An evaluation of CALIOP/CALIPSO's aerosol-above-cloud (AAC) detection and retrieval capability over North America

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Purpose of this work

Accurate AAC detection and quantification are of utmost importance for **aerosol-climate studies** under all-sky conditions [1]

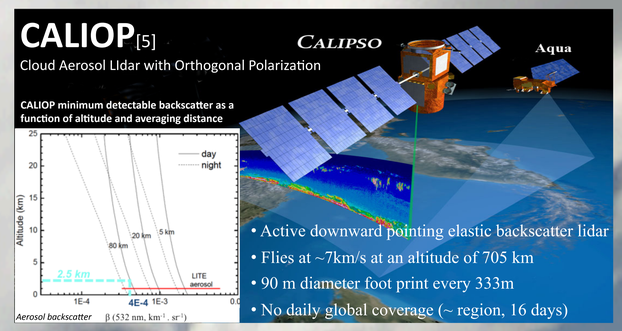
Lack of global experimental **validation** for many AAC retrievals from passive sensors (OMI [2], POLDER [3], SCIAMACHY [4] etc…)

Active space-borne lidar **CALIOP** [5] **well suited** for AAC observations (i.e. high resolution, narrow source)

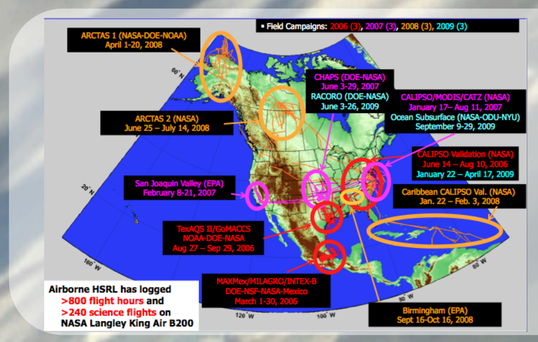
Peer-reviewed evaluations of CALIOP aerosol observations **restricted to cloud-free** conditions

CALIOP[5]

Cloud Aerosol LIdar with Orthogonal Polarization



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



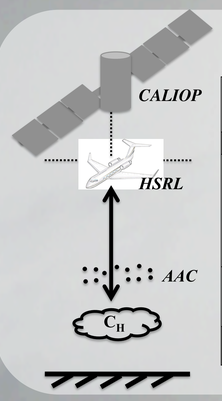
HSRL

Airborne High Spectral Resolution Lidar

Mission	Date	Location	Number of CALIOP flights	Number of hours on CALIOP track
CC-VEX	Jun-Aug 2006	Eastern USA	11	16.2
TexAQS/GOMACCS	Aug-Sept 2006	Texas	10	13.8
CHAPS	Jun-07	Oklahoma City area	8	10.9
CATZ	Jul-Aug 2007	Eastern USA	4	7.6
CARIBBEAN	Jan-Feb 2008	Caribbean	7	13.2
ARCTAS (spring)	Apr-08	Alaska	12	17.5
ARCTAS (summer)	Jun-Jul 2008	Canada	11	10.3
Nighttime calibration	Jan-Apr 2009	Eastern USA	11	15.9
RACORO	Jun-09	Oklahoma	3	4
Other	2007-2009	North America	9	6.3
Total			86 flights	115.7 h

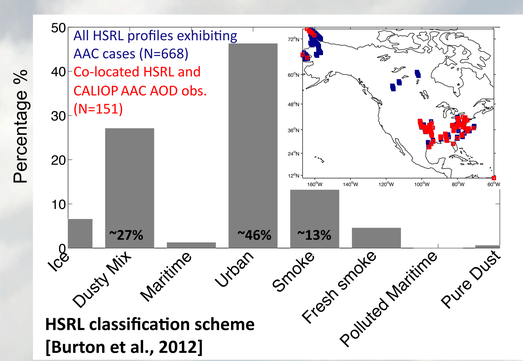
- Measures directly aerosol extinction and S_a, without ancillary aerosol measurements or assumptions on aerosol type [6]
- Systematic error on 532 nm extinction < 0.01 km^{-1} for typical aerosol loading [7]

Method

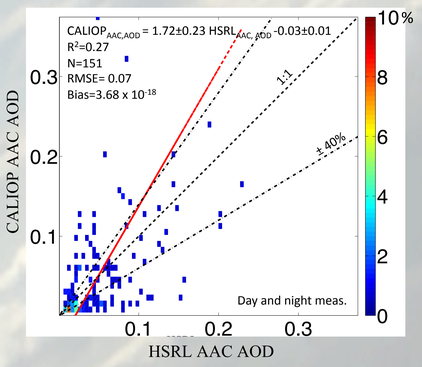


No cloud or aerosol above HSRL-airplane	Delete profile if aerosol and/ or cloud detected by CALIOP above HSRL-airplane
HSRL airplane	
CALIOP cloud-free AAC AOD	Delete lower part of profile if CALIOP σ_a not satisfying : • $-0.1<\sigma_a<1.25$ km^{-1} • σ_a QC=0,1,2,16,18,129* • $\lvert\delta(\sigma_a)x100/\sigma_a\rvert$ <400% *with S_a between 20 and 80 sr
HSRL cloud-free AAC AOD	Select only HSRL σ_a>0.01 km^{-1} and delete profile if less than five σ_a>0.01 km^{-1} on vertical
Cloud top height *defined by HSRL for both HSRL and CALIOP AAC*	

HSRL versus CALIOP AAC



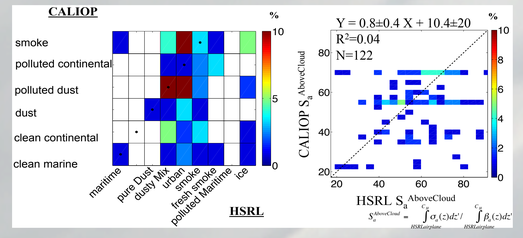
CALIOP detects ~23% of the HSRL-detected AAC (i.e. CALIOP records at least one valid aerosol extinction coefficient above the cloud with coincident HSRL AAC).



- **Minority** (32%) **of the CALIOP-HSRL AOD** dataset (N=48) **within ±40% envelope**,
- 25% of the dataset lie above the +40% line (i.e. CALIOP overestimates HSRL) and 43% lie below the -40% line (i.e. **CALIOP underestimates HSRL**),
- Points in the 0-0.1 CALIOP AAC AOD range show a **majority of HSRL AAC backscatter coefficient below 4 x 10^{-4} $km^{-1}.sr^{-1}$**.

Potential errors in CALIOP AAC

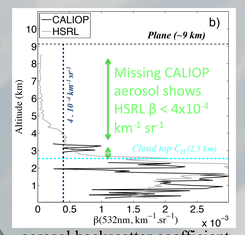
1. Calibration uncertainties in CALIOP 532 nm (expected to have a bias no larger than ~3% according to Rogers et al. [2011])
2. Potential temporal/ horizontal mismatch between CALIOP and HSRL observations
3. Aerosol type misclassification



- Misclassified: Smoke, polluted continental, dust, clean marine
- No correlation between CALIOP and HSRL $S_a^{AboveCloud}$

Misclassification caused by (i) low CALIOP Signal-to-Noise Ratio (further decreased by attenuation through thick aerosol & noise added by cloud reflection), (ii) use of info indirectly related to aerosol type (i.e. volume depolarization, attenuated backscatter, aerosol location, height and surface type) and (iii) erroneous S_a could be assumed even when the aerosol type is correctly defined

4. Misdetection of full or partial aerosol vertical extent

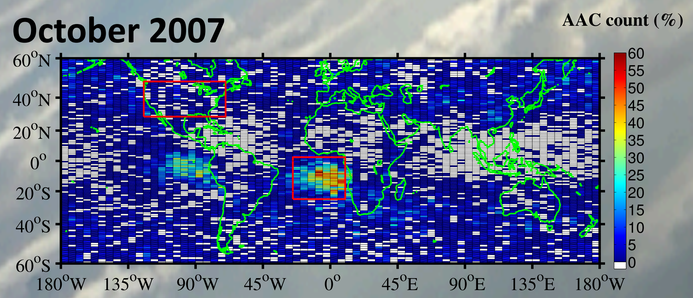


CALIOP retrieves aerosol extinction coefficients only in regions where it identifies aerosol layers

Which error is dominant in our study?

Impact of correction for **CALIOP misdetection of aerosol vertical extent** (i.e. using vertical integration of HSRL extinction coefficients) is more successful in reducing CALIOP-HSRL differences in AAC AOD than correction for CALIOP aerosol type misclassification (i.e. using HSRL $S_a^{AboveCloud}$)

October 2007



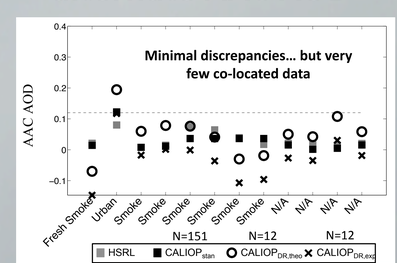
Mean 2007-global uppermost AAC aerosol layer shows AOD of 0.03, is between 3.78 ± 0.31 km and 3.20 ± 0.30 km and above an uppermost cloud top at 2.47 ± 0.30 km

Representativeness of our CALIOP-HSRL AAC dataset

- **Our CALIOP-HSRL dataset is sparse**: CALIOP airborne calibration validation experiments required the HSRL to fly in largely cloud-free conditions; and majority of CALIOP-HSRL coincident tracks are located over land
- **Our CALIOP-HSRL dataset mean AAC AOD is**
  - **Higher** than 2007-yearly average over the **globe**
  - **Higher** than 2007-yearly average over **North America** (inc. peak months of Marc-May 2007)
  - **Lower** than 2007-yearly average over **South East Atlantic** (inc. peak months of Aug-Oct 2007)

Aerosol Above Cloud	Lidar	Mean AOD	Max AOD
Globe 2007	CALIOP (N=7.87E+05)	0.03 ± 0.03	1.53
South East Atlantic 2007	CALIOP (N=6.90E+04)	0.06 ± 0.04	1.11
North America 2007	CALIOP (N=1.09E+05)	0.02 ± 0.01	0.43
Mostly USA 86 flights of Table 1	CALIOP (N=171)	0.05 ± 0.06	0.37
	HSRL (N=668)	0.04 ± 0.05	0.63

CALIOP standard and alternate AAC AOD



DR[8]: Depolarization Ratio method

Conclusion

In our study (i.e. mostly **over continental US**)…

- **CALIOP underestimates AAC occurrence**
- CALIOP detects AAC in ~23% of the cases in which it is observed by HSRL. This is due to a majority of the AAC AOD values below 0.1
- **CALIOP shows little agreement with HSRL AAC AOD**
- Non-detection or underestimation of AAC AOD mostly due to tenuous aerosol layers having **backscatter coefficients that lie below the CALIPSO minimum detection limit**

Need for additional airborne field campaigns in regions of high AAC occurrence (e.g. South East Atlantic):

See Redemann et al. A51A-0013 Moscone South AM 12/13/2013

1. Process-level understanding of AAC aerosol-radiation interaction,
2. Cloud adjustments to the AAC aerosol-radiation interaction,
3. Aerosol-cloud interaction,
4. Higher number of coincident CALIOP-HSRL AAC cases with wider AAC AOD range to further investigate the CALIOP standard and alternate detection and retrieval of AAC.

[1] Sakaeda et al., 2011, [2] Torres et al., 2012, [3] Waquet et al., 2012, [4] De Graff et al., 2012, [5] Winker et al., 2009, [6] Hair et al., 2001, [7] Hair et al., 2008, [8] Chand et al., 2008

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