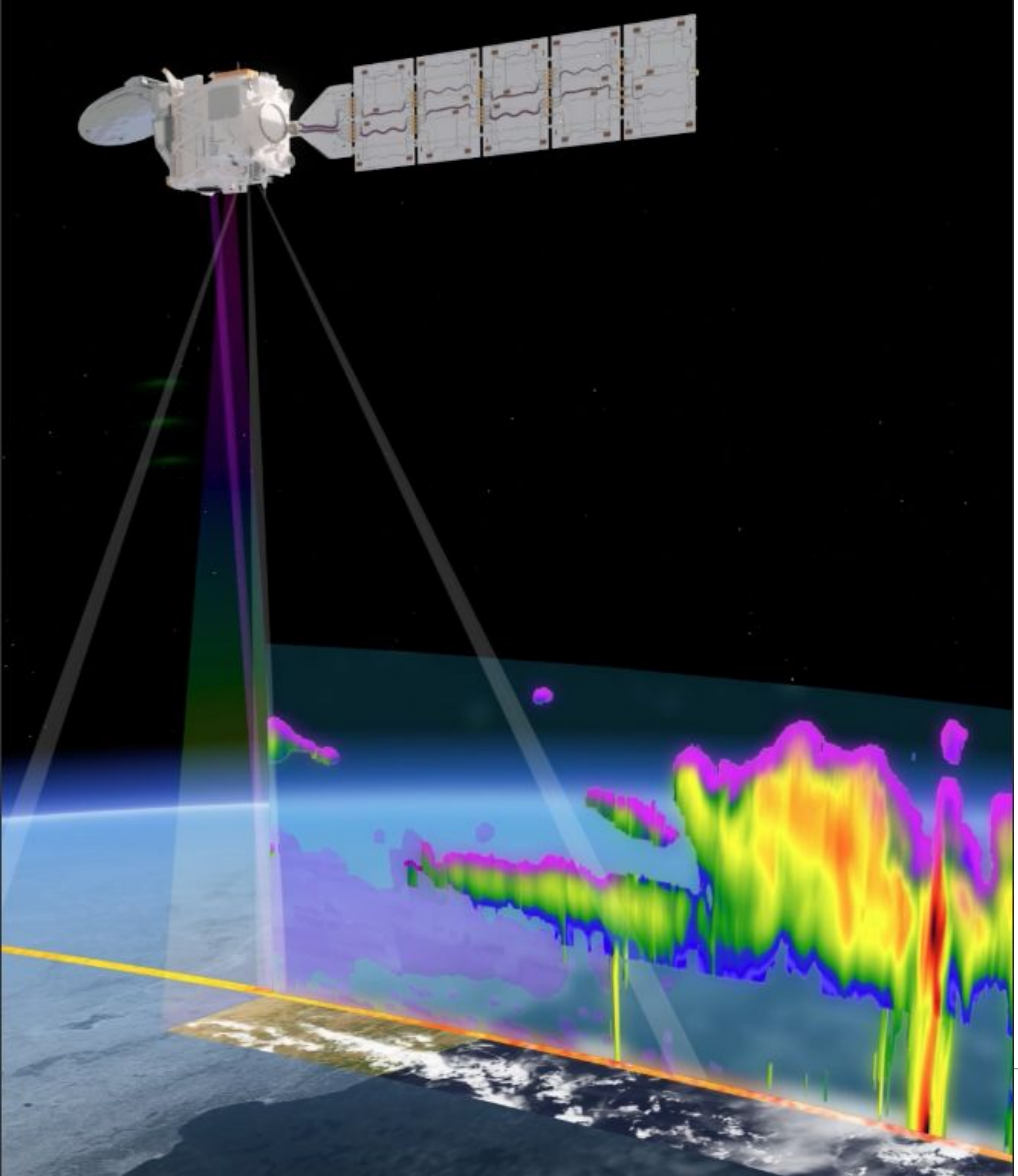

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CCRES Satellite Calibration/Validation Overview

EarthCARE activities

Lukas Pfitzenmaier
Nathan Feuillard, Felipe Toledo Bittner
Ewan O'Connor, Simo Tukiainen
et. al.

CCRES/CLU Spring Workshop, online, 19-20 May 2025

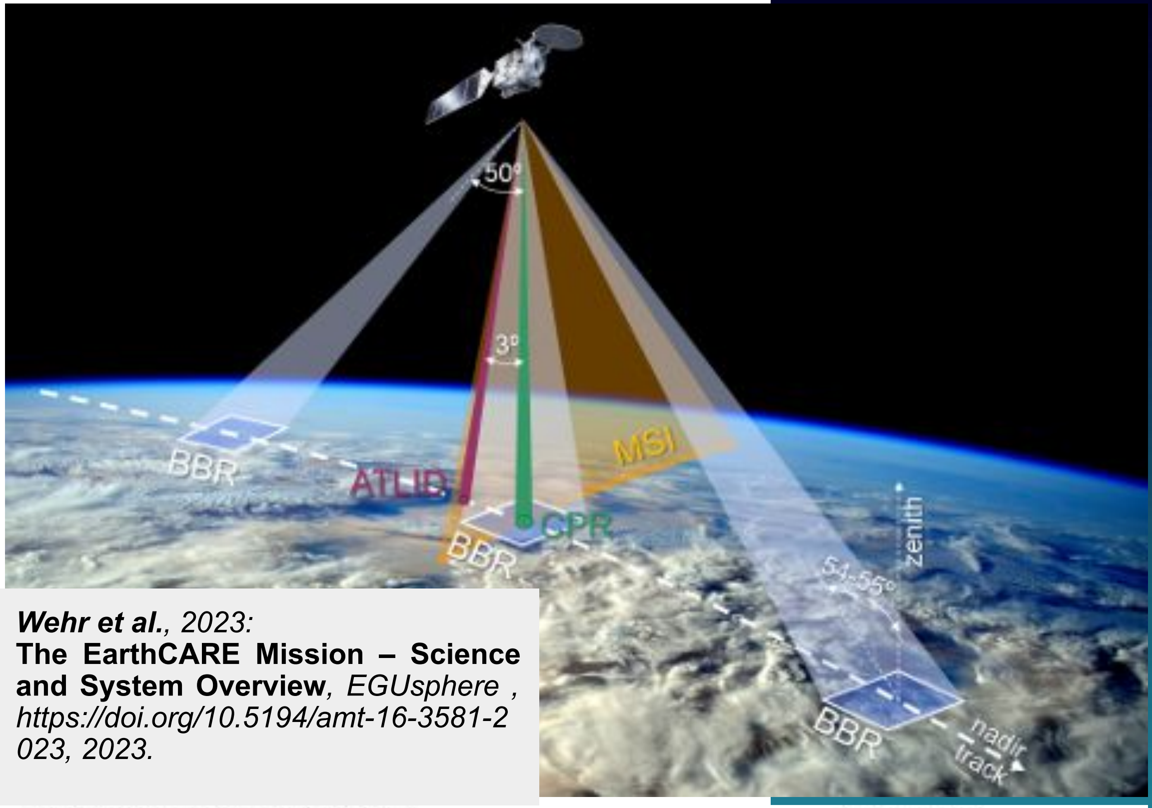
EarthCARE a flying Cloudnet site

Brought Band Radiometer (BBR)
- channels: 0.25 - 0.50µm & 0.50 - 4 µm
- 10 km by 10 km pixels

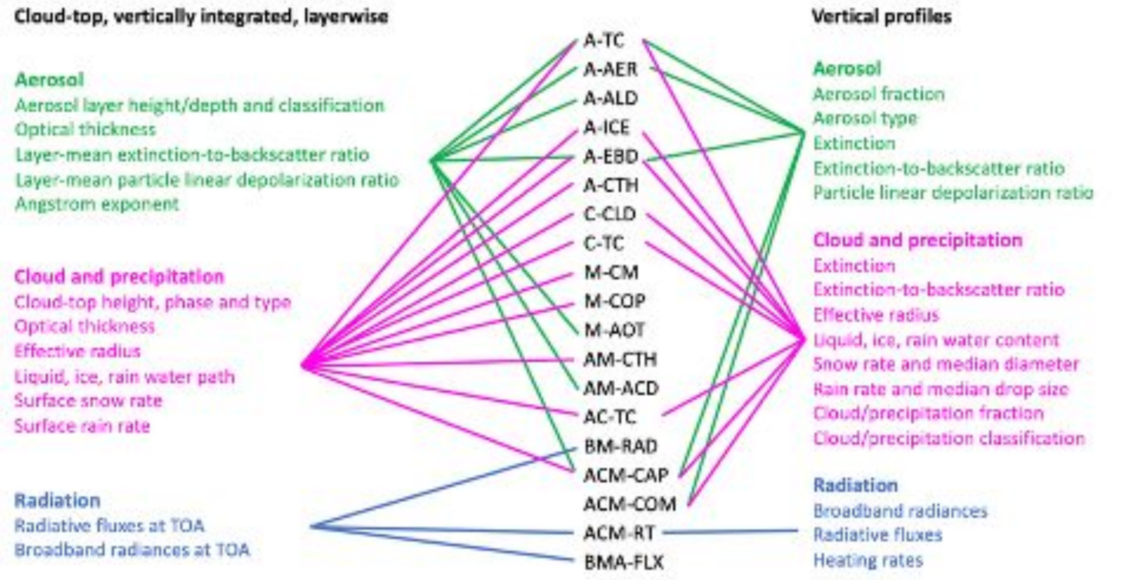
Multi Spectral Imager (MSI)
- channels: 0.670, 0.865, 1.65, 2.21, 8.80, 10.80. 12.00 µm
- view: 35 km to the right and 115 to the left

Cloud Profiling Radar (CPR)
- 94.05 GHz - range resolution 100m - footprint 800m
- First Doppler capable radar in space!
- Sensitivity: ~ -37 dBZ & +/- 5.6 m/s
- Doppler uncertainty: <= 0.5 m/s for Ze > -20 dBZ

Atmospheric Lidar (ATLID)
- High spectral resolution Lidar (HRSL) - range resolution 103 m - footprint 30
- 355 nm, Raylight and Mie and depolarisation channel



***Wehr et al.**, 2023:*
The EarthCARE Mission – Science and System Overview, *EGUsphere , https://doi.org/10.5194/amt-16-3581-2023, 2023.*



General overview EarthCARE mission

- BBR
  - Works well
  - It needs more validation of its performance – by fare the lowest contribution
- MSI
  - The diffuser of the MSI does not work
  - VNS calibration is needed
  - Calibration will need additional information/satellites, etc, and time
    - Because techniques have to be developed, people must work on the resources needed!
  - L1 and the resulting products have problems
- CPR
  - Doppler velocity can be used down to -20 /-25 dBZ
  - Antenna pointing correction has to be applied 0.04 – 0.08; otherwise, the error is between 0.4 – 0.8 m/s Publication by B. Puigdonènech Treserras et al., AMTD, 2025
  - Antenna pointing varies with time due to heating of the antenna by the sun
- ATLID
  - Impressive performance – a milestone for future space-borne Lidars
  - Lots of extinction products for different purposes – more explanation needed

General overview EarthCARE mission

- Validation of model parameterisations using EarthCARE data – ORCHESTRA model intercomparison project
  - Mase size relationships
- Low-level clouds
  - Cloud boundaries - LWP, LWC - mean droplet radius - precipitation at the ground
  - Radiative effects and their representation in models
- AI to improve surface precipitation detection
- Retrievals of low rain amounts from ground and space (limitation of Disdrometer and ground-based radar)
- Radiation measurements from the ground to compare with BBR
- Cloud target classification from the ground: graupel, drizzle, ice particle shapes in Cloudnet!
- Super-cooled liquid layer detection
- motions within clouds – convection, also the state of the convection
- Utilise statistics to determine characteristic particle fall velocities and microphysical processes
- Compare ESA and JAXA products and what we can learn from the differences, and the comparable performance

EarthCARE general comments and take home:

- All instruments are performing well!
  - MSI still has calibration problems
  - L2 products are affected!
- Data are available at ESA and JAXA
  - L2 products might differ
  - **ESA and JAXA have different L2 algorithms!**
  - **EarthCARE L2 Data access**
  - https://earth.esa.int/eogateway/catalog/earthcare-esa-l2-products

- **Script downloading data**
  - oads_download.py L. König
- **Scripts reading and plotting etc…**
  - ectools.py by S. Mason

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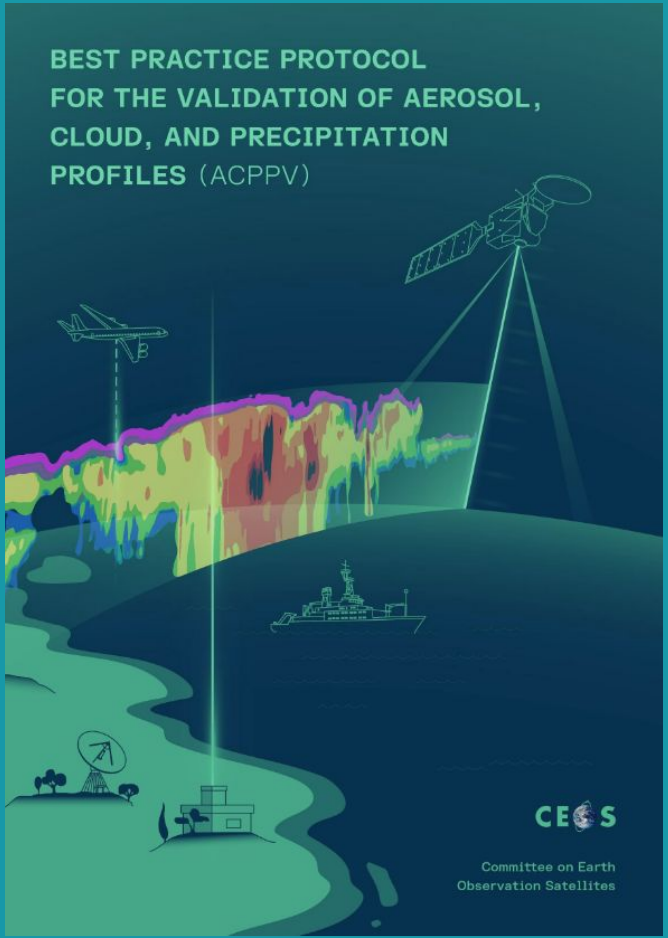
EarthCARE general comments and take home:

Best practice protocol for the validation for Aerosol, Cloud and Precipitation profiles
Cite: https://zenodo.org/records/15025627

- Validation techniques all kind of profiling instrumentation - airplane and ground to satellite
- What to validate?
- How best validate?
- Which techniques are available?
- What is done already - Cloudsat, Calipso, GPM,... ?
- Validate a case studies or statistical approaches?
- Which code/tools might be available?
- What are the open questions and gaps in calibration/validation?
- ….



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Reflectivity validation

CCRES/CLU Spring Workshop, online, 19-20 May 2025

Methodology

EarthCARE-ACTRIS reflectivity comparison algorithm.

Data selection inspired from Protat et al (2009).

- ➢ CPR: sample overpass in 200 km range from sites.
- ➢ Ground: zenith observations in ±1h around overpass time.

→

Filter liquid clouds: take account of differences in attenuation.

- ➢ CPR: L2a target classification.
- ➢ Ground: CloudNet classification.

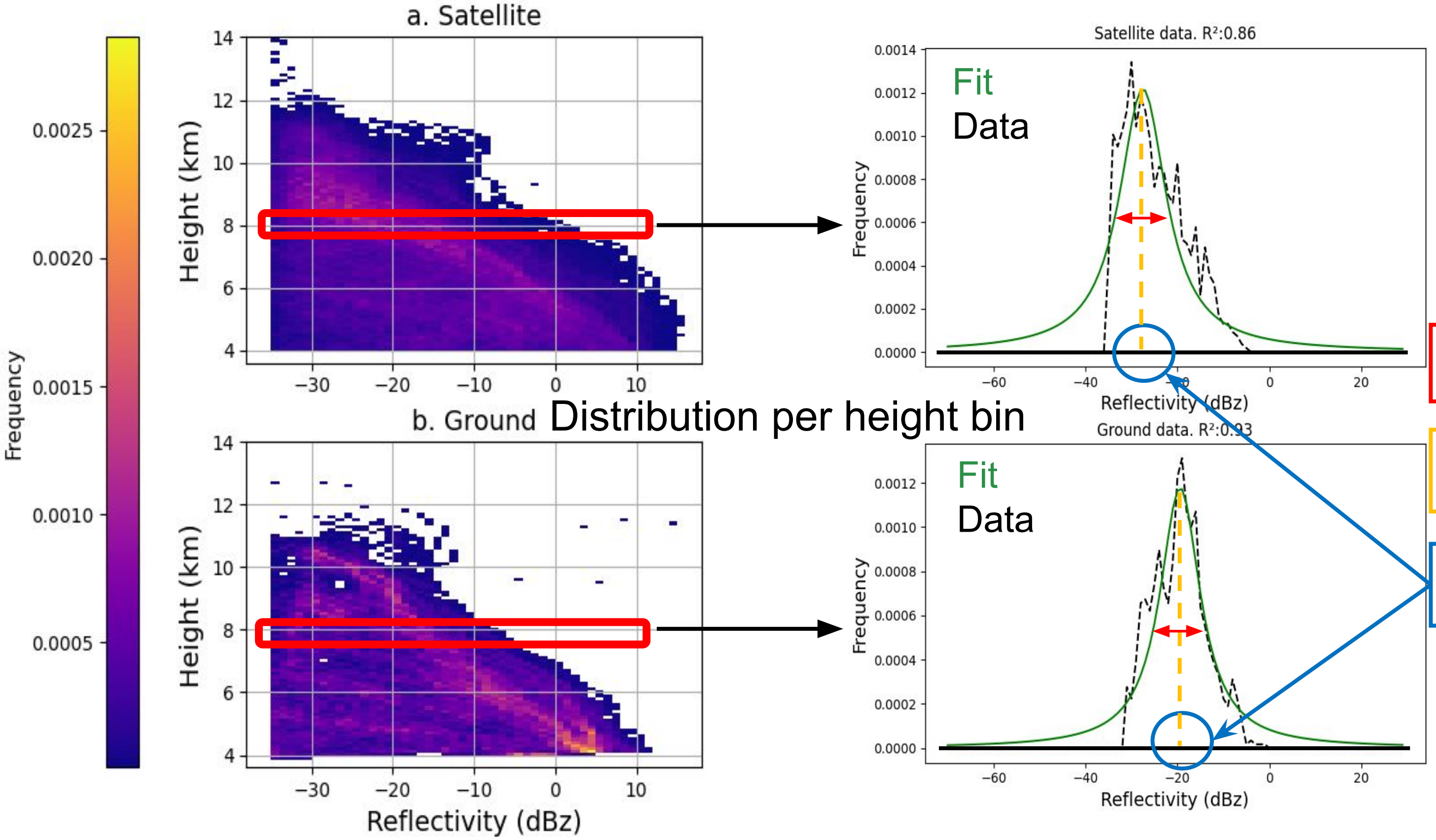
→

- Ground data resampling to match satellite range.
- Sensitivity matching.

↓

Reflectivity comparison between CPR and ground based radar.

Methodology



Lorentzian model criteria:

R² of the fit

Width of the distribution

Amplitude of the distribution

Center of the distribution

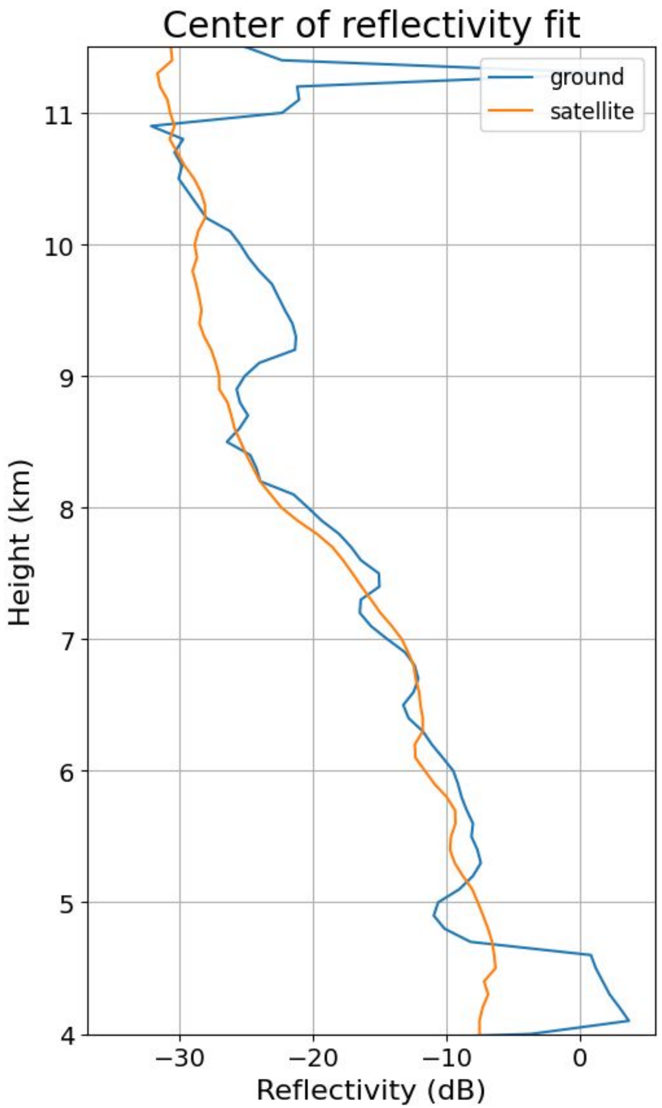
Fit with a Lorentzian model to sort data (threshold based):

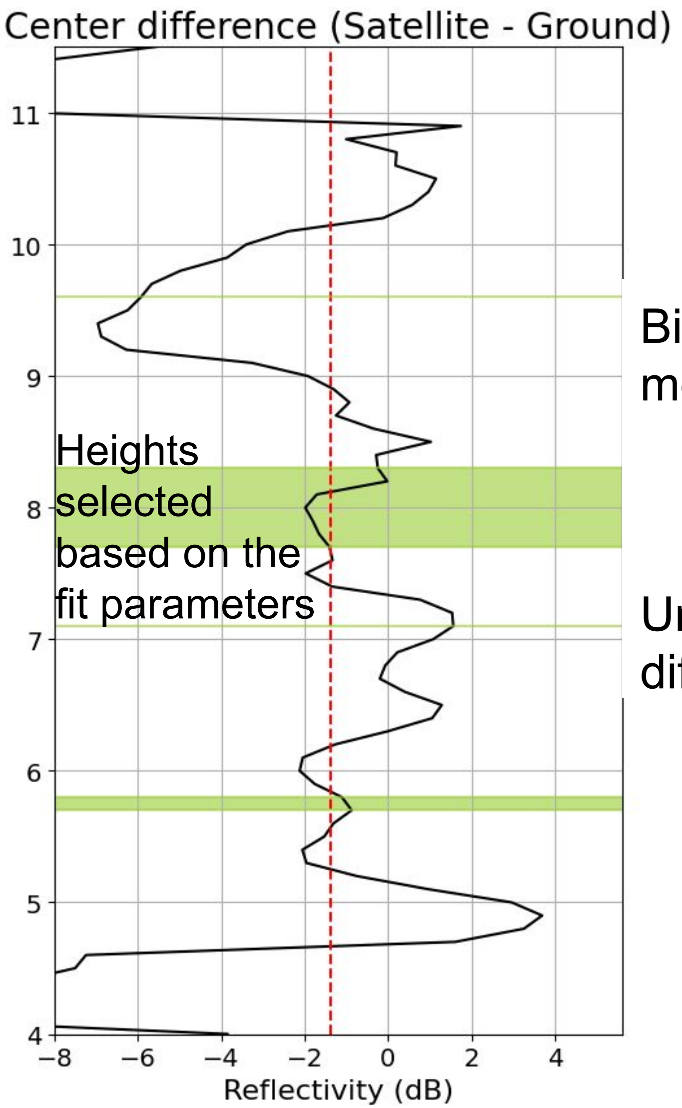
- If criteria fulfilled bin selected (width difference, center correlations, R^2).
- Otherwise bin filtered out.

The center of the fit is used as the estimator for the bias.

Methodology

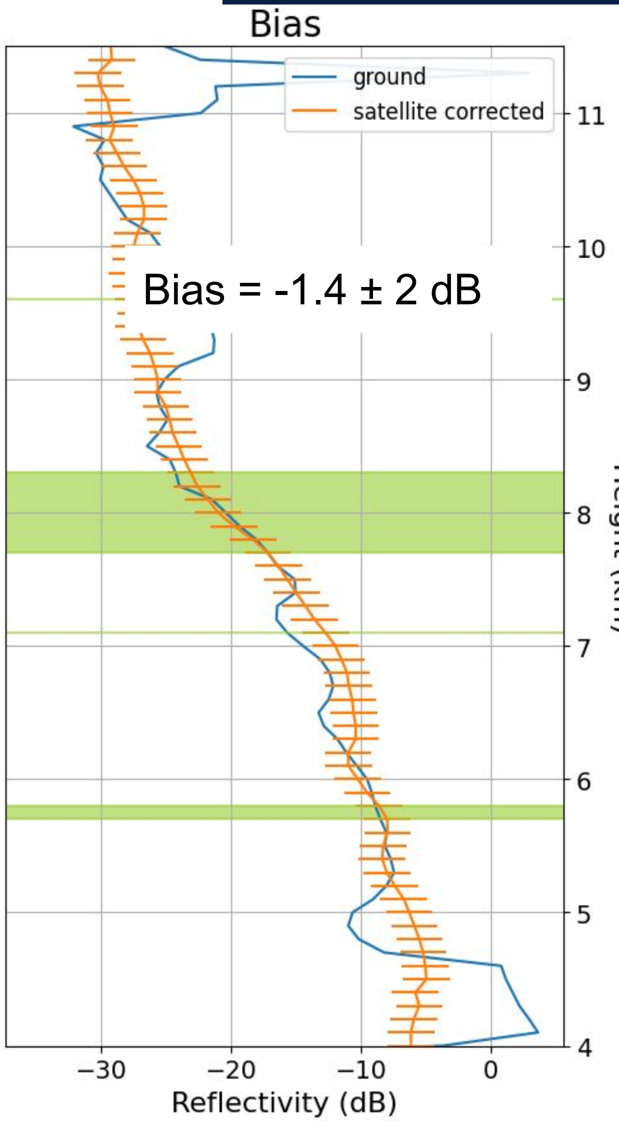
Jülich site, period from 12/24 to 05/25 (~4.5 months).





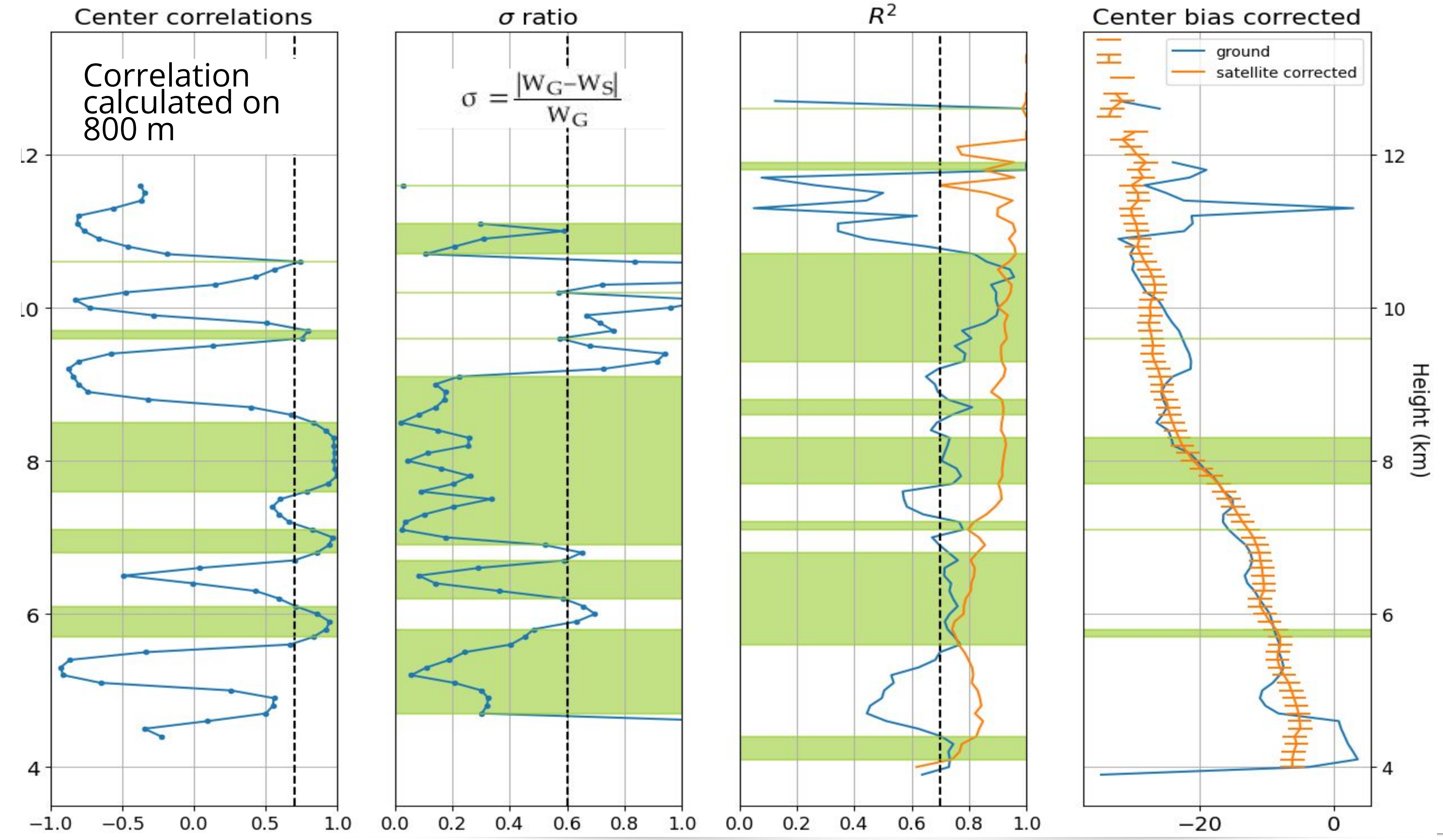
Bias = mean(centers differences)

Uncertainty = std(centers differences)



Methodology

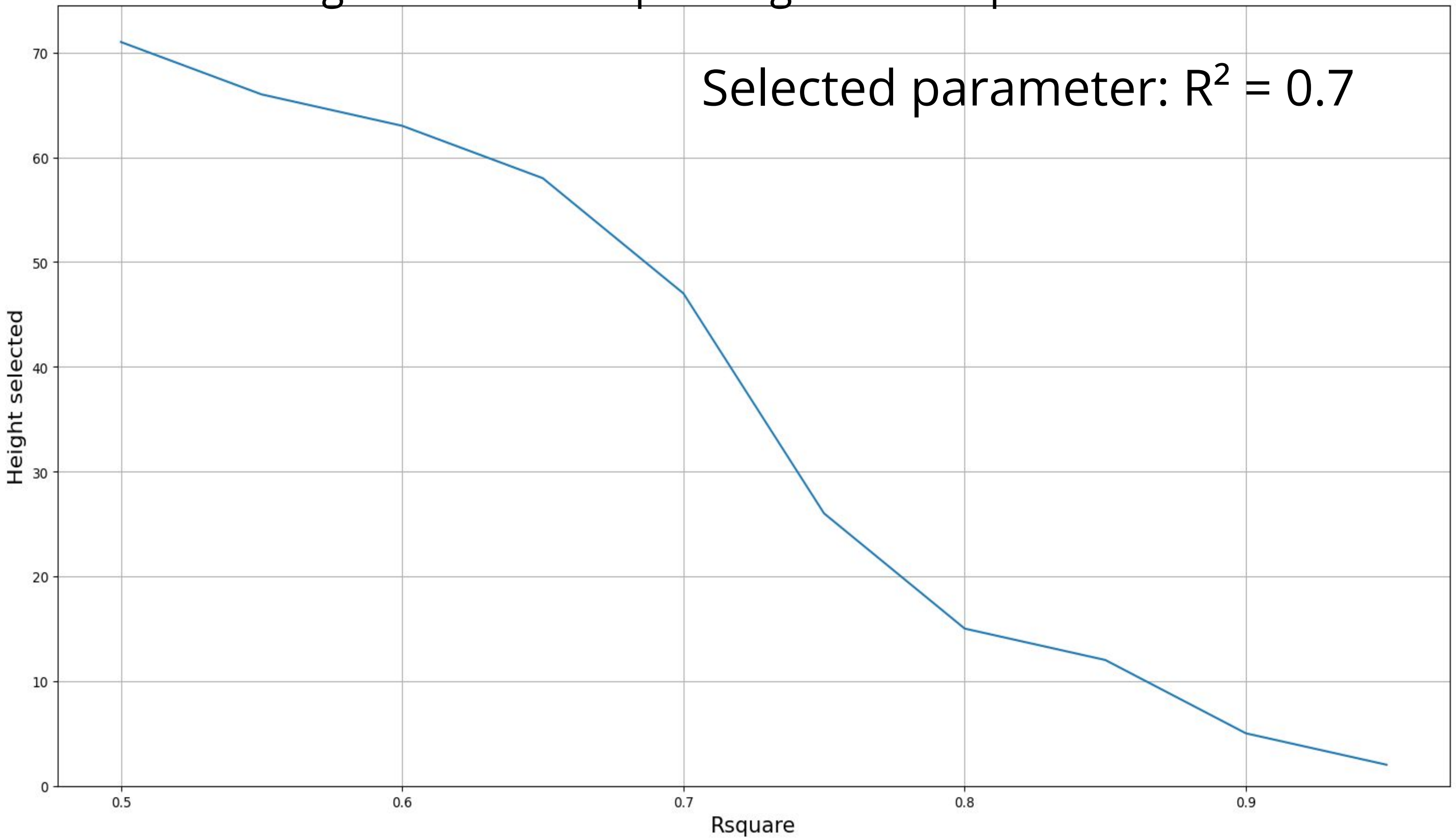
Parameters for the height selection, Jülich site.



Selection parameters study

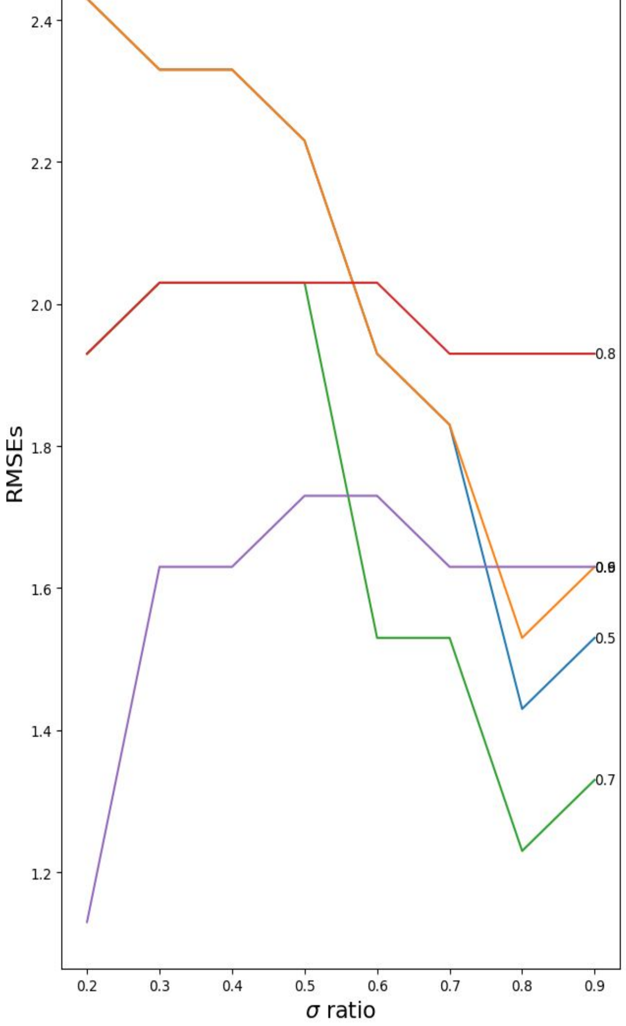
R^2 = goodness of the fit. If not well adjusted other parameters don't make sense.
This parameter **does not** evaluate any statistical similarities.
=> Don't be too conservative on height selection.

Number of heights selected depending on the R^2 parameter

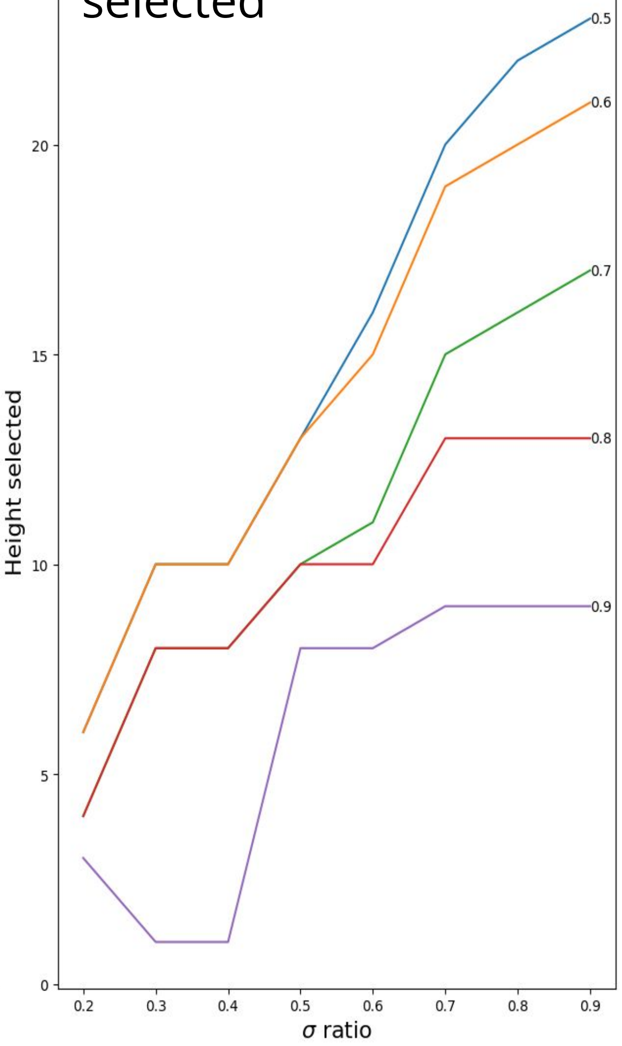


Selection parameters study

RMSE between ground and corrected satellite data



Number of height bin selected



Each curve represent a different value for centers correlations (CC).

Need to **select the most height** while **minimizing the RMSE**.

Selected values for the parameters:

- CC = 0.7
  - Data correlated enough
  - Enough height selected
- σ ratio = 0.6

These parameters are not fixed and still need some refinement.

Uncertainty study

Uncertainty sources identified:

- σ_{Gr} : uncertainty in ground radar measurements. => characterized
- σ_{Ce} : uncertainty from the estimation of the centers. => characterized
- σ_{B} : uncertainty from the bias estimation. => characterized
- σ_{Ga} : uncertainty from the gaseous attenuation correction. => negligible
- σ_{Co} : uncertainty from the conversion 35 GHz to 94 GHz. => negligible

Total uncertainty : $\sqrt{\sigma_{Gr}^2 + \sigma_{Ce}^2 + \sigma_{B}^2}$

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Code validation plan

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At this moment the method implemented has not been validated.

Make use of the ground well characterized and calibrated radars for the validation.
=> ie use the sites of Palaiseau, Jülich and Leipzig.

The Satellite-Ground bias should be the same for each site, taking the correction from the calibration into account.

➢ At this moment the bias evaluated for Jülich and Leipzig are in the same range.

As the method is statistical, more time of observation will be needed to confirm these results.

Conclusion – Perspectives

Conclusion:

- 4.5 months of data used for these analyzes.
  - More time is needed for better estimations (6-9 months)
- Selection parameters still need some adjustments.
- Validation is in progress and still needed for the method.

Perspectives:

- Analyzes for the whole network with refined parameters (implementation of time series).
- Article in preparation

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Doppler velocity validation

CCRES/CLU Spring Workshop, online, 19-20 May 2025

Results: Doppler velocity Val 1st workshop (January)

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- Work in progress

- Used L1 data:
  - NUBF not corrected
  - Doppler velocity unfolded
- Expect improvements using L2 CPR data

- Tendency of the L1 data is:
  - Overestimation of ground-based Doppler velocity
  - Outliers are not dramatic
  - Mean range: 0.50 ms^{-1}
  - Other Doppler velocity validation results to compare are missing.

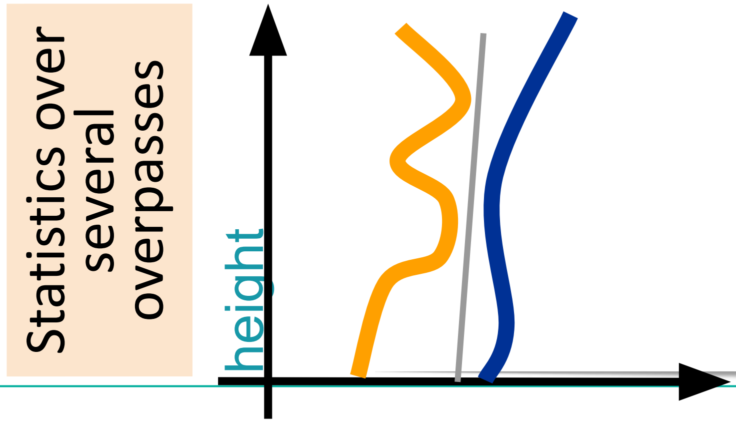
Number of overpasses → North

Site	Vm bias/ RMSE (BA)	Vm bias (BB)	
Ny Ålesund	0.65 / 0.67 ms^{-1}	no ground data	**BA overpasses (91)**
Hyytiälä	0.40 / 0.42 ms^{-1}	0.25 ms^{-1}	**mirroring ground echo** BA overpasses (34)
Lindenberg	0.59/ 0.61 ms^{-1}	0.43 ms^{-1}	BA overpasses (20)
Cabauw	0.65 / 0.70 ms^{-1}	0.33 ms^{-1}	BA overpasses (19)
Jülich	0.29 / 0.86 ms^{-1}	Not enough data	BA overpasses (29)
Palaiseau	0.53 / 0.72 ms^{-1}	0.47 ms^{-1}	
Munich			No analyzed
Galati	0.49 / 0.52 ms^{-1}	0.34 ms^{-1}	BA overpasses (20)
Bucharest	0.71 / 0.77 ms^{-1}	0.46 ms^{-1}	BA overpasses (16)
Potenza			No analyzed
Granada	0.44 / 0.53 ms^{-1}	not enough data	BA overpasses (23)
Mindelo			No analyzed
Neumayer	0.18 / 0.32 ms^{-1}	0.42 ms^{-1}	BA overpasses (41)

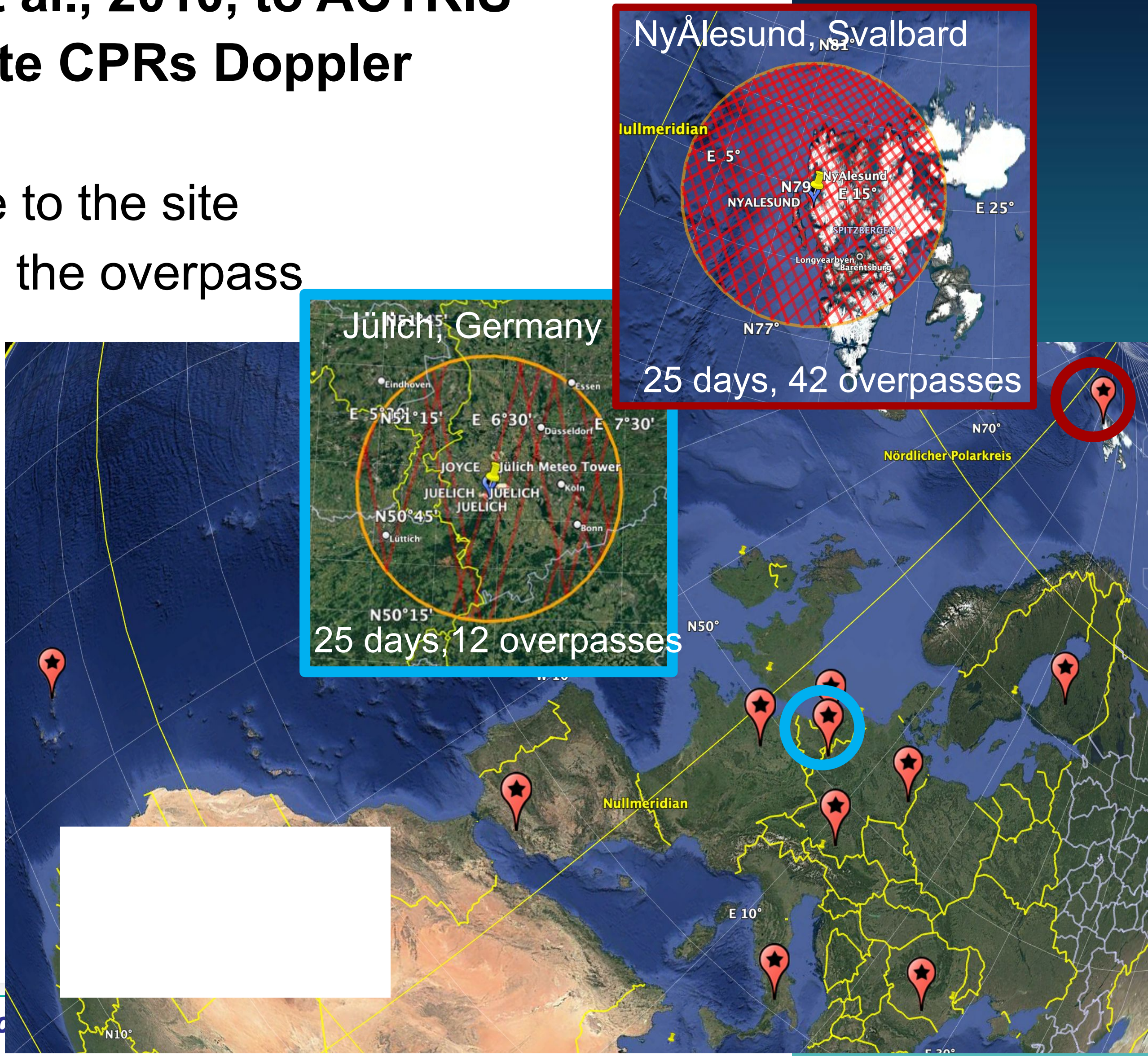
Doppler velocity Cal/Val – Method: statistical comparison

Adapt the statistical comparison of Protat et al., 2010, to ACTRIS ground-based cloud radar network to validate CPRs Doppler velocity

- **CPR:** sample **all overpasses ± 100km** distance to the site
- **GROUND: zenith observations ± 1.5 h** around the overpass
- compare values only where
  - **Ze_{CPR}/Ze_{GROUND} > -15 dBZ**
  - **3.5km and higher from the ground**
- use CPR **baseline BA and BB data**
- **CPR L2 is planned for the future**

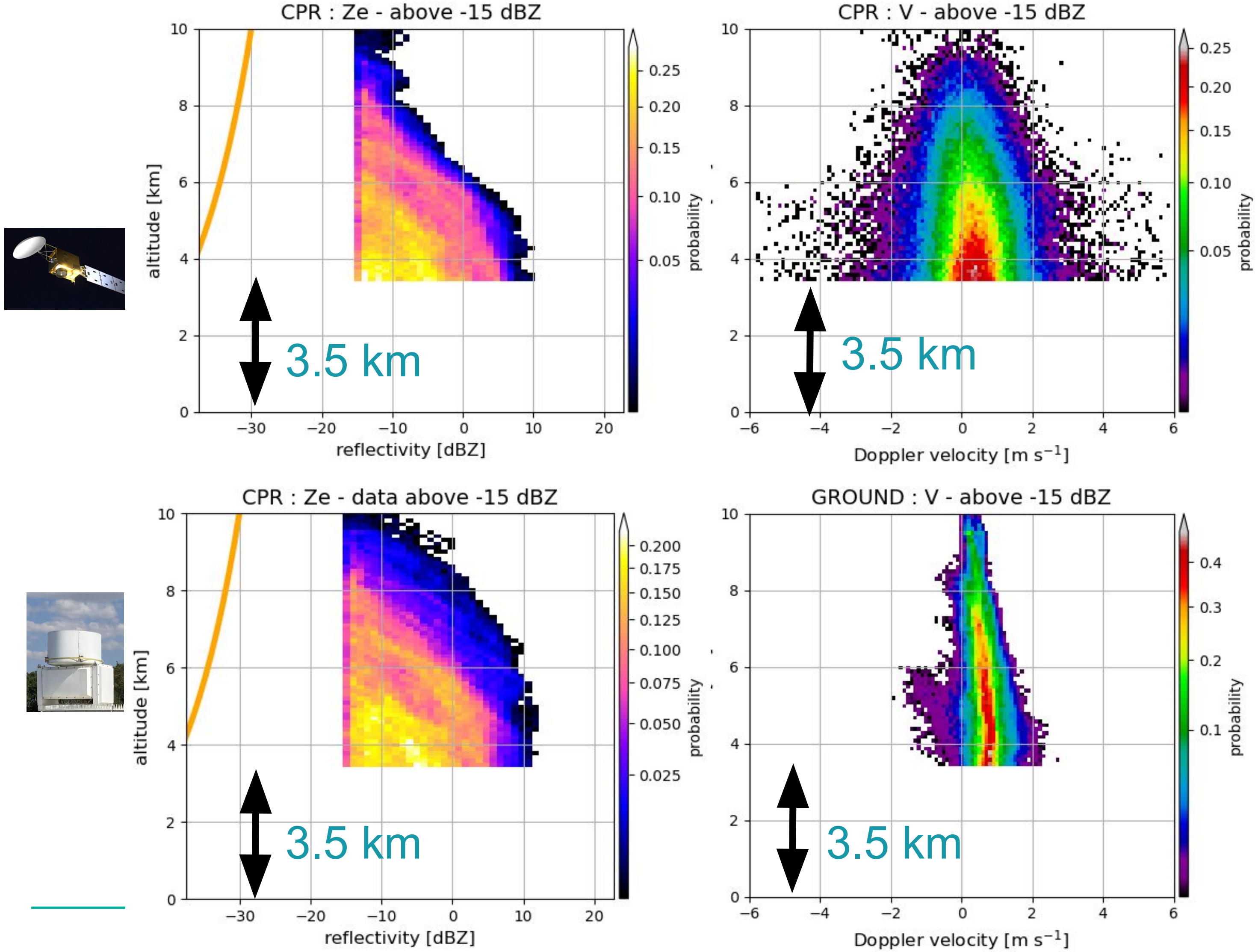


Mean of GROUND and CPR data set > estimate the mean bias

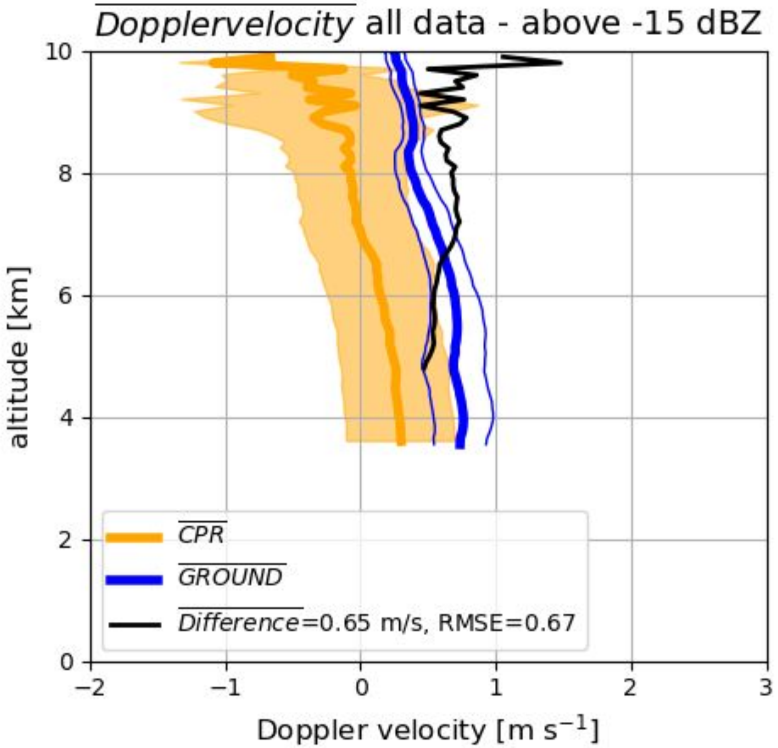


Example Doppler velocity val – NyÅlesund - BL BA

All overpass from baseline BA, NyÅlesund ~ 60 overpasses



- Applying ground - based radar SNR to filter CPR
- Better Doppler velocity data
  - Vm only above -15 dBZ
  - Site - dependent height clipping
- Mean profiles of overpass vs



Results: Doppler velocity Val 2st workshop

ACTRIS CCRES

- Work in progress
- Used L1 data:
  - NUBF not corrected
  - Doppler velocity unfolded
- Tendency of the L1 data is:
  - Overestimation of ground-based Doppler velocity
  - Longer temporal averaging reduces bias

 Variation of the Doppler in time?

- Other Doppler velocity validation results to compare are missing.

North

Number of overpasses

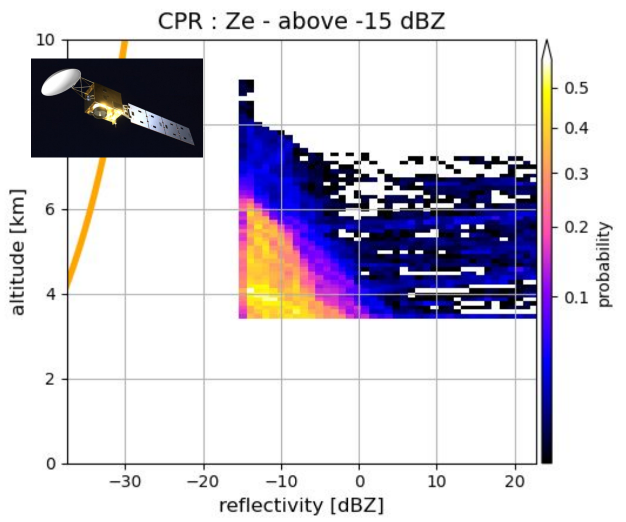
Site	Vm bias (BA)	Vm bias (BB)	Vm bias (CA, 2025)	Vm bias (CA, all)
Ny Ålesund	0.65 ms^{-1}	ms^{-1}	0.14 ms^{-1}	0.17 ms^{-1}
Hyytiälä	0.40 ms^{-1}	0.25 ms^{-1}	0.16 ms^{-1}	0.26 ms^{-1}
Lindenberg	0.59 ms^{-1}	0.43 ms^{-1}	0.06 ms^{-1}	- 0.21 ms^{-1}
Cabauw	0.65 ms^{-1}	0.33 ms^{-1}	0.48 ms^{-1}	0.42 ms^{-1}
Jülich	0.29 ms^{-1}	No enough data	0. 27 ms^{-1}	0.26 ms^{-1}
Palaiseau	0.53 ms^{-1}	0.47 ms^{-1}	- 0.05 ms^{-1}	0.28 ms^{-1}
Munich			0.19 ms^{-1}	0.44 ms^{-1}
Galati	0.49 ms^{-1}	0.34 ms^{-1}	-0.24 ms^{-1}	-0.09 ms^{-1}
Bucharest	0.71 ms^{-1}	0.46 ms^{-1}	0.08 ms^{-1}	0.08 ms^{-1}
Potenza			0.16 ms^{-1}	0.32 ms^{-1}
Granada	0.44 ms^{-1}	ms^{-1}	- 0.34 ms^{-1}	0.01 ms^{-1}
Mindelo	No enough data	No enough data	No enough data	No enough data
Neumayer	0.18 ms^{-1}	0.42 ms^{-1}	0.39 ms^{-1}	- 0.31 ms^{-1}

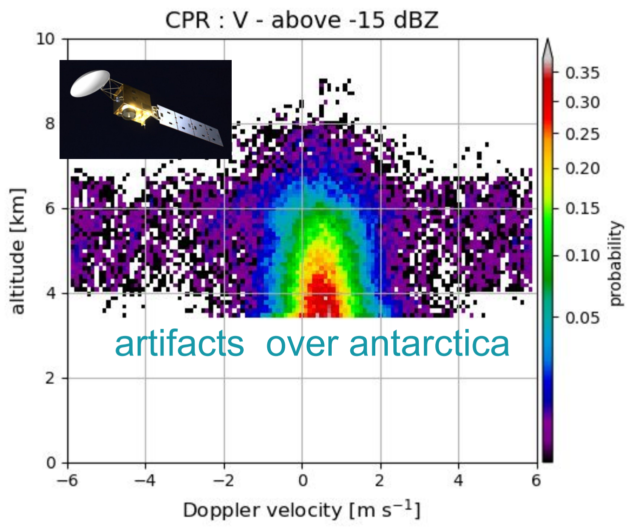
north hemisphere
ies in CPR L1 data
Hyytiälä example next slide
Mindelo example next slide
Neumayer example next slide

CRES/C

Issues CPR L1 and limitation of the current method:

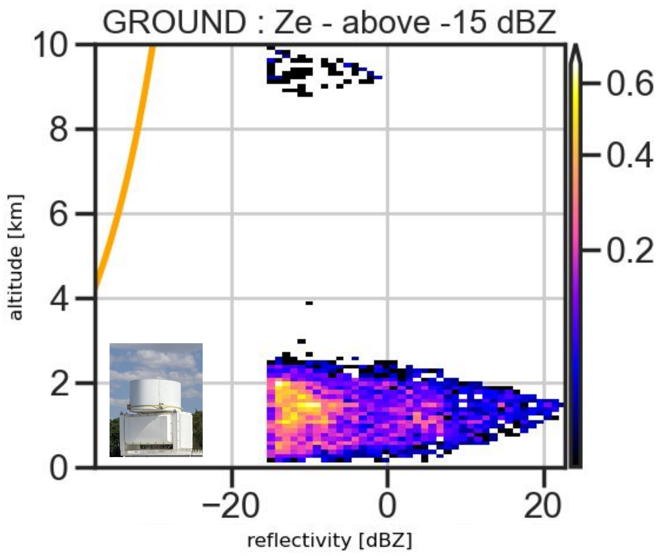
Nenmayer, BL BA

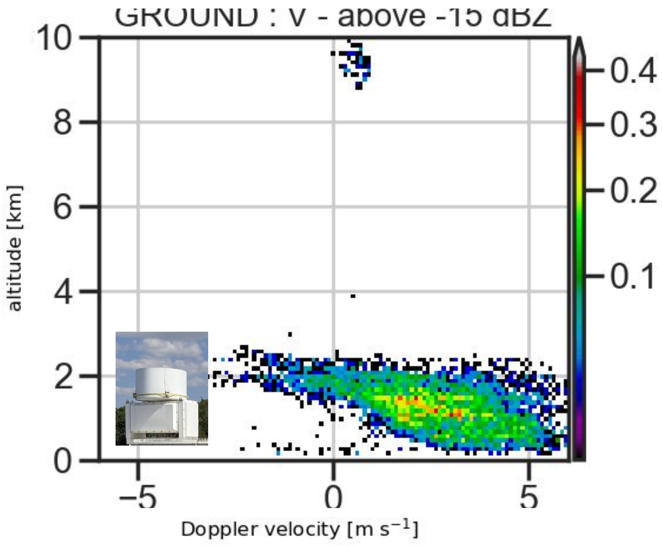




Data are near ground
□ filtering
Data are below -15 dBZ
□ cirrus removed

Mindelo, CA 07-2024 – 02-2025

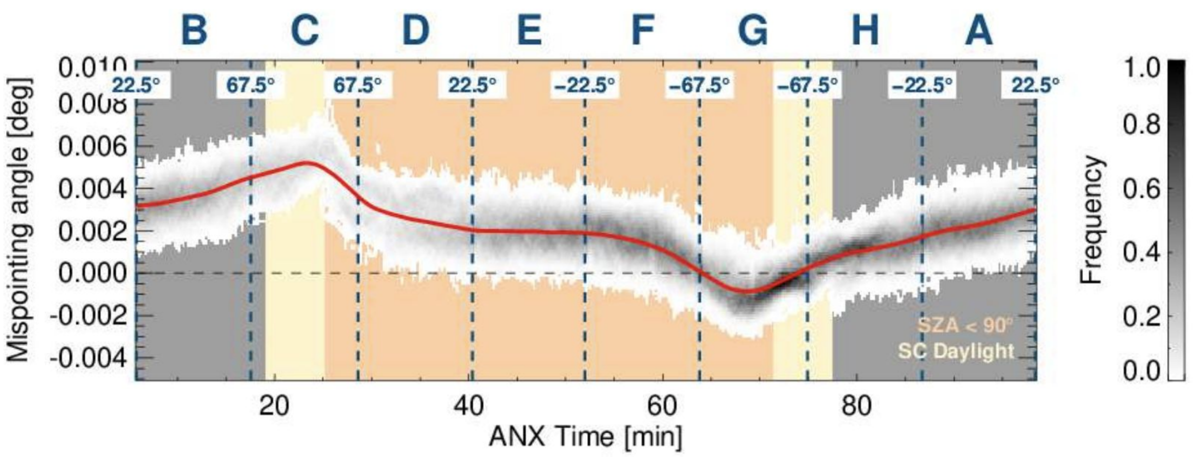




Some artifacts in the L1 data □ disturb the statistics

Not enough data to compare

Question: Driftzs in the Doppler velocity offsets?



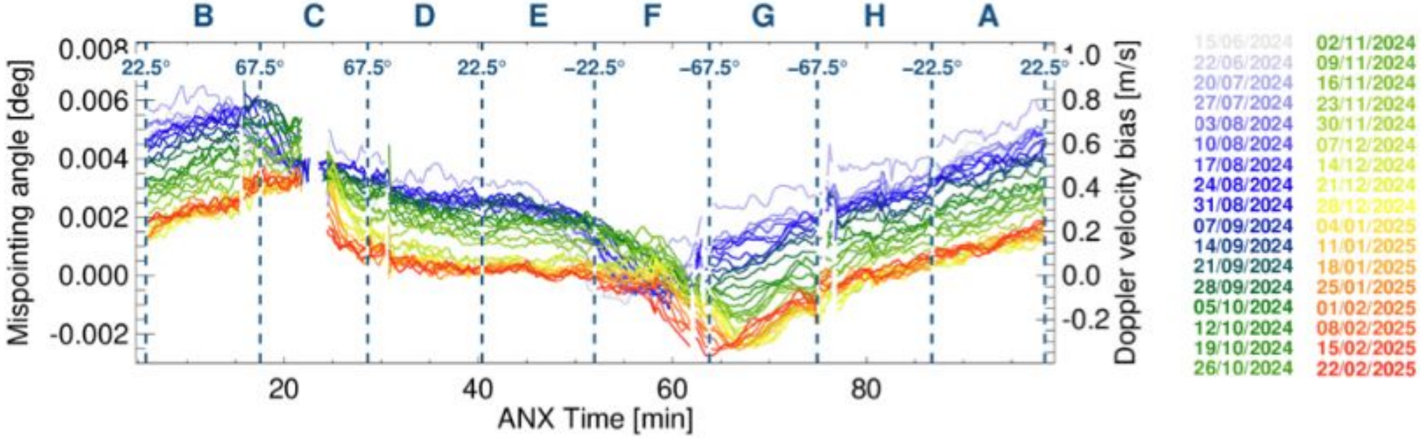
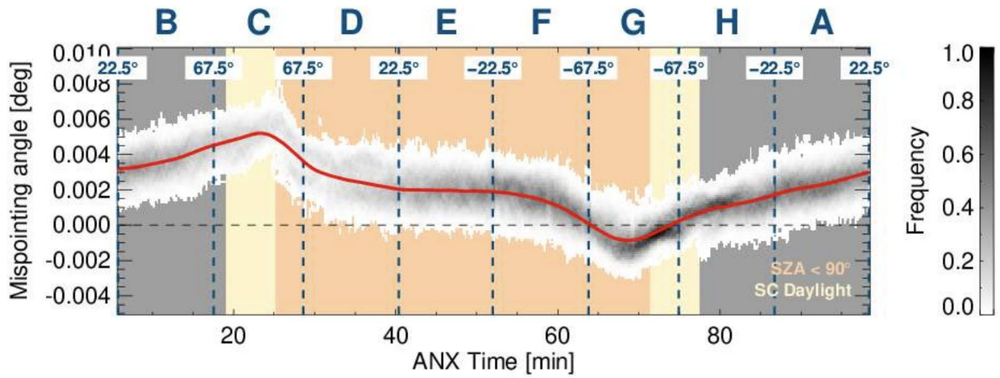


Figure 4: Weekly averaged EarthCARE´s CPR antenna mispointing angle as a function of ANX time (time since ascending node crossing) derived from clear-sky surface Doppler velocity measurements collected over sea surface (free of ice) and snow-covered land from June 2024 to February 2025. The letters on top correspond to the frame ID, which denote the different segments of the orbit, each spanning a specific latitude and time range marked by the dashed vertical lines, with the corresponding latitude values displayed above them.

- How stable is the Vm offset?
- Do we observe a trend?
- Do L1 and L2 products show differences?
- Can we monitor the antenna misspointing?

Results: Doppler velocity 3 Month average

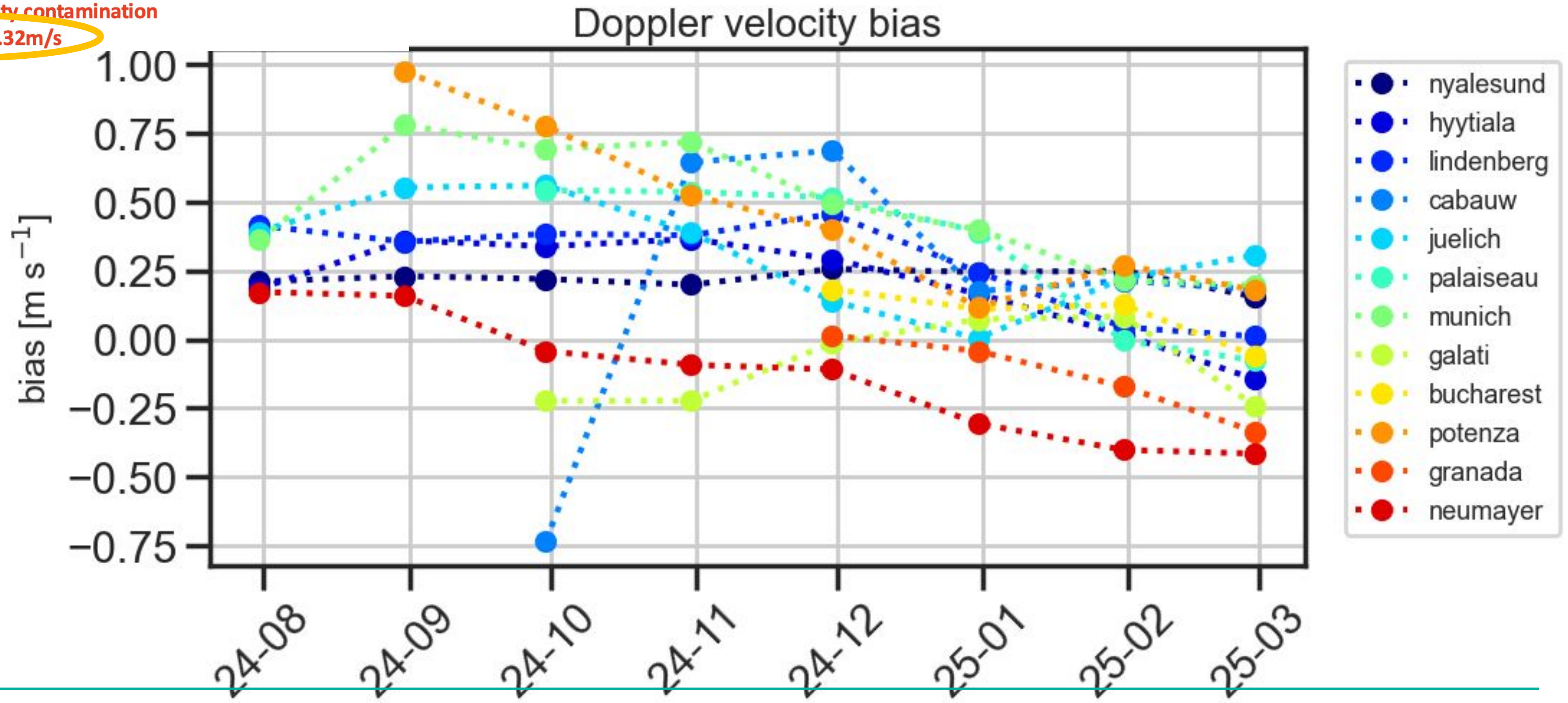
B. Puigdonènech Treserras et al., AMTD, 2025



Satellite line-of-sight velocity contamination
$0.01º_{(7.6km/s)} \rightarrow 1.32m/s$

- How stable is the Vm offset?
- What does the trend mean?

Calculate antenna pointing using
- The trend in the antenna pointing is visible at some sites
- Does the trend is consistent with offset found by others?
- Work in progress



Results: Doppler velocity Val 2st workshop

ACTRIS CCRES

Work in progress! Next steps:

- Validate L2a CPR data against ground-based radar data
- Compare our method with other Doppler velocity validation results
- Monitor the ground-based radar pointing

Questions:

- What can we lead from temporal variation of the Doppler velocity offsets in L1?
- Monitoring of the CPR antenna pointing?

Number of overpasses → North

Site	Vm bias (BA)	Vm bias (BB)	Vm bias (CA, 2025)	Vm bias (CA, all)
Ny Ålesund	0.65 ms^{-1}	ms^{-1}	0.14 ms^{-1}	0.17 ms^{-1}
Hyytiälä	0.40 ms^{-1}	0.25 ms^{-1}	0.16 ms^{-1}	0.26 ms^{-1}
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Bucharest	0.71 ms^{-1}	0.46 ms^{-1}	0.08 ms^{-1}	0.08 ms^{-1}
Potenza			0.16 ms^{-1}	0.32 ms^{-1}
Granada	0.44 ms^{-1}	ms^{-1}	- 0.34 ms^{-1}	0.01 ms^{-1}
Mindelo	No enough data	No enough data	No enough data	No enough data
Neumayer	0.18 ms^{-1}	0.42 ms^{-1}	0.39 ms^{-1}	- 0.31 ms^{-1}

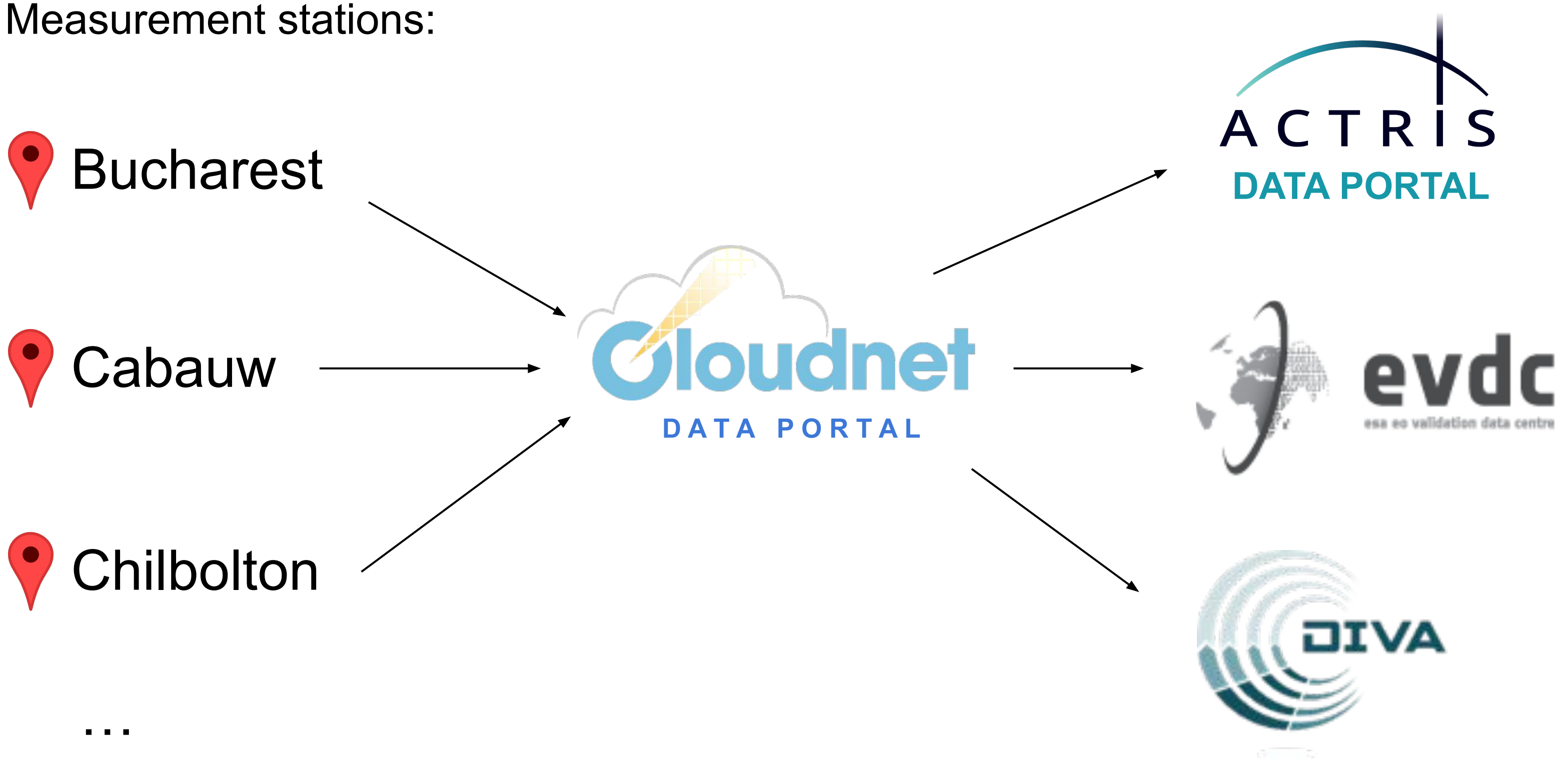
UPDATES FROM CLU

- Orbital Radar tool operational
- Attenuation correction updated
- Doppler velocity dealiaising

EarthCARE Cal/Val related updates from CLU

Data distribution via CLU

Measurement stations:



So, your data is distributed automatically as long as you push it to CLU

NEW PRODUCT: Orbital-Radar simulator

ACTRIS
CCRES

Geosci. Model Dev., 18, 101–115, 2025
https://doi.org/10.5194/gmd-18-101-2025

Geoscientific Model Development
Open Access
EGU

Model description paper

Orbital-Radar v1.0.0: a tool to transform suborbital radar observations to synthetic EarthCARE cloud radar data

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Received: 8 July 2024 – Discussion started: 3 September 2024
Revised: 30 October 2024 – Accepted: 4 November 2024 – Published: 14 January 2025

Abstract. The Earth Cloud, Aerosol and Radiation Explorer (EarthCARE) satellite developed by the European Space Agency (ESA) and the Japan Aerospace Exploration Agency (JAXA) launched in May 2024 carries a novel 94 GHz cloud profiling radar (CPR) with Doppler capability. This work describes the open-source instrument simulator Orbital-Radar, which transforms high-resolution radar data from field observations or forward simulations of numerical models to CPR primary measurements and uncertainties. The transformation accounts for sampling geometry and surface effects. We demonstrate Orbital-Radar's ability to provide realistic CPR views of typical cloud and precipitation scenes. The presented case studies show small-scale convection, marine stratus clouds, and Arctic mixed-phase cloud cases. These results provide valuable insights into the capabilities and challenges of the EarthCARE CPR mission and its advantages over the CloudSat CPR. Finally, Orbital-Radar allows for evaluating kilometre-scale numerical weather prediction models with EarthCARE CPR observations. So, Orbital-Radar can generate calibration and validation (Cal/Val) data sets already prelaunch. Nevertheless, an evaluation of synthetic CPR output data to accurate EarthCARE CPR data is missing.

1 Introduction

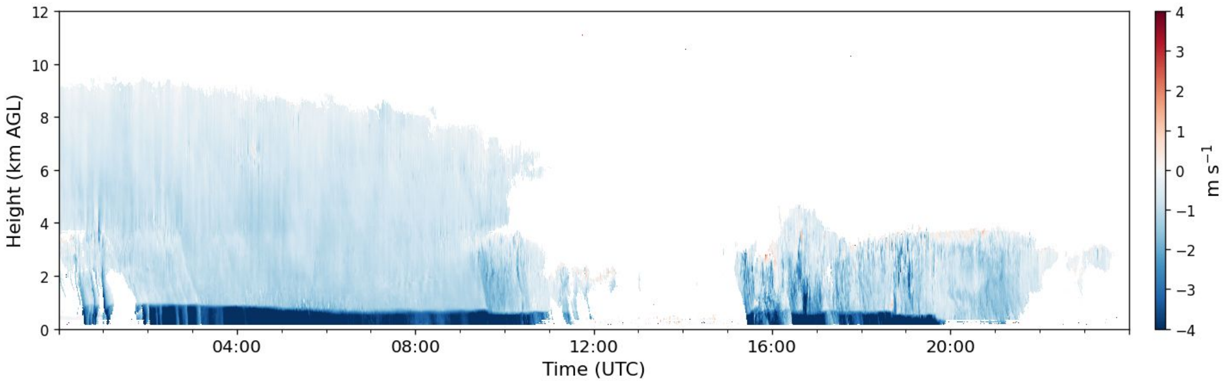
Spaceborne radars offer a unique opportunity to monitor clouds and precipitation globally. For instance, the National Aeronautics and Space Administration (NASA) CloudSat Cloud Profiling Radar (CloudSat CPR; Stephens et al., 2008, 2018) enabled several advances in cloud and precipitation physics (Rapp et al., 2013; Stephens et al., 2018; Battaglia et al., 2020b). In 2024, the next-generation CPR in space was launched on board the Earth Cloud, Aerosol and Radiation Explorer (EarthCARE) satellite (Illingworth et al., 2015; Wehr et al., 2023). The EarthCARE CPR is the first Doppler radar in space, thus providing the first set of global Doppler velocity measurements (Kollias et al., 2022). In addition to the Doppler capability, the EarthCARE CPR has higher sensitivity than its predecessor (−35 dBZ vs. −30 dBZ) as well as a smaller footprint (0.8 km vs. 1.4 km) and shorter along-track integration (500 m vs 1.1 km).

Spaceborne radars operate from platforms that orbit the Earth at speeds that exceed 7 km s^{-1} and employ relatively long pulses to map the vertical structure of hydrometeors in the atmosphere. The strongest echo a spaceborne radar detects is from the Earth's surface. Instrument simulators are a well-established methodology for accounting for the effects of the observing system sampling geometry and surface effects on its performance (i.e. detection limit, measurement uncertainty). For example, Lamer et al. (2020) developed an instrument forward simulator to evaluate the impact of different spaceborne CPR configurations on our ability to detect low-level clouds

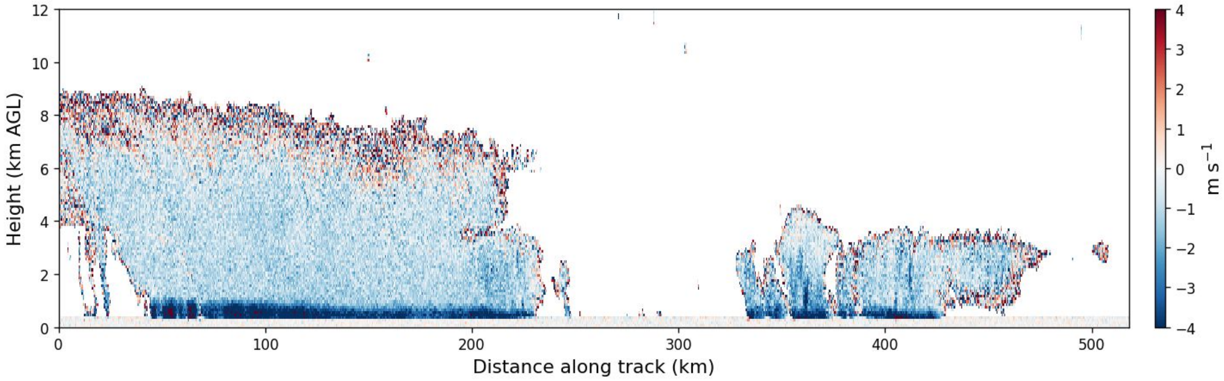
Published by Copernicus Publications on behalf of the European Geosciences Union.

Pfitzenmaier et al., Geosci. Model Dev. (2025)

Ground-based radar data

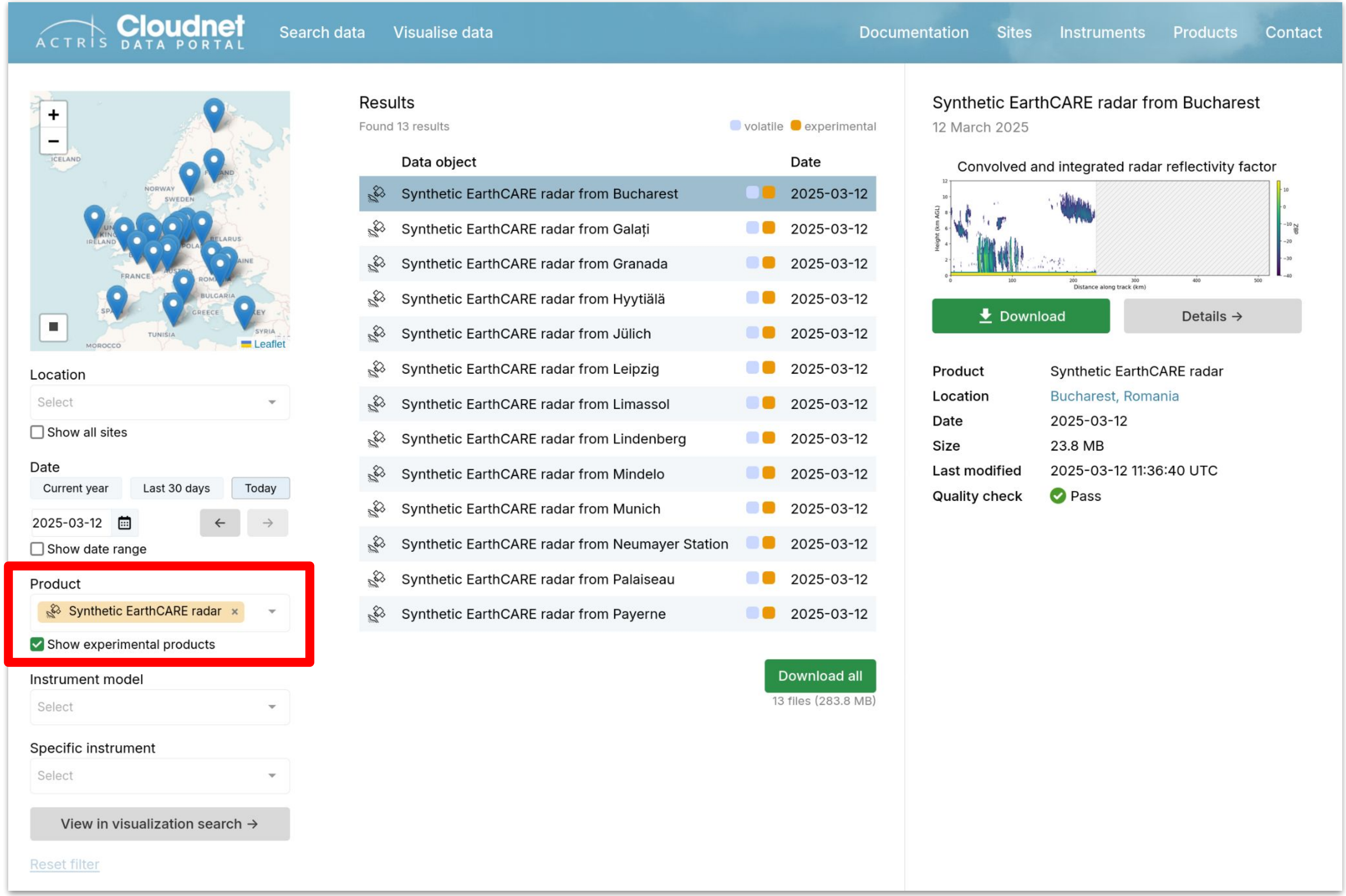


"Synthetic EarthCARE data"

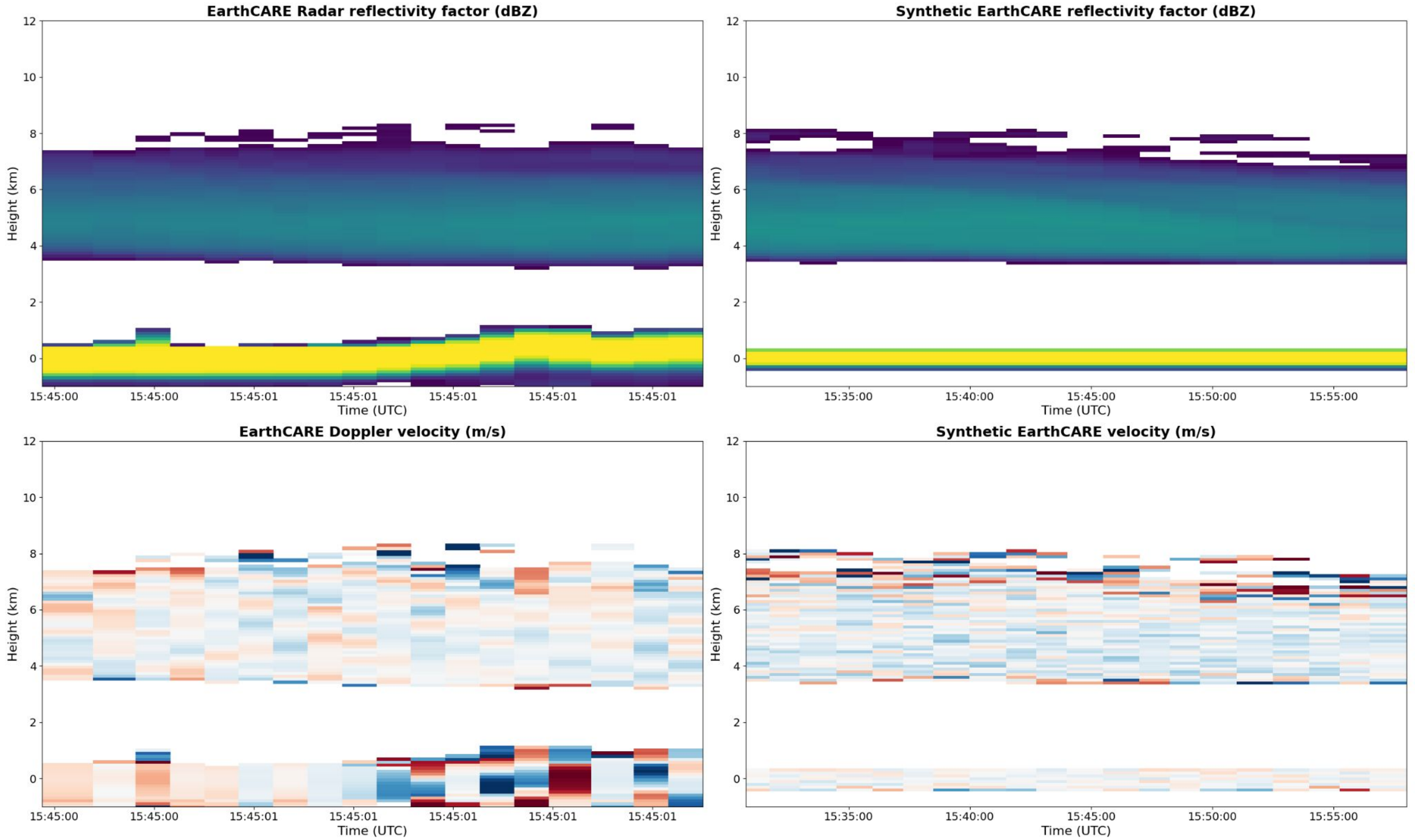


(experimental Cloudnet product)

NEW PRODUCT: Real-time Orbital-Radar data in Cloudnet

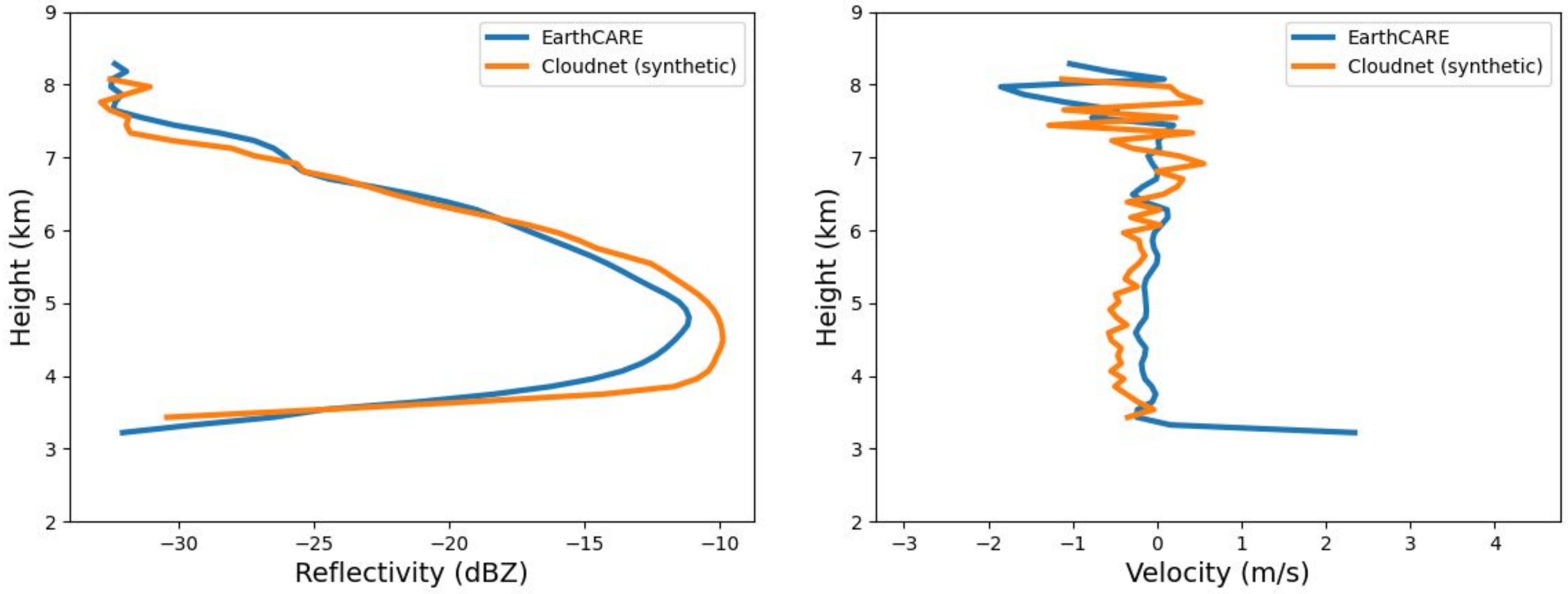


NEW PRODUCT: Example, Ny-Ålesund 2025-01-15



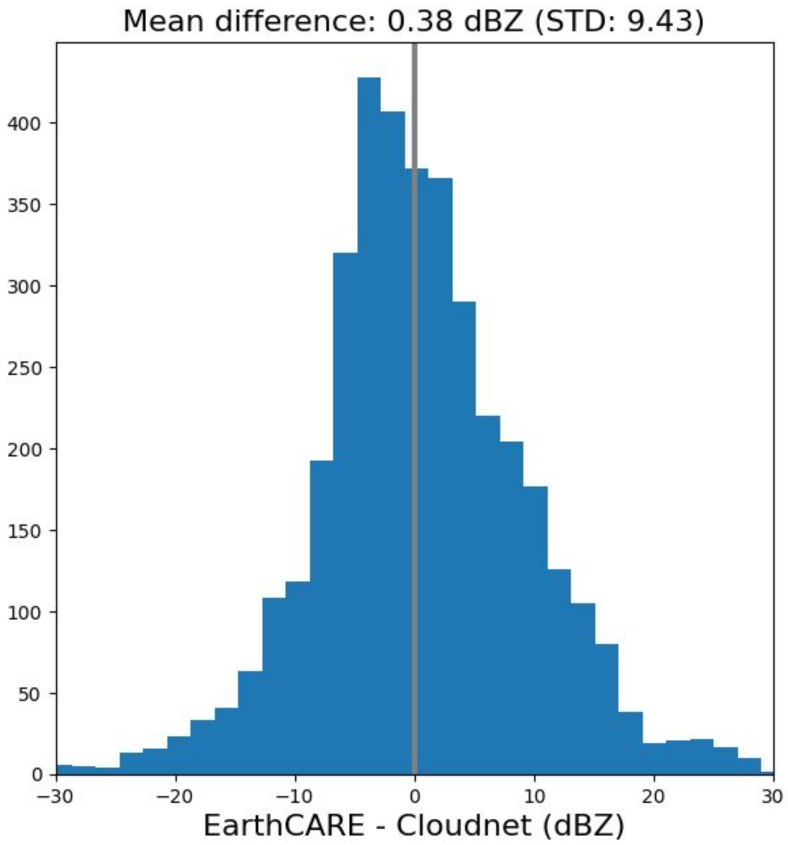
- •EarthCARE CPR L1 data (basline CA) within 5 km of the site
- •Cloudnet data 5 min before and after the overpass

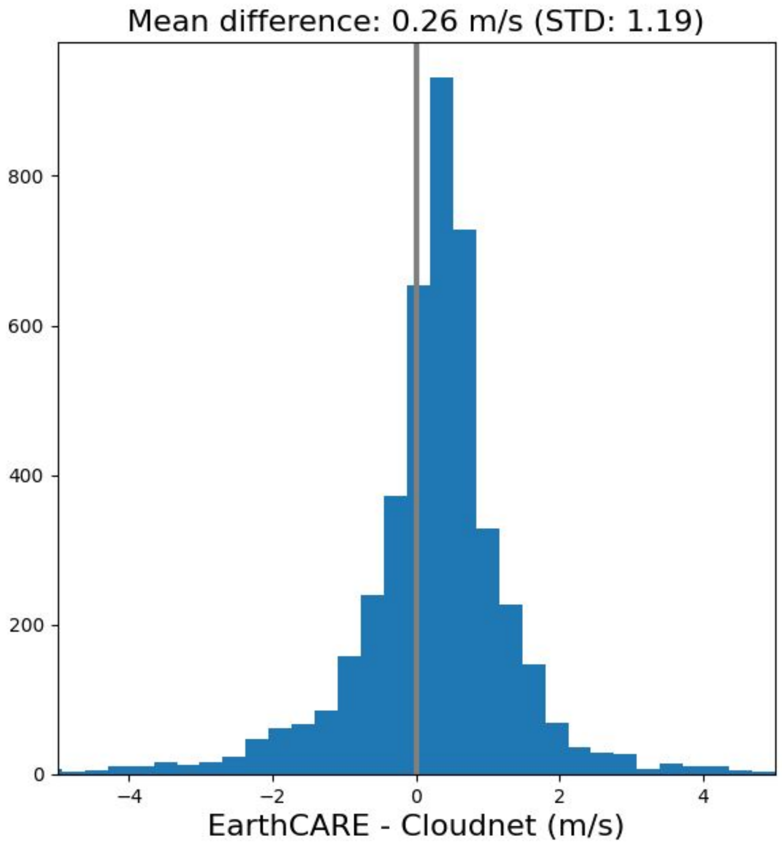
NEW PRODUCT: Example, Ny-Ålesund 2025-01-15 mean profiles



Height > 2 km

NEW PRODUCT: Example, Differences (all matching heights)





Radius	N	Correlation
10	11	0.95
20	32	0.86
50	68	0.77
100	32	0.62

For RPG 94 GHz only

Overpasses < 50 km (n =111)

- study the impact of the overpass distances to the sites - correlation length
- find “golden” cases for case study analysis - L2 data validation
- …

NEW PRODUCT: Orbital-Radar simulator summery

Sub-orbital to orbital tool operational

- In real time
- All sites

- Use to evaluate EarthCARE data directly with overpasses
- Determine a suitable averaging radius

- Also use to investigate the impact of long pulses on cloud boundaries over larger ground-based datasets.

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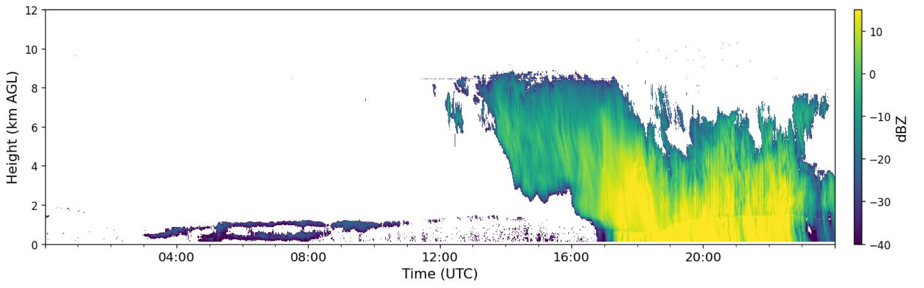
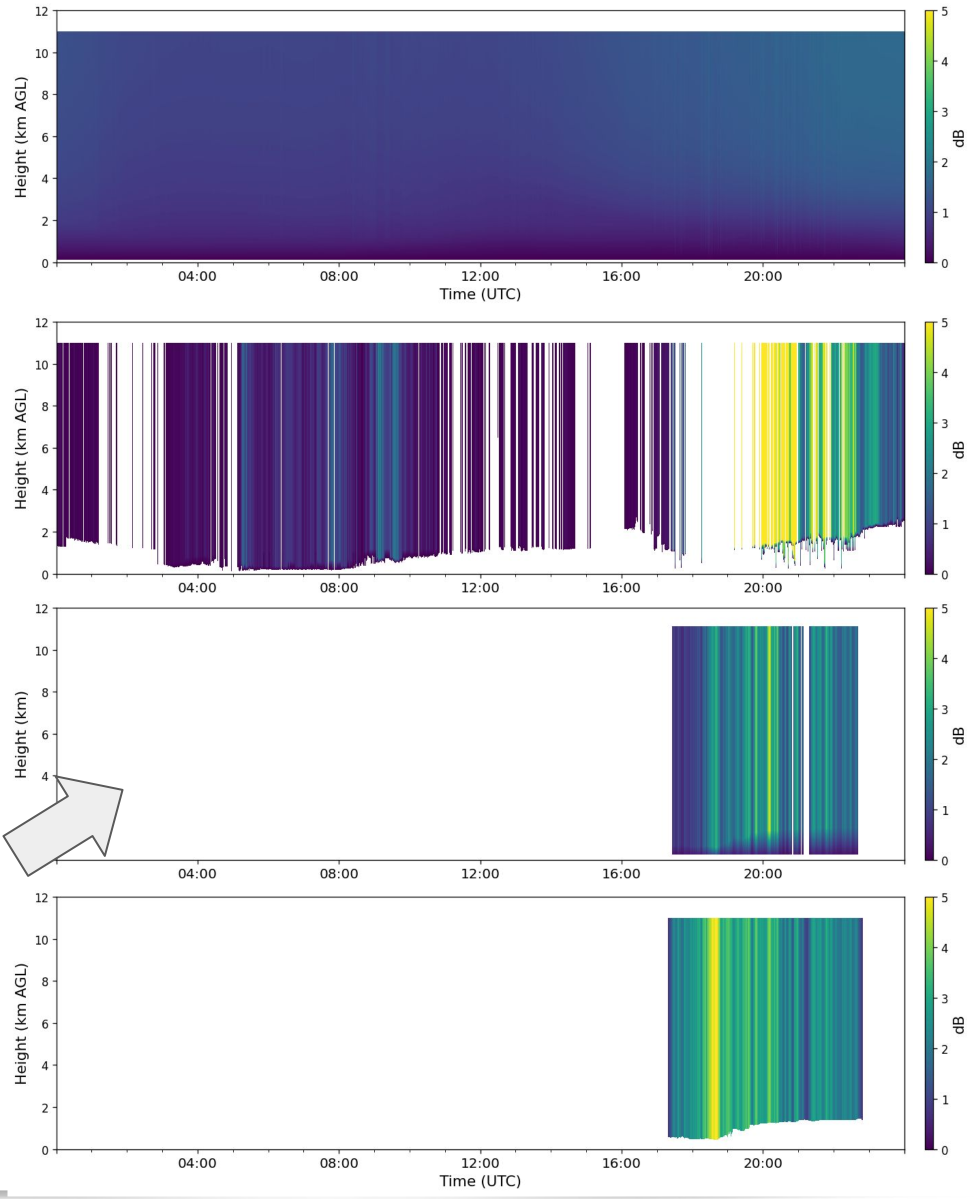
UPDATE: Attenuation correction

Cloudnet radar data is corrected for **gas** and **liquid water** attenuation. Now, we have initial implementation for **rain** and **melting layer** attenuation.

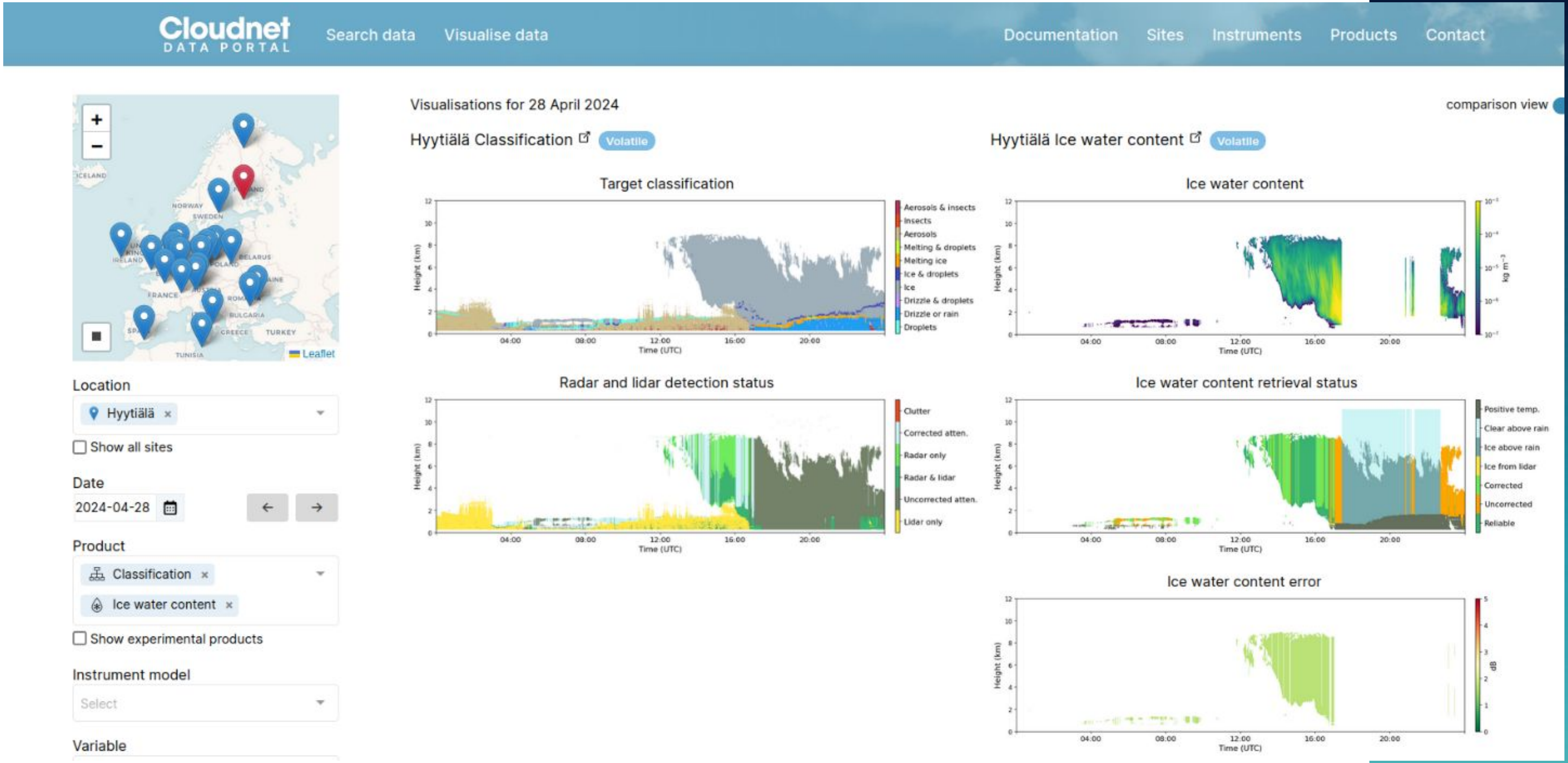
→ increase data availability for statistical validation of Ze (and vm)



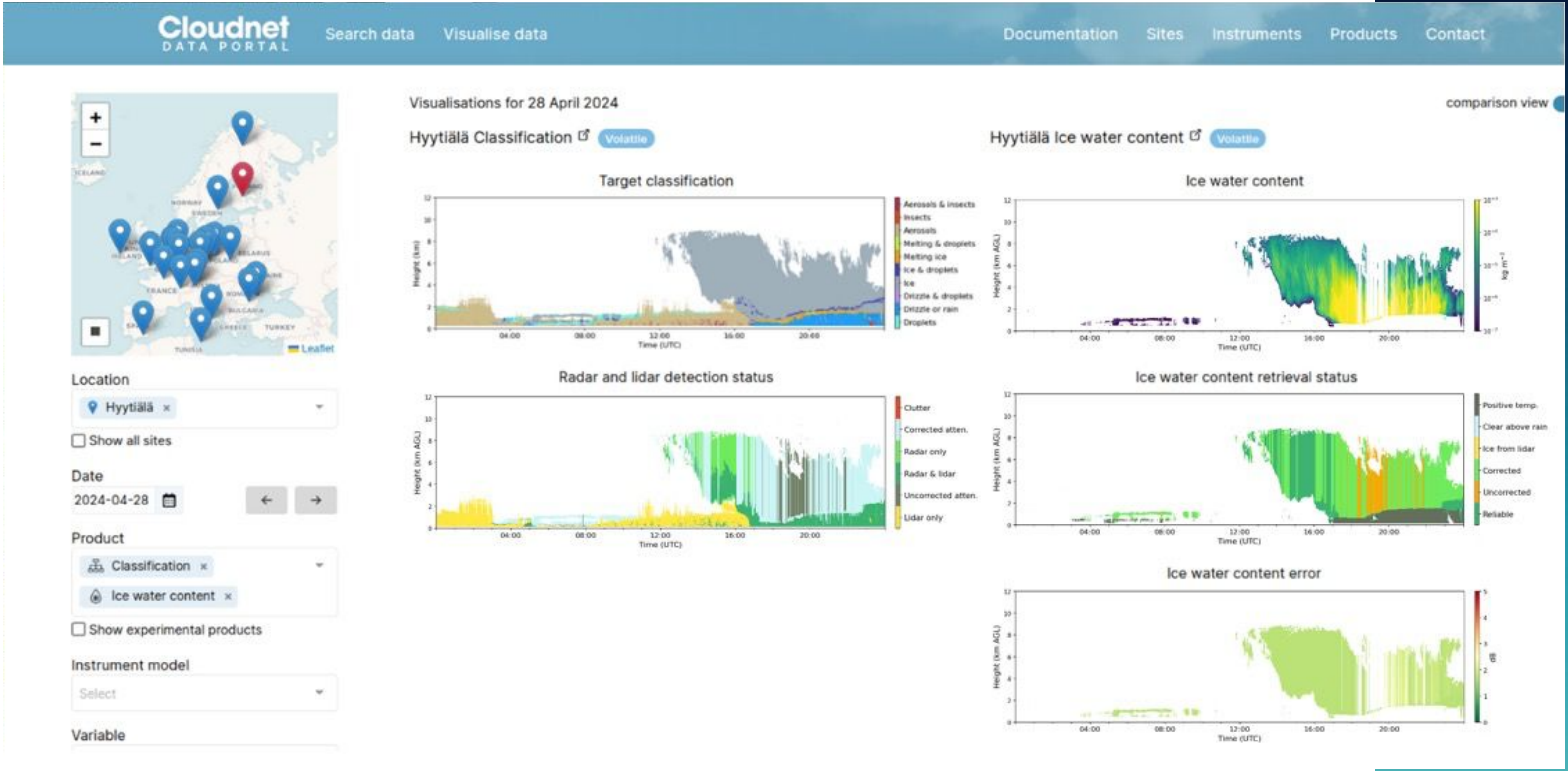
Hyytiälä 2024-04-28



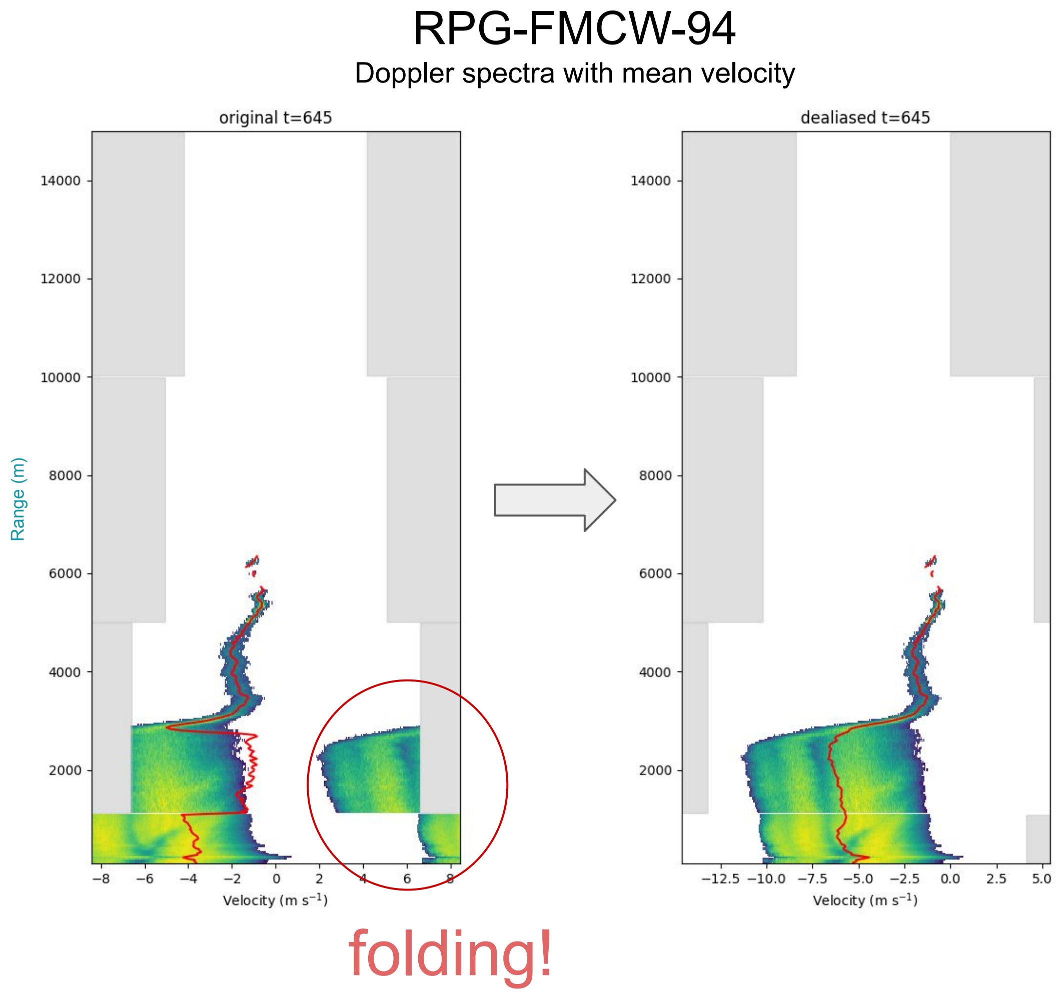
UPDATE: Attenuation correction

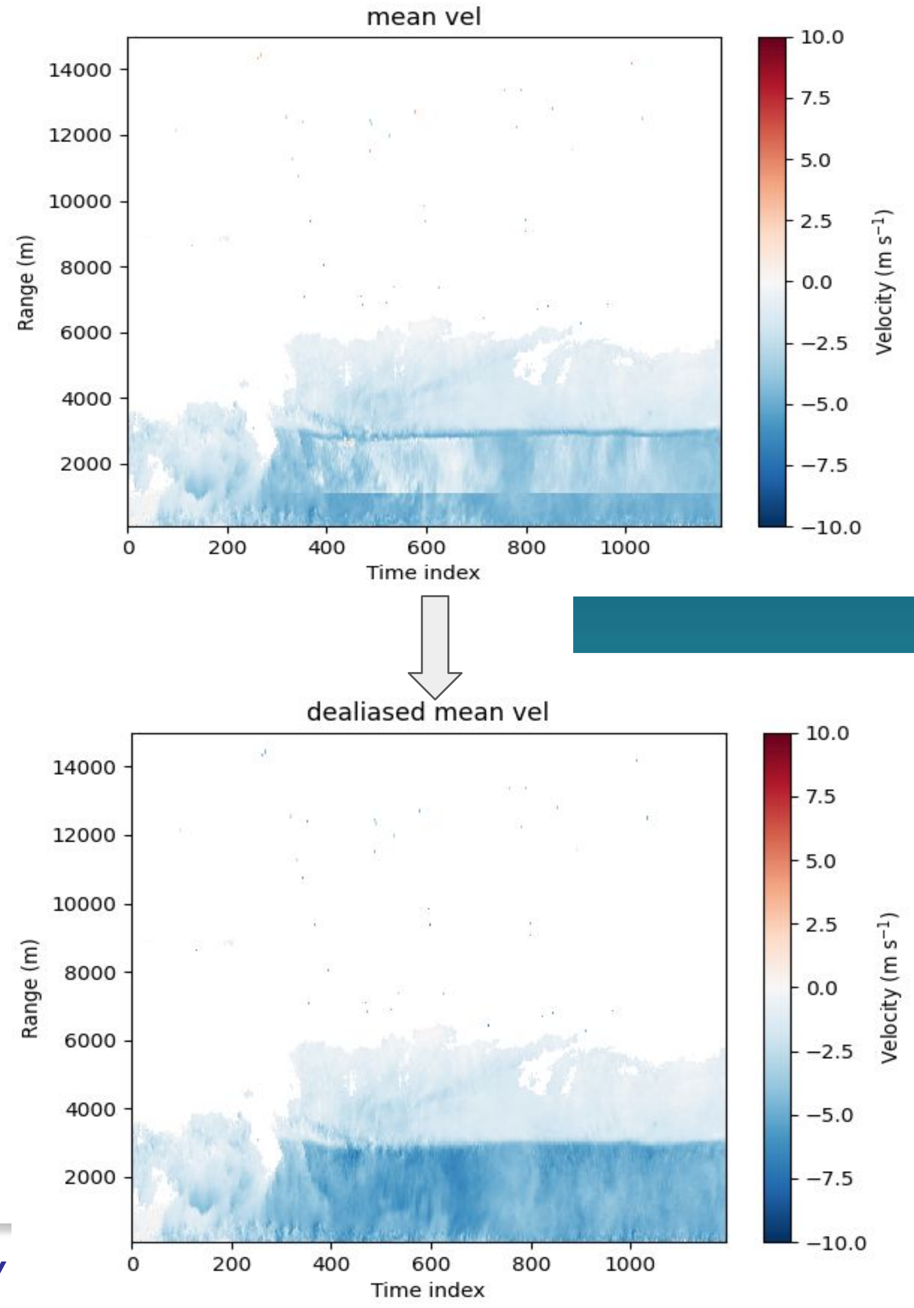


UPDATE: Attenuation correction



IN PROGRESS: Folding in ground-based measurements





See for Matheus presentation later on for more insights

Conclusion

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- Sub-orbital to orbital tool operational for all sites
- Method for dealiasing ground-based radar measurements in testing – works > 95 % of profiles
- Reliable attenuation correction of ground-based data will substantially increase the proportion of data available for comparison

Next steps

- Implement operational dealiasing method for ground-based radar measurements – with status flags
- Validate attenuation corrections, including radome
- Extend validation to cloud classification

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Thank you !