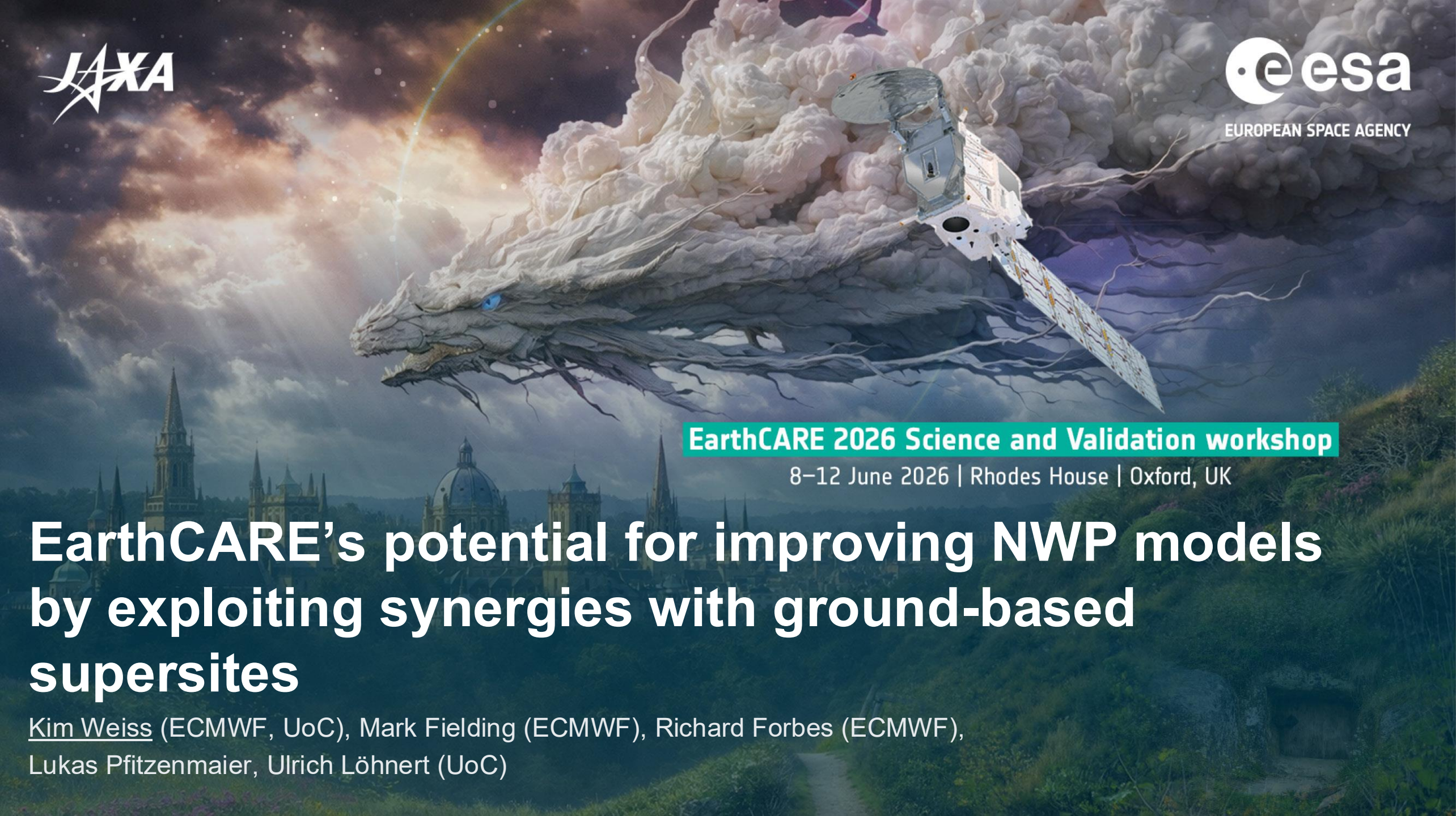


EarthCARE's potential for improving NWP models by exploiting synergies with ground-based supersites

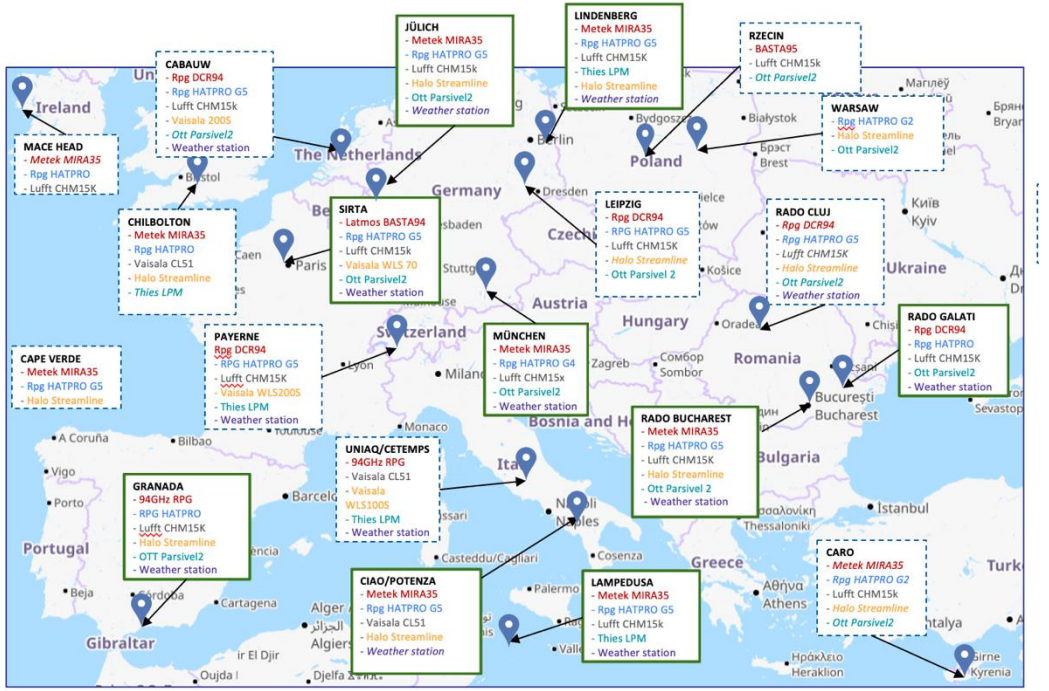
Kim Weiss (ECMWF, UoC), Mark Fielding (ECMWF), Richard Forbes (ECMWF),
Lukas Pfitzenmaier, Ulrich Löhnert (UoC)

Motivation

- EarthCARE
  - Provides synergistic observations of aerosols, clouds & radiation
  - Objectives: Better understand cloud microphysics & evaluate NWP models *(Wehr et al. (2023))*

- ACTRIS Centre for Cloud Remote Sensing (CCRES)
  - Europe-wide measurement network for aerosols, clouds & radiation
  - Objectives: Study cloud microphysical processes
    Evaluate clouds in NWP models

➢ ***Combine datasets → How beneficial for model evaluation?***



Motivation

- EarthCARE & Cloudnet – Each have their own strengths & weaknesses:

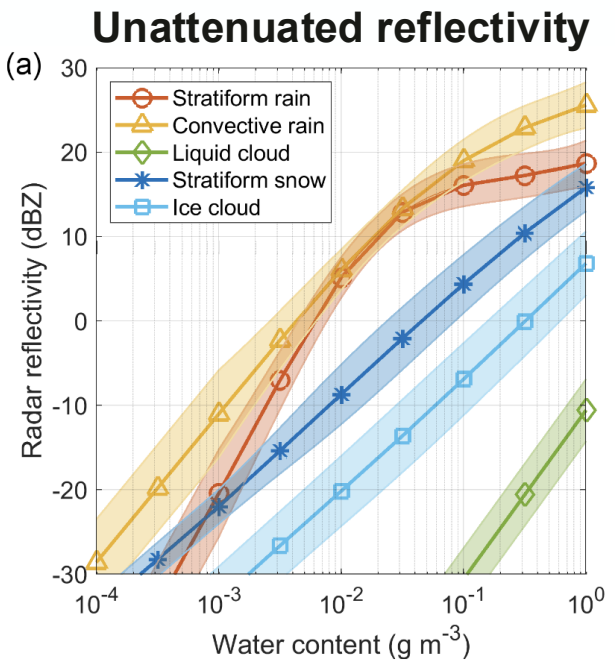
	EarthCARE CPR	Ground-based Radars
Limitations in sensitivity	Low-level clouds → No measurements below 500m	High clouds → Affected by (liquid) attenuation
Vertical resolution	~ 100m	Few 10s of meters
Diurnal cycle	Sparse sampling (some sites with ASC & DESC orbits) e.g. Bucharest ~12:30 & ~23:40 UTC	Well captured
Spatial coverage	Covers entire globe BUT small footprint	Localized

- ***Combine satellite & ground-perspective to complement their strengths! (Synergies)***
- ***Comparison with IFS: What cloud features & processes are misrepresented?***

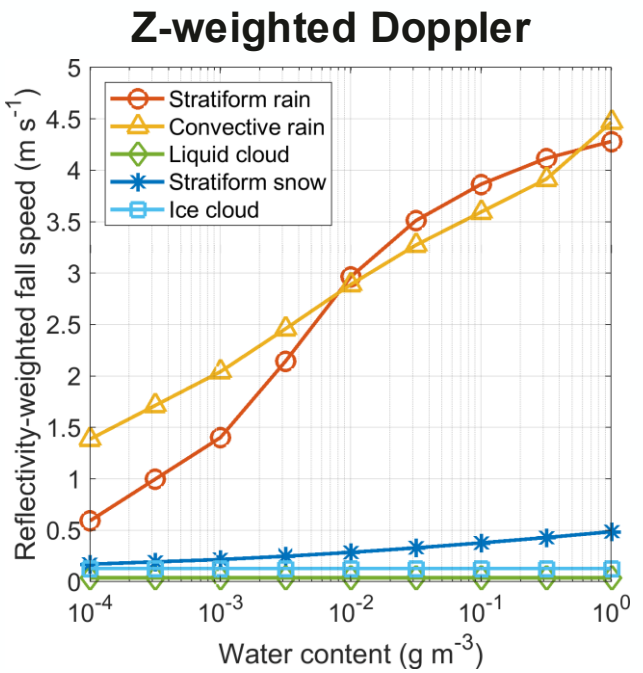
How to compare OBS and IFS?

Forward Operator (ZmVar)

- Converts model fields → "Radar"-space
  (p, T, q, W, cc, six hydrometeor types) → (Zh, v)
- Assumptions on particle size distribution (PSD) & scattering (Rayleigh, Mie, …)



From: Fielding & Janisková (2020)



Credit: Mark Fielding

How to compare OBS and IFS?

EarthCARE

- CPR Level 2A products:
  - Variables: reflectivity_masked *(CPR_FMR_2A)*
    doppler_velocity_best_estimate *(CPR_CD_2A)*
  - **Baseline – BA** *(until 17.11.2025)*
  - **Frames – "BCD"** *(EU-domain)*
- Spatial-averaged: 1km → 20km (along-track)
  100m (vertical)

IFS

- Forward Operator ZmVar: Along-track computation
- Time period: 01/2025 – 07/2025 *(2093 orbits)*

Ground-based Radars

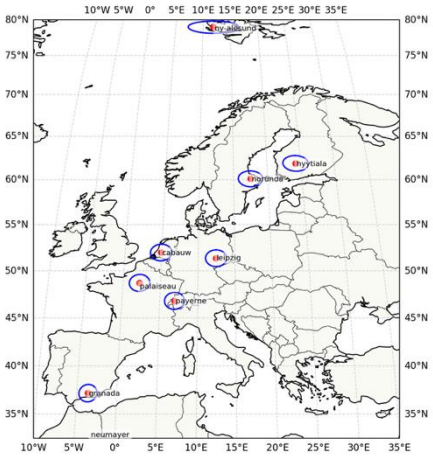
- Categorize-product *(synergistic product)*
  - Removal of clear-sky, aerosols, insects
  - Removal of attenuation-correction terms
    (gas, liquid, melting ice, rain)

Classification product

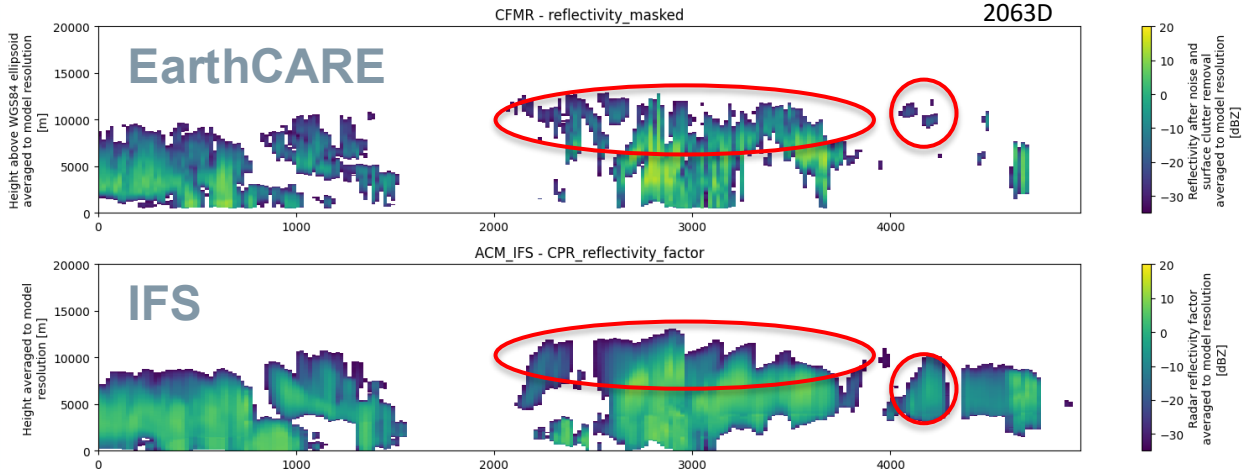
- Based on 94GHz + IFS data available → 9 sites
- Time-averaged: ~3s → 7.5min (model timestep)
  100m (vertical)

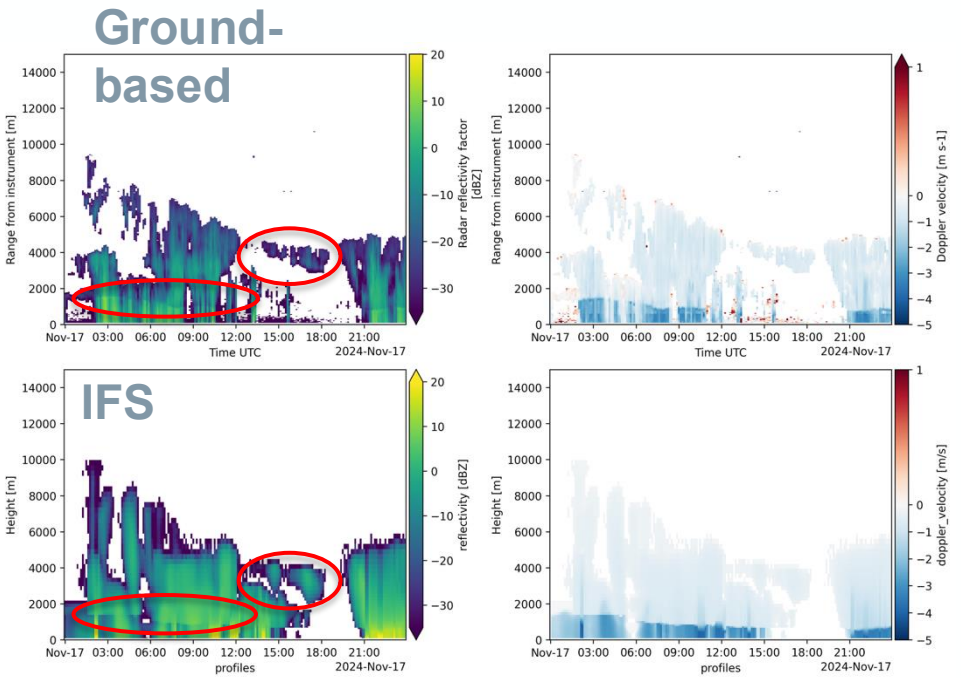
IFS

- Forward Operator ZmVar:
  Single grid-box "around" ground-site
- Time period: 06/2024 – 04/2026



How to compare OBS and IFS?



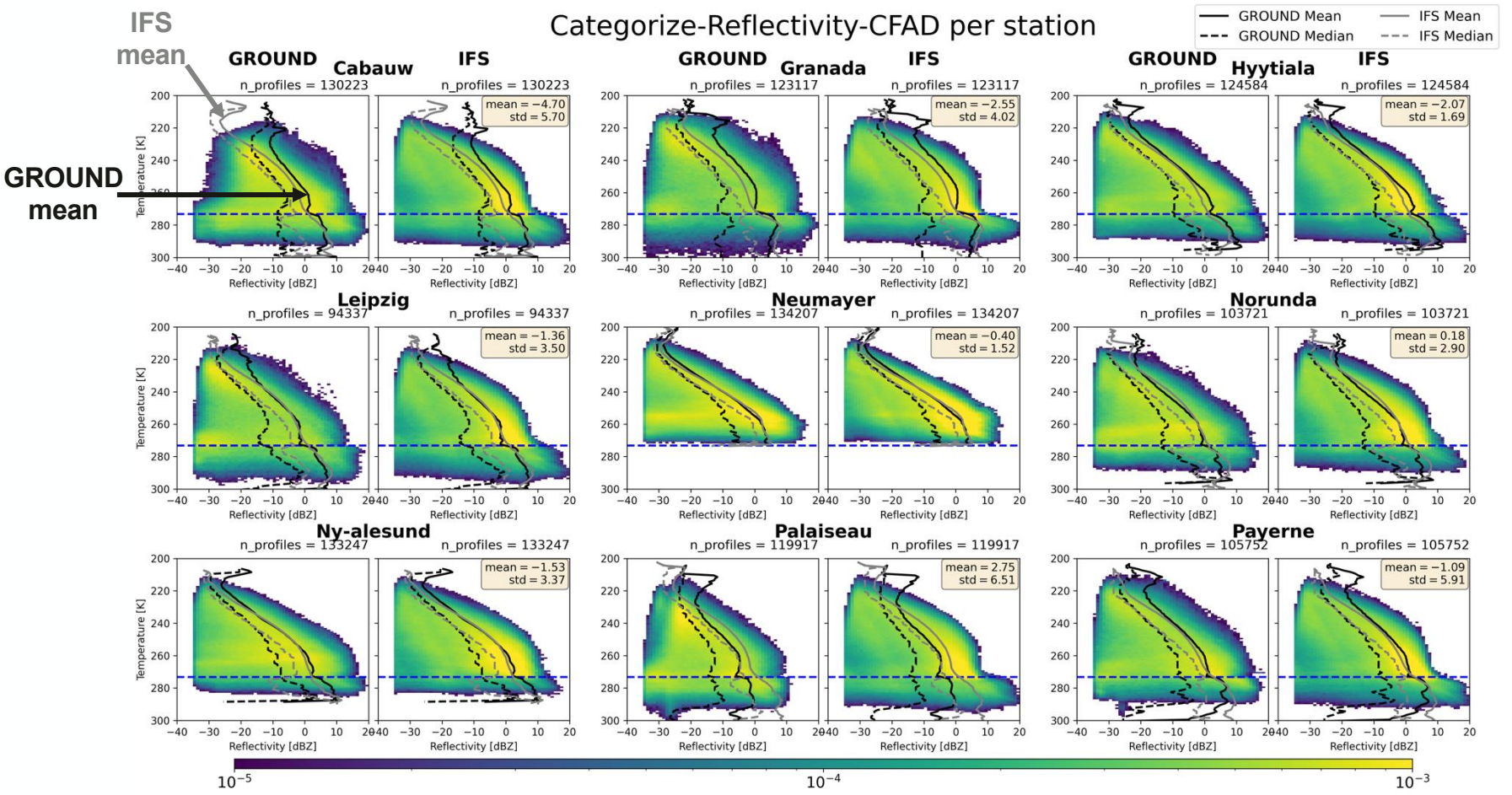


- Bigger picture: Observations & IFS match quite well
- Some differences: E.g. IFS coarser, larger clouds, “rapid” transitions, etc.

Can we trust the individual sites?

Reflectivity

- Bias from -4.7 dB to 2.75 dB
- All stations bias: -1.25 dB



Can we trust the individual sites?

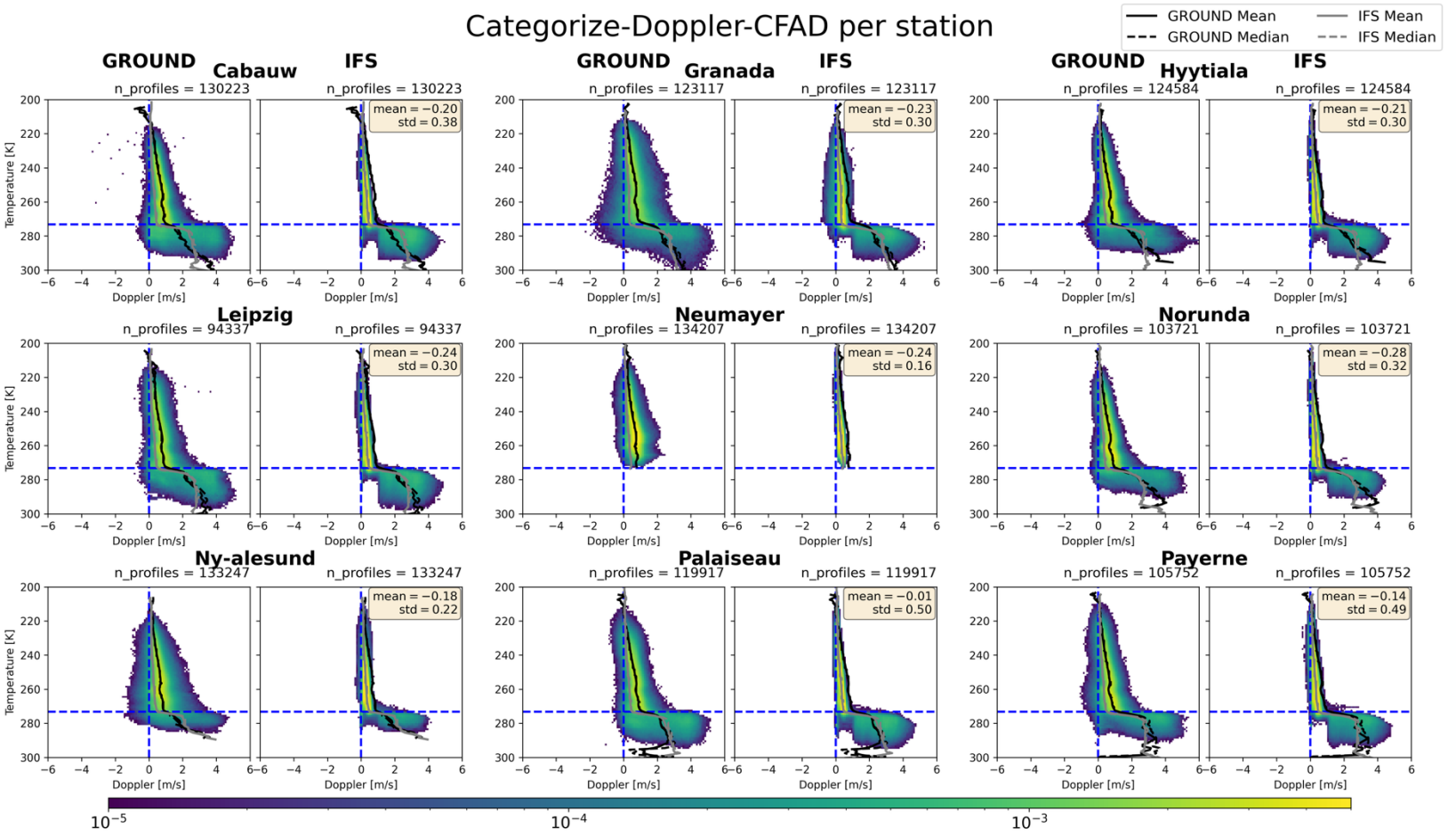
Reflectivity

- Bias from -4.7 dB to 2.75 dB
- All stations bias: -1.25 dB

Doppler

- Bias from -0.28 m/s to -0.01 m/s
- All stations bias: -0.14 m/s

➢ **Similar bias between GROUND & IFS across stations!**



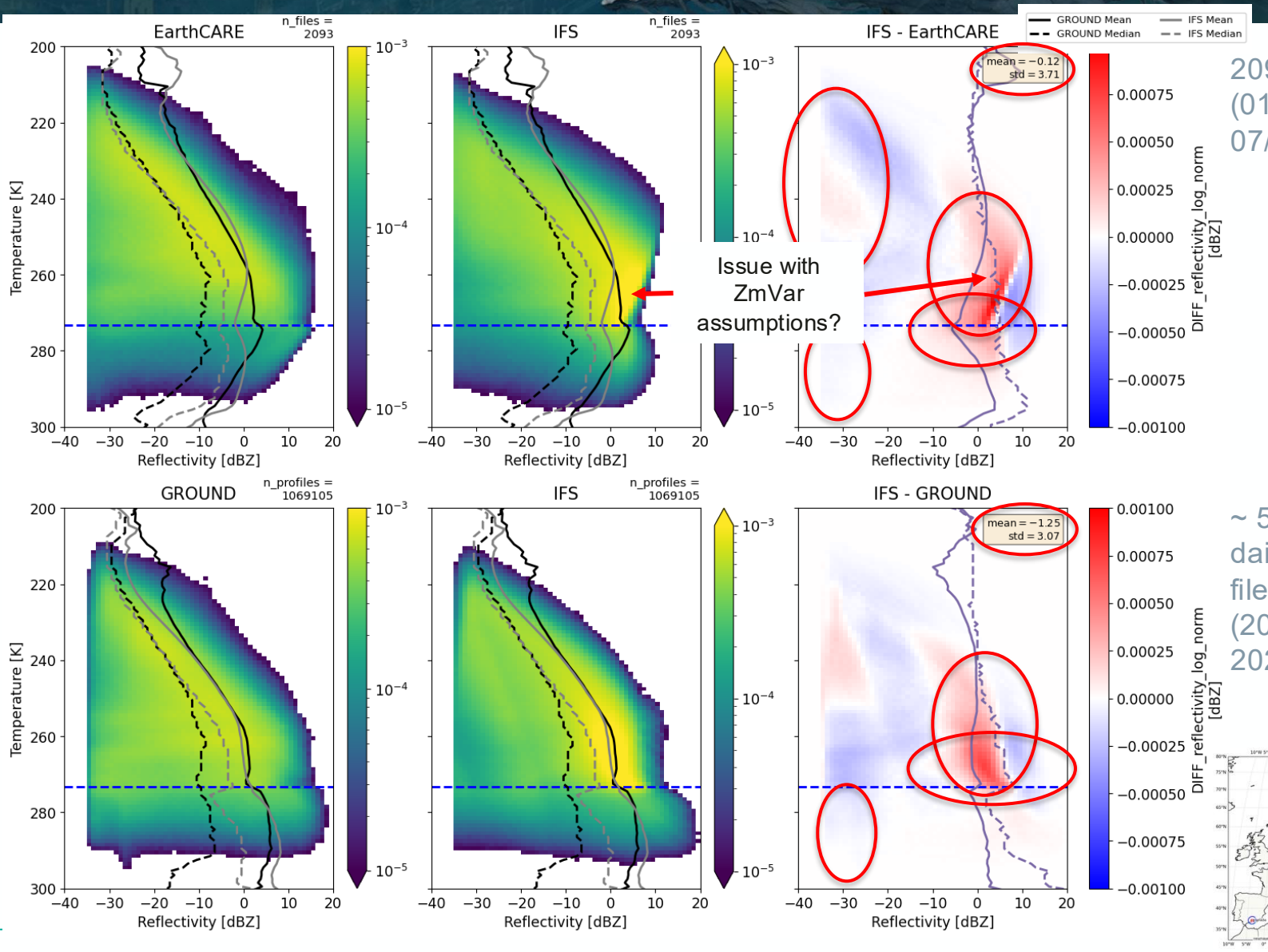
OBS vs. IFS – Reflectivity

EarthCARE vs. IFS

- Snow & ice – largest difference
  → ***Due to snow & ice related processes (e.g. sublimation)?***
- High clouds – IFS misses at ~220K
  → ***Too low in IFS?***
- Low-level clouds – small bias
- Over-/underestimation of precip.
  → ***PSD too narrow?***

GROUND vs. IFS

- Snow & ice – largest difference!
- Low-level clouds – small bias
- Close to 0°C → ***PSD too narrow?***



OBS vs. IFS – Reflectivity

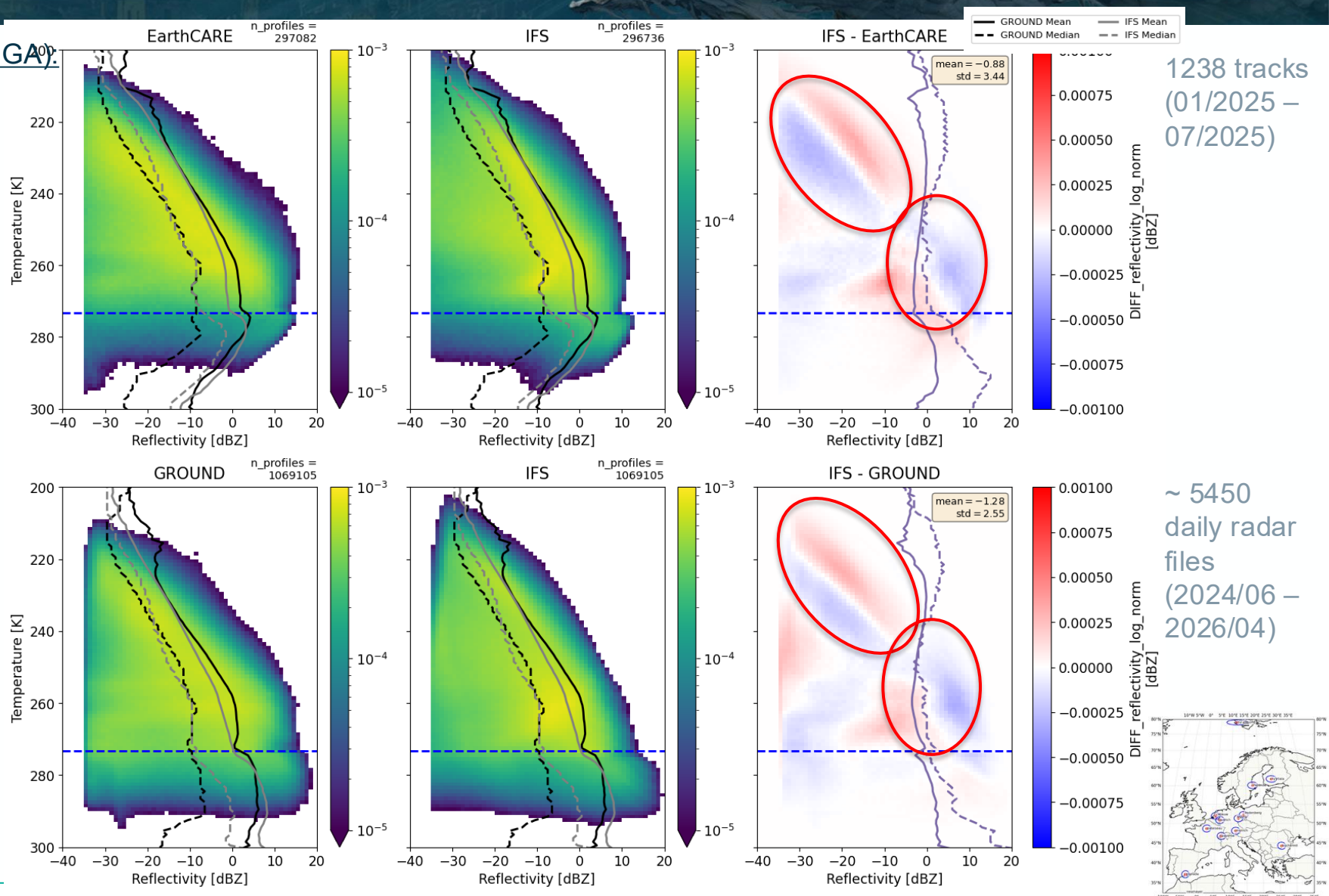
Self-Similar Rayleigh-Gans Approximation (SSRGA):
Snow & ice as aggregates (bulk scattering)
Hogan & Westbrook (2014)

EarthCARE vs. IFS

- >250K: Large bias gone!
  Bias at [-10, 10] dBZ
  → ***Issue with PSD?***
- <250K: Reflectivity of high clouds **now overestimated**
- Lower bias; similar to GROUND

GROUND vs. IFS

- >250K: Large bias gone!
  Bias at [-10, 10] dBZ
  → ***Issue with PSD?***
- <250K: High clouds now overestimated
- Marginal changes



1238 tracks (01/2025 – 07/2025)

~ 5450 daily radar files (2024/06 – 2026/04)

OBS vs. IFS – Doppler

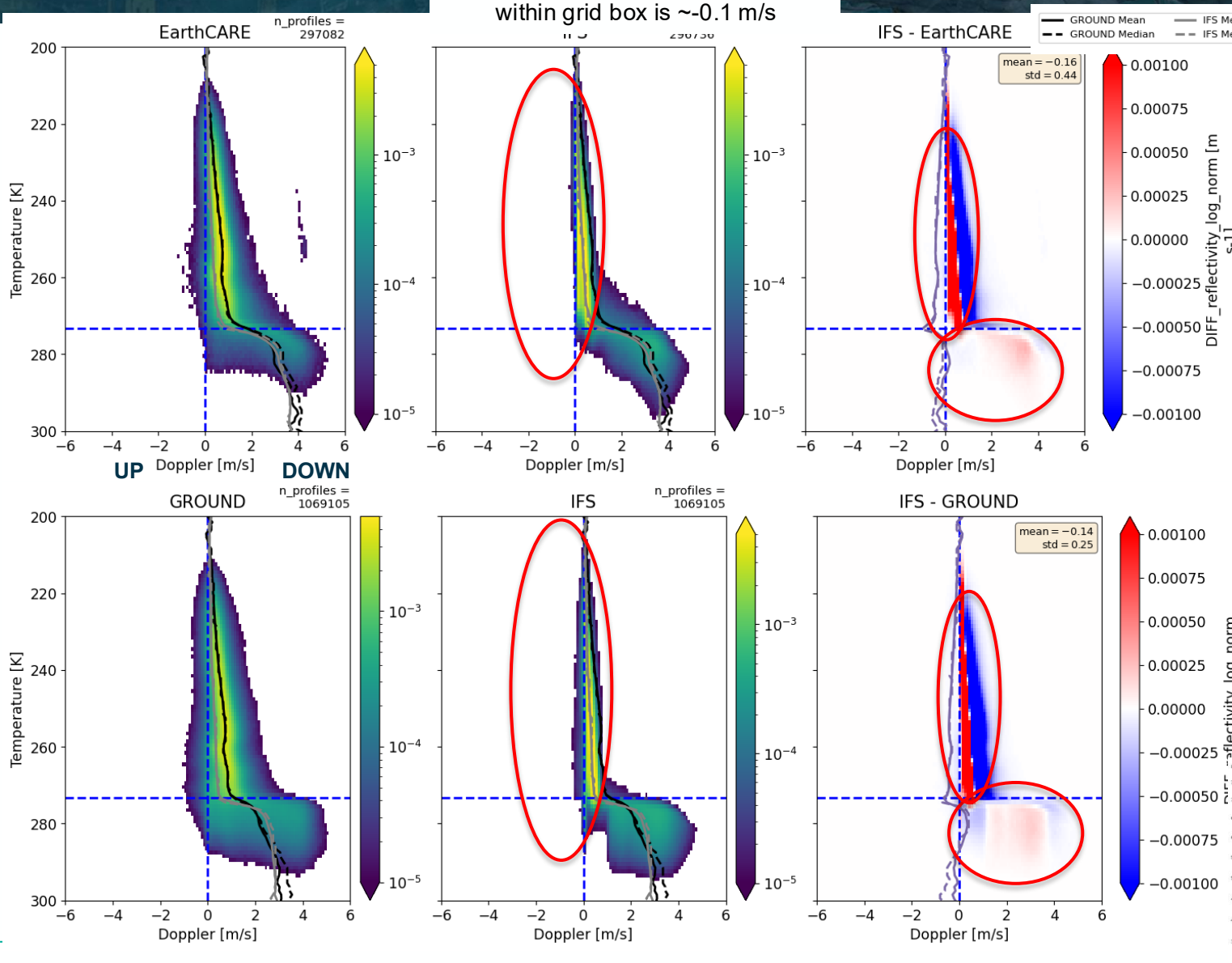
EarthCARE vs. IFS

- Large differences
  → ***Low variability of snow & ice fallspeeds in IFS***
- IFS ”overestimates” drizzle/light rain

GROUND vs. IFS

- Large differences
  → ***Low variability of snow & ice fallspeeds in IFS***
- Over-/Underestimation of fallspeeds
  → ***PSD of liq. precip too narrow?***

Mean vertical velocity within grid box is ~-0.1 m/s



2093 tracks (01/2025 – 07/2025)

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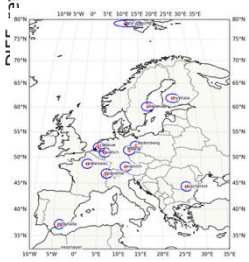


OBS vs. IFS – Doppler

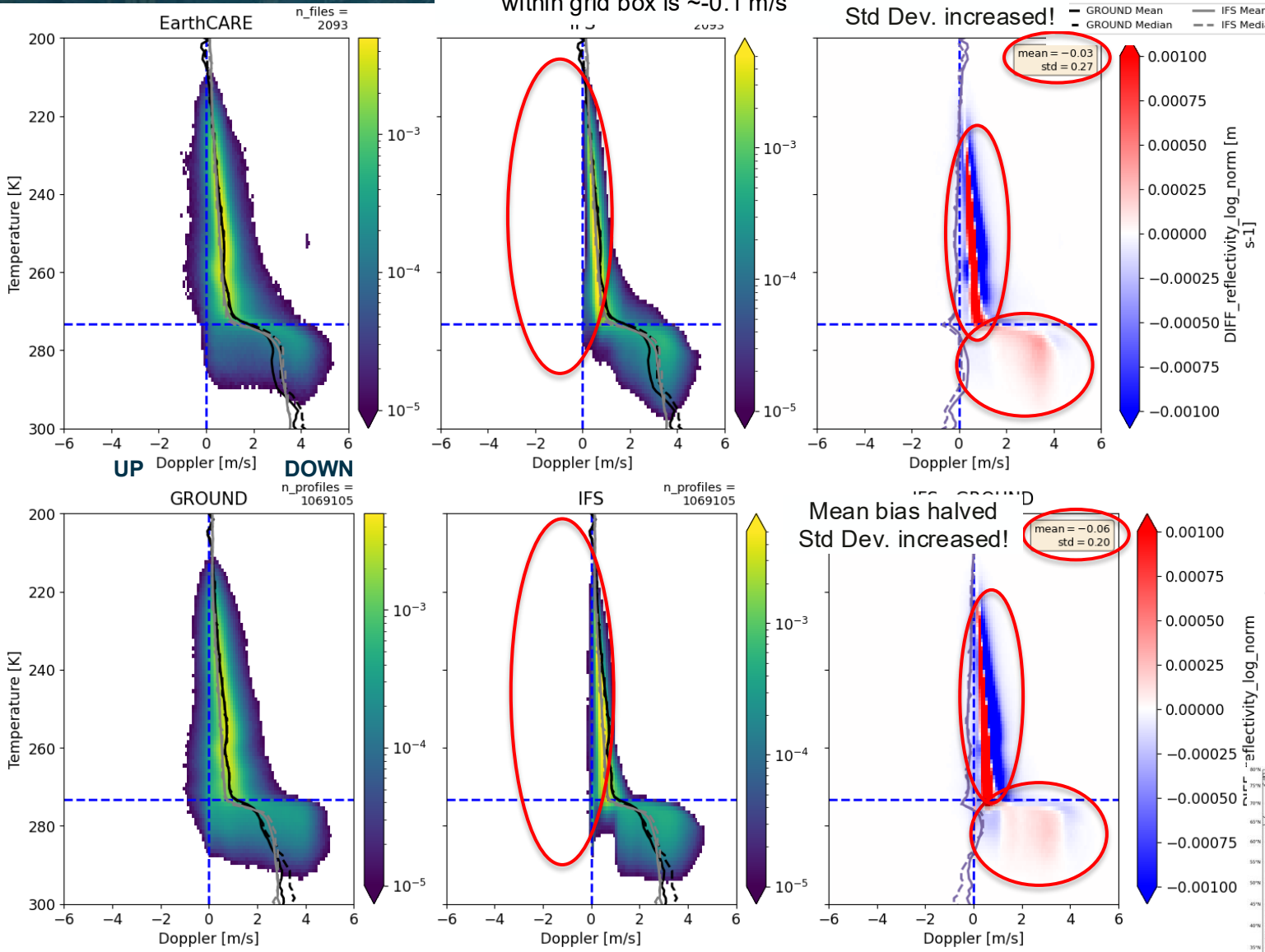
New assumptions:

Variable snow fallspeed

- Differences/patterns essentially the same
- Cold phase:
  Shift towards higher fallspeeds
  → Mean & Median profiles are closer together
- Smaller mean bias
  - Top: -0.16 m/s vs. -0.03 m/s
  - Bottom: -0.34 m/s vs. -0.06 m/s

Mean vertical velocity within grid box is ~-0.1 m/s

Mean bias halved
Std Dev. increased!



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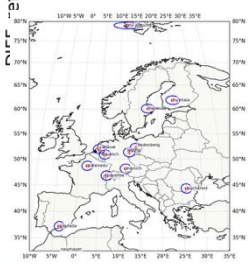

Summary

- On average IFS does a great job in reproducing EarthCARE & Ground-based radar observations
  → EarthCARE vs. IFS mean bias: ***-0.12 dB; -0.16 m/s*** *(standard assumptions)*
  → GROUND vs. IFS mean bias: ***-1.25 dB; -0.14 m/s*** *(standard assumptions)*
- However, there are some **"problem areas" within the IFS**
  - Reflectivity: Cold phase – reflectivity of high clouds
    Warm phase – (small) bias w.r.t. to low-level clouds
    Over-/underestimation of precipitation at -10 dBZ < Zh < 10 dBZ
    → PSD might be too narrow (too many small, too few larger particles)
  - Doppler: Cold phase – (fixed) snow & ice fallspeeds
    Warm phase – (light) rain not variable enough; PSD too narrow?
- Next steps:
  - Re-run ZmVar with different microphysical & scattering assumptions
  - Extend analysis to different regimes (BL clouds, cirrus clouds, etc.)
  - Extend analysis to diurnal cycle (make more use of GROUND data)


JAXA
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THANK YOU!