UNCERTAINTY SOURCES THAT LIMIT THE PRECIPITATION IDENTIFICATION / QUANTIFICATION AND EXTINCTION COEFFICIENT DETERMINATION CAPABILITIES OF OPTICAL PRESENT WEATHER AND VISIBILITY SENSORS

Klaus Heyn[1], Jan Lönnqvist[2], Tommi Linna[2]

[1]Vaisala GmbH, Hamburg, Germany
[2]Vaisala Oyj, Helsinki, Finland

ABSTRACT

The common and the slightly different performance limitations of optical visibility and present weather sensors need to be seen in the context of the utilized measurement technology. We will identify and disclose the common measurement uncertainty sources and their impact on the precipitation identification / quantification and extinction coefficient determination capabilities.
This paper shall help the users to understand the natural limitations of certain measurement technologies in order to formulate realistic and technically and economically achievable requirements. Conventional optical disdrometers as well as forward scatter measurement based present weather sensors incorporate a number of technology depending weaknesses that will be discussed in detail.
Optical disdrometers resp. laser disdrometers utilize the attenuation behavior of precipitation particles and decide about the precipitation type by evaluating the particle width and fall speed and a correlation to the respective scientific models. The visibility determination capabilities of this technology is very limited since only the precipitation particle related portion of the extinction coefficient can be determined.
Forward scatter sensors in contrast are optimized to measure the total extinction coefficient under a typical angle in the range from 30° to 50°. The possibility to estimate as well size and residence time of precipitation particles that pass the measurement volume enabled the design of the conventional present weather sensors in forward scatter geometry. However, the conical transmitter light beam typically incorporates an uneven intensity distribution. Depending where a precipitation particle passes the measurement volume the particle residence time and the detection sensitivity may vary significantly and keeps the size / fall speed analysis capabilities on a rudimentary level. In order to reduce the incorporated measurement and detection uncertainties to an acceptable level the utilization of additional information is necessary and unavoidable.
The detailed discussion will illustrate that a reliable detection and classification especially for small, mixed and frozen precipitation particles is hard to achieve with the conventional technologies.

MEASUREMENT CONCEPTS INTRODUCTION

Optical disdrometers

Optical disdrometers utilize the optical attenuation behavior of precipitation particles (transmissometer concept) and decide about the precipitation type by evaluating the particle max. width and fall speed. This kind of measurement devices are called “optical disdrometer” or "laser disdrometer“. The optical transmitter generates a horizontal light band, the optical receiver is positioned vice versa and detects the signal changes when particles pass the light band.

Figure 1. *Side and top view of an optical disdrometer.*

Precipitation particles that pass the light band generate signal drops.

- The strength of the signal drop provides information about the particle size.
- The particle residence time in the light band contains the fall speed information.

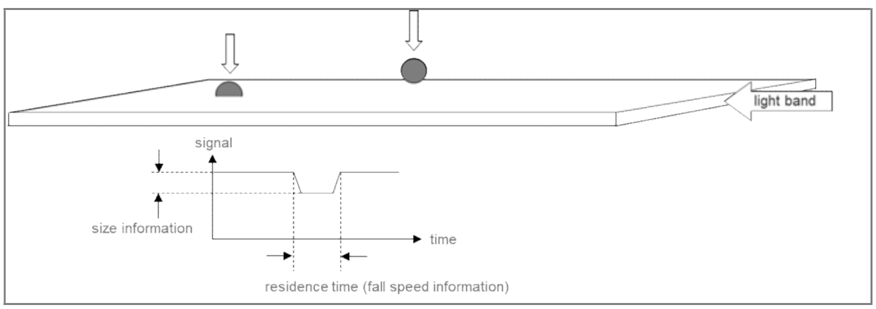

Figure 2. *Optical disdrometer concept.*

Visibility and present weather sensors in forward scatter geometry

Forward scatter sensors had originally been developed to exclusively measure visibility under a typical forward scatter angle in the range of 30°…50°.
However, the possibility to detect as well size and residence time of precipitation particles that pass the measurement volume enabled the design of present weather sensors in forward scatter geometry.
Typically a conical transmitter light beam is combined with an optoelectronic receiver.

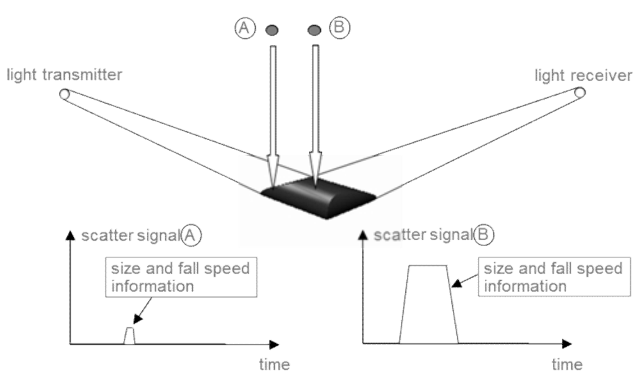

Figure 3. *Droplet responses of an optical sensor in forward scatter geometry.*

Due to the conical transmitter light beam the “height” of the measurement volume (and therefore the particle residence time) and the sensitivity varies over the entire measurement volume. If a reliable precipitation detection and classification shall be achieved, the utilization of additional information is unavoidable.
The Vaisala FD12P and PWD technology for example utilizes the information about the water content of precipitation particles from a capacitive grid type sensor RAINCAP© and the temperature as additional parameters to the forward scatter signal.

THE MEASUREMENT UNCERTAINTY COMPONENTS

The measurement uncertainty of visibility and present weather sensors is a very complex parameter that incorporates a significant amount of different influence factors.
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).
A realistic measurement performance judgment needs to consider as many influence factors as possible. Typically field comparisons against reference sensors need to be conducted in order to cover these.

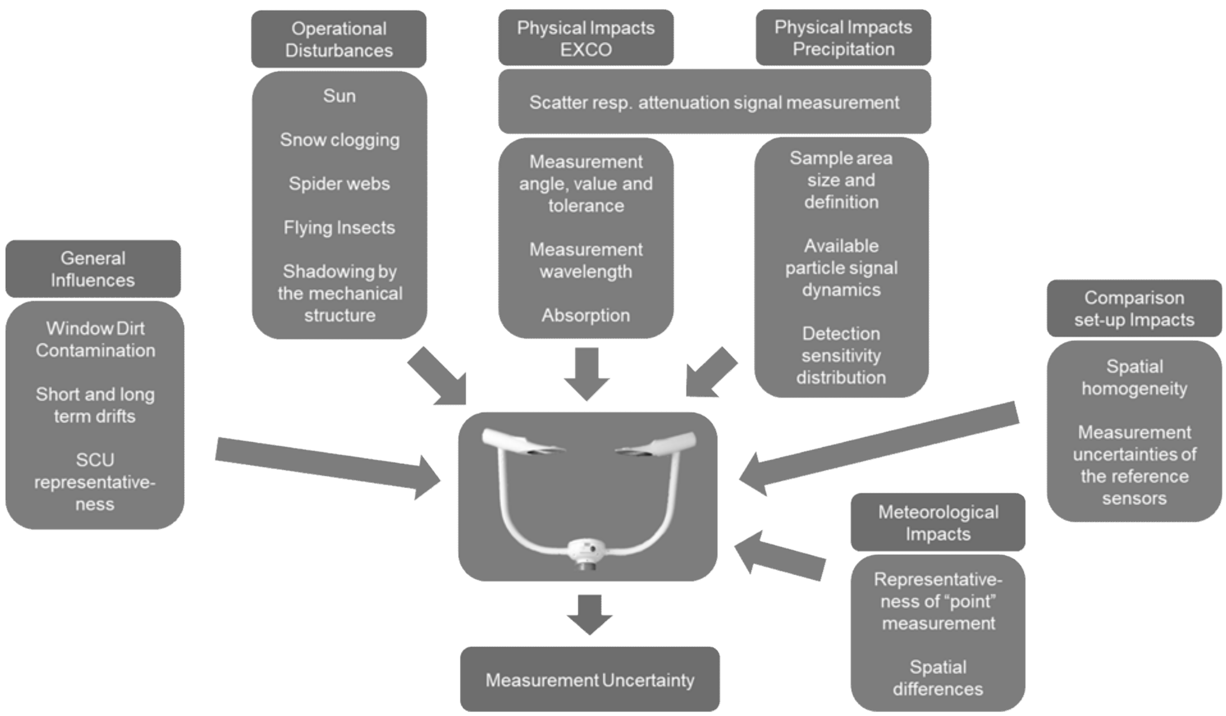

Figure 4. *The measurement uncertainty sources of optical present weather and visibility sensors.*

GENERAL INFLUENCES

Window Dirt Contamination and other Short and Long-term Drifts

Optical disdrometers that are based on the transmittance measurement allow a continuous consideration of any effects that influence the total signal strength (window dirt contamination, light source power, receiver sensitivity etc.).
The remaining impact of a not perfect reference level estimation on the measured precipitation particle width can be assumed to be almost negligible. Even low visibility conditions will only have a very small impact on the mean transmittance reduction and the uncertainty for the estimation of the reference signal strength for the precipitation particle measurement.
The major source of uncertainty for the optical disdrometers is not the window dirt contamination, but the limited detection sensitivity, the limited light band homogeneity and the not negligible shadowing impact.
Many present weather sensors in contrast provide no or only limited or optional window dirt contamination measurement and correction. In some cases only a detection, but no correction is foreseen. Consequently the windows need to be cleaned more often; always when the window dirt contamination has reached a critical level that might be performance relevant when not corrected for.
It needs to be considered that the window dirt contamination influences directly the strength of the scatter signal response. Signals from single precipitation particles that represent the particle size and the scatter signal from the conglomerate of very small hydro- and/or lithometeors that generate the typical visibility reducing phenomena like fog, mist and haze are proportionally damped by a reduced optical window transparency of the sensor due to accumulated dirt.
Growing measurement uncertainties between the window cleanings are unavoidable if the dirt contamination is not or not sufficiently measured and corrected for. Consequently the windows need to be cleaned much more often when the measurement performance shall be maintained.

While the window dirt contamination impact for the EXCO (Extinction Coefficient) is proportional (reduction to 90% window transparency reduces the EXCO to 90% of it’s real value), the impact on the particle signal generates a more severe uncertainty for the liquid water content determination (see Figure 5 below).

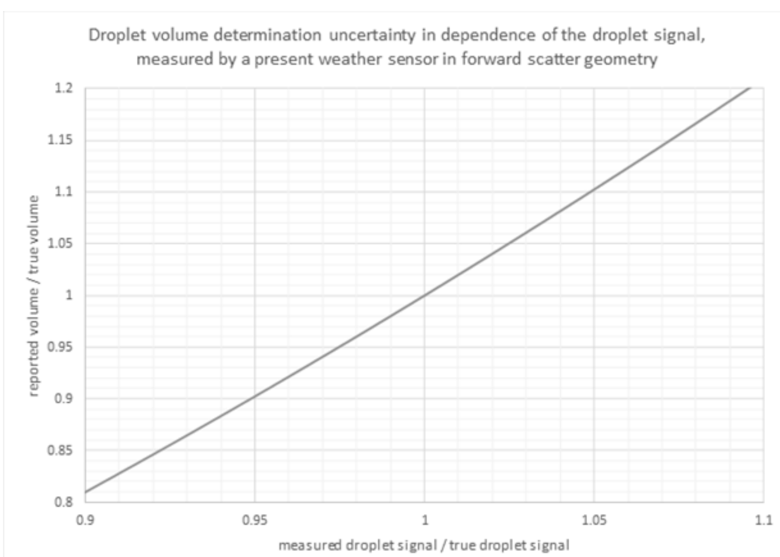

Figure 5. *Droplet signal measurement error impact on the determined droplet volume for a forward scatter sensor.*

With e.g. a droplet signal underestimation of 90% from it’s true value, a volume underestimation of ~20% must be expected. This volume underestimation would consequently result in a proportional underestimation of the liquid water content and therefore of the precipitation intensity and liquid water accumulation determination.

In order to keep the window dirt contamination impact potential as low as possible a visibility and present weather sensor should be equipped with long transmitter and receiver hoods in look-down geometry that provide an optimal protection against wind driven precipitation and other contaminants.
A window dirt contamination determination and correction is mandatory and needs to be separately carried out for the light transmitter and the light receiver windows and should enable to keep the measurement performance (visibility and precipitation) within the required borders for an untouched operation time of at least 90 days.

The light transmitter intensity, the light receiver sensitivity and the mechanical structure over time, temperature and other environmental influences must be stable enough to keep the measurement uncertainty within the desired borders even when the various other uncertainty components are considered.

SCU (Scatter meter Calibration Unit) representativeness

Essential precondition for developing and maintaining a visibility and present weather sensor with sufficient performance is the availability of a scientifically valid and regularly maintained calibration chain.
The SCU (Scatter meter Calibration Unit) of a visibility and present weather sensor and its attachment precision must allow to adjust (calibrate) the sensor's scatter signal response within narrow borders of typically 2%...3% to allow consideration of the various other uncertainty components.
The validity of an SCU need to be regularly verified. In order to guarantee the traceability, SCU adjusted forward scatter sensors need to be continuously compared with reference sensors in an outdoor testfield and under all weather conditions. See ICAO "Manual of Runway Visual Range Observing and Reporting Practices" DOC 9328 AN/908, Section 8.3 and Section 9.4.

OPERATIONAL DISTURBANCES

Sun

Sun radiation on the photoelectric receiver needs to be avoided for optical disdrometers as well as for optical forward scatter sensors. In both cases, the strength of the electrical noise will increase with increasing illumination of the photoelectric sensor element and the risk of false particle detections increases significantly.
Optical disdrometers cannot utilize a look down geometry that avoids direct sun radiation during sunrise resp. sun set to enter the sensor window and optical system. Even the transmitter and the receiver are placed directly opposite and in a short distance from each other, sunrays under certain angles may enter the disdrometer’s window.
As well, a number of forward scatter sensors do not utilize a look down geometry and expose the sensor window and optical system directly to all kinds of disturbances.
The strength of the electrical noise increases with increasing illumination by daylight and/or direct sunlight of the photoelectric sensor element and the risk of false particle detections and too pessimistic visibility reporting increases significantly.

Sun radiation on the photoelectric receiver needs to be avoided for all optical sensors that are utilized to determine visibility and/or precipitation.

Snow Clogging and Window Protection

A number of present weather sensors do not utilize the look down geometry and therefore expose the sensor windows directly to wind driven precipitation and other contaminants. This results in a rapidly growing window dirt contamination and the risk of snow clogging situations. Some sensors do not provide a sufficient heating power resp. heating concept for the windows and the weather protection hoods.
In worst-case moisture can build-up on the windowpanes and disturbing snow and ice will not melt fast enough or not at all.

The sensor windows should not be directly exposed to wind driven precipitation and other contaminants. It is recommendable that a visibility and present weather sensor utilizes a look down geometry whenever possible.
The weather protection hoods should be equipped with an efficient heating system that safely prevents from ice or snow build-ups.

Spider Webs

Optical disdrometers suffer from the fact that spider webs can easily be placed within their sampling area. The opposite enclosure parts and the connecting structure allow the spiders to find a sufficient number of supporting points for their web construction.
The silk and/or collected dewdrops can easily generate significant false particle detections.

Spider webs that are partly or entirely placed in their measurement volume may disturb as well a number of present weather sensors that do not utilize the look down geometry. These sensors react with low visibility (MOR, Meteorological Optical Range) indications and false particle detections.

Generally, a visibility and present weather sensor should not expose any supporting points that would allow placing a spider web inside or close to the measurement volume.

Flying Insects

Significant MOR reductions reported by forward scatter sensors have been observed by various Meteorological Institutes and Weather Services. These reductions where clearly related to the presence of insects in the measurement volume.
The transmitter light in combination with the heat radiation from the weather protection hoods seem to attract mosquitos and other small flying insects during specific seasons and climate conditions.
Especially during sunrise and sunset in humid air, insect swarms may reside close to and/or inside the measurement volume for periods that are sufficiently long to disturb the measured atmospheric scatter signal and reduce the reported MOR. Unnatural MOR "drops" even below 1000 m over time spans of several minutes can be the consequence.

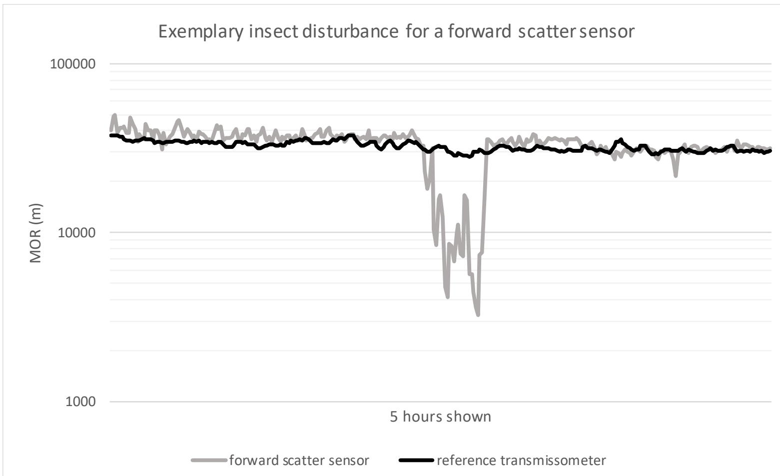

Figure 6. *Flying insects' disturbance example.*

The example in Figure 6 illustrates a flying insects disturbance that lasted ~30 minutes during sunset and reduced the MOR reporting of a forward scatter sensor from 30…40 km down to 3…4 km.

A visibility and present weather sensor should incorporate an effective insect filtering algorithm that is based on an identification of flying insects in the measurement volume.

Shadowing by the Mechanical Structure

Optical disdrometers must utilize a measurement area that covers the entire path length between light transmitter and light receiver protection windows.
It is unavoidable that the enclosures generate a significant wind direction depending “shadowing” of the measurement area (see Figure 7).

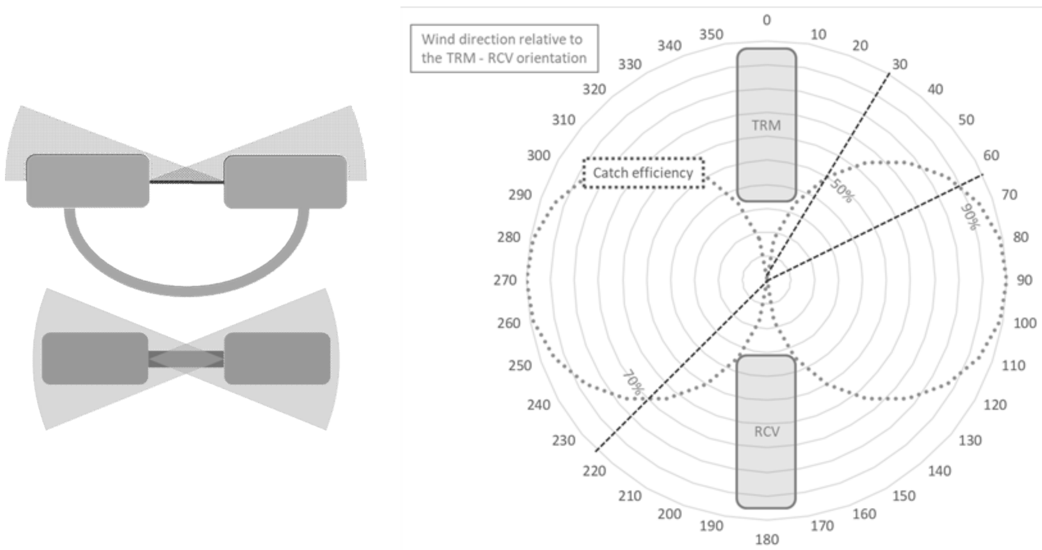

Figure 7. *Sampling area shadowing of optical disdrometers.*

Comparison tests with differently orientated optical disdrometers showed a not negligible masking effect by the disdrometer enclosure. The capture efficiency was found to be significantly higher for wind directions perpendicular to the transmitter-receiver axis of the instruments.

As well rain gauges suffer from an uncertain capture efficiency. Various comparison tests show an uncertainty that is very similar to a shadowing impact. Due to up winds at the enclosure a significant wind speed dependent under-catch occurs.

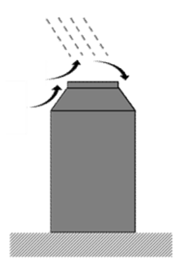

Figure 8. *Under-catch due to upwind effects at a rain gauge.*

In order to keep the uncertainty due to missed particle detections in the sampling volume low, a visibility and present weather sensor should avoid shadowing effects by the mechanical structure.

COMPARISON SET-UP AND METEOROLOGICAL IMPACTS

A realistic measurement performance judgment needs to consider as many influence factors as possible. Typically, field comparisons against reference sensors are conducted in order to cover these.
However, the measurement uncertainties of the utilized reference sensors, the limited homogeneity and the resulting spatial differences in the visibility and precipitation events incorporate a number of not negligible uncertainties that need to be considered when sensor intercomparisons are conducted and evaluated.
These uncertainty components regarding the comparison set-up and the meteorological conditions that are common for all technologies are not subject matter of this paper.

PHYSICAL IMPACTS – PRECIPITATION

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.
For the exemplary drizzle event in Figure 9 below the high resolution reference sensor (right) identified droplets with diameters exclusively between 0.14 and 0.22 mm.
The optical disdrometer in contrast (left) falsely reported droplets in the 0.25 – 0.375 mm diameter class and above and underestimated the number of droplets per cm² in the 0.125 – 0.25 mm class.
The exemplary size distribution of a drizzle event illustrates that a significant random number of false diameter determinations seems unavoidable.

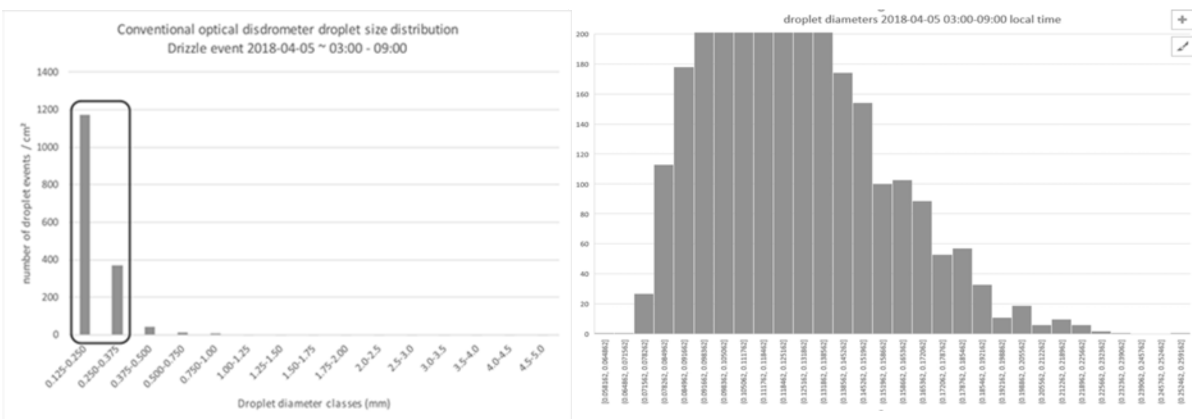

Figure 9. Drizzle event example.

Present weather sensors that utilize a transmitter light cone have naturally a lower light power density than optical disdrometers if the eye safety requirements shall be met, since the light is distributed over the entire cross sectional area of the cone.
These forward scatter arrangements may provide a ~0.5 mm diameter droplet detection sensitivity in the center of the measurement volume. However, the sensitivity decreases rapidly for droplets that do not pass the measurement volume center.
For that reason only a low number of the present drizzle particles will be identified and the event will be underestimated or even partly ignored.

The Vaisala present weather sensors FD12P, PWD and FS11P for example utilize information about the water content of precipitation particles and the temperature as additional parameters to the forward scatter signal that contains the information about the particle size.
In order to enable reliable precipitation detection and classification this “look and feel” concept allows to additionally check if the detected droplet signals are “wet” and therefore allows to operate with a higher detection sensitivity for the optical measurements since unwanted noise spikes can be identified more reliably. The water content of the precipitation is estimated with a capacitive grid type sensor RAINCAP©.

The small particles detection sensitivity is an essential precondition for all precipitation type differentiations since it defines how reliable the 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 when the small particle detection sensitivity shall be increased under consideration of the naturally given signal to noise ratio that limits the particle detection sensitivity of the optical receiver.

The Figure 10 below illustrates exemplary the resulting smallest detectable droplet diameter with the currently available technologies in comparison with the optimal detection sensitivity.

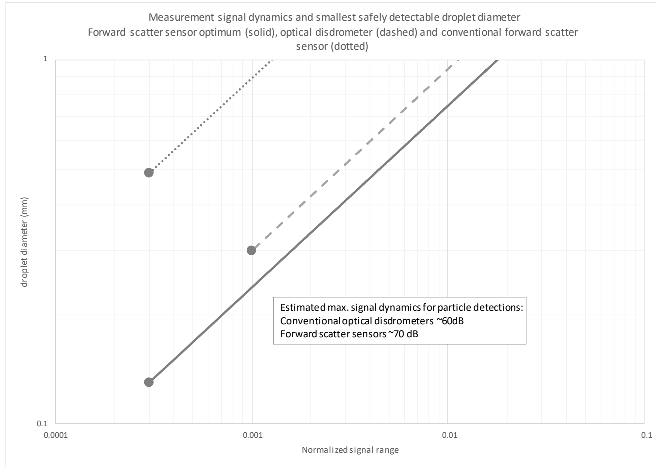

Figure 10. *Impact of the effective light intensity on the small droplet detection capability.*

In order to overcome the limitations of the conventional optical disdrometers and present weather sensors a larger effective light intensity needs to be used in connection with a forward scatter arrangement.
Exclusively such an arrangement would allow a sufficiently sensitive and reliable small precipitation particle detection.

Available Particle Signal Dynamics, Detection Sensitivity Distribution – Precipitation Type Differentiation

Optical disdrometers need to base the liquid / frozen particle differentiation exclusively on size and fall speed information (typically supported by ambient temperature information), which is not fully reliable in certain aspects.
With decreasing particle sizes their fall speeds tend to be more and more similar. A fall speed only based differentiation is not sufficient.

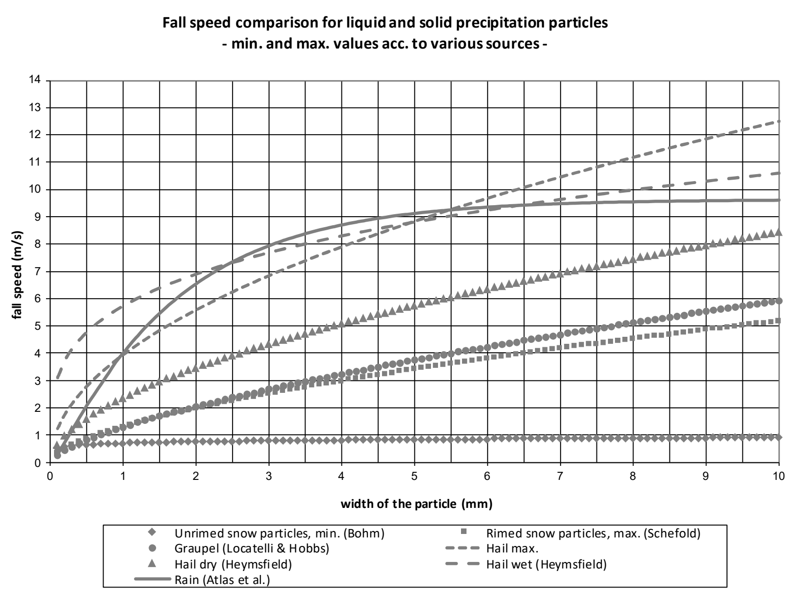

Figure 11. *Fall speed examples for different precipitation particle types and sizes.*

Same applies for the differentiation between rain drops and wet snow flakes, snow pellets and hail stones. The size and fall speed can be very similar for these phenomena (see Figure 11 above). Present weather sensors in forward scatter geometry provide normally only a poor size / fall speed information if at all. These sensors typically do not conduct single particle evaluations, but process mean values over a typical one minute or longer observation period instead. The precipitation type determination capability is naturally very limited.
In order to decrease the uncertainties, the scatter measurement from a conical measurement volume may be combined with other information like a separate liquid water content measurement.

Many of the optical disdrometers and present weather sensors do not have the capability to detect Snow Pellets (small Hail, Graupel) resp. Hail directly. The size and fall speed only does not allow to safely differentiating hailstones from large raindrops (see Figure 11 above).
Typically an additional impact sensor is utilized that tries to identify the “large and frozen” appearance of the precipitation particles. A reliable optical identification is not possible with the conventional disdrometer and forward scatter technologies.

Sample area size and definition

Depending on the individual inhomogeneity of the detection sensitivity along the measurement area of optical disdrometers, diameter determination errors of >= 5% need to be expected.
This leads already to remarkable volume and therefore LWC (Liquid Water Content) determination errors (see Figure 12 below).

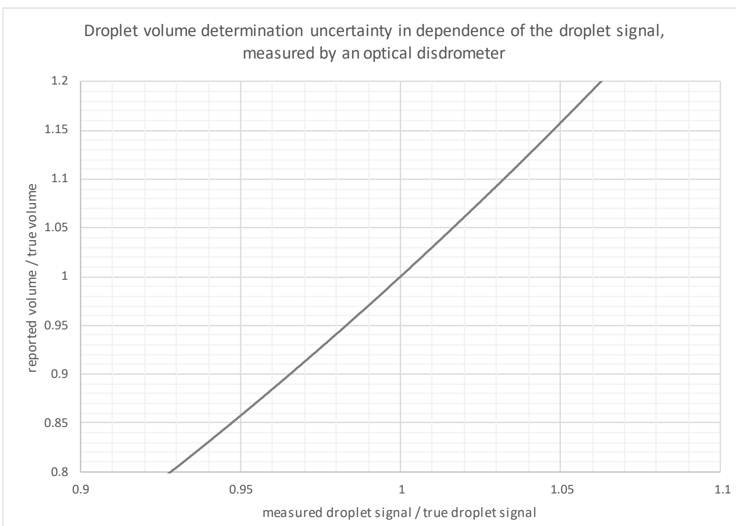

Figure 12. *Droplet signal measurement error impact on the determined droplet volume for an optical disdrometer.*

Furthermore the sampling area is not very well defined since it naturally starts and ends directly at the enclosure resp. weather protection hood.
Only a sensor in forward scatter geometry can provide a sampling volume that is sufficiently remote from any enclosure parts and the mechanical structure in order to avoid shadowing effects by enclosure parts.

For present weather sensors the LWC calibration is more complicated than for optical disdrometers since the sensitivity distribution is naturally less even and steel balls with known diameters can not be used since the scattered light portion and not the attenuation is utilized for the particle size measurement.
The LWC calibration is determined from the total scatter measurement sensitivity over the entire measurement volume (SCU, scatter plates). Therefore, it applies only correctly when the transmitter light intensity distribution is repeatable between different sensors of the same type. This is normally not the case; typically there are remarkable transmitter to transmitter and receiver viewing field differences that do not allow to apply the total scatter signal calibration to the single precipitation particle scatter signal strength which represents the liquid water content of the single droplet. For this reason the LWC resp. the LWA (Liquid Water Accumulation) reporting of conventional present weather sensors is more uncertain than the reported LWA from optical disdrometers.
The light distribution within the cross-sectional area of transmitter light cone and receiver viewing field dictate the size of the sampling volume and the relative forward scatter signal strength. Sampling volume portions with lower transmitter intensity will scatter less signal towards the receiver which has a direct impact on the droplet size estimation and therefore on the precipitation intensity determination.
The SCU based calibration adjustment utilizes the total transmitter light and diffuses a defined portion into the receiver field of view. This calibration integrates the light intensity over the entire sampling volume.
However, the transmitter light intensity may distribute slightly different, based on the tolerances of the light source and the optical system. The Figure 13 illustrates the effect with an idealized Bell-shaped intensity distribution. The peak value varies; even the total intensity is the same.

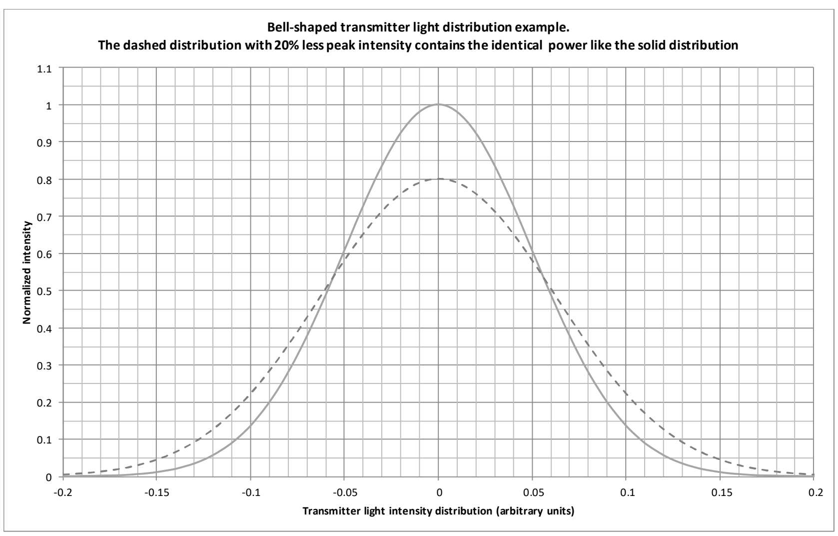

Figure 13. *Bell-shaped transmitter light intensity distributions with different peak power, but identical total power.*

A visibility and present weather sensor allows a SCU based field calibration adjustment of both, visibility and precipitation intensity only when the sampling volume size and the transmitter light intensity distribution are clearly defined and repeatable from sensor unit to sensor unit.

PHYSICAL IMPACTS – EXTINCTION COEFFICIENT

Optical disdrometers do not allow a measurement of the EXCO apart from the EXCO component that is directly related to the precipitation particles.
However, safety relevant visibility reductions are never exclusively related to precipitation particles only, but as well to the small fog particles that can not be detected by any optical disdrometer.
With ~0.2 m the measurement base line length of disdrometers is much too short to allow a reliable measurement of the total extinction coefficient and therefore the visibility (MOR) for litho- and hydrometeors like present in fog, mist, haze or dust.

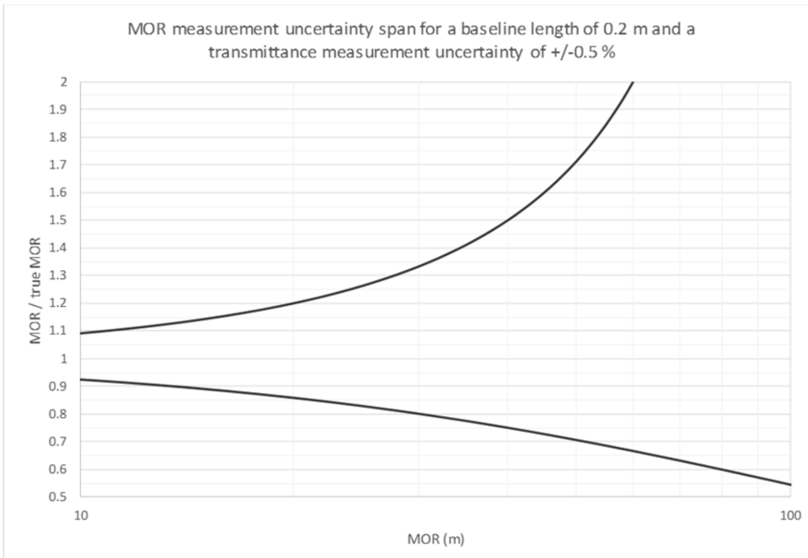

Figure 14. *MOR reporting uncertainties for an optical disdrometer.*

Figure 14 shows the resulting MOR reporting span for a practically achievable transmittance measurement uncertainty of +/-0.5%. Already above 12 m the MOR reporting uncertainties will exceed 10% and increase rapidly to unacceptable large deviations for MOR beyond 20…30 m. Consequently a serious MOR reporting is not possible with optical disdrometers.

Measurement angle

However, present weather sensors are typically based on a forward scatter arrangement that allows an EXCO measurement between 300/km and 0.06/km, corresponding to an MOR between 10 m and 50 km.

It needs to be pointed out that a number of sensors do not utilize the forward scatter angle range of 40°…45° that had been found optimal. The FAA document "United States Experience Using Forward Scatter Meters For Runway Visual Range" DOT/FAA/AND-97/1, Section 2.3.1 substantiates these findings:
"In the development of the US RVR forward scatter meter, described in Section 4.5.1.2, it was found that using a nominal scattering angle of 42 degrees gives approximately equal calibration in fog and snow."
Only this angle allows to determine the EXCO in snow reliably when the sensor is calibrated for an optimal fog response. Other measurement angles increase the unavoidable uncertainties.
Related ICAO "Manual of Runway Visual Range Observing and Reporting Practices" DOC 9328 AN/908, Paragraph 8.1.3 b citation:
"*At an angle of approximately 40 degrees, fog and snow have the same ratio of scattering to extinction coefficient…"*

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

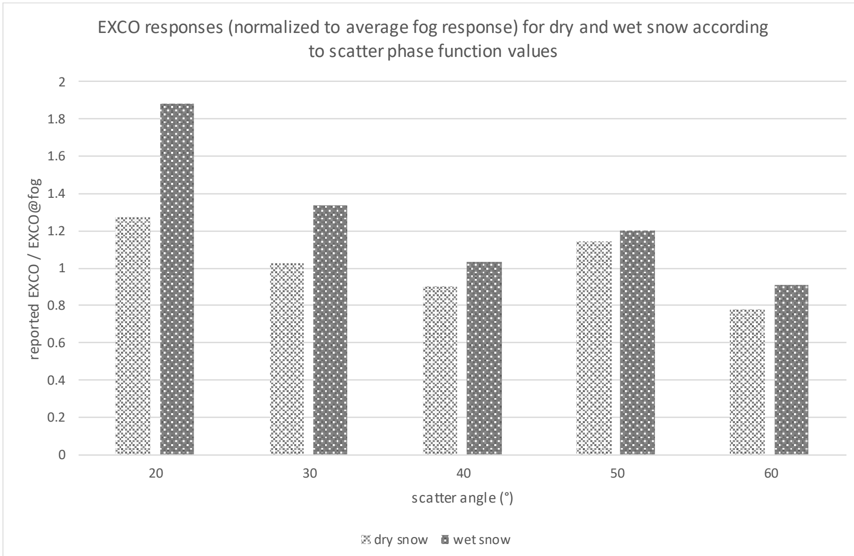

Figure 15. *Scatter phase function based EXCO error examples for snow and different scatter angles.*

Figure 15 illustrates the values of the scatter phase functions (representing the scatter signal strength) for wet and dry snow (after A. Macke et.al. IfM, Universität Kiel, 1999) relative to average fog for different angles from 20° to 60°. It is obvious that an angle between 40° and 50° will provide the best agreement.

However, even the optimal forward scatter angle does not allow to apply the fog calibration directly to rain. For rain an increasing EXCO overestimation with increasing rain intensity must be taken into account ("United States Experience Using Forward Scatter Meters For Runway Visual Range" DOT/FAA/AND-97/1, Section 5.2.5.3).
The expectable signal strength for pure heavy rain can assumed to be 40…50% larger than for fog with identical EXCO.
Conventional forward scatter sensors typically need to live with these measurement uncertainties since a dedicated correction of the fog calibrated EXCO is only possible when the phenomenon and its intensity can be safely characterized and separated from the fog response.
Only a precipitation type, intensity and particle size distribution depending determination of the precipitation related EXCO portion would allow to reduce the visibility measurement uncertainty in rain.

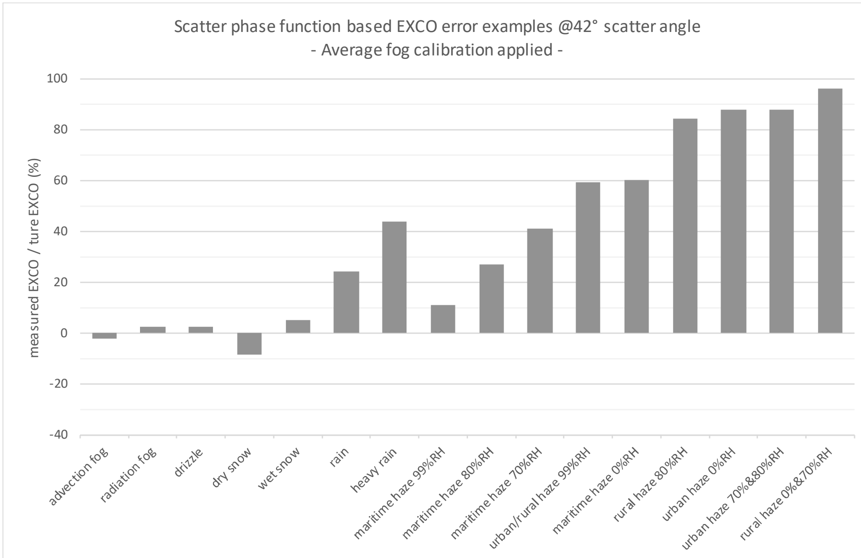

Figure 16. *Scatter phase function based EXCO error examples for different phenomena.*

The optimal forward scatter angle does not allow to apply the fog calibration directly to haze. Figure 16 shows the significant EXCO error magnitude for different haze types (LOWTRAN 6, F.X. Kneizys et.al.) relative to average fog.
The expectable worst-case signal strength for dry rural haze is approximately 95% higher than for a fog with identical EXCO. As well other haze types show large expectable EXCO errors between 85% and 90%.
If these uncertainties in haze are not sufficiently taken into account a forward scatter sensor may in some occasions report only half of the true MOR value.

Measurement angle tolerance

Figure 17 shows radiation and advection fog scatter phase functions for the forward scatter angle range from 41° to 43° (LOWTRAN 6, F.X. Kneizys et.al.). The SCU response in contrast will practically not be sensitive at all for this small angle variation span. If the error for the fog response after SCU calibration adjustment shall be kept below 2%, a forward scatter angle tolerance below +/-0.25° is required.

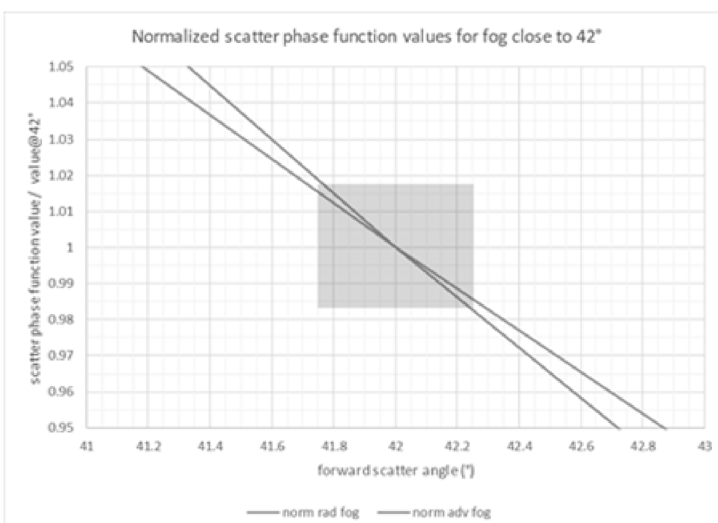

Figure 17. *Fog scatter phase functions close to 42°.*

In order to achieve a representative calibration of the fog response a forward scatter angle tolerance of only +/-0.25 degrees is tolerable.
The FAA document “United States Experience Using Forward Scatter Meters For Runway Visual Range” DOT/FAA/AND-97/1, Section 5.1.2 substantiates the requirement:
“The scattering angle between the transmitter and receiver beam centers must be 42° +/-0.25°.”

Measurement wavelength

As well the utilized measurement wavelength has an impact on the scatter measurement. Due to different scatter properties, the small not liquid particles in haze will generate less scattering and will therefore be underestimated.
Figure 18 illustrates the measurement wavelength impact on the extinction coefficient measurement for different particle radii. For smaller particles larger deviations must be expected when other wavelengths (e.g. NIR) than the nominal 550 nm are used which is normally the case for forward scatter sensors.

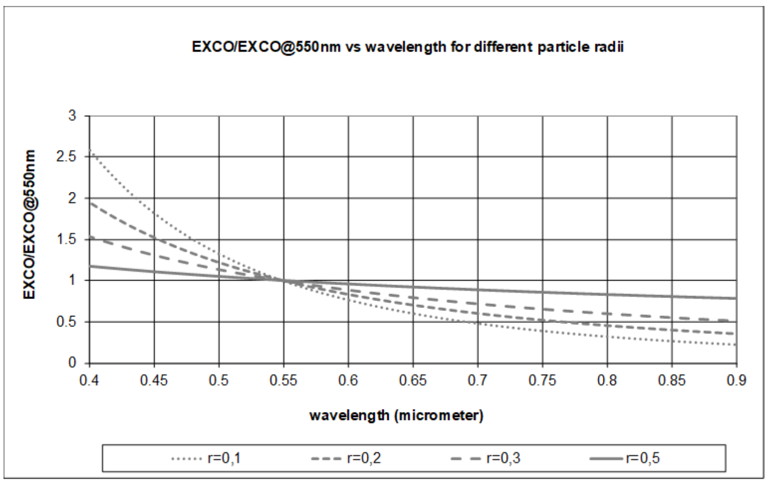

Figure 18. *Measurement wavelength impact for different particle radii.*

Figure 19 illustrates exemplarily the resulting deviation of the measured extinction coefficient @785 nm versus the true extinction coefficient @550 nm when the general wavelength impact on the extinction coefficient according to Angström is applied and the typical visibility range depending exponents according Middleton et.al. are utilized.

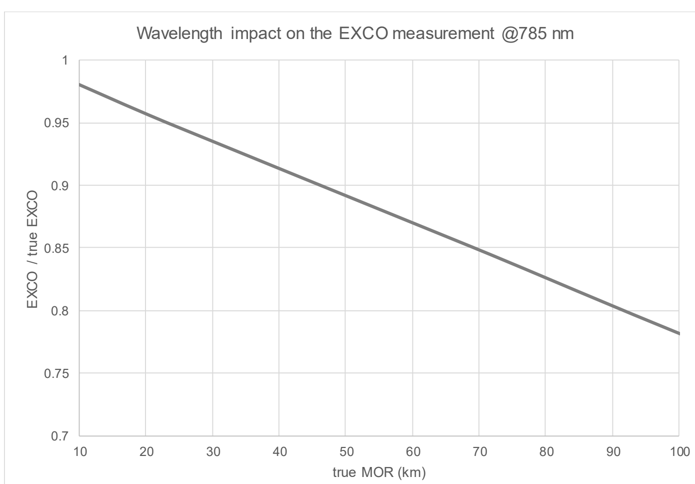

Figure 19. *Wavelength impact on the EXCO, 785 nm example.*

Combined phenomenon and wavelength depending impact

For the MOR measurement range beyond 10 km (haze) both, the impact of the measurement wavelength <u>and</u> the phenomenon (described by the scatter phase function) need to be taken into account that fortunately partly compensate for each other when an infrared wavelength is chosen (for 550 nm the entire phenomenon depending error applies like shown in Figure 16 above).
The combination of the measurement wavelength and the phenomenon depending impact represents the aerosol type related measurement uncertainties that need to be generally taken into account for all forward scatter meters, independently from the brand.
The Figures 20 and 21 below illustrate the wavelength depending impact (785 nm example) for MOR = 10 km and MOR = 100 km.

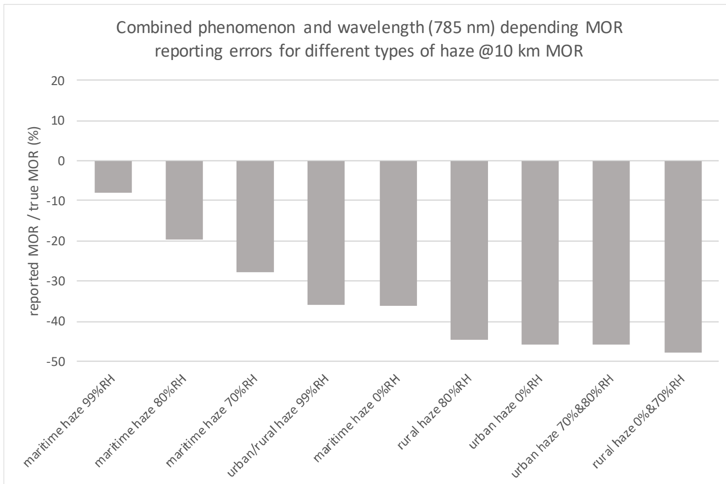

Figure 20. *Wavelength impact on the reported MOR (10 km), 785 nm example.*

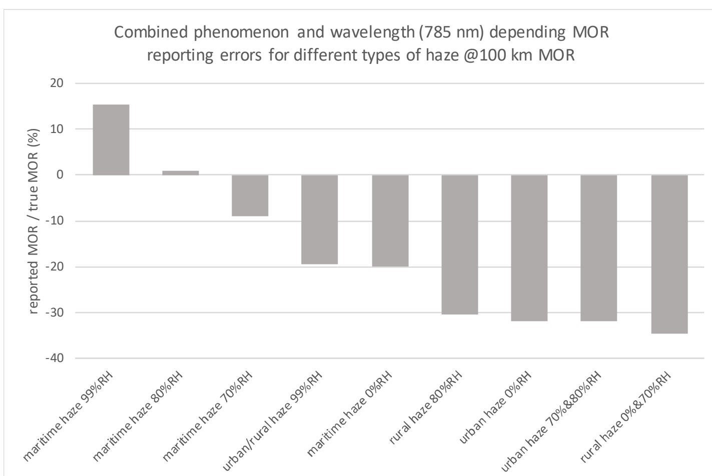

Figure 21. *Wavelength impact on the reported MOR (100 km), 785 nm example.*

Depending on the most dominant haze phenomenon (dictated by the installation site), the resulting MOR reporting deviations must be expected to exceed -40% in some cases.
These can only be reduced if a haze type depending correction would be applied which is unfortunately not feasible with current technologies.

However, in order to minimize the MOR reporting error in haze a visibility and present weather sensor should at least utilize a measurement wavelength in the near infrared region and if possible apply a wavelength depending correction for the determined extinction coefficient.

Absorption

The EXCO (Extinction Coefficient resp. Attenuation Coefficient) describes the extent to which the radiant flux of a beam is reduced (absorbed and scattered) as it passes through the atmosphere.
A forward scatter sensor can exclusively measure the scattered portion of the EXCO and needs to assume that the absorbed portion of light is small enough to be neglected.

The single-scattering albedo (ratio of the scattering coefficient to the total extinction) is used as a measure for the relative contribution of scattering and absorption to the EXCO. The single-scattering albedo is unitless, and a value of unity implies that all particle extinction is due to scattering; conversely, a single-scattering albedo of zero implies that all extinction is due to absorption.

Especially the urban aerosol contains a significant amount of light absorbing particulates.
Therefore the light absorption can not be neglected like for rural (single-scattering albedo >0.93) and maritime aerosols (single-scattering albedo >0.97).

For the urban aerosol, the single-scattering albedo is only 0.6 for the dry aerosol and increases to 0.95 with increasing relative humidity (all values after R.W. Fenn et.al, 1985, estimated @ approximately 800 nm).
Figures 22 and 23 illustrate the exemplary absorption impact for the urban aerosol.

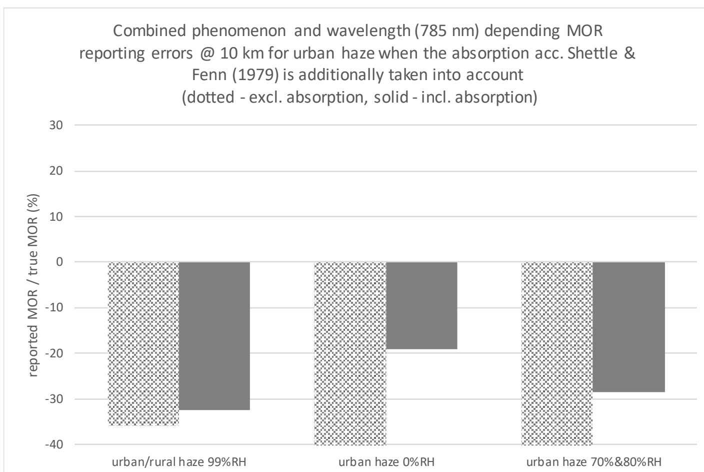

Figure 22. *Combined phenomenon and wavelength depending impact on the reported MOR @10 km with and without absorption.*

The MOR errors decrease slightly when the absorption is taken into account. The phenomenon depending scatter signal overestimation is partly compensated and a remaining maximum error magnitude of approximately -30%...-35% must be expected for the MOR (see Figure 22).

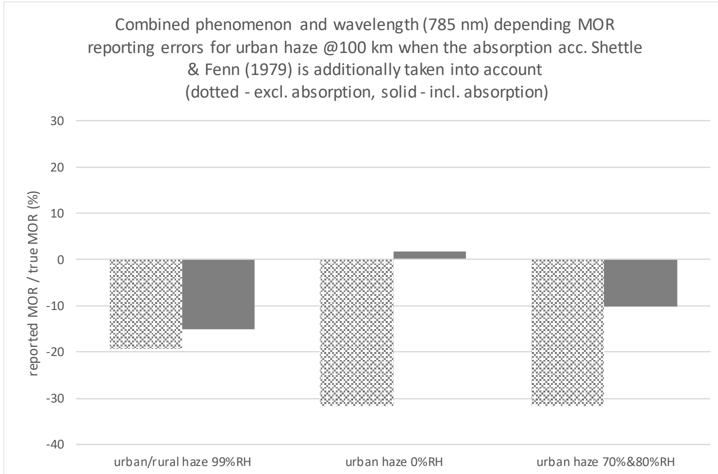

Figure 23. *Combined phenomenon and wavelength depending impact on the reported MOR @100 km with and without absorption.*

With increasing MOR the compensation effect increases and reduces the remaining MOR error to less than -20% (see Figure 23).

The additional consideration of the absorption does not significantly change the expectable MOR underestimation of -30%...-40% that is obviously unavoidable for certain haze types.
However, this moderate MOR error magnitude can only be achieved when a measurement wavelength in the near infrared region is used. Otherwise significantly larger MOR reporting errors in haze are unavoidable.

CONCLUSION

The measurement uncertainty of visibility and present weather sensors is a very complex parameter that incorporates a significant amount of different influence factors.
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). A realistic measurement performance judgment needs to consider as many influence factors as possible.
The light transmitter intensity, the light receiver sensitivity and the mechanical structure over time, temperature and other environmental influences must be stable enough to keep the measurement uncertainty within the desired borders even when the various other uncertainty components are considered.
Operational impacts and disturbances should be avoided as much as possible due to window dirt contamination measurement and correction, window clogging detection, window protection against contaminants, effective heating against moisture, ice and snow, no supporting points for spider webs, flying insects signal filtering, no direct sun radiation into the receiver, no shadowing effects by the mechanical structure.

Present weather sensors in forward scatter geometry provide normally only a poor size / fall speed information if at all. These sensors typically do not conduct single particle evaluations, but process mean values over a typical one minute or longer observation period instead. The precipitation type determination capability is therefore very limited. However, as well optical disdrometers that can utilize the size / fall speed information show clear precipitation type differentiation limitations, since these parameters alone do not allow identifying all phenomena.
The scatter measurement from a conical measurement volume may be combined with other information like a separate liquid water content measurement.
In order to allow a sufficiently sensitive and reliable small precipitation particle detection a larger effective light intensity would be required for all conventional technologies.
The sampling volume size and the transmitter light intensity distribution of forward scatter sensors need to be clearly defined and repeatable from unit to unit, allowing a SCU based field calibration of both, visibility and precipitation intensity.

For rain an increasing EXCO overestimation with increasing rain intensity must be taken into account. The expectable signal strength for pure heavy rain can assumed to be 40%…50% larger than for a fog with identical EXCO. Conventional forward scatter sensors typically need to live with these measurement uncertainties since a dedicated correction of the fog calibrated EXCO is only possible when the phenomenon and its intensity can be safely characterized and separated from the fog response.

Depending on the most dominant haze phenomenon (dictated by the installation site), the related MOR reporting deviation magnitude must be expected to exceed 40% for some haze cases. These can only be reduced if a haze type depending correction would be applied which is unfortunately not feasible with current technologies.
The expectable MOR error magnitude decreases slightly when the absorption is additionally taken into account. The phenomenon depending scatter signal overestimation is partly compensated and a remaining maximum MOR error magnitude of approximately -30%...-35% must be expected for urban haze.
However, these moderate MOR errors can only be achieved when a measurement wavelength in the near infrared region is used. Otherwise significantly larger MOR reporting errors in haze are unavoidable.

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