Evaluating EarthCARE retrievals of ice microphysics and vertical air motion using in-situ aircraft measurements

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We use in-situ aircraft measurements in ice clouds (rejecting those with significant supercooled liquid) from the VERIFY campaign (north-west of the UK) and the ECALOT campaign (Ontario) to evaluate:

- **C-CD:** radar-only retrievals of terminal fall speed and vertical air motion
- **A-EBD:** lidar-only retrievals of extinction coefficient
- **ACM-CAP:** synergy retrievals of extinction, ice water content and effective radius
- **Scattering/fall-speed models** and a priori assumptions in ACM-CAP, e.g. mass-size relationship

We test two mass-size relationships, both for processing aircraft and as an a-priori assumption in ACM-CAP:

- **Brown & Francis (1995)**, BF95: $m = 0.0185\,D^{1.9}$ (SI units, D is mean of image x and z dimensions)
- **"Denser" model:** $m = 0.051\,D^{2.01}$ (10% of the way from BF95 to solid ice)

Date	Flight	Frame	Temp.	Typical Z	Mass-size	Cloud type, comment
14 Jan 2025	VERIFY6	03589D	−45°C	−30 dBZ	BF95	Thin cirrus, no Doppler (not shown here)
7 Nov 2024	VERIFY2	02531D	−45°C	−15 dBZ	BF95	Cirrus, gravity wave
4 Nov 2024	ECALOT3	02487D	−17°C	0 dBZ	BF95	Nimbostratus
27 Jan 2025	ECALOT6	03794D	−23°C	0 dBZ	Denser	Nimbostratus, gravity wave
18 Nov 2024	VERIFY4	02702D	−10°C	10 dBZ	Denser	Nimbostratus, non-Rayleigh scattering

Method

1. **Mass-size relationship:** Use aircraft optical array probes (OAPs) to compute 94-GHz radar reflectivity (Z) & ice water content (IWC) assuming either BF95 or Denser model, and compare to EarthCARE CPR and Nevzorov probe
2. **Radar scattering model:** Use Self-Similar Rayleigh Gans Approx. (SSRGA, Hogan & Westbrook 2014) to compute deviation from Rayleigh scattering
3. **Vertical air motion:** Evaluate separation of Doppler velocity into terminal fall speed and vertical air motion by C-CD (BB baseline)
4. **Fall-speed model:** Use Heymsfield & Westbrook (2010) model to compute Z-weighted terminal fall speed
5. **Extinction coefficient:** Use OAPs to test ice extinction in A-EBD & ACM-CAP (insensitive to mass-size relationship)
6. **Ice water content & effective radius:** Evaluate ACM-CAP

Results

BF95 works for Z and IWC in weaker cases VERIFY2, VERIFY6 & ECALOT3, and Denser works best for VERIFY4 and ECALOT6 (except for Z in VERIFY2 which is too high from optical array probes)

Strong non-Rayleigh scattering in VERIFY4 (15 dB difference with Rayleigh): SSRGA captures it perfectly

Aircraft shows rapid fluctuations in Doppler due to air motion, average values to terminal fall speed: **C-CD vertical air motion excellent in VERIFY2 & ECALOT6**
Aircraft estimated terminal fall speed typically 10-20 cm/s higher than C-CD

Excellent agreement when lidar has signal; ACM-CAP also infers extinction well when lidar attenuated
IWC typically a little low in ACM-CAP, and **effective radius up to 10 μm too low**, but very good in ECALOT3

Conclusions

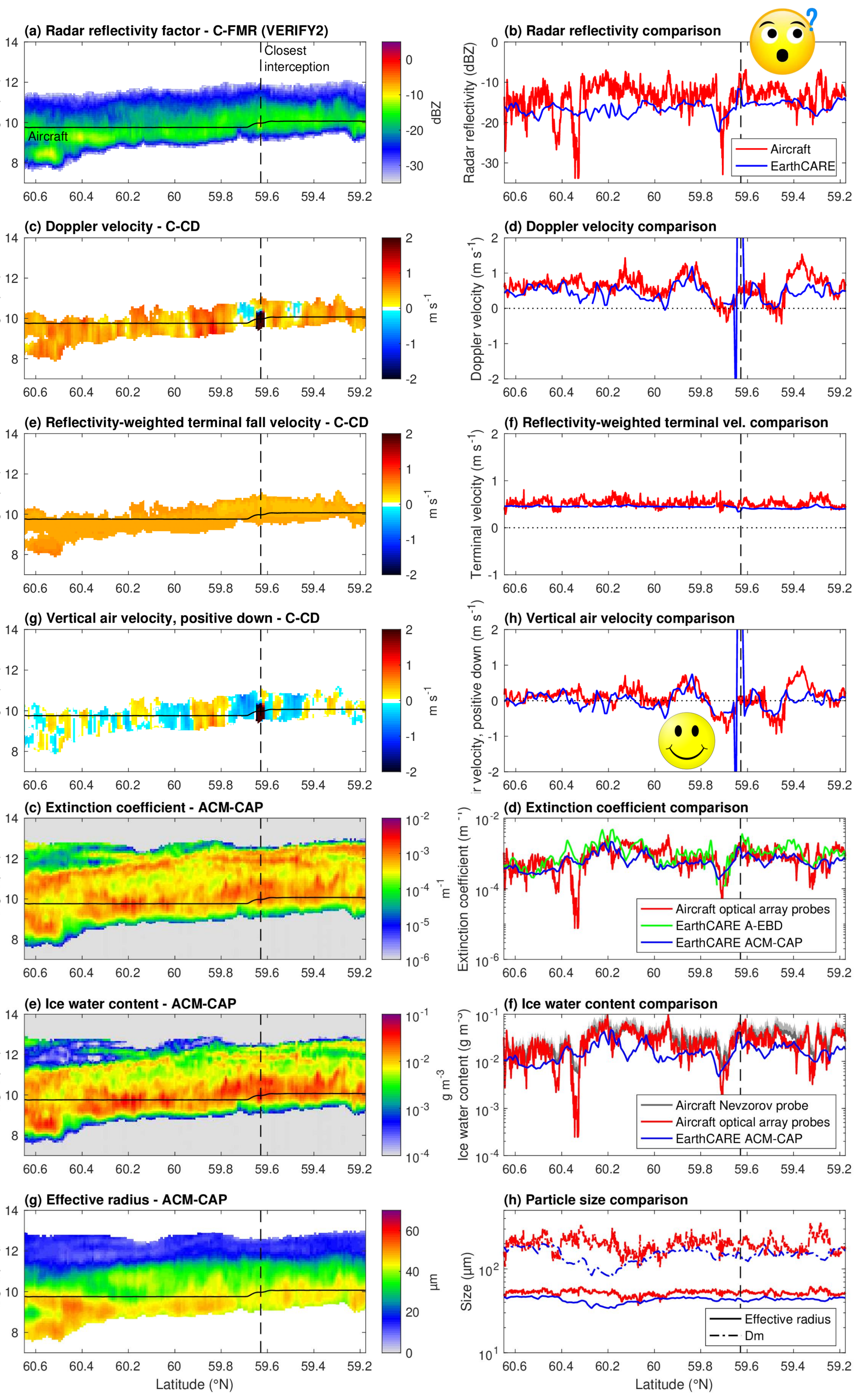
BF95 is a good model for most ice clouds, but can ACM-CAP infer denser ice from faster terminal fall velocity? Currently it just infers larger particles.

SSRGA works well (used in ACM-CAP), but we need more cases with snowflakes of different sizes

These aircraft observations have been crucial in C-CD development!

Is Heymsfield & Westbrook fall speed model biased high, or is there another explanation?
This is a good validation of HSRL technique, and ACM-CAP extrapolates downwards well
Change prior assumptions in ACM-CAP? **Aircraft uncertain too:** undercounting of small particles & rebounding from Nevzorov?

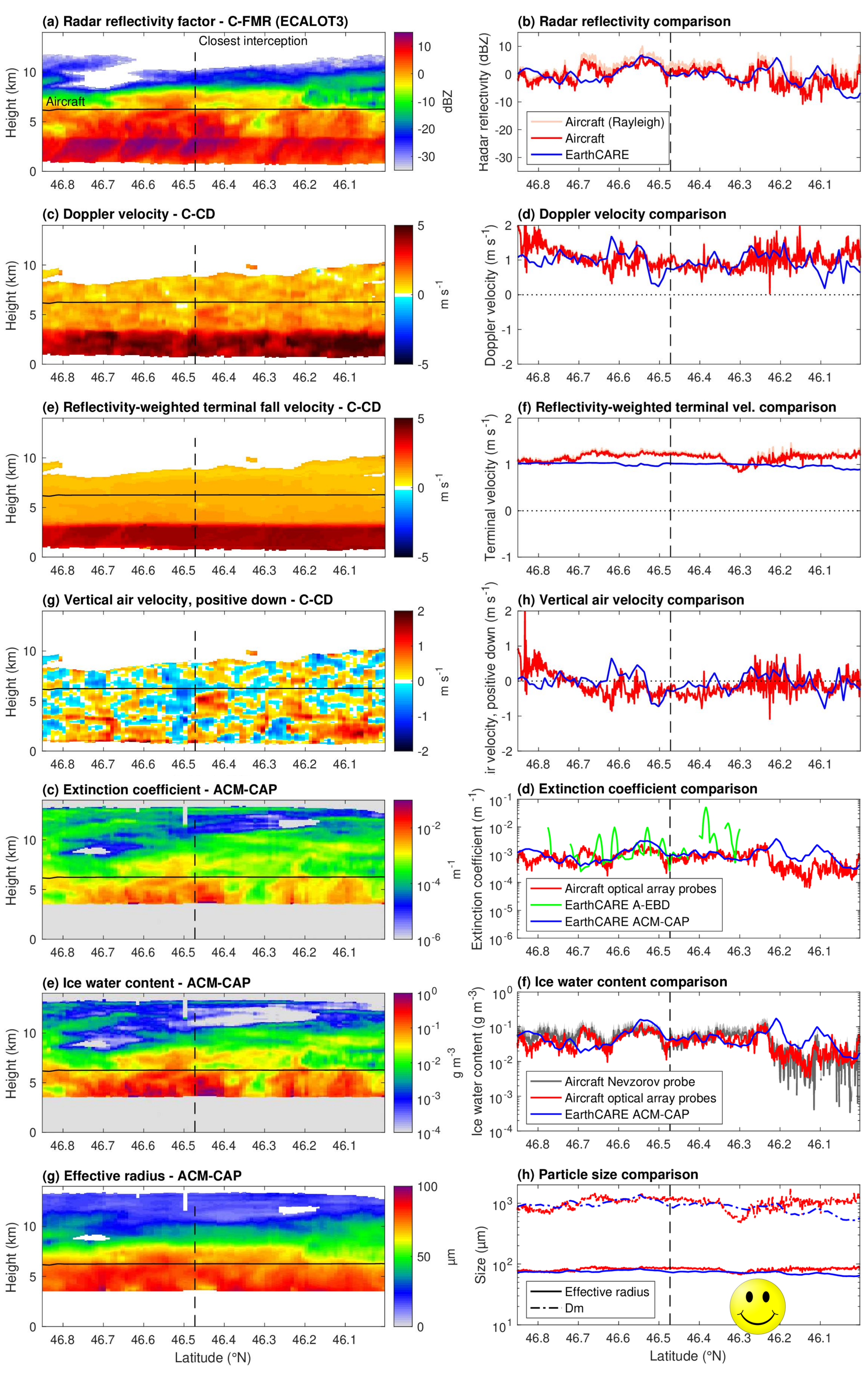
VERIFY2: Cirrus −45°C



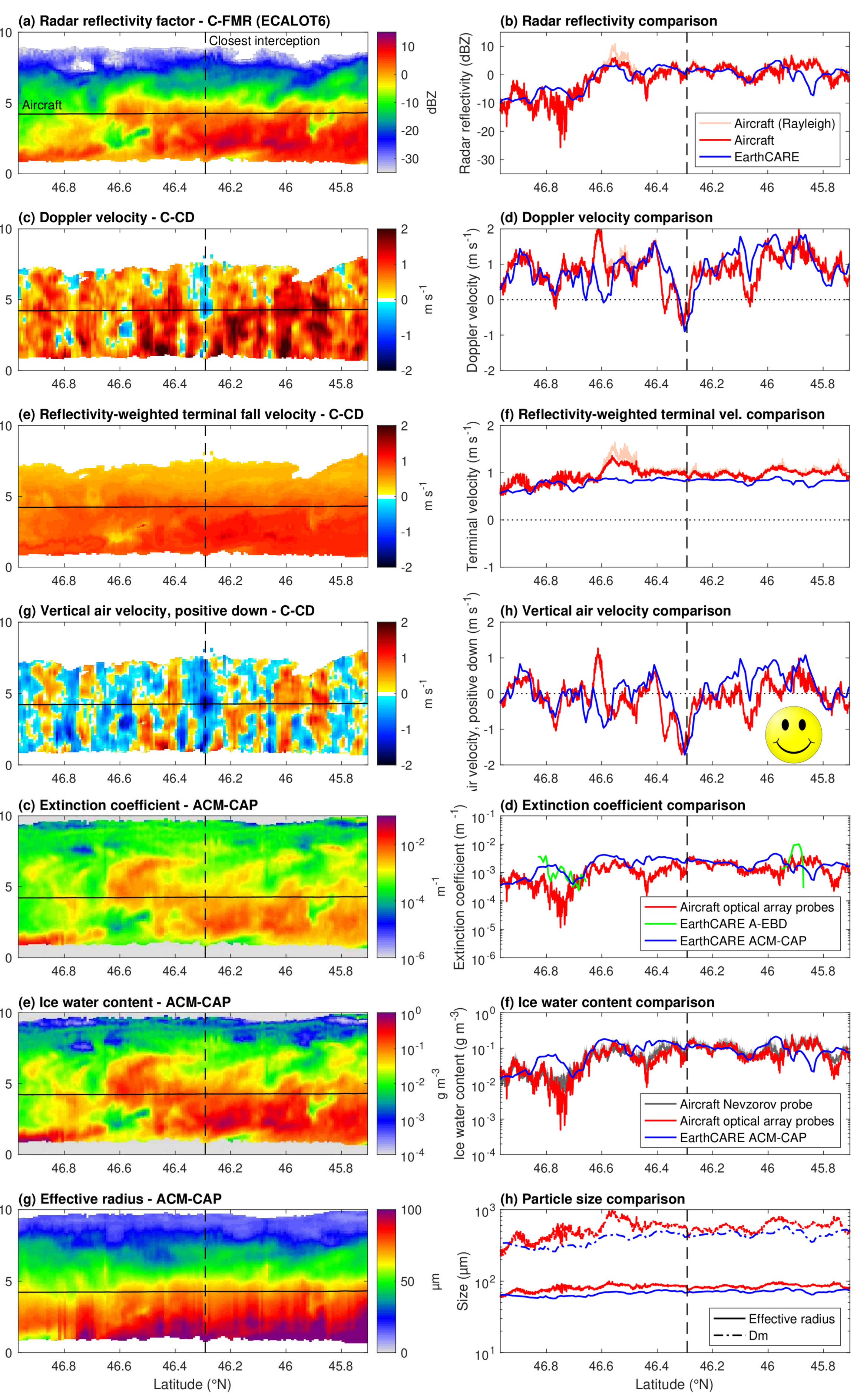
References

Brown & Francis (1995): doi:10.1175/1520-0426(1995)012<0410:IMOTIW>2.0.CO;2
Heymsfield & Westbrook (2010): doi: 10.1175/2010JAS3379.1
Hogan & Westbrook (2014): doi:10.1175/JAS-D-13-0347.1

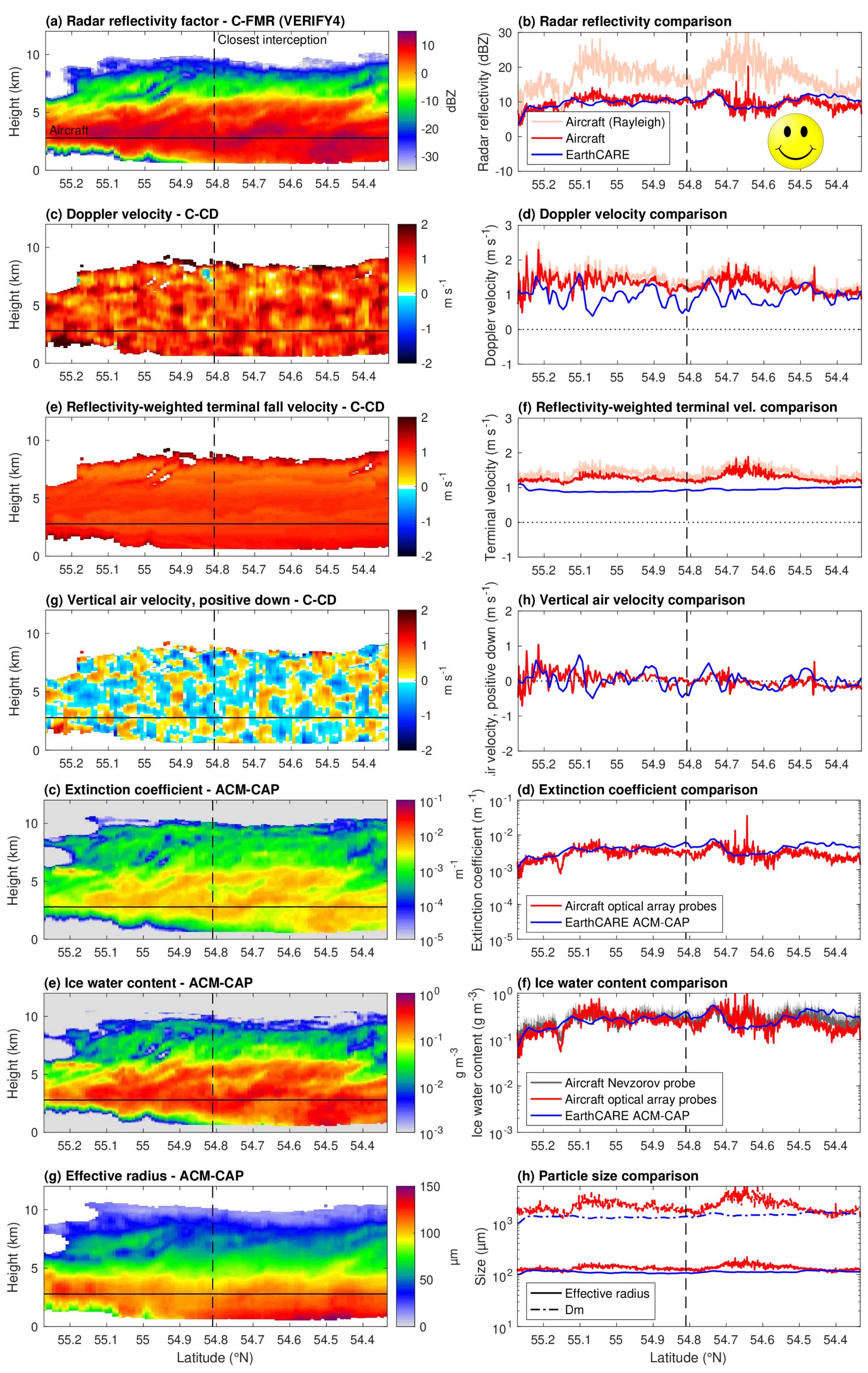
ECALOT3: Nimbostratus −17°C



ECALOT6: Nimbostratus −23°C



VERIFY4: Nimbostratus −10°C



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