Validation of ESA and JAXA EarthCARE Level-2 CPR and Synergistic Precipitation Products over Coastal Antarctica using K2W-based Ground Radar and Disdrometer Observations

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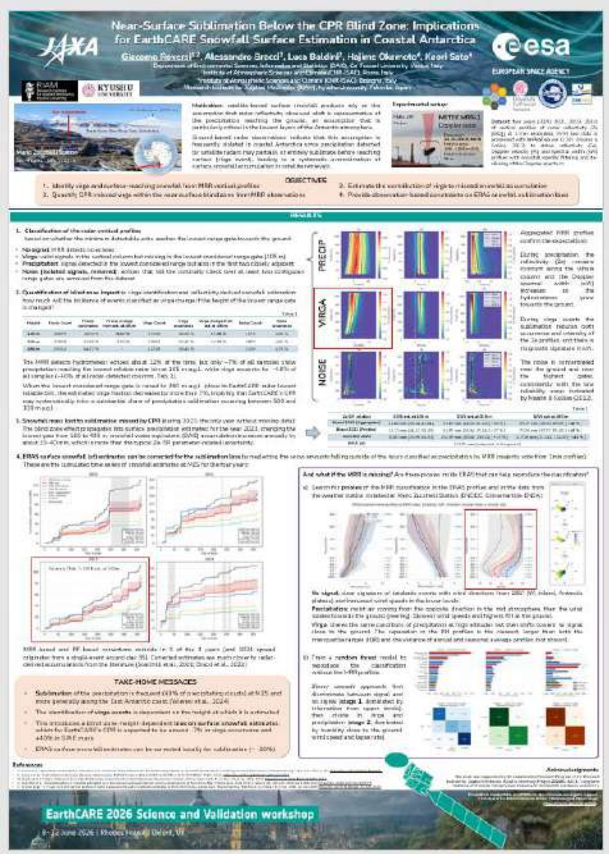
This work was supported by the Collaborative Research Program of the Research Institute for Applied Mechanics, Kyushu University (Project **2024EC-EA-1**: "*Long-term Statistics of Snowfall Microphysical Features for EarthCARE Validation Activities*").

Motivation

- **Precipitation in Antarctica** plays a key role in global water and energy budgets and in modelling the **mass balance of the Antarctic ice sheet**

- CPR surface snowfall retrievals need ground measurements to constrain:
    1. the microphysical variability
    2. the physical processes occurring inside the CPR blind zone (~500 m), such as **sublimation** →

Poster P050 for more!

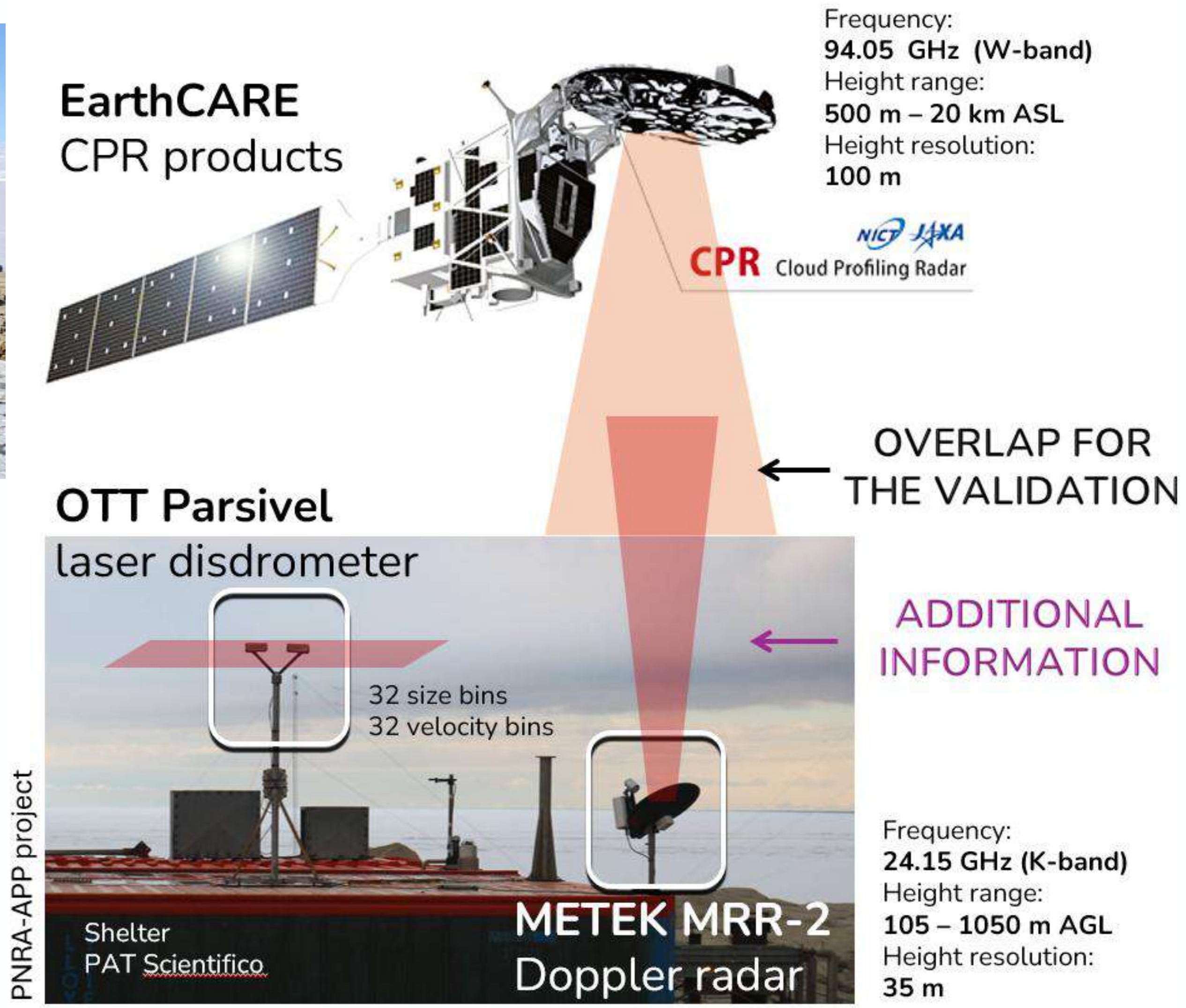


A quick recap: our infrastructure

Mario Zucchelli Station   Lat: -74.694,   Lon: 164.115

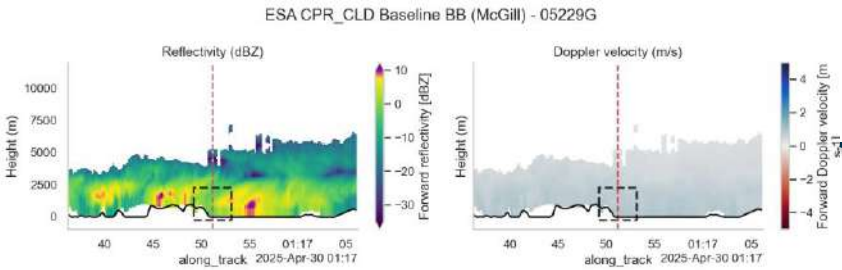
Basic setup available at several Antarctic stations

Our MRR measures from **105 m** to **1050 m** a.g.l.
- In the upper part of the profile, we can validate the retrievals (CPR overlap)
- In the lower part, we can add new information inside the CPR blind zone

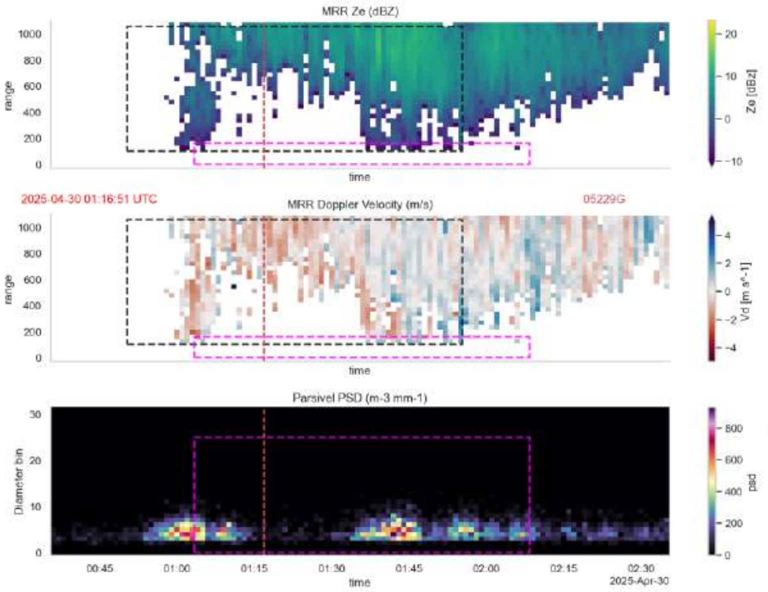


A quick recap: our methodology

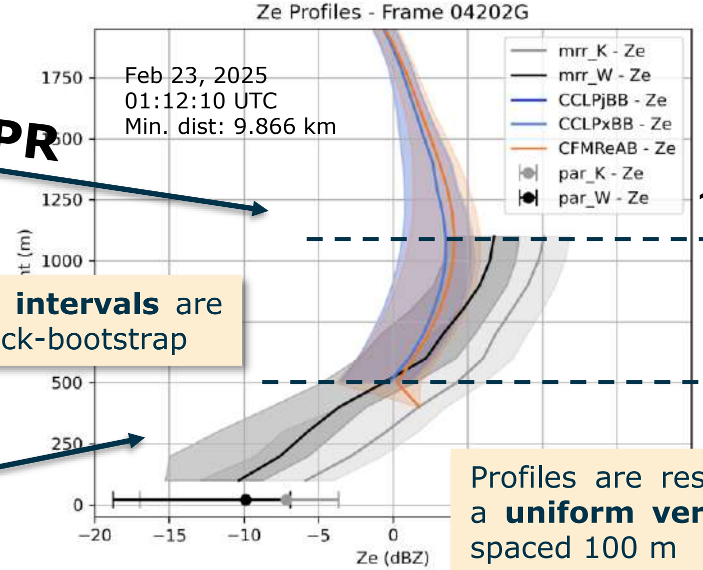
From EarthCARE:



From Mario Zucchelli Station:



Average profiles of CPR equivalent reflectivity factor Ze (dBZ) in the selected windows (30 km)



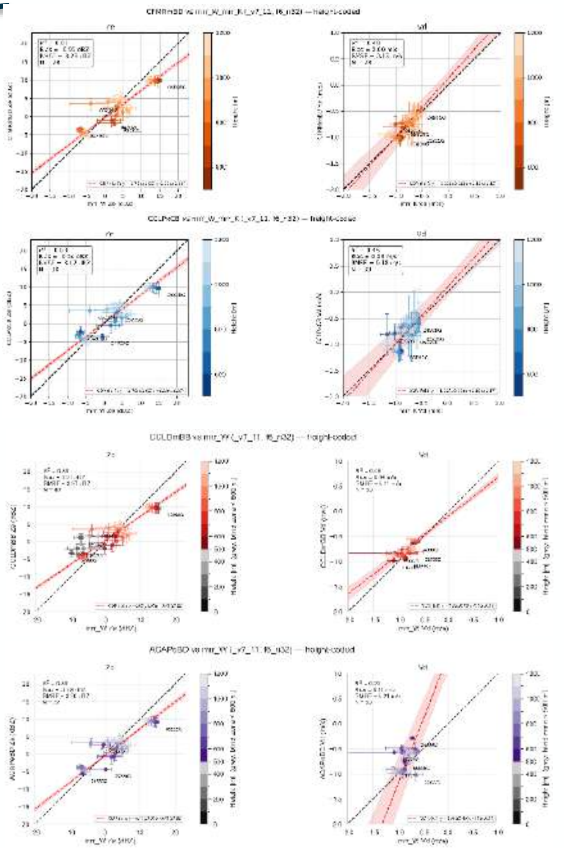
95% confidence intervals are calculated with block-bootstrap

Profiles are resampled on a **uniform vertical grid**, spaced 100 m

$$\text{ZeDISD} = 10^{18} \frac{\lambda^4}{\pi^5 |K|^2} \int_{D_{min}}^{D_{max}} \sigma(D)\, N(D)\, dD$$

K2W

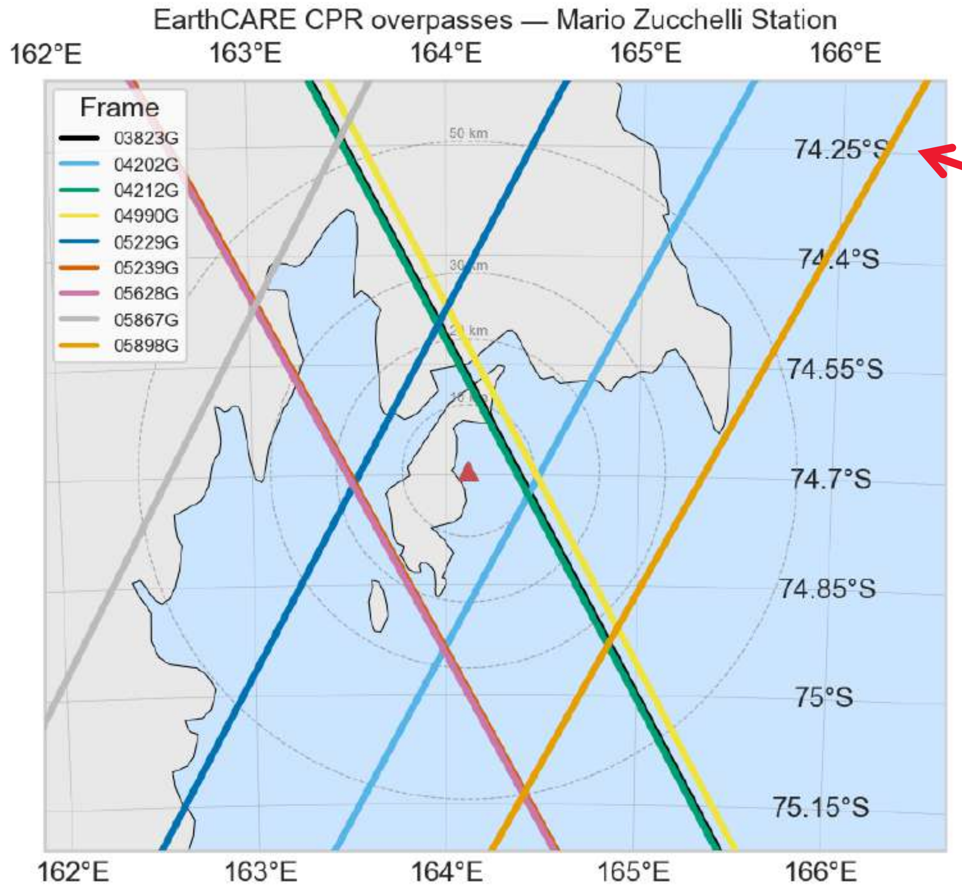
$$\eta_{v,W}(v_s) = \eta_{v,K}(v_s) \frac{C_{bk,W}(v = g(D))}{C_{bk,K}(v = g(D))} \Rightarrow Z_{e,W},\ V_{D,W}$$

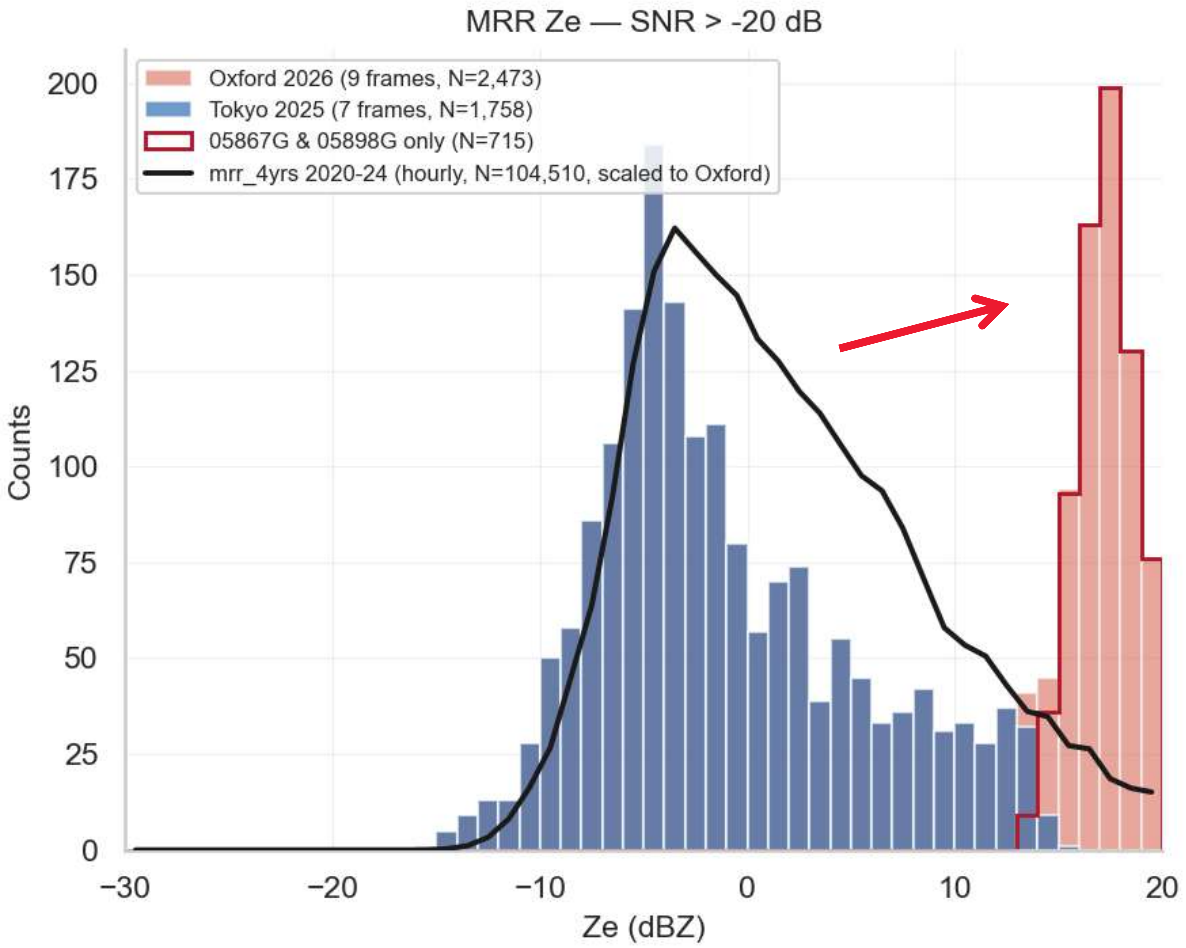


Comparisons of ESA and JAXA products L2A + L2B

A. Bracci, K. Sato, L. Baldini, F. Porcù, H. Okamoto, Development of a methodology for evaluating spaceborne W-band Doppler radar by combined use of Micro Rain Radar and a disdrometer in Antarctica, Remote Sensing of Environment (2023), https://doi.org/10.1016/j.rse.2023.113630

Now a more complete dataset





Relaxing the minimum distance from 20 to 32 km, we added a **new overpass** during statistically extreme conditions

Katabatic instrusion scheme at DDU from Julien et al. (2020)
https://doi.org/10.5194/tc-14-1685-2020

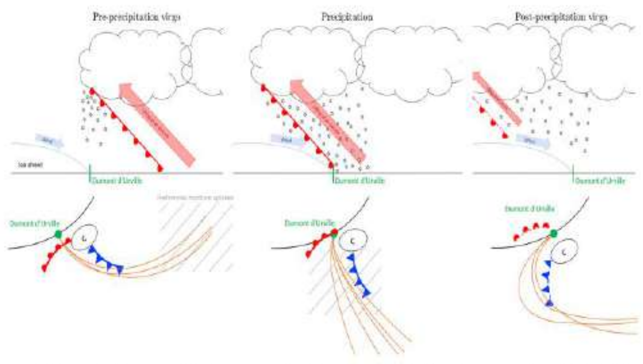
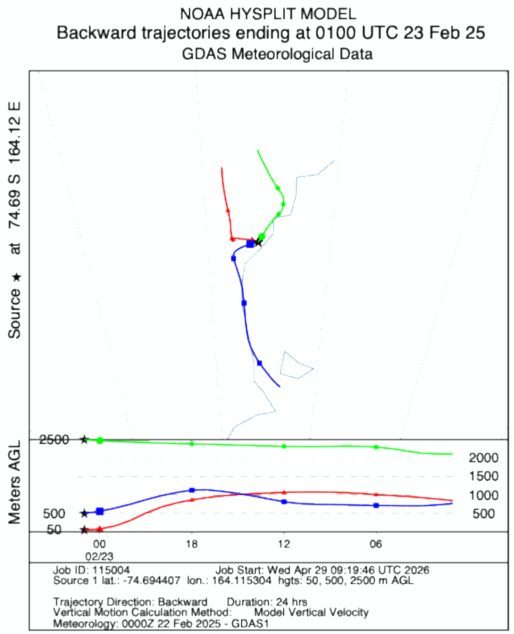
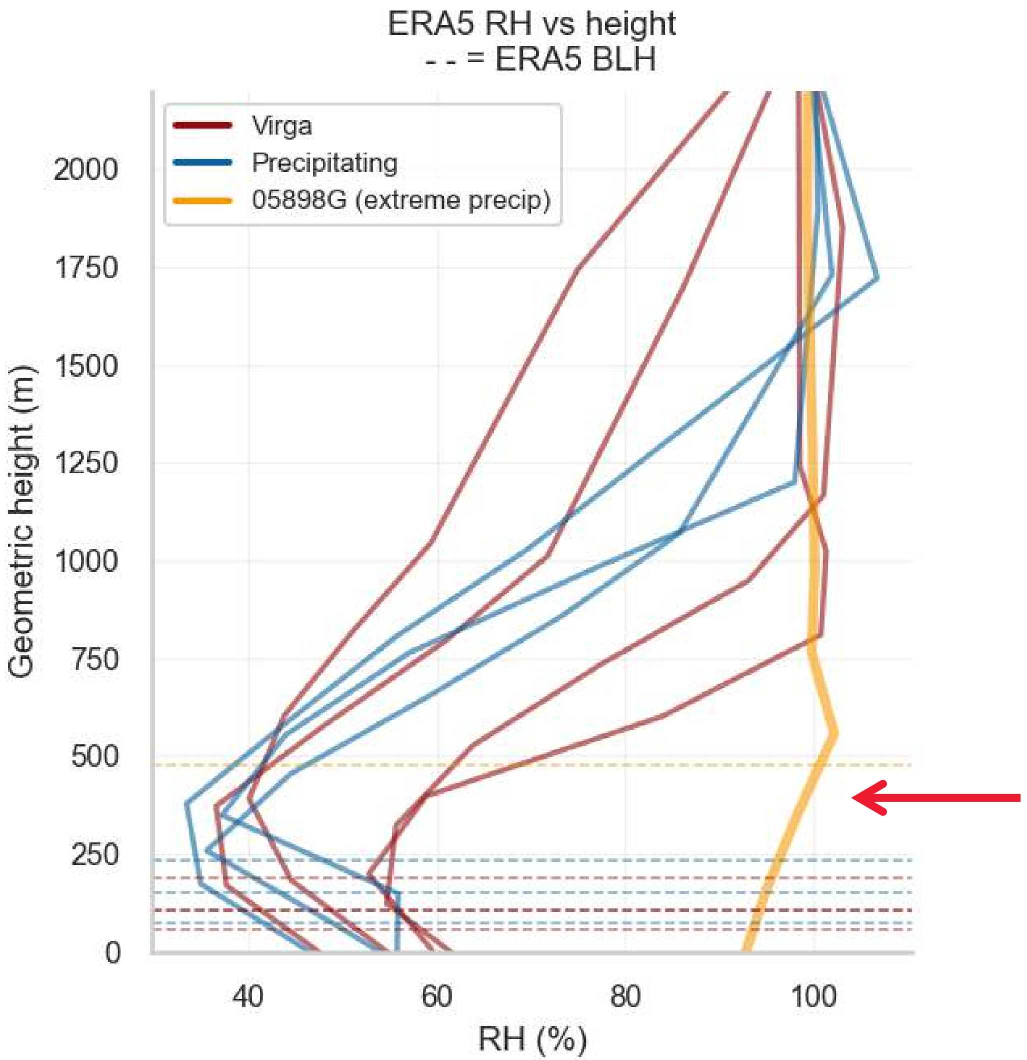


Figure 11. Conceptual scheme summarizing the sequence of the different phases of a typical warm front event and associated precipitation over DDU station. The trajectories in orange arrive in the layer where precipitation forms. In the bottom subplots, the south pole is towards the top left corner direction.





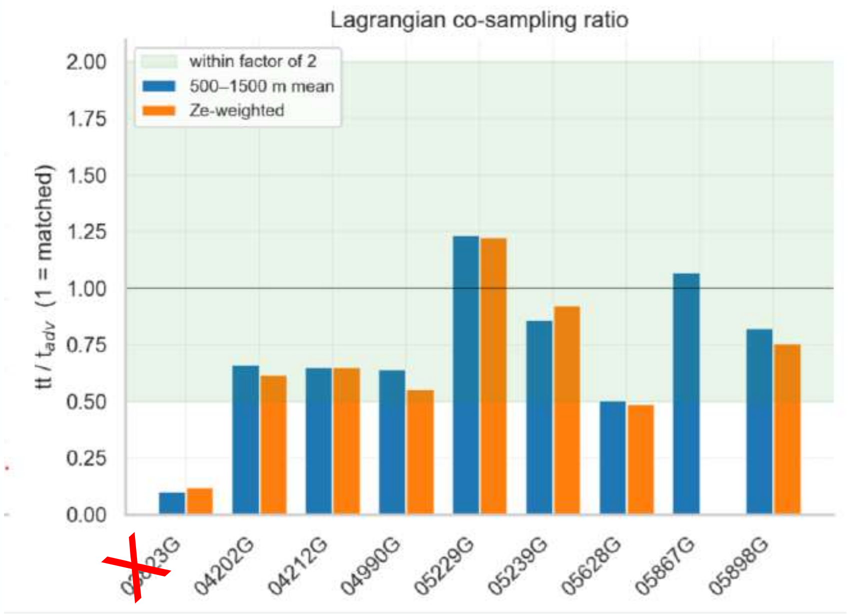
Virga are associated with dry intrusions of katabatic flows, usually before and after the arrive of frontal systems.

All the profiles except the new overpass were affected by complete or incomplete sublimation.

Now a more robust framework

What level of **spatial and temporal representativeness** can we achieve with our instruments?
Numerical data driven optimization (max R^2 and min RMSE) but physically consistent results:

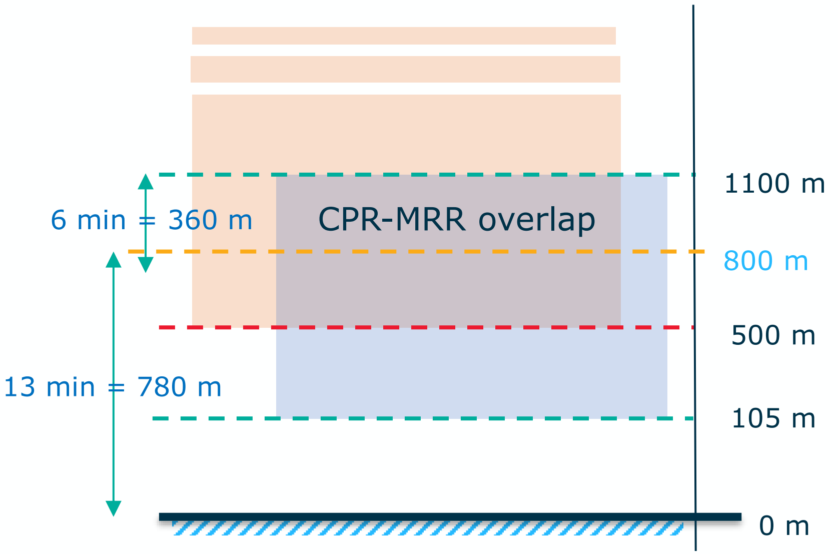
CPR along track window length	Time window length at the ground	Relative vertical delays
3.91 seconds (30 km)	65 minutes	6 min (CPR→MRR) 13 min (MRR→PAR)



Comparison with the horizontal and vertical scales of air motion:

← ERA5 horiz. winds

1m/s vertical speed →

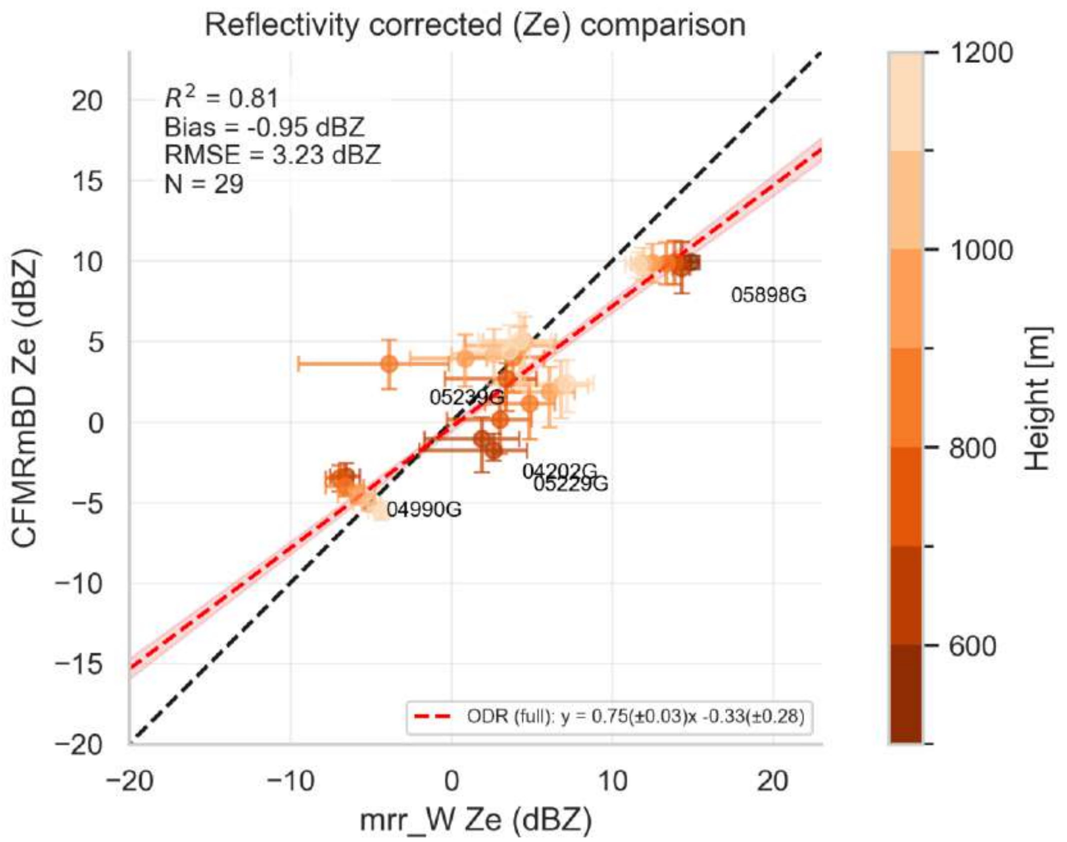


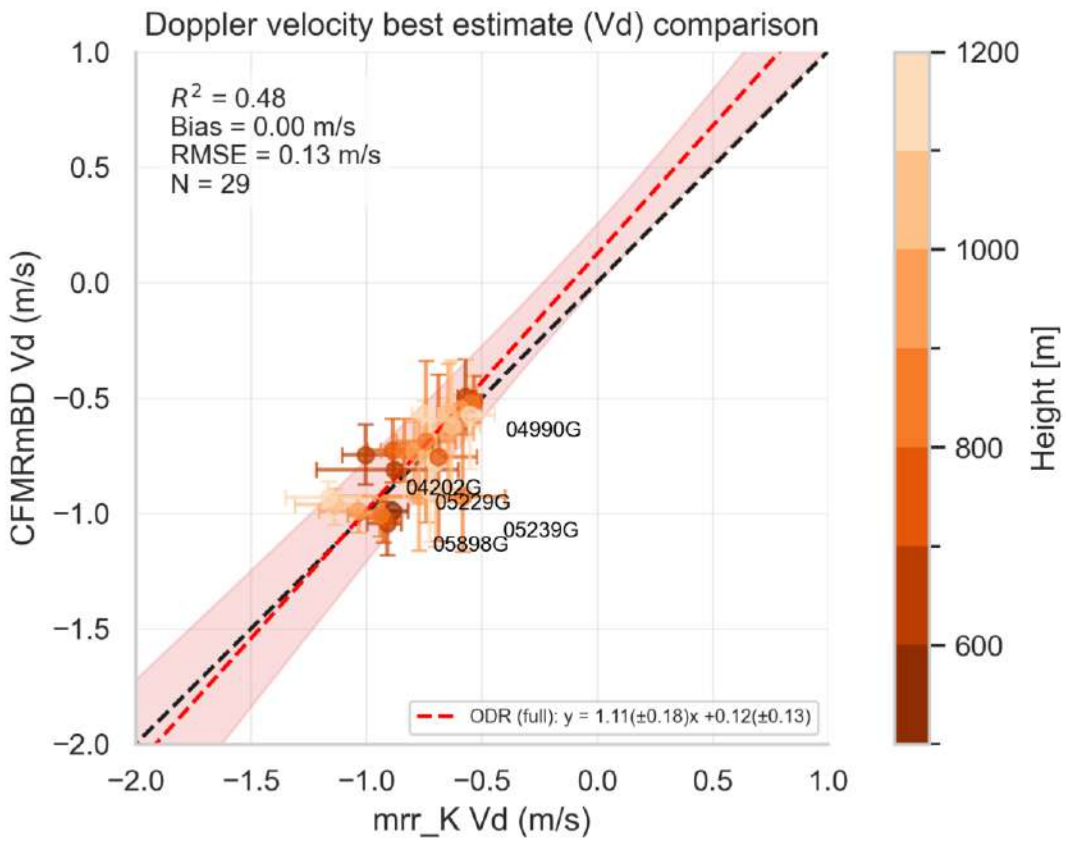
Results

- Ze, Vd in L2A products (measured + corrections)
- Ze, Vd in L2B products (forward model reconstructions)

Level 2A ESA (FMR/CD) baseline BD (McGill)

CFMRmBD vs mrr_W_mrr_K (_v7_11, f6_n32) — height-coded

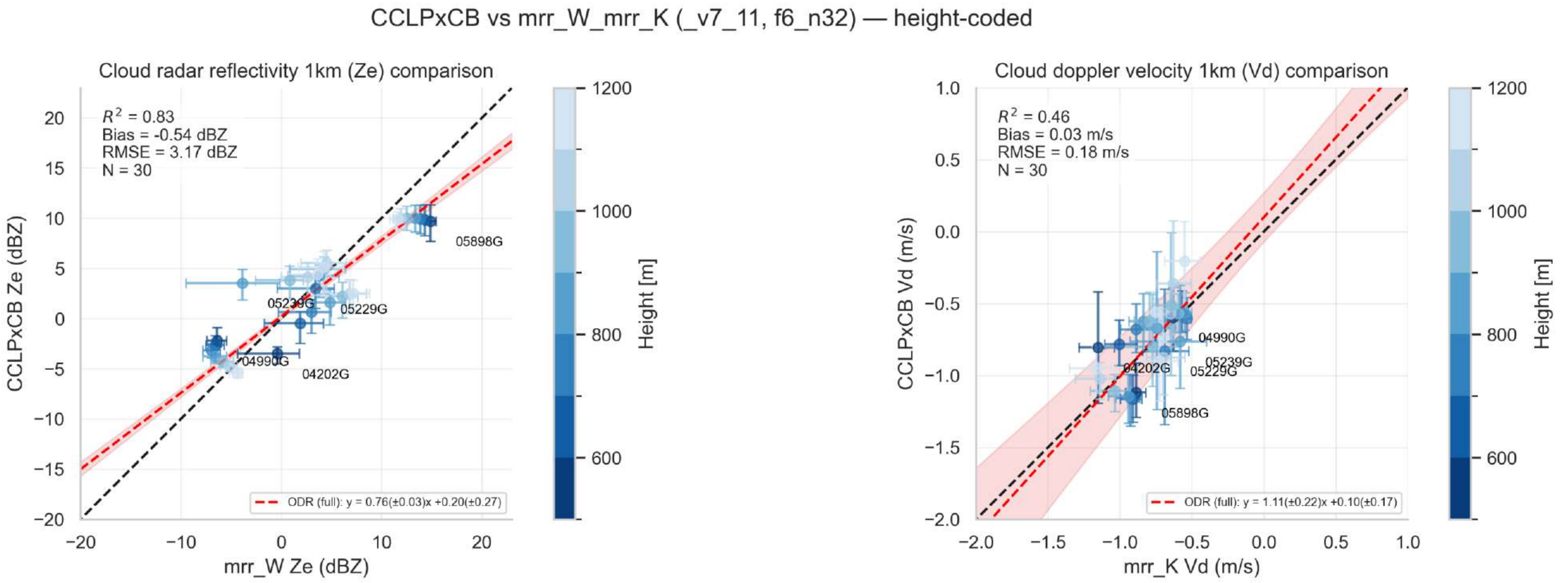




Ze high dynamic range produces **good correlation**, RMSE and bias are inside the expected sensitivities

Vd has lower correlation (due to the lower dynamic), but very good RMSE and **0 m/s bias** ☺

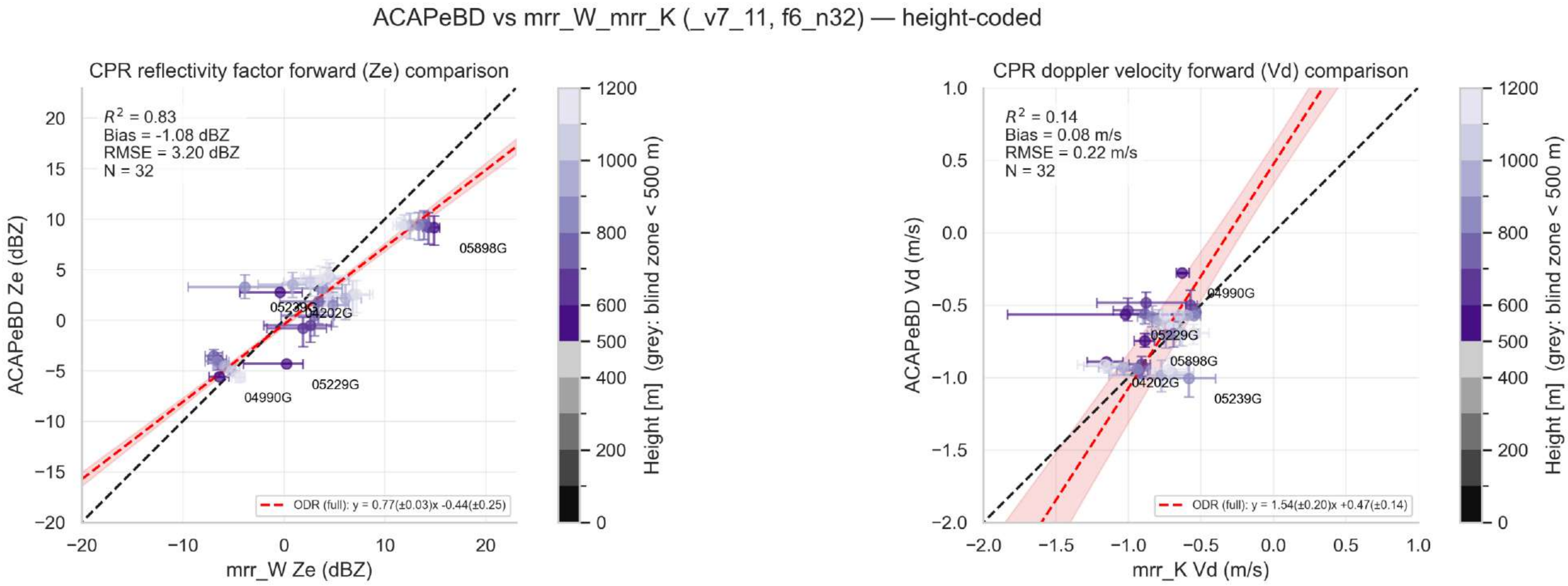
Level 2A JAXA (CLP) baseline CB (RIAM)



Ze: quite similar, slightly better correlation and bias

Vd: same good bias, bigger uncertainty bars due to less averaging (cloud_doppler_velocity_1km)

Level 2B ESA (ACM-CAP) baseline BD (ECMWF)

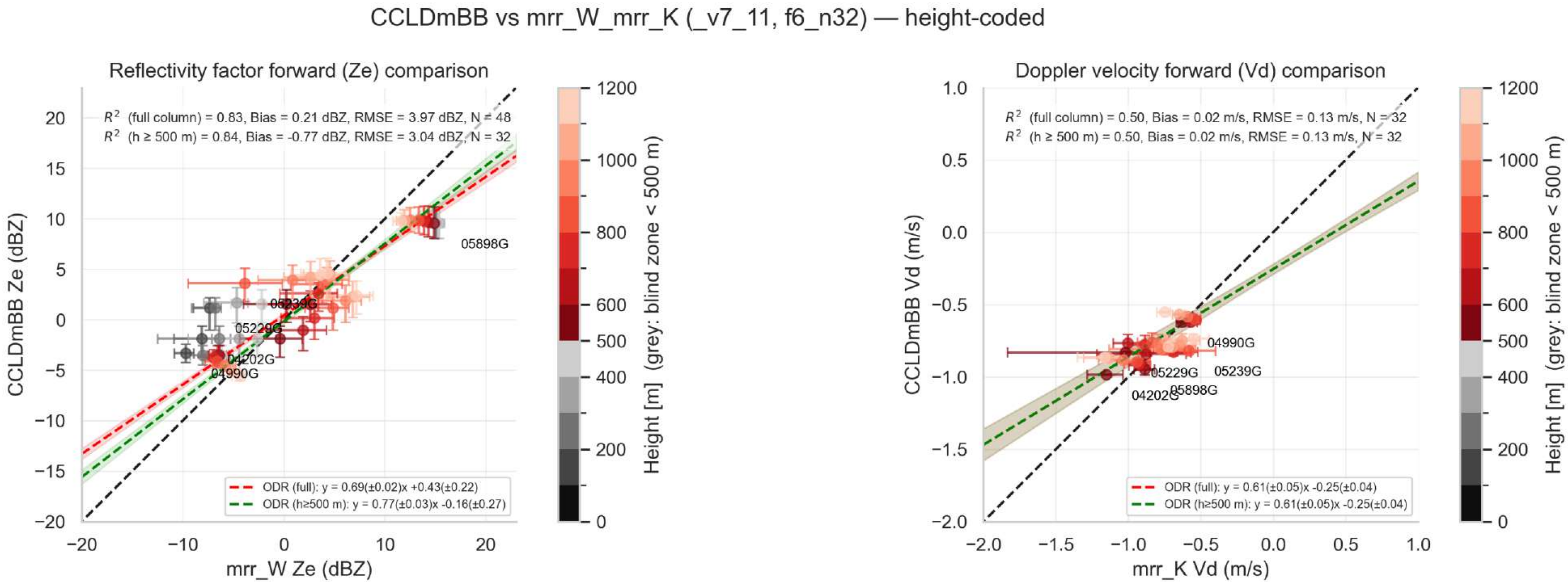


Ze is consistent with FMR

Vd shows slightly more dynamic range than CD and a 1.5 trend

(some new points here, but they carry noisy measurements: can be a masking issue)

Level 2B ESA (CLD) baseline BB (McGill)



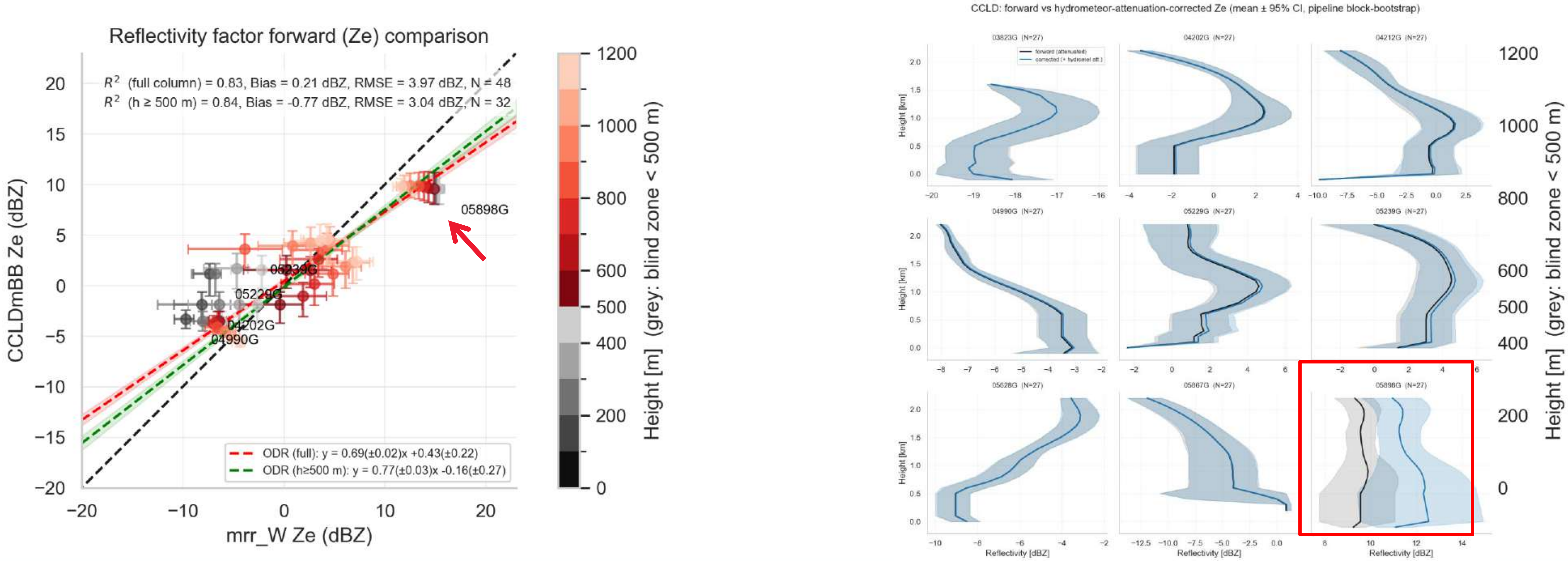
Ze also here is almost like the FMR product

Vd here has less dynamic range than in CD

Discussion 1: two linear fits, with (**red**) and without (**green**) the points inside the **blind zone** of CPR (h < 500 m)

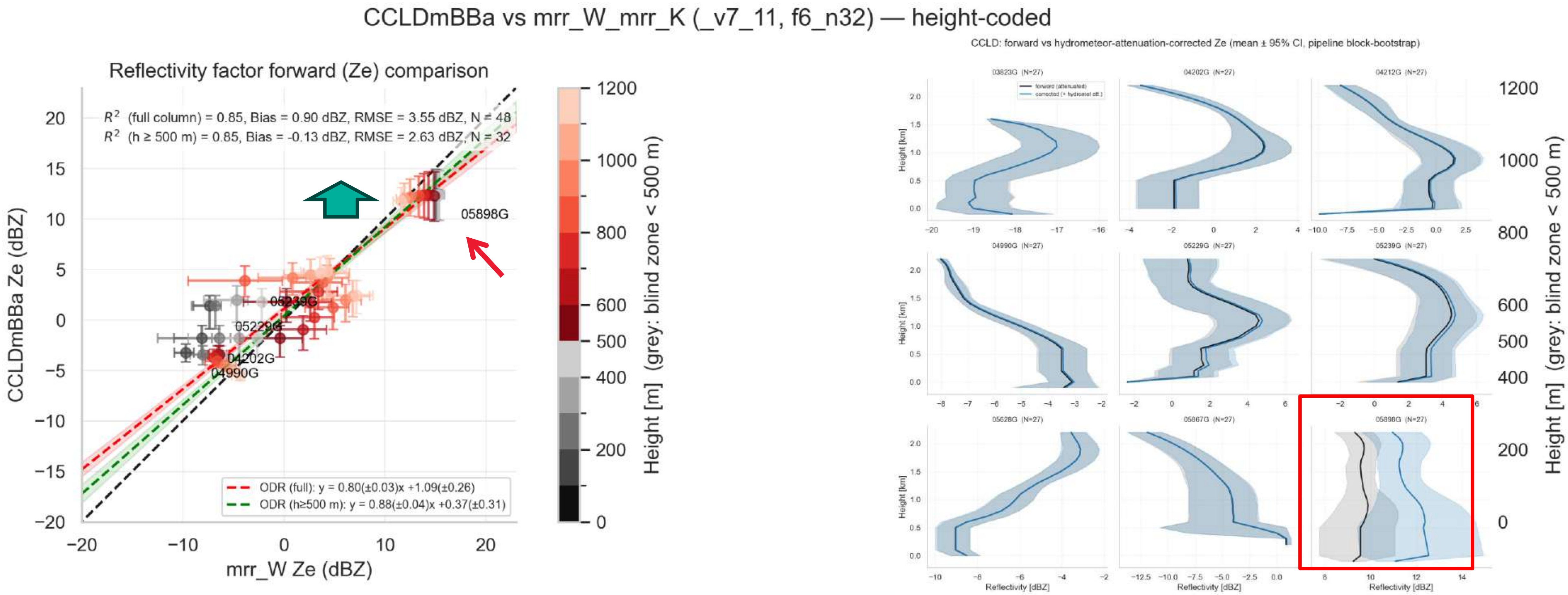
Discussion 2: attenuation

CCLDmBB vs mrr_W_mrr_K (_v7_11, f6_n32) — height-coded



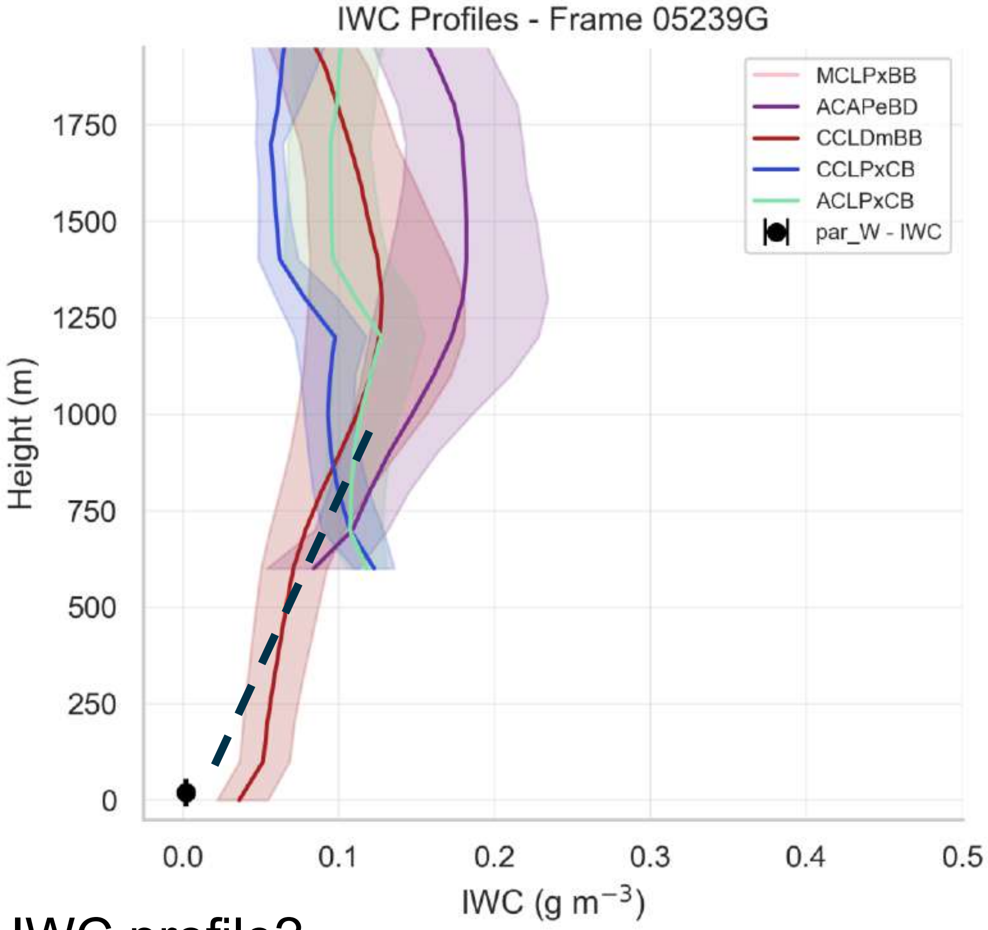
Attenuation is negligible for all frames but the last one.
CCLD estimates around 2.5 dB of attenuation close to the ground

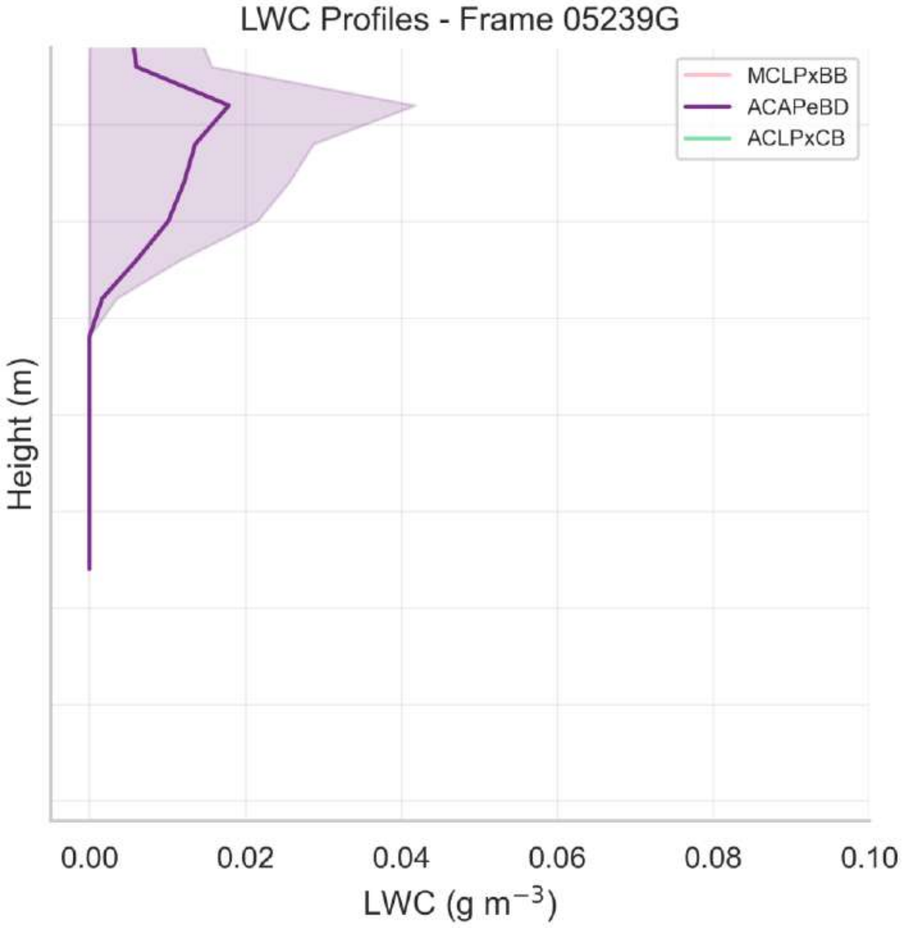
Discussion 2: attenuation



Attenuation correction can account for a substantial part of the bias for the strongest case.

Work in progress: geophysical ground reference





MRR IWC profile?

Conclusions

Take home messages

- Precipitation in coastal Antarctica is important, yet an observational gap remains
- EarthCARE has great potential to close this gap: excellent instruments and continental scale coverage
- Extending the estimates to ground level is not trivial

We now have a framework and pipeline ready to:

- help validate algorithms that extrapolate radar profiles to the ground, e.g. to produce surface snowfall estimates
- extend this validation to other MRR–disdrometer Antarctic sites

Work in progress

We are also working towards providing a reference for geophysical variables such as ice water content and effective radius, both at the ground and along the MRR column. Some further work and testing is needed on our side — more on this in the future!

Thanks for your attention!

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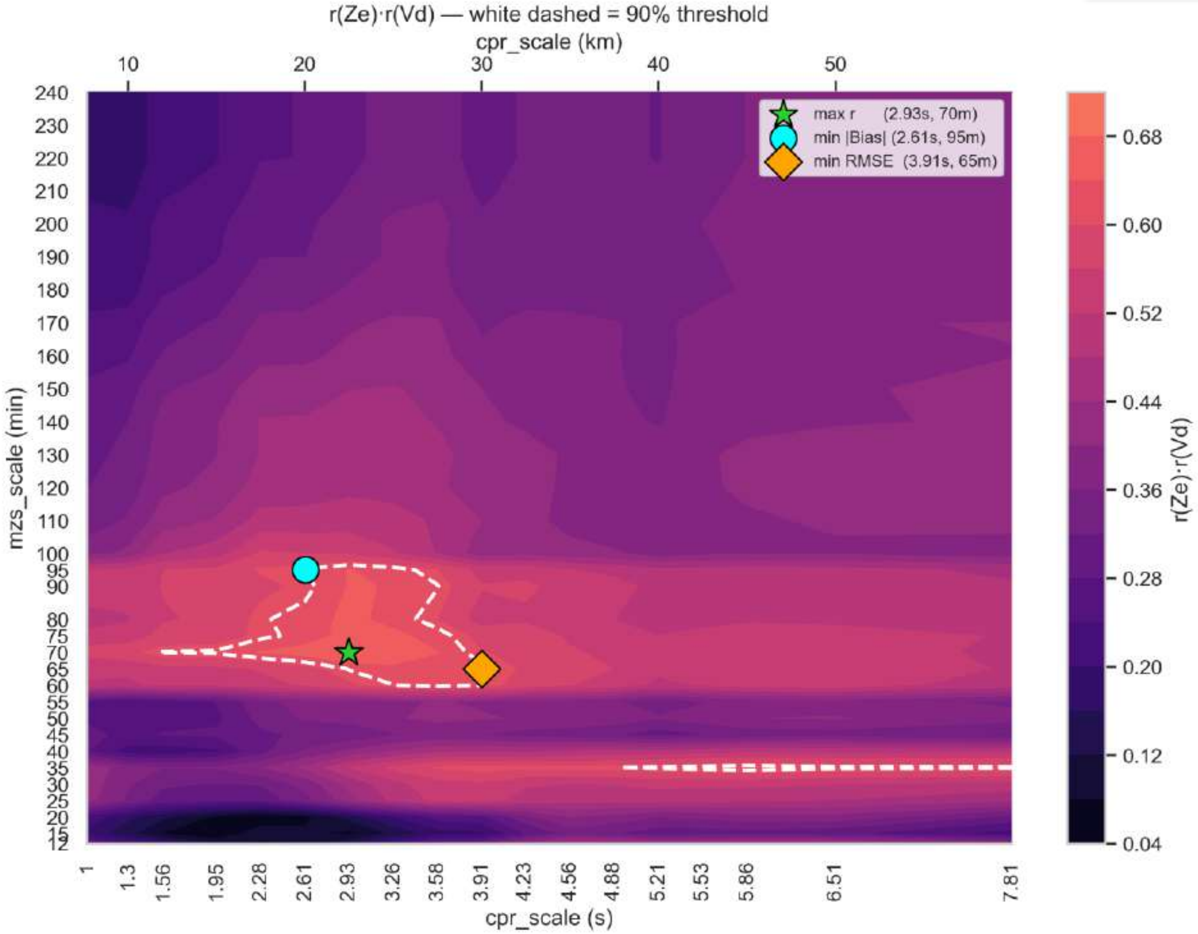
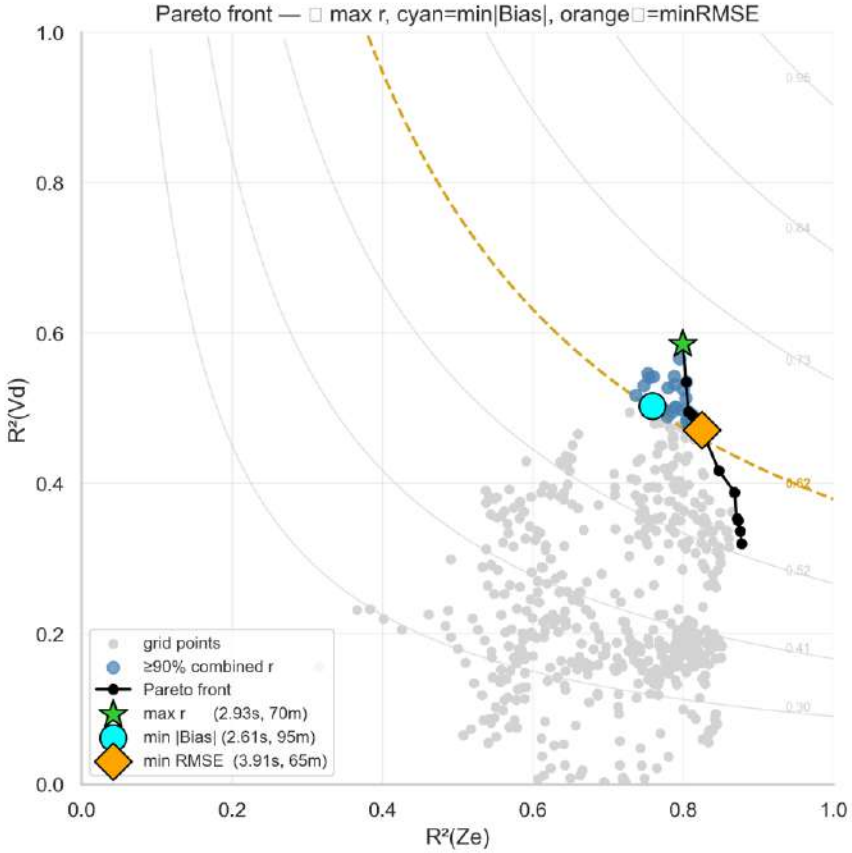
Parameters optimization: selection windows widths

Optimal point selection algorithm: inside the 90% of the maximum combined R2, go to the minimum combined normalized RMSE

(3.91s, 65m)

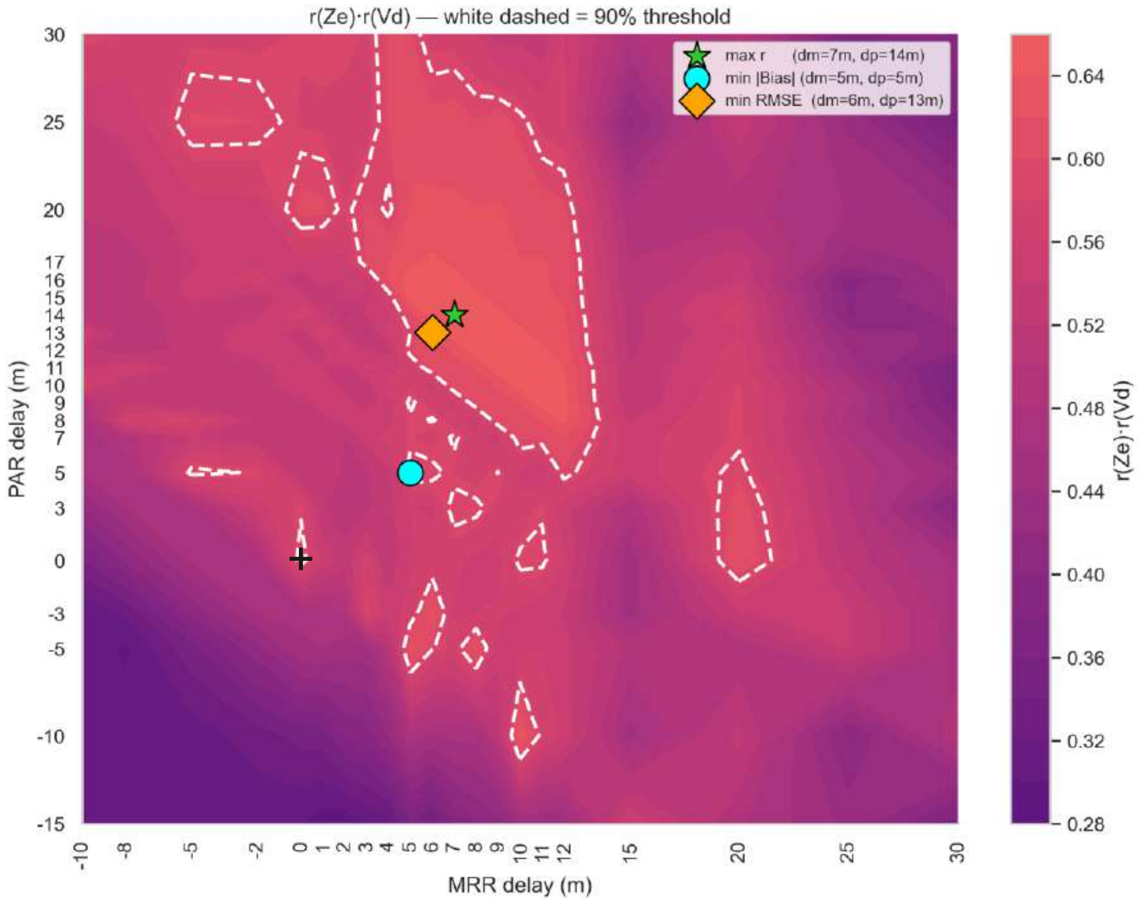


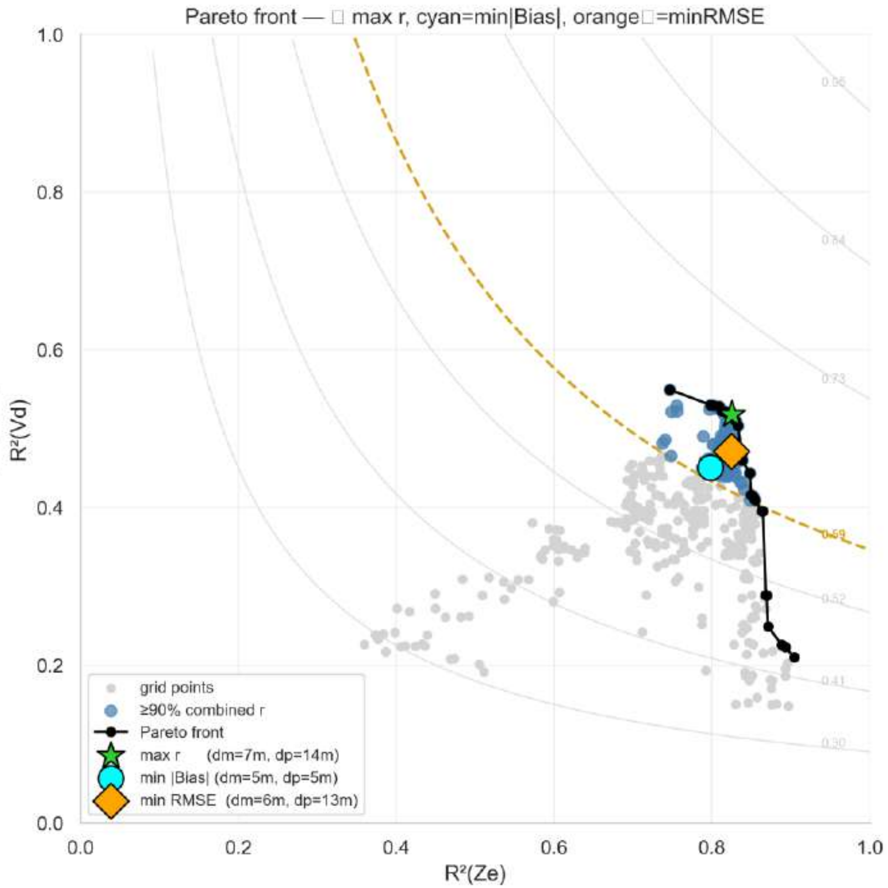


Parameters optimization: delays

Optimal point selection algorithm: inside the 90% of the maximum combined R2, go to the minimum combined normalized RMSE

(6m, 13m)





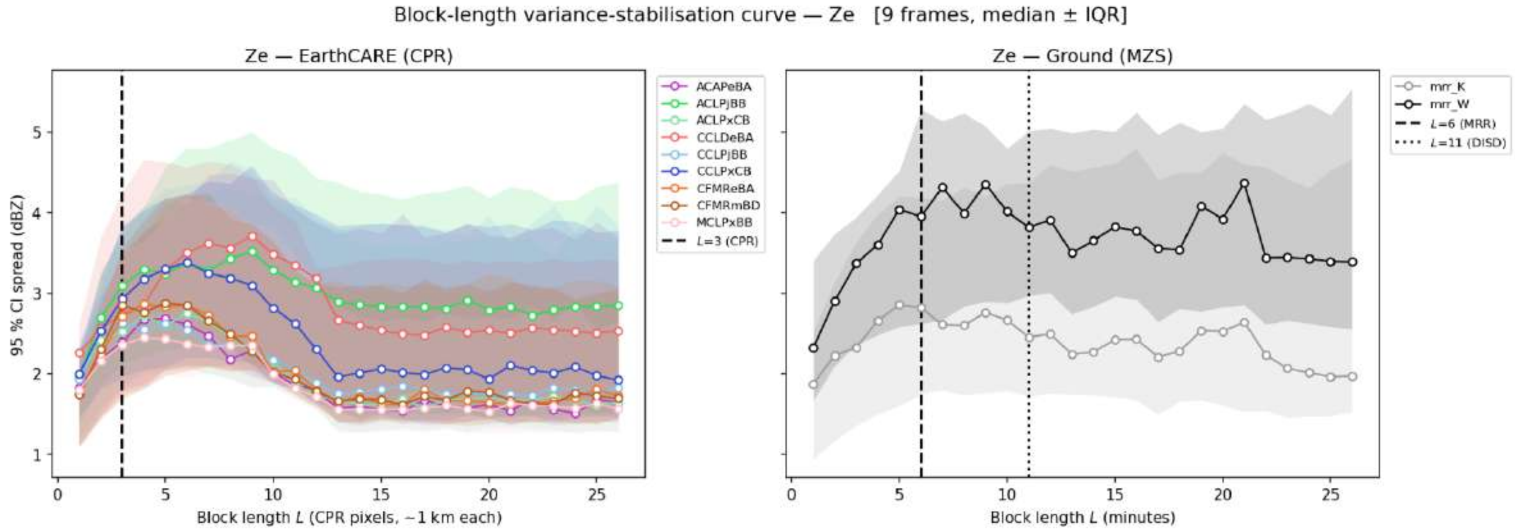
Parameters optimization: block length

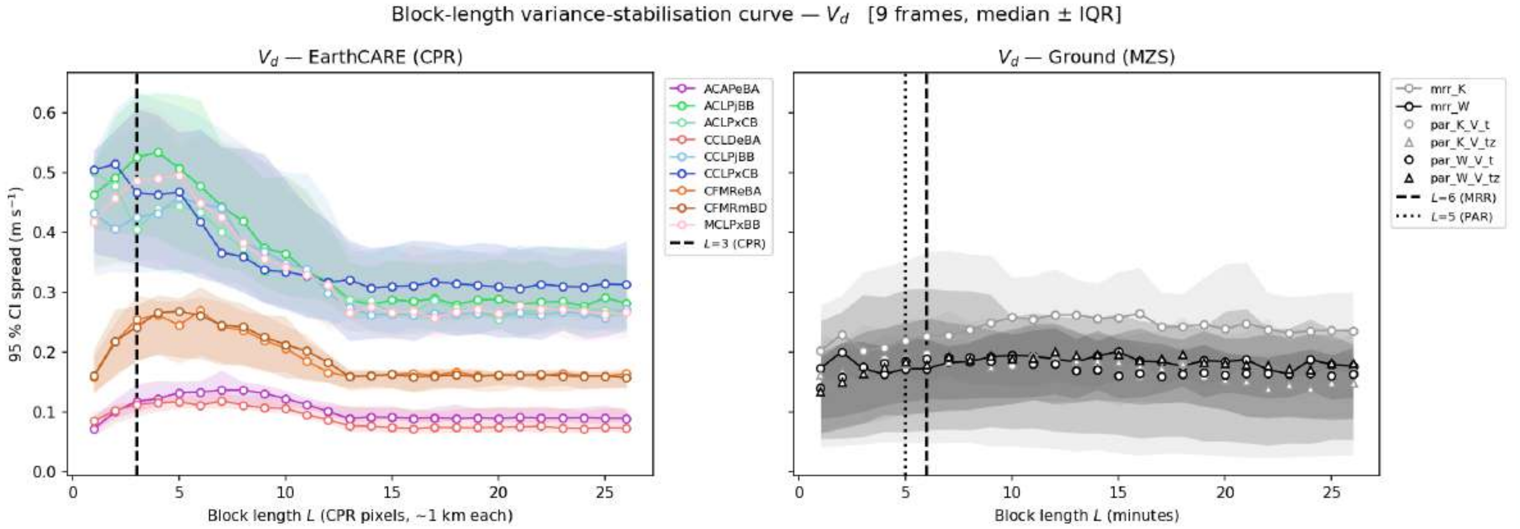
How do we estimate a robust 95% confidence interval (C.I.)?
→ **Bootstrap**

But data is autocorrelated!
→ **Block-bootstrap** to avoid underestimation of the C.I.

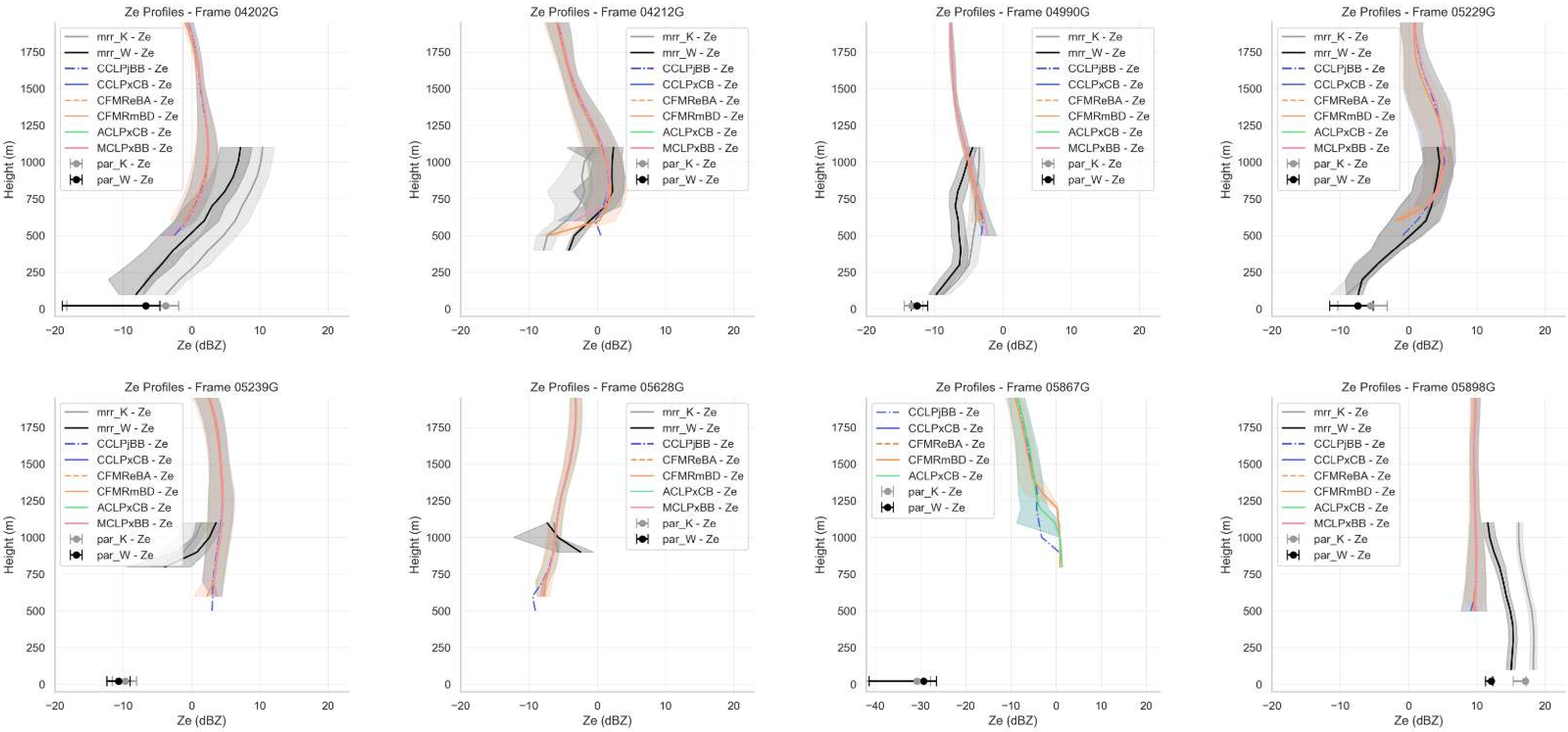
The length of the block (L) should be chosen as greater than the autocorrelation distance but the shortest possible to grant a sufficient number of different blocks.

Shading represents the variability between different overpasses.

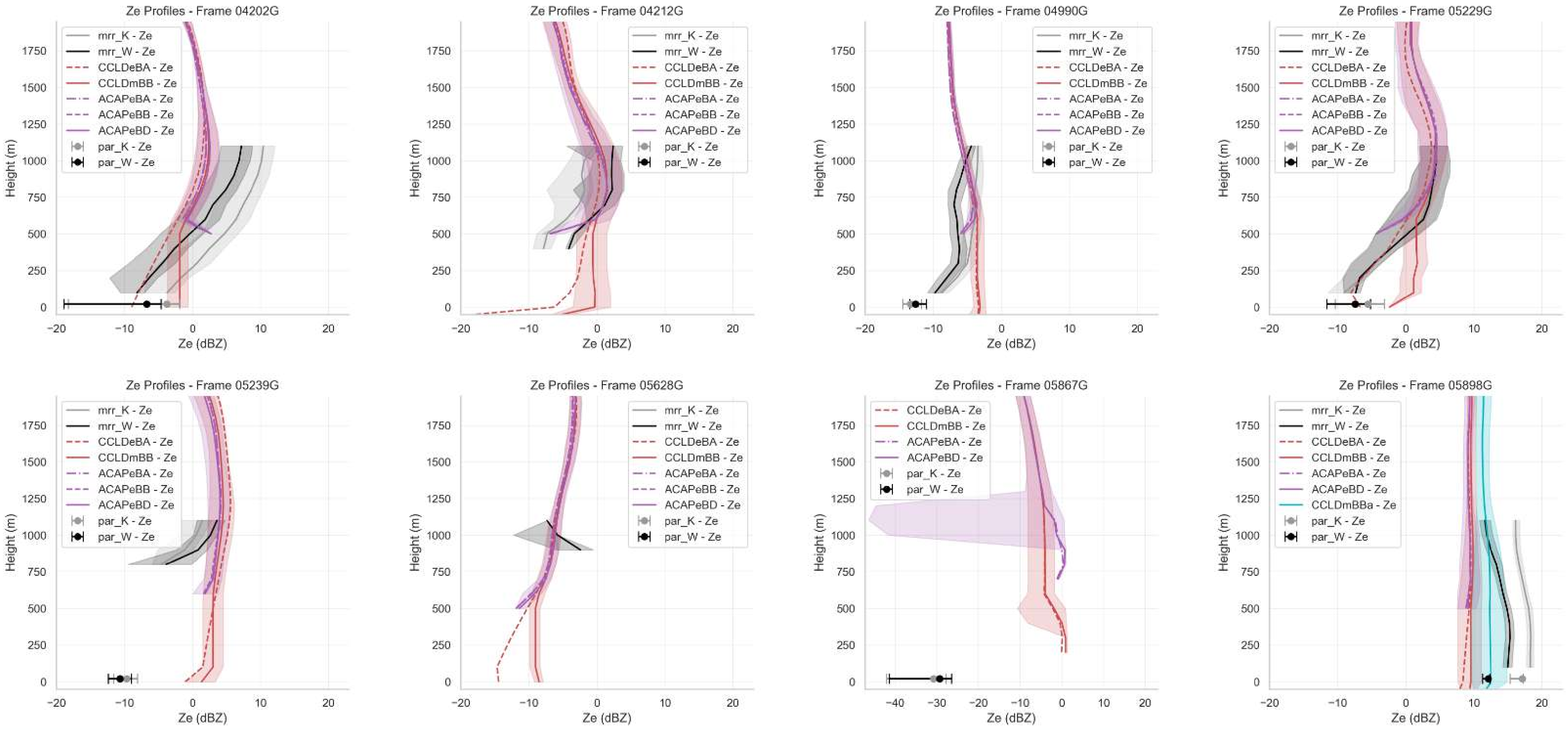




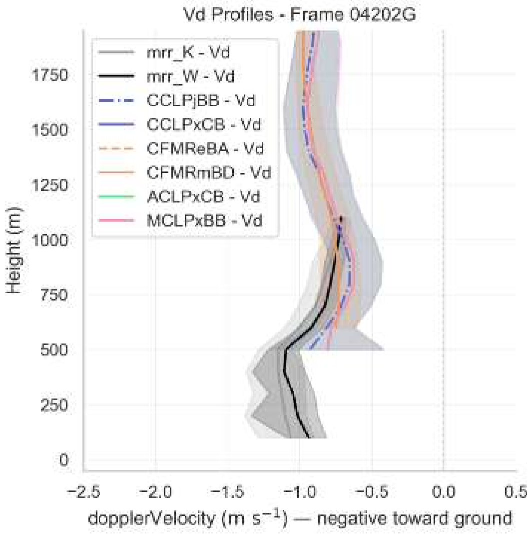
Profiles: Reflectivity

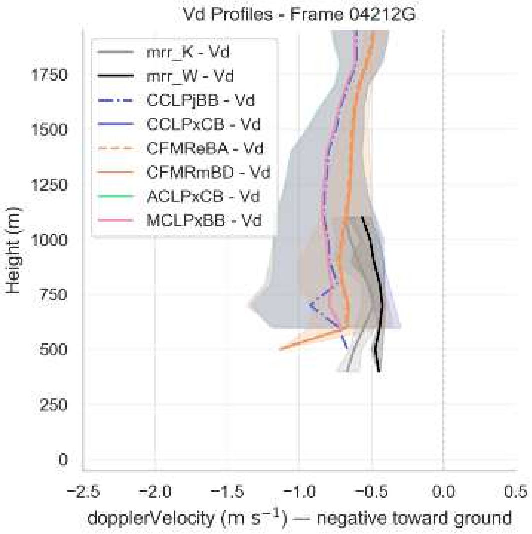


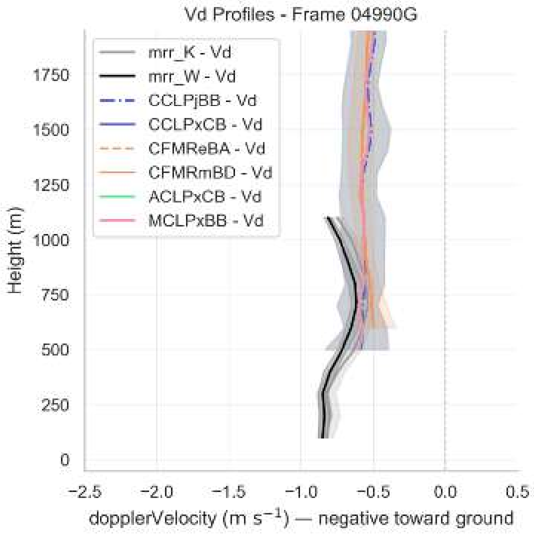
Profiles: Reflectivity forward modelled

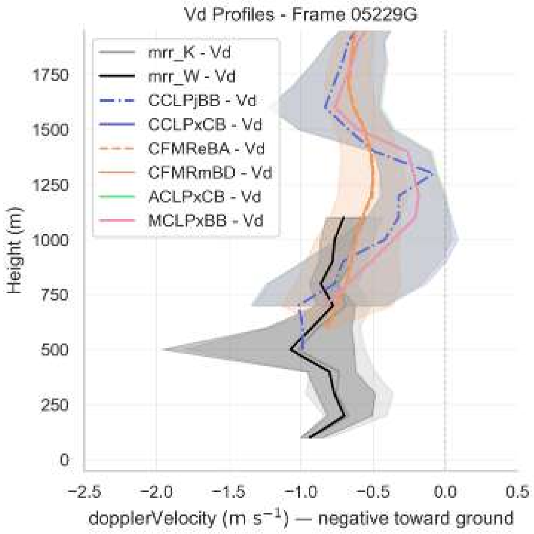


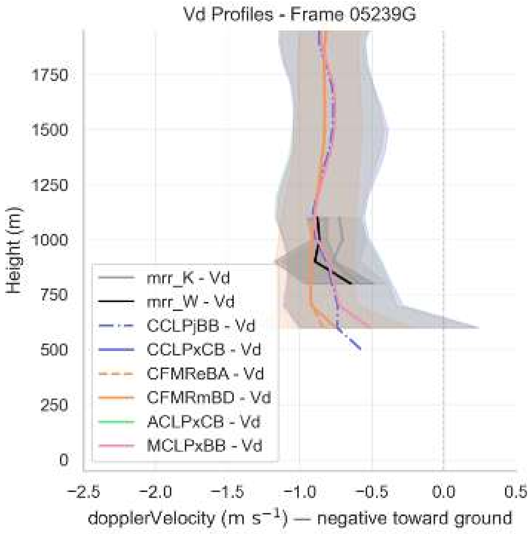
Profiles: Doppler Velocity

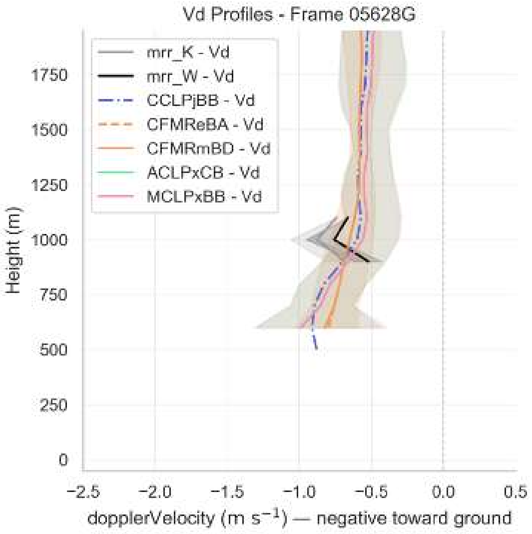


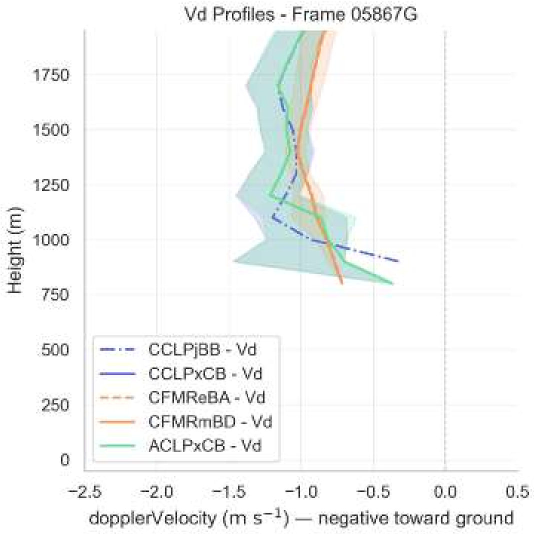


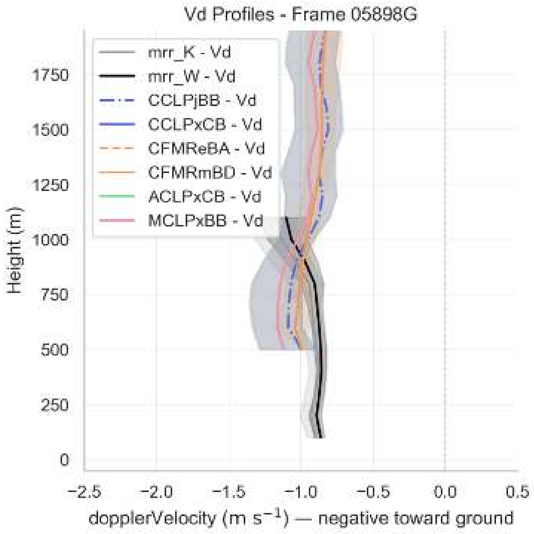






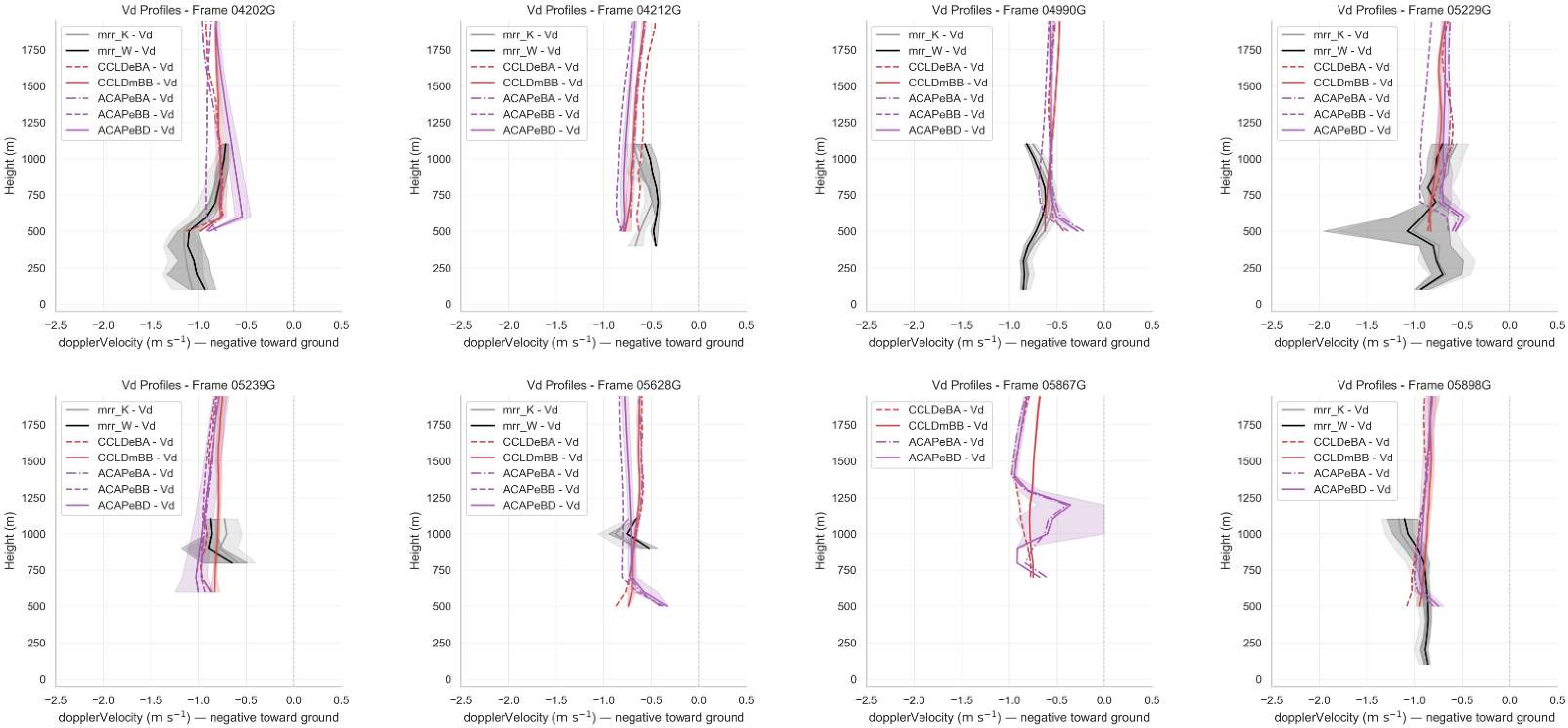






Profiles: Doppler Velocity forward modelled

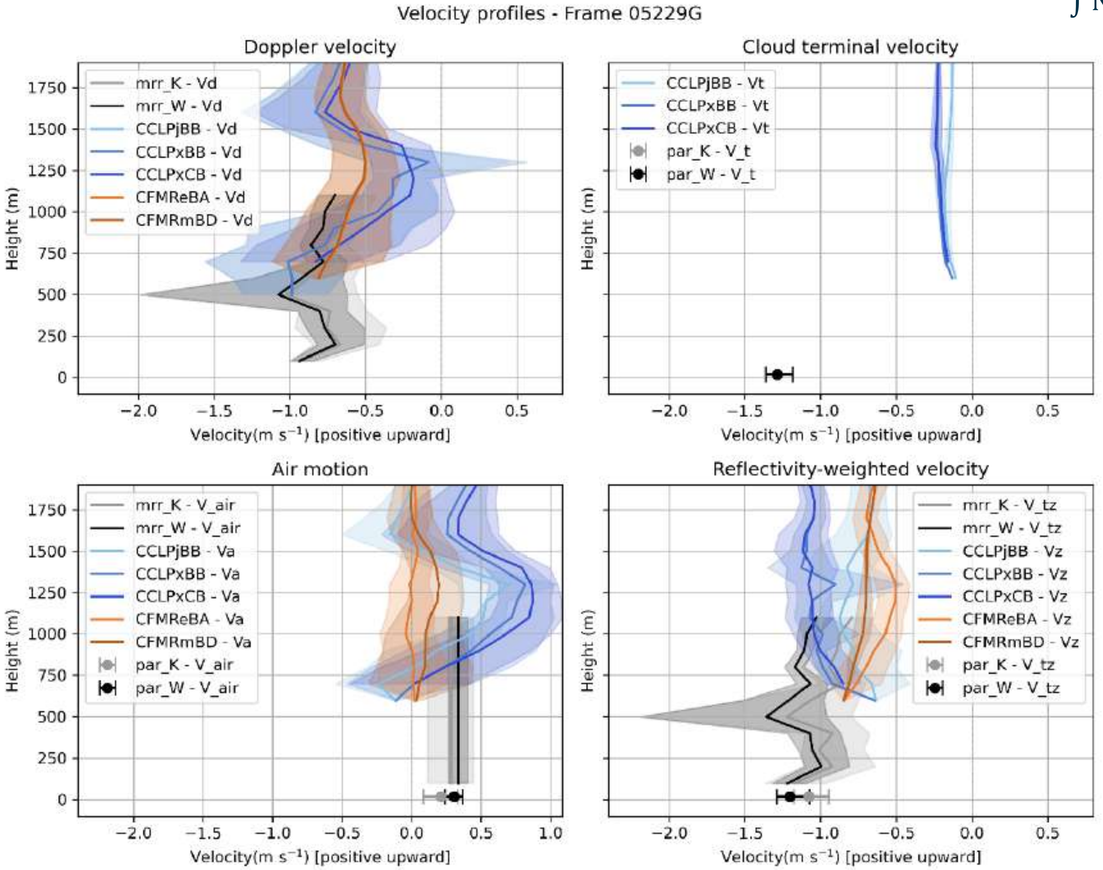
JAXA
esa
EUROPEAN SPACE AGENCY

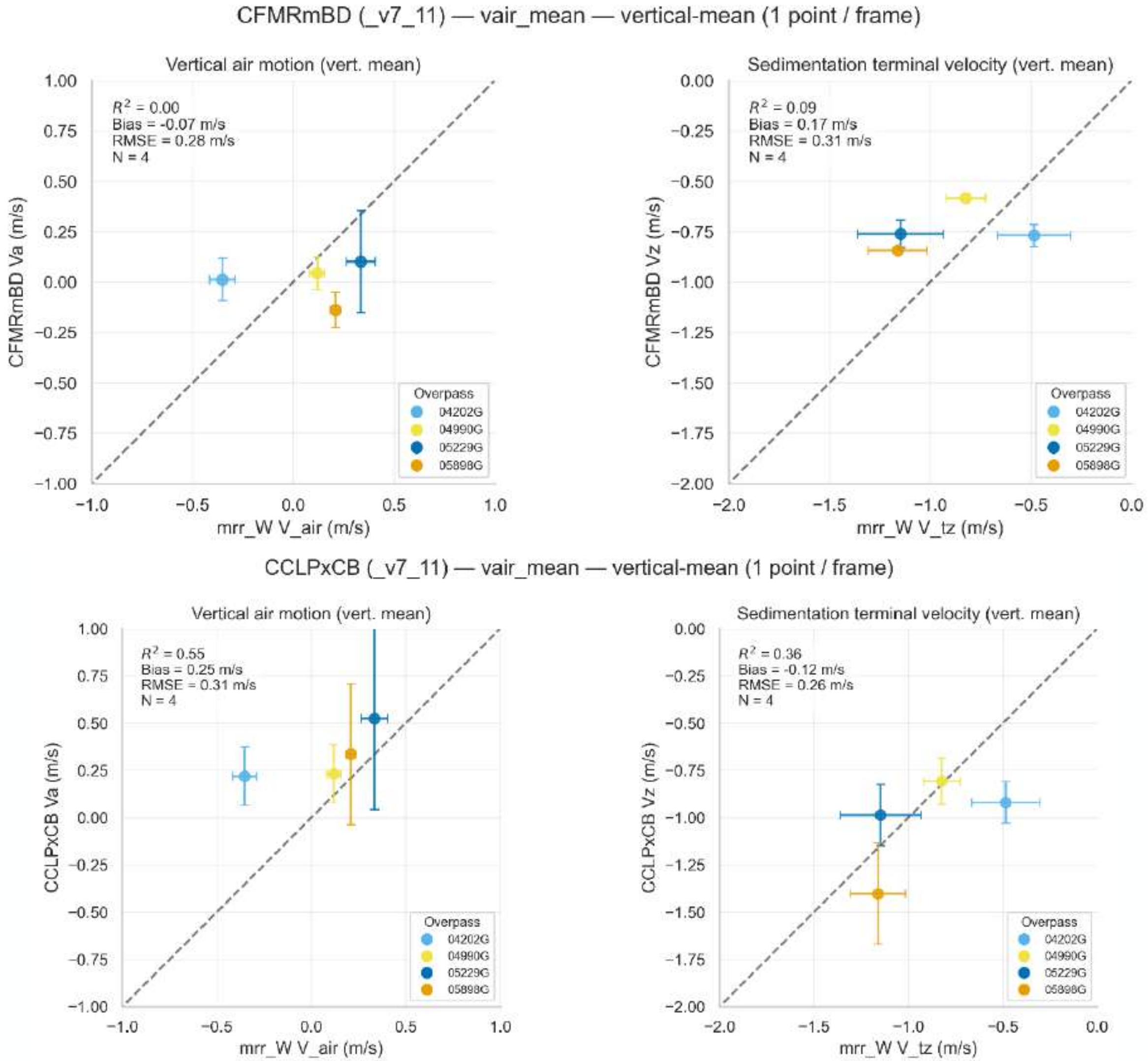


Preliminary results: Vd decomposition

$$Vd = Vtz + Vair$$

$$VtPAR = \frac{\int V(D)\, N(D)\, dD}{\int N(D)\, dD}$$





$$Vair(estimated) = Vd(MRR\ @105m) - Vtz(PAR)$$

[(Adirosi et al. 2016)]

$$VtzPAR = \frac{\int V(D)\, Cbk(D)\, N(D)\, dD}{\int C_{bk}(D)\, N(D)\, dD}$$