Validation of EarthCARE products under ACROSS Mediterranean activities

EarthCARE 2026 Science and Validation workshop

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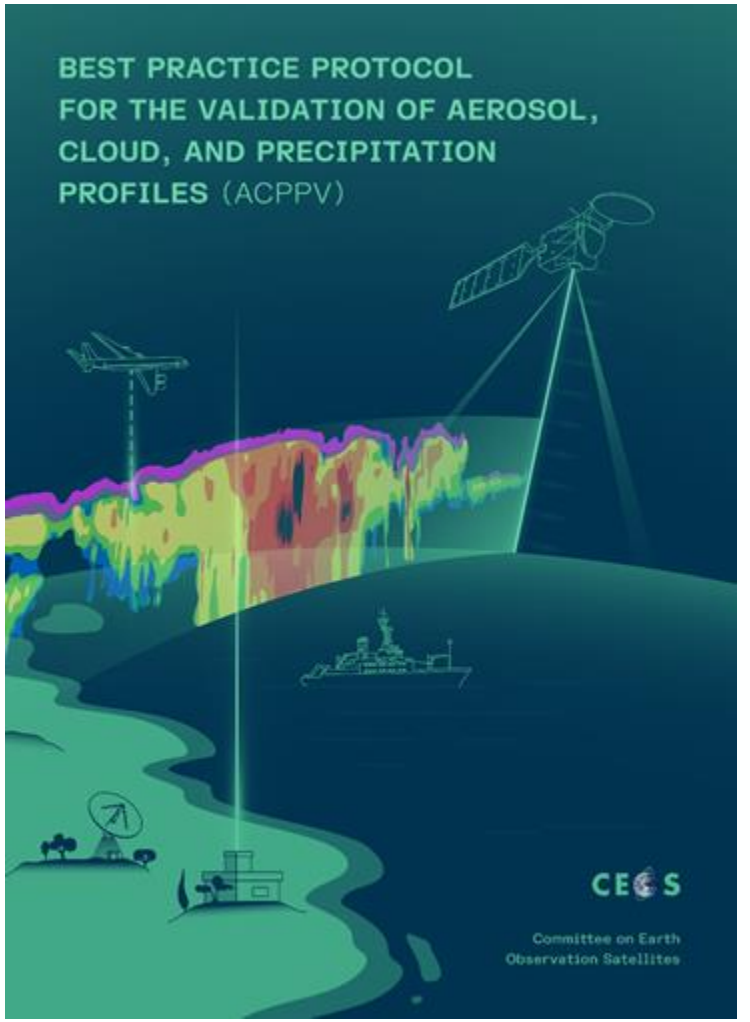
Best Practice Protocols for the Validation of Aerosol, Cloud, and Precipitation Profiles (ACPPV)

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)**



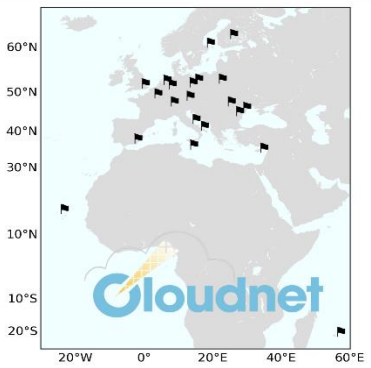
Consortium of 97 scientists

CEOS Committee on Earth Observation Satellites

https://zenodo.org/records/15025627

57 space agencies, institutes, universities

L2 AC-TC classification



EarthCARE AC-TC Baseline BA, BC vs Cloudnet

21 Cloudnet Stations, May 2024 – May 2026

Spatiotemporal collocation:

- ± 5 minutes around overpass time
- <50 km radius around site
- 1114 collocated cases

Methodology

EarthCARE AC-TC classes

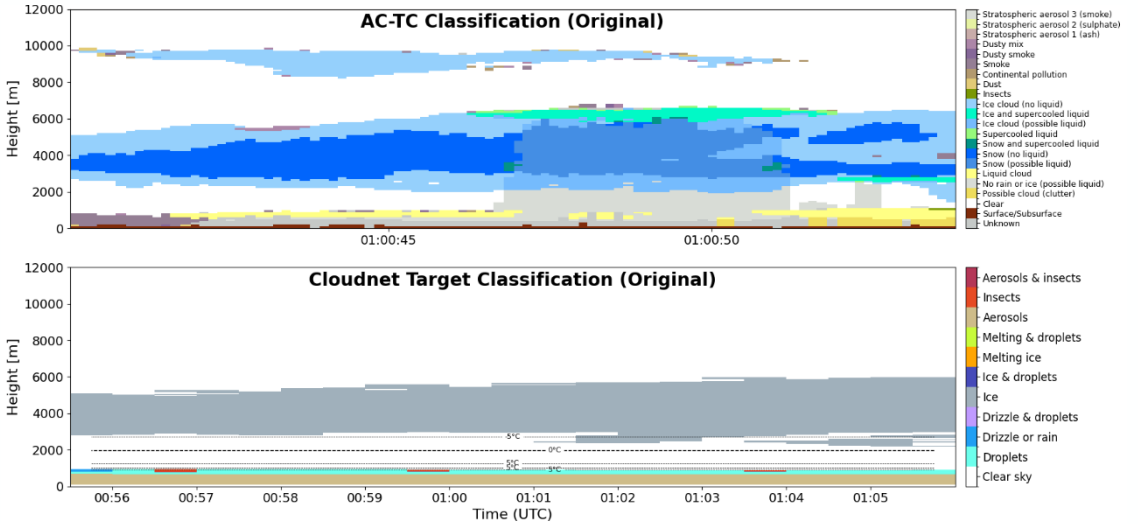
(1) Stratospheric aerosol 3 (smoke)
(2) Stratospheric aerosol 2 (sulphate)
(3) Stratospheric aerosol 1 (ash)
(4) Dusty mix
(5) Dusty smoke
(6) Smoke
(7) Continental pollution
(8) Sea salt
(9) Dust
(10) Insects
(11) PSC Ib (NAT)
(12) PSC Ia (STS)
(13) Stratospheric ice (PSC II)
(14) Ice cloud (no liquid)
(15) Ice and supercooled liquid
(16) Ice cloud (possible liquid)
(17) Supercooled liquid
(18) Snow and supercooled liquid
(19) Rimed snow and supercooled liquid
(20) Rimed snow (possible liquid)
(21) Snow (no liquid)
(22) Snow (possible liquid)
(23) Melting snow
(24) Cold rain
(25) Warm rain
(26) Drizzling liquid cloud
(27) Liquid cloud
(28) No rain or ice (possible liquid)
(29) Heavy mixed-phase precipitation
(30) Heavy rain
(31) Possible cloud (clutter)
(32) Possible snow (clutter)
(33) Possible rain (clutter)
(34) Clear
(35) Surface/Subsurface
(36) Unknown

Cloudnet classes

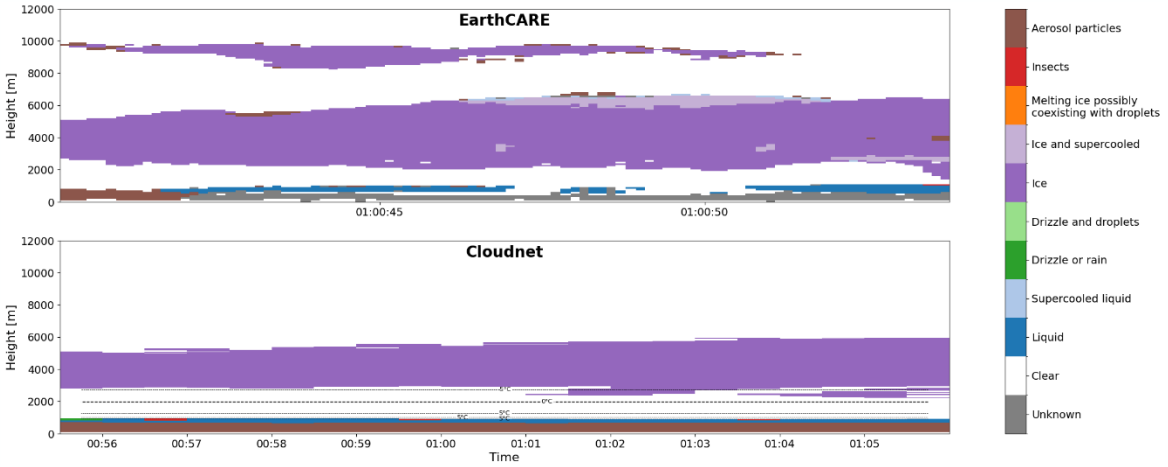
(a) Aerosols & insects
(b) Insects
(c) Aerosols
(d) Melting & droplets
(e) Melting ice
(f) Ice & droplets
(g) Ice
(h) Drizzle & droplets
(i) Drizzle or rain
(j) Droplets
(k) Clear sky

Combined classes

Aerosol particles (1-9), (a), (c)
Insects (10), (b)
Melting ice possibly coexisting with droplets (23), (d), (e)
Ice and droplets (29), (18), (15), (f)
Ice (19-22, (14), (g)
Drizzle and droplets (26), (h)
Drizzle or rain (24-25), (30, (i)
Droplets T<0°C (17), (j with T<0°C)
Droplets T>0°C (27), (j with T>0°C)
Clear (34), (28), (k)
Unknown (36)

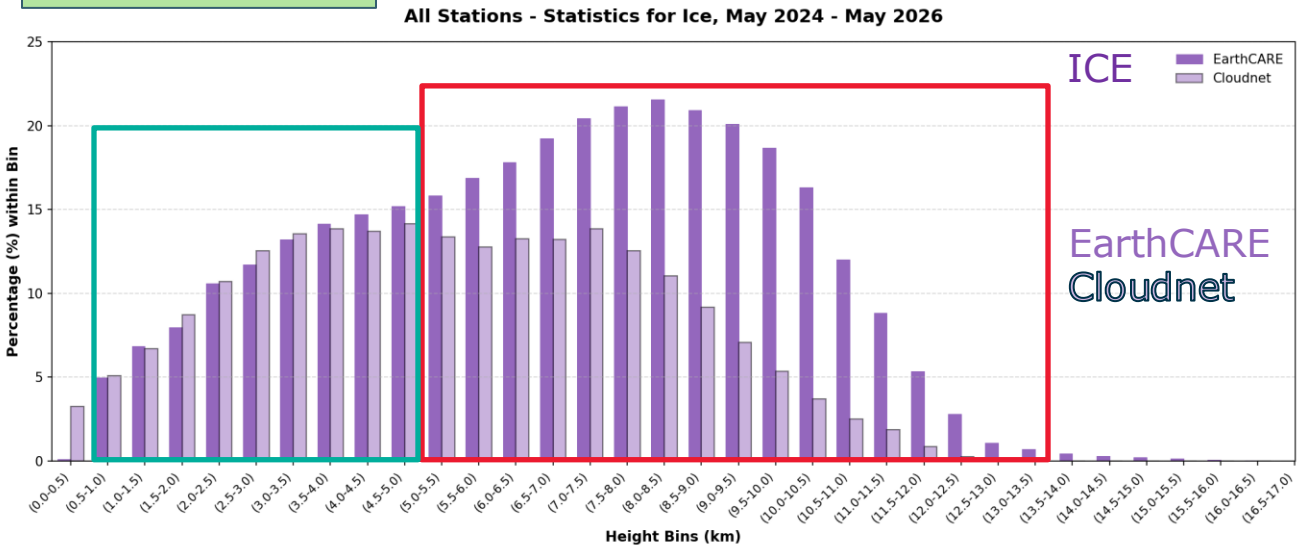


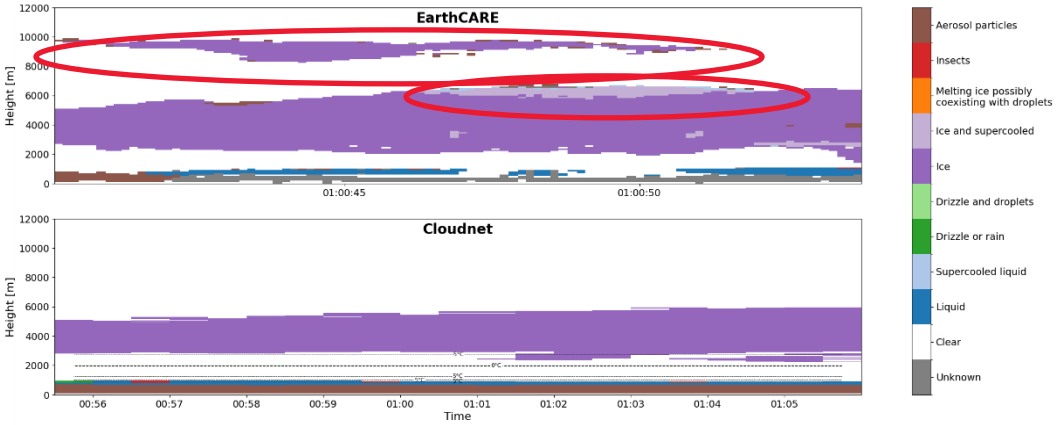
Case-by-case comparison in Homogeneous cases & **overall statistics**

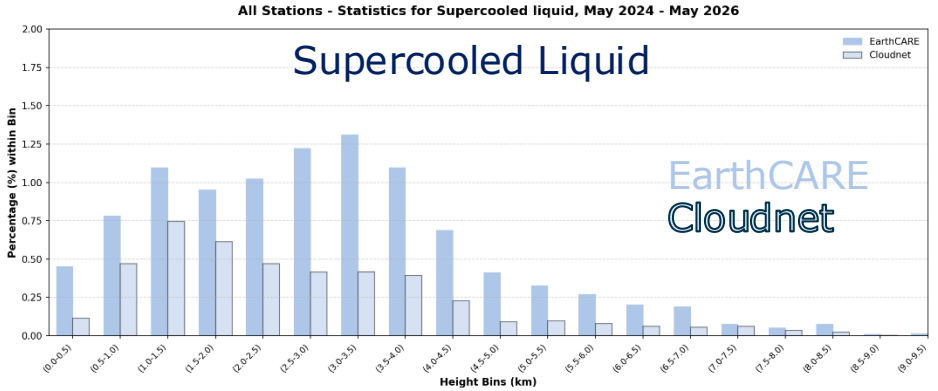


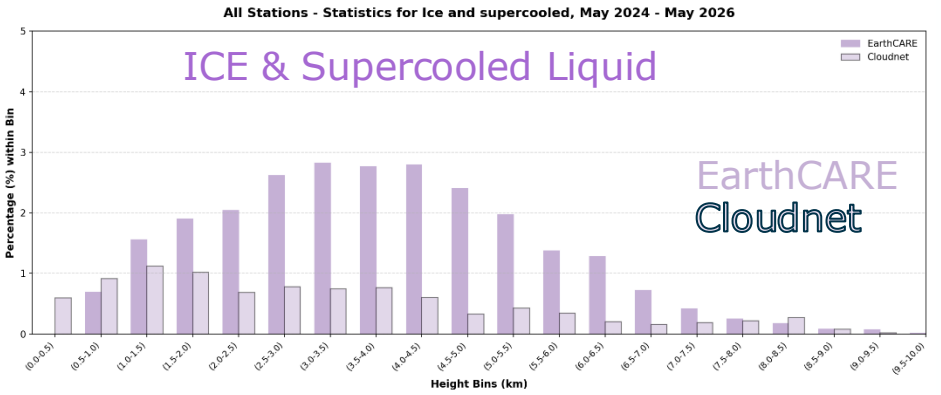
L2 AC-TC classification – Ice & supercooled clouds

2-year statistics





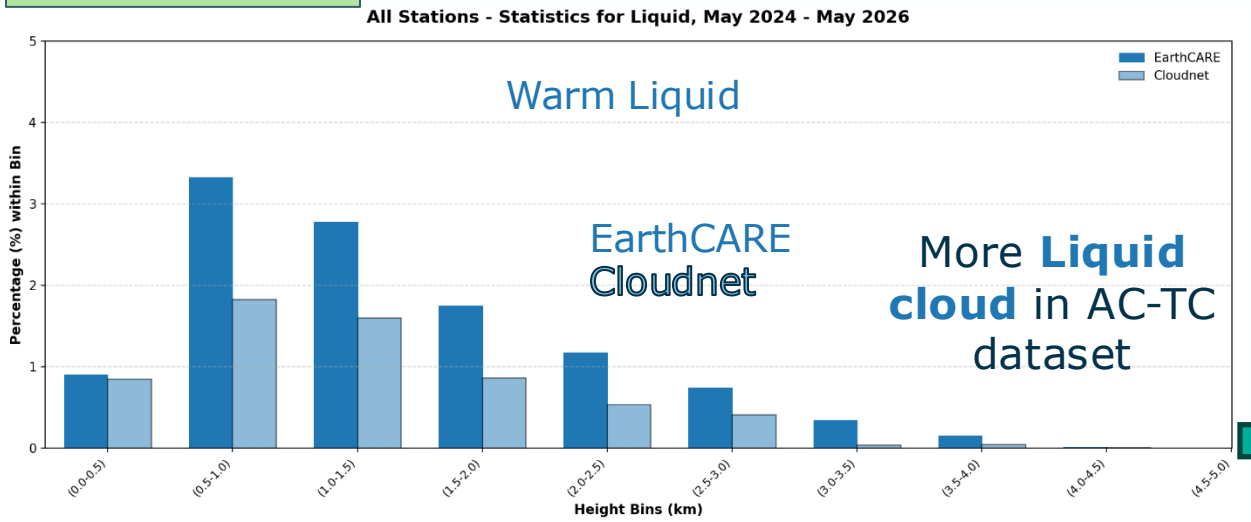


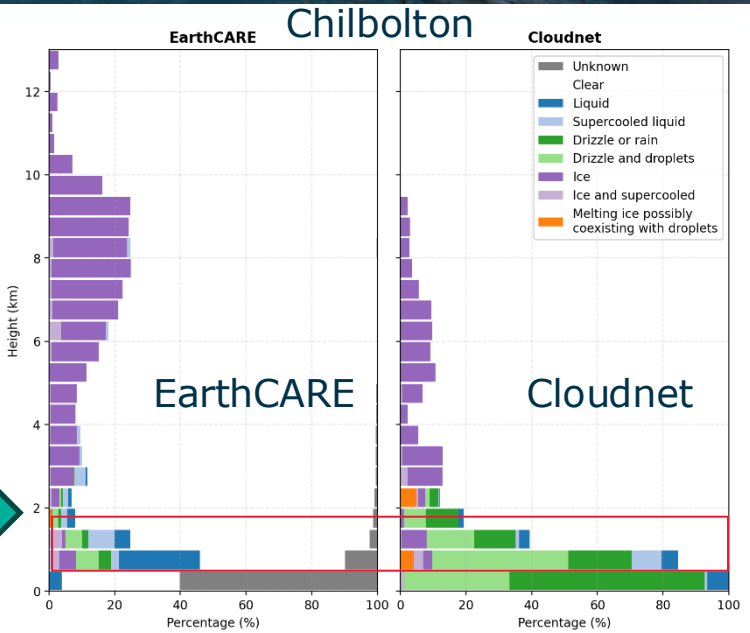


- Ice clouds:
  - @ 0.5-5 km: Good statistical agreement
  - @ > 5km: more ice clouds in the EarthCARE dataset due to Cloudnet undetections & EarthCARE aerosol misclassifications
- More **Supercooled Liquid** & **ICE & Supercooled** layers in the EarthCARE dataset

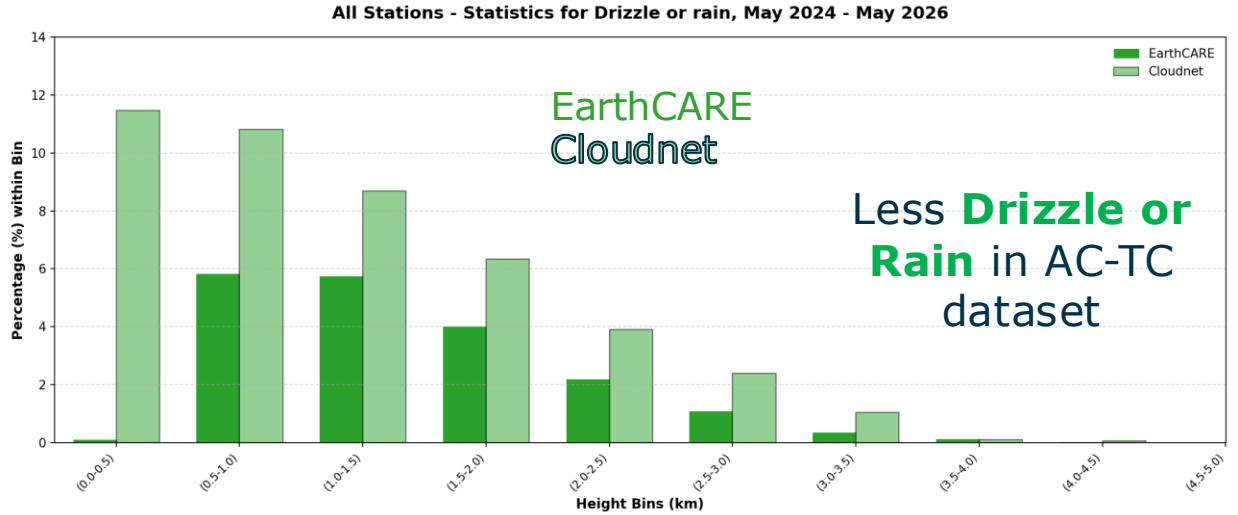
L2 AC-TC classification – Warm liquid & Drizzle/rain

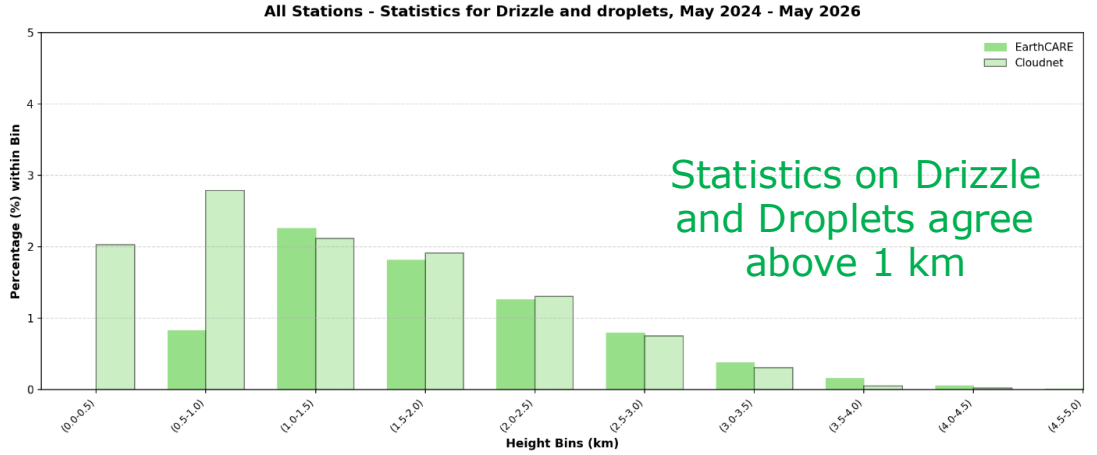
2-year statistics





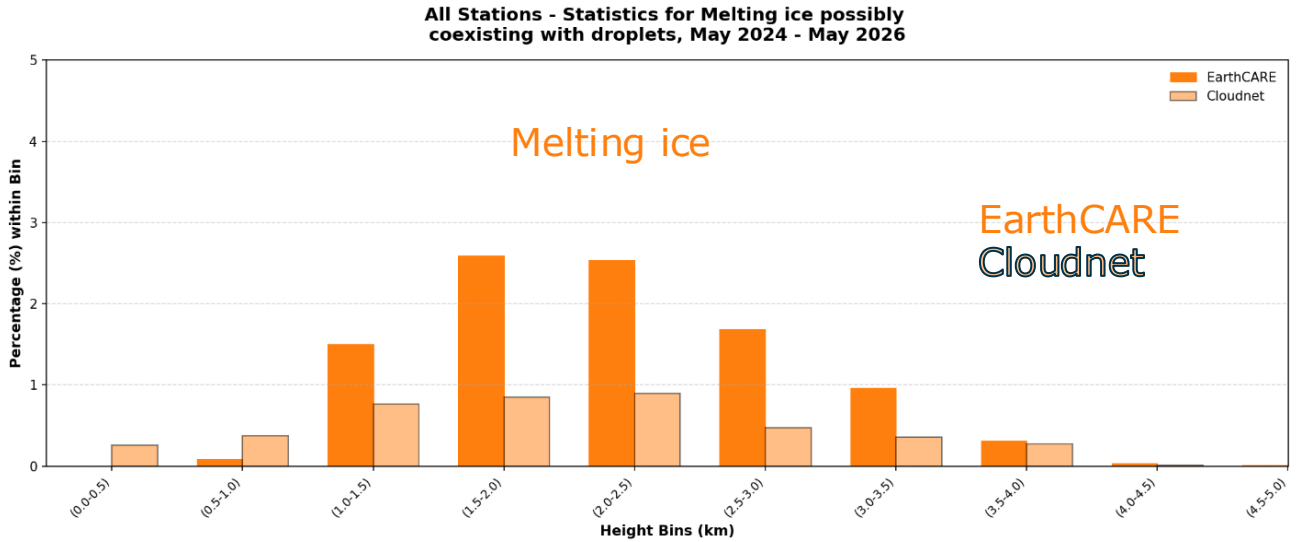
Possible missclassification of Drizzle/rain as liquid in AC-TC





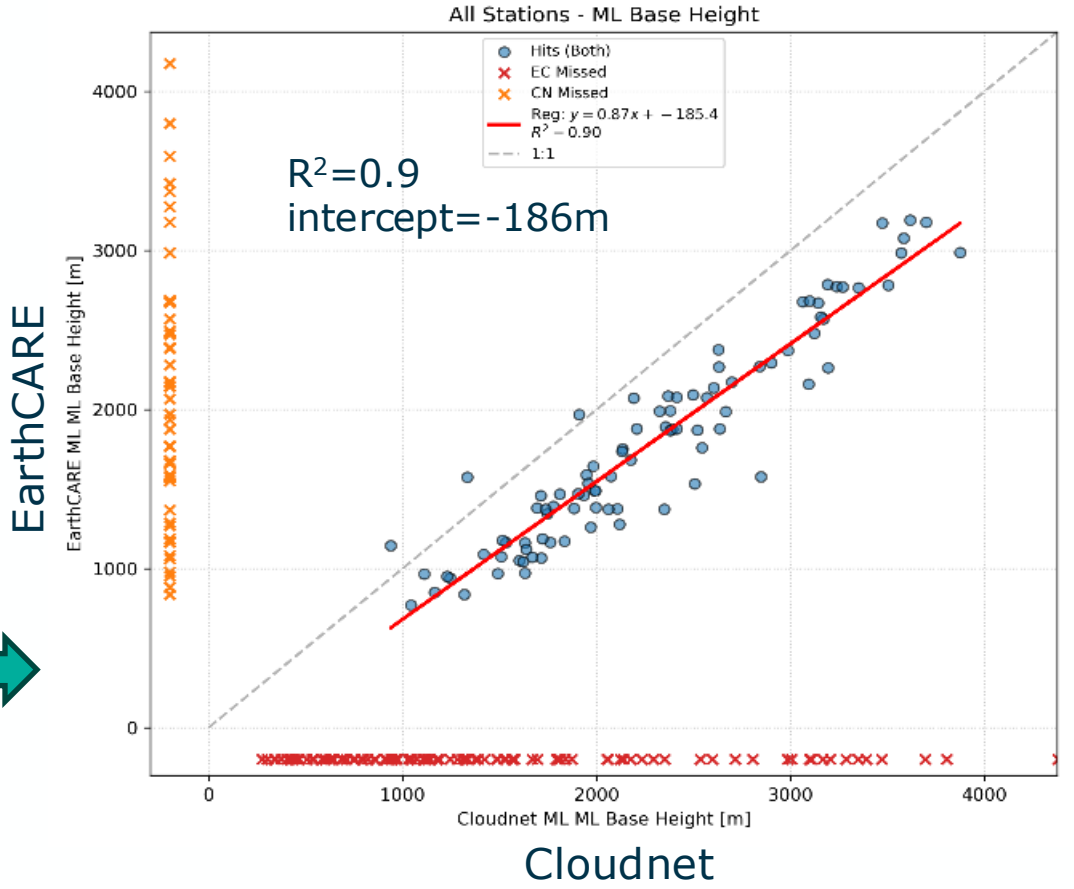
L2 AC-TC classification – Melting layer

2-year statistics



Melting Layer base intercomparison:
good agreement within the EarthCARE vertical resolution!

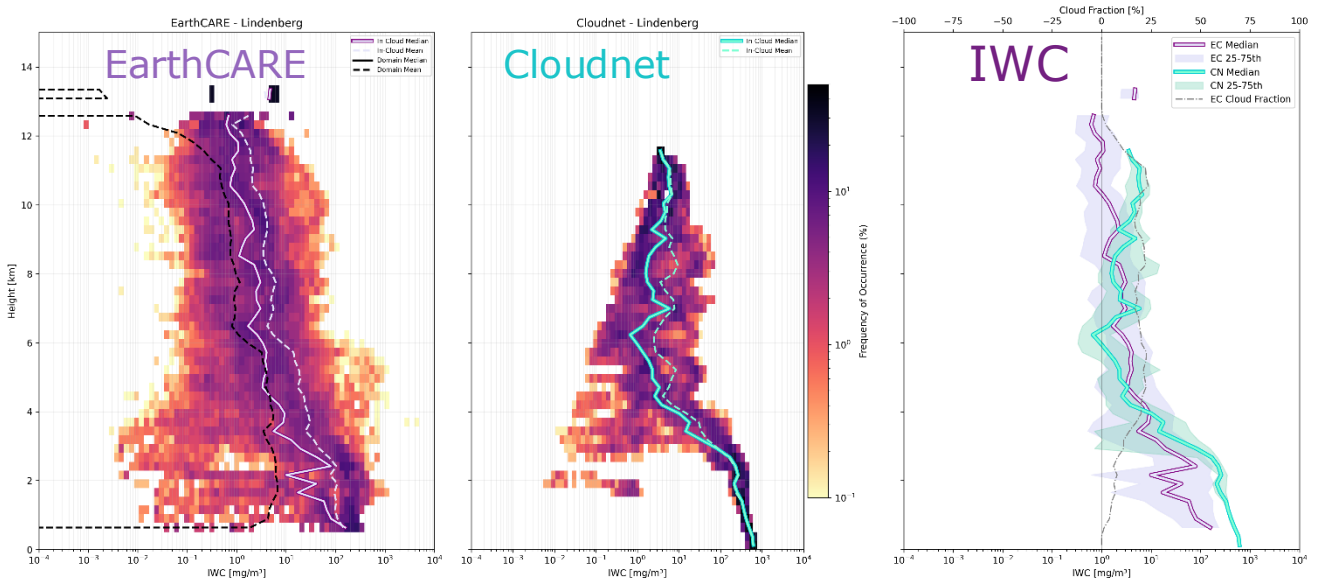
Melting Layer base

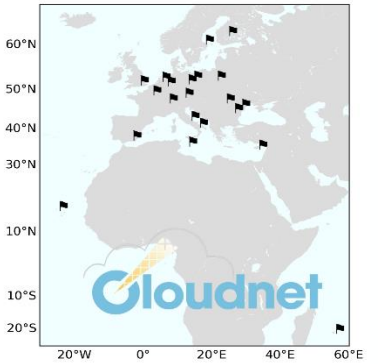


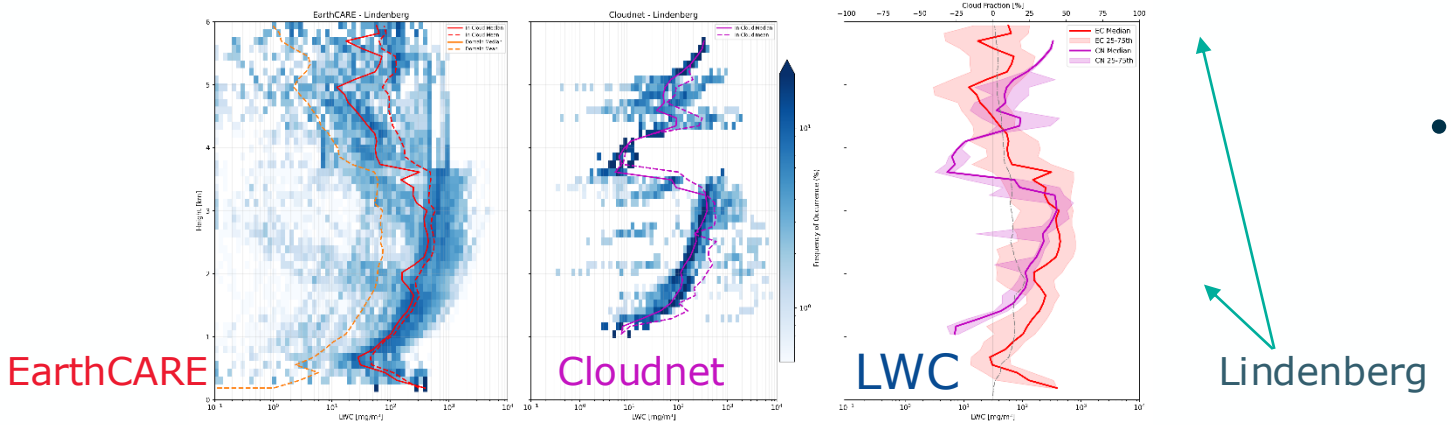
L2 ACM-COM microphysics – IWC & LWC

2-year statistics

Contoured Frequency by Altitude Diagrams (CFADs)







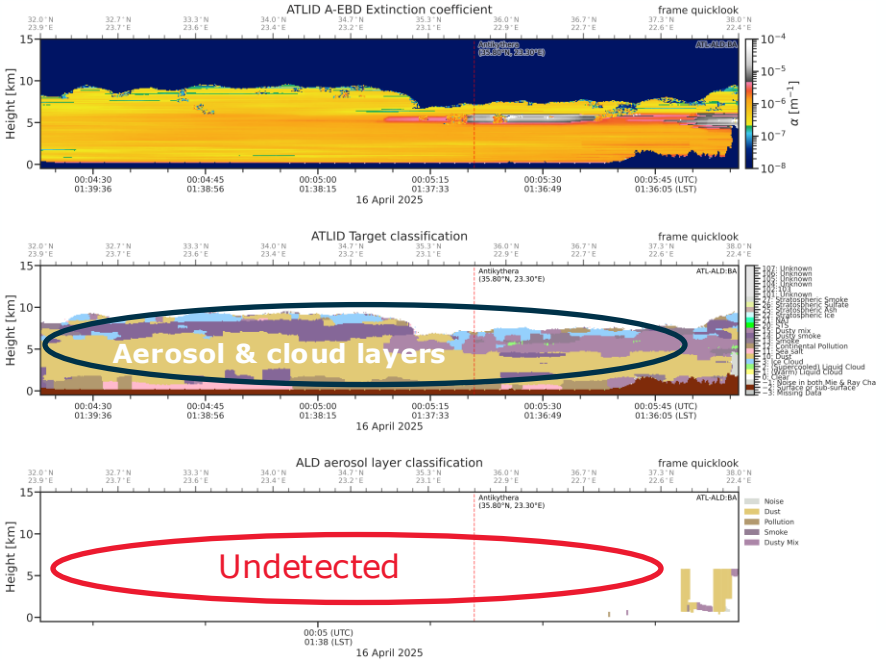
- Bulk comparison of all collocated cases
- In-cloud median, 25th &75th percentiles of **Ice Water Content** and **Liquid Water Content** are **consistent** between the 2 datasets
- Differences in ~0-2 km range

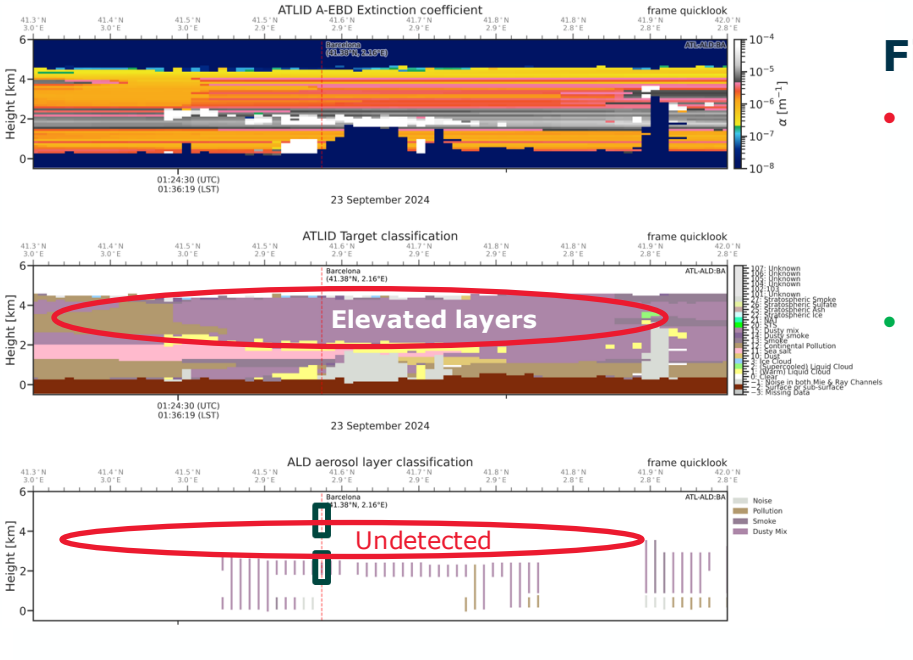
See Tsikoudi et al., P065

L2 A-ALD aerosol layer height

- **EarthCARE aerosol layer heights** (ATL_ALD_2A; **Baseline BA, BB**)
- Collocated ACTRIS/EARLINET ground-based lidar measurements in ± 2hrs, ± 50 km
- EARLINET Layer height: derived using the **LTOOL module** (Siomos et al., 2018; Voudouri et al., 2022)

EARLINET/ACTRIS dataset





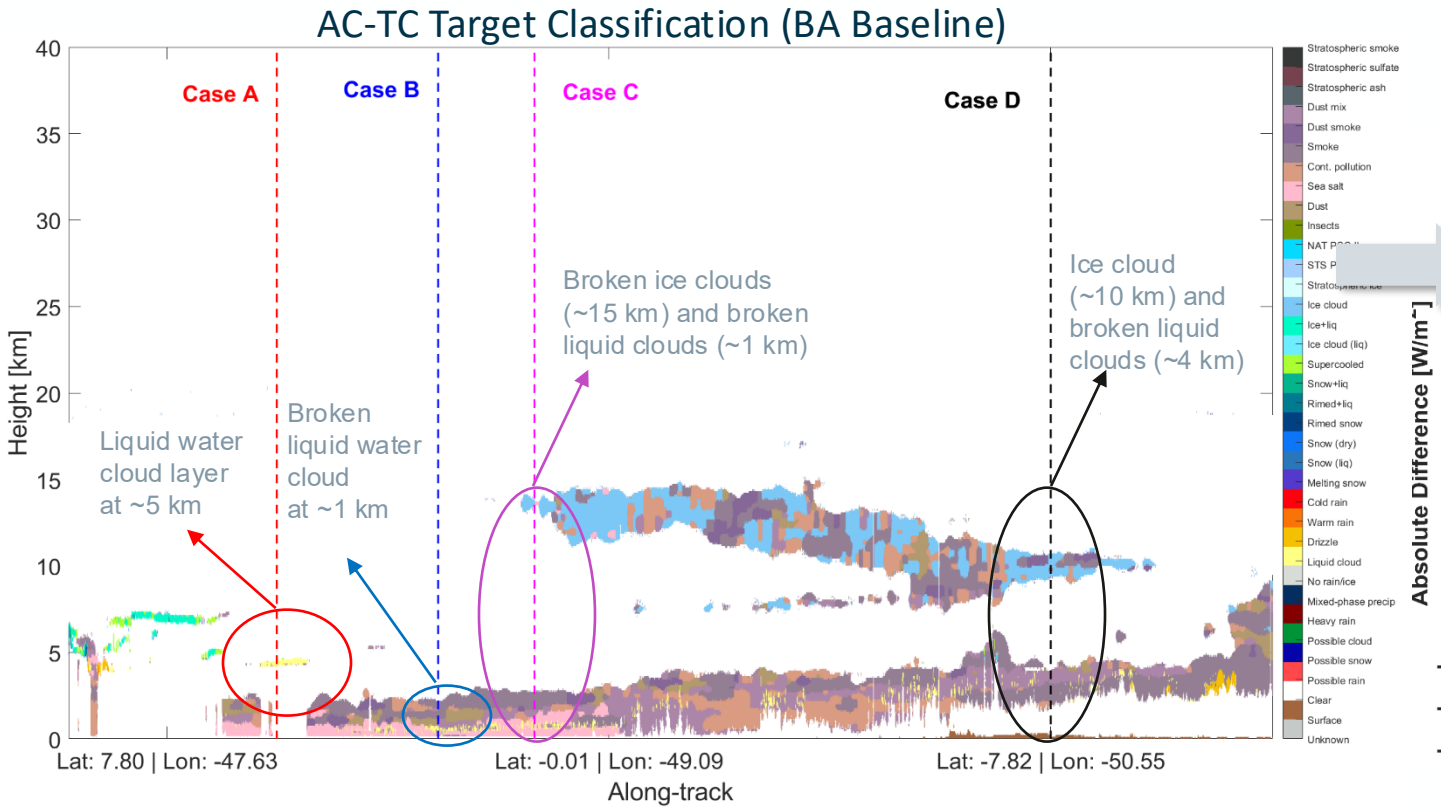
Findings:

- Several undetected layers, usually marine or multiple layers
- When layers are detected, heights are accurately assigned

See Voudouri et al., P037

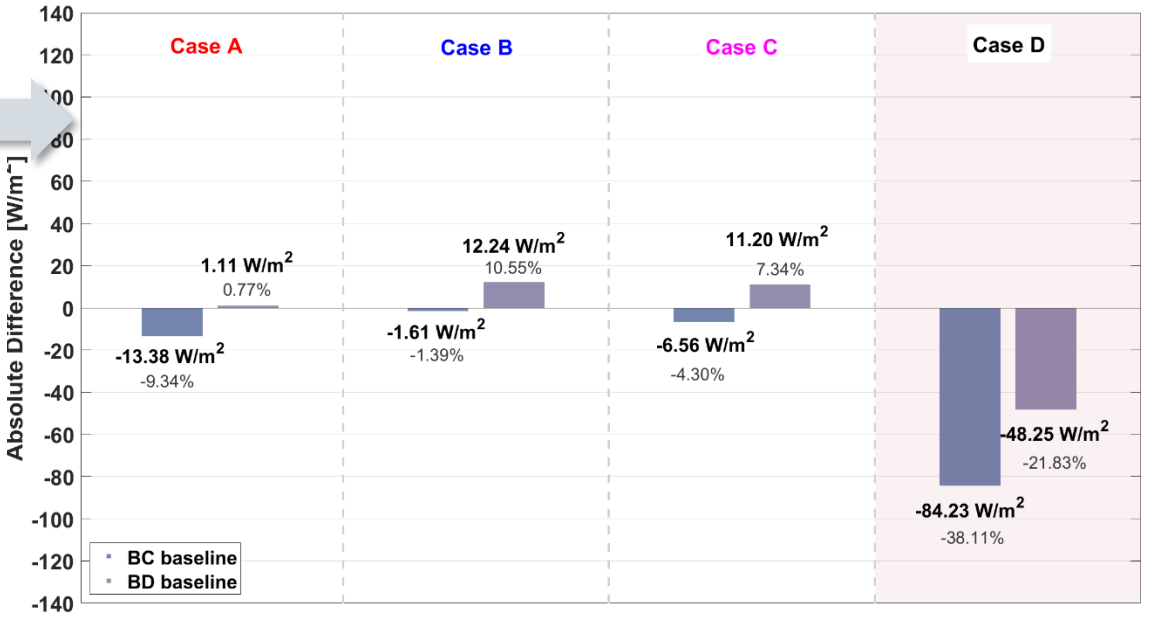
Comparison of ACM-CAP in Radiative Closures

Radiative Closures during ORCESTRA/PERCUSION with BBR effective fluxes at TOA under cloud-sky conditions



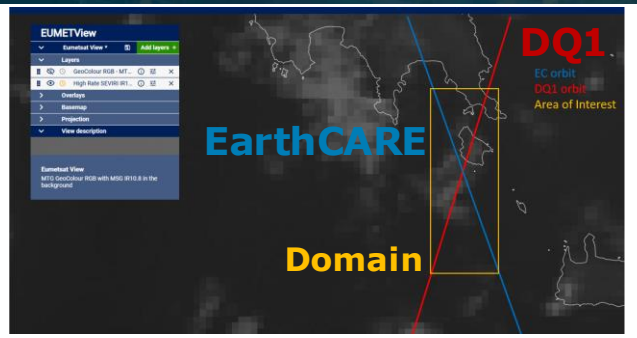
Kouklaki et al., T313

EarthCARE L2b ACM-CAP product
Comparison of closures with Baselines BC and BD



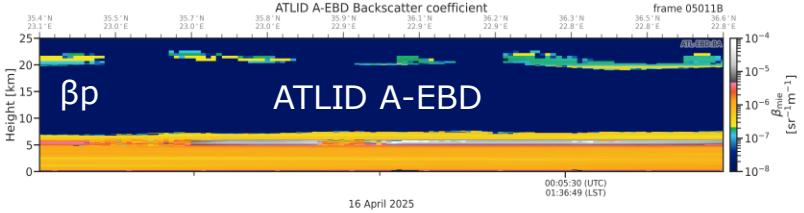
- Overall **good agreement** (close to ±10 W m⁻² mission target)
- One exception (Case D) - large deviations for **both baselines**
- **No systematic difference** between BC and BD was found
- **BD** generally led to **higher TOA fluxes** than BC

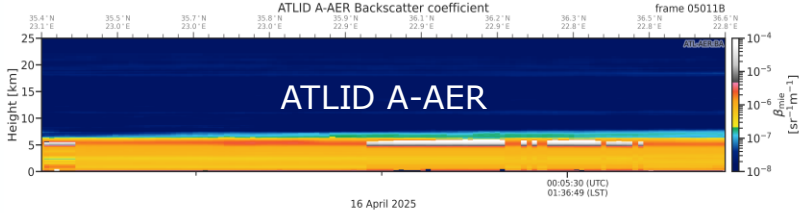
ATLID vs ACDL classification intercomparison over PANGEA/ACTRIS site

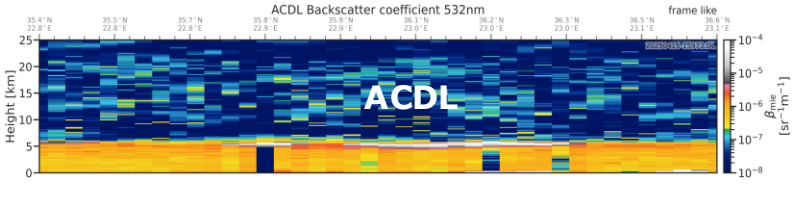


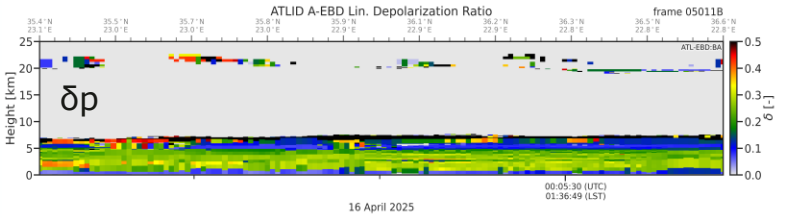
Results from the Classification intercomparison:

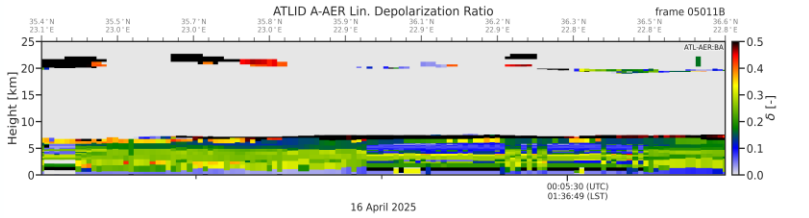
- Both instruments detect the stratospheric layers, correctly classified as aerosols in EarthCARE
- More clouds in ATLID A-EBD & A-AER classification products vs the ACDL classification products
- Upcoming product of subtyping for ACDL is expected with the public release of the data

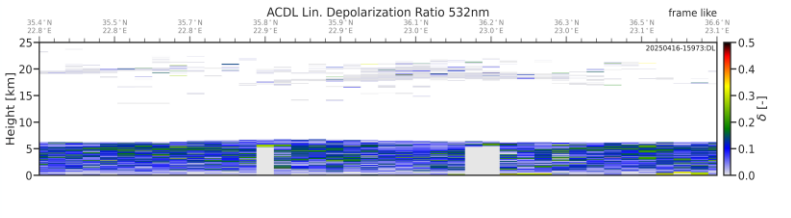


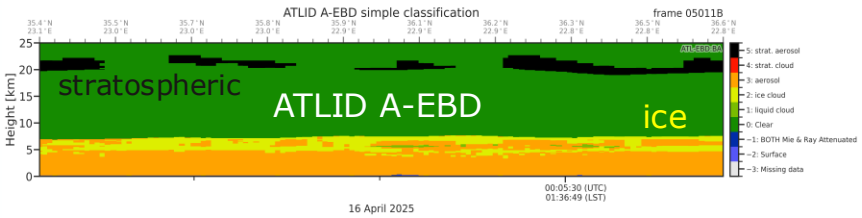


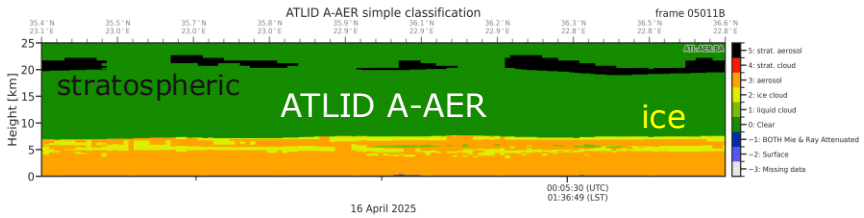


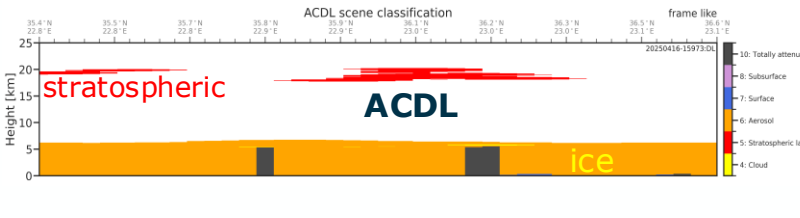












Evaluation of the satellite products vs suborbital measurements

- **Depolarization:** ATLID depolarization is ~2× higher than the suborbital reference in the aerosol layer; ACDL underestimates by a comparable factor
- **Ångström exponent:** Good ATLID retrieval at 355 nm; cross-instrument ATLID/ACDL ratio shows larger variability

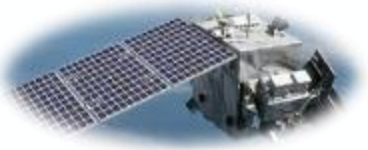
L2 A-EBD aerosol layers height vs PACE/SPEXone ALH

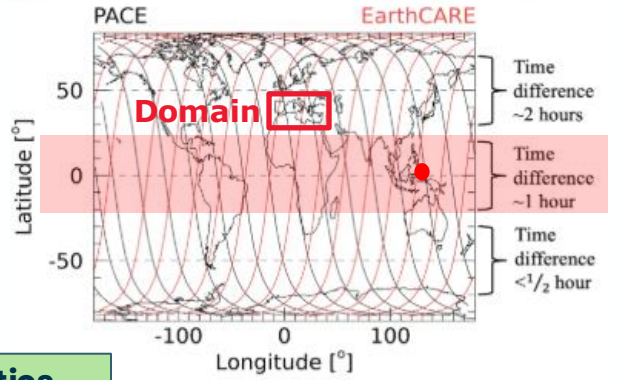
Use of EarthCARE A-EBD products to evaluate PACE/SPEXone Aerosol layer height products

- Time Period: 2025
- Domain: Mediterranean
- Collection critica: ± 2hrs, ± 50 km
- A-EBD ALH retrieved using Kim et al. (2025) method in backscatter & extinction profiles
- Evaluation of SpexONE remoTAP & FastMAPOL algorithms

Findings:

- FastMAPOL algorithm in better agreement with A-EBD ALH ($R = 0.5$)
- Higher agreement in dust and smoke layers (typically higher AODs)

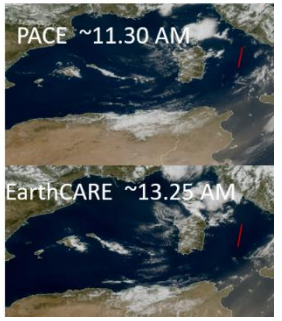


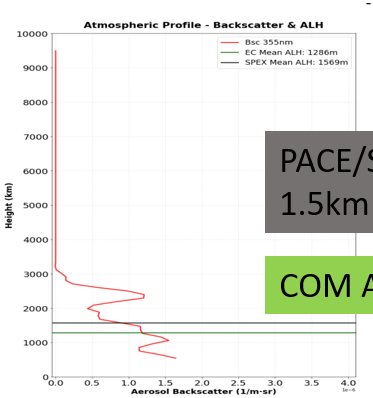


Case study

Case study – Dusty Smoke / Dusty mix

26-7-2025: smoke ~2.5-3km, overpass diff time ~2h

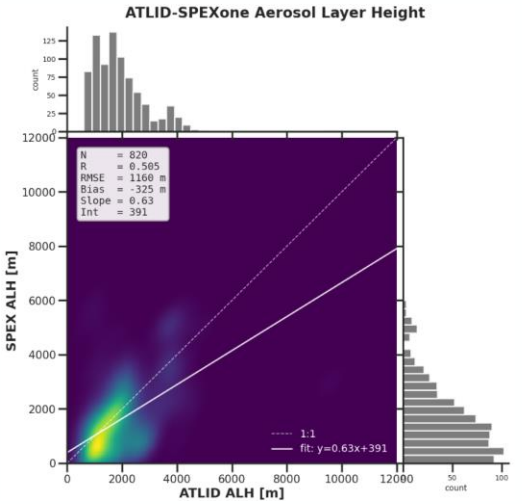




PACE/SPEXone ALH = 1.5km

COM ALH= 1.28km

2025 statistics

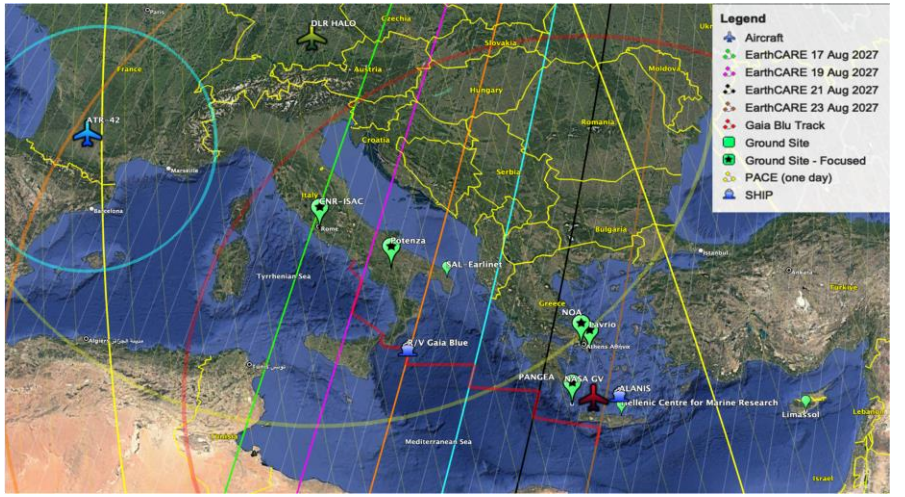


Voudouri et al., under preparation

Future activities: Mediterranean CoSense-EU Campaign – Summer-Autumn 2027

Mediterranean CoSense-EU campaign

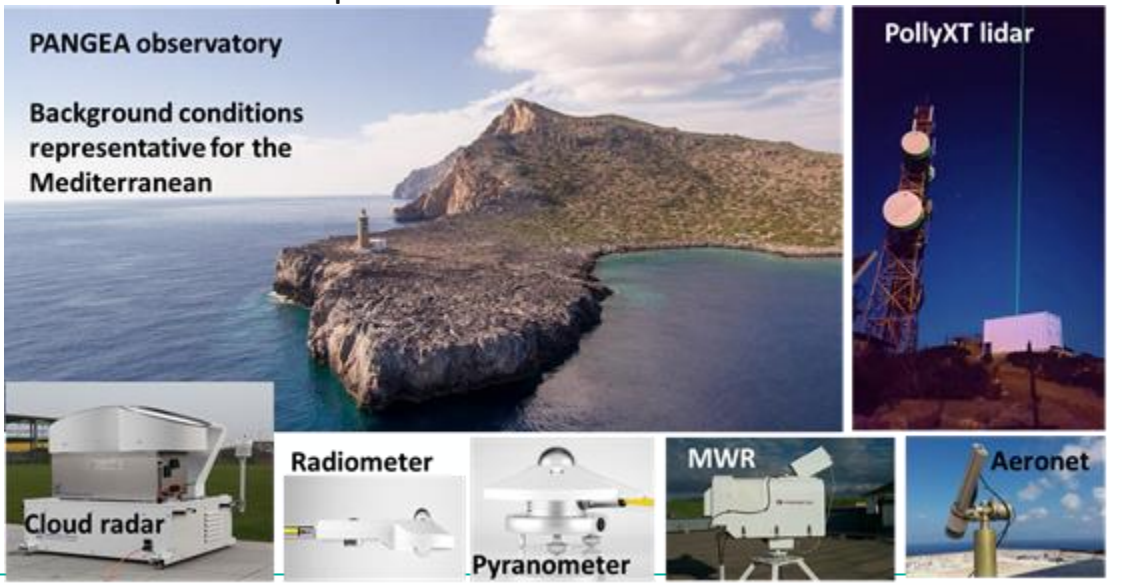
- Ground-based and Airborne platforms for aerosol, clouds, and radiation measurements
  - ✓ 3 ACTRIS Aerosol remote sensing facilities in Greece + ESA's eVe lidar in EC cross-point (Evoia)
  - ✓ 1 ACTRIS Cloud remote sensing facility (Evoia)
  - ✓ Longwave and Shortwave radiometers
  - ✓ Airborne aerosol in-situ (CyI)



Example of suborbital instrumentation

Campaign Objectives

- Adaptation of EarthCARE ML-based NASA retrievals in the Mediterranean
- multiple scattering studies using eVe's dual-field-of-view measurements
- Fire smoke & mixtures properties
- Test EarthCARE for Air Quality applications



Future work

- Finalize ACROSS validation studies for the EarthCARE special issue (including A-TC vs EARLINET, A-EBD vs Pangea, AC-TC vs Cloudnet)
- Investigate differences in liquid cloud layers
- Evaluate more parameters from ACM-COM product
- Continuous suborbital measurements with Antikythera & Thessaloniki lidars
- Participation in the 2027 Mediterranean campaign
- Expand the intercomparison of EarthCARE and DQ1 products
- Use of EarthCARE products for Sentinel 4 & 5 validation (aerosol layer height)
- Cal/Val working group under WG3 of EARLICOST cost action (2025-2029) https://www.cost.eu/actions/CA24135/ or https://earlicost.eu/

Thank you!