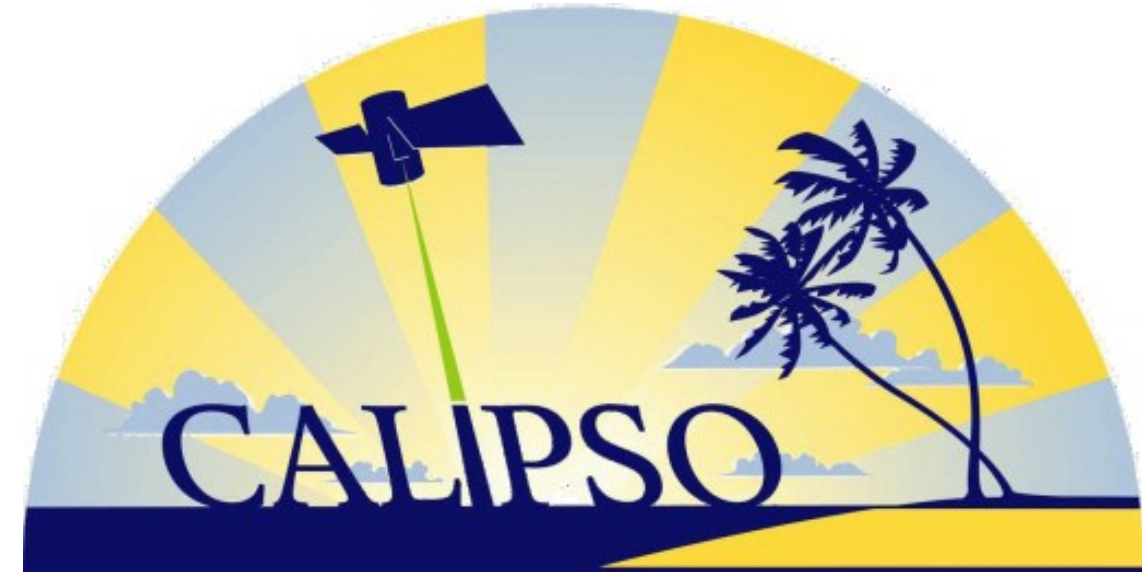




Evaluation of CALIOP 532-nm AOD over Clouds

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A51A-0007

AGU Fall Meeting
December 9-13, 2013
San Francisco, CA

Validation of the CALIOP data products remains an ongoing task for the CALIPSO team. Validating the optical properties of aerosols located above clouds is especially difficult, because independent measurements are usually not available. In this presentation we analyze 532-nm aerosol optical depth (AOD) above clouds, comparing results from the standard CALIOP algorithm with two alternate algorithms applied to CALIOP data acquired along the transport pathways of African dust and biomass burning aerosols. Multiple years of the CALIPSO nighttime data (2007-2012) were examined. The analysis was limited to cases where there are opaque water clouds below aerosol layers that can be used as a reference to retrieve AOD of the overlying aerosol layer.

Four Different Retrievals for Comparison

1. CALIOP standard level 2 (L2) retrieval
- No multiple scattering; i.e., $\eta = 1$
 - Only applied to layers detected

$$\beta_a(r) = \frac{\beta'(r)}{\exp\left(-2\eta S_a \int_{r_0}^r \beta_a(r') dr' - 2S_m \int_{r_0}^r \beta_m(r') dr'\right)} - \beta_m(r)$$
$$\sigma_a(r) = S_a \beta_a(r) \quad AOD = \int_{top}^{base} \sigma_a(r) dr$$

Young, S. A. and M. A. Vaughan, *J. Atmos. Oceanic Technol.*, **26**, 1105-1111, 2009.

2. Rescaled L2 extinction coefficients σ_a

- $\sigma_{a,rescaled}(r) = \sigma_a(r) \times K_s$
- Scaling factor $K_s = S_{a,dust}/S_{a,other}$ in the dust region, $K_s = S_{a,smoke}/S_{a,other}$ in the smoke region
- Useful for evaluating possible misclassification in typing

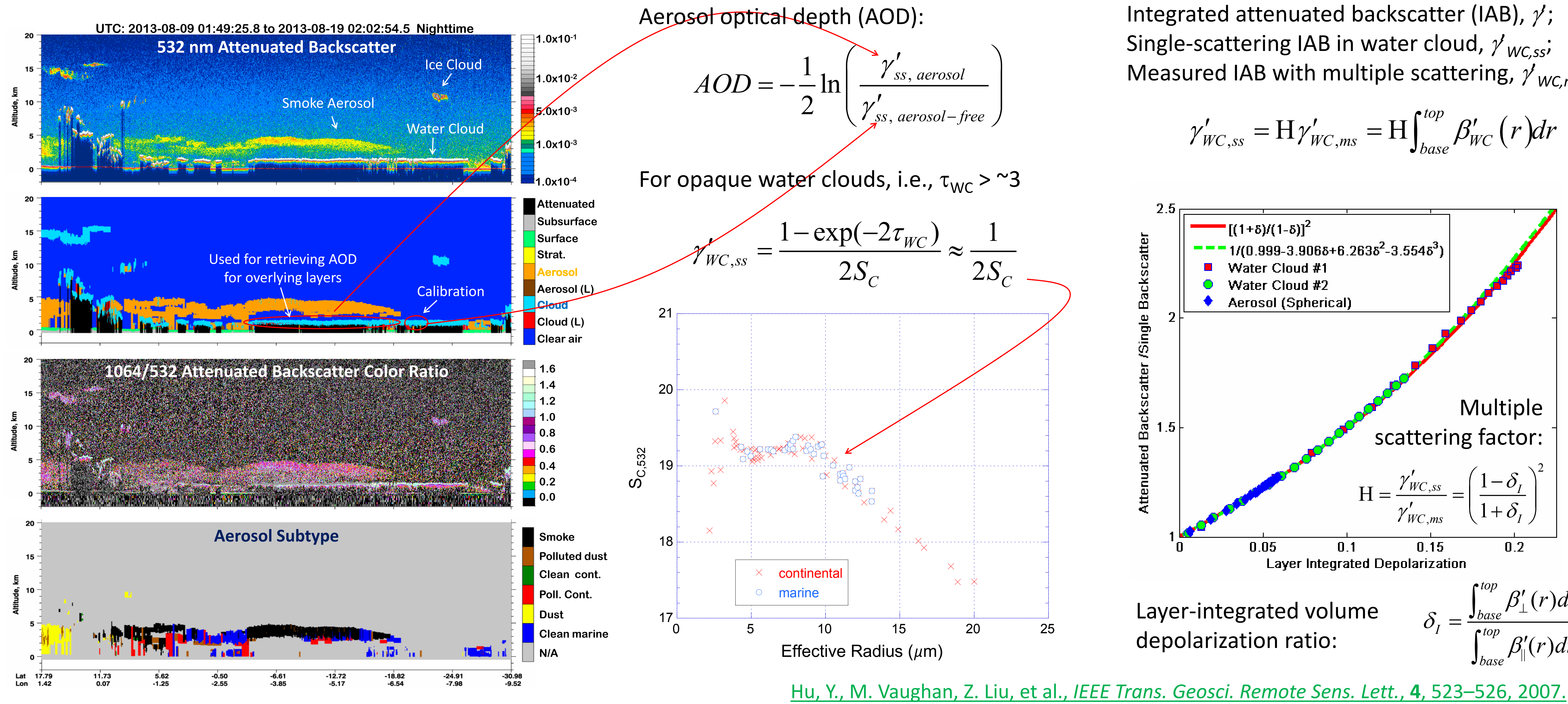
3. Full column (FC) retrieval

- Fixed lidar ratio $S_a = 35, 40, 45, \dots$
- Forward (downward) retrieval from 10 km to the water cloud top
- A reference for comparison, useful for determining discrepancies due to layer detection limits.

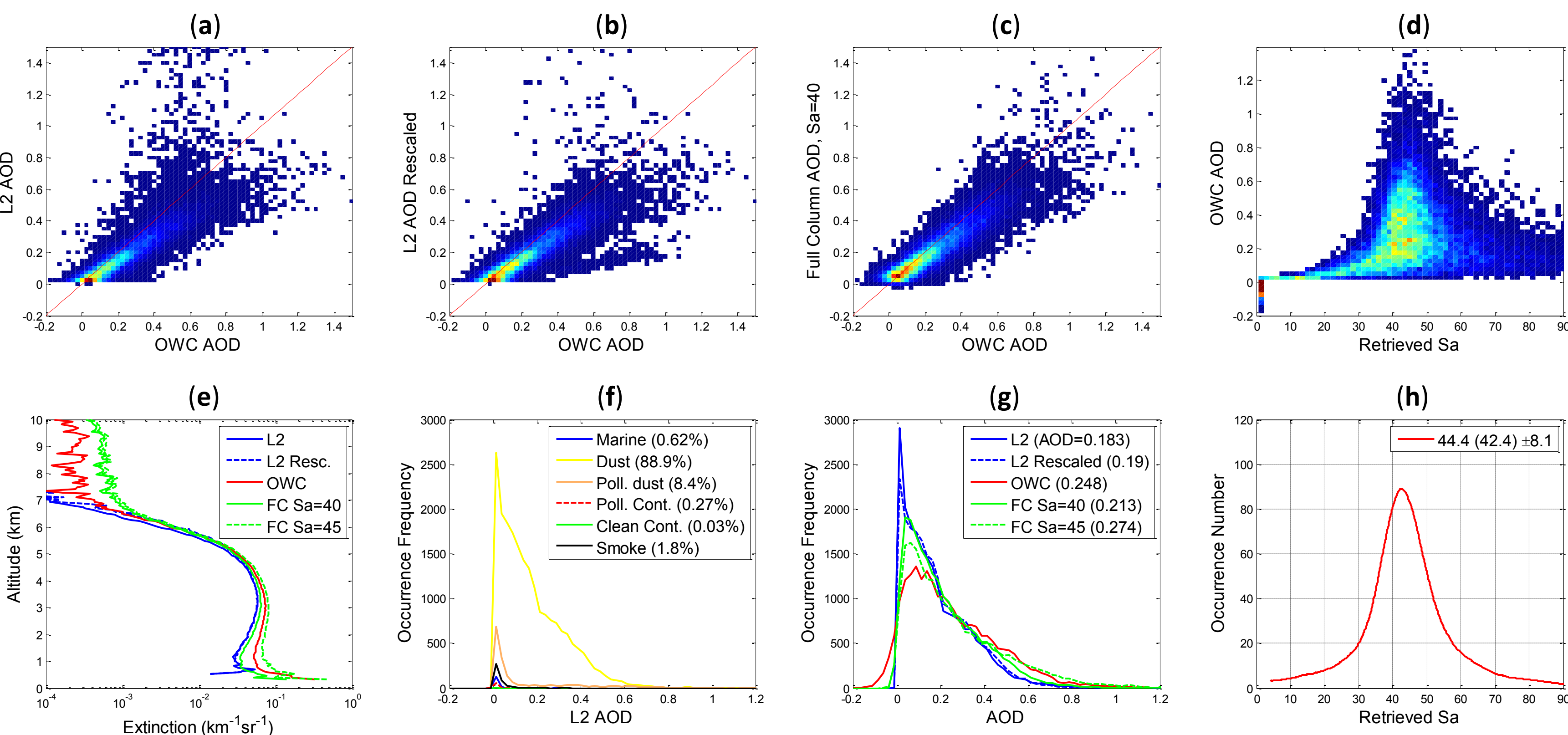
4. Opaque water cloud (OWC) constrained retrieval

- Opaque water cloud (top < 2 km), which are good isolators separating transported dust and the marine boundary layer, are used as a reference to determine AOD of overlying aerosol layers (more details provided on the right)
- AOD retrieval from opaque water clouds can be more accurate, SNR of the lidar signals from these clouds is high
- Lidar ratio S_a is retrieved as well

Opaque Water Cloud Constrained Retrieval



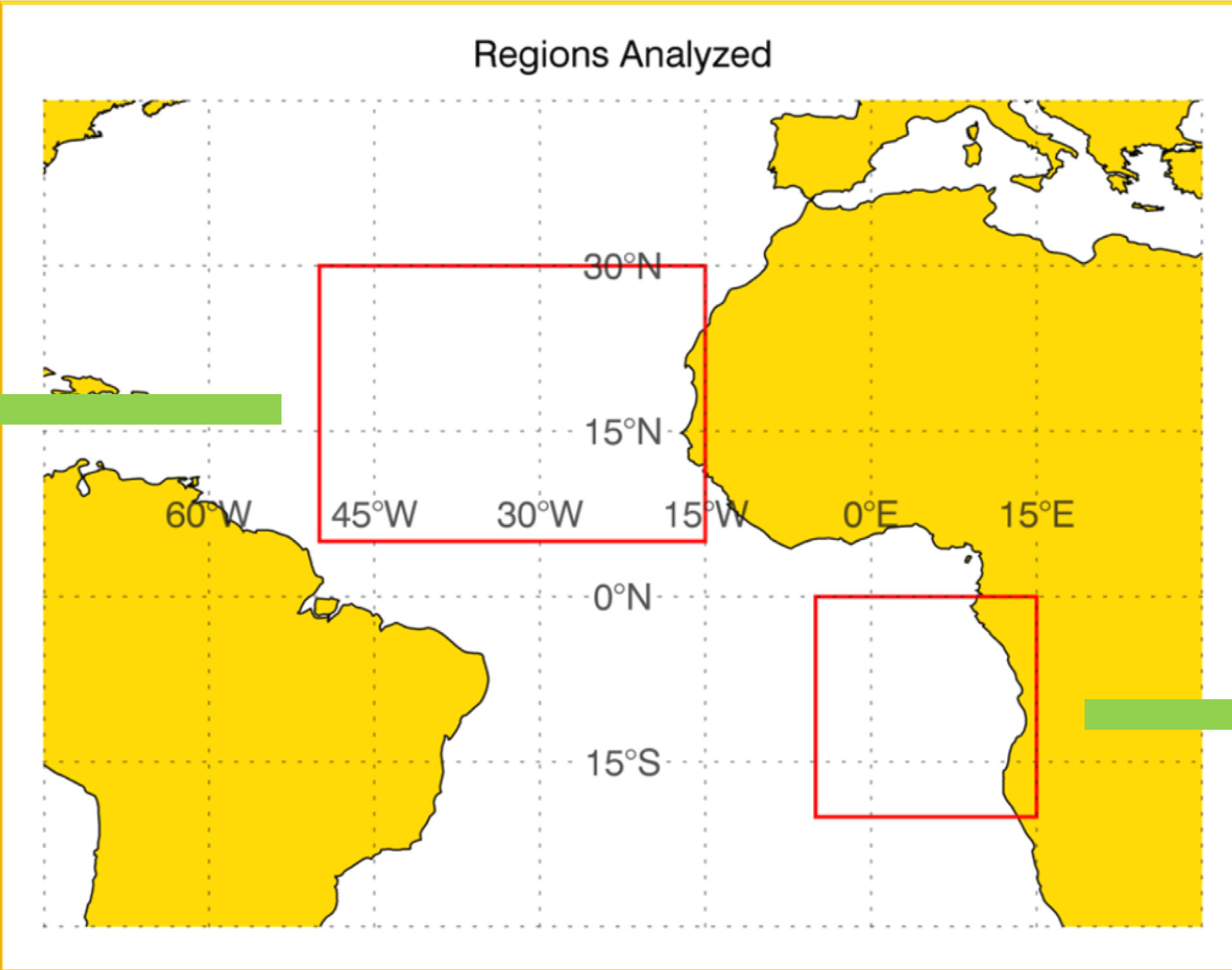
Results for Dust Transport Region



- Version 3 nighttime data, June – August, 2007 – 2012
- AOD produced by the CALIPSO L2 retrieval for transported Saharan dust has a good correlation with that from the OWC retrieval (a). However, the mean value for the L2 AOD is 0.183 (g), 26.2% smaller than the mean value of OWC AOD (0.248). Several factors may contribute to the AOD discrepancy
 - The type of aerosols identified (f) is dominated by “dust” (88.9%), followed by “polluted dust” (8.4%). This is consistent with expectations for the area. Rescaling the extinction of each range bin that is classified as a type of aerosols other than “dust” increases the AOD only by 0.007, accounting for ~11% of the AOD discrepancy. This indicates that the impact of possible misclassification of aerosol type on the AOD retrieval is small for the dust over clouds.
 - The mean AOD value for the full column retrieval using the modeled $S_a = 40$ sr for “dust” is 0.213, 16.4% larger than that for the L2 AOD. This implies that failure to detect those parts of the aerosol layer(s) that lie below the CALIOP detection limit may contribute ~46% to the AOD discrepancy. Aerosols are generally missed above ~7km where the aerosol load is generally very small and to some extent at lower altitudes (e).
 - The distribution of the OWC-derived lidar S_a is not symmetric (h). Its peak is at 42.9 sr, its mean value is 44.8 sr and it has a half width at half maximum (HWHM) of 8.0 sr. By either measure, the standard CALIOP modeled S_a value (40 sr) is smaller than the OWC retrieved value (h), and thus contributes ~54% to the AOD discrepancy. A previous study (Liu et al., 2011) derived a S_a distribution for opaque dust layers (AOD > ~2) over North Africa that has a mean value of 38.5 ± 9.2 sr. The presence of enhanced multiple scattering in these opaque dust layers decreases the effective lidar ratio by 10-20% relative to the transparent layers analyzed with the OWC technique.

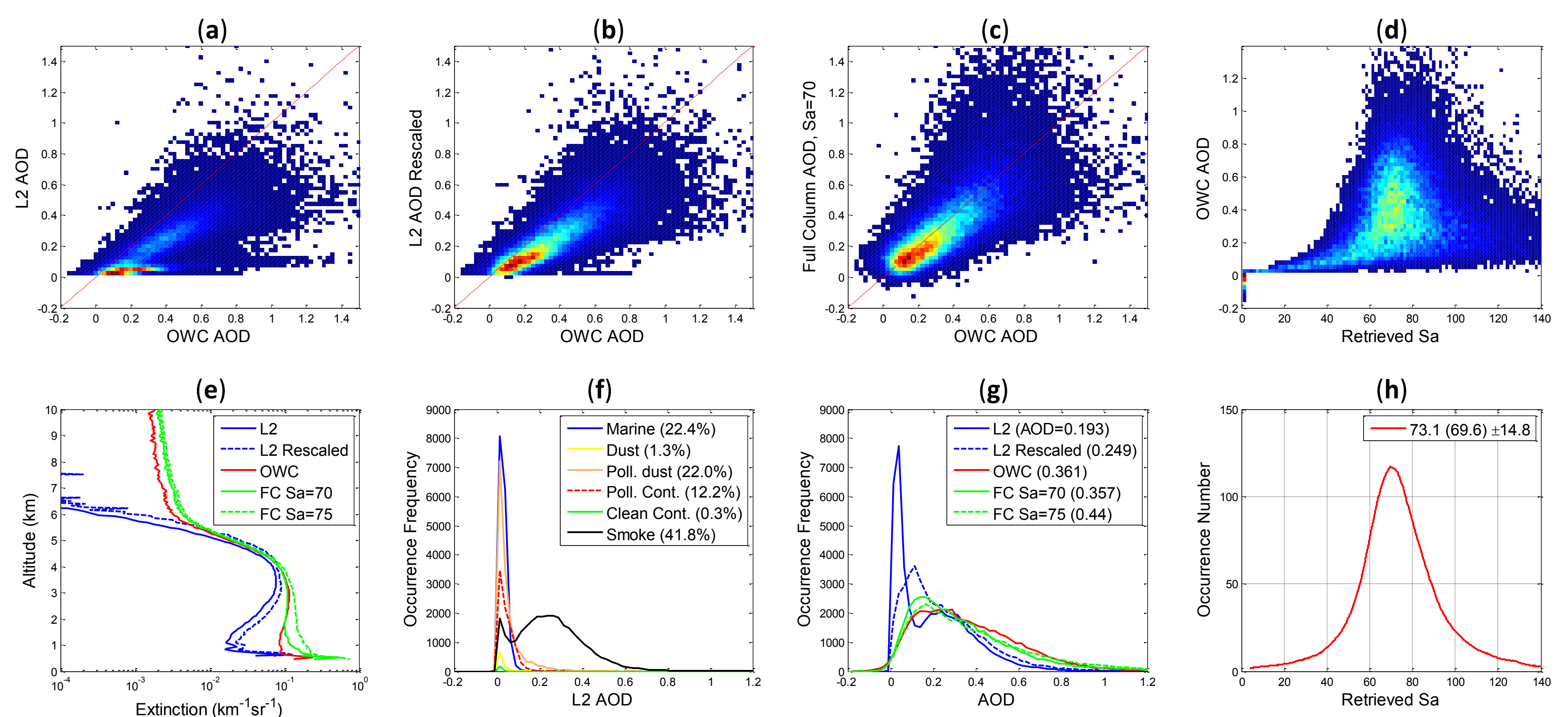
Liu, Z., D. Winker, A. Omar, et al., *JQSRT*, **112**, 204-213, 2011.

Regions Analyzed



CALIPSO Subtypes	Dust Transport Region		Smoke Transport Region	
	Mean AOD	Fraction in L2 AOD	Mean AOD	Fraction in L2 AOD
Marine	0.001	0.62%	0.043	22.4%
Dust	0.163	88.9%	0.003	1.3%
Polluted dust	0.015	8.4%	0.042	22.0%
Polluted cont.	0.001	0.27%	0.024	12.2%
Clean cont.	0.000	0.03%	0.001	0.3%
Smoke	0.003	1.8%	0.081	41.8%
Different Retrievals		Fractional difference relative to OWC AOD		Fractional difference relative to OWC AOD
L2	0.183	-26.2%	0.193	-46.5%
L2 rescaled	0.190	-22.4%	0.249	-31.0%
OWC	0.248		0.361	
FC	0.213	-14.1%, ($S_a = 40$)	0.357	-1.1%, ($S_a = 70$)
FC	0.274	10.5%, ($S_a = 45$)	0.440	21.9%, ($S_a = 75$)

Results for Smoke Transport Region



- Version 3 nighttime data, July – September, 2007 – 2012
- AOD produced by the CALIPSO L2 retrieval for transported smoke has a poorer correlation with the OWC AOD (a) compared with the transported dust. The L2 AOD is smaller than the OWC AOD by 44.1%. The combination of several factors contributes to this large AOD discrepancy.
 - The dominant type of aerosols (f) is “smoke” (41.8%), which is as expected. The next most dominant types are “marine” (22.4%) and “polluted dust” (22.0%). “Polluted dust” is possible for this area. However, “marine” aerosols are unlikely to be present above the opaque clouds found in this region. Rescaling the extinction coefficients of those aerosols classified as types other than “smoke” increases the AOD by 0.056, which corresponds to ~33% of the total AOD discrepancy, and somewhat improves the correlation with the OWC AOD.
 - The mean AOD value for the full column retrieval using the modeled $S_a = 70$ sr for “smoke” is 0.357, 85.0% larger than that for the L2 AOD. This implies that a failure to detect the full extent of the aerosol layers lying above the clouds, whether due to inherent detection limits or algorithm inefficiencies, may contribute ~88% to the AOD discrepancy. The full column retrievals suggest that the L2 retrieval captured the top of smoke layers well, but underestimated the lower part (< 3km) significantly (e). Misdetected aerosol layers appears to be a main cause. Smoke aerosols generally have large absorption at visible wavelengths, causes increased detection difficulties as the signal penetrates into the lower, more highly attenuated parts of a layer (see the above example).
 - The derived lidar S_a peaks at 69.6 sr with a mean value of 73.1 sr and a HWHM of 14.8 sr (h). The modeled S_a value of 70 sr (Omar et al., 2009) appears to be quite representative for the transported smoke when compared with the OWC retrieved S_a (h). The OWC AOD and FC ($S_a = 70$) AOD are different only by ~2.4%.

Omar, A., D. Winker, C. Kittaka, et al., *J. Atmos. Oceanic Technol.*, **26**, 1994-2014, 2009.