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Swelling of transported smoke from savanna fires over the Southeast Atlantic Ocean

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ABSTRACT

We use the recently released Cloud Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) Version 4.1 (V4) lidar data to study the smoke plumes transported from Southern African biomass burning areas. Significant improvements in the CALIPSO V4 Level 1 calibration and V4 Level 2 algorithms lead to a better representation of their optical properties, with the aerosol subtype improvements being particularly relevant to smoke over this area. For the first time, we show evidence of smoke particles increasing in size, as demonstrated by their particulate color ratios, as they are transported over the South Atlantic Ocean from the source regions over Southern Africa. We hypothesize that this is due to hygroscopic swelling of the smoke particles and is reflected in the higher relative humidity in the middle troposphere for profiles with smoke. This finding may have implications for radiative forcing estimates over this area and is also relevant to the ORACLES field mission.

1. Introduction

The impact of different types of aerosols on our environment is not very well understood and there is an ever-increasing need to characterize the various aerosol types in different parts of the globe (IPCC, 2013). In particular, the smoke from biomass burning needs to be better understood because of the important radiative effects of black carbon (Bond et al., 2013), and because forest fires have been growing in size and frequency in many parts of the world. As such, there have been many studies of smoke from biomass burning, its properties and their evolution with time (e.g., Reid et al., 2005; Semeniuk et al., 2007; Saide, 2015). Some of these properties depend upon the location and type of burning (e.g., smoldering or flaming).

Over Southern Africa, savanna burning occurs every year between June and October and constitutes the largest source of biomass burning smoke over the globe (Van der Werf et al., 2010; IPCC, 2013). The smoke plumes from these fires are transported over the Southeast Atlantic Ocean within 5–7 days, overlying one of the largest low altitude extended stratus cloud decks anywhere on the globe, which has consequences for radiative forcing estimates in this area. The direct radiative forcing can be complex under such circumstances, changing from cooling in absence of clouds to potentially heating at the top of the atmosphere, depending upon the aerosol loading as well as the albedo and fractional coverage of the underlying clouds (Chand et al., 2009; Wilcox, 2012; Yu and Zhang, 2013). Passive satellite sensors have generally limited utility here because the aerosol retrievals are done mostly for cloud-free conditions. However, progress has been made in recent years, with researchers exploiting the spectral dependence of the absorption of the upwelling radiation by the aerosols to simultaneously retrieve the cloud and aerosol optical depths for cloudy scenes (Jethva et al., 2013, 2016; Meyer et al., 2015; Sayer et al., 2016). Multi-angle polarization information from the POLDER instrument has also been utilized to retrieve the AOD (Waquet et al., 2013; Peers et al. 2015; Deaconu et al., 2017). However, passive sensors cannot provide vertically resolved information on these clouds and aerosols, which is crucial for a proper assessment of the radiative forcing, both direct and indirect. This vertical information has become possible in the last decade because of the space borne lidar CALIPSO, which has been providing high quality measurements of the aerosol vertical profiles globally since June 2006 (Winker et al., 2009). Measurements from CALIPSO have been used to derive accurate estimates of radiative forcing of the aerosols above clouds in this region (Chand et al., 2008, 2009).

In the CALIPSO data processing sequence, the attenuated backscatter data are first examined to detect layers using a thresholding algorithm (Vaughan et al., 2009) and then the layers are classified as either a cloud or aerosol (Liu et al., 2009). The aerosol layers are subsequently assigned various subtypes based on their optical properties (layer integrated attenuated backscatter and estimated particulate depolarization ratio), the underlying surface type and altitude of the

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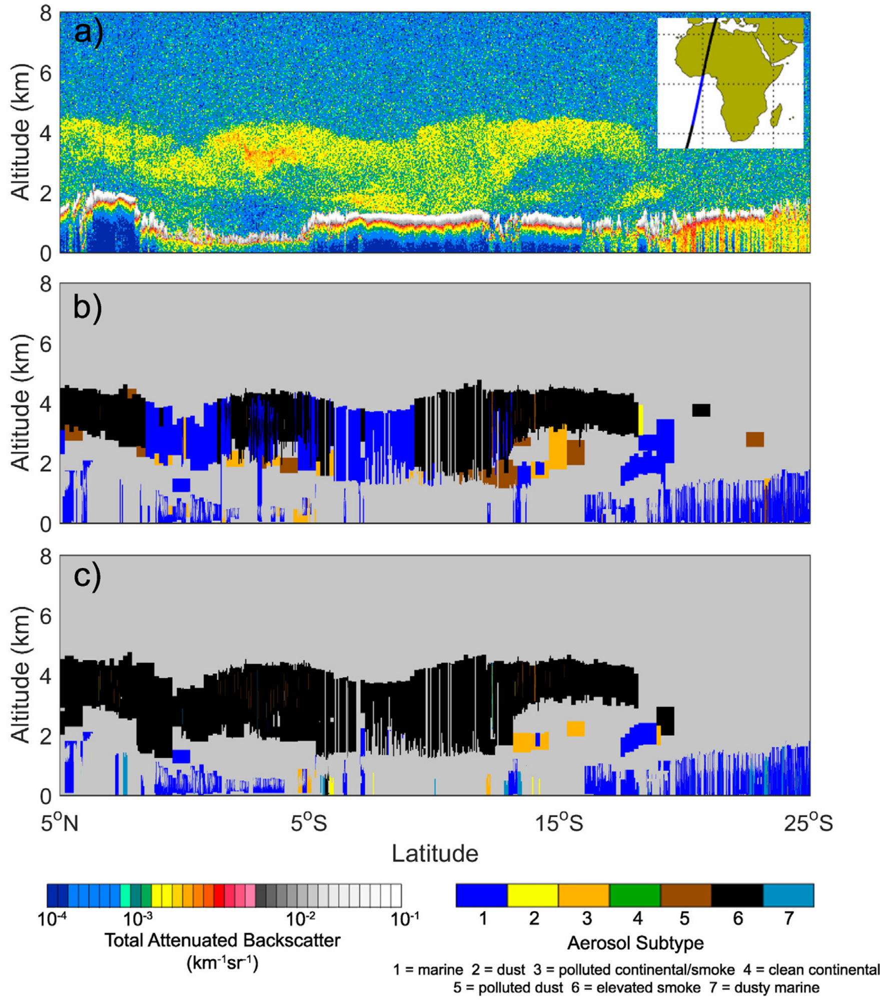

Fig. 1. CALIPSO browse images from September 5, 2010 of a) 532 nm attenuated backscatter coefficients; b) aerosol subtypes reported in the V3 data products; and c) aerosol subtypes reported in the V4 data products. (For interpretation of the references to color in this figure, the reader is referred to the web version of this article.)

layer (Omar et al., 2009). The November 2016 release of Version 4.1 (V4) of the CALIPSO lidar Level 2 data products incorporates significant improvements to the retrieval algorithms, including the aerosol subtype assignments. These changes have improved the global characterization of aerosol types using the CALIPSO measurements. In particular, there was a significant anomaly in the subtyping over the Southeast Atlantic in earlier versions, where many smoke layers were misclassified as marine layers. This has since been addressed in V4. Many more smoke layers are now identified over the Atlantic, thus presenting a good opportunity for further study of these extensive and regularly occurring smoke plumes. In particular, the evolution of the optical properties of these smoke plumes as they are transported great distances over the South Atlantic may now be better characterized.

In this short report, we use V4 CALIPSO data to present evidence of the evolution of size of the smoke particles being exported from the Southern African savanna burning zones. We show that these particles tend to increase in size as they are transported large distances over the ocean. Recent work has noted a close correlation between the smoke plumes and moisture over the South east Atlantic with a general increase in mid-tropospheric moisture in polluted conditions (Adebiyi et al., 2015). While most constituents of smoke plumes are generally hydrophobic, aging and oxidation processes during the transport might make them hydrophilic, and the signatures of this behavior could be discerned in the relative humidity data. This result will have implications for regional radiative forcing as well as for simulations of the transport of these extensive smoke plumes and should be of interest to the currently ongoing ObseRvations of Aerosols above CLouds and their intEractionS (ORACLES) aircraft mission studying the smoke and its interaction with clouds over the same area (Zuidema et al., 2016).

2. Data

We use the CALIPSO V4 level 2 aerosol profile product, which reports height-resolved profiles of the total backscatter and extinction coefficients at 532 nm and 1064 nm, as well as the perpendicular backscatter coefficients at 532 nm for all layers detected. The horizontal resolution of the data is 5 km while the vertical resolution is 60 m up to 20 km and 180 m above that. As part of the V4 level 2 updates, the retrieval algorithms were optimized to take maximum advantage of the changes in the V4 level 1 data, released earlier, with significant improvements in both the 532 nm and 1064 nm channel calibrations (Getzewich et al., 2015). In particular, the improvement in 1064 nm channel calibration makes it feasible to study the optical properties of particles using both the channels with a higher degree of confidence in this new data set. We shall use the particulate color ratio (χ) of the aerosols, which is defined by the relation:

$$\chi(z) = \frac{\beta_{1064}(z)}{\beta_{532}(z)} \quad (1)$$

where $\beta_{1064}(z)$ and $\beta_{532}(z)$ are the particulate backscatter coefficients