NRC·CNRC

Impact of a finite thickness integrating sphere port on diffuse reflectance measurements

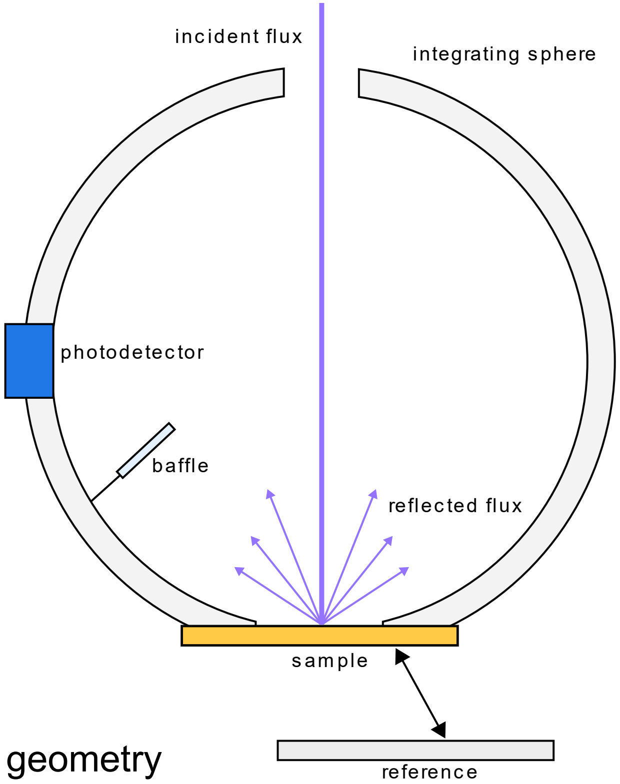
Luke Sandilands and Tom Cameron, NRC Metrology

Joint Biennial CORM-CIE Conference
November 6, 2023

Outline

- The problem of a finite thickness integrating sphere port
- Modelling a realistic port geometry with Monte Carlo ray tracing
- Experimental tests
- Strategies for mitigation

Measurement of diffuse reflectance with an integrating sphere



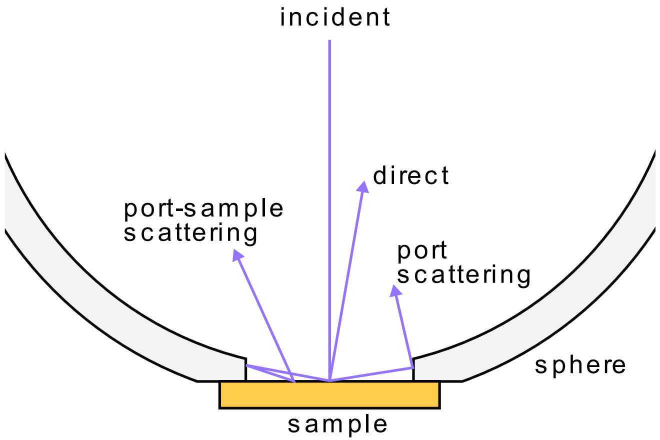
0°/t geometry

- An integrating sphere with photodetector may be used to measure the reflected flux
- Photocurrent is measured for the test sample and for a calibrated reflectance standard
- Usual measurement equation:

$$\rho_s = \frac{i_s}{i_r} \times \rho_r$$

- Complications:
  - Sphere substitution error
  - Baffles
  - Detector FOV
  - **Finite thickness port**

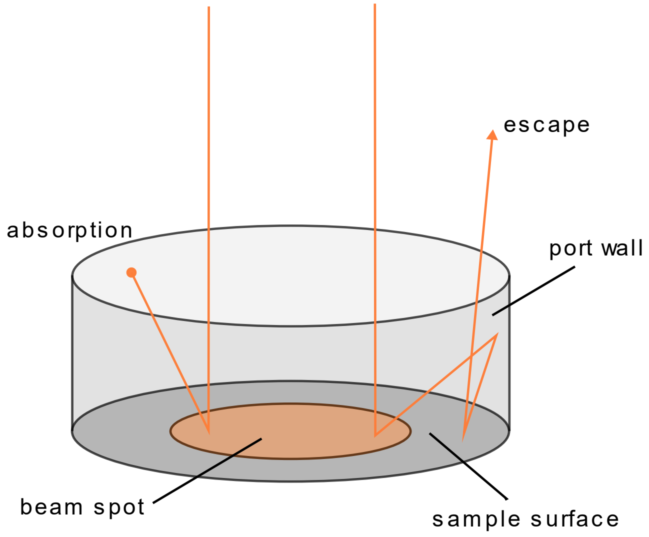
Impact of finite port thickness



- For finite thickness port, some fraction of flux will intersect the port edge, rather then directly enter the sphere
- Two effects:
  1. Angular response of the measurement is affected
  2. Photocurrent becomes a non-linear function of reflectance
- Depends on the geometry of the port, the excitation beam size, and the optical properties of the test sample and port walls
- Not a new issue!

- **Can we quantify this effect?**

Monte Carlo Ray Tracing



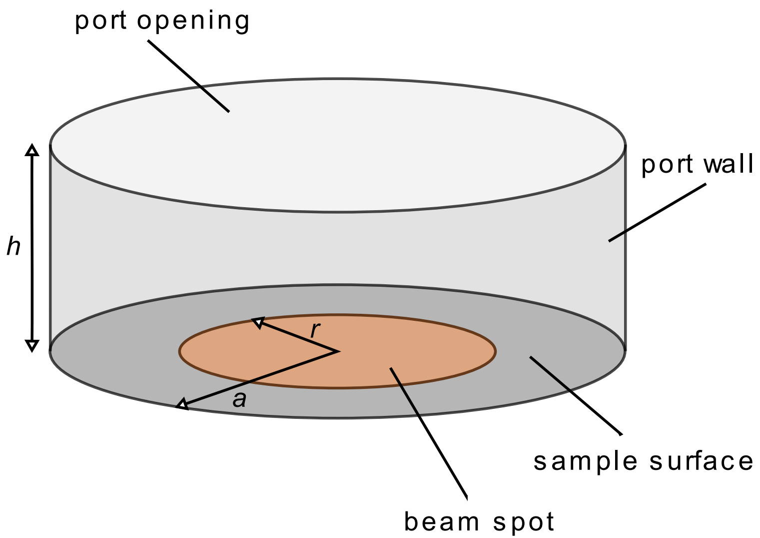
- Model optical radiation as randomly propagating rays
- Ray absorption and scattering are treated probabilistically

$$\rho'_s = \frac{\#\ escaping\ rays}{\#\ incident\ rays}$$

$$\Delta\rho_s = \rho'_s - \rho_s$$

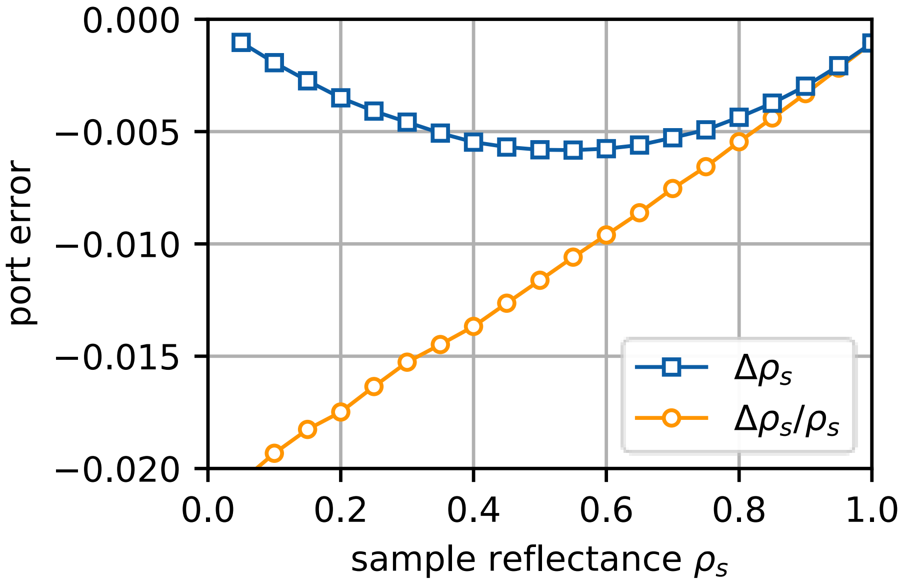
- Assume Lambertian surfaces & ignore translucency

Port geometry and optical properties



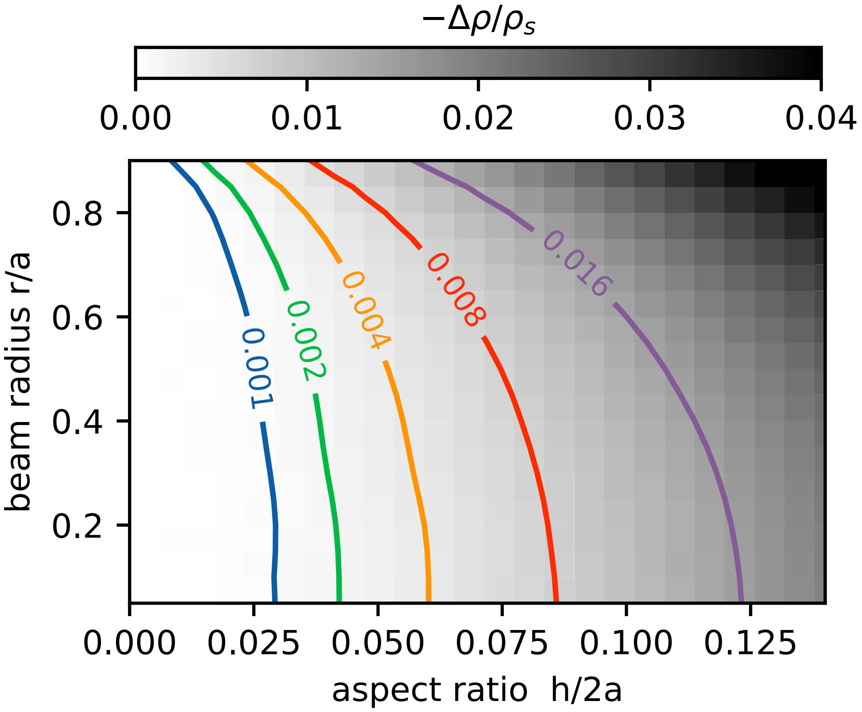
Term	Symbol
Port Radius	a
Port Thickness	h
Beam radius	r
Port Wall Reflectance	ρ_w
Sample Reflectance	ρ_s
Aspect Ratio	h/2a
Relative beam radius	r/a

MC port error vs. sample reflectance



Parameter	Value
h/2a	0.1
r/a	0.3
ρ_W	0.98

MC port error vs. beam radius & aspect ratio



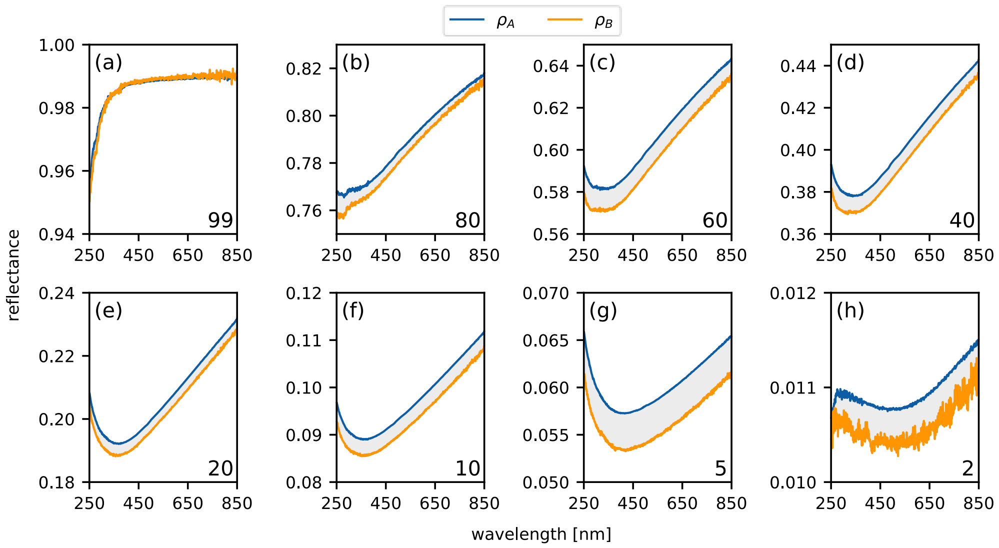
Parameter	Value
ρ_s	0.5
ρ_W	0.98

Experimental Validation

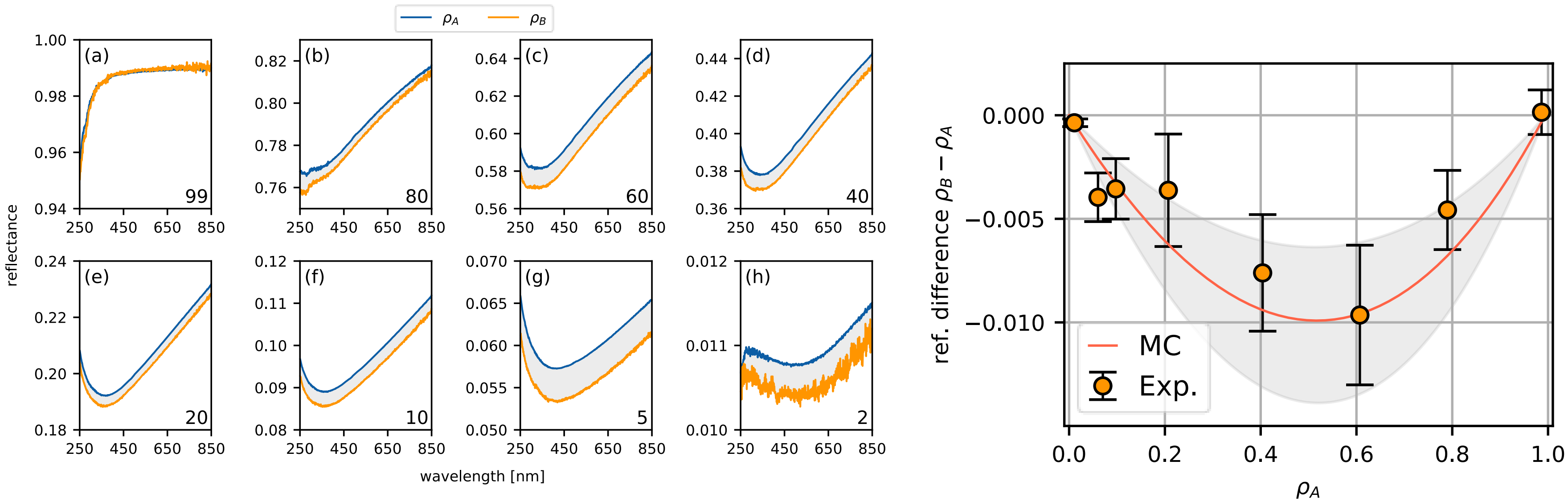
- Collect spectral reflectance data using two spheres of differing aspect ratio
- Difference between readings can be compared with the MC port error
- Test samples: Grey Spectralon Set (nominal reflectance 2 to 99)
- Instruments are double-beam type.
- Pressed PTFE was used as a reflectance standard.

Parameter	Sphere A	Sphere B
Sphere radius [mm]	75	75
Port radius [mm]	12.5	11.3
Port Thickness [mm]	0.75	3.2 ± 0.7
Beam Dimensions [mm]	14 × 7.5	7 × 7
Aspect Ratio	0.034	0.142 ± 0.031

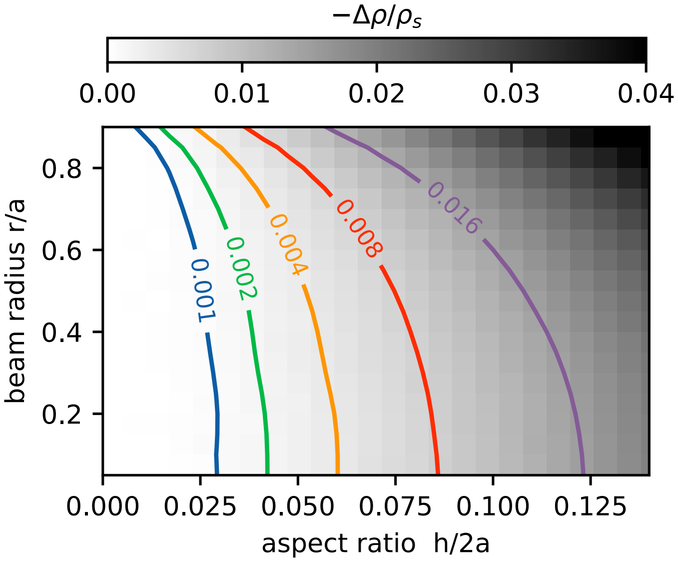
Experimental Validation



Experimental Validation



How to mitigate?



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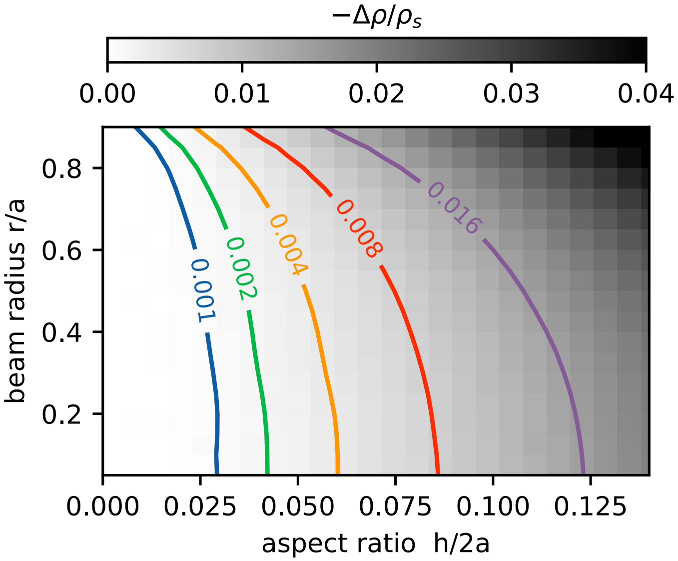
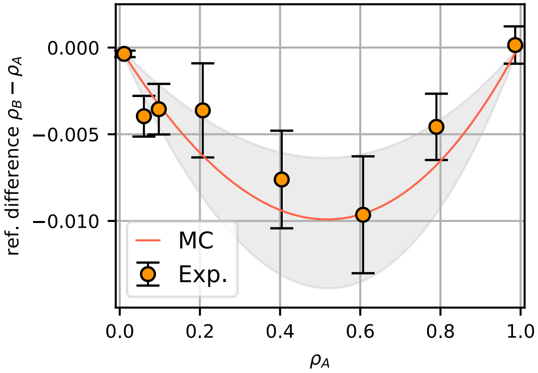
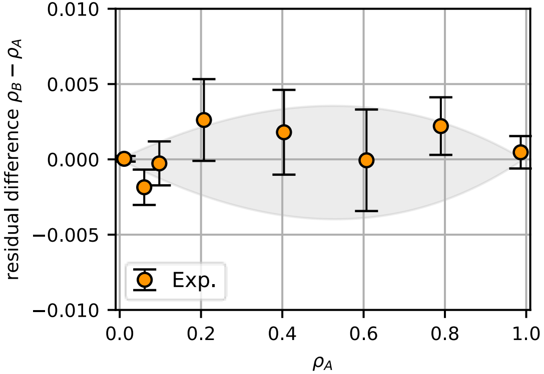




Uncorrected
(mean Δρ = -0.0041)



Corrected
(mean Δρ = 0.0006)

Summary

- Quantitative estimates of the integrating sphere port error were obtained via Monte Carlo ray tracing
- The numerical results were validated by comparison with data collected on two reflectometers with differing port geometries
- Ray tracing results may be used as a basis for a correction or uncertainty estimate

Details: LS and T. Cameron, Applied Optics 62 29 (2023)

Contact: luke.sandilands@nrc-cnrc.gc.ca

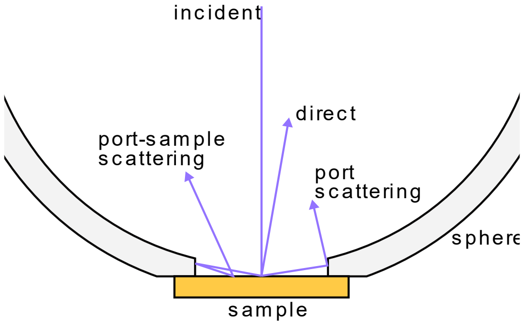
Apparent reflectance of the port-sample assembly

- Divide flux impinging on the sample surface into two parts:
  - direct component due to illumination beam (φ_i)
  - secondary component from the port edge (φ_p)

- The flux entering the sphere (φ_e) and the secondary component are:

$$\varphi_e = a\rho_s\varphi_i + b\rho_s\varphi_p$$

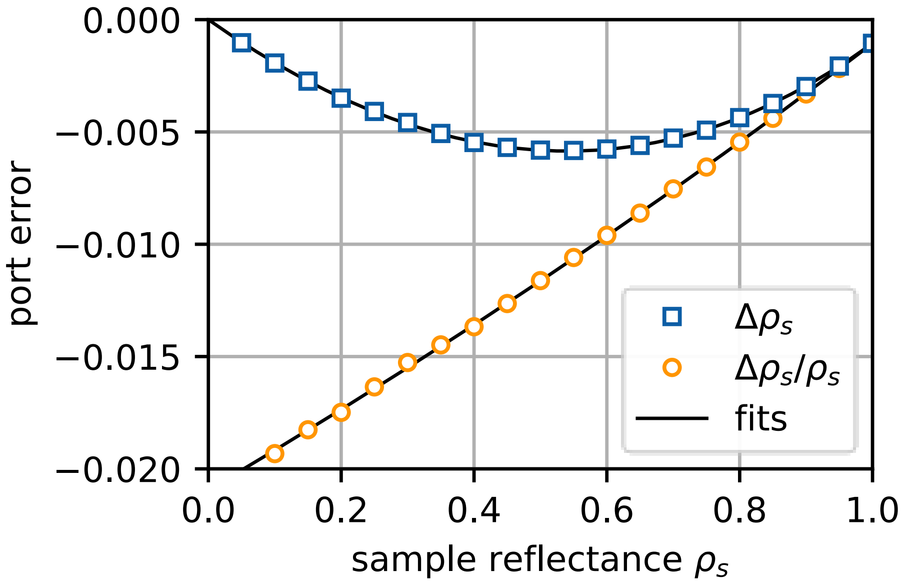
$$\varphi_p = c\rho_s\varphi_i + d\rho_s\varphi_p$$



- The apparent reflectance (ρ'_s) is then:

$$\rho'_s = \frac{\varphi_e}{\varphi_i} = a\rho_s \times \left(1 - \frac{bc}{d}\frac{\rho_s}{1 - d\rho_s}\right)$$

MC port error vs. sample reflectance



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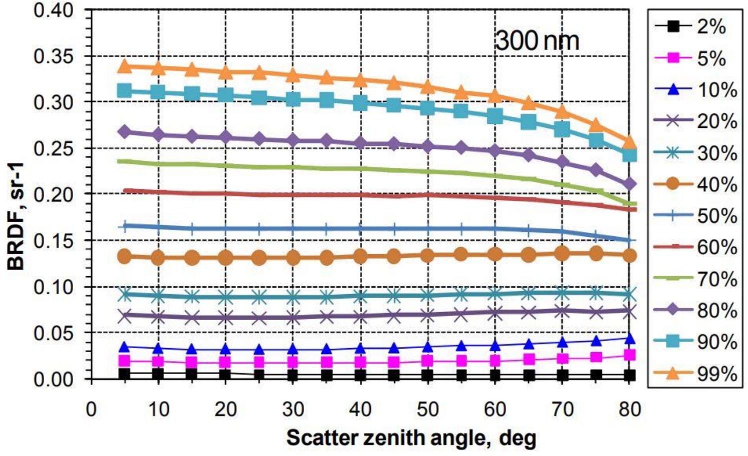
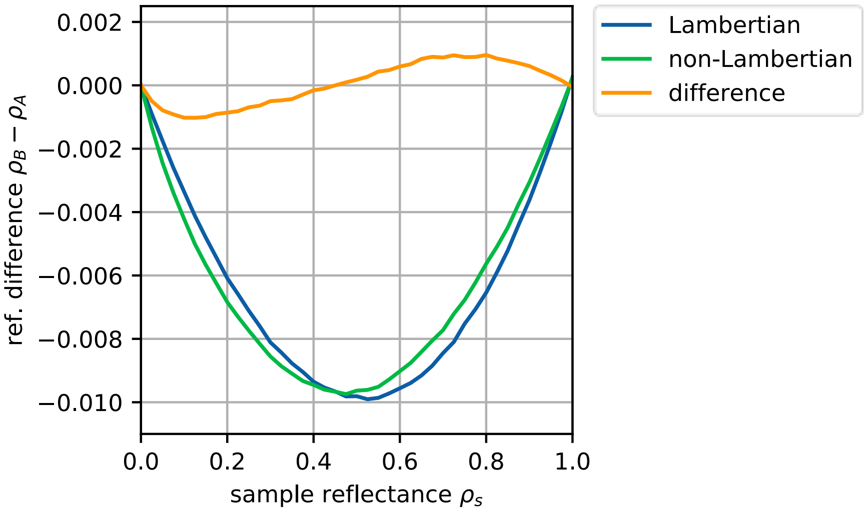
What about BRDF?

Grey Spectralon BRDF, 0° AOI





Georgiev & Butler, SPIE 2008

What about BRDF?