# All-sky simulations of the Ice Cloud Imager (ICI)

## With focus on particle models

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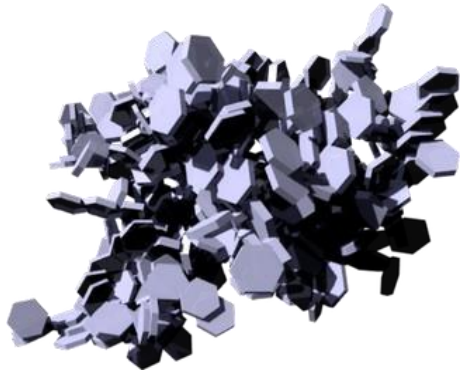


# The Ice Cloud Imager (ICI) instrument

Channels: 183-664 GHz

Conical scanner, 15 km footprint

Launch: 2026?


Copyright: EUMETSAT

λ < 1 mm

**Entering a new regime:** sub-mm wavelengths

Suited to observe ice hydrometeors

Main usage of ICI data:

- Assimilation of radiances
- Stand-alone retrievals

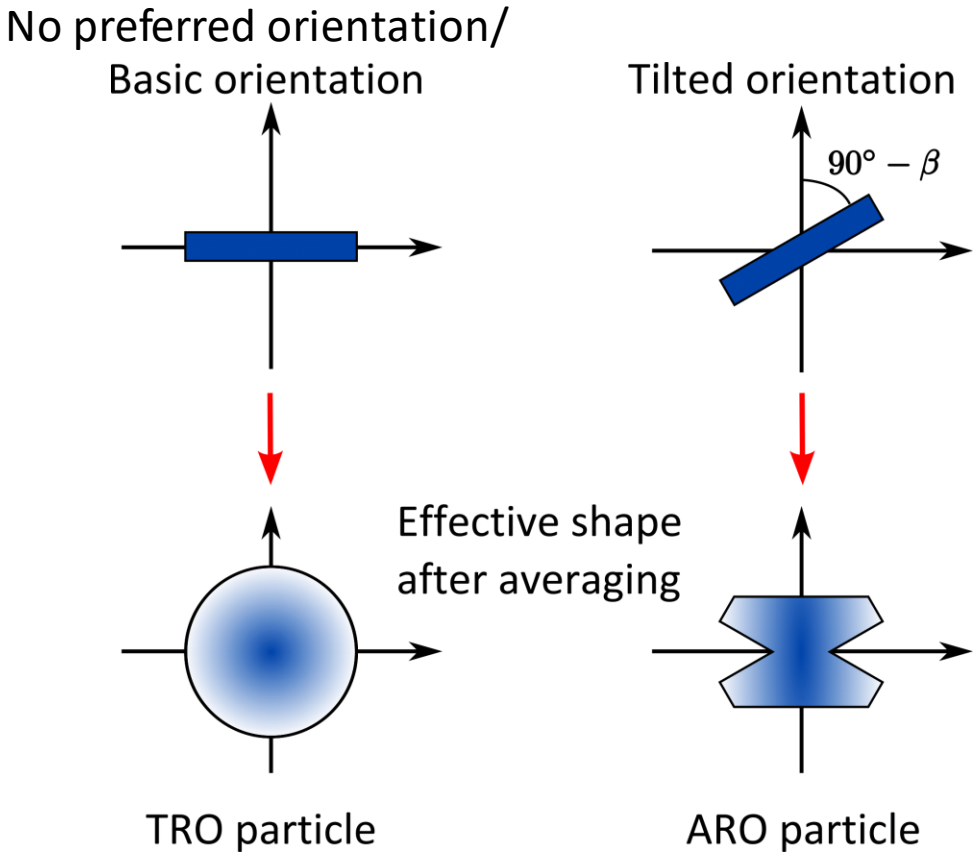
Need to investigate and develop radiative transfer at sub-mm wavelengths!

# Detailed particle models needed

## From clear-sky to all-sky simulations

Representation of hydrometeors need:

- Particle size distribution
  - e.g., F07, MGD, …
- Particle shape (habit)
  - e.g., plates, columns, aggregates, ...
- Particle orientation
  - Totally random orientation (TRO)
  - Azimuthally random orientation (ARO)
- Single scattering properties

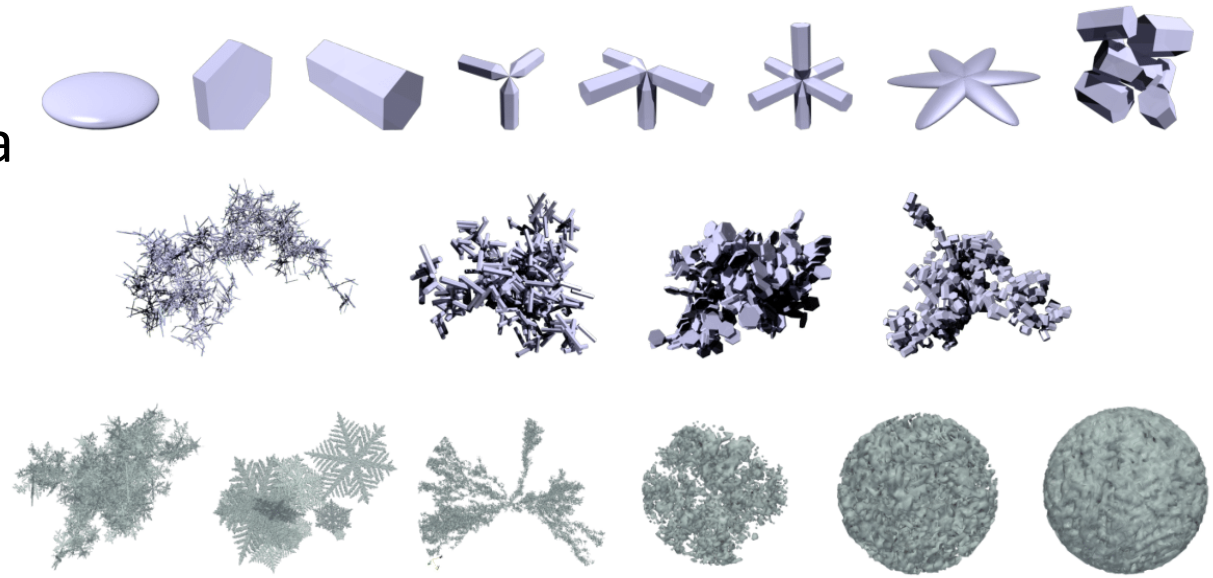



Brath et al., AMT, 2020

# ARTS Single scattering database

- 34 particle habits for TRO
- 2 particle habits for ARO
  - Heavy to generate and store the data
  - Not all solvers handle ARO
- > 30 sizes and 3 temperatures per habit
- Broad frequency coverage
  - Data supports sub-mm channels

Examples on shapes/habits for TRO



| Frequency coverage | Temperature coverage |
|---|---|
| 1 - 886 GHz | 190 – 270 K |

Eriksson et al., ESSD, 2018

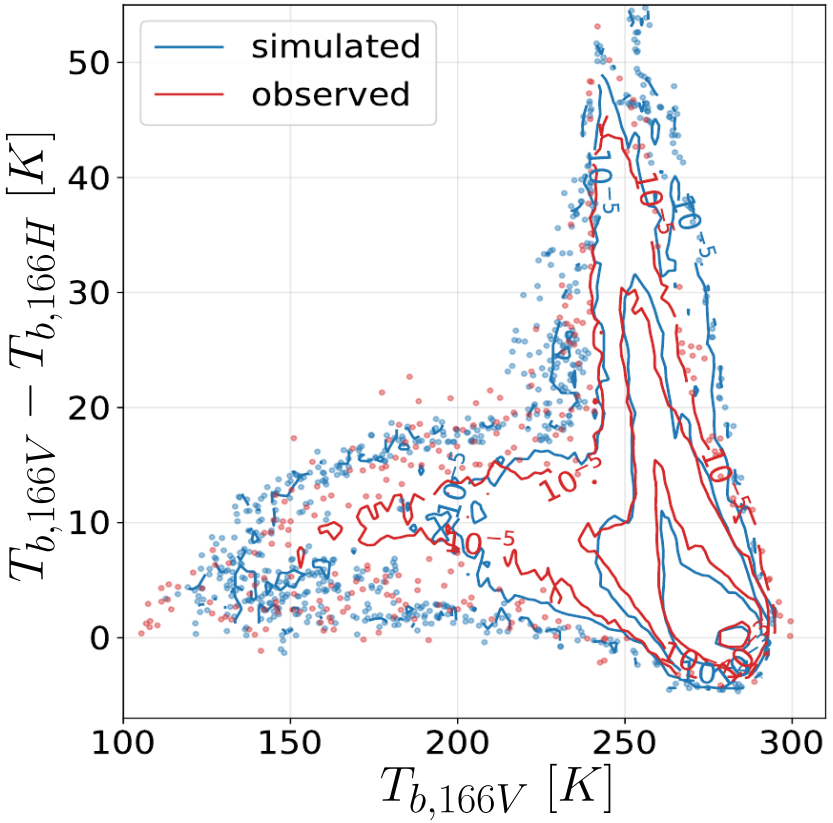
# Approximated azimuthally random orientation (aARO) scheme

General principle:

- Scaling of TRO radiances to approximate ARO effect on V and H polarisation
- Polarisation ratio (ρ) tuned to recreate observed polarisation signals

$$\rho = \frac{\tau_{ARO,H}}{\tau_{ARO,V}} = \frac{\tau_{TRO} \cdot (1+\alpha)}{\tau_{TRO} \cdot (1-\alpha)} = \frac{(1+\alpha)}{(1-\alpha)}$$

Polarisation signal of GMI 166 GHz




Barlakas et al., AMT, 2021
Kaur et al., Remote Sens., 2022

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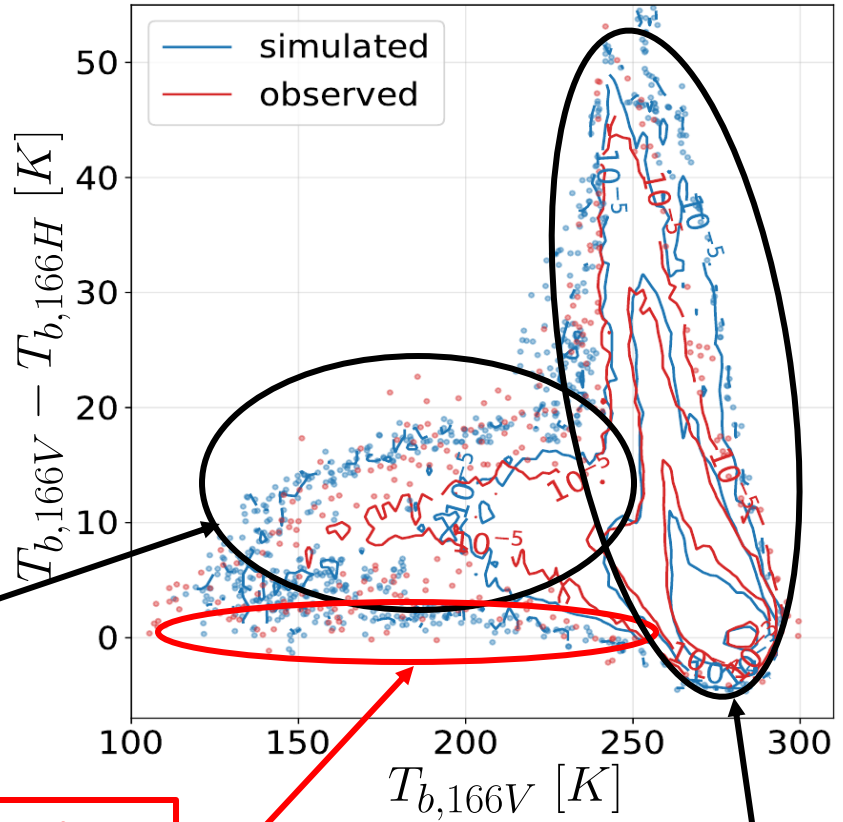



Polarisation signal due to oriented hydrometeors

Particles with no preferred orientation, i.e., TRO particles

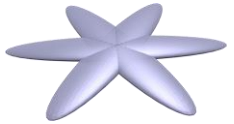
Polarisation signal due to surface impact

Barlakas et al., AMT, 2021
Kaur et al., Remote Sens., 2022

# Assimilation:
## contributions to community models

- ARTS single scattering database
  - Available for both RTTOV-SCATT and CRTM v3.0
  - Sub-mm region covered
  - Improved representation of aggregates

Evolution of snow habit in RTTOV-SCATT



Previous snow habit
Sector snowflake

New snow habit
Large plate aggregate

- Approximated ARO scheme
  - "Empirical scaling" in RTTOV-SCATT v13.0 (updated scheme in v13.2)
  - Fixed scaling factor, ρ = 1.4 (Barlakas et al.)
  - Oriented particles (without increased computational load)

Geer et al., AMT, 2020

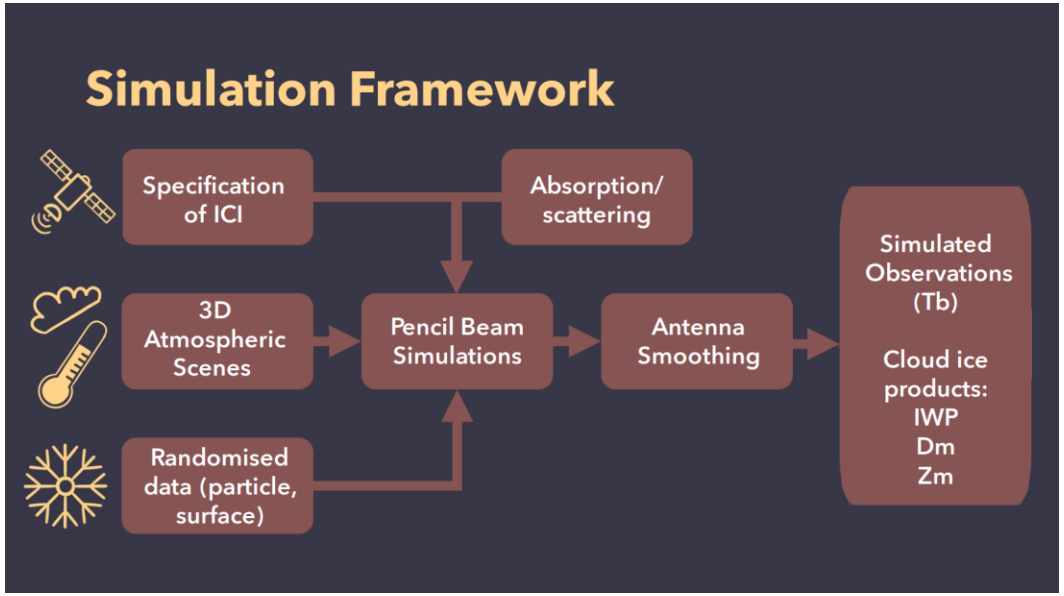
# Stand-alone retrievals:
## upcoming products

Chalmers research products:

- Machine learning based retrievals of Ice Water Path (IWP)
- Possible to get vertical profiles of Ice Water Content (IWC)?

EUMETSAT operational products for ICI:

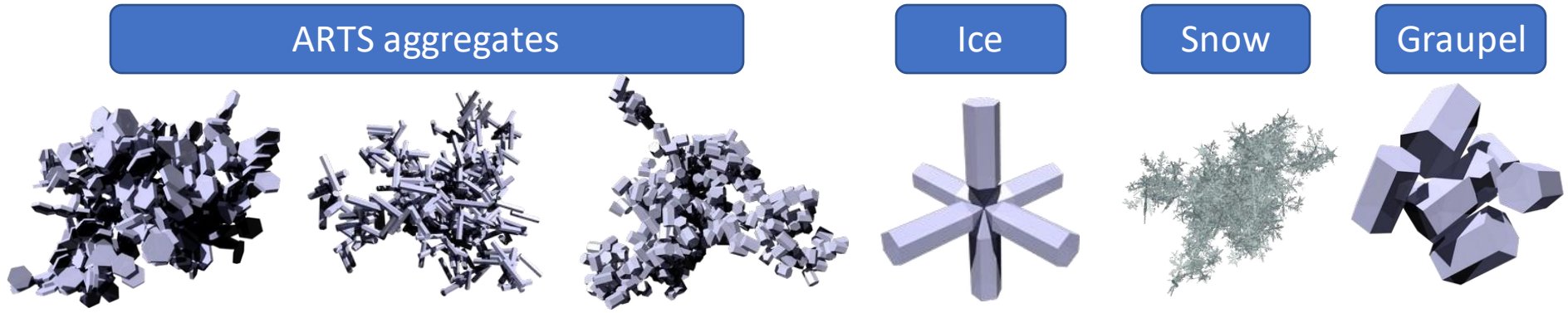
- IWP, mean cloud diameter, mean mass altitude
- Development of radiation database for the operational algorithm



# Stand-alone retrievals:
## randomized particle models

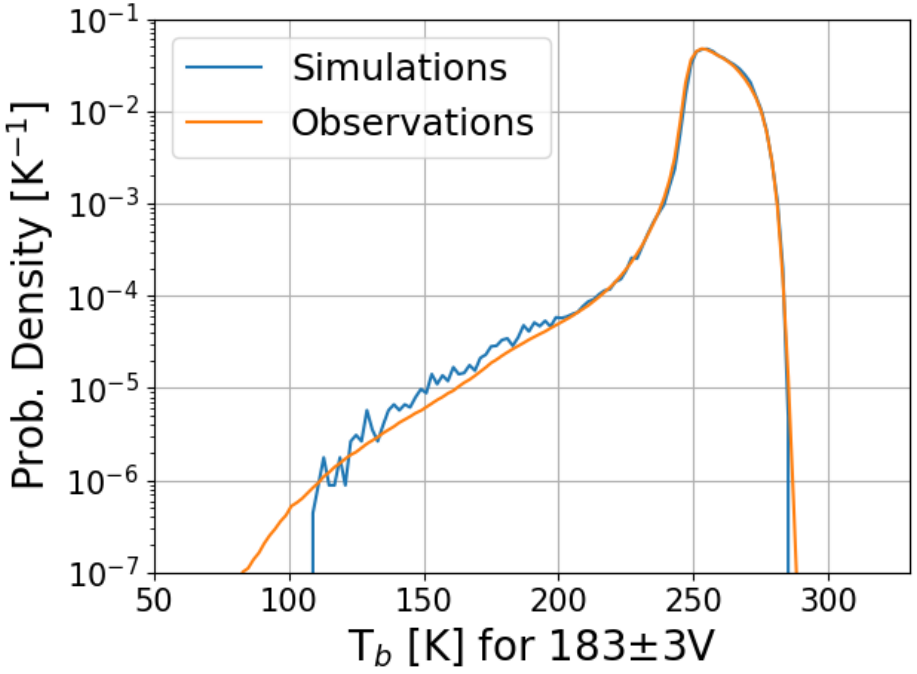
- Single scattering data from ARTS database
- aARO scheme with random scaling factor
- 6 particle models
  - Habit + PSD + aARO factor
- Randomly selected with probability, $p_i$

| Particle Model | Habit | PSD | aARO factor | $p_i$ |
|---|---|---|---|---|
| AA1 | Large plate aggregate | F07 - Tropics | 1 - 1.6 | 0.3 |
| AA2 | Large column aggregate | F07 - Tropics | 1 - 1.6 | 0.1 |
| AA3 | Large block aggregate | D14 | 1 - 1.6 | 0.13 |
| IWC | Six bullet rosette | D14 | 1 - 1.6 | 0.2 |
| Snow | Evans snow aggregate | F07 - Midlatitude | 1.4 - 1.6 | 0.1 |
| Graupel | Eight column aggregate | D14 | 1 - 1.2 | 0.17 |

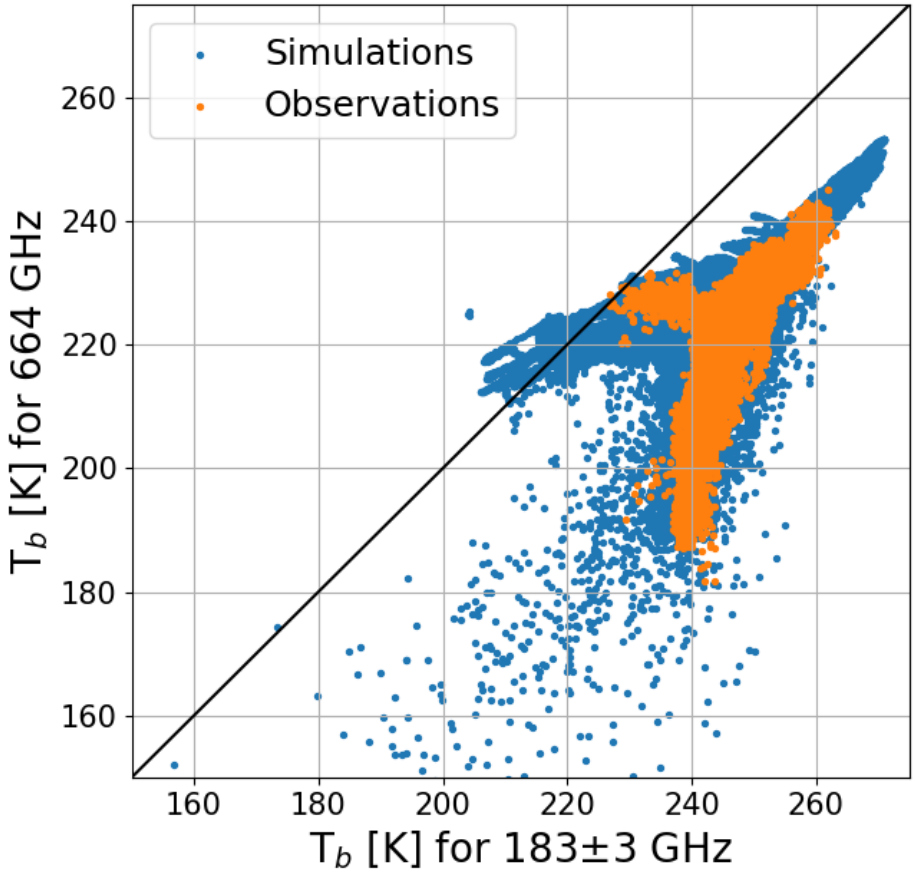


# Stand-alone retrievals:
## validation of forward model

Comparison to satellite observations (GMI)
- Simulations of conical scanner in MW-regime ok!




Comparison to airborne observations (ISMAR)
- Sub-mm (664 GHz) features captured



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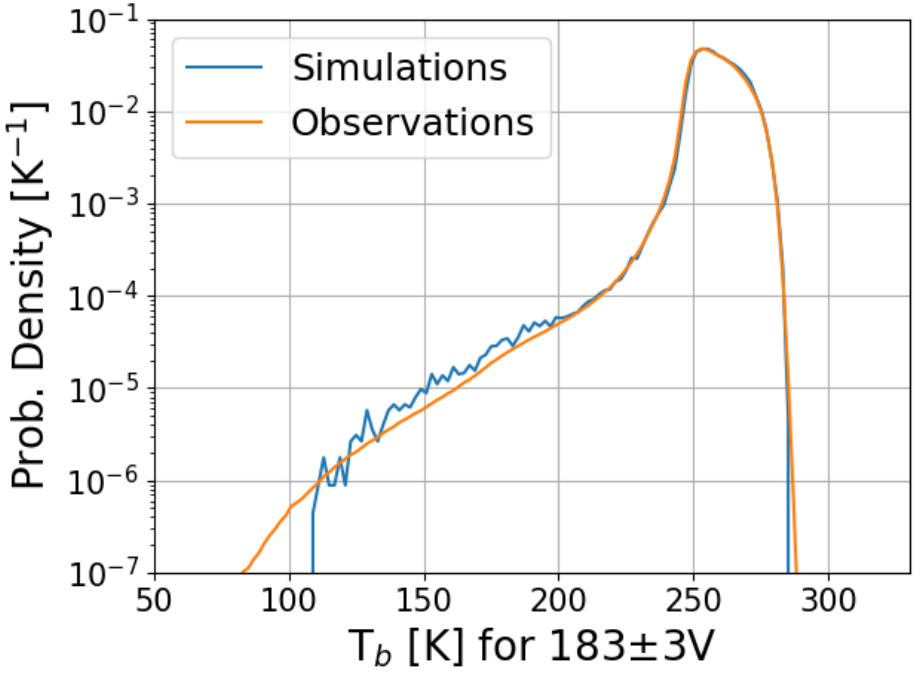


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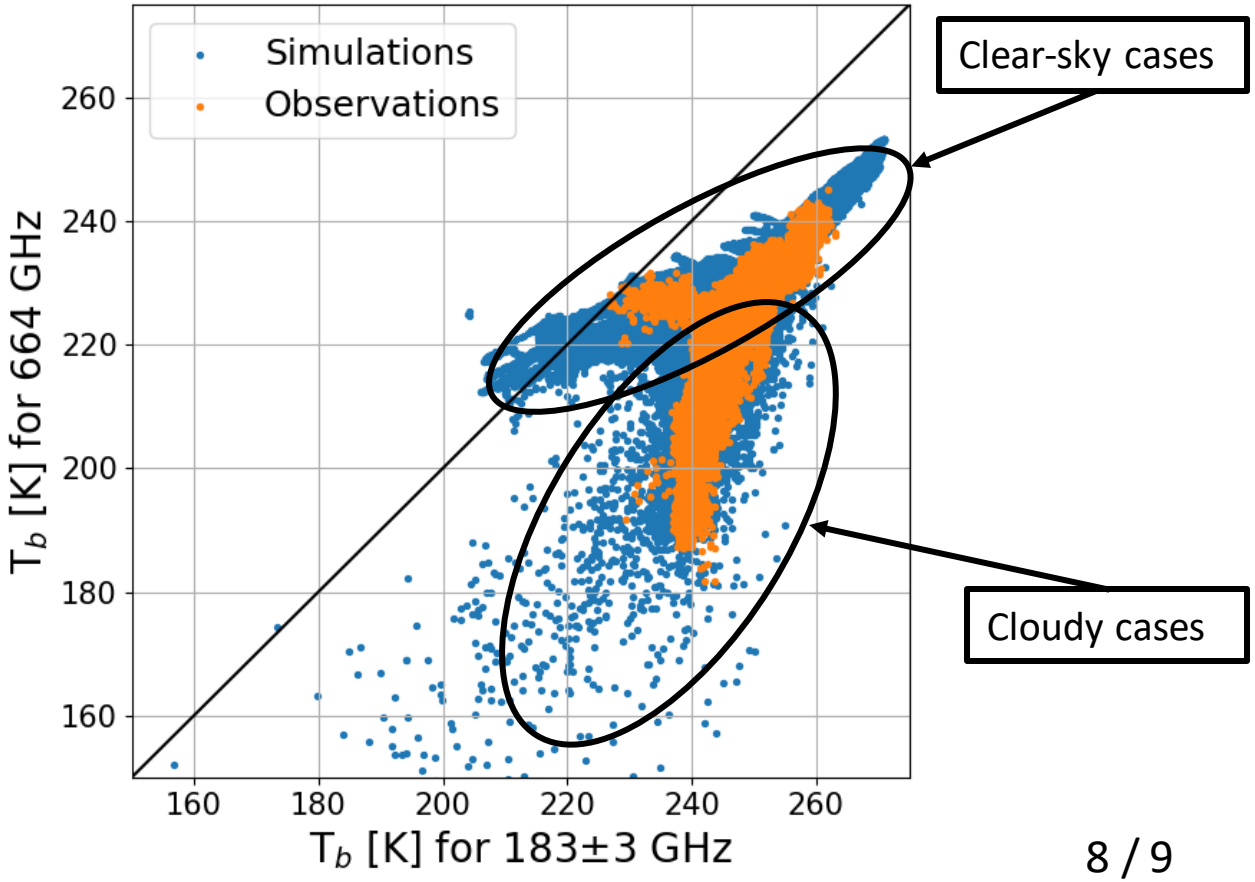
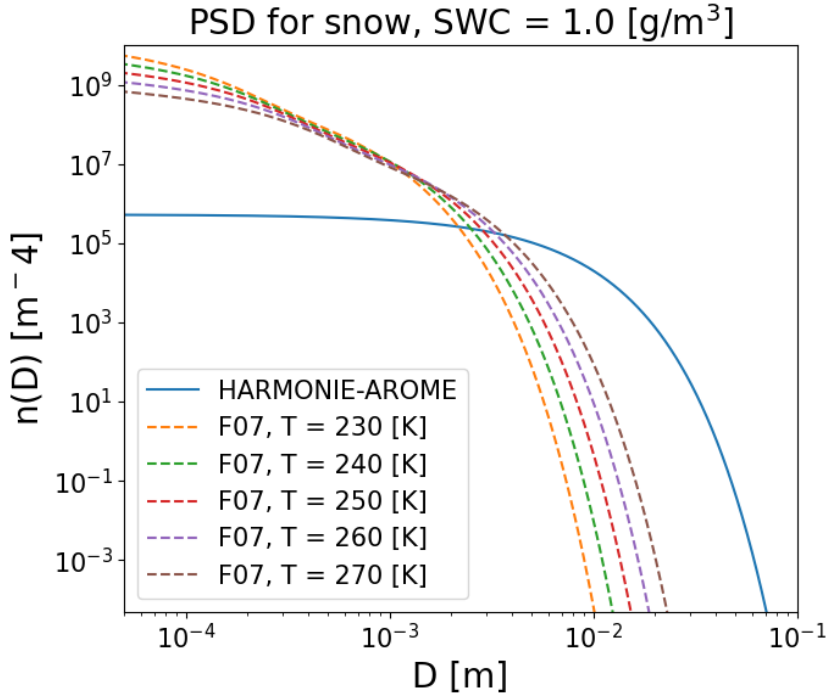


## Outlook

- Further investigate what habits to use
- Large uncertainties in particle size distributions (PSD)
- Arctic Weather Satellite first sub-mm?




## Summary

- EUMETSAT operational retrievals ready
  - Retrieval database delivered
- All-sky part ready for initial assimilation of ICI radiances
  - RTTOV-SCATT and CRTM updated to be prepared for ICI

# Extra

# Stand-alone retrievals:

## Atmospheric absorption and surface emissivity models

Atmospheric absorption

- Nitrogen: continuum model of Liebe et al. (1993)
- Oxygen: Rosenkranz (1993) (molecular transitions and continuum)
- Water vapor: Molecular transitions up to 1.65 THz (Atmospheric & Environmental Research group)
- Ozone: JPL line catalogue

Surface emissivity models

- Empirical emissivities for land and ocean (TELSEM, TESSEM)
- Developed a stochastic model for snow and sea-ice (tuned to GMI) to capture observed variation of emissivity with different snow-packs at higher frequencies