Role of imaging spectrometer data for model-based cross-calibration of imaging sensors

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Need for cross-calibration

Climate-system modeling will rely on a wide array of current and future systems

- Research-quality systems (OLI and MSI)
- Operational weather systems (VIIRS and OLCI)
- Requires consistently calibrated and validated data sets
  - Intercalibration to a few high-quality sensors
  - Valid across time and multiple countries

Terra platform synergy of multiple sensors has been key to the mission’s success
Talk overview

Discuss SI-traceable cross-calibration approach relying on test site characterization

- Site characterization benefits from imaging spectrometry to determine spectral bi-directional reflectance of a well-understood surface

Outline
  - Cross calibration approaches
  - Uncertainties
  - Role of imaging spectrometry
  - Model-based site characterization
  - Application to product validation
On-orbit cross calibration

Recent years have seen great advancements in approaches for cross-calibration.

- Typically near-coincident views
  - Simultaneous Nadir Overpasses at Arctic sites
  - Chance coincidence at mid-latitude sites

- More recent work has emphasized methods that do not require simultaneous data collections
  - Invariant scene approaches
  - In-situ ground measurement methods

- Methods with SI traceability do not require sensor data to overlap in time
Scatter in coincident view cross-calibration

Calibration for ASTER green band using MODIS

MODIS and ASTER “easiest” case

- Same platform, coincident views, similar bands
- ASTER Band 1 (green band) results using MODIS
- Scatter caused by
  - Spectral band differences
  - Registration effects

Railroad Valley Playa only and includes spectral correction

Multiple site results with estimated spectral correction
# Spectral band differences – We know this already

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<th>ETM+ Band 2 Analogs</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
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Uncertainty due to spectral differences decrease as hyperspectral data of sites are accumulated. Ground data, Hyperion, SCIAMACHY
Calibration relative to in-situ

Calibration to SI-traceable, ground-based measurements

- Cross-calibration relative to in-situ data
- Requires sensors at ground site at overpass time
Best of both worlds

Combine philosophy of in-situ measurements with invariant site approaches

- Site measurements become basis for a physically-based model
  - Atmospheric
  - Surface
- Goal is SI-traceable result
- Requires innovative measurement approaches
Multidimensionality of the at-sensor radiance and non-identical sensors cause scatter

- View/solar geometry differences
  - Surface reflectance changes (BRDF)
  - Atmospheric effects
- Temporal differences
  - Solar angle
  - Surface reflectance
  - Atmospheric changes
- Spatial differences and registration effects
- Spectral differences
- Sensor effects
- All successful methods attempt to account for these effects or minimize the sensitivity
High-accuracy, imaging spectrometry would provide necessary understanding of test sites

- Cannot decouple
  - On-orbit sensor effects
  - Atmospheric variability
  - Surface variability

- Past results indicate that all three play a role
  - Note that the comparison of sensors improves in the NIR
  - Bands with highest SNR for on-orbit and ground-based sensors
  - Atmospheric effects are not as dominant

- Sensors to do this need to be improved
Site characterization

Well-characterized imaging spectrometers such as CLARREO or TRUTHS or HyspIRI can provide site characterizations for SI-traceable cross calibrations.
SI-traceable sensors for climate model evaluations

- Traceable Radiometry Underpinning Terrestrial- and Helio- Studies
- Climate Absolute Radiance and Refractivity Observatory
- Spectrometer resolution
- Unprecedented uncertainties
  - Earth reflected solar radiance < 0.3% \( (k=2) \)
  - Earth emitted infrared (IR) radiances < 0.1 K \( (k=3) \)
- Rely on both
  - Direct climate benchmark
  - Improving other sensors to provide independent climate benchmarks
Current scatter due to instruments?

First question asked in cross-calibration is which instrument is better calibrated

- CLARREO and TRUTH-like accuracies would remove that issue
- Absolute uncertainties <0.3% in band-integrated albedo allows separation of surface effects from atmospheric effects permitting the development of the needed models for the at-sensor radiance prediction
- Similarly well-calibrated and characterized ground-based instrumentation and airborne sensors are likewise needed to improve site assessments
Basic approach

Selected Test Site

Ground-based Measurements

Satellite-based Measurements

Airborne-based Measurements

Model-based “Measurements”

Predicted At-sensor radiance

Radiance is for arbitrary
1) Time
2) View angle
3) Sun angle

Emphasizes the source radiance

Moves away from one-to-one cross calibrations and empirical only

SI-Traceable with documented error budget and uncertainty
Model-based measurements

Others have used a similar pathway

- Dome C empirical corrections for BRDF and atmospheric effects
- Inclusion of BRDF models in desert site work for MODIS, AVHRR, MSG
  - Surface BRDF model corrected by Terra MODIS or POLDER
  - Includes atmospheric corrections based on climatological values
- Coupling automated data with surface models
- Deep convective cloud calculations in radiance
Key measurements

Spectral and directional reflectance of surfaces are highest priority

- Temporal sampling
  - directional reflectance (or at least validation)
  - Site stability
- Imaging provides spatial information
- Spectral samples aggregated to simulate bands
- Imaging spectrometry can lead to knowledge of surface morphology
Climate-quality data products

Level 2 data products would also benefit from TRUTHS and CLARREO

- Same basic methods as the sensor calibration
- Much of the efforts rely on
  - On-orbit comparisons
  - Airborne systems
  - Ground-based
- Goal is to understand the biophysical processes and impacts from scaling
- Current systems limited by the sensors
  - Implementing CLARREO-like calibration approaches will
  - Consider if Hyperion has been higher SNR and better accuracy
Switch from sensor-centric to SI-traceable source-centric mentality is key

- One-by-one empirical comparisons between sensors have been successful but have limits
- Combination of physically-based modeling and empirical data is not be trivial
- Inclusion of highly-accurate, imaging sensors is necessary to develop the physical models
- Method will provide improved relative calibration precision and absolute calibration that has the capability of matching current methods