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Evaluation of MODIS and VIIRS Aerosol Optical Depth Retrievals: An update

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Motivation

- In the NPP/NPOESS 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. Both are important climate parameters.
- Evaluation of VIIRS aerosol algorithm under a wide variety of real conditions over a long period are needed.

Recapping Previous Results

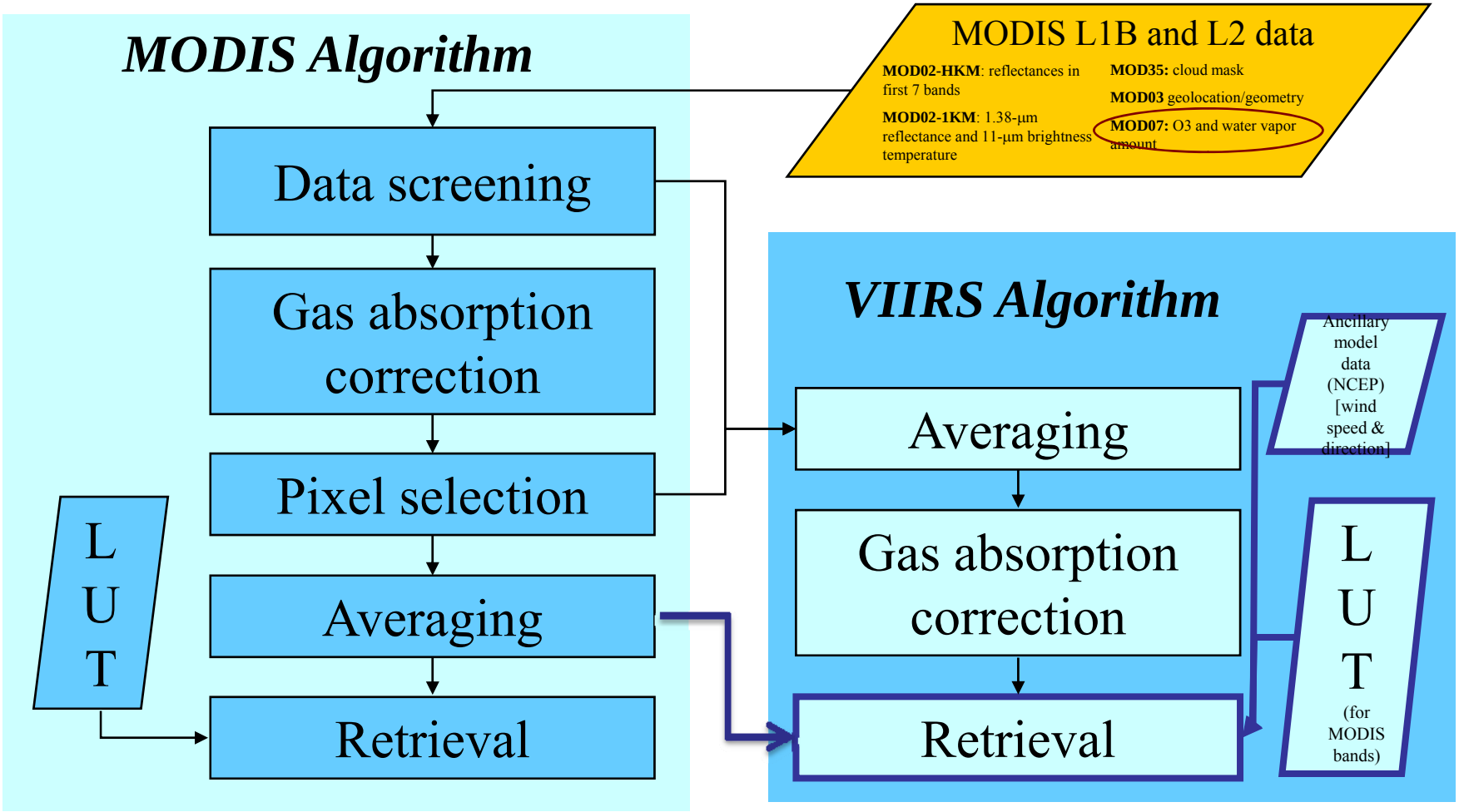
Two STMs ago …

- 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 typical (0.1) AOD) (but RMS = 40%!)
  - Land: bias = 0.009 (6% MODIS) (=1/10 of expected MODIS error (0.08) for typical (0.2) AOD)
- Aerosol model and FMW retrievals also differ.
  - Factors affecting the calculation of residual can affect the AOD by selecting very different models.
- AOD retrieval is most sensitive to the choice of reference channel and surface reflectance calculation/retrieval. **===> NGST has changed reference channel in over-ocean retrieval!**

Strategy

- Use one year (2007) global MODIS Terra retrievals
- Use clear-sky TOA reflectance from C5 MOD04
  - Cloud-screened, gas-absorption-corrected, spatially-filtered/averaged MODIS reflectance
  - Use above reflectances directly in VIIRS algorithm (bypassing gas absorption correction) to avoid sampling difference.
  - **Only algorithm differences affect the AOD!**
- Compare VIIRS and MODIS retrievals
- **NEW:** Compare VIIRS and MODIS retrievals with AERONET measurements (Level 1.5, spatial (50km) and temporal (1hr) match-up)

The MODIS-VIIRS Test Bed



Features of MODIS and VIIRS AOD … (cont)

Over water		
	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	Same as MODIS collection 4
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 originally; was changed to 0.86μm**

Features of MODIS and VIIRS AOD … (cont)

Over water		
	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 C5	**VIIRS**
Surface pressure	Actual pressure is from surface elevation.	Elevation and synoptic variation of surface pressure are considered.
	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, 0.66 and 2.12 μm	0.488 and 0.672 μm
Reference ch	0.47 μm	0.488 μm
Aerosol models	3 nondust and one dust model (updated using AERONET). Mixture is determined separately for each retrieval.	Five typical land aerosol models from AERONET.

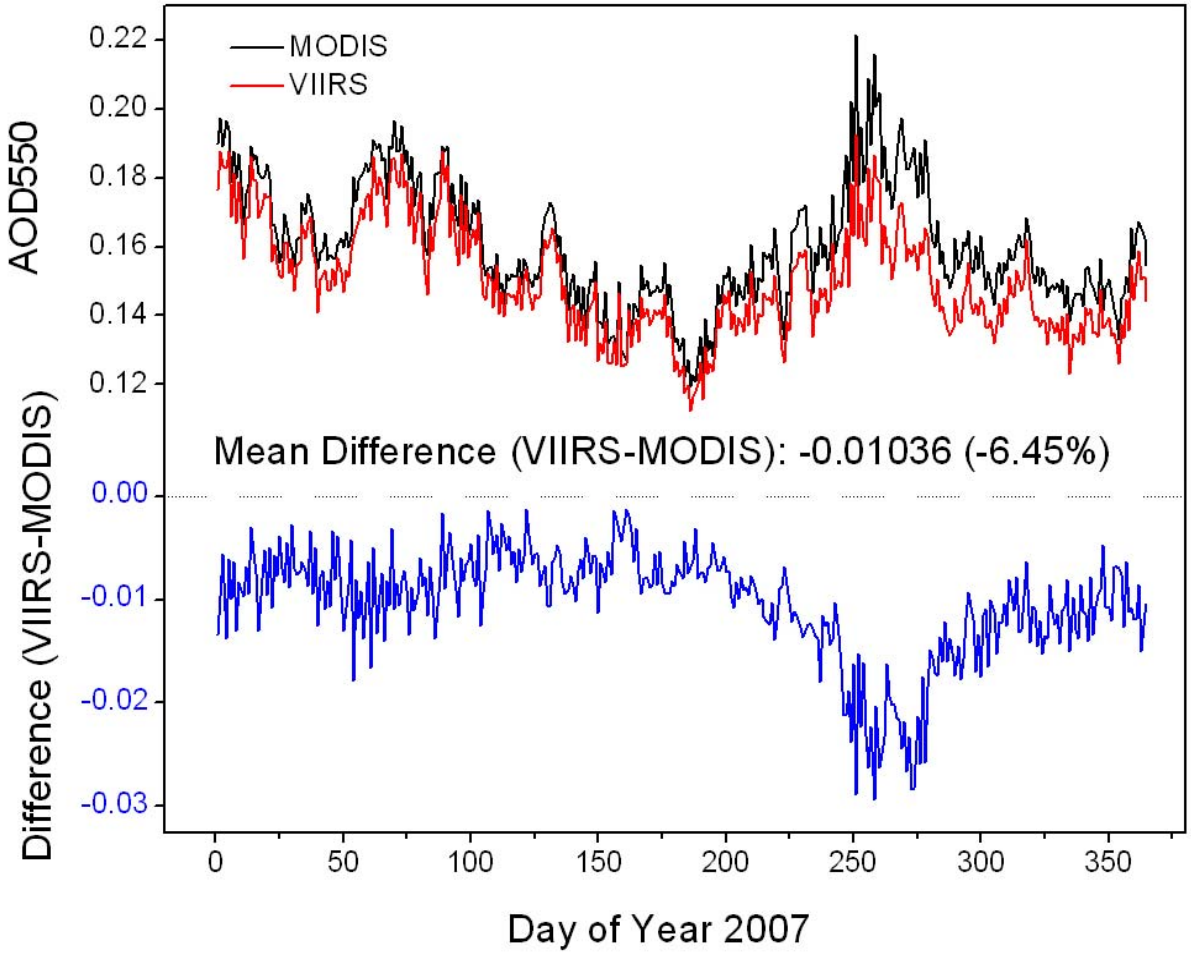
Features of MODIS and VIIRS AOD … (cont)

Over land		
	MODIS C5	**VIIRS**
Surface reflectance	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	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	RT3 (Evans and Stephens)	6sV1.1

RESULTS

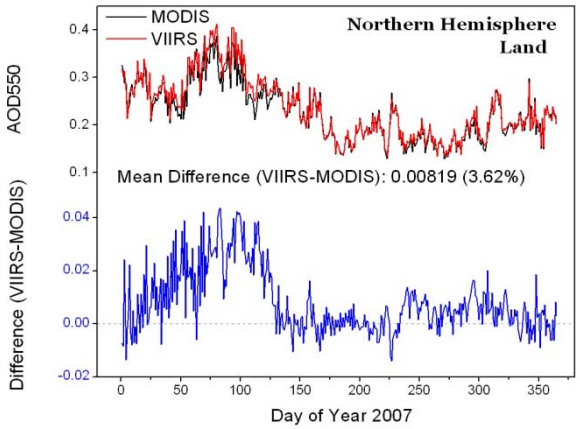
- Comparison of VIIRS AOD with MODIS AOD
  - global, hemispheric and regional averages
- Comparison with AERONET

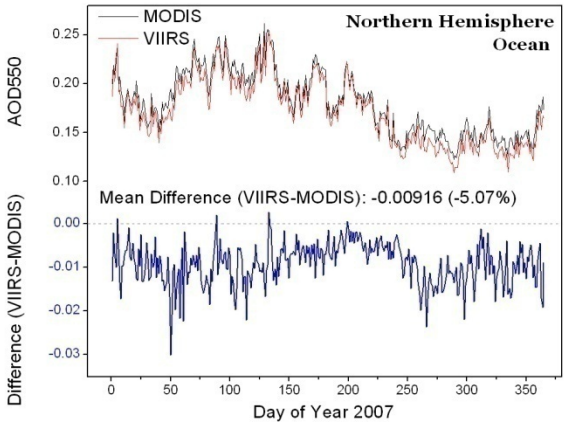
Time series of Global AOD

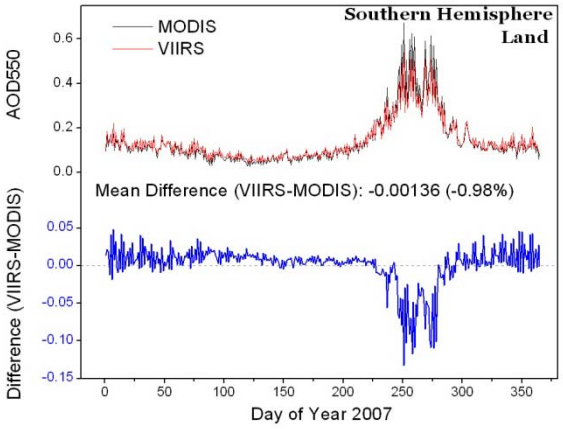


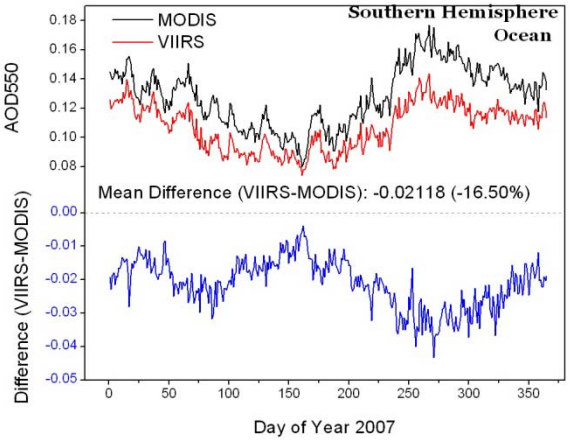
- Global AOD (550 nm) is underestimated by VIIRS relative to MODIS year round.
- More significant in September.

Hemispheric Averages









VIIRS AOD relative to MODIS AOD

Over Land:

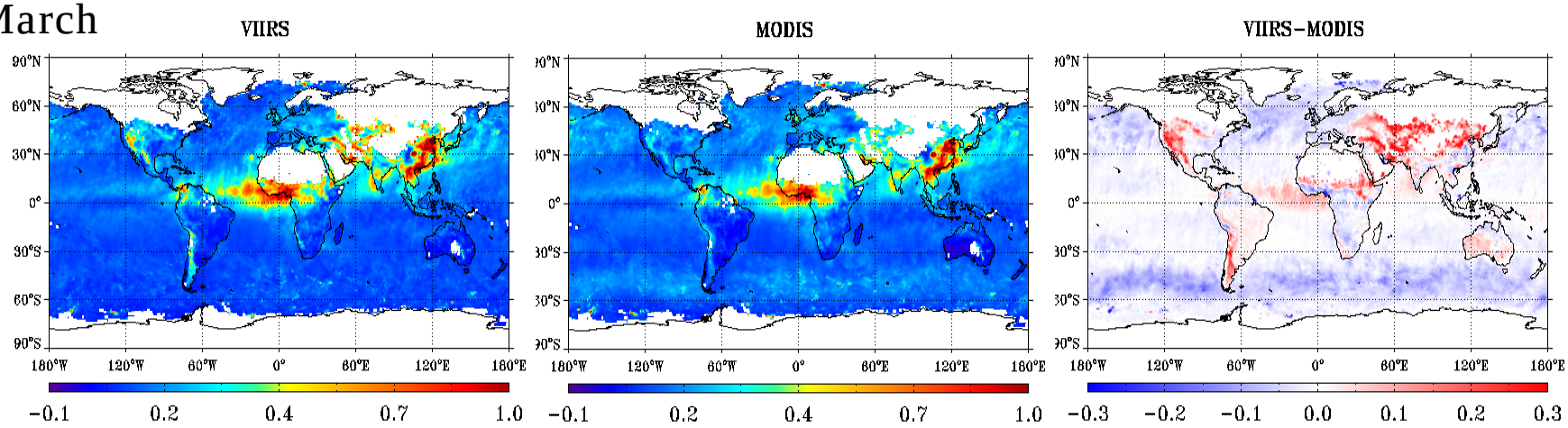
- Overestimation in NH (spring)
- Underestimation in SH (Sep)

Over Ocean:

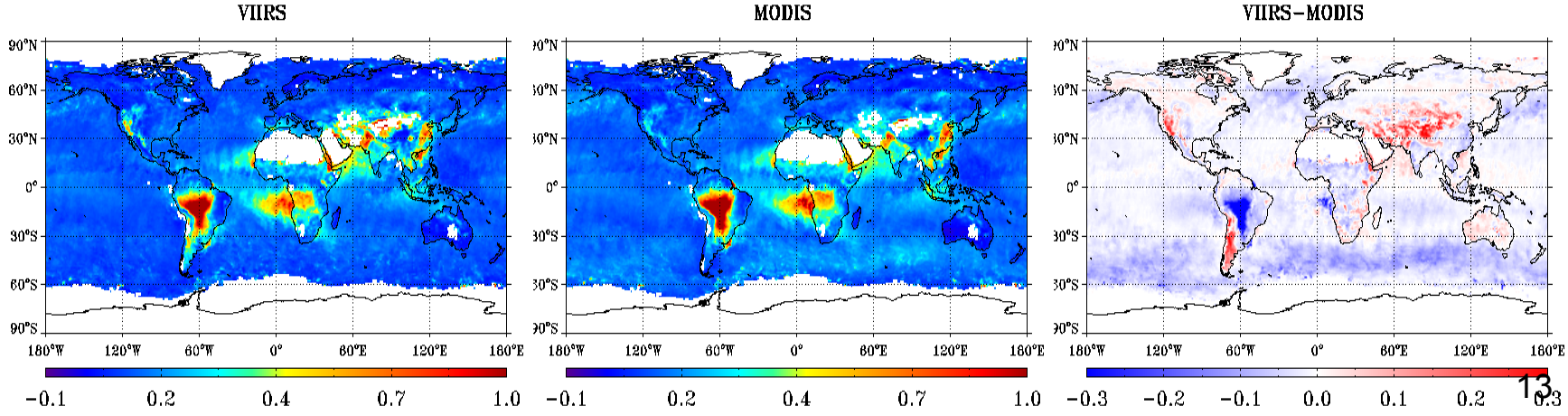
- Underestimation in both hemispheres
- More negative bias in SH

Regional Monthly Averages

March



September



Regional Monthly Averages (cont.)

Land:

- Overestimation over bright surface
- Underestimation of biomass burning aerosol over South America

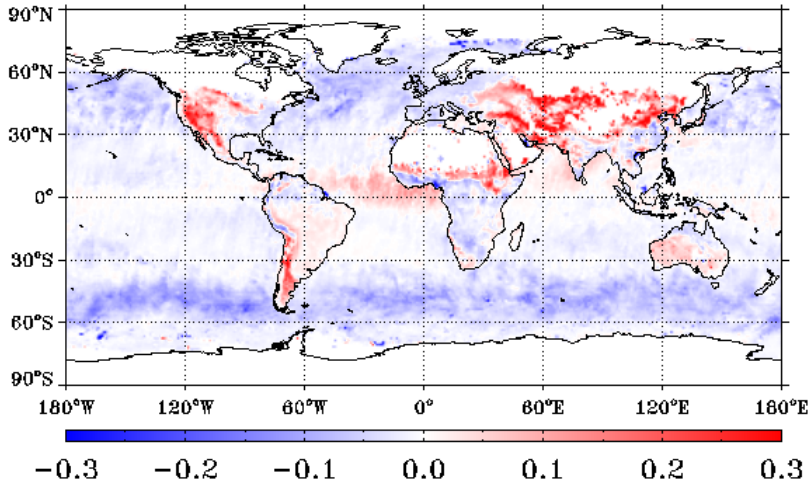
Ocean:

- Underestimation over mid- and high-latitudes
- Overestimation at dust dominated regions
- Underestimation of smoke AOD around South Africa

Monthly Averaged AOD – March 2007

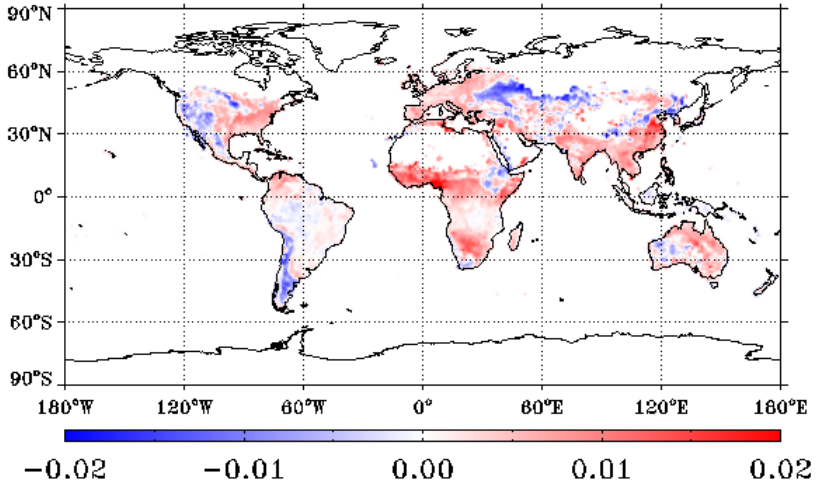
Difference of retrieved AOD at 0.55µm

VIIRS−MODIS



Difference of land surface reflectance at 0.466µm

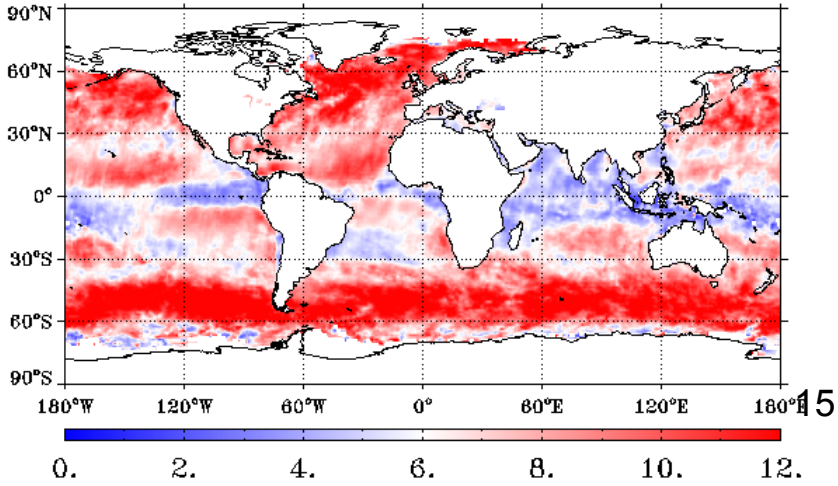
VIIRS−MODIS



- Over land, VIIRS-MODIS AOD and surface reflectance differences are correlated. (R = -0.49)
- Over ocean, underestimation of AOD by VIIRS is correlated with high wind speed. (R = -0.63)

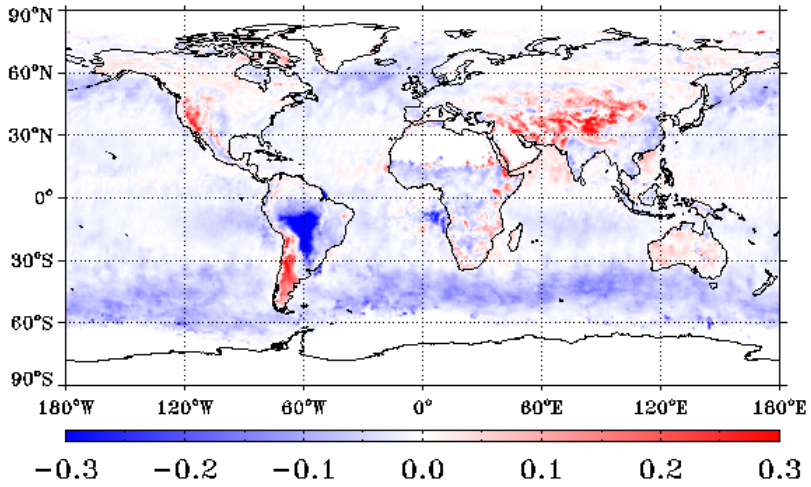
NCEP Reanalysis wind speed at 10m altitude (m/s)

Wind Speed

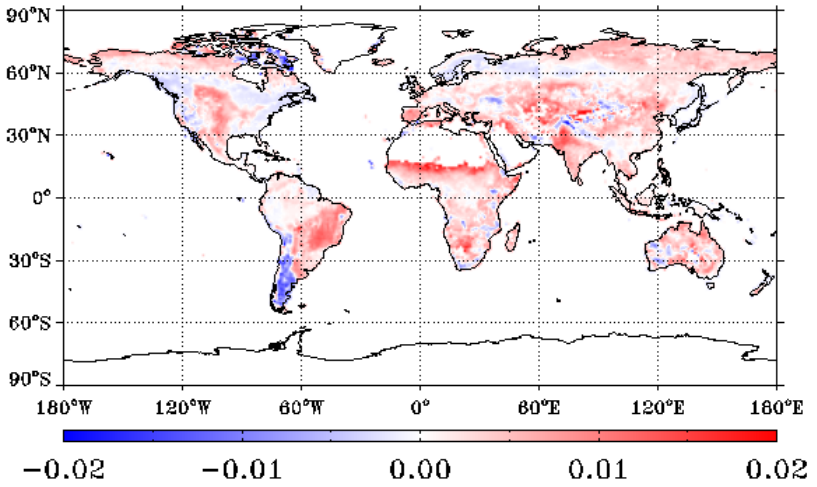


Monthly Averaged AOD – September 2007

Difference of retrieved AOT at 0.55µm

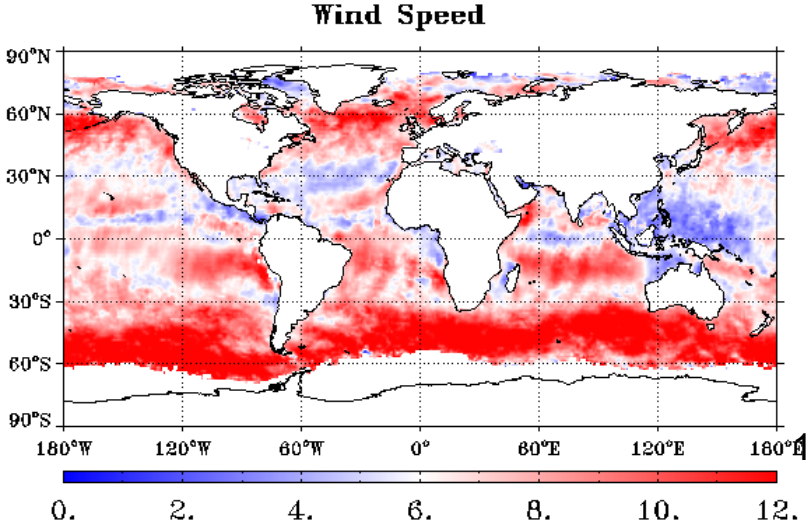


Difference of land surface reflectance at 0.466µm

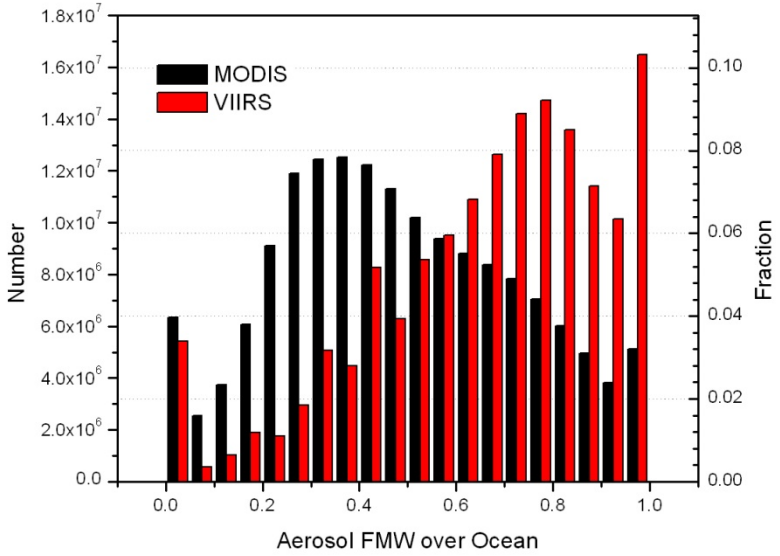


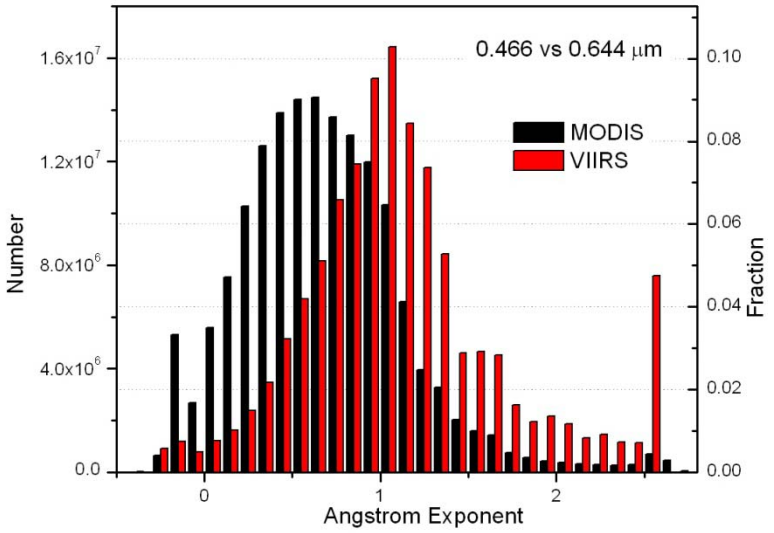
- In addition to surface effects, difference in aerosol model also contributes to the difference of AOD between VIIRS and MODIS:
  - South America
  - West coast of South Africa

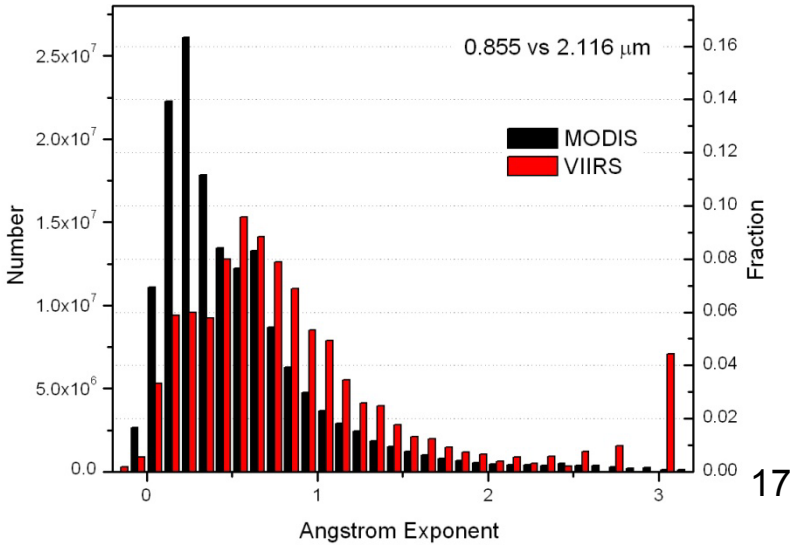
NCEP Reanalysis wind speed at 10m altitude (m/s)



Aerosol Fine Mode Weight and Ångström Exponent over Ocean





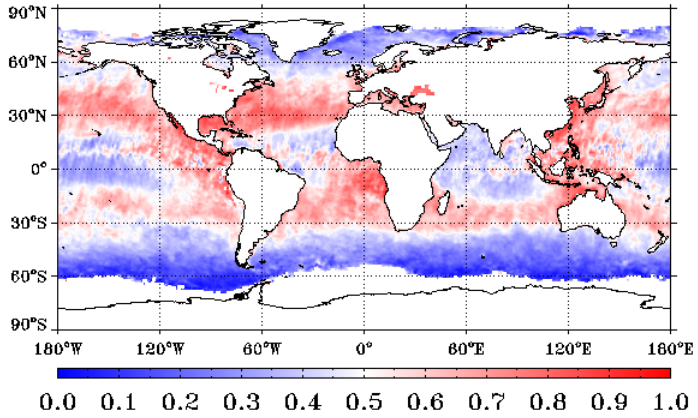


- VIIRS retrieval suggests more fine mode particles than MODIS, therefore, higher Ångström Exponent.

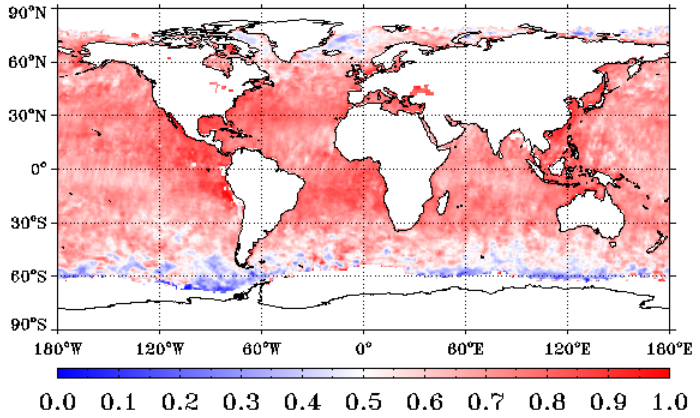
Sensitivity Tests: FMW over Ocean

September

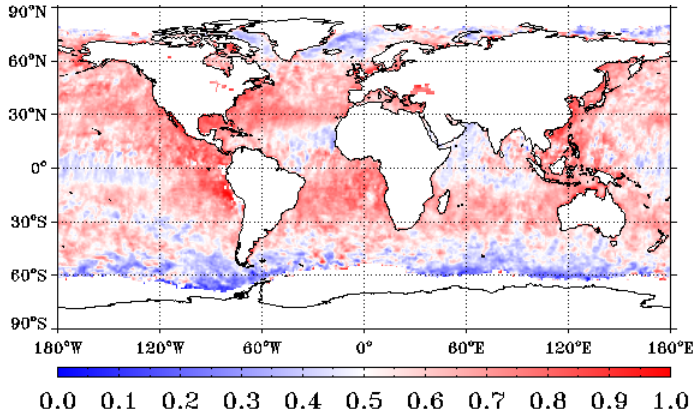
MODIS



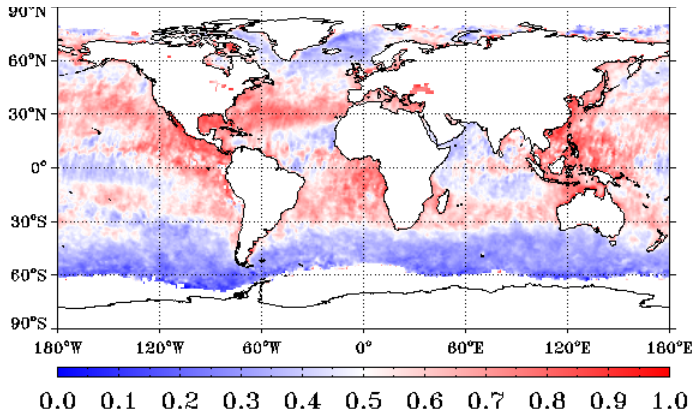
VIIRS



VIIRS with MODIS C5 Aerosol Models



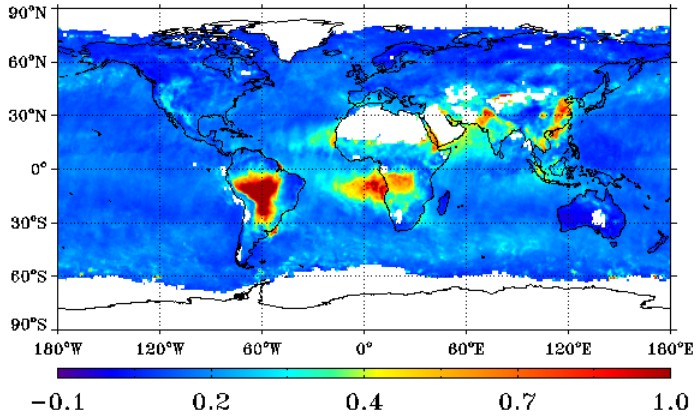
VIIRS with MODIS C5 Aerosol Models & Wind speed fixed at 6m/s



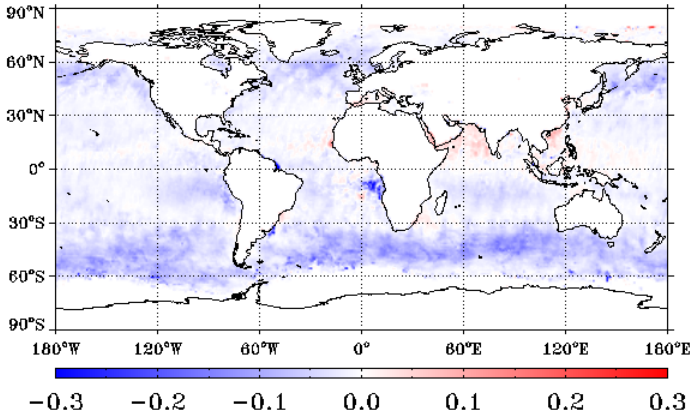
Sensitivity Tests: Effects on AOD

September

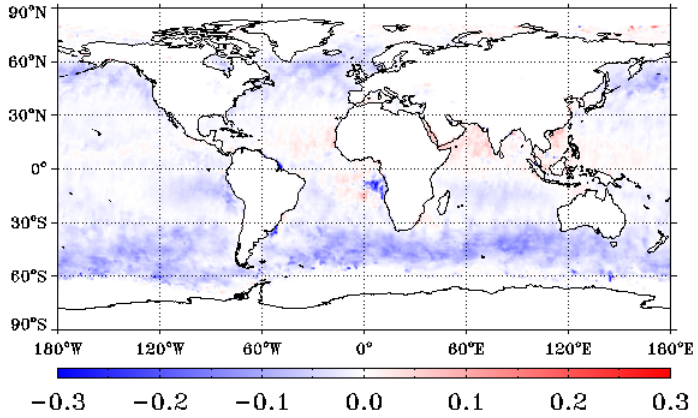
MODIS



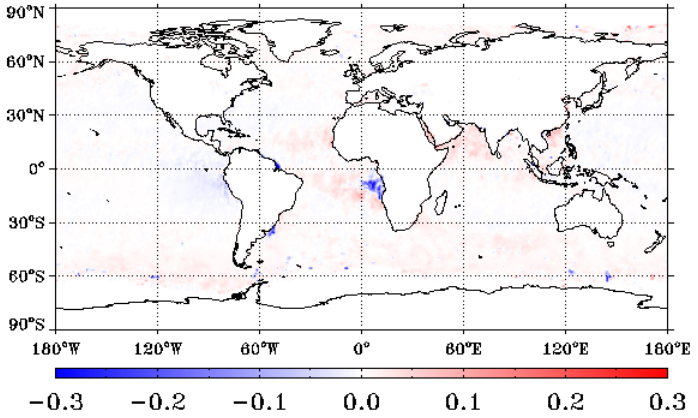
VIIRS−MODIS



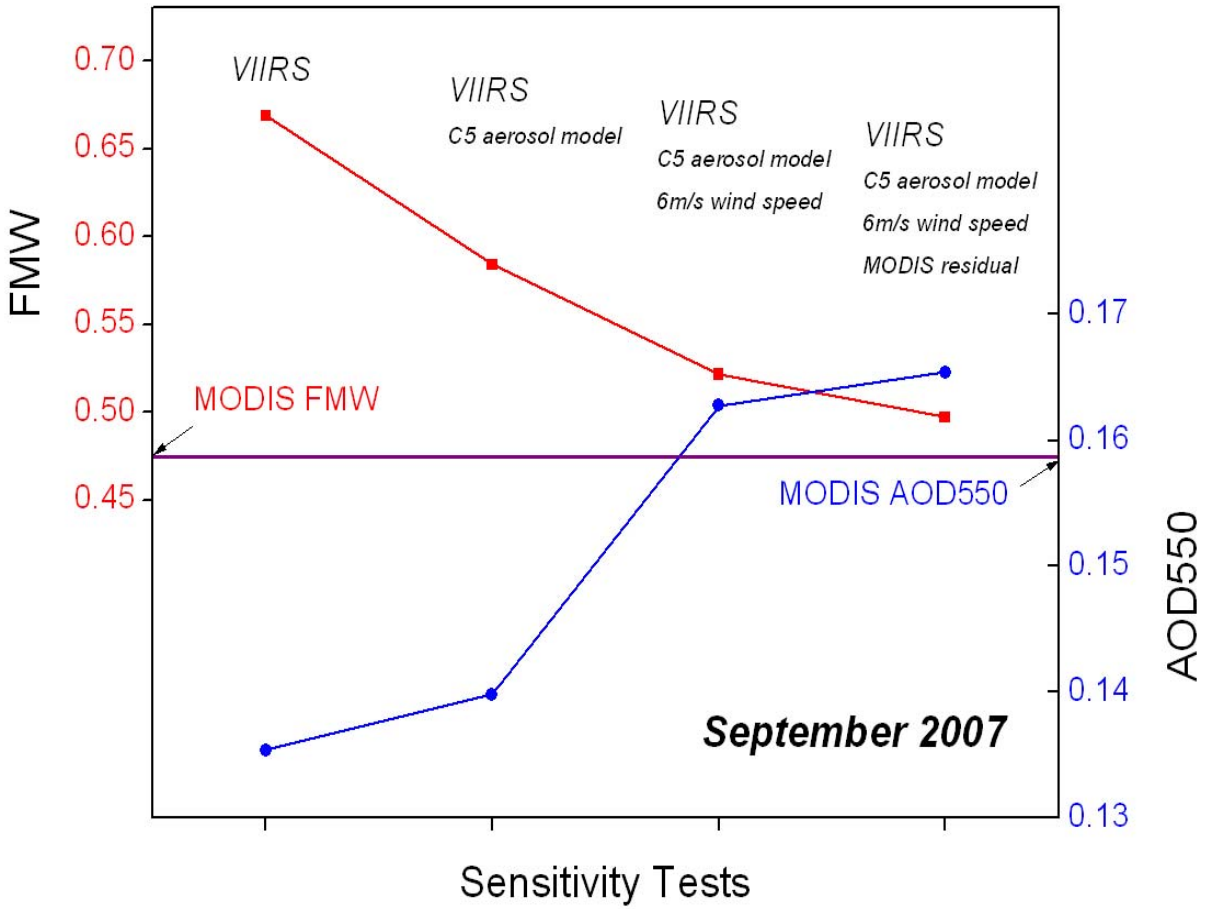
VIIRS with MODIS C5 Aerosol Models



VIIRS with MODIS C5 Aerosol Models & Wind speed fixed at 6m/s



Summary of Sensitivity Tests Over Ocean

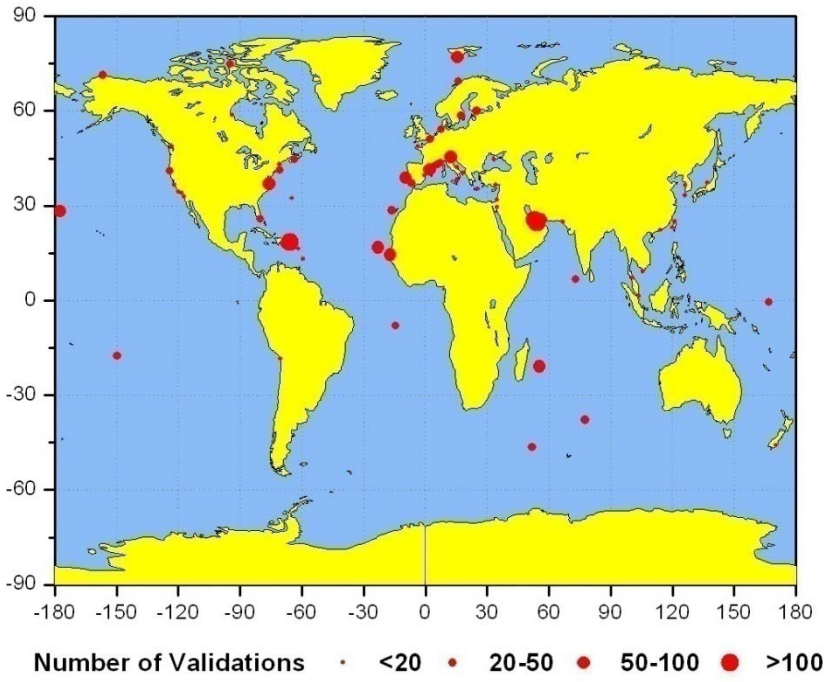


- Global average AOD and FMW for Sep 2007.
- Switching to MODIS C5 aerosol models and fixed wind speed in VIIRS reduces AOD and FMW differences
- Changing aerosol models reduces FMW by -0.085 (12.65%), while increases AOD by 0.004 (3.28%)

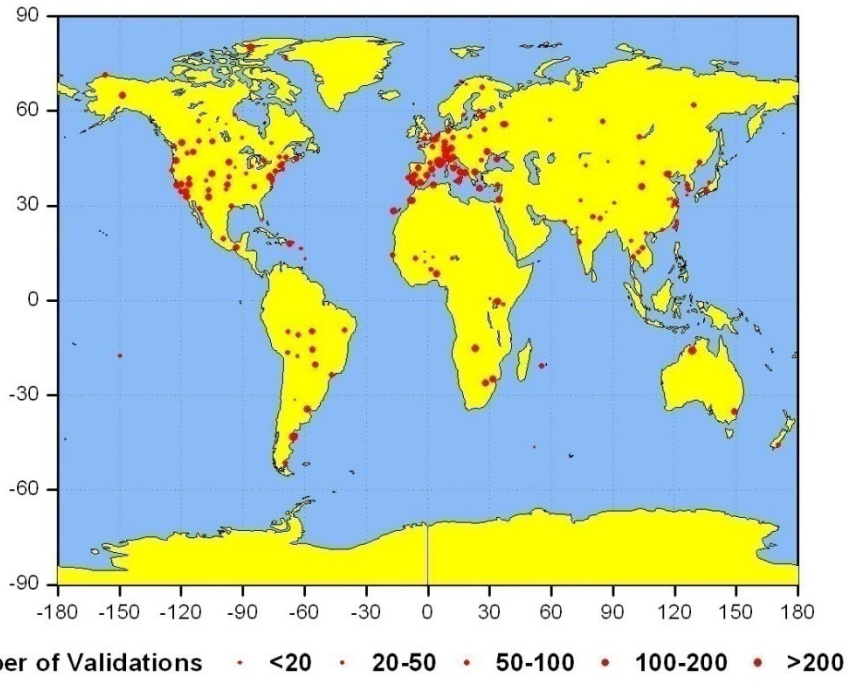
COMPARISON WITH AERONET

AERONET sites

Ocean (77)



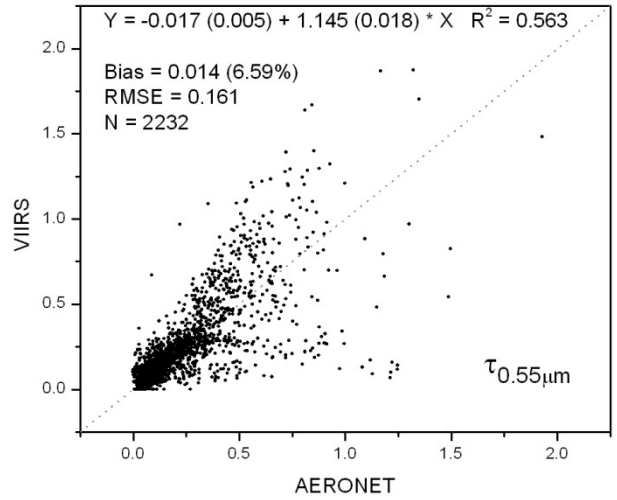
Land (226)

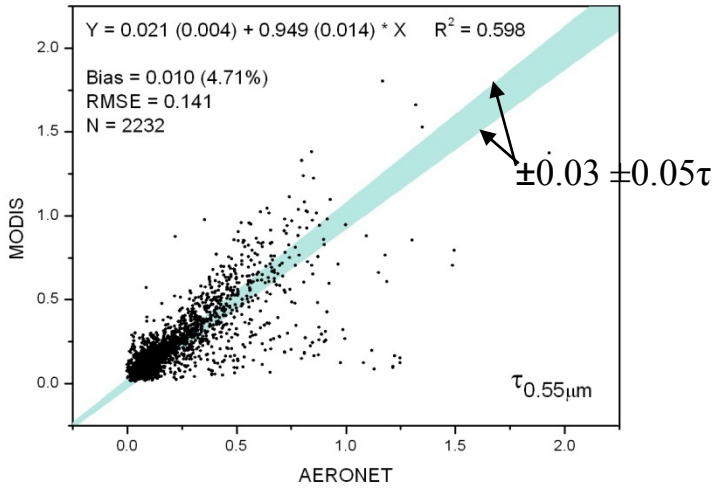


Symbol size is proportional to number of comparisons.

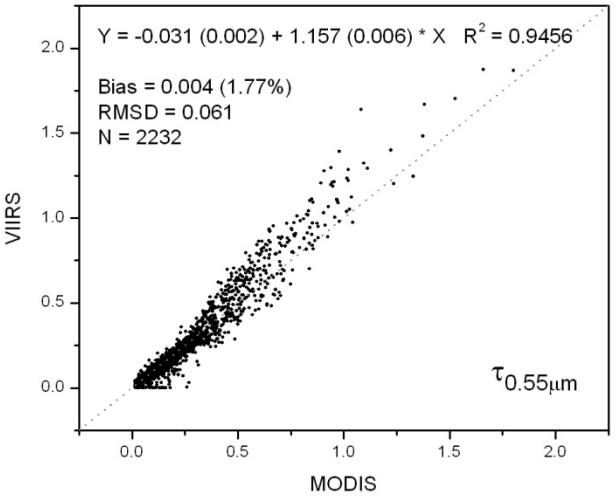
- Uneven distribution of stations.
- Many ocean stations are in coastal areas.

Comparison with AERONET over Ocean

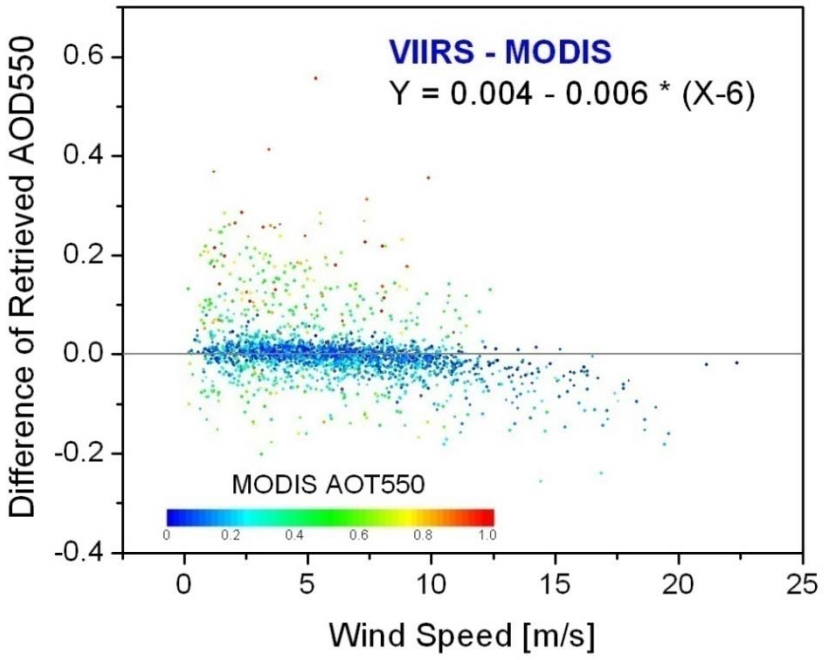


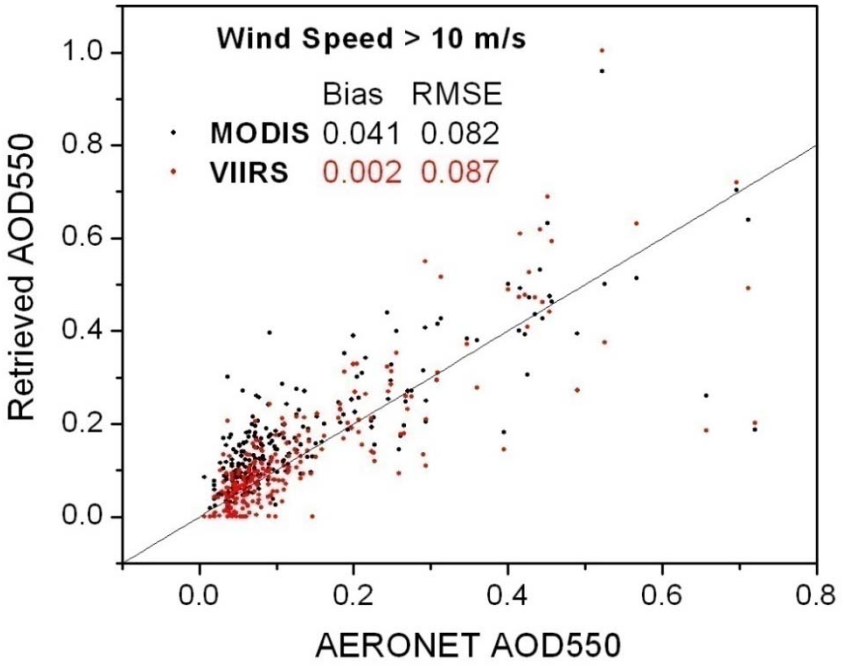


- Orthogonal fit; standard errors are in parenthesis.
- Compared with AERONET, VIIRS has a slightly larger positive bias and RMSE than MODIS.
- Satellite estimates agree better with each other than with ground measurements.



Wind Speed Effect

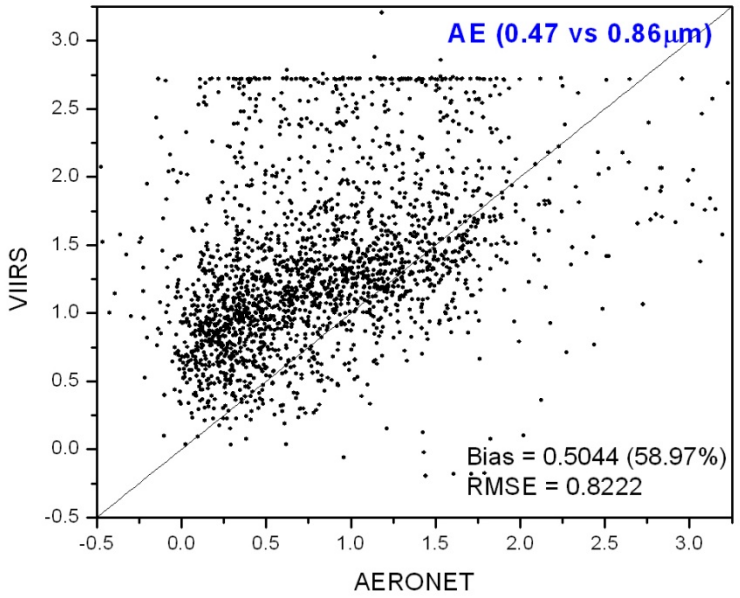


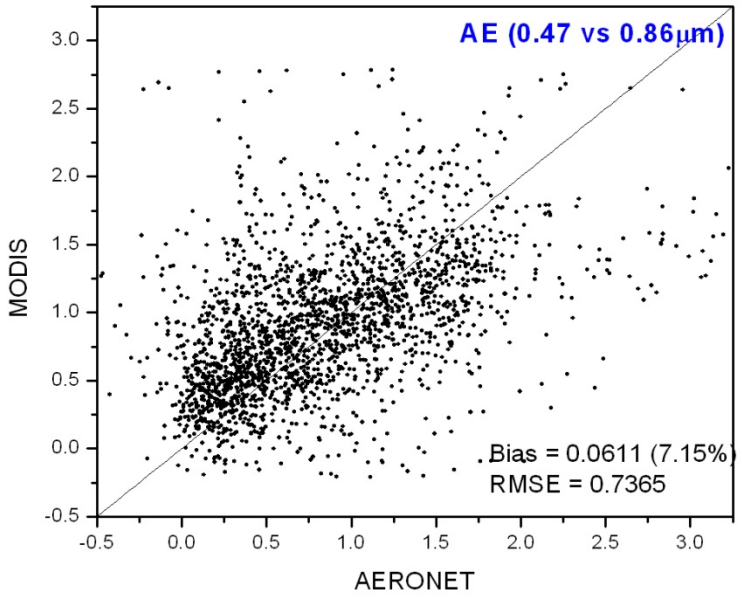


- AOD_{VIIRS} < AOD_{MODIS} for high (>10 m/s) wind speed.
- AOD_{MODIS} > $AOD_{AERONET}$ for high wind speed (Zhang & Reid, 2006)

- For high (>10 m/s) wind speed, VIIRS-AERONET bias << MODIS-AERONET bias, but RMSEs are about the same.

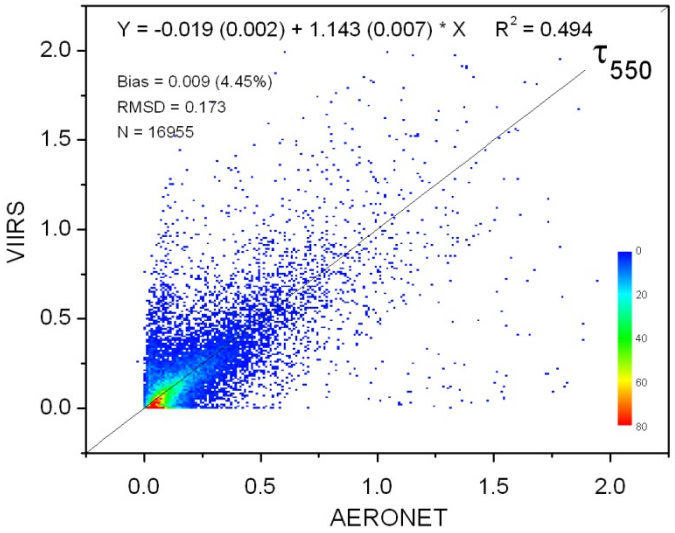
Ångström Exponent

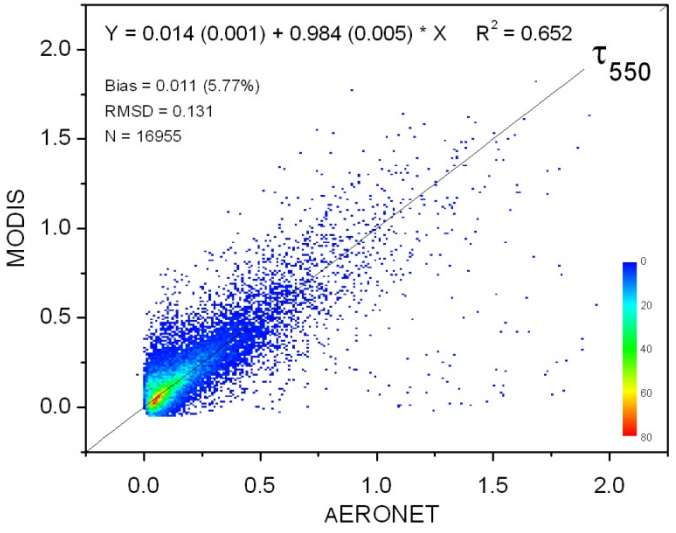




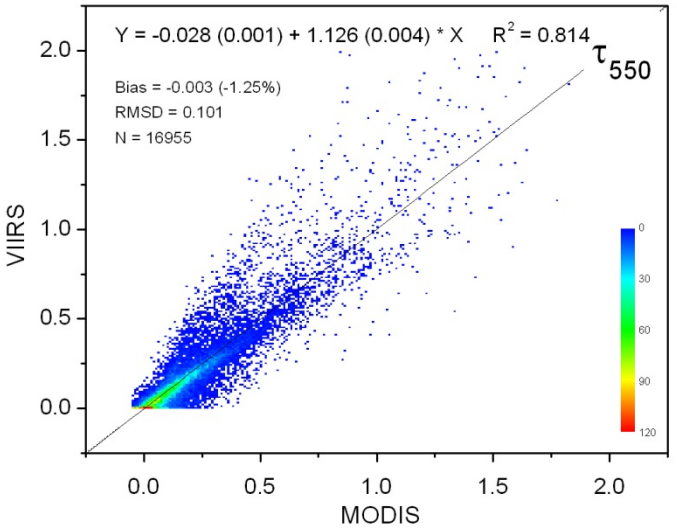
- Ångström Exponent (AE) calculated from AOD at 0.47 and 0.86 μm.
- Compared with AERONET, VIIRS AE bias is much higher than MODIS due to higher FMW retrieved by the VIIRS algorithm.

Comparison with AERONET over Land

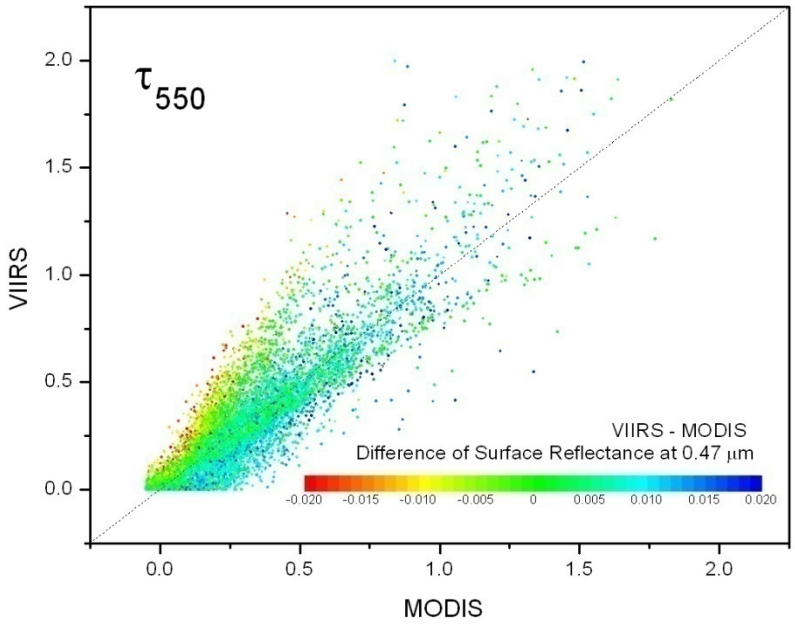


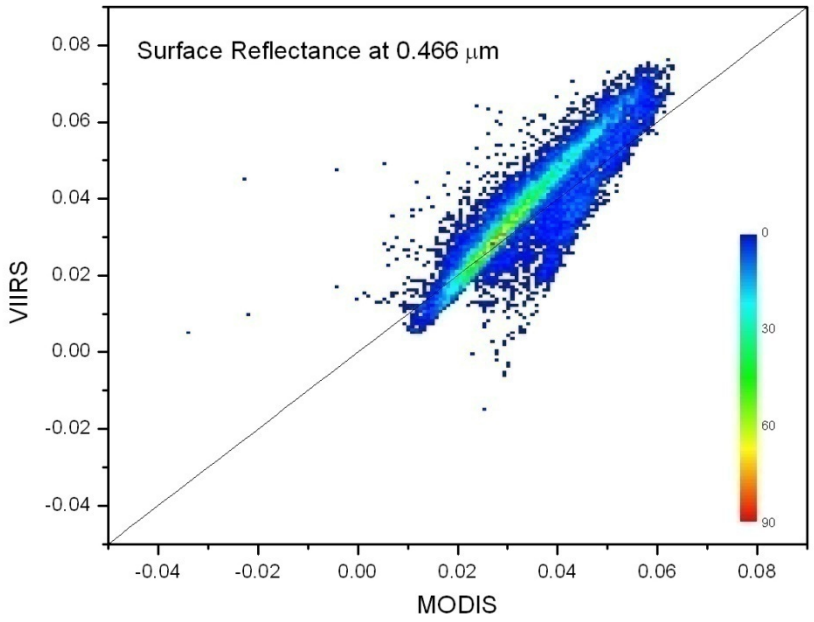


- Compared with AERONET, VIIRS and MODIS biases are comparable.
- RMSD of VIIRS AOD is larger than that from MODIS.



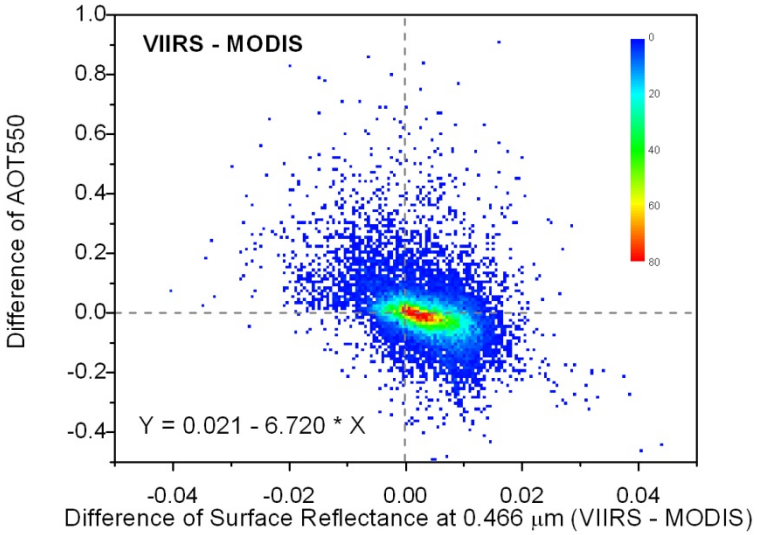
Surface Effects

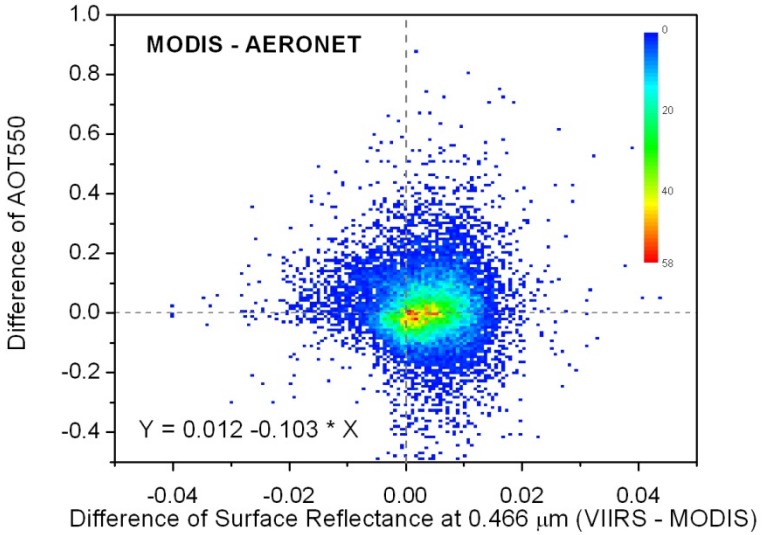




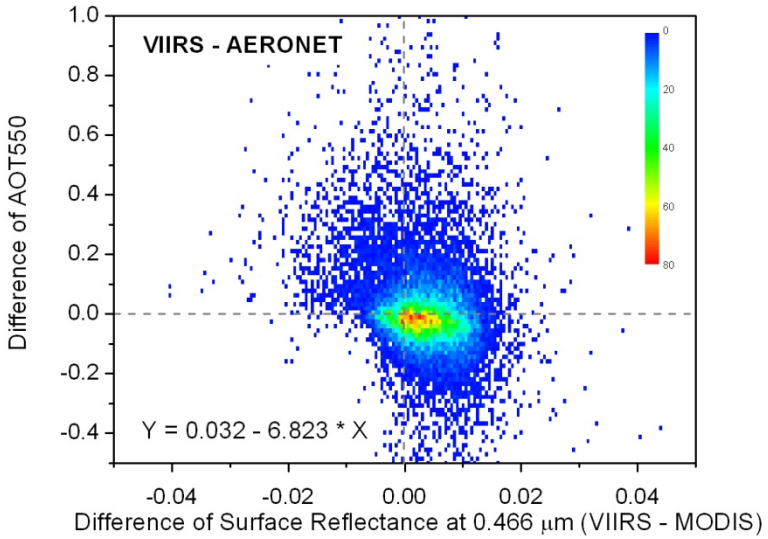
- Difference in surface reflectance estimation contributes to the difference of retrieved AOD.
- VIIRS applies two distinct relationships for ‘vegetation’ and ‘soil’ dominated surfaces

Surface Effects (cont.)

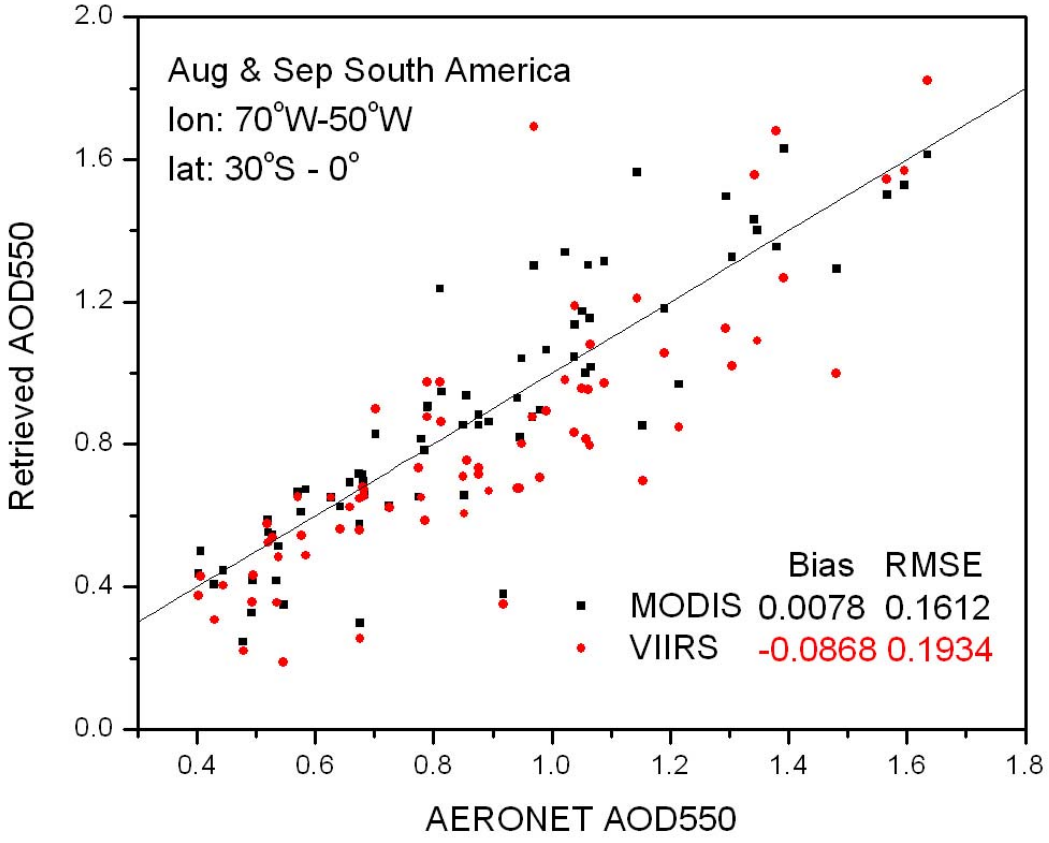


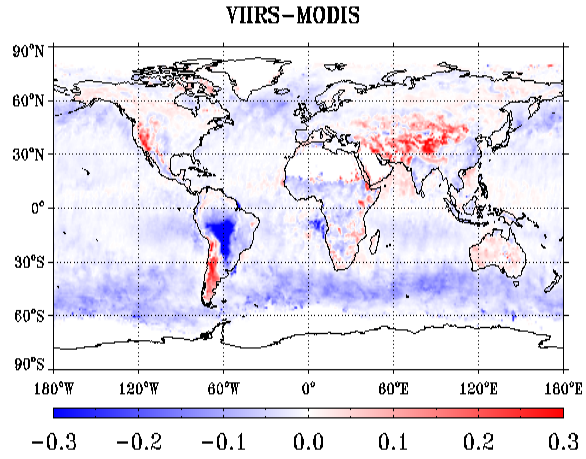


- Large difference of AOD even for the same surface reflectance.
- New surface scheme in VIIRS retrieval did not improve AOD retrieval.



Case study: Biomass Burning





- AOD_{VIIRS}<AOD_{MODIS} in South America in Sep.
- AOD is dominated by biomass burning in August and September.
- Compared with AERONET, VIIRS does underestimate smoke AOD.

Summary

Over Ocean

- Compared to MODIS:
  - VIIRS has a negative AOD bias (-0.016 ~ 11%), largely due to high wind speed over mid- and high- latitude regions.
  - VIIRS overestimates dust AOD.
  - VIIRS underestimates smoke AOD coming from South Africa.
  - VIIRS retrieves higher FMW (larger AE).
- Compared with AERONET:
  - VIIRS has larger positive AOD and AE bias and RMSE than those from MODIS.

Over land

- Difference in estimated surface reflectance contributes to difference of retrieved VIIRS and MODIS AODs.
- Compared to MODIS:
  - VIIRS retrieves higher AOD over relatively bright surfaces and underestimates smoke AOD over South America.
  - VIIRS AOD is more variable (Std is 1.5 times that of MODIS).
- Compared with AERONET:
  - VIIRS AOD has larger RMSE than MODIS.

Summary (cont)

- *NGST finding*: Compared to AERONET over ocean, the VIIRS 550-nm AOD retrievals have a smaller bias and a smaller standard deviation than the corresponding MODIS retrievals (Jackson and Vermote, March 2008 TIM):
  - Bias (MODIS) = -0.010, STD(MODIS) = 0.057
  - Bias (VIIRS) = -0.002, STD(VIIRS) = 0.046
  - Statistics from 78 points.
- VIIRS(NESDIS) ≈ VIIRS(NGST), but likely not identical (e.g., LUTs used with MODIS data are likely to be different)
- More investigation is needed!