



**Simulation of Atmospheric Effects on Laser Light:**  
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### Background



HELEEOS (High Energy Laser End-to-End Operational Simulation) was developed by the Air Force Institute of Technology's Center for Directed Energy.

HELEEOS uses Mie theory to calculate extinction, scattering, and absorption coefficients for laser light in the atmosphere.

$$\beta_{e,s,a} = \sum_{i=r_{\min}}^{r_{\max}} Q_{e,s,a} \pi r_i^2 n(r) \Delta r_i$$

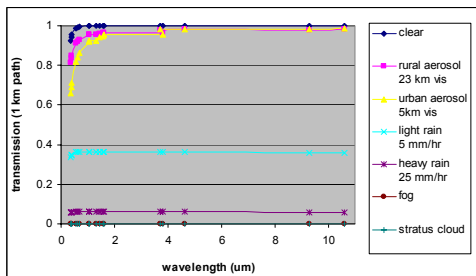
- $Q_{e,s,a}$  are the extinction, scattering, and absorption efficiencies
- $n(r)$  is the particle size distribution

### Aerosols

For aerosols, HELEEOS uses a lognormal particle size distribution.

$$n(r) = \frac{N}{\sqrt{2\pi r \ln 10} \log \sigma} \exp\left[\frac{1}{2} \left(\frac{\log r - \log r_{\text{mod}}}{\log \sigma}\right)^2\right]$$

- $N$  is the particle number density in  $\text{cm}^{-3}$
- $\sigma$  is the standard deviation
- $r_{\text{mod}}$  is the modal radius in  $\mu\text{m}$



Transmission for various aerosol types, cloud types, and rain rates

### Clouds and Fog

To give HELEEOS the additional capability to calculate the effect of clouds and fog on laser light, a gamma particle size distribution was used to calculate the extinction, scattering, and absorption coefficients.

$$n(r) = N a r^\alpha \exp\left[\frac{-\alpha}{\gamma} \left(\frac{r}{r_{\text{mod}}}\right)^\gamma\right]$$

The coefficients calculated in HELEEOS using the gamma particle size distribution were successfully compared to coefficients calculated using OPAC (Optical Properties of Aerosols and Clouds)



### Rain

To give HELEEOS the additional capability to calculate the effect of rain on laser light, a Marshall-Palmer particle size distribution was used to calculate the extinction, scattering, and absorption coefficients.

$$n(r) = 2 N e^{-2 \Lambda r}$$

$$\Lambda = 4.1 R^{-0.21}$$

•  $R$  is the rain rate in mm/hr

The coefficients calculated in HELEEOS using the Marshall-Palmer particle size distribution were successfully compared to coefficients calculated using Plexus.

### Scattering Angle

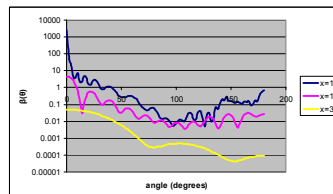
Use the scattering phase function to calculate how much light is scattered in a certain direction.

$$\beta(\theta) := \frac{\lambda^2}{4 \cdot \pi^2} \sum_{i=r_{\min}}^{r_{\max}} n(r) \frac{i_1 + i_2}{2} \Delta r_i$$

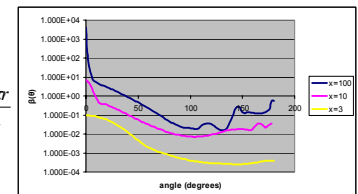
$$i_1 = S_1 S_1^* \quad \text{and} \quad i_2 = S_2 S_2^*$$

•  $S_1$  and  $S_2$  are intensity functions

•  $n(r)$  is the particle size distribution



Scattering phase function with one particle



Scattering phase function with a distribution of particles ( $r = r_{\text{mod}}$ )

### References

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