than for a fog/mist with identical EXCO.

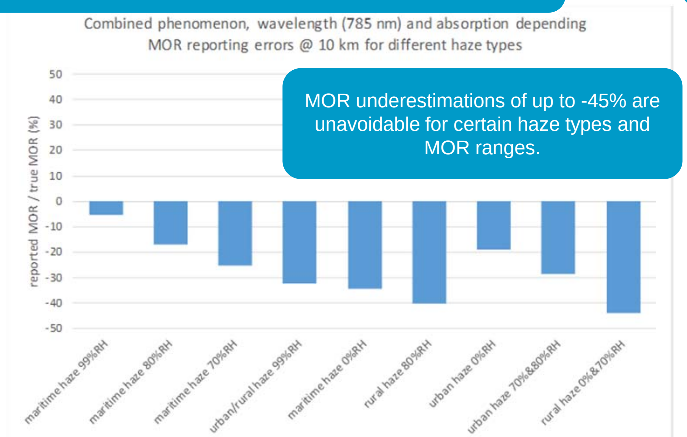
As well other haze types show large measurement angle depending signal strength overestimations between 85% and 90%.



Additionally to the scatter angle related errors as shown in the figure above the utilized measurement wavelength and the light absorption need to be taken into account.

Especially the urban aerosol contains a significant amount of light absorbing particulates that can't be neglected.

The figure illustrates the final impact on the reported MOR for different haze types when the scatter angle, the wavelength and the absorption impacts are considered.



MOR underestimations of up to -45% are unavoidable for certain haze types and MOR ranges.

The moderate MOR error magnitude like illustrated can only be achieved when a measurement wavelength in the near infrared region is used.

Only an obscuration type and measurement wavelength specific calibration would allow to reduce the significant MOR reporting uncertainties in haze further.

Novel technologies can significantly reduce the measurement uncertainties of visibility and present weather sensors

Thanks for Your Attention

and Welcome to an Expert Talk at Booth #9000