Investigating smoke optical properties in Eastern Mediterranean: Lidar observations in Cyprus

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Wildfires:

Large, uncontrolled fires that often occur in rural or sparsely populated areas.

Causes:
- Natural factors (heatwaves, drought, lightning)
- Human activity (arson, powerlines)

➢ **IPCC** (AR6): "weather conditions favoring wildfires have become more probable in southern Europe, northern Eurasia, the USA, and Australia over the last century" *(medium confidence)*

Smoke particles:

➢ Significant role in the <u>climate system</u>:
- *Direct impacts* [absorbing solar radiation]
- *Indirect impacts* [influencing cloud formation as cloud condensation nuclei (CCN) and ice-nucleating particles (INPs)]

➢ They also impact air quality, visibility, and pose health risks.

Studying their **optical properties** is essential for understanding their **role** in the **climate system** and improving **weather** and **climate models**.
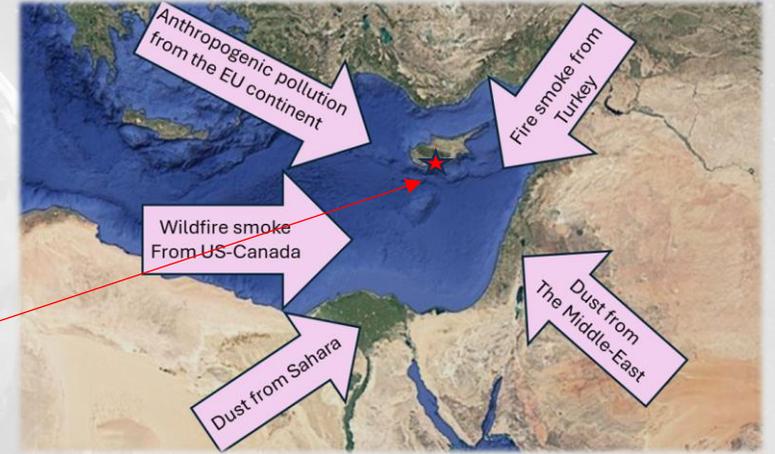
Mediterranean region is a key area for atmospheric studies due to the diverse aerosol types it experiences.

Cyprus provides a strategic location for investigating the vertical distribution of aerosols
marine particles, *desert dust*, *smoke*, and *anthropogenic particles*

Great opportunity to study the behavior of smoke in such aerosol mixtures

→ This study emphasizes on the intense activity of wildfires in Turkey's Mediterranean Region in July and August 2021.

Anthropogenic pollution from the EU continent
Fire smoke from Turkey
Wildfire smoke From US-Canada
Dust from The Middle-East
Dust from Sahara

CARO station
ERATOSTHENES - Cyprus Atmospheric Remote Sensing Observatory

ACTRIS AEROSOL REMOTE SENSING OBSERVATIONAL PLATFORM
- AERONET Sun/sky-photometer
- Polly^{XT} Raman LIDAR
- Wind Doppler lidar (Streamline-XR)

ACTRIS CLOUD REMOTE SENSING OBSERVATIONAL PLATFORM
- Microwave radiometer
- Ceilometer
- Optical precipitation disdrometer
- 35 GHz MiRA cloud radar

SOLAR STATION
- Sky Camera
- Brewer
- Pyranometer

Disdrometer
Microwave Radiometer
Polly^{XT} Raman lidar
Cloud Radar
Doppler lidar
solar radiation station Sun-lunar photometer

Multiwavelength polarization Raman LIDAR - POLLY^{XT}

$3\beta + 2\alpha + 2\delta$

Inside the container

System set-up

Backscatter coefficients at 3 wavelengths
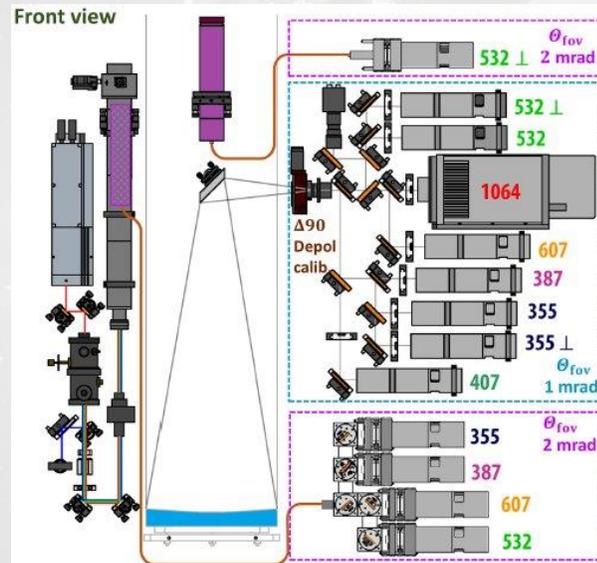*(1064nm, 532nm, 355nm)*

Extinction coefficients at 2 wavelengths
(532nm, 355nm)

Depolarization ratios at 2 wavelengths
(532nm, 355nm)

- **13 channels** in total

- **Raman** measurements at 387, 407, 607 nm

- **Far** and **near-range** channels

- Four near-field channels *(355, 387, 532, and 607 nm)* extend the vertical range of the lidar towards lower altitudes.

- **Water-vapor** Raman channel at 407 nm

- The lidar is mounted in a container.

- The system runs autonomously.

- It is operated continuously (day and night).

Smoke layers + Tools

Identifying Atmospheric Particle Layers

Use of the:

- Temporal evolution of attenuated backscatter coefficient (1064 nm)
- Volume depolarization ratio (532 nm)

Key Indicators:

- High backscatter coefficient → **aerosol loading**
- Low depolarization ratio → **smoke signature** (for tropospheric layers)

Haarig, M. et. al. 2018; Floutsi, A. A. et. al., 2023; Janicka, L. and Stachlewska, I. S, 2019

Tools

HYSPLIT model

- Examination of the backward trajectories
- Origin source
- Calculation of the arrival time at the reference station

FIRMS data

- VIIRS fire and thermal anomalies data (joint NASA/NOAA Suomi NPP satellite)
- Fire hotspots
- Fire Radiative Power data (MW)

CORINE land cover product

- Characterization of the vegetation burned

POLLY : NET

NOAA — Air Resources Laboratory / HYSPLiT

FIRMS

CORINE — Copernicus Land Monitoring Service (CLMS)

1. Layer Identification

o Detection of intense particle layers during July and August 2021 by the POLLY^{XT} – CYP lidar instrument

o HYSPLIT model → Backward trajectories → Smoke particles from wildfires in Turkey's south coast
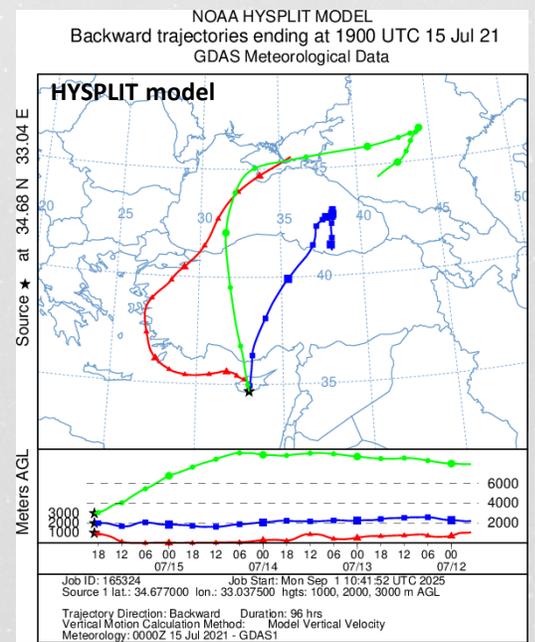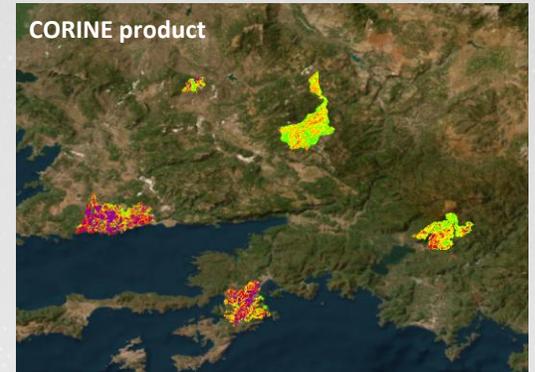
2. Fire radiative power (FRP)

o Estimation of the FRP at **two key clusters** based on the temporal evolution of the hotspots observed with FIRMS data

o Use of **VIIRS 375 m active fire product** from the **Suomi NPP** satellite

o Only FRP values with **high** or **nominal detection confidence level** were used

3. CORINE land cover

o Characterization of the **vegetation burned** at the two **key clusters**

4. Statistical analysis of the particles' optical properties

o Analysis of **nighttime measurements** → **Raman** method

o **Temporal averaging** window of **60–70 minutes** (Smooth 500 m)

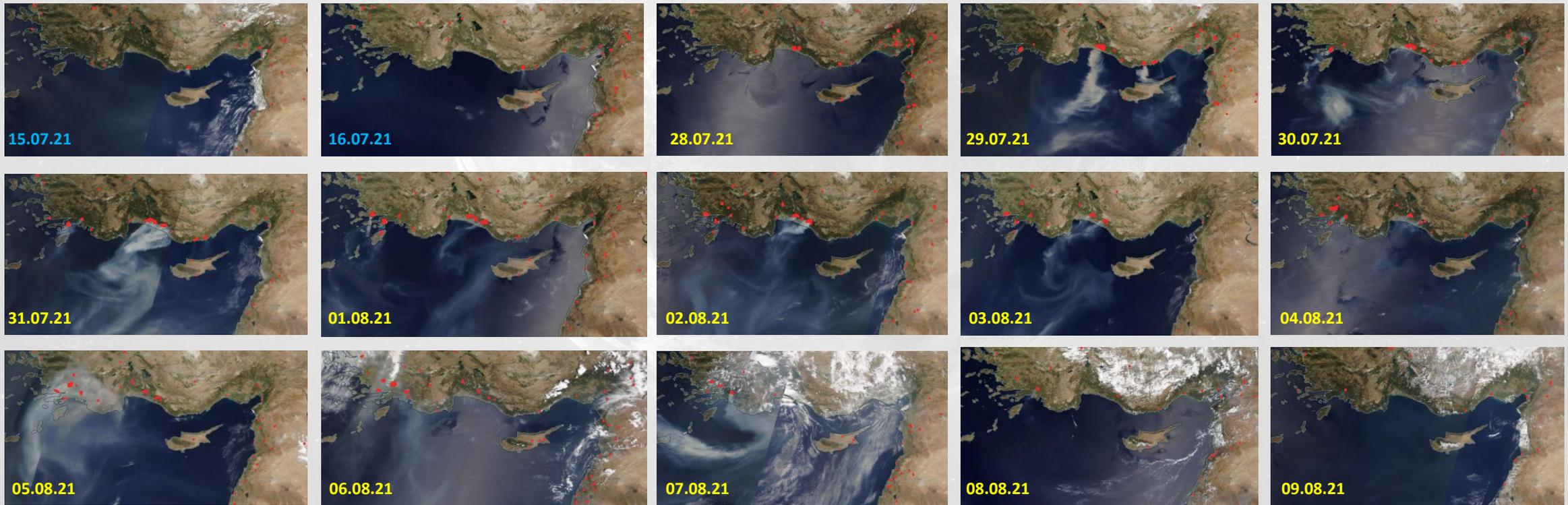o For each case, the **mean PLDR** and **LR** within the detected aerosol layers were calculated

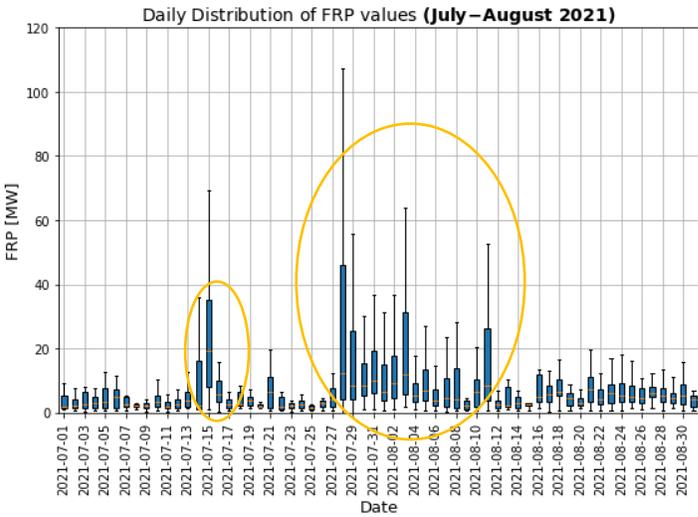CORINE product

NOAA HYSPLIT MODEL
Backward trajectories ending at 1900 UTC 15 Jul 21
GDAS Meteorological Data

HYSPLIT model

RESULTS

According to World Meteorological Organization (**WMO**), **extreme temperatures** were observed across the **Mediterranean Basin** during **2021**. **Turkey's Mediterranean coasts** were particularly **affected** by these extreme events in **July** and **August 2021.** The fires began in July 2021 and continued until August 12, 2021. The wildfire event resulted in the **highest loss of area** in the history of forest fires in Turkey and reached the level of **disaster**. The event was clearly captured via **satellite imagery**.

July 2021 / August 2021 (MODIS true color images)
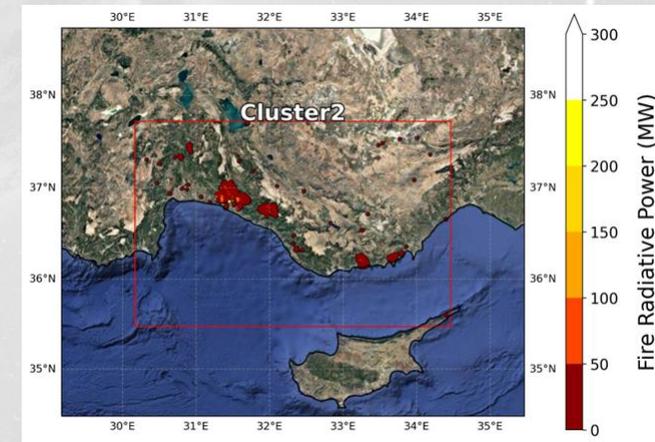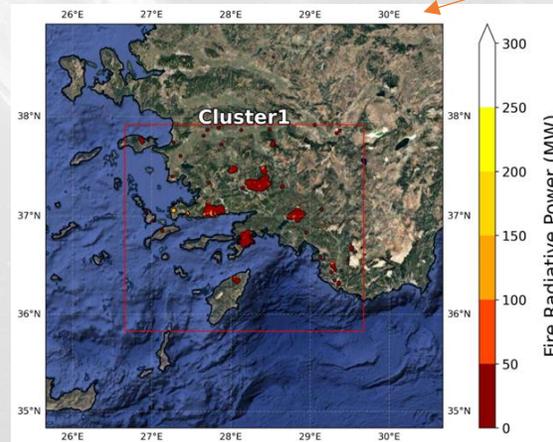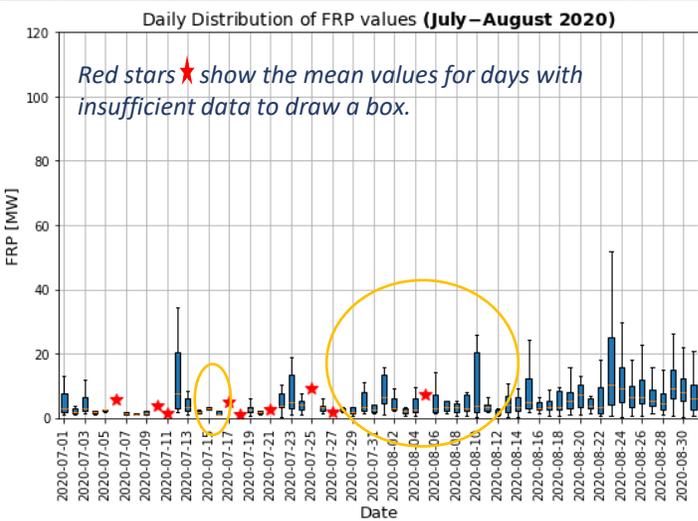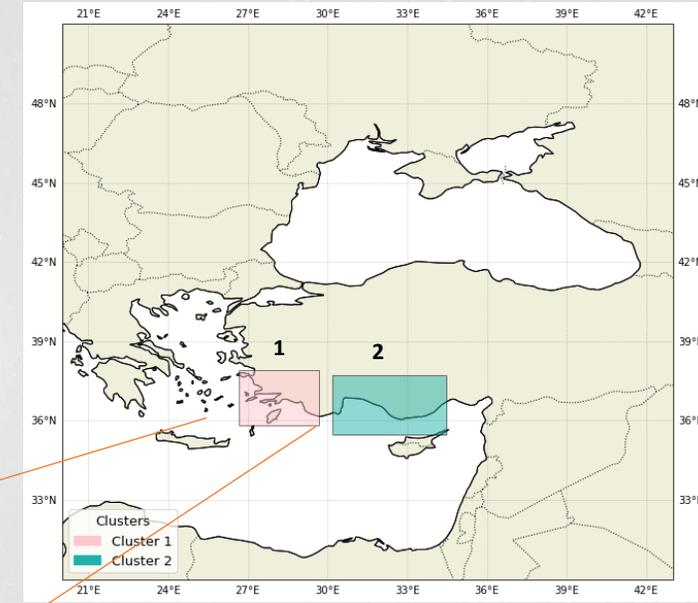

*Thermal anomalies

Daily Distribution of FRP values (July–August 2021)

Daily Distribution of FRP values (July–August 2020)

Red stars ★ show the mean values for days with insufficient data to draw a box.

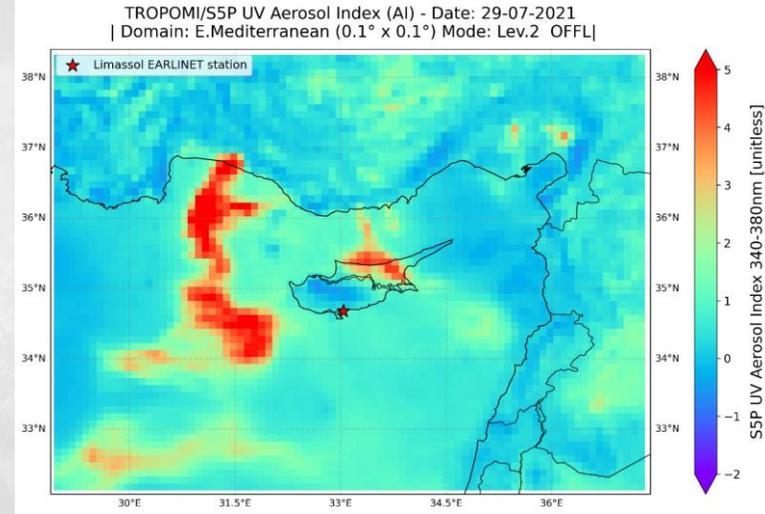o Daily distribution of FRP values for July-August 2021:

28 July–12 August 2021
15-16 July 2021 } High FRP values comparing to the other days.

2021 variability: Wide range of boxplot values indicates significant fluctuations, with maximum FRP reaching nearly 100 MW.

o Some fire pixels in these regions displayed high values reaching 300 MW but most of them ranged between 50-100 MW.

o The comparison of FRP values with the previous year showed the severity of these wildfire events → extreme events

Cluster1

Cluster2

Area per land cover type

Cluster 1

Cluster 2

Cluster 1

Land cover — area — Cluster 1
- Coniferous forest — 316.93 km² (55.9%)
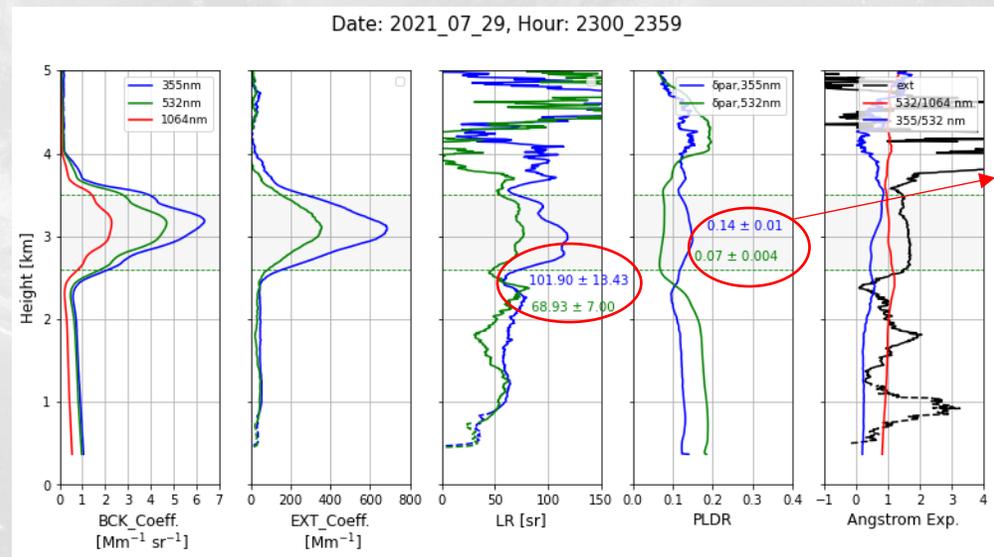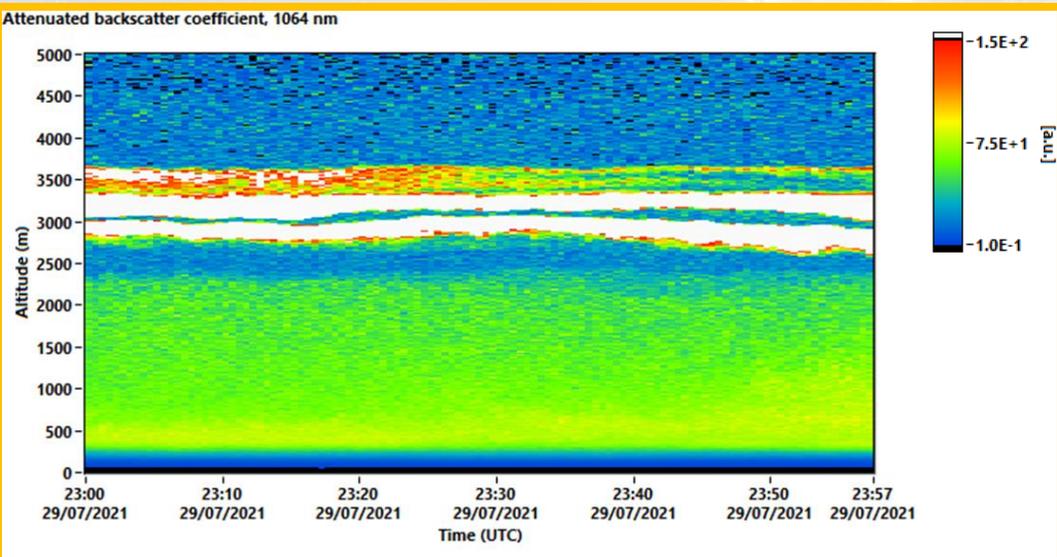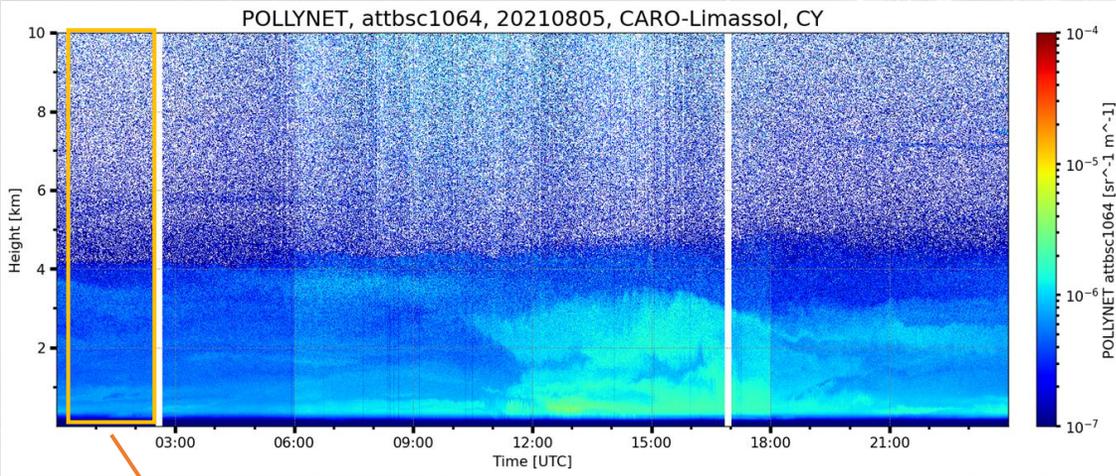- Transitional woodland-shrub — 139.24 km² (24.6%)
- Land principally occupied by agriculture, with significant areas of natural vegetation — 29.41 km² (5.2%)
- Sclerophyllous vegetation — 14.90 km² (2.6%)
- Complex cultivation patterns — 13.79 km² (2.4%)
- Broad-leaved forest — 11.94 km² (2.1%)
- Natural grasslands — 11.88 km² (2.1%)
- Mixed forest — 10.31 km² (1.8%)
- Sparsely vegetated areas — 8.69 km² (1.5%)
- Other — 9.86 km² (1.7%)

Cluster 2

Land cover — area — Cluster 2
- Coniferous forest — 408.49 km² (47.4%)
- Transitional woodland-shrub — 207.12 km² (24.0%)
- Complex cultivation patterns — 77.43 km² (9.0%)
- Land principally occupied by agriculture, with significant areas of natural vegetation — 73.99 km² (8.6%)
- Mixed forest — 23.59 km² (2.7%)
- Sclerophyllous vegetation — 18.37 km² (2.1%)
- Sparsely vegetated areas — 17.98 km² (2.1%)
- Non-irrigated arable land — 15.38 km² (1.8%)
- Other — 19.86 km² (2.3%)

Corine Land Cover
- Agro-forestry areas
- Airports
- Annual crops associated with permanent crops
- Bare rocks
- Beaches, dunes, sands
- Broad-leaved forest
- Coastal lagoons
- Complex cultivation patterns
- Coniferous forest
- Construction sites
- Continuous urban fabric
- Discontinuous urban fabric
- Dump sites
- Estuaries
- Fruit trees and berry plantations
- Glaciers and perpetual snow
- Green urban areas
- Industrial or commercial units
- Inland marshes
- Land principally occupied by agriculture, with significant areas of natural vegetation
- Mineral extraction sites
- Mixed forest
- Moors and heathland
- Natural grasslands
- Non-irrigated arable land
- Olive groves
- Pastures
- Permanently irrigated land
- Port areas
- Rice fields
- Road and rail networks and associated land
- Salines
- Salt marshes
- Sclerophyllous vegetation
- Sea and ocean
- Sparsely vegetated areas
- Sport and leisure facilities
- Transitional woodland-shrub
- Vineyards
- Water bodies
- Water courses

Burned areas were primarily characterized by **coniferous forest** and **transitional woodland-shrub** for both clusters.

29.07.2021

POLLYNET, attbsc1064, 20210729, CARO-Limassol, CY

TROPOMI/S5P UV Aerosol Index (AI) - Date: 29-07-2021 | Domain: E.Mediterranean (0.1° x 0.1°) Mode: Lev.2 OFFL|

Spatial distribution of gridded UV **Aerosol Index** measurements obtained by the **TROPOMI/Sentinel-5p** on 29.07.2021

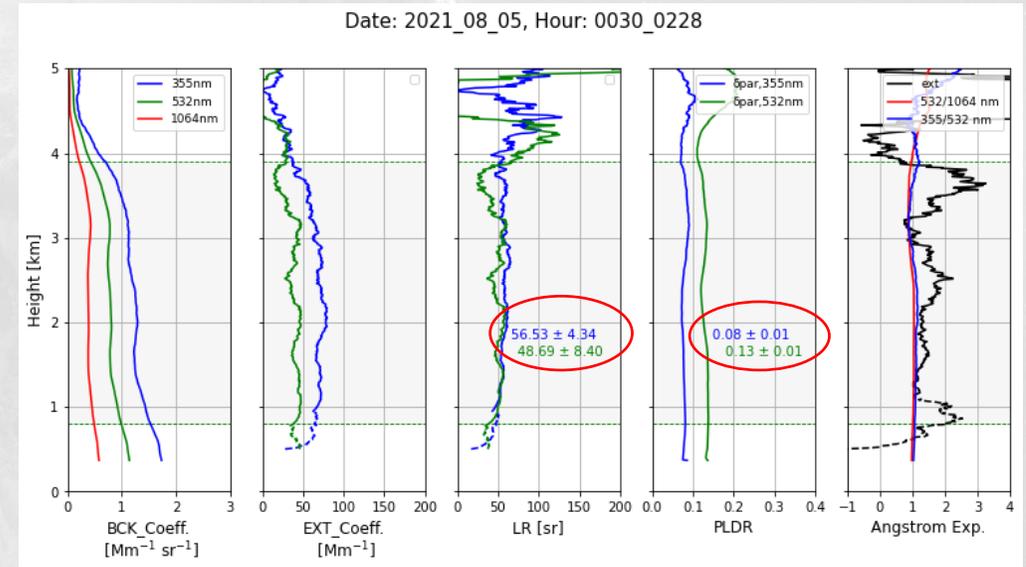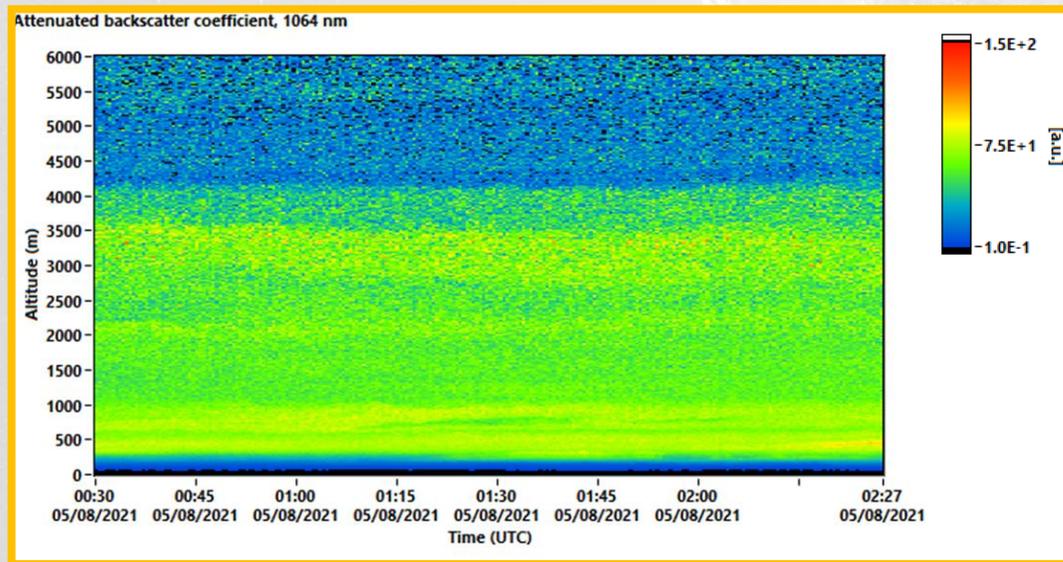Attenuated backscatter coefficient, 1064 nm

Date: 2021_07_29, Hour: 2300_2359

Slightly enhanced values → possible influence of **soil dust** and **dust injected during the fire** in the aerosol mixture *(Nisantzi et. al. 2014)*

Layer: **2.6 – 3.5 km**
Travel time: < 12 hrs
Fresh smoke

05.08.2021

POLLYNET, attbsc1064, 20210805, CARO-Limassol, CY

Attenuated backscatter coefficient, 1064 nm

Layer: **0.8 – 4.0 km**
Background smoke

Date: 2021_08_05, Hour: 0030_0228

56.53 ± 4.34
48.69 ± 8.40

0.08 ± 0.01
0.13 ± 0.01

Mean Values	LR355 [sr]	LR532 [sr]	δ355	δ532	AB 532/1064	AB 355/532	AE	CRLR
Cluster 1	72 ± 12	59 ± 9	0.07 ± 0.01	0.08 ± 0.03	0.8 ± 0.2	0.9 ± 0.1	1.5 ± 0.2	0.8 ± 0.05
Cluster 2	75 ± 21	62 ± 16	0.10 ± 0.03	0.12 ± 0.04	0.9 ± 0.2	0.8 ± 0.2	1.3 ± 0.4	0.9 ± 0.2

Mean Values	LR355 [sr]	LR532 [sr]	δ355	δ532	AB 532/1064	AB 355/532	AE	CRLR
Fresh Smoke	86 ± 17	69 ± 13	0.10 ± 0.04	0.09 ± 0.03	0.9 ± 0.2	0.8 ± 0.2	1.3 ± 0.5	0.8 ± 0.2
Background -fresh Smoke	58 ± 4	50 ± 6	0.08 ± 0.02	0.13 ± 0.03	0.7 ± 0.2	0.9 ± 0.2	1.3 ± 0.2	0.9 ± 0.1

o Differences > 40 % for the lidar ratio at both wavelengths
o Enhanced values for the part. depol. ratio → dust injection

Fresh Smoke

Background Smoke
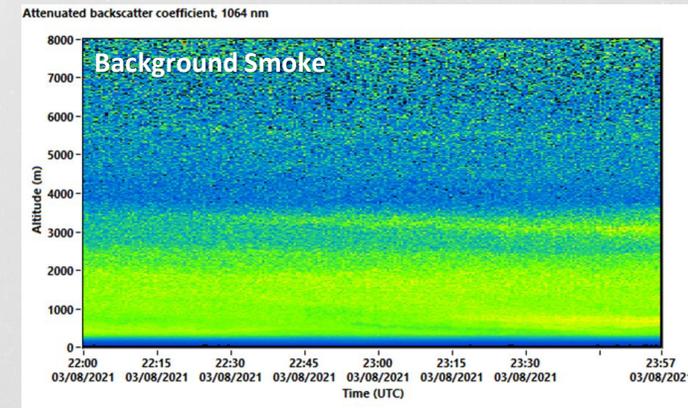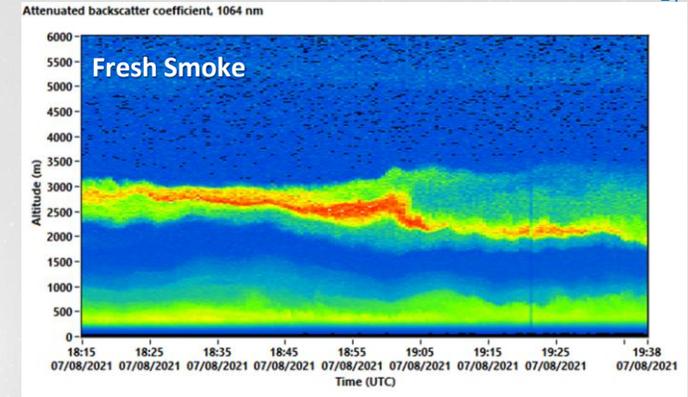
Fresh smoke layers

A series of wildfires burned approximately **120 km²** in Cyprus' Limassol district. The fire was worsened by a heatwave with temperatures exceeding 40°C and strong winds.
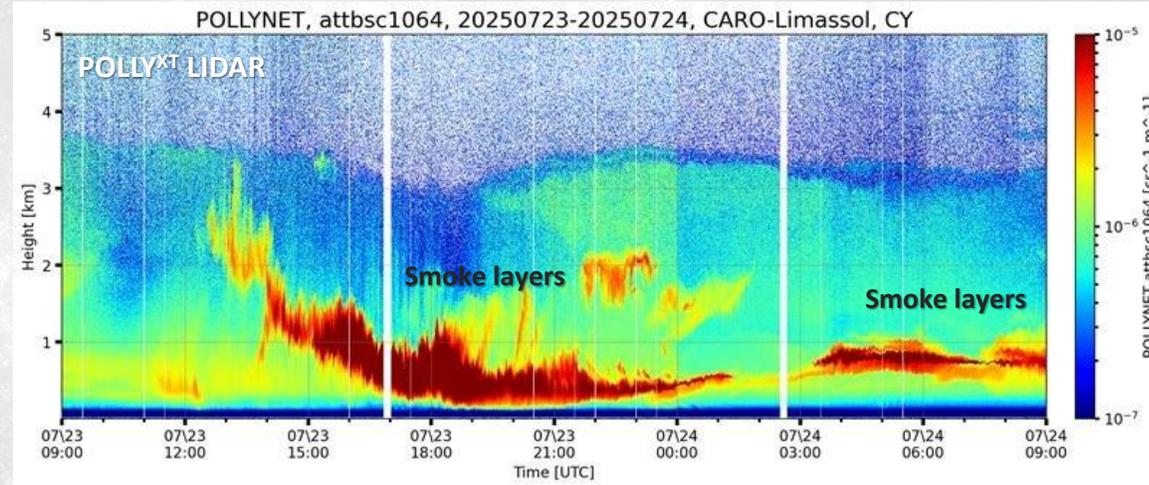
CARO Observations

→ **Poster** #60
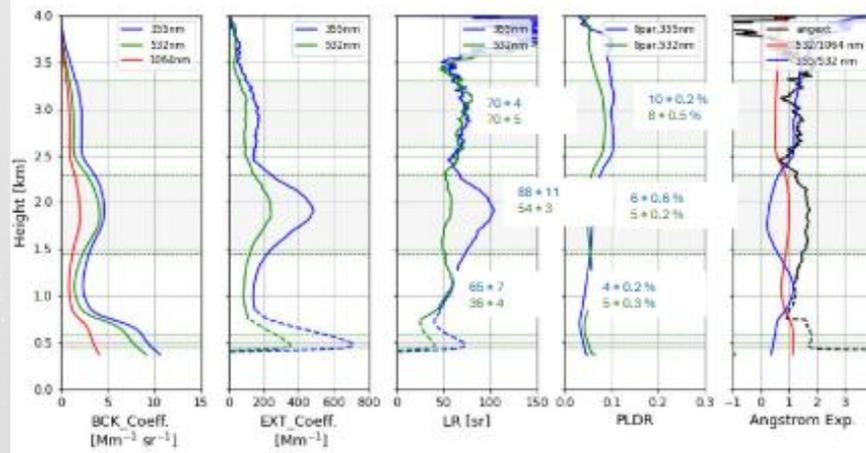Session 5

- Polly^{XT} lidar in Limassol, Cyprus, detected smoke layers from Turkey's Mediterranean wildfires (July–Aug 2021)

  → A total of **14 smoke cases** were analyzed

- Burned areas west coast vs south coast:

  → Mainly coniferous forest and woodland–shrub, for both clusters
  → **LR**: no major differences
  → **PLDR**: higher at both wavelengths when smoke came from Cluster 2 – south coast fires (dust injection, dispersion)

- Fresh smoke vs background smoke:

  → Differences depending on layer intensity and geometrical characteristics
  → **LR**: higher values for fresh smoke at both wavelengths
  → **PLDR**: higher values for fresh smoke at 355nm, while lower values at 532nm
  → In both cases LR532/LR355 < 1

- Angstrom Exponents in both cases indicated the presence of smoke and dust mixtures

- **_Further analysis_** for smoke cases (low altitude layers, Canadian smoke, dust & smoke mixtures, smoke particles & clouds)

Thank you!!

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