

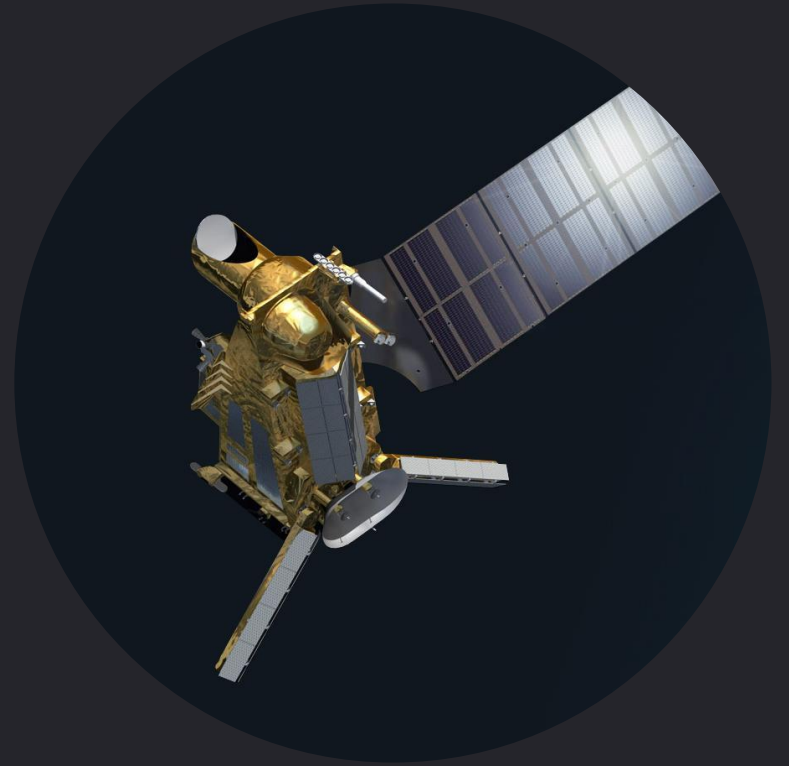
The Ice Cloud Imager: new retrieval possibilities

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Patrick Eriksson¹, Hanna Hallborn¹

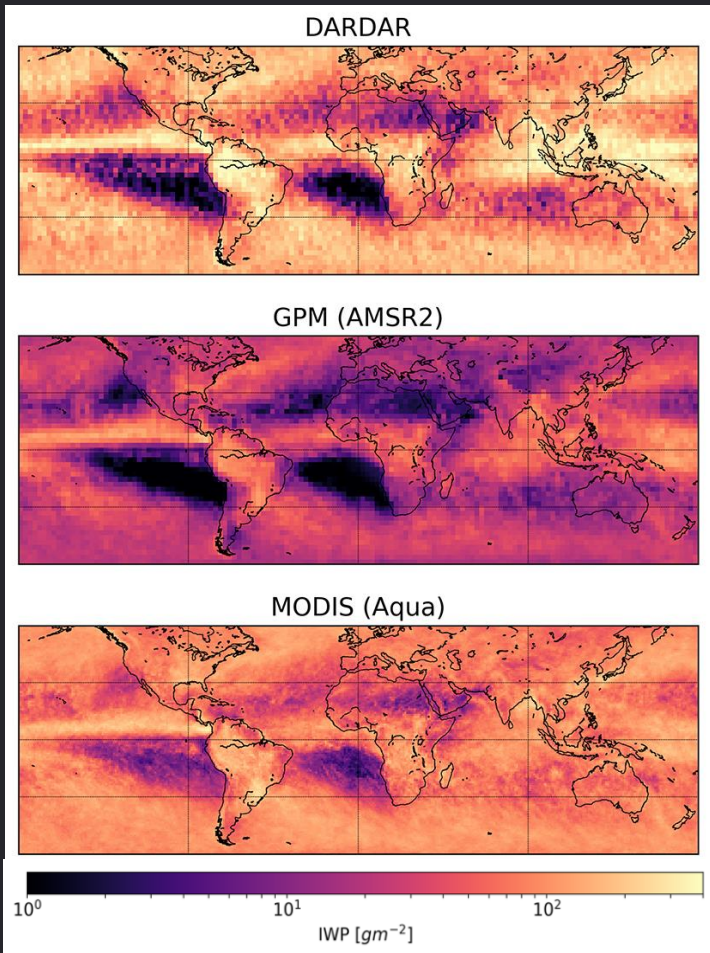
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Ice mass in the atmosphere



I Duncan, P Eriksson (2018)

DARDAR

CloudSat, CALIPSO
Radar + lidar

GPM

Microwave

MODIS

Visible + infrared

There are significant discrepancies between datasets.

Why?

One reason is the lack of satellite observations suited to measure ice hydrometeors

The Ice Cloud Imager (ICI)

EUMETSAT'S Polar System – Second Generation

ICI on METOP-SG

- Microwave and sub-mm (183 – 664 GHz).
- V and H polarised channels.
- Close to global coverage on daily basis.
- Swath width: ~1500km
- Footprint: 20 km x 8.5 km

Launch scheduled for early 2026.



Image copyright: EUMETSAT

Retrieval product

Variables: Ice water path (IWP), mean mass height (Zm), mean mass diameter (Dm).

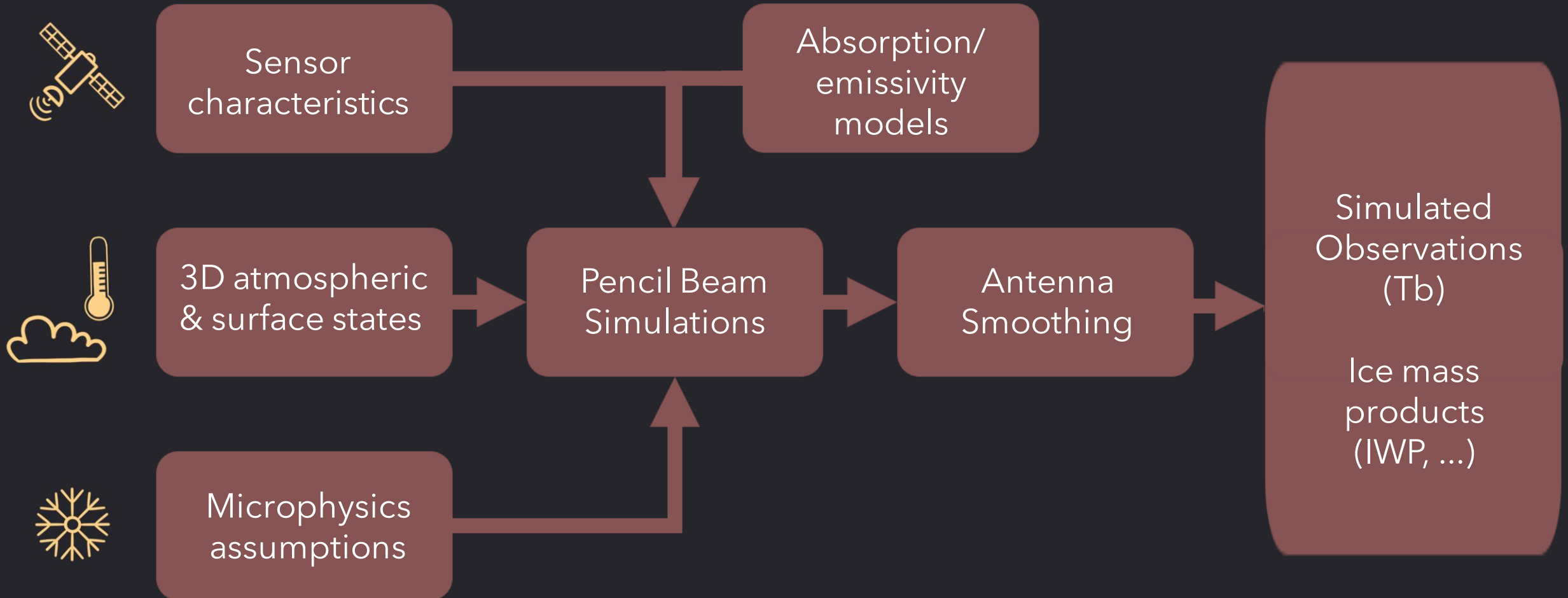


The retrieval database:

- Empirical not possible - no sub-mm observations.
- Need **simulated** observations.

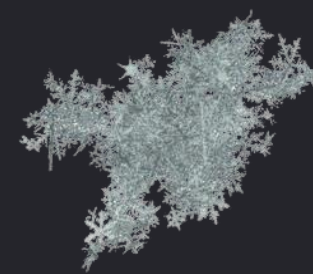
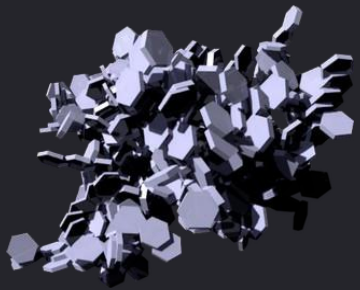
Database to be used operationally for ICI retrievals at EUMETSAT.

Simulation framework



Database generation - Microphysics

6 hydrometeor models from ARTS scattering database:



ARTS aggregates

Ice

Snow

Graupel

Each particle model includes:

Habit, PSD, occurrence probability, and a **scaling factor to mimic azimuthal orientation** (aARO factor).

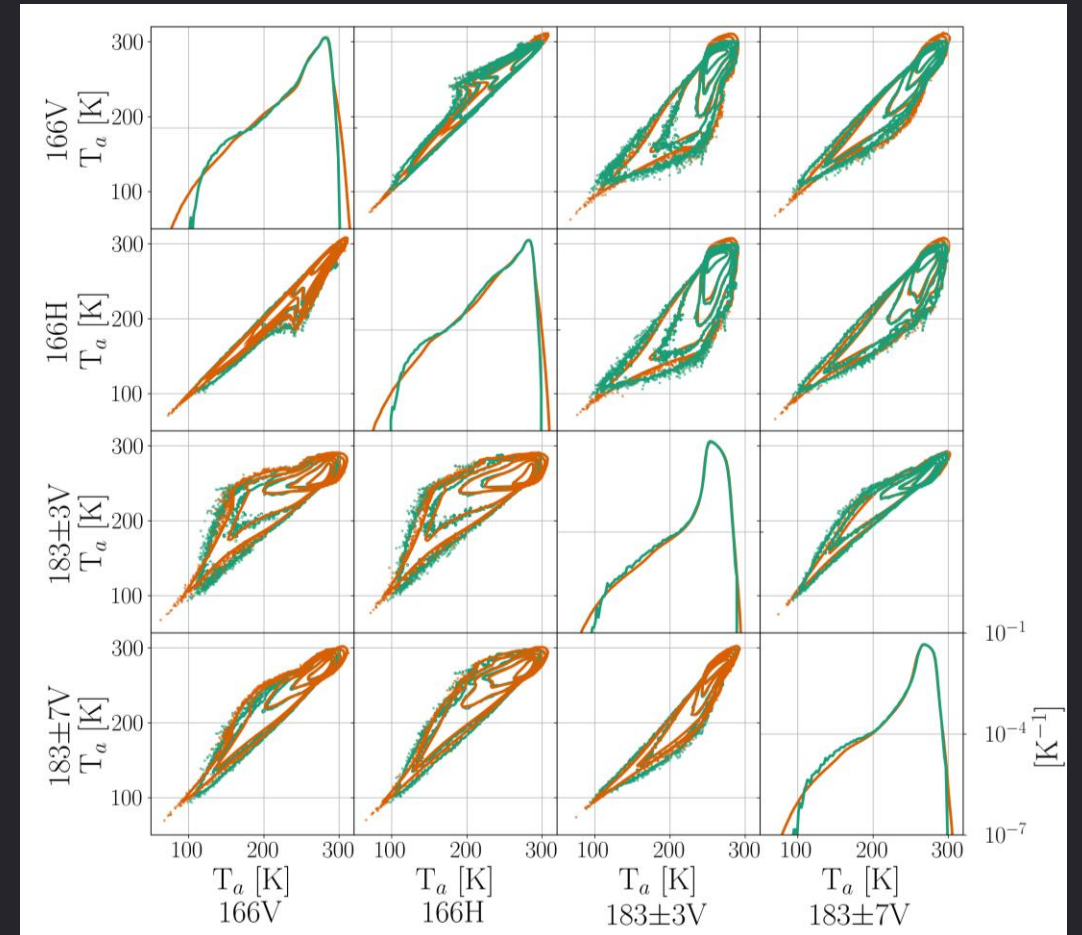
Validation: simulated radiances

Comparison of simulations of GMP Microwave Imager (GMI) and real GMI observations.

- Overlap with ICI channels
- Both V and H polarised channels available

Simulated: green

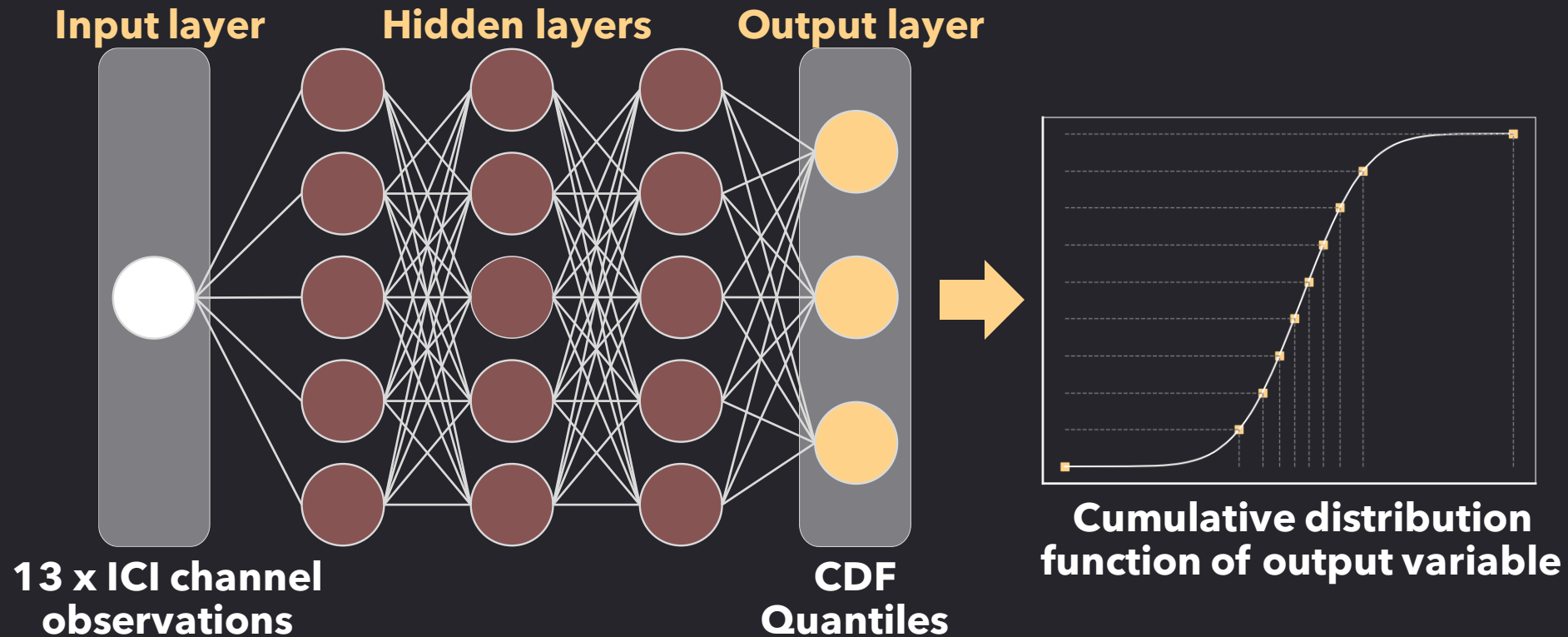
Observed: orange



Quantile Regression Neural Networks

Output: Probabilistic estimates suited for ill-posed problem.

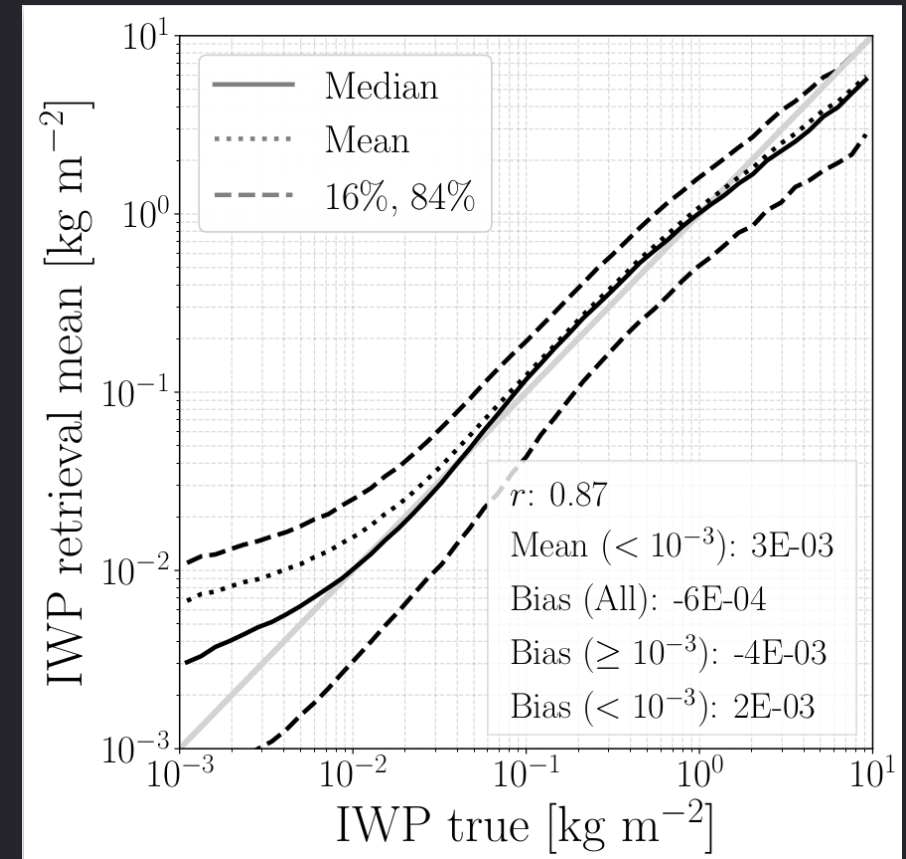
Allows for non-Gaussian statistics.



Database retrieval performance

Sensitive to $10 \text{ g/m}^2 \leq \text{IWP} \leq 10 \text{ kg/m}^2$

Retrieved IWP (mean of dist.)

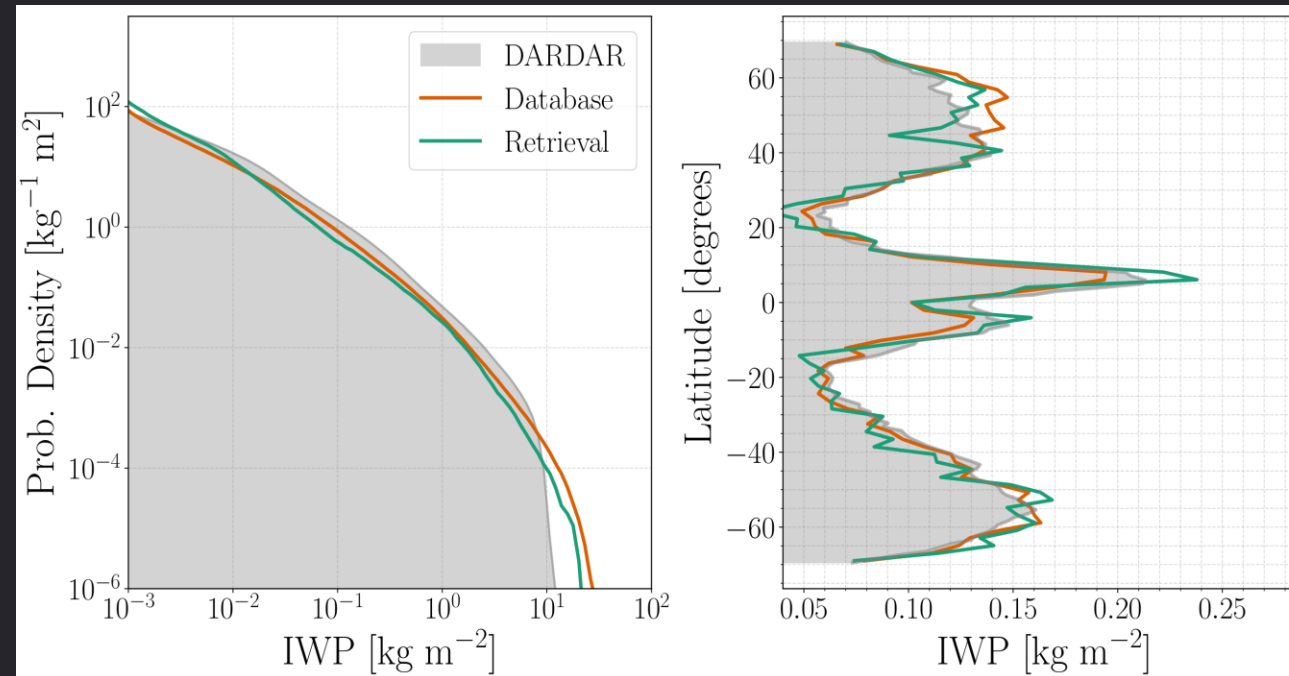


Database retrieval performance

Aims: Database **statistically consistent** with reality.

Retrievals consistent with database.

Distribution of retrieved IWP



ICI level-2 product



The Ice Cloud Imager: retrieval of frozen water column properties

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Further retrieval possibilities

Radar and lidar are the best sources of information on the vertical distribution of ice.

Can ICI offer a complimentary source of data?

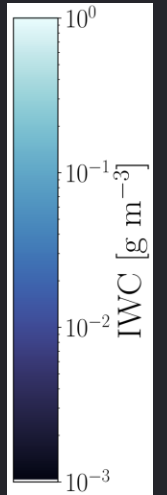
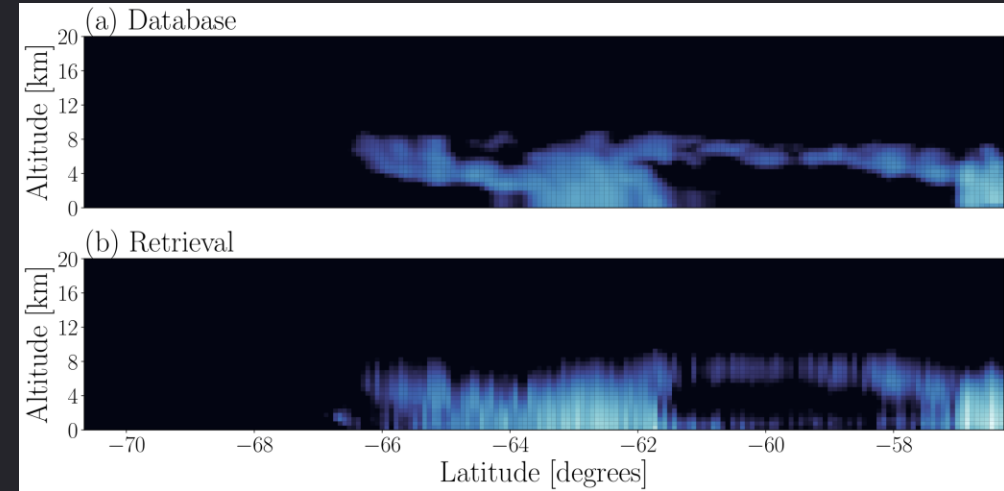
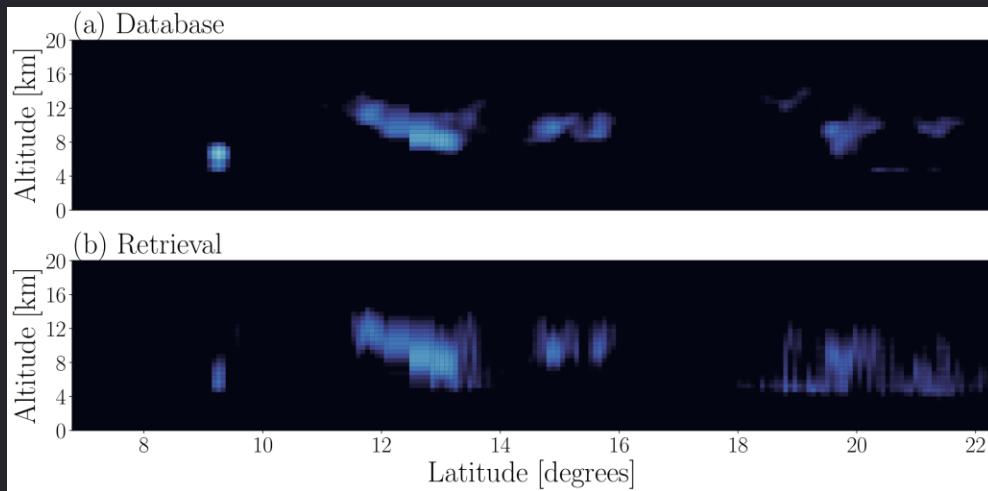
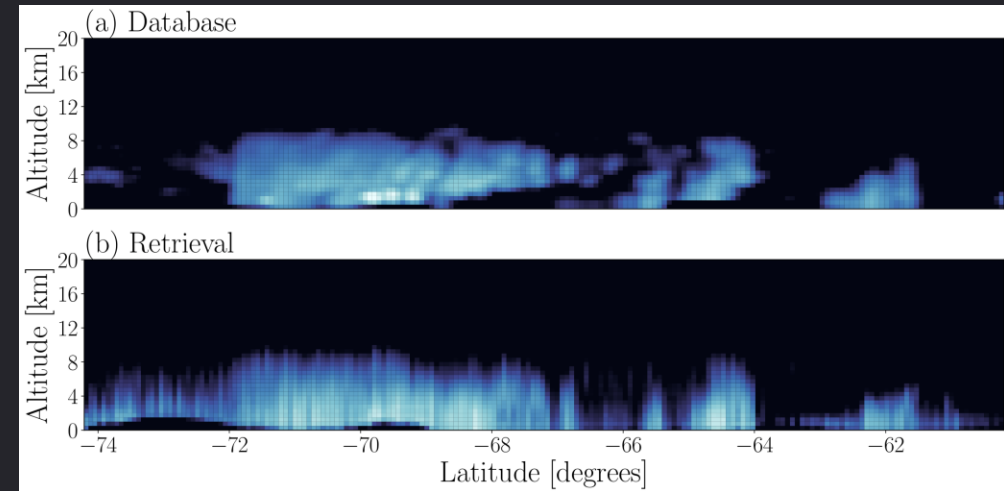
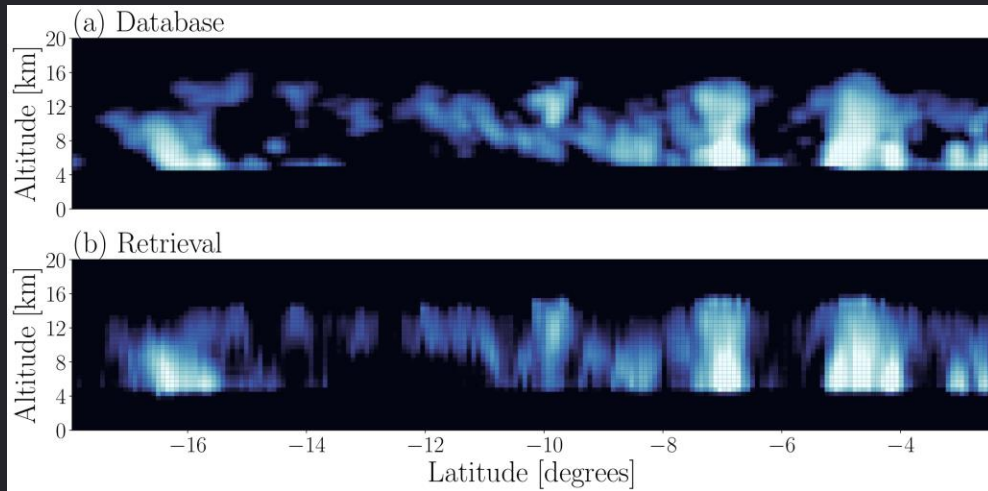
EarthCARE

- ✓ Good vertical resolution
- ✗ Short lifespan (~3 years)
- ✗ Narrow swath

ICI

- ✗ Poorer resolution
- ✓ Long lifespan (~22 years)
- ✓ Wider swath
- ✓ 13 channels

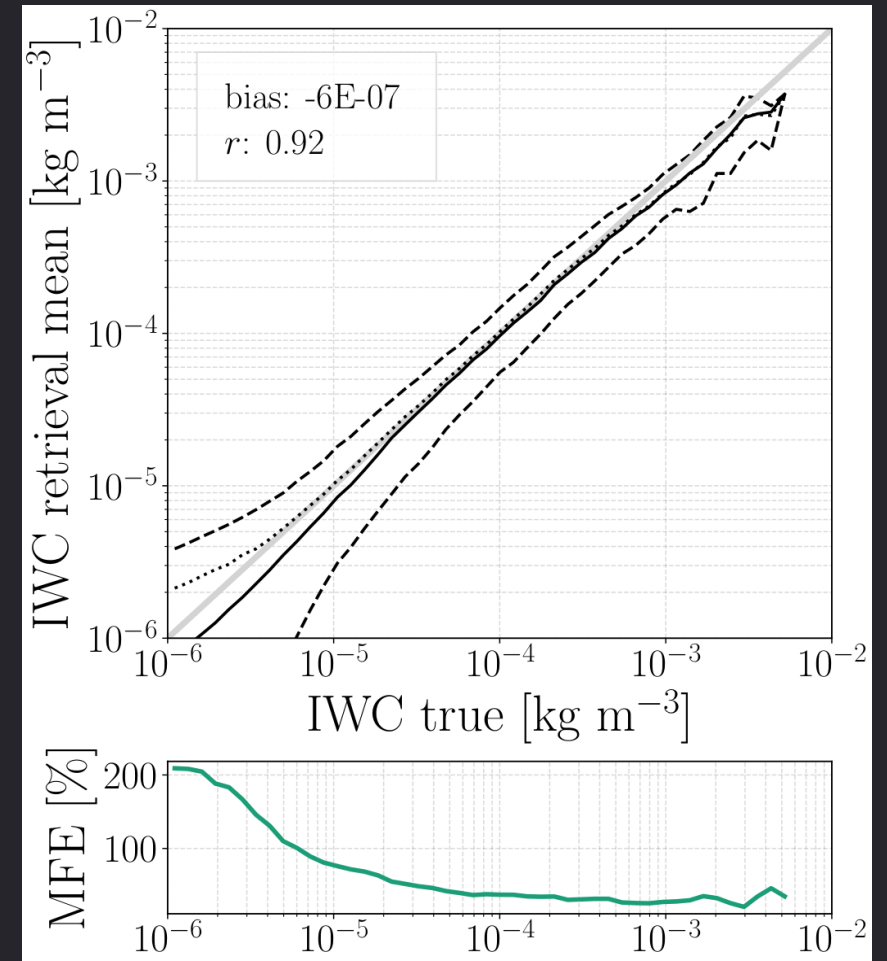
Retrieval of ice water content



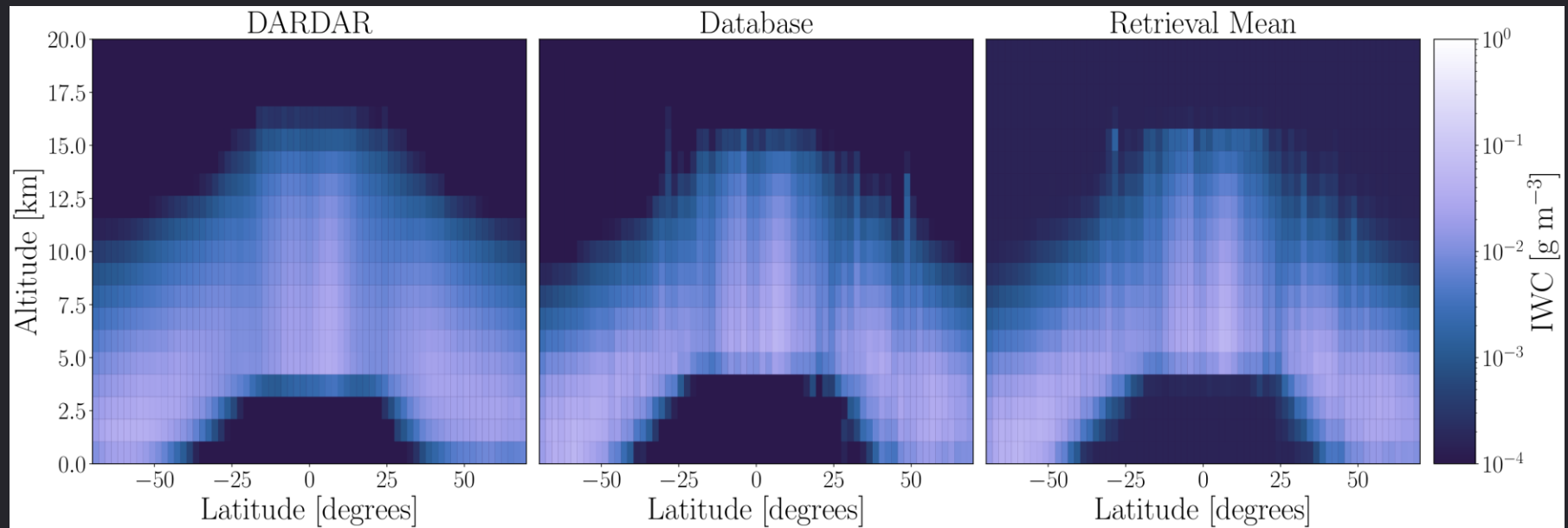
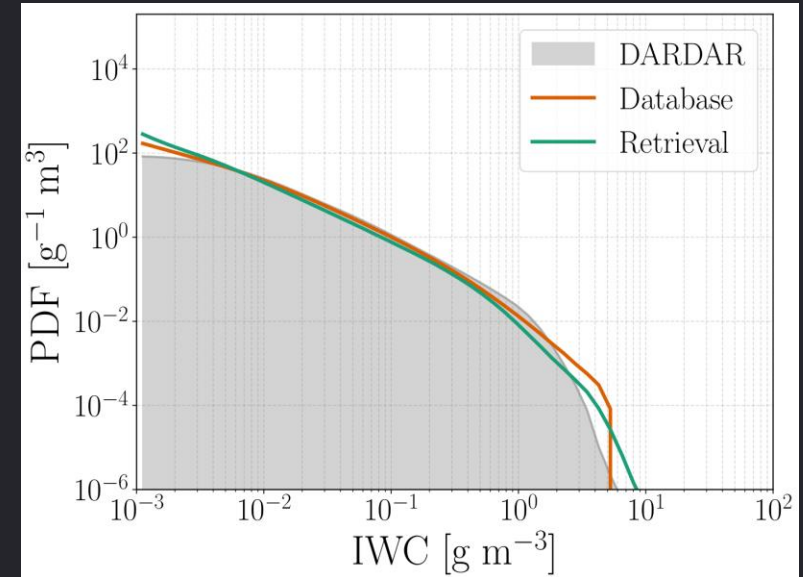
Retrieval of ice water content

Retrieved IWC at altitude of 8.75 km.

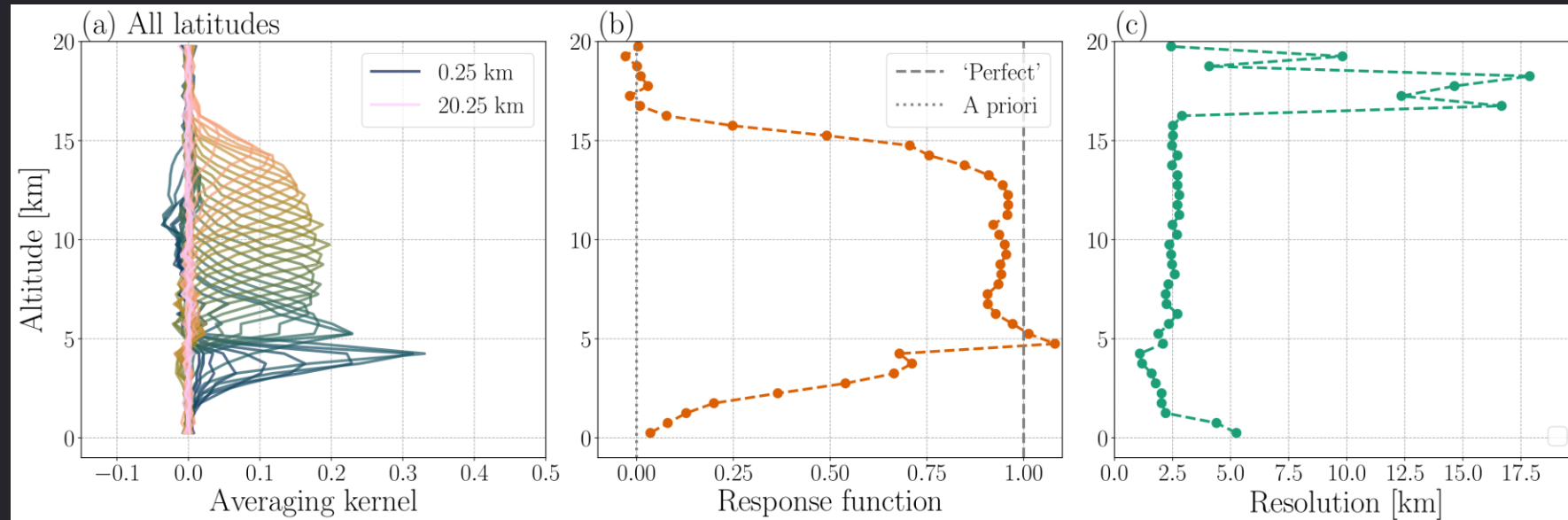
$$\text{MFE} = \text{median} \left(\exp_{10} \left(\left| \log_{10} \frac{x_{\text{retrieved}}}{x_{\text{true}}} \right| \right) - 1 \right)$$



Retrieval of IWC



IWC retrieval resolution



$$\hat{\mathbf{x}} = \mathbf{x}_a + \mathbf{A}(\mathbf{x} - \mathbf{x}_a),$$

$$\mathbf{A} = \left((\Delta\mathbf{X}\Delta\mathbf{X}^T)^{-1} \Delta\mathbf{X}\Delta\hat{\mathbf{X}}^T \right)^T$$

Resolution - FWHM of the averaging kernels.

$$\Delta\mathbf{X} = [\mathbf{x}_1 - \mathbf{x}_a, \mathbf{x}_2 - \mathbf{x}_a, \dots, \mathbf{x}_n - \mathbf{x}_a]$$

$$\Delta\hat{\mathbf{X}} = [\hat{\mathbf{x}}_1 - \mathbf{x}_a, \hat{\mathbf{x}}_2 - \mathbf{x}_a, \dots, \hat{\mathbf{x}}_n - \mathbf{x}_a]$$

Further retrieval possibilities: aARO

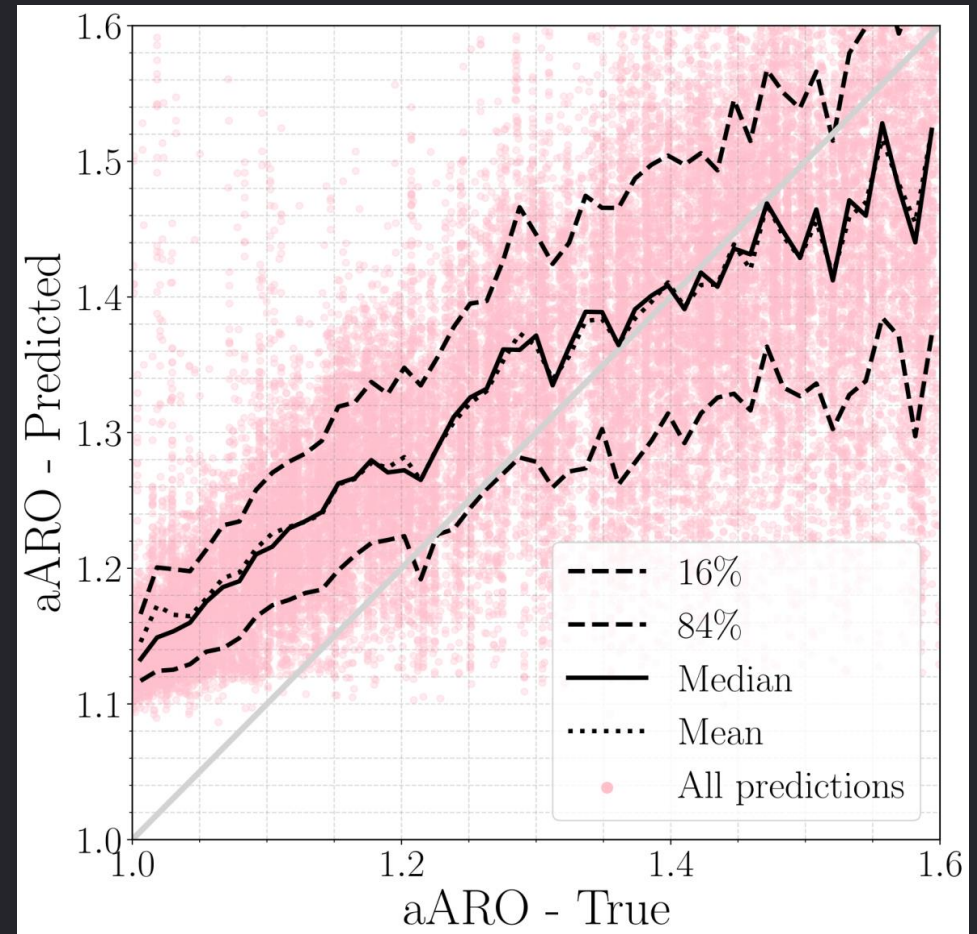
Azimuthal orientation scheme developed by Barlakas et al. (2021).

aARO factor - Scaling factor applied to the extinction values obtained from assumption of totally random orientation.

AARO factor is randomly selected from a predetermined range (e.g. 1.0 - 1.6).

Preliminary result.

Short training of a neural network, only for high IWP cases.



Summary

- Our retrieval database, containing the most detailed simulations to-date, will be used within operational retrievals at EUMETSAT from day-one of ICI launch.
- Simulated observations are consistent with reality.
- Reliable retrievals of ice water path are possible, and statistically consistent with DARDAR.
- Possible to retrieve ice water content with ICI observations, and potentially additional variables (aARO).

