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

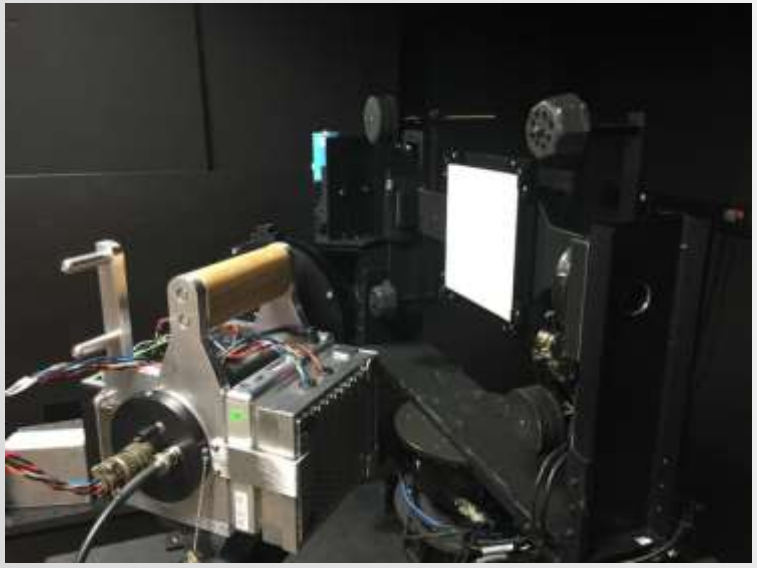
Introduction to RadCaTS

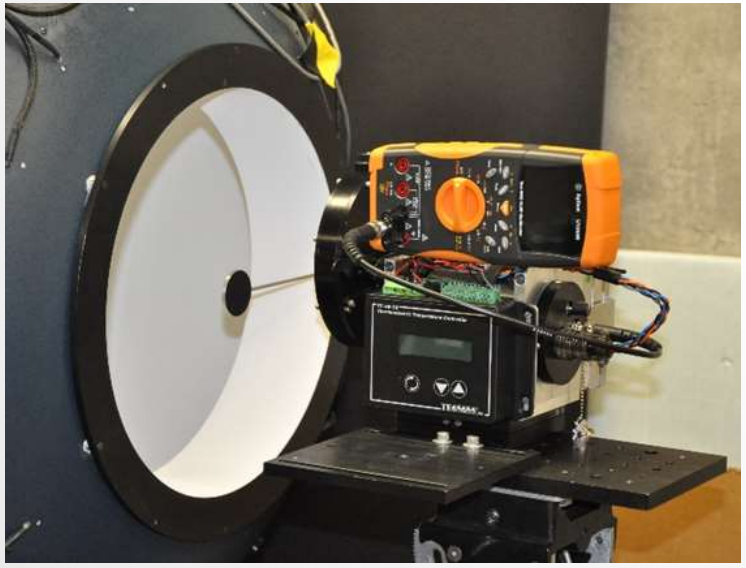
- Developed as an automated ground-based vicarious calibration system
- Originally designed to supplement reflectance-based approach
  - On-site personnel
  - Portable spectroradiometers, reference panels (surface reflectance)
  - Solar radiometers, ancillary weather equipment (atmospheric measurements)
  - 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

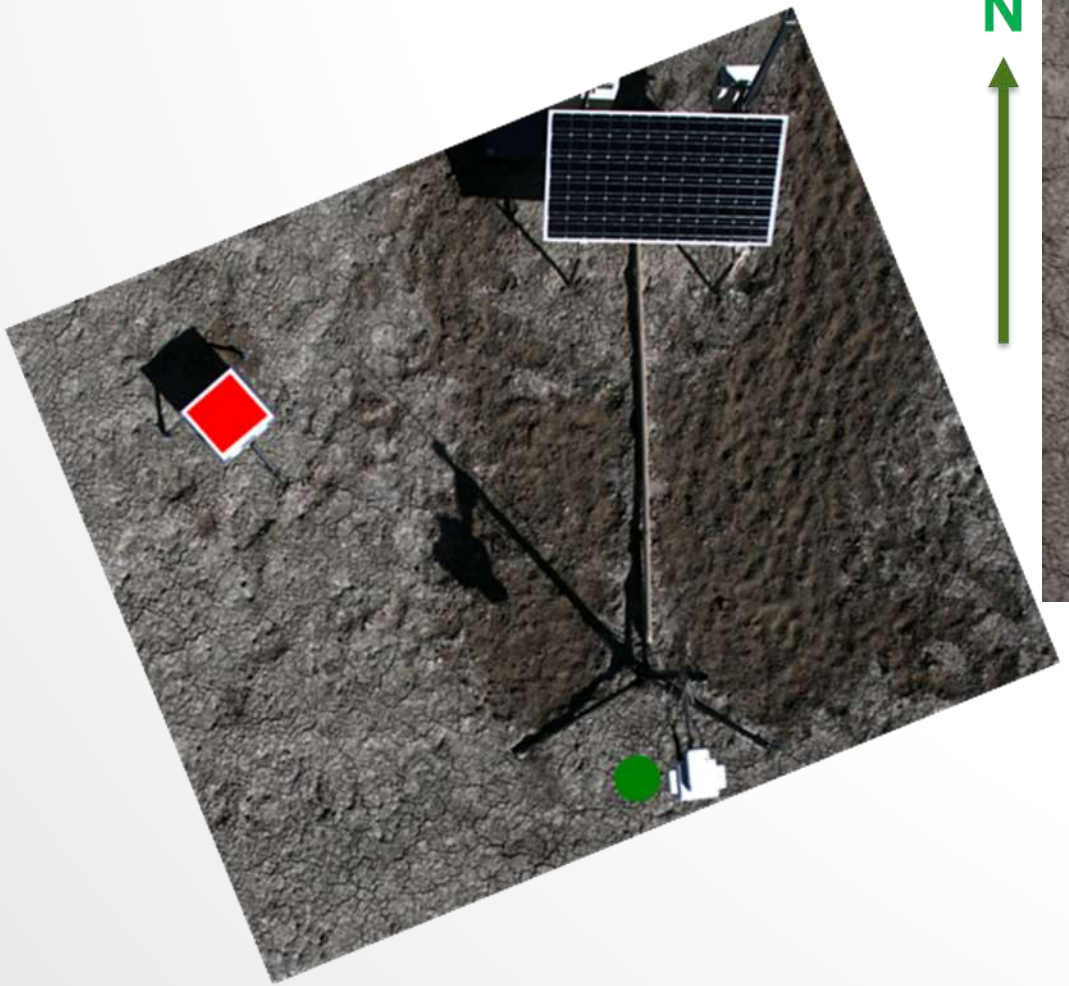
- **Calibration Test Site SI-Traceable Transfer Radiometer (CaTSSITTR)**
  - Two versions: -A and -G (Arizona and Goddard)
  - Same 7 VNIR bands as RadCaTS ground-viewing radiometer
    - 400, 450, 500, 550, 650, 850, 1000 nm
  - One person operation, wireless data logging
  - Temperature-controlled 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)



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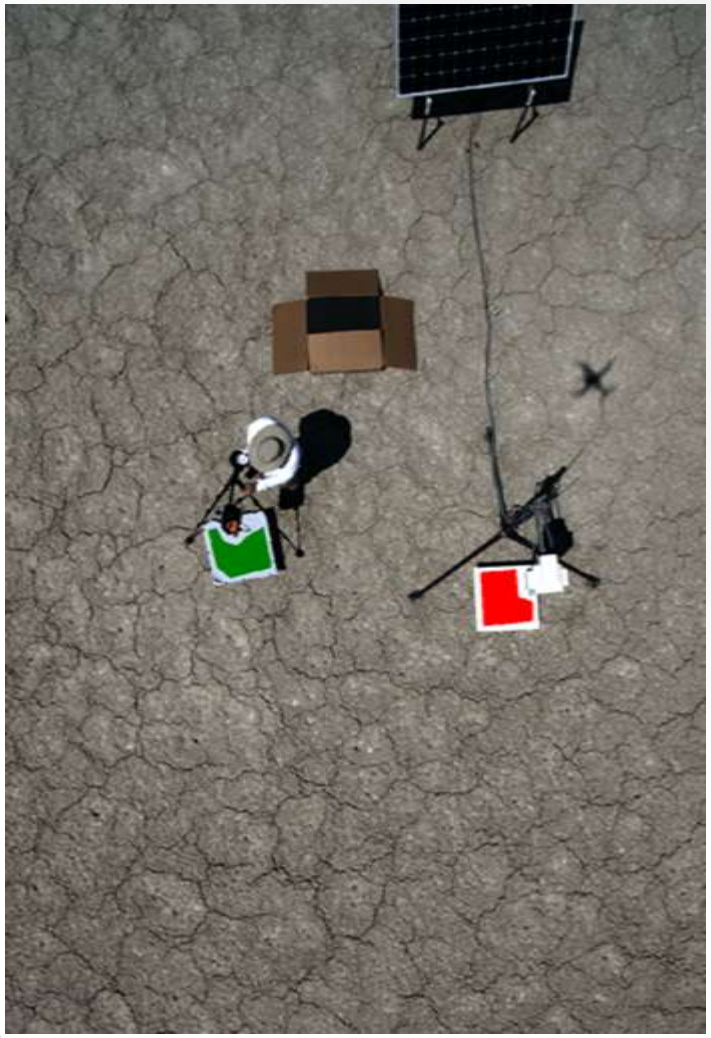
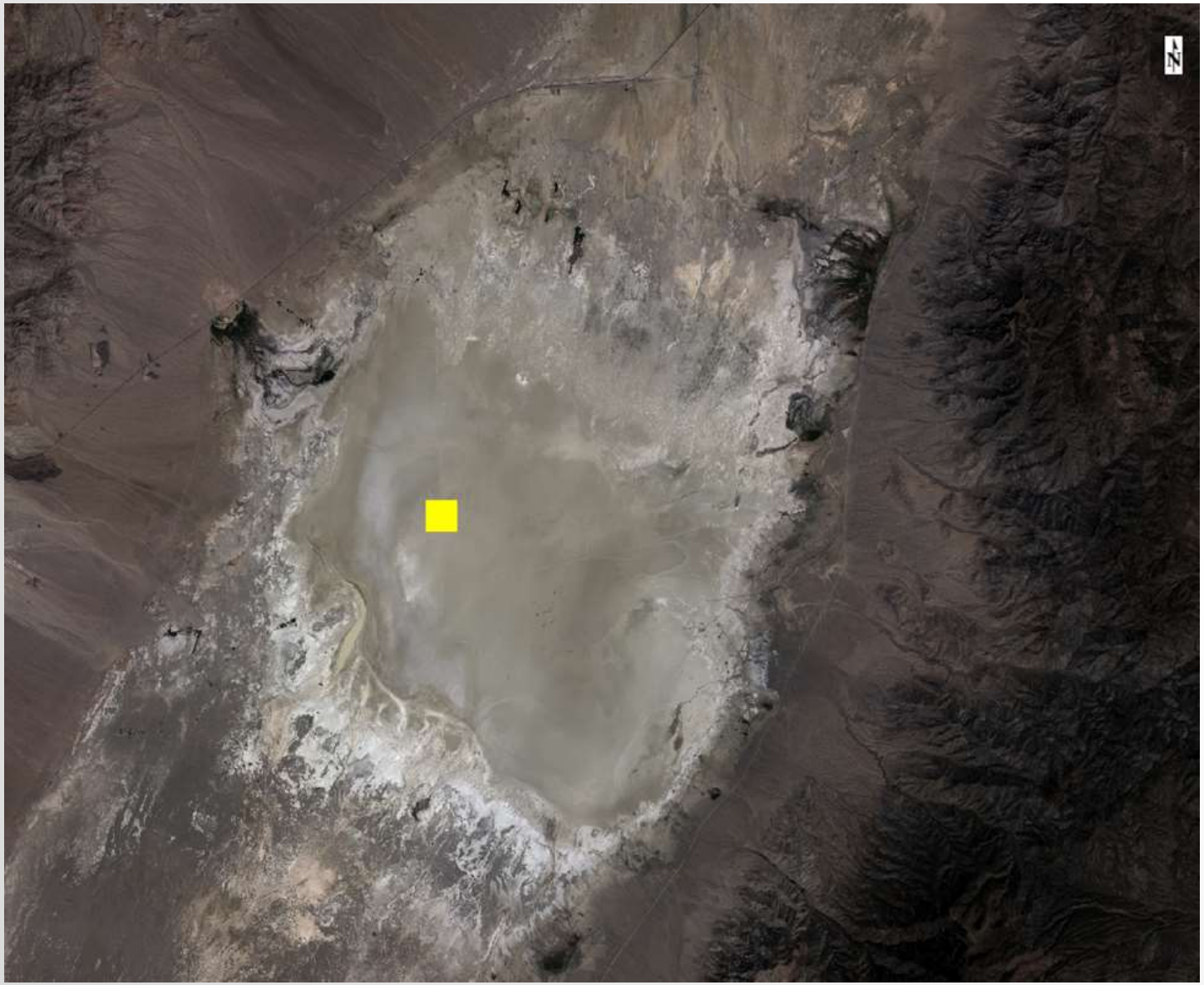
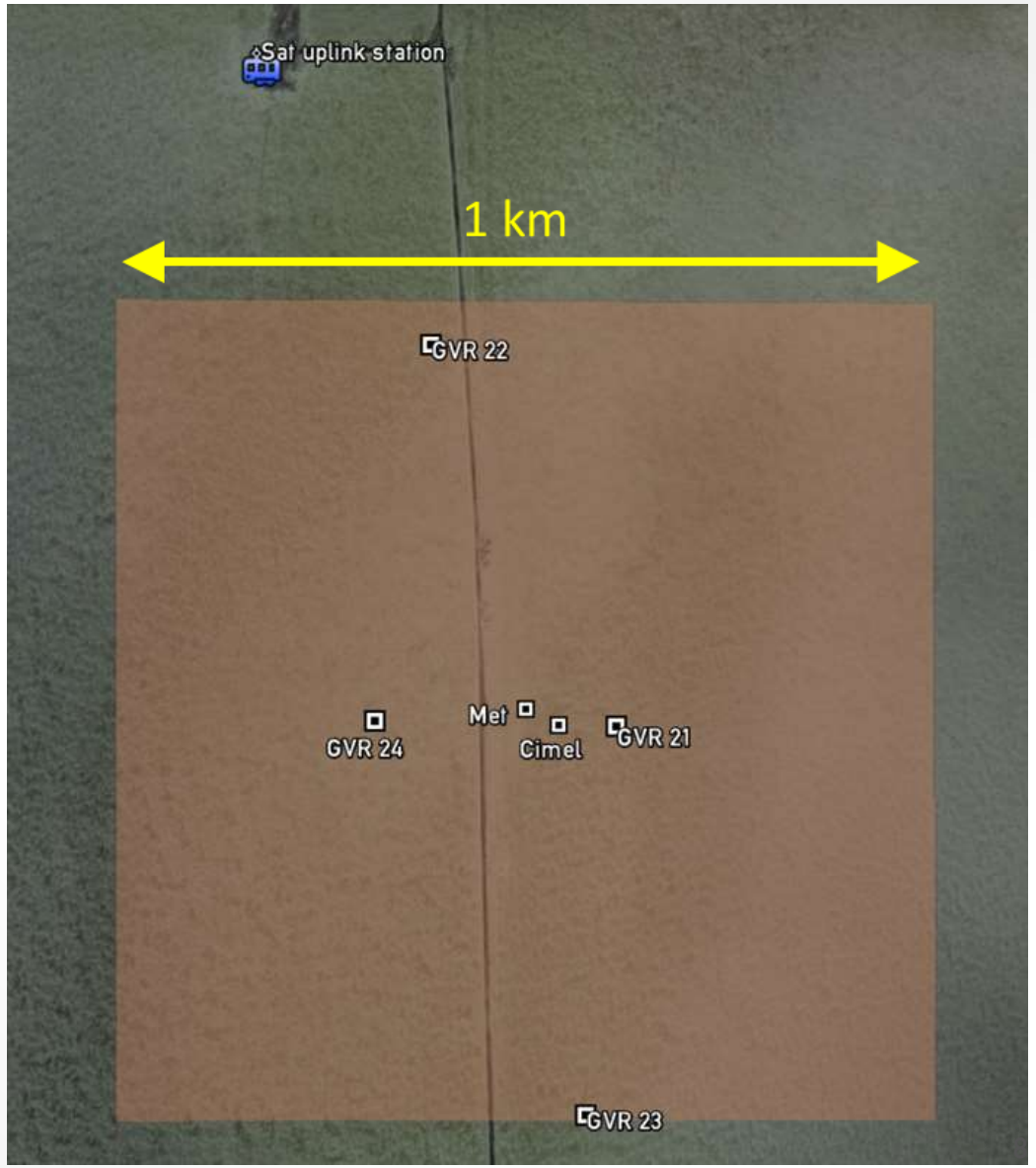


Other Instrumentation

- 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

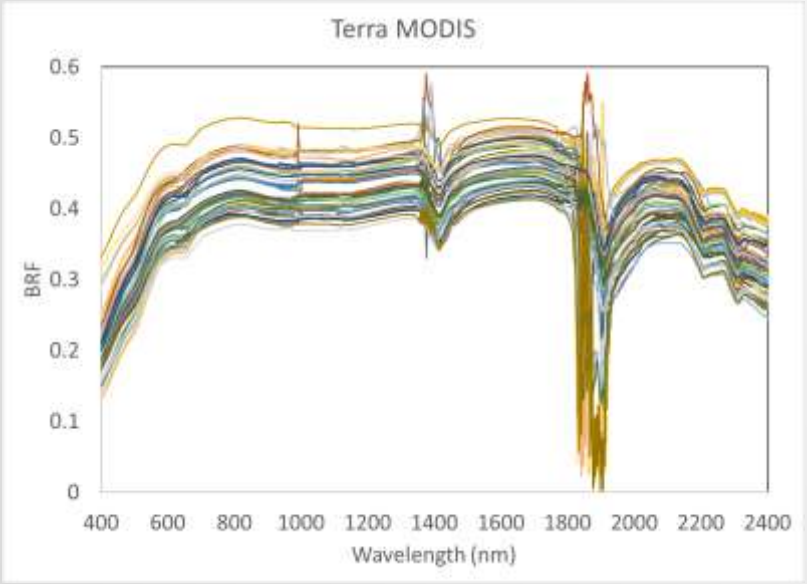
RadCaTS Layout

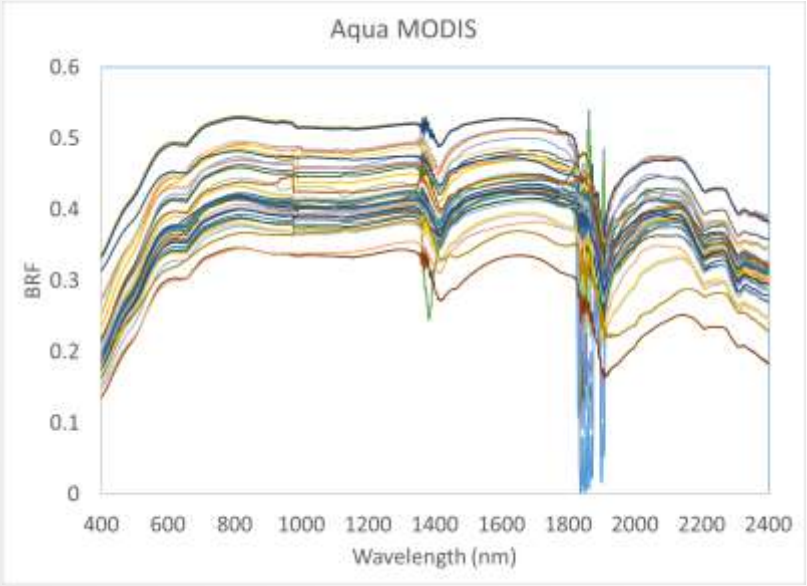


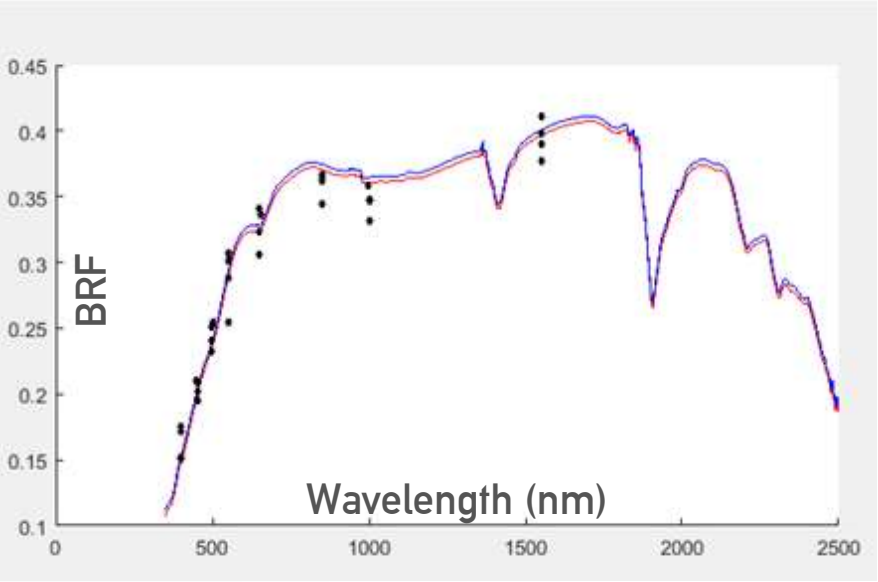


RadCaTS Measurements

- 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)







Band	1	2	3	4	5	6	7	8	9
Wave (nm)	645	856	466	553	1244	1632	2119	412	442

Example of Current RadCaTS Results

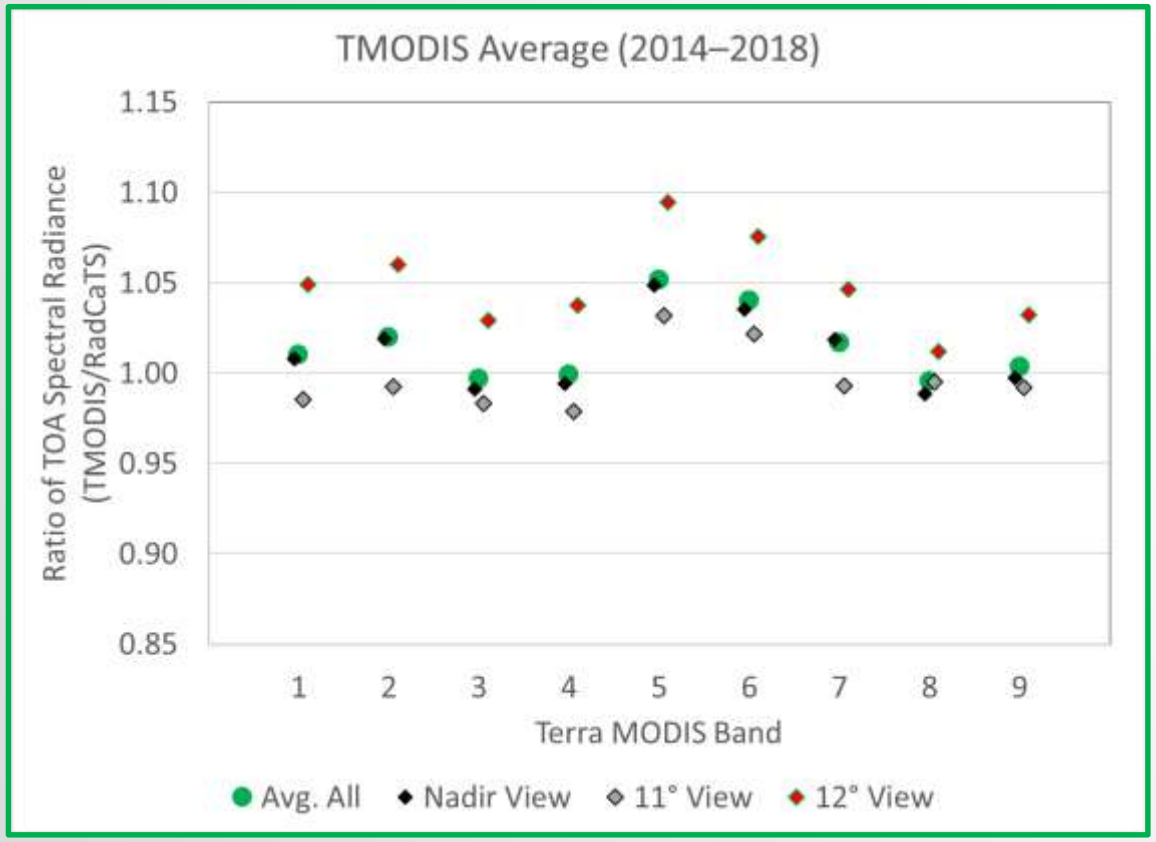
- Terra and Aqua MODIS (2014–2018)
  - Terra: N = 45, three near-nadir views
  - Aqua: N = 28, two near-nadir views
  - VZA: view zenith angle, VAA: view azimuth angle

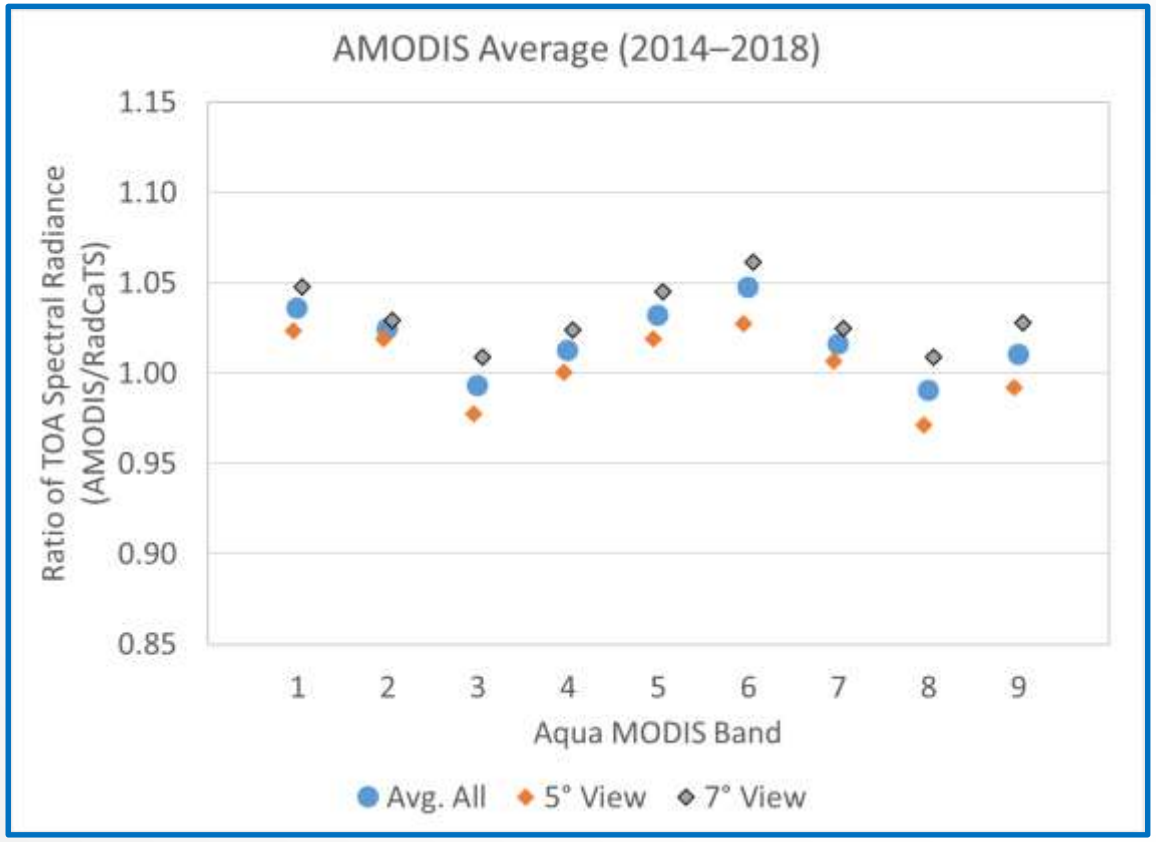
Terra

Time (UTC)	VZA (degrees)	VAA (degrees)
18:33	12.0	102.5
18:39	0.3	104.4
18:46	11.6	284.0

Aqua

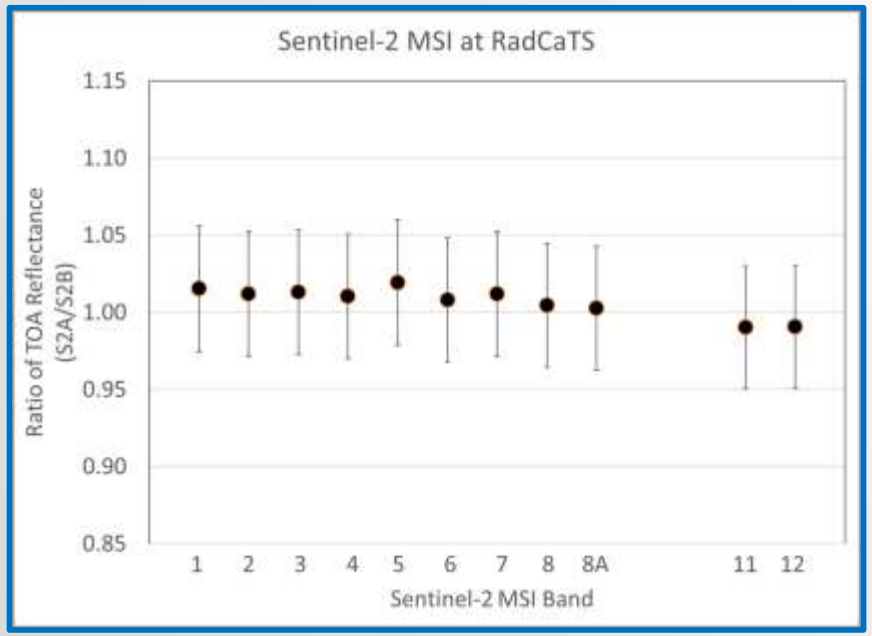
Time (UTC)	VZA (degrees)	VAA (degrees)
20:48	4.8	256.9
20:54	7.0	75.9



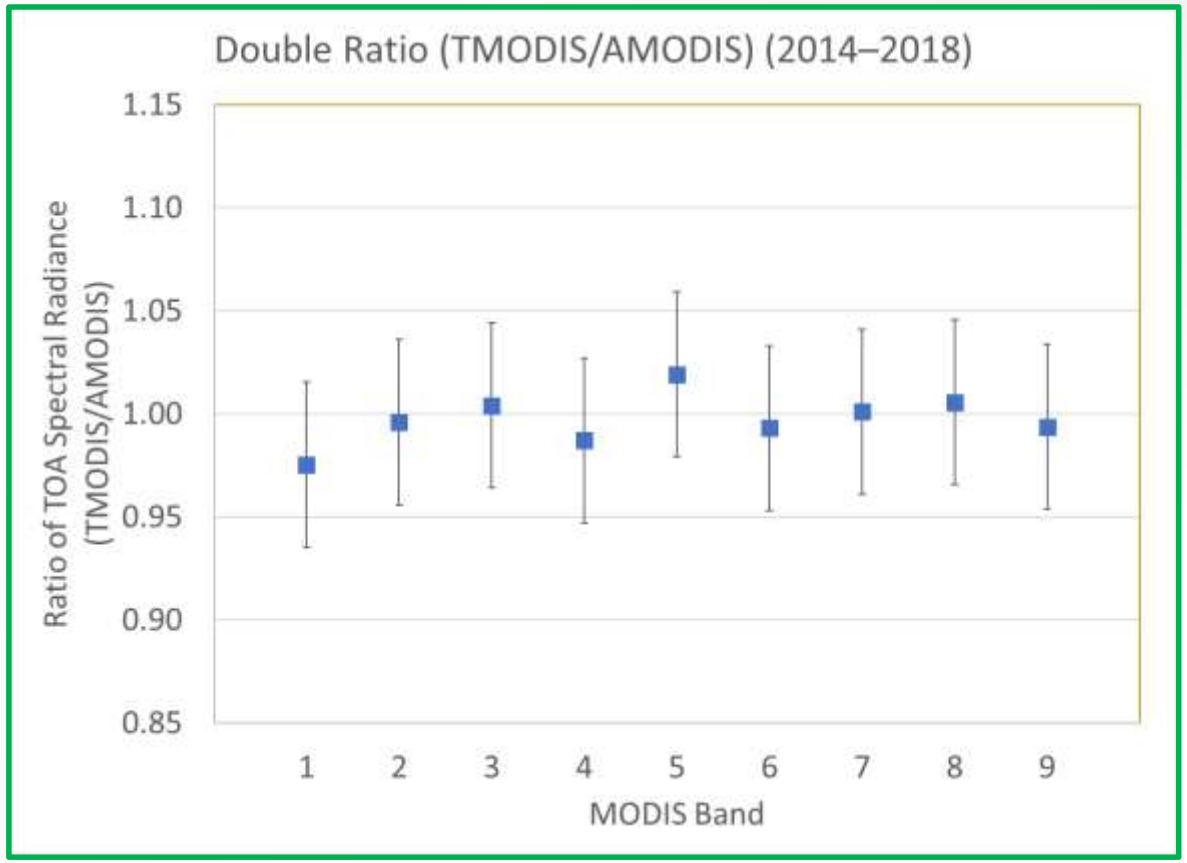


Example of Current RadCaTS Results

- Removal of RadCaTS from comparison
- Terra and Aqua MODIS double ratio:
  - (TMODIS/RadCaTS)/(AMODIS/RadCaTS) = TMODIS/AMODIS
  - ±4% uncertainty
- Sentinel-2A and -2B MSI



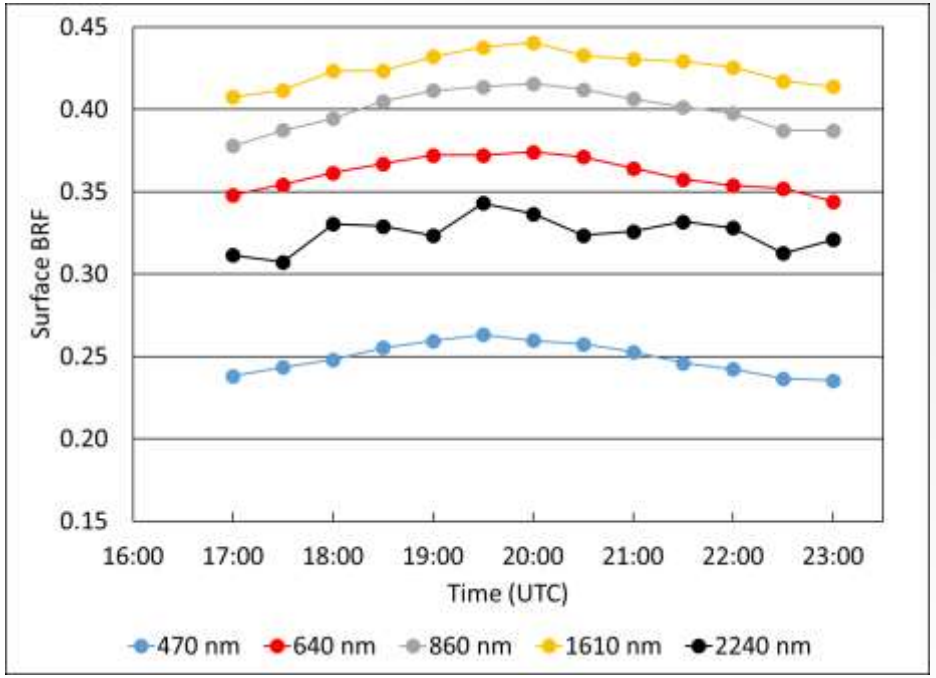
MSI Band	Wave (nm)
1	444
2	497
3	560
4	664
5	704
6	740
7	783
8	835
8A	865
9	945
10	1374
11	1614
12	2202

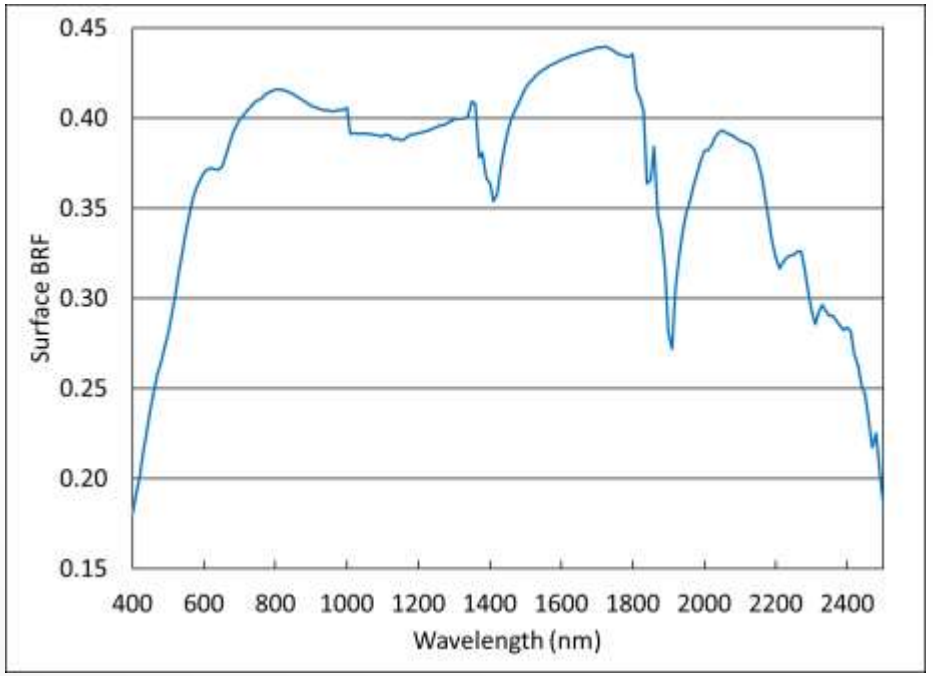


Band	1	2	3	4	5	6	7	8	9
Wave (nm)	645	856	466	553	1244	1632	2119	412	442

Another Example: GOES-16 ABI Radiometric Validation

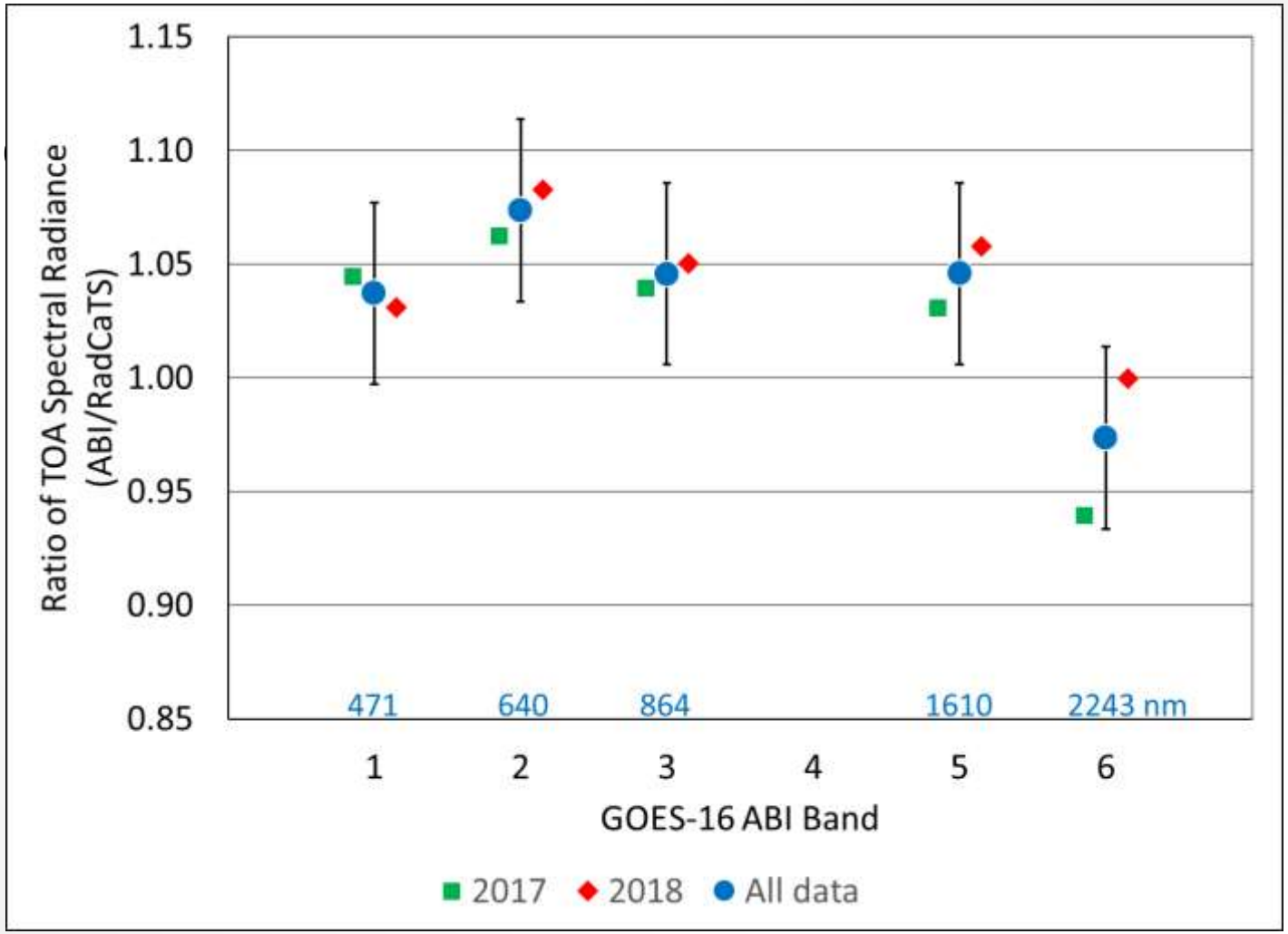
- Period of study: Apr 2017 to Sep 2018
- Based on 'good' RadCalNet days
  - Most (or all) 13 times throughout the day are processed
  - 17:00–23:00 UTC
  - Every 30 minutes
- Solar noon used for this study
- 2017: 17 dates
  - ABI view geometry: 52° zenith, 321° azimuth
- 2018: 21 dates
  - ABI view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





RadCaTS GOES-16 ABI Radiometric Validation Results

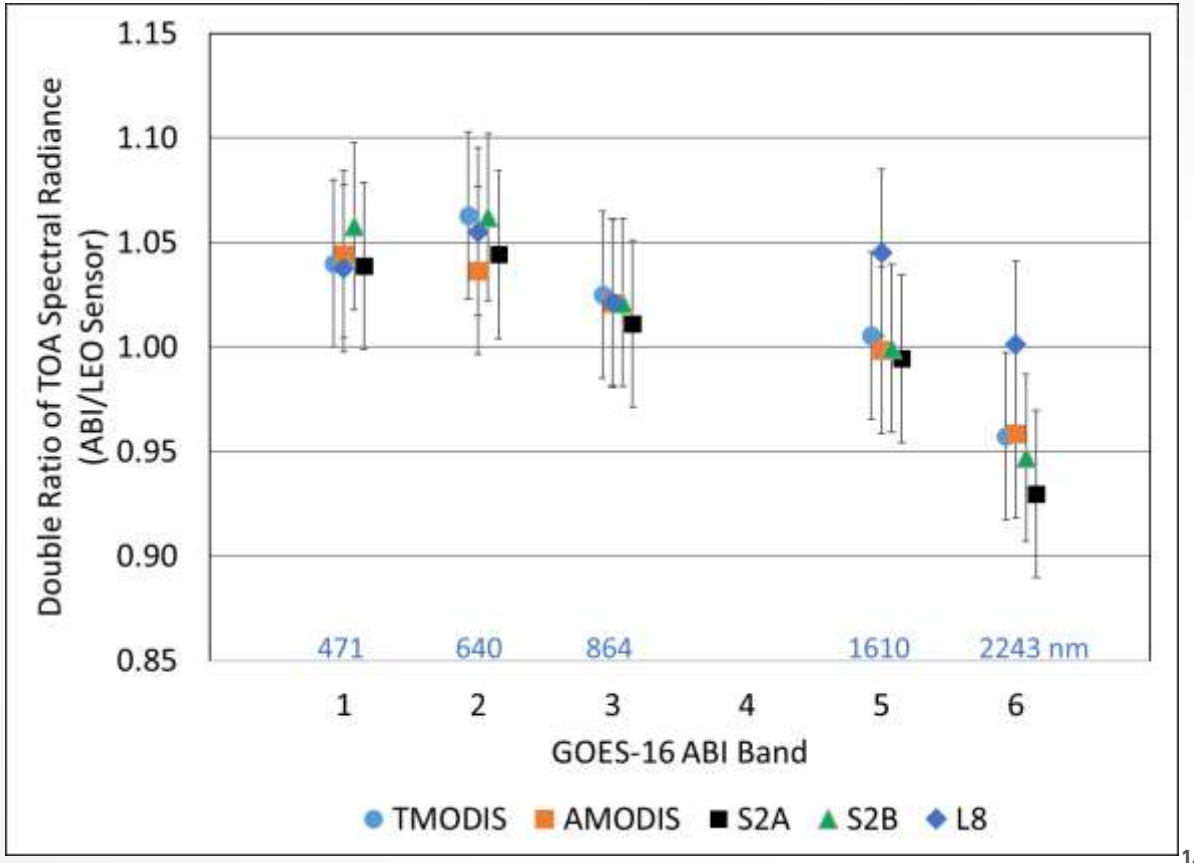
- Shown as average, 2017, and 2018
- Uncertainty bars are ±4% uncertainty (
  RadCaTS
- ABI pixel size (nadir)
  - Band 2: 500 m
  - Bands 1, 3, 5: 1000 m
  - Band 6: 2000 m
- Results show bias similar to in situ measurements in Bolivia



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

	ABI Center Wavelength (nm)				
	471	640	864	1610	2243
Sensor	**Band (Pixel size (m))**				
ABI	1 (1000)	2 (500)	3 (1000)	5 (1000)	6 (2000)
TMODIS	3 (500)	1 (250)	2 (250)	6 (500)	7 (500)
AMODIS	3 (500)	1 (250)	2 (250)	6 (500)	7 (500)
S2A	2 (10)	4 (10)	8A (20)	11 (20)	12 (20)
S2B	2 (10)	4 (10)	8A (20)	11 (20)	12 (20)
L8	2 (30)	4 (30)	5 (30)	6 (30)	7 (30)



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)

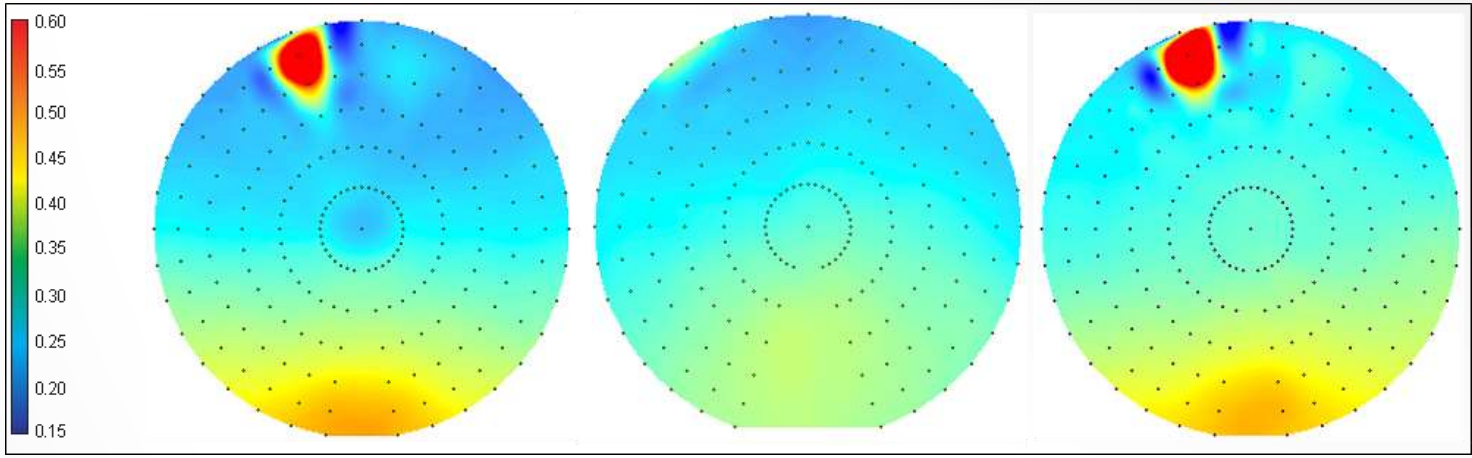
- Objectives:
  - Evaluate reflectance measurements
    - Repeatability and accuracy
    - Group intercomparison
    - Surface collection methodology (moving vs stop and stare)
  - BRDF measurements
    - ULGS-2 (U of Lethbridge)
    - PARABOLA (NASA JPL)
    - Multi-angle radiometers
  - RadCalNet evaluation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

U of Lethbridge Goniometer System (ULGS-2)

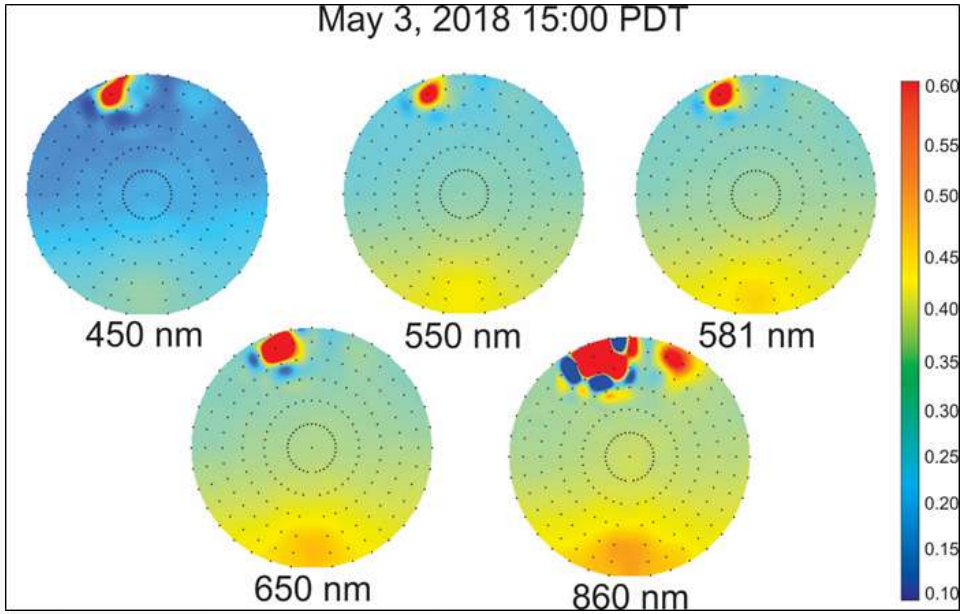
- Two Ocean Optics USB-4000
  - 350–1000 nm
  - Measures radiance reflected from ground
  - Measures downwelling irradiance (Spectralon cosine receptor)
  - Real-time spectral reflectance calculation
- Quarter circle arc mounted to pivoting beam
- Complete hemispherical sampling
- Operating radius: 2 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



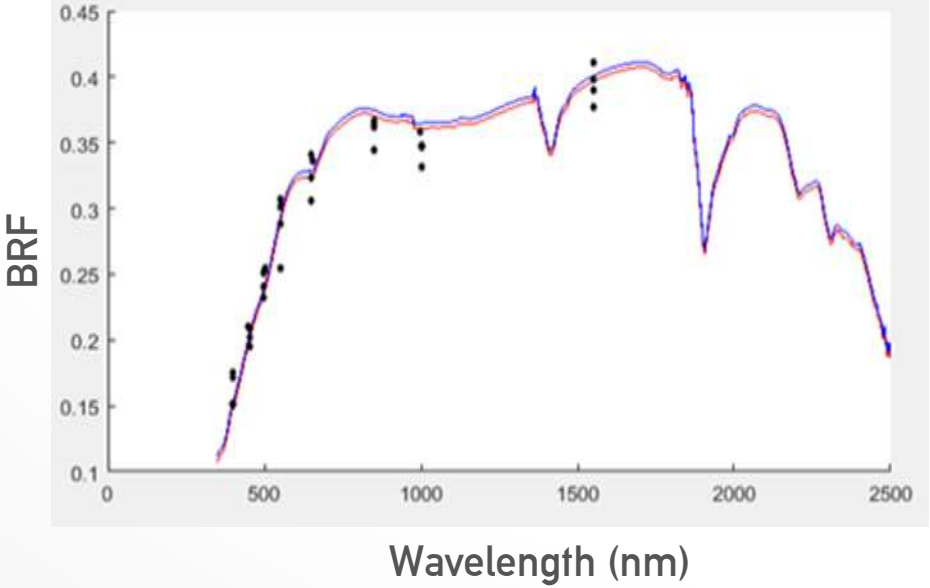
- Spectral example
  - 22:00 UTC
  - 450, 550, 581, 650, 860 nm
  - 0°–60° view zenith angle (ring of dots)
  - Solar principal plane in vertical direction
  - Anisotropic behavior is stronger at longer wavelengths



- Field campaign data reduction still in progress…

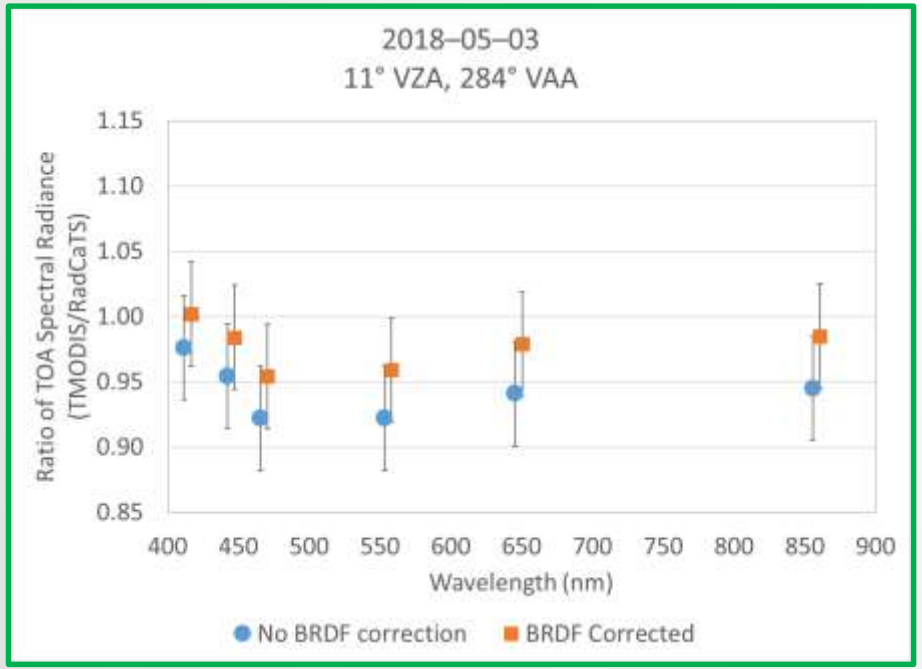
U of Arizona BRF Camera

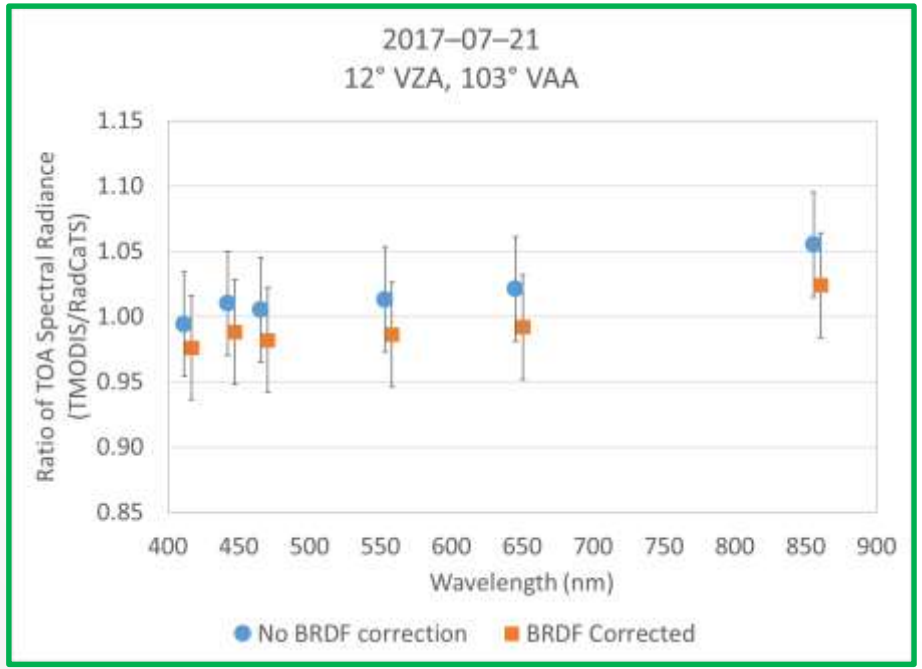
- Scientific-grade silicon CCD array (1024×1024 pixels)
- Coupled to Nikkor 8-mm fisheye lens (180° FOV), which includes filter wheel
- Spectral selection
  - Interference filters
  - 470, 575, 660, and 835 nm center wavelength
- Tradeoff between nonimaging hyperspectral portable spectroradiometer (e.g. 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

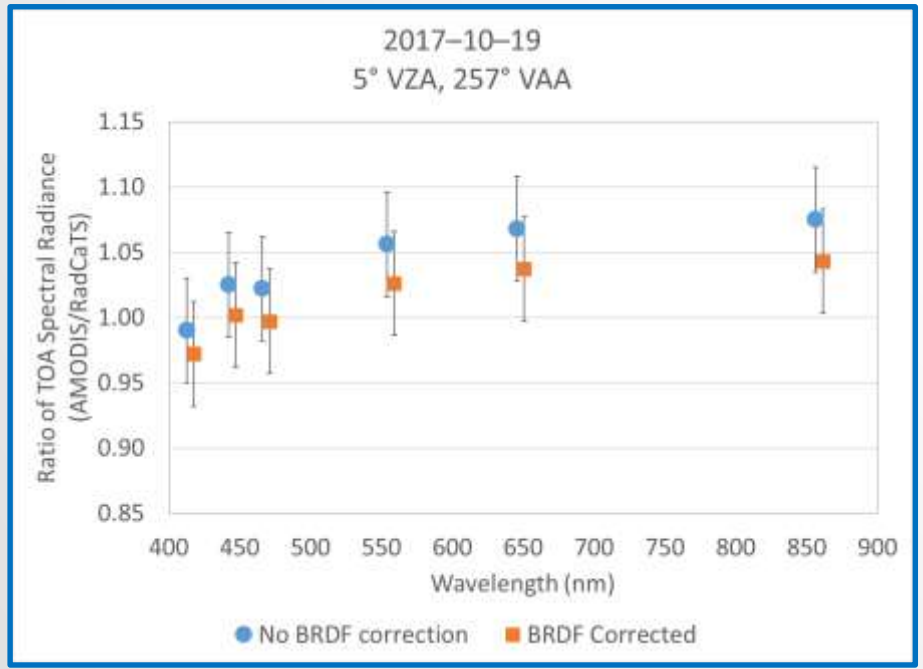
- BRDF correction factor from BRF camera applied to current RadCalNet results
- Example cases:
  - Two Terra MODIS near-nadir overpasses
  - Restricted to MODIS VNIR bands since BRF camera operates in this range
  - Bands 1–4, 8, and 9
  - VZA: view zenith angle, VAA: view azimuth angle
- Terra

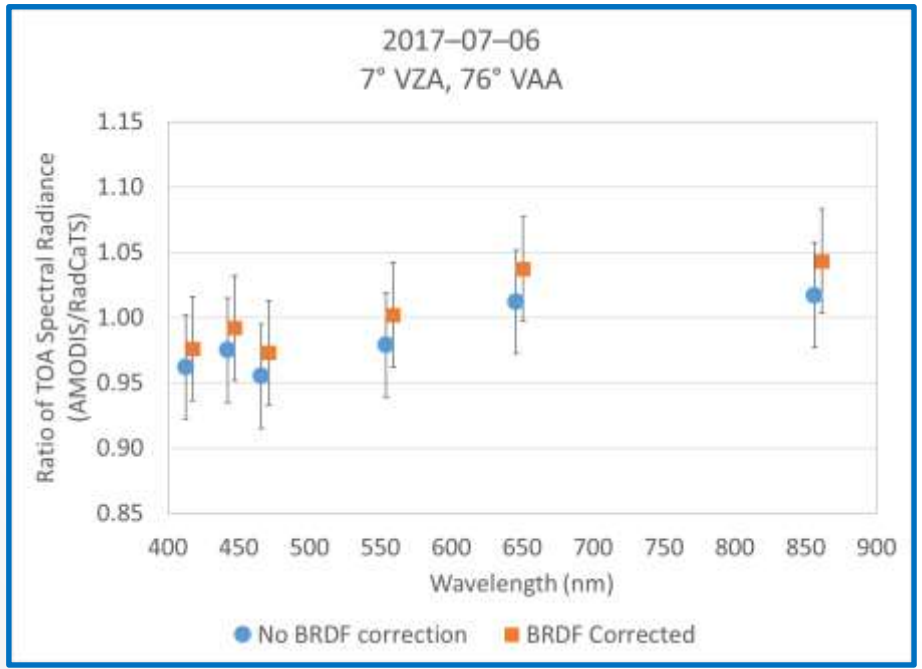




RadCaTS results corrected with BRF camera historical data

- 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



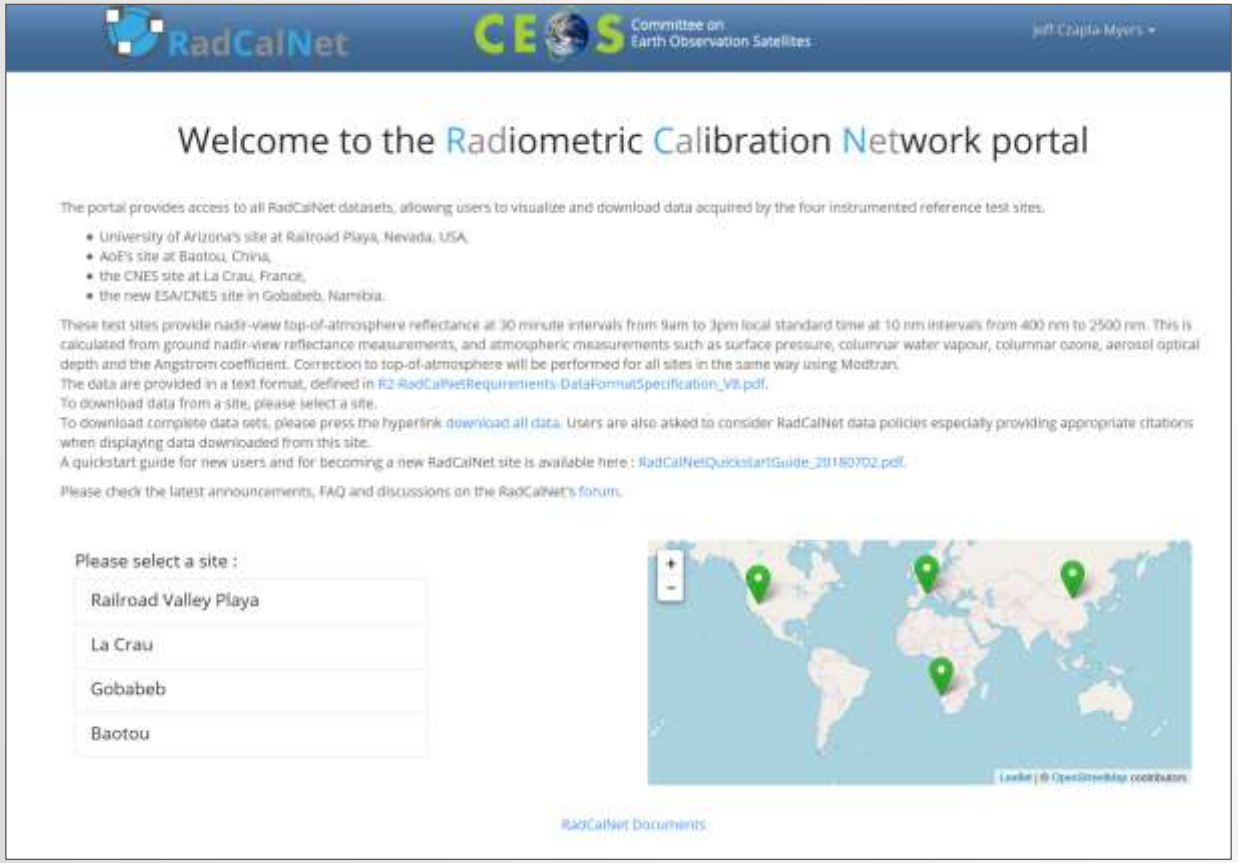


Summary

- 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-km^2 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!

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