Towards Operational Monitoring of Tropospheric Water Vapour with the Dual-Field Raman Lidar ALHAMBRA

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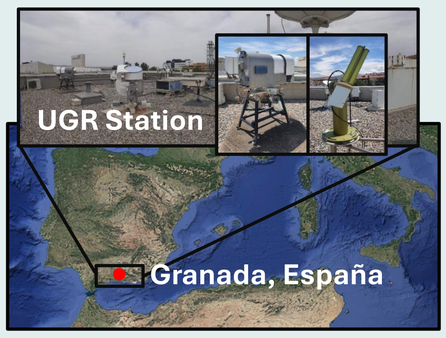
MOTIVATION

- Accurate **height-resolved water vapour measurements** are essential for understanding atmospheric thermodynamics, cloud formation and radiative processes.
- Raman lidar technique enables **high vertical and temporal resolution** water vapour profiling.
- The Dual-Field **Raman lidar ALHAMBRA** can retrieve nighttime water vapour profiles with two independent lidar subsystems.

EXPERIMENTAL SITE

- The **UGR Urban Station** is part of the **A**ndalusian **G**lobal **O**bse**R**vatory of the **A**tmosphere (**AGORA**)

37.16º N,3.61º W, 680 m asl



SYSTEM DESCRIPTION

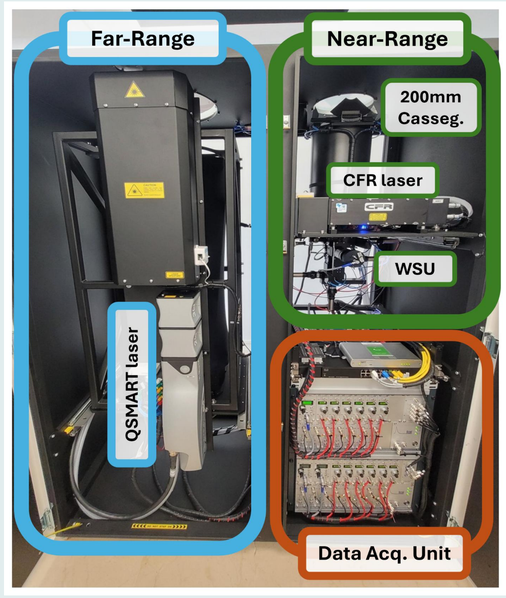
- **ALHAMBRA is a dual multiwavelength Raman lidar system with elastic, Raman, polarization and fluorescence capabilities, operating within EARLINET network and the ACTRIS research infrastructure.**

Far-Range

Component	Details
Laser	QUANTEL 10 Hz 6.3 ns 229 mJ (355 nm)
Telescope	400 mm Cassegrain
WV config.	408 nm H_2O VRR + 354 N_2-O_2 RR
FOV	1.125 mrad

Near-Range

Component	Details
Laser	QUANTEL 20 Hz 6.1 ns 86 mJ (355 nm)
Telescope	200 mm Cassegrain
WV config.	408 nm H_2O VRR + 387 N_2 VRR
FOV	2.5 mrad

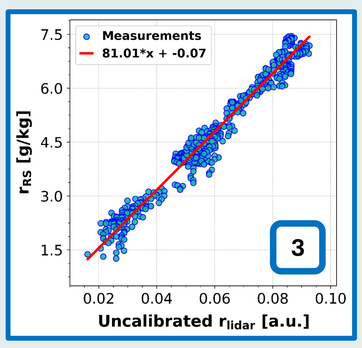


ALHAMBRA Raman Lidar system (Far-Range, Near-Range and Data Acq.).

METHODOLOGY

$$r(z) = \frac{P_{\lambda_{H_2O}}(z)}{P_{\lambda_{MR}}(z)} \cdot \frac{F_{MR}[T(z)]}{F_{H_2O}[T(z)]} \cdot K \cdot \frac{\mathcal{T}_{\lambda_{\mathcal{MR}}}}{\mathcal{T}_{\lambda_{\mathcal{H}_2O}}}$$

1. ***r(z)*** is obtained from the ratio of Raman backscatter signals from water vapour (408 nm H_2O VRR) and a molecular reference (354 nm N2-O2 RR / or 387 nm N2 VRR)
2. **Temperature-dependent variations** in the Raman cross-section **are** mitigated using 0.8 – 1.1 nm FWHM filters (Whiteman, 2003).



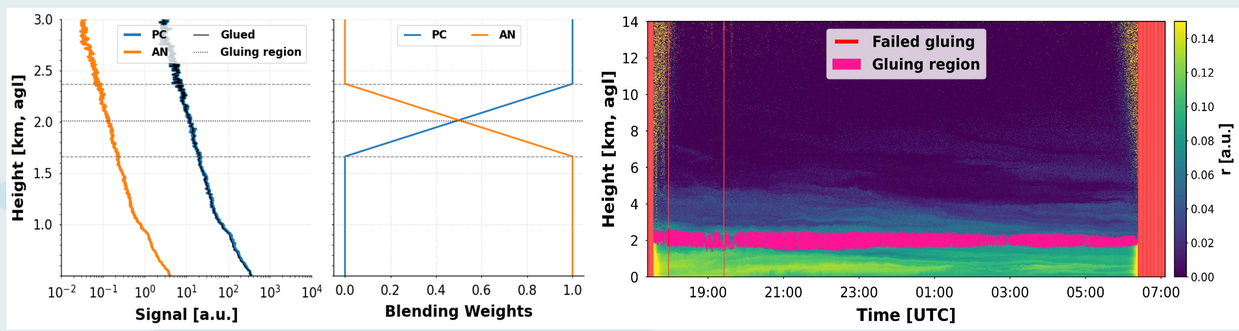
Radiosonde calibration.

3. The **calibration constant K** is obtained from radiosonde comparison using a modified iterative regression approach based on **Navas-Guzman et al. (2014). K** is computed from the **ratio** of the selected samples, avoiding linearity assumptions.
4. **Differential atmospheric transmission** can introduce systematic uncertainties of 5-15 % in ***r(z)***. The operational and automatic methodology proposed by **Díaz-Zurita et al. (2025)** is applied to account for this effect.

$$\alpha_{aer}(z,\lambda) = \frac{AOD(\lambda) \cdot e^{\left(-\frac{z}{H_{ABL}}\right)}}{\int_0^z e^{\left(-\frac{z'}{H_{ABL}}\right)} dz'}$$

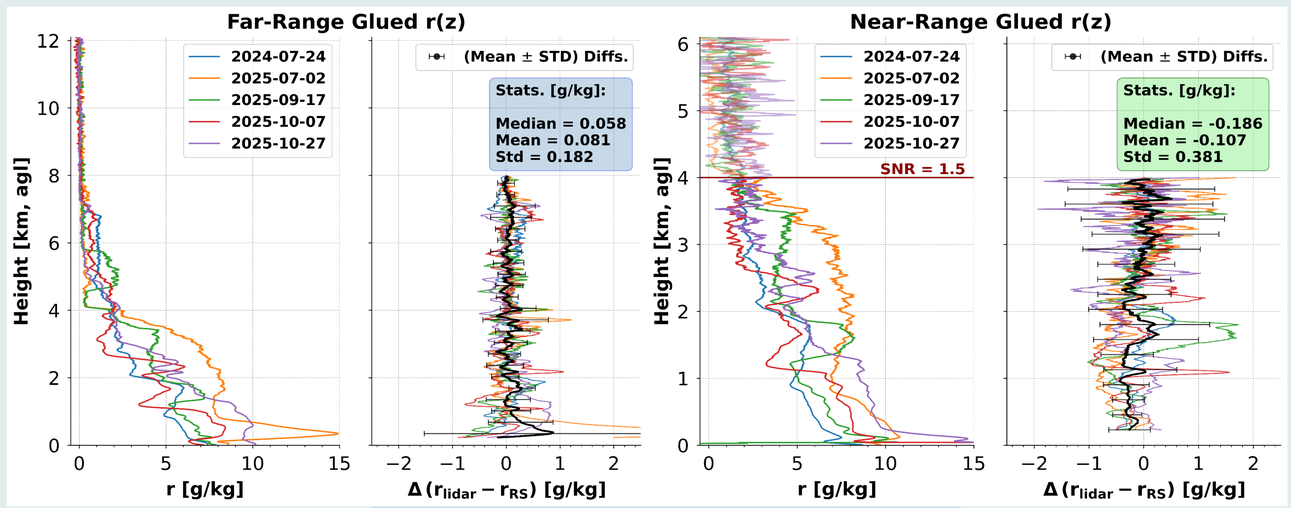
Signal Gluing

- **1-min** temporal and **3.75 m** raw vertical resolution analog (AN) and photoncounting (PC) signals are **glued** applying the **Single Calculus Chain (SCC) gluing algorithm** (D'Amico et al., 2016) locally. Linear blending of the weights within the gluing zone is applied to ensure smoother transitions between the signals.



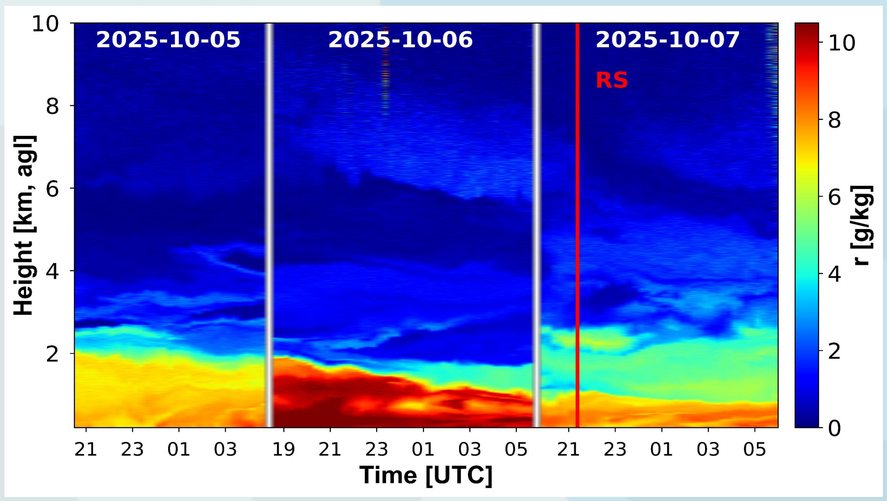
Gluing algorithm diagnostics: gluing weights linear blending (left) and gluing zone + failed profiles (right)

RESULTS



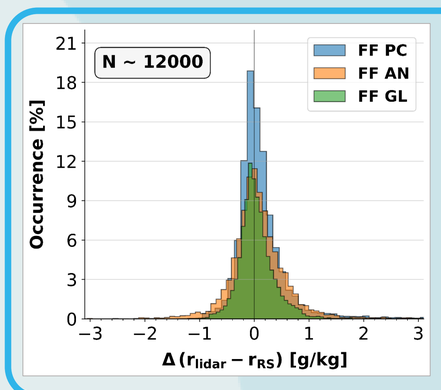
Validation of r(z) retrievals from the Far-Range (left) and Near-Range (right) lidar subsystems using RS measurements

- **Far-Range** mean bias is **0.08 ± 0.18 g/kg** between **0.2** and **8.0 km.**
- **Near-Range** mean bias is **-0.19 ± 0.38 g/kg** between **0.2** and **4.0 km.**
- Reducing the averaging time from 30 to 15 min increases the mean bias by **0.02 g/kg** and the STD by **0.1g/kg**



Three consecutive nights of Far-Range glued, 15-min averaged r(z)

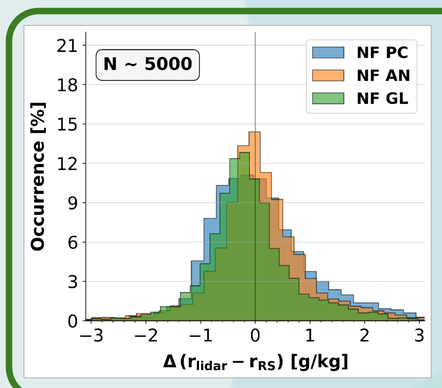
Far-Range



[g/kg]	FF PC	FF AN	FF GL
Median	0.03	0.03	0.01
Mean	0.19	0.09	0.07
STD	0.75	0.62	0.45

- The glued profiles show an overall **improvement** and a **significant reduction of the STD** of the differences.

Near-Range



[g/kg]	NF PC	NF AN	NF GL
Median	-0.02	0.03	-0.19
Mean	0.12	0.1	-0.11
STD	1.10	1.00	0.92

- **Lower SNR** hinders gluing procedure and scaling of AN and PC signal
- Glued signal presents **reduced STD** but greater underestimation

FUTURE STEPS

- Test different **temporal and vertical resolution combinations** to optimise retrieval performance.
- Consider multi-instrument **synergies** for **atmospheric thermodynamic profiling**
- Explore **machine learning approaches** for lidar calibration

CONCLUDING REMARKS

- The dual-Raman lidar ALHAMBRA accurately captures the vertical water vapour mixing ratio structure with both Far-Field and Near-Field subsystems
- Reliable **r(z)** retrievals achieved at **15-min temporal** and **3.75-m vertical resolution.**
- The **Far-Range** subsystem extends **vertical coverage up to 12 km** owing to its larger telescope and higher laser pulse energy.
- High signal quality **enables SCC gluing,** reducing the overlap height to approximately 200 m and mitigating photon-counting signal non-linearity

Save it!

REFERENCES

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ACKNOWLEDGEMENTS

V.M.N.H and S.F.C received funding from the Spanish Ministry of Science, Innovation and Universities, grant **FPU 23/01327** and grant PRE2021-098351, respectively (co-funded by the European Social Fund Plus). This work was supported by Spanish national projects PID2024-162154OB-I00, PID2023-151817OA-I00, CNS2023-145435, and the Horizon Europe program under the Marie Skłodowska-Curie Staff Exchange Actions with the project GRASP-SYNERGY (grant agreement no. 101131631). The work made use of the strategic networks RED2022-134824-E and RED2024-153821-E and infrastructure grants EQC2019-006192-P and EQC2019-006423-P founded by MCIN/AEI /10.13039/501100011033, ATMO-ACCESS grant agreement No 101008004, ACTRIS-IMP grant agreement No 871115, and Scientific Unit of Excellence: Earth System (UCE-PP2017-02). It is also partially funded by the project AEROMOST (ProExcel_00204) by the "Junta de Andalucía". **Part of this work was developed by the COST Action CA24135 (EARLICOST – *https://earlicost.eu*), and supported by COST (European Cooperation in Science and Technology).**