Validation of EarthCARE Aerosol, Cloud, and Synergistic Products within ACROSS Activities

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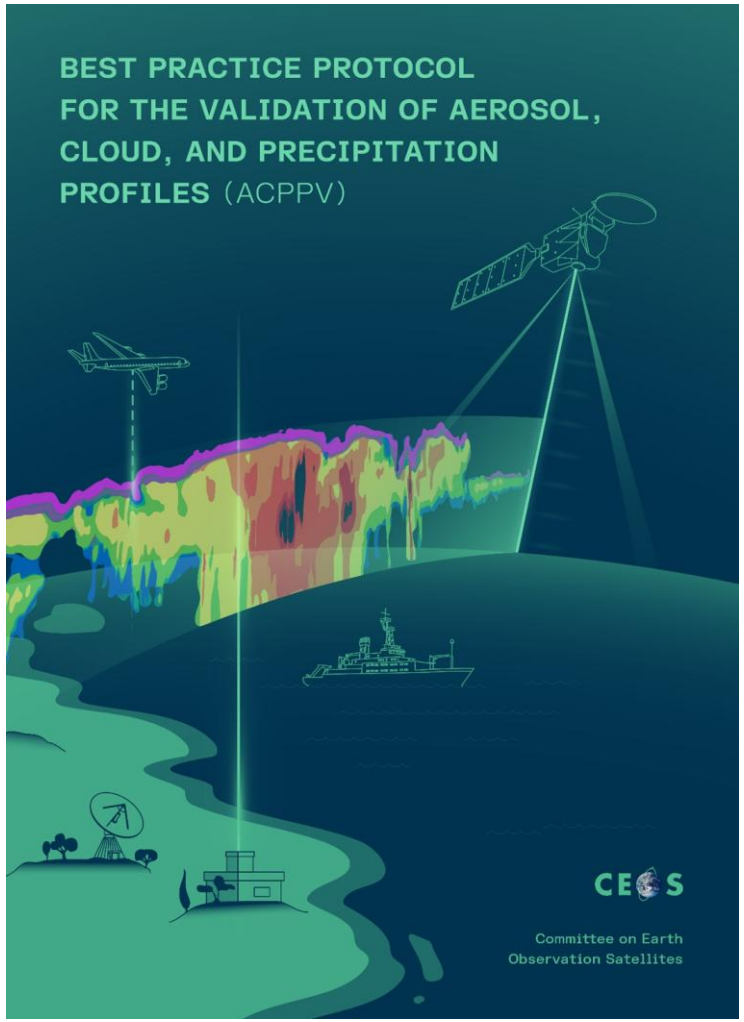
Best Practice Protocols for the Validation of Aerosol, Cloud, and Precipitation Profiles (ACPPV)

Lidar profiling validation challenges:

- Extremely narrow sampling volume
- Small correlation length of Target features
- Need for in-situ Measurements of microphysical properties
- Synergistic validation
- Gaps in spaceborne data records

Convergence in **Best Practice Protocols for the Validation of Aerosol, Cloud, and Precipitation Profiles (ACPPV) (Amiridis et al. 2025)**



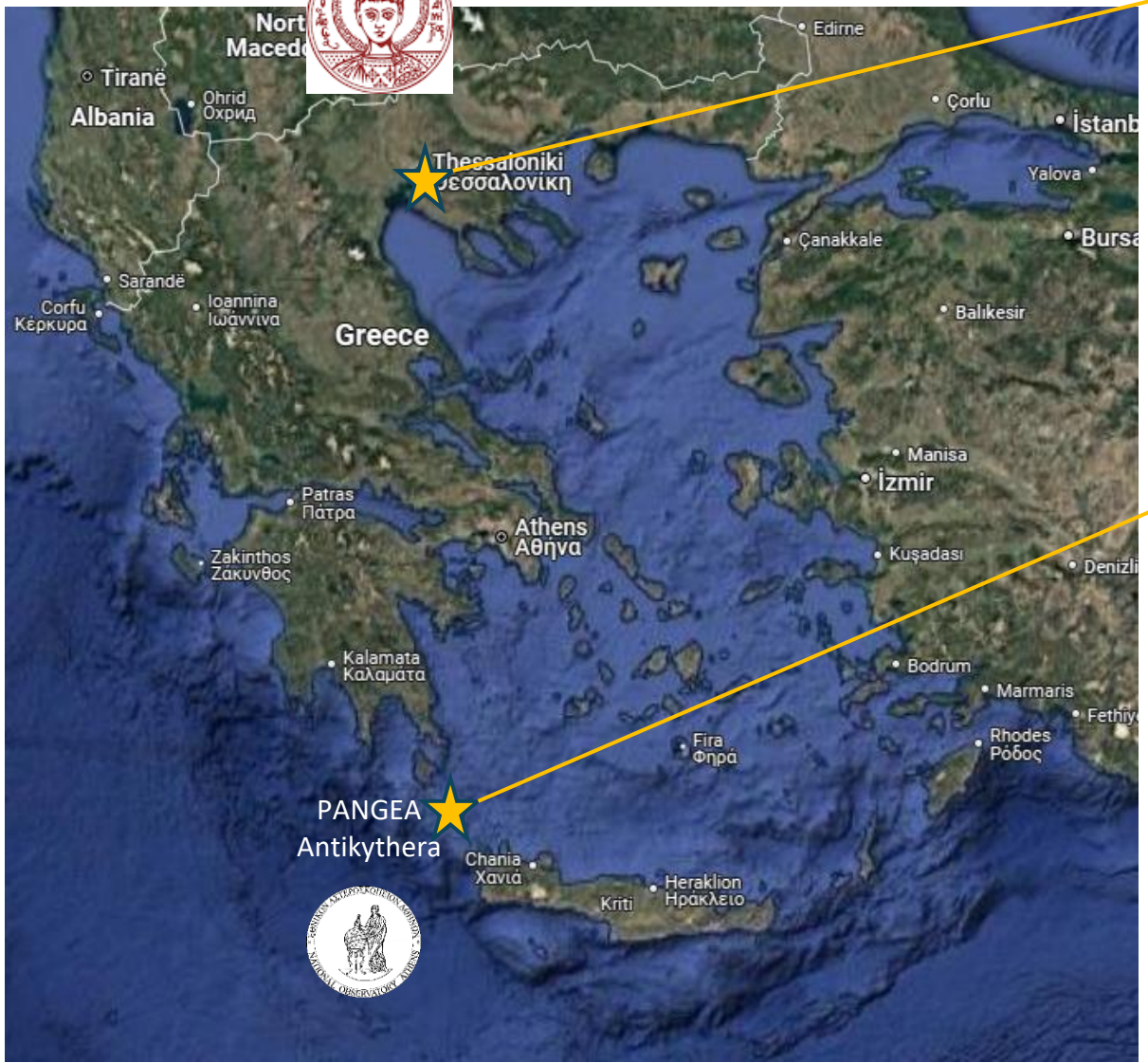
Consortium of 97 scientists

CEOS Committee on Earth Observation Satellites

https://zenodo.org/records/15025627

57 space agencies, institutes, universities

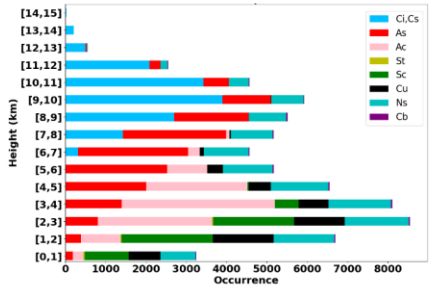
ACROSS suborbital Lidar sites for the Evaluation of ATLID products



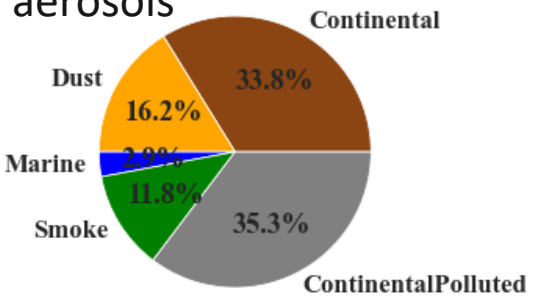
Thessaloniki Urban site

Typical obs.: aerosols: Continental + Polluted continental in PBL; other types elevated/transported

CloudSat Cloud Types occurrence (2007 – 2017)



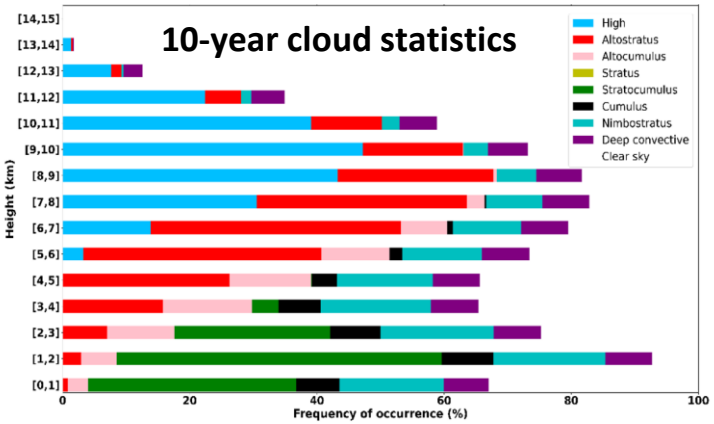
aerosols



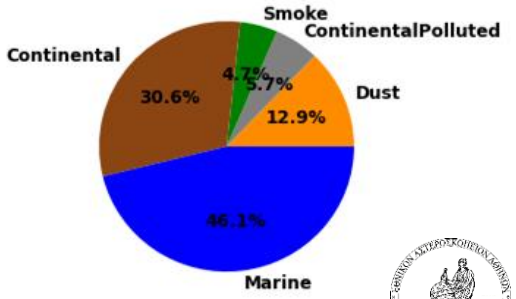
Antikythera background marine site

Typical obs.: clouds in the PBL;
aerosols: Sea salt in PBL; other types elevated layers

CloudSat Cloud Types occurrence (2007 – 2017)

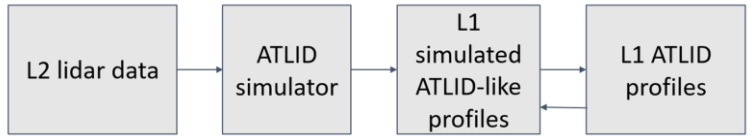


aerosols

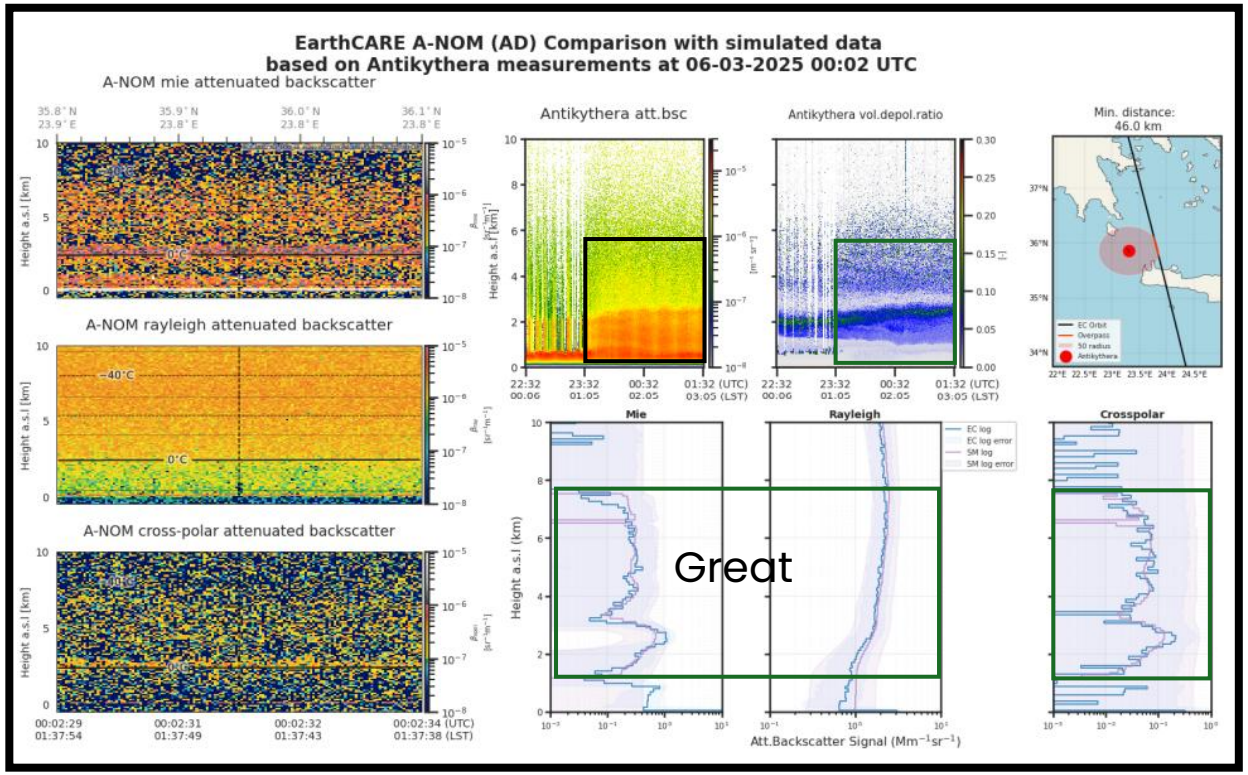


ALTID L1 A-NOM intercomparisons

Using averaged EC profiles at 50 km radius & suborbital Raman retrievals through the ATLID CCT simulator



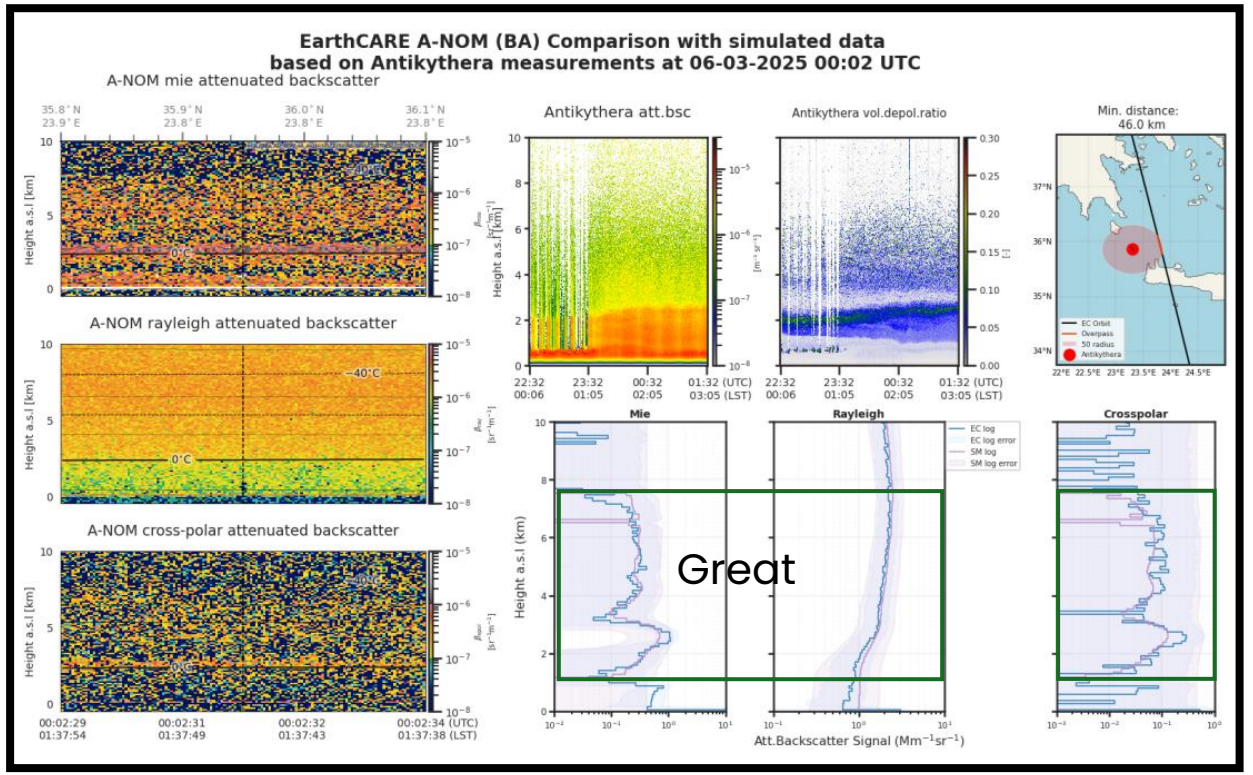
Baseline AD



very good

- use only homogeneous scenes & altitudes with aerosol features
- cloud-free suborbital profiles

Baseline BA



overestimation

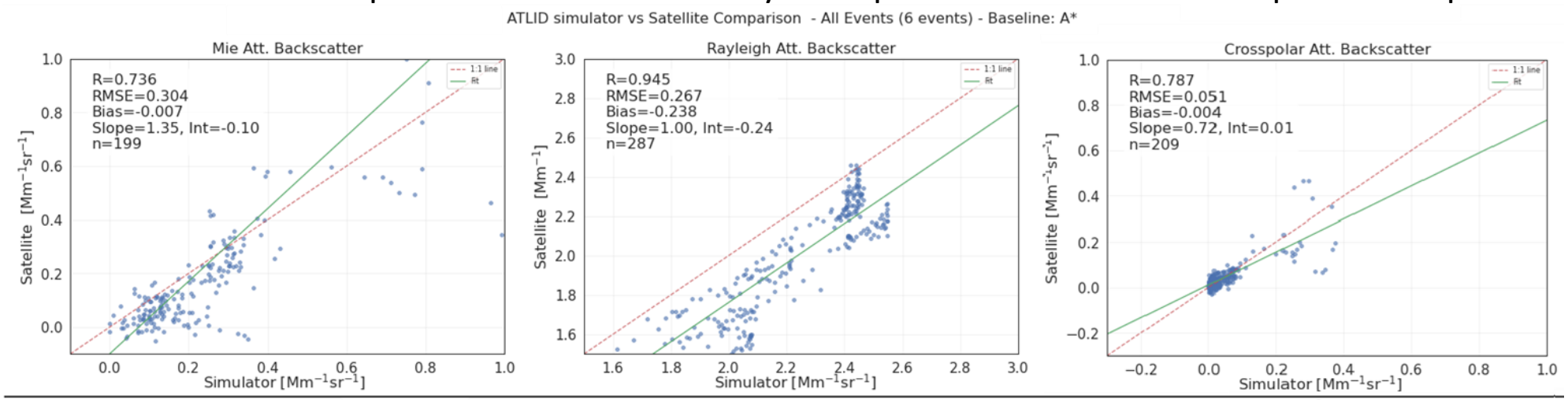
Example of a dust & smoke case
A-NOM Mie & Rayleigh profiles: Great agreement

ATLID L1 A-NOM – statistics from 6 events

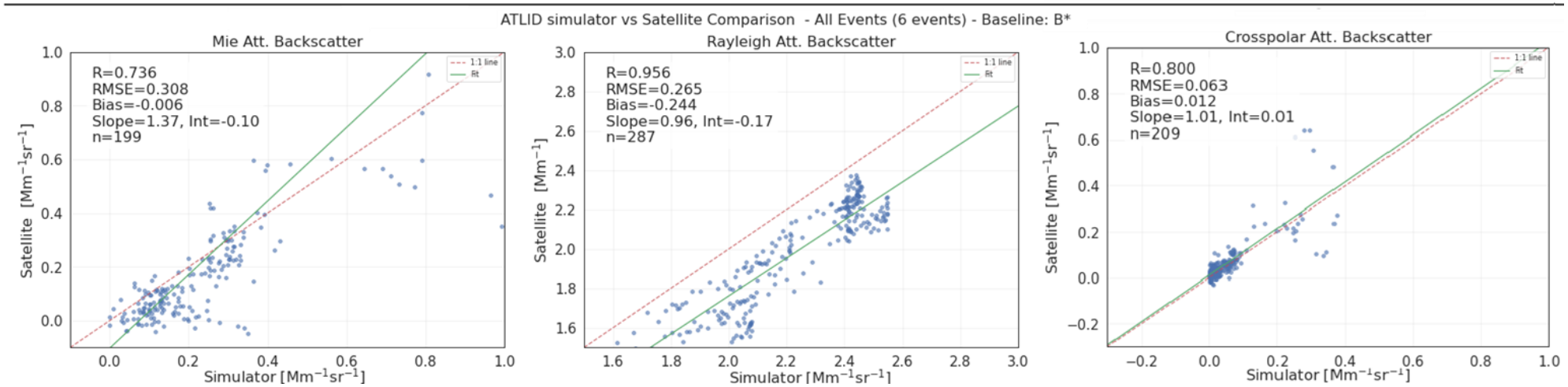
6 events

Mie Att. Bp. | Ray Att. Bp. | cross polar Att. Bp

Baseline A*



Baseline BA



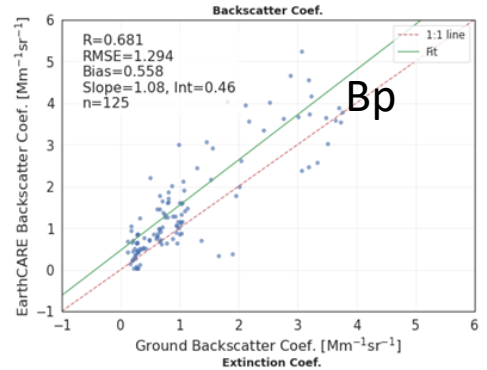
Significant L1 cross-polar improvement in Baseline BA!

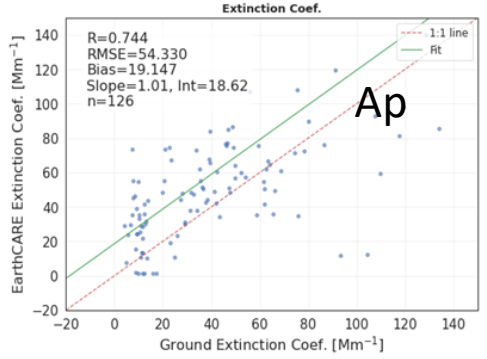
ATLID L2 A-EBD – statistics from 7 events

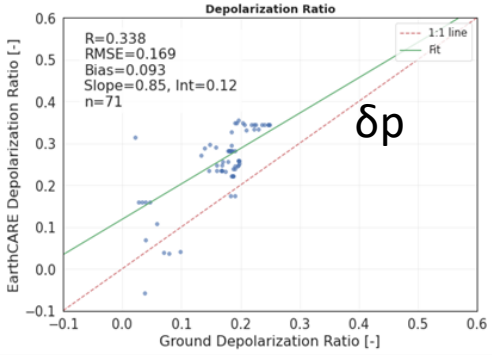
Single EC profiles at distance < 50 km

medium resolution

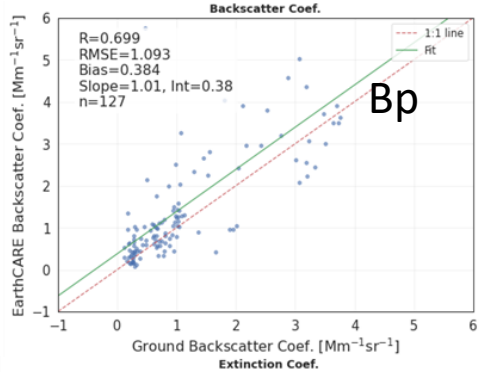
Baseline A*

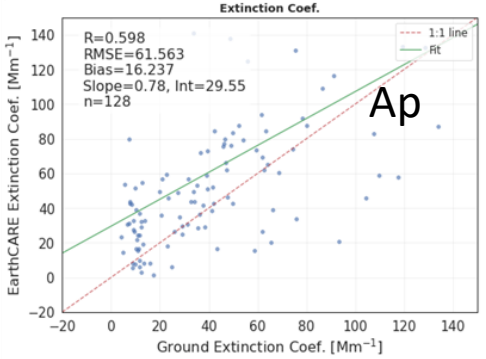


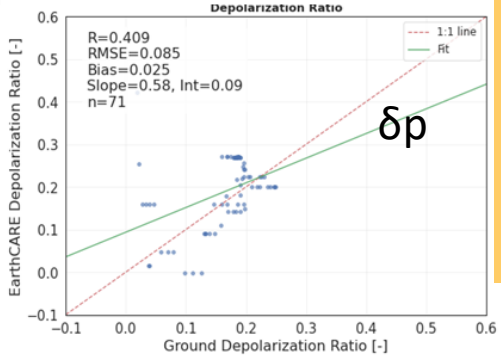




Baseline BA



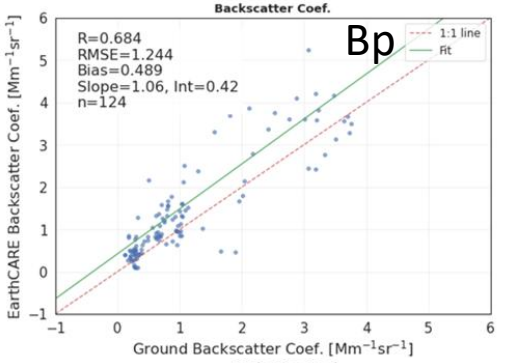


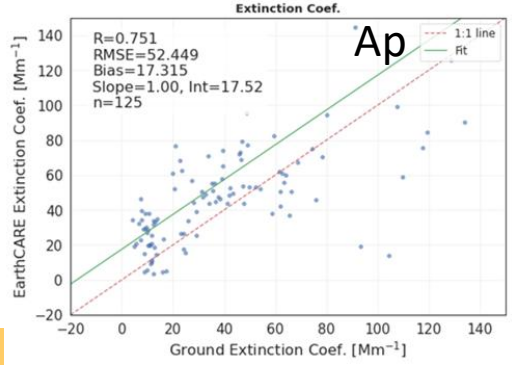


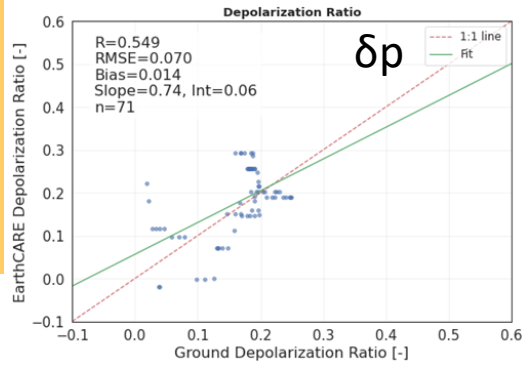
Significant depolarization improvement in Baseline BA for low resolution! improvement in medium res. also

low resolution

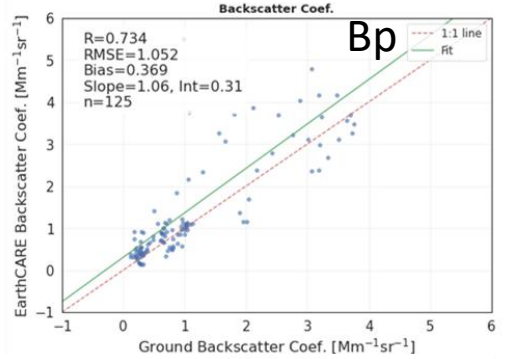
Baseline A*

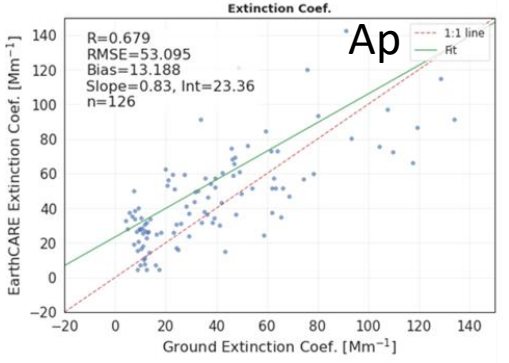


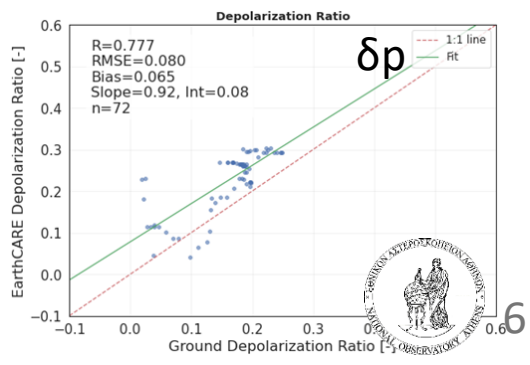




Baseline BA







L2 A-TC aerosol classification - using EARLINET/ACTRIS sites

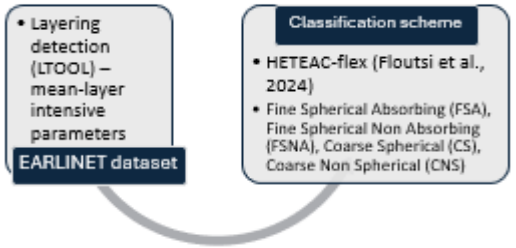
19 Stations for period: August 2024 – August 2025

EarthCARE A-TC Baseline BA

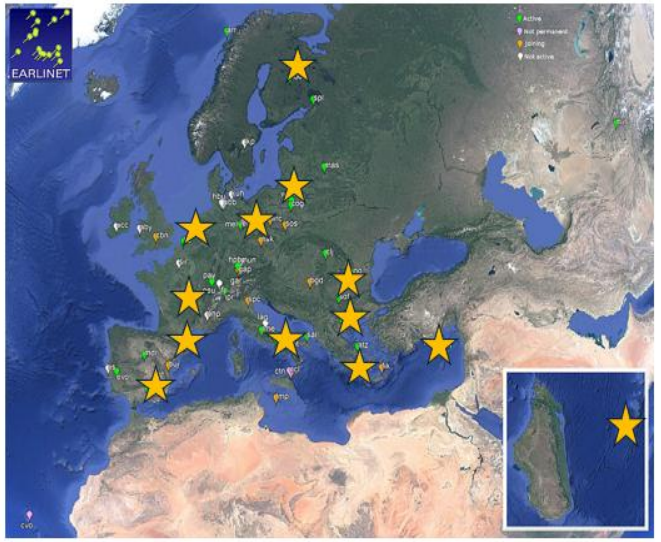
EARLINET Inputs: particle backscatter, extinction, lidar ratio, angstrom exponent, depolarization ratio

Spatiotemporal collocation: ± 90 minutes around overpass time, overpass at <100 km radius around site

Methodology



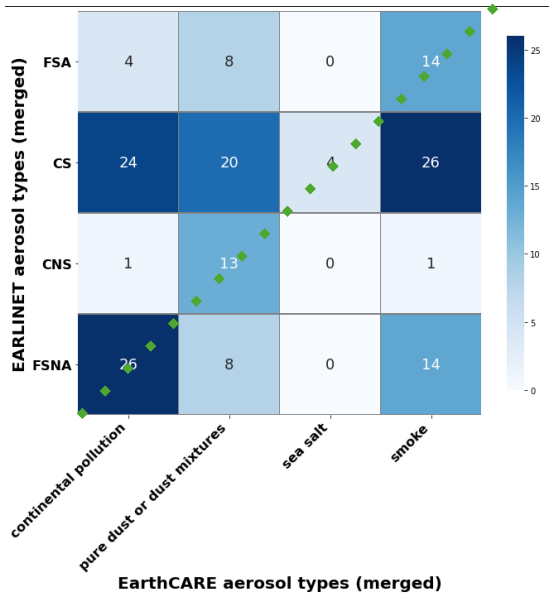
EARLINET/ACTRIS dataset ensure optimal spatio-temporal coverage, seasonal changes, variability in aerosol types



EarthCARE vs EARLINET aerosol types

A-TC aerosol types (Wandinger et al., 2023)	HETEAC Flex (Floutsi et al., 2023)
Dust, Dusty smoke, Dusty mix	Coarse non spherical (CNS)
Sea salt	Coarse spherical (CS)
Continental pollution	Fine spherical non absorbing (FSNA)
Smoke	Fine spherical (FSA)

Statistics



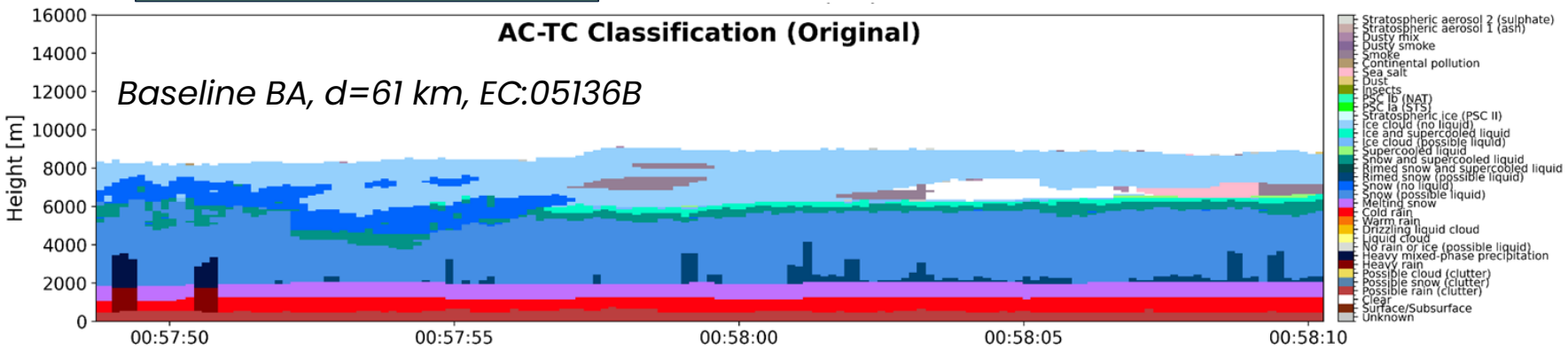
Continental pollution, Dusty, & Smoke categories are predominantly typed correctly! Sea salt category is not.

Voudouri et al., Poster Day 2, Annex 4

L2 AC-TC cloud classification - using Cloudnet products

EarthCARE → CPR & ATLID
Cloudnet → cloud radar & ceilometer

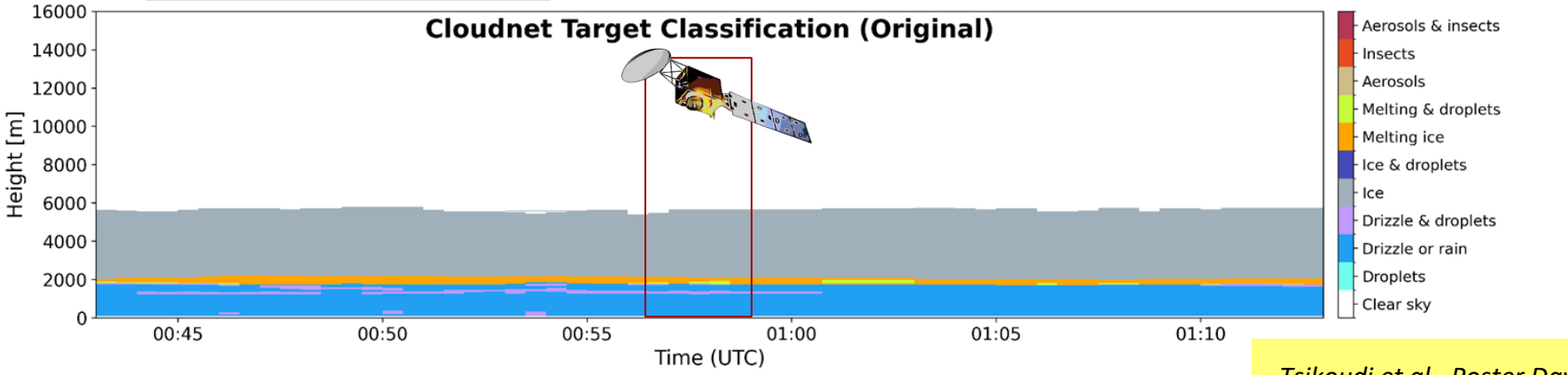
EarthCARE AC-TC target classification



EarthCARE classes (36)

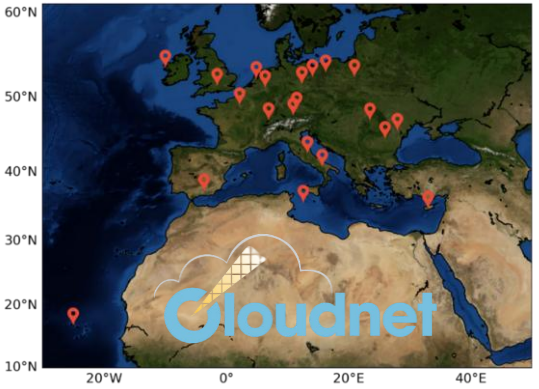
- Stratospheric aerosol 2 (sulphate)
- Stratospheric aerosol 1 (ash)
- Dusty mix
- Dusty smoke
- Smoke
- Continental pollution
- Sea salt
- Dust
- Insects
- PSC Ib (NAT)
- PSC Ia (STS)
- Stratospheric ice (PSC II)
- Ice cloud (no liquid)
- Ice and supercooled liquid
- Ice cloud (possible liquid)
- Supercooled liquid
- Snow and supercooled liquid
- Rimed snow and supercooled liquid
- Rimed snow (possible liquid)
- Snow (no liquid)
- Snow (possible liquid)
- Melting snow
- Cold rain
- Warm rain
- Drizzling liquid cloud
- Liquid cloud
- No rain or ice (possible liquid)
- Heavy mixed-phase precipitation
- Heavy rain
- Possible cloud (clutter)
- Possible snow (clutter)
- Possible rain (clutter)
- Clear
- Surface/Subsurface
- Unknown

Cloudnet target Classification



Cloudnet classes (11)

- Aerosols & insects
- Insects
- Aerosols
- Melting & droplets
- Melting ice
- Ice & droplets
- Ice
- Drizzle & droplets
- Drizzle or rain
- Droplets
- Clear sky

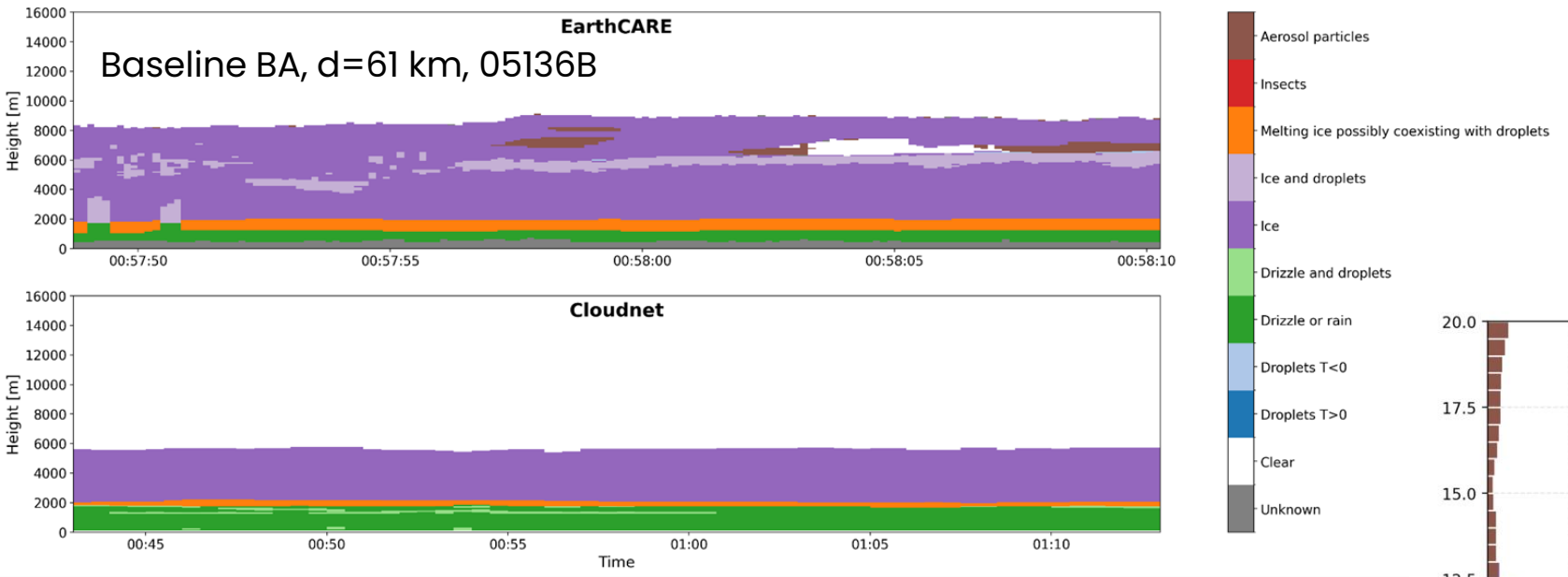


Merged classes (11)

- Aerosol particles
- Insects
- Melting ice possibly coexisting with droplets
- Ice and droplets
- Ice
- Drizzle and droplets
- Drizzle or rain
- Droplets T<0°C
- Droplets T>0°C
- Clear
- Unknown

Tsikoudi et al., Poster Day 3, Annex 58

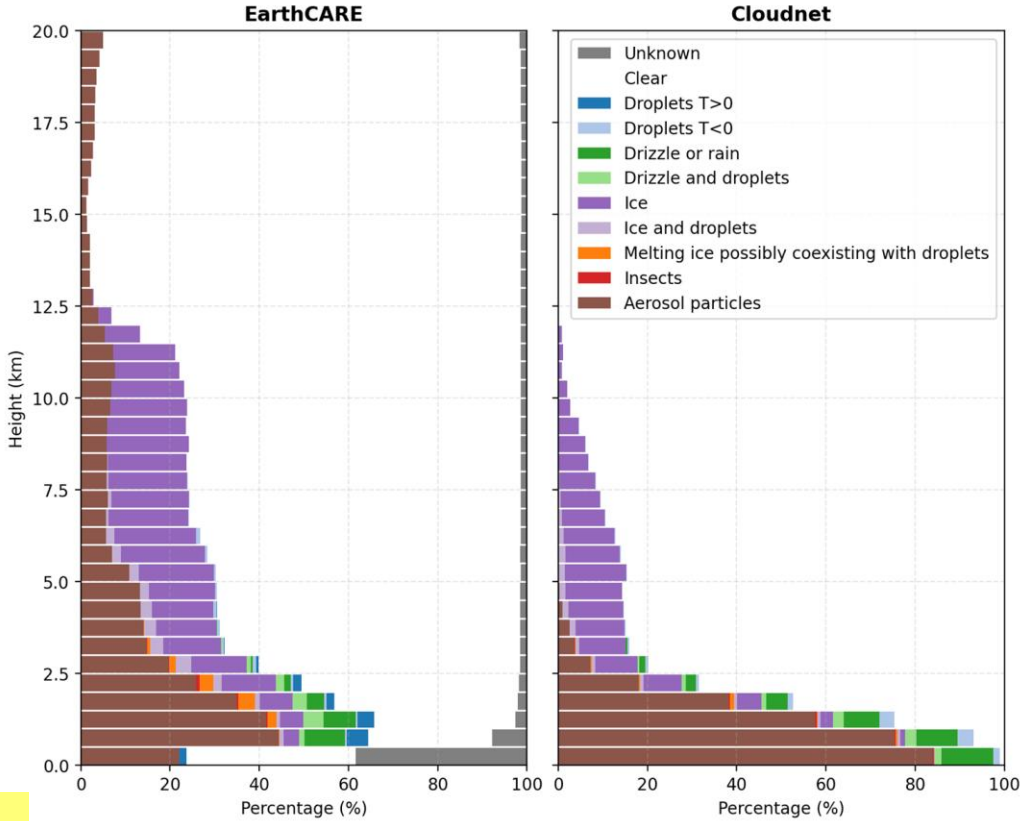
L2 AC-TC cloud classification - using Cloudnet products (2)



- **732 collocated cases** between July 2024 - November 2025
- **EarthCARE Baseline BA**
- Spatiotemporal collocation: overpasses at **<100 km** (~10''), **± 15 minutes** around overpass time.
- **10 sites**: Cabauw, Granada, Julich, Lampedusa, Lindenberg, Munich, Norunda, Palaiseau, Payerne, Potenza. **Geographical diversity & different atmospheric conditions.**
- Statistics at 500m vertical resolution.

More supercool layers in EarthCARE
In this case, melting layer is nicely captured by EarthCARE

1.5yr statistics @Cabauw (92 cases)

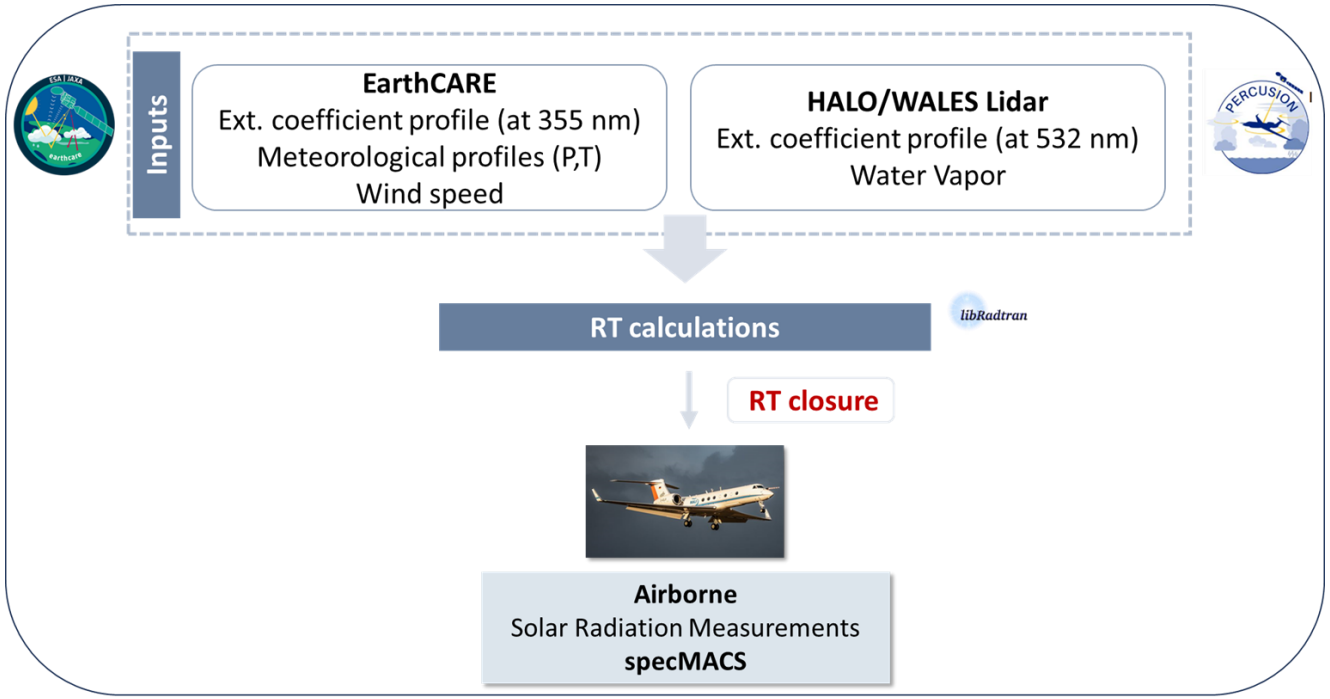


Tsikoudi et al., Poster Day 3, Annex 58

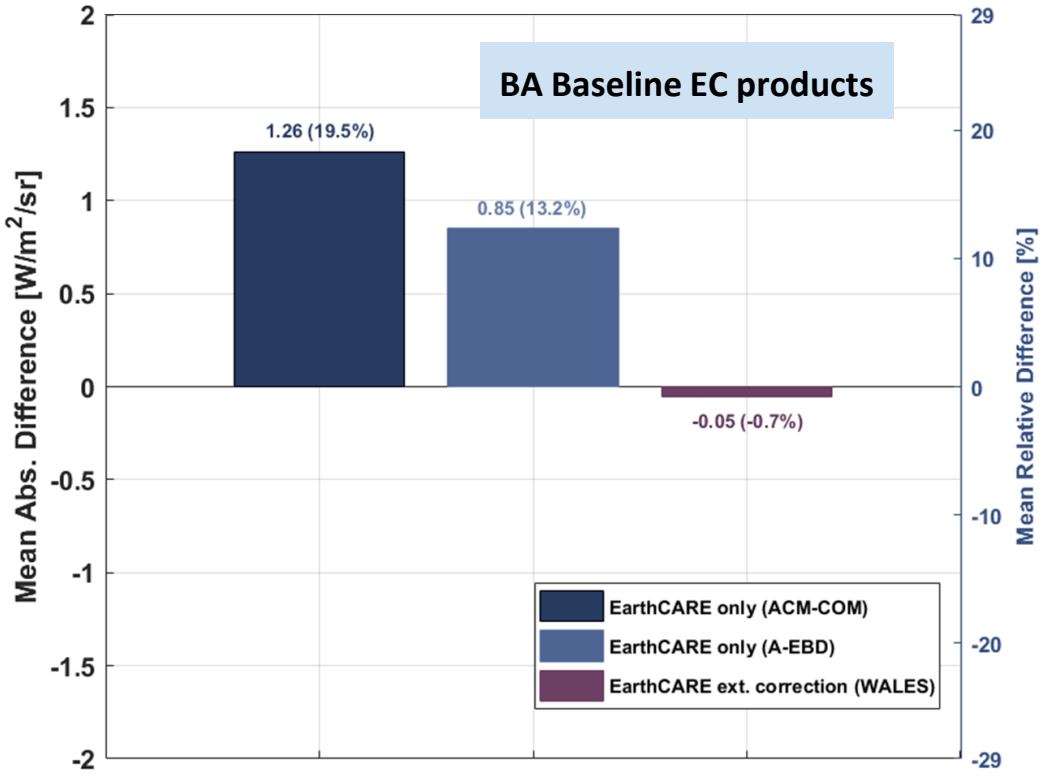
Radiative Closures - Clear sky case study

Radiative closure **at aircraft level** during the ORCESTRA/PERCUSION campaign under clear-sky conditions

Case study: 22/08/2024



For the 10km along EarthCARE track



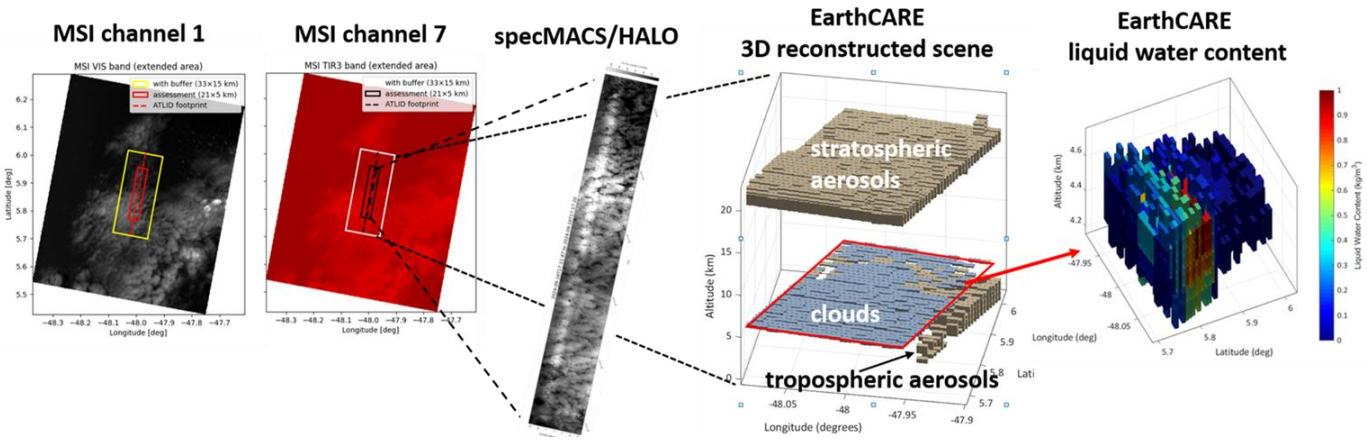
Kouklaki et al.

Radiative Closures - Cloudy case study

3D Radiative closure at TOA, with BBR, and at aircraft level, with HALO-specMACS, during the ORCESTRA/PERCUSION campaign

Case study: 16/09/2024

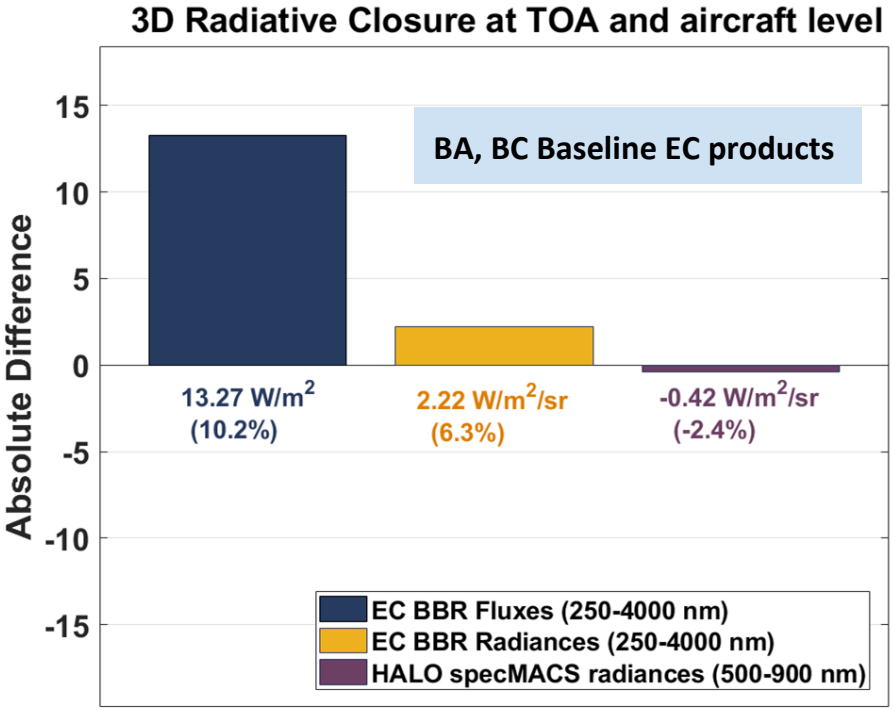
- **3D Radiative Transfer Simulations** with EarthCARE products (ACMD-3D, ACM-CAP)
- EarthCARE-**BBR radiances and effective fluxes at TOA for the assessment domain**
- ORCESTRA/PERCUSION campaign **radiances at aircraft level for the underpass time**



*Scene with stratospheric aerosol at 20km and **water clouds at ~5km***

libRadtran
MYSTIC
(Mayer et al. 2009)

ACM-CAP:
Ext. coeff profiles
Liquid water content
Liquid effect. radious



Overall good agreement, BBR fluxes close to 10W/m2 EarthCARE target

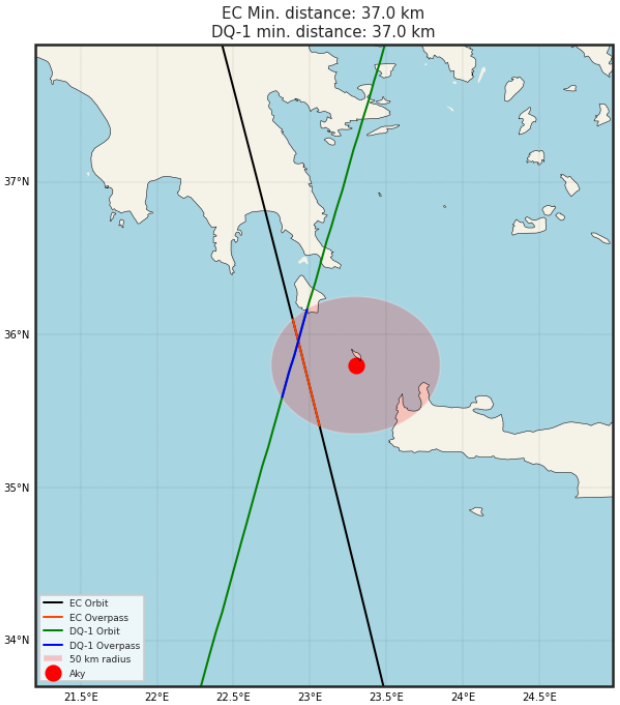
Kouklaki et al., Talk, Day 5, 8:54
Tsekeri et al., Poster Day 1, Lobby 9

Intercomparison between EarthCARE and DQ-1

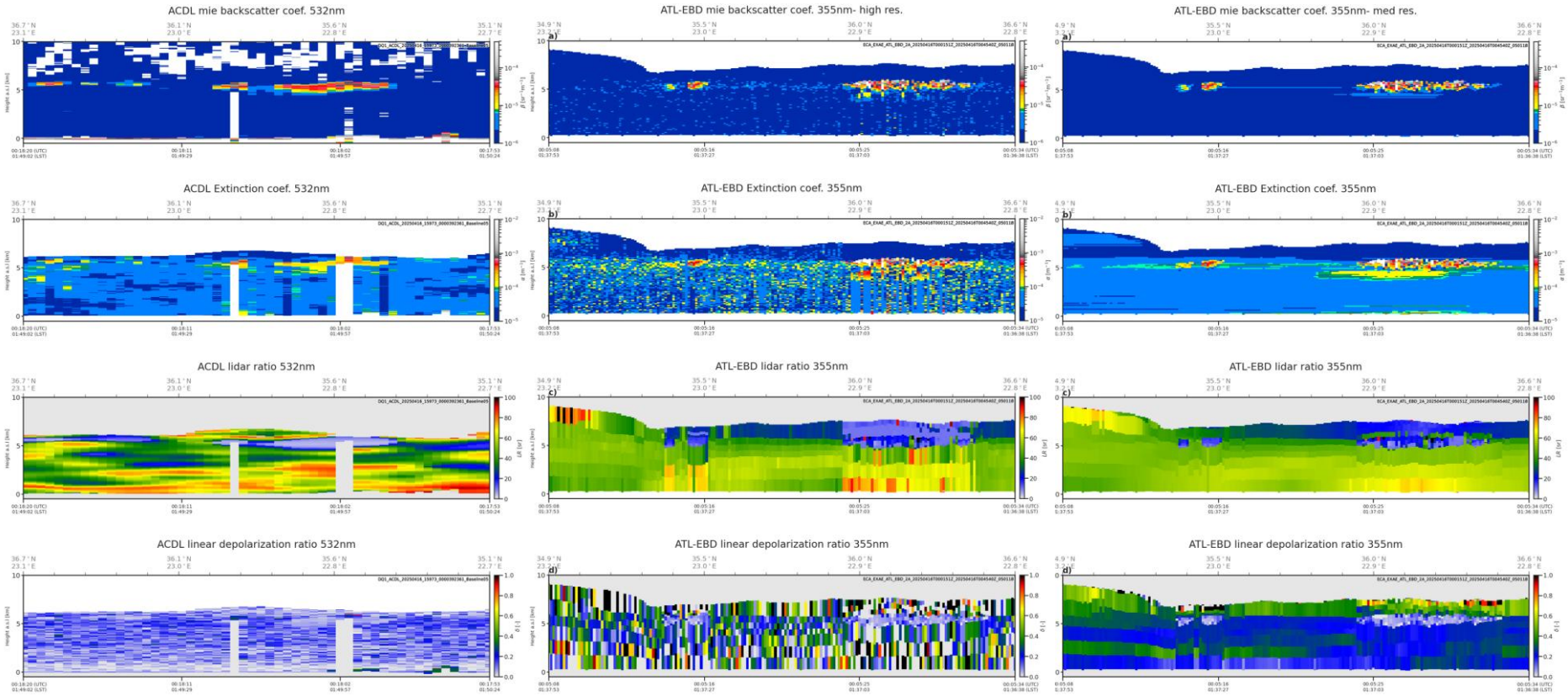
GOLDEN CASE

16/04/2025

Overpass difference ~ 12 mins



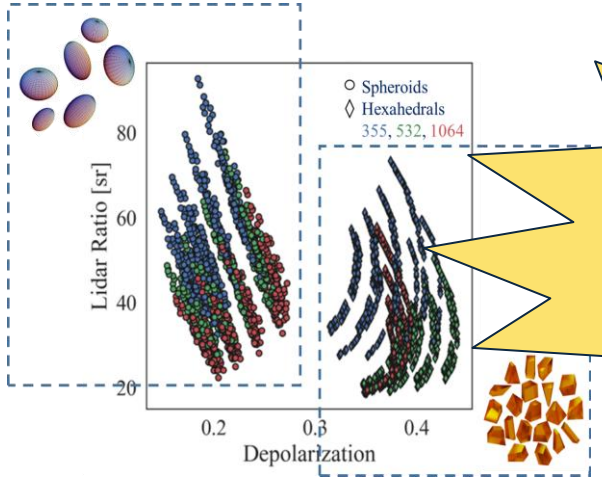
ACDL (3.3km) | **ATLID (1km)** | **ATLID (10km)**



- Same features detected
- Similar values for Bp, Ext, LR, variations due to different resolutions and wavelength
- Depolarization: ATLID @1km too noisy, @10km nicely captures the layers
  ACDL lower values than ATLID

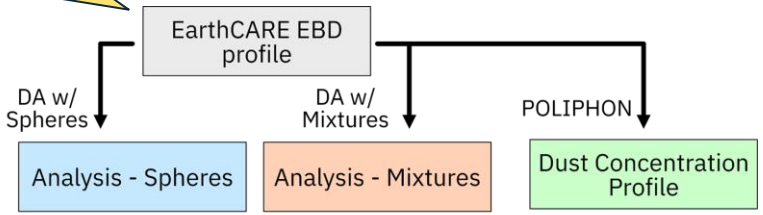
Karipis et al., Poster Day 2, Annex 18

Data Assimilation of EarthCARE ATLID & Optical Properties

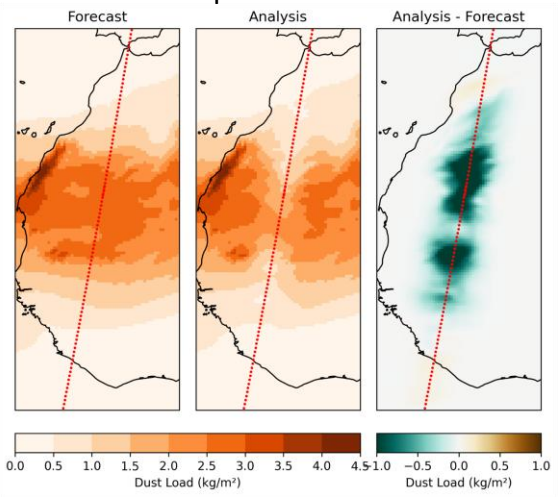


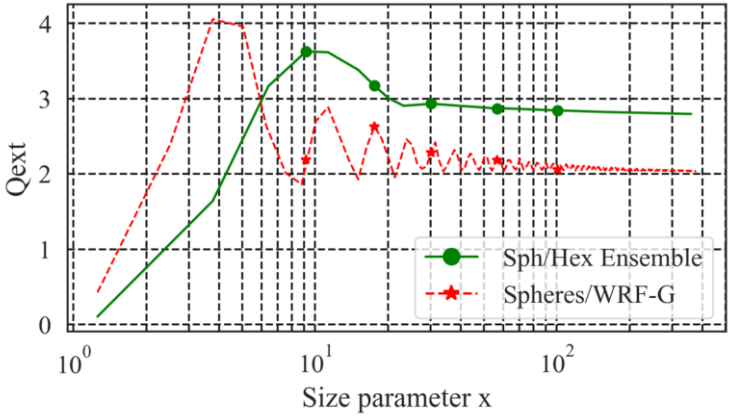
New optical model for dust that can reproduce spectral lidar observations

Used in data assimilation operators!

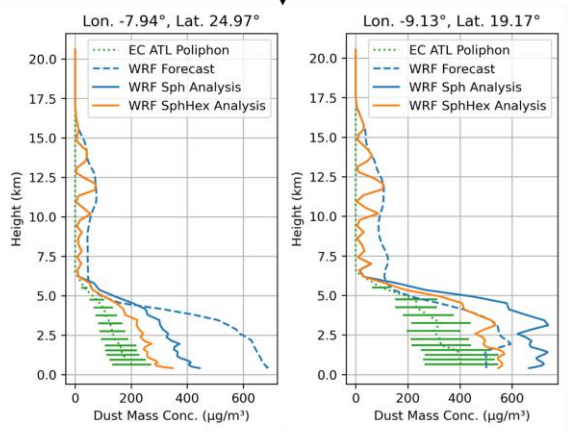


EC ATLID Overpass DA in WRF-CHEM

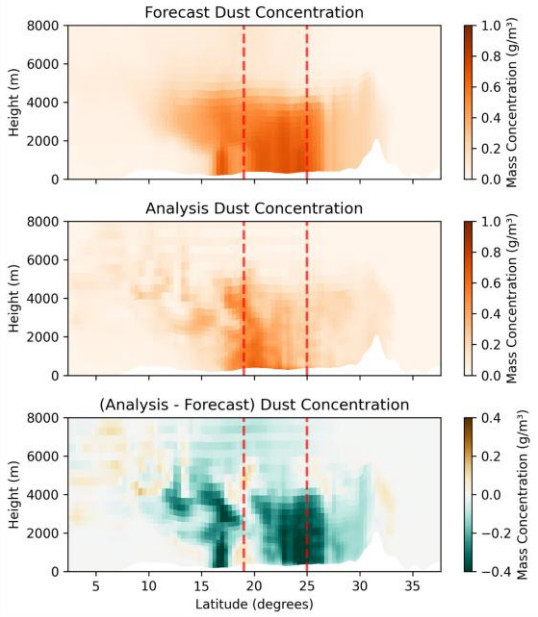




Extinction efficiency here is calculated as extinction cross section of the non-spherical dust shapes/projected surface area of the volume equivalent sphere, following *Kok et al., 2017*.



Using the new optical properties (mixtures of hexahedral and spheroids) brings the analysis closer to the concentration profile derived by the POLIPHON method (*Mamouri & Ansmann, 2014*).

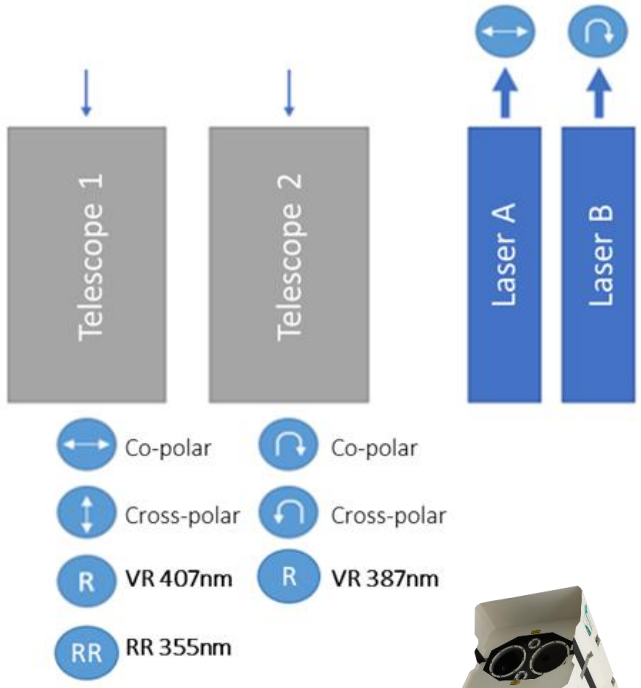


Georgiou et al., Poster Day 4, Annex 65

Ongoing activities: ESA's eVe lidar upgrade

ESA eVe lidar

- **ESA's ground reference lidar system for cal/val of ESA satellite missions**
- Combined linear/circular depolarization and Raman measurements
- Dual-laser/dual-telescope configuration → 4 lidars in one system
- **System upgrade → optimized for EarthCARE cal/val and enhanced dual-FOV capabilities**



Lidar products:

- 355nm: $\beta_{particle}$, **daytime $\alpha_{particle}$**, Lidar Ratio, δ_{linear}, $\delta_{circular}$
- **water vapor mixing ratio**

Capabilities:

1. Calibration and validation of spaceborne lidar products (ATLID/EarthCARE, Aeolus I & II)

1. Validate the theoretical relationship $\delta_{circular} = \frac{2\delta_{linear}}{1-\delta_{linear}}$ *(Mishchenko and Hovenier, Opt. Lett., 1995)*
   → Provide signs of particle orientation and/or multiple scattering

1. **Dual-FOV lidar measurements** *(Jimenez et al., ACP, 2022; Donovan et al., AMT., 2015)*
   → Study multiple scattering, Aerosol-Cloud-Interactions

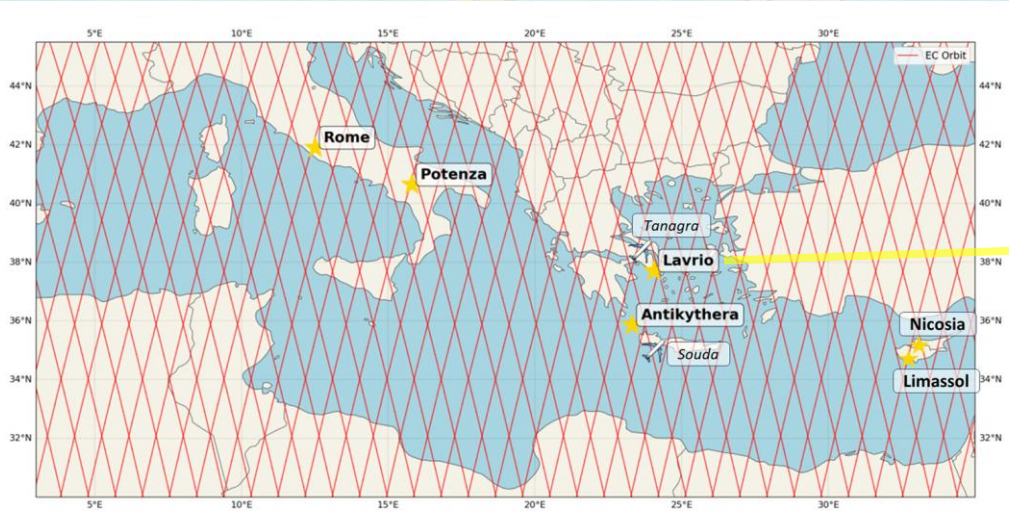
(Paschou et al., AMT, 2022)

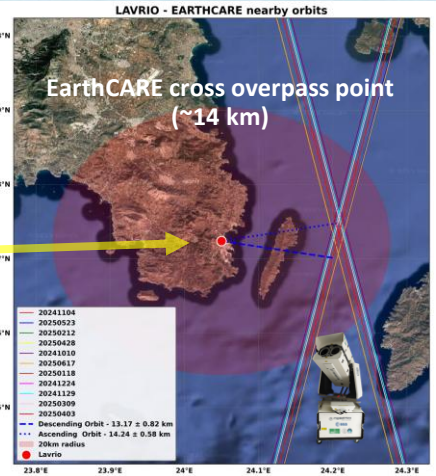
Paschou et al., Poster
Day 2, Annex 16

Future activities: Mediterranean Campaign - 2026/2027

EarthCARE Mediterranean cal/val campaign

- Ground-based and Airborne platforms for aerosol, clouds and radiation measurements
  - ✓ 5 ACTRIS Aerosol remote sensing facilities + ESA's eVe lidar in EC cross-point (Lavrio)
  - ✓ 3 ACTRIS Cloud remote sensing facilities
  - ✓ Longwave and Shortwave radiometers
  - ✓ Airborne aerosol in-situ (CyI)
  - \+ Possible HSRL-2 (NASA)

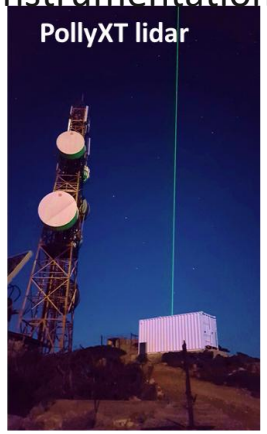




Campaign Objectives

- Validation of EarthCARE products
- Aerosol-Cloud-Radiation Interaction studies
- Radiation closure
- lidar multiple scattering effects

Example of suborbital instrumentation



Future work

- Evaluate other products (A-ALH, C-CLD, ACM-CAP) including the products under OREO & Obs3rve EarthCARE+ projects
- Update radiative closures with latest baselines and investigate more cases
- Comparison of radiative closures at TOA with ACM-RT EarthCARE product
- Intercompare EarthCARE and DQ1 products
- Use of EarthCARE products for Sentinel 4 & 5 validation (aerosol layer height)
- Paper publications with current results
- **Cal/Val working group under WG3 of EARLICOST cost action (2025-2029) (https://www.cost.eu/actions/CA24135/)**

Thank you!

Funded by EU

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CERTAINTY
CLOUD-AEROSOL INTERACTIONS & THEIR IMPACTS IN THE EARTH SYSTEM