Uncertainty Analysis for the Radiometric Calibration Test Site (RadCaTS) at Railroad Valley, Nevada

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Outline

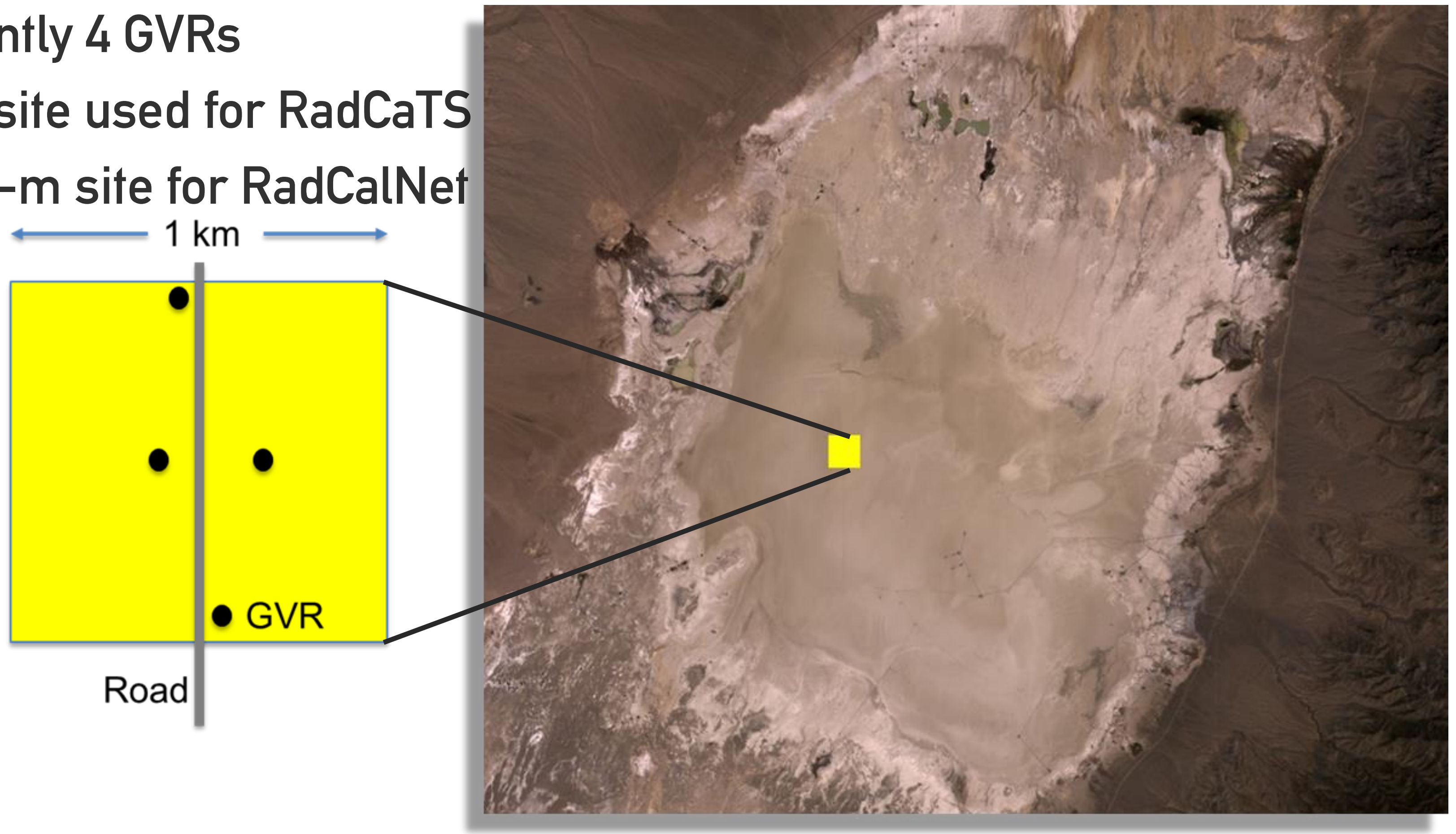
- RadCaTS concept
- Sample of current results
- Involvement in the CEOS WGCV Radiometric Calibration Network (RadCalNet)
- Uncertainty in TOA product
  - Previous U. Arizona work
  - Current NPL work
- Summary and future work

RadCaTS Concept

- U of Arizona has been transitioning from in situ measurements using on-site personnel to automated measurements
- More effective temporal coverage (e.g. satellite constellations)
- Method based on decades of earlier work
- Instrument transition
  - Atmospheric: automated solar radiometer –> Cimel
  - Surface reflectance: ASD –> ground-viewing radiometer (GVR)
- Goals:
  - Maintain accuracy and precision at same level as reflectance-based approach
  - Greatly increase number of collections throughout the year
  - Daily uploading and processing for use in RadCalNet

RadCaTS layout at Railroad Valley

- 4 GVRs situated within 150 m of access road
- Previous studies to determine where and how many GVRs needed
- Currently 4 GVRs
- 1-km site used for RadCaTS
- 50×50-m site for RadCalNet



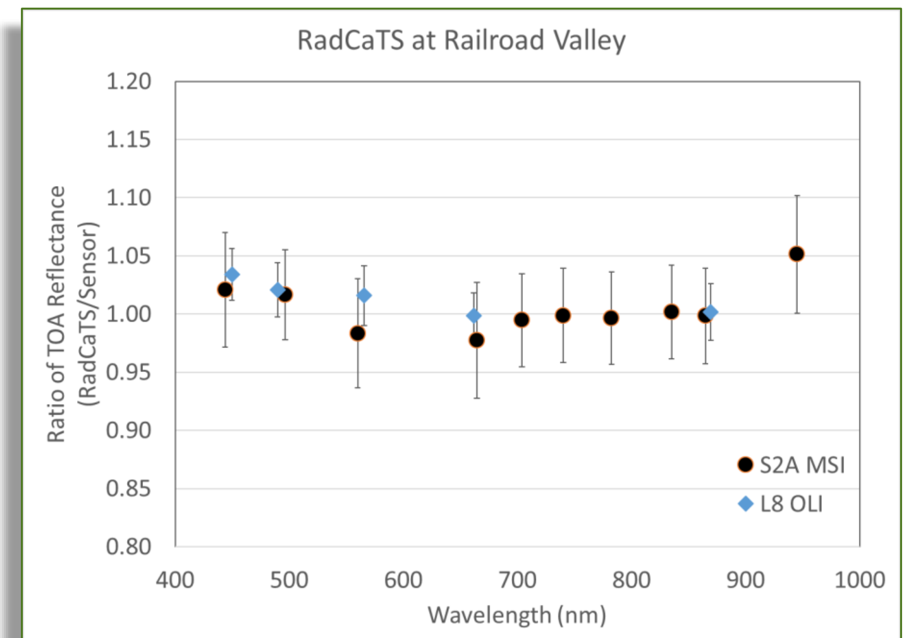
RadCaTS instrumentation

- **On-site instrumentation**
  - Cimel sun photometer (a)
  - Satellite communication uplink (b)
  - 4 ground-viewing radiometers (GVRs) (c)
  - Meteorological station

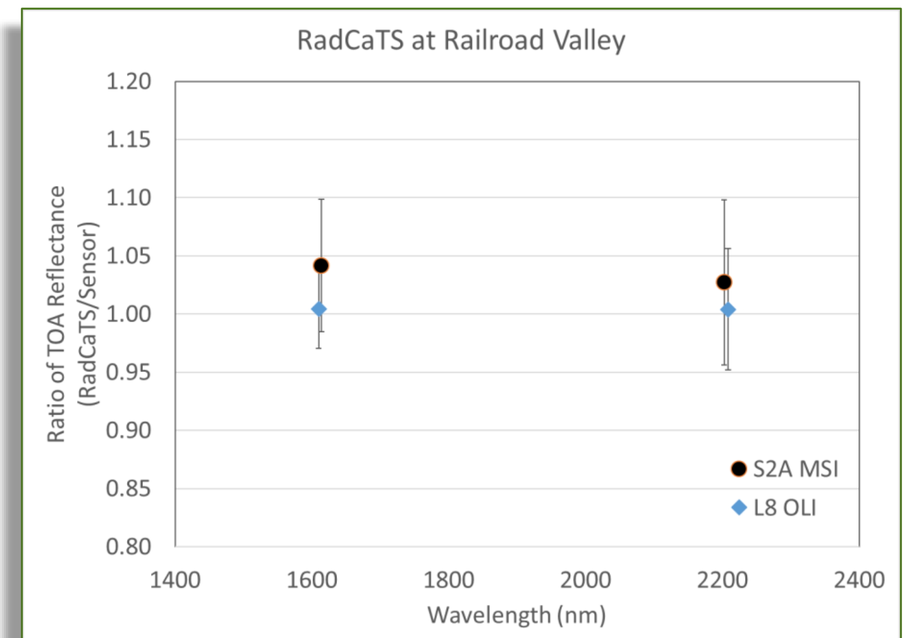
Example of RadCaTS Results

- Landsat 8 OLI (2013–2016) and Sentinel-2A MSI (2015–2016)
- Comparison of TOA reflectance products
- Uncertainty bars are the 1σ standard deviation of the measurements

VNIR

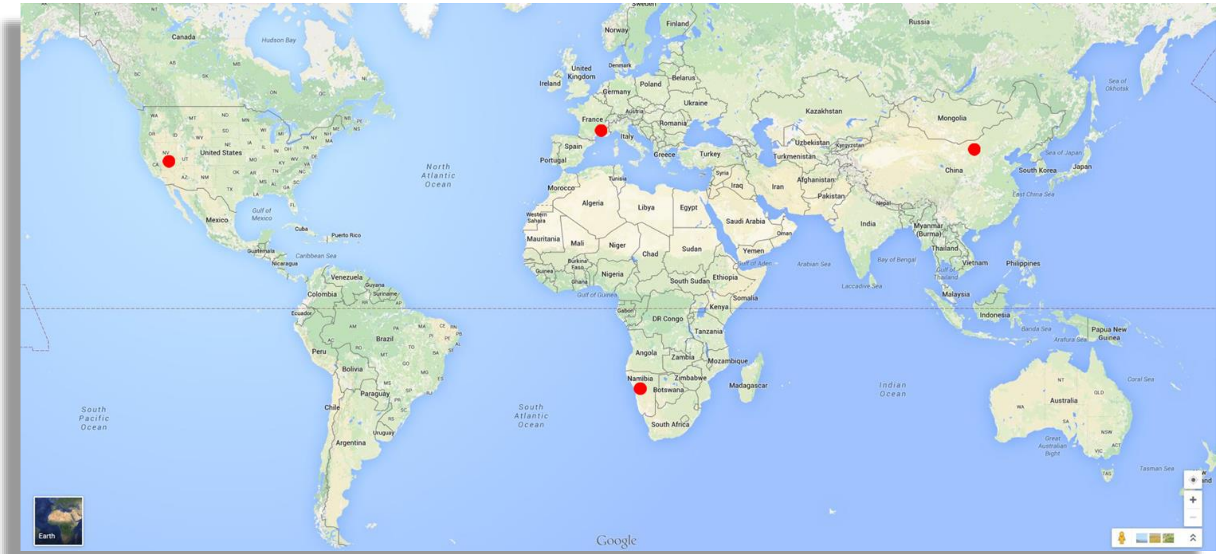


SWIR



Participation in CEOS RadCalNet

- **CEOS WGCV RadCalNet: shared vision of calibration site network**
  - Increase number of in situ measurements and space observations
  - Ensure SI traceability
  - Support Global Earth Observation System of Systems (GEOSS)
  - Two-year prototyping phase: 2014–2016
- **RadCaTS is currently 1 of 4 sites in RadCalNet**



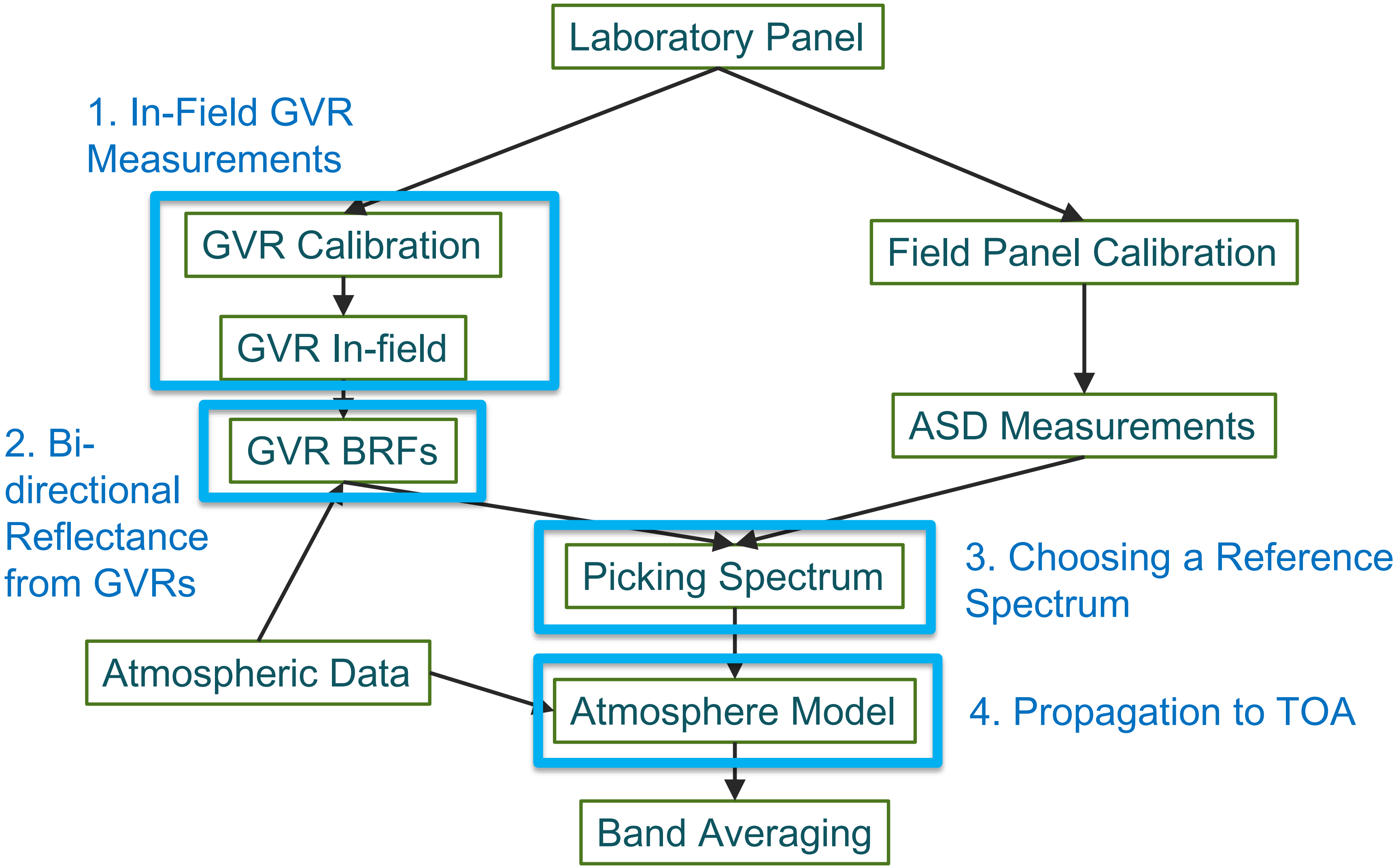
Preliminary Uncertainty Analysis of RadCaTS

- Uncertainty analysis performed in 2015 by U. Arizona as part of Landsat work
- Main uncertainty sources:
  - Radiometric calibration of GVRs
  - Radiometric resolution of GVRs
  - Exoatmospheric solar irradiance
  - Atmospheric transmission
  - Diffuse sky irradiance
  - Surface reflectance retrieval
- Results of surface reflectance retrieval uncertainty: 2.9–4.0% (1σ)
- Results of TOA spectral radiance uncertainty: 3.1–4.1% (1σ)

Current Uncertainty Analysis of RadCaTS

- Being performed by the National Physical Laboratory (NPL) in the UK
- Follows process outlined in NPL *Uncertainty Analysis for Earth Observation* course (www.meteoc.org/training.html)
- Uncertainty budget includes:
  - Instrumentation accuracy and repeatability
  - Data sources (e.g. exoatmospheric solar irradiance models)
  - Spatial homogeneity of the site, and spatial sampling using the GVRs
  - Radiative transfer code (currently MODTRAN 5.3.2)
  - Scaling of hyperspectral reference BRF data with multispectral GVR data
- Analysis performed using a combination of:
  - Literature
  - Laboratory results
  - Monte Carlo analysis
  - Image analysis of Railroad Valley

Current Uncertainty Analysis of RadCaTS

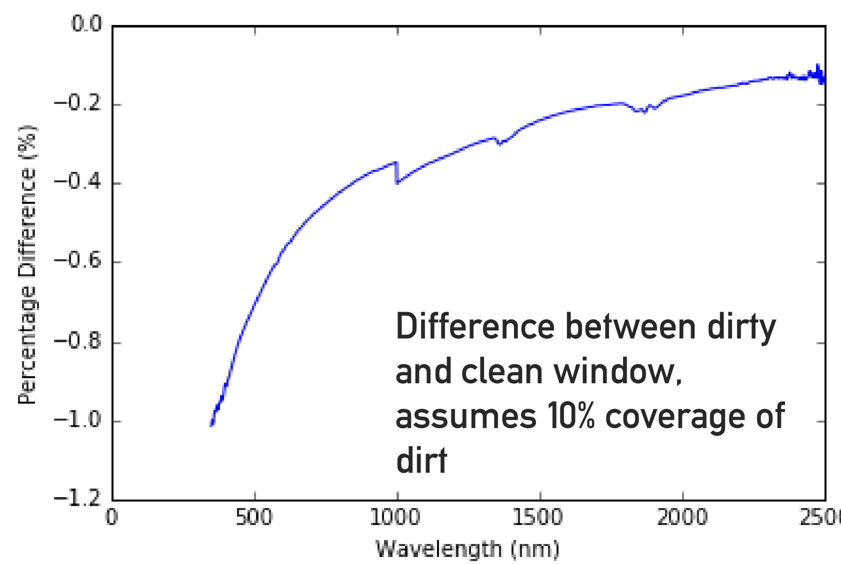


Current Uncertainty Analysis of RadCaTS

1. In-Field GVR Measurements

- GVR absolute calibration uncertainty = 2.0%
- Temperature changes shown to have negligible effect = 0.0%
- Size of source effect commonly estimated in laboratory = 0.3%
- “Temporary degradation” i.e. cleanliness of equipment = 0.2–0.9%

Total = 2.0–2.2 %



Current Uncertainty Analysis of RadCaTS

2. Bi-directional Reflectance from GVRs

For each GVR band: $$\rho = \frac{\pi C_{GVR} V_{GVR}}{\frac{E_0}{d^2} \tau_A \cos\theta + E_{SKY}}$$

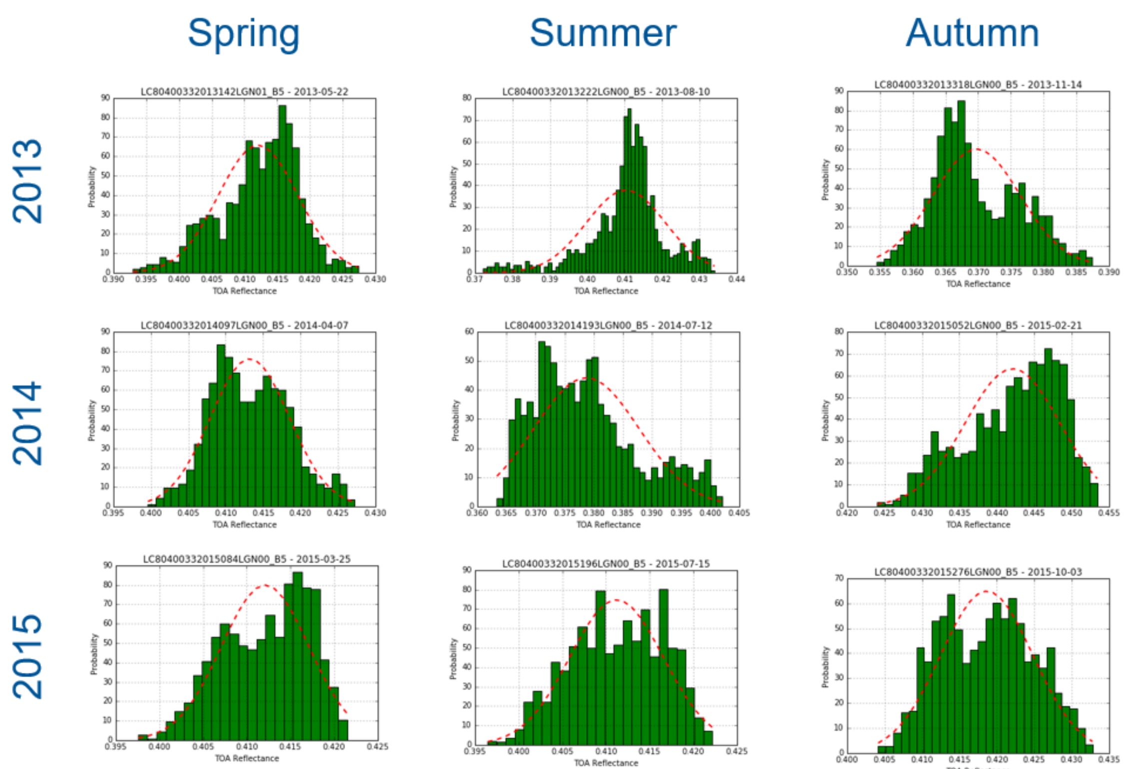
- $C_{GVR}V_{GVR}$ (GVR measurements) from previous slide = 2.0–2.2%
- E_0 (solar irradiance) from Thuillier uncertainties + differences between Thuillier and the utilized ChKur model = 2.0–5.3%
- τ_A (atmospheric transmission) from Monte Carlo through MODTRAN = 0.7–1.4%
- cos theta (solar zenith angle) uncertainty estimated as difference across site = 0.55%
- E_{SKY} (diffuse irradiance) to be estimated from MODTRAN = In progress

Total = 3.3–5.9 %

Current Uncertainty Analysis of RadCaTS

3. Choosing a Reference Spectrum

- Average of BRF values from each of the GVRs used to find best match spectrum.

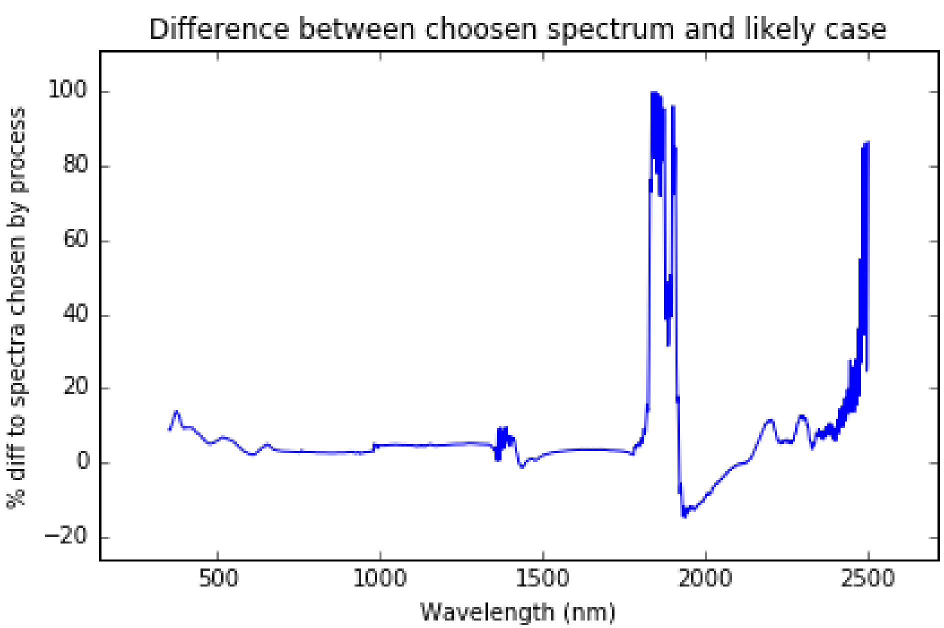


- Work ongoing to determine the uncertainty introduced by this assumption.
- Panel shows extreme cases where assumption may result in "largest" uncertainties.

Current Uncertainty Analysis of RadCaTS

3. Choosing a Reference Spectrum

- Monte Carlo analysis used to determine the final chosen spectrum if input GVR BRF values are perturbed within uncertainties (Note: inclusion of reference spectrum uncertainties to follow).



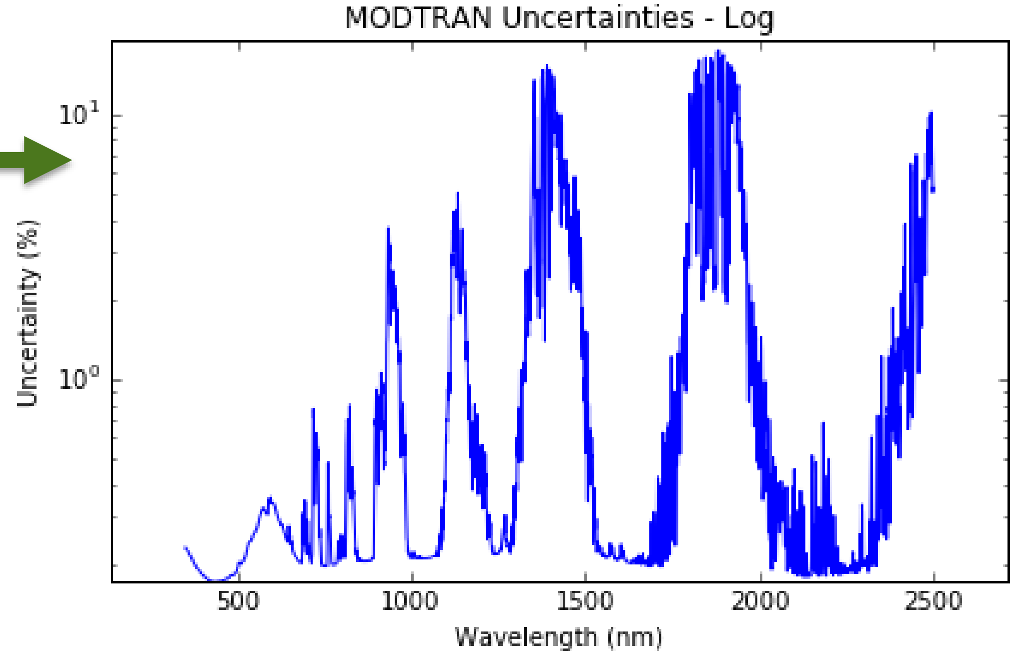
- It is likely (about 65% probability) that the maximum difference between the spectrum chosen by the process and that which could be chosen if the GVR values are somewhere within the bounds of their uncertainties are shown.

Current Uncertainty Analysis of RadCaTS

4. Propagation to TOA

- **Monte Carlo analysis used to determine uncertainties due to atmospheric input parameters (Gaussian PDFs assumed):**
- **For propagation to TOA:**

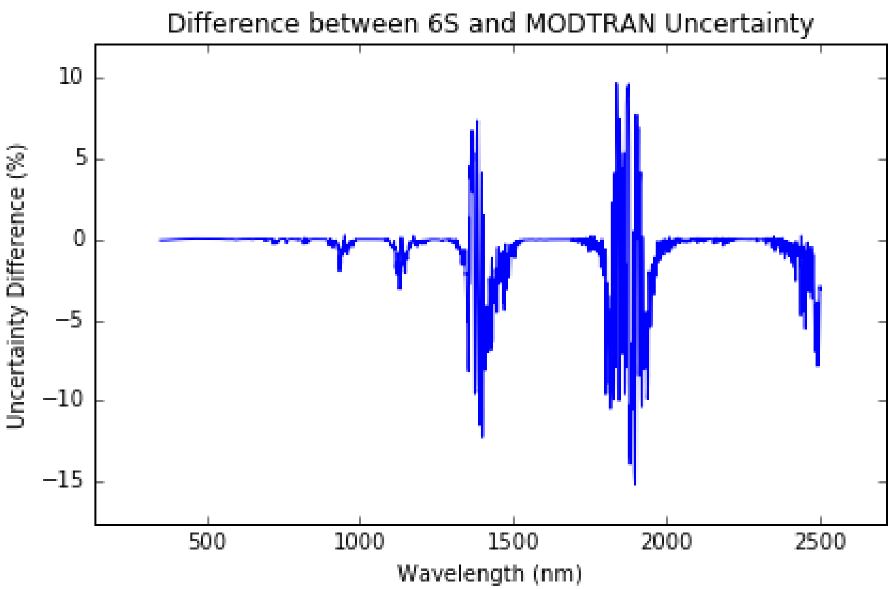
Parameter	Uncertainty
Temperature	0.1
Water vapour optical depth	5%
Columnar ozone	3%
Aerosol optical depth at 550 nm	0.010
Relative solar azimuth	0.2 degrees
Solar zenith angle	0.2 degrees



Current Uncertainty Analysis of RadCaTS

4. Propagation to TOA

- Comparison of the outputs of MODTRAN and 6S has been completed.



L8 Band Designation		6S Uncertainty (%)	MODTRAN Uncertainty (%)
1	Coastal	0.24	0.22
2	Blue	0.23	0.18
3	Green	0.30	0.27
4	Red	0.25	0.20
5	NIR	0.22	0.19
6	SWIR (5)	0.19	0.21
7	SWIR (7)	0.22	0.23
8	Pan	0.30	0.27
9	Cirrus	7.05	6.84

Current Uncertainty Analysis of RadCaTS

Results of analysis thus far…

- GVR BRF uncertainties almost complete – further work on diffuse irradiance required.
- Assumption of spatial uncertainty is being investigated and expected to support results of earlier U of Arizona work.
- Choosing a reference spectrum work will be used to generate an ensemble of spectra which will be processed through MODTRAN.
- Further analysis of MODTRAN will be undertaken including using uniform input PDFs.
- Final expected uncertainty is not yet clear but is likely to be < 10 %

U. Arizona
Future Work

- Automate processing and upload of surface BRF data for distribution by NASA
- Continued participation in RadCalNet
- Assist NPL with uncertainty analysis (to be finalized in 2016)
- Development of GVR Transfer Radiometer (GVR TR), to be used as a travelling calibration standard for RadCalNet work
- Continue to work on the calibration/validation of Earth-observing sensors such as
  - Landsat 7 ETM+ and Landsat 8 OLI
  - Terra and Aqua MODIS
  - SNPP VIIRS
  - RapidEye
  - Sentinel-2 MSI

Acknowledgements

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Thanks!

- Questions?