Directional Reflectance Analysis of Railroad Valley, Nevada

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JACIE
NOAA Center for Weather and Climate Prediction
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Topics

• Introduction to RadCaTS
• Instrumentation and methodology
• Sample of current results
• Motivation for directional studies
• Updated results
• Future work
Introduction to RadCaTS

- Developed as an automated ground-based vicarious calibration system
- Originally designed to supplement reflectance-based approach
  - On-site personnel
  - Portable spectroradiometers, reference panels (surface reflectance)
  - Solar radiometers, ancillary weather equipment (atmospheric measurements)
  - Used with many flagship scientific and commercial sensors
  - One small drawback: we have to be on site to deploy instruments
- RadCaTS uses a combination of custom and commercially-available instruments
  - GVR: ground-viewing radiometer (designed and built at U of Arizona)
  - Cimel CE318-T solar lunar photometer (AERONET)
  - Weather station
  - Wireless base station, connected to U of Arizona via satellite uplink
RadCaTS Instrumentation
Support Instrumentation

• Calibration Test Site SI-Traceable Transfer Radiometer (CaTSSITTR)
  • Two versions: -A and -G (Arizona and Goddard)
  • Same 7 VNIR bands as RadCaTS ground-viewing radiometer
    • 400, 450, 500, 550, 650, 850, 1000 nm
  • One person operation, wireless data logging
  • Temperature-controlled focal plane (35°C)
  • Travelling transfer radiometer for test site intercomparison and uncertainty analysis (e.g. RadCalNet)
Other Instrumentation

• Commercial sUAS for spatial uniformity analysis (SPIE 2017)
Other Instrumentation

- Web camera (Campbell Scientific CCFC)
  - Installed in May 2018, views south
  - Images collected at 09:00–15:00 local standard time (17:00–23:00 UTC)
  - Every 30 minutes

- Images currently stored on site with option to download to U of Arizona
RadCaTS Layout
RadCaTS Measurements

- Ground radiometers make measurements every 2 minutes throughout day
- Cimel(s) make measurements based on AERONET protocol
- Ground radiometer and met station data uploaded daily to U of Arizona
- Multispectral reflectance data converted to hyperspectral using library of data collected from 2000–2018 (~700)
Example of Current RadCaTS Results

- **Terra and Aqua MODIS (2014–2018)**
  - **Terra**: \( N = 45 \), three near-nadir views
  - **Aqua**: \( N = 28 \), two near-nadir views
  - VZA: view zenith angle, VAA: view azimuth angle

<table>
<thead>
<tr>
<th>Band</th>
<th>Wave (nm)</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>645</td>
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<tr>
<td>2</td>
<td>856</td>
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<tr>
<td>3</td>
<td>466</td>
</tr>
<tr>
<td>4</td>
<td>553</td>
</tr>
<tr>
<td>5</td>
<td>1244</td>
</tr>
<tr>
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<tr>
<td>8</td>
<td>412</td>
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<tr>
<td>9</td>
<td>442</td>
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<table>
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<th>VAA (degrees)</th>
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<td>18:39</td>
<td>0.3</td>
<td>104.4</td>
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<td>18:46</td>
<td>11.6</td>
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<td>20:54</td>
<td>7.0</td>
<td>75.9</td>
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Example of Current RadCaTS Results

- Removal of RadCaTS from comparison

- Terra and Aqua MODIS double ratio:
  - \[ \left( \frac{\text{TMODIS}}{\text{RadCaTS}} \right) / \left( \frac{\text{AMODIS}}{\text{RadCaTS}} \right) = \frac{\text{TMODIS}}{\text{AMODIS}} \]
  - \( \pm 4\% \) uncertainty

- Sentinel-2A and -2B MSI

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<td>740</td>
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<td>835</td>
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<td>12</td>
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<td>11</td>
<td>1614</td>
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<tr>
<td>12</td>
<td>2202</td>
</tr>
</tbody>
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Ratio of TOA Spectral Radiance (TMODIS/AMODIS)
Another Example: GOES-16 ABI Radiometric Validation

- Period of study: Apr 2017 to Sep 2018
- Based on ‘good’ RadCalNet days
  - Most (or all) 13 times throughout the day are processed
  - 17:00–23:00 UTC
  - Every 30 minutes
- Solar noon used for this study
- 2017: 17 dates
  - ABI view geometry: 52° zenith, 321° azimuth
- 2018: 21 dates
  - ABI view geometry: 61° zenith, 306° azimuth
- GOES-16 CONUS imagery
RadCaTS GOES-16 ABI Radiometric Validation Results

- Shown as average, 2017, and 2018
- Uncertainty bars are ±4% uncertainty RadCaTS
- ABI pixel size (nadir)
  - Band 2: 500 m
  - Bands 1, 3, 5: 1000 m
  - Band 6: 2000 m
- Results show bias similar to in situ measurements in Bolivia
RadCaTS GOES-16 ABI Intercomparison Results

• Results compiled from Apr 2017 to Sep 2018

• ‘Double ratio’ used to remove bias between each sensor and RadCaTS
  • E.g. (ABI/RadCaTS) / (MODIS/RadCaTS) = ABI/MODIS

<table>
<thead>
<tr>
<th>Sensor</th>
<th>ABI Center Wavelength (nm)</th>
<th>Band (Pixel size (m))</th>
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<tbody>
<tr>
<td>ABI</td>
<td>471</td>
<td>640</td>
</tr>
<tr>
<td>TMODIS</td>
<td>3 (500)</td>
<td>1 (250)</td>
</tr>
<tr>
<td>AMODIS</td>
<td>3 (500)</td>
<td>1 (250)</td>
</tr>
<tr>
<td>S2A</td>
<td>2 (10)</td>
<td>4 (10)</td>
</tr>
<tr>
<td>S2B</td>
<td>2 (10)</td>
<td>4 (10)</td>
</tr>
<tr>
<td>L8</td>
<td>2 (30)</td>
<td>4 (30)</td>
</tr>
</tbody>
</table>
Motivation for Current Work

- Only two GVRs dedicated to large off-nadir view angles (GOES-16 and -17 ABI)
- Impossible to dedicate other GVR views to large range of current satellite sensors

Current study:
- Data from BRF camera developed at U of Arizona (but no longer in use)
- Round-robin field measurements at Railroad Valley in May 2018
  - U of Arizona
  - U of Lethbridge (Canada)
  - NASA GSFC
  - NASA JPL
  - DigitalGlobe
  - GSJ/AIST (Japan)
  - NGA
Round-Robin Field Campaign: May 2018

- Follow on to past campaigns such as Lunar Lake, Nevada (1996), Tuz Golu, Turkey (2011), Tucson (2012), Algodones Dunes (2015)

- Objectives:
  - Evaluate reflectance measurements
    - Repeatability and accuracy
    - Group intercomparison
    - Surface collection methodology (moving vs stop and stare)
  - BRDF measurements
    - ULGS-2 (U of Lethbridge)
    - PARABOLA (NASA JPL)
    - Multi-angle radiometers
  - RadCalNet evaluation
    - Examine absolute radiometric calibration of RadCaTS radiometers
    - Comparison with hyperspectral spectroradiometers (e.g. ASDs) and CaTSSITTR
U of Lethbridge Goniometer System (ULGS-2)

- Two Ocean Optics USB-4000
  - 350–1000 nm
  - Measures radiance reflected from ground
  - Measures downwelling irradiance (Spectralon cosine receptor)
  - Real-time spectral reflectance calculation

- Quarter circle arc mounted to pivoting beam
- Complete hemispherical sampling
- Operating radius: 2 m
- 8° foreoptic
- Ground sampling size: 60-cm diameter
- Also used during Algodones Dunes round-robin field campaign in 2015
Sample of Results for ULGS-2

- 3 May 2018
- Temporal example
  - 580 nm
  - 0°–60° view zenith angle (ring of dots)
  - Solar principal plane in vertical direction

- Spectral example
  - 22:00 UTC
  - 450, 550, 581, 650, 860 nm
  - 0°–60° view zenith angle (ring of dots)
  - Solar principal plane in vertical direction
  - Anisotropic behavior is stronger at longer wavelengths

- Field campaign data reduction still in progress...
U of Arizona BRF Camera

- Scientific-grade silicon CCD array (1024\times1024 pixels)
- Coupled to Nikkor 8-mm fisheye lens (180° FOV), which includes filter wheel
- Spectral selection
  - Interference filters
  - 470, 575, 660, and 835 nm center wavelength
- Tradeoff between nonimaging hyperspectral portable spectroradiometer (e.g. ASD)
- Requires complex cooling system to maintain –32°C
  - Thermoelectric cooler coupled to ethylene glycol system
  - Coupled to an ice-water bath
- BRF camera data used to modify current RadCaTS hyperspectral surface reflectance (scale up or down)
  - Using table of phase values vs scatter angle
  - Not spectral at this time, but will be updated
RadCaTS results corrected with BRF camera historical data

- BRDF correction factor from BRF camera applied to current RadCalNet results

- Example cases:
  - Two Terra MODIS near-nadir overpasses
  - Restricted to MODIS VNIR bands since BRF camera operates in this range
  - Bands 1–4, 8, and 9
  - VZA: view zenith angle, VAA: view azimuth angle

![Graphs showing ratio of TOA spectral radiance](image)
RadCaTS results corrected with BRF camera historical data

- BRDF correction factor from BRF camera applied to current RadCalNet results

- Example cases:
  - Two Aqua MODIS near-nadir overpasses
  - Restricted to MODIS VNIR bands since BRF camera operates in this range
  - Bands 1–4, 8, and 9
  - VZA: view zenith angle, VAA: view azimuth angle

- Aqua
Summary

• The work presented here is a preliminary effort to correct RadCaTS data for directional reflectance

• Historical BRF camera data appear to be providing a reasonable BRDF correction for current RadCaTS data

• Automation of the process will allow all RadCaTS data to be re-evaluated

• May 2018 round robin data are still being evaluated, and the groups involved will be consolidating their results to present a coherent answer

• Include BRDF-corrected reflectance from 4 nadir-viewing GVRs with the tilted GVRs to obtain better spatial sampling of 1-km² site for GOES work

• Results will be presented in a suitable journal. Stay tuned…
Radiometric Calibration Network (RadCalNet)

- Online data portal went live in Jul 2018: www.radcalnet.org
- Railroad Valley: 2014–present (typical latency of ~5 days)
- RadCalNet forum: forum.radcalnet.org (announcements, FAQs, documentation, etc.)
Thanks!

- The authors would like to thank the Bureau of Land Management (BLM), Tonopah, Nevada office, for assistance and access to Railroad Valley.

- We would also like to thank NASA for funding this work, and AERONET for processing and distributing the Cimel data.