A Generic Method for Retrieval of Aerosol over Land from Passive Optical Remote Sensing Data

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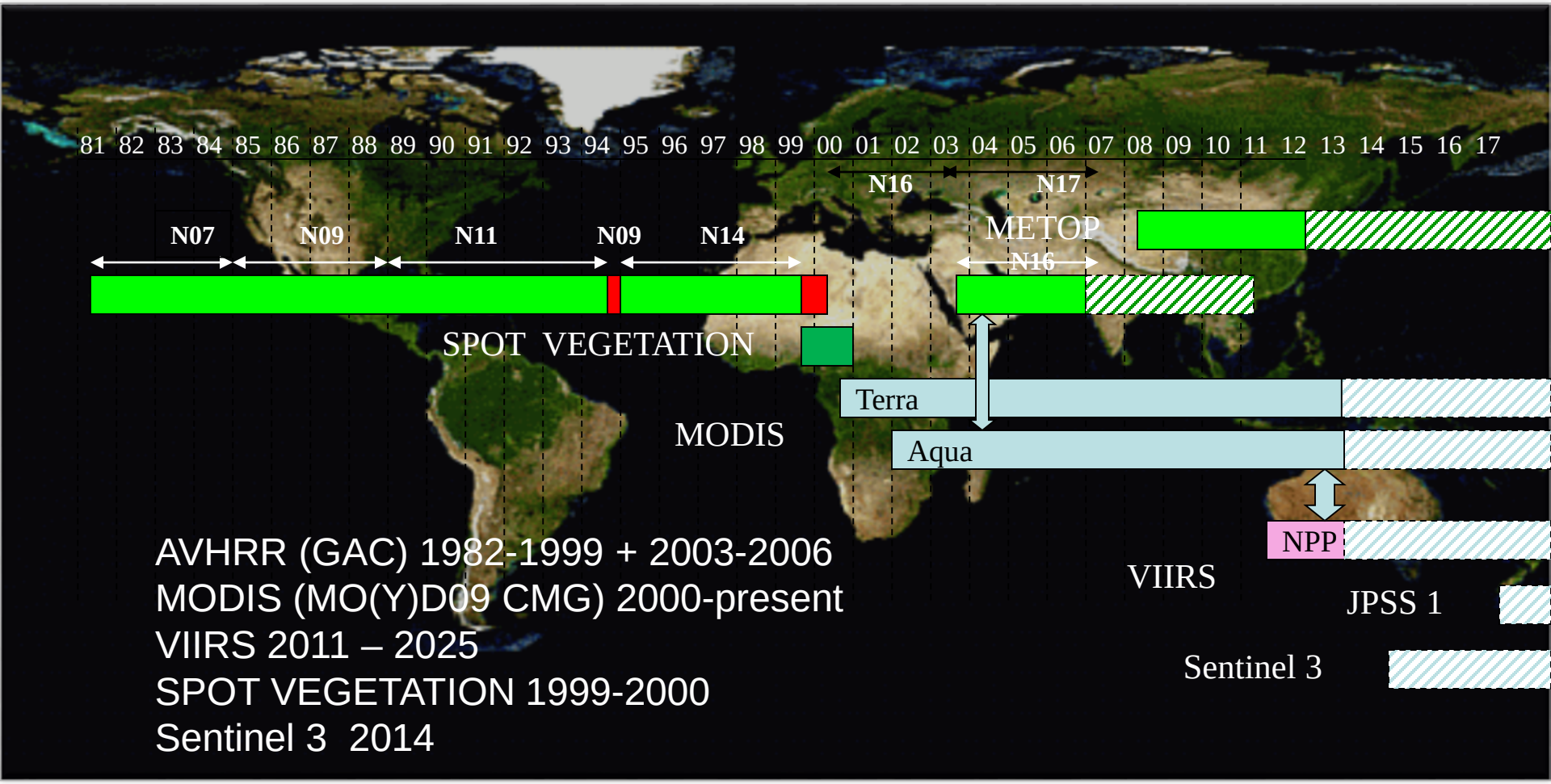
A Land Climate Data Record

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



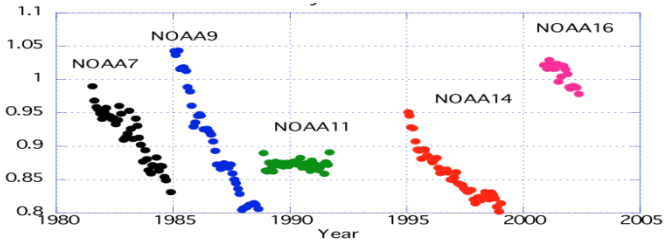
Emphasis on data consistency – characterization rather than degrading/smoothing the data

Land Climate Data Record (Approach)

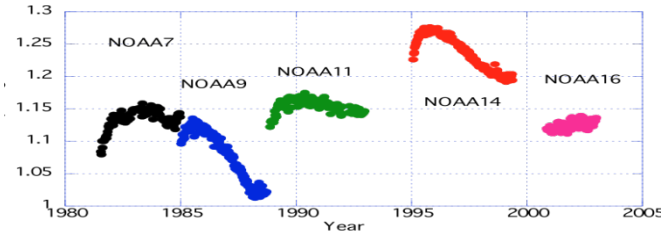
Needs to address geolocation,calibration, atmospheric/BRDF correction issues

CALIBRATION

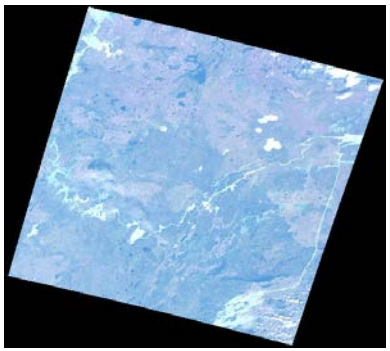
Degradation in channel 1
(from Ocean observations)

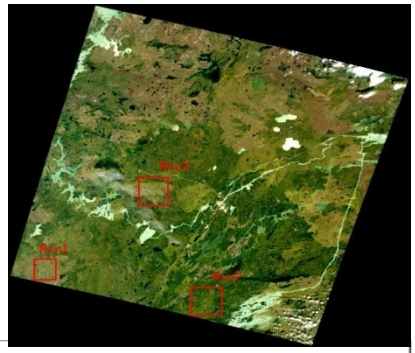


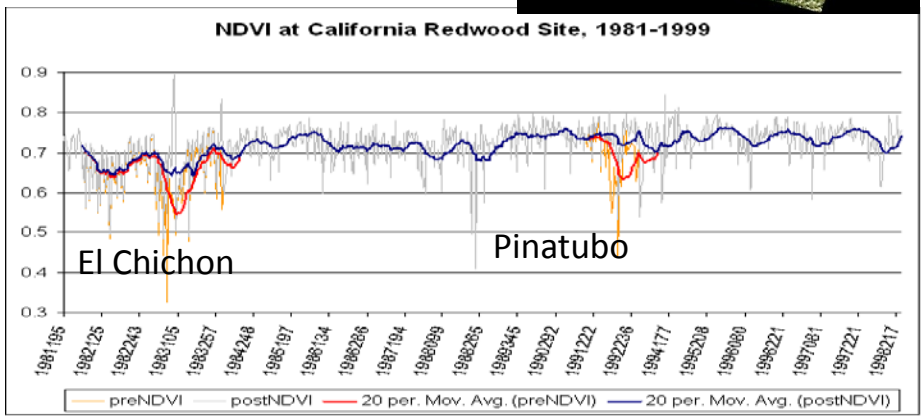
Channel1/Channel2 ratio
(from Clouds observations)



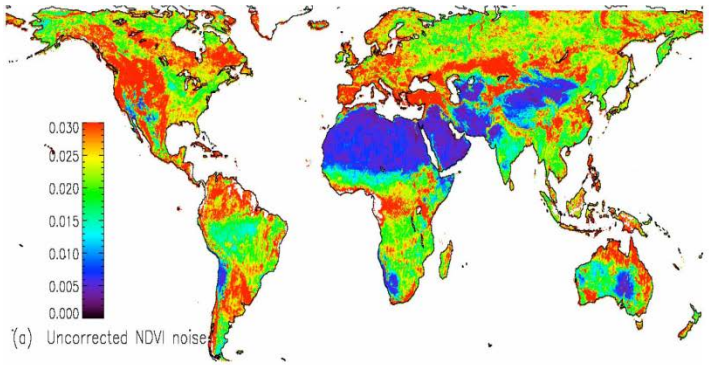
ATMOSPHERIC CORRECTION

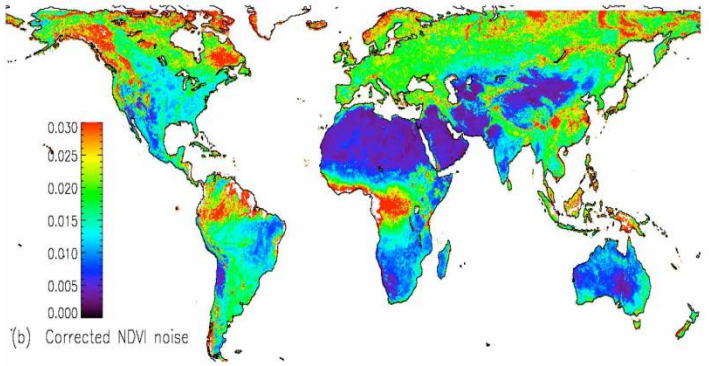


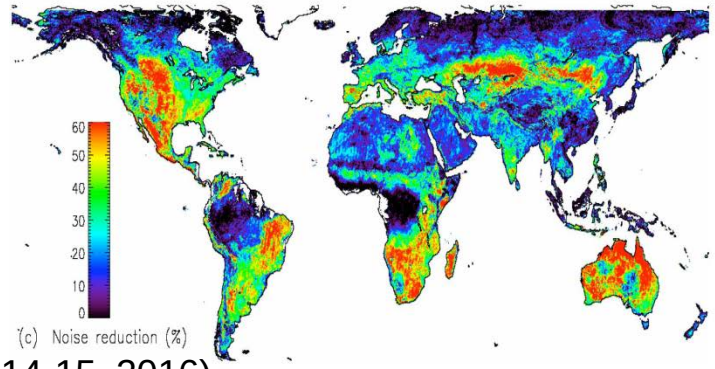




BRDF CORRECTION







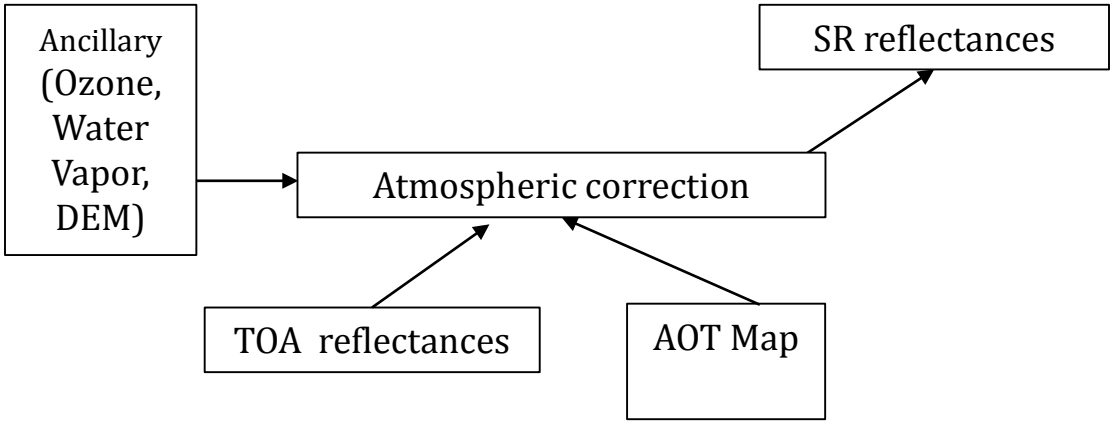
Generic Surface reflectance algorithm

The Surface reflectance algorithm relies on

- the use of very accurate (better than 1%) vector radiative transfer modeling of the coupled atmosphere-surface system
- the inversion of key atmospheric parameters (aerosol, water vapor)

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

Generic flowchart for atmospheric correction



Generic Aerosol inversion

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…

Using an assumed relationship between the blue surface reflectance (~450nm) and the red surface reflectance (~650nm) and fixing the aerosol model we are able to retrieve the **AOT.**

We loop the AOT until $(\rho_{surf}$ blue / ρ_{surf} red$)_{derived} = (\rho_{surf}$ blue / ρ_{surf} red$)_{assumed}$

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

The retrieved AOT is used to compute the surface reflectance at other wavelengths in the blue and SWIR to make a more robust inversion and refine the aerosol model. by minimizing the residual.

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

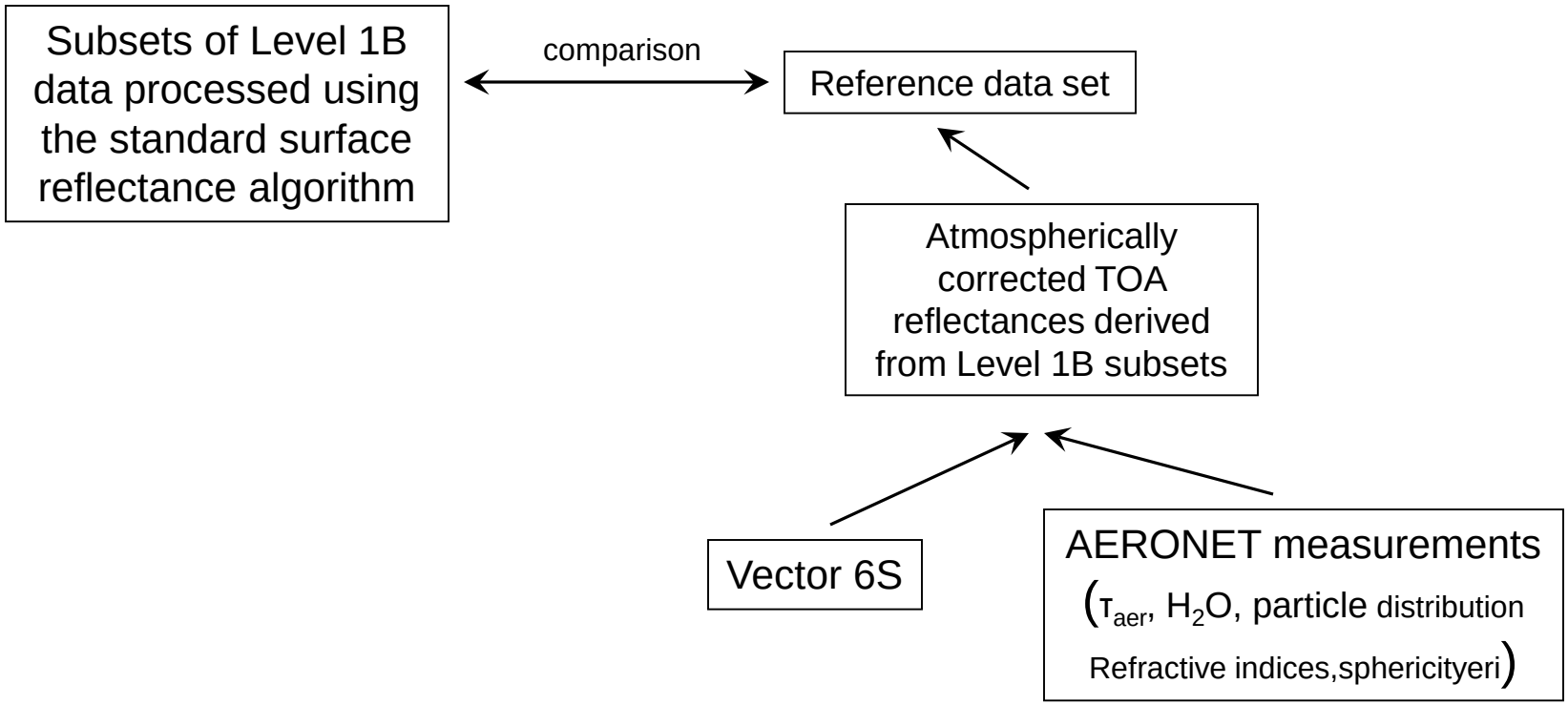
Computation of **surface reflectances** for all channels

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

Surface reflectance for each pixel and each band

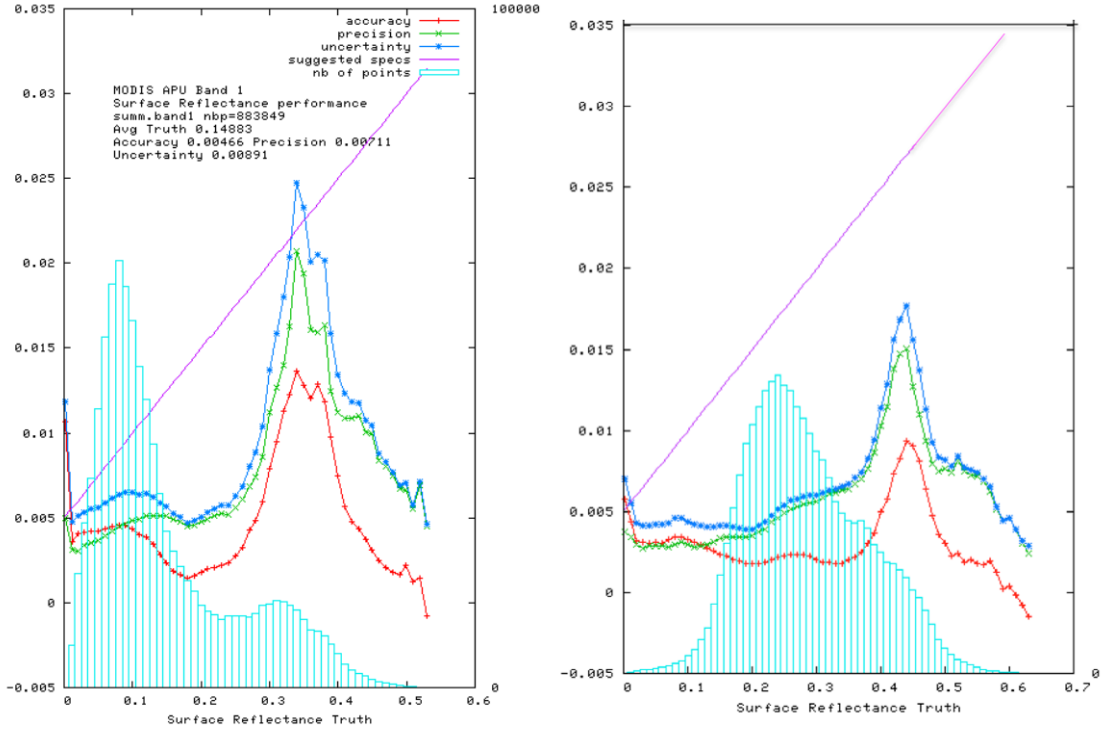
$$(*)\quad \rho_{surf} = \frac{Y}{1 + S_{atm}.Y} \quad \text{with} \quad Y = \frac{1}{T_{atm}.tg^{wv}}\left[\left(\frac{\rho_{TOA}}{tg^{O3}.tg^{others}} - \right) - \left(\rho_{atm} - \rho_{ray}\right).tg^{wv/2} - \rho_{ray}\right]$$

Methodology for evaluating the performance of surface reflectance



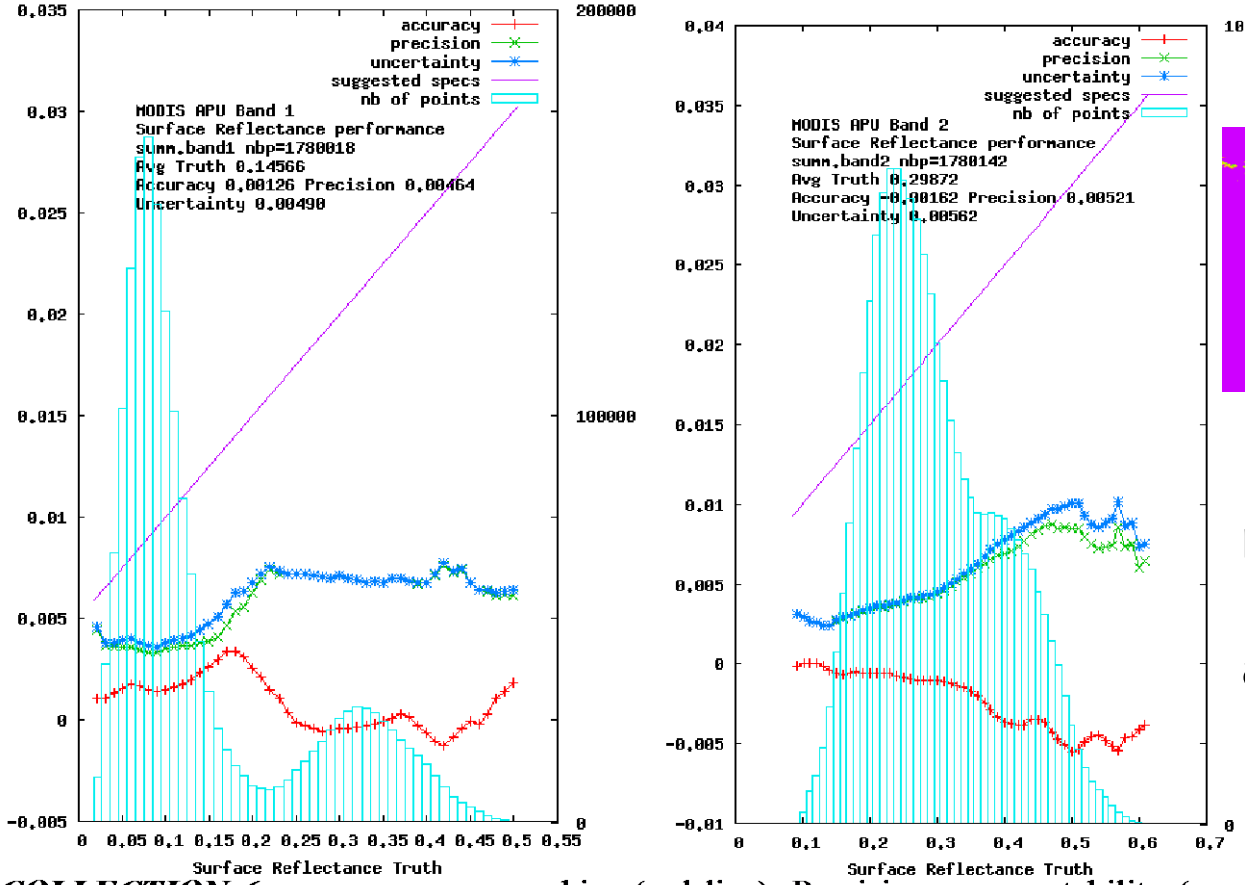
http://mod09val.ltdri.org/cgi-bin/mod09_c005_public_allsites_onecollection.cgi

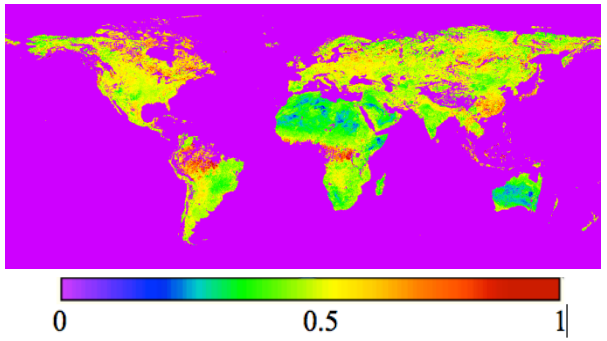
quantitative assessment of performances (APU) for MODIS (Collection 5: Fixed ratio blue/red)



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

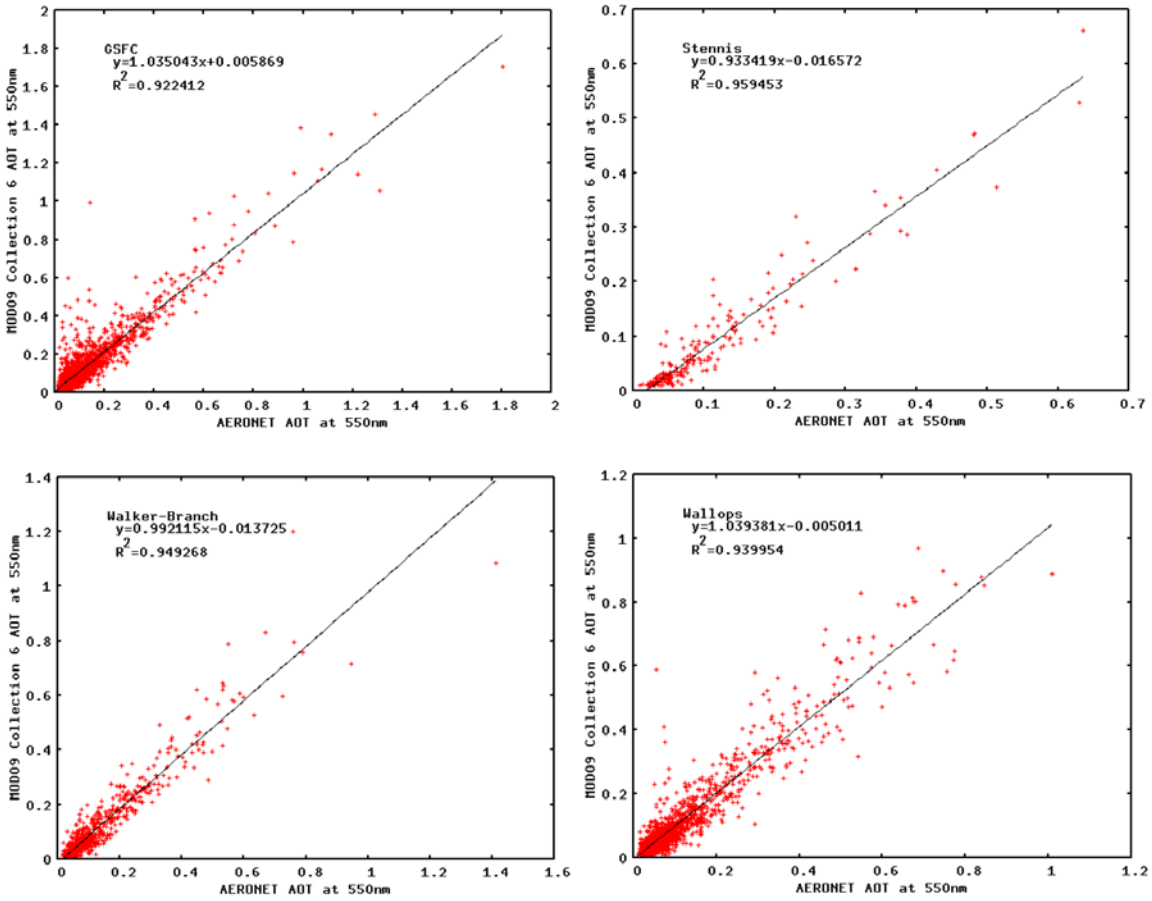




ratio blue/red derived using MODIS top of the atmosphere corrected with MISR aerosol optical depth

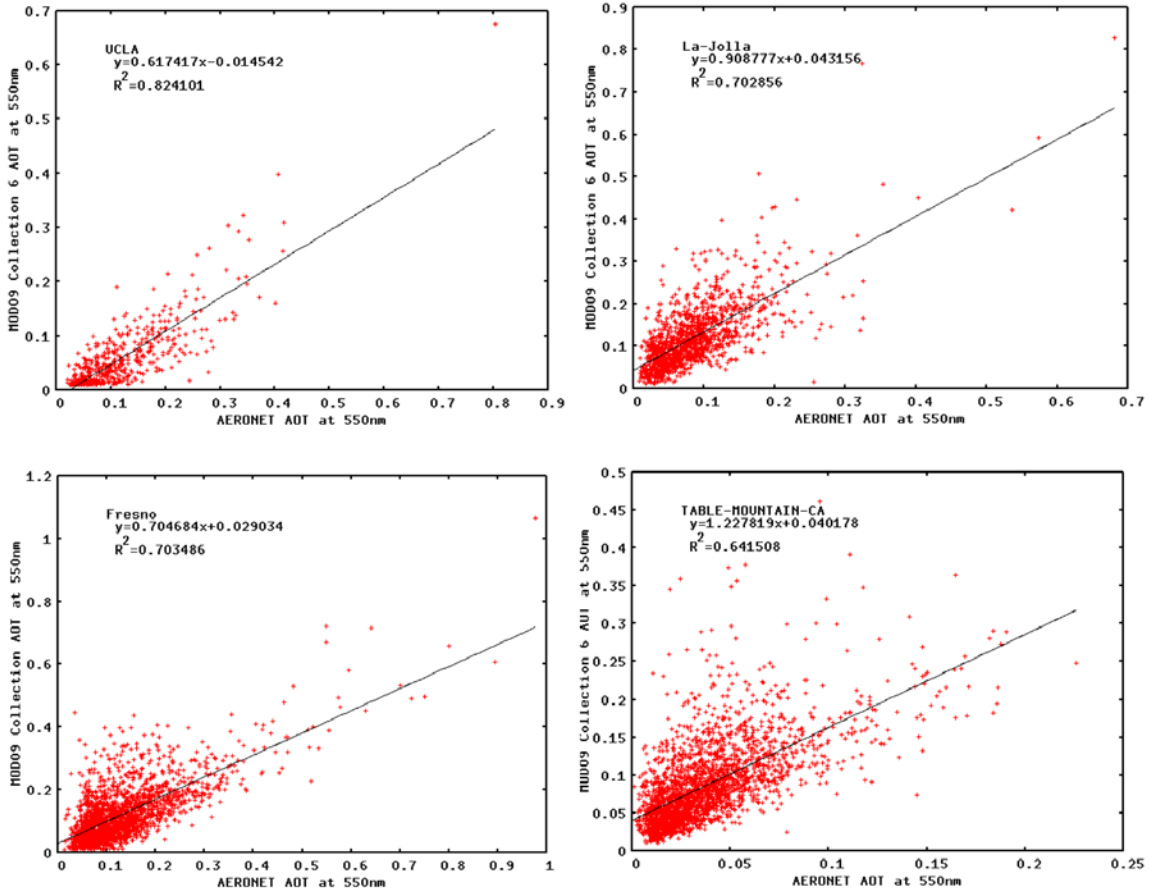
COLLECTION 6: accuracy or mean bias (red line), Precision or repeatability (green line) and Uncertainty or quadratic sum of Accuracy and Precision (blue line) of the surface reflectance in band 1 in the Red (top left), band 2 in the Near Infrared (top right also shown is the uncertainty specification (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.

Aerosol retrieval also shows improvement



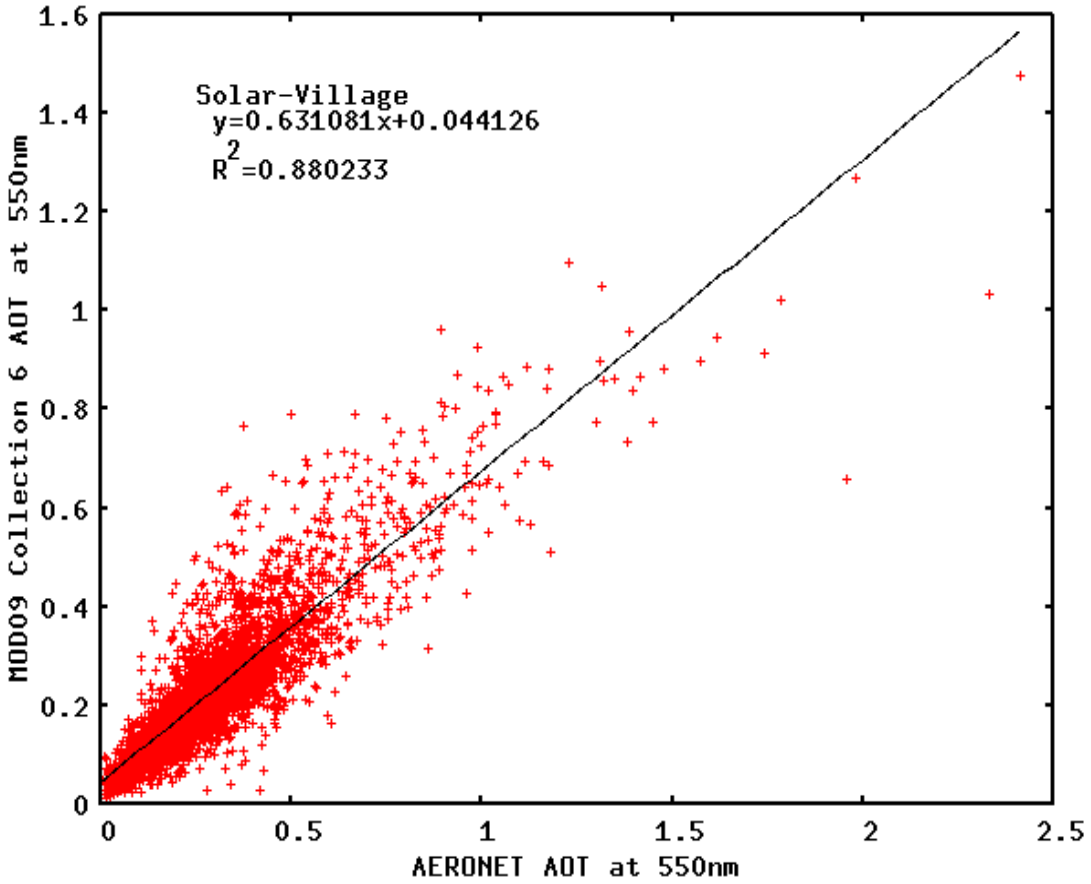
Scatterplot of the MOD09 AOT at 550nm versus the AERONET measured AOT at 550nm for East Coast sites selection: GSFC (top left), Stennis (top right), Walker Branch (bottom left) and Wallops (bottom right).

Aerosol retrieval also shows improvement



Scatterplot of the MOD09 AOT at 550nm versus the AERONET measured AOT at 550nm for the West Coast sites selection: UCLA (top left), La Jolla (top right), and Fresno (bottom left) and Table Mountain (bottom right).

Aerosol retrieval also shows improvement



Scatterplot of the MOD09 AOT at 550nm versus the AERONET measured AOT at 550nm for for a very bright site in Saudi Arabia (Solar Village)

This Surface Reflectance is applied to Landsat8/OLI and Sentinel 2

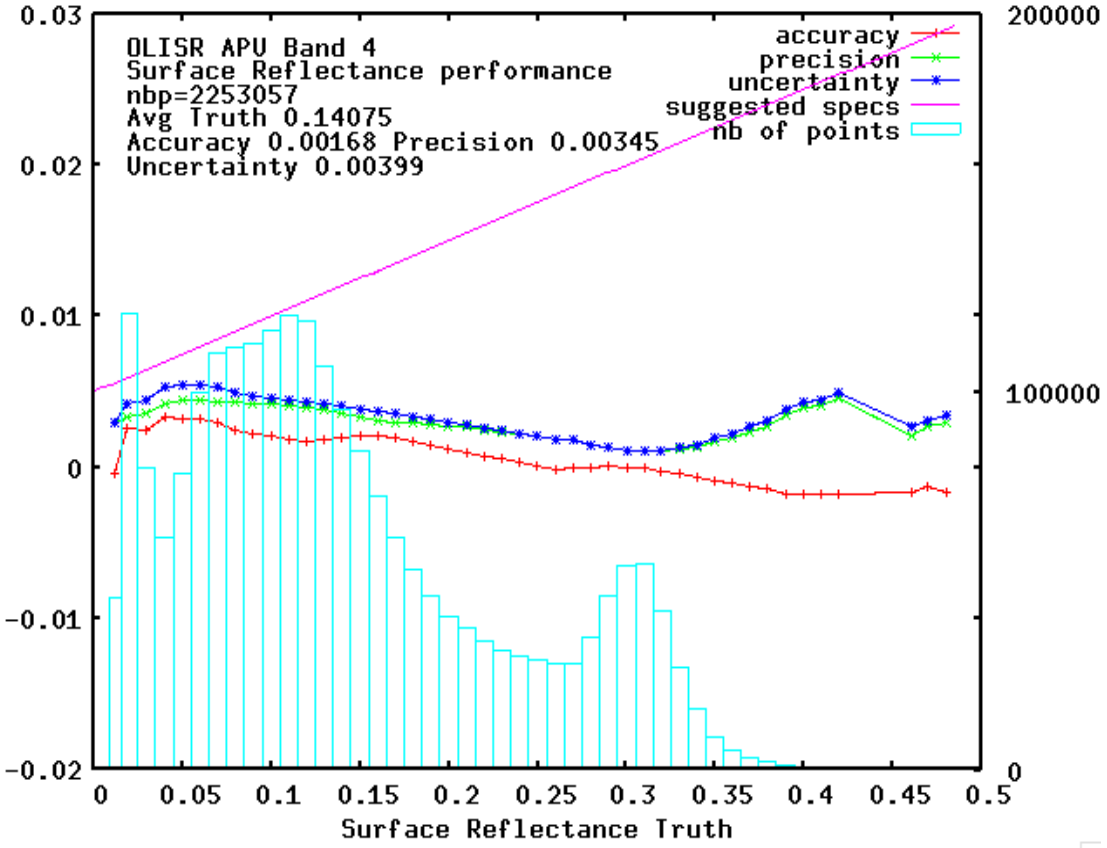
Algorithm reference for L8: Vermote E.F., Justice C., Claverie M. and Franch B., “Preliminary analysis of the performance of the Landsat 8/OLI land surface reflectance product” Remote Sensing of Environment. In Press.

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

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

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

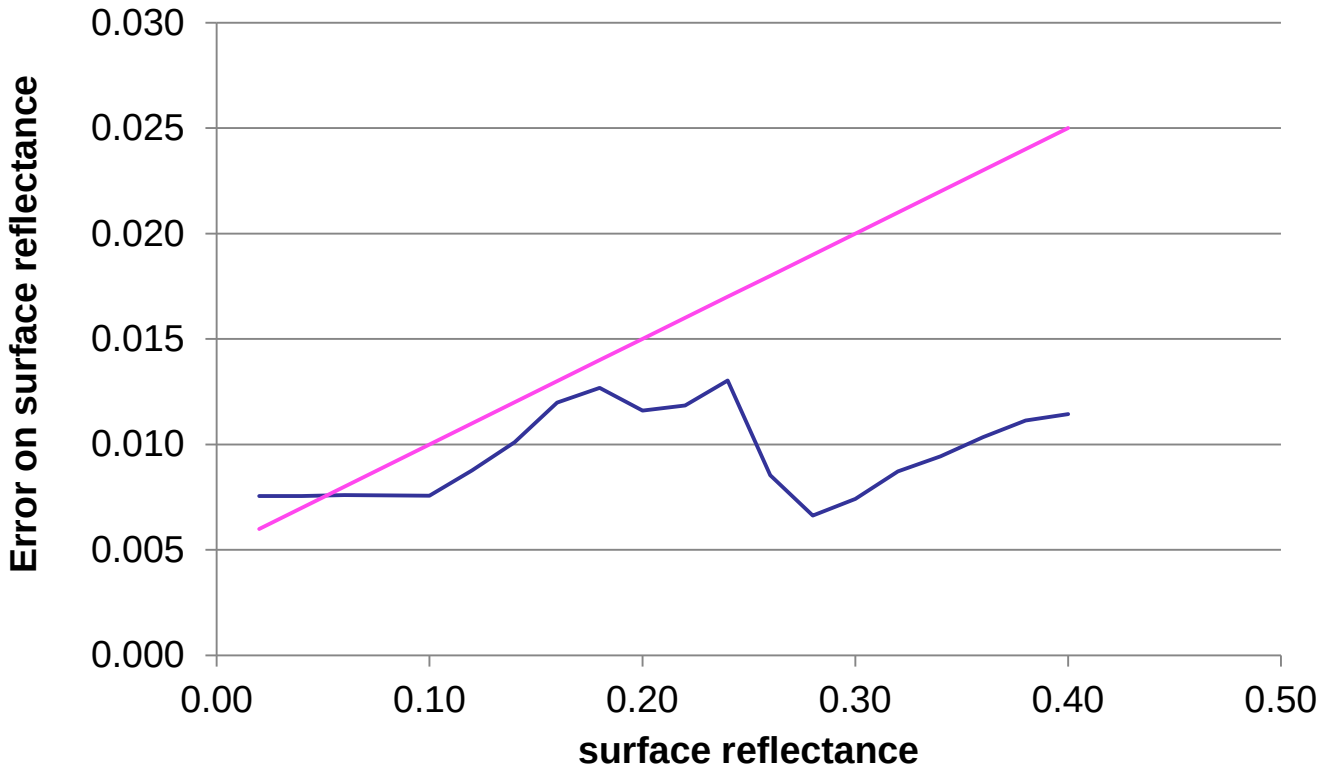
This is confirmed by comparison with MODIS

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.

Sentinel 2 SR “validation” (6 scenes only)

For the Red channel (Band 4 @ 665nm)



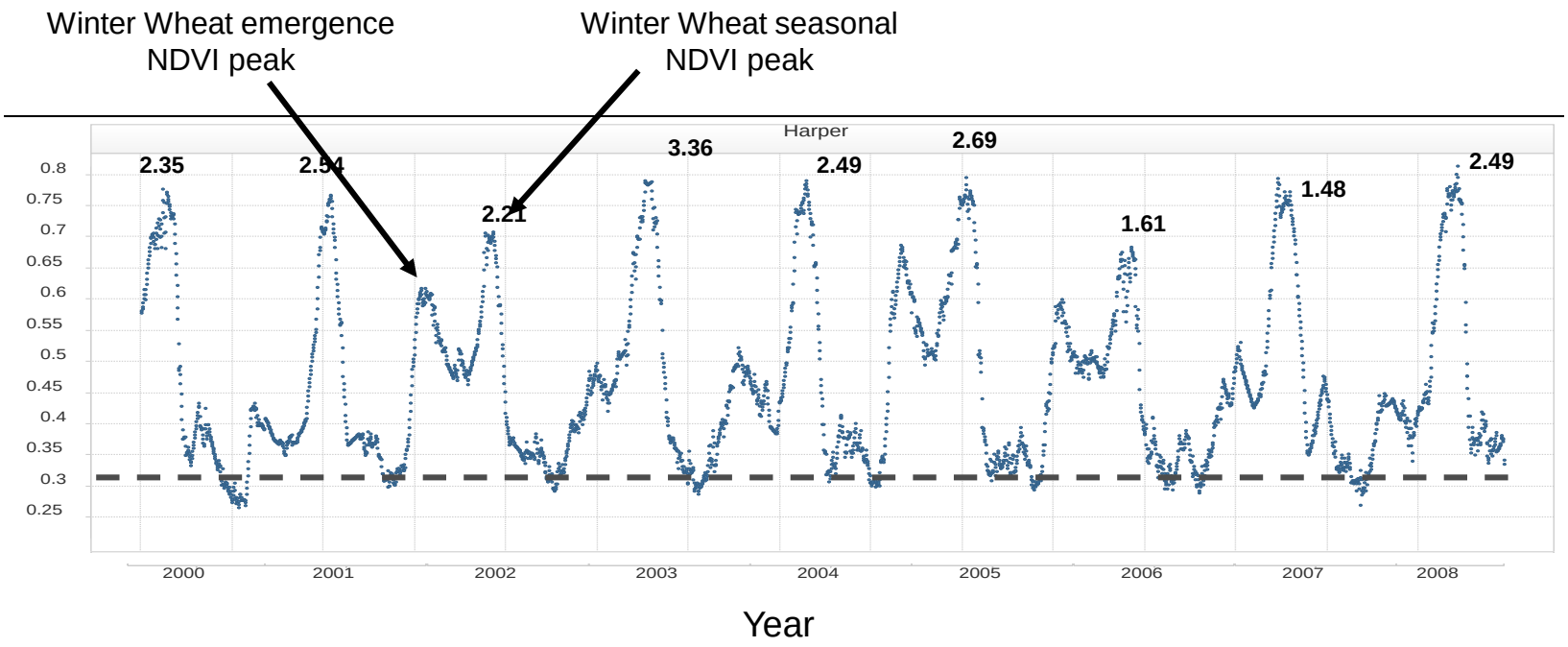
YIELD MONITORING

Basis: **Strong correlation between NDVI Peak and yield**

Tucker 1980, Hatfield 1983, Benedetti 1993, Doraiswamy 1995, Rasmussen 1997, Mika 2002

Daily Normalized Difference Vegetation Index (NDVI from MODIS) 2000-2008, Harper County
Numbers are Yield (MT/Ha)

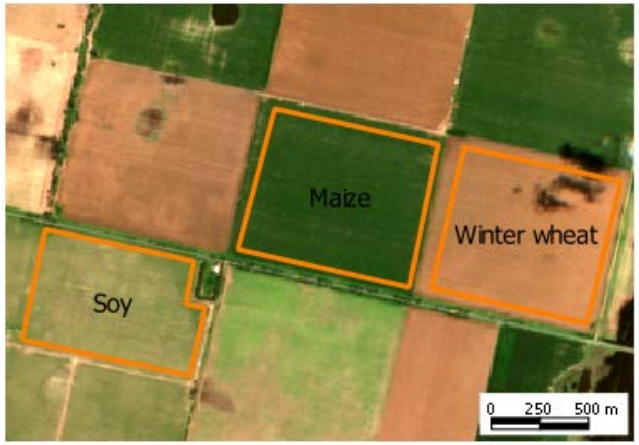
Kansas



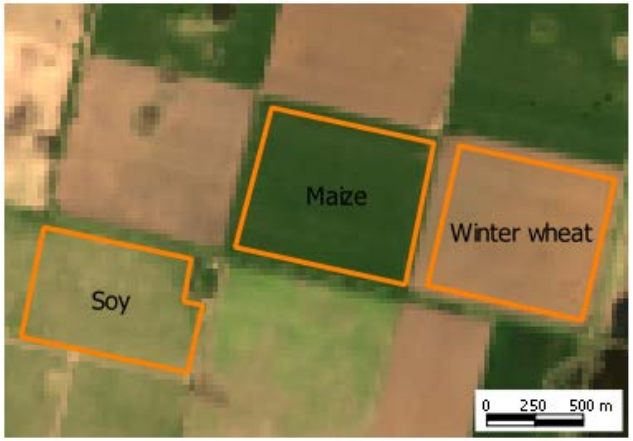
Becker-Reshef I, Vermote E, Lindeman M, Justice C. 2010. In Remote Sensing of Environment, 114, 1312–1323.

Temporal information is now available at the field level

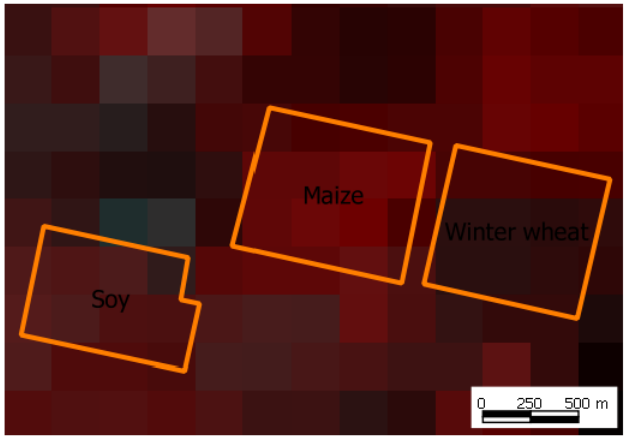
NDVI aggregated at field level (Argentina, S2A tile 20HNH).



Sentinel-2A image acquired on 04-Dec-15, 10m, true color B04-03-02 (SR, scaled 0-0.15)



Landsat-8 image acquired on 04-Dec-15, 30m, true color B4-3-2 (SR, scaled 0-0.15)



MOD09GQ image acquired on 04-Dec-15, 250m, false color B2-1-1, SR

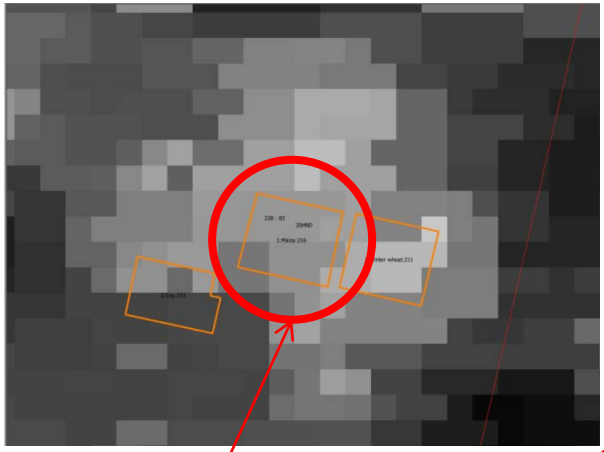
Sentinel-2A image acquired on 23-Jan-16, 10m, true color B04-03-02 (SR, scaled 0-0.15)

Landsat-8 image acquired on 21-Jan-16, 30m, true color B4-3-2 (SR, scaled 0-0.15)

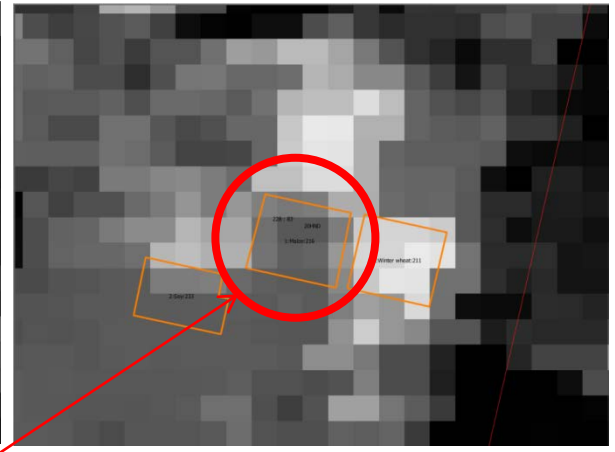
Temporal information is now available at the field level

NDVI aggregated at field level (Argentina, S2A tile 20HNH).

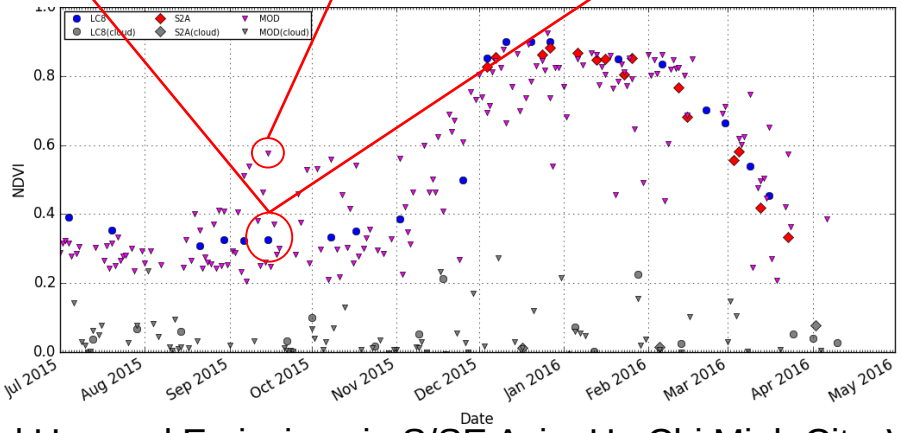
LC8 acquired on **15-Sep-2015** (30m). SR NIR band scaled 0.05-0.55



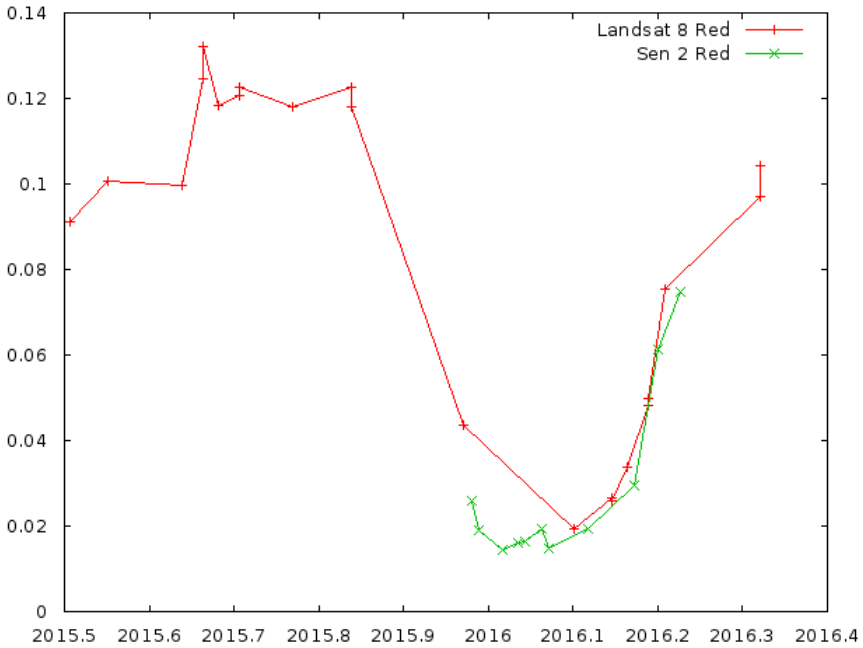
MODIS/Terra (MOD09GQ) acquired on **15-Sep-2015** (250 m). SR NIR band scaled 0.05-0.55

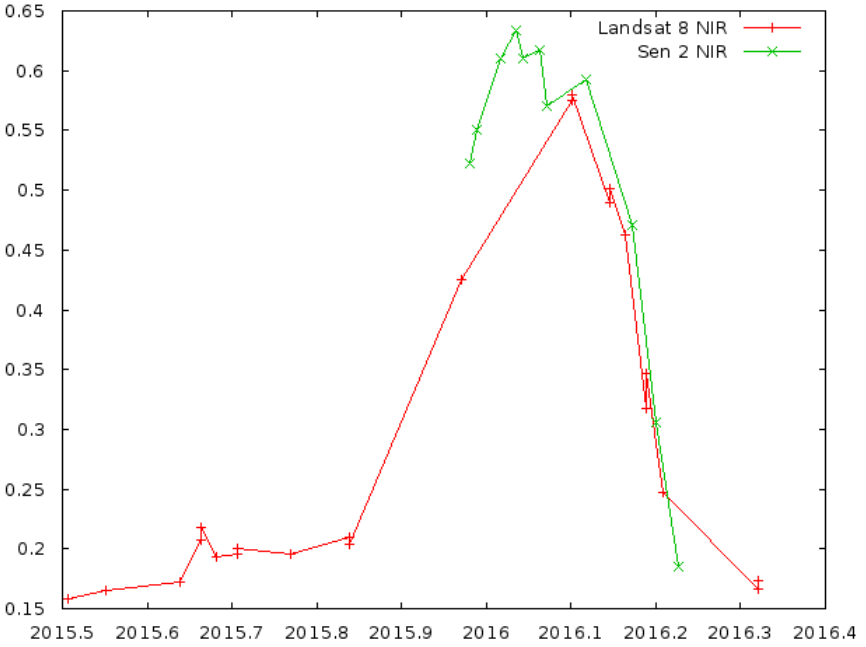


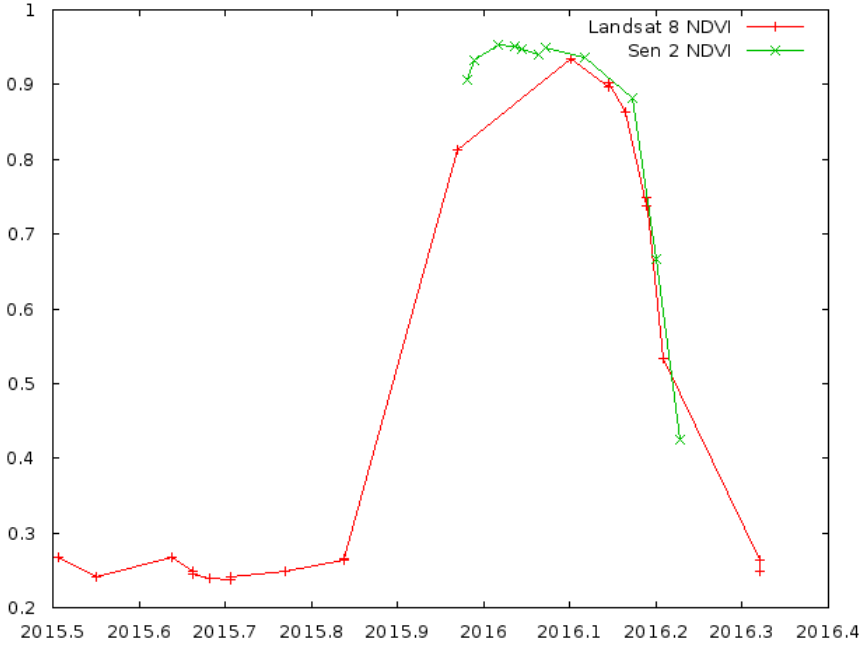
MODIS/Terra (MOD09GQ) acquired on **16-Sep-2015** (250 m). SR NIR band scaled 0.05-0.55



Maize


Landsat 8 Red
Sen 2 Red
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
2015.5
2015.6
2015.7
2015.8
2015.9
2016
2016.1
2016.2
2016.3
2016.4


Landsat 8 NIR
Sen 2 NIR
0.65
0.6
0.55
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
2015.5
2015.6
2015.7
2015.8
2015.9
2016
2016.1
2016.2
2016.3
2016.4


Landsat 8 NDVI
Sen 2 NDVI
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
2015.5
2015.6
2015.7
2015.8
2015.9
2016
2016.1
2016.2
2016.3
2016.4

ACIX: CEOS-WGCV Atmospheric Correction Inter-comparison Exercise (ESA/NASA/UMD)

The exercise aims to bring together available AC processors (**actually 14 processors including SEN2COR, MACCS, L8-S2-6SAC, …**) to generate the corresponding SR products.

The input data will be **Landsat-8 and Sentinel-2 imagery** of various test sites, i.e. coastal, agricultural, forest, snow/artic areas and deserts.

Objectives
- To better understand uncertainties and issues on L8 and S2 AC products
- To propose further improvements of the future AC schemes

* 1st Workshop in June 21st-22nd @ University of Maryland (by invitation): to elaborate concepts, protocols and guidelines for the inter-comparison and validation of SR products

Program (with first suggestions) will be provide April 30th (available on the web site for eventual end users feedbacks)

* 2nd workshop in April 2017 (open)

https://earth.esa.int/web/sppa/meetings-workshops/acix

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…)
- Preliminary Sentinel 2 surface reflectance validation shows good performance and will be validated over AERONET (about ~500 scenes shortly)