EARLINET observations of Saharan dust intrusions over the northern Mediterranean region (2014-2017): Properties and impact in radiative forcing

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EARLINET observations of Saharan dust intrusions over the northern Mediterranean region (2014–2017): properties and impact on radiative forcing

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OUTLINE

- Why dust aerosols are important ?
- Studied Area: The Mediterranean basin
- Instrumentation (EARLINET) and data selection (dusty layers)
- Aerosol’s properties (Optical, Geometrical, Mixing, Microphysical)
- Radiative Forcing estimations (LibRadtran)
- Conclusions

W H Y   A E R O S O L S   A R E   I M P O R T A N T   ?

The presence of aerosols:

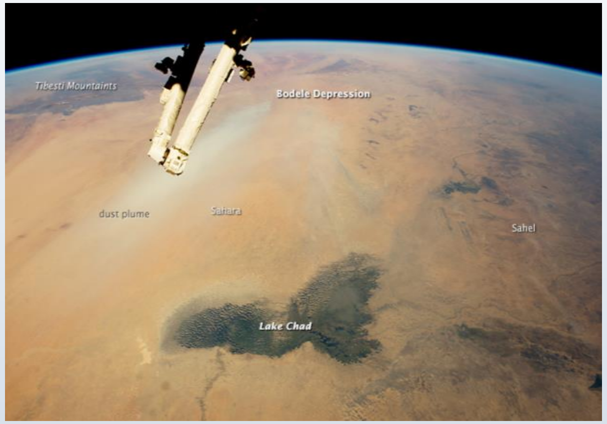
- ❖ **modifies** the optical thickness of the atmosphere
- ❖ **changes** the clouds’ lifetime, precipitation and albedo
- ❖ is **strongly dependent** on the atmospheric circulation

Mineral dust:

- ❖ **key component** of the Earth’s climate system
- ❖ most **abundant** component of atmospheric aerosol (naturally emitted)
- ❖ **magnitude** and **sign** of dust solar radiative forcing highly **uncertain** (IPCC, 2014)

Current scientific questions:

- ➢ What is the orientation of dust particles? (ReACT team)
- ➢ Why models miss most of the coarse dust? (Adebiyi and Kok., 2020)
- ➢ How giant mineral dust particles can be long-range transported? (van der Does et al., 2018)



https://earthobservatory.nasa.gov/images/85588/lake-chad-and-a-bodele-dust-plume

MEDITERRANEAN BASIN: A REGION VULNERABLE TO CLIMATE CHANGE

▪Geographical position: Europe, **Africa**, Asia

▪Saharan desert: the largest natural source of aerosols

▪Affected by South Asian Summer Monsoon and North Atlantic oscillation

▪Dust advections modulated by meteorology (H-L, regular seasonal patterns)

▪High evaporation, low precipitation, remarkable solar activity

▪Long-range transport of aerosols - aging and mixing processes

▪3 major sub-areas: Western, Central, Eastern Mediterranean region

▪Biomass, sea salt, anthropogenic, volcanic aerosols also present

INSTRUMENTATION AND DATA

EARLINET STATIONS:

(LIDAR DATA, 2014-2017)

EARLINET STATIONS

Granada	Potenza	Athens	Limassol
MULHACEN	MUSA	EOLE/AIAS	Polarization Raman Lidar
3β+2α+1δ(532 nm)	**3β+2α+1δ(532 nm)**	**3β+2α+1δ(532 nm)**	**1β+1α+1δ, (532 nm)**
Overlap: 500 m a.g.l.	Overlap: 405 m a.g.l.	Overlap: 800 m a.g.l.	Overlap: 250 m a.g.l.
37.16° N, 3.61° W, elev. 680 m	40.60° N, 15.72° E, elev. 760 m	37.96° N, 23.78° E, elev. 212 m	34.67° N, 33.04° E, elev. 10 m
(Guerrero-Rascado et al., 2008)	(Madonna et al., 2011)	(Papayannis et al., 2020)	(Nisantzi et al., 2015)

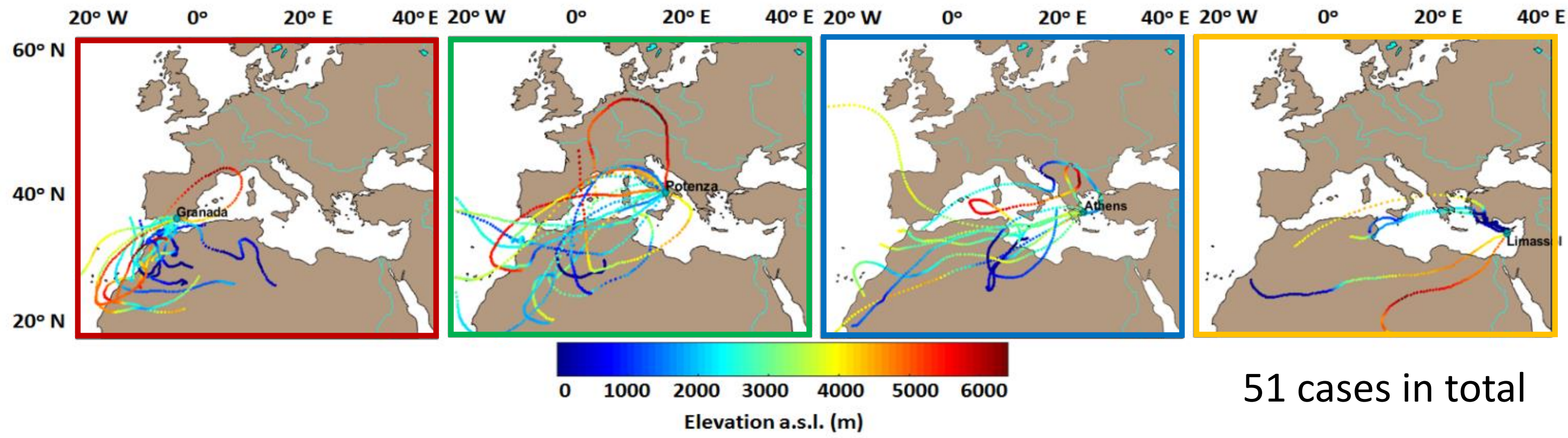
DATA SELECTION (2014-2017):

<u>3 criteria</u>:

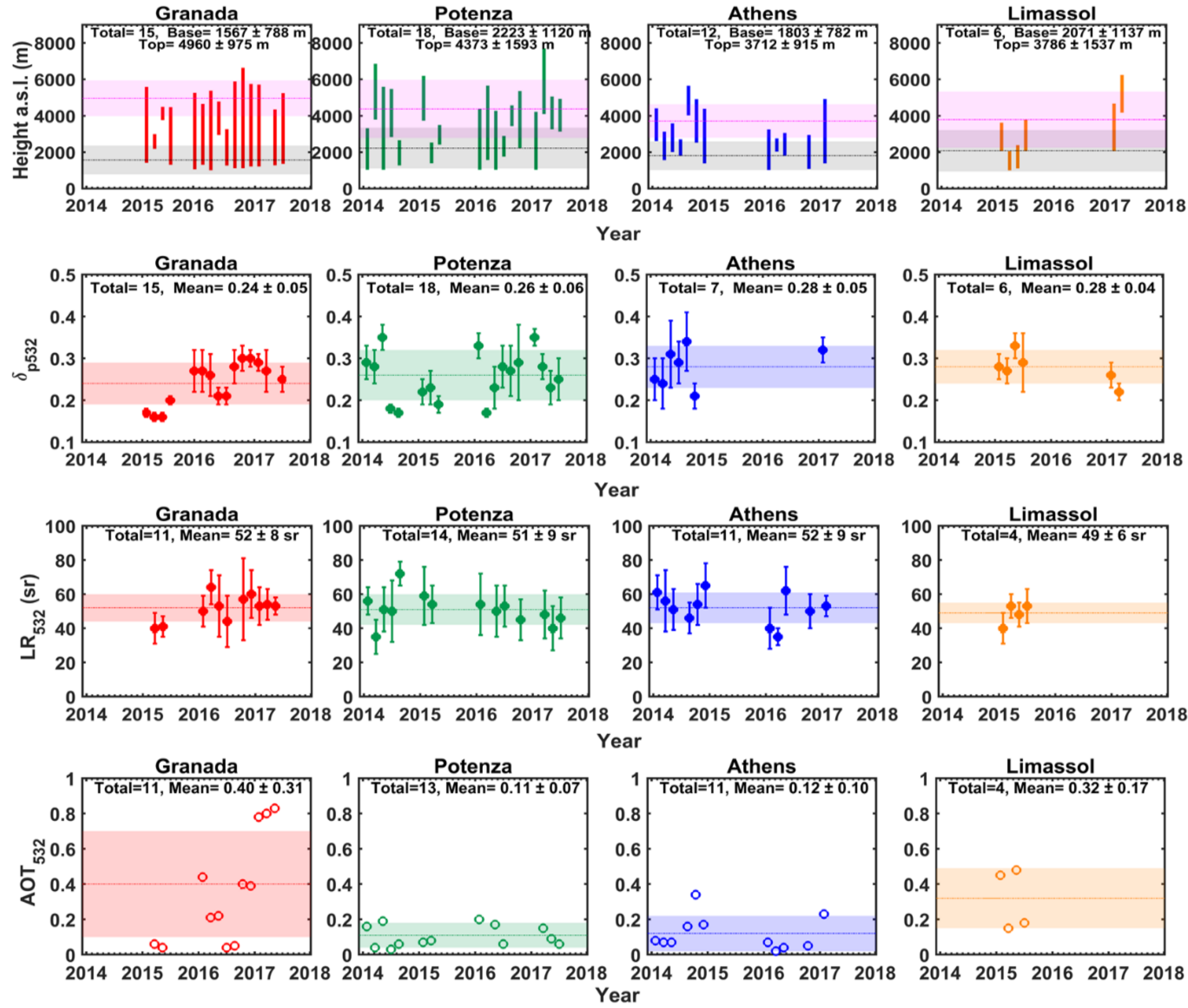
i) $\delta_{p532} \geq 0.16$ (free troposphere)

ii) **35 sr ≤ LR_{532} ≤75 sr** (free troposphere)

iii) **thickness ≥ 500 m**



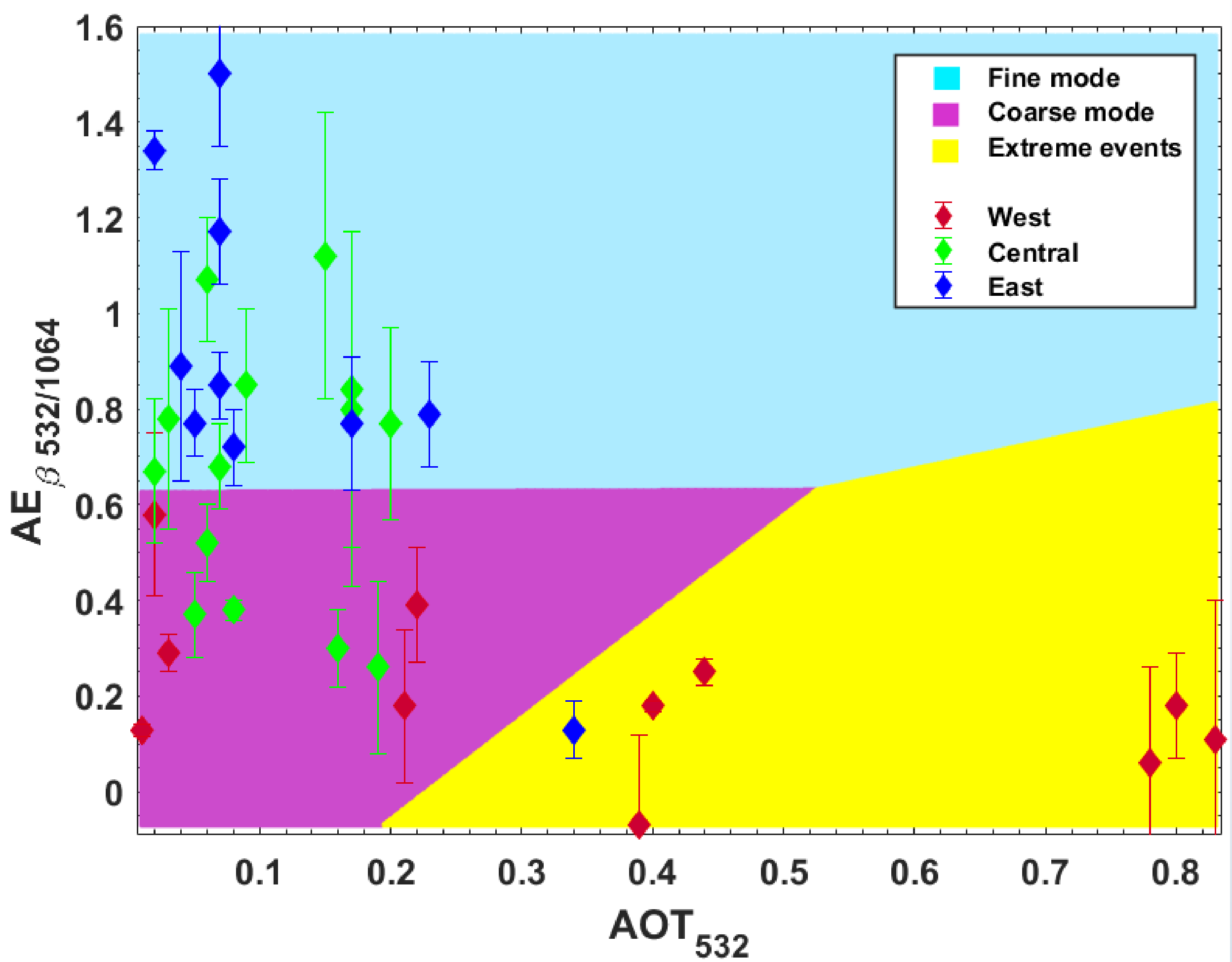
51 cases in total



AEROSOL GEOMETRICAL AND OPTICAL PROPERTIES PER SITE

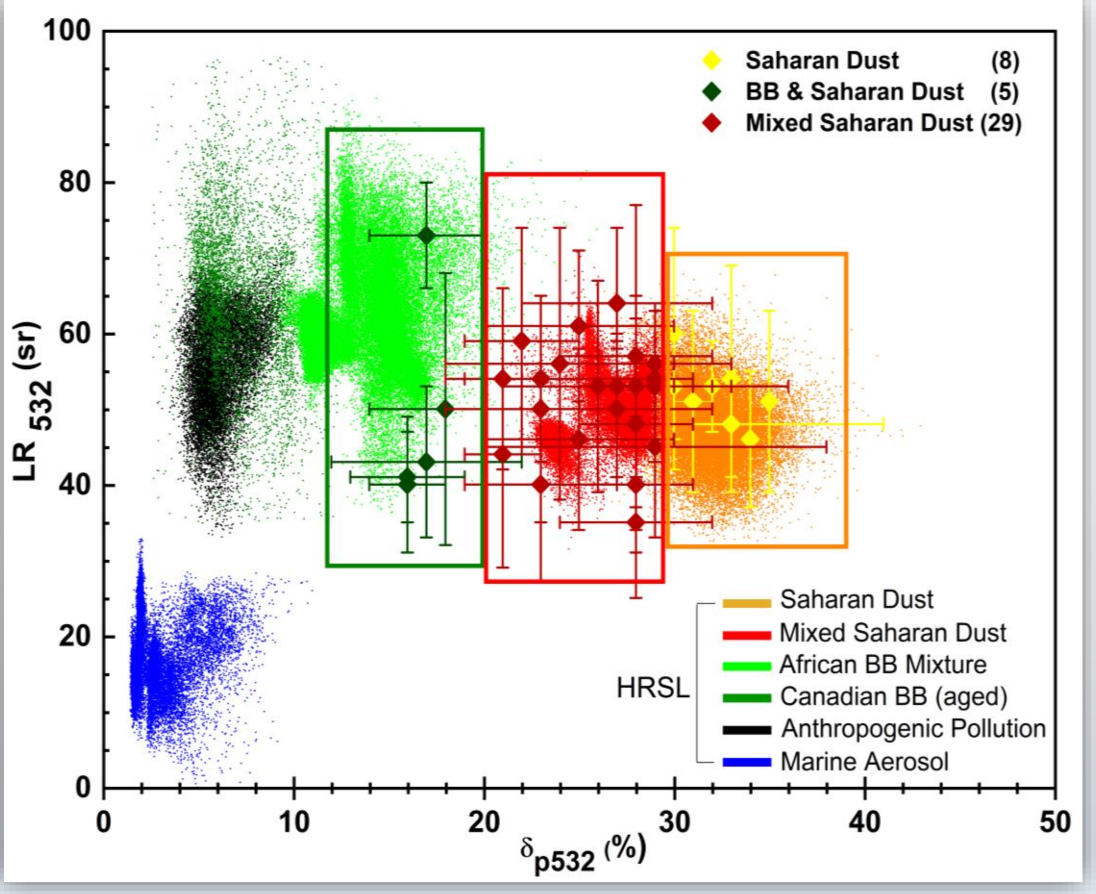
K-means Clustering

3 main clusters



AEROSOL CLASSIFICATION PER REGION

CLUSTERING PER MIXING STATE



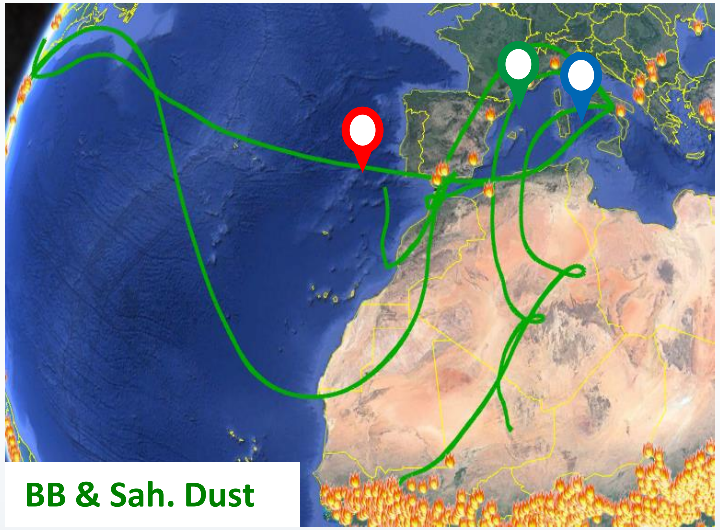
(Groβ et al., 2013)

OPTICAL, MIXING STATE AND MICROPHYSICAL PROPERTIES OF DUSTY LAYERS OF 3 CLUSTERS

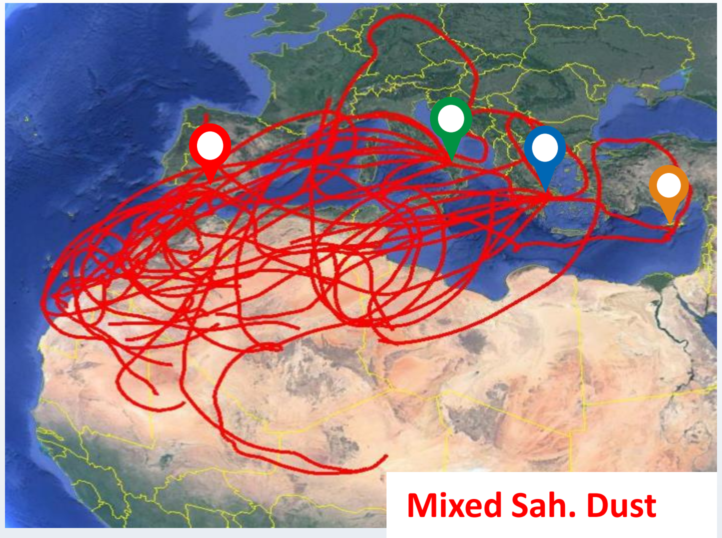
	Parameters	Clusters: BB & Sah. Dust	Clusters: Mixed Sah. Dust	Clusters: Saharan Dust
Optical Properties	β_{532} ($km^{-1}sr^{-1}$)	1.10±0.15 [$x10^{-3}$]	1.24±0.80 [$x10^{-3}$]	1.54±1.05 [$x10^{-3}$]
	α_{532} (km^{-1})	0.47±0.28	0.74±0.48	0.80±0.27
	AOT_{532}	0.03 ± 0.02	0.15 ± 0.10	0.32 ± 0.25
	LR_{532} (sr)	51 ± 15	50 ± 7	52 ± 5
	LR_{355} (sr)	35 ± 13	42 ± 7	51 ± 10
	LR_{355}/LR_{532}	0.69 ± 0.24	0.84 ± 0.16	0.98 ± 0.16
	δ_{p532}	0.17 ± 0.01	0.26 ± 0.03	0.32 ± 0.02
	$AE_{\beta355/532}$	0.44 ± 0.59	0.52 ± 0.61	0.35 ± 0.45
Geometry & Mixing	Thickness (km)	0.79 ± 0.21	2.08 ± 0.76	3.10 ± 1.72
	Distance (km)	3496 ± 1185	3662 ± 1617	4845 ± 2825
	Mixing (hours)	41 ± 26	66 ± 41	26 ± 13
Microphysical Properties (SphInX tool) (Samaras, 2016)	R_{eff} (μm)	0.293 ± 0.074	0.360 ± 0.081	0.387 ± 0.070
	RRI	1.50 ± 0.00	1.47 ± 0.05	1.47 ± 0.05
	IRI	0.005 ± 0.000	0.0046 ± 0.0045	0.0041 ± 0.0018
	SSA_{532}	0.948 ± 0.002	0.964± 0.018	0.964± 0.022
	SSA_{355}	0.937 ±0.007	0.958 ± 0.022	0.952 ± 0.026

CLUSTERING PER MIXING STATE

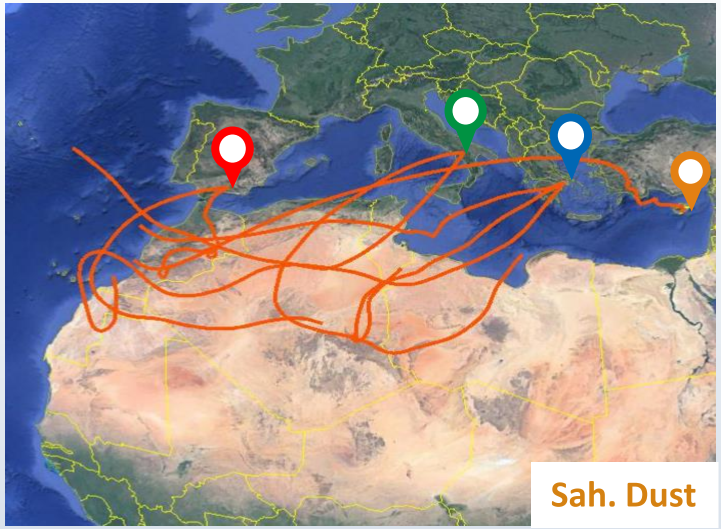
Clear influence of BB aerosols (#5)



Circulation over Mediterranean & Europe (#29)

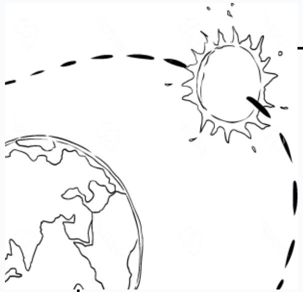


Long and fast trajectories (#8)



MODIS

TRANSFER (LIBRADTRAN) PACKAGE



Central program: *uvspec* →calculates the radiation field in the Earth's atmosphere

uvspec* < *input file* > *output file

SW and LW separately

(Mayer and Kylling, 2005)

Here:

1.

disort radiative transfer equation (1-D geometry)
Mid-latitude conditions (AFGL, 0–120 km),
typical surface albedo value (0.16), SW range, urban cities

2.

The **OPAC** data set (v. 4.0, Koepke et al., 2015) desert spheroids (T-matrix calculations), $R_{MIAM} \in [0.005, 20]$ μm

→ aerosol extinction, scattering, and absorption coefficients, SSA, gg, phase function
61 wavelengths [0.25 - 40 μm]

3.

Vertical profiles of **Lidar data** & **BCS-DREAM8b** dust mass simulations as additional input

METHODOLOGY

RADIATIVE FORCING OF DUSTY LAYERS OVER THE MEDITERRANEAN BASIN

Fixed height levels of the OPAC dataset

(0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 35 km)

4 sets of simulations:

"clear"-SW, "clear"-LW, "dusty"-SW, "dusty"-LW

3 different SZA: 25°, 45° and 65°

Calculation of the Aerosol Radiative Forcing

$$ARF(z) = \Delta F^{dusty}(z) - \Delta F^{clear}(z), \quad \Delta F(z) = F\downarrow(z) - F\uparrow(z)$$

$$ARF_{NET}(z) = ARF_{SW}(z) + ARF_{LW}(z), \quad ARF_{Atm} = ARF_{TOA} - ARF_{BOA}$$

APPLIED METHODOLOGY FOR RADIATIVE SIMULATIONS:

3 DIFFERENT SCHEMES

Initial Data

mass(z) [μg m^{-3}] (BSC-DREAM8b)	**β_{532} [Mm^{-1} sr^{-1}]** Lidar	**α_{532} [Mm^{-1}]** Lidar

Inputs

Scheme A	Scheme B	Scheme C
mass (z_{OPAC}) [g m^{-3}] miam desert spheroids	**$\beta_{dust,532}$ [Mm^{-1} sr^{-1}]** δ_d=0.31, δ_{nd}=0.05 Tesche et al. (2009) ↓ mass(z) [μg m^{-3}] ρ_d=2.6 g m^{-3}, v_d/τ_d (AERONET) Ansmann et al. (2012)	SW: α_{532nm} (z_{atm}), $\overline{AOT}_{532nm}$ ↓ $\alpha_0=\alpha_1(\lambda_1/\lambda_0)^{AE1}$ Shang et al. (2018) ↓ LW: $\alpha_{10\mu m}$ (z_{atm}), $\overline{AOT}_{10\mu m}$

LibRadtran Simulations

SW & LW range

Outputs

Z_{out}, e_{dir}, e_{glo}, e_{dn}, e_{up}, heat

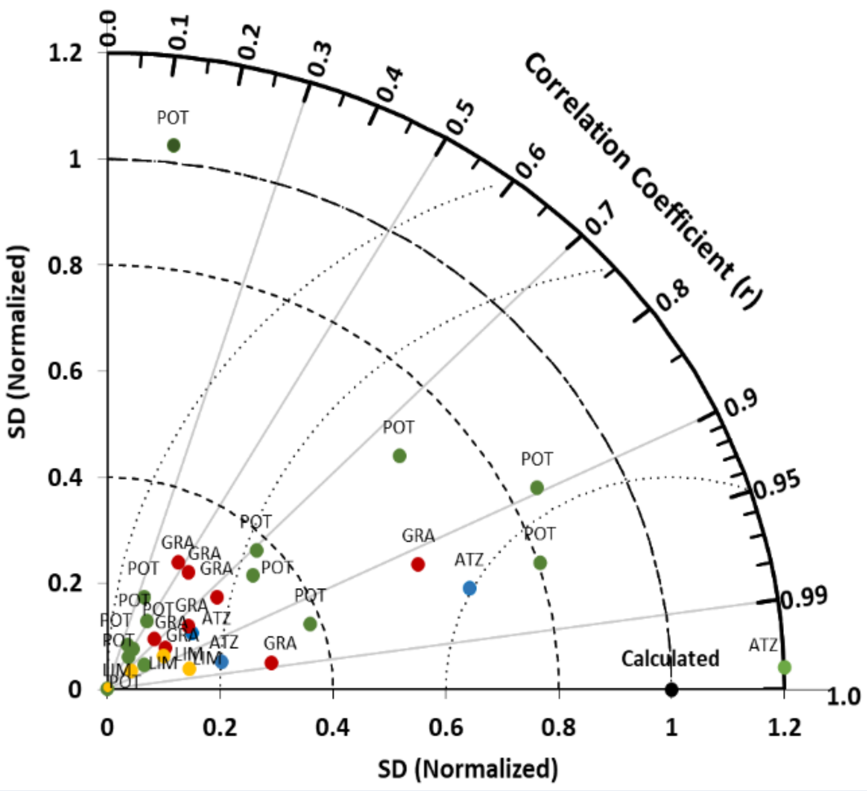
OVER THE MEDITERRANEAN BASIN

EVALUATION OF THE AEROSOL MASS CONCENTRATION VERTICAL PROFILES (SCHEME A VS. SCHEME B)

- 66 % of the cases → good correlation ($r > 0.6$)→ model: good prediction of the shape
- 96 % of the cases → $norm.\ SD < 1$ → model: underestimation (intensity, mass concentration)

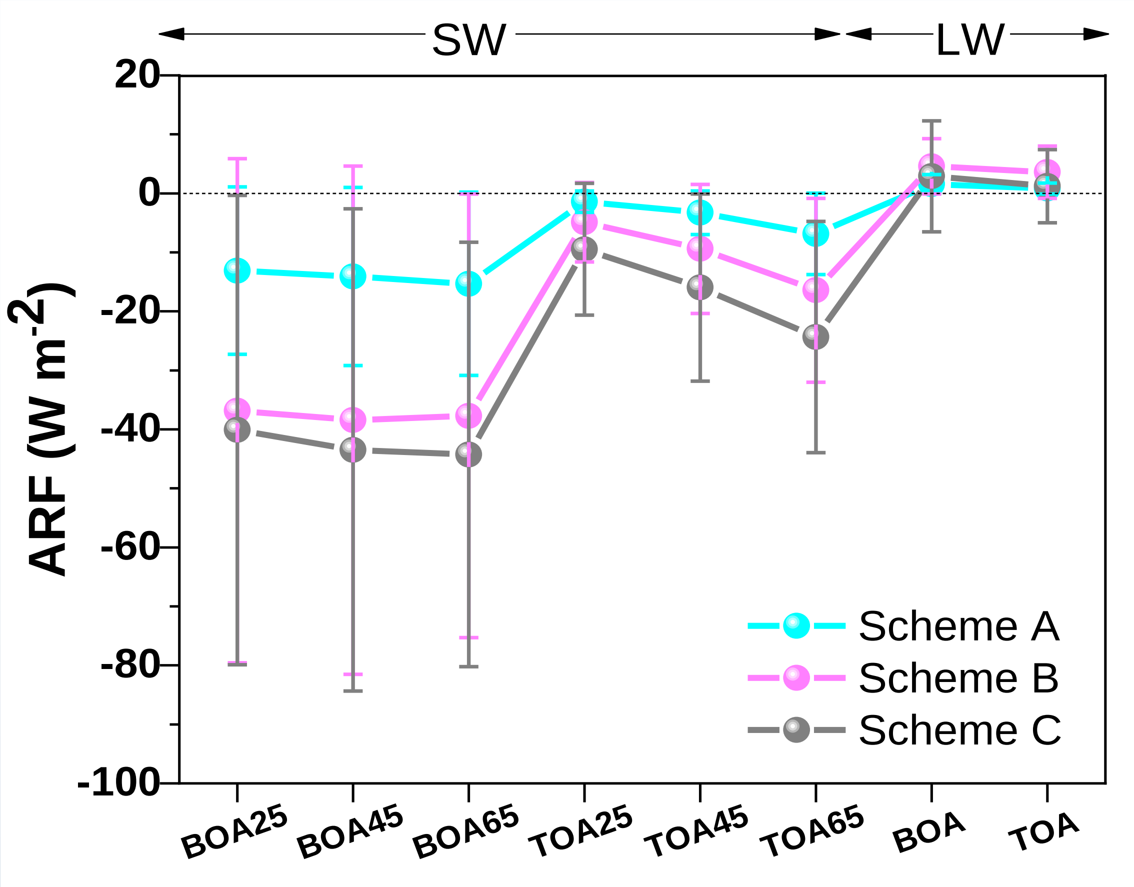
<u>After further comparison:</u>

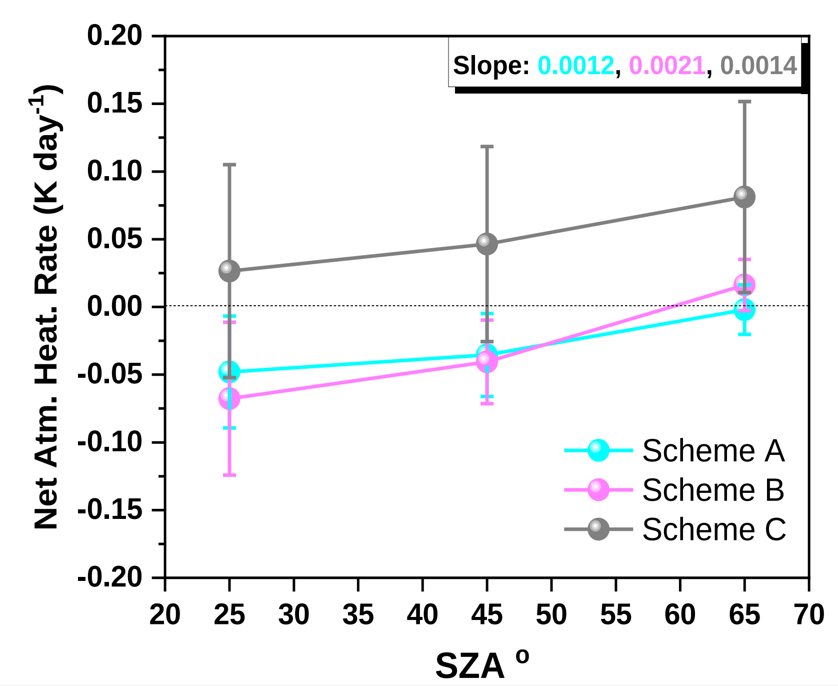
- mean **$CoM_{BSC-DREAM8b}$** $= 2.6 \pm 1.0$ km **<** **CoM_{lidar}** $= 3.2 \pm 1.1$ km
- Max concentration: 2-3 km (both in modeled and observed data)
- BCS-DREAM8b→ smoother, layer's **base** to **lower** altitudes (~1km, 100% of the cases), **top** at **higher** altitudes (86% of the cases) (Mona et al., 2014; Binietoglou et al., 2015)



OVER THE MEDITERRANEAN BASIN

- PER SCHEME

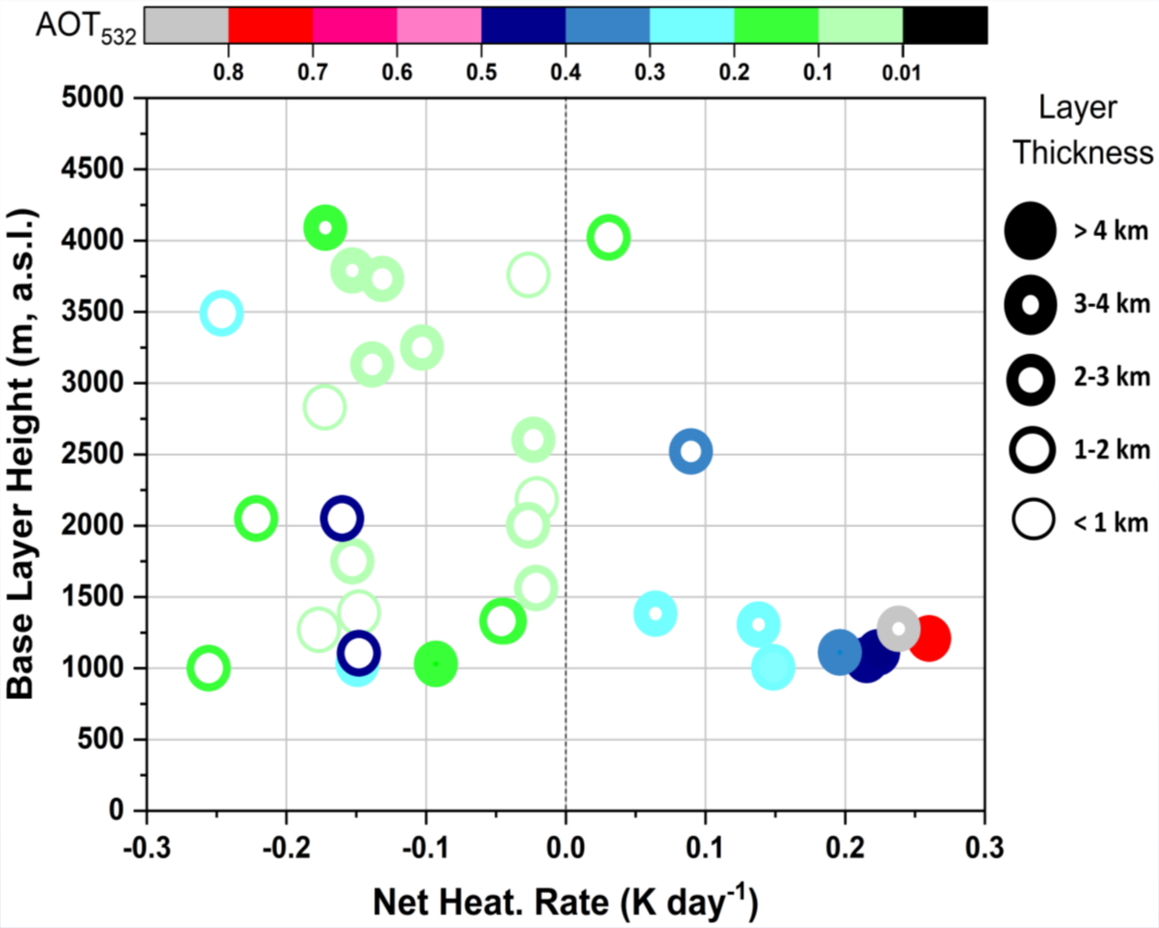




(Previous studies: Meloni et al., 2003, 2015; Sicard et al., 2014; Granados-Muñoz et al., 2019)

OVER THE MEDITERRANEAN BASIN

- SCHEME C, BOA, 25° SZA, ALL CASES

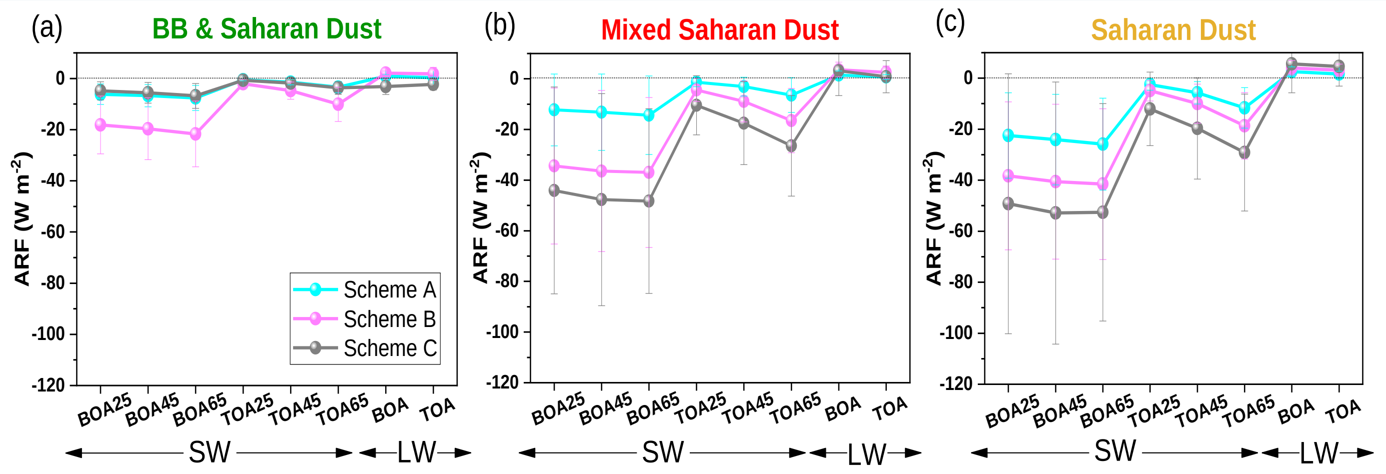


↓AOT_{532} & ↓thick, net heating rate < 0

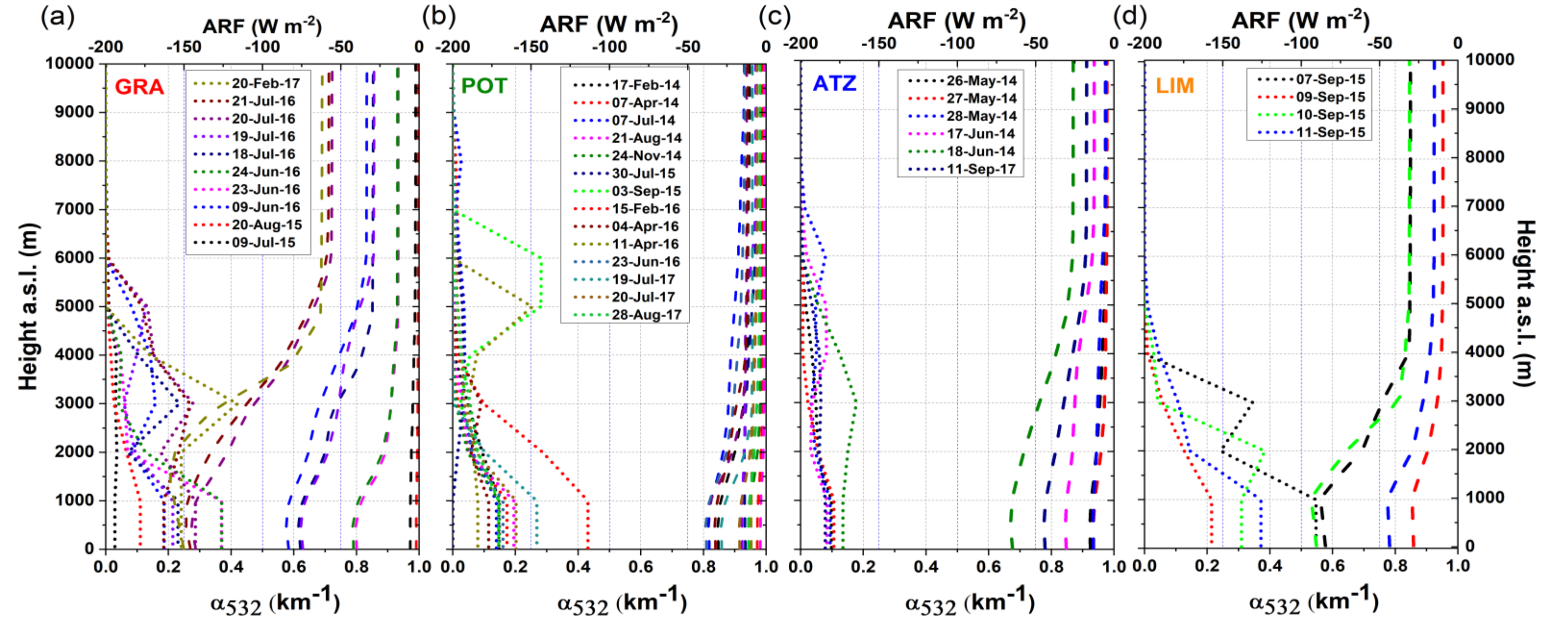
↓ BOA , ↑ net heating rate values

OVER THE MEDITERRANEAN BASIN

- PER MIXING STATE
ALL SCHEMES, ALL SZA



- PER STATION
SCHEME C, 45° SZA, SW



CONCLUSIONS

OPTICAL, GEOMETRICAL, MICROPHYSICAL PROPERTIES

- Analysis in a *regional coverage* with ground-based (high resolution) instruments
- Long-range transported dust is always a mixture of various elements
  Intensity and abundance designate the aerosol optical & microphysical properties
- ↓δ_{p532} (0.17 ± 0.01) & ↓AOD_{532} (0.03 ± 0.02) & ↓thick (786±212 m) → high mixing ratio
- ↑δ_{p532} (0.32 ± 0.02) & ↑ AOD_{532} (0.32 ± 0.23) & ↑thick (3158±1605 m) → less mixed dust layers
- LR_{355}/LR_{532} → 1 as mixing decreases, $AE_{\beta 355/532}$ → 0, case of "pure" dust

RADIATIVE FORCING

- Vertical structure, base, thickness and intensity → critically important in ARF estimations
  SW: −59 to −22 W m^{-2} BOA, −24 to −1 W m^{-2} TOA
  LW: +2 to +4 W m^{-2} BOA, +1 to +3 W m^{-2} TOA
- In modeling the ARF, vertical profiles of β_{aer} and α_{aer}, could be basic input parameters
- ARF more sensitive in the SW range and at the BOA → cooling effect

T S

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AERONET for providing high-quality sun/sky photometer measurements

Google Earth for providing distance calculator tool

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THANK YOU !

TIME FOR DISCUSSION