Land Surface Reflectance Code (LaSRC), Generic Atmospheric Correction for Coarse-to-High Spatial Resolution Sensors: Description and Validation

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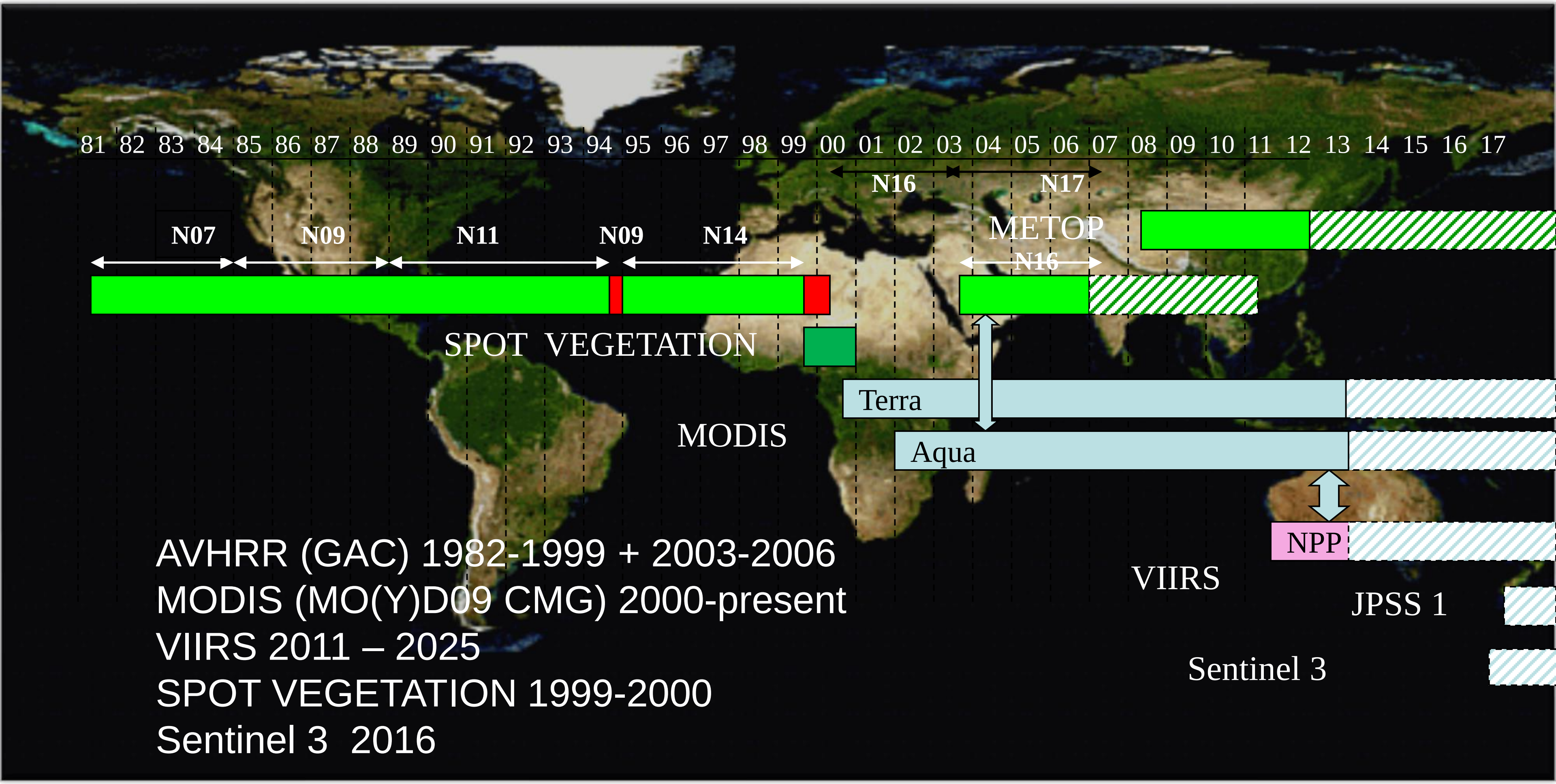
A Land Climate Data Record

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



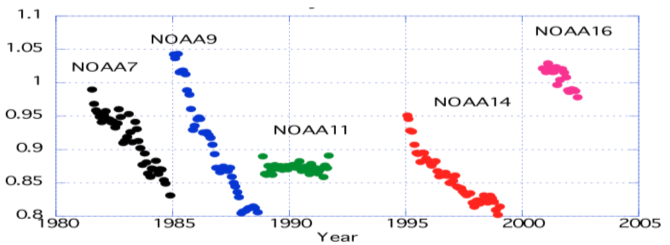
Emphasis on data consistency – characterization rather than degrading/smoothing the data

Land Climate Data Record (Approach)

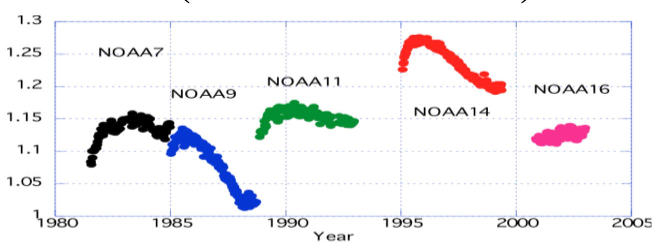
Needs to address geolocation,calibration, atmospheric/BRDF correction issues

CALIBRATION

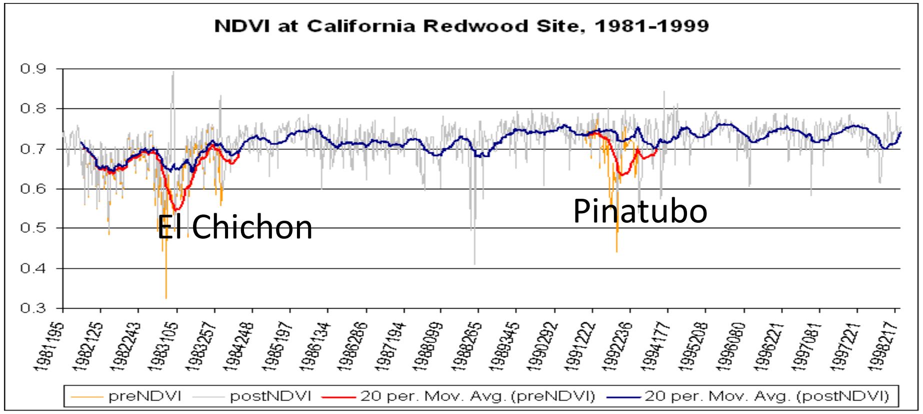
Degradation in channel 1
(from Ocean observations)



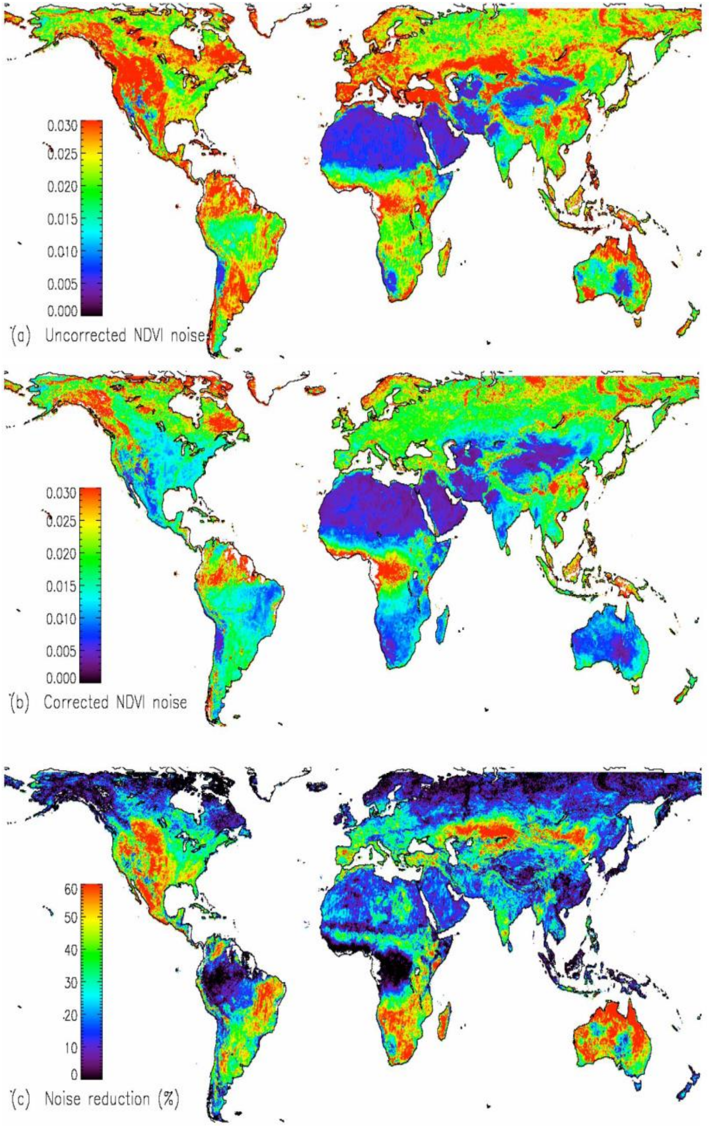
Channel1/Channel2 ratio
(from Clouds observations)



ATMOSPHERIC CORRECTION



BRDF CORRECTION



AVHRR LTDR APPLICATIONS

nature
International journal of science

Letter | Published: 08 August 2018

Global land change from 1982 to 2016

Xiao-Peng Song, Matthew C. Hansen, Stephen V. Stehman, Peter V. Potapov, Alexandra Tyukavina, Eric F. Vermote & John R. Townshend

Here we analyse 35 years' worth of satellite data and provide a comprehensive record of global land-change dynamics during the period 1982–2016. We show that—contrary to the prevailing view that forest area has declined globally[5]—tree cover has increased by 2.24 million km^2 (+7.1% relative to the 1982 level). This overall net gain is the result of a net loss in the tropics being outweighed by a net gain in the extratropics.

Extended Data Table 1 Estimates of 1982 land-cover area and 1982–2016 land-cover change at continental and global scales

From: Global land change from 1982 to 2016

Continent	Tree canopy cover: Area 1982 (10^3 km^2)	Annual net change: Slope (10^3 km^2 yr^{-1})	Lower (10^3 km^2 yr^{-1})	Upper (10^3 km^2 yr^{-1})	p	Gross change: loss (10^3 km^2)	gain (10^3 km^2)
Africa	4672	-1.9	-7.6	3.6	0.609	-267	262
Asia	8457	37.5	28.0	45.3	0.000	-178	1170
Europe	2719	28.3	20.4	32.8	0.000	-17	758
North America	5815	15.6	3.5	24.2	0.020	-205	583
South America	8767	-14.1	-20.5	-7.4	0.001	-621	190
Oceania	680	0.1	-1.4	1.7	0.887	-40	56
Global	31628	66.0	27.3	100.5	0.008	-1331	3039

Continent	Short vegetation cover: Area 1982 (10^3 km^2)	Annual net change: Slope (10^3 km^2 yr^{-1})	Lower (10^3 km^2 yr^{-1})	Upper (10^3 km^2 yr^{-1})	p	Gross change: loss (10^3 km^2)	gain (10^3 km^2)
Africa	11653	14.8	6.5	23.2	0.016	-268	571
Asia	21774	-22.9	-34.5	-9.6	0.008	-1261	760
Europe	6320	-22.0	-27.3	-14.7	0.000	-673	50
North America	12921	-12.7	-4.1	-2.2	0.031	-594	286
South America	7165	14.8	8.1	21.0	0.002	-224	655
Oceania	4600	-4.4	-12.1	3.4	0.349	-132	50
Global	64539	-26.0	-64.8	15.2	0.244	-3170	2380

Continent	Bare ground cover: Area 1982 (10^3 km^2)	Annual net change: Slope (10^3 km^2 yr^{-1})	Lower (10^3 km^2 yr^{-1})	Upper (10^3 km^2 yr^{-1})	p	Gross change: loss (10^3 km^2)	gain (10^3 km^2)
Africa	13413	-12.4	-19.9	-4.7	0.020	-371	105
Asia	13926	-15.1	-23.1	-7.4	0.002	-798	358
Europe	668	-4.3	-5.8	-2.6	0.000	-92	9
North America	4847	-2.5	-7.3	2.2	0.363	-186	140
South America	1717	1.9	-1.2	3.8	0.307	-92	102
Oceania	2772	5.2	-3.9	12.5	0.280	-35	113
Global	37412	-34.0	-52.3	-10.0	0.023	-1582	830

Annual net change in land cover (slope) and 1982 land-cover area were estimated using Theil–Sen regression of the time series of annual land-cover area per continent or over the globe (excluding Antarctica). Lower and upper slopes represent the 90% confidence interval. Reported P value is for the two-sided Mann–Kendall test for trend, with $P < 0.05$ used to define statistical significance, and a sample size of $n = 35$ years. Gross change in land cover was estimated on the basis of per-pixel non-parametric trend analysis. Per-pixel loss and gain were summed to derive gross loss and gain at the aggregated scales.

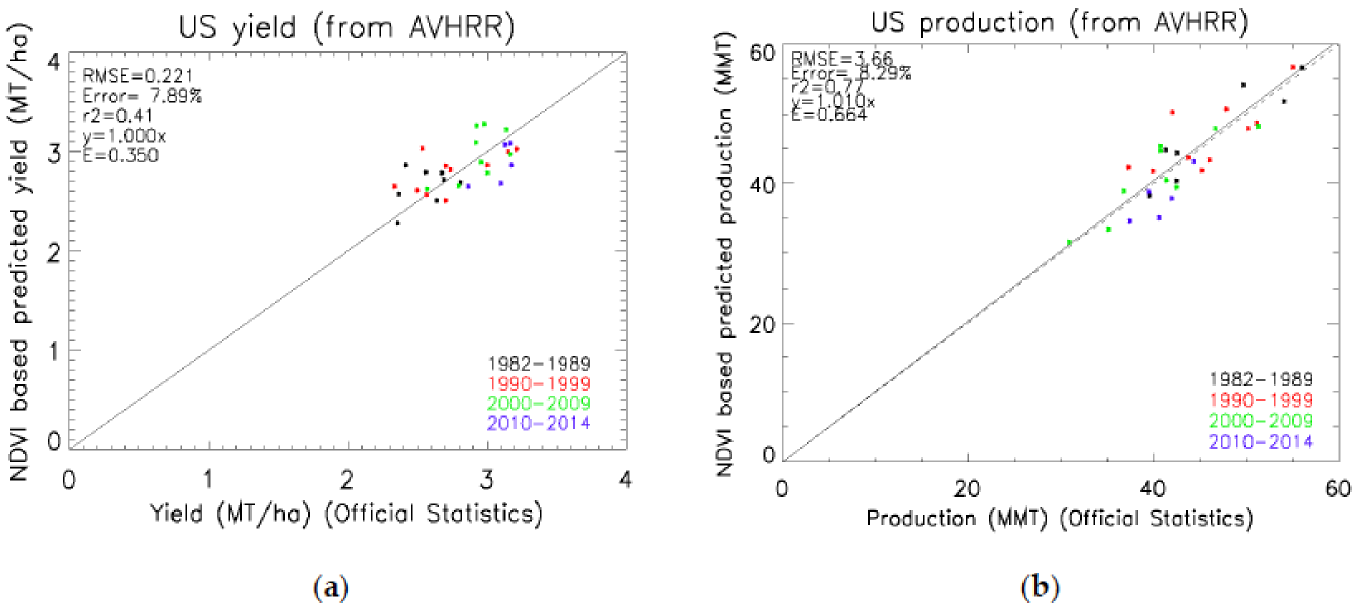


Figure 9. National winter wheat predicted yield (**a**) and production (**b**) in the U.S., applying the 'original' method [1] to AVHRR data plotted against USDA-reported statistics (https://quickstats.nass.usda.gov).

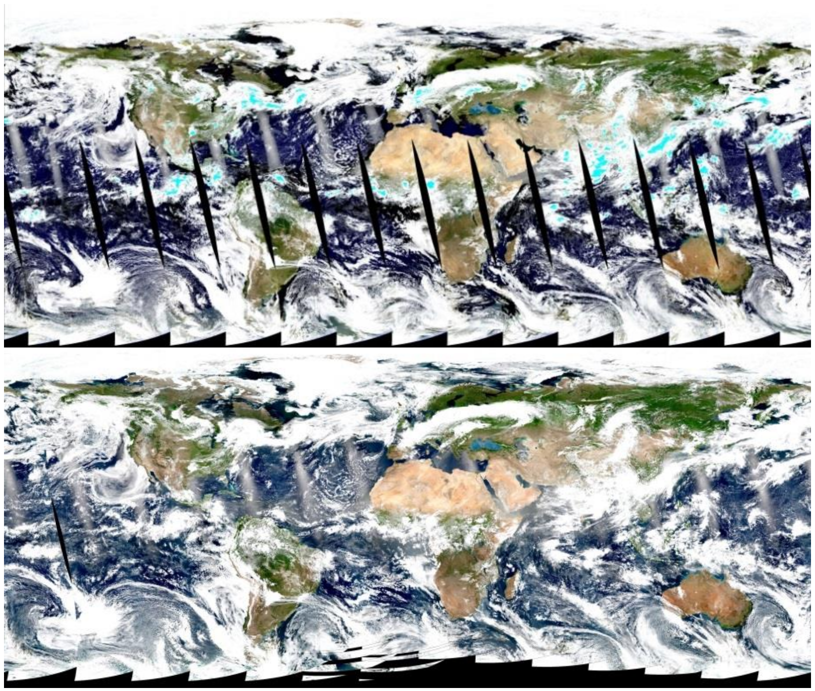
Franch, B., Vermote, E., Roger, J.C., Murphy, E., Becker-Reshef, I., Justice, C., Claverie, M., Nagol, J., Csiszar, I., Meyer, D., Baret, F., Masuoka, E., Wolfe, R. and Devadiga, S., 2016, A 30+ year AVHRR Land Surface Reflectance Climate Data Record and its application to wheat yield monitoring, Remote Sensing, 9, 296; doi:10.3390/rs9030296

Atmospheric correction (AC)

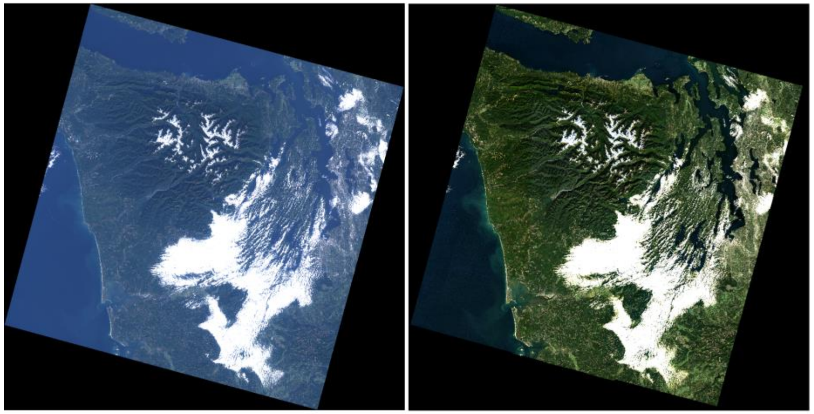
- Estimate of the **surface spectral reflectance**, as would have been measured at ground level if there were **no atmospheric scattering or absorption**

- 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

LaSRC 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**
    - ***Water vapor and ozone from daily MODIS product.***

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

Generic approach for aerosol inversion and atmospheric correction

Reading **Inputs, LUT** and **Ancillary data**

ρ_{surf} determined (*) using ρ_{atm}, T_{atm} and S_{atm} **from LUT** assuming AOT, Aerosol model and knowing pressure, altitude, water vapor, ozone…

Aerosol Opt. Thick. and **Aerosol model** for each pixel

Using the relationship between the blue surface reflectance (490 nm) and the red surface reflectance (665 nm) known from MODIS, we are able to retrieve the **AOT.**

We loop the AOT until $(\rho_{surf}\ \text{blue} / \rho_{surf}\ \text{red})_{MSI} = (\rho_{surf}\ \text{blue} / \rho_{surf}\ \text{red})_{MODIS}$

The retrieved AOT is used to compute the surface reflectance at 443 and 2190 nm.
The **aerosol model** is then derived by minimizing the residual.

$$residual = \frac{\sum_{i=1}^{2}\left(\rho^{i}_{surf} - Ratio^{i}_{665} * \rho^{665}_{surf}\right)}{2}$$

Surface reflectance for each pixel and each band

Computation of **surface reflectances** for all channels

ρ_{surf} determined (*) using ρ_{atm}, T_{atm} and S_{atm} **from LUT** knowing AOT, Aerosol model, pressure, altitude, water vapor, ozone…

$$(*)\quad \rho_{surf} = \frac{Y}{1+S_{atm}.Y} \quad \text{with} \quad Y = \frac{1}{T_{atm}.tg^{wv}}\left[\left(\frac{\rho_{TOA}}{tg^{O3}.tg^{others}}\right) - \left(\rho_{atm} - \rho_{ray}\right).tg^{wv/2} - \rho_{ray}\right]$$

Methodology for evaluating the performance of LaSRC surface reflectance

Subsets of Level 1B data processed using the standard surface reflectance algorithm

comparison

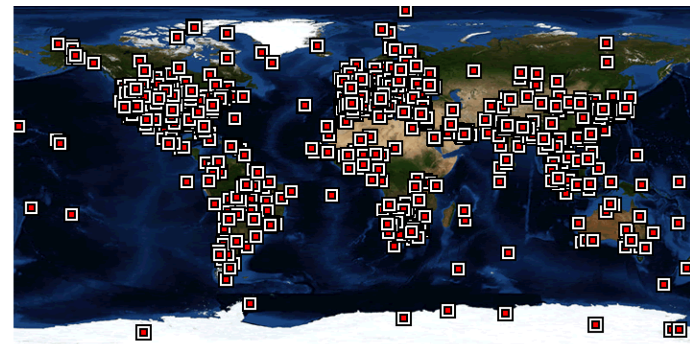
Reference data set

Atmospherically corrected TOA reflectances derived from Level 1B subsets

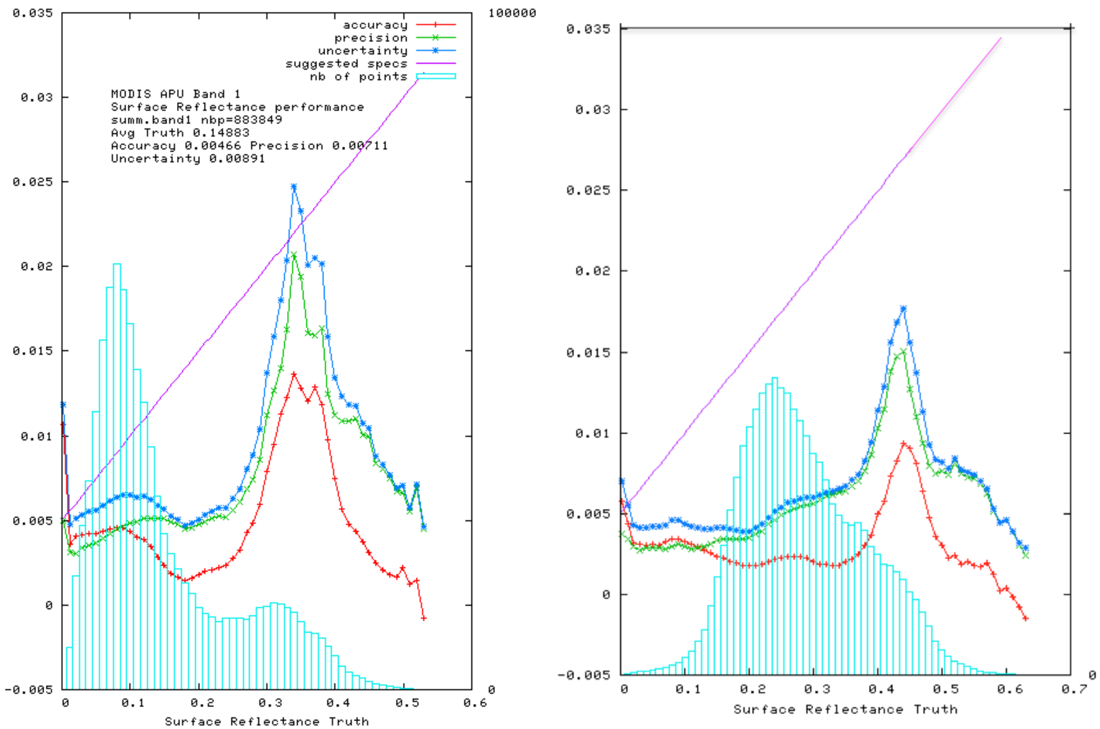
Vector 6S

AERONET measurements

($|_{aer}$, H_2O, particle distribution Refractive indices,sphericity)

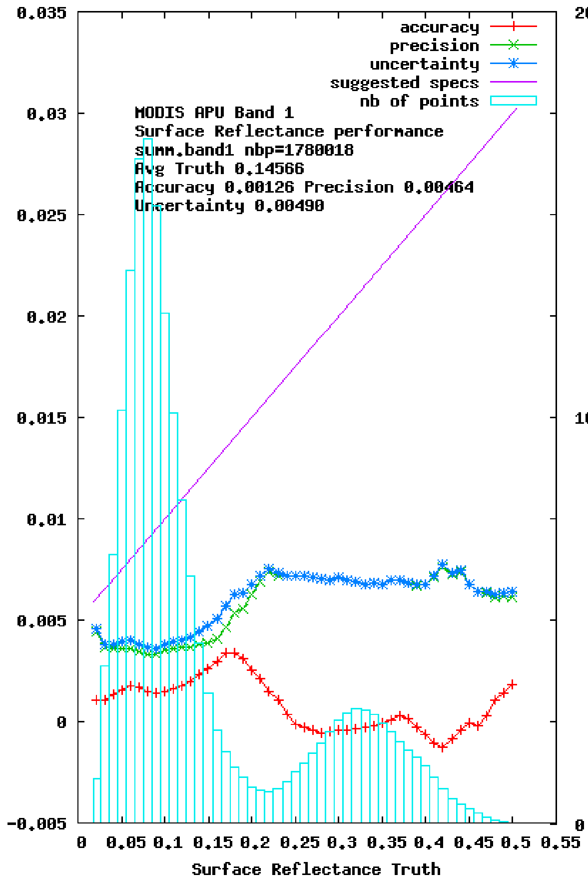


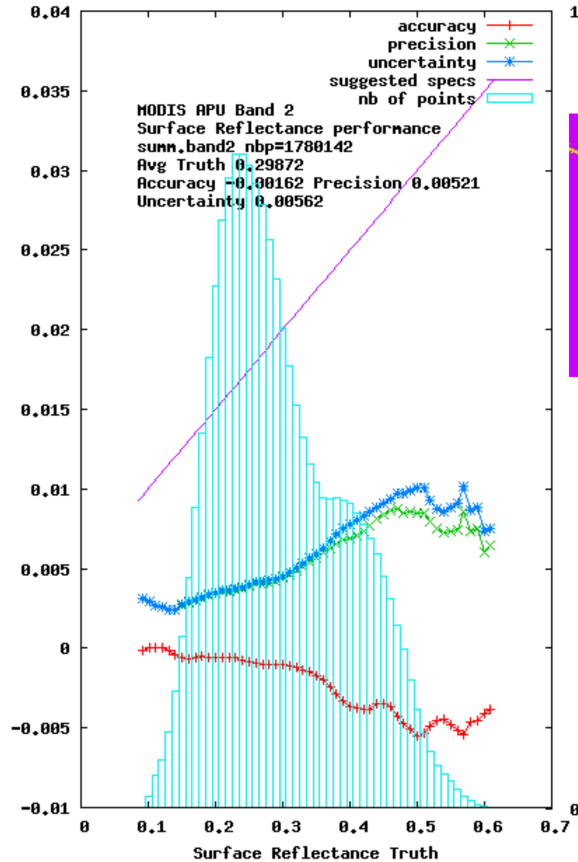
quantitative assessment of performances (APU) for MODIS

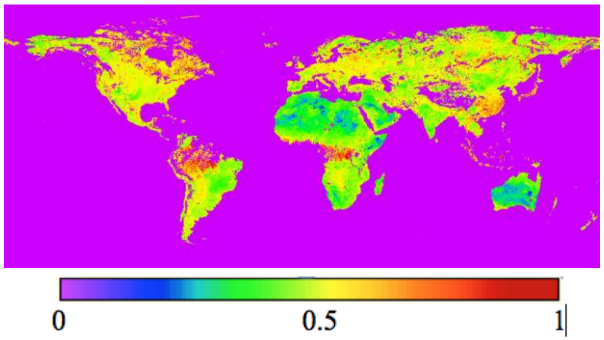


COLLECTION 5: accuracy or mean bias (red line), Precision or repeatability (green line) and Uncertainty or quadratic sum of Accuracy and Precision (blue line) of the surface reflectance in band 1 in the Red (top left), band 2 in the Near Infrared (top right also shown is the uncertainty specification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



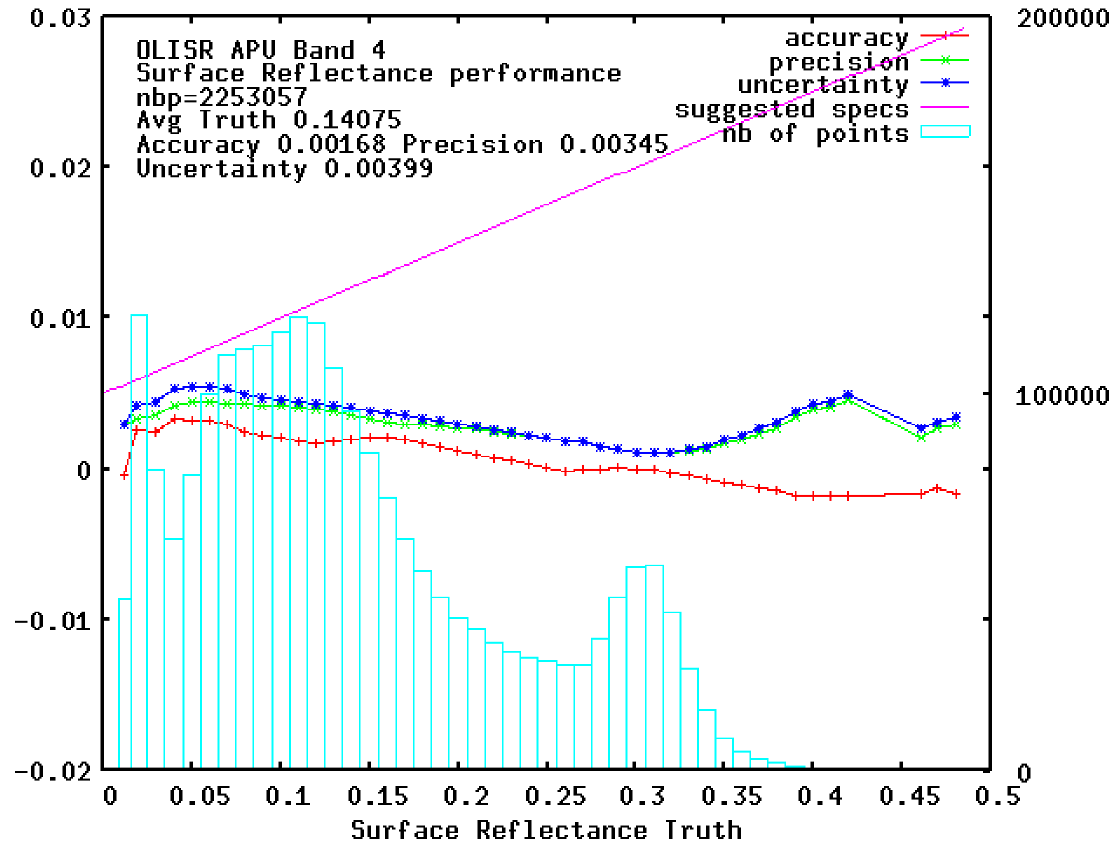




ratio band3/band1 derived using MODIS top of the atmosphere corrected with MISR aerosol optical depth

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

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.

ACIX

Atmospheric Correction Inter-comparison eXercise

ACIX is an international collaborative initiative to inter-compare a set of atmospheric correction (AC) processors for high-spatial resolution optical sensors. The exercise will focus on Landsat-8 and Sentinel-2 imagery over a set of test areas. The inter-comparison of the derived Bottom-of-Atmosphere (BOA) products is expected to contribute to the understanding of the different uncertainty contributors and help in improving the AC processors

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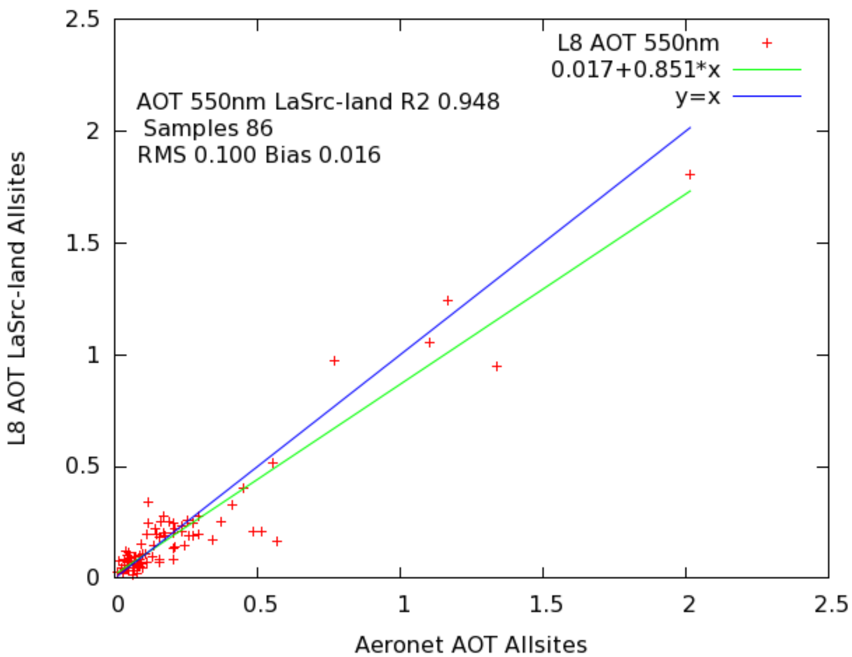
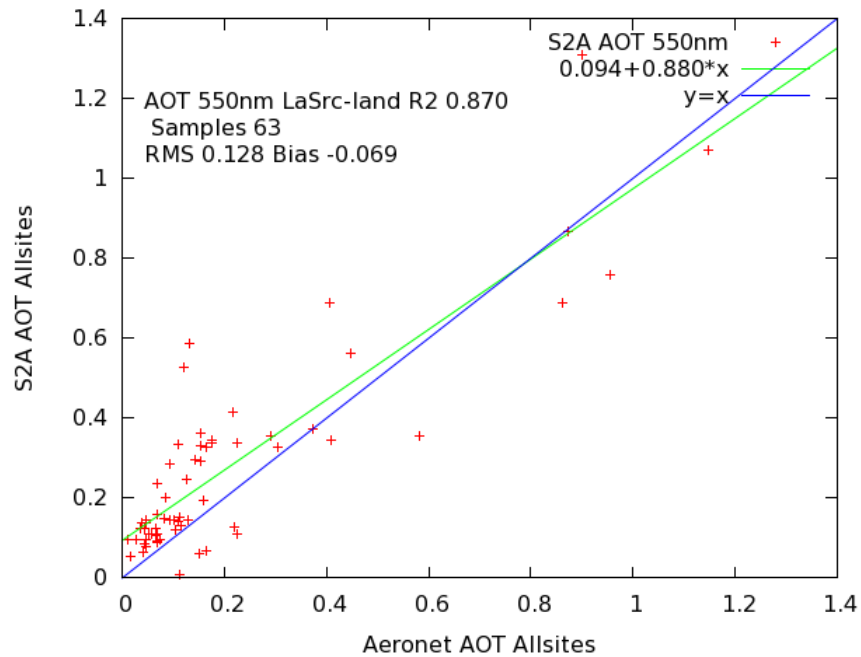
Eric Vermote | NASA, eric.f.vermote@nasa.gov

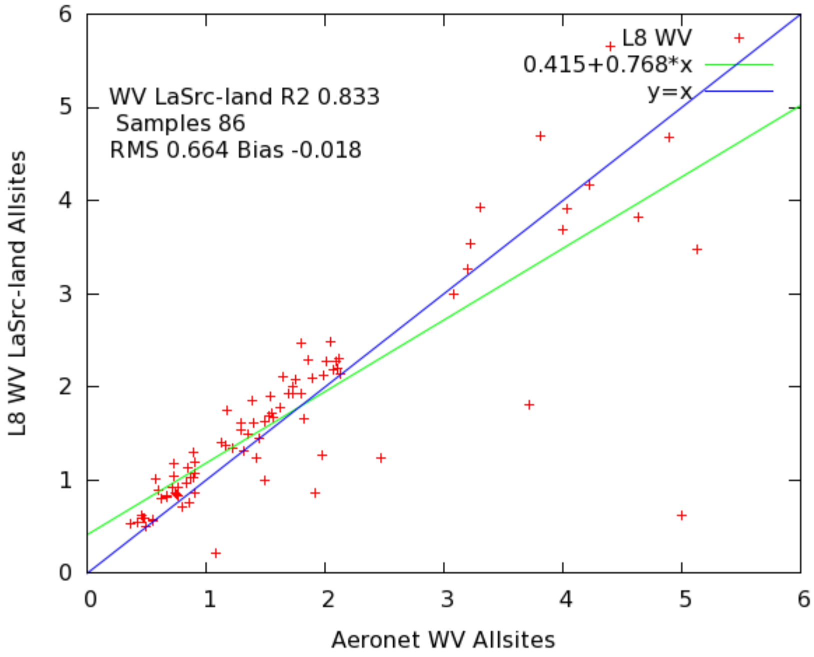
Doxani, G., Vermote, E., Roger, J.C., Gascon, F., Adriaensen, S., Frantz, D., Hagolle, O., Hollstein, A., Kirches, G., Li, F. and Louis, J., 2018. Atmospheric correction inter-comparison exercise. Remote Sensing, 10(2), p.352.

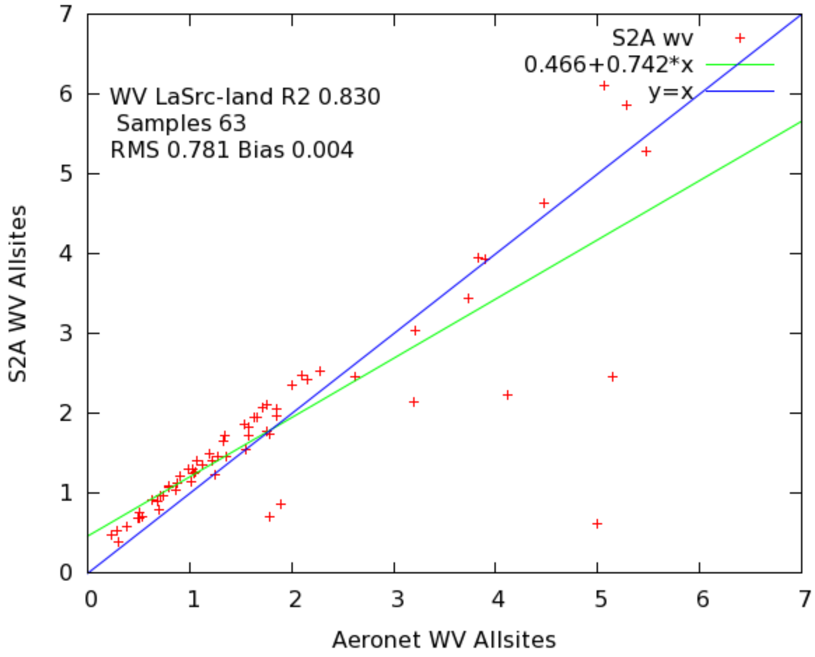
ACIX results for the LaSRC algorithm (L8/S2A) (Land sites only, no cloud)



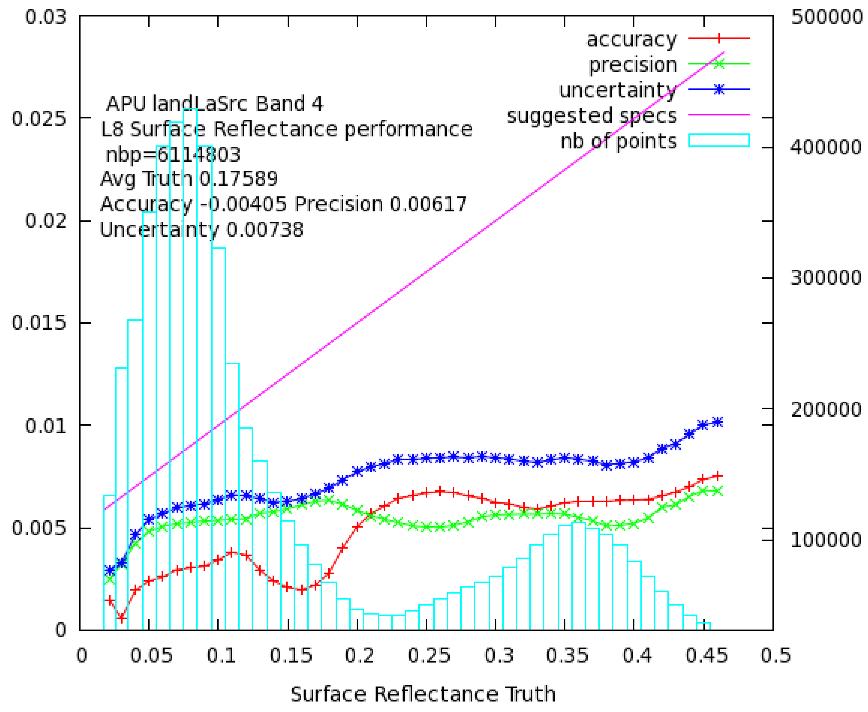


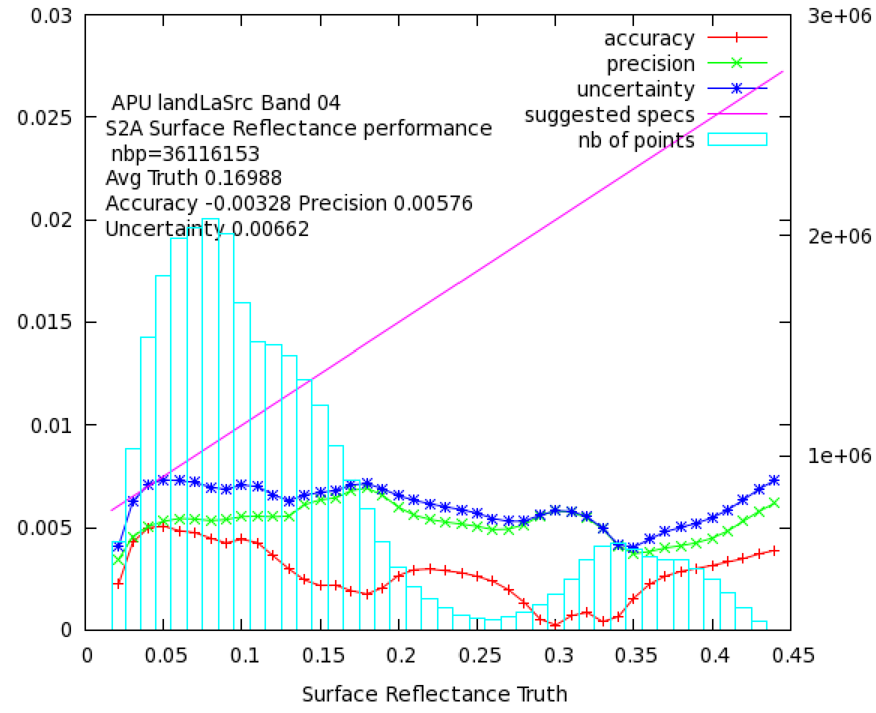
ACIX results for the LaSRC algorithm (L8/S2A) (Land sites only, no cloud)



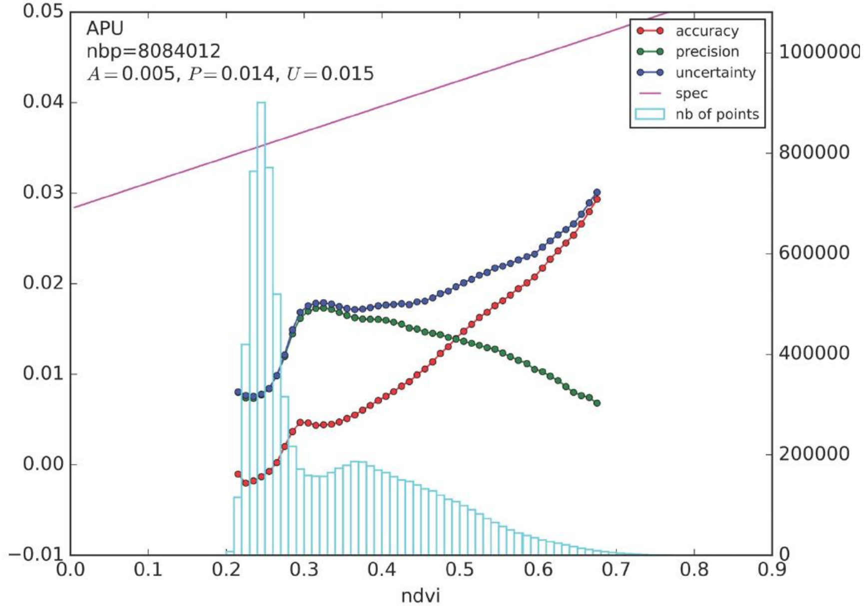


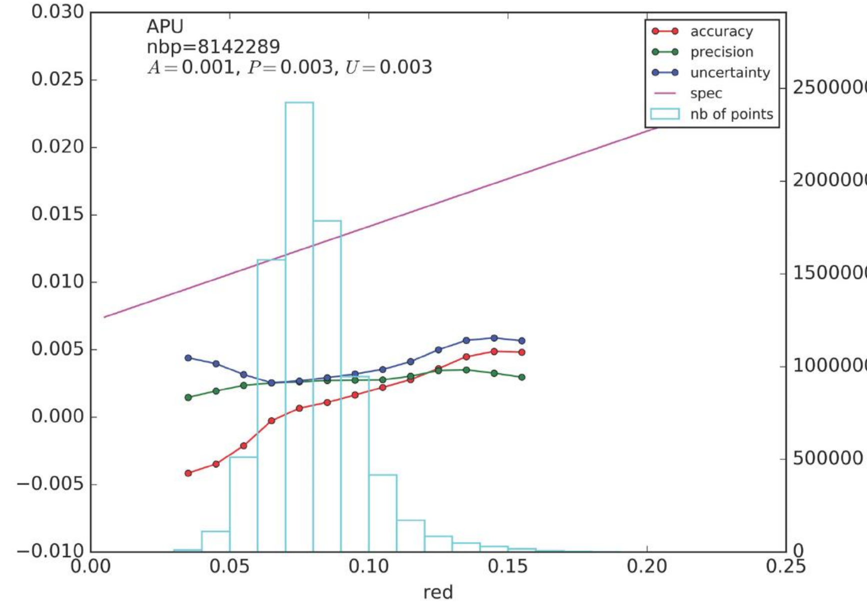
ACIX results for the LaSRC algorithm (L8/S2A) (Land sites only, no cloud)

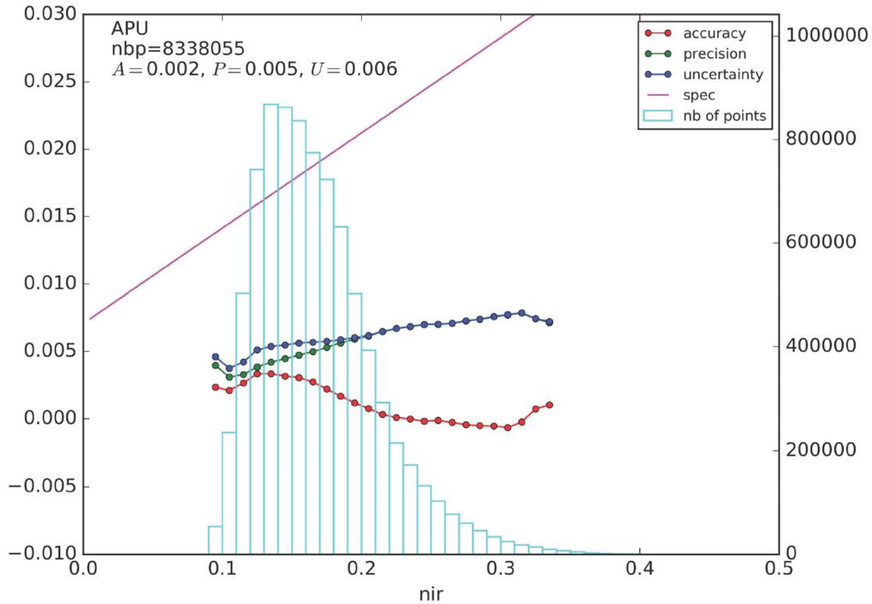




Use of combined L8/S2A is on-going







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 is on-going

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.

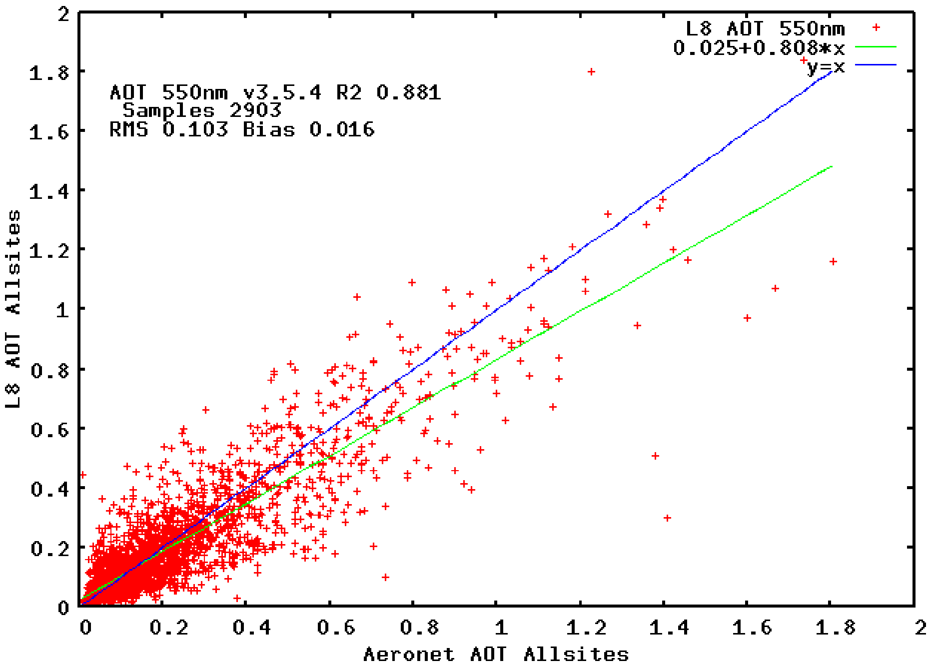
Metric	LC8-S2A	LC8	S2A
A	612	1081	839
P	1719	5061	1962
U	1785	5056	2090
rU, %	11.6	32.7	13.5
R^2	0.90	0.64	0.88

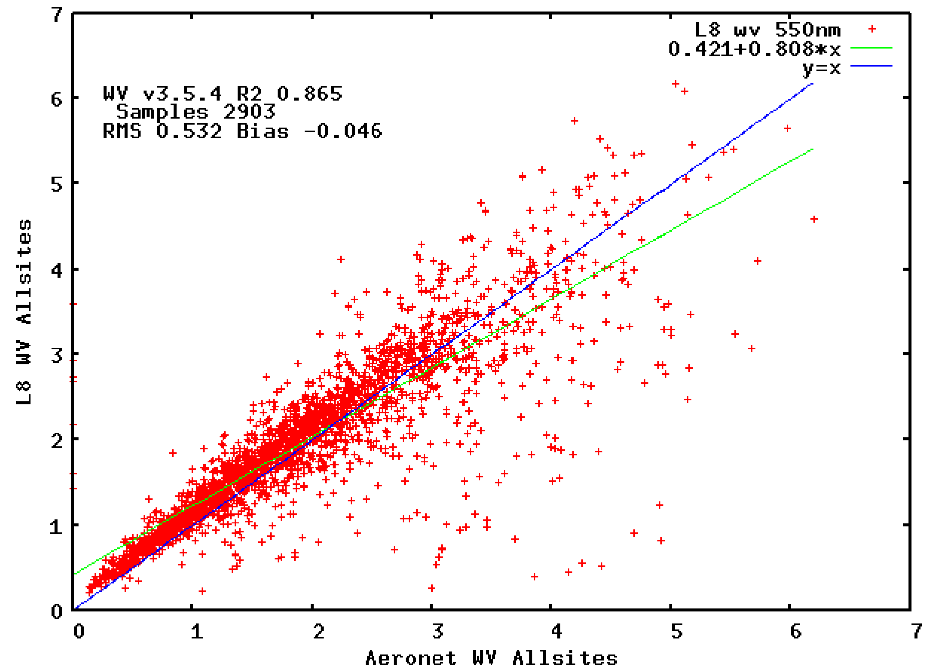
Table 2. Comparison of satellite-derived winter wheat yields with official statistics at district level without using GDD and using GDD. Estimates of the *APU* metrics are given in t/ha.

	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

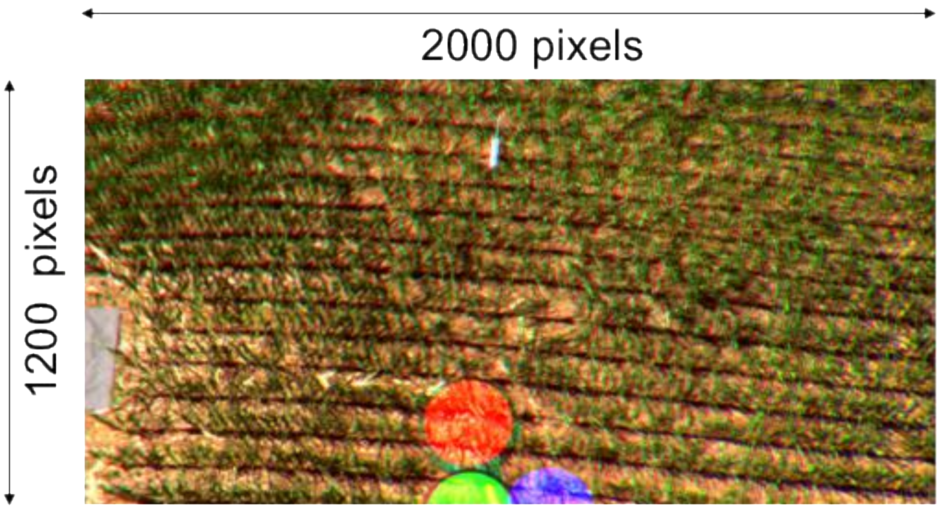
Skakun, S., Vermote, E., Roger, J.C. and Franch, B., 2017. Combined Use of Landsat-8 and Sentinel-2A Images for Winter Crop Mapping and Winter Wheat Yield Assessment at Regional Scale. AIMS Geosciences, 3(2), pp.163-186.

Validation is on-going moving into a systematic routine assesment





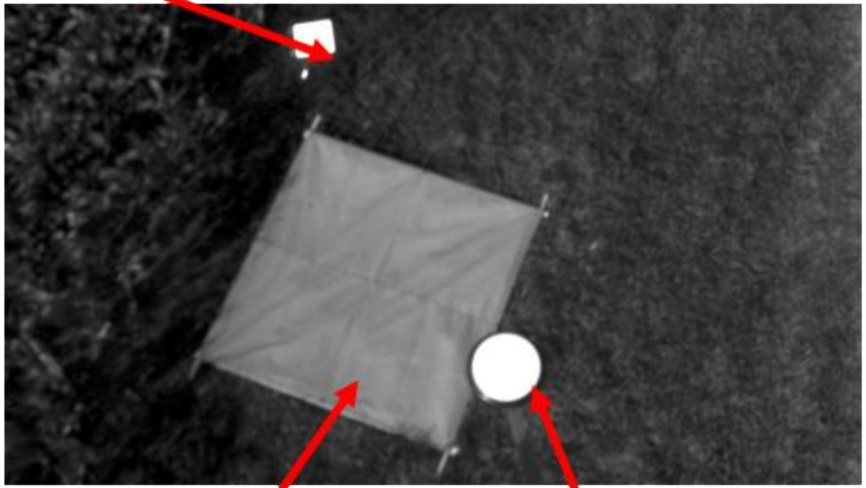
Ground Validation is on going



Measurements were taken 100 feet above the corn field using a boom-lift

Ground Validation is on going

Reflectance retrieval verification: Use in-scene reference targets on the ground (tarp and calibration panel) to compare against reflectance calculation based on 2-inch target.

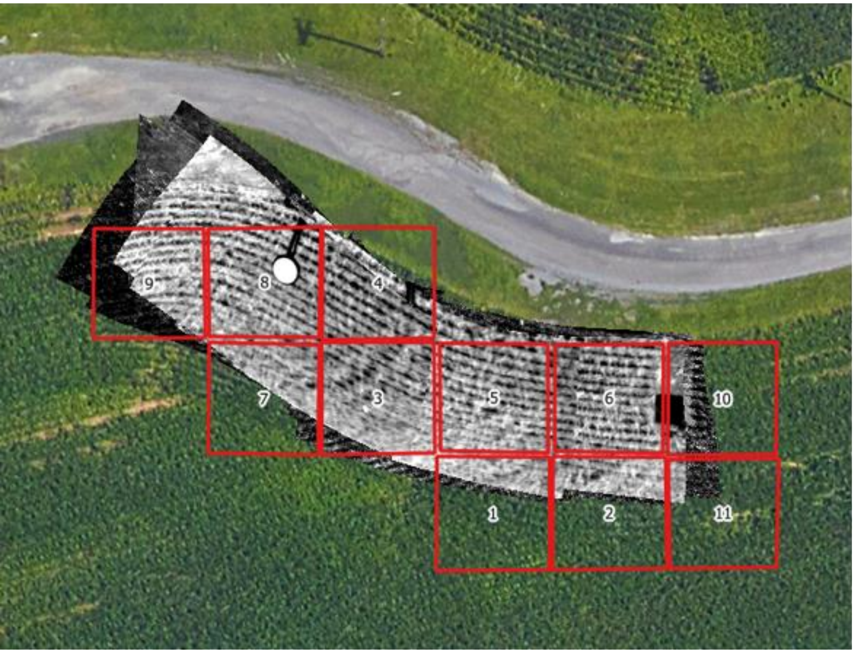


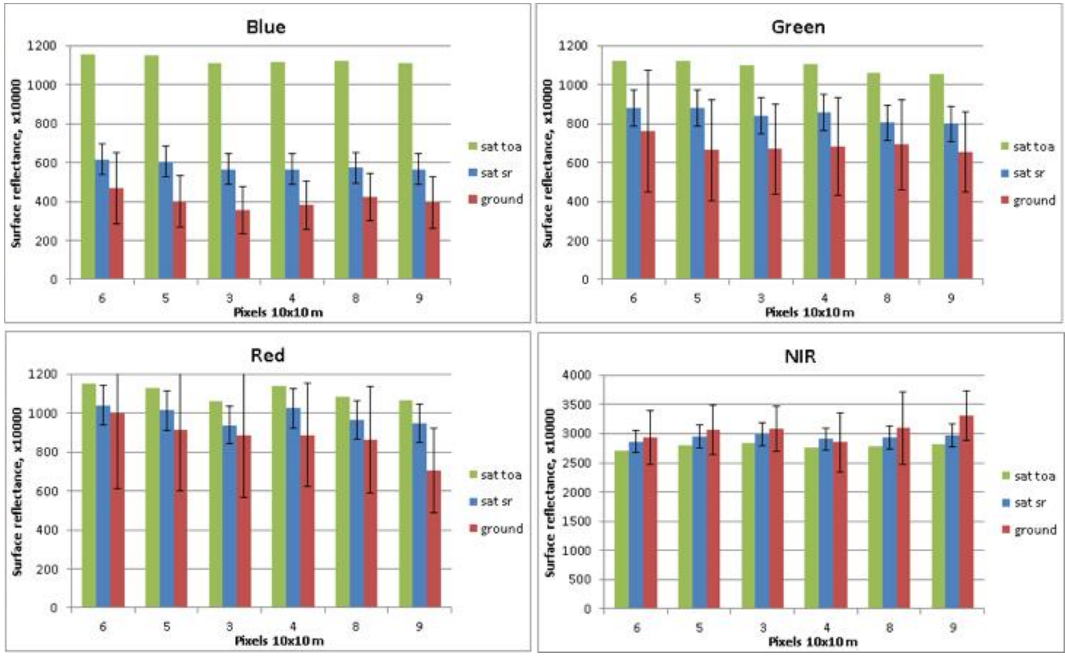
Spectral channel	CAMSIS Tarp	Tarp Ref	CAMSIS CP	CP ref
Blue	0.135	0.13	1.01	0.995
Green	0.14	0.13	Sat.	0.995
Red	0.15	0.13	0.97	0.995
NIR	0.16	0.11	0.90	0.995

Ground Validation is on going

Validation of Sentinel 2 reflectance (from AERONET) :

Example for July 10 2018, AOT ~ 0.1



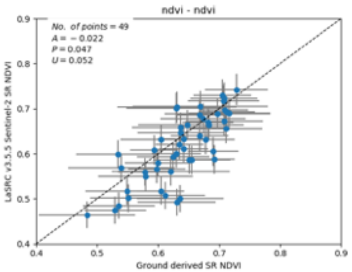


Ground Validation is on going

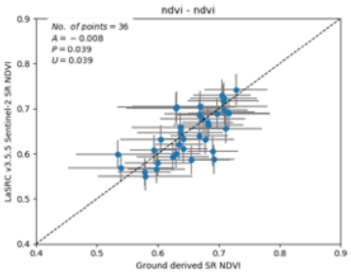
Preliminary multidate comparison:

Date of ground measurements	Date of satellite acquisition	Satellite
20180808	20180809	Sentinel-2A
20180824	20180824	Sentinel-2B
20180829	20180829	Sentinel-2A
20180904	20180903	Sentinel-2B

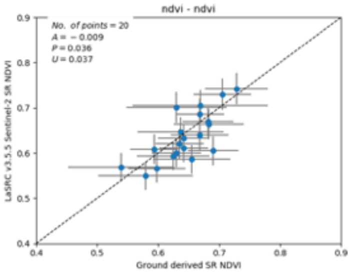
Threshold = 10%



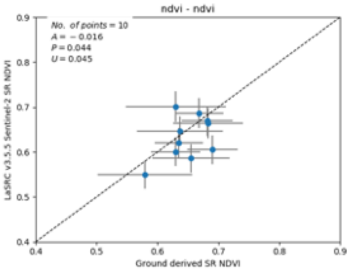
Threshold = 50%



Threshold = 90%



Threshold = 100%



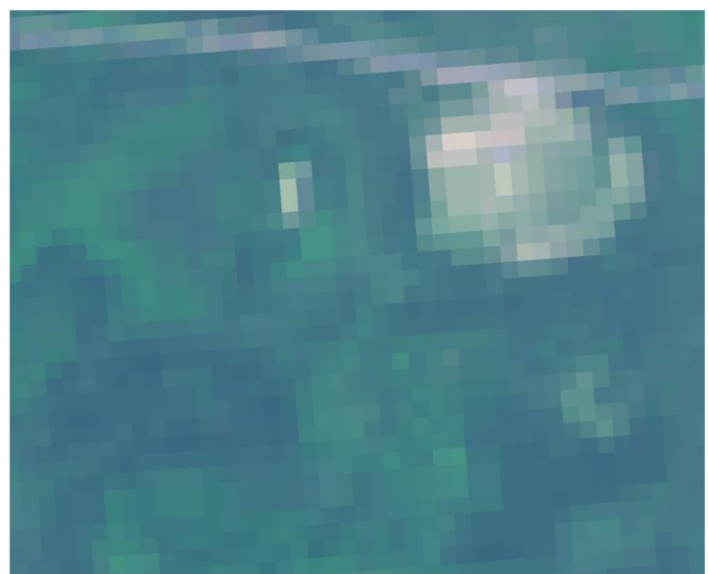
Ground Validation is on going

Image from Google Earth

Planet, 3m, 6 June 2019

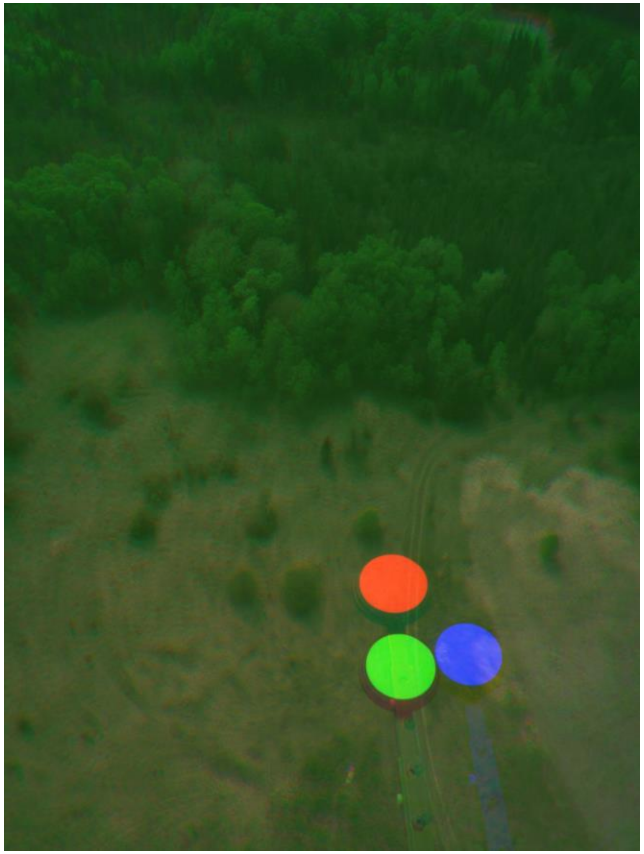
Sentinel-2, 10m, 8 June 2019

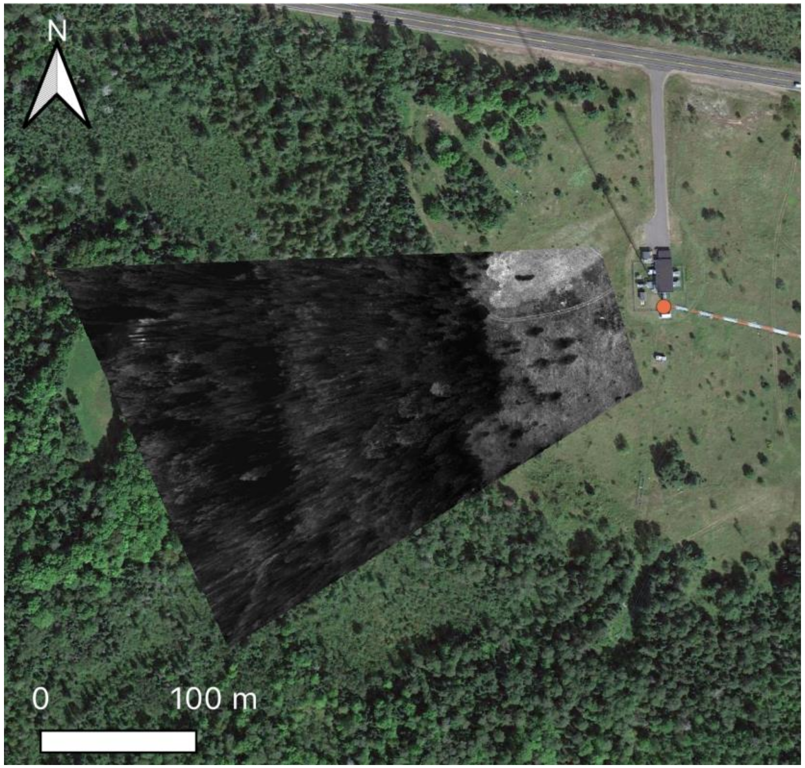
Landsat 8, 30m, 15 June 2019

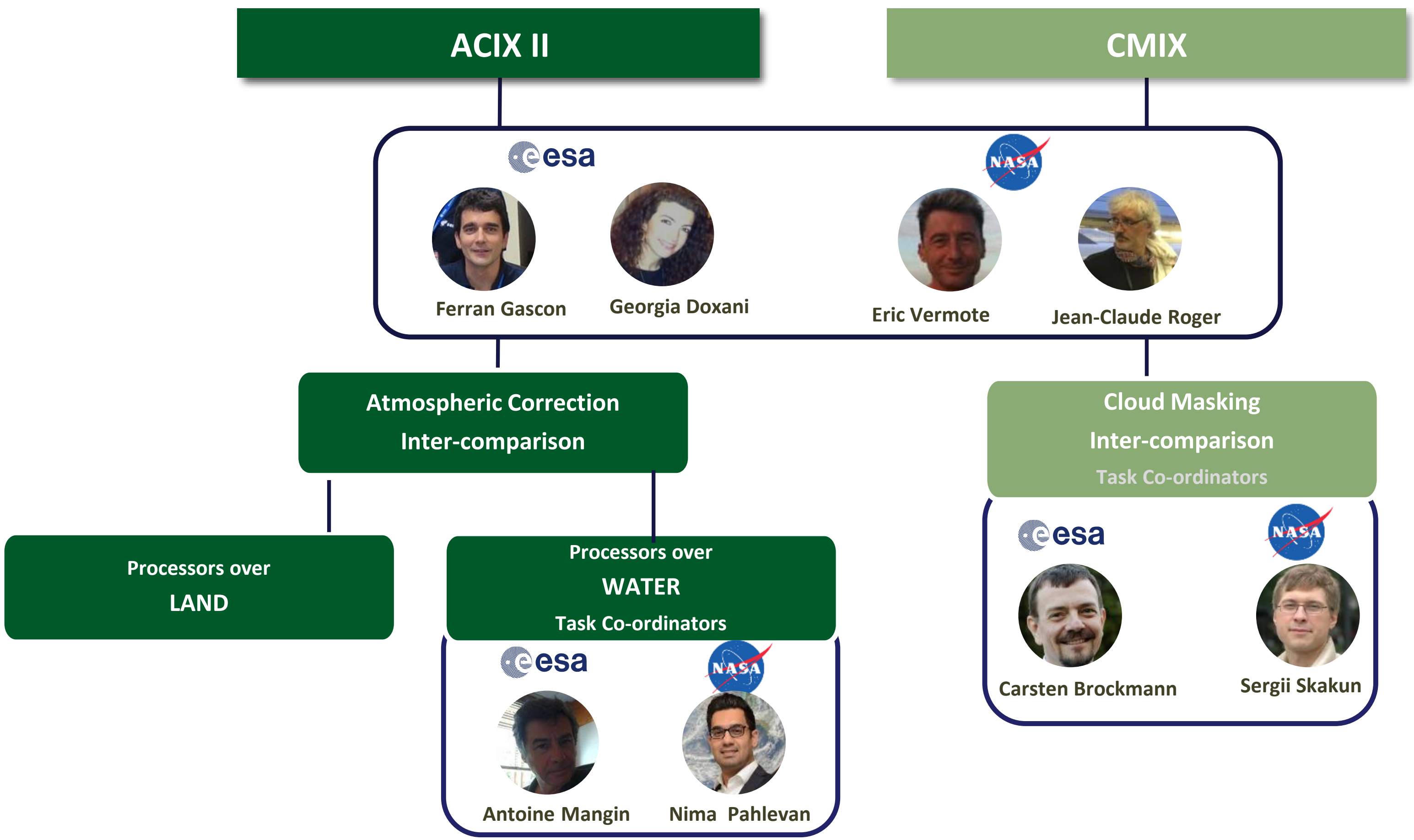


L8, S2, Planet are true color TOA refl. (red-green-blue) with 0-0.15

Ground Validation is on going







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CMIX
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Atmospheric Correction
Inter-comparison
Cloud Masking
Inter-comparison
Task Co-ordinators
Carsten Brockmann
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Processors over
LAND
Processors over
WATER
Task Co-ordinators
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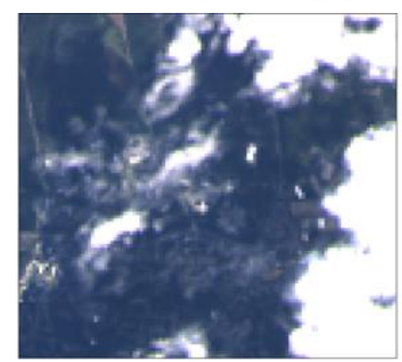
CMIX – Cloud Masking Inter-comparison eXercise

- Within the Atmospheric Correction Inter-comparison Exercise (ACIX-II)

- Objective:
  - to inter-compare a set of cloud detection algorithms for space-borne high-spatial resolution (10-30 m) optical sensors



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ACIX-Land

ACIX-II

18

Teams
from various Space Agencies, R&D Companies, Research Institutes and Universities

115

Study Sites
spread globally based on the AERONET stations (location & measurements availability)

6500

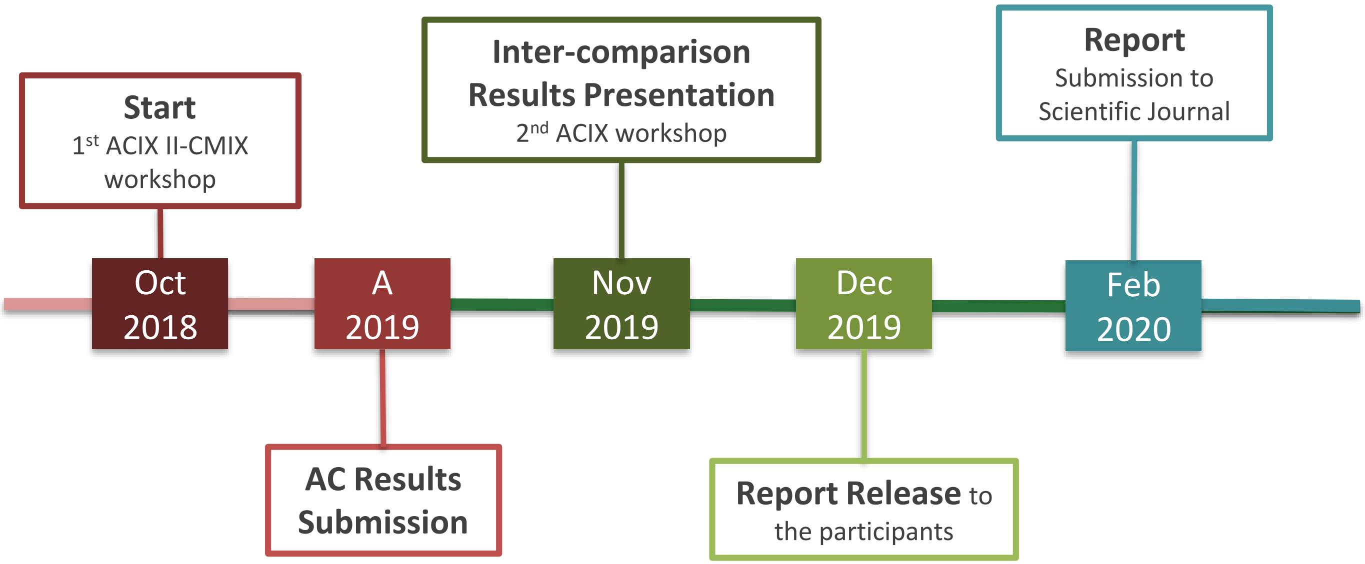
Image Scenes
to be processed acquired by Sentinel-2A, -2B and Landsat-8

3

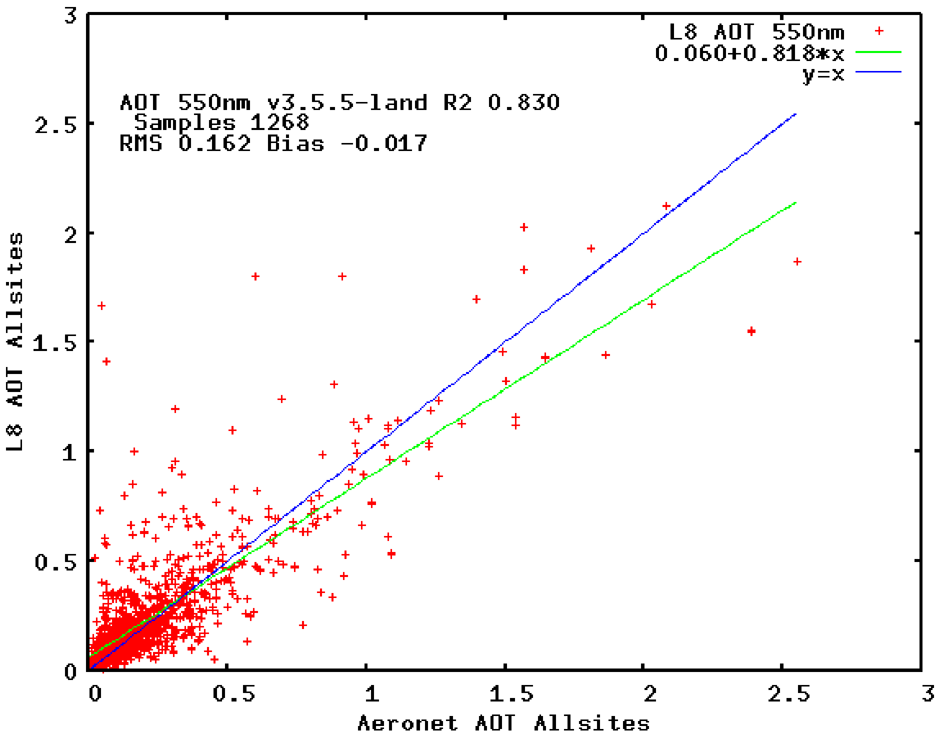
Months
for the participants to submit their results

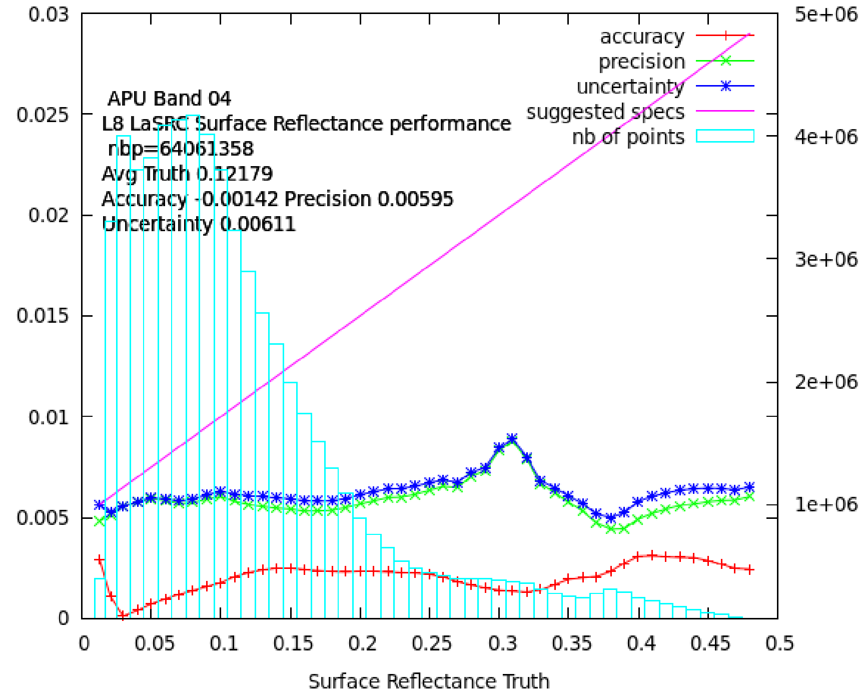
CMIX
ACIX-Land

ACIX-II Schedule



ACIX-II Preliminary results (L8)





Conclusions

- Surface reflectance code (LaSRC) 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, LDCM, Landsat, Sentinel 2 ,Sentinel 3…)