Analysis of SGP MFRSR network data: NO_2, water vapor, and absorbing aerosols

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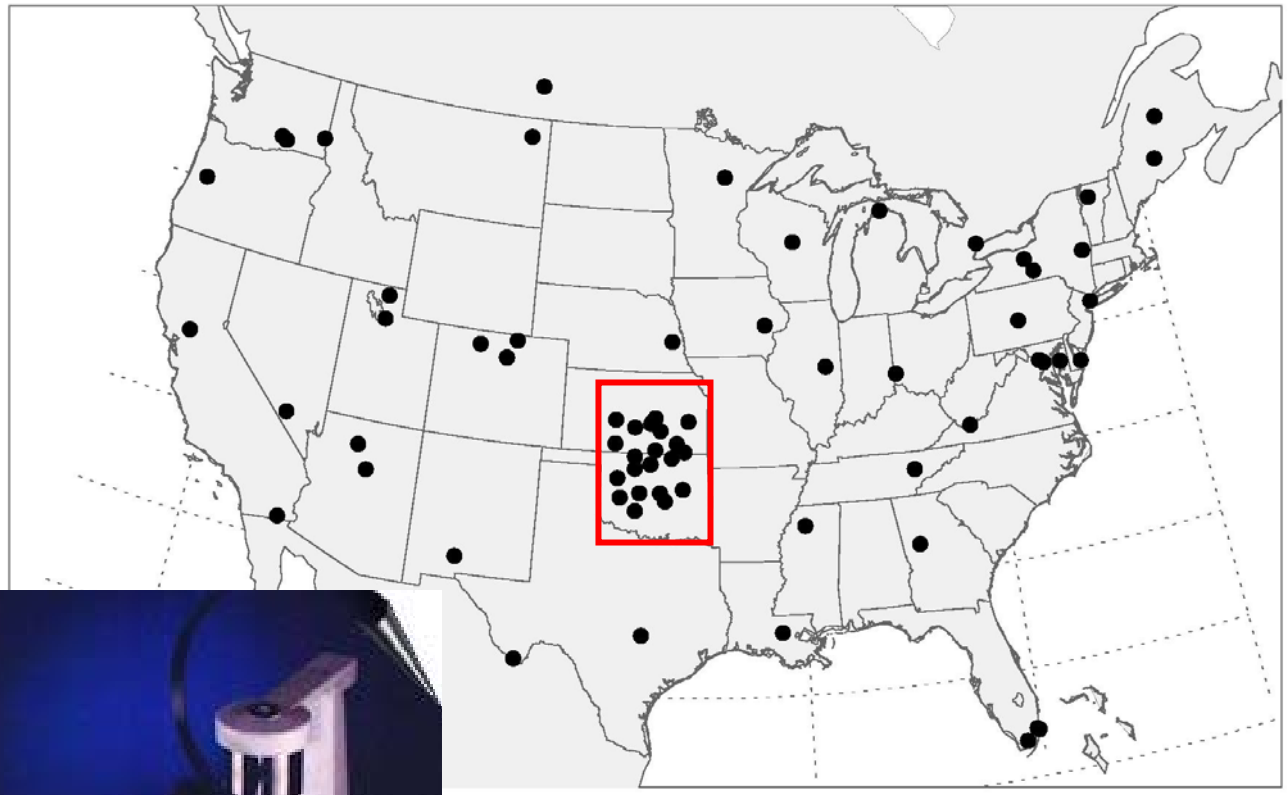
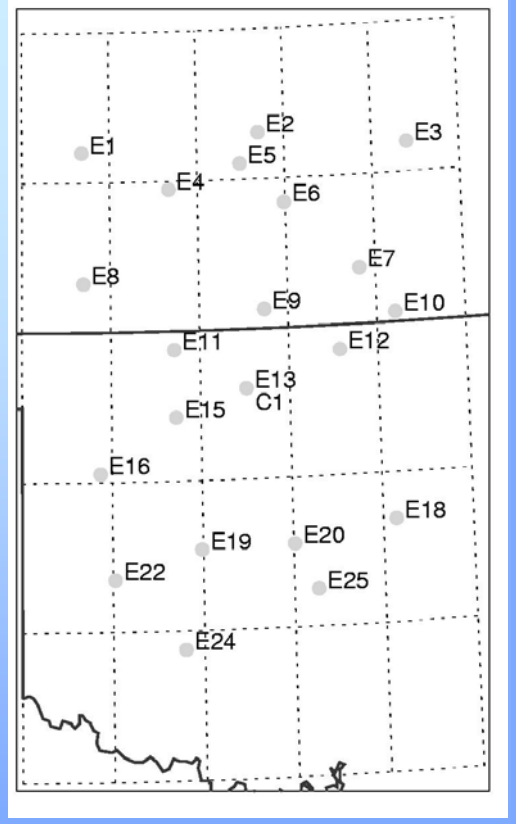
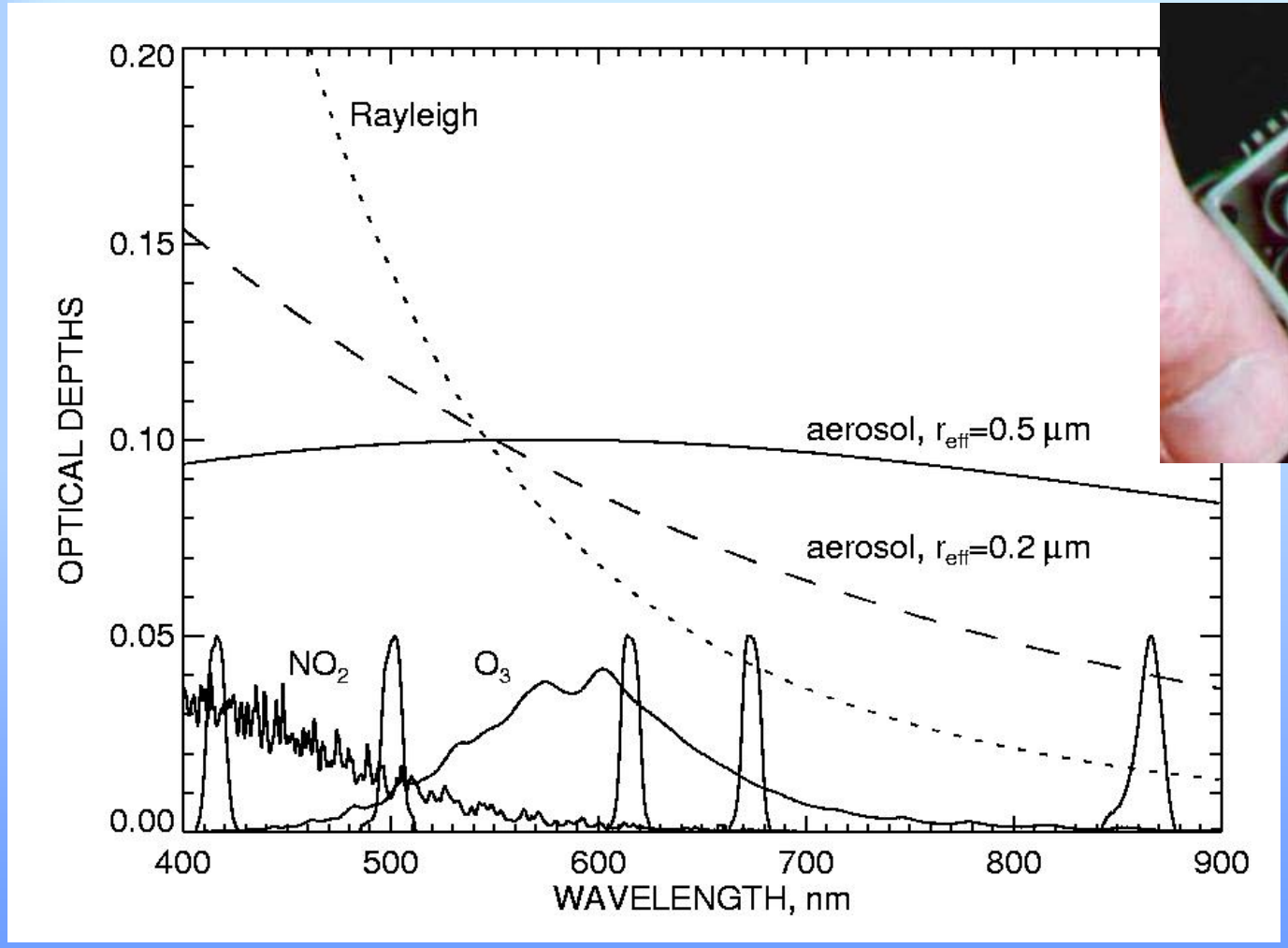
MFRSR networks

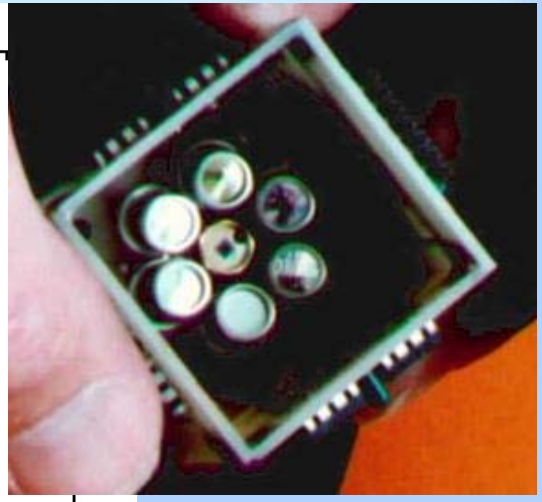




Southern Great Plains Network (DOE ARM)

MFRSR spectral sensitivity





MFRSR channels:
415 nm
500 nm
615 nm
670 nm
870 nm
940 nm (WV)
1550 nm (proposed)

Retrieval algorithm

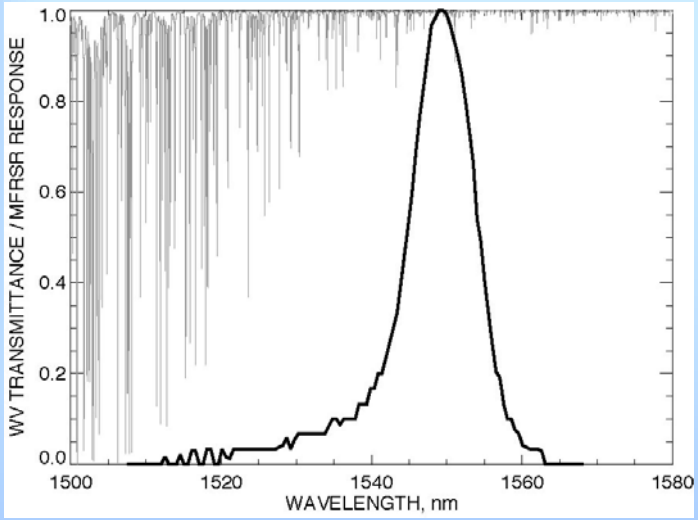
Aerosol size model: bimodal Gamma

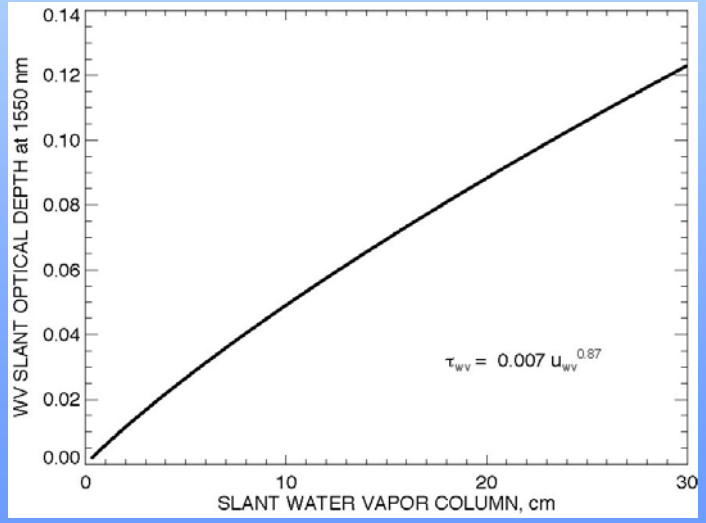
V_{eff}=0.2 both modes

Retrieval parameters:

- Fine mode AOT and R_{eff}
- Coarse mode AOT (fixed R_{eff}=1.5 μm)
- O_3 column
- NO_2 column should be taken from other measurements (RSS, SCIAMACHY).

Proposed 1550 nm channel



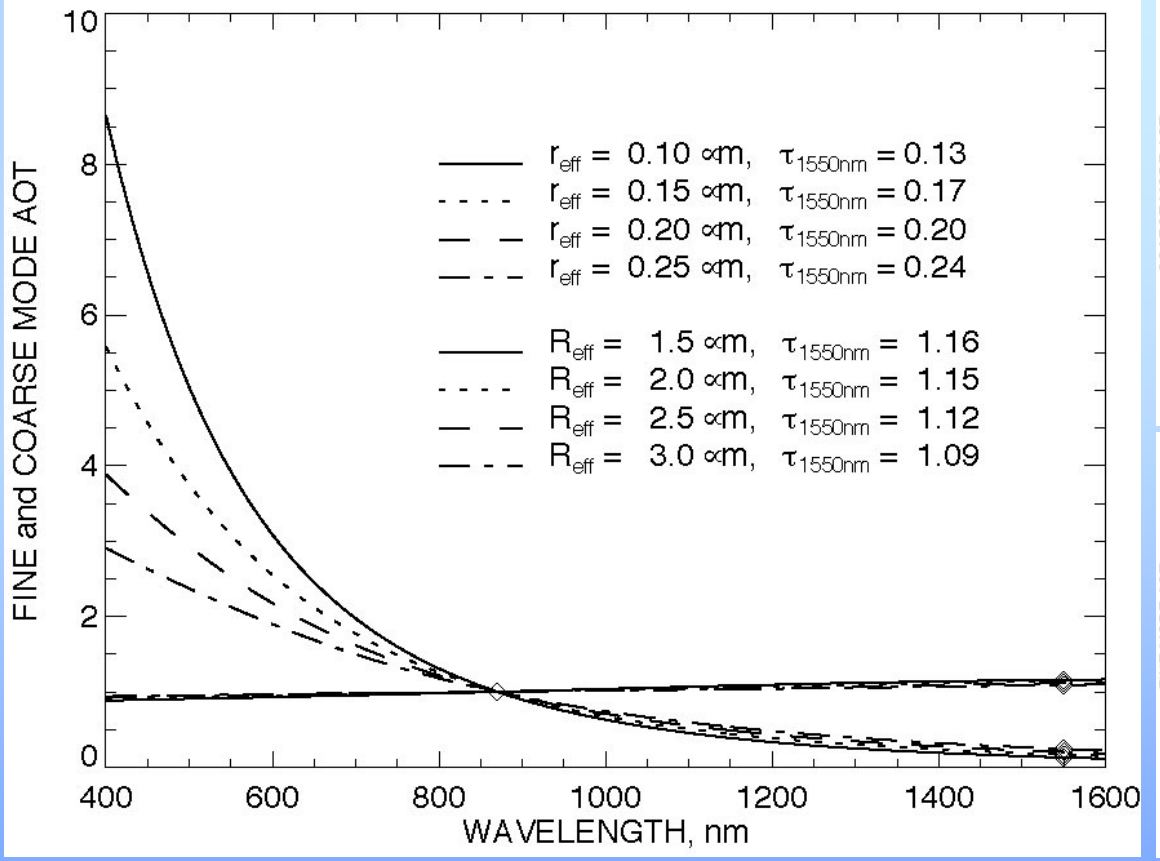


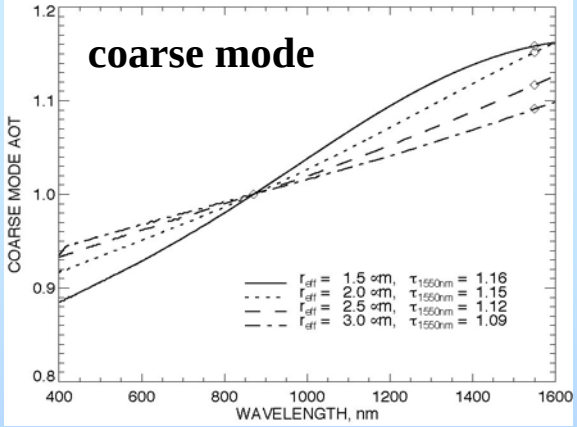
- Proposed 1550 nm channel is weakly affected by WV absorption band (top plot).
- WV amount can be estimated from 940 nm channel with 10% accuracy.
- The growth curve (bottom) obtained by integrating MFRSR spectral response function with WV absorption spectra from HITRAN 2004 implies that

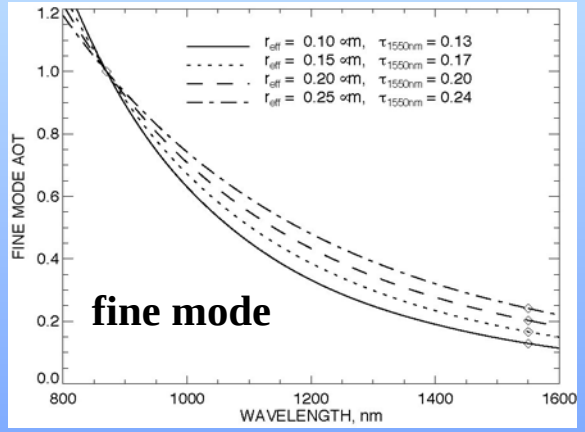
$$\Delta\tau = 0.005\ \Delta u_{wv}$$

i.e. error in AOT due to uncertainty in WV amount is smaller than measurement accuracy.

Spectral AOT in 415-1550 nm



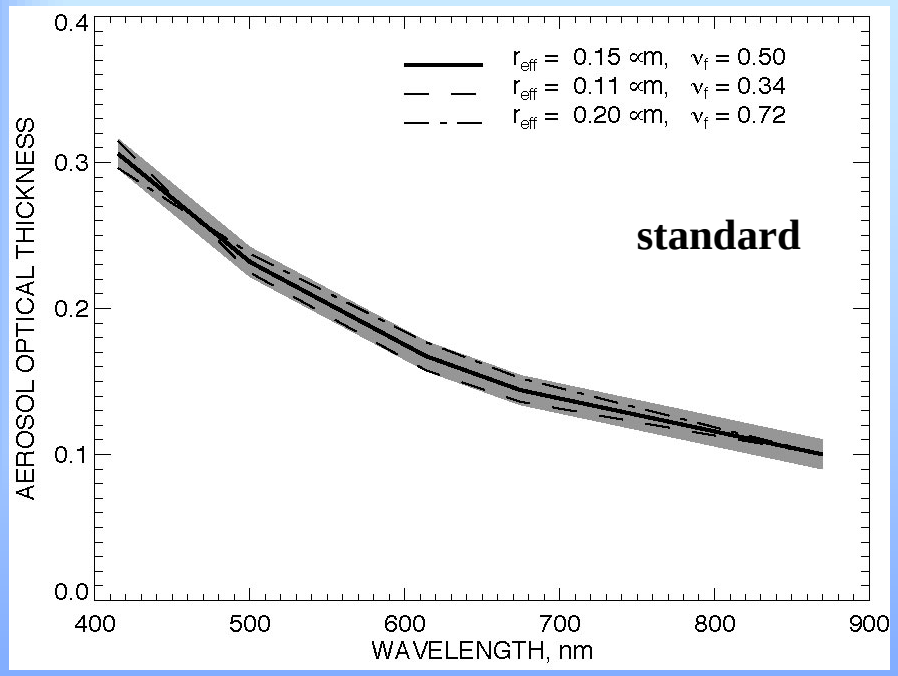


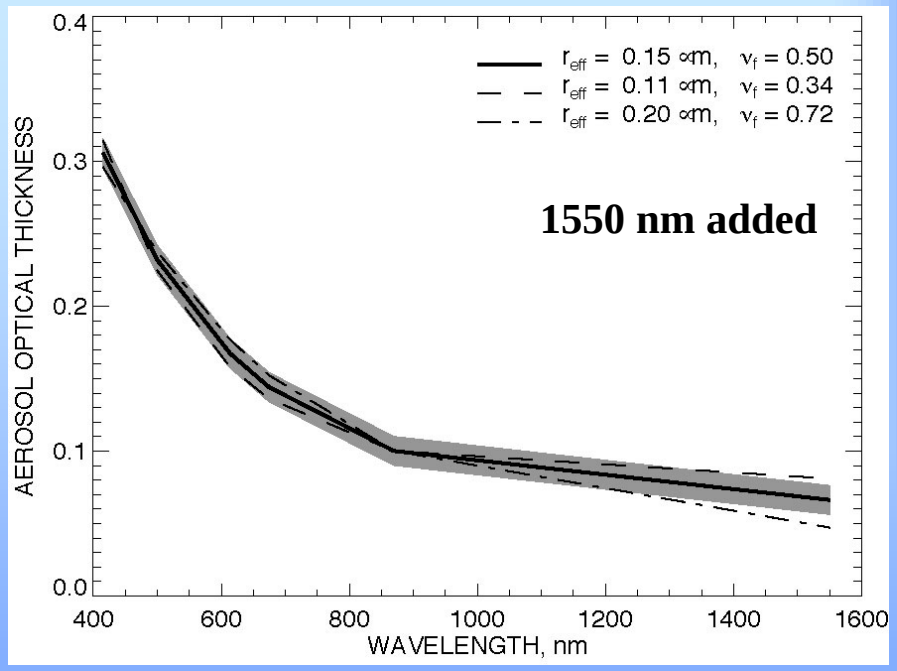


Spectral AOT in 870 - 1600 nm region is more sensitive to fine mode fraction, than to fine and coarse particle size.

Improving aerosol retrievals

1550 nm channel allows to separate between aerosol models that are indistinguishable within the standard MFRSR range and accuracy.

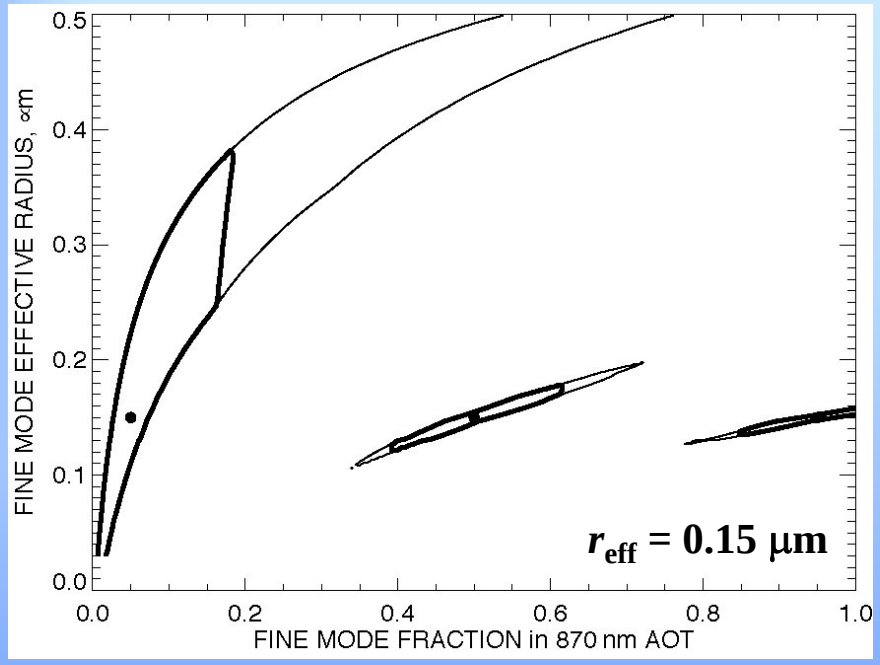


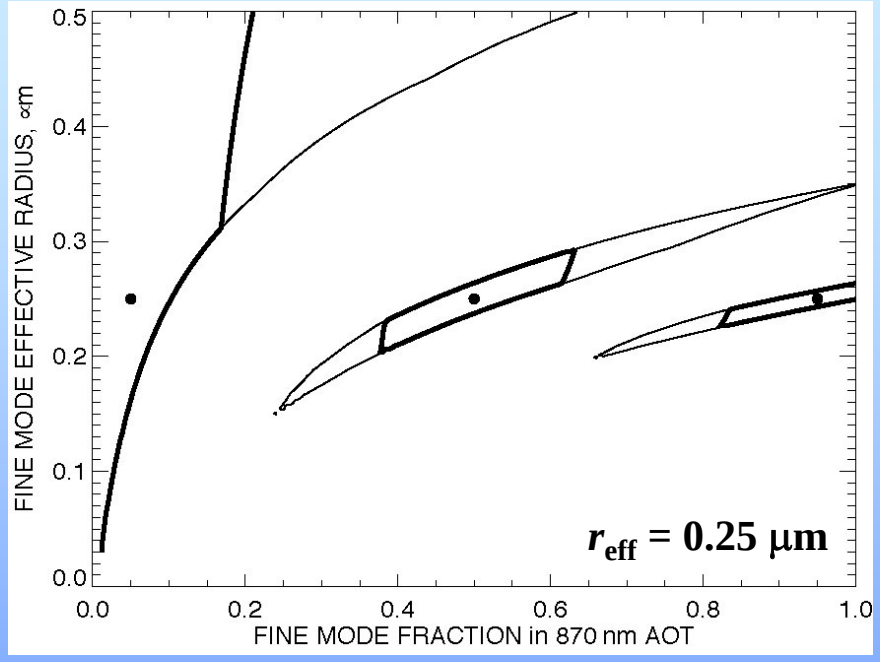


The model spectral AOT curve (solid) derived using Mie theory for bimodal gamma size distribution with fine r_{eff} = 0.15 μm, coarse r_{eff} = 1.5 μm, and 50% fine mode fraction in 870 nm AOT (set to 0.1). AOTs from two competitive aerosol models fitting within 0.01 error margin (grey area) in 415 - 870 nm spectral range are shown by dashed and dash-dotted lines.

Improving aerosol retrievals II

1550 nm AOT imposes additional constraints on fine mode fraction.

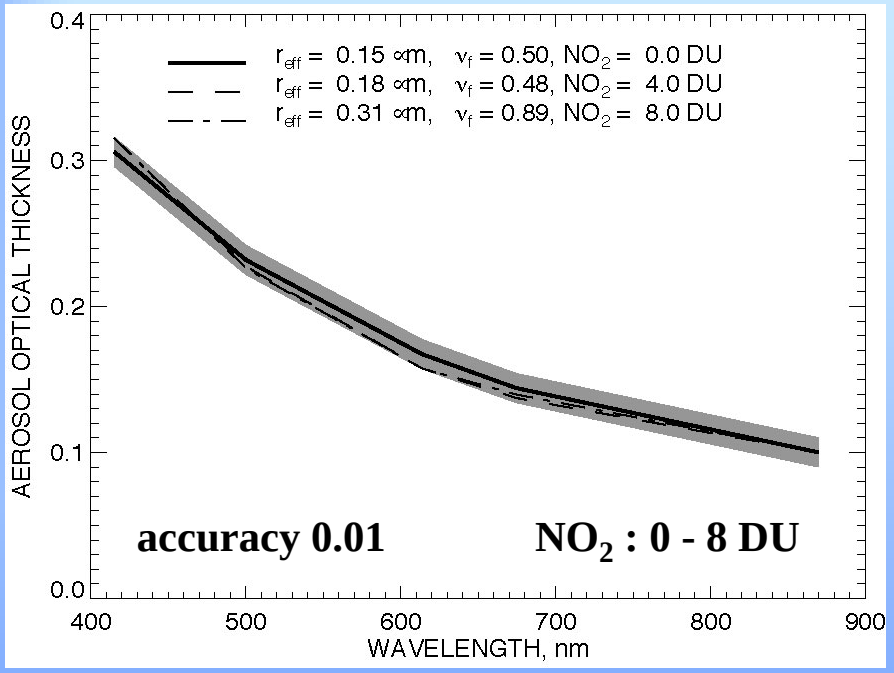


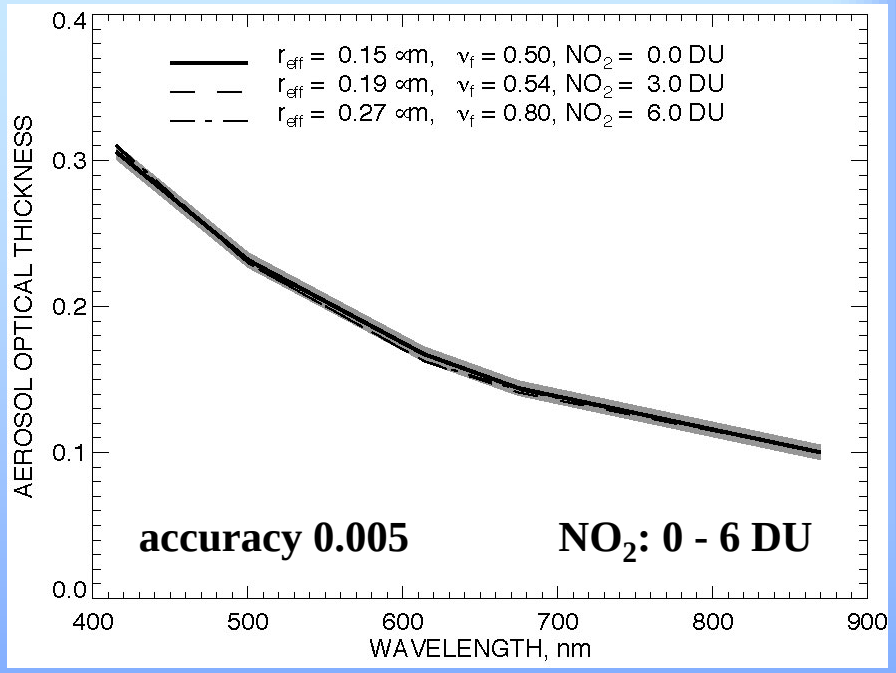


Sensitivity of MFRSR retrievals of fine r_{eff} and fine mode fraction in 870 nm AOT ν_f to an error of 0.01 in measured AOT. Three test models (depicted by bullets) with ν_f = 0.05, 0.5, 0.95 are shown in each plot. The lines show the sets of aerosol models fit to the test ones within 0.01 in AOT. Thin lines correspond to standard MFRSR wavelengths, thick - to these with 1550 nm channel added.

Aerosol - NO_2 trade-offs

Spectral optical thickness in MFRSR range can be interpreted using different aerosol models and absorption of 0 - 8 DU of NO_2 within 0.01 accuracy.





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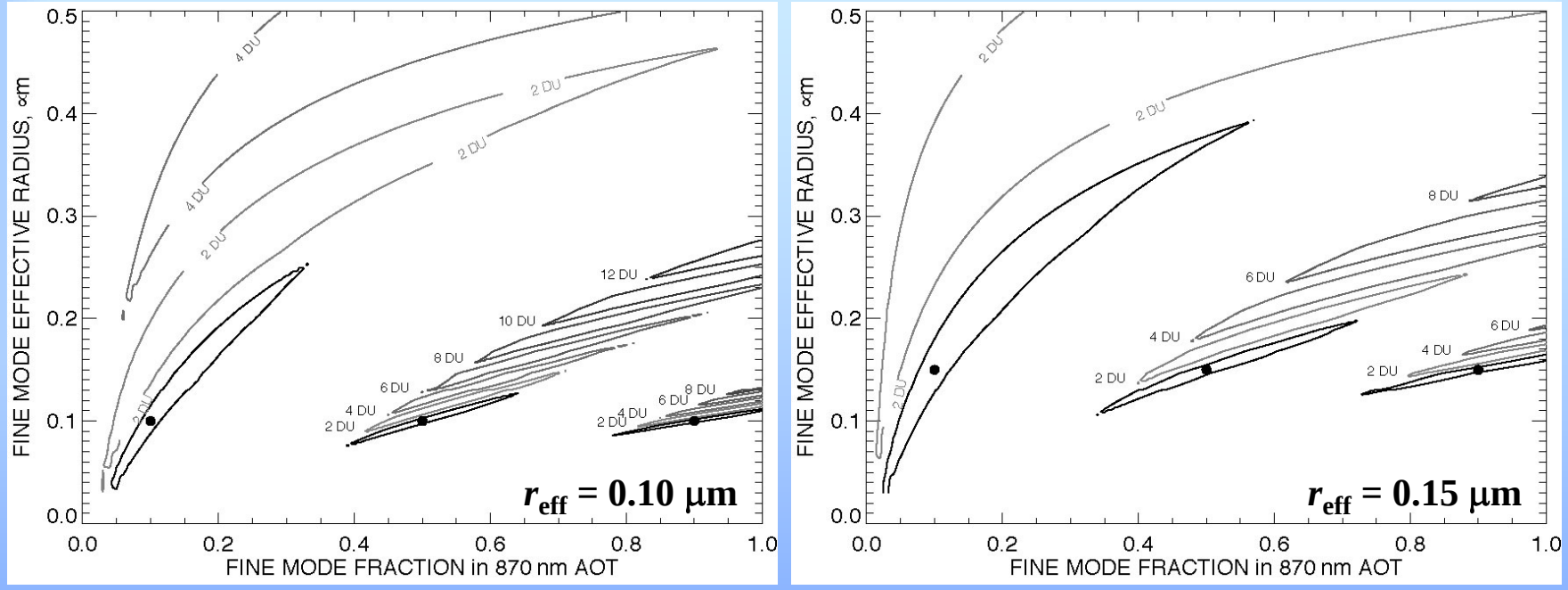
Aerosol - NO_2 trade-offs

Dependence on aerosol parameters



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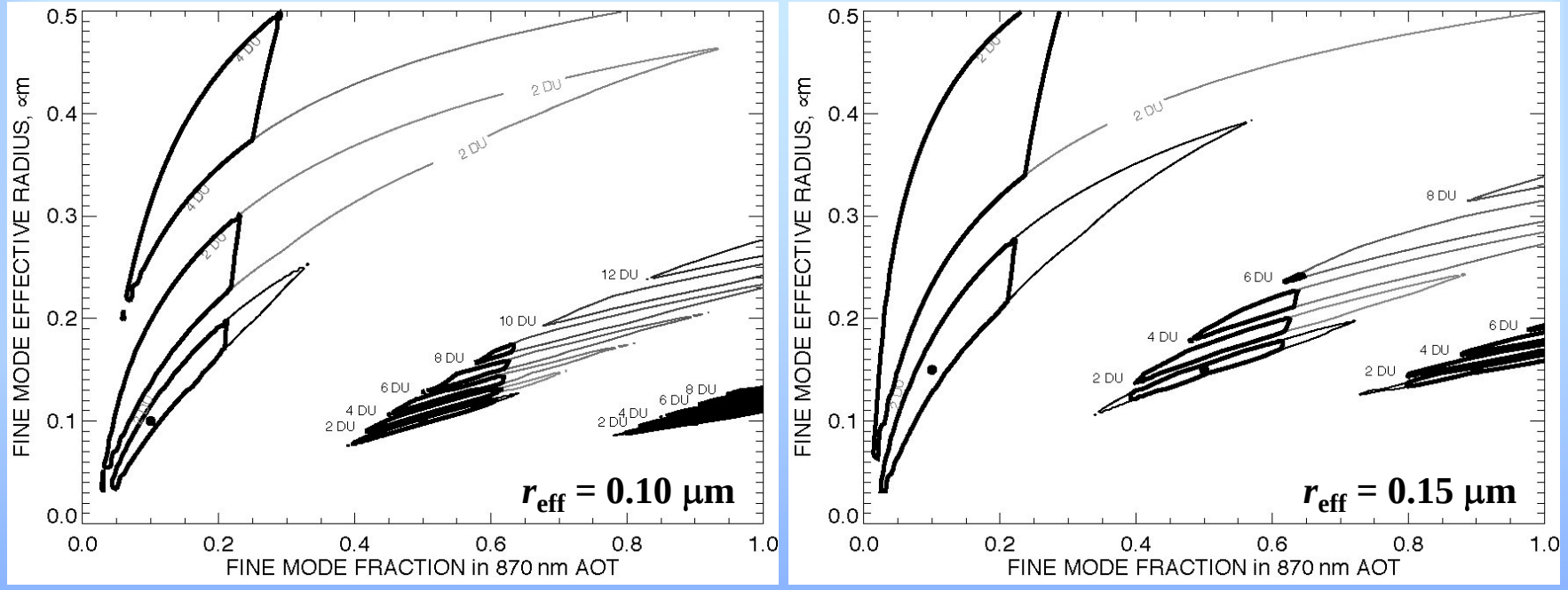
Aerosol - NO_2 trade-offs

Effect of additional 1550 nm channel



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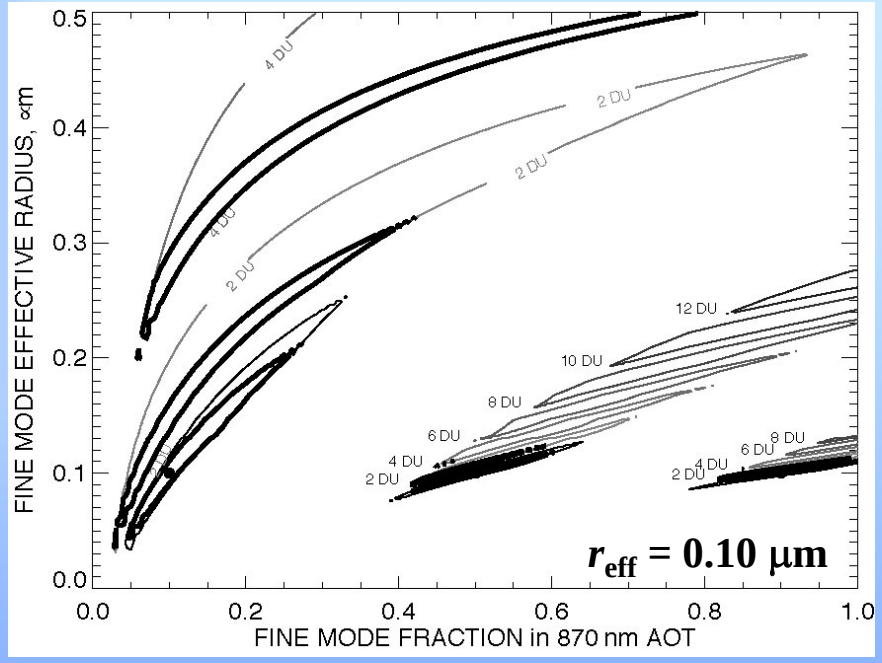
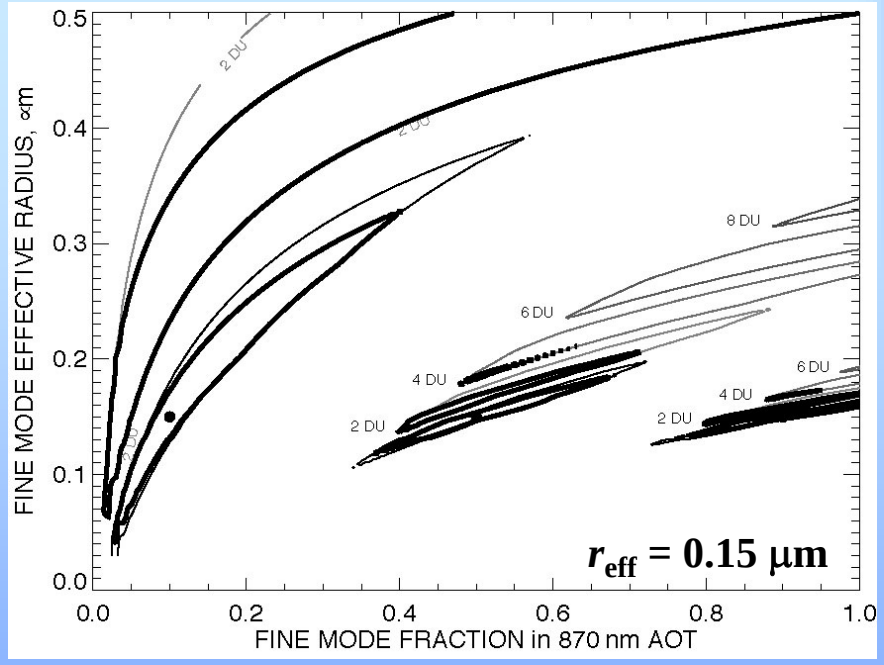
Aerosol - NO_2 trade-offs

Effect of additional 380 nm channel

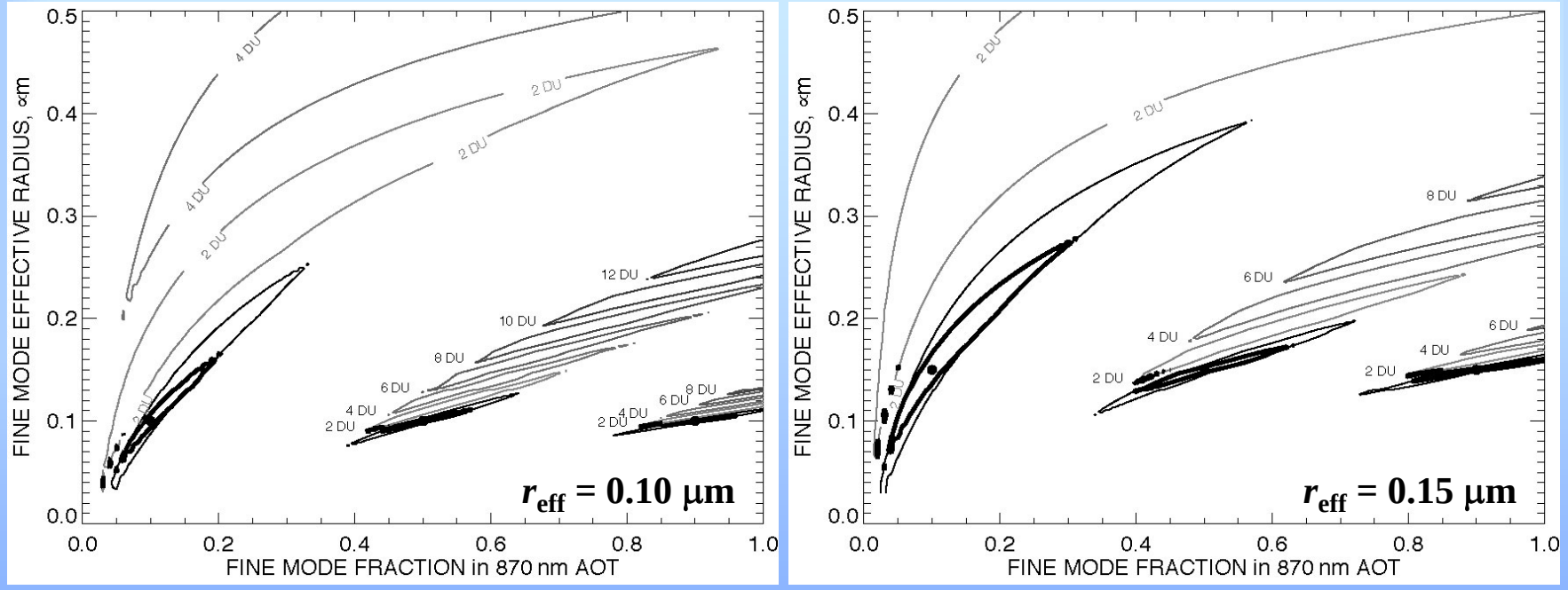




Sensitivity of MFRSR retrievals of fine r_{eff} and fine mode fraction in 870 nm AOT ν_f to an error of 0.01 in measured AOT. Three test models (depicted by bullets) with ν_f = 0.05, 0.5, 0.95 are shown in each plot. The lines show the sets of aerosol models fit to the test ones within 0.01 in AOT for a range of assumed NO_2 column amounts: 0, 2, 4, …, 12 DU. Thin lines correspond to standard MFRSR wavelengths, thick - to these with 380 nm channel added.

Aerosol - NO_2 trade-offs

Effect of additional 340 and 380 nm channels



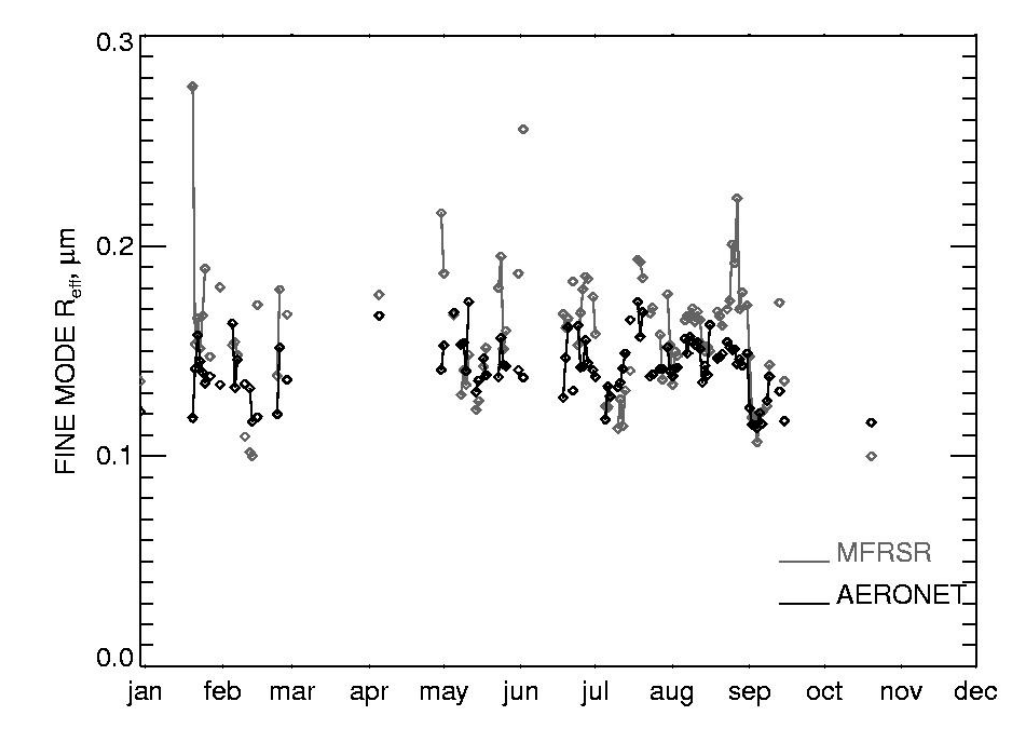
Sensitivity of MFRSR retrievals of fine r_{eff} and fine mode fraction in 870 nm AOT ν_f to an error of 0.01 in measured AOT. Three test models (depicted by bullets) with ν_f = 0.05, 0.5, 0.95 are shown in each plot. The lines show the sets of aerosol models fit to the test ones within 0.01 in AOT for a range of assumed NO_2 column amounts: 0, 2, 4, …, 12 DU. Thin lines correspond to standard MFRSR wavelengths, thick - to these with 340 and 380 nm channels added.

Constrained retrievals

- MFRSR measurements cannot provide an estimate of NO_2 column amounts with a reasonable accuracy (less than 1 DU).

- NO_2 column amounts should be taken from other measurements (Brewer, RSS, SCIAMACHY) or from climatology.

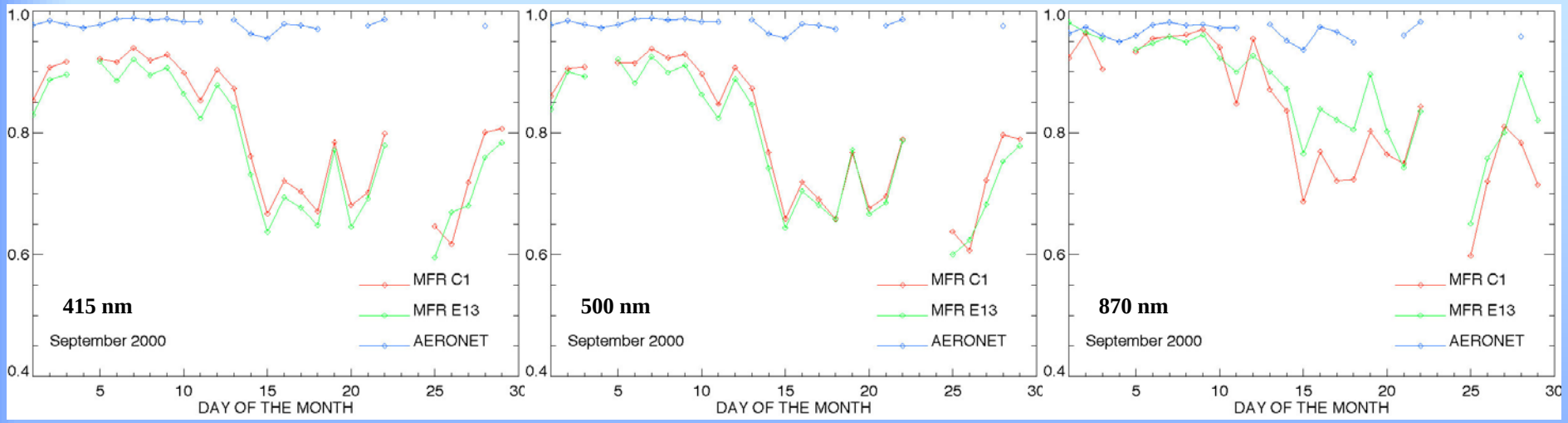
- Retrievals of fine mode r_{eff} assuming zero NO_2 are in agreement with AERONET almucantar scan values.



Time series of daily mean fine mode r_{eff} retrieved from E13 MFRSR (assuming zero NO_2) compared with values from AERONET almucantar scan analysis for the same days in 2000.

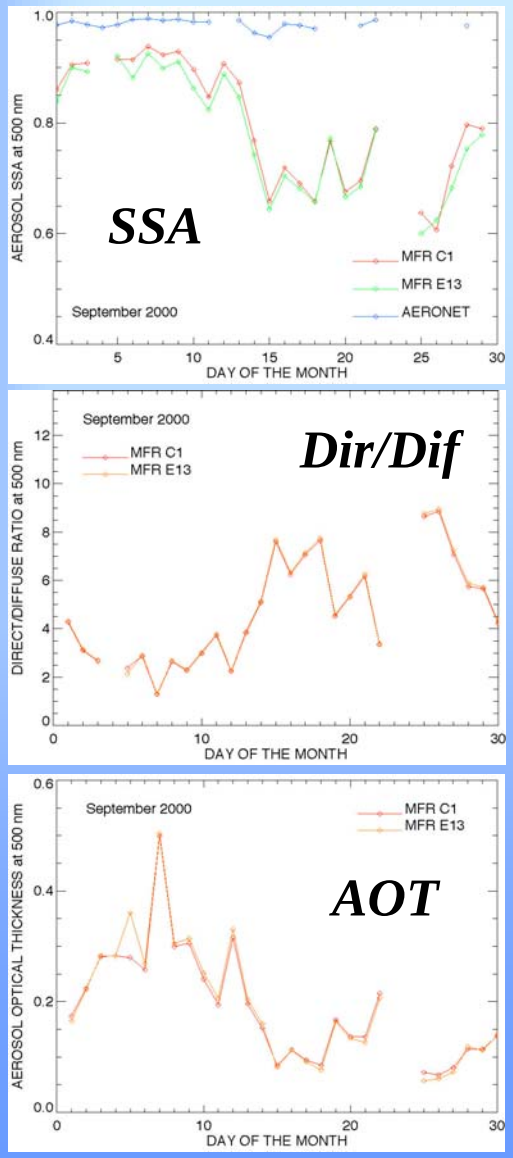
Aerosol Single Scattering Albedo

The retrieved aerosol parameters are used together with direct/diffuse ratios to derive aerosol absorption properties: imaginary part of the refractive index and aerosol single scattering albedo (SSA).



Time series of daily mean values of aerosol SSA retrieved from measurements by SGP Central Facility MFRSRs (C1, E13) made in September 2000 (preliminary results). AERONET's values (almucantar scan analysis) are shown for comparison. Constrained (zero NO2) MFRSR analysis algorithm had been used for these plots.

Problems in SSA retrievals



- MFRSR SSA values are substantially smaller than those from AERONET analysis.
- The SSA values are particularly low when AOT and <u>fine mode fraction are small</u>, and diffuse flux is small compared to the direct beam.
- Testing different aerosol models do not significantly improve the result.
- Possible explanation may be an error in separation between direct and diffuse irradiances by MFRSR shadowbanding process (increasing diffuse and decreasing direct flux by the same amount leads to higher SSA). Direct modeling of shadowbanding is needed.
- SSA in 870 nm channel appears to be higher than in 670 nm channel, which may be an indication of spectral leaks in the first four channels.

SSA: Empirical correction

To correct for an error in separation between direct and diffuse irradiances we adjust Direct/Diffuse ratios:

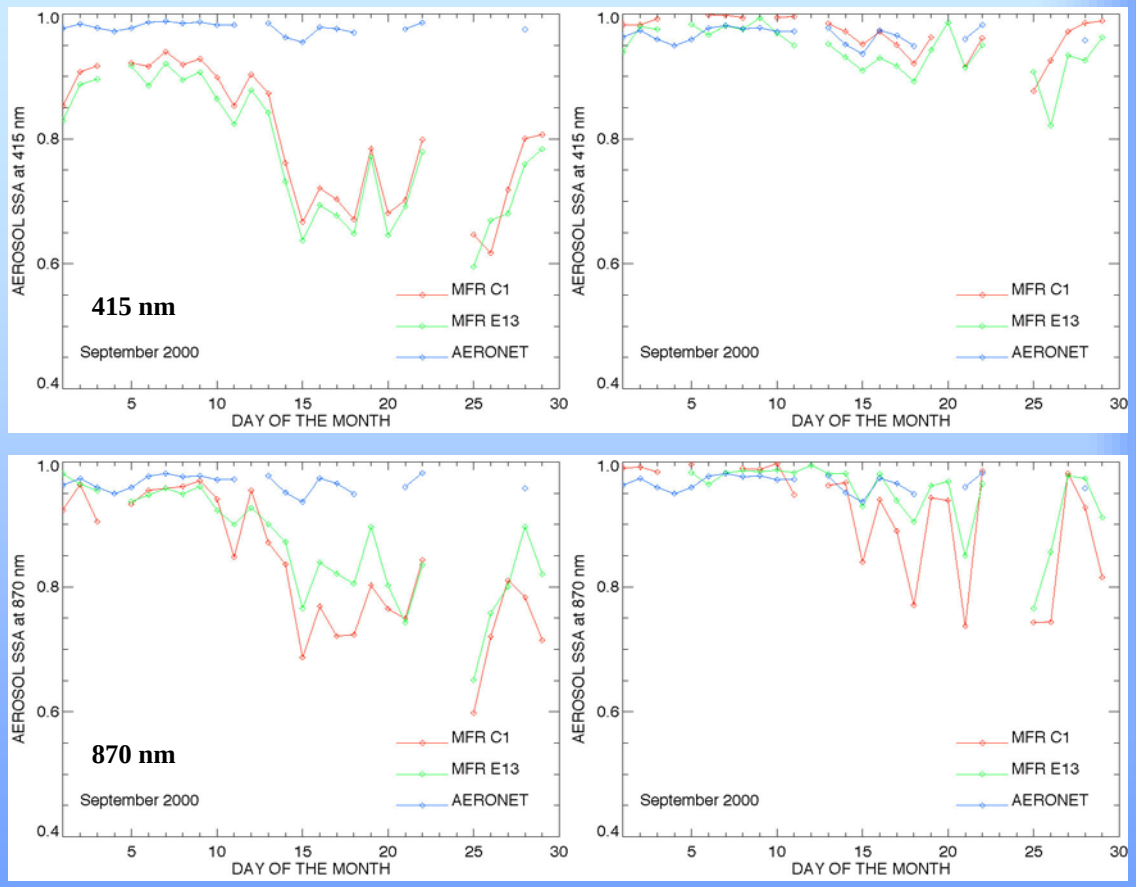
$$D = \frac{I_{dir}}{I_{dif}} \rightarrow D' = \frac{I_{dir} - \delta I_{dif} / \cos(\theta)}{(1+\delta) I_{dif}}$$

where

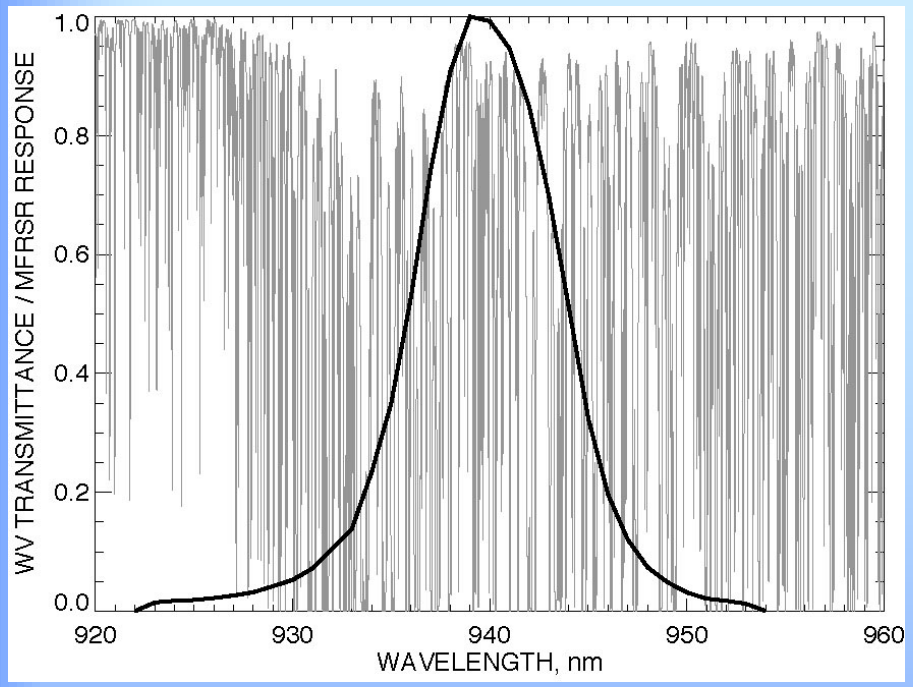
$$\delta = 0.2\left(1 - \frac{\tau_{fine}(870nm)}{\tau_{total}(870nm)}\right)$$

reflects effective size of aerosol particles.

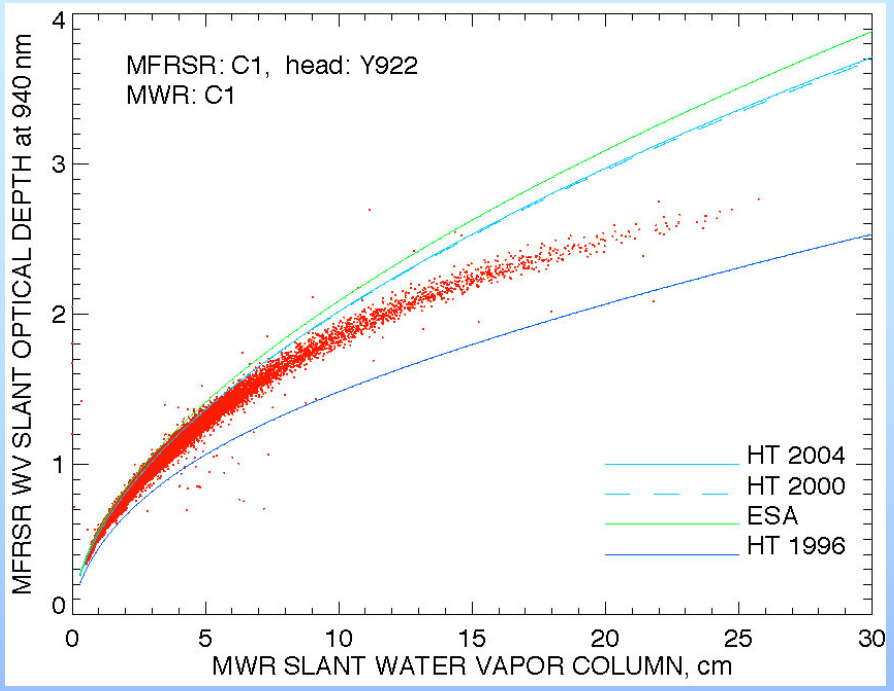
Original Corrected



Precipitable Water Vapor



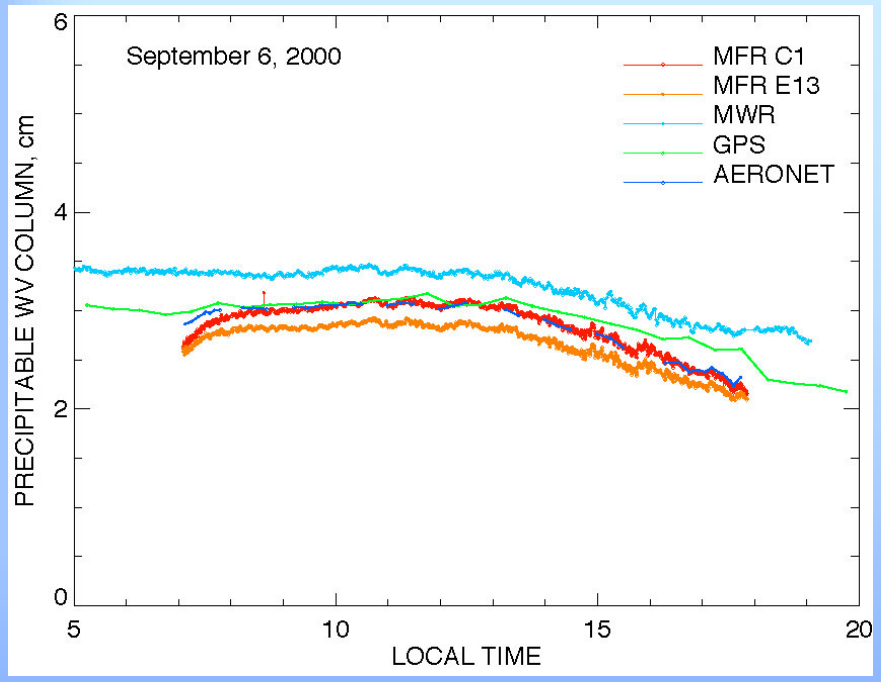
Spectral transmittance of Water Vapor (1 cm column) computed using HITRAN 2004 database (grey), and the MFRSR (head 922) 940 nm channel spectral response function normalized to unity at the maximum (black).

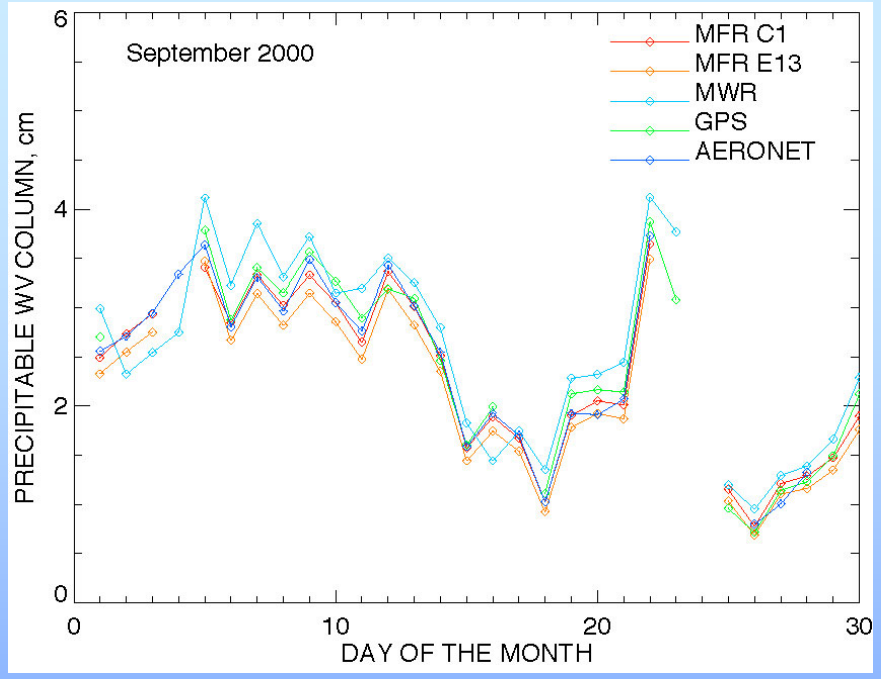


Experimental growth curve (MFRSR-derived slant optical thickness (with AOT subtracted) v.s. MWR-derived slant WV column, SGP CF, 2000). Theoretical growth curves computed using various spectral databases are shown by solid lines.

WV retrievals from MFRSR

Results for September 2000 and comparison with MWR, GPS and AERONET retrievals

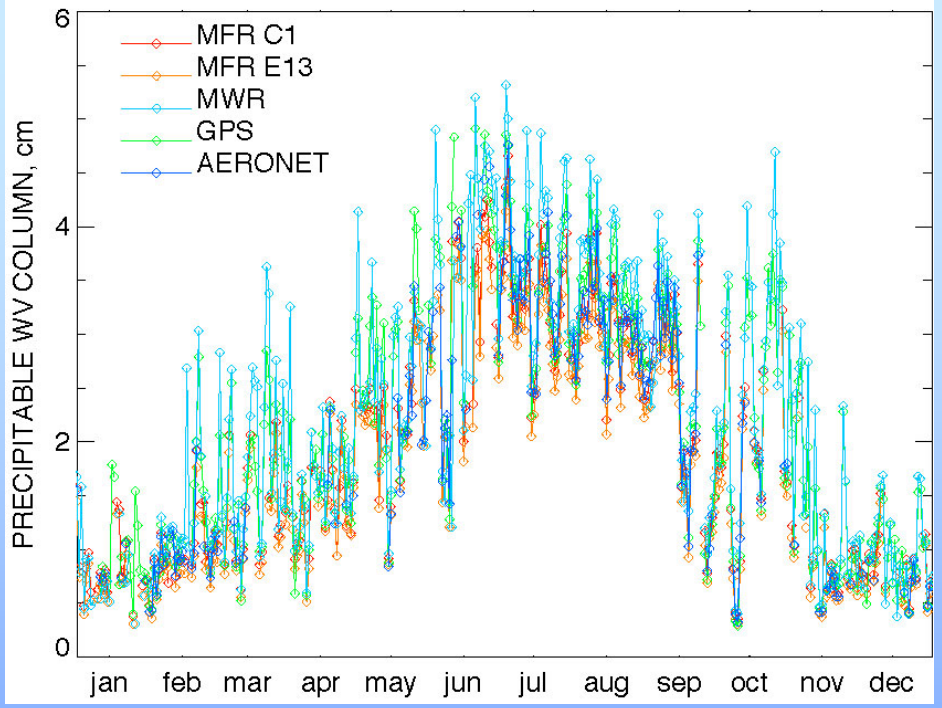




Retrievals of column WV for September 2000 using data from two MFRSRs at SGP's Central Facility (C1 and E13). HITRAN 2004 spectral database has been used. The systematic difference between C1 and E13 values is likely due to uncertainties in 940 nm channel spectral responses. C1 data appears to be almost indistinguishable from AERONET retrievals and in better agreement with GPS than with MWR, which yields systematically higher values.

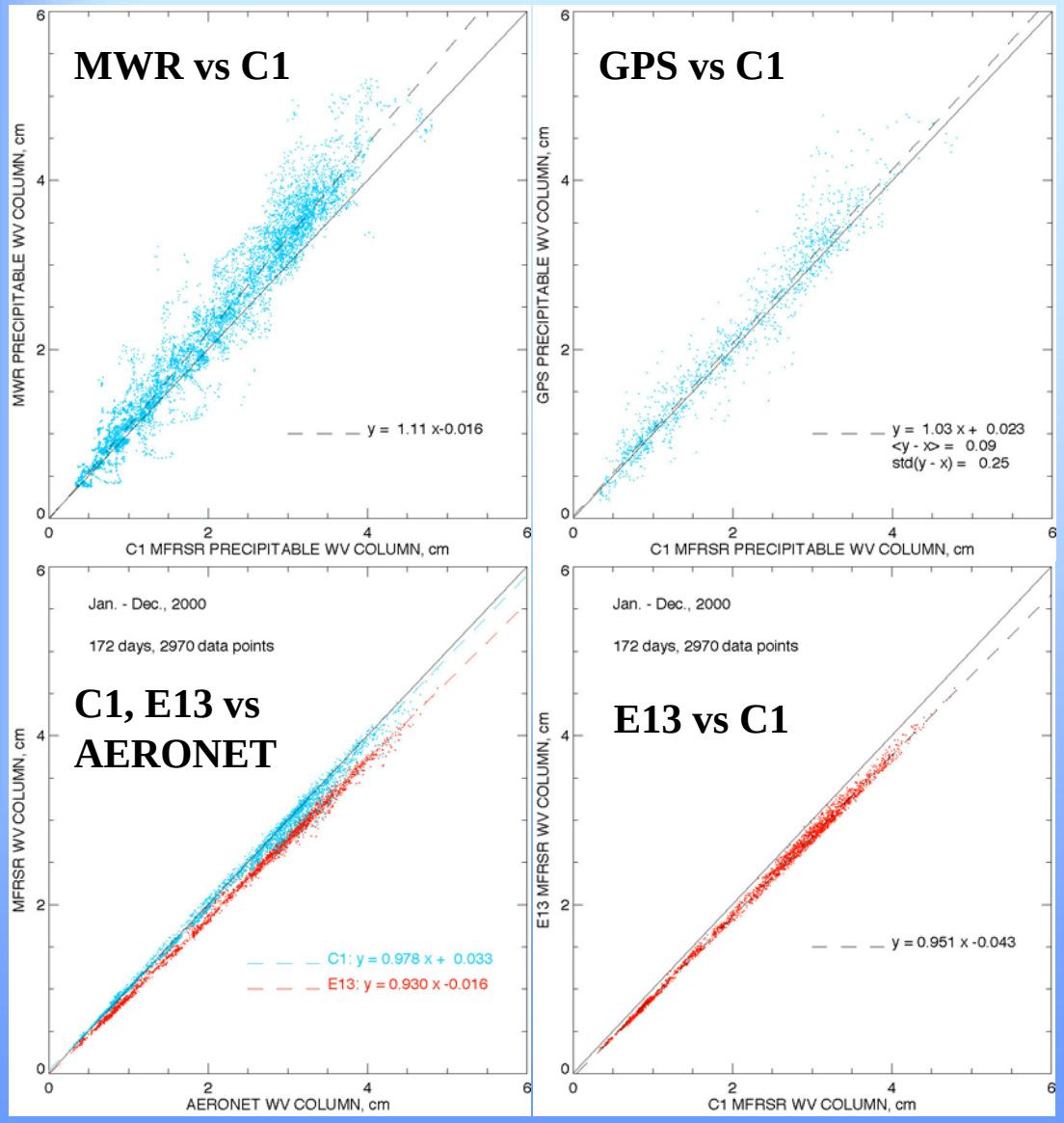
WV retrievals from MFRSR

Results for the year 2000 and comparison with MWR, GPS and AERONET retrievals



Time series of daily mean MFRSR-derived WV column values from SGP Central Facility (C1 and E13) compared with MWR, GPS and AERONET retrievals for the whole year 2000.

MFRSR v.s. other instruments

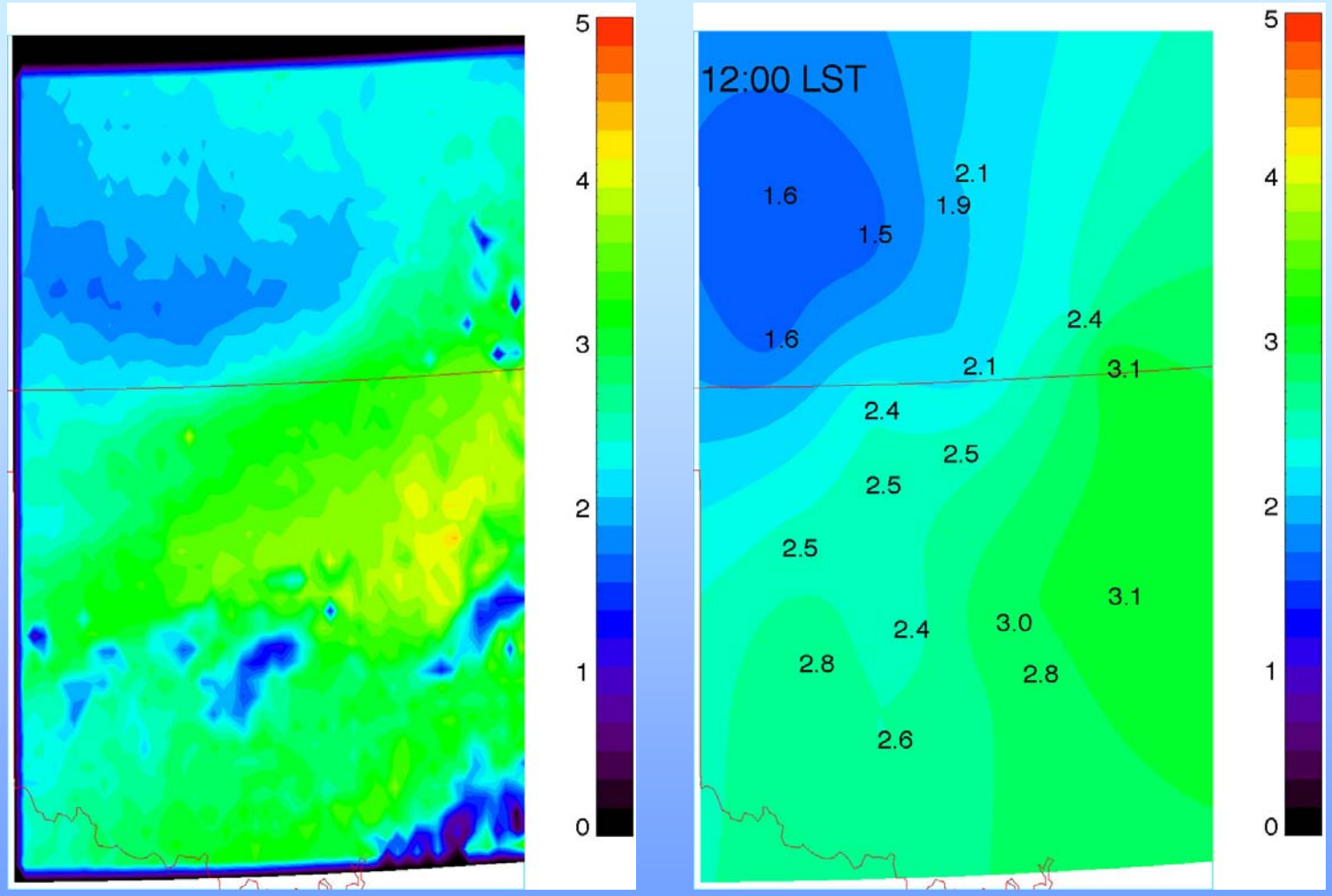


Comparisons between column WV retrievals from MFRSRs (C1 and E13) and from co-located
MWR (11% bias),
WPDN GPS station (3% bias),
AERONET (2 & 7% bias).

E13 values are 5% lower than C1. This may be improved by updating spectral response of MFRSR's 940 nm channel.

C1 MWR values for the year 2000 are 6 - 9 % higher than GPS.

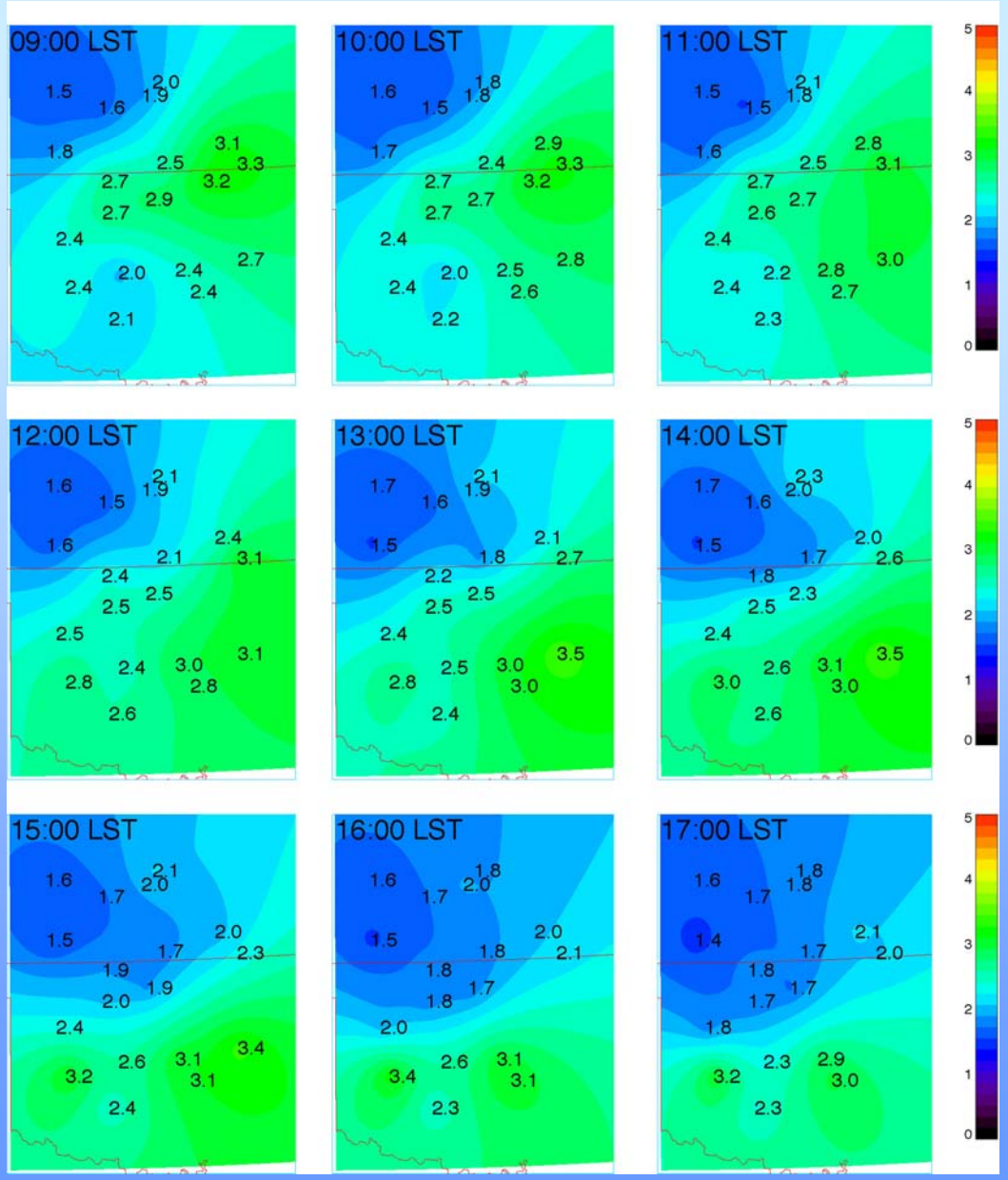
Spatial structure of WV field

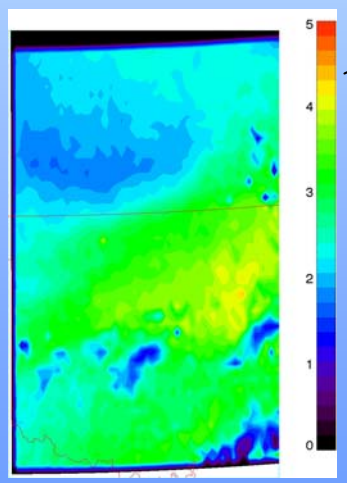


MODIS Level 2 WV product over SGP site (left) and spatial structure obtained by interpolation of MFRSR network data (left) from September 14, 2000.

Evolution of WV field

Variation of WV spatial structure during the day of September 14, 2000. The images are obtained by interpolation of MFRSR network data.





MODIS overpass

Conclusions

- ***MFRSR measurements allow for separation between fine and coarse aerosol modes, estimation of fine mode effective radius, and O_2 column retrievals. NO_2 absorption is the main source of uncertainty in aerosol size retrievals. NO_2 columns cannot be effectively estimated from MFRSR data and should be taken from correlative high spectral-resolution measurements or climatology.***

- ***Retrievals of aerosol Single Scattering Albedo show lower values compared to AERONET, that may indicate error in separation between direct and diffuse irradiances by MFRSR.***

- ***Precipitable Water Vapor retrievals from MFRSR data are in good agreement with correlative MWR, GPS, and AERONET values. Spatial structure of WV field derived from SGP MFRSR network agrees with MODIS product and may extend it beyond the time of satellite overpass.***