Reflectance-based method – The surface

Reflectance-based error budget discussion
Reflectance is dominant
Reflectance errors dominate

High reflectance of sites means that reflectance is the dominant error source

- Reflectance errors are caused by uncertainty in knowledge of reference sample
  - Spatial heterogeneity
  - Bi-directional effects
- Instrumental effects are becoming more important
Error assessment for the reflectance-based method from earlier work by Slater et al.\textsuperscript{18} giving uncertainties as estimated in 1996 and those predicted based on anticipated improvements in the measurements. Current values are also listed based on sensitivity analysis using results of ETM+ measurements. All values in table are percentage values. Those in the “Source error” column list the percent error in the determination of that parameter. Values in the “TOA error” column are the percent changes in the top-of-atmosphere (TOA) radiance due to the source errors.

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<tr>
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<th>1996 values</th>
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<th>Current values</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Source error</td>
<td>TOA error</td>
<td>Source error</td>
</tr>
<tr>
<td>Ground reflectance measurement</td>
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<tr>
<td>Reference panel calibration (BRF)</td>
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<td>Diffuse-field correction</td>
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<tr>
<td>Measurement errors</td>
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<td>Partition into Mie and Rayleigh</td>
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<tr>
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<td>(2.0)</td>
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<td>Choice of aerosol size distribution</td>
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<td>Size limits</td>
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<td>Junge parameter</td>
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<tr>
<td>Non-lambertian ground characteristics</td>
<td>(1.2)</td>
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<td>(0.5)</td>
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<td>Other</td>
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<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
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<td>Inherent code accuracy</td>
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<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
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<tr>
<td>Uncertainty in solar zenith angle</td>
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<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
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<tr>
<td>TOTAL RSS ERROR</td>
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<td>4.9</td>
<td>3.3</td>
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# Reflectance-based uncertainties

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<th>Top-of-atmos. Radiance % uncert.</th>
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<tbody>
<tr>
<td>Ground reflectance measurement</td>
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<tr>
<td>Optical depth measurements</td>
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<tr>
<td>Absorption computations</td>
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<tr>
<td>Aerosol complex index (aerosol composition)</td>
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<td>Radiative transfer code uncertainty</td>
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<td><strong>TOTAL ROOT SUM SQUARE (RSS) ERROR</strong></td>
<td><strong>2.5</strong></td>
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Reflectance-based error budget – Surface effects

- Reflectance uncertainty a true error budget
- Traceability is through reference standard

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<td>1.0</td>
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Reflectance - based error budget – Surface effects
The UofA reflectance-based results are traceable to NIST via pressed PTFE reflectance standard

- Radiance-based measurements are traceable to standards of spectral irradiance
- UofA also has a primary standard of reflectance from NIST
- Solar irradiance models that are used have traceability to standards of spectral irradiance
- Error budgets can be developed based on the NIST traceability
  - Also evaluated using sensitivity studies
  - Finally evaluated compared to measured data
Reflectance retrieval - accuracy

RSG should be able to assess the reflectance of a surface to better than 2% of the reflectance

- That is, a level of 0.01 in reflectance at a reflectance of 0.5
- This has been “validated” by comparisons with other groups
  - Accuracy of the blacklab-derived BRF has been compared to other groups
  - Multiple groups collecting data in the same way with the same processing giving results that agree to better than 2%
  - May actually be a precision of 2% since accuracy is not a well-defined concept in the case of reflectance retrievals
- Reference panel is calibrated to 1% accuracy
- Other sources of uncertainty are more difficult to determine
  - Instrumental effects
  - Sampling effects
  - Atmospheric influences
Reflectance retrieval - accuracy

Problem is easy relative to others because we use “homogeneous” and spectrally flat surfaces with high reflectance (high SNR) and clear skies and low aerosol

- Sampling issues on inhomogeneous sites lead to inaccurate assessment of reflectance for a given sensor pixel
  - Angular field of view of ground-based sensor causing BRDF problems
  - Spatial differences from registration and sampling standpoint
  - Spectral sampling, both bandwidth and band center
- More atmospheric scattering leads to several other issues
  - Assumption of bi-directional nature of the problem
  - Temporal changes in the solar zenith angle, panel BRDF, and surface BRDF during finite time to collect measurements
- The key is to understand the problem by understanding the instrumentation being used
- Next step is to understand the site being measured
- Final step is to evaluate your sensitivity to mistakes in your assumptions, models, and data
Sampling

- Evaluated effects caused by sampling
  - Spatial imagery
  - Site measurement resampling

- Conclusion
  - Four random samples are sufficient to retrieve the reflectance to better than 3% of full 512 sample
  - Difficult to do random sampling
  - Safer to do the oversampling
Instrumental effects

Other measurement errors are related to panel reference and field spectrometers

- Thermal effect in radiometer
- Panel leveling
- ASD relative to panel
- ASD relative to ground
Reflectance-based error budget – Surface effects

- Reflectance uncertainty a true error budget
- Traceability is through reference standard

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Figure 1. Modified Hapke model used to study effects of non-lambertian surfaces.
Figure 2. Effect due to assuming a non-lambertian surface instead of a Lambertian surface. Differences exist cases which are somewhat counterintuitive in that there are smaller uncertainties than would be expected for

Lambertian model
Non-lambertian model
Backscatter direction = 180 degrees

Junge Parameter = 3.00
Backscatter case
Aerosol Optical Depth = 0.04
Solar Zenith = 20, View angle = 45
Wavelength = 479 nm
Wavelength = 835 nm
Reflectance - improving accuracy

Currently, the weakest links in the results is the measurement of the reference and operator error

- More frequent reference measurements would mean transporting the reference with the radiometer
  - Not feasible with the RSG’s 18-inch Spectralons due to weight and size
  - Smaller panel is feasible but have to evaluate out-of-field response of the radiometer
  - Also increases the amount of foot traffic on the site which can damage the reflectance
- Spatial inhomogeneity in the reference is a factor when the operator does not use the same area of the reference as measured in the laboratory
  - Out-of-field response can be a problem here
  - Methods of repeatably pointing the sensor during reference collection will improve this
- Person leveling the panel may forget to do so
- Spectrometer operator may forget to point the sensor at nadir while collecting
CEOS cross-comparison in Tuz Golu

Gathered multiple groups at site in Turkey to evaluate errors in reflectance retrievals

- Determine biases between field instrumentation using laboratory and in situ cross-comparisons
- Estimate reflectance uncertainties
- Evaluate differences in sampling methods
- Document “best practices” used by the participants
- **Not** intended to force identical data collection and processing approaches
Round robins have been done in the past
Lessons Learned from Tuz Golu campaigns

2-3% absolute uncertainty for reflectance-based calibration requires well developed error budgets

- Collaborative efforts between NMIs and vicarious calibration laboratories are essential
- Future comparisons must include a greater diversity of field instrumentation
- Knowledge of type B errors and uncertainties is inadequate
- Data collected are insufficient to determine Type A uncertainties
- Clearer understanding of systematic and random biases/errors is necessary
  - Ensure SI traceability
  - Development of proper error budgets
**Recommendation:** Establish a standardised format for reflectance-based calibration measurements to enable easier comparisons of data from site characterisations

- Comparing results from separate groups is complicated by differences in data formats.
- Standardised format includes appropriate documentation of errors and uncertainties
  - Type A is the uncertainty resulting from the statistical analysis of the data
  - Type B standard uncertainty quantified by means other than statistical analysis of data
- Use of both Type A and B permits evaluation of equipment verses methodology uncertainties
All groups used a PTFE-based white reference

- White reference calibration relied on the calibration supplied by the manufacturer
- One group characterized their own reference in their own laboratory
- One group relied on a third party to characterize their reference
- All manufacturer-based calibrations were in terms of a hemispheric-directional characterization
Measurement approaches

Logistics typically determines how a group collects data

- Single, specific approach for characterization not feasible due to differences in vicarious methods
- Methodology based on
  - Number of personnel available
  - Length of time to collect
  - Slowest method is stop and stare
  - Fastest is continuous sampling
- Equipment carrying varies by group
- Interference between user and measurement
Recommendation: Use of an invariant standard before and after site characterizations is needed to evaluate instrument performance.

Recommendation: A standardised radiometer should be developed that can act as transfer standard to link test-sites traceability.

- Limited bands with limited field of view
- Likely not portable – not suitable for characterizing the test site
- Provide means to ensure calibration of white reference
- Monitor field radiometer behavior across multiple groups
- Travelling standard allows a few groups to shoulder the costs of developing and operating radiometer
**Recommendation:** Reflectance factor of white reference panel and test site should be based on a bi-directional (Gonio) characterisation at appropriate angle(s)

- Processing methodology currently plays a limited role in surface reflectance differences
  - Sun angle effects
  - White reference calibration
- **Largest Type B error attributed to using hemispheric-directional reflectance**
**Recommendation:** Look-up table of panel BRF for range of incident angles should be developed as a first order correction

- A bi-directional characterization creates far lower Type B errors, especially at longer wavelengths.
- Offers the opportunity for a correction of diffuse-light effects at shorter wavelengths.
Tuz Golu - Measurement protocols

**Goal** of measurement protocols is to improve methods so sampling dominates differences

- Protocols must use methods usable by all groups
- Sensitivity studies and defensible and traceable error budgets provide the basis for improvements
- Surface properties and uniformity should dominate
- Reduce impact from instrument and other error sources
**Recommendation:** Perform "repeatability measurement" before and during site characterisation based on ratio of repeated panel views to repeated views of a single surface location

- Provides a Type A uncertainty assessment
- Describes effects such as measurement repeatability and the variability of the site

**Recommendation:** Individual site "point measurements" should consist of statistically significant number