Validation of a field-deployed detection system for angular light scattering measurements under natural conditions

Andreas Peckhaus[1*], Thomas Hall[1], Ute Bierbrauer[2], Carsten Pargmann[3] and Frank Duschek[2]
1 German Aerospace Center (DLR), Institute of Technical Physics, Pfaffenwaldring 38-40, 70569 Stuttgart, Germany
2 German Aerospace Center (DLR), Institute of Technical Physics, Langer Grund, 74239 Hardthausen, Germany
3 Heilbronn University of Applied Sciences, Faculty of Mechanics and Electronics, Max-Planck-Straße 39, 74081 Heilbronn, Germany
**andreas.peckhaus@dlr.de*

Abstract: High power laser radiation scattered outside of the beam axis can be a potential threat. A novel detection system based on angular light scattering can help to access the risk of scattering by atmospheric particles.

1. Introduction

The propagation of high power laser radiation is affected by the presence of molecules, aerosol particles, and precipitation in the atmosphere. Laser radiation can be absorbed or scattered by atmospheric constituents. The magnitude of scattering strongly depends on the abundance and chemical nature of these constituents. It can be hypothesized that the individual contributions of scattering particles that are irradiated by high power laser radiation add up to a potential concern for personnel working nearby the laser system or for aircraft/spacecraft [1]. Therefore, experimental investigations are realized to access the risk of scattering due to atmospheric particles.

For the angle-dependent detection of scattered light polar nephelometers are commonly used. A large body of literature exists on this subject describing different types of polar nephelometers. These instruments encompass polar nephelometers with a rotating detector [2], polar nephelometers with fixed detector arrays in and off the scattering plane [3], imaging polar nephelometers [4], integrating [5] and reciprocal nephelometers [6]. However, these instruments are restricted to either laboratory-scale measurements of aerosol particles or airborne applications for the measurement of optical and microphysical properties of cloud droplets and ice particles.

To overcome these restrictions, a field-deployed detection system was developed to measure the angular light scattering under natural weather conditions. The detection system is capable of measuring the scattered radiation under clear and hazy conditions as well as under precipitation (i.e. rain, snow, and hail). The scattering particles do not have to be sampled (i.e. no dilution and aerodynamic focusing of the aerosol flow is required) to enter the detection volume. In addition, undesired stray light from optical parts, walls and housing can be neglected. The detection system has been validated by numerical calculations of the scattered light based on measured number size distributions of the scattering particles.

2. Experimental

The experimental setup for the detection of angular scattered radiation is located at a distance of 120 m in front of the transmitting station. The laser beam propagates horizontally with a lateral distance of 120 mm to the detection system. In Fig. 1, a schematic sketch and a photograph of the detection system are shown. The scattered radiation is coupled into fiber couplers (RC12FC-P01, Thorlabs), which contain off-axis parabolic (OAP) mirrors. The entrance aperture is 22 mm and the distance between the fiber couplers and the center of the detection volume is 500 mm. In front of each fiber coupler, there are a plastic tube and a 980 nm long-pass filter to suppress the background radiation. The fiber couplers are mounted on a moveable goniometer unit (AGC245, Aerotech) at five scattering angles (30°, 60°, 90°, 120°, and 150°) relative to the direction of propagation of the laser beam. The scattered radiation is detected by photoreceivers (OE-200-SI, Femto) and the signal is transferred to lock-in amplifiers (LIA-MVD-200-L, Femto). The data acquisition is carried out with an oscilloscope (PicoScope 4824, Pico Technology) and a computer unit (cDAQ National Instruments). The entire detection system is integrated into a temperature-controlled aluminum box (Zarges K 470), which allows for simultaneous scattered radiation measurements under different environmental conditions. The calibration procedure for measuring the absolute scattered powers is described in detail elsewhere [7].

A diode-pumped thin-disk laser (TruDisk 6001 (4C), Trumpf) provides continuous unpolarized high power radiation at 1.03µm. The output power can be varied in the range from 0.18 and 6 kW. All scattering experiments were performed at 3 kW. The laser radiation is modulated with 10 Hz, which is used as a trigger signal for the lock-in amplifiers.

3. Results

The scattered powers are smooth curves under clear weather conditions, whereas under rainy and snowy conditions the scattered powers are strongly structured. The scattered powers at five detection angles are distinctly separated with the highest measured powers in the forward scattering direction. By comparing the experimental scattered powers with calculated scattered powers based on measured number size distributions of particles and Mie-theory or geometric optics it can be concluded that the experimental and calculated powers show a correlation under clear weather conditions. A noticeable variation in the data is observed due to the lack of knowledge of the specific complex refractive index of aerosol particles. A constant refractive index for a rural environment is assumed which does not reflect changes over time. In addition, aerosol particles have a non-negligible imaginary part of the refractive index and can absorb laser energy by the passage of the laser beam. This can lead to smaller particle sizes and lower measured scattered powers. The agreement between experimental and calculated scattered powers under rainy conditions is fairly well reflecting the rather constant refractive index and the slight interaction of rain droplets with the laser beam (see Fig. 1). The experimental scattered powers correlate also with the calculated scattered powers under snowy conditions. A better agreement in the side- and backscattering region is obtained when the scattering particles are represented as hexagonal prisms compared to spherical particles.

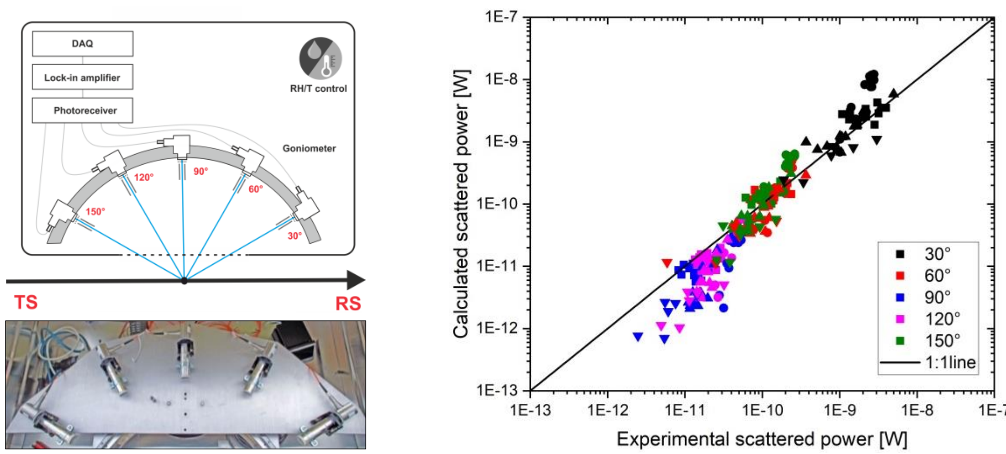

Fig. 1. Experimental setup and photograph (left) and calculated and experimental scattered powers of the detection system under rainy weather conditions (right). The symbols in the right panel denote different measurement series.

4. References

[1] Stillwell, R. A., Pilewskie, P., Thayer, J. P., O'Neill, M. and Neely, R. R., Monte Carlo method for the analysis of laser safety for a high-powered lidar system under different atmospheric conditions , *Journal of Laser Applications,* 2017, 29(2), 022002.
[2] Muñoz, O. and Hovenier, J., Laboratory measurements of single light scattering by ensembles of randomly oriented small irregular particles in air. A review, *Journal of Quantitative Spectroscopy and Radiative Transfer*, 2011, 112, 1646 – 1657.
[3] Nakagawa, M., Nakayama, T., Sasago, H., Ueda, S., Venables, D. S. and Matsumi, Y., Design and characterization of a novel single-particle polar nephelometer, *Aerosol Science and Technology*, Taylor and Francis, 2016, 50, 392-40.
[4] Dolgos, G. & Martins, J. V., Polarized Imaging Nephelometer for in situ airborne measurements of aerosol light scattering, *Opt. Express,* OSA, 2014, 22, 21972-21990.
[5] Heintzenberg, J. and Charlson, R., Design and Applications of the Integrating Nephelometer: A Review, *Journal of Atmospheric and Oceanic Technology,* 1996, 13, 987-1000.
[6] Mulholland, G. W. and Bryner, N. P., Radiometric model of the transmission cell-reciprocal nephelometer, *Atmospheric Environment,* 1994, 28, 873 – 887.
[7] Pargmann, C., Becker, P., Peckhaus, A. and Duschek, F., Angle dependent stray light measurements of high power laser radiation in natural atmospheric environments , *Proc. SPIE*, 10787-15, 2018.