Optical Characterization of PV Glass Coupons and PV Modules Related to Soiling Losses

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CLEO: OSA Nanophotonics Technical Group 20x20 Talks
Monday, 14 May 2018,
19:00 – 20:30
Room 230A, SJCC

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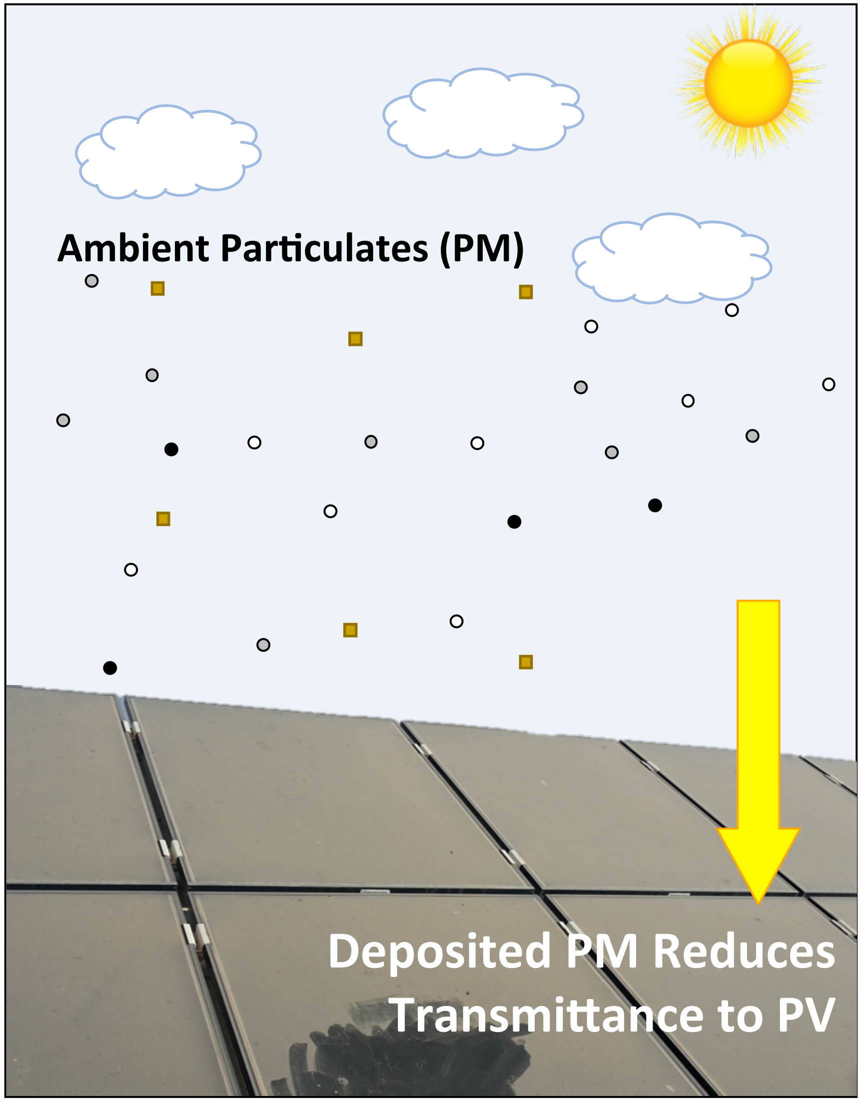
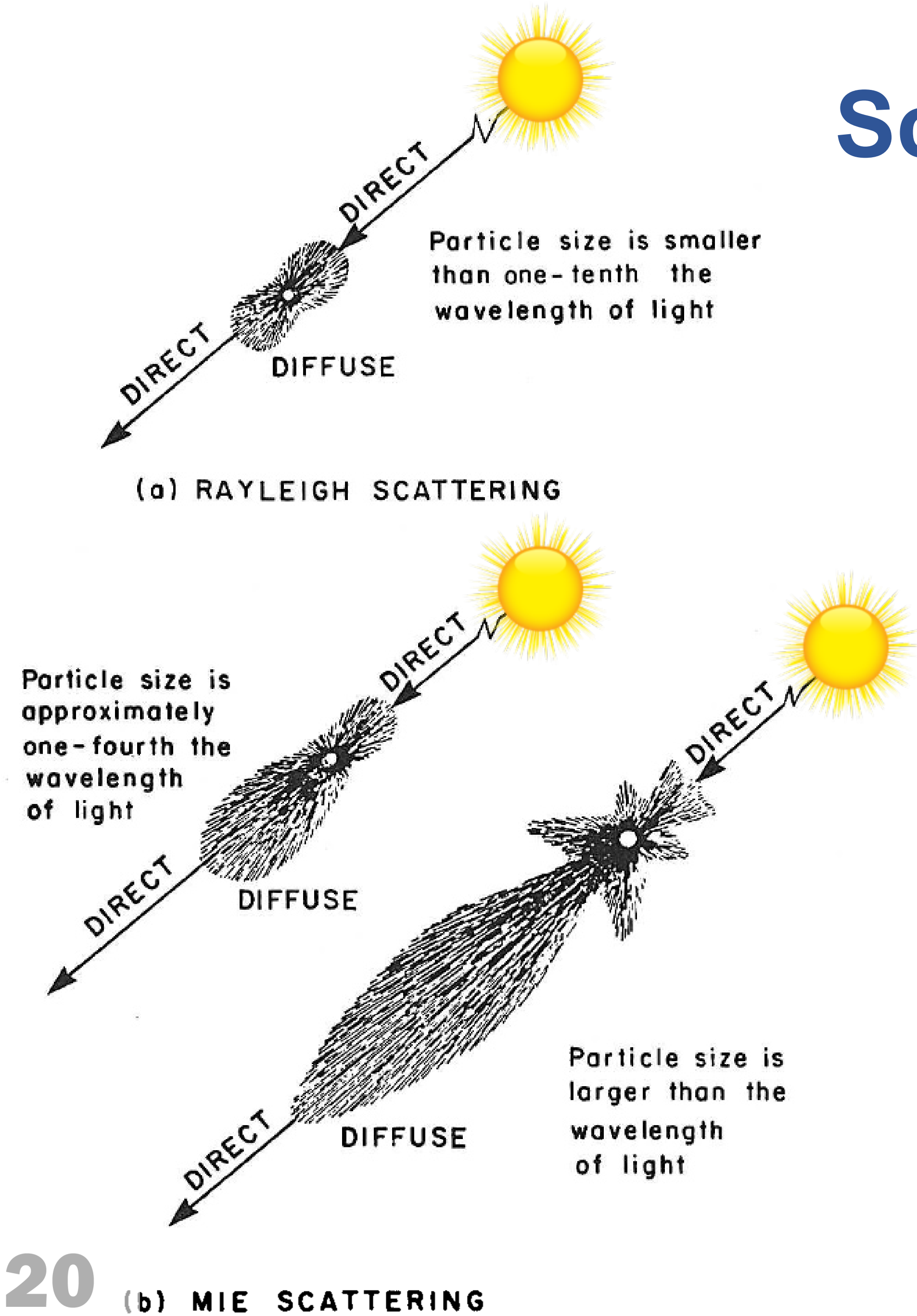
The Challenge



Graphic: Mike H. Bergin (Duke University)

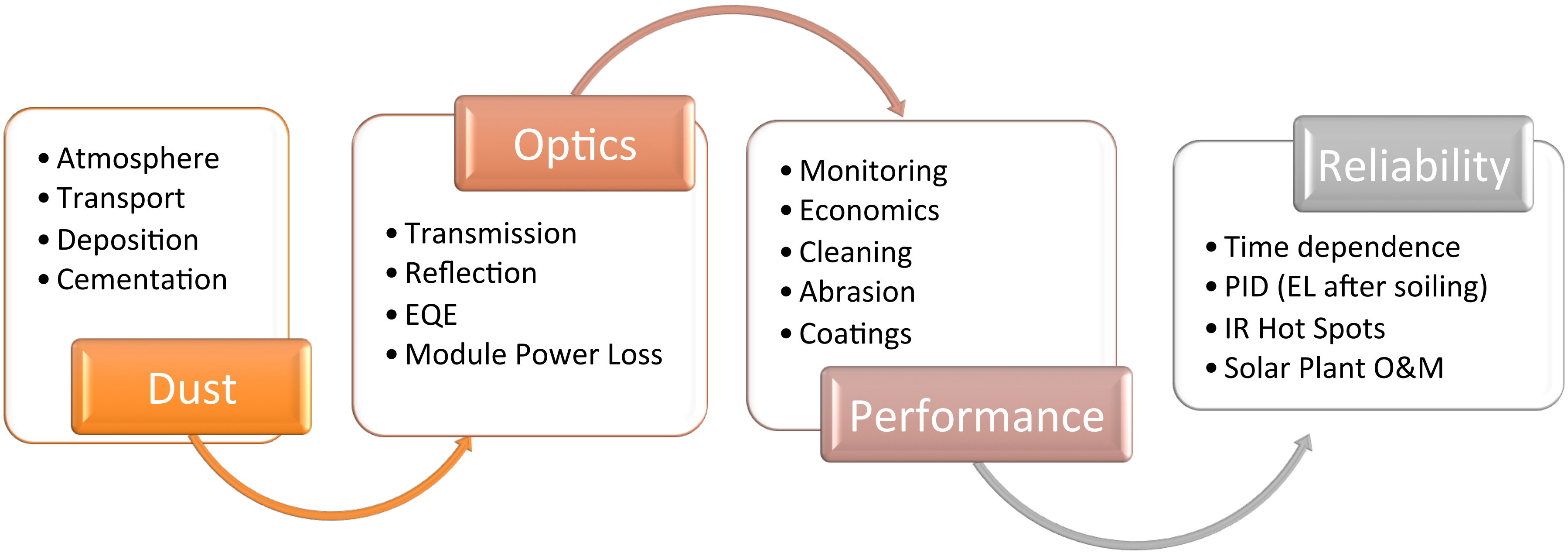
Scattering
Atmospheric

An Introduction to Solar Radiation, Muhammad Iqbal, Academic Press, New York, 1983, Chapter 6.



Mie Scattering

The Context of the Study



Graphic: G. Smestad

Optical Configuration

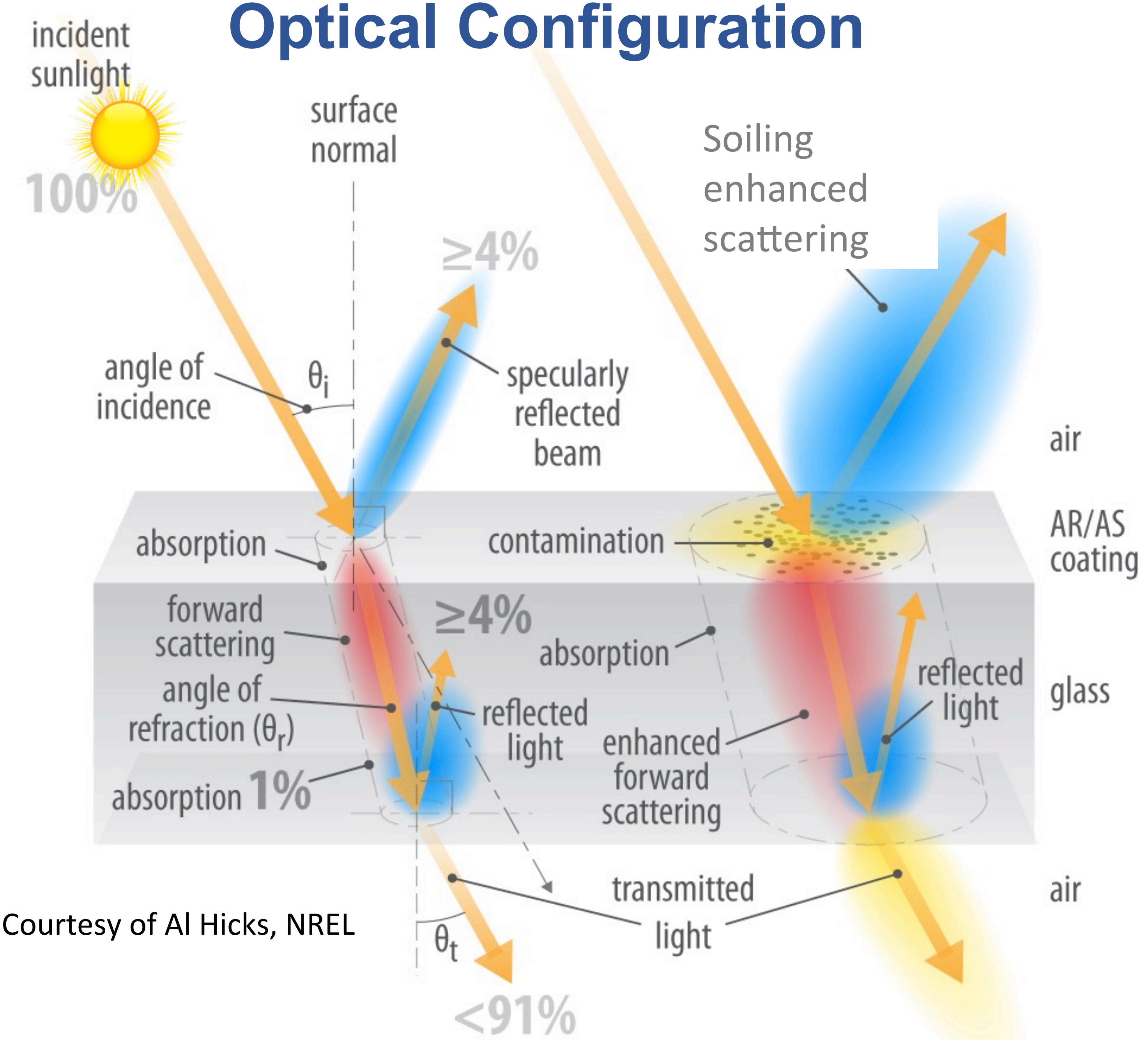
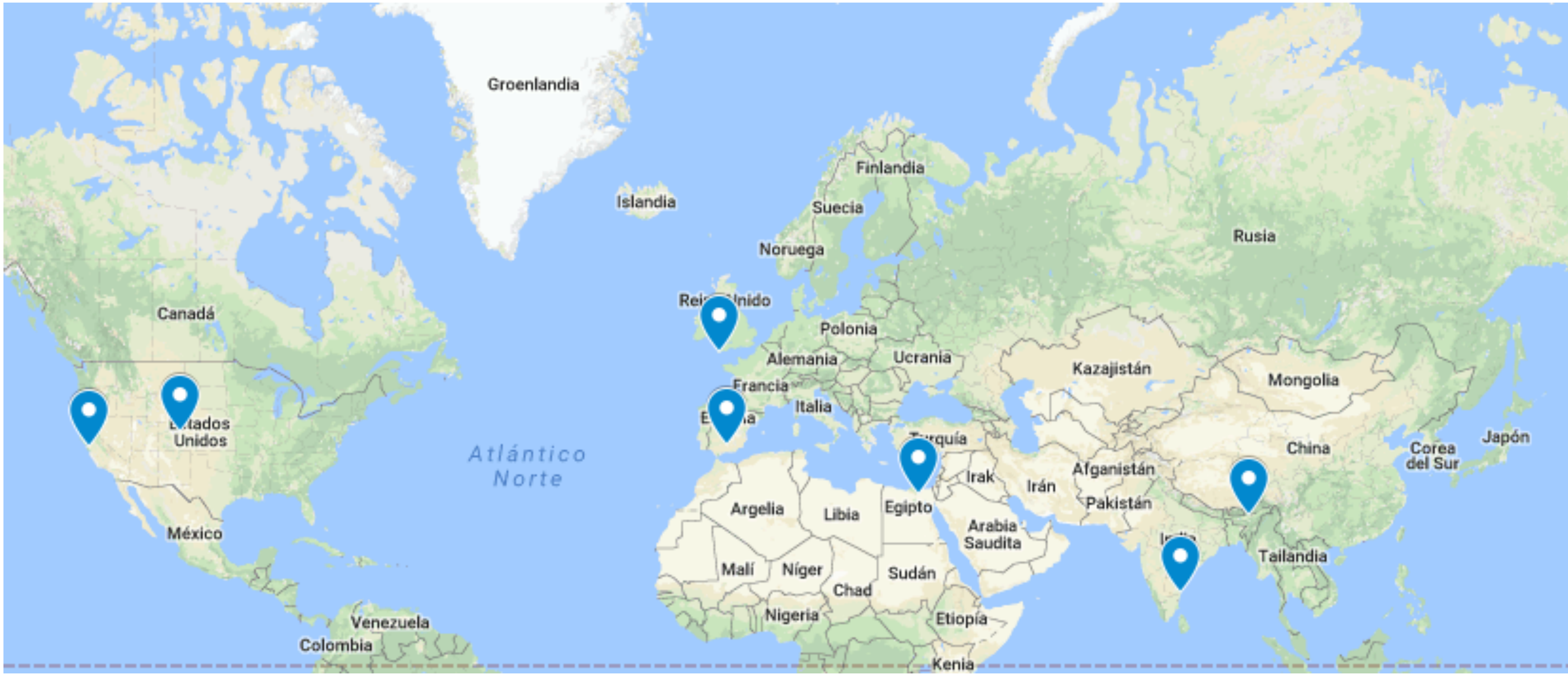


Diagram Courtesy of Al Hicks, NREL

Spectral impact of soiling: Experiments



City, Country	*Coordinates*	*Climate classification*
Chennai, India	13.08, 80.27	Equatorial savannah with dry winter (Aw)
El Shorouk City, Egypt	30.12, 31.61	Desert climate (Bwh)
Golden (CO), USA	39.74, -105.18	Snow climate, fully humid (Dfb)
Jaén, Spain	37.79, -3.78	Warm temperate climate with dry summer (Csa)
Penryn, UK	50.17,-5.13	Warm temperate climate, fully humid (Cfb)
San José (CA), USA	37.29, -121.91	Warm temperate climate with dry summer (Csb)
Tezpur, India	26.70, 92.83	Warm temperate climate with dry winter (Cwa)

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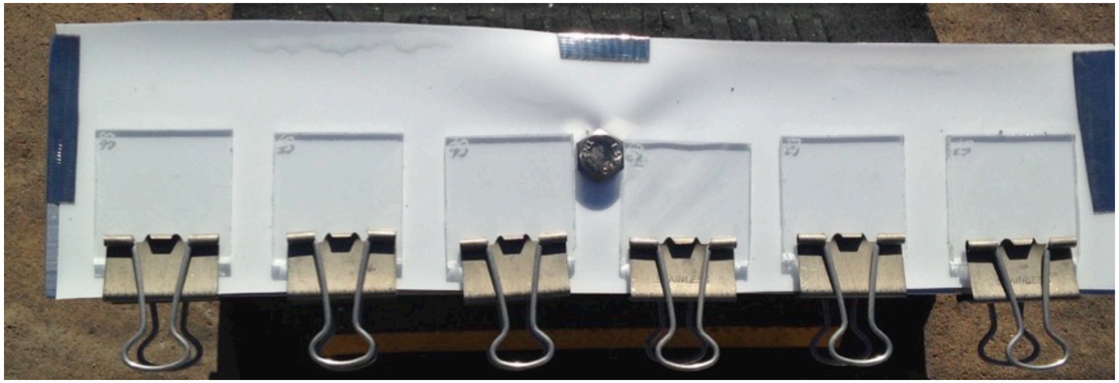
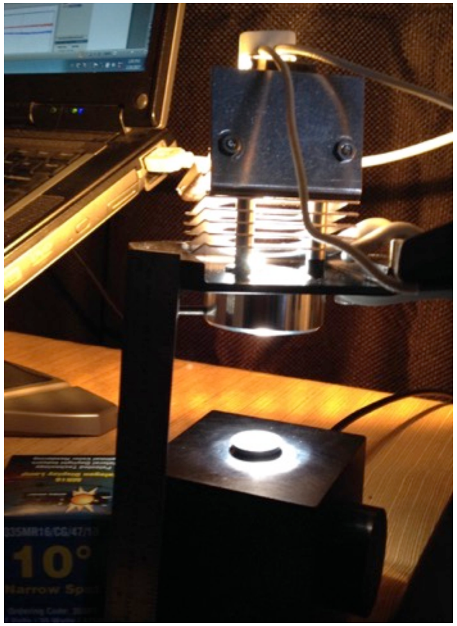
Experimental Procedure



4 cm x 4 cm
x 3 mm-thick

1. **Soil Saint-Gobain DIAMANT PV glass coupons outdoors.**



2. **Measure spectral transmittance of soiled glass using an Integrating Sphere.**

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After 8 Weeks (San José, CA)

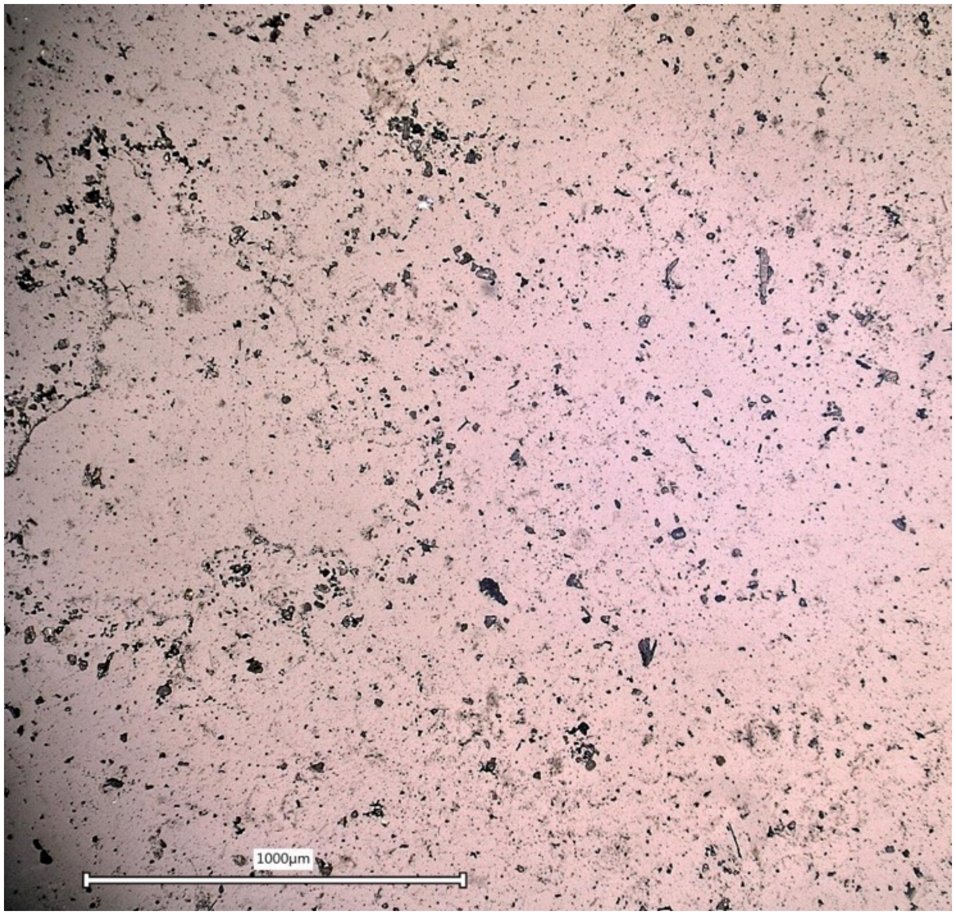


Photo: NREL, optical microscope 100x

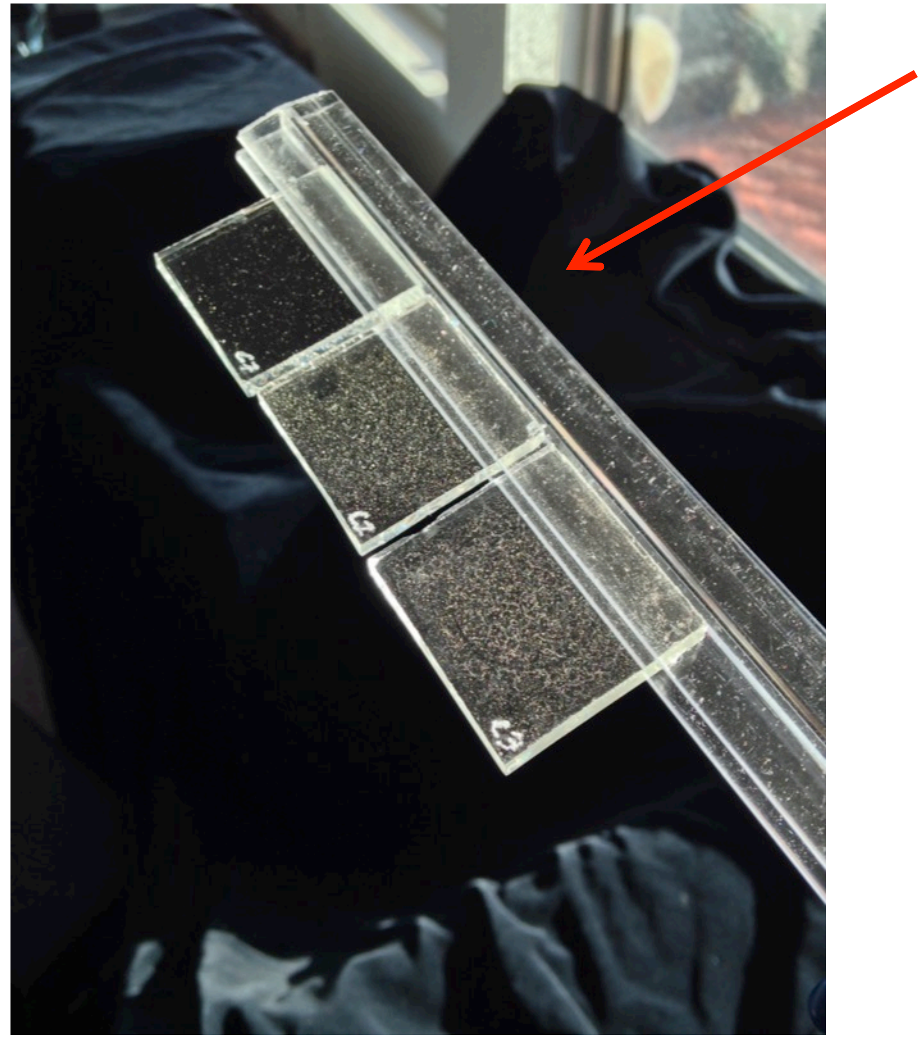
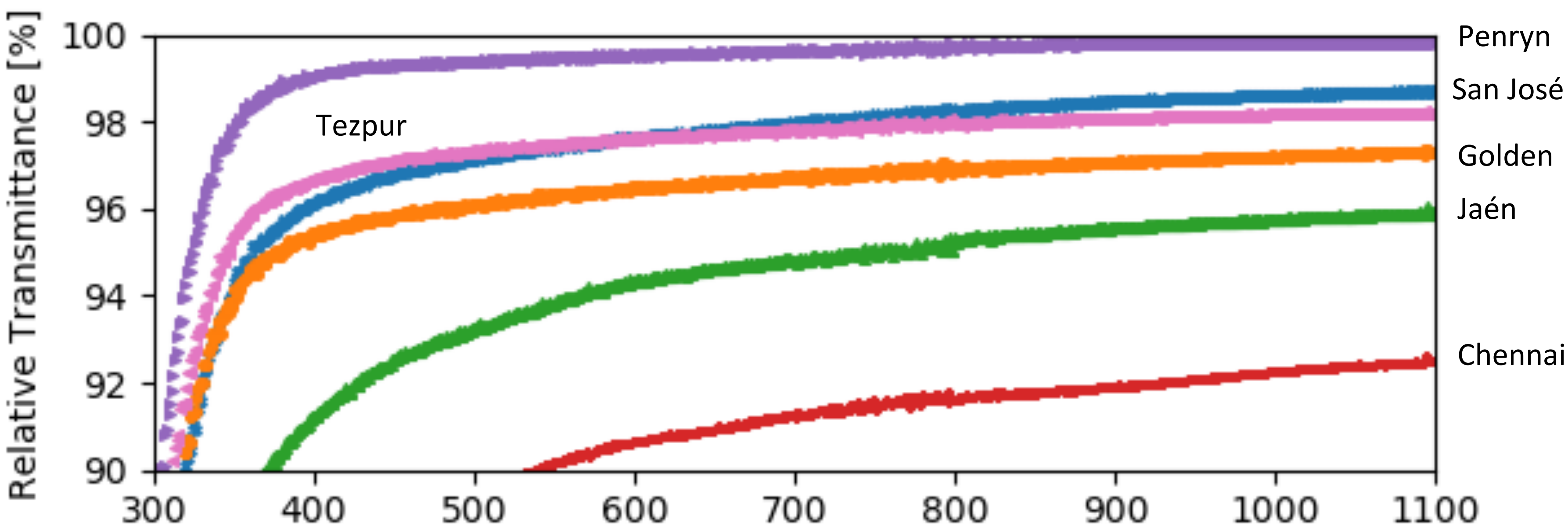


Photo: Greg Smestad

Hemispherical transmittance (data)

Relative to the transmittance of clean glass



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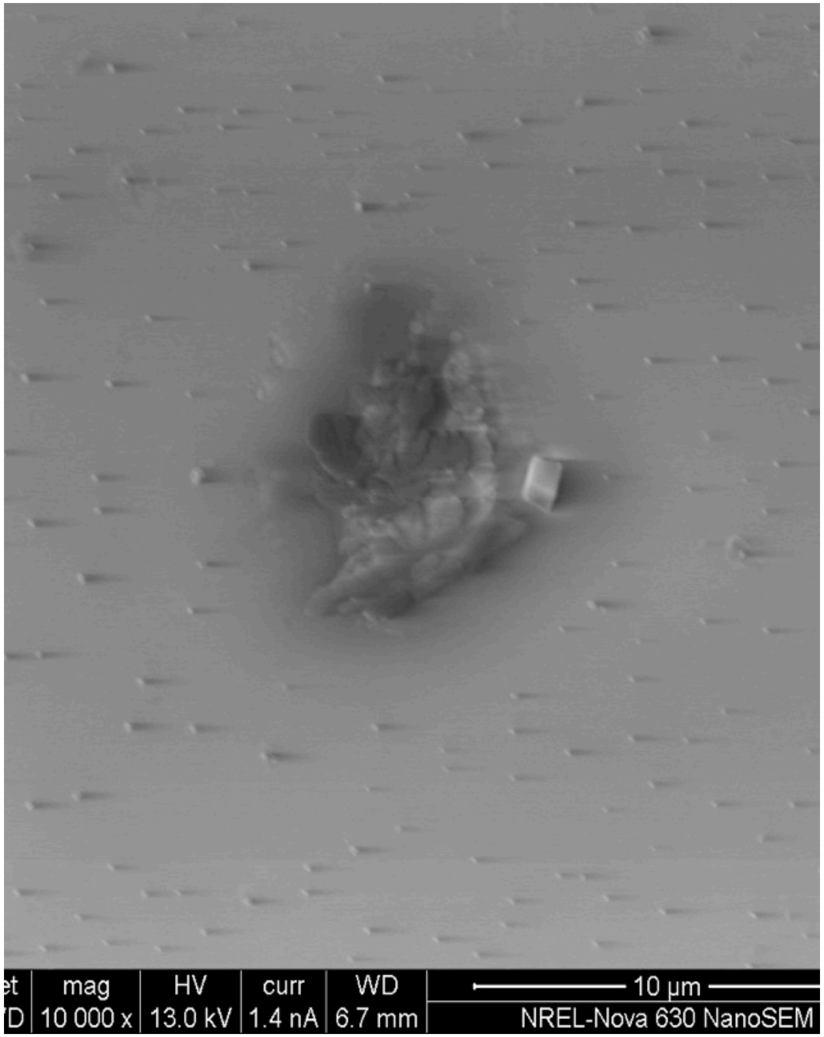
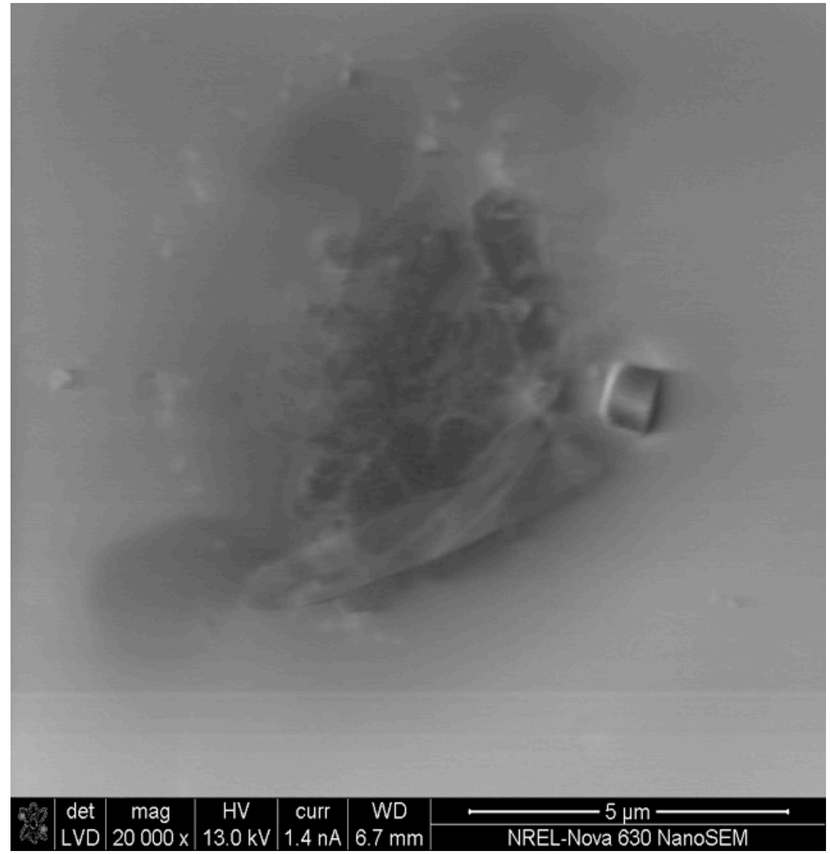
SEM (San José, CA)

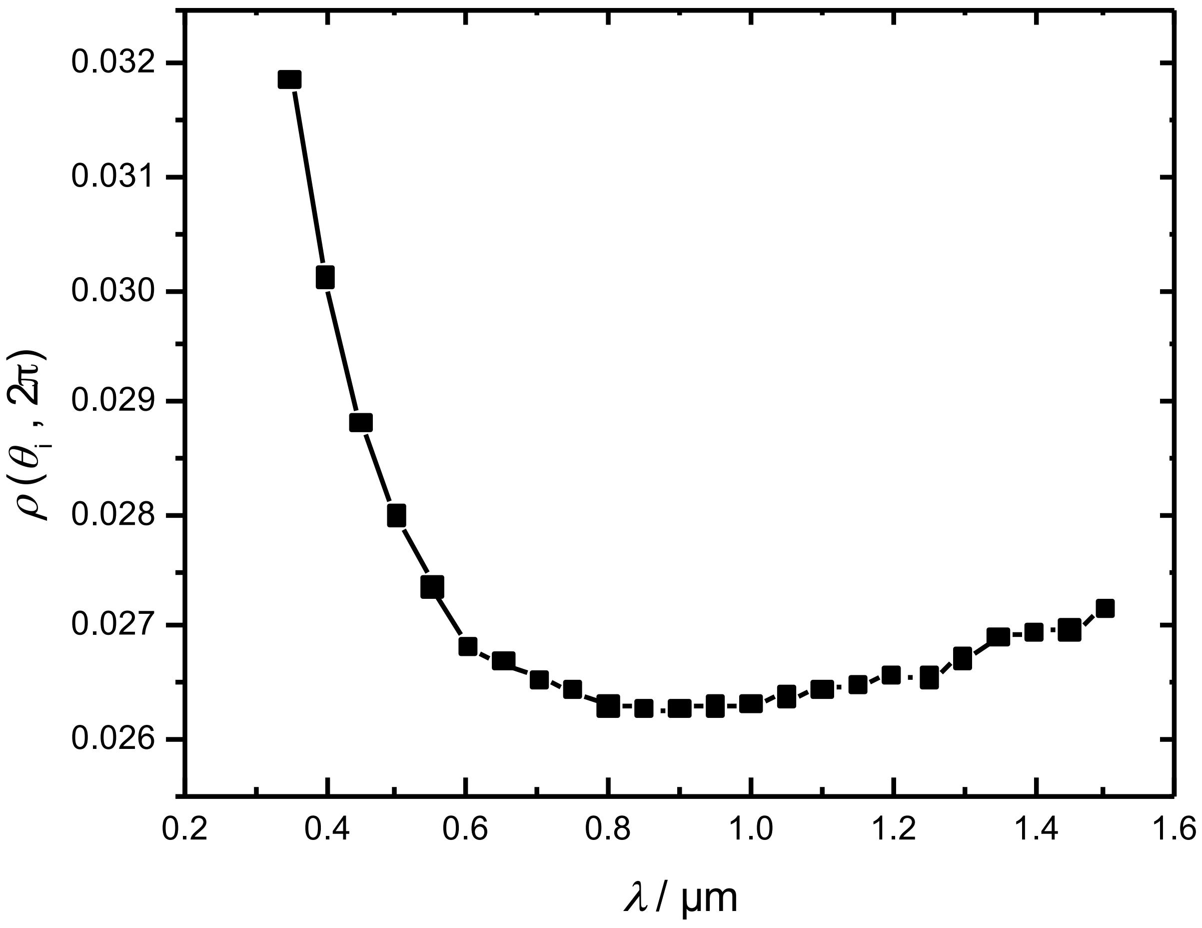




Source: 2017 NIST talk, Greg P. Smestad et al., Images by
Helio Moutinho, Ph.D.
National Renewable Energy Laboratory

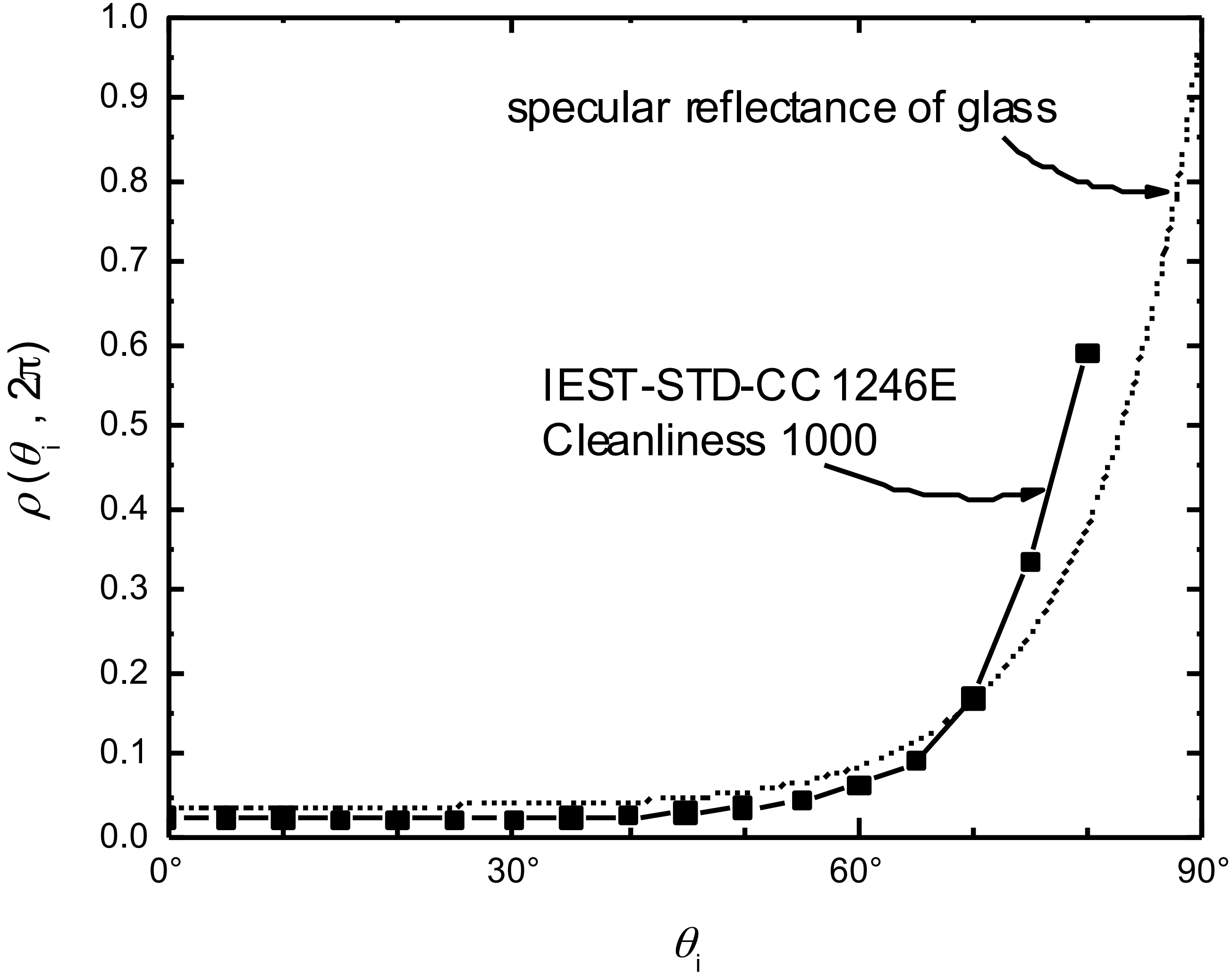
Calculated Hemispherical Reflectance of Soot Particles

Using IEST-STD-CC 1246E Distribution Cleanliness 1000



Modeled by: Thomas A. Germer, NIST

Reflectivity vs. Incidence Angle



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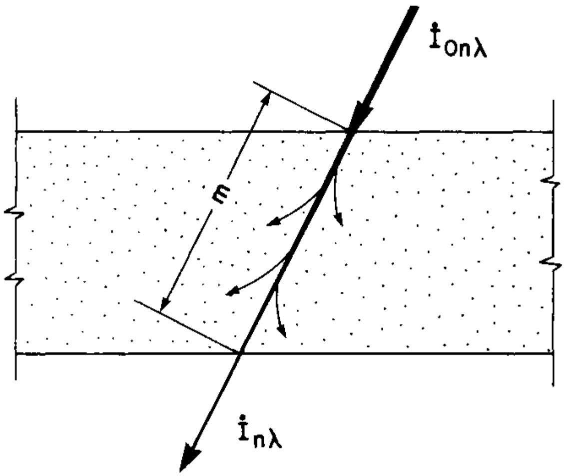
Modeled by: Thomas A. Germer, NIST

Ångström Turbidity Formula

$$\tau_{a\lambda} = \exp(-\beta\lambda^{-\alpha} m_a)$$



$\beta \rightarrow 0.0$ to 0.5 or even higher

An index representing the amount of aerosols (particles) present

for small non-absorbing particles
for small absorbing particles
for large particles

Wavelength (λ) exponent
Generally 0.5 to 2.5
(Ångström suggested 1.3)

m_a is the optical path length

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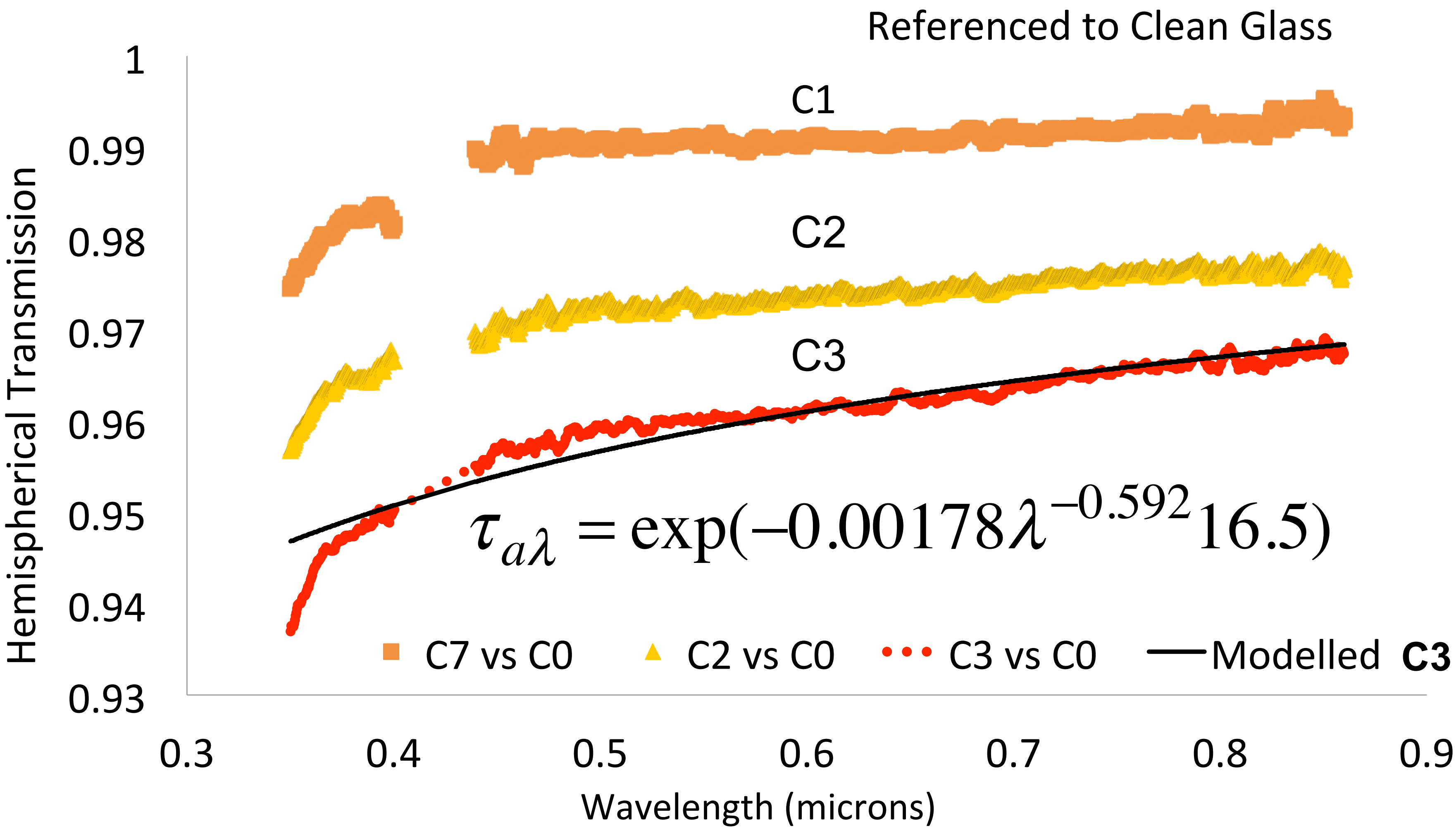
Fitting San José Transmission Data



B&W Tek, Inc. iSpec fiber optic spectrometer with Integrating Sphere

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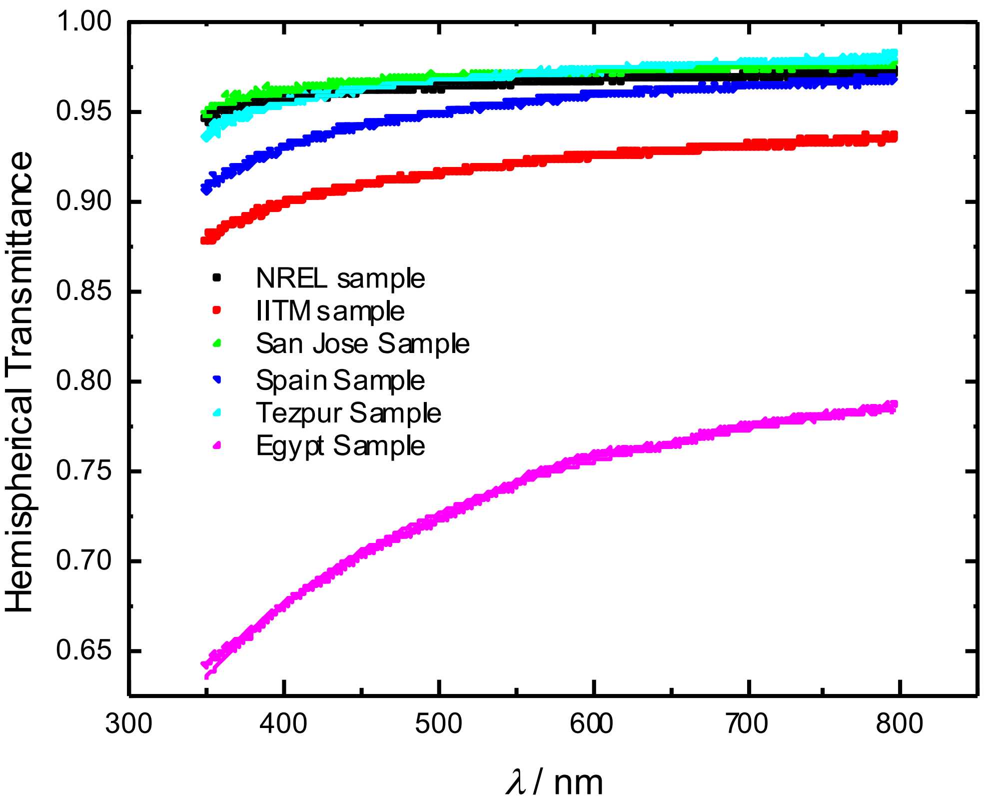
Fitting the Transmittance Data for All Sites



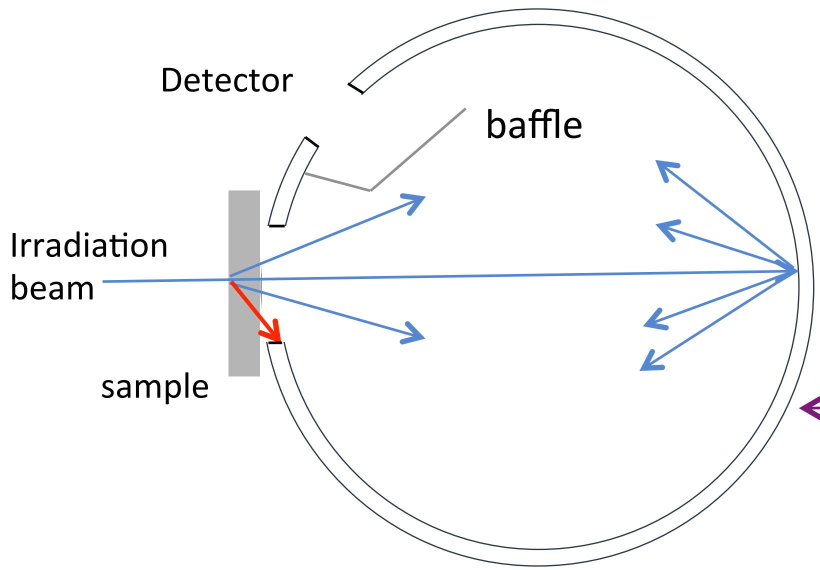
Why?

$$\tau_{a\lambda} = \exp(-\beta\lambda^{-\alpha} m_a) + \gamma$$

	NREL	IITM	San Jose	Spain	Tezpur	Egypt
beta	0.0015	0.0058	0.0010	0.0035	0.0021	0.0266
alpha	2.7	2.3	3.1	2.8	2.9	2.0
gamma	-0.026	-0.056	-0.023	-0.026	-0.018	-0.175

Does all Scattered Light Reach the Entrance?

Why a γ ?



Measure spectral transmittance of soiled glass using an Integrating Sphere.

Transmittance τ

Transmittance τ (for incident radiation of given spectral composition, polarization and geometrical distribution) is the ratio of the transmitted radiant or luminous flux to the incident flux in the given conditions. The measurement of transmittance is made with a collimated or conical radiation beam. The signals of the detector are calculated as follows:

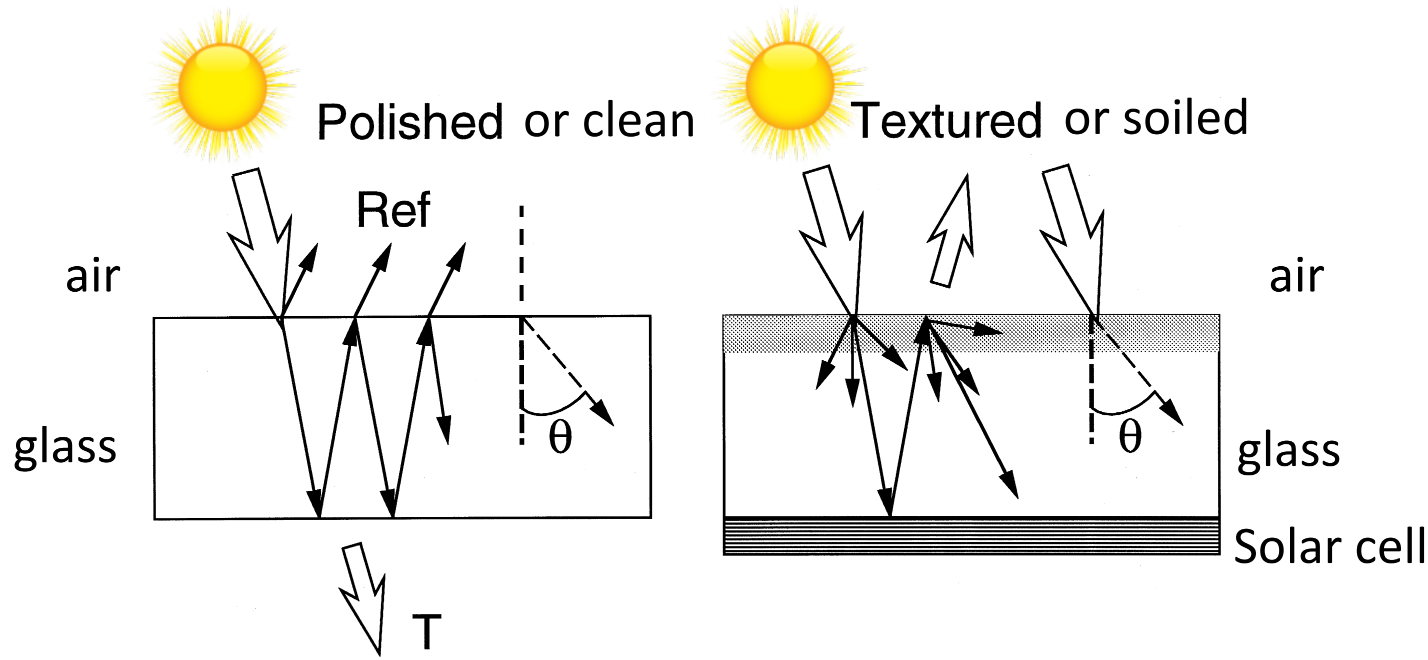
$$\tau = \frac{I\,(X)}{I\,(open)}$$

I (X): signal with sample irradiation

I (open): signal with open measurement port

Graphic: G. Smestad after gigahertz-optik.de

Passage of light through coupon <u>is not</u> equivalent to PV Module



Smestad, Greg P.
Optoelectronics of solar cells / by Greg P. Smestad.
p. cm.-- (SPIE Press monograph ; PM115)
Includes bibliographical references and index.
ISBN 0-8194-4440-5 (softcover)
1. Solar cells. 2. Optics. I. Title. II. Series.

Mini-Modules for External Quantum Efficiency (SR) Study

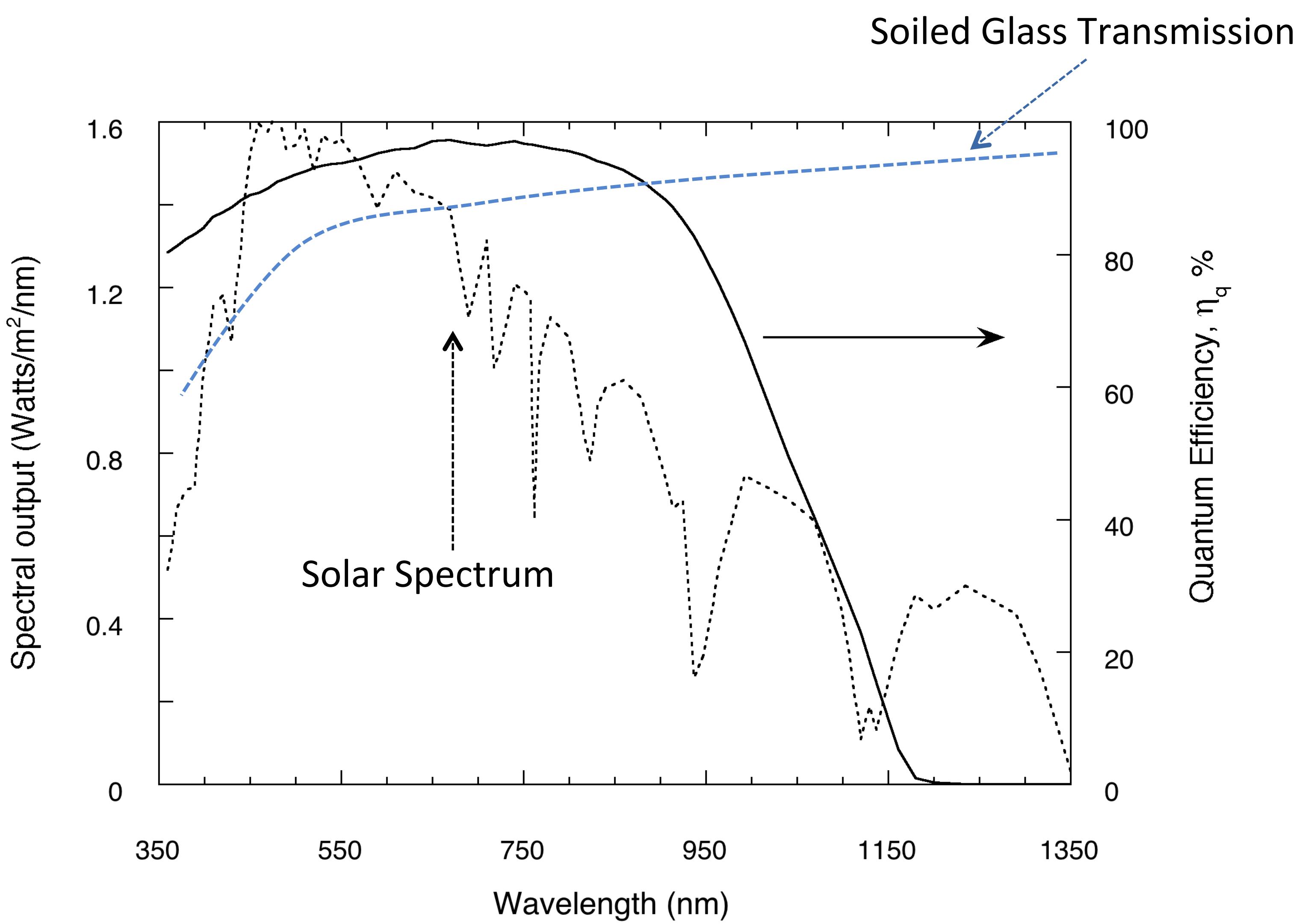
Photo: Greg Smestad

Estimating soiling losses using the transmission from glass coupons may not easily translate to exact knowledge about power losses from PV modules.

Measure Spectral Response of soiled and unsoiled PV modules.

Fabricated by: Jaewon Oh; Govindasamy Tamizhmani
Arizona State University

Silicon PV External Quantum Efficiency



Graphic: Greg Smestad

Conclusions

- We have measured the hemispherical transmission of soiled PV glass coupons.
- Natural soiling yields more or less a *neutral density filter*.
- Soiling produces a higher attenuation at shorter wavelengths compared to longer wavelengths.
  - Analogous to the Ångström turbidity formula.
- Estimating soiling losses using the transmission from glass coupons may not easily translate to exact knowledge about power losses from PV modules.
  - EQE (SR) on soiled and unsoiled PV modules is being undertaken to confirm.

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