Accuracy Assessment for the Radiometric Calibration of Imaging Sensors Using Preflight Techniques Relying on the Sun as a Source

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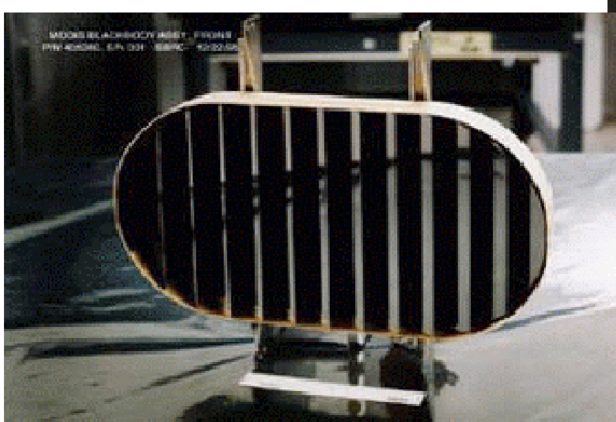
Introduction

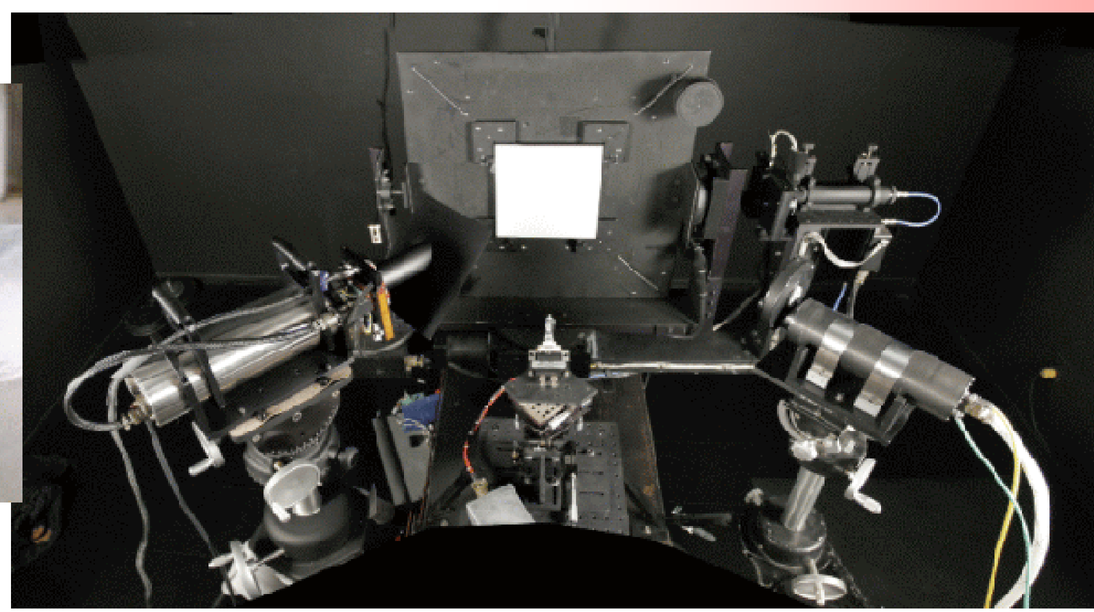
- Multiple methods are required to provide accurate and traceable radiometric and spectral calibration
  - Intercomparison between sensors
  - Climate data records
- Discuss the use of the sun as a preflight calibration source allowing sensor intercomparison
- Talk overview
  - Solar calibration approaches
  - Dominant error sources and uncertainties
  - Summary and conclusions
- Discussion that follows omits numerous terms and effects for the sake of simplicity

Source-based radiometric calibration

Preflight and inflight calibration require sources of known output

- Blackbodies in the thermal emissive
- Lamps and sphere sources in reflective
- Cross-calibration requires moving the sources from place to place

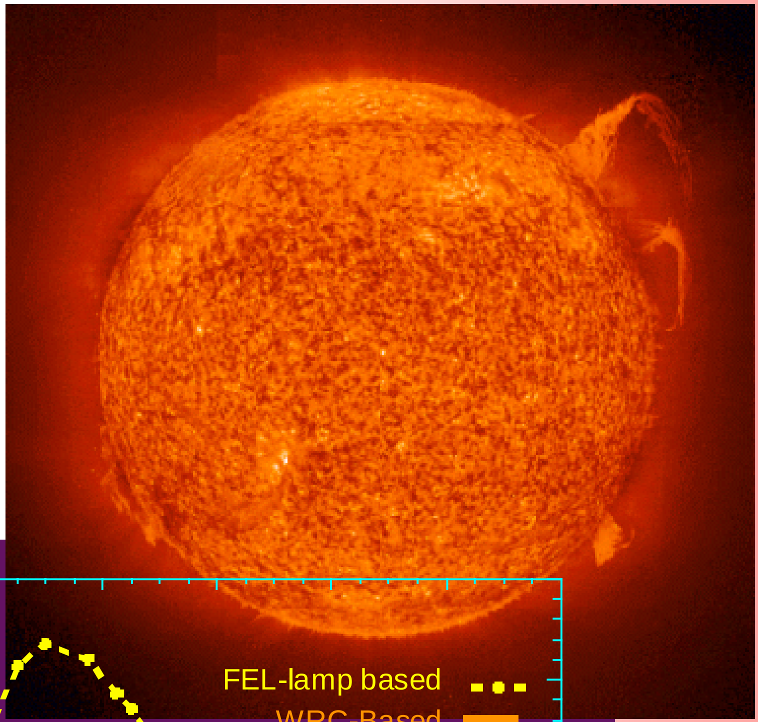


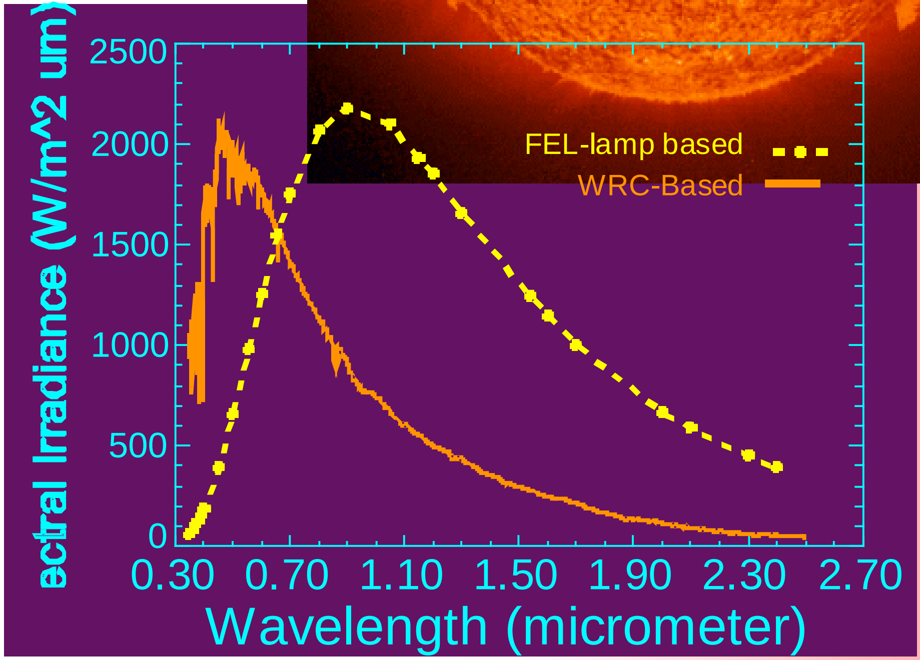


Radiometric calibration - solar-based

Sun provides a constant source with identical spectral output anywhere on the earth

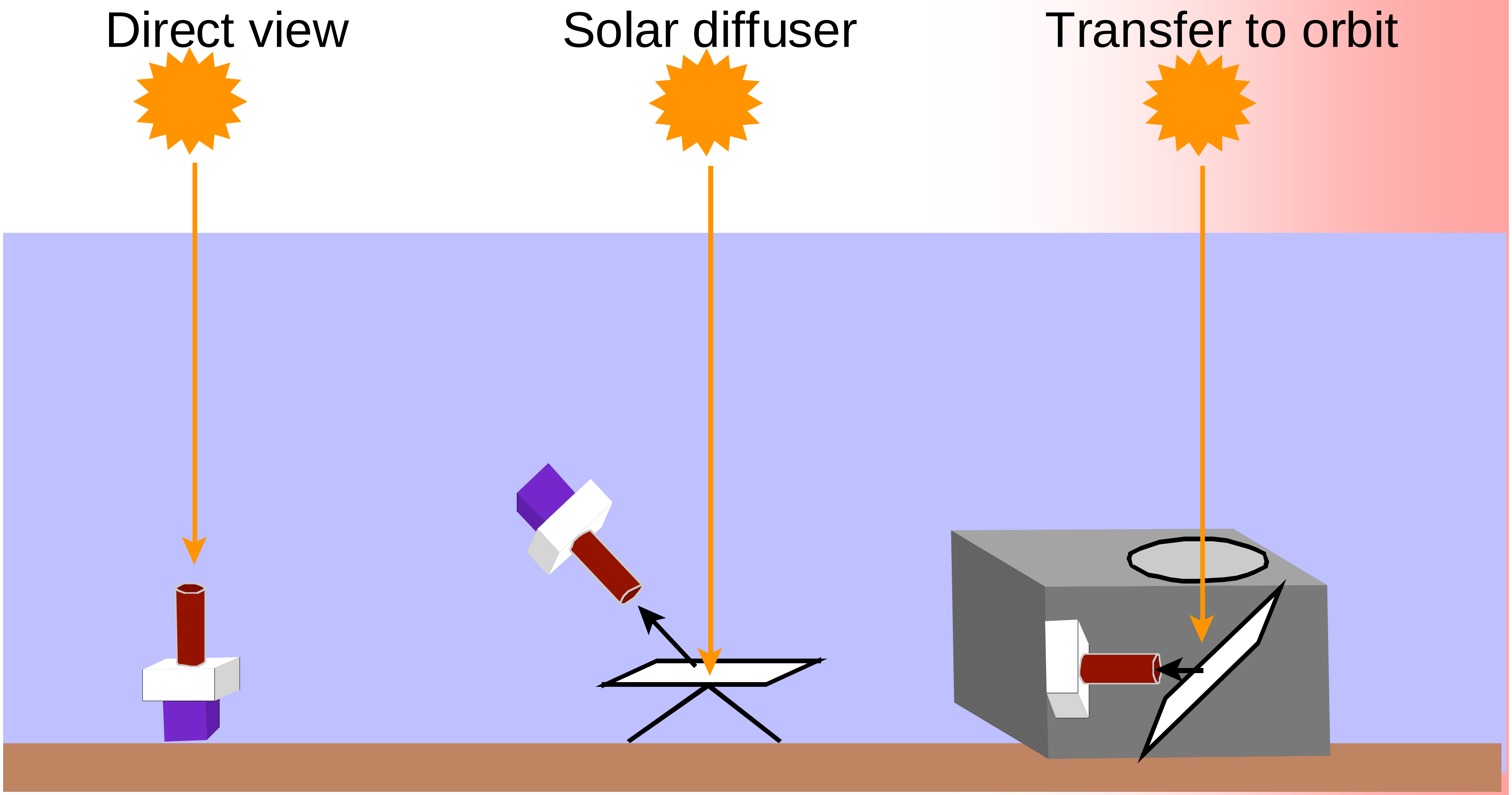
- Not exactly the case at the surface
- Sun can be used as a source both preflight and in flight
  - Direct views on ground and space
  - Diffusers on orbit
  - Feasible to use diffusers on ground





Solar-based approaches - overview

Three basic approaches using sun as a source for preflight calibration of sensors are discussed here



Solar approaches - Direct view

Direct solar view approach points the instrument at the sun and collects transmitted solar irradiance

- Irradiance on the sensor [W/m2] depends on
  - Incident irradiance (sun angle and earth-sun distance effects)
  - Atmospheric transmittance

$$E_{sensor} = \tau_{atm} E_{sun}$$

- Atmospheric transmittance can be written in terms of optical depth and airmass

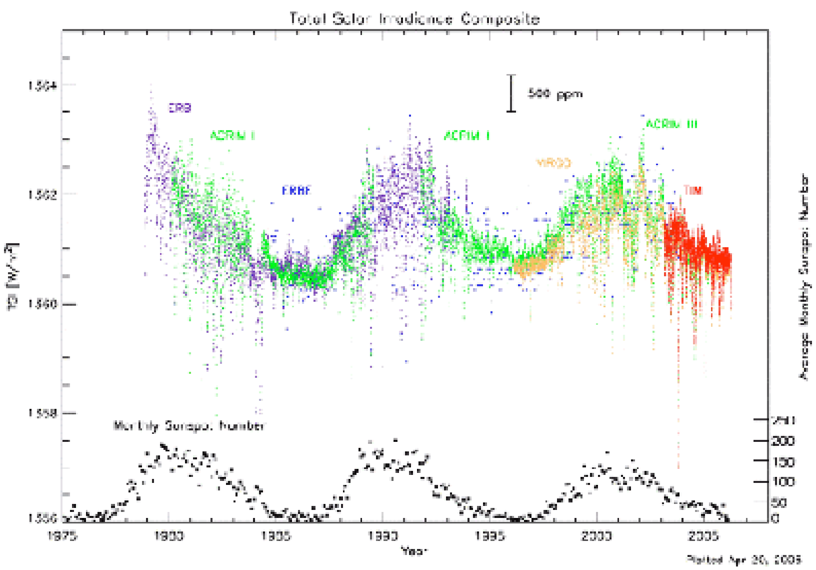
$$E_{sensor} = \tau_{atm} E_{sun} = E_{sun} e^{-m\delta_{atm}}$$

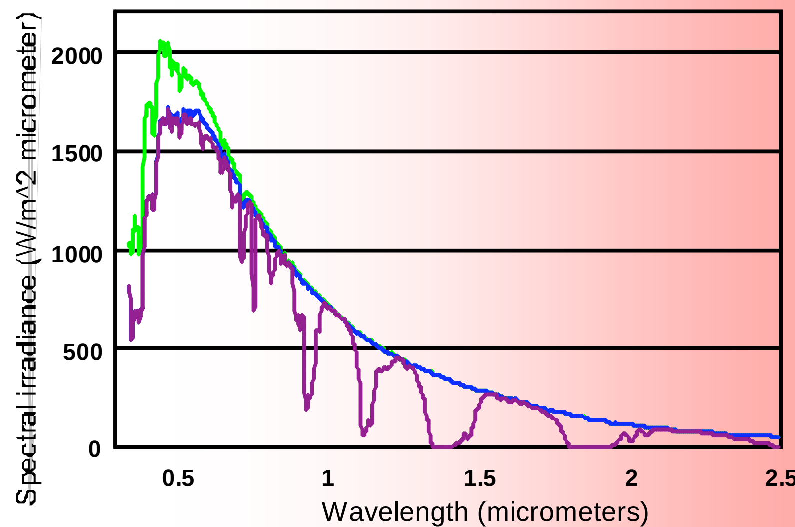
Solar approaches - direct view

Direct view used primarily to determine the solar "constant" and determine atmospheric composition

Satellite-based measurements of the solar irradiance versus time

Data have been forced to match through intercomparisons





Model-based atmospheric transmittance versus wavelength

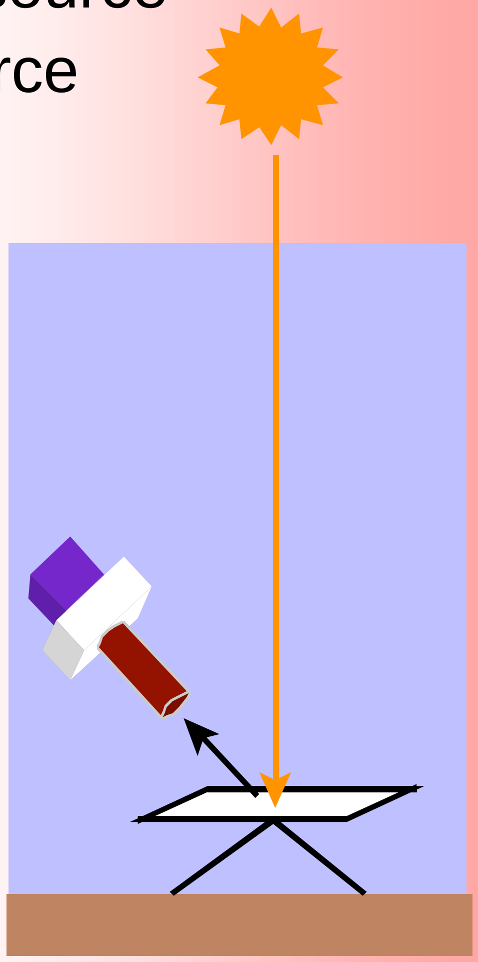
Log form of Beer's law allows Langley approach to sensor calibration

$$\ln E_{sensor} = \ln E_{sun} - m\delta_{atm}$$

Solar approaches - Diffuser

Use of a solar diffuser allows sunlight to be used as an extended source

- Sun can be well-approximated by a point source
- Imaging systems require an extended source
- Analogous to using a spherical integrating source with a lamp
- Radiance on the sensor [W/(m2 sr)] depends on
  - Atmospheric transmittance
  - Incident solar irradiance
  - Panel reflectance



$$L_{sensor} = f_{diffuser\_BRDF}(\theta_{sun})\tau_{atm}E_{sun}\cos\theta_{sun} + \frac{E_{sky}\rho_{diffuser}}{\pi}$$

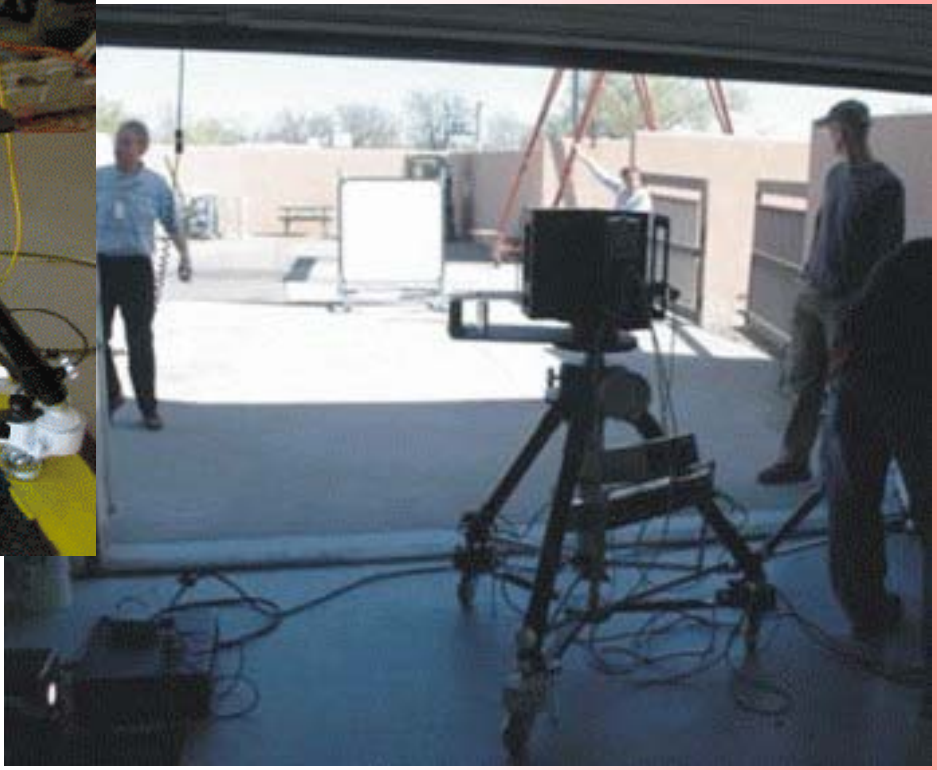
- There is also a skylight term that is present

Diffuser approach and skylight

Skylight can be removed by shadowing system and differencing diffuse and global

Diffuser approach and skylight

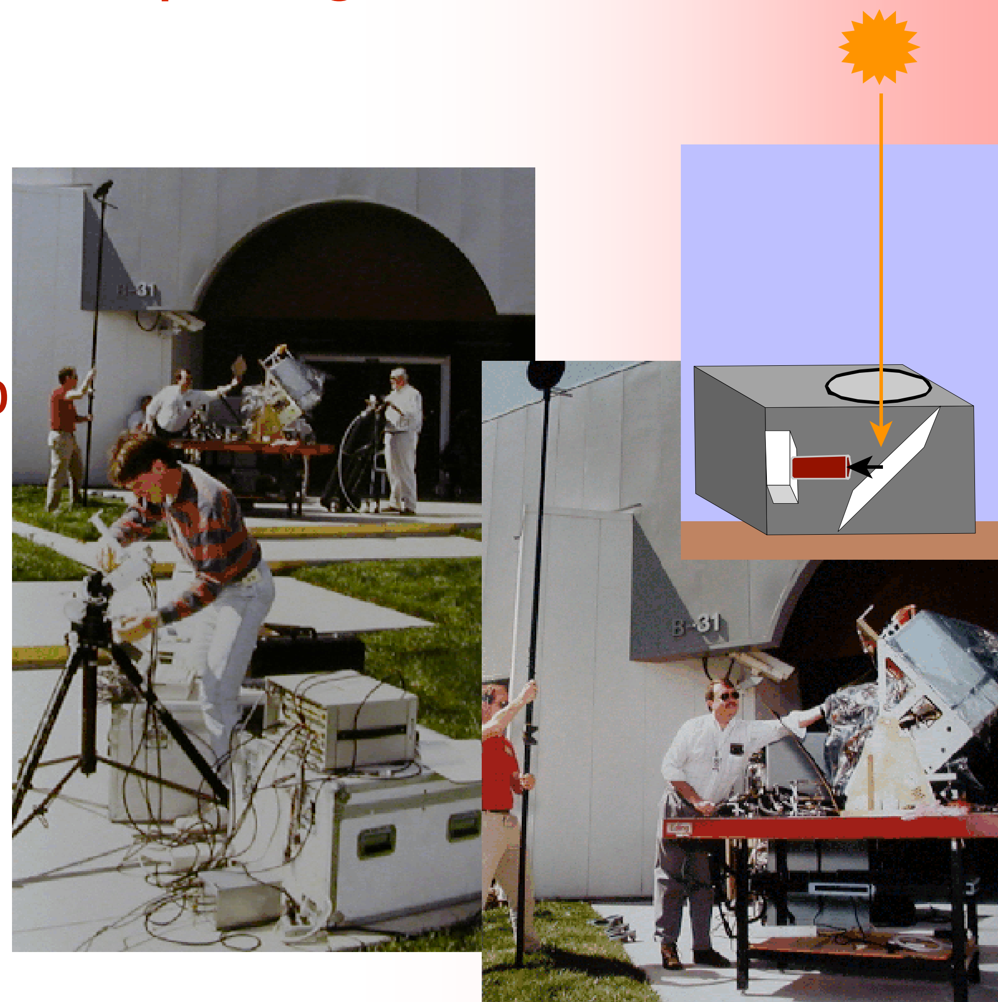
Diffuse light can be ignored by characterizing the total energy from the diffuser using calibrated radiometers



Solar Approaches – Transfer to Orbit

Sensors with on-board diffusers can be calibrated relative to the solar beam preflight

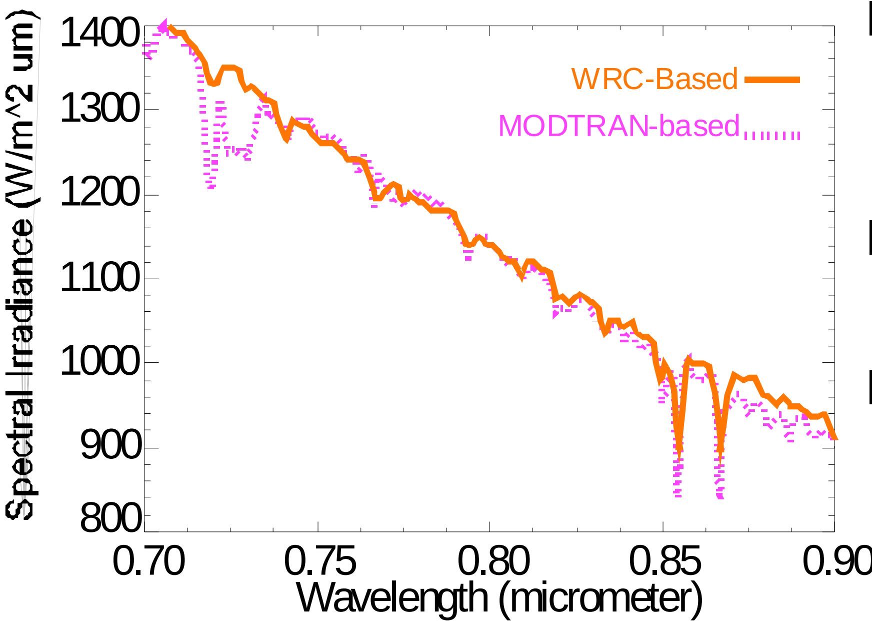
- First done for SeaWiFS
- Approach is identical to diffuser approach
  - Know conversion to radiance
  - System output is converted to that expected on orbit after correction for atmosphere



Solar Approaches - Traceability

Intercomparison between sensors requires traceable approaches and known uncertainties

- **Direct solar approach** has traceability (to NIST) via the solar model that is chosen
  - Standards of spectral irradiance
  - Electrical substitution radiometers



- **Diffuser approach** has traceability through reflectance standards
- **Transfer to orbit** has no traceability in traditional sense
- Characterization of the reflected radiance in the diffuser case has traceability to standards of spectral irradiance

Uncertainties - Direct solar

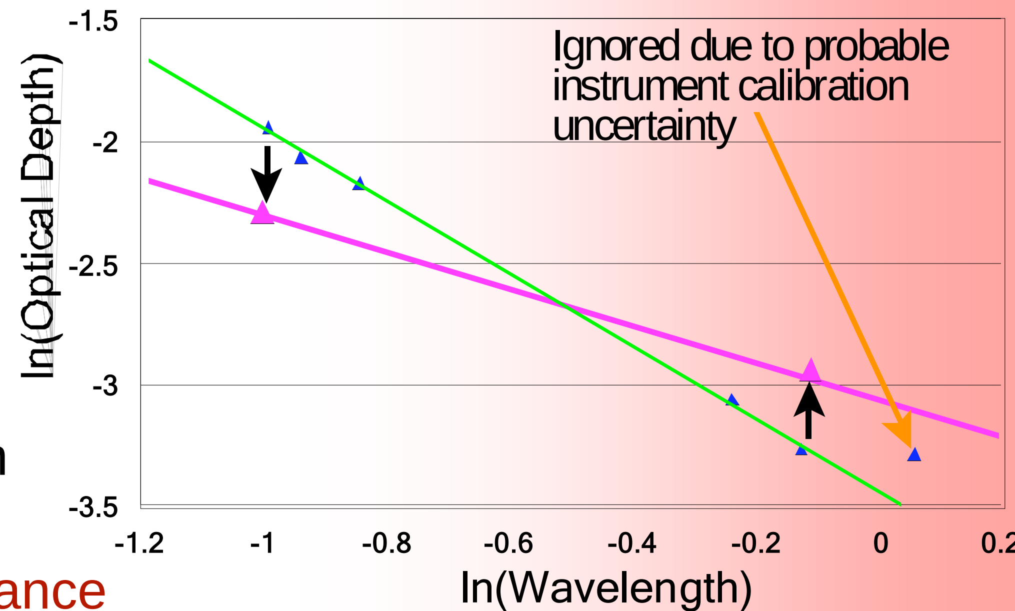
Errors are dominated by solar model and transmittance knowledge

- Errors from airmass (solar angle) uncertainty are minimal
  - Keep solar zenith angles <60 degrees
  - Know time to better than 1 second
- Solar model leads to an absolute error but can be cancelled in comparisons between sensors
- Transmittance error is both in precision and “absolute”
  - Instrument variations typically an order of magnitude smaller than atmospheric changes
  - Solar radiometer can be calibrated to better than 0.3%
  - Two solar radiometers calibrated under similar conditions agree to better than 0.005 in optical depth
  - Differences are 0.01 to 0.02 in optical depth between two independent radiometers (<2% in transmittance)

Uncertainties – Direct Solar

Not discussed at this point is that the transmittance is measured as a function of wavlength

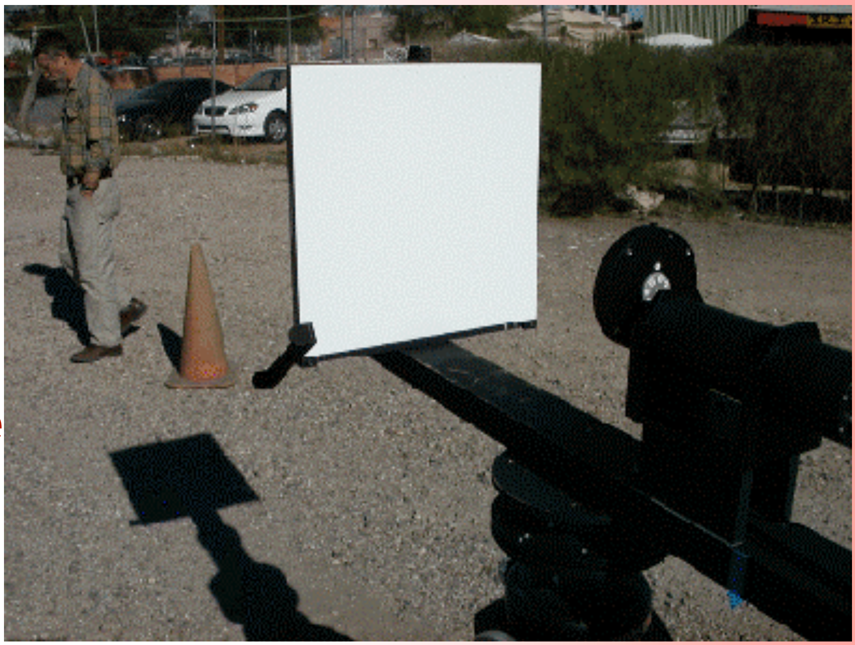
- Rely on a aerosol model to convert from multispectral to hyperspectral
- Optical depth uncertainties lead to errors in aerosol model
- Pathological case of optical depth error of -0.02 at 450 nm and +0.01 at 850 nm
  - Largest errors in transmittance
  - -5% at longest wavelengths in SWIR and 5% at 350 nm
- Random error gives 2% transmittance error at shortest wavelength and 1% error opposite sign at longest



Uncertainties – Diffuser approaches

Errors are same as for direct solar approach with added uncertainty from reflectance characerization

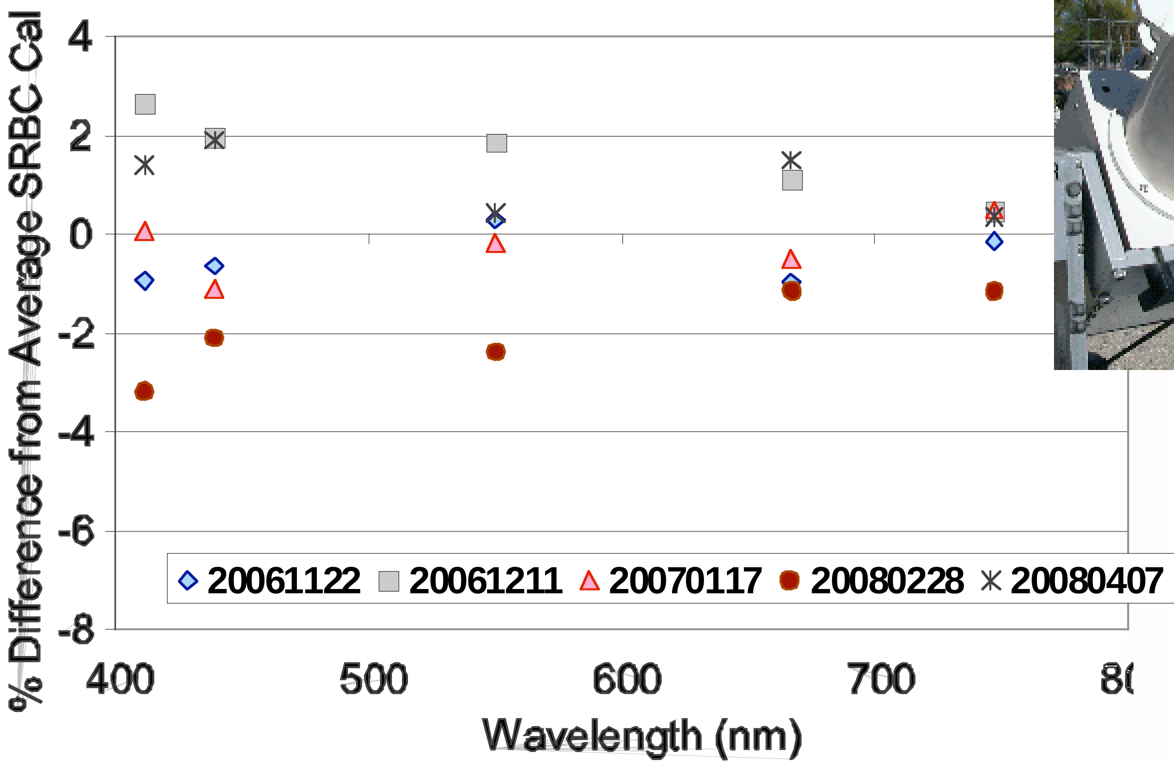
- Errors in measuring reflectance of diffuser panels can approach a 1% uncertainty (all errors are 1)
- Minimal errors caused by knowledge of
  - View direction
  - Incident direction
- Combine reflectance uncertainty
- direct solar irradiance uncertainty
  - Ever popular root-sum-square
  - 2.2% at wavelengths in the blue
  - 1.4% in the SWIR
- Assumes diffuse-light effects and forward scatter are correcte



Uncertainties – Diffuser approaches

Uncertainties have been “verified” through multiple calibrations of UofA transfer radiometers

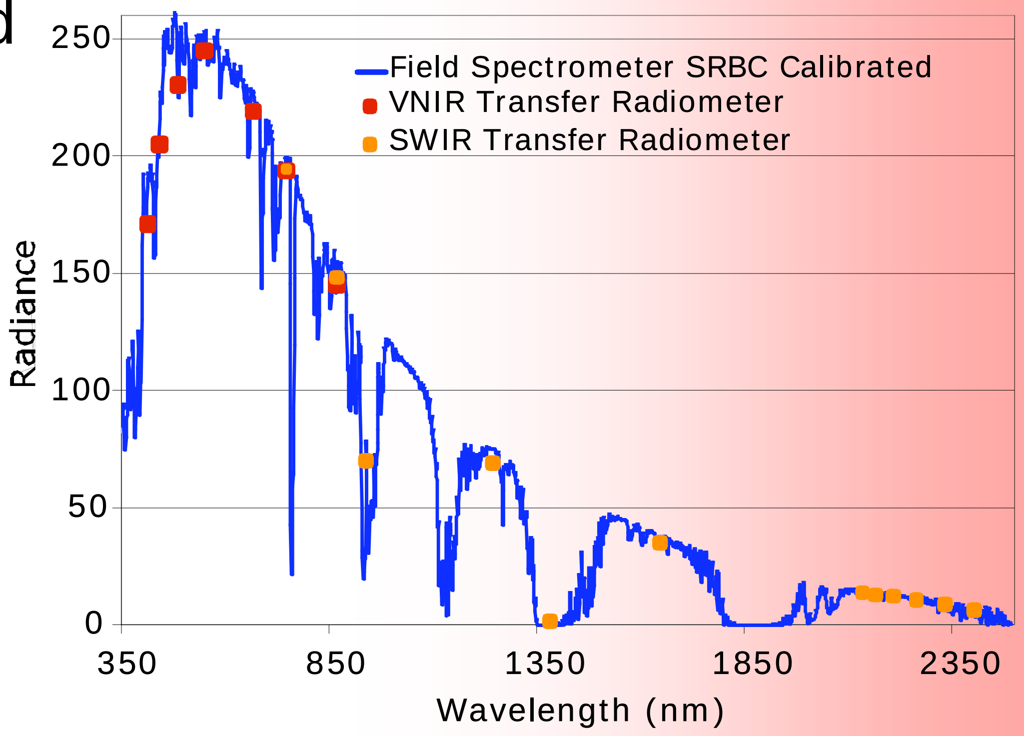
- Errors are shown relative to average
- Largest uncertainties in the blue



Uncertainties – Direct characterization

Measure the at-sensor radiance using a well-calibrated radiometr

- Transfer radiometer uncertainties are <2% in the VNIR
- Larger uncertainties in SWIR
- Additional error caused by interpolating from transfer radiometer bands
- Need to account for atmospheric variations
- Proper selection of spectral bands limits errors
- May not be better to use hyperspectral sensor

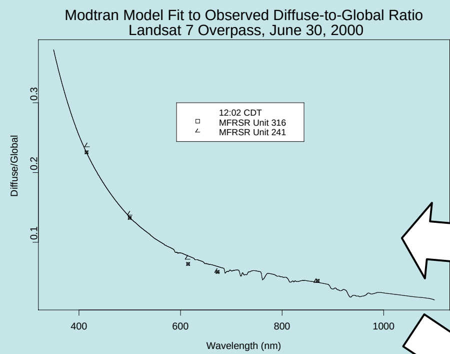


Transfer to orbit

Transfer-to-orbit uncertainties will be similar in value to those of the direct solar

- Method is relative to the solar model
- Typical solar radiometer errors as described previously lead to
  - Optical depth errors are ±0.02 at 450 nm and ±0.01 at 850 nm
  - 2% error at shortest wavelength
  - 1% error opposite sign at longest wavelength
- Correlation is the biggest issue that requires further study

In flight, Reflectance-based method

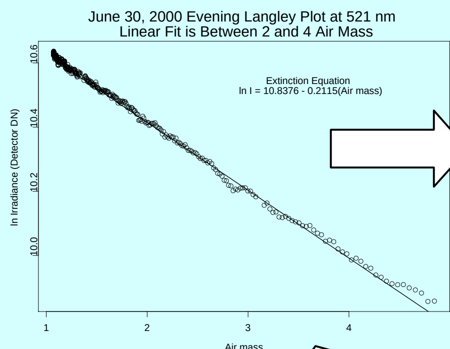


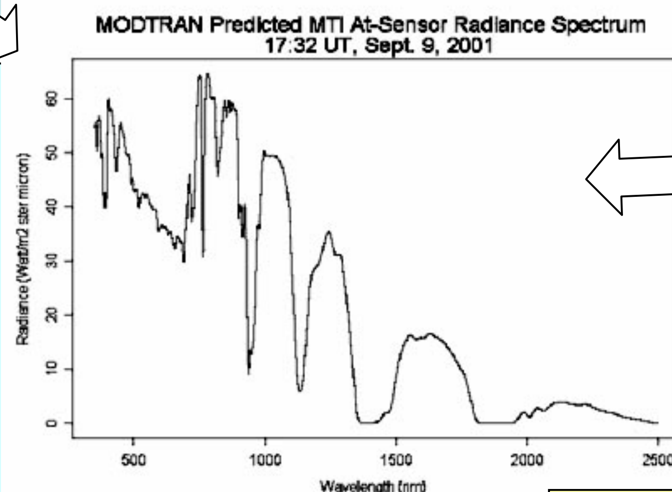
Measure and Model Diffuse-to-Global Ratio

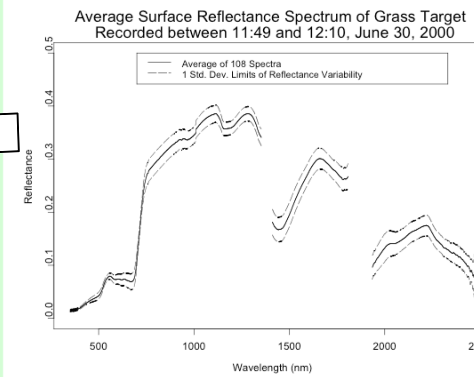
2

Measure and Input Target Reflectance

3







Measure and Model Atmospheric Transmittance

1

Calculate At-Sensor Radiance Spectrum (L)

Note this is the same sun used for SRBC

4

Input Solar Spectral Constant

Conclusions

All methods described here are suitable with absolute uncertainty <3%

- Errors largest at shortest wavelengths
  - Atmospheric effects have largest uncertainties in blue
  - Laboratory calibrations have largest uncertainties in the blue (low lamp output)
- Absolute uncertainties are slightly larger than those in the laboratory
  - Direct characterization with transfer radiometers gives only slightly larger errors
  - Diffuser approaches require accurate diffuser characterization
  - Biggest advantage is the sun shines brightly the same everywhere (at least that’s the conclusion from Arizona)