Vertical estimate of Saharan dust mass concentrations derived by ground-based lidar observations in synergy with airborne in-situ measurements

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Seawifs image

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Introduction

- The vertical distribution of dust plays a significant role in climate-related issues.
- Height-resolved information of the dust properties is also required for both aerosol transport modeling (i.e., DREAMS, NAAPS) and satellite data validation (i.e., CALIPSO, MODIS).
- ESA Earth Observation programs (future EarthCARE and Sentinels missions) are focused on vertical monitoring of aerosols and clouds.
- Their microphysical and optical properties are retrieved for radiative forcing considerations.

AMISOC-TNF campaign:

Dust profiling features

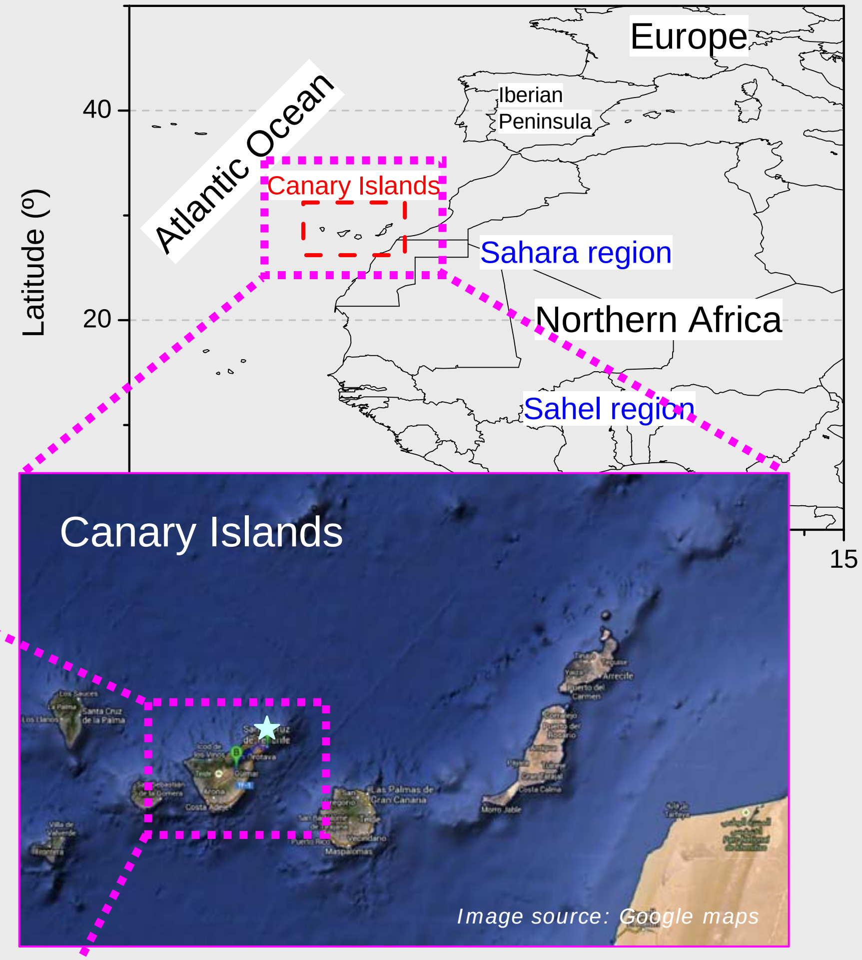
AMISOC-TNF campaign: *Measurement area*

Canary Islands: a suitable region for dust monitoring as located downwind of the Saharan sources.

The arrival of dust plumes are frequent in this area, mainly in summertime and extended up to high altitudes.

Santa Cruz de Tenerife observatory (SCO):

28.5°N 16.2°W 52 m a.s.l.

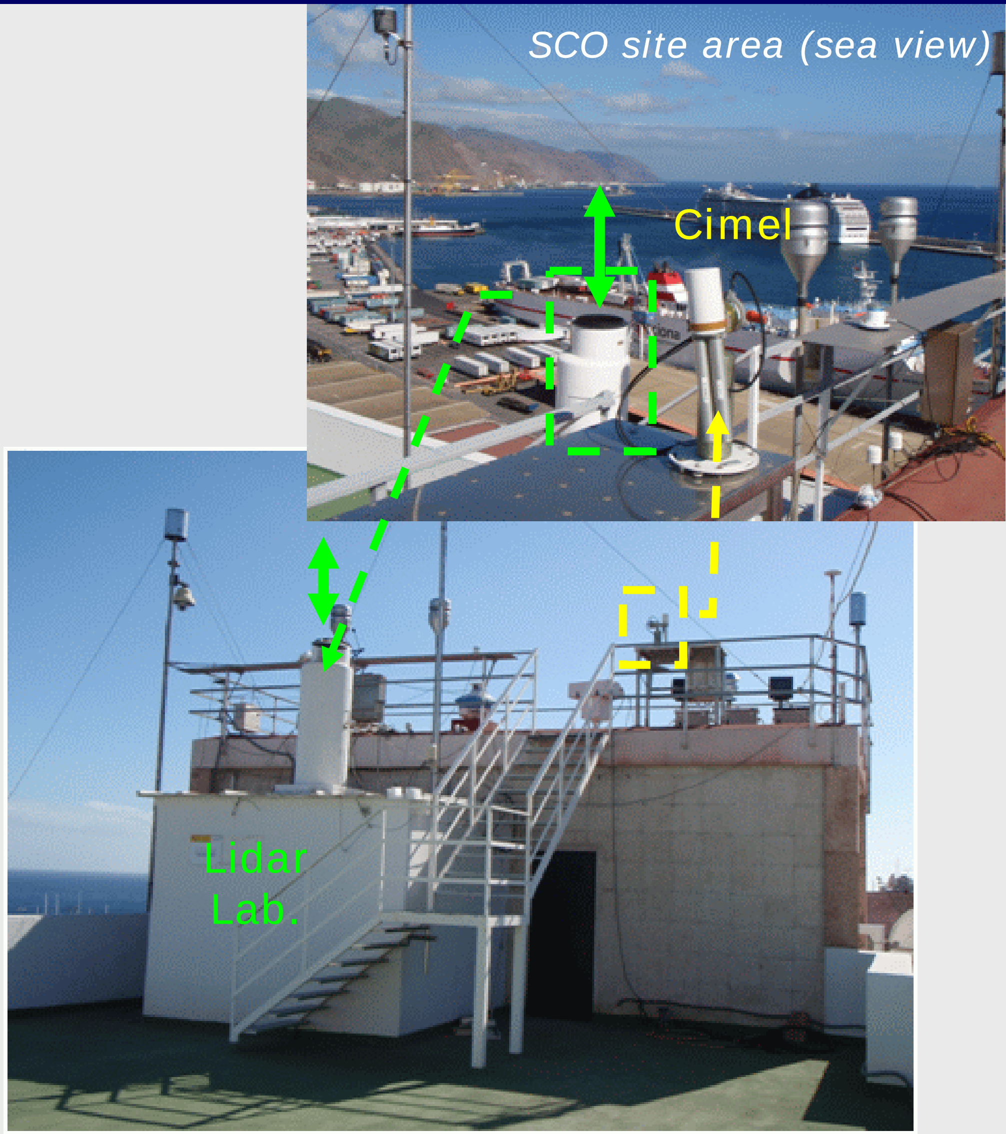


*Map showing the geographical situation respect to Saharan dust sources of the Santa Cruz de Tenerife observatory (**SCO**).*

AMISOC-TNF campaign: *this work*

- A multi-instrumented campaign carried out from 01 July 2013 to 11 August 2013 (42 days in summertime) over Tenerife area.
- Synergy of multi-platform in-situ and remote sensing techniques: vertically-resolved optical and microphysical properties.
- Instrumentation:
  - Ground-based remote-sensing observations: optical properties (i.e., extinction, σ).
  - Airborne in-situ measurements: microphysical properties (i.e., size distributions, SD).
- Vertical estimate of the Mass Concentration of Saharan dust particles, related to their radiative impact factor.

Instrumentation I: *Ground-based measurements*



CIAI roof
(Lidar laboratory and
Cimel installed on the terrace)

Santa Cruz Observatory (SCO): Subtropical coastal site

Location: 28.5ºN 16.2ºW, 52 m a.s.l.

Aerosol networks:

- NASA/AERONET (*http://aeronet.gsf.nasa.gov*)
- NASA/MPLNET (*http://mplnet.gsfc.nasa.gov*)
- SPALINET (*Spanish and Portuguese Aerosol LIdar NETwork*)

Remote sensing instrumentation: *LIDAR vs. Sun-photometry*

INTA/Micropulse lidar v.3 (MPL-3)

“Tandem” system

Co-located instrumentation in **SCO site**

AEMET/CIMEL-318

- **MPLNET elastic lidar**
- Highly-pulsed (2500 Hz) and low-energy (10 μJ, max.) laser at **523 nm**
- Receiving system: Cassegrain-type telescope
- Small, easy-handle system with coaxial configuration
- High autonomy and low attendance, operational in full-time continuous mode (24 h day^{-1}/365 days year^{-1})
- Routine measurements (MPLNET settings): 75-m vertical resolution and 1-minute integrating time

- **AERONET sun-photometers**
- Spectral channels: 440 nm, **500 nm**, 675 nm, 870 nm, 940 nm and 1020 nm
- Inversion products level 1.5 (Cloud Screened) and 2.0 (Quality-assured): spectrally resolved Aerosol Optical Depth (AOD) and Ångström Exponent (AEx), among others, in addition to microphysical properties

LIDAR profiles: *Optical properties retrieval*

INTA/Micropulse lidar v.3 (MPL-3)

Saharan dust particles:

- Vertically-resolved extinction coefficients: an inversion algorithm, based on a modified version of the Fernald-Klett elastic retrieval in synergy with AERONET sun-photometer data (*Córdoba-Jabonero et al., 2014*).
- The Lidar Ratio (LR, =extinction-to-backscatter ratio) is also retrieved by AOD constraint.

Instrumentation II: *Airborne measurements*

Flight trajectory area:

Two flights under dusty conditions

31 July 2013

01 August 2013

Similar measurement zone

Aircraft in-situ instrumentation: *Aerosol sonde*

PCASP (OPC):

Passive Cavity Aerosol Spectrometer Probe 100X

Size distribution range:

By assuming a representative refractive index for Saharan dust of 1.49 (*Schuster et al., 2012*), neglecting the absorption:

0.1 - 3.3 μm in 13 channels

PCASP profiles: Microphysical properties

PCASP:

‘Nominal’ size range:

0.1-3.3 μm in 13 channels

Several single size channels are selected and assembled into three ‘wider’ size range:

D1: 0.16-0.34 μm (3-6 chs.) *Fine Mode (FM)*

D2: 0.34-1.34 μm (7-10 chs.) *Fine Mode (FM)*

D3: 1.34-2.83 μm (11-12 chs.) *Coarse Mode (CM)*

<u>Profiles</u> of:

Number SDs (**NSD**, cm^{-3})

Volume SDs (**VSD**, $\mu m^3\ cm^{-3}$)

Results

- ✓ Saharan dust occurrence during AMISOC-TNF
- ✓ Vertical dust profiling features: optical and microphysical properties
- ✓ Total Mass Concentration of Saharan dust particles

Both Cimel and MPL-3 measurements are hourly-averaged

PCASP profiles were obtained between 10:00–12:00 UTC (flight time)

Saharan dust signature criterion: *Dusty cases*

Dusty conditions are defined by using the criterion for Saharan dust particles (*) based on :

a. AERONET AOD/AEx data: ***evidence of coarse particles***

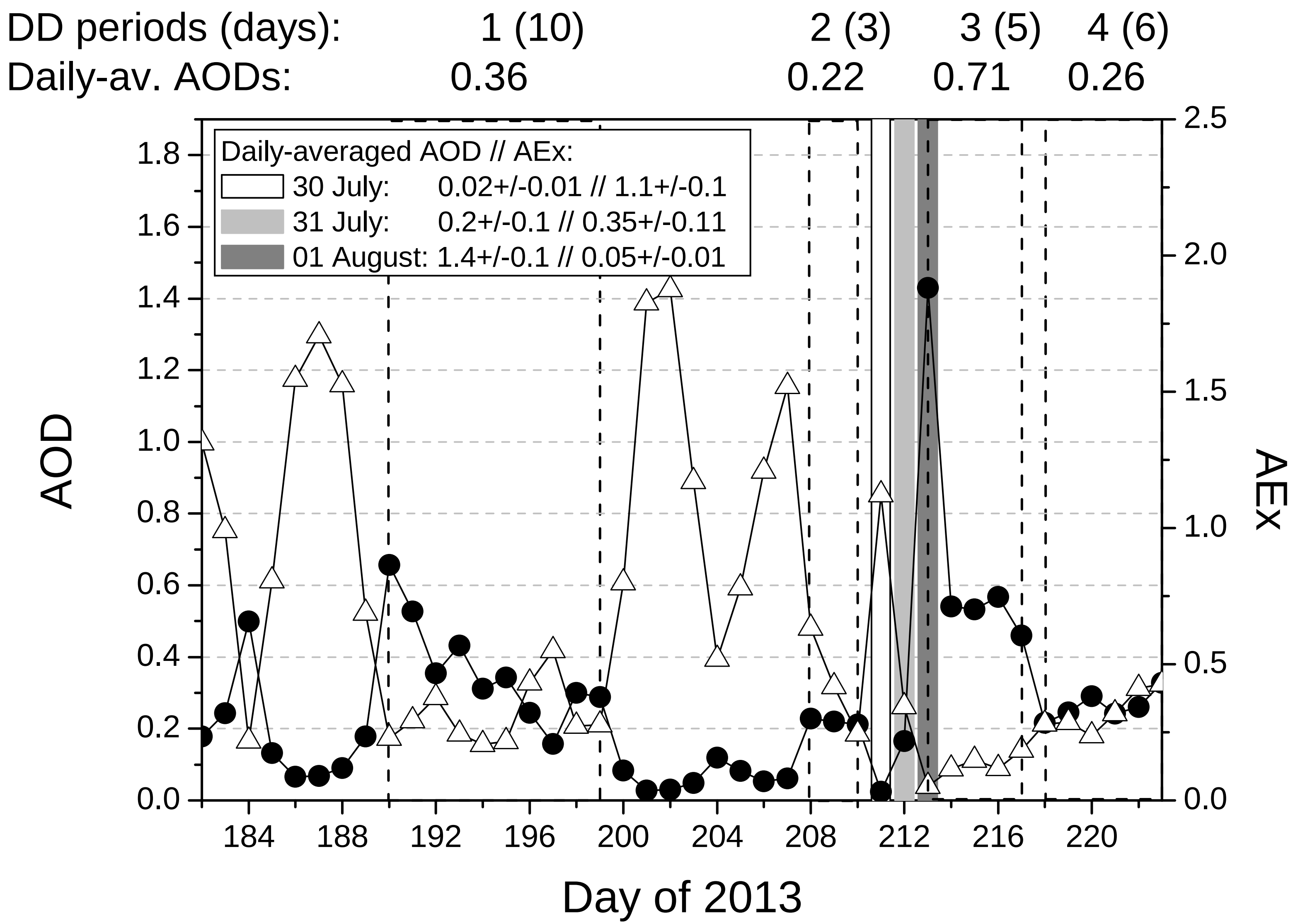
- *High-moderate AOD at 500 nm: AOD > 0.2*
- *Low AEx for 440/675 nm wavelength pair: AEx < 0.5*
- *These both threshold values must be during > 40% of the day-time period*

b. HYSPLIT backtrajectory analysis: ***Saharan origin of the air masses***

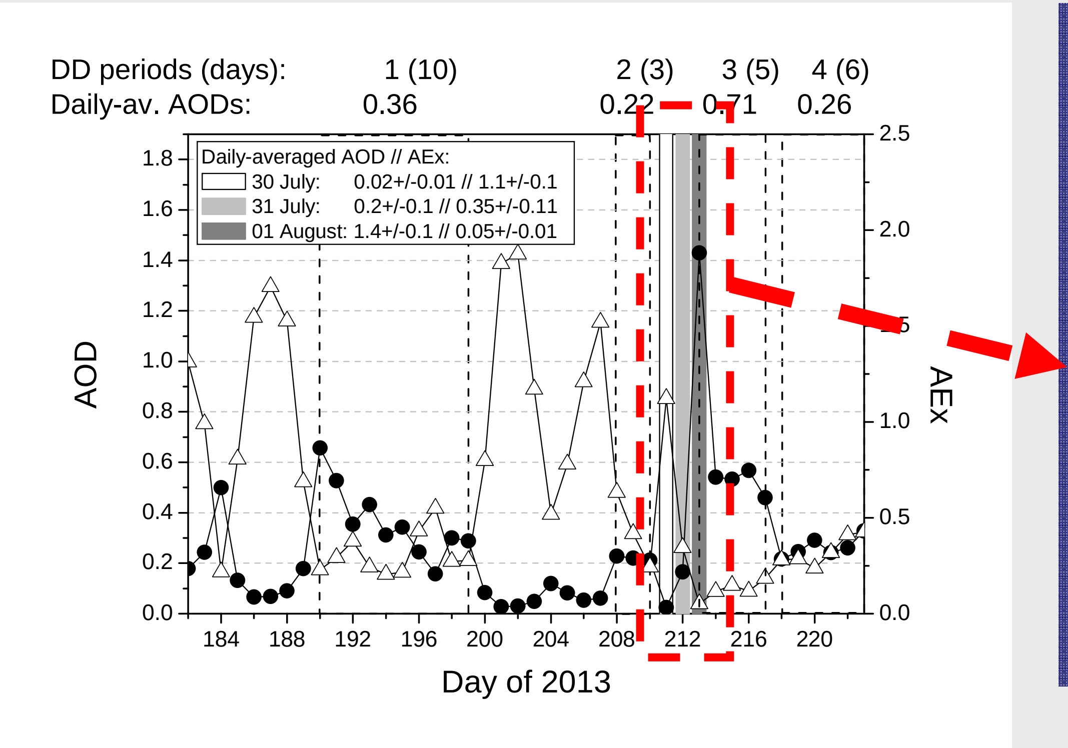
- *5-day backtrajectories at several altitudes (a.g.l.): 500 m (near the surface), 1000 m (representative of BL top), 2000, 3000 and 5000 m (at FT heights), and three predominant origins depending on the arrival altitude are examined:*
  - *No-African (Atlantic ocean) sources,*
  - *Sahara area (North-Africa latitudes > 20ºN)*
  - *Sahel region (North-Africa latitudes 0-20ºN)*

(*) As adopted from Córdoba-Jabonero et al., ACP (2011)

AERONET data: *Dusty cases*



AERONET data: *Dusty cases*

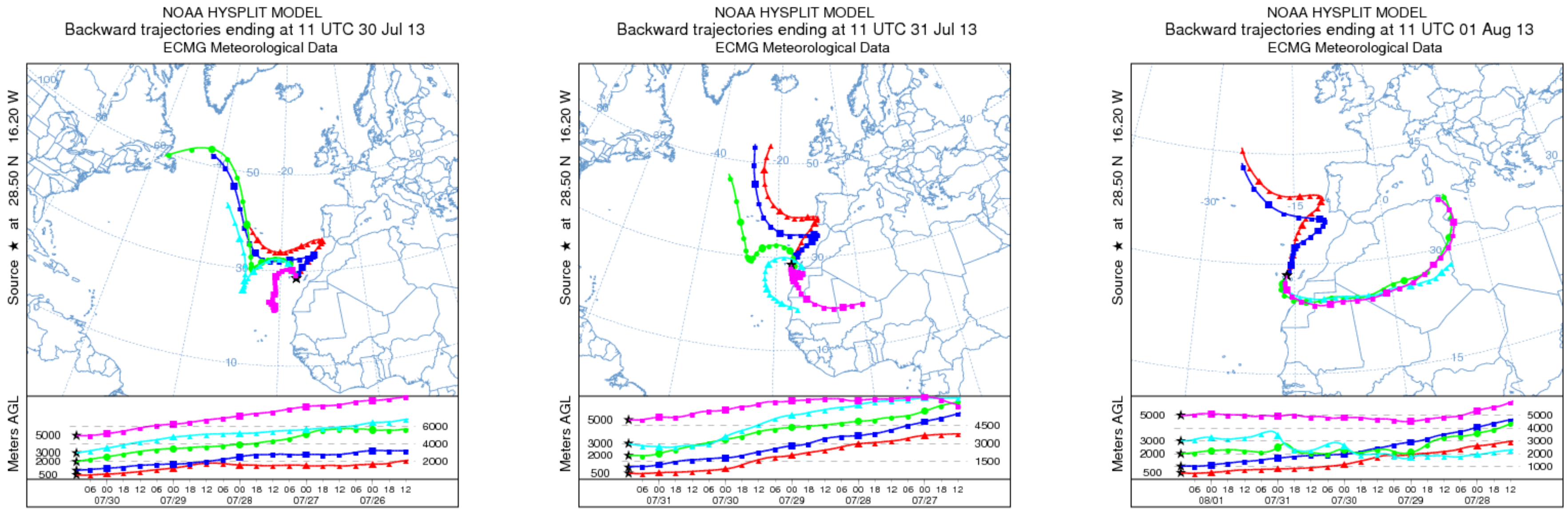


- 24 days (**57.1 %**) were identified as dusty (DD)
- Four DD periods were observed (mean AOD > 0.2)
- ***Aircraft flights***:
  - 30 July (white)
  - 31 July (light grey)
  - 01 August (grey)

DD cases examined:

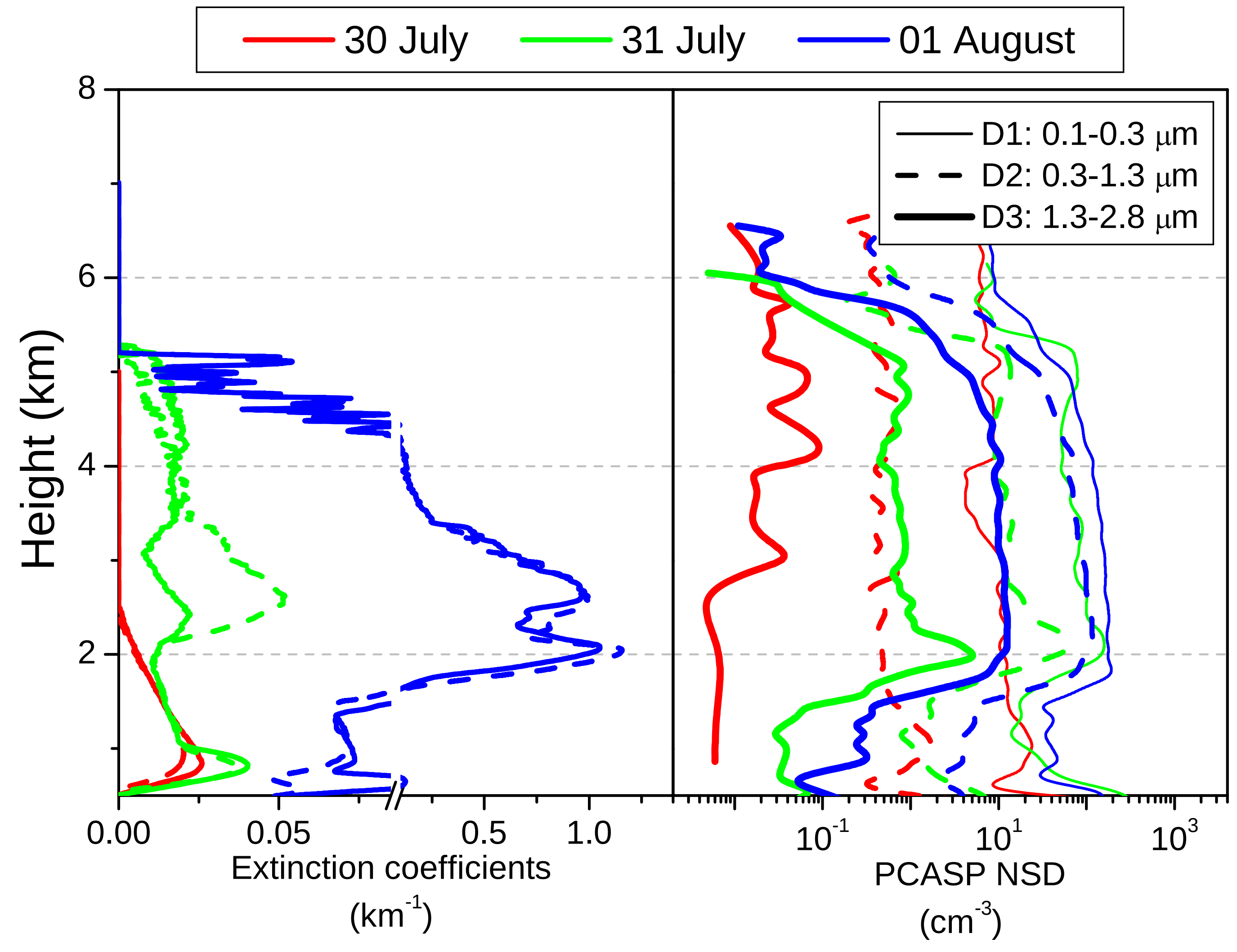
- 30 July (AOD=0.02, AEx=1.1): ***non-dusty (ND) day as reference***
- 31 July (AOD=0.2, AEx=0.35): ***moderate dust intrusion***
- 01 August (AOD=1.4, AEx=0.05): ***strong dust intrusion***

HYSPLIT 5-day backtrajectories: *Saharan origin*



- ✓ Saharan air masses are arriving in a layer between 2000 and 5000 m a.g.l. height (FT altitudes).
- ✓ BL is mostly affected by no dust incidence with cleaner Atlantic Ocean air masses (mainly marine particles contribution).

Vertical dust profiling features:
Optical and microphysical properties



Vertical dust profiling features: *Optical and microphysical properties*

		30 July		31 July		01 August	
Airborne data							
	NSD increase respect to ND case	FT	BL	FT	BL	FT	BL
	D1	1	1	7	3	12	4
	D2	1	1	26	2	110	3
	D3	1	1	56	45	471	268
Lidar data							
	Extinction increase respect to ND case	FT	BL	FT	BL	FT	BL
		1	1	7	1.4	139	4.3
	LR (sr)	daily	flight time	daily	flight time	daily	flight time
		30 ± 1	similar values	38 ± 8	31 - 50	51 ± 16	53 - 55

Vertical dust profiling features

- **Dust layer**: between 1.7 and 6 km height, being much stronger on 01 August, as expected.
- **Dust incidence:** mostly affected the FT altitudes with almost no incidence in the BL.
- **D2 and D3 particles** are enhanced respect to D1 particles, and mostly at FT heights.
- **Similar D3 contributions are at FT and BL heights** on these two DD days: increase of larger particles in the BL can be related to gravitational processes from higher altitudes.

Vertical dust profiling features: *Optical and microphysical properties*

Lidar data		30 July		31 July		01 August	
	Extinction increase respect to ND case	FT	BL	FT	BL	FT	BL
		1	1	7	1.4	139	4.3
	LR (sr)	daily	flight time	daily	flight time	daily	flight time
		30 ± 1	similar values	38 ± 8	31 - 50	51 ± 16	53 - 55

Marine mixtures with other particles with predominance of sea salt particles

Variability in time of DD conditions. **Weak progressively arriving dust intrusion**.

Representative values for **pure Saharan dust particles**. DD conditions along all the day.

Total Mass Concentration of Saharan dust particles

Mass extinction efficiency (MEE , $m^2\ g^{-1}$) of dust:

- A measure of the aerosol effectiveness on solar radiation.
- Relation between both optical and microphysical properties.

$$\sigma^{ext} = MEE \times TMC$$

Extinction coefficient (m^{-1})

Total Mass Concentration ($g\ m^{-3}$) for all the particles

MEE value for dust particles:

0.75 $m^2\ g^{-1}$, assumed as in *Reid et al. (2003)*

PCASP Mass Concentration estimation

$$MC = \sum_{i=1}^{3} d_p \times VSD(D_i)$$

Mass Concentration (MC) for particles in each size range D_i (=D1, D2 and D3 'wide' channels) and for those with diameter < 2.8 μm (D1+D2+D3), where:

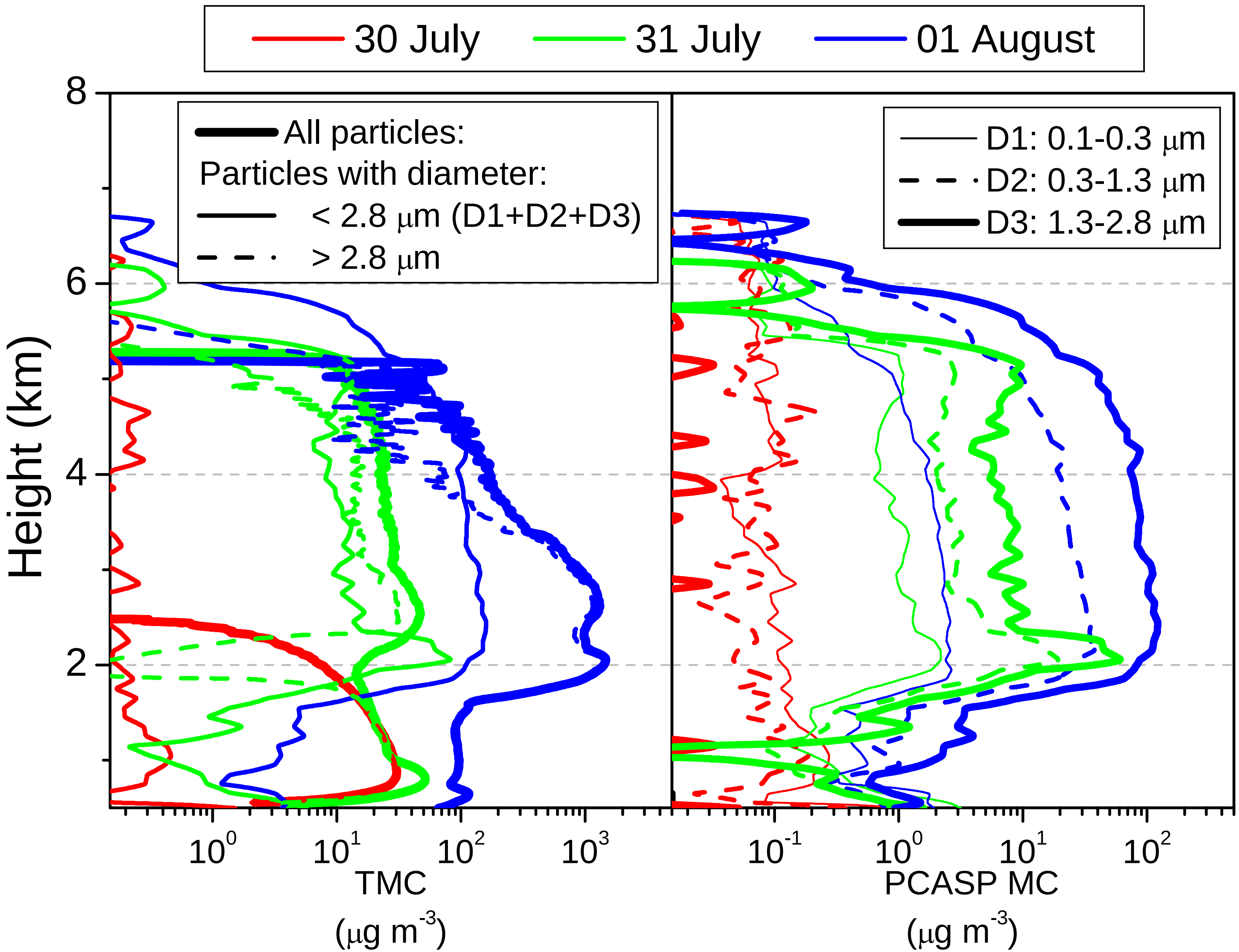
d_p = particle density (=2.0 g cm^{-3}, assumed)

VSD (D_i) = VSD for particles in each size range (=D1, D2 and D3 'wide' channels)

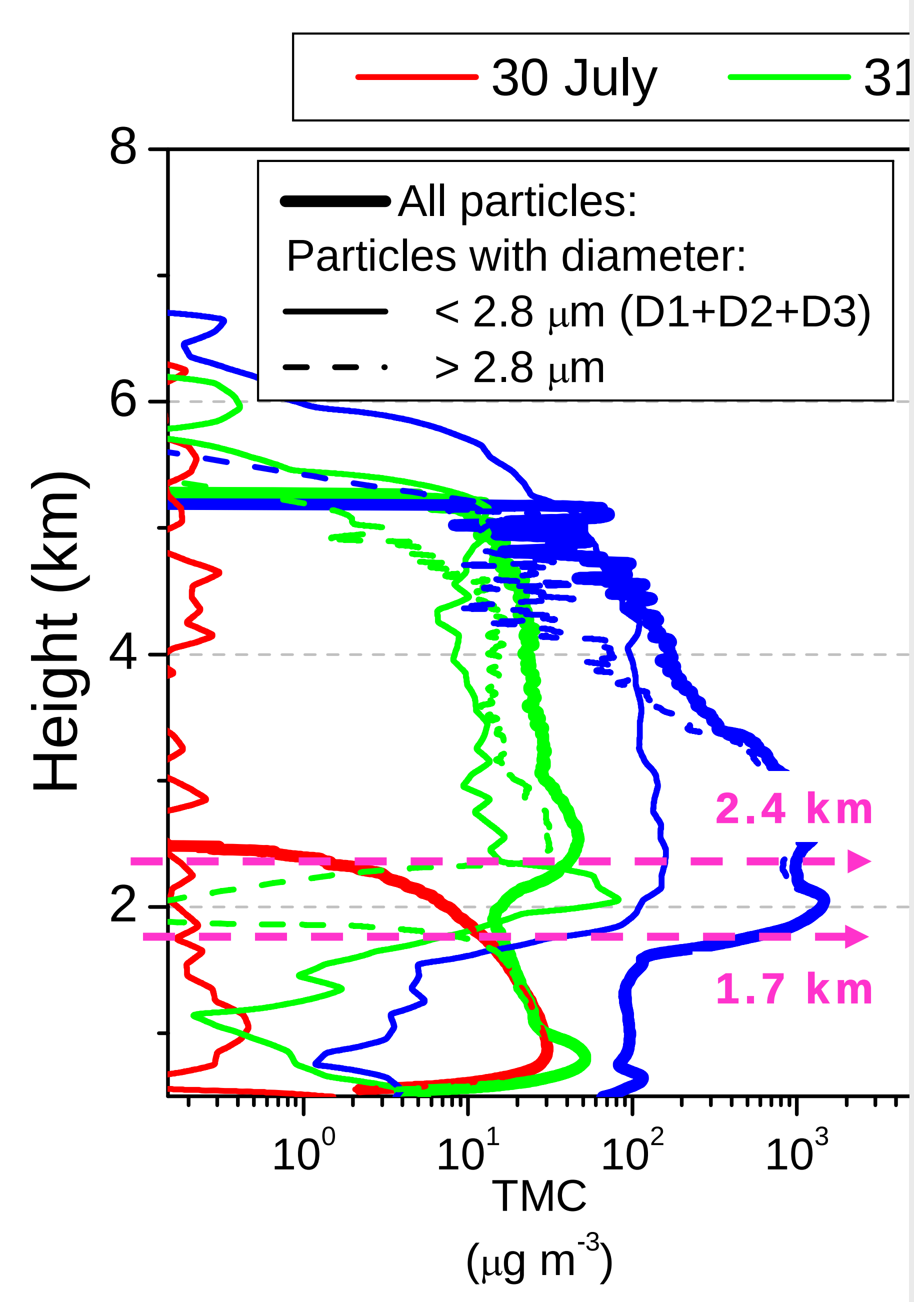
A vertical estimate of the **Total Mass Concentration (TMC) for <u>all the particles</u>** can be obtained from lidar-derived *extinction* in combination with that assumed *MEE value*.

Discrete MC profiles are also obtained for particles within each D1, D2 (fine mode) and D3 (coarse mode) size range and for those particles with diameter < 2.8 μm (i.e., within the extended fine-to-coarse D1+D2+D3 mode).

Total Mass Concentration (TMC)



Total Mass Concentration: *31 July 2013*



31 July (weak DD case):

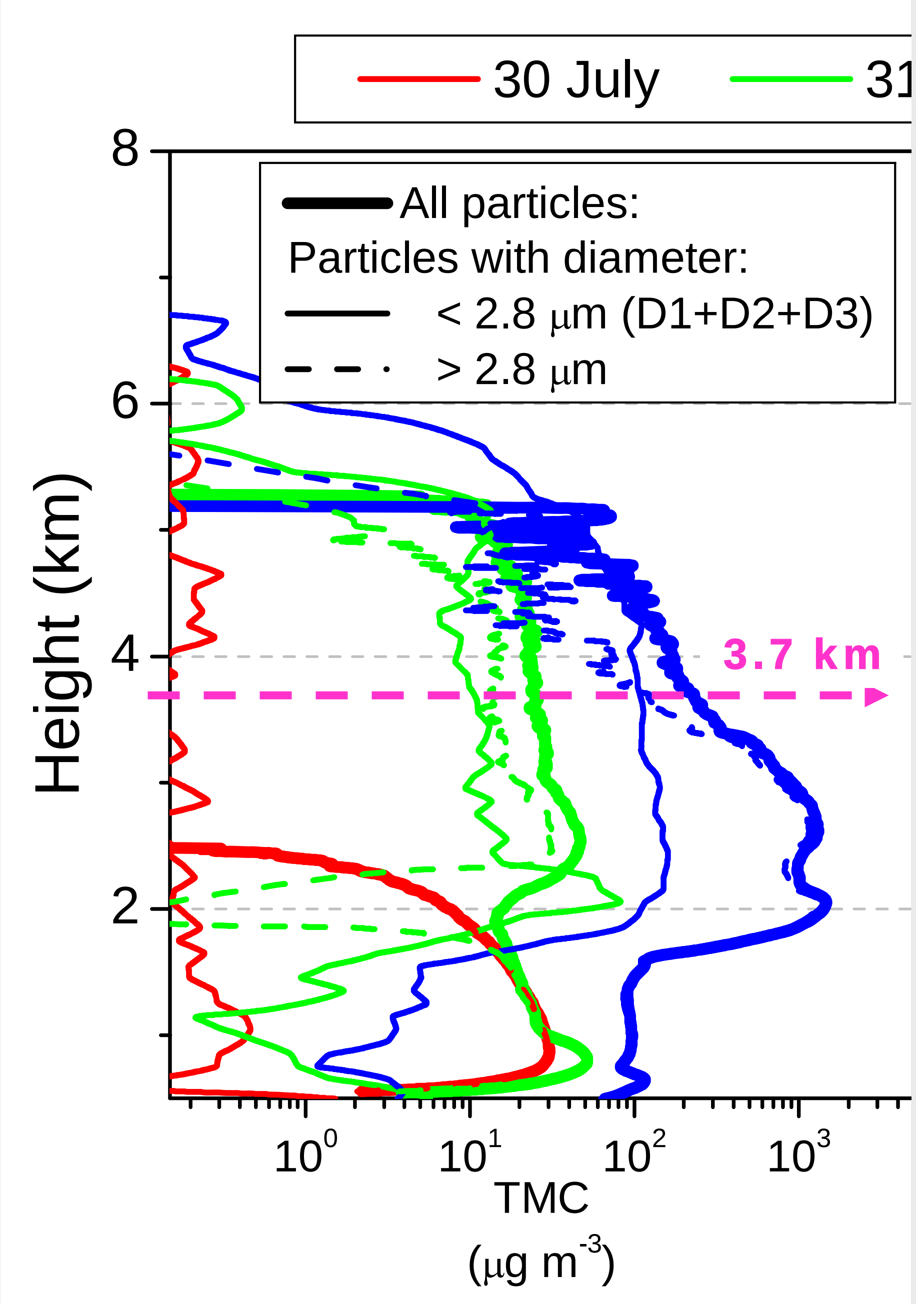
- MC of particles > 2.8 μm diameter is distributed at BL and FT altitudes.
- MC of particles < 2.8 μm diameter is mostly found in the FT.
- ***1.7 - 2.4 km layer:***

MC (< 2.8 μm) is higher than TMC (???). Some hypothesis:

(1) MEE and d_p values can be different from those assumed in this work, and hence the estimated TMC could be higher; or

(2) SDs derived from airborne measurements can present uncertainties associated to PCASP data errors.

Total Mass Concentration: *01 August 2013*



01 August (strong DD case):

- Lower than 3.7 km: predominance of particles > 2.8 μm diameter.
- Higher than 3.7 km: predominance of particles < 2.8 μm diameter.
- Hence, a selective contribution by the particle size is clearly observed, likely due to gravitational settling processes of larger particles.

Summary

- ✓ Vertical profiles of both dust extinction and mass concentration as derived from lidar measurements and airborne instrumentation during AMISOC-TNF campaign are presented.
- ✓ A good agreement is found between the optical and microphysical properties showing dust particles confined in a wide layer of 4.3 km thickness from 1.7 to 6 km height.
- ✓ Dust incidence mostly affected the FT altitudes, being rather lower in the BL.
- ✓ The synergy between lidar observations and airborne measurements has been shown in order to derive a vertical estimate of the Total Mass Concentration of Saharan dust particles, highlighting the dust impact in both the BL and FT in terms of the different contribution of particles within the fine and coarse modes.

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Thank you for your attention