Ground Validation of CPR Radar Reflectivity, Doppler and Microphysics Products at the Mario Zucchelli Antarctic Site

using the K2W Methodology with 24 GHz Doppler Radar and Disdrometer measurements

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FILL THE GAP

The first 500 m inside the EarthCARE CPR ground clutter

In **Antarctica**: a harsh, remote, complex environment

that is fundamental for the Earth system

Seasonal base (Oct-Feb)
Operational since 1985
Hosts up to 120 people.

Mario Zucchelli Station

Lat: -74.694, Lon: 164.115

Terra Nova Bay

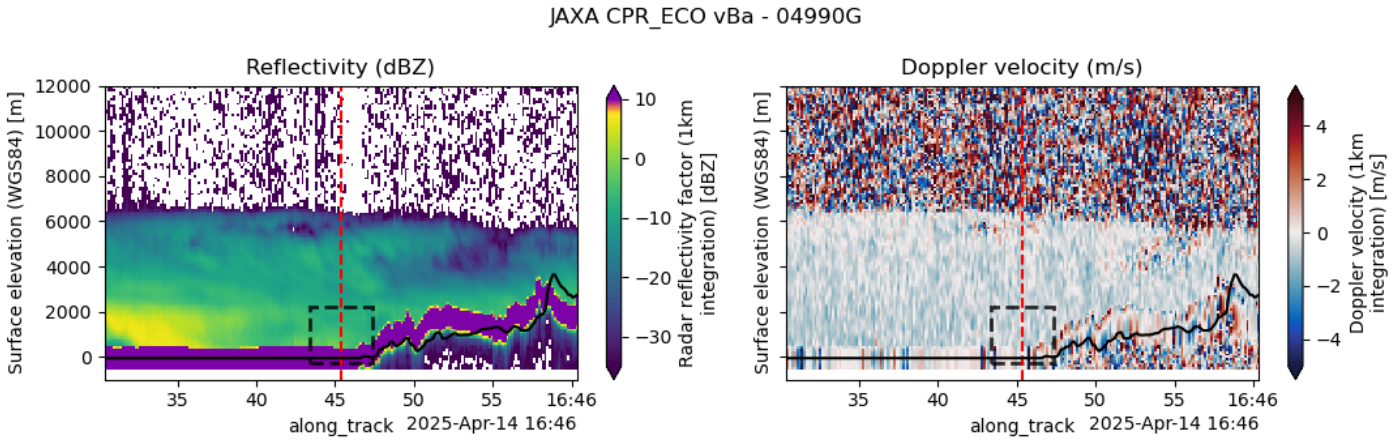
Ross Sea, Antarctica

Experimental setup

CPR Cloud Profiling Radar

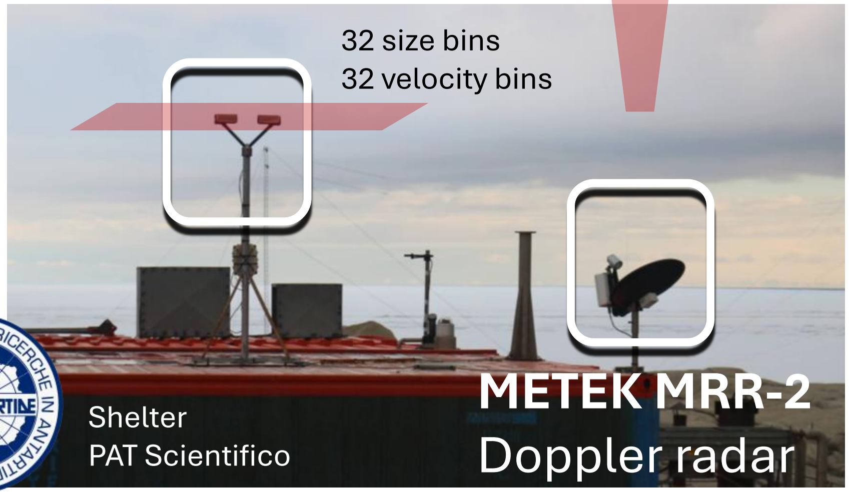
Frequency:
94.05 GHz (W-band)

EarthCARE
CPR products



OTT Parsivel
laser disdrometer

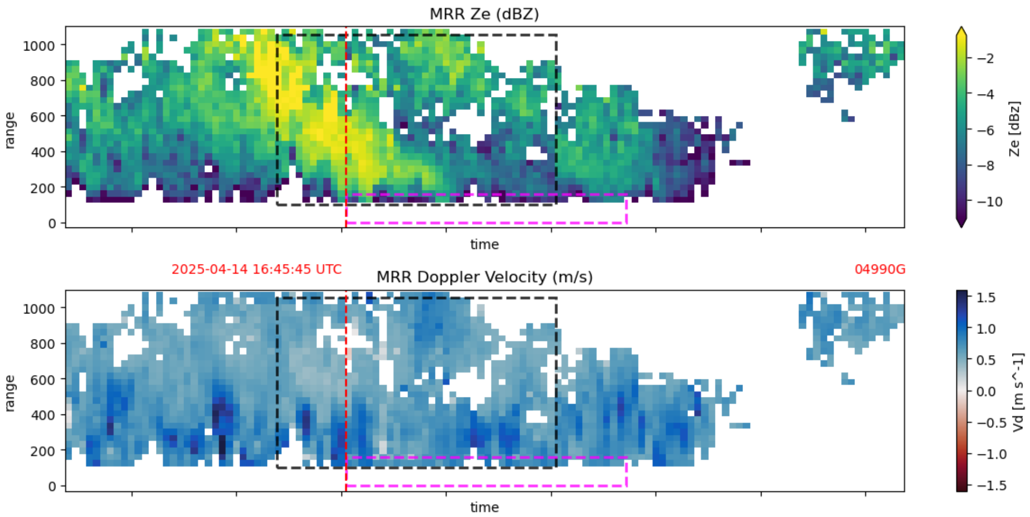
PNRA-APP project



METEK MRR-2
Doppler radar

Ze

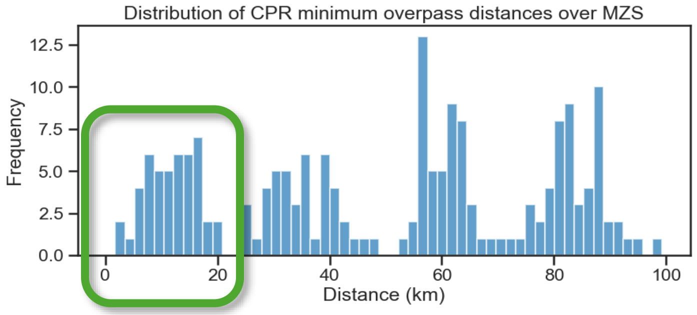
Vd

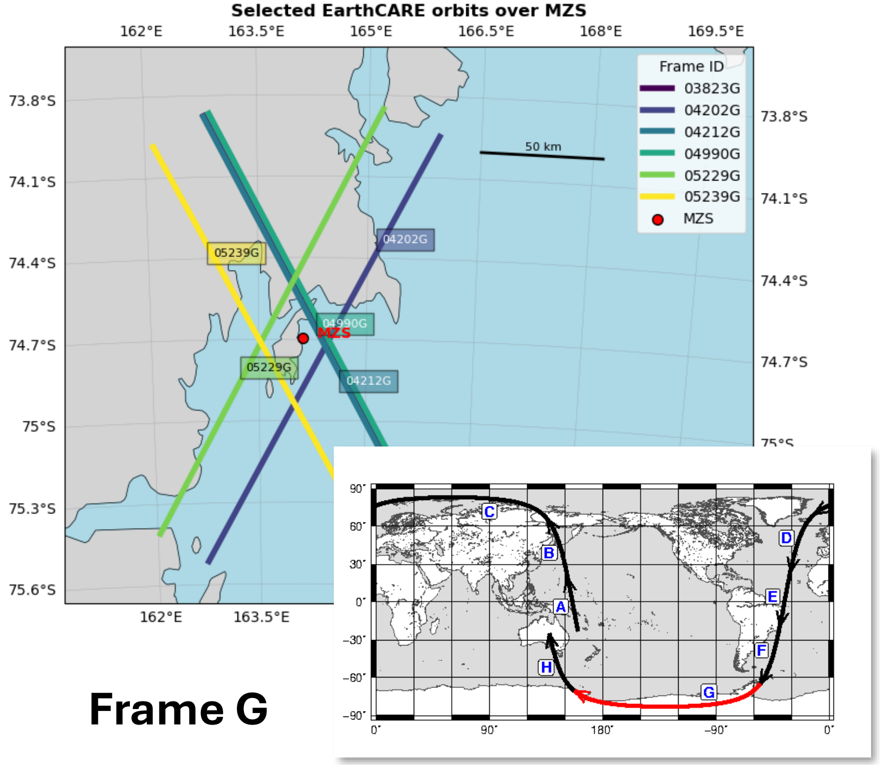


IMProToo by Maahn & Kollias (2012) allows MRR snow retrievals

Frequency:
24.15 GHz (K-band)
Height range:
105 – 1050 m AGL
Height res.:
35 m

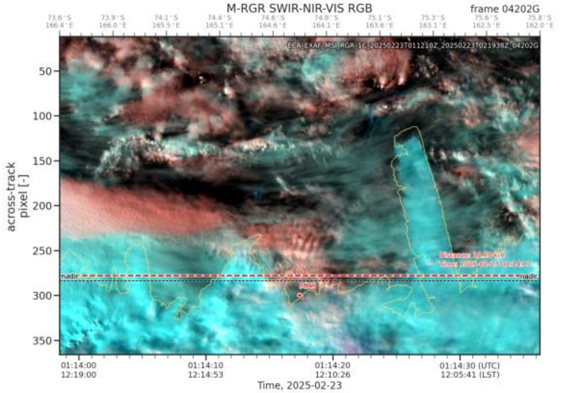
EarthCARE overpasses at MZS during precipitation





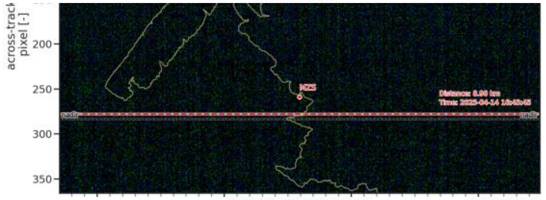
Frame G

From July 2024 to June 2025, **42** orbits fly closer than 20 km from MZS. **7** of them show non-zero reflectivity at the closest distance, but only during **3** there is a complete event at the ground (i.e. seen from both PAR and MRR):



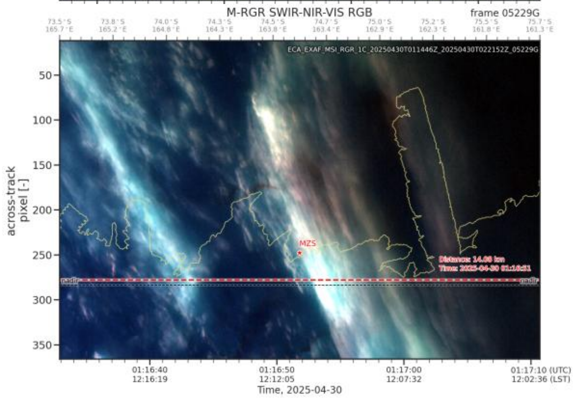
04202G
Feb 23, 2025
01:12:10 UTC

Descending orbit
Min. distance: **9.866** km



04990G
Apr 14, 2025
16:36:34 UTC

Ascending orbit (night)
Min. distance: **8.917** km



05229G
Apr 30, 2025
01:14:46 UTC

Descending orbit
Min. distance: **14.383** km

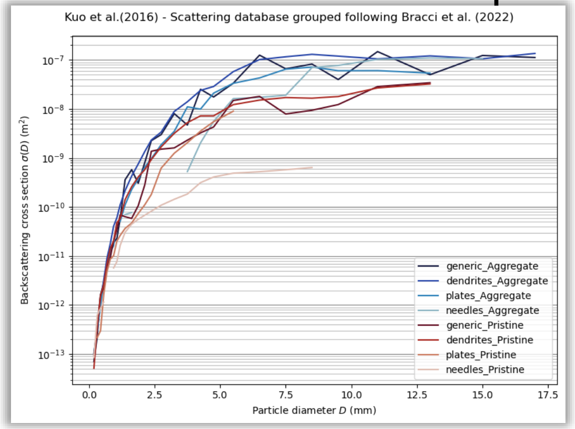
Methods: **K2W**

K2W derives an invertible Vt = *g*(D) relation (D = *f*(v)) to use the backscattering cross sections (function of D_{max}) to convert the positive (downward) part of the K-band Doppler spectrum in its W-band equivalent, from which to derive Ze Vd

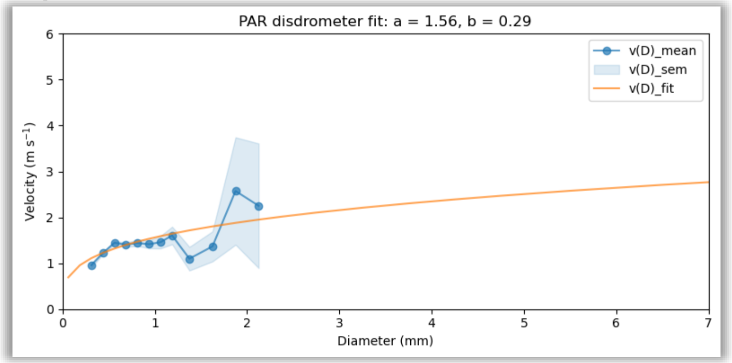
First test with CloudSat CPR *(Bracci et al., 2023)*

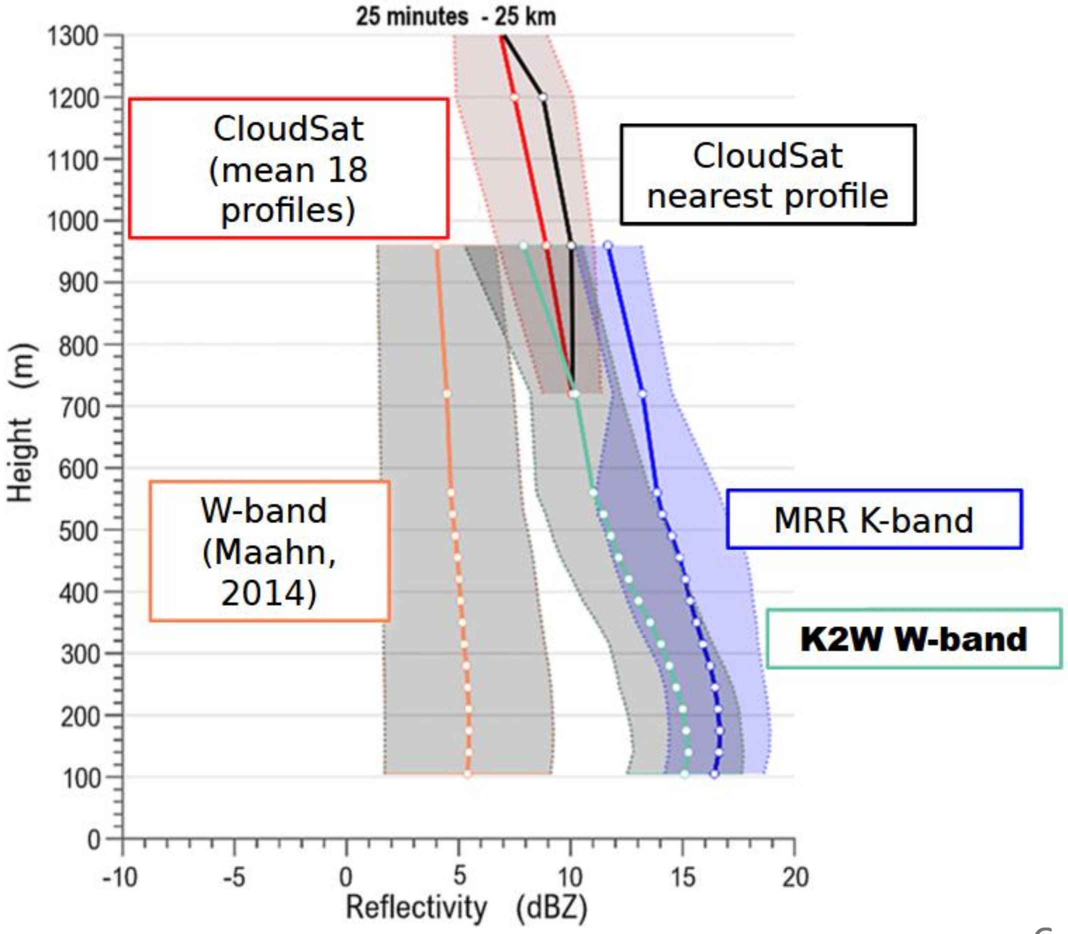
$$\eta_{v,W}(v_s) = \eta_{v,K}(v_s)\frac{C_{bk,W}(v = g(D))}{C_{bk,K}(v = g(D))} \rightarrow Z_{e,W}, V_{D,w}$$

Kuo et al. (2016) database

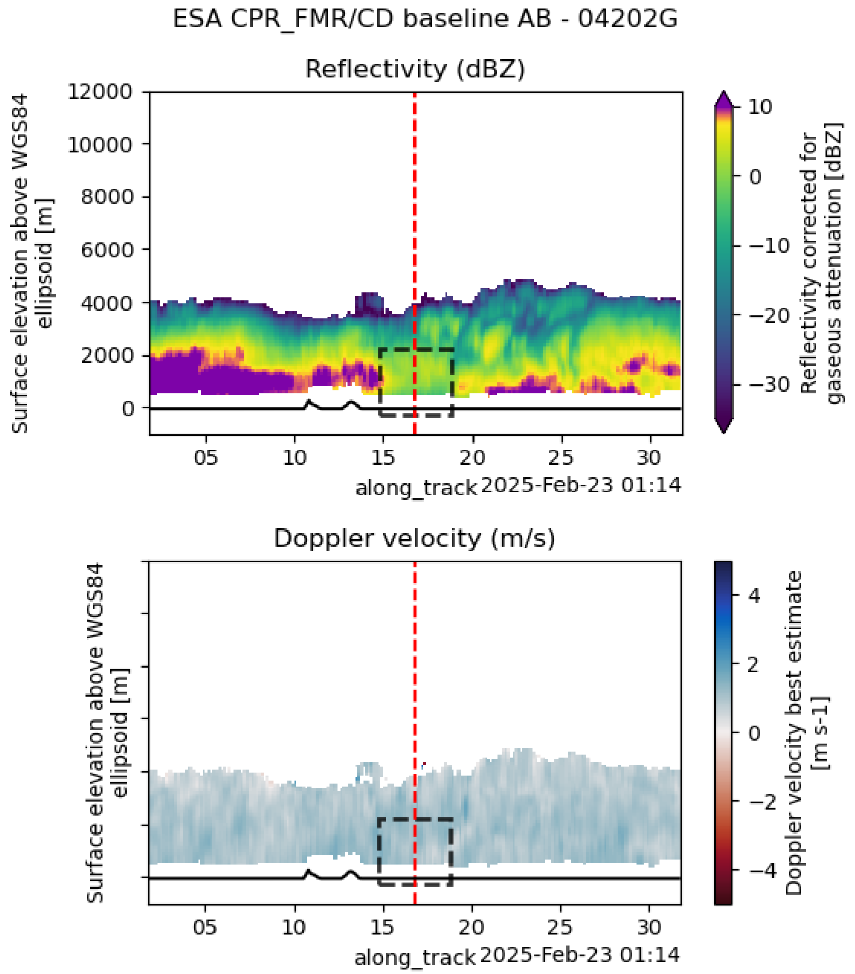


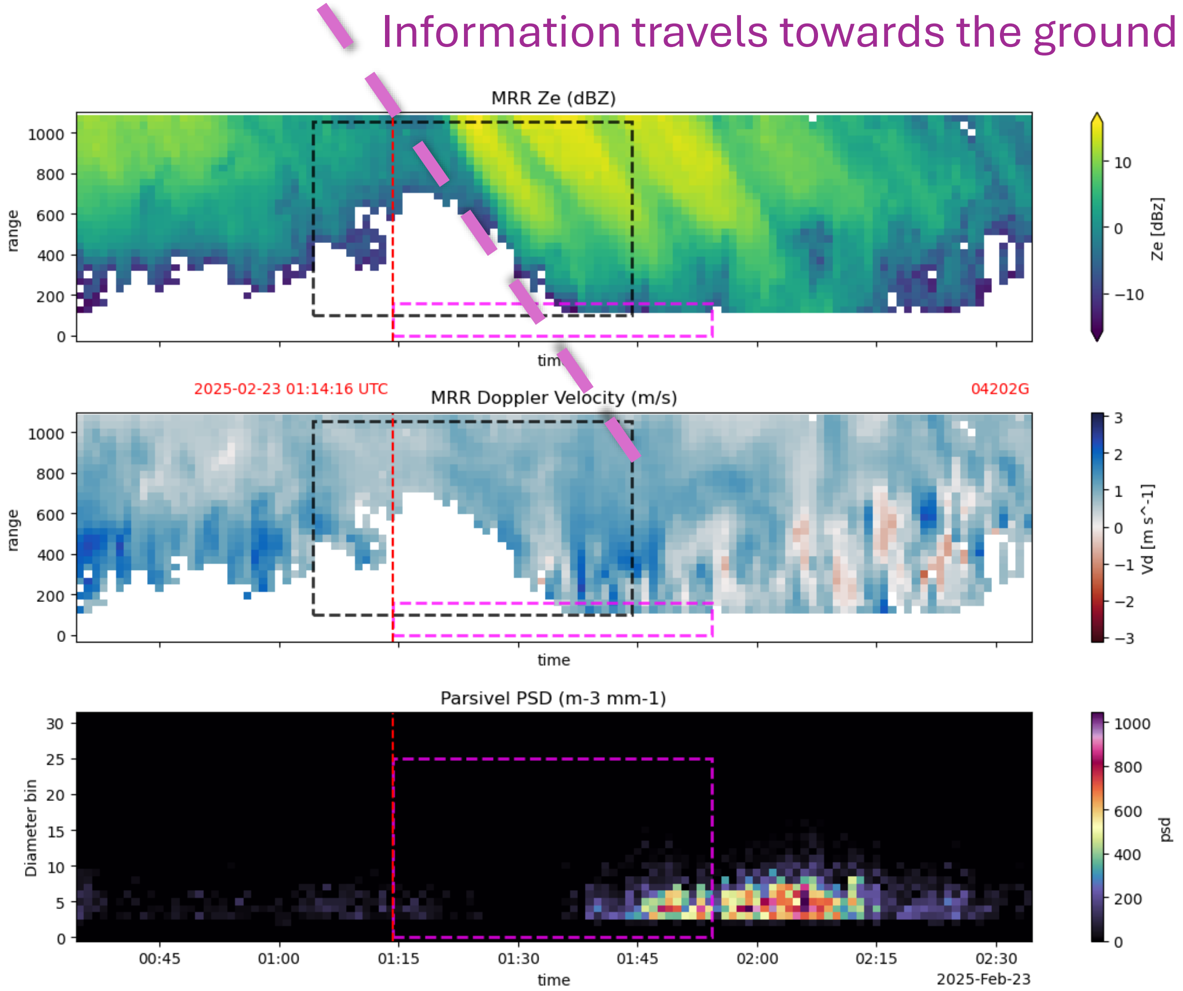
Vt = a D^b fit from the disdrometer





Methods: Windows and delays



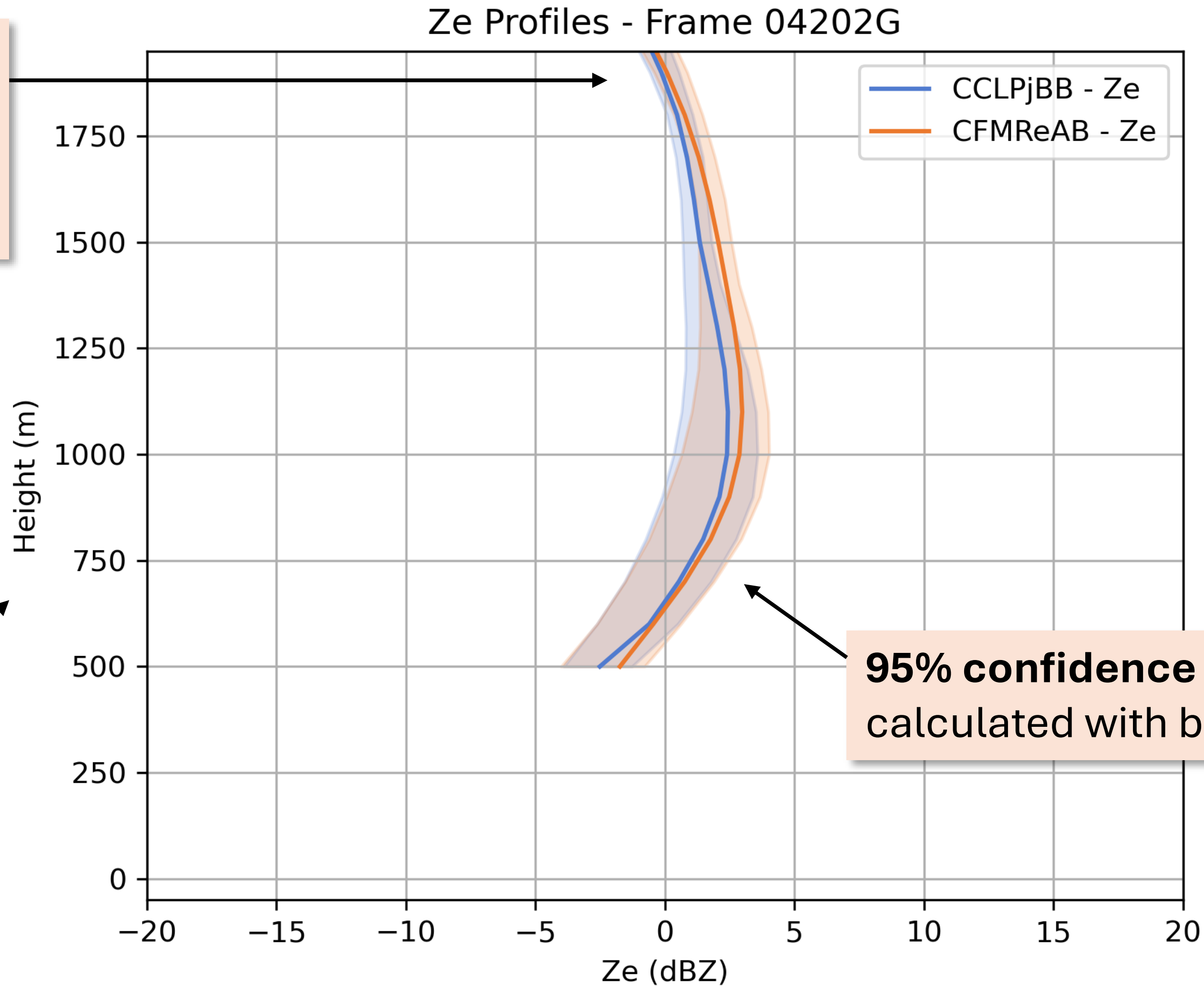


3.91 s along track: **30 km**, centred around the time of closest distance

40 min at the ground, with appropriate shifts/delays, chosen in accordance with the typical heights and falling velocities scales

Methods: Vertical profiles

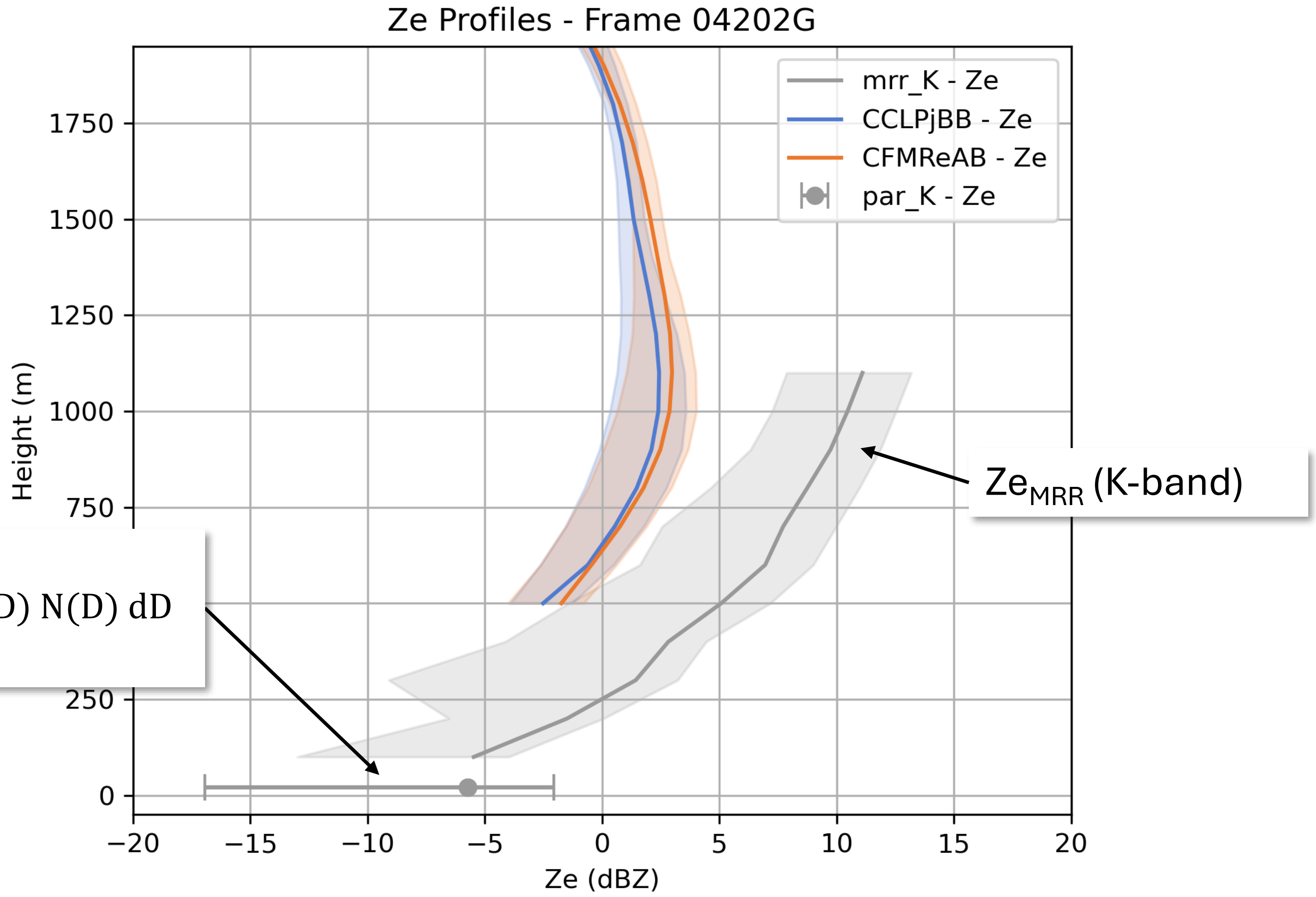
Average profiles of radar equivalent reflectivity factor Ze (dBZ) during the selected windows (30 km)



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

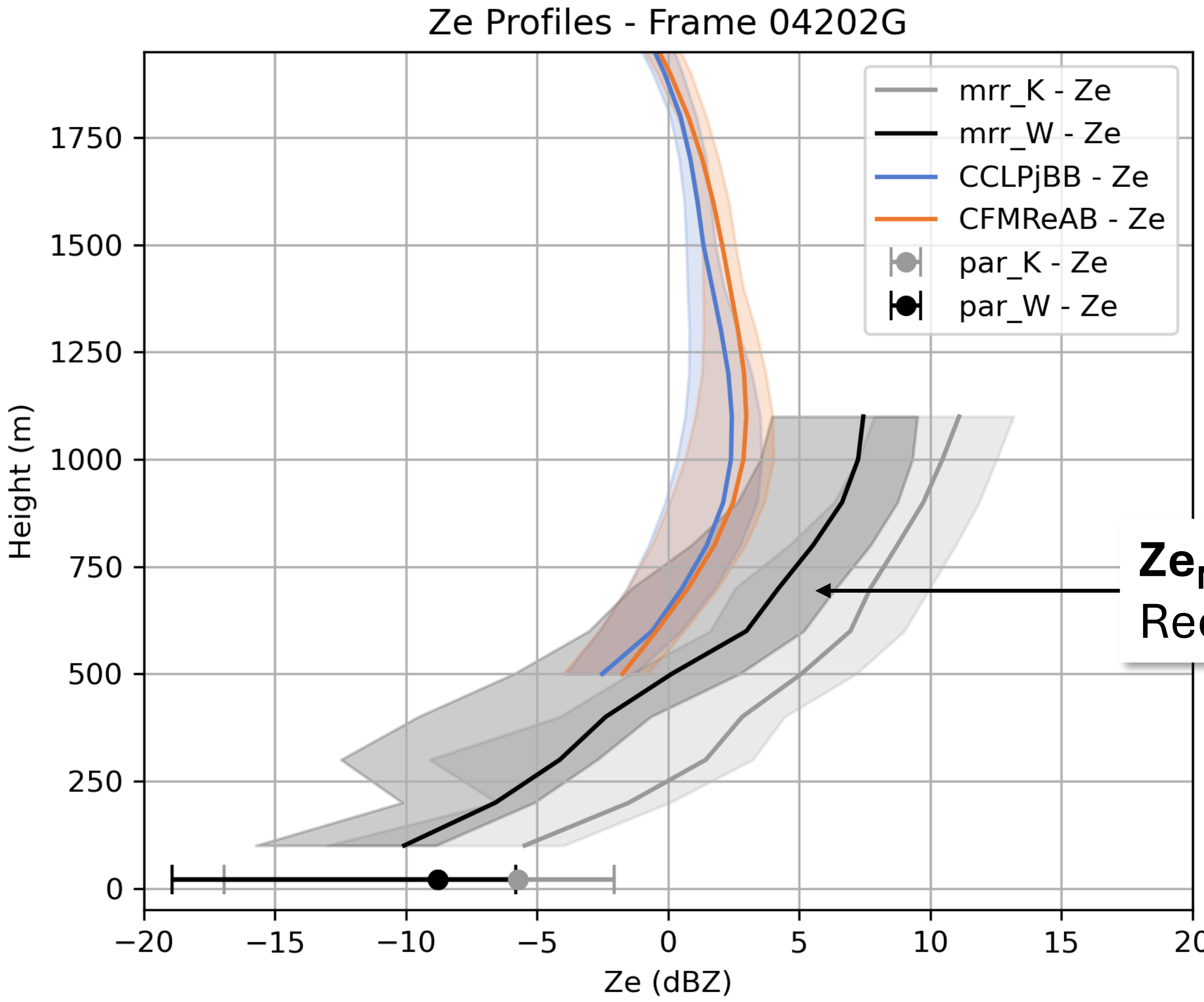
95% confidence intervals are calculated with block-bootstrap

Methods: Vertical profiles



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

Methods: Vertical profiles

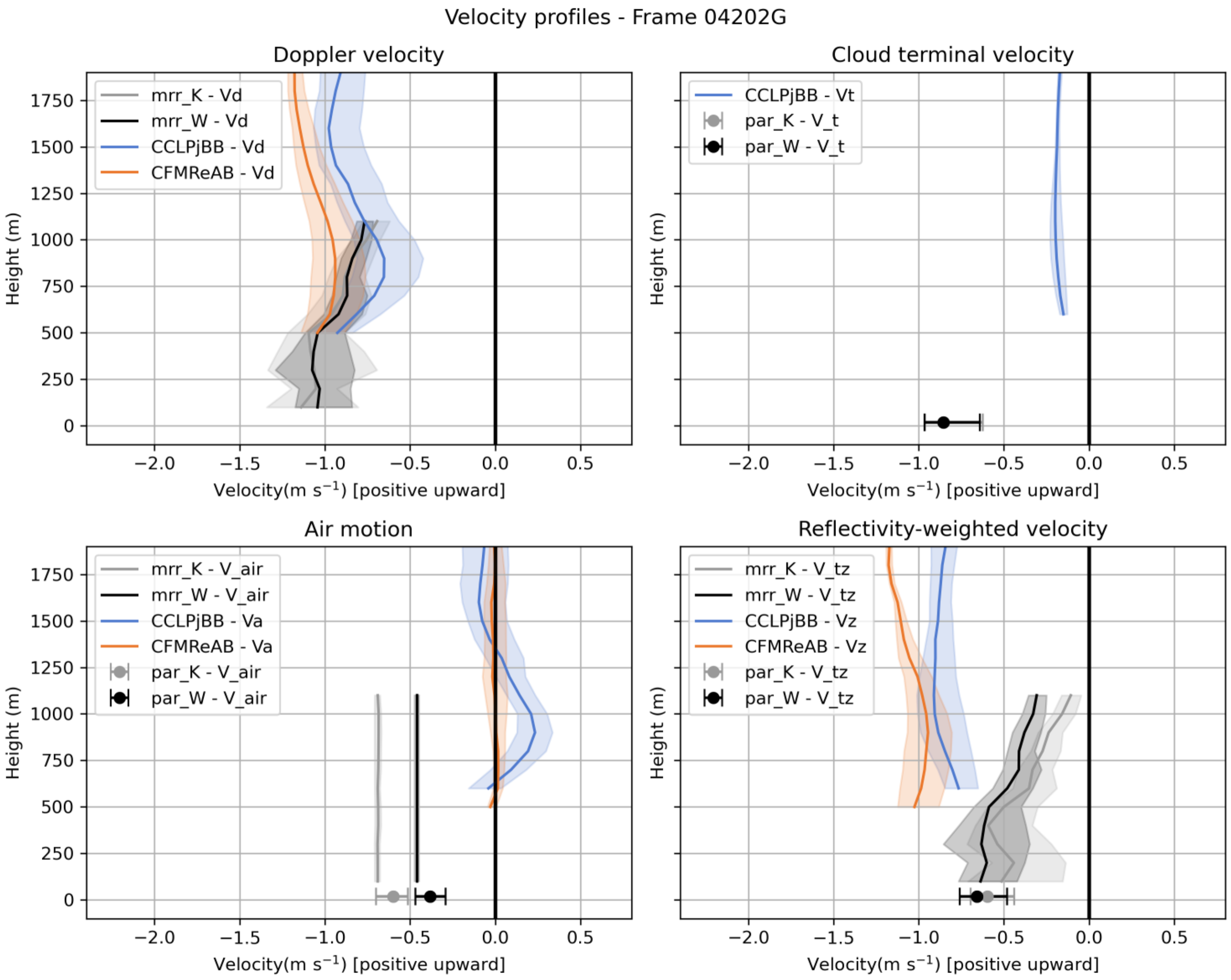


Ze_{MRR} (W-band)
Reconstructed with K2W

The knowledge is extended inside the ground clutter down to 100 m a.s.l.

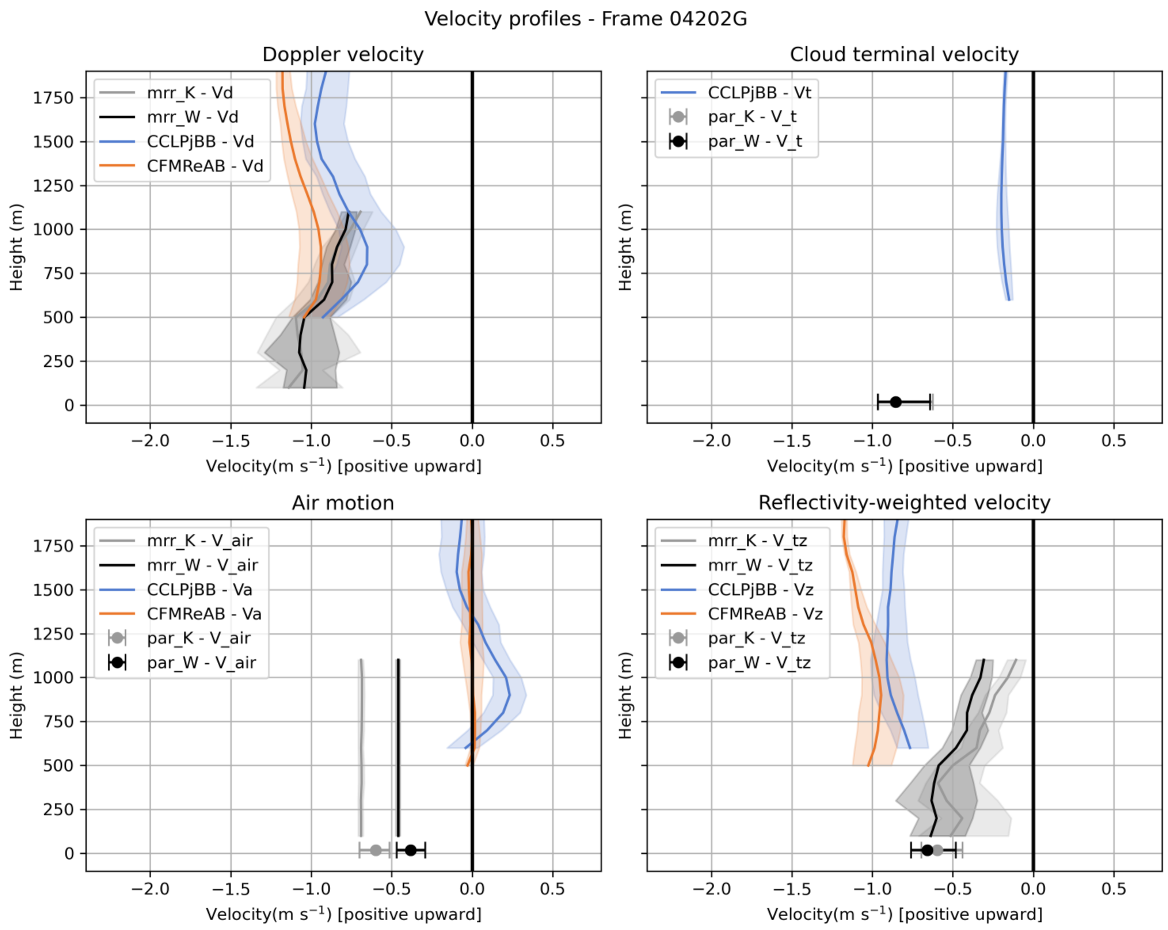
L2A Measurements re-gridded and corrected for gaseous attenuation

Methods II: Four vertical velocities



Methods II: Four vertical velocities

Vd = Vtz + Vair



Methods II: Four vertical velocities

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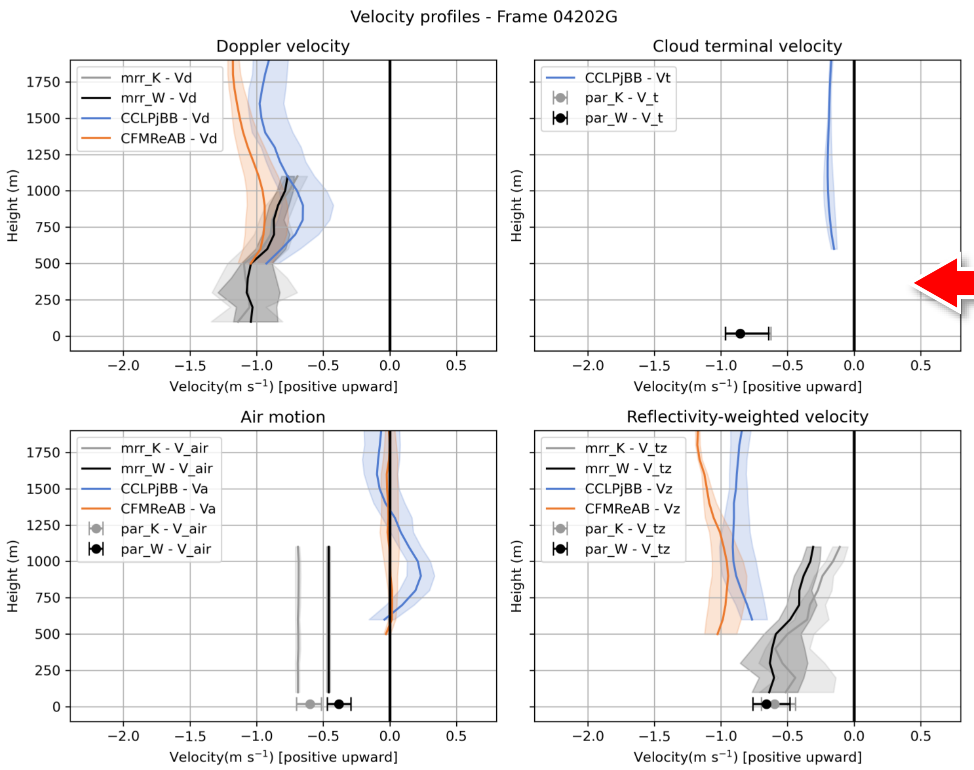
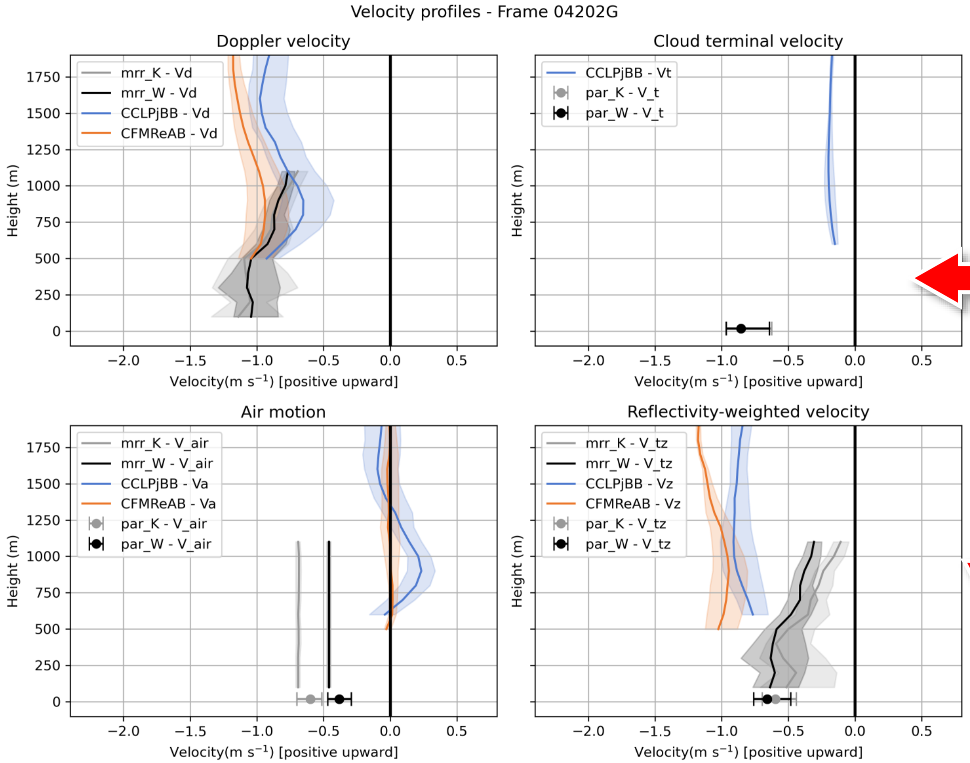


from Parsivel measurements, frequency independent

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

Methods II: Four vertical velocities

$$Vd = Vtz + Vair$$



from Parsivel measurements, frequency independent

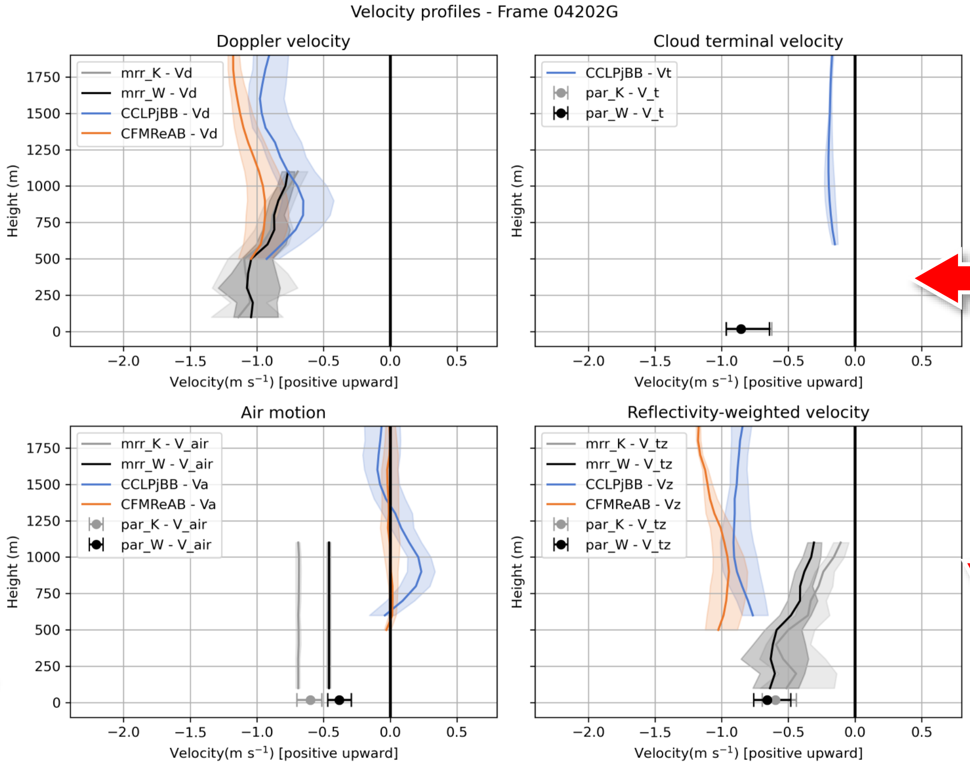
$$VtPAR = \frac{\int V(D)\, N(D)\, dD}{\int N(D)\, dD}$$

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

Reflectivity weighted terminal velocity, a.k.a. sedimentation velocity

Methods II: Four vertical velocities

$$Vd = Vtz + Vair$$



from Parsivel measurements, frequency independent

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

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

$$Vair(estimated) = Vd(MRR\ @105m) - Vtz(PAR)$$ *(Adirosi et al. 2016)*

Vair can be estimated with some assumptions on the scales of variability involved

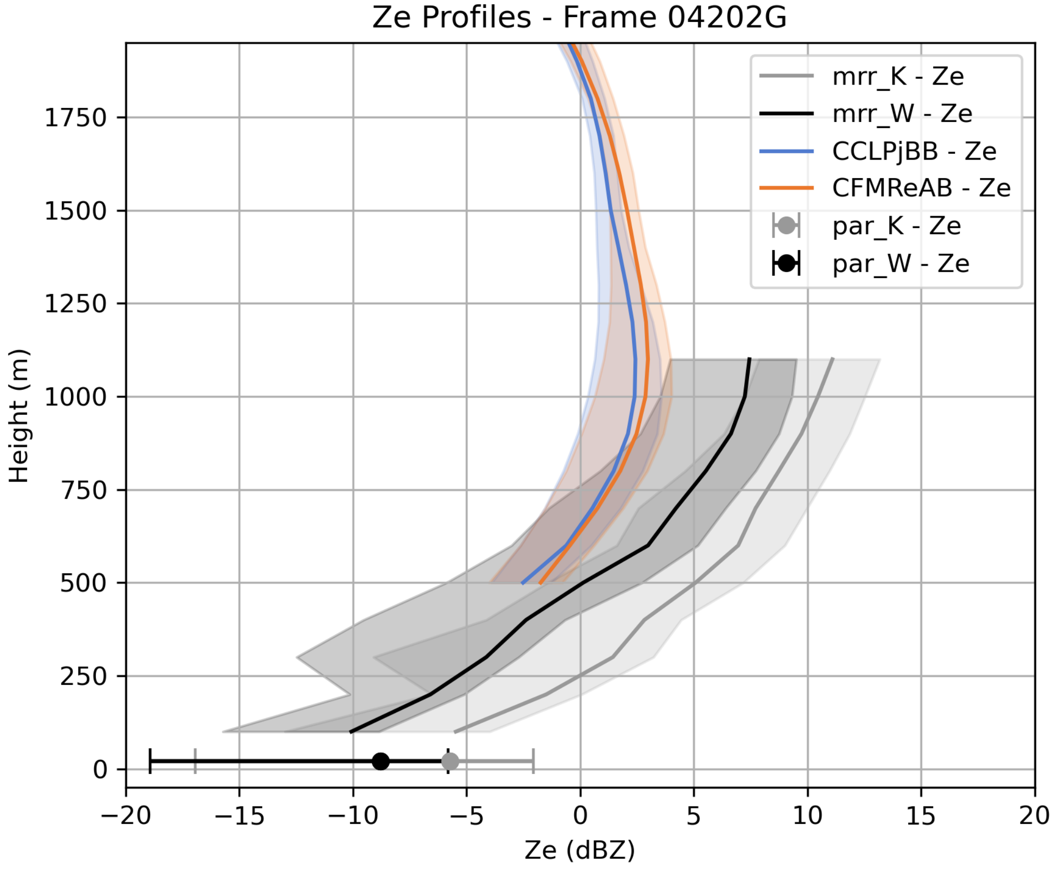
Reflectivity weighted terminal velocity, a.k.a. sedimentation velocity

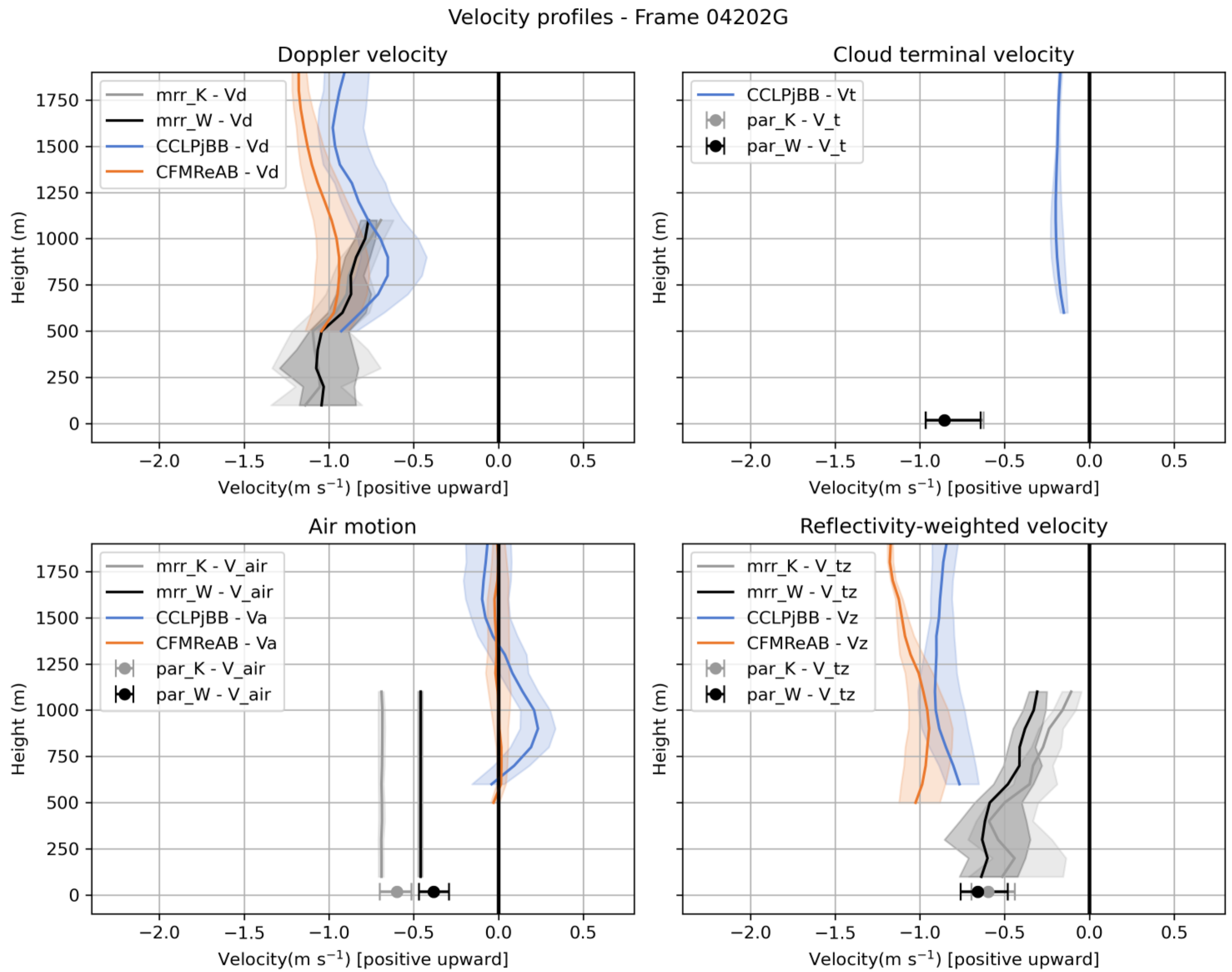
Results: Profiles

04202G

Feb 23, 2025 — Descending orbit

01:12:10 UTC — Min. distance: 9.866 km





Results: Profiles

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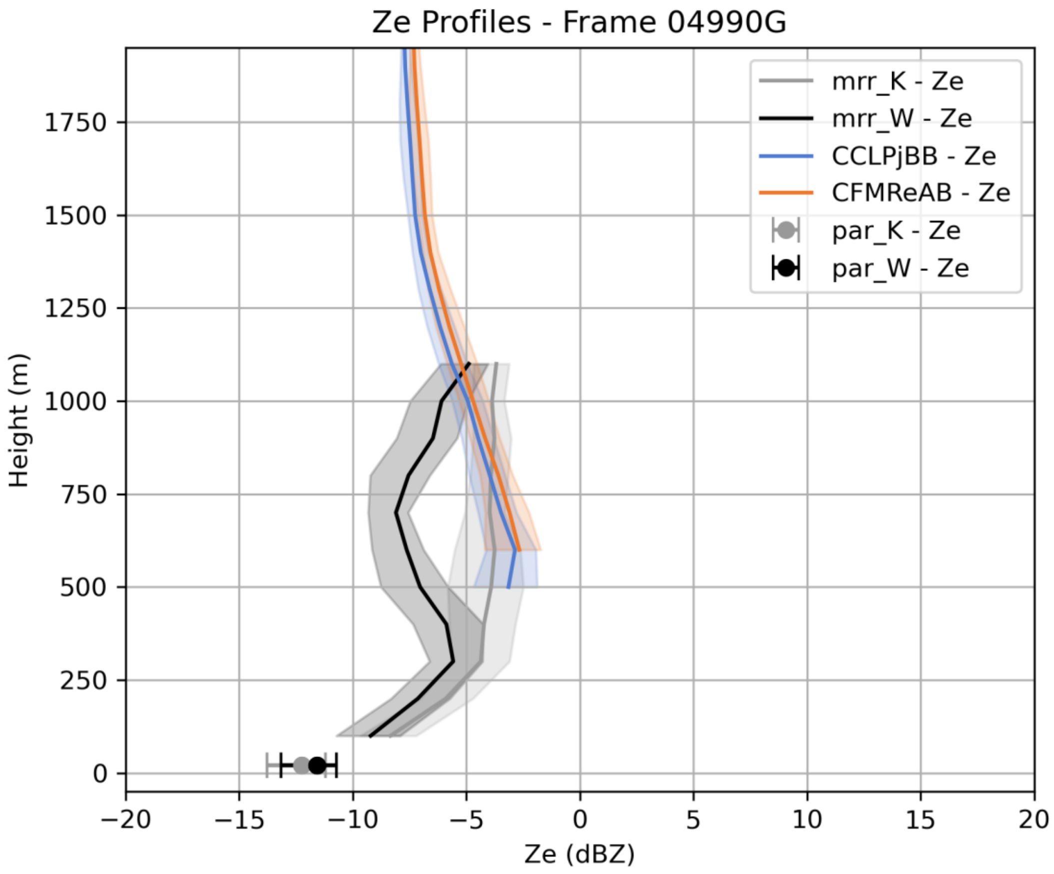
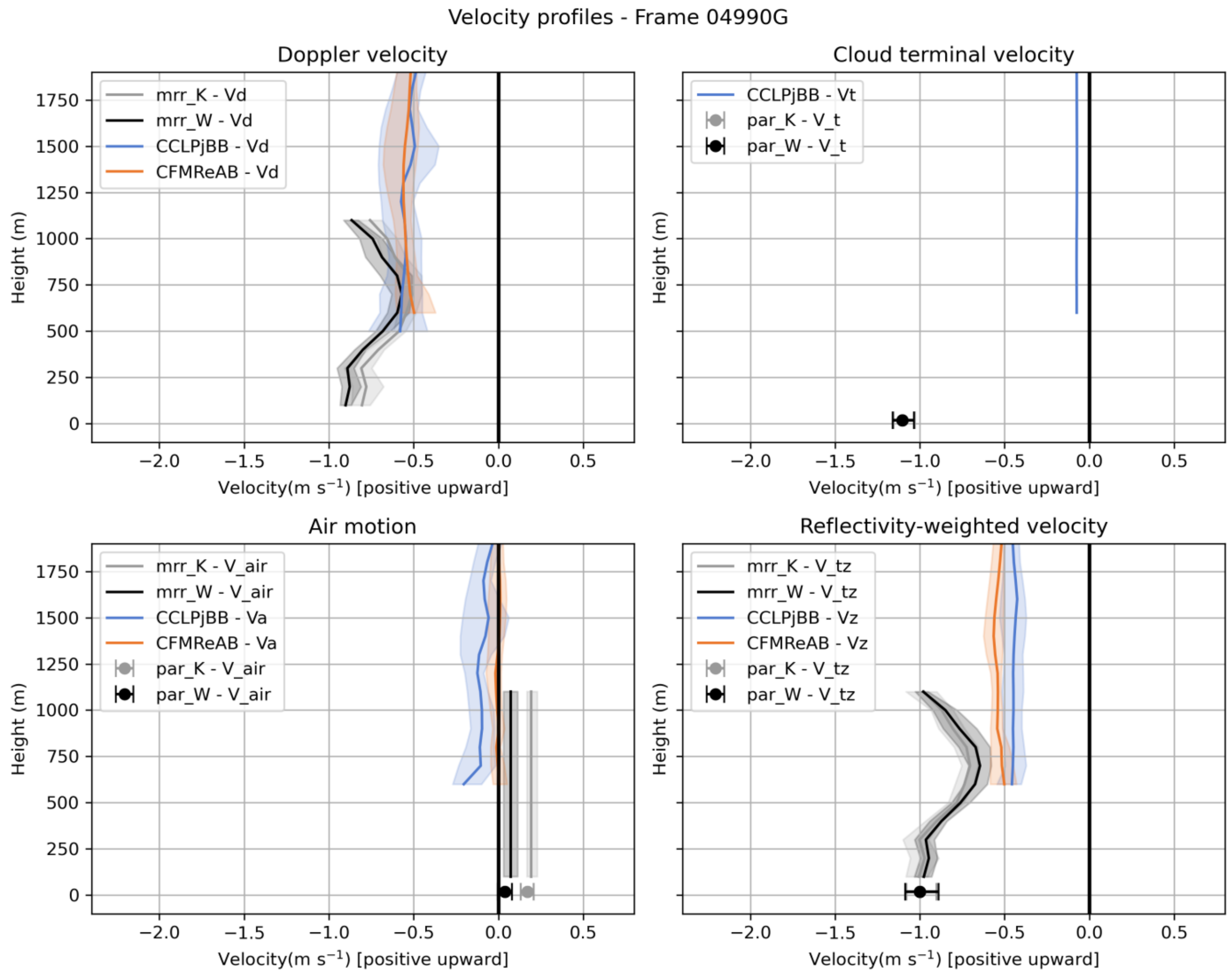
Apr 14, 2025 — Ascending orbit
16:36:34 UTC — Min. distance: 8.917 km





Results: Profiles

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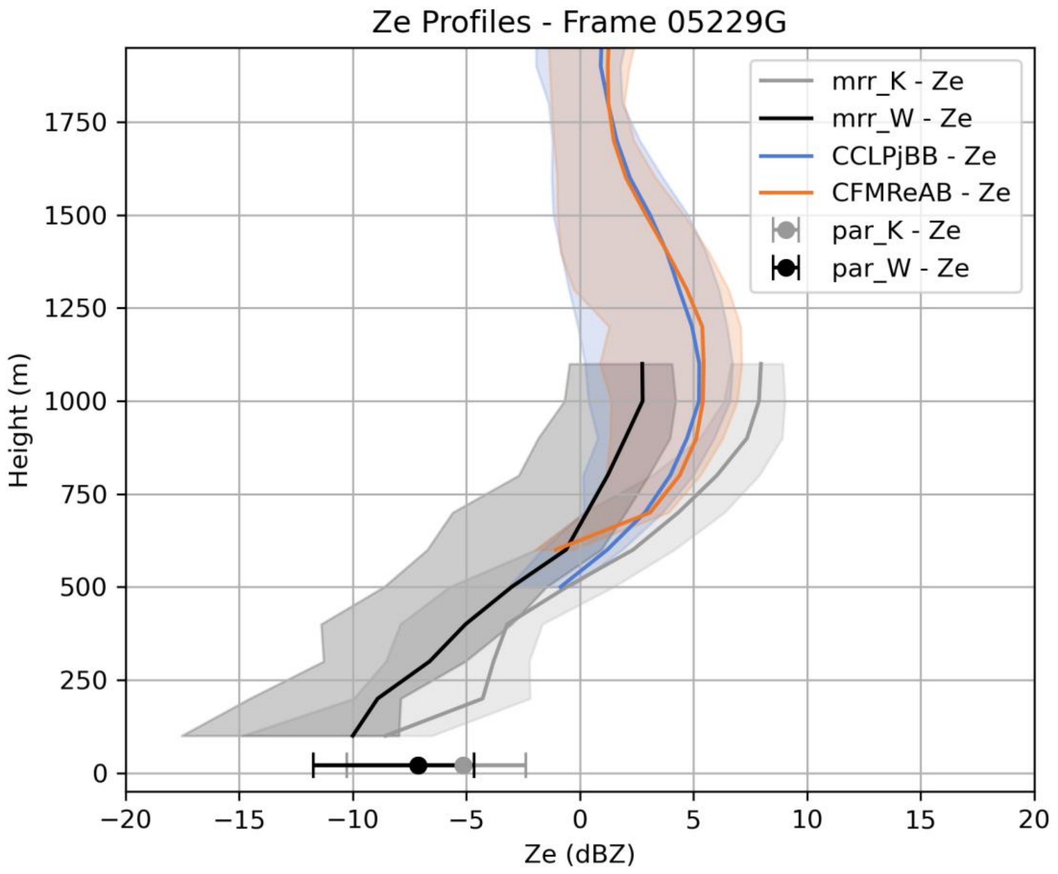
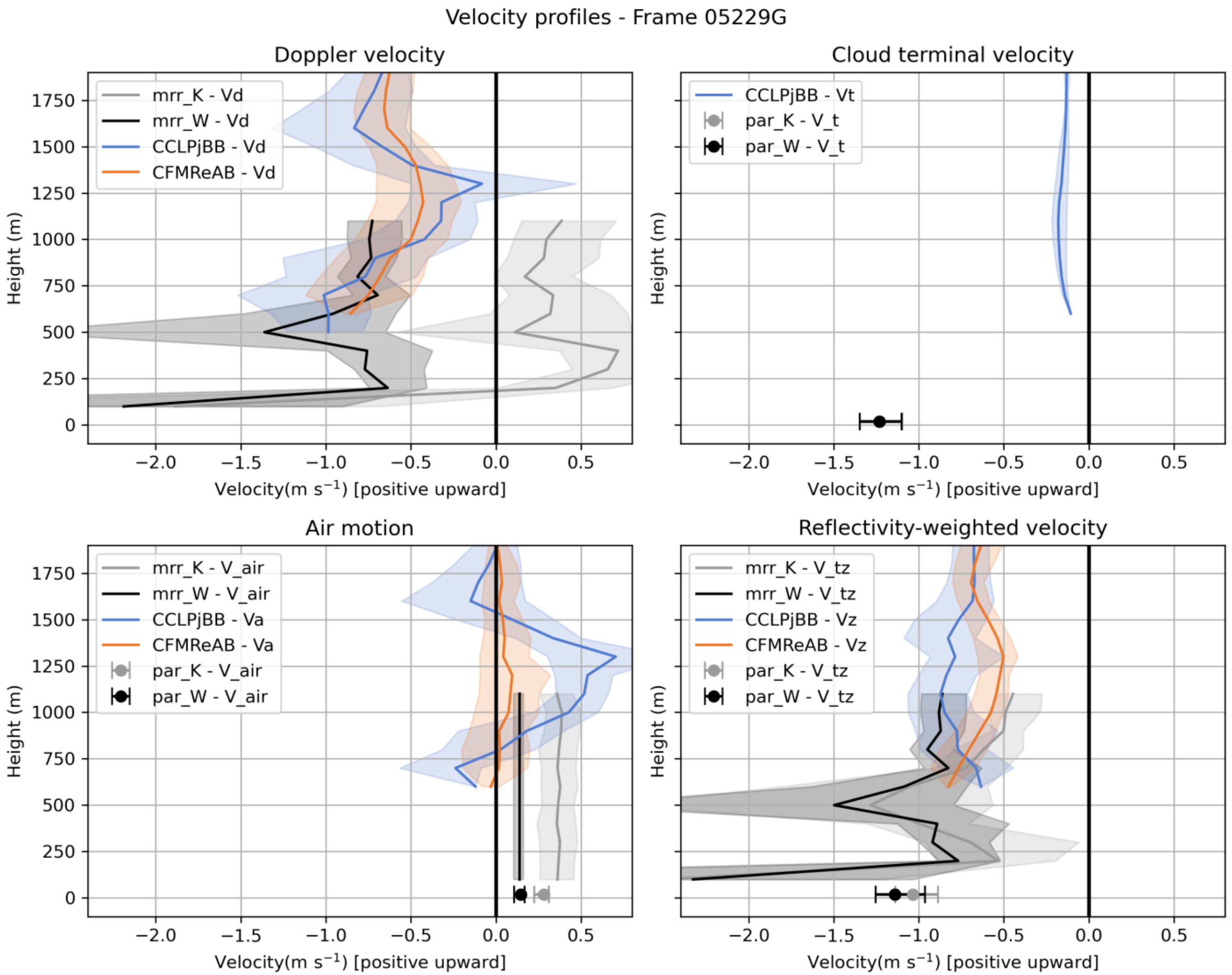
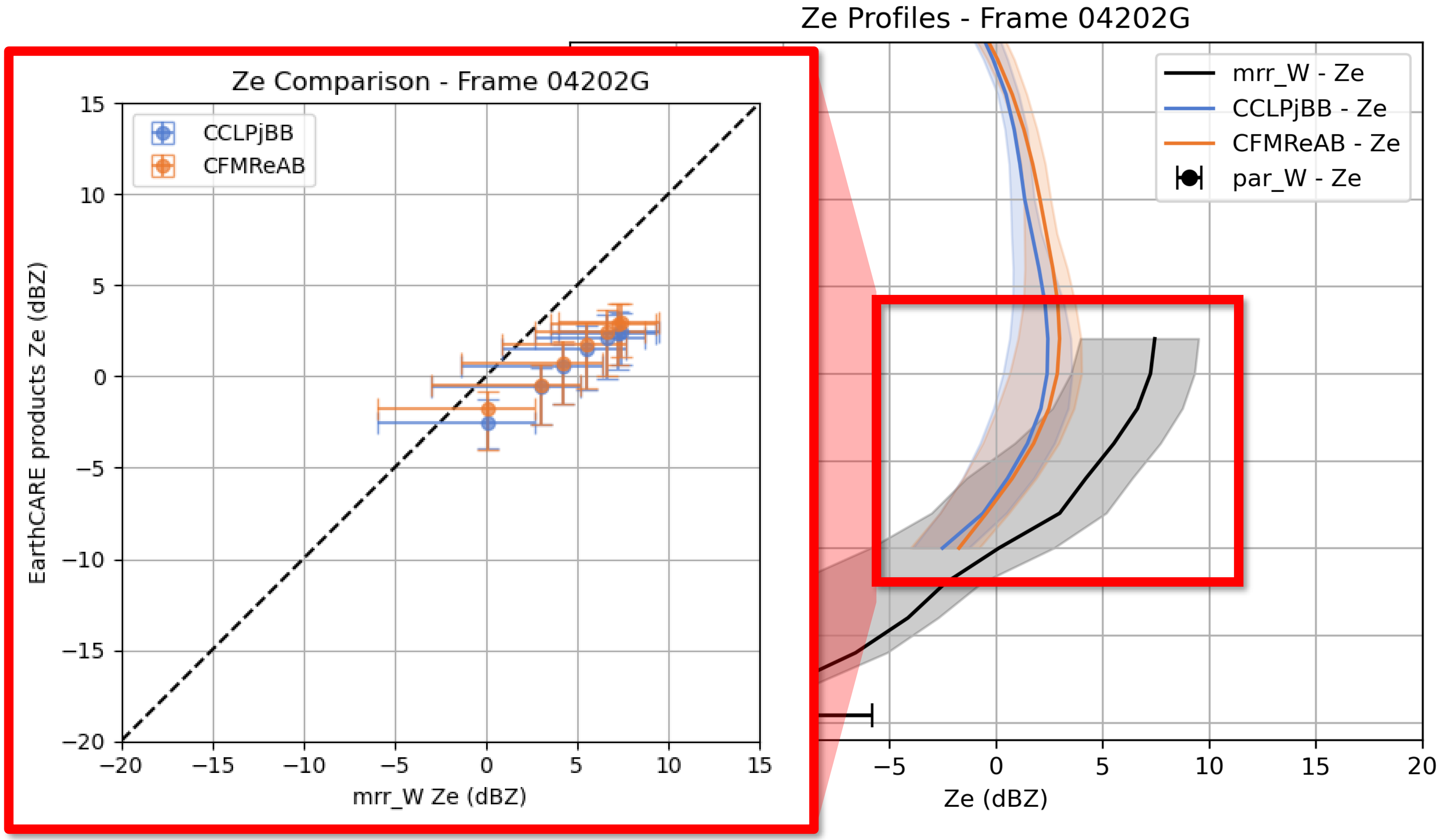
Apr 30, 2025 — Descending orbit

01:14:46 UTC — Min. distance: 14.383 km



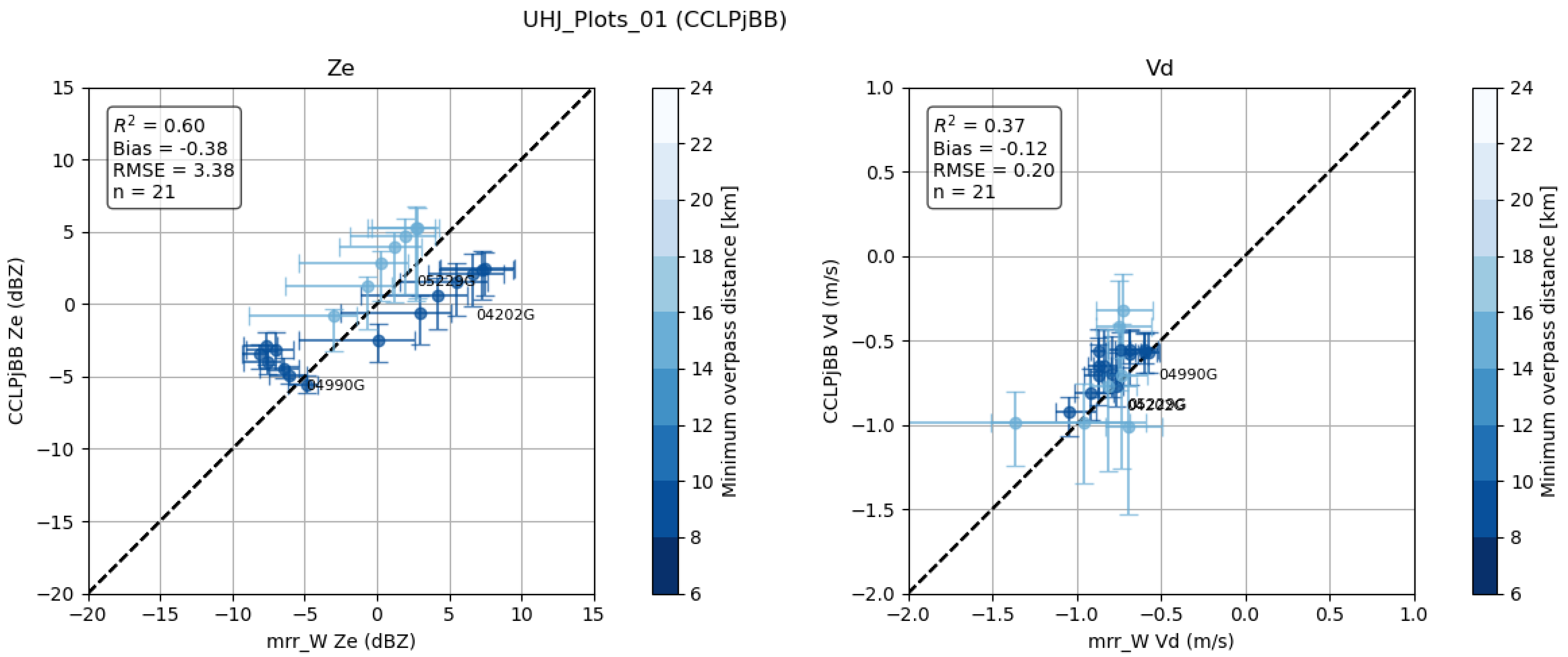


Results: Scatterplots

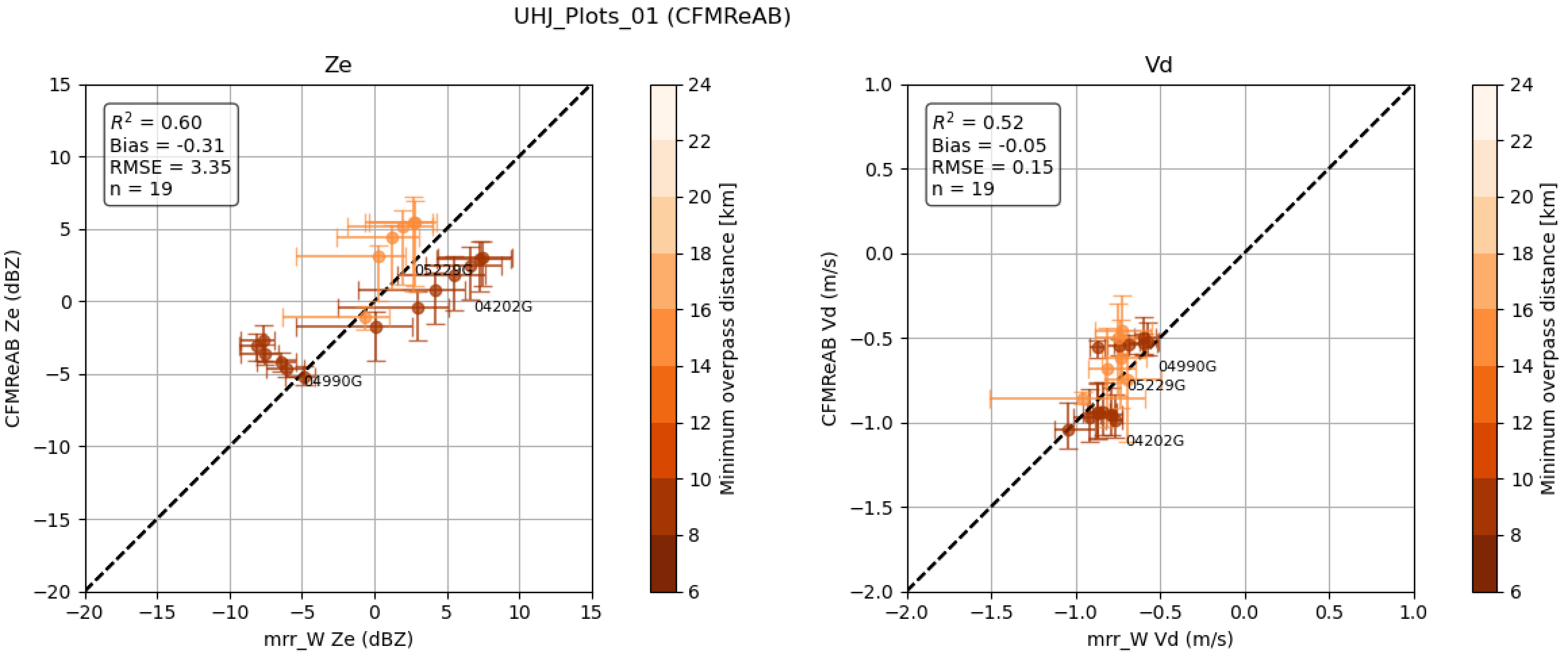


The overlap between 500 and 1200 m a.s.l. on the common vertical grid allows 1:1 comparisons

Results: Scatterplots



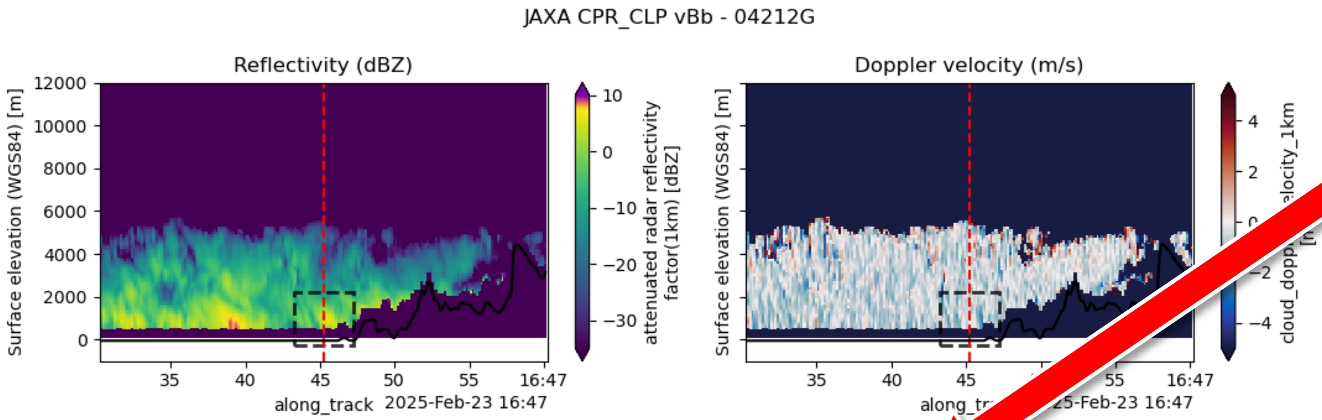
Results: Scatterplots

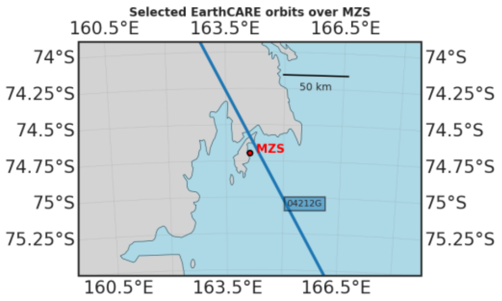


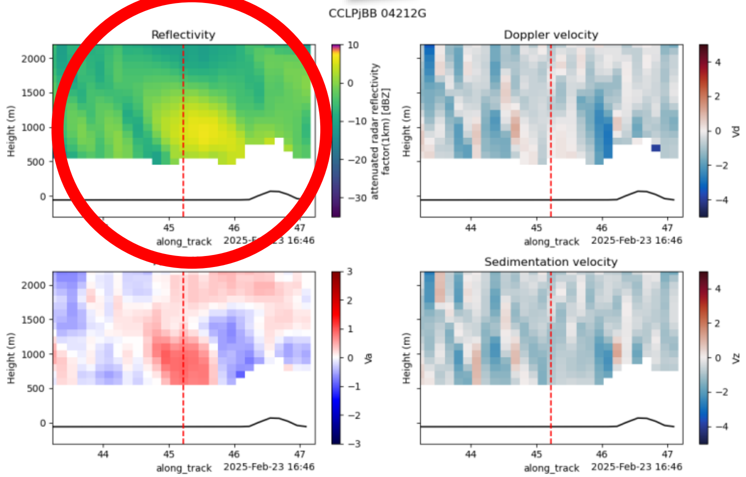
Results: Virga

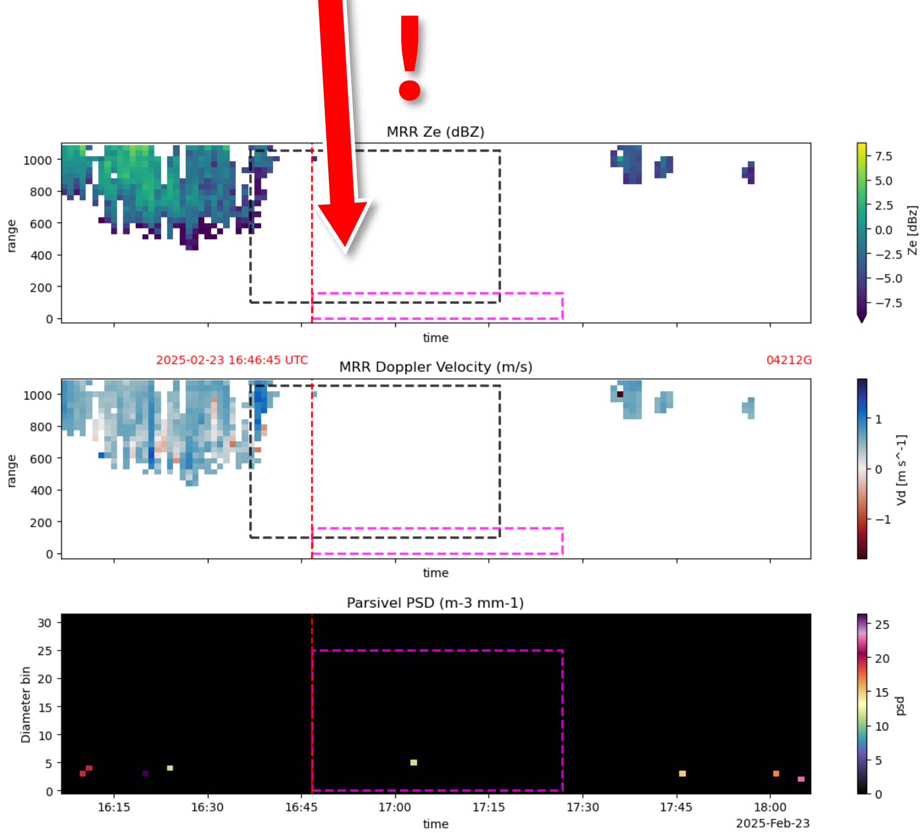
EarthCARE sees a cloud, likely precipitating…

…but nothing seems to reach the ground!









Ground instruments are needed to resolve this ambiguity.

No particles detected by Parsivel

Conclusions

Key messages:

- There are processes in the first 500 meters of atmosphere
- EarthCARE is not able to measure so close to the ground due to clutter
- The gap can be closed through synergy between ground observations
- K2W can provide converted W-band profiles of eq. reflectivity and Doppler velocity, and an estimate of the vertical air motion

Next steps:

- Include a correction for air motion into K2W (work in progress)
- Include microphysical variability, to validate Reff, IWC, etc..
- Scale up towards a validation based on statistics rather than 1:1 match-up

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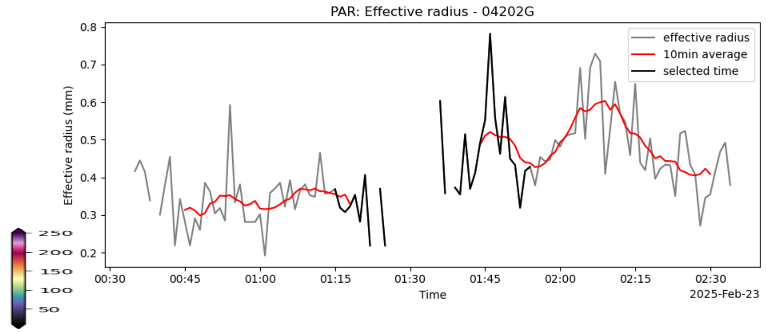
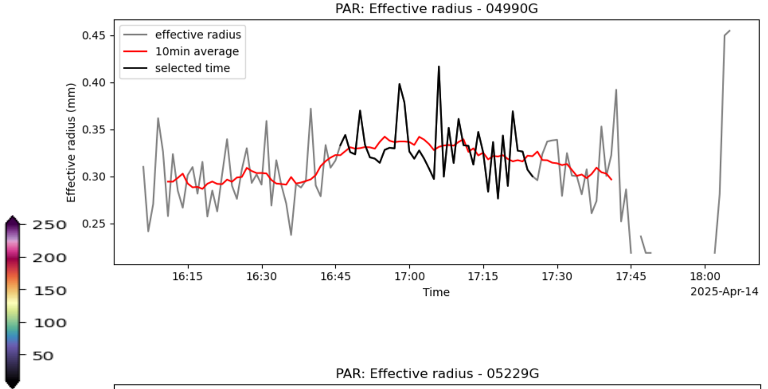
Photo: Giacomo Roversi

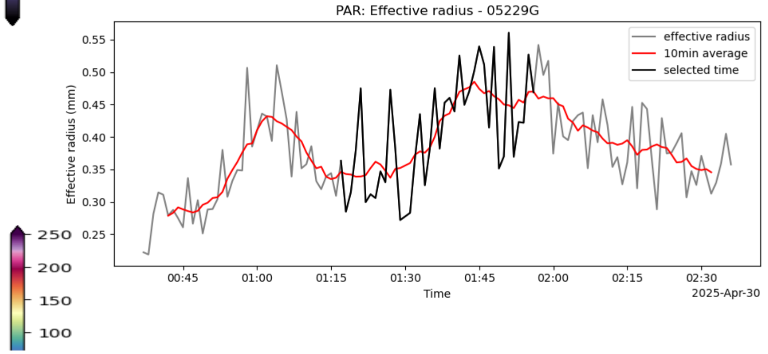
Thanks for your attention!

Ice effective radius r_{eff}

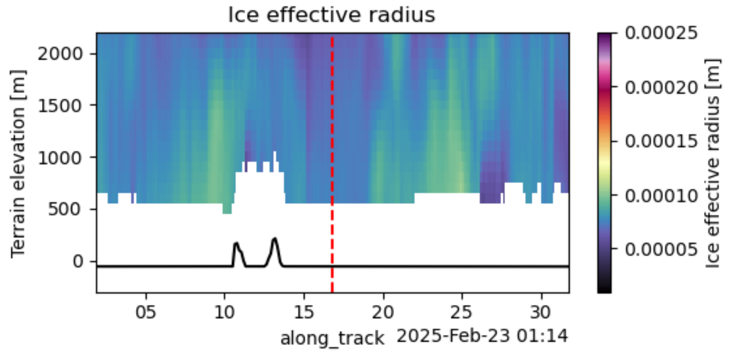
Parsivel

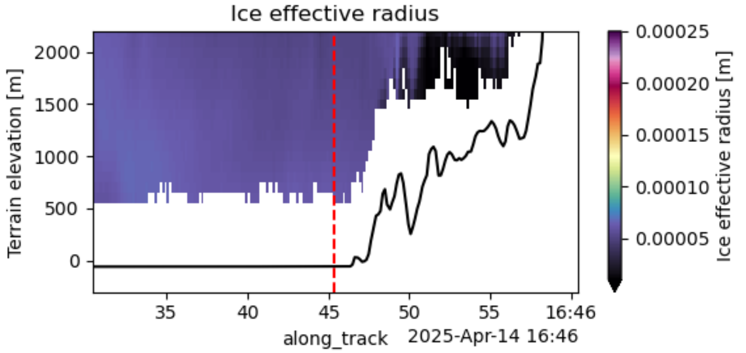


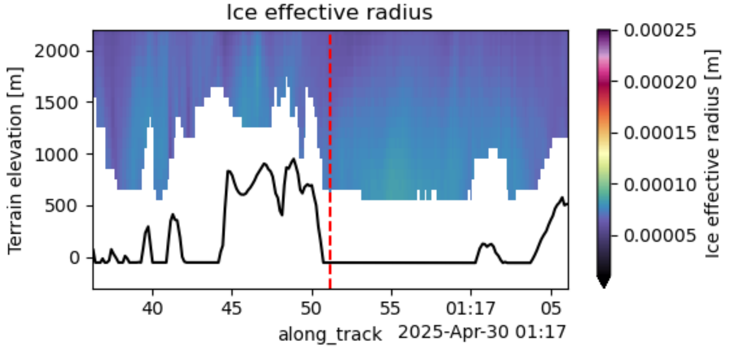




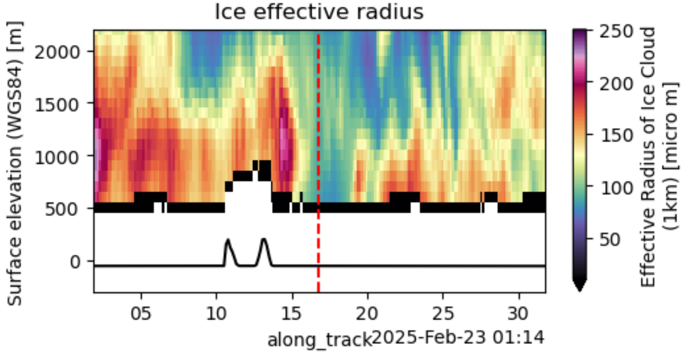
ACM-CAP (BB)

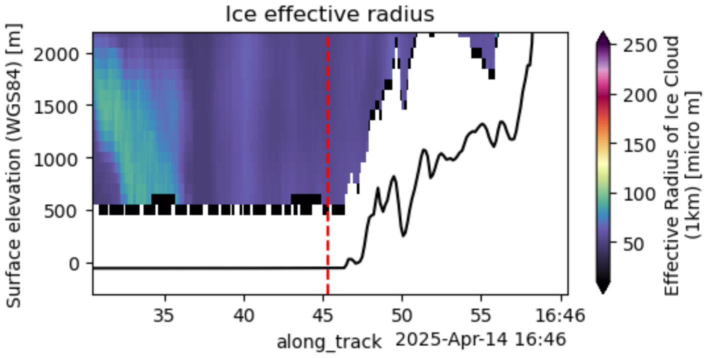


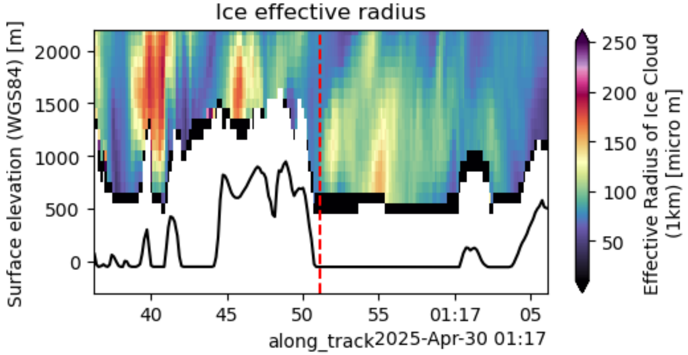




CPR-CLP (vBb)

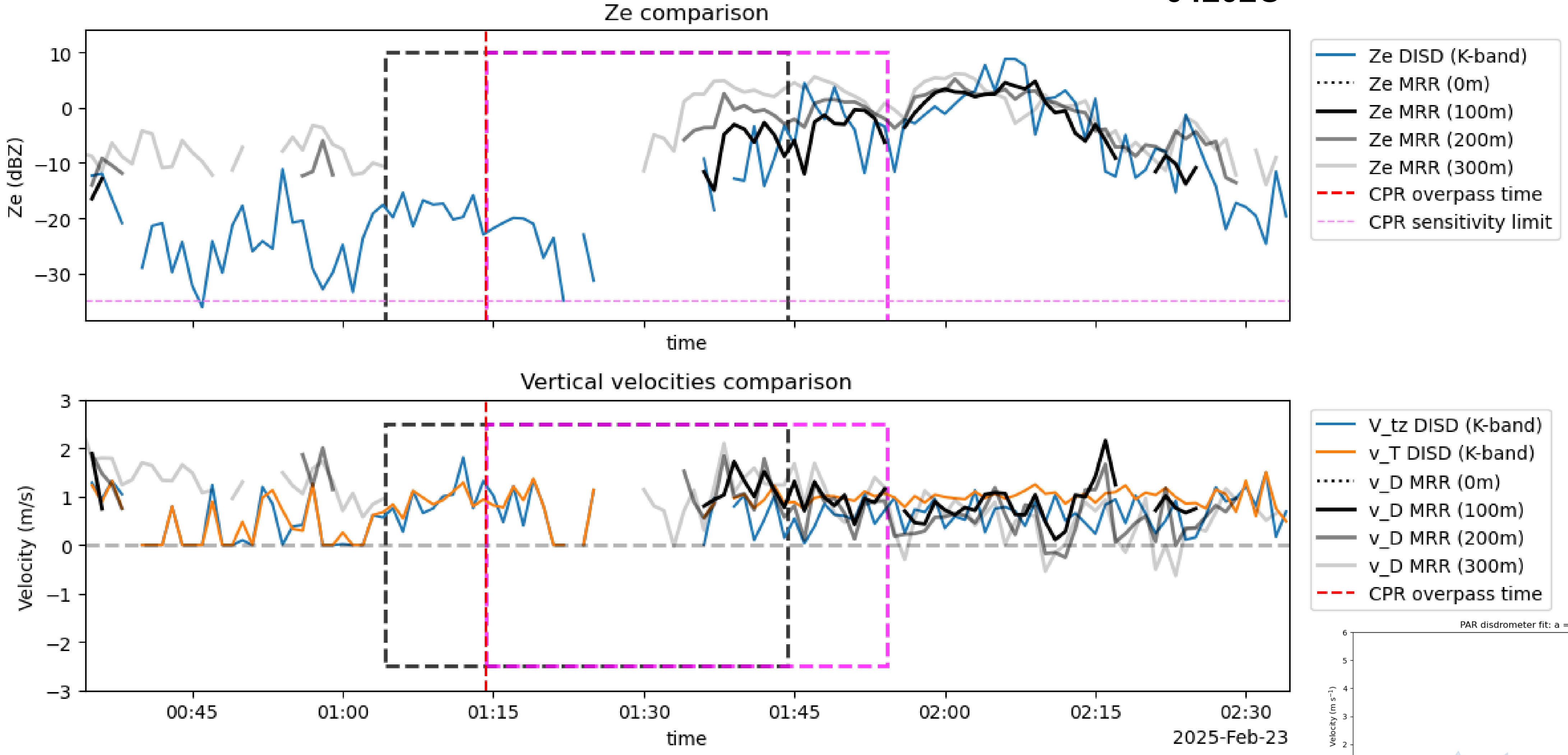


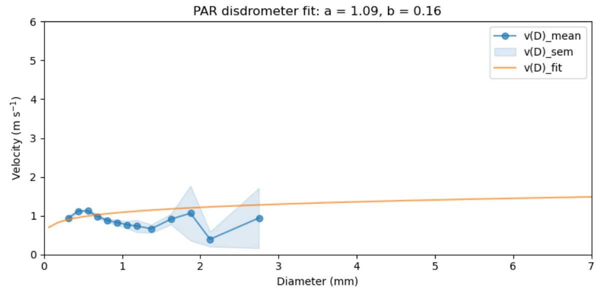




Ground instruments time-serie (1 min resolution)

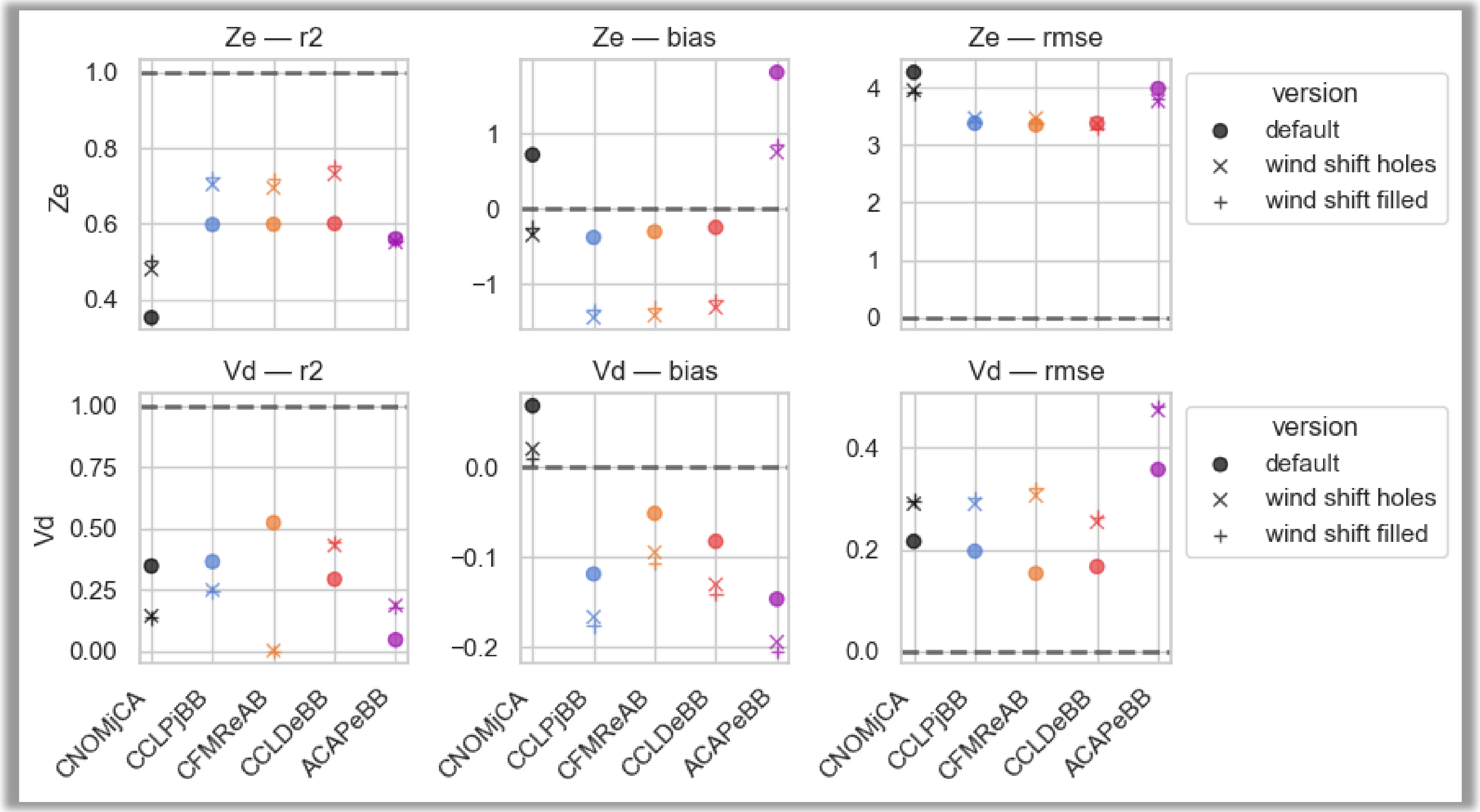
04202G





Vertical air motion correction inside K2W

Scores against MRR
K2W reconstructed W-band



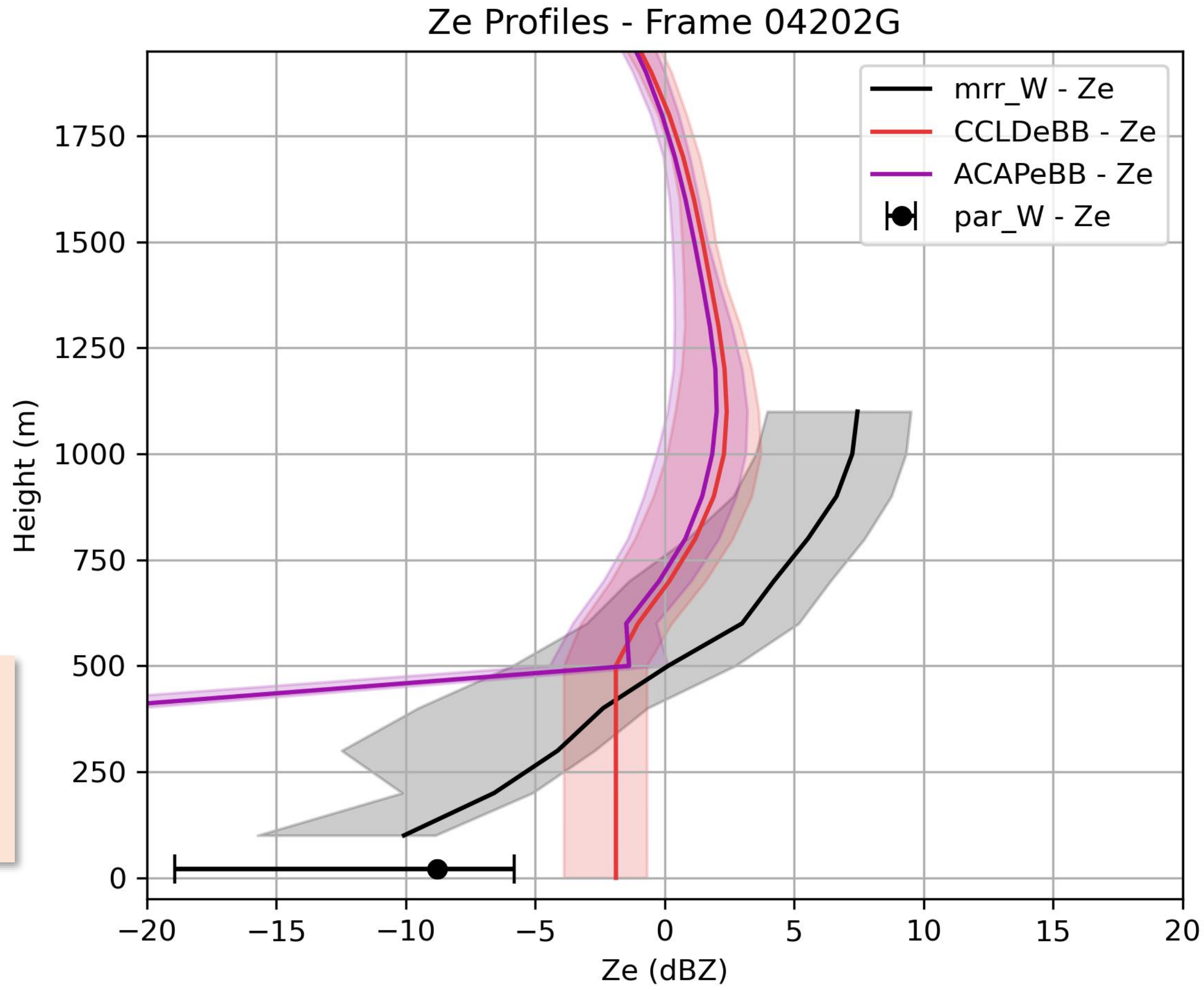
Different corrections based on estimated vertical air motion

Level 1 + clutter mask

Level 2A 1km integrated

Level 2A/B forward modelled

Results: Reflectivity from forward modelled variables



ACM-CAP_BB here shows very low reflectivity values in the ground clutter

CPR-CLD_BB here fills the ground clutter with a constant Ze profile

L2B Outputs of optimal estimation retrieval models (forward)

Results: forward modelled variables

04202G

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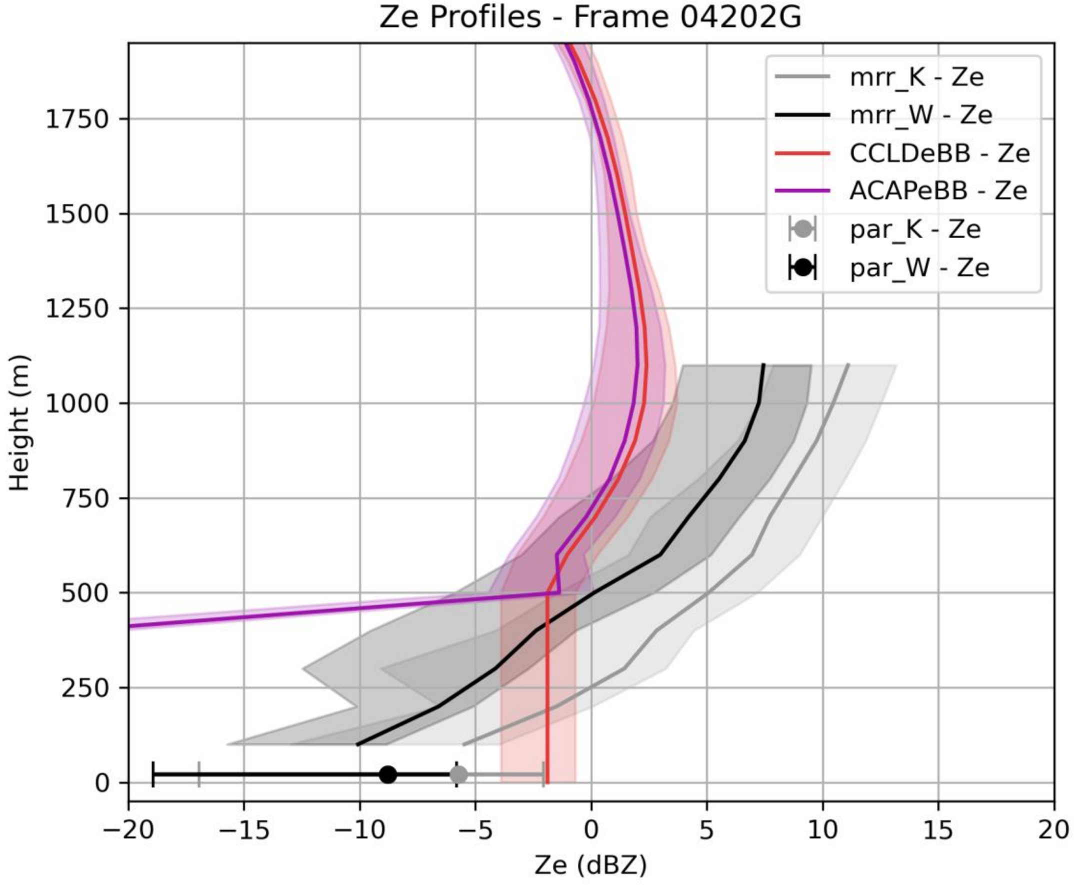

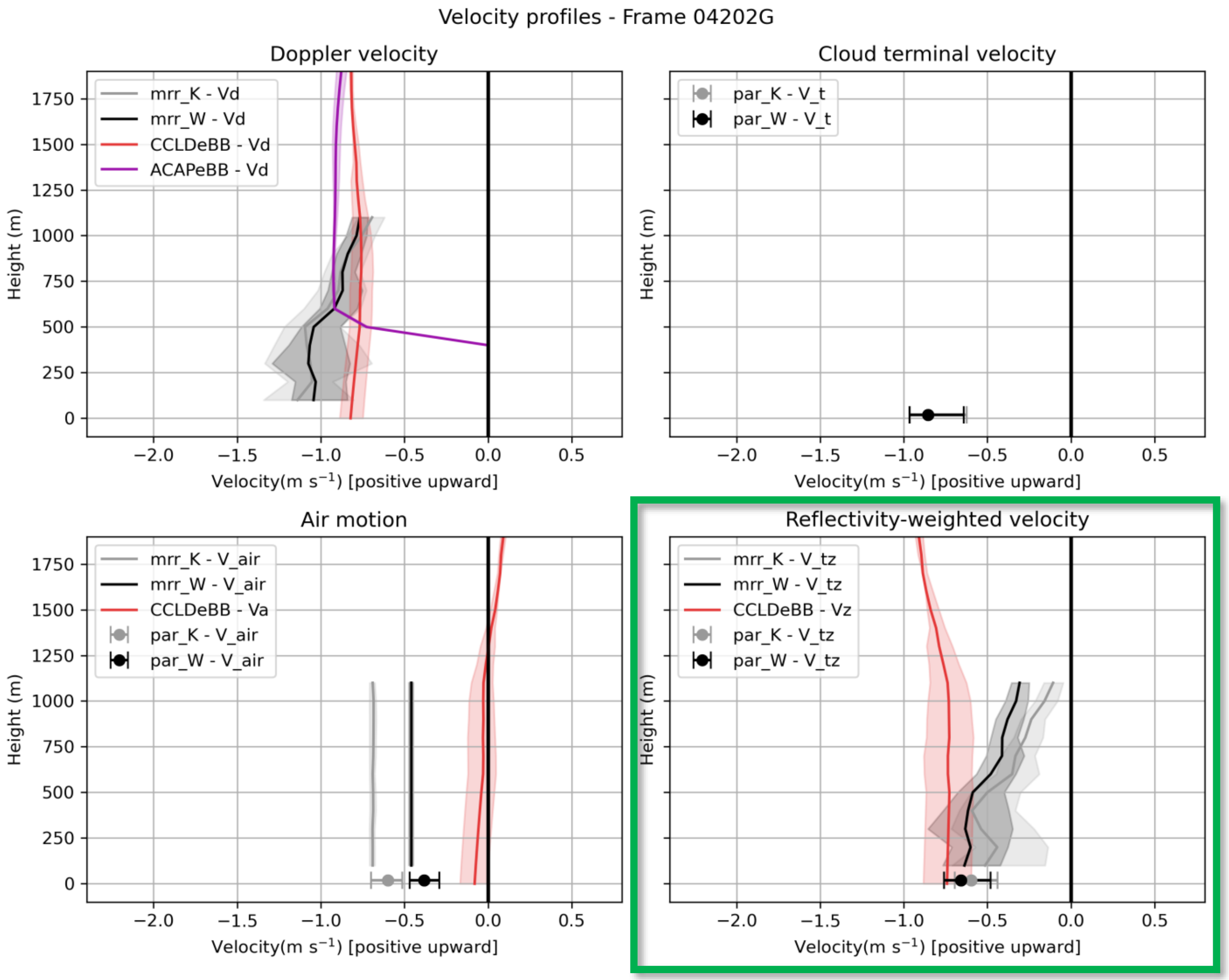

Results: forward modelled variables

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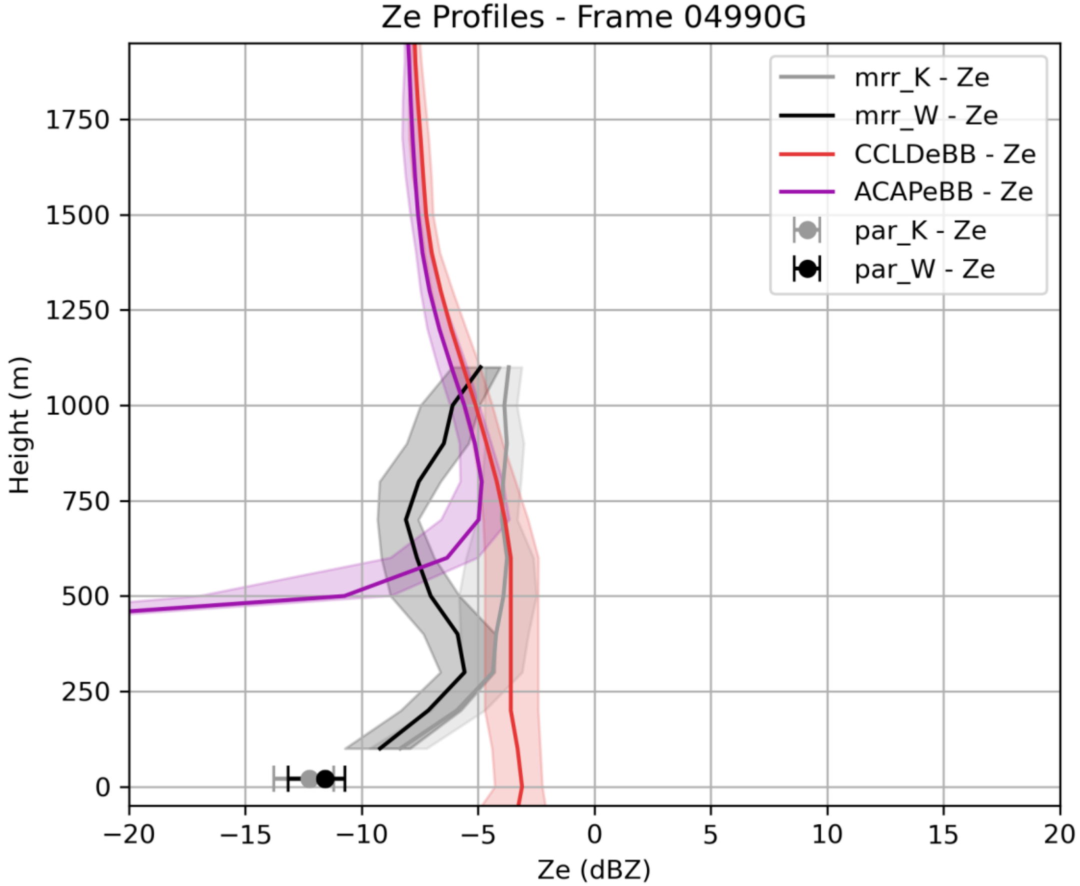

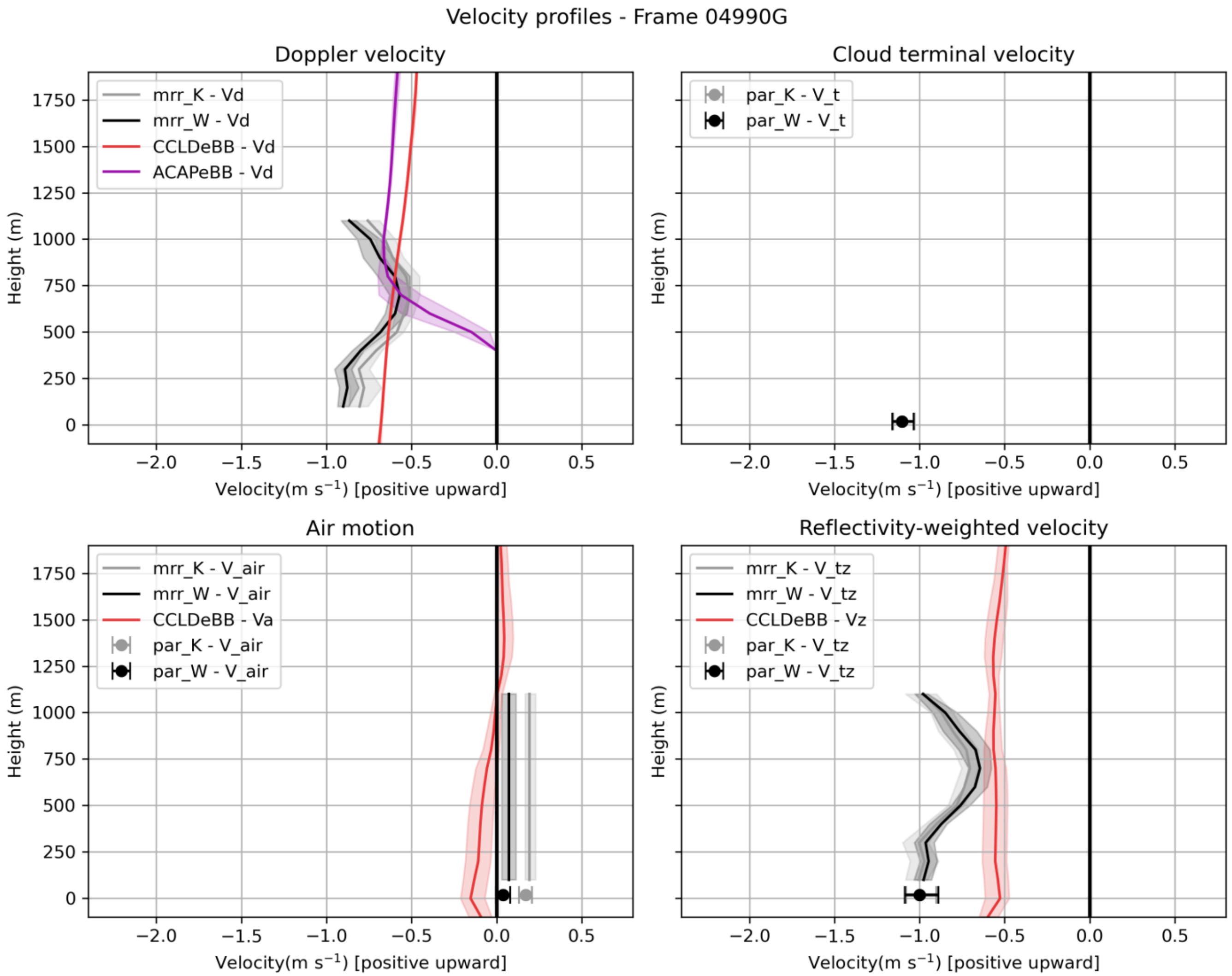

Results: forward modelled variables

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