Measurements of downwelling irradiance using a diffuse reflectance standard and calibrated radiometer for validation of modeled bias errors

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Outline

- Ocean Color remote-sensing reflectance
- In-air, hand-held protocol
- Status of existing field (on ships) validation
- Sensitivity modeling for downwelling irradiance
- Roof top experiment
- Preliminary results

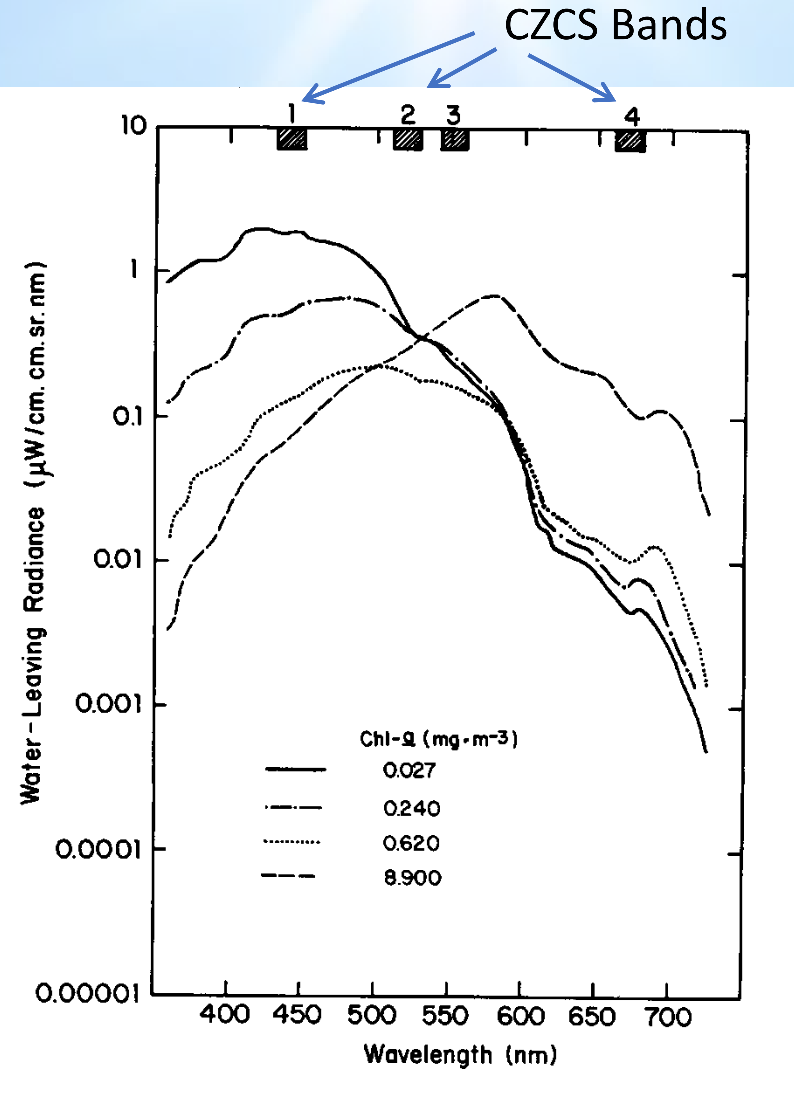


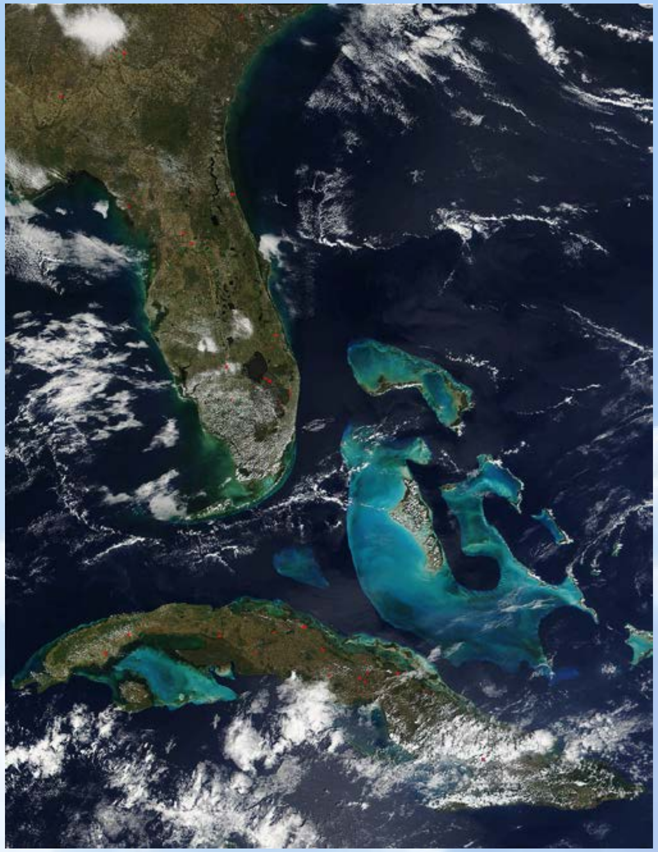
Figure from Gordon *et al*., 1985, in "Satellite Oceanic Remote Sensing," by way of K. Voss, UM

The water-leaving radiance, $L_w(\lambda)$, or the remote sensing reflectance, $R_{RS}(\lambda)$, are related to the optical properties of the water:

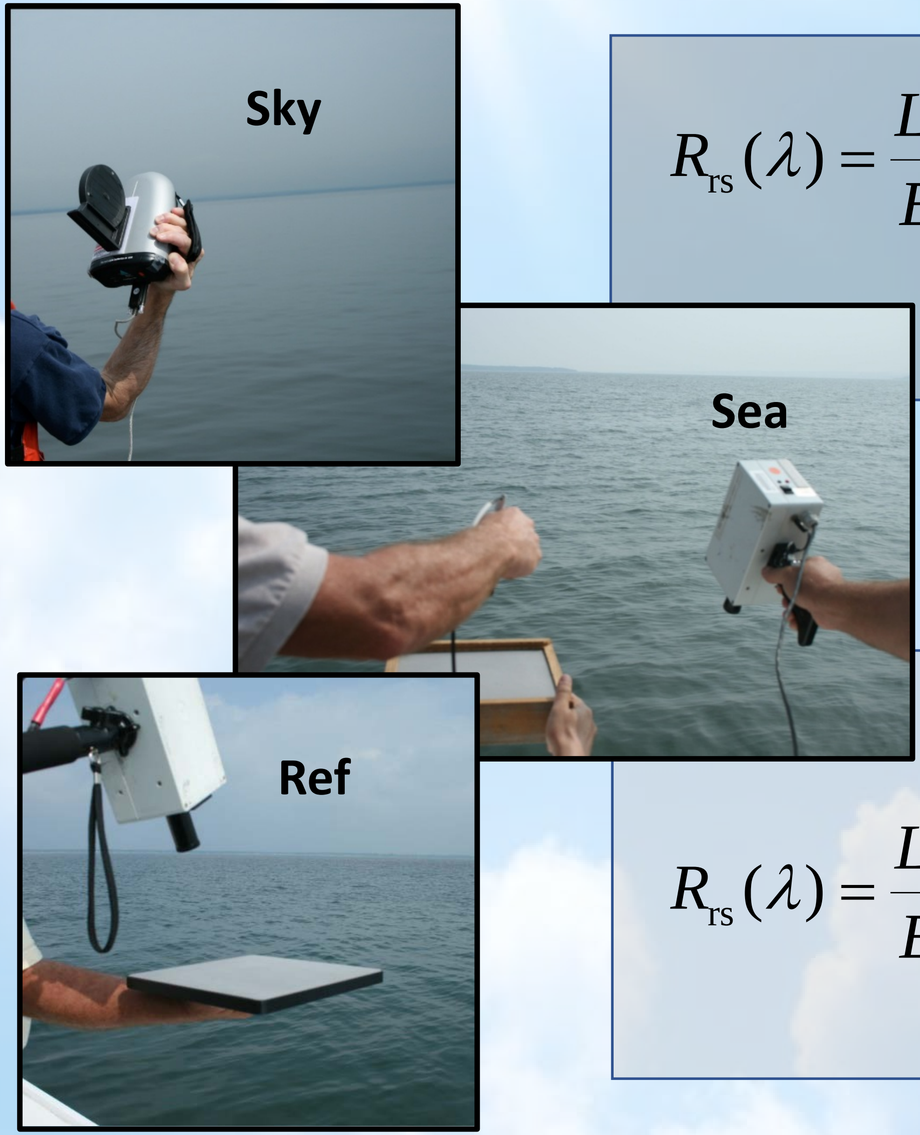
$$R_{rs}(\lambda) = \frac{L_w(\lambda)}{E_s(\lambda)} = fn\left(\frac{b_b(\lambda,z)}{a(\lambda,z)+b_b(\lambda,z)}\right)$$

$a(\lambda)$ = absorption coefficient;
$b_b(\lambda)$ = backscatter coefficient.

This is the theoretical basis of bio-optical algorithms that relate $L_w(\lambda)$ or $R_{rs}(\lambda)$ to chlorophyll concentrations.



MODIS true color image



$$R_{rs}(\lambda) = \frac{L_w(\lambda)}{E_s(\lambda)} = \frac{\left(L_{sea}(\lambda) - \rho(\lambda) L_{sky}(\lambda)\right)}{E_s(\lambda)}$$

Calibrated Radiometers

Approaches in the Literature

Un-Calibrated Radiometers

$$R_{rs}(\lambda) = \frac{L_w(\lambda)}{E_s(\lambda)} = \frac{\left(S_{sea}(\lambda) - \rho(\lambda) S_{sky}(\lambda)\right)}{\frac{\pi}{R_{ref}} S_{ref}(\lambda)}$$

What is this factor and what is R_{ref}?

It is actually an apparent optical property (depends on the sky radiance distribution)

Need *K* factor.

$$R_{rs}(\lambda) = \frac{L_w(\lambda)}{E_s(\lambda)} = \frac{\left(L_{sea}(\lambda) - \rho(\lambda) L_{sky}(\lambda)\right)}{K L_{ref}} = \frac{\left(S_{sea}(\lambda) - \rho(\lambda) S_{sky}(\lambda)\right)}{K S_{ref}}$$

If you knew the sky radiance at the surface and the reference target BRDF, you can determine the *K* factor. But if we knew the sky radiance we wouldn't have to measure the reference at all!

So, we must approximate *K*.

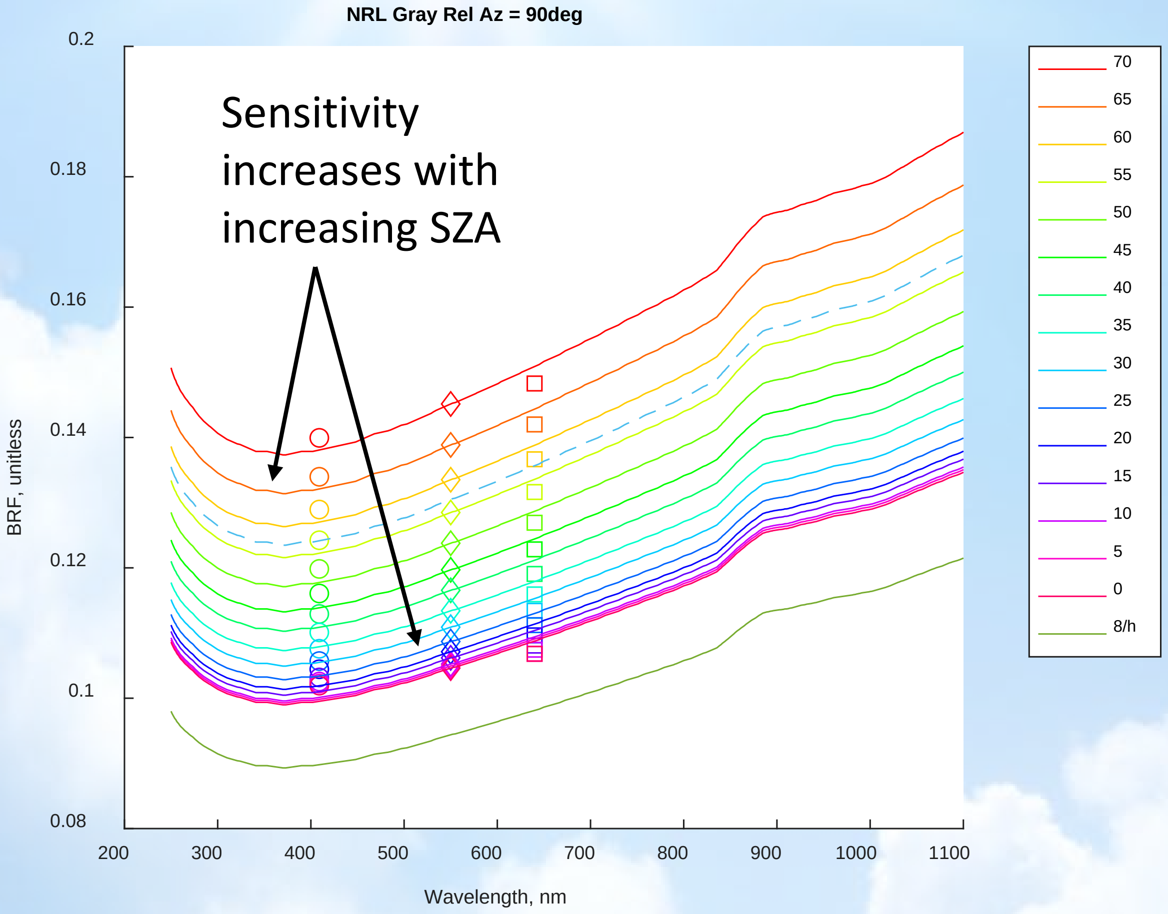
1, the plaque is a perfect in every way except it is allowed to absorb radiation, aka "Lambertian" case. We are insensitive to sky radiance distribution and can we use any measure of plaque reflectance factor (directional / hemispherical, bi-directional…)

$$E_s(\lambda) = \frac{\pi L_{ref}(\theta_v, \phi_v, \lambda)}{R_{ref}}$$

2, there is no diffuse irradiance component, only the direct sunlight, aka "Black Sky" case, then we need the BRDF at the measurement geometry

$$E_s(\lambda) = \frac{L_{ref}(\theta_v, \phi_v, \lambda)}{f_{ref}(\theta_\odot, \phi_\odot, \theta_v, \phi_v, \lambda)}$$

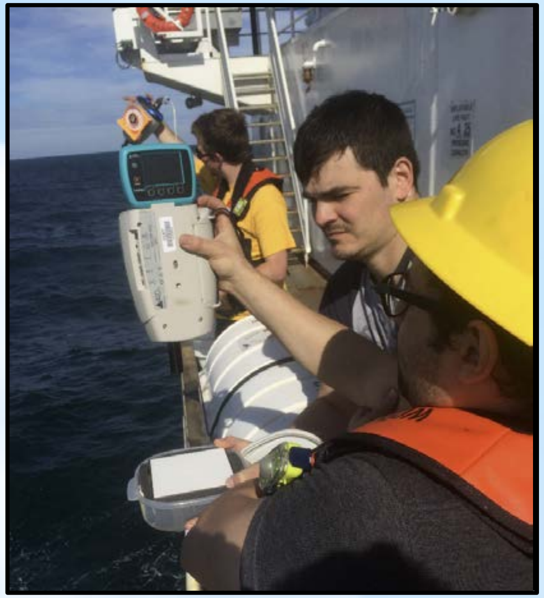
$R_{ref}(\lambda)$ = reflectance factor, $f_{ref}(\lambda)$ = BRDF, $\odot$ refers to solar angle of incidence



BRF of 10% gray Teflon-based target at 45° view angle

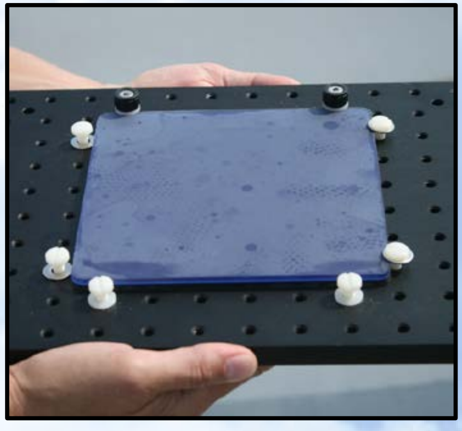
Reference measurement, back deck *Nancy Foster*

How can we validate the $E_s(\lambda)$ or $S_{ref}(\lambda)$ portion of the protocol?
How about measuring a second reference target – A) or B) or both?

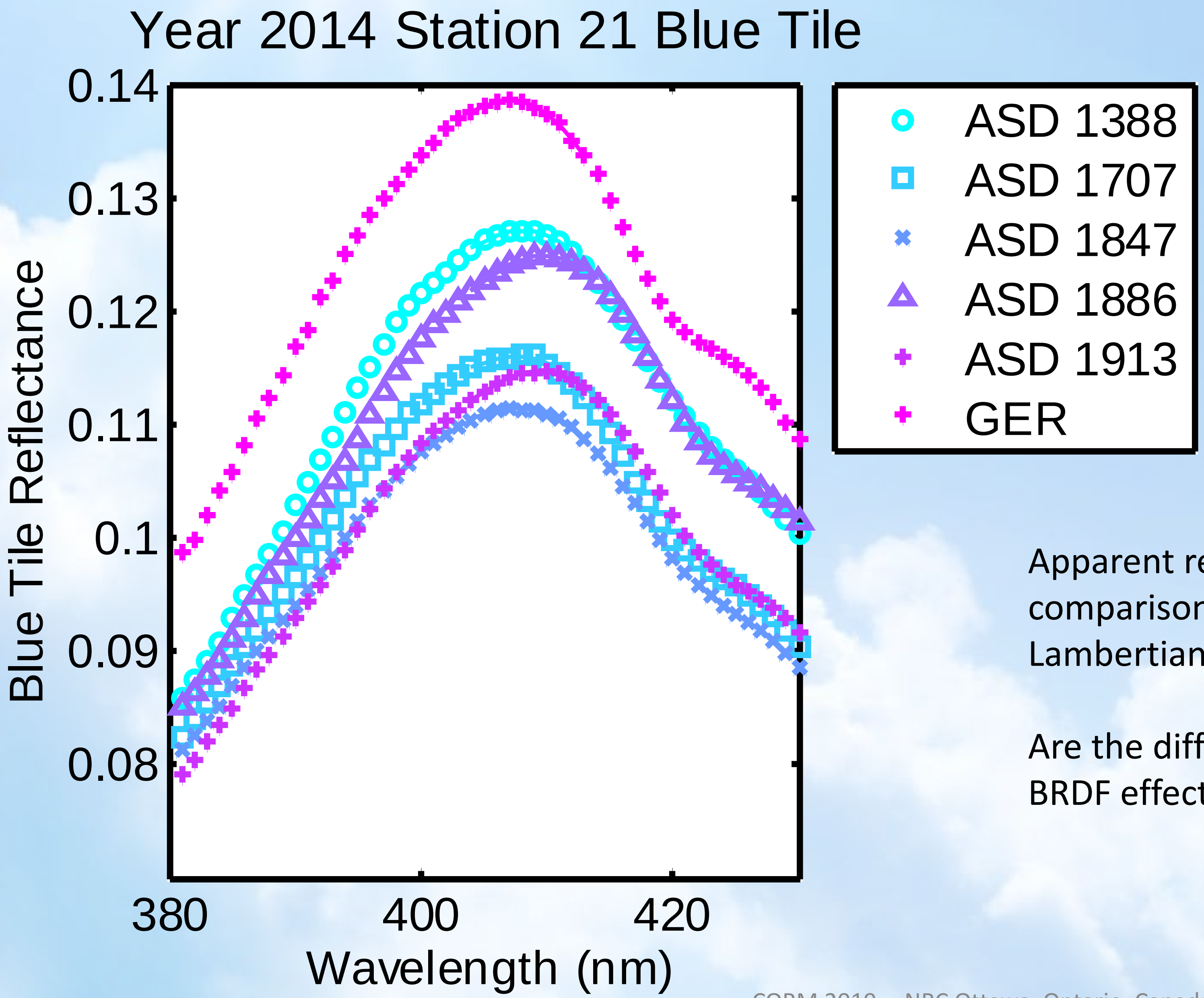


Field Measurements

A) Additional white or gray Teflon-based target



B) Additional faux-water target, sand-blasted blue glass



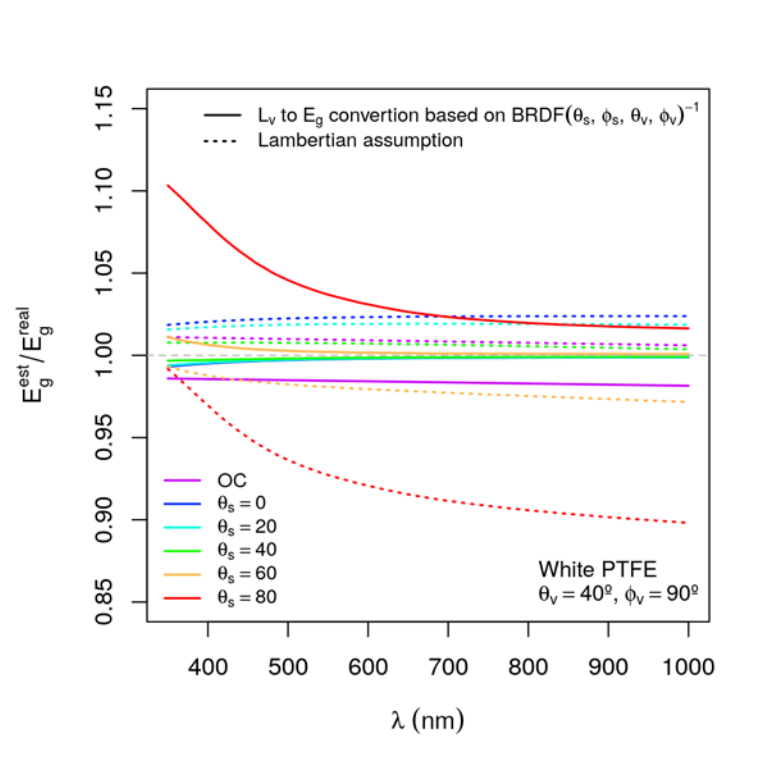
Apparent reflectance of the blue tile derived by comparison to the reference target and assuming Lambertian behavior.

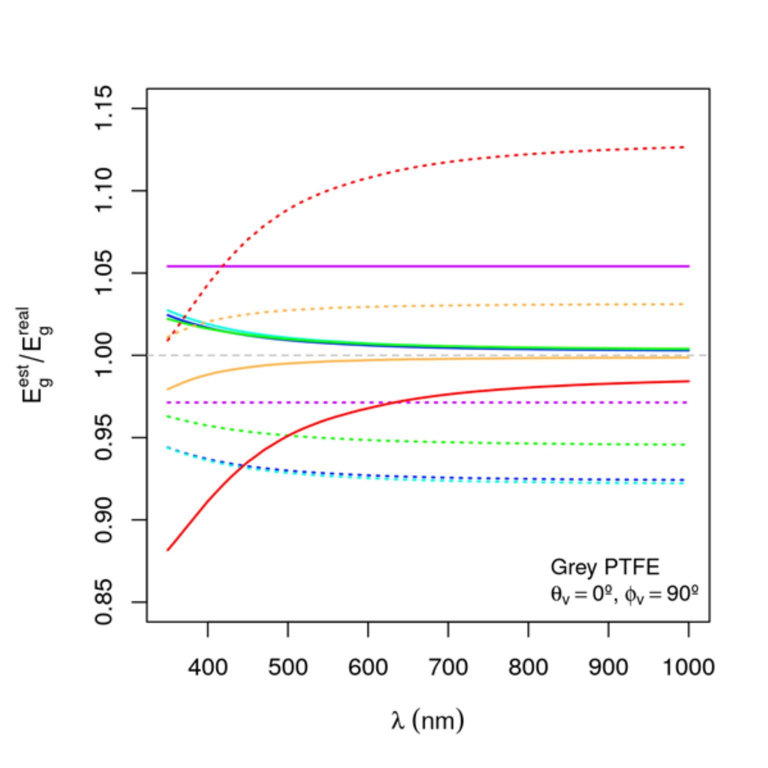
Are the differences due to changes in illumination and BRDF effects, or other sources of bias?

Castagna's uncertainty results are from modeling under these conditions:

- Spectral averaged results for the visible;
- Ideal Conditions: Clear sky, SZA between 20°and 60°, a relative azimuth of 90° from sun plane
- Results reported for both Lambertian and Black Sky
- Examined biases from three sources:
  - BRDF effects for 99% and 10% Spectralon
  - sky blocking from a person holding the radiometer
  - tilt angles 3° to 12°

BRDF



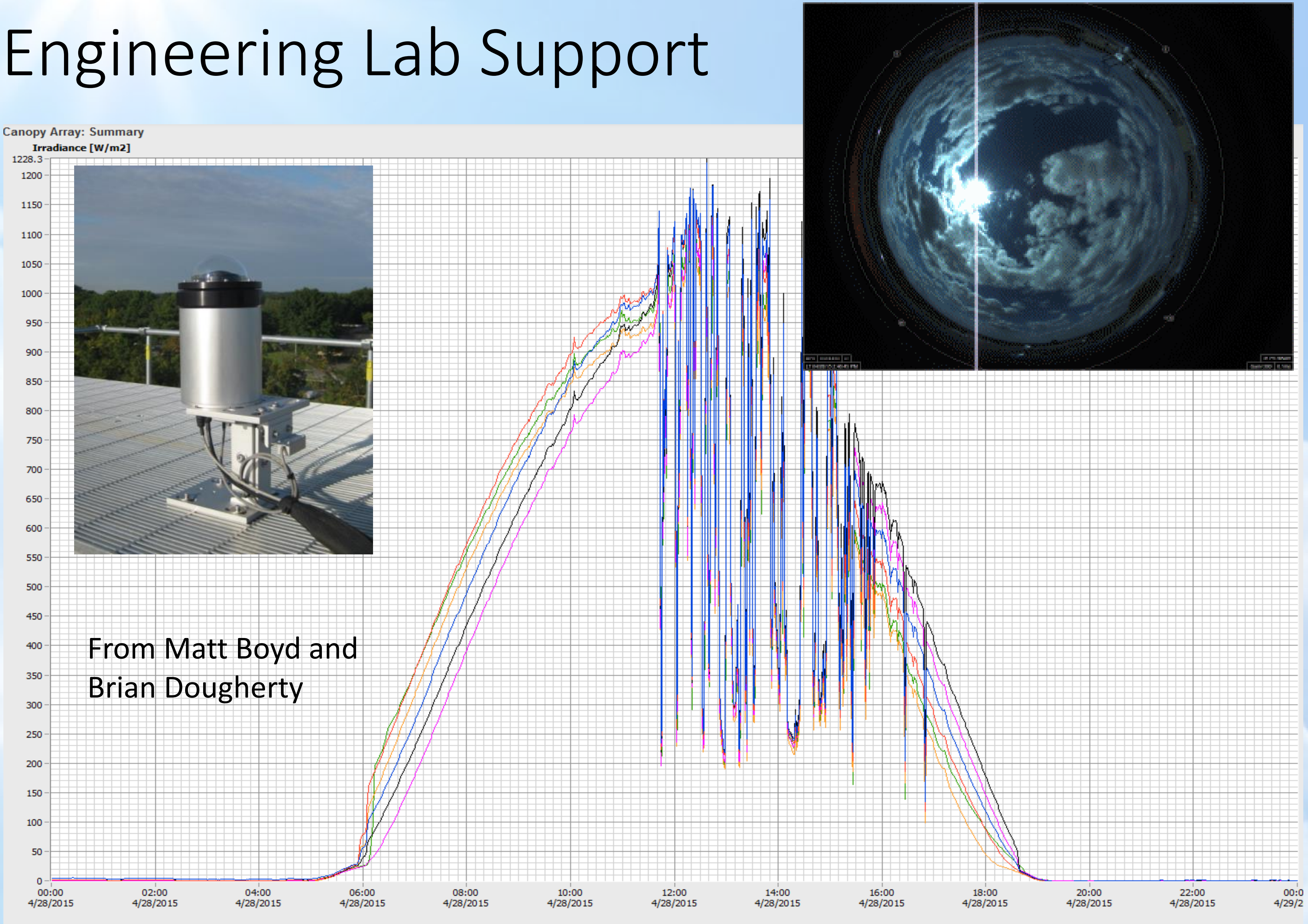


Castagna et al., 2019 "Uncertainty in global downwelling plane irradiance estimates from sintered PTFE plaque radiance measurements," Applied Optics 58(16), 4497 – 4511.

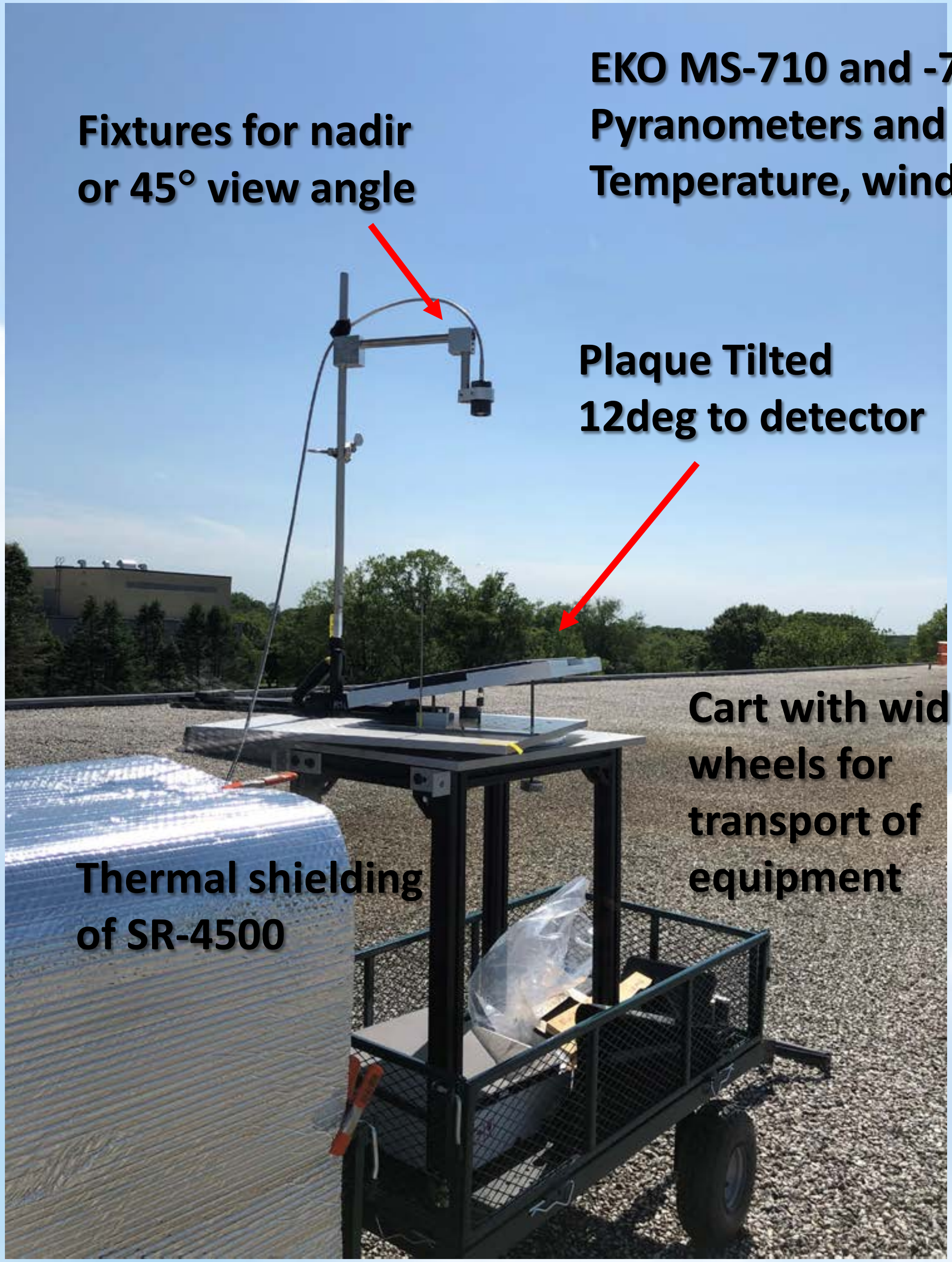
Roof Top Experiment

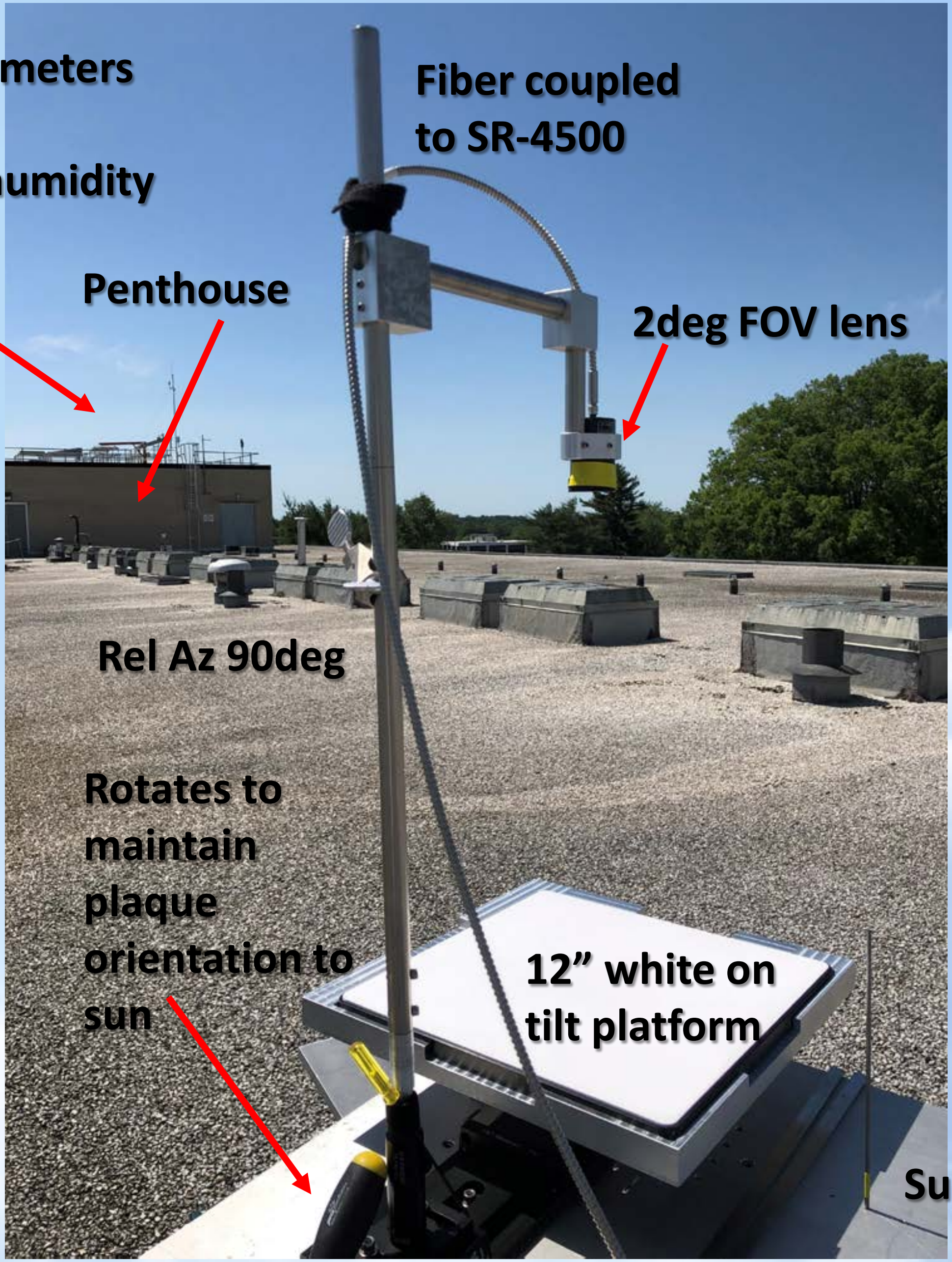
- Examine biases predicted by Alexandre Castagna's modeling
- Document variability under range of sky conditions
- Replicate / assess in situ cross calibration of gray Spectralon using white Spectralon
- Investigate possible test standards, e.g. colored samples
- Compare to *E*s measurements (radiometer is calibrated)
- Monitor sky conditions (sun photometer from GSFC; radiometric and environmental data from NIST Engineering Laboratory)
- Utilize laboratory BRDF or other ancillary data to improve *E*s estimates

NIST Engineering Lab Support



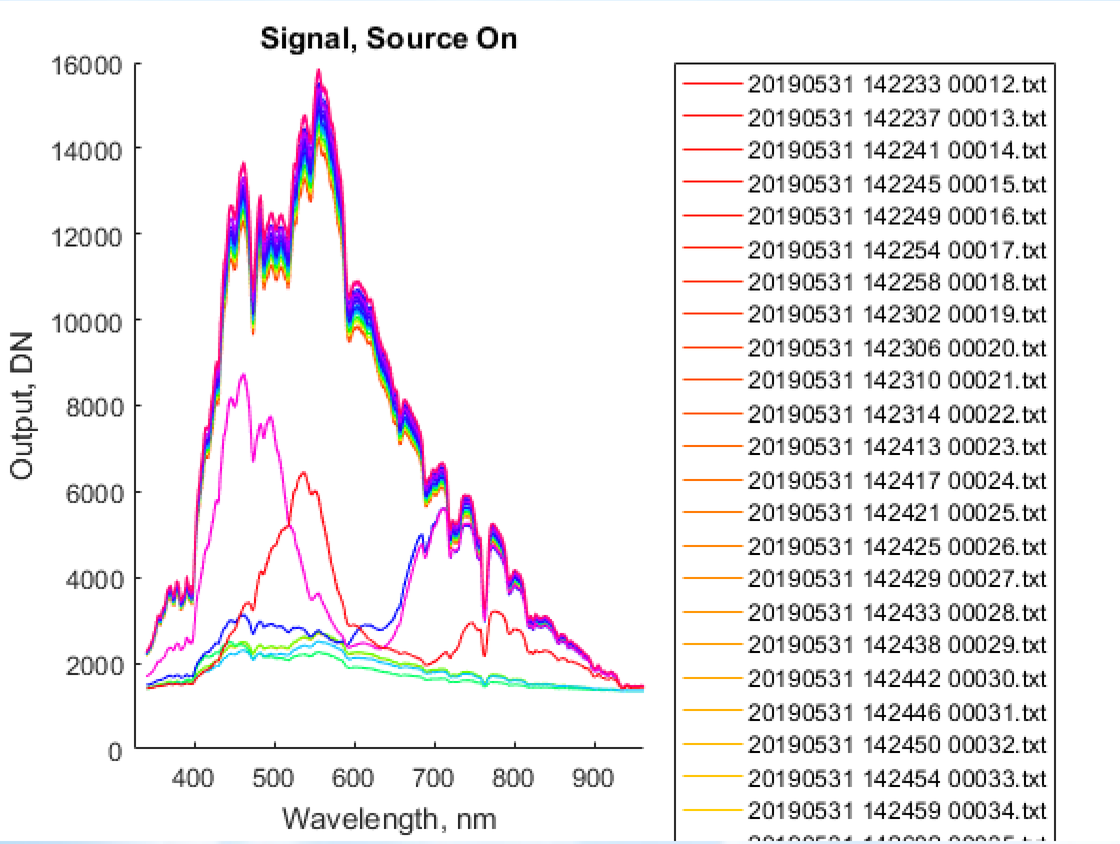
From Matt Boyd and Brian Dougherty


EKO MS-710 and -712 Es spectroradiometers
Pyranometers and Pyrheliometers
Temperature, wind velocity, relative humidity
Fixtures for nadir
or 45° view angle
Plaque Tilted
12deg to detector
Cart with wide
wheels for
transport of
equipment
Thermal shielding
of SR-4500

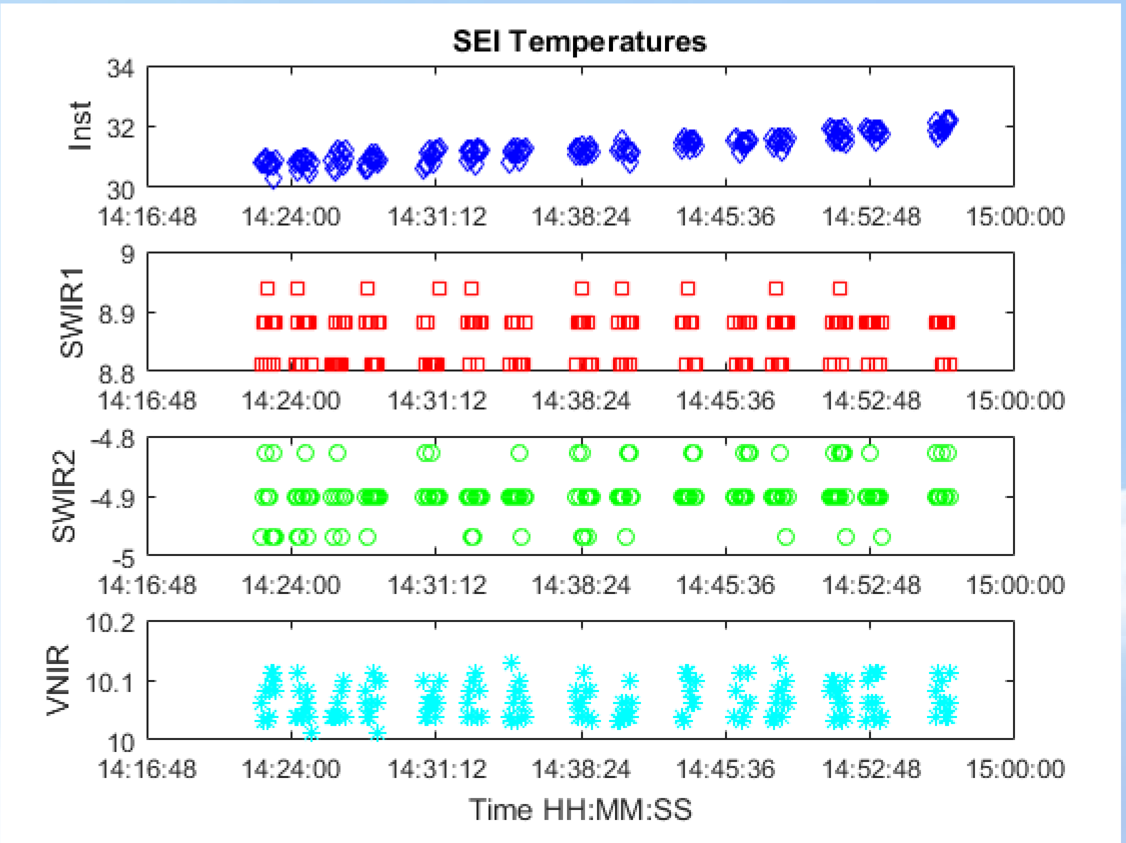

Fiber coupled
to SR-4500
Penthouse
2deg FOV lens
Rel Az 90deg
Rotates to
maintain
plaque
orientation to
sun
12" white on
tilt platform
Sundial

Protocol

- Set up viewing geometry (nadir or 45°) in Penthouse; move outdoors
- Level tilt platform, record darks, adjust all clock timing (UTC) using Garmin, take sun photometer readings (no clouds over Sun)
- Verify alignment using fiber-coupled LED source to the SR-4500 lens
- Wait for stable conditions
- Perform study sequences
    - BRDF: sets of white, target, white
    - Tilt: white, gray, white; either as one target, vary angles, or one angle, vary targets
    - Sky Blocking: white – blocked and unblocked; gray – blocked and unblocked
- To date, 10 days (24-May to 27 Sep), SZA from 16.7° to 81.8°
- Record sun photometer at midday and at the end
- Occasional scans with SRM2065 wavelength standard over lens
- Move back indoors
- Some days integration times fixed for all targets, other days it was optimized

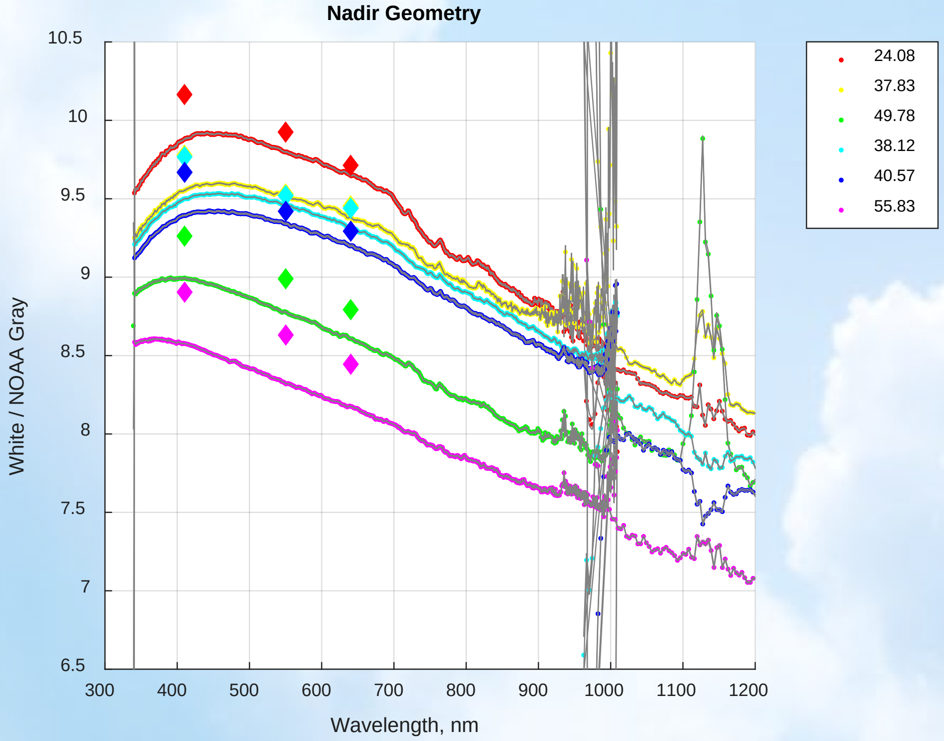


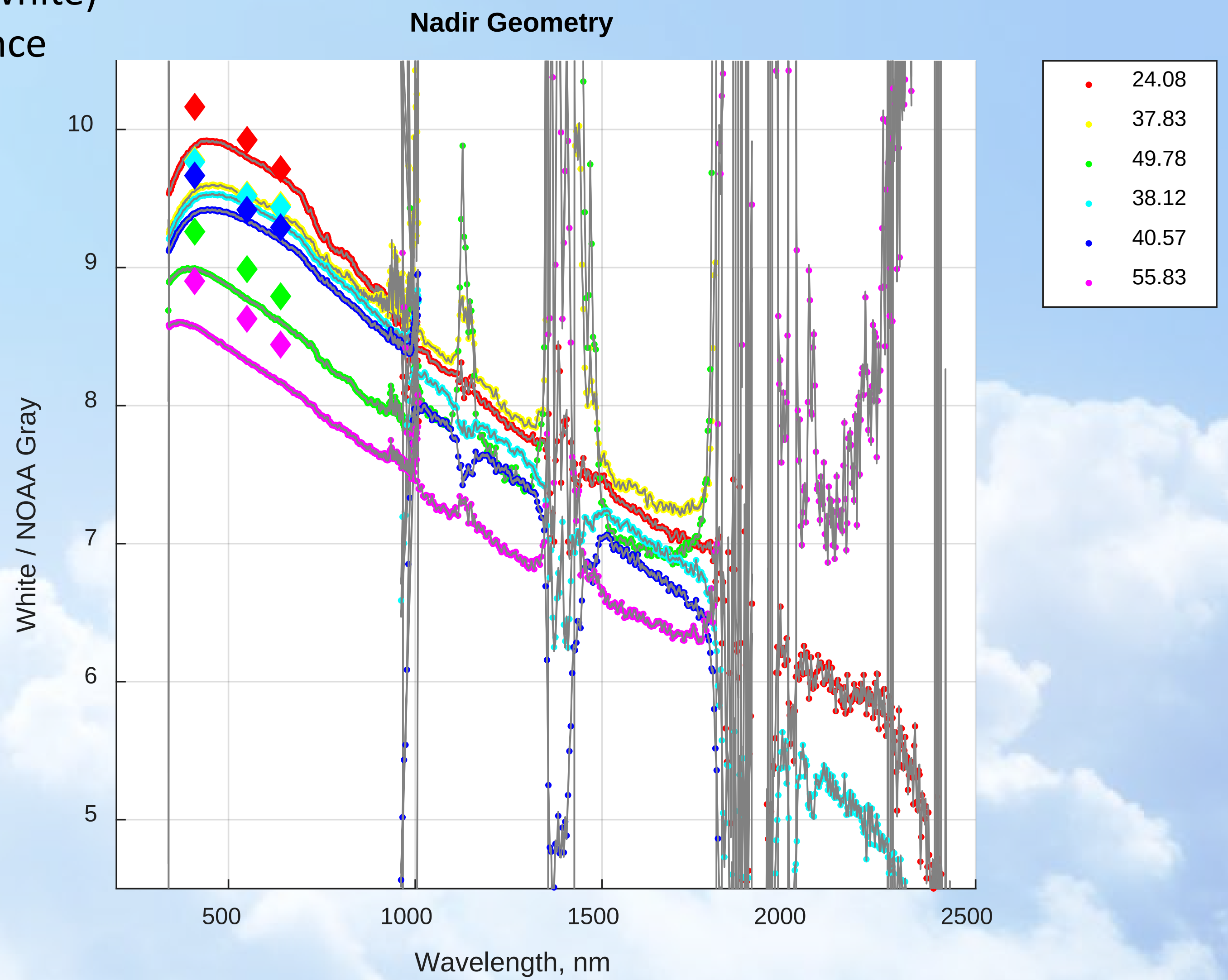
Compare raw spectra, 31-May
Files 23 to 196



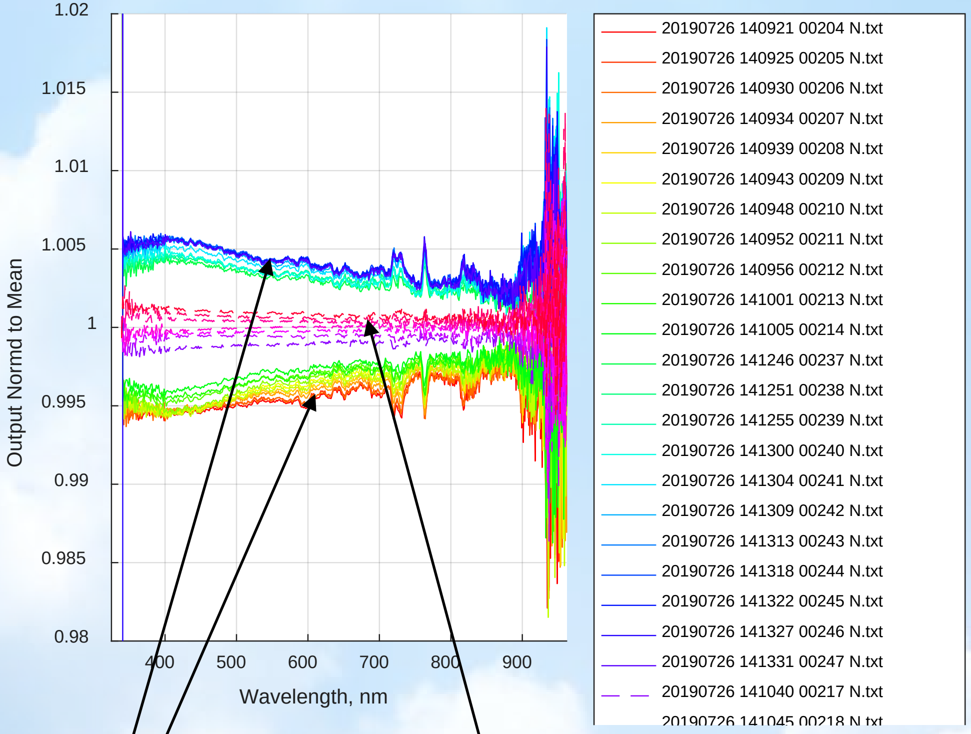
SR-4500 temperatures files 22 to 196 31-May

Sequence was White, Gray, White
Average the two Whites and find ratio
Compare to Lab BRDF ratios (but was different white)
Illumination correction for SZA, Earth-Sun distance
No correction (yet) for stray light effects (if any)
Lab ratios generally higher than measured
Sample of results: 31-May, 26-Jul, 20-Sep

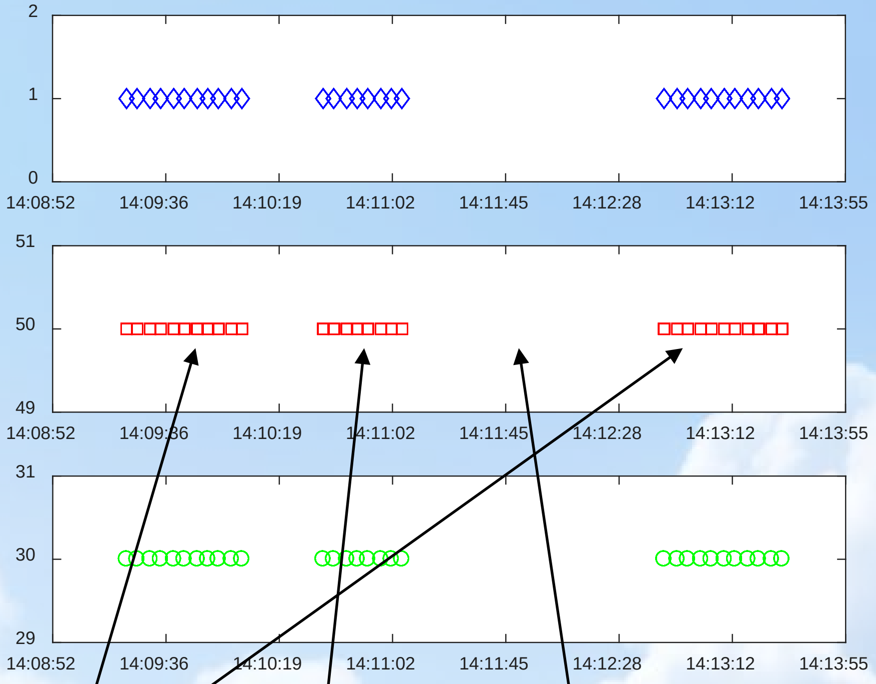




Example of sky blocking on 26-Jul-2019 (person) – white, blocked, white, nadir view



File Integration times

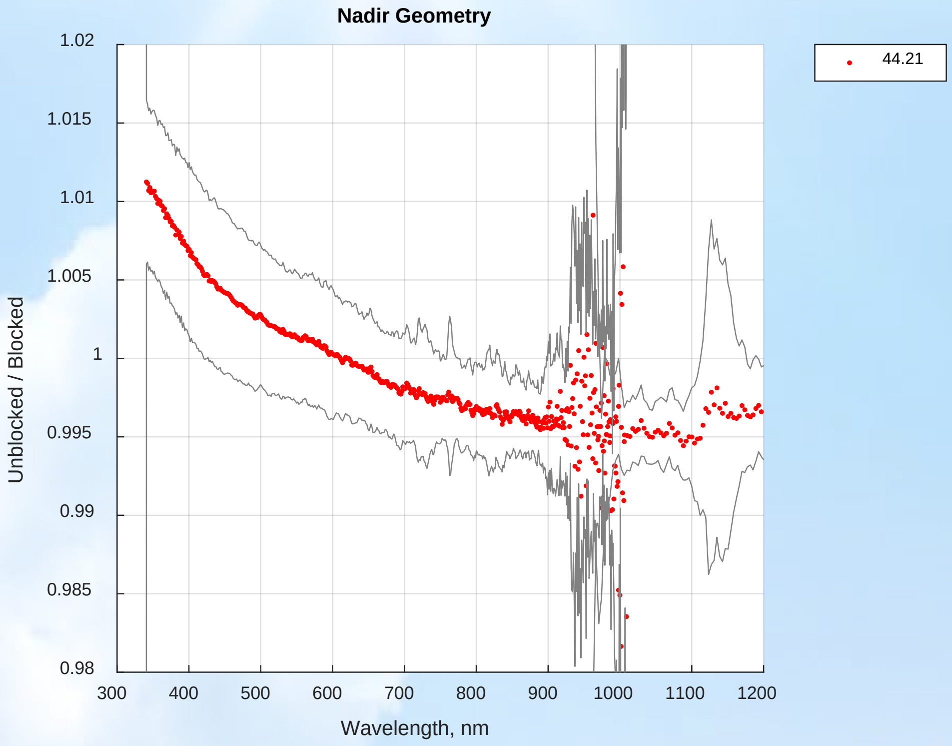


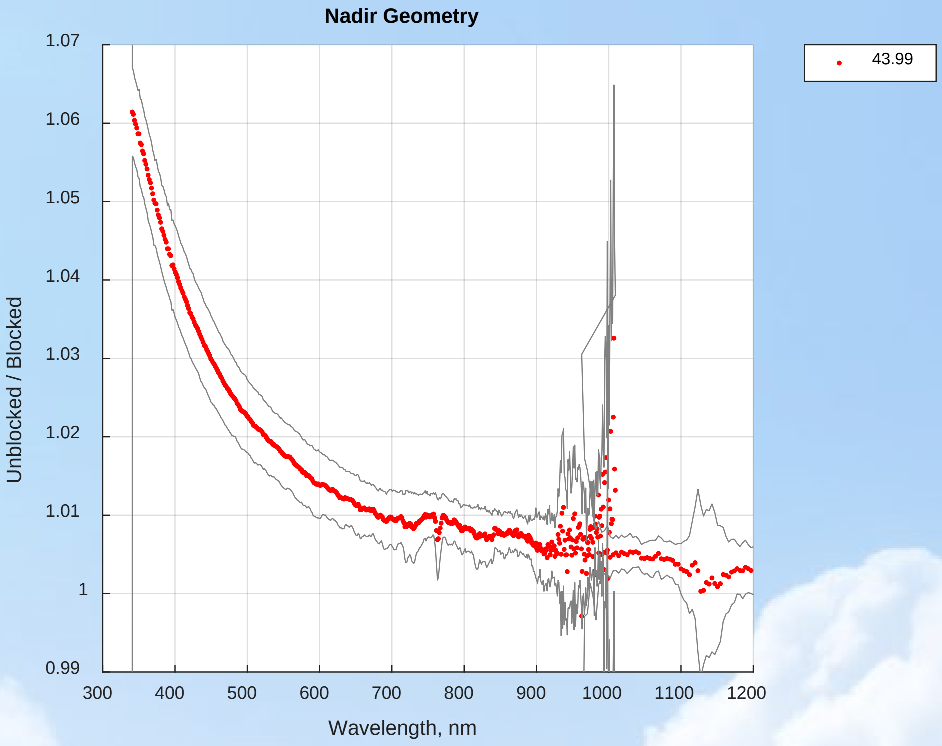
Unblocked (1,4)

Person Block (2)

Person holding black hardboard (3)

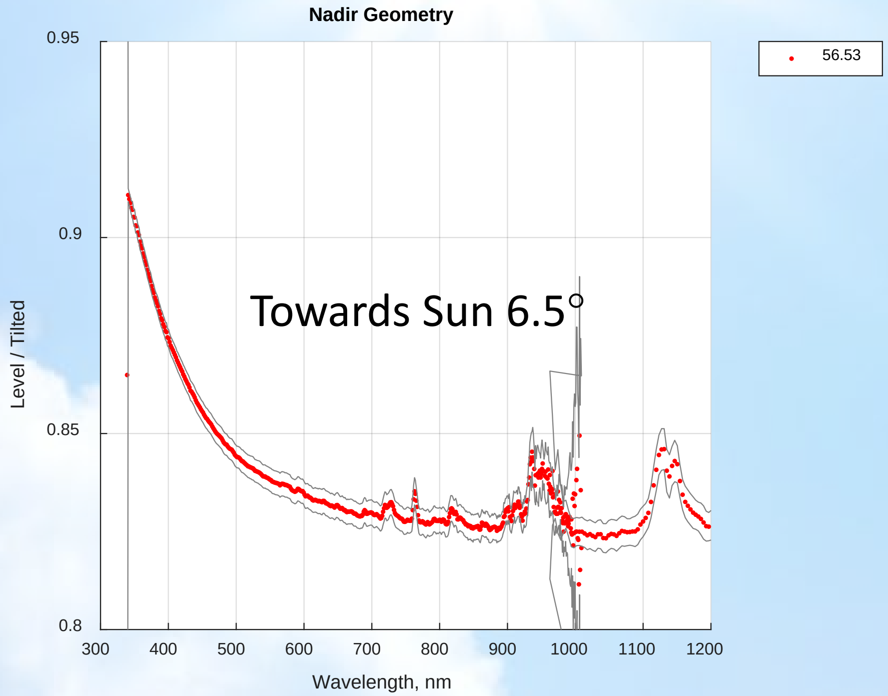
Solid lines, unblocked; Dashed lines, person standing by radiometer head arm (as in the field).

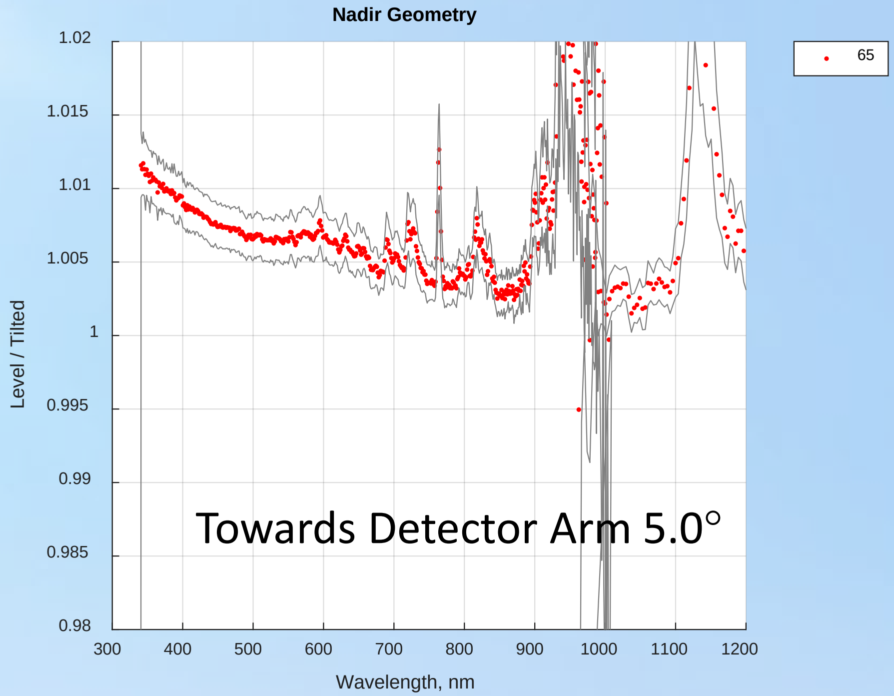


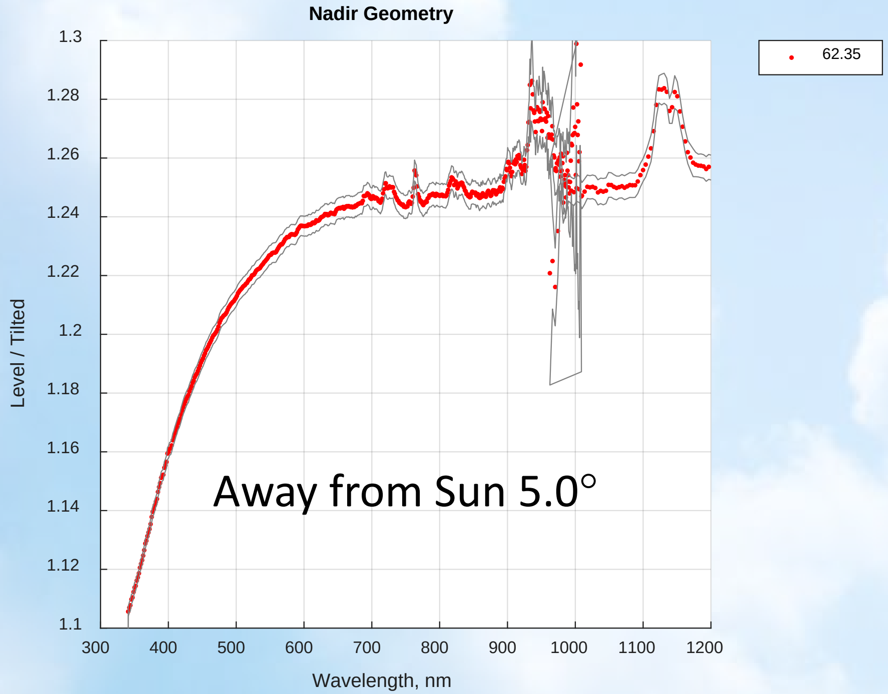


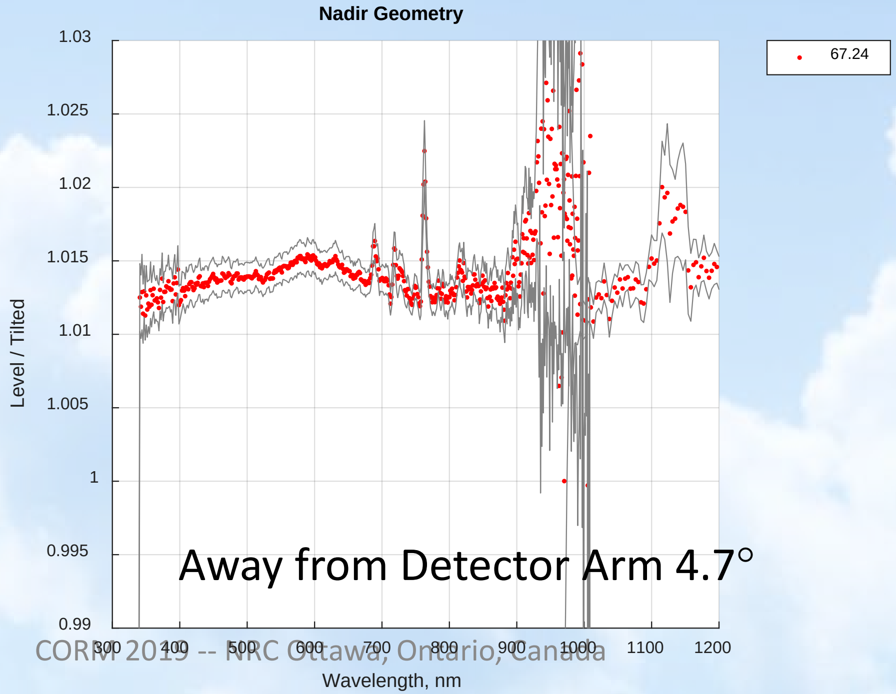
Person Only
26-Jul-2019
UB = 204-214 & 237-247
B = 217-223

Person holding 61 cm x 61 cm painted black hardboard 24”x24”
26-Jul-2019
UB = 204-214 & 237-247
B = 228-234









Tilt for White
20-Sep-2019
Measure Level, then Tilted, form ratio

Theory predicts greatest effect to/from sun, negligible effect to/from detector

Summary

- Agreement with theory
  - Trends in right direction
  - Magnitude of effects seem reasonable
- Over the course of the experiment
  - Modified to adjust integration times for darker samples
  - Modified to capture Reference and Test as close as possible in time
  - Learned where alignment errors were made
  - Experienced various sky conditions
- Next steps
  - Full processing requires integration into data base for automation
    - Correct for known effects (solar normalization, instrument effects…)
    - Describe atmospheric conditions
    - Develop automated filtering algorithms (matchups with EKO, sky camera, cloud screening…)
    - Develop automated file selection based on target type and matchups
    - Results published to internal web pages
    - Compare to theory and EKO Es results