Recent Surface Reflectance Measurement Campaigns With Emphasis on Best Practices, SI Traceability and Uncertainty Estimation

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Maui, HI

Dennis Helder[1], Kurt Thome[2], Dave Aaron[1], Larry Leigh[1], Jeff Czapla-Myers[3], Nathan Leisso[3], Stuart Biggar[3], Nik Anderson[3]

[1]South Dakota State University, Brookings, SD
[2]NASA Goddard Space Flight Center, Greenbelt, MD
[3]University of Arizona, Tucson, AZ

South Dakota State University
Image Processing Lab

Outline

- Recent Field Campaigns
  - 2011 Arizona Round Robin Campaign
  - 2010 Tuz Golu Campaign
- Surface Reflectance Measurements
  - Arizona: the 48% Tracor tarp
  - Tuz Golu: the M1 strip
  - Uncertainties and SI Traceability
- Discussion & Conclusions

Problem Statement

- What are the uncertainties associated with various aspects of the measurement?
- How can reproducibility of measurements between groups be improved?
- What are the best practices for measuring surface reflectance?

Arizona Round Robin Campaign

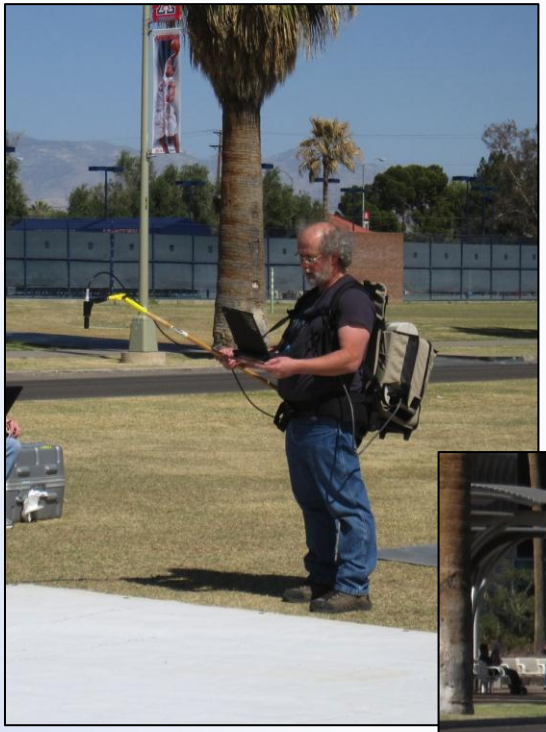
- Purpose
  - To develop consistent procedures for vicarious satellite calibration methodologies, particularly with respect to surface reflectance measurements
  - To improve our understanding of error sources and uncertainties
  - To re-calibrate field equipment, primarily Spectralon panels
  - To develop methodologies useful for cross-comparison of calibration groups
- Procedure
  - 1 day spent in the lab calibrating panels
  - 2 days spent in the field measuring surface reflectance
- 3 teams participated: University of Arizona, South Dakota State University, and Goddard Space Flight Center

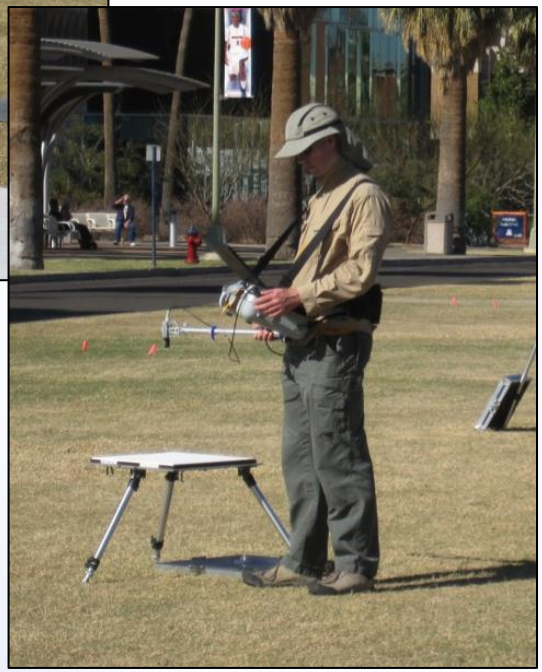
AZ Round Robin Participants

- 8-9 Mar 2011
- ASD Spectrometers:
  - SDSU: 2
  - UofA: 2
  - GSFC: 1
- Spectralon Panels:
  - SDSU: 1
  - UofA: 1
  - GSFC: 1

Surface Reflectance Measurement Procedures

- Instrumentation:
  - ASD Spectrometers
  - Spectralon Reflectance Panels
  - Natural and man-made targets
- Procedures:
  - Warm up ASD's for two hours
  - Begin at specified time (illumination geometry)
  - Begin measurements
    - Measure calibration panel
    - Measure next target
    - Repeat
  - All target measurements made 2-3 times
  - 45 minutes per data collect
- Site Location/Conditions
  - U of Arizona campus green
  - Sky condition: Severe Clear

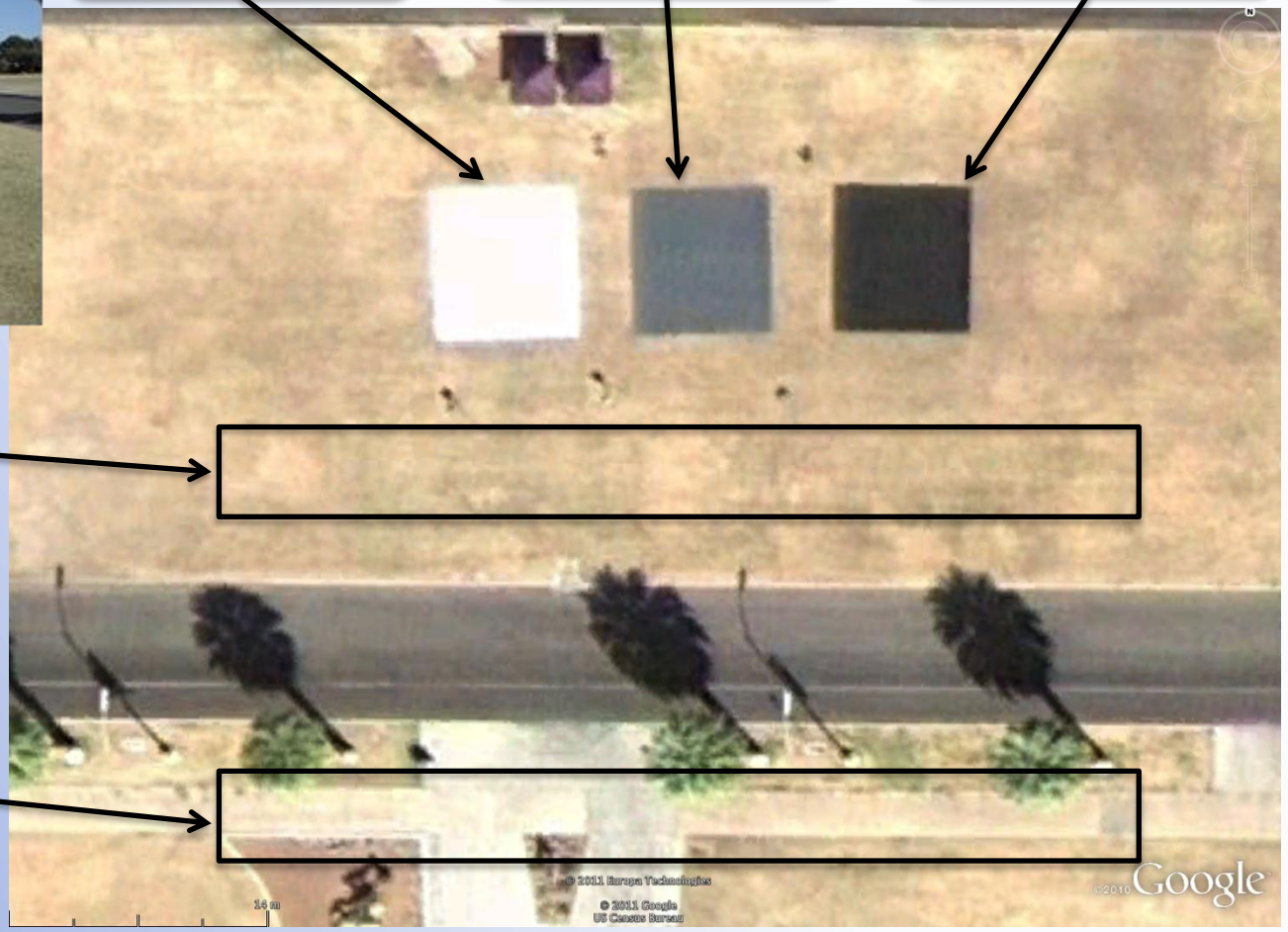




(Photos courtesy of Nathan Leisso, U. of AZ)

Reflectance targets

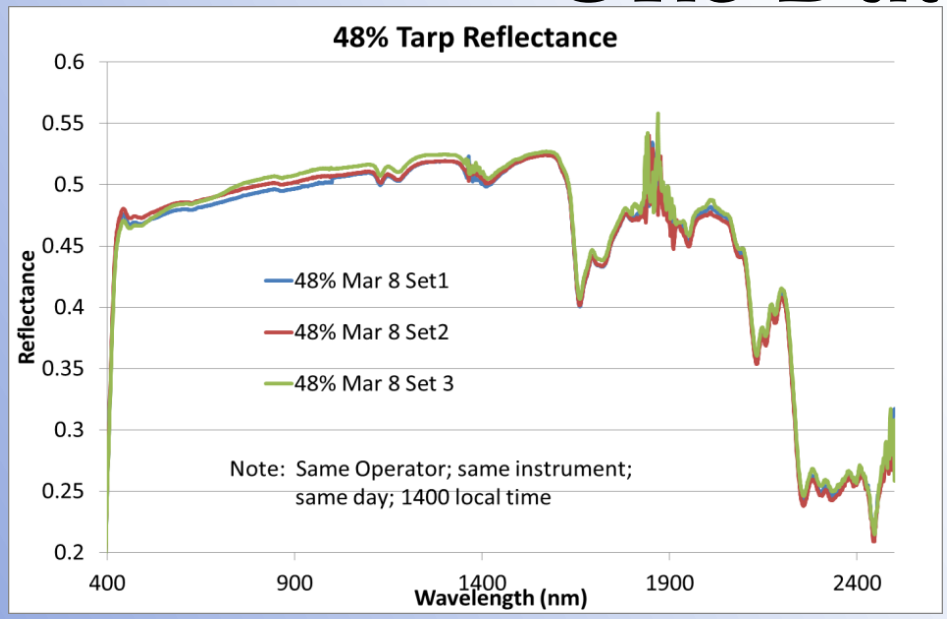
(slide courtesy Nathan Leisso, U. of AZ)

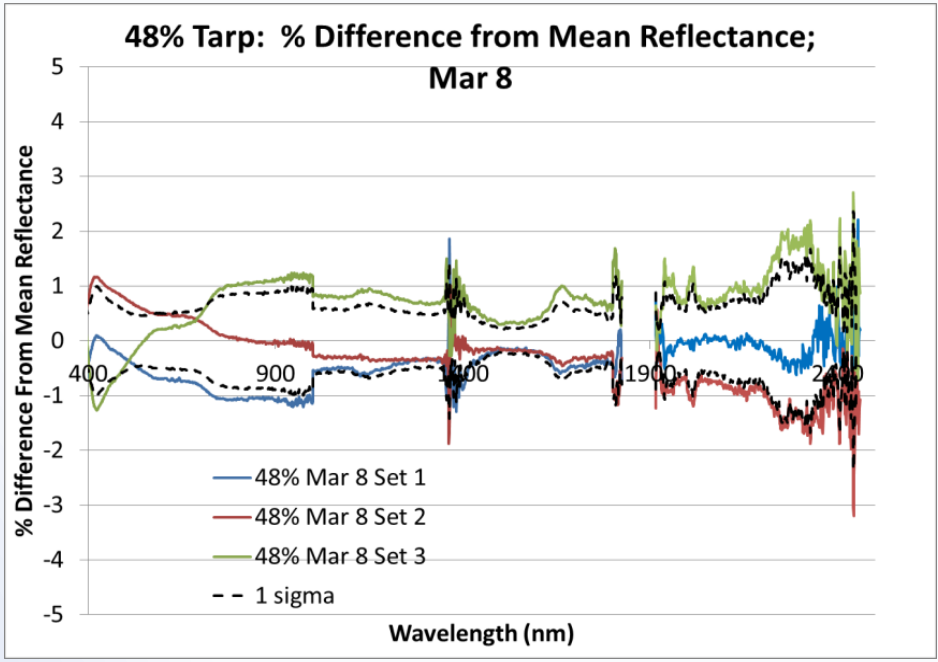


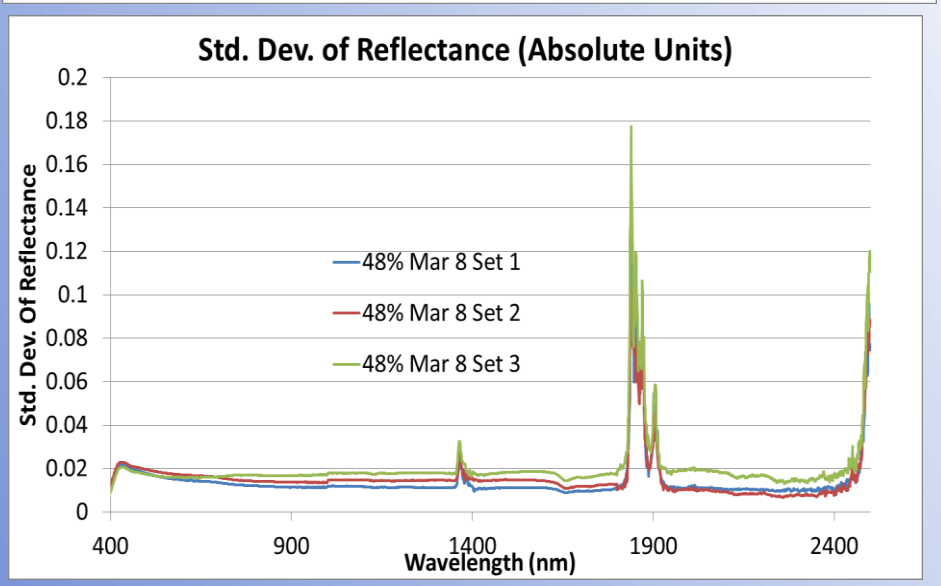
Questions to address:

- How repeatable is a surface reflectance measurement by one operator, one instrument, on one date?
- How reproducible is a surface reflectance measurement by one operator, one instrument, **multiple (2) dates**, one illumination geometry?
- How reproducible is a surface reflectance measurement by **2 operators, 2 instruments**, one date?
- How reproducible is a surface reflectance measurement by **2 operators**, **one instrument, multiple (2) dates**, one illumination geometry?
- How reproducible is a surface reflectance measurement by **3 operators**, two instruments, multiple (2) dates, one illumination geometry?

One Operator, One Instrument, One Date (Mar 8)

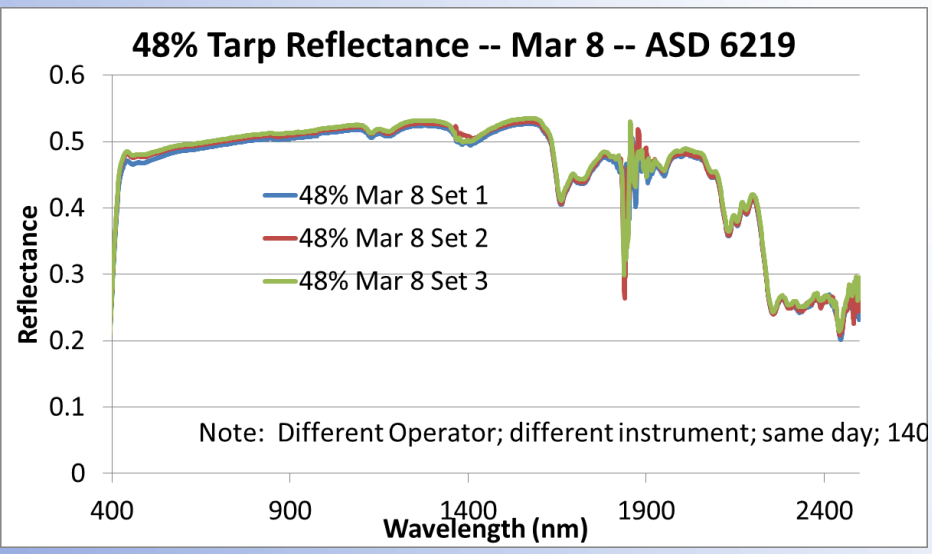


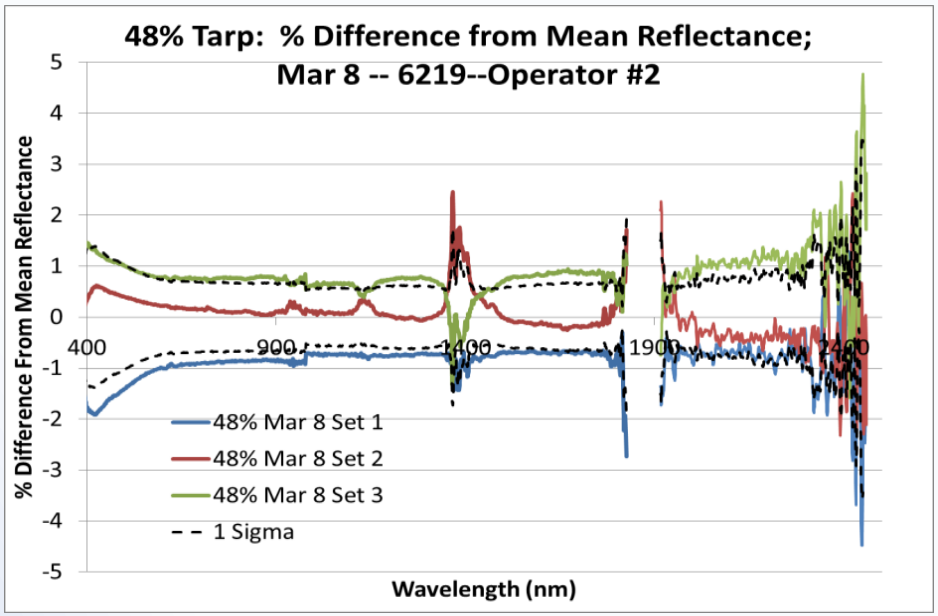


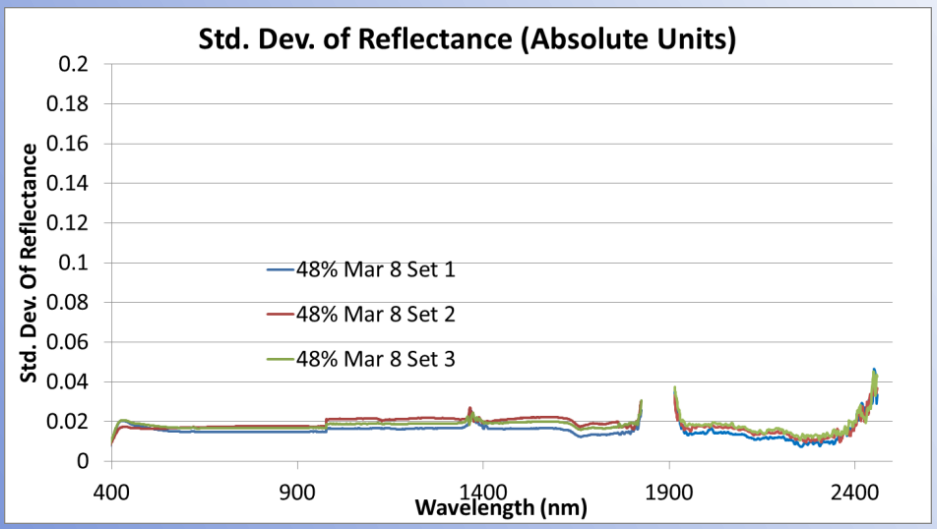


- Note the high reflectance of the tarp.
- Each measurement comprised of approximately 30 spectra. $1\sigma \leq 0.2$ ($\approx$ 4% inVNIR)
- Type A standard uncertainty is <1%
- Most highly trained operator using our 'best' ASD.

One Operator (#2), One Instrument, One Date (Mar 9)

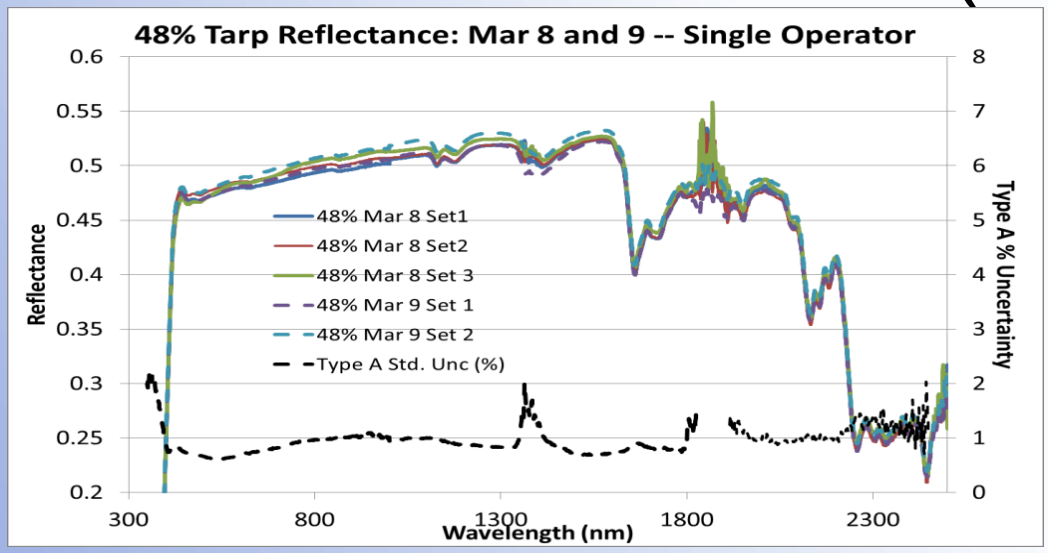


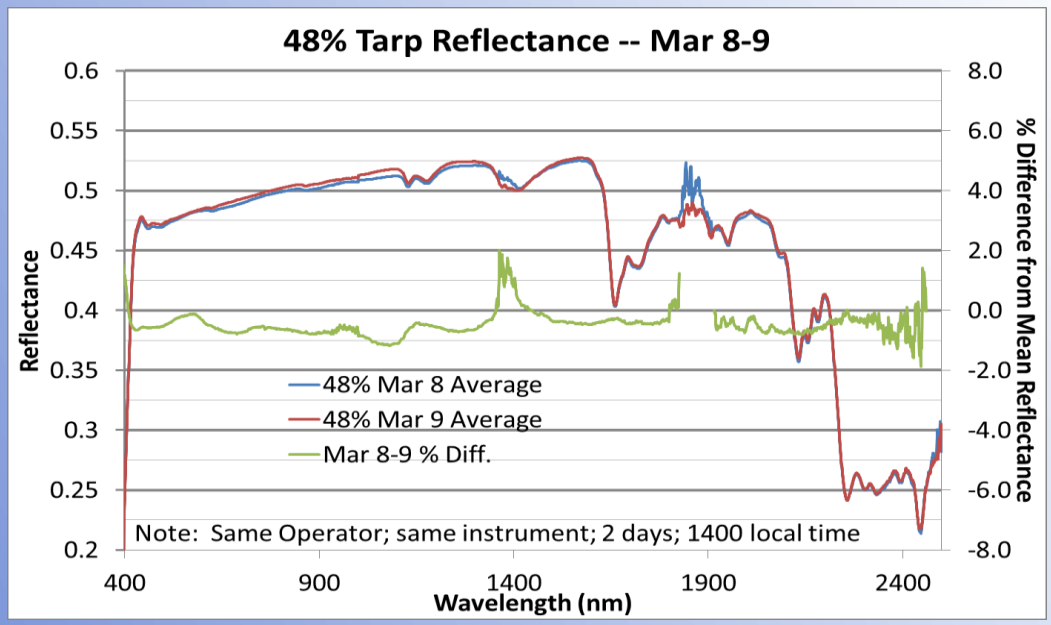




- Similar to previous, except Operator #2, ASD 6219
- Note similar standard deviations of measurement, solid at 0.02 absolute units.
- Note Type A Standard Uncertainty at 1%, (except at ends of spectrum approaching 1.5%).

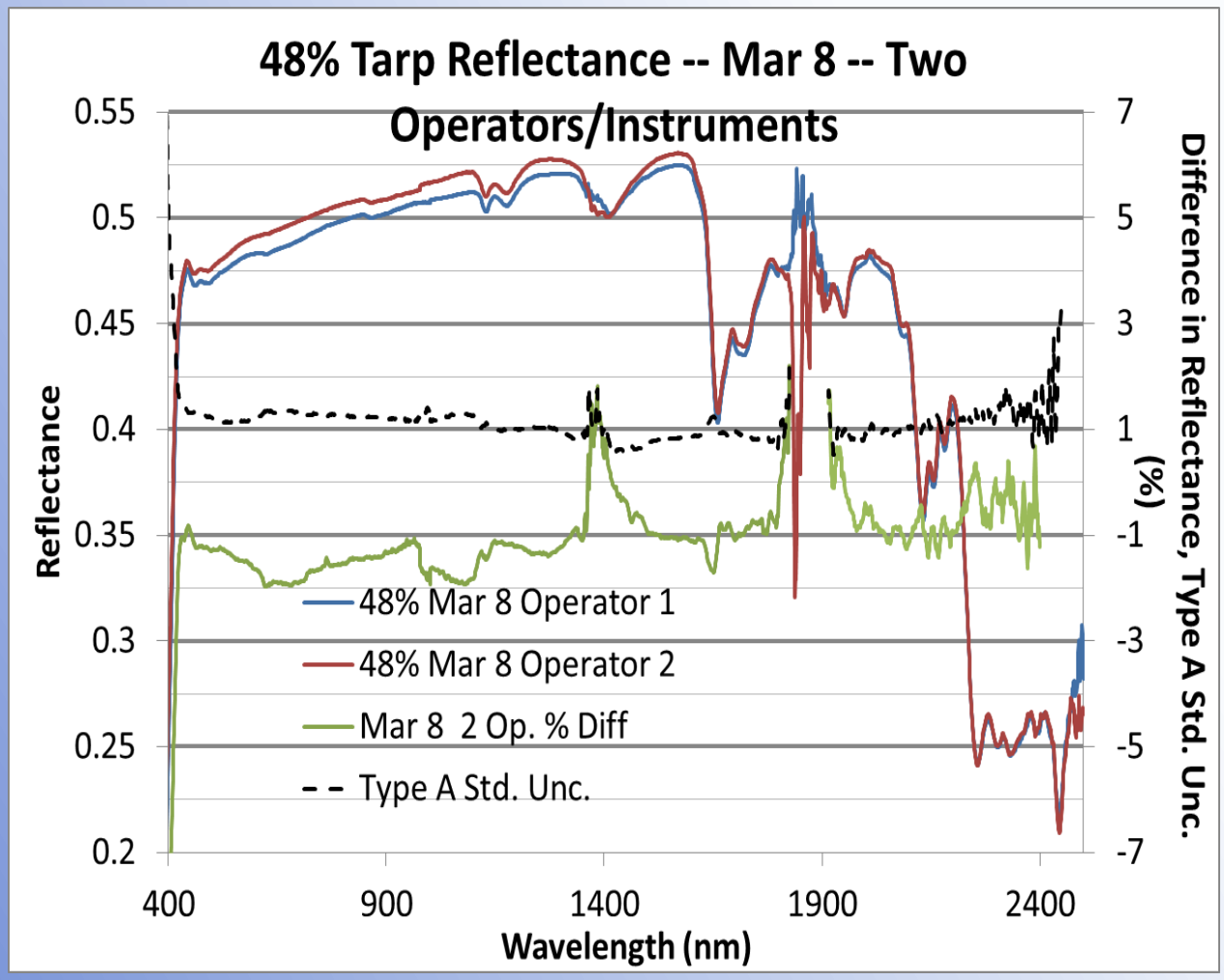
One Operator, One Instrument, Two Dates (Mar 8-9)





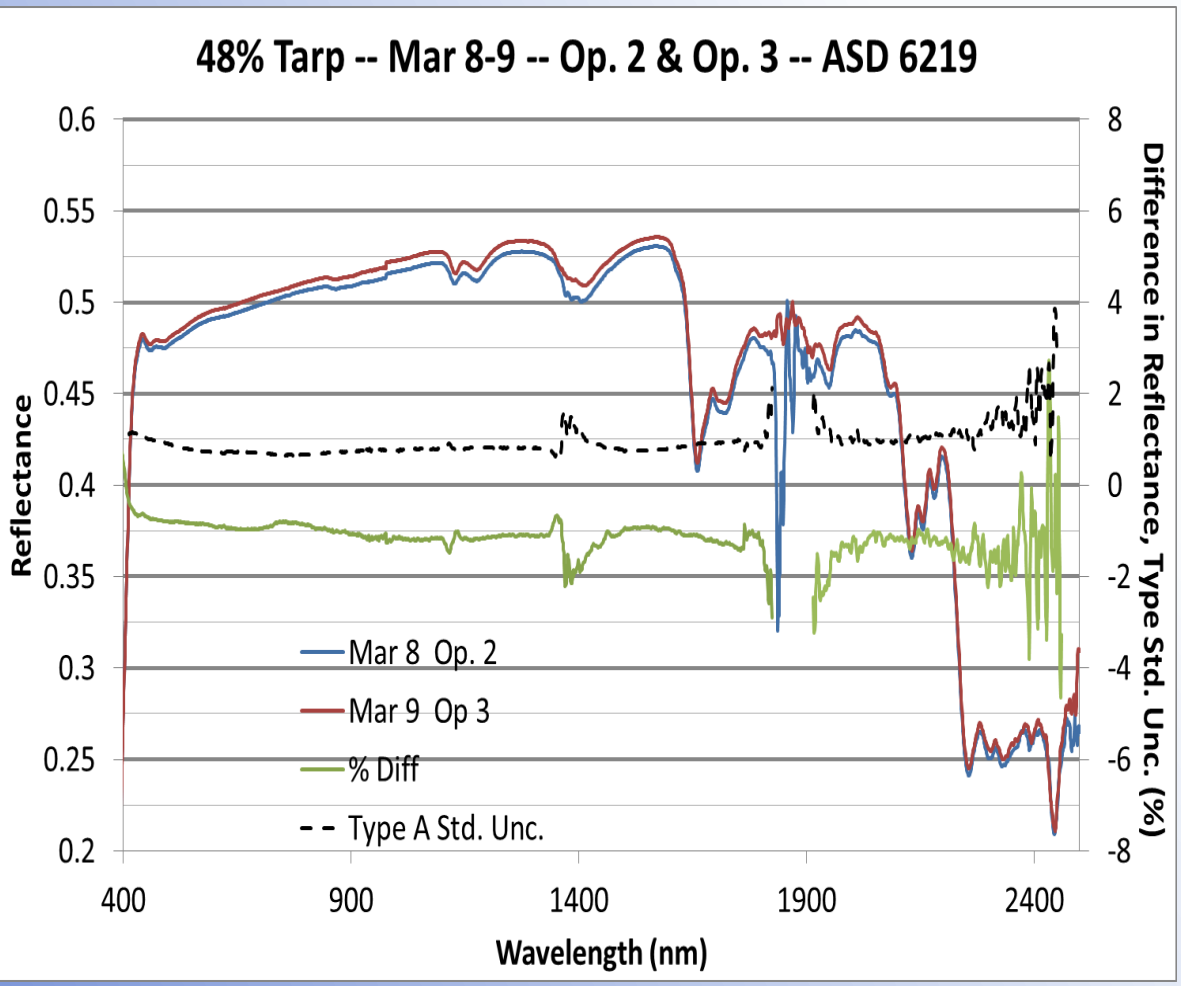
- Top chart indicates all 5 tarp reflectance measurements made during the two day period.
- Standard deviations of measurements on the second day were similar to the first day.
- Type A Standard Uncertainty at 1% except for shortest wavelengths
- Bottom chart shows average reflectance measurements (red/blue curves) obtained on the two days.
- Reproducibility is indicated by the green curve with better than1% agreement at all but the shortest wavelengths.
  - Observed even at longer wavelengths where tarp reflectance is much lower.

Two Operators, Two Instruments, One Date (Mar 8)



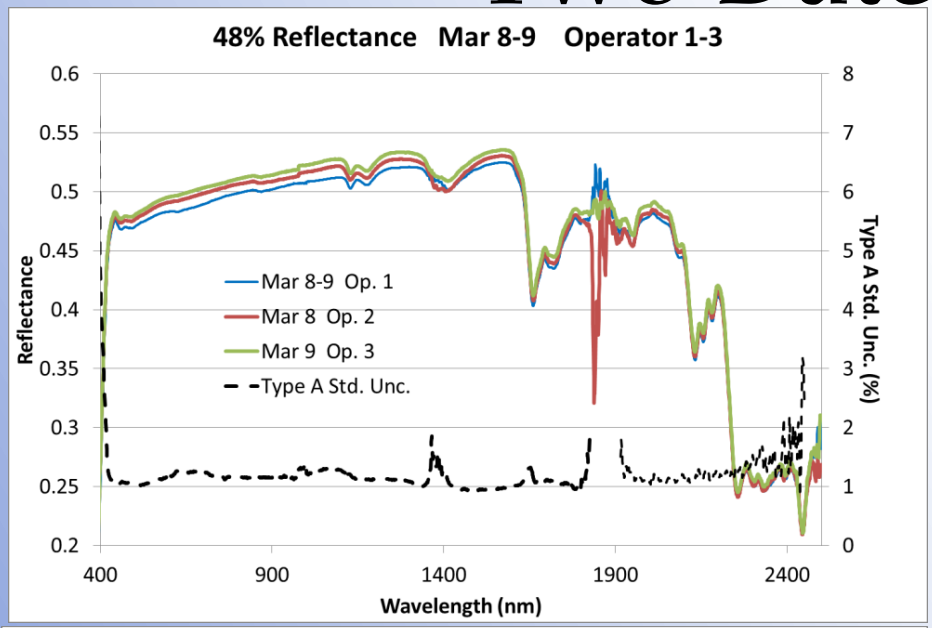
- Two operators, using two ASDs simultaneously 1400 local time.
  - Both experienced operators
  - Operator 1 carried 'pristine' ASD; Operator 2 carried 'backup' ASD.
- Strong agreement between operators, especially in the SWIR.
- Type A Std. Unc. = 1%
- Reproducibility with this scenario increases to 2% as indicated by green curve.

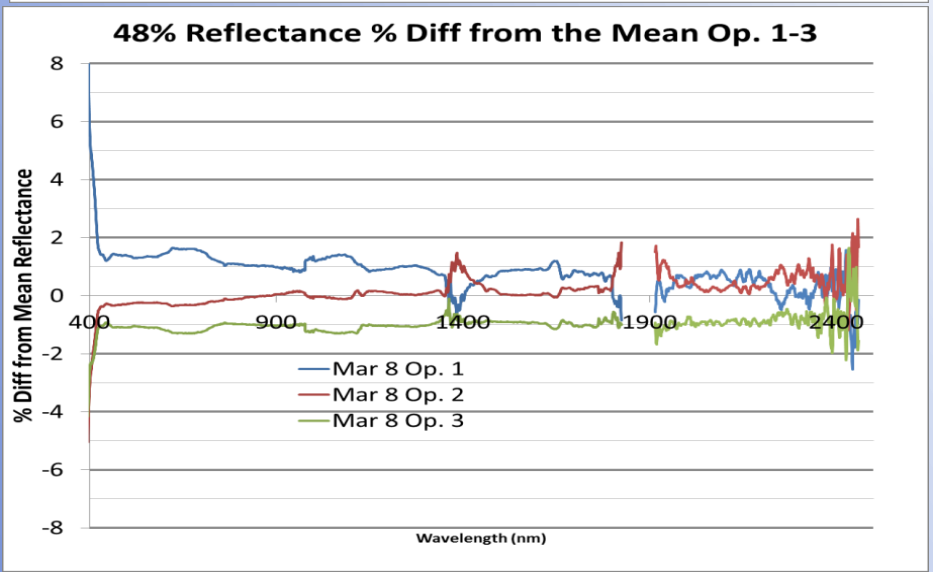
Two Operators, One Instrument, Two Dates (Mar 8-9)



- Two operators used the same instrument (ASD 6219, 'backup') on consecutive dates
  - Operator #2 – experienced
  - Operator #3 – inexperienced, but uncertainties very similar to Operators #1 and 2
- Consistent difference between measurements throughout most of spectrum
- Type A Std. Unc. = 1% at most wavelengths.
- Reproducibility best at shorter wavelengths (approaching 1%) and worse at longer wavelengths (approaching 2%)

Three Operators, Two Instruments, Two Dates (Mar 8-9)



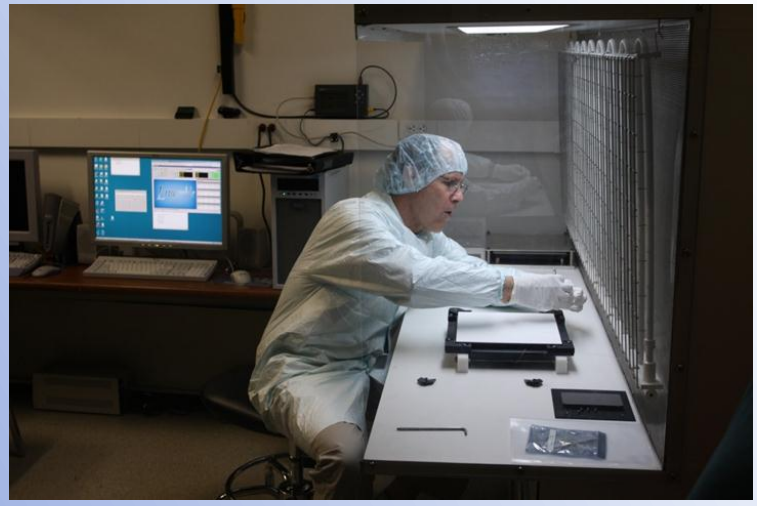


- Overall combination of all operators, instruments, and dates.
  - Consistent reflectance measurements made by all three operators.
- Type A Std. Unc. < 1.5% and approaching 1% at some wavelengths.
- Reproducibility of measurements clearly under 2% and approaching 1% at longer wavelengths.

AZ Round Robin Reproducibility Summary

Situation	Reproducibility	Comments
One operator, one instrument, one day	Approaching 1%	Slightly worse at shorter wavelengths.
One operator, multiple dates	1%	
Two operators, one instrument, two dates	1-1.5%	Better at shorter, worse at longer wavelengths.
Two operators, two instruments, single date	2%	Slightly worse at shorter wavelengths.
Two operators, two instruments, multiple dates	2%	Slightly worse at shorter wavelengths.
Three Operators, two instruments, two dates	1-2%	Worse at shorter, better at longer wavelengths.

Arizona Round Robin Calibration Panel Uncertainties



- Panel calibration performed in U of Arizona's cal lab.
  - Data courtesy of Stu Biggar
- Uncertainty is spectrally dependent
  - Lamp current uncertainties
  - Instrumentation uncertainties
- Uncertainties range from 1.0 to 1.7%
- A combination of both Type A and Type B uncertainties.

Spectralon Panel Calibration: % Uncertainty								
Wavelength	445	485	560	657	863	1372	1611	2206
Lamp effects								
Stray light	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Lamp current uncertainty	0.07	0.06	0.05	0.04	0.03	0.02	0.02	0.01
Lamp current stability	0.09	0.08	0.06	0.05	0.04	0.02	0.02	0.01
Lamp current uncertainty	0.07	0.06	0.05	0.04	0.03	0.02	0.02	0.01
Lamp current stability	0.09	0.08	0.06	0.05	0.04	0.02	0.02	0.01
Alignment	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Lamp ageing and drift	0.5	0.4	0.3	0.2	0.15	0.1	0.1	0.1
Reference effects								
RF spectral change	0.1	0.1	0.1	0.1	0.1	0.1	0.1	1.0
NIST uncertainty in RF	0.33	0.33	0.33	0.33	0.33	0.31	0.31	0.33
Instrumentation								
Spectral uncertainty	0.5	0.4	0.2	0.16	0.13	0.1	0.1	0.1
HP34970A/Lock-in uncertainty	0.03	0.03	0.03	0.03	0.03	1.0	1.0	1.0
Detector/amplifier SNR	0.5	0.45	0.4	0.3	0.3	0.1	0.1	0.1
Detector/amplifier SNR	0.5	0.45	0.4	0.3	0.3	0.1	0.1	0.1
Stability	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Repeatability	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Transmittance	0.1	0.1	0.1	0.1	0.1	1.0	0.1	0.1
Total	**1.4**	**1.3**	**1.1**	**1.0**	**1.0**	**1.7**	**1.4**	**1.7**

Arizona Round Robin Total Uncertainties

Wavelength (nm)		445	485	560	657	863	1372	1611	2206
Total Panel Uncertainty	(%)	1.4	1.3	1.1	1	1	1.7	1.4	1.7
Field Campaign Uncertainty									
Single operator/instrument /day	1	1.7	1.6	1.5	1.4	1.4	2.0	1.7	2.0
Single operator/ instrument/two dates	1	1.7	1.6	1.5	1.4	1.4	2.0	1.7	2.0
Two operators/ single instrument/two dates	1.5	2.1	2.0	1.9	1.8	1.8	2.3	2.1	2.3
Two operators/two instruments/one date	2	2.4	2.4	2.3	2.2	2.2	2.6	2.4	2.6
Two operators/two instruments/two dates	2	2.4	2.4	2.3	2.2	2.2	2.6	2.4	2.6
Three operators/two instruments/two dates	2	2.4	2.4	2.3	2.2	2.2	2.6	2.4	2.6

- Total uncertainties (in %) indicated as a function of wavelength and type of field campaign.
- Single operator approach can be as low as ~1.5% total uncertainty.
- Multiple operator approach adds another percent, up to ~2.5%.
- A combination of Type A and Type B uncertainties.

Comparison to the 2010 Tuz Golu Field Campaign

--following 6 slides courtesy of Larry Leigh

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Tuz Gölü Campaign Overview

- CEOS field campaign which took place Aug 13 – 23, 2010
- Consisted of 13 different teams from across the planet.
- Primary goals,
  - Evaluate differences in field instrument primary calibrations
  - Evaluate differences in methods for characterizing and assigning “radiometric value” to a site, for multiple view angles
  - Establish formal traceability of Tuz Gölü reference site based on an evaluation of all comparison results.
  - Establish “best practice” guidance for above and/or knowledge of variance between methodologies.
  - Provide a multi-satellite sensor comparison linked to the ground calibration derived from the multi-team comparison.
  - Identify the minimum and ideal specifications for characterization/instrumentation for a CEOS “reference standard”

Tuz Gölü Campaign Overview

- Located in central Turkey.
  - 1 hour north of Aksaray, about 2 hours south of Ankara.
  - Salt flat at an elevation of about 3000 ft.
  - Covering an area of 14 miles wide x 22 miles long
  - Covered with water for most of the year.
  - Bright in the short wavelengths.

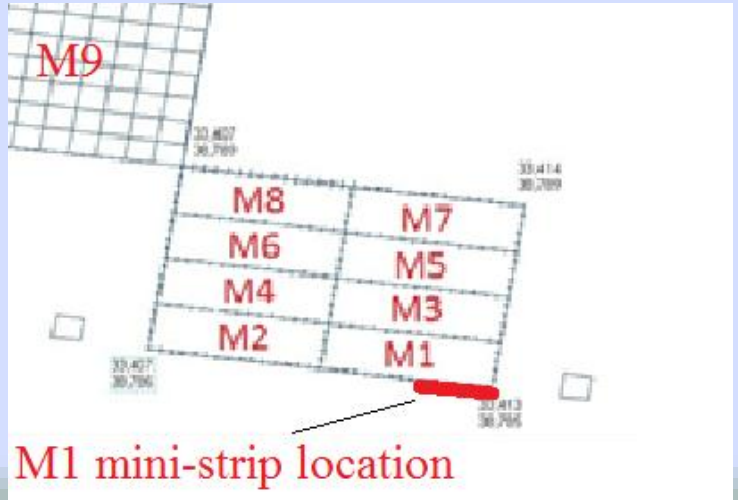
Tuz Gölü Spectral Reflectance Study

- Primary Goal was to develop a comprehensive understanding of:
  - best practices for surface measurements
  - uncertainties associated surface measurements
  - The absolute ground level spectral reflectance of the site
  - The variability in reflectance both spatially and temporally
- The site measurement phase of the study commenced with identifying, marking, and subsequently measuring a series of sub-sites on the Tuz Golu salt flat. These sub-sites were identified as:
  - *M1 mini-strip* - for temporal analysis
  - *M1 test site* - for small scale variability
  - *M1-M9 test sites* - for larger scale variability
- A more detailed description of the sub-sites and studies follows.

Tuz Gölü Spectral Reflectance Study:

Short Term Stability Study: *M1 min-strip*

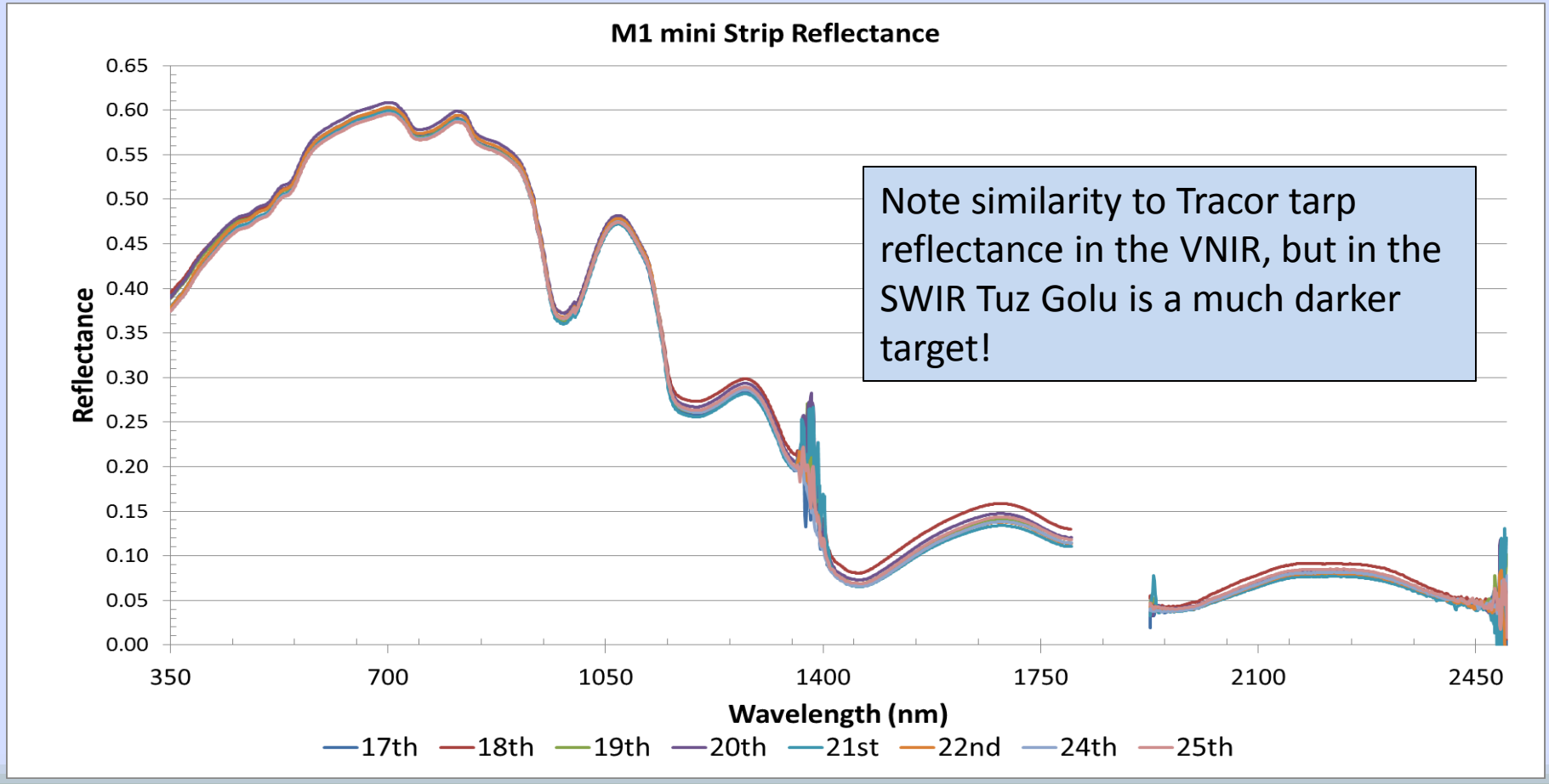
- To characterize short term temporal site stability and measurement uncertainty the small "*M1 mini-strip*" was used.
  - To reduce illumination angle differences and BRDF effects, acquisition of the *M1 mini-strip* data was restricted to 10:45-10:50am
  - The collection of data was confined to a precise 30 meter by 5 meter location.
    - 30 spectra "in motion" were taken down the center of the strip
    - This site was knowingly selected to be "pristine"
      - Maximal uniformity
      - Minimal degradation from traffic
      - Minimal "blemishes"



Tuz Gölü Spectral Reflectance Study:

Short Term Stability Study : *M1 mini-strip*

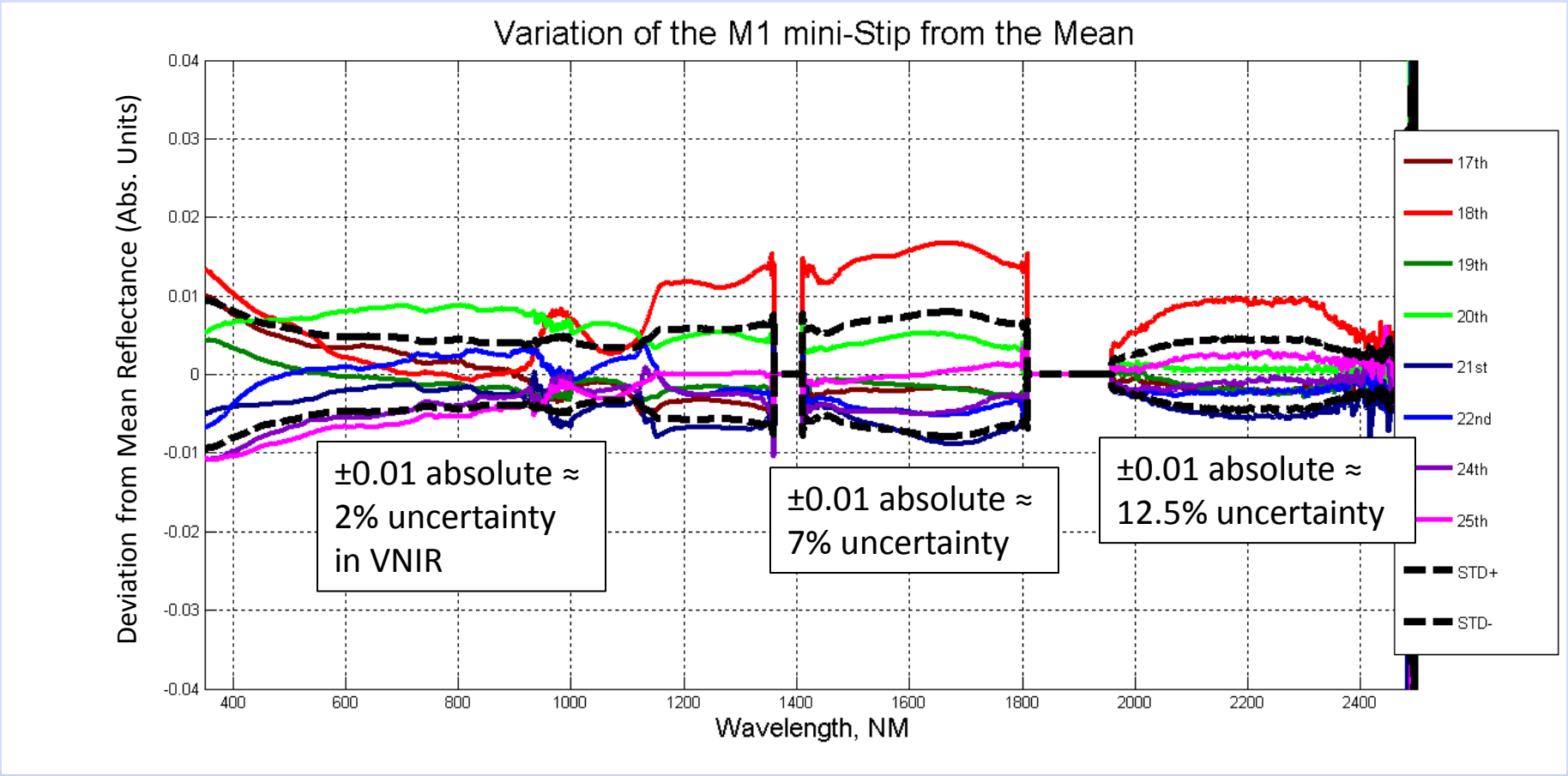
- Reflectance from 9 days of collection over *M1 mini-strip* show very good repeatability
  - For short wavelengths reflectance varies from 0.40 – 0.60.
  - For longer wavelengths reflectance drops off to 0.05 – 0.15



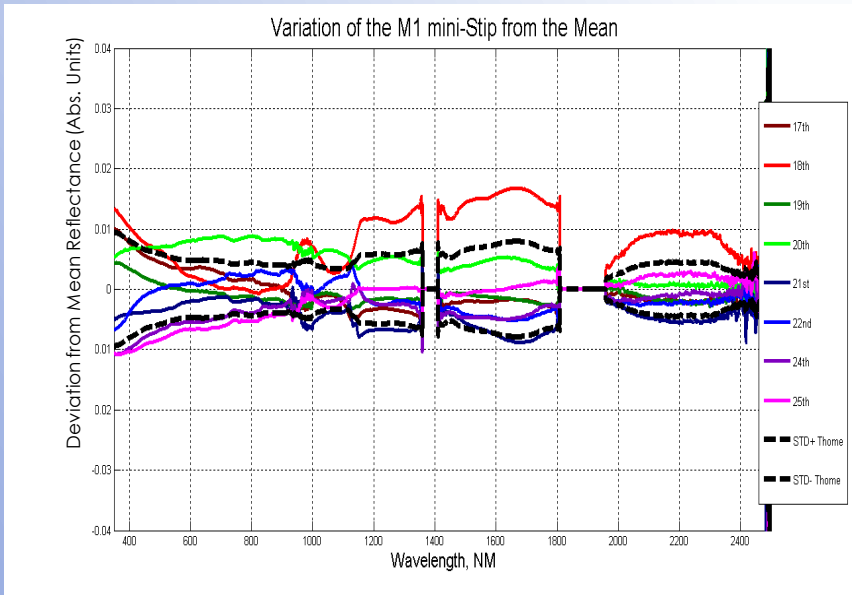
Tuz Gölü Spectral Reflectance Study:

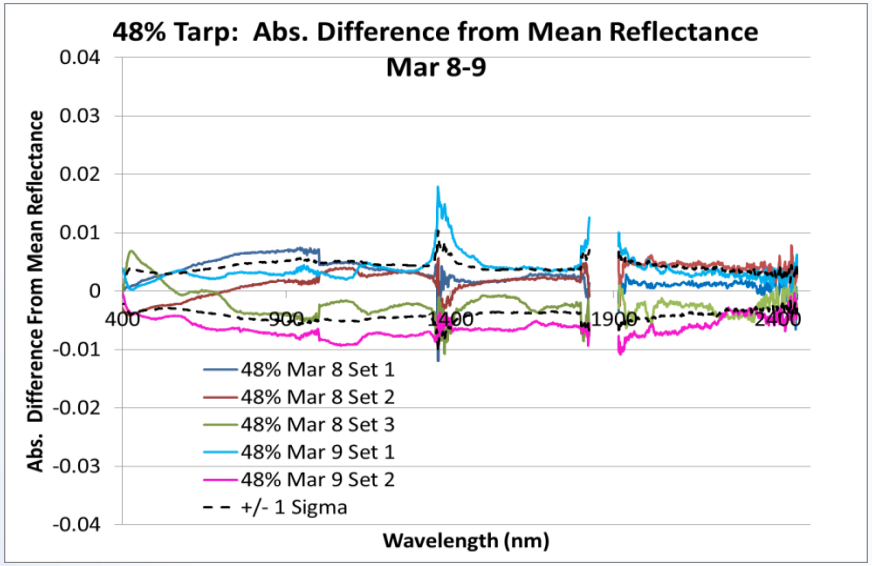
Short Term Stability Study : *M1 mini-strip*

- Reflectance variability for 'limited location, limited time' study is on the order of 0.01 reflectance units.
  - 8 days of consecutive data is shown
  - Black lines represent absolute standard deviation
    - +/- 0.01 in reflectance



Comparison of Repeatability between AZ and Tuz Golu Field Campaigns





- Tuz Golu results on the left are very similar to the AZ results on the right
  - Tuz Golu M1 Strip measured over 8 days
  - AZ Tracor Tarp measured over 2 days
  - Same operator, same instrument (ASD 16004)
- In terms of absolute units, repeatability of the measurements are similar, with perhaps some advantage with the Tracor tarps.
- Reproducibility is 0.01 or less with $\sigma = 0.005$ or better.

Discussion

- AZ Round Robin
  - Conducted under very good sky conditions
  - Demonstrates the capability of experienced operators
  - Advantages with bright, spectrally flat target
  - Exact sources of uncertainties remain
    - ASD stability
    - Operator stability/repeatability
    - Degradations of target during campaign (debris)
    - Small atmospheric changes?
- Tuz Golu Campaign
  - Conducted under more variable sky conditions
  - Advantages of very large, uniform target
    - However, target was dark in the SWIR
  - Same operator/instrument within 6 months makes an excellent comparison
  - Sources of uncertainty likely very similar to AZ campaign

Conclusions

- Type A uncertainties consistently around 1%, worst case (3 operators) still under 1.5%
- Field reproducibility can be as good as 1%
  - Single operator/instrument: 1%
  - Multiple operators/instruments: 2%
  - Normally under 0.01 reflectance units (abs.) at all wavelengths independent of target reflectance
- Calibration panel uncertainty (Type B?): 1-1.7% (wavelength dependent).
- Total uncertainty can approach 1.5% for certain wavelengths and be as large as 2.5% for other wavelengths.
- These results demonstrated by experienced teams with good field conditions.
- Results using Tracor tarps suggests a means for comparing teams worldwide
  - Rather than bringing teams to a common site, a common target can be shipped to the teams.
  - Each team can measure tarp reflectance using their instrumentation and calibration standard.
  - Care must be taken during shipment of deployment of tarps to maintain spectral reflectance properties.
  - Virtual Round Robin campaigns could be conducted on regular (annual or bi-annual) basis to develop short and long term comparisons