Introduction to atmospheric correction over land (Optical Domain)

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Atmospheric Correction of Earth Observation Data for Environmental Monitoring: Theory and Best Practises

MODIS Land Products

Energy Balance Product Suite

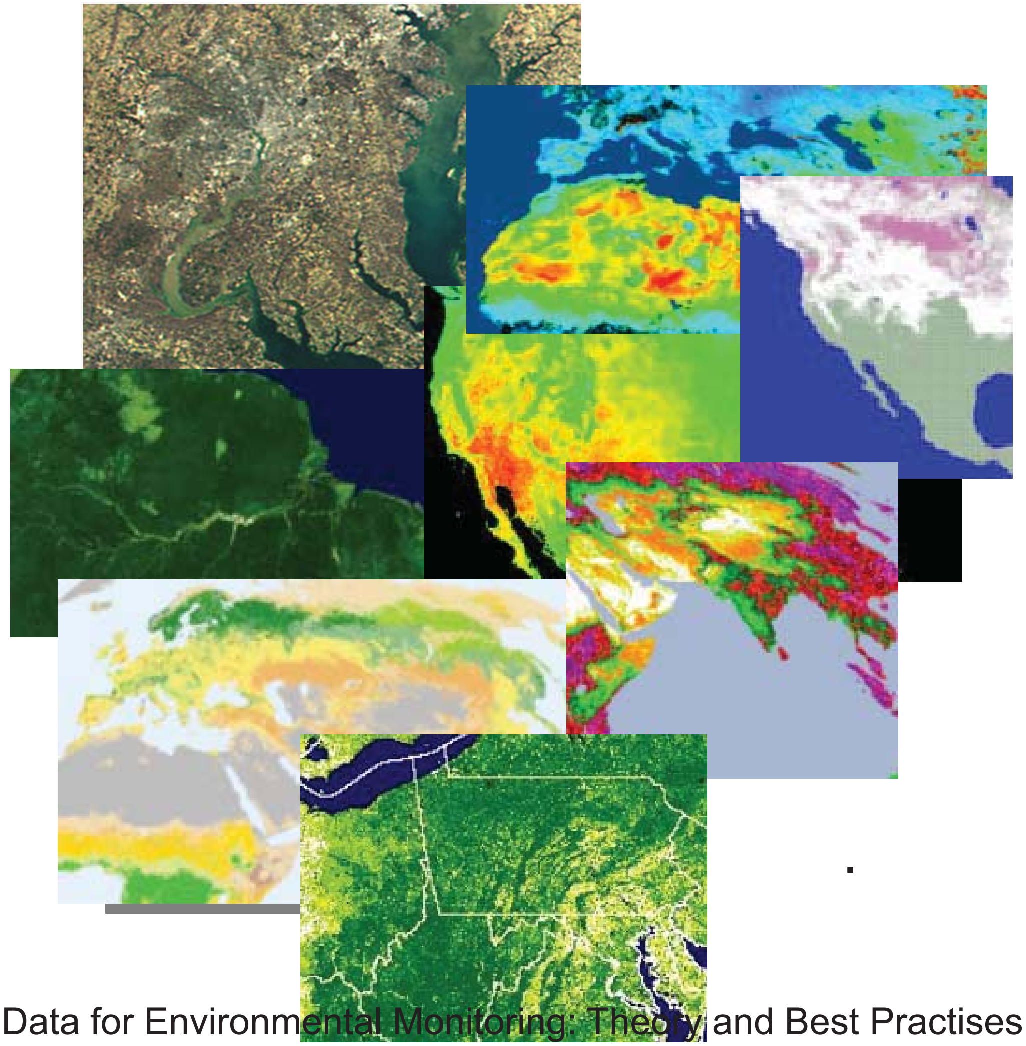
- Surface Reflectance
- Land Surface Temperature, Emmisivity
- BRDF/Albedo
- Snow/Sea-ice Cover

Vegetation Parameters Suite

- Vegetation Indices
- LAI/FPAR
- GPP/NPP

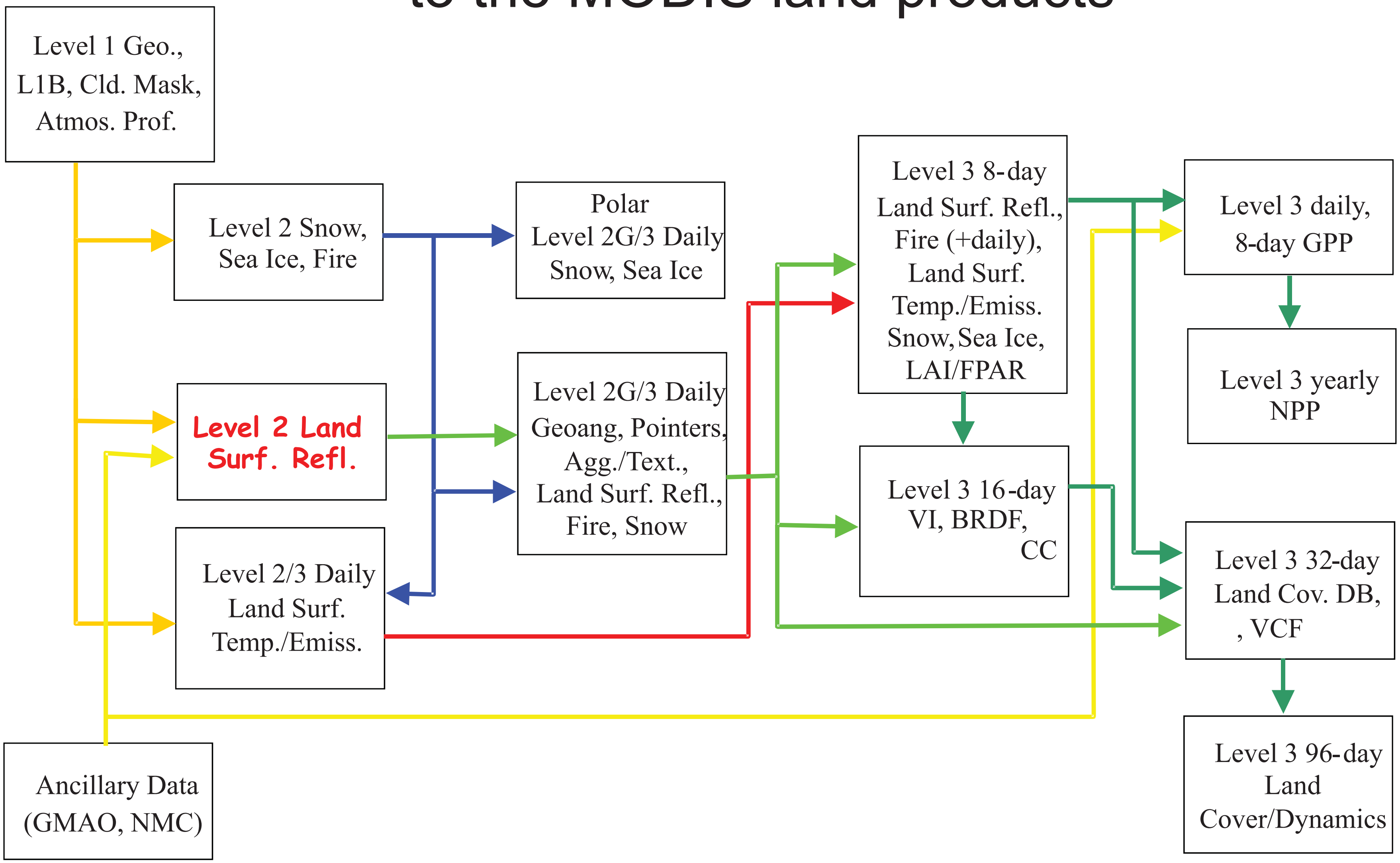
Land Cover/Land Use Suite

- Land Cover/Vegetation Dynamics
- Vegetation Continuous Fields
- Fire and Burned Area



MODIS Land Data Production Processing Chart

Atmospheric Correction Product (MOD09) crucial input to the MODIS land products

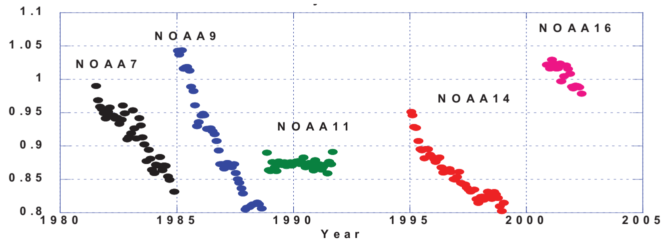


Land Climate Data Record

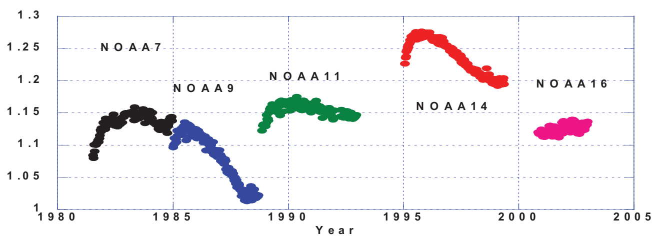
Needs to address calibration, atmospheric/BRDF correction issues

CALIBRATION

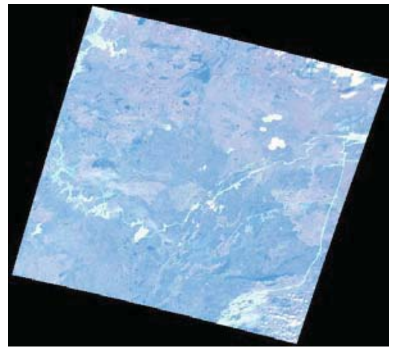
Degradation in channel 1
(from Ocean observations)

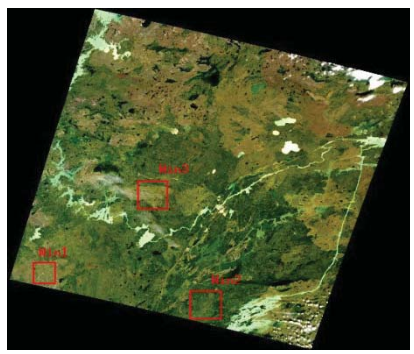


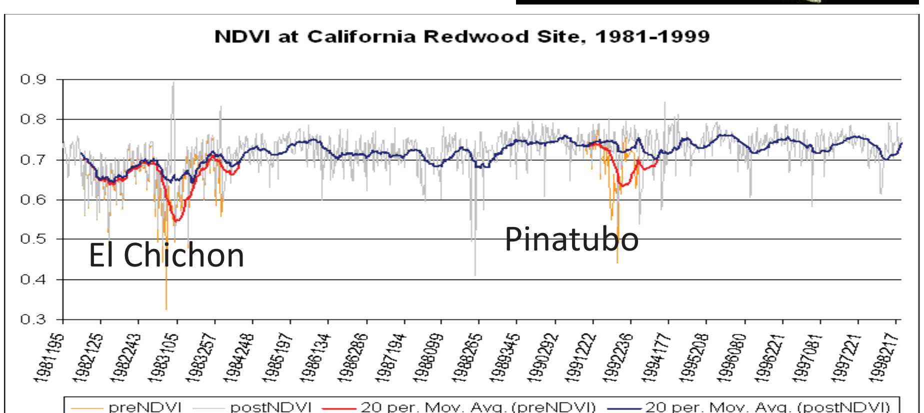
Channel1/Channel2 ratio
(from Clouds observations)



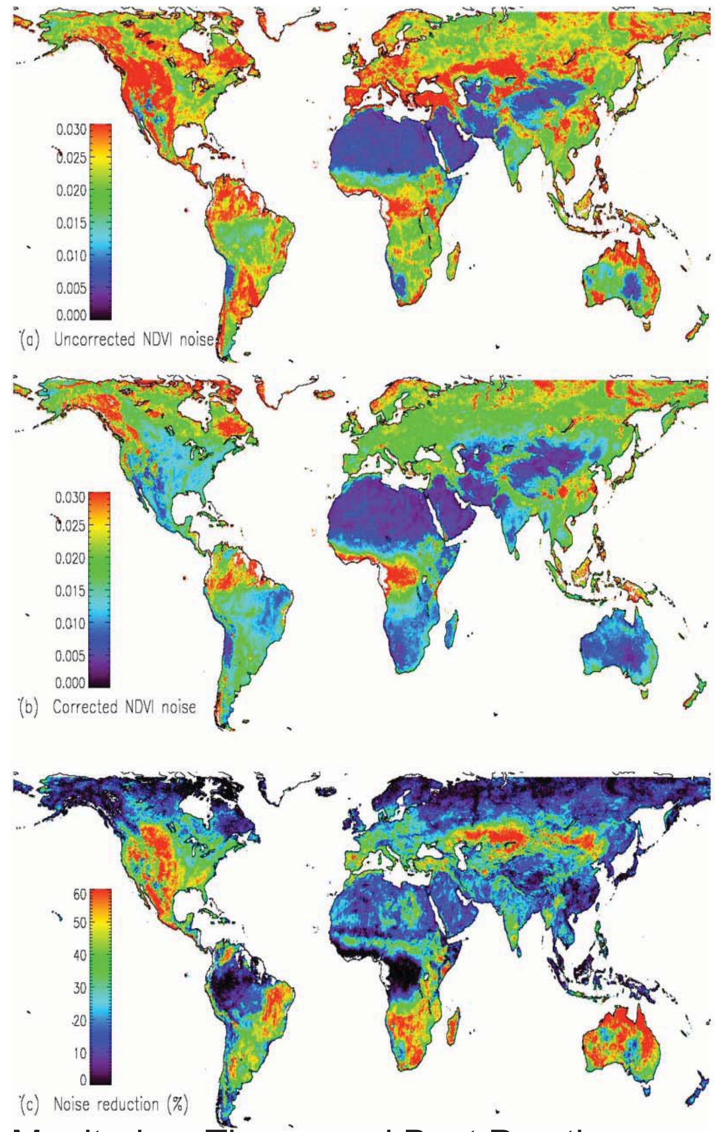
ATMOSPHERIC CORRECTION







BRDF CORRECTION

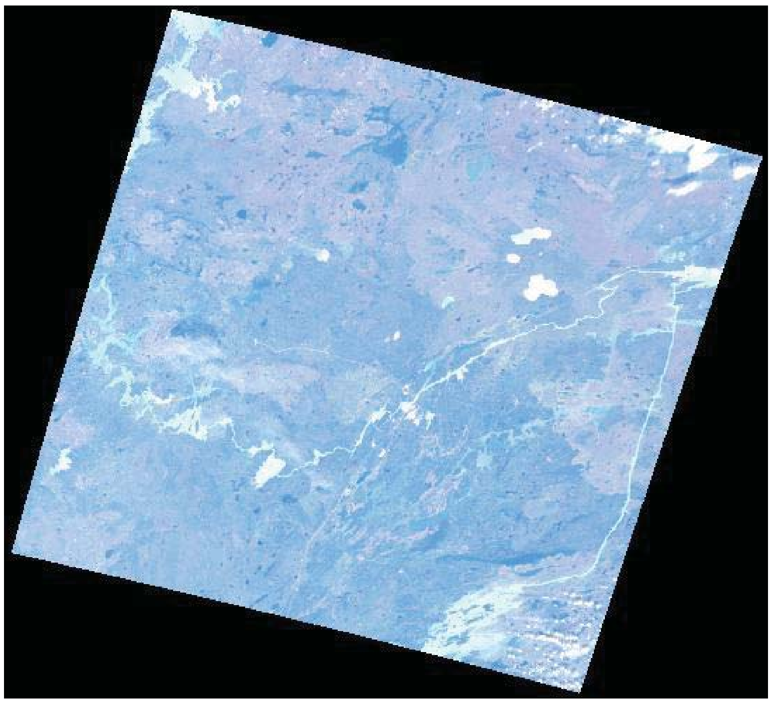


Atmospheric Correction of Earth Observation Data for Environmental Monitoring: Theory and Best Practises

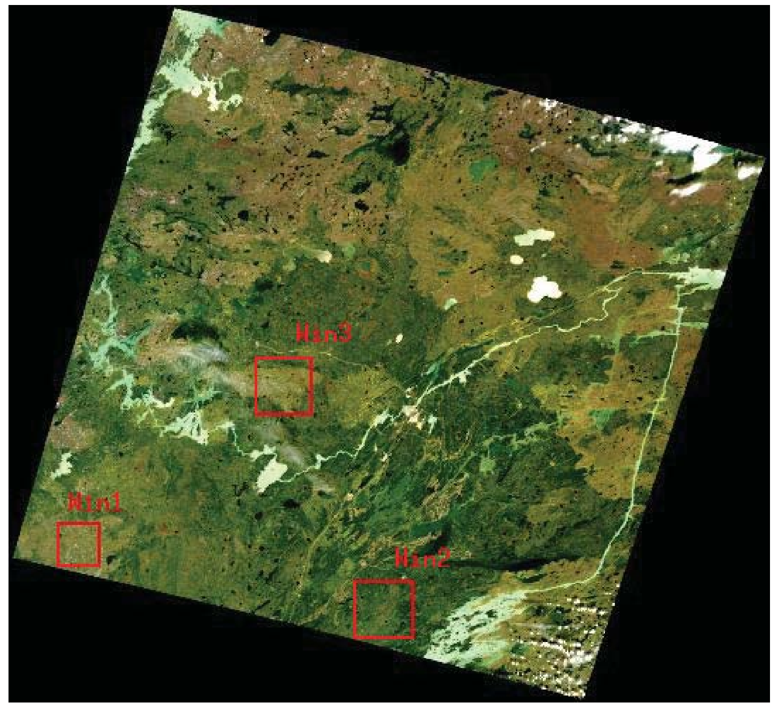
The need for Surface Reflectance
BOREAS ETM+ scene

Scene: p033r021

Date: 09/17/2001

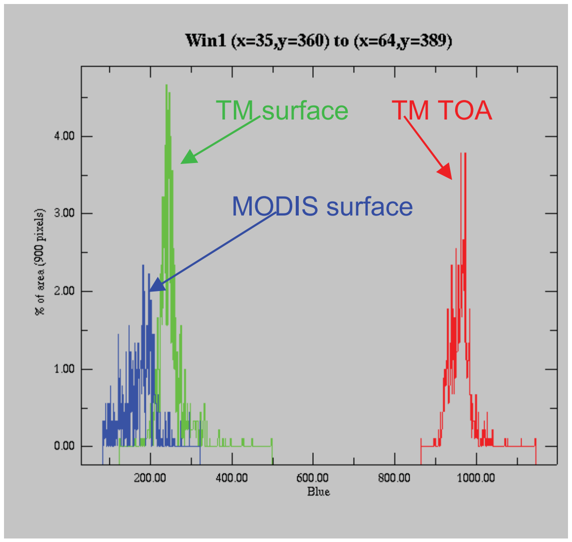


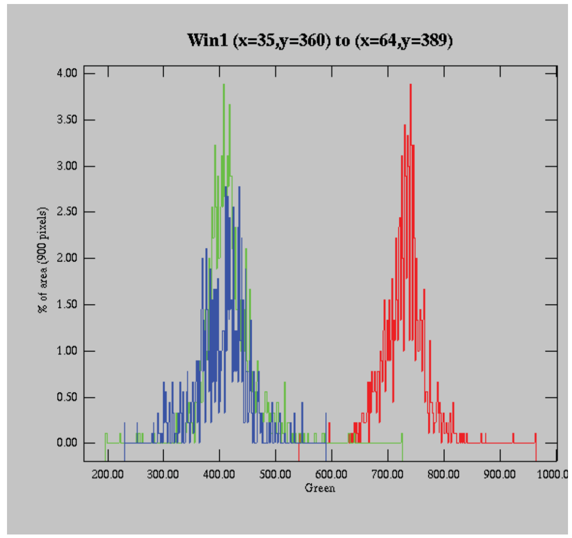
Top-of-atmosphere TOA

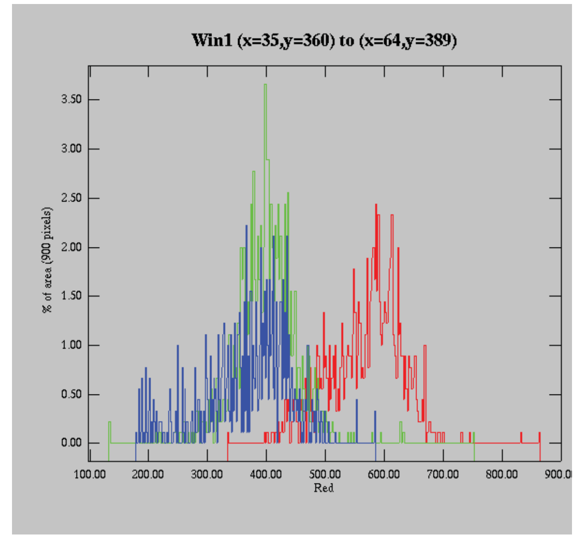


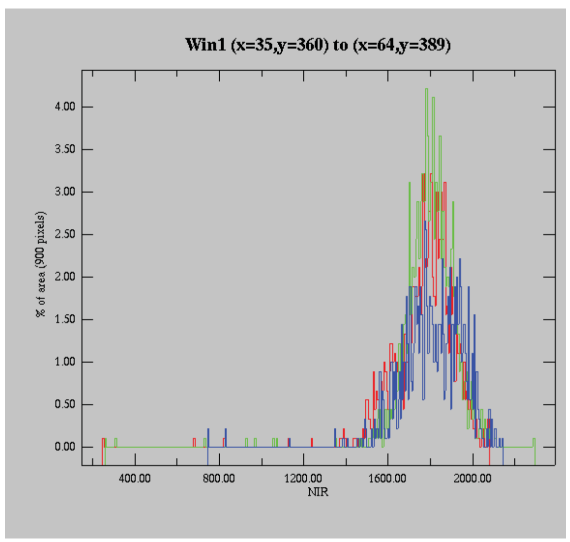
Surface Reflectance

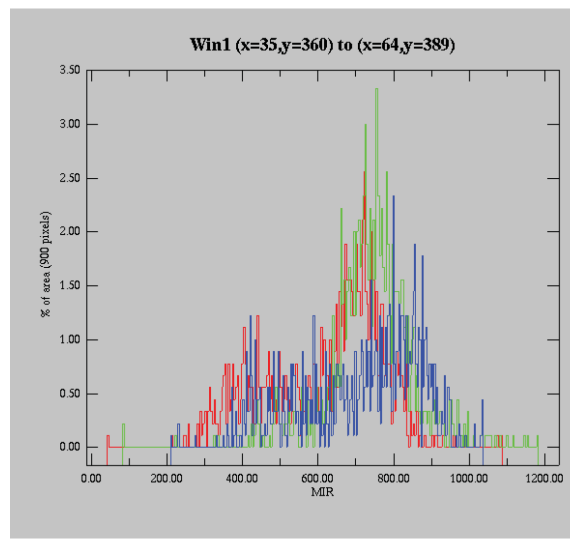
Window 1


Win1 (x=35,y=360) to (x=64,y=389)
TM surface
TM TOA
MODIS surface
% of area (900 pixels)
Blue


Win1 (x=35,y=360) to (x=64,y=389)
% of area (900 pixels)
Green


Win1 (x=35,y=360) to (x=64,y=389)
% of area (900 pixels)
Red


Win1 (x=35,y=360) to (x=64,y=389)
% of area (900 pixels)
NIR


Win1 (x=35,y=360) to (x=64,y=389)
% of area (900 pixels)
MIR

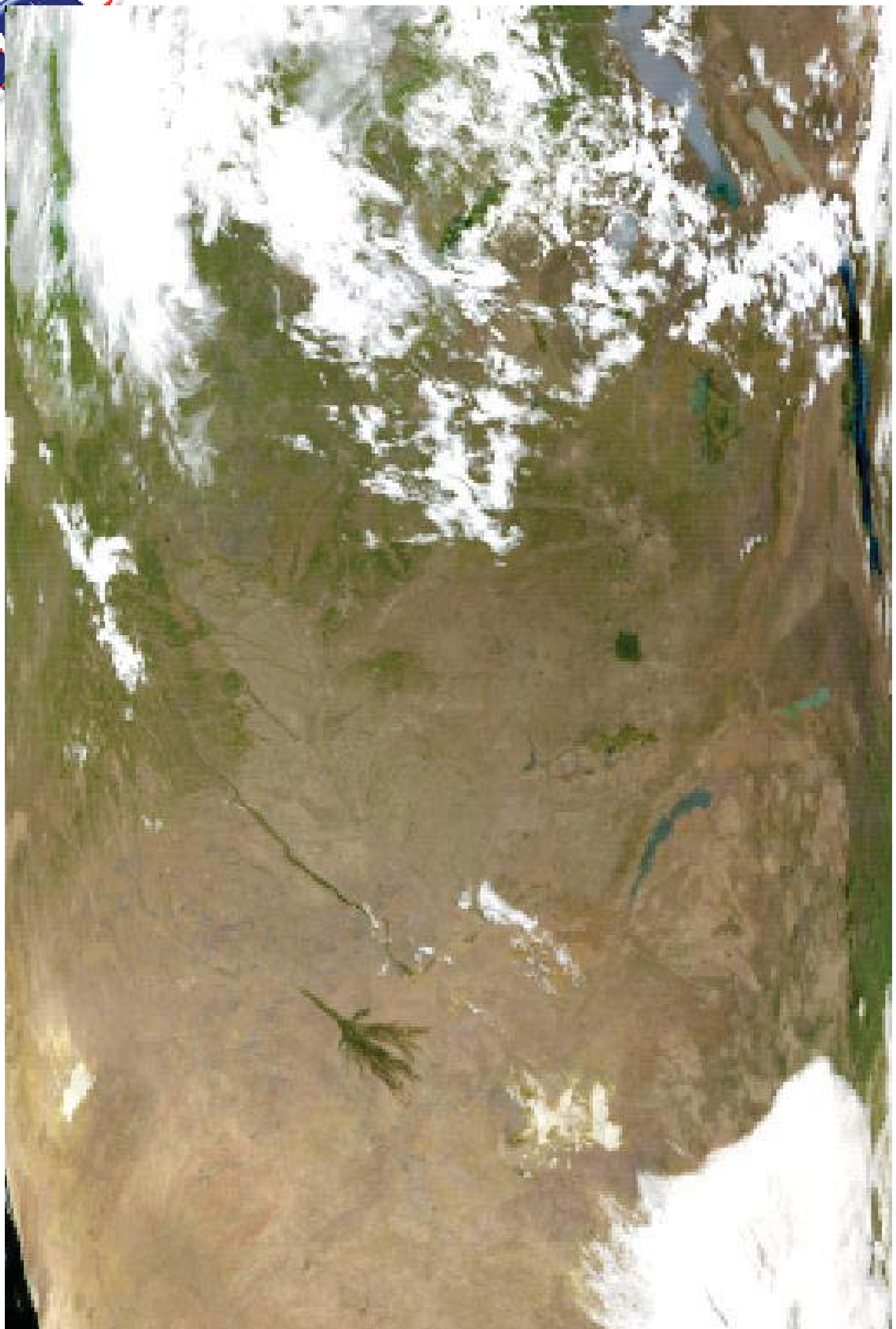
MODIS Granule over Southern Africa (Sept 13,2001, 8:45 to 8:50 GMT)

Red, Green, Blue MODIS top of atmosphere reflectance

No atmospheric correction

Surface Reflectance: Atmospheric effect has a strong impact on remotely sensed data

of Earth Observation
Data for Environmental



MODIS Granule over Southern Africa
(Sept 13,2001, 8:45 to 8:50 GMT)

Red, Green, Blue MODIS surface reflectance

With atmospheric correction

of Earth Observation
Data for Environmental

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).

Goal: to remove the influence of

- atmospheric gases
  - NIR differential absorption for water vapor
  - EPTOMS for ozone
- aerosols
  - own aerosol inversion

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

Movie credit: Blue Marble Project (by R. Stöckli)
Reference: R. Stöckli, E. Vermote, N. Saleous, R. Simmon, and D. Herring (2006) "True Color Earth Data Set Includes Seasonal Dynamics", EOS, vol. 87(5), 49-55.
www.nasa.gov/vision/earth/features/blue_marble.html

Basis of the AC algorithm

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)

Vector RT modeling

The **Collection 5 atmospheric correction algorithm look-up tables** are created on the basis of RT simulations performed by the **6SV** (**S**econd **S**imulation of a **S**atellite **S**ignal in the **S**olar **S**pectrum, **V**ector) code, which enables accounting for **radiation polarization**.

May 2005: the release of a β-version of the vector 6S (**6SV1.0B**)

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. . . . e x t e n s i v e   v a l i d a t i o n   a n d   t e s t i n g . . . . .

. . . .

May 2007: the release of version 1.1 of the vector 6S (**6SV1.1**)

6SV Features

Spectrum: 350 to 3750 nm

Molecular atmosphere: 7 code-embedded + 6 user-defined models

Aerosol atmosphere: 6 code-embedded + 4 user-defined (based on components and distributions) + AERONET

Ground surface: homogeneous and non-homogeneous with/without directional effect (10 BRDF + 1 user-defined)

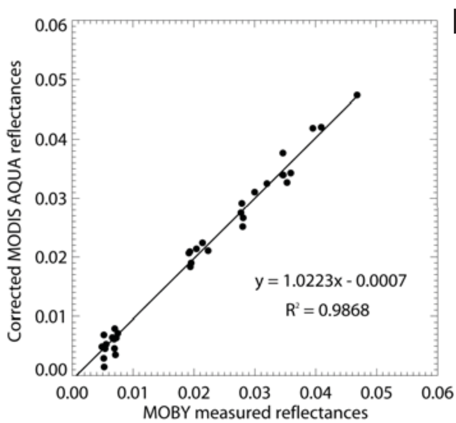
Instruments: AATSR, ALI, ASTER, AVHRR, ETM, GLI, GOES, HRV, HYPBLUE, MAS, MERIS, METEO, MSS, TM, MODIS, POLDER, SeaWiFS, VIIRS, and VGT

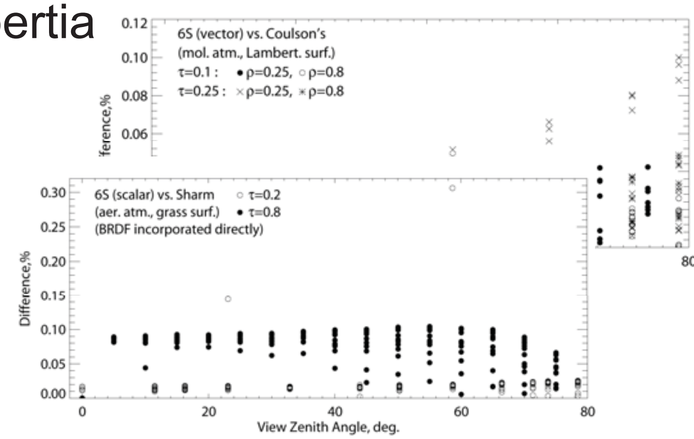
6SV Validation Effort

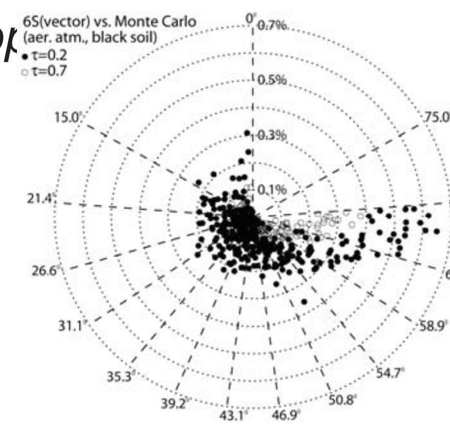
The complete 6SV validation effort is summarized in two manuscripts:

- S. Y. Kotchenova, E. F. Vermote, R. Matarrese, & F. Klemm, 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), 6726-6774, 2006.

- S. Y. Kotchenova & E. F. Vermote, Validation of a vector version of the 6S radiative transfer code for atmospheric correction of satellite data. Part II: mbertia ... *Ap*

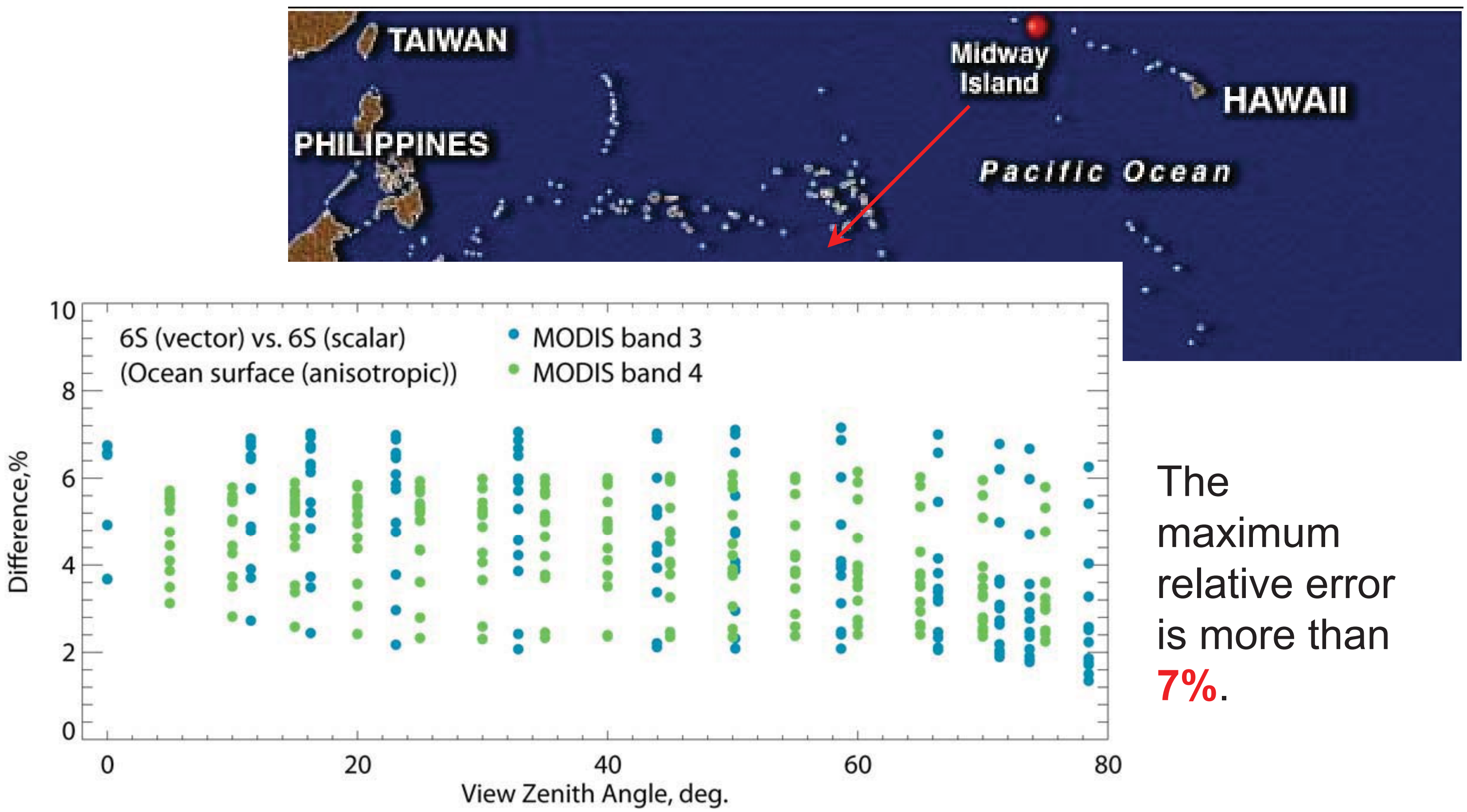






Effects of Polarization

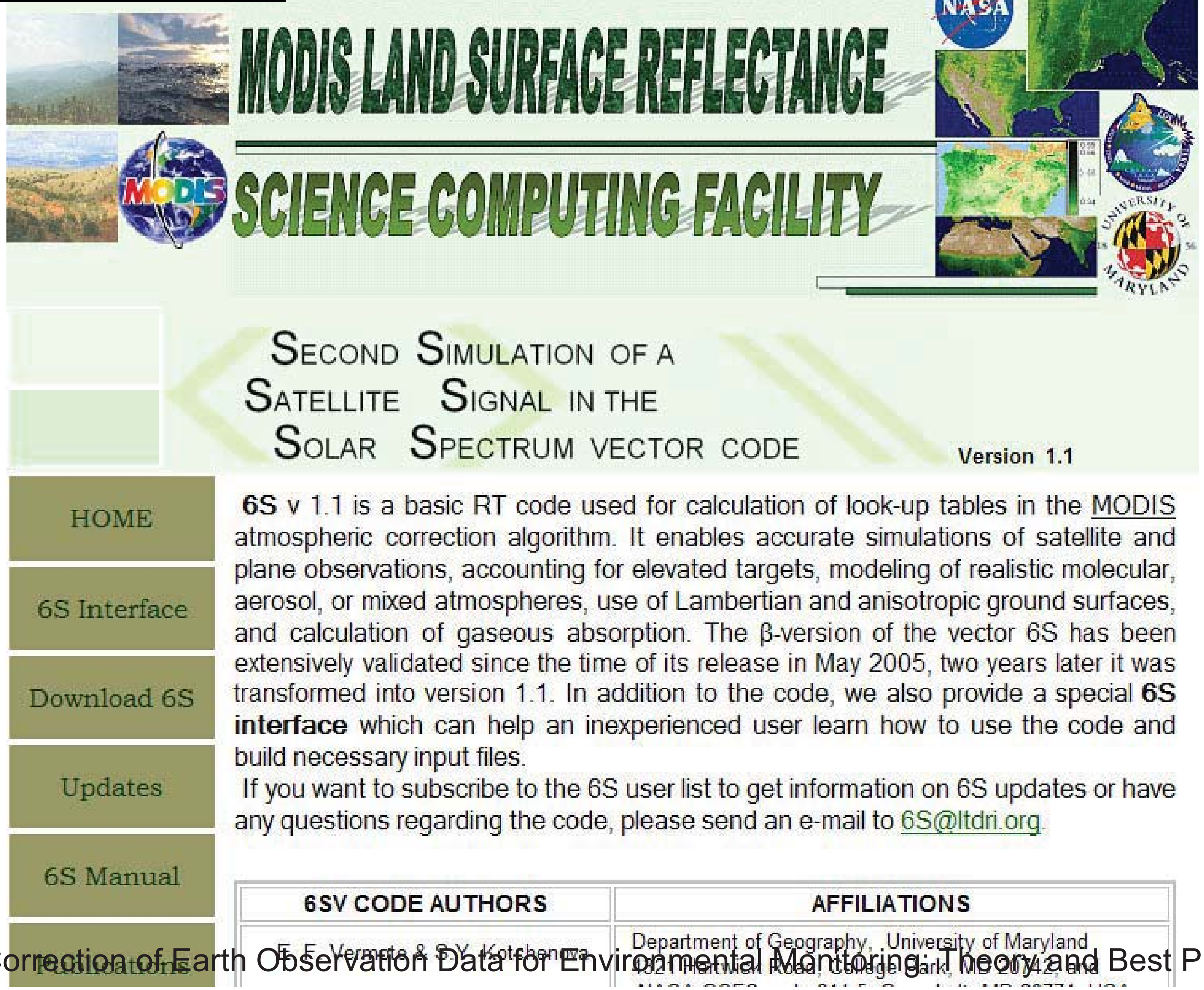
Example: Effects of polarization for the mixed (aerosol (from AERONET) + molecular) atmosphere bounded by a dark surface.



The maximum relative error is more than 7%.

6SV Web page

http://6S.ltdri.org



6SV Interface

We provide a special Web interface which can help an inexperienced user learn how to use 6SV and build necessary input files.

Make your own atmospheric correction

The 6s code predicts the satellite signal from 0.25 to 4.0 microns assuming cloudless atmosphere. The main atm
account. Non-uniform surfaces may be considered,as well as bidirectional reflectances as boundary conditions.

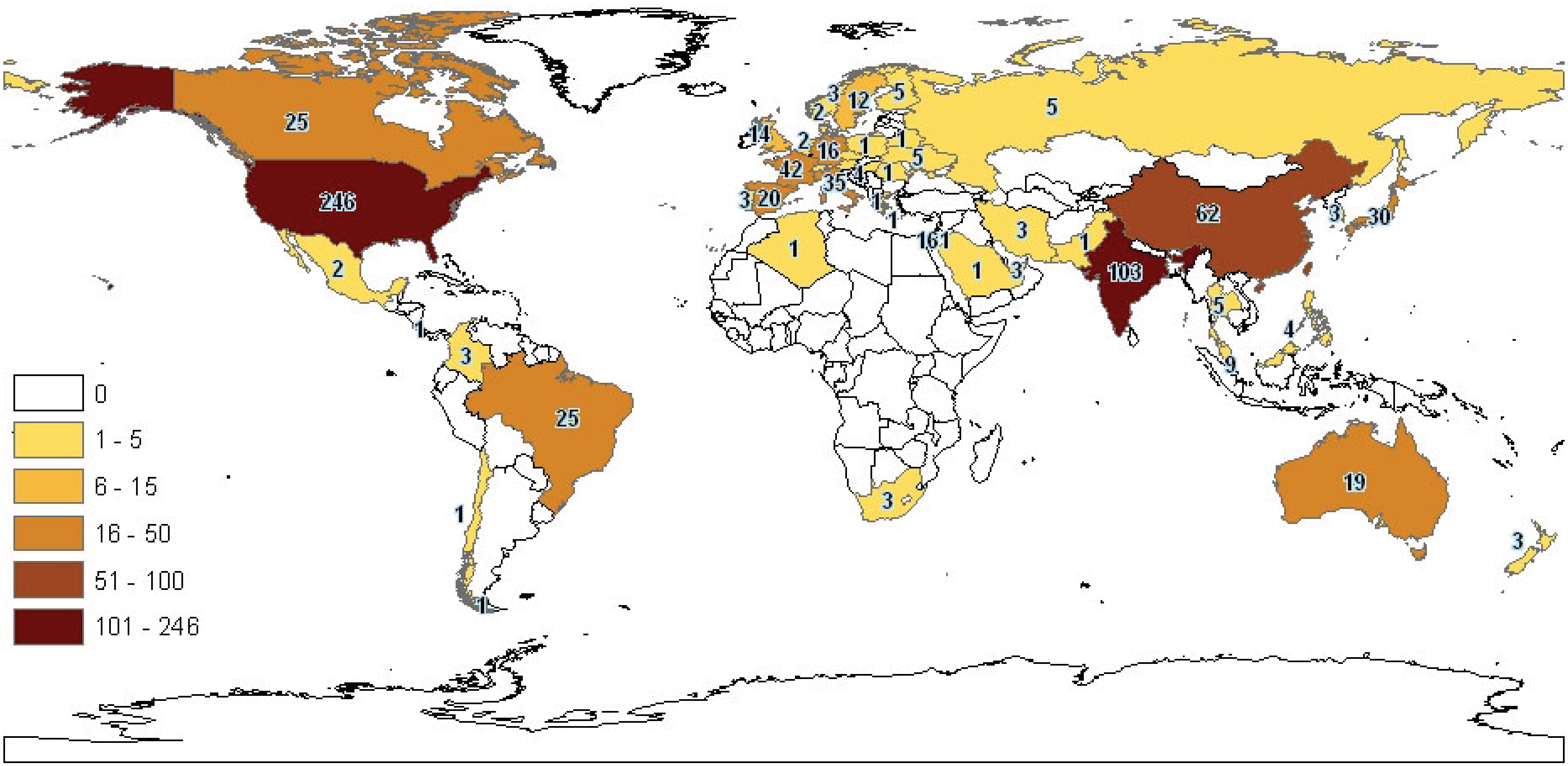
The following input parameters are needed

1. Geometrical conditions
2. Atmospherical Model
3. Target & Sensor Altitude
4. Spectral Conditions
5. Ground Reflectance
6. Signal
7. Results

At each step, you can either select some proposed standard conditions (for example, spectral bands of satellite

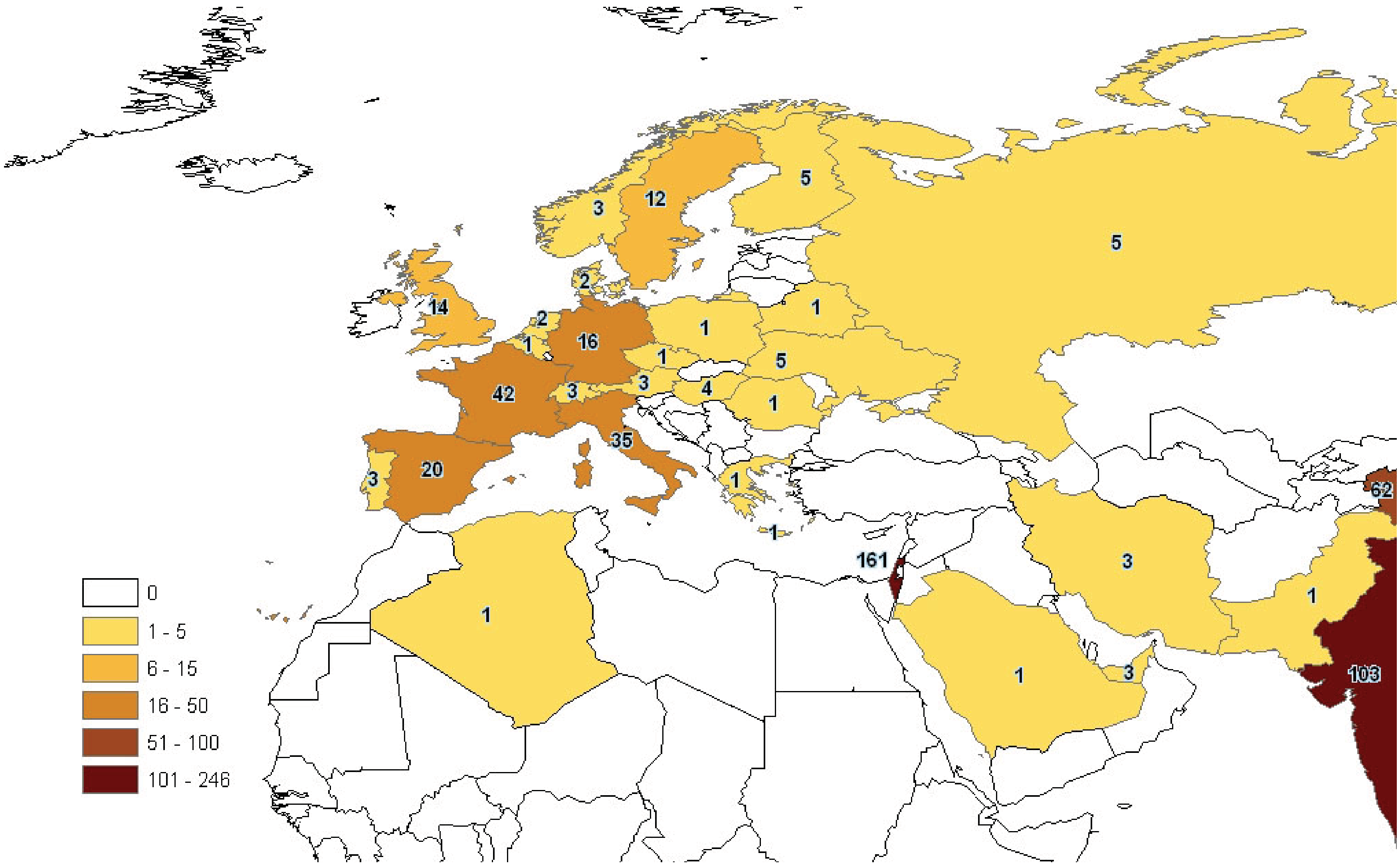
This interface also lets us track the number and location of 6SV users based on their IP addresses.

6SV Users (over the World)

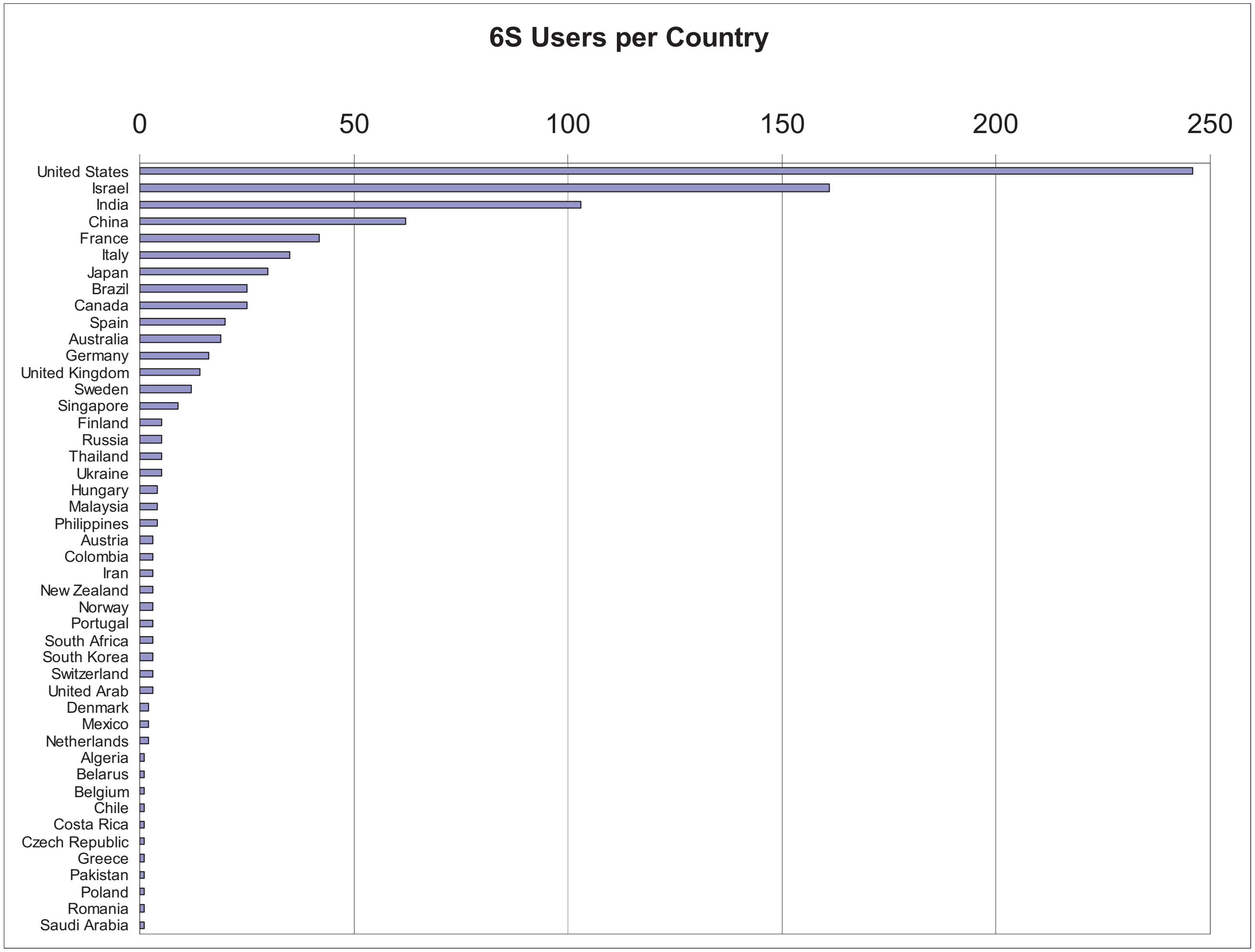


Total: 898 users

6SV Users (in Europe)

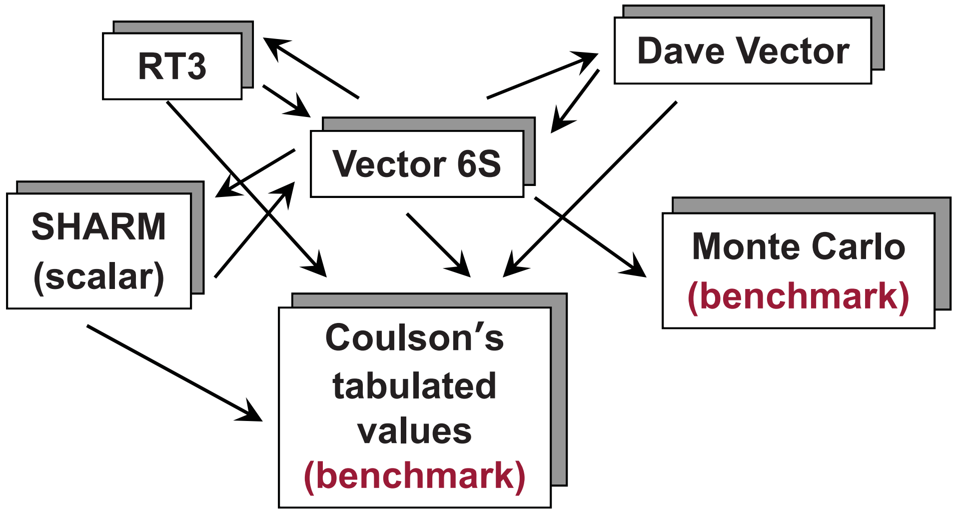


6SV Users (Distribution per Country)

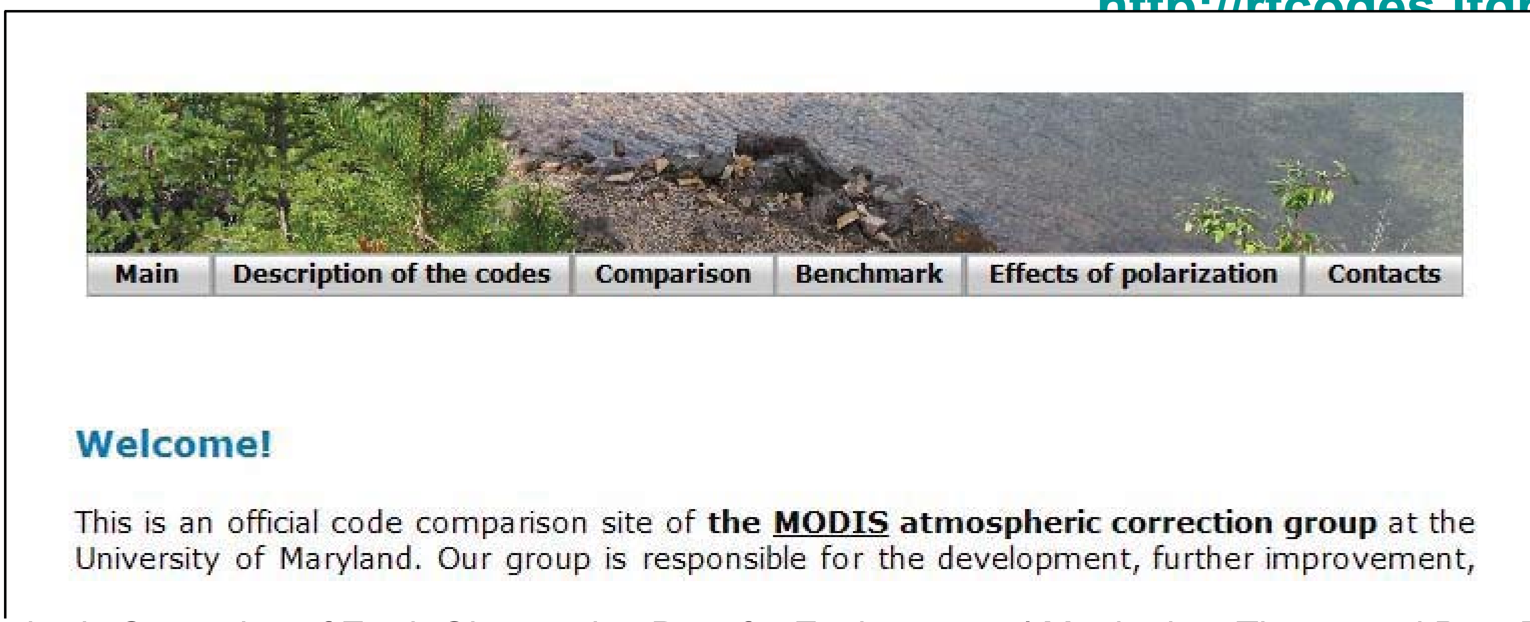


6SV e-mail distribution list: 142 users

Code Comparison Project (1)



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

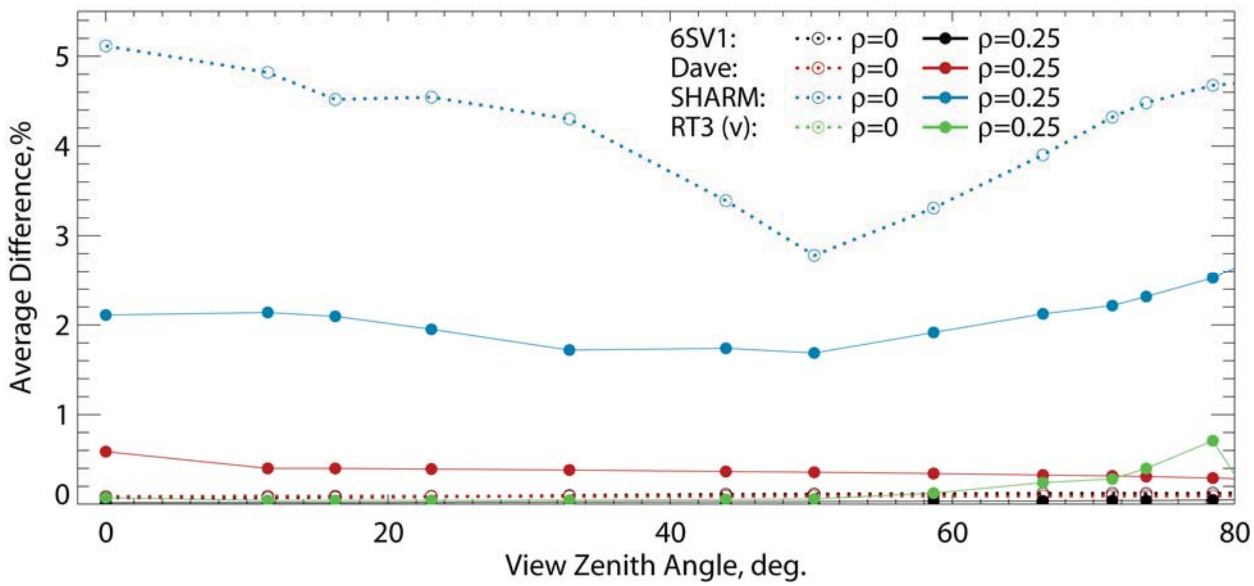


Code Comparison Project (2)

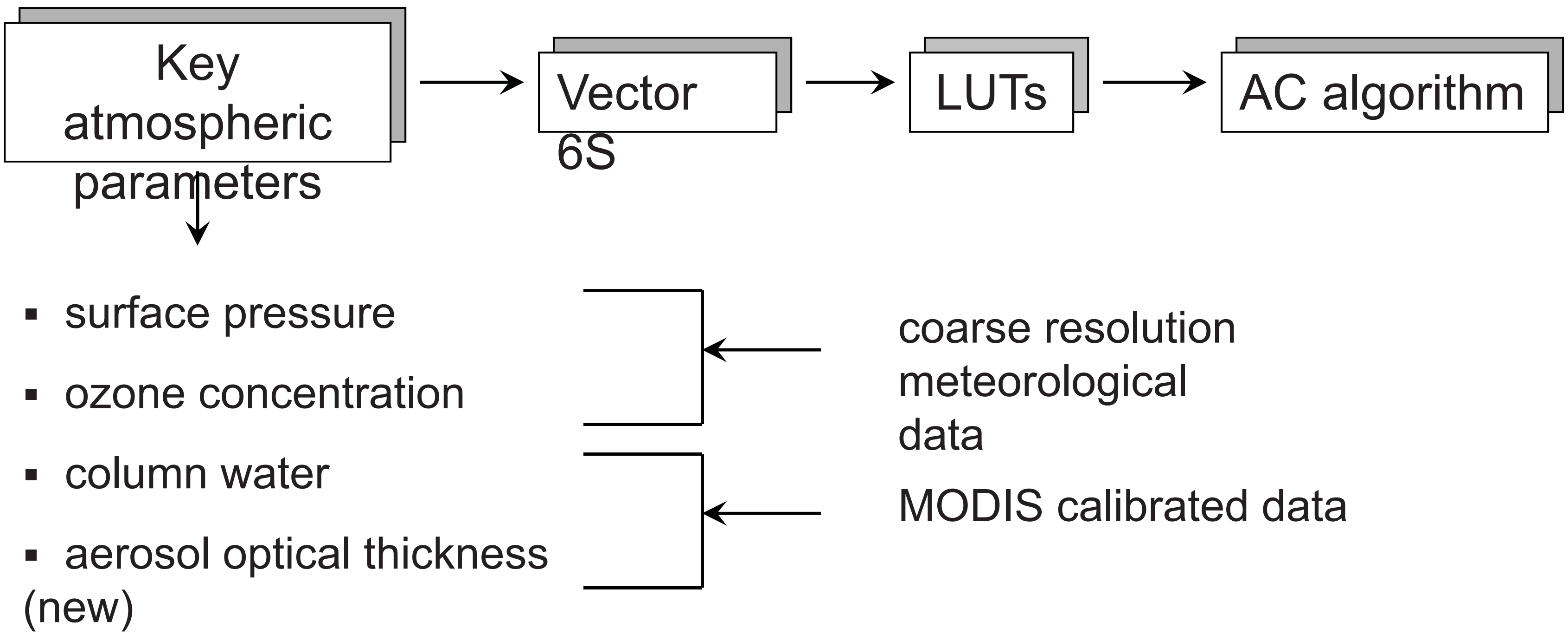
Goals:

- to illustrate the differences between individual simulations of the codes
- to determine how the revealed differences influence on the accuracy of atmospheric correction and aerosol retrieval algorithms

Example: Results of the comparison for a molecular atmosphere with τ = 0.25.



Input Data for Atmospheric Correction



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 (collection 4)

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

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 τ_{aer} considered.

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

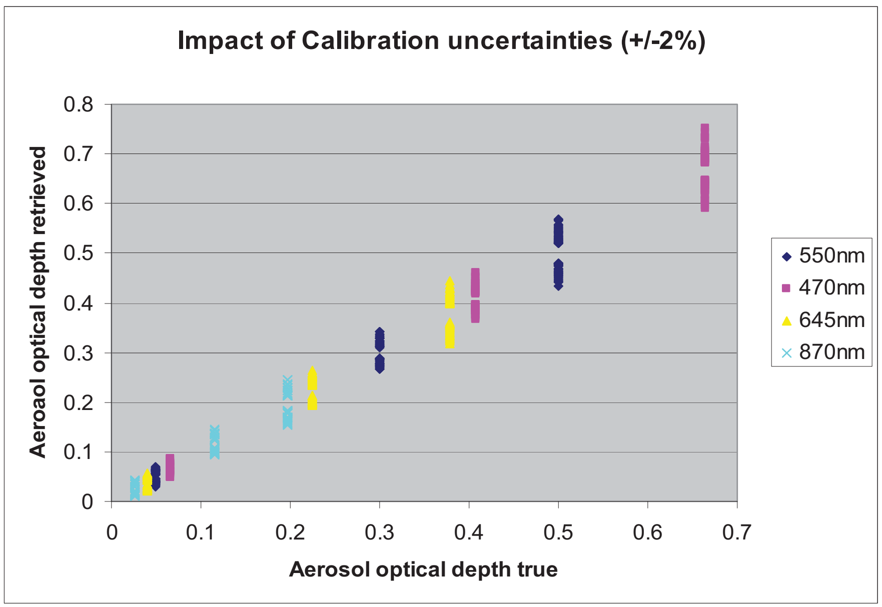


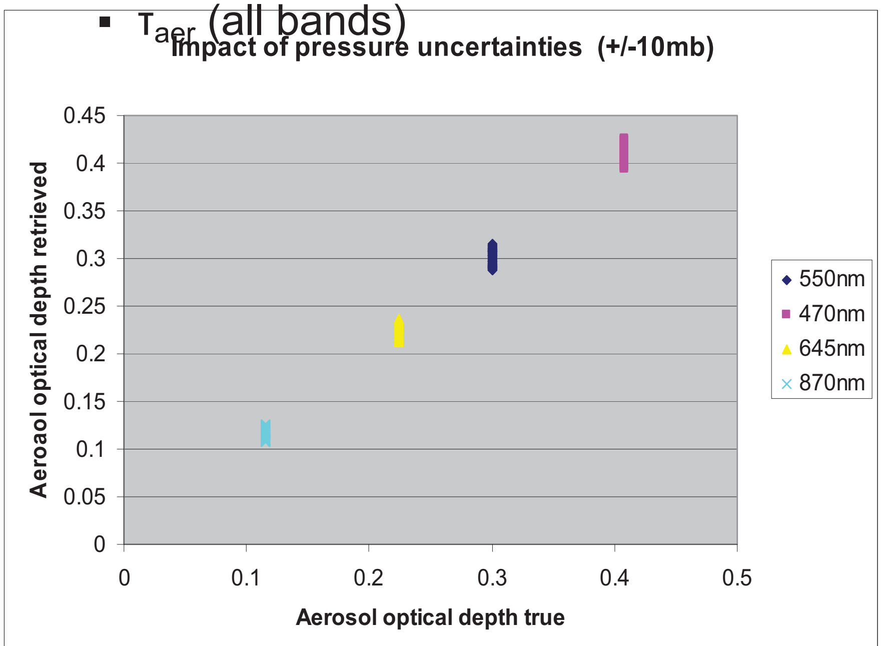
Table (example): Error on the surface reflectance (x 10,000) due to uncertainties in the absolute calibration for the Savanna site.

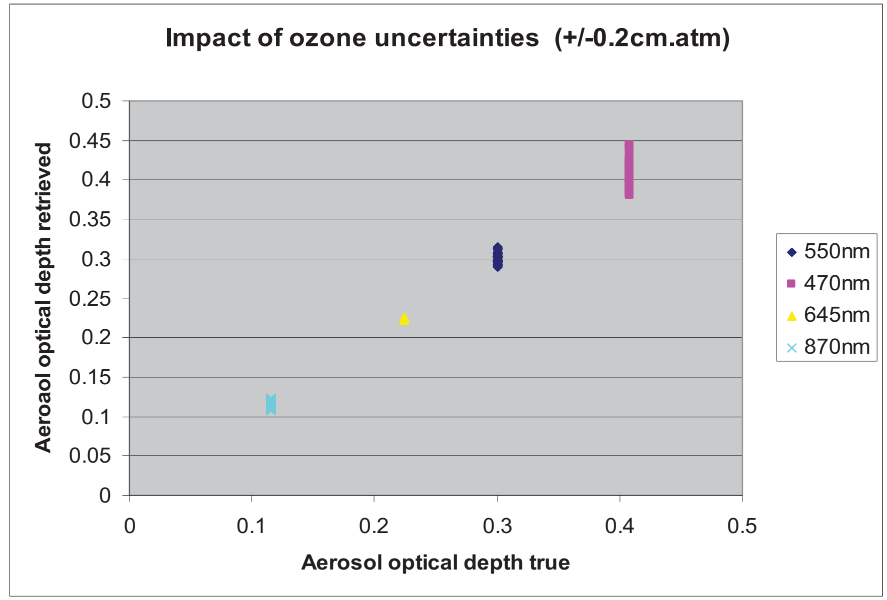
Central Wavelength (nm)		470	550	645	870	1,240	1,650	2,130
Surface Reflectance × 10,000		400	636	800	2,226	2,880	2,483	1,600
Maximum Error × 10,000	Clear	0013j	0013b	0024i	0065i	0080i	0080i	0080i
	Avg.	0015i	0015i	0030i	0074i	0079i	0070i	0054i
	High	0013d	0011a	0049i	0101i	0098i	0088i	0071i
Minimum Error × 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

Uncertainties on Pressure and Ozone

The pressure error has impact on

- molecular scattering (specific band)
- the concentration of trace gases (specific band)
- τ_{aer} (all bands)





The ozone error has impact on

- the band at 550 nm (mostly)
- the band at 470 nm → the retrieval of → τ_{aer} all bands

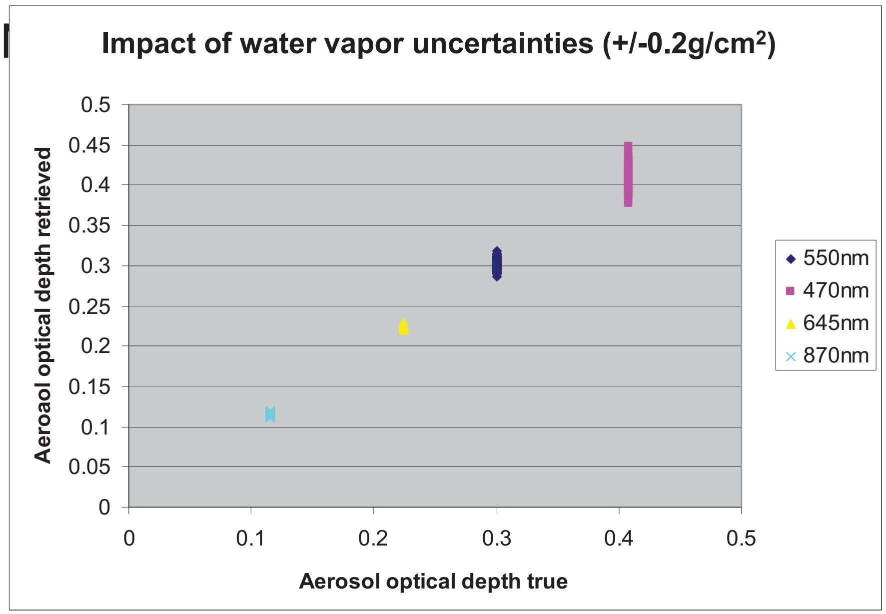
Uncertainties on Water Vapor

Retrieval of the column water vapor content:

- if possible, from MODIS bands 18 (931-941 nm) and 19 (915 – 965 nm) by using
  the differential absorption technique. The accuracy is better than 0.2 g/cm^2.
- if not, from meteorological data from I

Table (example): Error on the surface reflectance (x 10,000) due to uncertainties in the water vapor content for the Semi-arid site

Central Wavelength (nm)		470	550	645	870	1,240	1,650	2,130
Surface Reflectance × 10,000		700	1,246	1,400	2,324	2,929	3,085	2,800
Maximum Error × 10,000	Clear	0004d	0024j	0011i	0030i	0024i	0018i	0014i
	Avg.	0004d	0024j	0011i	0030i	0024i	0018i	0014i
	High	0004d	0024j	0011i	0030i	0024i	0018i	0014i
Minimum Error × 10,000	Clear	0001a	0005a	0008c	0005c	0000c	0000a	0015c
	Avg.	0001a	0004a	0006a	0004c	0000f	0000a	0010c
	High	0001a	0003a	0004c	0003c	0000c	0000a	0008c
Average Error × 10,000	Clear	3	7	11	9	4	1	21
	Avg.	2	4	7	6	2	0	13
	High	1	3	5	4	2	0	10



Retrieval of Aerosol Optical Thickness

Original approach: "dark and dense vegetation (DDV) technique" → a linear relationship between ρ_{VIS} → and ρ_{NIR} limitation to the scope of dark targets

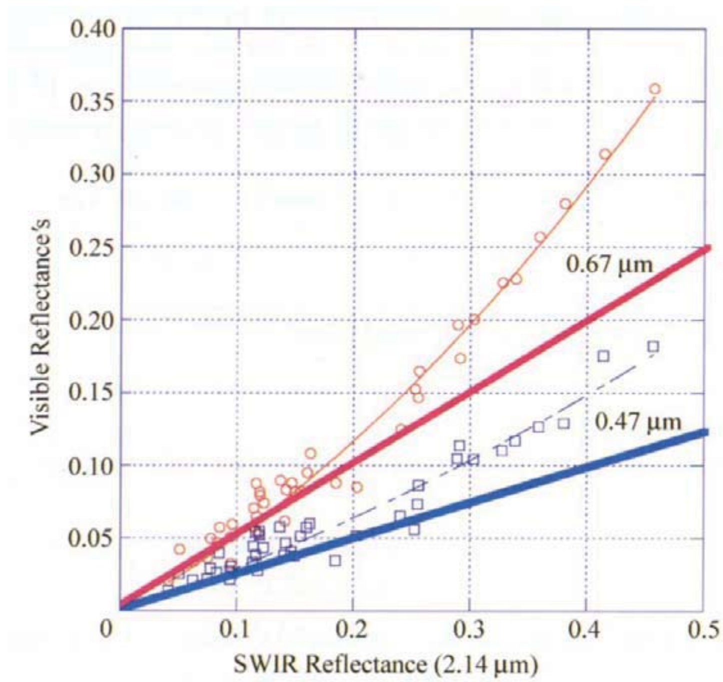
Current approach: a more robust "dark target inversion scheme"

↓

a non-linear relationship derived using a set of 40 AERONET sites representative of different land covers

↓

can be applied to brighter targets



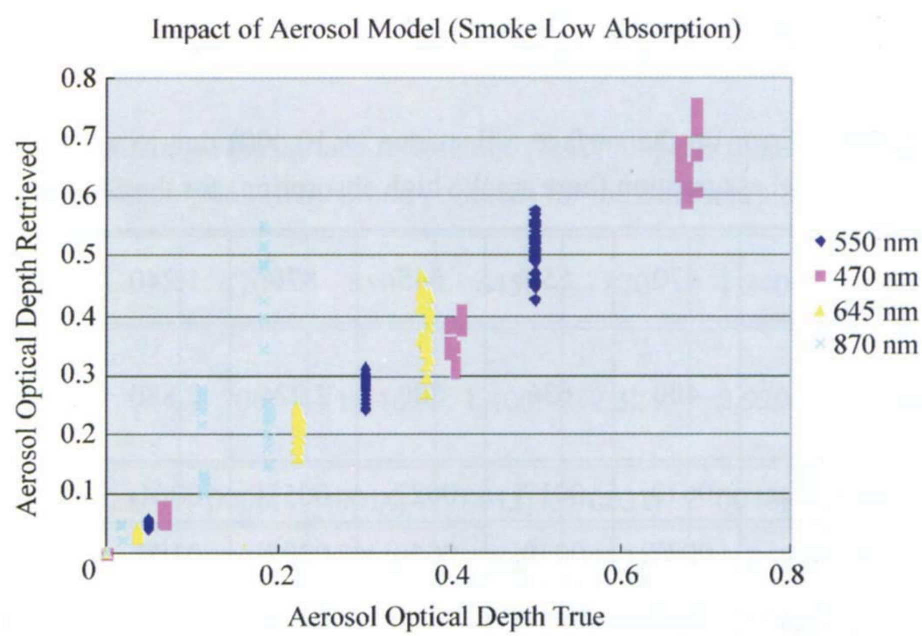
Uncertainties on the Aerosol Model

In the AC algorithm, an aerosol model is prescribed depending on the geographic location. We studied an error generated by the use of an improper model.

Prescribed: urban clean

Additional: urban polluted, smoke low absorption, smoke high absorption

The choice of the aerosol model is critical for the theoretical accuracy of the current product (in particular, for the accuracy of optical thickness retrievals).



Collection 5 Aerosol Inversion Algorithm

Pioneer aerosol inversion algorithms for AVHRR, Landsat and MODIS (*Kaufman et al.*)

(the shortest λ is used to estimate the aerosol properties)

Refined aerosol inversion algorithm

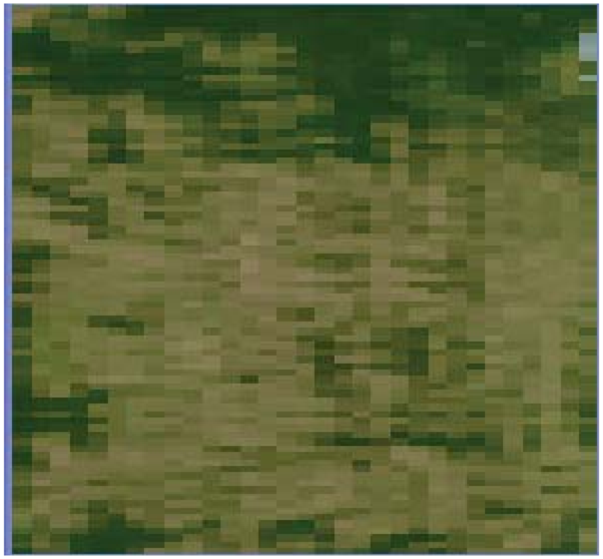
- use of all available MODIS bands (land + ocean e.g. 412nm as in Deep Blue)
- improved LUTs
- improved aerosol models based on the AERONET climatology
- a more robust "dark target inversion scheme" using Red to predict the blue reflectance values (in tune with *Levy et al.*)
- inversion of the aerosol model (rudimentary)

Example 1: Alta_Floresta 2003197 14:30 (SCF)

Aeronet				
AOT	delta AOT	WV	delta WV	DTaot
0.29856	0.00153	2.91618	0.01956	15

MOD09				
avg AOT	std AOT	avg WV	std WV	nb obs
0.22569	0.02469	3.08241	0.06199	46

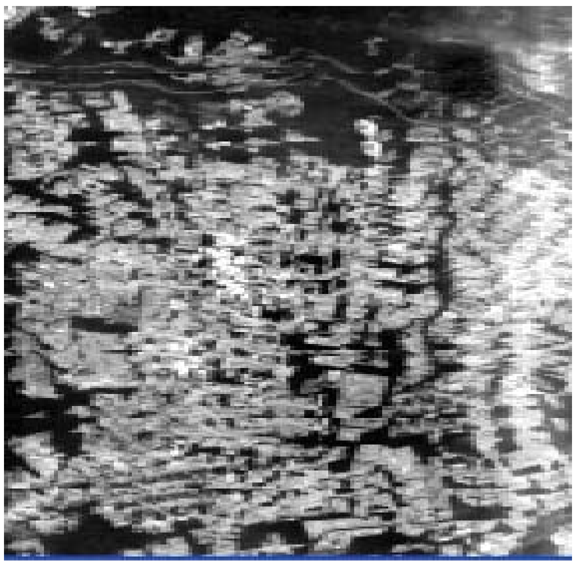
RGB (670 nm, 550 nm, 470 nm)
Top-of-atmosphere reflectance



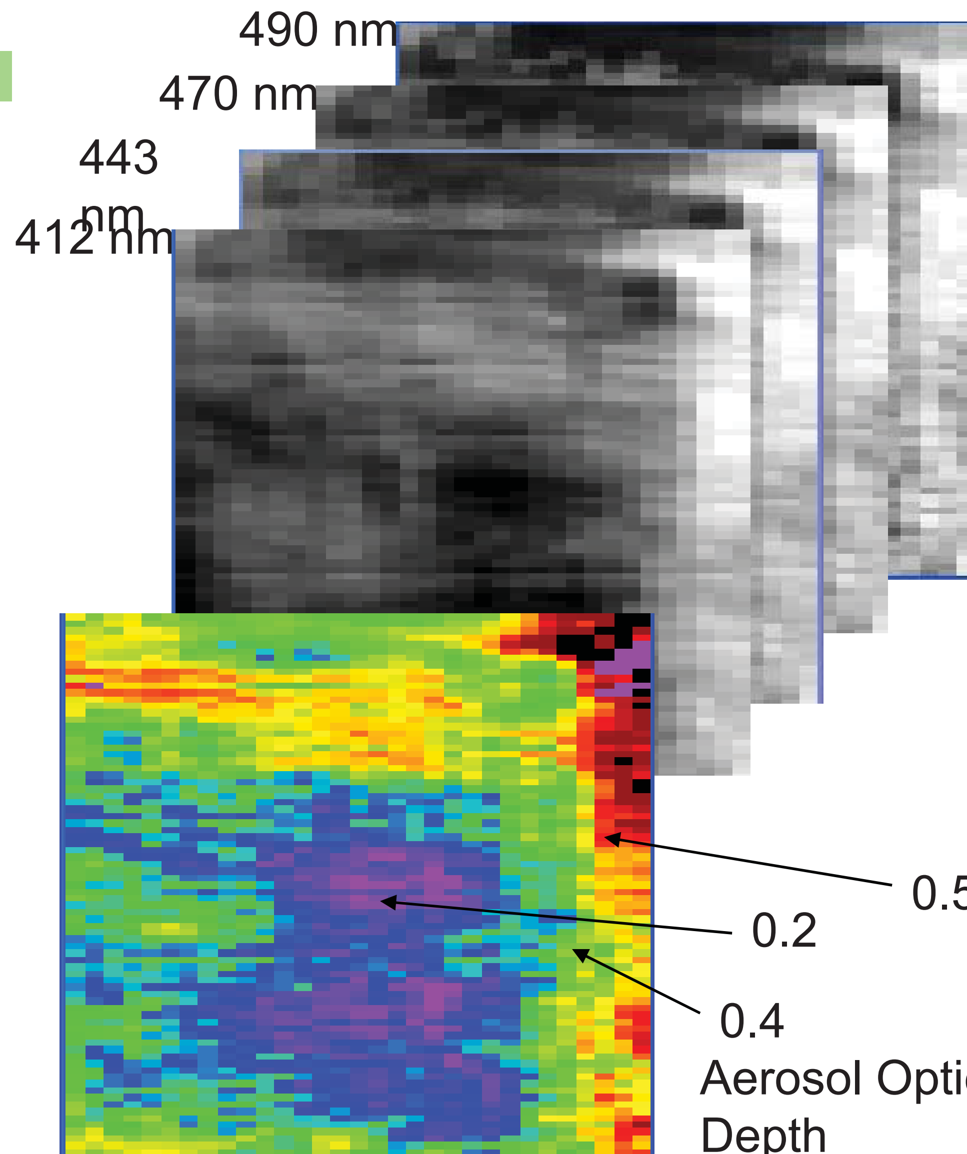
RGB (670 nm, 550 nm, 470 nm)
Surface reflectance

Example 1: **Alta_Floresta 2003197 14:30 (SCF)**

Aeronet				
AOT	delta AOT	WV	delta WV	DTaot
0.29856	0.00153	2.91618	0.01956	15



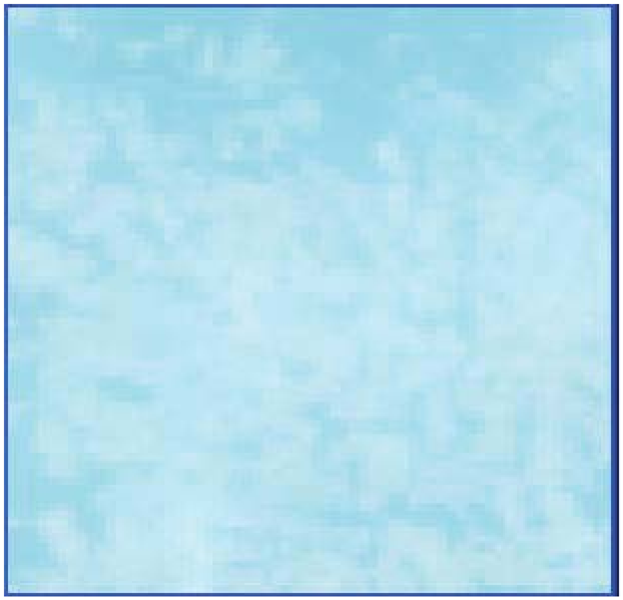
Red (670nm)
Top-of-atmosphere reflectance



Example 2: **Alta_Floresta 2003256 14:10 (SCF)**

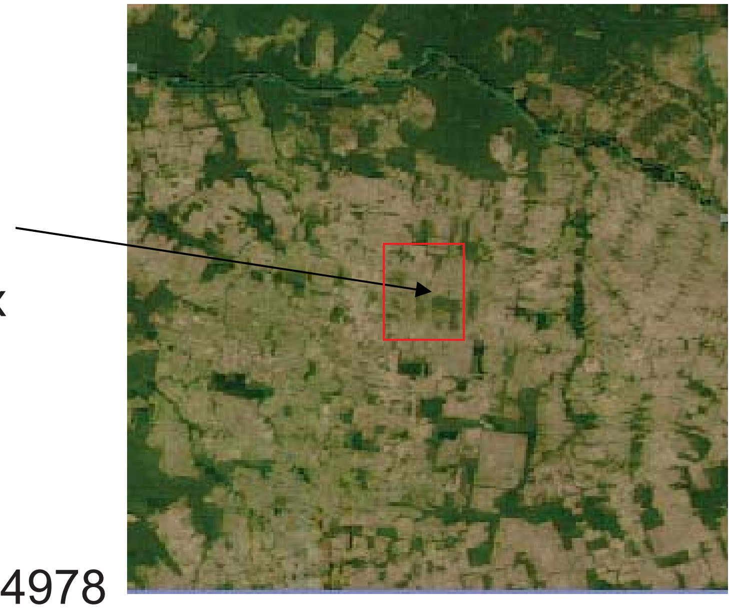
Aeronet				
AOT	delta AOT	WV	delta WV	DTaot
0.86180	0.01204	5.94636	0.00395	14

MOD09				
avg AOT	std AOT	avg WV	std WV	nb obs
0.95974	0.26412	3.67405	0.06463	0



RGB (670 nm, 550 nm, 470 nm)
Top-of-atmosphere reflectance

AOT= 0.896 (7km x 7km)
Model residual:
Smoke LABS: 0.003082
Smoke HABS: 0.004978
Urban POLU: 0.04601
Urban CLEAN: 0.006710



RGB (670 nm, 550 nm, 470 nm)
Surface reflectance

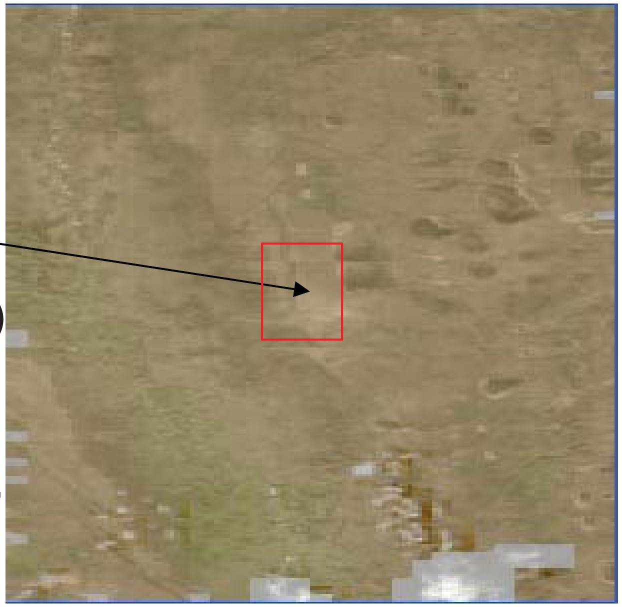
Example 3: **Mongu 2003257 08:20 (SCF)**

Aeronet				
AOT	delta AOT	WV	delta WV	DTaot
0.98179	0.01919	2.18265	0.00130	14

MOD09				
avg AOT	std AOT	avg WV	std WV	nb obs
0.98953	0.04857	1.87310	0.04040	0

RGB (670 nm, 550 nm, 470 nm)
Top-of-atmosphere reflectance

AOT= 0.927 (7km x 7km)
Model residual:
Smoke LABS: 0.005666
Smoke HABS: 0.004334
Urban POLU: 0.004360
Urban CLEAN: 0.005234



RGB (670 nm, 550 nm, 470 nm)
Surface reflectance

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.

Performance of the MODIS C5 algorithms

To evaluate the performance of the MODIS Collection 5 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

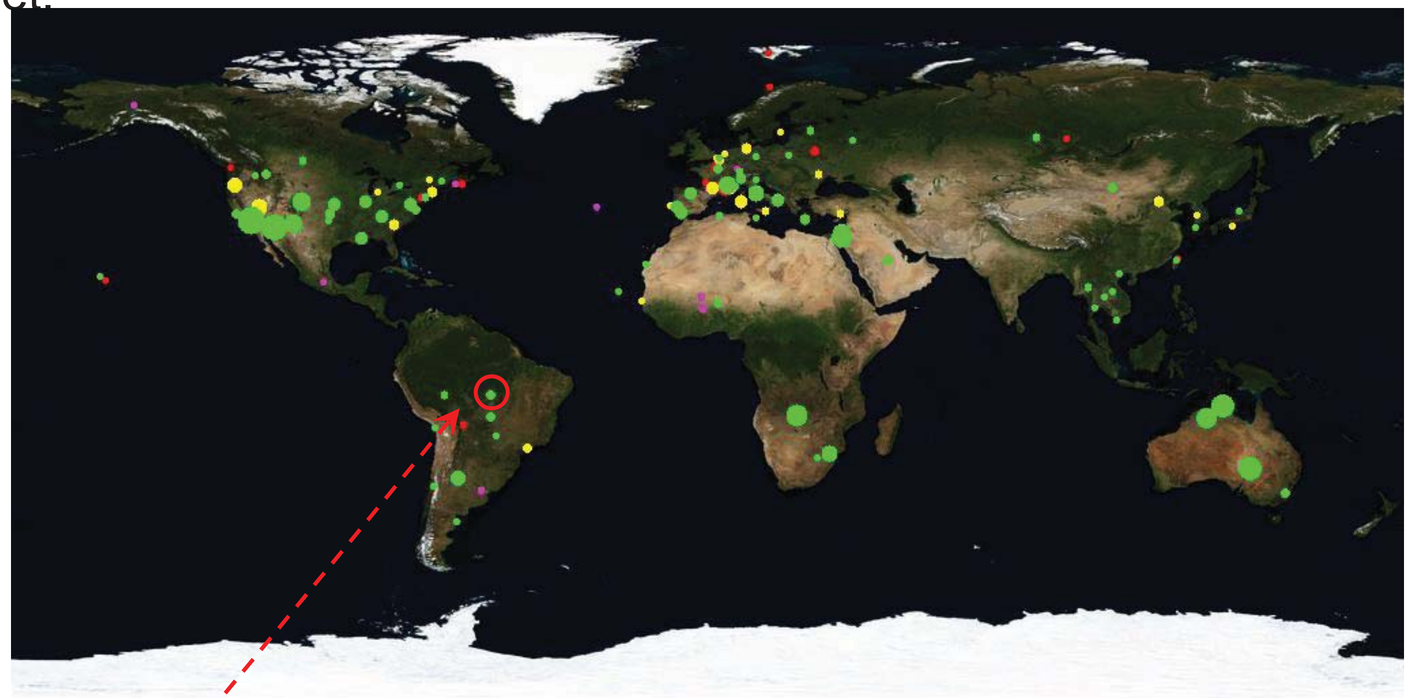
AERONET measurements (τ_{aer}, H_2O, particle distribution)

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 (1)

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:

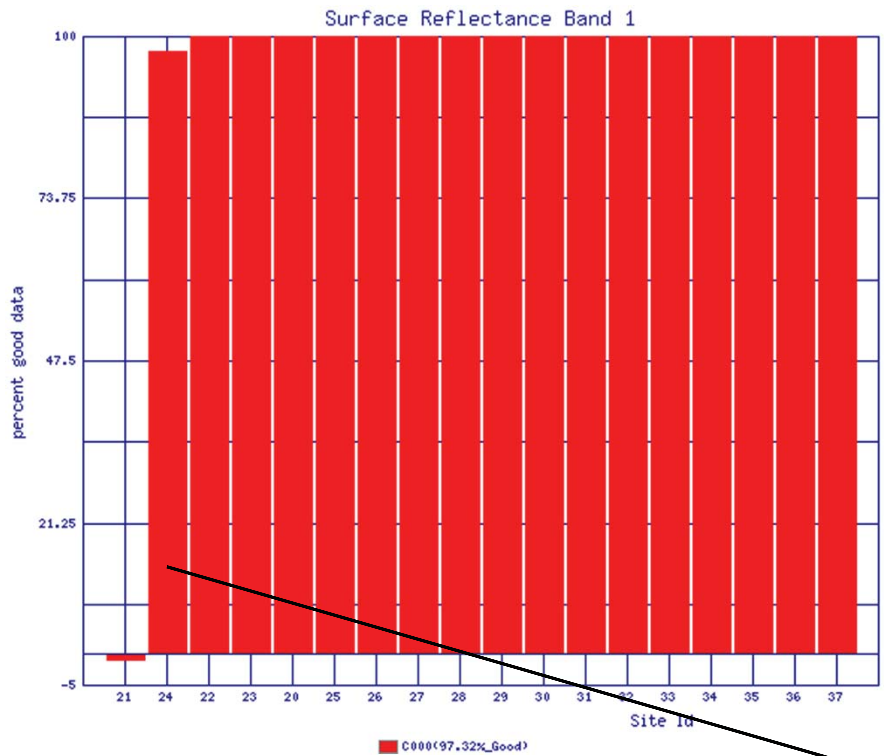
green > 80%, 65% < yellow <80%, 55% < magenta < 65%, red <55%.

The circle radius is proportional to the number of observations.

Clicking on a particular site will provide more detailed results for this site.

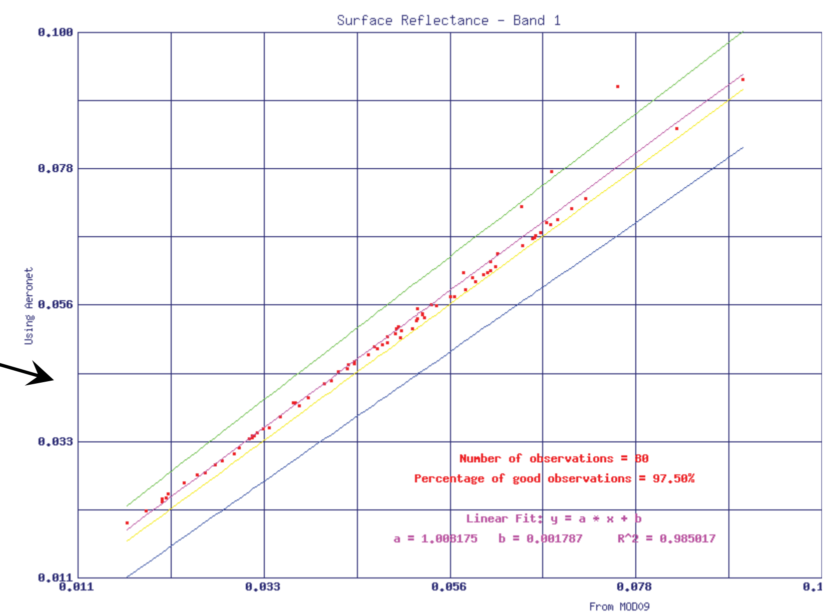
Validation of MOD09 (2)

Example: Summary of the results for the Alta Foresta site.



Each bar: date & time when coincident MODIS and AERONET observations are available

The size of a bar: the % of "good" surface reflectance observations



Scatter plot: the retrieved surface reflectances vs. the reference data set along with the linear fit results

Validation of MOD09 (3)

In addition to the plots, the Web site displays a table summarizing the AERONET measurement and geometrical conditions, and shows browse images of the site.

MOD09-SFC

Similar results are available for all MODIS surface reflectance products (bands 1-7).

Percentage of good:

band 1 – 86.62% band 5 – 96.36%

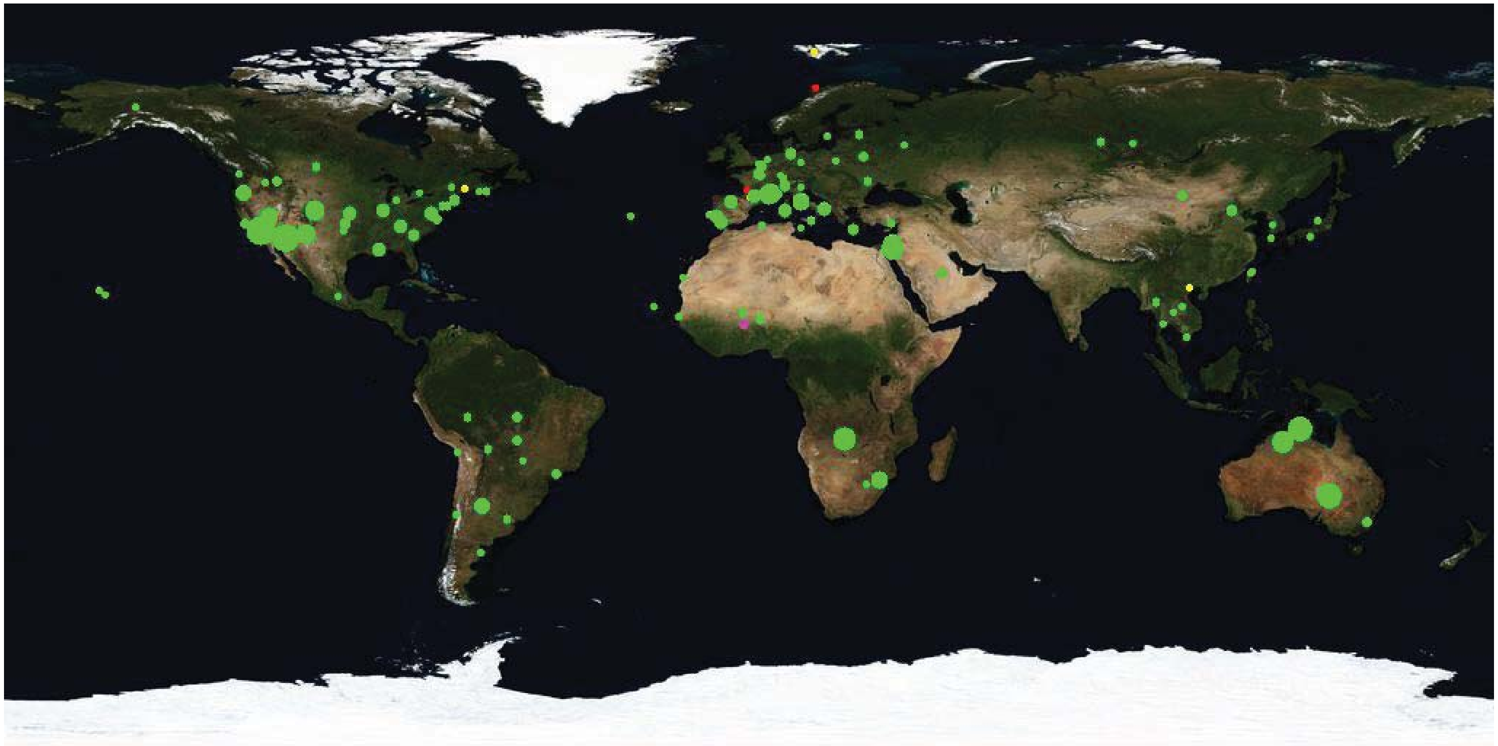
band 2 – 94.13% band 6 – 97.69%

band 3 – 51.30% band 7 – 98.64%

band 4 – 75.18%

Validation of MOD13 (NDVI)

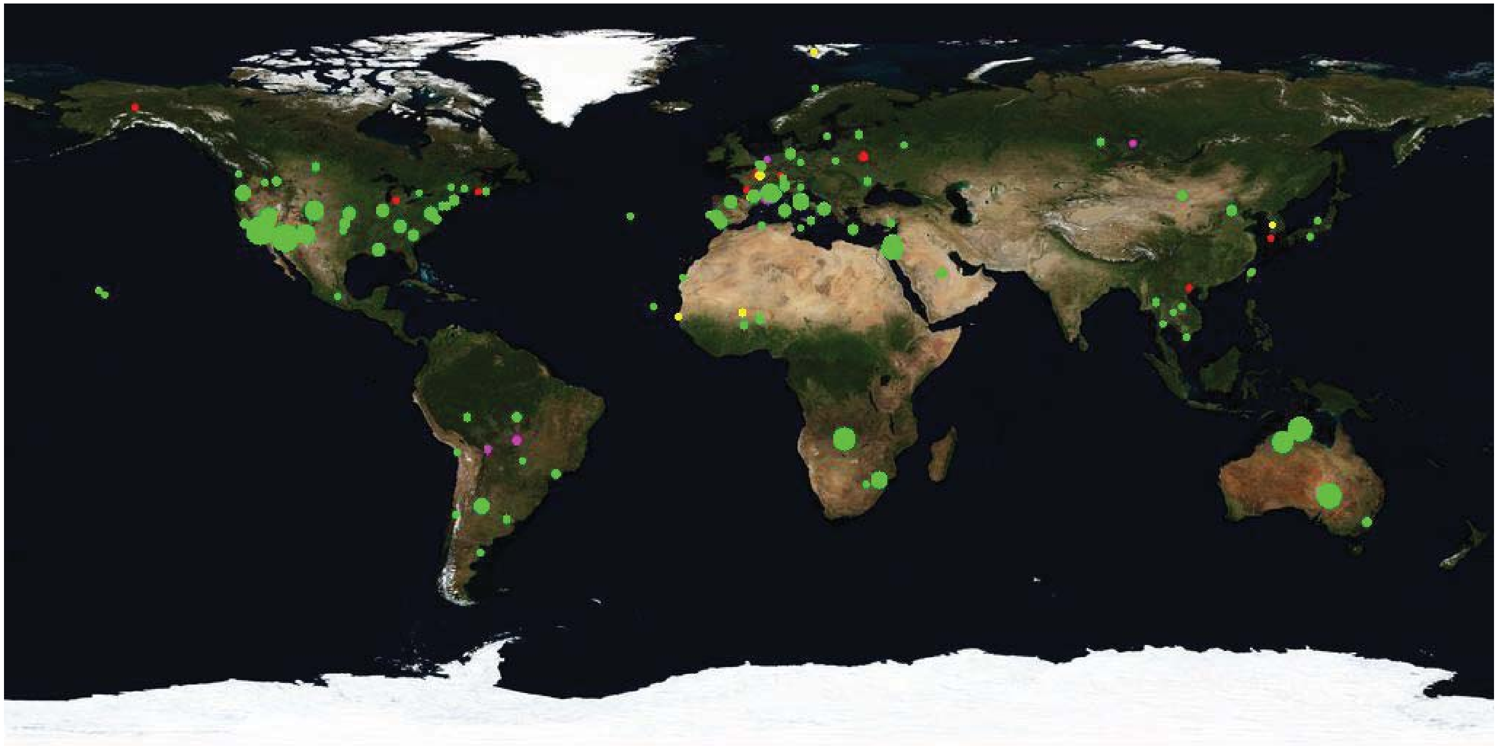
Comparison of MODIS NDVI and the reference data set for all available AERONET data for 2003. Globally, 97.11% of the comparison fall within the theoretical MODIS 1-sigma error bar (±(0.02 + 0.02VI)).



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

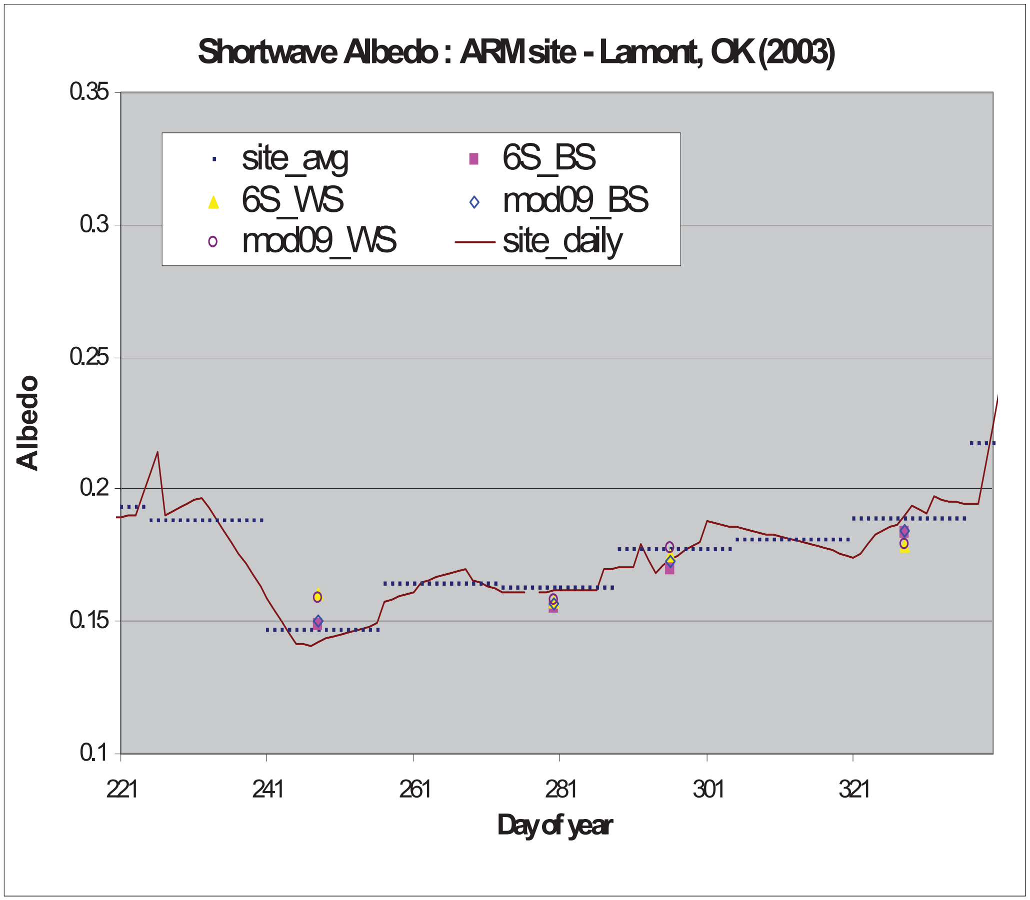
Validation of MOD09 (EVI)

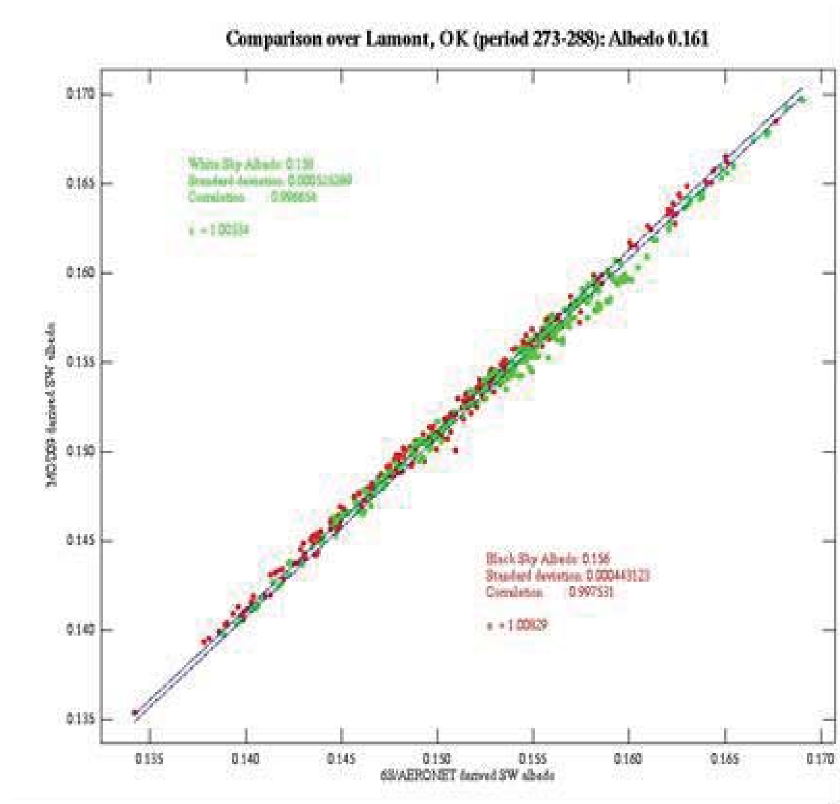
Comparison of MODIS EVI and the reference data set for all available AERONET data for 2003. Globally, 93.64% of the comparison fall within the theoretical MODIS 1-sigma error bar (±(0.02 + 0.02VI)).



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

Generalization of the approach for downstream product (e.g., Albedo)





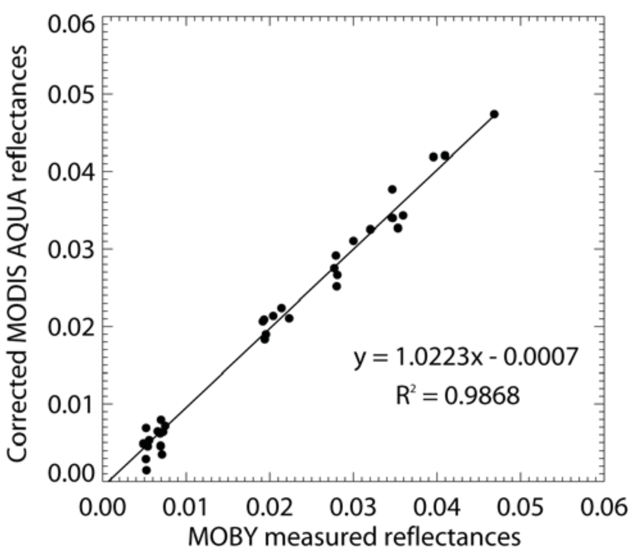
Collection 5

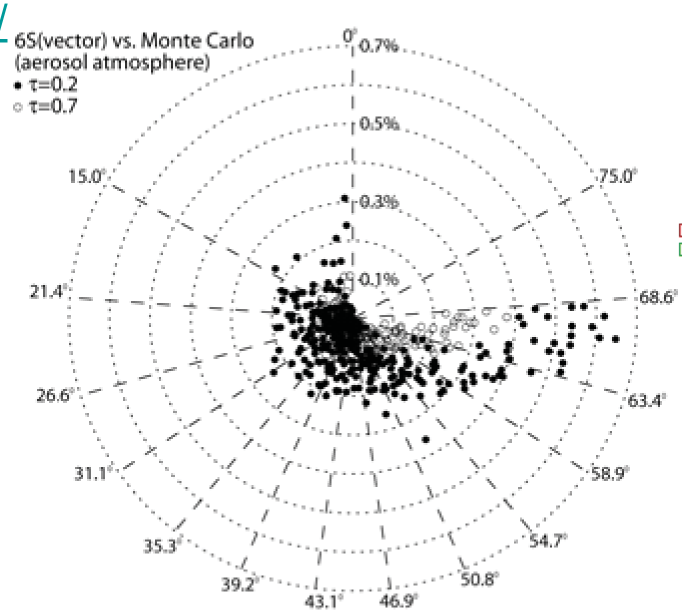
Collection 5:	Terra	Aqua
Surface Reflectance Daily L2G Global 250 m	MOD09GQ	MYD09GQ
Surface Reflectance Daily L2G Global 500 m and 1 km	MOD09GA	MYD09GA
Surface Reflectance 8-Day L3 Global 250 m	MOD09Q1	~~MYD09Q1~~
Surface Reflectance 8-Day L3 Global 500 m	MOD09A1	MYD09A1
Surface Reflectance Quality Daily L2G Global 1km	MOD09GST	MYD09GST
Surface Reflectance Daily L3 Global 0.05Deg CMG	MOD09CMG	MYD09CMG

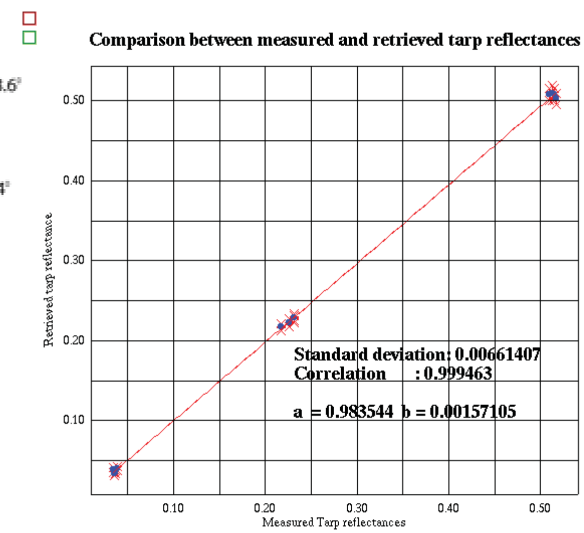
Description: http://modis-sr.ltdri.org
Availability: February 2000 through December 2000, Terra only
* CMG – Climate Modeling Grid

Approach for the surface reflectance product

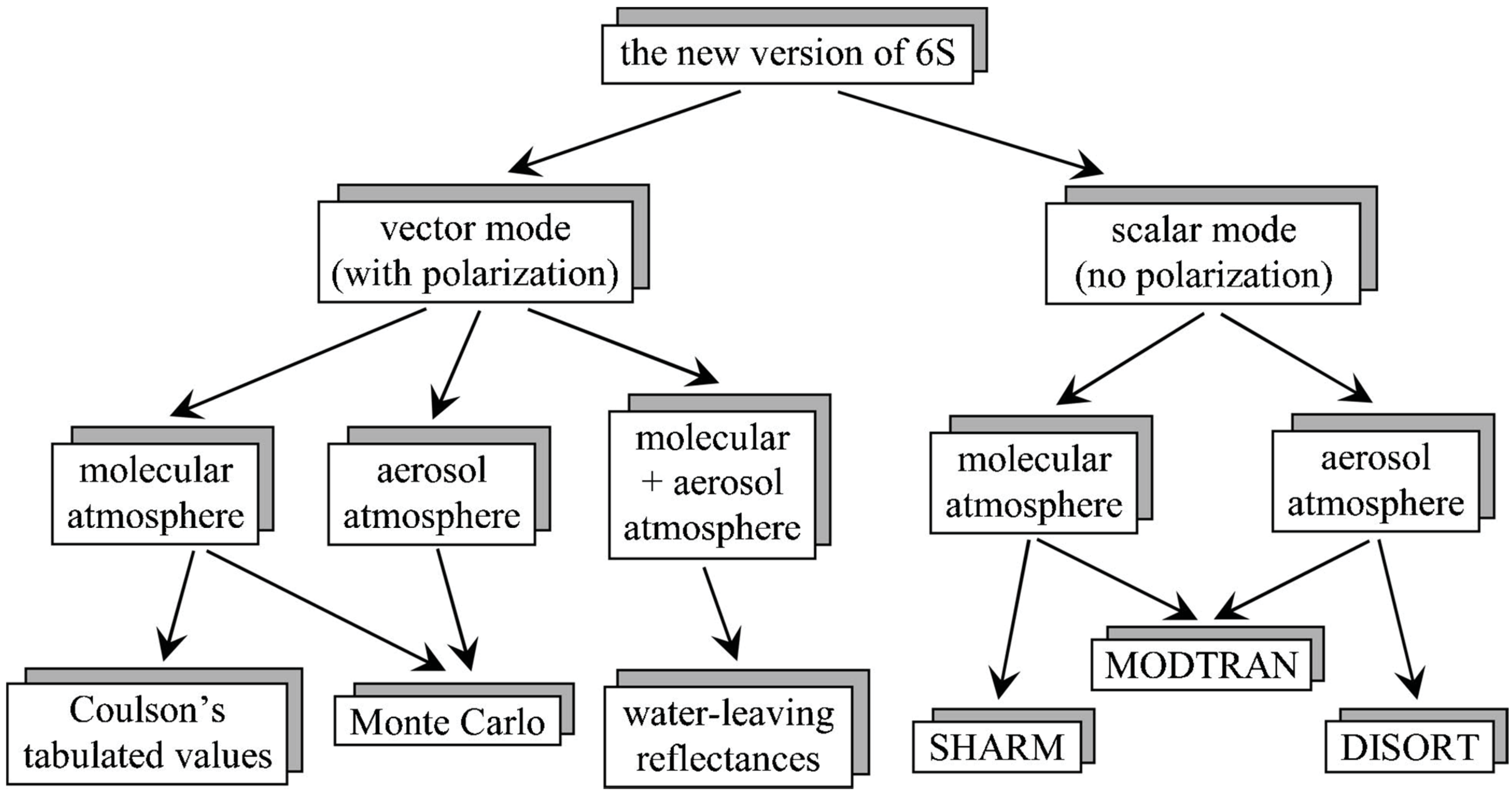
- **Atmospheric correction consistent with the MODIS, AVHRR and NPP-VIIRS approach, ensuring consistent reflectance data across resolutions based on rigorous radiative transfer**
  - http://6s.ltdri.org
  - http://rtcodes.ltdri.org/



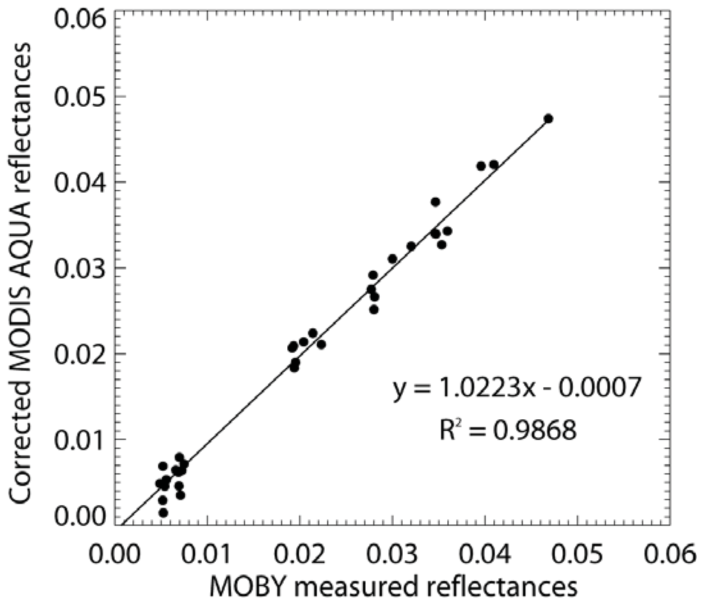




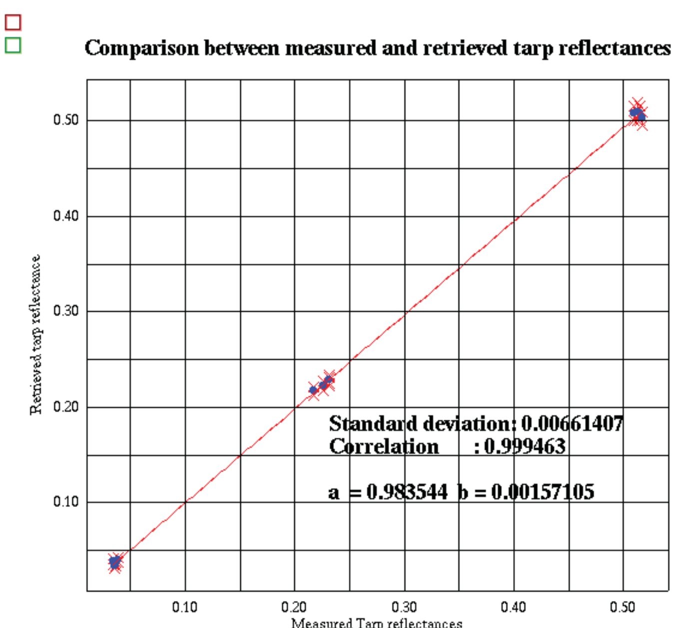
Validation of the 6S code



6SV Validation from ground measurements



The corrected MODIS AQUA water-leaving reflectances using AERONET and 6SV vs. the MOBY-measured water-leaving reflectances for λ = {412; 443; 490; 530; 550} nm. The MOBY data were collected off the coast of Lanai Island (Hawaii) during the year 2003 **(From Kotchenova et al., 2006).**



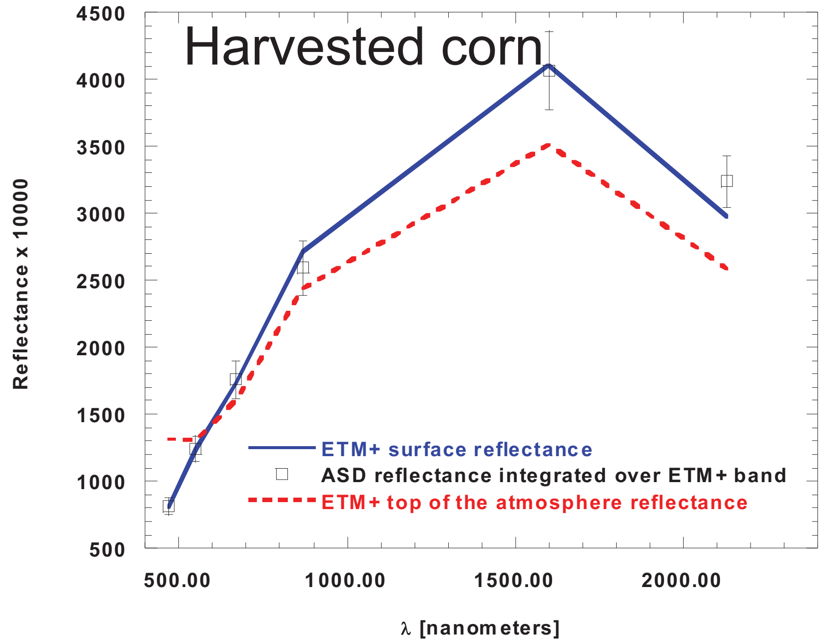
The corrected IKONOS reflectance's using AERONET and 6SV (including adjacency effect correction) vs. the reference tarp reflectance's. The data were acquired over Stennis Space flight Center on February, 15, 2002.

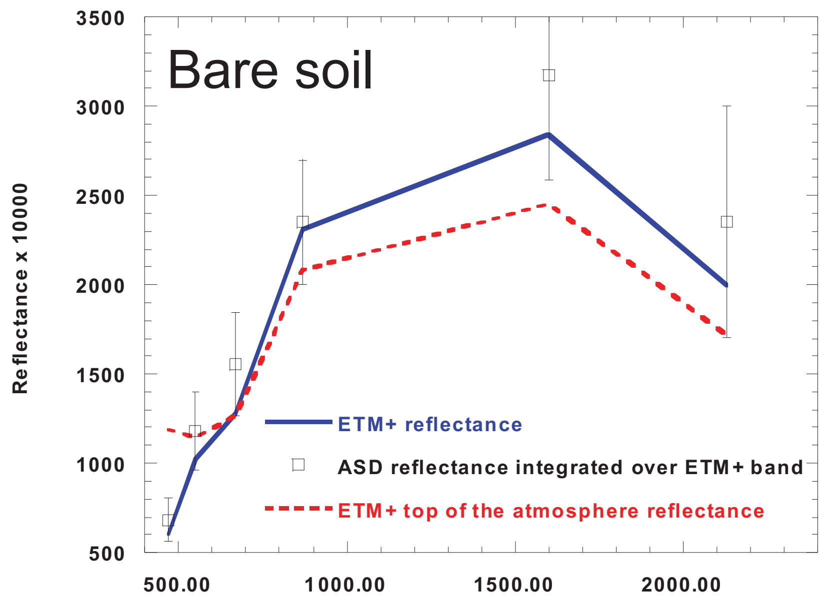
6S Radiative transfer code validation (Landsat)

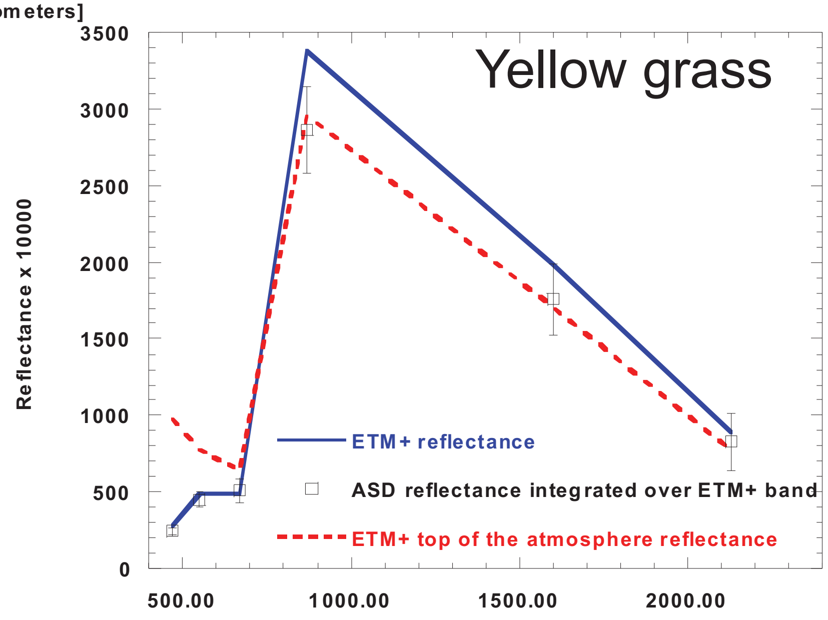
- Using AERONET sun photometer measurements, the atmospheric correction was performed over site where simultaneous measurements of the surface reflectance over selected sites (Bare soil, Harvested corn, Yellow grass) using a ASD spectrometer were performed.

- Despite strong heterogeneity of the sites showed by the measured standard deviation the agreement between the LANDSAT surface reflectance and the surface measurements is very good especially in the visible where the aerosol effect is the strongest.

6S Radiative transfer code validation (Landsat)



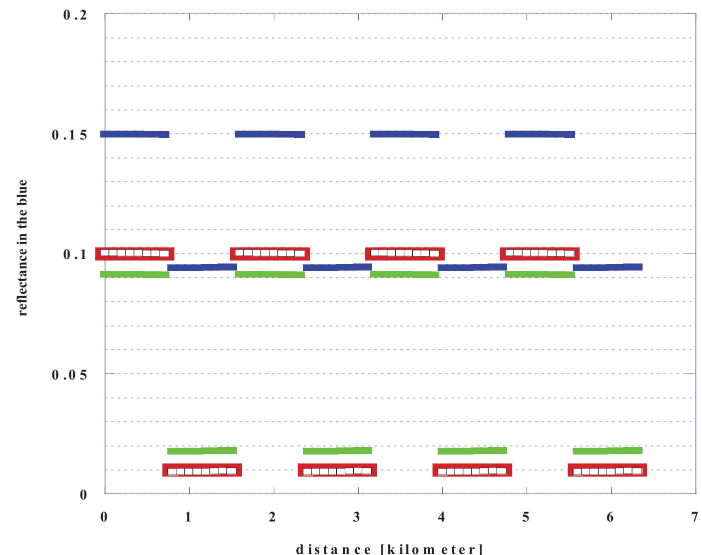


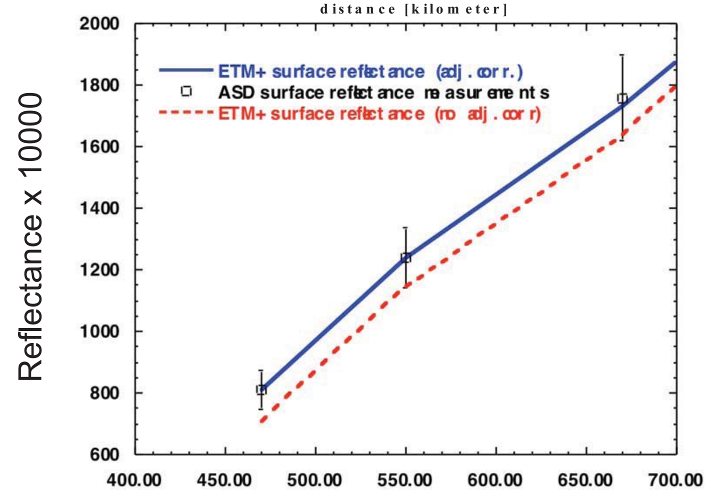


6SV Radiative transfer code validation (Landsat)

- Using the Harvested corn site (bright surrounded by dark forest) we were able to show that the adjacency effect correction tested theoretically was improved the agreement between measurement and Landsat surface reflectance

Reflectance's observed over a horizontal transect on the checkerboard. The red bars are the "true" surface reflectance, the blue bars correspond to the top of the atmosphere signal including adjacency effect. The green bars correspond to the corrected data using the infinite target assumption. The open square correspond to the data corrected for the adjacency effect using the operational method developed.





Theoretical uncertainties for the surface reflectance MODIS product

- **Validation and uncertainties estimates. Theoretical error budget, comprehensive evaluation.**

FOREST

Belterra

λ [nm]	ρ x10000	Clear	Average	Hazy
		$\Delta\rho$x10000		
470	120	52	51	52
550	375	49	55	64
645	240	52	59	65
870	2931	40	152	246
1240	3083	38	110	179
1650	1591	29	52	84
2130	480	41	28	42
NDVIx1000		ΔNDVI x1000		
849		30	34	40

SAVANNA

Skukuza

λ [nm]	ρ x10000	Clear	Average	Hazy
		$\Delta\rho$x10000		
470	400	52	52	53
550	636	52	58	64
645	800	53	62	67
870	2226	35	103	164
1240	2880	38	97	158
1650	2483	35	66	104
2130	1600	40	36	53
NDVIx1000		ΔNDVI x1000		
471		22	28	33

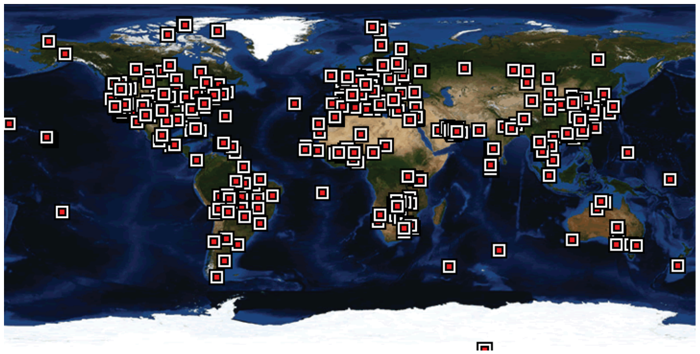
SEMI-ARID

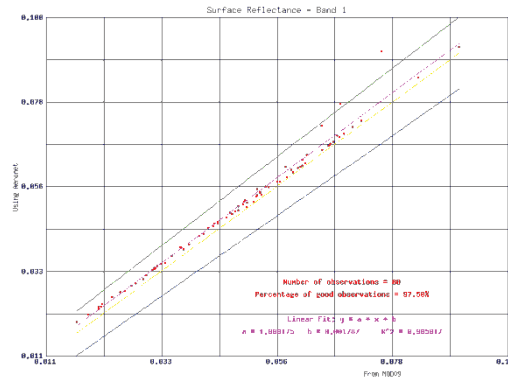
Sevilleta

λ [nm]	ρ x10000	Clear	Average	Hazy
		$\Delta\rho$x10000		
470	700	51	53	55
550	1246	51	70	85
645	1400	57	74	85
870	2324	41	95	146
1240	2929	45	93	148
1650	3085	55	81	125
2130	2800	56	60	87
NDVIx1000		ΔNDVI x1000		
248		11	15	19

Error in ~0.5% in reflectance unit

Verification over AERONET sites





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

↑

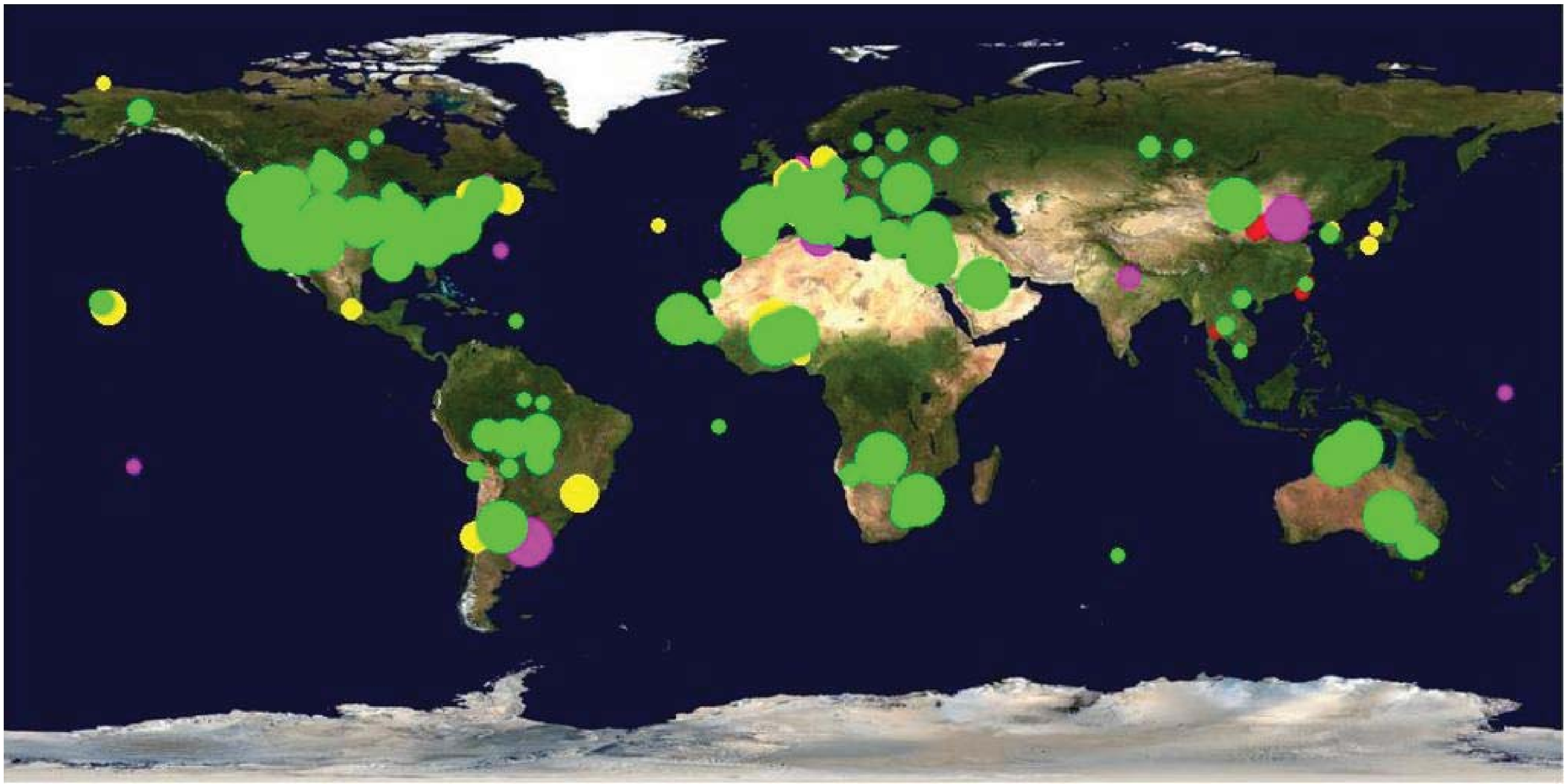
Vector 6S

AERONET measurements
(τ_{aer}, H_2O, particle distribution)
Level 1.5 filtered for abnormal imaginary part of refractive index (Climatology based on level 2.0 data)

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

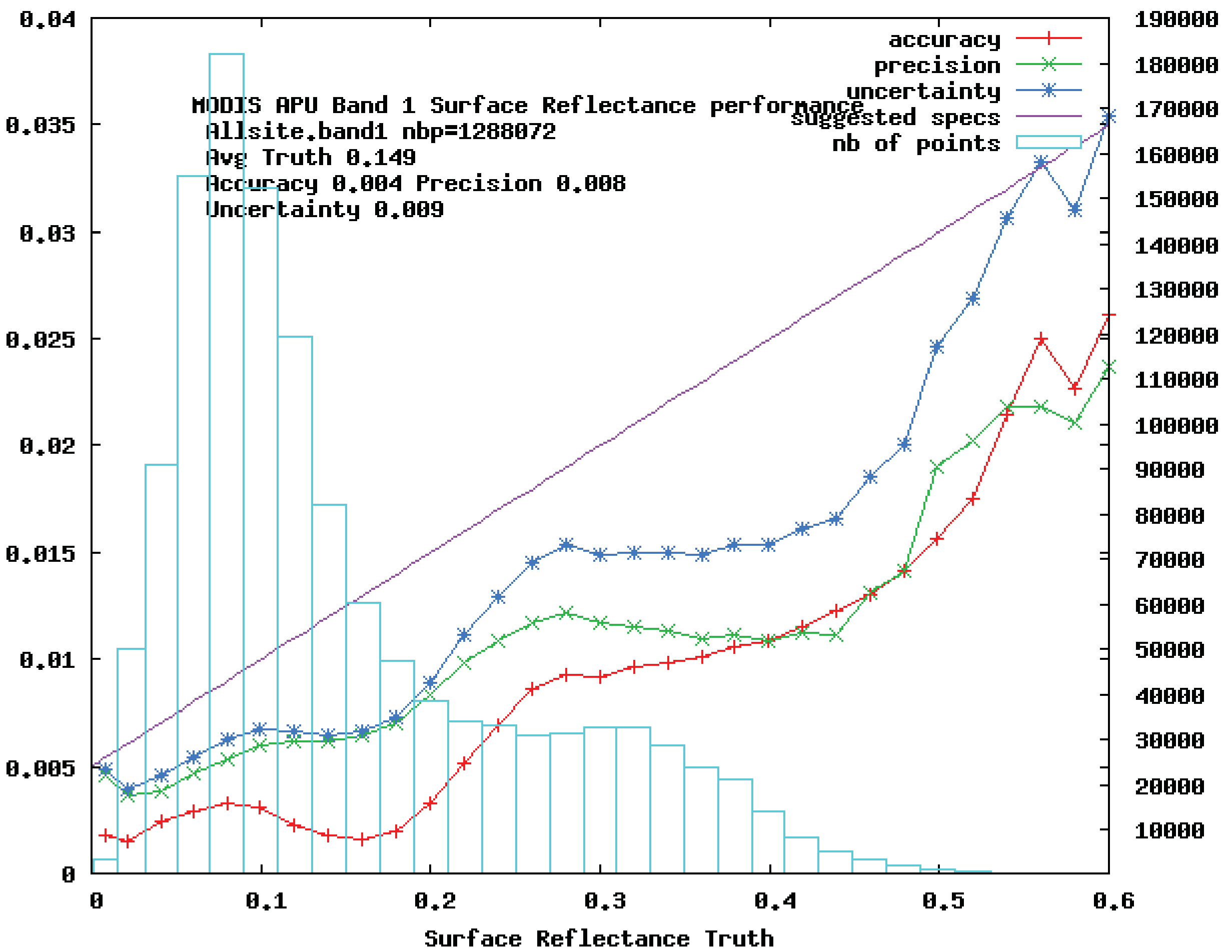
http://mod09val.ltdri.org/cgi-bin/mod09_c005_public_allsites_onecollection.cgi

Comprehensive analysis of performance using the AERONET network 2000-2007 Results (25542 cases)



Version 2 AERONET (i.e. with Background correction and spheroid)

Toward a quantitative assessment of performances (APU)



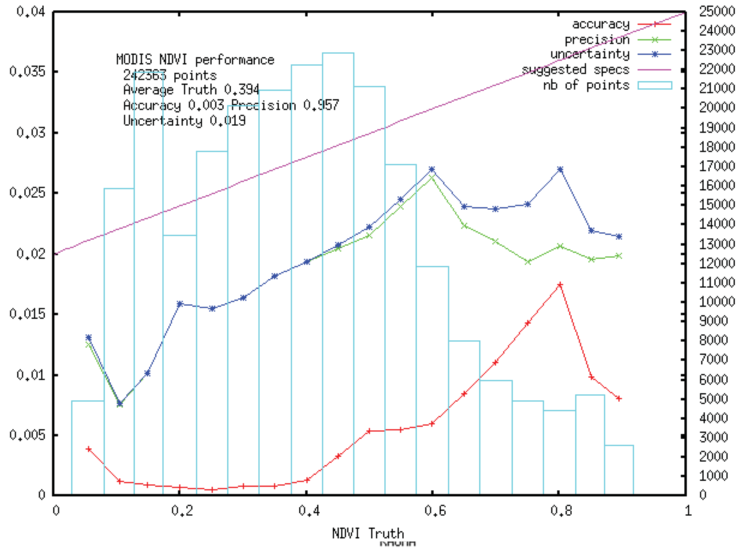
1,3 Millions 1 km pixels were analyzed for each band.

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

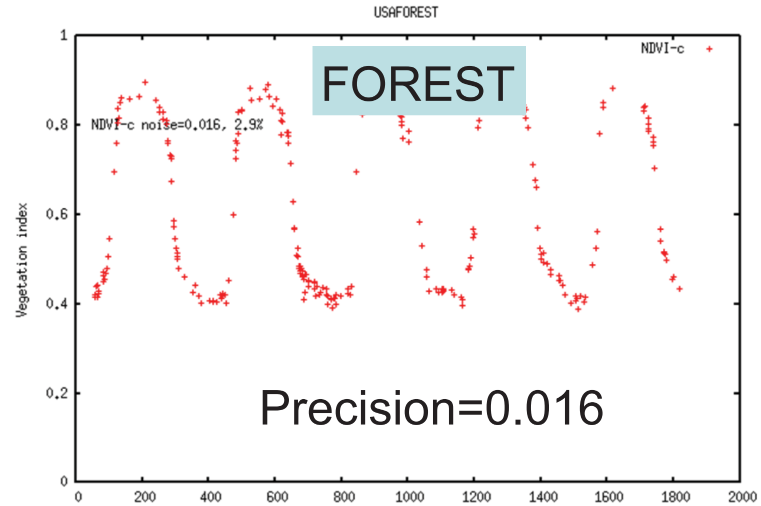
On average well below magenta theoretical error bar

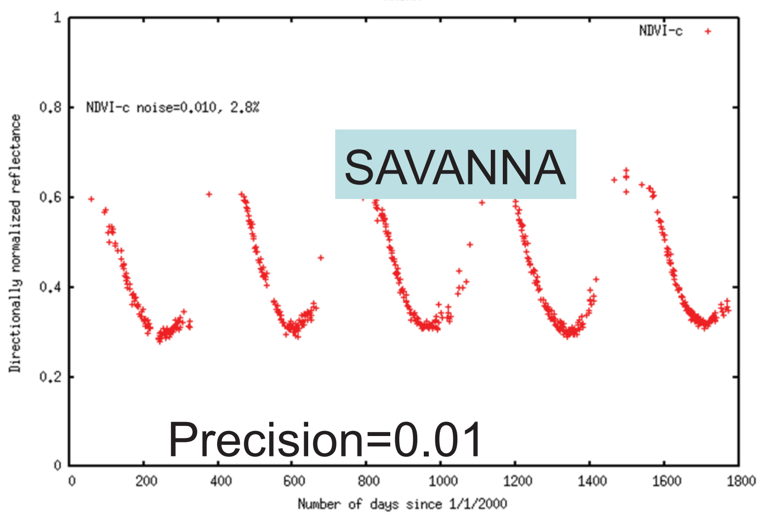
MODIS used as a reference for past and future land data record (example NDVI)

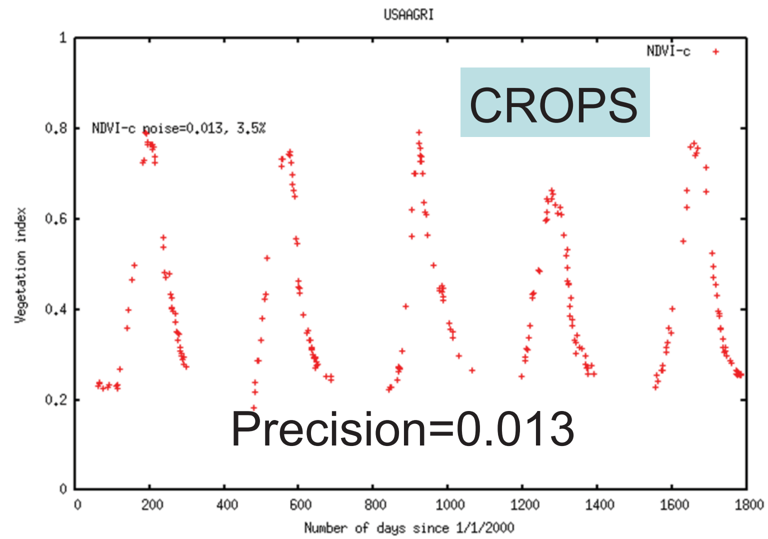
Evaluation over AERONET (2003)
0.007 <Precision < 0.017



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

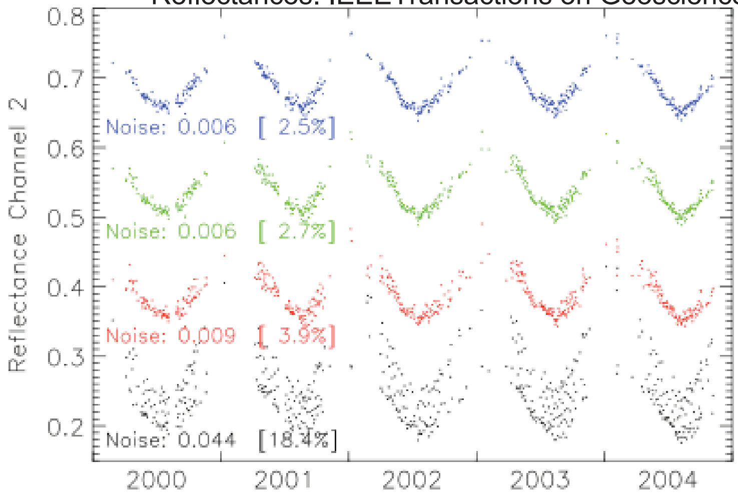




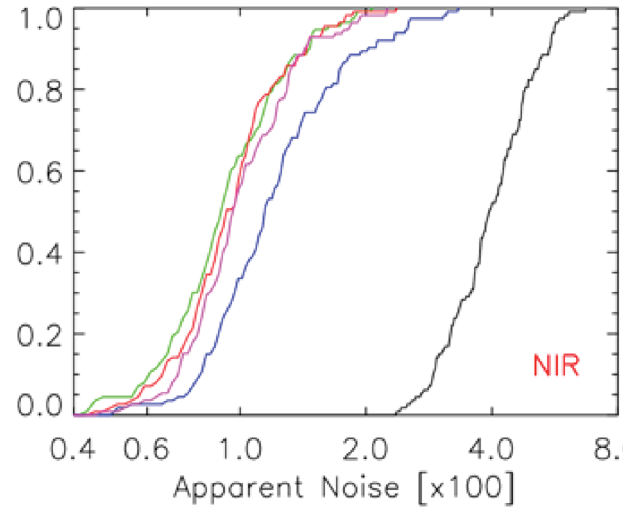


BRDF/Atmosphere coupling correction

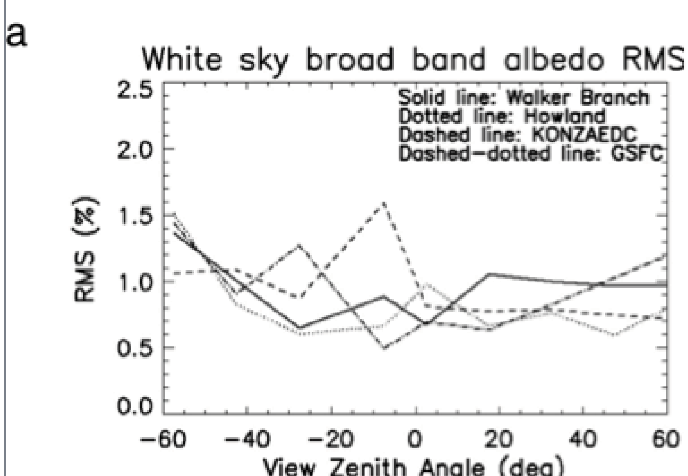
Franch B., Vermote E., Sobrino J.A. and Fédèle E. **(2013)**. Analysis of directional effects on atmospheric correction, Remote Sensing of Envi 128, 276-288.
Breon, F.M., & Vermote, E. **(2012)**. Correction of MODIS surface reflectance time series for BRDF effects. Remote Sensing of Environment,
Vermote, E., Justice, C.O., & Breon, F.M. **(2009).** Towards a Generalized Approach for Correction of the BRDF Effect in MODIS Directional Reflectances. IEEETransactions on Geoscience and Remote Sensing, 47, 898-908

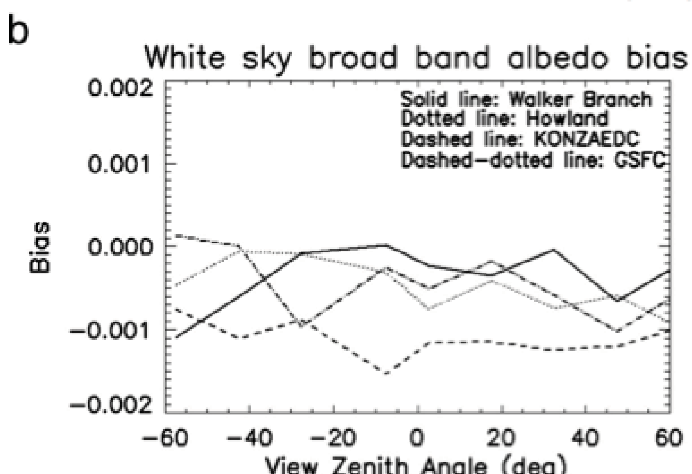


Time series of surface reflectance derived from Terra/MODIS reflectances at Kaoma (Zambia) for different level of processing.



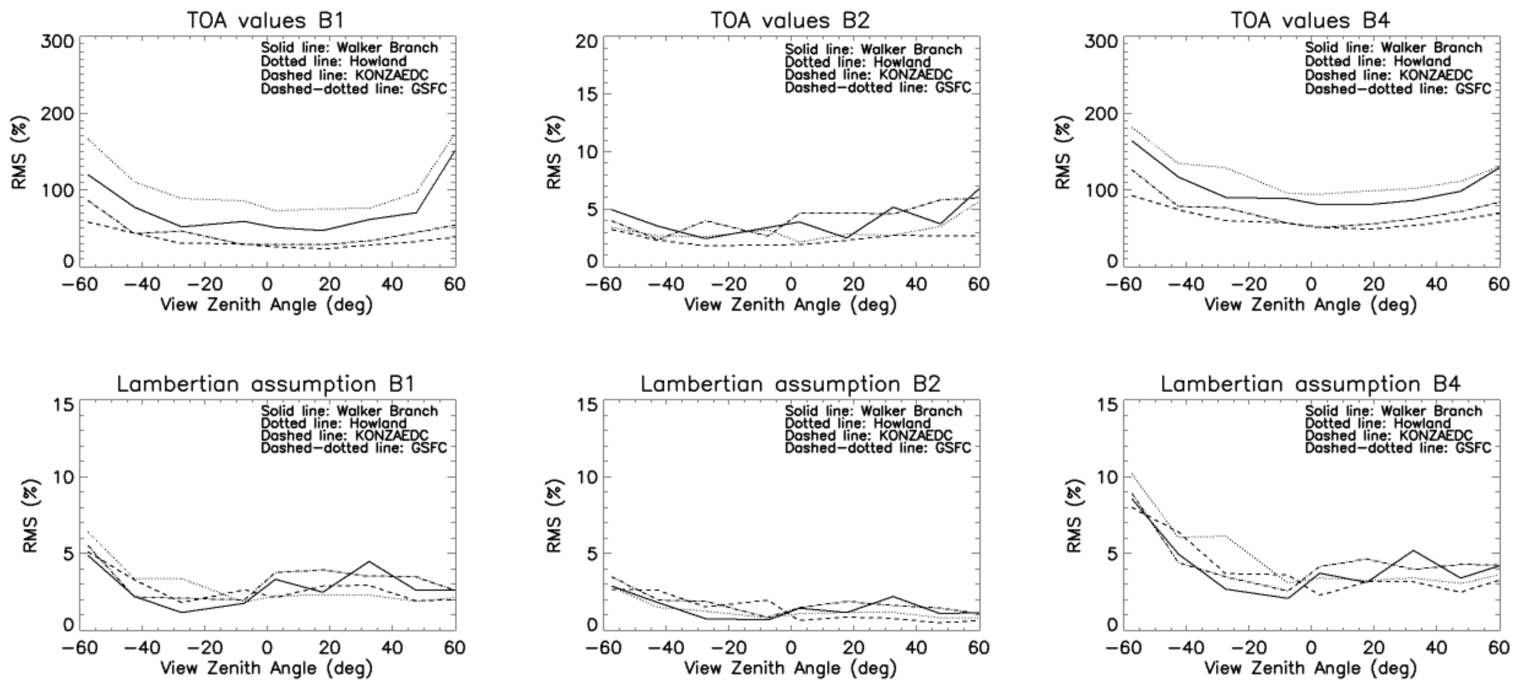
Cumulative histogram of the apparent noise of the reflectance (Black) and corrected reflectance (blue average model, green red and magenta classical and 2009 approach) time series in MODIS Channel 2 (from 2012 paper). Derived from 100 sites over one year.





Impact of the coupling atmosphere BRDF on the retrieval of the broad band albedo (a) RMS (b) bias.

BRDF/Atmosphere coupling correction

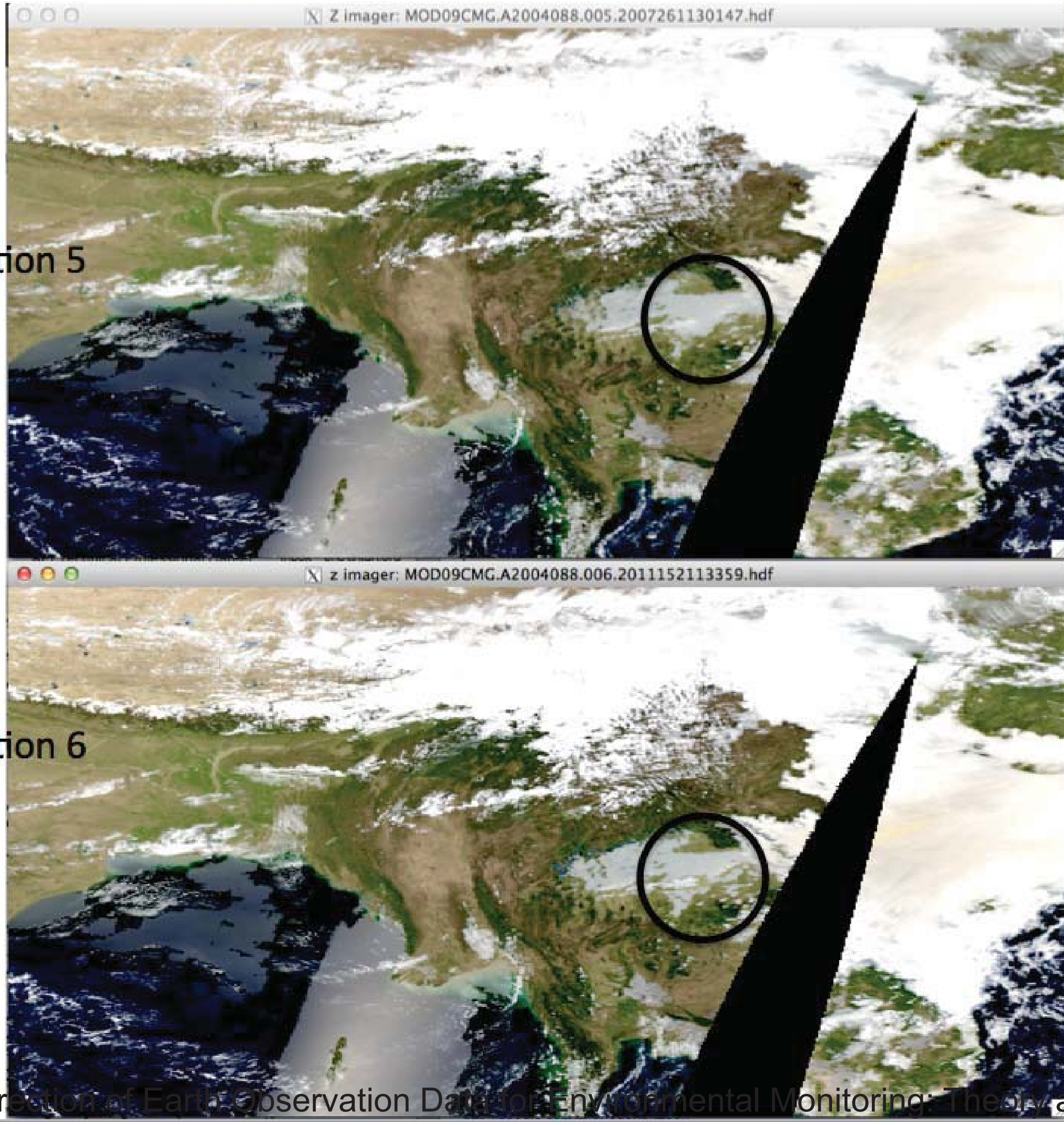


Error due to atmospheric effect in MODIS band 1,2 and 4, (bottom) residual error for the same bands due to the Lambertian assumption in the MODIS surface reflectance collection 5 algorithm [*Franch et al.*, 2013]. It should be noted than in the visible the residual error is about 20 times lower than the original perturbation. This work confirmed the magnitude of this effect (5%-10%) as previously derived results using a variety of sources of surface BRDF and radiative transfer approach [*Lee and Kaufman*, 1986] [*Hu et al.*, 1999; *Lyapustin*, 1999] as the recent work of [*Wang et al.*, 2010] seemed to indicate much higher effect (15%-40%).

Internal cloud mask improvement

Collection 5

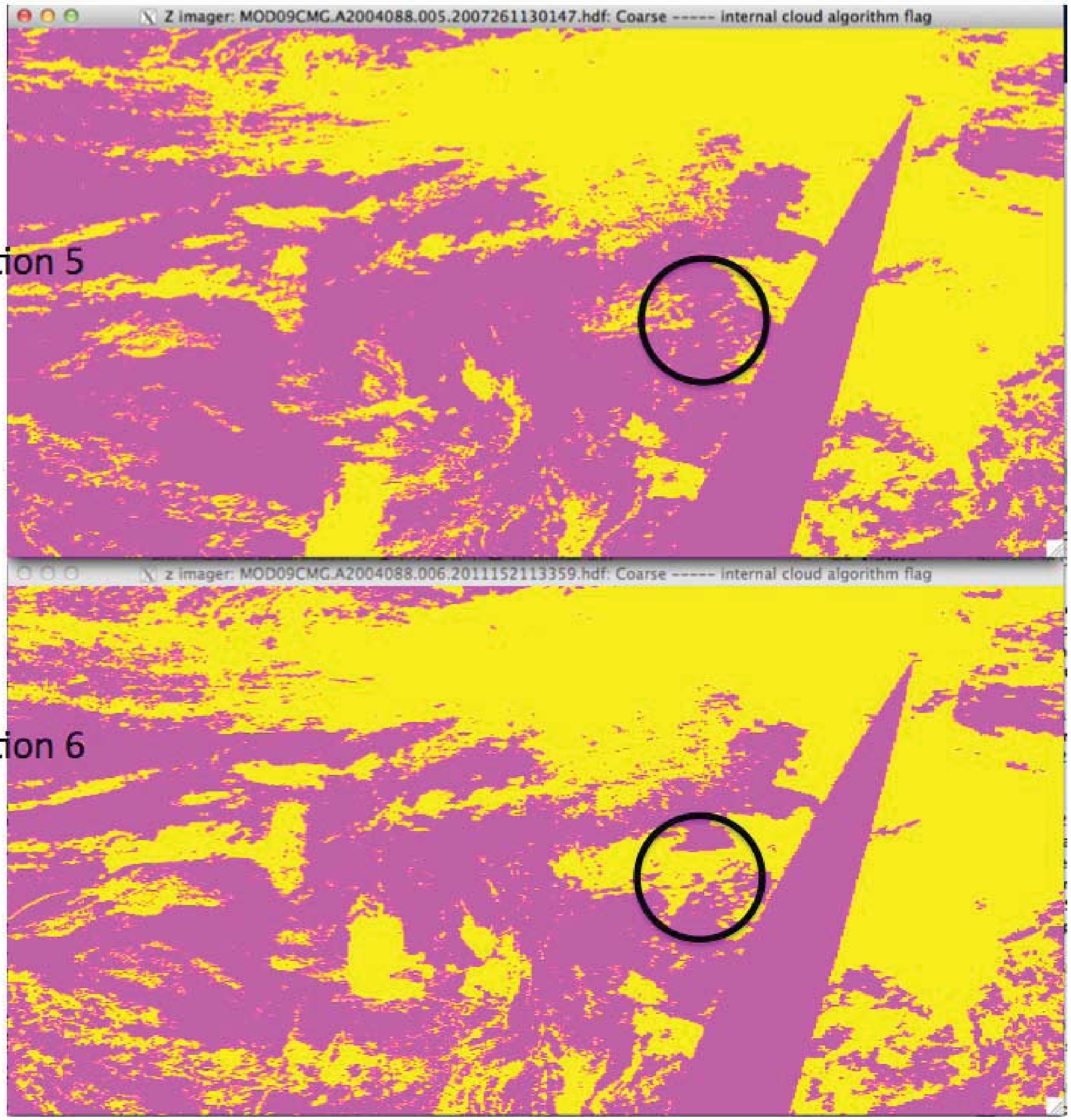
Collection 6



Internal cloud mask improvement

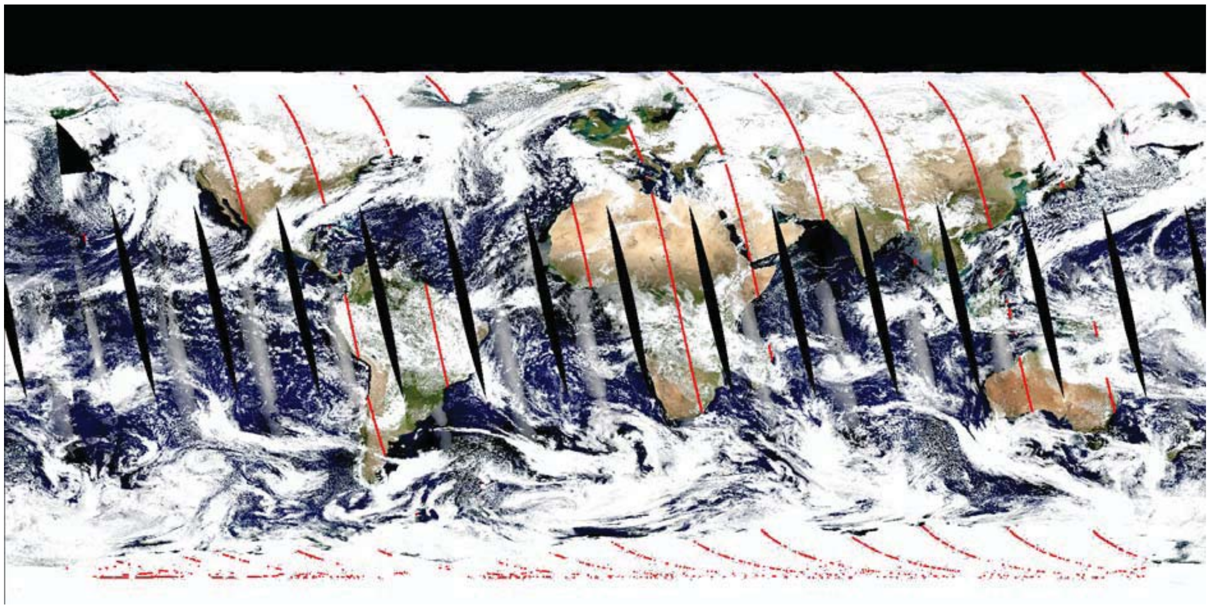
Collection 5

Collection 6



Collection 5 internal Cloud mask flag (yellow) let a substantial amount of cloud go through (leakage)

Monitoring of product quality (exclusion conditions cloud mask)



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

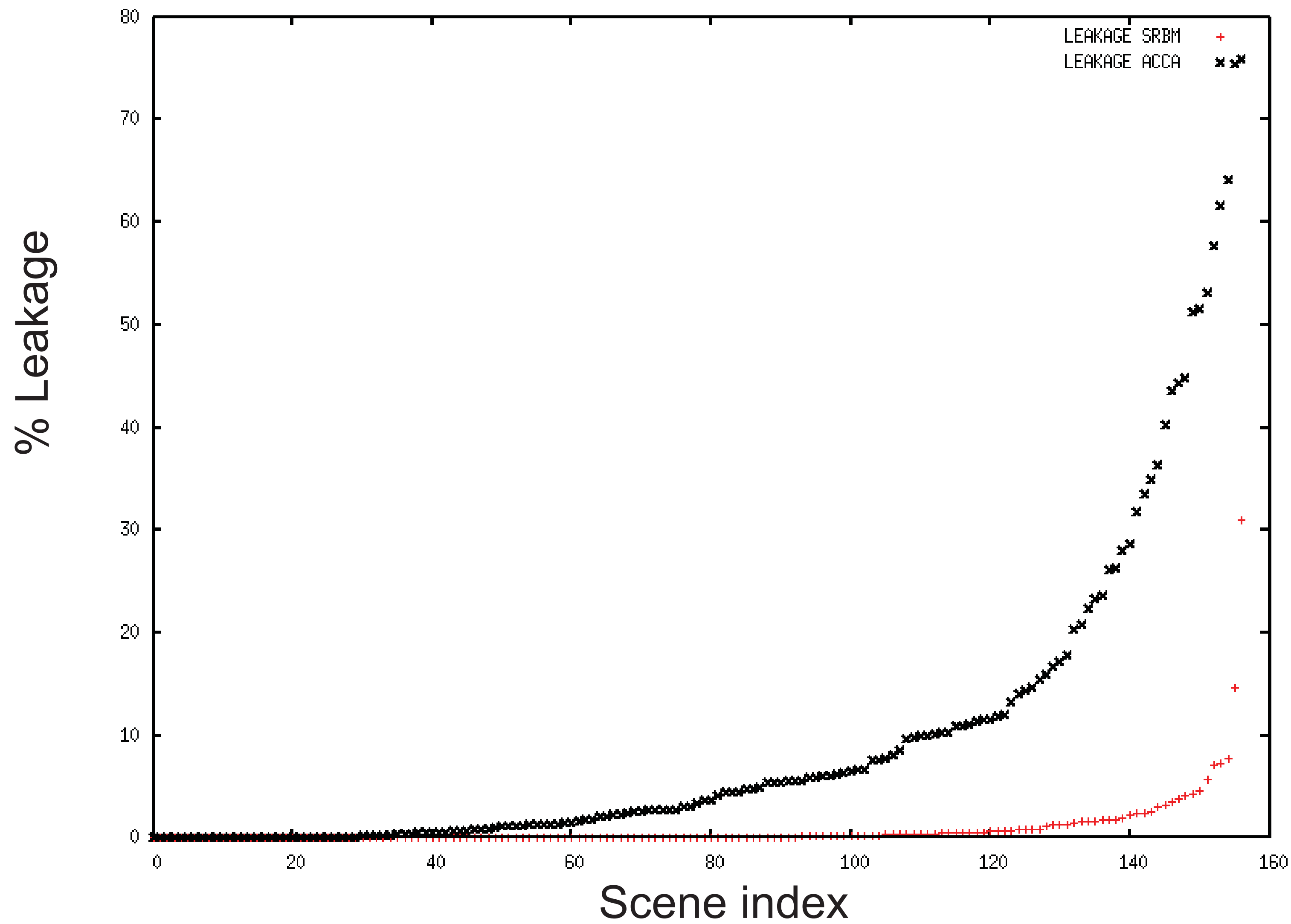
	MOD35 Global	MOD35 60S-60N	ICM Global	ICM 60S-60N	ICM Global Case1	ICM Global Case2
Leakage	6.1%	5.6%	5.8%	**4.0%**	**2.6%**	**2.1%**
False Det.	6.1%	6.4%	6.5%	6.7%	6.5%	6.5%

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).

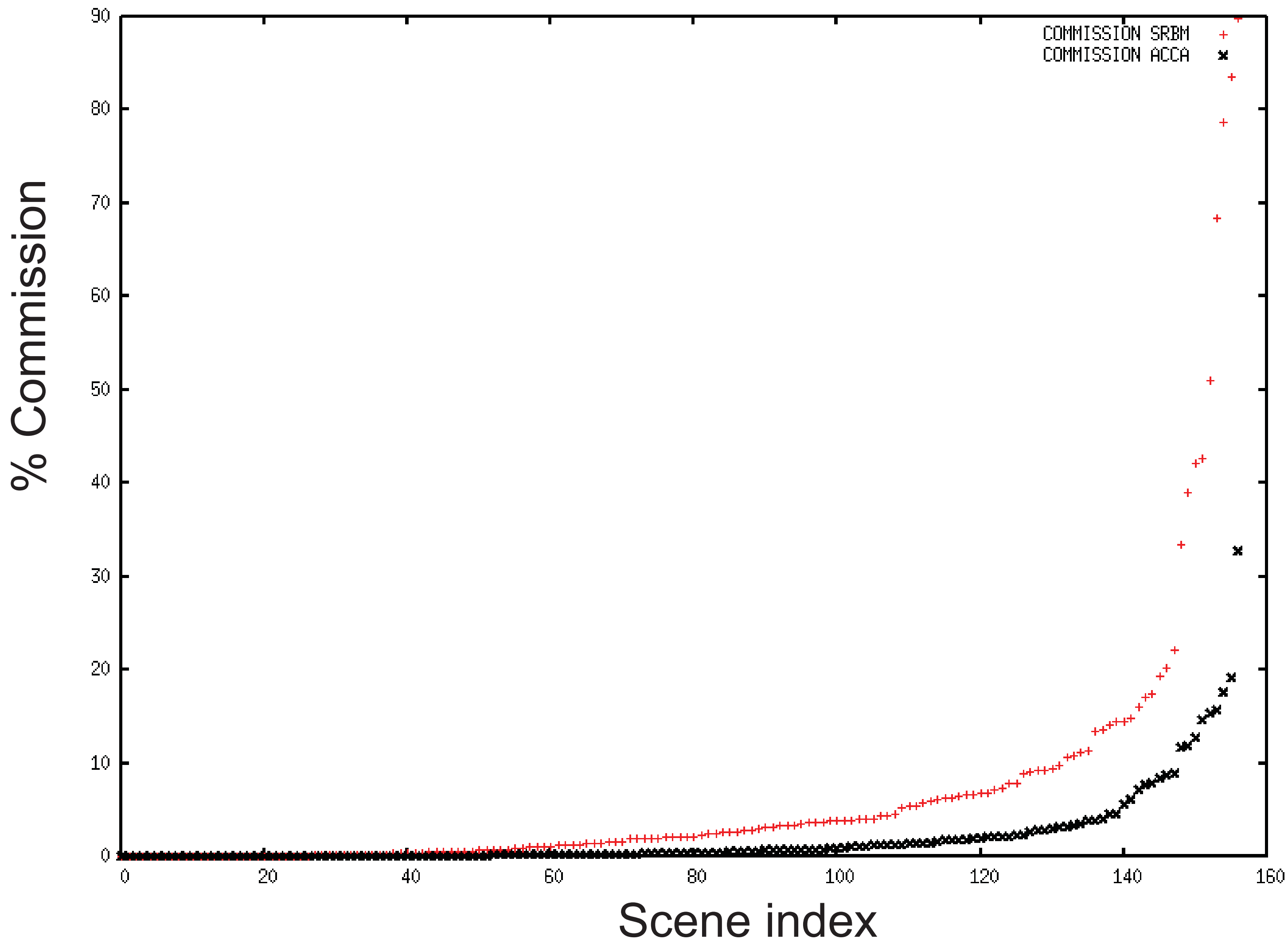
Validation of cloud/cloud shadow mask on TM data

- Evaluated for 157 Landsat scenes covering a variety of conditions
- Cloud mask comparison
  - ACCA cloud mask
  - SRBM (Surface reflectance Based Mask): Internal cloud mask based on SR product
  - VCM :Truth Validation Cloud Mask (operator made)
- Metrics for cloud detection versus VCM
  - Rate of omission of cloud %: Leakage
  - Rate of commission of cloud % : False detection
- As far as leakage the internal cloud mask, SRBM, is superior to ACCA/ In term of commission ACCA has better performance than SRBM
- LEDAPS SRB shadow algorithm needs improvements

LEAKAGE RATE comparison



COMMISSION RATE Comparison

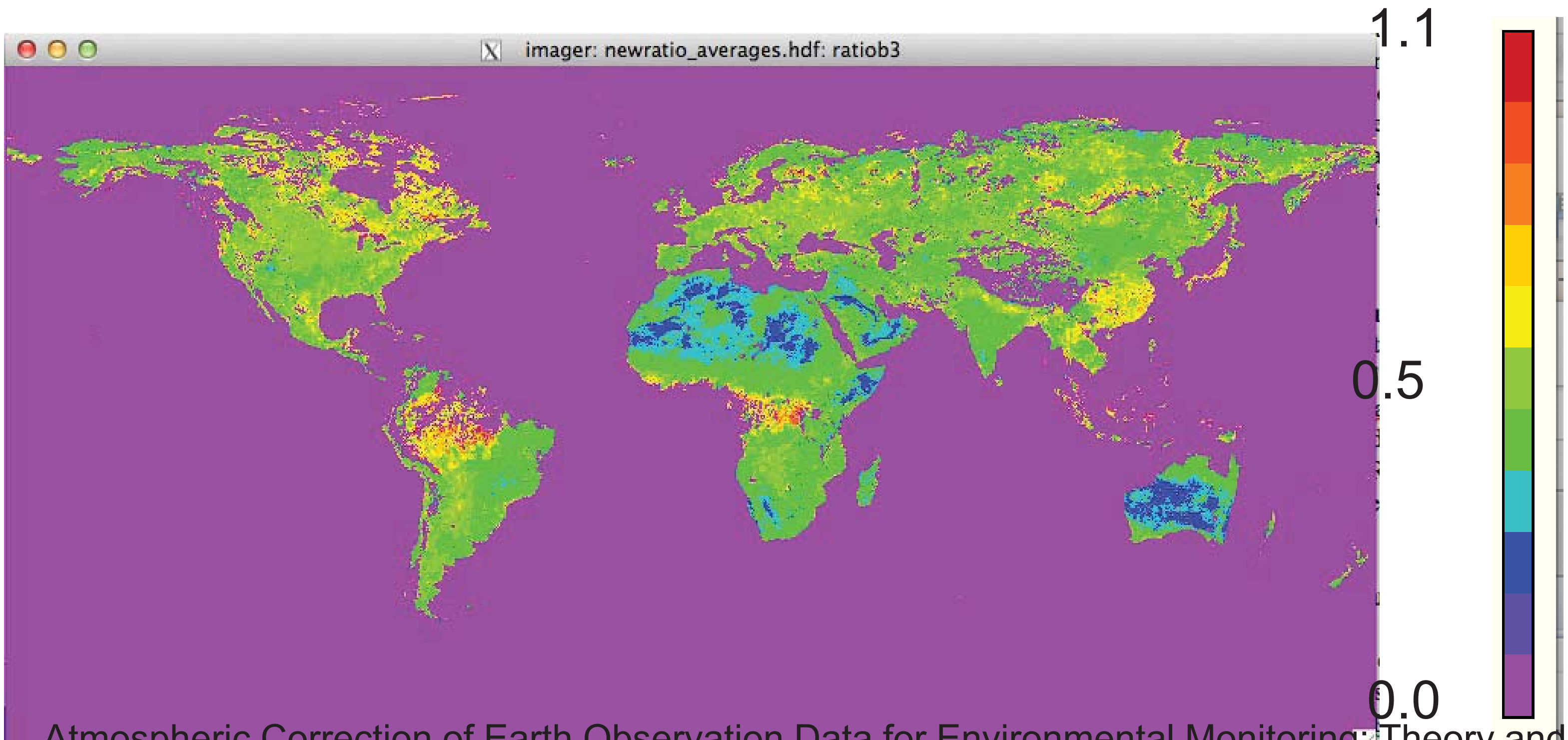


Atmospheric Correction of Earth Observation Data for Environmental Monitoring: Theory and Best Practises

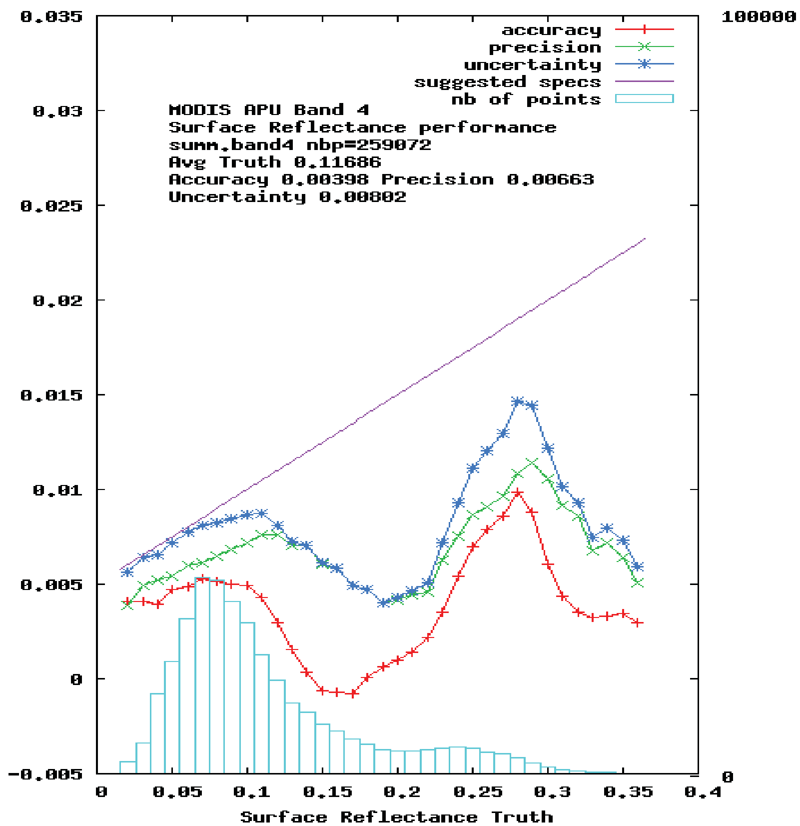
Improving the aerosol retrieval

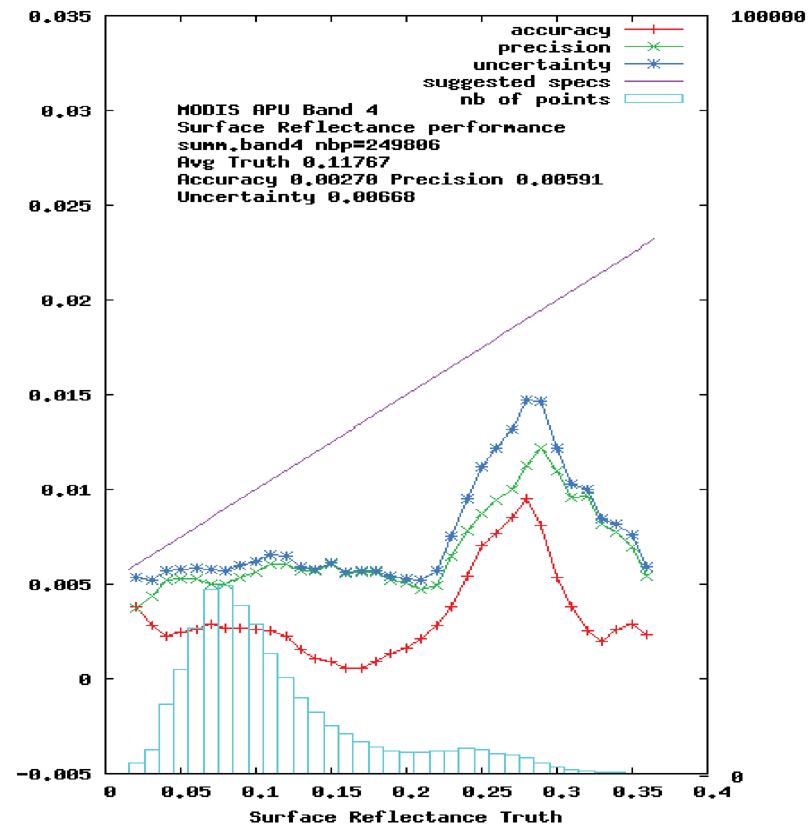
(a) Revised the aerosol model using the latest result of the AERONET database, in particular the accounting for particles non-sphericity and the version 2, level 2 particles properties inversions. A new model for dust is under development.

(b) Started Improving the ratio used in the visible and swir used in the inversion. Currently a default value is used globally, that value is adequate for vegetated area but not on sparsely vegetated or desert area, We used the MISR data and the CMG product to produce a spatially explicit CMG climatology of these ratios and will use those in the aerosol inversion.



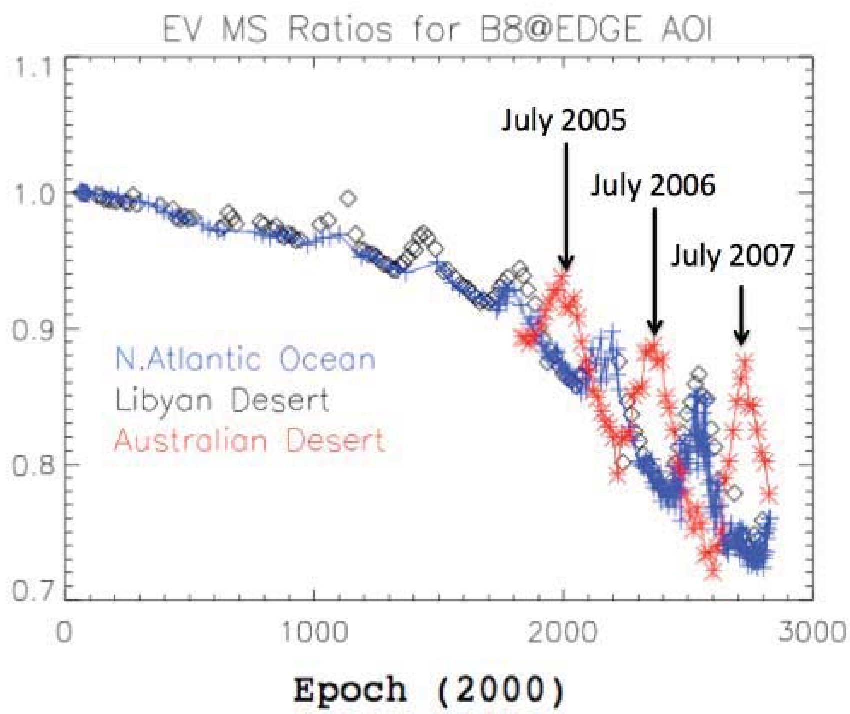
Improving the aerosol retrieval

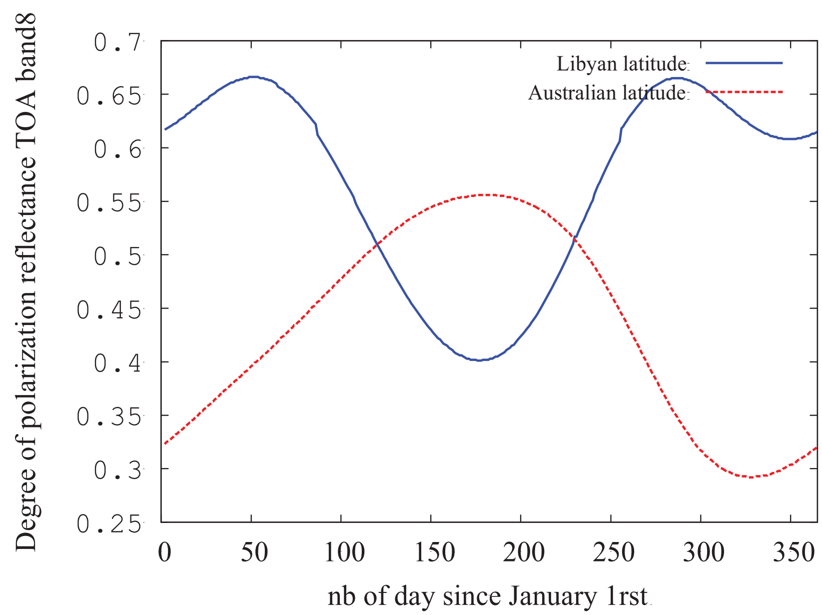




The performance of the reflectance product for band 4 (550nm) for the fixed ratio (left side) versus spatially variable (right side), although modest the improvement in the performance of the product is clearly visible especially in the lower range of reflectance's that correspond to vegetation/forest.

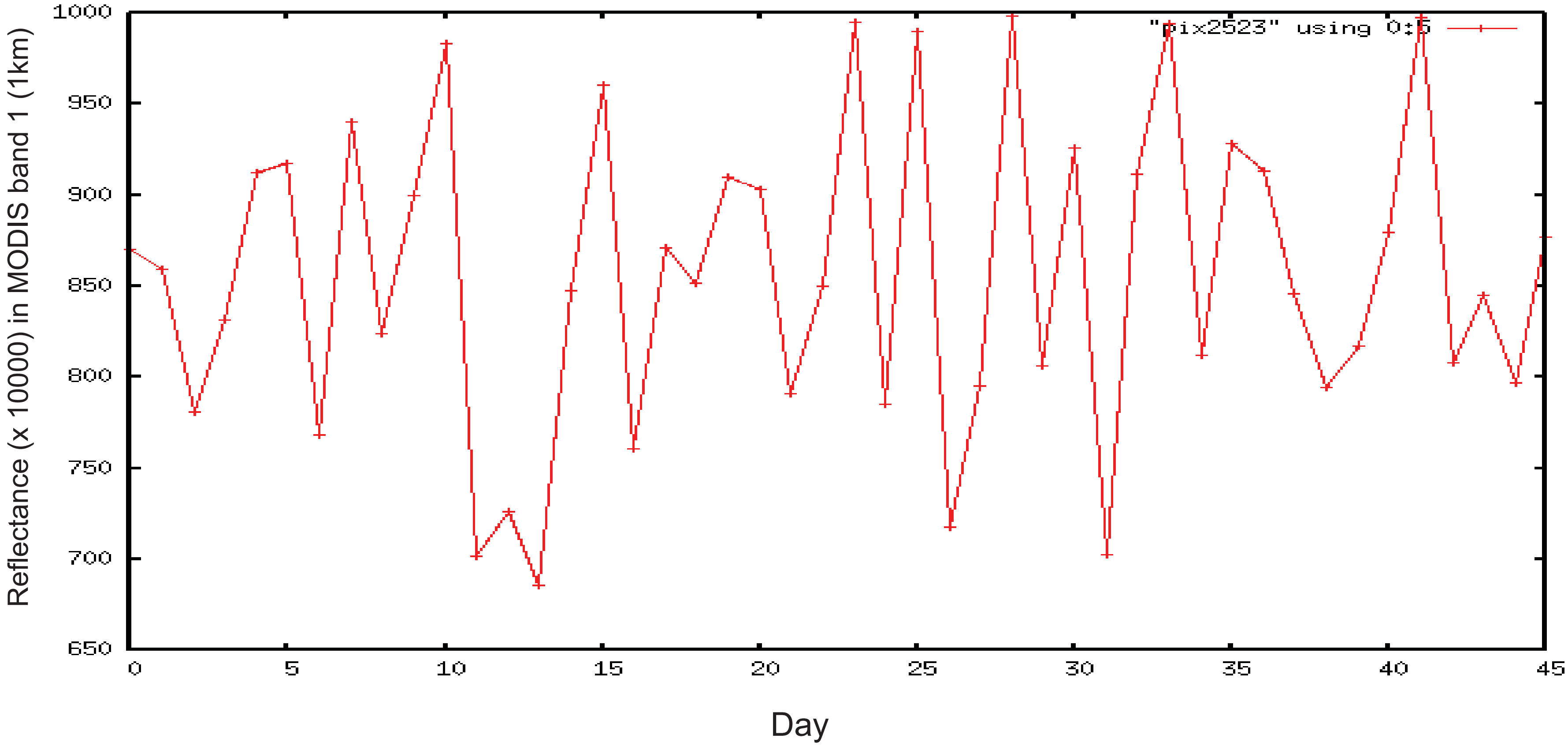
Accounting for instrument polarization





Evidence of different polarization sensitivity sensitivities of the two mirror sides of MODIS Terra, (left side, *courtesy of MODIS Calibration Science Team*) the oscillations of the mirror side ratio over Libya/N. Atlantic Ocean and Australia that are offset by ~6 months in phase. This is well explained by the expected degree of polarization (right side, simulated using 6S [*Kotchenova and Vermote*, 2007; *Kotchenova et al.*, 2006]) that shows the same phase offset between the Atlantic/Libya (blue) and Australia latitudes (red).

Understanding spatial characteristics of different sensors



Using Landsat 30m data we simulate the reflectance observed in the MODIS 1km footprint over 45 days. If MODIS was a perfect 1km footprint always assigned to the same location, the data will show a constant reflectance, however here due to pixel size growth with view zenith angle and other gridding artifacts, we see a substantial variation of the reflectance (+/-0.015) (The site is in BONDVILLE, IL)