Surface Reflectance

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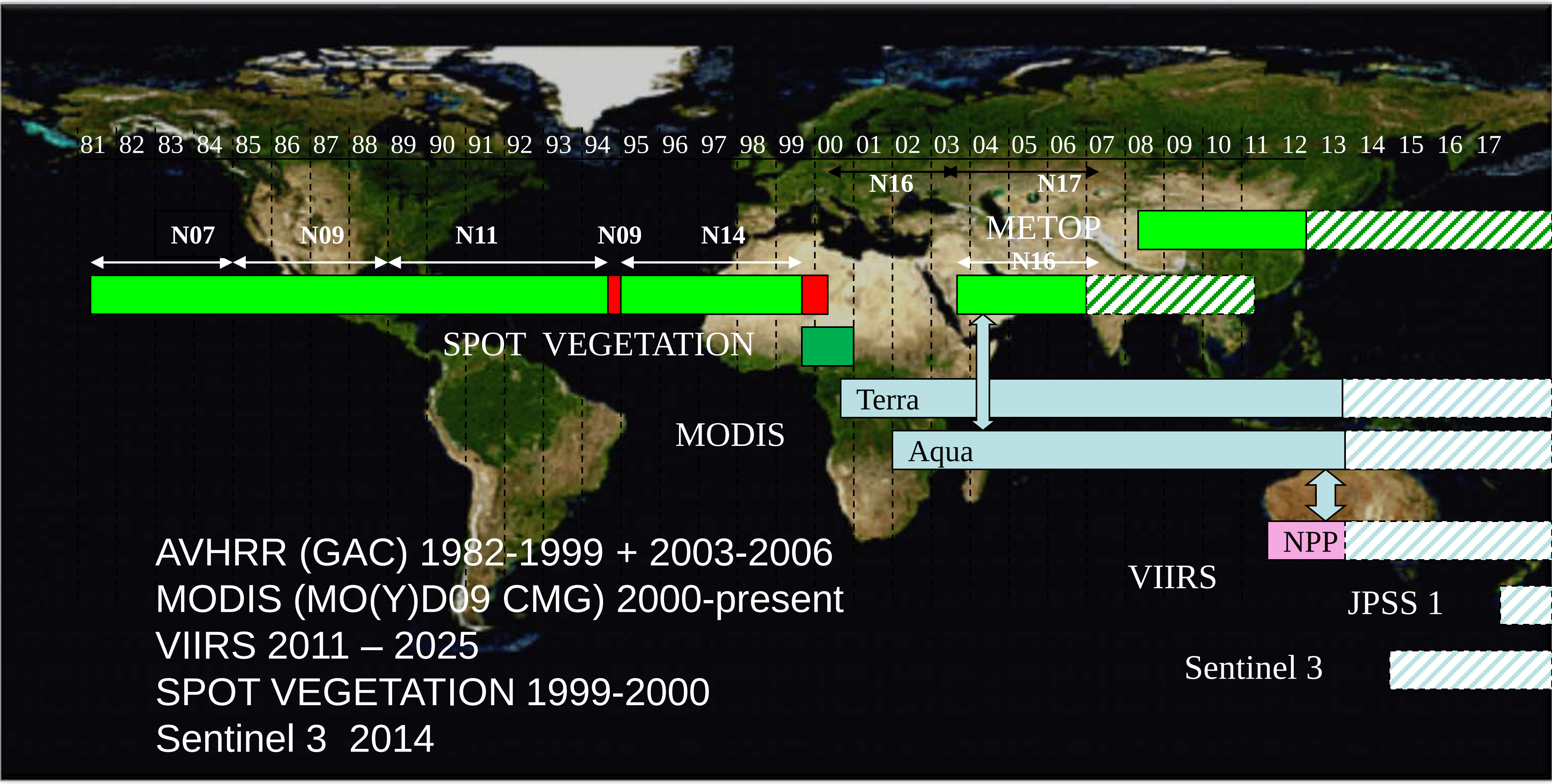
A Land Climate Data Record

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



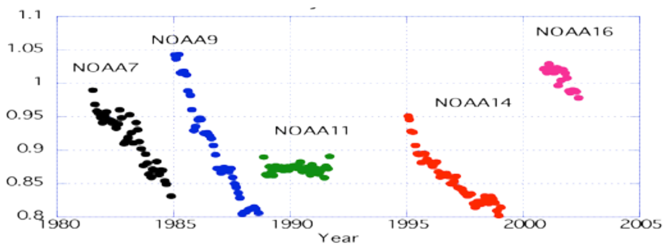
Emphasis on data consistency – characterization rather than degrading/smoothing the data

Land Climate Data Record (Approach)

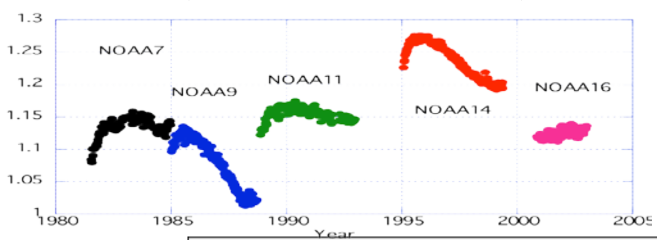
Needs to address geolocation,calibration, atmospheric/BRDF correction issues

CALIBRATION

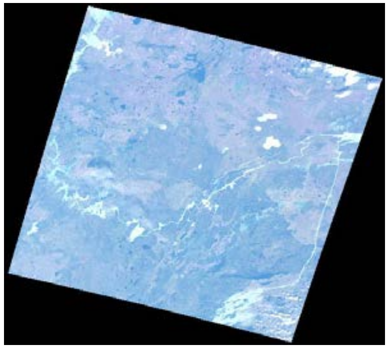
Degradation in channel 1
(from Ocean observations)

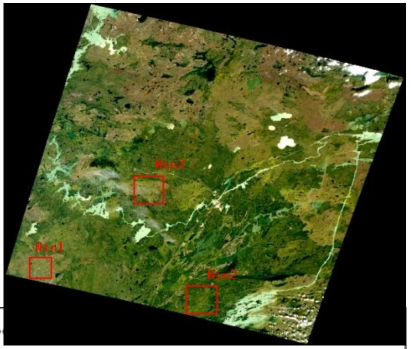


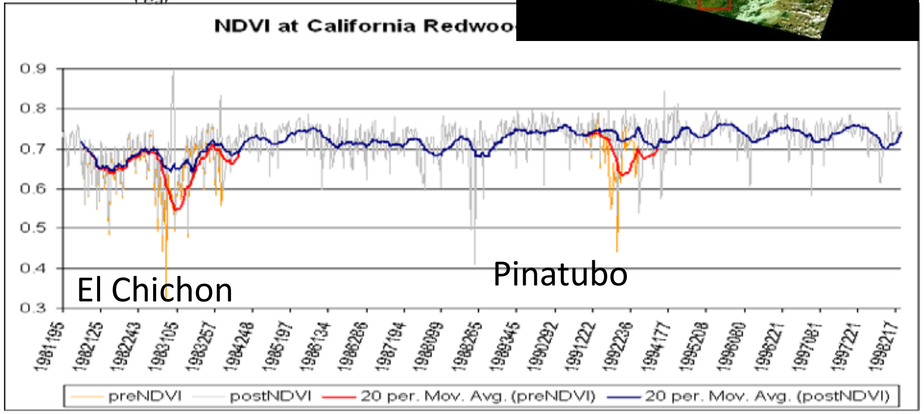
Channel1/Channel2 ratio
(from Clouds observations)



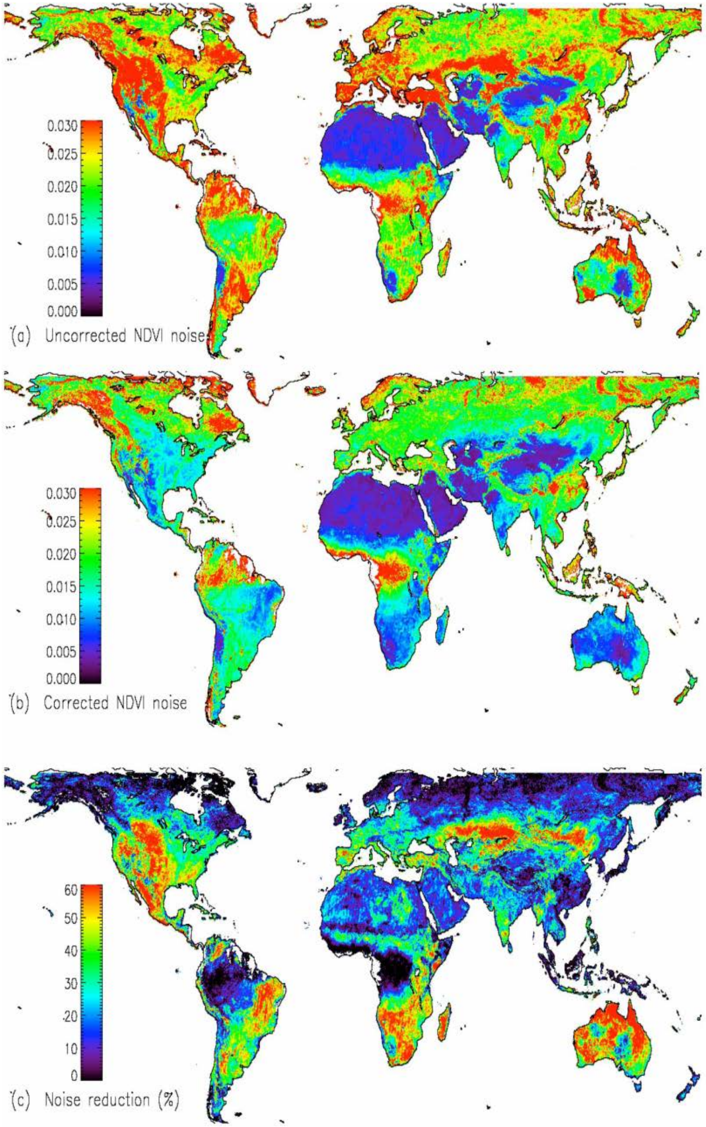
ATMOSPHERIC CORRECTION







BRDF CORRECTION



Generic Surface Reflectance Algorithm for VIIRS, MODIS Landsat 8…

The surface reflectance algorithm relies on:

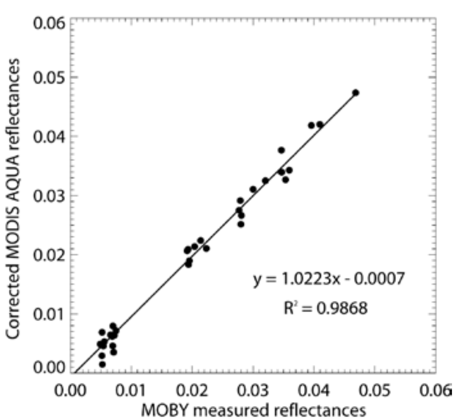
- the use of very accurate (better than 1%) vector radiative transfer modeling of the coupled atmosphere-surface system
- the inversion of key atmospheric parameters (aerosol, water vapor)

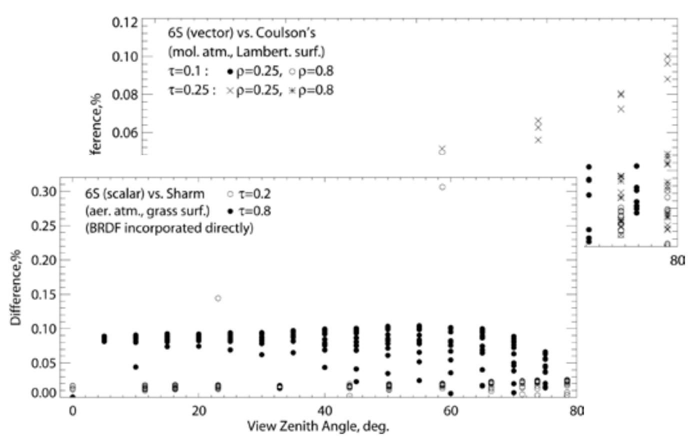
Home page: http://modis-sr.ltdri.org

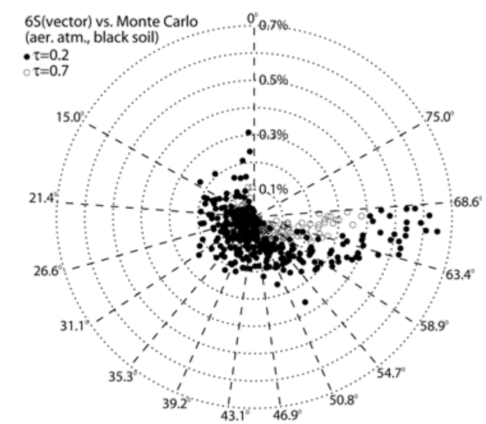
6SV Validation Effort

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

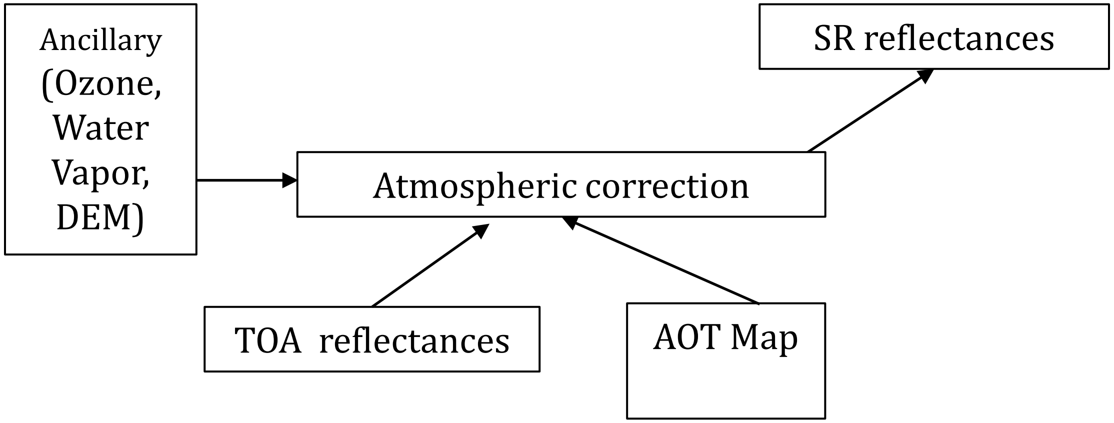
- Kotchenova, S. Y., Vermote, E. F., Matarrese, R., & Klemm Jr, F. J. (2006). Validation of a vector version of the 6S radiative transfer code for atmospheric correction of satellite data. Part I: Path radiance. *Applied Optics*, *45*(26), 6762-6774.
- Kotchenova, S. Y., & Vermote, E. F. (2007). Validation 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.







Generic flowchart for atmospheric correction



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…

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.

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

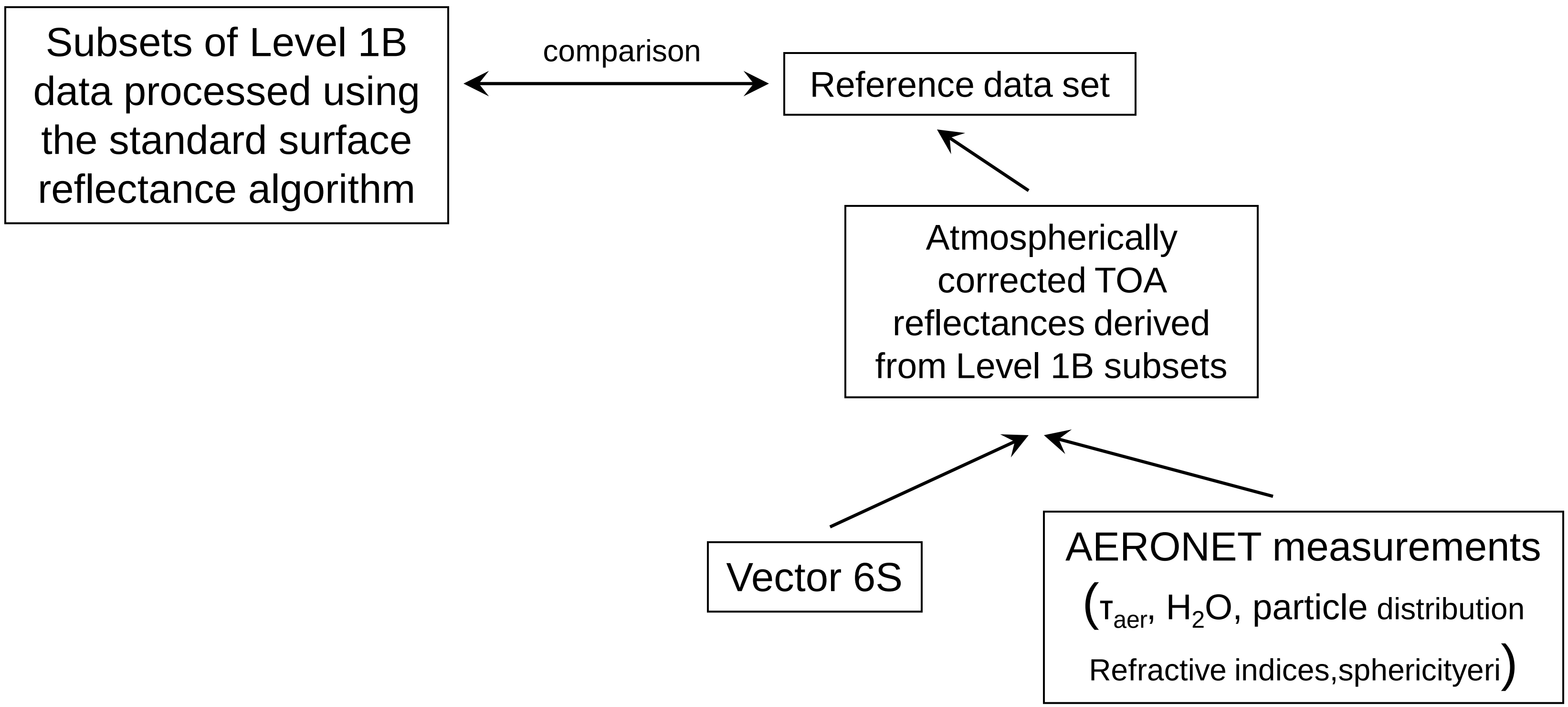
Surface reflectance for each pixel and each band

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…

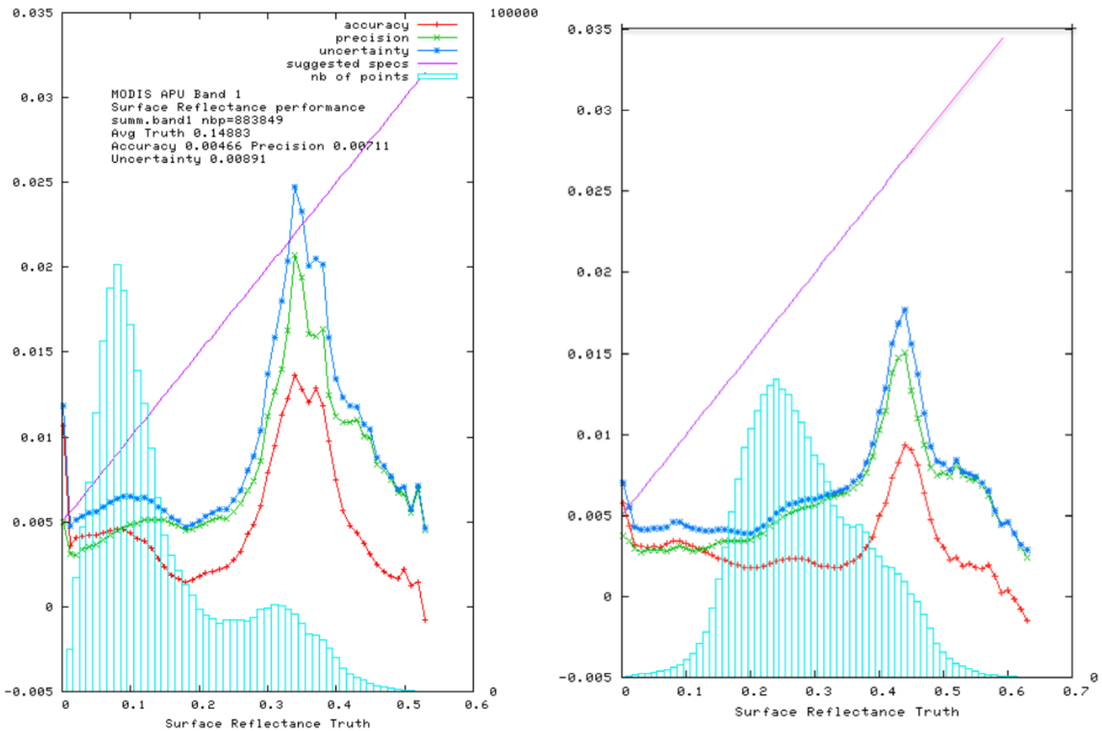
$$(*) \quad \rho_{surf} = \frac{Y}{1+S_{atm}.Y} \quad \text{with} \quad Y = \frac{1}{T_{atm}.tg^{wv}}\left[\left(\frac{\rho_{TOA}}{tg^{O3}.tg^{others}} - \right) - \left(\rho_{atm} - \rho_{ray}\right).tg^{wv/2} - \rho_{ray}\right]$$

Methodology for evaluating the performance of surface reflectance



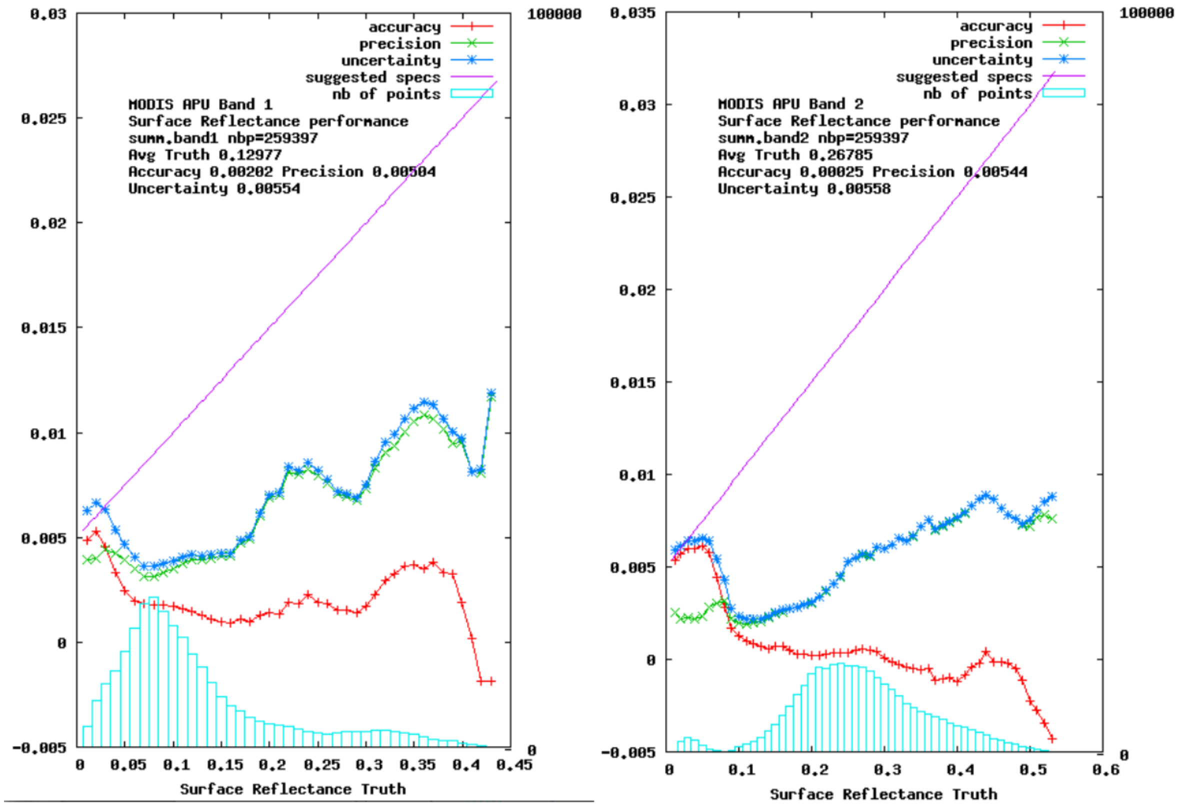
http://mod09val.ltdri.org/cgi-bin/mod09_c005_public_allsites_onecollection.cgi

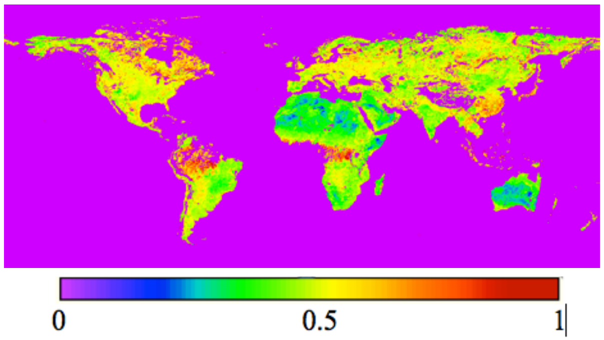
quantitative assessment of performances (APU)



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

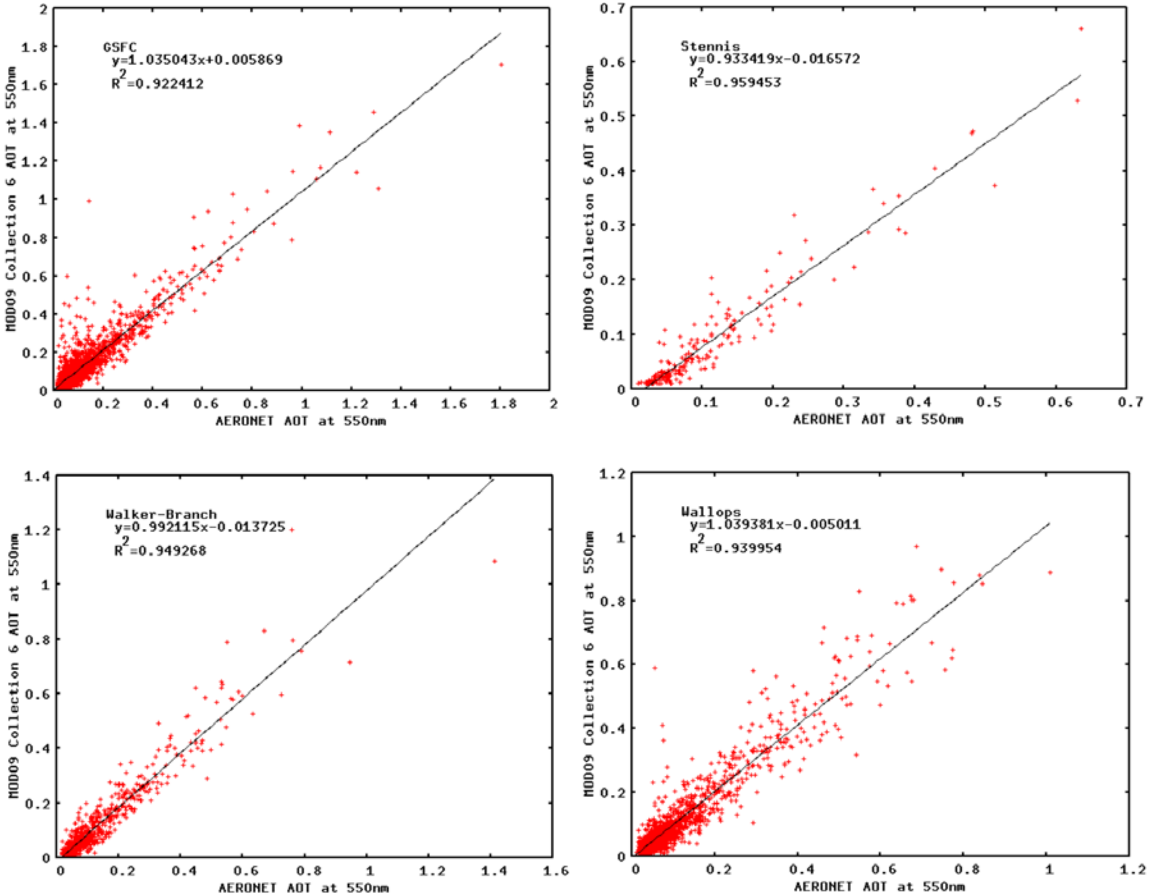




ratio band3/band1 derived using MODIS top of the atmosphere corrected with MISR aerosol optical depth

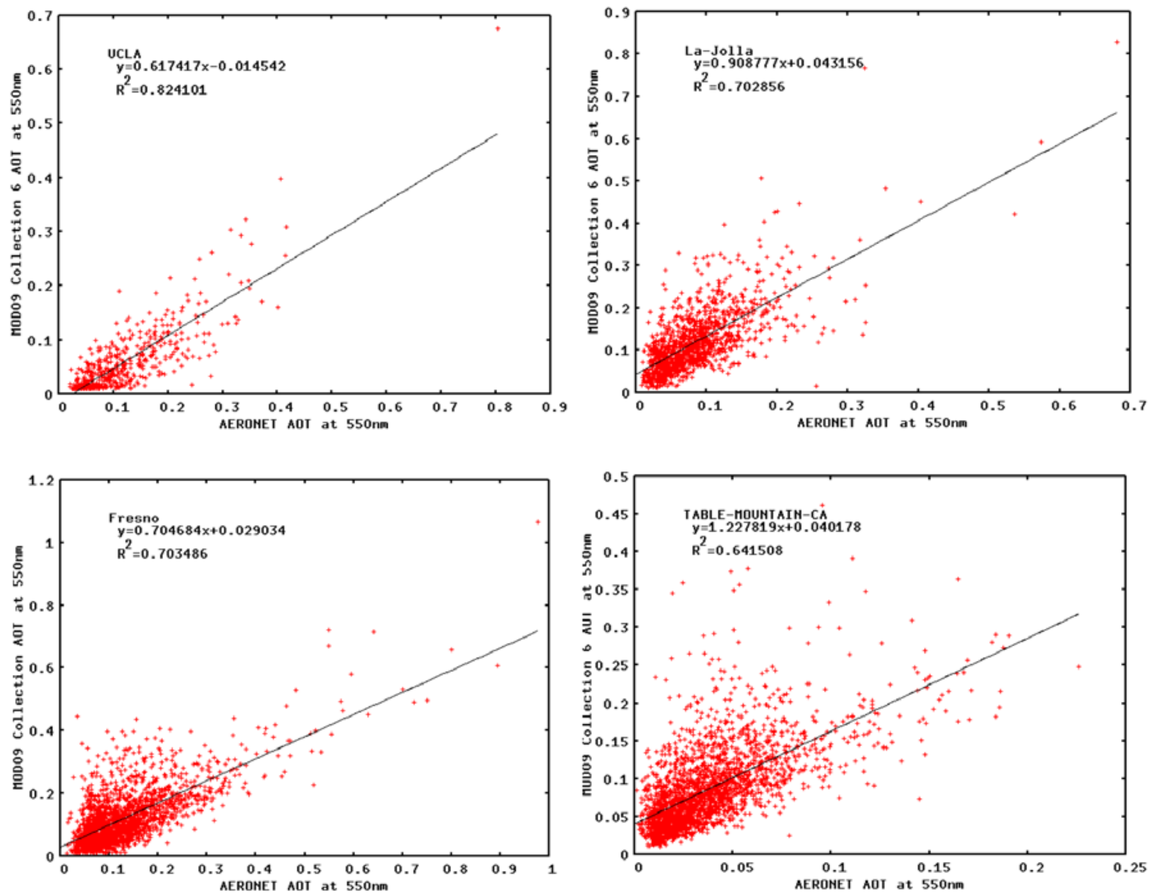
COLLECTION 6: accuracy or mean bias (red line), Precision or repeatability (green line) and Uncertainty or quadratic sum of Accuracy and Precision (blue line) of the surface reflectance in band 1 in the Red (top left), band 2 in the Near Infrared (top right also shown is the uncertainty specification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



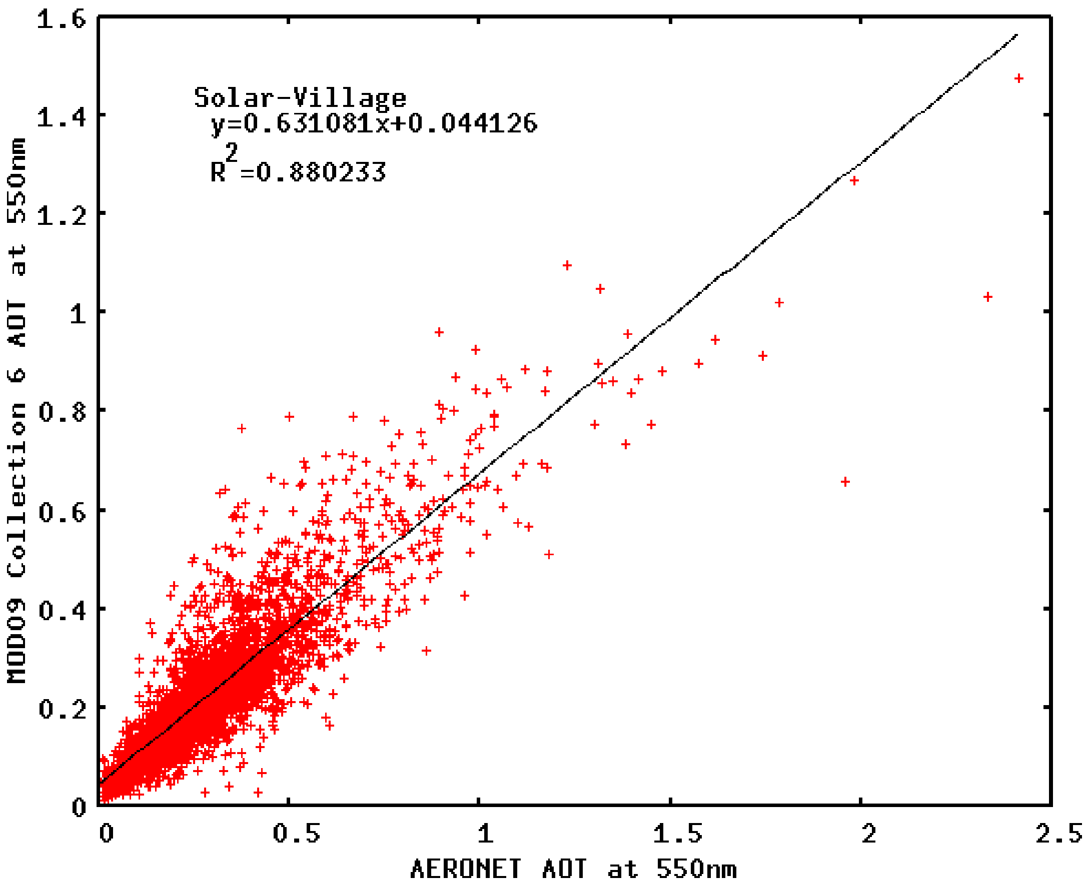
Scatterplot of the MOD09 AOT at 550nm versus the AERONET measured AOT at 550nm for East Coast sites selection: GSFC (top left), Stennis (top right), Walker Branch (bottom left) and Wallops (bottom right).

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



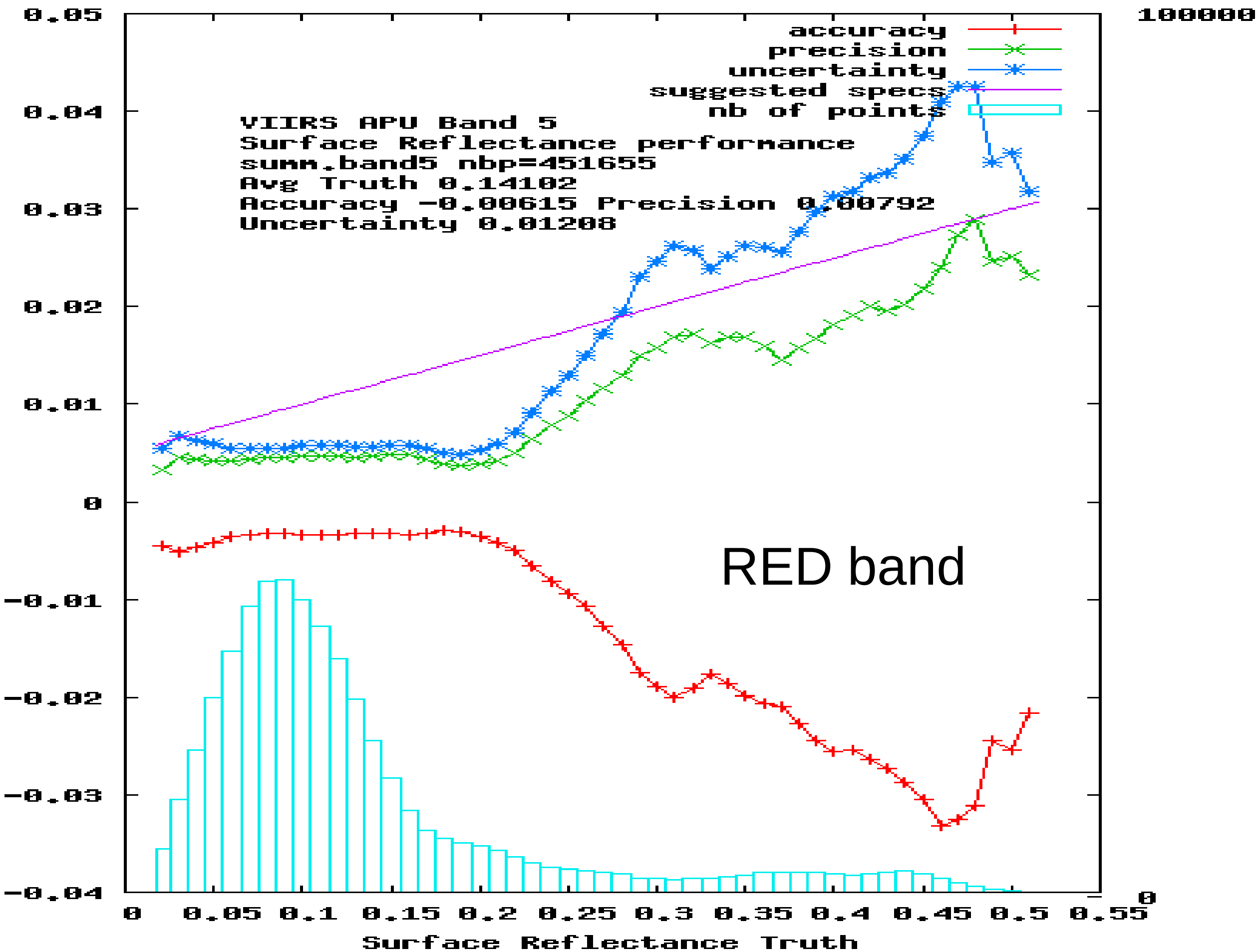
Scatterplot of the MOD09 AOT at 550nm versus the AERONET measured AOT at 550nm for for a very bright site in Saudi Arabia (Solar Village)

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 are being integrated into the VIIRS algorithm and shared with the NOAA JPSS project for possible inclusion in future versions of the operational product (NDE) .

Evaluation of Algorithm Performance

VIIRS C11 reprocessing (2013-2015)

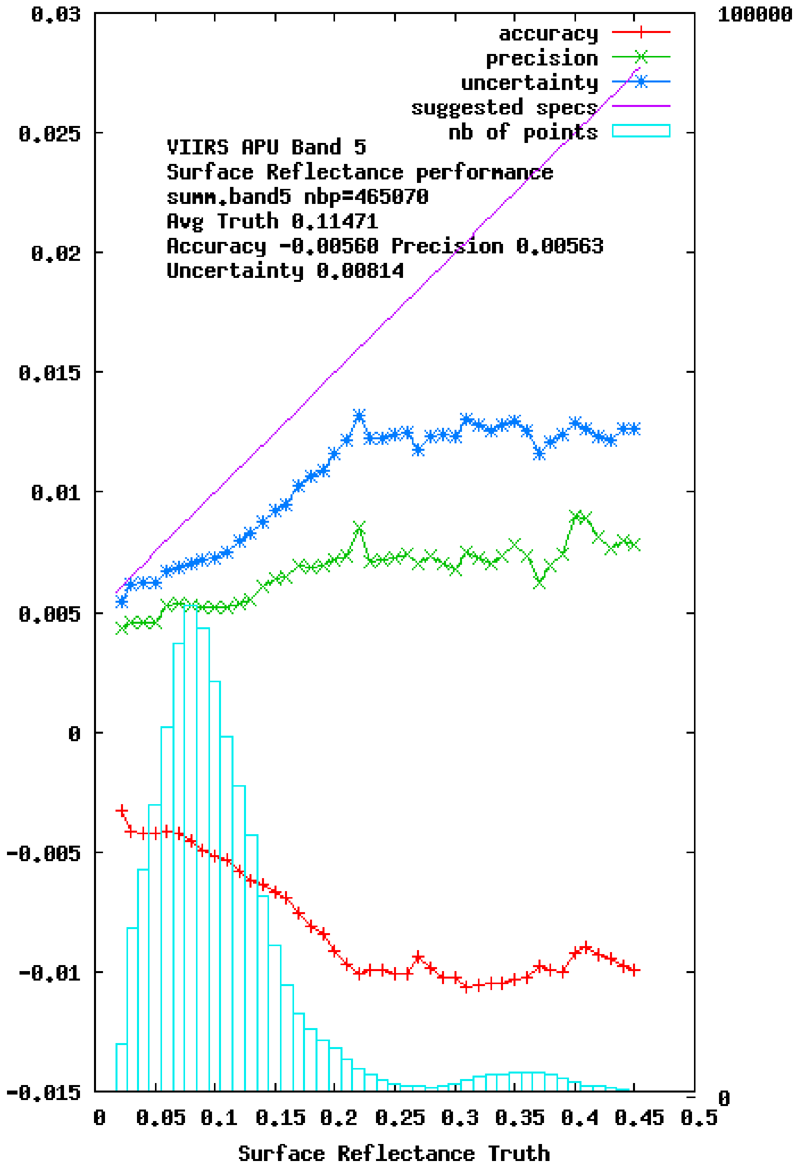


450000 pixels were analyzed for each band.

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

On average well below magenta theoretical error bar

VIIRS AS5000 reprocessing (NDE version)



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)

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

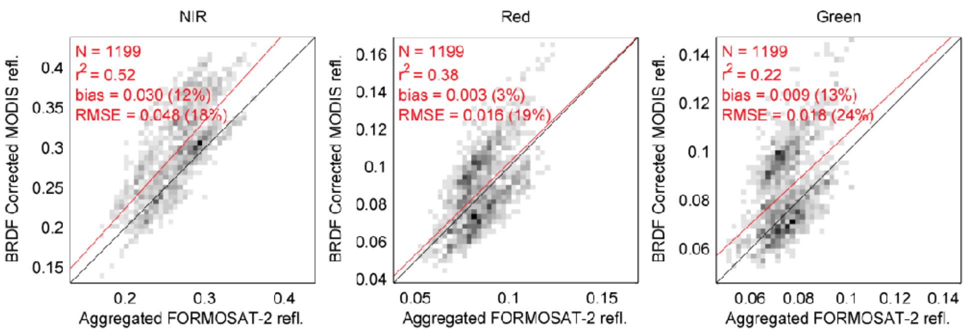
* 1st Workshop in June 21st-22nd @ University of Maryland (by invitation): to elaborate concepts, protocols and guidelines for the inter-comparison and validation of SR products

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

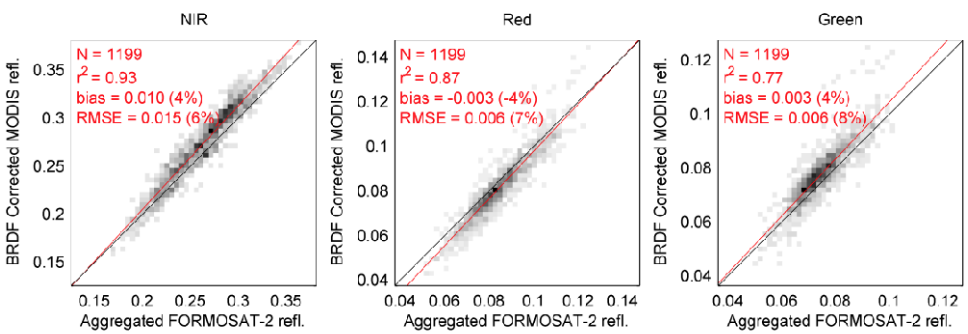
* 2nd workshop in January 2017 (open)

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

Use of BRDF correction for product cross-comparison



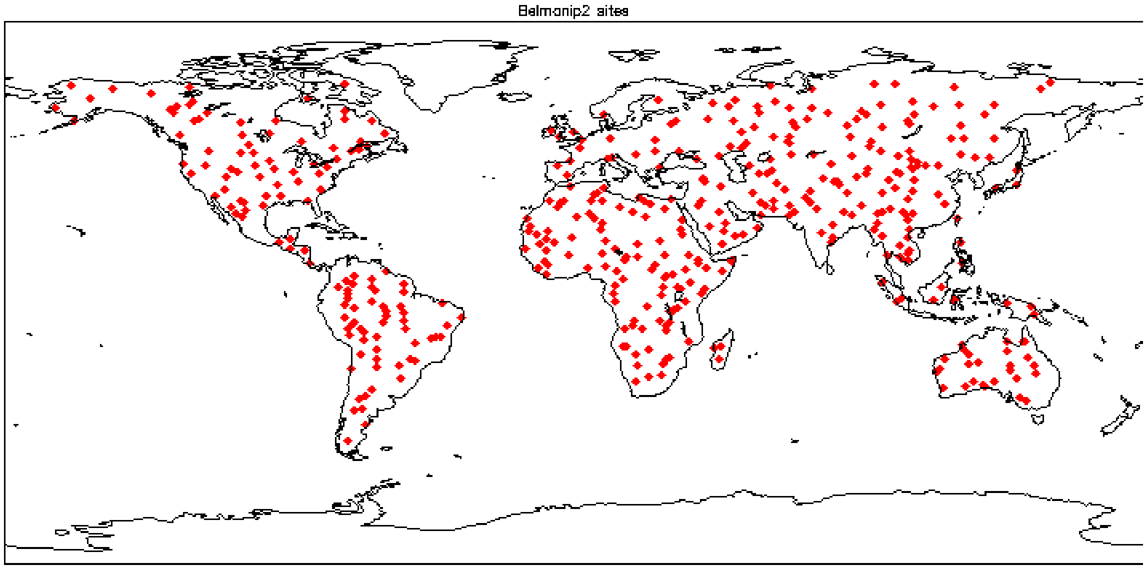
Comparison of aggregated FORMOSAT-2 reflectance and MODIS reflectance. No BRDF correction. Density function from light grey (minimum) to black (maximum); white = no data.

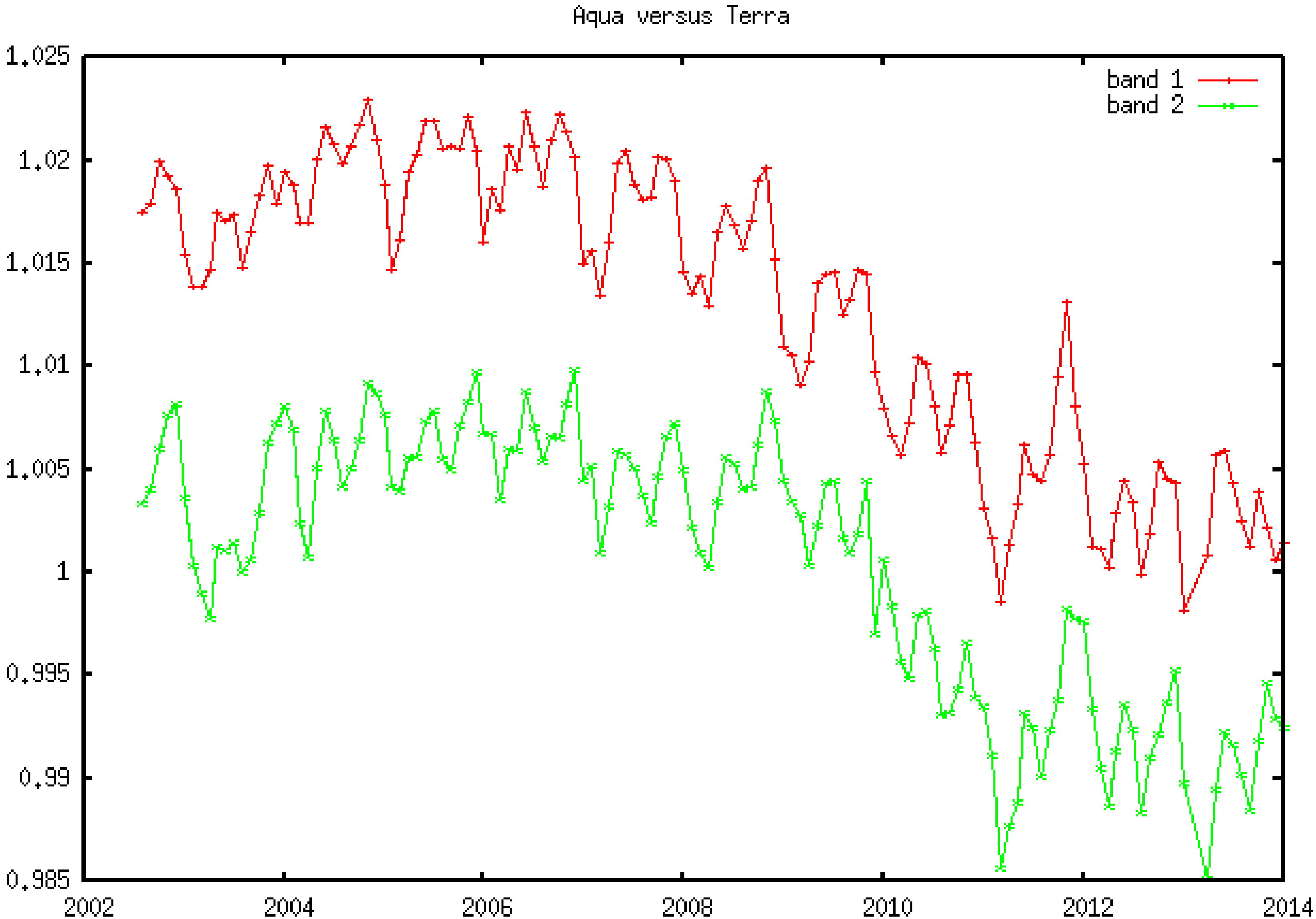


Comparison of aggregated FORMOSAT-2 reflectance and BRDF corrected MODIS reflectance. Corrections were performed with Vermote al. (2009) method using for each day of acquisition, the angular configuration of FORMOSAT-2 data.

Cross comparison with MODIS over BELMANIP2

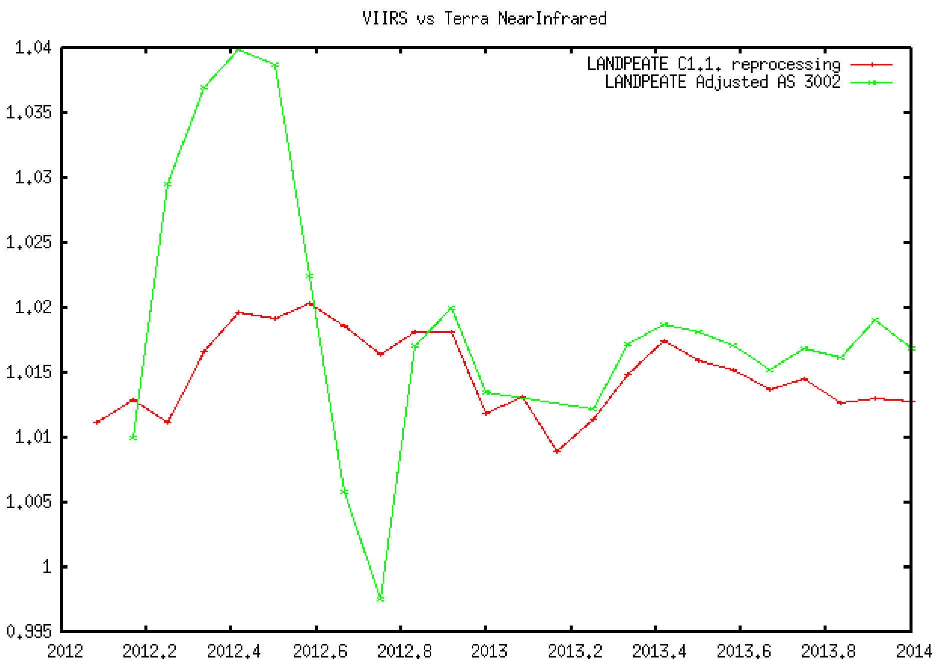
The VIIRS SR is now monitored at more than 400 sites (red losanges) through cross-comparison with MODIS.

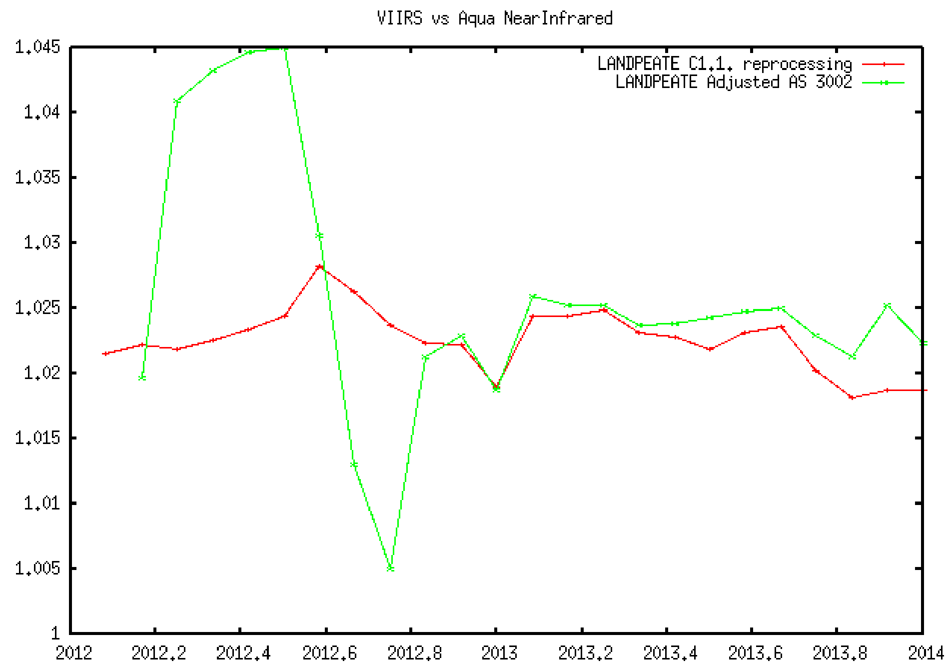


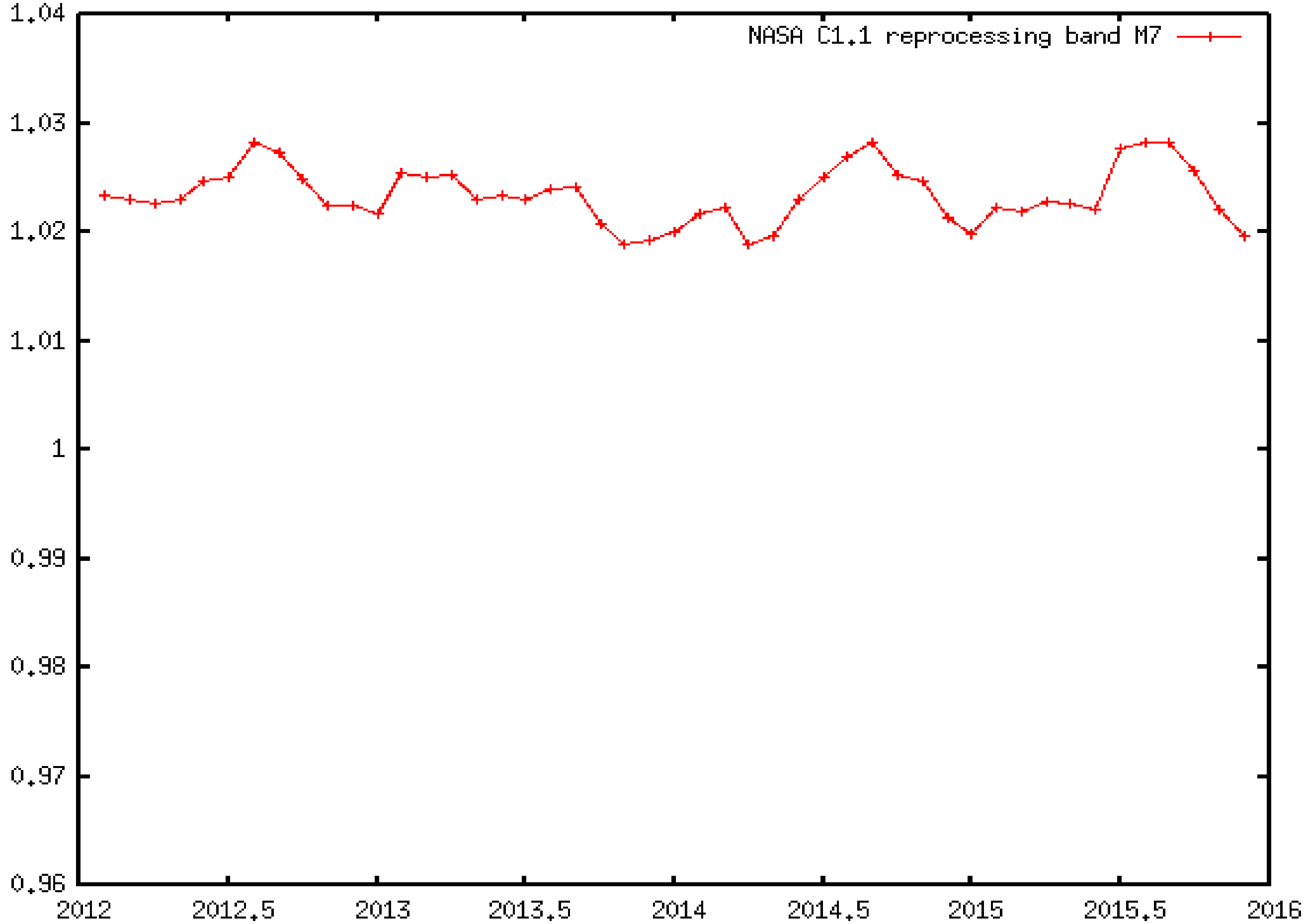


Aqua versus Terra
band 1
band 2
1.025
1.02
1.015
1.01
1.005
1
0.995
0.99
0.985
2002
2004
2006
2008
2010
2012
2014

Results over BELMANIP2

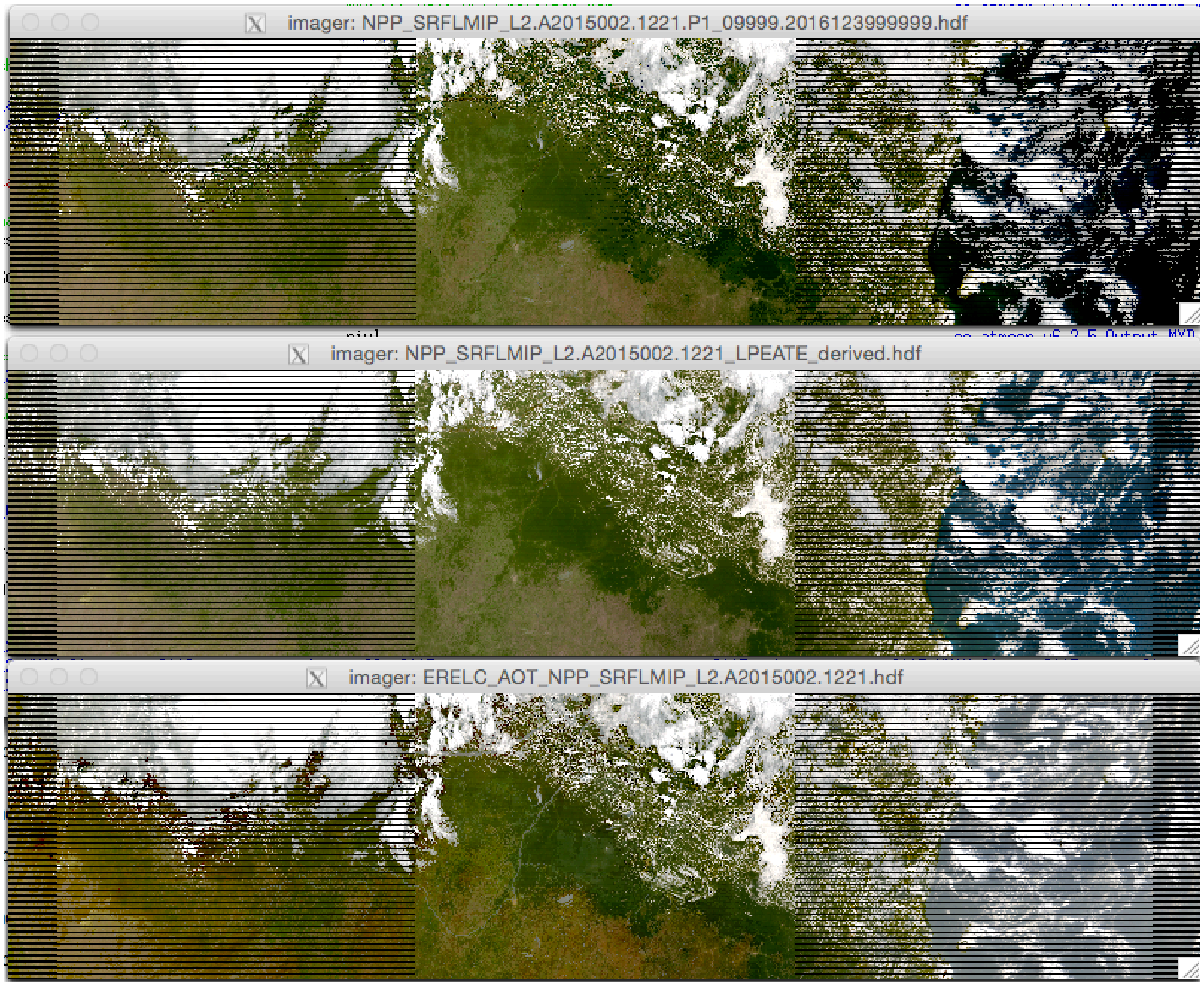






Cross comparison results of the VIIRS and MODIS-Aqua SR product on a monthly basis for the BELMANIP sites reprocessed version (C1.1) for the near infrared band (M7).

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)
```

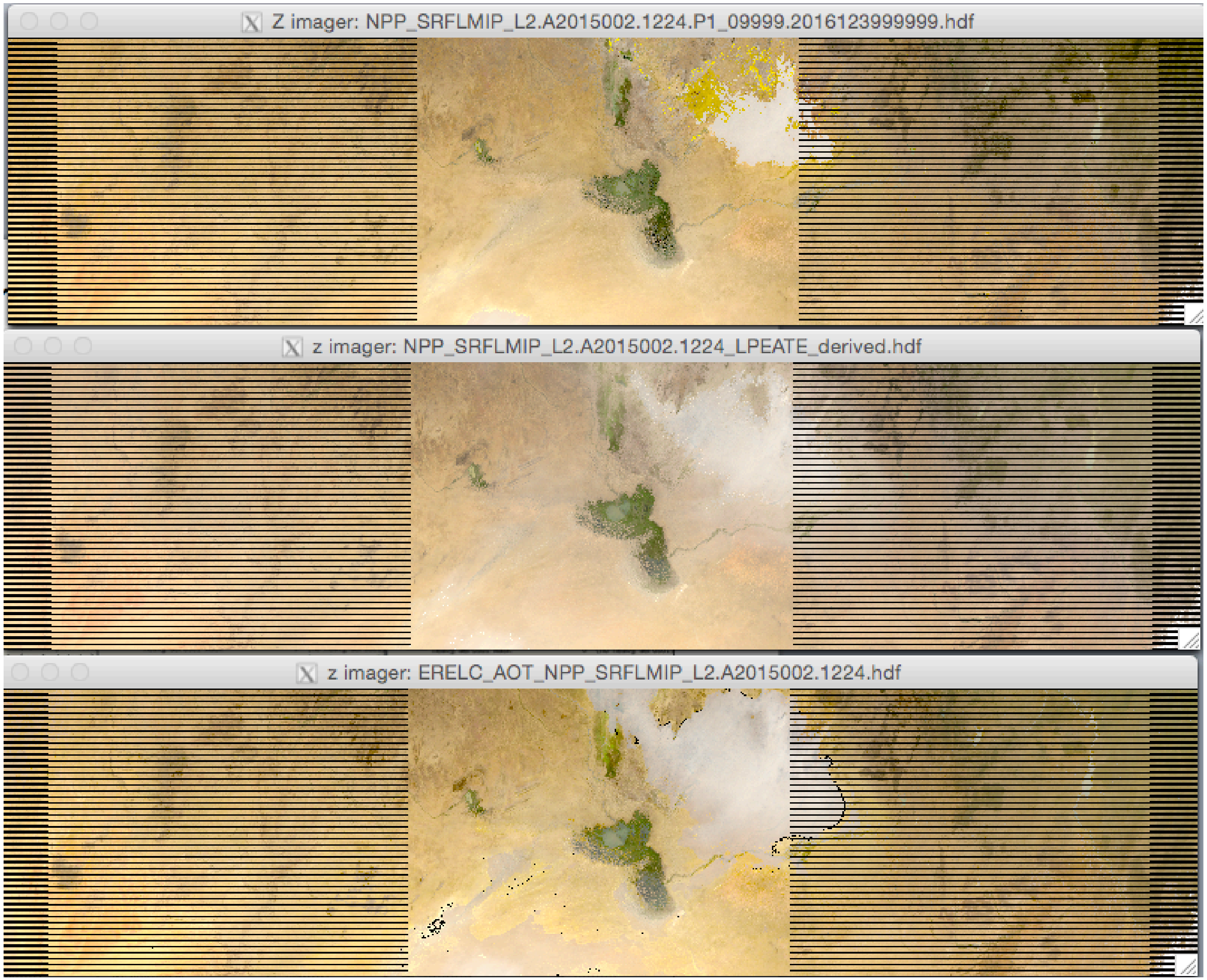
```
imager pixel values

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 (three windows)

Row 536, column 1556, current resolution 1 --> [page

Field	Window 1	Window 2	Window 3
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)