DUSTER lidar: Transatlantic transport of aerosol particles from the Sahara and other sources: first results from the recently installed lidar and sunphotometer in Natal/Brazil

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ABSTRACT

The lidar confederative network for monitoring optical properties of aerosol on Latin America, LALINET, faces an important challenger to cover a large area of Latin America with so few lidar systems. Currently in Brazil there are only three operative lidar systems, two operating on Southeastern region and other on North region of Brazil. Taking into accounting the large dimension of Brazilian territory there is a lack of lidar system monitoring in several regions. In 2014 Laser Environmental Application Laboratory (LEAL) at Nuclear and Energy Research Institute (IPEN) together with Federal University of Rio Grande do Norte (UFRN), have started the first efforts to install a depolarization lidar system at the city of Natal-RN ($5^o50'29''\ S$,$35^o11'57''\ W$, 0 m asl), in the Northeast region of Brazil. This new lidar station intends to be in the future integrated to the LALINET network, and has as a first aim to detect and to identify aerosol layers from Saharan dust and biomass burning type arriving from African continent. To examine these transports it is paramount to have a temporally and spatially well resolved observational platforms, which will be able to describe with accuracy the transport patterns followed by these aerosol layers over the Atlantic. To yield a good coverage based on the previously mentioned requirements satellite-based platforms are very well suited, but unless a geostationary system is provided a reasonable temporal representativeness may not be achieved. Our current study is devoted to the first results aiming to detect and identify aerosol layers arriving over the Northeastern region of the South American continent, with a lidar and a sun-photometer recently installed in the city of Natal. Here we present the first aerosol observation results with the lidar system and the sunphotometer carried out from January through May 2016 with the indication of potential dust and other-type aerosol layers through some backscatter profiles.

Keywords: Aerosols, Dust, Depolarization, Long Range Transport

1. INTRODUCTION

Long range transport of dust is a well known phenomenon important in atmospheric radiative budget with global impact on climate, air quality and human health.[1–5] It is estimated that about 3 billion tons of dust from the Sahara are transported per year and there are considerable suspicions about the influence of these aerosols on the radiative balance of Earth thus creating an observation network for such environmental occurrence is a challenge which requires a lot of resources. The existing observation networks[6] are concetrated regionally and there still is some gaps to be filled in order to obtain full global coverage. In South America LALINET is one of such networks with the goal of measuring biomass burning plumes, volcanic ashes and dust transport into and out of

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the continent[7] and more recently a lidar system was deployed at Natal-RN ($5^o50'29'' \ S$,$35^o11'57'' \ W$, sea level), in Brazil's northeastern region.

The so called *window of opportunity* to observe dust transported into the continent at these latitudes is strongly influenced by the ITCZ (Intertropical Convergence Zone) migration putting this region under a variety of circulation patterns similar to those observed in the Caribbean counterpart around Barbados.[5] Given these mechanisms the dust transport into this region occurs most likely during December, January and February (DJF) at $\approx 5^o$ N and the less likely chance to observe this phenomenon should be in June, July and August (JJA) at $\approx 20^o$ N. This migration is strongly affected major oscillations such as ENSO and El Niño.[8] The predominant observed transport take place westwards of the African continent under strong influence of trend winds with some portions towards north over the Mediterranean sea. This pattern of transport follows a trend towards the Caribean in JJA months and towards South America (SA) in DJF. This trend was tracked and confirmed by CALIPSO[9] and a seasonal dependence was also observed in the measured plume altitude, which was higher in JJA and slightly above the Planetary Boundary Layer (PBL) in DJF. In SA the transport over the Amazon basin is a well known process.[10]

The city of Natal is the capital of the state of Rio Grande do Norte (RN), located at the coast in Northeastern Brazil. The city of Natal and surroundings comprise a large diversity of different ecosystems, such as dune landscape, Mangrove- and Atlantic rain forests. The city has an area of approximately 170 km^2 and an increasing population of about 870,000 inhabitants, according to the Brazilian Institute of Geography and Statistics (IBGE) in 2015. The climate of Natal is considered tropical wet with dry summer (austral) and an annual mean temperature of 26^oC. The temperature may drop to 24^oC in winter and reach about 30^oC during summer, according to the National Institute for Meteorology (INMET). Solar irradiation yields elevated indices of up to 3,000 hours of insolation per year. According to the climate normals, the average precipitation is 1.465 mm/year (INMET) and occurs primarily from March through June with a maximum in April (265 mm).

DUSTER is a depolarization lidar system originally designed to detect and identify aerosol dust layers from Saharan Desert which are transported across the Atlantic Ocean. These observations should be in coordination with a sunphotometer (CIMEL Ce318 radiometer included in AERONET) deployed in Natal and also with CALIPSO's observation of these transport events.[11]

The DUSTER operation will be on a regular basis with the purpose of being incorporated to LALINET and creating a database of African dust transportation, and to characterize the optical properties of this material so that these results can be assimilated by a radiative transfer model, as well as atmospheric chemistry models, allowing to quantify the impact of this event in regions such as the Amazon and the Brazilian Northeast.

This multi-wavelength elastic depolarization system was developed by the Center of Lasers and Applications at IPEN for performing vertical profiling of particle aerosols optical properties, i.e. backscatter and extinction coefficients and particle depolarization ratio at 532 nm. After tests DUSTER was disassembled at IPEN/São Paulo, and transported to Natal, at Universidade Federal do Rio Grande do Norte. There it was setup in a 40 foot container specially adapted to receive the lidar system. Also a sunphotometer was ceded by University of Granada, Spain, and added to the AERONET[12] network to make co-located measurements and aid in achieving aerosol microphysical properties.

The first measurements carried out with the depolarization channels started in February 2016, and the retrieved vertical profiles of particle backscatter coefficients are here presented as well three-dimensional air mass backtrajectory data to identify the particle sources.

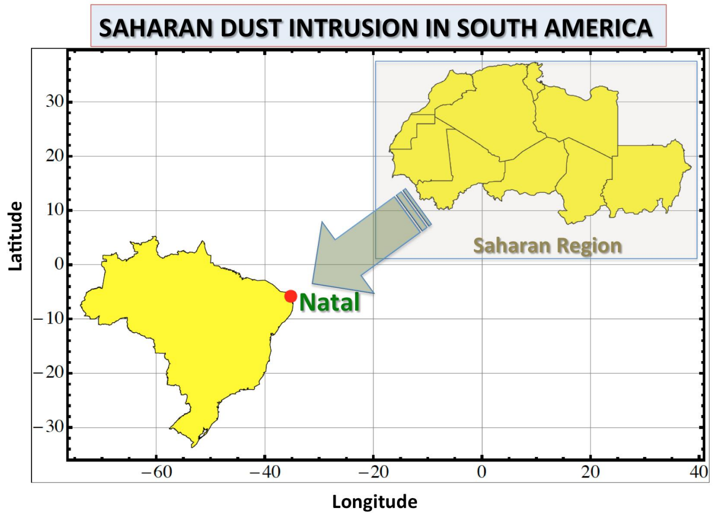

Figure 1. Dust track direction and trajectory from Saharan region towards Natal.

2. SYSTEM SETUP

2.1 DUSTER LIDAR

The lidar system was conceived to measure aerosols and with emphasis in identifying dust particles. The system has 4 channels at 1064 nm, 532 nm ($\|$), 532 nm ($\perp$) and 355 nm coupled to a 300 mm Cassegranian Carbon-Plastic telescope developed at Optosystems (www.optosystems.ru). Each channel has interference filters to block sunlight background with bandwidths of (25 nm FWHM at each channel). The laser source emits at 1064 nm, 532 nm and 355 nm, with energy per pulse of about 300 mJ, 150 mJ and 90 mJ, respectively. The detection box has an Avalanche Photo-diode (APD) for 1064 nm radiation detection and 3 photomultipliers, for both polarizations at 532 nm and 355 nm. Their signal is digitized by a transient recorder operating in analog and photoncounting modes (Licel GmbH).

The depolarization measurement capability of DUSTER let to distinguish and to identify unambiguously the volumen linear depolarization ratio parameters. This parameter is defined as the ratio of the crosspolarized lidar return signal to the parallel-polarized backscatter signal, [*] the signal are selected in the optical reception box by means of a polarizing beamsplitter cube (PBC). To retrieve the linear volume depolarization ratio δ_ν one has to follow a calibration procedure which involves the amplification factor $\eta*$ by applying a $\Delta 90^o$ calibration using a $\lambda/2$ plate (HWP).[13,14] The HWP was located in front of laser emitter and several measurements should be taken to get the amplification due to polarization changes.

2.2 SUNPHOTOMETER

The AErosol RObotic NETwork (AERONET)[12] is an international system of ground-based sun photometers that provides automatic sun and sky scanning measurements. The sunphotometer located at Natal is setup about 200 m from the DUSTER Lidar system. This performs aureole and sky radiances measurements in order to retrieve the Aerosol Optical Thickness for aerosols at several wavelengths. The standard measurements are taken in the completely spectral interval, and their number depends on the daytime duration. Besides the AOD, it is possible to obtain the aerosol size distribution, the phase function, single scattering albedo and extinction-to-backscatter ratio. The sunphotometer like the others in this network is periodically calibrated by a remote computer or locally., in this case this unit is calibrated in the facilities of AERONET-EUROPE in the frame of ACTRIS (actris2.nilu.no). This procedure assures measurement accuracy to within 13%. However, various instruments,

[*]Strictly the Volume Depolarization is defined as the ratio of atmospheric backscatters, but it is computed as the ratio of signals

Table 1. DUSTER LIDAR SPECIFICATIONS
Table 2. LIDAR system setup.

Laser	
Laser type	Nd:YAG Laser (BRILLIANT Quantel SA)
Wavelengths	355, 532, 1064 nm
Pulse energy	100 mJ (355 nm), 200 mJ (532 nm) and 400 mJ (1064 nm)
Repetition rate	20 Hz
Pulse duration	(7 ± 2) ns
Receiver	
Optical design	300 mm diameter cassegranian telescope
Focal length	2000 mm
Field of view	≤ 1 mrad
Detection	@ 1064 nm @ 532 nm @ 355 nm
Transient recorder	Licel (TR20-80) 10 - 250 MHz bandwidth

calibration, atmospheric, and methodological factors can influence the precision and accuracy achieved and the total uncertainty in the AOT might reach around 5 10%.[15]

2.3 CALIPSO

The CALIPSO satellite was launched in April 2006 and flies in a 705 km sun-synchronous polar orbit with an equator-crossing time of about 13:30 local solar time, covering the whole globe in a repeat cycle of 16 days.[16] The primary instrument aboard CALIPSO is the Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP), a two-wavelength laser (532 nm and 1064 nm) operating at a pulse repetition rate of 20.16 Hz. The CALIOP data products are assembled from the backscattered signals measured by the receiver system and are divided in two different categories. Level 1 products are composed of calibrated and geolocated profiles of the attenuated backscatter signal and are separated into the total attenuated backscatter profile at 1064 nm, the total attenuated backscatter profile at 532 nm (i.e., the sum of parallel and perpendicular signals) and the perpendicular attenuated backscatter signal at 532 nm. The level 2 products are derived from the level 1 products and three different level 2 products are distributed according to the layer products, profile products and the vertical feature mask (VMF). The set of CALIPSO algorithms uses an aerosol classification scheme to assign each aerosol layer to one of the six aerosol types, namely dust, biomass burning, clean continental, polluted continental, marine, and polluted dust.[17] CALIOP data can provide the layer top and base altitude of dust aerosol over the DUSTER site and also helps to detect the aerosol dust transported over the Atlantic to South America.

3. RESULTS

DUSTER started its operation in February 2016 following LALINET's measurement schedule protocol, with regular measuremnts every Monday and Thursday. Initially the measurements were carried on to check system performance and depolarization calibratrion procedure. On June 1st a distinctive layer was observed at 3000 m which was identified as mostly consisting of dust aerosols, figure 2. The depolarization measured in this plume were compatible with those identified as dust[18] as one can see in figure 3. Some values encountered are not in the expected range indicating a rerun of the calibration procedure, however for the sake of qualitatively showing the presence of a depolirizing plume which might be identified as dust when validated by the sunphotometer adn CALIPSO data. One locally aspect worth mentioning is the fact that observing these plumes becomes a challenge as they soon move away due a steady wind field present in the Natal area, certainly an aspect easily recognizable by the presence of Trade Winds, also the presence of low clouds also poses a difficulty to the observing site.

Synoptically, according to the automatic INMET meteorological station in Natal, this day was a clear day without precipitation, with an average temperature of 26C, ranging from 24C in the early morning to 30C at 4 p.m. local time (UTC-03) and a relative humidity of 63-92%. Winds were from South in the morning and Southeast in the afternoon and evening at 3-6 m/s, with their maximum from 3 p.m. to 7 p.m. local time. Solar radiation was at its maximum at 3 p.m. local time with 3,227 $kJm^{-2}h^{-1}$.

In order to validate the source of these dust plumes a HYSPLIT trajectory model simulation was carried on to provide backtrajectories which ended on June 1^{st} and described the air masses from 12 days back to the Northern African West and Southwest Coast as shown in figure 4.

Suppoting the dust plume identified by DUSTER we have positively realized these data thorugh CALIPSO Total Attenueated Backscatter and Aerosol Subtype plots corresponding to the Natal region. The sunphotometer data for 2016 first semester clearly indicates some aerosols as being of dust nature in February, March and June. Since the presence of dust layers were not expect for this time of the year one might speculate about anomalies like ENSO and El Niño and whatever mechanism brought these aerosols further inspection should be taken.

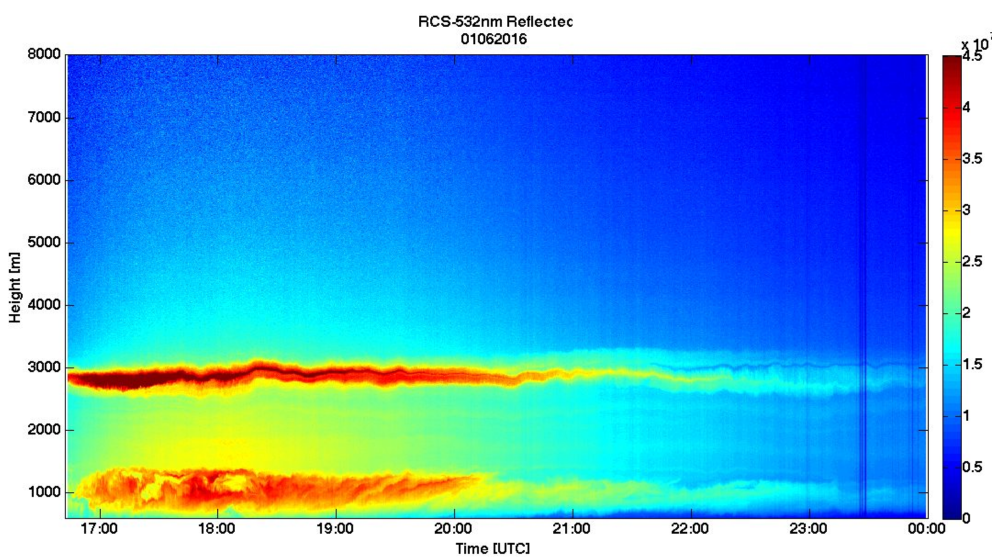

Figure 2. Dust layer identified over Natal on June 1^{st} 2016. There were two layers, one around 1000 m and another above at 3000 m. Natal has strong and continuos winds (trend winds) due its closeness to the ITCZ line.

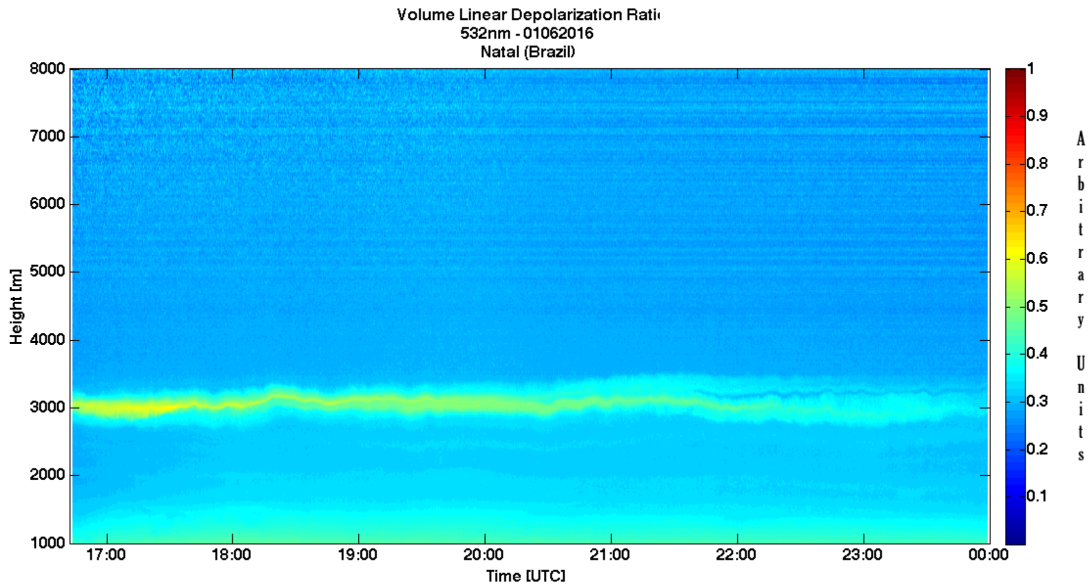

Figure 3. Volumetric Depolarization Ratio obtained with DUSTER helped in anaylizing the upper plume with a strong possibility of being dust transported over the ocean. Further analysis will enhance this observation. The expected depolarization values which could be due mixing of aerosols need ra more detailed calibration procedure. The lower plume has very low depolarization and indicates as being with some confidence a marine aerosol plume.

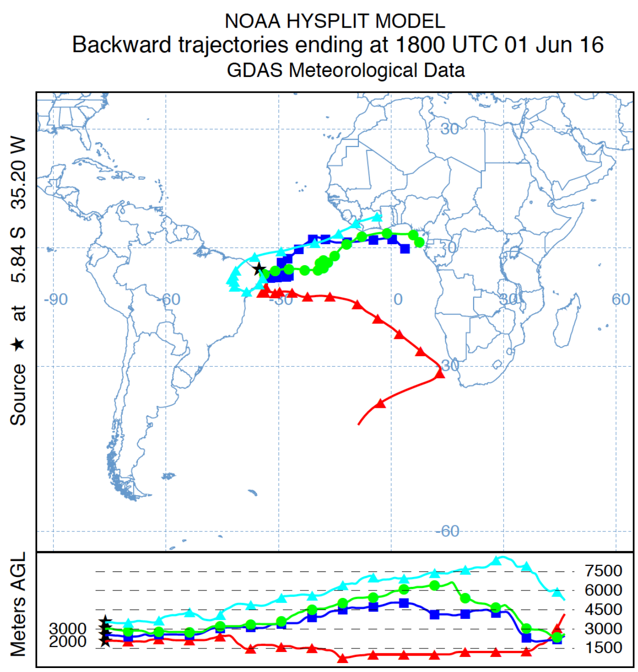

Figure 4. Dust track direction and trajectory from Saharan region towards Natal obtained with HYSPLIT.

ACKNOWLEDGMENTS

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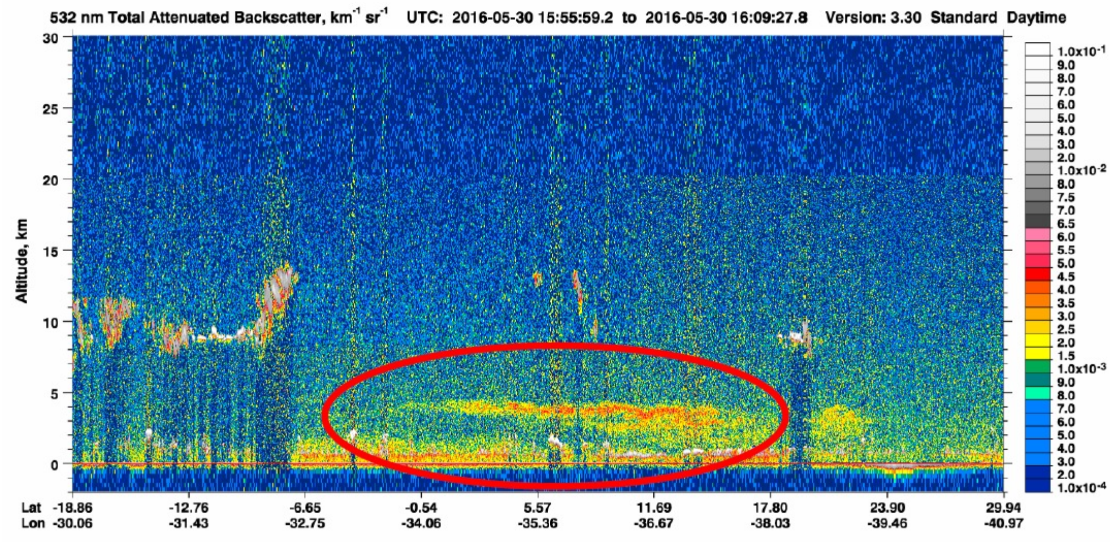

Figure 5. CALIPSO Total Attenuated Backscatter curtain plot over the Natal region on May 30^{th}, 2016. A large and dense dust plume was detected together with high alitude clouds.

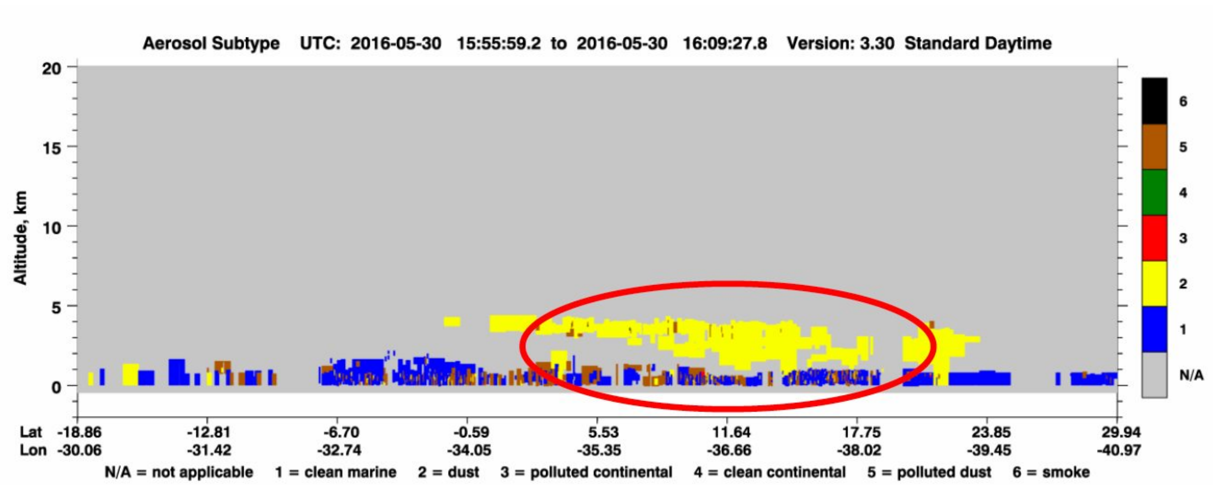

Figure 6. Aerosol Subtype for May, 30^{th} displaying the presence of marine, polluted dust and *pure* dust in the Natal region. These layers in June are not within the *window of opportunity* period.

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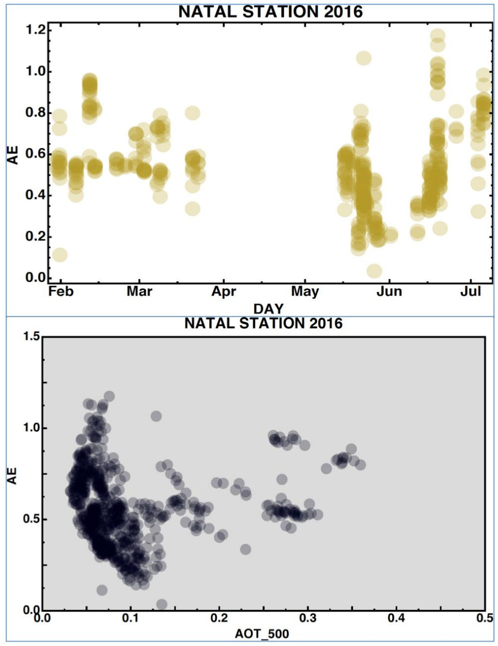

Figure 7. Sunphotmeter Angström Exponent and AOT×AE plots during the first semester of 2016. Some periods in February, mid March and early June are corresponding to dust aerosols.

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