National Oceanic and Atmospheric Administration
Cooperative Remote Sensing Science and Technology Center

Development of High-resolution surface albedo correlation maps for improved resolution and retrieval of aerosols over urban scenes

Min Min Oo, Matthias Jerg, Ana Picon,Yonghua Wu
Barry Gross, Fred Moshary, Sam Ahmed

Optical Remote Sensing Lab
City College of New York

Presentation at NOAA (31st October 2008)

Aerosol Retrieval from Satellites over Coastal Urban Areas

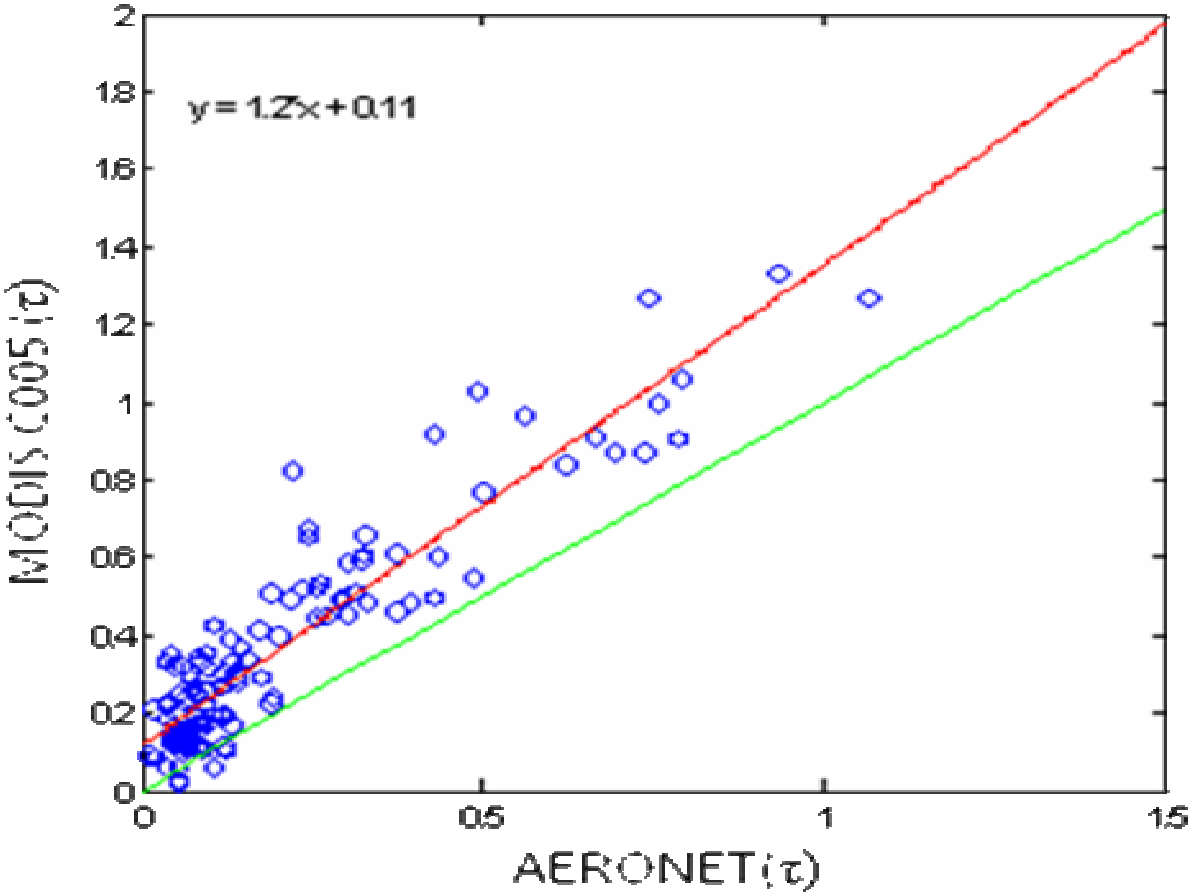
- Comparisons of MODIS AOD to our ground based Aeronet sky radiometer AOD retrievals reveal the aerosol optical depth derived from the MODIS sensor is significantly overestimated over New York City

- Current algorithms do not model the surface albedo for urban areas very well which is critical since the ground reflectance in the visible is determined as some correlation multiplied by the MIR (2.1um) reflectance

- A better understanding of this correlation between the visible and mid-infrared surface albedo is needed to “tune” the algorithm for urban areas

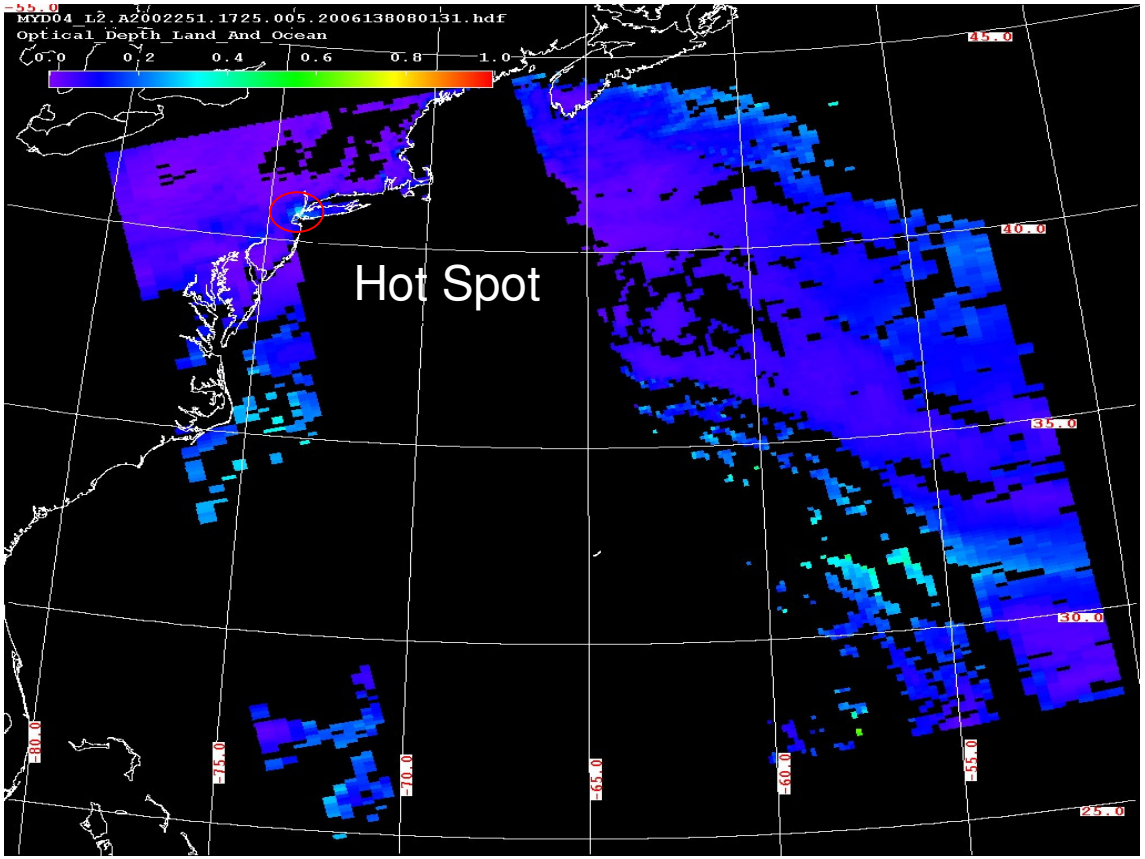
MODIS and Aeronet AOD Comparison (10km) using C005

Significant overestimate seen in operational product



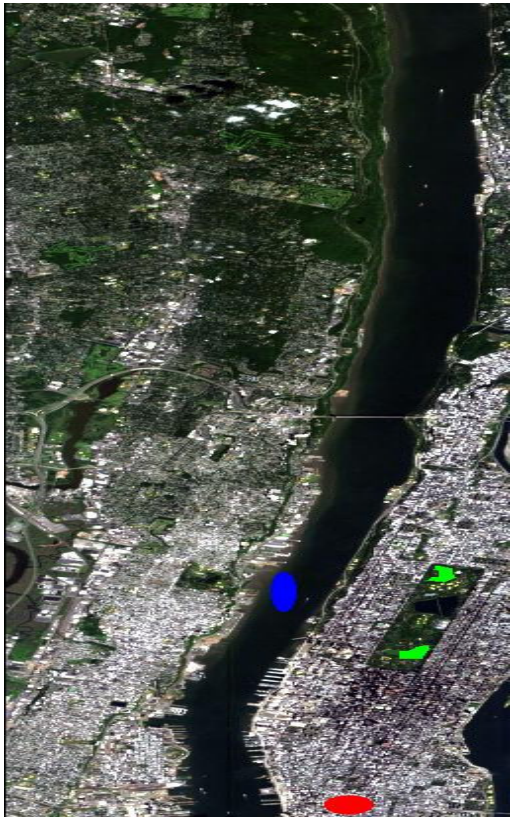
- AERONET (CIMEL) dataset was the average of a 4 hour interval surrounding the MODIS observation and at least 10 data points must be available and stable within relative standard deviation 20%
- (2001-2007)

NYC Urban Area is still resulting In overestimating AOD spots

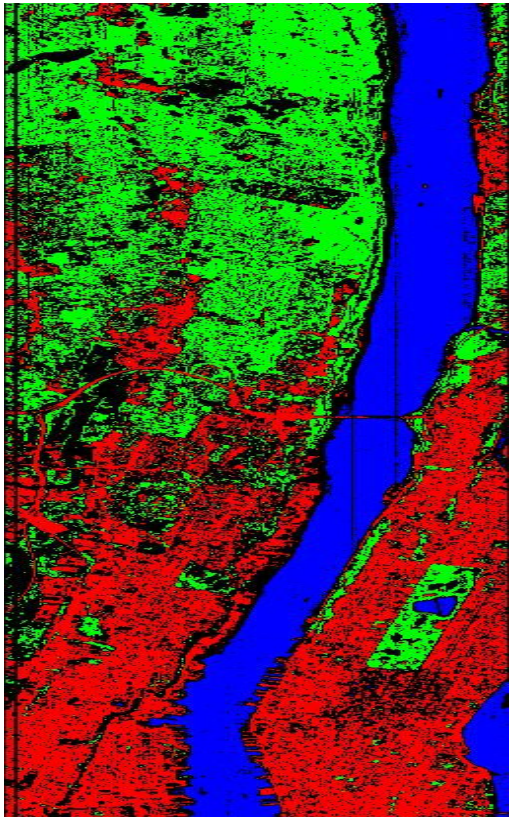


Direct surface using Hyperion Imagery including Supervised Classification

RGB Image with Training regions



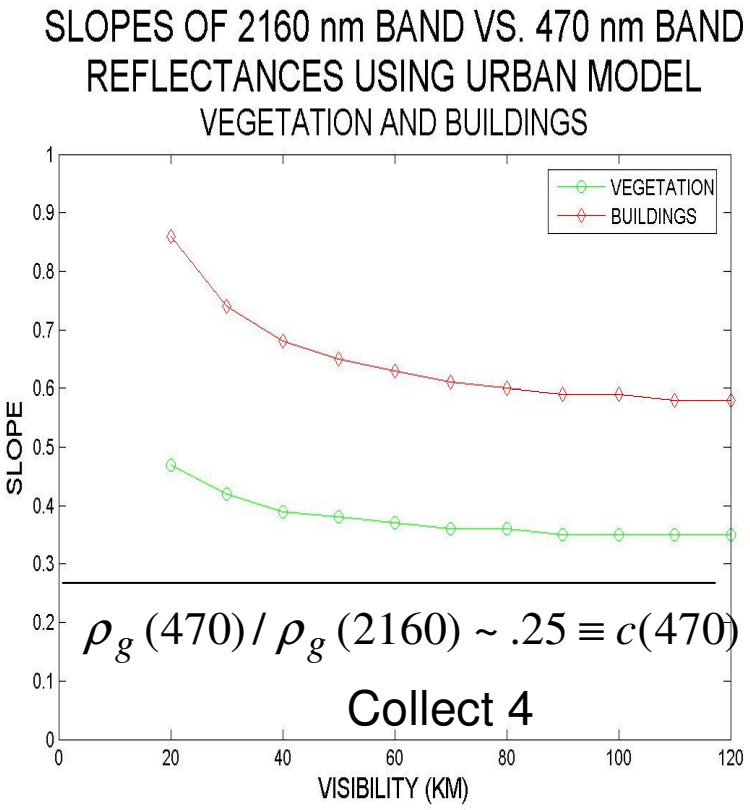
Segmented Image

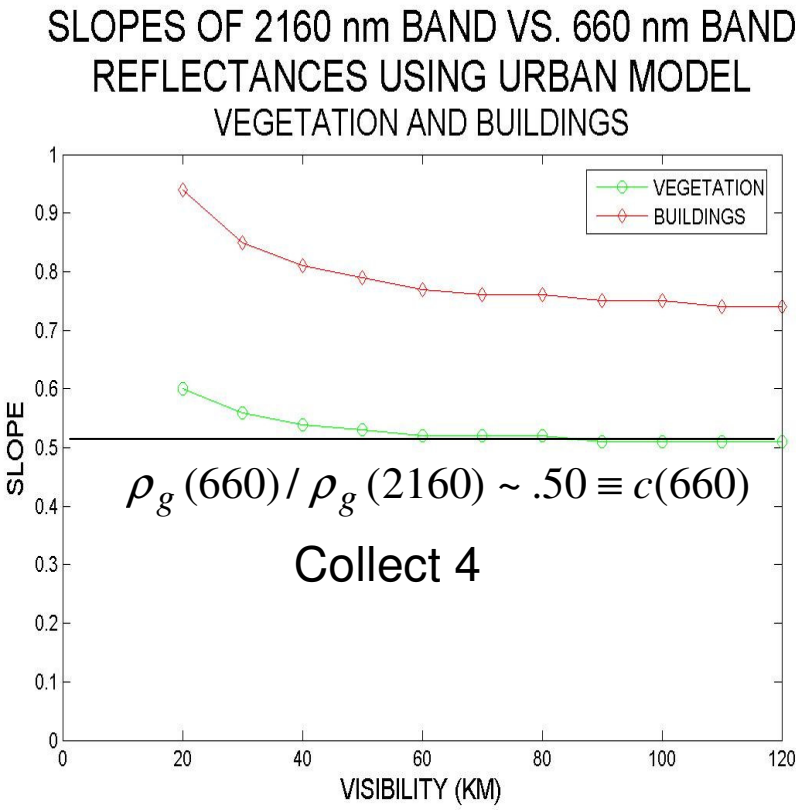


Blue=Water
Green=Vegetation
Red=Urban

Atmospheric correction Included using FLAASH software based on Visibility level of 120km (as seen on next slide) and the use of a standard urban aerosol model

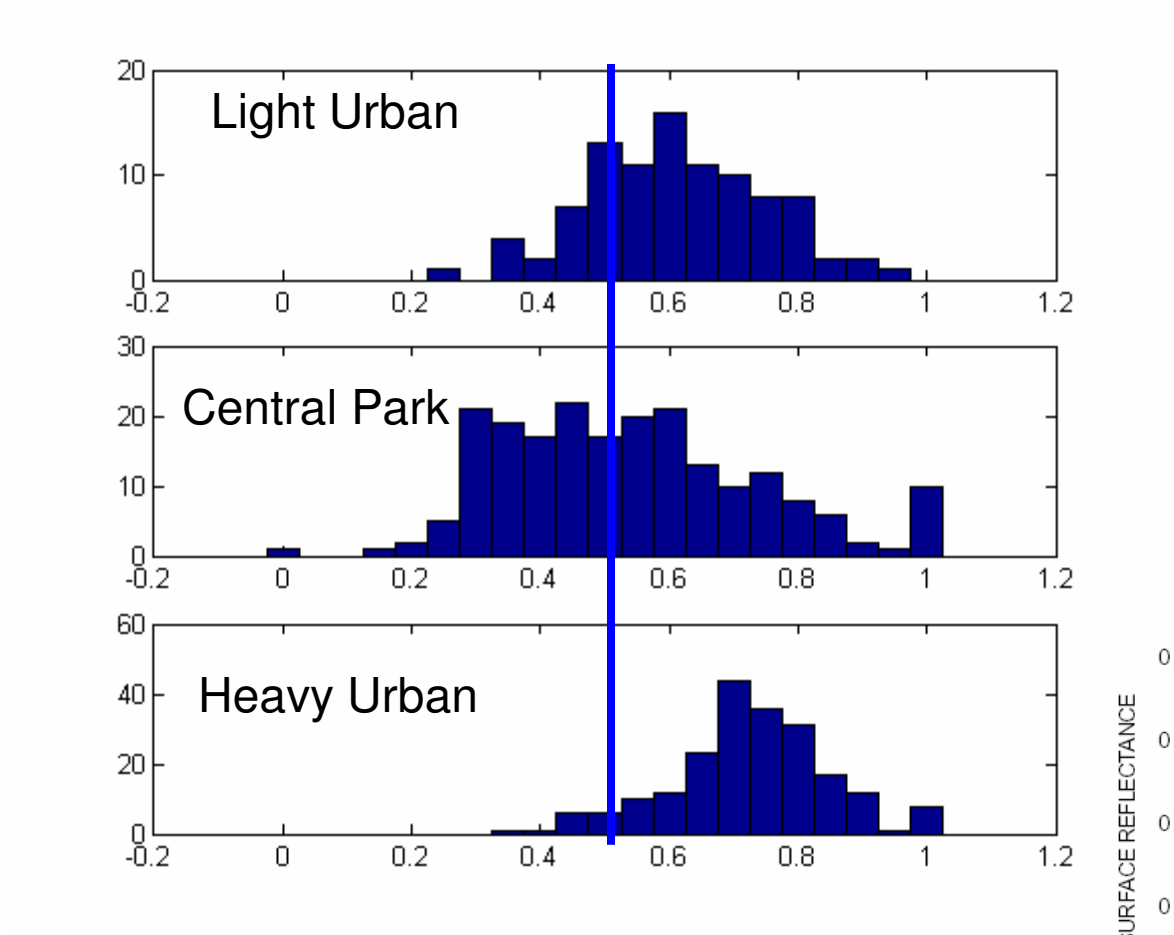
Sensitivity to atmospheric correction





Urban scenes have a significantly larger VIS/MIR coefficient.
Since algorithm underestimates albedo, AOD is generally overestimated

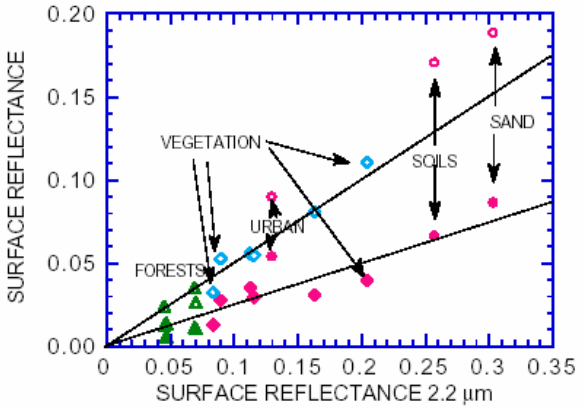
Ground reflection correlation frequency histogram No angle dependence (Lambertian) assumption



$c(660,2160)$

Correlation larger than MODIS assumption of 0.5

This has been Observed elsewhere as seen below



* Source MODIS ATBD Document

Collection 5 approach (adopted to region)

- As we have seen, different surfaces have different correlations with clear differences between vegetation and urban scenes so old (Collection 4) algorithm was not reasonable
- The Collect 5 approach allows the VIS-MIR ground albedo correlation coefficients to be a function of surface type (urban/vegetation MVI) and observation angles (scattering angle).
- In our modification, we match aerosol AOD from aeronet and use MODIS urban fine mode aerosol cases only to retrieve VIS/MIR surface ratios
- The data used in training surface requires AOD < 0.2, angstrom coefficient > 1 and homogeneous conditions which allow us to extrapolate AOD over entire domain

Obtaining surface albedos using Combined MODIS – Aeronet Data

Aeronet Optical Depth + MODIS Aerosol Phase Function consistent with AOD

$$\left[\tau_{aer}^{550}\right]_{aeronet} \longrightarrow \left[P_{aer}\left(\Theta_{scat}, \tau_{aer}^{550}, \lambda\right)\right]_{urban-nonabs}$$

Use Aeronet AOD to fix the MODIS Aerosol Phase function model
From this, we can get all relevant atmospheric scattering parameters

$\rho_{atm}(\lambda, \theta_v, \theta_i, \Delta\phi) =$ **path reflectance**

$\longrightarrow$ $T_{d,u}(\lambda, \theta) =$ **Upward and downward total transmission**

$s(\lambda) =$ **Atmospheric spherical albedo**

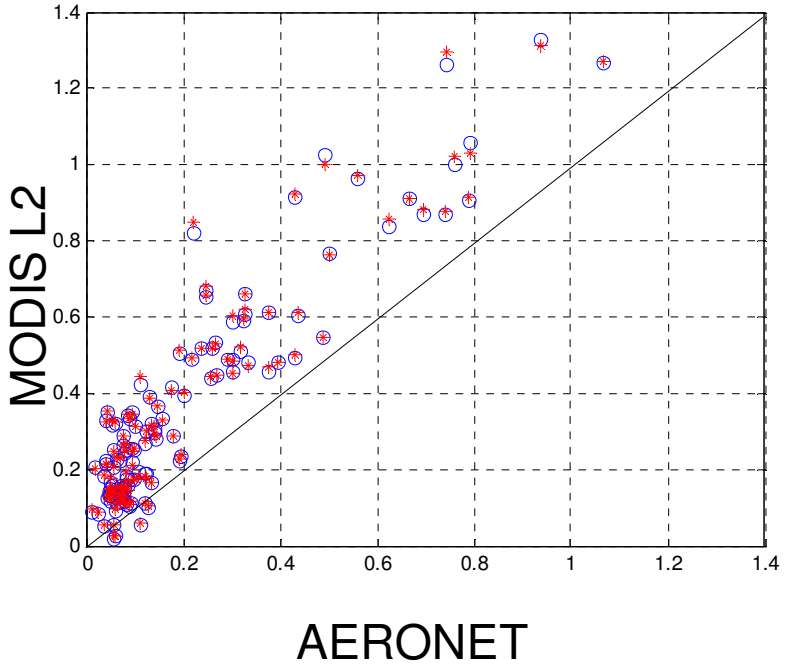
Once this is done, we can Isolate Lambertian albedo

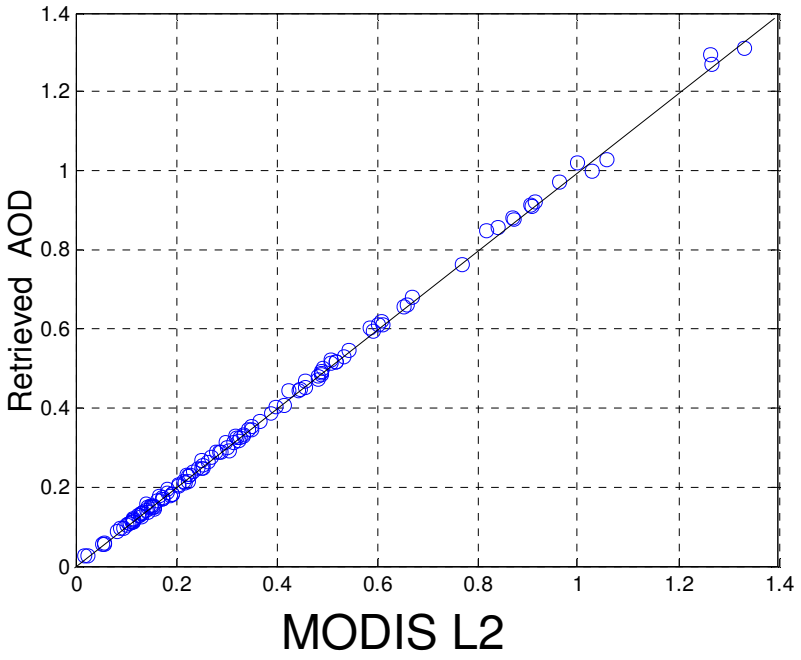
$$\rho_{TOA} = \rho_{atm} + \frac{\rho_g T_d T_u}{1 - s\rho_g} \qquad \Rightarrow \rho_g = \frac{\rho_{TOA} - \rho_{atm}}{T_d T_u + s(\rho_{TOA} - \rho_{atm})}$$

Higher spatial resolution retrievals

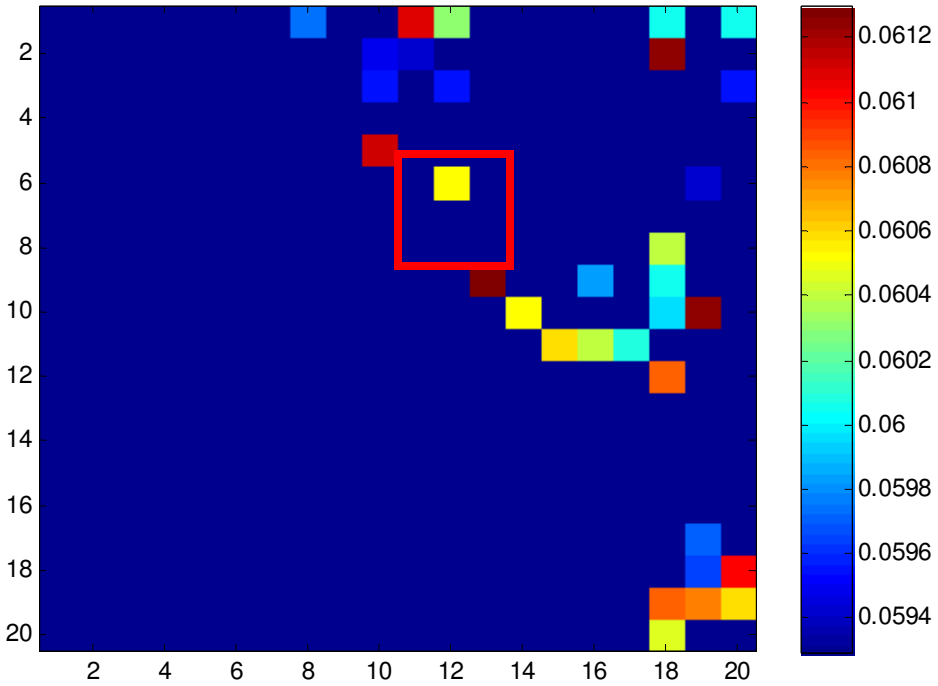
- To assess the effects of urban surfaces on aerosol retrieval at higher resolution, a reprocessing of the (500m) L1B product must be initiated.
- This is done by using the MODIS operational aerosol retrieval algorithm as a separate module and performing cloud clearing at high resolution
- In examining higher resolution, we break the data into 3 x 3 cells (like the standard algorithm) and mark the center pixel clear if all radiometric and smoothness tests are passed
- However, unlike the standard 10km mask that requires a certain percentage of cloud cleared pixels, we perform our processing directly on the high resolution data
- To assess our external cloud clearing, we match our cloud cleared AOD retrievals at 10km to the DAAC AOD 10km products.

MODIS Land AOD validation with MODIS-Operational software





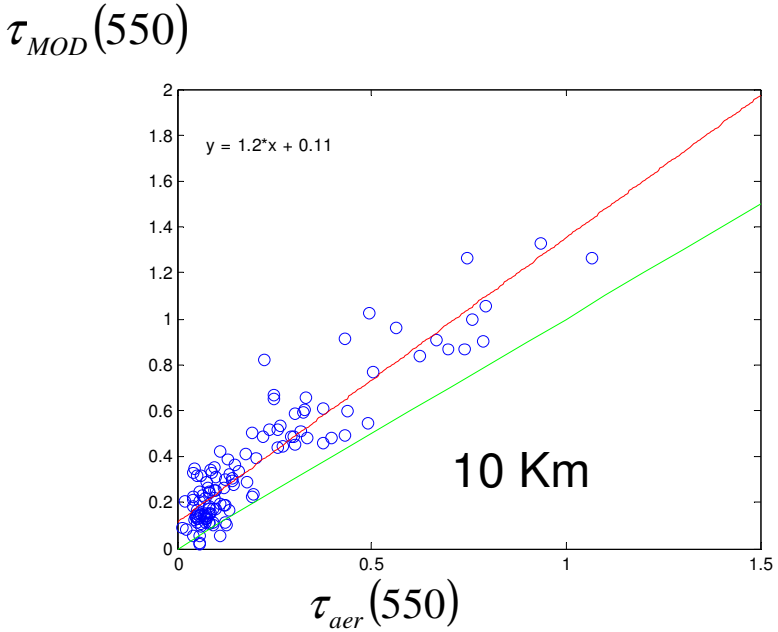
High resolution cloud clearing Image (example)

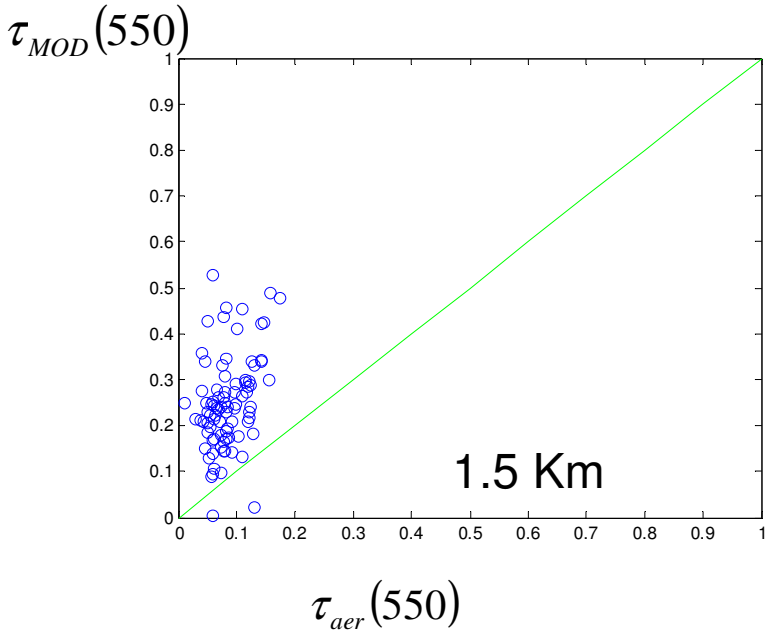


If the red cell represents the 1.5 km region around the CIMEL Radiometer, the Reflectance is taken to be the mean of all TOA reflectances In the region (even if only 1 500m pixel is chosen)

This is done to obtain more Data for analysis without Too much error expected

Intercomparison at higher resolutions assuming C005 albedo





Our high resolution data was only collected when aerosols were fine mode and optical depth < .2 since this filtering is needed for calculating surface reflection directly (in 2120nm)

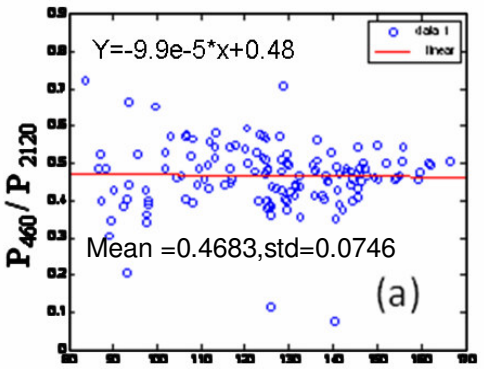
Observations

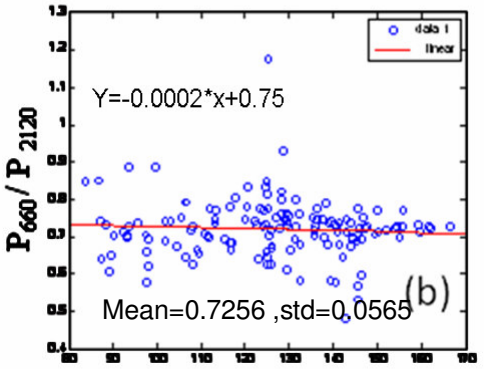
- Increasing the spatial resolution from 10km to 1.5 km leads to significant increase in bias
- We trace this affect to water contamination from a river body near CCNY
- Even small error in the ground reflectance model will lead to dramatic changes in AOD (if AOD is small)
- We find it necessary to refine the surface reflection model to remove the bias even for the 10km product as well as when pushing the resolution higher

Correlation coefficients as function of scattering angle 10x10km,3x3km and1.5x1.5km resolution

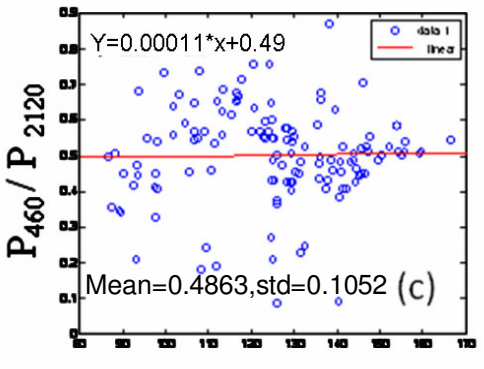
(not masked for inland water bodies)

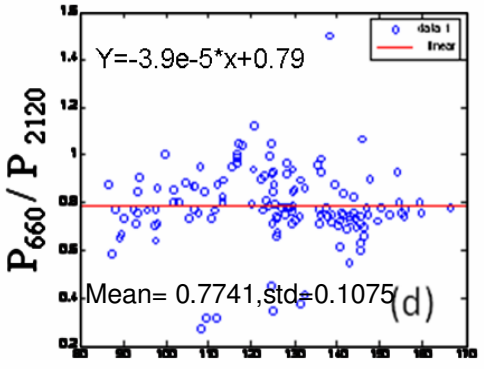
10x10 km



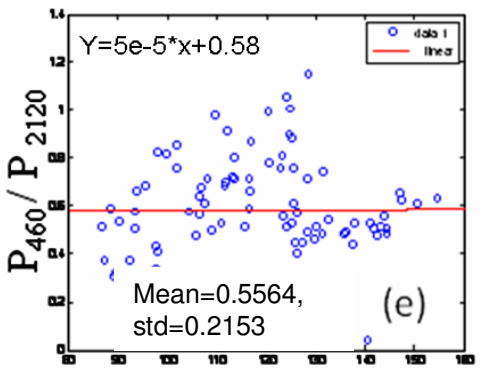


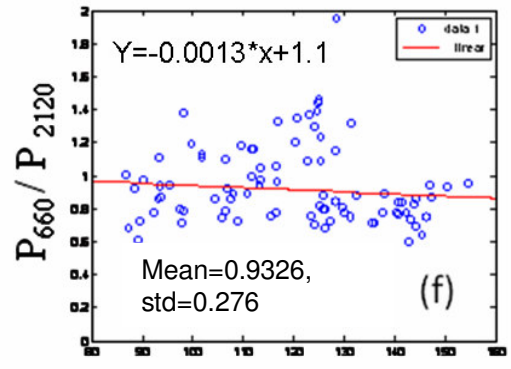
3x3 km



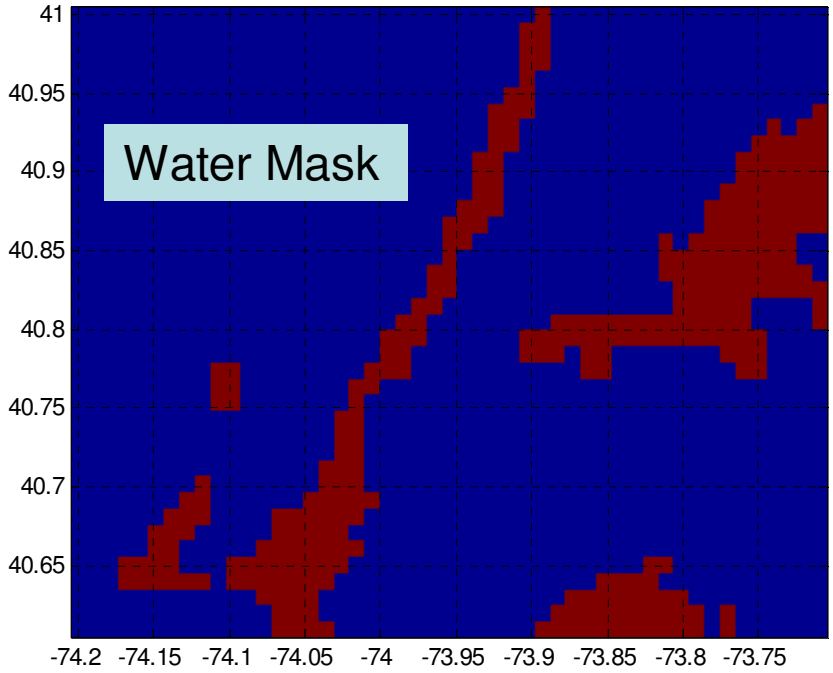


1.5x1.5 km





Water Mask (Example)

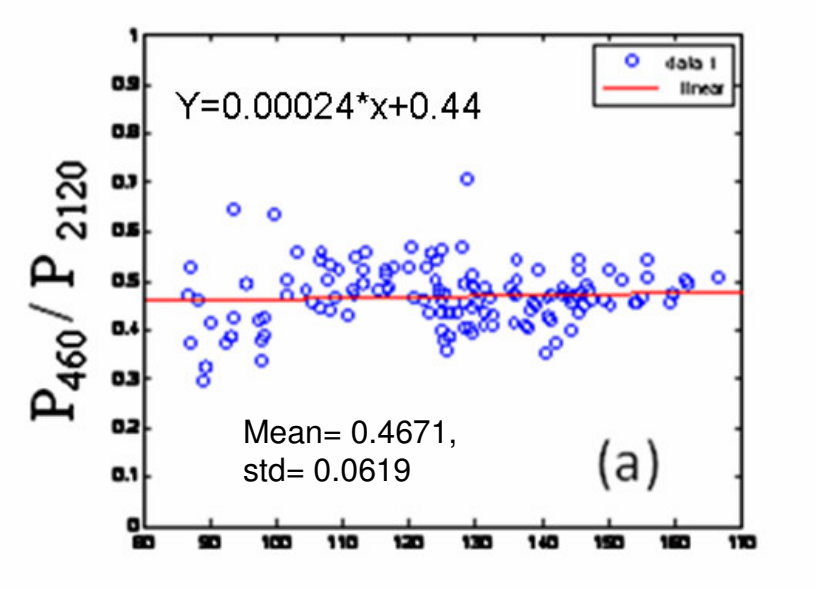


•After masking the pixels Rho_2120<0.05

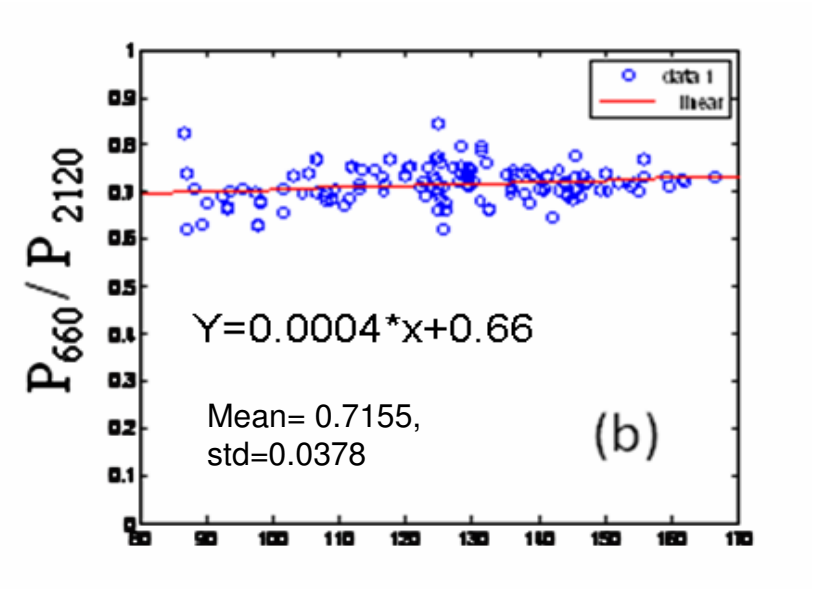
Correlation coefficients as function of scattering angle 10x10 km resolution

masked for inland water bodies

Rho460/Rho2120



Rho660/Rho2120



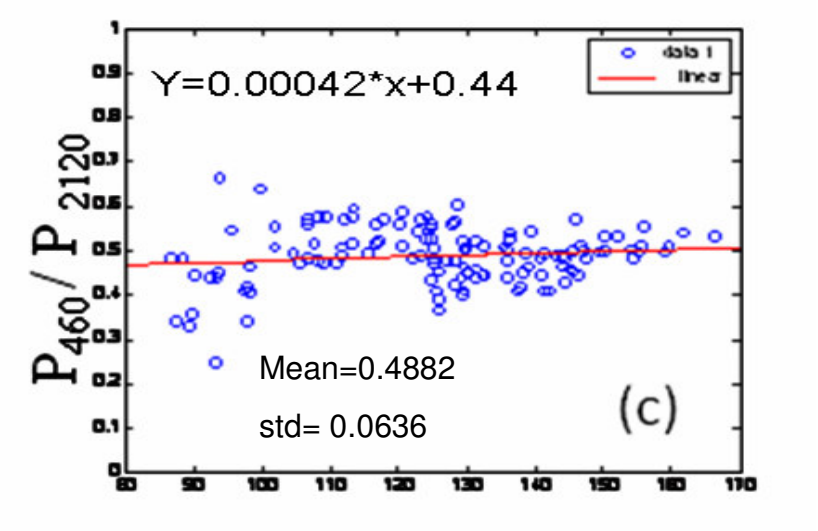
Scattering angle

Scattering angle

Very small changes observed as function of scatter angle
Lambertian assumption seems reasonable in first order

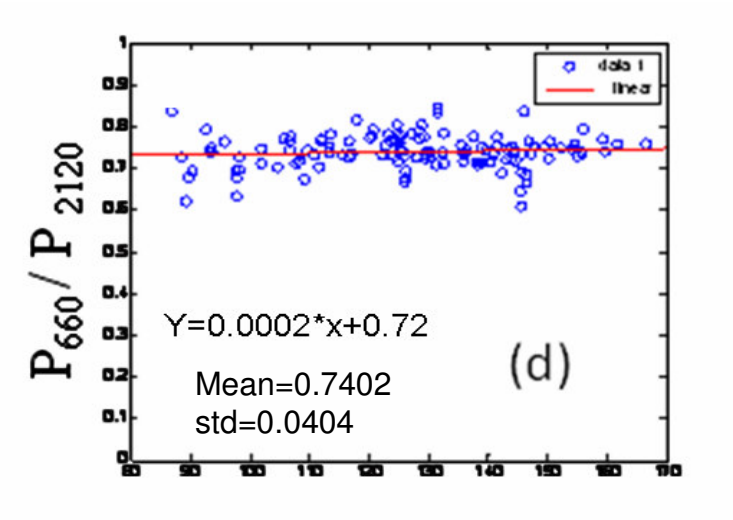
Correlation coefficients as function of scattering angle 3x3 km resolution

Rho460/Rho2120



Scattering angle

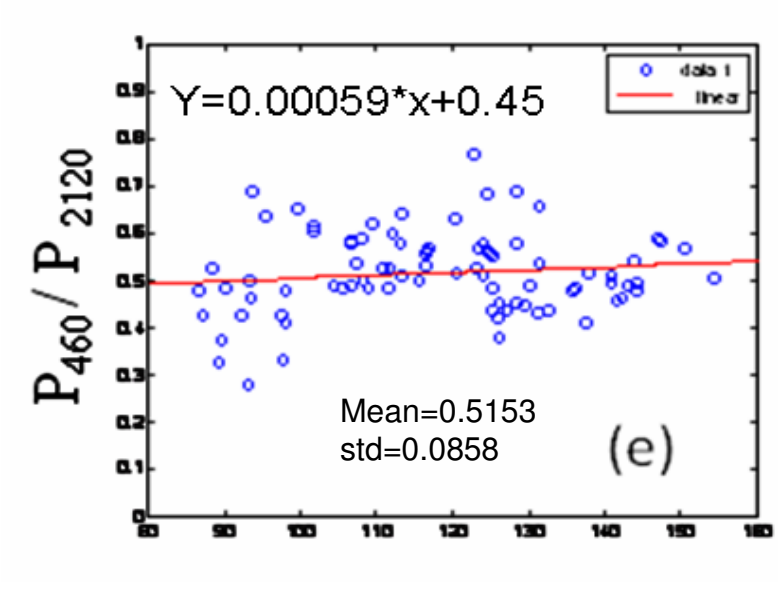
Rho660/Rho2120



Scattering angle

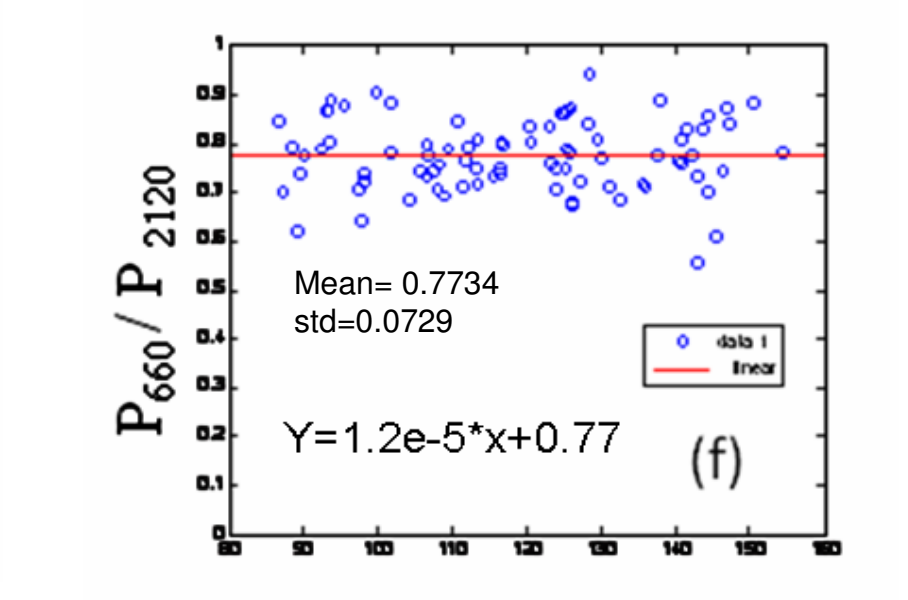
Correlation coefficients as function of scattering angle 1.5 km resolution

Rho460/Rho2120



Scattering angle

Rho660/Rho2120

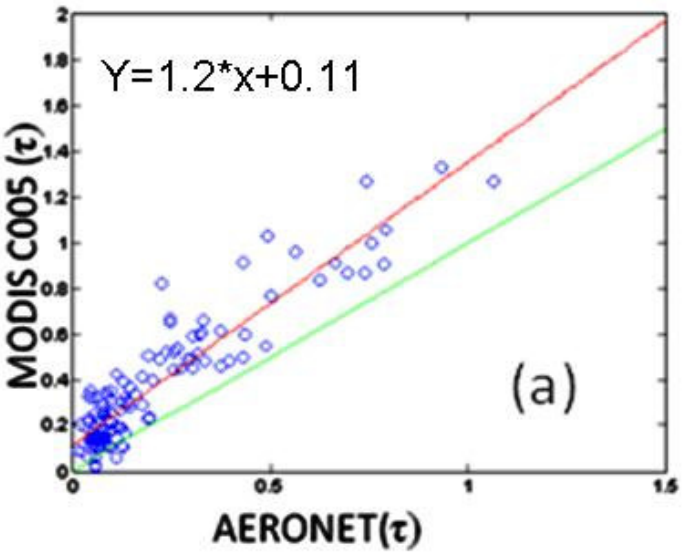


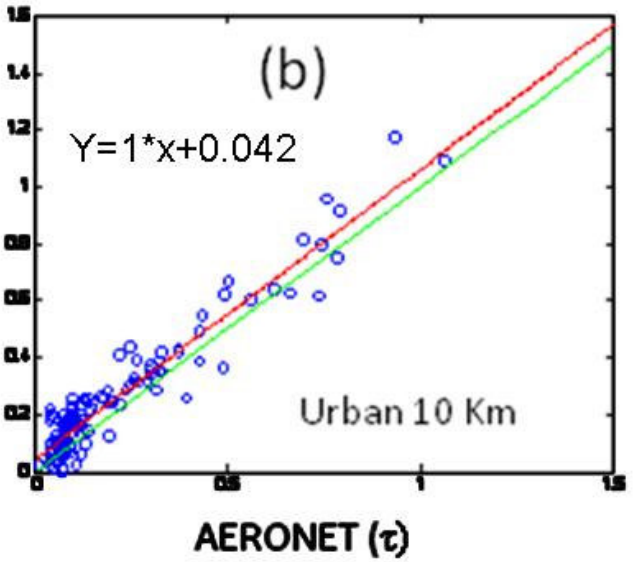
Scattering angle

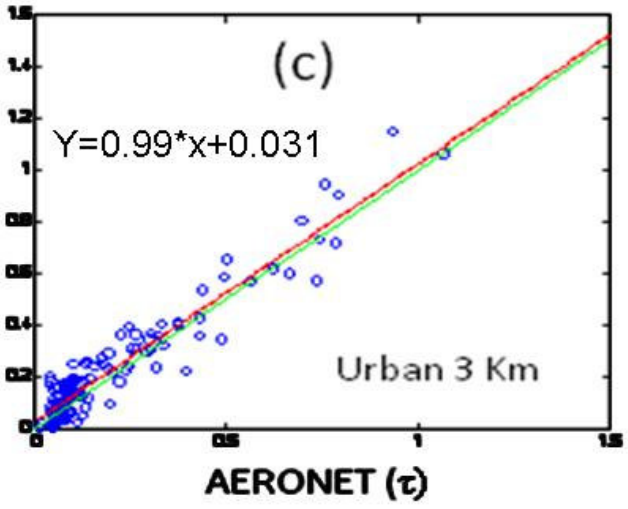
$$\rho_g(\lambda_i) = f_i(\Theta_s)\rho_g(2120)$$
$$i = 1:2$$

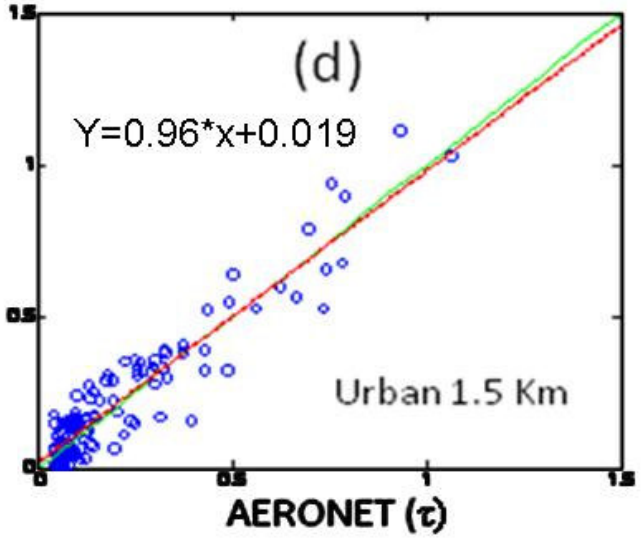
Once new correlations are found, we can replace the COO5 Correlation procedures and assess retrieval of AOD (**for all cases**)

AOD Retrieval with refined model at different resolutions









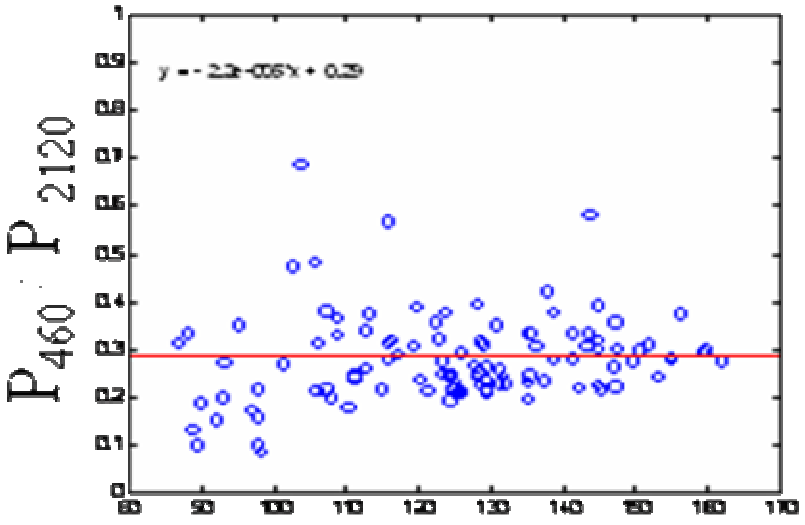
Comparisons

	No Mask				Mask			
	460/2120		660/2120		460/2120		660/2120	
	mean	**std**	**mean**	**std**	**mean**	**std**	**mean**	**std**
10x10km	**0.4683**	**0.0746**	**0.7256**	**0.0565**	**0.4671**	**0.0619**	**0.7155**	**0.0378**
3x3 km	**0.4863**	**0.1052**	**0.7741**	**0.1075**	**0.4882**	**0.0636**	**0.7402**	**0.0404**
1.5x1.5km	**0.5564**	**0.2153**	**0.9326**	**0.2761**	**0.5153**	**0.0858**	**0.7734**	**0.0729**

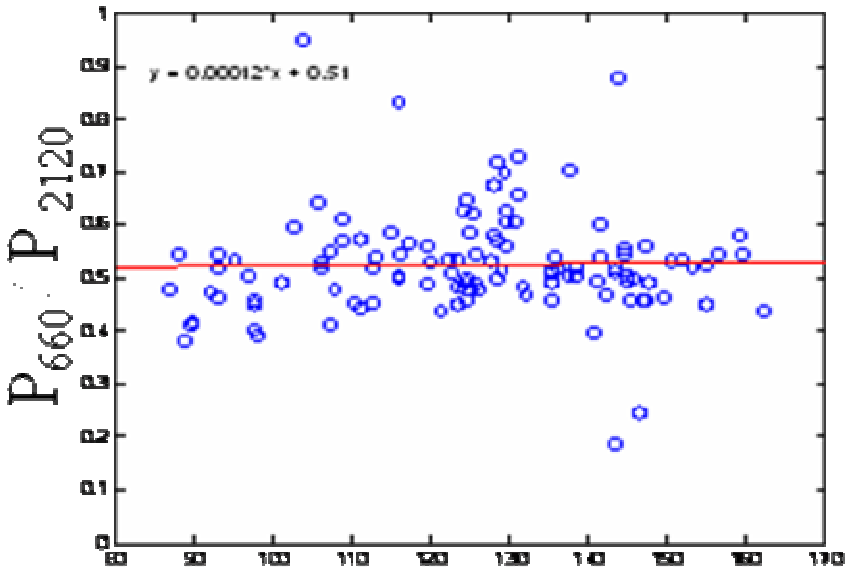
Validation of Surface albedo model over vegetation (rural)

1.5 Km resolution

460/2120



660/2120

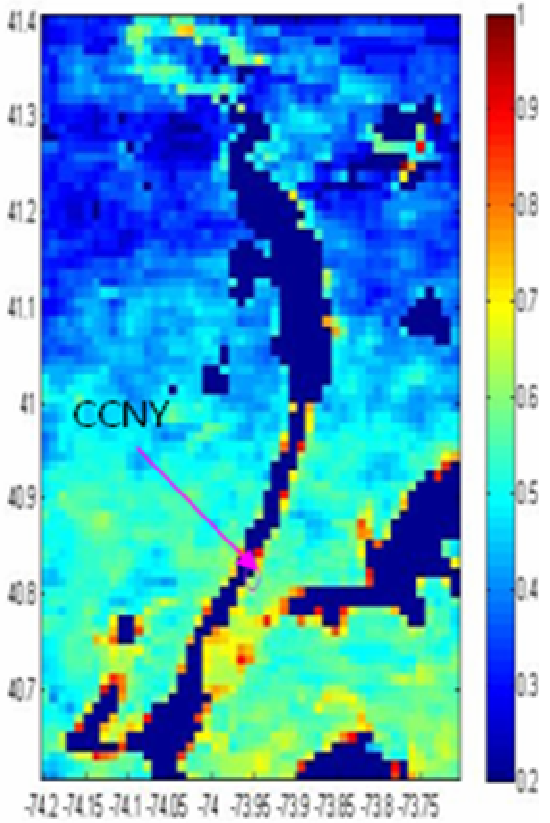


- Good agreement to C004/C005 reference
- Due to surface albedo ratios of both urban and vegetated area weakly depend on scattering angle, the surface albedo ratios MAP can be considered (next slide)

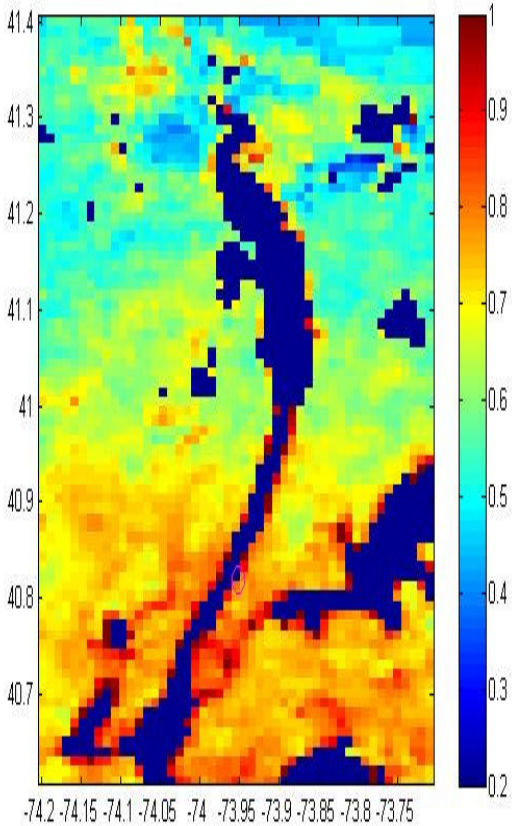
Surface Reflectance Ratio MAP

Google MAP

$\rho_{460}^{surface} / \rho_{2120}^{surface}$



$\rho_{660}^{surface} / \rho_{2120}^{surface}$

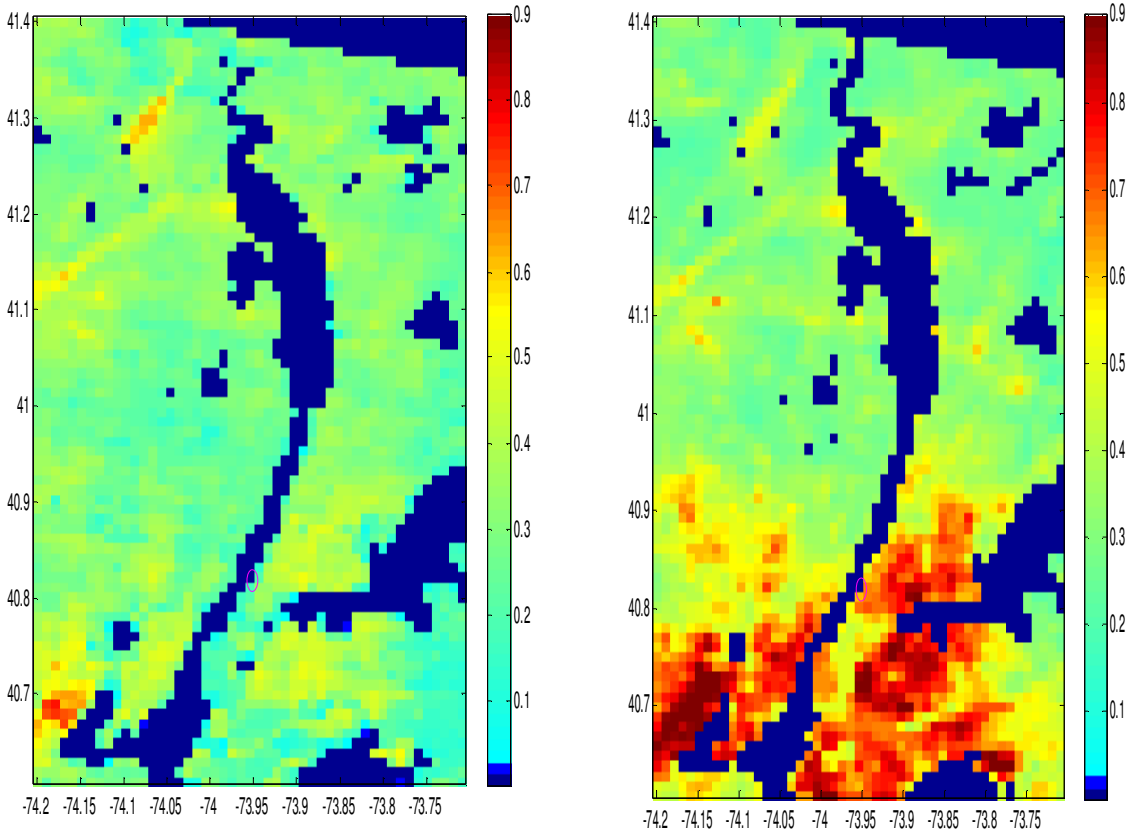


VIS/MIR correlation coefficient ratios of 460nm/2120nm and 660nm/2120nm in nearby New York City area. VIS/MIR ratio is significantly higher in the urban area compared to the vegetated areas

Observations

- No tuning is needed for vegetative areas since correlation coefficients are in good agreement with operational results
- Refined correlation coefficient model is needed for urban area and significantly improves the final AOD retrieval
- To assess whether high resolution AOD retrieval is possible, we need to examine the resolution of the underlying retrieved surface.

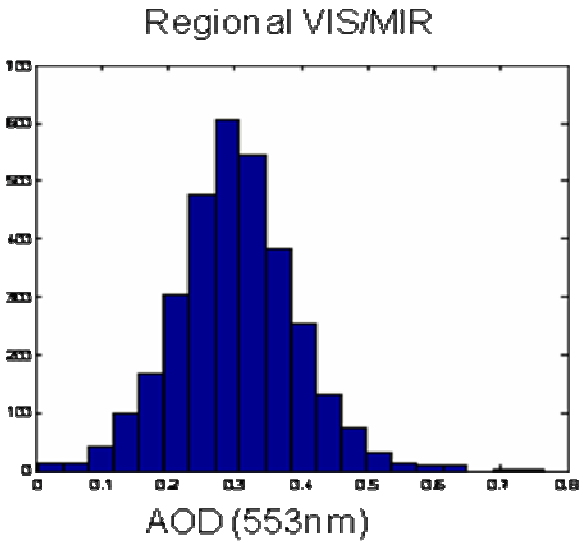
New York City regional AOD retrieval Example (10-3-2006)

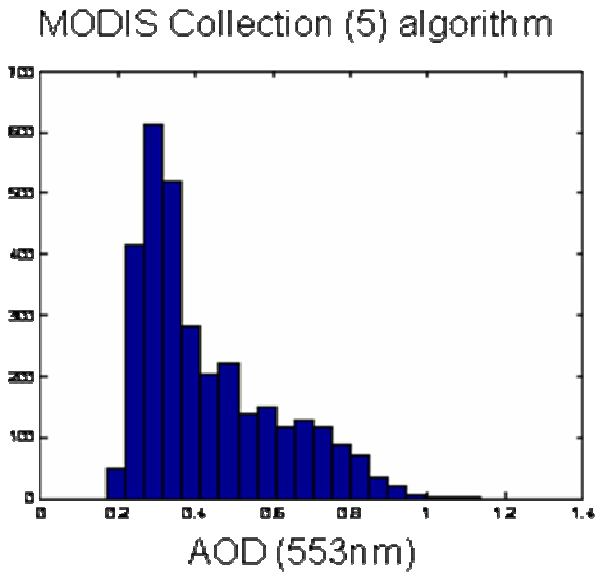


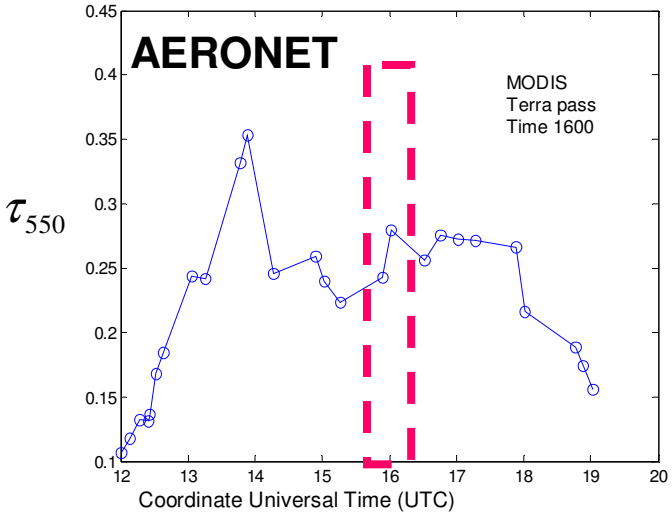
- A significant improvement can be observed as artificial hot spots in the AOD map are significantly reduced

Regional map of AOD (550nm) retrieval with modified VIS/SWIR ratio (left panel) and retrieval with Collection (5) algorithm (right panel) Date: 10-03-2006.

Histogram of retrieved AOD (10-03-2006)





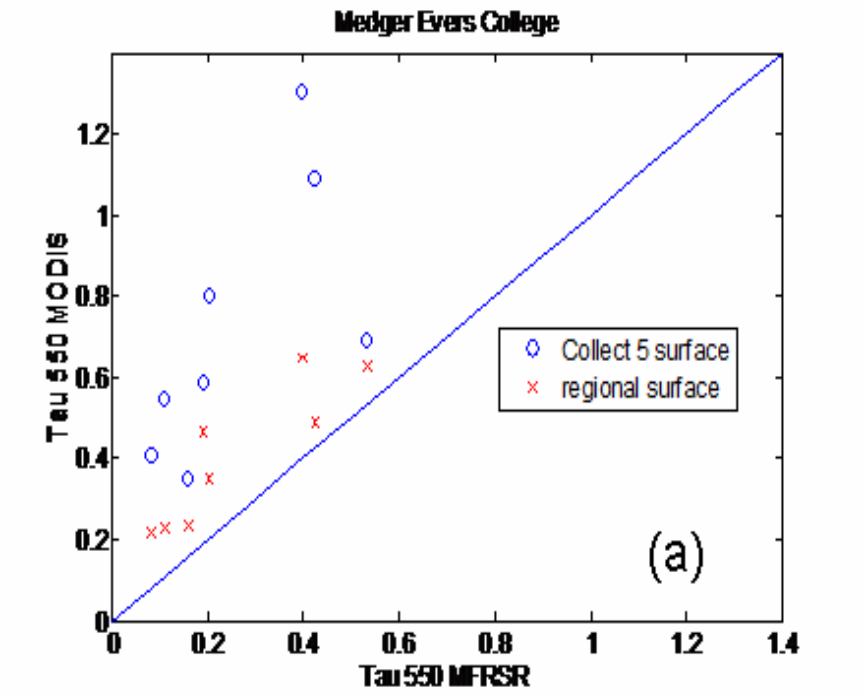


CCNY AERONET station derived AOD ~ 0.26

MODIS (C005) L2 data AOD = 0.52

MODIS (modified VIS/MIR) AOD = 0.32

Comparison of MODIS with MFRSR AOT



•MFRSR shadowband radiometer at Medger Evers College is 16Km away from CCNY

• Using of the surface ratios obtained from CCNY shows significant improvement in AOD retrieval compare to MFRSR derived AOD (data available only Sept, Oct 2007)

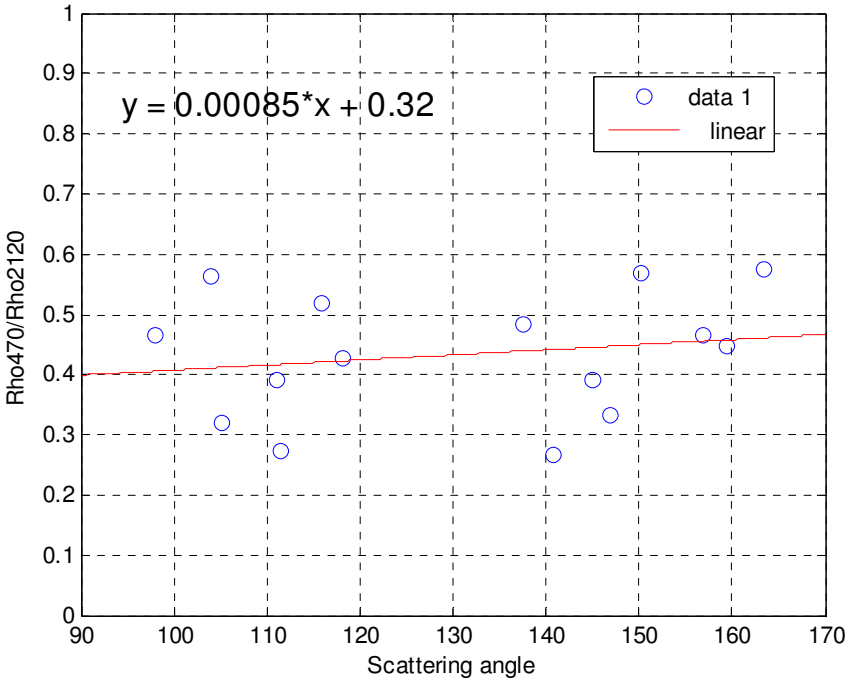
Conclusions

- Operational algorithms significantly underestimate the critical surface correlation coefficient ratios over urban areas.
- Overestimates in aerosol retrieval in heavy urban area can be corrected using refined surface reflection obtained from coincident AERONET radiometer / MODIS measurements
- Application of surface correlation maps are shown to remove anomalous hot spots in the retrieval and result in much better statistics in comparison to aeronet.
- Application of surface model at remote location is seen to remove most of the bias illustrating the general soundness of extrapolating AOD during surface training

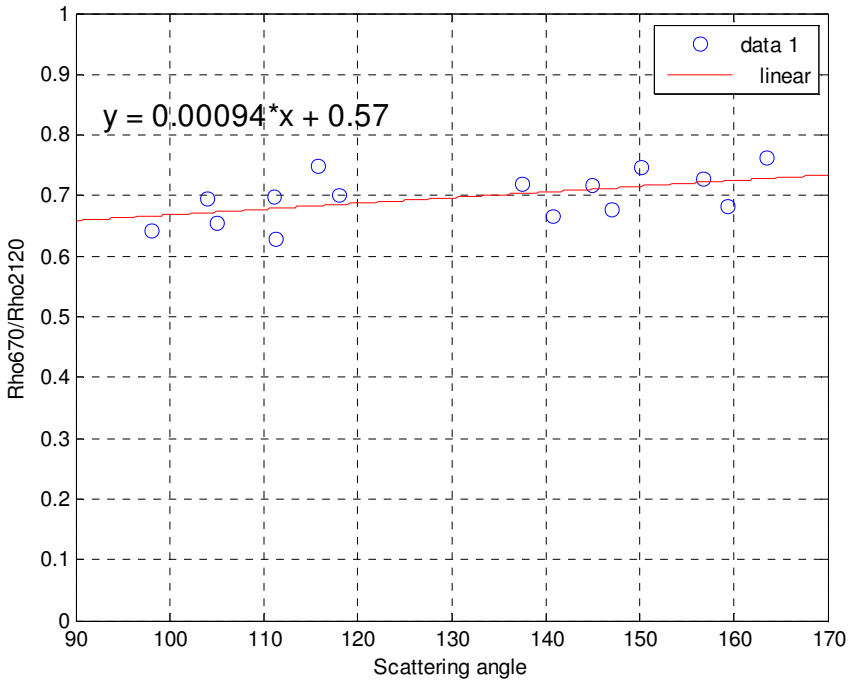
Mexico City urban area

- To verify with another heavy urban area, Mexico City is selected
- Unlike New York City, Mexico City is situated ~ 2.2 Km above sea level and most of the fine mode aerosol model is within Smoke Aerosol model (MODIS LUT) category
- In comparison to NYC, mexico city has far less frequent cases where aerosols are fine mode dominated
- Therefore, statistics of data for surface retrieval is less than NYC case
- surface reflectance ratios and AOD retrieval procedure are the same method as before in NY City case
- The results of VIS/MIR surface ratios are similar to NY City urban area's outcome (next slide)

Mexico City surface reflectance ratios (10x10 Km^2)

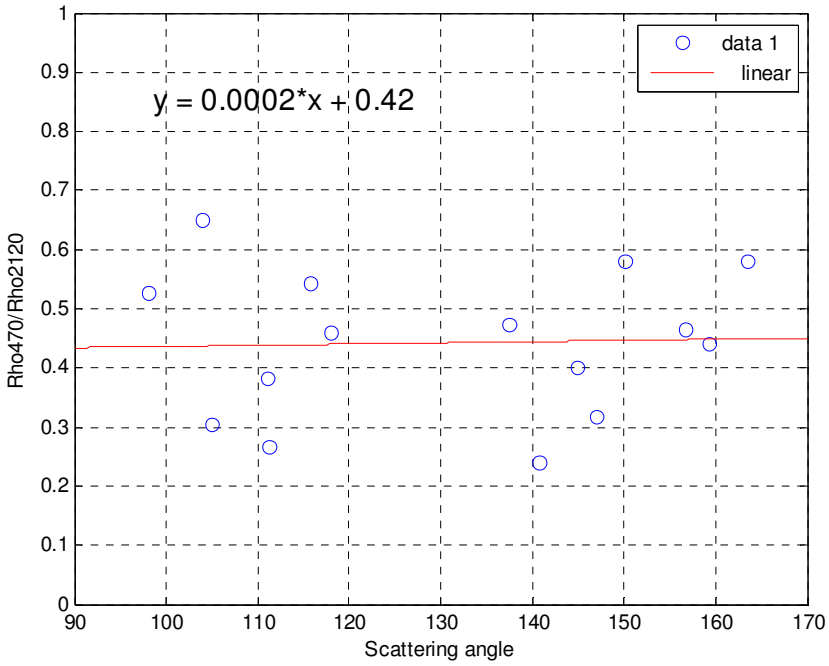


Average rho470/rho2120~ 0.4335, std=0.1026

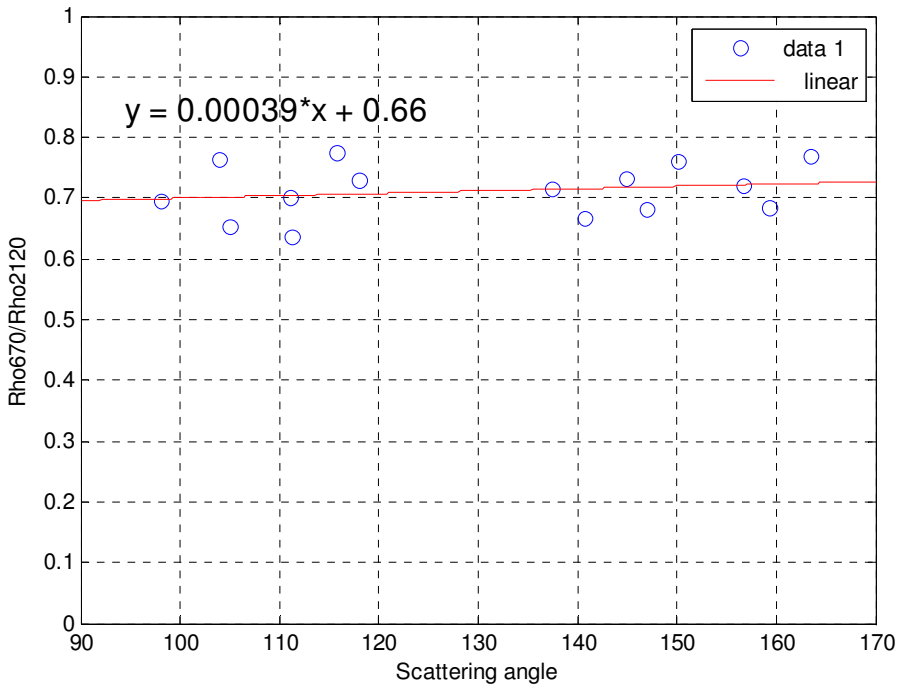


Average rho670/rho2120~ 0.6974, std=0.0398

Mexico City surface reflectance ratios (3x3 Km^2)

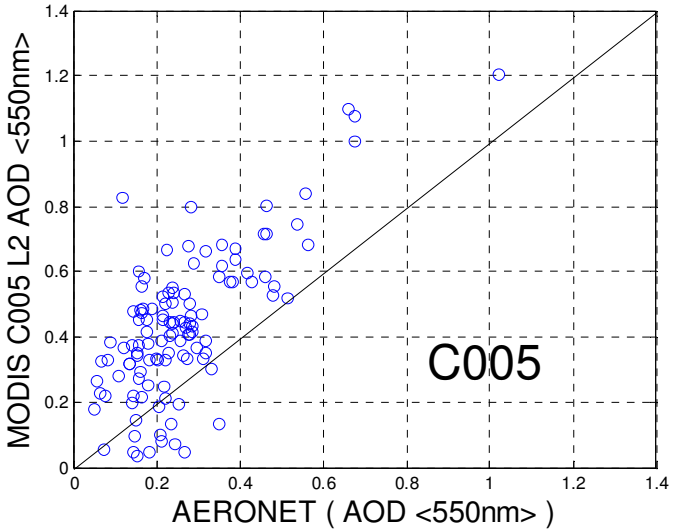


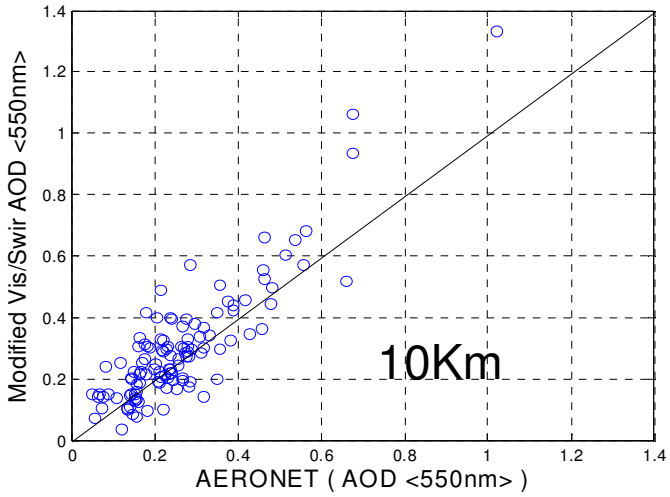
Average rho470/rho2120~ 0.4424, std=0.1230

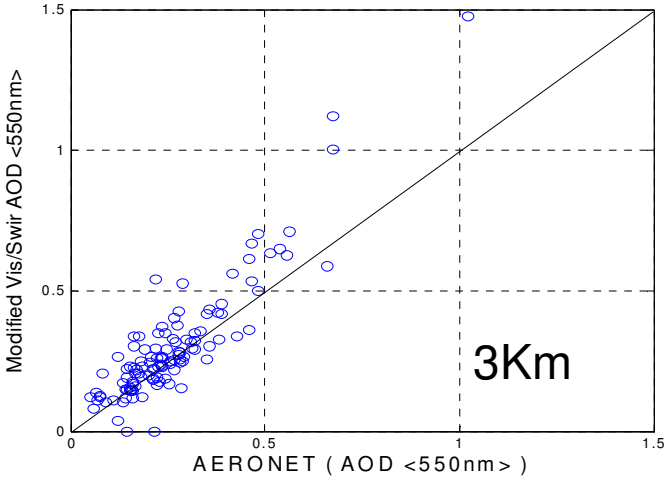


Average rho670/rho2120~ 0.7121, std=0.0431

AOD Retrieval with local (tune) VIS/MIR surface reflectance ratio







•Using local Vis/MIR surface reflectance ratios, significant improvement in retrieved AOD matchup with Mexico City's AERONET station is obtained

Assessment of Lambertian Assumption

- Aerosol retrieval and surface albedo modeling is done under lambertian assumption
- To assess BRDF effects, we normalize the MODIS DAAC BRDF to the lambertian value seen at the observation geometry and use SHARM radiative transfer code
- How does this error compare to errors we find in the retrieval of the correlation coefficients
- We find that the errors in neglecting the BRDF are on the same order as the uncertainty in correlation coefficients

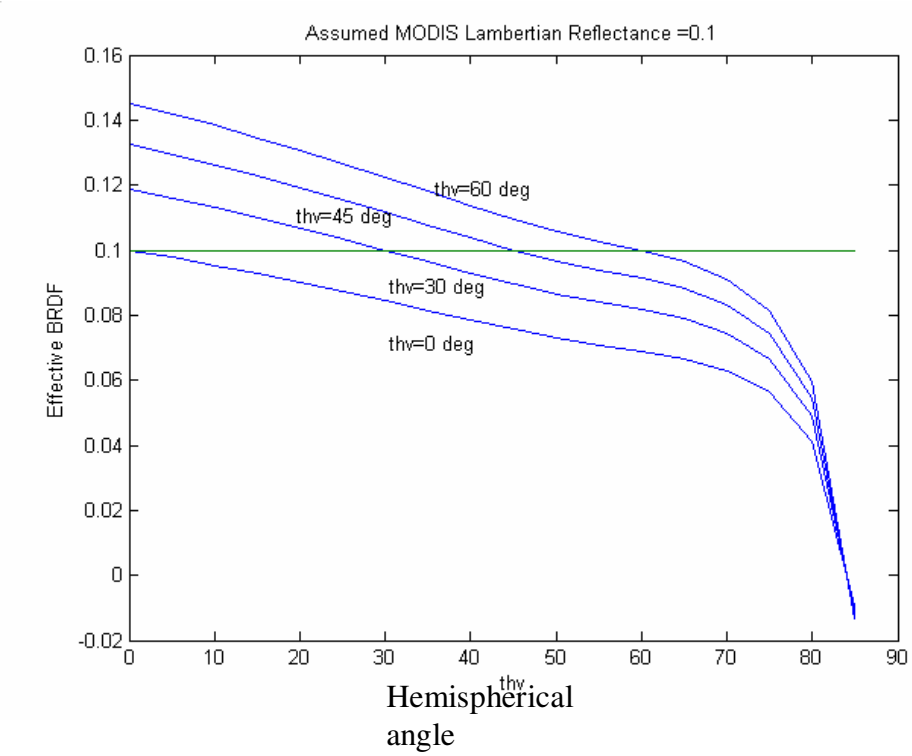
Sensitivity of AOD retrieval (Lambertian surface assumption over urban area)

•First, consider a nadir solar angle

•For different view angles, the normalization occurs for different regions of the BRDF curve

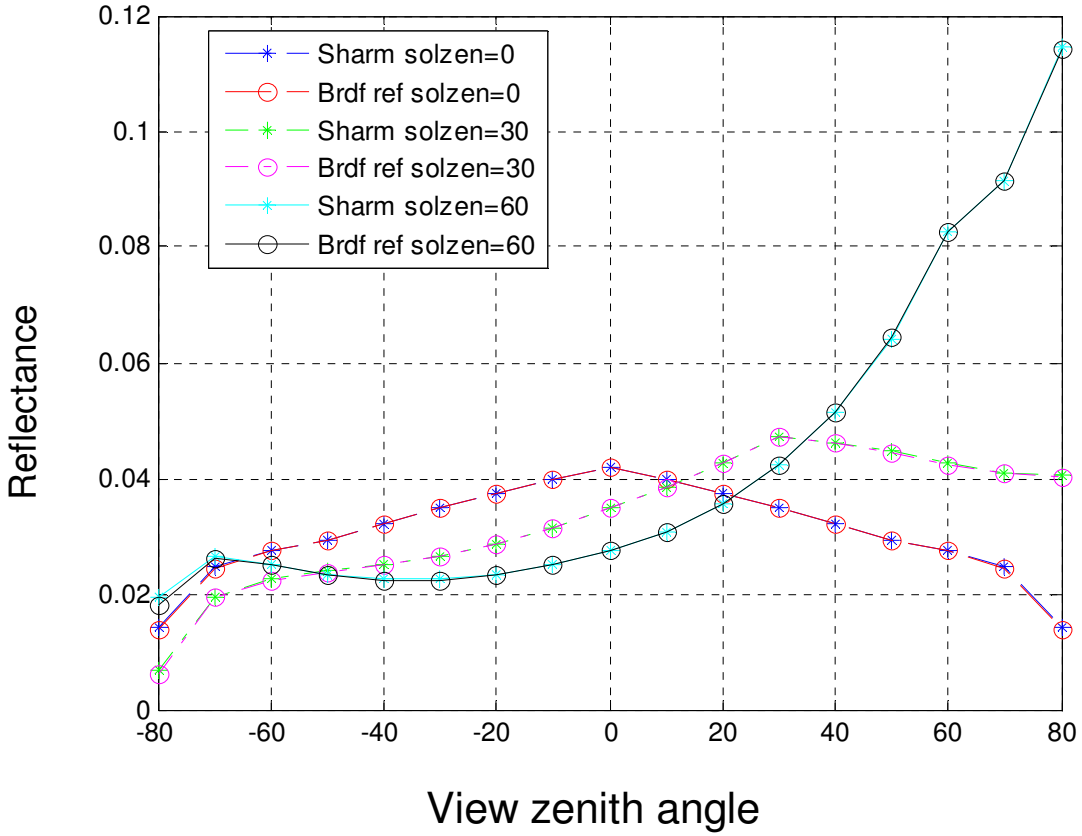
• At view=0, the normalization is at the peak of the BRDF response so the effective BRDF underestimates the ground albedo for all view angles

•As the view angle increases, the normalization changes and the effective BRDF often is larger than the lambertian equivalent.



$$\rho_g(\mu_s,\mu_v,\Delta\phi) = f_{iso} + f_{vol}k_{thick}(\mu_s,\mu_v,\Delta\phi) + f_{geo}k_{sparseR}(\mu_s,\mu_v,\Delta\phi)$$

SHARM's BRDF model Vs MODIS BRDF model

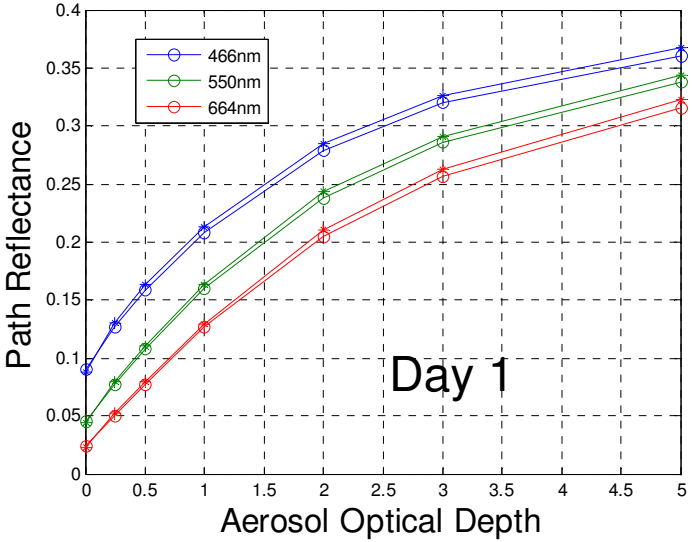


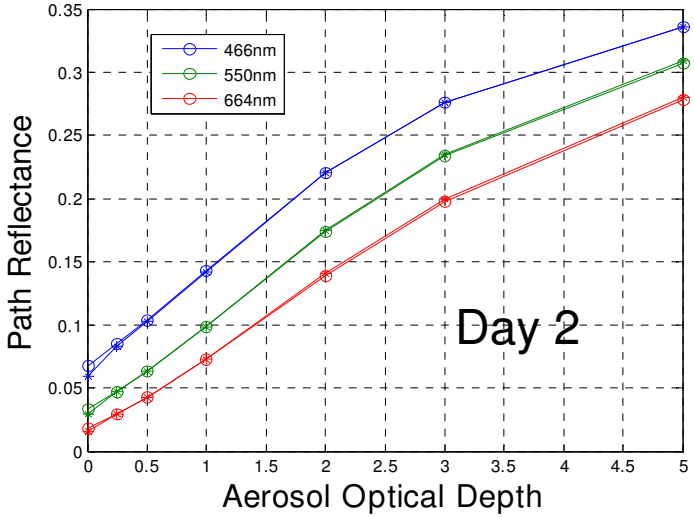
Match up between SHARM reflectance (zero aerosol optical thickness applied to 2120nm wavelength

) at TOA with MODIS BRDF model effective Albedo

This match up confirm SHARM BRDF model agree with MODIS BRDF model

SHARM RADIATIVR Transfer software Vs MODIS LUT





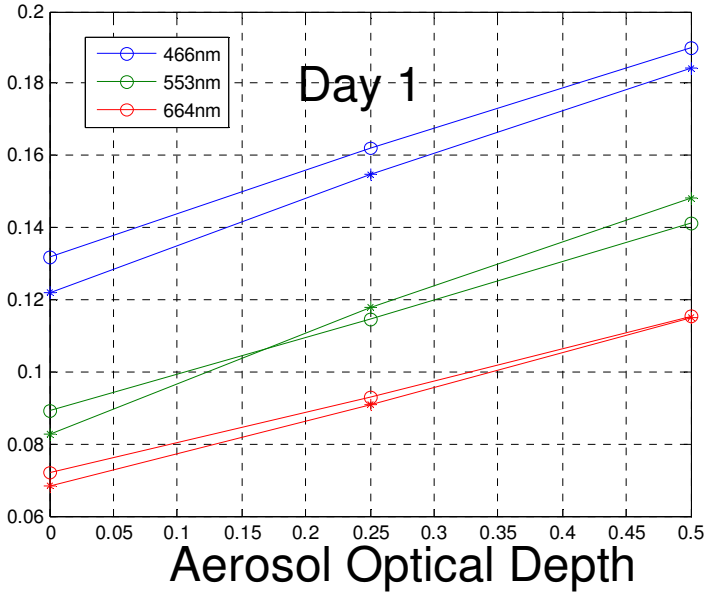
Day1 : 2006-149

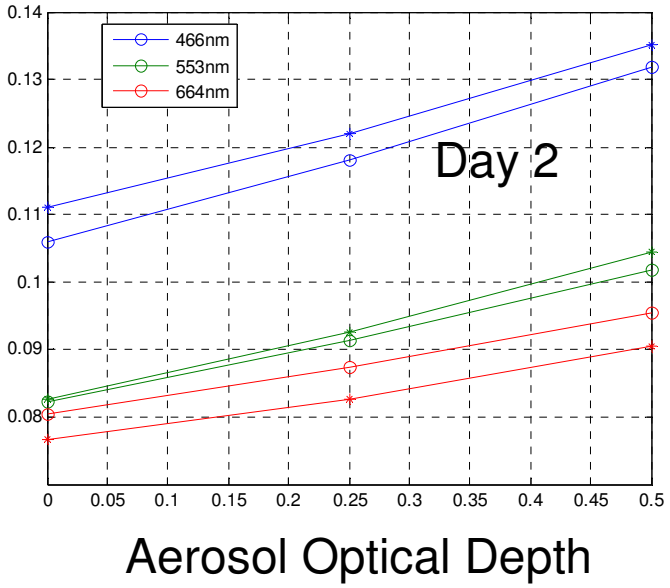
Day2 : 2006-152

SHARM code ‘o’

MODIS LUT ‘*’

TOA reflectance (simulation) calculated by Lambertian surface and BRDF surface assumption





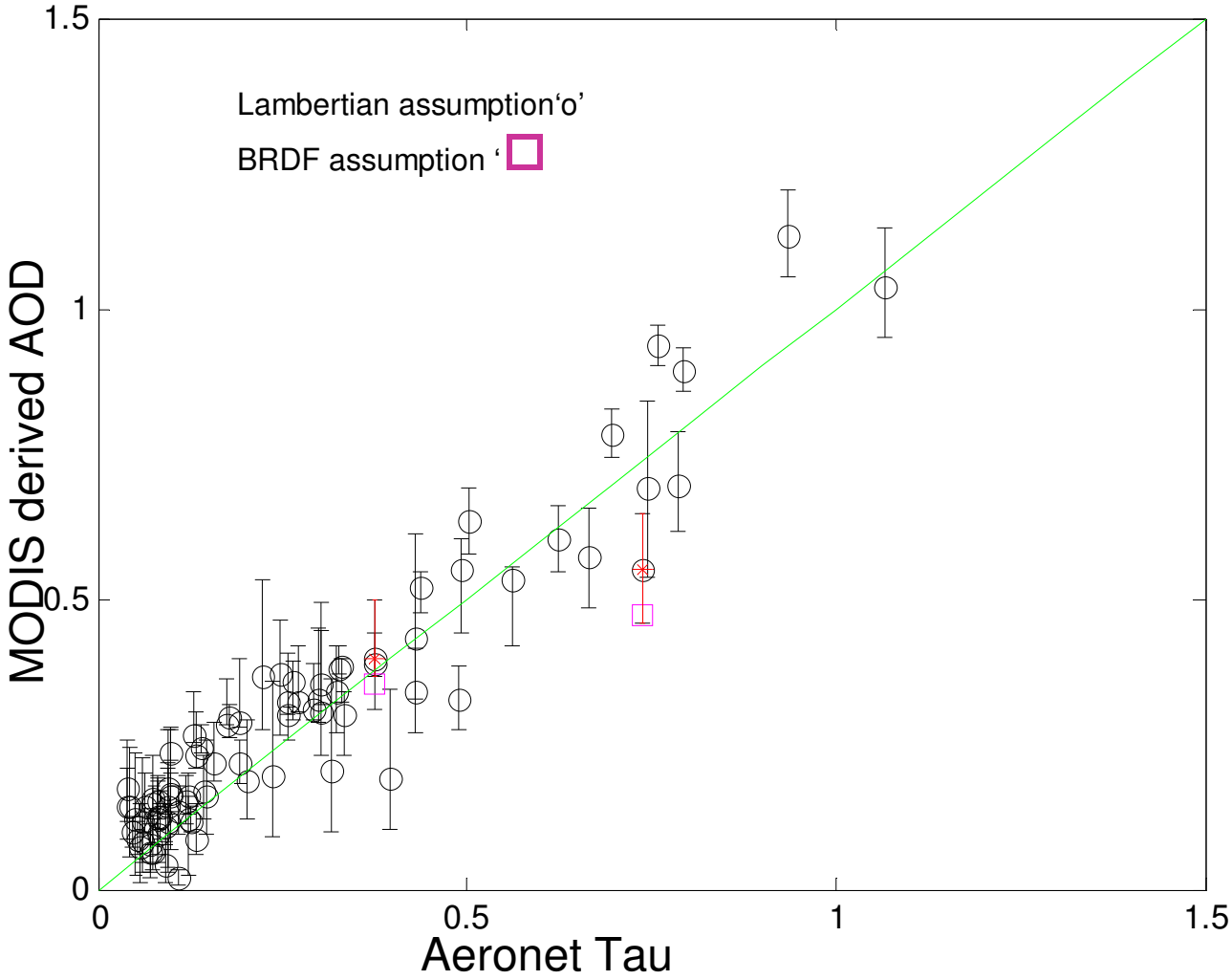
Day1 : 2006-149

Day2 : 2006-152

TOA reflectance assuming Lambertian ground reflectance “o”

BRDF surf reflectance “*”

Assessment of BRDF angle effects compared to uncertainty

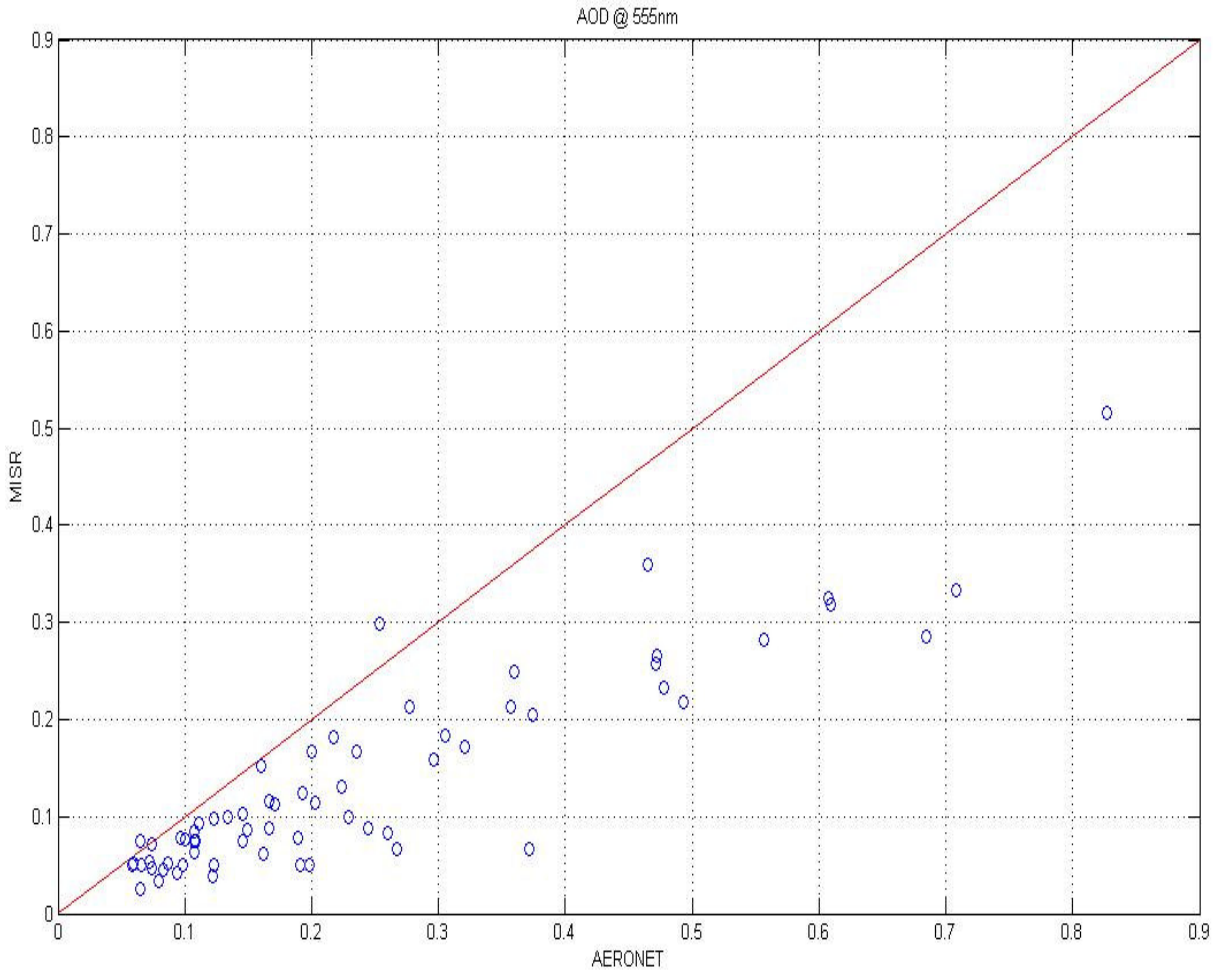


Error due to lambertian assumption is within the order of error due to uncertainty in correlation coefficient

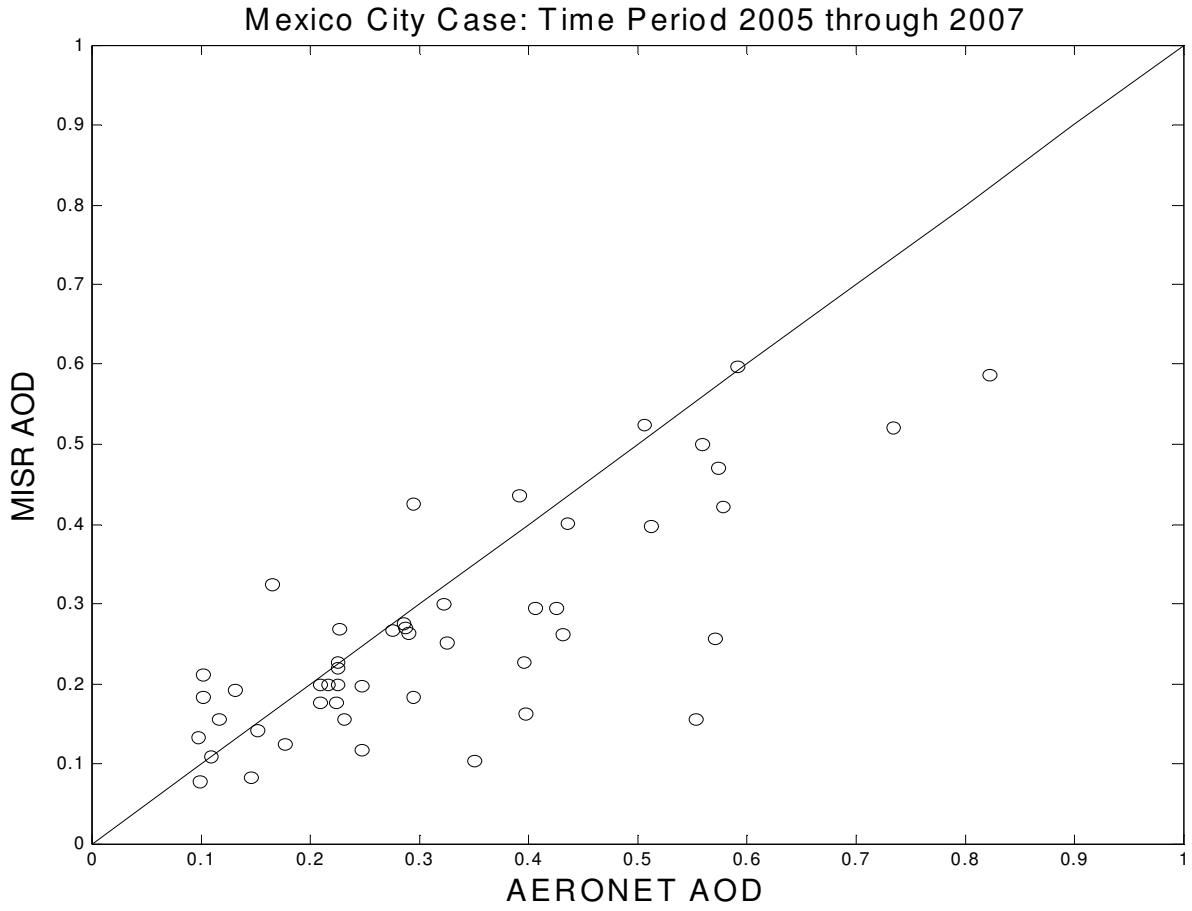
Comparison of MISR-AERONET AOD

- Match up the MISR retrieved AOD product with AERONET derived AOD over NYC areas and show that the MISR retrieved AOD is underestimated (next slide)
- That might be due to an overestimate of the surface by MISR

Comparison of MISR-AERONET AOD at 550nm (NYC data)



Comparison of AOD in Mexico City (MISR-AERONET)

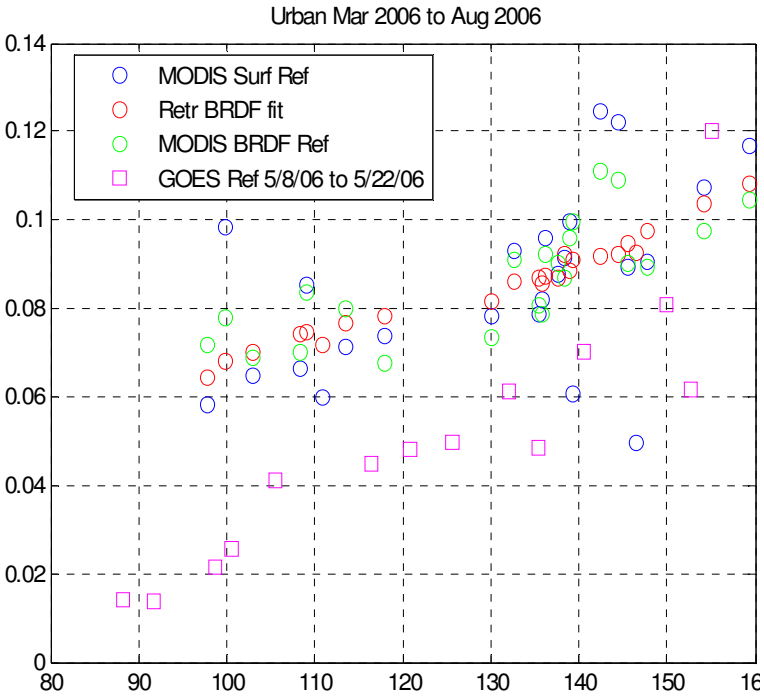


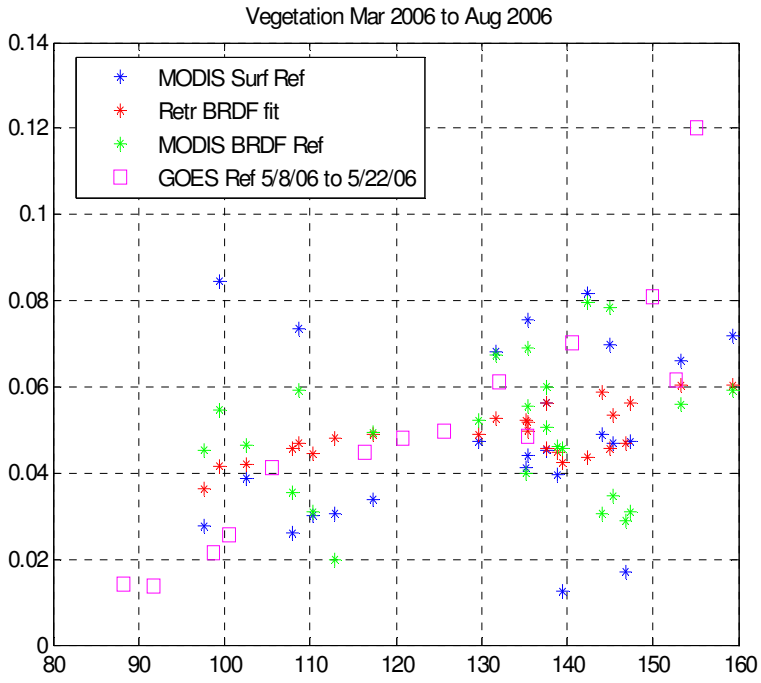
Need to investigate

Current Work

- Further assessment of urban areas around the world
- Improve regional training using distributed aerosol data from MFRSR shadowband radiometer network being established between CCNY and NASA GISS
- Apply surface models data to GOES satellite observations and compare to GASP aerosol and surface retrievals.

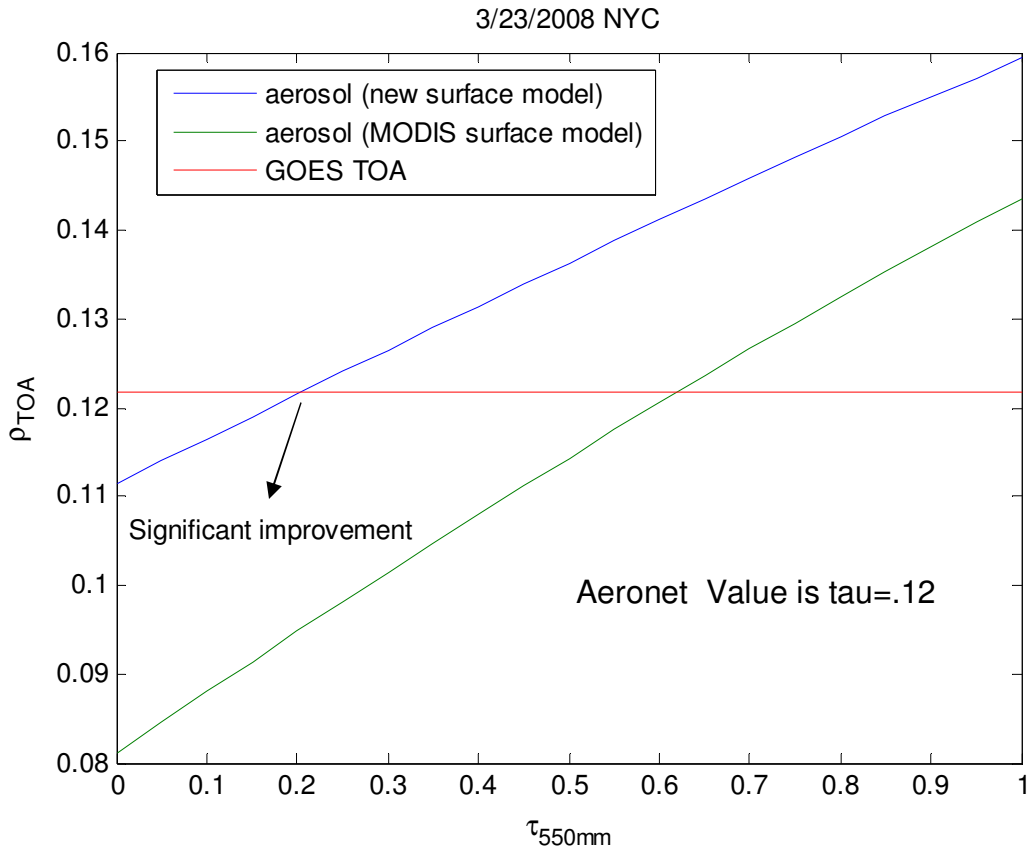
Preliminary Comparisons





Note differences between GOES in urban areas
Need to investigate.

Using modified surface models to retrieve AOD from GOES Data



FTOA reflectance from 6S using operational and regional surface models