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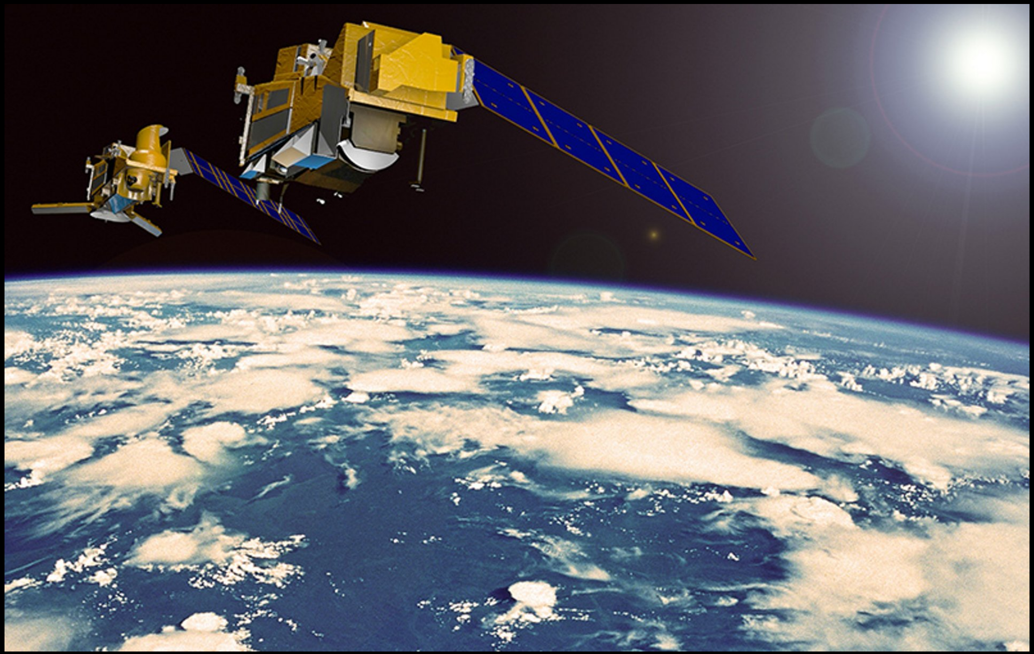
Uncertainty characterization of sub-mm and MW in all-sky radiative transfer

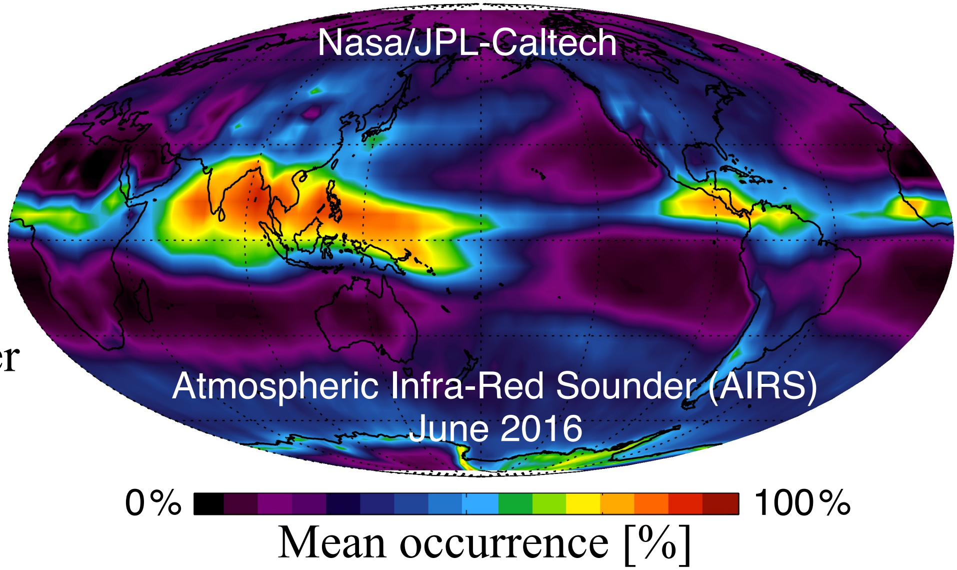
Vasileios Barlakas, Patrick Eriksson, Robin Ekelund



ECMWF EUMETSAT

Why ice clouds?

- Cover ~30% of the Earth
- A significant role in the energy budget
- Large uncertainties in numerical weather prediction (NWP) and climate models



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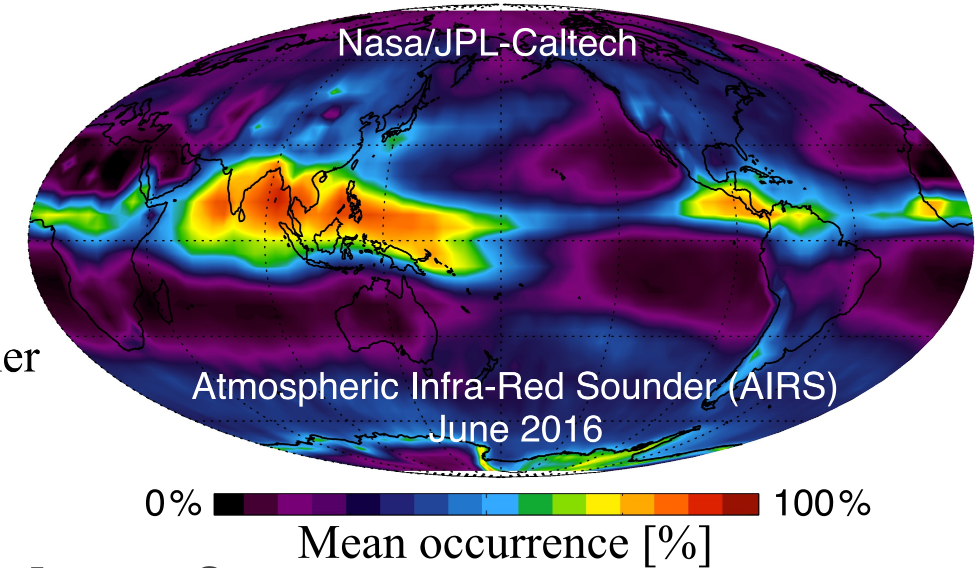
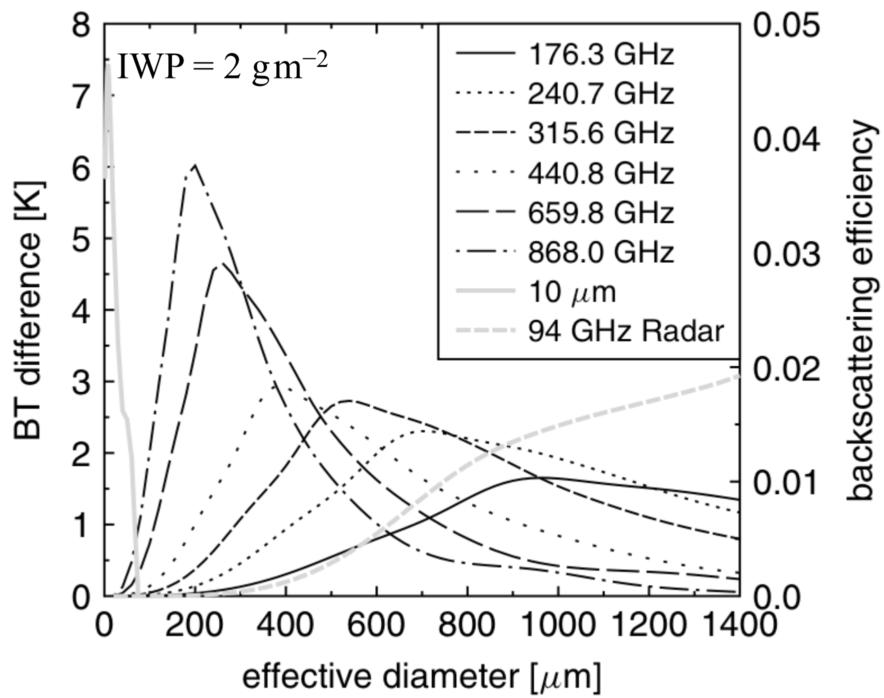


Why microwave (MW) and sub-mm?

- The assimilation of MW observations comprises ~40% of the observation impact.
- Sensitive to both large and small ice hydrometeors.



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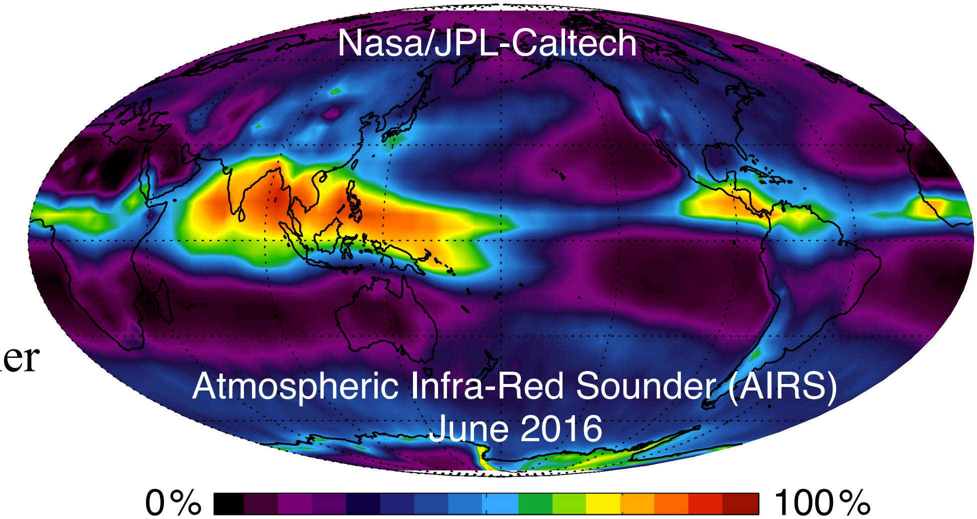

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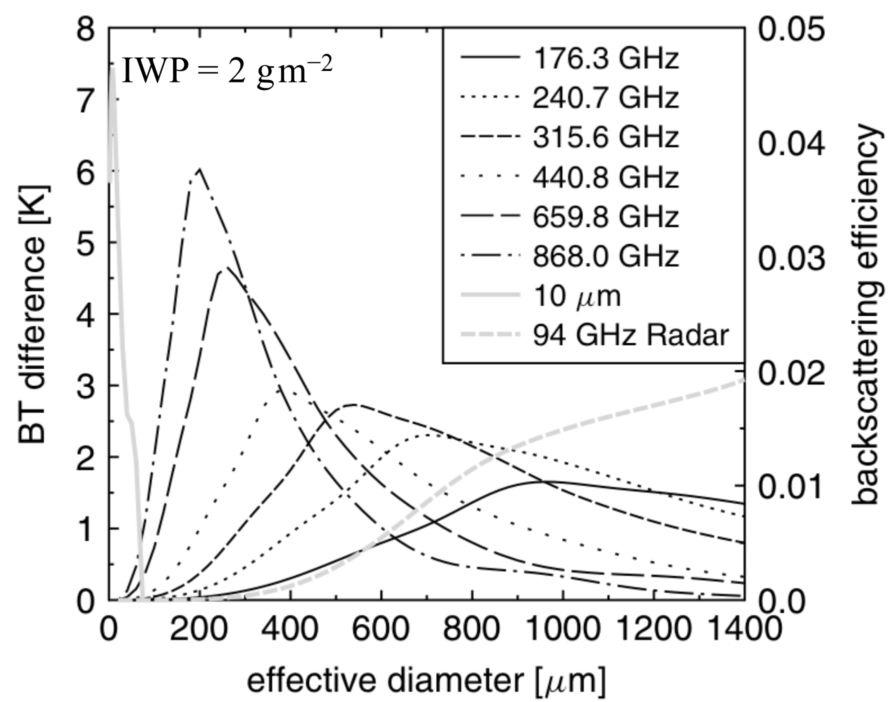


<u>Ice Cloud Imager (ICI)</u>

- 183.31–664 GHz (15 km footprint)
- Improved ice cloud representation
- Extend the scope of MW assimilations

In stand-alone retrievals and data assimilation (DA), several assumptions are still employed:

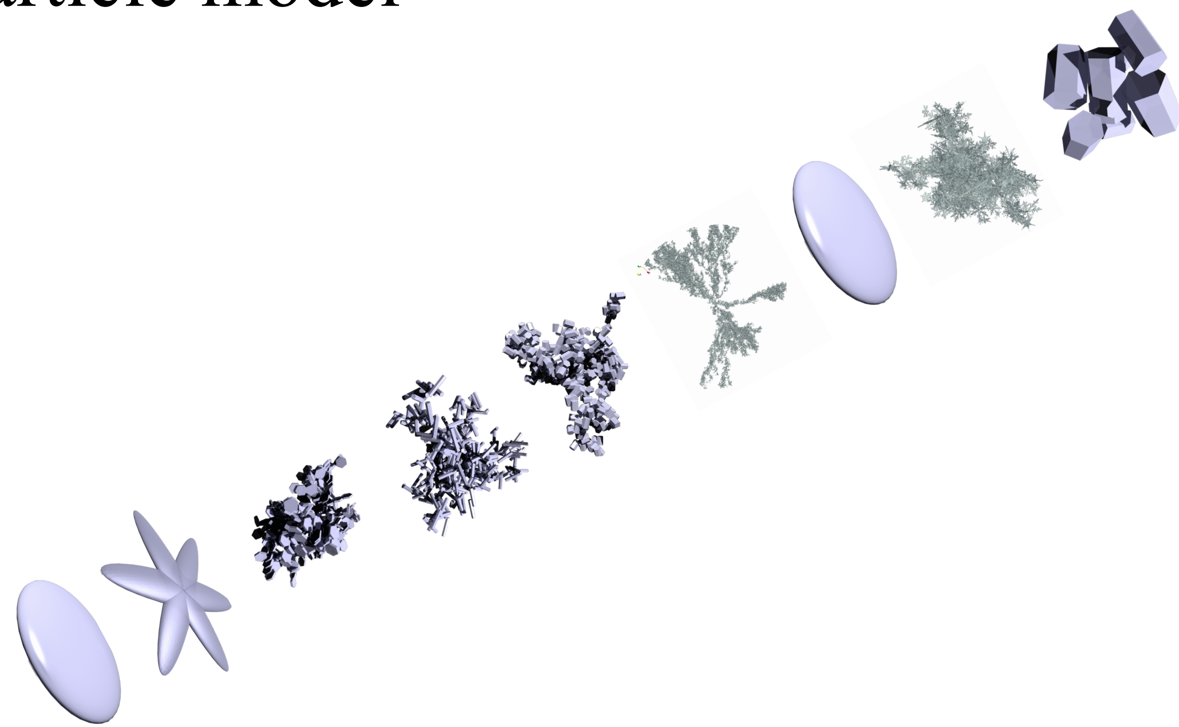
- particle size distributions (PSDs) and particle models (PMs) are poorly considered,
- three-dimensional (3D) radiative transfer is ignored.

⬇

① Can combined active and passive measurements be used to constrain ice PMs？

② Are retrievals at mm/sub-mm wavelengths affected by 3D effects？

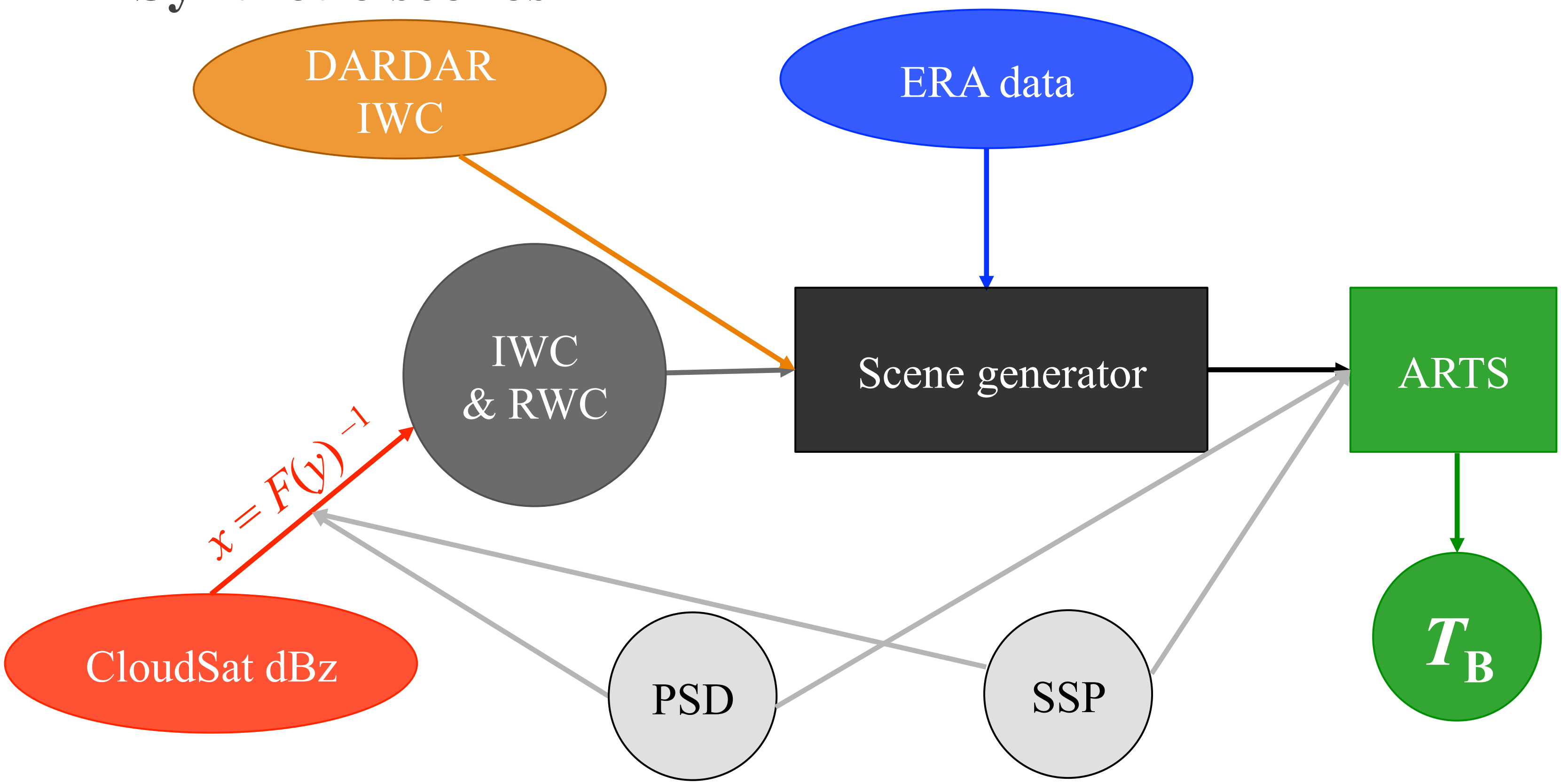
Using passive and active microwave observations to constrain ice particle model

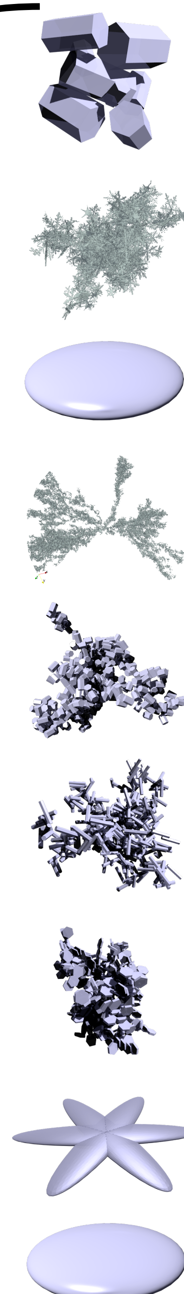


Ekelund et al., *Atmos. Meas. Tech. Discus.*, 2019

Can we constrain ice particle models?

Synthetic scenes





Data and tools:

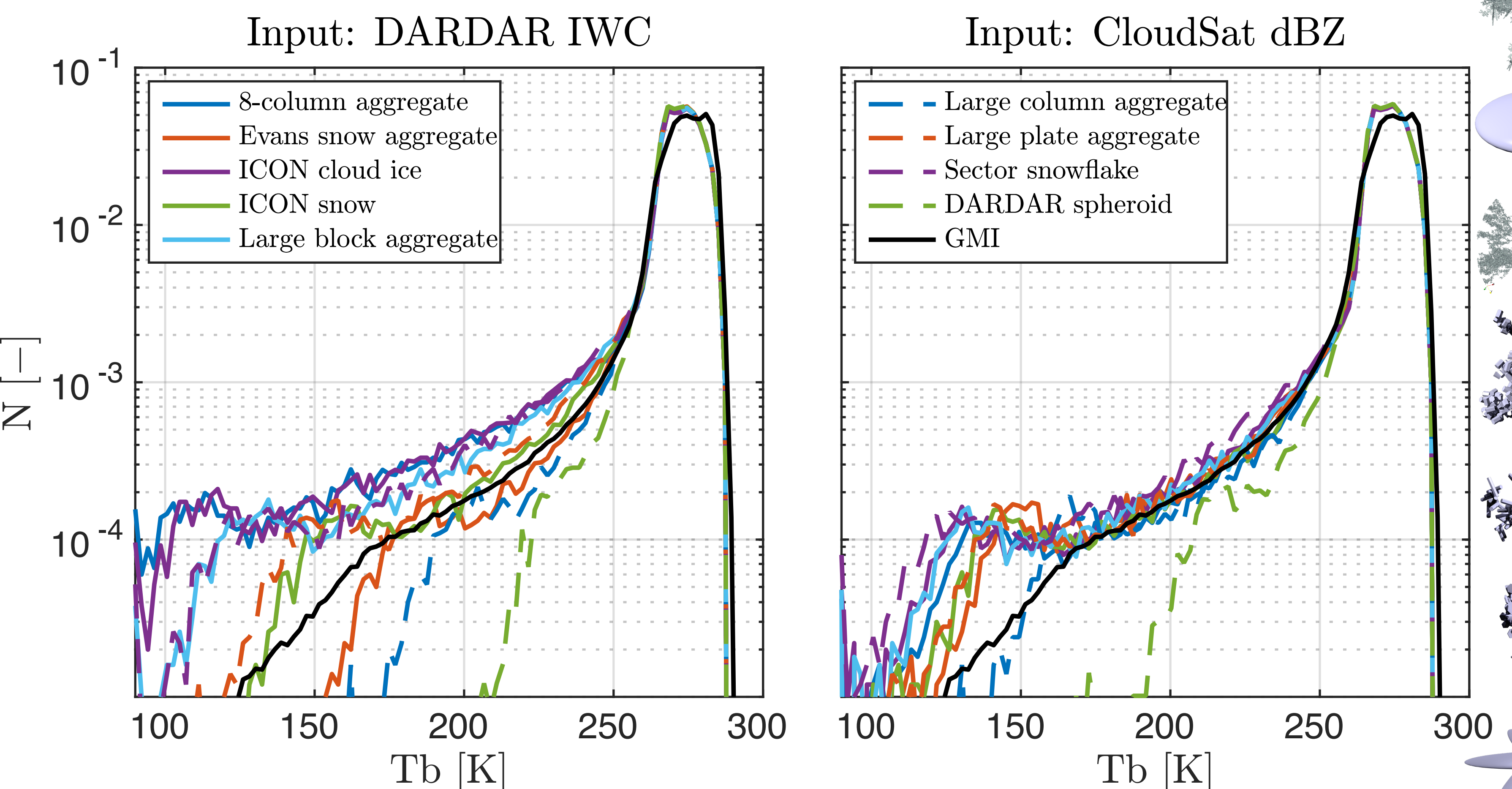
- CloudSat orbits: 59 (July 2015) over Tropics
- PSD: (a) Field et al., 2007 (**F07**)
  (b) McFarquhar & Heymsfield, 1997 (**MH97**)
- GMI-wise simulations vs observations
- ICI-wise simulations

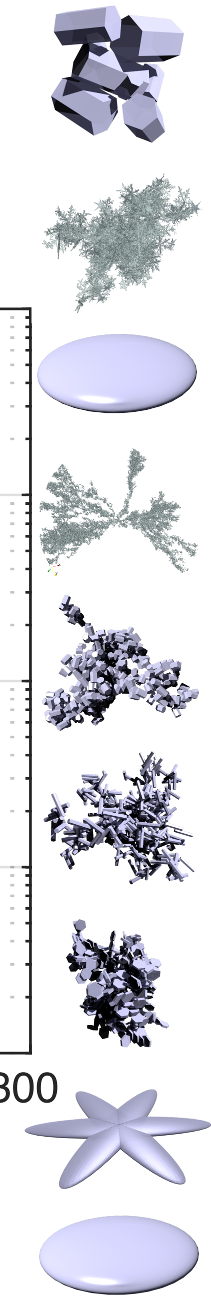
ARTS scattering database

- 34 freq.: 1-886.4 GHz
- 34 particle models (PM)
- 35-45 sizes per PM
- Method: DDA

Eriksson et al., 2018

Brightness temperature distributions – 190.31 GHz





PSD used: F07

Ekelund et al., 2019

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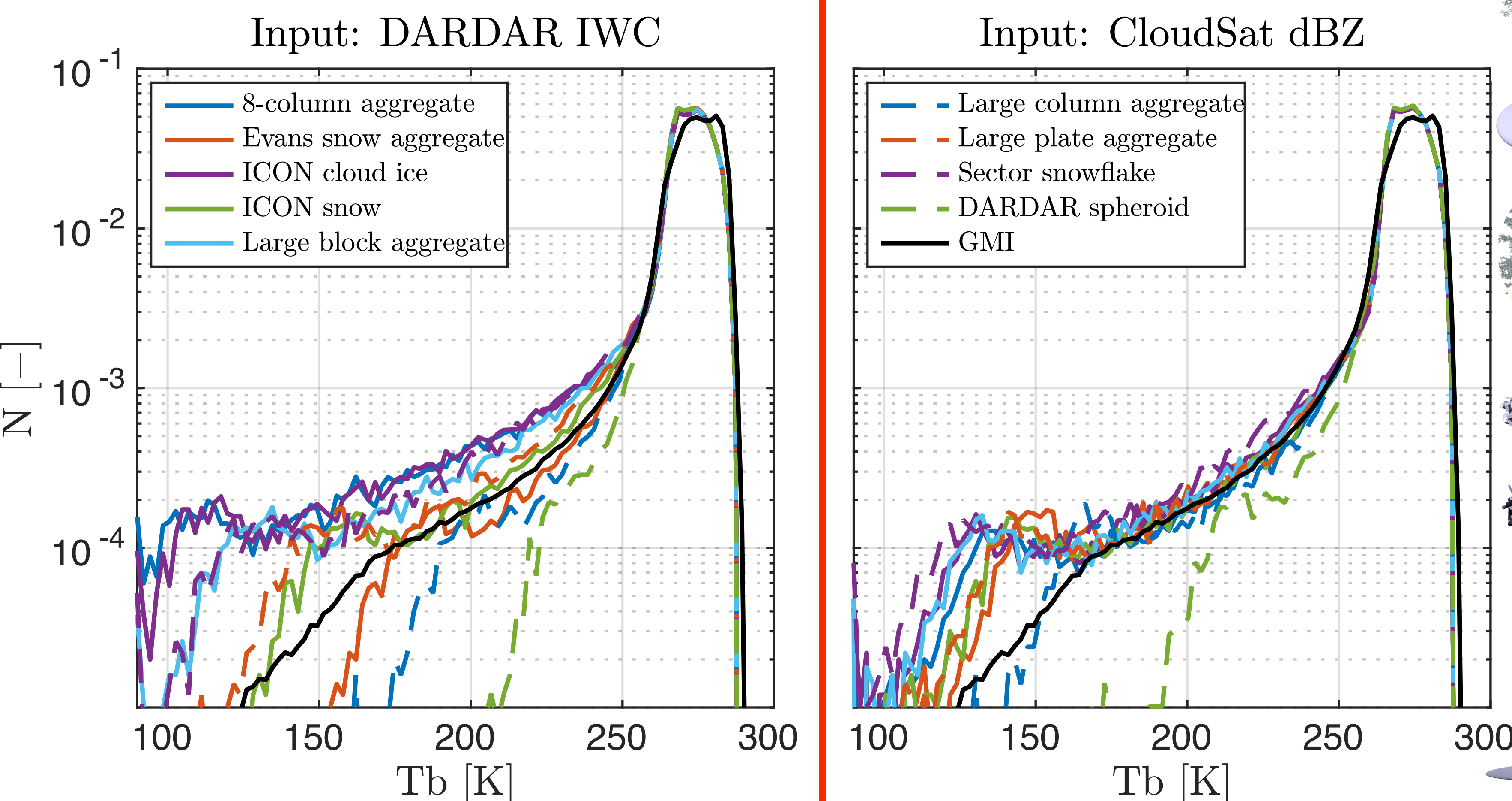

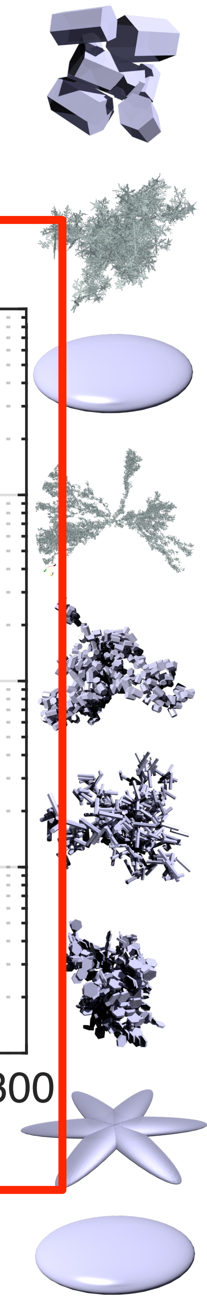

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Ekelund et al., 2019

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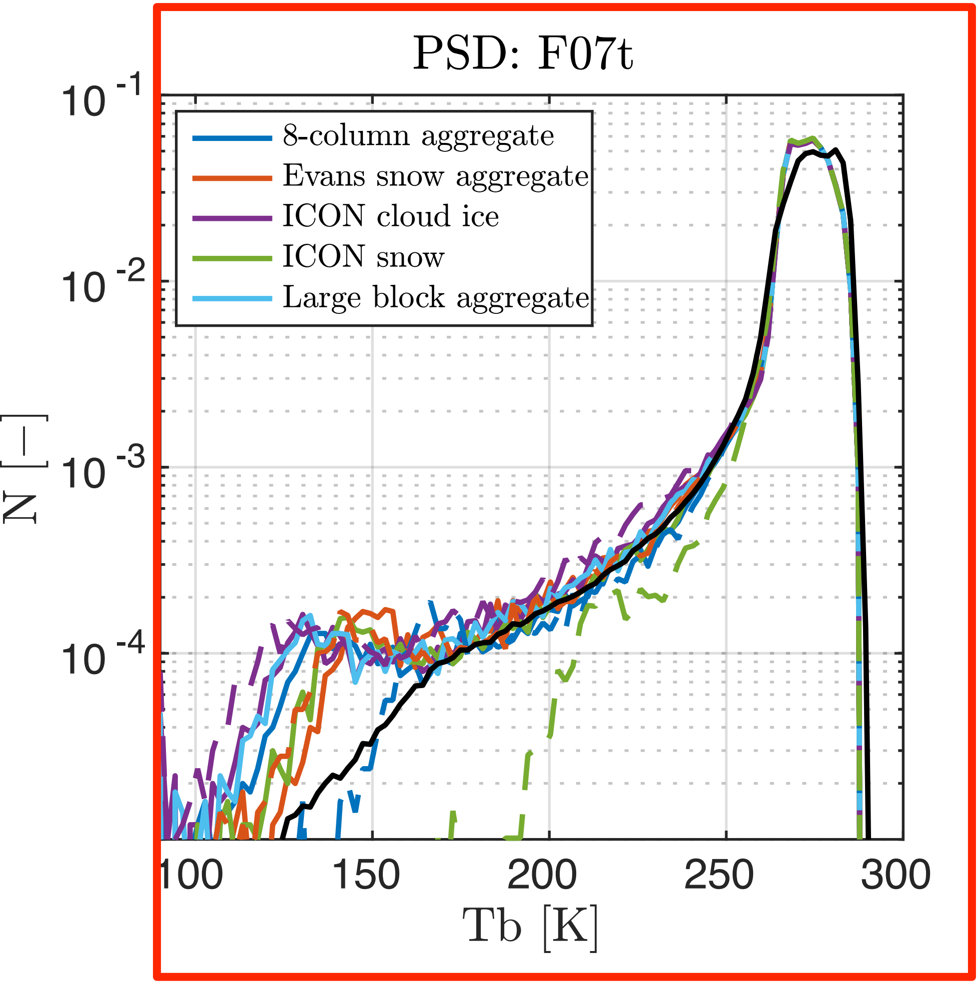
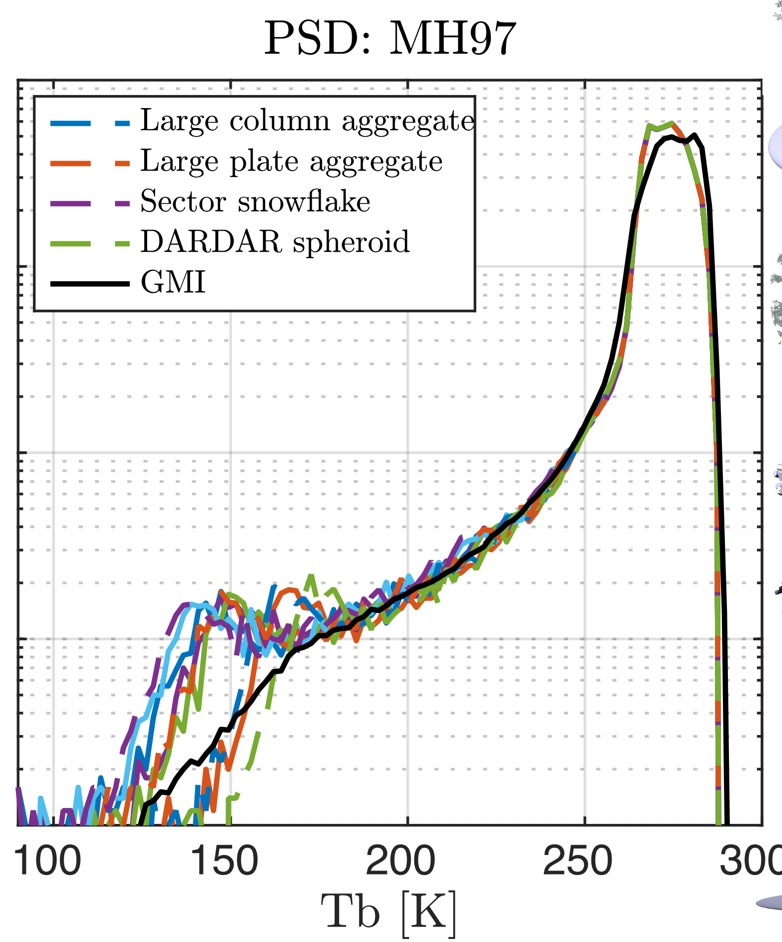
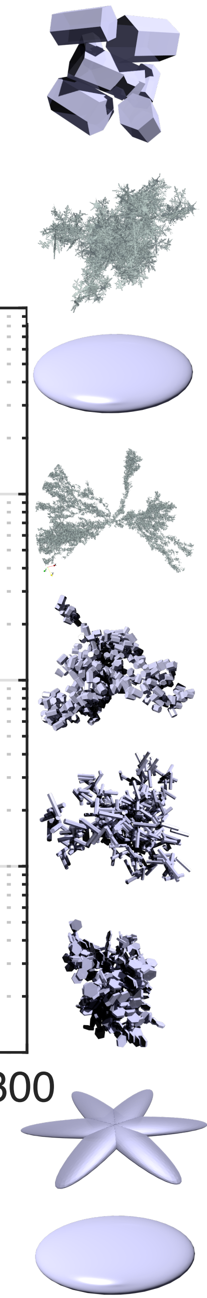




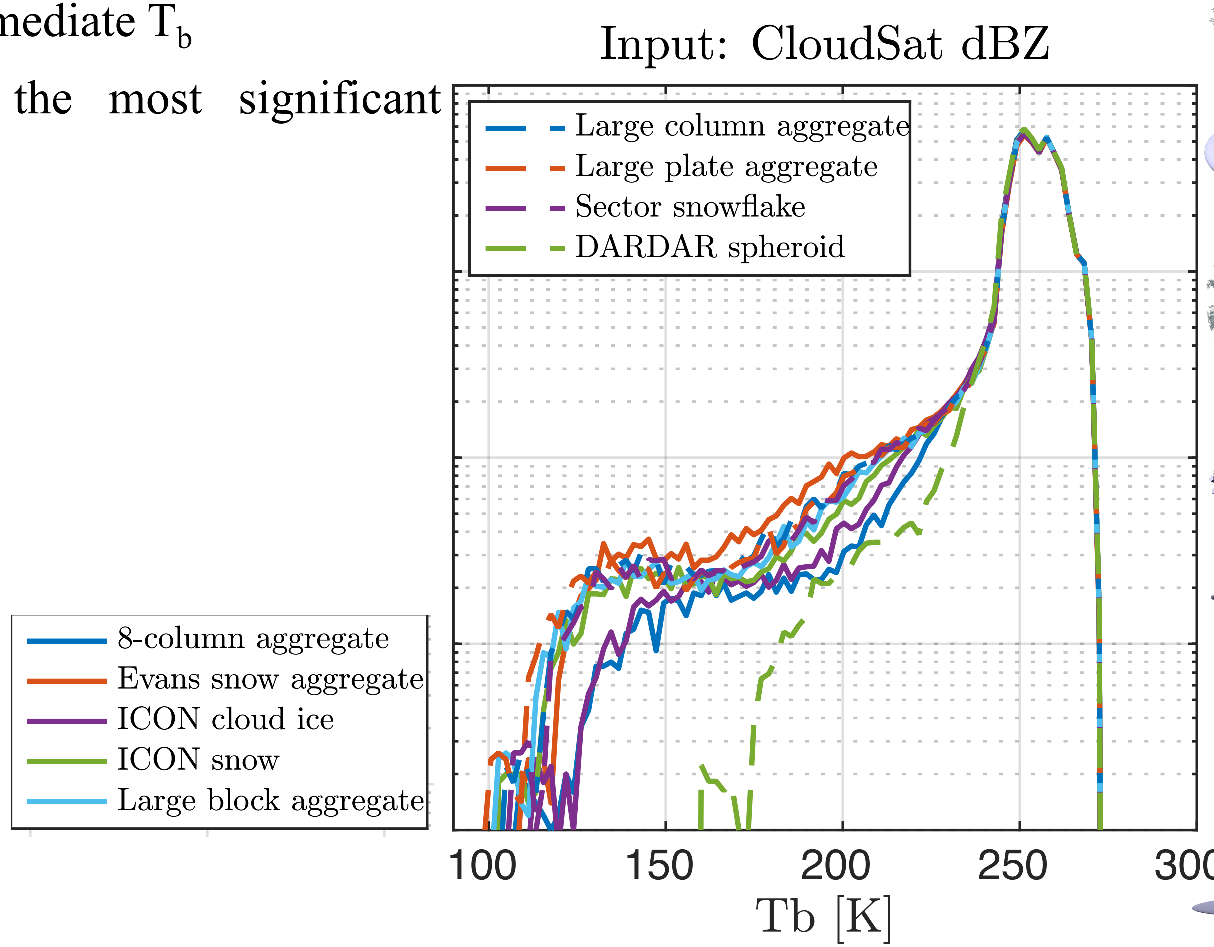


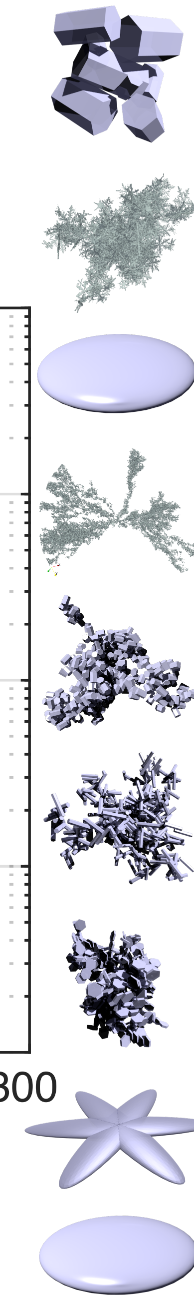
Ekelund et al., 2019

Brightness temperature distributions – 668.20 GHz

Compared to 190.31 GHz:

- Larger spread at intermediate T_b
- DARDAR spheroid the most significant outlier





PSD used: F07

Ekelund et al., 2019

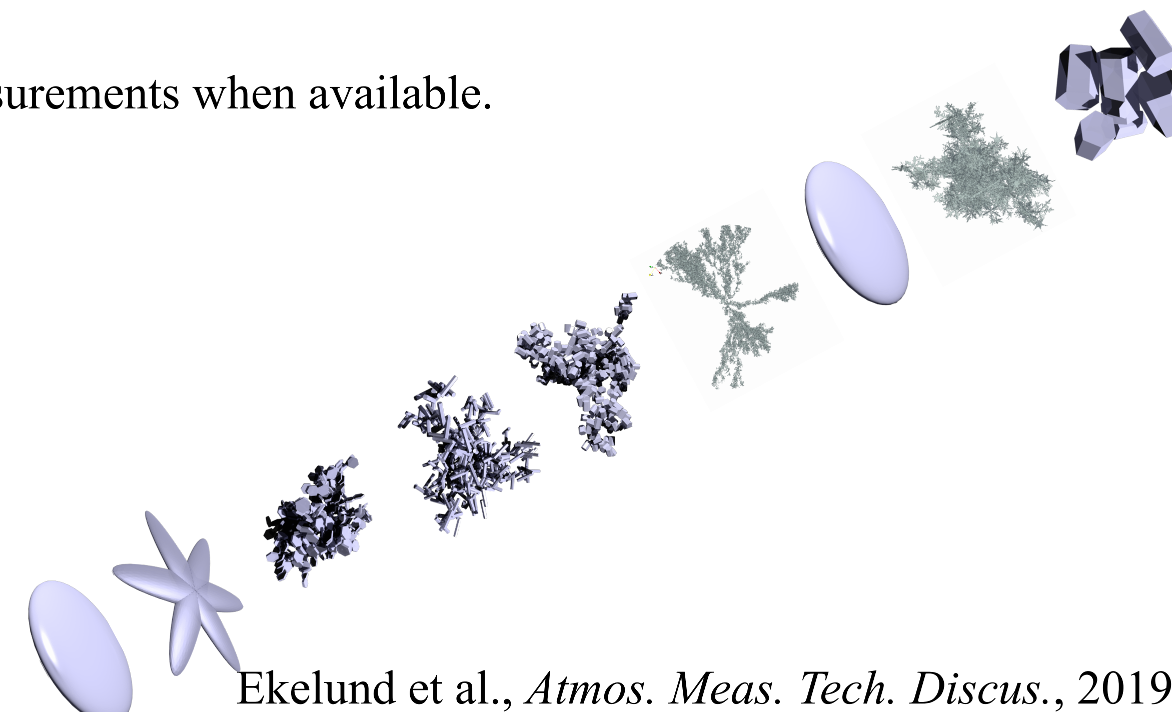
Can we constrain ice particle models?

Summary

- Overall, T_B-distributions agree well with GMI observations.
- Most particle models perform well compared to GMI at intermediate T_B-values.
- Of tested PSDs, the one by McFarquhar and Heymsfield (1997) leads to smaller discrepancies.
- At sub-mm wavelengths, a significantly higher sensitivity to the assumed particle models is found.

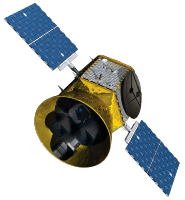
Outlook

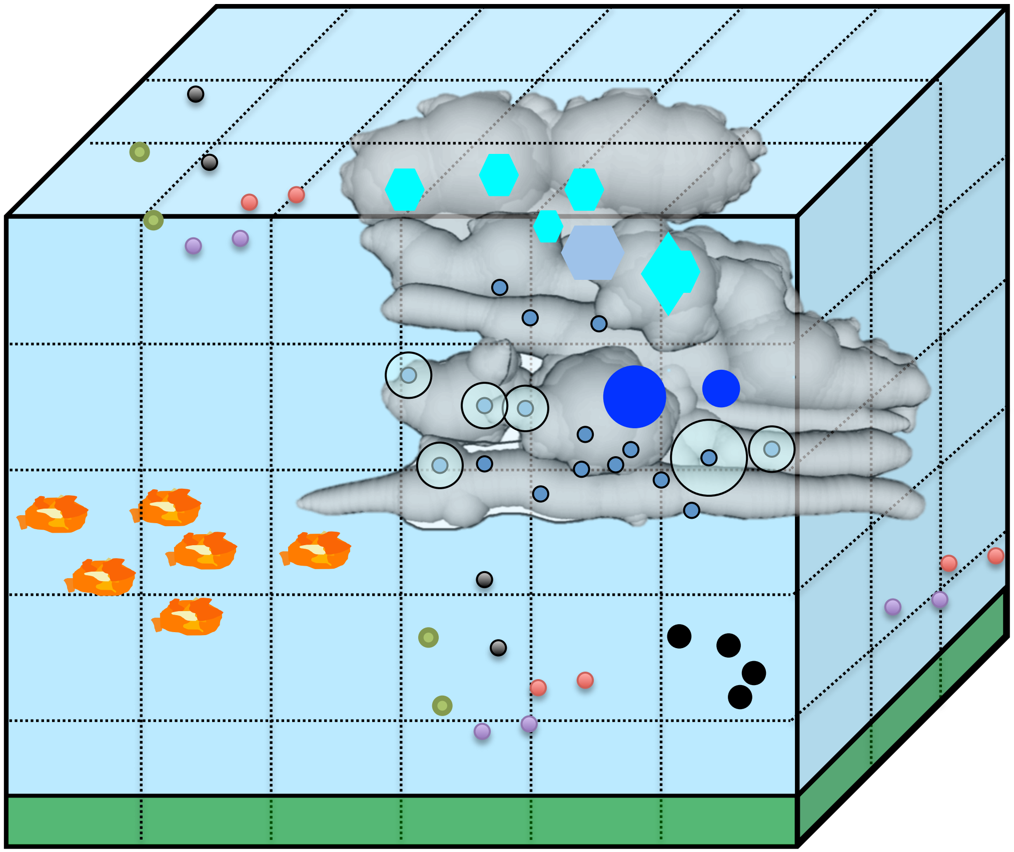
- Apply methodology to ICI measurements when available.



Ekelund et al., *Atmos. Meas. Tech. Discus.*, 2019

Three Dimensional Radiative Effects in Passive **mm/sub-mm** All-sky Observations

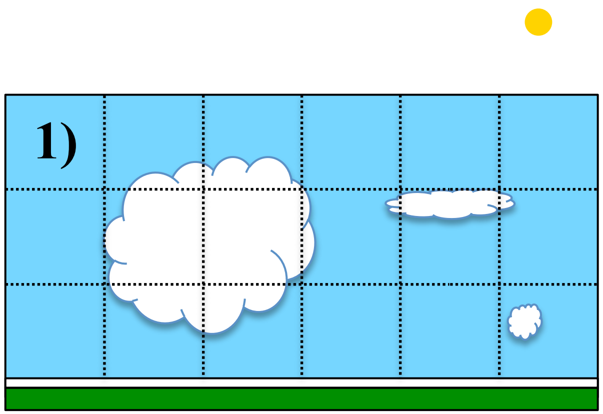




Barlakas and Eriksson., *Remote Sens.*, 2020

Calculation modes – 3D, IBA, 1D

1) A **3D** mode (ARTS-MC)



β_1	β_2	β_3
β_4	β_5	β_6
β_7	β_8	β_9

2D slice of 3D

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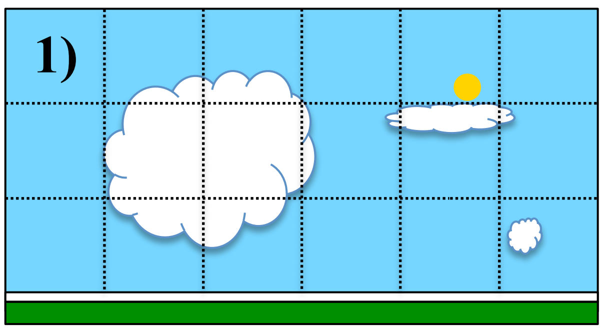

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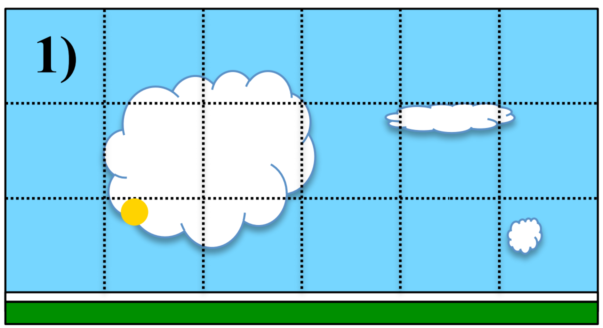

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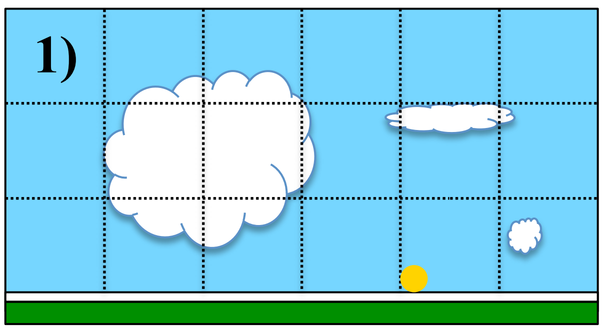

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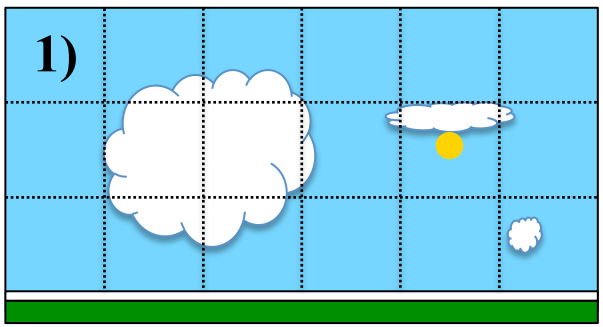

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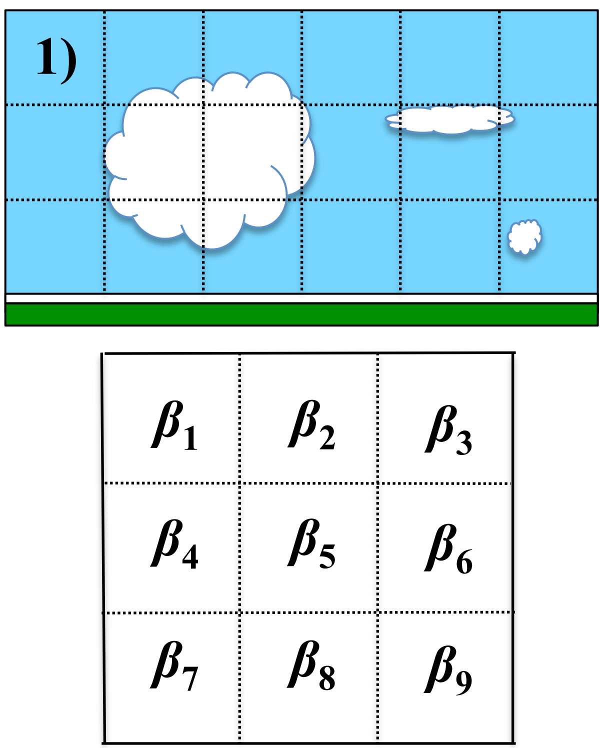

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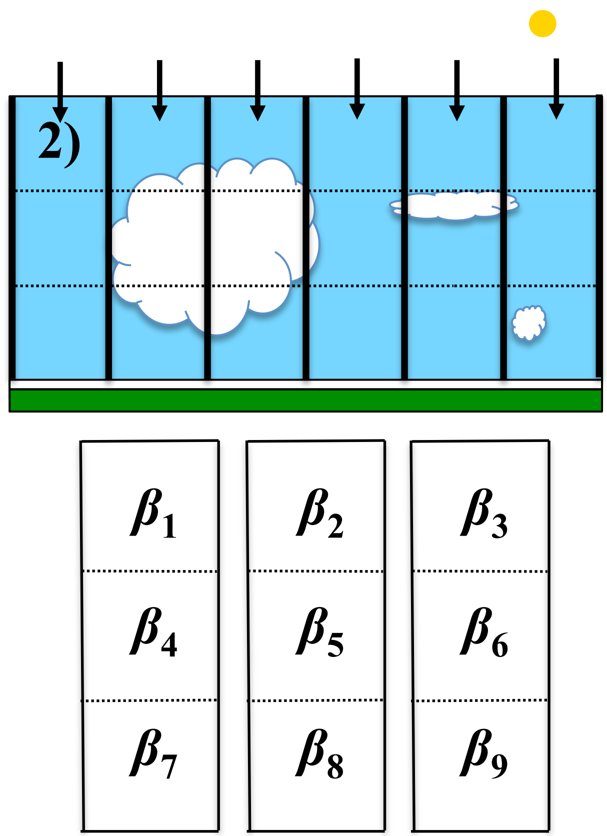

IBA

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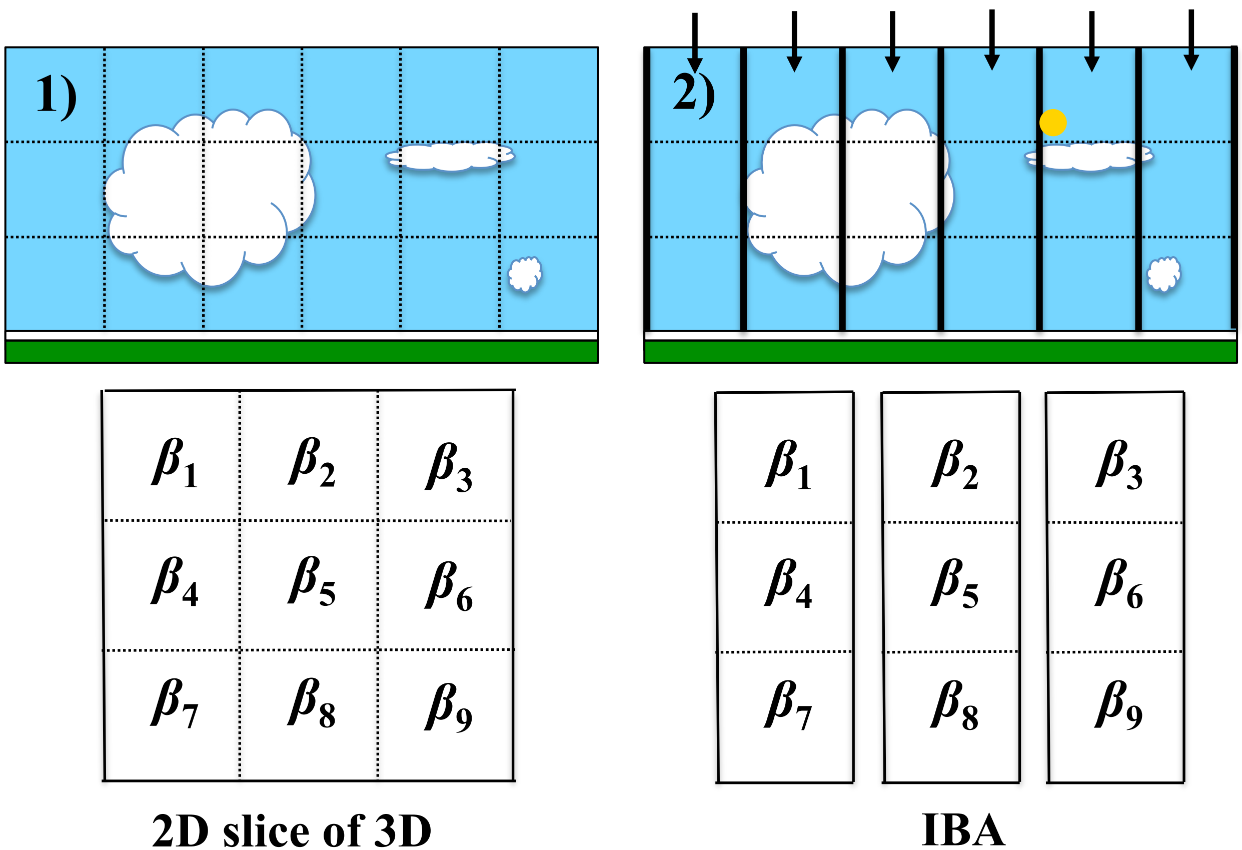

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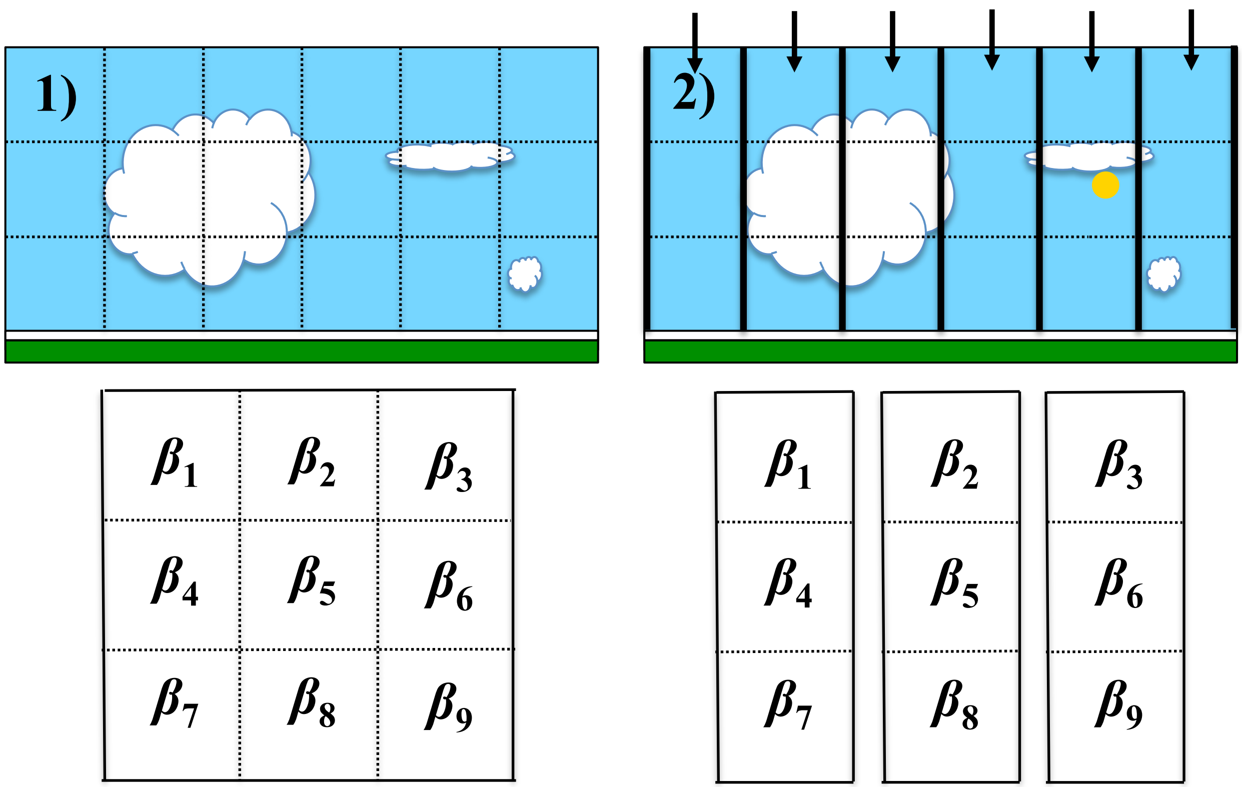

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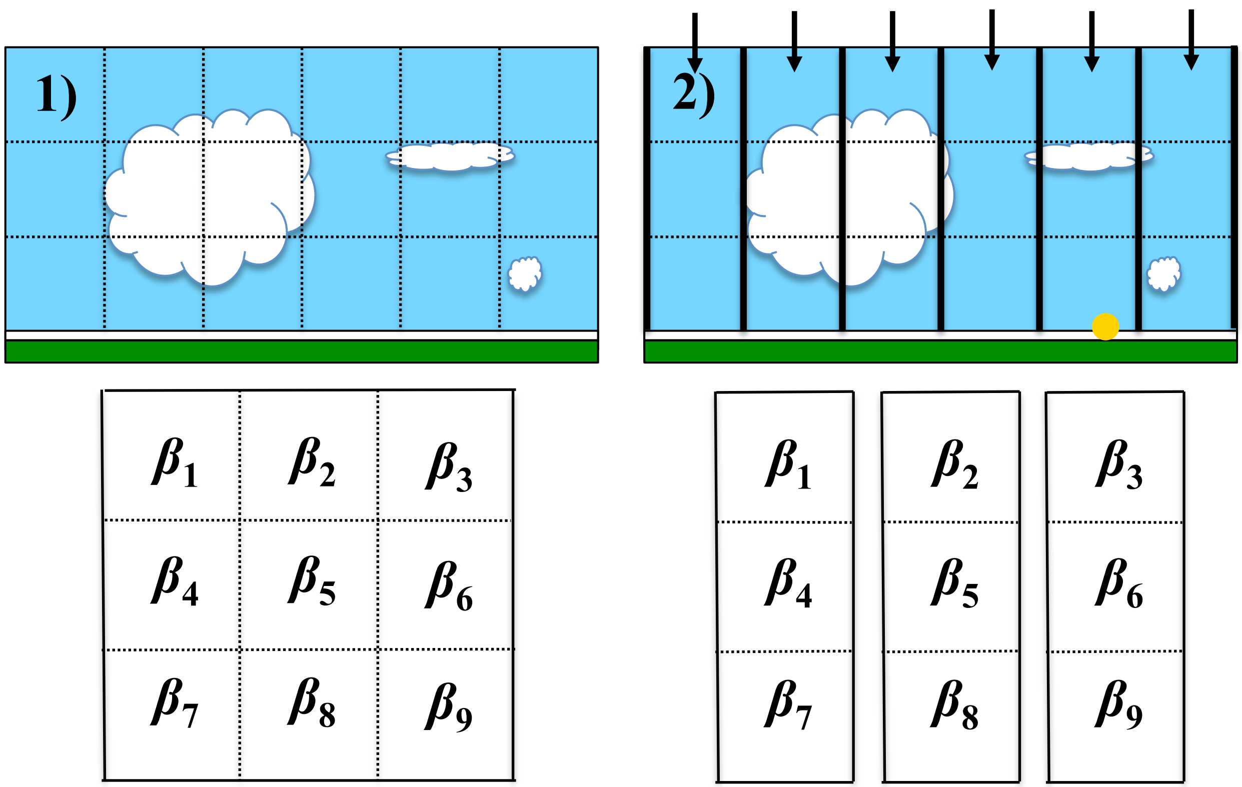

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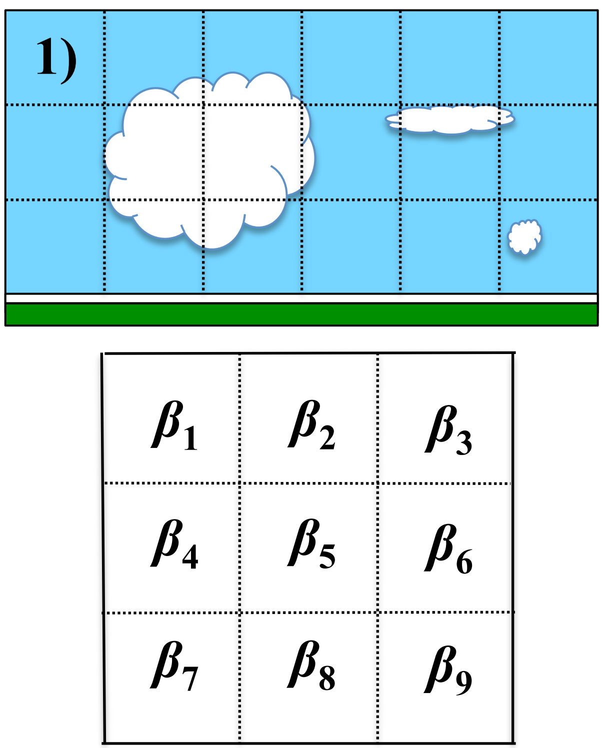

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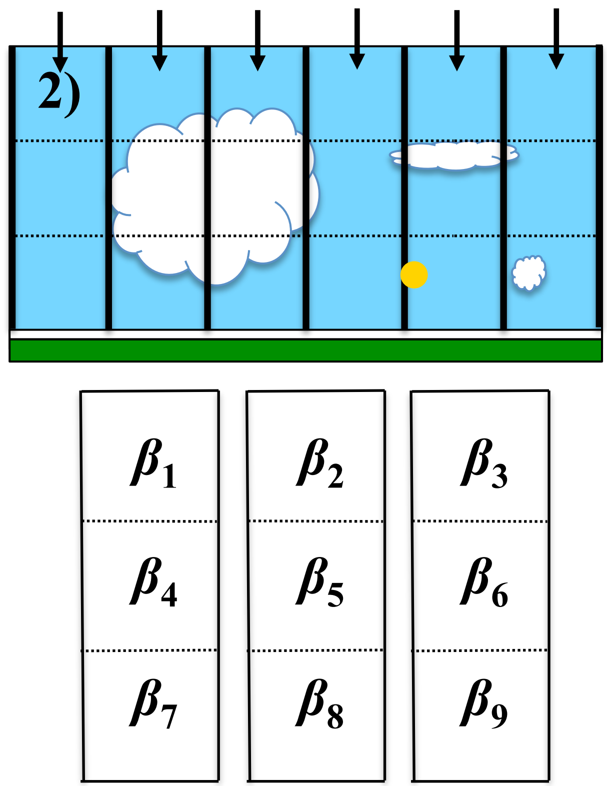

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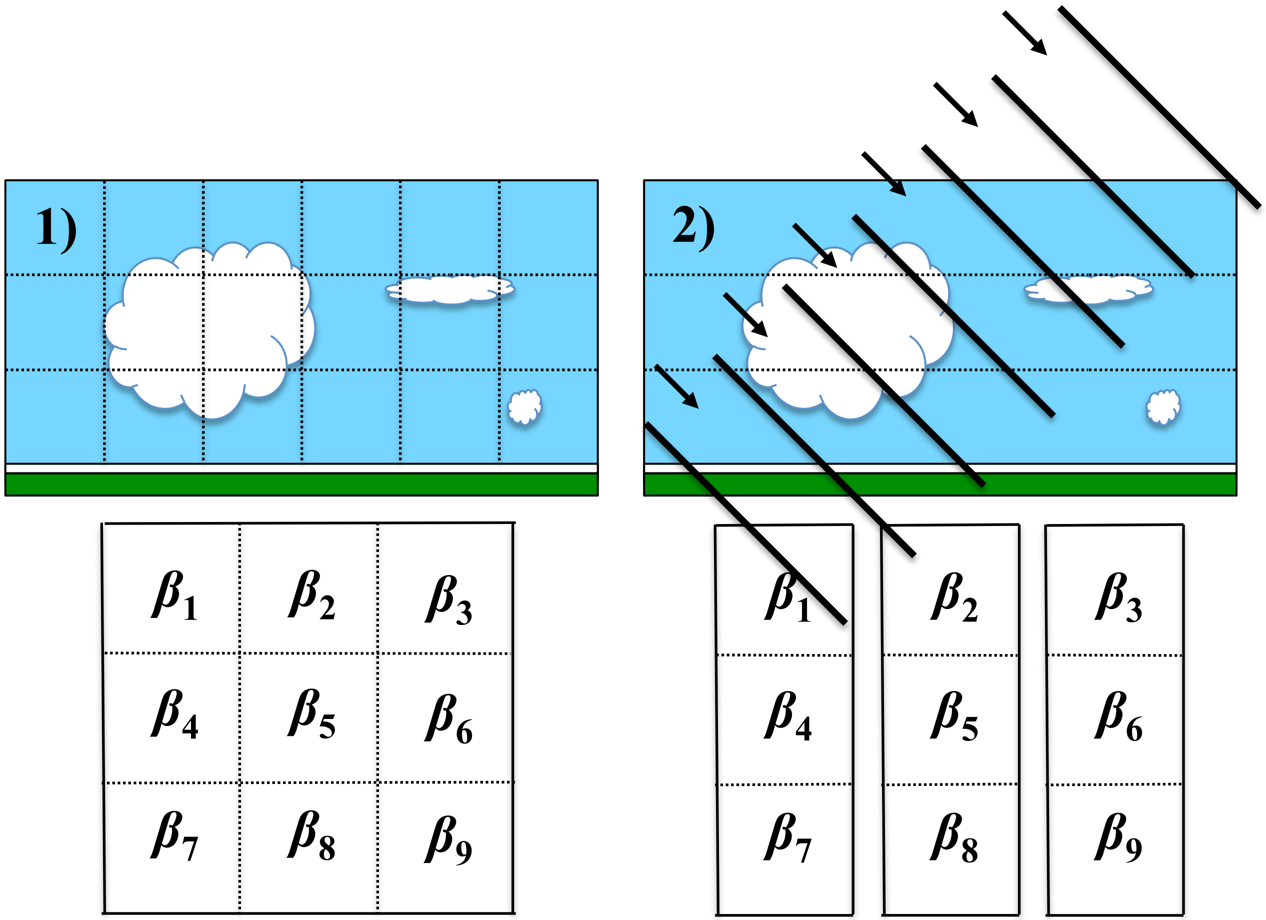

2D slice of 3D **IBA**

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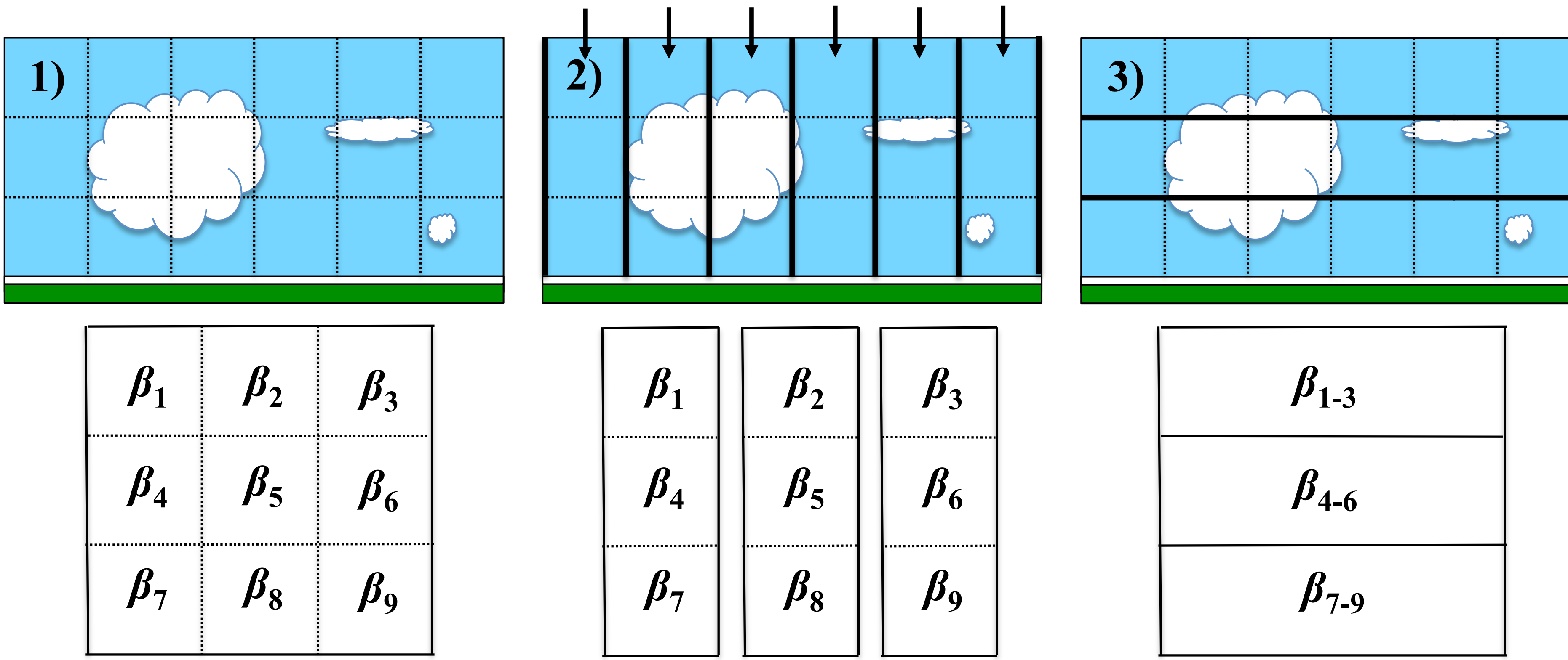
   - ✓ Hydrometeor Number Density – average (HND-avg)
   - ✓ Hydrometeor Content – average (HC-avg)



2D slice of 3D **IBA** **1D**

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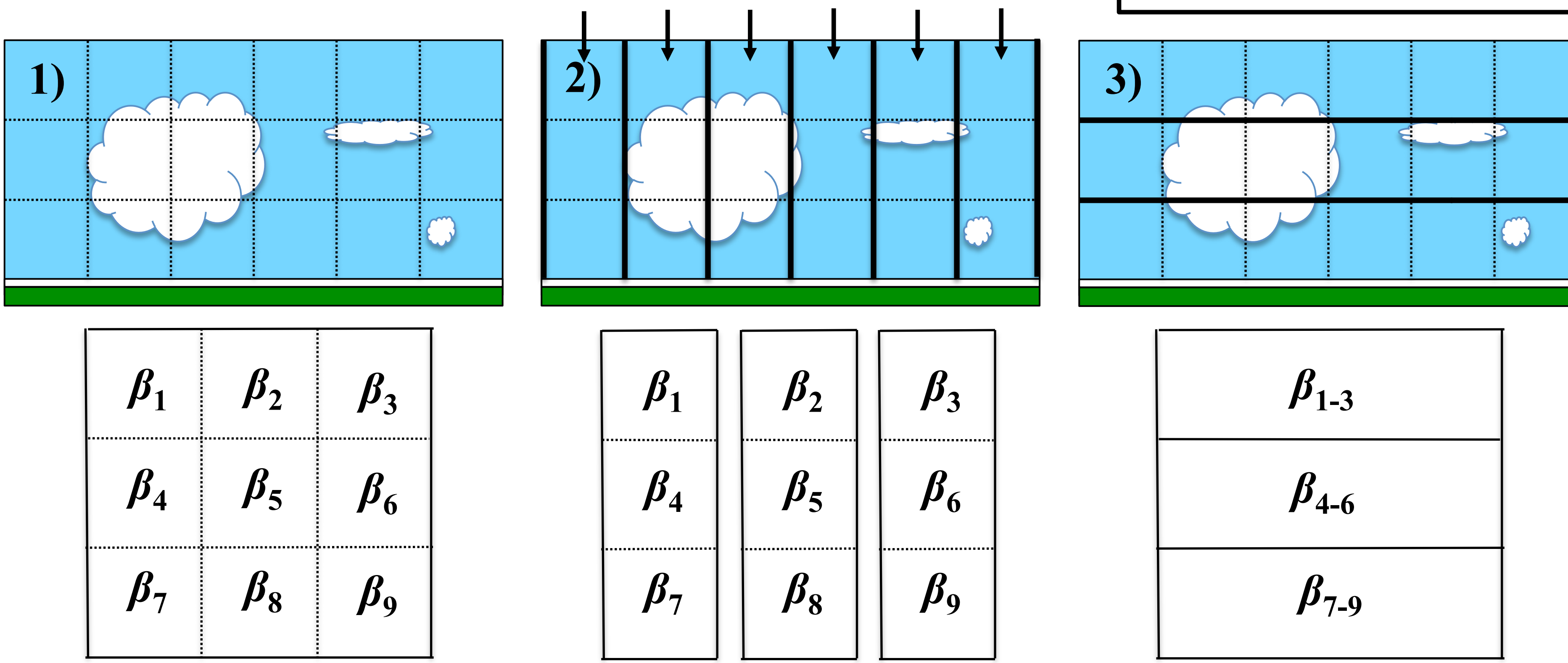
Settings:

- Freq.: 186.3 & 668 GHz
- FOV–Gauss: 6 & 15 km



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Post-processing:

- Simulations in 2km grid
- Average over FOV

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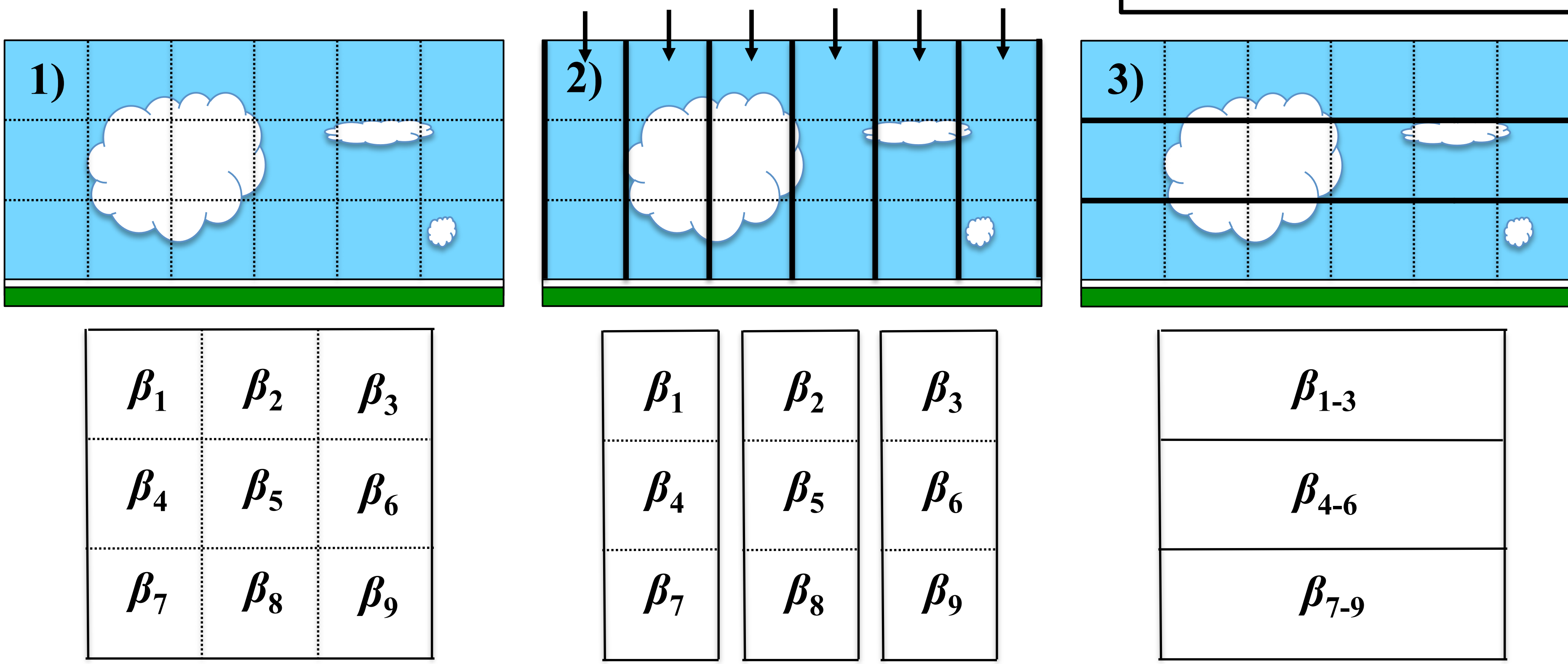

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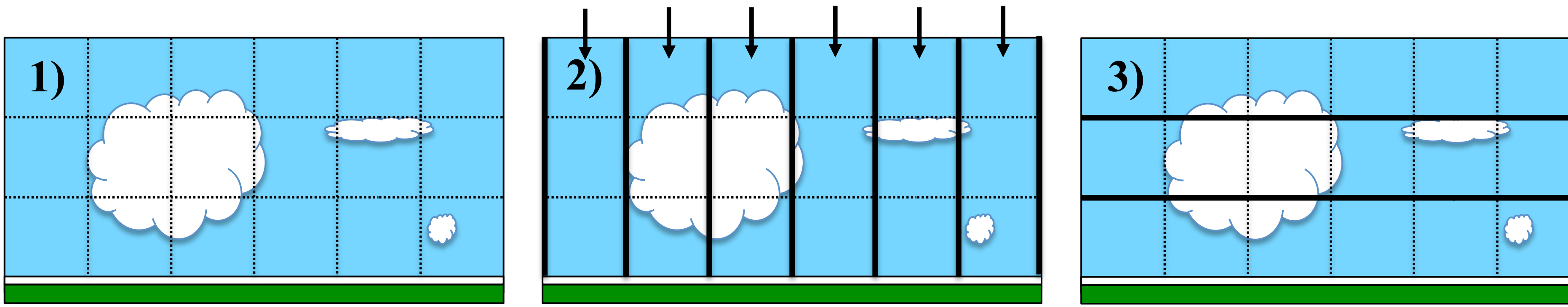
Hydrometeor Impact:

$\Delta T_B = T_{B,cloudy} - T_{B,clear}$



3D vs IBA → Horizontal Photon Transport (**HPT**) effect
=> Neglect of HPT along areas with different properties

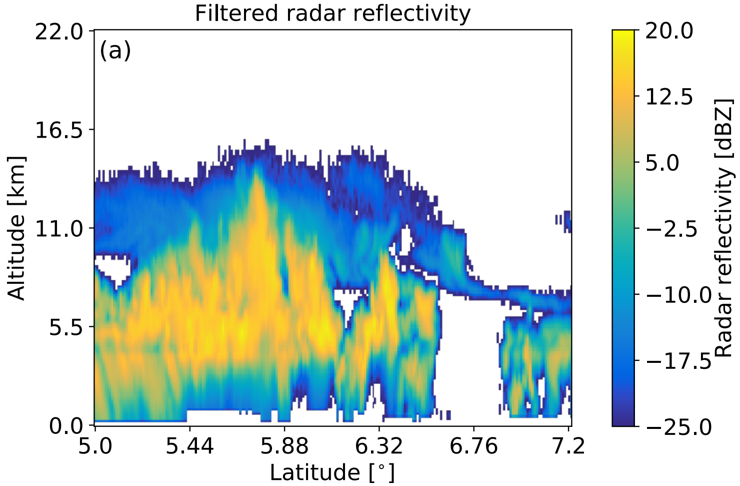
IBA vs 1D → **Beam–Filling (BF)** effect
=> Neglect of domain heterogeneities

3D vs 1D → **Total Effect**

3D Radiative effects – Synthetic scene

ERA data

CloudSat dBz



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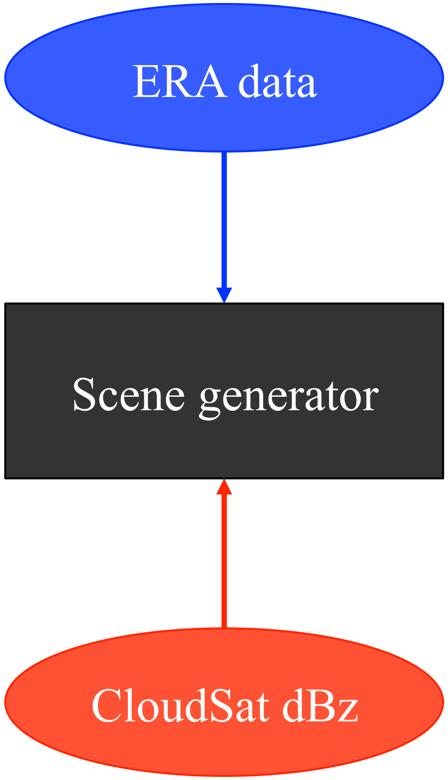

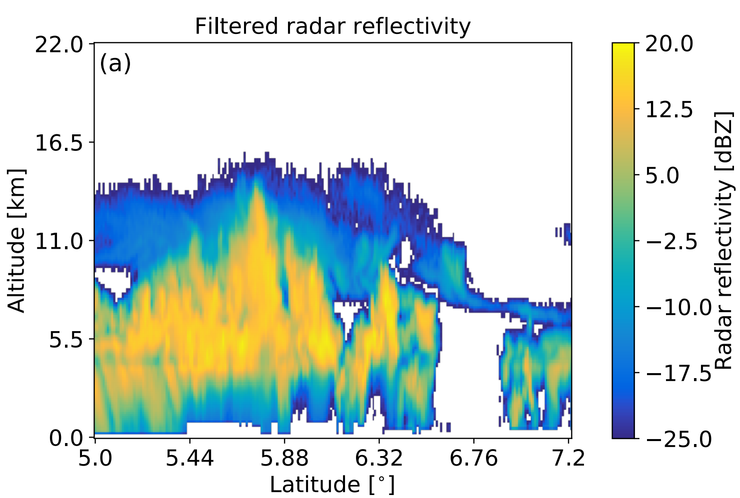

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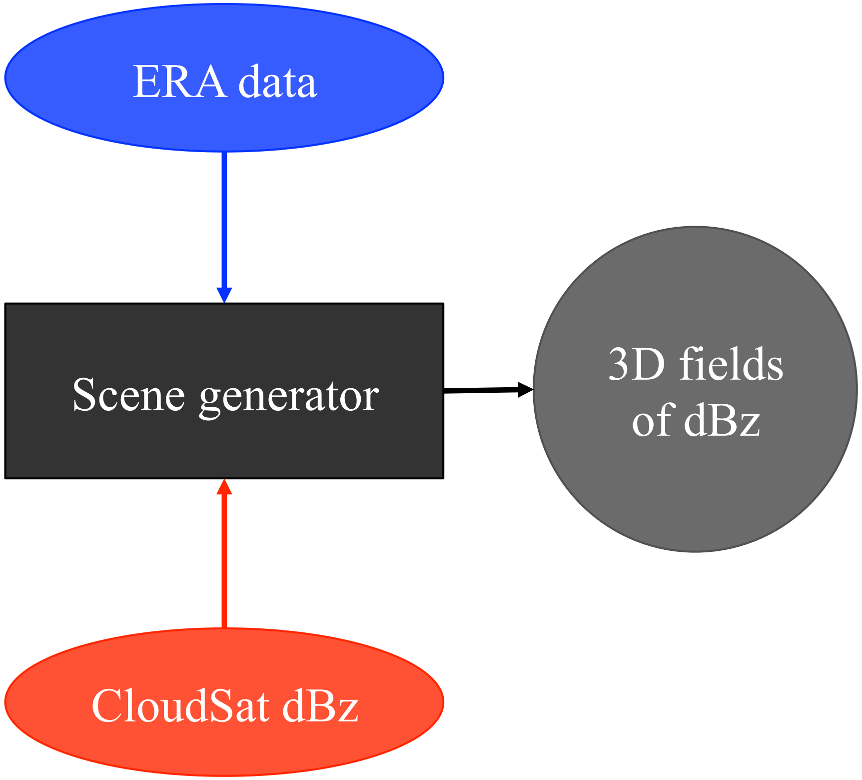
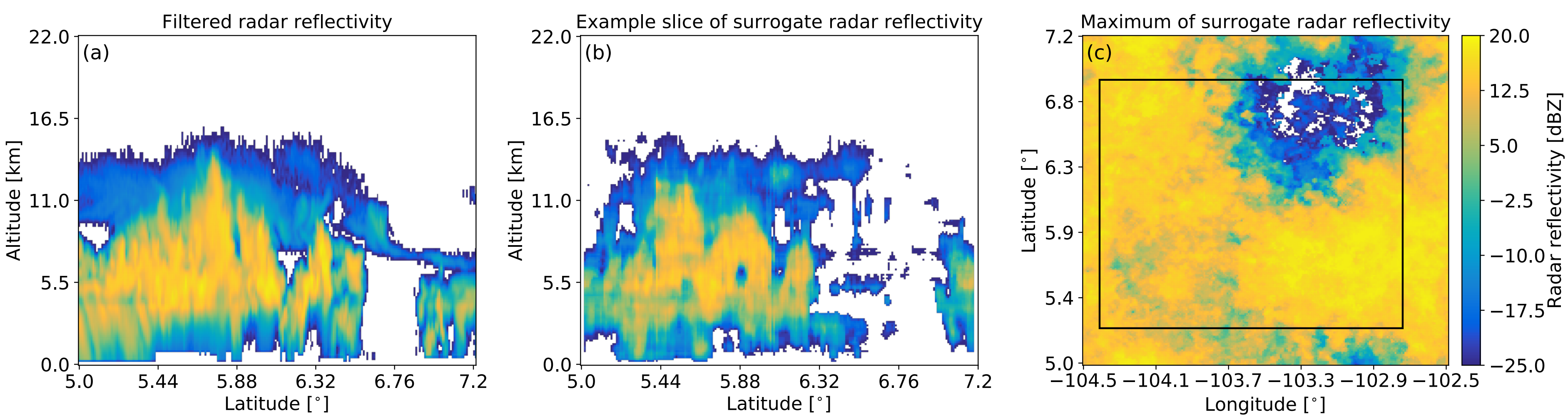


CloudSat overpasses:

- Tropics: 30 (July 2015) => 55 scenes
- Mid-Latitudes: 29 (January 2015)=> 58 scenes
- Each scene: 160 km by 200 km



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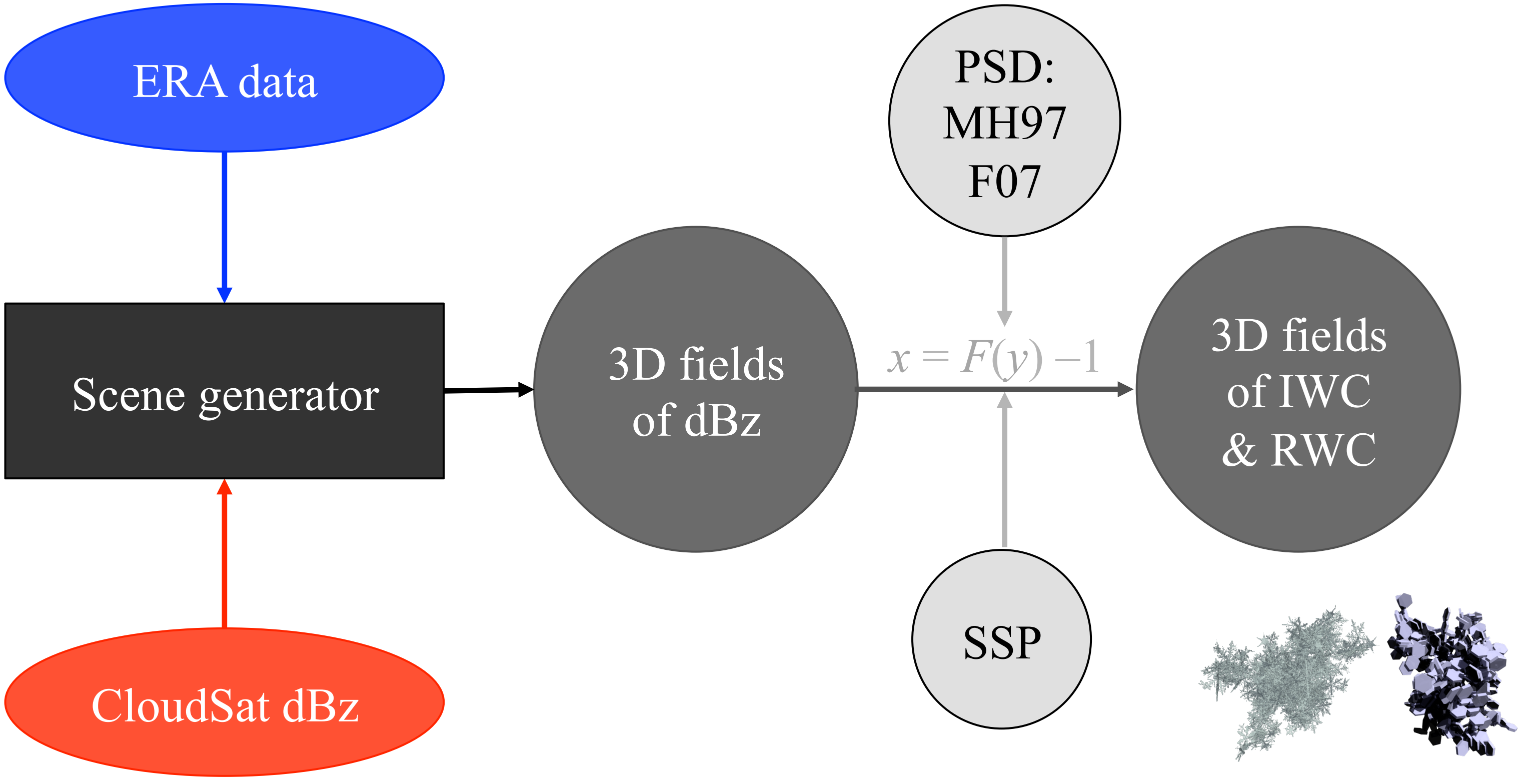

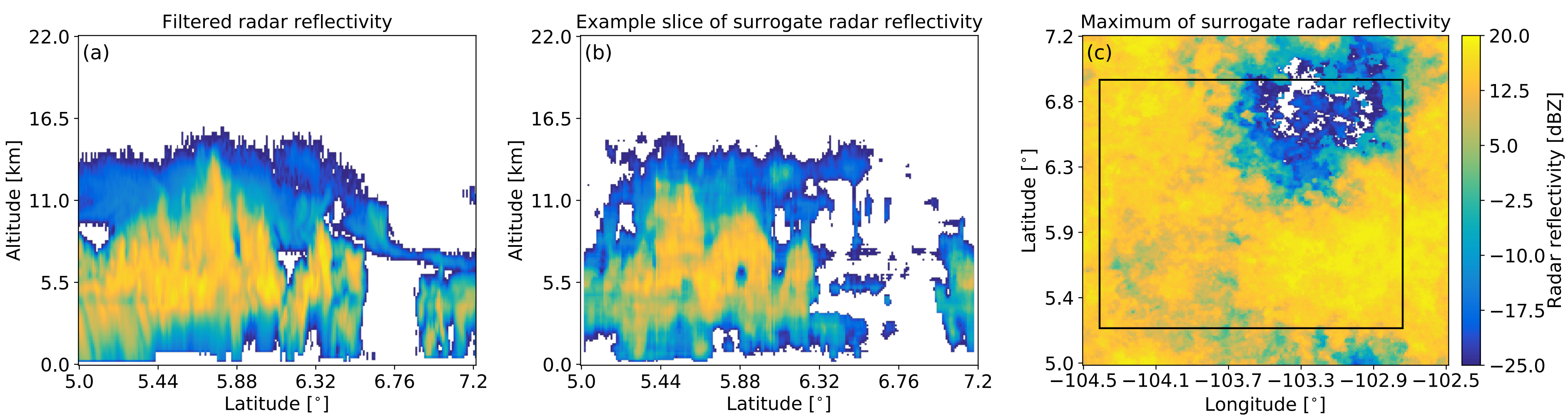

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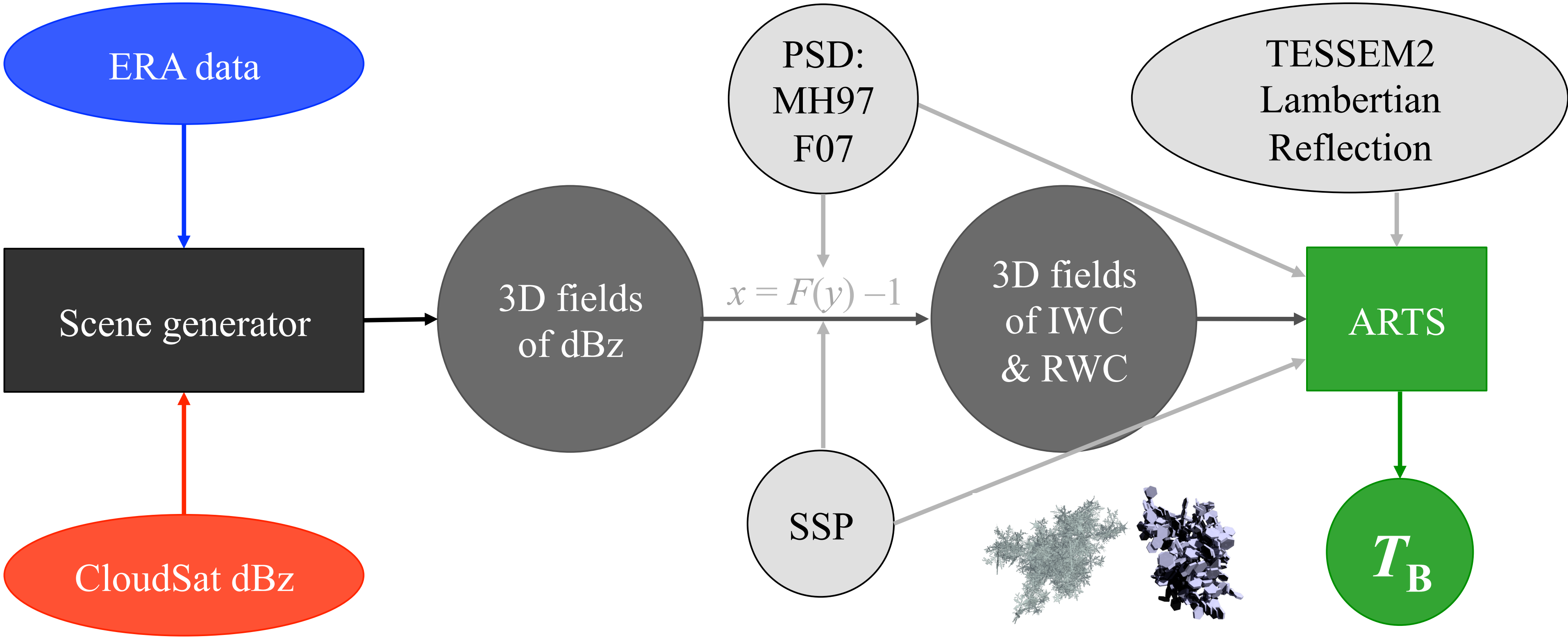
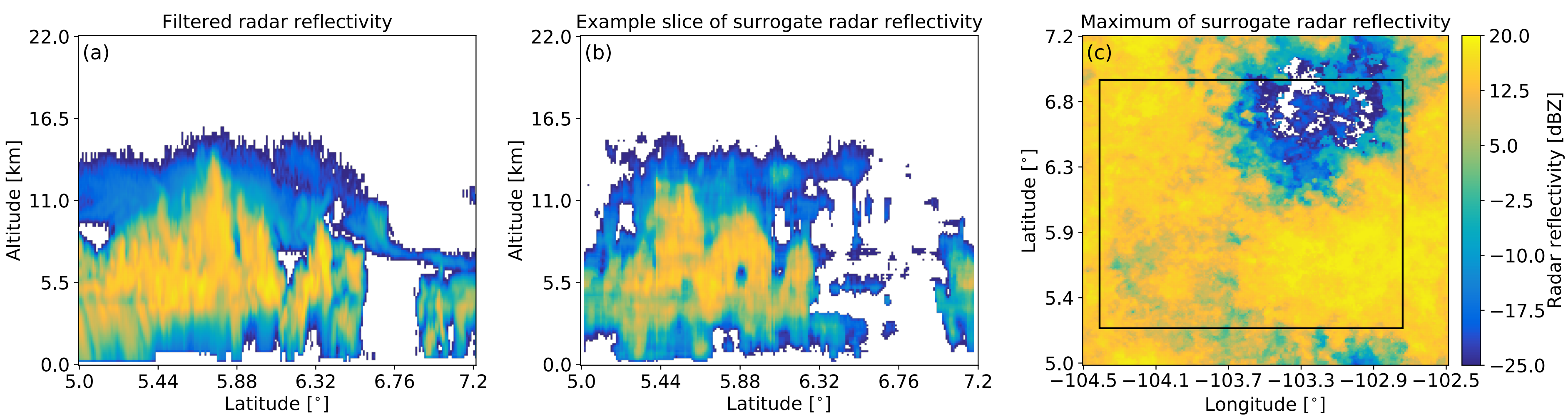
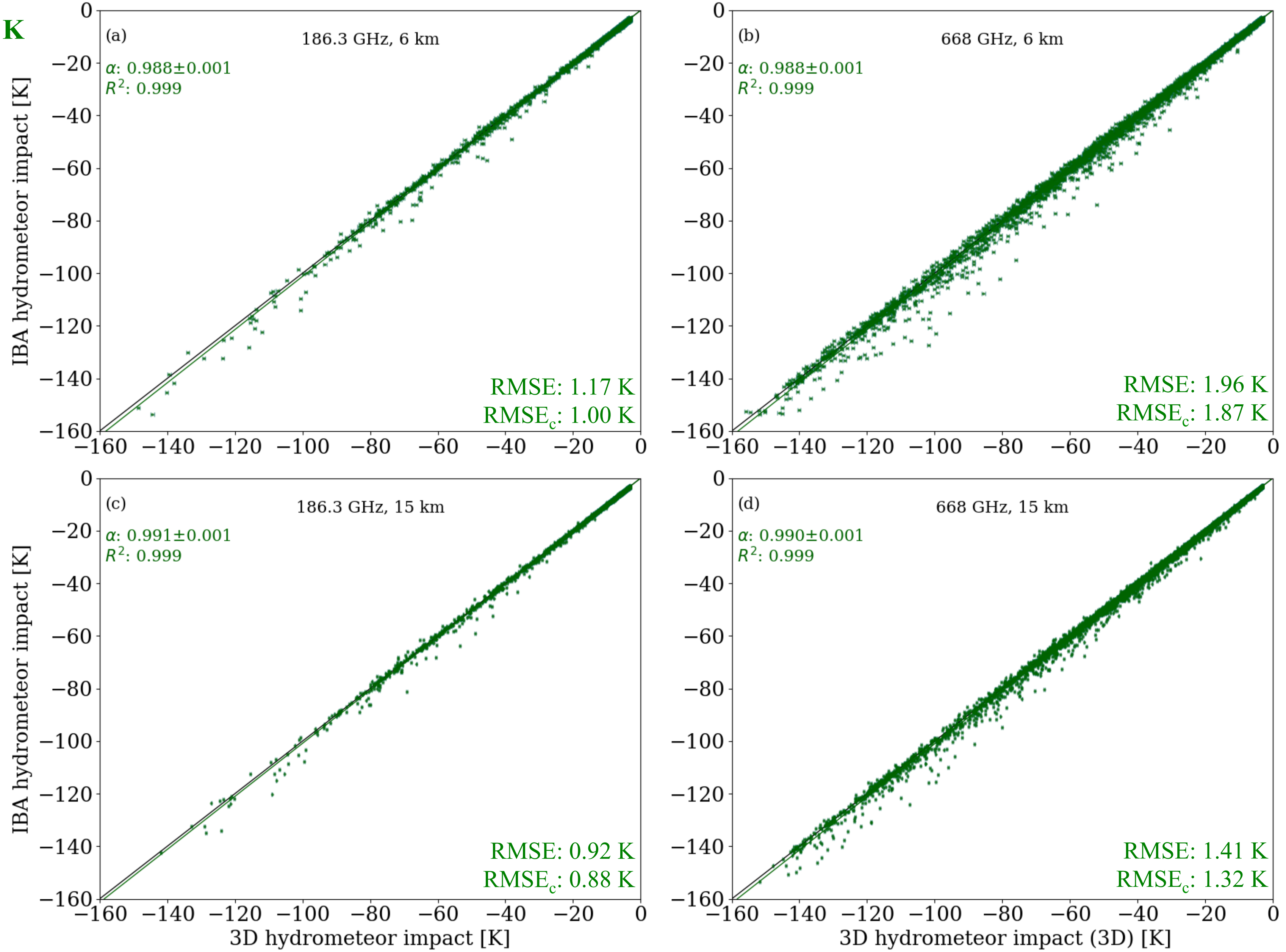




3D Radiative effects – HPT effect

Overall:
mean < 0.43 K



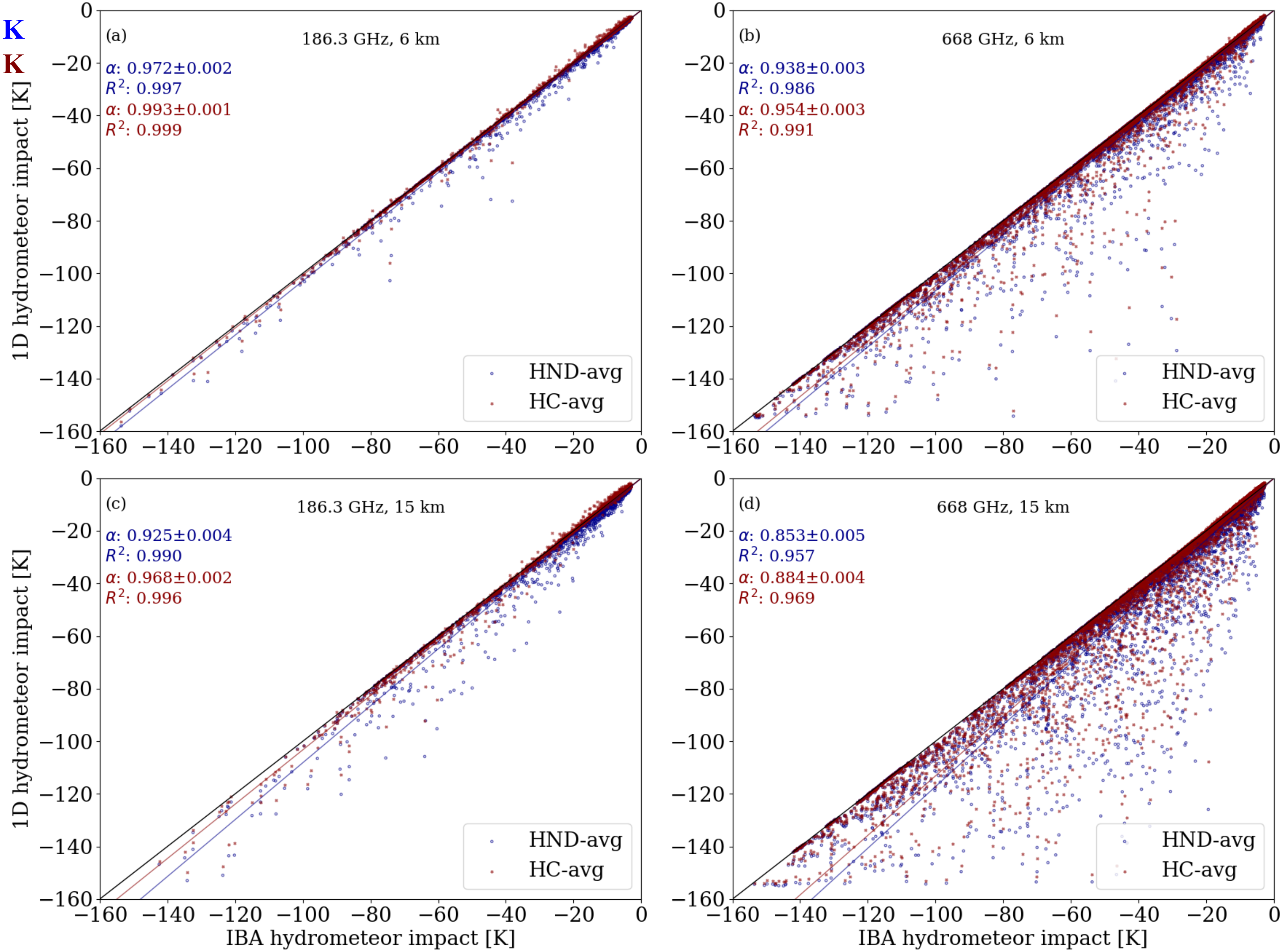
Barlakas and Eriksson., 2020

3D Radiative effects – BF effect

Overall:

mean < 5.97 K

mean < 4.10 K



<u>Barlakas and Eriksson., 2020</u>

3D Radiative effects – BF effect

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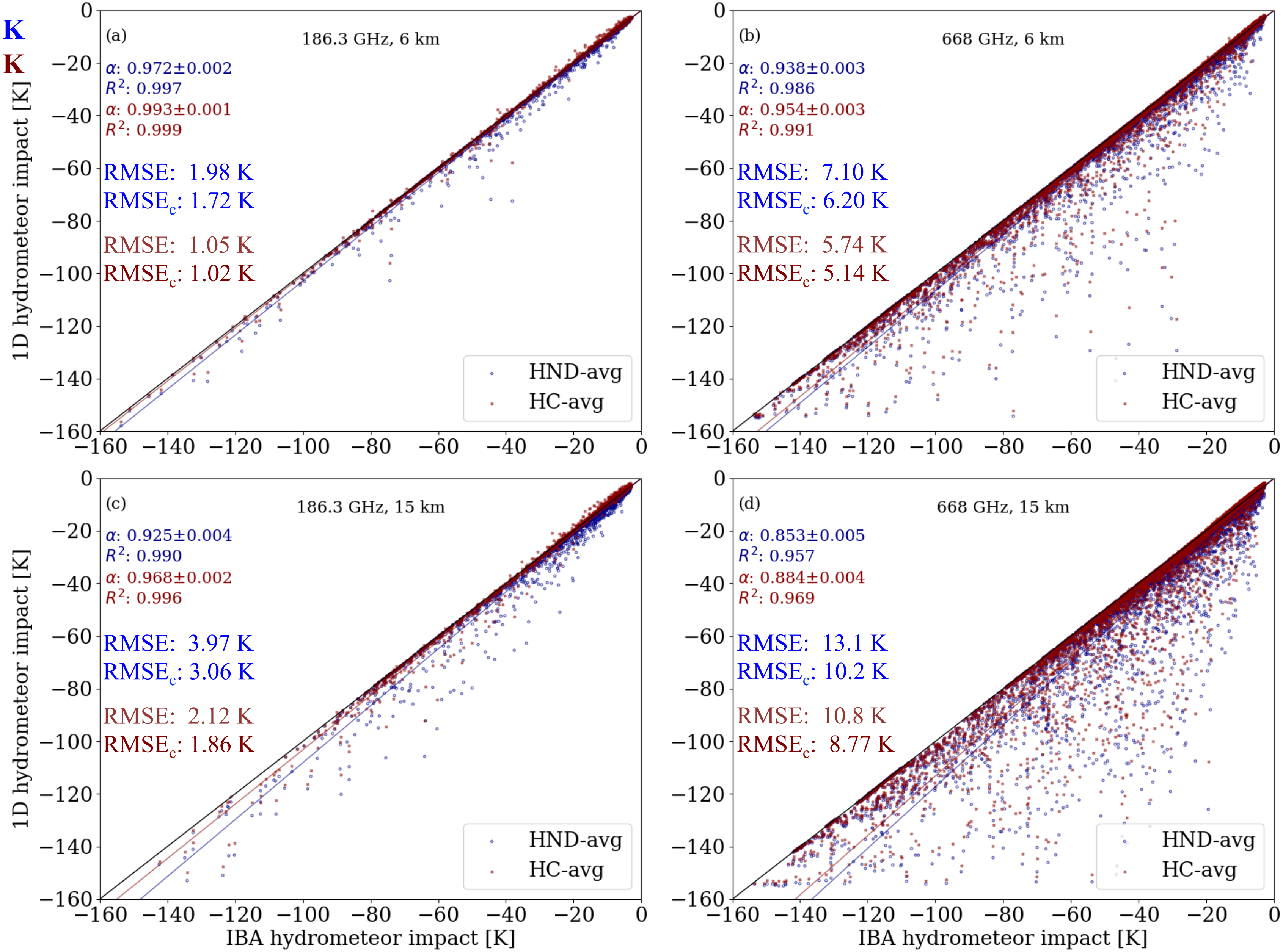

Barlakas and Eriksson., 2020

Summary

- The horizontal photon transport effect induces a slight overestimation and chiefly random errors. Thus, 3D simulations could be replaced by a bias correction in the forward model.

- The total effect is consistent with the BF effect. The root mean square error (RMSE) in:
  - ✓ 1DVAR[1] retrievals, it can be ~14 K at the highest frequency and footprint size.
  - ✓ Data assimilation (183 GHz and footprints between 9 and 36 km) is above ~4 K.

- A significant beam-filling (BF) effect that increases primarily with frequency and, secondly, with footprint size and slant path; RMSE up to ~14 K.

- Independent beam approximation (IBA) is a necessity (e.g., retrieval databases).

- A statistical correction scheme by means of a multiplication factor has been developed that compels the errors induced by the 3D effects to be more symmetric (up to 3.2 K).

Outlook

- Explore the use or the development of correction schemes for the BF effect at mm/sub-mm.
- Particle orientation and 3D effects including polarization.

[1] 1D variational retrievals: AMSU-B
ATMS, GMI, MHS, SSMIS, ICI, MWI,…

Barlakas and Eriksson., *Remote Sens.*, 2020

On the way…

Intercomparison

- ARTS vs RRTOV (-SCATT):
  - Clear sky conditions
  - All-sky conditions

Particle orientation and polarization

- Adapt/extend RRTOV-SCATT:
  - Polarization treatment
  - Particle orientation

Thank you so much for your attention!