Surface reflectance over Land

Eric Vermote
NASA GSFC Code 619
Eric.f.vermote@nasa.gov

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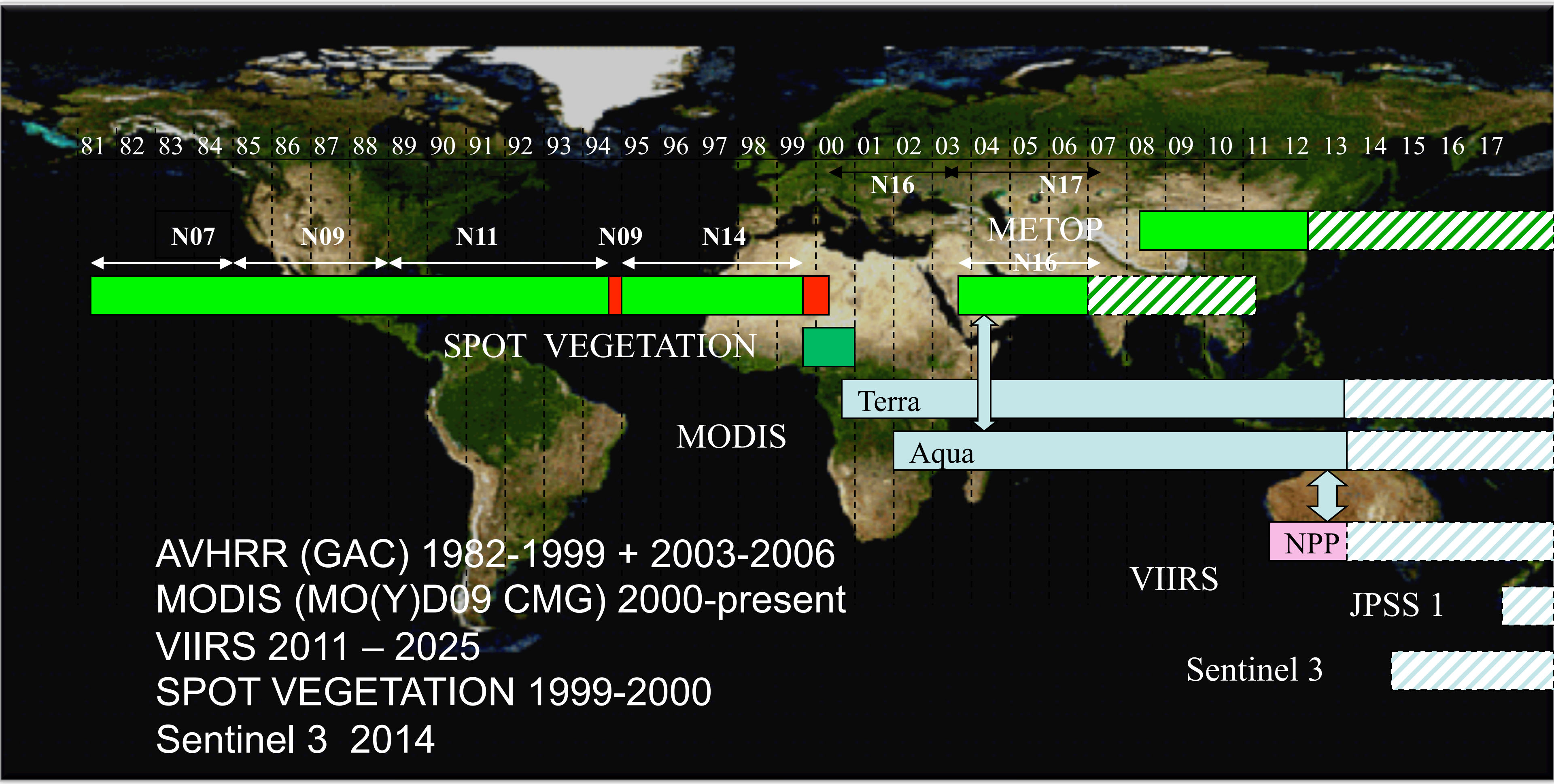
A Land Climate Data Record

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



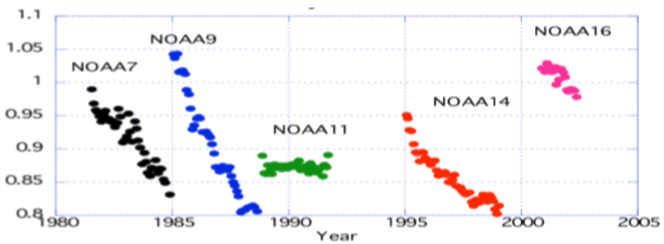
Emphasis on data consistency – characterization rather than degrading/smoothing the data

Land Climate Data Record (Approach)

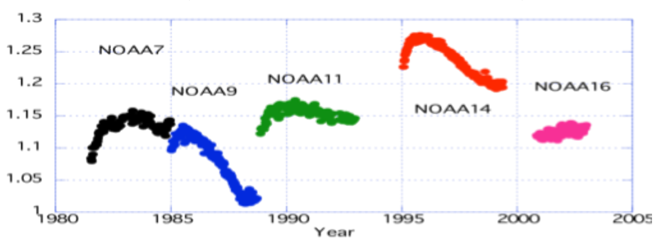
Needs to address geolocation,calibration, atmospheric/BRDF correction issues

CALIBRATION

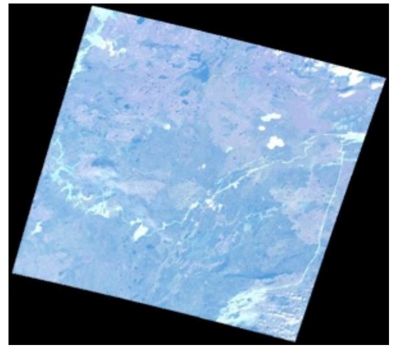
Degradation in channel 1
(from Ocean observations)

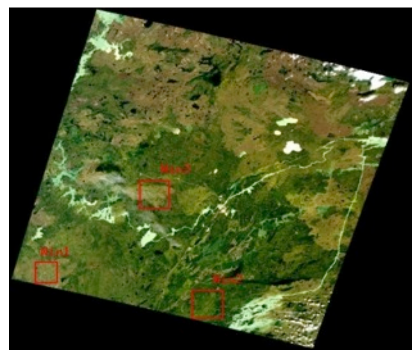


Channel1/Channel2 ratio
(from Clouds observations)

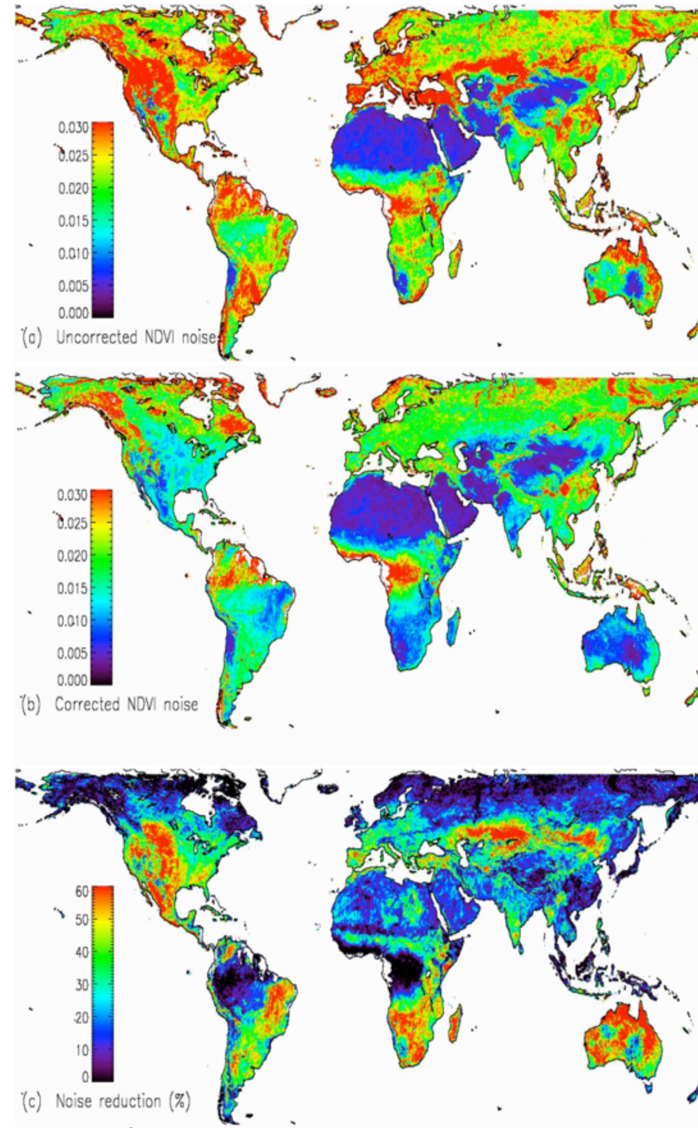


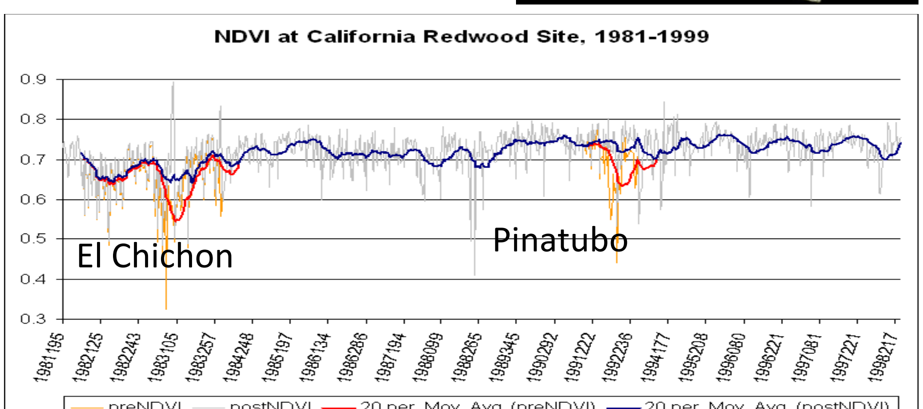
ATMOSPHERIC CORRECTION





BRDF CORRECTION





Goals/requirements for atmospheric correction

- *Ensuring compatibility of missions in support of their combined use for science and application (example Climate Data Record)*
- A prerequisite is the careful absolute calibration that could be insured by cross-comparison over specific sites (e.g. desert)
- We need consistency between the different AC approaches and traceability but it does not mean the same approach is required – (i.e. in most cases it is not practical)
- Have a consistent methodology to evaluate surface reflectance products:
  - AERONET sites
  - Ground measurements
- In order to meaningfully compare different reflectance product we need to:
  - Understand their spatial characteristics
  - Account for directional effects
  - Understand the spectral differences
- One can never over-emphasize the need for efficient cloud/cloud shadow screening

Surface Reflectance (MOD09)

The **Collection 5 atmospheric correction algorithm** is used to produce MOD09 (the surface spectral reflectance for seven MODIS bands as it would have been measured at ground level if there were no atmospheric scattering and absorption).

The **Collection 5 AC algorithm** relies on

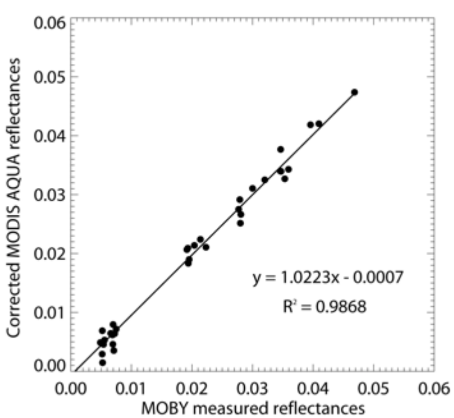
- the use of very accurate (better than 1%) vector radiative transfer modeling of the coupled atmosphere-surface system
- the inversion of key atmospheric parameters (aerosol, water vapor)

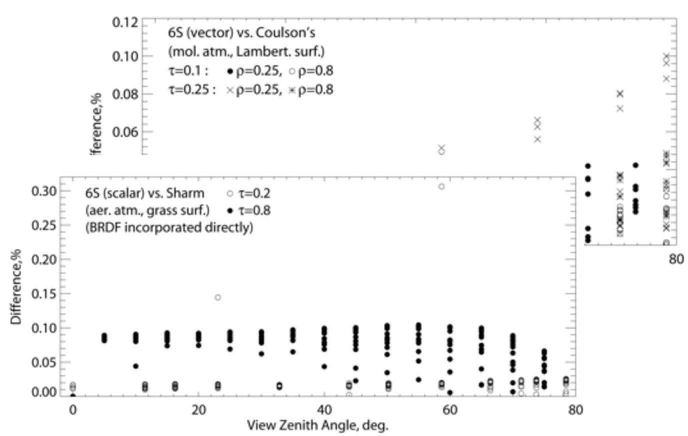
Home page: http://modis-sr.ltdri.org

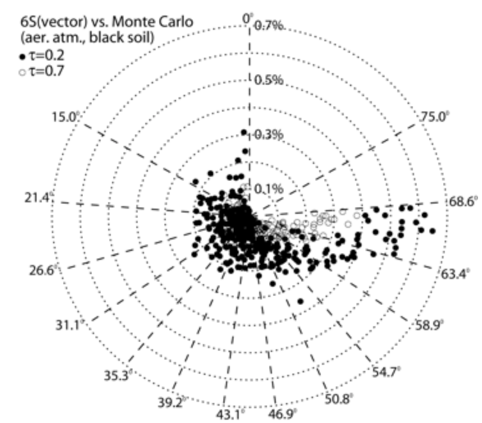
6SV Validation Effort

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

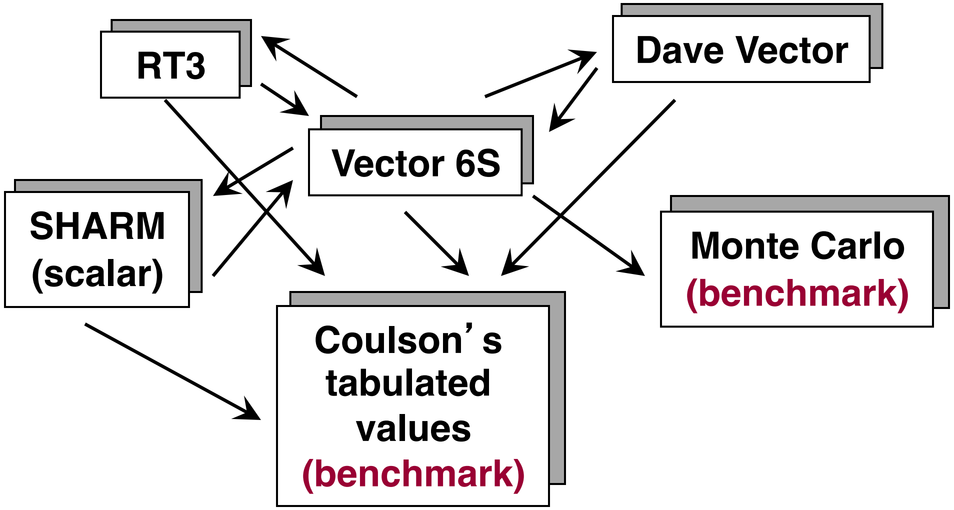
- Kotchenova, S. Y., Vermote, E. F., Matarrese, R., & Klemm Jr, F. J. (2006). Validation of a vector version of the 6S radiative transfer code for atmospheric correction of satellite data. Part I: Path radiance. *Applied Optics*, *45*(26), 6762-6774.
- Kotchenova, S. Y., & Vermote, E. F. (2007). Validation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



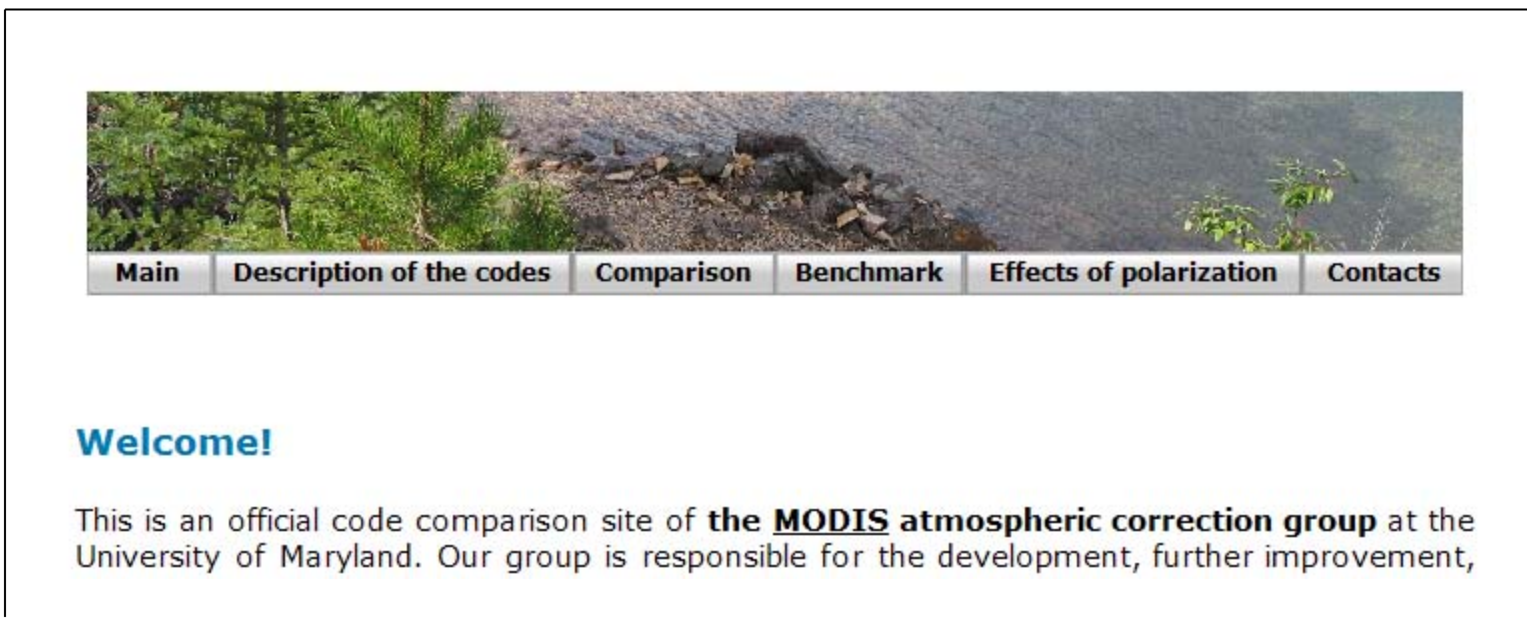




Code Comparison Project



All information on this project can be found at http://rtcodes.ltdri.org



Error Budget

Goal: to estimate the accuracy of the atmospheric correction under several scenarios

Input parameters	Values
Geometrical conditions	10 different cases
Aerosol optical thickness	0.05 (clear), 0.30 (average), 0.50 (high)
Aerosol model	Urban clear, Urban polluted, Smoke low absorption, Smoke high absorption (from AERONET)
Water vapor content (g/cm^2)	1.0, 3.0, 5.0 (uncertainties ± 0.2)
Ozone content (cm · atm)	0.25, 0.3, 0.35 (uncertainties ± 0.02)
Pressure (mb)	1013, 930, 845 (uncertainties ± 10)
Surface	forest, savanna, semi-arid

Reference: Vermote, E. F. & El Saleous, N. Z. (2006). Operational atmospheric correction of MODIS visible to middle infrared land surface data in the case of an infinite Lambertian target, In: Earth Science Satellite Remote Sensing, Science and Instruments, (eds: Qu. J. et al), vol. 1, chapter 8, 123 - 153.

Error budget Example: Calibration Uncertainties

We simulated an error of ±2% in the absolute calibration across all 7 MODIS bands.

Results: The overall error stays under 2% in relative for all aerosol cases considered.

(*In all study cases, the results are presented in the form of tables and graphs.*)

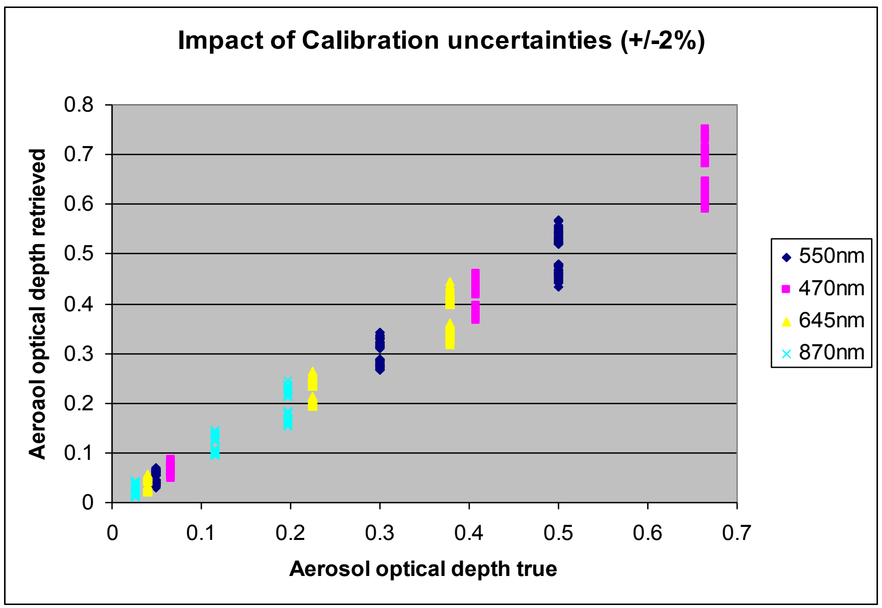


Table (example): Error on the surface reflectance (x 10,000) due to uncertainties in the absolute calibration for the Savanna site.

Central Wavelength (nm)		470	550	645	870	1,240	1,650	2,130
Surface Reflectance × 10,000		400	636	800	2,226	2,880	2,483	1,600
Maximum Error × 10,000	Clear	0013j	0013b	0024i	0065i	0080i	0080i	0080i
	Avg.	0015i	0015i	0030i	0074i	0079i	0070i	0054i
	High	0013d	0011a	0049i	0101i	0098i	0088i	0071i
Minimum Error × 10,000	Clear	0008a	0009j	0016c	0045c	0056f	0048f	0031f
	Avg.	0006c	0004j	0016c	0046c	0058c	0049c	0032c
	High	0001e	0005j	0018c	0048c	0058c	0050c	0032c
Average Error × 10,000	Clear	9	11	17	49	61	56	45
	Avg.	8	11	19	53	63	54	37
	High	6	9	24	63	68	59	42

Overall Theoretical Accuracy

Overall theoretical accuracy of the atmospheric correction method considering the error source on calibration, ancillary data, and aerosol inversion for 3 τaer = {0.05 (clear), 0.3 (avg.), 0.5 (hazy)}:

Reflectance/ VI	Forest				Savanna				Semi-arid			
	value	Aerosol Optical Depth			value	Aerosol Optical Depth			value	Aerosol Optical Depth		
		clear	avg	hazy		clear	avg	hazy		clear	avg	hazy
ρ3 (470 nm)	0.012	0.0052	0.0051	0.0052	0.04	0.0052	0.0052	0.0053	0.07	0.0051	0.0053	0.0055
ρ4 (550 nm)	0.0375	0.0049	0.0055	0.0064	0.0636	0.0052	0.0058	0.0064	0.1246	0.0051	0.007	0.0085
ρ1 (645 nm)	0.024	0.0052	0.0059	0.0065	0.08	0.0053	0.0062	0.0067	0.14	0.0057	0.0074	0.0085
ρ2 (870 nm)	0.2931	0.004	0.0152	0.0246	0.2226	0.0035	0.0103	0.0164	0.2324	0.0041	0.0095	0.0146
ρ5 (1240 nm)	0.3083	0.0038	0.011	0.0179	0.288	0.0038	0.0097	0.0158	0.2929	0.0045	0.0093	0.0148
ρ6 (1650 nm)	0.1591	0.0029	0.0052	0.0084	0.2483	0.0035	0.0066	0.0104	0.3085	0.0055	0.0081	0.0125
ρ7 (2130 nm)	0.048	0.0041	0.0028	0.0042	0.16	0.004	0.0036	0.0053	0.28	0.0056	0.006	0.0087
NDVI	0.849	0.03	0.034	**0.04**	0.471	0.022	0.028	0.033	0.248	**0.011**	0.015	0.019
EVI	0.399	0.005	0.006	**0.007**	0.203	0.003	0.005	0.005	0.119	**0.002**	0.004	0.004

The selected sites are Savanna (Skukuza), Forest (Belterra), and Semi-arid (Sevilleta). The uncertainties are considered independent and summed in quadratic.

Methodology for evaluating the performance of MOD09

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

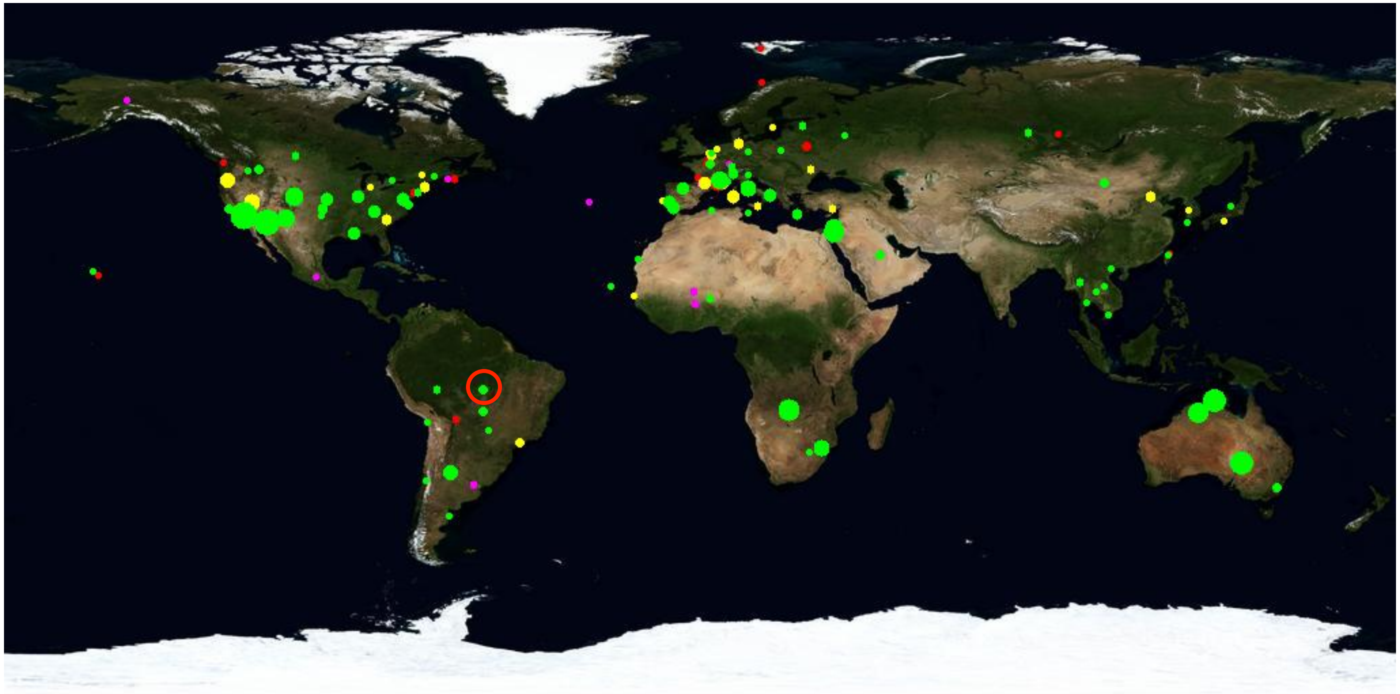
AERONET measurements (τ_{aer}, H_2O, particle distribution Refractive indices,sphericityeri)

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

Validation of MOD09

Comparison between the MODIS band 1 surface reflectance and the reference data set.

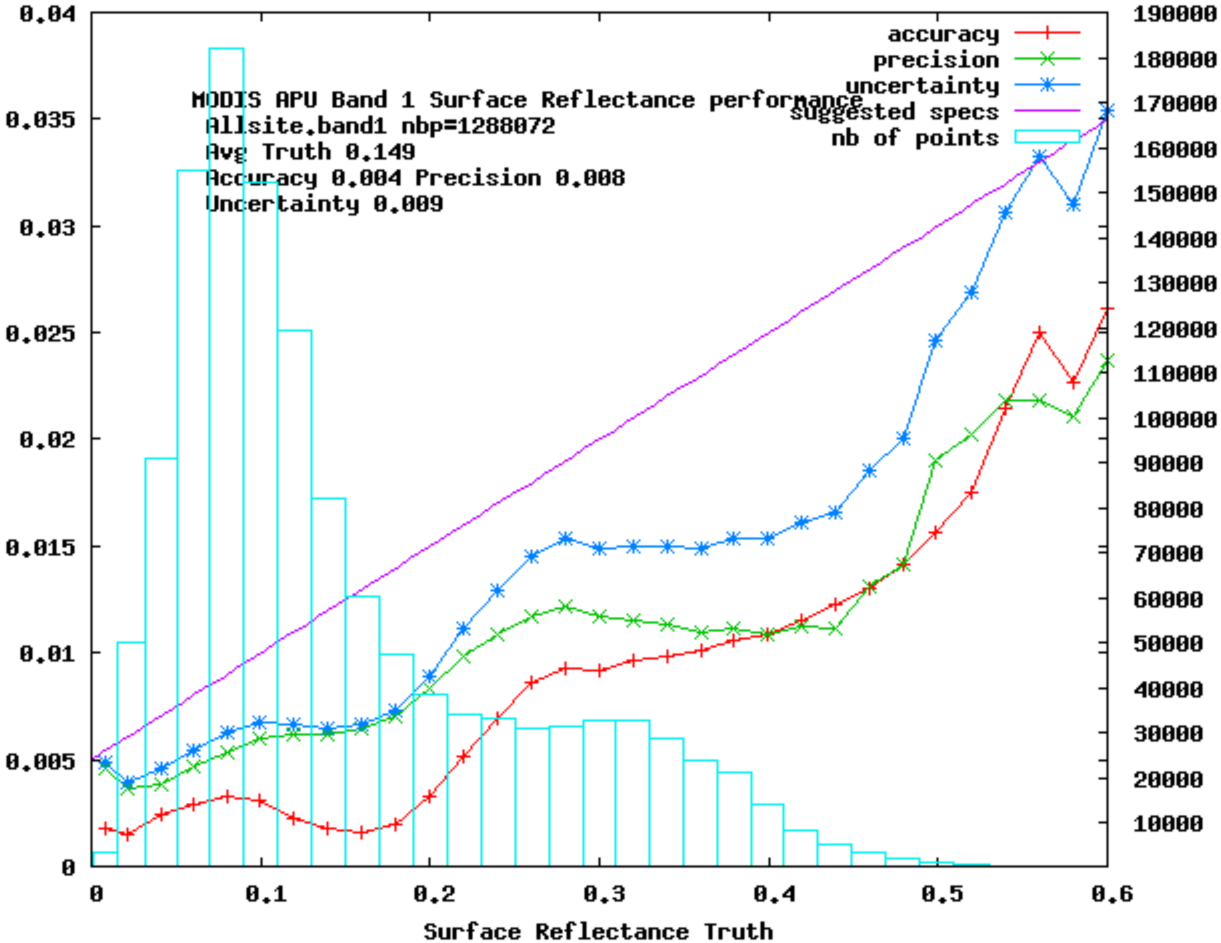


The circle color indicates the % of comparisons within the theoretical MODIS 1-sigma error bar:

green > 80%, 65% < yellow <80%, 55% < magenta < 65%, red <55%.

The circle radius is proportional to the number of observations.

Toward a quantitative assessment of performances (APU)

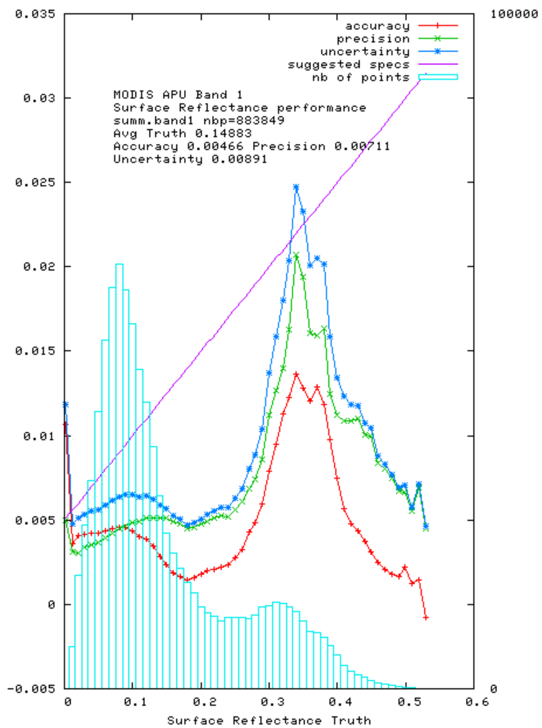


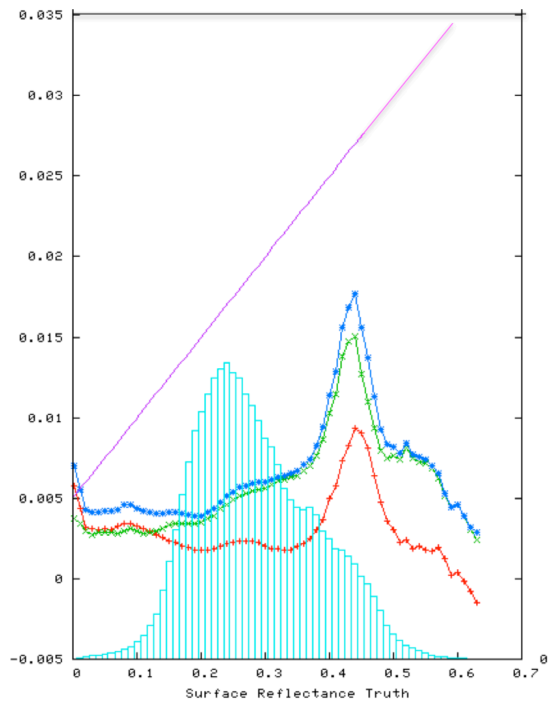
1,3 Millions 1 km pixels were analyzed for each band.

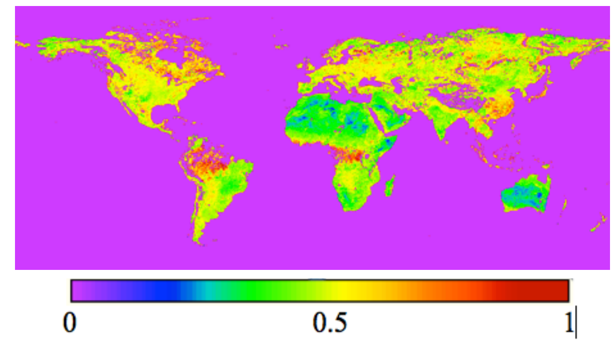
Red = Accuracy (mean bias)
Green = Precision (repeatability)
Blue = Uncertainty (quadatric sum of A and P)

On average well below magenta theoretical error bar

Improving the aerosol retrieval (by using a ratio map instead of fixed ratio) in collection 6 well reflected in APU metrics



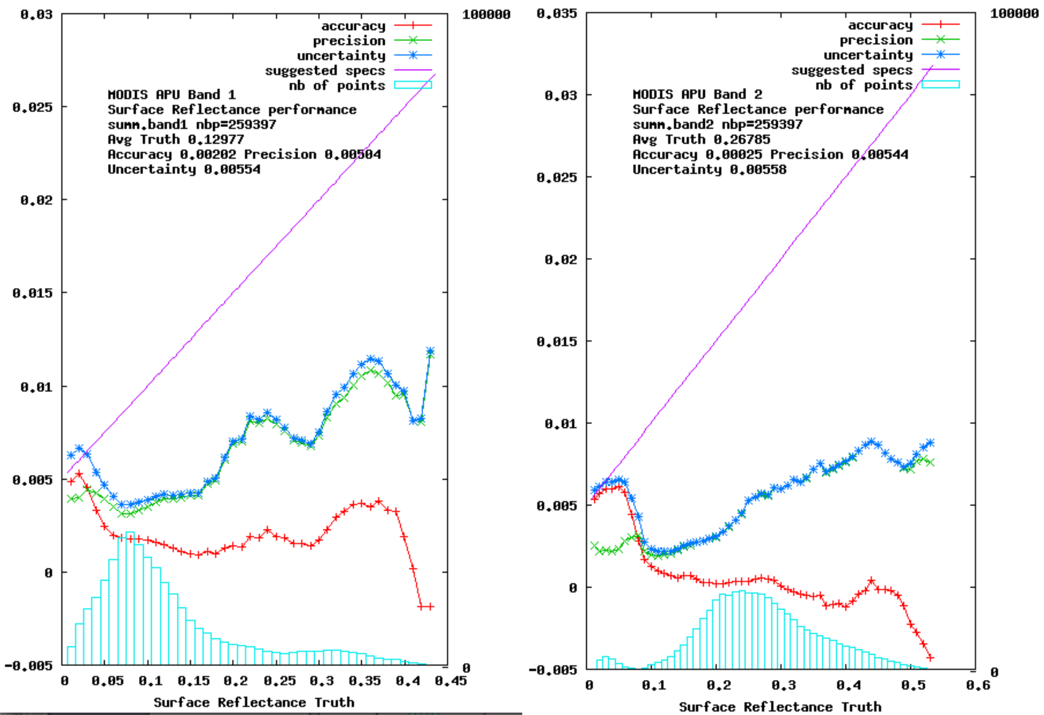




ratio band3/band1 derived using MODIS top of the atmosphere corrected with MISR aerosol optical depth

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 from 2003.

MODIS product and validation methodology used to evaluate other surface reflectance product: example LANDSAT TM/ETM+

- WELD (D. Roy) 120 acquisitions over 23 AERONET sites (CONUS)

  Junchang Ju, David P. Roy, Eric Vermote, Jeffrey Masek, Valeriy Kovalskyy, Continental-scale validation of MODIS-based and LEDAPS Landsat ETM+ atmospheric correction methods, **Remote Sensing of Environment** (2012), Available online 10 February 2012, ISSN 0034-4257, 10.1016/j.rse.2011.12.025.

- GFCC: Comparison with MODIS SR products
  - GLS 2000 demonstration

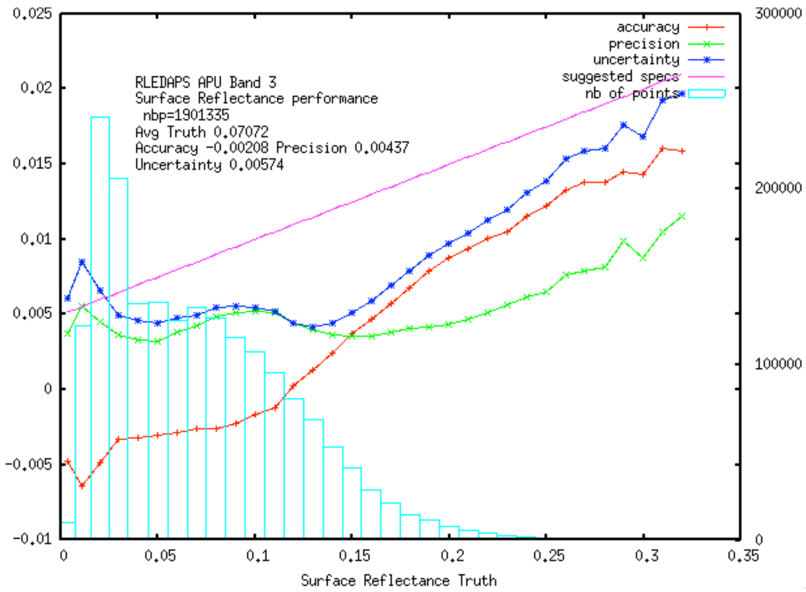
    Min Feng, Chengquan Huang, Saurabh Channan, Eric F. Vermote, Jeffrey G. Masek, John R. Townshend, Quality assessment of Landsat surface reflectance products using MODIS data, **Computers & Geosciences**, Volume 38, Issue 1, January 2012, Pages 9-22, ISSN 0098-3004, 10.1016.
  - GLS 2005 (TM and ETM+)

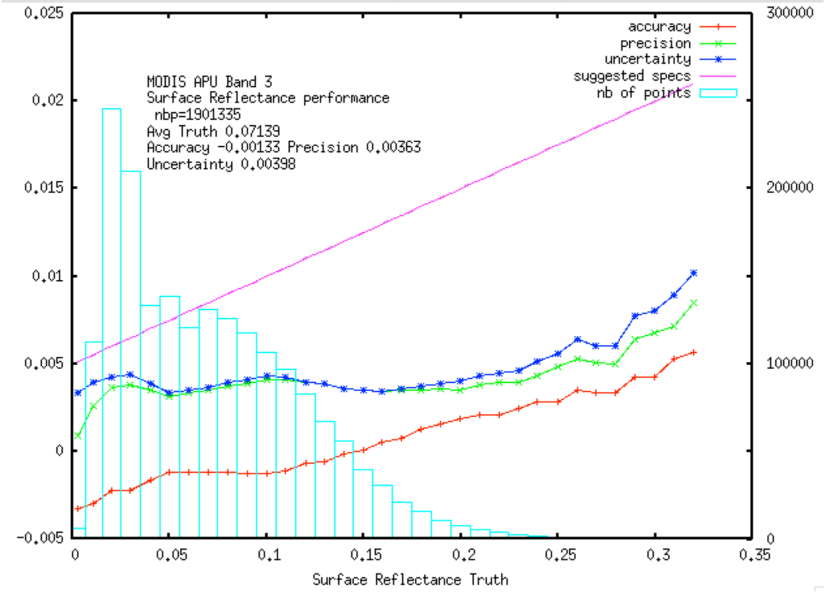
    Min Feng Joseph O. Sexton, Chengquan Huang, Jeffrey G. Masek, Eric F. Vermote, Feng Gao, Raghuram Narasimhan, Saurabh Channan, Robert E. Wolfe, John R. Townshend ,Global, long-term surface reflectance records from Landsat: a comparison of the Global Land Survey and MODIS surface reflectance datasets. **Remote Sensing of the Environment (in review)**

WELD/LEDAPS/LDCM results (Red-band3)

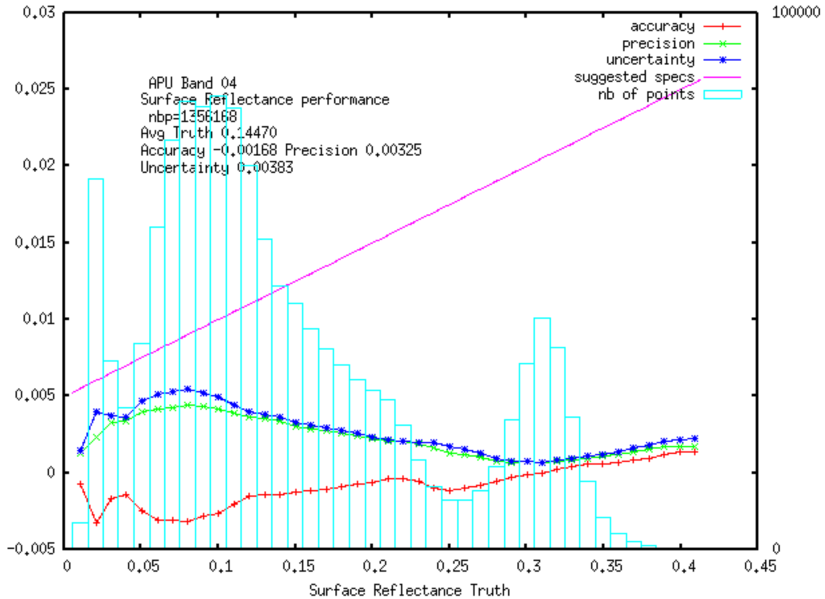
LEDAPS

WELD uses MODIS aerosol



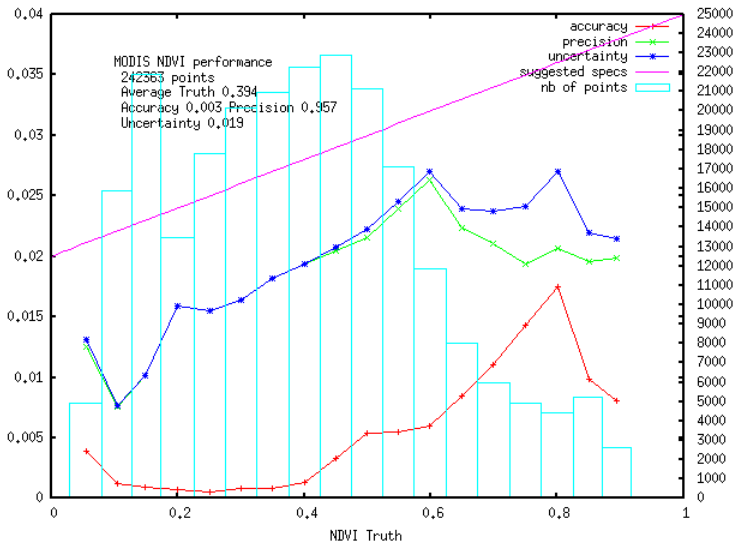


LDCM

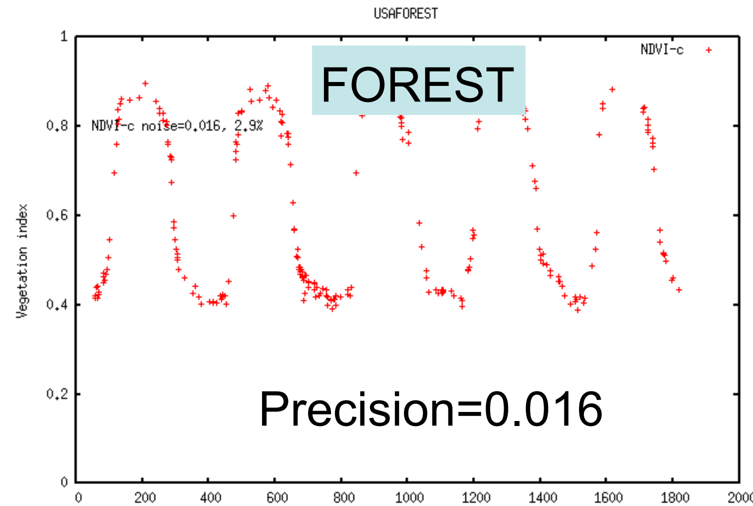


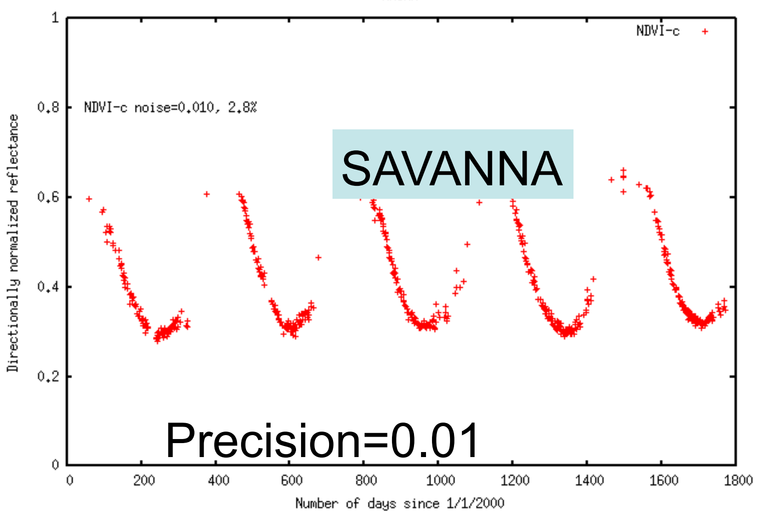
Continuous analysis of time series allow an independent assessment of precision

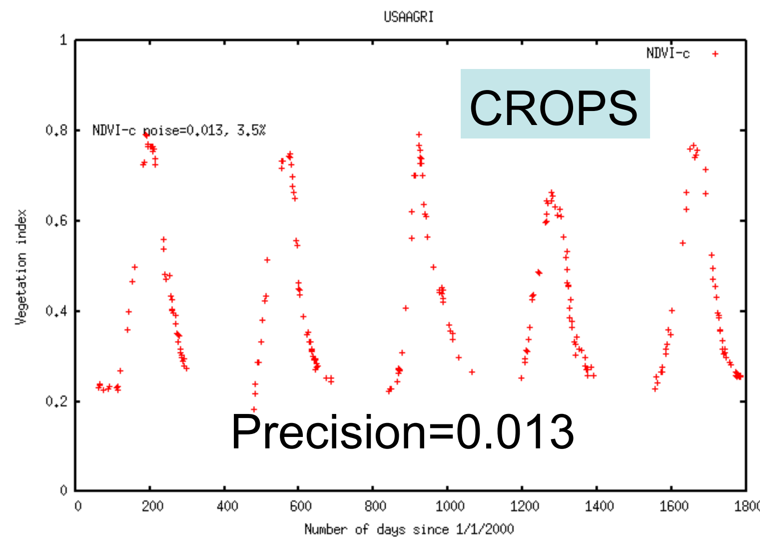
Evaluation over AERONET (2003)
0.007 <Precision < 0.017



Independent evaluation of the precision
Over 2000-2004 CMG daily time series







Quantification of time series noise

- For each triplet of observations, one can estimate middle one from the earlier and later:

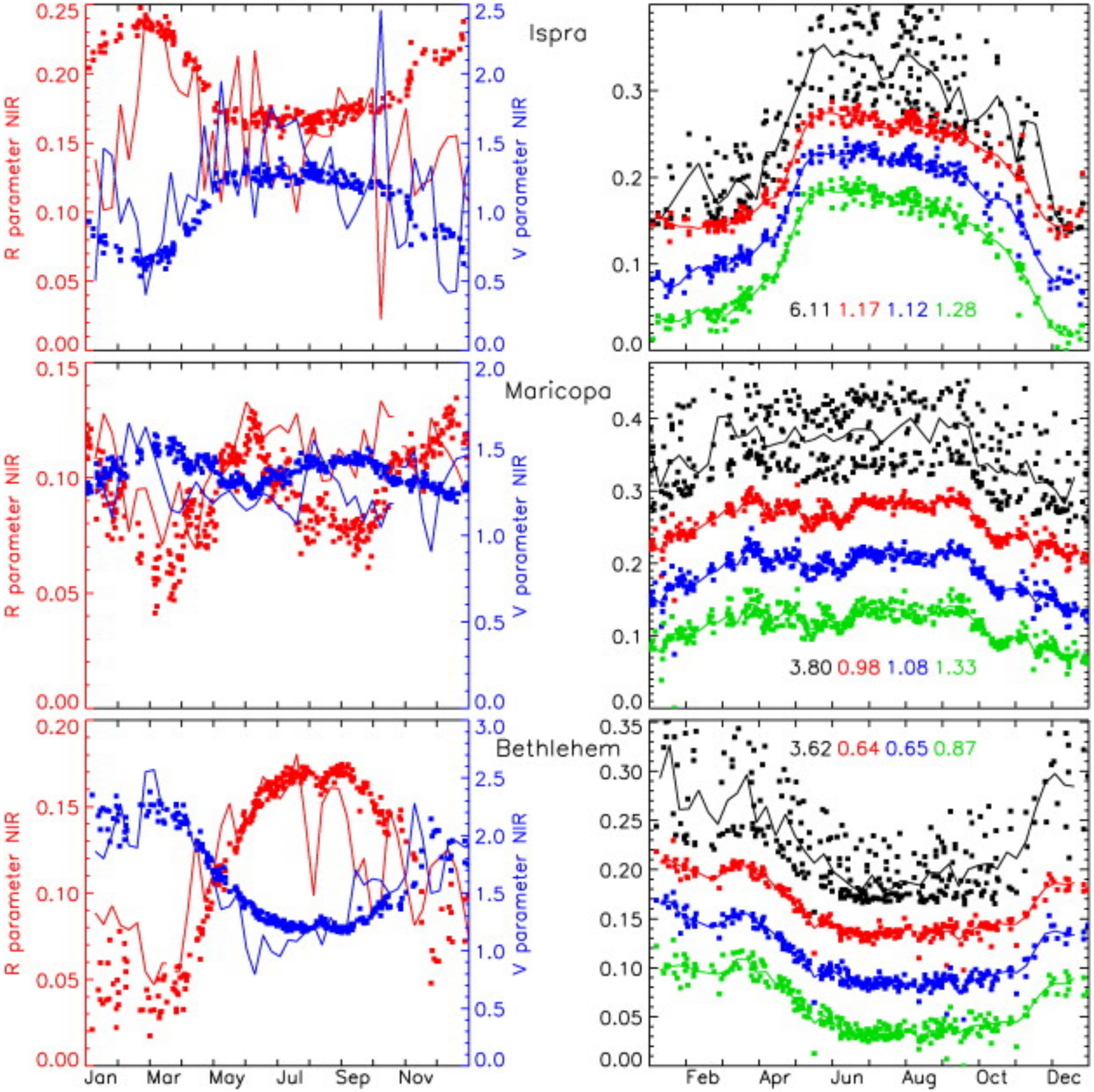
$$\rho_i^* = \frac{(t_i - t_{i-1})\rho_{i+1} + (t_{i+1} - t_i)\rho_{i-1}}{t_{i+1} - t_{i-1}}$$

One can then compute a “noise” from the quadratic sum of the difference between the measurement and their interpolated counterpart:

$$\sigma^2(\rho) = \frac{\sum_{i=2}^{N-1} \frac{1}{t_{i+1} - t_{i-1}} (\rho_i^* - \rho_i)^2}{\sum_{i=2}^{N-1} \frac{1}{t_{i+1} - t_{i-1}}}$$

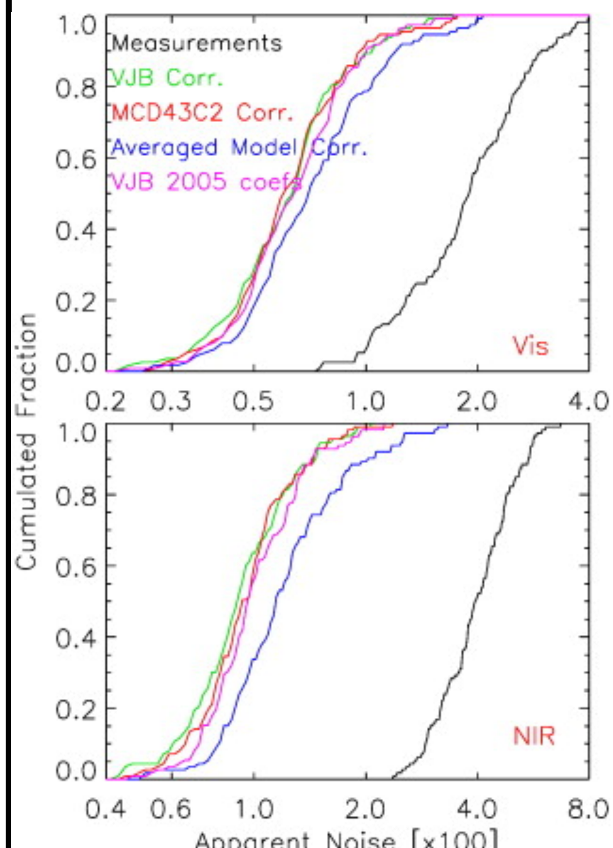
We use this definition in the following to quantify the time series quality

Evaluation of VJB BRDF correction at CMG spatial resolution (0.05 deg) over AERONET sites (Bréon and Vermote,2012)

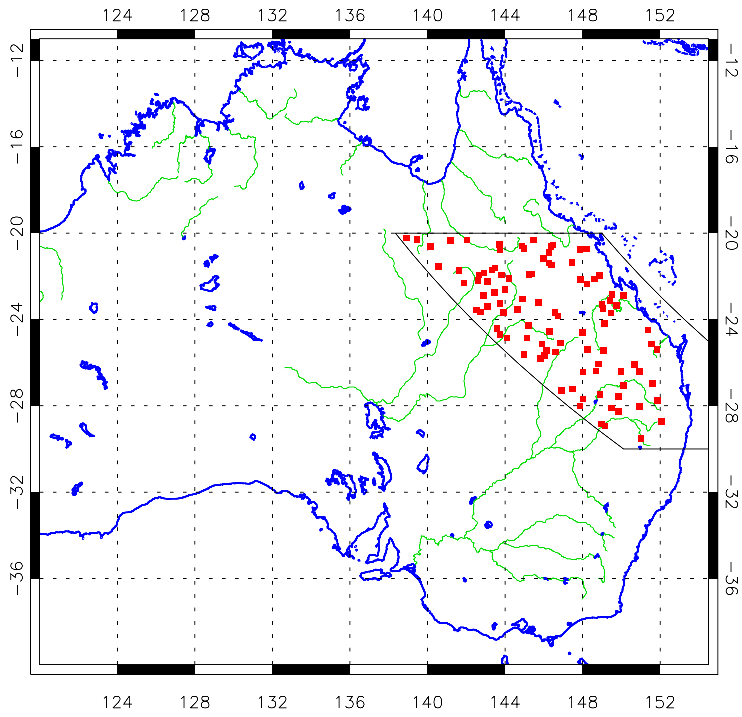


Examples over 3 sites
Black: Original
Red: VJB
Blue: MCD43A2
Green: average

Results over 115 sites

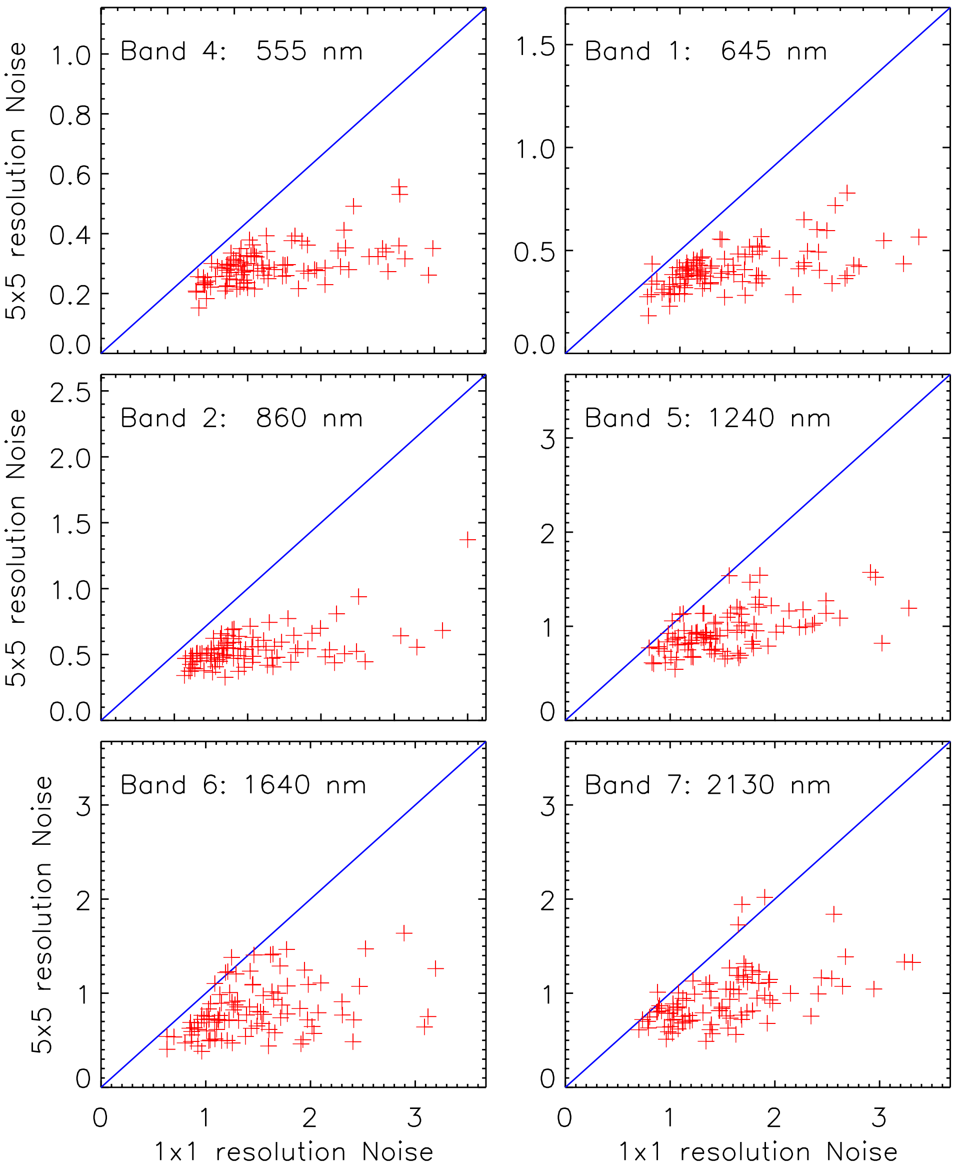


Evaluation of BRDF correction at native spatial resolution (500m) over Australia



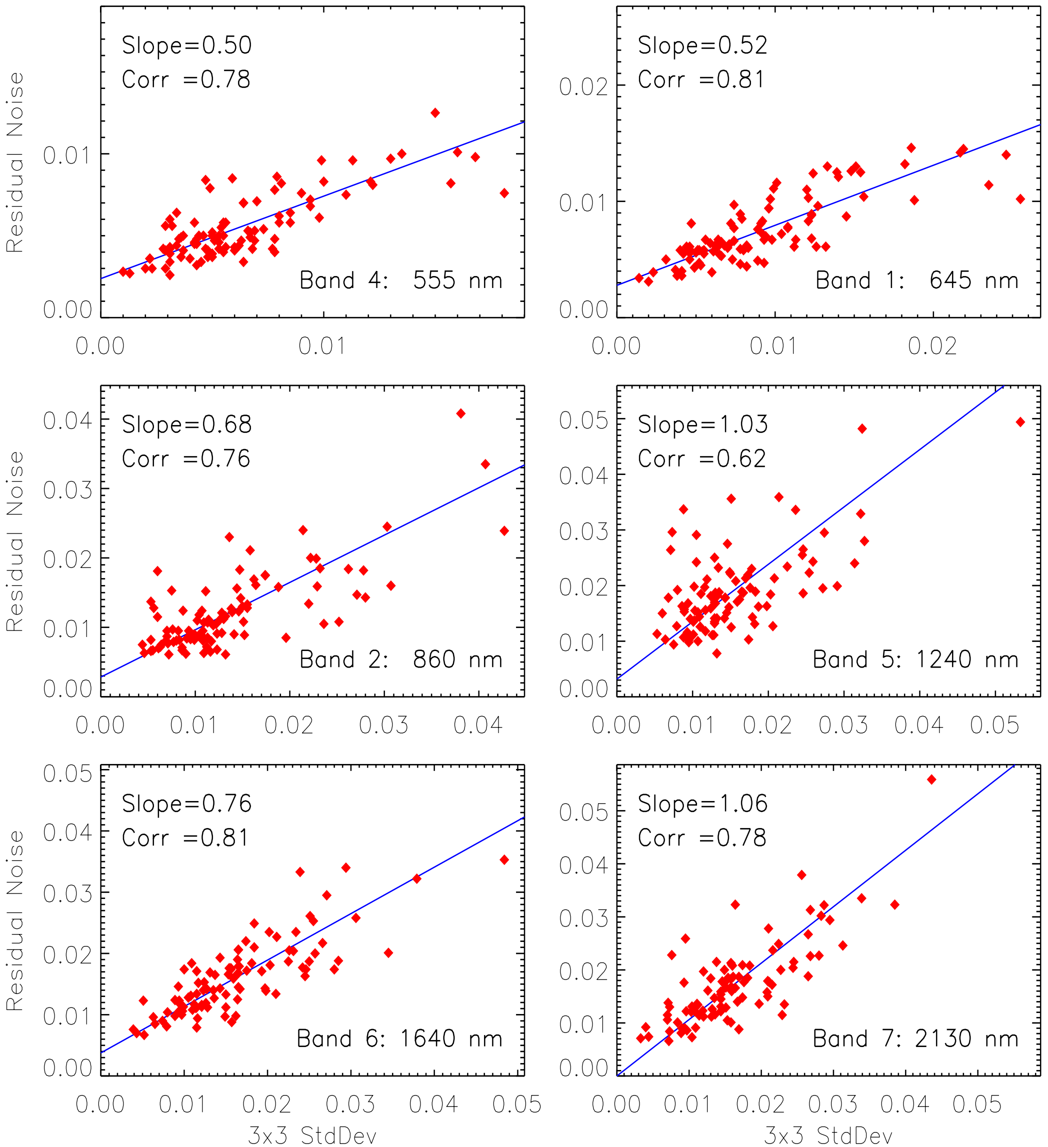
- MODIS data are distributed as “tiles” (10° of lat.)
- To limit data volume, we focus on a single tile
- Select a tile over Eastern Australia for (i) variety of surface cover, (ii) number of clear observations, (iii) low aerosol load

Impact of spatial scale



- The noise of the corrected time series is much larger than that we obtained earlier using CMG (Climate Modeling Grid : 5 km) lower resolution data.
- We show here a comparison of the noise obtained at the full resolution against that obtained when aggregating 5x5 pixels.

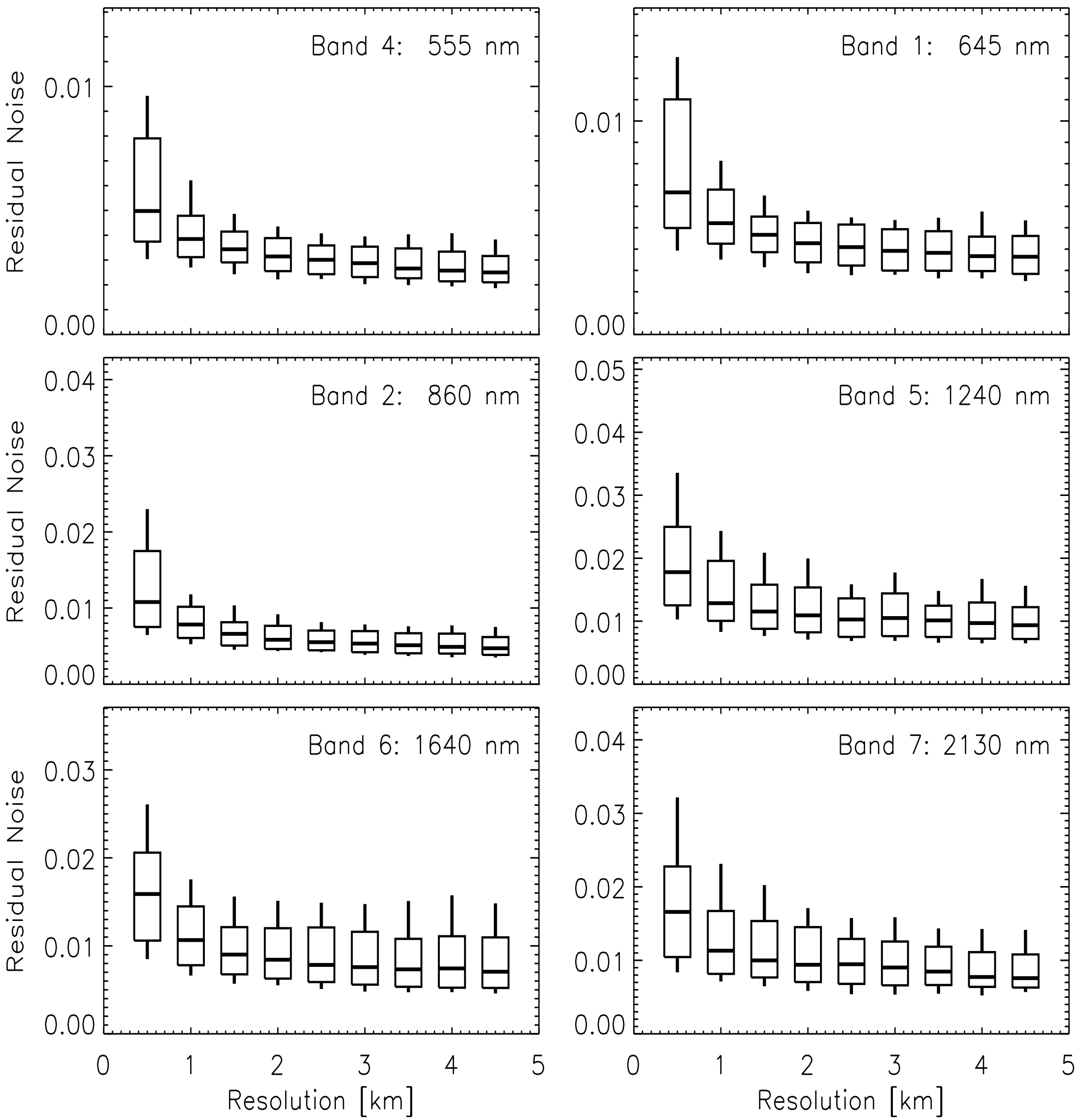
Noise vs Spatial heterogeneity



- There is a very strong correlation between the spatial heterogeneity (quantified here as the 3x3 standard deviation) and the noise on the corrected time series.

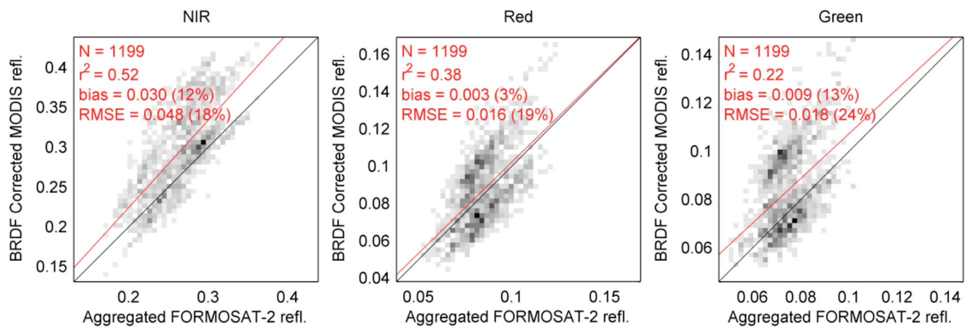
- Clearly, the spatial heterogeneity affects the quality of the time series and there is an easy explanation for that (gridding and FOV)

Impact of spatial scale

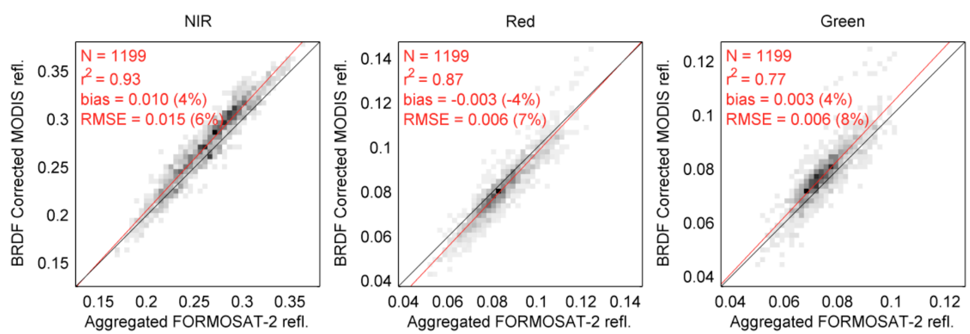


- The “noise” of the time series decreases when the spatial aggregation increases. There seems to be an optimal scale at 2 km (4x4 pixels)

Use of BRDF correction for product cross-comparison

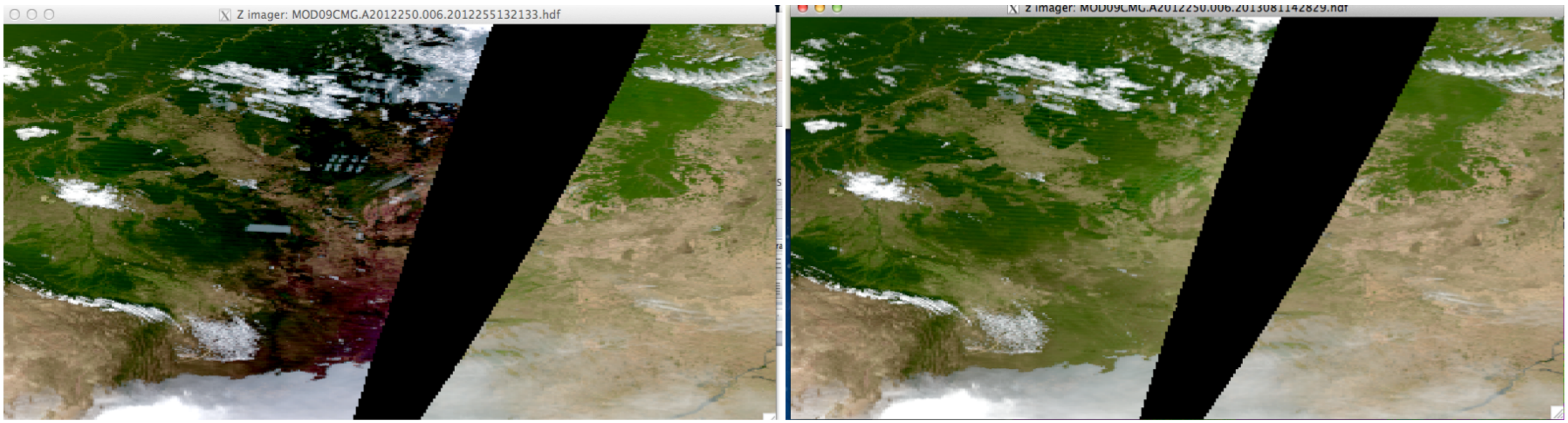


Comparison of aggregated FORMOSAT-2 reflectance and MODIS reflectance. No BRDF correction. Density function from light grey (minimum) to black (maximum); white = no data.



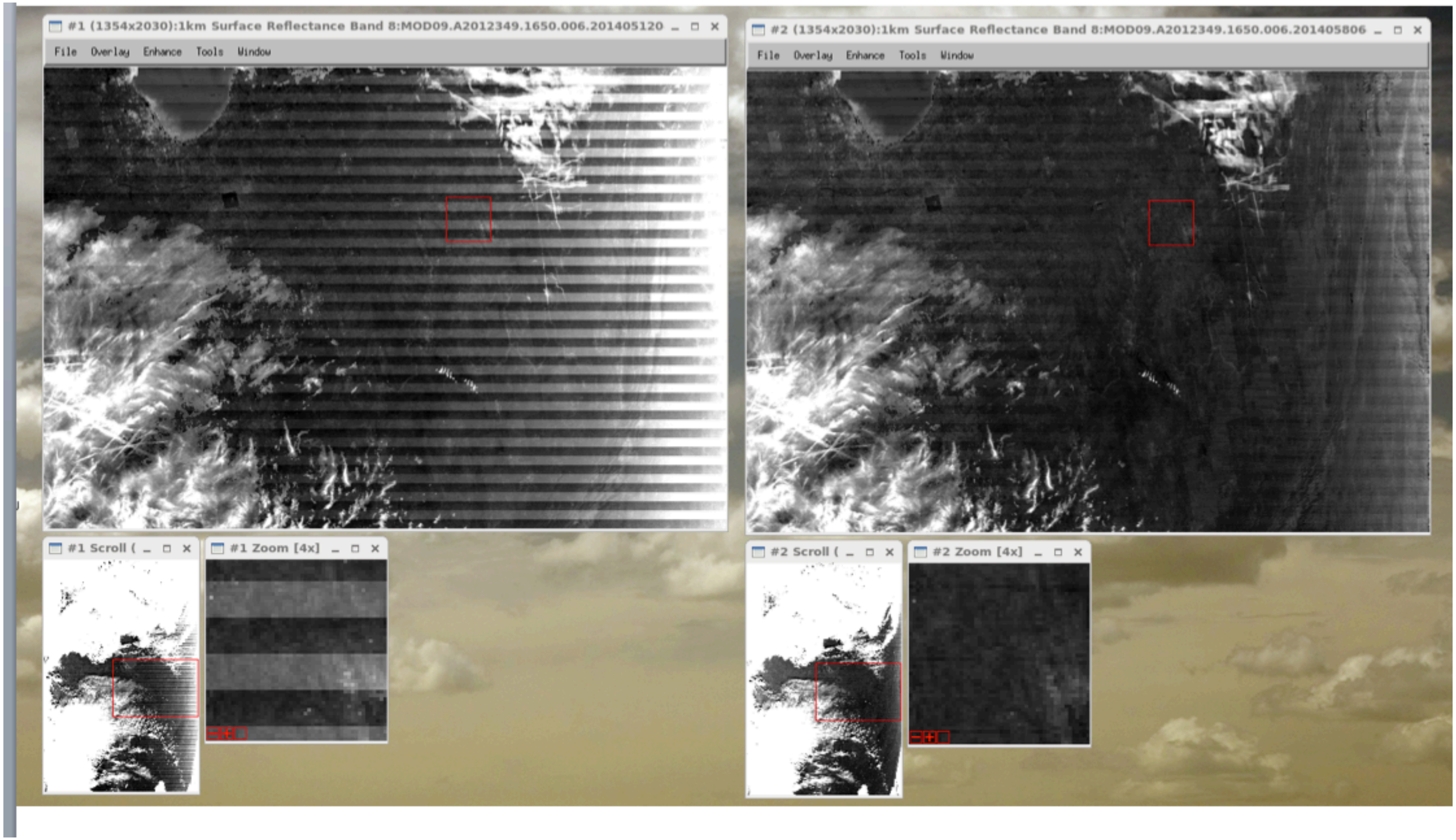
Comparison of aggregated FORMOSAT-2 reflectance and BRDF corrected MODIS reflectance. Corrections were performed with Vermote al. (2009) method using for each day of acquisition, the angular configuration of FORMOSAT-2 data.

Continuous monitoring and assessment of instrument performance is also important
CALIBRATION

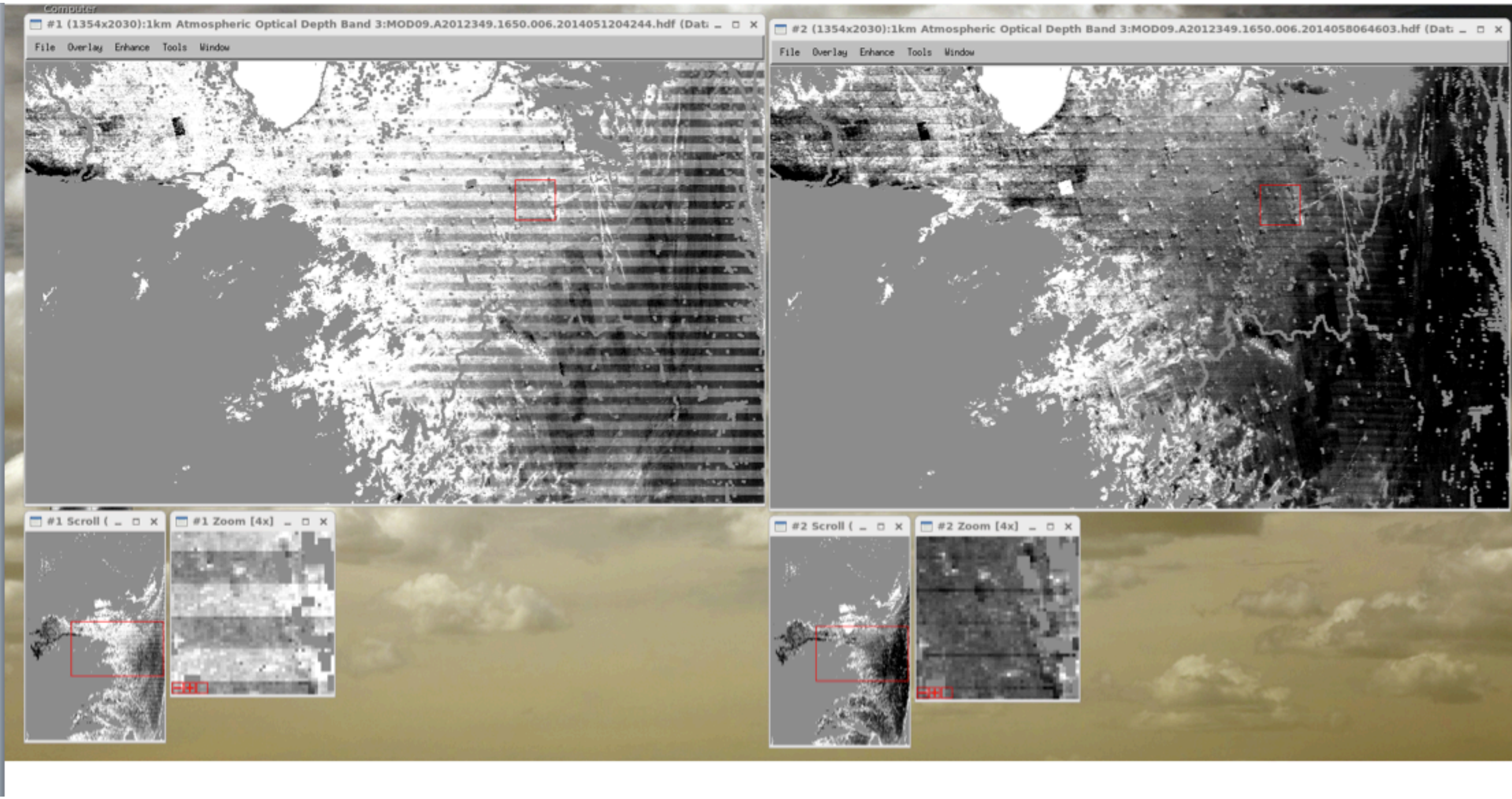


Comparison of a preliminary Collection 6 MODIS Terra surface reflectance true color composite (RGB, band 1,4,3) using Level 1B Collection 5 input (left) or 6 (right). The artifacts due to the suboptimal calibration of Collection 5 are clearly visible (the reddish abnormal color over vegetated surfaces) and result from non-uniform mirror degradation that could not be tracked properly by the use of the on-board calibration system and periodic lunar looks. The approach taken for Terra calibration in Collection 6 is different than Collection 5 (use of ground desert targets in addition to lunar and on-board calibration) and provides much better results as evidenced by the Surface Reflectance product.

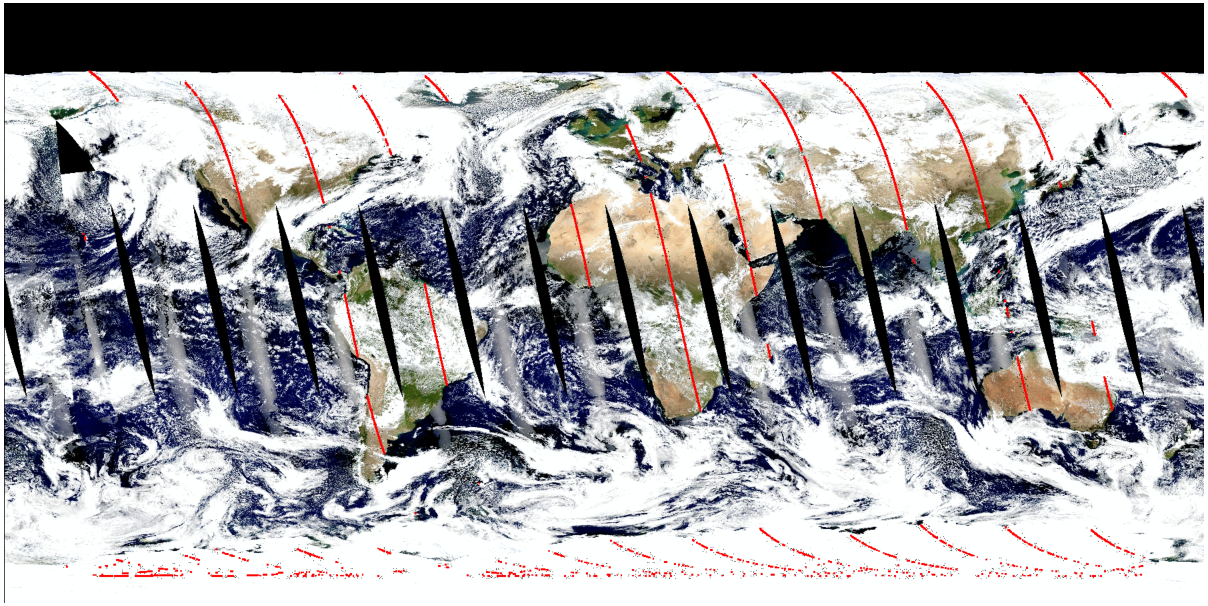
Continuous monitoring and assessment of instrument performance is also important
POLARIZATION EFFECT (BAND8)



Continuous monitoring and assessment of instrument performance is also important
POLARIZATION EFFECT (Aerosol optical thickness)



Monitoring of product quality (exclusion conditions cloud mask using CALIOP)



Aqua true color surface reflectance image for March, 2, 2007. The CALIOP track is shown in red, only matchups over Land are selected.

	MOD35 Global	MOD35 60S-60N	ICM Global	ICM 60S-60N	ICM Global Case1	ICM Global Case2
Leakage	6.1%	5.6%	5.8%	**4.0%**	**2.6%**	**2.1%**
False Det.	6.1%	6.4%	6.5%	6.7%	6.5%	6.5%

Analysis of the performance of MOD35 and ICM under various scenarios. Global (Global), excluding latitude higher than 60N or lower than 60S (60S-60N), excluding cloud incorrectly detected as snow (ICM Global Case1) using the ICM snow quality flag, and finally further excluding ICM cloud adjacent quality flag (ICM Global Case2).

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…)
- Cloud and cloud shadow mask validation protocol needs to be fully developed.