Surface Reflectance

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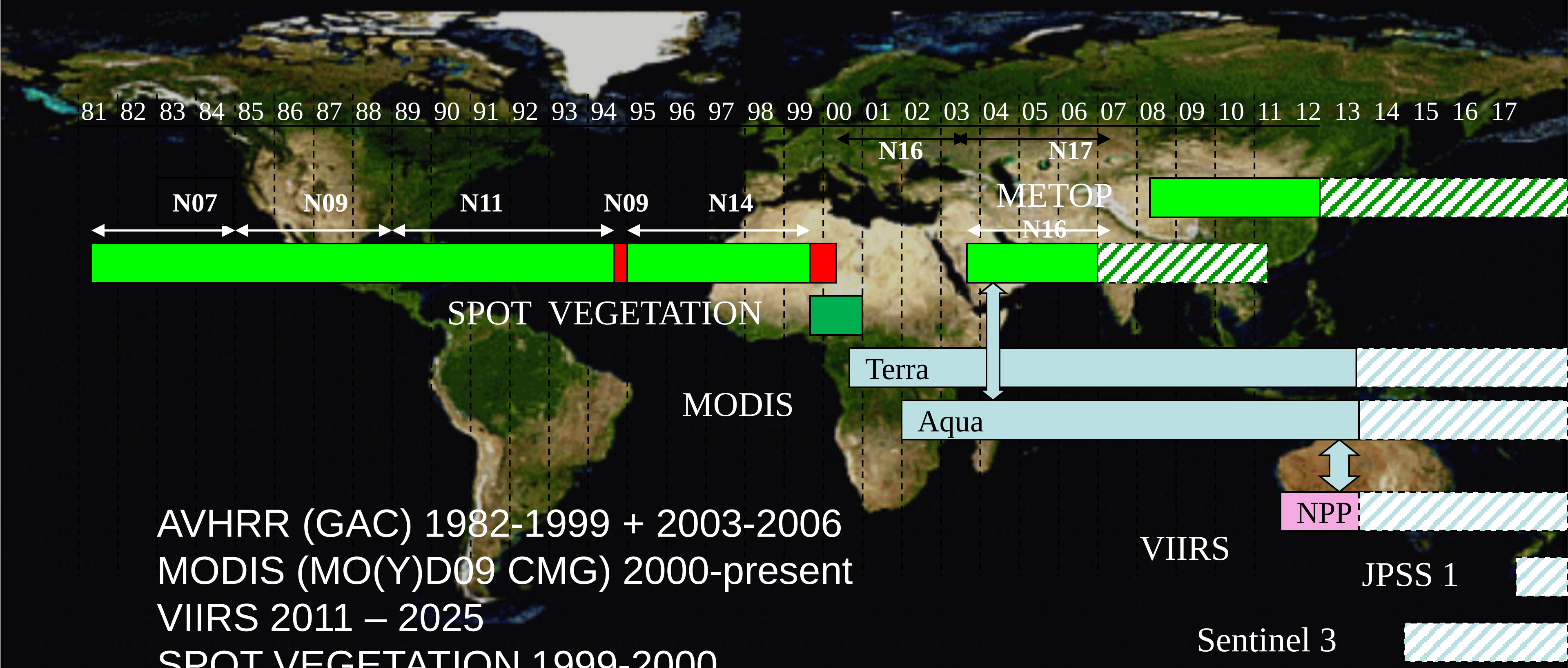
A Land Climate Data Record

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



AVHRR (GAC) 1982-1999 + 2003-2006

MODIS (MO(Y)D09 CMG) 2000-present

VIIRS 2011 – 2025

SPOT VEGETATION 1999-2000

Sentinel 3 2014

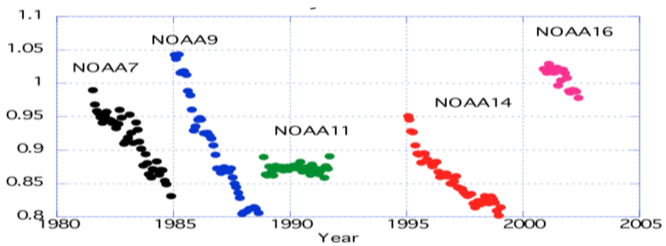
Emphasis on data consistency – characterization rather than degrading/smoothing the data

Land Climate Data Record (Approach)

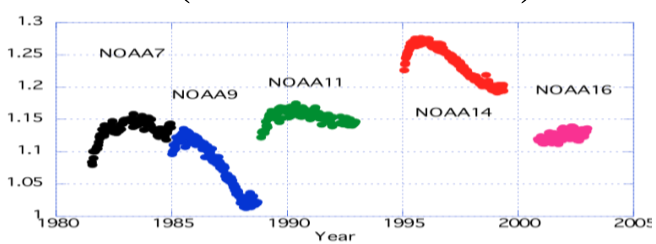
Needs to address geolocation,calibration, atmospheric/BRDF correction issues

CALIBRATION

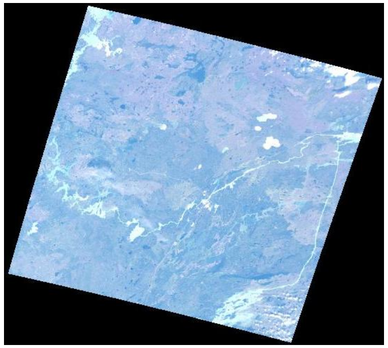
Degradation in channel 1
(from Ocean observations)

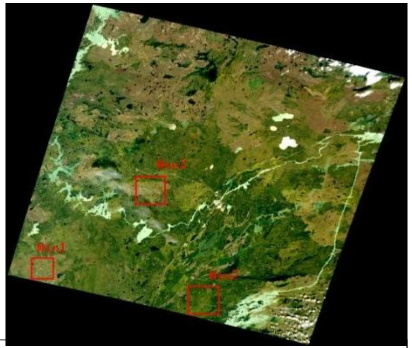


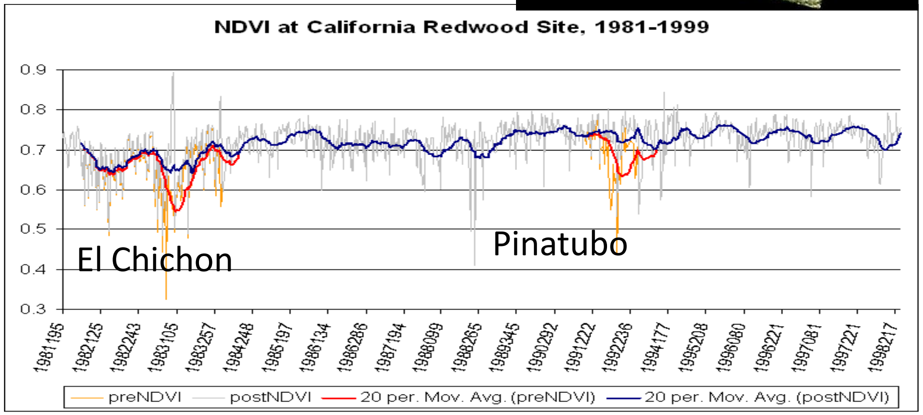
Channel1/Channel2 ratio
(from Clouds observations)



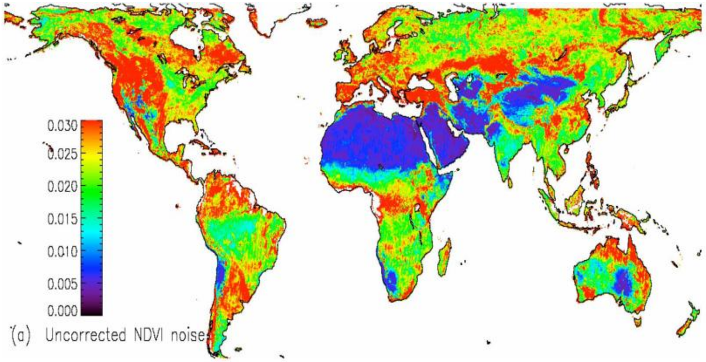
ATMOSPHERIC CORRECTION

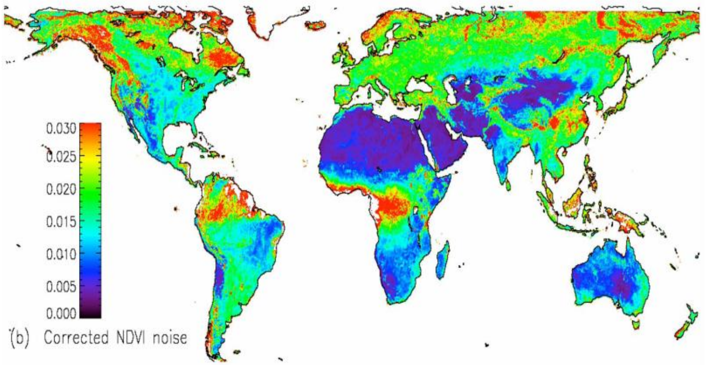


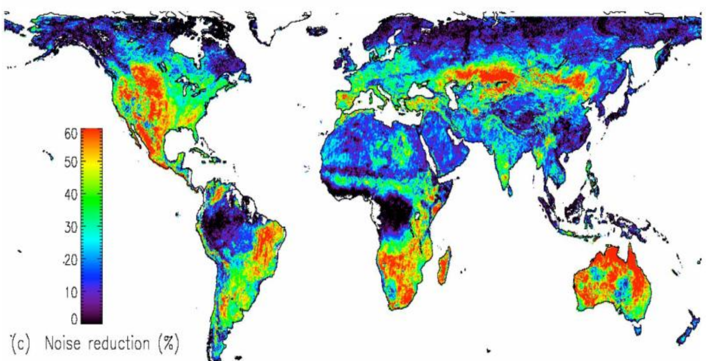




BRDF CORRECTION







VIIRS Surface Reflectance based MODIS C5

The MODIS **Collection 5 AC algorithm** relies on

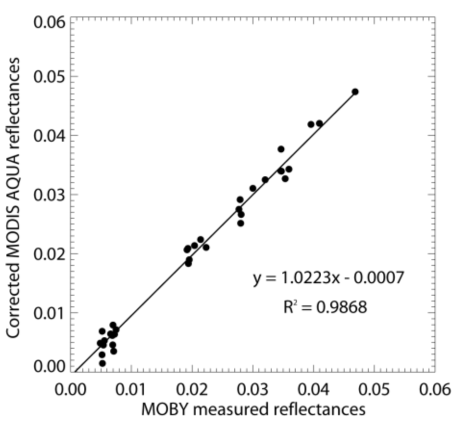
- the use of very accurate (better than 1%) vector radiative transfer modeling of the coupled atmosphere-surface system
- the inversion of key atmospheric parameters (aerosol, water vapor)

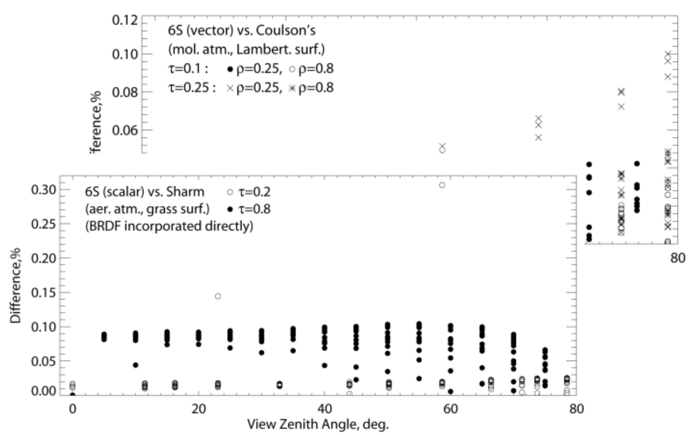
Home page: http://modis-sr.ltdri.org

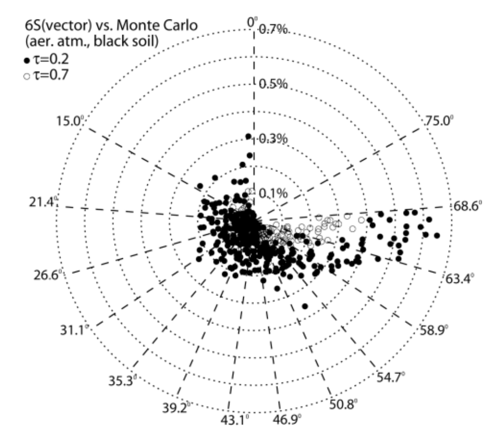
6SV Validation Effort

The complete 6SV validation effort is summarized in three manuscripts:

- Kotchenova, S. Y., Vermote, E. F., Matarrese, R., & Klemm Jr, F. J. (2006). Validation of a vector version of the 6S radiative transfer code for atmospheric correction of satellite data. Part I: Path radiance. *Applied Optics*, *45*(26), 6762-6774.
- Kotchenova, S. Y., & Vermote, E. F. (2007). Validation of a vector version of the 6S radiative transfer code for atmospheric correction of satellite data. Part II. Homogeneous Lambertian and anisotropic surfaces. *Applied Optics*, *46*(20), 4455-4464.
- Kotchenova, S. Y., Vermote, E. F., Levy, R., & Lyapustin, A. (2008). Radiative transfer codes for atmospheric correction and aerosol retrieval: intercomparison study. *Applied Optics*, *47*(13), 2215-2226.







Methodology for evaluating the performance of VIIRS/MODIS

To first evaluate the performance of the MODIS Collection 5 SR algorithms, we analyzed 1 year of Terra data (2003) over **127** AERONET sites (**4988** cases in total).

Methodology:

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

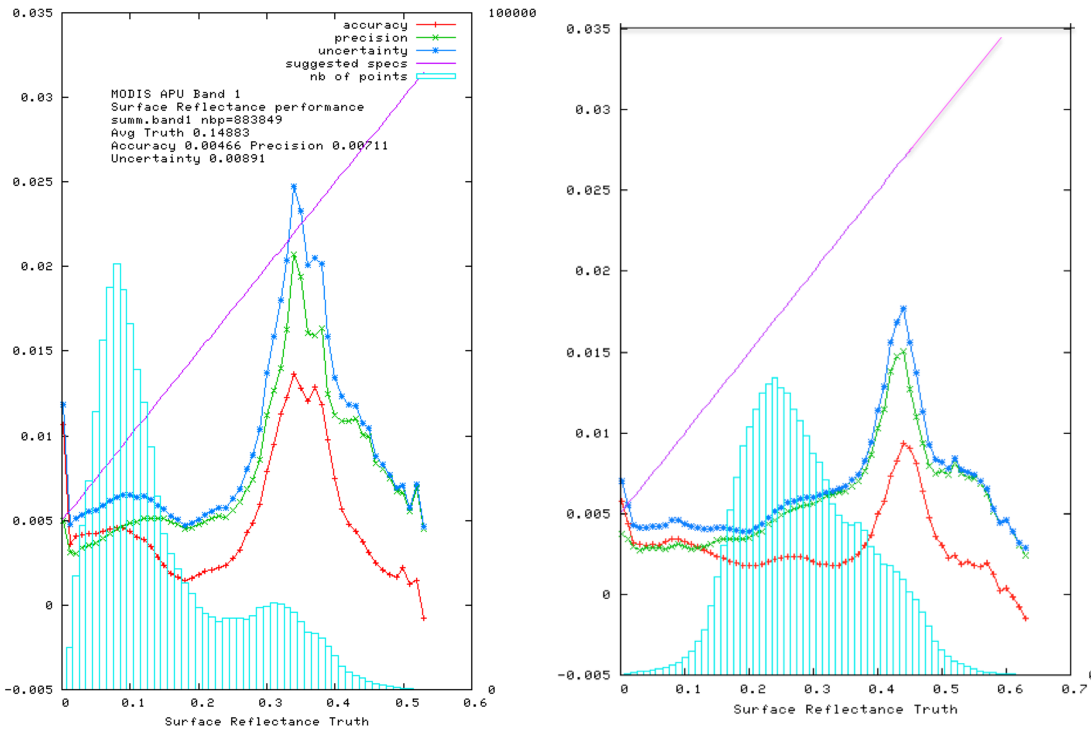
Vector 6S

AERONET measurements (τ_{aer}, H_2O, particle distribution Refractive indices,sphericityeri)

If the difference is within ±(0.005+0.05ρ), the observation is "good".

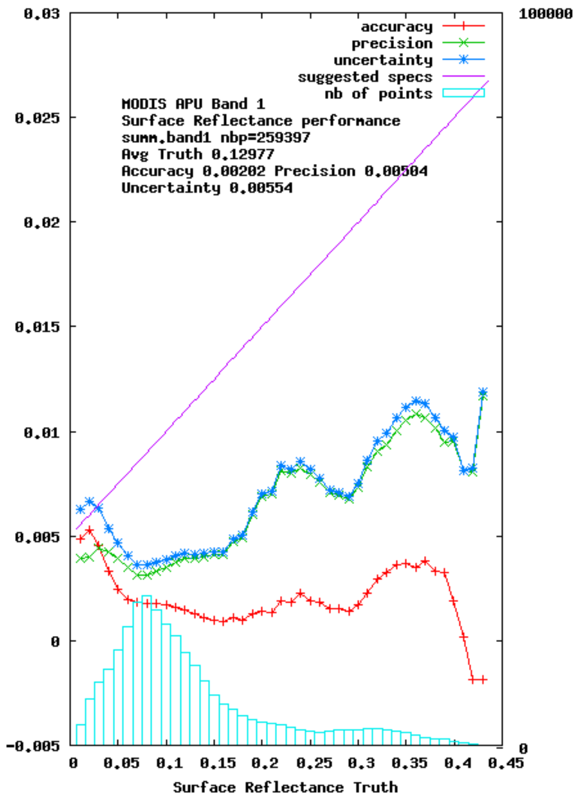
http://mod09val.ltdri.org/cgi-bin/mod09_c005_public_allsites_onecollection.cgi

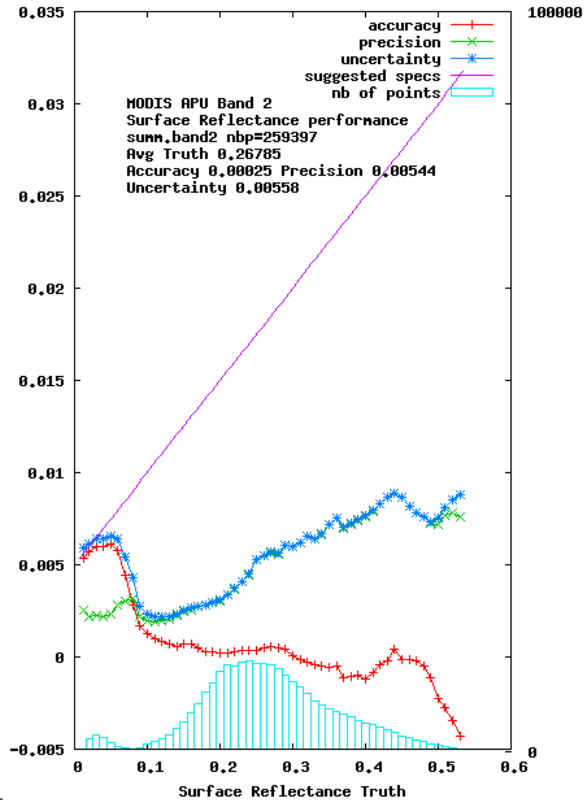
quantitative assessment of performances (APU)

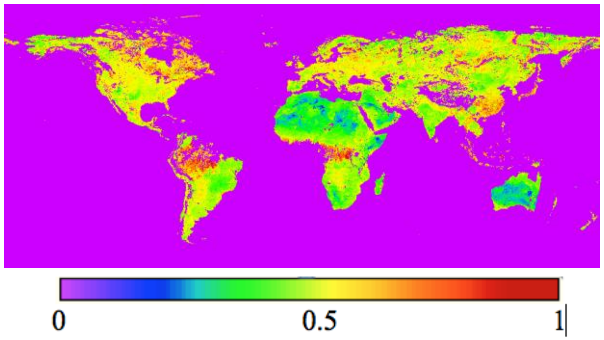


COLLECTION 5: accuracy or mean bias (red line), Precision or repeatability (green line) and Uncertainty or quadratic sum of Accuracy and Precision (blue line) of the surface reflectance in band 1 in the Red (top left), band 2 in the Near Infrared (top right also shown is the uncertainty specification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



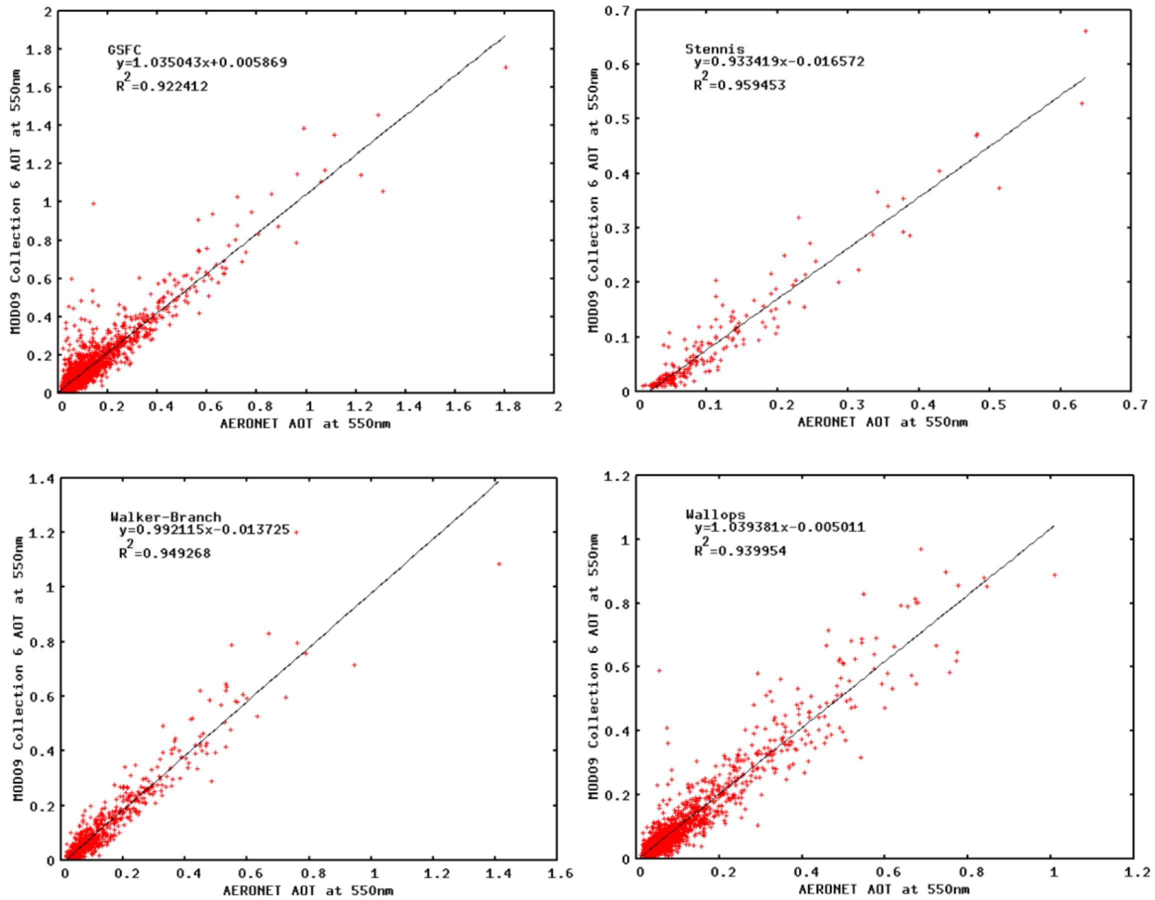




ratio band3/band1 derived using MODIS top of the atmosphere corrected with MISR aerosol optical depth

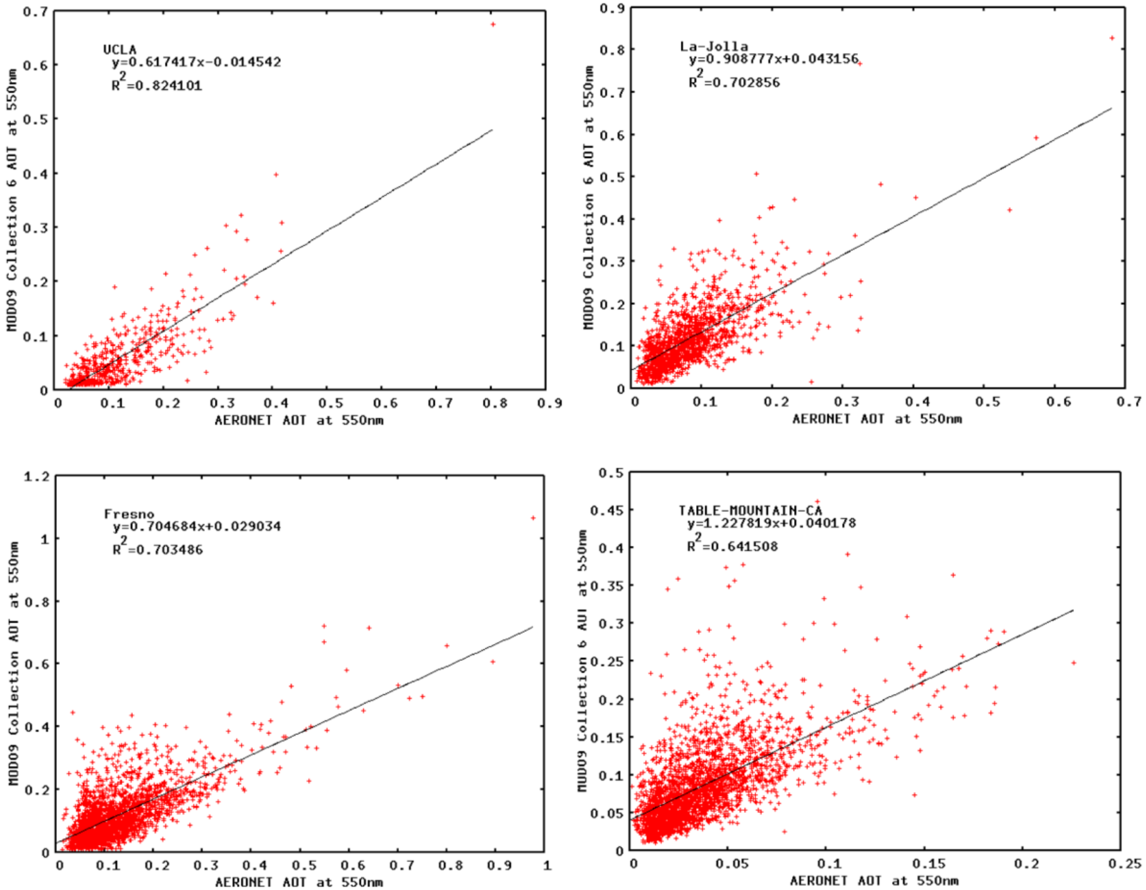
COLLECTION 6: accuracy or mean bias (red line), Precision or repeatability (green line) and Uncertainty or quadratic sum of Accuracy and Precision (blue line) of the surface reflectance in band 1 in the Red (top left), band 2 in the Near Infrared (top right also shown is the uncertainty specification (the line in magenta), that was derived from the theoretical error budget. Data collected from Terra over 200 AERONET sites from 2003.

Aerosol retrieval also shows improvement



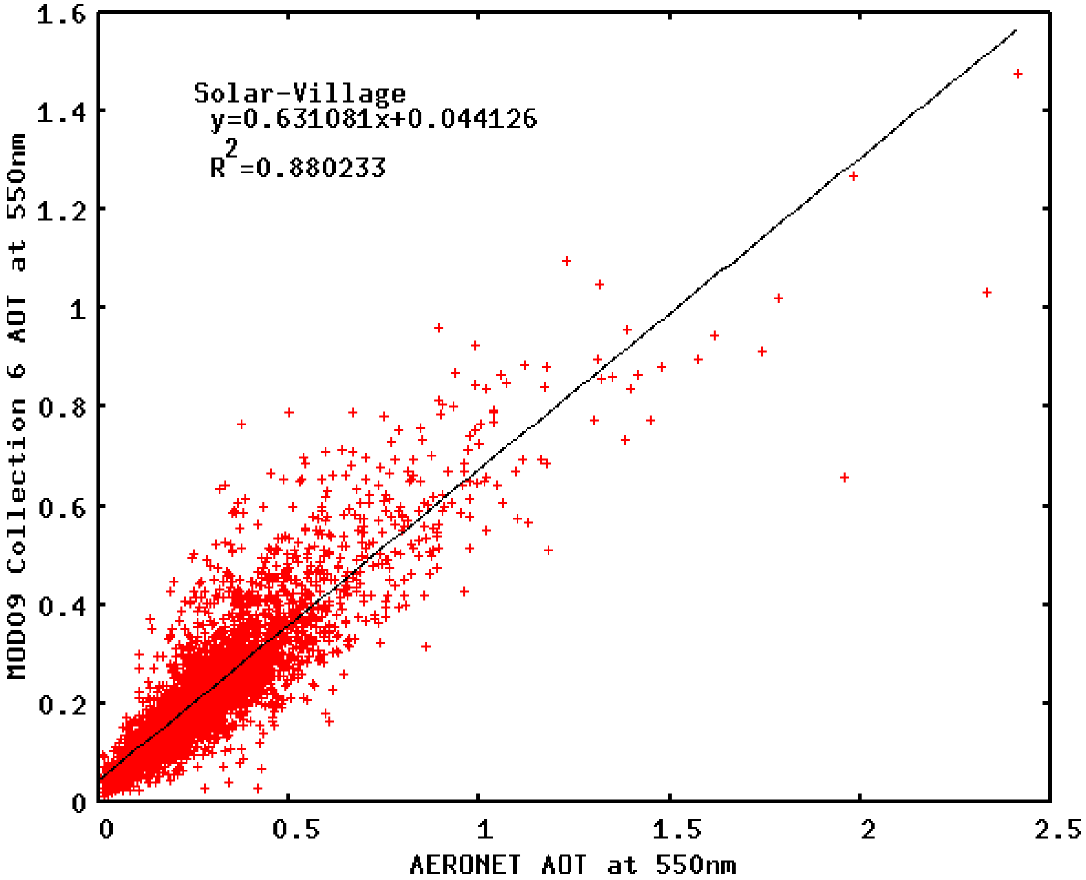
Scatterplot of the MOD09 AOT at 550nm versus the AERONET measured AOT at 550nm for East Coast sites selection: GSFC (top left), Stennis (top right), Walker Branch (bottom left) and Wallops (bottom right).

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



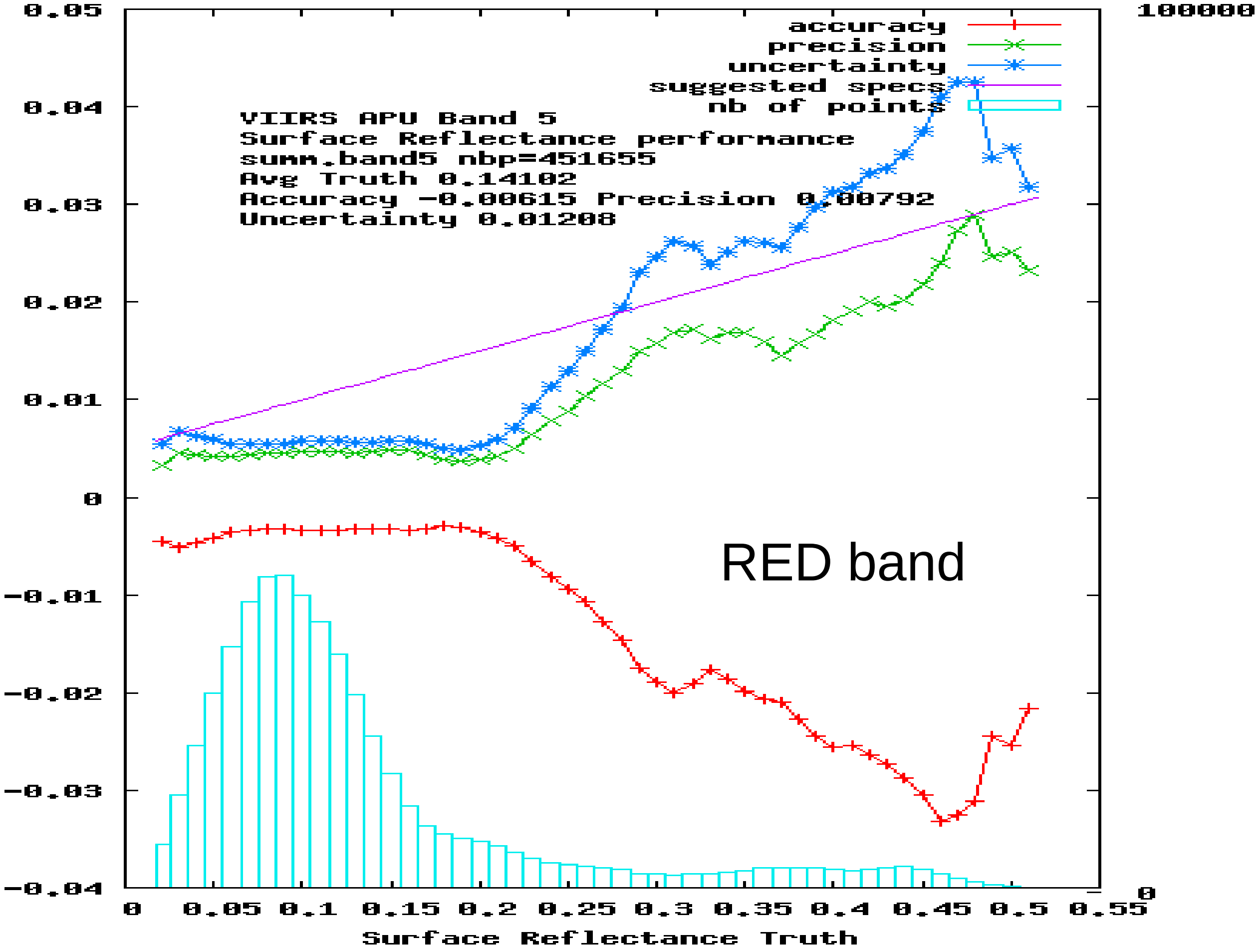
Scatterplot of the MOD09 AOT at 550nm versus the AERONET measured AOT at 550nm for for a very bright site in Saudi Arabia (Solar Village)

VIIRS Surface reflectance

- the VIIRS SR product is directly heritage from collection 5 MODIS and that it has been validated to stage 1 (Land PEATE adjusted version)
- MODIS algorithm refinements from Collection 6 will be integrated into the VIIRS algorithm and shared with the NOAA JPSS project for possible inclusion in future versions of the operational product .

Evaluation of Algorithm Performance

VIIRS C11 reprocessing



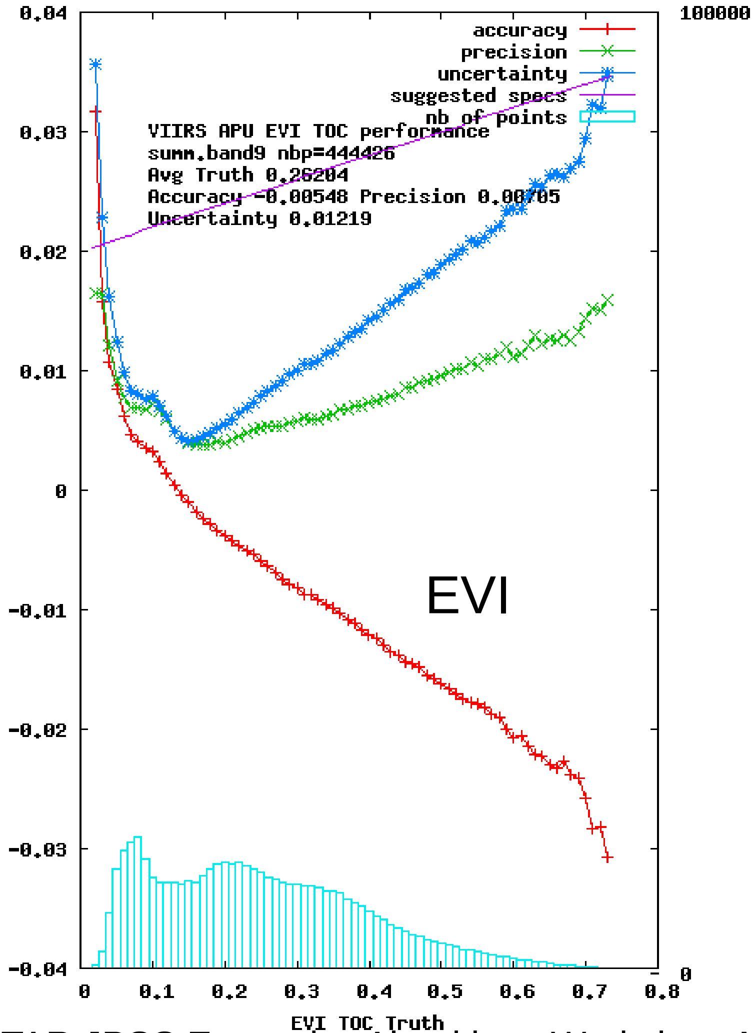
450000 pixels were analyzed for each band.

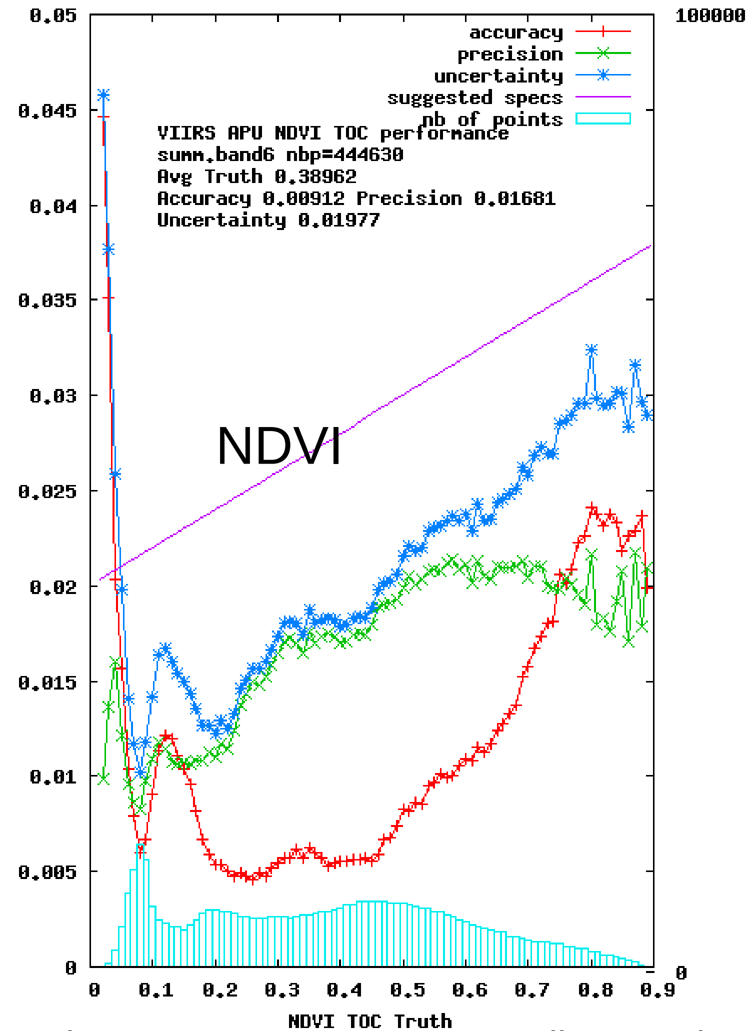
Red = Accuracy (mean bias)
Green = Precision (repeatability)
Blue = Uncertainty (quadatric sum of A and P)

On average well below magenta theoretical error bar

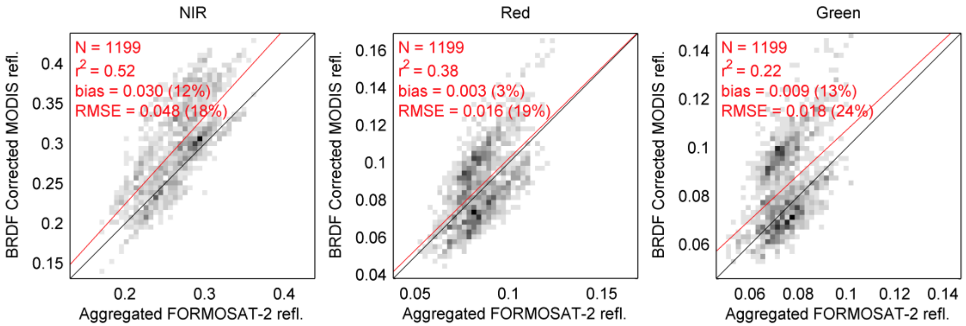
Evaluation of Algorithm Performance

VIIRS C11 reprocessing

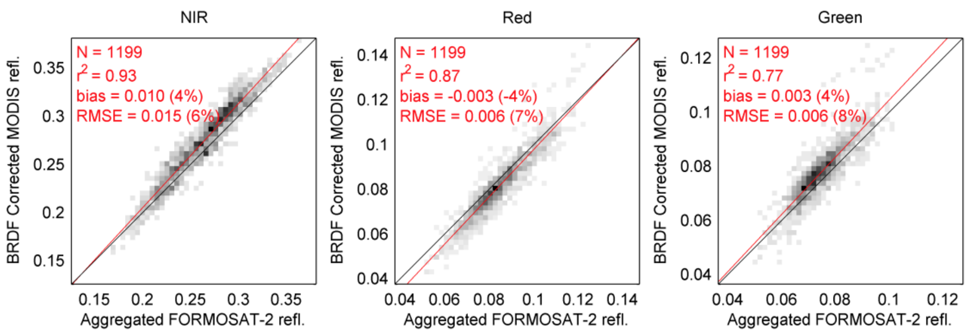




Use of BRDF correction for product cross-comparison



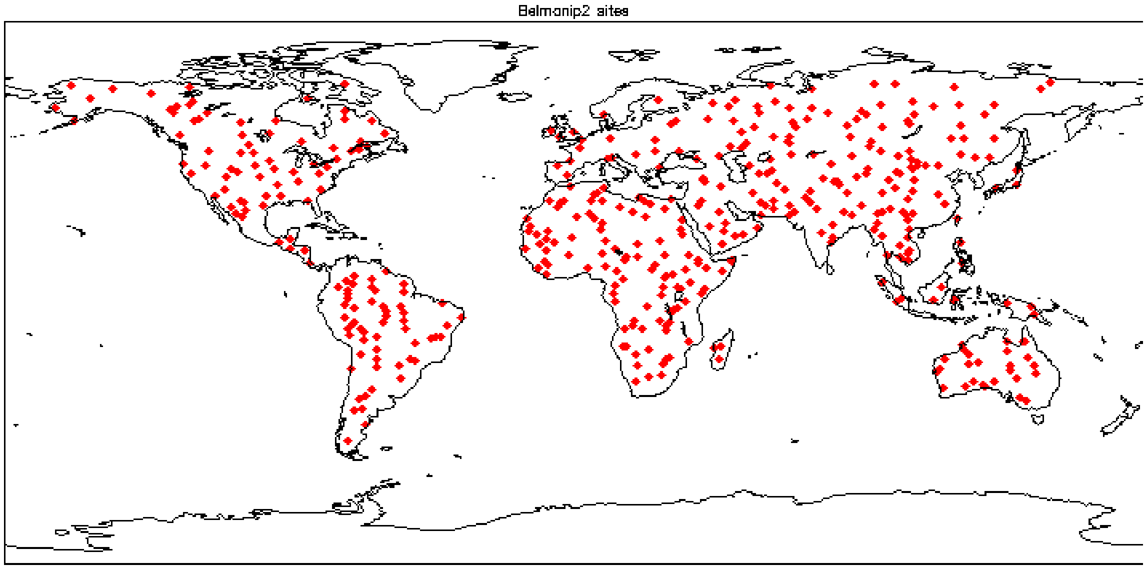
Comparison of aggregated FORMOSAT-2 reflectance and MODIS reflectance. No BRDF correction. Density function from light grey (minimum) to black (maximum); white = no data.

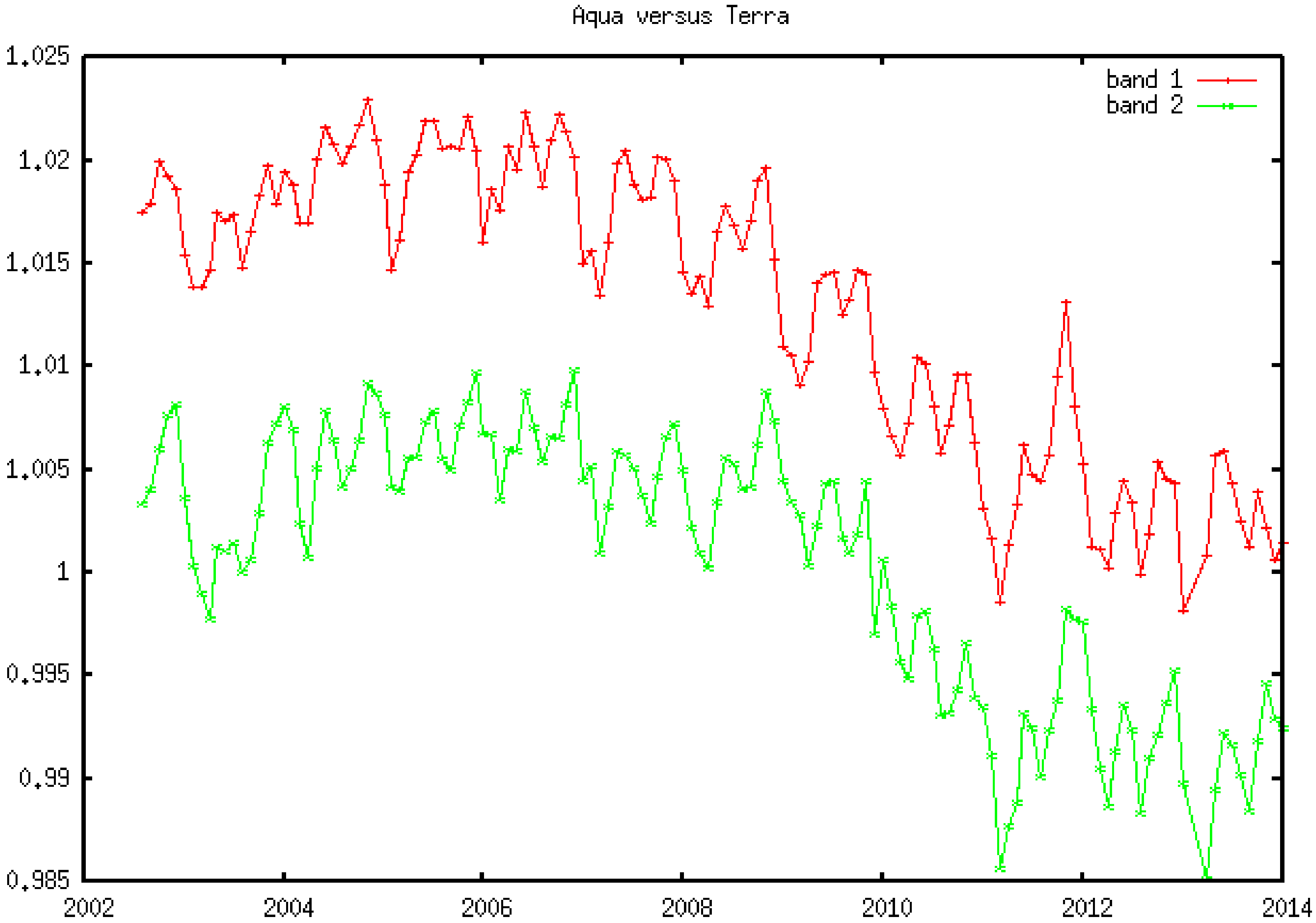


Comparison of aggregated FORMOSAT-2 reflectance and BRDF corrected MODIS reflectance. Corrections were performed with Vermote al. (2009) method using for each day of acquisition, the angular configuration of FORMOSAT-2 data.

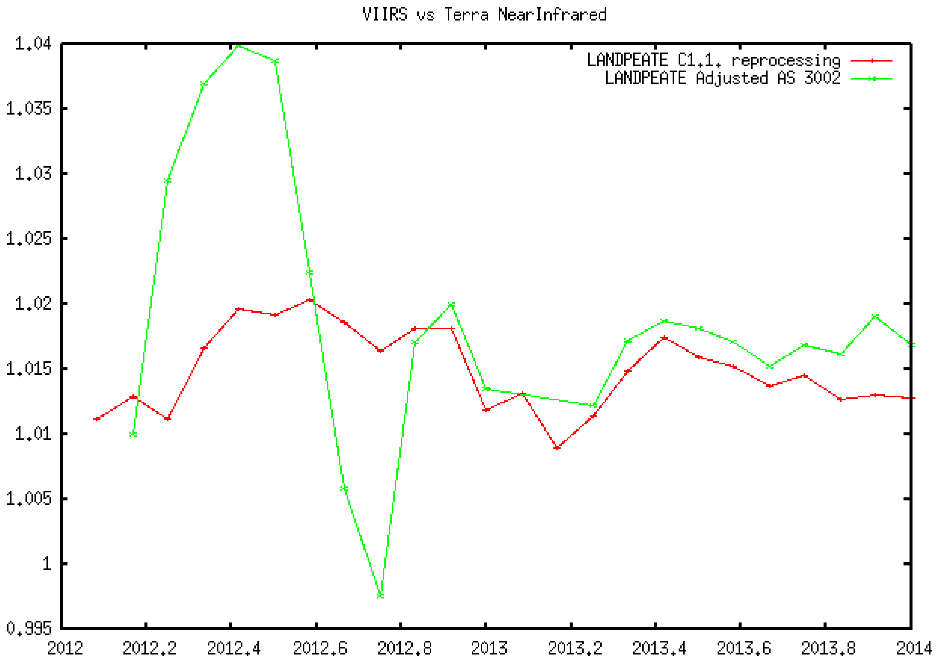
Cross comparison with MODIS over BELMANIP2

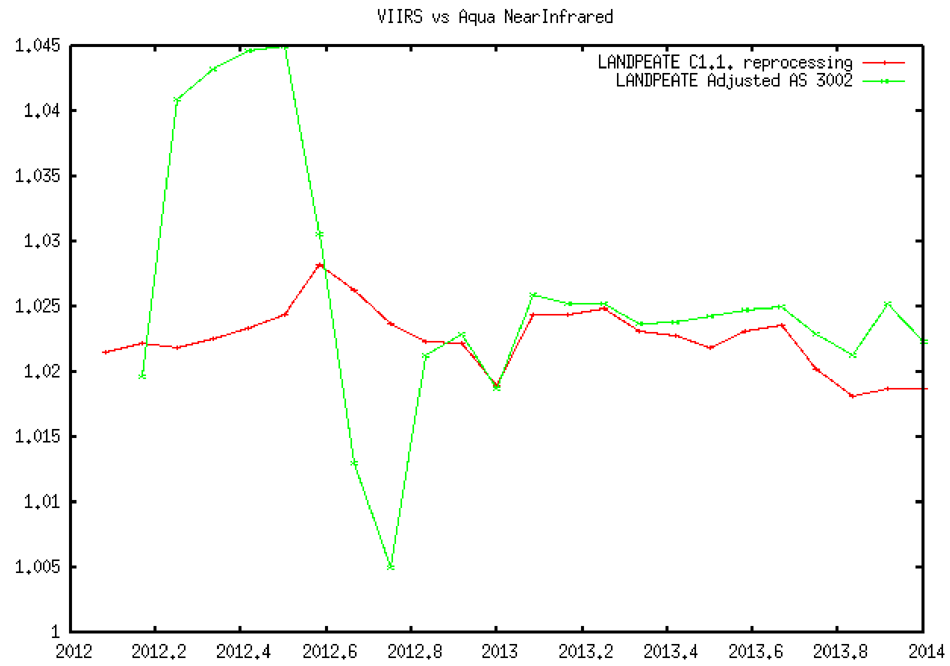
The VIIRS SR is now monitored at more than 400 sites (red losanges) through cross-comparison with MODIS.

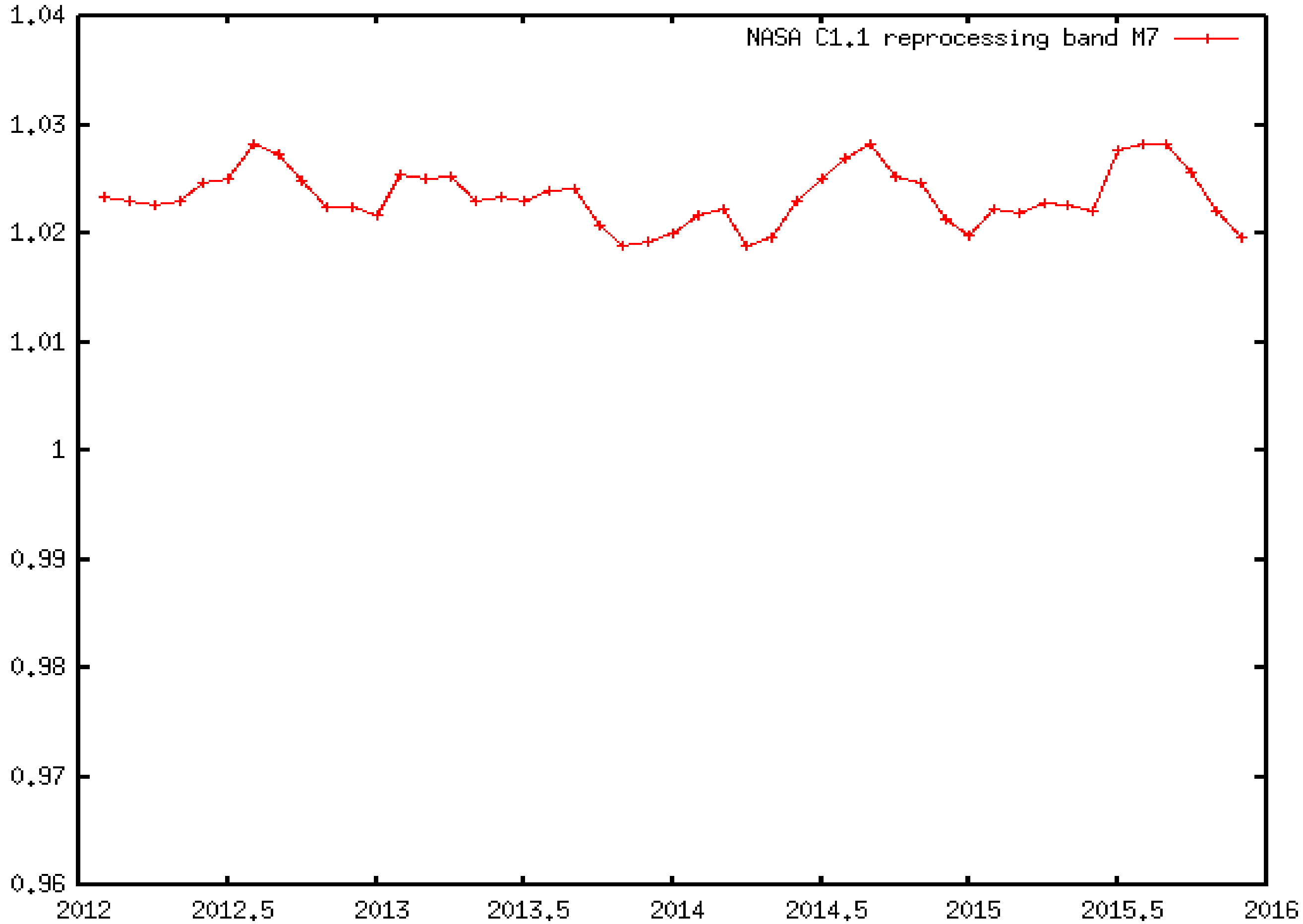



Aqua versus Terra
1.025
1.02
1.015
1.01
1.005
1
0.995
0.99
0.985
2002
2004
2006
2008
2010
2012
2014
band 1
band 2

Results over BELMANIP2

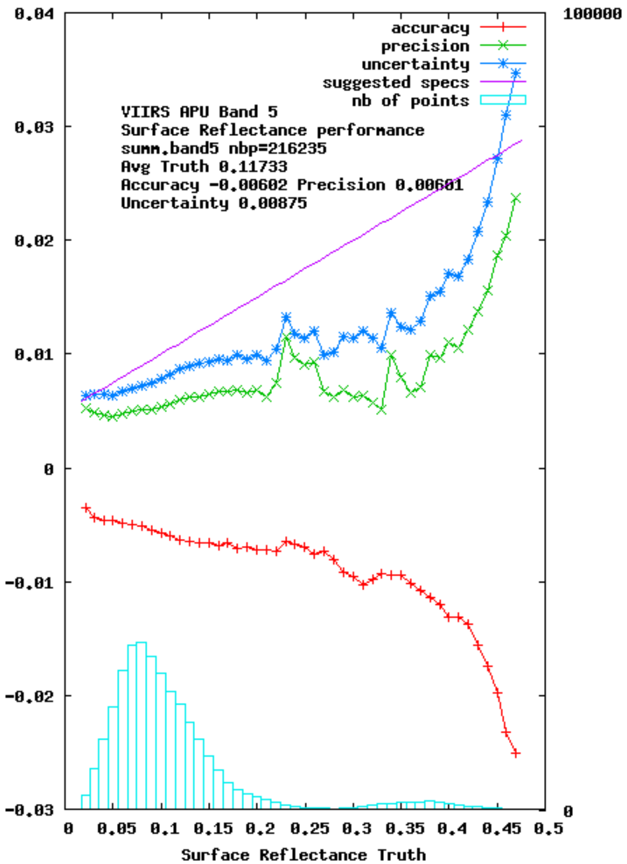


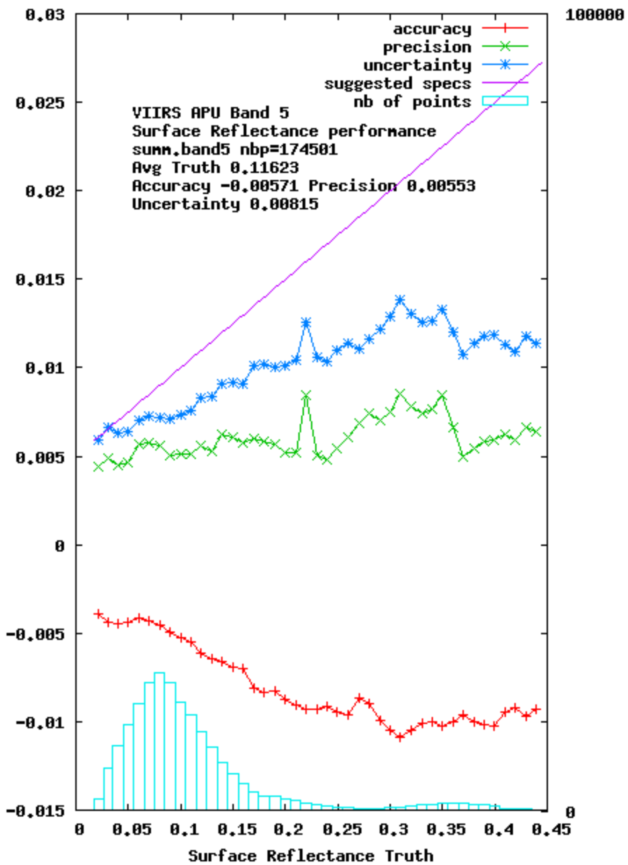




Cross comparison results of the VIIRS and MODIS-Aqua SR product on a monthly basis for the BELMANIP sites reprocessed version (C1.1) for the near infrared band (M7).

Testing of MODIS Collection 6 implementation for VIIRS





Performances of the VIIRS surface reflectance in the red band derived over AERONET sites for 2012 (Left side)and 2013 (right side).

The need for a protocol to use of AERONET data

To correctly take into account the aerosols, we need the **aerosol microphysical properties** provided by the AERONET network including size-distribution (%C_f, %C_c, C_f, C_c, r_f, r_c, σ_r, σ_c), complex refractive indices and sphericity.

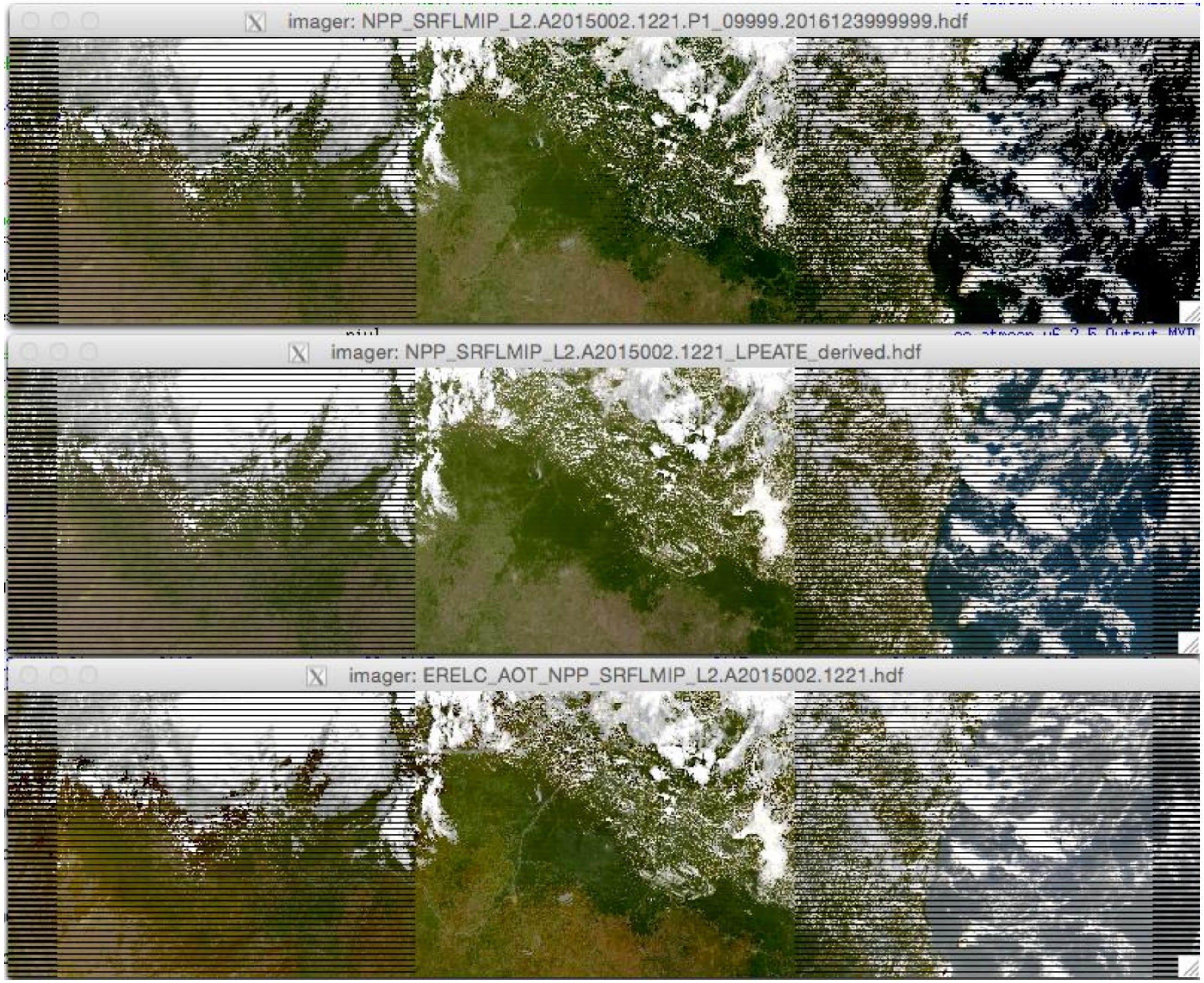
Over the 670 available AERONET sites, we selected **230 sites** with sufficient data.

To be useful for validation, the aerosol model should be readily available anytime, which is not usually the case.

Following *Dubovik et al.*, 2002, JAS,*[2] one can used regressions for each microphysical parameters using as parameter either τ_{550} (aot) or τ_{440} and α (*Angström* coeff.).

The protocol needs to be further agreed on and its uncertainties assessed (work in progress)

Preliminary version of Enterprise VIIRS SR has been tested



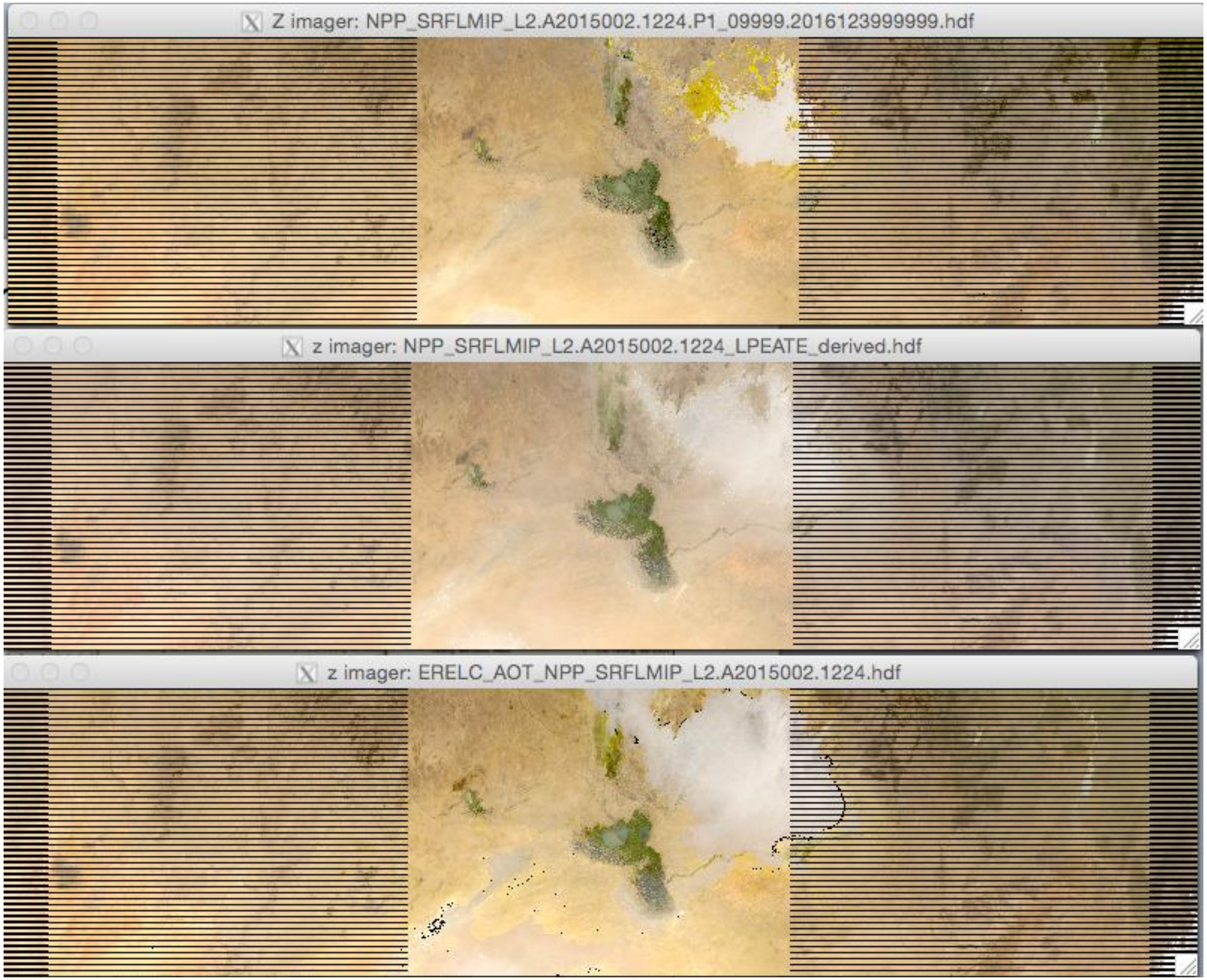
Preliminary version of Enterprise VIIRS SR has been tested

```
imager pixel values
Row 460, column 1492, current resolution 1 -->           [page
m1                                          69  (0.006900)
m2                                         115  (0.011500)
m3                                         174  (0.017400)
m4                                         356  (0.035600)
m5  *                                      270  (0.027000)
m7                                        2601  (0.260100)
m8                                        2633  (0.263300)
m10                                       1273  (0.127300)
m11                                        514  (0.051400)
QF1_VIIRSSRIPSDR                   2  (00000010)
 ----- SUN GLINT                          0  (none)
 ----- low sun mask                       0  (high)
 ----- day/night                          0  (day)
 ----- cloud detection & confidence       0  (confident clear)
 ----- cloud mask quality                 2  (medium)
QF2_VIIRSSRIPSDR                   1  (00000001)
 ----- thin cirrus emissive               0  (no cloud)
 ----- thin cirrus reflective             0  (no cloud)
 ----- snow/ice                           0  (no snow/ice)
 ----- heavy aerosol mask                 0  (no heavy aerosol)
 ----- shadow mask                        0  (no cloud shadow)
 ----- land/water background              1  (land no desert)
QF3_VIIRSSRIPSDR                   0  (00000000)
 ----- bad M10 SDR data                   0  (no)
 ----- bad M8 SDR data                    0  (no)
 ----- bad M7 SDR data                    0  (no)
 ----- bad M5 SDR data                    0  (no)
 ----- bad M4 SDR data                    0  (no)
 ----- bad M3 SDR data                    0  (no)
 ----- bad M2 SDR data                    0  (no)
 ----- bad M1 SDR data                    0  (no)
QF4_VIIRSSRIPSDR                   0  (00000000)
 ----- missing PW input data              0  (no)
 ----- invalid land AM input data         0  (valid)
 ----- missing AOT input data             0  (no)
 ----- overall quality of AOT             0  (good)
 ----- bad I3 SDR data                    0  (no)
 ----- bad I2 SDR data                    0  (no)
 ----- bad I1 SDR data                    0  (no)
 ----- bad M11 SDR data                   0  (no)
QF5_VIIRSSRIPSDR                 252  (11111100)
 ----- overall quality M7 SR data         1  (bad)
 ----- overall quality M5 SR data         1  (bad)
 ----- overall quality M4 SR data         1  (bad)
 ----- overall quality M3 SR data         1  (bad)
 ----- overall quality M2 SR data         1  (bad)
 ----- overall quality M1 SR data         1  (bad)
 ----- missing SP input data              0  (no)
 ----- missing OZ input data              0  (no)
QF6_VIIRSSRIPSDR                  63  (00111111)
```

```
imager pixel values
Row 460, column 1492, current resolution 1 -->           [page
m1                                          73  (0.007300)
m2                                         106  (0.010600)
m3                                         179  (0.017900)
m4                                         356  (0.035600)
m5  *                                      270  (0.027000)
m7                                        2590  (0.259000)
m8                                        2633  (0.263300)
m10                                       1258  (0.125800)
m11                                        499  (0.049900)
QF1_VIIRSSRIPSDR                   2  (00000010)
 ----- SUN GLINT                          0  (none)
 ----- low sun mask                       0  (high)
 ----- day/night                          0  (day)
 ----- cloud detection & confidence       0  (confident clear)
 ----- cloud mask quality                 2  (medium)
QF2_VIIRSSRIPSDR                   1  (00000001)
 ----- thin cirrus emissive               0  (no cloud)
 ----- thin cirrus reflective             0  (no cloud)
 ----- snow/ice                           0  (no snow/ice)
 ----- heavy aerosol mask                 0  (no heavy aerosol)
 ----- shadow mask                        0  (no cloud shadow)
 ----- land/water background              1  (land no desert)
QF3_VIIRSSRIPSDR                   0  (00000000)
 ----- bad M10 SDR data                   0  (no)
 ----- bad M8 SDR data                    0  (no)
 ----- bad M7 SDR data                    0  (no)
 ----- bad M5 SDR data                    0  (no)
 ----- bad M4 SDR data                    0  (no)
 ----- bad M3 SDR data                    0  (no)
 ----- bad M2 SDR data                    0  (no)
 ----- bad M1 SDR data                    0  (no)
QF4_VIIRSSRIPSDR                   0  (00000000)
 ----- missing PW input data              0  (no)
 ----- invalid land AM input data         0  (valid)
 ----- missing AOT input data             0  (no)
 ----- overall quality of AOT             0  (good)
 ----- bad I3 SDR data                    0  (no)
 ----- bad I2 SDR data                    0  (no)
 ----- bad I1 SDR data                    0  (no)
 ----- bad M11 SDR data                   0  (no)
QF5_VIIRSSRIPSDR                 252  (11111100)
 ----- overall quality M7 SR data         1  (bad)
 ----- overall quality M5 SR data         1  (bad)
 ----- overall quality M4 SR data         1  (bad)
 ----- overall quality M3 SR data         1  (bad)
 ----- overall quality M2 SR data         1  (bad)
 ----- overall quality M1 SR data         1  (bad)
 ----- missing SP input data              0  (no)
 ----- missing OZ input data              0  (no)
QF6_VIIRSSRIPSDR                  63  (00111111)
```

```
imager pixel values
Row 460, column 1492, current resolution 1 -->           [page
m1                                         152  (0.015200)
m2                                         192  (0.019200)
m3                                         239  (0.023900)
m4                                         401  (0.040100)
m5  *                                      307  (0.030700)
m7                                        2559  (0.255900)
m8                                        2603  (0.260300)
m10                                       1262  (0.126200)
m11                                        508  (0.050800)
QF1_VIIRSSRIPSDR                   2  (00000010)
 ----- SUN GLINT                          0  (none)
 ----- low sun mask                       0  (high)
 ----- day/night                          0  (day)
 ----- cloud detection & confidence       0  (confident clear)
 ----- cloud mask quality                 2  (medium)
QF2_VIIRSSRIPSDR                   1  (00000001)
 ----- thin cirrus emissive               0  (no cloud)
 ----- thin cirrus reflective             0  (no cloud)
 ----- snow/ice                           0  (no snow/ice)
 ----- heavy aerosol mask                 0  (no heavy aerosol)
 ----- shadow mask                        0  (no cloud shadow)
 ----- land/water background              1  (land no desert)
QF3_VIIRSSRIPSDR                   0  (00000000)
 ----- bad M10 SDR data                   0  (no)
 ----- bad M8 SDR data                    0  (no)
 ----- bad M7 SDR data                    0  (no)
 ----- bad M5 SDR data                    0  (no)
 ----- bad M4 SDR data                    0  (no)
 ----- bad M3 SDR data                    0  (no)
 ----- bad M2 SDR data                    0  (no)
 ----- bad M1 SDR data                    0  (no)
QF4_VIIRSSRIPSDR                   0  (00000000)
 ----- missing PW input data              0  (no)
 ----- invalid land AM input data         0  (valid)
 ----- missing AOT input data             0  (no)
 ----- overall quality of AOT             0  (good)
 ----- bad I3 SDR data                    0  (no)
 ----- bad I2 SDR data                    0  (no)
 ----- bad I1 SDR data                    0  (no)
 ----- bad M11 SDR data                   0  (no)
QF5_VIIRSSRIPSDR                 252  (11111100)
 ----- overall quality M7 SR data         1  (bad)
 ----- overall quality M5 SR data         1  (bad)
 ----- overall quality M4 SR data         1  (bad)
 ----- overall quality M3 SR data         1  (bad)
 ----- overall quality M2 SR data         1  (bad)
 ----- overall quality M1 SR data         1  (bad)
 ----- missing SP input data              0  (no)
 ----- missing OZ input data              0  (no)
QF6_VIIRSSRIPSDR                  63  (00111111)
```

Preliminary version of Enterprise VIIRS SR has been tested



Preliminary version of Enterprise VIIRS SR has been tested

	imager pixel values	imager pixel values	imager pixel values
Row 536, column 1556, current resolution 1 --> [page			
m1	855 (0.085500)	1111 (0.111100)	698 (0.069800)
m2	1142 (0.114200)	1346 (0.134600)	1138 (0.113800)
m3	1520 (0.152000)	1629 (0.162900)	1628 (0.162800)
m4	2217 (0.221700)	2241 (0.224100)	2528 (0.252800)
m5 *	3409 (0.340900)	3323 (0.332300)	3864 (0.386400)
m7	4505 (0.450500)	4344 (0.434400)	4902 (0.490200)
m8	5698 (0.569800)	5523 (0.552300)	5983 (0.598300)
m10	6033 (0.603300)	5898 (0.589800)	6264 (0.626400)
m11	5033 (0.503300)	4940 (0.494000)	5156 (0.515600)
QF1_VIIRSSRIPSDR	2 (00000010)	2 (00000010)	2 (00000010)
----- SUN GLINT	0 (none)	0 (none)	0 (none)
----- low sun mask	0 (high)	0 (high)	0 (high)
----- day/night	0 (day)	0 (day)	0 (day)
----- cloud detection & confidence	0 (confident clear)	0 (confident clear)	0 (confident clear)
----- cloud mask quality	2 (medium)	2 (medium)	2 (medium)
QF2_VIIRSSRIPSDR	1 (00000001)	1 (00000001)	1 (00000001)
----- thin cirrus emissive	0 (no cloud)	0 (no cloud)	0 (no cloud)
----- thin cirrus reflective	0 (no cloud)	0 (no cloud)	0 (no cloud)
----- snow/ice	0 (no snow/ice)	0 (no snow/ice)	0 (no snow/ice)
----- heavy aerosol mask	0 (no heavy aerosol	0 (no heavy aerosol)	0 (no heavy aerosol)
----- shadow mask	0 (no cloud shadow)	0 (no cloud shadow)	0 (no cloud shadow)
----- land/water background	1 (land no desert)	1 (land no desert)	1 (land no desert)
QF3_VIIRSSRIPSDR	0 (00000000)	0 (00000000)	0 (00000000)
----- bad M10 SDR data	0 (no)	0 (no)	0 (no)
----- bad M8 SDR data	0 (no)	0 (no)	0 (no)
----- bad M7 SDR data	0 (no)	0 (no)	0 (no)
----- bad M5 SDR data	0 (no)	0 (no)	0 (no)
----- bad M4 SDR data	0 (no)	0 (no)	0 (no)
----- bad M3 SDR data	0 (no)	0 (no)	0 (no)
----- bad M2 SDR data	0 (no)	0 (no)	0 (no)
----- bad M1 SDR data	0 (no)	0 (no)	0 (no)
QF4_VIIRSSRIPSDR	0 (00000000)	16 (00010000)	16 (00010000)
----- missing PW input data	0 (no)	0 (no)	0 (no)
----- invalid land AM input data	0 (valid)	0 (valid)	0 (valid)
----- missing AOT input data	0 (no)	0 (no)	0 (no)
----- overall quality of AOT	0 (good)	1 (bad)	1 (bad)
----- bad I3 SDR data	0 (no)	0 (no)	0 (no)
----- bad I2 SDR data	0 (no)	0 (no)	0 (no)
----- bad I1 SDR data	0 (no)	0 (no)	0 (no)
----- bad M11 SDR data	0 (no)	0 (no)	0 (no)
QF5_VIIRSSRIPSDR	252 (11111100)	252 (11111100)	252 (11111100)
----- overall quality M7 SR data	1 (bad)	1 (bad)	1 (bad)
----- overall quality M5 SR data	1 (bad)	1 (bad)	1 (bad)
----- overall quality M4 SR data	1 (bad)	1 (bad)	1 (bad)
----- overall quality M3 SR data	1 (bad)	1 (bad)	1 (bad)
----- overall quality M2 SR data	1 (bad)	1 (bad)	1 (bad)
----- overall quality M1 SR data	1 (bad)	1 (bad)	1 (bad)
----- missing SP input data	0 (no)	0 (no)	0 (no)
----- missing OZ input data	0 (no)	0 (no)	0 (no)
QF6_VIIRSSRIPSDR	63 (00111111)	63 (00111111)	63 (00111111)

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, LDCM, Landsat, Sentinel 2 ,Sentinel 3…)
- AERONET is central to SR validation and a “standard” protocol for its use to be defined (CEOS CVWG initiative)