

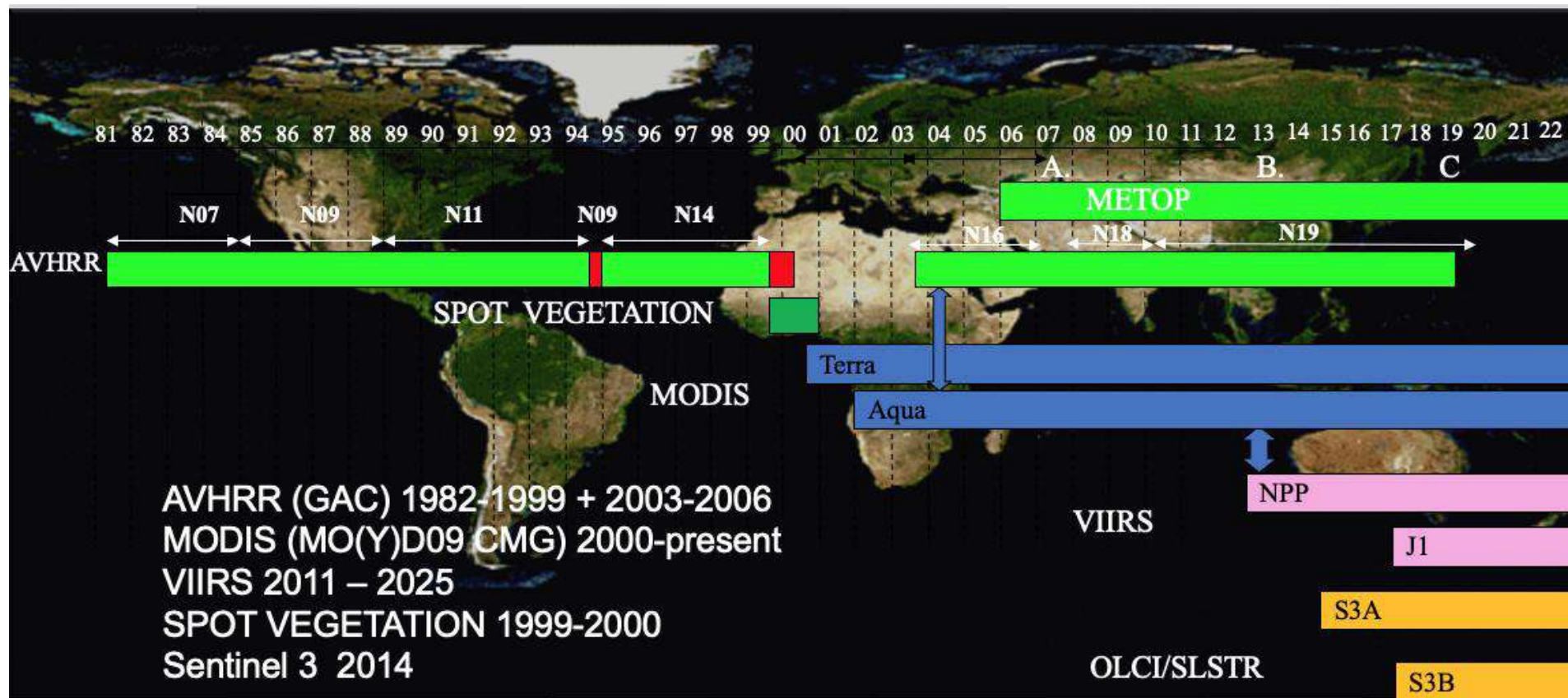
Evaluation of the Sentinel 3 Synergy Surface Reflectance Product

Vermote et al.

NASA/GSFC

A Land Climate Data Record

Multi instrument/Multi sensor Science Quality Data Records used to quantify trends and changes



<https://ltdr.modaps.eosdis.nasa.gov>

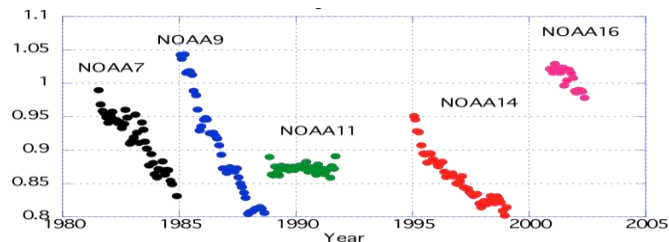
Emphasis on data consistency – characterization rather than degrading/smoothing the data

Land Climate Data Record (Approach)

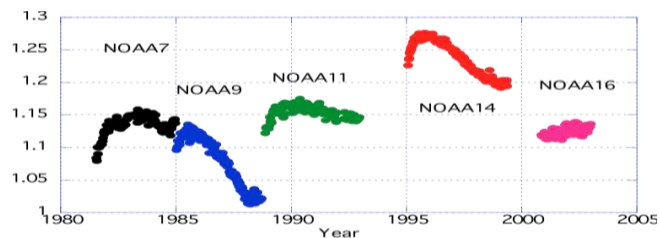
Needs to address geolocation, calibration, atmospheric/BRDF correction issues

CALIBRATION

Degradation in channel 1
(from Ocean observations)



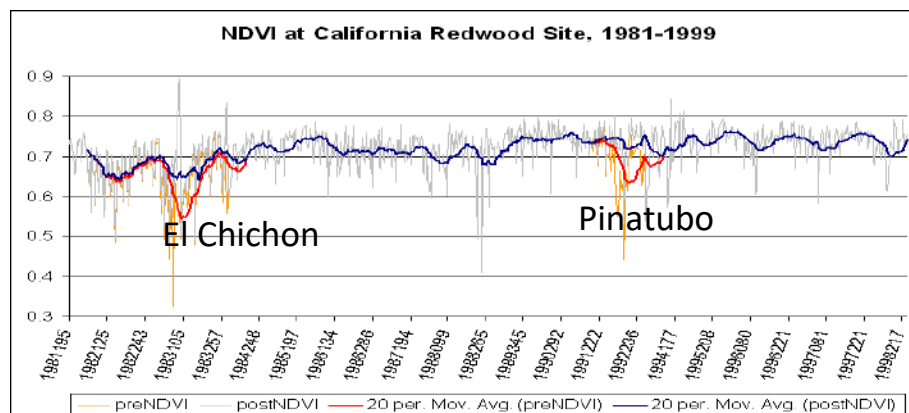
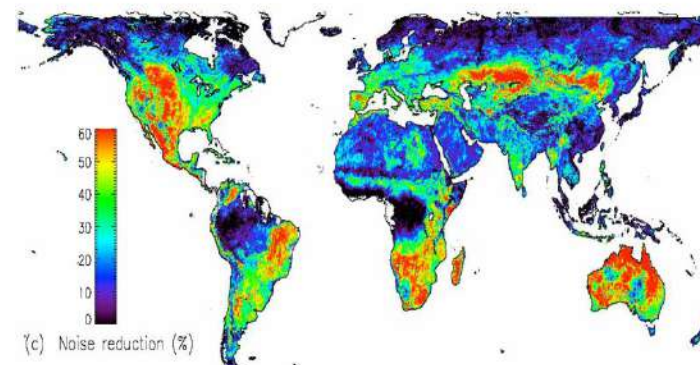
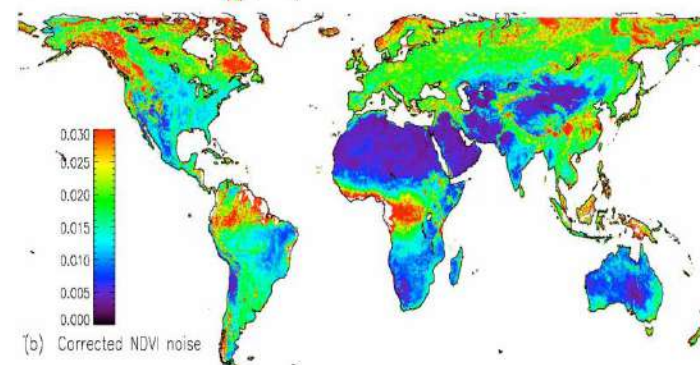
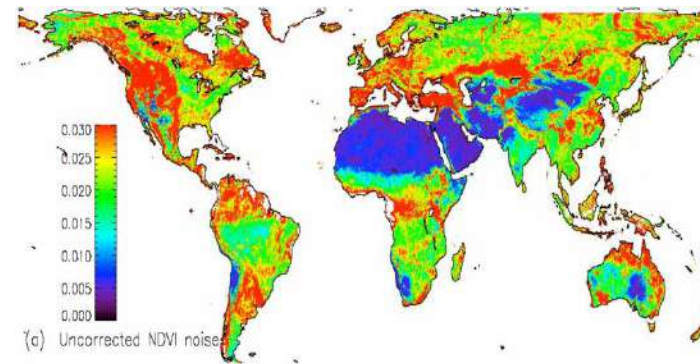
Channel1/Channel2 ratio
(from Clouds observations)



ATMOSPHERIC CORRECTION

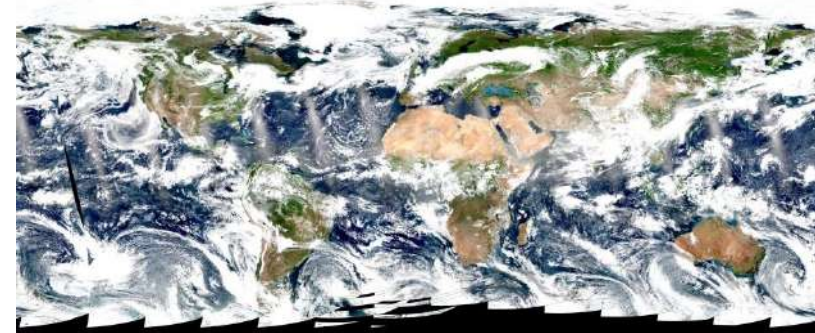
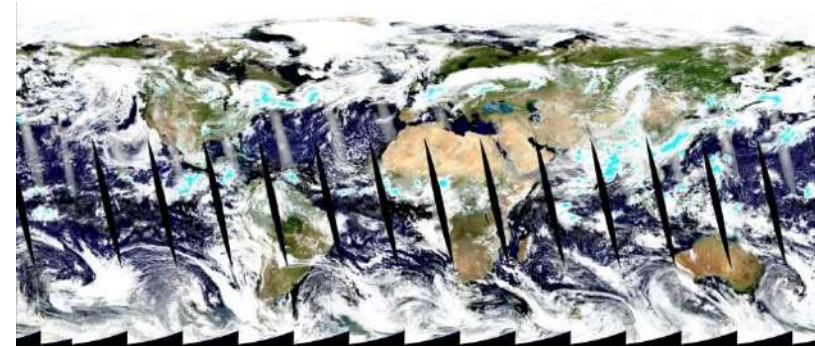


BRDF CORRECTION



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)
 - 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

LaSRC Surface Reflectance is largely based on MODIS C6

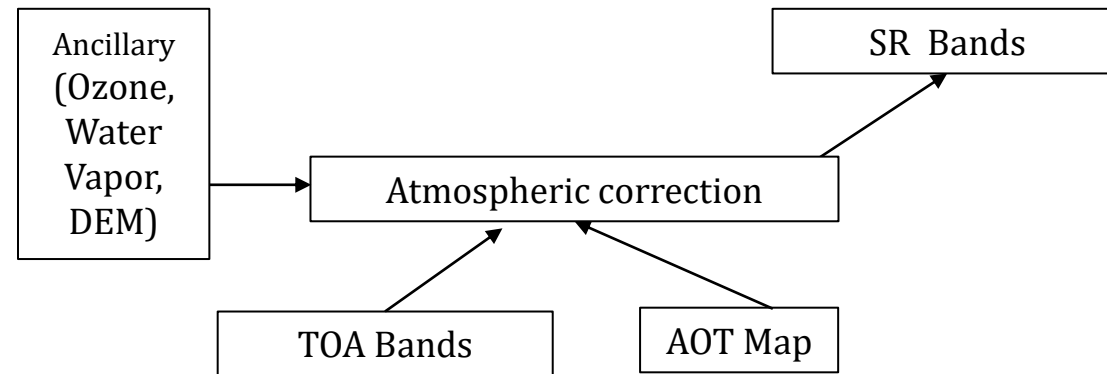
Algorithm reference for L8: Vermote E., Justice C., Claverie M., Franch B., (2016) "Preliminary analysis of the performance of the Landsat 8/OLI land surface reflectance product", Remote Sensing of Environment, 185,46-56.

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 processed from Landsat8/Sentinel 2 images***
 - ***Water vapor and ozone from daily MODIS product.***

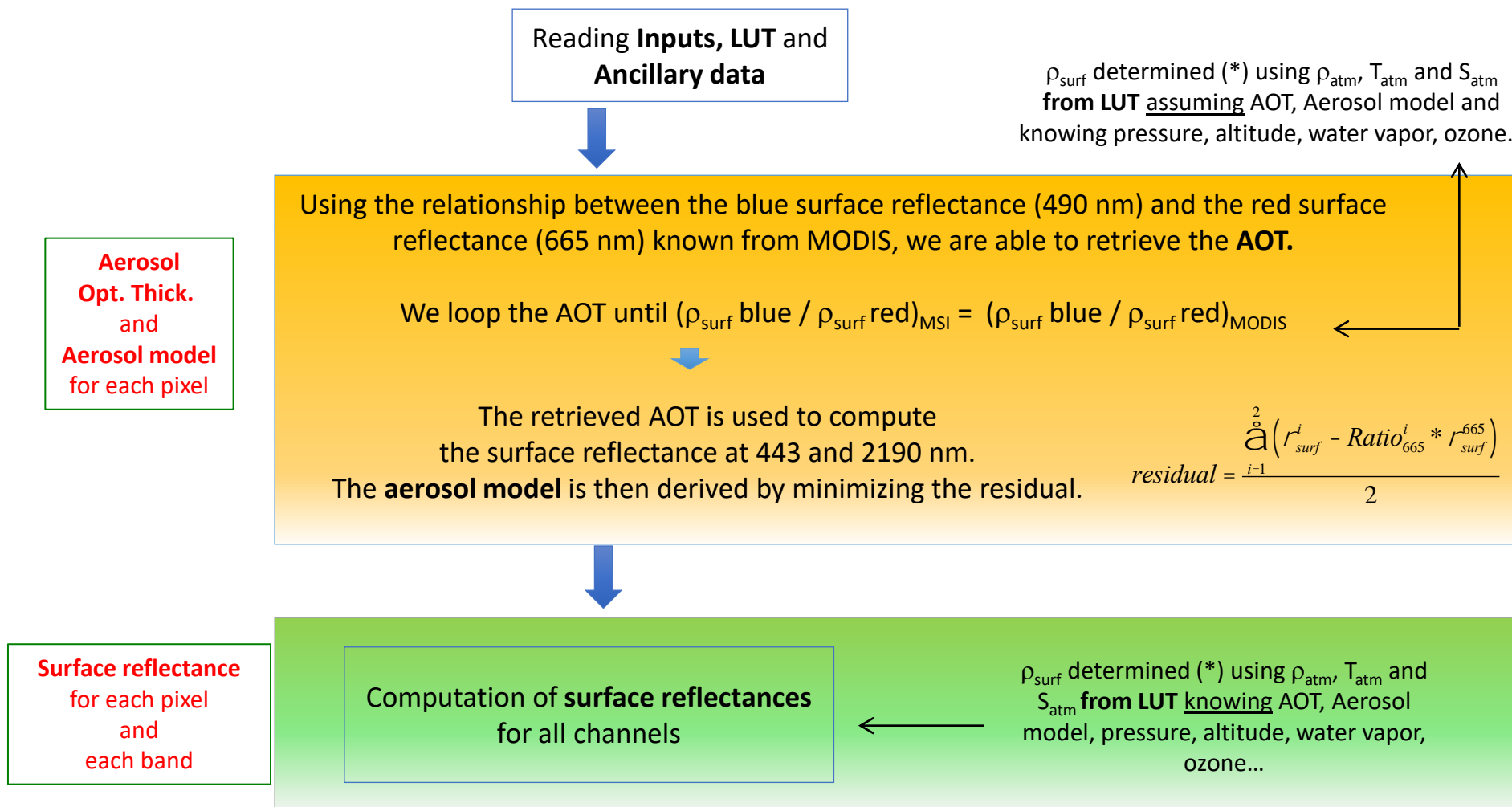
Home page: <http://modis-sr.ltdri.org>

Flowchart of the LaSRC atmospheric correction scheme



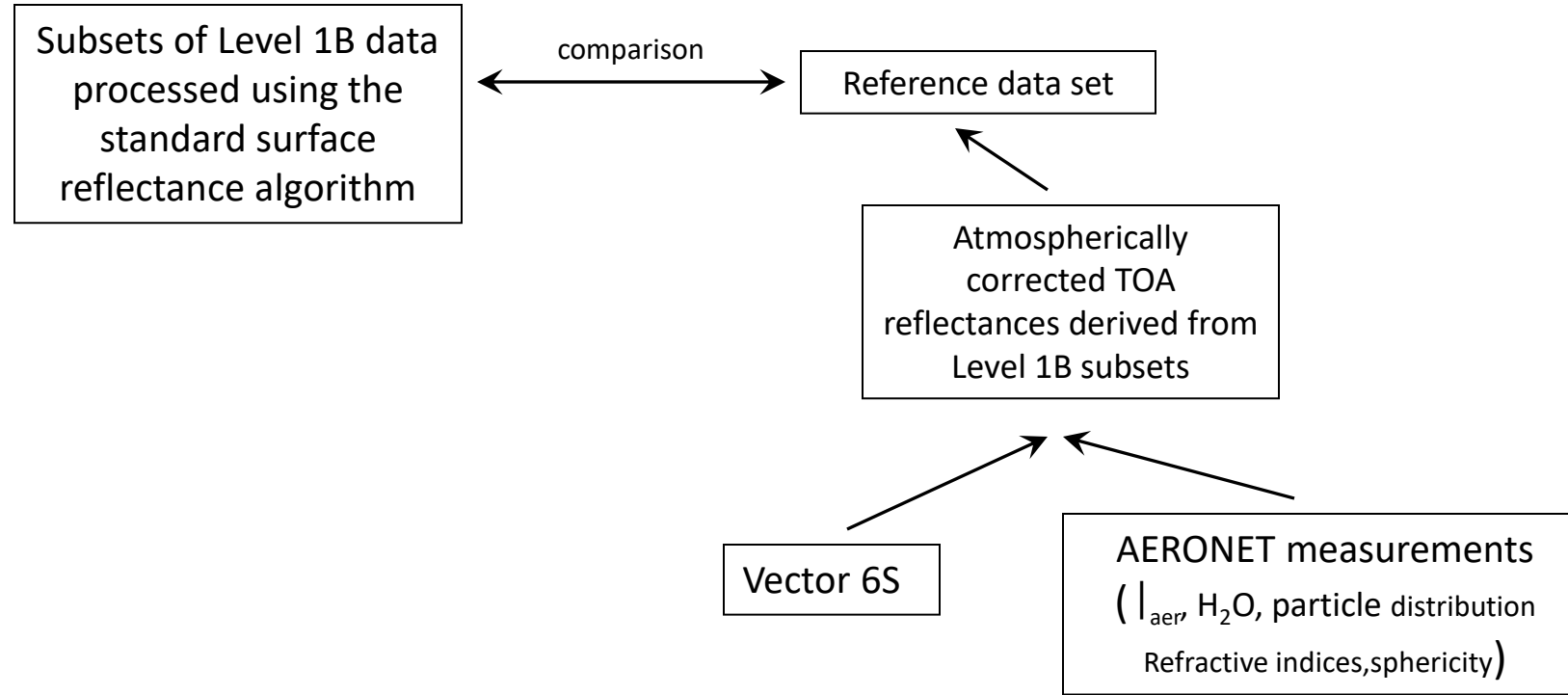
Vermote E., Justice C., Claverie M., Franch B., (2016) "Preliminary analysis of the performance of the Landsat 8/OLI land surface reflectance product", Remote Sensing of Environment, 185,46-56.

LaSRC atmospheric correction

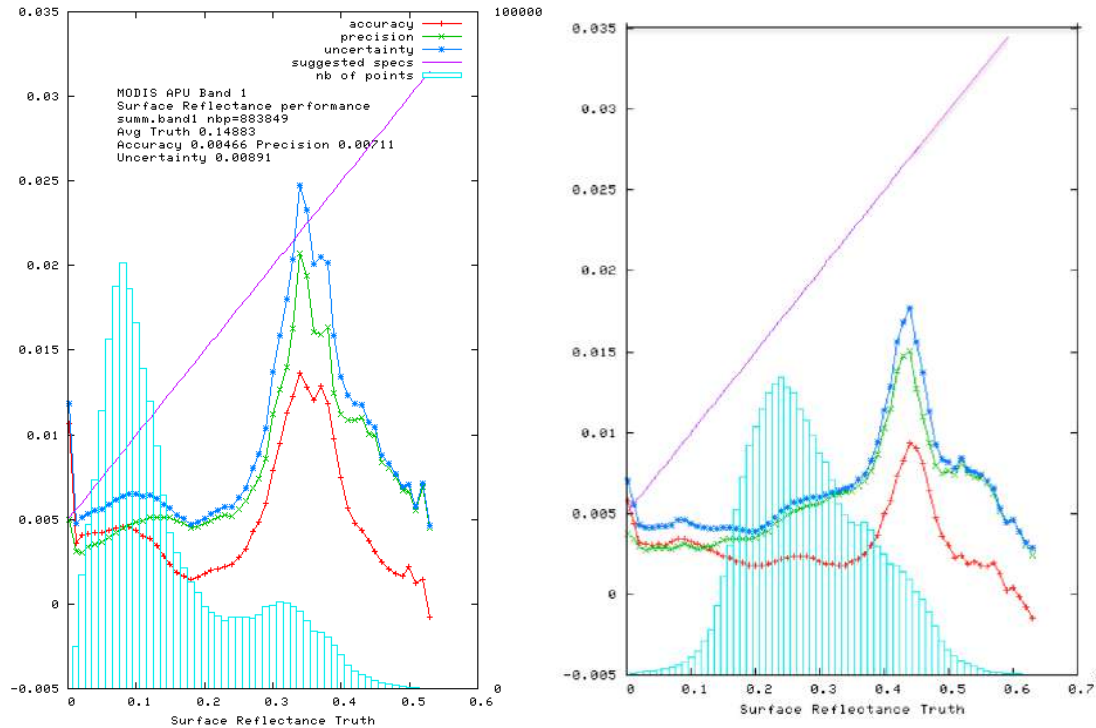


$$(*) \quad r_{surf} = \frac{Y}{1 + S_{atm} \cdot Y} \quad \text{with} \quad Y = \frac{1}{T_{atm} \cdot tg^{wv}} \left(\frac{e_a}{e_c} \frac{r_{TOA}}{e_c} - \frac{O_3}{e_c} \frac{r_{TOA}}{e_c} - \frac{O_2}{e_c} \frac{r_{TOA}}{e_c} - \frac{O_1}{e_c} \frac{r_{TOA}}{e_c} - (r_{atm} - r_{ray}) \cdot tg^{wv/2} - r_{ray} \right)$$

Methodology for evaluating the performance of LaSRC

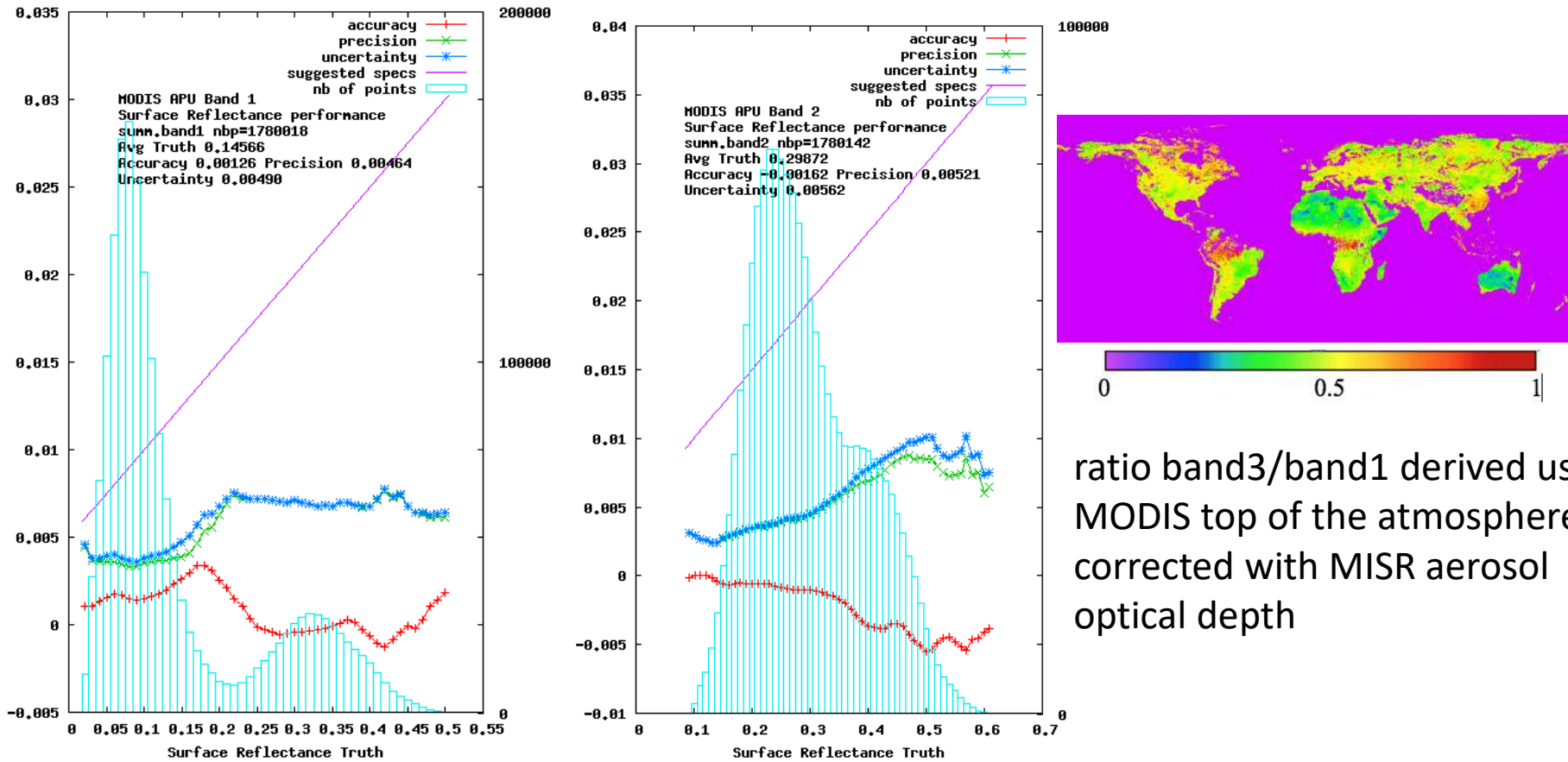


quantitative assessment of performances (APU) for MODIS



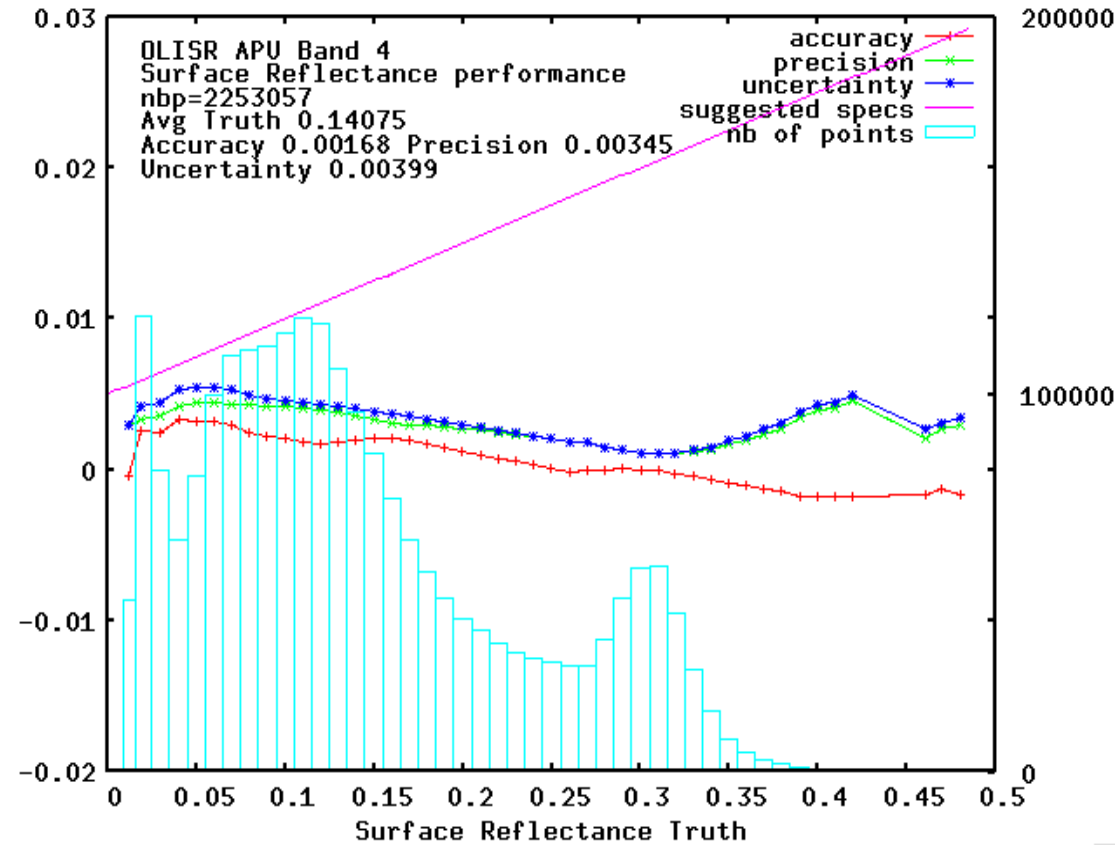
COLLECTION 5: accuracy or mean bias (red line), Precision or repeatability (green line) and Uncertainty or quadratic sum of Accuracy and Precision (blue line) of the surface reflectance in band 1 in the Red (top left), band 2 in the Near Infrared (top right also shown is the uncertainty specification (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



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

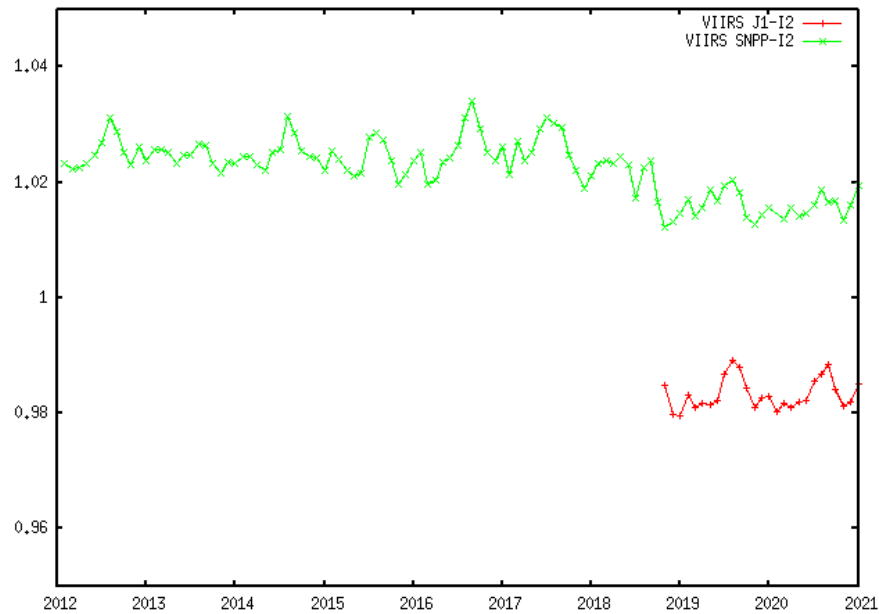
This is confirmed by comparison with MODIS

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?

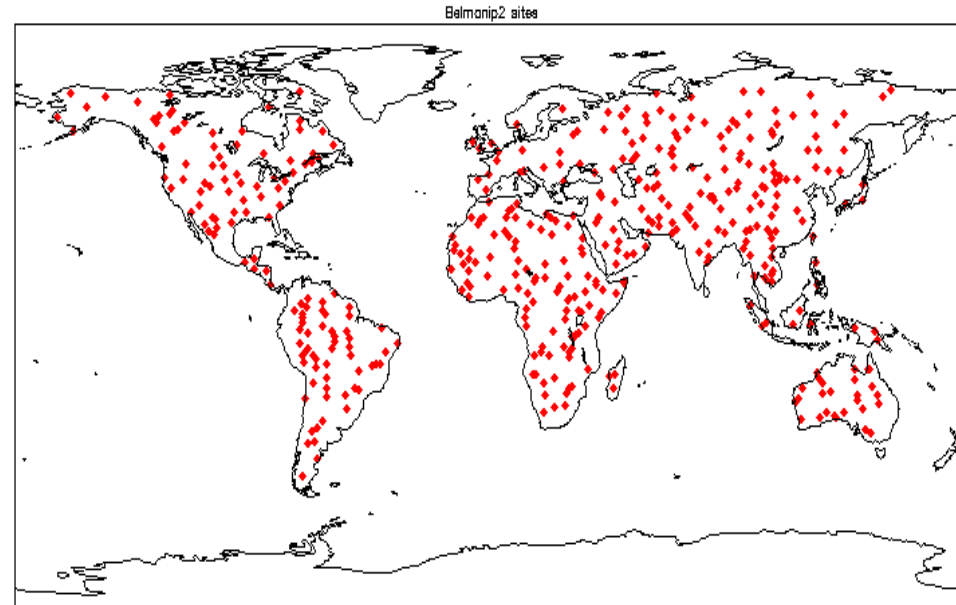
OLI surface reflectance APU scores expressed in 10^{-3} reflectance (compared to TM and ETM+ surface reflectance APU by Claverie et al. (2015) using Aqua MODIS BRDF and spectrally adjusted surface reflectance CMG product as reference, the OLI surface reflectance was aggregated over the CMG. Band number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

Datasets

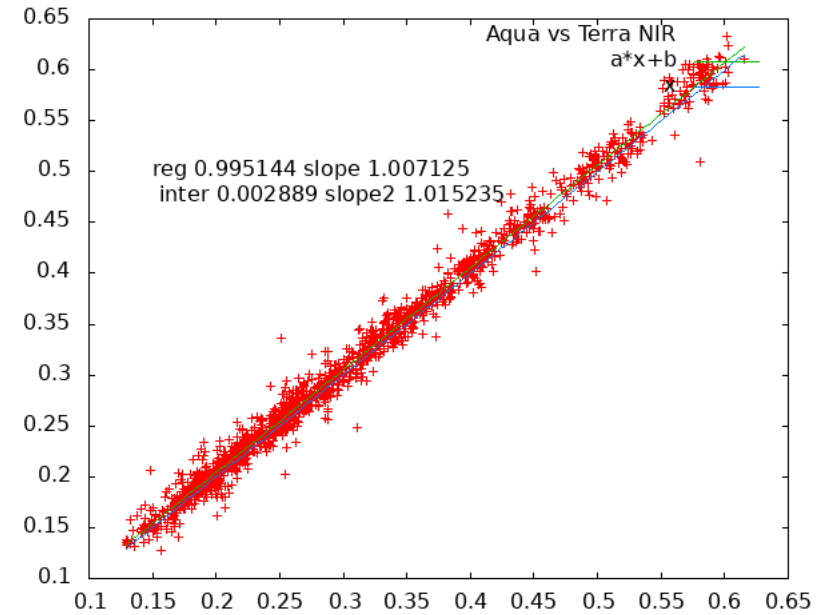
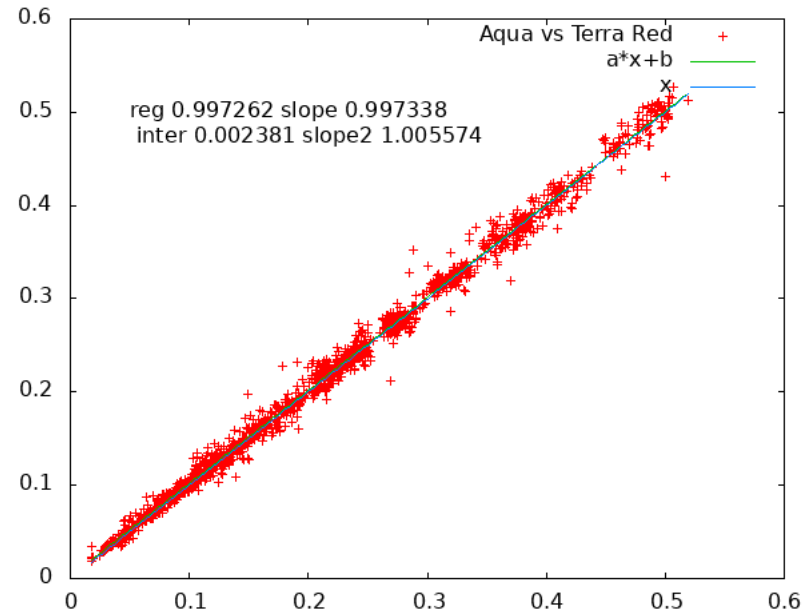
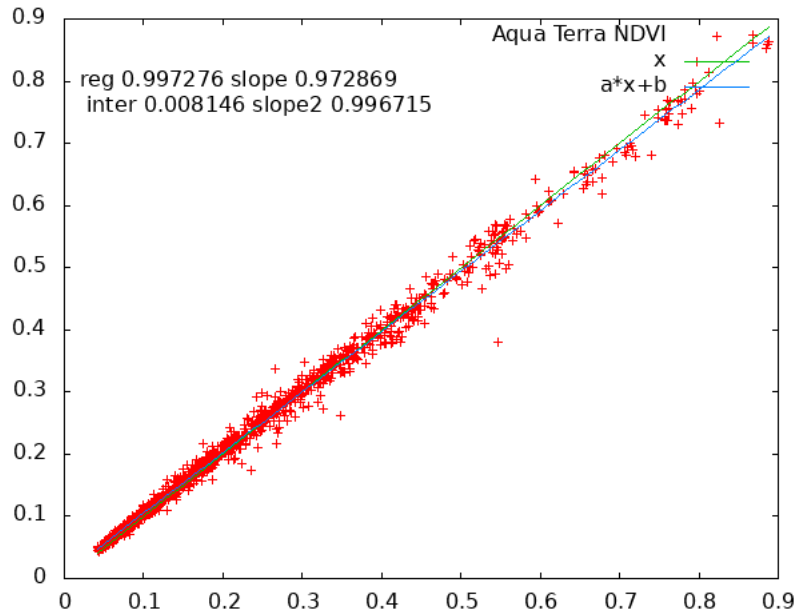
- MODIS Terra, Aqua, S3 (CMG) over Belmanip sites (422) during December 2018.
- Data were corrected for BRDF and normalize to Nadir view sun at 45deg.



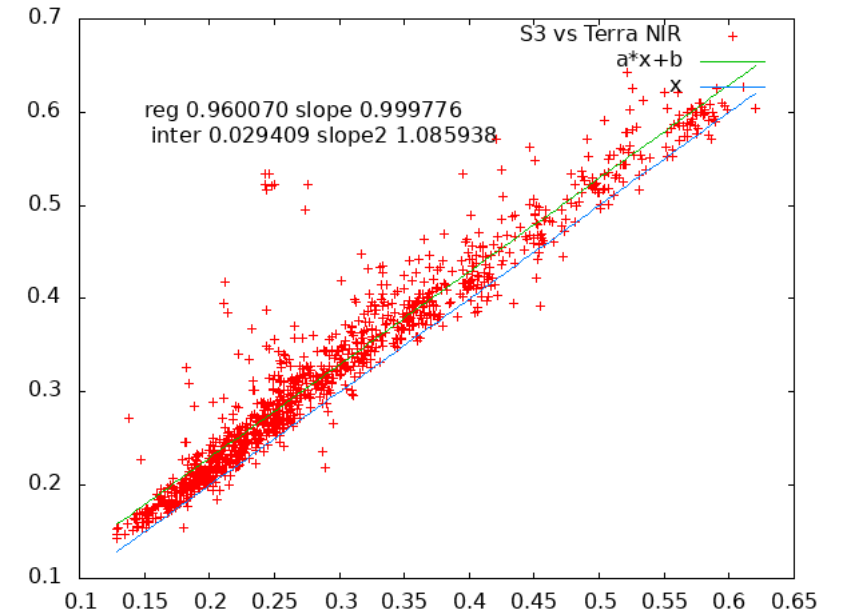
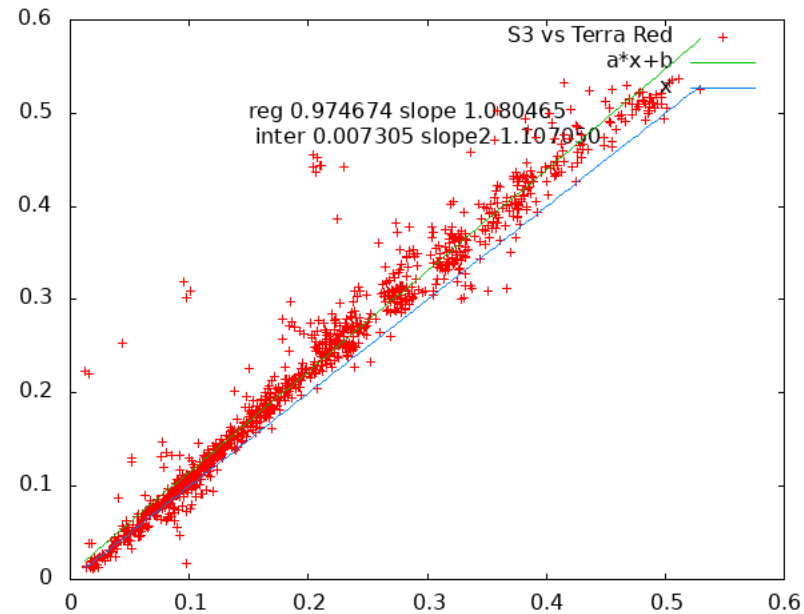
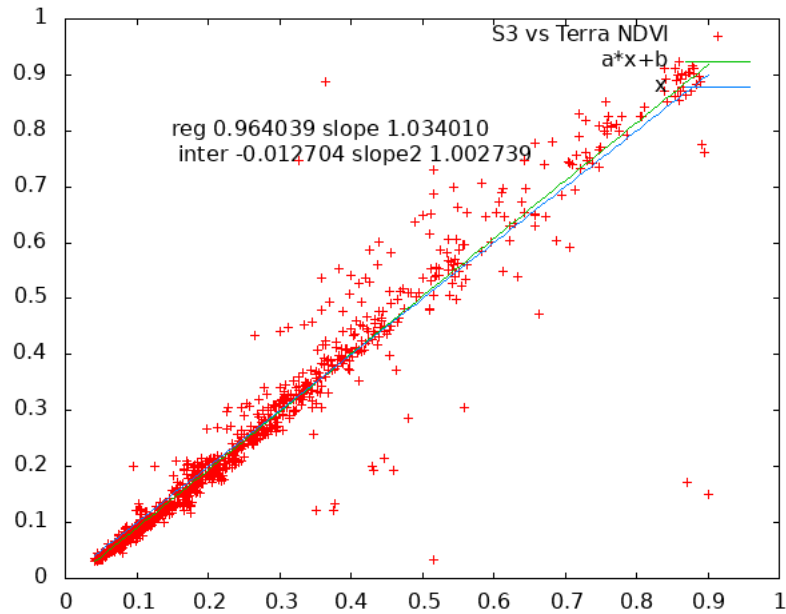
Automated monthly VIIRS cross comparison (over BELMANIP sites) with MODIS Aqua from 2012. the stability of both VIIRS and MODIS Aqua is excellent in both red and NIR as shown (+/- 0.5%).



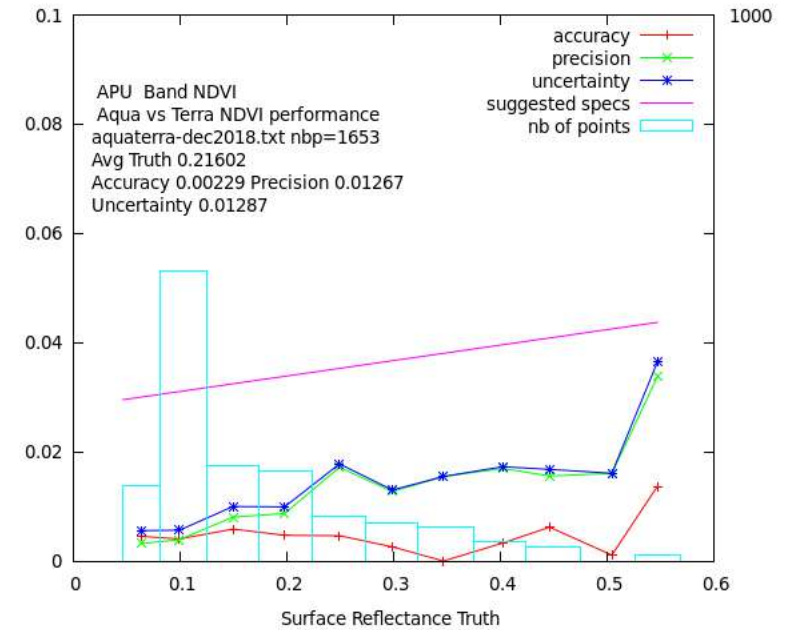
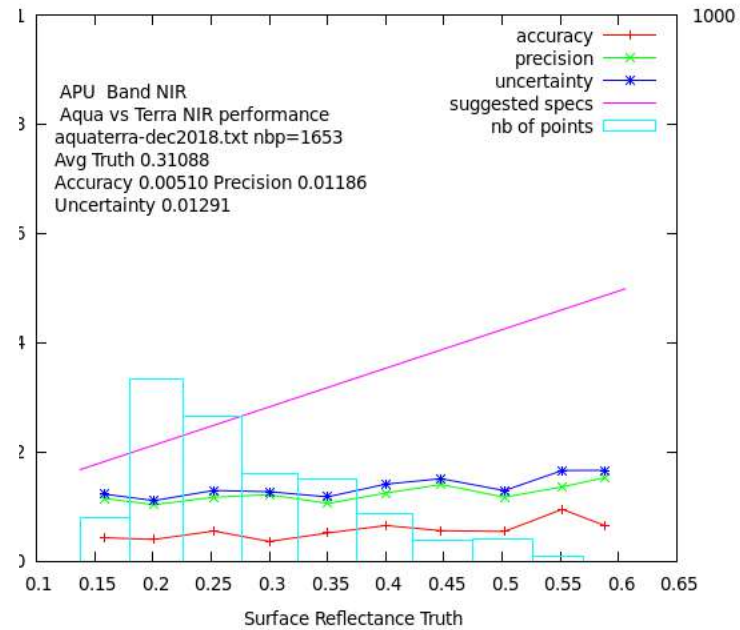
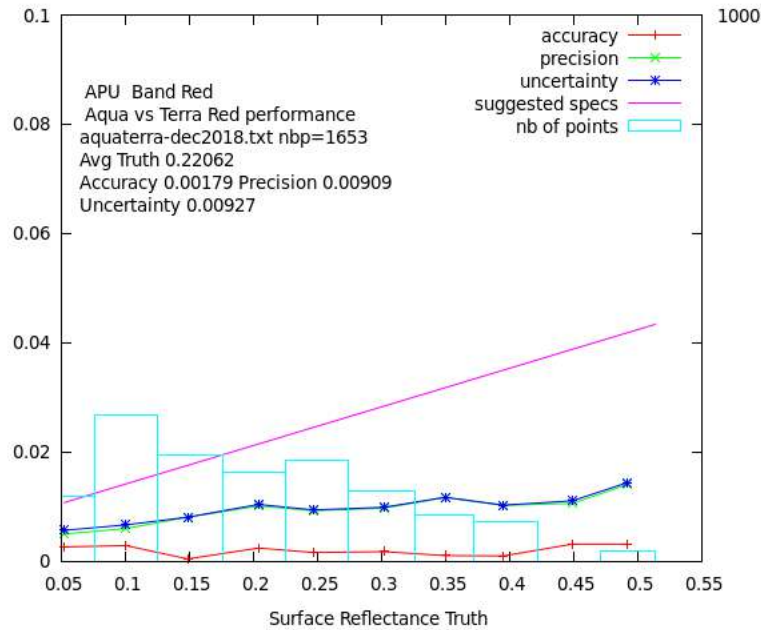
Scatters plot : Aqua vs Terra Dec 2018



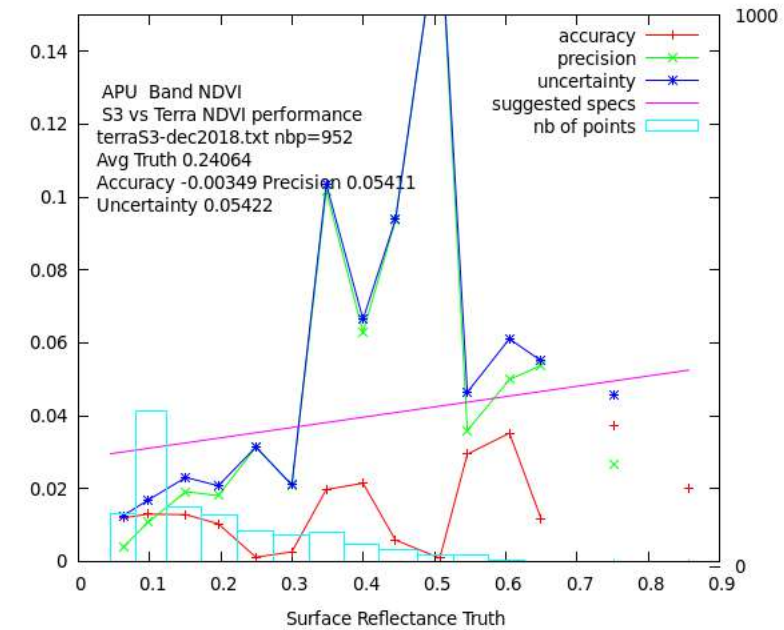
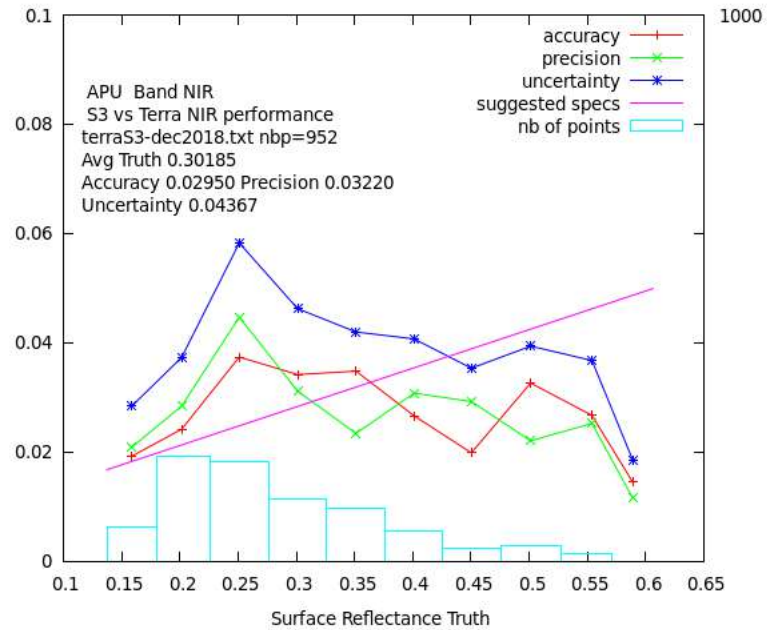
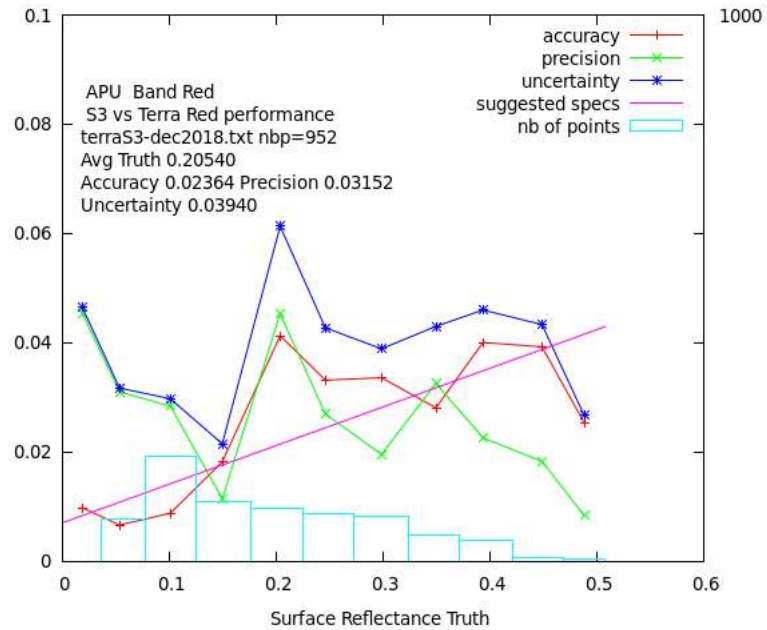
Scatters plot : S3 vs Terra Dec 2018



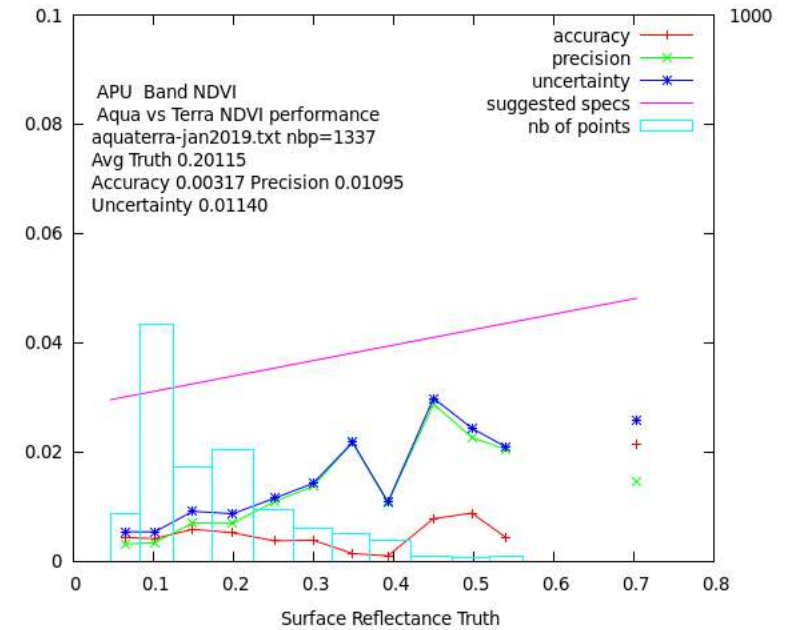
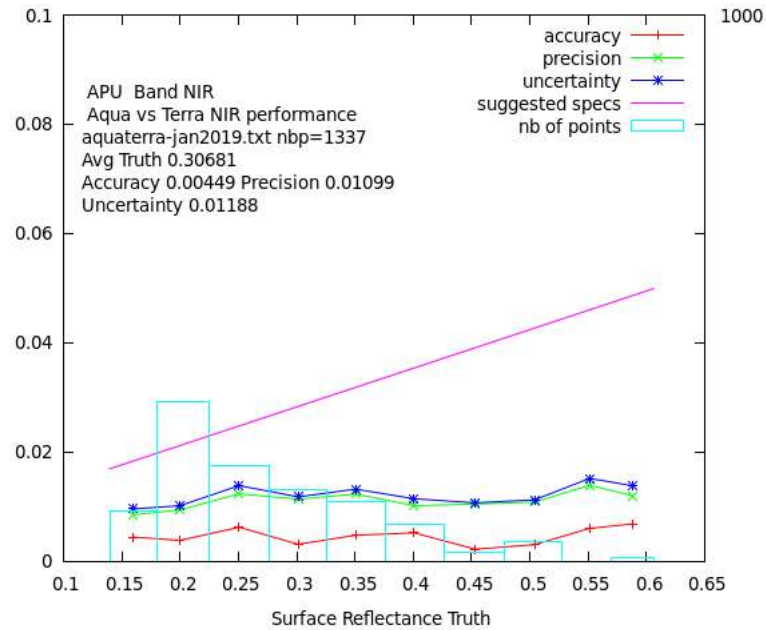
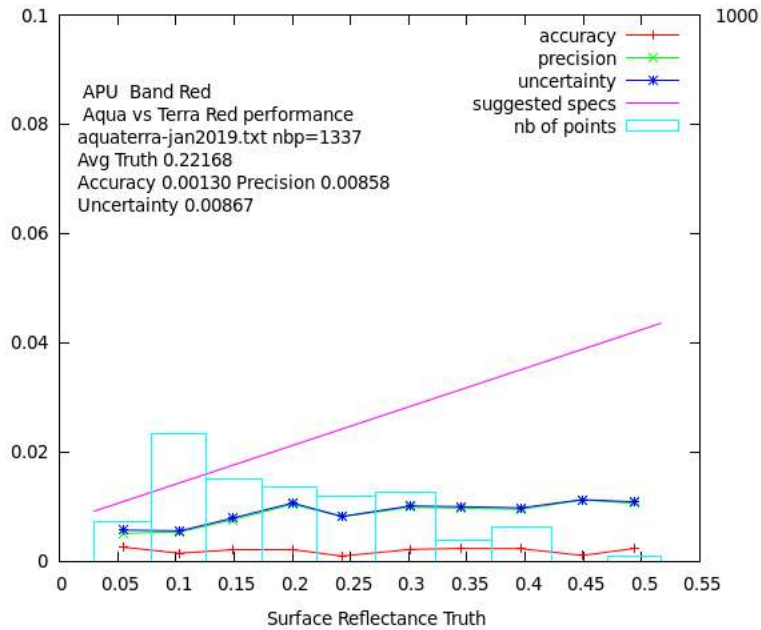
APU: Aqua vs Terra Dec 2018



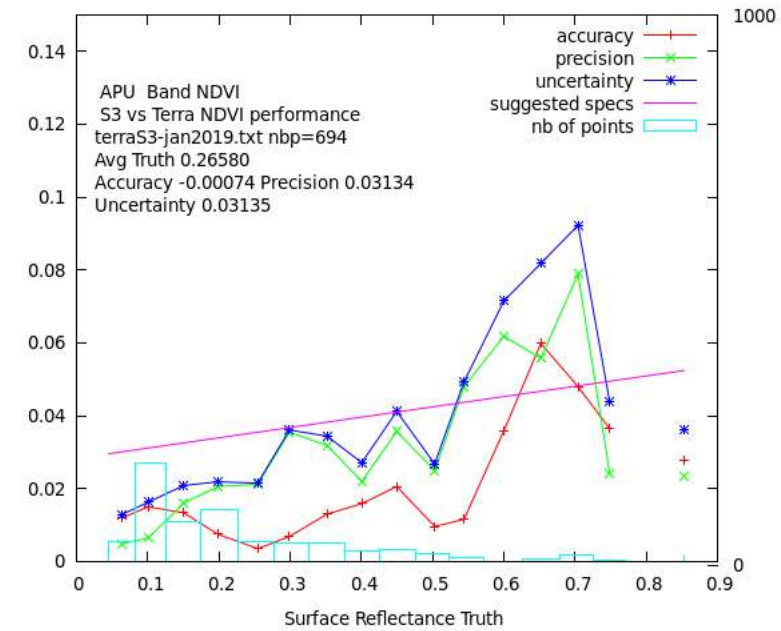
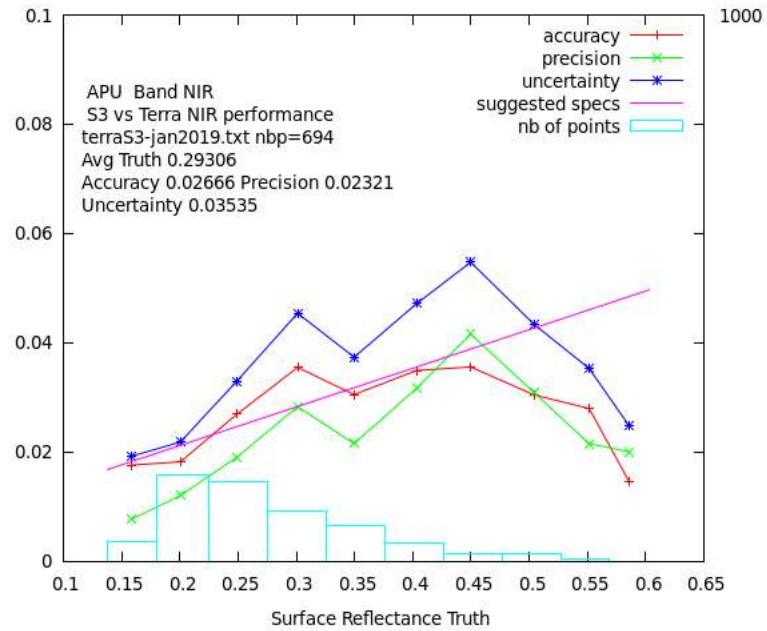
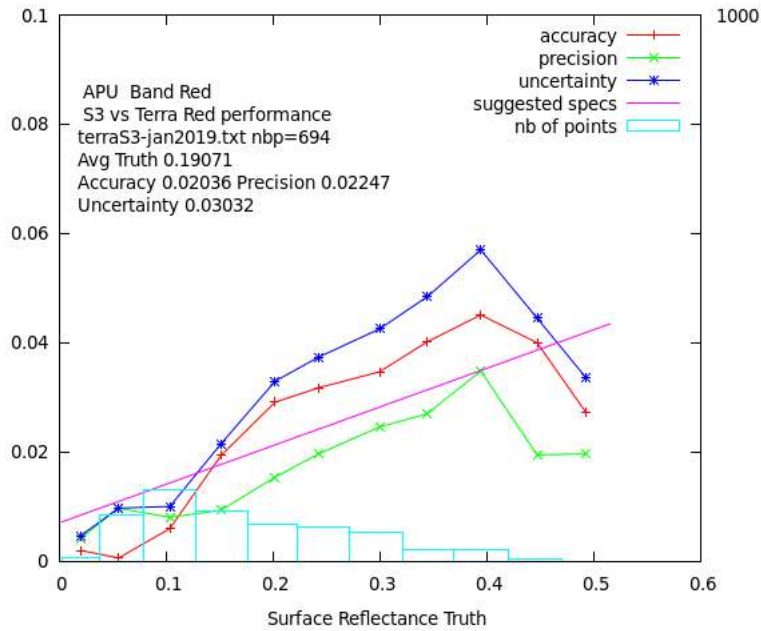
APU: S3 vs Terra Dec 2018



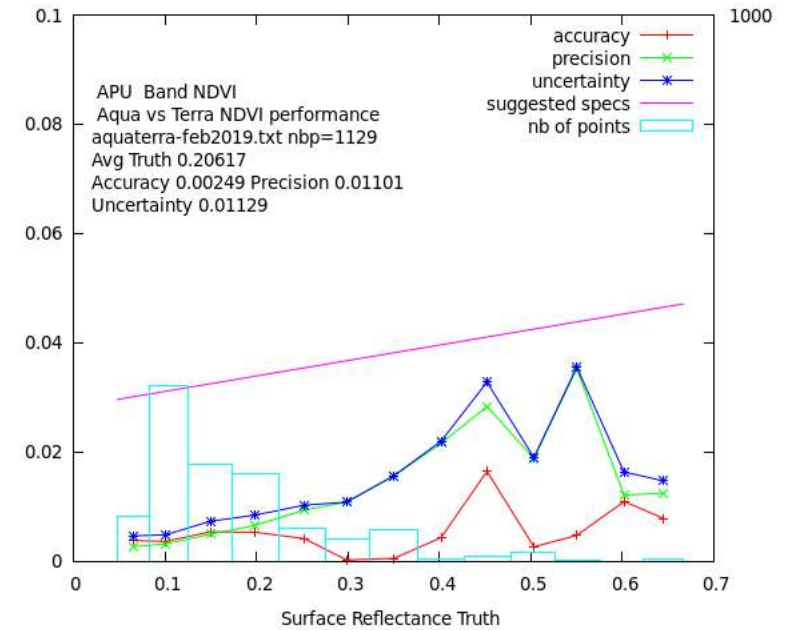
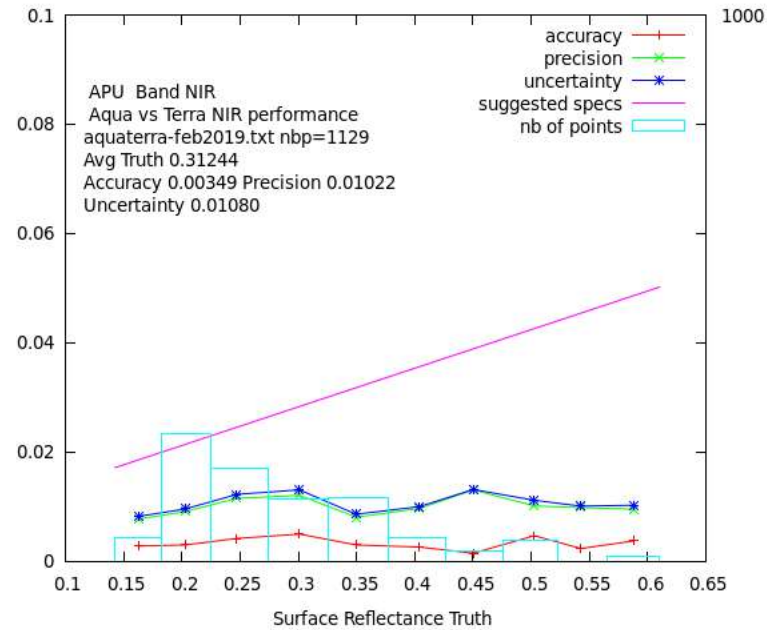
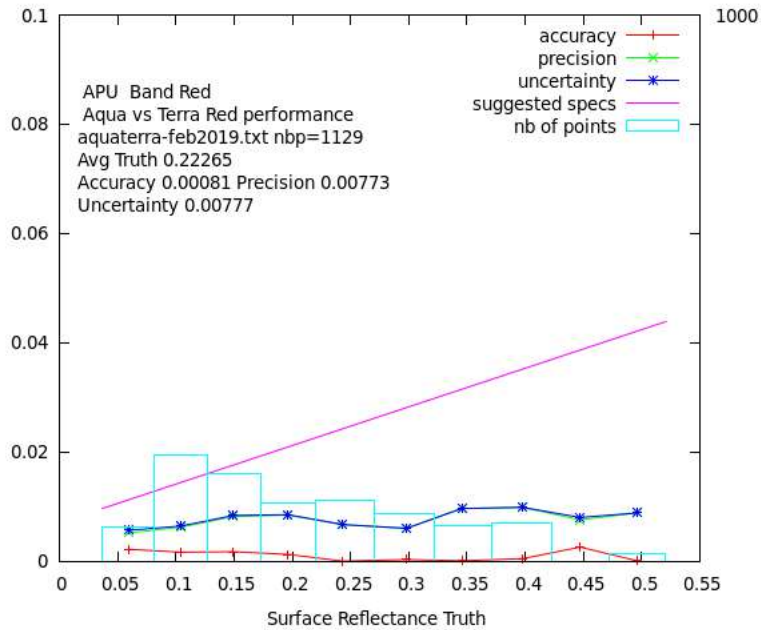
APU: Aqua vs Terra Jan 2019



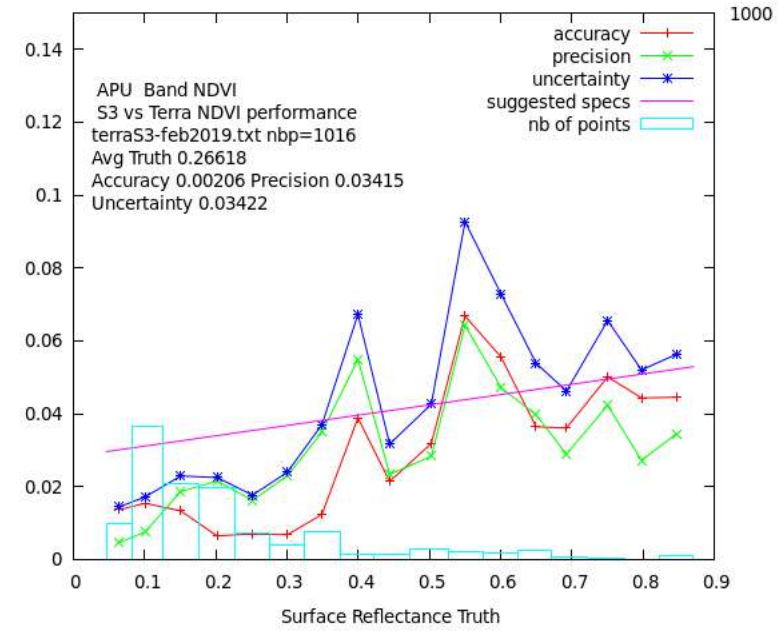
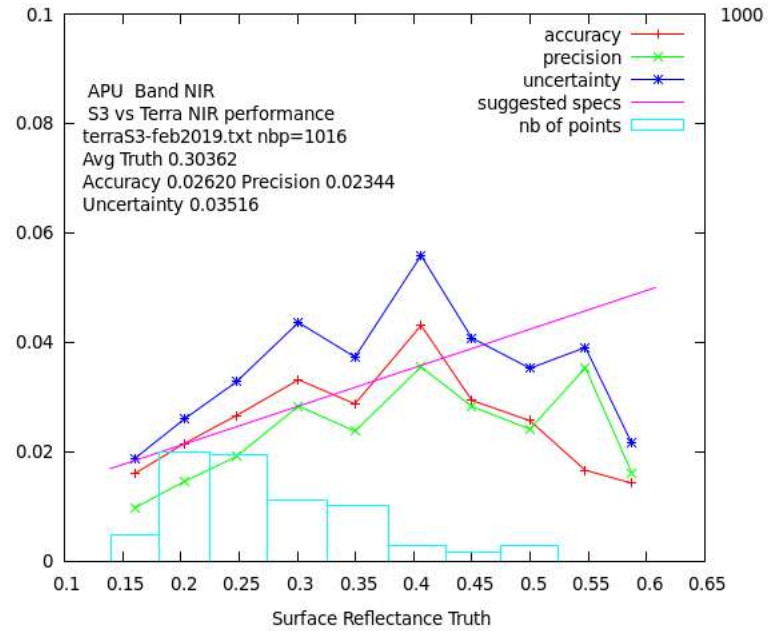
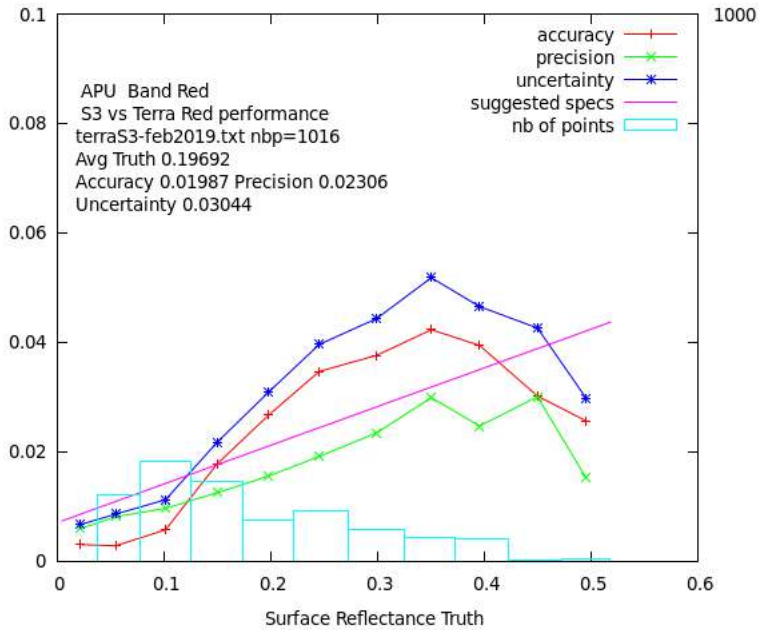
APU: S3 vs Terra Jan 2019

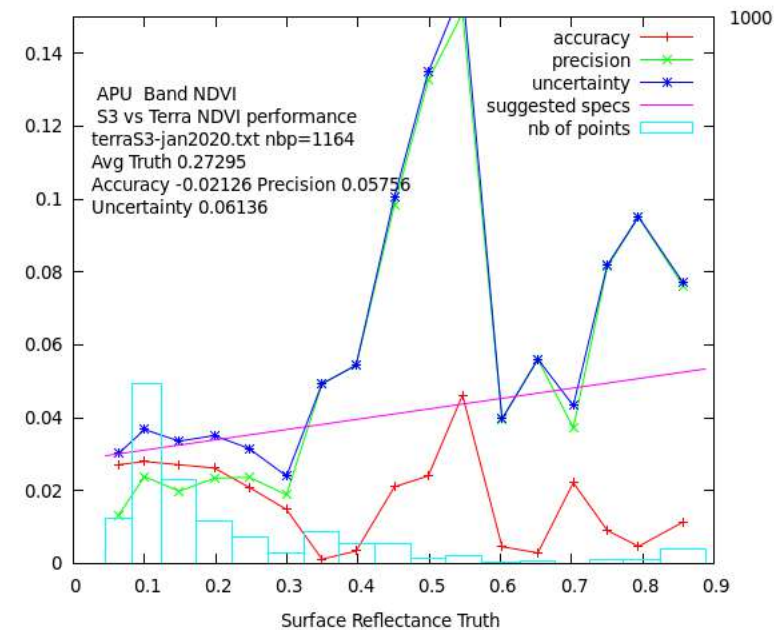
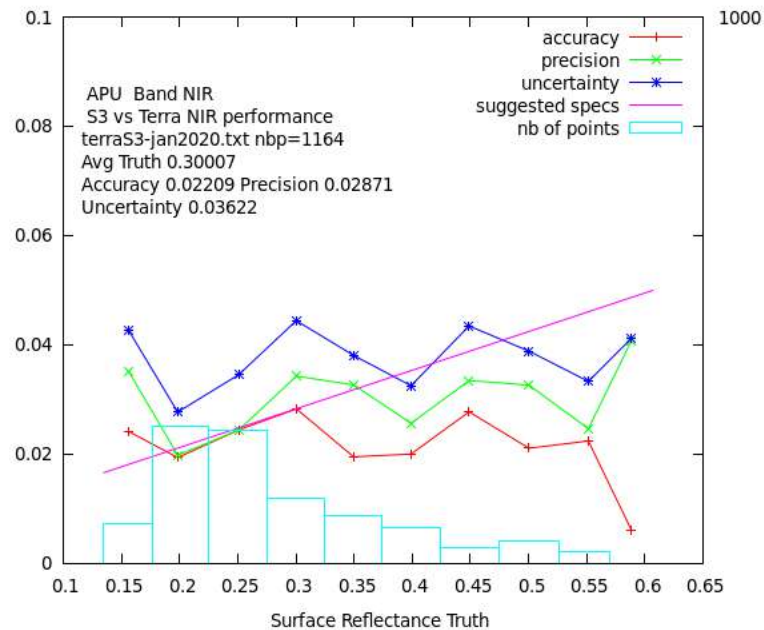
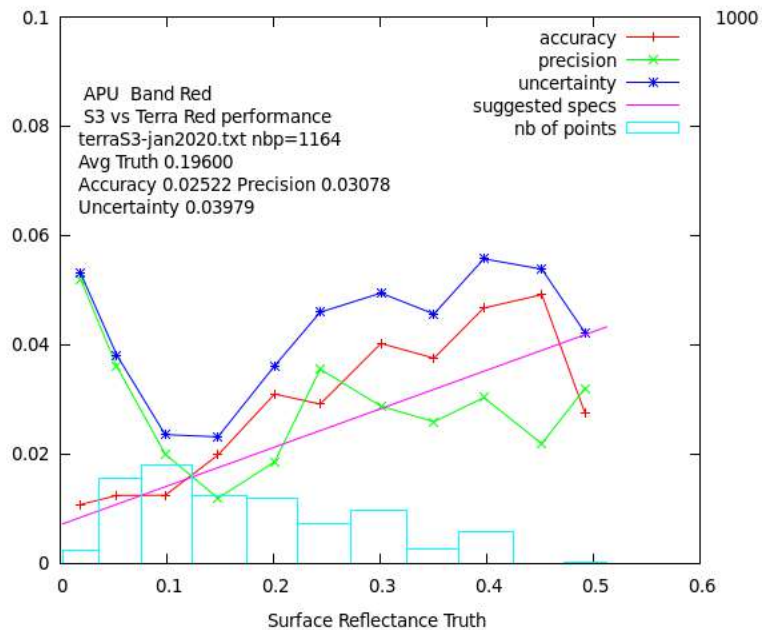


APU: Aqua vs Terra Feb 2019

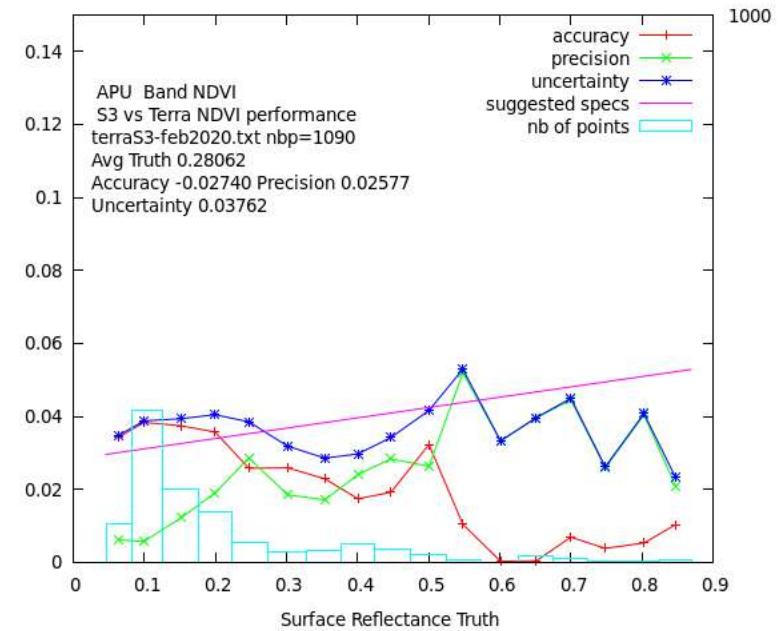
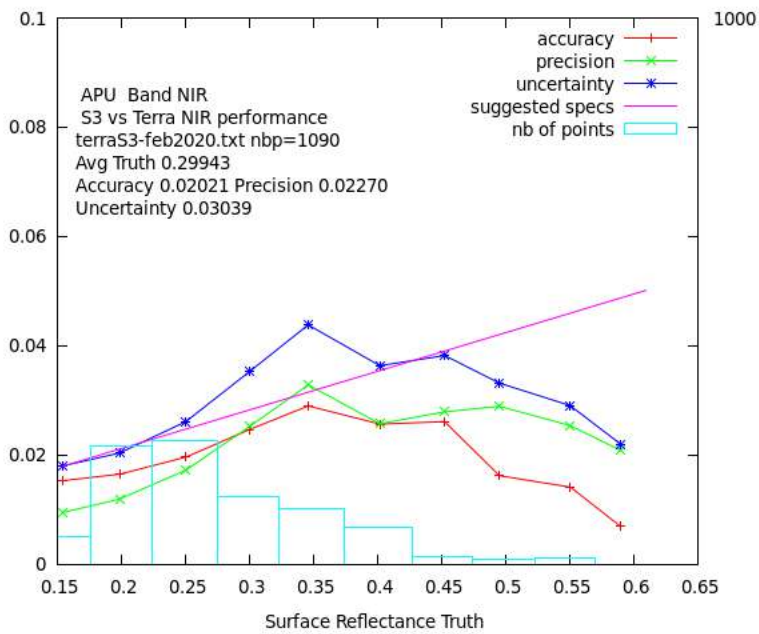
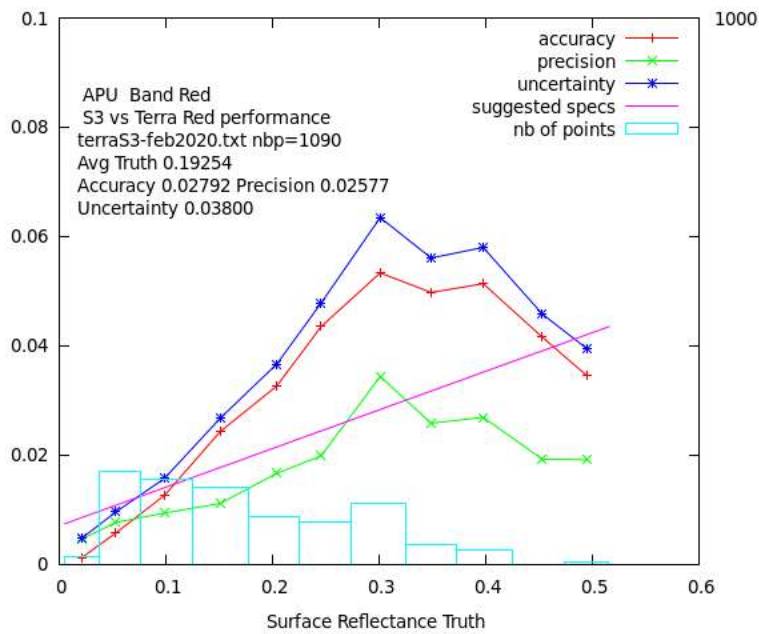


APU: S3 vs Terra Feb 2019

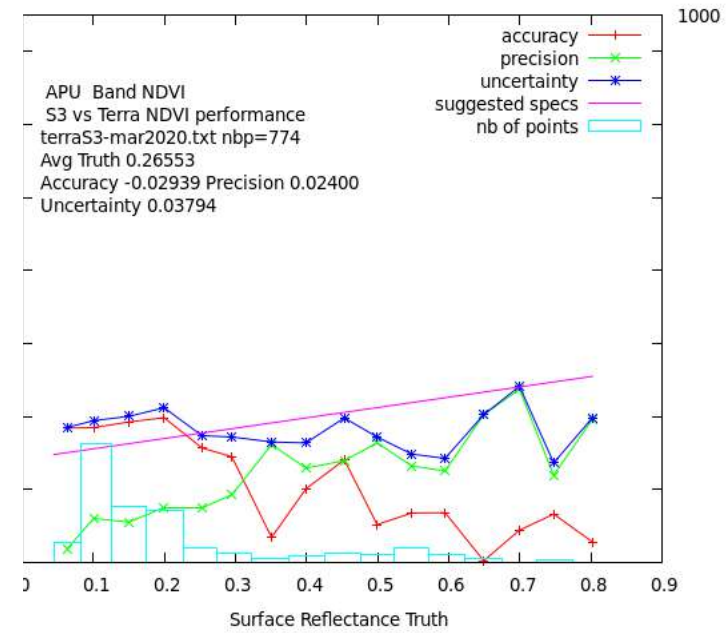
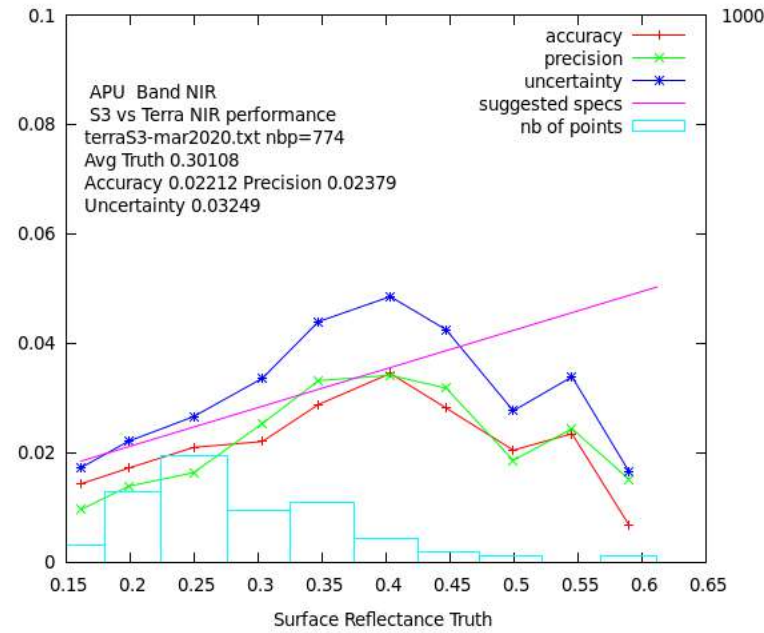
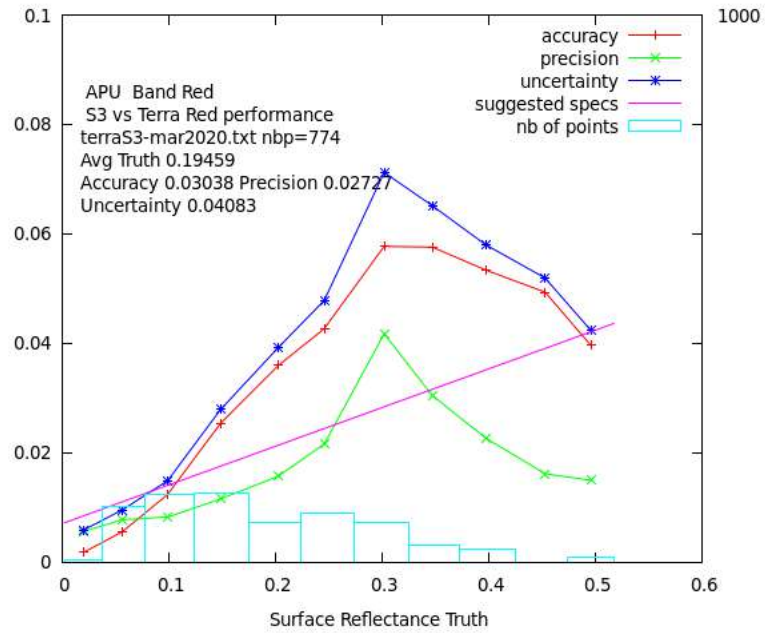




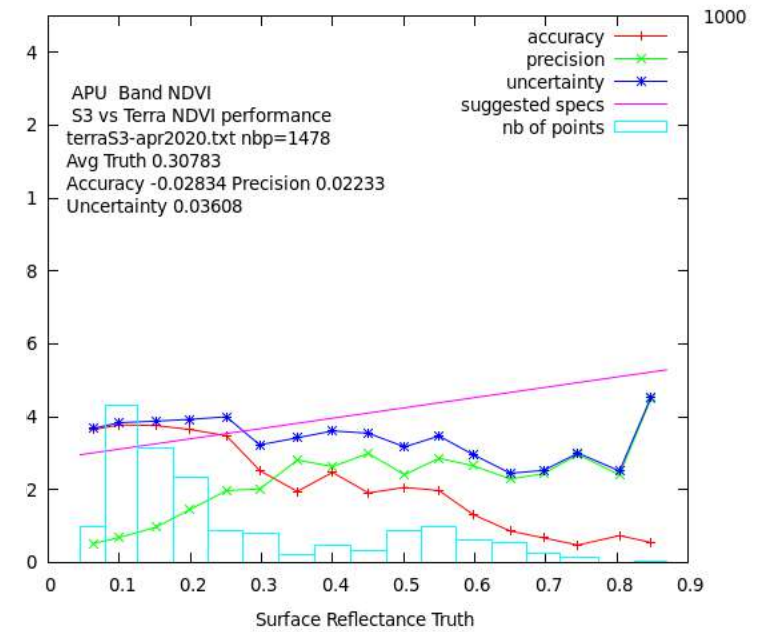
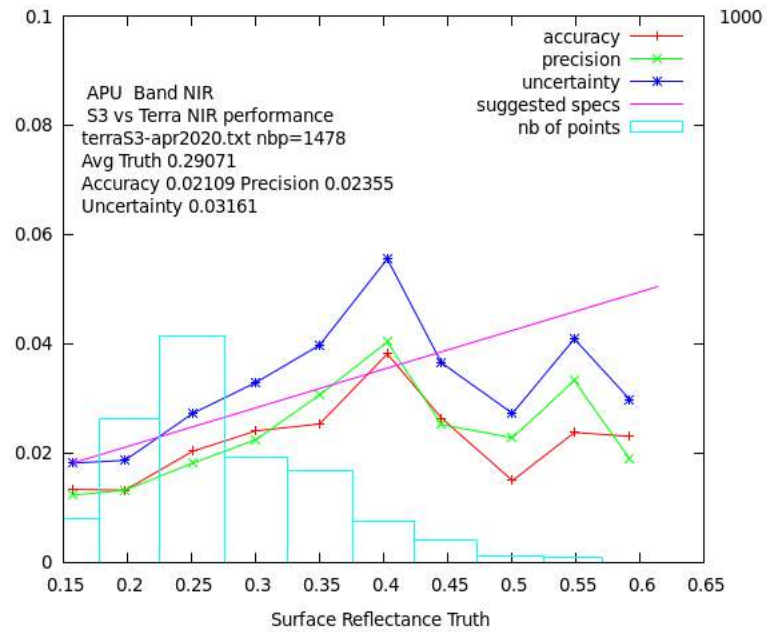
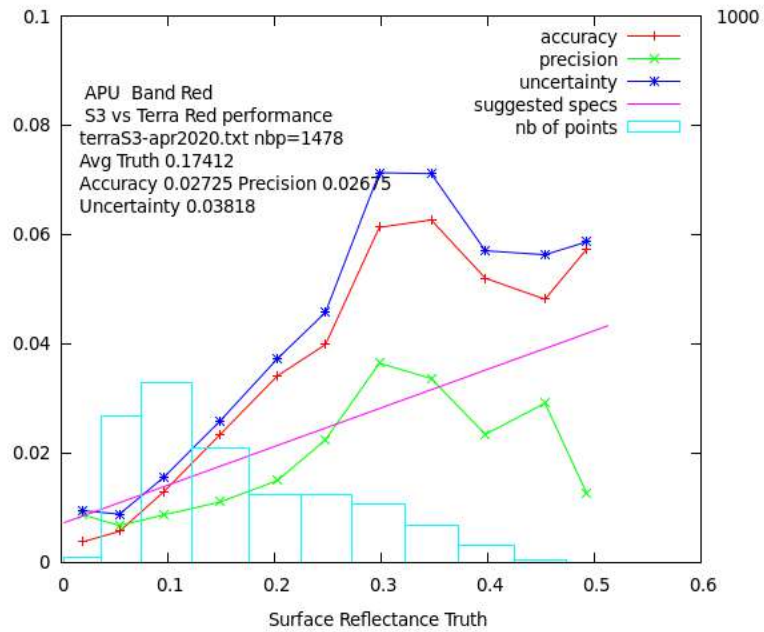
Sentinel 3 versus Terra (APU) Jan 2020



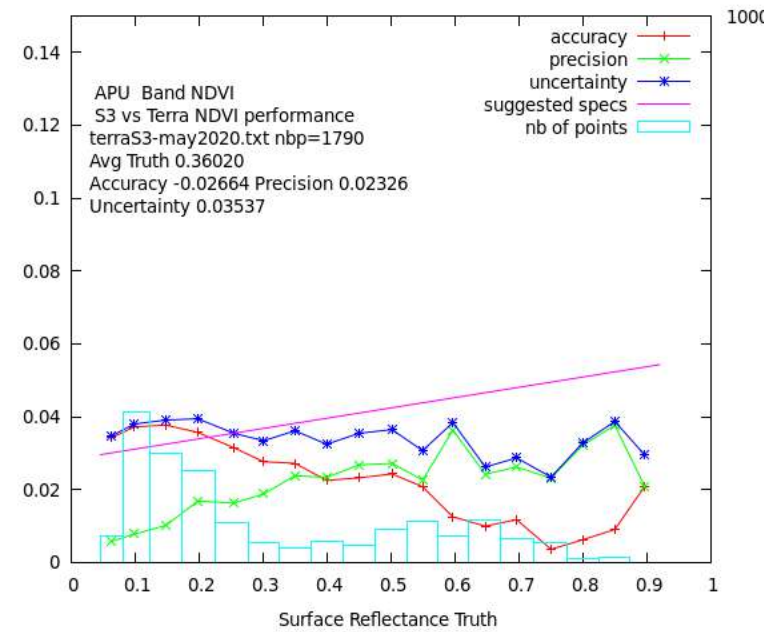
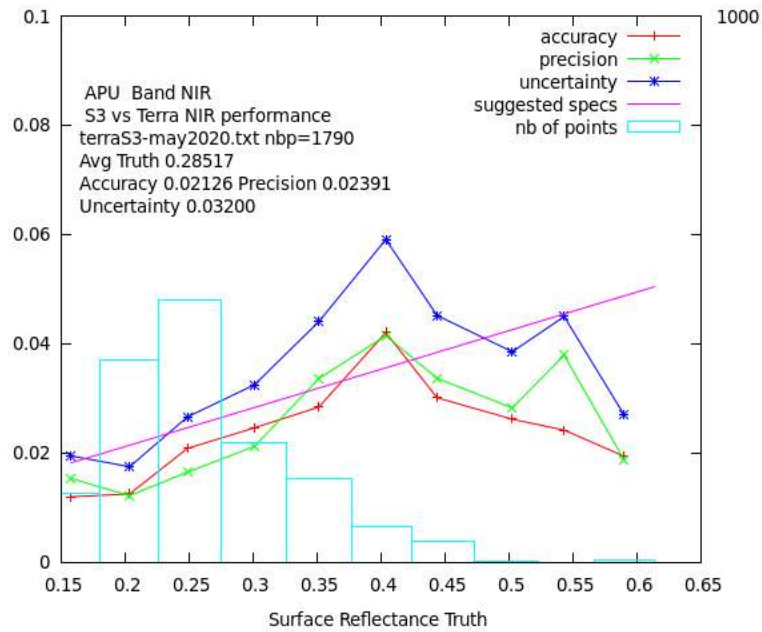
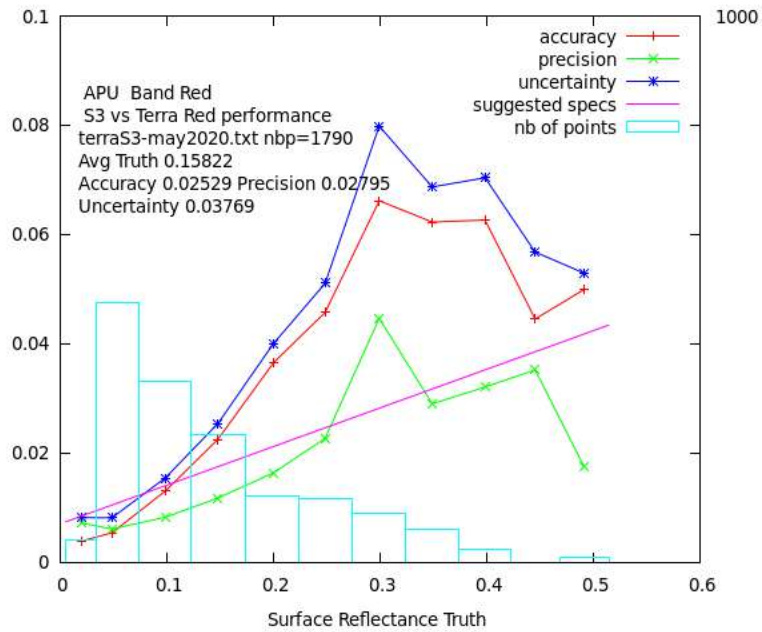
Sentinel 3 versus Terra (APU) Feb 2020



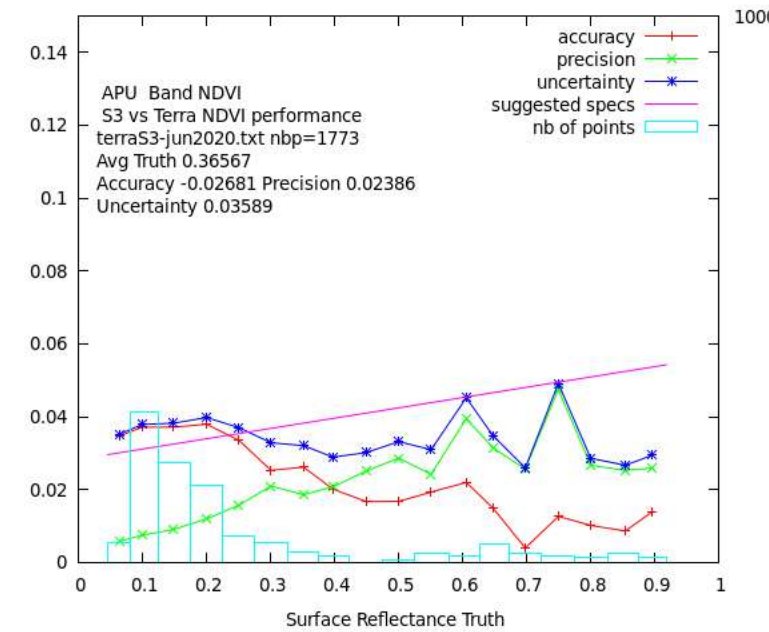
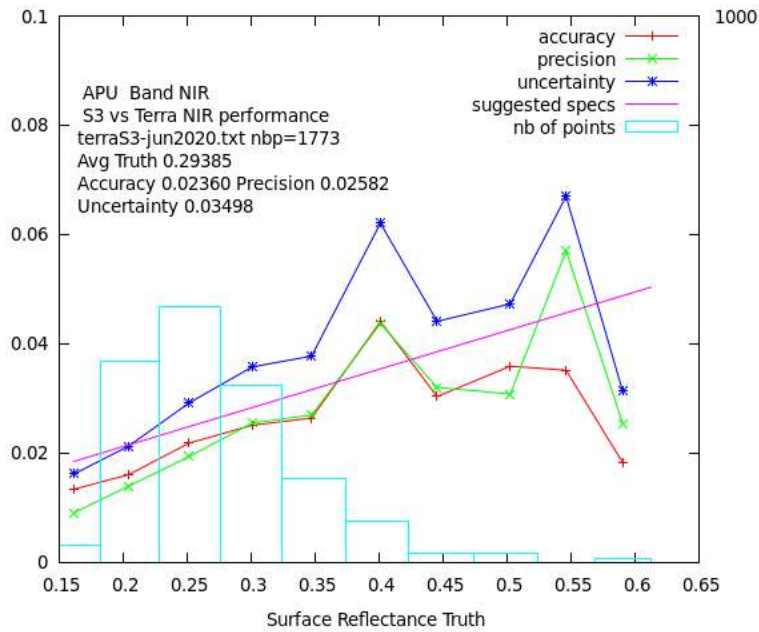
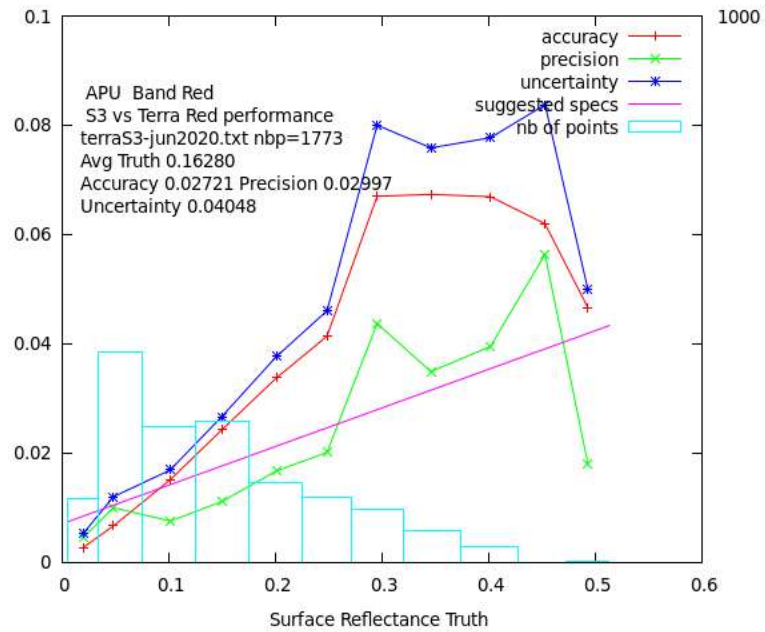
Sentinel 3 versus Terra (APU) Mar 2020



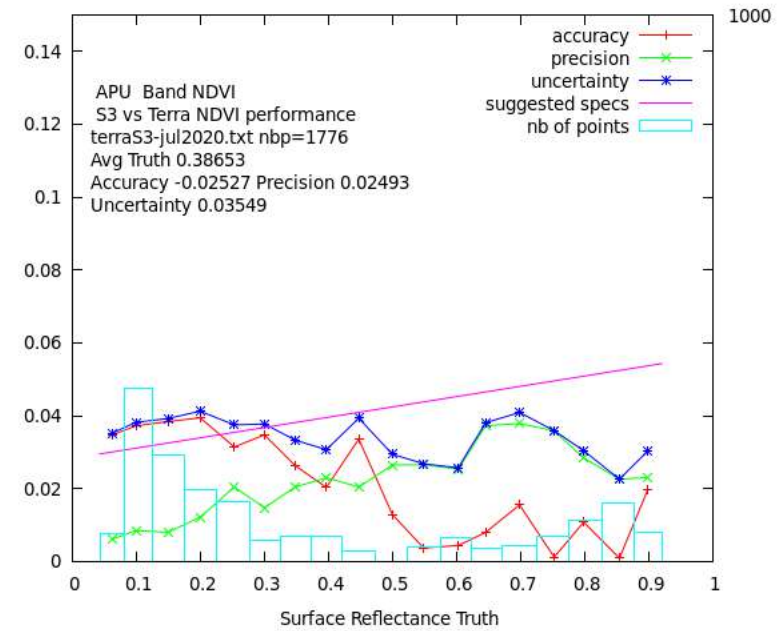
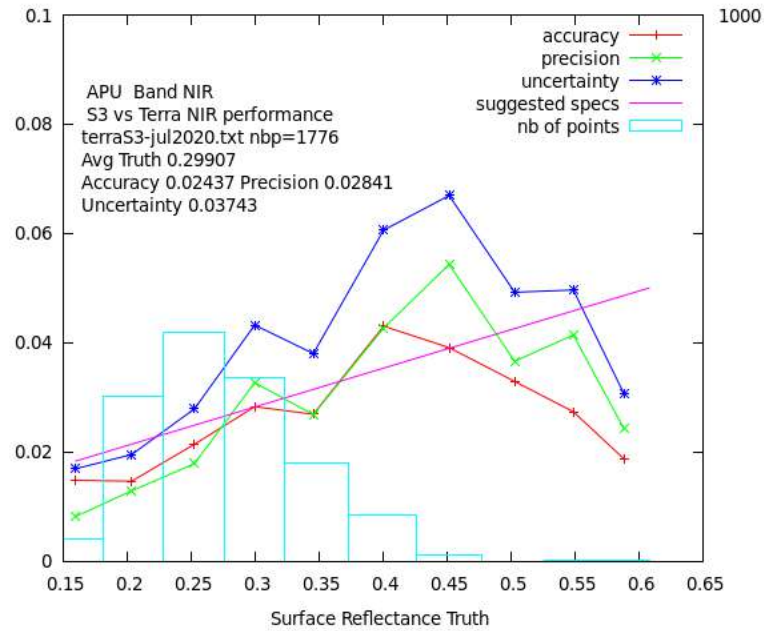
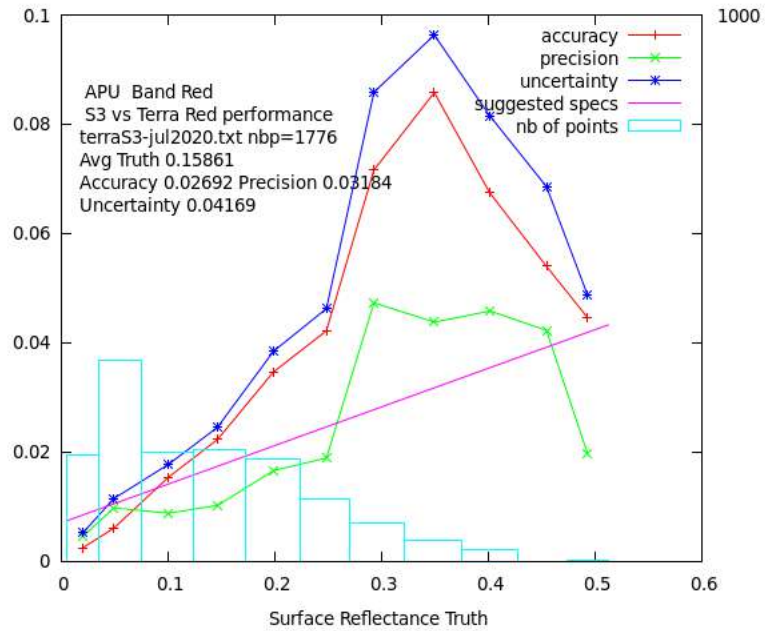
Sentinel 3 versus Terra (APU) Apr 2020



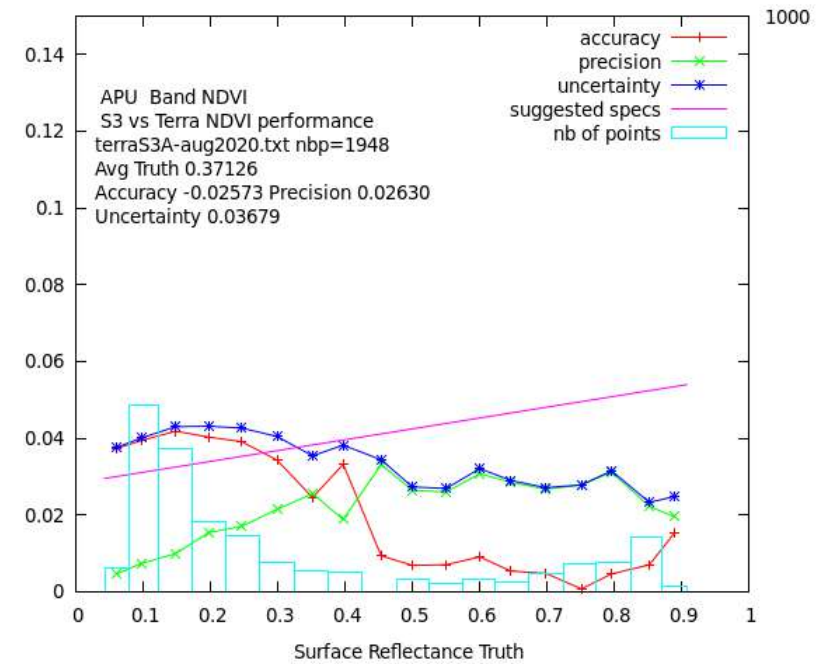
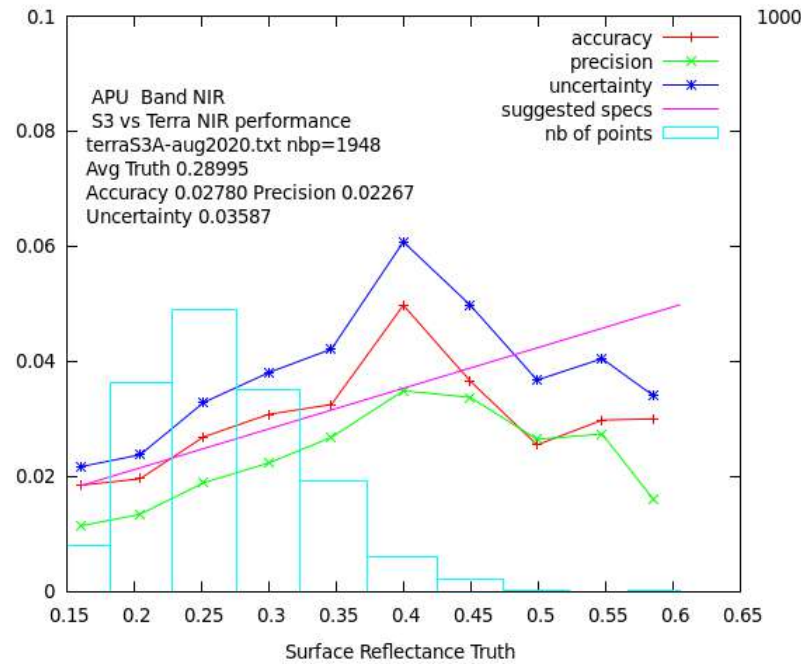
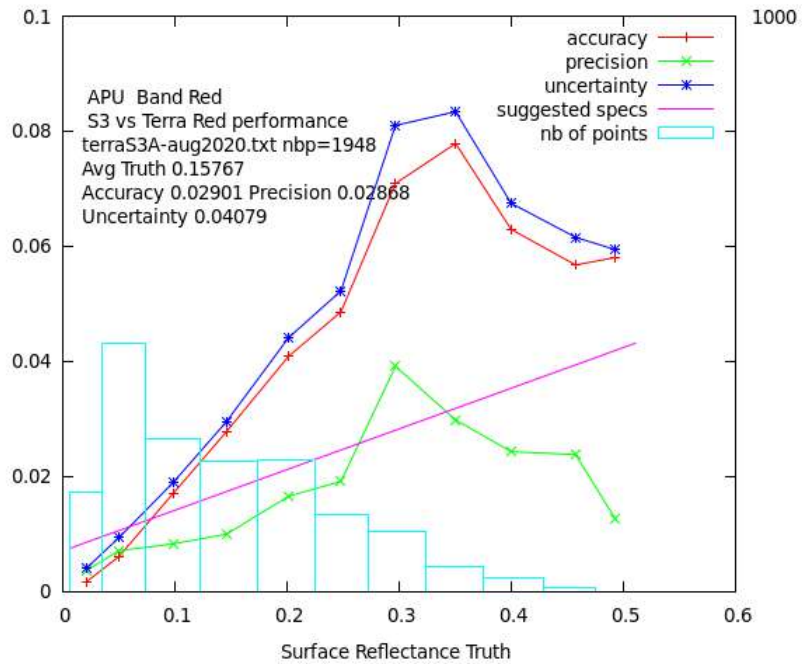
Sentinel 3 versus Terra (APU) May 2020



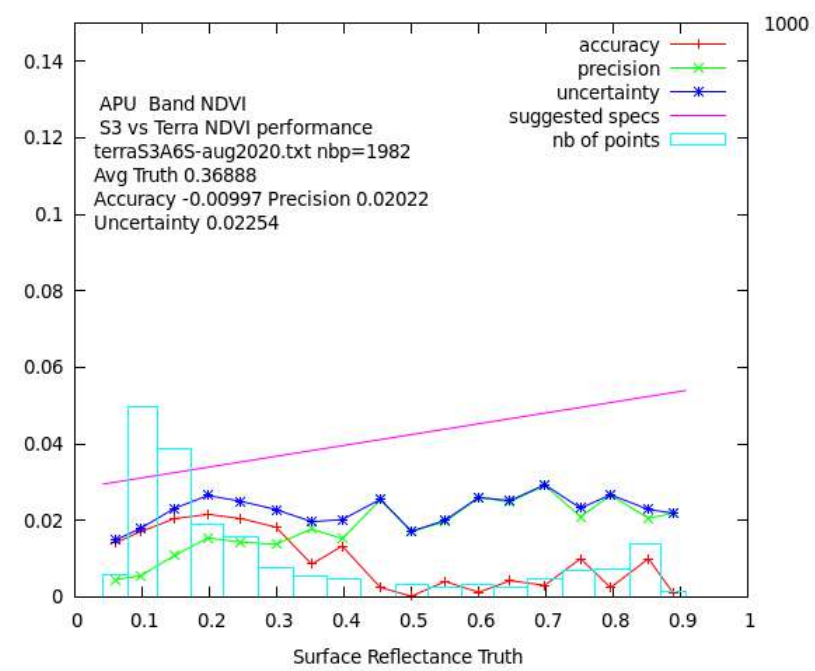
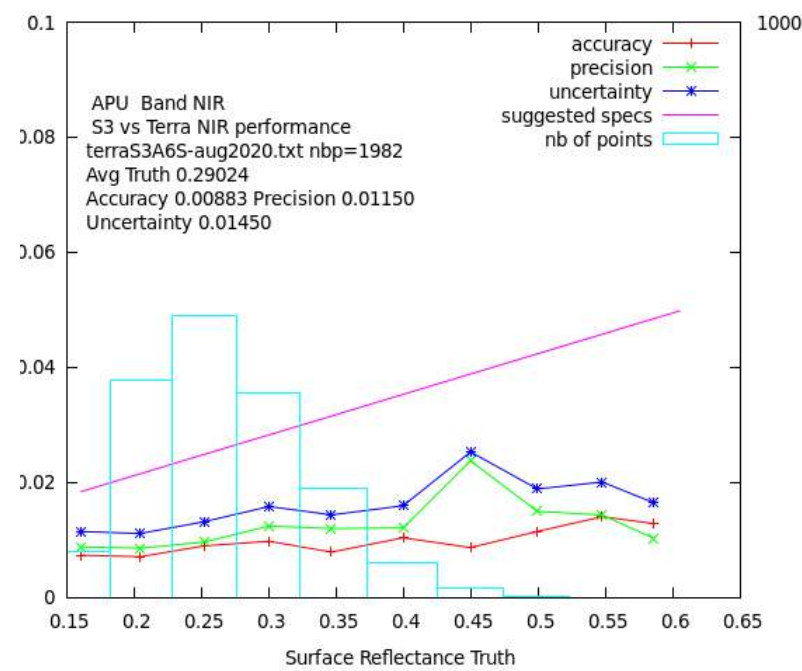
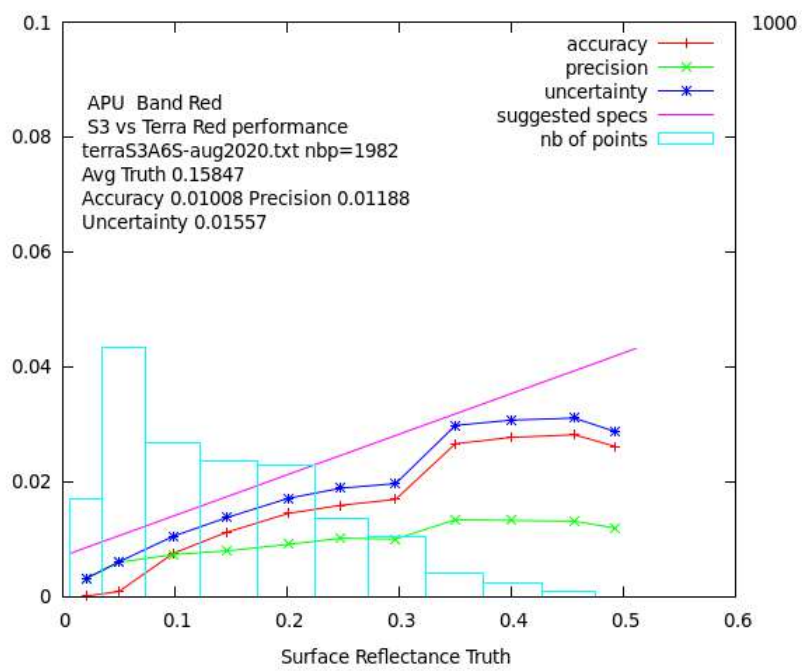
Sentinel 3 versus Terra (APU) June 2020



Sentinel 3 versus Terra (APU) July 2020



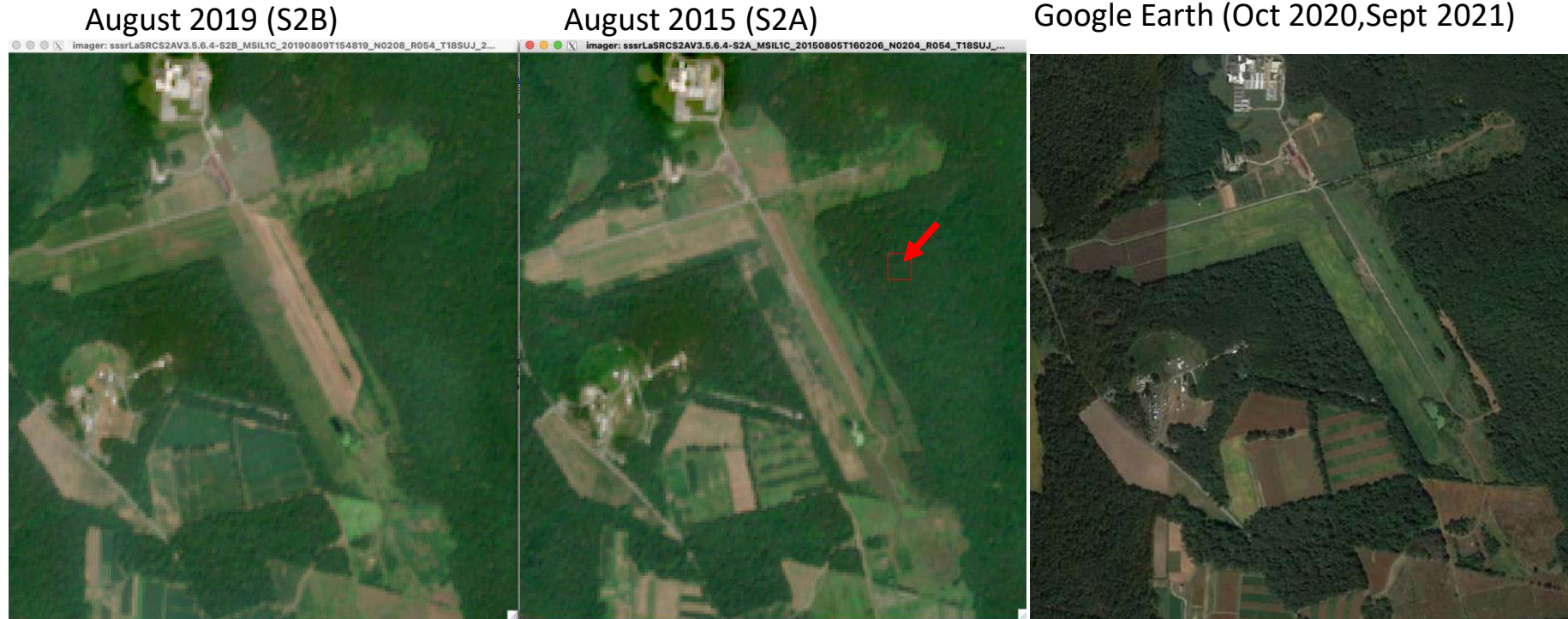
Sentinel 3 SR versus Terra (APU) Aug 2020



Sentinel 3 6S-SR versus Terra (APU) Aug 2020

Time series analysis

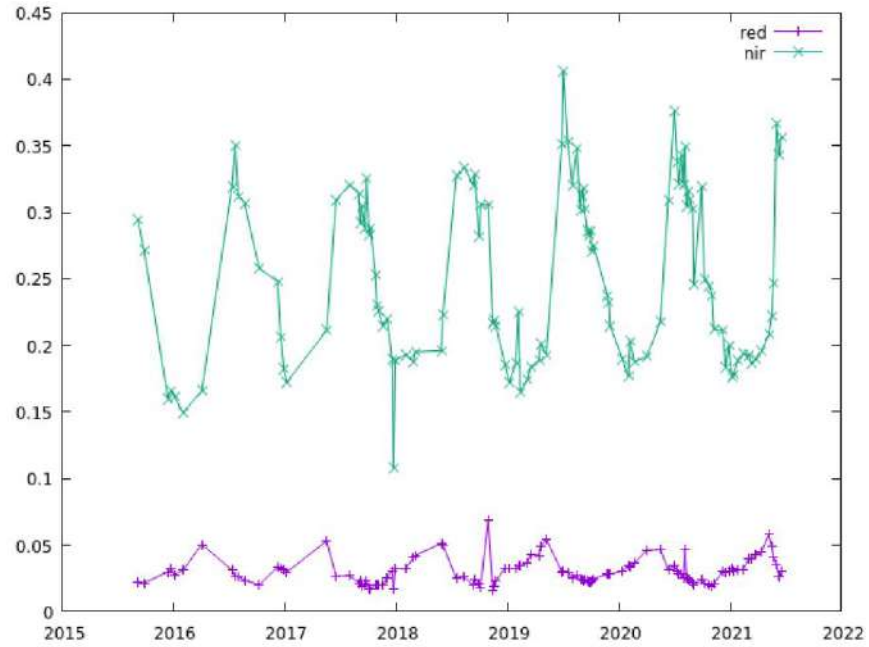
GSFC-BELTSVILLE Site 1920 meters x 1920 meters



$$\text{Noise} = \sqrt{\frac{\sum_{i=1}^{n-2} \left(\rho_{i+1} \frac{\rho_{i+2} - \rho_i}{d_{i+2} - d_i} (d_{i+1} - d_i) - \rho_i \right)^2}{n-2}}$$

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

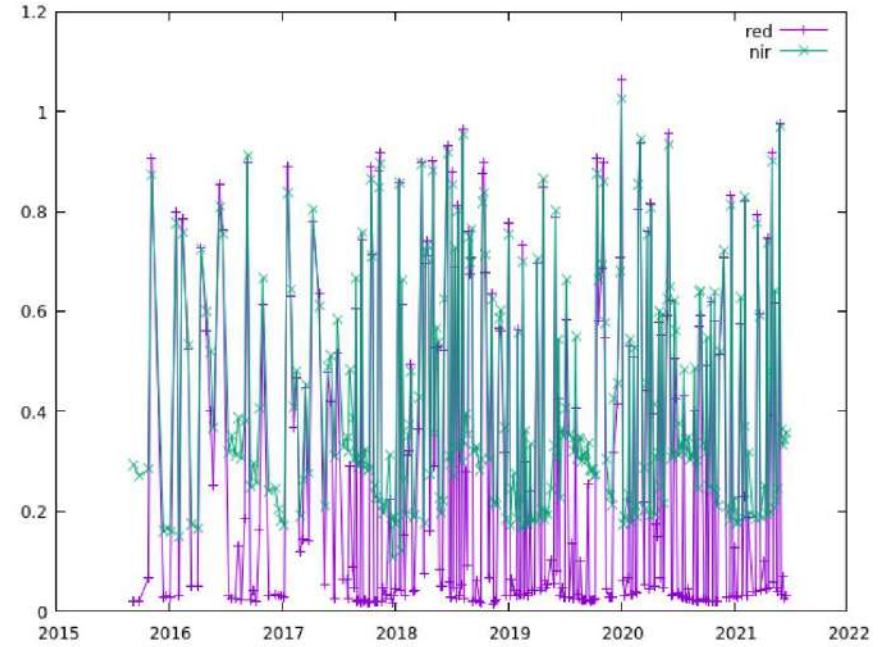
Surface reflectance LaSRC S2A,B



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

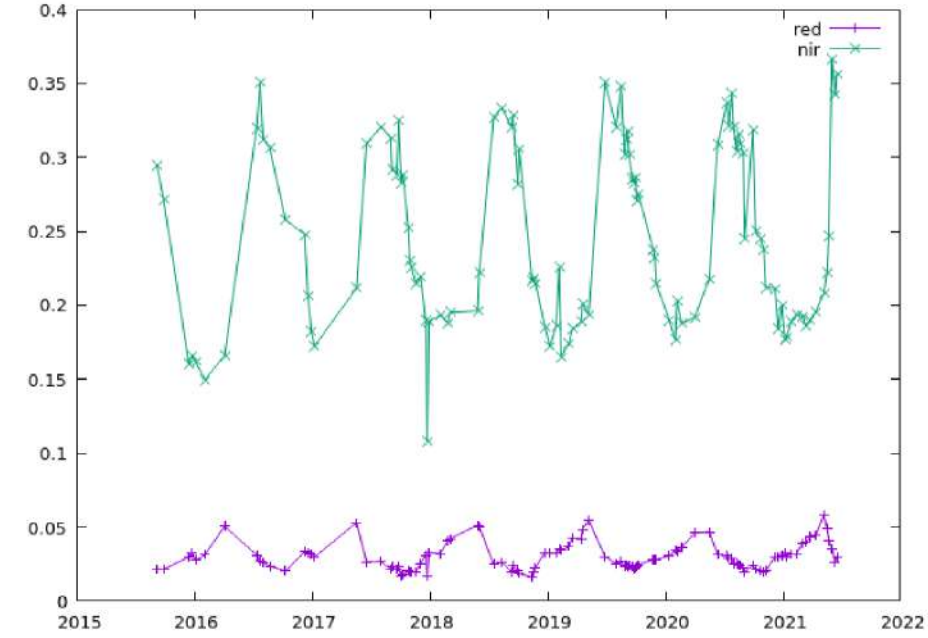
Surface reflectance LaSRC S2A,B no QA applied



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

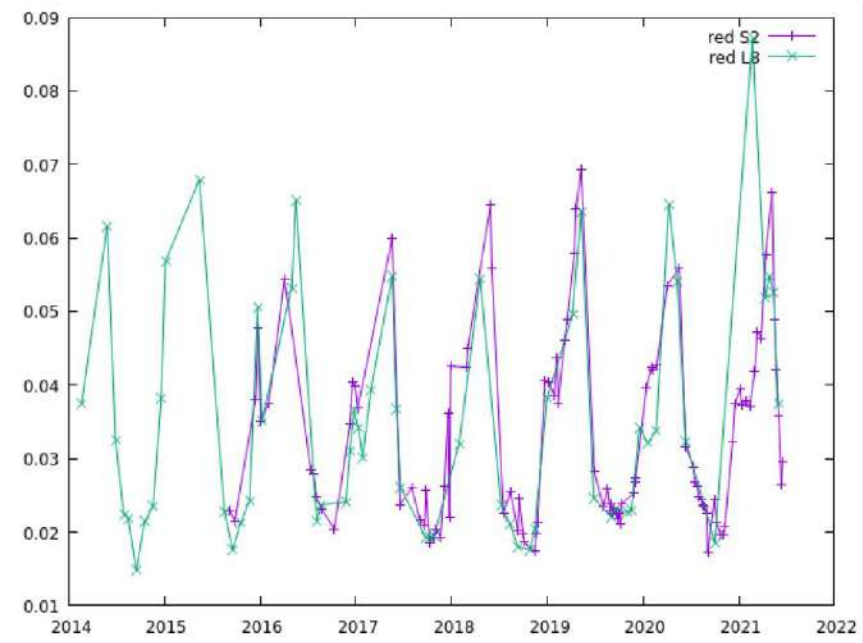
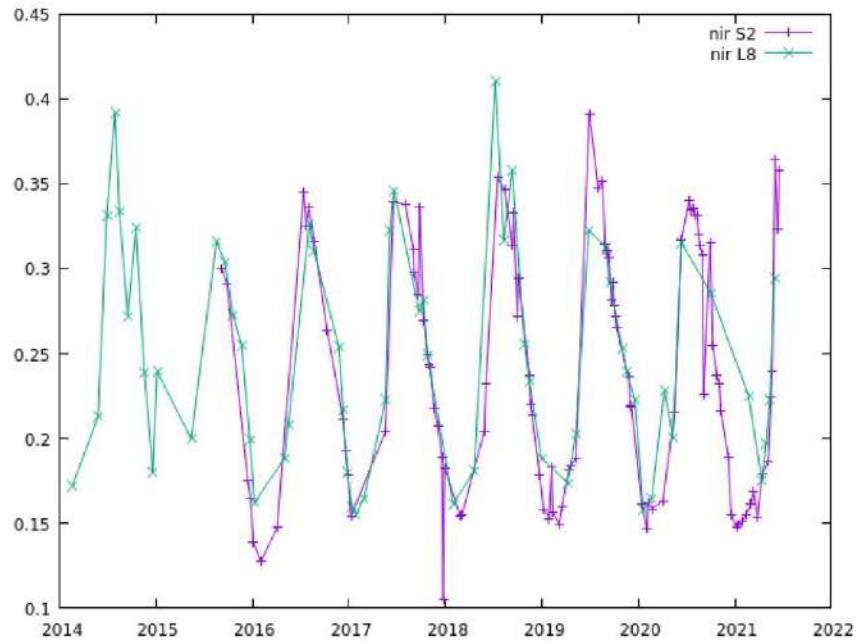
band	Noise	Noise (95%)	NB
red	0.332	0.340	294/279
nir	0.239	0.245	294/279

Surface reflectance LaSRC (QA 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



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

$$\text{RNoise} = 100 * \text{Noise} / \text{average}$$

CMIX:Cloud Mask Intercomparison eXercise

Sergii **Skakun**, Jan **Wevers**, Carsten **Brockmann**, Georgia **Doxani**, Matej **Aleksandrov**, Matej **Batič**, David **Frantz**, Ferran **Gascon**, Luis **Gómez-Chova**, Olivier **Hagolle**, Dan **López-Puigdollers**, Jérôme **Louis**, Matic **Lubej**, Gonzalo **Mateo-García**, Julien **Osman**, Devis **Peressutti**, Bringfried **Pflug**, Jernej **Puc**, Rudolf **Richter**, Jean-Claude **Roger**, Pat **Scaramuzza**, Eric **Vermote**, Nejc **Vesel**, Anže **Zupanc**, Lojze **Žust**



SINERGISE



DLR



VNIVERSITAT DE VALÈNCIA



Major findings of CMIX

Remote Sensing of Environment 274 (2022) 112990



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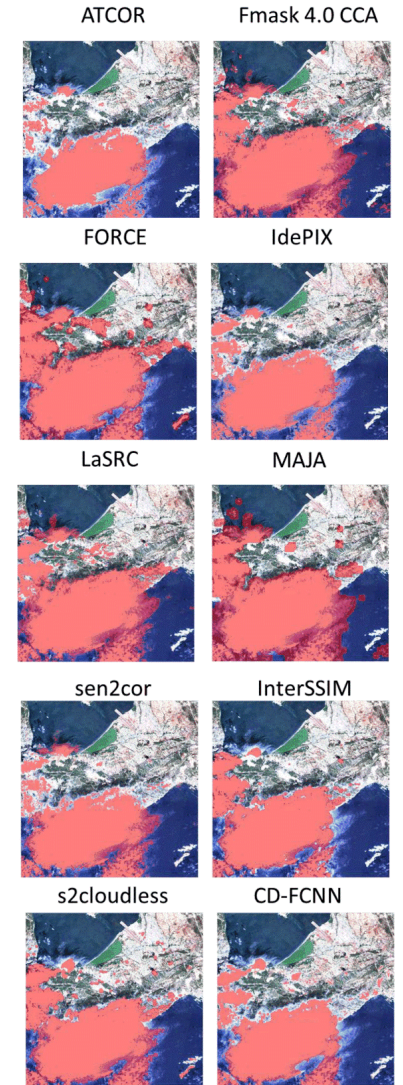
Remote Sensing of Environment

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



Cloud Mask Intercomparison eXercise (CMIX): An evaluation of cloud masking algorithms for Landsat 8 and Sentinel-2

- Performance varied depending on the reference data
- Average OA for Sentinel-2: 80% to 89%
- Average OA for Landsat 8: 80% to 98%
- Performance improved when thin/semi-transparent clouds not considered

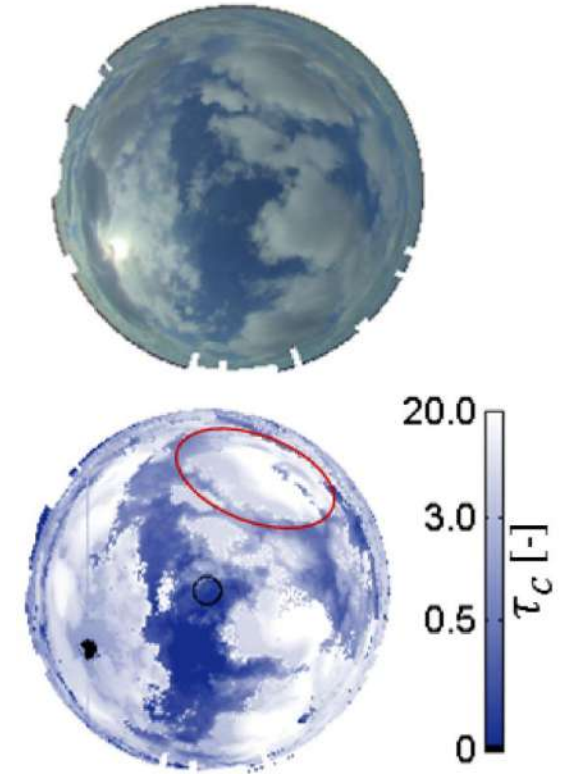


CMIX Recommendations

- Definition of clouds
 - Cloud optical depth
- New validation/reference data
 - Consistent cloud definition
 - Cloud boundary
 - Time series
- Analysis framework
 - Sample-based vs area-based
 - Temporal analysis
 - Application-based

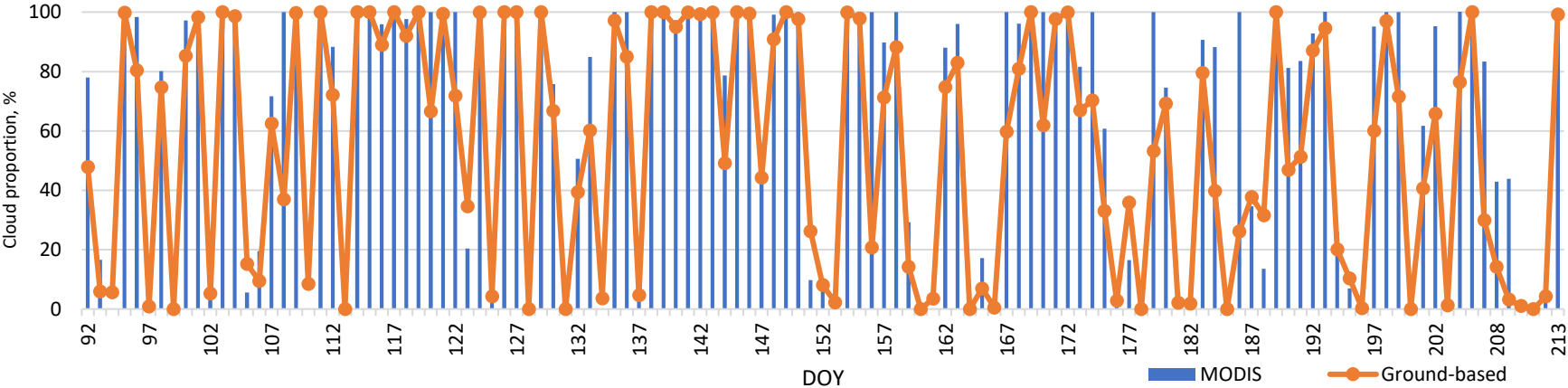
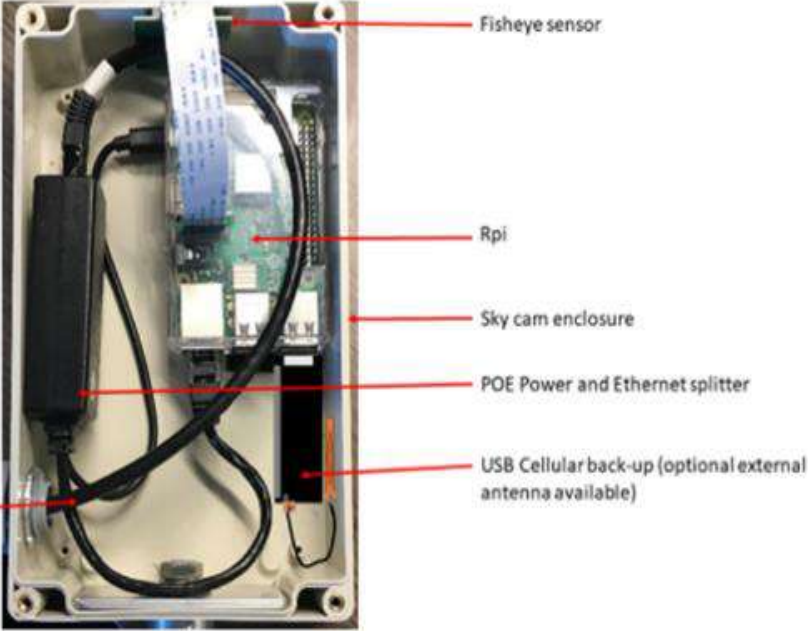
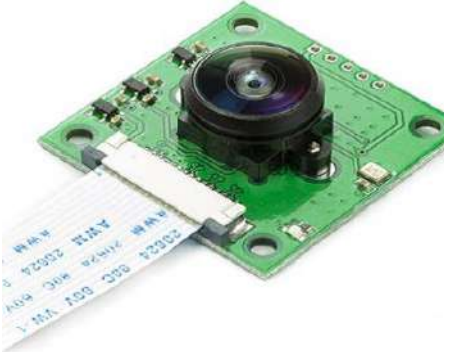
Network of sky imagery:

- NASA GSFC, **Greenbelt, MD, USA**
- Sapienza University, **Rome, Italy**
- Valencia University, **Valencia, Spain**
- Sao Paulo University, **Sao Paulo, Brazil**
- Princess Elisabeth Station, **Antarctica**
- WLEF, **Park Falls, WI, USA**



Cloud optical depth retrieval from ground-based cloud imager (Mejia et al., 2016)

SkyCam system @ NASA/GSFC



CONCLUSIONS

- NASA/GSFC is prototyping a S3 LaSRC based SR product to potentially fill the gap from MODIS Terra Decommissioning
- A complete package of validation routine activities: AERONET based evaluation, Inter-instrument consistency (BELMANIP type) and Cloud Mask Validation should be developed for S3, VIIRS SR suite