Transition from MODIS to NPP/NPOESS-VIIRS Aerosol Retrieval

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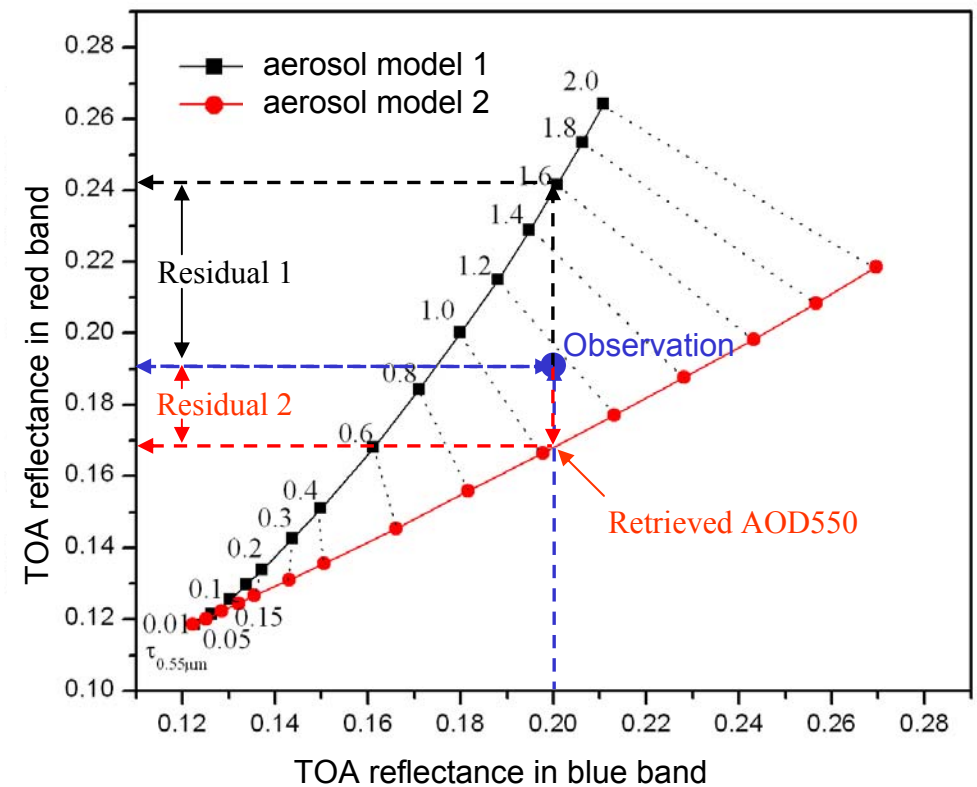
Motivation

- In the NPP/NPOES era the MODIS aerosol retrievals will be replaced by those from the Visible Infrared Imaging Radiometer Suite (VIIRS).
- Current MODIS and VIIRS aerosol algorithms are sufficiently different to potentially produce different AOD.
- The differences might effect the continuity of MODIS aerosol record, and they might effect the radiation budget derived from satellite measurements.

Multi-channel Aerosol Retrieval

General features:

- Uses two or more spectral bands.
- Separate algorithms for water and land.
- Aerosol and surface signals are separated by estimating surface reflectance in “blue” and “red” channels from that in SWIR for land.
- Surface contribution of water is from model.
- AOD and model is from the “minimum” residual between observed and calculated spectral reflectances.



Features of MODIS and VIIRS AOD Algorithms

	MODIS C4	MODIS C5	VIIRS
Data screening	Independent complete internal checks: over land for cloud, snow and inland water; over water for cloud, cirrus, sediment, shallow water and sunglint (MODIS cloud mask (M?D35) bit 11, 15 and 18 are used by screening over ocean)		• External cloud mask. • Internal checks: over land for cloud, cirrus, sunglint, fire and snow; over water for turbid water, sunglint and ice.
Data averaging	To nominal 10x10-km grids (Ocean: discard the darkest and brightest 25% of pixels defined by ρ0.86; Land: discard the darkest 20% and brightest 50% of pixels defined by ρ0.66).		N/A
Water vapor absorption	Corrected at TOA. All water vapor is above the aerosol.		Aerosol reflectance is attenuated by half of water vapor. Well mixed with aerosol.

Features of MODIS and VIIRS AOD … (cont)

Over water			
	MODIS C4	**MODIS C5**	**VIIRS**
Surface pressure	Constant – sea level.		Rayleigh optical functions are corrected to actual surface pressure.
Aerosol models	4 fine modes 5 coarse modes	Refractive index of first three coarse modes of collection 4 is updated.	Same as MODIS collection 4; some difference in refractive index.
Channels used	0.55, 0.66, 0.86, 1.24, 1.64 and 2.13μm		0.672, 0.746, 0.865, 1.240, 1.610, 2.250μm
Reference channel	0.86μm		1.24μm

Features of MODIS and VIIRS AOD … (cont)

Over water			
	MODIS C4	**MODIS C5**	**VIIRS**
Residual calculation	$\sqrt{\sum_{\lambda=1}^{6} N_\lambda \left(\frac{\rho_\lambda^m - \rho_\lambda^{LUT}}{\rho_\lambda^m - \rho_\lambda^{ray} + 0.01} \right)^2 / \sum_{\lambda=1}^{6} N_\lambda}$		$\sqrt{\sum_{\lambda=1}^{6} \left(\rho_\lambda^m - \rho_\lambda^{LUT} \right)^2}$
Searching for the FMW	Interval halving		Brute force. (discrete 101 fractions with interval of 0.01)
Surface reflectance contribution	Constant wind speed (6 m/s) Built into LUT		Explicit calculation of the direct and diffuse water reflection given ancillary wind speed and direct. TOA reflectance is calculated by combining atmospheric and surface contributions.
RTM for LUT	Ahmad and Fraser (1981)		6sV1.1

Features of MODIS and VIIRS AOD … (cont)

Over land			
	MODIS C4	**MODIS C5**	**VIIRS**
Surface pressure	Actual pressure is from surface elevation.		Elevation and synoptic variation of surface pressure are considered.
	AOD is adjusted by the optical depth that was neglected by assuming sea level.	LUT is adjusted to simulate different molecular optical depth by adjusting the wavelength.	Molecular contribution is adjusted in calculation of TOA reflectance.
Channels used	0.47 and 0.66 μm	0.47, 0.66 and 2.12 μm	0.488 and 0.672 μm
Reference ch	0.47 μm	0.47 μm	0.488 μm
Aerosol models	3 nondust and one dust model; mixture is determined from the ratio of 660-nm to 470-nm path reflectance.	3 nondust and one dust model (updated using AERONET). Mixture is determined separately for each retrieval.	Five typical land aerosol models from AERONET.

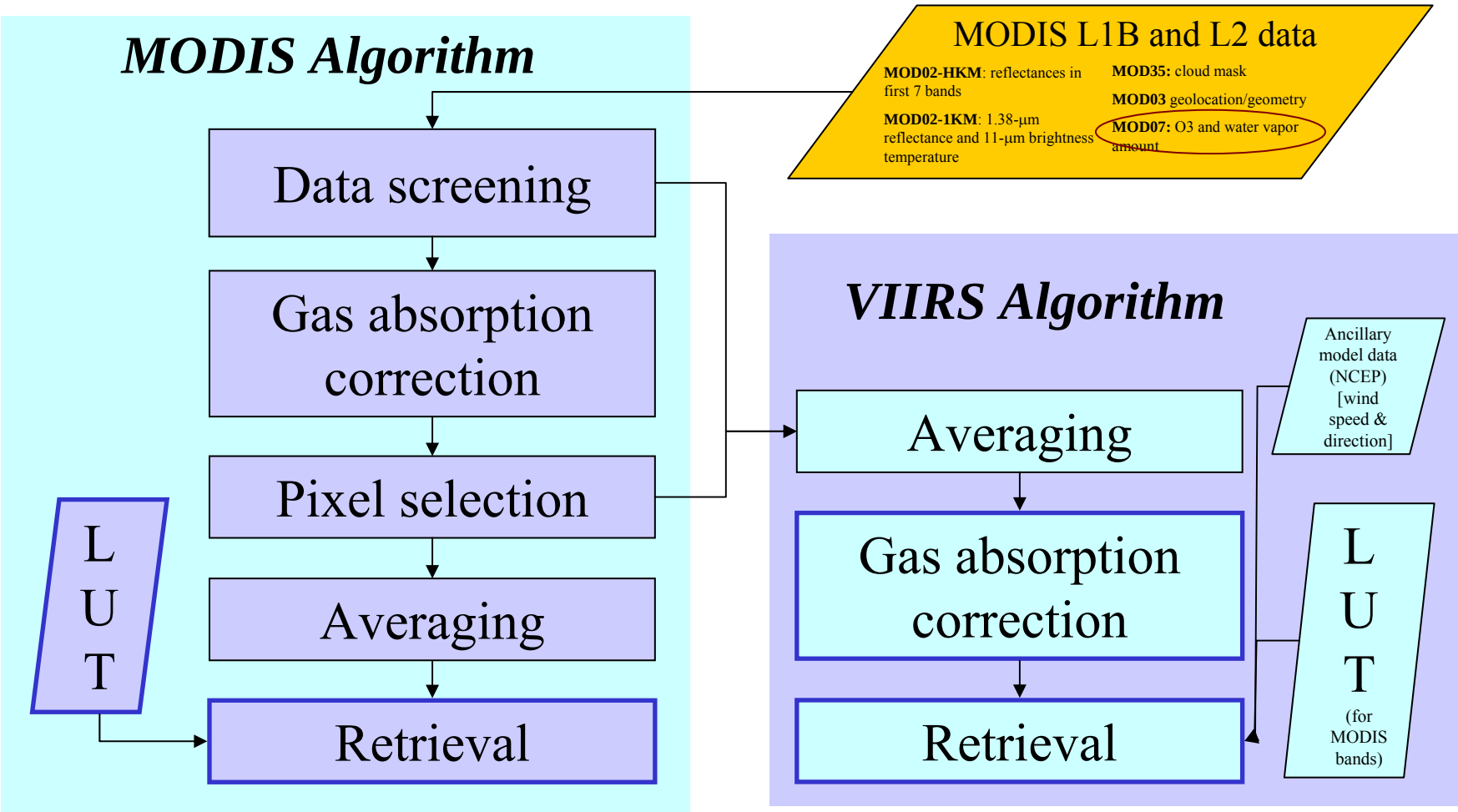
Features of MODIS and VIIRS AOD … (cont)

Over land			
	MODIS C4	**MODIS C5**	**VIIRS**
Surface reflectance	Assumes SWIR TOA reflectance equals SWIR surface reflectance. Linear relationship between VIS and SWIR for dark surface.	Surface reflectance at SWIR is determined in conjunction with AOD and FMW retrieval. Updated linear relationship between VIS and SWIR for dark surface.	Separate linear relationships between VIS and SWIR for vegetation and soil dominated surface.
Retrieval	1) surface reflectance in each band; 2) aerosol mixture, 3) AOD retrieval.	Simultaneous retrieval of surface reflectance, AOD and FMW.	1) surface reflectance in each band; 2) AOD and residual for candidate models. 3) AOD and model from smallest residual.
RTM for LUT	Dave (1970) scalar RT model	RT3 (Evans and Stephens)	6sV1.1

Strategy

- Adopt stand-alone versions of MODIS C5 and VIIRS algorithms
  - Use MODIS radiances in both algorithms. (VIIRS LUT)
  - Check local implementation of MODIS (“local” MODIS) with “standard” (MOD04) MODIS:
    - use reflectance directly from MOD04;
    - use reflectance from L1B MODIS.
- Compare VIIRS and MODIS retrievals under realistic conditions. :
    - use MODIS L1B reflectance and L2 ancillary data.

The MODIS-VIIRS test bed

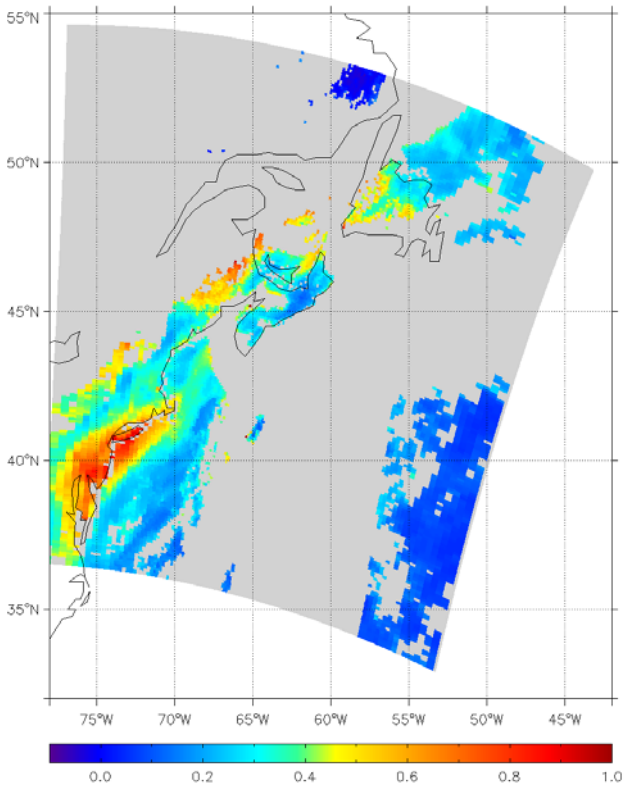


“Local” vs. “standard” MODIS retrieval

MOD04 inputs

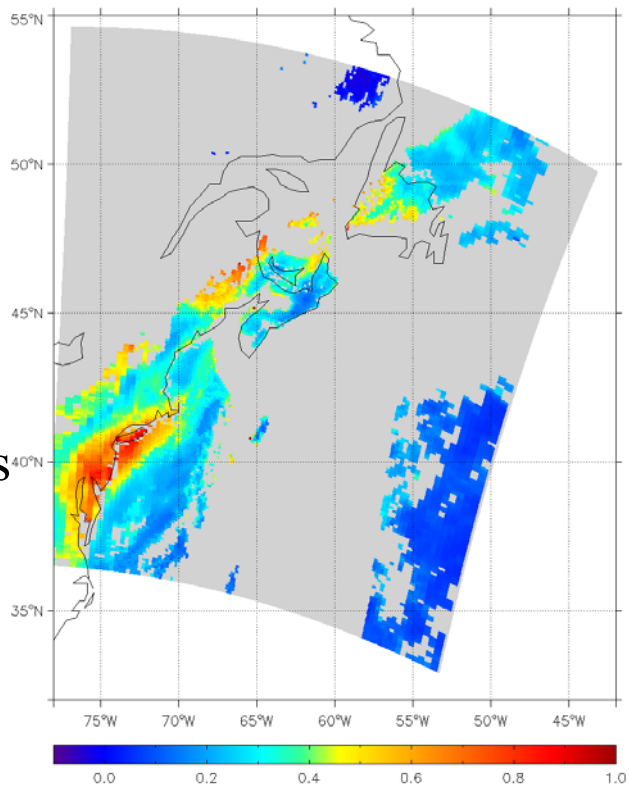
Single Terra granule 2006/09/09

MODIS Collection 5 AOD550
(MOD04 best quality)

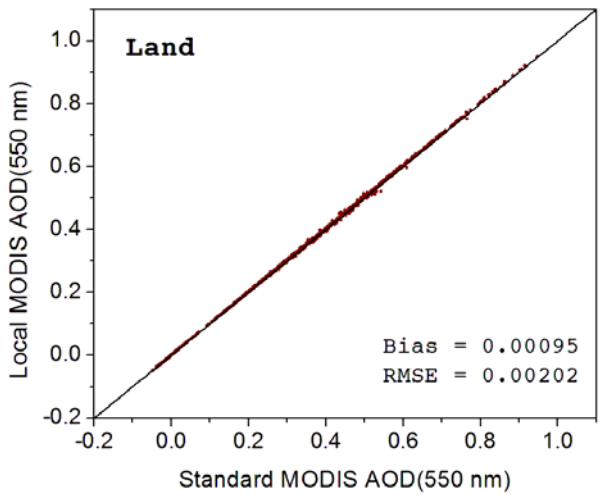


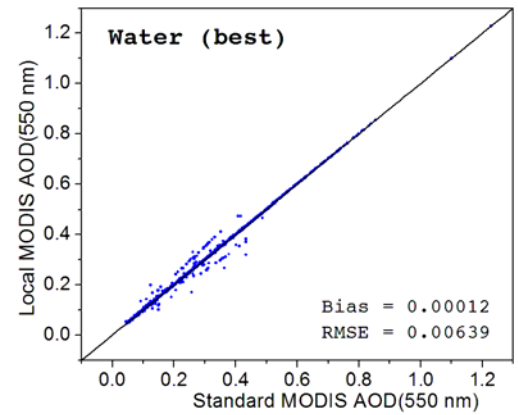
No obvious differences are seen but …

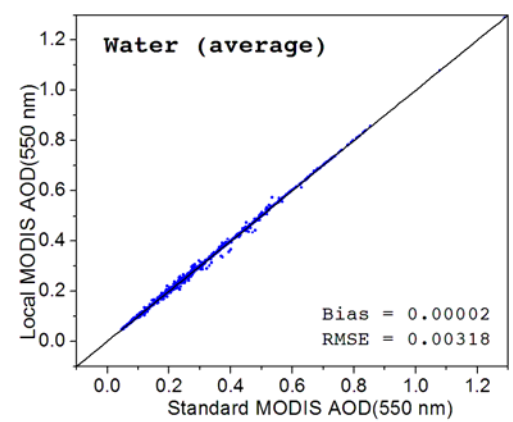
local MODIS AOD550
(Inputs from MOD04)



Scatter plot of “local” vs. “standard” MODIS retrieval - MOD04 inputs





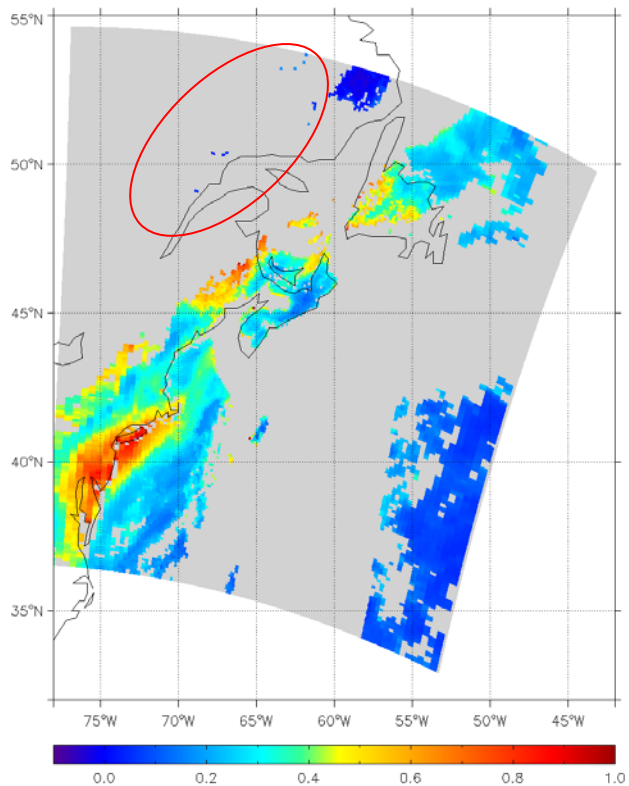


- Local MODIS agrees well with standard MODIS, but not identical.
- **MOD04 reflectance used** in local retrieval may not be exactly the same as that in “standard” retrieval (due, for example, to truncation).
- Small differences are due to platform dependence (more evident over water with “best” solution)

“Local” vs. “standard” MODIS retrieval

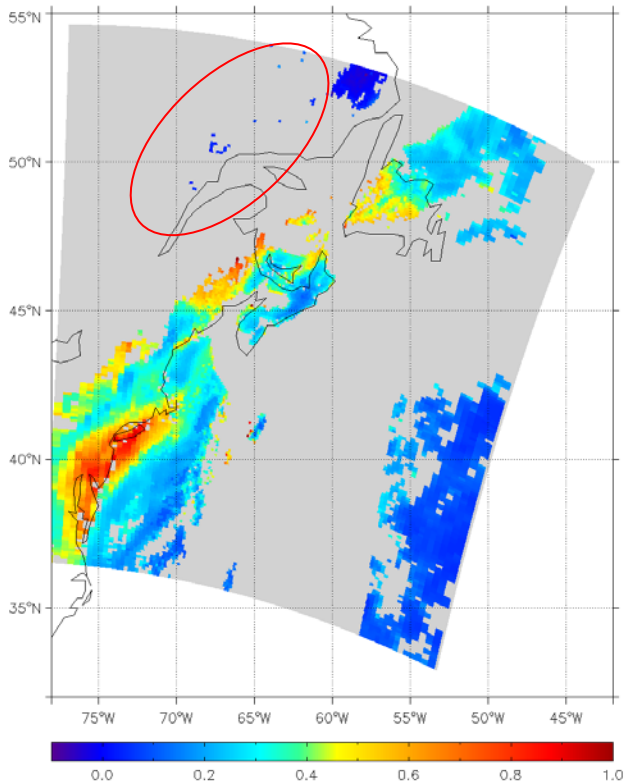
L1B inputs

MODIS Collection 5 AOD550
(MOD04 all available retrieval)

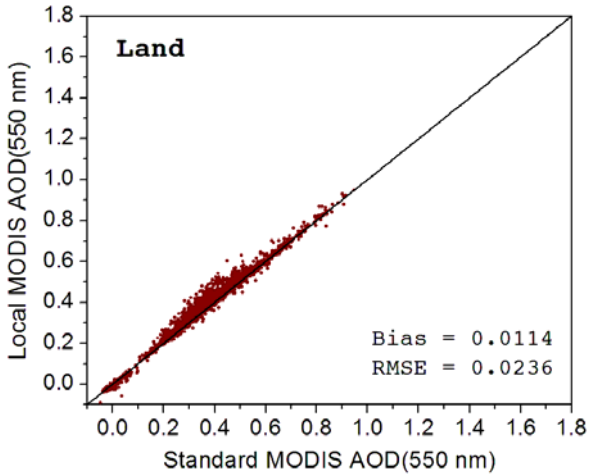


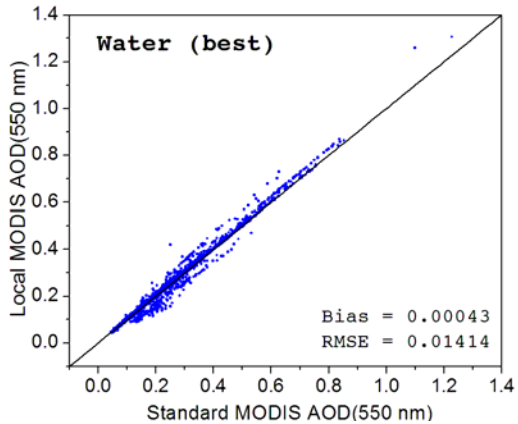
Some differences start showing up when L1B is used in local retrieval.

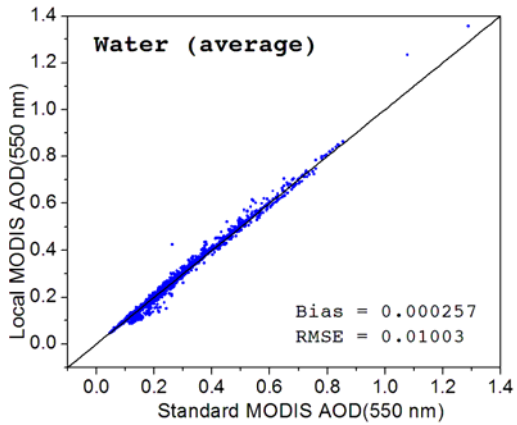
Local MODIS AOD550
(Using MODIS L1B data)



Scatter plot of “local” vs. “standard” MODIS retrieval - L1B inputs







- Input for local retrieval is generated from **MODIS L1B data**; it is not exactly the same as from MOD04.
- Differences are due to processing differences: gas absorption correction, different pixels participating in averaging due to difference in cloud screening, etc.

VIIRS algorithm tests over water

Changes were introduced to make the VIIRS algorithm gradually more similar to the MODIS algorithm:

Test 1: LUT is updated with MODIS collection-005 aerosol models.

Test 2: Test 1 + reference channel is changed to 0.87μm, and corresponding residual channels are 0.553, 0.644, 1.243, 1.632, 2.119 μm.

Test 3: Test 2 + water vapor is placed above the aerosol layer.

Test 4: Test 3 + no correction for actual surface elevation/pressure.

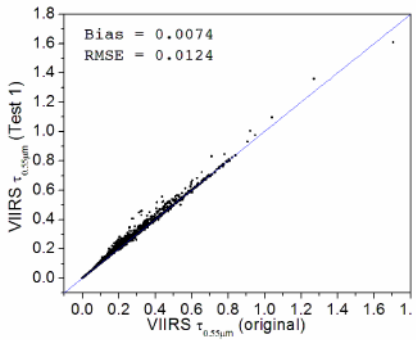
Test 5: Test 4 + residual is calculated as in MODIS.

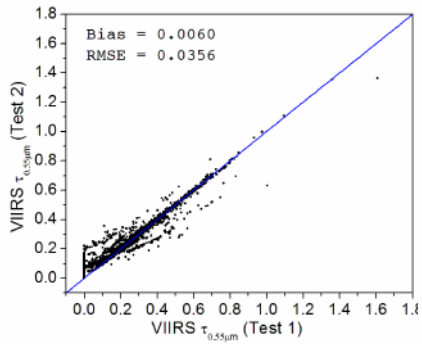
Test 6: Test 5 + Fine Mode Weight (FMW) is determined as in MODIS.

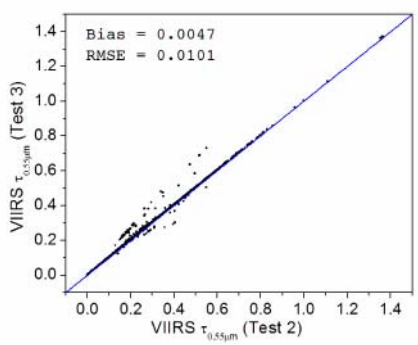
Test 7: Test 6 + constant wind speed (6m/s) and direction (due north).

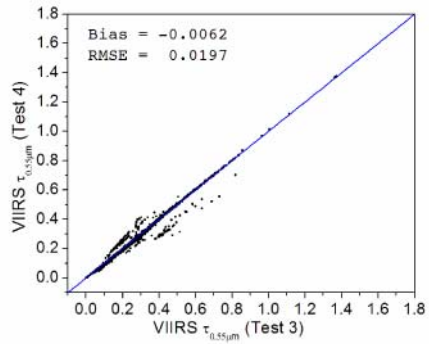
VIIRS-Test 7 algorithm ≈ MODIS algorithm

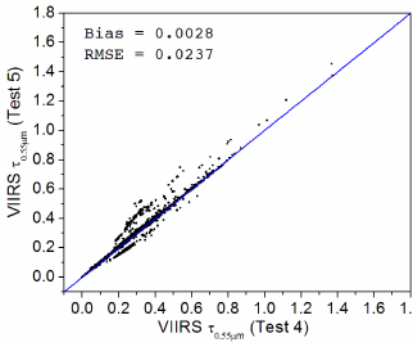
Effect of VIIRS changes on AOD: over water (single granule)

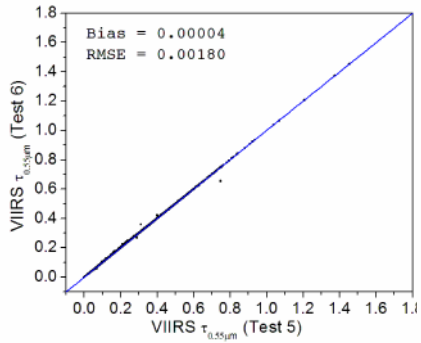


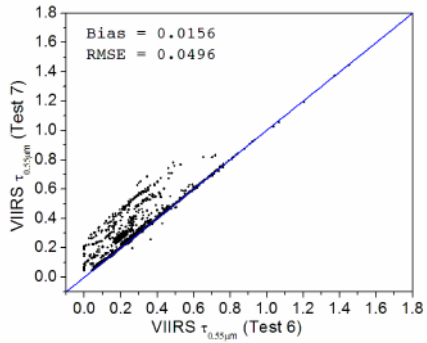










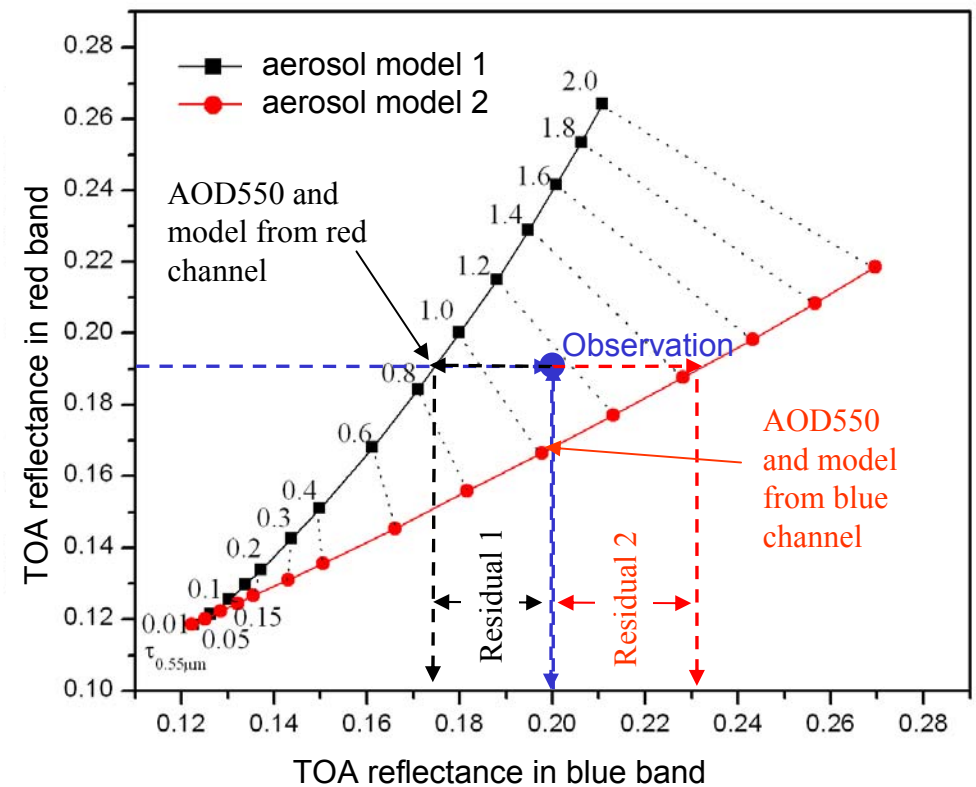


Test 1: LUT
Test 2: reference channel
Test 3: water vapor
Test 4: surface pressure
Test 5: residual
Test 6: FMW
Test 7: wind speed/direct.

The largest effects on AOD are due to change in the reference channel (Test 2) and in wind speed/direction (Test 7). FMW and fine/coarse mode also changes.

Sensitivity to “reference” channel

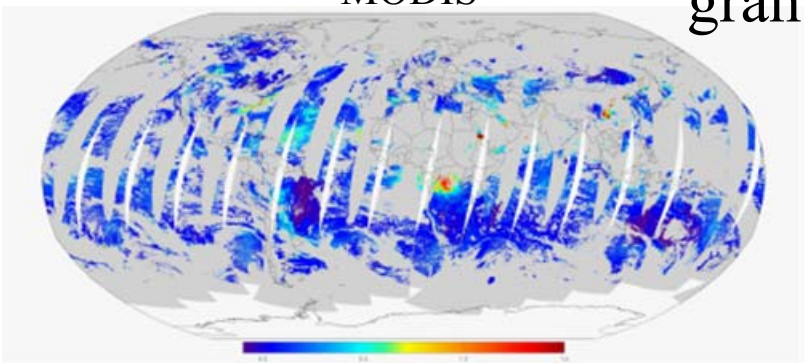
- Reference channels are selected to minimize uncertainty in surface.
- A change in the reference channel:
  - forces a different set of channels for calculation of residuals.
  - can lead to different AOD and model.



MODIS and VIIRS AOD

08/08/2006

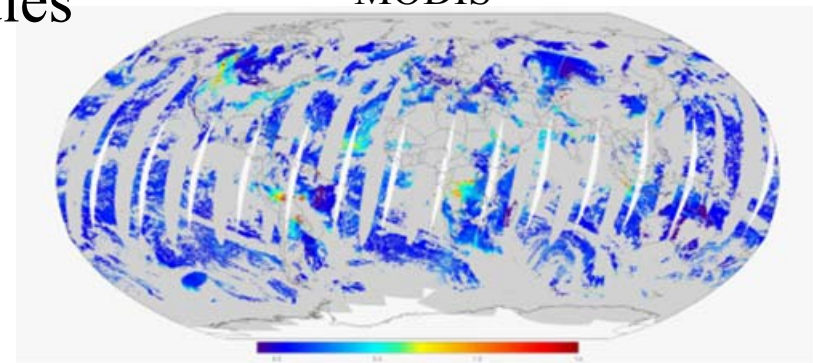
MODIS



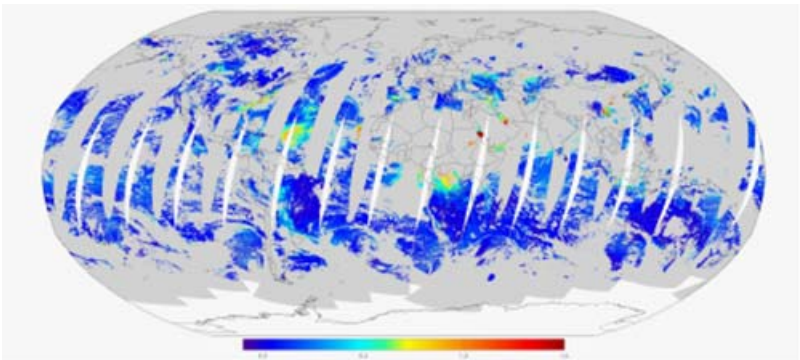
277 daytime granules

09/09/2006

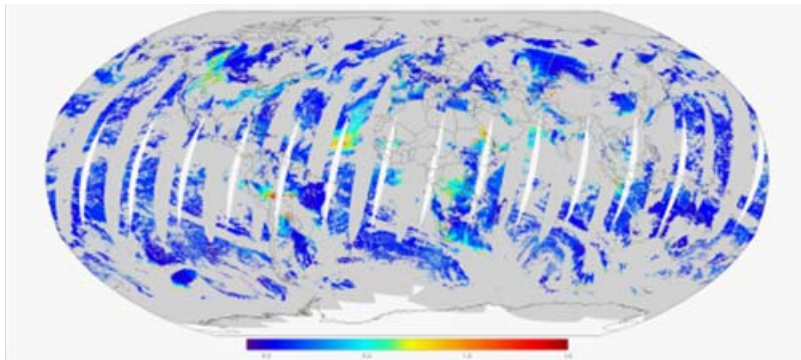
MODIS



VIIRS



VIIRS



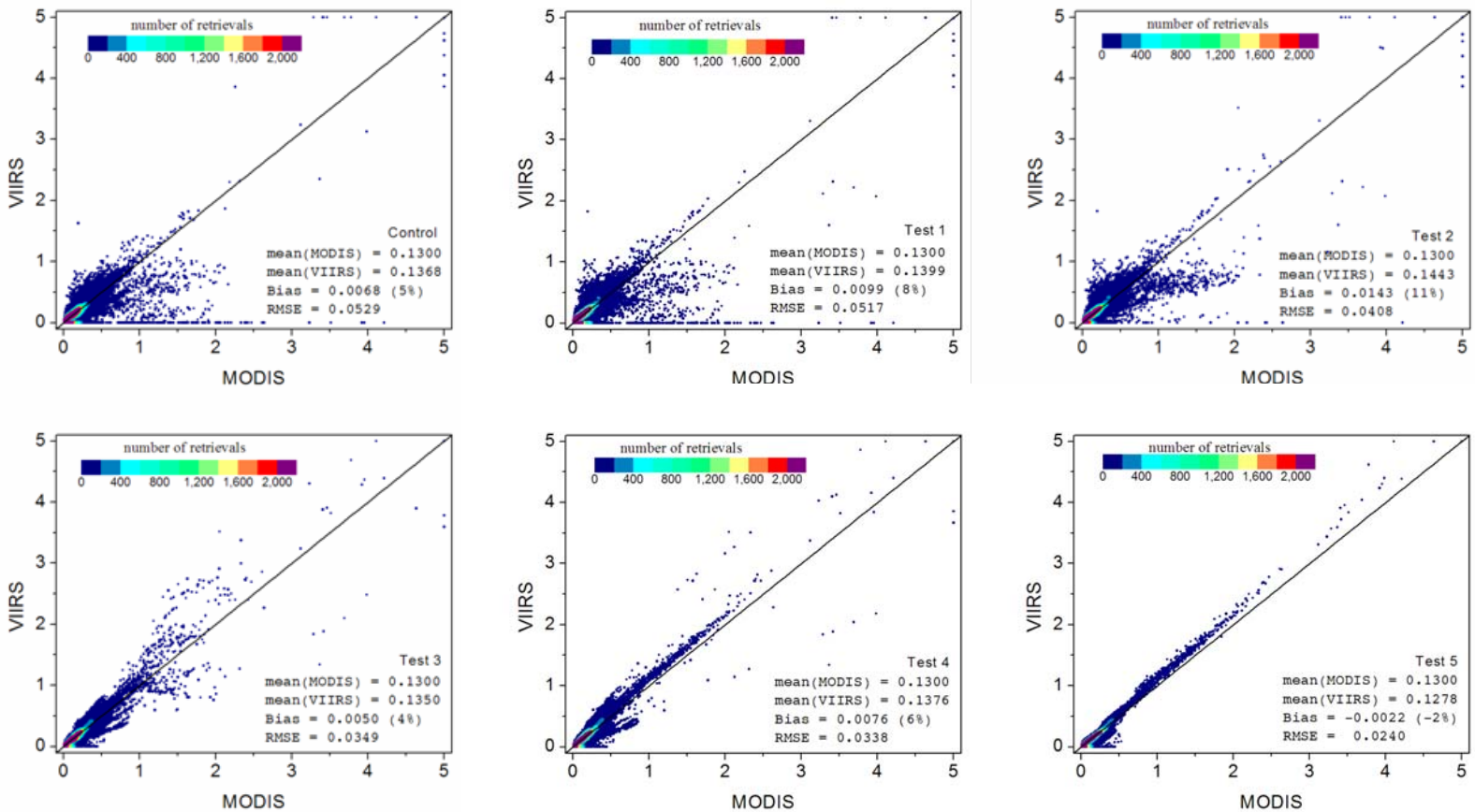
VIIRS tests for two-day global AOD

- Tests are designed to eliminate most of the differences between the MODIS and VIIRS algorithms. The changes are introduced gradually into the VIIRS algorithm.

- **Test 1**: LUT updated.
- **Test 2**: Test 1+ constant wind speed and direction
- **Test 3**: Test 2 + switch reference channel from 1.24 to 0.87 μm
- **Test 4**: Test 3 + residual calculation follows MODIS
- **Test 5**: Test 4 + force VIIRS to use MODIS-retrieved aerosol model and FMW.

Comparison of VIIRS and MODIS over water: all AOD

884,163 retrievals

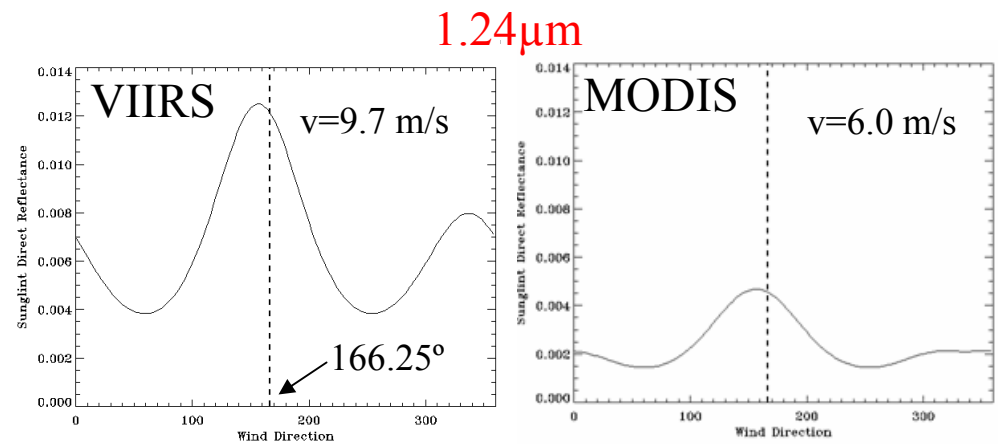


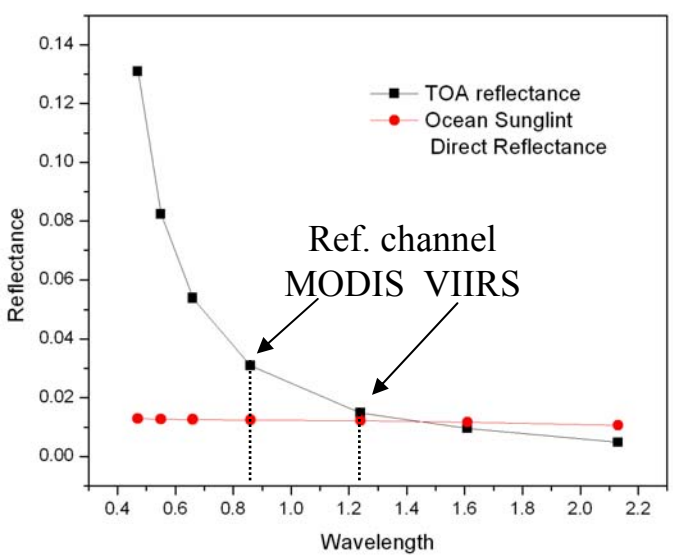
Fixing the wind speed (Test 2) and switching the residual channel (Test 3) eliminated some of the extreme disagreements.

Surface wind effect: A case study

θs=43.2125º; θv=2.985º;
Φs=159.9975º; Φv=106.11º;
Wind speed: 9.7 m/s
Wind direction: 166.25º

MODIS AOD550: 0.3854
VIIRS AOD550: 0.0



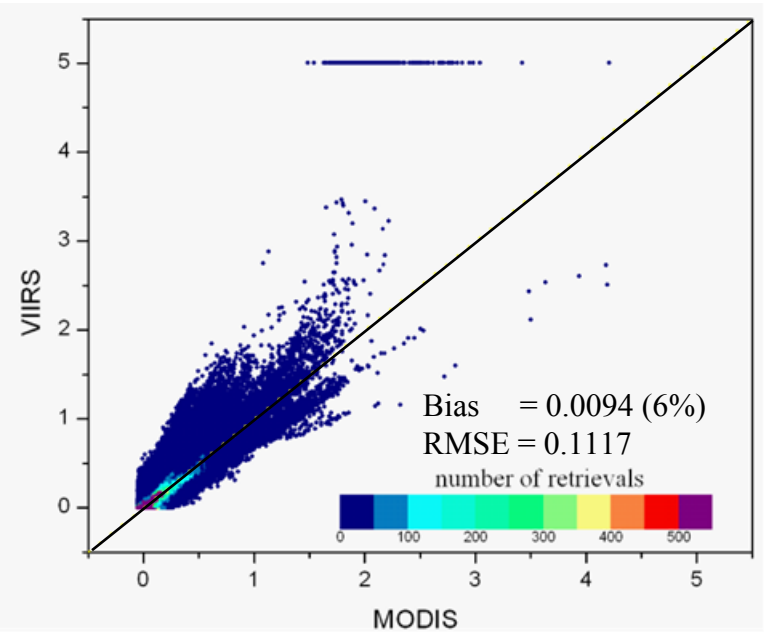


- Surface reflectance from VIIRS is larger than that from MODIS → VIIRS AOD is smaller.
- VIIRS surface reflectance is close to observed TOA reflectance → VIIRS AOD ≈ 0.
- <u>Note</u>: if VIIRS used the MODIS reference channel AOD > 0.

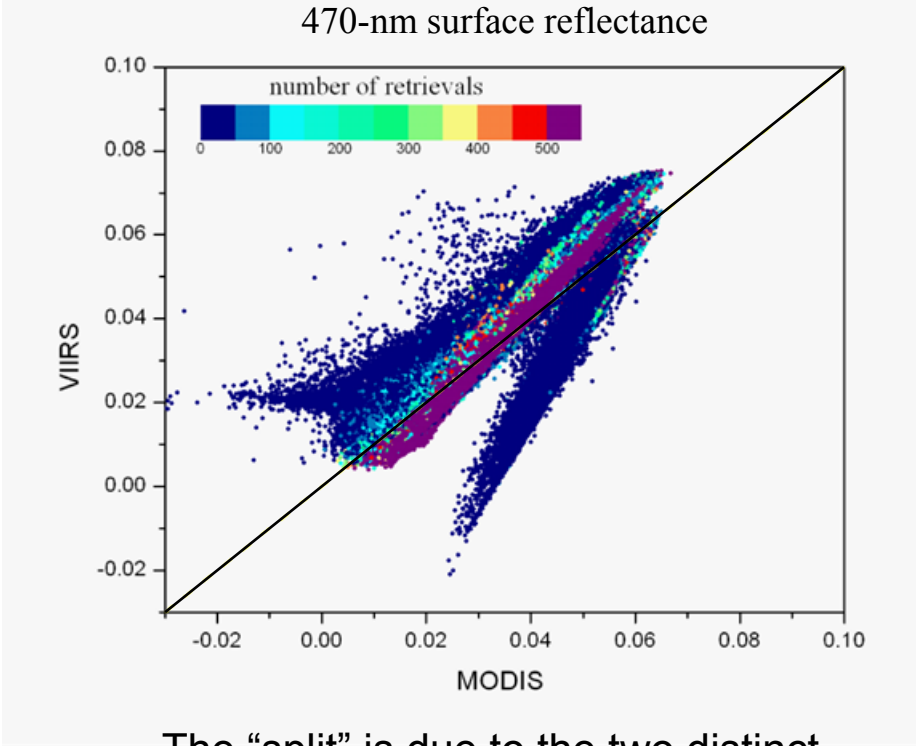
Comparison over land

394,004 retrievals

AOD (550 nm)



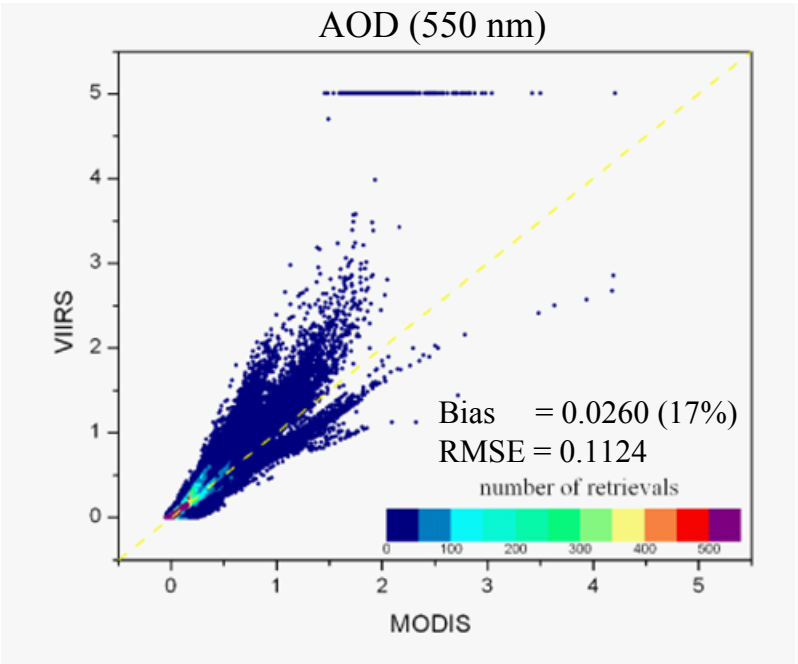
470-nm surface reflectance

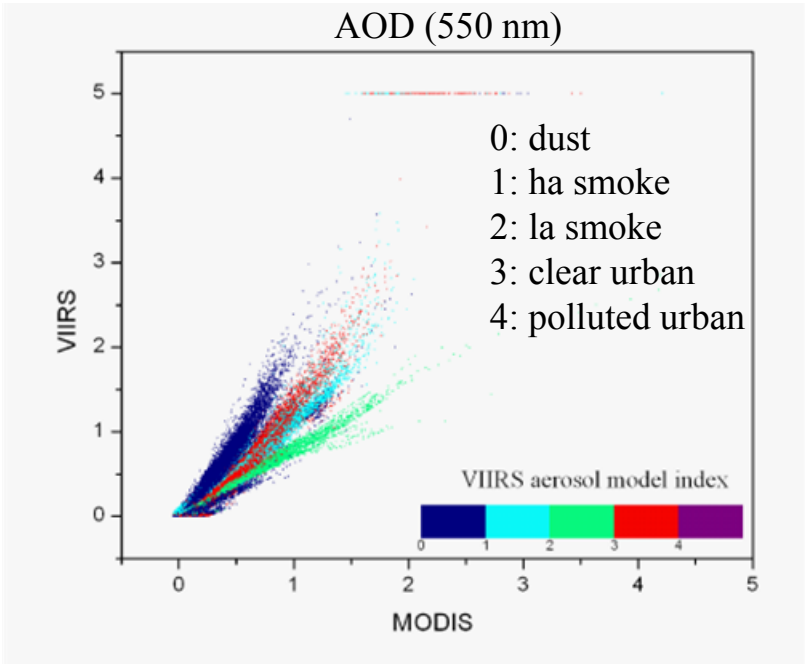


Retrieval "philosophy" of MODIS C5 and VIIRS over land is different; not easy to make VIIRS similar to MODIS.

The "split" is due to the two distinct relationships VIIRS uses for estimating surface reflectance.

Comparison over land (cont)





- Left: VIIRS was forced to use MODIS-retrieved surface reflectance (aerosol model)
- Right: color coded in terms of VIIRS-determined aerosol model index

Summary

- Have set up a system for routine retrieval and comparison of MODIS and VIIRS AOD.
- From the two days studied:
  - Water: bias = 0.007 (5% MODIS) (=2/10 of expected MODIS error (0.035) for AOD=0.1, but RMS = 40%!)
  - Land: bias = 0.009 (6% MODIS) (=1/10 of expected MODIS error (0.08) for AOD=0.2, but RMS = 70%!)
- Aerosol model and FMW retrievals also differ.
  - Factors affecting the calculation of residual can affect the AOD by selecting very different models.
- Determination of AOD, FMW and aerosol model selection are intertwined in a complex manner so sorting out causes of differences is not straightforward.
- AOD retrieval is most sensitive to the choice of reference channel and surface reflectance calculation/retrieval.