# Intercomparison of GEO and LEO Earth-observation sensors using RadCaTS

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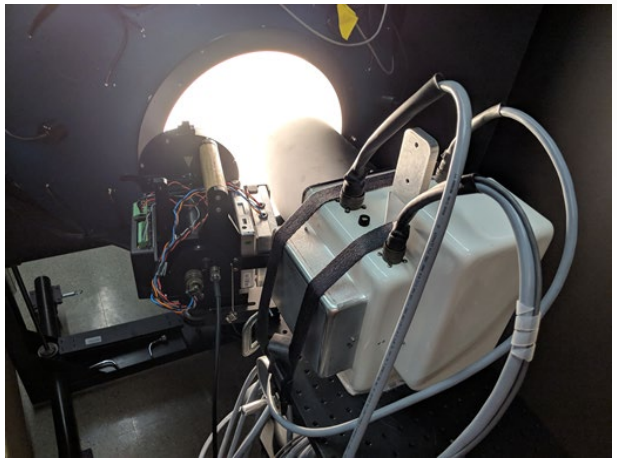
# Topics

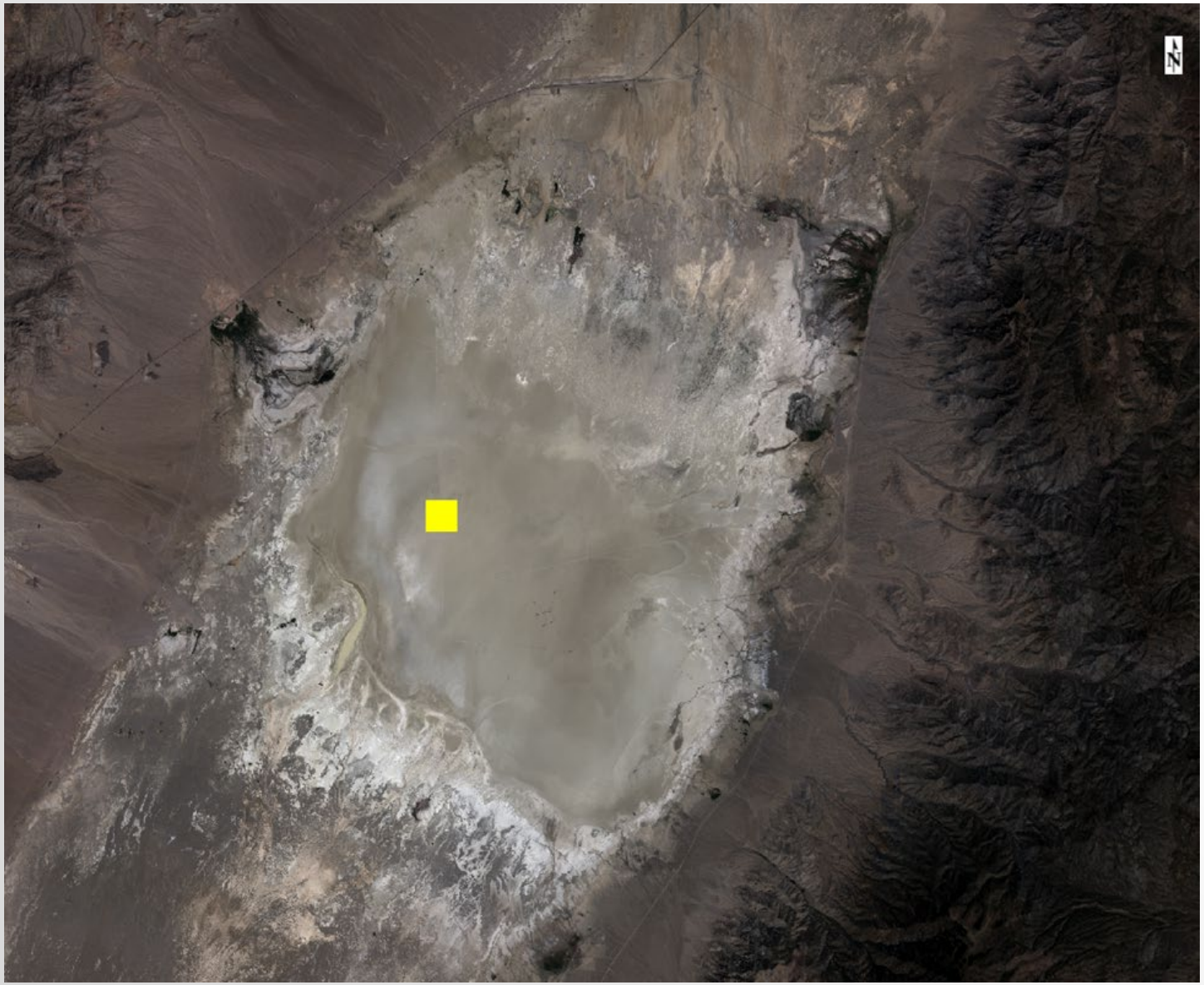
- Current status of Radiometric Calibration Test Site (RadCaTS) at Railroad Valley
- GOES-16 and -17 ABI
- Current results
  - Radiometric validation of ABI using RadCaTS
  - Intercomparison of ABI with LEO sensors
- Summary and future work

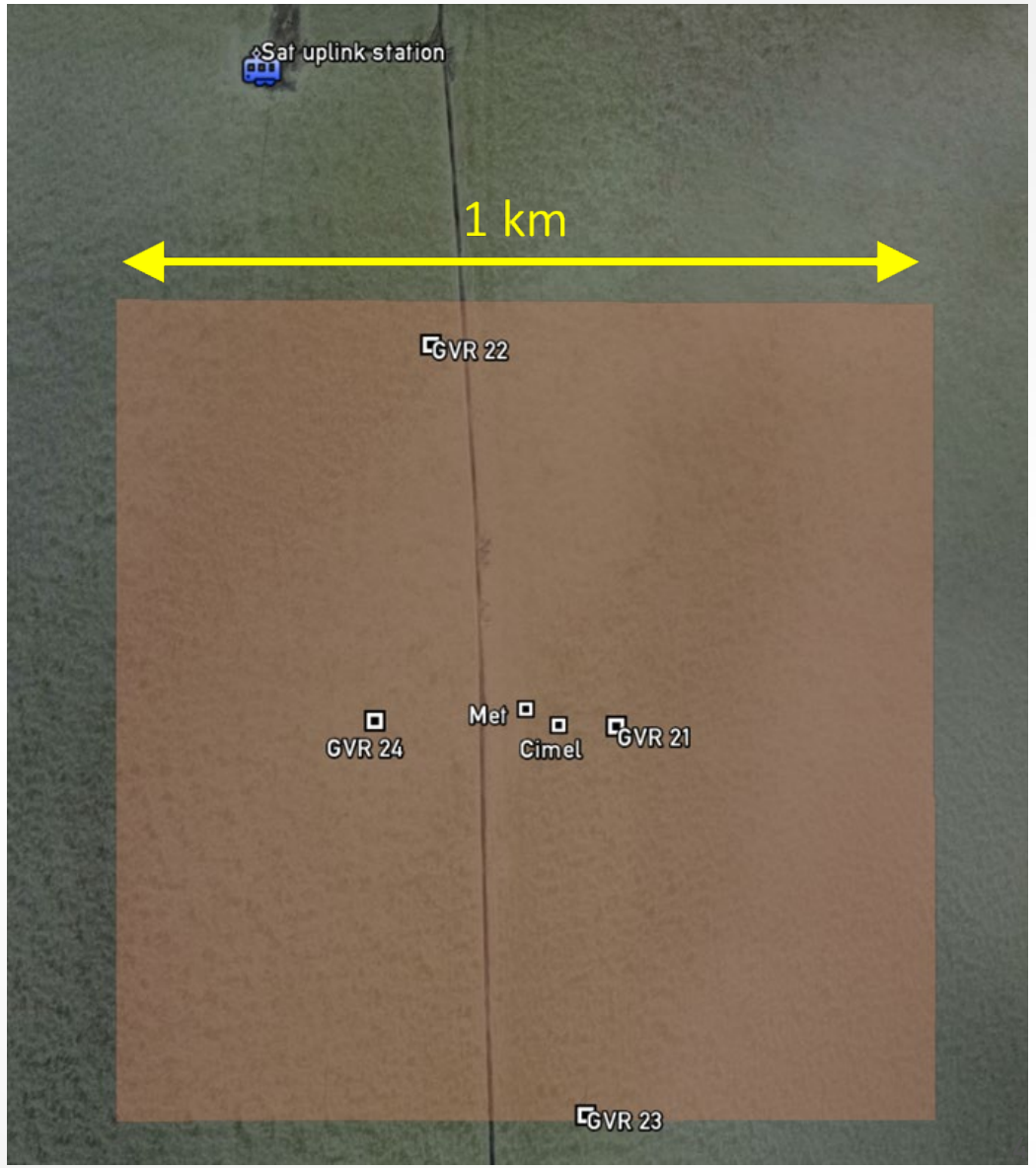
# Current Status of RadCaTS

- 6 Ground-viewing radiometers (GVRs)
  - 4 in nadir-viewing configuration
  - 1 in GOES-East viewing configuration (60° zenith angle, 306° azimuth angle)
  - 1 in GOES-West viewing configuration (50° zenith angle, 32° azimuth angle, installed in Nov 2018)
- 1 more GVR in development (nadir view)
- 2 Cimel sun photometers
  - #314 currently operating at Railroad Valley
  - #786 back from AERONET for repairs
- Meteorological station
  - Redundant temperature and pressure sensors
- Satellite uplink station
  - Daily upload of all data
- Web camera
  - Download on site only in order to reduce cost



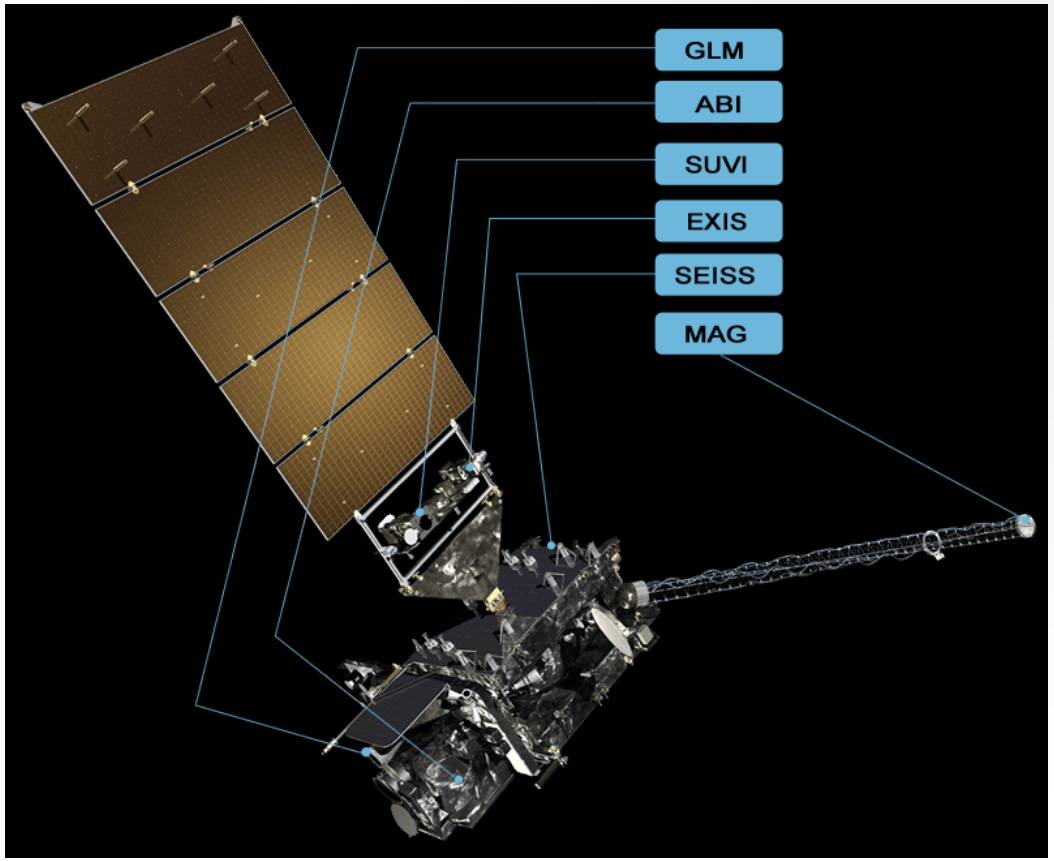
# RadCaTS Layout





# GOES-16 (no -17 results yet)

- GOES-R prior to launch
- Launch: 19 Nov 2016
  - Reached geostationary orbit a few days later
  - 1-year checkout and validation phase (–89.5° lon)
  - Moved to GOES East position on 11 Dec 2017 (–75.2° lon)
- Declared operational on 18 Dec 2017
- Six instruments (Earth and Sun facing)
  - Advanced Baseline Imager (ABI)
  - Geostationary Lightning Mapper (GLM)
  - Extreme Ultraviolet and X-ray Irradiance Sensors (EXIS)
  - Solar Ultraviolet Imager (SUV)
  - Space Environment In-Situ Suite (SEISS)
  - Magnetometer (MAG)




# GOES-16
# Advanced Baseline Imager

- Primary imaging sensor on GOES
- Provides 65% of all GOES data products
- Vast improvement over previous Imager
  - 3× more spectral information
  - 4× greater spatial information
  - 5× faster coverage
  - Onboard calibration
- 16 spectral bands
  - 5 solar reflective (VNIR & SWIR, 0.4–2.5 μm)
  - 5 mid-wave infrared (MWIR, 3–8 μm)
  - 6 thermal infrared (TIR, 8–14 μm)
- This work uses ABI bands 1–3, 5, and 6

TABLE 1. Summary of the wavelengths, resolution, and sample use and heritage instrument(s) of the ABI bands. The minimum and maximum wavelength range represent the full width at half maximum (FWHM or 50%) points. [The Instantaneous Geometric Field Of View (IGFOV).]

| Future GOES imager (ABI) band | Wavelength range (μm) | Central wavelength (μm) | Nominal subsatellite IGFOV (km) | Sample use | Heritage instrument(s) |
|---|---|---|---|---|---|
| 1 | 0.45–0.49 | 0.47 | 1 | Daytime aerosol over land, coastal water mapping | MODIS |
| 2 | 0.59–0.69 | 0.64 | 0.5 | Daytime clouds fog, insolation, winds | Current GOES imager/sounder |
| 3 | 0.846–0.885 | 0.865 | 1 | Daytime vegetation/burn scar and aerosol over water, winds | VIIRS, spectrally modified AVHRR |
| 4 | 1.371–1.386 | 1.378 | 2 | Daytime cirrus cloud | VIIRS, MODIS |
| 5 | 1.58–1.64 | 1.61 | 1 | Daytime cloud-top phase and particle size, snow | VIIRS, spectrally modified AVHRR |
| 6 | 2.225–2.275 | 2.25 | 2 | Daytime land/cloud properties, particle size, vegetation, snow | VIIRS, similar to MODIS |
| 7 | 3.80–4.00 | 3.90 | 2 | Surface and cloud, fog at night, fire, winds | Current GOES imager |
| 8 | 5.77–6.6 | 6.19 | 2 | High-level atmospheric water vapor, winds, rainfall | Current GOES imager |
| 9 | 6.75–7.15 | 6.95 | 2 | Midlevel atmospheric water vapor, winds, rainfall | Current GOES sounder |
| 10 | 7.24–7.44 | 7.34 | 2 | Lower-level water vapor, winds, and $SO_2$ | Spectrally modified current GOES sounder |
| 11 | 8.3–8.7 | 8.5 | 2 | Total water for stability, cloud phase, dust, $SO_2$ rainfall | MAS |
| 12 | 9.42–9.8 | 9.61 | 2 | Total ozone, turbulence, and winds | Spectrally modified current sounder |
| 13 | 10.1–10.6 | 10.35 | 2 | Surface and cloud | MAS |
| 14 | 10.8–11.6 | 11.2 | 2 | Imagery, SST, clouds, rainfall | Current GOES sounder |
| 15 | 11.8–12.8 | 12.3 | 2 | Total water, ash, and SST | Current GOES sounder |
| 16 | 13.0–13.6 | 13.3 | 2 | Air temperature, cloud heights and amounts | Current GOES sounder/*GOES-12+* imager |

Source: Schmit, T.J., Gunshor, M.M., Menzel, W.P., Gurka, J.J., Li, J., Bachmeier, A.S., 2005, Introducing the Next-Generation Advanced Baseline Imager on GOES-R, Bulletin of the American Meteorological Society, v. 86, p. 1079-1096.

# GOES-16 Advanced Baseline Imager

- **Full disk**
  - Hemispheric coverage
  - Temporal resolution: 5–15 minutes
- **CONUS**
  - 3000×5000 km
  - Temporal resolution: 5 minutes
- **Mesoscale**
  - 1000×1000 km
  - Temporal resolution: 30 s
- **Flex Mode**
  - Full disk scan every 15 minutes
  - CONUS every 5 minutes
  - Two mesoscale every 60 s

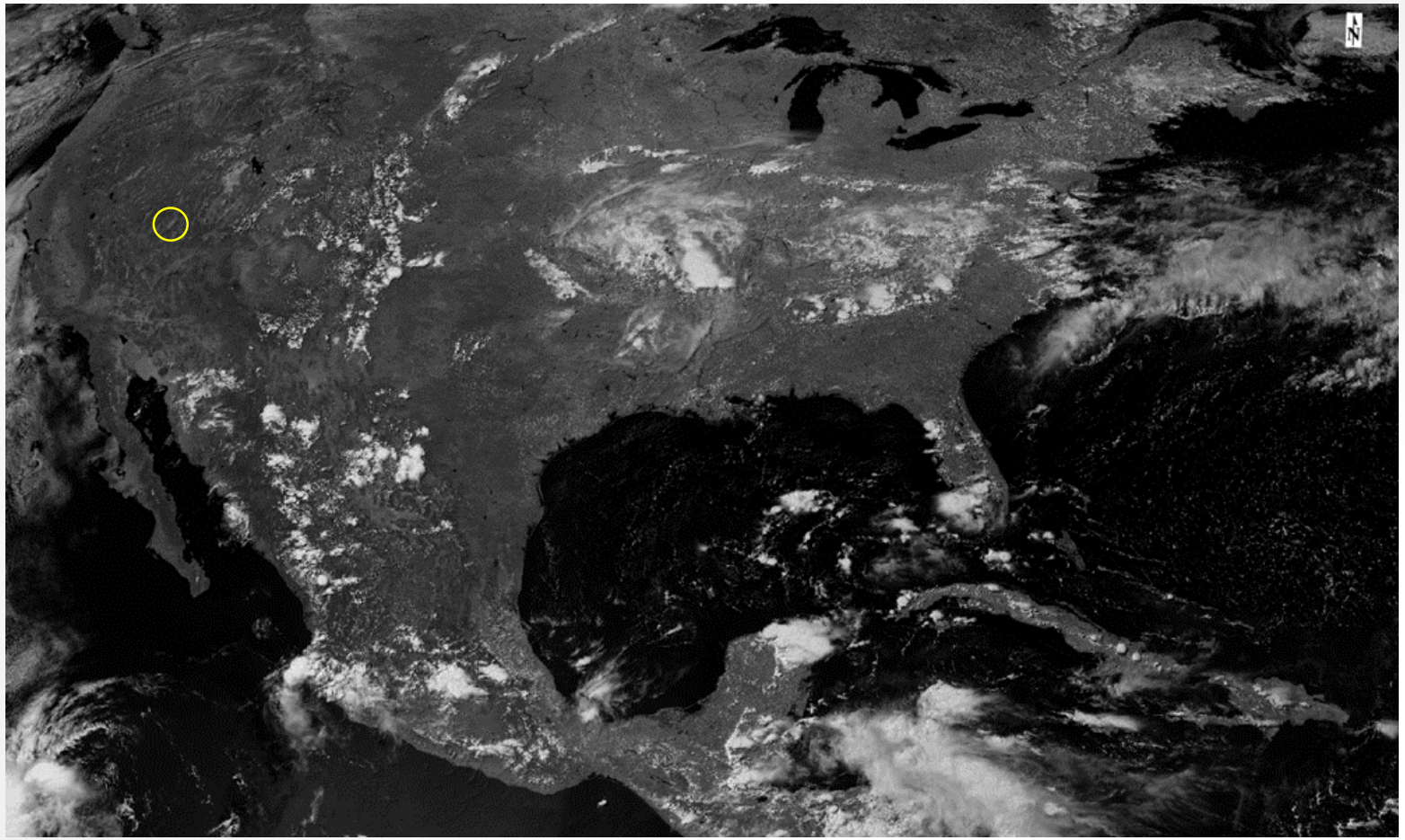
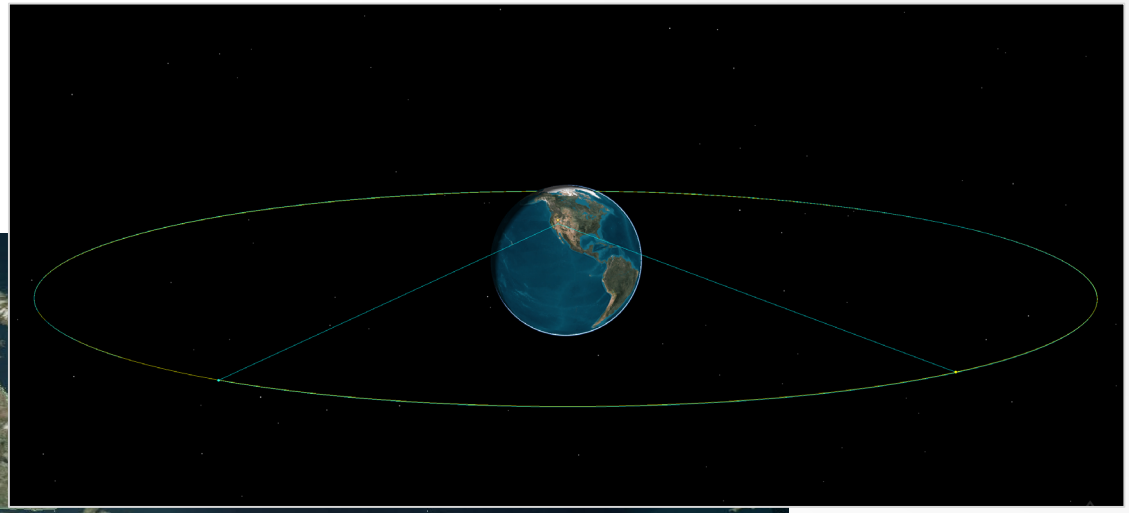
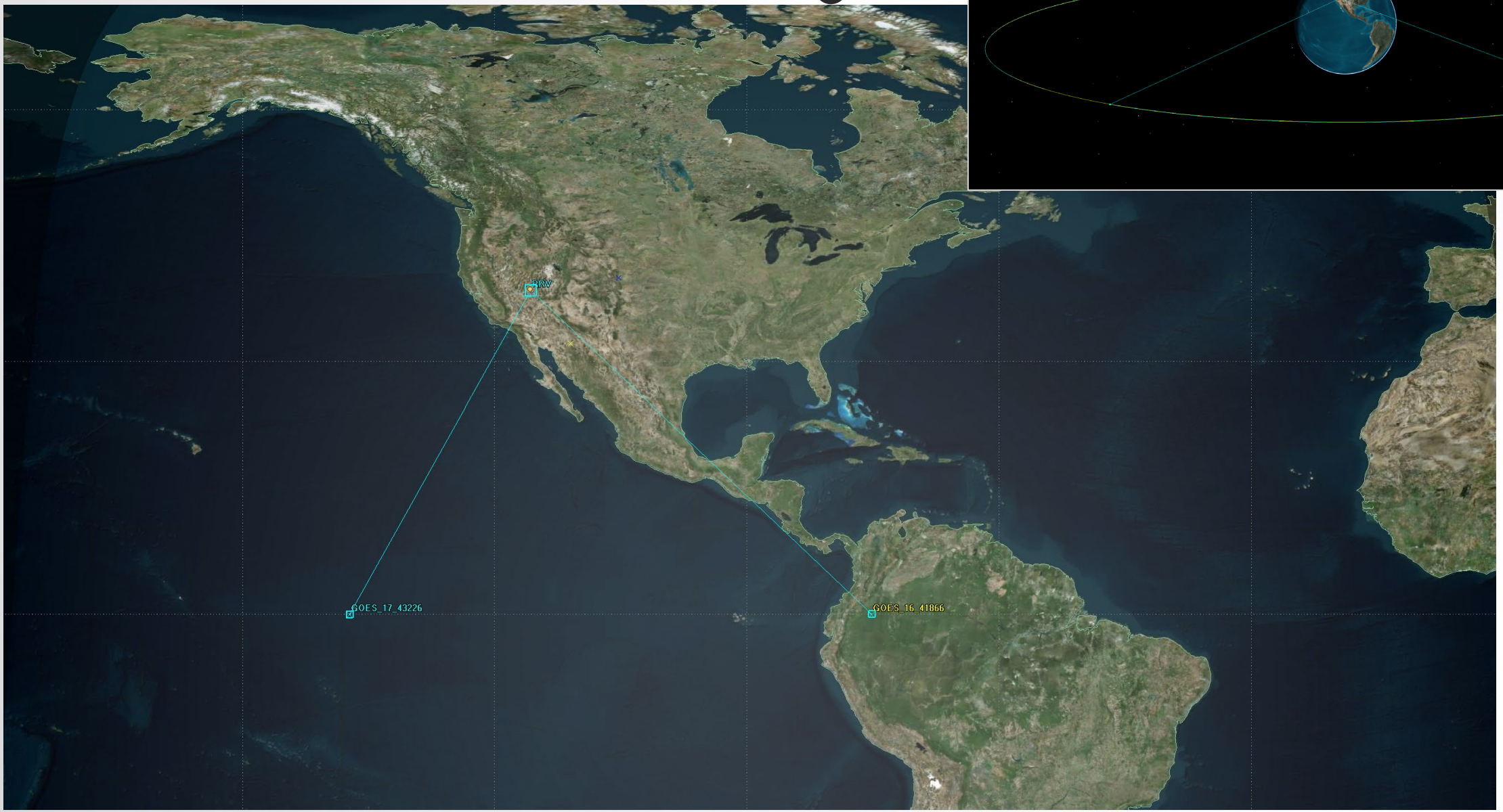


Image: 4 Jul 2017

Images downloaded from NOAA CLASS

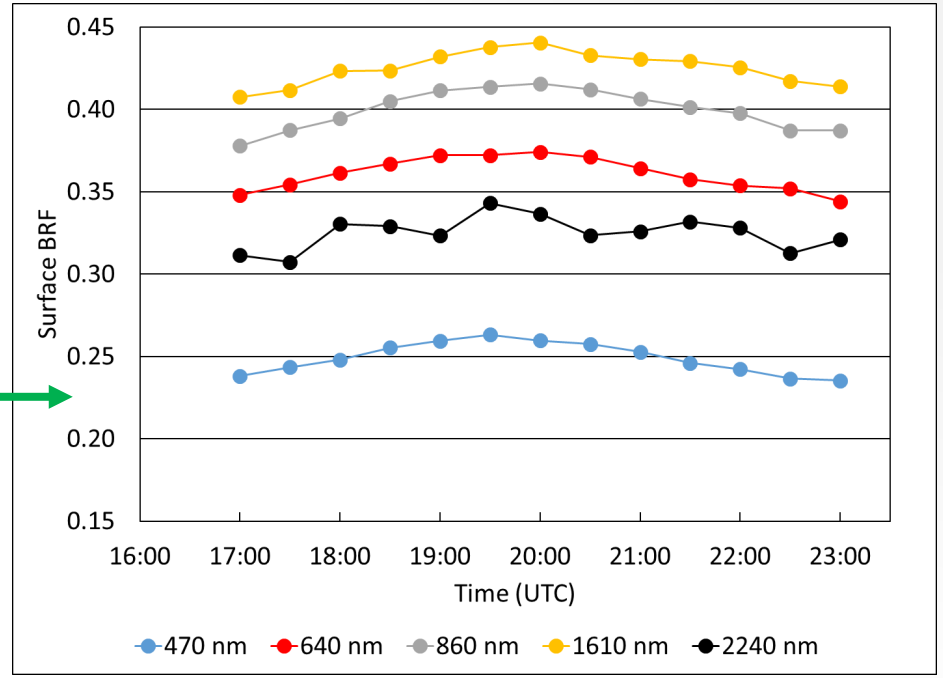
# GOES-16 and -17 View Angles

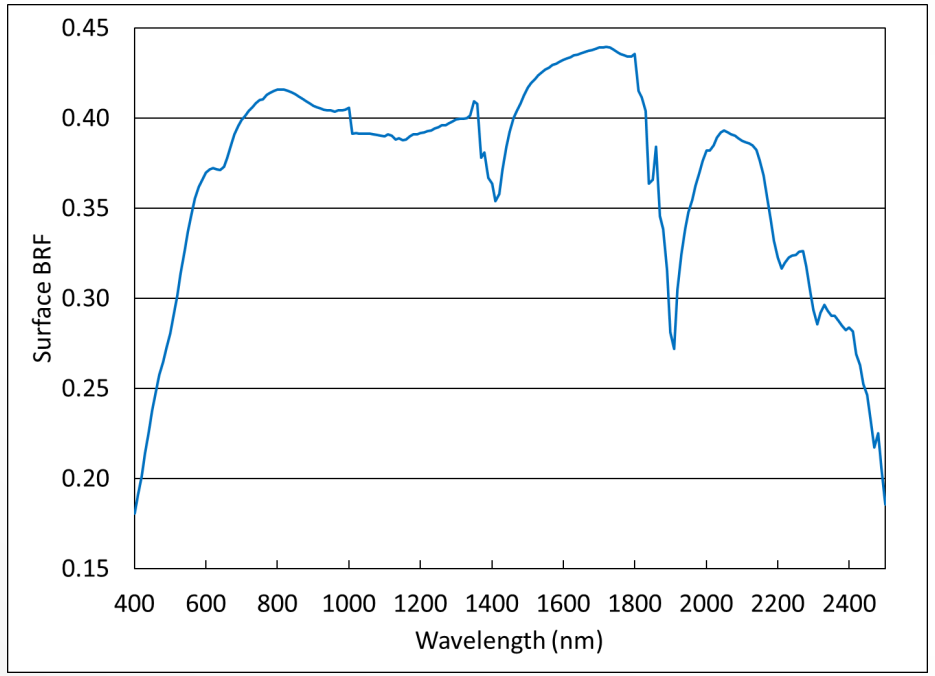




# ABI Radiometric Validation Data

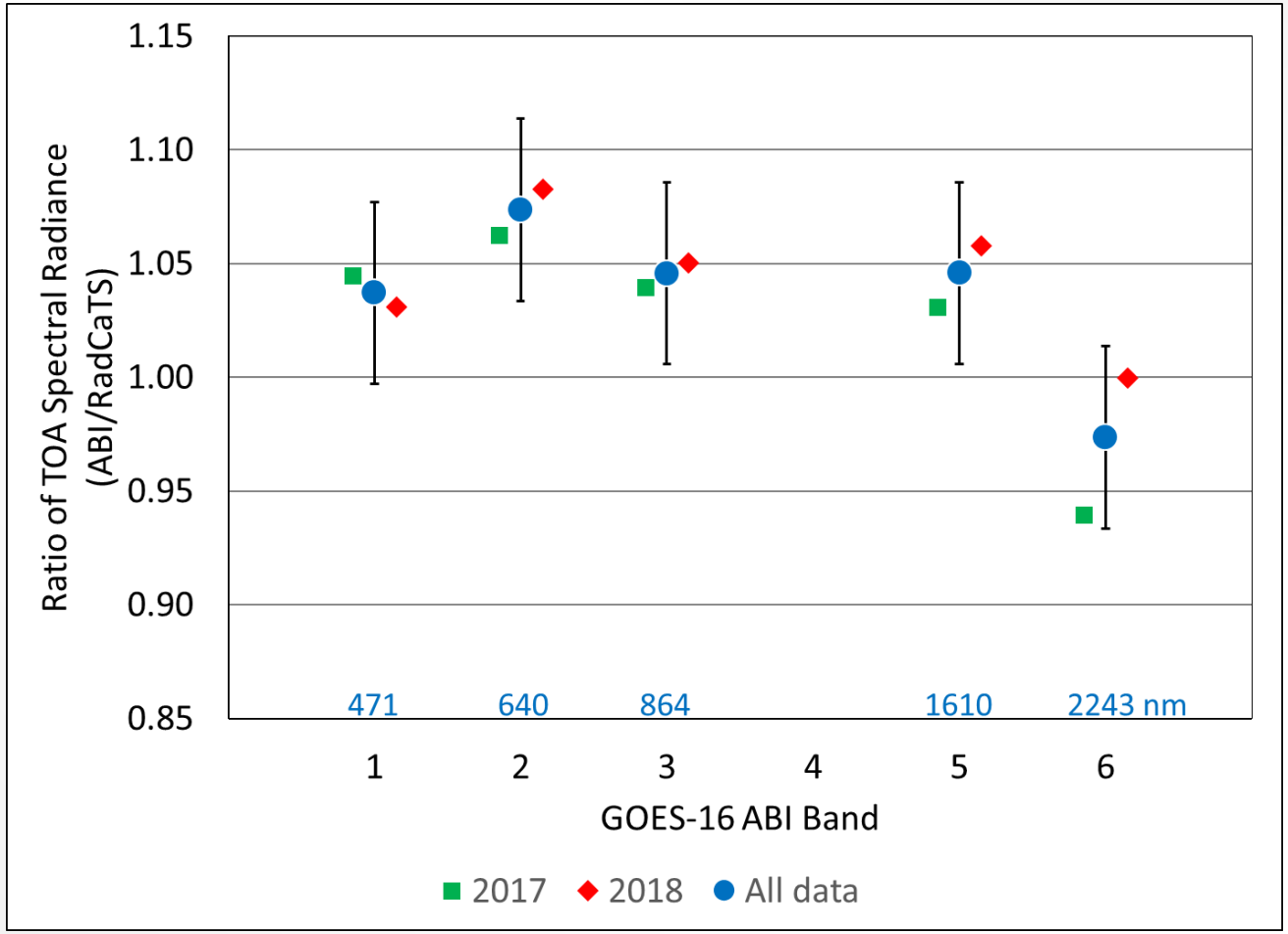
- Period of study: Apr 2017 to Mar 2019
- Initial assessment based on 'good' RadCalNet days
  - Most (or all) 13 times throughout the day are processed
  - 17:00–23:00 UTC
  - Every 30 minutes
- Solar noon used for this study (~19:47 UTC)
- Recent study uses RadCalNet quality control criterion
- 2017: 17 dates
  - ABI view geometry: 52° zenith, 321° azimuth
- 2018: 24 dates
  - ABI view geometry: 61° zenith, 306° azimuth
- 2019: 0 dates
- GOES-16 CONUS imagery



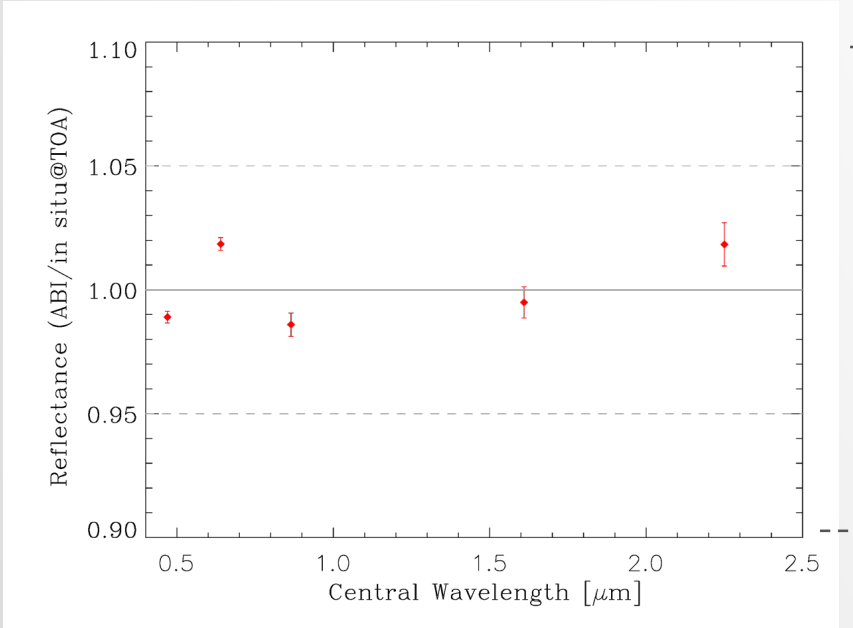
# RadCaTS ABI Radiometric Validation Results

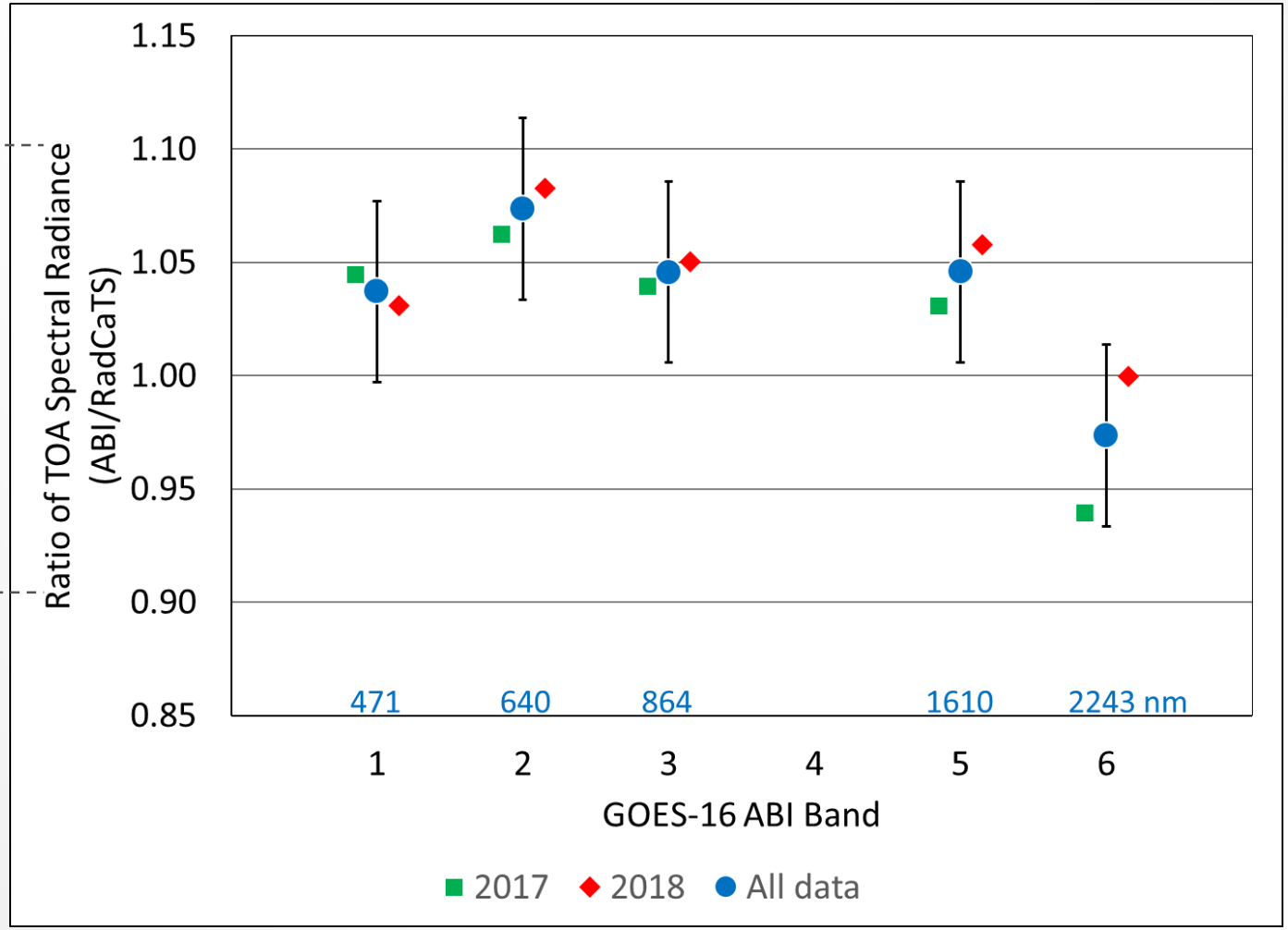
- Results compiled from Apr 2017 to Sep 2018
- Shown as 2017, 2018, and all
- Uncertainty bars are ±4% uncertainty of RadCaTS
- ABI nadir pixel size
  - Band 2: 500 m
  - Bands 1, 3, 5: 1000 m
  - Band 6: 2000 m
- Results show bias similar to in situ measurements in Bolivia



# RadCaTS ABI Radiometric Validation Results: Comparison with In Situ Measurements

- GOES-16 ABI Salar de Uyuni results courtesy of Joel McCorkel (NASA GSFC)
- In situ data collected in 2018 (5 days)



# GOES-16 ABI Intercomparison Data

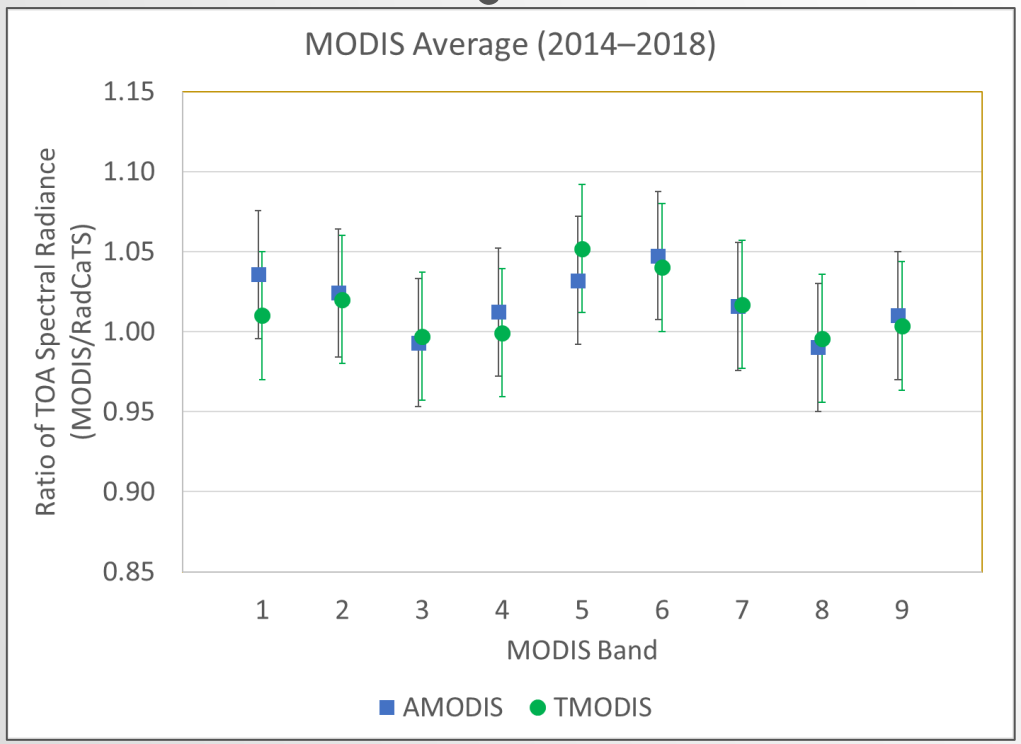
| | ABI Center Wavelength (nm) | | | | |
|---|---|---|---|---|---|
| | 471 | 640 | 864 | 1610 | 2243 |
| **Sensor** | **Band (Pixel size (m))** | | | | |
| ABI | 1 (1000) | 2 (500) | 3 (1000) | 5 (1000) | 6 (2000) |
| TMODIS | 3 (500) | 1 (250) | 2 (250) | 6 (500) | 7 (500) |
| AMODIS | 3 (500) | 1 (250) | 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) |
| S3A | 4 (300) | 8 (300) | 17 (300) | - | - |

| Sensor | Period | Number of Dates |
|---|---|---|
| ABI | 2017–2018 | 41 |
| TMODIS | 2014–2018 | 42 |
| AMODIS | 2014–2018 | 28 |
| S2A | 2015–2018 | 34 |
| S2B | 2017–2018 | 11 |
| L8 | 2013–2018 | 23 |
| S3A | 2016–2018 | 26 |

| Platform | Time (UTC) | VZA | VAA | Time | VZA | VAA | Time | VZA | VAA | Time | VZA | VAA | Time | VZA | VAA | Orbit | Repeat (days) | Launch Date |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Landsat-8** | 18:21 | 0.6 | 102.9 | | | | | | | | | | | | | D | 16 | 11 Feb 2013 |
| **TMODIS** | 18:40 | 0.8 | 103.5 | 18:33 | 11.0 | 102.6 | 18:45 | 12.4 | 284.4 | | | | | | | D | 16 | 18 Dec 1999 |
| **AMODIS** | 20:54 | 4.3 | 256.9 | 20:48 | 7.4 | 75.9 | | | | | | | | | | A | 16 | 4 May 2002 |
| **SNPP** | 20:40 | 0.6 | 75.7 | 20:34 | 11.0 | 74.7 | 20:46 | 9.8 | 256.7 | | | | | | | A | 16 | 28 Oct 2011 |
| **NOAA-20** | 20:39 | 0.2 | 75.8 | 20:32 | 10.5 | 74.8 | 20:45 | 10.2 | 256.7 | | | | | | | A | 16 | 18 Nov 2017 |
| **S2A** | 18:33 | 11.2 | 103.0 | 18:43 | 6.0 | 284.5 | | | | | | | | | | D | 10 | 23 Jun 2015 |
| **S2B** | 18:33 | 11.2 | 103.0 | 18:43 | 6.0 | 284.5 | | | | | | | | | | D | 10 | 7 Mar 2017 |
| **S3A** | 18:04 | 10.7 | 103.1 | 18:08 | 4.5 | 103.6 | 18:11 | 1.9 | 284.5 | 18:15 | 8.2 | 284.9 | 18:19 | 14.3 | 285.4 | D | 27 | 16 Feb 2016 |
| **S3B** | | | | | | | | | | | | | | | | D | 27 | 25 Apr 2018 |
| **GOES-16** | | 61.1 | 306.1 | | | | | | | | | | | | | G | - | 19 Nov 2016 |
| **GOES-17** | | 49.9 | 32.4 | | | | | | | | | | | | | G | - | 1 Mar 2018 |

# Example of Current RadCaTS Results: MODIS and VIIRS

- 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

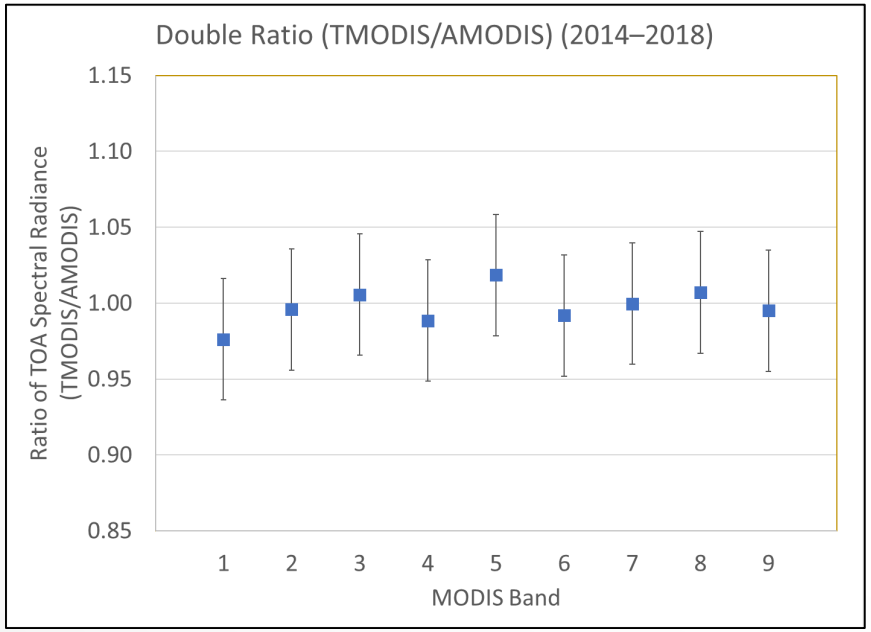



| Band | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| Wave (nm) | 645 | 856 | 466 | 553 | 1244 | 1632 | 2119 | 412 | 442 |

| 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 |

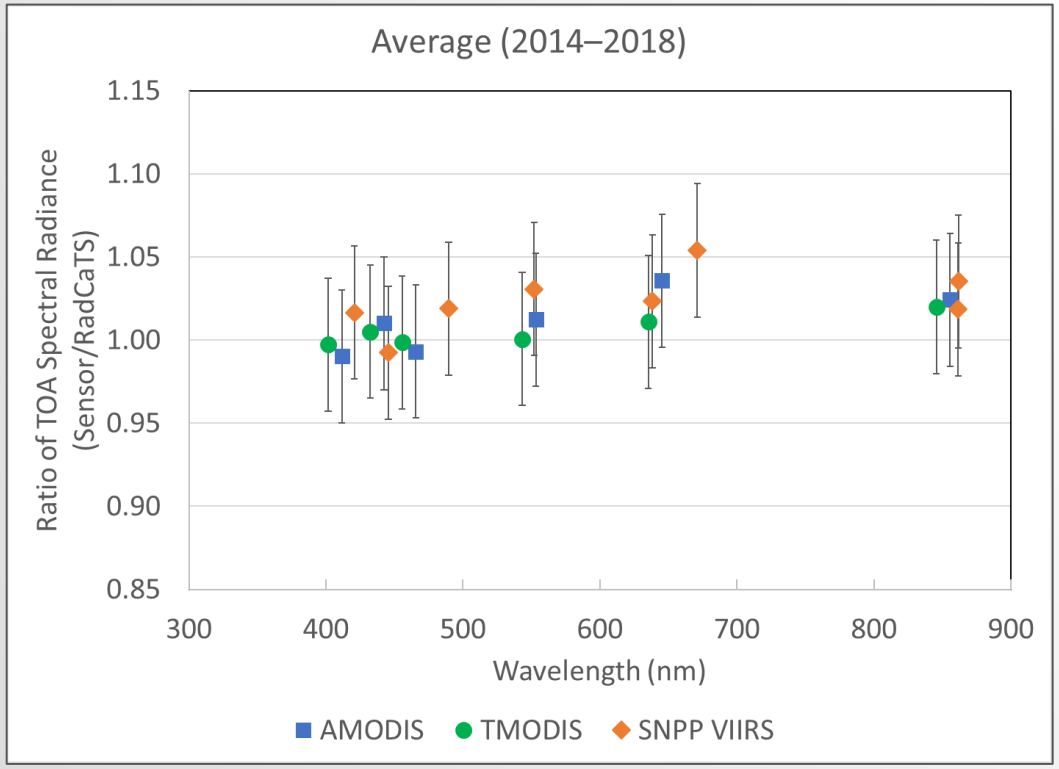
## Double Ratio



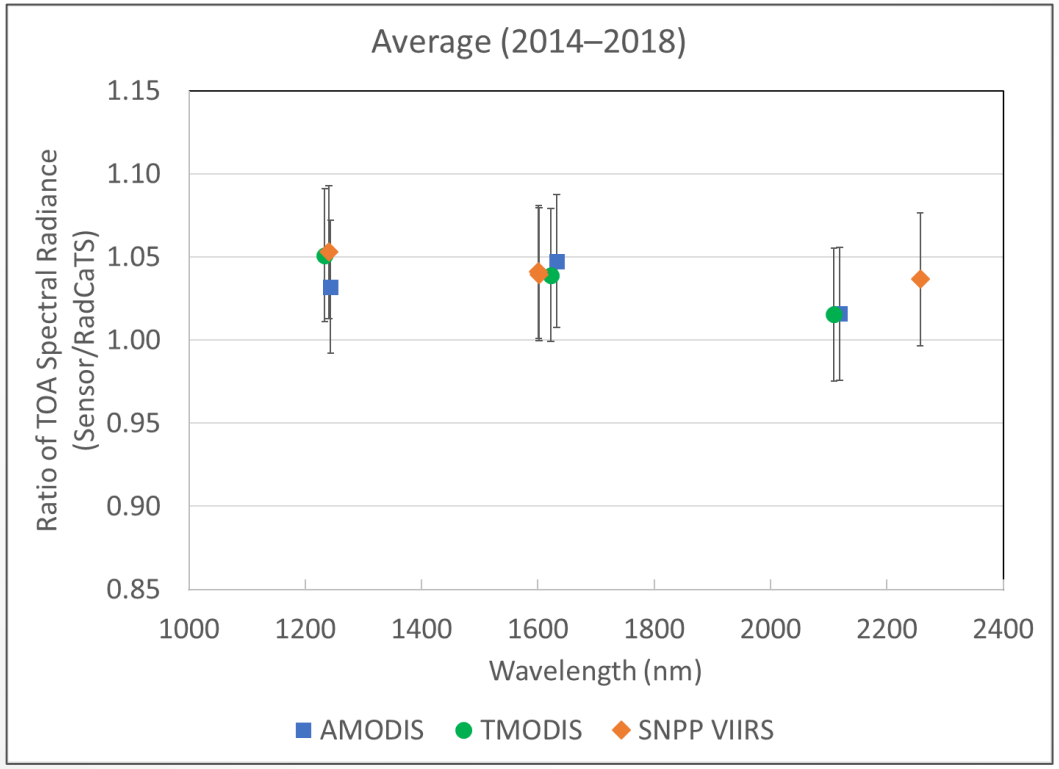
# Example of Current RadCaTS Results: MODIS and VIIRS

- Terra and Aqua MODIS, and SNPP VIIRS (2014–2018)
  - Terra: N = 45, three near-nadir views
  - Aqua: N = 28, two near-nadir views
  - SNPP VIIRS: N = 41, three near-nadir views

VNIR

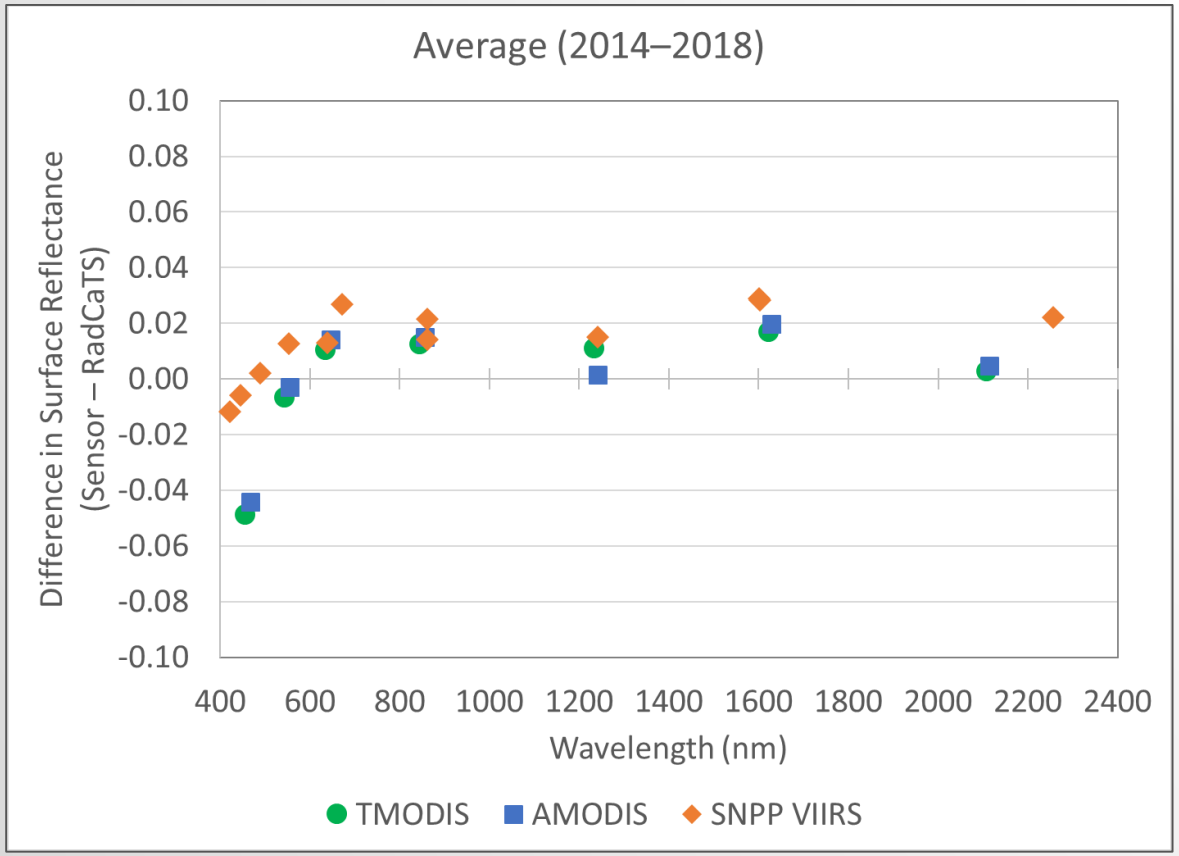



SWIR

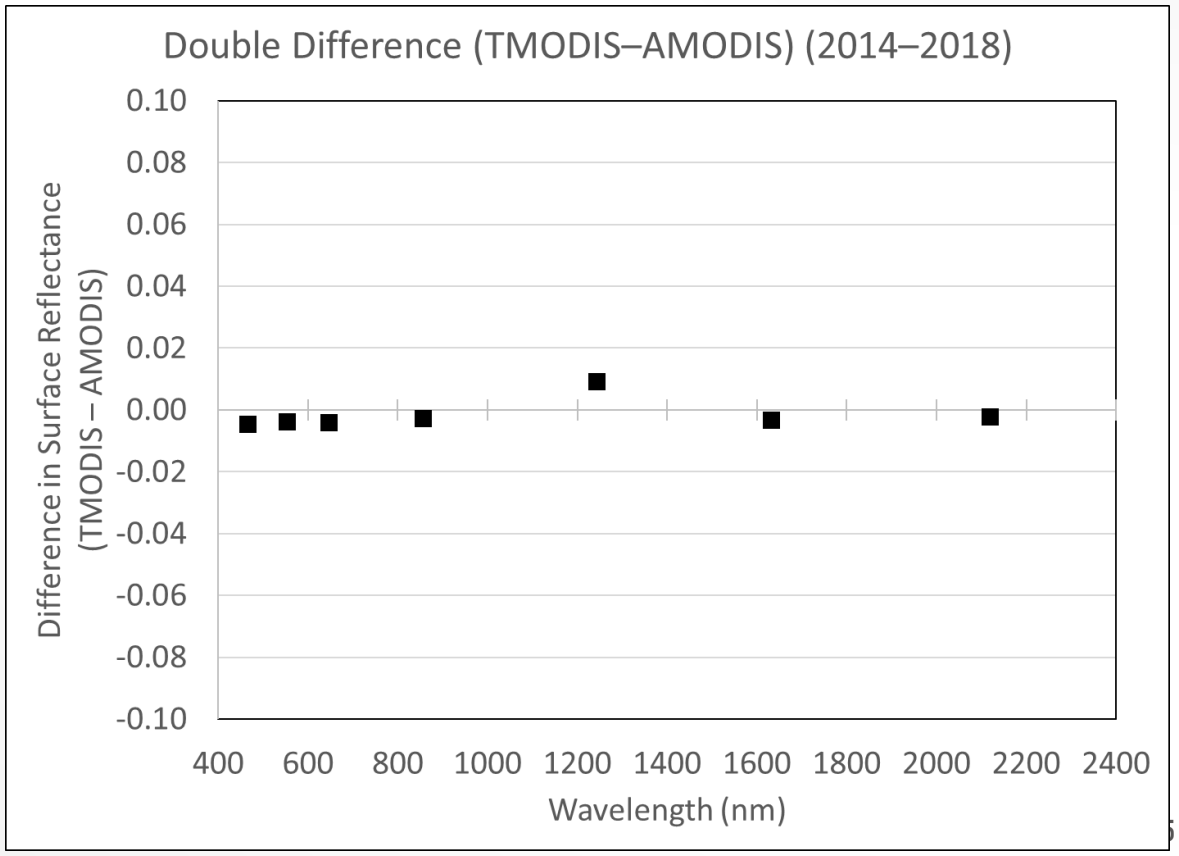


# Example of Current RadCaTS Results: MODIS and VIIRS Surface Reflectance Validation

- Terra and Aqua MODIS, and SNPP VIIRS (2014–2018)
  - Terra: N = 45, three near-nadir views
  - Aqua: N = 28, two near-nadir views
  - SNPP VIIRS: N = 41, three near-nadir views



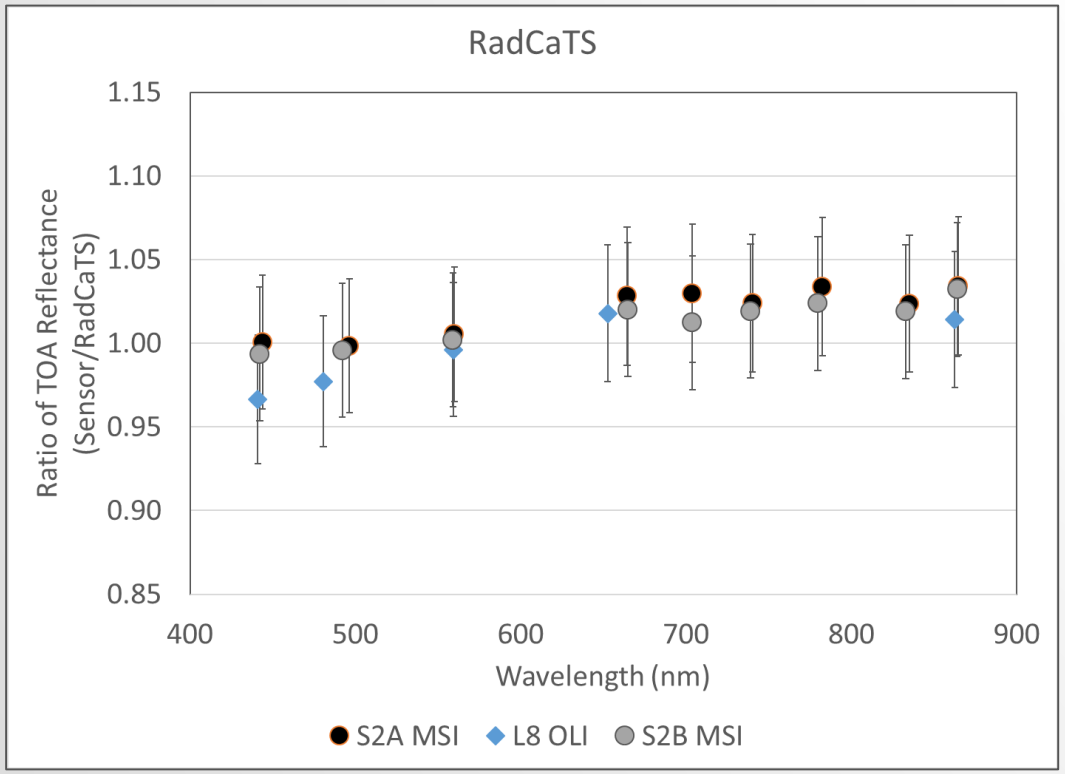

Double Difference (MODIS Surface Reflectance)



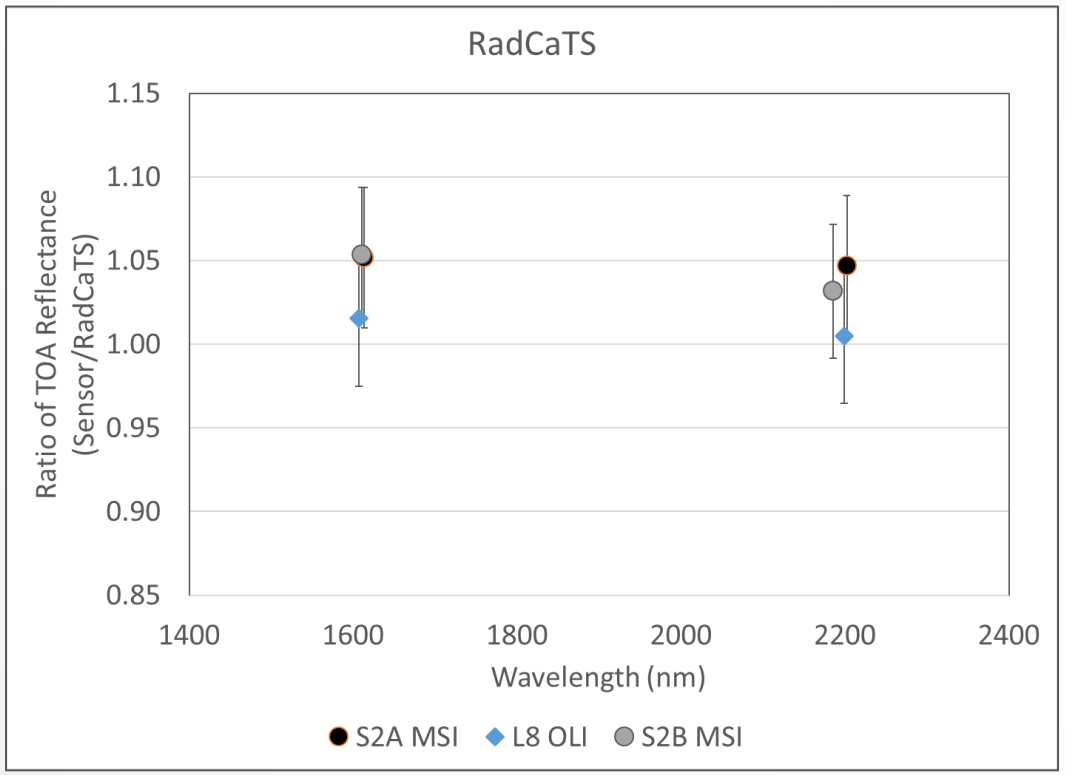
# Example of Current RadCaTS Results: Landsat-8 OLI and Sentinel-2 MSI

- Landsat-8 (2014–2018) and Sentinel-2A (2015–2018) and Sentinel-2B (2017–2018)
  - L8: N = 23, nadir view only
  - S2A: N = 34, two off-nadir views
  - S2B: N = 11, two off-nadir views

VNIR

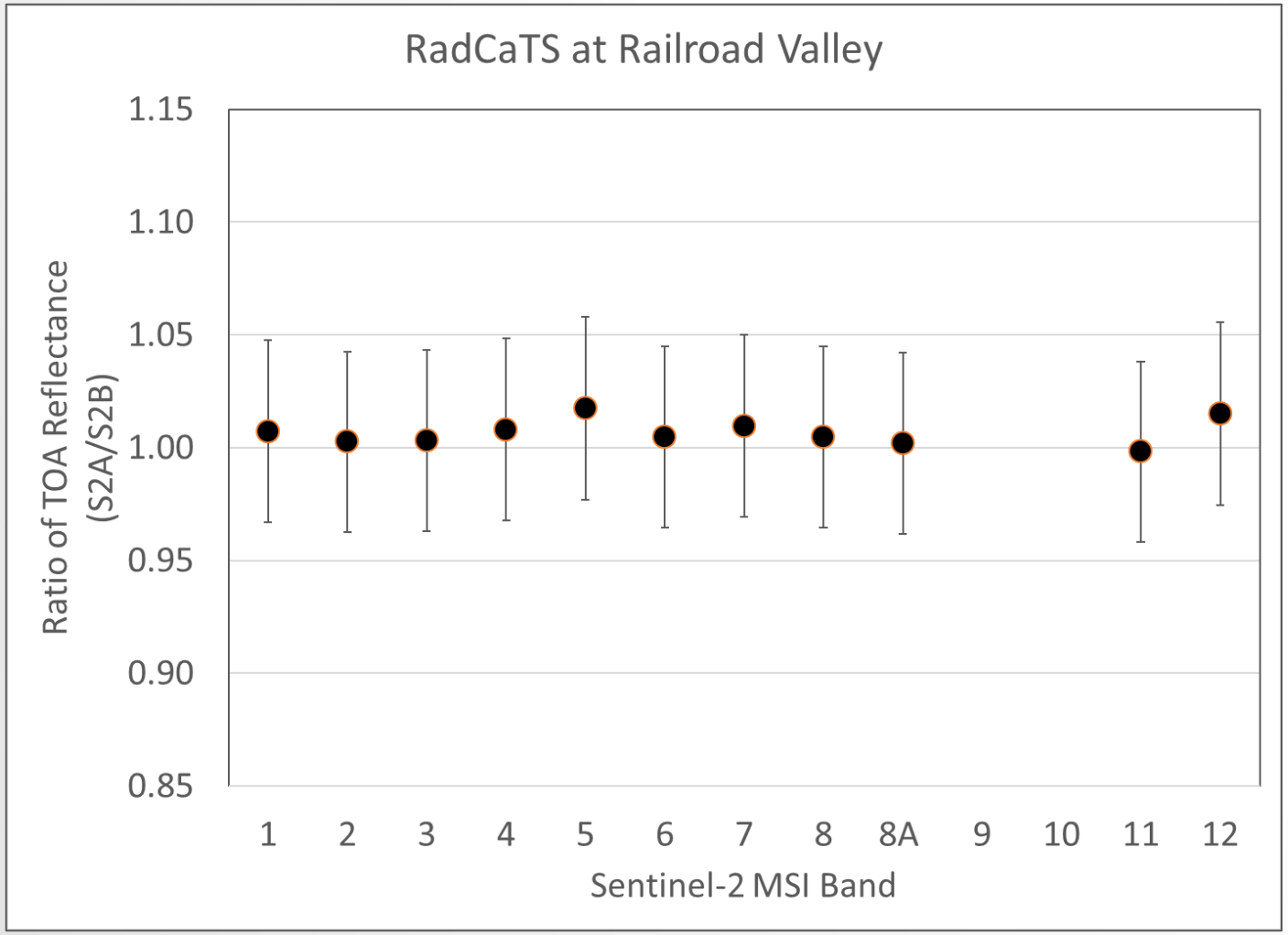



SWIR



# Example of Current RadCaTS Results: Sentinel-2 MSI

- Double ratio to remove RadCaTS bias



# Example of Current RadCaTS Results: Sentinel-3A OLCI (2016–2018)

- 27 day repeat, 5 view angles used in this study
- N = 26
- TOA $L_\lambda$

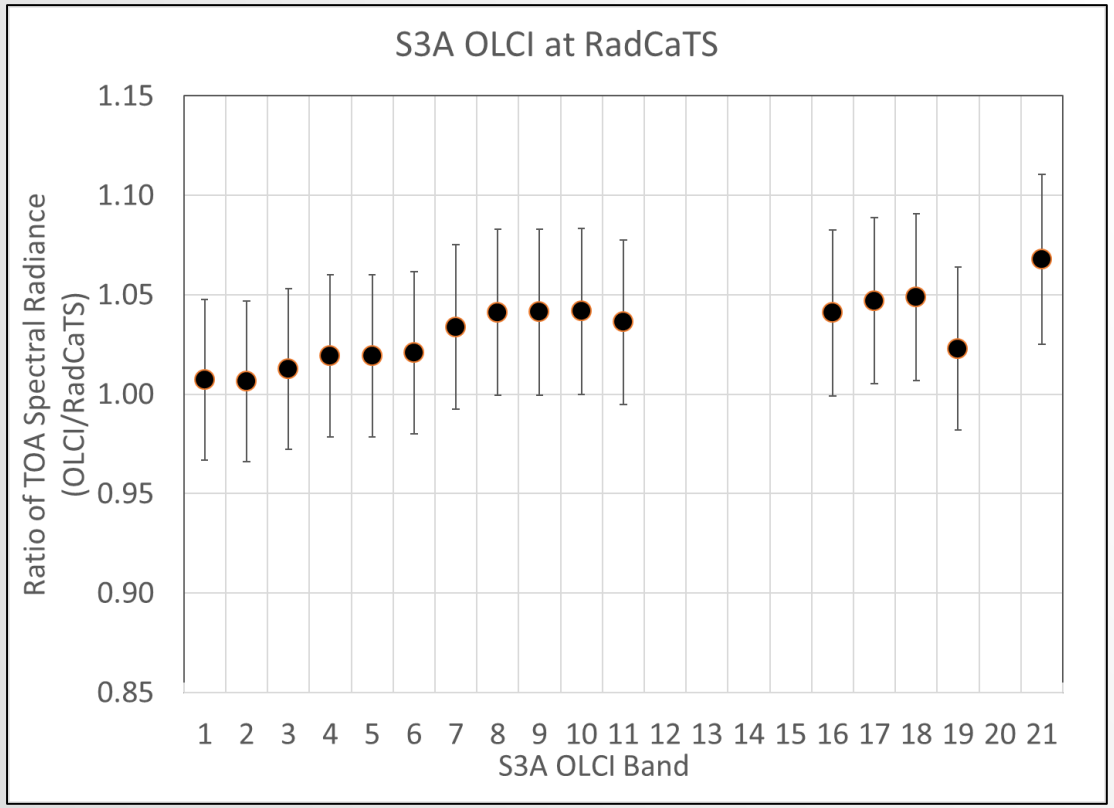
| OLCI Band | Wave (nm) | Pixel (m) | FWHM (nm) |
|---|---|---|---|
| 1 | 400.3 | 300 | 15 |
| 2 | 411.8 | 300 | 10 |
| 3 | 443.0 | 300 | 10 |
| 4 | 490.5 | 300 | 10 |
| 5 | 510.5 | 300 | 10 |
| 6 | 560.5 | 300 | 10 |
| 7 | 620.4 | 300 | 10 |
| 8 | 665.3 | 300 | 10 |
| 9 | 674.0 | 300 | 7.5 |
| 10 | 681.6 | 300 | 7.5 |
| 11 | 709.1 | 300 | 10 |
| 12 | 754.2 | 300 | 7.5 |
| 13 | 761.7 | 300 | 2.5 |
| 14 | 764.8 | 300 | 3.75 |
| 15 | 767.9 | 300 | 2.5 |
| 16 | 779.3 | 300 | 15 |
| 17 | 865.4 | 300 | 20 |
| 18 | 884.3 | 300 | 10 |
| 19 | 899.3 | 300 | 10 |
| 20 | 939.0 | 300 | 20 |
| 21 | 1015.8 | 300 | 40 |

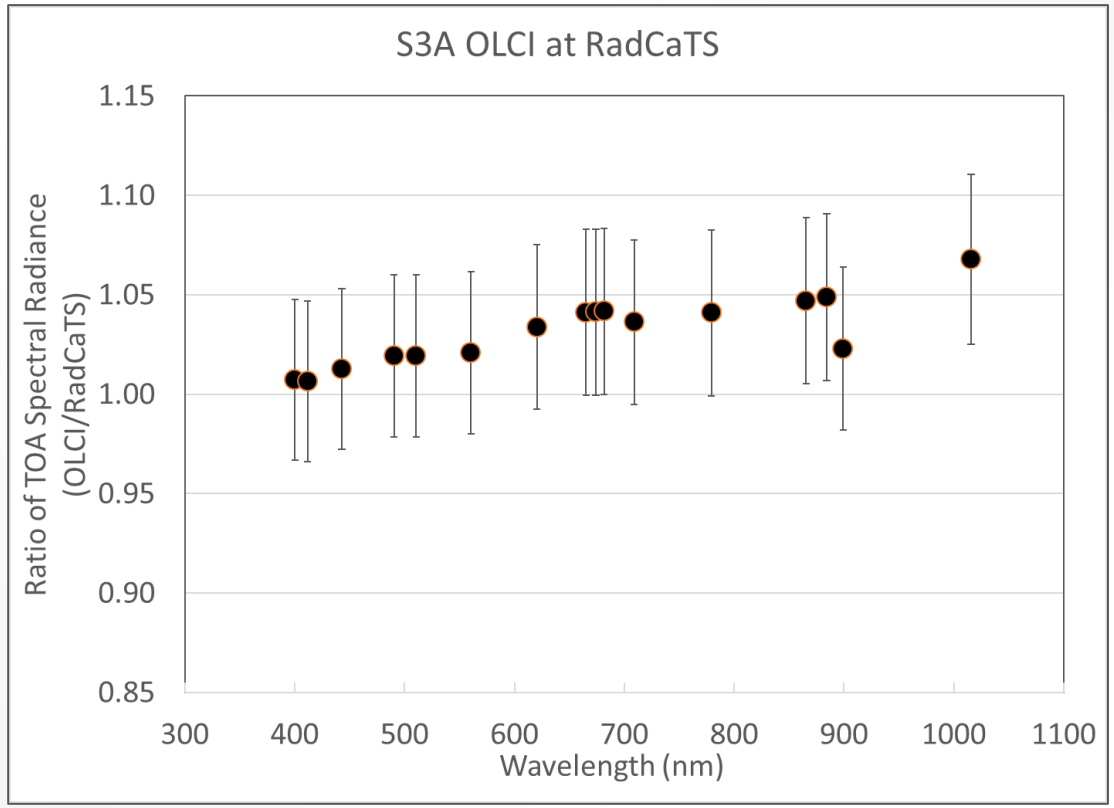
**Table 1: OLCI Band characteristics**

| Band | λ centre (nm) | Width (nm) | Function |
|---|---|---|---|
| Oa01 | 400 | 15 | Aerosol correction, improved water constituent retrieval |
| Oa02 | 412.5 | 10 | Yellow substance and detrital pigments (turbidity) |
| Oa03 | 442.5 | 10 | Chlorophyll absorption maximum, biogeochemistry, vegetation |
| Oa04 | 490 | 10 | High Chlorophyll, |
| Oa05 | 510 | 10 | Chlorophyll, sediment, turbidity, red tide |
| Oa06 | 560 | 10 | Chlorophyll reference (Chlorophyll minimum) |
| Oa07 | 620 | 10 | Sediment loading |
| Oa08 | 665 | 10 | Chlorophyll (2nd Chlorophyll absorption maximum), sediment, yellow substance/vegetation |
| Oa09 | 673.75 | 7.5 | For improved fluorescence retrieval and to better account for smile together with the bands 665 and 680 nm |
| Oa10 | 681.25 | 7.5 | Chlorophyll fluorescence peak, red edge |
| Oa11 | 708.75 | 10 | Chlorophyll fluorescence baseline, red edge transition |
| Oa12 | 753.75 | 7.5 | O2 absorption/clouds, vegetation |
| Oa13 | 761.25 | 2.5 | O2 absorption band/aerosol correction. |
| Oa14 | 764.375 | 3.75 | Atmospheric correction |
| Oa15 | 767.5 | 2.5 | O2A used for cloud top pressure, fluorescence over land |
| Oa16 | 778.75 | 15 | Atmos. corr./aerosol corr. |
| Oa17 | 865 | 20 | Atmospheric correction/aerosol correction, clouds, pixel co-registration |
| Oa18 | 885 | 10 | Water vapour absorption reference band. Common reference band with SLSTR instrument. Vegetation monitoring |
| Oa19 | 900 | 10 | Water vapour absorption/vegetation monitoring (maximum reflectance) |
| Oa20 | 940 | 20 | Water vapour absorption, Atmospheric correction/aerosol correction |
| Oa21 | 1 020 | 40 | Atmospheric correction/aerosol correction |

# Example of Current RadCaTS Results: Sentinel-3A OLCI (2016–2018)

- 27 day repeat, 5 view angles at Railroad Valley
- N = 26

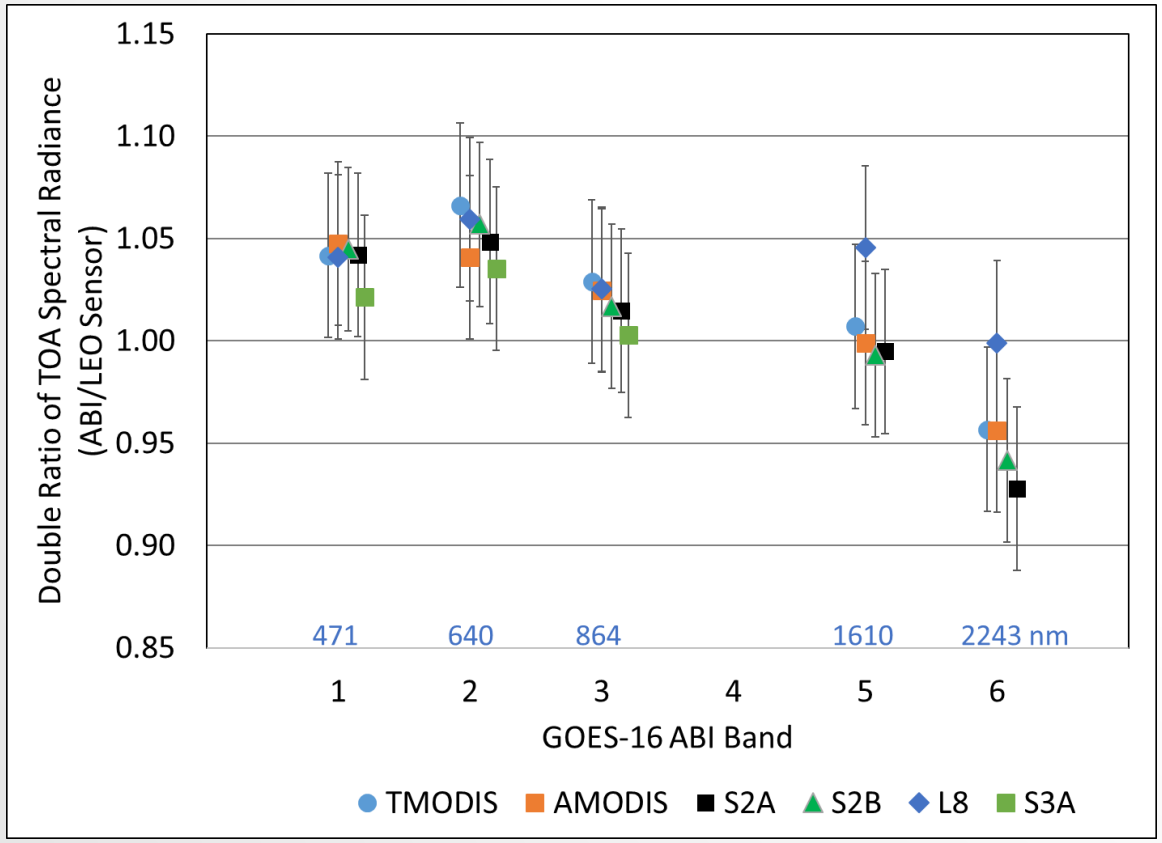



| Platform | Time (UTC) | VZA | VAA | Time | VZA | VAA | Time | VZA | VAA | Time | VZA | VAA | Time | VZA | VAA | Orbit | Repeat (days) | Launch Date |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S3A | 18:04 | 10.7 | 103.1 | 18:08 | 4.5 | 103.6 | 18:11 | 1.9 | 284.5 | 18:15 | 8.2 | 284.9 | 18:19 | 14.3 | 285.4 | D | 27 | 16 Feb 2016 |

# RadCaTS Intercomparison Results

- GOES-16 ABI 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



# Summary

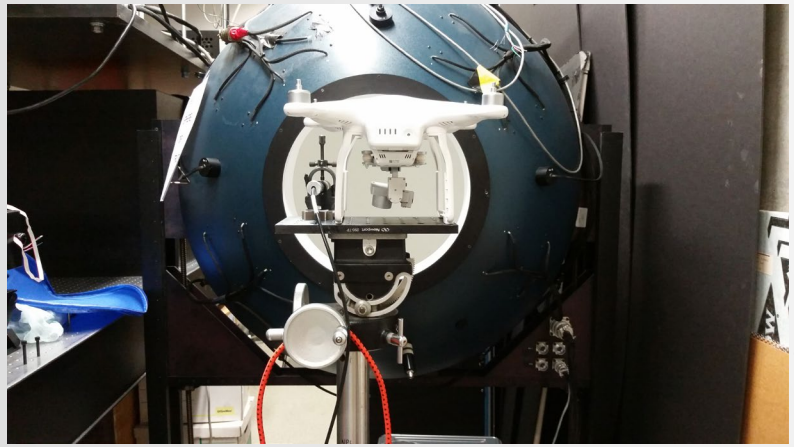
- The work presented here is a preliminary effort to provide radiometric validation data for GOES-16 ABI
- GOES-17 ABI analysis will begin in 2019
- Results show a bias between RadCaTS and ABI
  - Similar in shape to in situ field measurements by other teams (e.g. Salar de Uyuni salt flats in Bolivia), but larger value at Railroad Valley
  - Double ratio also shows bias between ABI and LEO sensors
- Results presented here were limited to one ABI collect time per day
- Future work
  - Investigate daily results (e.g. 5-min CONUS intervals throughout the day)
  - Investigate temporal trends with temporal matchups of ABI and LEO sensors
  - Update results of ALL sensors using new QC criteria (v04.input for RadCalNet)
  - Continue to work on BRDF analysis for off-nadir view angles

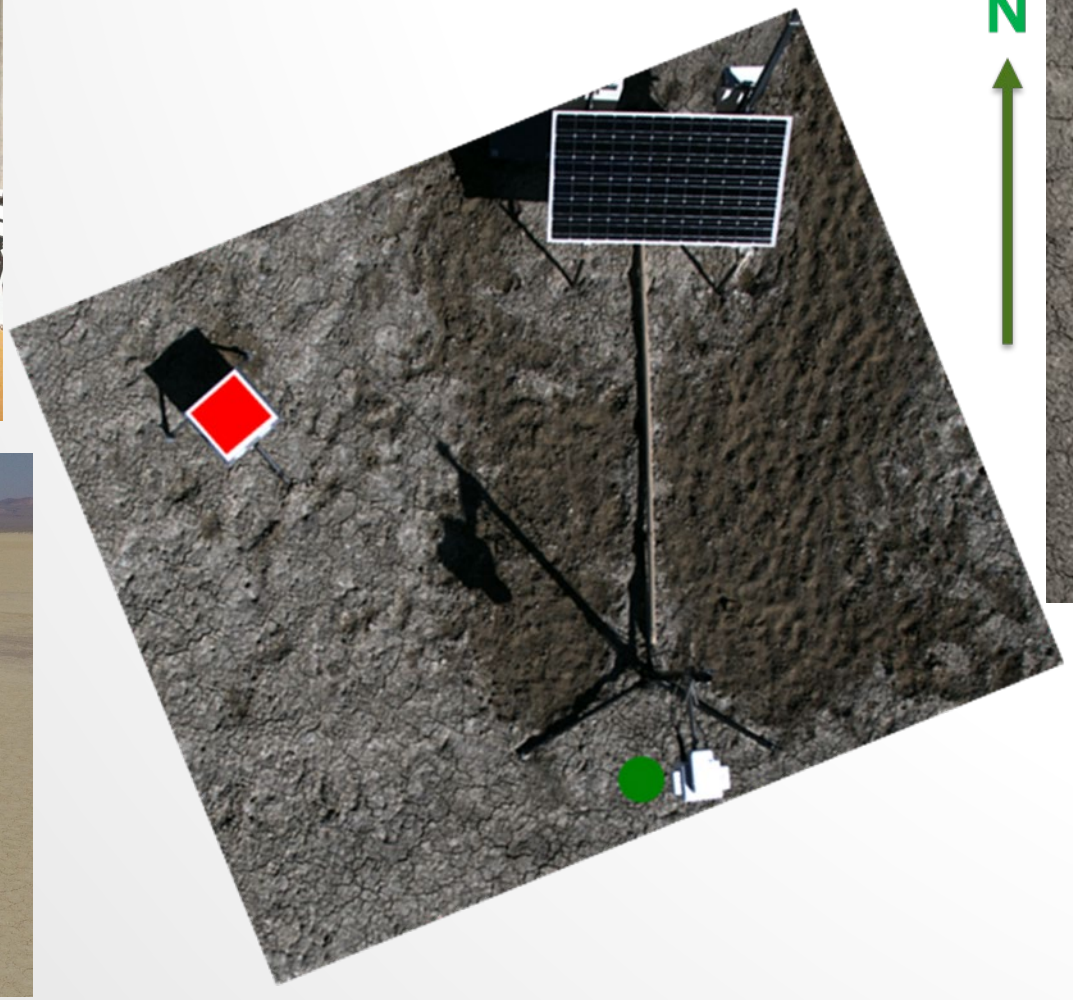
# Thanks!

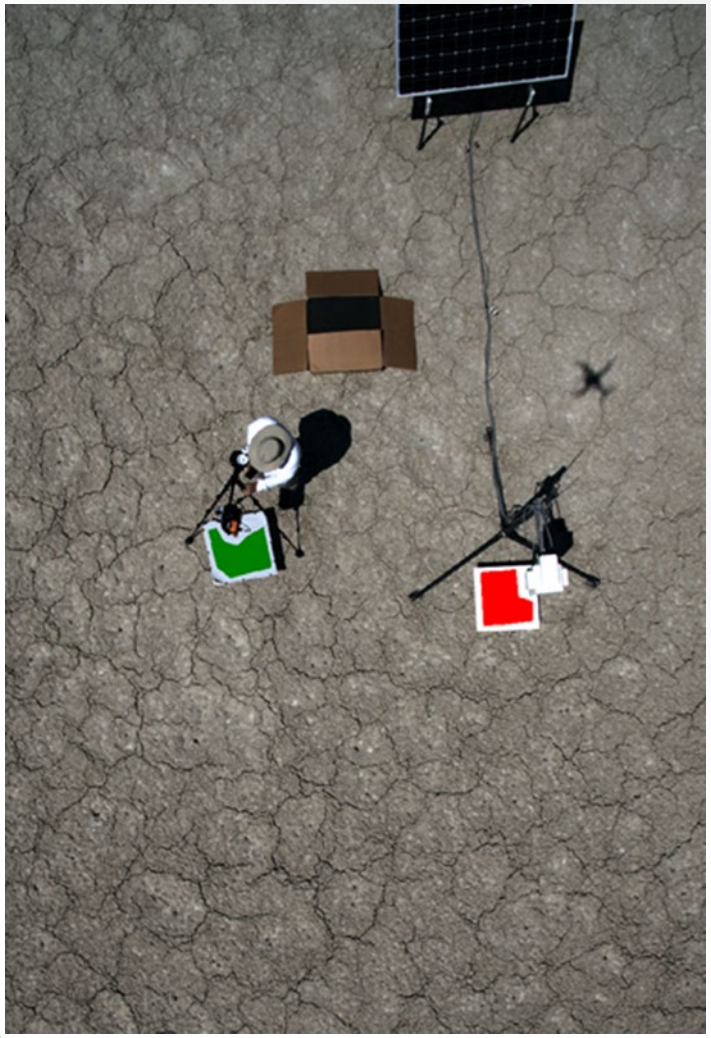

- The authors would like to thank the Bureau of Land Management (BLM), Tonopah, Nevada office, for assistance and access to Railroad Valley
- We would also like to thank NASA and USGS for funding this work, and AERONET for processing the Cimel data


# Other Instrumentation

- Commercial sUAS for spatial uniformity analysis (SPIE 2017)

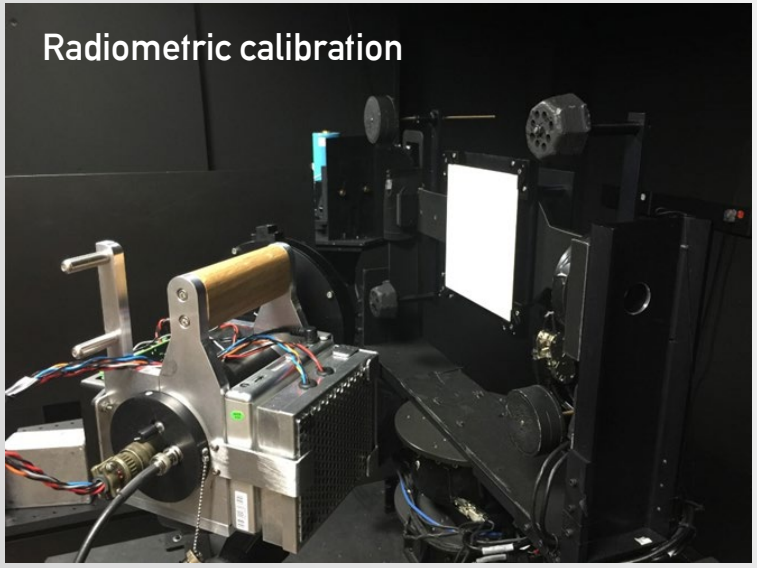


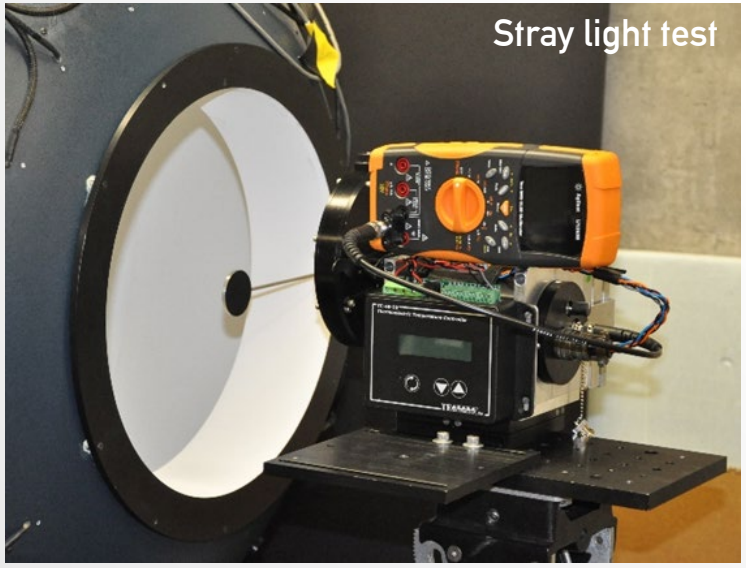


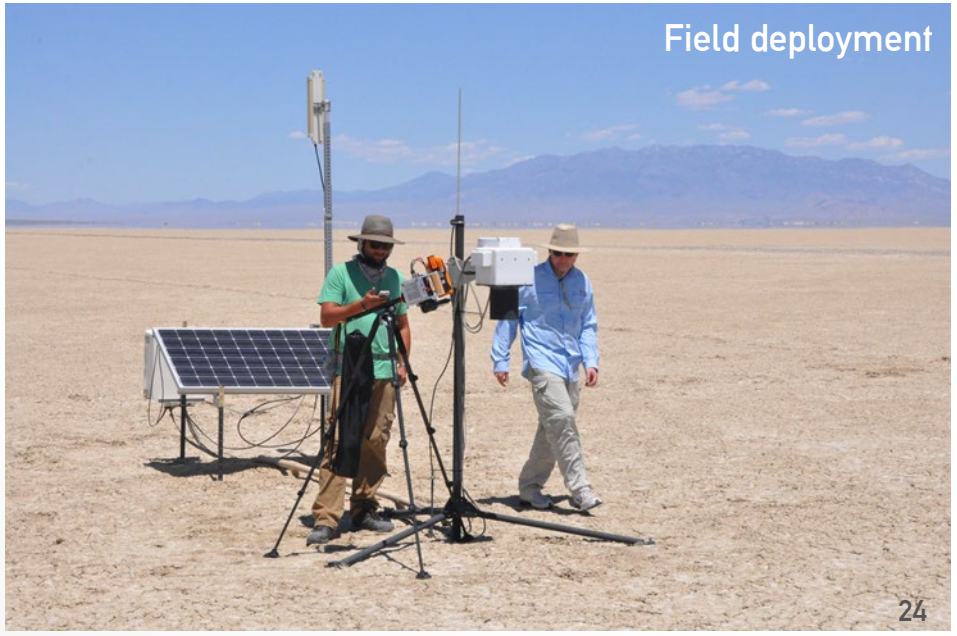



# Other Instrumentation

- Calibration Test Site SI-Traceable Transfer Radiometer (CaTSSITTR)
- 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

- 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