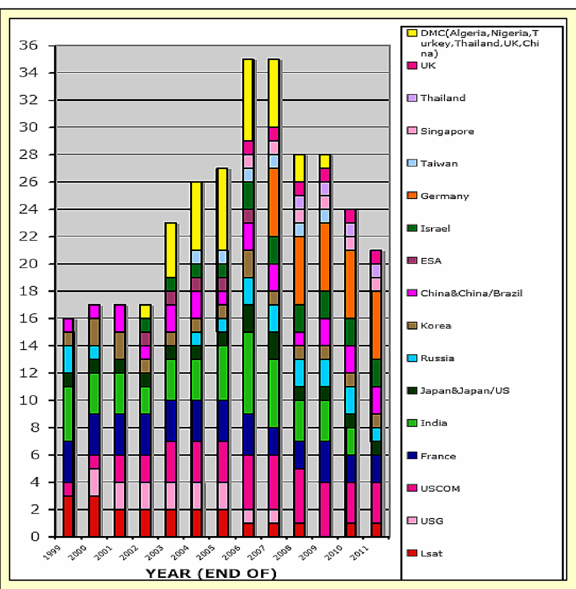
Emerging Techniques for Vicarious Calibration of Visible Through Short Wave Infrared Remote Sensing Systems

Authors: Robert E. Ryan,[1] Gary Harrington,[1] Kara Holekamp,[1] Mary Pagnutti,[1] Jeffrey Russell,[2] Troy Frisbie,[3] Thomas Stanley[3]



Background

- Over the next several years, more than 50 optical satellite imaging systems with 39 m or better resolution will be in orbit
  - 13 countries presently have imaging satellites in orbit; 20 countries will have imaging satellites in orbit by 2010
  - 30 imaging systems are in orbit; 25 imaging systems are planned by 2010
- These figures do not include the large number of advanced airborne multispectral imaging systems

Source: Stoney, W.E., 2006. *Guide to Land Imaging Satellites.* February 2, p. 10. http://www.asprs.org/news/satellites/ASPRS_DATABASE_020206.pdf

Issues

- The scientific community needs geometrically and radiometrically accurate products from the present and future "constellation" of spaceborne and airborne systems
  - Insight into the system construction, calibration, and performance will be limited in many cases
  - Most systems will not have any onboard radiometric calibration
- Cal/Val (vicarious calibration) will be essential
  - Multiple approaches are desirable
  - Ground-based reflectance radiometric methods have the greatest utility because all systems image the ground
- Ground-based radiometric calibrations currently require teams of trained staff taking coincident data at the time of overpass and analysts to estimate Top-of-the-Atmosphere (TOA) radiance
  - Costly
  - Significant coordination is required between the imagery provider and the calibration team
  - A variety of sites is needed
- Improved TOA radiance estimates are needed
  - Level of confidence in ground truth data is limited because robust instrument Cal/Val is lacking
  - Level of confidence in radiative transfer modeling is limited because independent validation methods are lacking
- Robust automated systems are clearly needed to effectively calibrate and validate products from such a large number of systems
  - Several years away
  - Concerted, well-funded projects will be need to be established

Ground-based Radiometric Cal/Val Needs

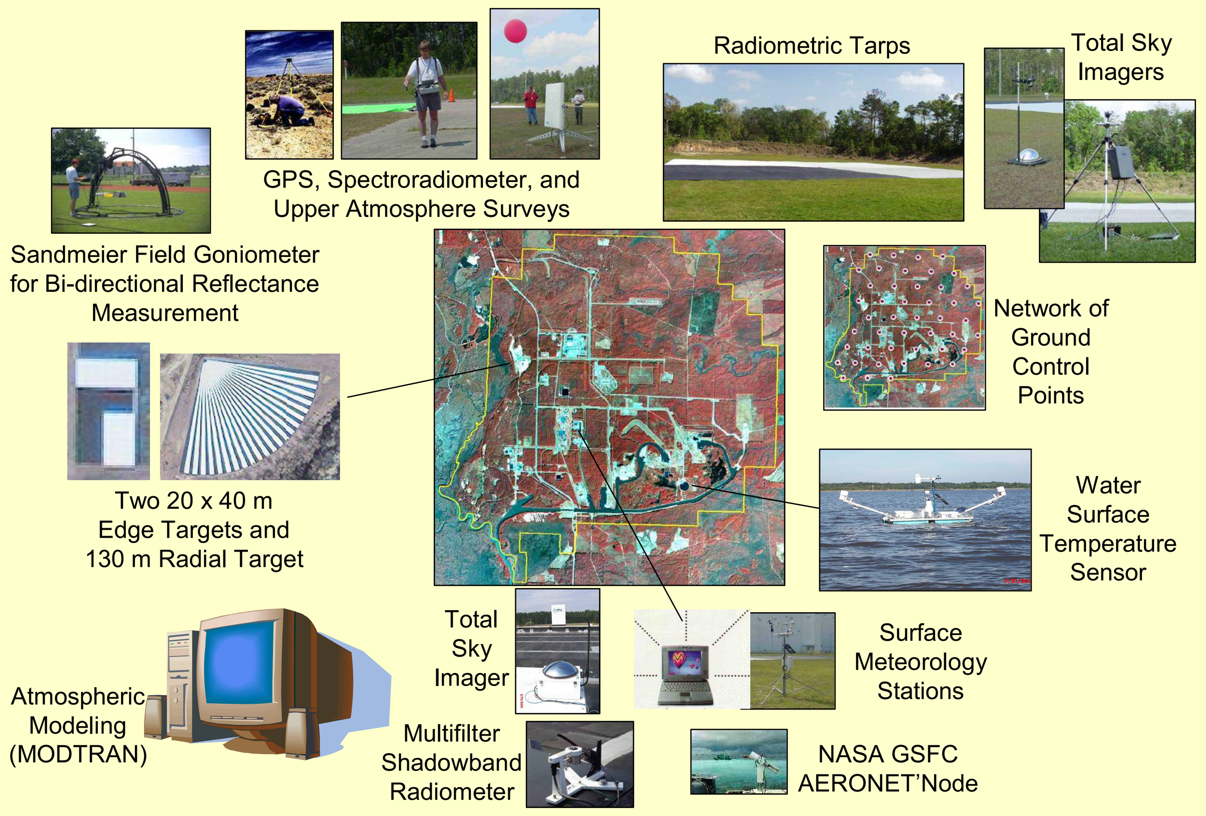
- Near-term
  - Increased confidence through independent validation of ground truth and modeling
  - Measurement techniques that reduce or at least do not increase staff
  - Simpler and more accurate calibration approaches
- Mid-term
  - Development of techniques that are compatible with autonomous measurements
- Long-term
  - Fully autonomous vicarious calibration techniques and sites

SSC Near-Term Cal/Val Development Goals

- Improved accuracy and higher confidence in TOA radiance estimates
  - Radiative transfer modeling validation
  - Alternative sun photometer calibration and validation
  - Low-cost, simple, in-field, NIST-traceable radiometric calibration source

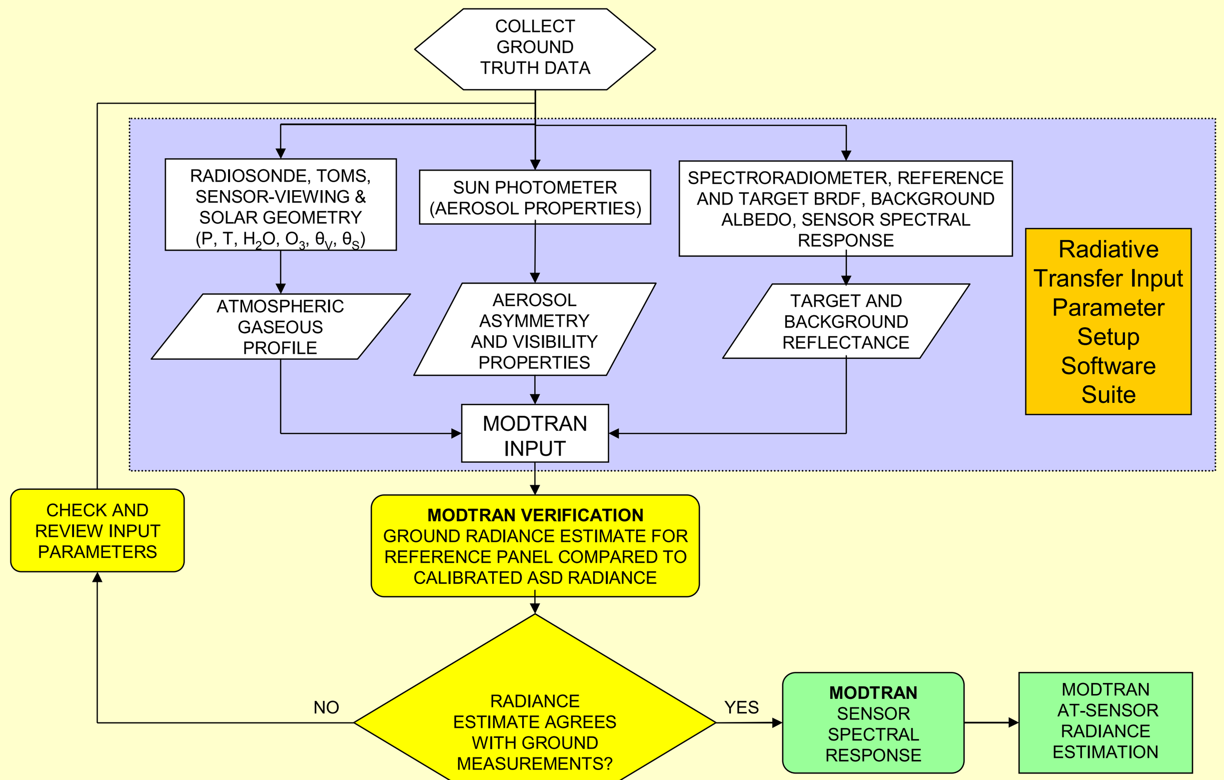
Autonomous approaches will evolve from improved, traditional, labor-intensive radiometric calibrations

Stennis Verification & Validation (V&V) Site



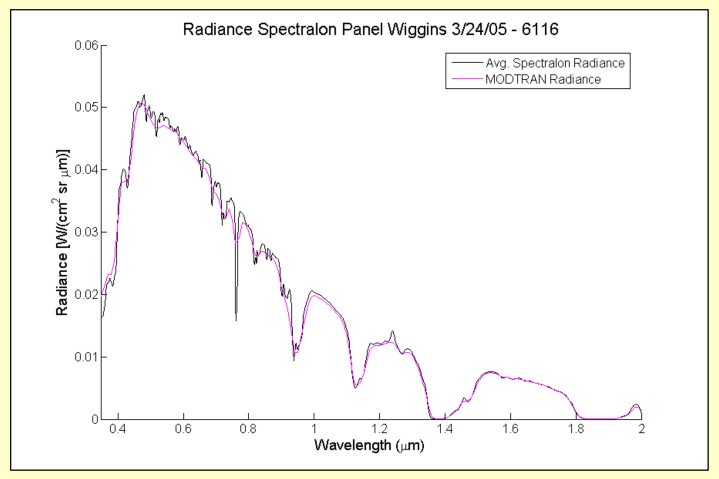
Participation in this work by Science Systems and Applications, Inc., and by Computer Sciences Corporation was supported by NASA at the John C. Stennis Space Center, Mississippi, under Task Order NNS04AB54T.

Typical Radiometric Vicarious Calibration



Radiative Transfer Validation

- Verify parameters used to generate MODTRAN at-sensor radiance estimate
  - Measure the radiance off a Spectralon® panel with a well-calibrated spectroradiometer
  - Use ground truth data and geometry that models an ASD FieldSpec® FR (Full Range) spectroradiometer measuring a 99% reflectance Spectralon panel as input to MODTRAN to predict radiance
  - Compare MODTRAN-calculated radiance to actual radiance measured from Spectralon panel to verify the atmospheric model
  - After panel Bi-directional Reflectance Distribution Function (BRDF) correction and radiometric calibration with NIST-calibrated integrating sphere, the expected panel radiance measurement uncertainty is ~2%



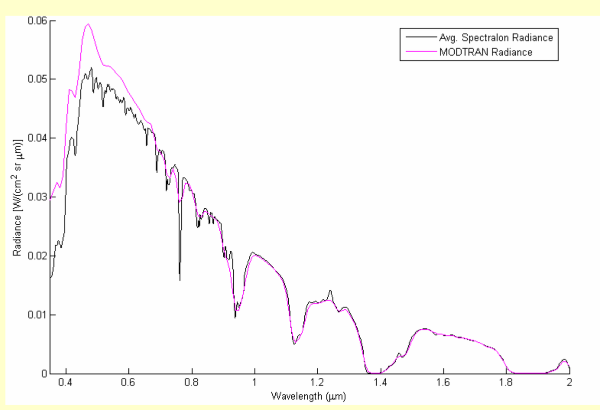
Calibration and Characterization of ASD FieldSpec Spectroradiometers

- NASA SSC maintains four ASD FieldSpec FR spectroradiometers
  - Laboratory transfer radiometers
  - Ground surface reflectance for V&V field collection activities
- Radiometric Calibration
  - NIST-calibrated integrating sphere serves as source with known spectral radiance
- Spectral Calibration
  - Laser and pen lamp illumination of integrating sphere
- Environmental Testing
  - Temperature stability tests performed in environmental chamber

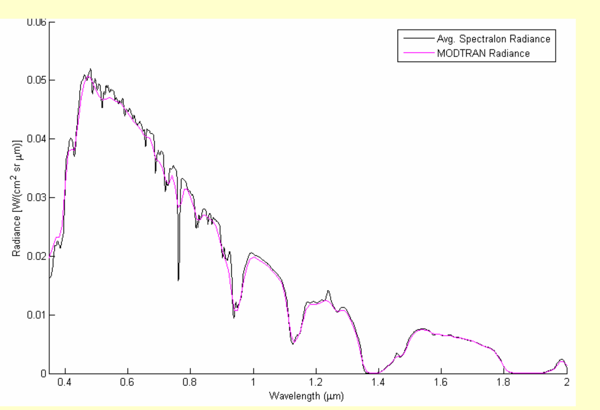
Environmental Chamber with ASD

Radiative Transfer Validation Example

MODTRAN Radiance vs. Average Spectralon Radiance from ASD



Background Reflectance Set Equal to Target Reflectance



Background Reflectance Selected by Average Region of Interest Reflectance

Adjacency as well as other radiative transfer modeling is validated

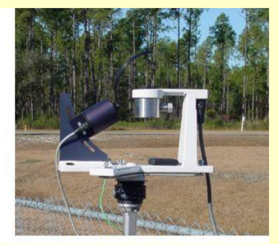
[1]Science Systems and Applications Inc., SSC [2]Computer Sciences Corporation, SSC
[3]Applied Research & Technology Project Office, NASA, SSC
POC: Robert E. Ryan, rryan@ssc.nasa.gov; Mary Pagnutti, mpagnutt@ssc.nasa.gov

Typical Sun Photometer Measurements

- Ground-level irradiance
  - Direct Normal (e.g., Arizona Solar Radiometer)
  - Total, Diffuse, and Derived Normal (e.g., Multifilter Rotating Shadowband Radiometers)
- Solar atmospheric transmission
  - Optical depth
  - Note: TOA radiance estimates are very sensitive to atmospheric transmission measurements.
- Most sun photometers support measurements in several bands to separate key molecular and aerosol scattering and absorption bands

University of Arizona Automated Solar Radiometer (ASR) "Reagan"

- 10 narrow bands
- 10 nm bandwidth
- Direct solar irradiance

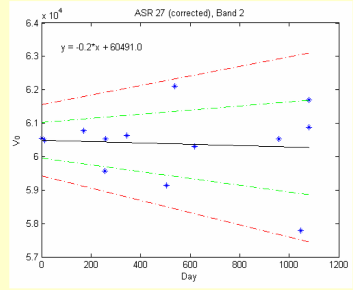


Multifilter Rotating Shadowband Radiometer (MFRSR)

- 6 narrow bands
- 10 nm bandwidth
- Total and diffuse solar irradiance

Traditional In-field Calibration of Sun Photometers

- Langley plot calibration requires many clear days with stationary atmospheres
  - Not practical in many locations
  - 5% or more errors in transmission are quite possible
- Built-in irradiance source or laboratory irradiance calibration could improve accuracy in areas where stationary atmospheres are difficult to achieve



Shadowband Sun Photometer Measurements

- Total irradiance is equal to the sum of the direct component and the diffuse component $E_{total} = E_{direct} + E_{diffuse}$
- The direct component of irradiance can be written in the following terms:

$$E_{total} = E_0 e^{-\tau_0 m} \cos(\theta) + E_{diffuse}$$

  - Extraterrestrial irradiance (E_0)
  - Atmospheric optical thickness (tau)
  - Relative air mass (m)
- Solving for tau $\tau_0 = \dfrac{\ln(E_0) - \ln(E_{direct})}{m}$
- Diffuse-to-global ratio (D2G) used to determine molecular scattering can be defined as: $E_{diffuse}/E_{total}$

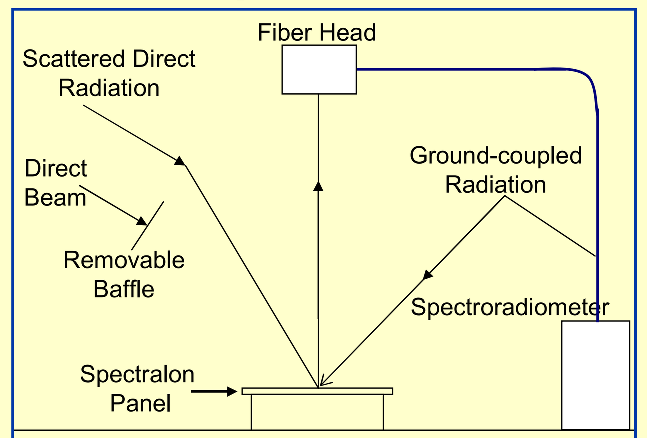
Alternative Sun Photometer Implementation

- Spectralon can be considered an irradiance-to-radiance converter if the spectroradiometer is radiometrically calibrated

$$L_{direct} = L_{total} - L_{diffuse}$$

- Knowing the reflectance factor ρ as a function of zenith angle and azimuth angle

$$E_{direct} = \frac{\pi L_{direct}}{\rho \cos(\theta)}$$



Diffuse-to-global measurement setup

Test Case Evaluations

TOA radiance values for selected targets on two days. Radiance values generated with alternative sun photometer optical depth are compared to radiance values generated with the traditional method.

Date	Original Vis/ IHAZE	New Vis/ IHAZE	Targets	Bands	Original Radiance	New Radiance	Percent Difference
1/10/04	119 / 1	184 / 1	52%	Blue	151.83	153.10	-0.84 %
				Green	143.80	145.33	-1.06 %
				Red	127.23	128.65	-1.12 %
				NIR	90.845	91.688	-0.93 %
			34%	Blue	108.04	107.29	0.69 %
				Green	97.263	96.883	0.39 %
				Red	81.465	81.362	0.13 %
				NIR	55.754	55.710	0.08 %
			3.5%	Blue	39.209	38.418	2.02 %
				Green	27.305	26.649	2.40 %
				Red	16.809	16.322	2.90 %
				NIR	9.5891	9.2478	3.56 %
4/27/05	166 / 6	84 / 6	BL (Veg.)	Green	40.732	41.179	-1.10 %
				Red	20.992	21.554	-2.68 %
				NIR	132.03	130.32	1.30 %
				SWIR	11.251	11.314	-0.56 %
			DG (Sand)	Green	162.37	161.79	0.36 %
				Red	183.29	182.68	0.33 %
				NIR	143.02	143.70	-0.48 %
				SWIR	40.295	40.198	0.24 %

Differences in TOA radiance between the two methods are negligible in most cases.

Alternative Sun Photometer Summary

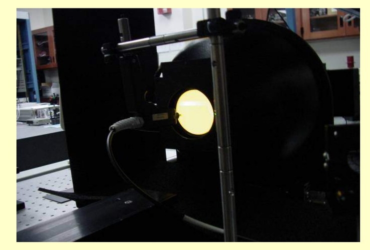
- Differences between the alternative and traditional sun photometer data (tau, D2G) are relatively small in most cases (<0.02)
  - Additional analysis shows that in certain cases, the prototype may produce more accurate measurements than the traditional method in a Stennis-like environment for lack of sufficient Langley plots
  - Improves confidence in all sun photometer measurements
- Utilizes existing commonly used vicarious calibration equipment
  - Spectralon panel and calibrated spectroradiometer
- The need for early deployment to catch many sunrises and sunsets can be minimized
- Current configuration takes hyperspectral measurements
  - Current processing uses spectral synthesis to generate bands for either MFRSR or ASR
- Spectroradiometer calibration critical to success
  - High-quality, in-field calibration could be extremely beneficial

Desired In-field Radiometric Calibration Source

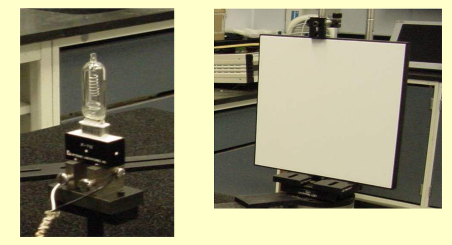
- Radiance level comparable to sea-level solar radiance values off terrestrial targets over the solar reflective region
- Radiometric stability equal to or better than 1%
- Capable of operating over a wide temperature range (10–40 °C)
- Spatially uniform light field over at least a 25 mm diameter aperture
- Spectrally stable
- Capable of operating for a continuous period of 8 hours without a line source
- Single-person portable

Typical Laboratory Radiometric Sources

1) Integrating spheres (Not easily field deployable or reliable)



2) Spectralon panels with traditional Tungsten-Halogen lamps (irradiance source)



Illumination Sources

Traditional Calibration Source: Tungsten-Halogen Lamps

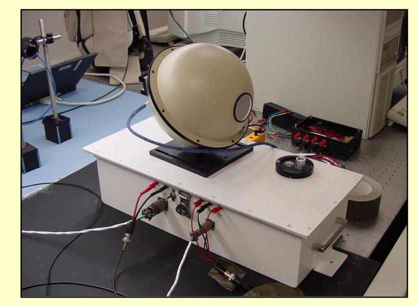
- Advantages
  - Smooth spectral curve
- Disadvantages
  - Expensive calibration ($12000 at NIST)
  - Low energy efficiency
  - Filament non-uniformity
  - Short valid calibration period (less than 100 hours)
  - Large power requirements

New Calibration Approach: High-Intensity LEDs

- Advantages
  - Extreme long life 50–100 thousands of hours to 50% of initial output
  - Reduced maintenance costs
  - Energy efficient
  - Small footprint
  - Solid state (no filament to break)
- Disadvantages
  - Narrow spectrum (white phosphors help; sometimes an advantage)

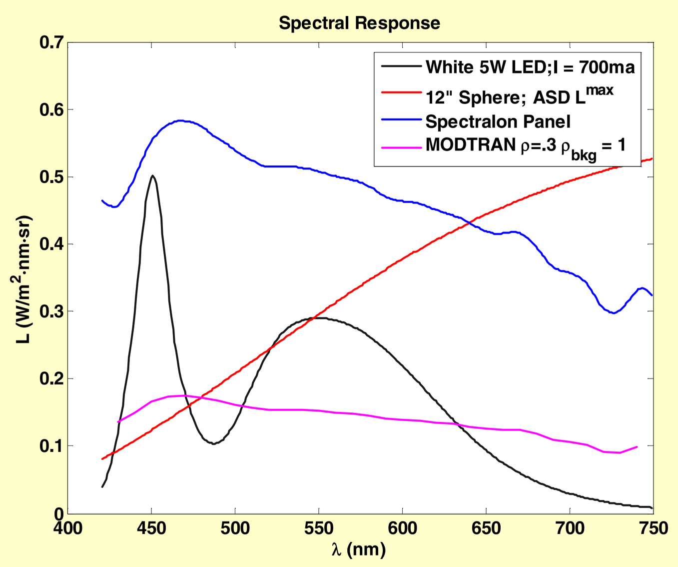
LED-based Radiance Source

- **LED-based Approach**
  - Exploit recent developments in high-power LED sources
  - Utilize integrating sphere to create uniform light field
  - Use light-stabilization control to achieve radiometric stability
  - Test and characterize system with environmental chamber and independent spectroradiometer
- **LED-based Radiance Source Characteristics**
  - Temperature-stabilized white light LED
    - Spectral range: 420–750 nm
    - Other LEDs would increase the spectral range
  - Temperature-stabilized photodiode and feedback loop stabilize integrating sphere radiance level
  - Short term lab drift <0.2%
  - Short term drift <0.5% over temperature range 10–40 °C and over large spectral range



LED-illuminated integrating sphere radiometric calibration source with photodiode stabilization

- **Comparison of LED Integrating Sphere with Traditional Sources**
  - MODTRAN calculations for 30 degree solar zenith, mid-latitude summer atmosphere, 23 km visibility and rural aerosol
  - TOA radiance levels calculated for 30% reflectance targets and 1 m above Spectralon panel
  - 12" sphere data for 3200 K Tungsten lamp



White light LED source in 8" sphere produces radiance levels comparable to brightly illuminated scenes in the visible

Summary

- Autonomous Visible to SWIR ground-based vicarious Cal/Val will be an essential Cal/Val component with such a large number of systems
- Radiometrically calibrated spectroradiometers can improve confidence in current ground truth data
  - Validation of radiometric modeling
  - Validation or replacement of traditional sun photometer measurements
  - Should enable significant reduction in deployed equipment such as equipment used in traditional sun photometer approaches
- Simple, field-portable, white light LED calibration source shows promise for visible range (420–750 nm)
  - Prototype demonstrated <0.5% drift over 10–40 °C temperature range
  - Additional complexity (more LEDs) will be necessary for extending spectral range into the NIR and SWIR
  - LED long lifetimes should produce at least several hundreds of hours or more of stability, minimizing need for expensive calibrations and supporting long-duration field campaigns
  - Enabling technology for developing autonomous sites