## The combined use of MODIS, CALIPSO and OMI level 2 aerosol products for calculating direct aerosol radiative effects

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# Outline

- → Goal: To devise a new, multi-instrument methodology to derive vertical structure of △F<sub>aerosol</sub>(z)
- Methodology for combining CALIOP, OMI and MODIS data
- Checking consistency of input data
  - Comparison of MODIS and CALIOP-derived AOD
  - → Differences in CALIOP V2 and V2.93 (V3 pre-release)
- Inversion methodology & usefulness of lidar backscatter for constraining aerosol radiative properties
- Sensitivity study using synthesized data
- Application to actual data from August 2007
- Conclusions



Motivation: Observation- and model-based estimates of direct aerosol radiatve forcing published in IPCC diverge



Goal: To use A-Train aerosol obs to constrain aerosol radiative properties to calculate  $\Delta F_{aerosol}(z)$ 

## Constraints/Input:

- MODIS AOD (7/2  $\lambda$ ) +  $\delta$ AOD - OMI AAOD (388 nm) +  $\delta$ AAOD
  - CALIPSO ext (532, 1064 nm) +  $\delta$ ext
  - CALIPSO back (532 , 1064 nm) +

## Issues to consider

Differences in data quality land/oceanImpact of assumptions,

e.g. refr. index ( $\lambda$ ),

restriction to MODIS modes



## Aerosol Optical Depth comparisons (CALIOP V2)

- Four months of data: January, April, July and October 2007
- Use CALIPSO 40km-avg. aerosol extinction profiles, and 5km aerosol and cloud layer products
- Find all (up to 4) instantaneously collocated, MODIS MYD04\_L2 (10x10km) aerosol retrievals traversed by 40km CALIPSO track
- → Apply three CALIPSO profile quality criteria:
  - 1. Alt\_top\_aerosol > Alt\_top\_cloud
  - 2. EQC532\_flag = 0 or 1
  - 3. Integrated attenuated backscatter @ 532 <= 0.011
- Stratify by MODIS cloud fraction
- Compare CALIPSO Day vs. Night retrievals
- → Break down geographically → zonal mean AOD comparisons and representativeness of MODIS obs. along CALIPSO track for ALL MODIS obs.
- Compare zonal means







CALIOP successful AOD retrievals collocated with MODIS-Aqua: V2 August 2007



Latitude

CALIOP successful AOD retrievals collocated with MODIS-Aqua: V2.93 August 2007



Latitude







## Geographical distribution of correlation data, all cloud fractions, V2

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80°N						
4001	n= 34 $r^2 = 0.026$ y = 0.157 x + 0.051 rms= 0.138, 158.9 % M aod = 0.087 C aod = 0.065	n=57 $r^{2} = 0.051$ $y = 0.050 \times + 0.089$ rms= 0.519, 150.6 % M aod = 0.345 C aod = 0.107	n= 209 r <sup>2</sup> = 0.004 y = 0.045 x + 0.067 rms= 0.313, 158.0 % M aod = 0.198 C aod = 0.076	$n= 236$ $r^{2} = 0.148$ $y = 0.292 \text{ x} + 0.050$ $rms= 0.137, 79.2 \%$ $M \text{ aod} = 0.173$ $C \text{ aod} = 0.101$	n= 11 $r^2 = 0.005$ y = -0.019 x + 0.022 rms = 0.145, 125.4 % M aod = 0.116 C aod = 0.020	n= 125 $r^{2} = 0.086$ y = 0.305 x + 0.040 rms= 0.217, 125.3 % M aod = 0.173 C aod = 0.093
	$\begin{array}{l} n=270 \\ r^2=0.030 \\ y=0.393 \ x+0.078 \\ rms=0.123, \ 117.4 \ \% \\ M \ aod = 0.105 \\ C \ aod = 0.119 \end{array}$	$\begin{array}{l} n=352\\ r^2=0.283\\ y=1.076x+-0.000\\ rms=0.191,106.9\%\\ M\ aod=0.178\\ C\ aod=0.192 \end{array}$	n = 1253       r2 = 0.104       y = 0.720 x + 0.066       rms = 0.309, 132.6 %       M aod = 0.233       C aod = 0.234	$n=725$ $r^{2} = 0.307$ $y = 0.651 x + 0.059$ $rms = 0.183, 69.4 \%$ $M aod = 0.263$ $C aod = 0.230$	$\begin{array}{l} n=177 \\ r^2=0.175 \\ y=0.498 \ x+0.147 \\ rms=0.208, \ 78.7 \ \% \\ M \ aod = 0.265 \\ C \ aod = 0.279 \end{array}$	n= 274 r <sup>2</sup> = 0.043 y = 0.097 x + 0.127 rms= 0.355, 241.9 % M aod = 0.147 C aod = 0.141
		$\begin{array}{l} n=351 \\ r^2=0.146 \\ y=1.298 \ x+-0.040 \\ rms=0.185, \ 156.6 \ \% \\ M \ aod=0.118 \\ C \ aod=0.114 \end{array}$	$\begin{array}{l} n=1181 \\ r^2=0.051 \\ y=0.248 \ x+0.085 \\ rms=0.231, \ 89.9 \ \% \\ M \ aod=0.257 \\ C \ aod=0.149 \end{array}$	$\begin{array}{l} n=963 \\ r^2=0.113 \\ y=0.142 \ x+0.134 \\ rms=0.347, \ 137.7 \ \% \\ M \ aod=0.252 \\ C \ aod=0.170 \end{array}$	n = 837       r2 = 0.032       y = 0.454 x + 0.075       rms= 0.157, 114.6 %       M aod = 0.137       C aod = 0.137	n= 528 r <sup>2</sup> = 0.053 y = 0.520 x + 0.063 rms= 0.128, 114.5 % M aod = 0.112 C aod = 0.121
40°S	n= 26r2 = 0.053y = 0.712 x + 0.015rms= 0.092, 98.6 %M aod = 0.093C aod = 0.082	n= 29 $r^2$ = 0.063 y = -0.113 x + 0.089 rms= 0.214, 172.9 % M aod = 0.124 C aod = 0.075	n= 49 r <sup>2</sup> = 0.005 y = -0.016 x + 0.089 rms= 0.596, 301.6 % M aod = 0.198 C aod = 0.086	n= 38 $r^2$ = 0.187 y = 1.426 x + -0.008 rms= 0.207, 182.1 % M aod = 0.114 C aod = 0.154	n= 55 r <sup>2</sup> = 0.037 y = 0.246 x + 0.055 rms= 0.135, 116.3 % M aod = 0.116 C aod = 0.084	$n = 76$ $r^{2} = 0.044$ $y = 0.210 x + 0.056$ $rms = 0.079, 80.9 %$ M aod = 0.098 C aod = 0.076
80°S		0	0		0	
180°	vv 120	°VV 60	°W ( Longi	00 fude	re 120	J°E 18

Calipso old verion 40km,AOD scatter info.,2007-08,Ocean Only,3-QC



## Geographical distribution of correlation data, all cloud fractions, V2.93

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80°N n= 388 r <sup>2</sup> = 0.0 y = -0.0 rms= 0. M aod =	00 09 x + 0.054 187, 156.6 % = 0.119	n=219 $r^2=0.040$ y=0.044 x + 0.060 rms=0.374, 160.9 % M aod = 0.232	n= 1422 r <sup>2</sup> = 0.015 y = 0.087 x + 0.060 rms= 0.206, 119.5 % M aod = 0.172	n= 728 $r^2 = 0.092$ y = 0.390 x + 0.021 rms= 0.163, 108.8 % M aod = 0.150	n= 51 r <sup>2</sup> = 0.000 y = 0.002 x + 0.027 rms= 0.158, 156.1 % M aod = 0.101	n= 358 r <sup>2</sup> = 0.053 y = 0.125 x + 0.038 rms= 0.220, 127.5 % M aod = 0.173
40°N	• 0.053	C aod = 0.070	C aod = 0.075	C aod = 0.079	C aod = 0.027	C aod = 0.059
$r^2 = 0.0$ y = 0.38 rms= 0. M aod = C aod =	62 37 x + 0.030 105, 93.9 % = 0.111 = 0.073	$r^2 = 0.203$ y = 0.621 x + 0.014 rms= 0.150, 97.3 % M aod = 0.154 C aod = 0.110	$r^2 = 0.266$ y = 0.451 x + 0.041 rms = 0.157, 81.0 % M aod = 0.194 C aod = 0.128	$r^2 = 0.287$ y = 0.433 x + 0.051 rms= 0.197, 69.0 % M aod = 0.286 C aod = 0.175	$r^2 = 0.152$ y = 0.628 x + 0.047 rms= 0.249, 104.0 % M aod = 0.240 C aod = 0.198	r <sup>2</sup> = 0.041 y = 0.107 x + 0.056 rms= 0.160, 146.2 % M aod = 0.109 C aod = 0.068
n= 467 r <sup>2</sup> = 0.1 y = 0.38 rms= 0. M aod = C aod =	l 20 33 x + 0.032 091, 68.2 % = 0.134 = 0.083	$\begin{array}{l} n=3663 \\ r^2=0.099 \\ y=0.257 \ x+0.032 \\ rms=0.097, \ 74.6 \ \% \\ M \ aod = 0.130 \\ C \ aod = 0.065 \end{array}$	$\begin{array}{l} n=3848 \\ r^2=0.120 \\ y=0.194 \ x+0.048 \\ rms=0.160, 91.1 \ \% \\ M \ aod = 0.176 \\ C \ aod = 0.082 \end{array}$	$\begin{array}{l} n=3437\\ r^2=0.138\\ y=0.160\ x+0.068\\ rms=0.254,\ 131.3\ \%\\ M\ aod\ =0.193\\ C\ aod\ =0.099 \end{array}$	$      n= 4954 \\ r^2 = 0.103 \\ y = 0.493 x + 0.019 \\ rms= 0.131, 84.5 % \\ M aod = 0.155 \\ C aod = 0.096 \\                                   $	$\begin{array}{l} n = 3442 \\ r^2 = 0.071 \\ y = 0.304 \ x + 0.038 \\ rms = 0.100, 81.6 \ \% \\ M \ aod = 0.123 \\ C \ aod = 0.075 \end{array}$
n= 685 r <sup>2</sup> = 0.0 y = 0.3 rms= 0. M aod = C aod =	35 12 x + 0.054 129, 103.4 % = 0.124 = 0.093	n= 836 r <sup>2</sup> = 0.033 y = 0.275 x + 0.062 rms= 0.176, 146.7 % M aod = 0.120 C aod = 0.095	n= 734 r <sup>2</sup> = 0.011 y = 0.119 x + 0.058 rms= 0.136, 126.1 % M aod = 0.108 C aod = 0.071	n= 684 r <sup>2</sup> = 0.062 y = 0.420 x + 0.046 rms= 0.138, 107.1 % M aod = 0.129 C aod = 0.100	n= 839 r <sup>2</sup> = 0.033 y = 0.266 x + 0.066 rms= 0.173, 128.2 % M aod = 0.135 C aod = 0.102	$\begin{array}{l} n=1002\\ r^2=0.049\\ y=0.284\ x+0.042\\ rms=0.122,\ 110.2\ \%\\ M\ aod=0.111\\ C\ aod=0.073 \end{array}$
80°S						
180°W	120	°W 60'	W (	ያ 60 itudo	°E 120	0°E 18

#### Calipso V2.93 40km,AOD scatter info.,2007-08,Ocean Only,3-QC



# Zonal mean differences in AOD (550nm) from MODIS and CALIPSO over land and ocean during 4 months in 2007





# Comparison of zonal distributions of data density and AOD between V2 and V2.93 (V3, pre-release)



Part 2: Retrieval of aerosol radiative properties from A-Train observations - Methodology



### Refractive Index of MODIS modes as a function of wavelength



Step 1: Each observable (here AOD 550nm) is consistent with a range of fine/coarse mode particle concentrations for a given fine/coarse mode combination (here fine#1/coarse#5)



Step 2: The totality of all observables is consistent with a smaller range of fine/coarse mode particle concentrations for a given fine/coarse mode combination (here fine#1/coarse#5)



Step 3: For a different fine/coarse mode combination (here fine#3/coarse#6), the observables are consistent with a different range of fine/coarse mode particle concentrations



Step 4: For all possible fine/coarse mode combinations, the observables are consistent with a different range of fine/coarse mode particle concentrations





## Current choices in retrieval method:

## 1)Metric

$$\mathbf{X} = \left(\sum_{i} \log^2(x_i/\hat{x}_i)\right)^{1/2}$$

- $x_i$  : retrieved parameters
- $\hat{x}_i$  : observables

## 2)Observables

## 3)Use 10% best solutions in context of metric above



Step 5: The best 10% of possible fine/coarse mode combinations & concentrations, define a range of aerosol radiative properties.





## Constraints afforded by lidar backscatter retrieval - 1



MODIS AOD ( $\pm 0.03\pm5\%$ ) OMI AAOD ( $\pm 0.03\pm5\%$ ) No CALIOP  $\beta_{532}$ 



## Constraints afforded by lidar backscatter retrieval - 2



MODIS AOD ( $\pm 0.03 \pm 5\%$ ) OMI AAOD ( $\pm 0.03 \pm 5\%$ ) CALIOP  $\beta_{532}$  ( $\pm 20 \text{Mm}^{-1} \pm 10\%$ )



## Constraints afforded by lidar backscatter retrieval - 3



MODIS AOD ( $\pm 0.03\pm5\%$ ) OMI AAOD ( $\pm 0.03\pm5\%$ ) CALIOP  $\beta_{532}$  ( $\pm 10Mm^{-1}\pm10\%$ )



### Impact of retrieval uncertainty on instantaneous aerosol DRE





## Sensitivity: MODIS AOD ( $\pm 0.03+5\%$ ), OMI AAOD ( $\pm 0.03+5\%$ ),

## CALIOP $\beta_{532}$ (±10Mm<sup>-1</sup>±10%)

### EXTINCTION

AOD\SSA	0.8	0.9	0.98
0.05	58.84 +/- 14.88 (30.88/97.62)	49.40 +/- 13.03 (23.98/96.49)	47.53 +/- 13.73 (25.75/93.67)
	input 50.13	input 49.93	input 50.01
0.2	201.71 +/- 6.87 (187.96/219.39)	206.81 +/- 20.30 (159.51/256.14)	199.62 +/- 10.33 (172.22/234.64)
	input 199.29	input 200.54	input 200.11
0.7	696.87 +/- 6.23 (689.88/717.68)	708.94 +/- 22.61 (665.50/759.05)	702.61 +/- 23.40 (664.51/762.79)
	input 699.13	input 699.23	input 699.91

#### SSA

AOD\ <mark>SS</mark> A	0.8	0.9	0.98
0.05	0.83 +/- 0.05 (0.75/0.94)	0.87 +/- 0.05 (0.75/0.98)	0.97 +/- 0.01 (0.94/0.99)
	input 0.80	input 0.90	input 0.98
0.2	0.80 +/- 0.01 (0.77/0.83)	0.90 +/- 0.02 (0.85/0.93)	0.98 +/- 0.00 (0.97/0.98)
	input 0.80	input 0.90	input 0.98
0.7	0.80 +/- 0.00 (0.80/0.81)	0.90 +/- 0.00 (0.89/0.91)	0.98 +/- 0.00 (0.98/0.98)
	input 0.80	input 0.90	input 0.98

#### ASYMMETRY

AOD\SSA	0.8	0.9	0.98
0.05	0.80 +/- 0.04 (0.62/0.85)	0.76 +/- 0.05 (0.56/0.85)	0.77 +/- 0.03 (0.61/0.80)
	input 0.83	input 0.69	input 0.75
0.2	0.82 +/- 0.01 (0.79/0.84)	0.74 +/- 0.04 (0.62/0.78)	0.78 +/- 0.01 (0.72/0.79)
	input 0.83	input 0.69	input 0.75
0.7	0.83 +/- 0.00 (0.82/0.83)	0.71 +/- 0.02 (0.68/0.73)	0.77 +/- 0.01 (0.73/0.79)
	input 0.82	input 0.69	input 0.75

Example of successful retrieval from actual collocated OMI, MODIS, CALIOP (V2.93) data: Aug. 15, 2007



NASA

# Conclusions

- A. Different cloud screening techniques and assumptions in MODIS, OMI, and CALIPSO have serious implications for the use of collocated data.
- B. Monthly AOD comparisons show decent agreement after severe cloud clearing, and regional and zonal averaging. Initial comparisons of CALIOP V2.93 to MODIS-Aqua show increased data density and generally smaller rms differences from 40°S to 40°N.
- C. A methodology for the retrieval of aerosol radiative properties from MODIS AOD, OMI AAOD and CALIPSO  $\beta_{532}$  has been devised.
- D. A sensitivity study of current method shows good retrievals for almost all AOD/ssa combinations with AOD greater or equal to 0.2.
- E. Next steps:
  - 1) Test retrieval assumptions (metric, solution space, etc.)
  - 2) Use CALIOP V3
  - 3) Constrain OMI AOD retrievals with CALIOP height input
  - 4) Testing additional constraints afforded by APS
  - 5) Testing radiative properties against suborbital data
  - 6) rtx calculations to assess  $\delta \Delta F_{aerosol}(z)$
  - 7) Aerosol DRE above clouds

