Radiation, Smoke and Clouds Observed in the Southeastern Atlantic with the Research Scanning Polarimeter during ORACLES

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Background

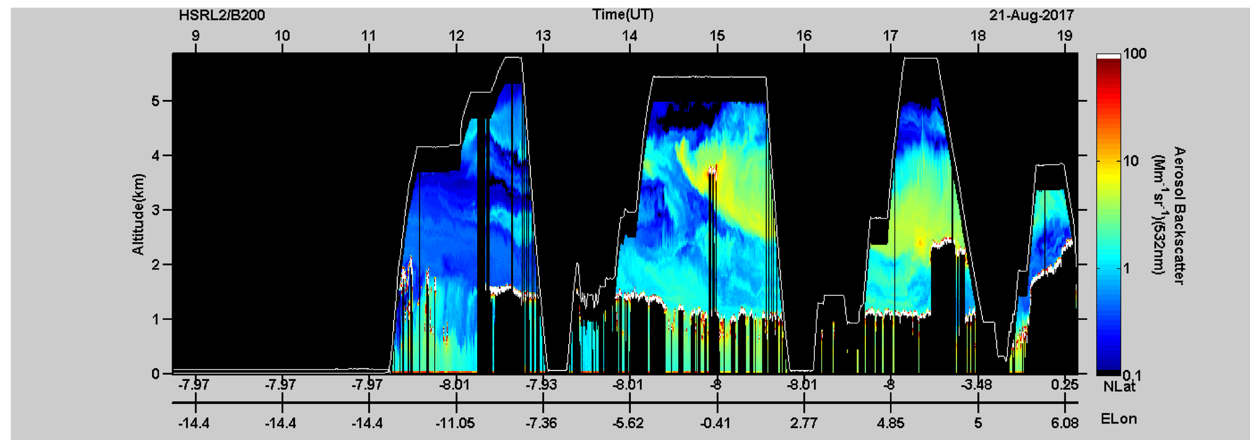


Figure 1: HSRL2 532 nm backscatter observations during transit flight from Ascencion Island to Sao Tomé on 20170821

- During August, September and October of each year smoke from biomass burning on the African continent is transported west over the the semi-permanent Namibian stratocumulus deck.
- The NASA ObseRvations of Aerosols above CLouds and their intEractionS (ORACLES) suborbital mission is making observations of the clouds and aerosols in these three months in three different years to better understand how the aerosols a
- The smoke can indirectly affect the clouds by providing a source of cloud condensation nuclei (CCN) that increases the number of cloud drops (Twomey 1977).
- The smoke particles absorb light and can therefore also significantly affect the radiation field above the cloud.
- Depending on how strongly the smoke particles absorb and how bright the clouds are the smoke may make the scene appear brighter (cooling) or darker (warming), a concept called the critical reflectance that was introduced by Fraser and Kaufman (1985) in the context of aerosol remote sensing over land surfaces.

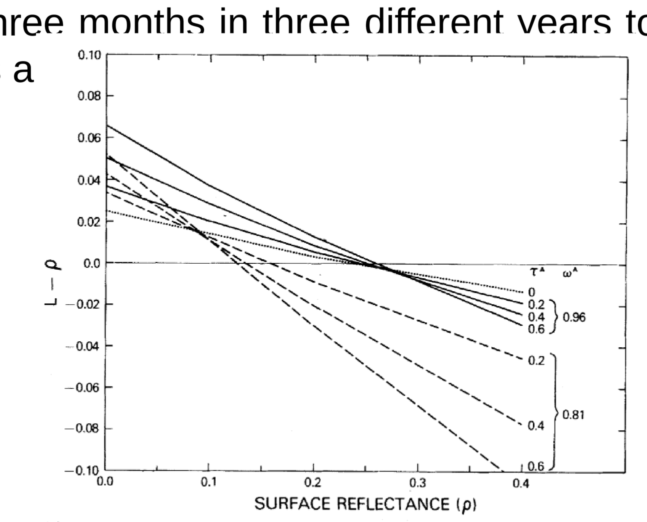


Fig. 2. The radiance of the Earth-atmosphere system minus the surface radiance (in reflectance units) for nadir observation, as a function of the surface reflectance. The total aerosol optical thickness τ^A and the single scattering albedo ω^A are indicated for each line. The solar zenith angle is 40°, the wavelength is 610 nm, and $\nu = 3$.

Research Objective

- Determine the effect of smoke on RSP retrievals of cloud optical depth and cloud droplet number concentration (CDNC) during the ORACLES campaign and develop methods to correct for them
- Determine the radiative effect of smoke aerosols above clouds in the Southeastern Atlantic during the ORACLES field experiments using remote sensing measurements from the Research Scanning Polarimeter

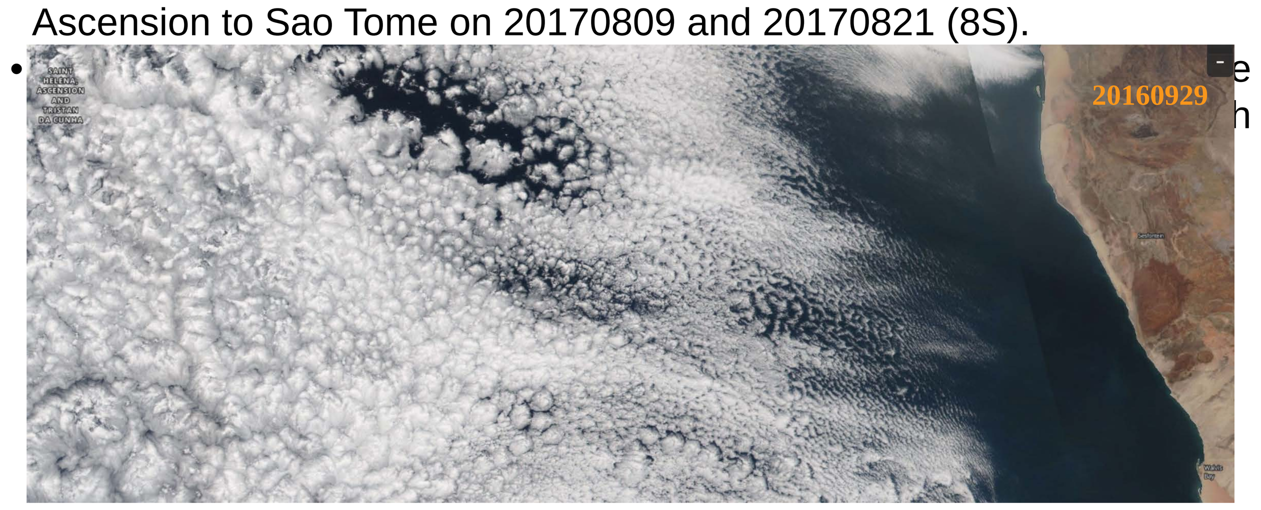
Measurements

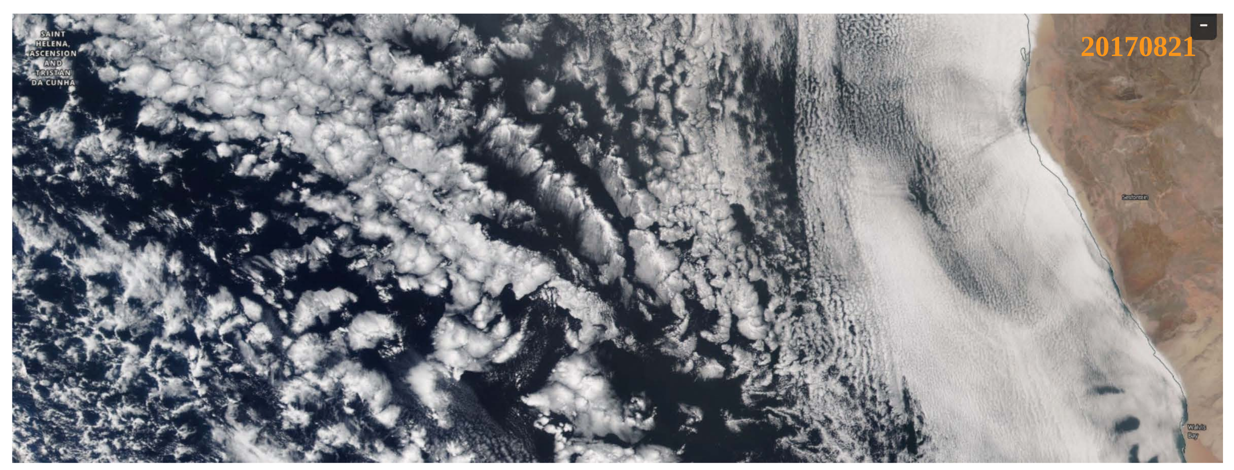
Research Scanning Polarimeter

- Prototype for Aerosol Polarimetry Sensor on the Glory satellite (2011) (Cairns et al., 1999)
- Along track scanning - 152 viewing angles per scene (±60°);14 mrad field of view
- Polarimetric and full intensity measurements in the visible and shortwave infrared over 9 bands: 410, 470, 555, 670, 864, 960, 1593, 1880, 2263 nm
- Measures aerosol: OT, R_{eff}, V_{eff}, R.I., single-scattering albedo, morphology
- Measures cloud: OT, R_{eff}, V_{eff}, CTH, cloud phase, ice asymmetry parameter, CDNC

Measurements

- Data for this analysis was collected during the NASA ORACLES (ObseRvations of Aerosols above CLouds and their intEractionS) in September 2016 and August 2017
- The RSP was aboard the P-3 aircraft flying at a range of altitudes during ORACLES in 2016 and 2017 and also on the high-altitude ER-2 aircraft during ORACLES in 2016
- Here we focus on observations close to 8S from Ascension Island along tracks heading to the East. This allows us to contrast the cloud conditions from 20160929 during the ER-2 transit from Walvis Bay to Recife, (9S) that passed over Ascension Island, with the transits from Ascension to Sao Tome on 20170809 and 20170821 (8S).

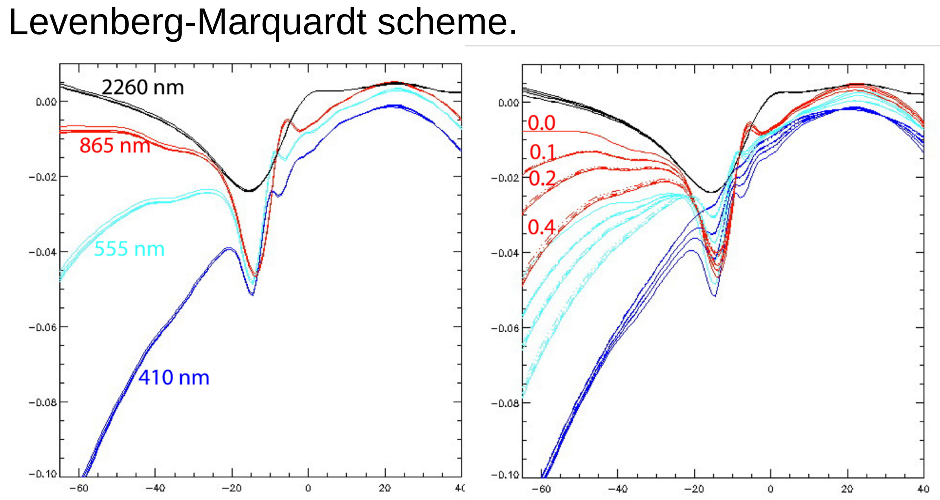




- The ORACLES domain is dominated by low-lying stratus clouds, although the macroscopic structure in 20170821 is very different to that in 20160929.

Method

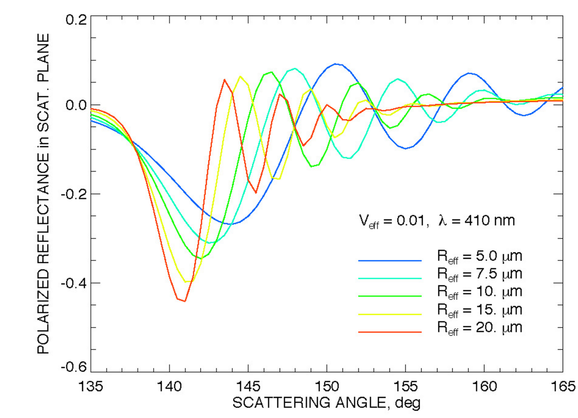
- Preliminary retrievals of the optical thickness, size and complex refractive index of aerosols above clouds from 20170821 are performed using an iterative Levenberg-Marquardt scheme.



- Panel above shows effect of clouds and aerosols on polarized reflectance. Left shows (small) effect of cloud optical thickness (increases from 5 to 20). Right shows (large) effect of aerosol optical thickness (AOT) (increases from 0 to 0.4). Polarized reflectance can therefore be used in retrievals without including the cloud optical thickness (e.g. Knobelspiesse *et al.* 2011).

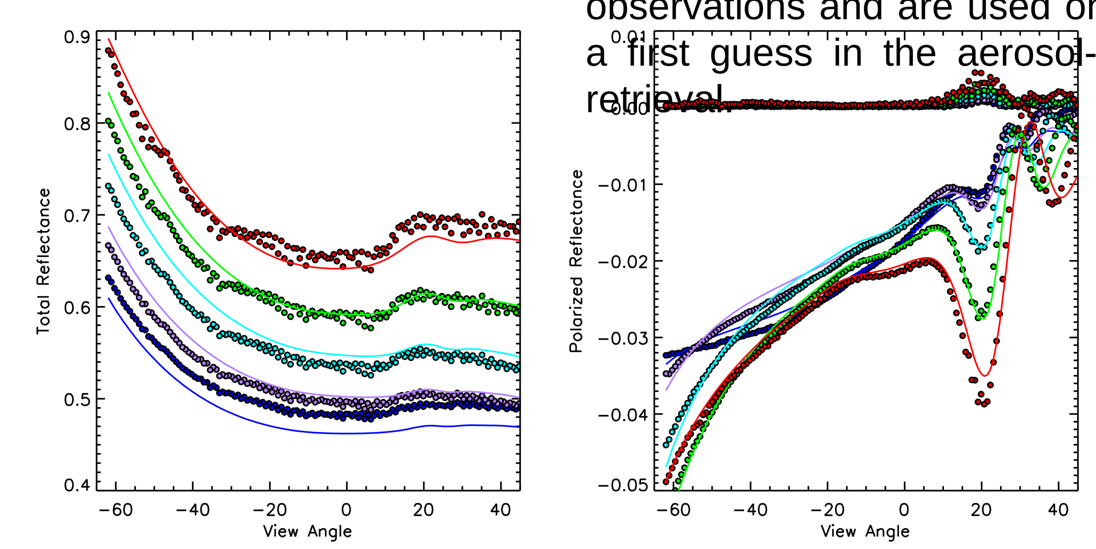
Method

Cloud Retrievals



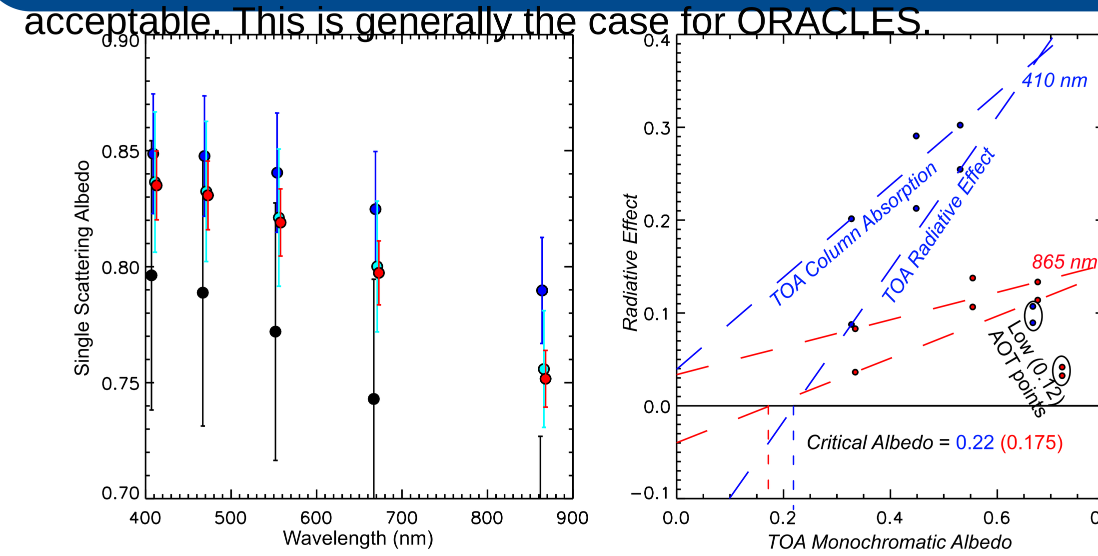
- RSP cloud droplet size retrievals use the angular variations in the polarized reflectance of the cloud bow, not their magnitude. This is not affected by aerosols and so is fixed in the aerosol/cloud optical depth retrieval (Alexandrov et al. 2012). RSP cloud optical thickness/liquid water path estimates use the absolute magnitude of the total radiance observations and are used only as a first guess in the aerosol-cloud retrieval.

Aerosol-Cloud Retrievals



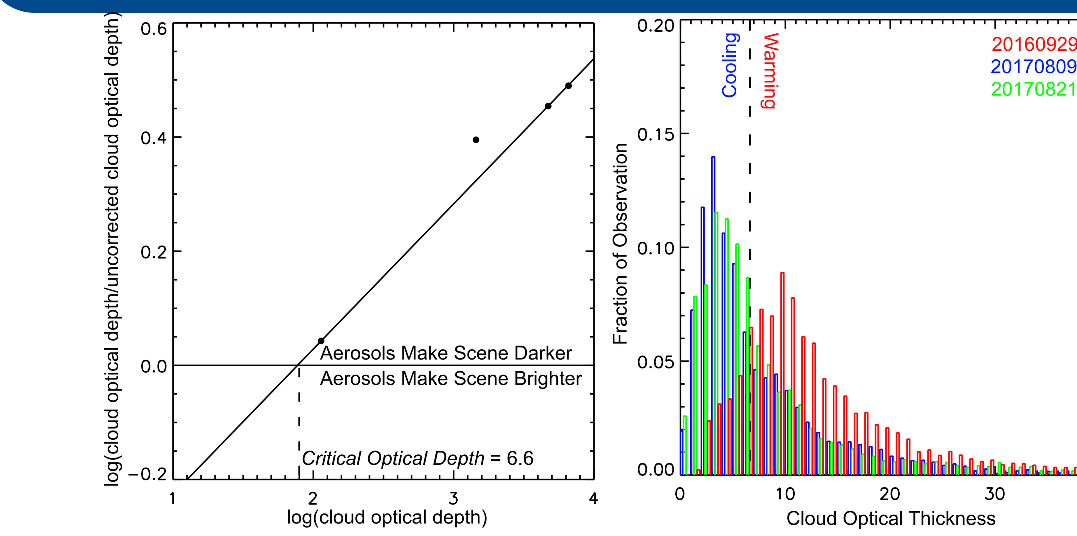
- The 5%/95% values of the HSRL2 532 nm backscatter integrated from the plane to cloud/surface are used to define the aerosol layer thickness.
- First guess for aerosol optical depth (AOD) and size uses table look up applied only to polarized reflectance observations.
- Iterative Levenberg-Marquardt retrieval is used to retrieve a best estimate of aerosol optical depth, complex refractive index and cloud optical thickness using the polarized reflectance and the Degree of Linear Polarization.
- The sample model/observations fit above indicates that the 1D radiative transfer model being used in the iterative retrieval is acceptable. This is generally the case for ORACLES.

Results



- The key determinant as to whether smoke above clouds will make them brighter, or darker is the Single Scattering Albedo (ssa, which is the fraction of light that is scattered at each collision with a smoke particle).
- Here we show the retrievals of SSA for a sample of locations above the smoke plumes that were shown in Fig. 1, together with their uncertainties. The optical depths of these samples vary from 0.12 (black) to 0.66 (blue).
- As part of the retrieval process the column absorption is computed and the radiative effect is evaluated by calculating the radiation field without aerosols, once the retrieval has converged. The albedo with aerosols is then subtracted from that with aerosols.

Results



- The critical albedo can alternatively be regarded as a critical cloud optical depth above which the TOA reflectance is decreased by aerosols (left figure above).
- The critical optical depth in this case is 6.6. In the right figure we show this critical optical depth on the cloud optical thickness histograms from the flight along 9S and over Ascension in 2016 (red) and the two flights along 8S from Ascension in 2017.

Conclusions

Conclusions

- The data shown here is along constant latitude lines (8S/9S) from Ascension (14E) to the Greenwich meridian.
- The cloud regime in 2017 is generally in a cooling regime because the cloud optical depths are low, whereas the majority of clouds in 2016 are in a regime where aerosols will warm the atmosphere.

Future Work

- Compare optical depths and intensive lidar variables with HSRL2 instrument.
- Compare aerosol sizes and ssa with in situ observations.
- Evaluate impact of aerosols on CDNC estimates from RSP

Collaboration

- 4STAR and SSFR observations have already been used to evaluate the aerosol radiative effect. RSP observations need to be integrated with this existing understanding.

Acknowledgements

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