

# Development and Characterization of an Advanced Holographic Instrument for Atmospheric Research

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Supplemental Material. **Particle attenuation and holographic quality.**

10 For inline holographic imaging, water particles are expected to attenuate the laser beam and cause multiple interferences. The attenuation effect of the particles can be analyzed using Mie theory, whereas the interference they produce will generate speckles in the inline imaging. To estimate holographic degradation caused by such interferences, Royer criteria can be employed (citation needed).

Mie theory describes the scattering behavior of spherical particles when the particle size is comparable to the wavelength of  
15 light, making it a suitable model for analyzing the behavior of water droplets in this study. Assuming a distribution of water particles, their scattering coefficients can be calculated using the *miepython* package in Python. The size of water droplets can vary depending on environmental conditions, and their interaction with laser beams also depends on the droplet size. For this experiment, a 405 nm laser is used to illuminate the particles, making scattering within this wavelength range the primary focus.

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Mie theory is particularly suitable for scenarios where the wavelength of light is comparable to the size of the particles causing scattering. In this experiment, the 405 nm laser wavelength, coupled with water particles having a minimum diameter of 5  $\mu\text{m}$ , results in a relatively constant scattering efficiency as shown in Figure S1. Additionally, water droplets are well-known for exhibiting strong forward scattering behavior.

25 The scattering, absorption, and extinction coefficients can be determined using the following equations:

$$\epsilon_{sc} = N \left( \frac{\pi D^2}{4} \right) Q_{sc} \quad (1)$$

$$\epsilon_{abs} = N \left( \frac{\pi D^2}{4} \right) Q_{abs} \quad (2)$$

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$$\epsilon_{ext} = N \left( \frac{\pi D^2}{4} \right) Q_{ext} \quad (3)$$

Here, N represents the number concentration of particles ((particles/cm<sup>3</sup>)), D is the particle diameter, and  $Q_x$  denotes the efficiency factors for scattering  $Q_{sc}$ , absorption  $Q_{abs}$ , and extinction  $Q_{ext}$ . The efficiency factors  $Q_x$  can be calculated for each particle in the distribution using the *miepython* package in Python at a wavelength of 405 nm .

35 To determine inline attenuation, the Beer-Lambert law is applied, assuming the single scattering approximation ((Noaa), 2008). Using the extinction coefficient, the attenuation of laser light intensity is calculated as:

$$I(z) = I_0 = e^{-\epsilon_{ext}z} \quad (4)$$

40 The attenuation behavior was modeled for various particle concentrations and propagation distances. The results are illustrated in Figure S1. Two different particle distribution are considered. The first case assumes the mean particle distribution is close to the wavelength of the laser light at 0.5  $\mu m$ . Then in the second case, with a mean 15  $\mu m$  which is consistent with the size of fog (Podzimek, 1997; Nelli et al., 2024). For an extreme case of 5000 particles per cubic centimeter ((particles/cm<sup>3</sup>)), laser light remains visible over a distance of up to 500 cm. This demonstrates the suitability of inline holographic imaging for  
45 environments with high particle densities

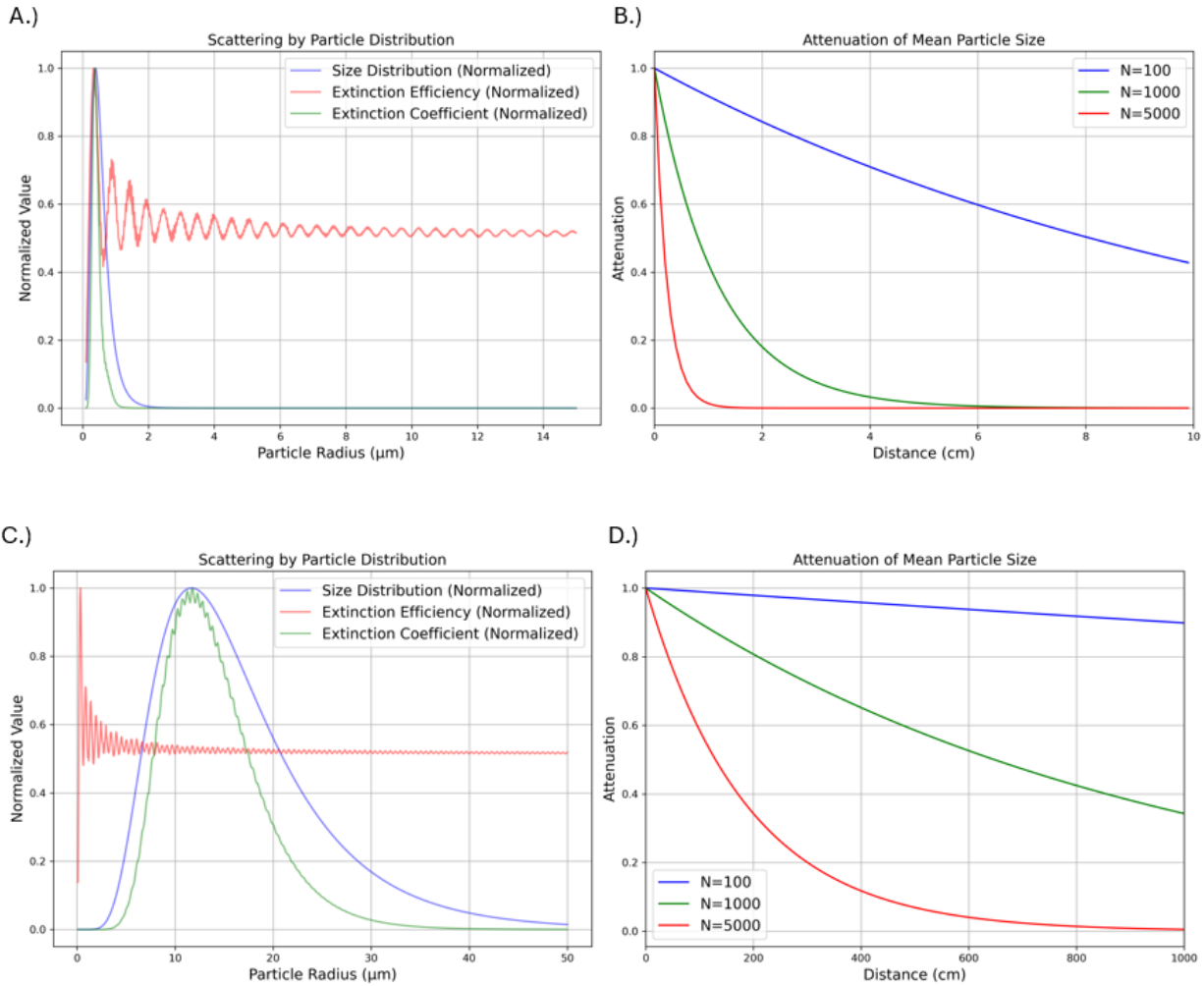


Figure S1: A.) A particle size distribution with the mean value is close to the wavelength of light at  $0.5 \mu\text{m}$ . B.) attenuation of light for different number concentration of water droplets (number/ $\mu\text{m}^3$ ) over 10 cm for a particle distribution in panel A.). C.) A particle distribution with a mean size of  $15 \mu\text{m}$  which is consistent with the size of fog. D.) attenuation of light for different number concentration of water droplets (number/ $\mu\text{m}^3$ ) over 1000 cm for a particle distribution in panel D.).

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In inline holography, the presence of water droplets acts as individual scatterers, contributing to speckle noise in the captured  
 55 hologram. The quality of the hologram after passing through a distribution of particles can be characterized by the shadow  
 density parameter, also known as the Royer criterion, given by the  
 equation:

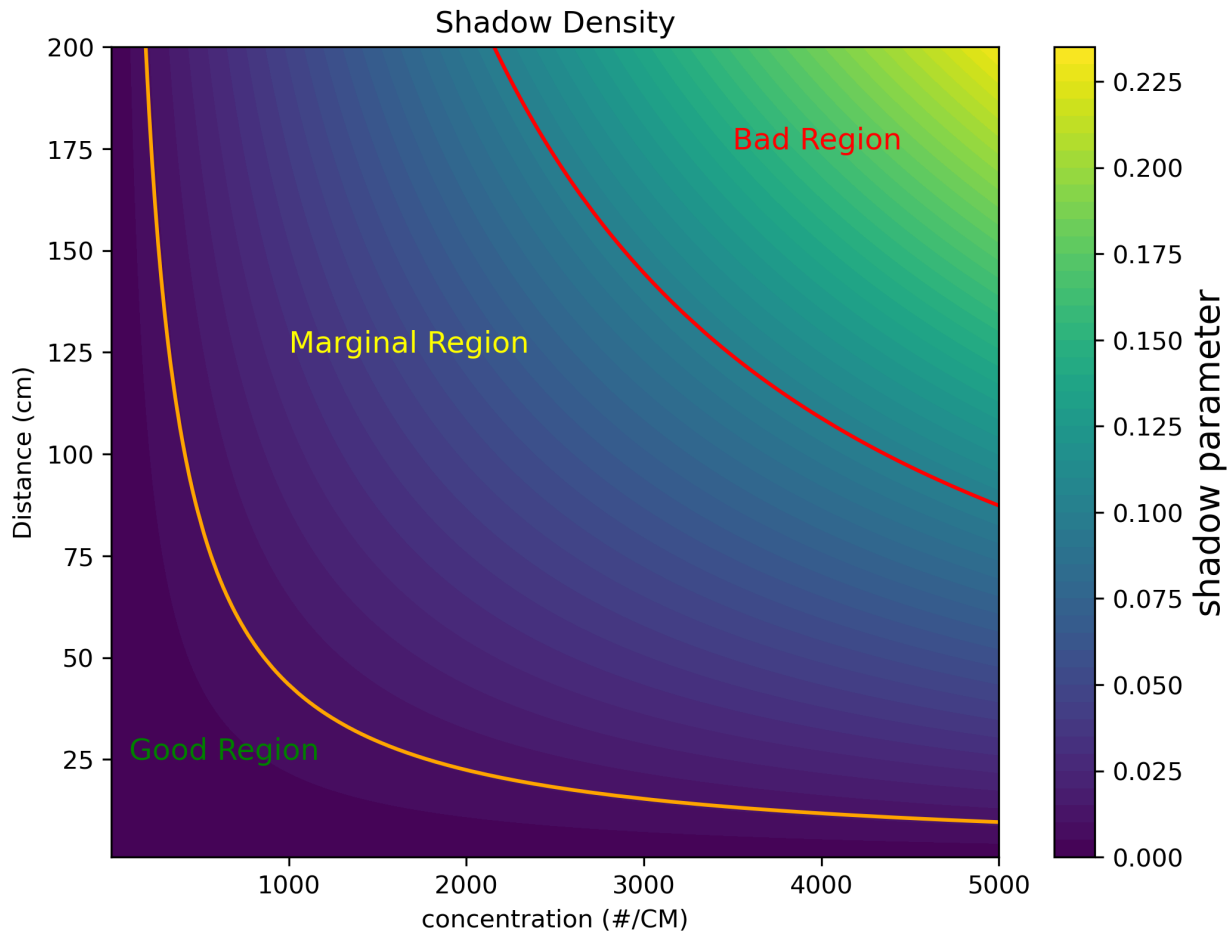
$$S = N(\pi D_{mean}^2)Z \quad (5)$$

Here,  $N$  represents the particle concentration ((particles/cm<sup>3</sup>)),  $D_{\text{mean}}$  is the mean particle diameter, and  $Z$  is the propagation distance (Meng et al., 1993).

As described in Meng et al. (Meng et al., 1993), the value of the shadow density parameter determines the quality of the resulting hologram:

- ( $S < 0.01$ ): High-quality hologram.
- ( $0.01 < S \leq 0.1$ ): Marginal hologram.
- ( $S > 0.1$ ): Poor-quality hologram.

The calculated results of the shadow density parameters for various experimental configurations are presented in Figure S2, demonstrating the relationship between particle concentration, mean particle size, and imaging distance on hologram quality.



70 **Figure S2 shadow parameters for holographic quality in terms of concentration and distance. The good, marginal and bad regions are separated by a line defining the respected value.**

