Wildfire Smoke characterization in Cyprus: CARO observations of fresh and aged plumes

Maria Poutli

PhD student in Cyprus University of Technology

Assistant Researcher A' in Environment & Climate Department, ECoE

Smoky Day 2026 – 31 March 2026

Motivation

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 **climate system**:

- ***Direct** impacts* [absorbing solar radiation]
- ***Indirect** impacts* [influencing cloud formation as cloud condensation nuclei (CCN) and ice-nucleating particles (INPs)]

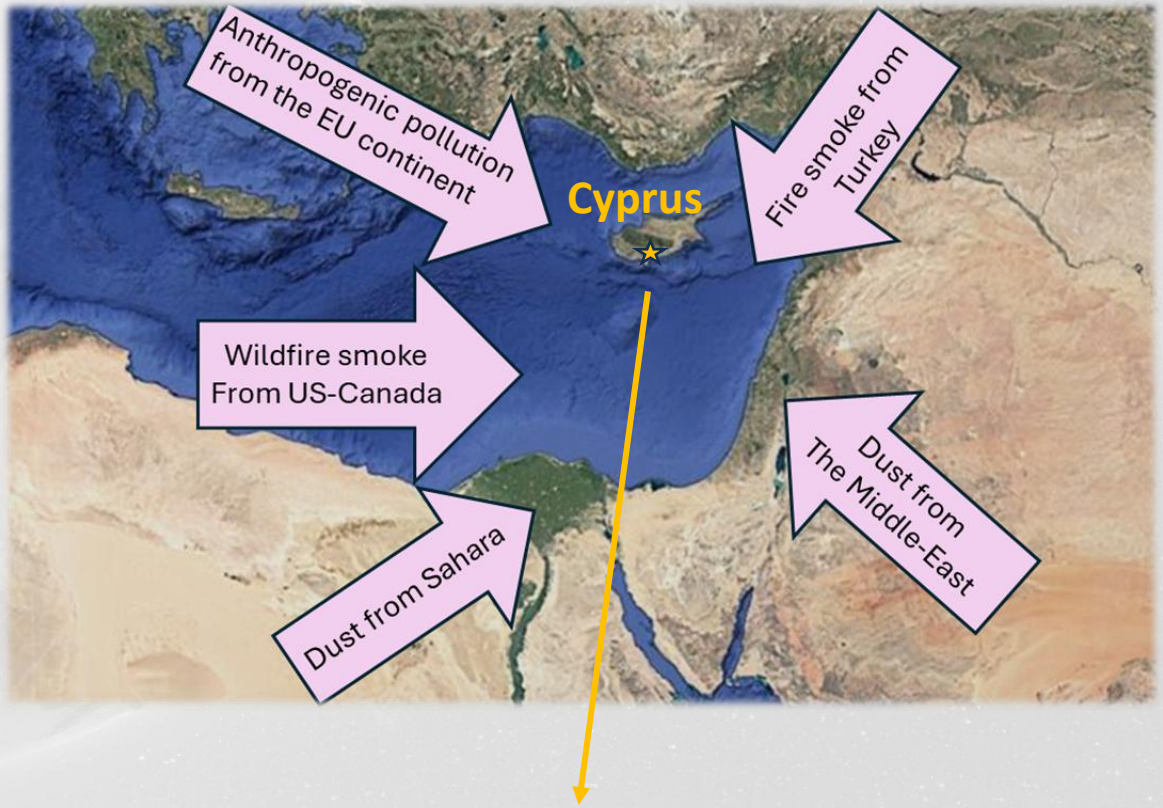
➢ They also impact air quality, visibility, and pose health risks

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** is based on multiwavelength polarization Raman LIDAR - **POLLY^{XT} measurements**

ACTRIS | Cyprus

CARO station

ERATOSTHENES - Cyprus Atmospheric Remote Sensing Observatory

ACTRIS AEROSOL REMOTE SENSING OBSERVATIONAL PLATFORM

- AERONET Sun/sky-photometer
- Polly^{XT} Raman LIDAR

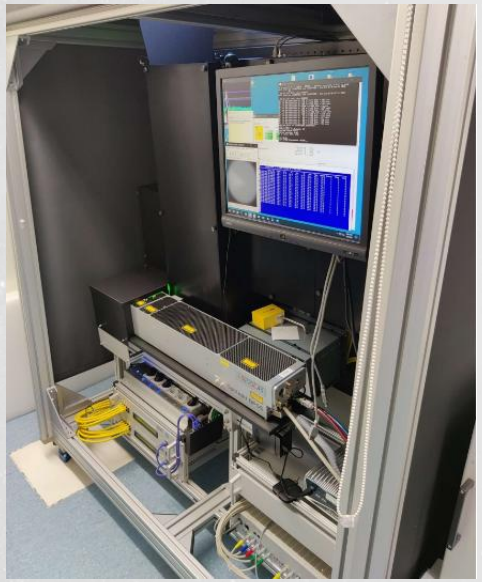
ACTRIS CLOUD REMOTE SENSING OBSERVATIONAL PLATFORM

- Microwave radiometer
- Ceilometer
- Optical precipitation disdrometer
- 35 GHz MiRA cloud radar
- Wind Doppler lidar

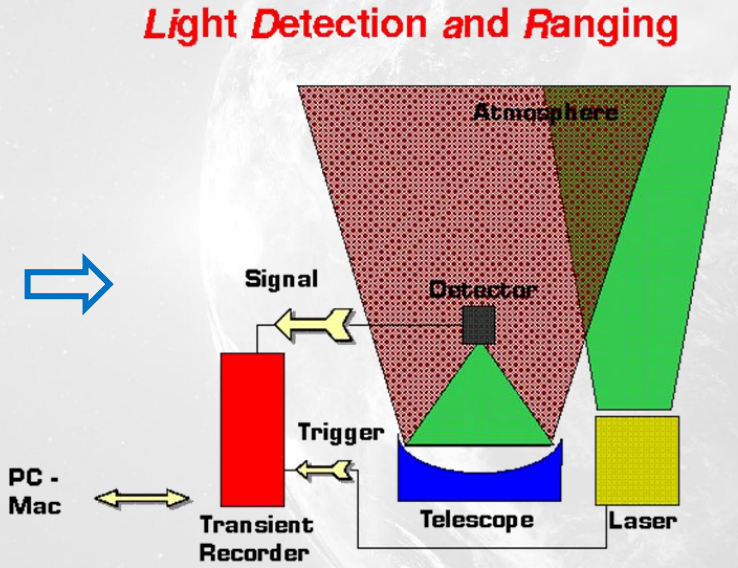
SOLAR STATION

- Sky Camera
- Brewer
- Pyranometer

Multiwavelength polarization Raman LIDAR - POLLY^{XT}



Inside the container



System set-up

3β + 2α + 2δ + 1w

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

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

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

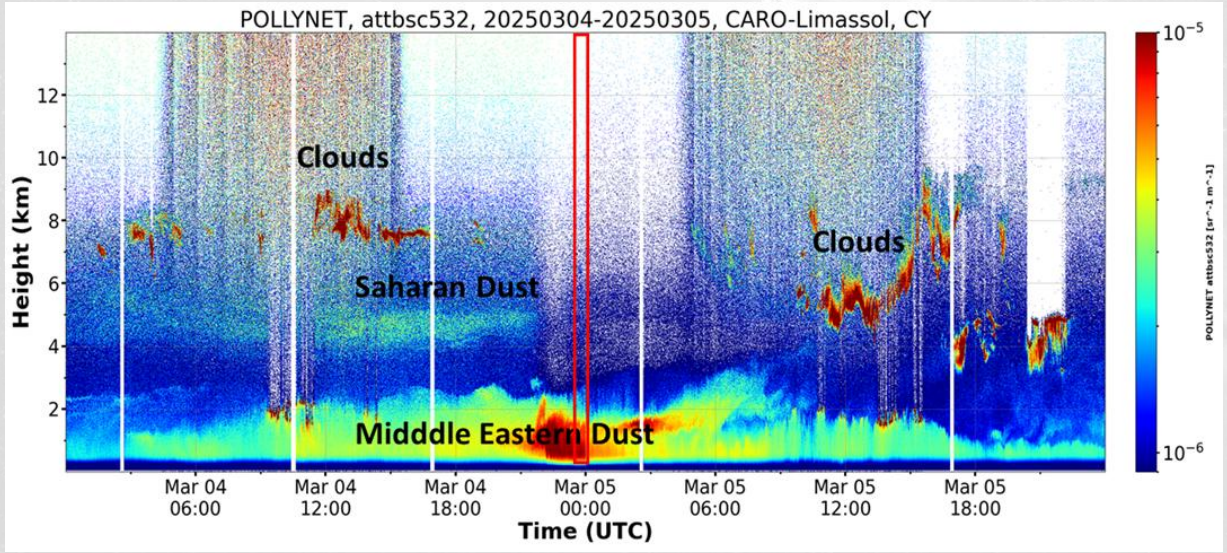
Water vapor mixing ratio *(407nm)*

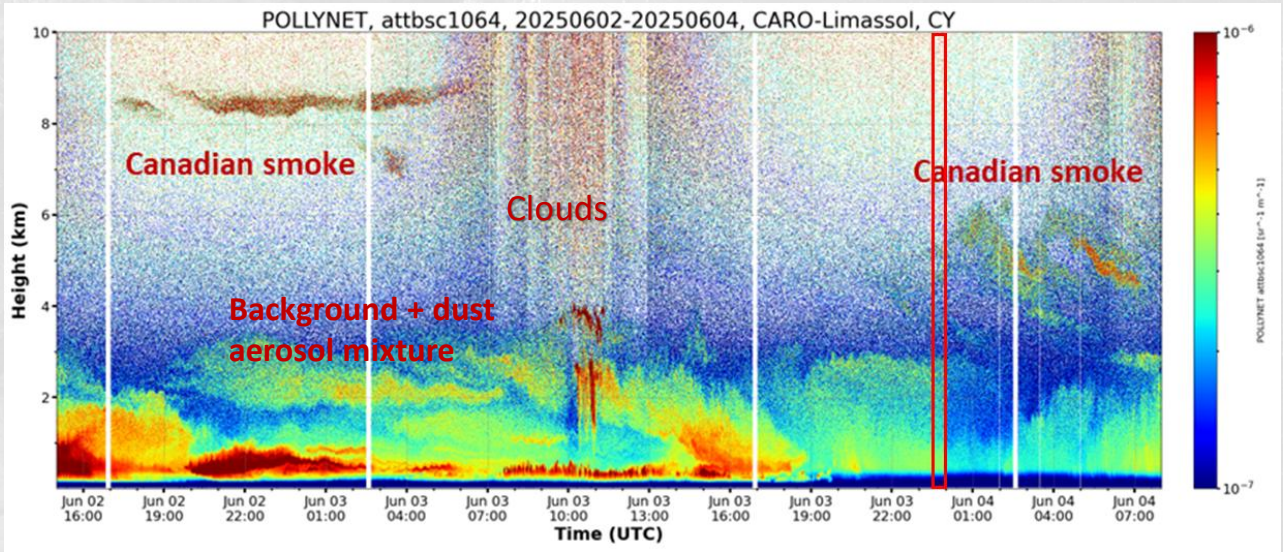
- The lidar is mounted in a container
- The system runs autonomously
- It is operated continuously (day and night)

- **13 channels** in total
- **Far** and **near-range** channels
- **Water-vapor** Raman channel at 407 nm

Multiwavelength polarization Raman LIDAR - POLLY^{XT}

- Operation since Oct. **2020**
- **Vertically-height** resolved profiles of **aerosol** optical properties
- High spatial & temporal resolution
- **Continuous** measurements
  → study of **extreme events**, statistical analysis





Optical properties

- **Aerosol Optical properties** play an important role in studying the atmosphere

  → information on the **type**, **size** & **shape** of the particles

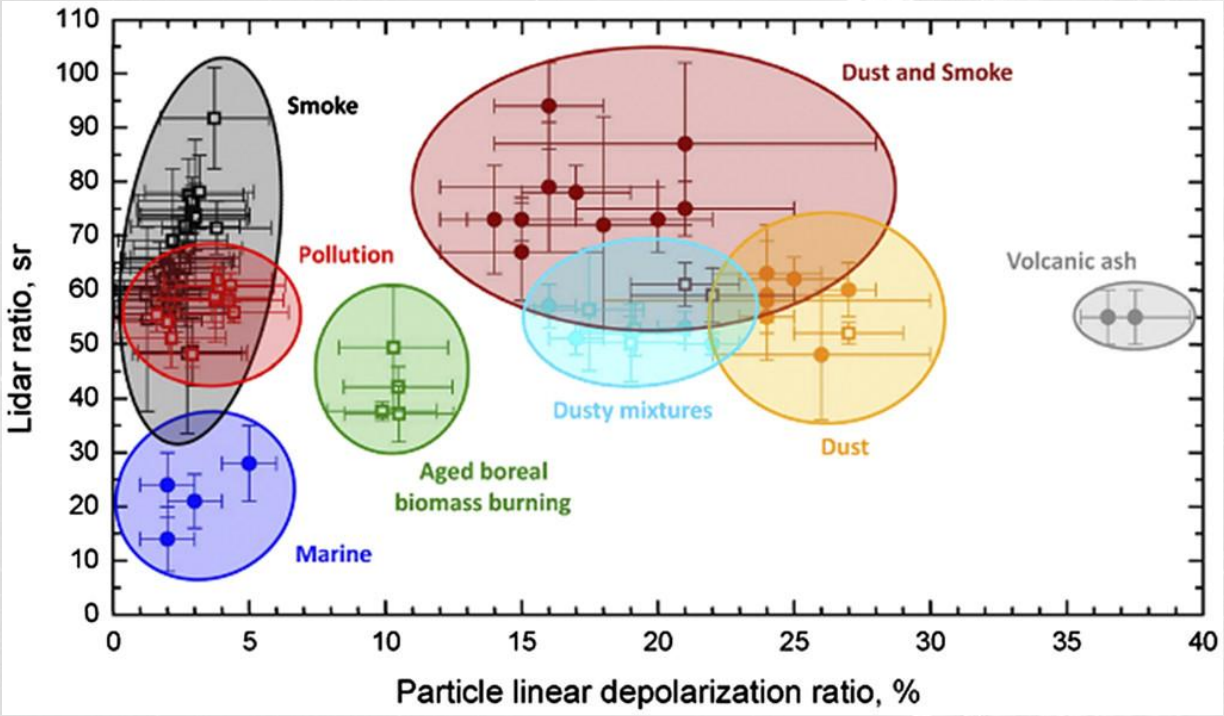
- The optical properties include:

  - **Backscatter** *β* & **extinction** coefficient *α* (aerosol load)
  - **Lidar ratio** (L=α/β, type of aerosol)
  - **Particle linear depolarization ratio *δpar*** (aerosol shape)
  - **Angstrom exponents** (AB, AE, aerosol size)

$$\delta_{\lambda,\mathrm{p}} = \beta^{\perp}_{\lambda,\mathrm{p}} / \beta^{\parallel}_{\lambda,\mathrm{p}}$$

Discrimination between **spherical** (e.g. smoke, anthropogenic particles) & **non-spherical** (e.g. dust) particles

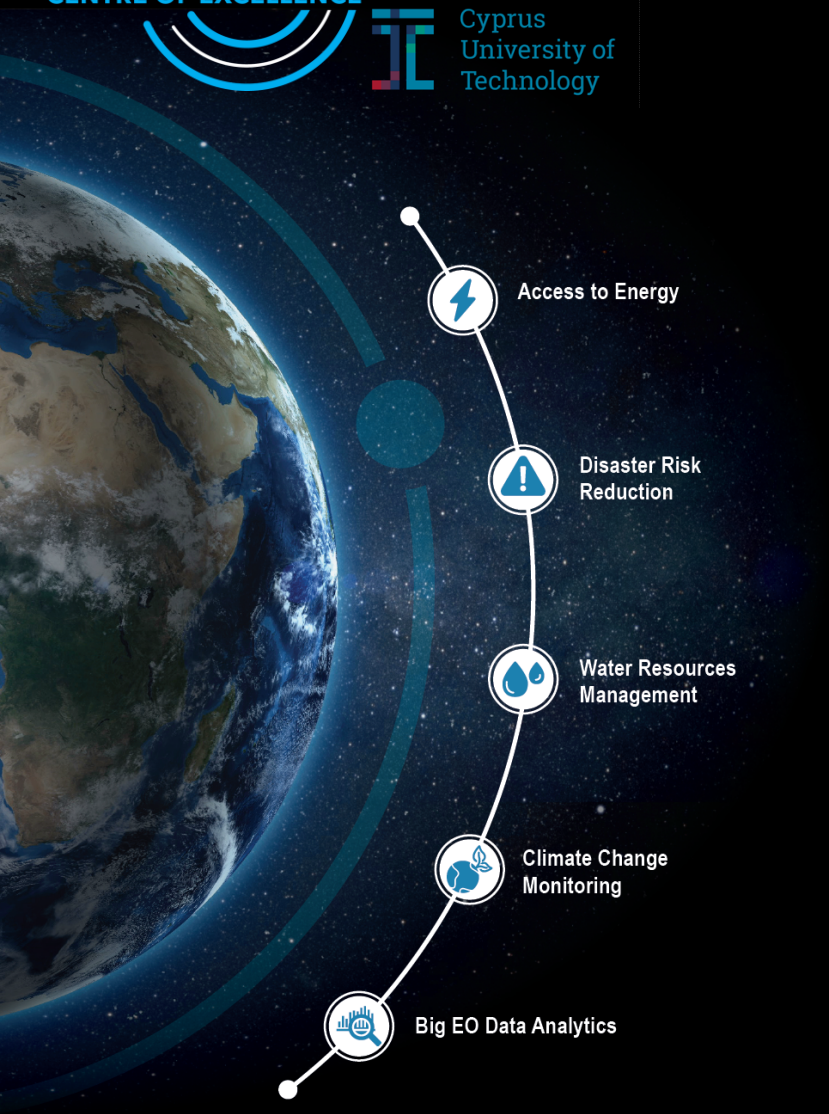
Optical properties



Illingworth A. J. et al., 2015

Floutsi A. A. et al., 2023

	S355 [sr]	S532 [sr]	δ355 [%]	δ532 [%]
Smoke	68.2 ± 7.4	71.8 ± 11.1	**2.7 ± 1.3**	**2.9 ± 0.6**
Dust & smoke	72.1 ± 7.7	56.3 ± 6.5	**15.7 ± 2**	**18.9 ± 1.4**



Smoke Cases detected by Polly^{XT} lidar, CARO station

Method & Tools

Smoke layers + Tools

Aerosol Layers

LabVIEW program

- Manual analysis of lidar data

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

* lidar measurements

Sources

HYSPLIT model

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

FIRMS data

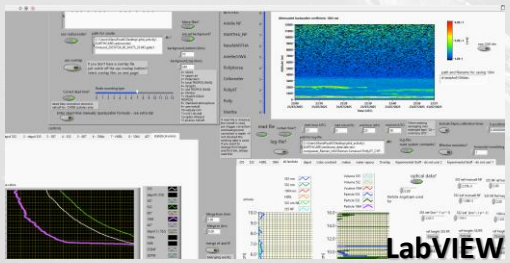
- VIIRS fire and thermal anomalies data (joint NASA/NOAA Suomi NPP satellite)
- Fire hotspots
- Fire Radiative Power data (MW)

CORINE land cover product

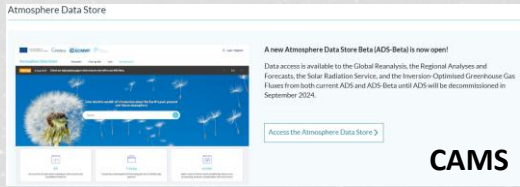
- Characterization of the vegetation burned

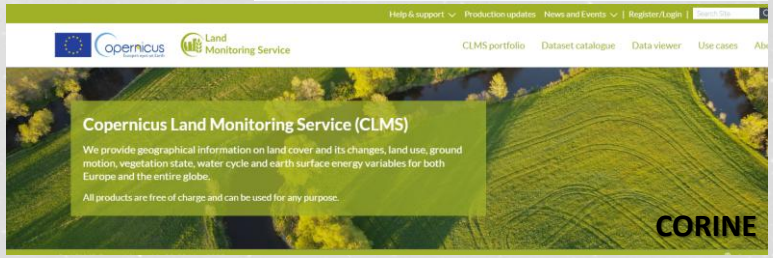
POLLY:NET

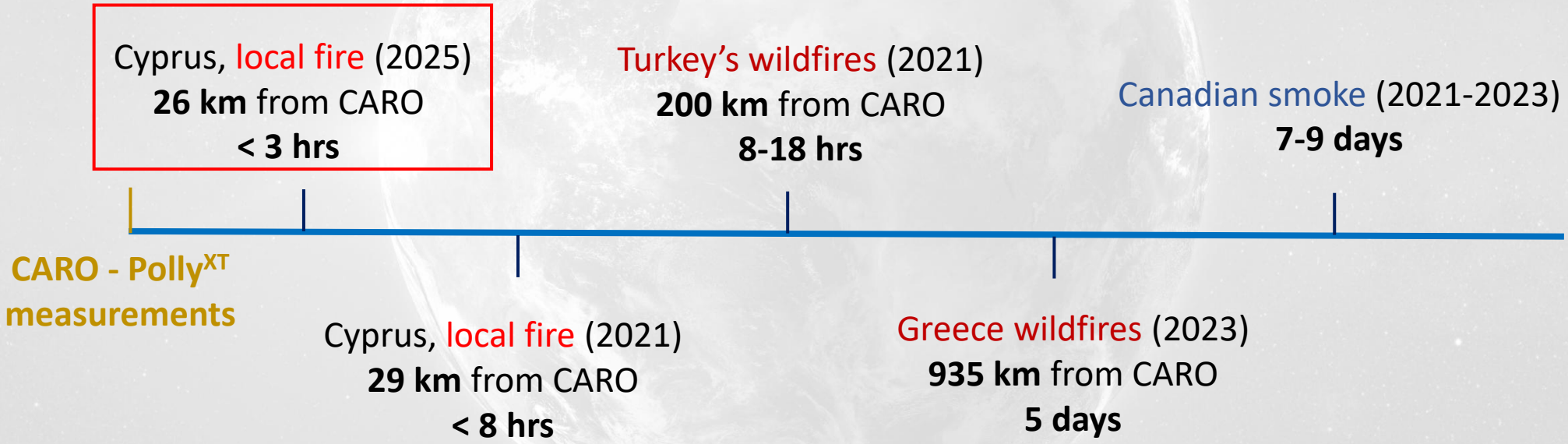
NOAA Air Resources Laboratory



HYSPLIT

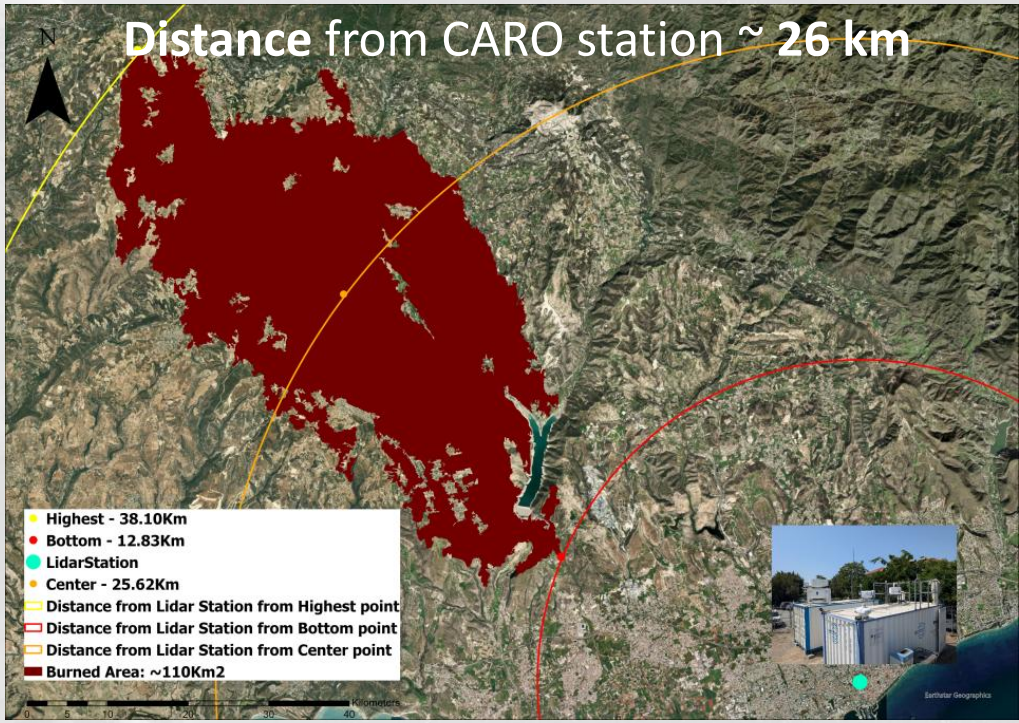


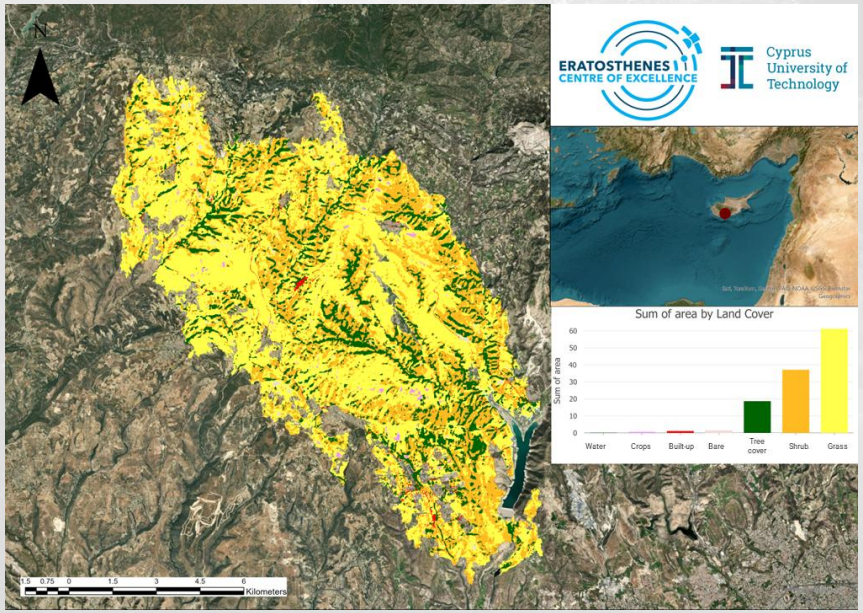



Cyprus, local fire (2025)
26 km from CARO
< 3 hrs
Turkey's wildfires (2021)
200 km from CARO
8-18 hrs
Canadian smoke (2021-2023)
7-9 days
CARO - Polly^XT measurements
Cyprus, local fire (2021)
29 km from CARO
< 8 hrs
Greece wildfires (2023)
935 km from CARO
5 days

Case of 23.07.2025

1. Fresh wildfire smoke layer – Local fire





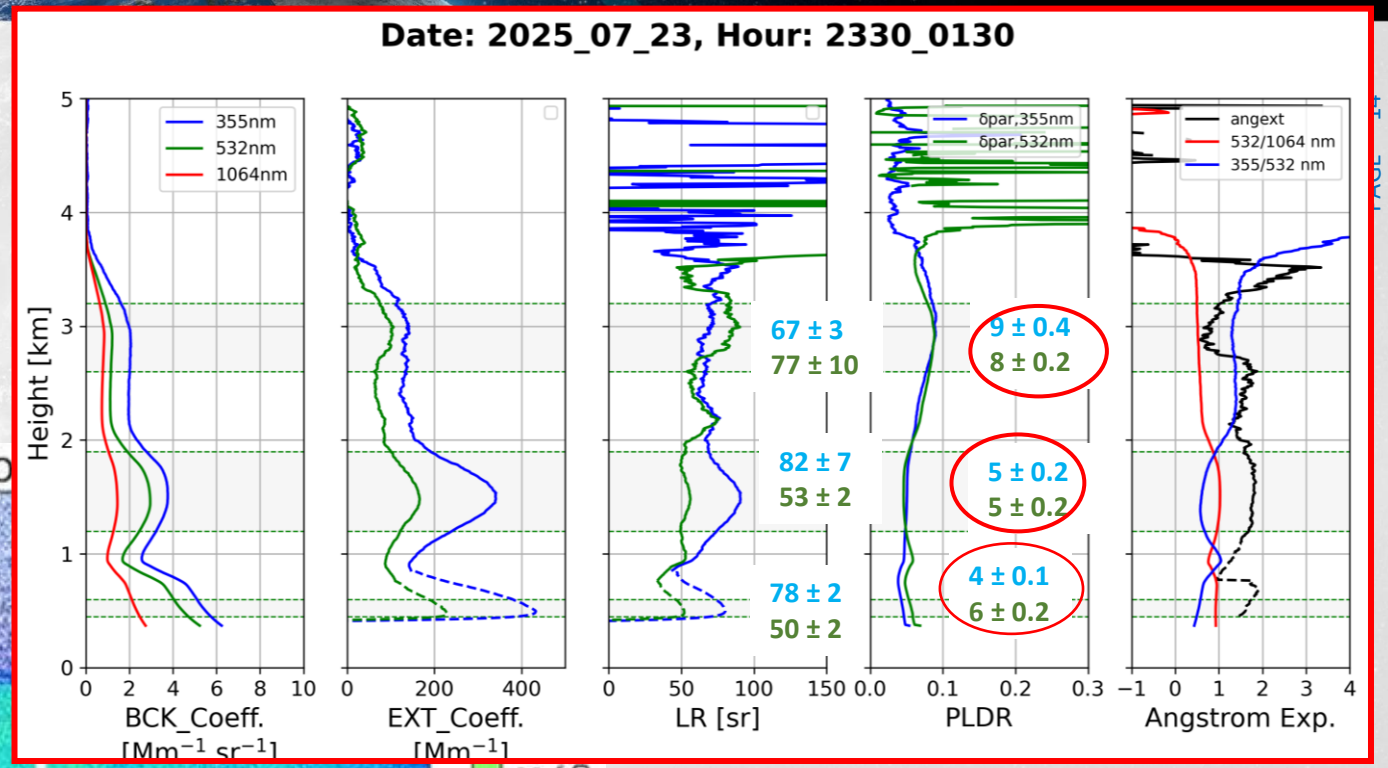
Vegetation burned:

1. Grass (60%)
2. Shrub (35%)
3. Tree cover (18%)

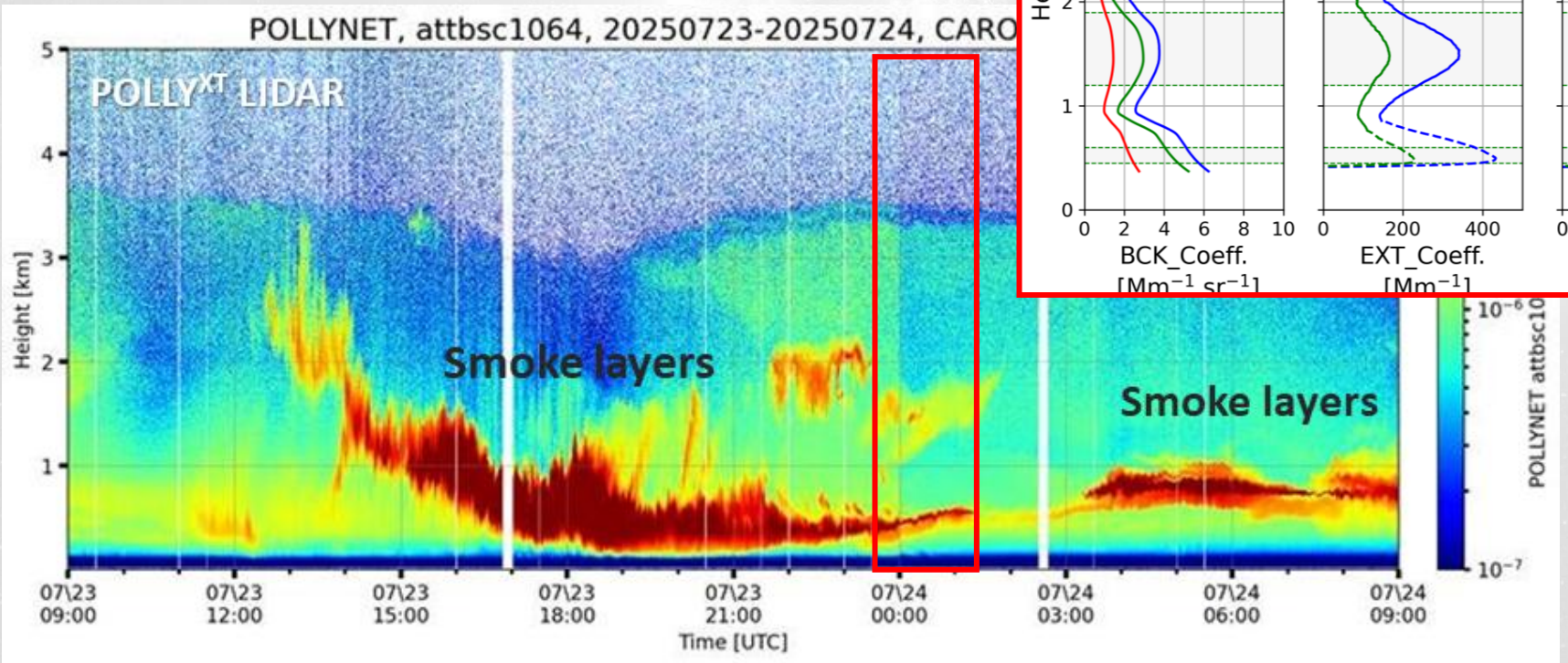
The **devastating wildfire** that broke out in the **Limassol district** on **23.07.2025** is estimated to have burned approximately **110 km²**, according to the latest analysis by the ERATOSTHENES Centre of Excellence.

Case of 23.07.2025

CARO – Polly^{XT} measurements



2330-0130 UTC

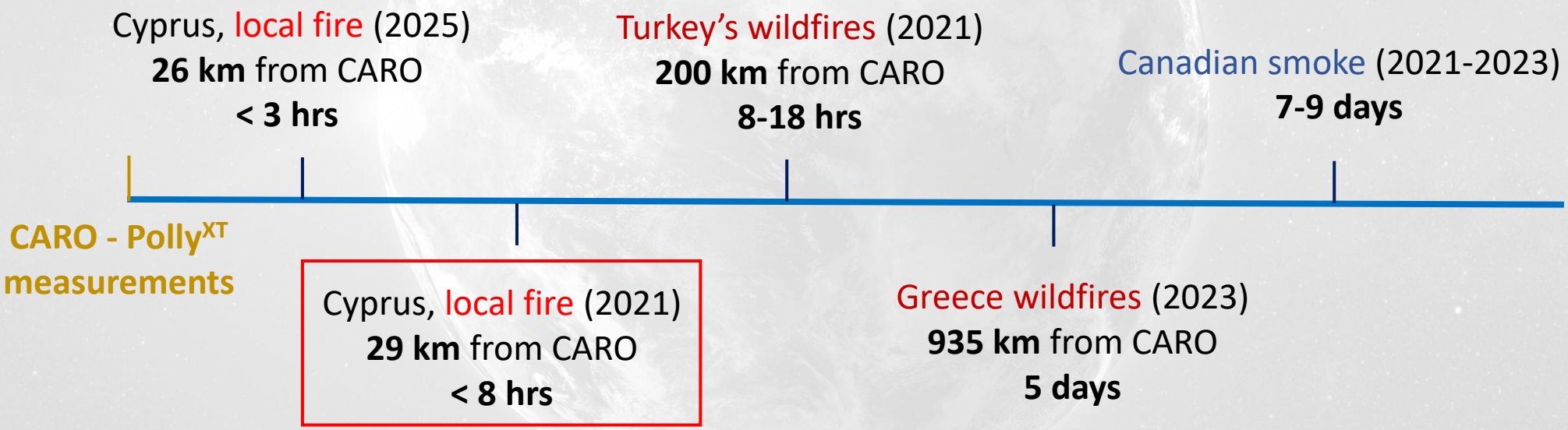


Height Range:

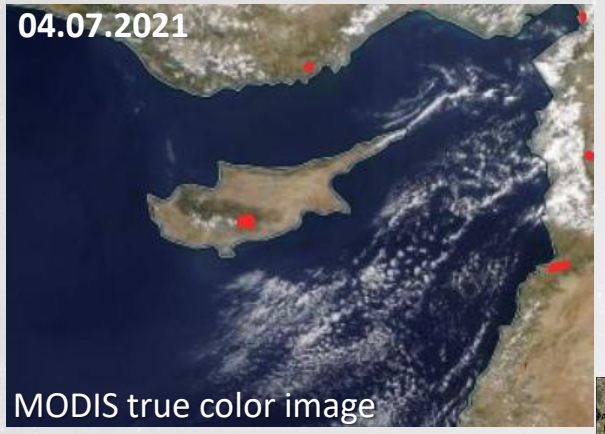
1st: 0.45-0.6 km

2nd: 1.2-1.9 km

3rd: 2.6-3.2 km

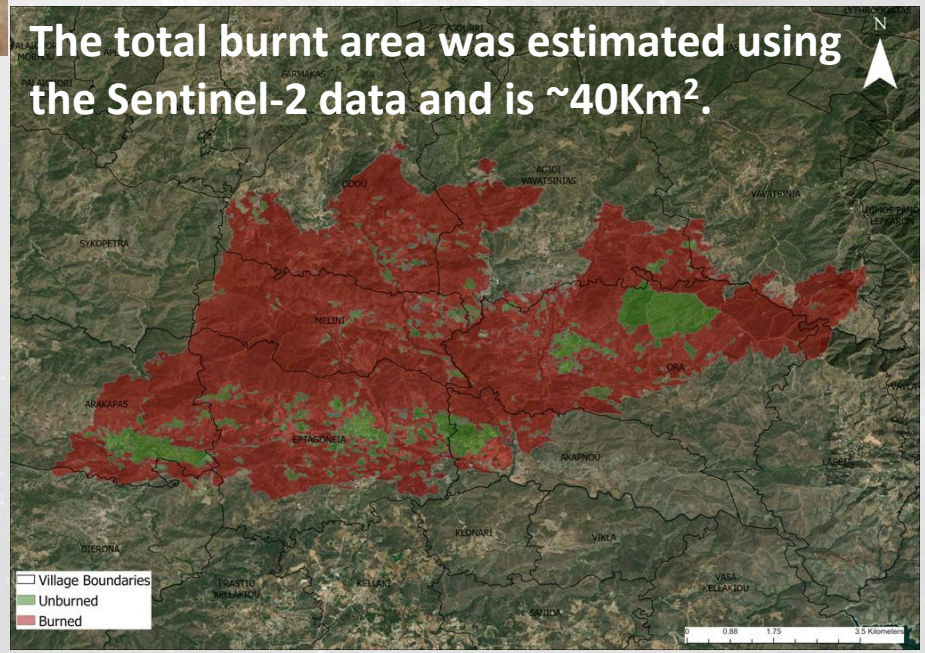

Cyprus, local fire (2025)
26 km from CARO
< 3 hrs
Turkey's wildfires (2021)
200 km from CARO
8-18 hrs
Canadian smoke (2021-2023)
7-9 days
CARO - Polly^XT measurements
Cyprus, local fire (2021)
29 km from CARO
< 8 hrs
Greece wildfires (2023)
935 km from CARO
5 days

2. Fresh wildfire smoke layer – Local fire

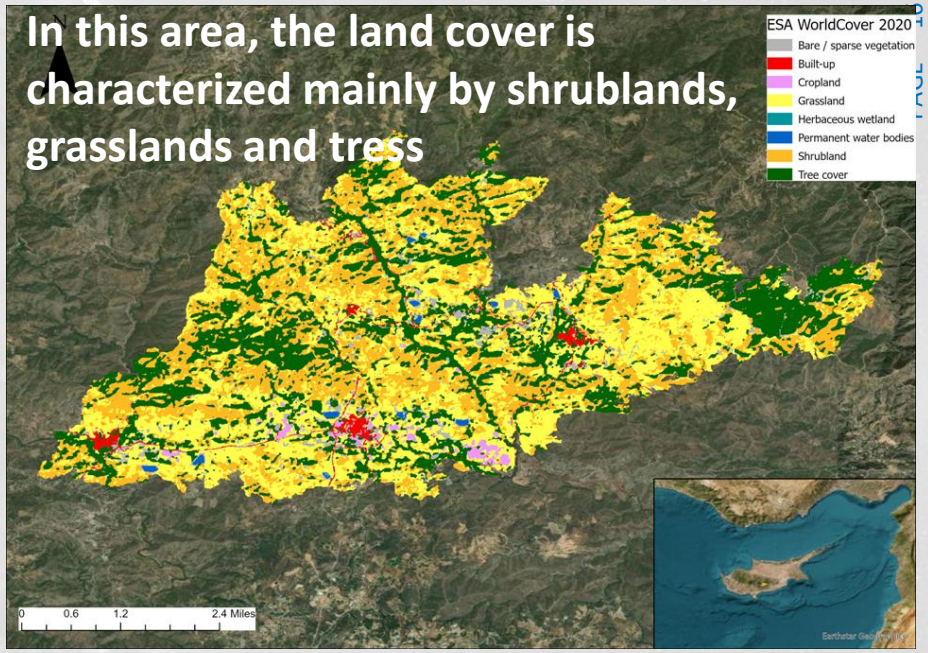


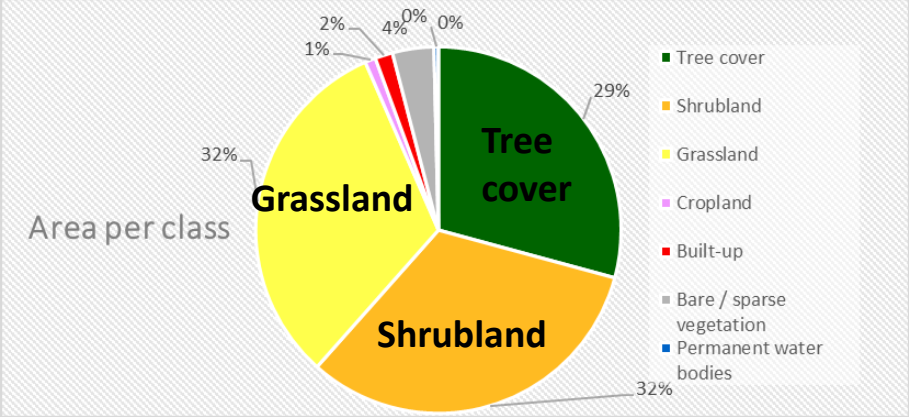
The fire event started on Saturday, the **3rd of July** in the **Limassol district** near the village of **Arakapas.**

Burned area



Land Cover

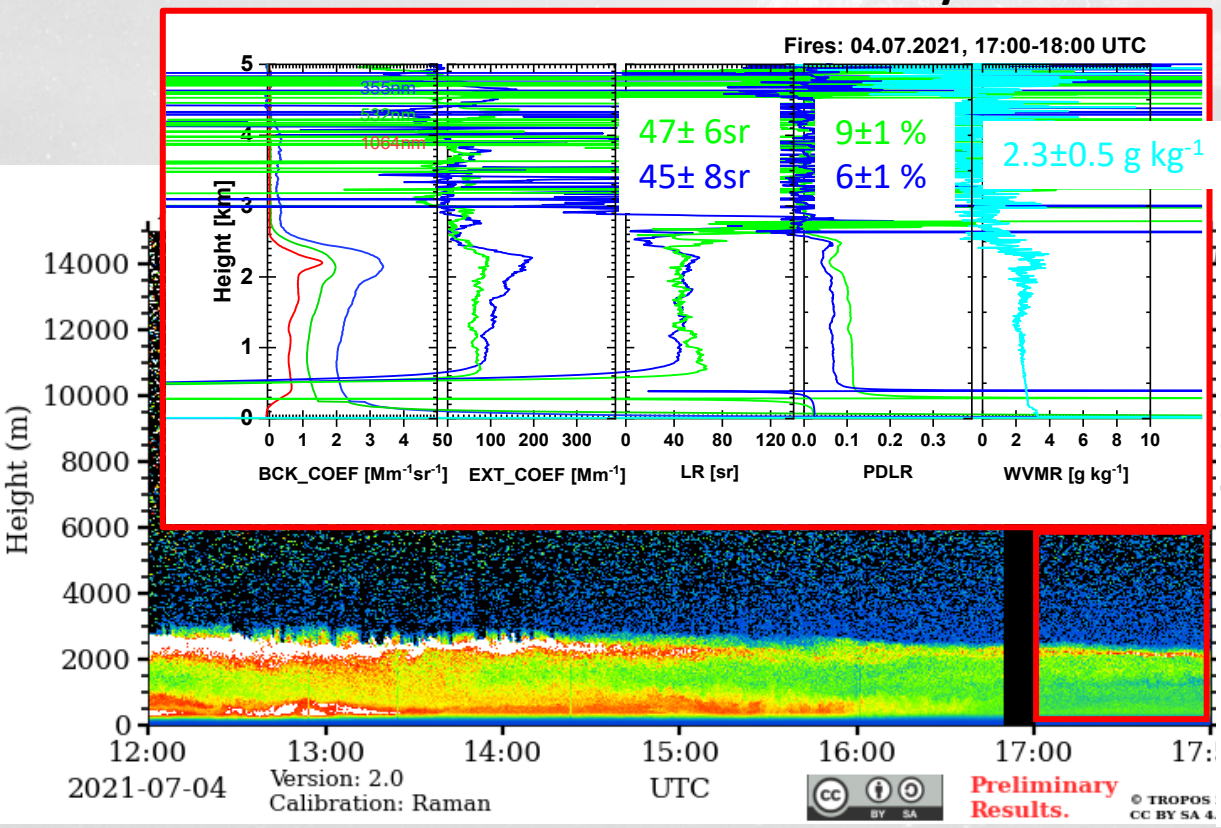




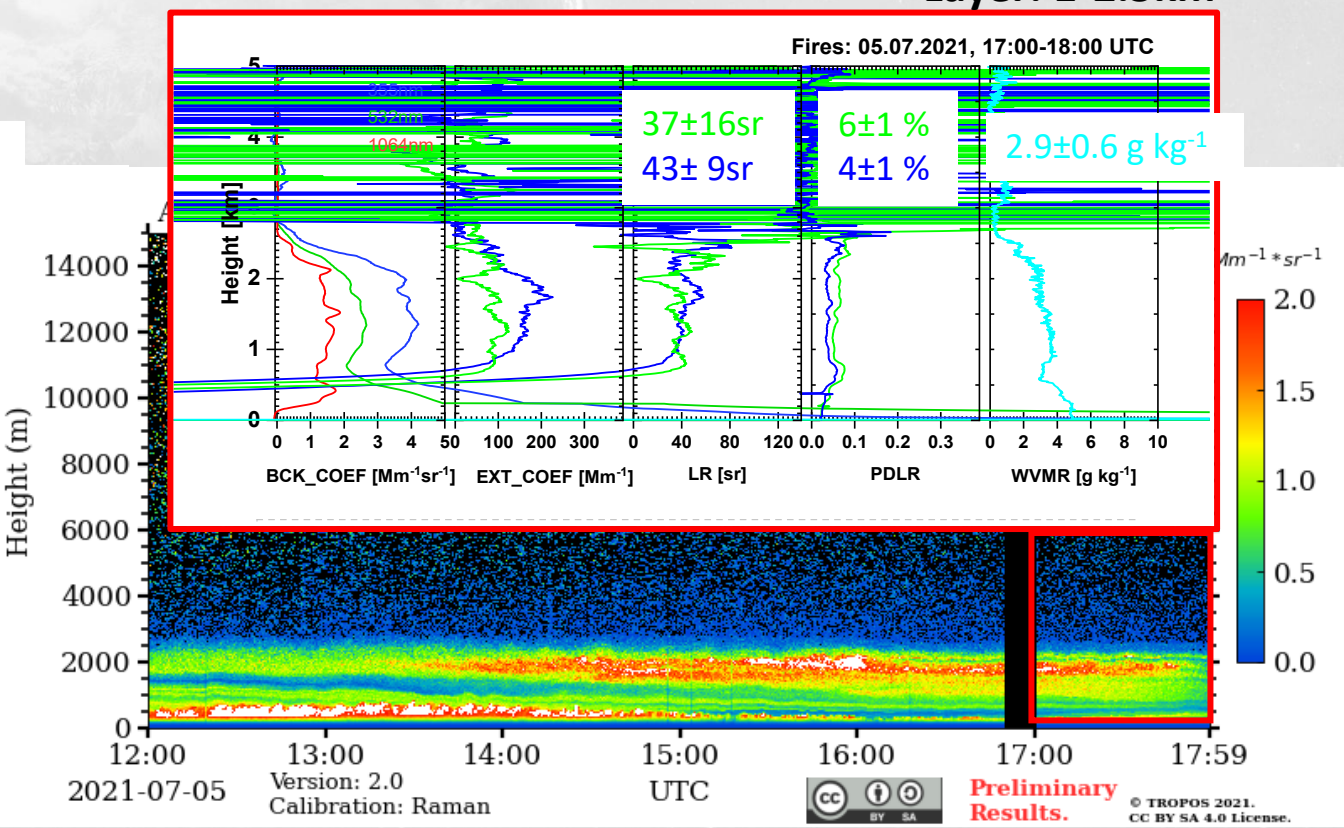
CARO – Polly^{XT} measurements

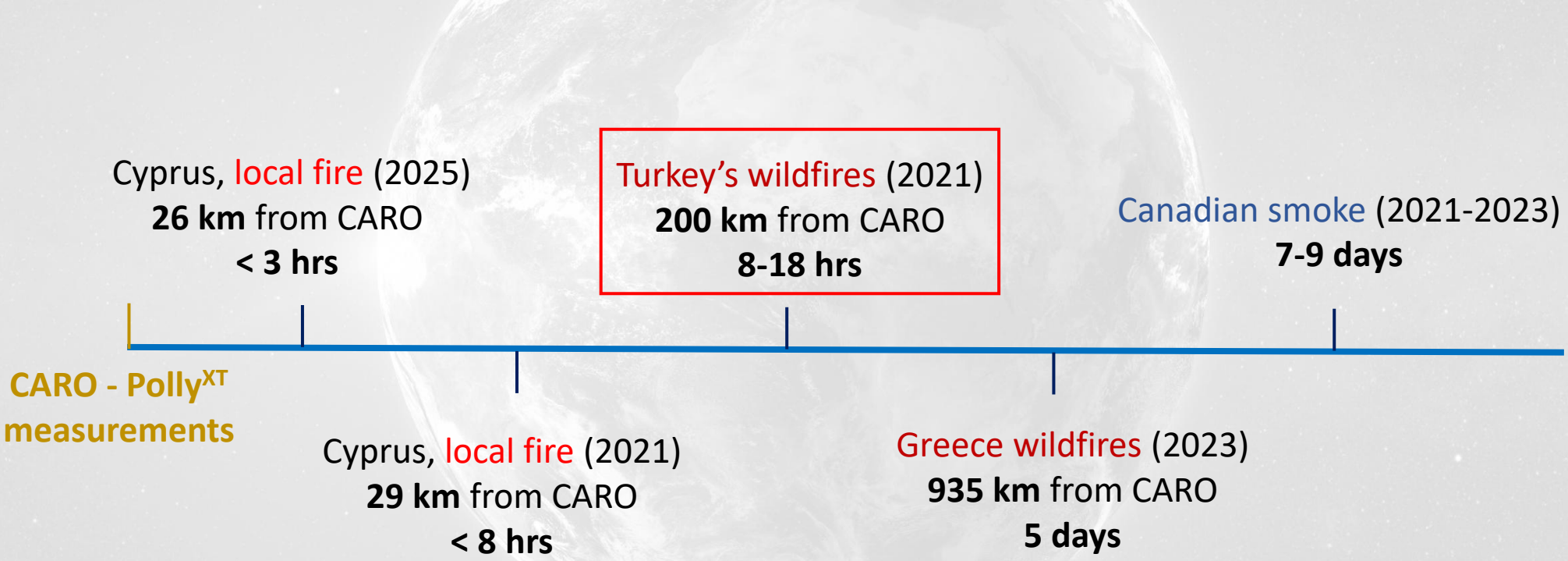
- **Multiple layers** were detected **between 0.5 and 3km** on 4th and 5th of July 2021
- Low **particle depolarization ratio** values: **4-6 %** for 355nm & **6-9%** for 532nm

Layer: 1-2.5km



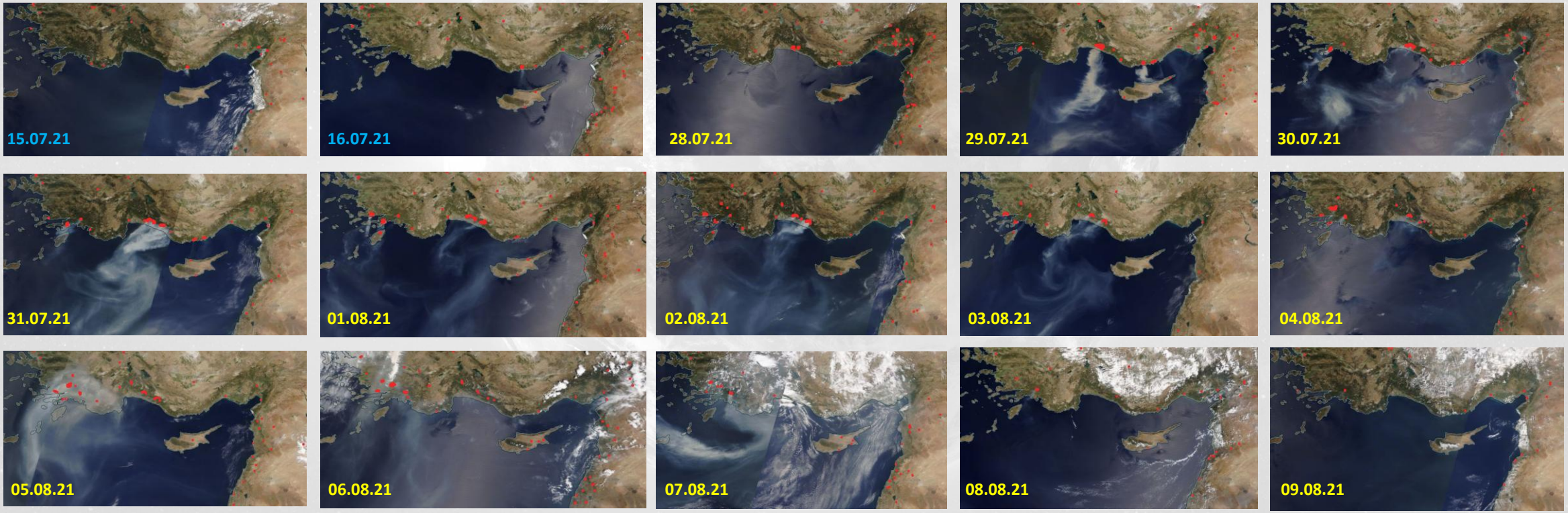
Layer: 1-2.5km




Cyprus, local fire (2025)
26 km from CARO
< 3 hrs
Turkey's wildfires (2021)
200 km from CARO
8-18 hrs
Canadian smoke (2021-2023)
7-9 days
CARO - Polly^XT measurements
Cyprus, local fire (2021)
29 km from CARO
< 8 hrs
Greece wildfires (2023)
935 km from CARO
5 days

3. Extreme Wildfires in Turkeys Mediterranean Region

July 2021 / August 2021 (MODIS true color images)



*Thermal anomalies

ERATOSTHENES CENTRE OF EXCELLENCE

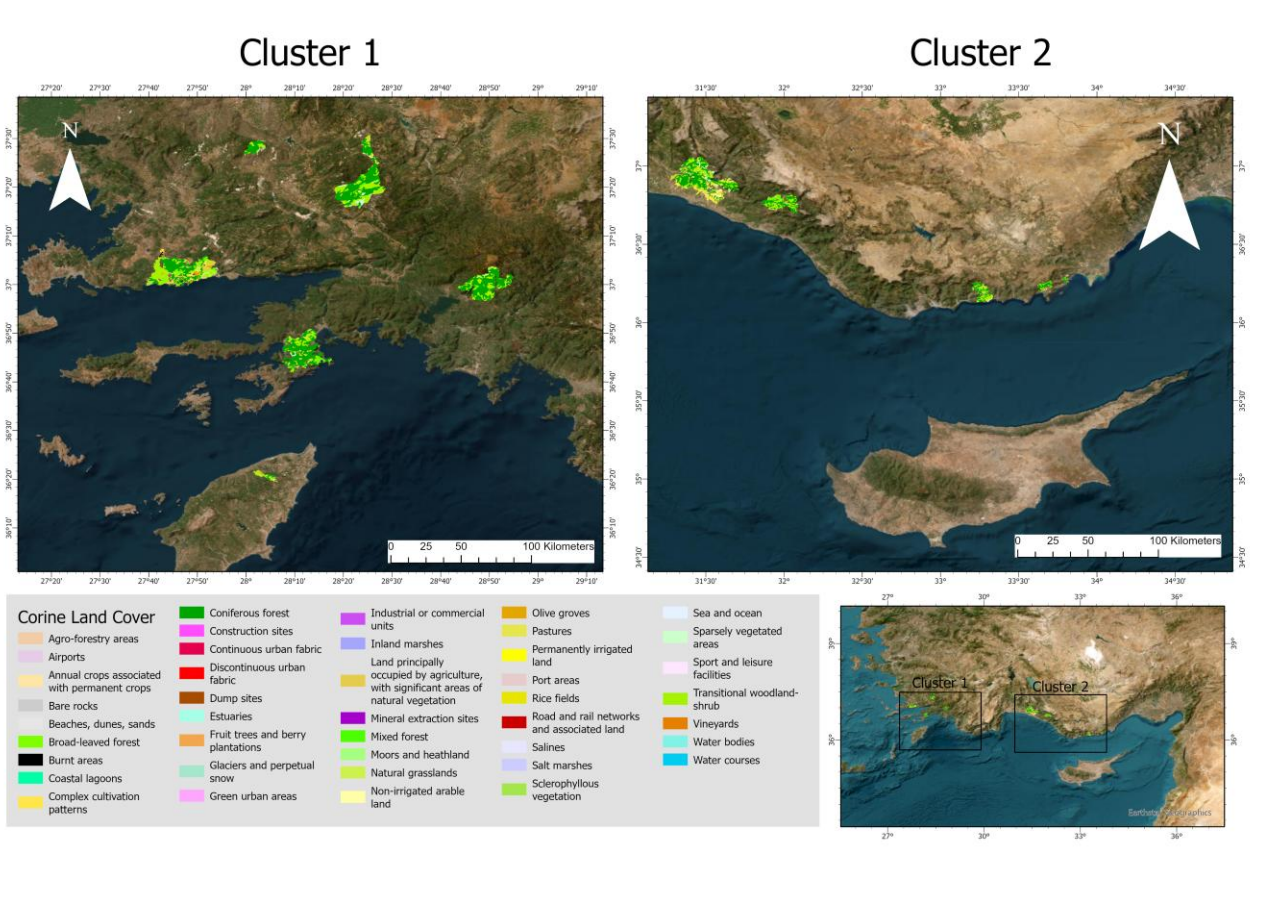
CARO by ERATOSTHENES Centre of Excellence

Cyprus University of Technology

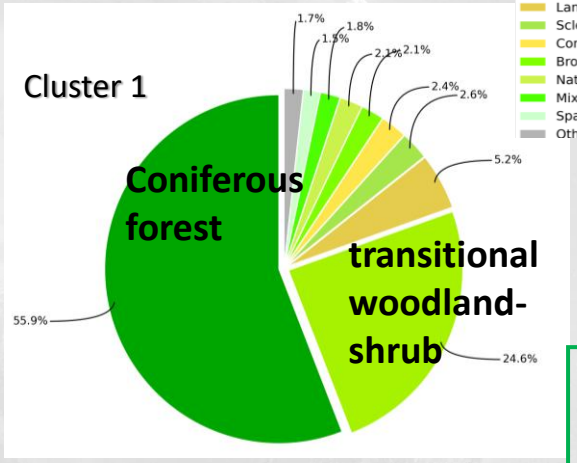
EXCELSIOR

July & August 2021

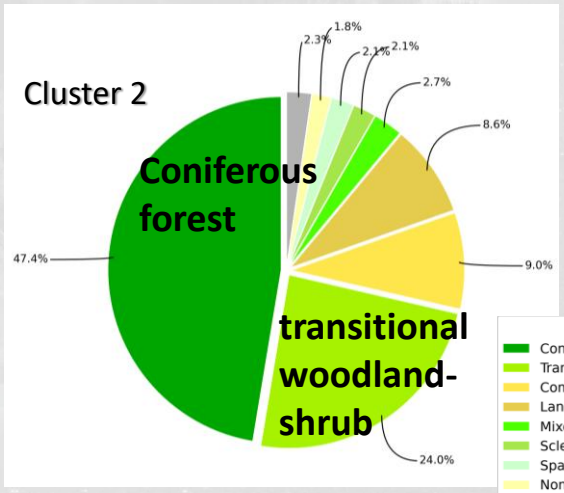
CORINE Land Cover Product



Area per land cover type



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%)



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%)

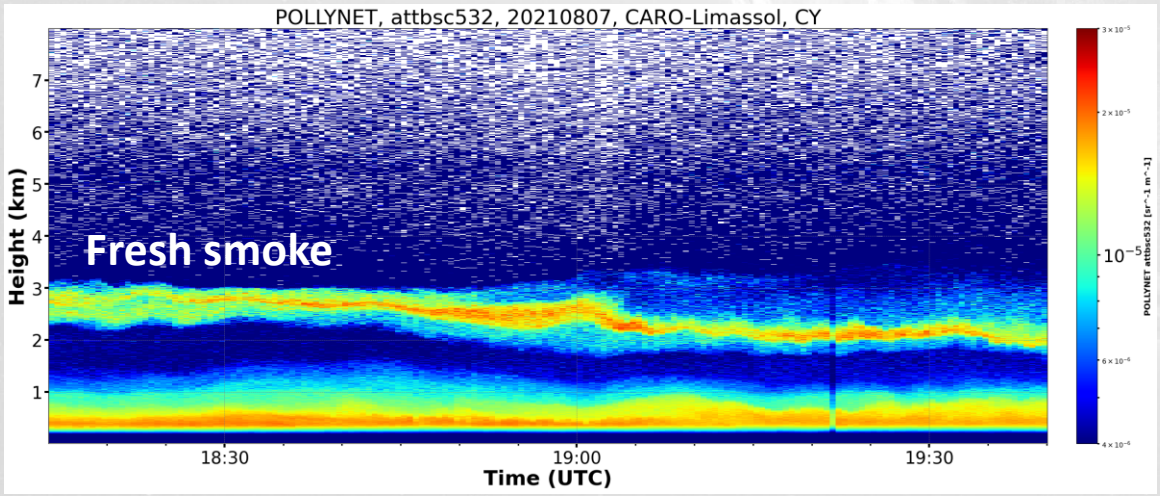
Burned areas were primarily characterized by coniferous forest and transitional woodland-shrub for both clusters.

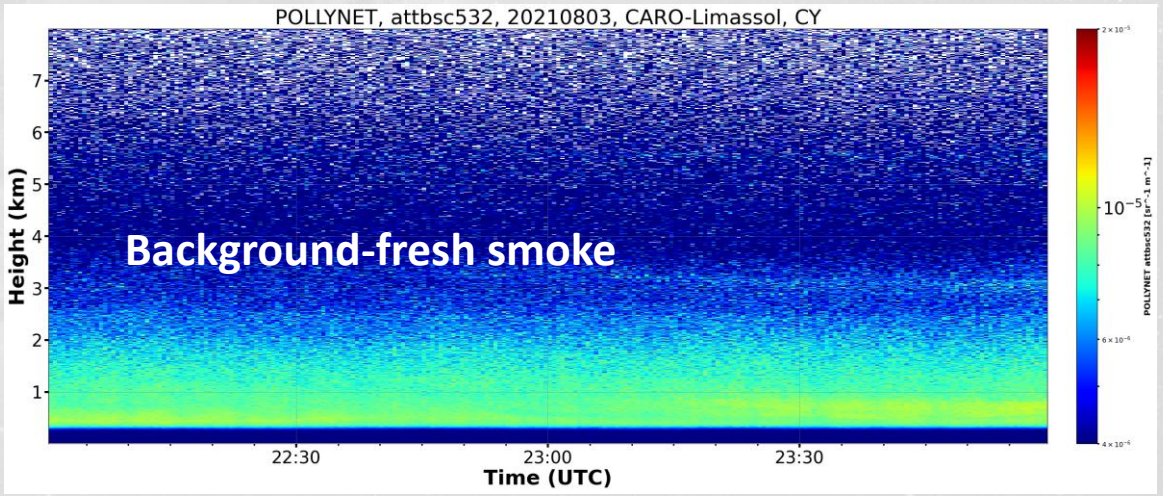
CARO – Polly^{XT} measurements

- **15 cases in total**
- **Fresh** smoke & **Background-fresh** smoke based on:
  1. Trasport time
  2. Layer Depth

15 cases	Fresh smoke [6 cases]	Background-fresh smoke [9 cases]
Transport time [hrs]	< 12	12-18 (including plume dispersion)
Layer Depth [km]	< 1.5	1.5 - 3 (occasionally lower)

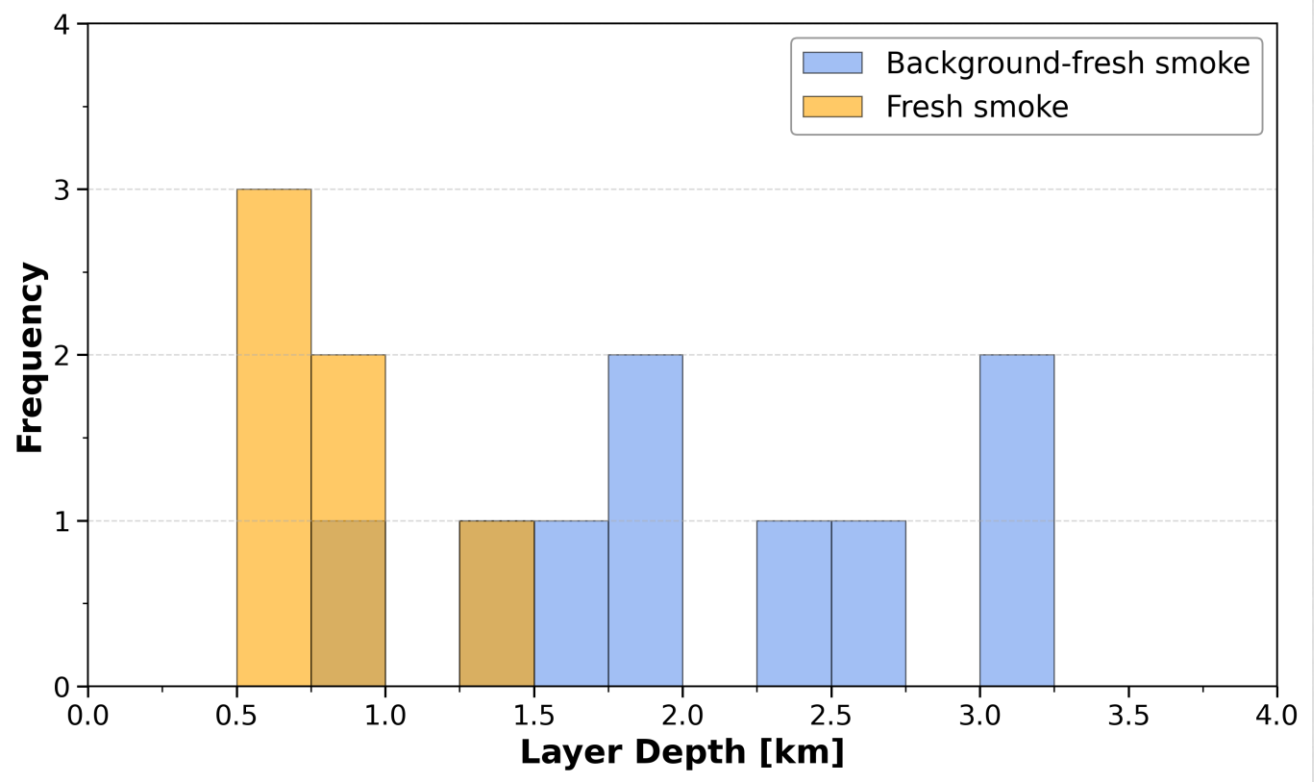
CARO Observations





Layer Depth

Layer Depth = top height – bottom height



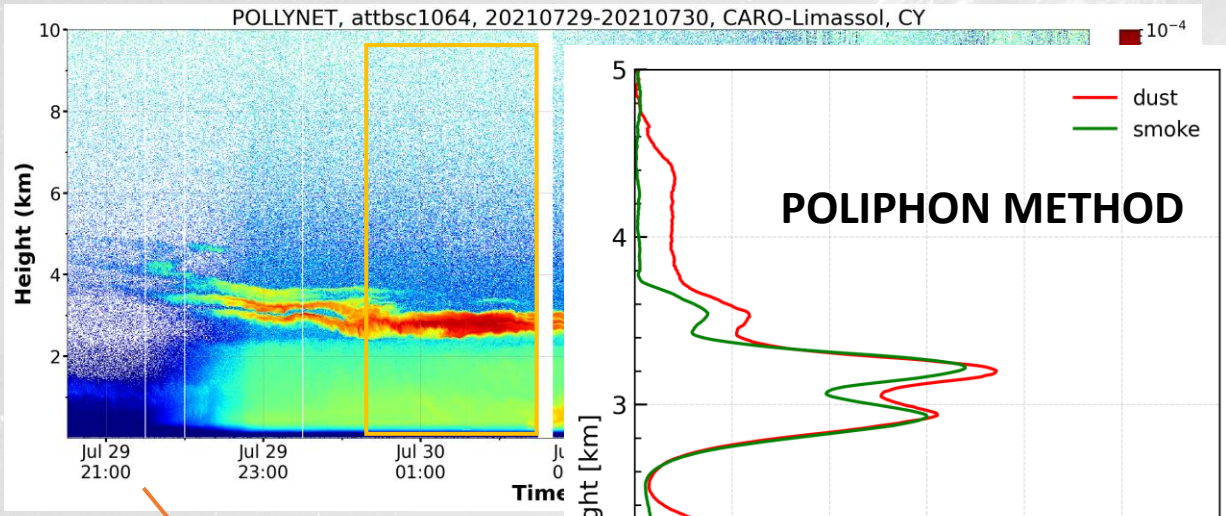
Fresh smoke layers:

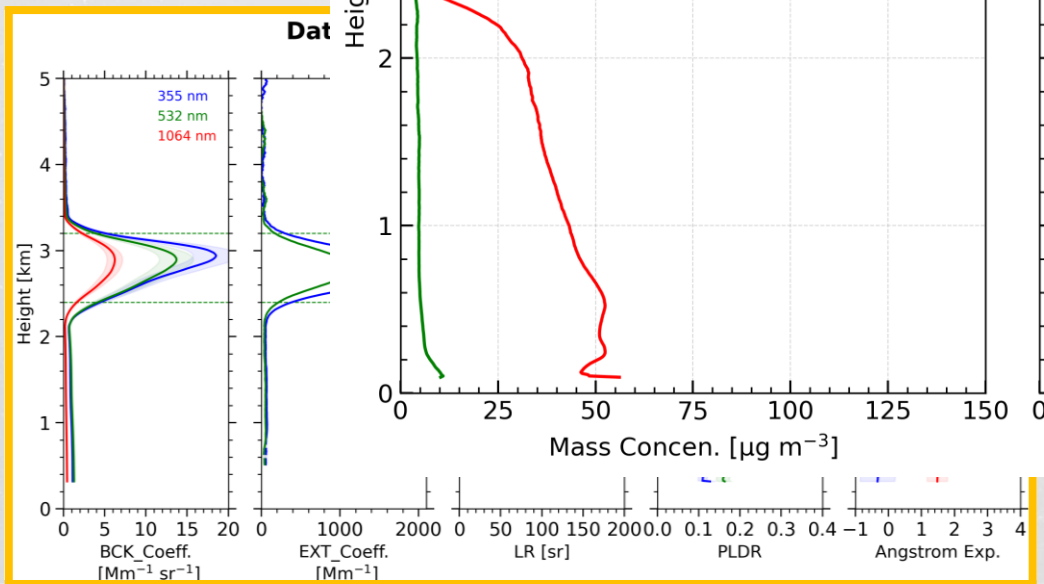
- Layer depth < 1.5 km
- Most values in the range of 0.5-1.0 km

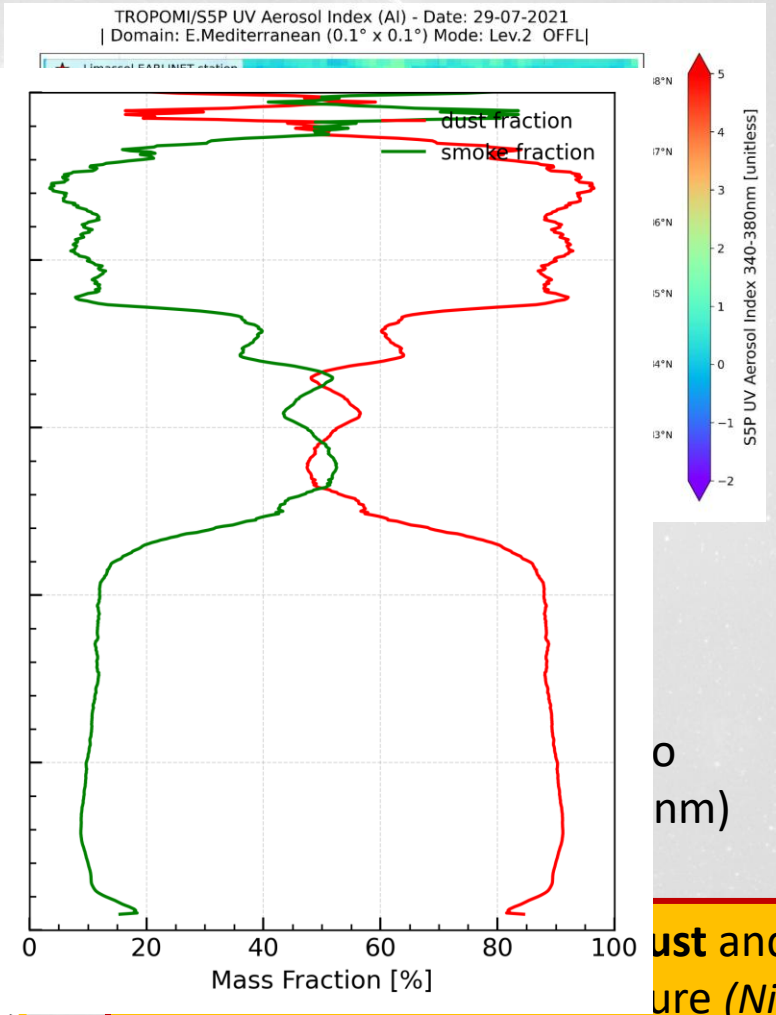
Background-fresh smoke layers:

- Most layer depth values > 1.5 km
- Maximum value in the range of 3.0-3.25 km

Fresh smoke - 29.07.2021





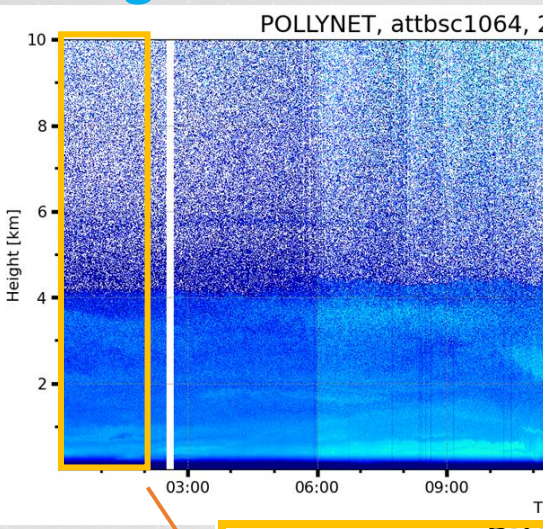


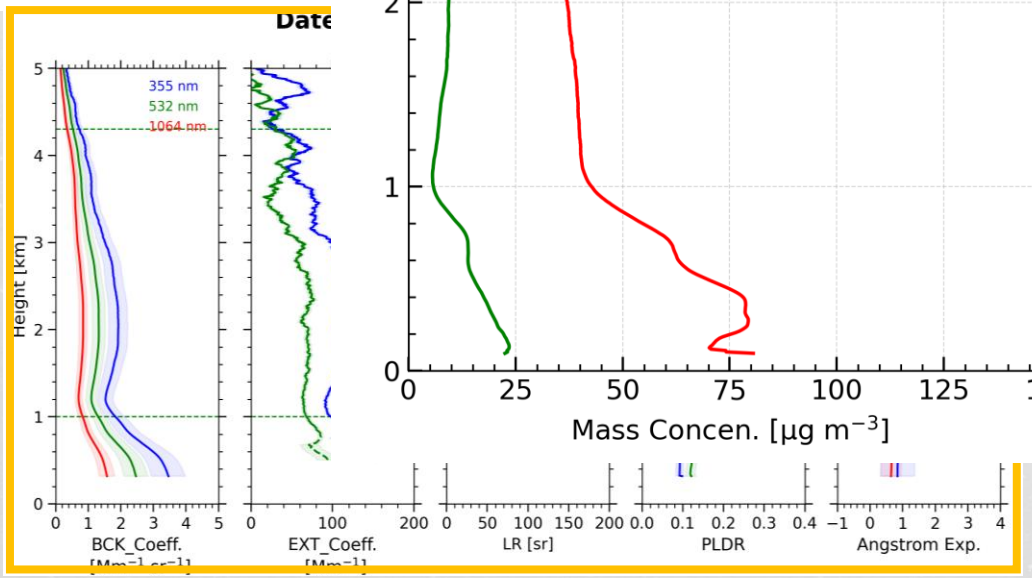
Spatial distribution of gridded UV **Aerosol Index** measurements obtained by the **TROPOMI/Sentinel-5p** on 29.07.2021

o
nm)

ust and **dust injected during**
ure *(Nisantzi et. al. 2014)*

Background-fresh sm

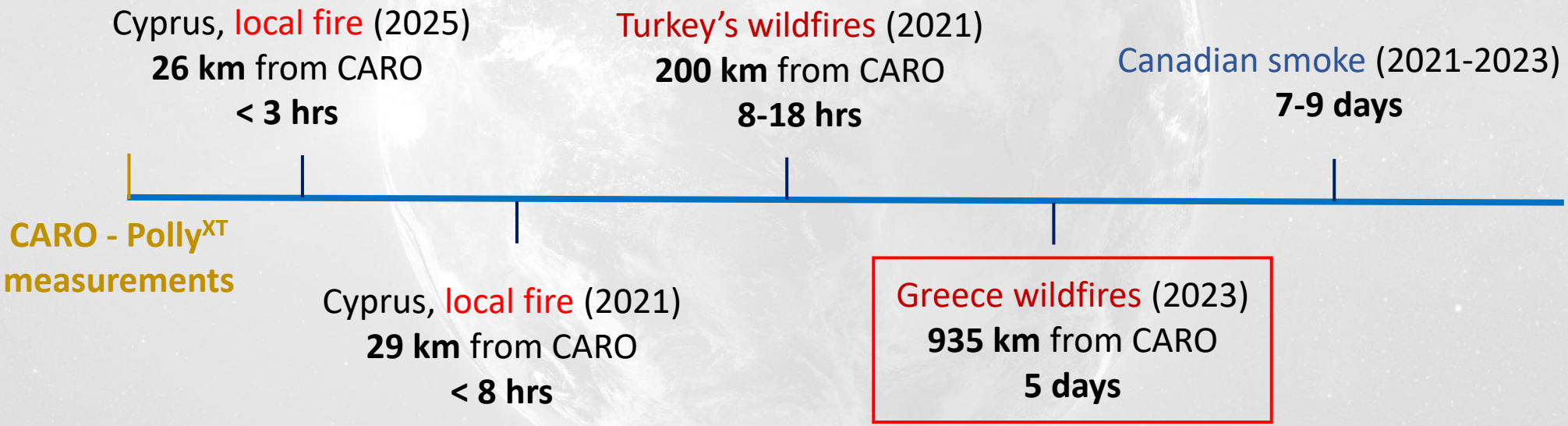




Spatial distribution of gridded UV **Aerosol Index** measurements obtained by the **TROPOMI/Sentinel-5p** on 05.08.2021

persion)

nd **dust injected during**
Nisantzi et. al. 2014)

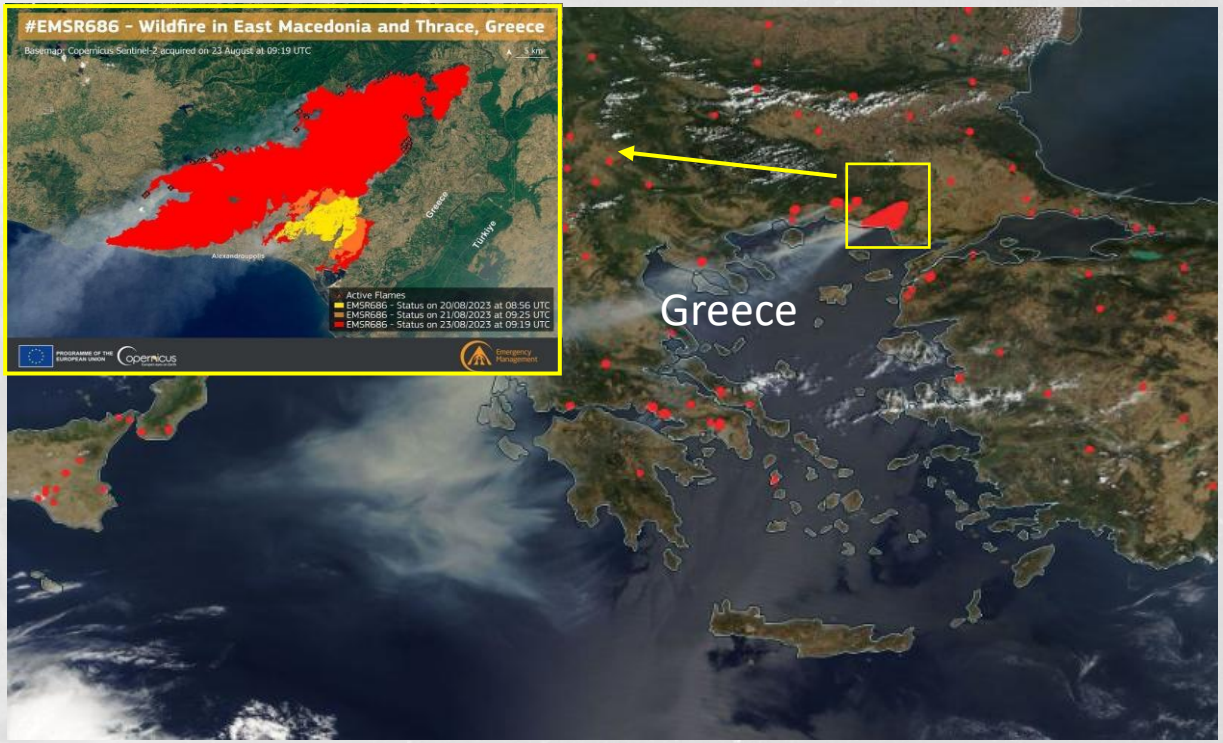

Cyprus, local fire (2025)
26 km from CARO
< 3 hrs
Turkey's wildfires (2021)
200 km from CARO
8-18 hrs
Canadian smoke (2021-2023)
7-9 days
CARO - Polly^XT measurements
Cyprus, local fire (2021)
29 km from CARO
< 8 hrs
Greece wildfires (2023)
935 km from CARO
5 days

4. Extreme wildfires over northern Greece

- **Major wildfire event** in the **Evros region** of northeastern Greece, close to the Turkish border, that started on **19 August 2023** and lasted for about **15 days**, burning more than **96,000 hectares**

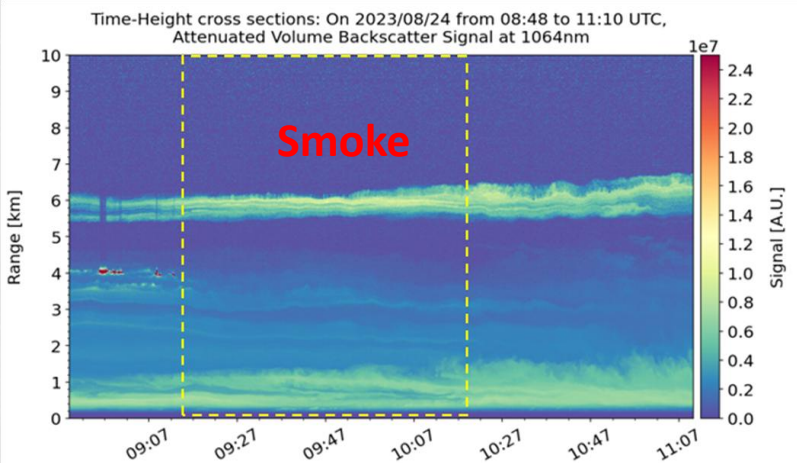
- **CAMS**: the largest wildfire ever recorded in Europe

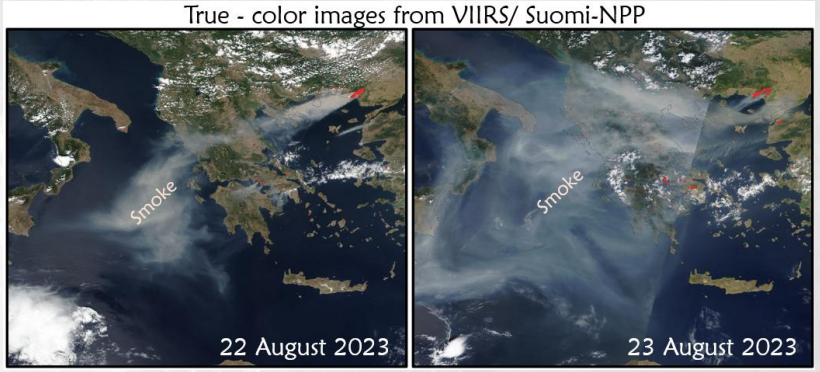
- The **smoke plume** travelled kilometers away, over central Greece and onwards towards Crete and southern Italy, **affecting** the **air quality of many regions**

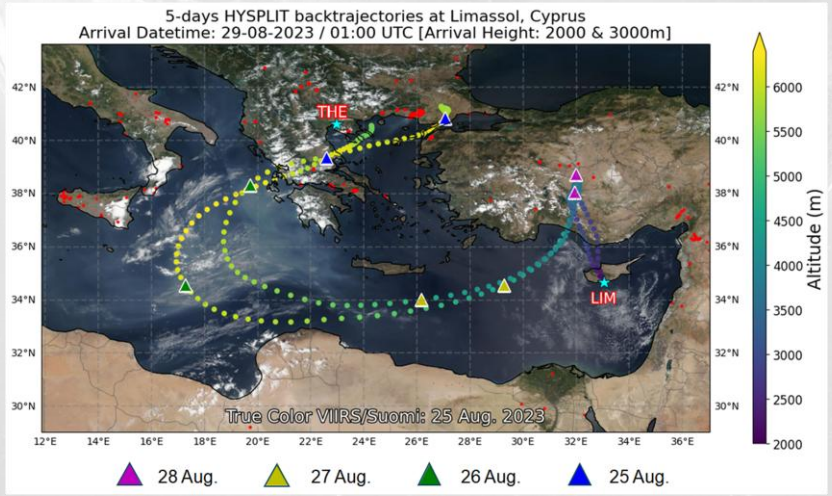


August 2023

Thessaloniki measurements (LapAUTH, THELISYS system)



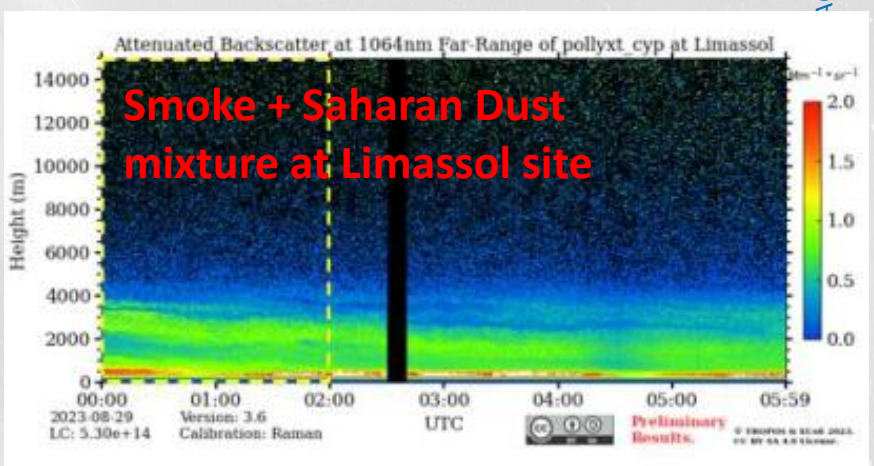




Height range: **5-6 km**
Transport time: **2 days**

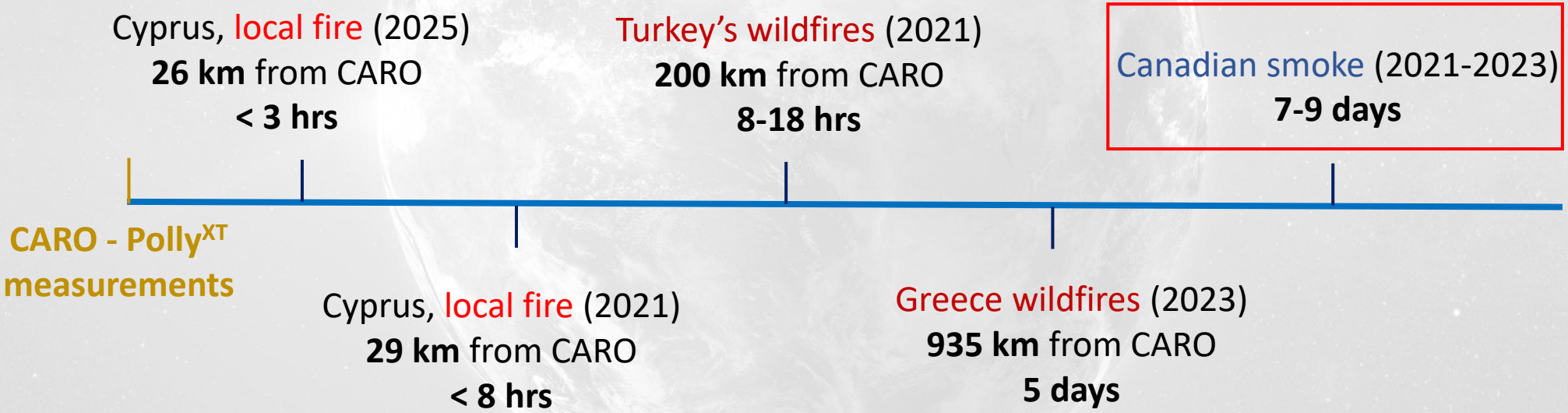
→ **δpar$_{532nm}$**: 10%

Limassol measurements (CARO, PollyXT-CYP)

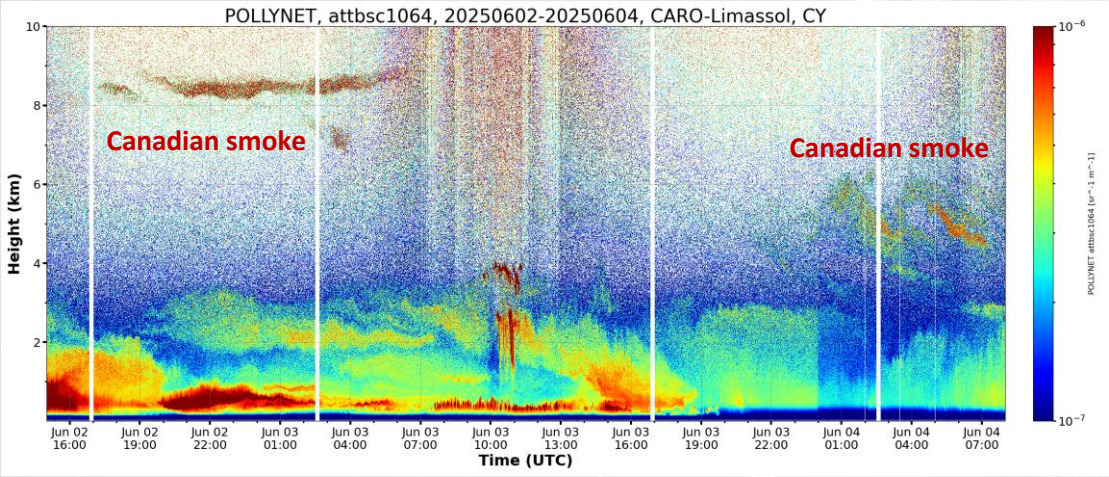


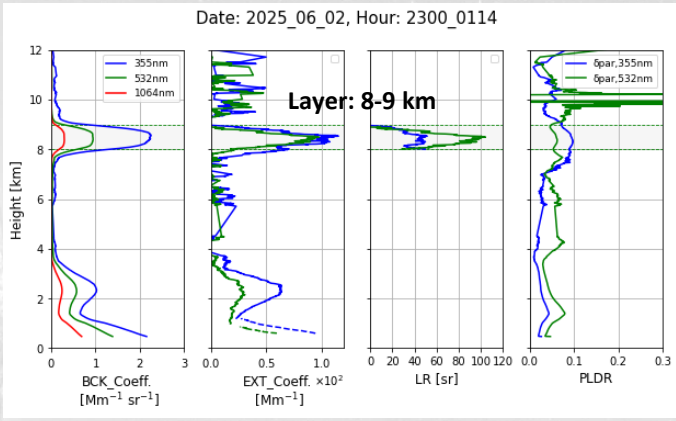
Height range: **1.5-3.2 km**
Transport time: **~ 5 days**

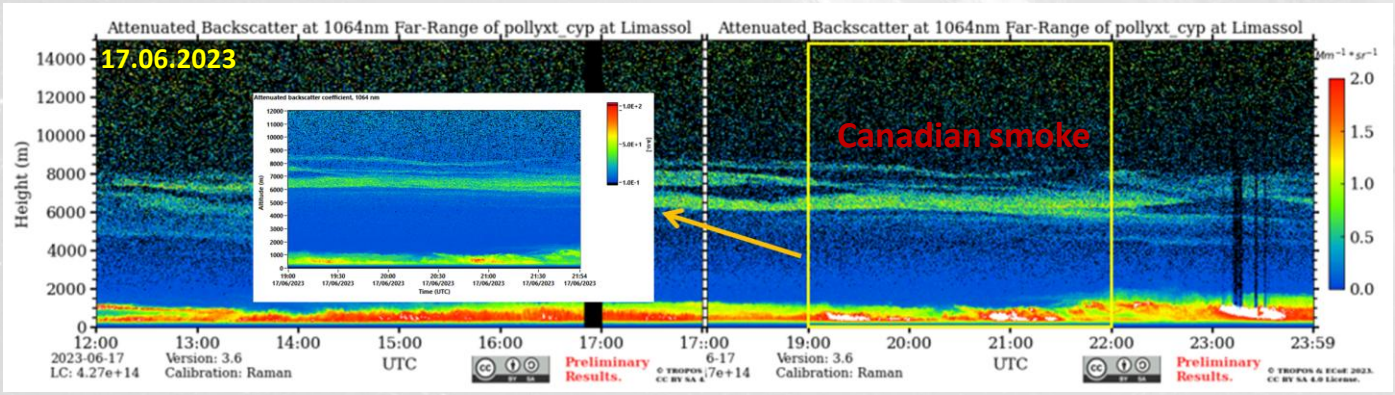
→ **δpar$_{532nm}$**: 10%
→ **δpar$_{355nm}$**: 5%


Cyprus, local fire (2025)
26 km from CARO
< 3 hrs
Turkey's wildfires (2021)
200 km from CARO
8-18 hrs
Canadian smoke (2021-2023)
7-9 days
CARO - Polly^XT measurements
Cyprus, local fire (2021)
29 km from CARO
< 8 hrs
Greece wildfires (2023)
935 km from CARO
5 days

5. Lofted smoke layers – Canadian smoke (aged)





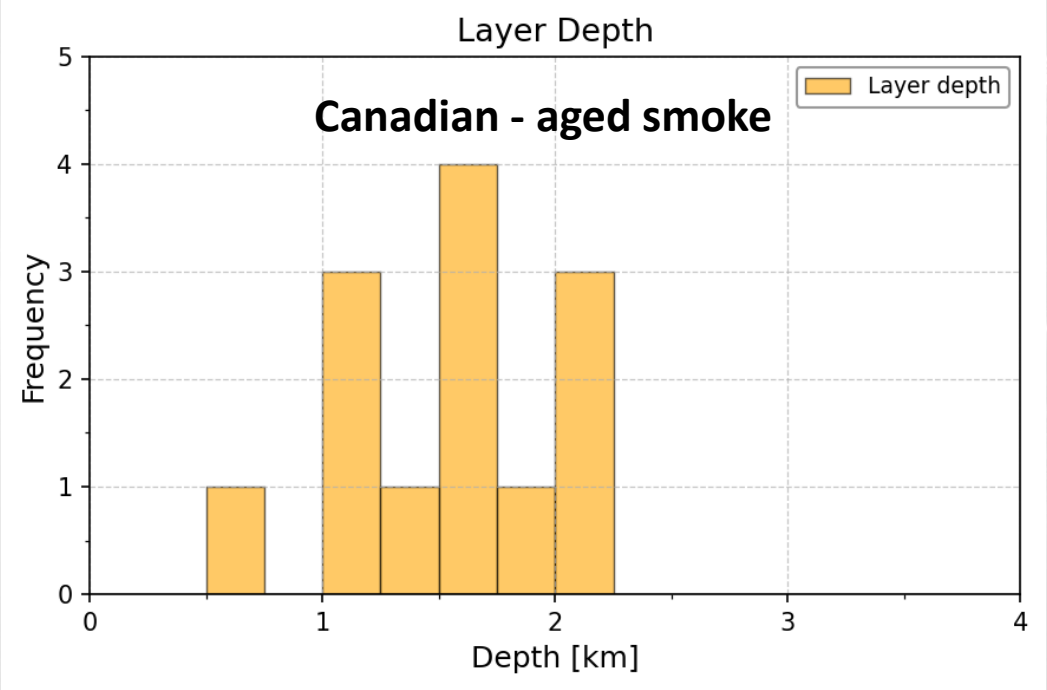


→ **13 cases** for the **summer** period of **2021-2023**

→ More cases will be analyzed for the next years

→ **Comparison** of the smoke properties between Mediterranean wildfires and Canadian/North American wildfires

5. Lofted smoke layers – Canadian smoke (aged)

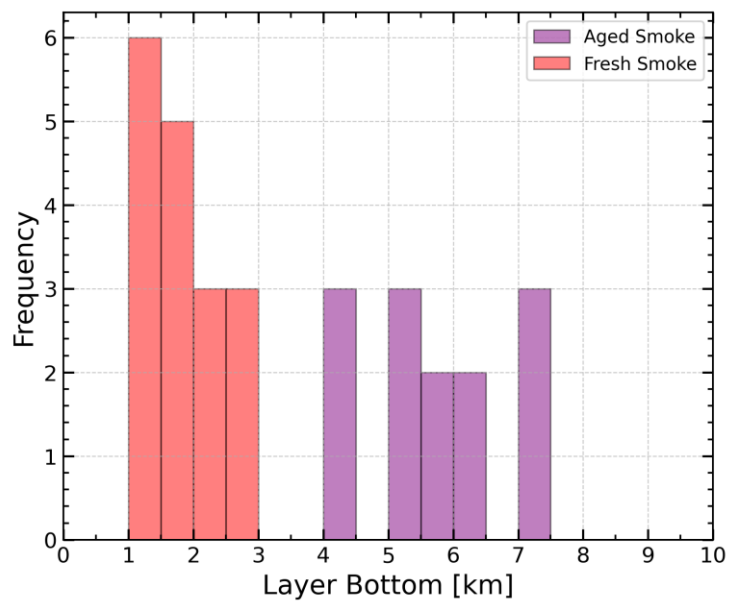


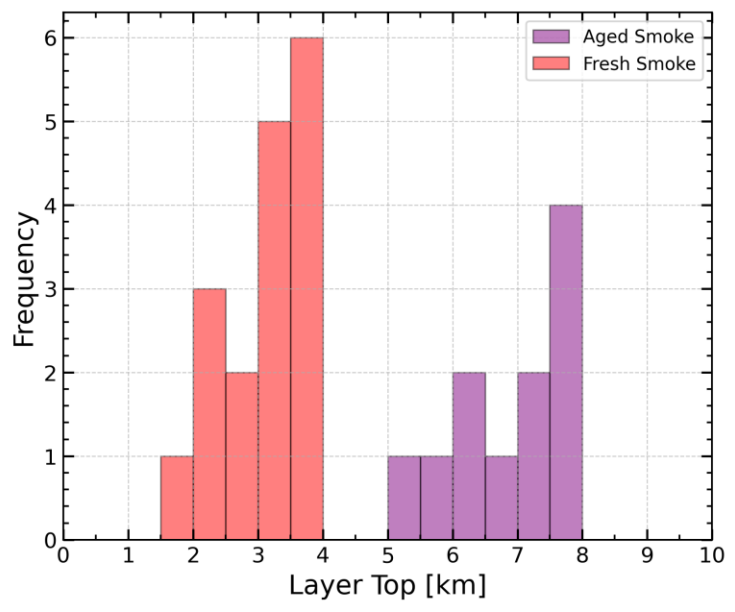
- Optical depth **range**: **1-3km**
- Minimum & maximum value: 1.1km & 2.6 km, respectively
- **Most frequently observed**: values in the bin of **2–2.3 km**

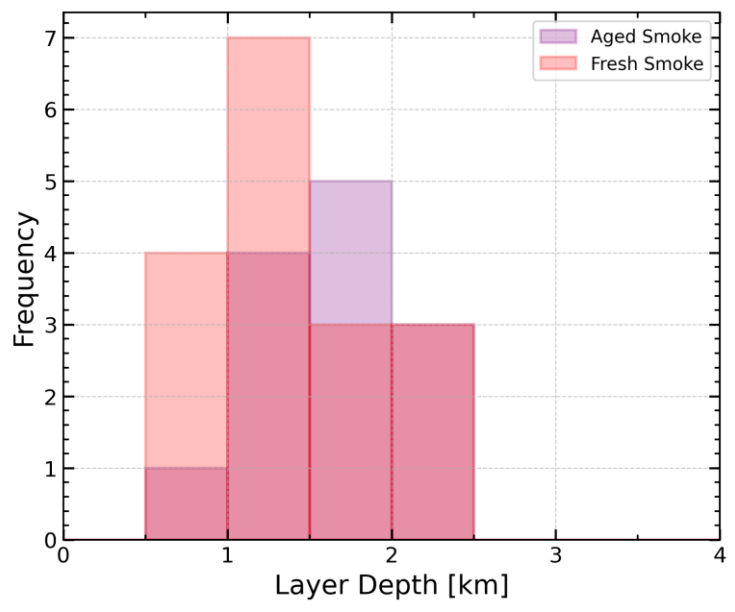
Aged and **fresh wildfire smoke** detected in Cyprus atmosphere, Eastern Mediterranean *(summer period 2021-2023)*

Geometrical properties

- **Comparison** between **fresh** (local fires, Turkey's wildfires) and **aged** (Canadian smoke) smoke plumes
- Study period: **summer 2021-2023**







Conclusions

- CARO station provides a unique opportunity to study smoke behavior
- The **origin** of the **source** and **transport time** significantly influence smoke optical properties
- Transport time ranges from a few hours to several days
- Smoke layers from local and neighboring sources were observed at 1–4 km, while Canadian smoke layers occurred at higher altitudes (4–8 km)
- Aged smoke (Canada) & Aged Smoke – dust mixture (Greece): low depol. values
- Fresh smoke (local fires): low depol. values
- Fresh & background fresh smoke (Turkey): enhanced depol. values
  → **significant influence** of soil dust, including dust injected during the fire

Thank you!!