# Atmospheric correction for the monitoring of land surfaces

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# 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 (aerosols, 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**)

. . . . . .

. . . . extensive validation and testing . . . .

. . . . . .

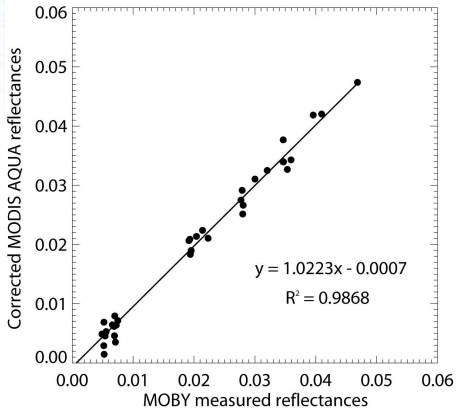
**May 2007:** the release of version 1.1 of the vector 6S (**6SV1.1**)

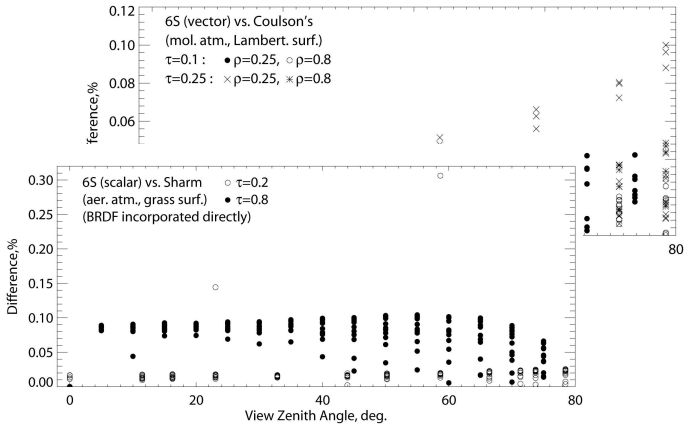
# 6SV Validation Effort

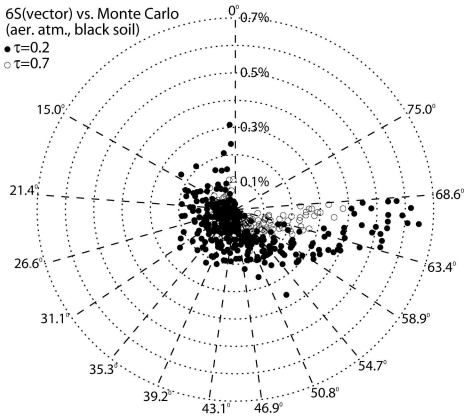
The complete 6SV validation effort is summarized in two manuscripts:

- 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.

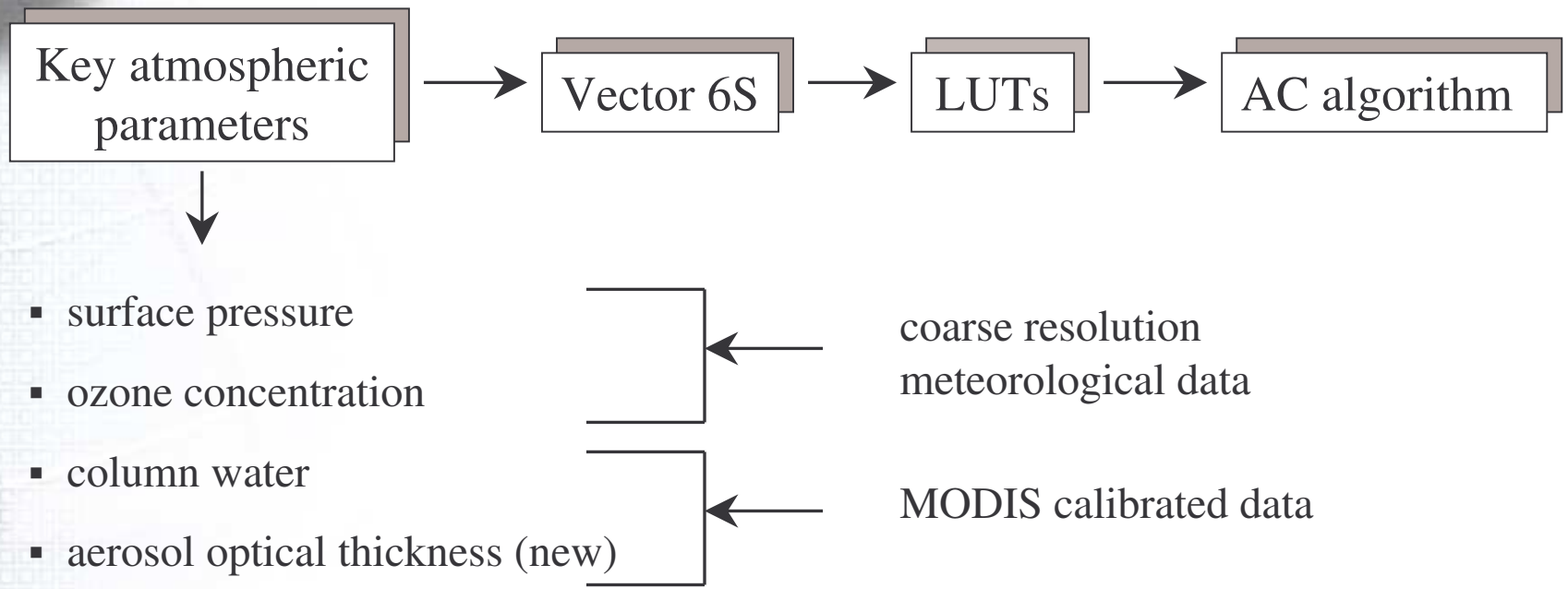
- S. Y. Kotchenova & E. F. Vermote, Validation of a vector version of the 6S radiative transfer code for atmospheric correction of satellite data. Part II: Homogeneous Lambertian and anisotropic surfaces, *Applied Optics*, in press, 2007.



# 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.

# 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.

# 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**

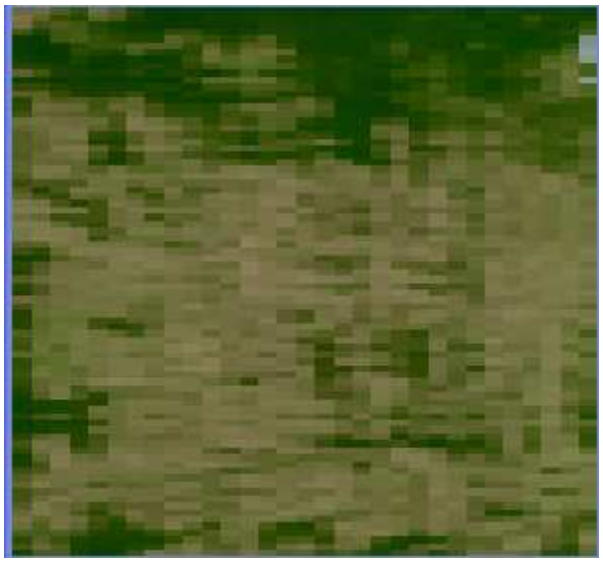
- use of all available MODIS bands (land + ocean, e.g. 412nm as in Deep Blue)
- improved LUTs
- improved aerosol models based on the AERONET climatology
- a more robust "dark target inversion scheme" using Red to predict the Blue reflectance values (in tune with *Levy et al.*)
- inversion of the aerosol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

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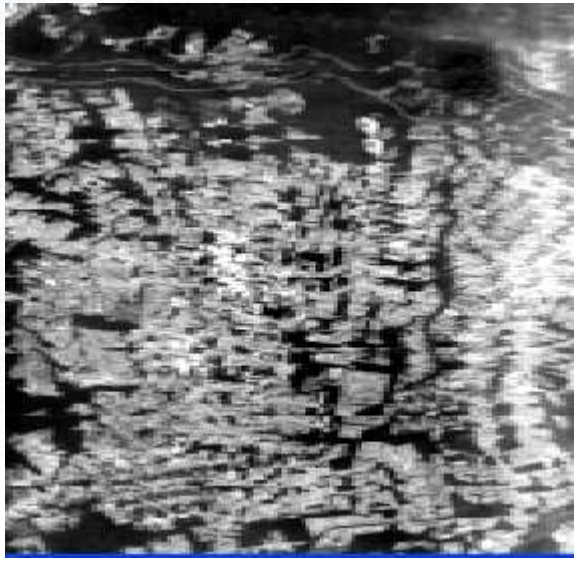
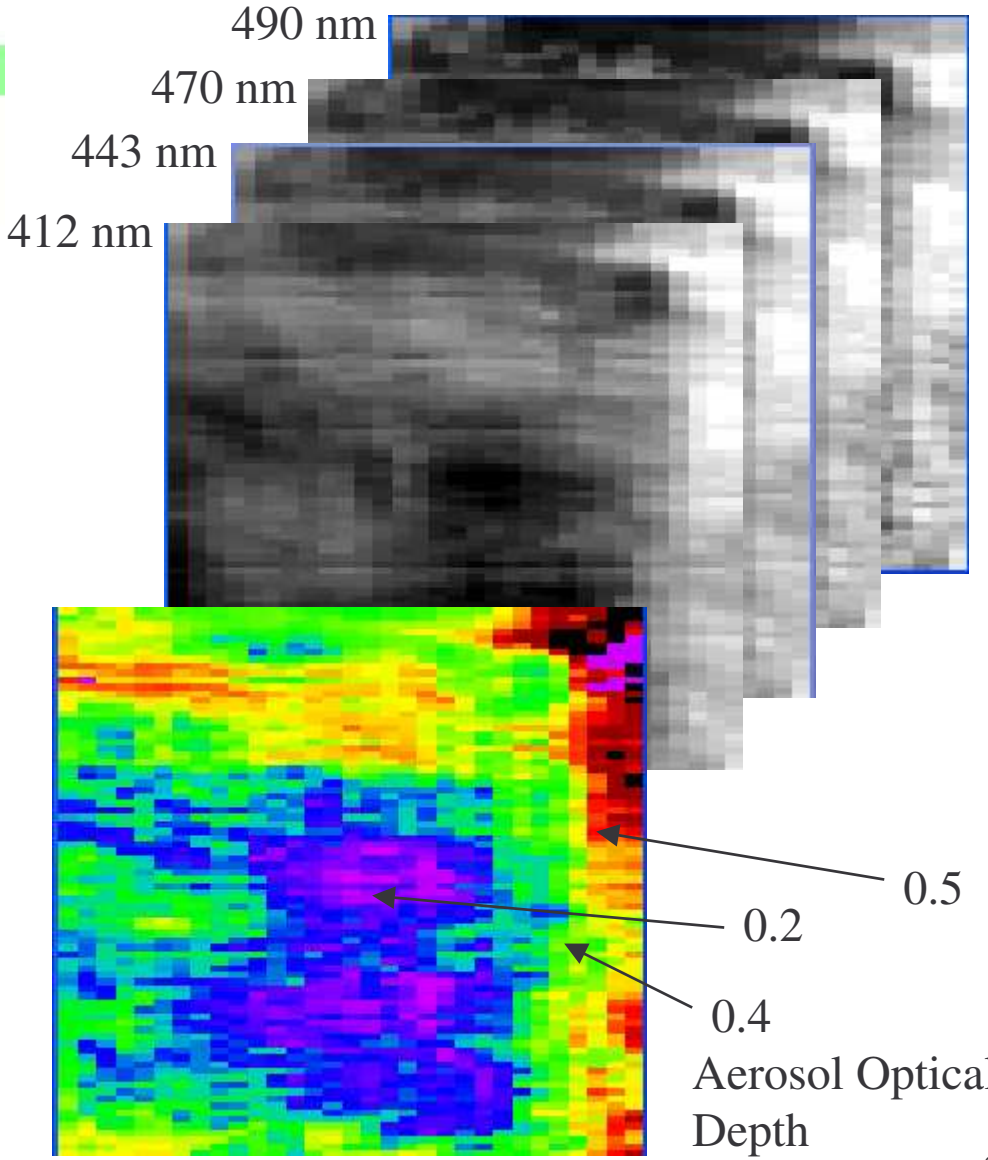


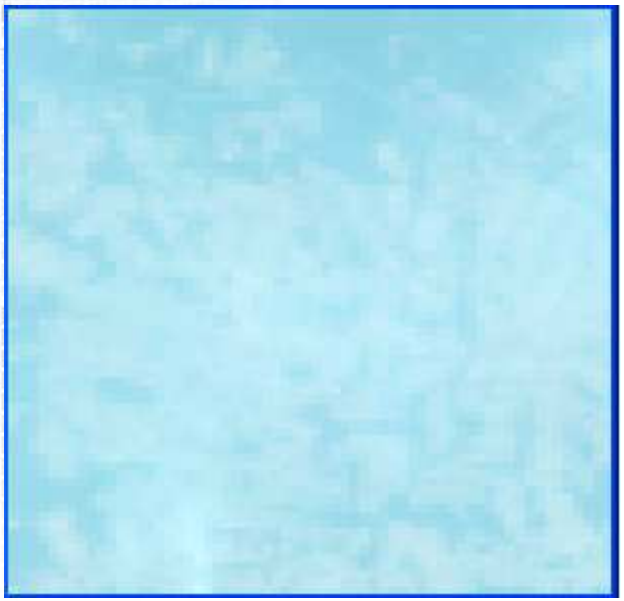
**Red (670 nm)**
**Top-of-atmosphere reflectance**



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

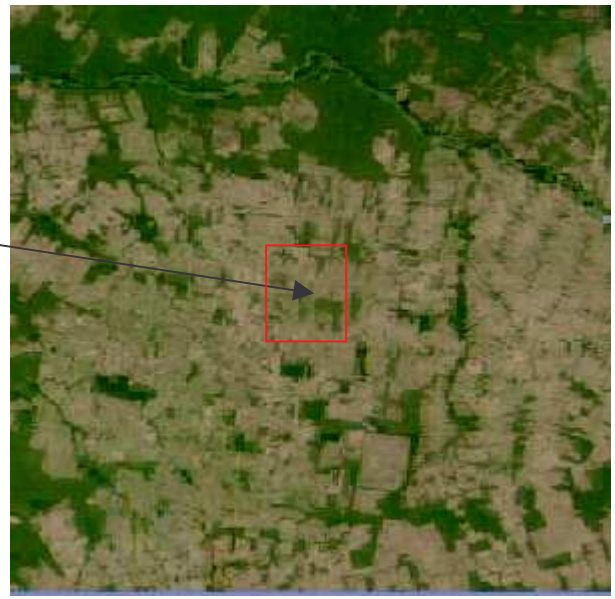
| Aeronet | | | | |
|---|---|---|---|---|
| AOT | delta AOT | WV | delta WV | DTaot |
| 0.86180 | 0.01204 | 5.94636 | 0.00395 | 14 |

| 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**

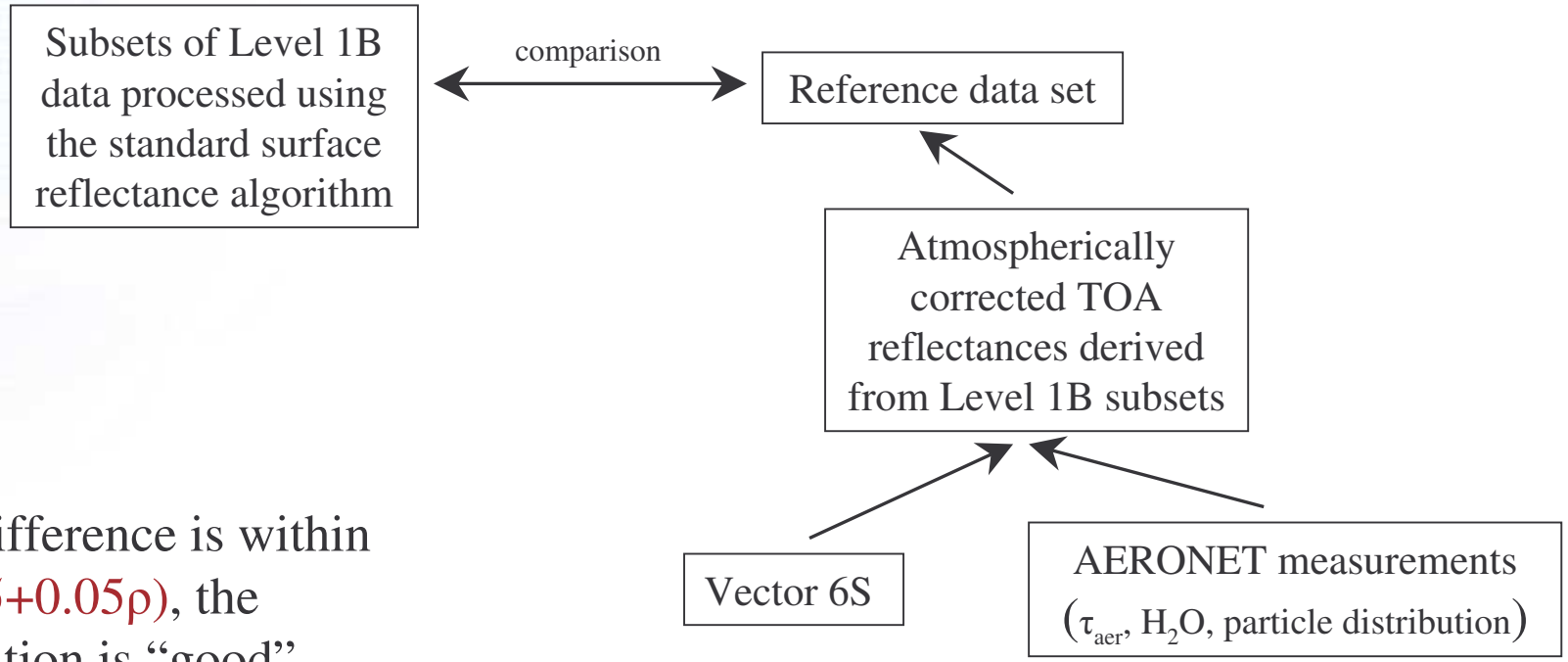
**AOT= 0.927** (7km x 7km)
Model residual:
Smoke LABS: 0.005666
**Smoke HABS: 0.004334**
Urban POLU: 0.004360
Urban CLEAN: 0.005234

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

# 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:**

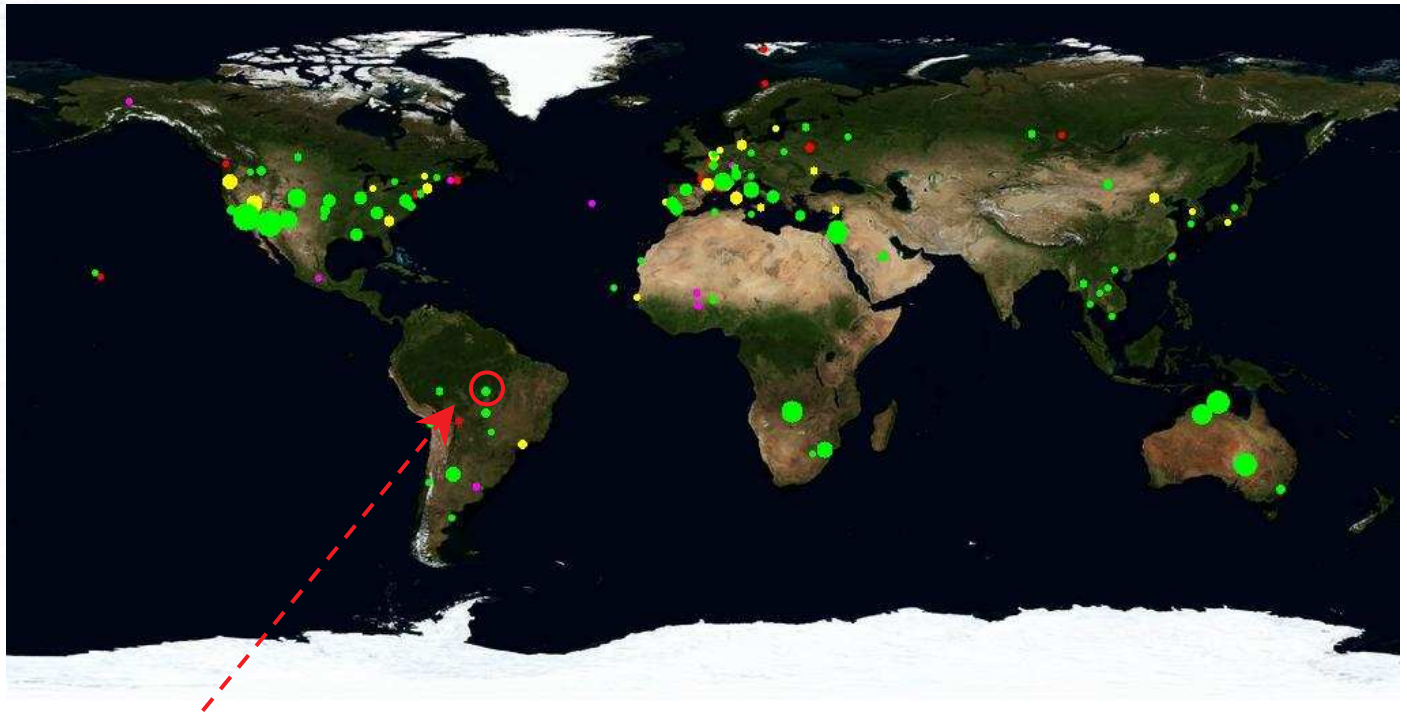



If the difference is within $\pm(0.005+0.05\rho)$, the observation is "good".

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.



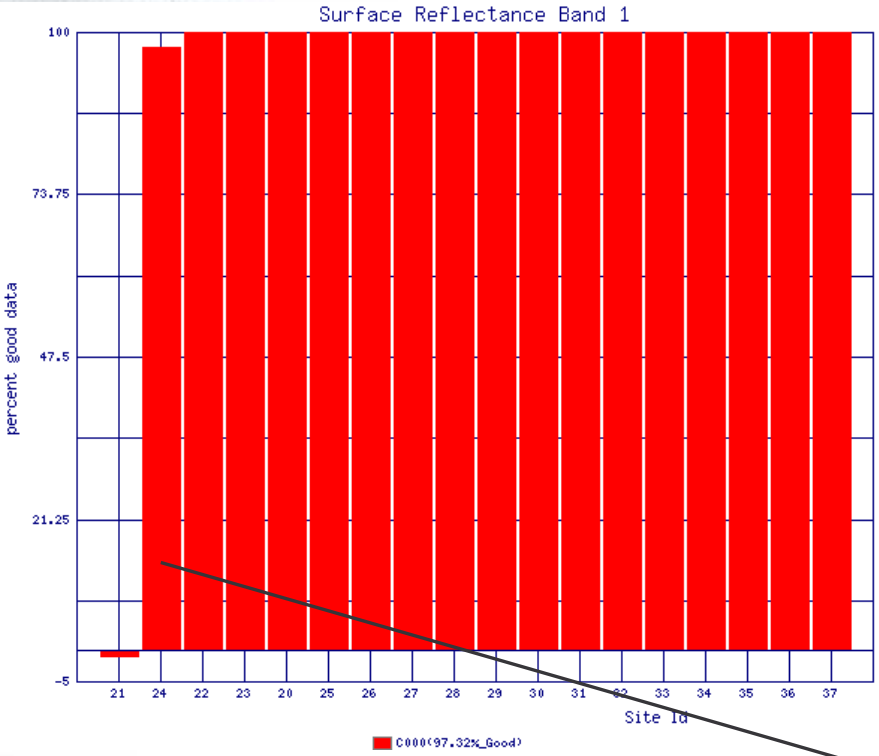
The circle color indicates the % of comparisons within the theoretical MODIS 1-sigma error bar:
green > 80%, 65% < yellow <80%, 55% < magenta < 65%, red <55%.

The circle radius is proportional to the number of observations.

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

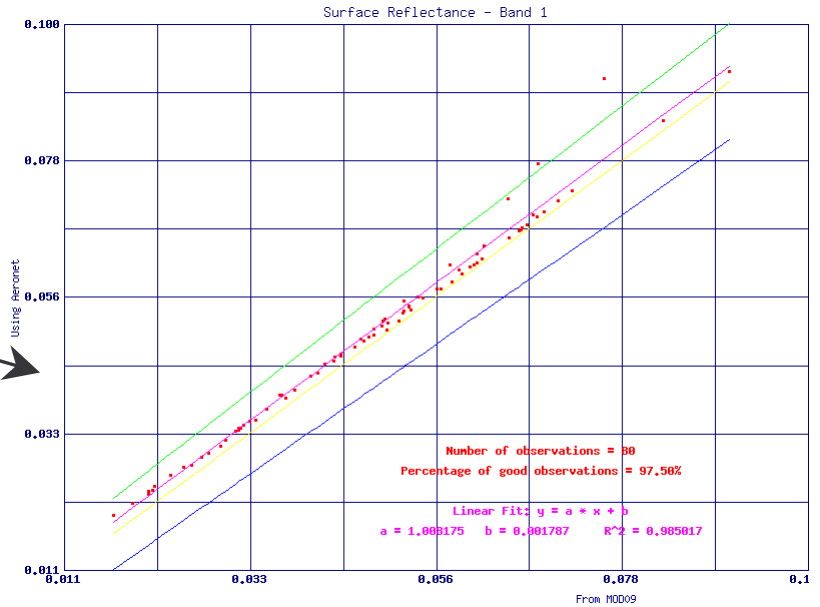
# Validation of MOD09 (2)

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




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

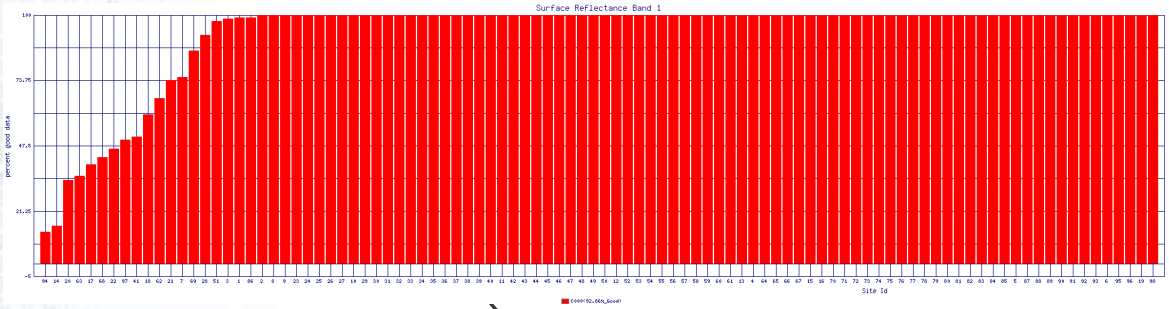
**The size of a bar**: the % of "good" surface reflectance observations

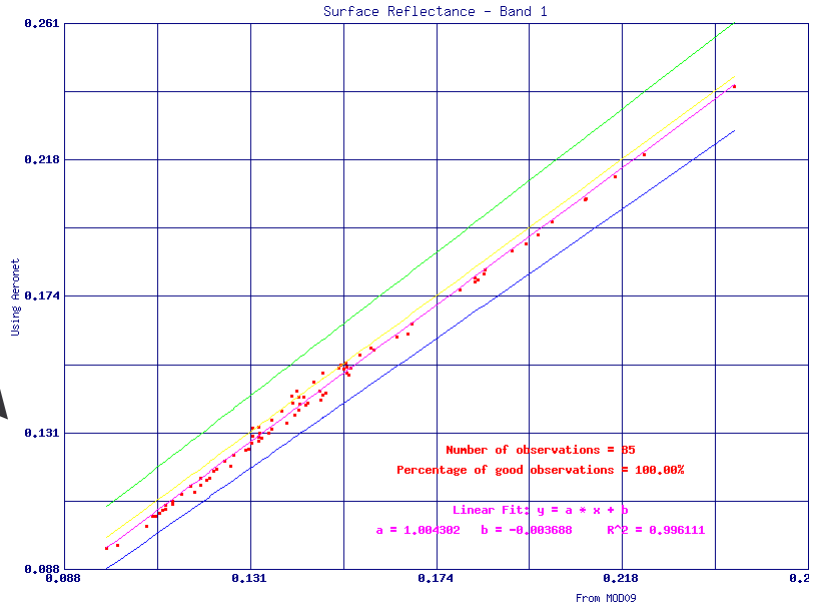



**Scatter plot**: the retrieved surface reflectances vs. the reference data set along with the linear fit results

# Validation of MOD09 (3)

Nes Ziona site (92.86%)




**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

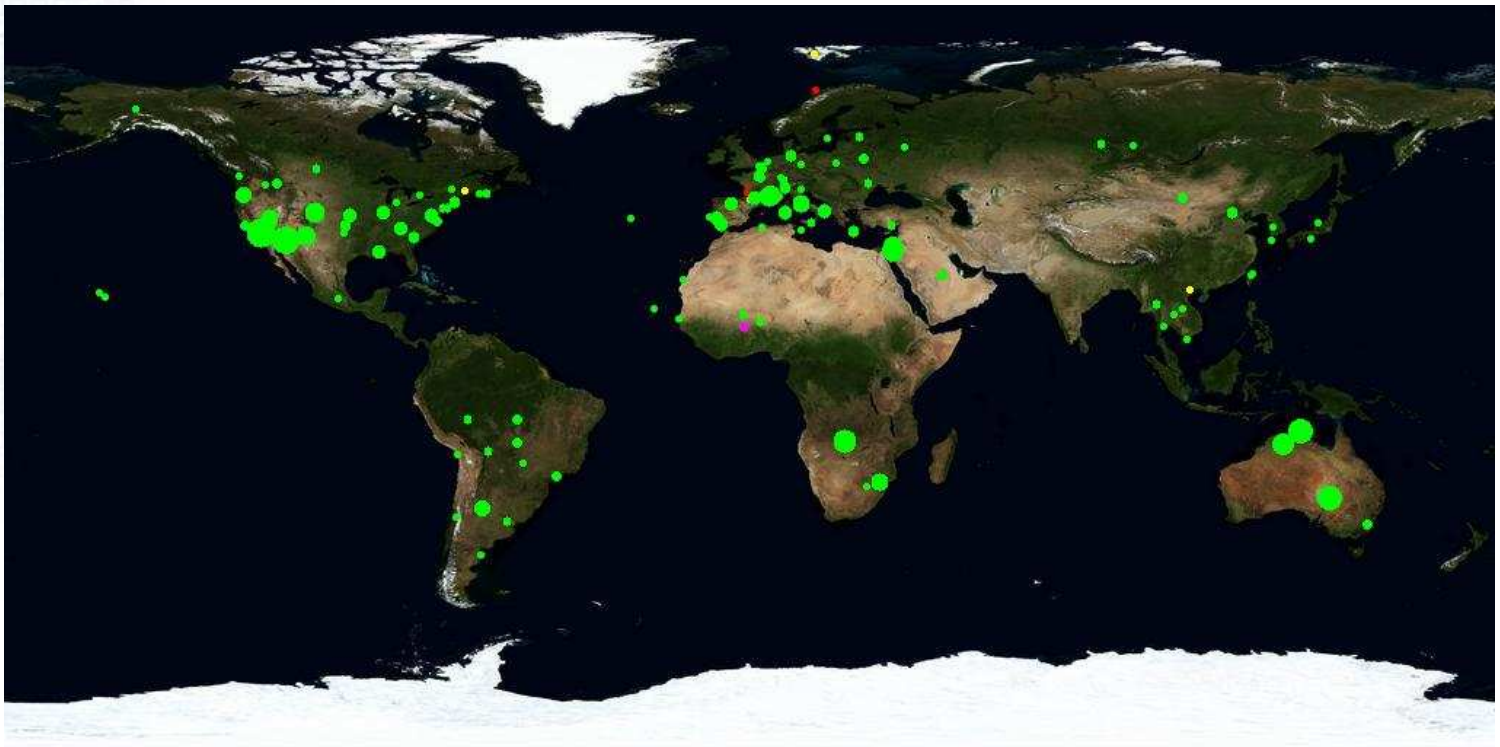
Similar results are available for all MODIS surface reflectance products (bands 1-7).

**Percentage of good:**

band 1 – 86.62%
band 2 – 94.13%
band 3 – 51.30%
band 4 – 75.18%
band 5 – 96.36%
band 6 – 97.69%
band 7 – 98.64%

# 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)).

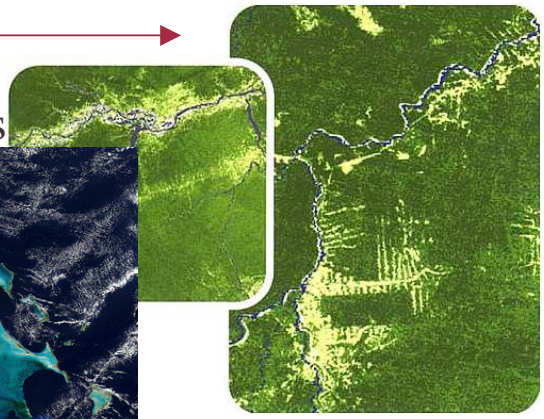


green > 80%, 65% < yellow <80%, 55% < magenta < 65%, red <55%

# MOD09 Applications

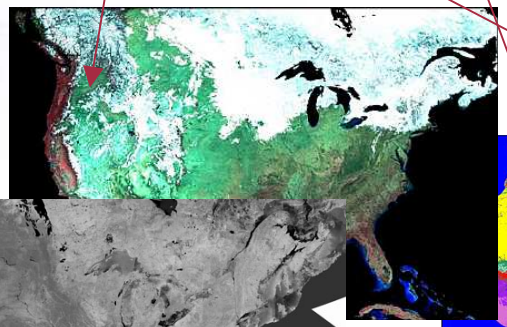
Surface Reflectance

Land Cover

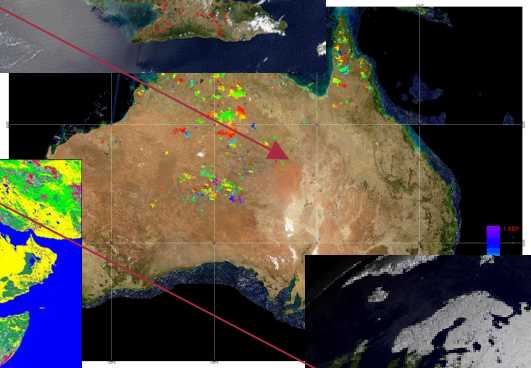


Thermal Anomalies

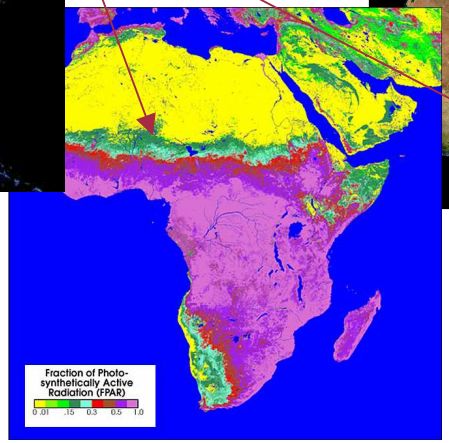
BRDF/Albedo



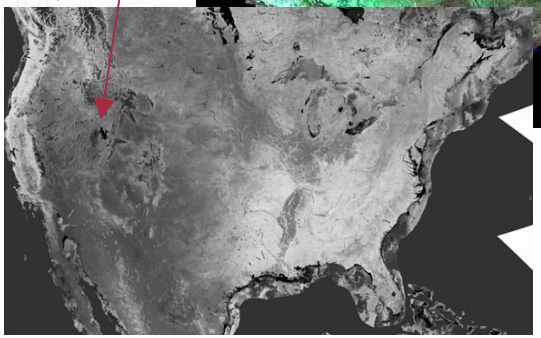
Burned Areas



LAI/FPAR




VI



Snow Cover

# MOD09 Direct Broadcast Code

- The collection 5 MOD09 DB code has been tested by beta users and streamlined by the SSEC Team (Liam Gumley & colleagues)

- DRL (Pat Coronado & colleagues) is going through the packaging for public release (expected in a couple of weeks).