Satellite remote sensing of Aerosols

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

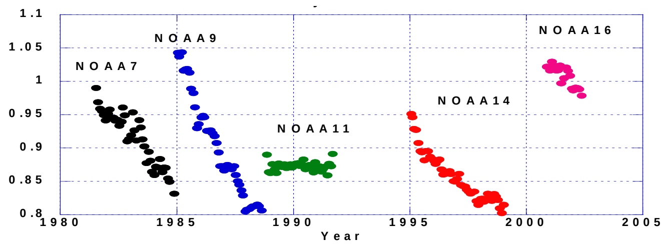
International Workshop on Land Use/Cover Changes and Air Pollution in Asia August 4-7th, 2015, Bogor, Indonesia

Land Climate Data Record

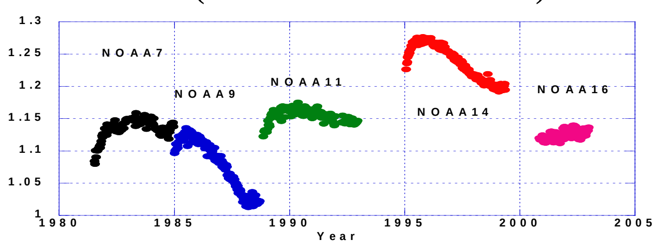
Needs to address calibration, atmospheric/BRDF correction issues

CALIBRATION

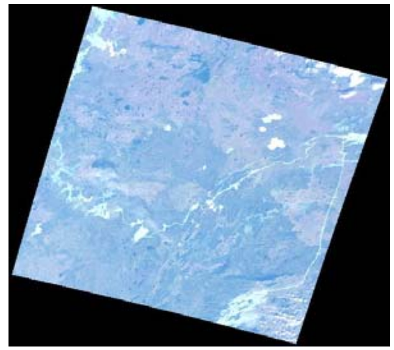
Degradation in channel 1
(from Ocean observations)

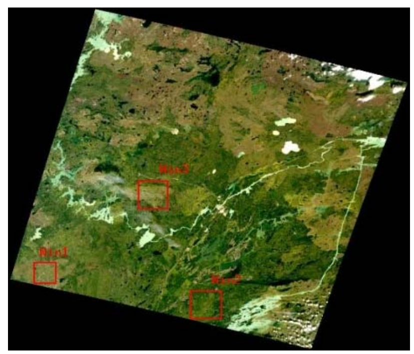


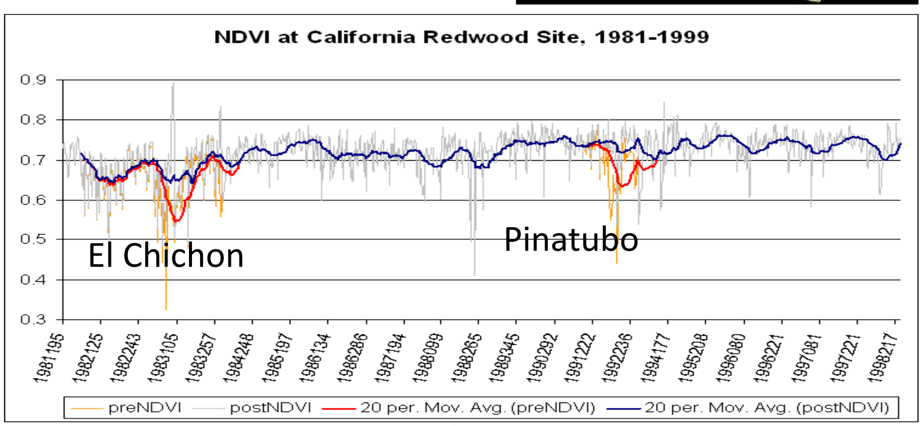
Channel1/Channel2 ratio
(from Clouds observations)



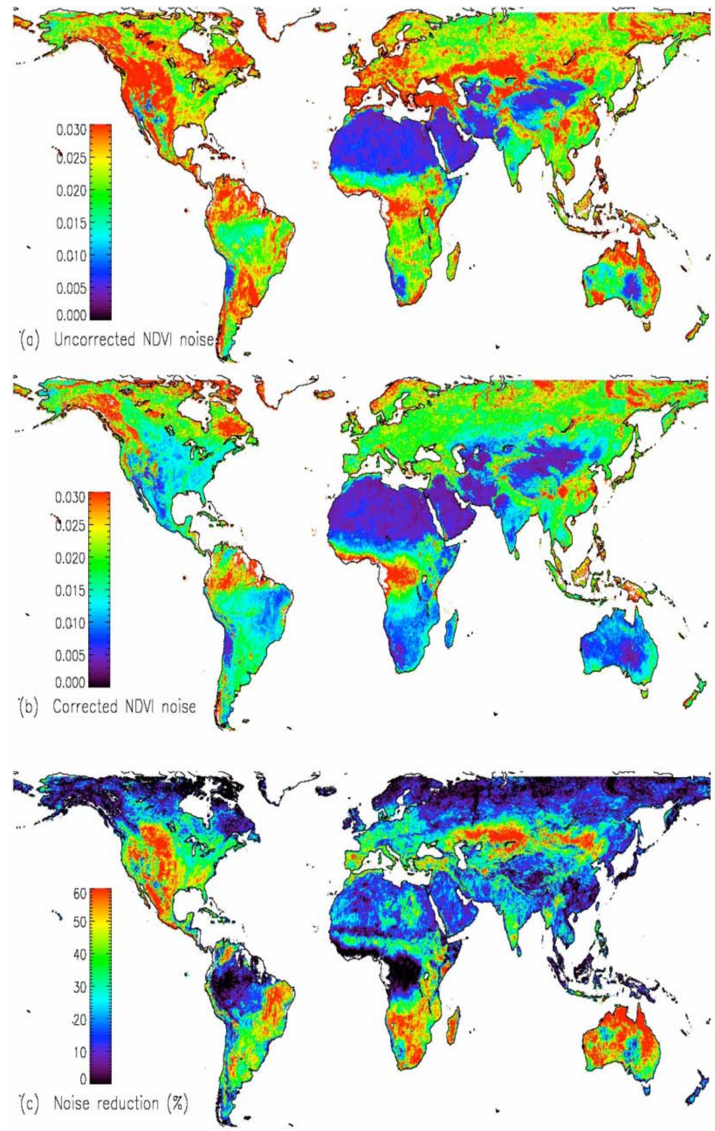
ATMOSPHERIC CORRECTION



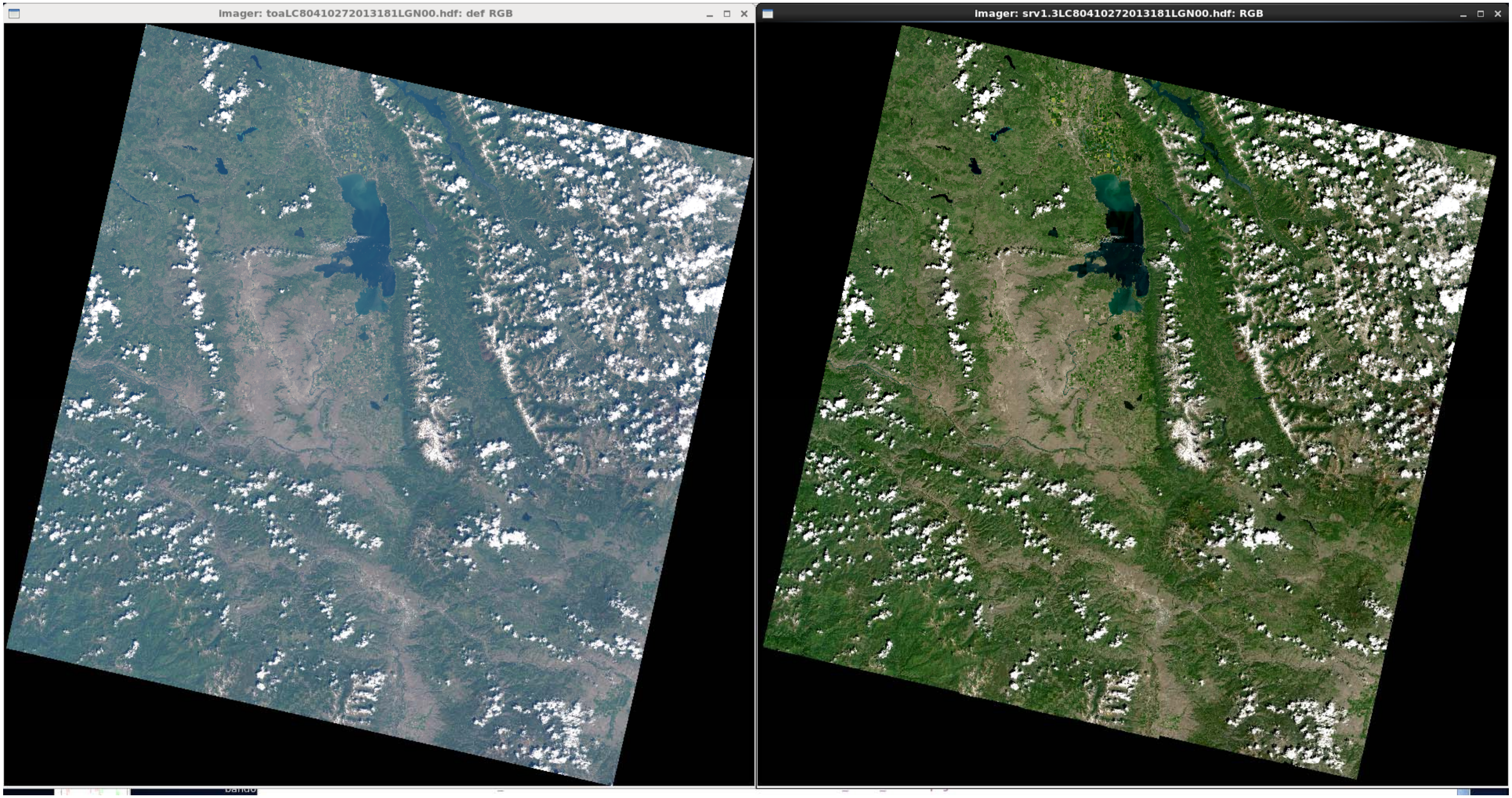




BRDF CORRECTION



EVIDENCE OF ATMOSPHERIC EFFECTS (SCATTERING)



Landsat 8/OLI RGB composite (Red Band04, Green Band03, Blue Band02), over Missoula, MT, acquired on June 30, 2013. The Left side corresponds to the reflectance at the top of the atmosphere, the right side to the surface reflectance. The “color stretch” used for both side is the same.

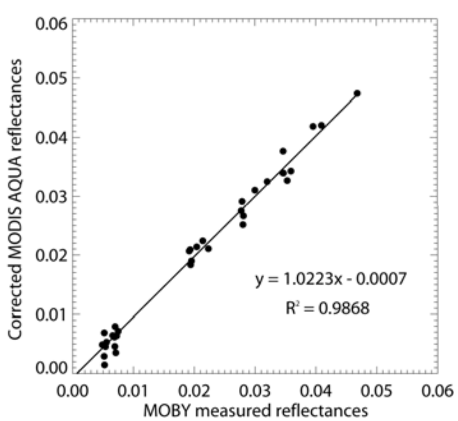
Goals/requirements for atmospheric correction

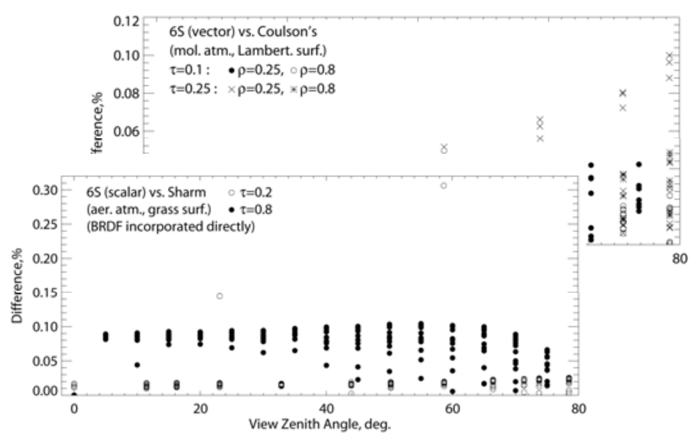
- *Ensuring compatibility of missions in support of their combined use for science and application (example Climate Data Record)*
- A prerequisite is the careful absolute calibration that could be insured by cross-comparison over specific sites (e.g. desert)
- We need consistency between the different 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

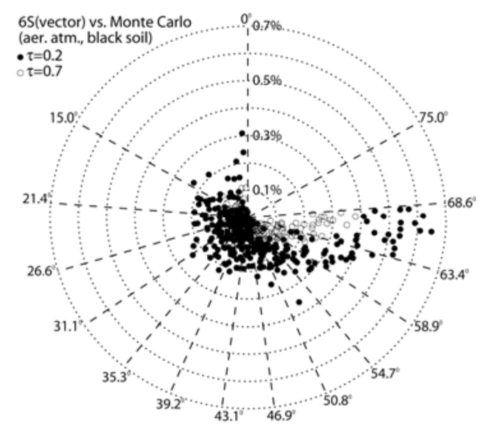
A robust accurate validated RT code is needed

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

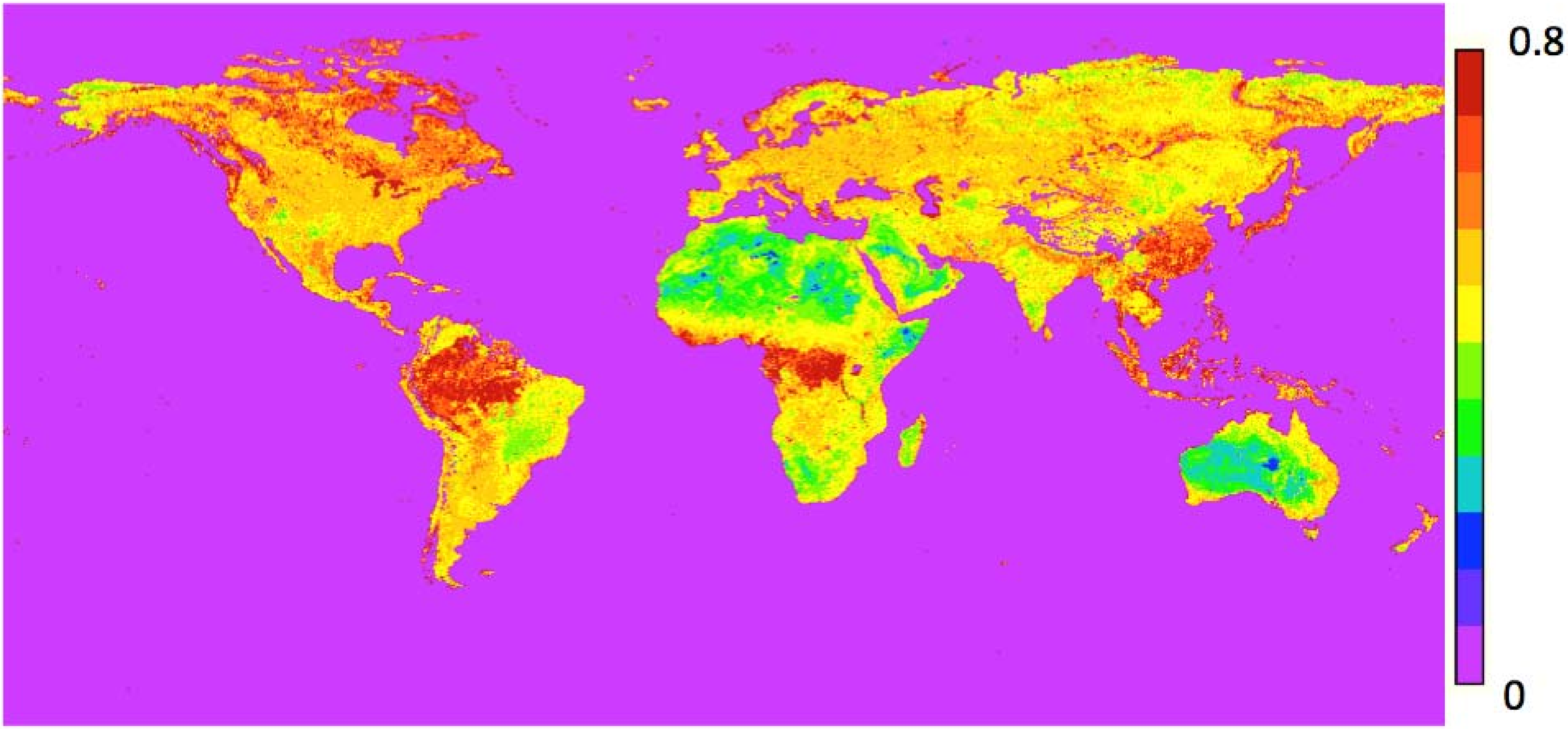
- Kotchenova, S. Y., Vermote, E. F., Matarrese, R., & Klemm Jr, F. J. (2006). Validation of a vector version of the 6S radiative transfer code for atmospheric correction of satellite data. Part I: Path radiance. *Applied Optics*, *45*(26), 6762-6774.
- Kotchenova, S. Y., & Vermote, E. F. (2007). Validation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





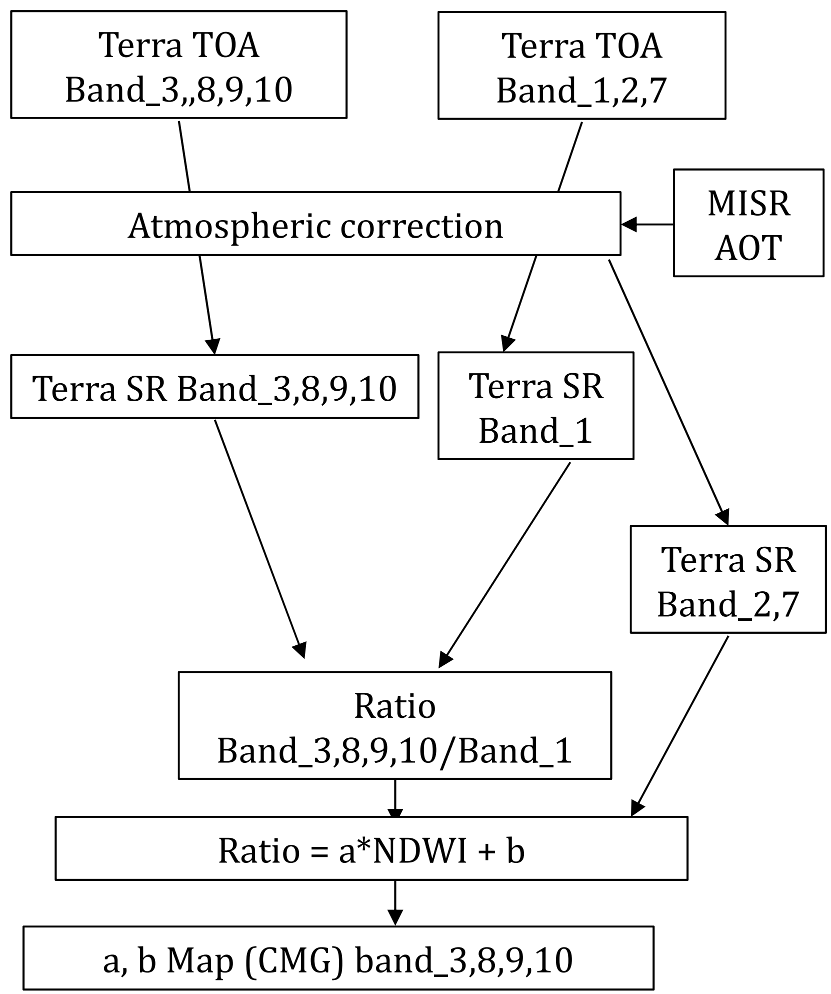


TOWARD A GENERIC AEROSOL RETRIEVAL/ATMOSPHERIC CORRECTION USING MODIS/MISR ~15 Years record



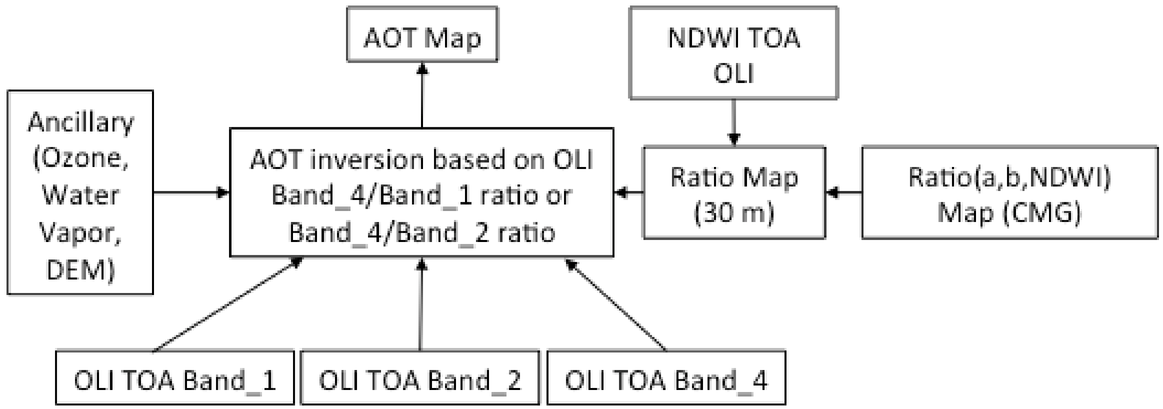
Map of the ratio between MODIS Terra band 3 (0.47µm) and band 1 (0.67µm). This is the average ratio observed over a period of 10 years using coincident MODIS/MISR observations and the optical thickness from MISR to perform atmospheric correction.

RATIO MAP RETRIEVAL FLOWCHART

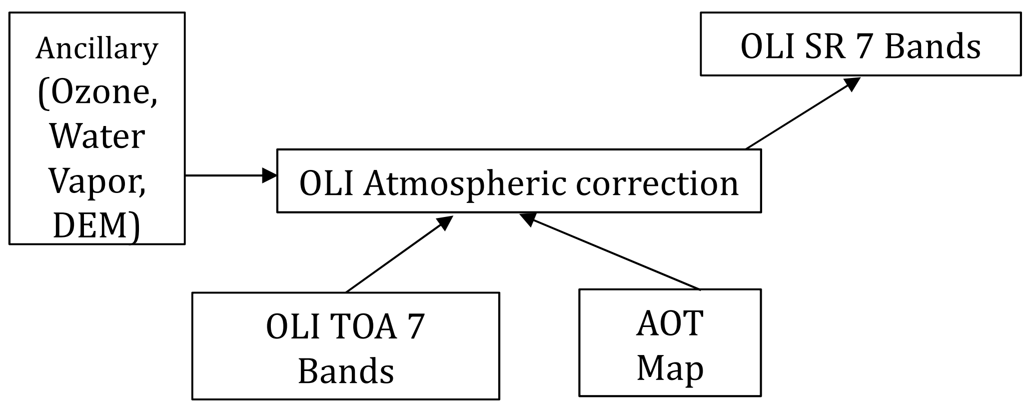


ATMOSPHERIC CORRECTION FLOWCHART

Aerosol retrieval



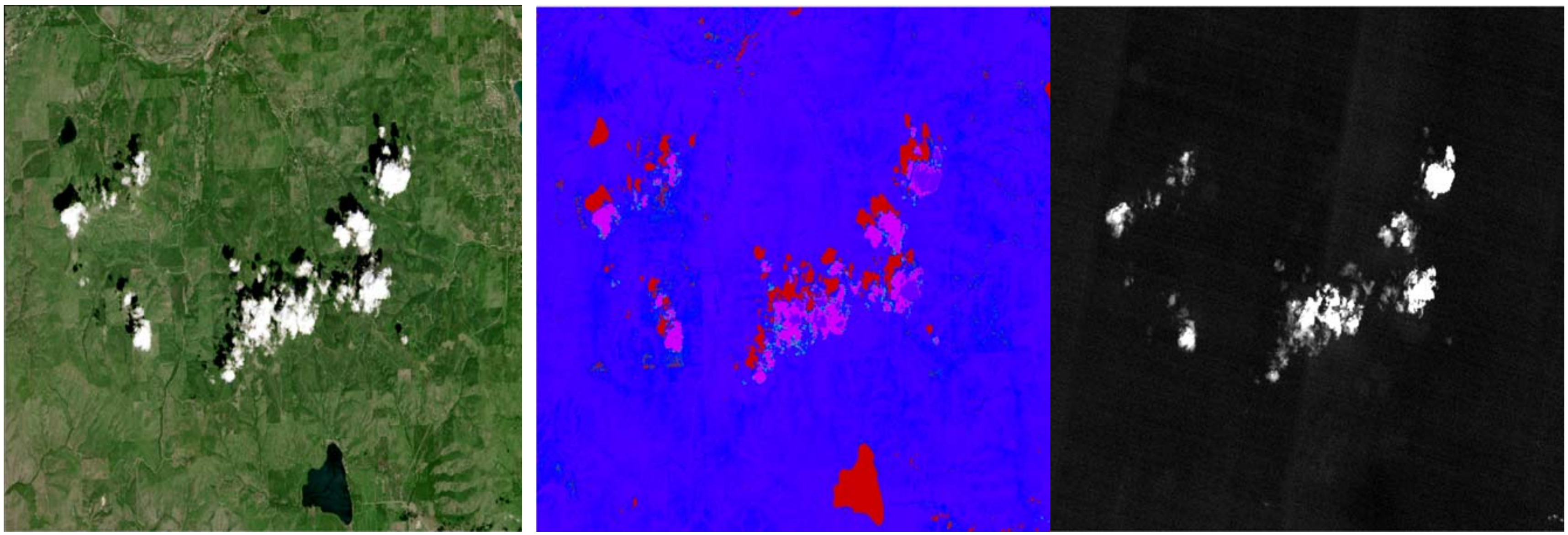
Atmospheric correction



Use of the residual from AOT retrieval for cloud identification

$$Residual = \sqrt{\frac{(\rho_s^1 - r_{1,4}\rho_s^4)^2 + (\rho_s^2 - r_{2,4}\rho_s^4)^2}{2}}$$

Residual is computed from Band 1,2 (blue) and 4 (red) after atmospheric correction using the ratio's ($r_{1,4}$ and $r_{2,4}$) derived from MODIS/MISR.

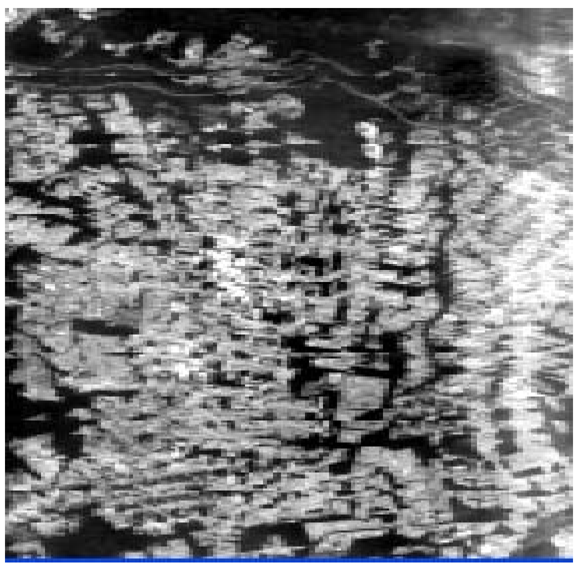


RGB detail of the Missoula scene (left), (center) color scaled residual: the Magenta pixels correspond to higher residual later flagged as cloud, the red were not flagged as cloud but discarded (in that case water and cloud shadow), the purple are clouds flagged early in the processing by the cirrus band (note the threshold on the cirrus band has been set very conservatively ~ 0.02 reflectance unit). (right) Cirrus band 09.

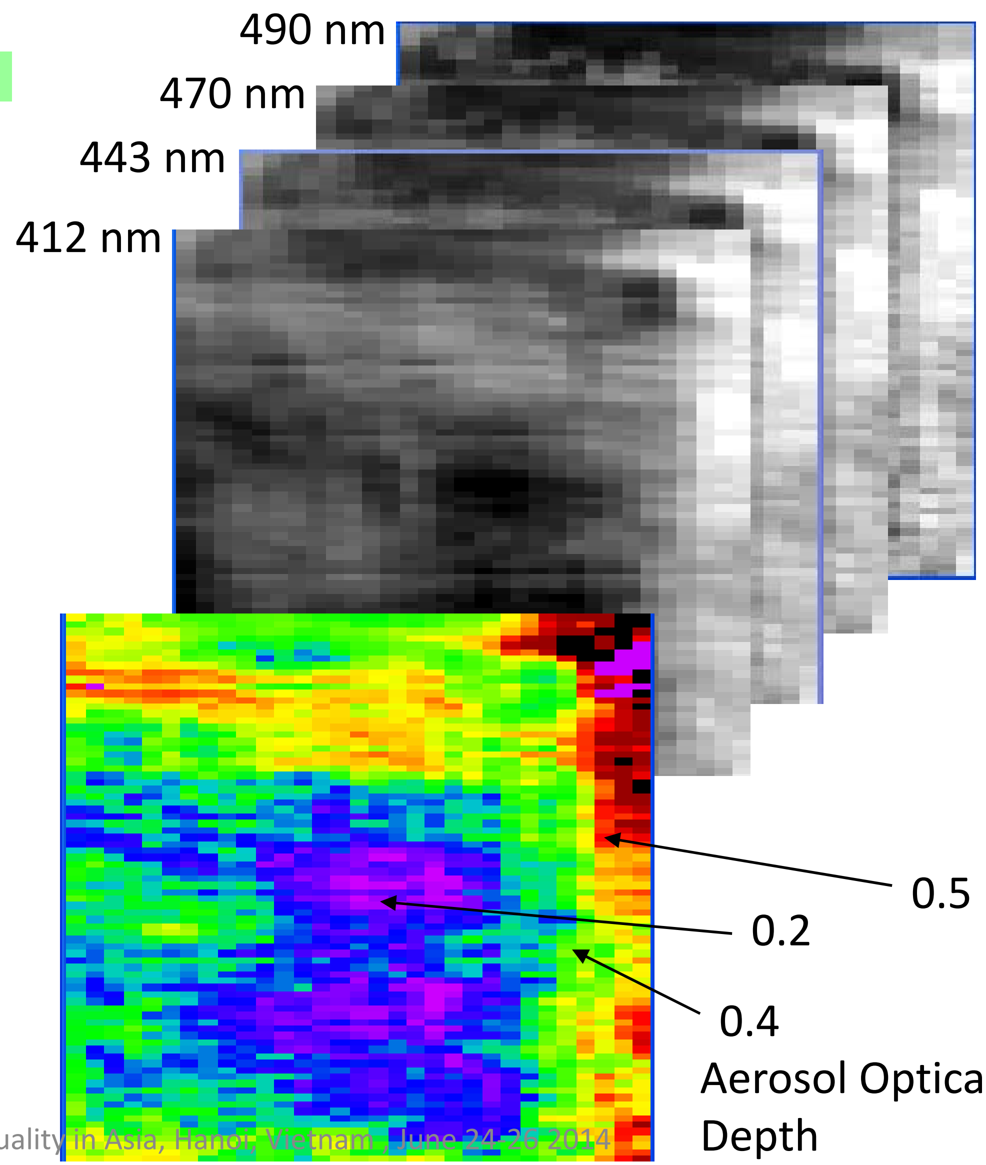
MODIS Aerosol Inversion

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

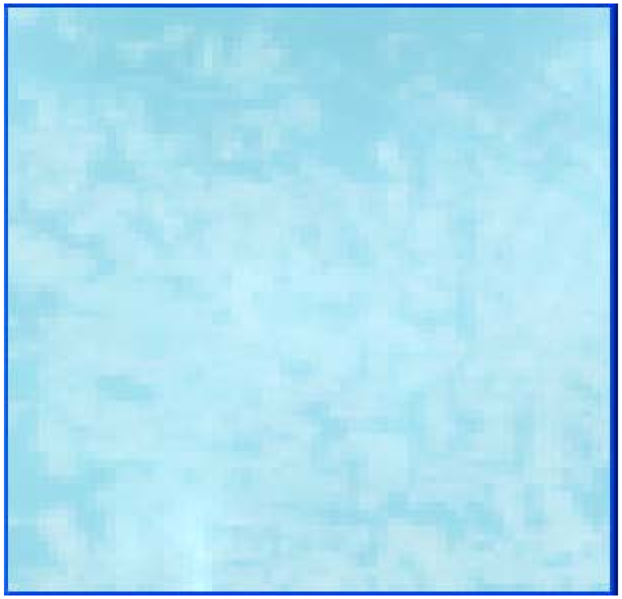


MODIS Aerosol Inversion

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

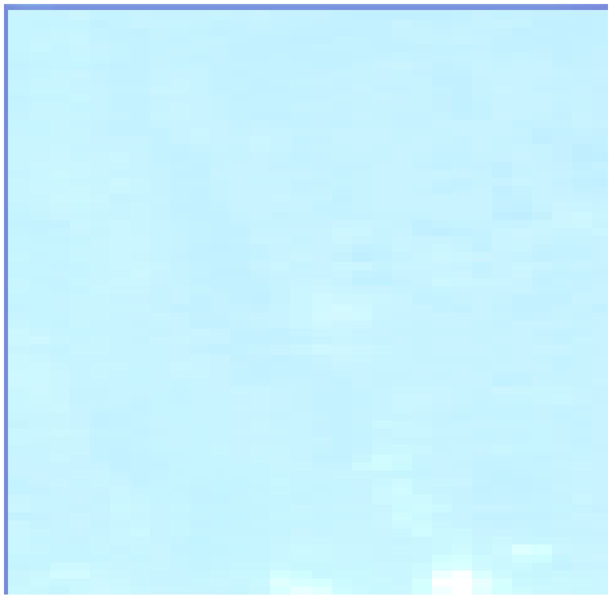
RGB (670 nm, 550 nm, 470 nm)
Surface reflectance

MODIS Aerosol Inversion

Mongu 2003257 08:20 (SCF)

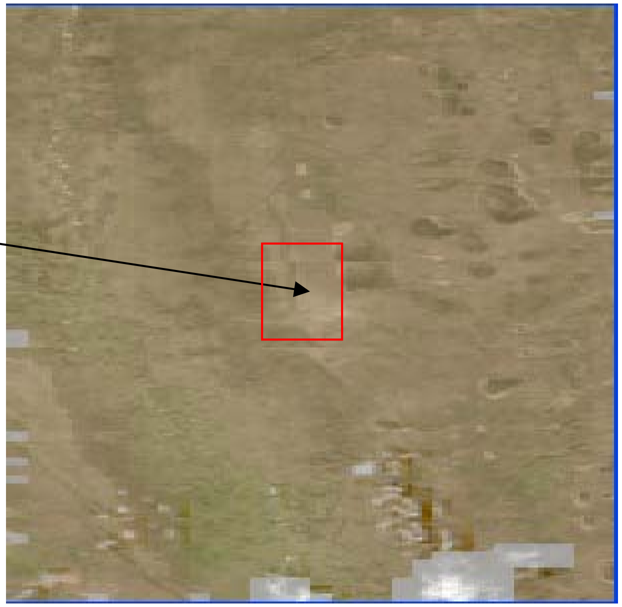
Aeronet				
AOT	delta AOT	WV	delta WV	DTaot
0.98179	0.01919	2.18265	0.00130	14

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



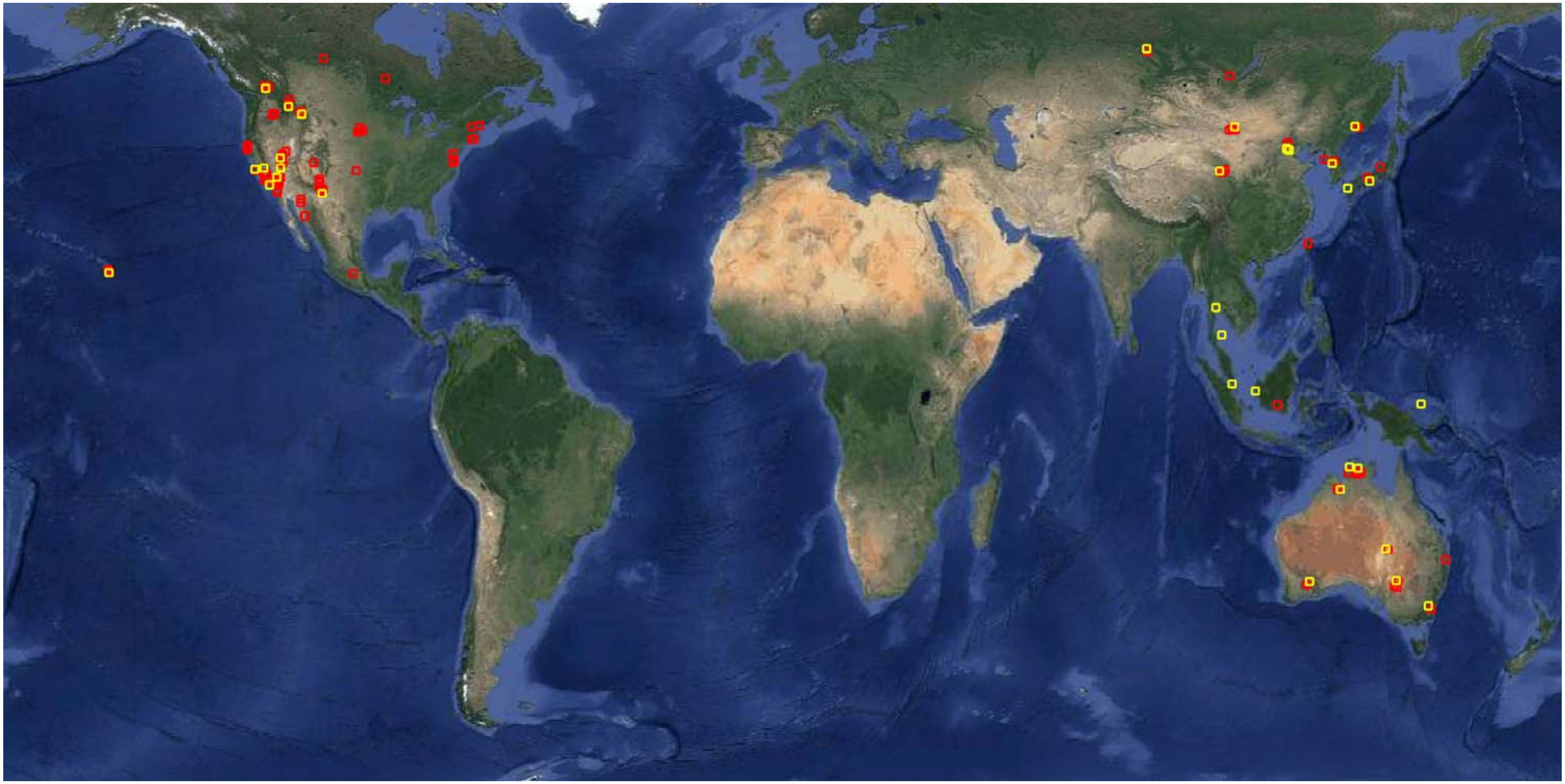
RGB (670 nm, 550 nm, 470 nm)
Top-of-atmosphere reflectance

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



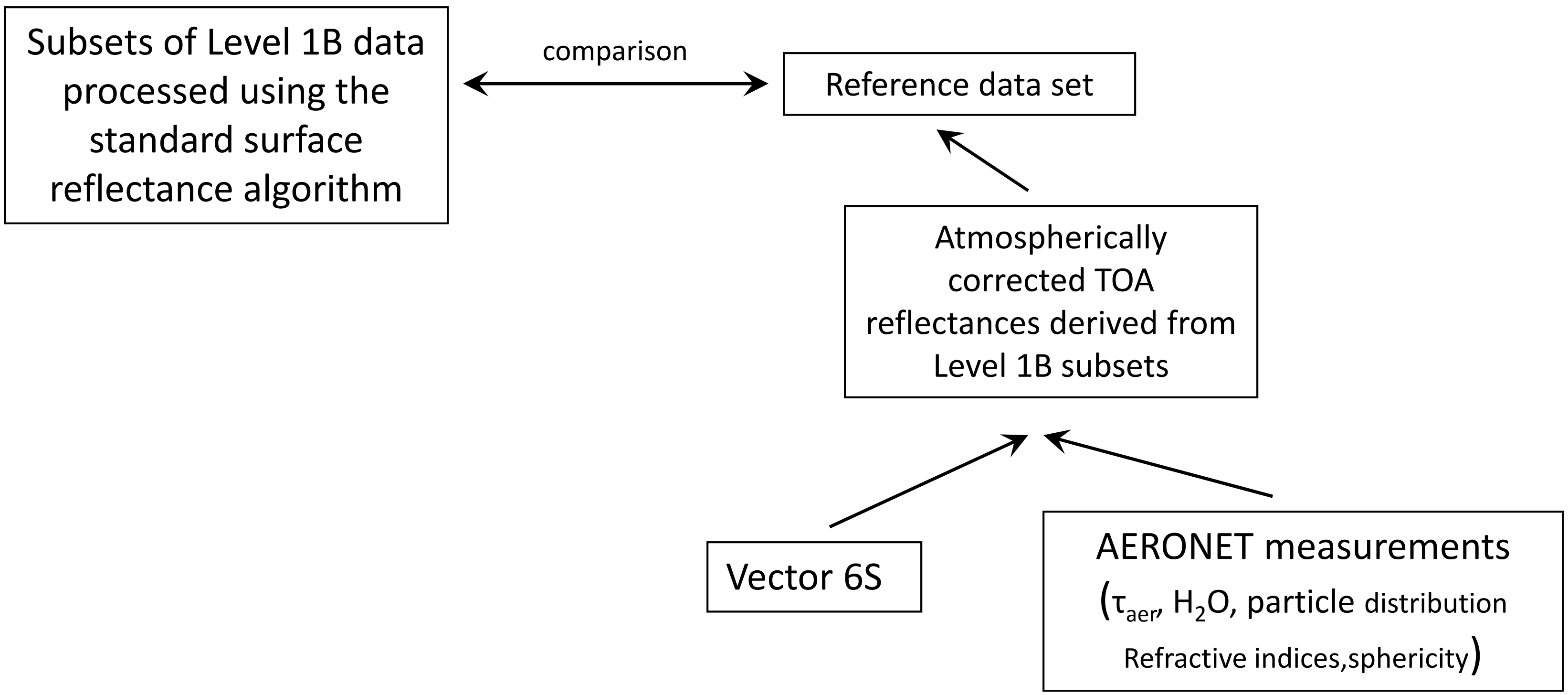
RGB (670 nm, 550 nm, 470 nm)
Surface reflectance

OLI surface reflectance validation: AERONET, MODIS, Flux towers



Map of the AERONET sites (yellow squares) used for the validation and the OLI scenes (red square) used for the OLI-MODIS inter-comparison

Methodology for evaluating the performance of surface reflectance product over AERONET (generic)



Validation Metrics

- Accuracy (A) = the bias

$$A = \frac{1}{N} \times \sum_{i=1}^{N} \varepsilon_i$$

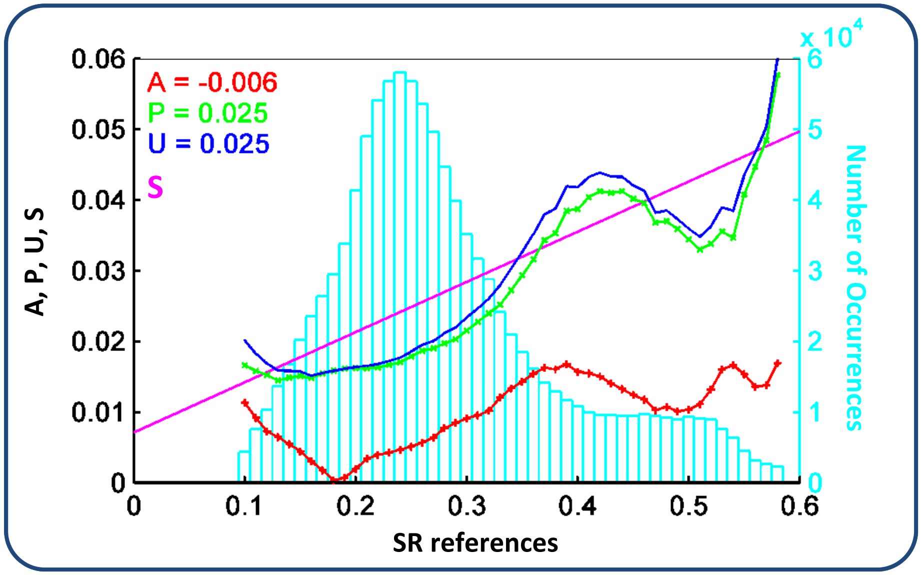
- Precision (P) = the repeatability

$$P = \sqrt{\frac{1}{N-1} \times \sum_{i=1}^{N} (\varepsilon_i - A)^2}$$

- Uncertainty (U) = the actual statistical deviation

$$U = \sqrt{\frac{1}{N} \times \sum_{i=1}^{N} {\varepsilon_i}^2}$$

$$U^2 = \frac{\sum_{i=1}^{N} (\mu_i^e - \mu_i^t - A + A)^2}{N} = \frac{N-1}{N} P^2 + A^2$$

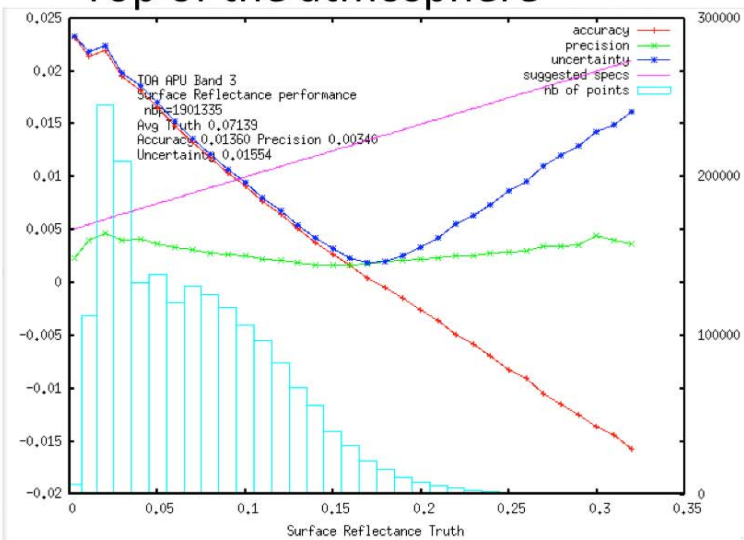


- ❑ Specification (S) = Uncertainty requirement

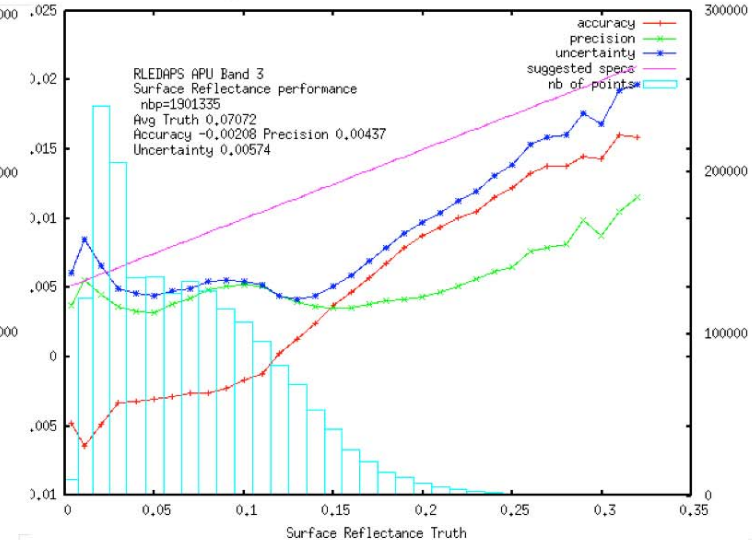
From Vermote and Kotchenova, 2008

APU's FOR RED BAND

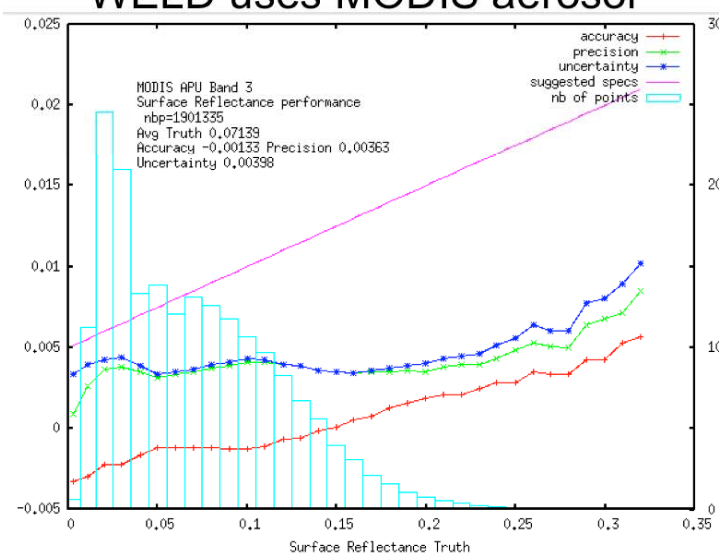
Top of the atmosphere



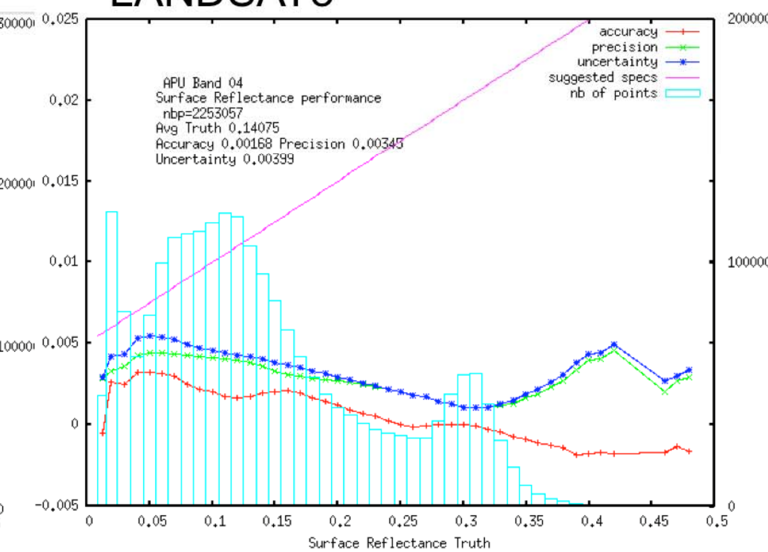
LEDAPS



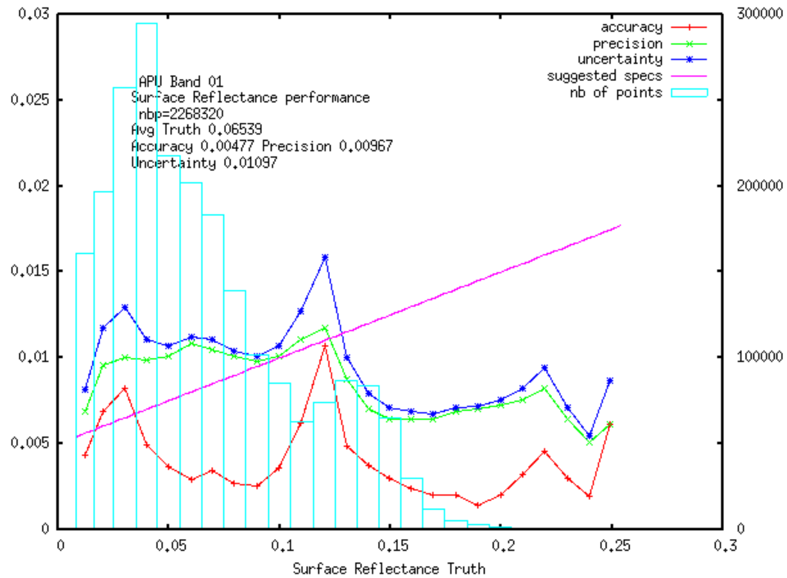
WELD uses MODIS aerosol

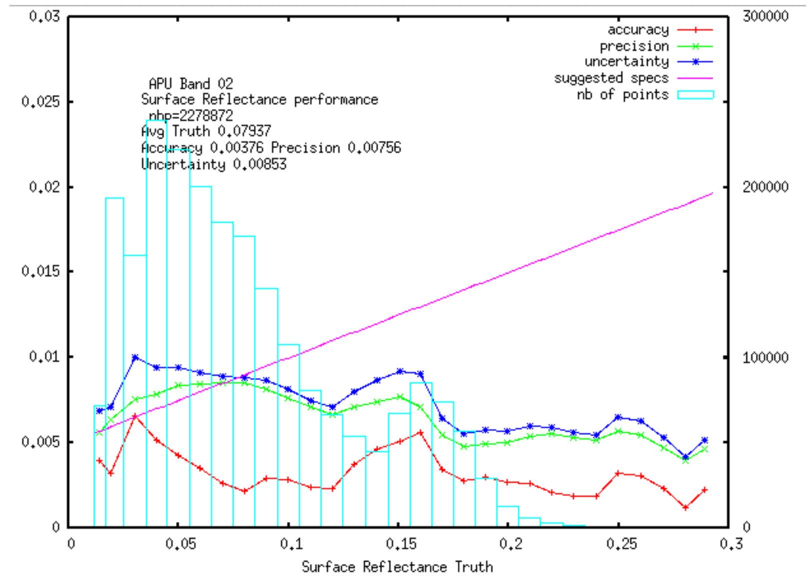


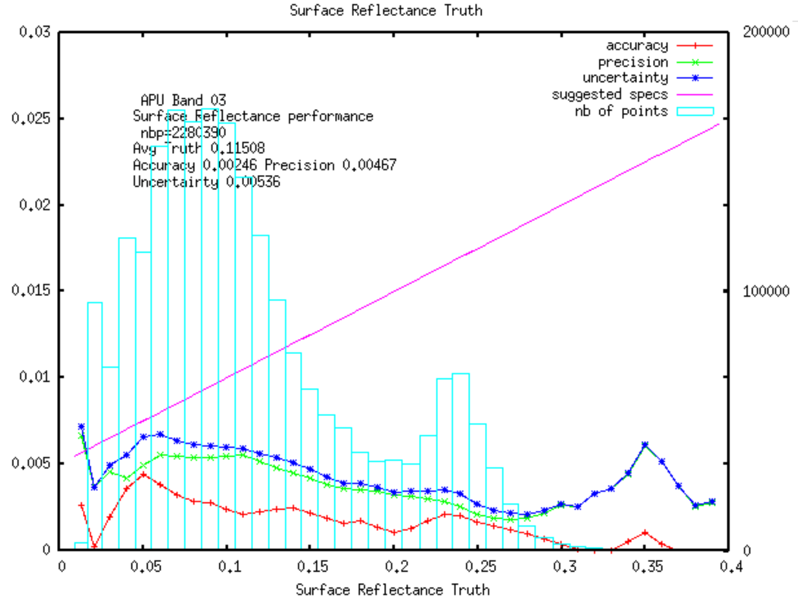
LANDSAT8

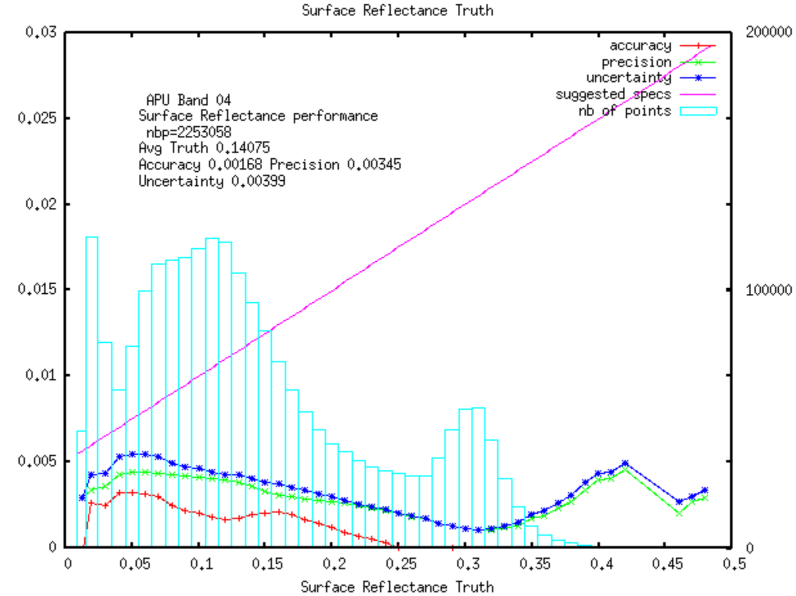


LANDSAT8 SR APU FOR BANDS 1,2,3,4

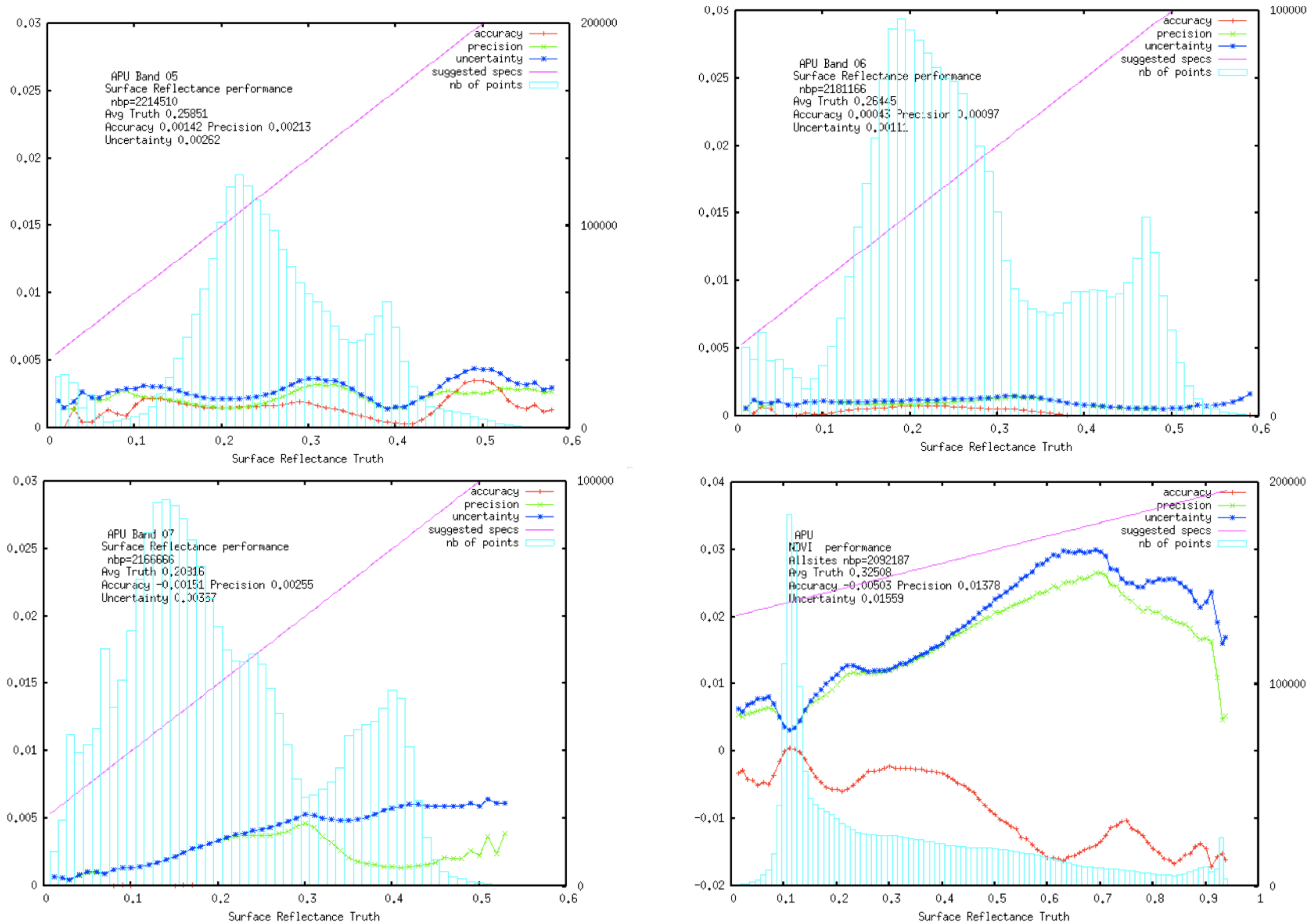




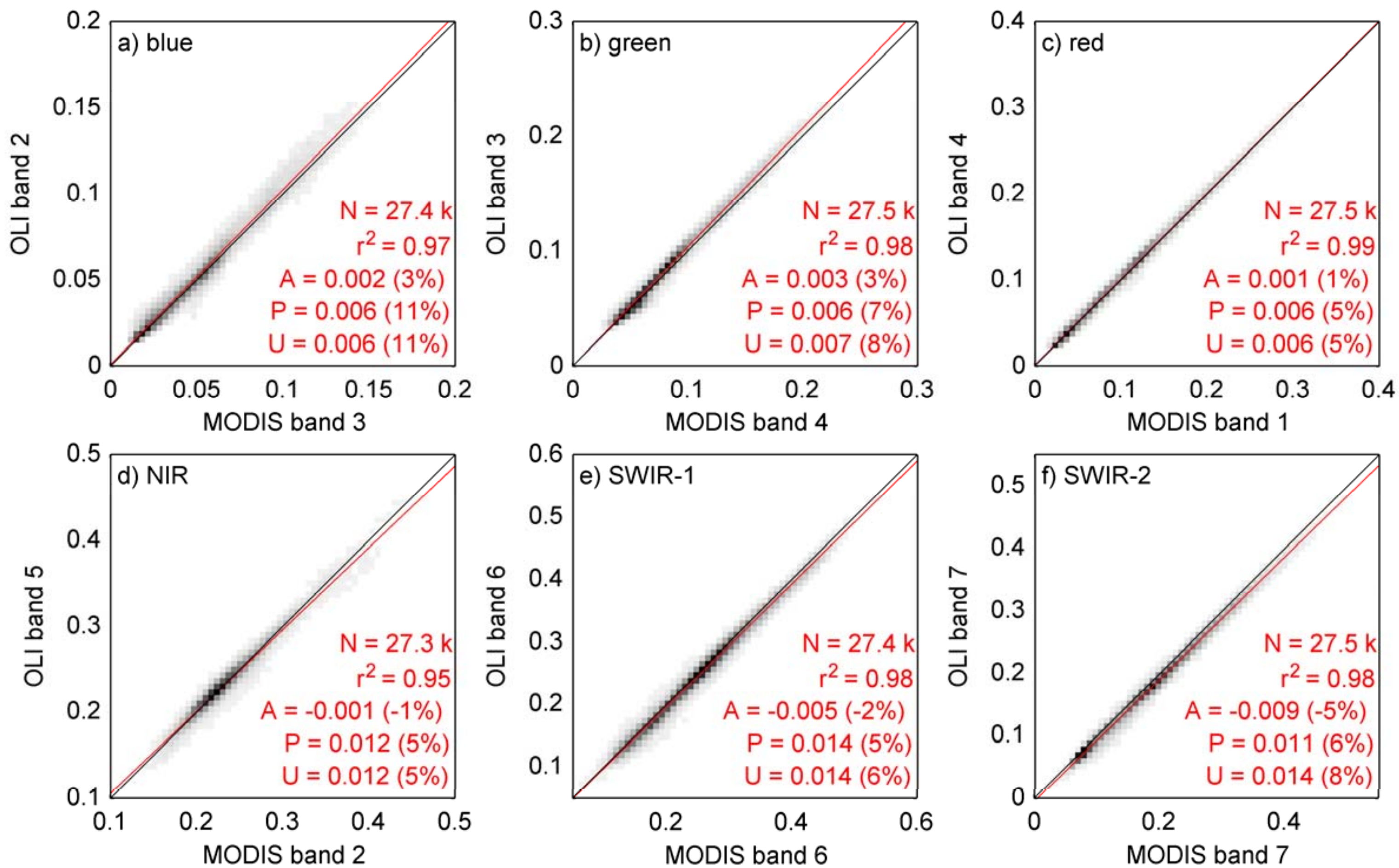




LANDSAT8 APU FOR BANDS 5,6,7 and NDVI

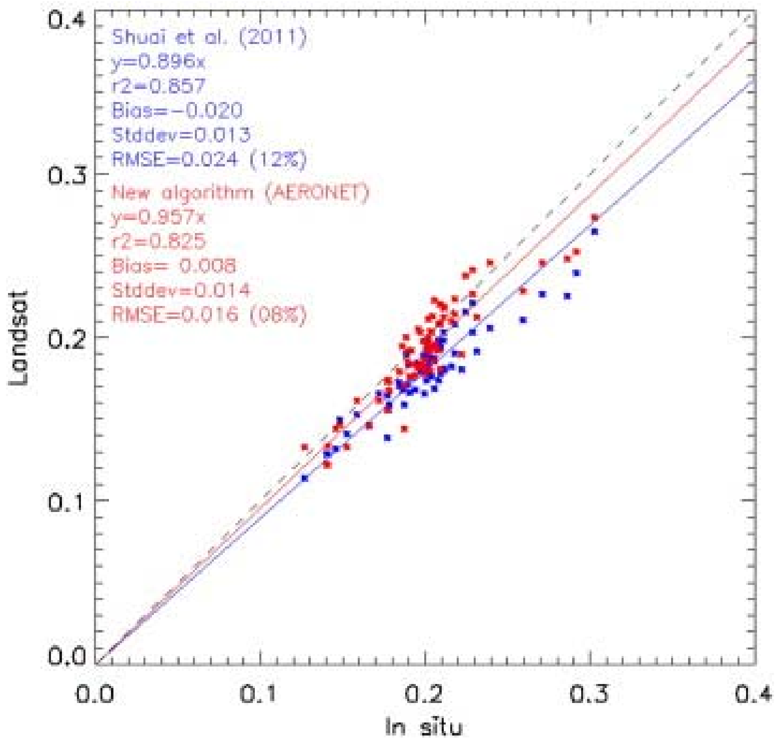


LANDSAT 8 / MODIS CROSS-COMPARISON

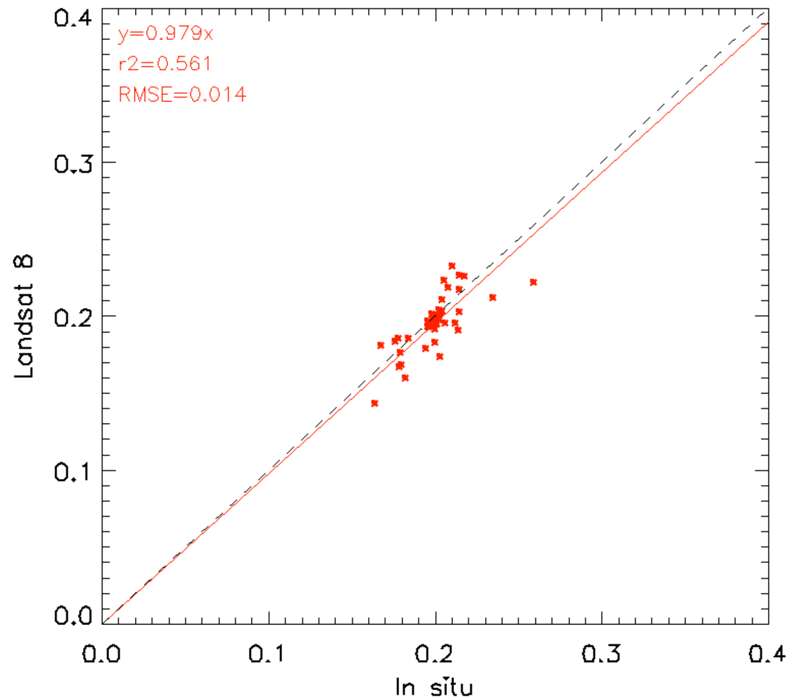


Cross-comparison between Aqua MODIS BRDF and spectrally adjusted SR CMG product and OLI SR aggregated over the CMG. The six subplots correspond to six OLI spectral bands used for the cross-comparison. Plots are represented through density function from light gray (minimum) to black (maximum); white means no data. Red lines correspond to the linear fits. r^2. Relatives A, P and U are reported under bracket. N is the number of points

LANDSAT 8 ALBEDO ANALYSIS



Validation of Landsat (5/7) Albedo derived by Shuai et al. (2011) and Franch et al. (2014). Note that Franch used AERONET data to improve the surface reflectance of the LEDAPS reflectance product used as input. (From Franch et al. 2014.)



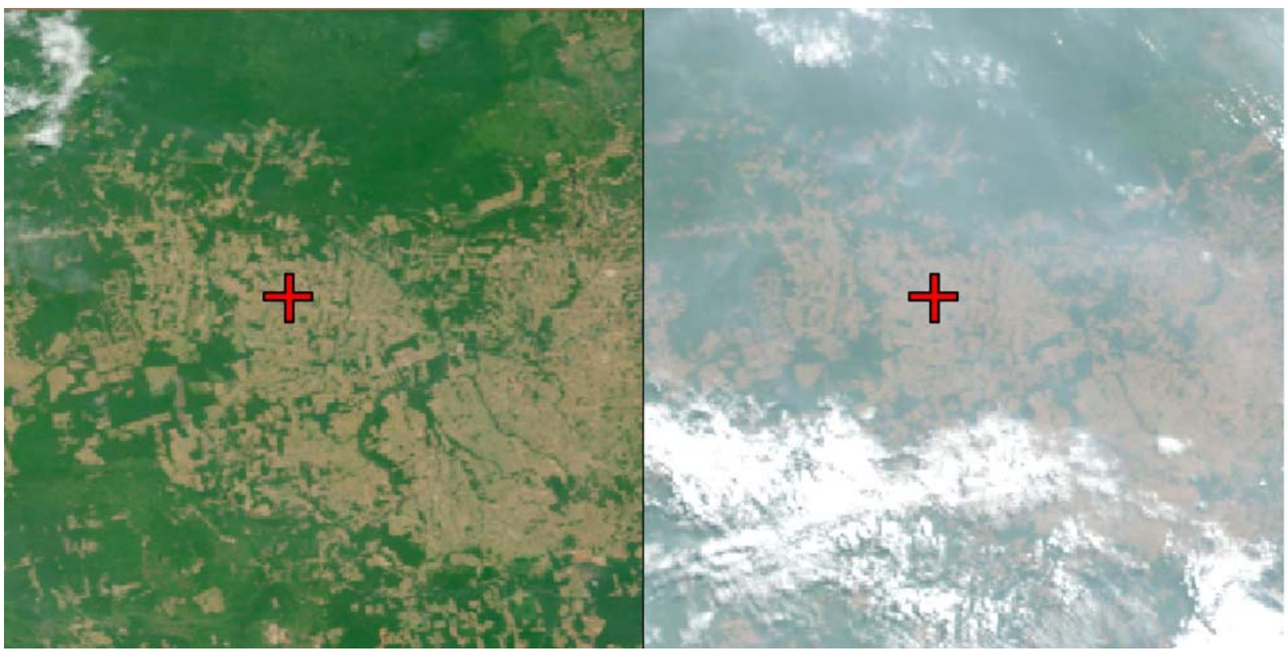
Same as left side but for Landsat8 Albedo, no AERONET data were used to improve the surface reflectance product

Merging dataset to improve aerosol characterization (absorption)

RGB image of the area near Mongu AERONET site (15.25 degree South, 23.15 degree East), for the clear day (July, 17, 2004) and for the hazy (August, 2, 2004). The data have been corrected for the molecular scattering effect. The location of the test site used in the analysis (3km x 3km) is indicated by a red cross.

Merging dataset to improve aerosol characterization (absorption)

RGB image of the area near the Alta Floresta AERONET site (9.92 degree South, 56.02 degree West), for the clear day (August, 2, 2002), and for the hazy day (August, 18, 2002). The data have been corrected for the molecular scattering effect. The location of the test site used in the analysis (3km x 3km) is indicated by a red cross



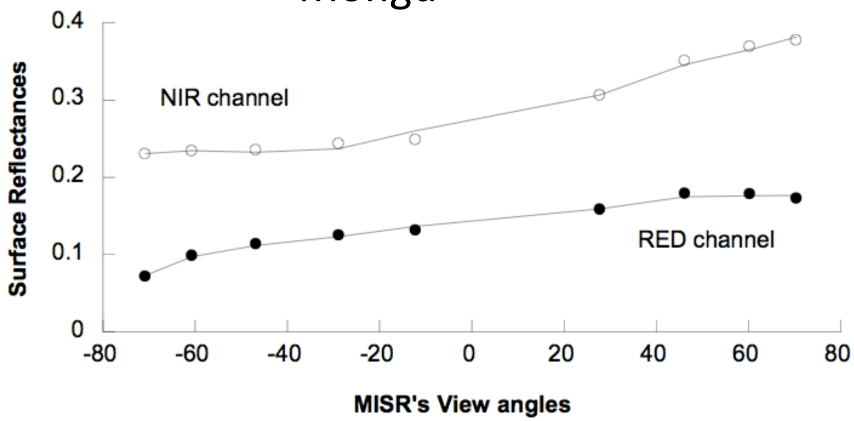
Merging dataset to improve aerosol characterization (absorption)

Case	Aerosol Optical depth at 550nm AERONET (MODIS for the clear day)	Angstrom Parameter AERONET	Ozone Content [cm.atm] NCEP	Water Content [g/cm^2] MODIS	Solar Zenith angle	View Zenith Angle MODIS	Relative Azimuth MODIS
Mongu 7/17/2004 08h50GMT	0.155 (0.21)	1.85	0.273	1..11	43.86	13.40	116.9
Mongu 8/2/2004 08h50GMT	0.428	1.85	0.278	1.42	41.11	13.40	118.11
Alta Floresta 7/22/2004 14h05GMT	0.116 (0.09)	1.7	0.2675	3.48	39.34	1.73	49.93
Alta Floresta 8/23/2004 14h05GMT	0.972	2.05	0.2675	4.13	32.56	1.73	40.95

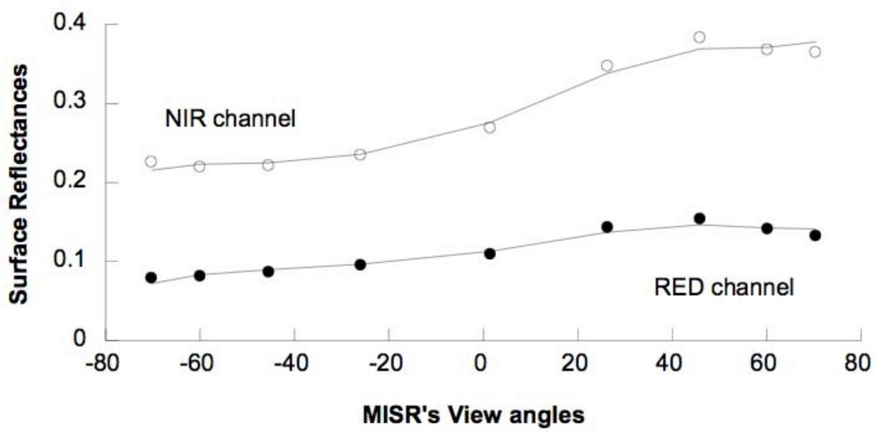
Merging dataset to improve aerosol characterization (absorption)

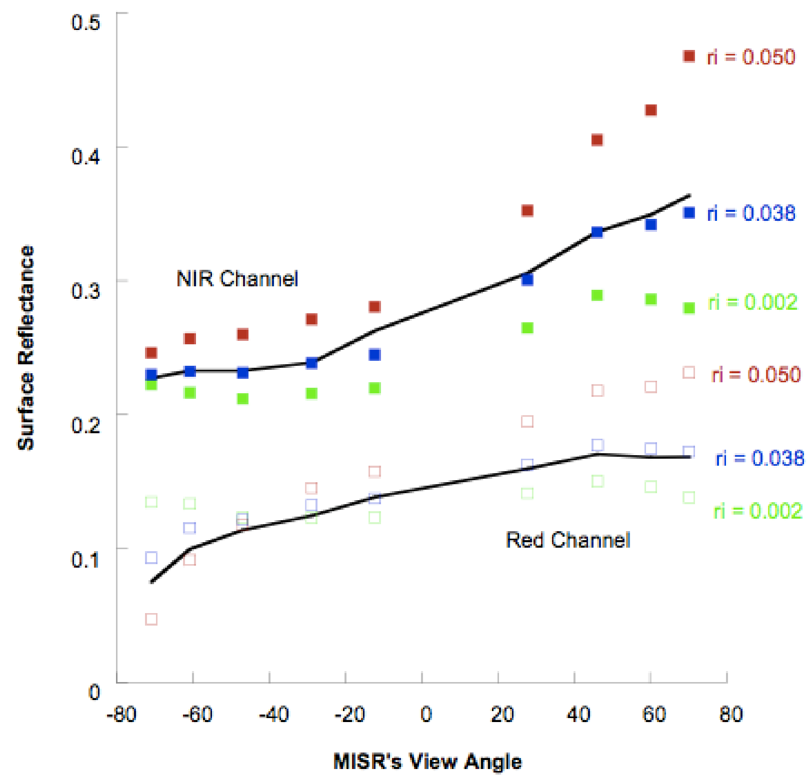
Surface properties (BRDF) are derived from MISR on the clear day and used during the Hazy days to invert the aerosol absorption

Mongu



Alta Floresta



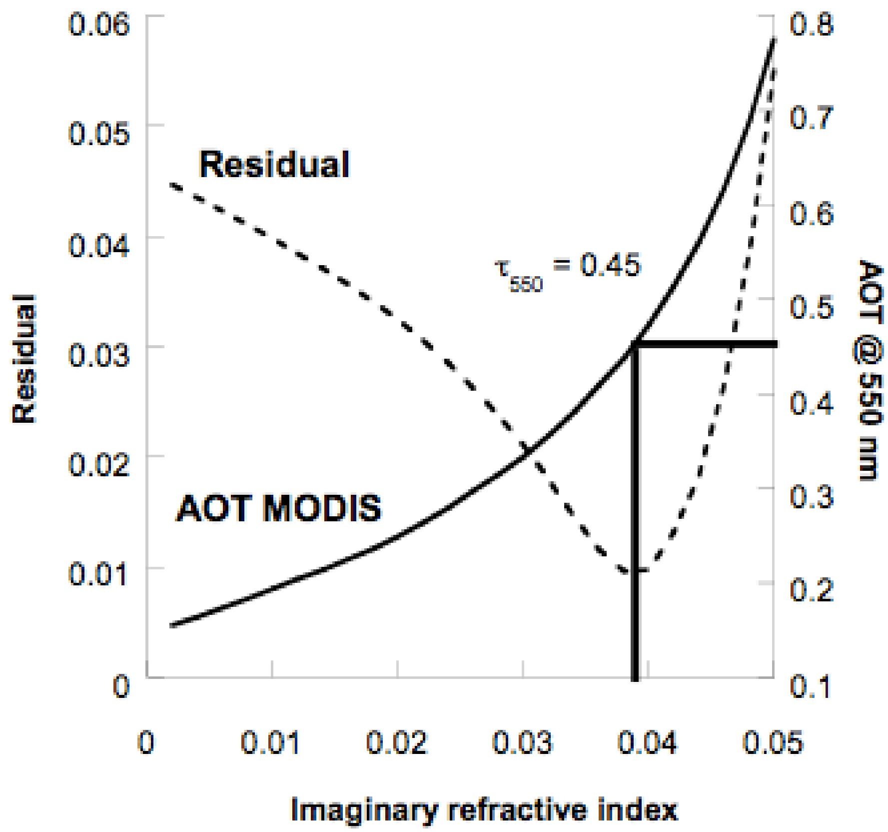


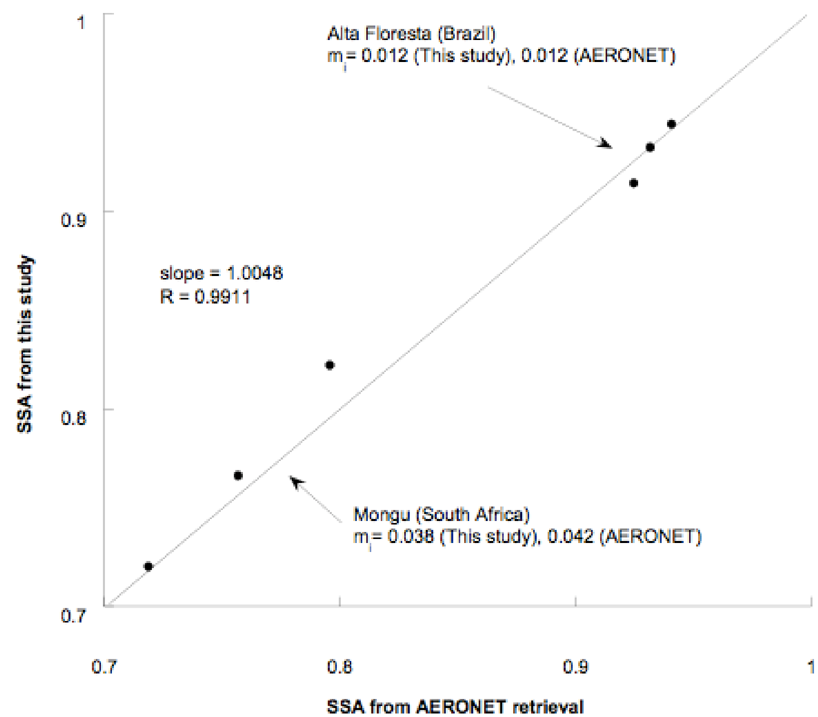
Merging dataset to improve aerosol characterization (absorption)

$$\text{Residual} = \frac{\sum_{i=1}^{9}\left|\rho_{red_i}^{cor} - \rho_{red_i}^{pred}\right|}{9} + \frac{\sum_{i=1}^{9}\left|\rho_{NIR_i}^{cor} - \rho_{NIR_i}^{pred}\right|}{9}$$

Where $\rho_{band_i}^{cor}$ is the corrected reflectance in red or NIR for camera i,

and $\rho_{band_i}^{pred}$ is the predicted reflectance in red or NIR for camera i





Conclusions

- Must revisit aerosol model and maybe be more flexible in inversion (no fixed model, angstrom exp?, follow the two modes ocean approach?)
- Take advantage of sensor fusion
- New sensors with high spatial, spectral and radiometric resolution are available (Landsat8, Sentinel 2) with improved cirrus detection capability should be very useful for air quality studies
- Need to adapt the aerosol inversion to the given problem at hand (like for atmospheric correction) to retrieve the most pertinent parameters to air quality
- Error budget, continuous ground observations and validation protocols are keys.