Preliminary Evaluation of the Mirror-Based Empirical Line Method using FLARE system (Surface Reflectance – Landsat Level 2)

SDSU Image Processing Laboratory

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CEOS – IVOS 34

South Dakota State University
Image Processing Lab

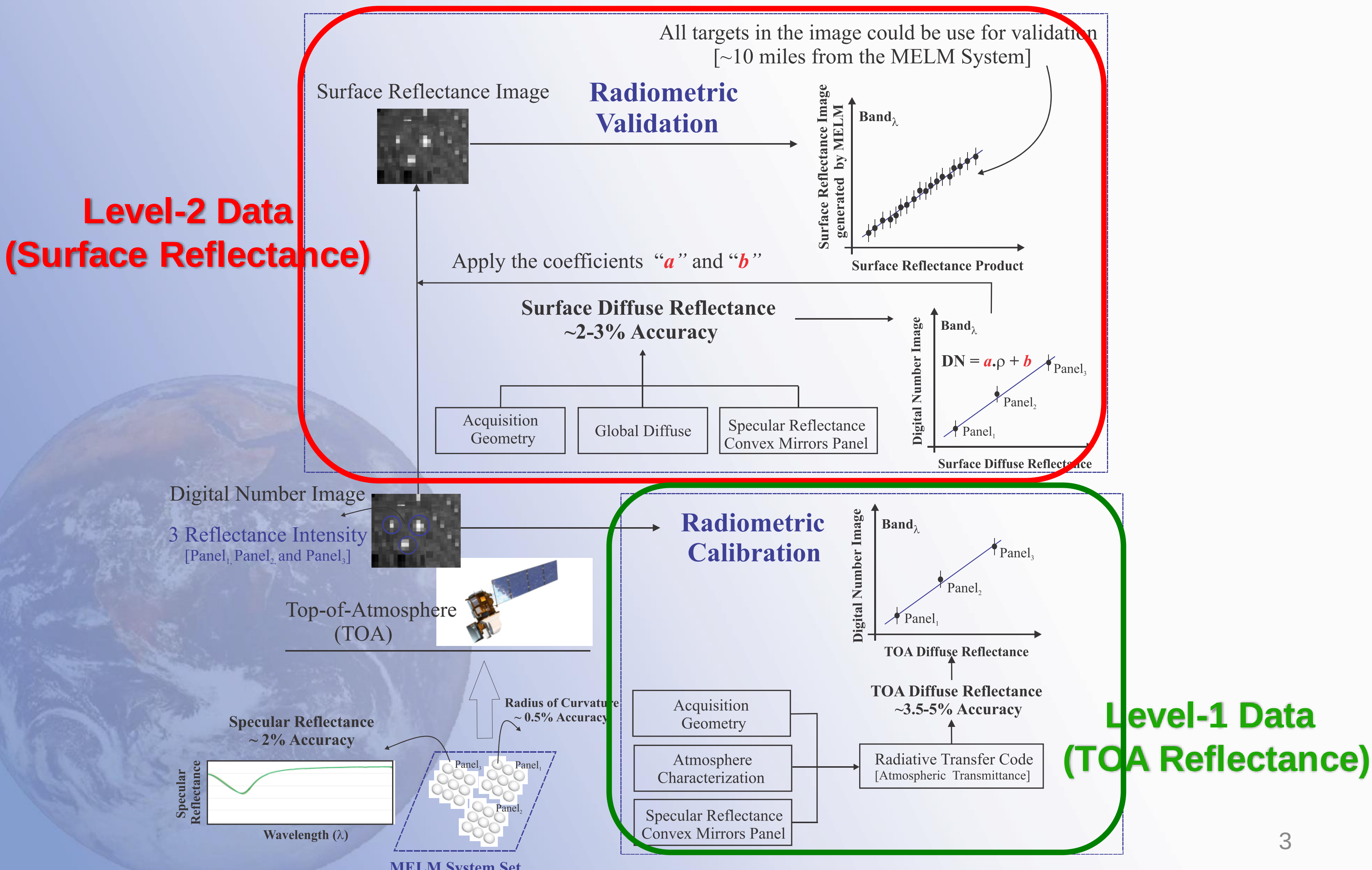
August 29 2022

Outline

- ✓ **Introduction**
- ✓ **Mirror Empirical Line Method;**
- ✓ **FLARE** [Field, Line-of-sight Automated Radiance Exposure]**;**
- ✓ **FLARE Radiometry;**
- ✓ **Lambertian (Diffuse) Equivalent Reflectance Factor;**
- ✓ **2020 & 2021 Data Acquisition ;**
- ✓ **Preliminary Results for Landsat;**
- ✓ **Final Considerations;**

Introduction

Mirror-based Empirical Line Method



Mirror-based Empirical Line Method

Empirical Line Method

- ✓ The MELM measures reference targets of known reflectance in the scene;
- ✓ The known reflectance targets are **convex mirrors**;
- ✓ If at least **two ground targets** with a known reflectance at different intensity levels are positioned within a scene, calibration/validation can be performed;
- ✓ The result from the regression calculation is the ***gain*** and ***offset*** coefficients that can be applied to all surfaces located in the scene [the assumption of a stable atmosphere within a minimum radius], providing ***surface reflectance*** retrieval image;
- ✓ This is the one of the key advantages of the MELM method: **making the larger region surrounding the convex mirror system location into an extended validation target**;

Mirror-based Empirical Line Method

FLARE Alpha deployed at Arlington's Farm (July 2020)

FLARE

South Dakota State University
Image Processing Lab

Labsphere

FLARE Alpha test platform long term loan agreement/partnership with **Labsphere**;

Mirror-based Empirical Line Method

Radiometry – Extended surface

TOA Intensity (Sensor Independent)

$$I(\lambda,\theta_r)_{TOA} = \tfrac{1}{4}\rho\left(\lambda,\theta_r\right)\tau_{\downarrow}(\lambda)\tau_{\uparrow}(\lambda)E_o\left(\lambda\right)R^2$$

[Watts/(sr micron)/mirror]

Effective At-Sensor Radiance (sensor and collection geometry specific)

$$L_{at-sensor}(\lambda,\theta_r) = \rho(\lambda,\theta_r)\tau_{\downarrow}(\lambda)\tau_{\uparrow}(\lambda)E_o(\lambda)\frac{R^2}{4GSD(x)GSD(y)}$$

[Watts/(m^2 sr micron)/mirror]

$\rho(\lambda,\theta_r)$ = Mirror specular reflectance at the reflectance angle θ_r;

$\tau_{\downarrow}(\lambda)$ = Sun to ground transmittance;

$\tau_{\uparrow}(\lambda)$ = Ground to sensor transmittance;

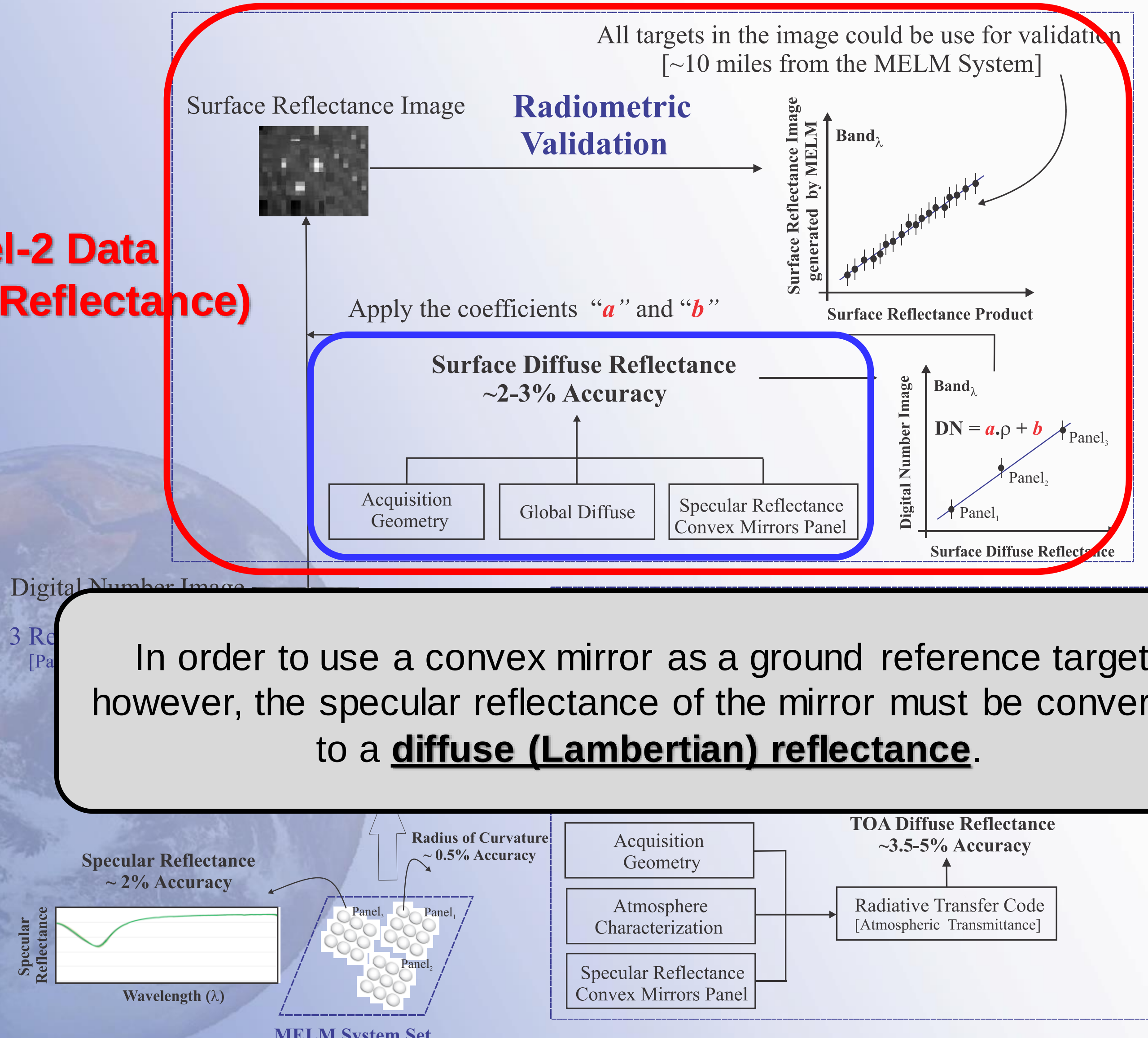
$E_o(\lambda)$ = Solar spectral constant;

R = Mirror radius of curvature (m);

GSD = Ground sample distance (m);

Mirror-based Empirical Line Method

Level-2 Data (Surface Reflectance)



In order to use a convex mirror as a ground reference target, however, the specular reflectance of the mirror must be converted to a **diffuse (Lambertian) reflectance**.

Mirror-based Empirical Line Method

August 23, 2020

Lambertian (Diffuse) Equivalent Reflectance Factor

$$\rho_F^{mir}(\lambda) = \left[\frac{1}{Cos\theta_o} + \left(f - \frac{1}{Cos\theta_o}\right) G(\lambda)\right] \frac{N\pi R^2}{4GSD_x GSD_y} \rho_m(\lambda)$$

$\rho\ (\lambda,\theta_r)$ = Mirror specular reflectance at the reflectance angle θ_r

θ_o = Solar zenith angle

f = Fraction of the hemispherical sky reflected by the mirror dome of half angular width θ_m.

$G(\lambda)$ = Diffuse to global ratio measured at the mirror target location

N = Number of mirrors

R = Mirror radius of curvature (m)

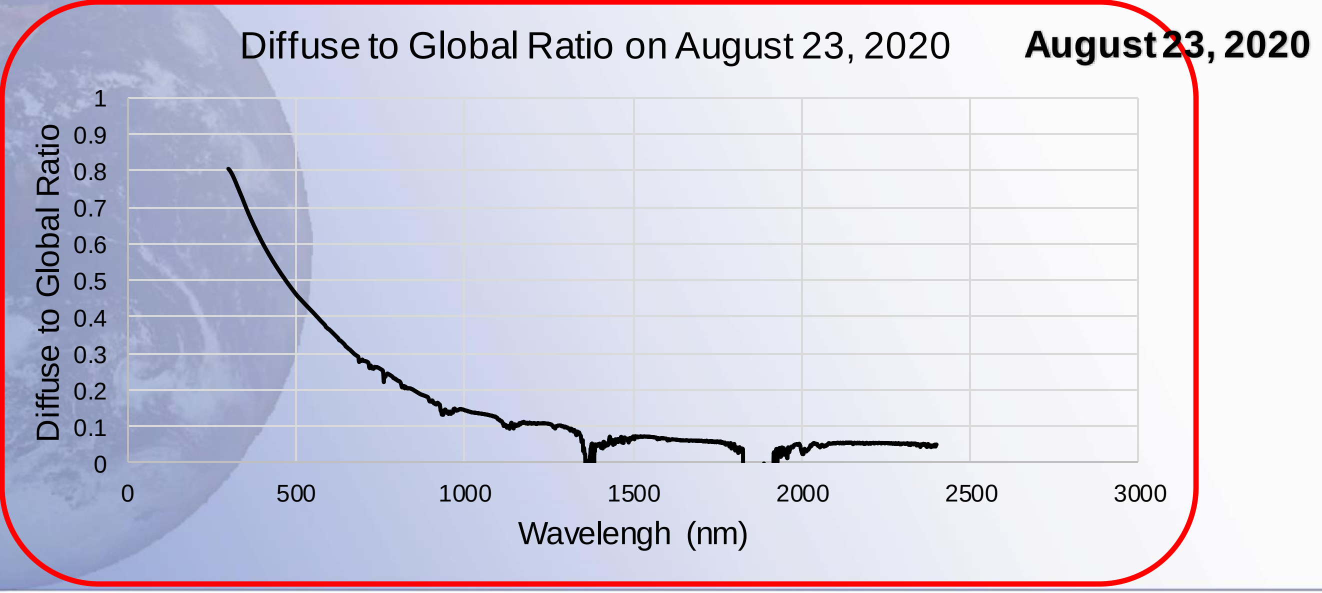
GSD = Line-of-site ground sample distance (m)

Mirror-based Empirical Line Method

August 23, 2020

Lambertian (Diffuse) Equivalent Reflectance Factor

$$\rho_F^{mir}(\lambda) = \left[\frac{1}{Cos\theta_o} + \left(f - \frac{1}{Cos\theta_o}\right) G(\lambda)\right] \frac{N\pi R^2}{4GSD_x GSD_y}\,\rho_m(\lambda)$$



Mirror-based Empirical Line Method

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Lambertian (Diffuse) Equivalent Reflectance Factor

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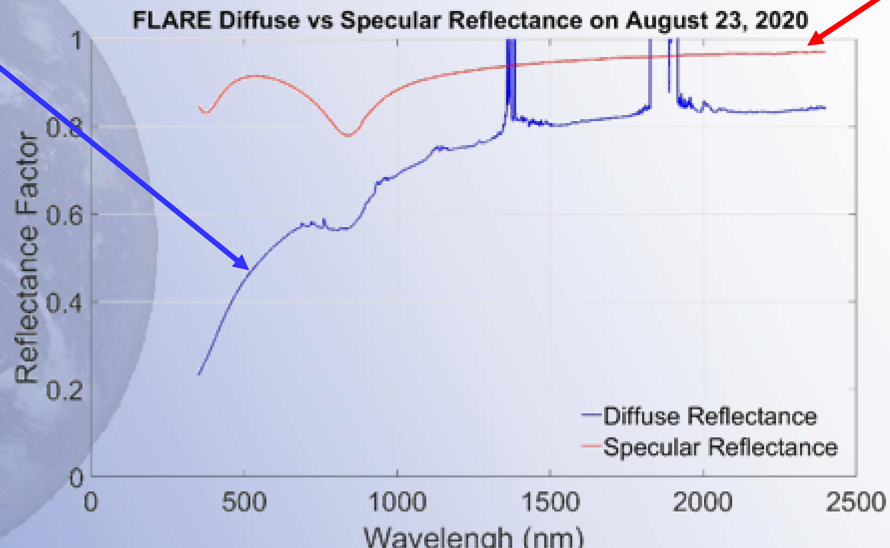
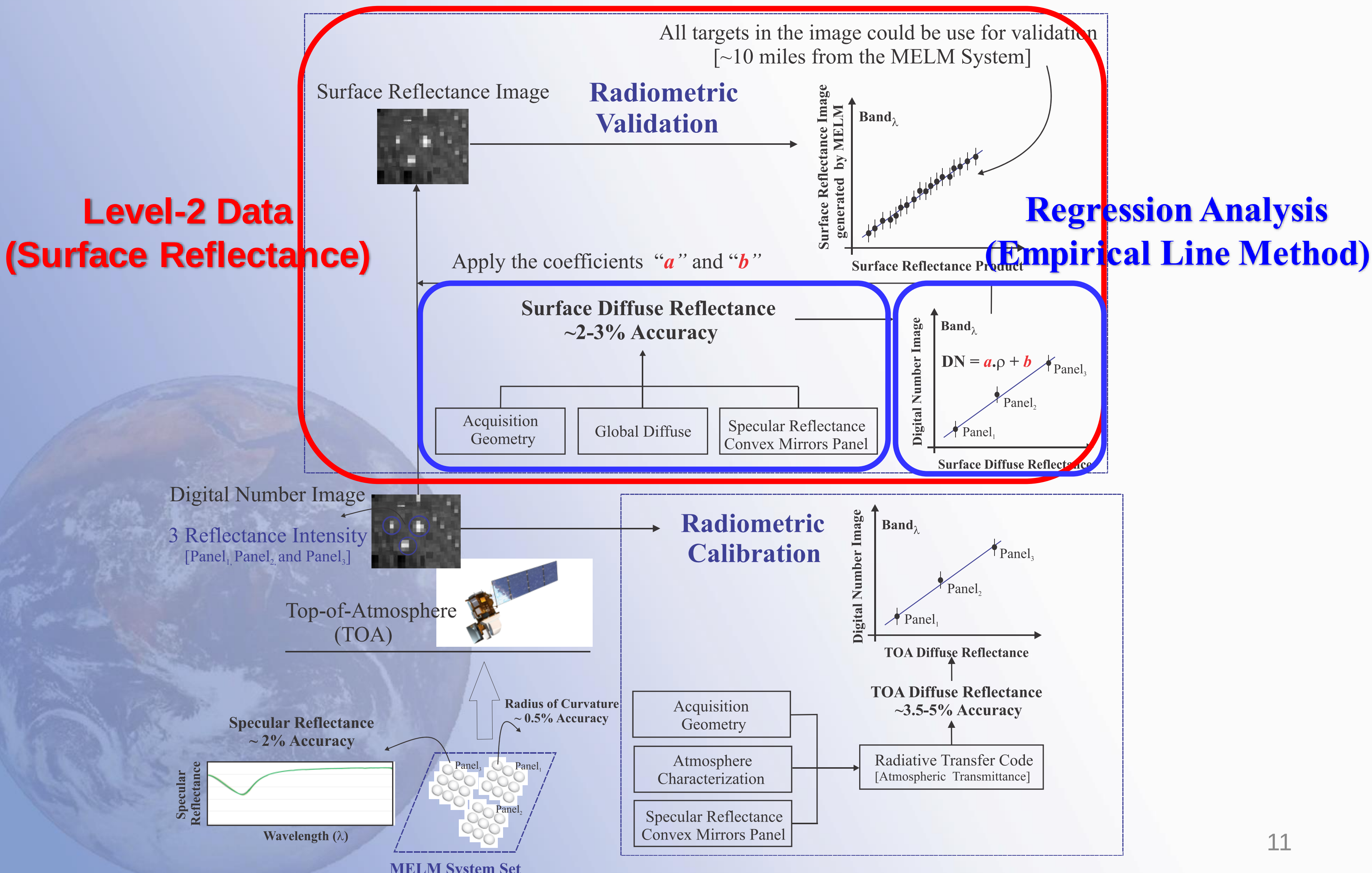
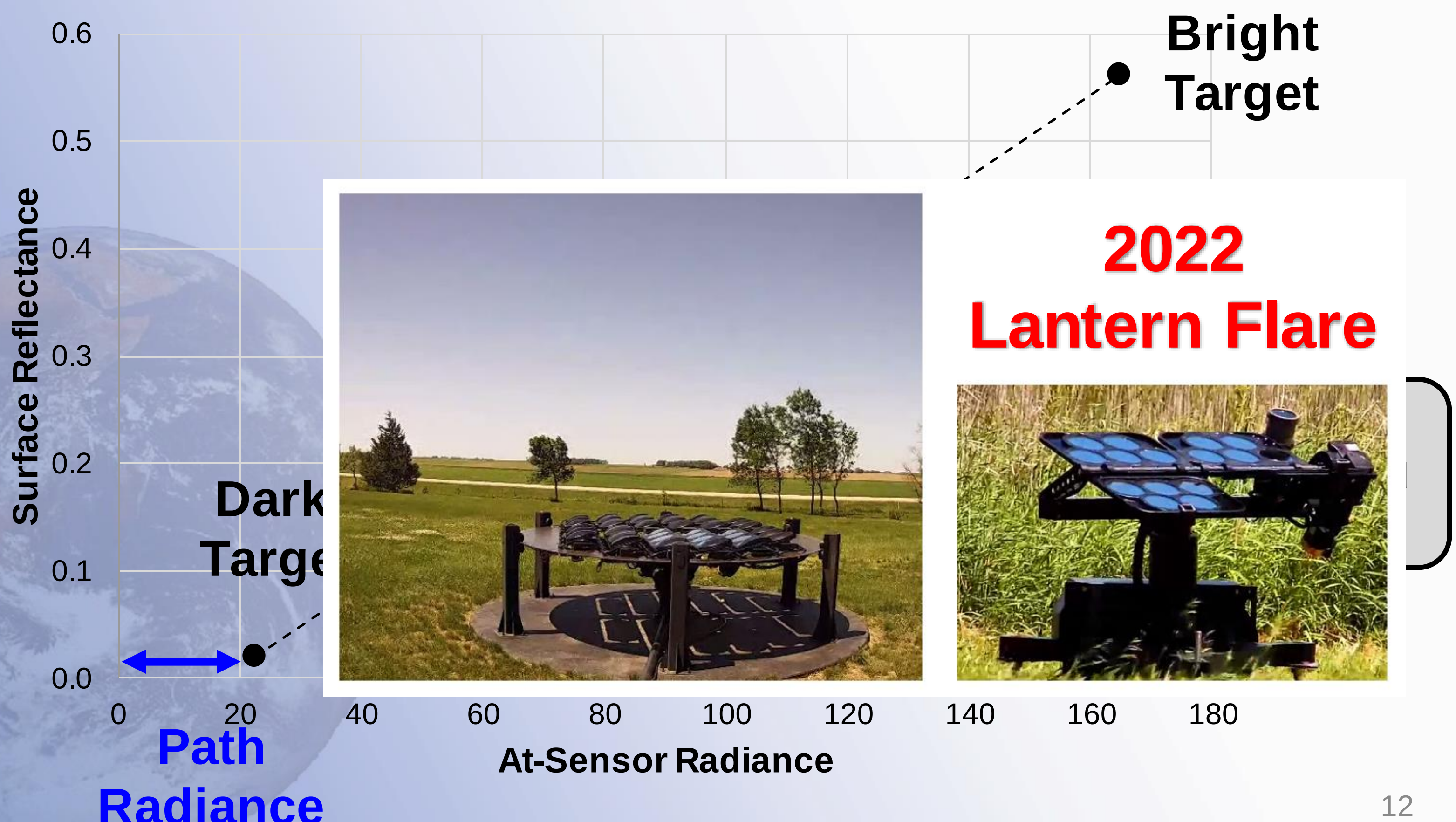


Mirror-based Empirical Line Method



Mirror-based Empirical Line Method

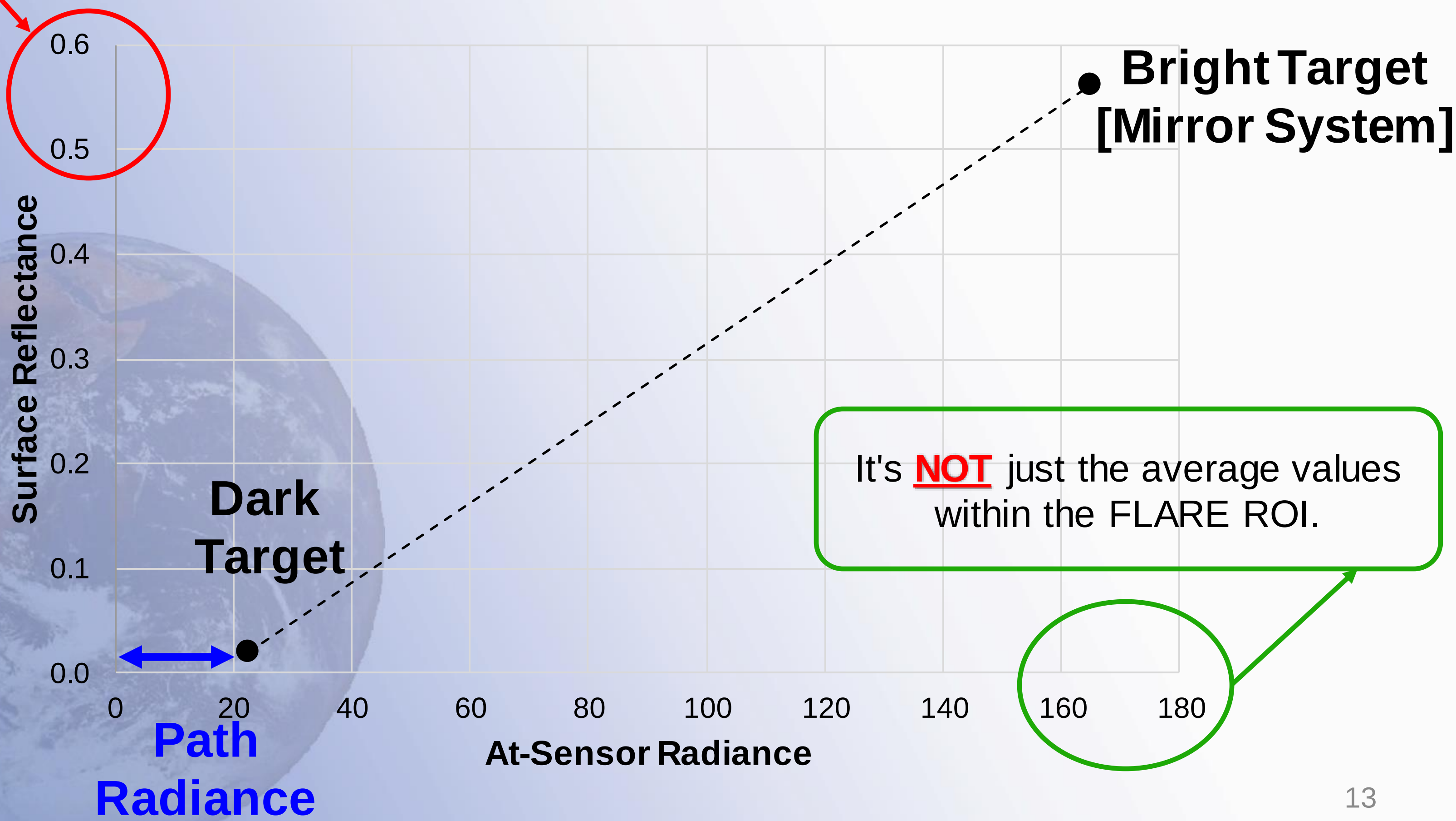
- ✓ Ideally, we would have more than one mirror system in the same scene - for a more robust regression ;
- ✓ 2020 and 2021 → **<u>one</u> FLARE system** - which provides the **bright target**;
- ✓ In some days we have the **ground measurement** (vegetation/soil) with the ASD - which provides the **dark target**;



Mirror-based Empirical Line Method

Diffuse Equivalent Reflectance Factor

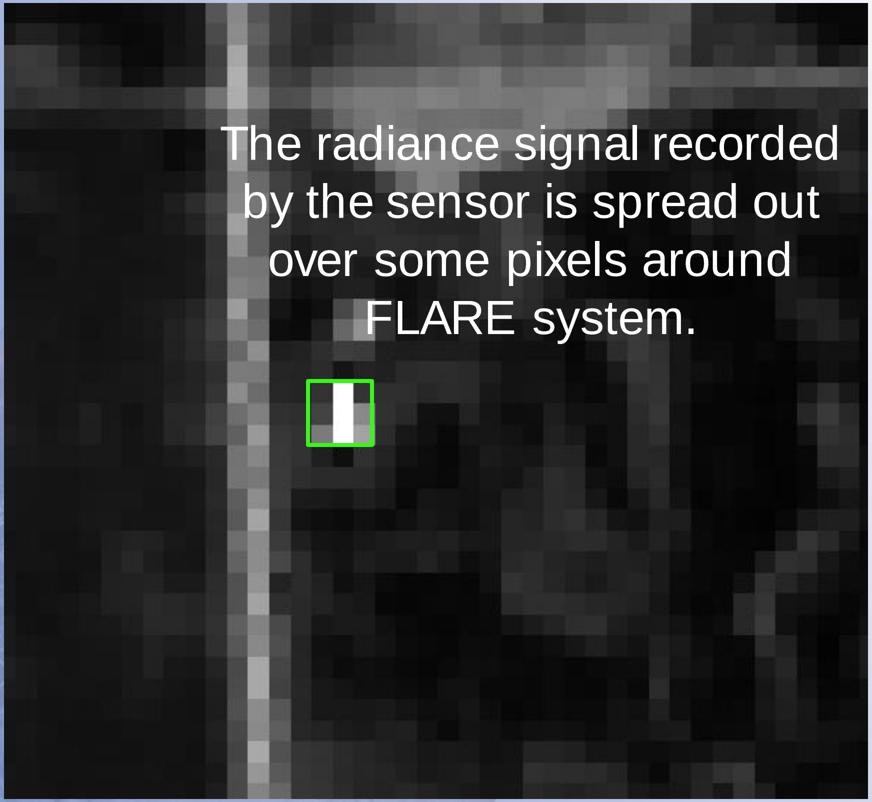
$$\rho_F^{mir}(\lambda) = \left[\frac{1}{Cos\theta_o} + \left(f - \frac{1}{Cos\theta_o}\right) G(\lambda)\right] \frac{N\pi R^2}{4GSD_x GSD_y} \rho_m(\lambda)$$



Mirror-based Empirical Line Method

August 23, 2020

FLARE At-Sensor Radiance measured from image:



Landsat-8 OLI

Assuming the FLARE system signal impacts 9 pixels:

$$L_{Image} = \sum L_{Integrated\_Response} = \sum_{n=1}^{9} \left(L_n - \overline{L_{background}} \right)$$

The critical key step is to remove the **background signal** and, consequently, leave only the signal coming from the FLARE/mirrors.

Mirror-based Empirical Line Method

August 23, 2020

Background: Image Derived

Background Signal:

Assumptions:

(a) these **3 pixels** are not affected by the FLARE system; and
(b) these **3 pixels** represent the same type of land cover* contained in the 9 pixels impacted by the FLARE system;

$$\overline{L_{background}} = \frac{\sum_{n=1}^{3} L_n}{3}$$

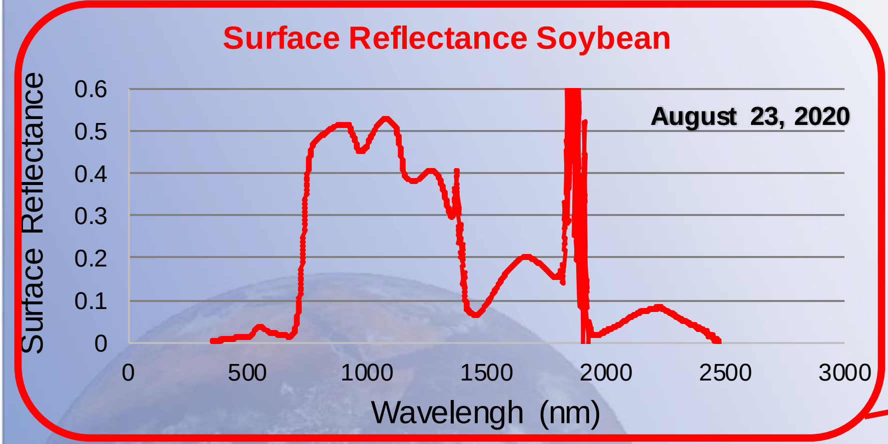
$$L_{Image} = \sum L_{Integrated\_Response} = \sum_{n=1}^{9} \left(L_n - \overline{L_{background}} \right)$$

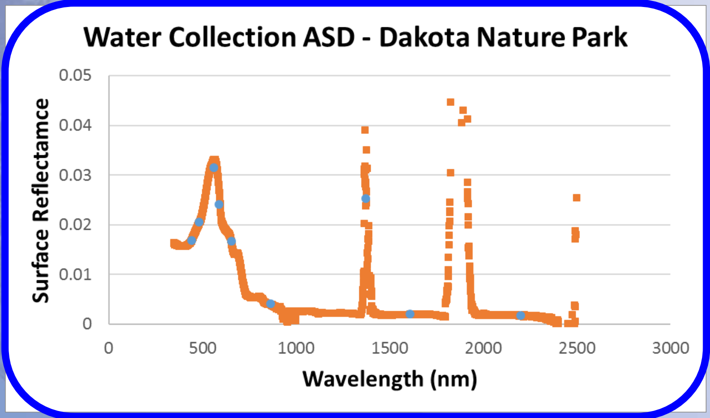
*Here the land cover is a mix of vegetation and soil.

Mirror-based Empirical Line Method

FLARE At-Sensor Radiance measured from image:

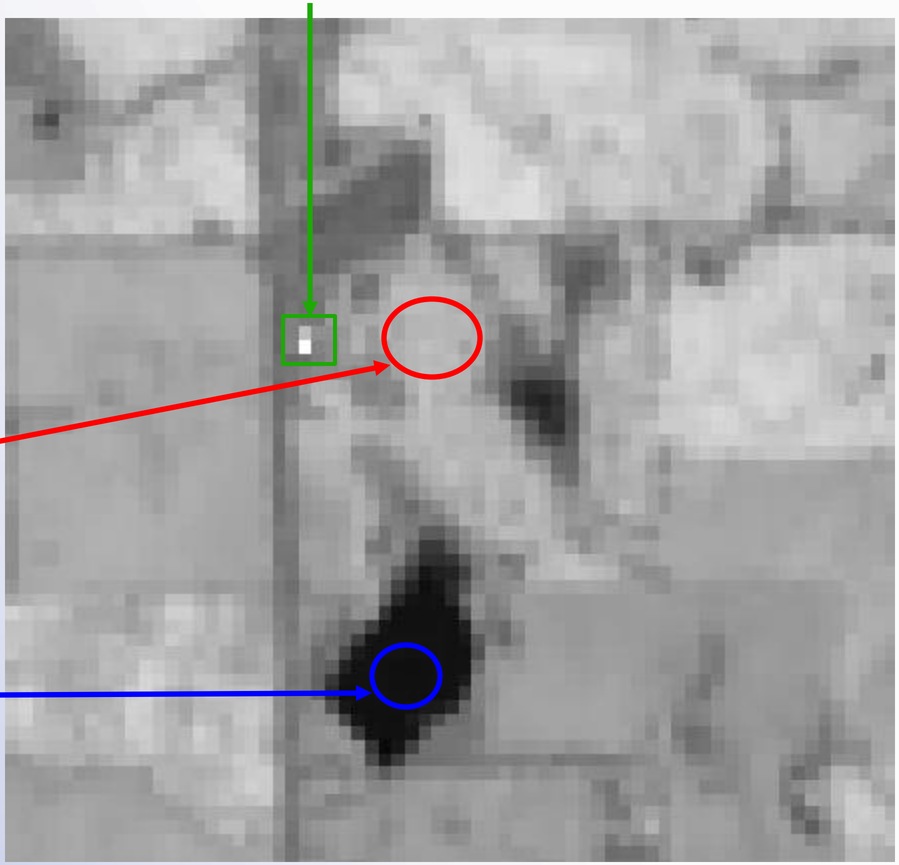
Soybean





Water

FLARE

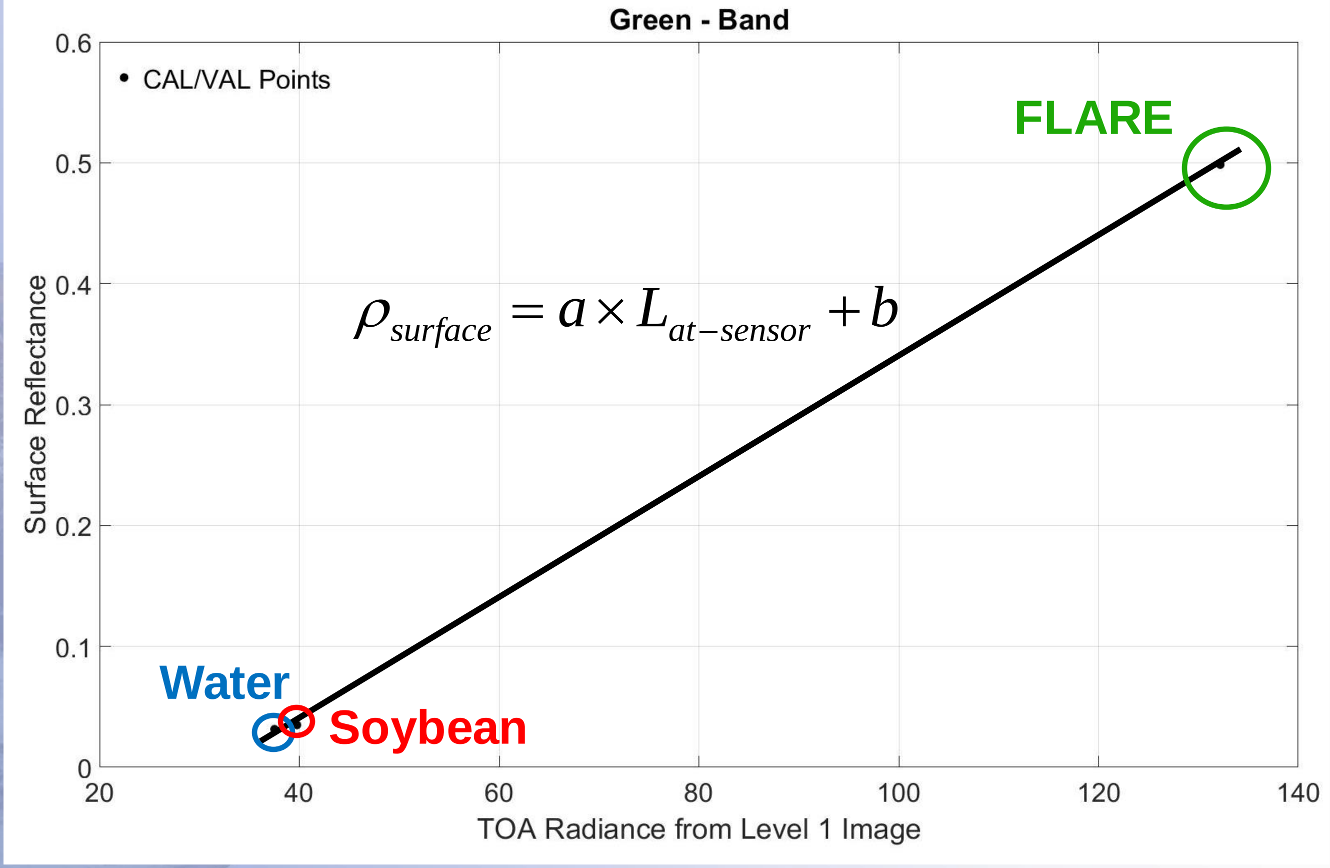


Mirror-based Empirical Line Method

Preliminary Results

August 23, 2020

Green Landsat-8

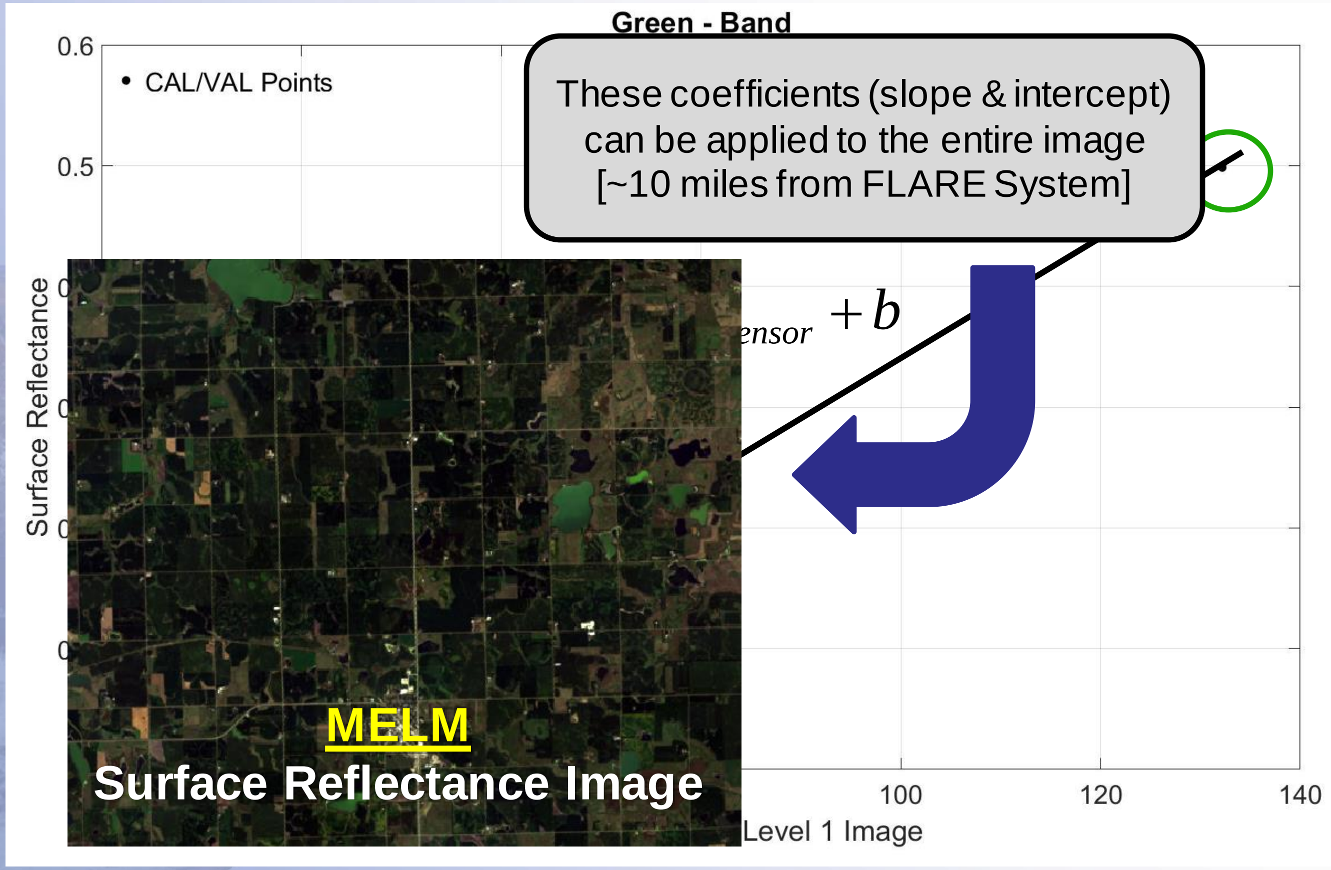


Mirror-based Empirical Line Method

August 23, 2020

Preliminary Results

Green Landsat-8



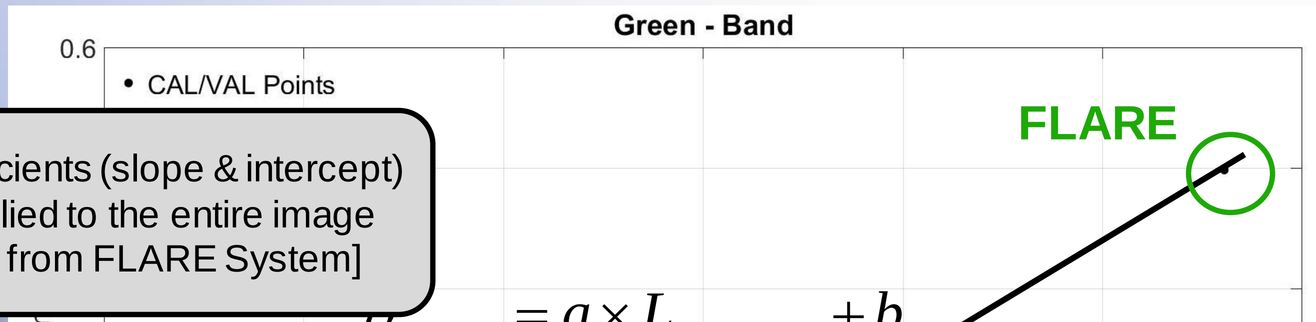
Mirror-based Empirical Line Method

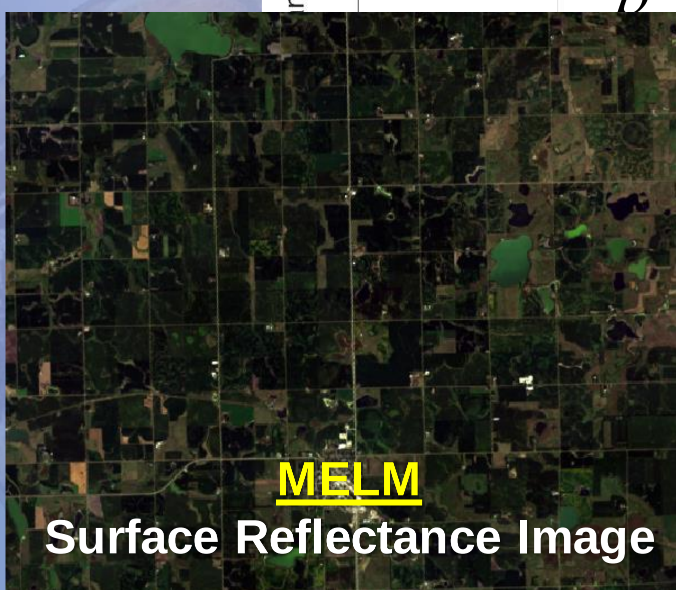
Preliminary Results

August 23, 2020

Green Landsat-8

These coefficients (slope & intercept) can be applied to the entire image [~10 miles from FLARE System]



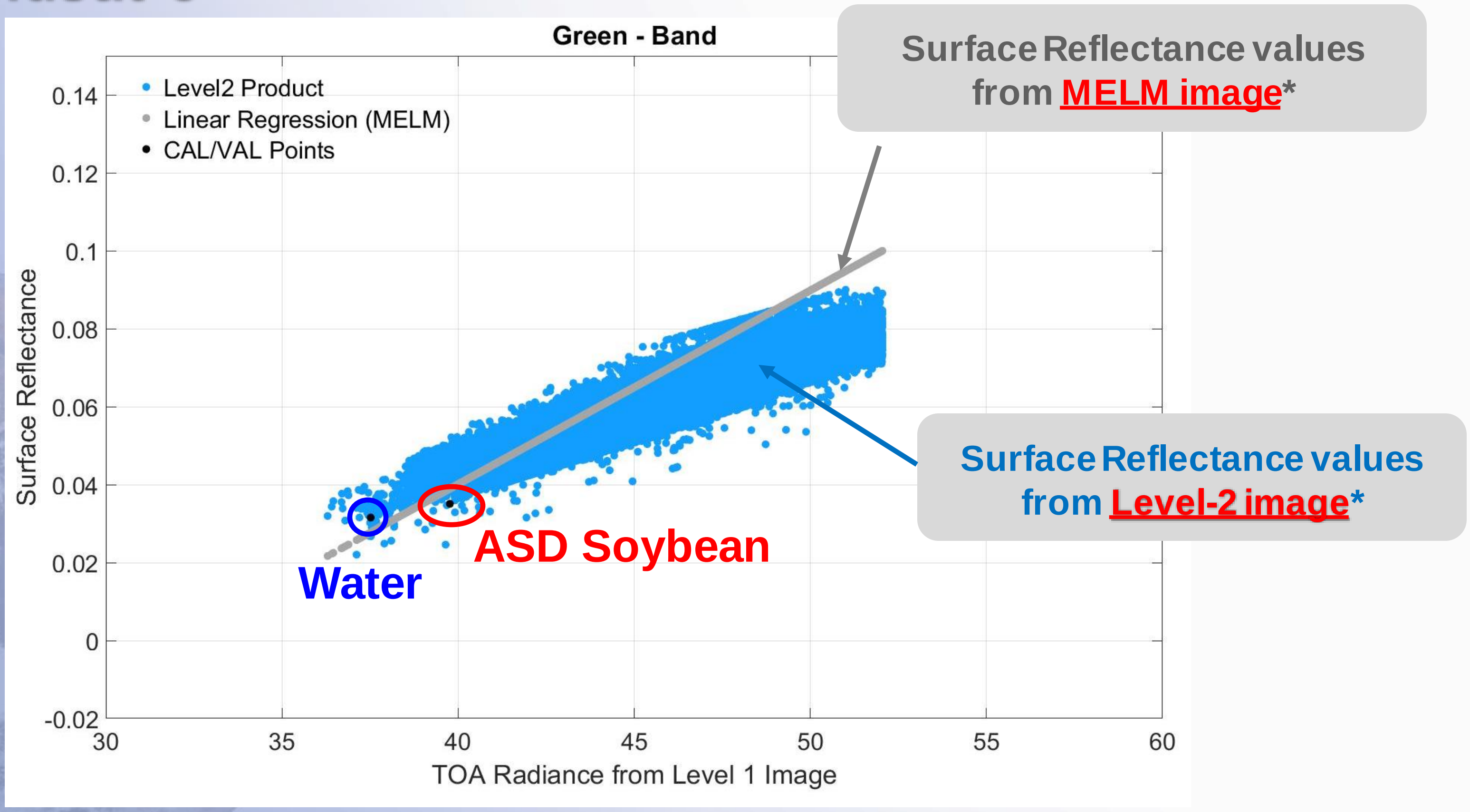


Mirror-based Empirical Line Method

Preliminary Results

August 23, 2020

Green Landsat-8



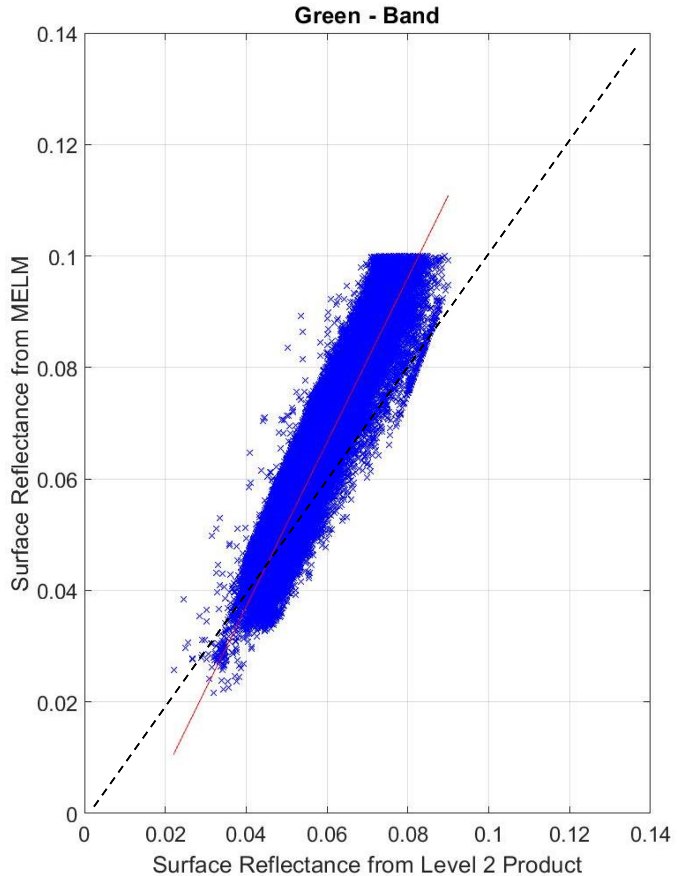
*[~10 miles from FLARE System]

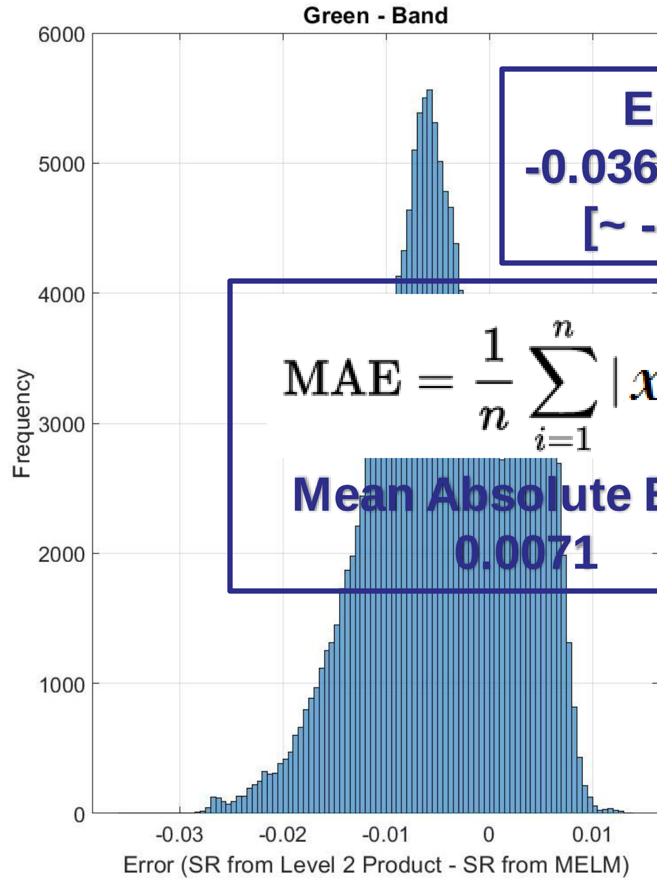
Mirror-based Empirical Line Method

Preliminary Results

August 23, 2020

Green Landsat-8





Error:
-0.036 to 0.014
[~ -0.004]

$$\text{MAE} = \frac{1}{n}\sum_{i=1}^{n} | x_i - x |$$

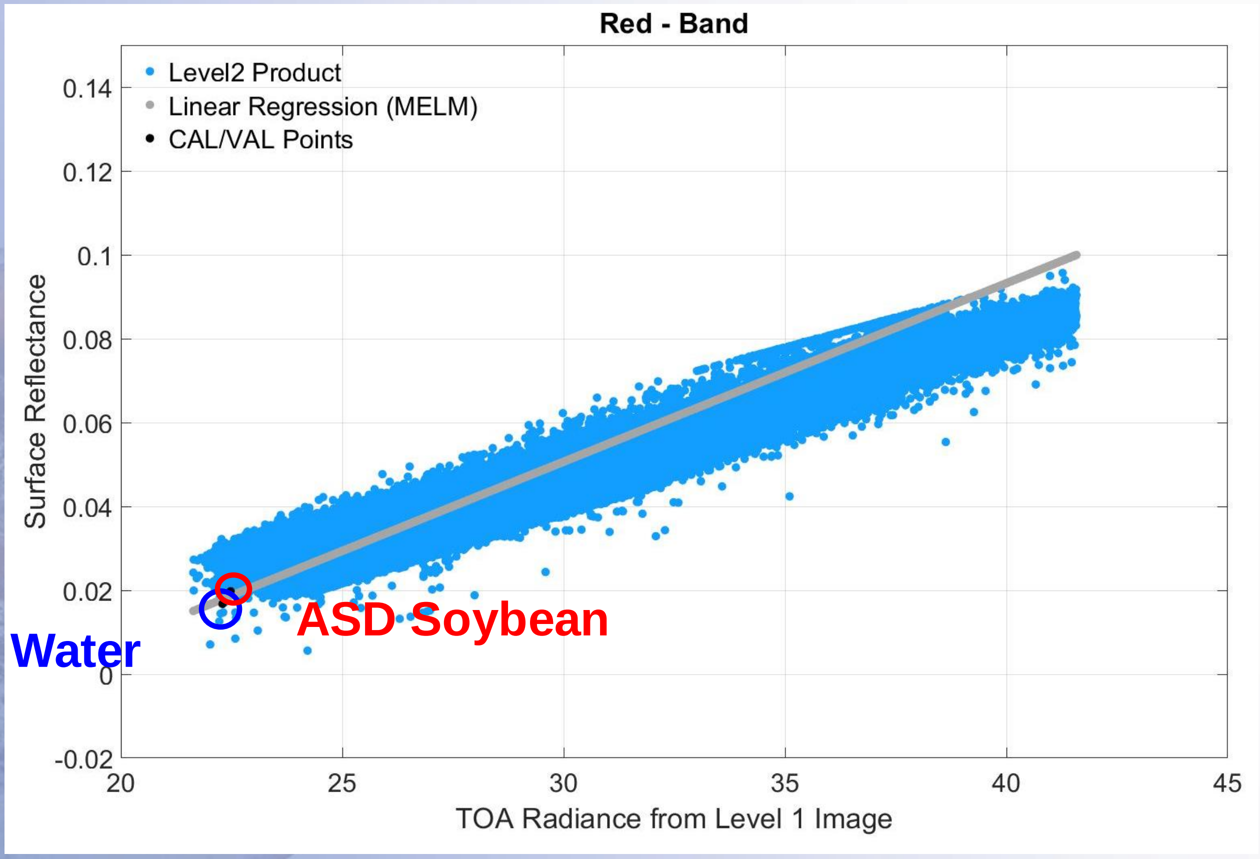
Mean Absolute Error
0.0071

Mirror-based Empirical Line Method

Preliminary Results

August 23, 2020

Red Landsat-8

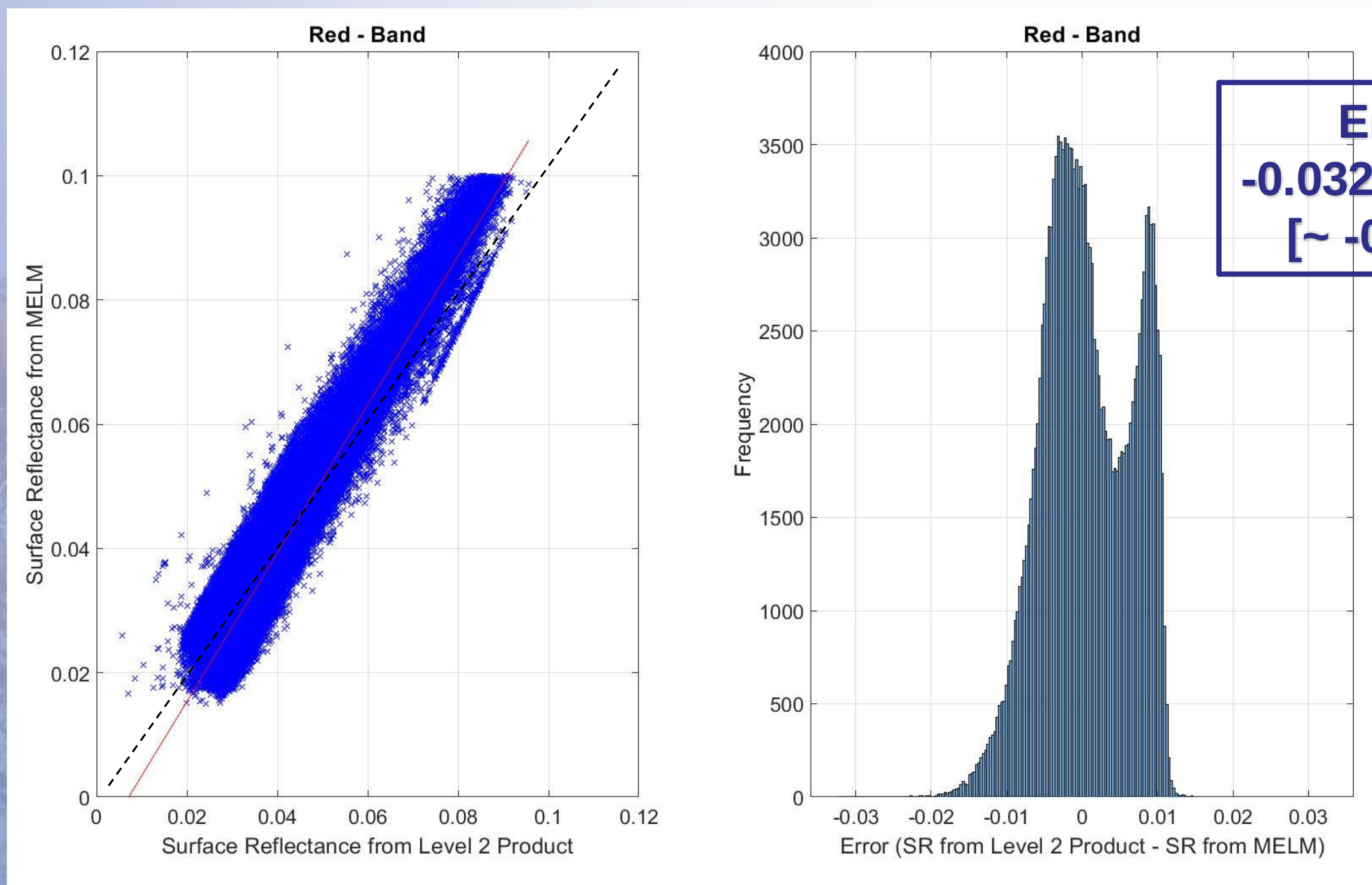


Mirror-based Empirical Line Method

Preliminary Results

August 23, 2020

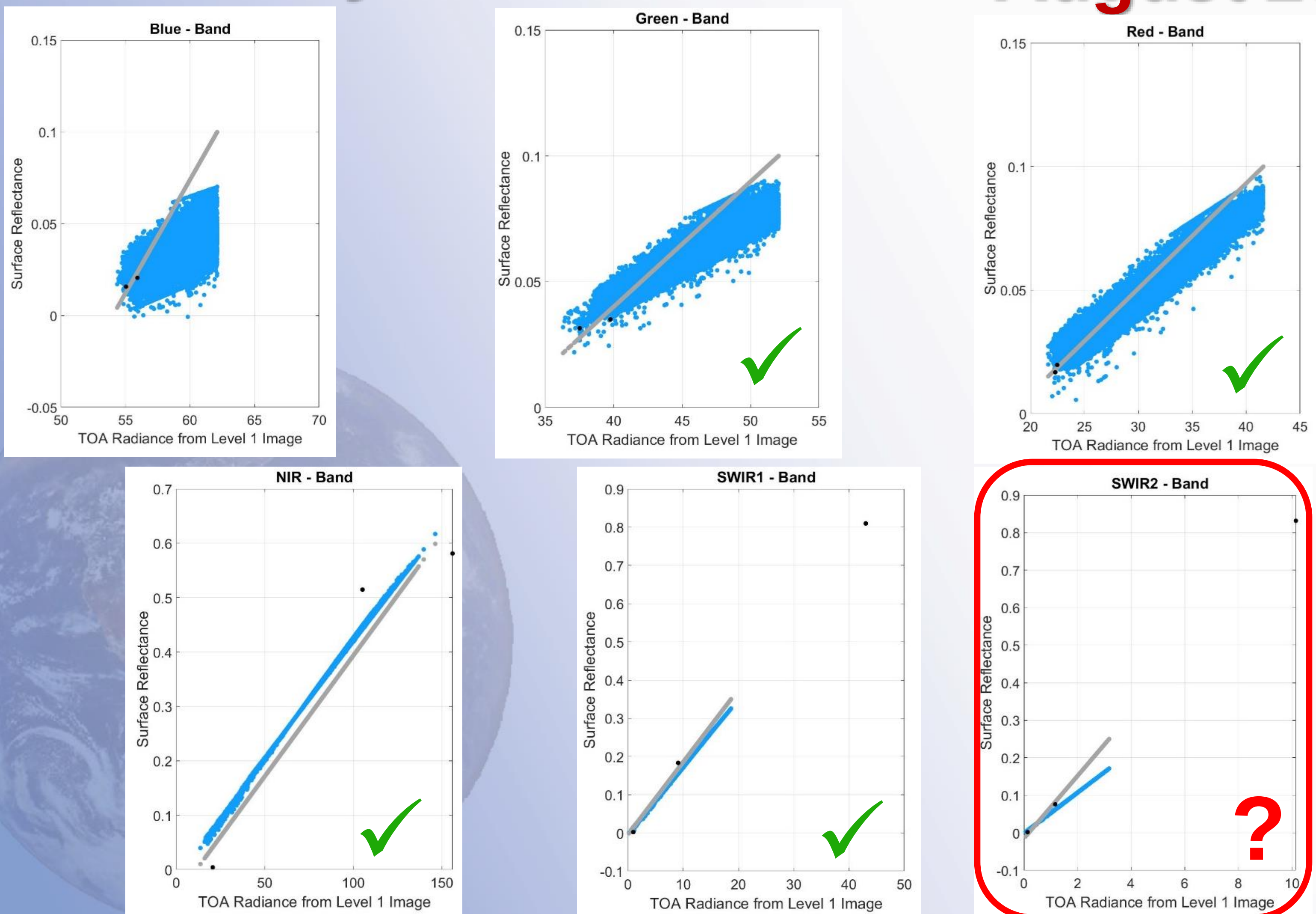
Red Landsat-8



Error:
-0.032 to 0.015
[~ -0.0006]

Mirror-based Empirical Line Method

Preliminary Results Landsat-8 August 23, 2020

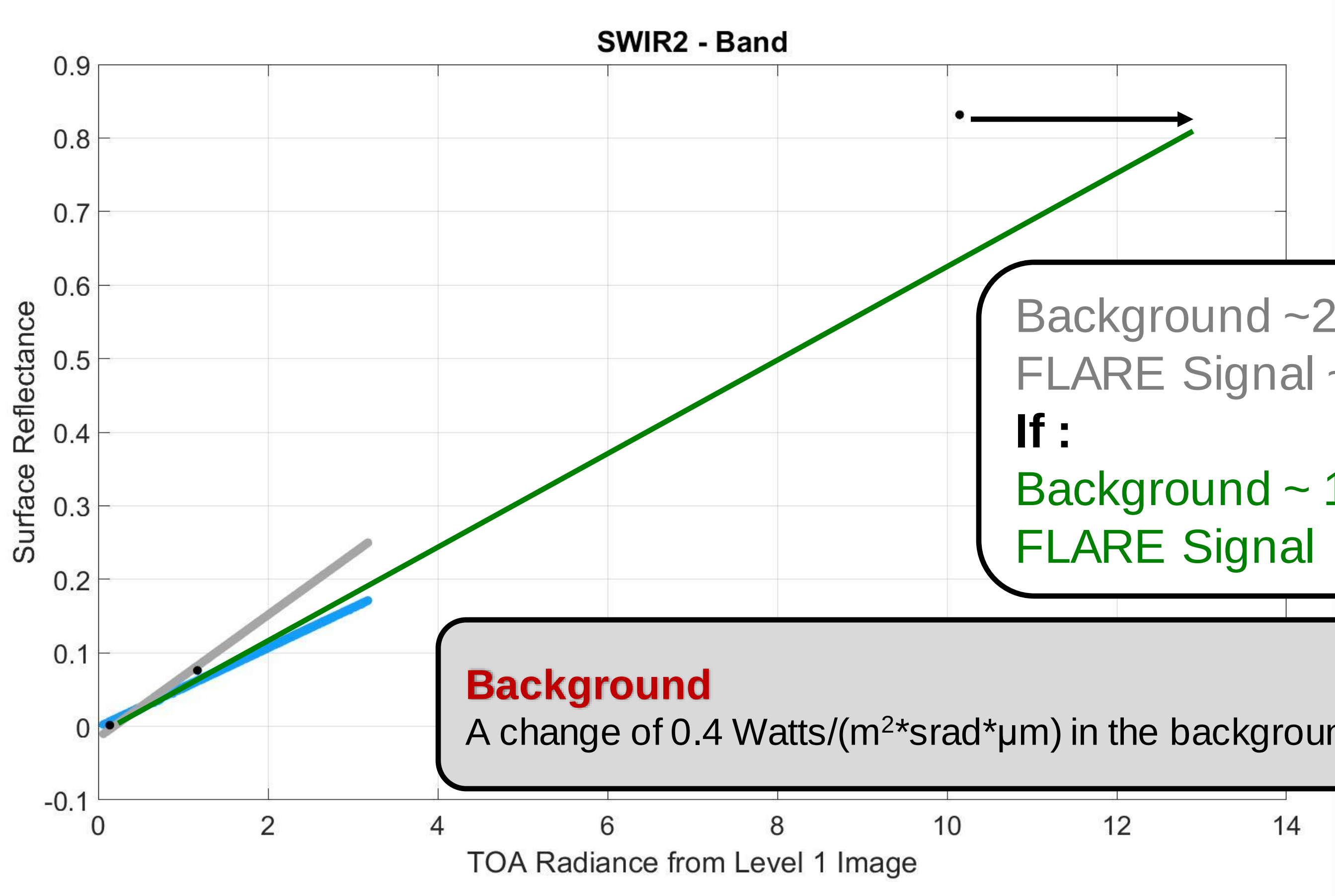


Mirror-based Empirical Line Method

Preliminary Results

August 23, 2020

SWIR2 Landsat-8



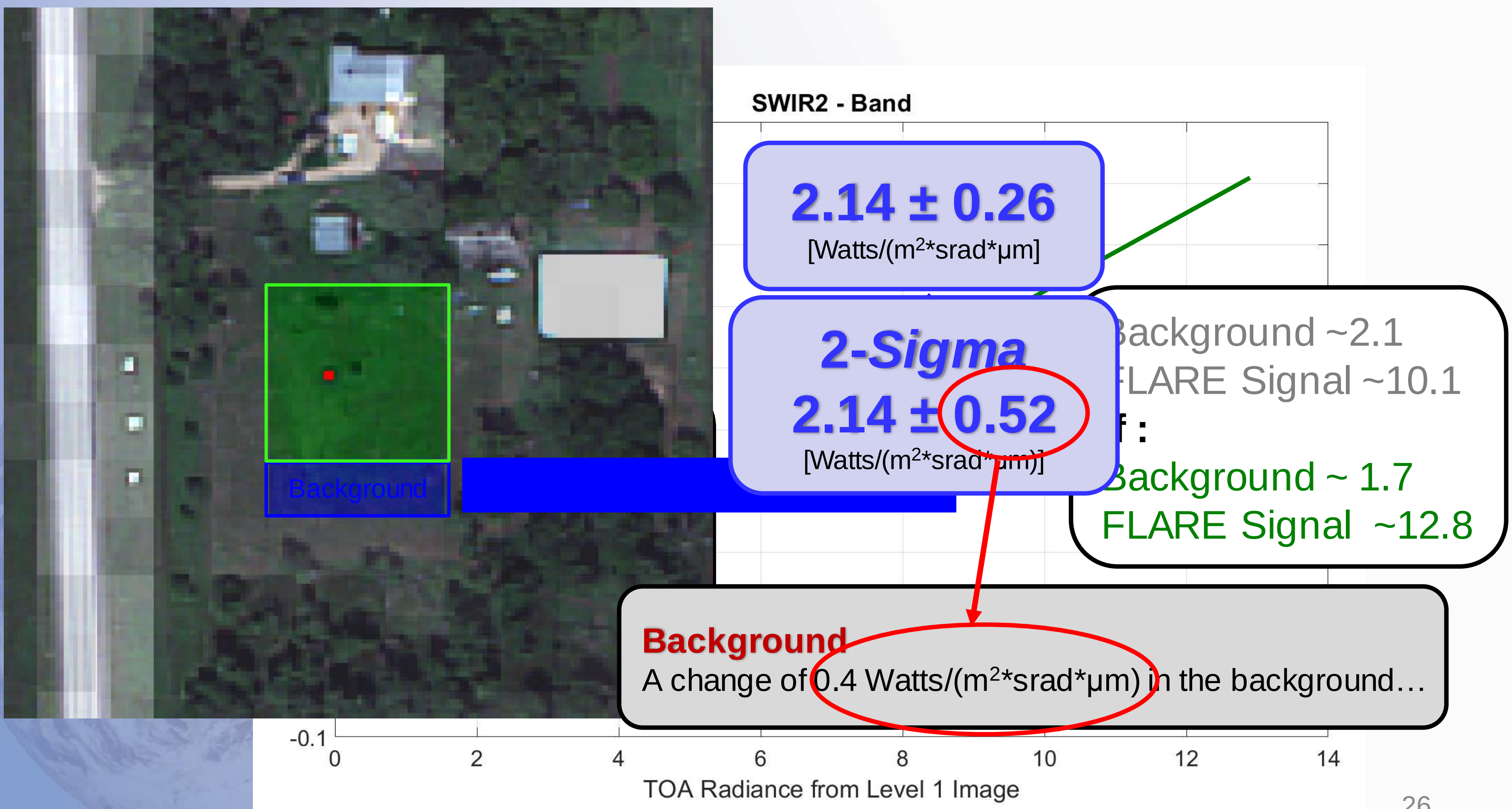
Background ~2.1
FLARE Signal ~10.1
If :
Background ~ 1.7
FLARE Signal ~12.8

Background
A change of 0.4 Watts/(m^2*srad*μm) in the background…

Mirror-based Empirical Line Method

Preliminary Results

August 23, 2020



Mirror-based Empirical Line Method

Preliminary Results Landsat-8

Summary → August 23, 2020

Mean Error

$$ME = \frac{1}{n}\sum_{i=1}^{n}(Y_i - \hat{Y}_i)$$

Mean Absolute Error

$$MAE = \frac{1}{n}\sum_{i=1}^{n}|Y_i - \hat{Y}_i|$$

Band	ME	MAE
CA	-0.133	0.136
Bl[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
SWIR-1	-0.013	0.013
SWIR-2	-0.032	0.033
All Bands	**-0.007**	**0.018**

[except the CA]

0.800 ± 0.018 (2.3%)

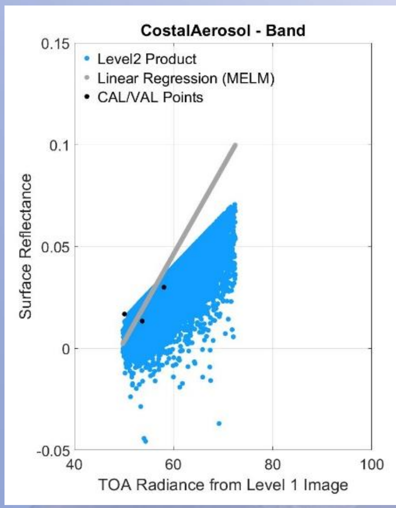
0.400 ± 0.018 (4.5%)

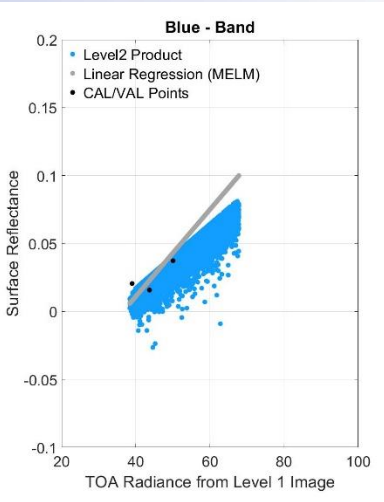
[reflectance units]

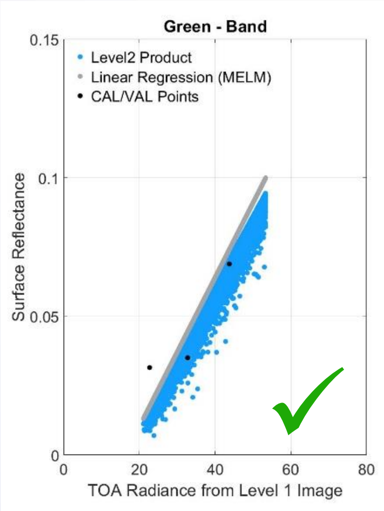
***Error** → (Surface Reflectance from Level 2 Product) – (Surface Reflectance from MELM)

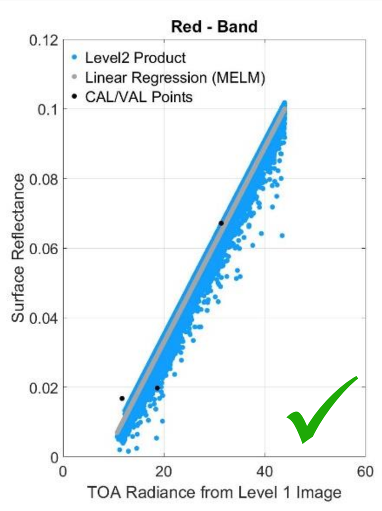
Mirror-based Empirical Line Method

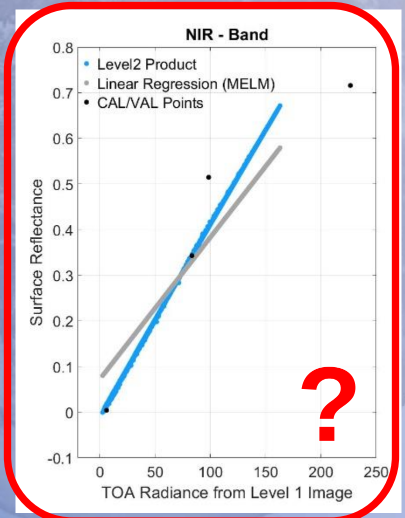
Preliminary Results Landsat-8 August 16, 2020

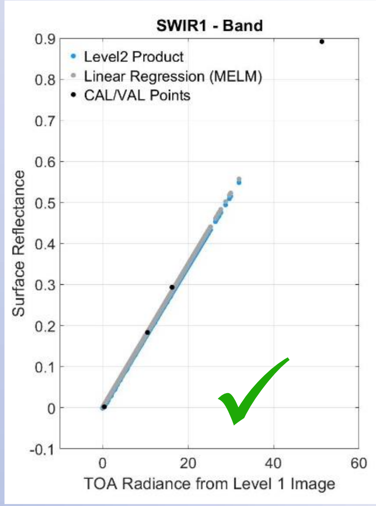


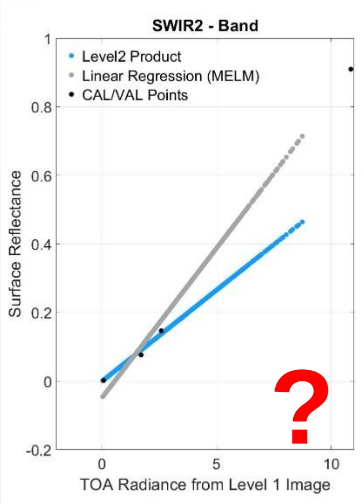










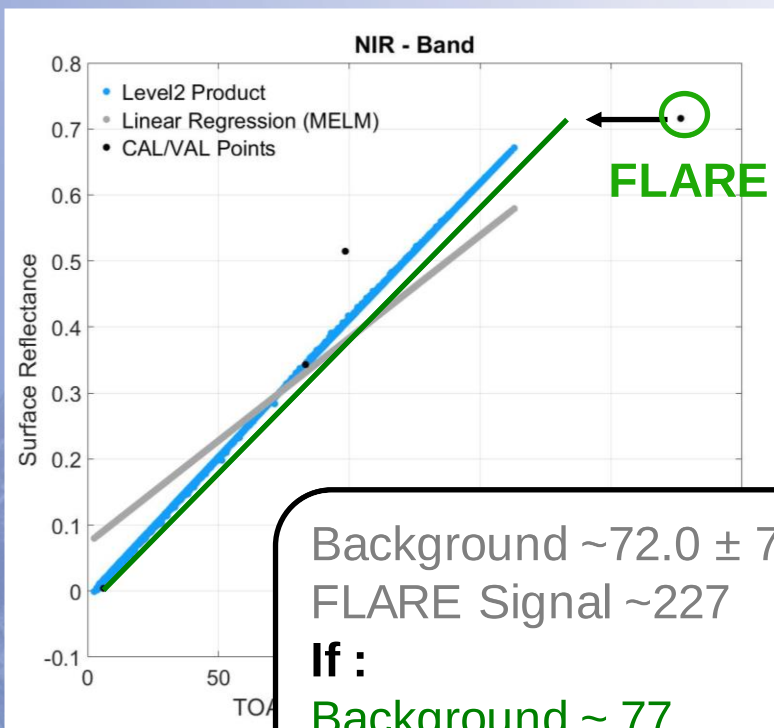


Mirror-based Empirical Line Method

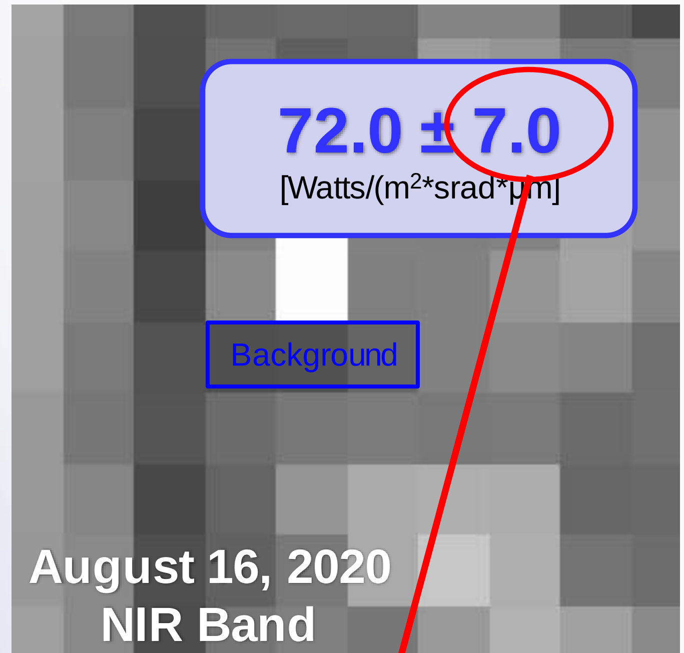
Preliminary Results

August 16, 2020

Landsat-8



Background ~72.0 ± 7.0
FLARE Signal ~227
If :
Background ~ 77
FLARE Signal ~196

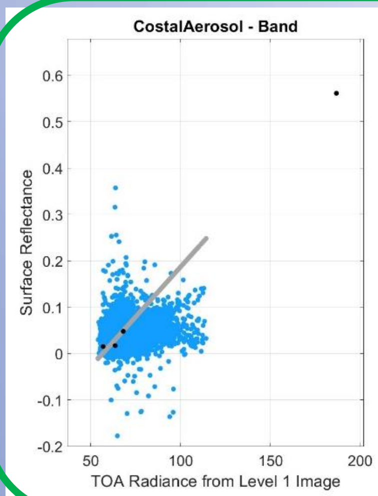


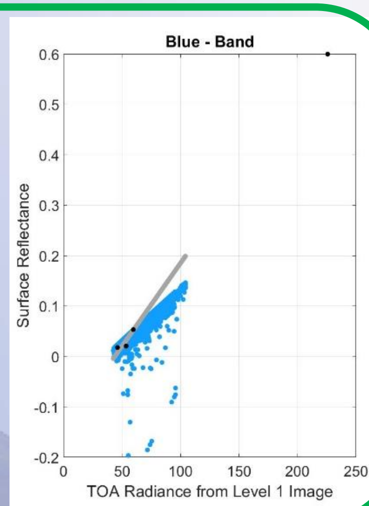
Background
A change of 5 Watts/(m^2*srad*µm) in the background.

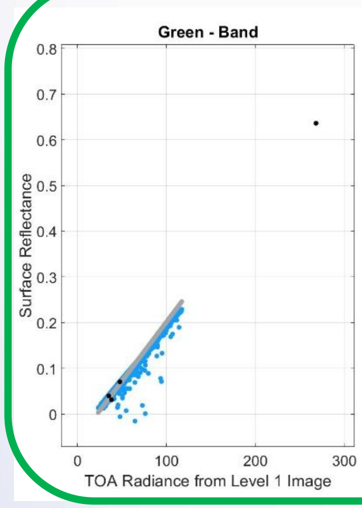
Radiance units: [Watts/(m^2*srad*µm)]

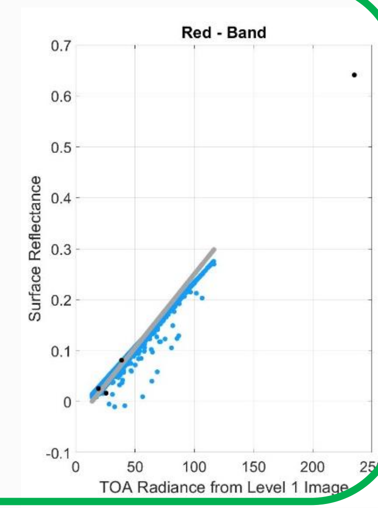
Mirror-based Empirical Line Method

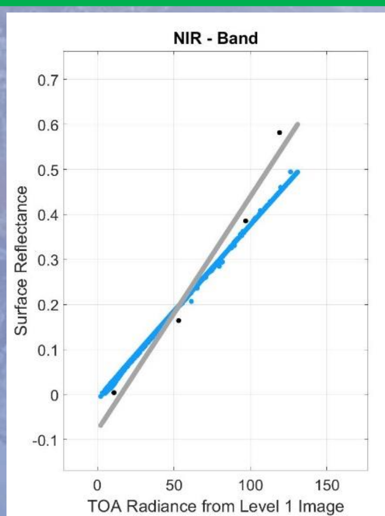
Preliminary Results Landsat-8 May, 31 2021

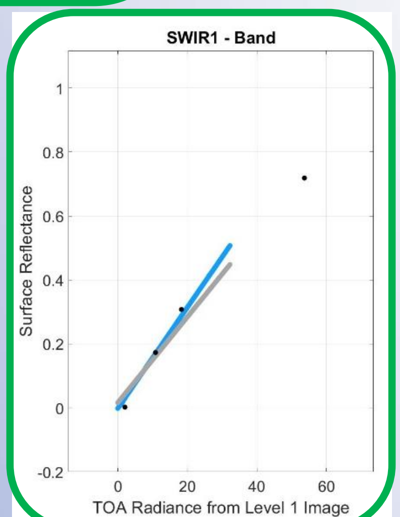


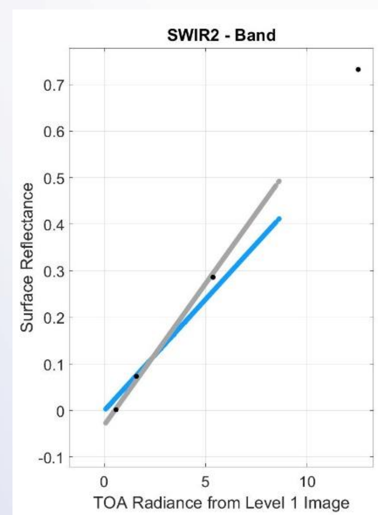






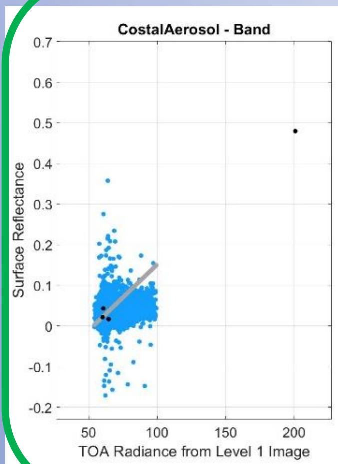


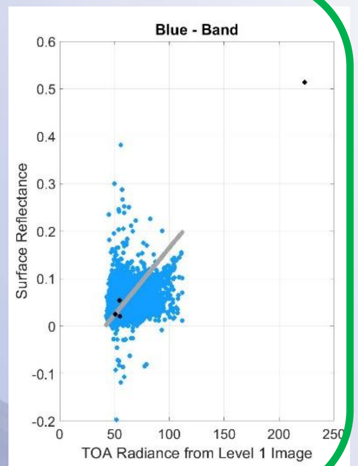


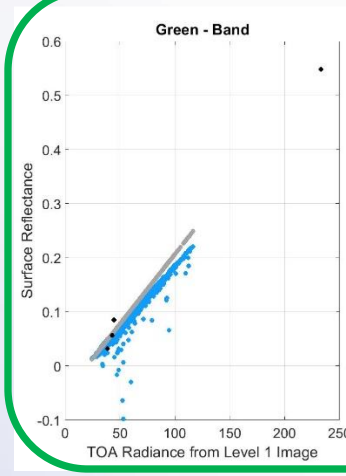


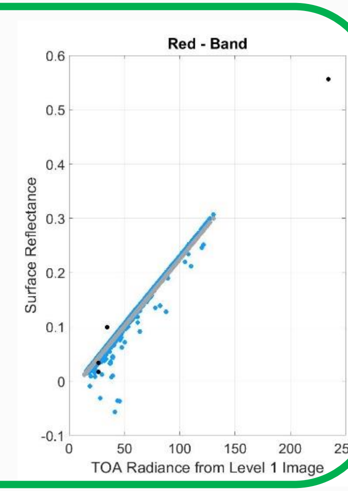
Mirror-based Empirical Line Method

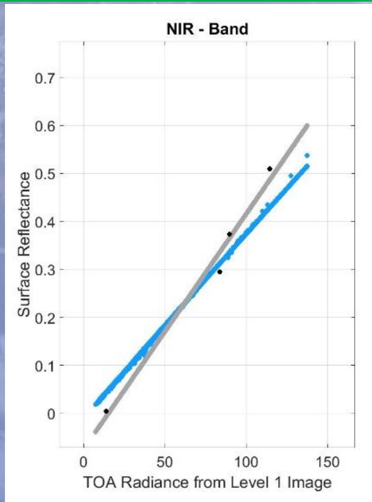
Preliminary Results Landsat-8 June, 23 2021

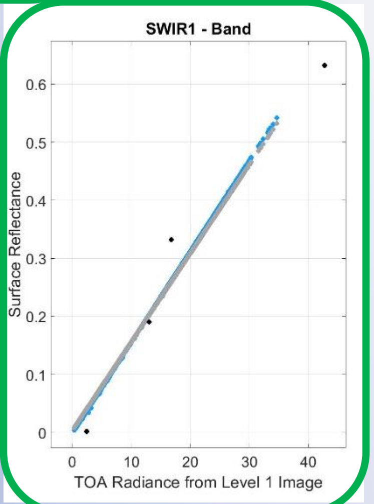


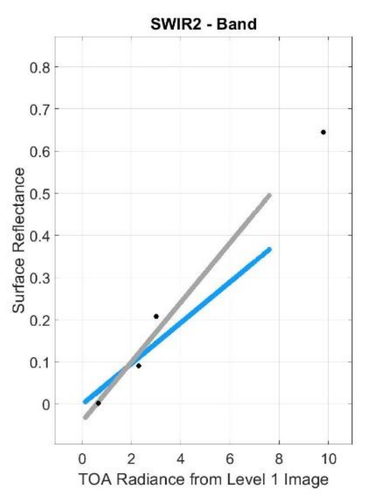












Mirror-based Empirical Line Method

Landsat-8 — Summary

- ✓ In 2020 the vegetation around FLARE was removed and then replanted;
- ✓ The area around FLARE was more homogeneous in **2021** - consequently the background signal estimation is more accurate.

The average error considering all spectral bands has been reduced:

2020	2021
MAE → ± 0.024 [reflectance units]	**MAE → ± 0.017** [reflectance units]
0.8 ± 0.024 → 3.0%	**0.8 ± 0.017 → 2.1%**
0.4 ± 0.024 → 6.0%	**0.4 ± 0.017 → 4.3%**

*Error → (Surface Reflectance from Level 2 Product) – (Surface Reflectance from MELM)

Mirror-based Empirical Line Method

Sentinel-2 → Bands 10m & 20 m

Sentinel-2 Bands	Central Wavelength (µm)	Resolution (m)
Band 1 - Coastal aerosol	0.443	60
Band 2 - Blue	0.490	10
Band 3 - Green	0.560	10
Band 4 - Red	0.665	10
Band 5 - Vegetation Red Edge	0.705	20
Band 6 - Vegetation Red Edge	0.740	20
Band 7 - Vegetation Red Edge	0.783	20
Band 8 - NIR	0.842	10
Band 8A - Vegetation Red Edge	0.865	20
Band 9 - Water vapour	0.945	60
Band 10 - SWIR - Cirrus	1.375	60
Band 11 - SWIR	1.610	20
Band 12 - SWIR	2.190	20

→ 9 pixels impacted by the FLARE system;

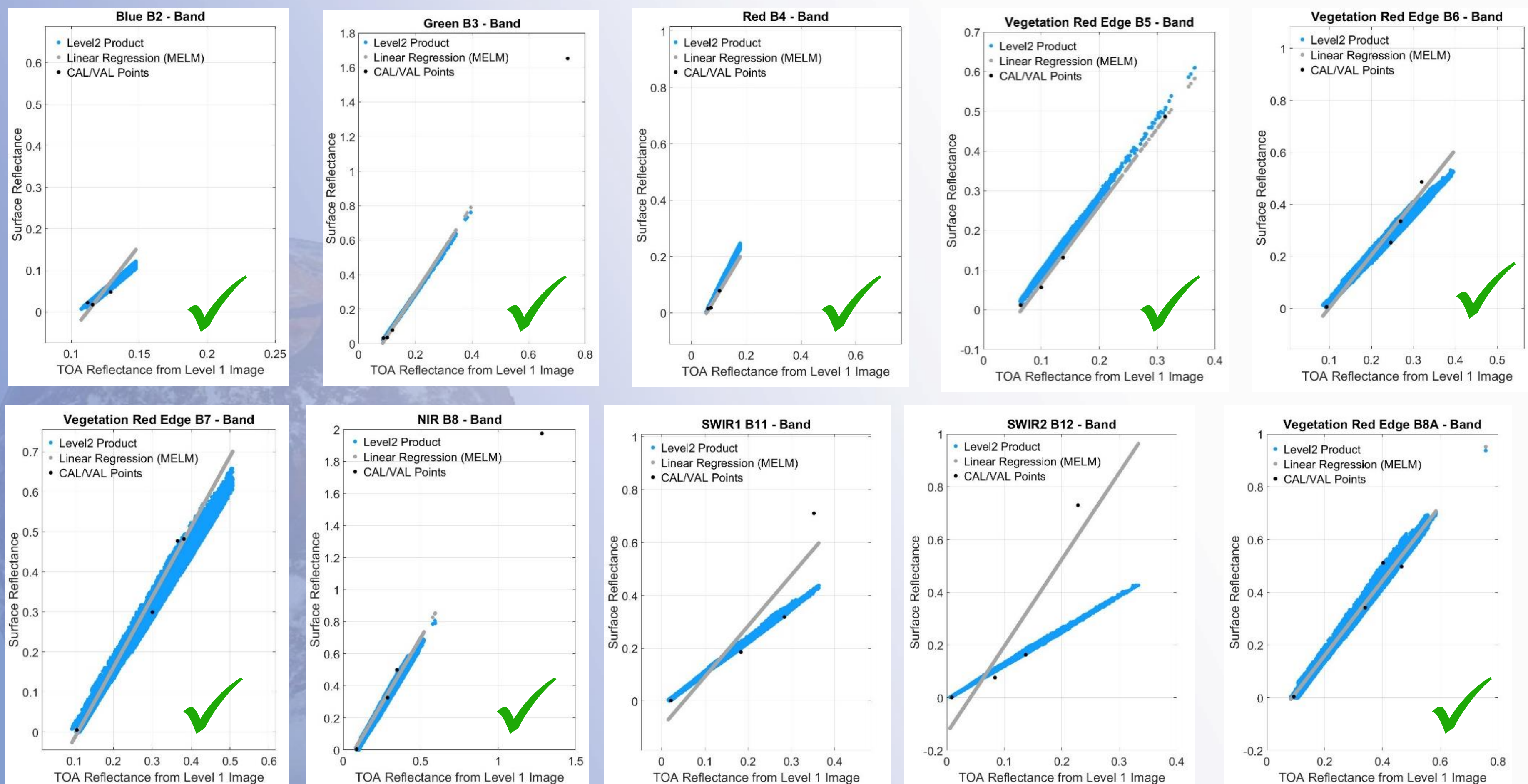
→ 4 pixels impacted by the FLARE system;

Mirror-based Empirical Line Method

Preliminary Results

August 25, 2020

Spectral Bands - Sentinel

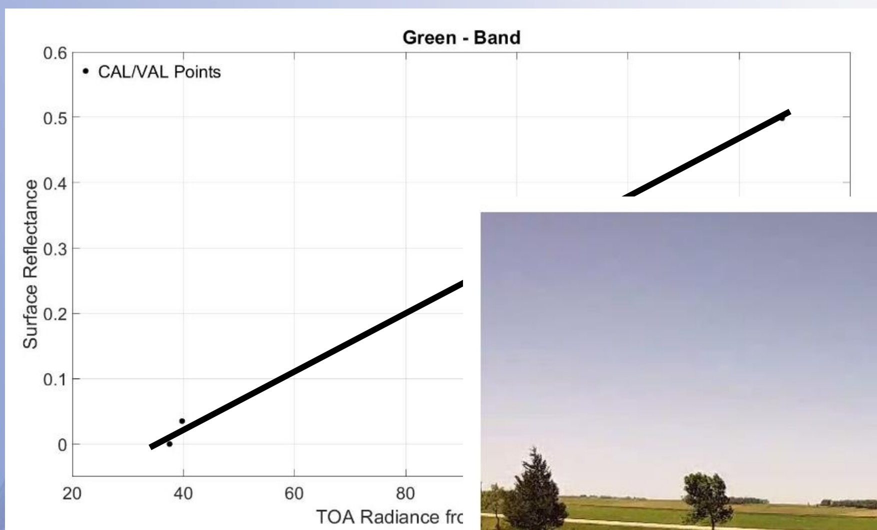


Future Work: Two Mirror Systems

Two mirror systems may eliminate the need to know the background value:

[but it MUST be exactly the same background - which may be hard to achieve]

$$slope = \frac{\rho_{surface\_diffuse\_mirror2} - \rho_{surface\_diffuse\_mirror1}}{L_{Image2} - L_{Image1}}$$



2022 Lantern Flare

$$slope = \frac{\Delta_Y}{\sum_1^n \left(L_{n\_mirror2}\right) - \sum_1^n \left(L_{n\_mirror1}\right)}$$

Future Work

Final Considerations

- ✓ The Mirror-based Empirical Line Method (FLARE system) has great potential for evaluating Level-2 products;
- ✓ Two key information for surface reflectance validation (Level-2):

  (1) **Diffuse to Global Ratio** [Lambertian Equivalent Reflectance Factor]; and

  (2) **Background Signal** [leave only the signal coming from the mirrors];

- ✓ Then Mean Absolute Error considering all spectral bands was **0.024** and **0.017** in 2020 and 2021, respectively.
- ✓ The area around FLARE is even more homogeneous in **2022** - consequently the background signal estimation is more accurate.

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Preliminary Evaluation of the Mirror-Based Empirical Line Method using FLARE system (Surface Reflectance – Landsat Level 2)

SDSU Image Processing Laboratory

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Thank you!

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