Operational implementation of the sub-orbital to orbital tool together with Doppler velocity unfolding across the ACTRIS cloud radar network for EarthCARE validation

Ewan O'Connor, Simo Tukiainen, Tuomas Siipola, and the ACTRIS cloud profiling community

Finnish Meteorological Institute

2nd ESA-JAXA EarthCARE In-Orbit Validation Workshop

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

What is Cloudnet?

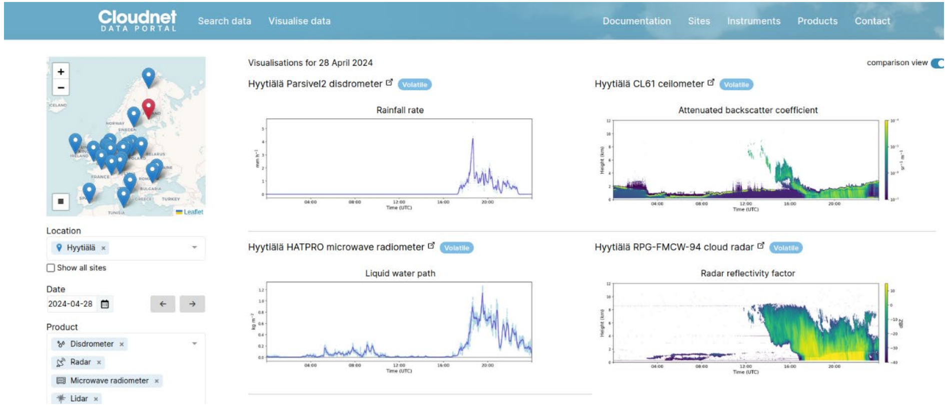
Cloudnet DATA PORTAL

Processing and archiving service for ground-based **cloud remote sensing** data (~20 active sites)

ACTRIS

Cloud remote sensing component of **ACTRIS research infrastructure**

[**cloudnet.fmi.fi**](cloudnet.fmi.fi)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DATA PORTAL
Search data
Visualise data
Documentation
Sites
Instruments
Products
Contact
Visualisations for 28 April 2024
comparison view
Hyytiälä Parsivel2 disdrometer
Volatile
Rainfall rate
Hyytiälä CL61 ceilometer
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Attenuated backscatter coefficient
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Radar reflectivity factor
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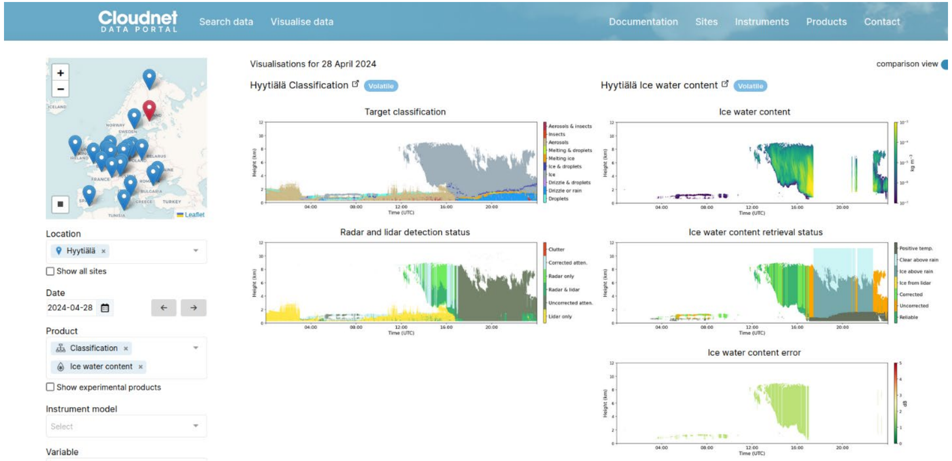
Date
2024-04-28
Product
Disdrometer
Radar
Microwave radiometer
Lidar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Search data
Visualise data
Documentation
Sites
Instruments
Products
Contact
Visualisations for 28 April 2024
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Volatile
Target classification
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Hyytiälä Ice water content
Volatile
Ice water content
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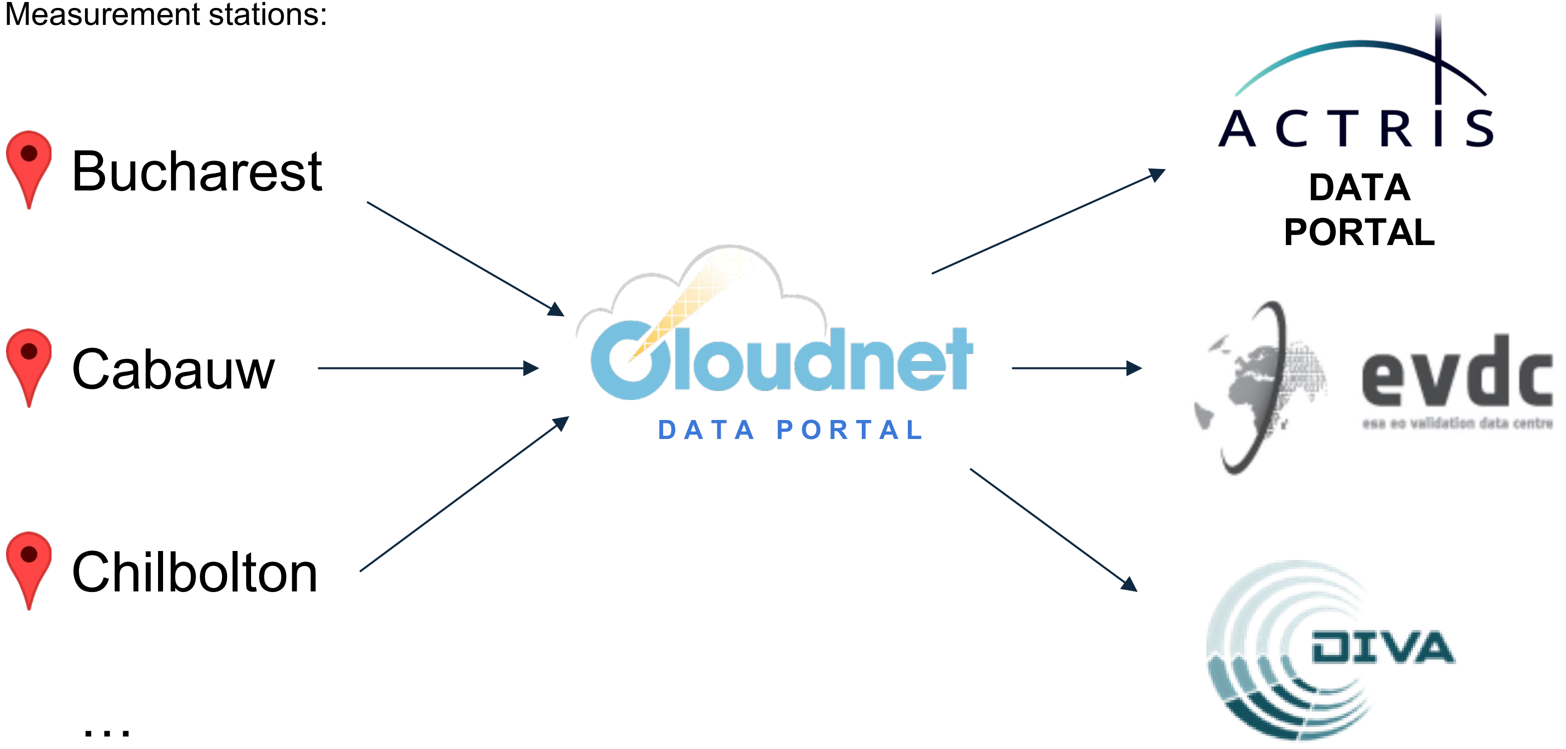
2024-04-28
Product
Classification
Ice water content
Show experimental products
Instrument model
Select
Variable

Measurement stations:



Ground-based radars in Cloudnet

Active cloud radars as of March 2025:

14 RPG FMCW 94 Ghz

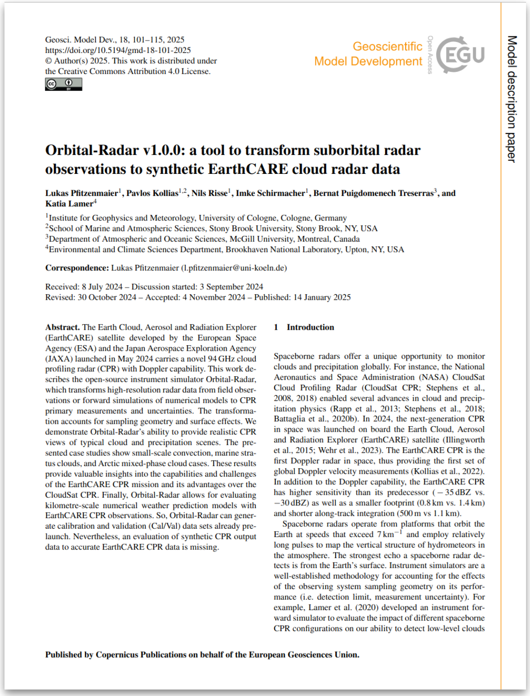
11 MIRA 35 GHz

3 RPG FMCW 35 GHz

2 BASTA 95 GHz

1 MIRA 10 GHz

Orbital-Radar simulator



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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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

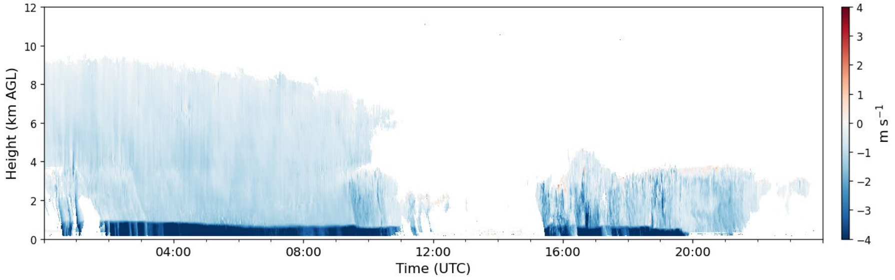
Spaceborne radars offer a unique opportunity to monitor clouds and precipitation globally. For instance, the National Aeronautics and Space Administration (NASA) CloudSat Cloud Profiling Radar (CloudSat CPR; Stephens et al., 2008, 2018) enabled several advances in cloud and precipitation physics (Rapp 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^{-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 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

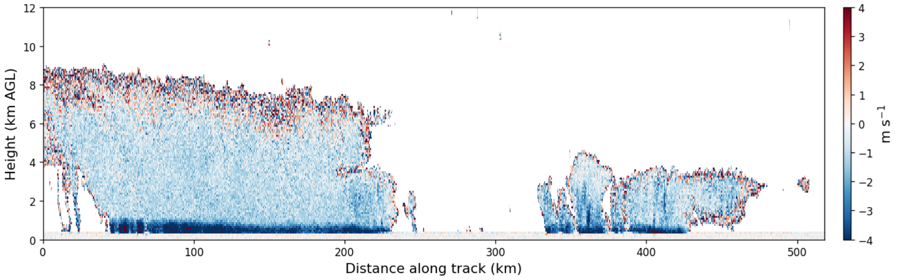
Published by Copernicus Publications on behalf of the European Geosciences Union.

Pfitzenmaier et al.,
Geosci. Model Dev. (2024)

Ground-based radar data

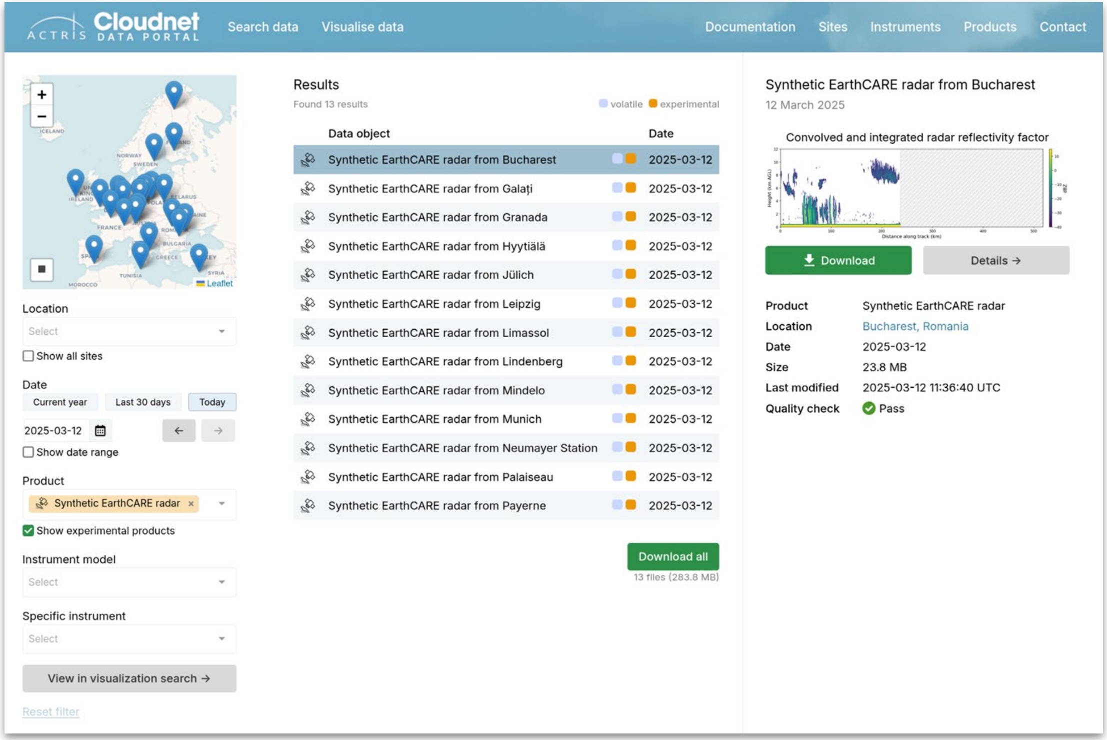


"Synthetic EarthCARE data"



(experimental Cloudnet product)

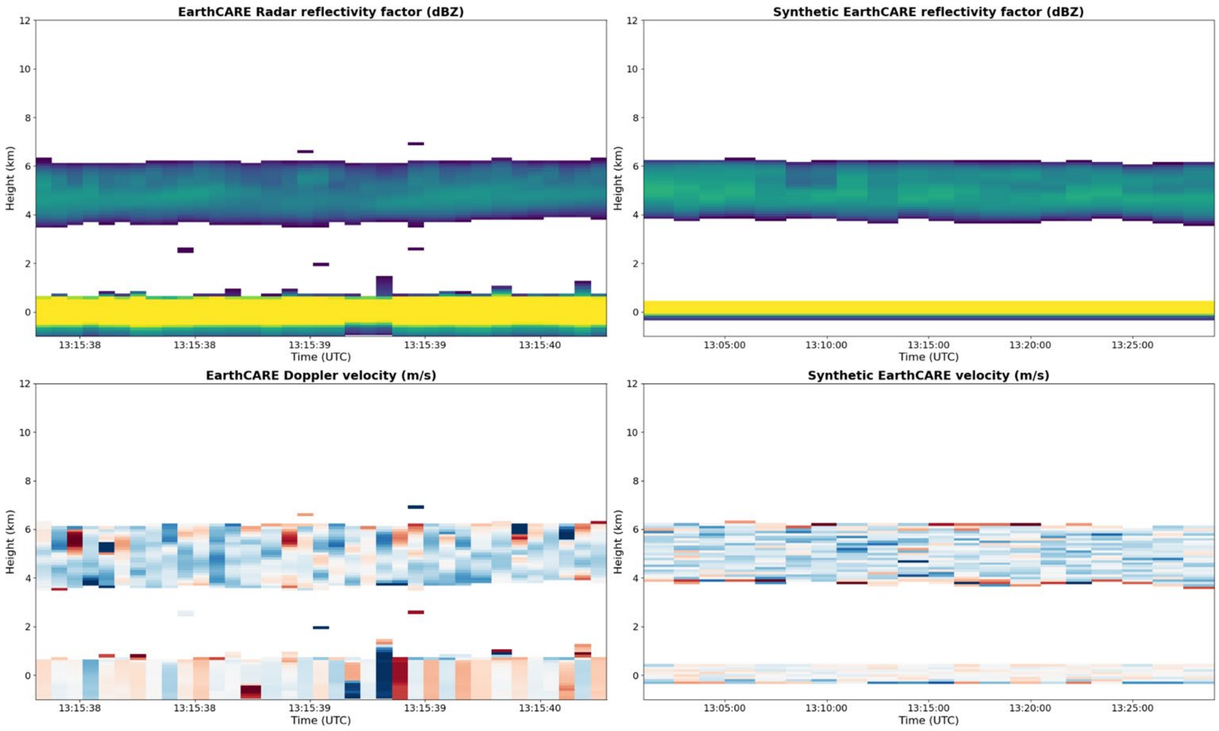
Real-time Orbital-Radar data in Cloudnet data portal:



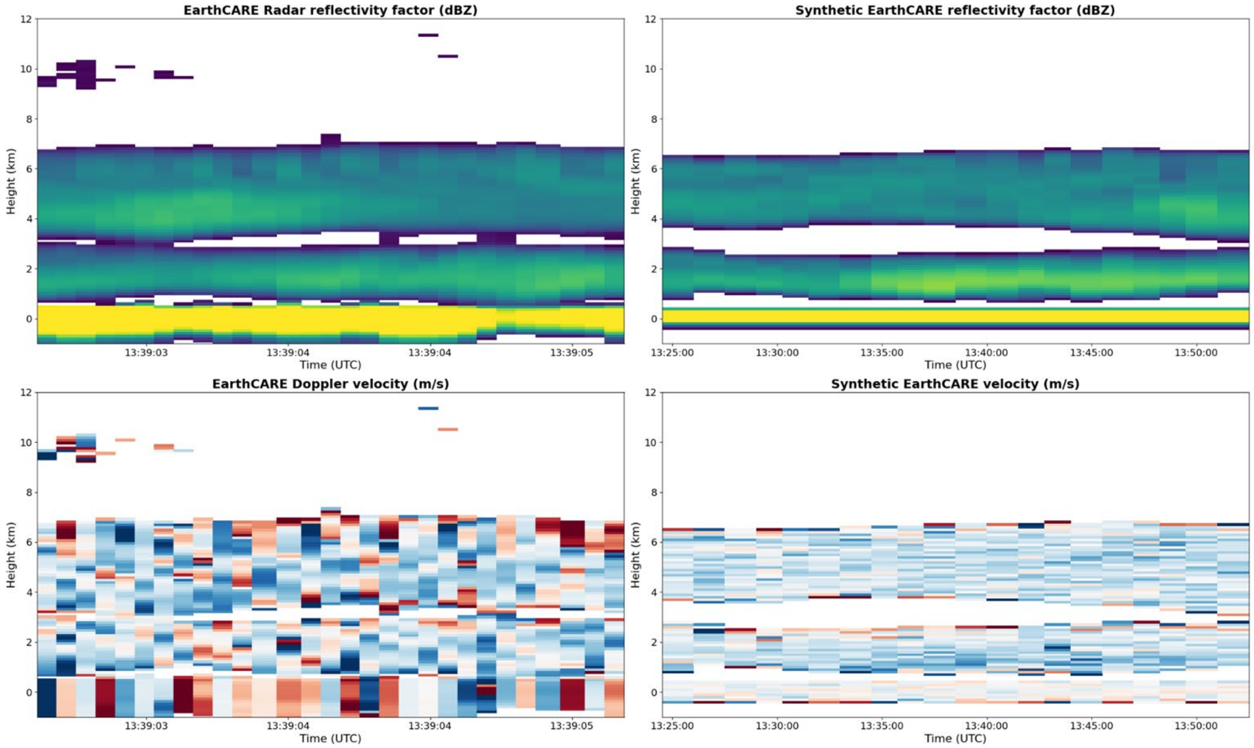
Examples of close overpasses

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

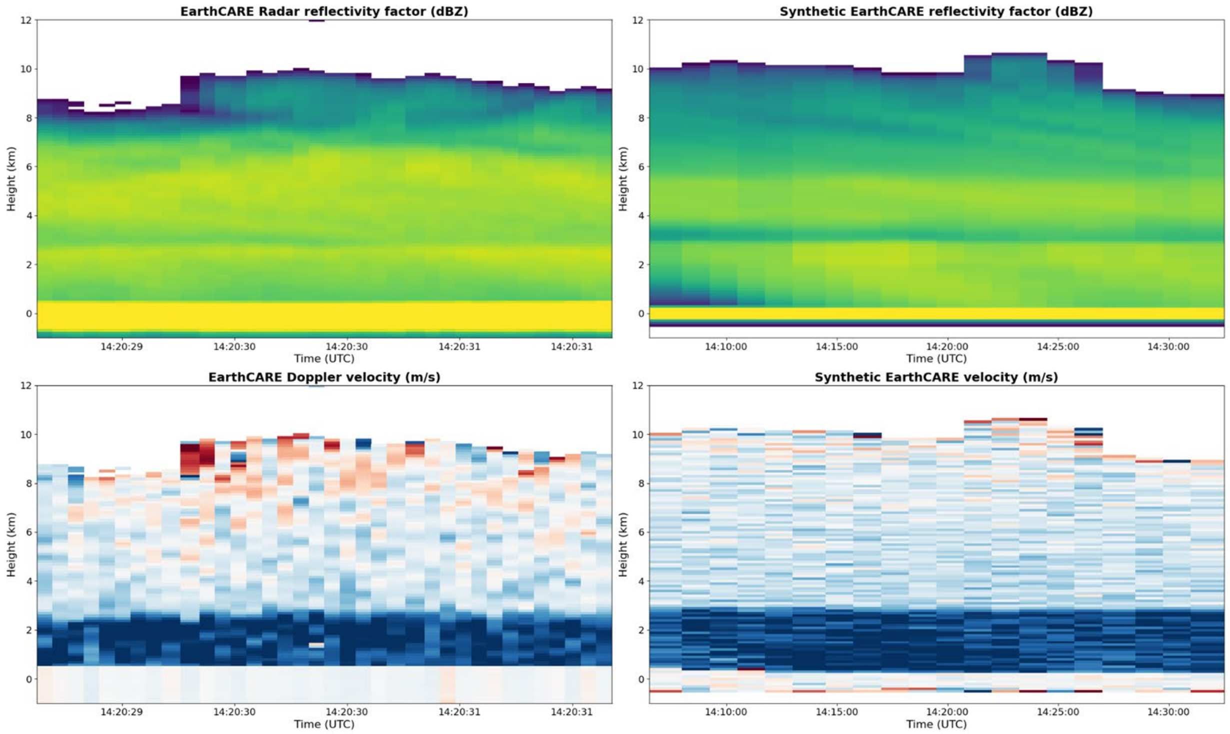
Hyytiälä 2024-12-29



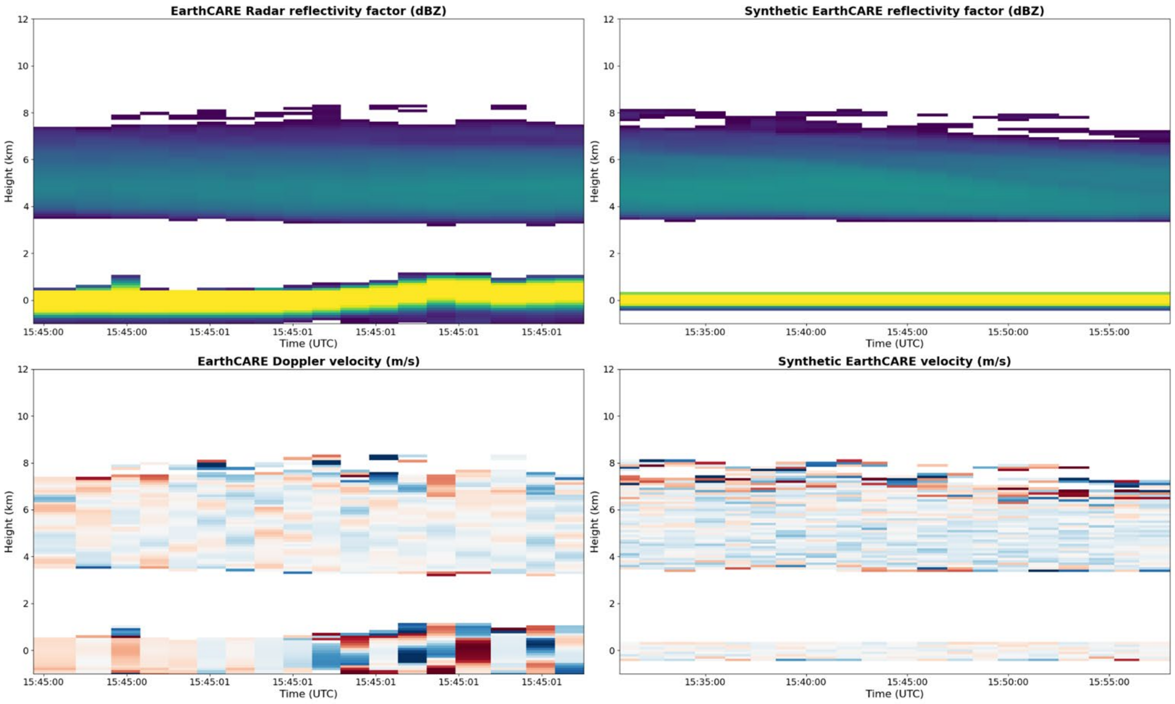
Lindenberg 2025-01-14



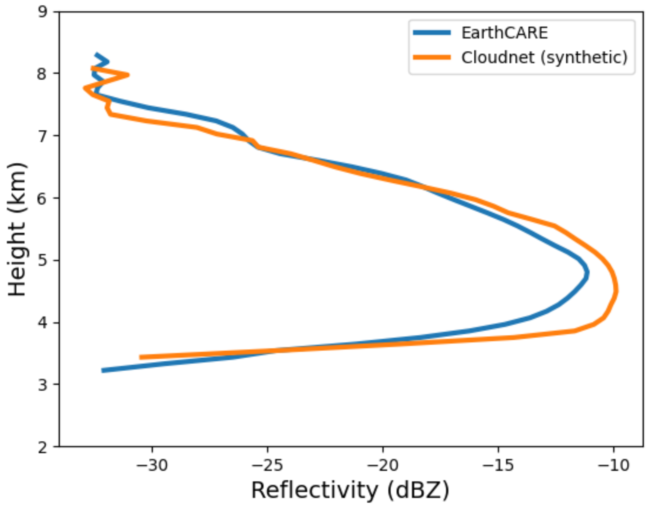
Cabauw 2024-06-18

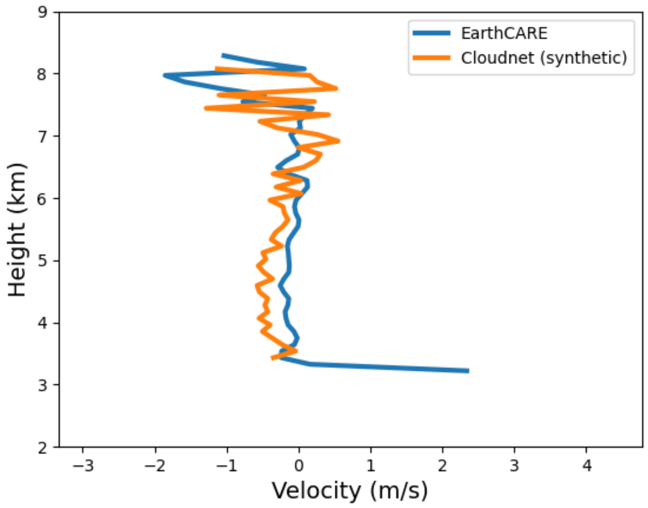


Ny-Ålesund 2025-01-15



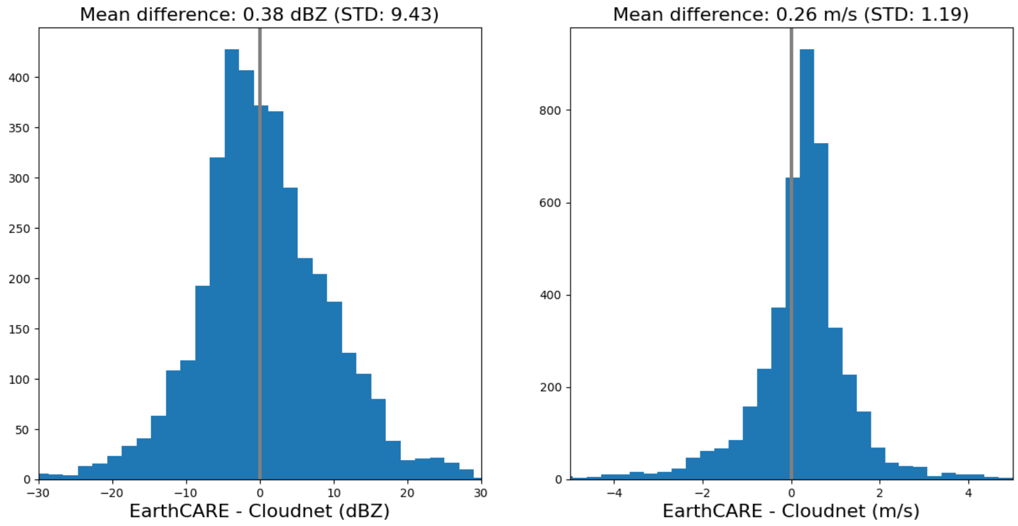
Ny-Ålesund 2025-01-15 mean profiles





Height > 2 km

Differences (all matching heights)



Overpasses < 50 km (n =111)

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

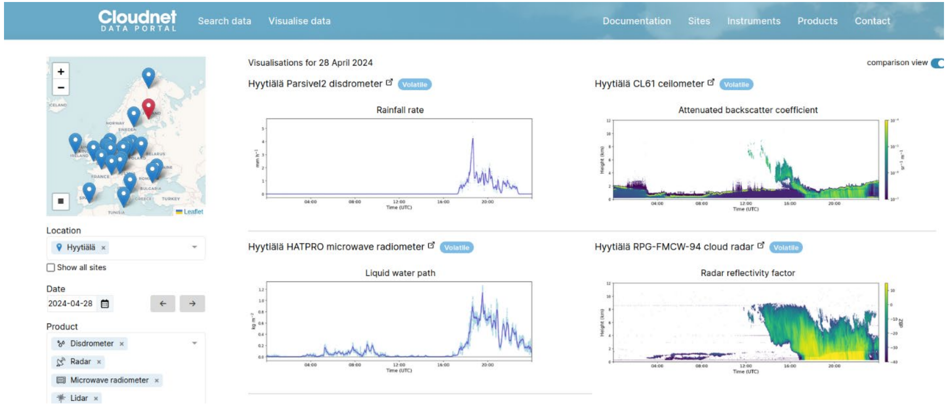
For RPG 94 GHz only

Sub-orbital to orbital tool operational

- In real time
- All sites

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

- Also use to investigate impact of long pulse on cloud boundaries over larger ground-based datasets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Search data
Visualise data
Documentation
Sites
Instruments
Products
Contact
Visualisations for 28 April 2024
comparison view
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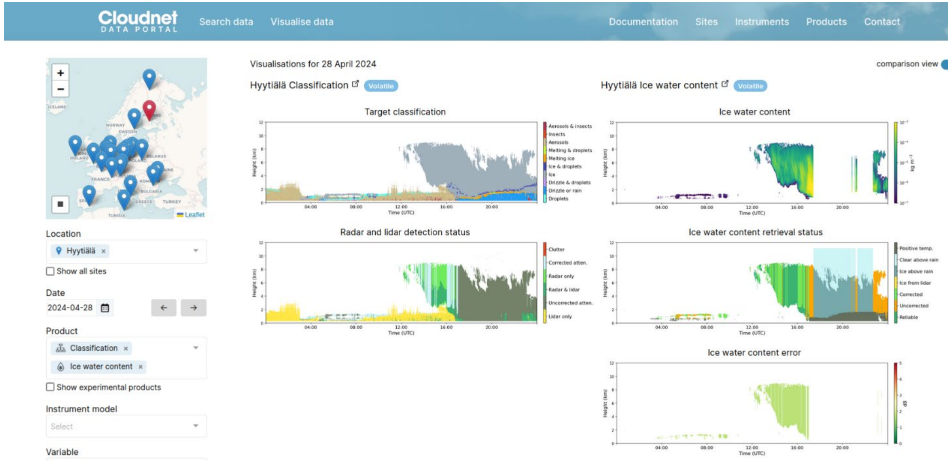
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Search data
Visualise data
Documentation
Sites
Instruments
Products
Contact
Visualisations for 28 April 2024
comparison view
Hyytiälä Classification
Volatile
Target classification
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Volatile
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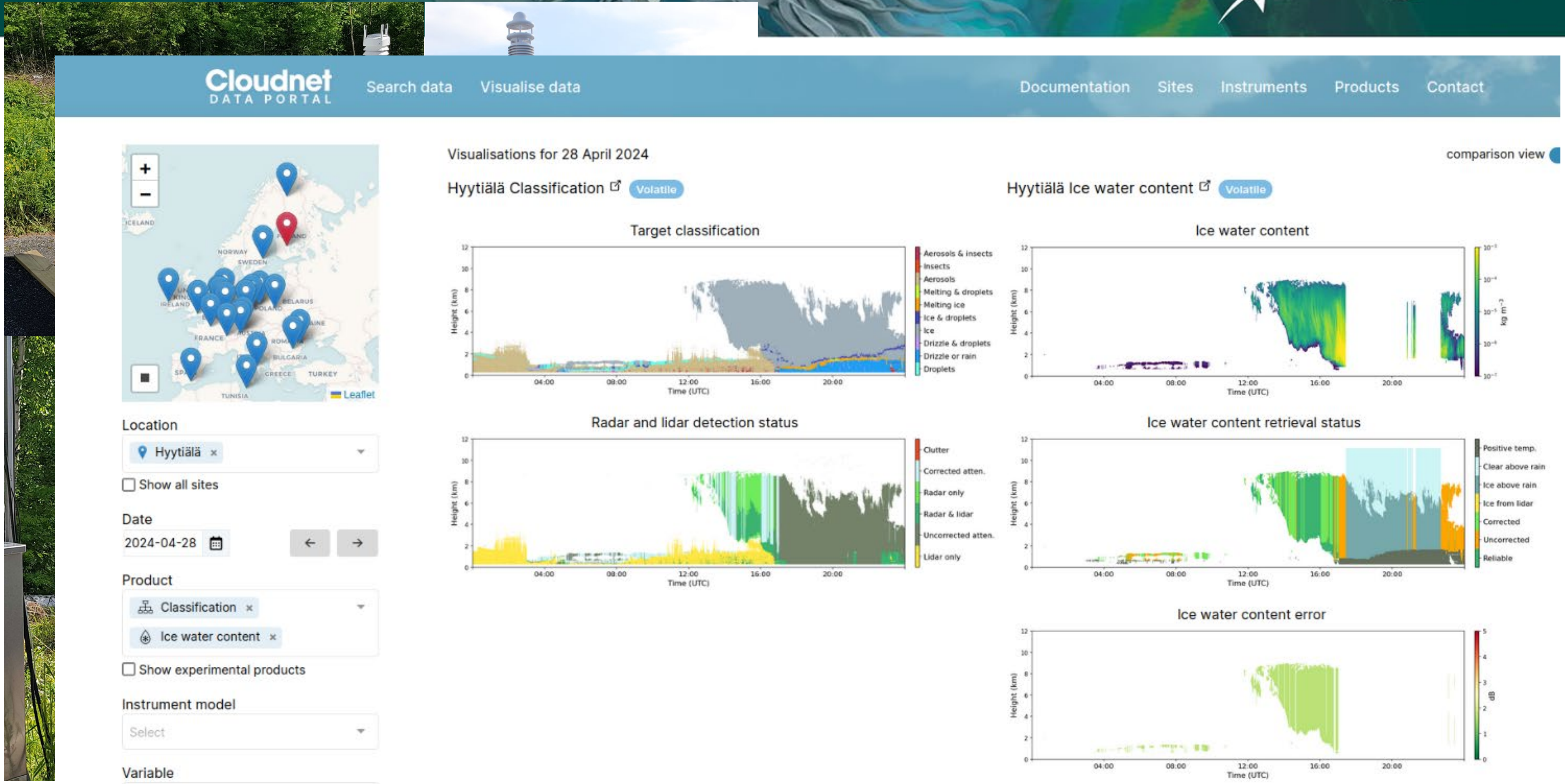
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DATA PORTAL
Search data
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Sites
Instruments
Products
Contact
Visualisations for 28 April 2024
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Aerosols & insects
Insects
Aerosols
Melting & droplets
Melting ice
Ice & droplets
Ice
Drizzle & droplets
Drizzle or rain
Droplets
Clutter
Corrected atten.
Radar only
Radar & lidar
Uncorrected atten.
Lidar only
Positive temp.
Clear above rain
Ice above rain
Ice from lidar
Corrected
Uncorrected
Reliable
Height (km)
Time (UTC)
Location
Hyytiälä
Show all sites
Date
2024-04-28
Product
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Ice water content
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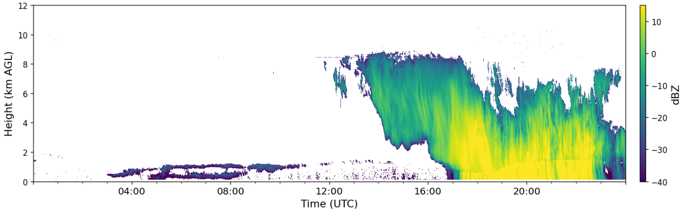
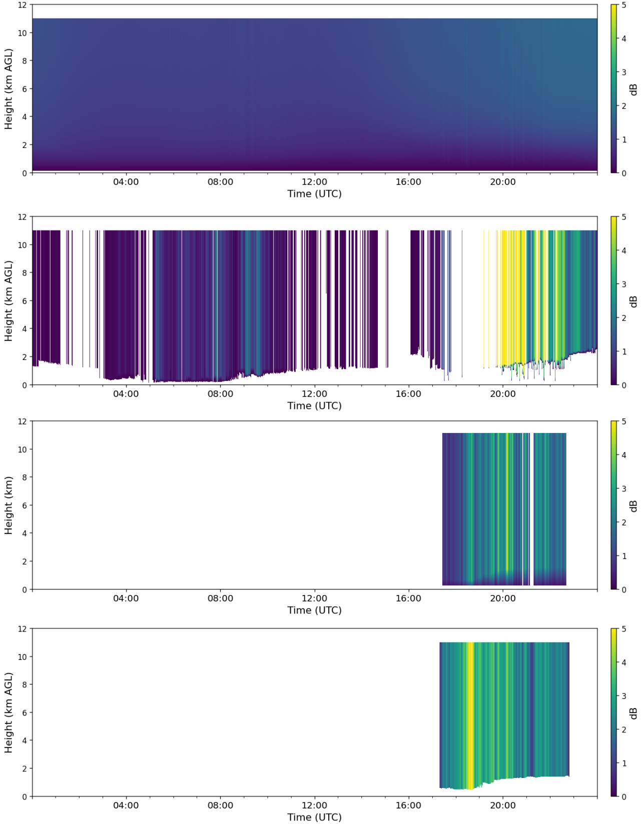
Variable
Leaflet

Attenuation correction

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



Hyytiälä 2024-04-28

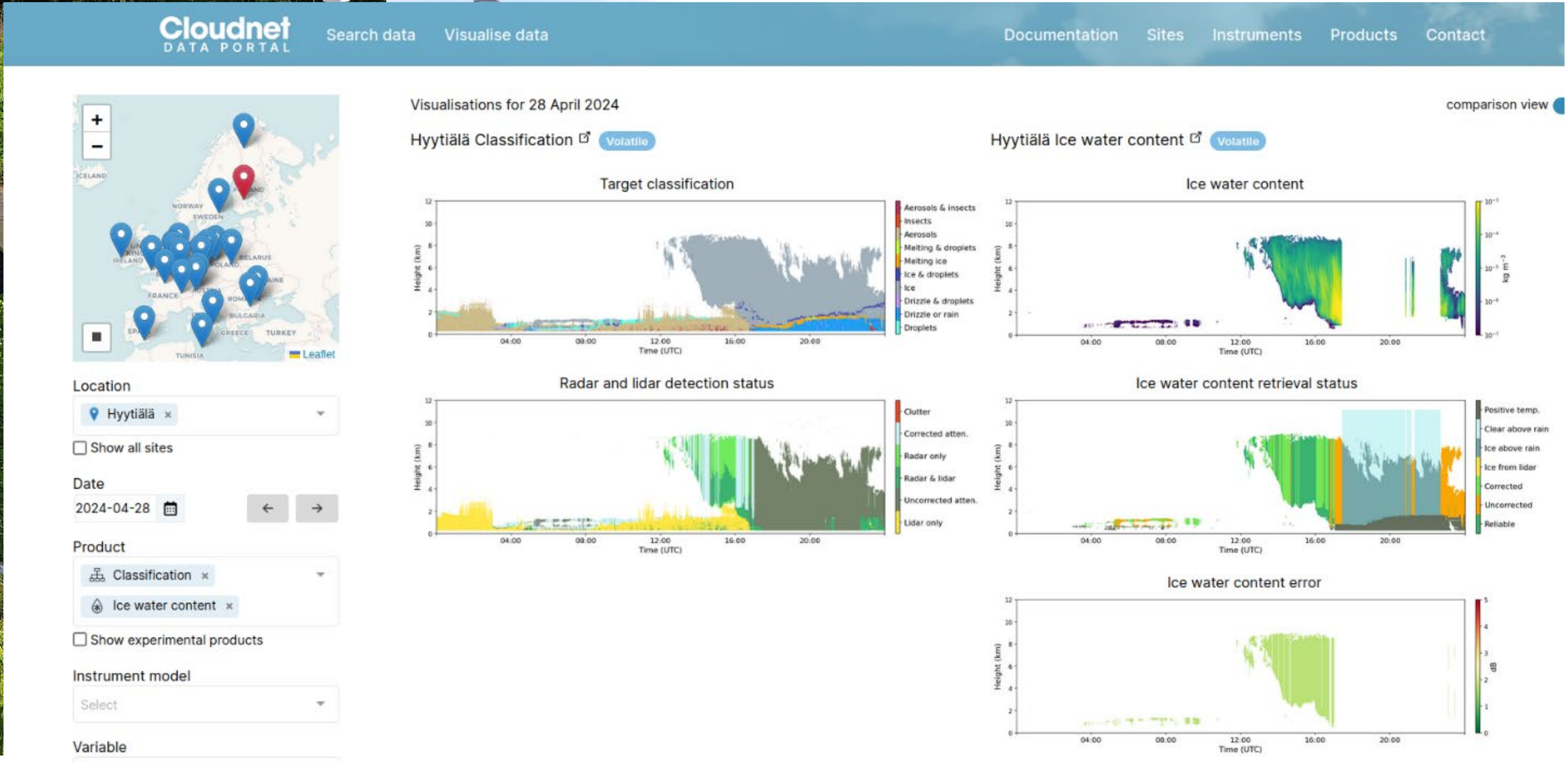


gas

liquid

rain

melting layer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Search data
Visualise data
Documentation
Sites
Instruments
Products
Contact
Visualisations for 28 April 2024
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Ice above rain
Ice from lidar
Corrected
Uncorrected
Reliable
Ice water content error
Height (km)
Time (UTC)
Location
Hyytiälä
Show all sites
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Product
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Variable
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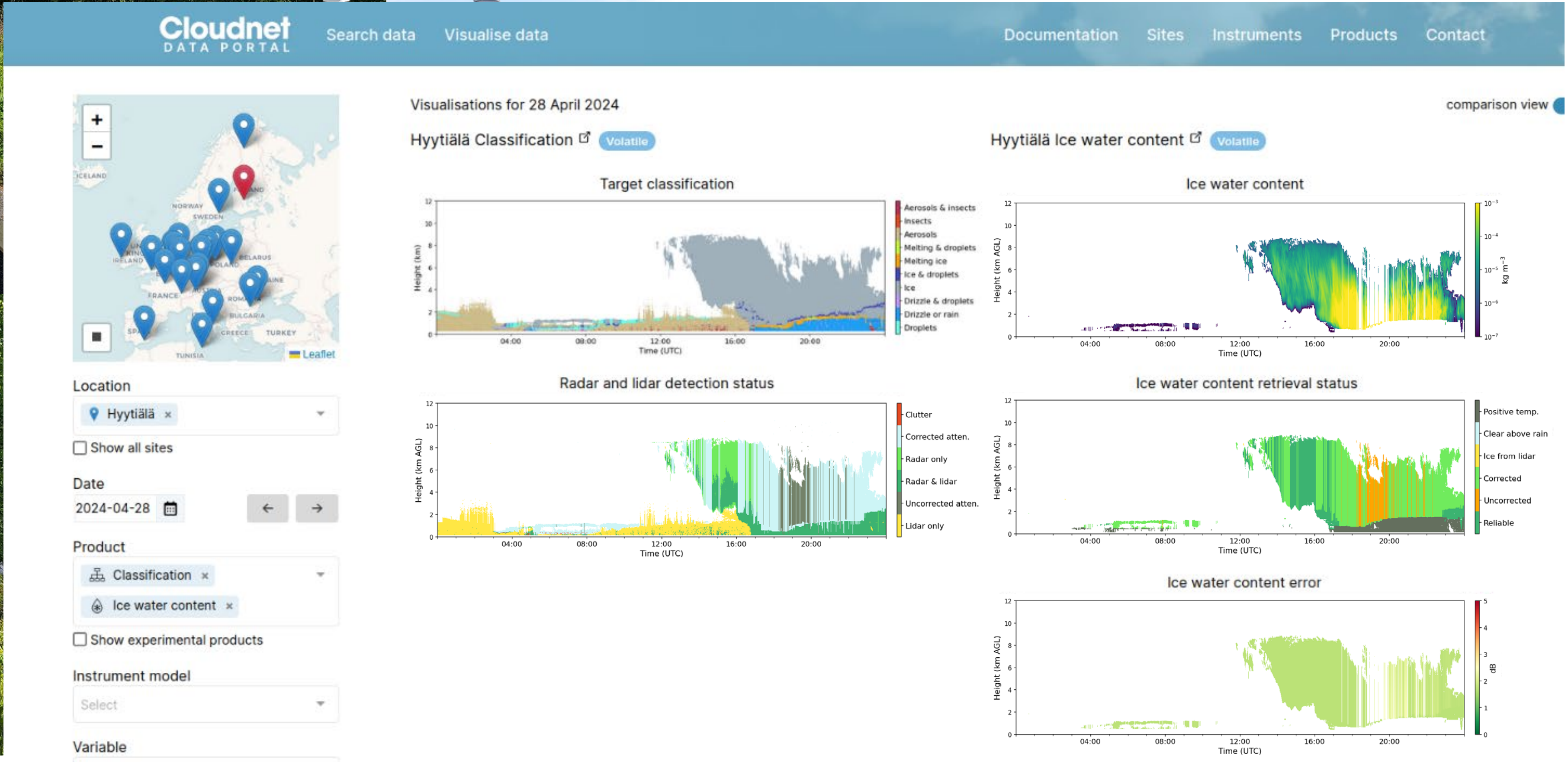

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Search data
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Drizzle or rain
Droplets
Time (UTC)
Ice water content
Height (km AGL)
kg m⁻³
Radar and lidar detection status
Clutter
Corrected atten.
Radar only
Radar & lidar
Uncorrected atten.
Lidar only
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Ground-based radars in Cloudnet

Active cloud radars as of March 2025:

14 RPG FMCW 94 Ghz

11 MIRA 35 GHz

3 RPG FMCW 35 GHz

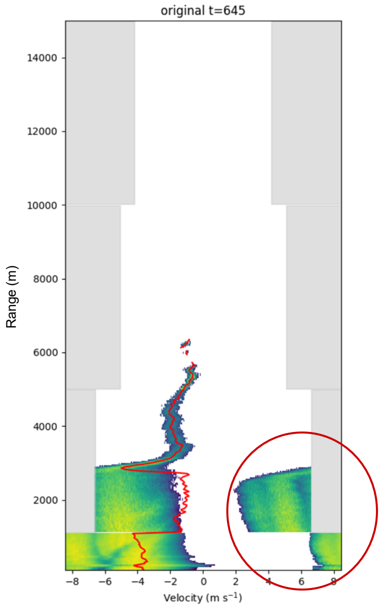
2 BASTA 95 GHz

1 MIRA 10 GHz

Folding in ground-based measurements

RPG-FMCW-94

Doppler spectra with mean velocity



folding!

Chirp 4: v_{ny} = 4.1 m s^{-1}

Chirp 3: v_{ny} = 4.9 m s^{-1}

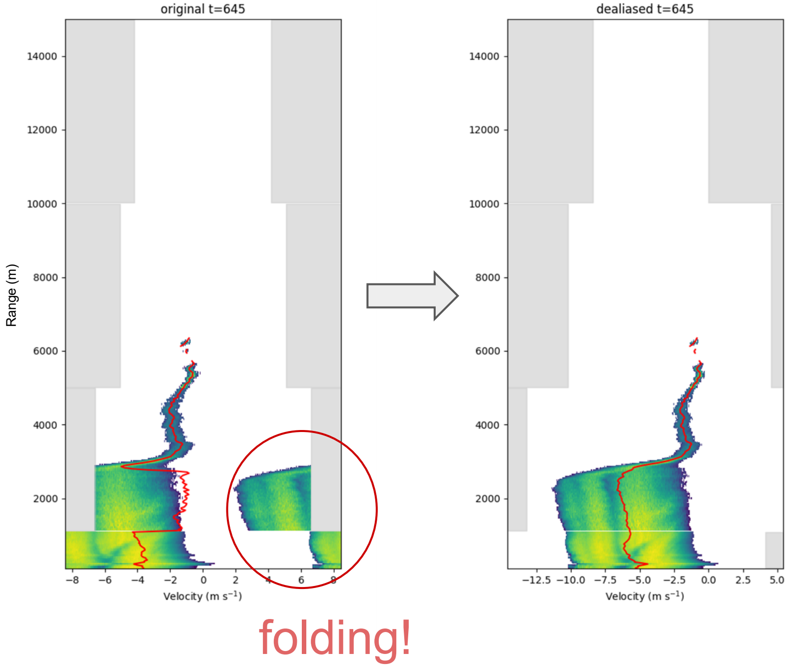
Chirp 2: v_{ny} = 6.1 m s^{-1}

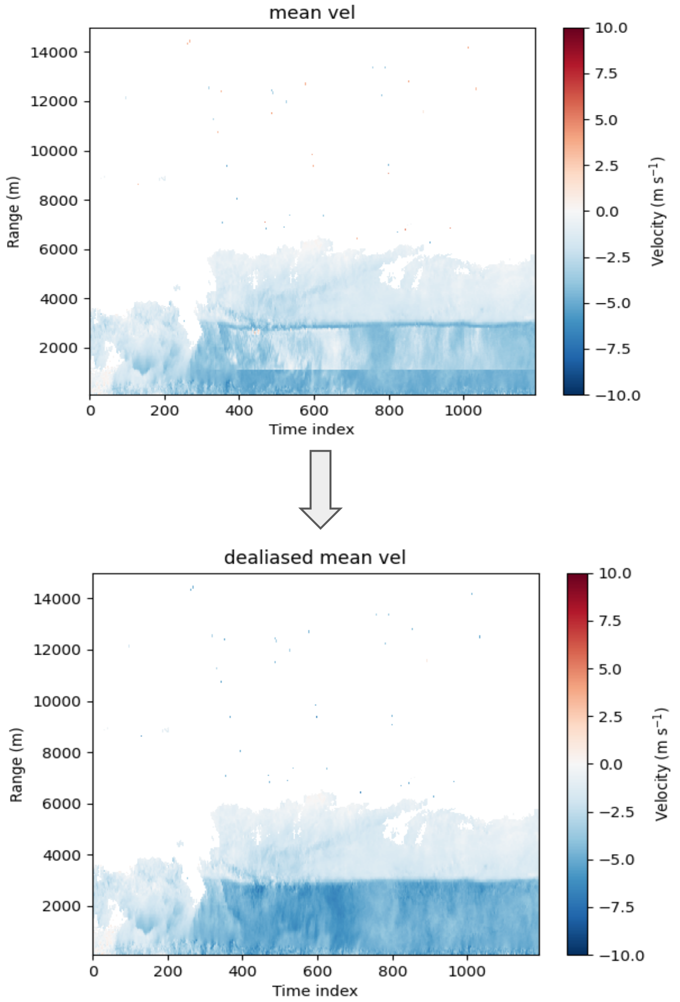
Chirp 1: v_{ny} = 8.4 m s^{-1}

Folding in ground-based measurem

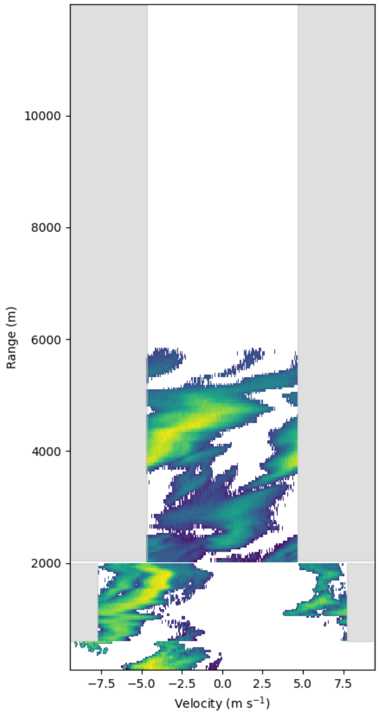
RPG-FMCW-94

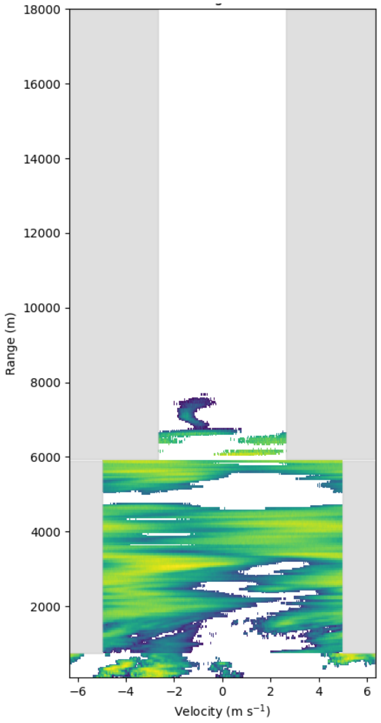
Doppler spectra with mean velocity





Folding: tricky cases





Conclusion

- 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 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