Validation of EarthCARE-derived Planetary Boundary Layer Height using radiosondes

M.Pérez-Hererra[1,2], O. Rodriguez-Navarro[1,2], J. Muñiz-Rosado[1,2], A. Díaz-Zurita[1,2], V. M. Naval-Hernández[1,2], D. Pérez-Ramírez[1,2], A. Cazorla[1,2], L. Alados-Arboledas[1,2], and F. Navas-Guzmán[1,2]

[1]Andalusian Institute for Earth System Research (IISTA-CEAMA), Granada 18071, Spain

[2]Applied Physics Department, University of Granada, Granada 18071, Spain

Correspondence: fguzman@ugr.es

UNIVERSIDAD DE GRANADA

EUROPEAN SPACE AGENCY

MOTIVATION

- The **Planetary Boundary Layer (PBL)** plays a **key role** in the **exchange** of **momentum, heat, moisture,** and **aerosol**.
- Characterising the **Planetary Boundary Layer Height (PBLH) is crucial for air control, climate modelling,** and **weather forecasting.**
- Thermodynamic PBLH retrievals rely on temperature, humidity, and wind profiles from radiosondes.
- **ATLID enables** the **characterisation** of the **vertical structure** of the **atmosphere**, facilitating the investigation of the PBLH with **improved temporal resolution** and **global coverage**.

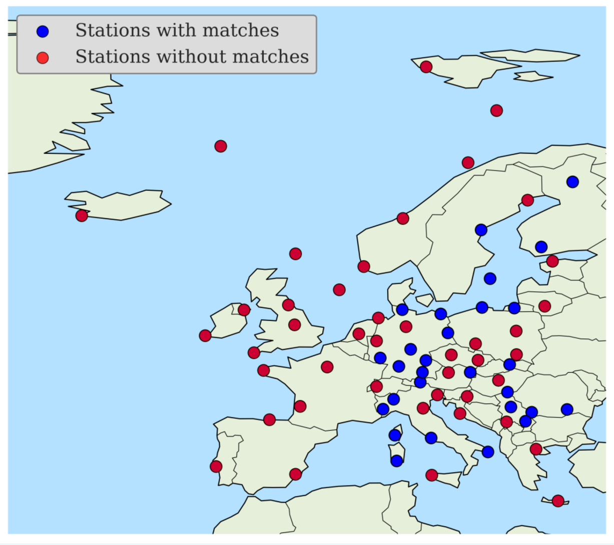
SATELLITE MISSION

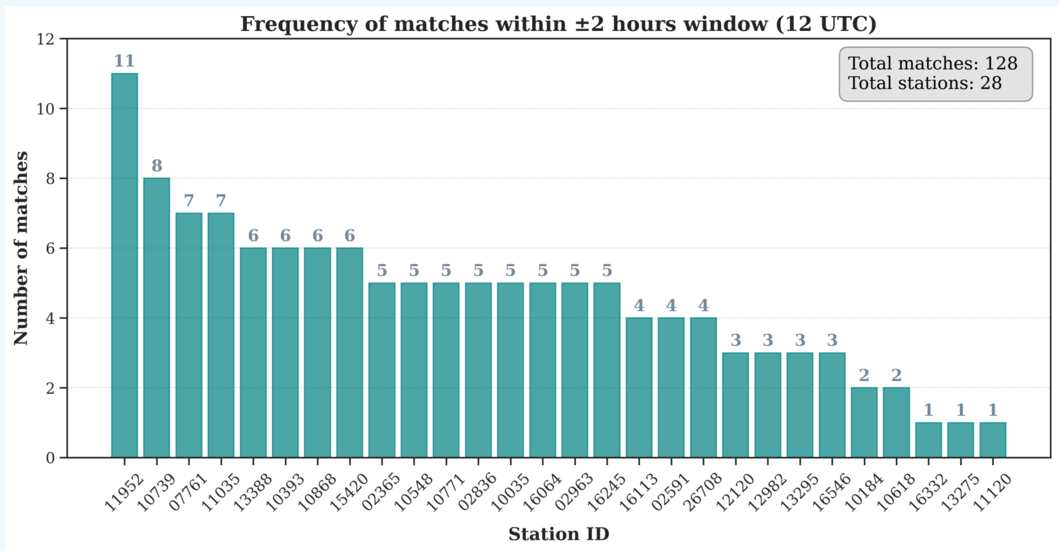
The **EarthCARE** mission (ESA/JAXA), launched in May 2024, carries four sensors on one platform (ATLID, CPR, MSI, and BBR). This unique synergy enables detailed atmospheric profiling along its path, providing crucial data on cloud-aerosol-radiation interactions.

ATLID is a high-spectral-resolution lidar operating at 355 nm, provides vertically resolved profiles of attenuated backscatter and depolarization. This capability enables new opportunities to characterize the vertical structure of aerosols and clouds and to investigate challenging variables such as the PBLH.

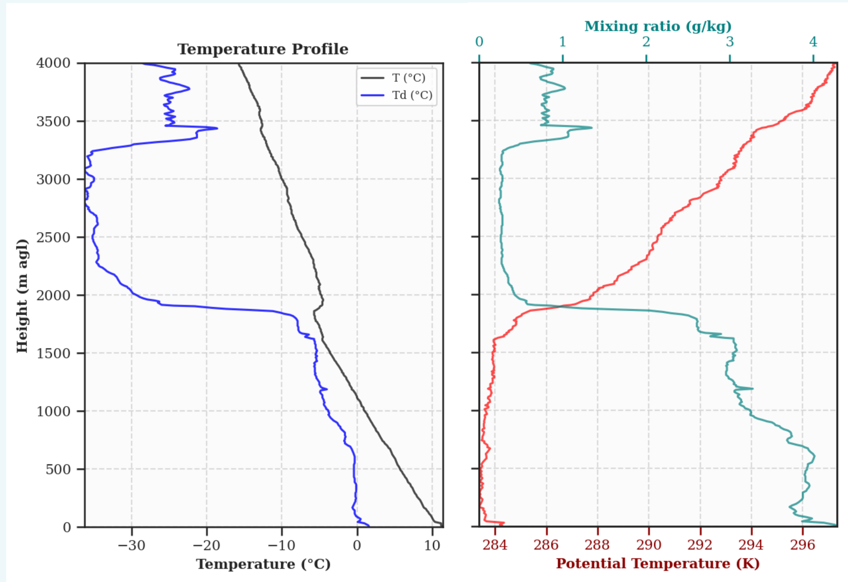
METHODOLOGY

- This study validates EarthCARE/ATLID PBLH retrievals using a **continental-scale reference dataset** derived from **radiosonde observations at 71 stations across Europe (July 2024–October 2025)**, retrieved from the University of Wyoming radiosonde archive.
- A total of **128 cases** where **satellite overpasses** occurred **within a 20 km radius** and a **± 2-hour window** of **12 UTC** radiosonde launches **under convective** or **neutral stability** regimes were identified.



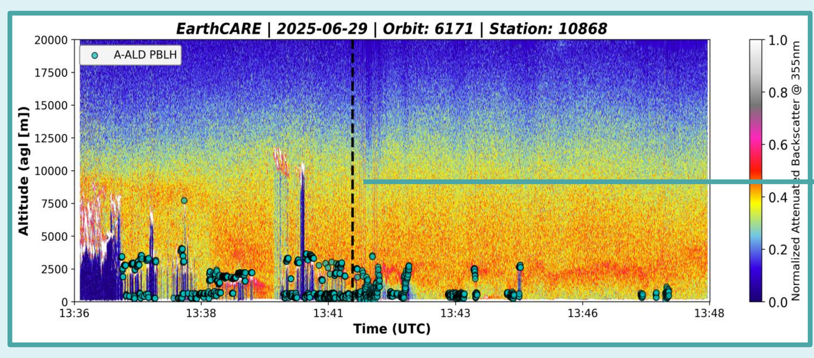


- **Reference PBLH** was **determined** from **radiosonde measurements** using **five diagnostic methods**: bulk Richardson number, parcel method, and the gradients of potential temperature, specific and absolute humidity.
- **Two ATLID-based approaches** were evaluated: the operational **ATLID Aerosol Layer Descriptor (A-ALD)** and **attenuated backscatter profiles from the A-EBD product**, both using data from **BA baseline**.
- **A-ALD** provides the **PBLH** as an **operational cloud-free product. Nearest track point** to the station was chosen**.**
- **Attenuated backscatter A-EBD profiles** were **cloud screened** with the **A-FM Feature Mask** and processed with a **custom methodology** based on a **variance gradient technique** to retrieve the PBLH.
- PBLH values **below 200 m** and **above 4000 m** have no physical sense and were **discarded**.



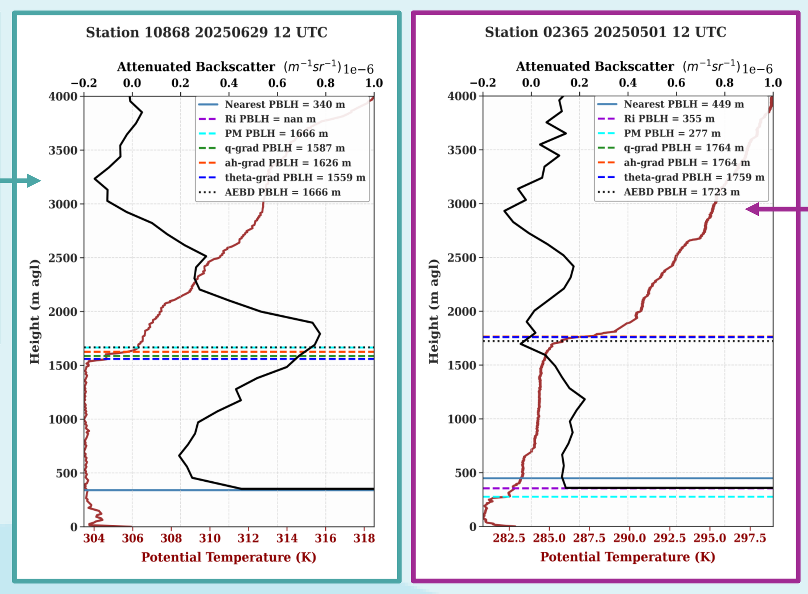
RESULTS

Individual cases:

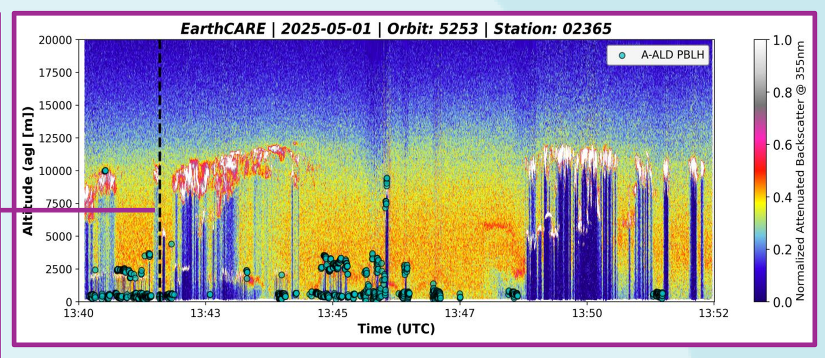


A-EBD Normalized Attenuated Backscatter with A-ALD PBLH estimations

- **Low-SNR** or saturated near-surface backscatter **peaks** are frequently **identified by A-ALD as the PBLH**.
- A-ALD presents problems with clouds.



Radiosonde θ and A-EBD attenuated backscatter profiles



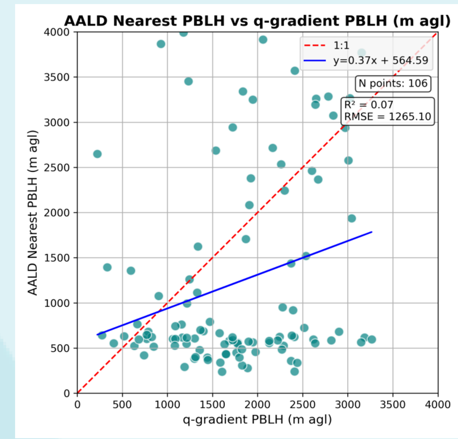
A-EBD Normalized Attenuated Backscatter with A-ALD PBLH estimations

- **Thermodynamic** and **gradient-based** radiosonde **PBLH** show **discrepancies.**
- **Gradient methods** are **consistent** across radiosondes and **ATLID A-EBD.**

A-ALD RESULTS

General behavior:

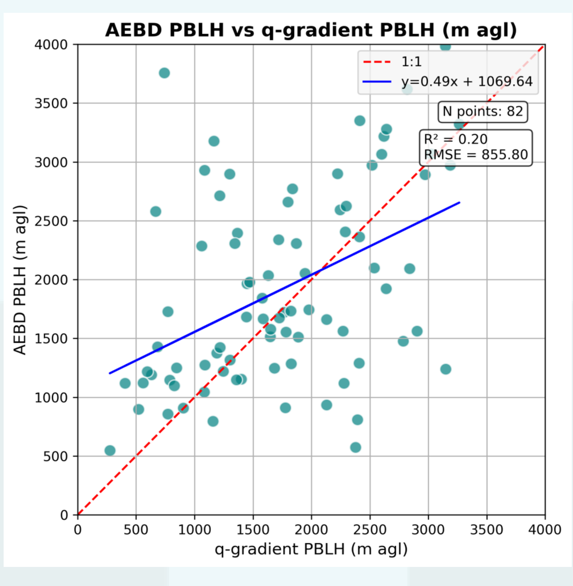
- **A-ALD product underestimates PBLH** and seems **unable to resolve vertical structures.**



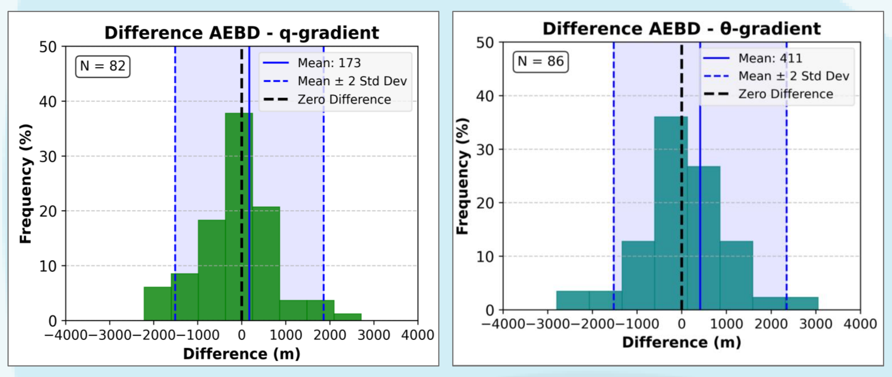
A-ALD vs. q-gradient PBLH comparison

m agl	Mean Bias	MAE	Std. Dev.
Richardson	199	802	1075
Parcel	95	860	1142
q-gradient	-545	1032	1147
ah-gradient	-211	878	1150
θ gradient	-351	1004	1225

A-EBD RESULTS



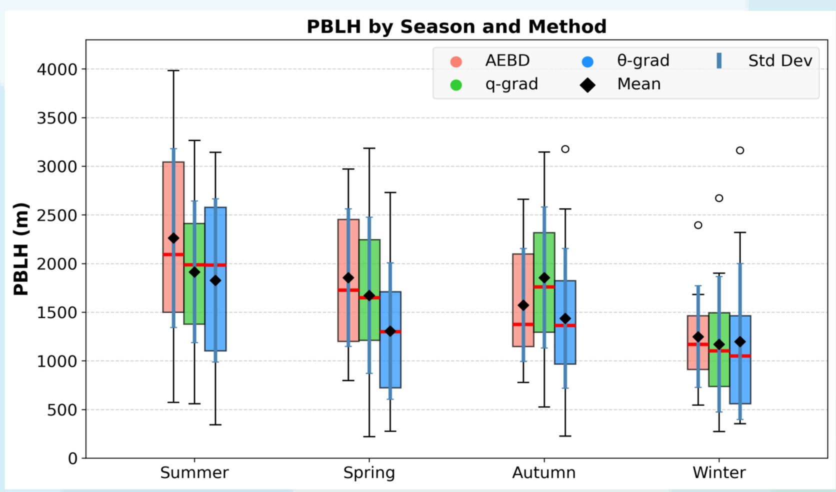
A-EBD vs. q-gradient PBLH comparison



Differences between A-EBD and q- and θ-gradient methods

	Mean Bias	MAE	Std. Dev.
Richardson	1092	1166	1061
Parcel	718	864	880
q-gradient	172	630	843
ah-gradient	557	763	801
θ gradient	441	774	997

- **A-EBD custom** approach represents an **improved PBLH estimation** when **compared with the A-ALD product.**



A-EBD and Radiosondes PBLH seasonal boxplots

- **A-EBD PBLH aligns** with radiosonde **q-gradient** and **θ–gradient PBLH estimations.**
- **A-EBD resolves natural PBHL seasonal variability**, with better agreement in winter.
- **Satelite A-EBD and Radiosonde PBLH show similar STD**, reinforcing physical consistency.

m agl	Summer		Spring		Autumn		Winter	
	Mean PBLH	Std. Dev.	Mean PBLH	Std. Dev.	Mean PBLH	Std. Dev.	Mean PBLH	Std. Dev.
AEBD	2261	920	1854	708	1573	581	1249	523
q-gradient	1913	728	1672	803	1855	725	1169	695
θ gradient	1826	839	1305	702	1436	718	1197	801

CONCLUDING REMARKS

- The comparative analysis reveals **distinct performance** metrics between the two satellite-derived approaches, showing **improvements** when using **the custom A-EBD approach**.
- **Custom A-EBD** retrievals show **physical consistency** with radiosonde-derived heights, whereas **A-ALD** generally **underestimates** the **PBLH**.
- Statistics indicates that **gradient-based radiosonde** methods **align** better with **ATLID retrievals** than thermodynamic approaches.
- Notably, the validation results exhibit a significant **dependence** on the **radiosonde-derived** PBLH **retrieval method**, highlighting the **challenges** of using radiosonde data as a benchmark.

REFERENCES

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2. Wehr, T., Kubota, T., Tzeremes, G., Wallace, K., Nakatsuka, H., Ohno, Y., Koopman, R., Rusli, S., Kikuchi, M., Eisinger, M., Tanaka, T., Taga, M., Deghaye, P., Tomita, E., and Bernaerts, D.: The EarthCARE mission – science and system overview, Atmos. Meas. Tech., 16, 3581–3608, 2023

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