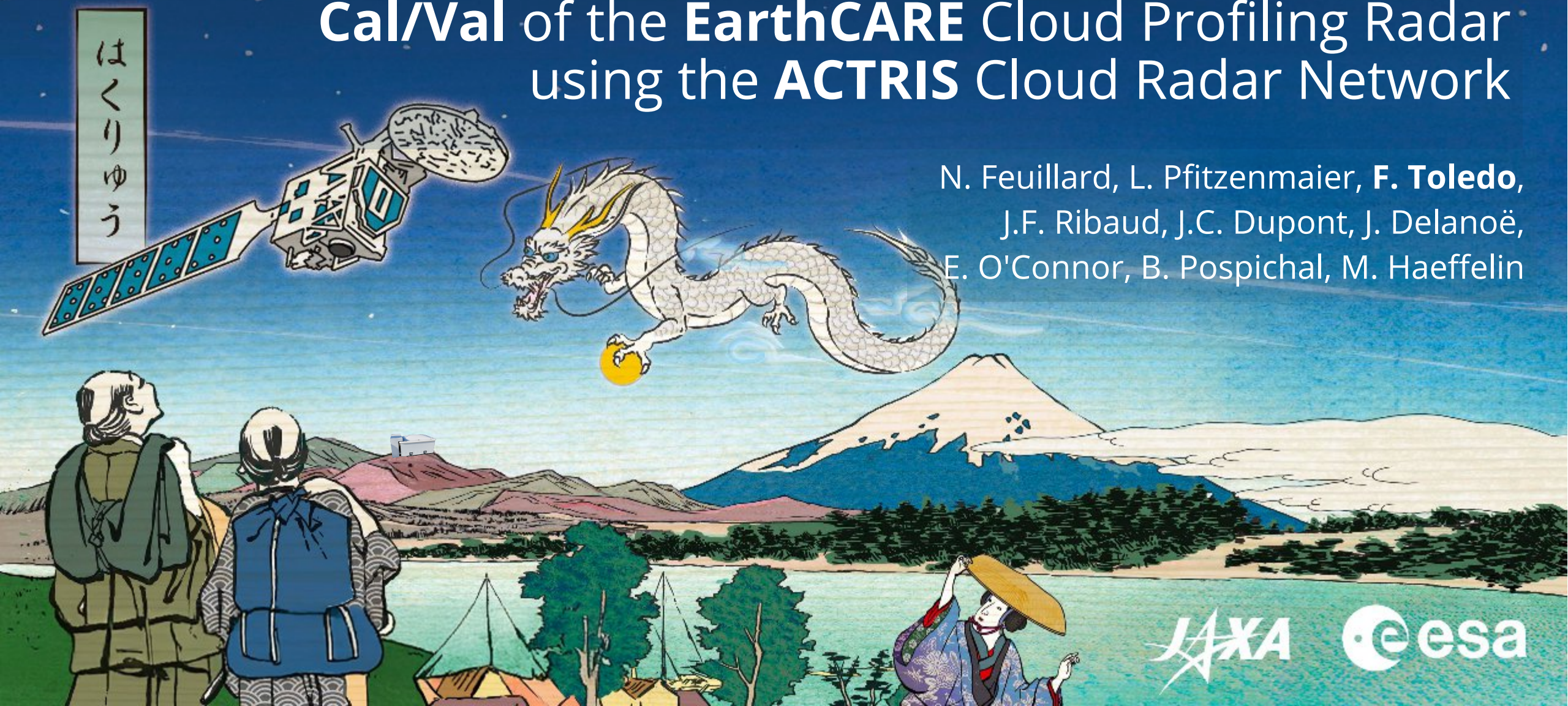
Cal/Val of the **EarthCARE** Cloud Profiling Radar using the **ACTRIS** Cloud Radar Network

N. Feuillard, L. Pfitzenmaier, **F. Toledo**,
J.F. Ribaud, J.C. Dupont, J. Delanoë,
E. O'Connor, B. Pospichal, M. Haeffelin

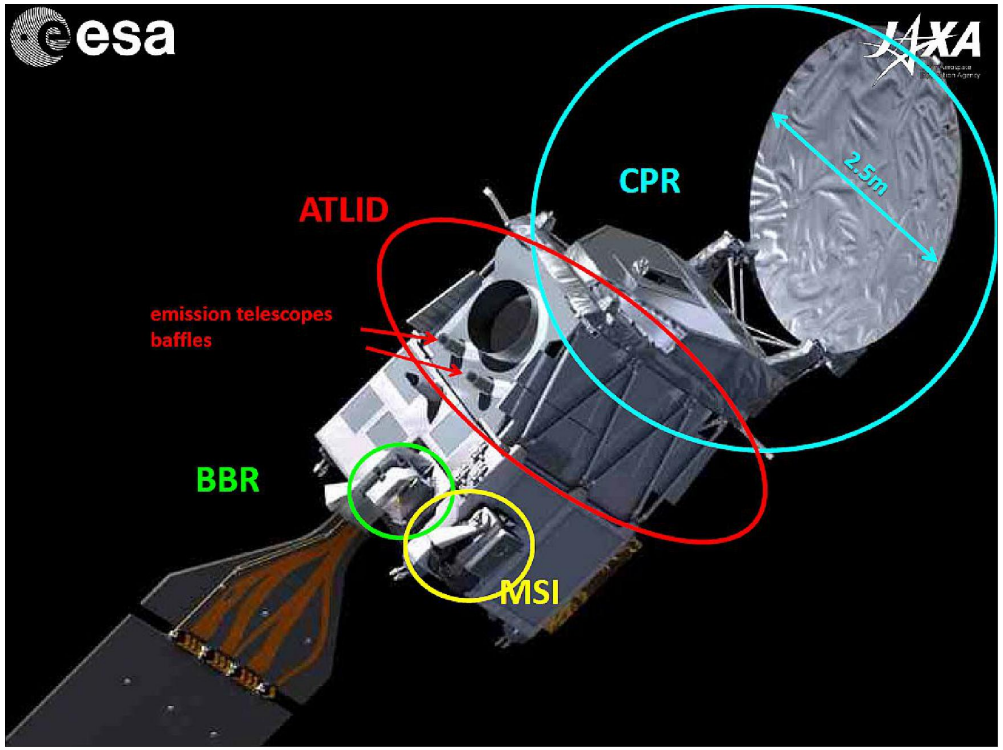


The EarthCARE satellite mission

- Collaboration between ESA and JAXA

- Satellite equipped with remote sensing instrumentation for the atmosphere:
  - Atmospheric Lidar (ATLID)
  - Multi-Spectral Imager (MSI)
  - Broad-Band Radiometer (BBR)
  - **Cloud Profiling Radar (CPR)**

- Mission expected to last for ten years, after its launch in May 2024



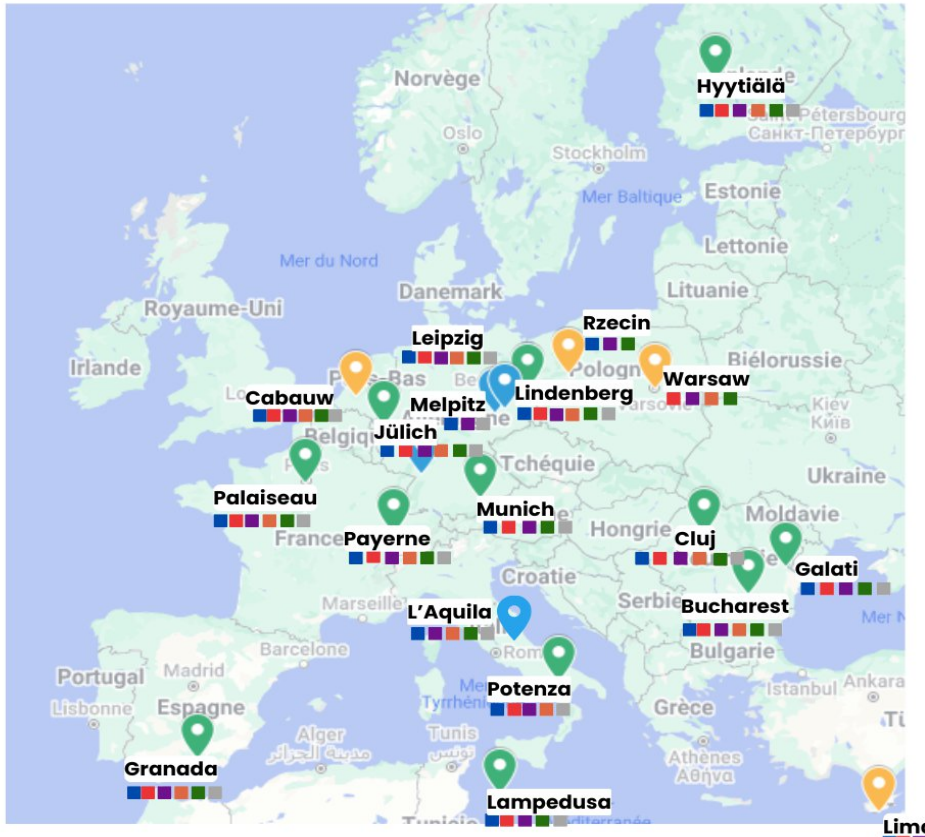
Cal/Val project Objectives

To evaluate EarthCARE reflectivity and doppler velocity measurements using the ACTRIS network

ACTRIS network advantages:

- Large geographical coverage and different types of clouds to observe
- Multi instrumented cloud remote sensing sites -> Hydrometeor classification available
- ACTRIS-CCRES:
  - Standard Operating Protocols (SOPs), calibration standards, automatic data processing and quality control (CLU)

v 05.2025



Doppler Cloud Radar

Microwave radiometer

Doppler lidar

Low power lidar and ceilometer

Disdrometer

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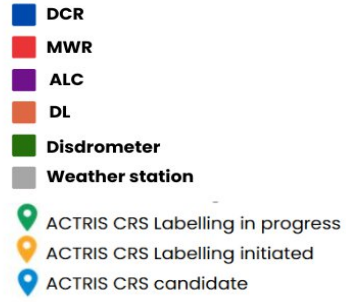
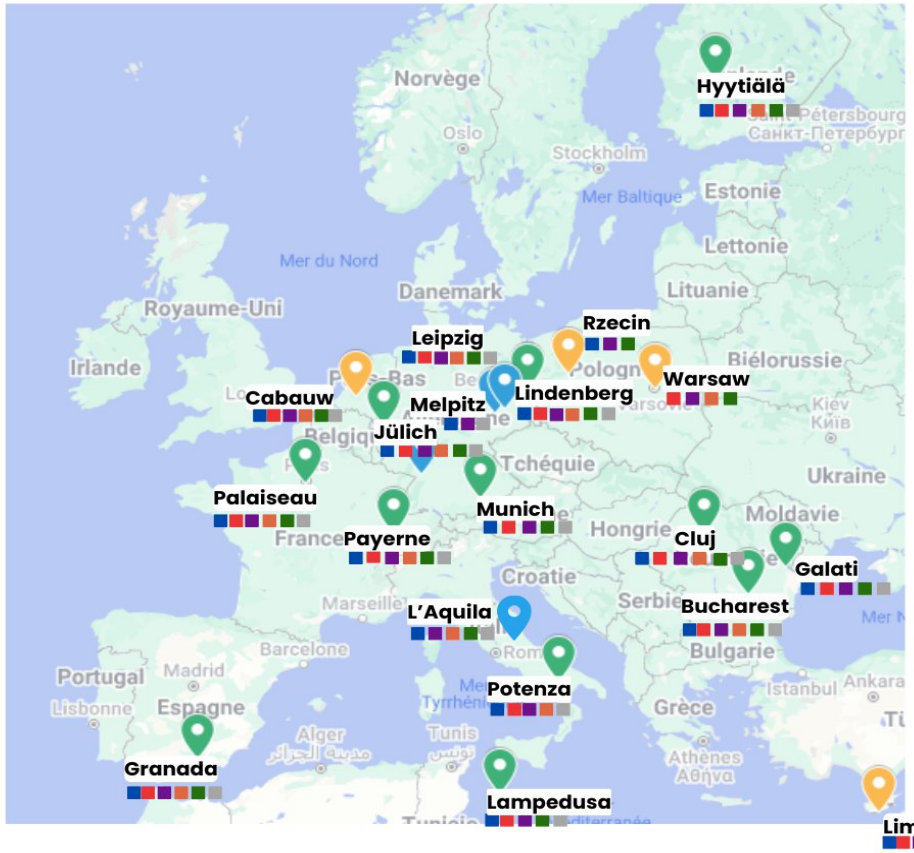


Cape Verde

v 05.2025



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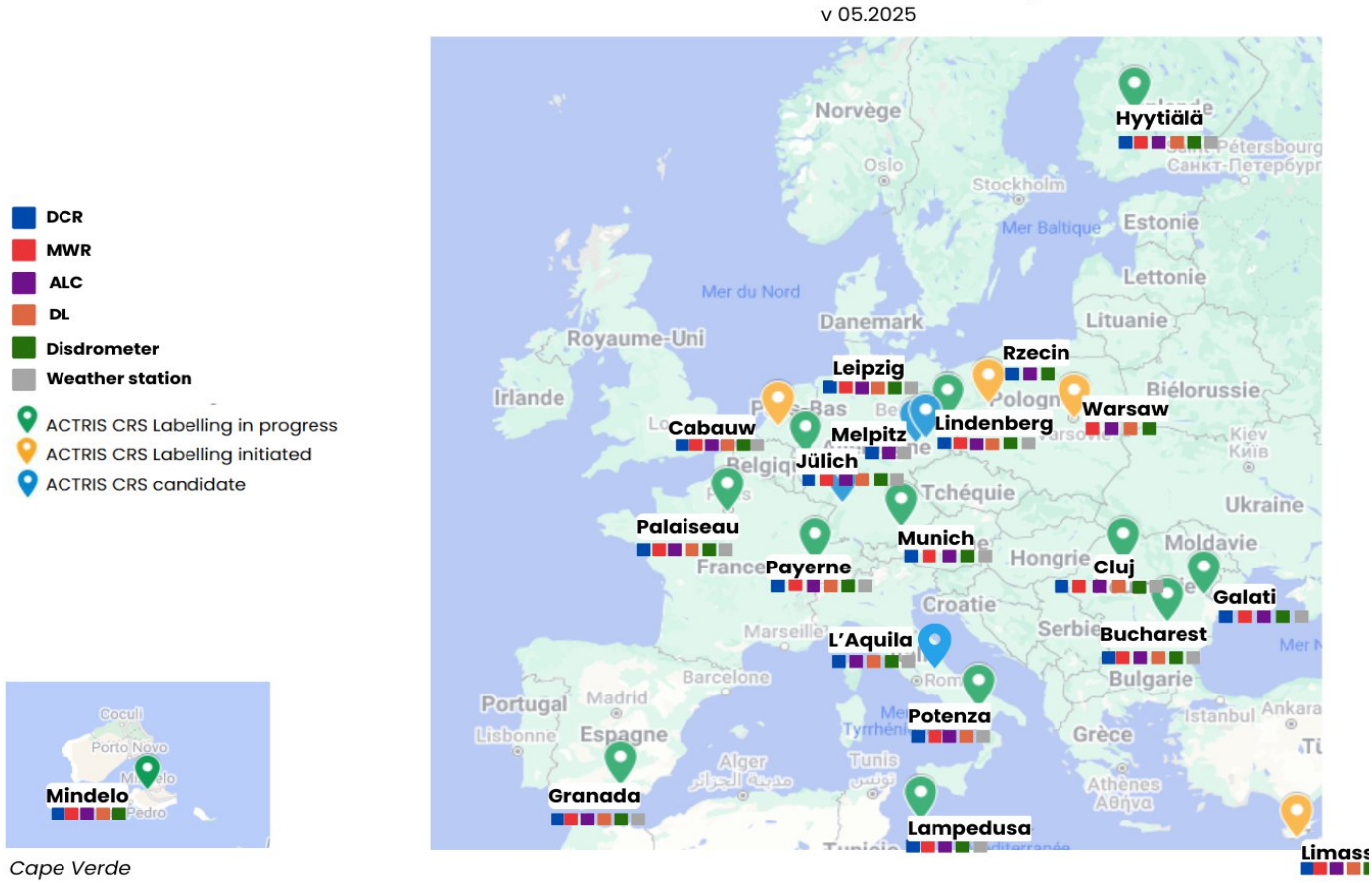
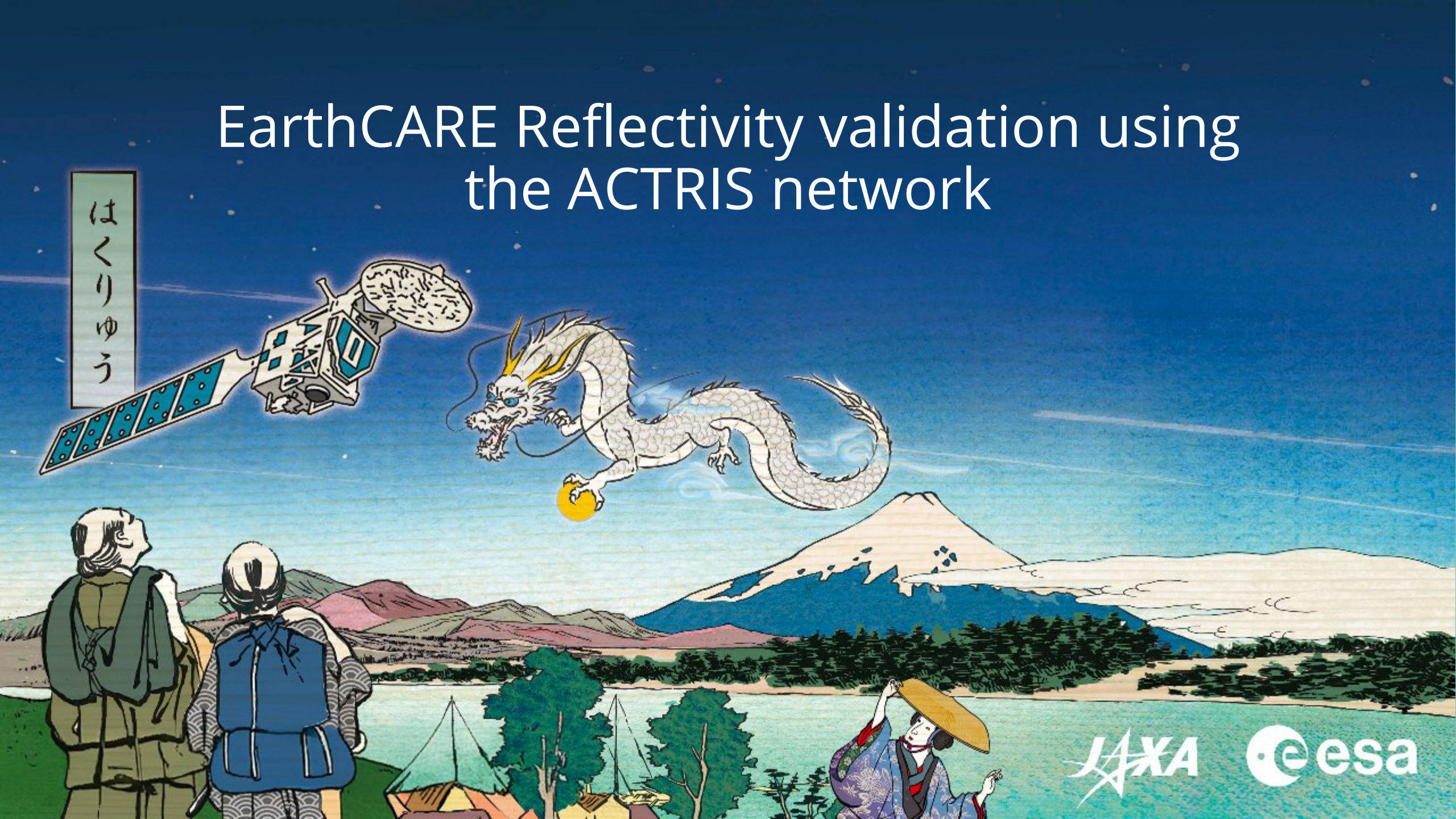


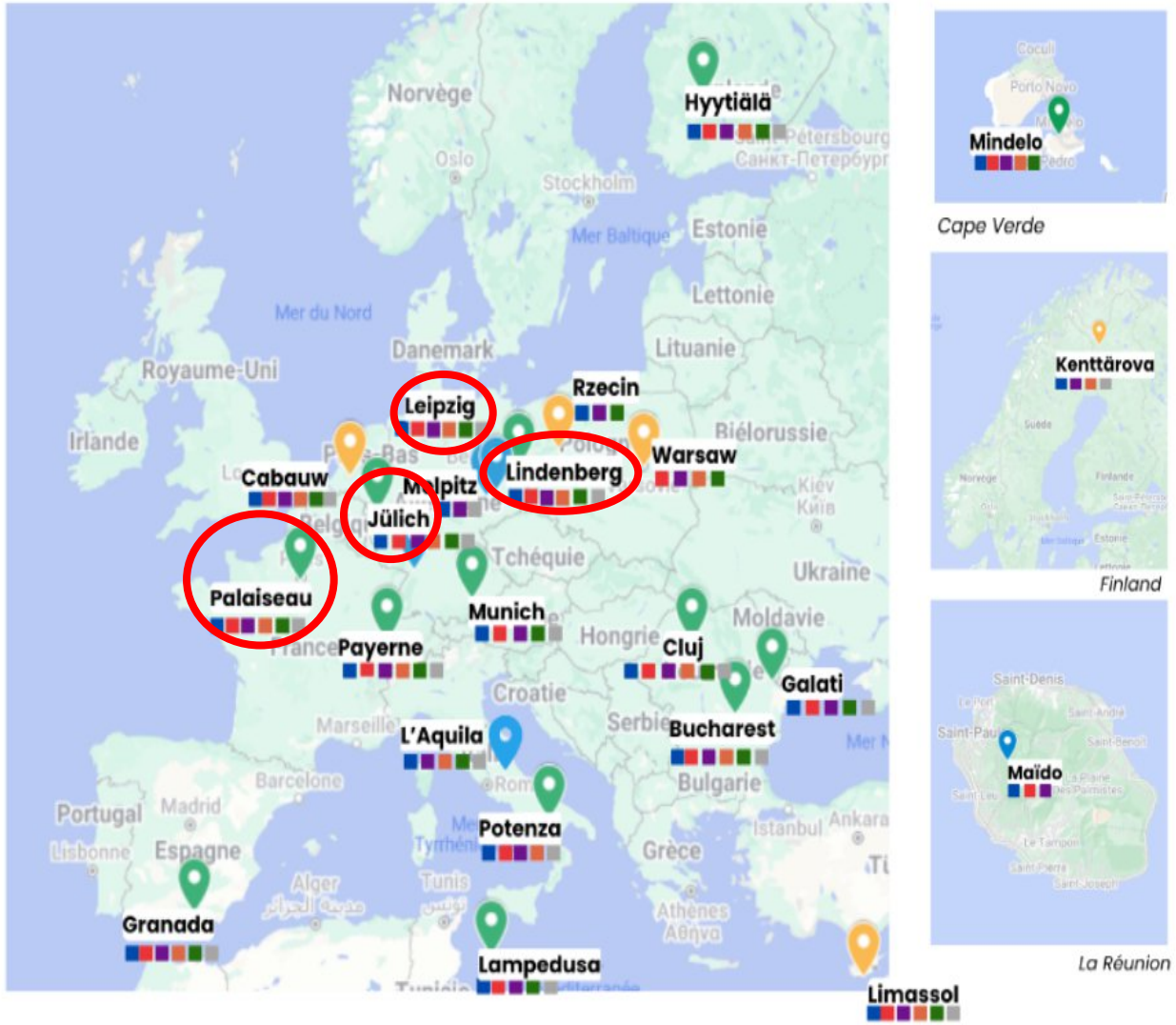
EarthCARE Reflectivity validation using the ACTRIS network



Strategy

- Develop a ground-vs-space reflectivity comparison algorithm tailored for the ACTRIS dataset

- Validation by closure:
  - Select ACTRIS sites calibrated using the same reference
  - Calculate the calibration offset over several months
  - Check if the offsets obtained between the different sites match

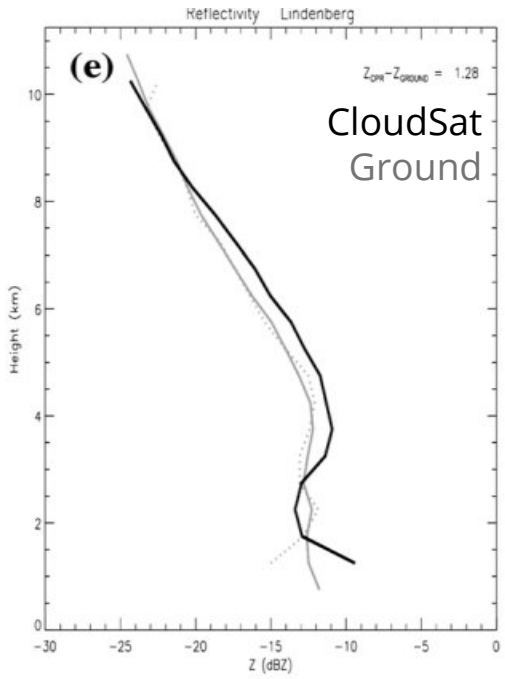


Sites calibrated at the time of this study

Ground vs Space reflectivity comparisons

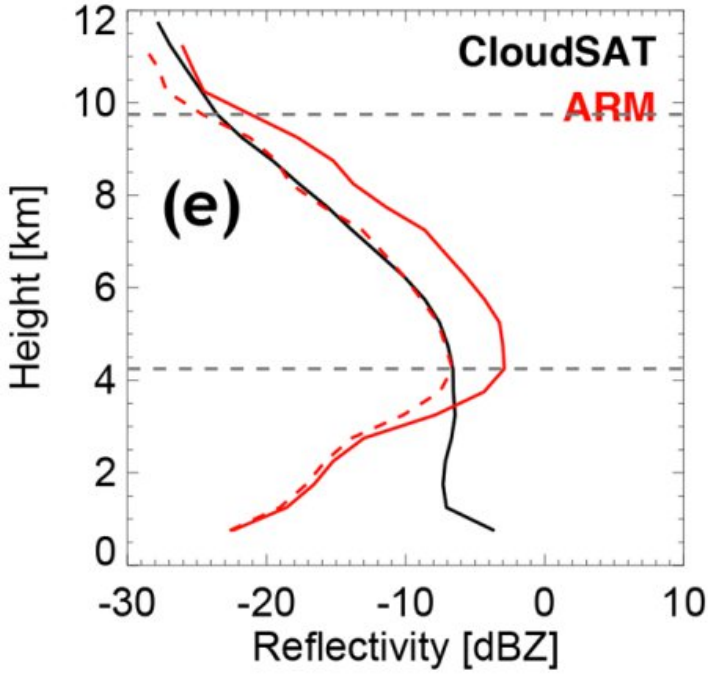
- Difficulties:
  - The satellite may never pass exactly above a site
  - Even if both radars sample an homogeneous cloud, reflectivity profiles can change within a few hundred or thousand meters

- Statistical approaches can reduce the impact of cloud variability, to estimate the actual calibration offset between ground and space



< Mean profiles of ground and satellite reflectivities. 9 months period. Protat et al (2009).

Mean profiles of ground and satellite reflectivities. 2 years period . Kollias et al (2019). >



Reflectivity comparison algorithm

Data selection:

- CPR: overpasses in a 200km radius around the ground site (based on Protat et al. 2009)
- Ground: All reflectivity profiles within the comparison period

Liquid water filtering: to account for differences in attenuation.

- CPR: L2b synergetic target classification
- Ground: CloudNet classification

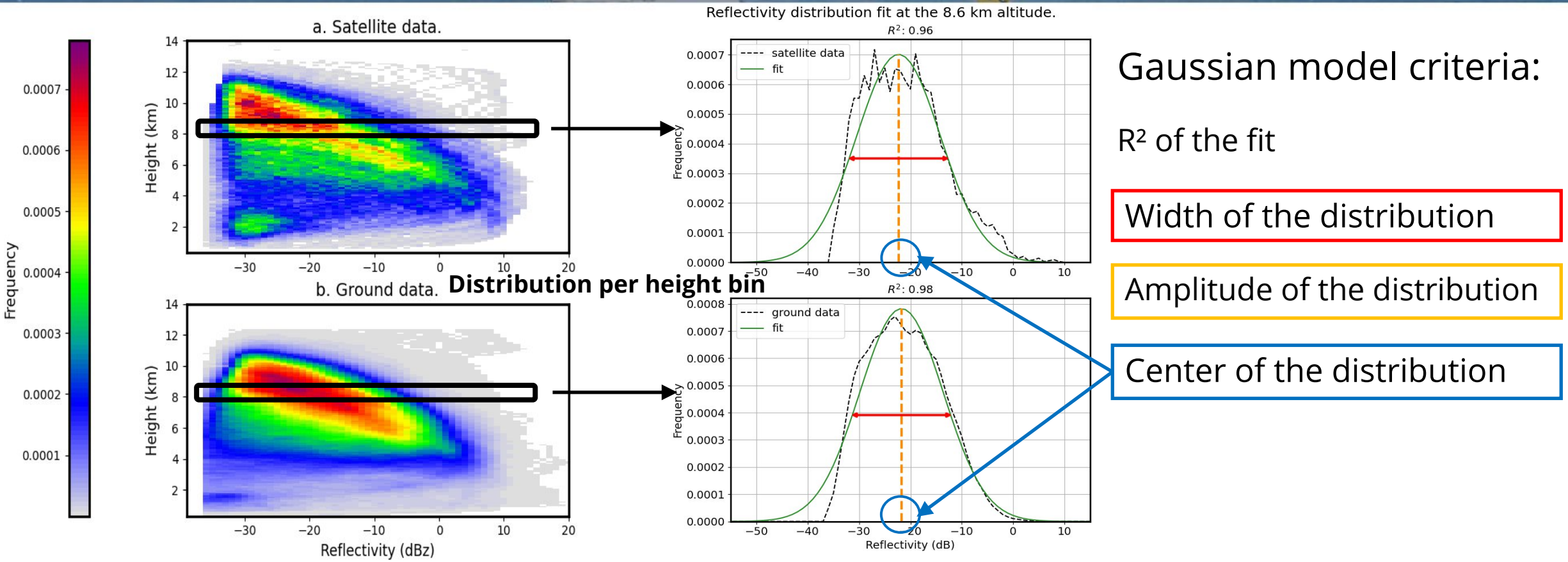
- Ground data resampling to match satellite resolution (Donovan et al. 2023)
- Sensitivity matching

Statistical check to select comparable height bins

Statistical comparison of ground vs CPR reflectivity profiles

Calibration offset between EarthCARE and the ground radar with uncertainty

Height bin selection method



Gaussian model criteria:

R^2 of the fit

Width of the distribution

Amplitude of the distribution

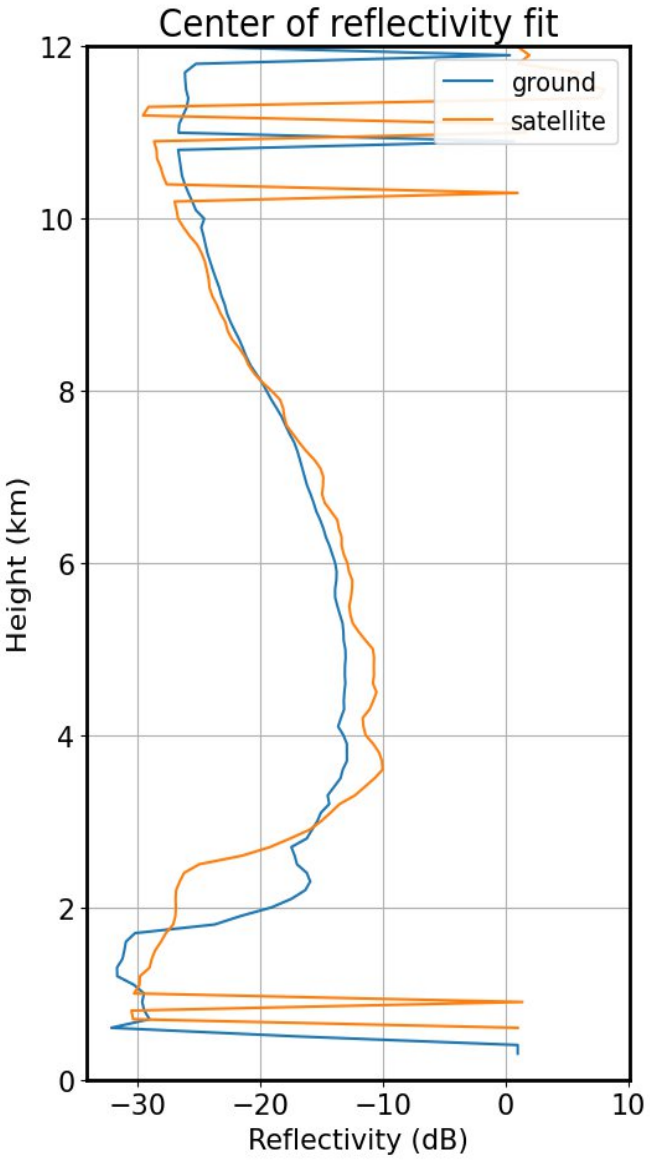
Center of the distribution

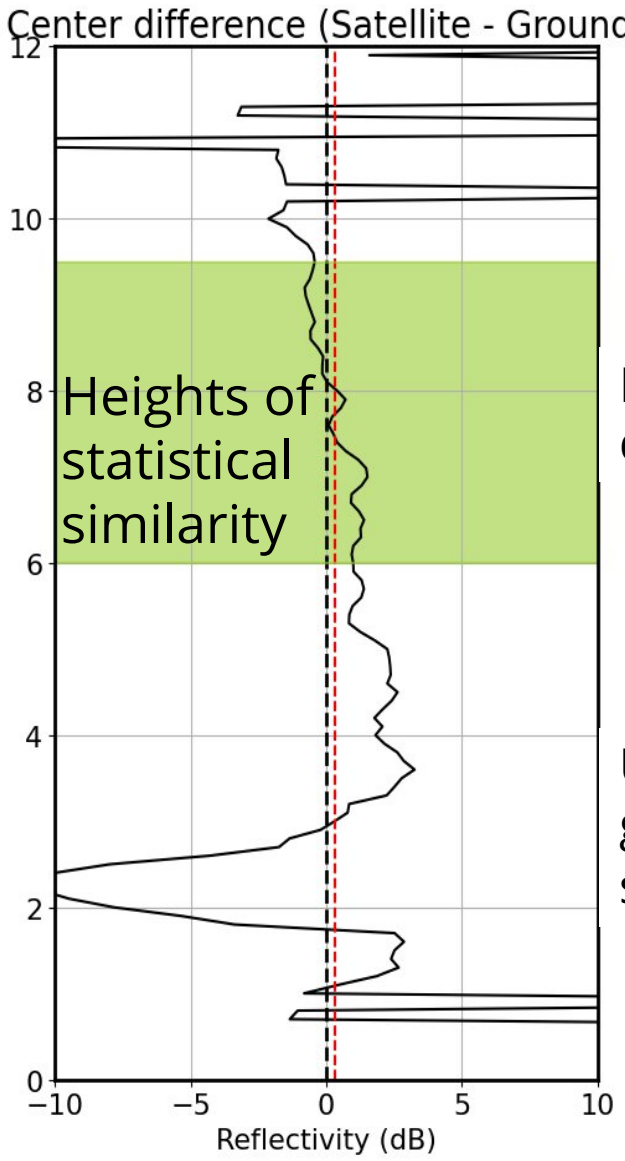
Fit with a Gaussian model to sort data (threshold based):

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

The difference between fit centers is used for the estimation of the bias

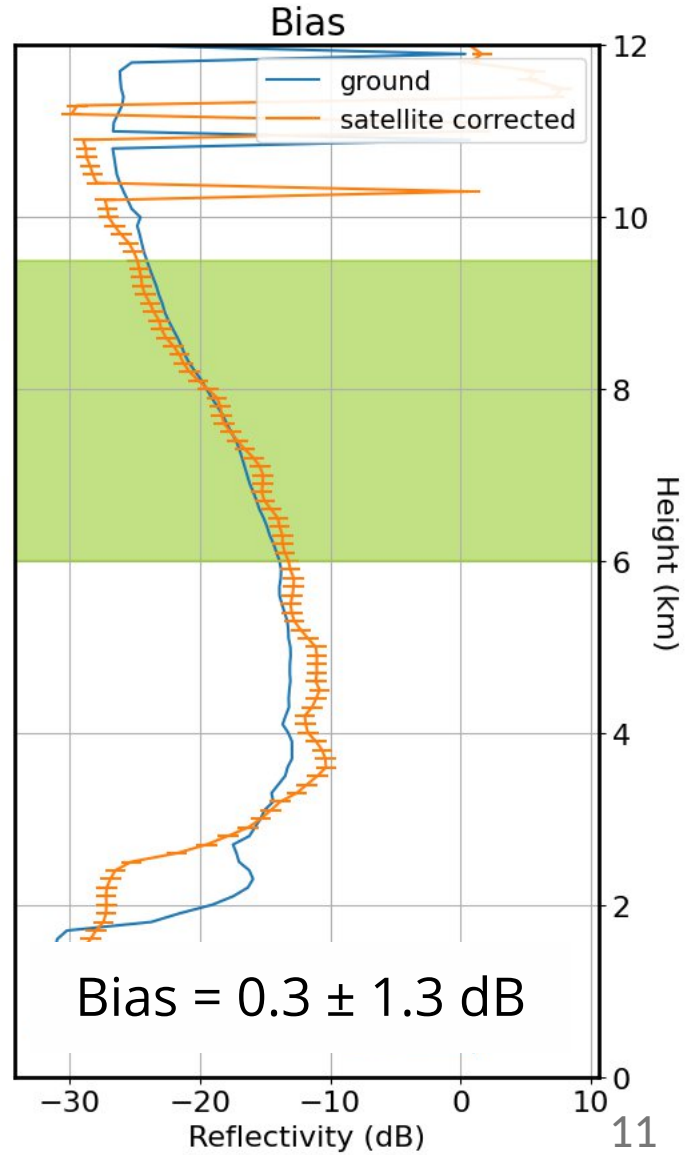
Ground – satellite bias estimation



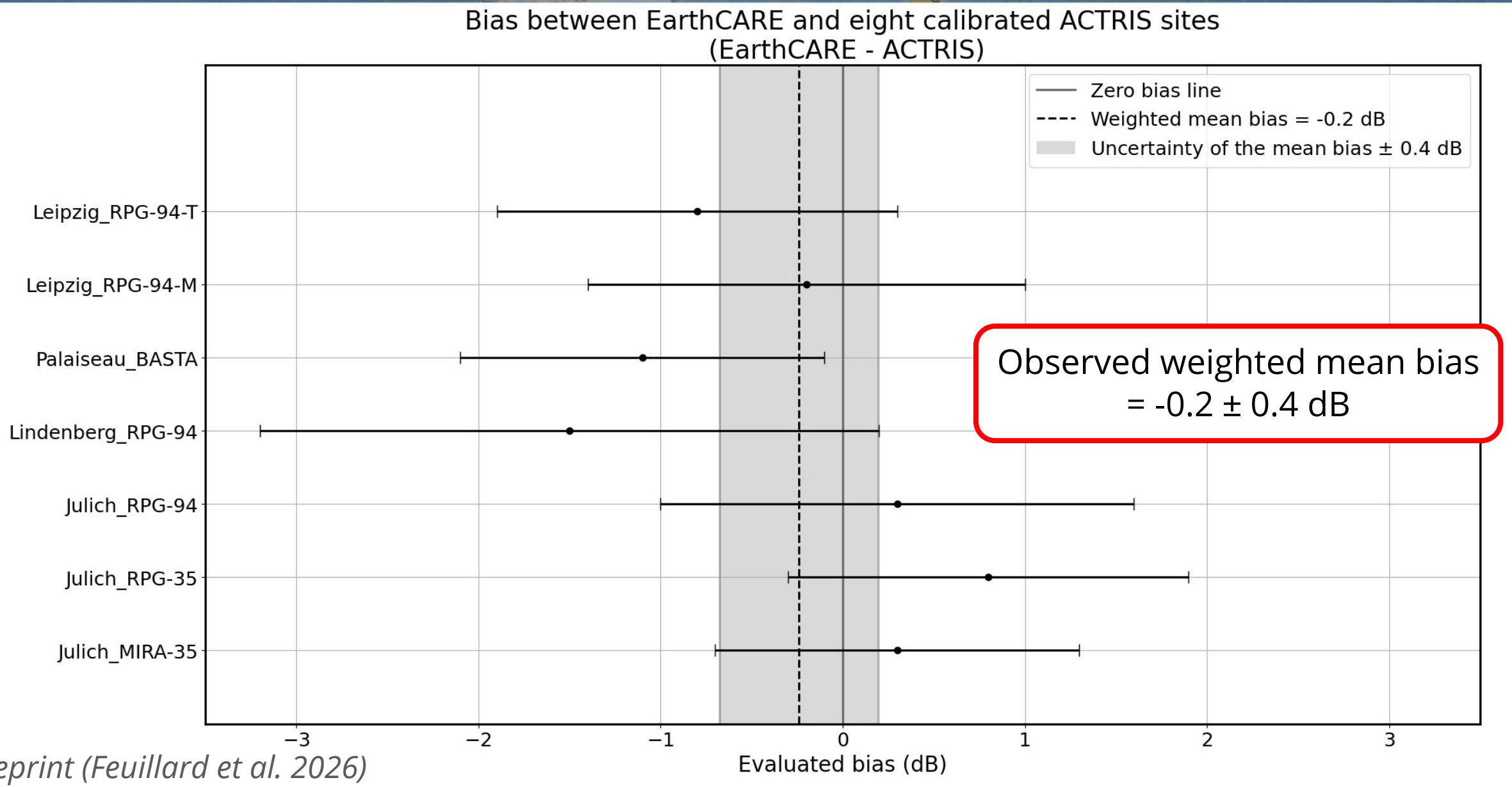


Bias = mean(centers difference)

Uncertainty = ground radar calib + std(centers difference)



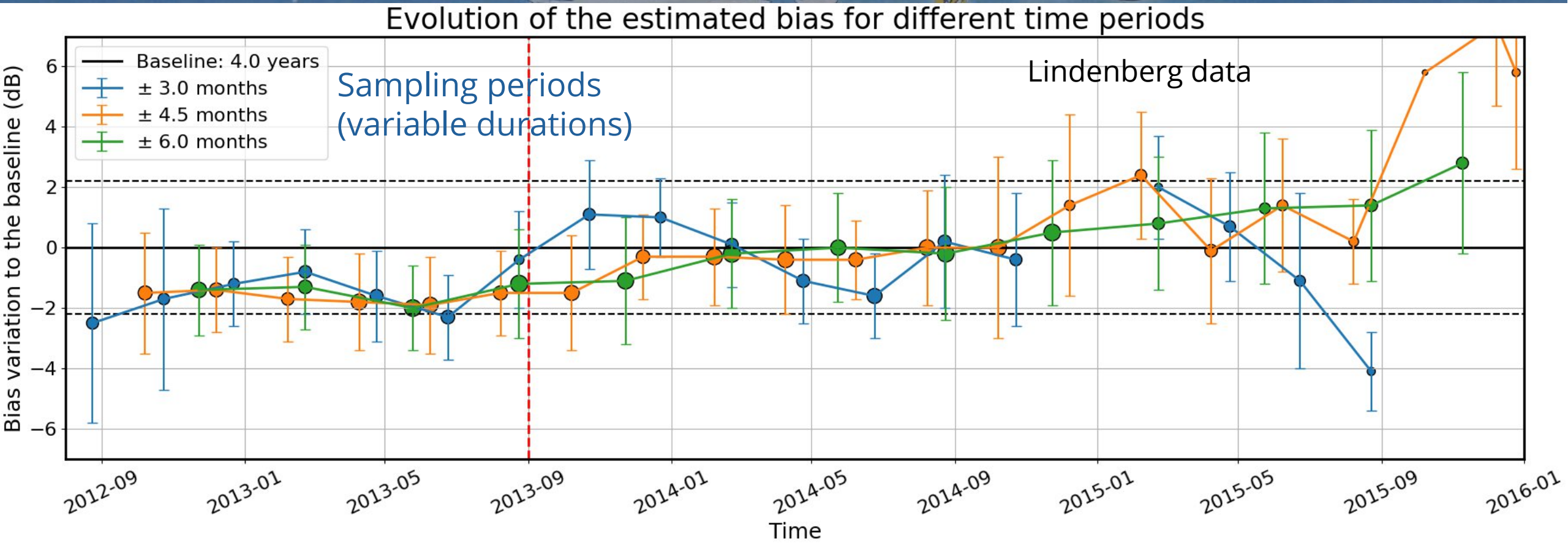
EarthCARE data validation



Observed weighted mean bias = -0.2 ± 0.4 dB

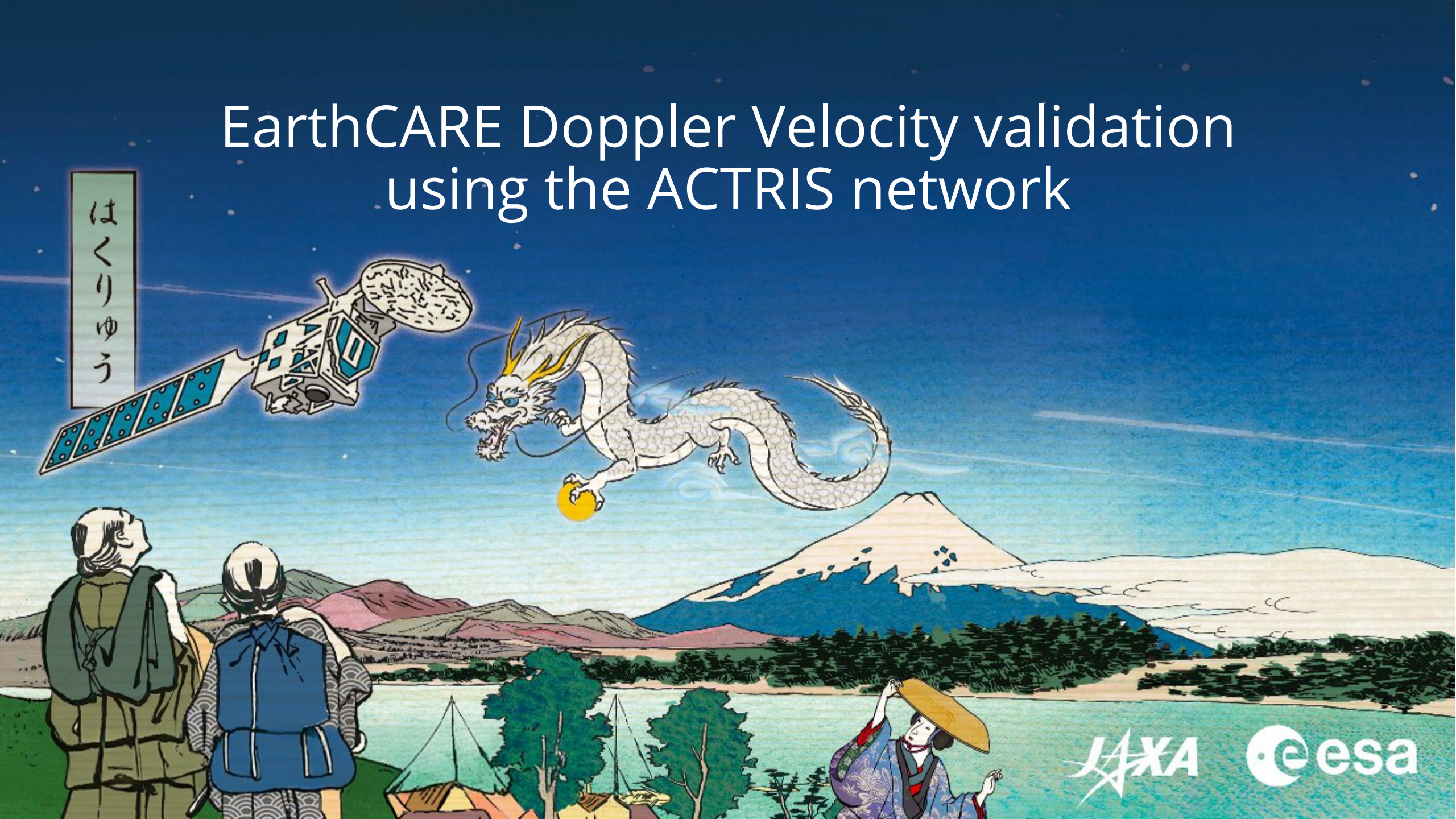
Preprint (Feuillard et al. 2026)

Comparison Time-Series



- The algorithm also works with CloudSat Dataset (with small parameter adjustements)
- Observed time series indicate that a period of 9 months to one year is the minimum needed for robust bias estimates

EarthCARE Doppler Velocity validation using the ACTRIS network



Introduction

- EarthCARE is the first spaceborne atmospheric radar with Doppler velocity capability

- There is little practical experience on ground-to-space Doppler velocity comparisons, altough several key pieces have been studied
  - Impact of low SNR, non-uniform beam filling, antenna pointing
  - (e.g. Kim et al. 2025

- Objective: to explore the potential of the ACTRIS network for Doppler Velocity CalVal

- The EarthCARE L1b and L2a uncorrected and best velocity estimates were evaluated. Only the L2a best estimate is shown here.

Comparison principle

Data selection inspired by Protat et al (2009).

- CPR: 100km radius around the ground site.
- Ground: ±30 min window around the overpass time.

SNR filtering: remove noisy data.

- EarthCARE and ground: data bellow -21 dB.
- Need for calibrated ground reflectivities.

Statistical filtering: remove outlayer data, remove height bins with low data count.

1. Data from ground based radars are forward simulated to improve comparability (Pfitzenmaier et al., 2025)
2. Ground-based radars are assumed perfectly vertical

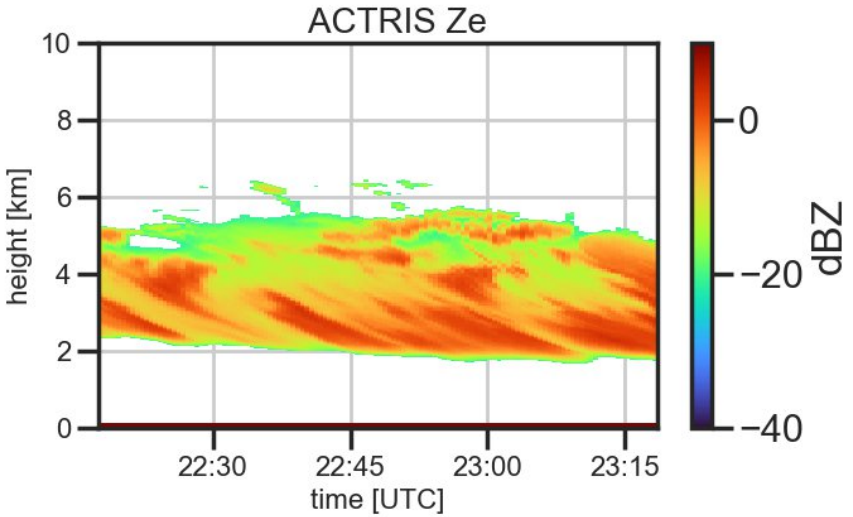
Comparisons of ground-CPR Doppler velocities

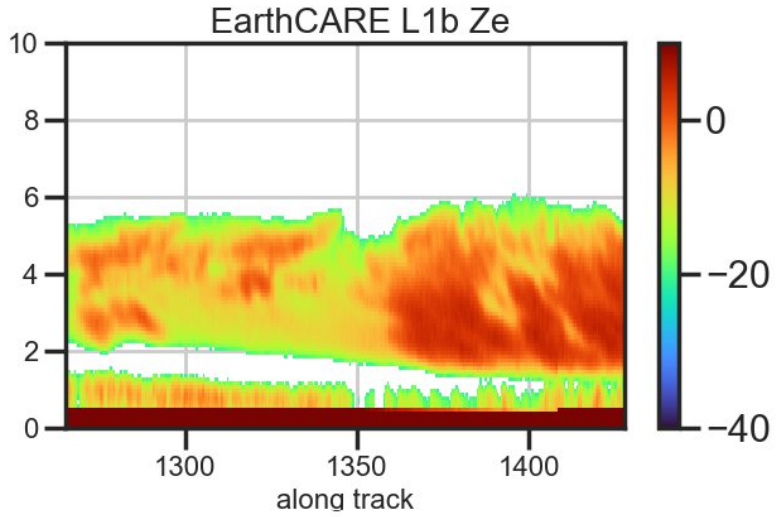
Bias estimator :

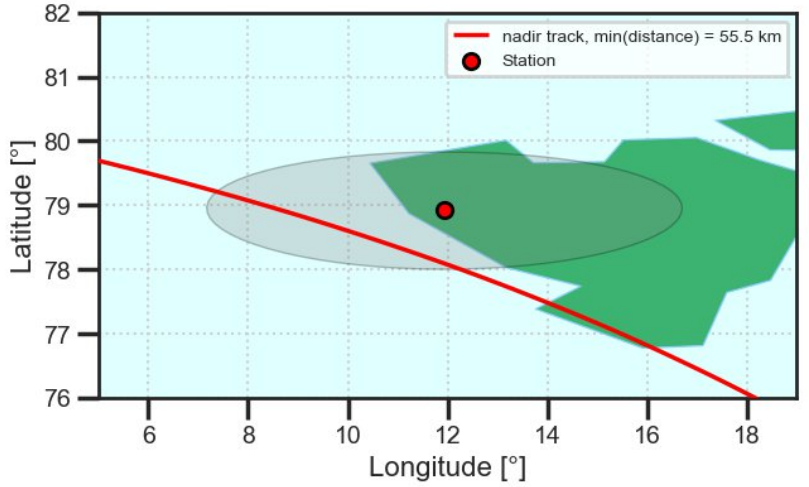
- $v_{diff} = median(v_{ground} - v_{sat})$

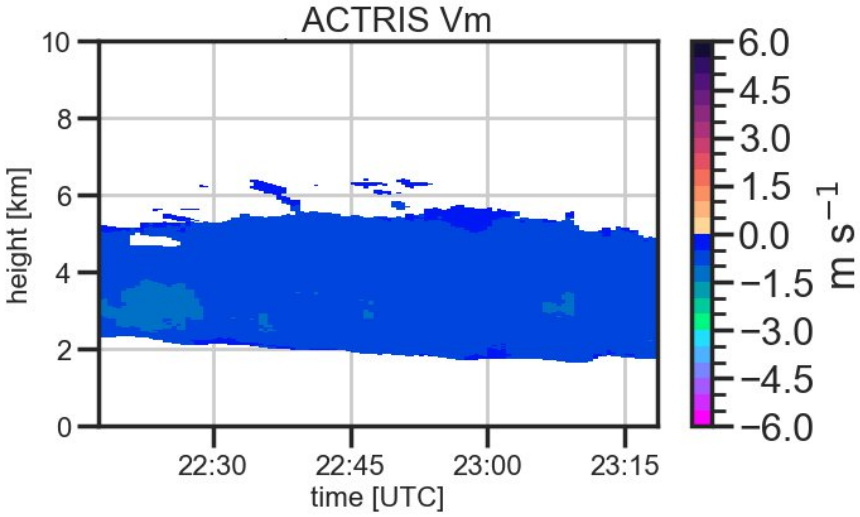
Example of an overpass

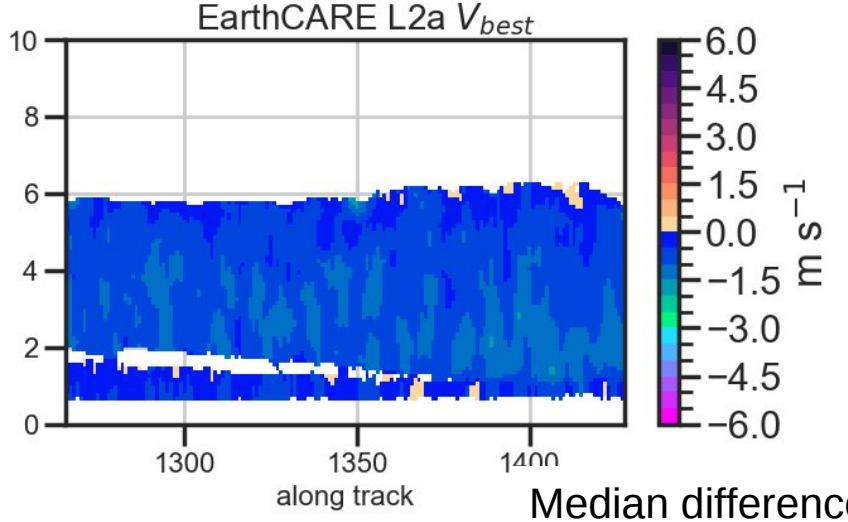
Overpass of the 6th April 2025 (22:47:48 UTC) over the Ny-Alesund site.

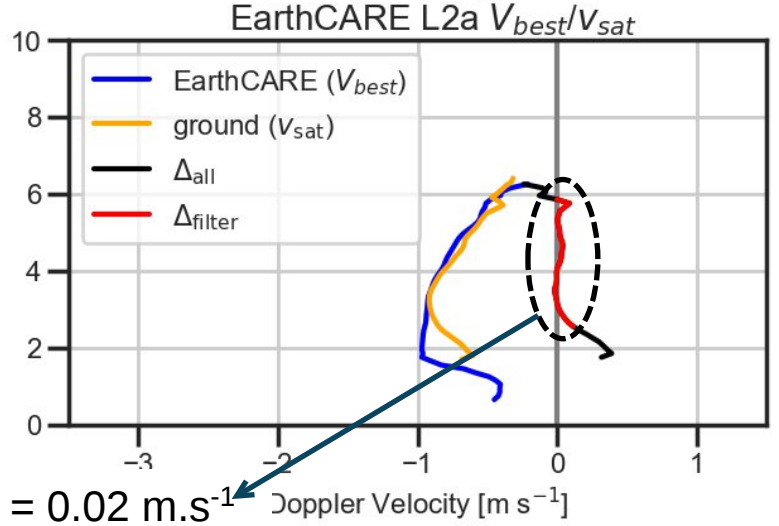








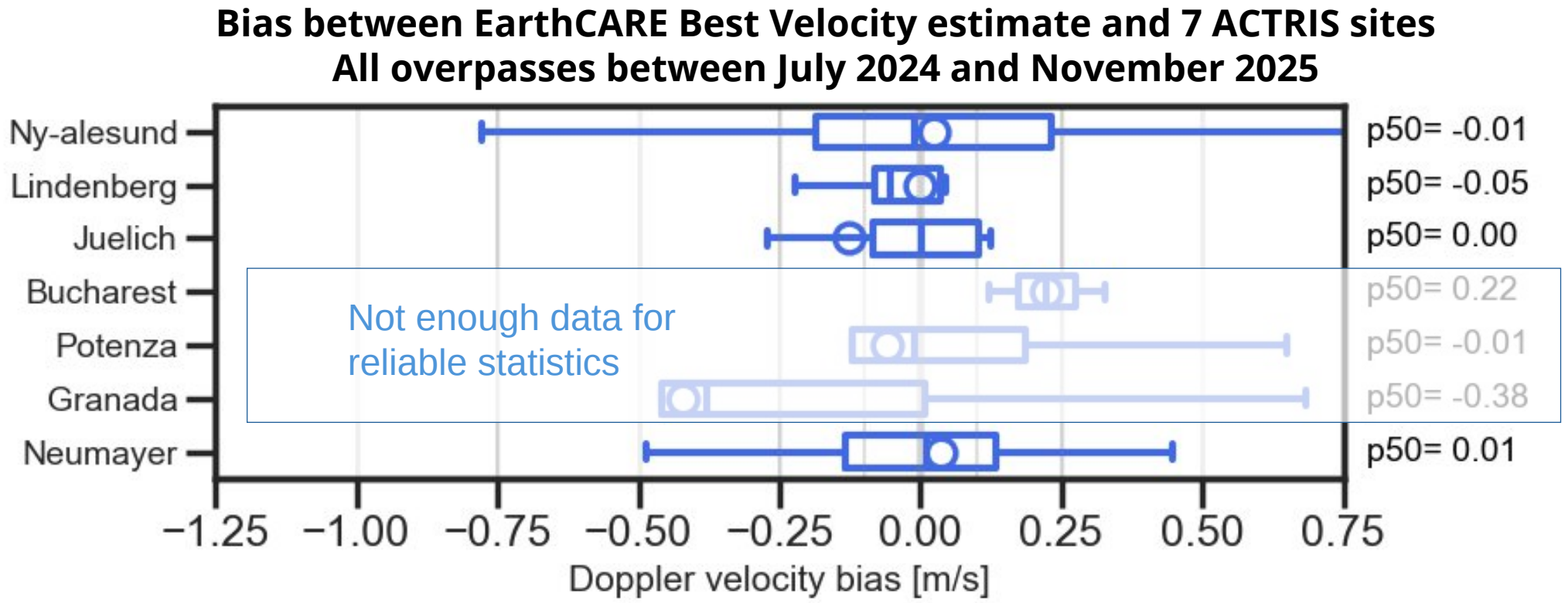




Median difference = 0.02 m.s^{-1}

=> Objective : 1 ms-1

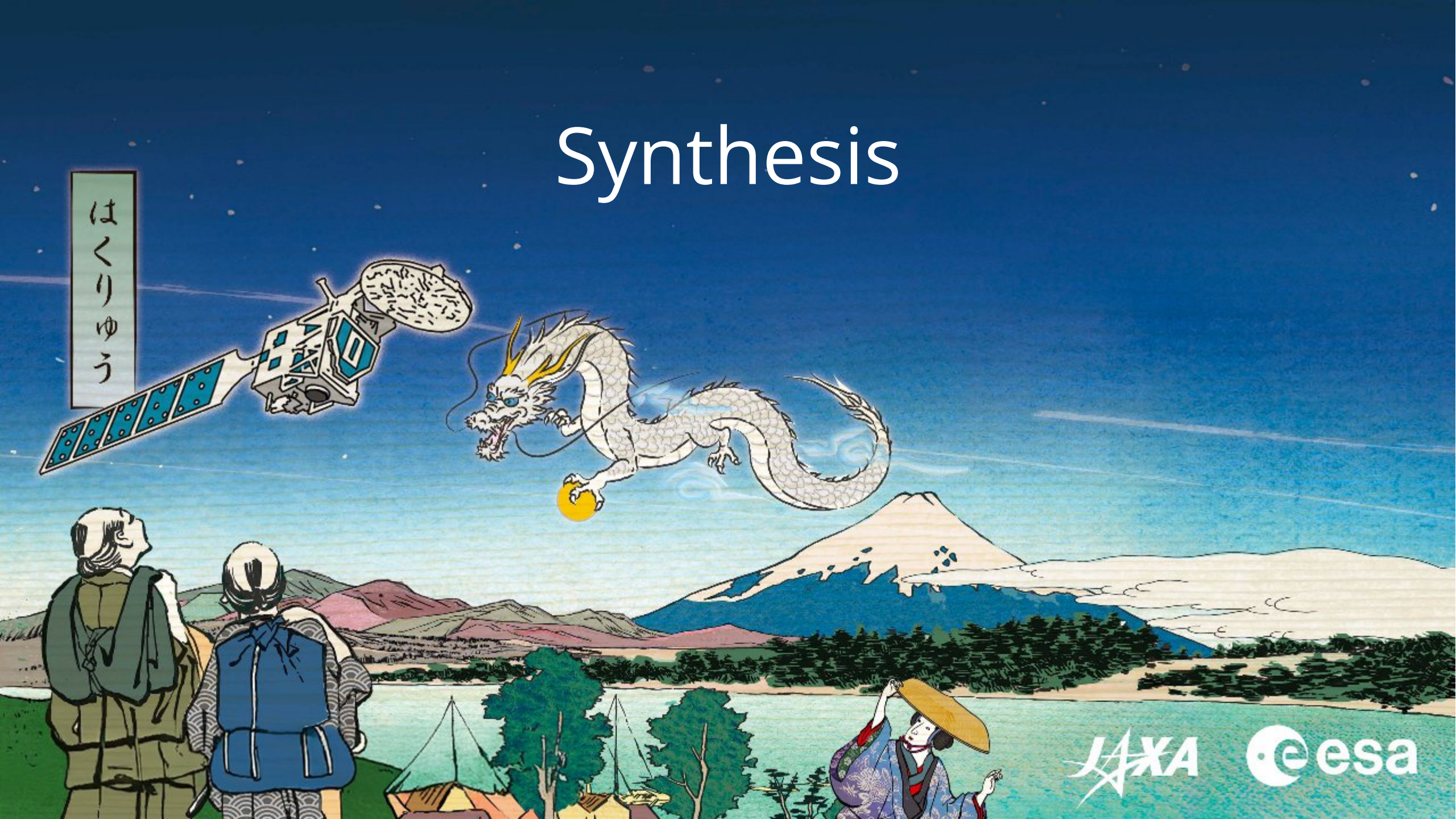
Results for some ACTRIS network sites



Median values of doppler velocity bias between 0.01 and 0.06 ms^{-1}

< 0.1 ms^{-1} mission objective

Synthesis



Synthesis

Reflectivity Cal-Val

- Comparison of satellite overpass data with ground-based reflectivity climatology
  - Side-result: EarthCARE appears to accurately capture the reflectivity climatology at the tested ACTRIS sites, given sufficient sampling time
- All ground-based radars were calibrated with the same reference and show compatible bias observations
  - Validation of the space-ground comparison method by closure
  - The calibration standards of CCRES are compatible with EarthCARE
- Estimated EarthCARE reflectivity bias using 7 radars = -0.2 ± 0.4 dB
- Time-series indicate that reliable comparions require at least 9 to 12 months
- Calibration changes can be identified and tracked, respecting this time resolution

Synthesis

Doppler velocity Cal-Val

- Profiles are compared in spatial and temporal proximity from satellite overpasses (100 km radius, ±30 min)
- Both instruments must observe a similar cloud scene, to enable a comparison of wind patterns
- Succesfull comparisons show a doppler velocity bias (for the best estimate) between 0.01 and 0.06 ms^{-1}, within the mission objective of 0.1 ms^{-1}
- Results for the other products confirm that the main error in EarthCARE's velocity retrievals come from small pointing changes of the satellite antenna (not shown here, Pfitzenmaier et al. in preparation)

Outlook

- Continue the validation of higher-level products using the ACTRIS network
- Assessing EarthCARE’s capability to capture the climatological variability of these products
- ACTRIS-wide calibration and quality control, closure validation with reference sites
- Refining the Doppler comparison method to improve the quantification of ground-based radar verticality

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Cal/Val of the **EarthCARE** Cloud Profiling Radar using the **ACTRIS** Cloud Radar Network

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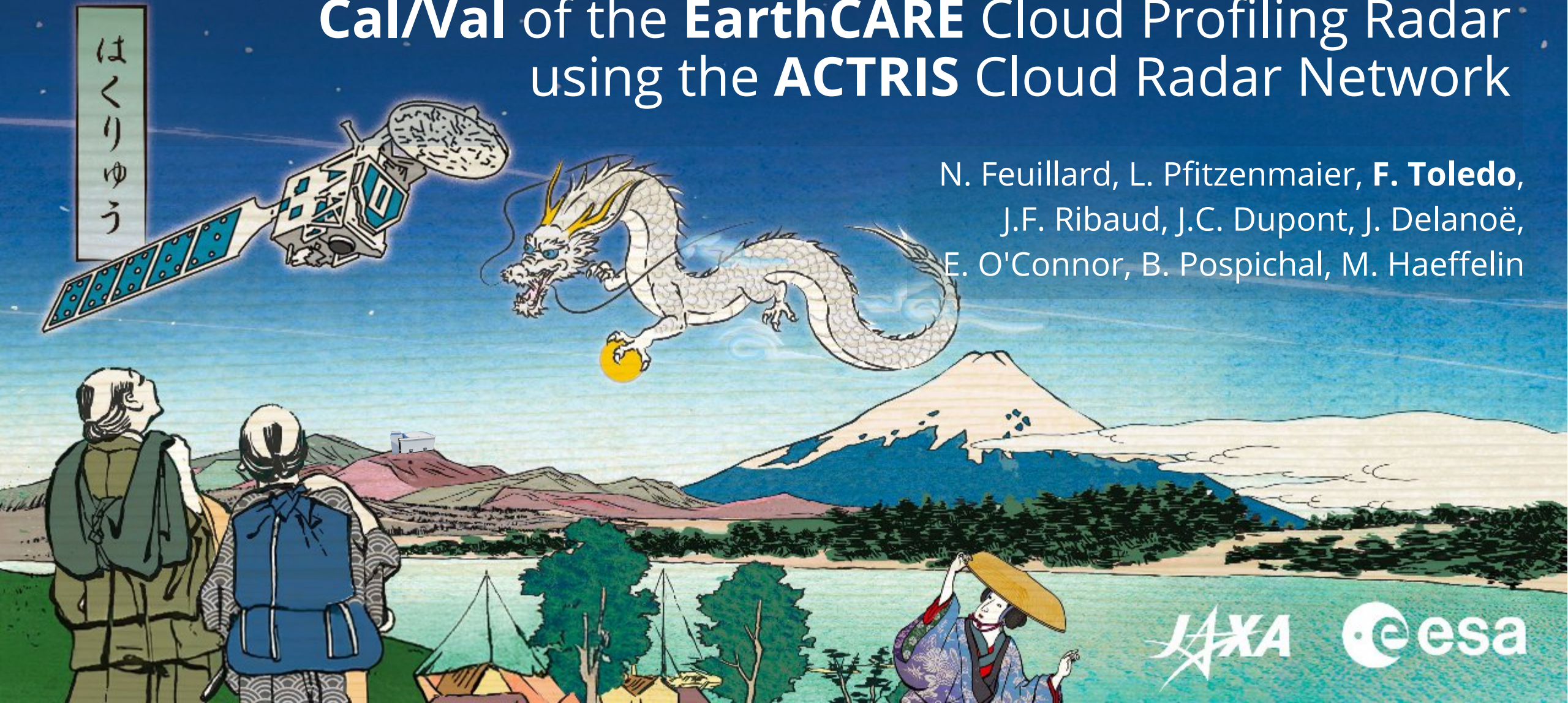
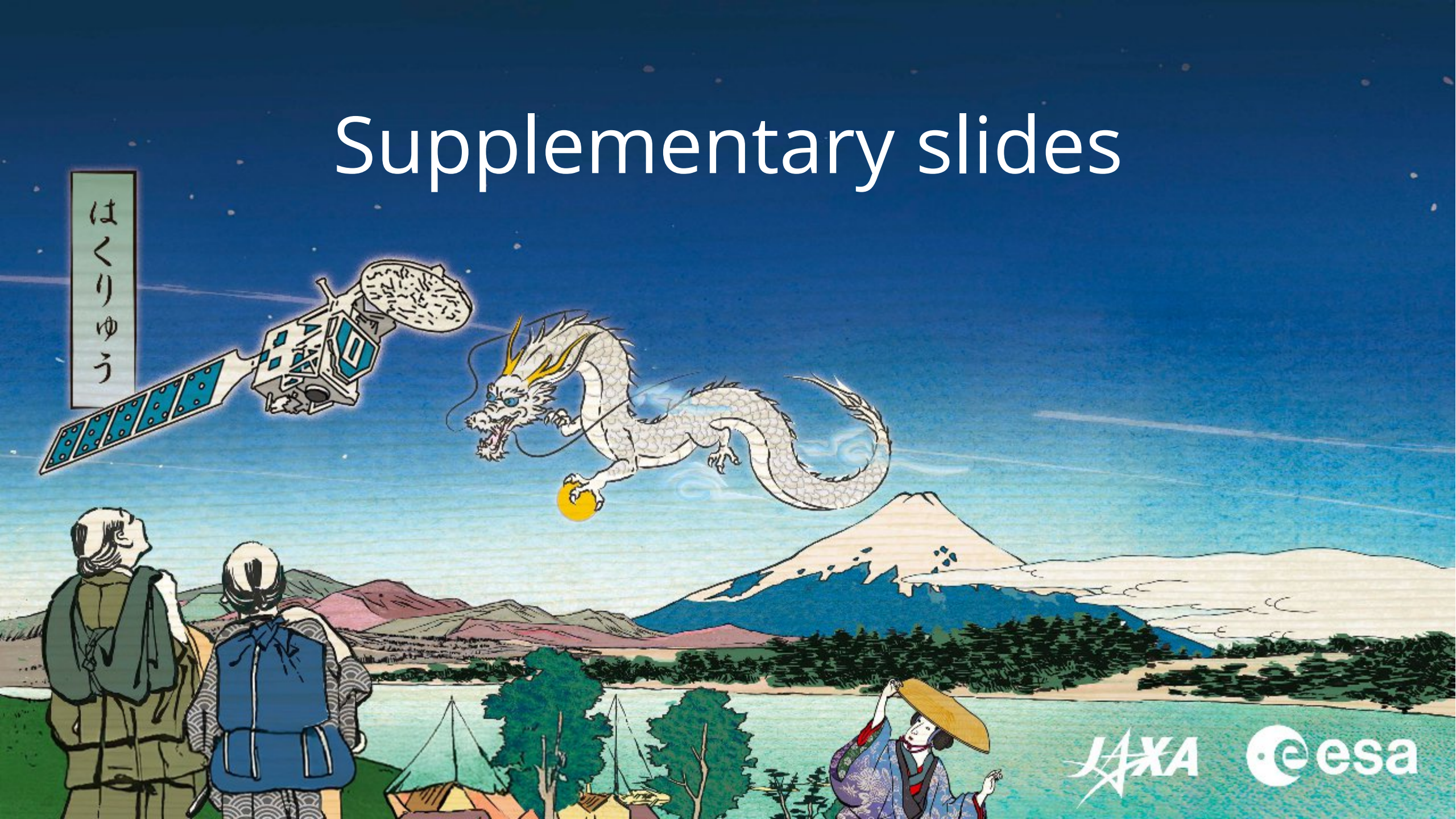
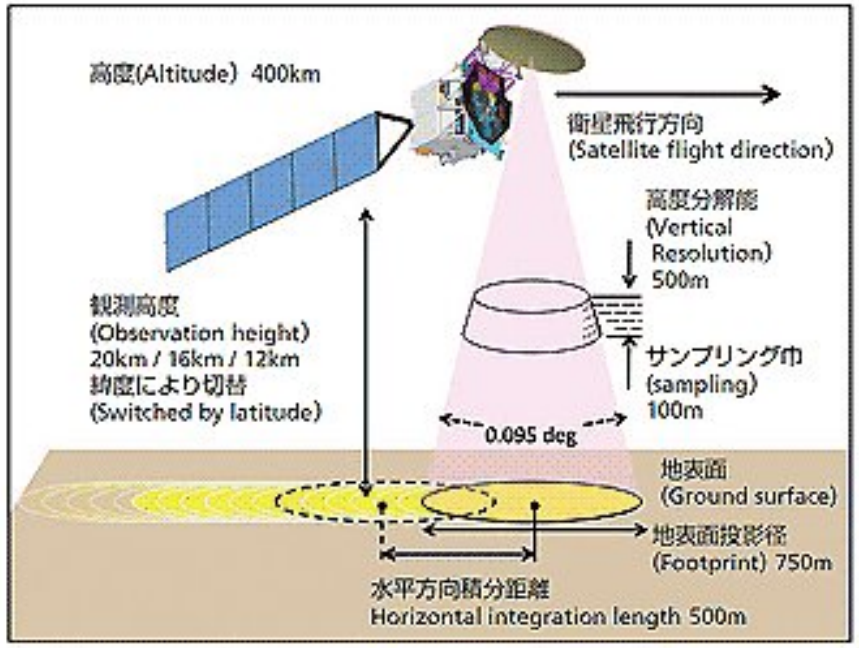


Supplementary slides



EarthCARE Cloud Profiling Radar (CPR)

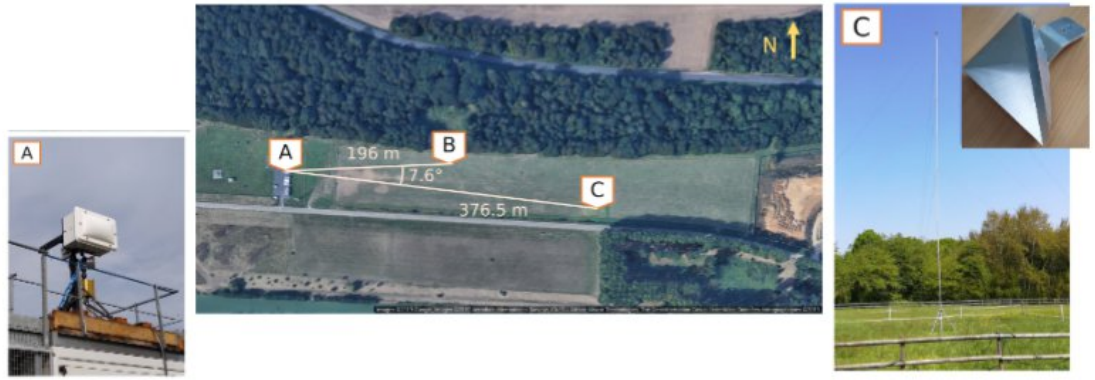
- Provides reflectivity (Z) and doppler velocity (Vd) profiles
- Pulse length: 3.3 μs (≈ 500 m range resolution)
- Vertical sampling resolution: 100 m
- Sensivity of -35 dBZ across the troposphere
- Capable of performing hydrometeor classification (instrumental synergy)
- Includes corrections for antenna pointing in Vd retrievals.



Reminder: ACTRIS Cloud Radar Calibration Strategy

- Calibrate the reference radar with a corner reflector at ACTRIS-CCRES
  - 0.8 dB calibration uncertainty
- Moving the calibrated radar to another ACTRIS site for calibration transfer
  - New calibration: 0.8 - 1 dB uncertainty
- Re-calibration of the reference radar at ACTRIS-CCRES to validate the campaign results
- Continous calibration tracking at the ACTRIS sites using disdrometers

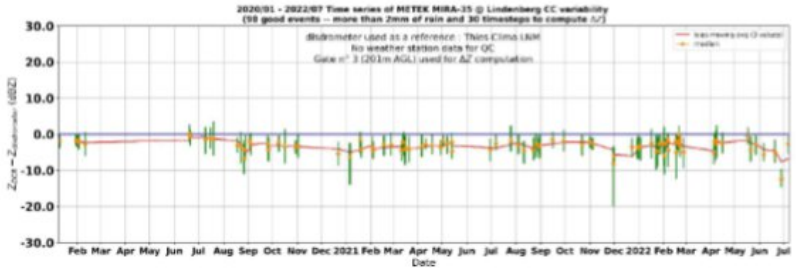
Method :
Toledo, Felipe, et al. "Absolute calibration method for frequency-modulated continuous wave (FMCW) cloud radars based on corner reflectors." Atmospheric Measurement Techniques 13.12 (2020): 6853-6875.



Joyce Obs. Radar
MIRA
Ka Band

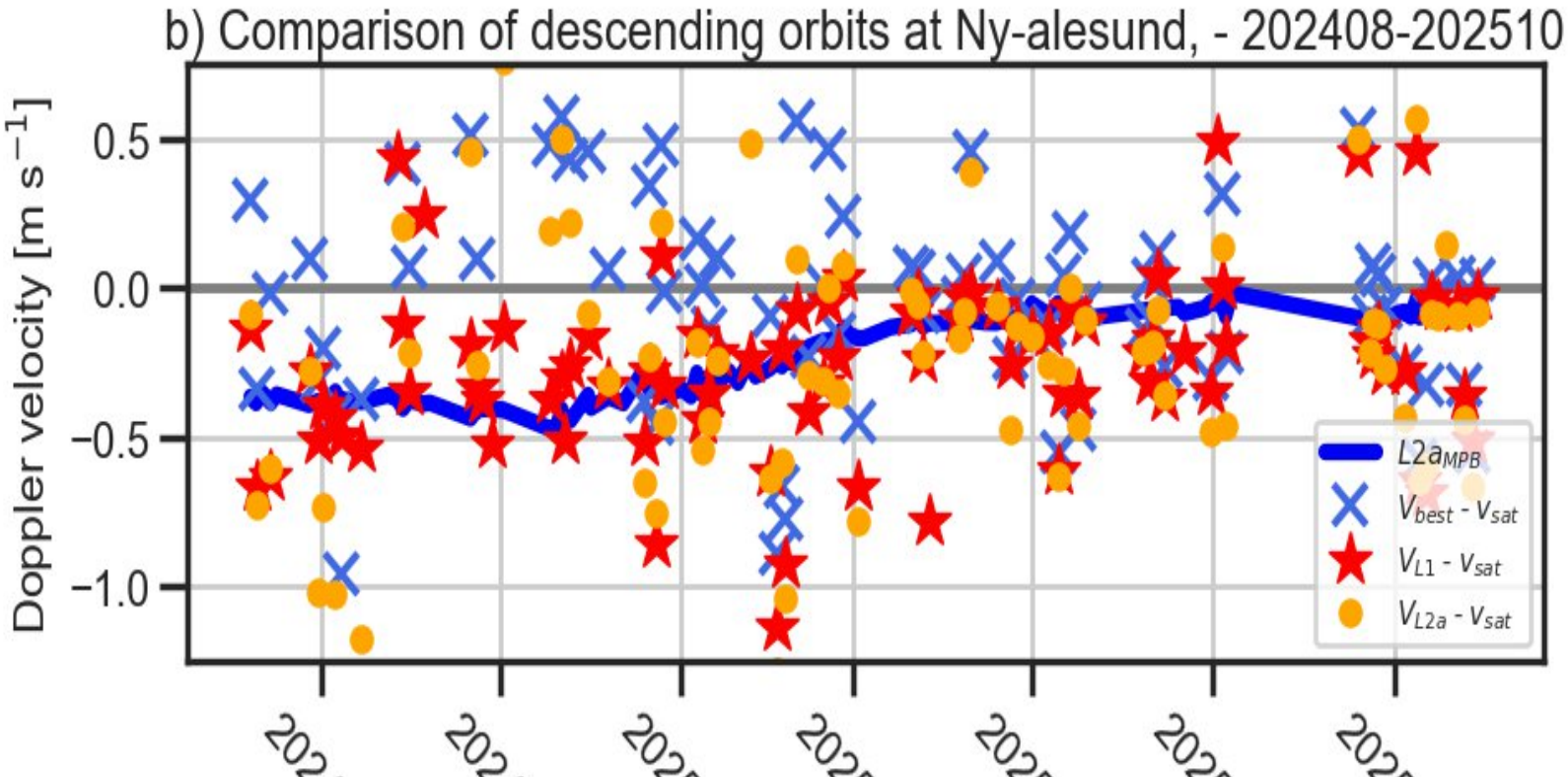
Reference Radar
BASTA-Mini CCRES
W Band

Method :
Jorquera, Susana, et al. "Calibration transfer methodology for cloud radars based on ice cloud observations." Journal of Atmospheric and Oceanic Technology 40.7 (2023): 773-788.



Results for the ACTRIS network

- EarthCARE L1b and L2a uncorrected and best estimate velocities were evaluated
- Results confirm that the main error in EarthCARE's velocity retrievals come from small pointing changes of the satellite antenna (Pfitzenmaier et al. in preparation).



95-35 GHz

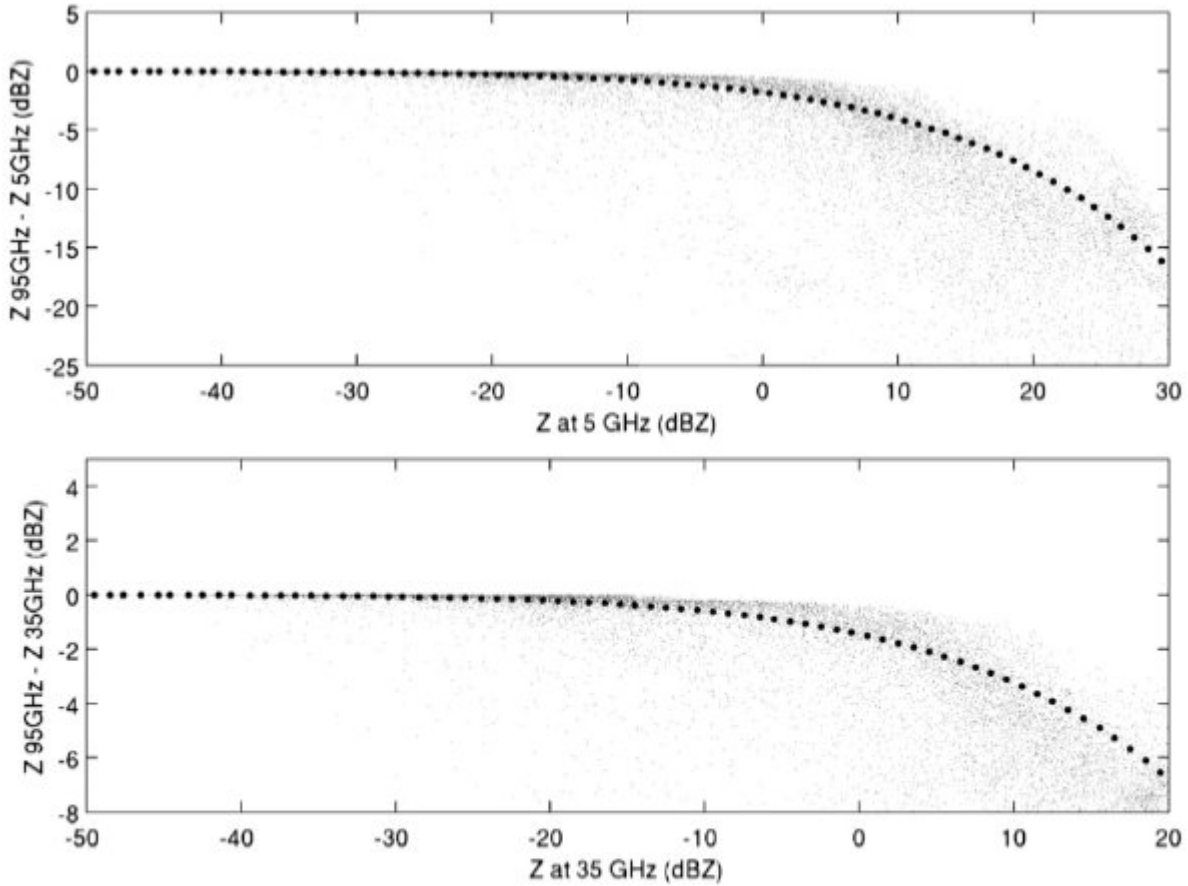
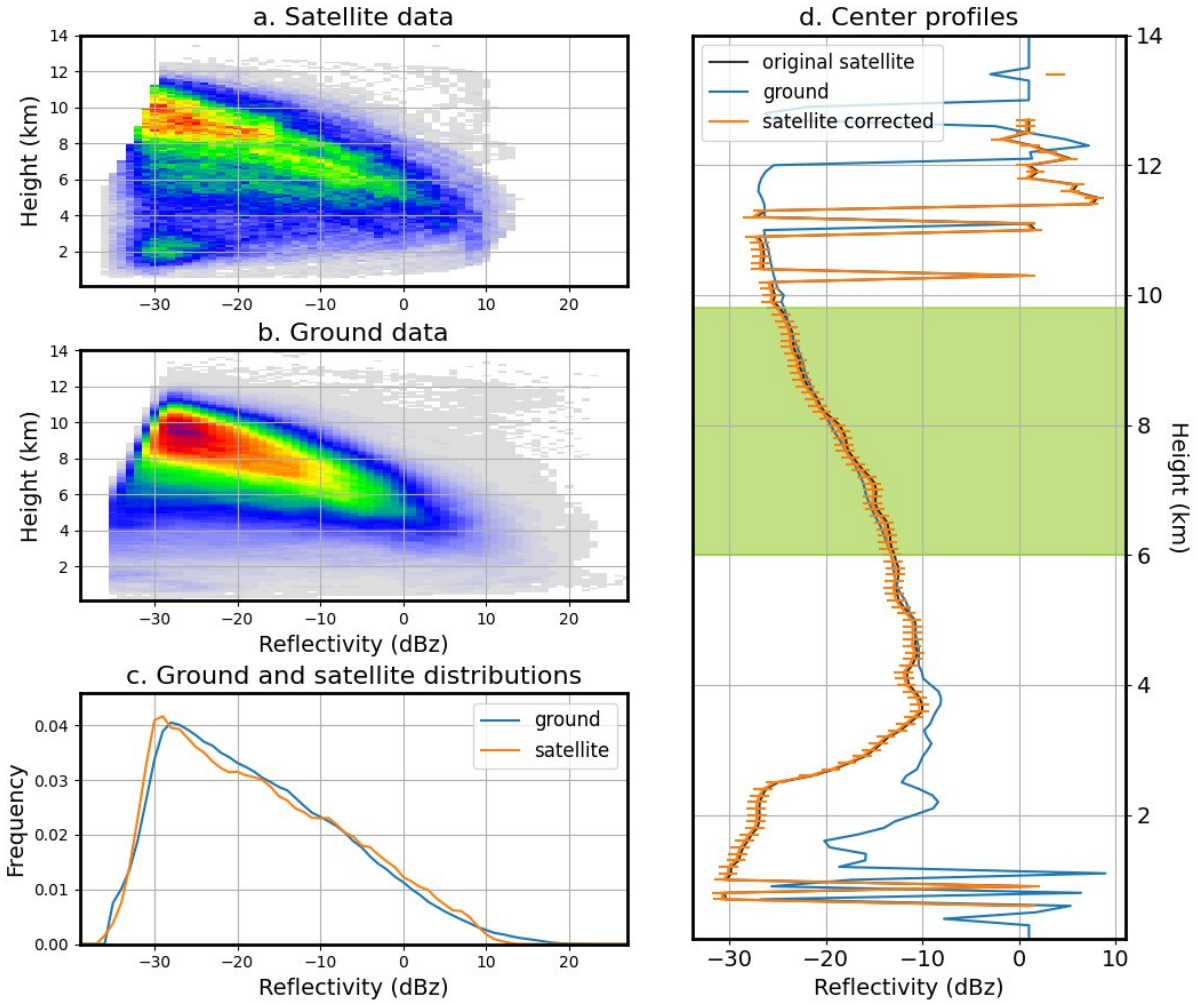
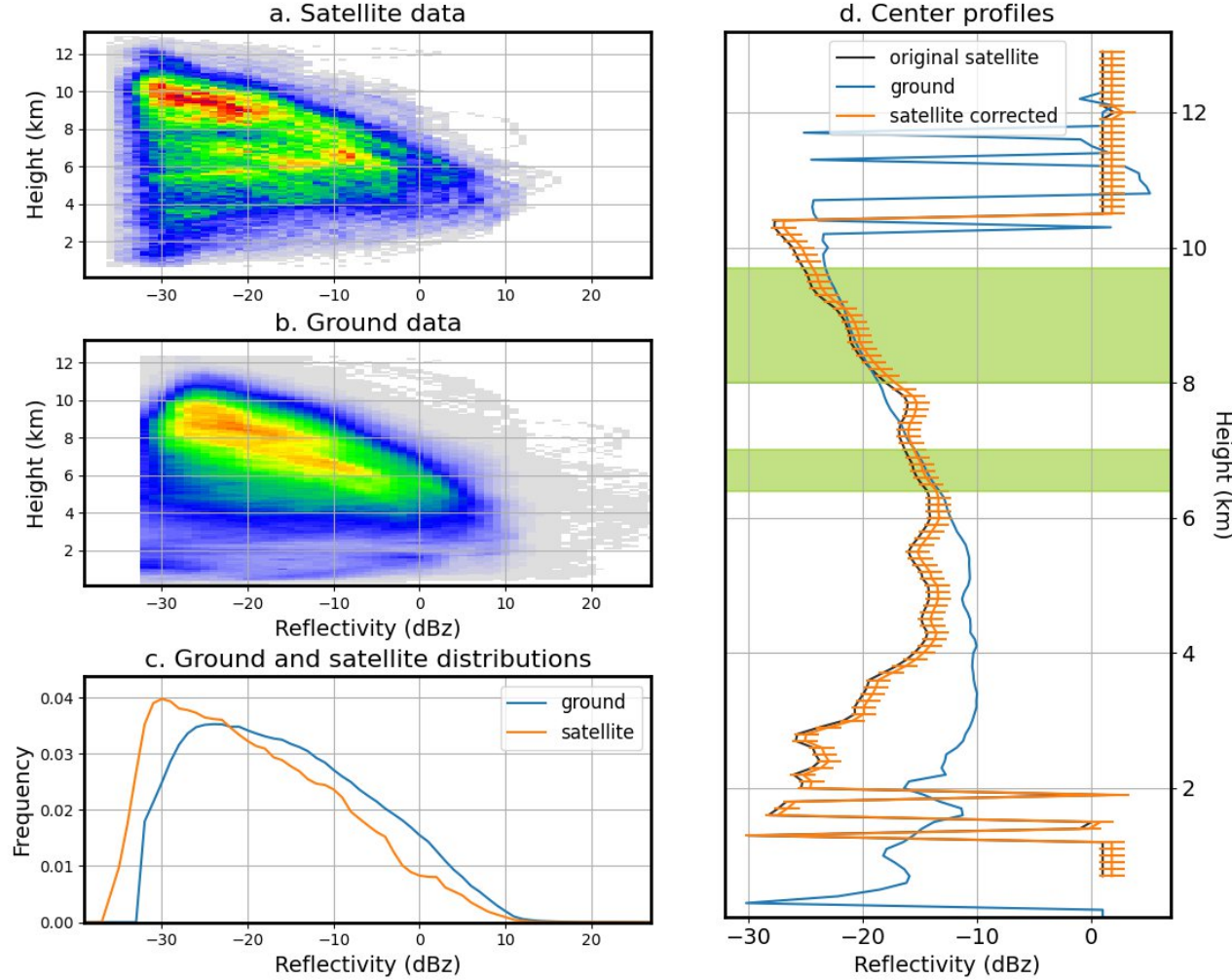


FIG. 9. Reflectivity differences at different wavelengths computed from in situ microphysical measurements of ice particle size distributions. The (top) 95–5-GHz and (bottom) 95–35-GHz reflectivity differences in dBZ as functions of the reflectivity at 5 and 35 GHz, respectively. The small dots are individual estimates and the large dots are from a least squares fit to the individual points (see text).

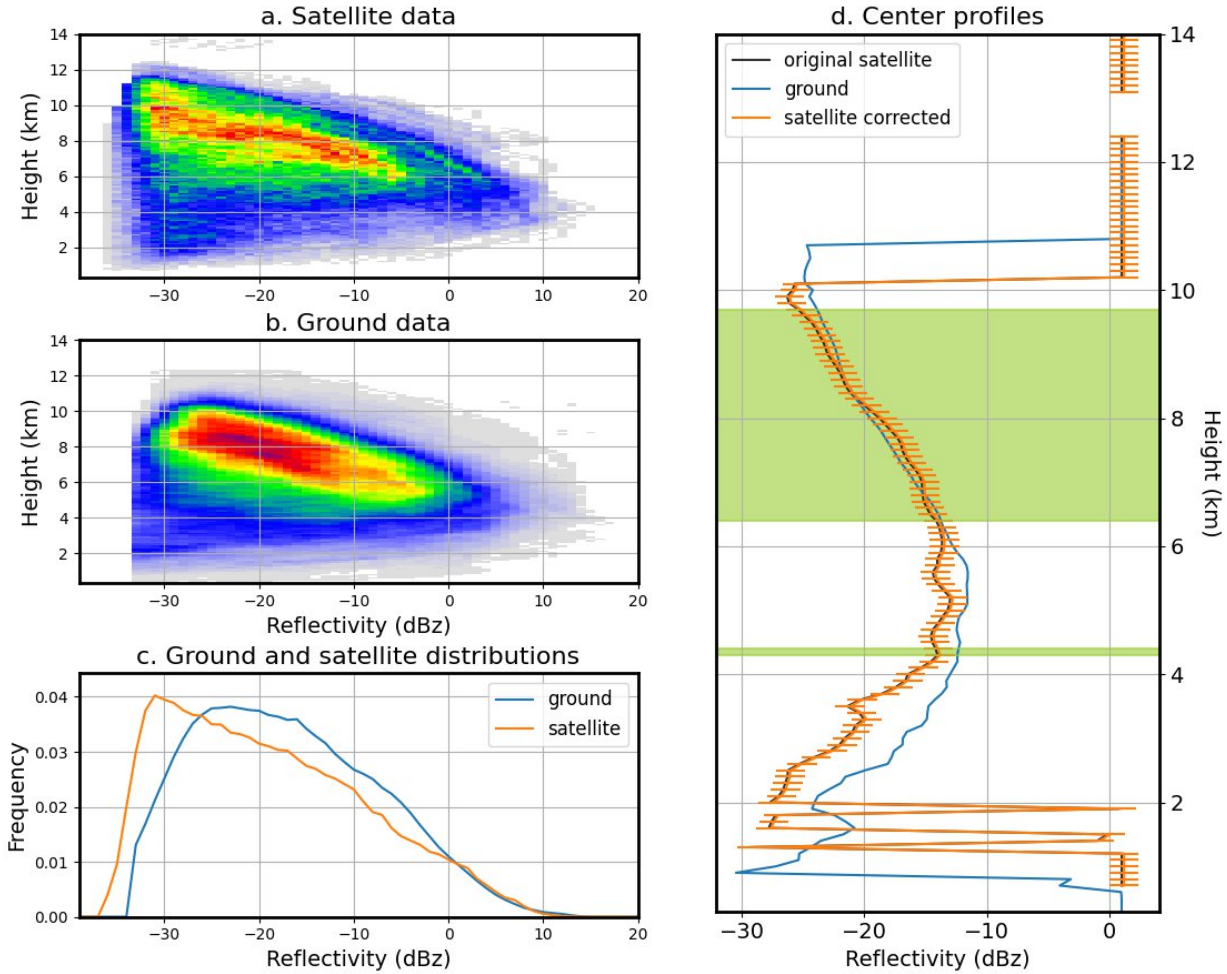
E / Jülich MIRA35-UOC comparison for the period: 2024-07-20--2025-11-18
Satellite profiles: 14846. Ground profiles:151765
Evaluated bias: 0.3 ± 1.0 dB



: / Leipzig RPG94-TROPOS comparison for the period: 2024-07-20--2025-03-24
Satellite profiles: 7985. Ground profiles:127168
Evaluated bias: -0.8 ± 1.1 dB



: / Leipzig RPG94-MELPITZ comparison for the period: 2025-01-28--2025-11-18
Satellite profiles: 11506. Ground profiles:82008
Evaluated bias: -0.2 ± 1.2 dB



RE / Palaiseau BASTA-IPSL comparison for the period: 2024-12-01--2025-06-25
Satellite profiles: 6029. Ground profiles:24315
Evaluated bias: -1.1 ± 1.0 dB