Analysis of the performances of the LaSRC Land Surface Reflectance: Landsat 8,9 and Sentinel 2A,B and Cloud Mask

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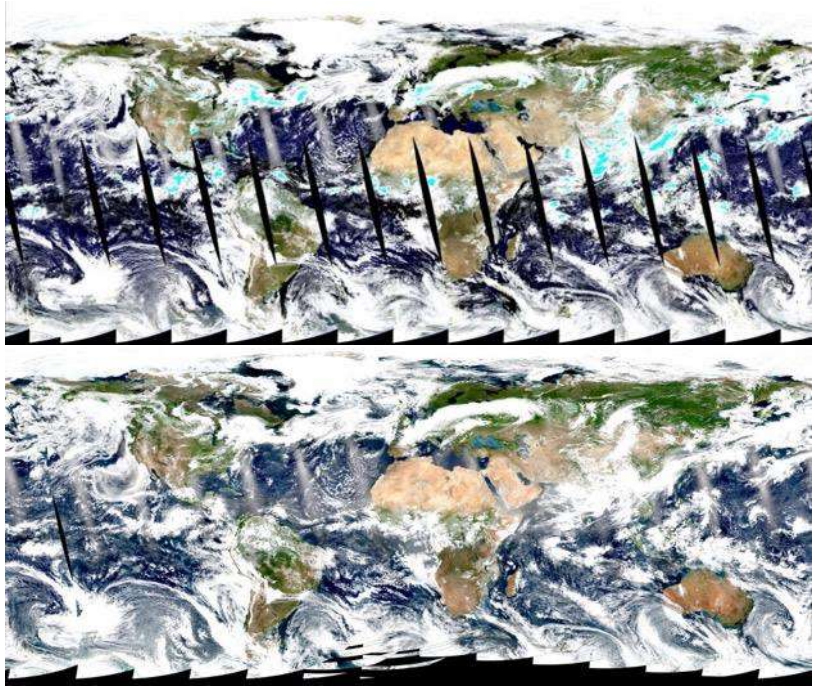
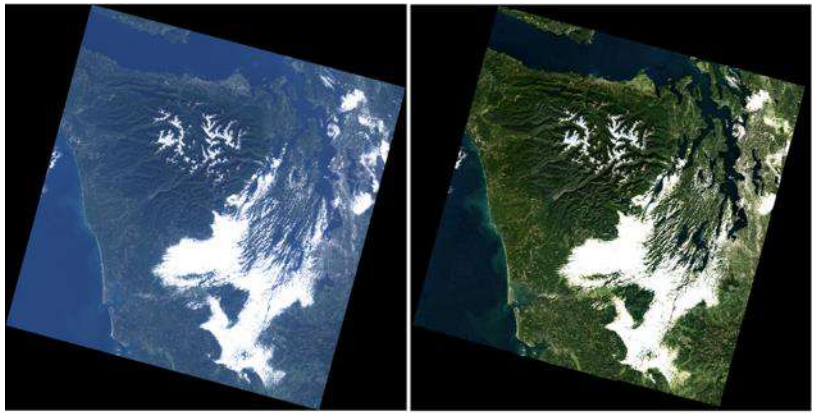
6th SENTINEL-2 VALIDATION TEAM MEETING 12-14 Sept 2023, ESRIN Frascati - Italy

Atmospheric correction (AC)

- Estimate of the **surface spectral reflectance**, as would have been measured at ground level if there were **no atmospheric scattering or absorption**
- Generic approach for AC for multiple sensors
- AC products for EO sensors:
  - MODIS (Terra, Aqua)
    - Products: MOD09, MYD09
  - VIIRS (S-NPP,JPSS1)
    - Products: VNP09
  - OLI (Landsat-8) and MSI (Sentinel-2)
    - LaSRC algorithm/product
    - Harmonization Landsat / Sentinel 2 (HLS) project
    - USGS' on demand SR product for OLI



A true color composite of MODIS/Aqua (*top*) and VIIRS/S-NPP (*bottom*) images acquired on July, 1, 2017



A true color composite of Landsat-8 image without AC (*left*) and with AC (*right*). Image is acquired on October, 14, 2013

Landsat8/OLI and Sentinel 2/MSI Surface Reflectance is largely based on MODIS C6 (LaSRC)

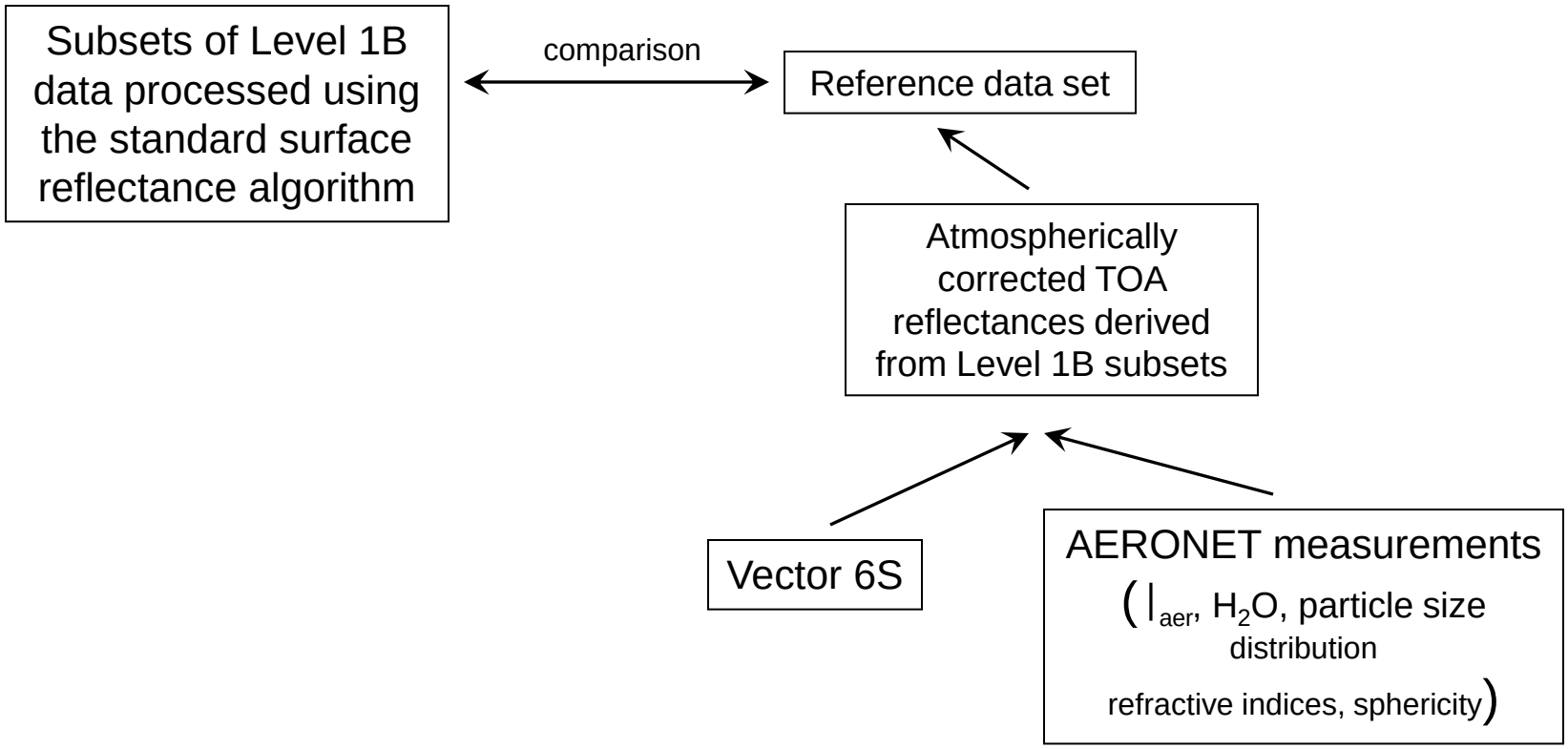
Algorithm reference for L8: Vermote E., Justice C., Claverie M., Franch B., (2016) “Preliminary analysis of the performance of the Landsat 8/OLI land surface reflectance product", Remote Sensing of Environment, 185,46-56.

The MODIS **Collection 6 AC algorithm** relies on

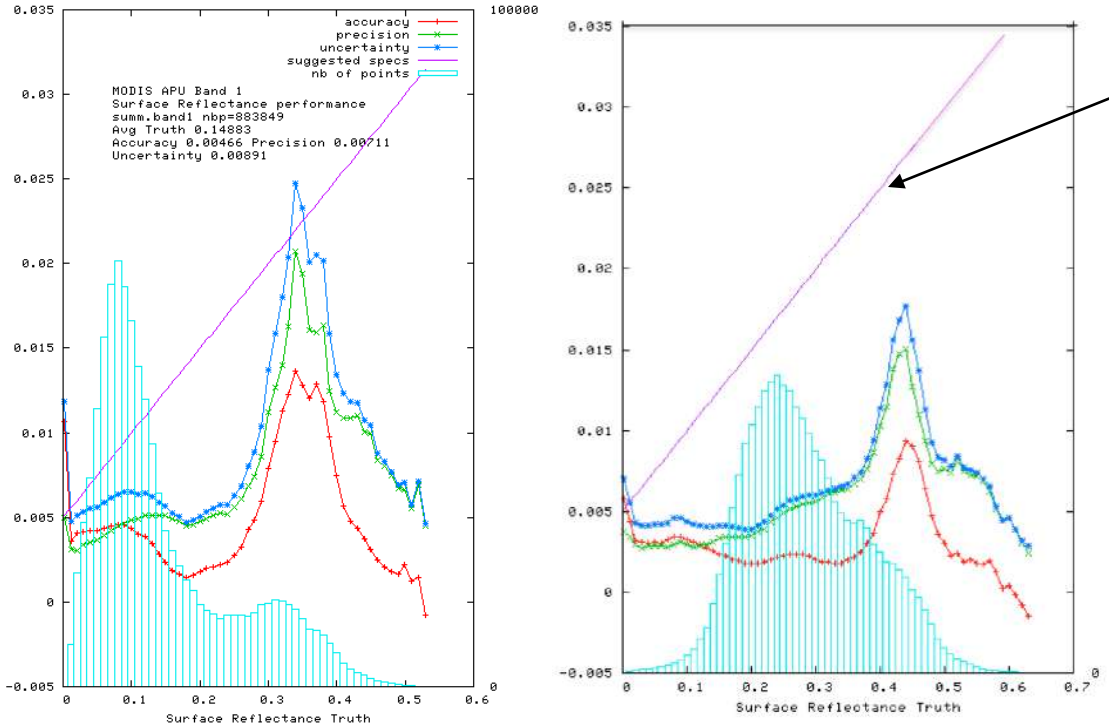
- the use of very accurate (better than 1%) vector radiative transfer modeling of the coupled atmosphere-surface system (6S)
- the inversion of key atmospheric parameters
  - ***Aerosols are retrieved from Landsat8/Sentinel 2 images***
  - ***Water vapor and ozone from daily MODIS product.***

Home page: http://modis-sr.ltdri.org

Methodology for evaluating the performance of Landsat8/Sentinel2 LaSRC product



quantitative assessment of performances (APU) for MODIS

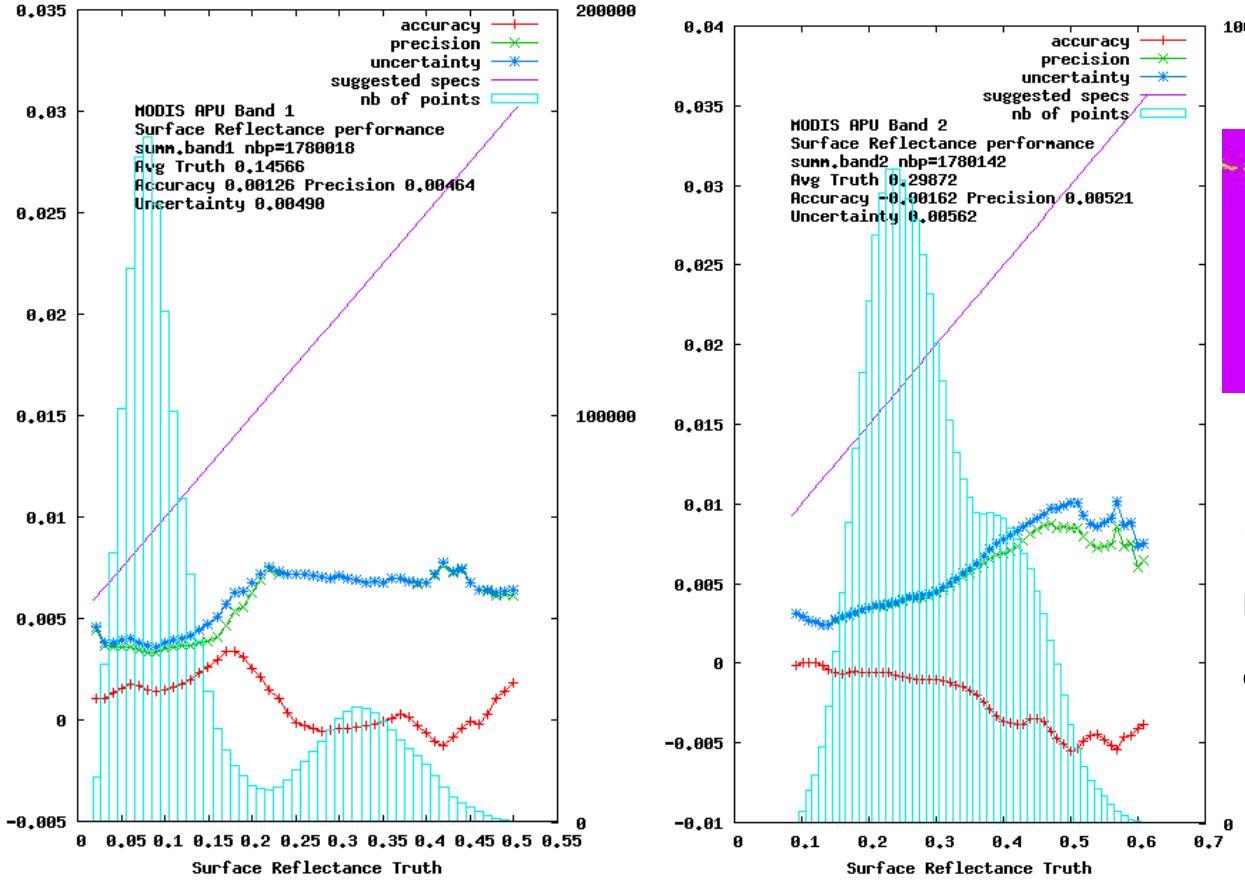


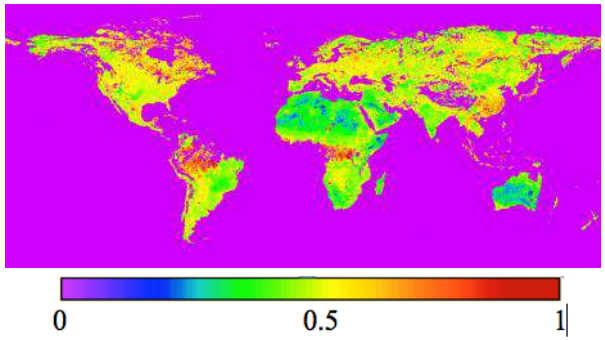
Specification:
Based on error budget for collection 4

E. Vermote and S. Y. Kotchenova, MODIS Directional surface reflectance product: Method, error estimates and validation. 2011. Land Remote Sensing and Global Environmental Change: NASA's Earth Observing System and the Science of ASTER and MODIS. Series: Remote Sensing and Digital Image Processing, Vol. 11, Springer Verlag. 873p. ISBN: 978-1-4419-6748-0

COLLECTION 5: accuracy or mean bias (red line), Precision or repeatability (green line) and Uncertainty or quadratic sum of Accuracy and Precision (blue line) of the surface reflectance in band 1 in the Red (top left), band 2 in the Near Infrared (top right also shown is the uncertainty specification (the line in magenta), that was derived from the theoretical error budget. Data collected from Terra over 200 AERONET sites from 2000 to 2009.

Improving the aerosol retrieval in collection 6 reflected in APU metrics

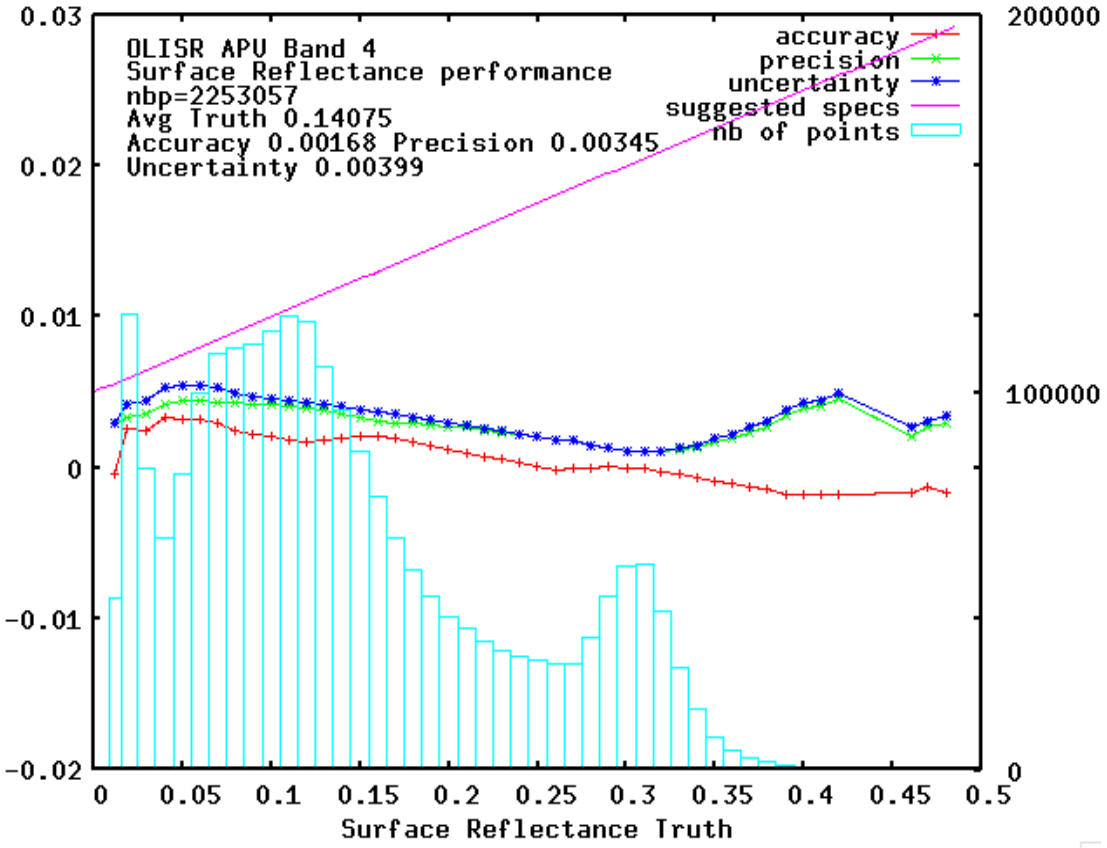




ratio band3/band1 derived using MODIS top of the atmosphere corrected with MISR aerosol optical depth

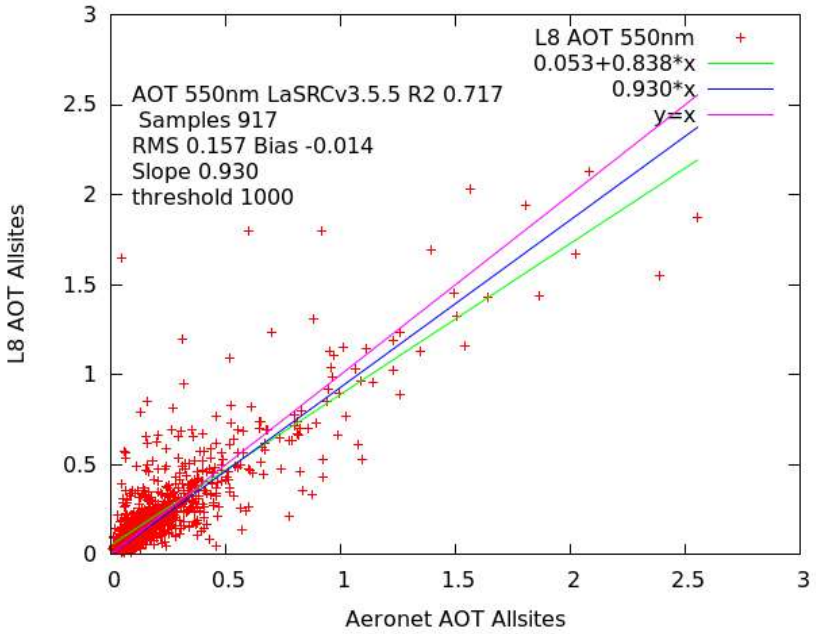
COLLECTION 6: accuracy or mean bias (red line), Precision or repeatability (green line) and Uncertainty or quadratic sum of Accuracy and Precision (blue line) of the surface reflectance in band 1 in the Red (top left), band 2 in the Near Infrared (top right also shown is the uncertainty specification (the line in magenta), that was derived from the theoretical error budget. Data collected from Terra over 200 AERONET sites for the whole Terra mission.

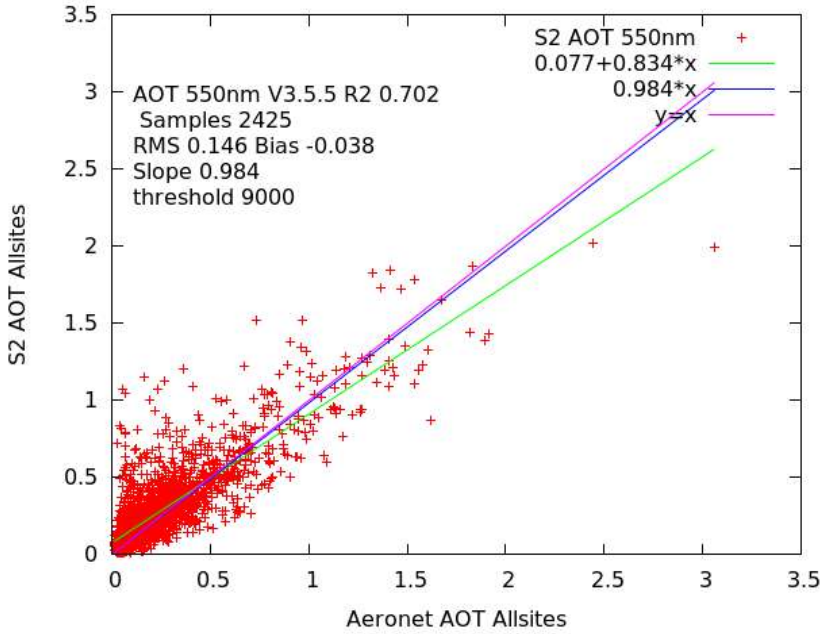
Evaluation of the performance of Landsat8



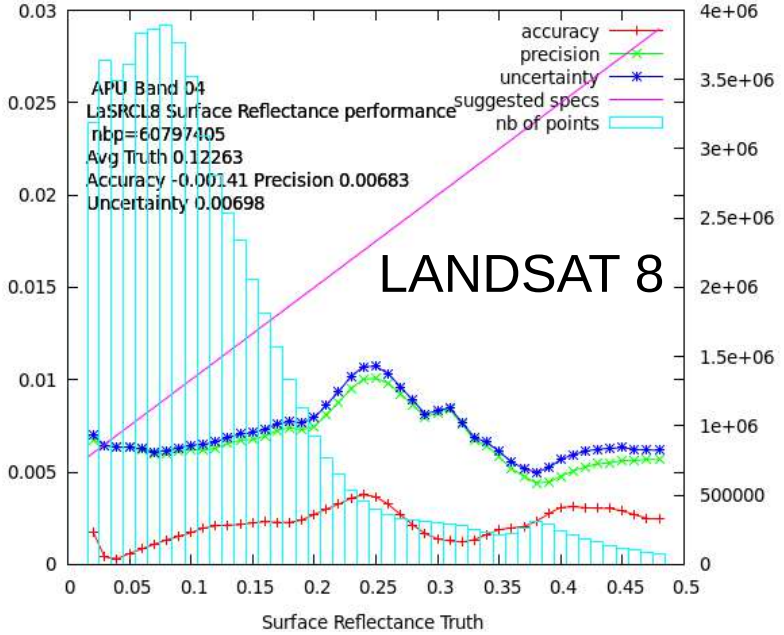
The “preliminary” analysis of OLI SR performance in the red band over AERONET is very similar to MODIS Collection 6

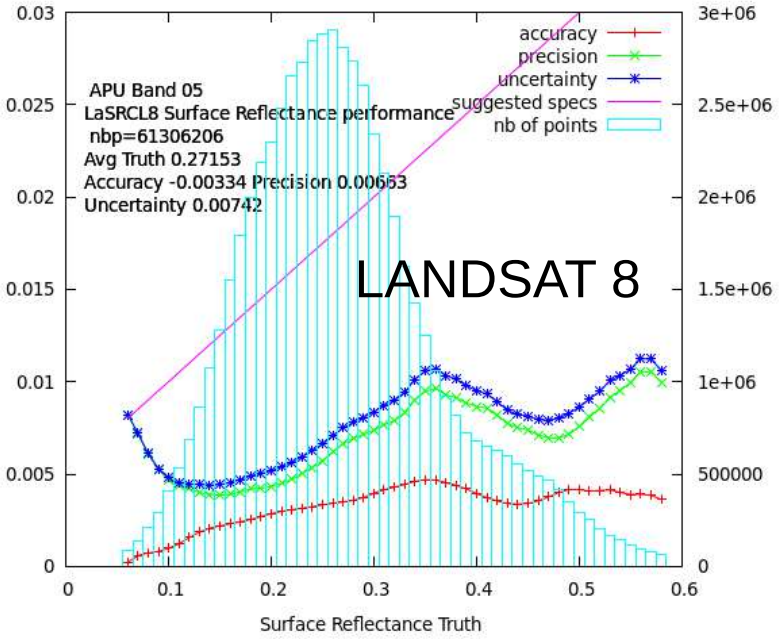
LaSRC AOT Results on ACIX-II

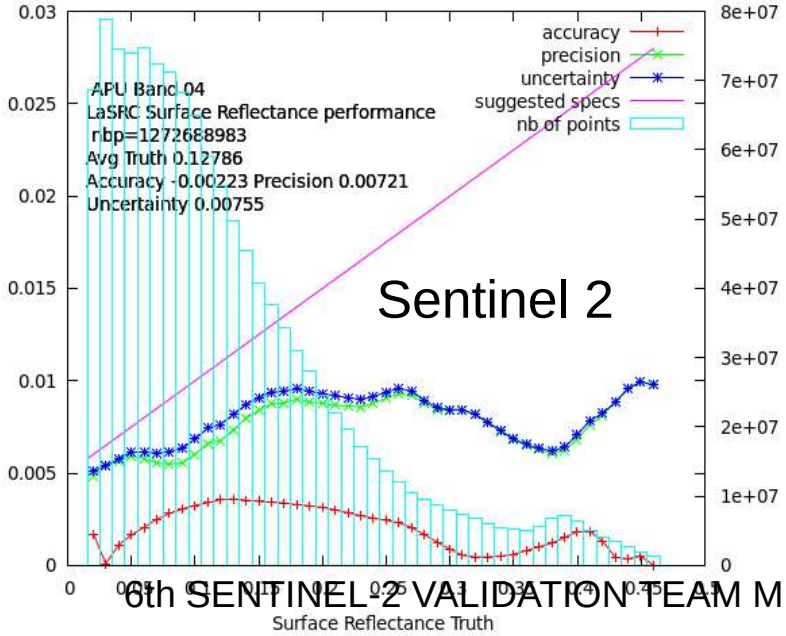


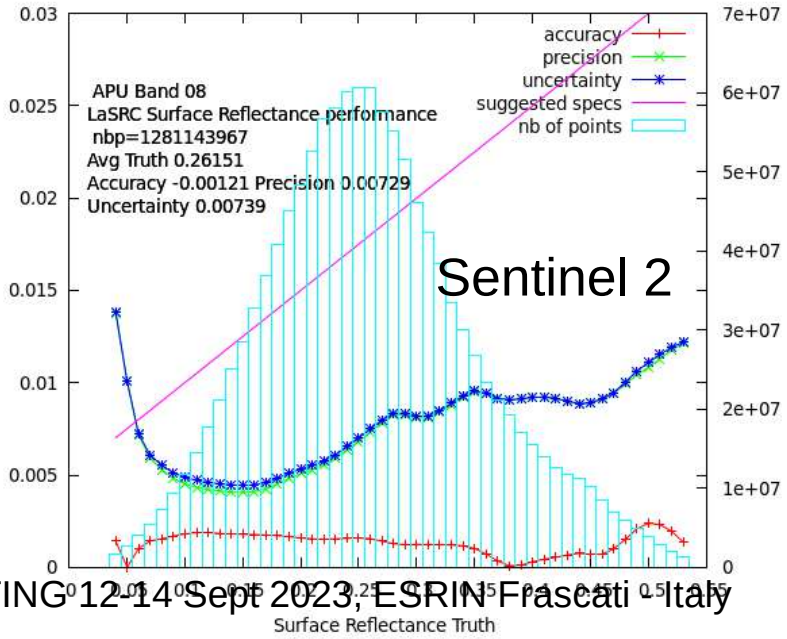


LaSRC APU results on ACIX-II







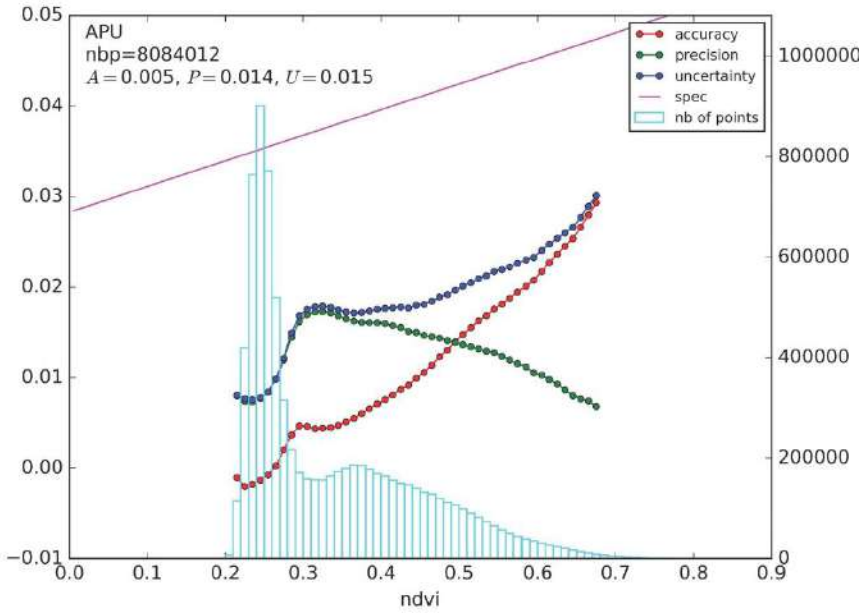


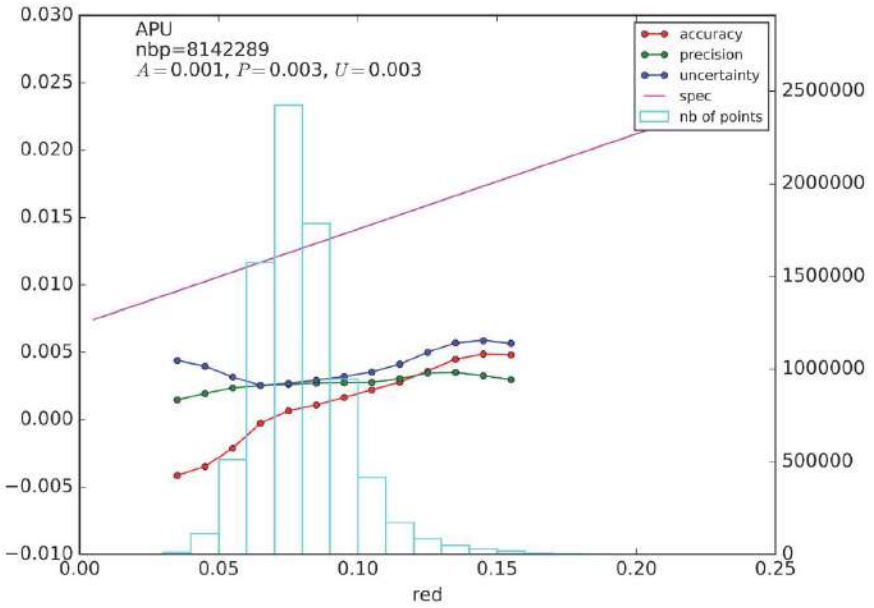
This is confirmed by comparison with MODIS

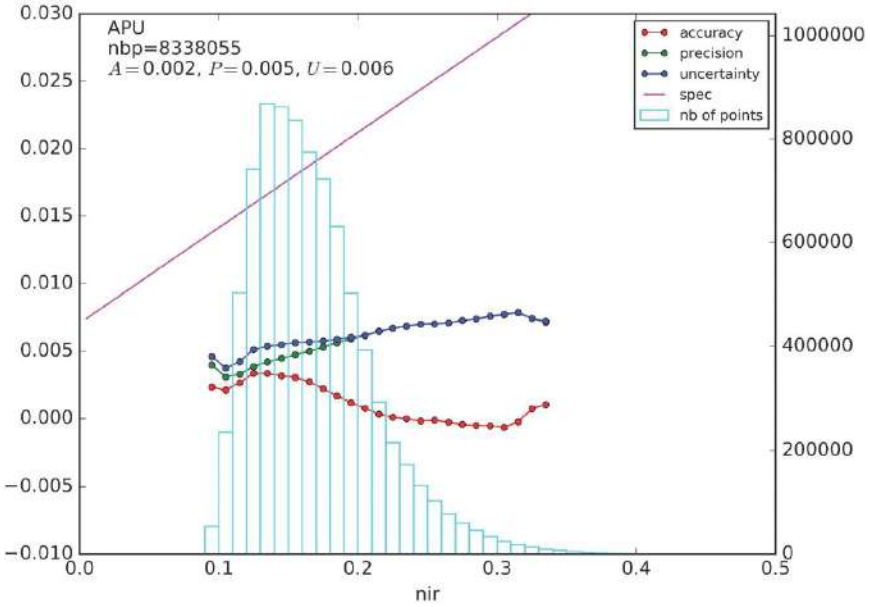
OLI Band	TM LEDAPS (Claverie et al., 2015)			ETM+ LEDAPS (Claverie et al., 2015)			OLI (Vermote et al., 2016)		
	A	P	**U**	A	P	**U**	A	P	**U**
2	7	9	**11**	9	7	**12**	2	6	**6**
3	1	9	**9**	6	9	**11**	3	6	**7**
4	9	10	**14**	1	9	**9**	1	6	**6**
5	5	17	**17**	3	14	**15**	2	12	**12**
7	1	14	**14**	5	15	**16**	9	11	**14**

OLI surface reflectance APU scores expressed in 10^{-3} reflectance (compared to TM and ETM+ surface reflectance APU by Claverie et al. (2015) using Aqua MODIS BRDF and spectrally adjusted surface reflectance CMG product as reference, the OLI surface reflectance was aggregated over the CMG. Band number corresponds to OLI band number designation and equivalent TM/ETM+ bands were reported.

Use of combined L8/S2A also confirmed ACIX results







The accuracy, precision and uncertainty (APU) values estimated when inter-comparing atmospherically corrected images acquired by Landsat-8/OLI and Sentinel-2A/MSI satellites

Skakun, S., Vermote, E., Roger, J.C. and Franch, B., 2017. Combined Use of Landsat-8 and Sentinel-2A Images for Winter Crop Mapping and Winter Wheat Yield Assessment at Regional Scale. AIMS Geosciences, 3(2), pp.163-186.

Use of combined L8/S2A also confirmed ACIX results

Table 1. Comparison of satellite-derived winter crop areas with official statistics on harvested areas at district level. Estimates of the *APU* metrics are given in ha.

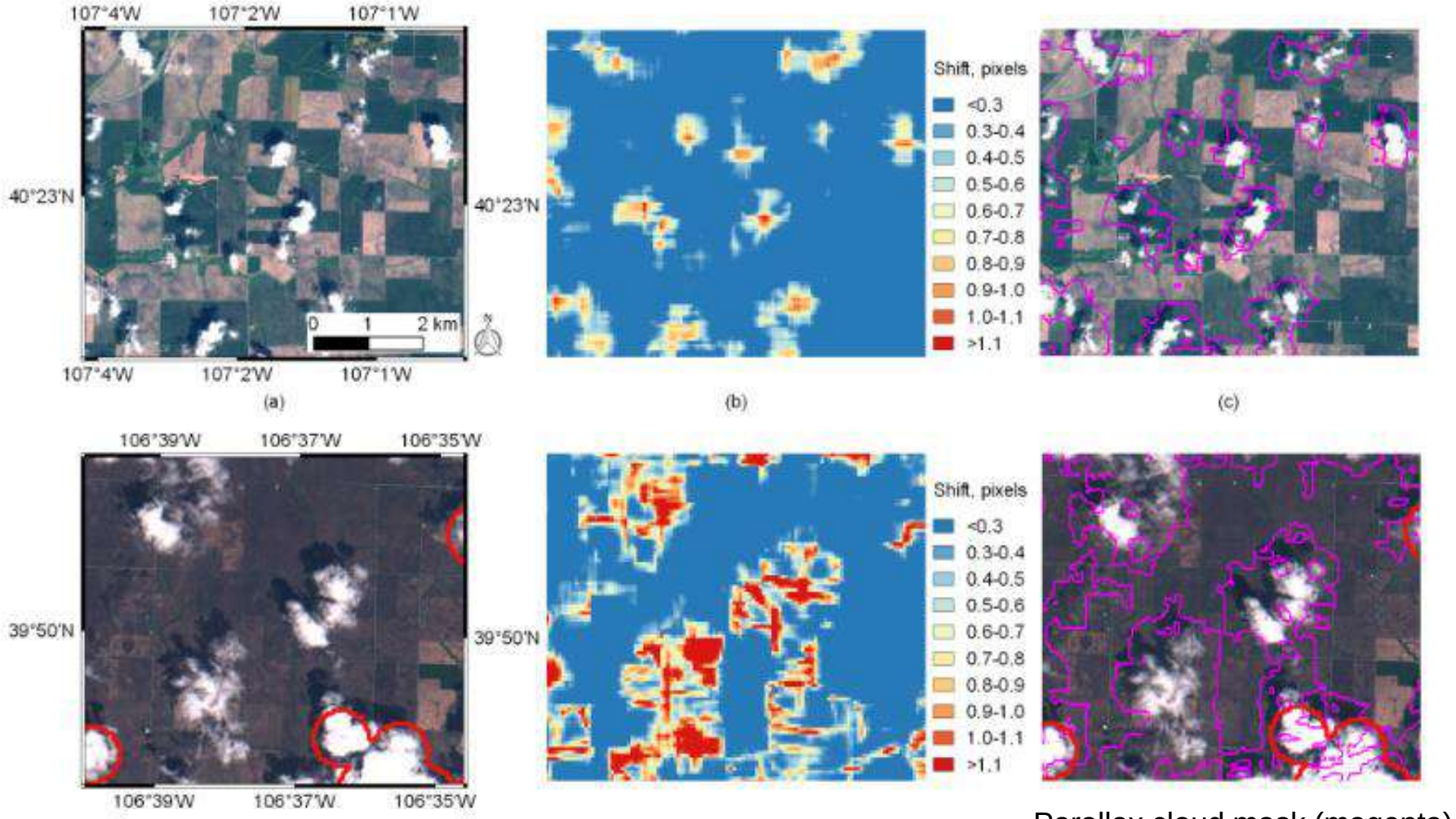
Metric	LC8-S2A	LC8	S2A
A	612	1081	839
P	1719	5061	1962
U	1785	5056	2090
rU, %	11.6	32.7	13.5
R^2	0.90	0.64	0.88

Table 2. Comparison of satellite-derived winter wheat yields with official statistics at district level without using GDD and using GDD. Estimates of the *APU* metrics are given in t/ha.

	No GDD			GDD		
Metric	LC8-S2A	LC8	S2A	LC8-S2A	LC8	S2A
A	-0.17	-0.48	-0.34	-0.06	-0.40	-0.22
P	0.26	0.31	0.32	0.26	0.31	0.32
U	0.31	0.57	0.46	0.26	0.50	0.38
rU, %	7.7	14.3	11.5	6.5	12.5	9.6
R^2	0.45	0.29	0.28	0.50	0.31	0.24

Skakun, S., Vermote, E., Roger, J.C. and Franch, B., 2017. Combined Use of Landsat-8 and Sentinel-2A Images for Winter Crop Mapping and Winter Wheat Yield Assessment at Regional Scale. AIMS Geosciences, 3(2), pp.163-186.

Sentinel 2 has “features” that help improving the SR product (e.g cloud mask)



L1C cloud mask (red)

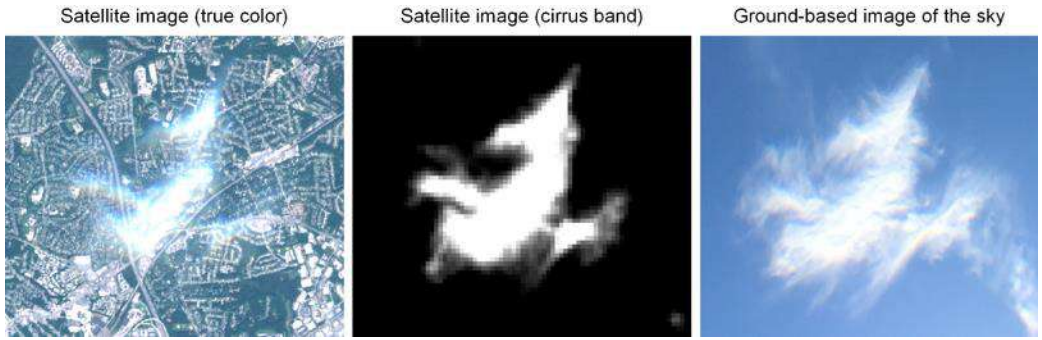
Shift between band 4 and 2

Parallax cloud mask (magenta)

Skakun, S., Vermote, E., Roger, J.C. and Justice, C., 2017. Multispectral Misregistration of Sentinel-2A Images: Analysis and Implications for Potential Applications. *IEEE Geoscience and Remote Sensing Letters*, *14*(12), pp.2408-2412.

Cloud validation: SkyCam

- Ground-based skycam
  - For objective validation of satellite-derived cloud masks
  - Proof of concept: manual iphone with fisheye lens over NASA GSFC
  - Current version: automatic, enabling replication over multiple sites
  - Part of validation dataset within CEOS CMIX-1 (Cloud Masking Inter-comparison Exercise)



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journal homepage: www.elsevier.com/locate/jag

An experimental sky-image-derived cloud validation dataset for Sentinel-2 and Landsat 8 satellites over NASA GSFC

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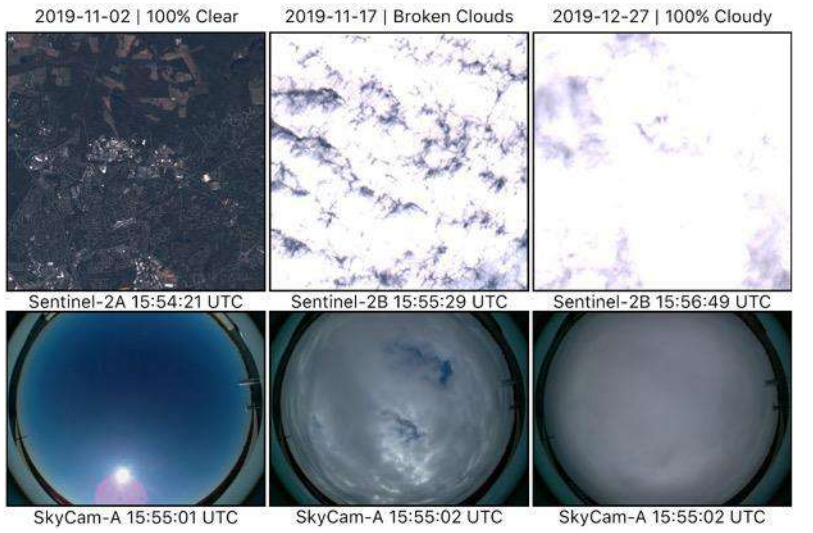
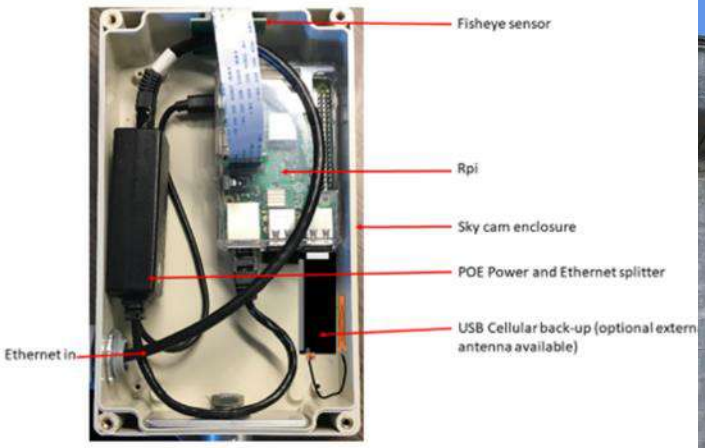
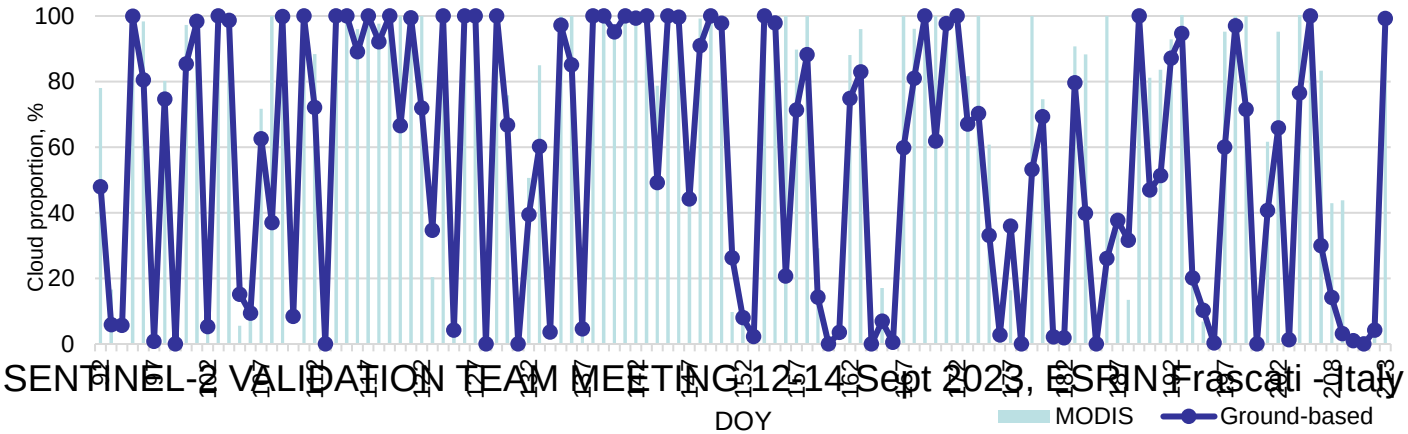
[a] Department of Geographical Sciences, University of Maryland, College Park, MD 20742, USA
[b] College of Information Studies (iSchool), University of Maryland, College Park, MD 20742, USA
[c] NASA Goddard Space Flight Center Code 619, 8800 Greenbelt Road, Greenbelt, MD 20771, USA



SkyCam system @ NASA/GSFC





12 cm

20 cm

Self-contained system:

RGB camera
~180-degree lens
Single board computer (Raspberry-Pi)
Power delivery (POE/Alternatives)
Weatherproof* enclosure (IP66/IP67)
Weight ~750g per unit.

7.5 cm

Power:

Power over ethernet.

Power over USB (5V/3.0A)

Data collection and management:

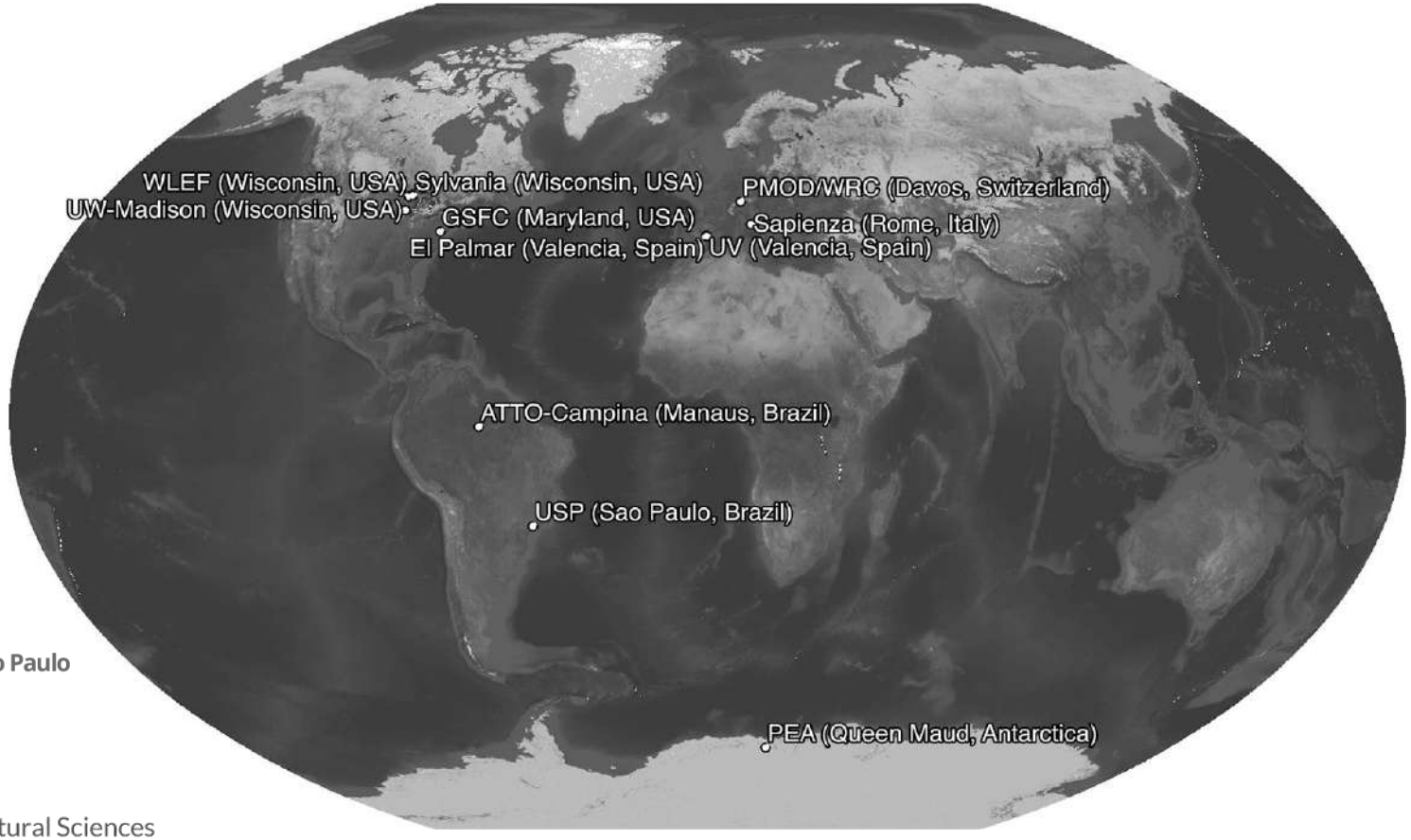
- Remotely via internet (WIFI/Ethernet).
- Locally via direct connection (WIFI/Ethernet).
- Locally via included USB drive.

Ideally two cameras installed per location.

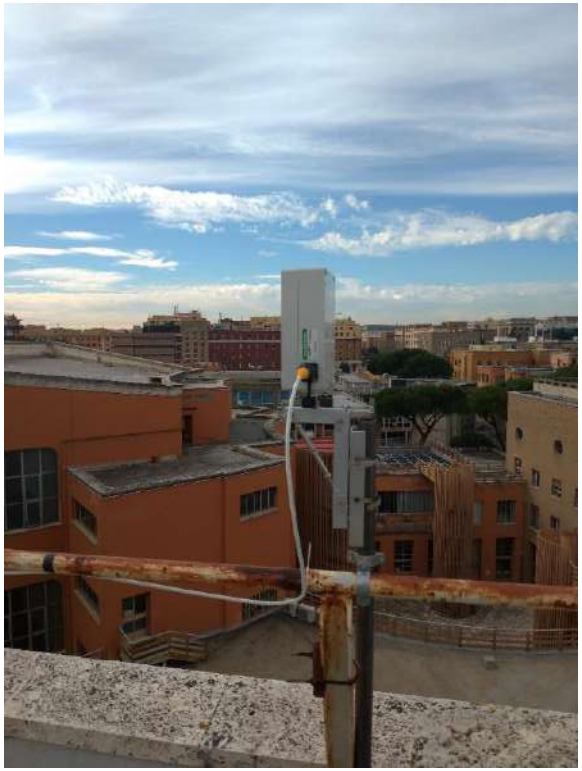
Skycam current and *near future* deployment (dual camera)

GSFC, Greenbelt, Maryland, USA
Sapienza University, Rome, Italy
Valencia University, Valencia, Spain
Sao Paulo University, Sao Paulo, Brazil
Princess Elisabeth Station, Antarctica
WLEF, Park Falls, Wisconsin, USA
ATTO Brazil

Thessaloniki, Greece
Canberra, Australia
Bucharest, Romania


WLEF (Wisconsin, USA)
Sylvania (Wisconsin, USA)
UW-Madison (Wisconsin, USA)
GSFC (Maryland, USA)
El Palmar (Valencia, Spain)
PMOD/WRC (Davos, Switzerland)
Sapienza (Rome, Italy)
UV (Valencia, Spain)
ATTO-Campina (Manaus, Brazil)
USP (Sao Paulo, Brazil)
PEA (Queen Maud, Antarctica)

SKYCAM1 at GSFC Building 33
Maryland, USA



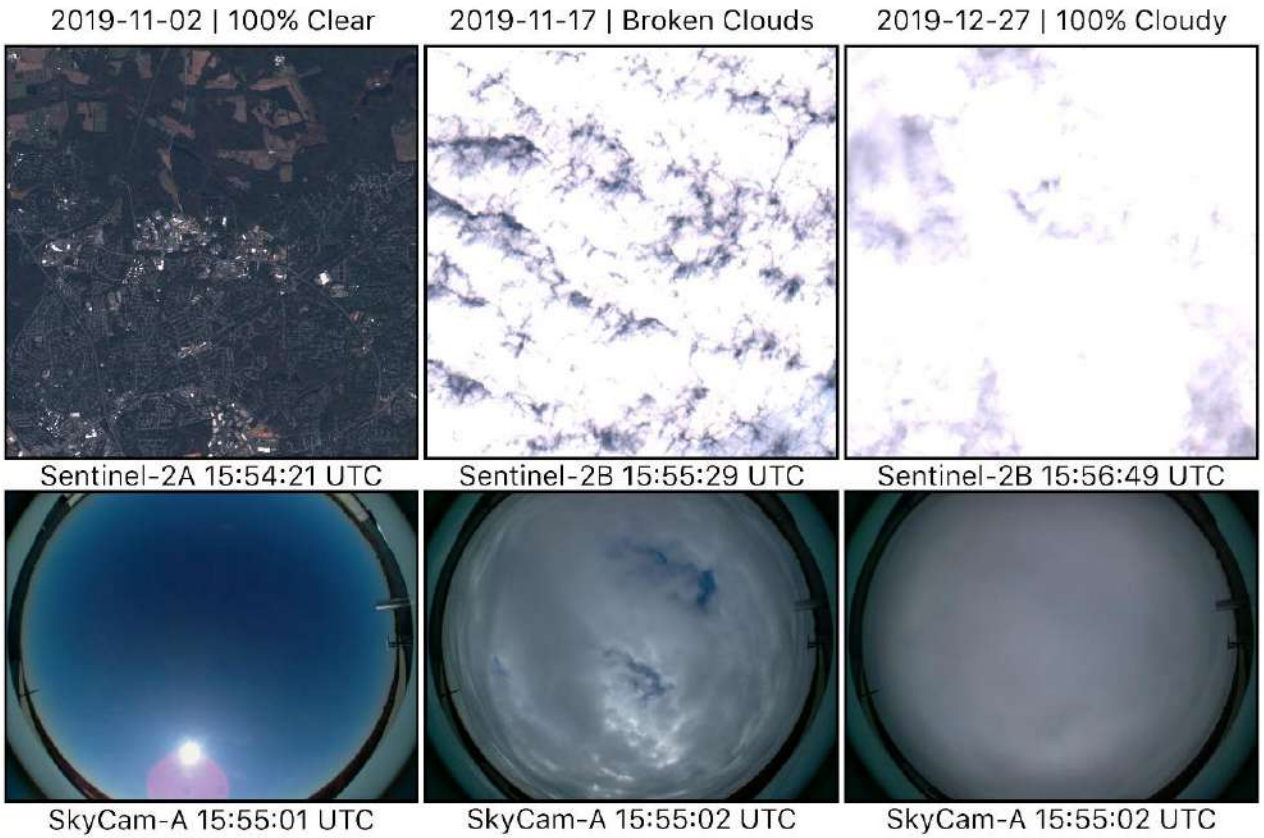
SKYCAM2 at U. Sapienza Physics Dept.
Rome, Italy

SKYCAM2 at U. Valencia Physics Dept.
Valencia, Spain

SKYCAM1 at PEA
Queen Maud, Antarctica

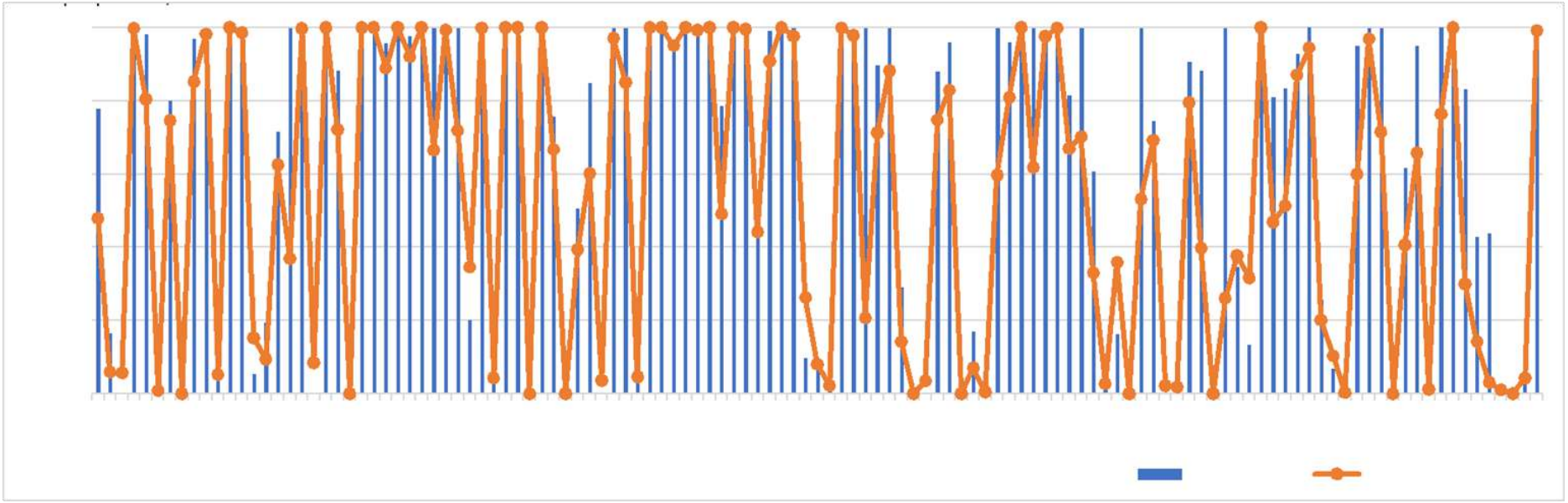
SKYCAM2 at El Palmar
Valencia, Spain

SKYCAM1 at PMOD/WRC
Davos, Switzerland


2019-11-02 | 100% Clear
2019-11-17 | Broken Clouds
2019-12-27 | 100% Cloudy
Sentinel-2A 15:54:21 UTC
Sentinel-2B 15:55:29 UTC
Sentinel-2B 15:56:49 UTC
SkyCam-A 15:55:01 UTC
SkyCam-A 15:55:02 UTC
SkyCam-A 15:55:02 UTC

Detection of clouds in ground-based image.
Area close to sun will be masked out in the future version of the algorithm.

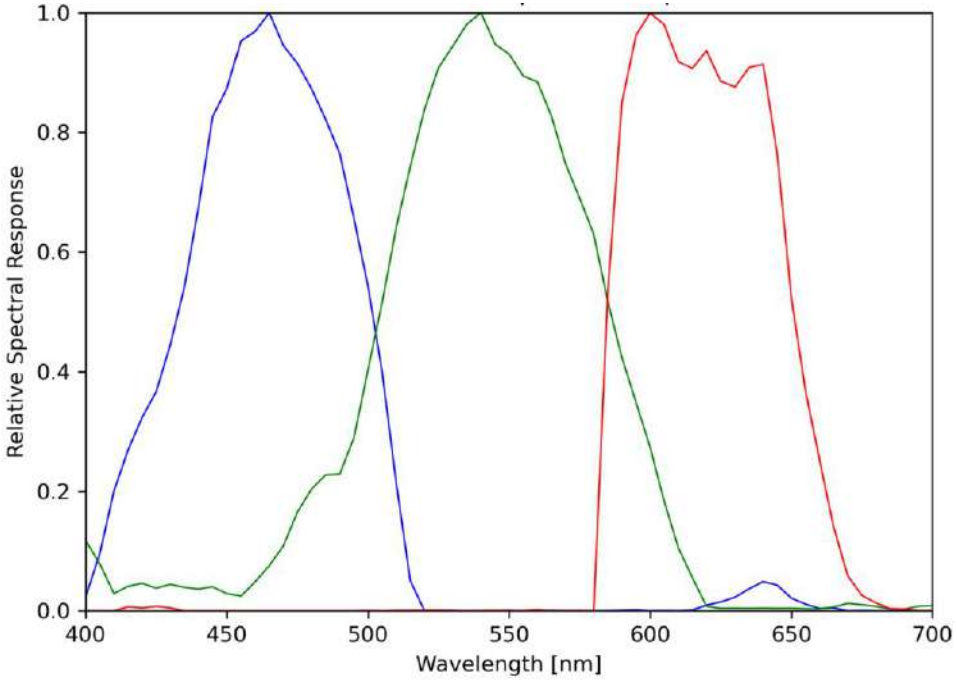
SKYCAM VERSUS MODIS



Accuracies for extreme cases:
fully clear (with AOT values <0.06)
overcast (fully cloudy)
The average MODIS-derived cloud proportions were: 0.5±0.9% (for clear) and 99.2±1.1% (for overcast).

SKYCAM Characterization

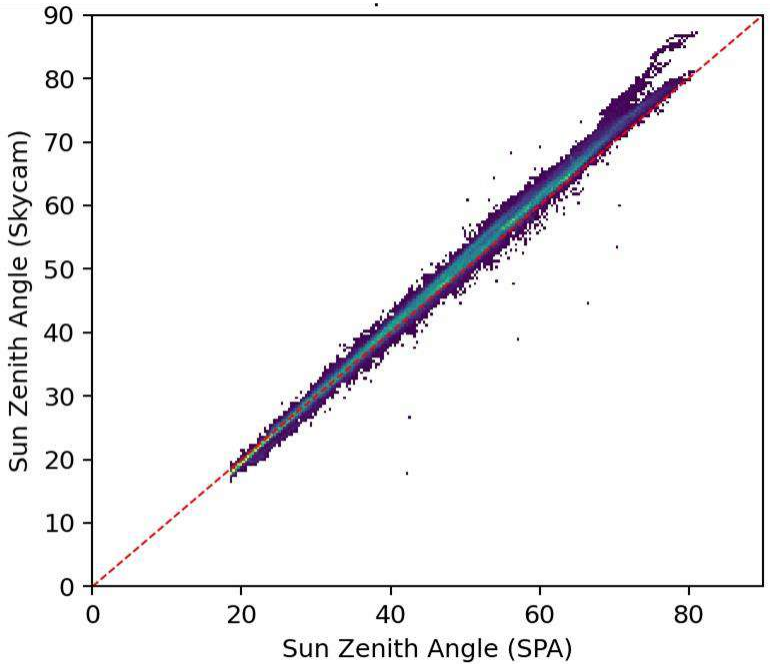
SKYCAM Relative Spectral Response[1]



[1]Measured at GSFC Code 618 using Digikröm DK240 Monochromator
and ASD Fieldspec Spectroradiometer

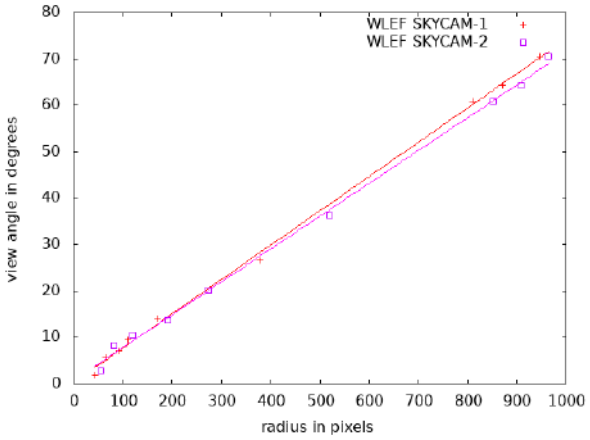
Sun Zenith Angle

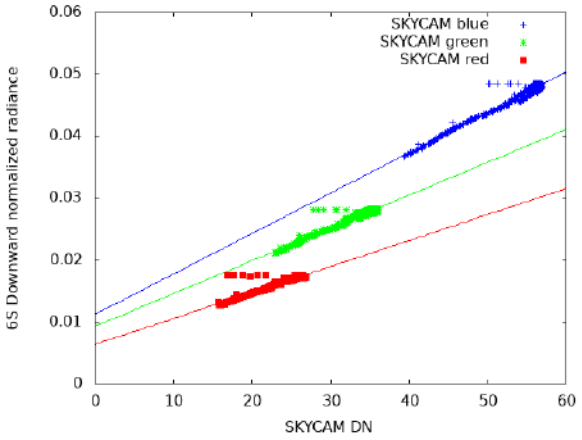
SKYCAM estimation vs NREL SPA[2]



[2]US National Renewable Energy Laboratory Solar Position Algorithm

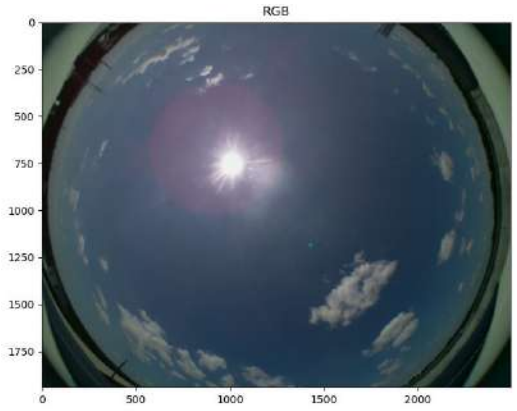
SKYCAM Calibration (geometric/radiometric)

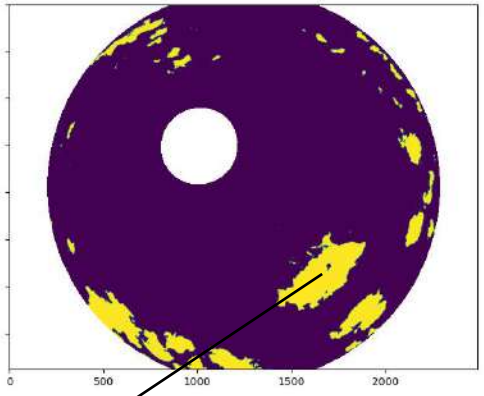




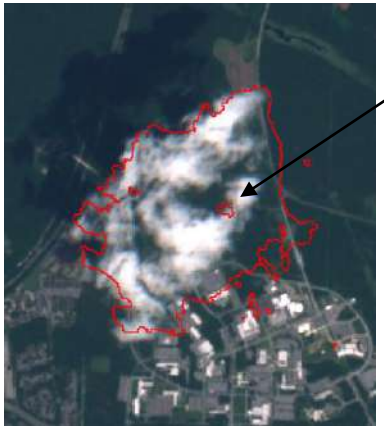
From Sky Camera to Satellite Cloud Mask

- Classification of cloud/non-cloud
  - MLP model based on a database of fully cloudy and cloud-free images
- Reprojection to satellite geometry
  - Requires cloud height
- Refining the cloud mask





Classification: cloud/non-cloud

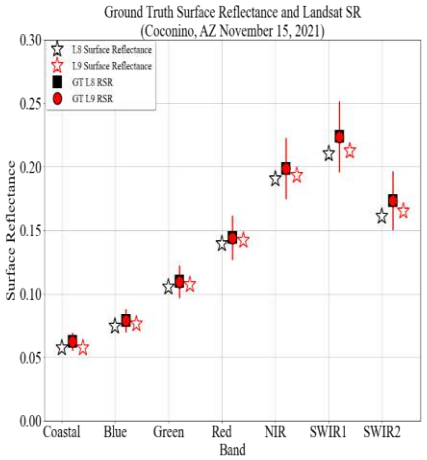


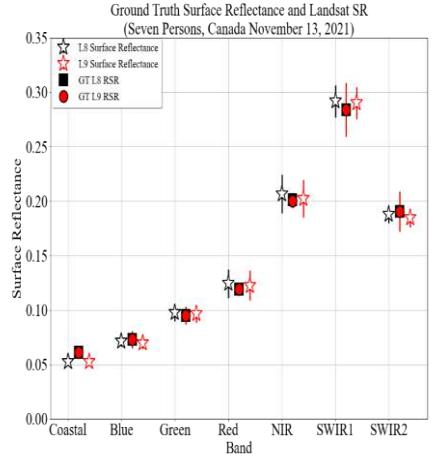
Automatic projection from skycam geometry to satellite

Refined cloud mask

Ground Validation using episodic ground measurements over uniform/stable/arid sites

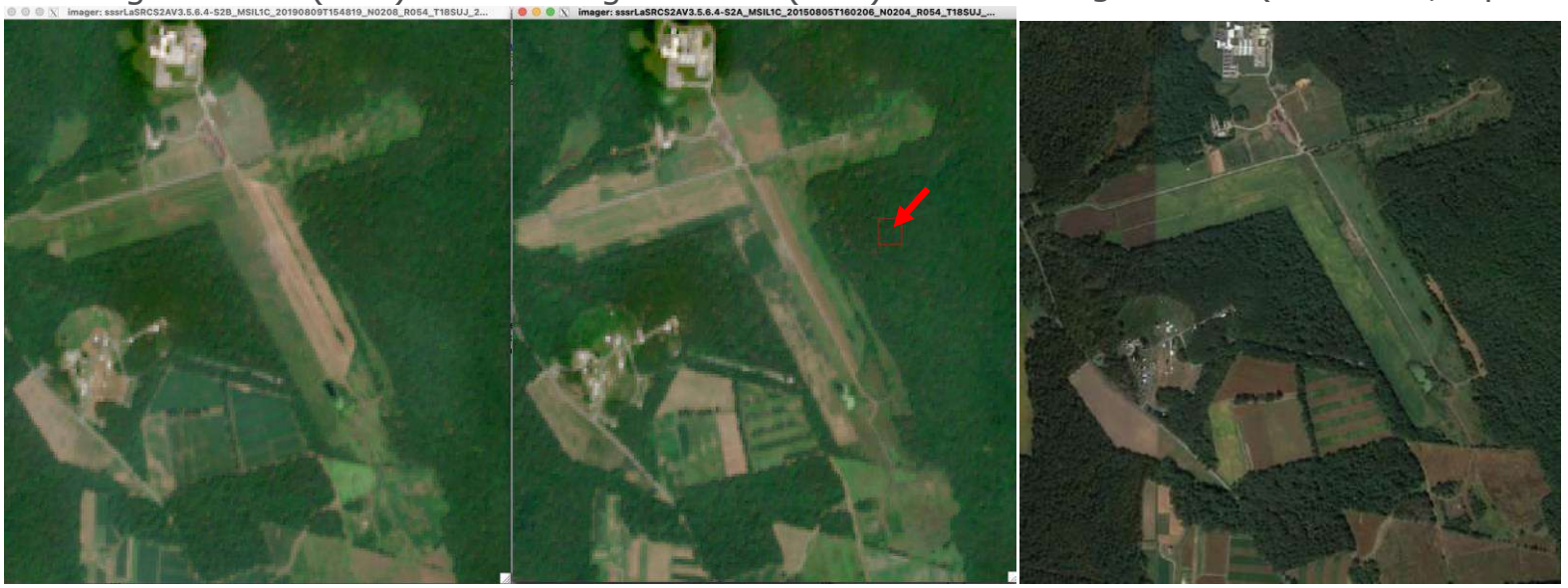
Ratio of L9 and L8 Surface Reflectance Products					
Band	**Guymon (ECCOE)**	**Coconino (ECCOE)**	**Ivanpah Playa (UArizona)**	**Seven Persons (U of Lethbridge)**	**Wilcannia (GA)**
Coastal/ Aerosol	0.995	0.999	0.97	0.996	1.005
Blue	0.980	1.023	0.99	0.974	1.001
Green	0.987	1.015	1.01	0.991	1.002
Red	0.991	1.019	1.00	0.986	0.998
NIR	0.999	1.014	0.98	0.979	1.001
SWIR1	0.995	1.011	1.02	0.994	1.007
SWIR2	0.989	1.026	1.03	0.982	0.994





GSFC-BELTSVILLE Site 1920 meters x 1920 meters

August 2019 (S2B) | August 2015 (S2A) | Google Earth (Oct 2020,Sept 2021

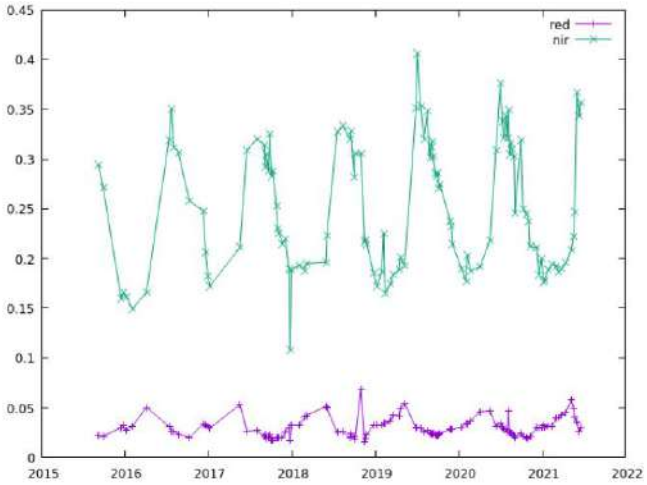


$$Noise = \sqrt{\frac{\sum_{ii=1}^{nt-2}\left(\rho_{ii+1} - \frac{\rho_{ii+2}-\rho_{ii}}{dt_{ii+2}-dt_{ii}}(dt_{ii+1}-dt_{ii}) - \rho_{ii}\right)^2}{nt-2}}$$

Original formula Vermote et al. 2019 (with threshold 20 days)

Time Series and noise with threshold at 60 days

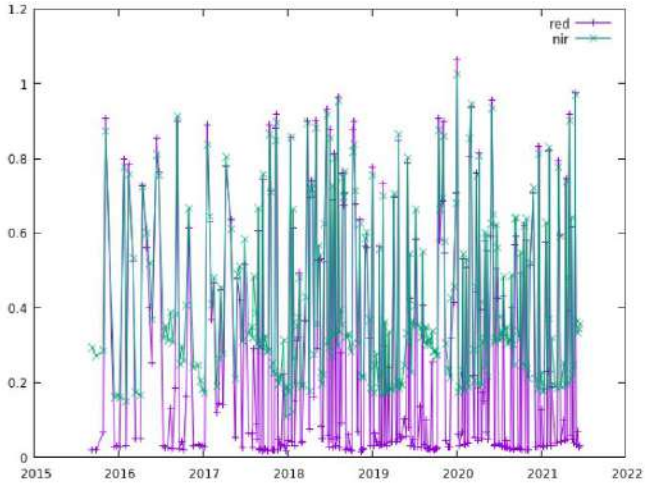
Surface reflectance LaSRC S2A,B



band	Avg	Std	CV Std/Avg	NB
red	0.030	0.010	0.326	116
nir	0.252	0.064	0.255	116

band	Noise	Noise (95%)	NB
red	0.003	0.003	94/89
nir	0.021	0.022	94/89

Surface reflectance LaSRC S2A,B no QA applied

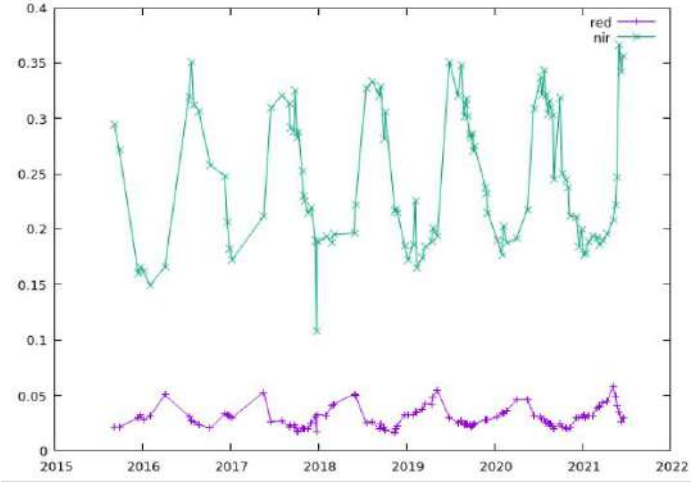


band	Avg	Std	CV Std/Avg	NB
red	0.277	0.314	1.134	296
nir	0.415	0.227	0.547	296

band	Noise	Noise (95%)	NB
red	0.332	0.340	294/279
nir	0.239	0.245	294/279

Time Series and metrics (threshold at 60 days)

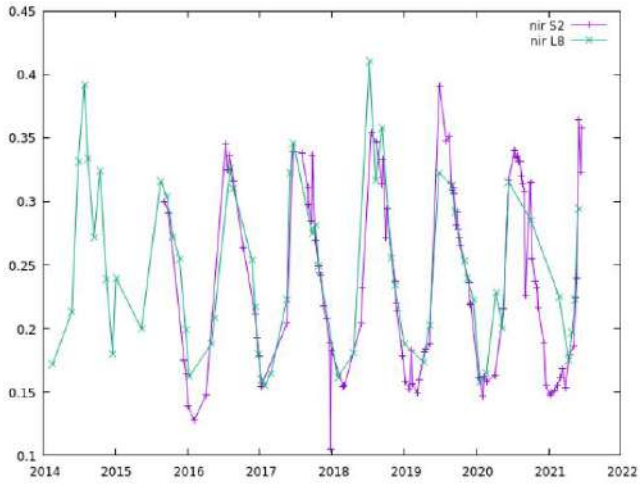
Surface reflectance LaSRC (OA Next generation experimental applied)

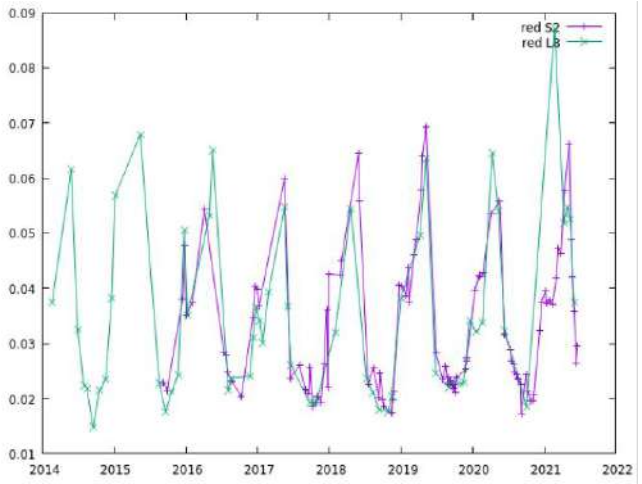


band	Avg	Std	CV	NB
red	0.030	0.009	0.310	110
nir	0.247	0. 061	0.248	116

band	Noise	Noise (95%)	NB
red	0.002	0.002	87/82
nir	0.019	0.019	87/82

Combining with Landsat 8





S2 (3x3)

band	Noise	Rnoise %	NB
red	0.0029	8.9	83
nir	0.0171	7.1	83

L8

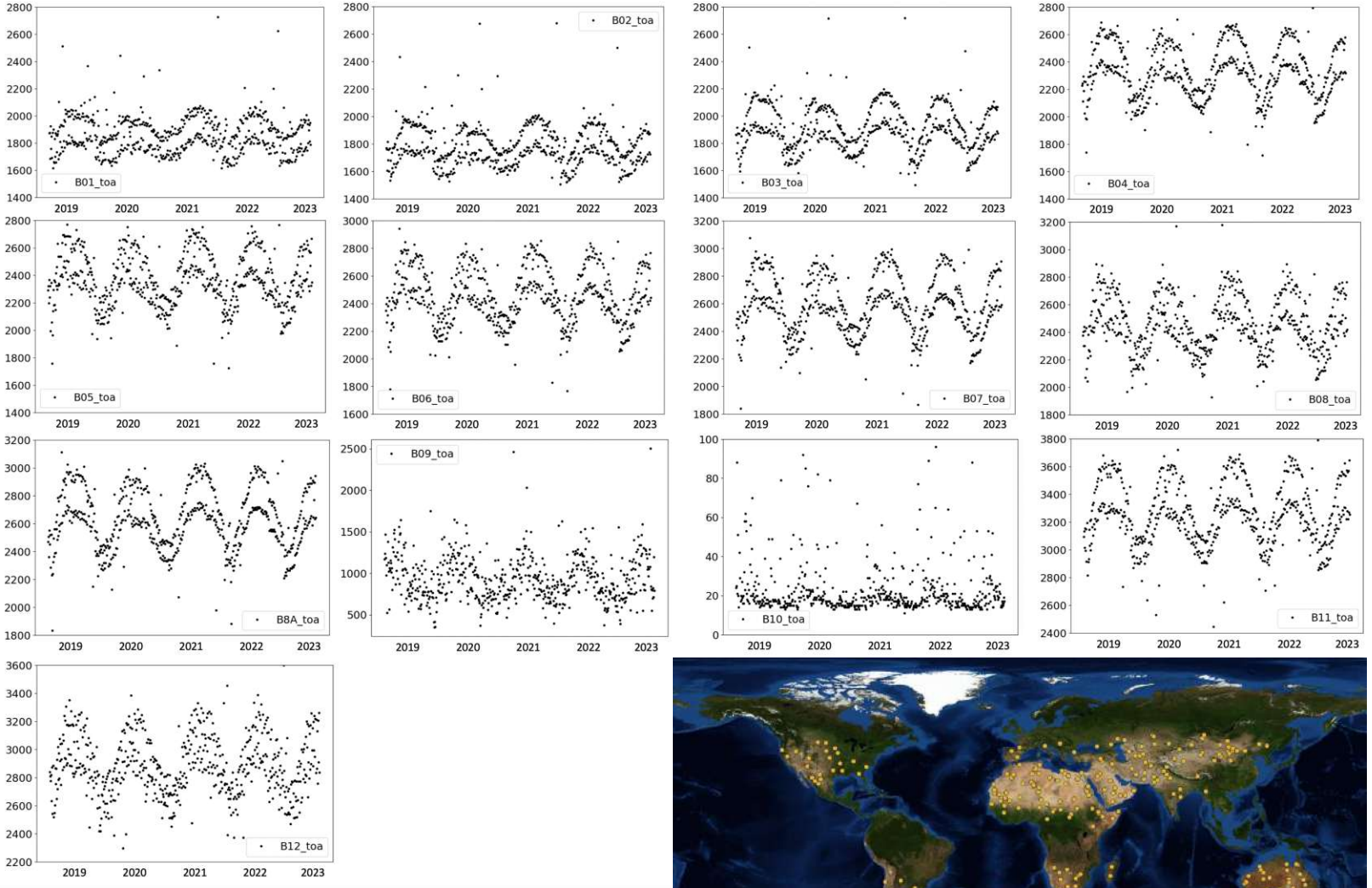
band	Noise	Rnoise %	NB
red	0.0038	10.8	13
nir	0.0222	9.0	13

S2+L8

band	Noise	Rnoise %	NB
red	0.0036	10.7	146
nir	0.0201	8.3	146

RNoise = 100*Noise/average

Extension for more sites (~ 120, on going)

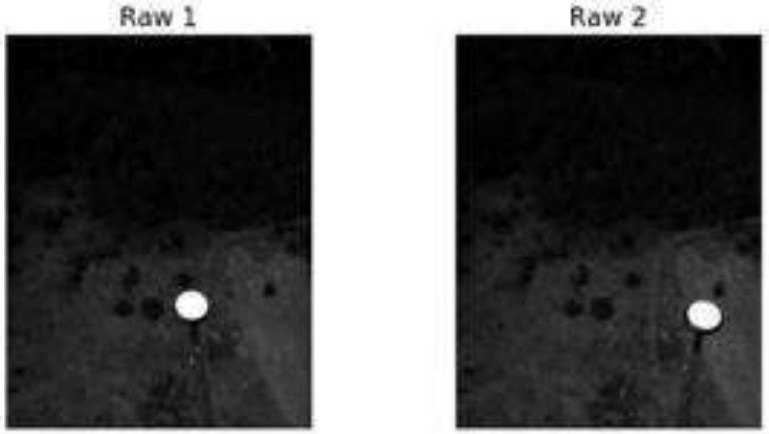


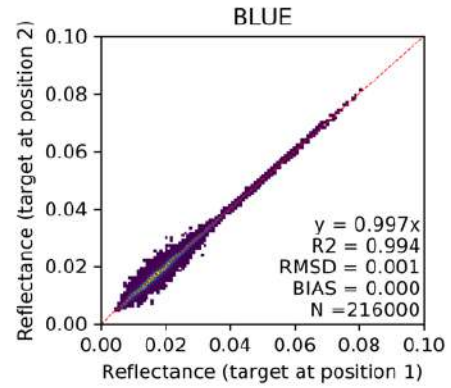
Ground Validation using CAMSIS

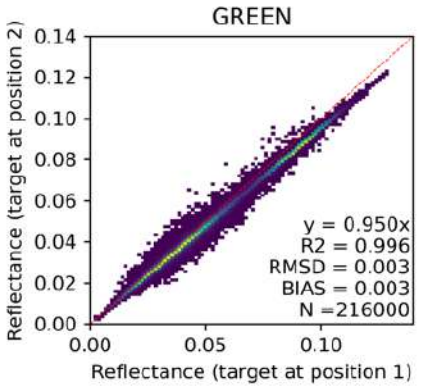
CAMSIS system

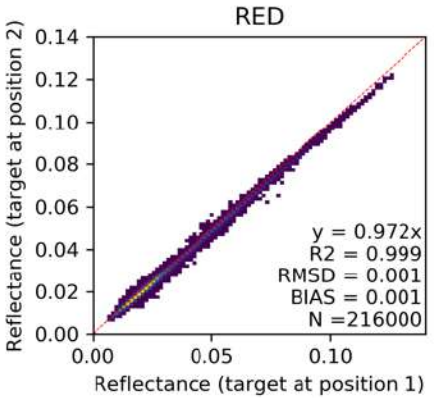
CAMSIS is installed at a height of 123m on a TV tower (WLEF) near Park Falls, WI at the Chequamegon National Forest

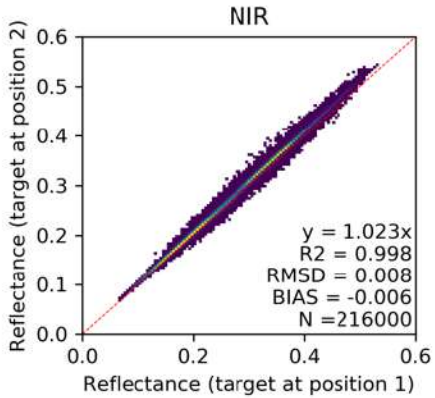
CAMSIS Data processing



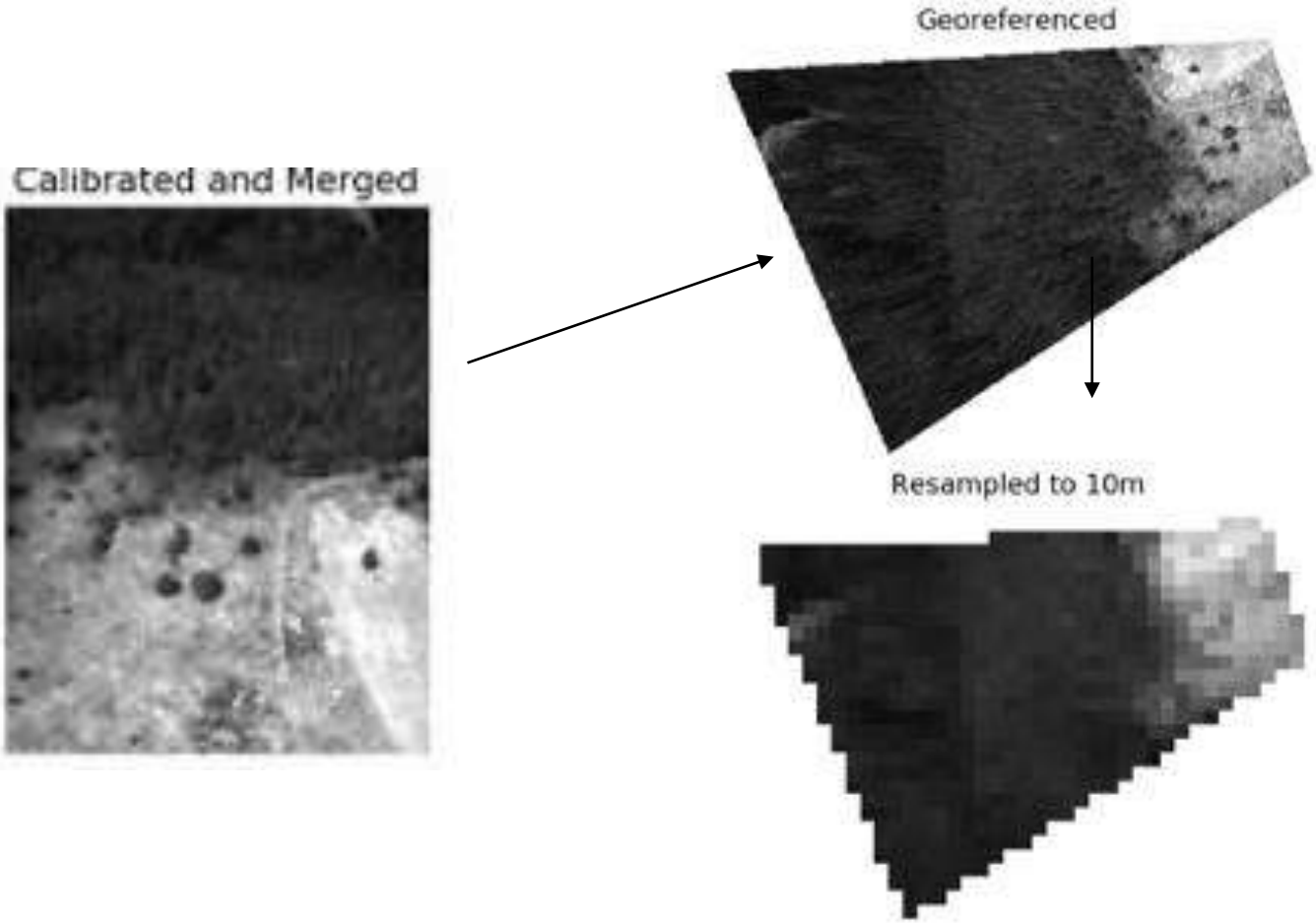




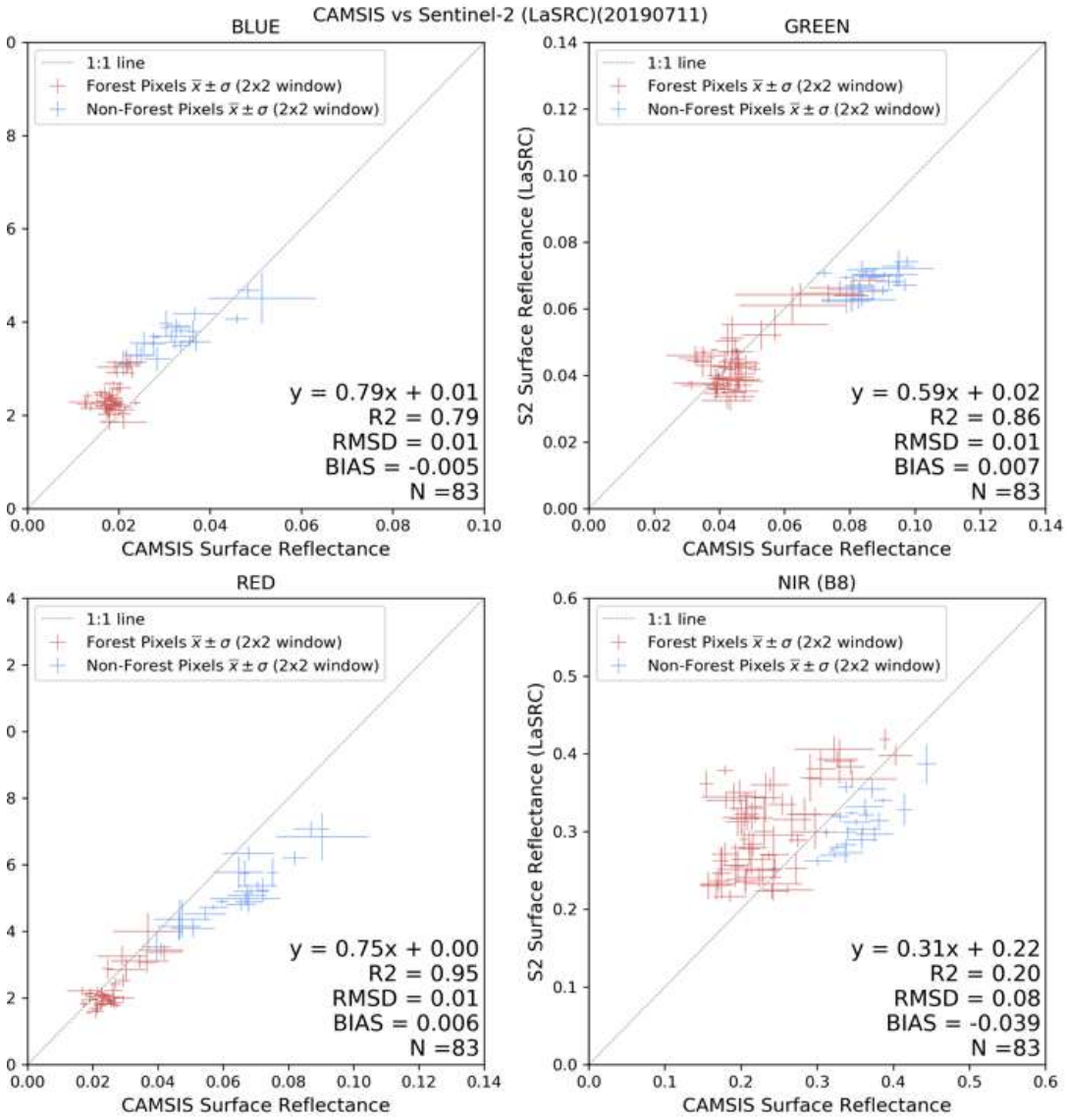


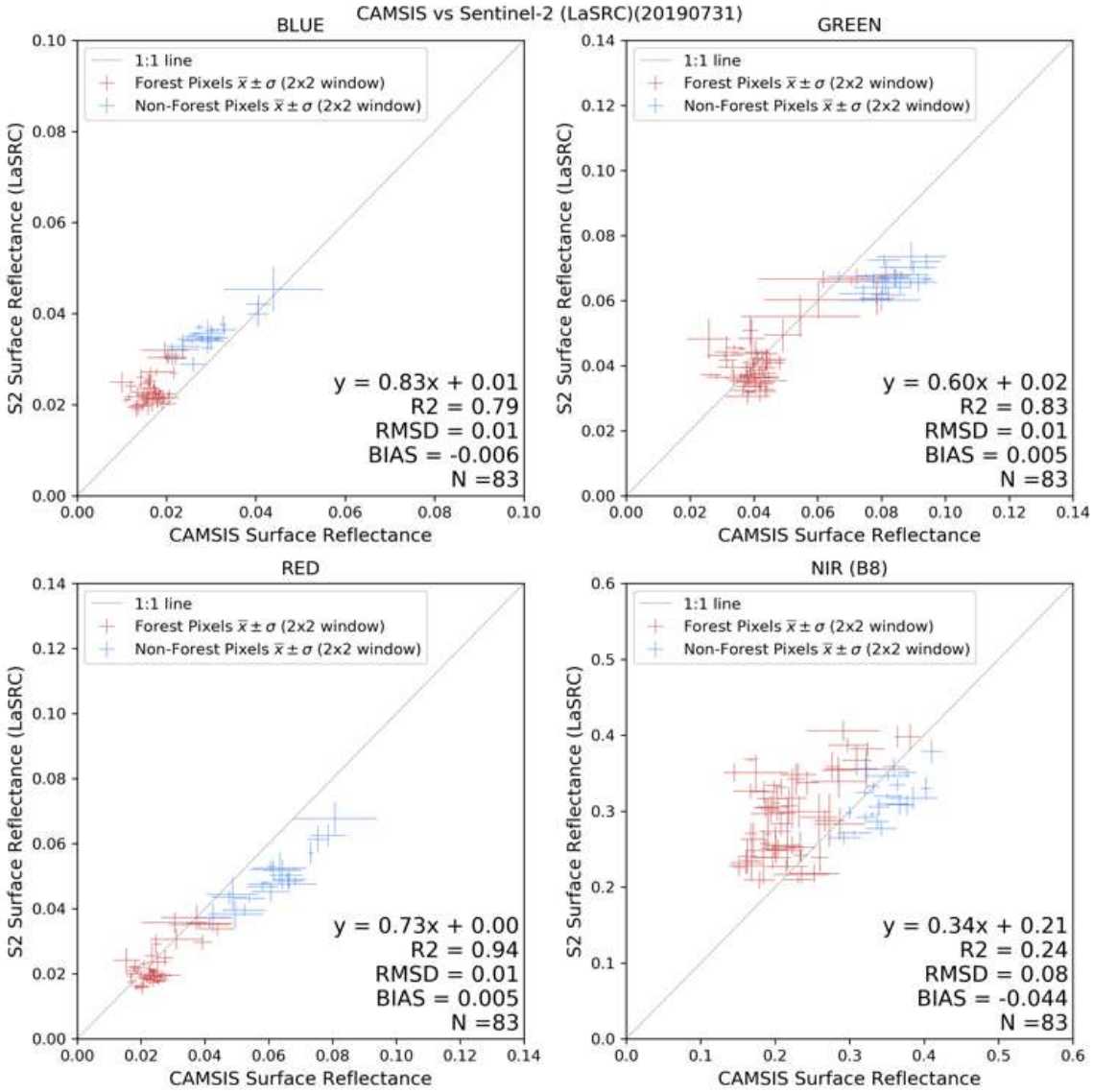


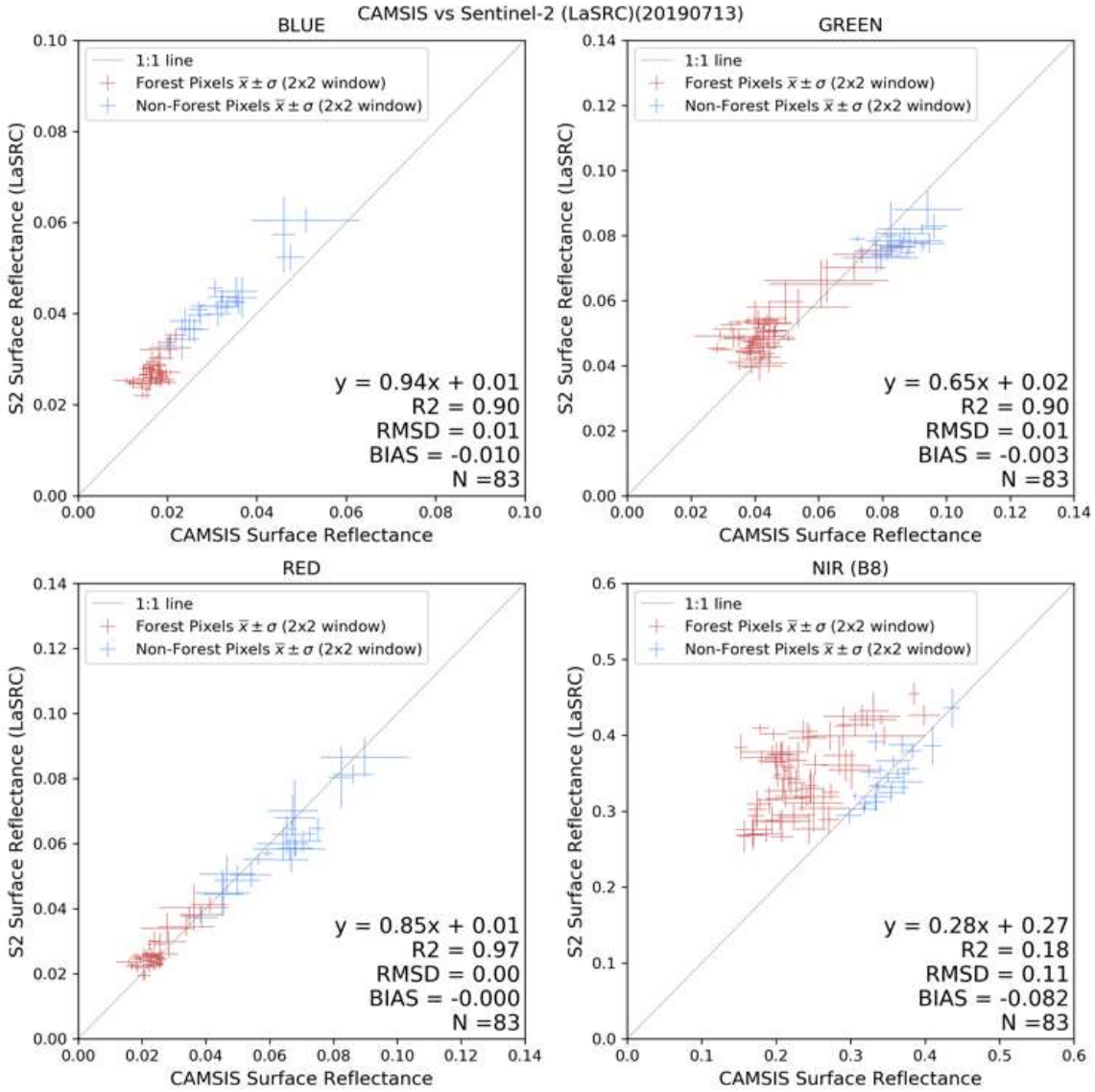
CAMSIS Data processing

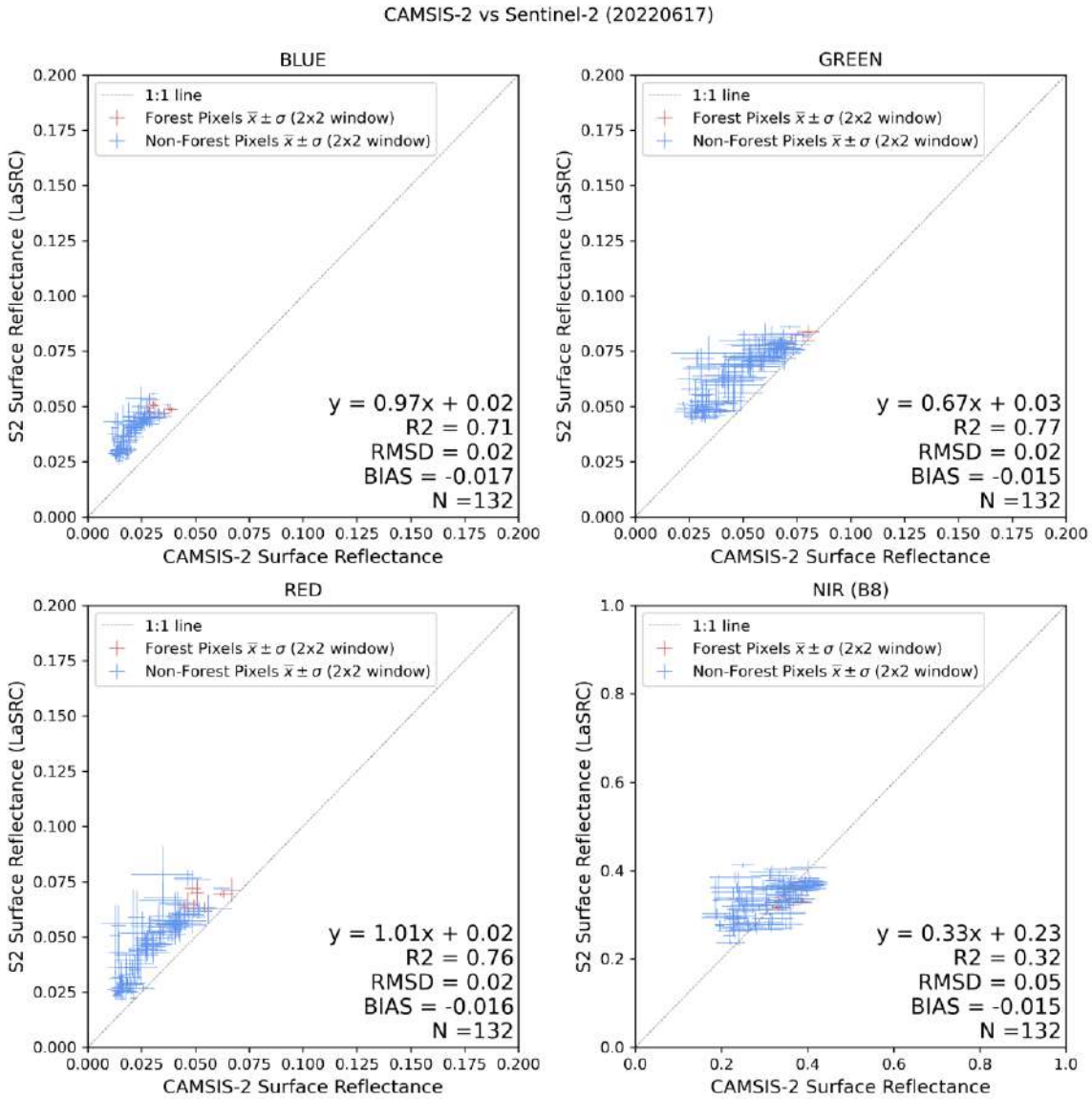


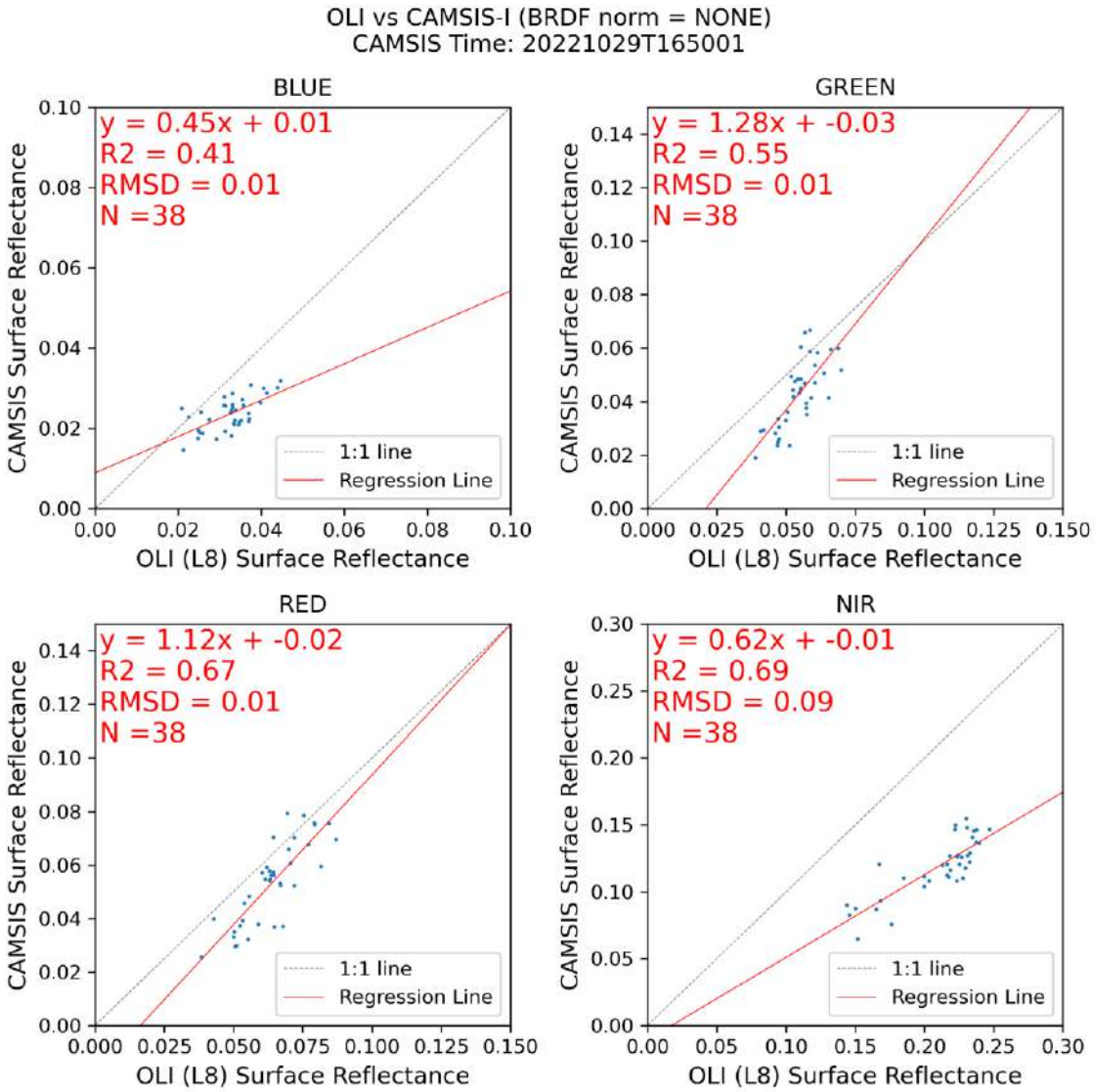
First results from CAMSIS on Sentinel 2

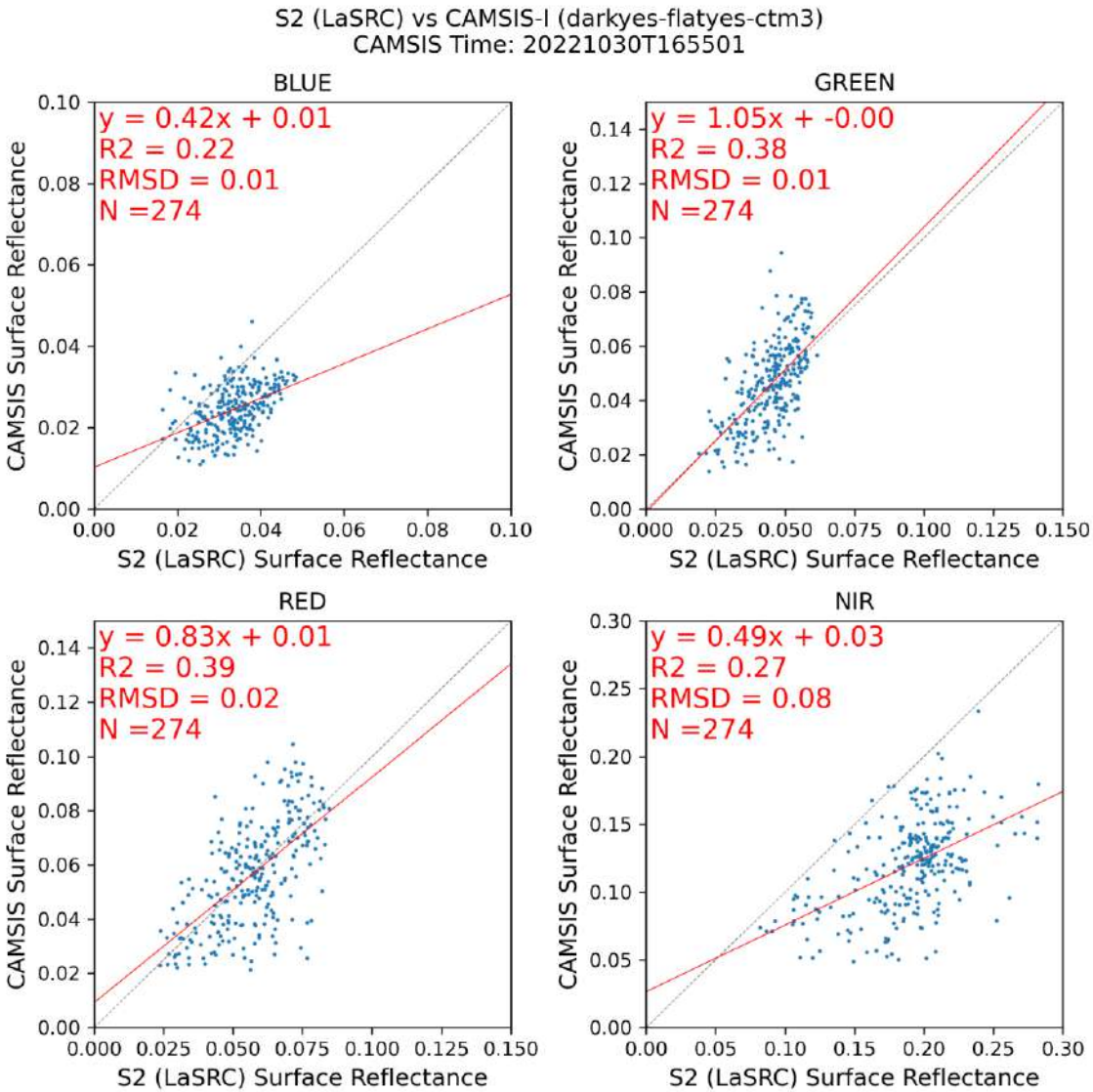



CAMSIS vs Sentinel-2 (LaSRC)(20190731)
BLUE
1:1 line
Forest Pixels $\bar{x} \pm \sigma$ (2x2 window)
Non-Forest Pixels $\bar{x} \pm \sigma$ (2x2 window)
y = 0.83x + 0.01
R2 = 0.79
RMSD = 0.01
BIAS = -0.006
N =83
GREEN
y = 0.60x + 0.02
R2 = 0.83
RMSD = 0.01
BIAS = 0.005
N =83
RED
y = 0.73x + 0.00
R2 = 0.94
RMSD = 0.01
BIAS = 0.005
N =83
NIR (B8)
y = 0.34x + 0.21
R2 = 0.24
RMSD = 0.08
BIAS = -0.044
N =83
S2 Surface Reflectance (LaSRC)
CAMSIS Surface Reflectance

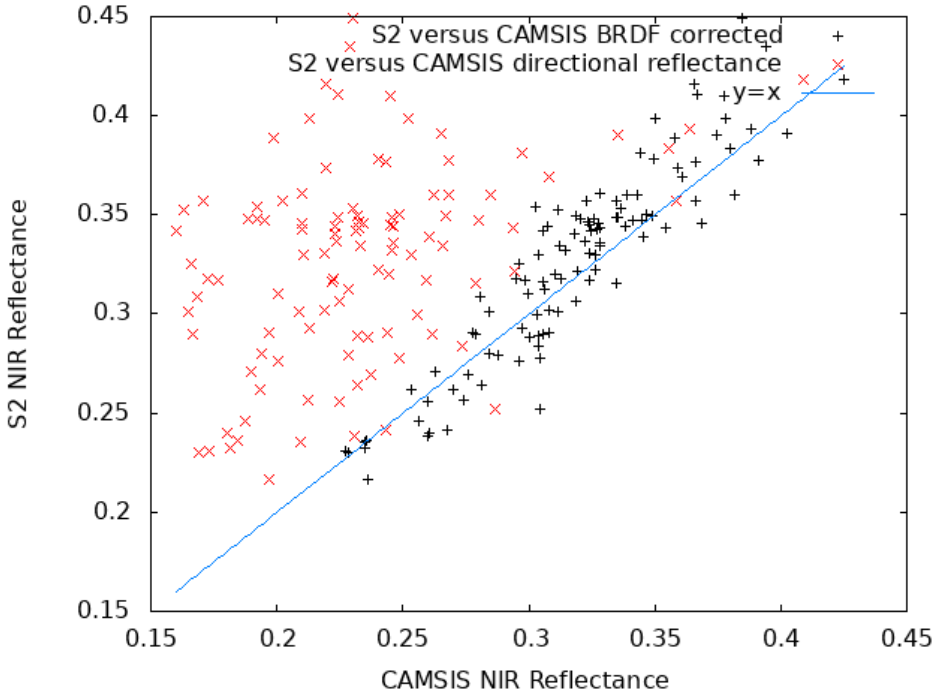

CAMSIS vs Sentinel-2 (LaSRC)(20190713)
BLUE
1:1 line
Forest Pixels $\overline{x} \pm \sigma$ (2x2 window)
Non-Forest Pixels $\overline{x} \pm \sigma$ (2x2 window)
y = 0.94x + 0.01
R2 = 0.90
RMSD = 0.01
BIAS = -0.010
N =83
S2 Surface Reflectance (LaSRC)
CAMSIS Surface Reflectance
GREEN
y = 0.65x + 0.02
R2 = 0.90
RMSD = 0.01
BIAS = -0.003
N =83
RED
y = 0.85x + 0.01
R2 = 0.97
RMSD = 0.00
BIAS = -0.000
N =83
NIR (B8)
y = 0.28x + 0.27
R2 = 0.18
RMSD = 0.11
BIAS = -0.082
N =83


CAMSIS-2 vs Sentinel-2 (20220617)
BLUE
GREEN
RED
NIR (B8)
1:1 line
Forest Pixels $\bar{x} \pm \sigma$ (2x2 window)
Non-Forest Pixels $\bar{x} \pm \sigma$ (2x2 window)
S2 Surface Reflectance (LaSRC)
CAMSIS-2 Surface Reflectance
y = 0.97x + 0.02
R2 = 0.71
RMSD = 0.02
BIAS = -0.017
N =132
y = 0.67x + 0.03
R2 = 0.77
RMSD = 0.02
BIAS = -0.015
N =132
y = 1.01x + 0.02
R2 = 0.76
RMSD = 0.02
BIAS = -0.016
N =132
y = 0.33x + 0.23
R2 = 0.32
RMSD = 0.05
BIAS = -0.015
N =132

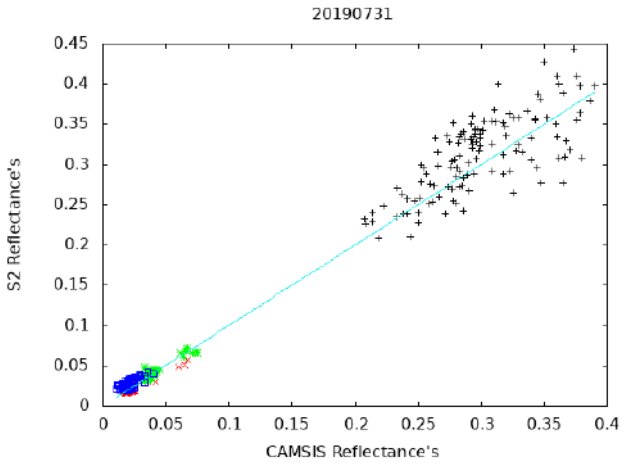

OLI vs CAMSIS-I (BRDF norm = NONE)
CAMSIS Time: 20221029T165001
BLUE
y = 0.45x + 0.01
R2 = 0.41
RMSD = 0.01
N =38
GREEN
y = 1.28x + -0.03
R2 = 0.55
RMSD = 0.01
N =38
RED
y = 1.12x + -0.02
R2 = 0.67
RMSD = 0.01
N =38
NIR
y = 0.62x + -0.01
R2 = 0.69
RMSD = 0.09
N =38
1:1 line
Regression Line
CAMSIS Surface Reflectance
OLI (L8) Surface Reflectance

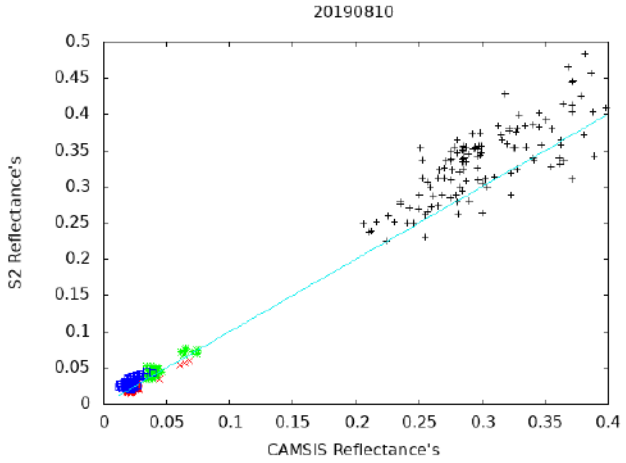

S2 (LaSRC) vs CAMSIS-I (darkyes-flatyes-ctm3)
CAMSIS Time: 20221030T165501
BLUE
y = 0.42x + 0.01
R2 = 0.22
RMSD = 0.01
N =274
GREEN
y = 1.05x + -0.00
R2 = 0.38
RMSD = 0.01
N =274
RED
y = 0.83x + 0.01
R2 = 0.39
RMSD = 0.02
N =274
NIR
y = 0.49x + 0.03
R2 = 0.27
RMSD = 0.08
N =274
CAMSIS Surface Reflectance
S2 (LaSRC) Surface Reflectance

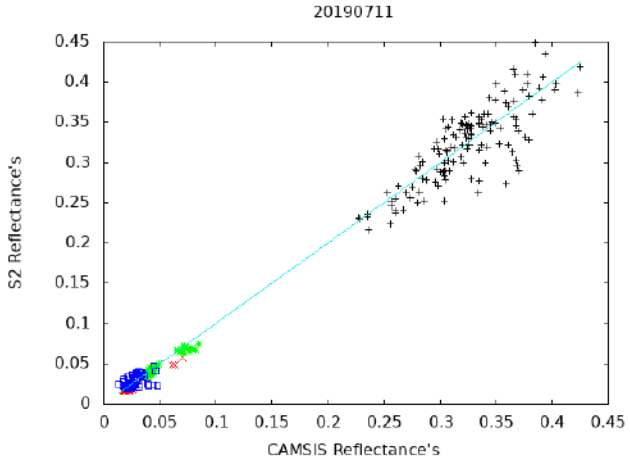
Applying BRDF correction to CAMSIS (NIR)



BRDF applied and starting quantitative comparison







El Palmar Super Site

SKYCAM 2

SKYCAM 1

AERONET

CAMSIS 1-2 “launch”

CAMSIS 1-2 installed

CAMSIS 2 NIR-RG

CAMSIS 2 RGB

Conclusions

- Surface reflectance (SR) algorithm is mature and pathway toward validation and automated QA is clearly identified.
- Algorithm is generic and tied to documented validated radiative transfer code so the accuracy is traceable enabling error budget.
- The use of BRDF correction enables easy cross-comparison of different sensors (MODIS,VIIRS,AVHRR, Landsat, Sentinel 2 ,Sentinel 3…).
- We are proposing a complete package for Surface reflectance validation at high spatial resolution (Landsat, S2,AERONET,CAMSIS,SKYCAM).