Airborne High Spectral Resolution Lidar Measurements of Smoke Aerosol above Clouds during ORACLES

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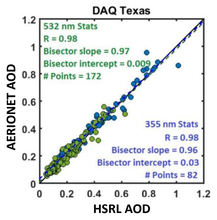
Introduction

The NASA Langley Research Center airborne High Spectral Resolution Lidar (HSRL-2) provided extensive measurements of smoke above shallow marine clouds while deployed from the NASA ER-2 aircraft during the NASA EV-S Observations of Aerosols above Clouds and their Interactions (ORACLES) mission. During the first ORACLES field campaign in September 2016, the ER-2 was deployed from Walvis Bay, Namibia and conducted flights over the southeastern Atlantic Ocean. HSRL-2 measured profiles of aerosol backscattering, extinction and aerosol optical depth (AOD) at 355 and 532 nm and aerosol backscattering and depolarization at 1064 nm and so provided an excellent characterization of the wide-spread smoke layers above shallow marine clouds. We use the HSRL-2 measurements to examine retrievals of AOD above clouds retrieved from A Train active (CALIOP) and passive (OMI, MODIS) sensors. We also present profiles of aerosol microphysical properties such as concentration and effective radius that are derived from the HSRL-2 multiwavelength measurements of backscatter and extinction.

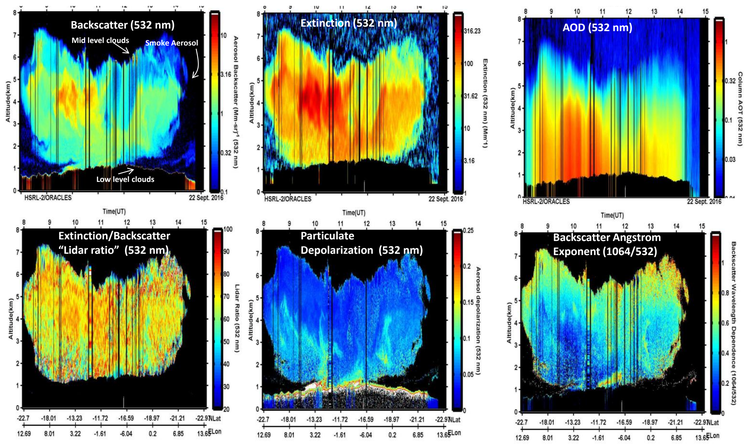
HSRL-2 Data/Measurements/Retrievals:

- Aerosol backscatter, depolarization (355, 532, 1064 nm)
- Aerosol extinction and AOD profiles (355, 532 nm)
- Qualitative aerosol classification
- Mixed layer height
- Multiwavelength aerosol retrievals of particle properties (e.g. effective radius, concentration)

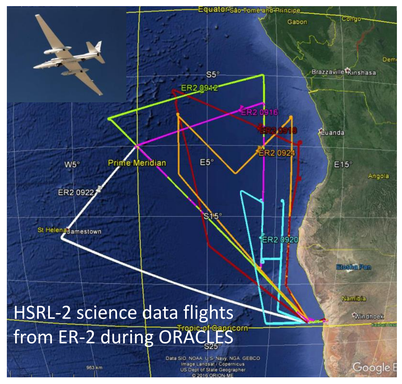
HSRL-2 measurements of aerosol optical depth (AOD) are routinely compared with those from AERONET. Here is an example from the DISCOVER-AQ campaign over Houston in 2013 *(Sawamura et al., 2017, ACPD)*



Examples of HSRL-2 Measurements Sept. 22, 2016



NASA ORACLES Mission



The NASA ORACLES EV-S mission is being conducted to study the climate impacts of African biomass buring aerosols. Smoke produced over Africa is transported over the southeastern Atlantic Ocean and above the subtropical stratocumulus cloud deck. The direct radiative effects of the smoke depend on the optical properties of the smoke as well as the reflectance and coverage of the clouds below. Dependig on the relative vertical location of the smoke aerosols and low level clouds, the smoke can change the cloud condesate, thickness, and lifetime. The airborne HSRL-2 provides an important suite of measurements to characterize the smoke and cloud cloud heights and thicknesses as well as the smoke layer optical properties. The HSRL-2 measurements also provide an important means to evaluate A-Train (MODIS, OMI, CALIOP) retrievals of above cloud aerosol optical depth (ACAOD).

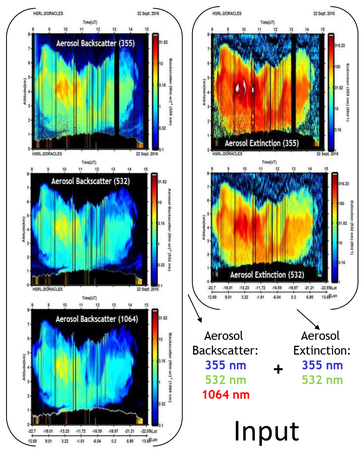
Summary

- NASA LaRC airborne HSRL-2, deployed on the NASA ER-2, characterized smoke layer properties over the Southeastern Atlantic Ocean during the first ORACLES mission
- Smoke layer was confined to altitudes between 1 and 6 km
- Low level clouds were ubiquitous and were confined to altitudes below 1 to 1.5 km
- Smoke layer was in contact with low level clouds over 40% of the time
- Aerosol-free gap layer was less than 1 km thick over 70% of the time
- CALIOP, MODIS, and OMI above cloud aerosol optical depths (ACAOD) were examined using HSRL-2 data
- CALIOP above cloud aerosol optical depths (ACAOD) computed using version 4 operational retrieval were a factor of 2-3 lower than HSRL-2 ACAOD
- CALIOP ACAOD computed using opaque water cloud technique (Hu et al., 2007) were in excellent agreement with HSRL-2 ACAOD (bias and rms differences less than 0.05 and 10%)
- OMI ACAOD (OMACA) (354, 500 nm) was in generally good agreement with HSRL-2 ACAOD (bias differences less than 0.1 (15%); rms differences less than 0.2 (33%))
- MODIS ACAOD (550 nm) was also in generally good agreement with HSRL-2 ACAOD (bias differences less than 0.1 (26%); rms differences less than 0.13 (34%))

Acknowledgements

We thank the ER-2 pilots, ground crew, and managers for their excellent support during ORACLES. We also thank the ORACLES team for their hard work in conducting and supporting the mission.

Multiwavelength "3β + 2α" Aerosol Retrievals using HSRL-2 Data from Sept. 22, 2016



Aerosol Backscatter: 355 nm + 532 nm + 1064 nm

Aerosol Extinction: 355 nm + 532 nm

Input

Multiwavelength lidar retrieval algorithms (Müller et al, 1999; Veselovskii et al. 2002; etc)

lidar measurements | particle size distribution

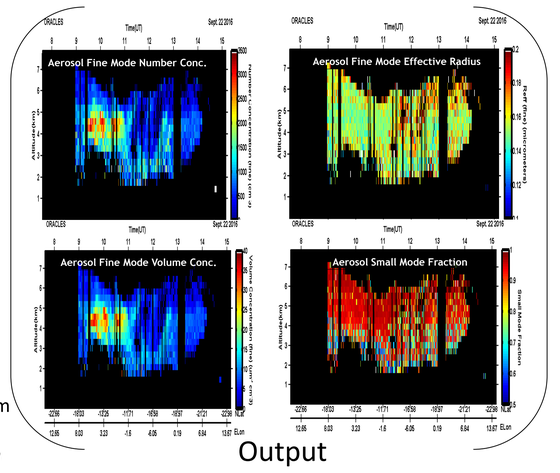
INVERSION

$$\beta(\lambda) = \int K_\beta(r, m, \lambda) v(r) dr$$

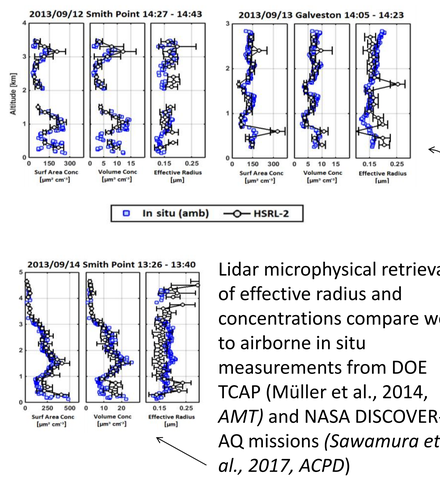
$$\alpha(\lambda) = \int K_\alpha(r, m, \lambda) v(r) dr$$

size, refractive index, wavelength

3β+2α (i.e. 3 backscatter + 2 extinction) considered the minimum information content necessary for microphysical retrievals (*Bockmann et al*, 2005)

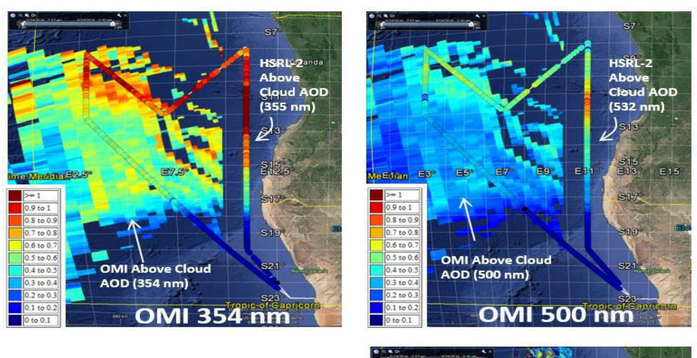


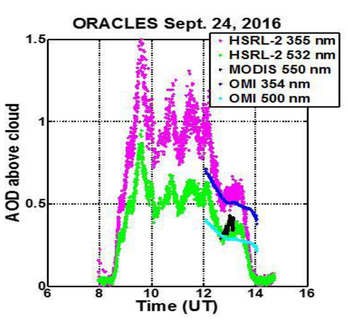
Output

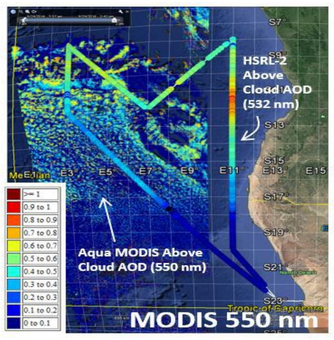


Lidar microphysical retrievals of effective radius and concentrations compare well to airborne in situ measurements from DOE TCAP (Müller et al., 2014, *AMT)* and NASA DISCOVER-AQ missions *(Sawamura et al., 2017, ACPD*)

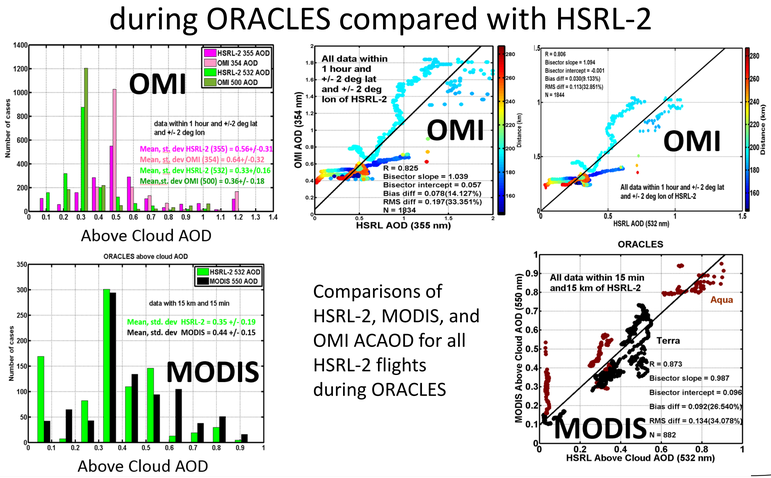
Above Cloud AOD derived from MODIS and OMI on Sept. 24, 2016 compared with HSRL-2





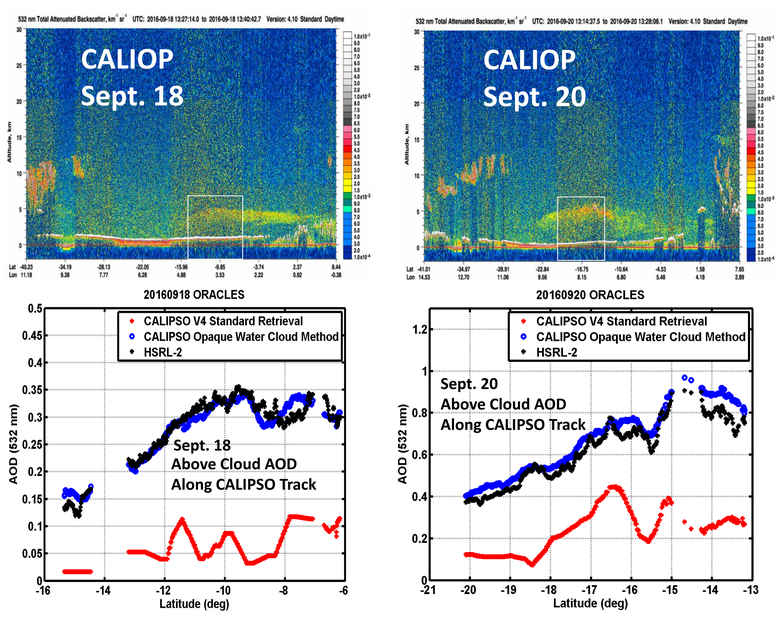


Above Cloud AOD derived from MODIS and OMI during ORACLES compared with HSRL-2

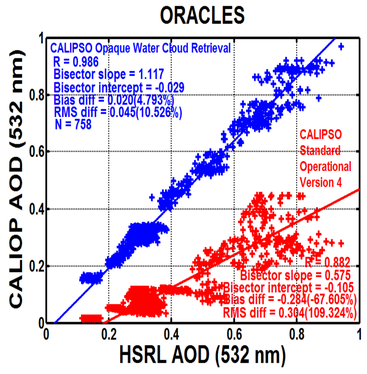


Comparisons of HSRL-2, MODIS, and OMI ACAOD for all HSRL-2 flights during ORACLES

Above Cloud AOD derived CALIOP on Sept. 18 and 20, 2016 compared with HSRL-2

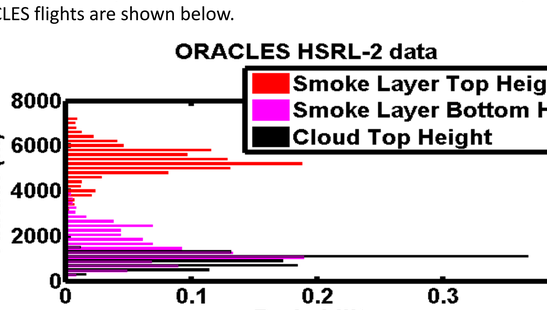


HSRL-2 measurements are used to examine CALIOP retrievals of above cloud AOD (ACAOD). The CALIOP V4 operational product uses a layer detection scheme combined with an extinction retrieval algorithm that requires an assumption of the aerosol extinction/backscatter ratio (Winker et al. 2009). The CALIOP opaque water cloud method uses layer-integrated attenuated backscatter and depolarization of opaque water clouds and assumption of cloud extinction/backscatter ratio of 18.9 sr (Hu et al., 2007).



HSRL-2 measurements are used to examine OMI and MODIS retrievals of above cloud AOD (ACAOD). The OMACA ACAOD product relies on the spectral contrast produced by aeosol absorption in two near-UV measurements (354 and 388 nm) to derive ACAOD (Torres et al., 2012). The MODIS ACAOD retrievals rely on the spectral contrast in aerosol absorption derived from reflectance measurements at six MODIS channels from the visible to the shortware infrared (Meyer et al., 2015).

Example of smoke and cloud layers measured on Sept. 22, 2016



HSRL-2 aerosol backscatter measurements are used to characterize smoke and cloud layer heights and thicknesses as well as the thickness of the aerosol-free layer between the smoke and cloud layers. The results for all HSRL-2 measurements acquired during all the ORACLES flights are shown below.