Assessing CPR radar reflectivity and doppler products with airborne observations from the PERCUSION campaign

F. Ewald[1], S. Groß[1], T. Kubota[2], S. Aoki[2] and the PERCUSION team

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2) Japan Aerospace Exploration Agency (JAXA), Earth Observation Research Center, Tsukuba-city, Japan

2nd ESA-JAXA EarthCARE In-Orbit Validation Workshop

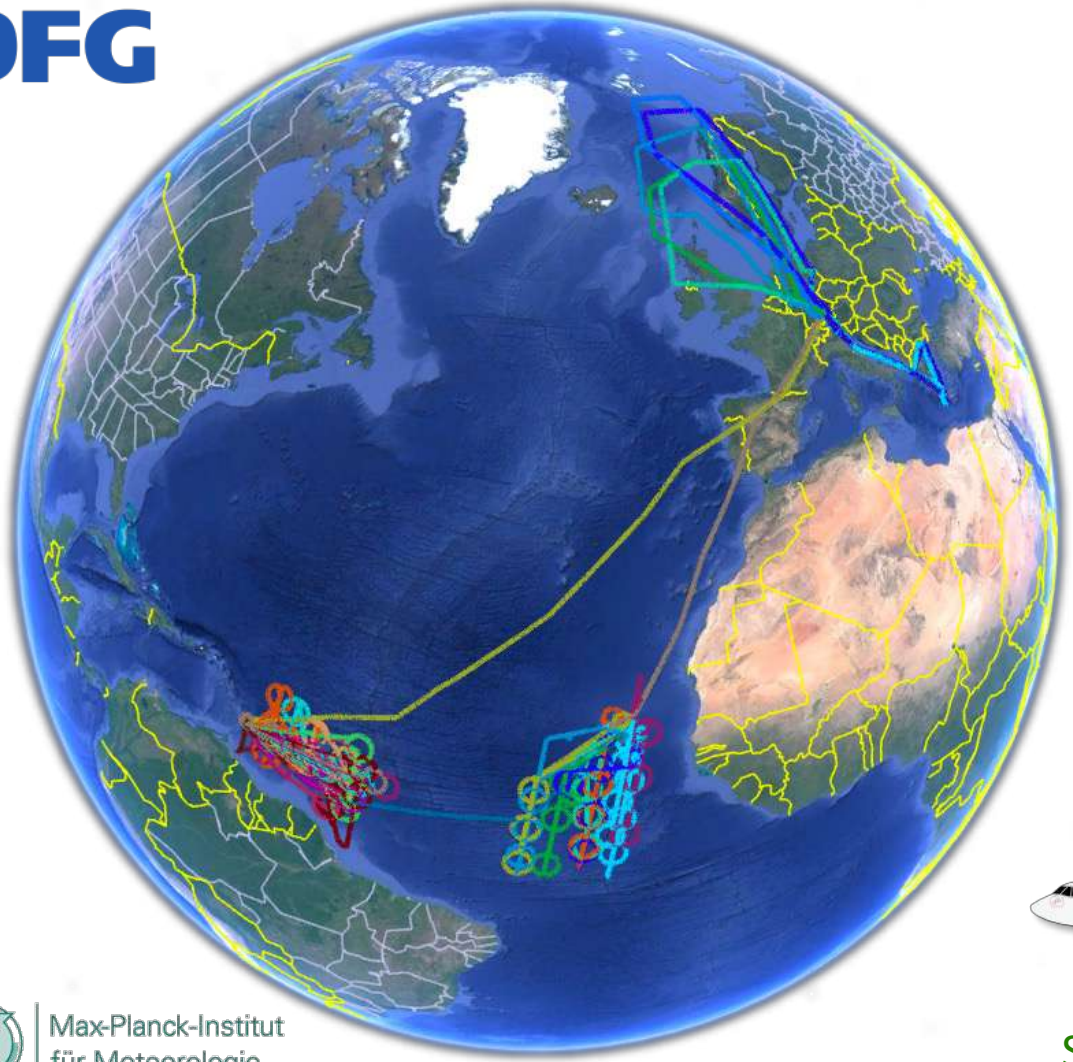
17 – 20 March 2025 | ESA-ESRIN | Frascati (Rome), Italy

PERCUSION

Persistent EarthCARE underflight studies of the ITCZ and organized convection

PERCUSION – A campaign with a focus on validation

Persistent EarthCARE underflight studies of the ITCZ and organized convection



Campaign period
09 Aug – 19 Nov 2024

Campaign locations

- Cape Verde / Sal: ITCZ, Aerosol
- Barbados: ITCZ, Convective organization
- Germany: Dedicated validation flights

Campaign duration – 9 weeks

- 296 flight hours (incl. transfer and certification)
- 28 Scientific flights: 11 (Sal), 10 (Barbados), 7 (Germany)
- 33 EarthCARE / 4 PACE underpasses
- Embedded within the *ORCESTRA* campaign:

MAESTRO
SAFIRE ATR-42

CELLO
INCAS King Air

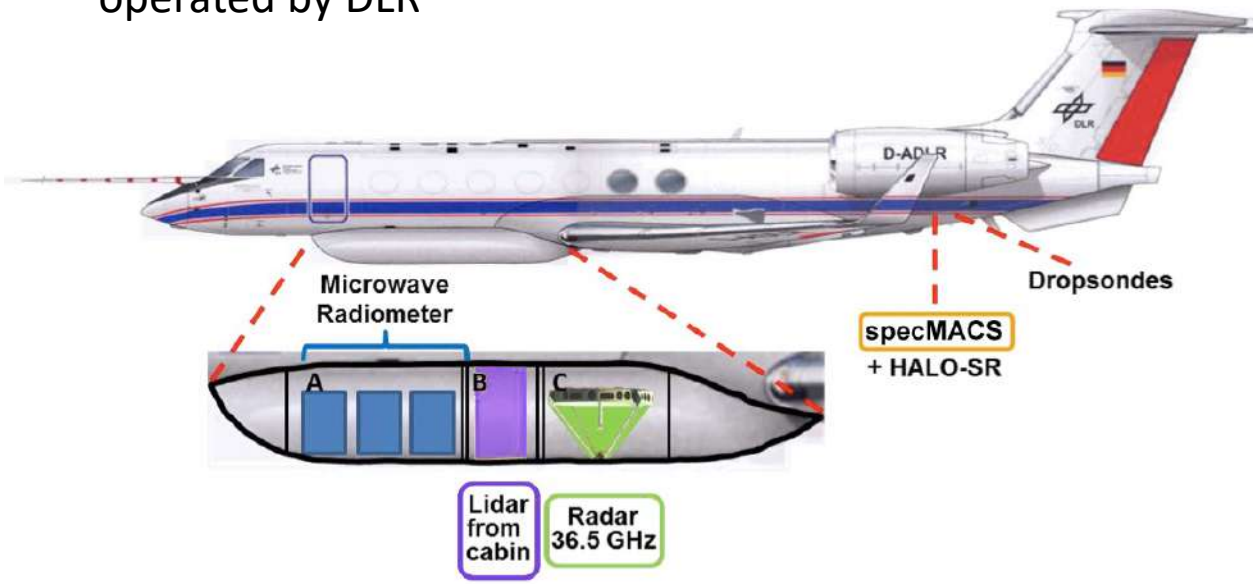
BOW-TIE / PICCOLO
RV METEOR / SEA-Pol

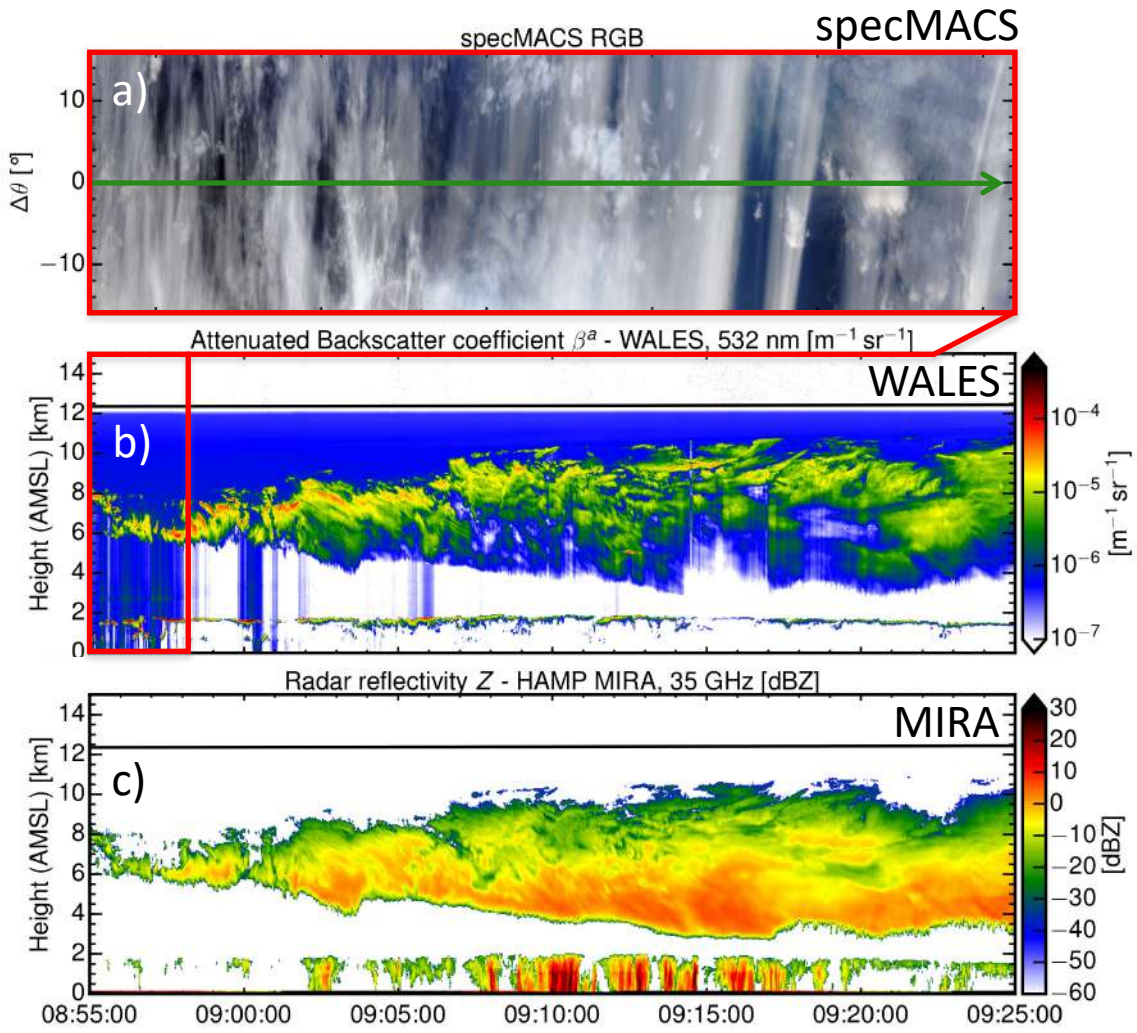
Max-Planck-Institut für Meteorologie

HALO – the High Altitude and Long Range Aircraft

The HALO remote sensing payload – a unique validation asset

- G550, max. alt 15 km / max. range: 8000 km
- In operation since 2012
- operated by DLR





Scientific Instruments

HSRL-Lidar (WALES, 532 nm – Wirth et al. 2009)

Cloud Radar (HAMP MIRA, 35 GHz – Ewald et al. 2019)

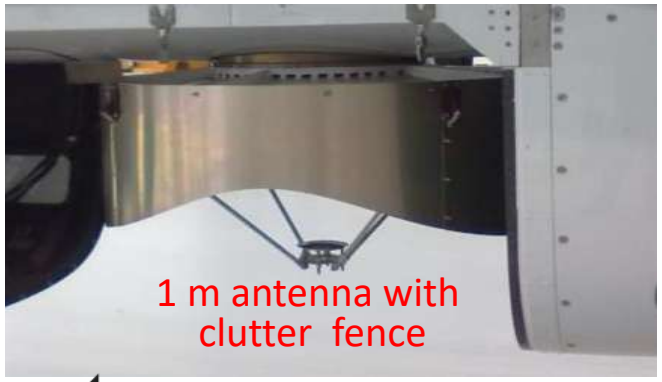
Hyper-Spektral Imager (specMACS – Ewald et al. 2016)

Microwave Radiometer (HAMP passive – Mech et al. 2014)

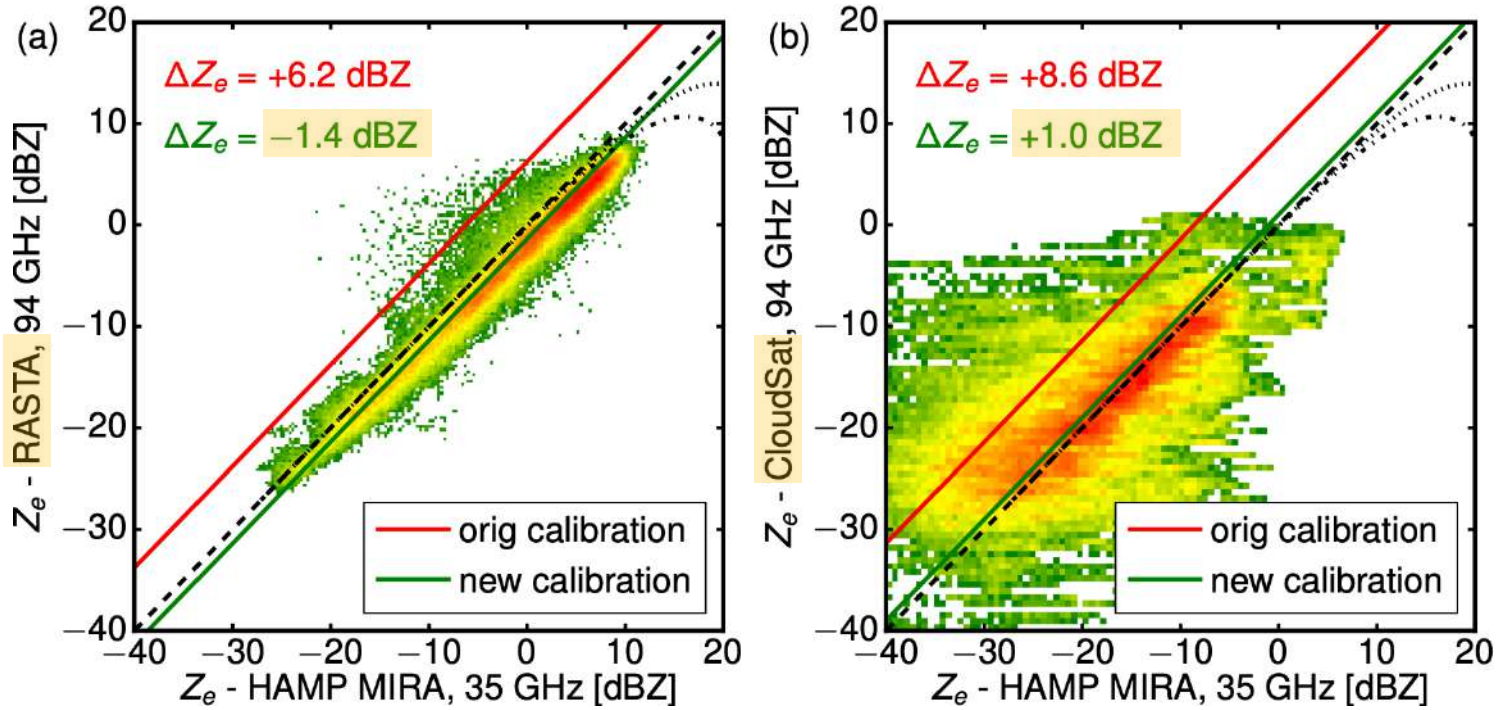
HAMP MIRA – cloud radar characteristics

HALO Microwave Package

HAMP MIRA	
Frequency	35.2 GHz
Pulse power	30 kW
Repetition rate	7.5 kHz
Range resolution	30 m
Antenna diameter	1 m
Beam width	0.6°
Footprint @ 10km	100 m
Min. detect. signal @ 10 km, 1 s integration	-42 dBZ
Effective sensitivity @ 10 km, 1 s, 200 m/s, 3° pitch	-34 dBZ



1 m antenna with clutter fence



Atmos. Meas. Tech., 12, 1815–1839, 2019
https://doi.org/10.5194/amt-12-1815-2019

Atmospheric Measurement Techniques
Open Access
EGU

Calibration of a 35 GHz airborne cloud radar: lessons learned and intercomparisons with 94 GHz cloud radars

Florian Ewald[1], Silke Groß[1], Martin Hagen[1], Lutz Hirsch[2], Julien Delanoë[3], and Matthias Bauer-Pfundstein[4]

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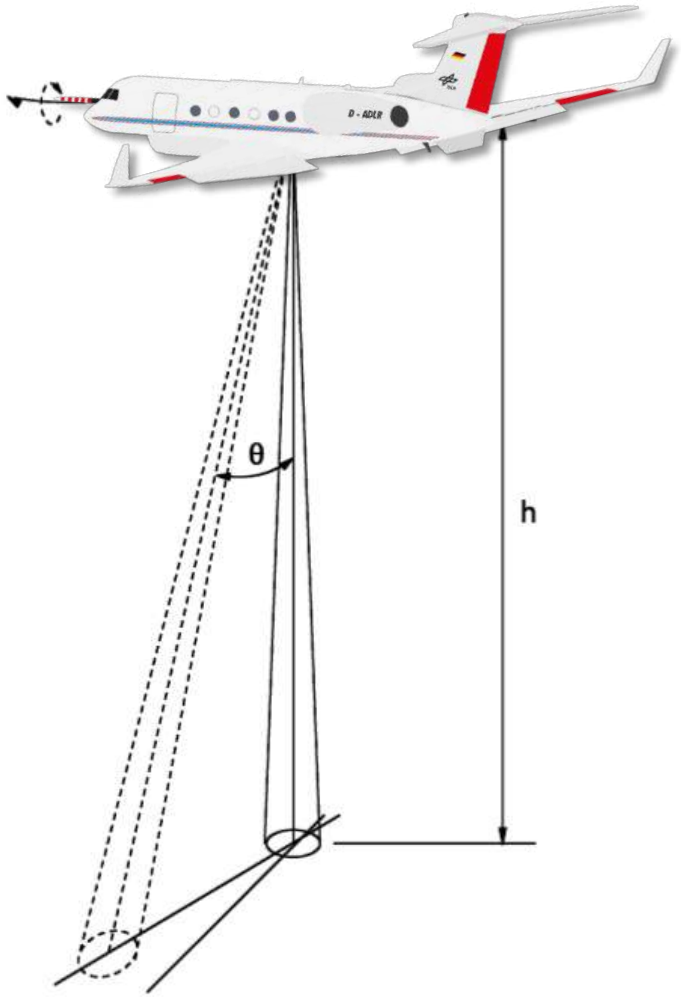
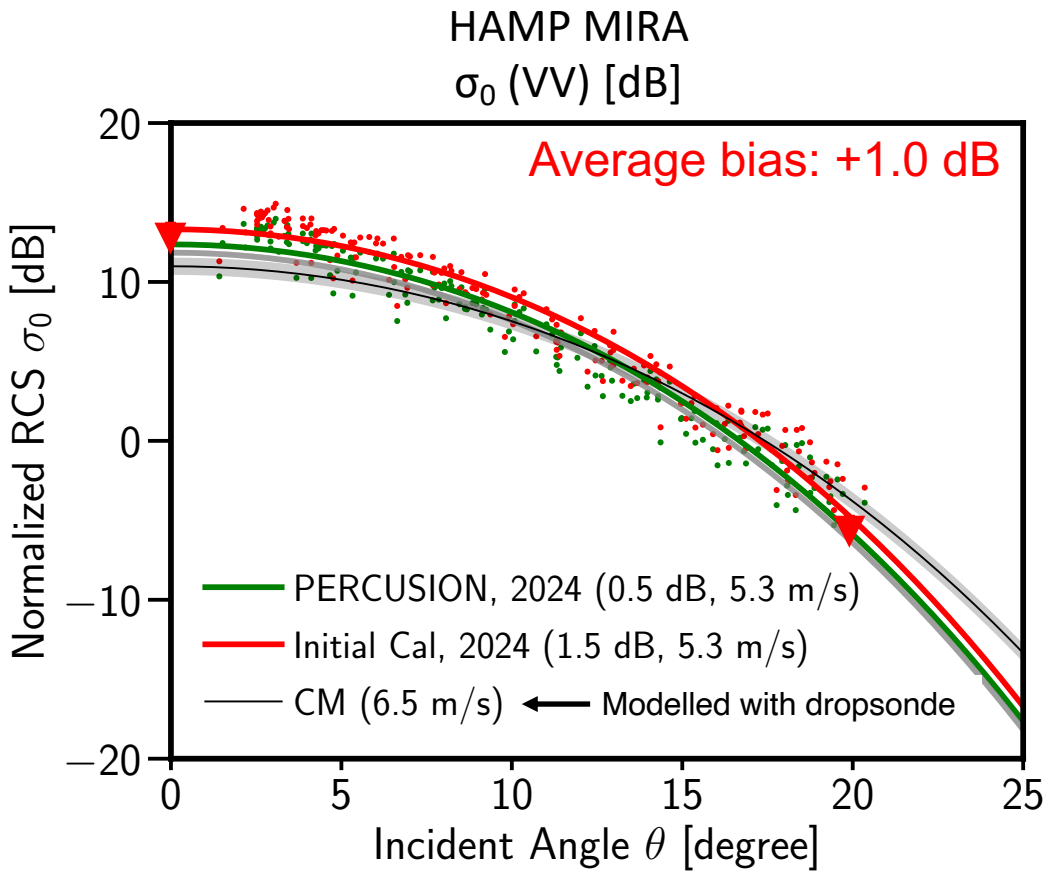
[2]Max Planck Institute for Meteorology, Hamburg, Germany

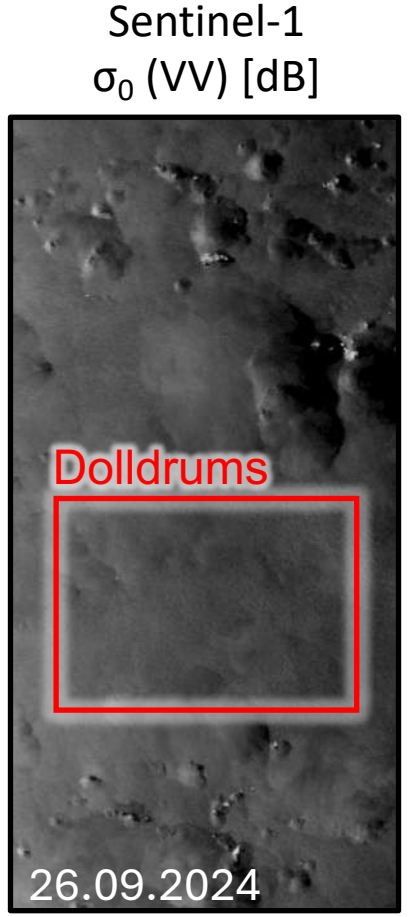
HAMP MIRA – absolut calibration during PERCUSION

Using the ocean backscatter as calibration target



following Li et al., 2005





→ ***9 successful roll*** *flight patterns during PERCUSION*

→ *Calibration finalized – publication for AMTD (2025) in prep.*

HAMP MIRA – absolut calibration during PERCUSION

Summary of all flight segments suitable for radar calibration

	date	$\Delta\sigma_0$ (old) [dB]	$\Delta\sigma_0$ (new) [dB]	u_{Fit} [m/s]	u_{Drop} [m/s]
RF04	240818	+1.23	+0.28	4.1	-
RF06	240822	+1.05	+0.10	4.2	5.3
RF10	240831	+1.46	+0.51	3.9	2.8
RF17	240919	+1.00	+0.05	5.5	4.4
RF19	240923	+0.55	-0.40	5.1	3.6
RF20	240924	+0.57	-0.38	5.7	5.4
RF21	240926	+1.47	+0.52	5.3	6.5
RF22	240928	+0.67	-0.28	3.7	5.2
RF26	241112	+0.62	-0.33	6.7	-
	avg.	**+1.0 dB**	**+0.0 dB**	**Δu = +0.03 m/s**	

→ *Initial radar reflectivity bias of +1.0 dB (RMSE: 0.35 dB), no drift during campaign*

→ *Fitted wind speed (U10) bias of -0.03 m/s (RMSE: 1.27 m/s) vs. last dropsonde height (ca. 10 – 25 m)*

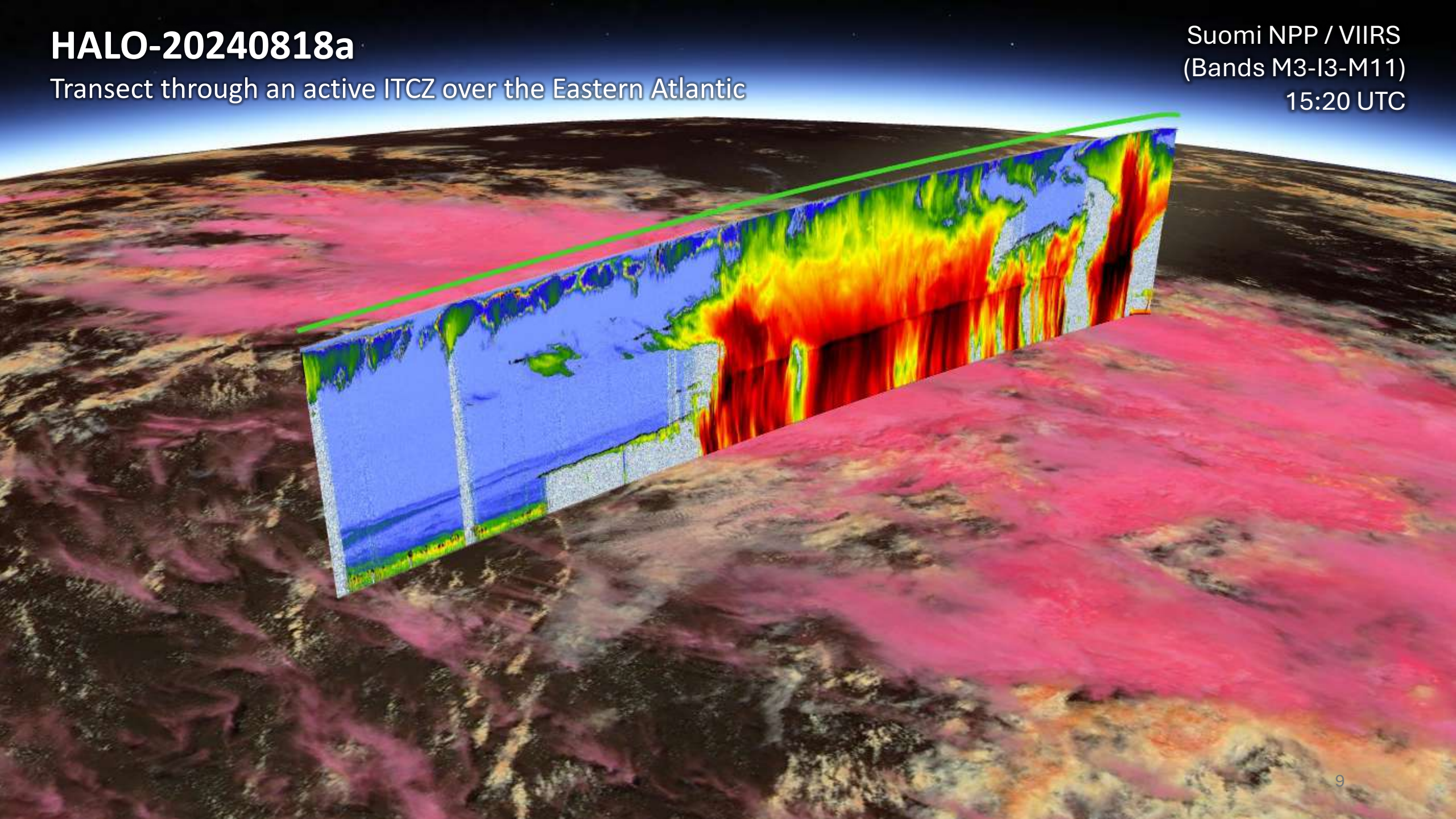
CPR Validation

Comparisons with L1 and L2 products

HALO-20240818a

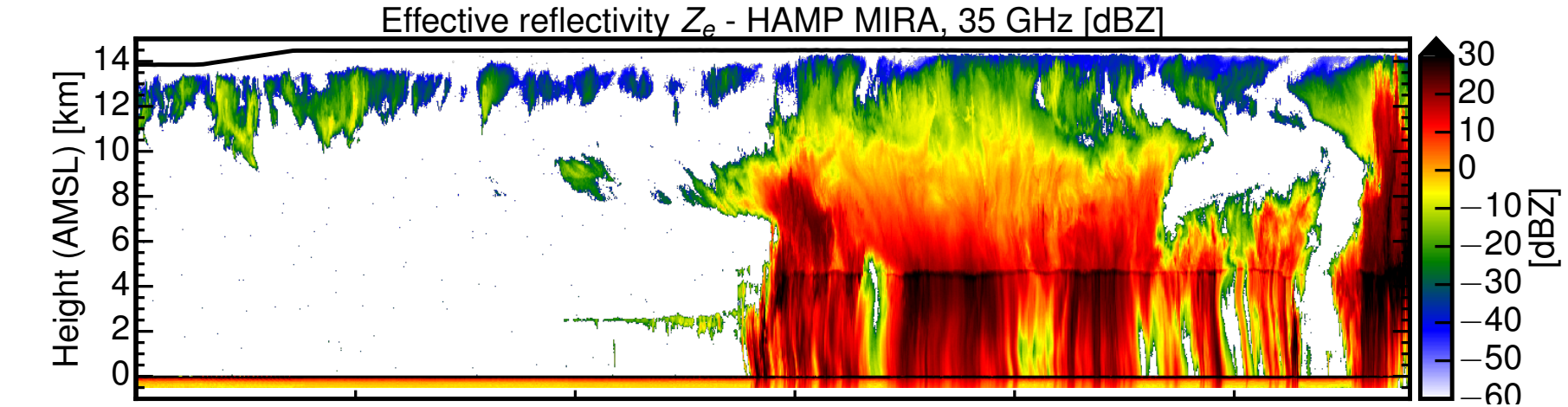
Transect through an active ITCZ over the Eastern Atlantic

Suomi NPP / VIIRS
(Bands M3-I3-M11)
15:20 UTC

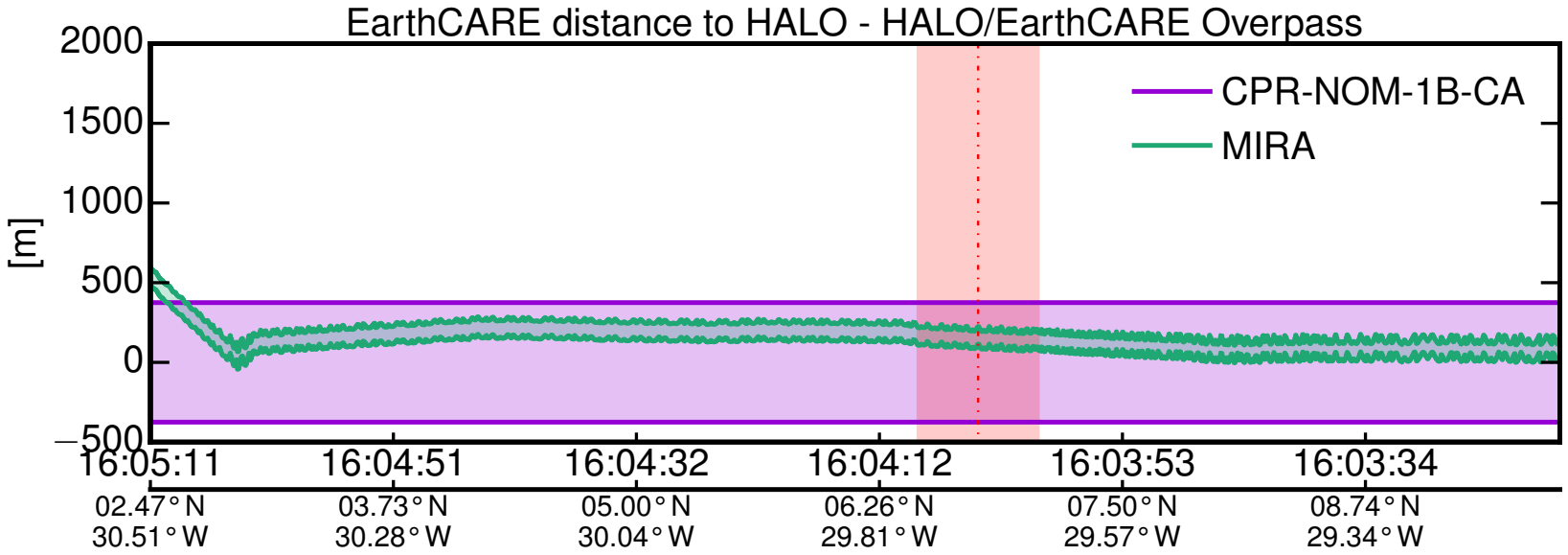


HALO-20240818a – HALO measurement

Observed radar reflectivity (MIRA) and underpass precision



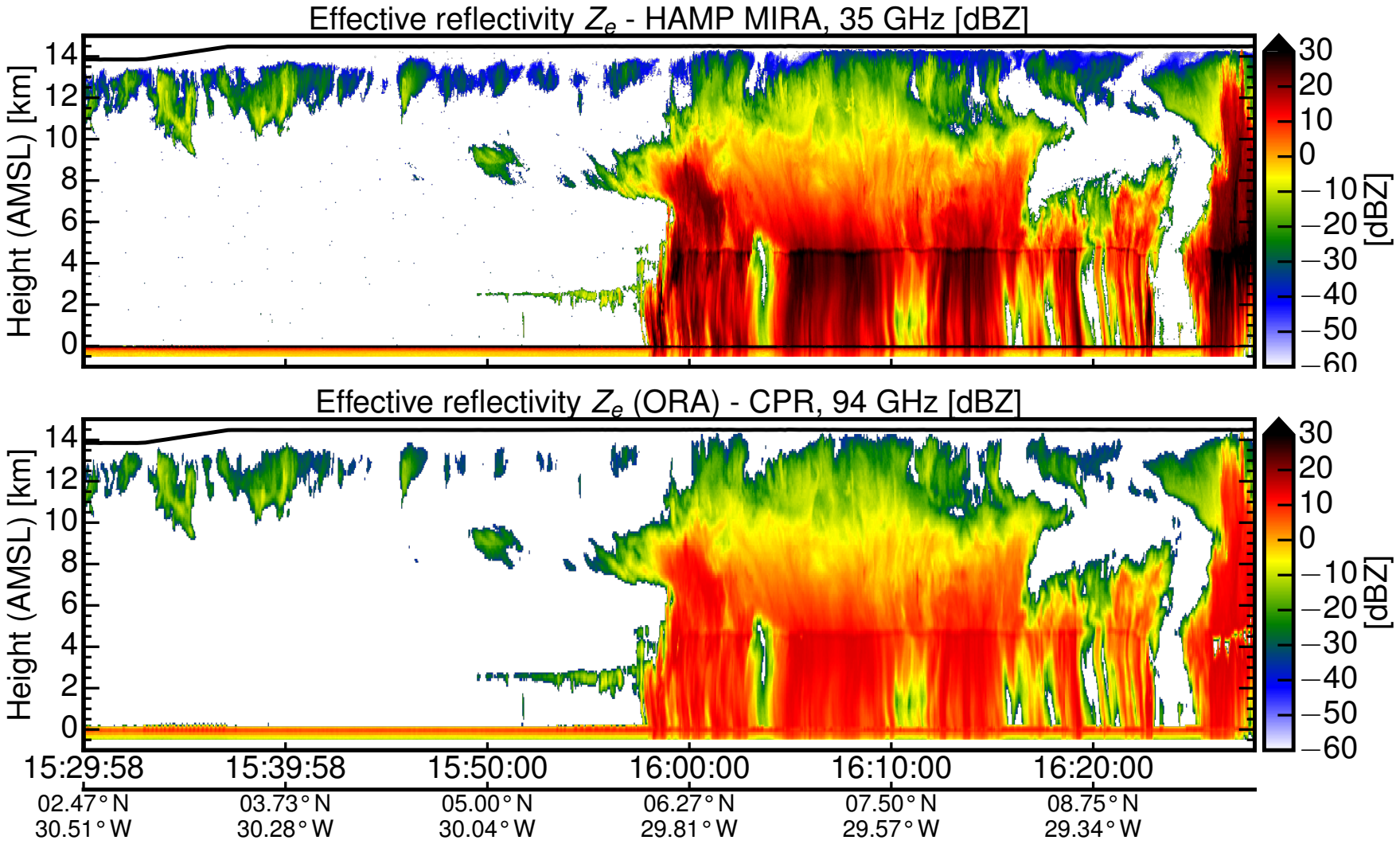
MIRA
Radar reflectivity



EC Track
Lateral deviation

HALO-20240818a – Simulation of L1 radar reflectivity

Observed and simulated radar reflectivity (MIRA)



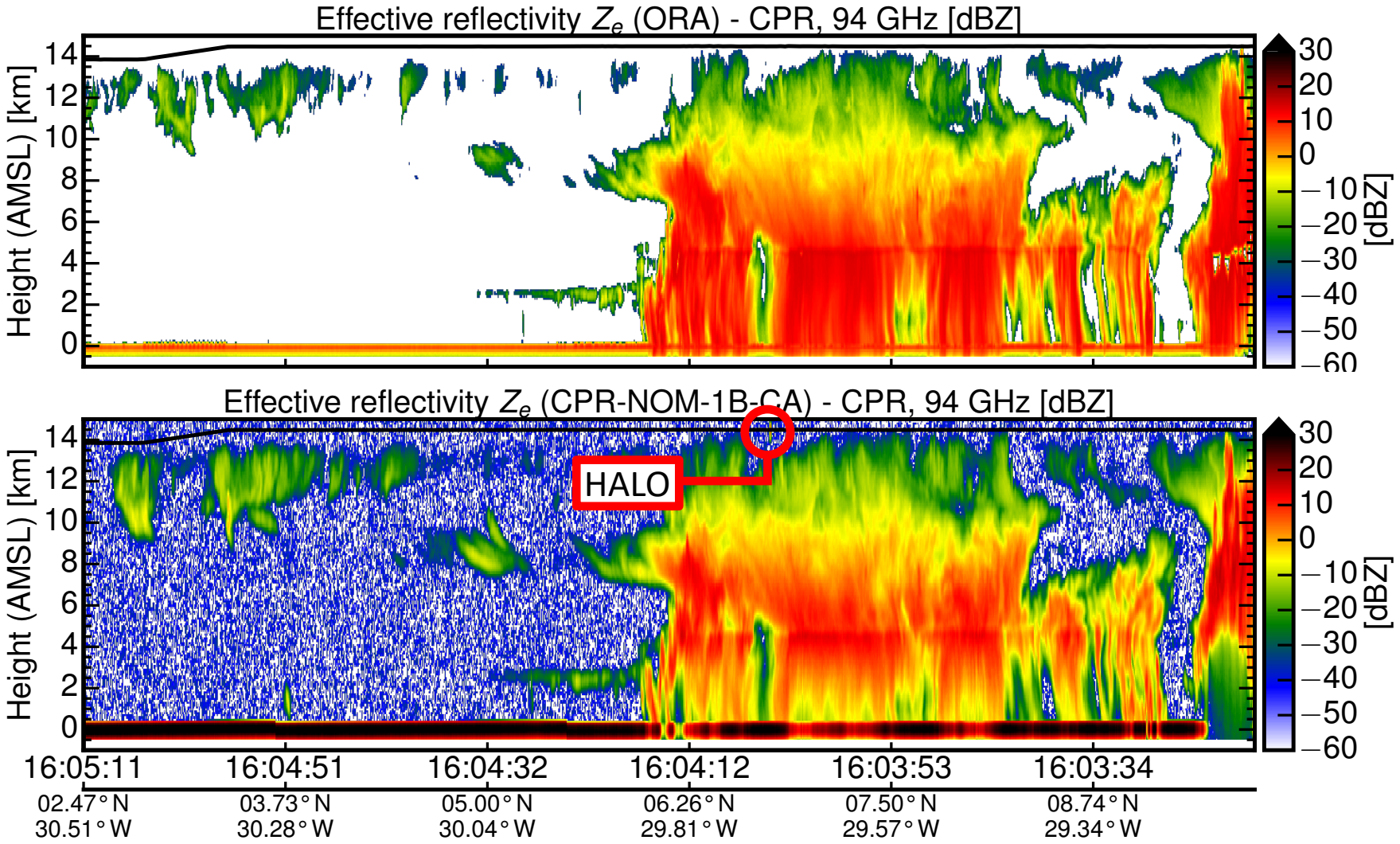
MIRA
Radar reflectivity

Orbital-Radar.py
CPR Simulator
Pfitzenmaier et al GMD, 2025

MIRA → CPR
Radar reflectivity

HALO-20240818a – Comparison of L1 radar reflectivity

Simulated (MIRA) and observed (CPR) radar reflectivity

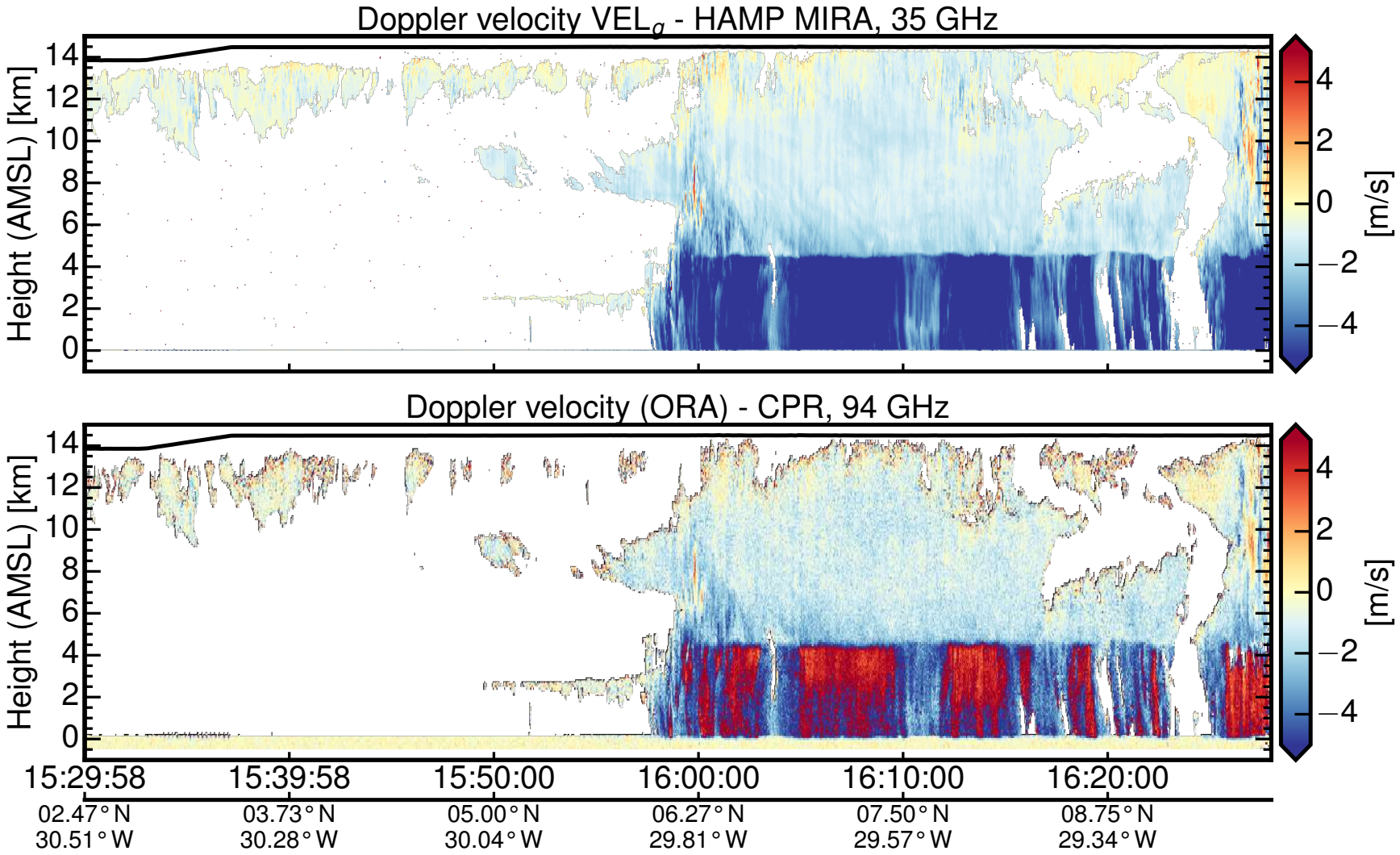


MIRA → CPR
Radar reflectivity

CPR-NOM-1B
Radar reflectivity (CA baseline)

HALO-20240818a – Simulation of L1 doppler velocities

Observed and simulated radar reflectivity (MIRA)



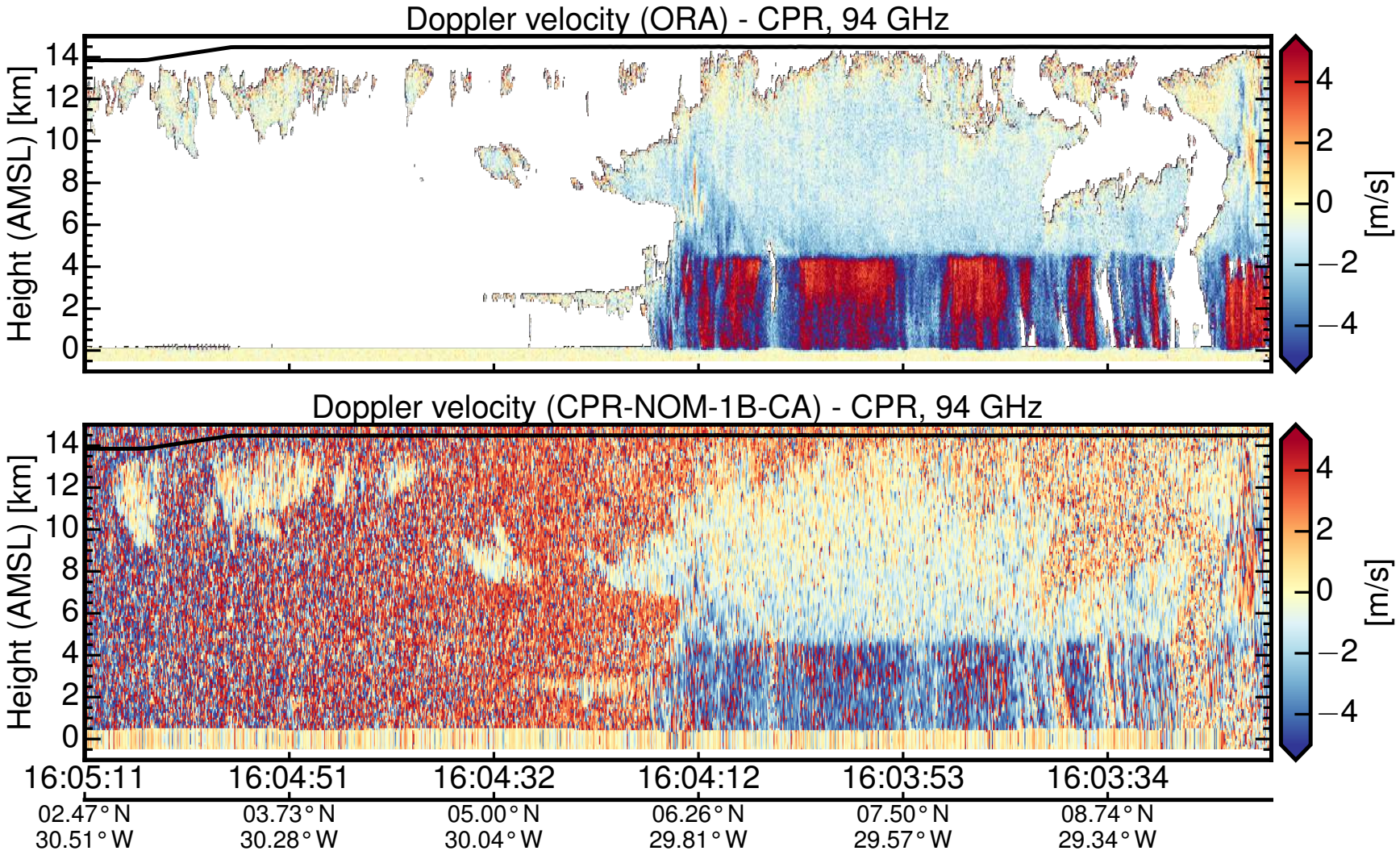
MIRA
Doppler velocity

Orbital-Radar.py
CPR Simulator
Pfitzenmaier et al GMD, 2025

MIRA → CPR
Doppler velocity

HALO-20240818a – Comparison of L1 doppler velocities

Simulated (MIRA) and observed doppler velocities (CPR)

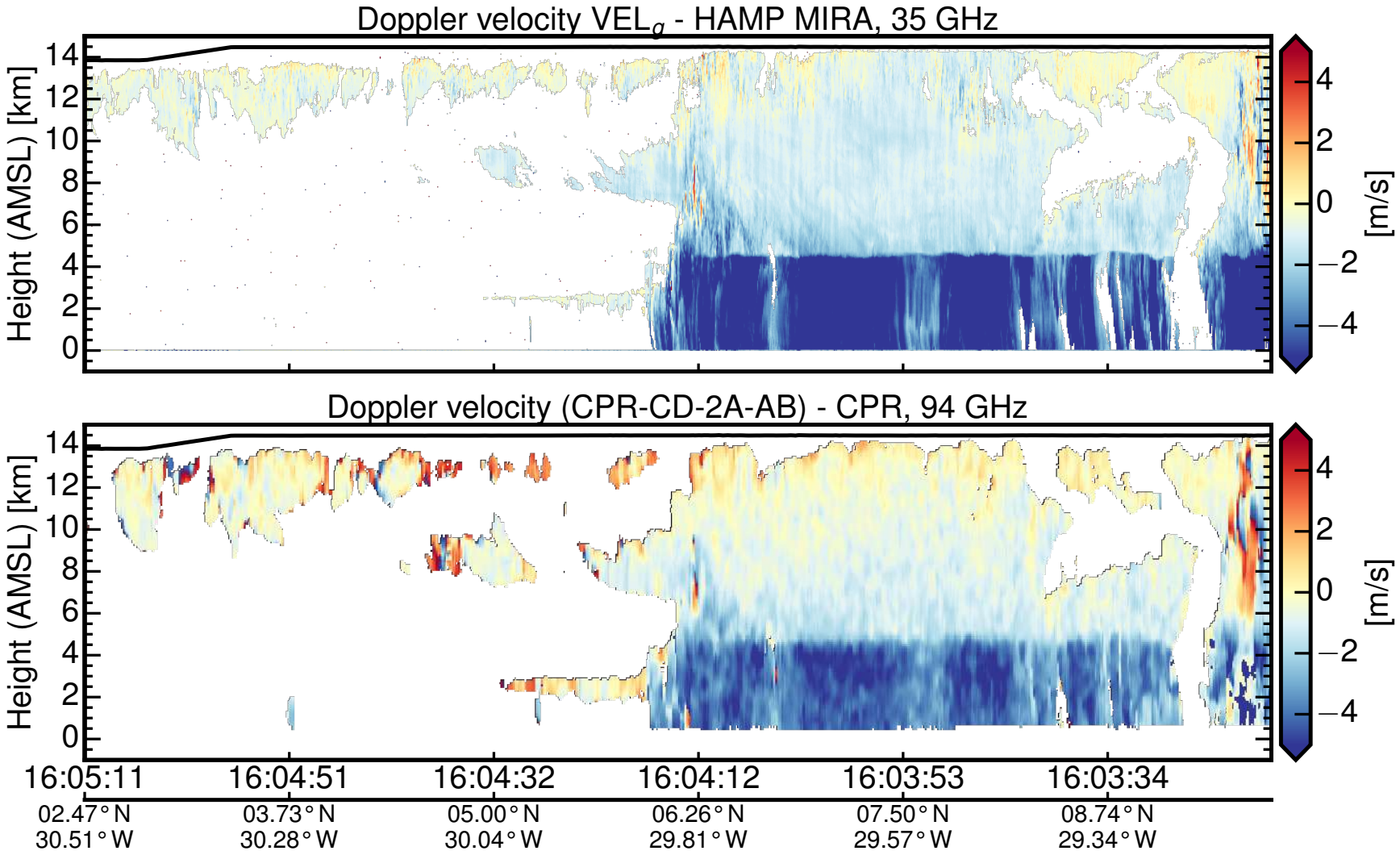


MIRA → CPR
Doppler velocity

CPR-NOM-1B
Doppler velocity (CA baseline)

HALO-20240818a – Comparison of L2 doppler velocities

Observed (MIRA) and observed doppler velocities (CPR)



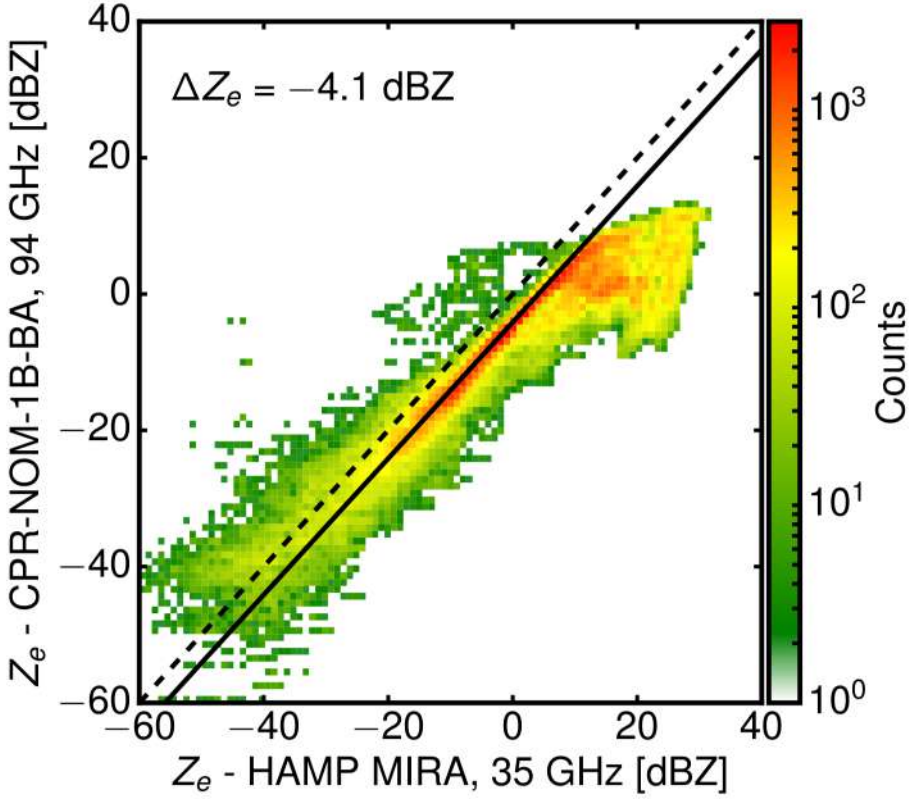
MIRA
Doppler velocity

CPR-CD-2A
Doppler velocity (AB baseline)

HALO-20240818a – Validation of CPR L1 and L2 products

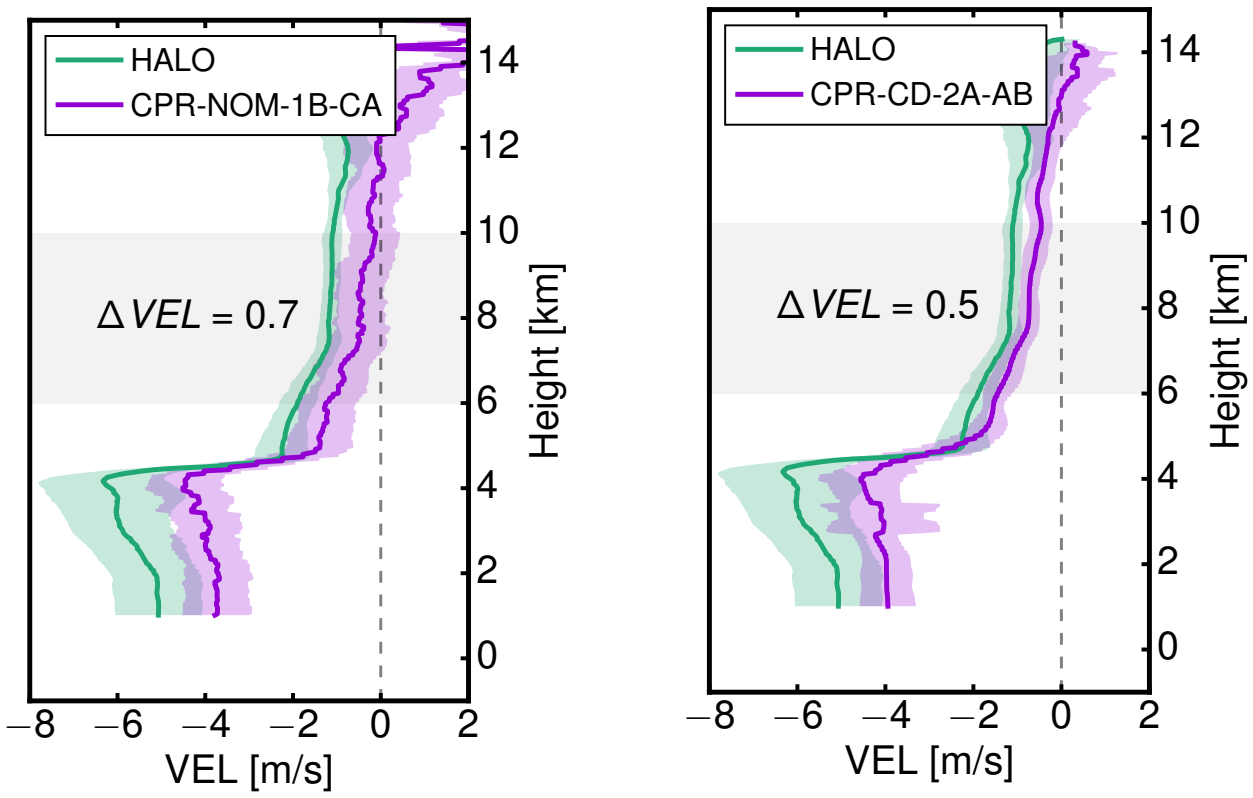
Old radar calibration (BA baseline) and doppler velocities for Z > -40 dBZ

Radar reflectivity (BA)



(Z > -40 dBZ)

Level 1 **Doppler velocity** Level 2



→ *Differences for Z > 0 dBZ and Z < -20 dBZ*

→ ***CPR-NOM-BA bias of -4.1 dB** (-20 to 0 dBZ)*

→ *+0.7 m/s bias of CPR-NOM-1B-CA*

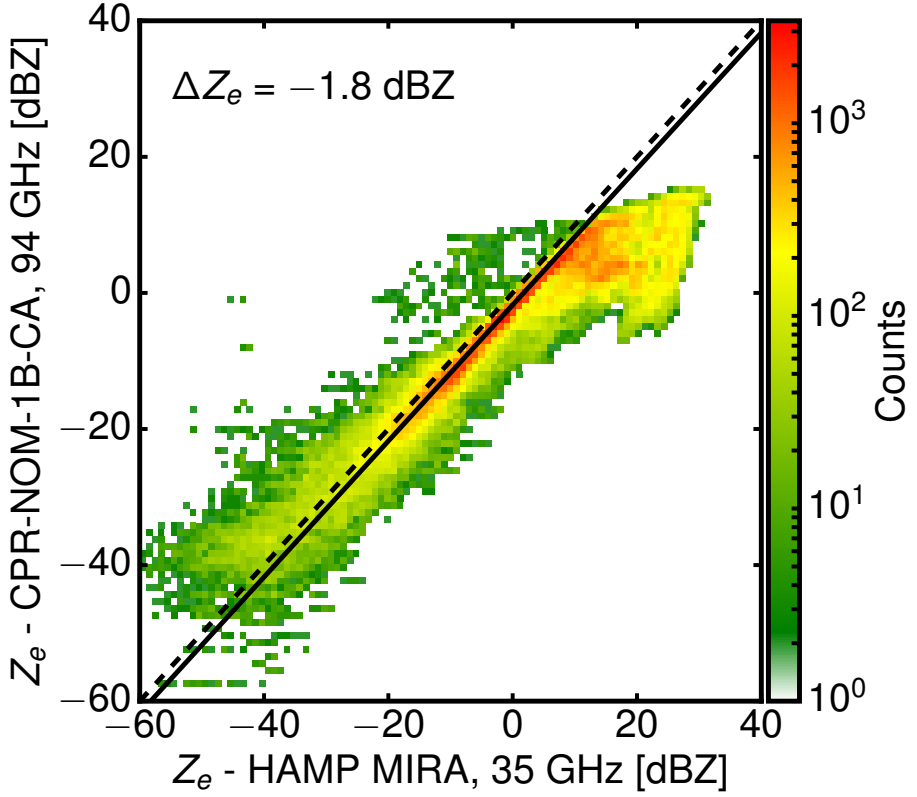
→ ***+0.5 m/s bias of CPR-CD-2A-AB***

HALO-20240818a – Validation of CPR L1 and L2 products

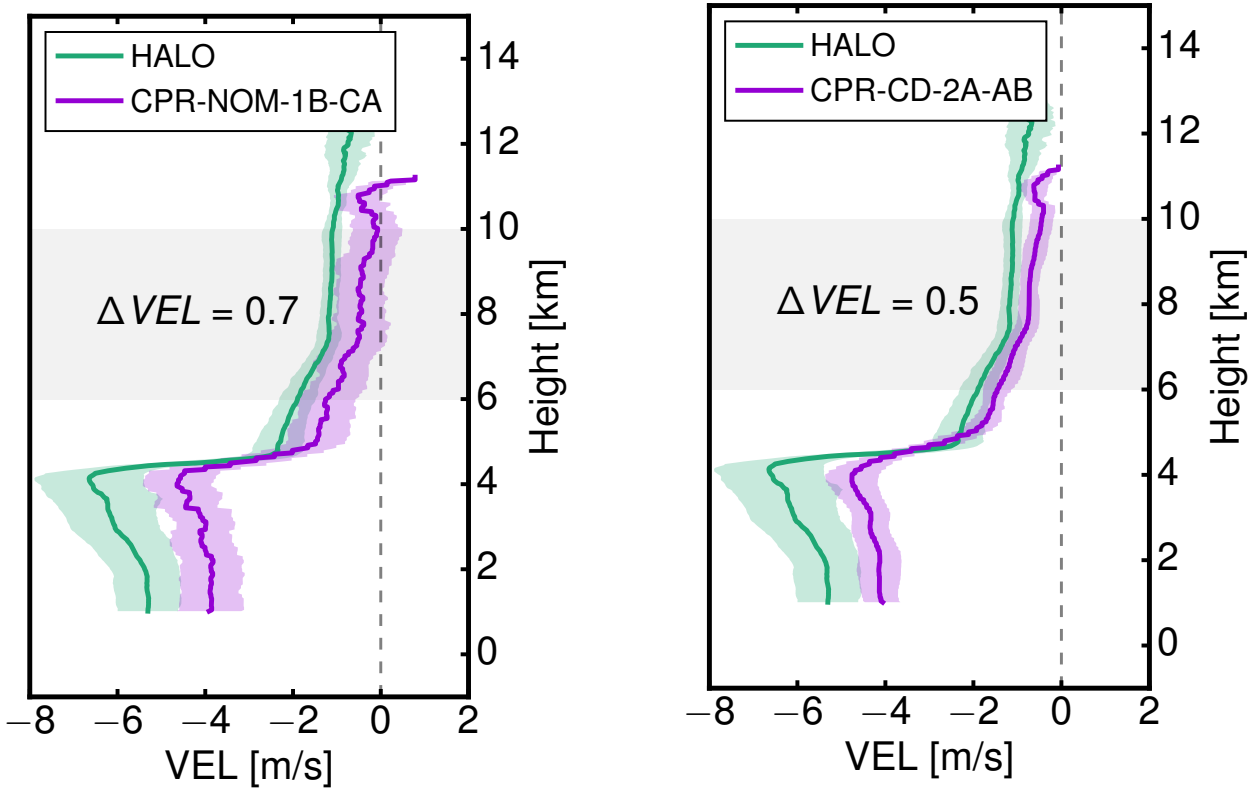
New radar calibration (CA baseline) and doppler velocities for Z > -10 dBZ

(Z > -10 dBZ)

Radar reflectivity (CA)



Level 1 **Doppler velocity** Level 2



→ *Differences for Z > 0 dBZ and Z < -20 dBZ*

→ ***CPR-NOM-BA bias of -1.8 dB*** *(-20 to 0 dBZ)*

→ *+0.7 m/s bias of CPR-NOM-1B-CA*

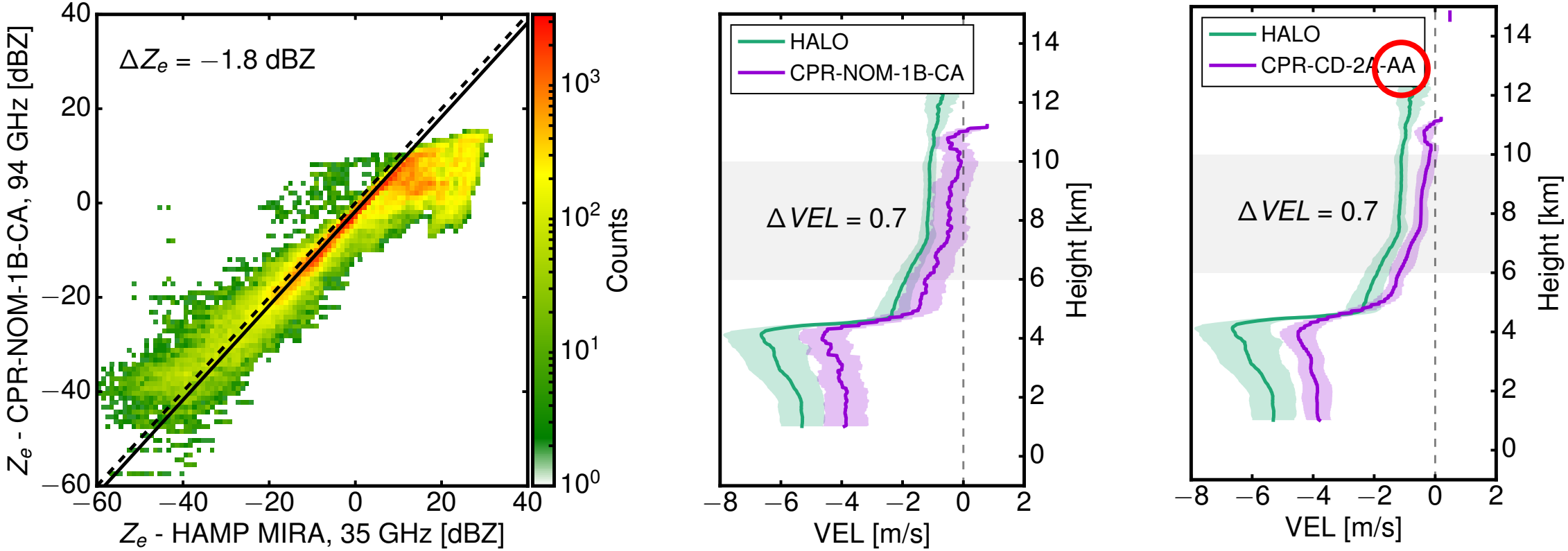
→ ***+0.5 m/s bias of CPR-CD-2A-AB***

HALO-20240818a – Validation of CPR L1 and L2 products

New radar calibration (CA baseline) and doppler velocities for Z > -10 dBZ

(Z > -10 dBZ)

Radar reflectivity (CA) | Level 1 **Doppler velocity** | Level 2



→ *Differences for Z > 0 dBZ and Z < -20 dBZ*

→ ***CPR-NOM-BA bias of -1.8 dB** (-20 to 0 dBZ)*

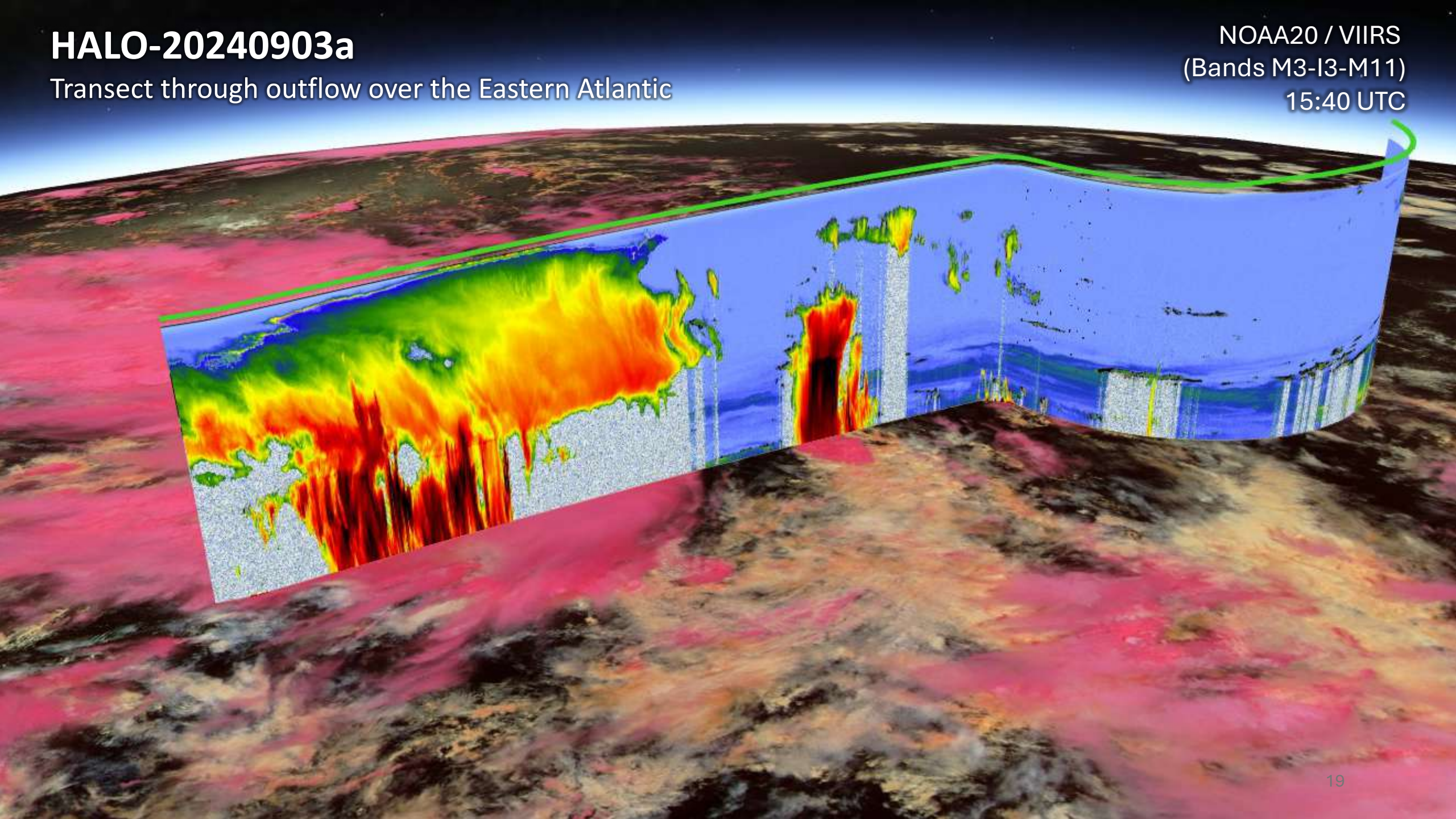
→ *+0.7 m/s bias of CPR-NOM-1B-CA*

→ ***+0.5 m/s bias of CPR-CD-2A-AB***

HALO-20240903a

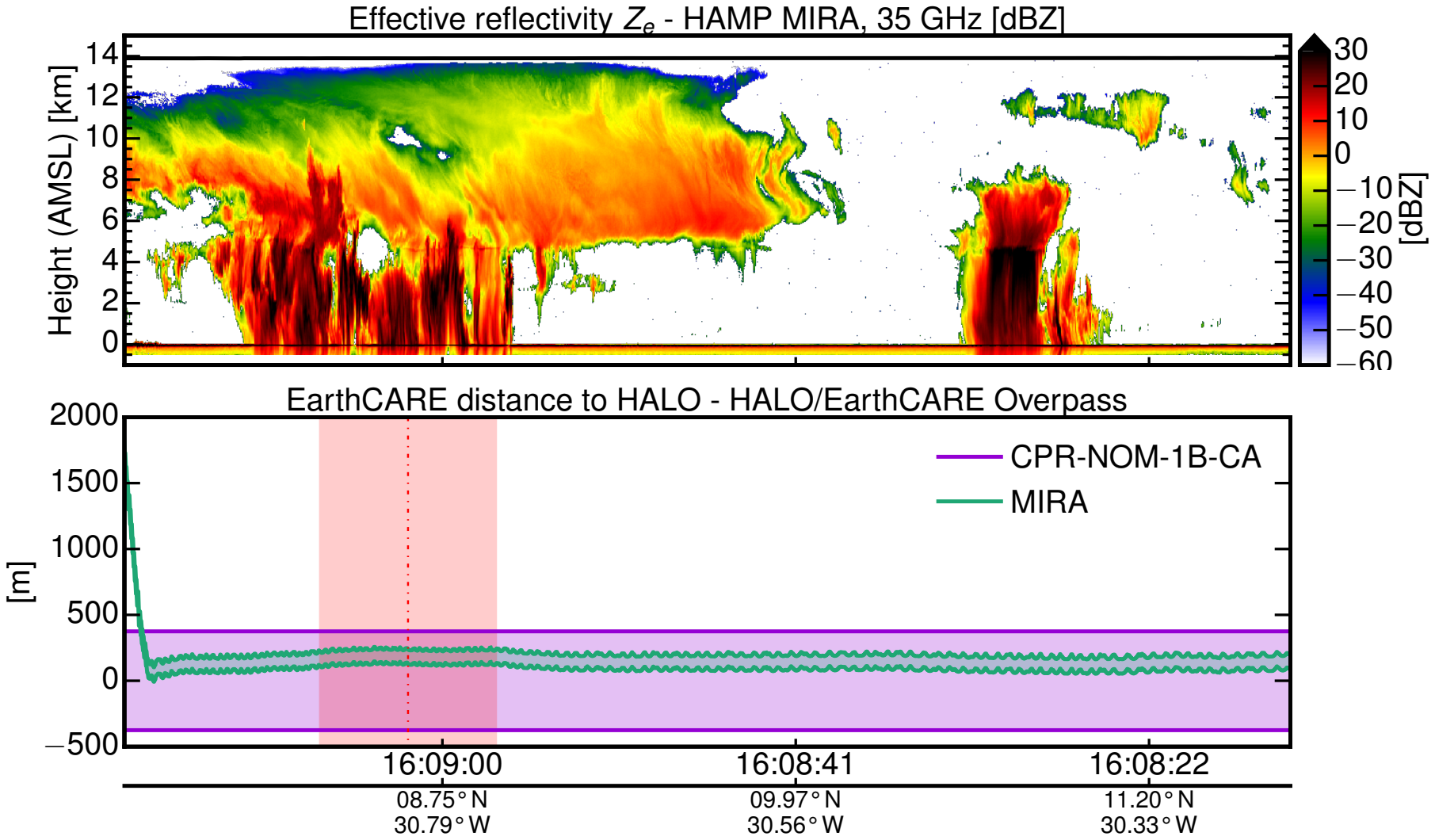
Transect through outflow over the Eastern Atlantic

NOAA20 / VIIRS
(Bands M3-I3-M11)
15:40 UTC



HALO-20240903a – HALO measurement

Observed radar reflectivity (MIRA) and underpass precision

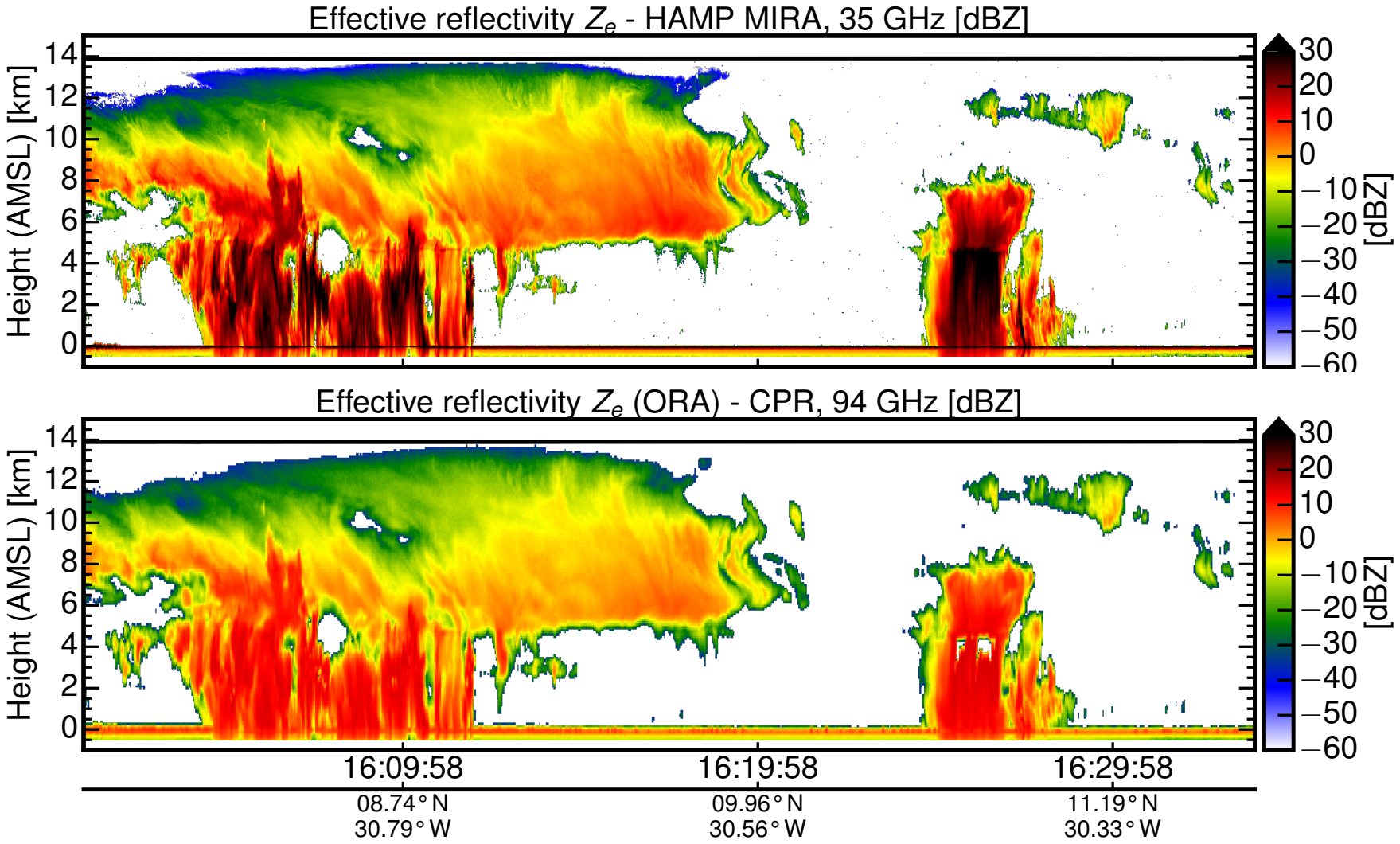


MIRA
Radar reflectivity

EC Track
Lateral deviation

HALO-20240903a – Simulation of L1 radar reflectivity

Observed and simulated radar reflectivity (MIRA)



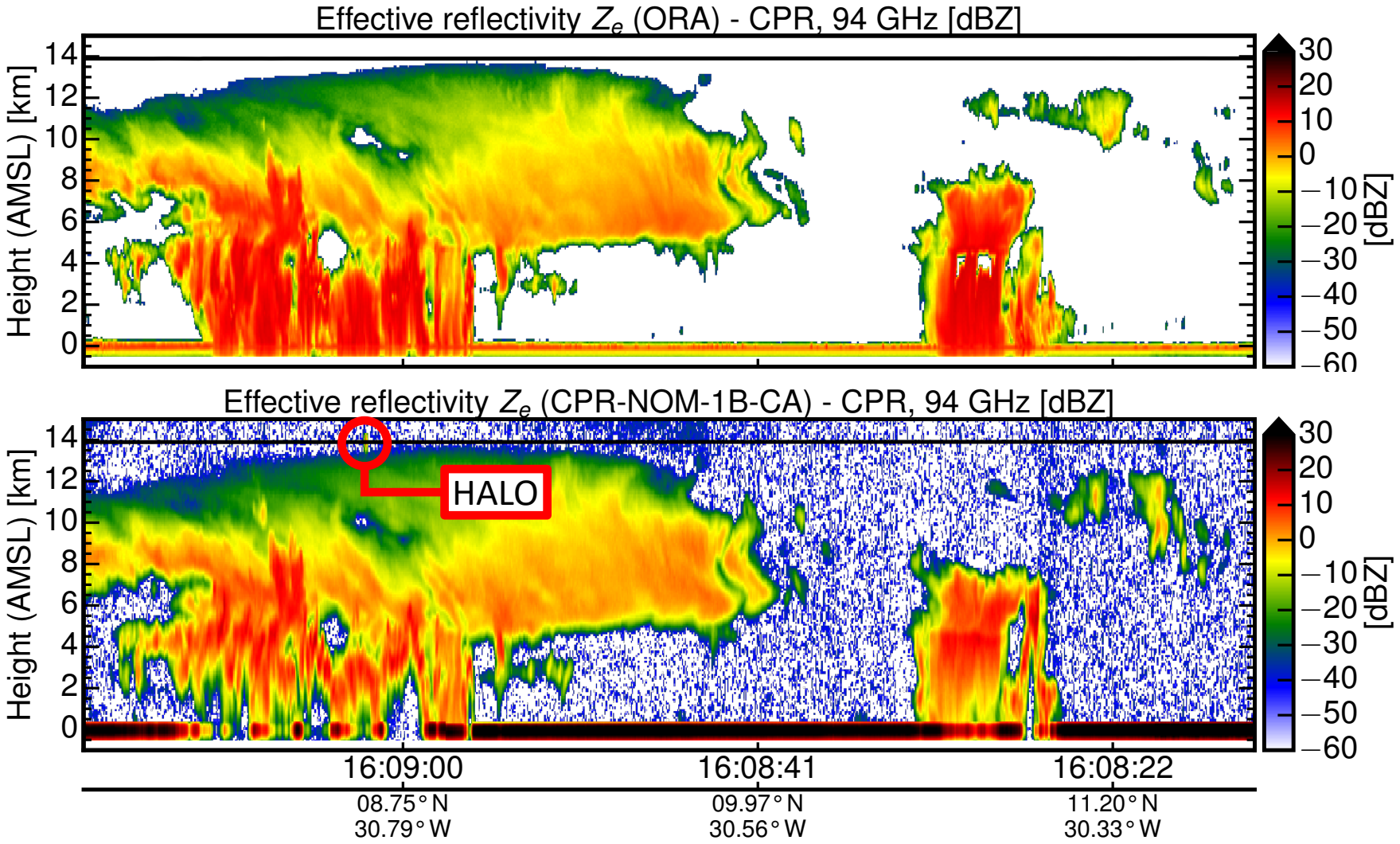
MIRA
Radar reflectivity

Orbital-Radar.py
CPR Simulator
Pfitzenmaier et al GMD, 2025

MIRA → CPR
Radar reflectivity

HALO-20240903a – Comparison of L1 radar reflectivity

Simulated (MIRA) and observed (CPR) radar reflectivity

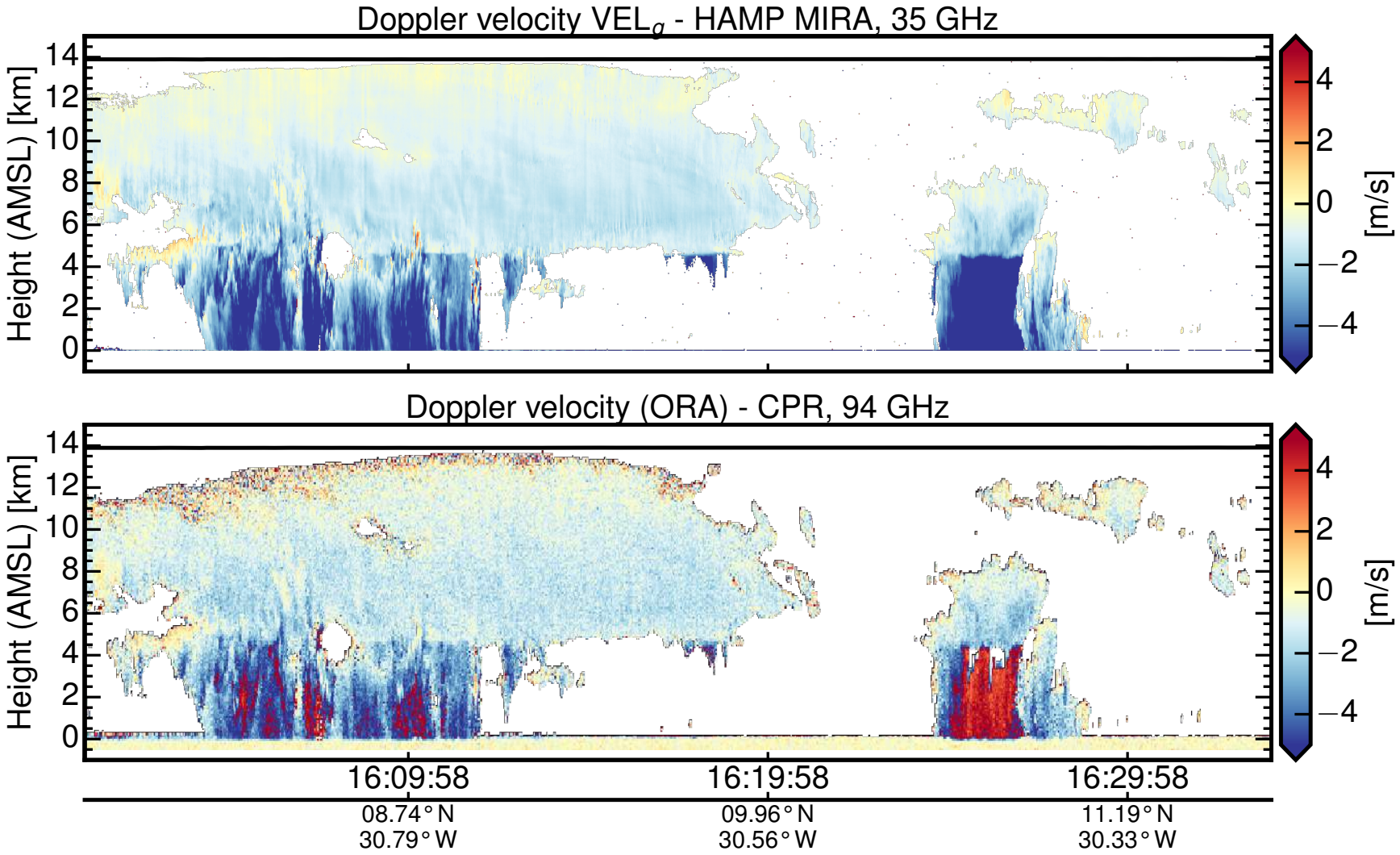


MIRA → CPR
Radar reflectivity

CPR-NOM-1B
Radar reflectivity (CA baseline)

HALO-20240903a – Simulation of L1 doppler velocities

Observed and simulated radar reflectivity (MIRA)



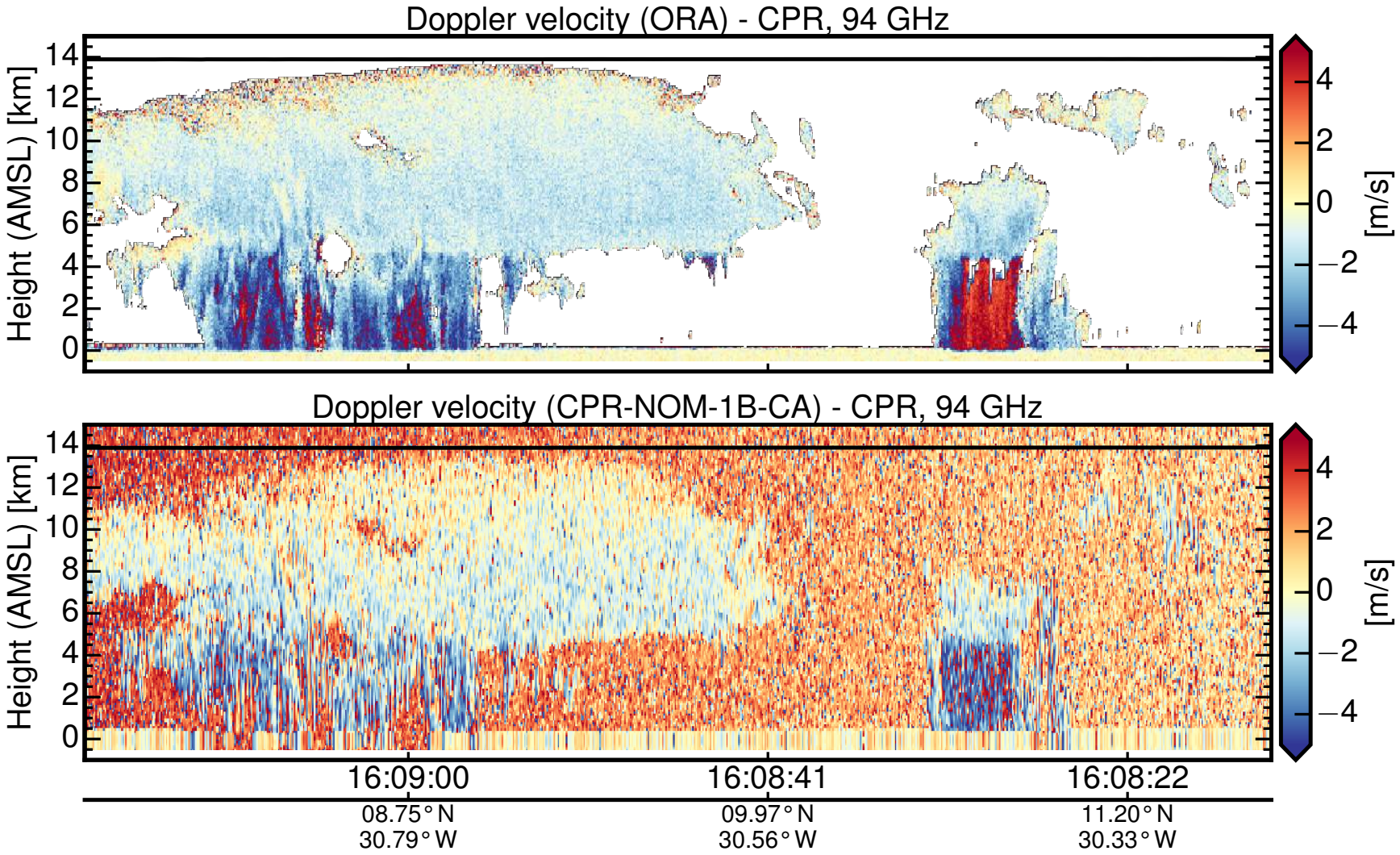
MIRA
Doppler velocity

Orbital-Radar.py
CPR Simulator
Pfitzenmaier et al GMD, 2025

MIRA → CPR
Doppler velocity

HALO-20240903a – Comparison of L1 doppler velocities

Simulated (MIRA) and observed doppler velocities (CPR)

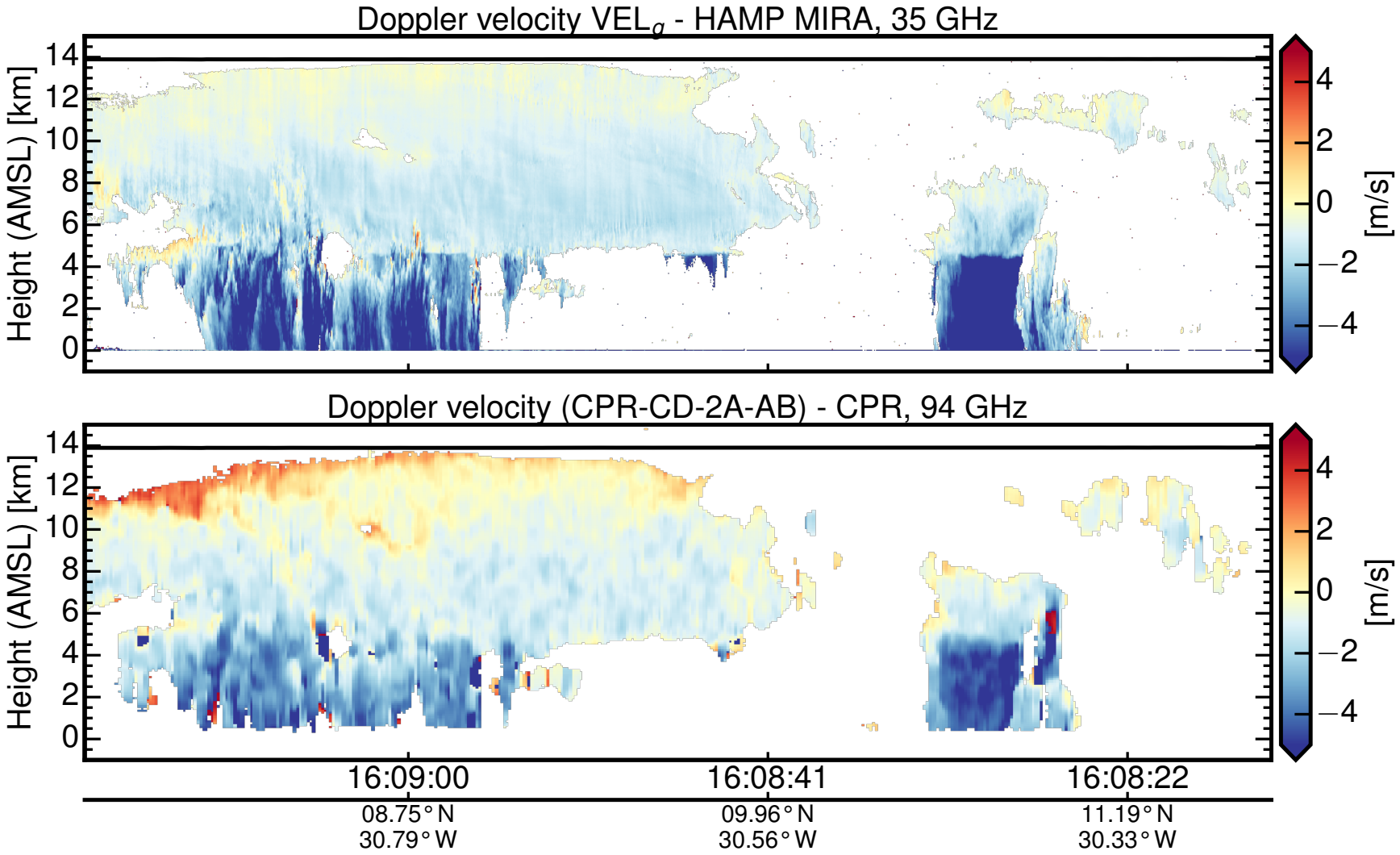


MIRA → CPR
Doppler velocity

CPR-NOM-1B
Doppler velocity (CA baseline)

HALO-20240903a – Comparison of L2 doppler velocities

Observed (MIRA) and observed doppler velocities (CPR)

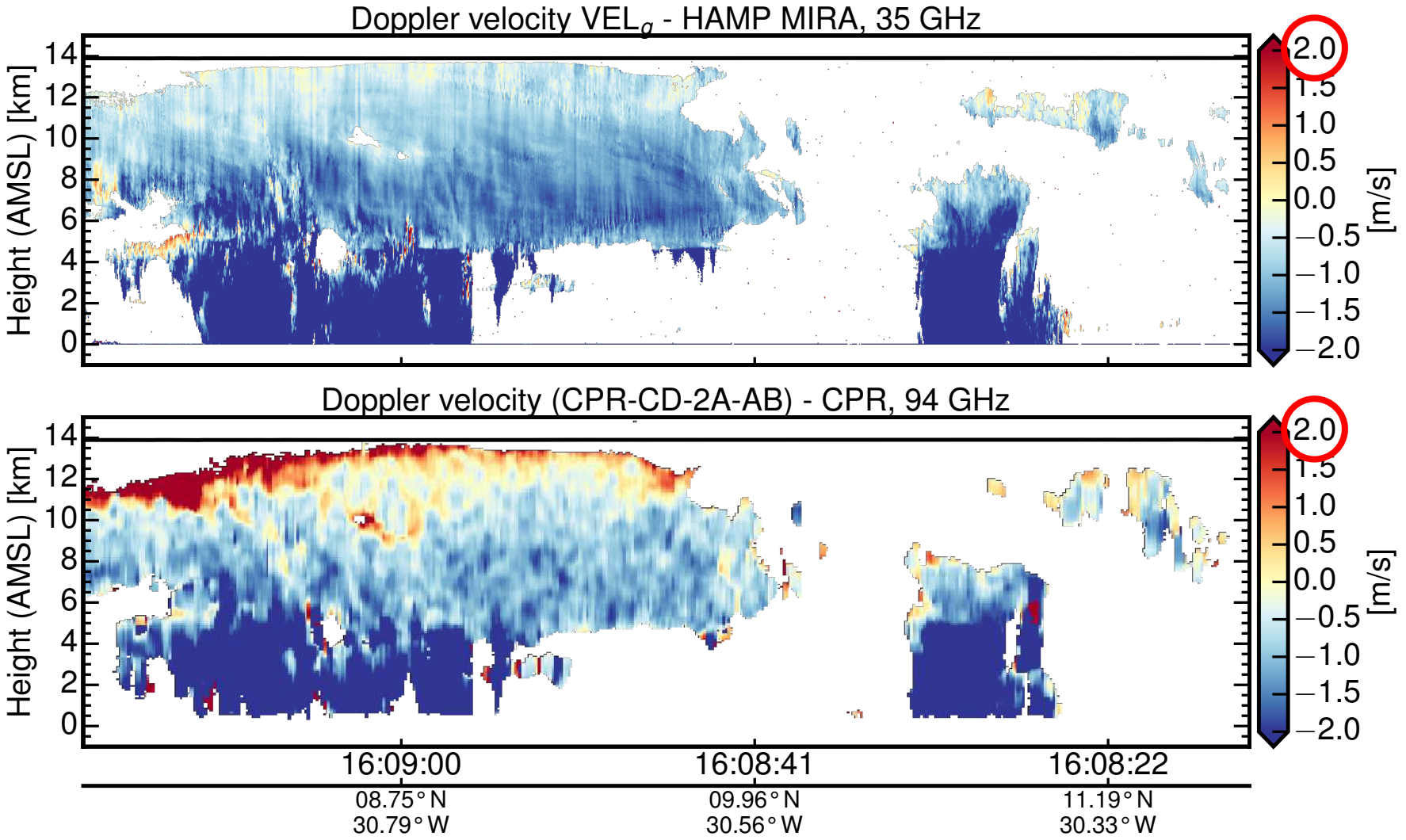


MIRA
Doppler velocity

CPR-CD-2A
Doppler velocity (AA baseline)

HALO-20240903a – Comparison of L2 doppler velocities

Observed (MIRA) and observed doppler velocities (CPR)

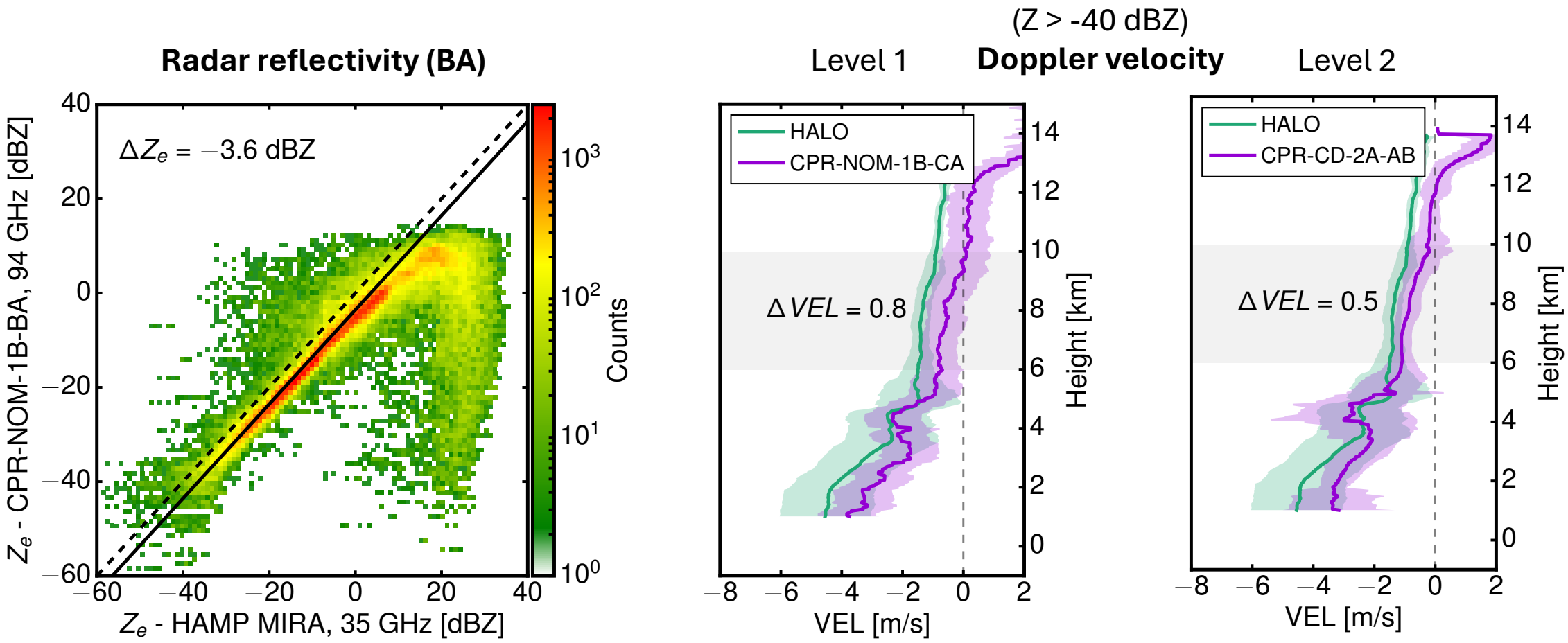


MIRA
Doppler velocity

CPR-CD-2A
Doppler velocity (AA baseline)

HALO-20240903a – Validation of CPR L1 and L2 products

Old radar calibration (BA baseline) and doppler velocities for Z > -40 dBZ



→ *Large differences for Z > 0 dBZ (attenuation!)*

→ ***CPR-NOM-BA bias of -3.6 dB*** *(-20 to 0 dBZ)*

→ *+0.8 m/s bias of CPR-NOM-1B-CA*

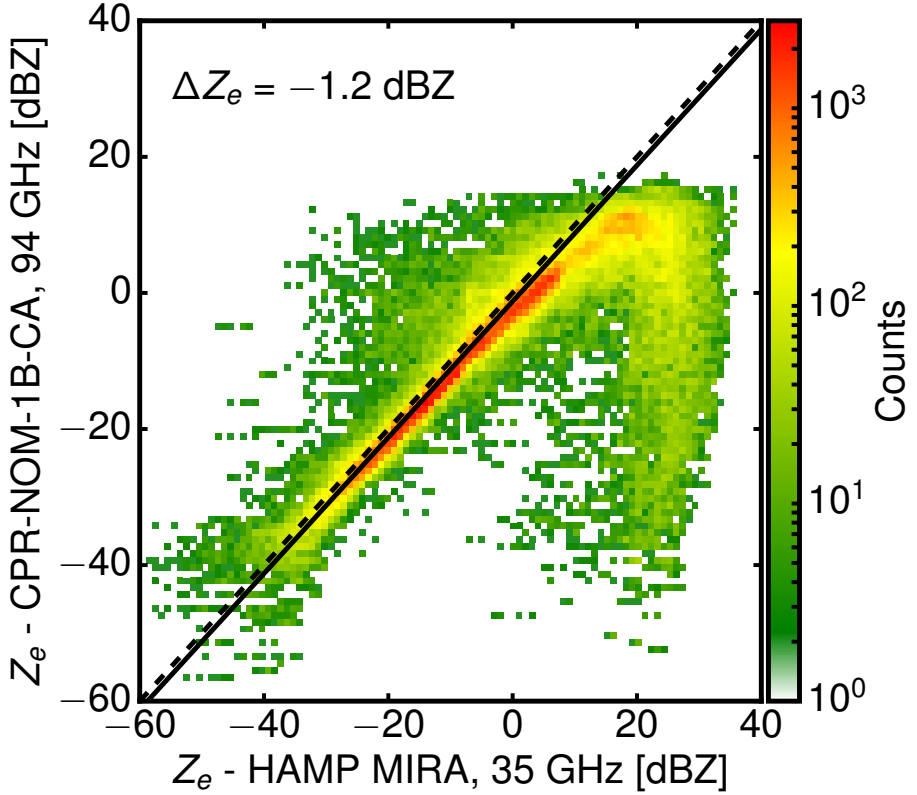
→ ***+0.5 m/s bias of CPR-CD-2A-AB***

HALO-20240903a – Validation of CPR L1 and L2 products

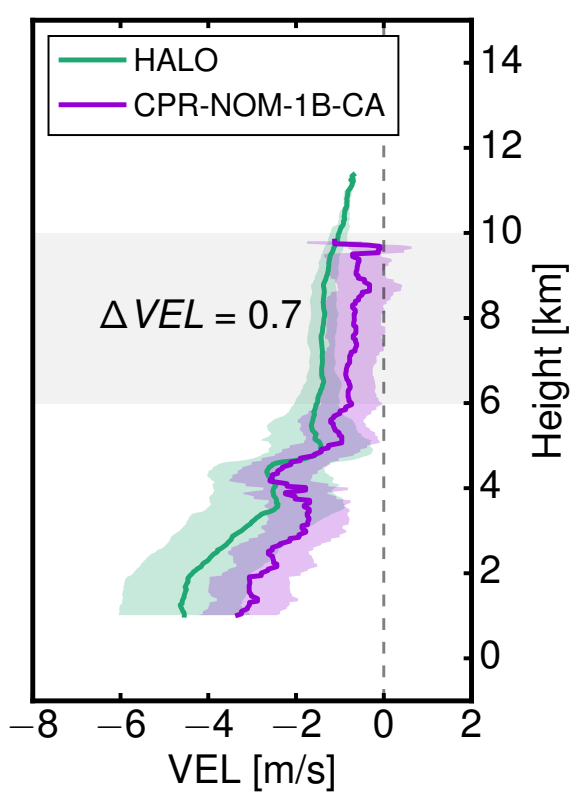
New radar calibration (CA baseline) and doppler velocities for Z > -10 dBZ

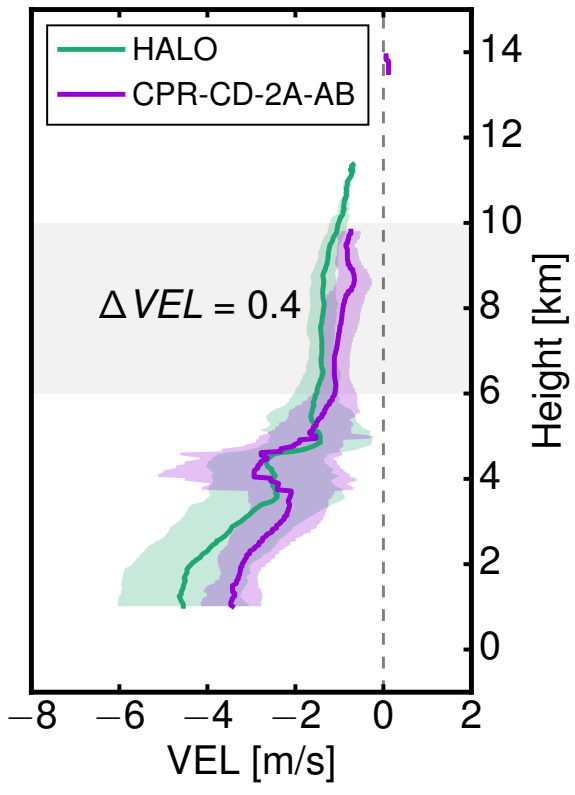
(Z > -10 dBZ)

Radar reflectivity (CA)



Level 1 **Doppler velocity** Level 2





→ *Large differences for Z > 0 dBZ (attenuation!)*

→ ***CPR-NOM-BA bias of -1.2 dB** (-20 to 0 dBZ)*

→ *+0.7 m/s bias of CPR-NOM-1B-CA*

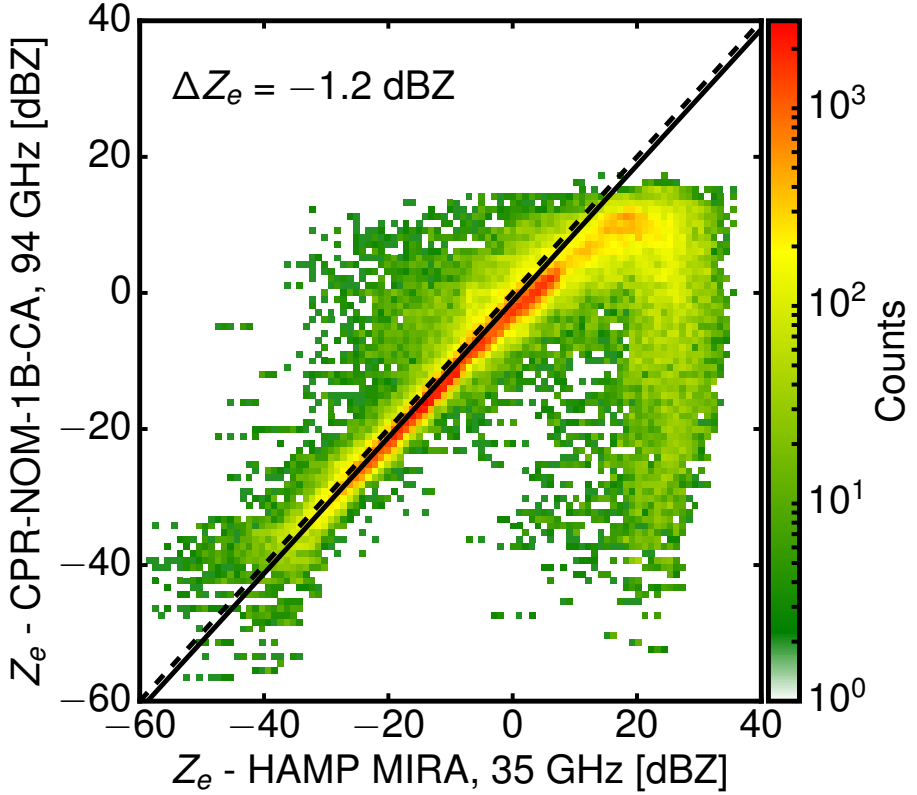
→ ***+0.4 m/s bias of CPR-CD-2A-AB***

HALO-20240903a – Validation of CPR L1 and L2 products

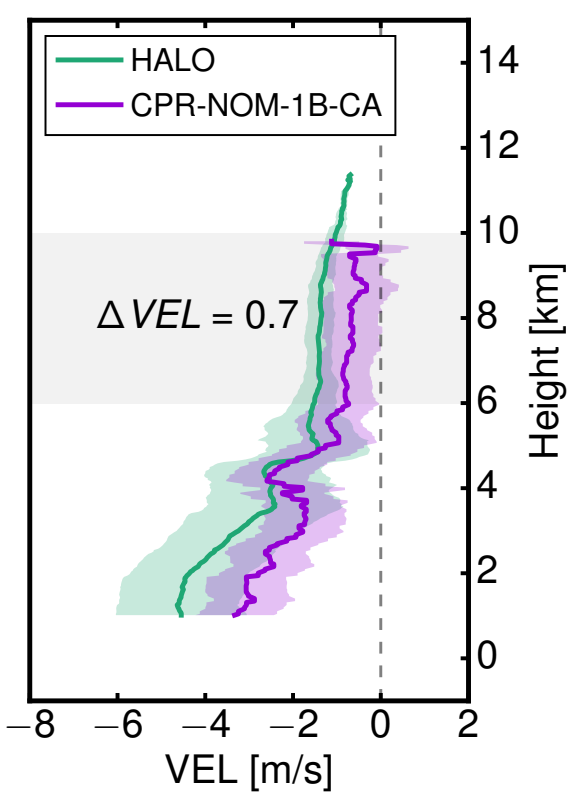
New radar calibration (CA baseline) and doppler velocities for Z > -10 dBZ

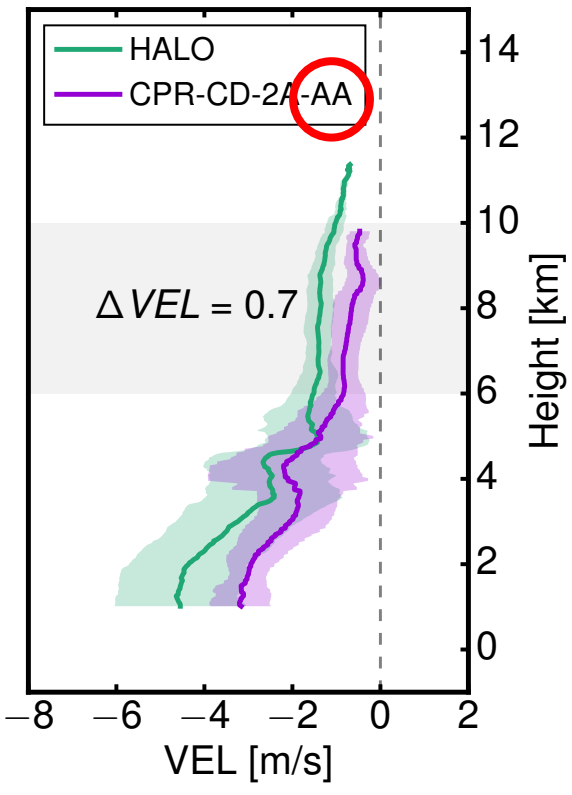
(Z > -10 dBZ)

Radar reflectivity (CA)



Level 1 **Doppler velocity** Level 2





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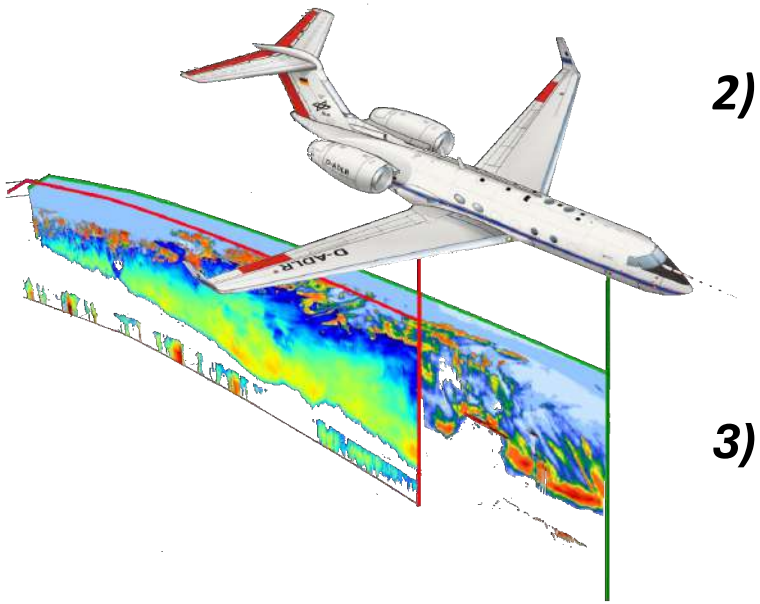
→ *+0.7 m/s bias of CPR-NOM-1B-CA*

→ ***+0.4 m/s bias of CPR-CD-2A-AB***

Summary – CPR L1 and L2 comparisons from PERCUSION

… what we found so far



1) ***Impressive sensitivity of CPR almost on par with airborne cloud radar***

   → *"Much more thin cirrus and low-level clouds visible compared to CloudSat,* ***nominal CPR sensitivity of -36 dBZ seems plausible****"*

2) ***Radar reflectivity bias -2 dB (C-NOM-1B-CA), -4 dB (C-NOM-1B-BA)***

   → *"Very stable CPR bias troughout campaign periode, absolute calibration constant of HAMP MIRA very similar to previous campaign"*

   → *L1B (Cal. Reflectivity / LOS) available since 15 Feb 2025 on EVDC*

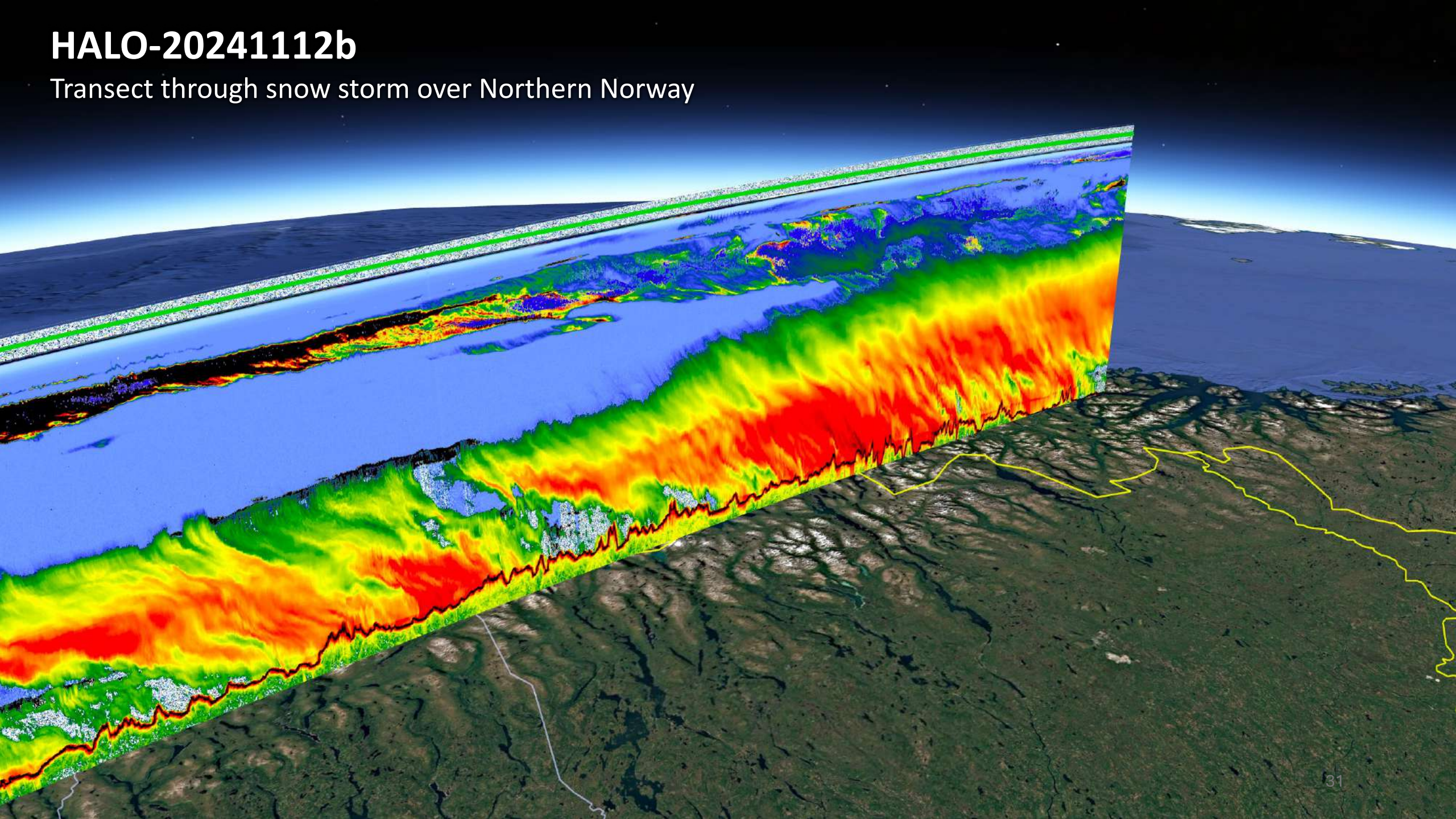
3) ***Doppler velocitiy bias +0.7 m/s (C-NOM-1B-CA), noisy at first***
   Doppler velocitiy bias +0.4 m/s (C-CD-2A-AB), pos. bias at cloud top

   → *"Results are only valid for SPU-A, improved SNR for SEP/NOV, velocity bias slightly larger compared to findings by Puidgomènech et al."*

   → *L2A (Vertical velocity) available until 28 Feb 2025 on EVDC*

HALO-20241112b

Transect through snow storm over Northern Norway

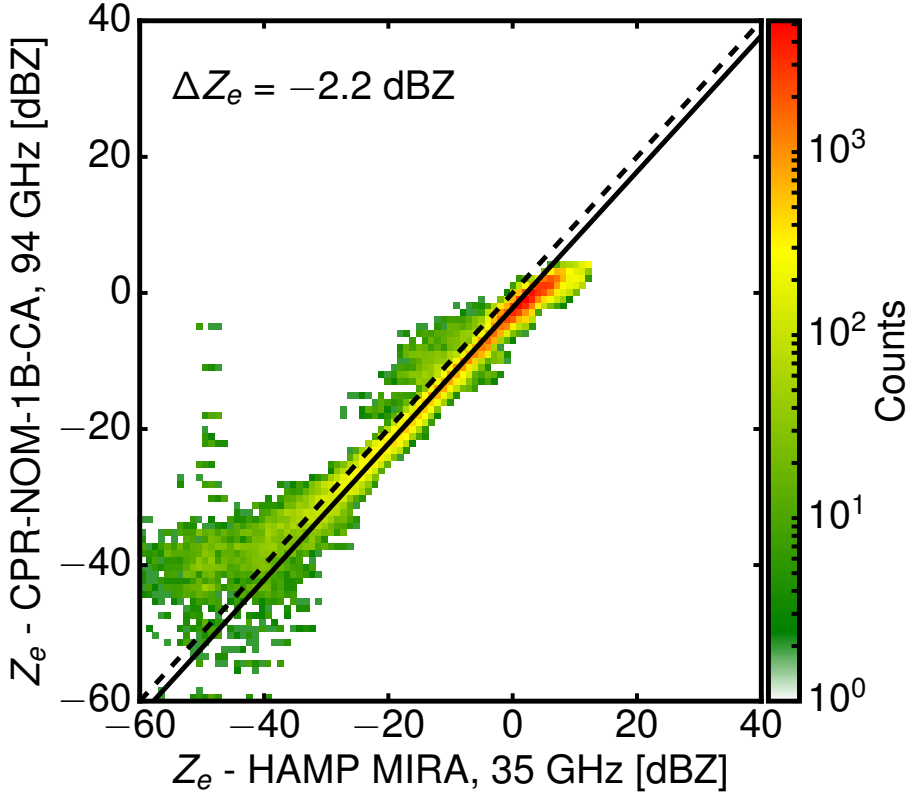


HALO-20240903a – Validation of CPR L1 and L2 products

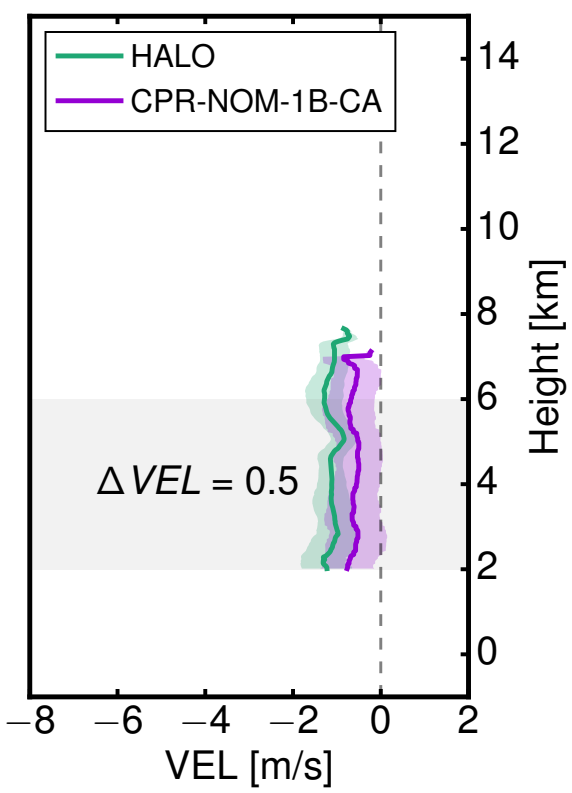
New radar calibration (CA baseline) and doppler velocities for Z > -10 dBZ

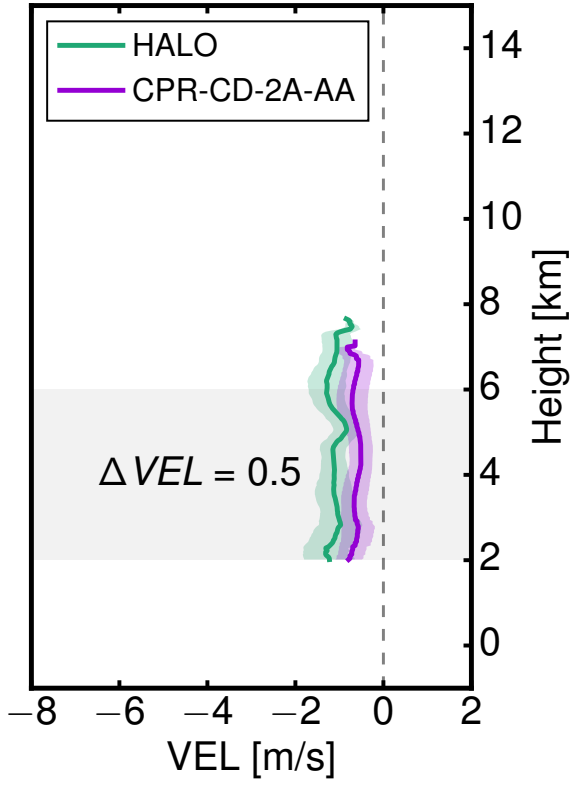
(Z > -10 dBZ)

Radar reflectivity (CA)



Level 1 **Doppler velocity** Level 2





→ *Very good agreement of Z (in snow)*

→ ***CPR-NOM-CA bias of -2.2 dB*** *(-20 to 0 dBZ)*

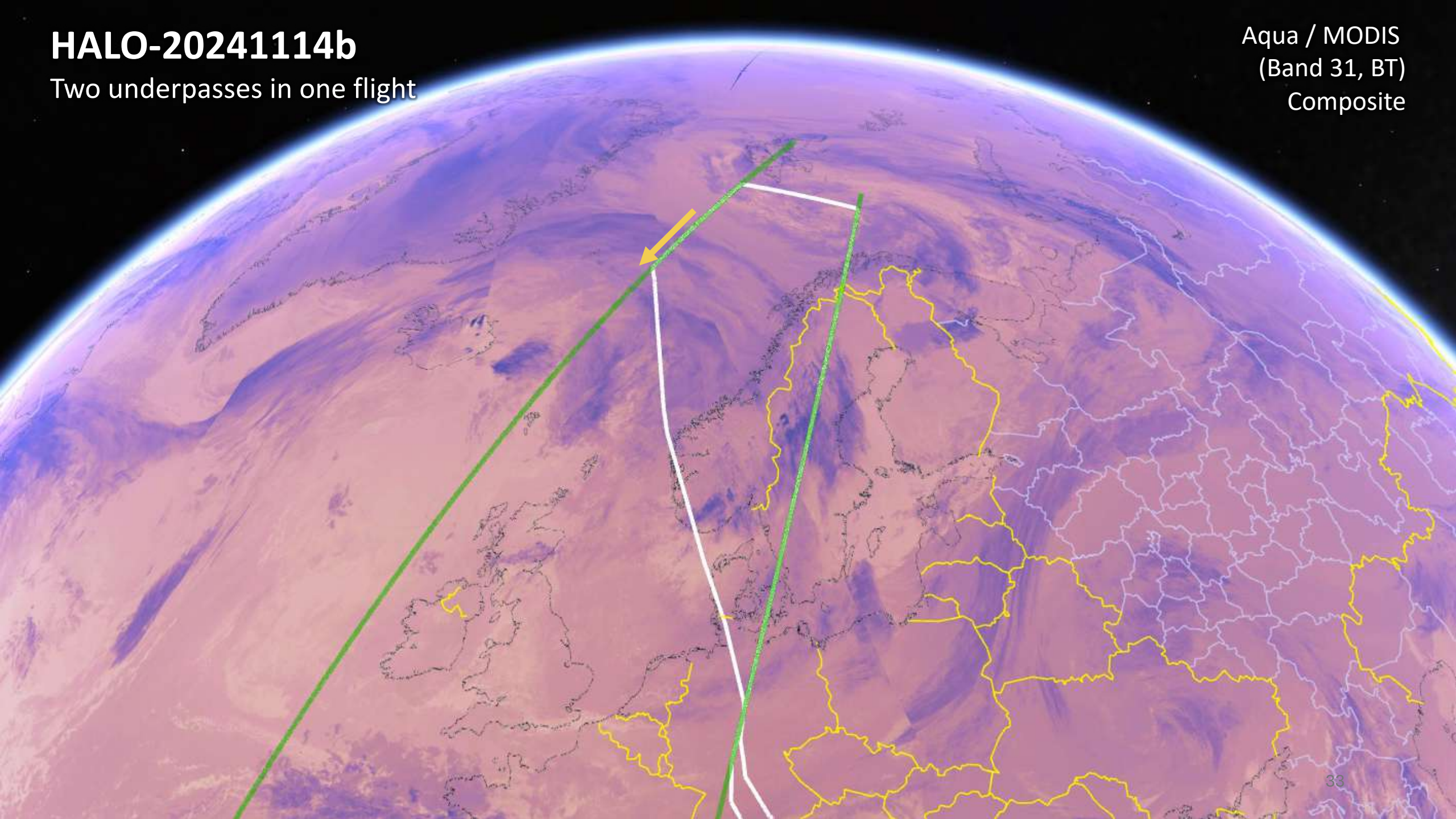
→ *+0.5 m/s bias of CPR-NOM-1B-CA*

→ ***+0.5 m/s bias of CPR-CD-2A-AA***

HALO-20241114b

Two underpasses in one flight

Aqua / MODIS
(Band 31, BT)
Composite

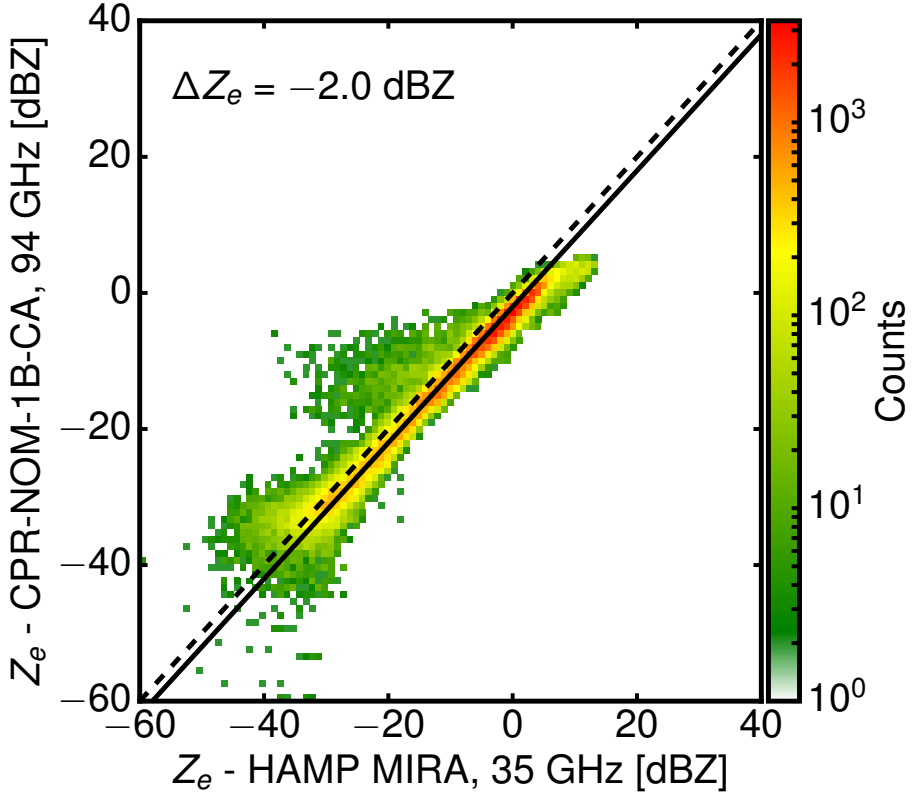


HALO-20241114b – Validation of CPR L1 and L2 products

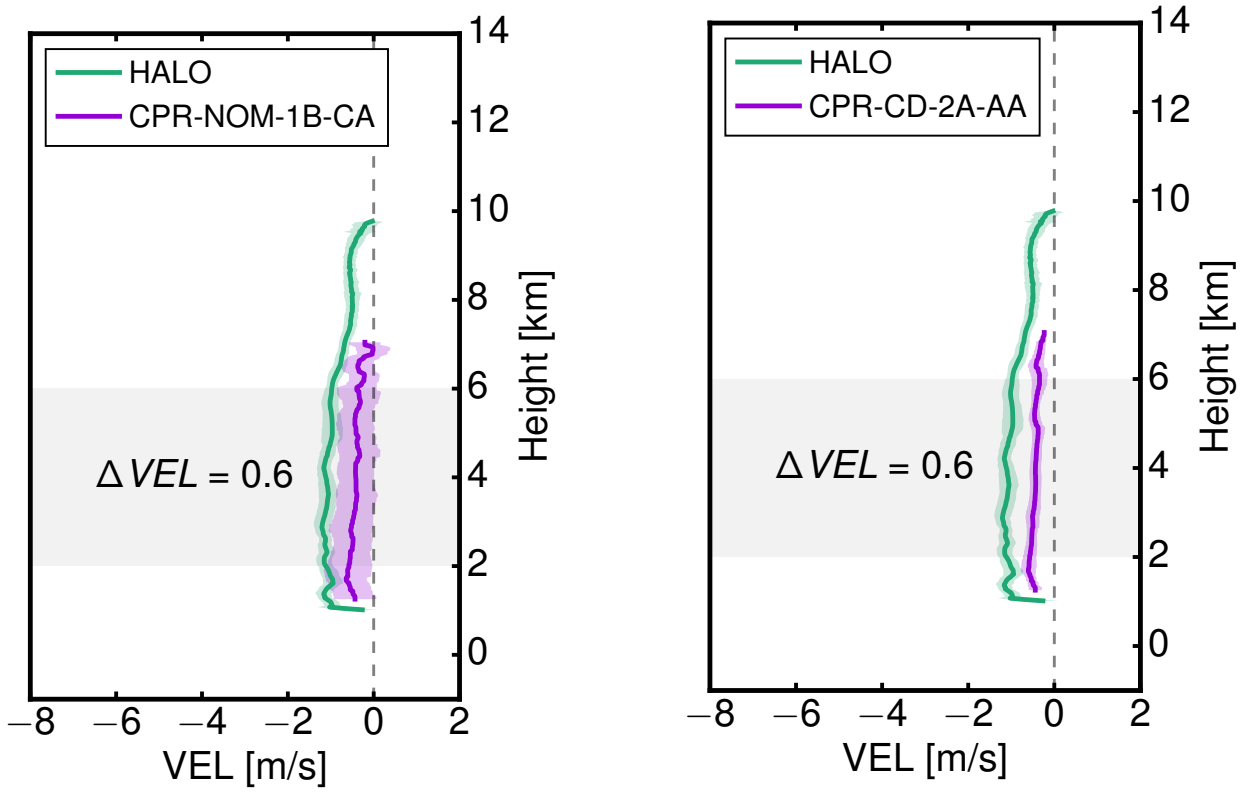
New radar calibration (CA baseline) and doppler velocities for Z > -10 dBZ

(Z > -10 dBZ)

Radar reflectivity (CA)



Level 1 **Doppler velocity** Level 2



→ *Very good agreement of Z (in snow)*

→ ***CPR-NOM-BA bias of -2.0 dB*** *(-20 to 0 dBZ)*

→ *+0.6 m/s bias of CPR-NOM-1B-CA*

→ ***+0.6 m/s bias of CPR-CD-2A-AA***