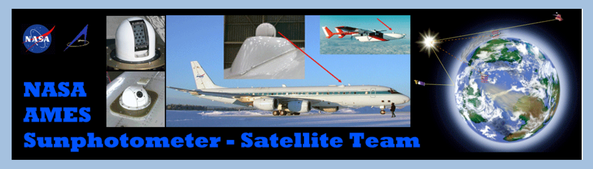


CALIOP/CALIPSO: Improvement in the retrieval algorithm and a few applications

NASA Postdoctoral Program
administered by Oak Ridge Associated Universities

Kacenelenbogen M.[1], M. A. Vaughan[2], J. Redemann[3], R. M. Hoff[4], R. R. Rogers[2], R. A. Ferrare[2], P. B. Russell[5], C. A. Hostetler[2], J. W. Hair[2], B. N. Holben[6].

[1] ORAU/ NASA Ames Research Center, Moffett Field, CA, USA; [2] NASA Langley Research Center, Hampton, VA, USA; [3] Bay Area Environmental Research Institute, Sonoma, CA, USA; [4] Joint Center for Earth Systems Technology (JCET)/ Goddard Earth Science and Technology Center (GEST), University of Baltimore County, MA, USA; [5] NASA Ames Research Center, Moffett Field, CA, USA; [6] NASA Goddard Space Flight Center, Greenbelt, MA, USA; contact: meloe.s.kacenelenbogen@nasa.gov

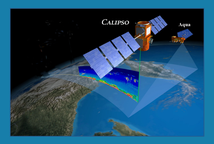
GOAL

Help identify potential shortcomings in the Version 2 level 2 aerosol extinction product

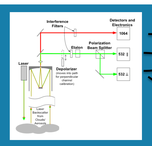
Illustrate motivation for changes introduced in next version of CALIOP data (Version 3, released in May 2010)

Will help understand and interpret results obtained in previous studies

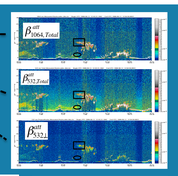
CALIOP

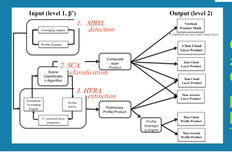


- Active downward pointing elastic lidar
- Flies at ~7km/s at an altitude of 705 km
- 90 m diameter foot print every 333m
- No daily global coverage (same region, 16 days)
- Vertical distribution, shape and size of aerosols



Level 1 products

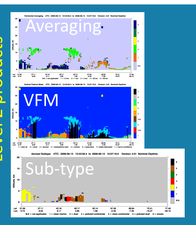




$$\beta'(z) = \beta(z) \times T(z_0, z)^2$$

0: height of CALIOP LIDAR
z: height of scattering layer
0-z_0: height where there are no aerosol
β': Attenuated backscatter coefficient (directly linked to lidar signal)
β: total backscatter coefficient (molecular + aerosol)
$T^2(z)$: Atmospheric two-way transmittance (signal attenuation).

Level 2 products



AERONET

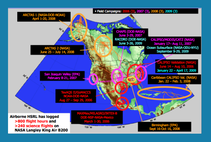
Aerosol Robotic NETwork [1]

- **Direct solar:** AOD (Aerosol Optical Depth, uncertainty ~0.01-0.02, [2]) and Ångström exponent

- **Almucantar:** Aerosol volume size distribution, SSA, etc…[3]

HSRL

Airborne High Spectral Resolution Lidar [4]



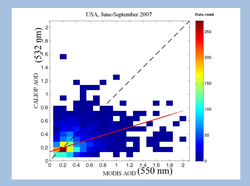
- Measures directly aerosol extinction and S_a, without ancillary aerosol measurements or assumptions on aerosol type
- Systematic error on 532 nm extinction < 0.01 km^{-1} for typical aerosol loading [4]

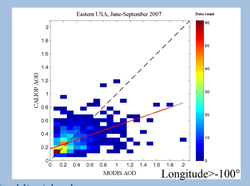
MODIS and POLDER

	MODIS on AQUA	POLDER-3 on PARASOL
Definition	Passive "MODerate resolution Imaging Spectroradiometer"	Passive "POLarization and Directionality of Earth's Reflectance"
Active period	Apr 2002- today	Dec 2004 – Dec 2009
Resolution for aerosols	Horizontal 10 x 10 Km	Horizontal 20 x 20 Km
Channels for aerosols	466, 553, 644, 855, 1243, 1632 and 2119 nm	490, 670 and 865 nm (all polarized)
Main asset	High spectral/ spatial resolution	Directional and polarized properties of reflected solar radiation

Expected uncertainty on MODIS AOD over dark land surfaces: ΔAOD=± 0.05 ± 0.15AOD [5]

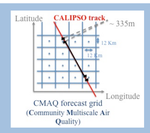
MODIS versus CALIPSO AOD[6]





First principal component regression method (red line) leads to
$AOD_{CALIOP} = 0.31(\pm 0.02)\ AOD_{MODIS} + 0.14(\pm 0.01)$, R=0.34, RMSD= 0.27, N=2791 for entire US
$AOD_{CALIOP} = 0.34(\pm 0.03)\ AOD_{MODIS} + 0.17(\pm 0.01)$, R=0.43, RMSD= 0.26, N=807 for Eastern US

- The standard V2 CALIPSO extinction product seems to underestimate MODIS AOD (by 66%, Eastern US)

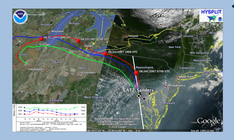


MODIS and CALIOP data are re-mapped on 12x12 km grid.

- MODIS AOD could be biased by: wrong surface reflectance, cirrus cloud contamination…
- CALIPSO AOD could be biased by: wrong extinction to backscatter lidar ratios over land (here US), very little detection of tenuous aerosol layers by day due to low SNR…

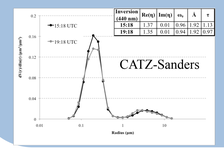
Multi-sensor case study

-August 4 2007[6]-



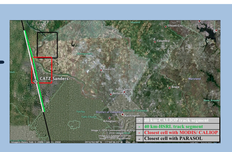
Dense haze over the East Coast:

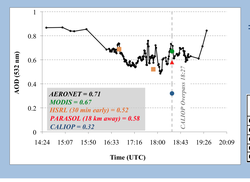
1. **Smoke from fires** in the North,
2. **Regional pollution**



Inversion (440 nm)	Re(η)	Im(η)	r_{eff}	A	σ
15:18	1.37	0.01	0.96	1.92	1.13
19:18	1.35	0.01	0.94	1.92	0.97

Aerosol plume
. predominantly composed of fine particles
. with significant light absorption

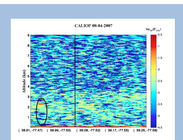


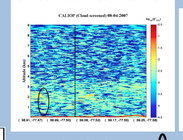


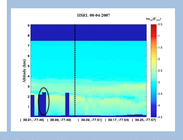
⇒ [MODIS (0.67), PARASOL (0.58) and HSRL (0.52)] are contained in the AERONET AOD envelope within ½ hour around the A-Train overpass (0.48 to 0.73 at 532 nm)

⇒ Not the case for CALIOP V2 AOD (0.32)

Distance (km)	CATZ_Sanders	Closest point on HSRL track	Closest point on CALIOP track	CMAQ cell with CALIOP/ MODIS AOD
CATZ_Sanders	-	-	-	-
Closest point on HSRL track	0.940	-	-	-
Closest point on CALIOP track	0.138	0.908	-	-
CMAQ cell with CALIOP/ MODIS AOD	5.809	5.315	5.680	-
CMAQ cell with POLDER AOD	17.703	17.339	17.569	12.067







Cloud screening:
All CALIOP β'_{532}@1/3km deleted underneath the highest detected cloud in cloud@1/3km

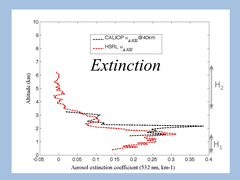
Differences between HSRL and CALIOP SNR

Two separate and spatially homogeneous stronger regions in the HSRL β'_{532} intensity on the vertical

CATZ-Sanders Region with cloud contamination

Closest point to CATZ-Sanders on the HSRL track fairly representative of the rest of the 40 km "curtain scene"

CALIOP versus HSRL[6]

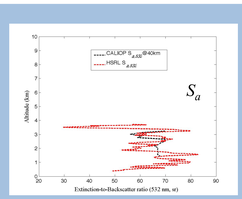


. Fairly good agreement, except for strong peak around 2.2 km (cloud contamination)

. Lack of CALIOP values below ~1.4 km and above ~3.2km and

Issue #1: CALIOP's failed detection of tenuous aerosol layers and its signal not reaching down to the ground

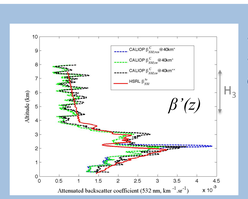
Integration of the HSRL $\alpha_{a,532}$ profile on H_1 (AOD of 0.23 from a few hundred meters to 1.5 km), and on H_2 (AOD of 0.01 from 3 km to the top) … **adds a total of 0.24 to the standard CALIOP AOD of 0.32.**



CALIOP smaller range of $S_{a,532}$@40km (from 56 to 70 sr) compared to HSRL (from 29 to 83 sr).

Issue #2: CALIOP's potentially erroneous assumed lidar extinction-to-backscatter ratio value per detected aerosol layer

An alternative CALIOP extinction profile was computed by applying a newly devised extinction retrieval to all previously cloud-screened CALIOP attenuated backscatter profiles in the 40 km region of interest using the HSRL Sa profile … **adds 0.12 to the standard CALIOP AOD of 0.32 (less effect than issue #1)**



- Cloud cleared CALIOP profile closer to HSRL
- **Two factors need to be considered when comparing HSRL and CALIOP:**

1. Different atmospheric attenuation of each lidar signal (CALIOP from 30km and HSRL from ~7.5kmis normalized)
2. Different calibration techniques/ accuracy (here, CALIOP seems well calibrated but not in general)

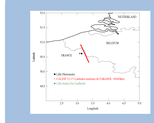
$\beta'^{C}_{532,nCS}$@40km* = average (β'_{532}@1/3km)
$\beta'^{C}_{532,cS}$@40km* = $\beta'^{C}_{532,nCS}$@40km* with cloud-screening
$\beta'^{C}_{532,cS}$@40km** normalized by mean (HSRL β'^{H}_{532}/ $\beta'^{C}_{532,cS}$@40km*) over H_3

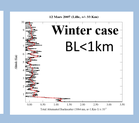
Issue #3: CALIOP's cloud clearing, averaging and calibration of the attenuated backscatter coefficient profile

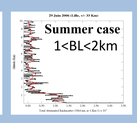
CALIOP version 3: Improvements

1. Level 1 data
++ Improved daytime calibration procedures [7]
2. Spatial location of layers (base and top altitudes)
++ Layer base extended close to the ground
3. Layer type (cloud/ aerosol and subtypes)
++ CAD now uses integrated volume depolarization ratio and bigger set of PDF
++ Elimination of bug in cloud clearing code [8]
++ Improved separation ice/ water clouds
4. Derived optical properties
++ Optical depth now "provisional" (before: "beta quality")

CALIOP application - Air quality[9]







Summer, 06/29/06 and Winter, 03/12/07

Lille	Parameter	Summer case	Winter case
$PM_{2.5}$ (µg/m³)	24h	16.08	16.96
	12h-14h	19	15
PARASOL	AOT (440nm)	0.21	0.12
	Number of pixel	6	6
	Spatial Std	0.06	0.03
AERONET	AOT (fine, 440 nm)	0.20	0.12
	Number of daily inversion	2	10
	Angstrom (440-676 nm)	1.72	1.64
MODIS-AQUA	AOT (470 nm)	0.38	0.18
	Number of pixel	26	25
	Spatial Std	0.09	0.03

$PM_{2.5}$: Particulate matter with d_p<2.5 µg/m³

Lille	Summer case	Winter case
AOT (Fine, 440 nm)	0.20	0.12
Angstrom (440-676 nm)	1.76	1.59
Re(η,440 nm)	1.44	1.48
Im(η,440 nm)	0.01	0.01
ω_0 (440 nm)	0.92	0.89
V_d (fine)	0.03	0.01
τ_{aer} (total)	0.24	0.32
Relative Humidity	57%	66%
Atmospheric Pressure (hPa)	1015	1019

- Smaller particles
- Same optical ptes

- Good agreement PARASOL – AERONET AOD
- AOD MODIS (total) > AOD PARASOL (fine)
- Lower PARASOL AOD in Winter case for same PM
- Smaller particles in Summer but ~ same optical properties
- Anticyclonic conditions (>1013 hPA, good mixing in BL)
- Lower BL in Winter case

⇒**Lower AOD in Winter mostly due to lower BL.** Use of CALIOP BL Height information to constrain the satellite AOD - PM relationship

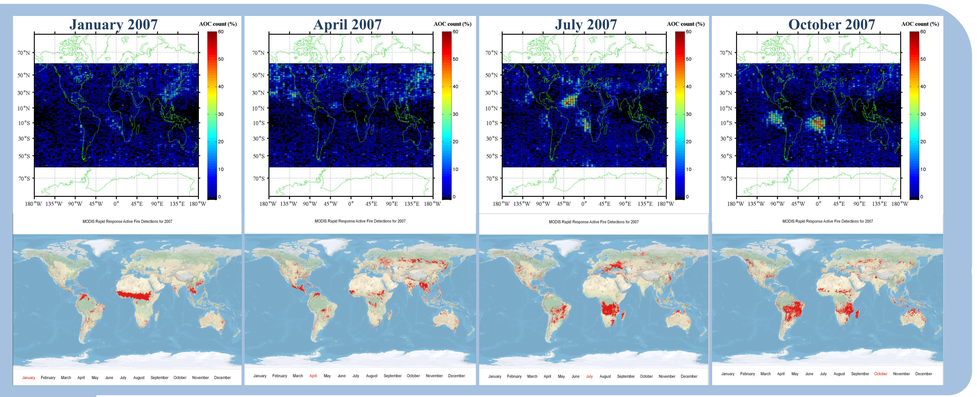
CALIOP application - Aerosol Over Cloud (AOC)

Main project: "Combined use of CALIPSO, MODIS and OMI level 2 aerosol products for calculating direct aerosol radiative effects"
abstract # 237 Jens Redemann –see presentation on Tuesday October 26, 2010, 15:10-15:30

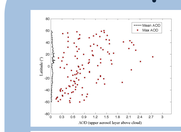
Over cloud? Biomass burning aerosols usually strongly absorbing, may cause local positive radiative forcing when over clouds

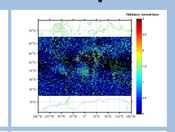
Preliminary results using CALIPSO 5km layer…

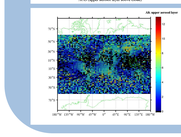
AOC: Where and When?

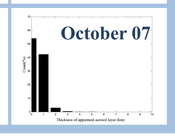


AOC: Optical Depth and layer thickness?









AOC: Summary

- Above 40% of **AOC** in July-October 2007
- 80-85% of **AOD** in [0-0.1] and 10-15% in [0.1-0.2]
- Above 45% of upper aerosol layer **altitude** at 1.5-4.5km (mostly 1.5-2.5km)
- 90% of upper aerosol layer **thickness** is 0-1.5km
- 80% of **distance [aerosol base-cloud top]** 0-1.5km

Evaluate CALIOP AOC detection using…

- NASA Ames Airborne Tracking Sunphotometer, AATS-14 retrieved AOD (when AOC) during ARCTAS field campaign (April 19th 2008, plane under CALIOP track)
- Considerable correlative EARLINET-CALIPSO database that includes aerosol layer properties [*Mona*, personal com.; *Pappalardo et al.*, 2010]
- Combined aerosol retrieval over clouds: OMI-CALIOP-AIRS [*Torres*, personal com.] or POLDER-MODIS [*Waquet et al.*, 2009]

References

1. Holben et al., *Remote Sensing Environment*, 66, p 1-16 (1998)
2. Eck et al., *J. Geophys. Res.*, 104, p 3133-31350 (1999)
3. Dubovik et al., *J. Geophys. Res.*, 105, p 20673-20696 (2000a)
4. Hair et al., *Appl. Optics*, 47, p 6734–6752 (2008)
5. Levy et al., *Atmos. Chem. Phys. Discuss.*, 10, p 14815–14873 (2010)
6. Kacenelenbogen et al., *Submitted to Atmos. Chem. Phys.* (July 2010)
7. Powell et al., *25th International Laser Radar Conference* (2010)
8. Vaughan et al., *25th International Laser Radar Conference* (ILRC), St. Petersburg, Russia, in Press
9. Kacenelenbogen et al., *Atmos. Chem. Phys.*, 6, 4851-4866 , 2006

Acknowledgements:
NOAA Air Resources Laboratory (ARL), AERONET (especially Thomas Eck), NASA HSRL, CALIPSO and MODIS team (especially Robert Levy), CNES POLDER team.
This research was supported by an appointment to the NASA Postdoctoral Program at the Ames Research Center, administered by Oak Ridge