Reflectance-based method – The surface

Equipment and reference standards
Reflectance references

Measurement of absolute radiance is not a trivial process

- Use of a standard of known reflectance permits a relative measurement
- Pressed PTFE is the NIST-traceable standard of reflectance
  - Sample of specified thickness and density
  - NIST measures the incident energy and can compute what would be reflected from a Lambertian surface
- Using the computed $\Phi_{\text{Lambertian}}$ and the measured $\Phi_{\text{sample}}$ gives the reflectance factor of the standard
- Then make a version of the standard in another laboratory
  - Take an arbitrary sample and measure the reflected energy from the sample and the standard
  - The reflectance factor of the sample is

\[
RF_{\text{sample}} = RF_{\text{standard}} \frac{\text{sample}}{\text{standard}}
\]
Pressed PTFE

Ideally, pressed PTFE should be used as the reference since it is a primary standard

- Not very robust
- Soft
- Difficult to make in large sizes
- Holder must be stainless steel to follow NIST requirements
  - Extremely heavy reducing portability
  - Costly to machine
- Availability is now an issue as well
  - NIST owns all of the NIST-traceable PTFE
  - UofA owns all of the only approved substitute
- No longer a strong need for PTFE now that NIST characterizes reflectance standards
  - Send your panel to NIST
  - Obtain a NIST primary standard of reflectance
Diffuser paints

There exist numerous paints ranging from space grade to commercially-available materials

- Barium sulfate paint applied carefully provided a near-lambertian diffuser
  - High reflectance
  - Used widely in the 1980s
  - Difficult to apply evenly
  - Absorbed water causing spectral reflectance features
  - Diffuse nature relied on the surface microstructure which was destroyed through usage
- Witness samples from space diffusers are an option
  - Costly
  - Can degrade at low altitudes faster than non-space grade
- Advantages to paints are it is relatively inexpensive to make additional panels or to reapply a layer
Spectralon

Spectralon is a trademarked material made by Labsphere from sintered PTFE

- Spectrally flat
- High reflectance
- Lightweight
- Large coefficient of thermal expansion
- Has become the industry standard in radiometry
- Can obtain NIST primary standards of reflectance made from Labsphere
- Labsphere will provide an 8-degree hemispheric reflectance factor
  - Empirical relationships exist to convert this to a bi-directional value
  - New piece of Spectralon has the interesting feature of having unity BRF at an incident angle of 45 degrees and normal view (0 degrees)
Spectralon

Available in multiple sizes and reflectance levels

- Large panels are now multiple pieces coupled together
- Gray and lower reflectance panels are doped with organic materials
  - Reduces lambertian nature
  - Spatial uniformity not as good
Panel requirements

Realistically, any material that can be characterized for its BRF in the laboratory is suitable as a reference

- One group at UofA has used teflon with great success
  - Some issues with specular
  - Characterized in the laboratory properly so not a source of uncertainty
- Near-lambertian quality reduces errors
  - Leveling not as critical except when cosine incident effects are large
  - View angle effects not as large an uncertainty source
- Spatial uniformity means that measurements in the laboratory are more valid when in the field
- Portability is key
- Large size is better since it reduces out-of-field effects
Reflectance - Reference calibration

The field reference is calibrated in the laboratory prior to use and after use to evaluate its BRDF properties

- Many groups rely on the calibration supplied by the vendor
  - Field references degrade with use
  - BRDF properties can change
  - Geometry of the vendor calibration is typically hemispheric-directional and at only one direction
- Goniometric measurements in a “blacklab” to characterize the BRF references
  - Traced to NIST standard of reflectance (pressed PTFE powder)
  - BRF is found only for nadir-viewing case since this simulates its use in the field
  - Important to measure throughout the spectrum
Blacklab collections

Ideal would be to simply use a pressed PTFE sample for the field measurements

- We have found that taking the “standard” of pressed Halon into the field is not feasible
  - Difficult to make a large enough sample
  - Not very robust and easily susceptible to damage
- Instead, we create a secondary standard that becomes our field reference
  - Barium sulfate painted on an aluminum sheet
  - Spectralon® produced by Labsphere
- Measure the BRF of the Spectralon® in the RSG blacklab relative to the Halon sample
Reference calibration

Graphs below show blacklab retrievals of BRF for two different Spectralon panels

- Panel on the right has had far greater exposure to sunlight causing a yellowing of the panel
- Panel on the left is also slightly more lambertian
Reference calibration

Graphs below show a single panel with data collected approximately one year apart

- Change in the spectral behavior of the panel due to solar exposure
- No significant change in the directionality of the reflectance
  - Panels clearly have an angle of incidence effect
  - If it is assumed that the value at 45 degrees is correct, then 5% errors can occur in summer (solar zenith of 10 degrees) and winter (solar zenith of 60 degrees)
Reflectance panels

Spectralon panels are handled carefully and touching the panels is avoided

- Created carrying cases for the panels
- Have shown that the panels can be cleaned but prefer to measure them
- Panels are checked before leaving site but then packed until needed again
  - Exception is when panels are measured in the laboratory
- Originally measured before and after each trip
  - Now done twice per year in VNIR
    - Reduces risk on pressed PTFE sample
    - Field references are stable on order of years
Many groups rely on Analytic Spectral Devices FieldSpec FRs for measuring upwelling radiance

- First used for reflectance-based calibration in 1994
  - Building a similar instrument at that time took five years and was not portable
  - Company founder was well known
  - Had worked with VNIR versions for more than five years
  - Customer service was excellent
- Other choices at the time were
  - Ocean Optics - no SWIR version
  - LiCor - not portable
  - Spectron - no SWIR version
  - GER - portability an issue and was redesigning the sensor
ASD FieldSpec FR

Sensor is a fiber-based collection optic with a single pass monochromator

- Three separate detectors
  - Silicon
  - Two InGaAs
- Computer interface to proprietary collection software
- Interchangeable fields of view
  - Bare fiber approximately 34 degree FOV
  - UofA typically uses 8-degree
- Multiple model versions
Other instruments

ASDs are not the only option available but continue to be widely used in the US

- Zeiss makes a pair of instruments that cover the VNIR and SWIR
- New commercial sensors are being developed
- Feasible to build sensors at reasonable cost and personnel time
  - UofA has built a prototype of a prism-based, VNIR system for under $500 in parts
  - ASTER Science Team member used self-built system for the first 5 years after launch
- Choice of spectrometer does not appear to be the limiting factor in accuracy
Field spectrometers

Most spectrometer systems used in the field rely on diffraction gratings

- Suffer from higher order effects
  - Light from multiple orders of wavelengths strike the detector
  - Cause problems when the detector is sensitive to both orders
- Readily corrected but must be characterized in the laboratory
  - Typical way is with tunable lasers
  - Not very economical
- Spectral calibration is also important to ensure that the measurements are associated with the appropriate center wavelength
  - Can be done in the laboratory using line sources
  - Atmospheric absorption features can be used in the field
Maintenance of ASDs can be an issue since they are critical to the calibration

- Overuse of the spectrometers can raise risk they will fail
- Some sensitive components are susceptible to failure
  - Batteries
  - Fiber optics
- When possible, two ASDs are used (or at least taken)
- Not feasible for most groups
- Use of additional gray standard helps evaluate when the sensor may have issues
- Thus, less an issue of maintenance as opposed to detection
Reflectance site

Setup a series of flags to mark lines that the user walks to sample the site

- Strictly not necessary since site should be uniform and the sampling should not impact results
- Good procedure since it ensures uniform sampling of the area
- Helps the ASD user know where to go
- Helps the person with the panel know where to go
- Flags are “permanent” at Railroad Valley
- Have to be deployed every trip at Ivanpah
  - Start at same corner
  - Orientation changes from trip to trip
- Cones used on asphalt
FIGOS - Field GOniometer System

- Developed by the Swiss and allows mounting of a variety of instruments
- Samples the “same” area of the ground
  - Spreading of the area into an ellipse at large view angles is unavoidable
  - Central area is basically the same
- Major problem with this device is the lack of portability
- Also difficult to get data close to the hot spot and specular directions
Developed originally by Don Deering at Goddard
- System consists of four rotating radiometers each with a separate spectral band
- All four radiometers rotate in zenith to see the sky and the ground
- The head rotates in azimuth
- Thus, the full $4\pi$ sr of solid angle are covered
- Sampling is currently done at approximately 5-degree intervals with a 15-degree field of view
- Major problem is that it does not measure the same area of the ground
BRDF

BRF Camera

- Similar in philosophy to PARABOLA except data collection is faster due to the imaging array approach
- Calibration far more difficult due to array and complicated optics
- Failed recently and cost to repair is not warranted by the improvement to results
BRDF

Example BRDF camera image

- Illustrates the difficulties with this approach
  - Distortion at large view angles
  - Spatial heterogeneity effects
- Collecting reflectance with similar view angle as imaging sensor reduces impact of BRDF effects