CHALMERS
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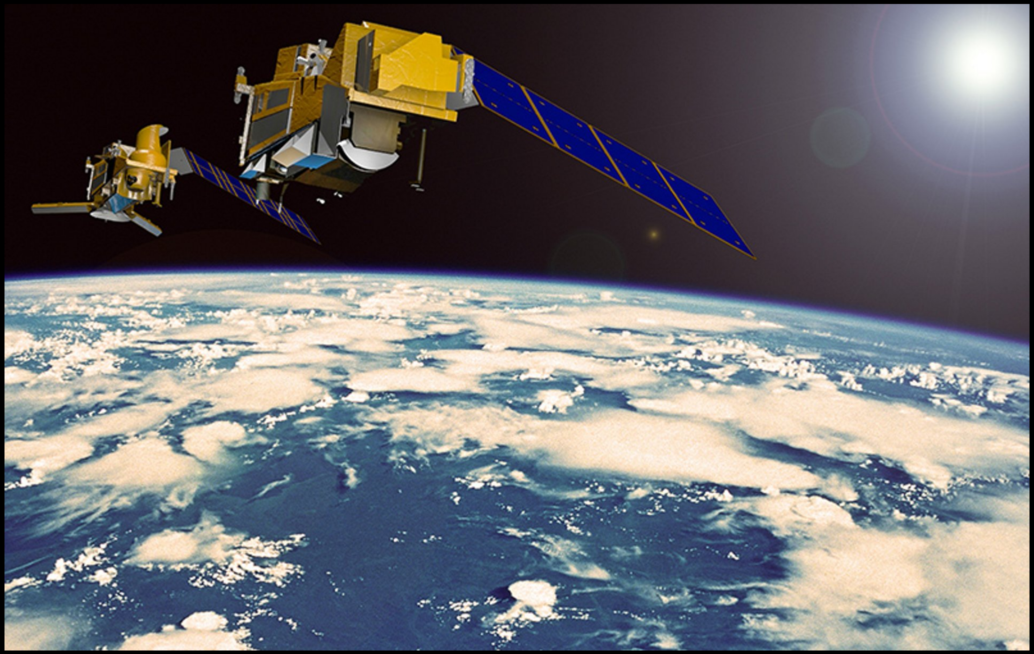
Uncertainty characterization of microwave and sub-millimeter in all-sky radiative transfer

Vasileios Barlakas

Annual Fellow Day
02.03.2020



ECMWF

EUMETSAT

Outline

① Introduction

② Three-dimensional effects in ice retrievals

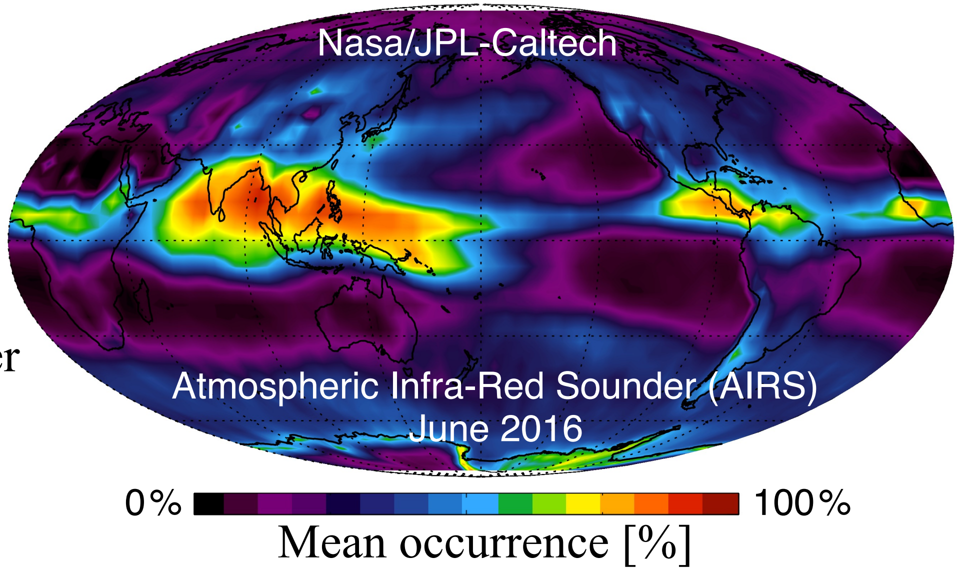
③ Intercomparison study: ARTS vs RTTOV (-SCATT)

④ Particle orientation in data assimilation

⑤ Outlook

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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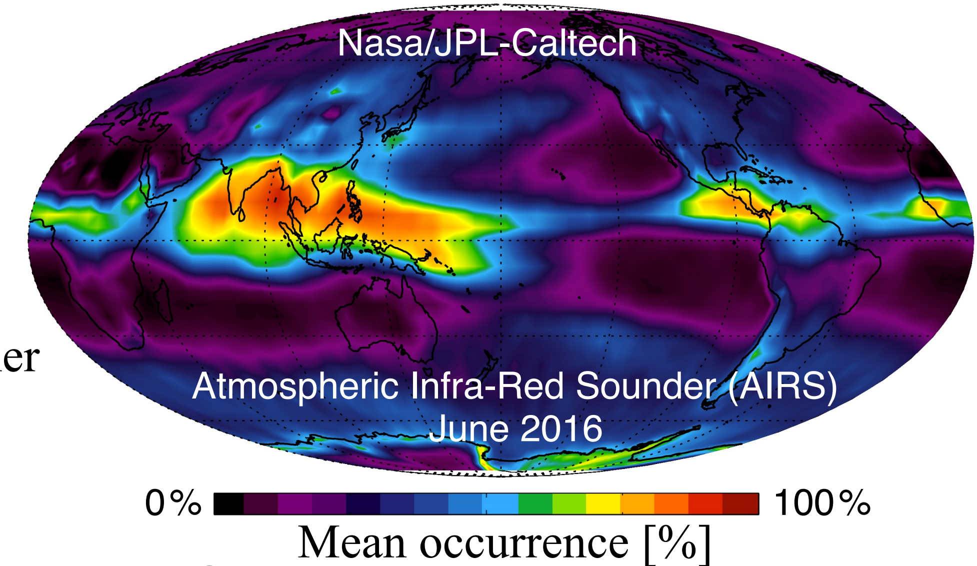
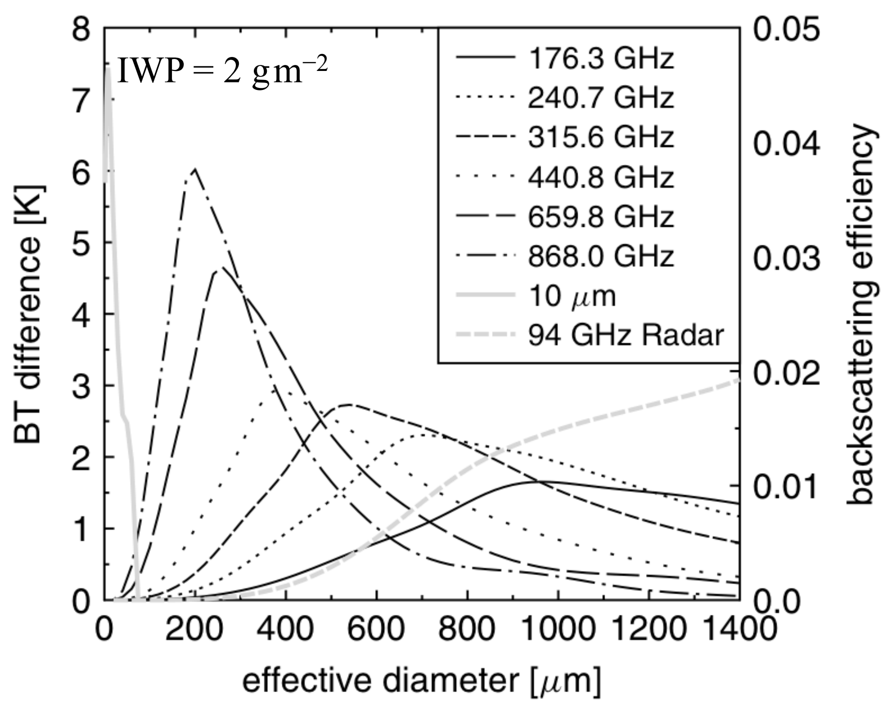


Why microwave (MW) and sub-mm?

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



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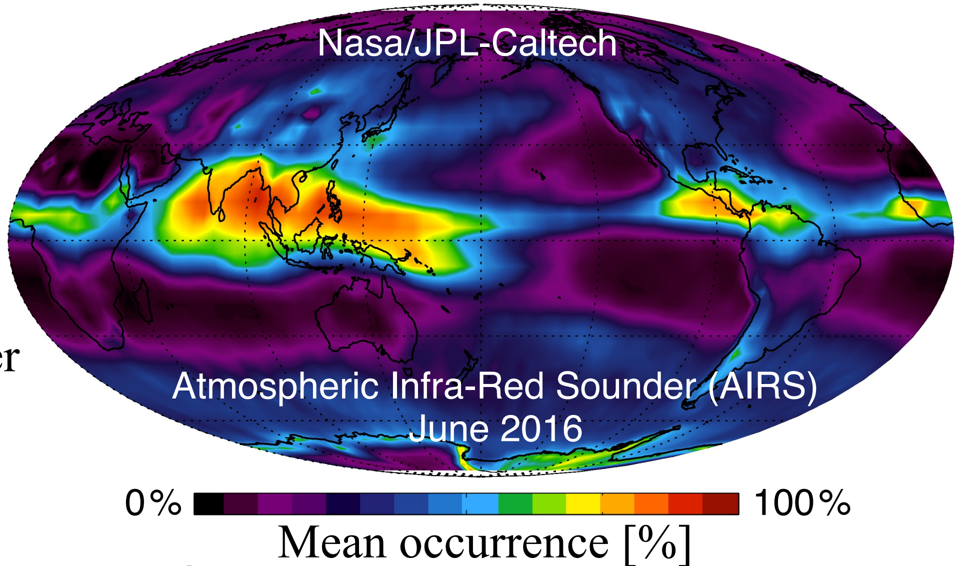

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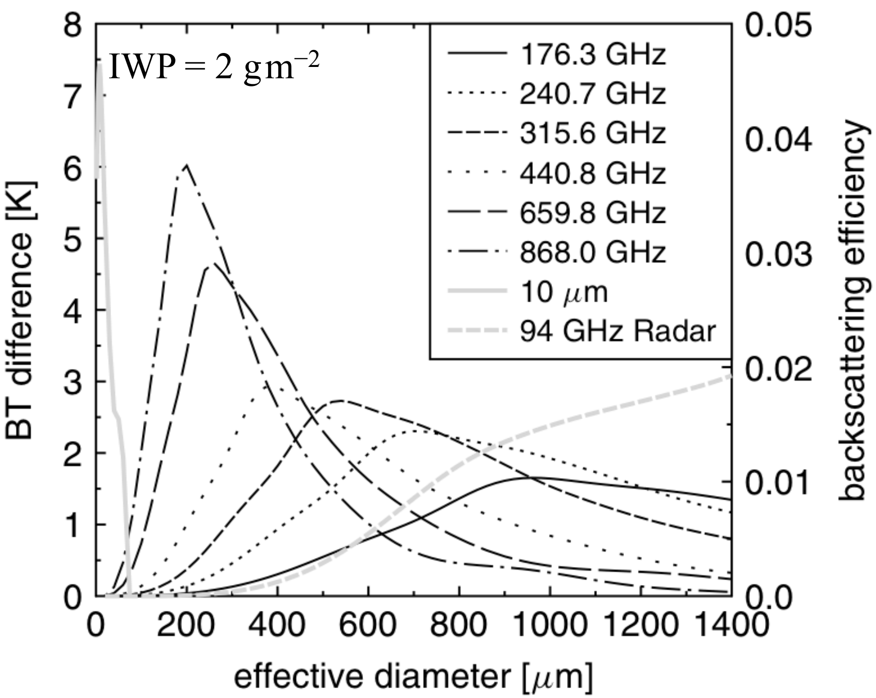


Ice Cloud Imager (ICI)

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

CREATE – Characterizing and REducing uncertainties in All-sky microwave radiative TransfEr

Sensors:

- Microwave Imager (MWI): 18.7 – 183.31 GHz
- **Ice Cloud Imager (ICI): 183.31 – 664 GHz**

CREATE – Characterizing and REducing uncertainties in All-sky microwave radiative TransfEr

Sensors:

- Microwave Imager (MWI): 18.7 – 183.31 GHz
- **Ice Cloud Imager (ICI): 183.31 – 664 GHz**

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

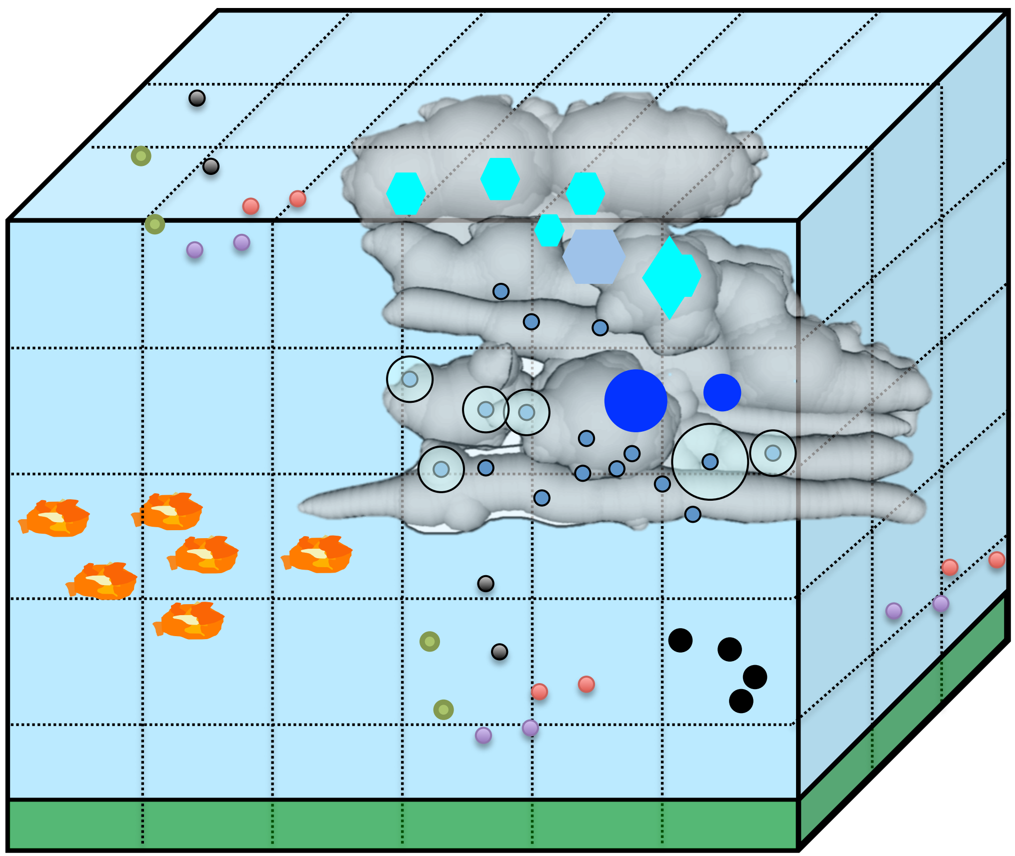
- three-dimensional (3D) radiative transfer is ignored,
- totally randomly oriented hydrometeors are only considered.

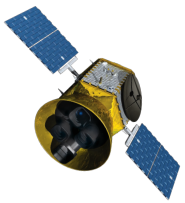
Models:

- ARTS
- RTTOV (–SCATT)

=> Prepare for all-sky assimilation of ICI data

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





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

Calculation modes – 3D, IBA, 1D

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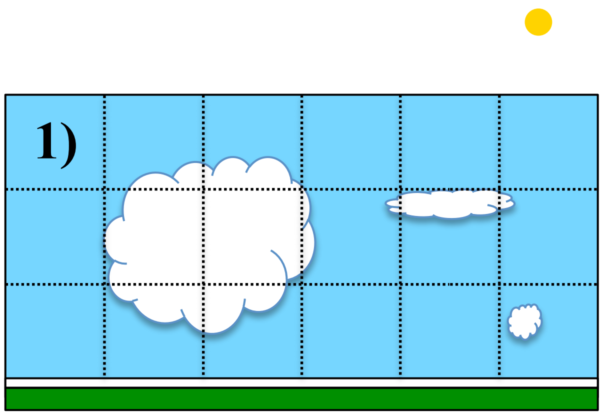

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β_4	β_5	β_6
β_7	β_8	β_9

2D slice of 3D

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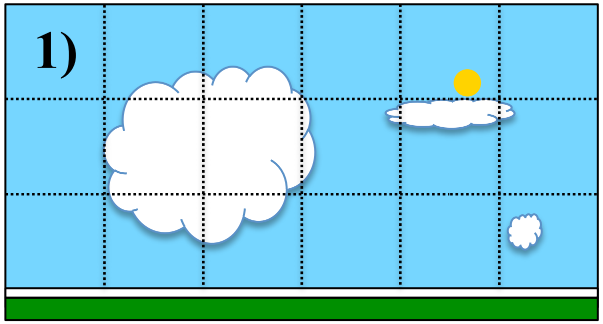

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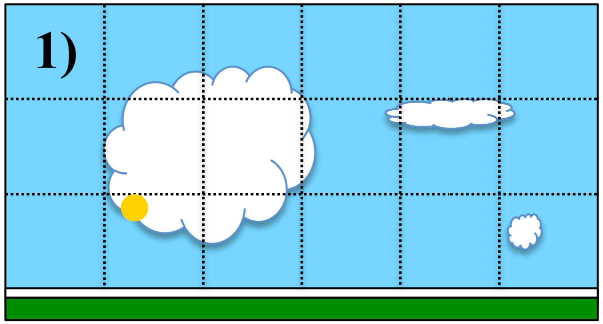

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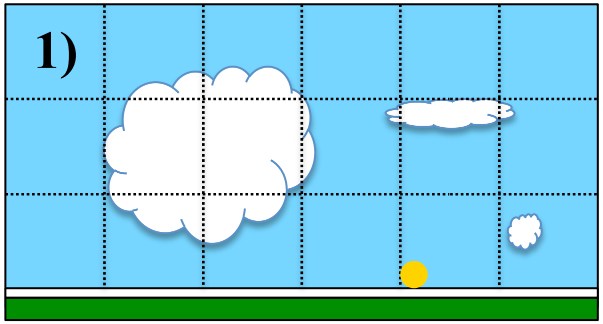

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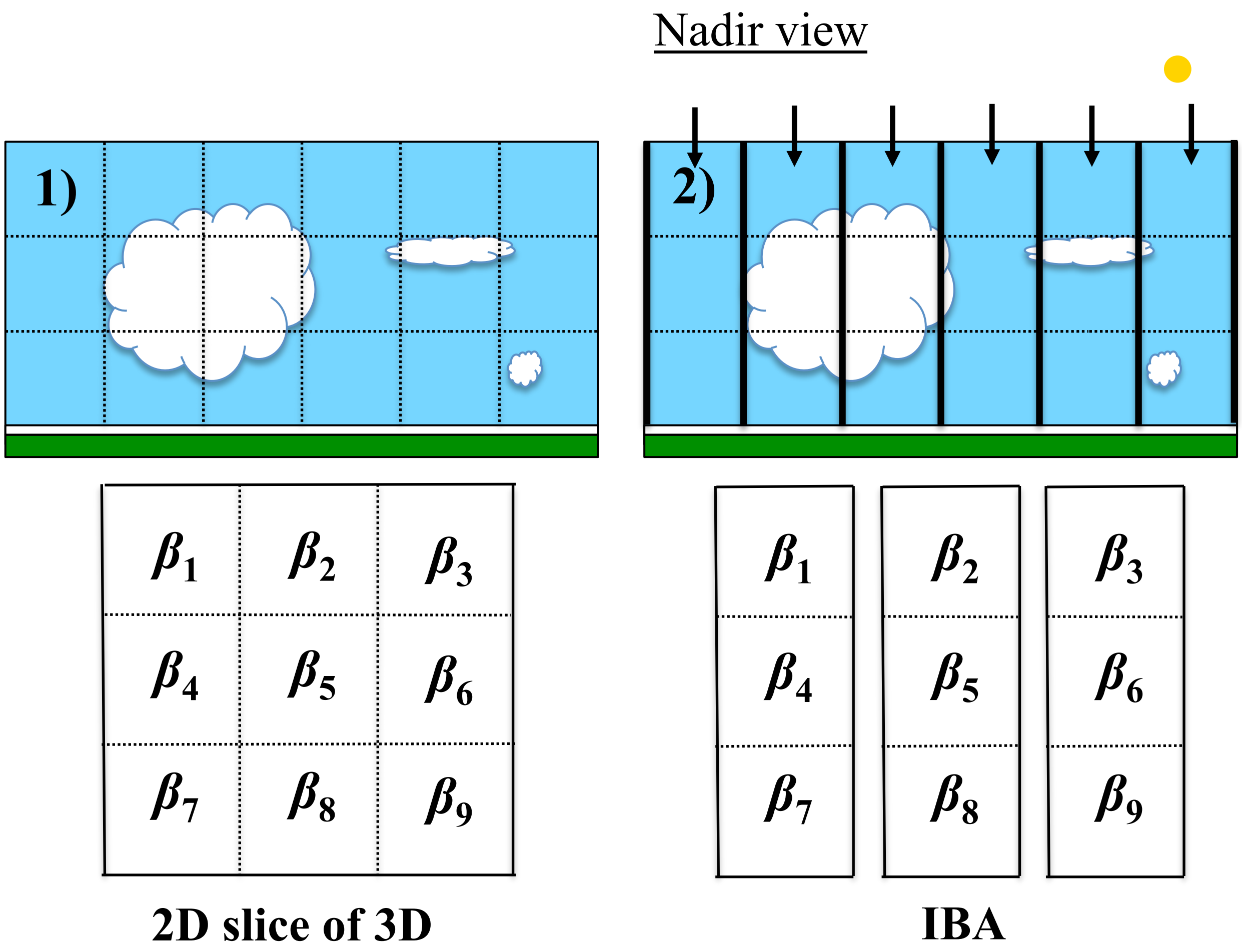

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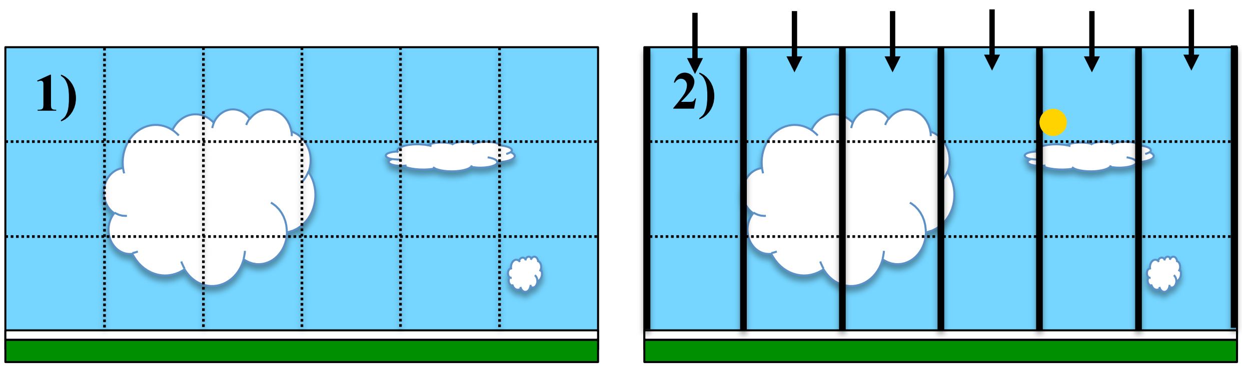

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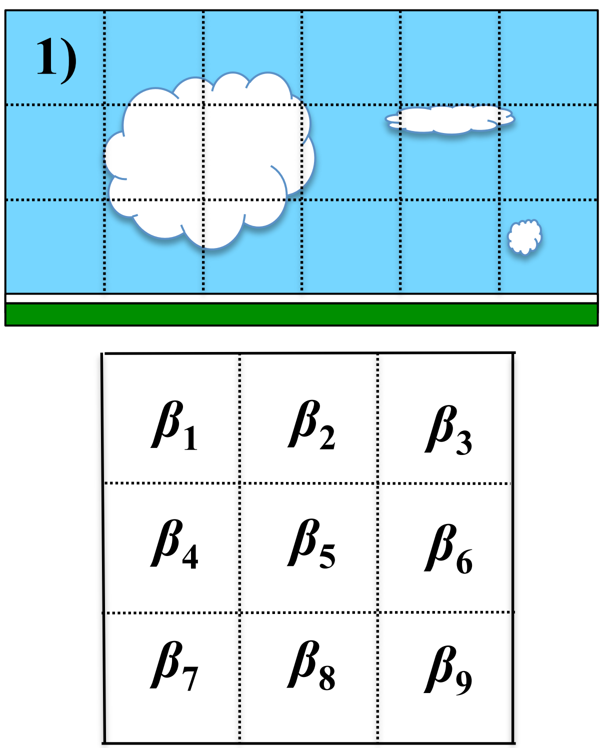

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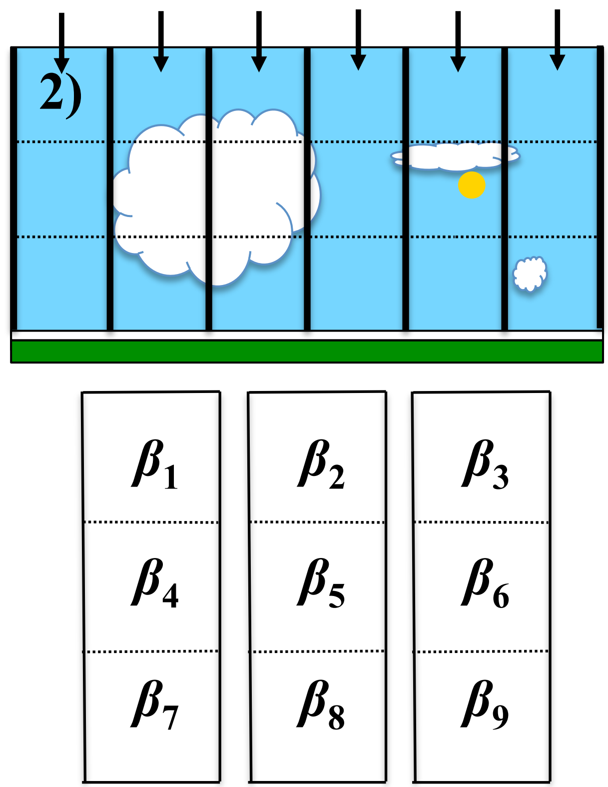

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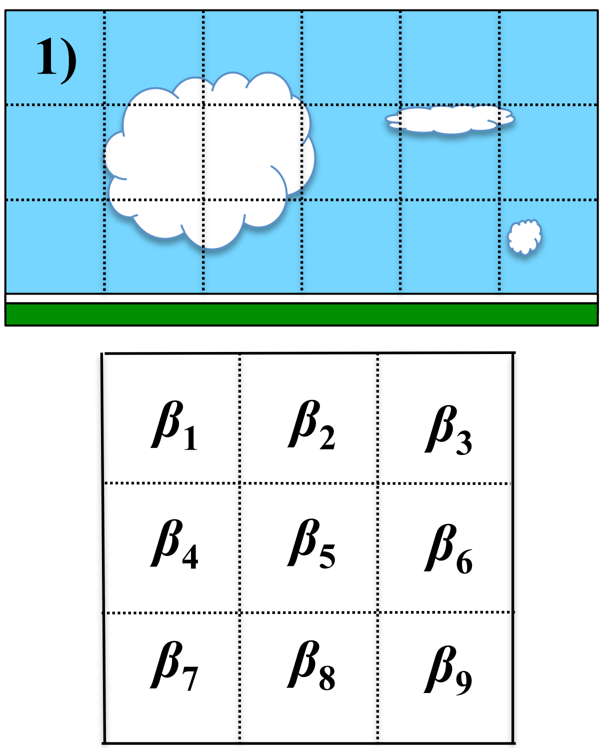

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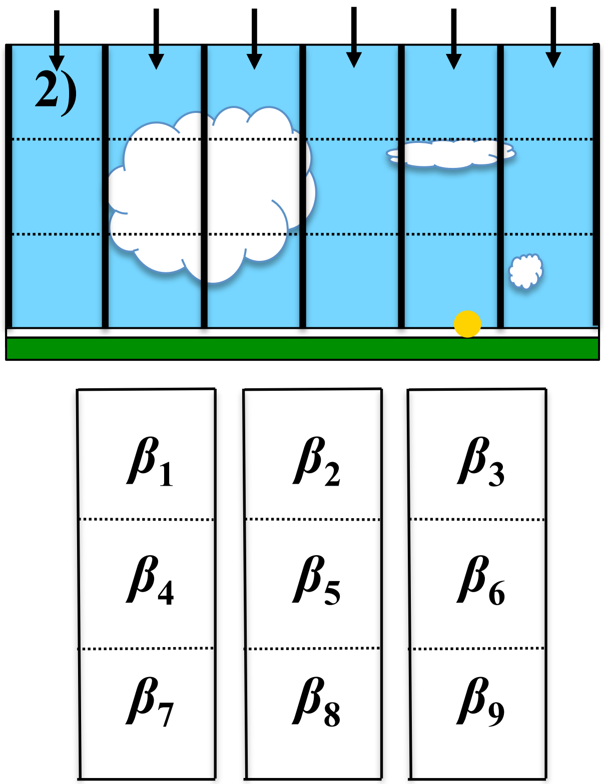

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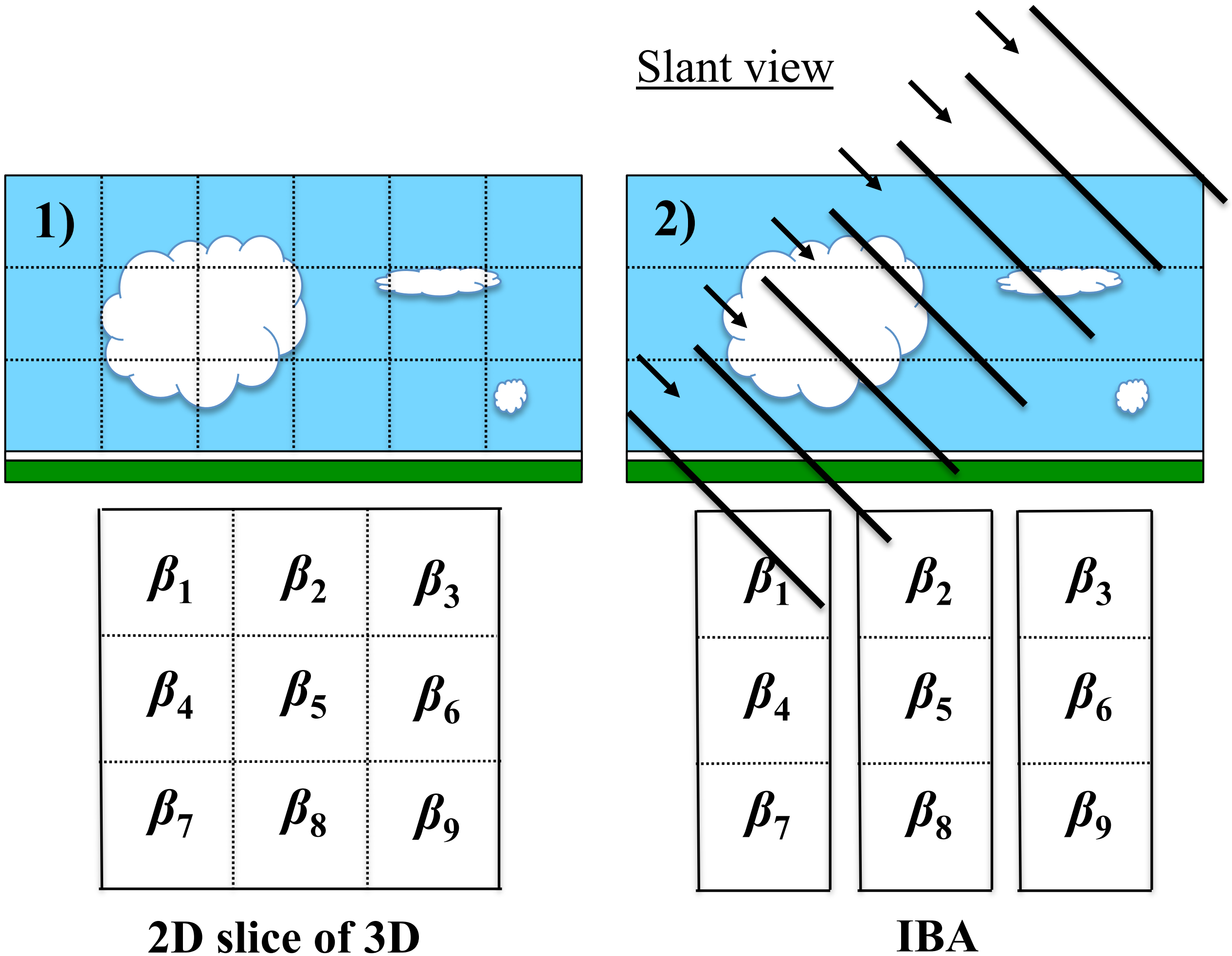

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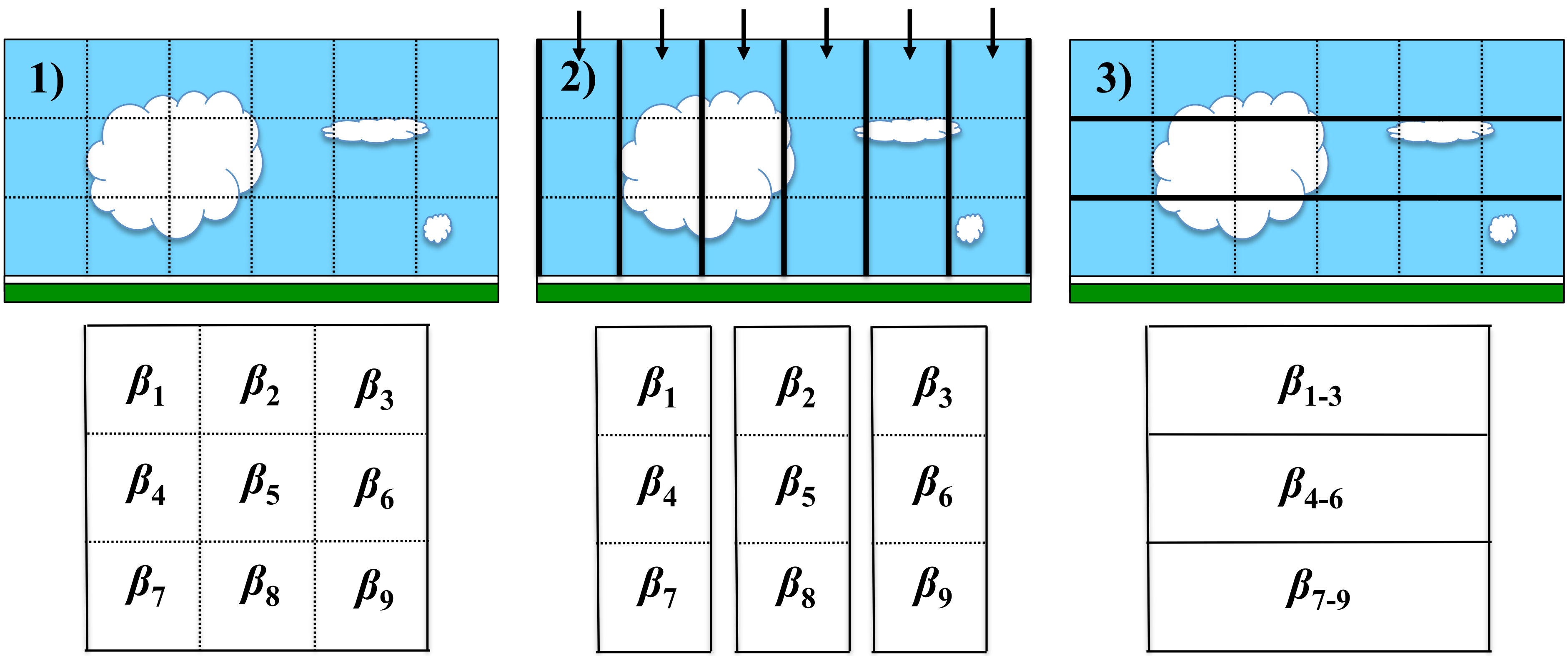
   - ✓ Hydrometeor Content – average (HC-avg)



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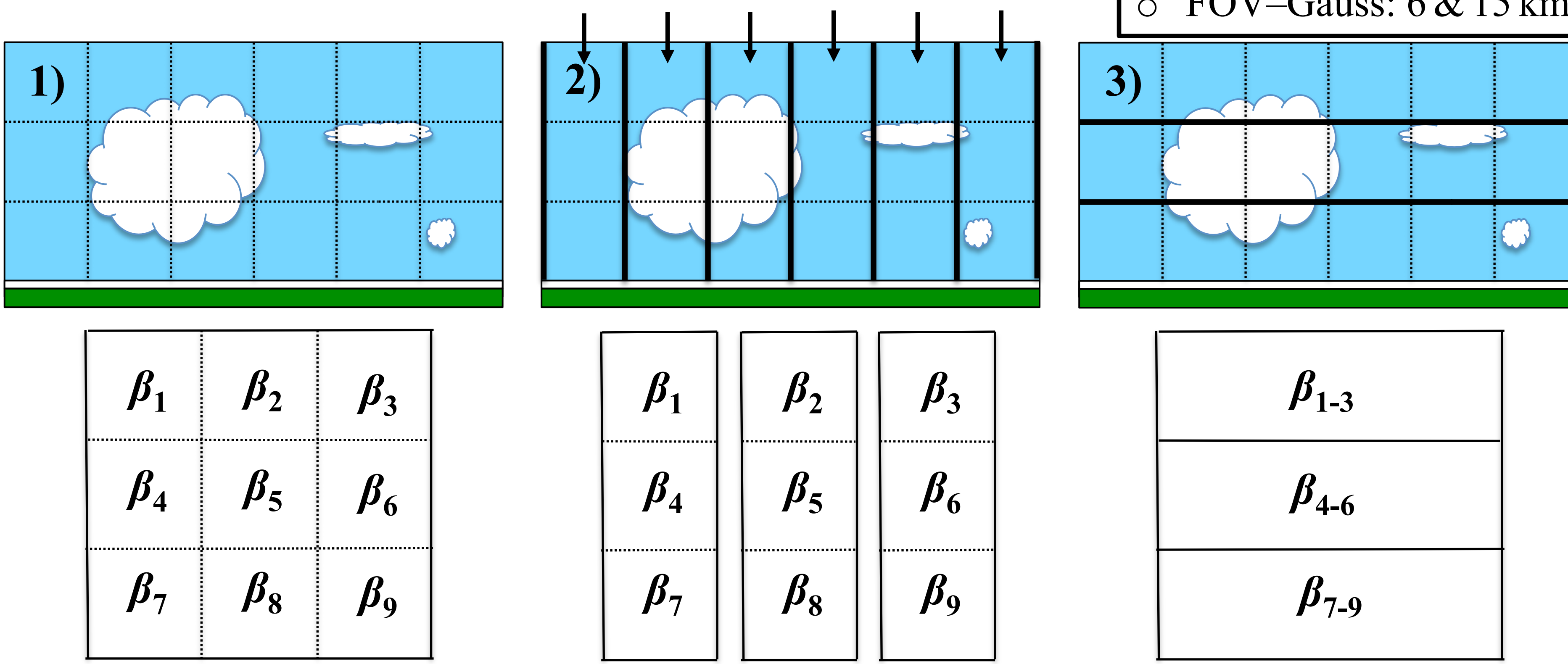
Settings:
- View: 0° & 53°
- Freq.: 186.3 & 668 GHz
- FOV–Gauss: 6 & 15 km



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Post-processing:

- Simulations in 2km grid
- Average over FOV

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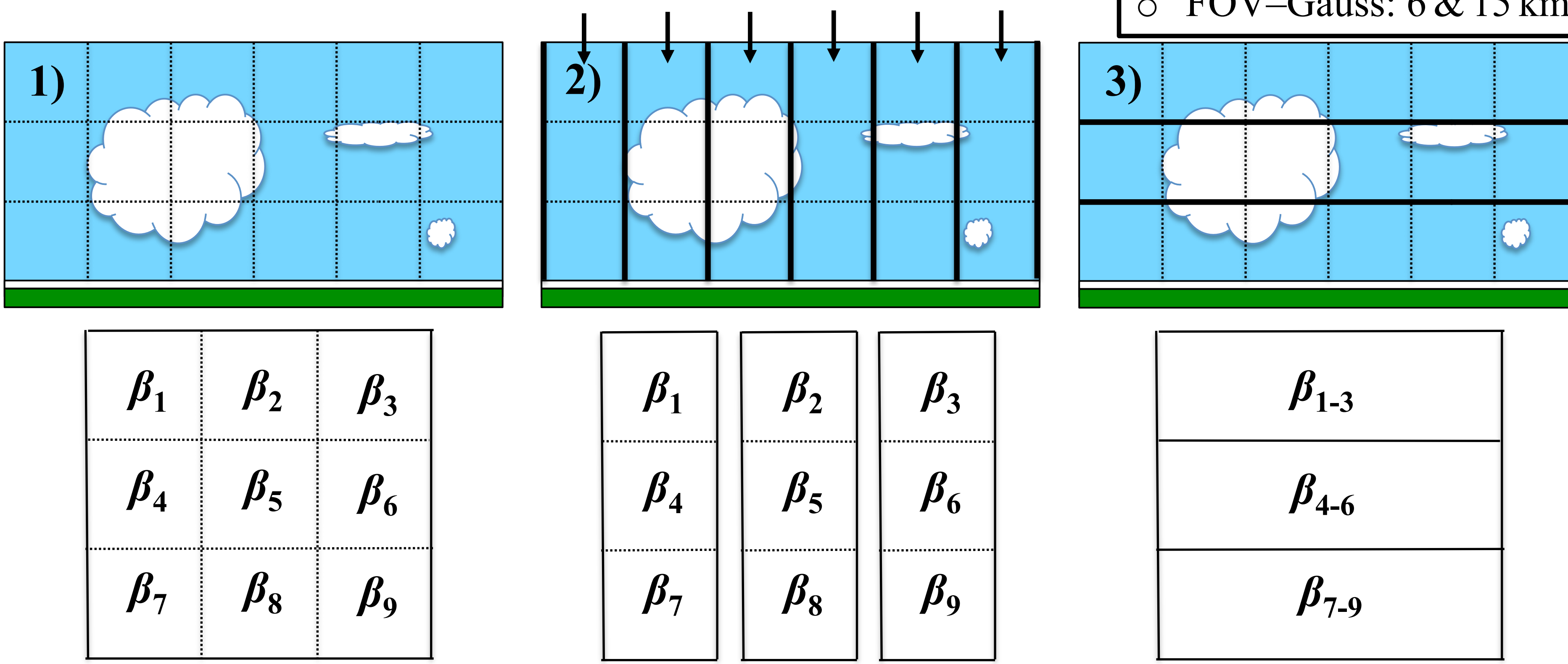

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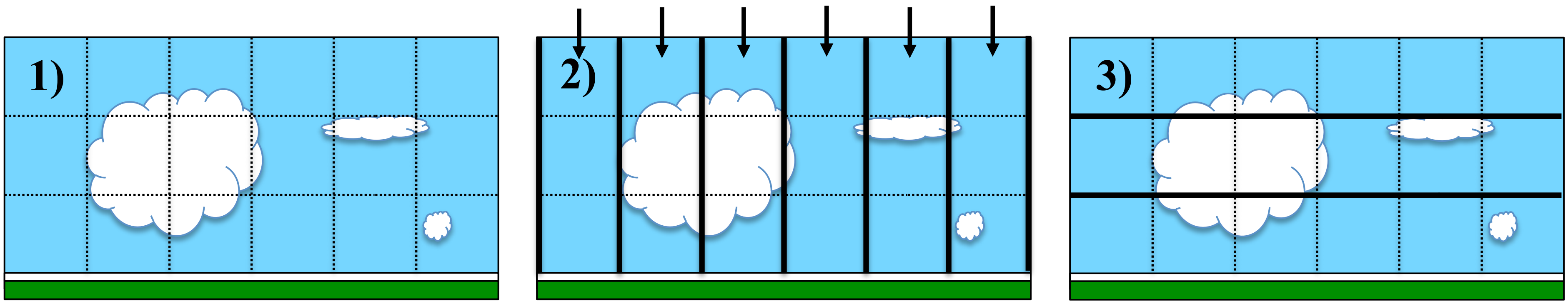
Hydrometeor Impact:

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



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

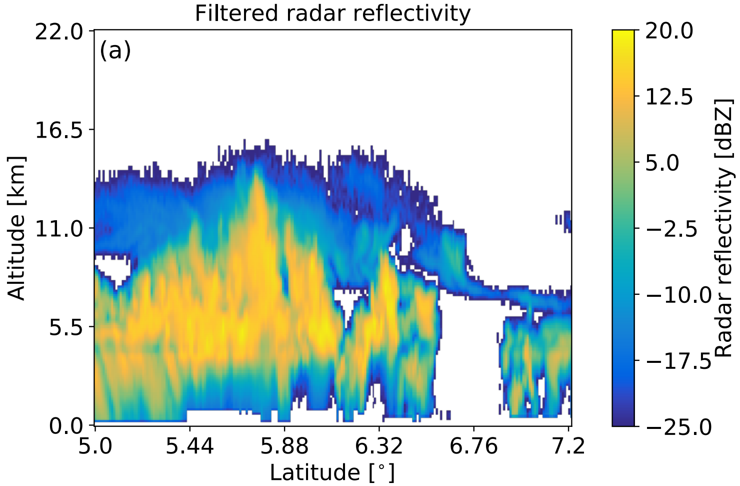
IBA vs 1D → **Beam–Filling (BF)** effect
=> Neglect of domain heterogeneities

3D vs 1D → **Total Effect**

3D Radiative effects – Synthetic scene

ERA data

CloudSat dBz



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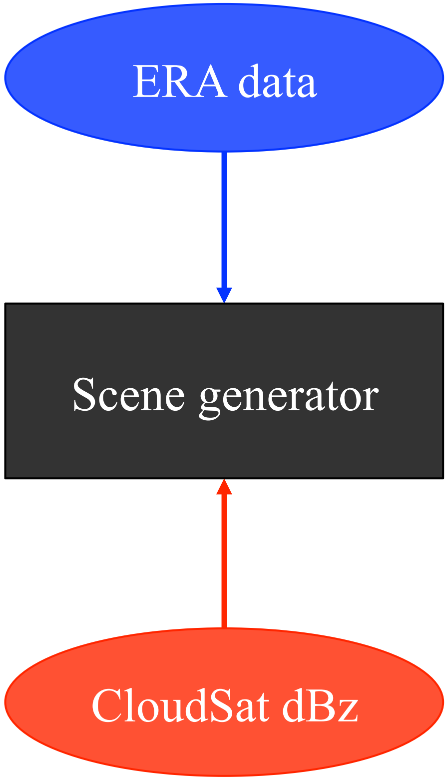

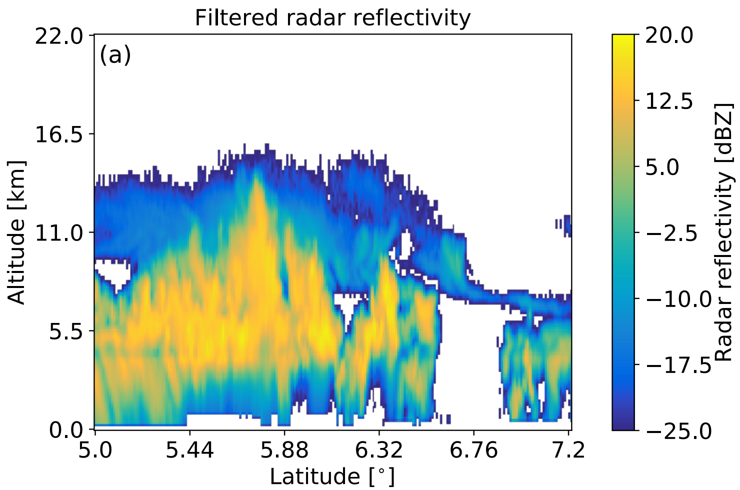

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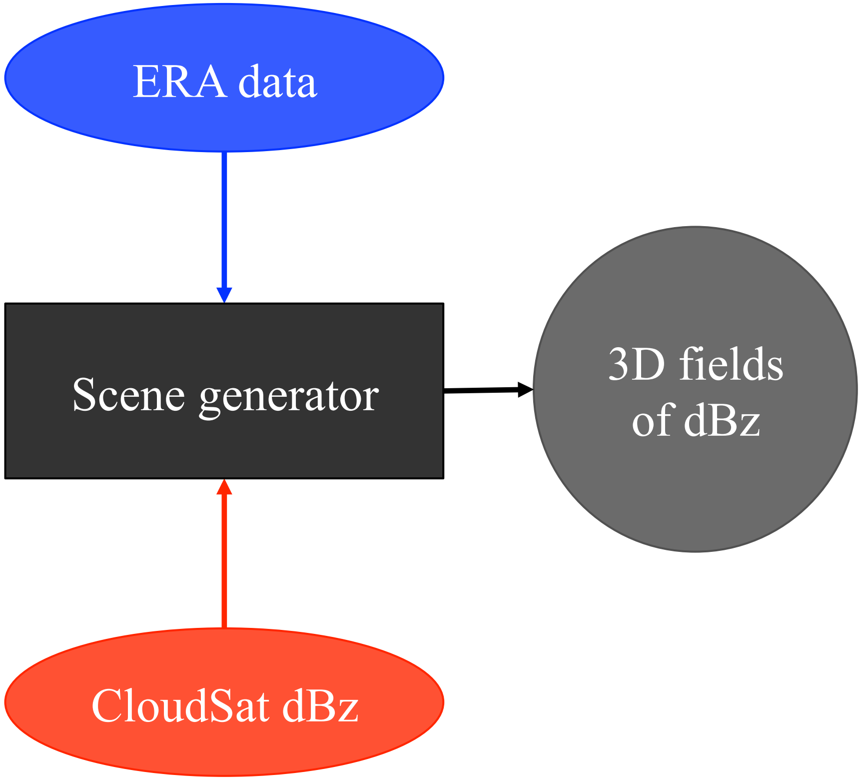
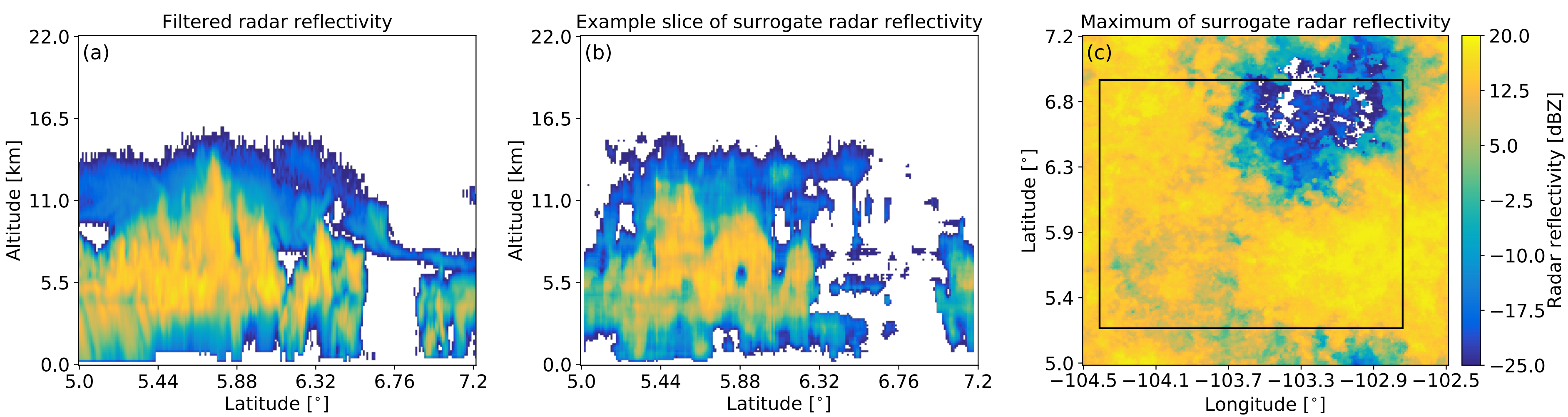


CloudSat overpasses:

- Tropics: 30 (July 2015) => 55 scenes
- Mid-Latitudes: 29 (January 2015)=> 58 scenes

- Each scene: 160 km by 200 km



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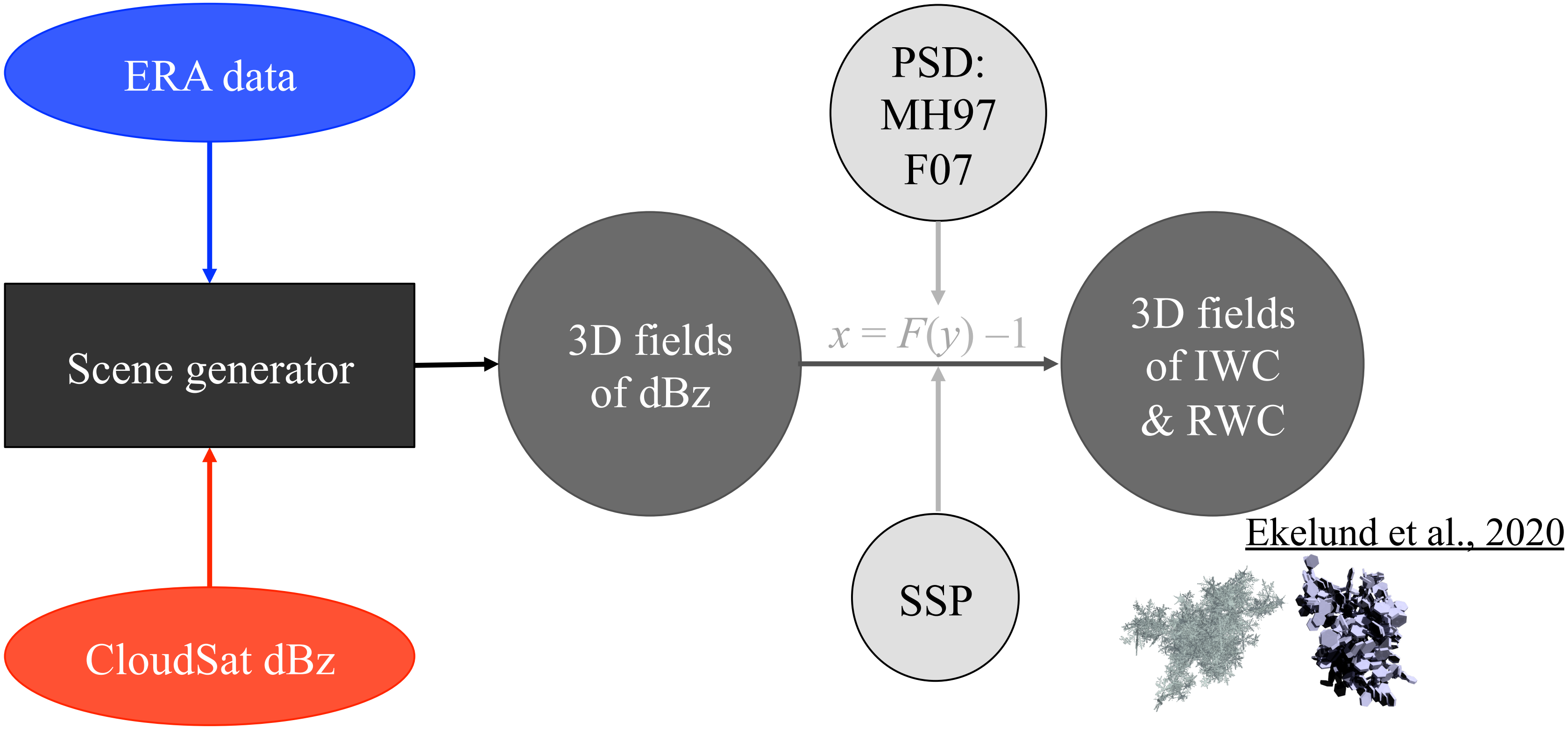

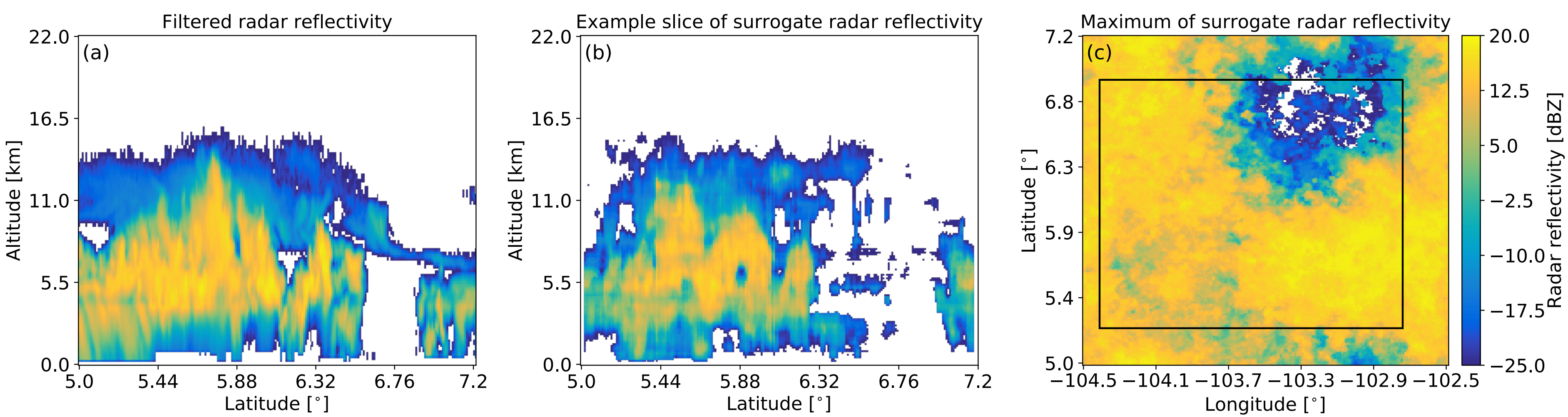

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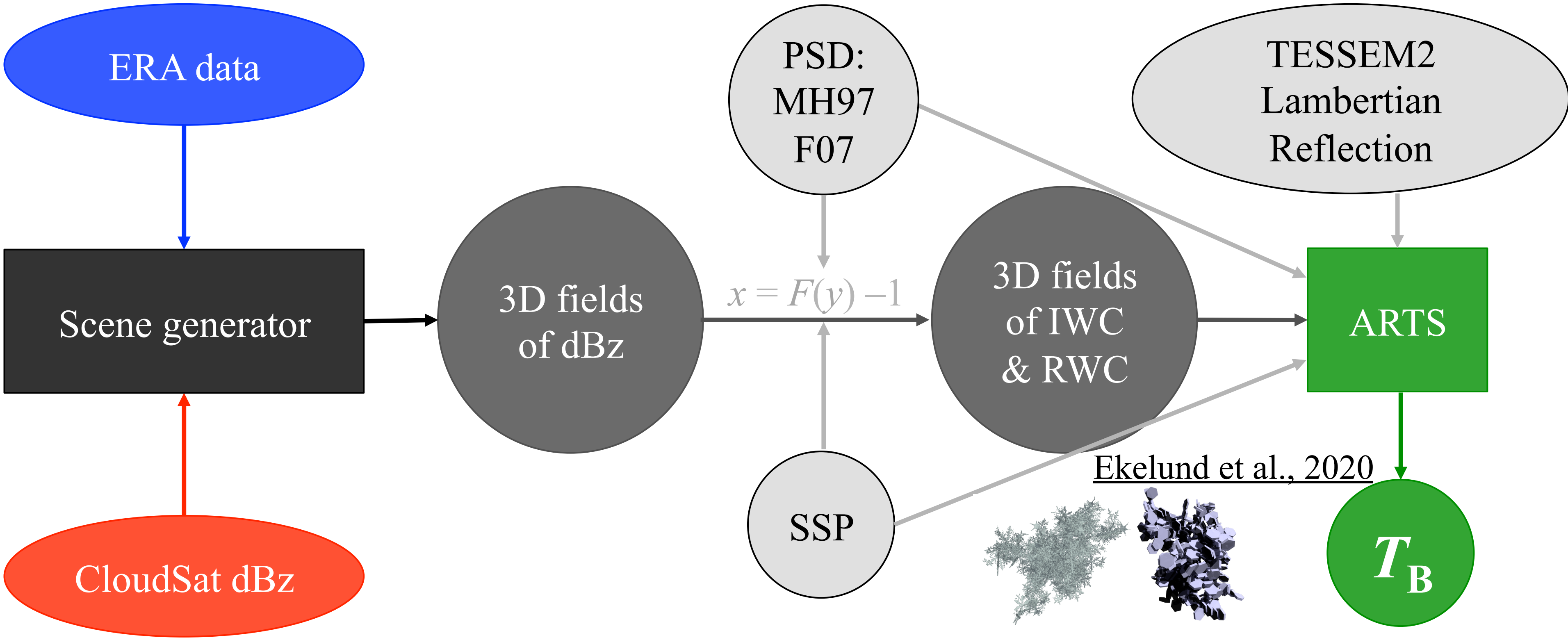
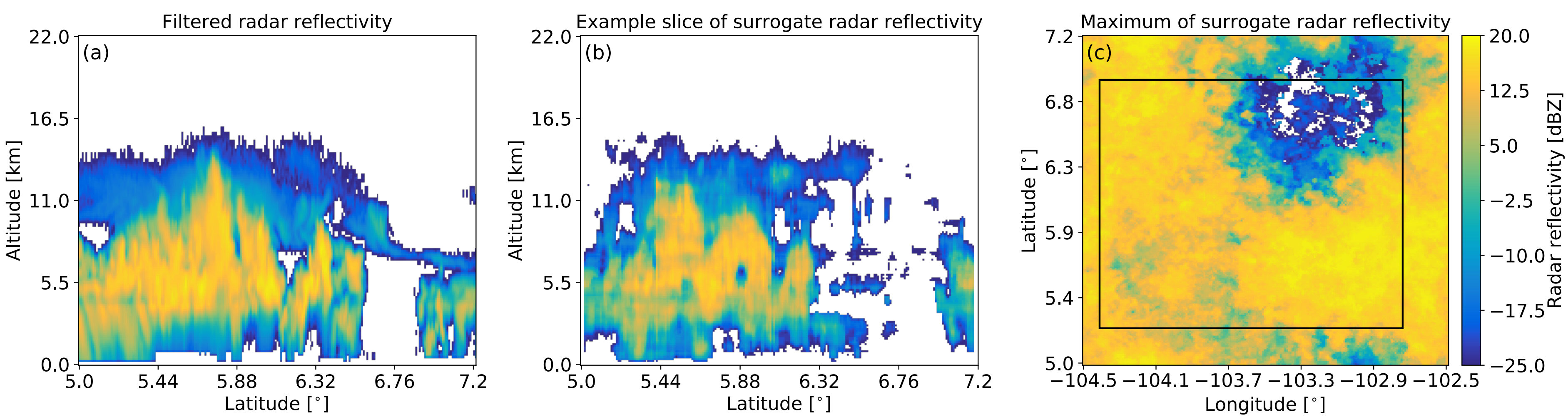
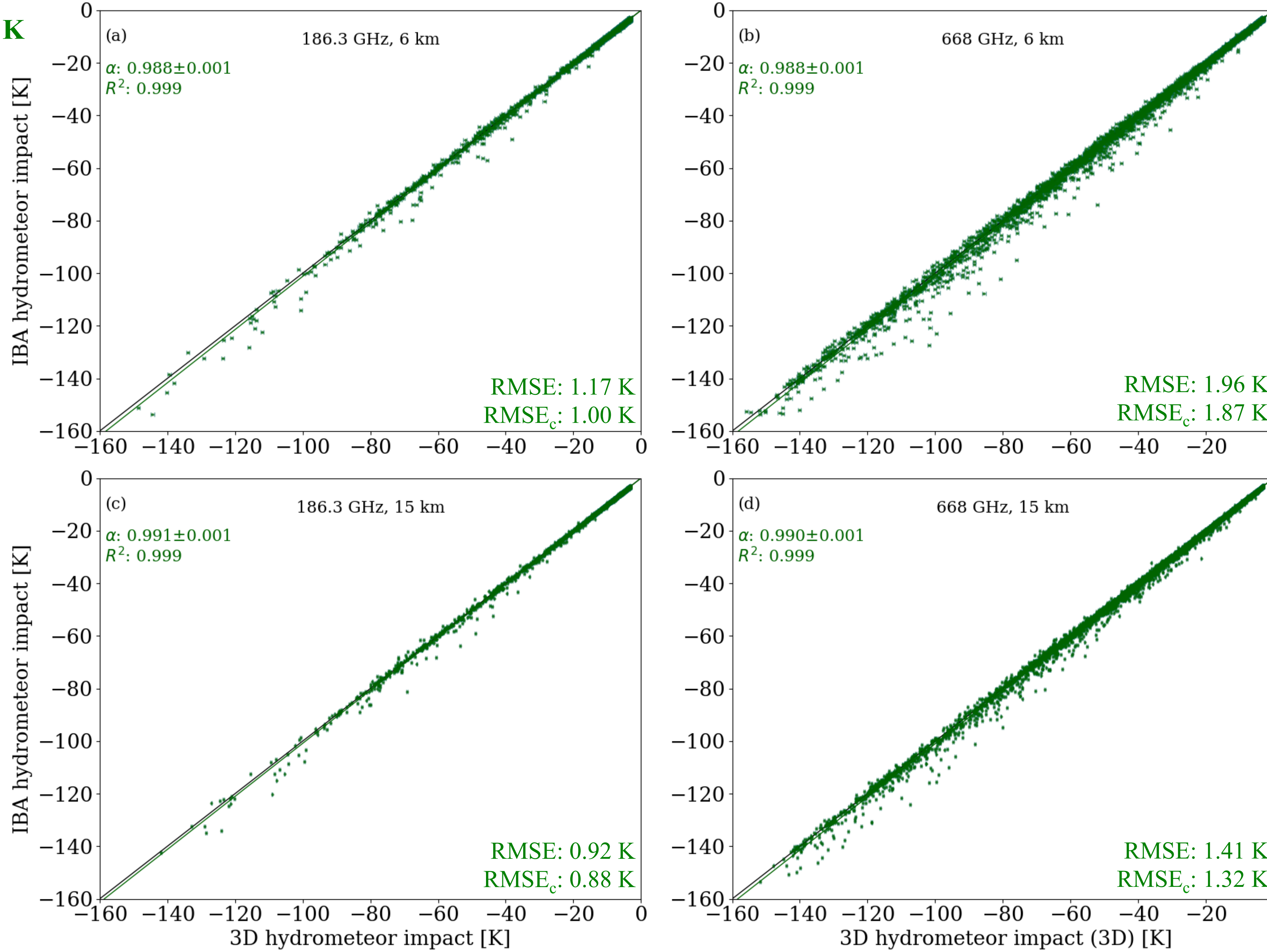




HPT effect – Tropics (slant view)

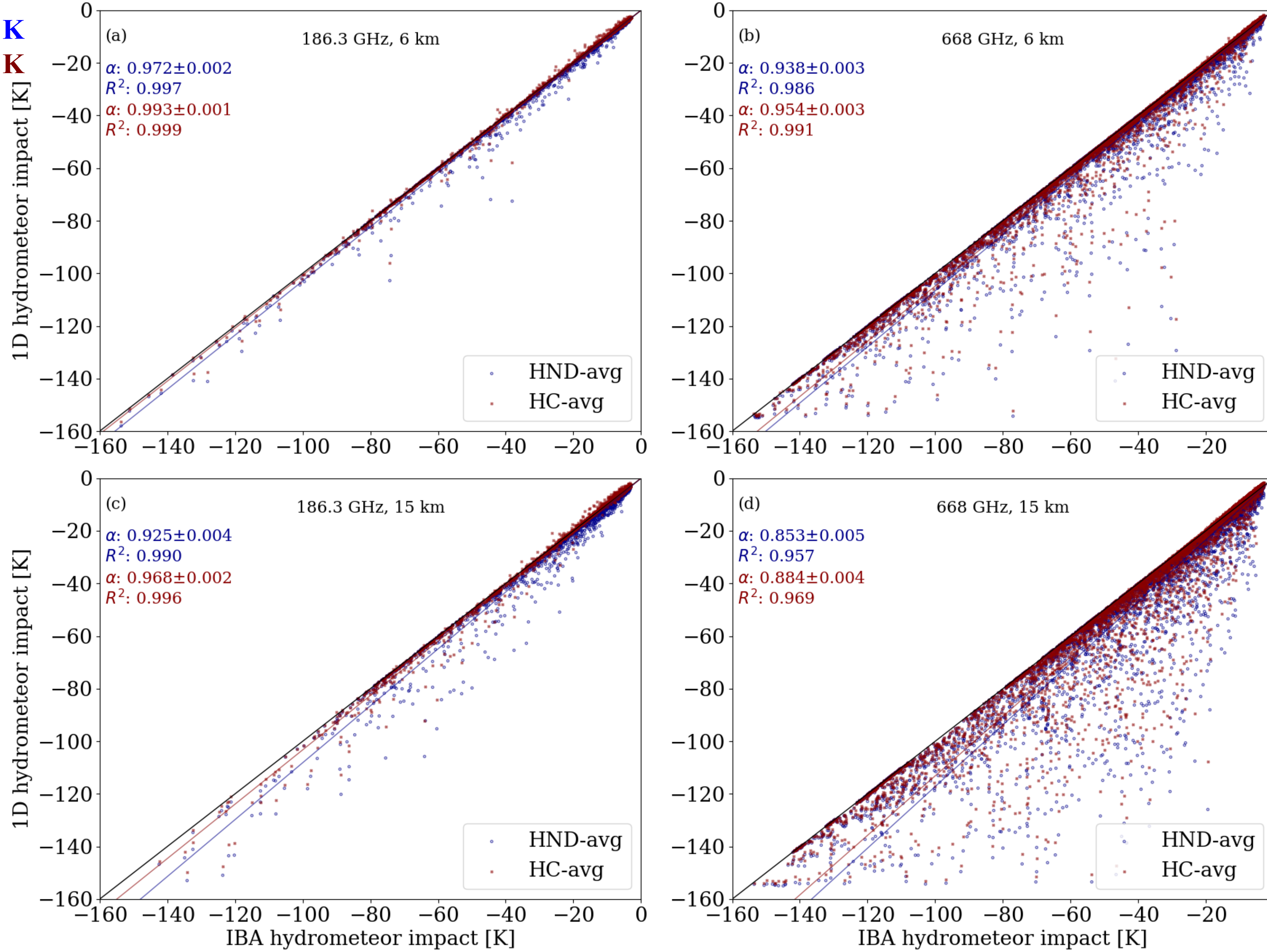
Overall:
mean < 0.43 K



Barlakas and Eriksson., 2020

BF effect – Tropics (slant view)

Overall:
mean < 5.97 K
mean < 4.10 K



Barlakas and Eriksson., 2020

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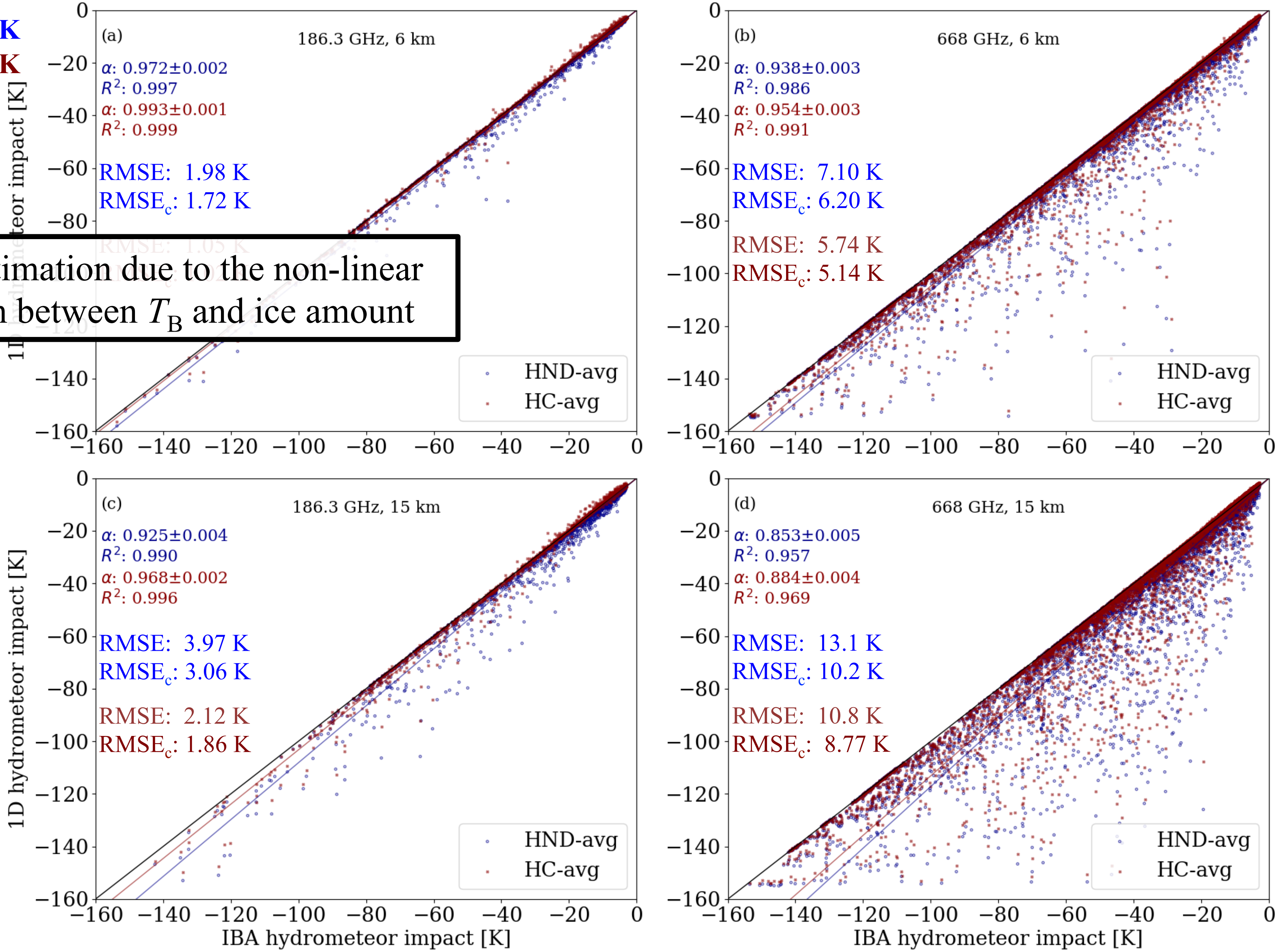

Overestimation due to the non-linear relation between T_B and ice amount

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).
- At mid-latitudes 3D effects are less pronounced due to less ice and more H_2O absorption.
- 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

Assumptions in RTTOV – SCATT

- Scattering of ice hydrometeors is treated in a simplified matter
  - Following Geer and Baordo (2014)
- It applies a two-stream approximation.
- Data is extracted column-wise and maximum cloud overlap is assumed.
- Three-dimensional effects are neglected.
- Particle orientation and polarization.

Objectives:

- By means of ARTS characterize and improve the accuracy of RTTOV–SCATT
- Prepare RTTOV–SCATT for ICI.

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

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ARTS vs RRTOV (–SCATT):
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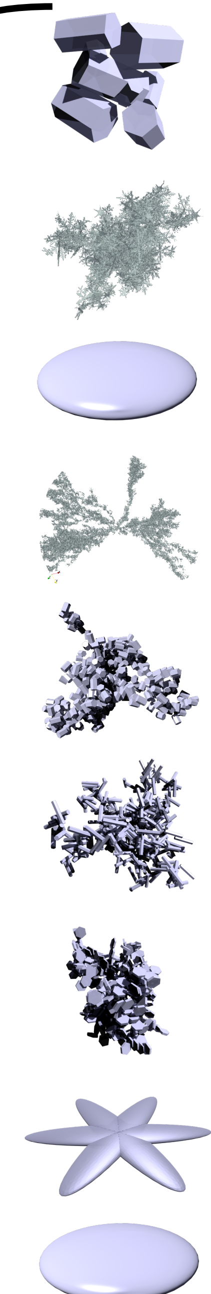
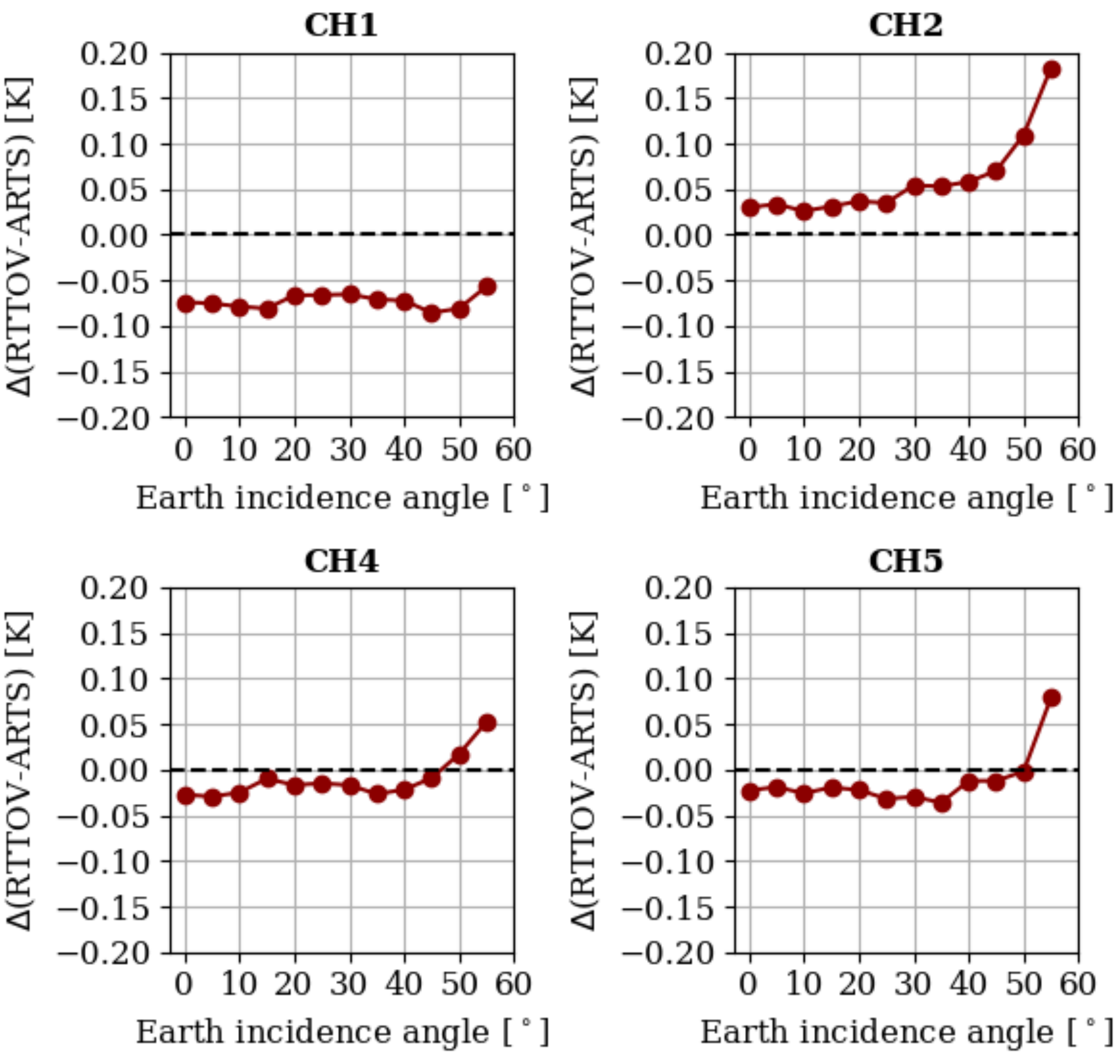
Currently:
- Microwave Humidity Sounder (MHS)
- ARTS Scattering database

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

Eriksson et al., 2018



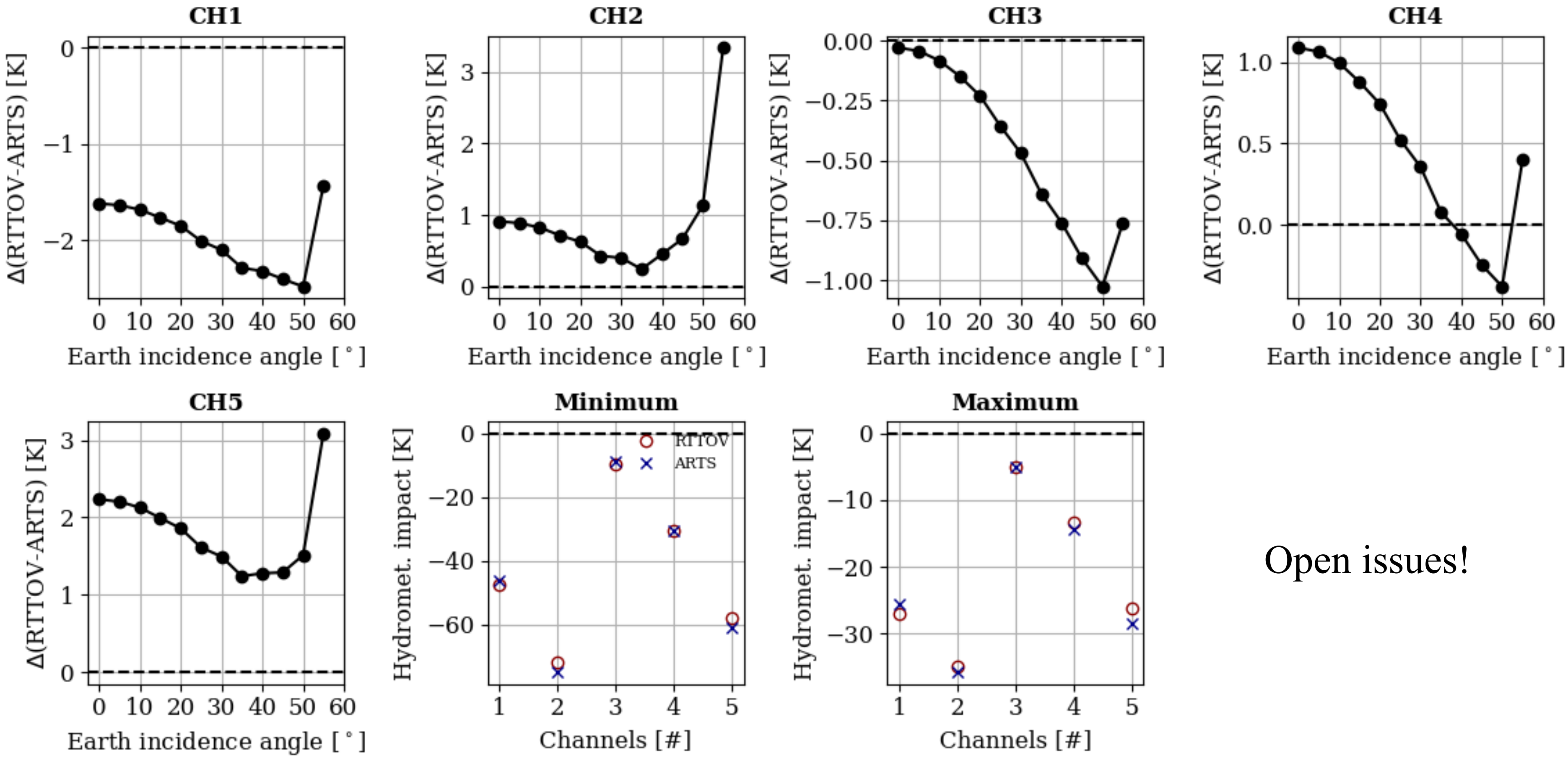
Clear–sky comparison



Settings:

- US standard atmosphere
- Surface emissivity = 1

All–sky comparison



Open issues!

Settings:

- US standard atmosphere
- Surface emissivity = 1
- Rain (Liquid spheres; Marshal & Palmer)
- Snow (LargePlateAggregate; Field 1997)
- Cloud ice water (6-BulletRosette; Field 1997)

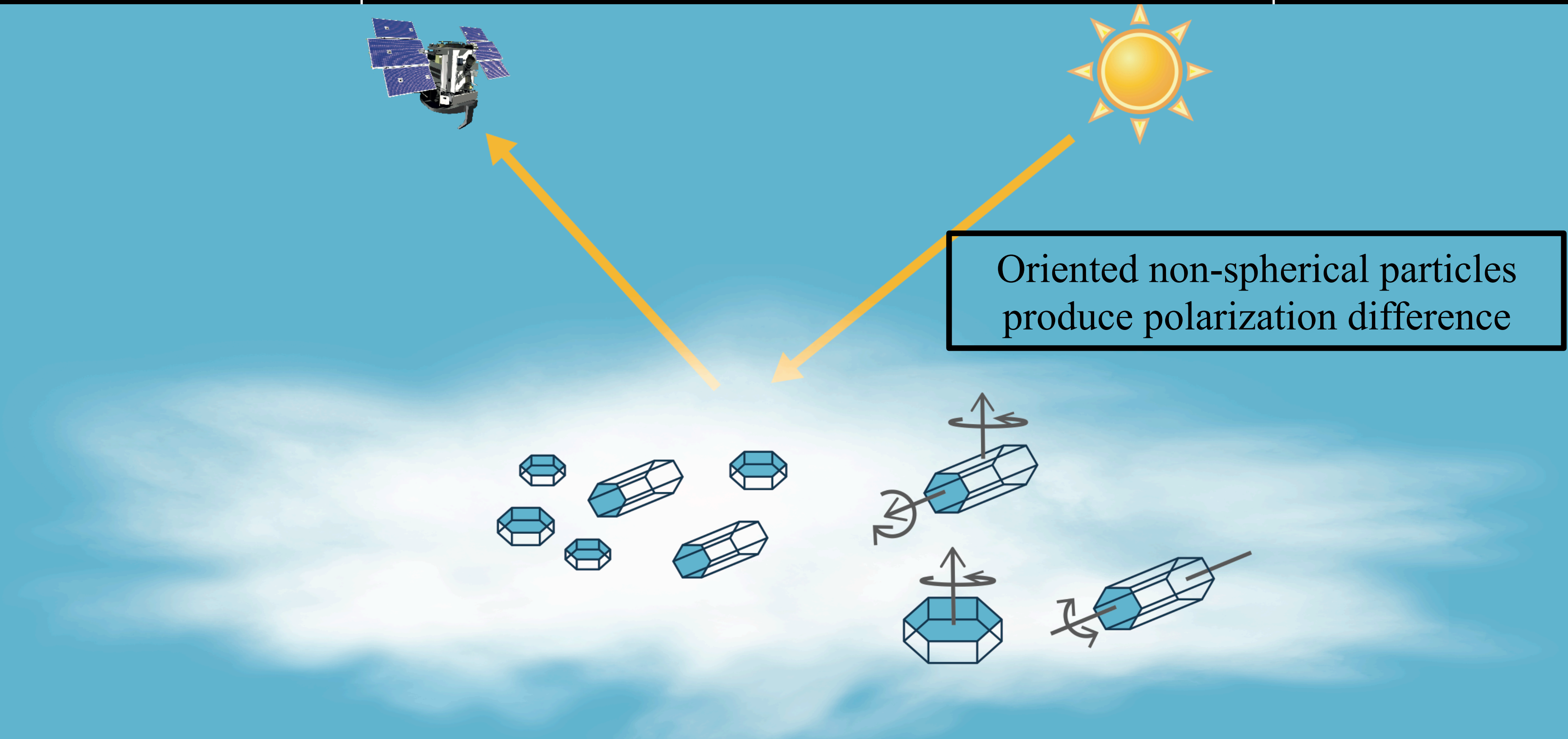
Summary

- An excellent agreement is found between ARTS and RTTOV (clear–sky): Errors are below ±0.1 K. For large earth incident angles, errors increase ±0.2 K due to interpolation.
- A good agreement is found between ARTS and RTTOV–SCATT (all–sky): Errors are below ± 4 K subject to hydrometeor content and interplolation.

Outlook

- Further explore the discrepancies between ARTS and RTTOV–SCATT: optical properties.
- It applies a two-stream approximation.
- Data is extracted column-wise and maximum cloud overlap is assumed.
- Three-dimensional effects are neglected.

Particle orientation – Assumptions



Assumptions in RTTOV-SCATT

- Totally randomly oriented hydrometeors only
- "Scalar" radiative transfer simulations only, i.e., V– or H–polarization
- Invariant scattering properties between V– and H–simulations

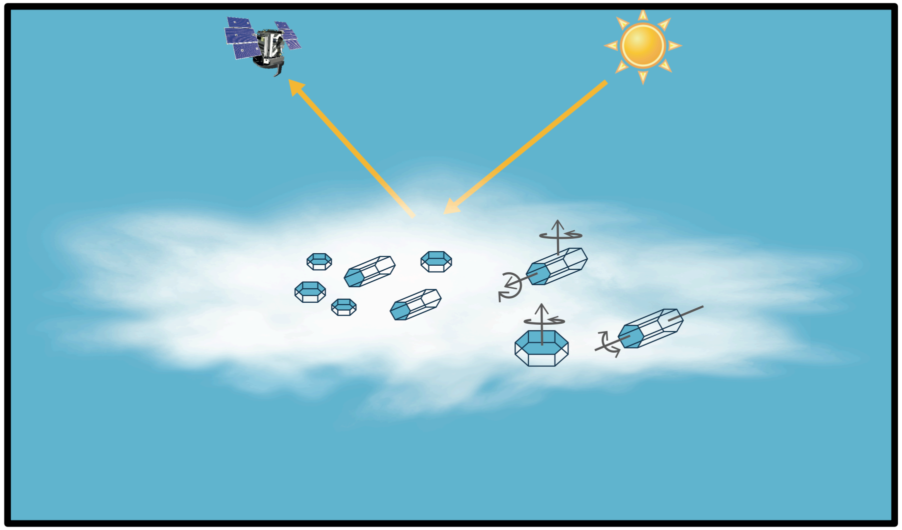
Particle orientation – Framework

Methods and Tools

- Framework following Gong and Wu 2017,

$$\rho = \frac{\tau_H}{\tau_V} = \frac{\tau(1+\alpha)}{\tau(1-\alpha)}, \quad 1.2 \le \rho \le 1.4$$

- Experiments varying ρ (& shape to be applied)
- GMI observations at 166 GHz (V/H)



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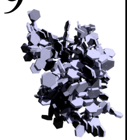
Control run: 13.06 – 13.07.2019



1) Rain (Mie)
2) Snow (Liu; Sector snowflace)
3) Graupel (Liu; Sector snowflace)
4) Cloud liquid water (Mie)
5) Cloud ice water (Mie)

Results: 1 week only, ρ = 1.22

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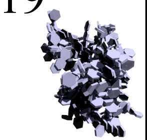
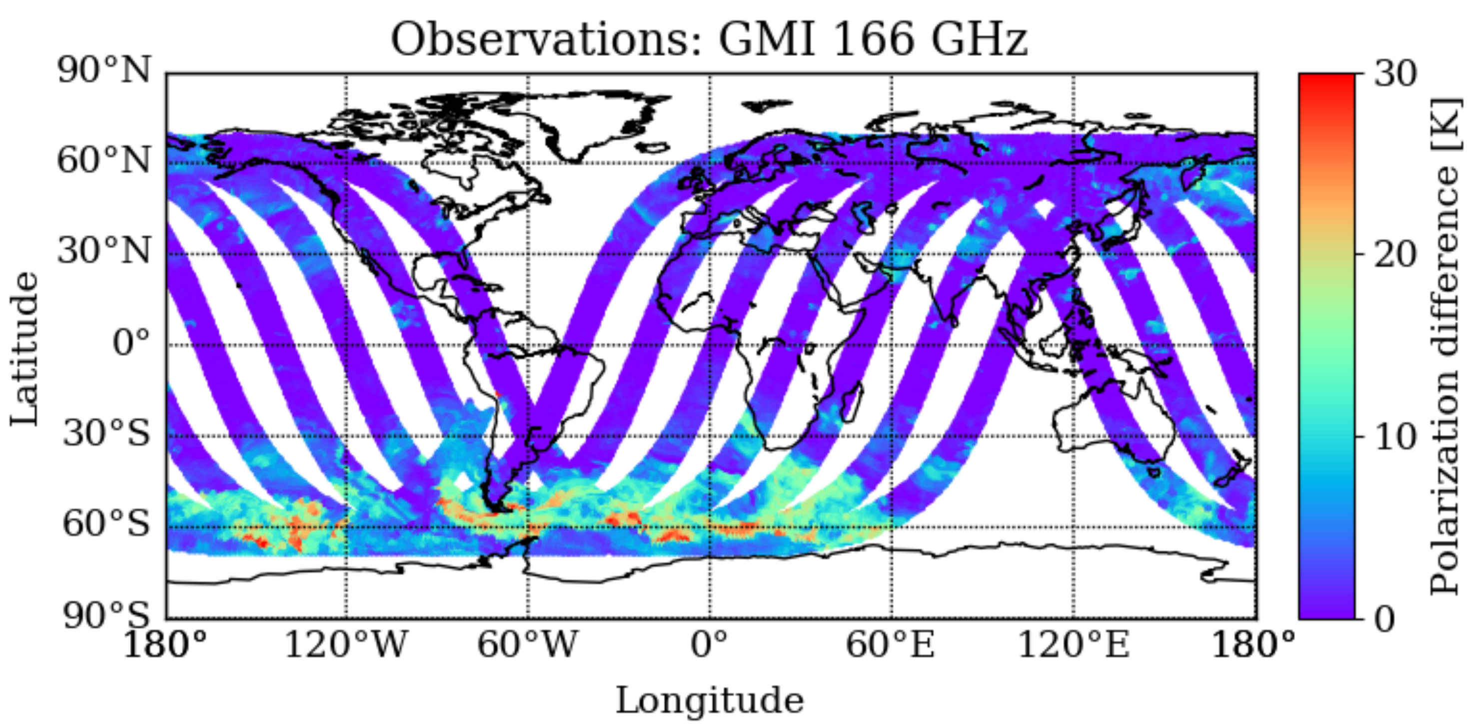


1) Rain (Mie)
2) Snow (Liu; Sector snowflace)
3) Graupel (Liu; Sector snowflace)
4) Cloud liquid water (Mie)
5) Cloud ice water (Mie)

Results: 1 week only, ρ = 1.22



Particle orientation – Framework

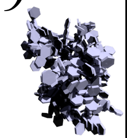
Methods and Tools

- Framework following Gong and Wu 2017,

$$\rho = \frac{\tau_H}{\tau_V} = \frac{\tau(1+\alpha)}{\tau(1-\alpha)}, \quad 1.2 \leq \rho \leq 1.4$$

- Experiments varying ρ (& shape to be applied)
- GMI observations at 166 GHz (V/H)

Control run: 13.06 – 13.07.2019



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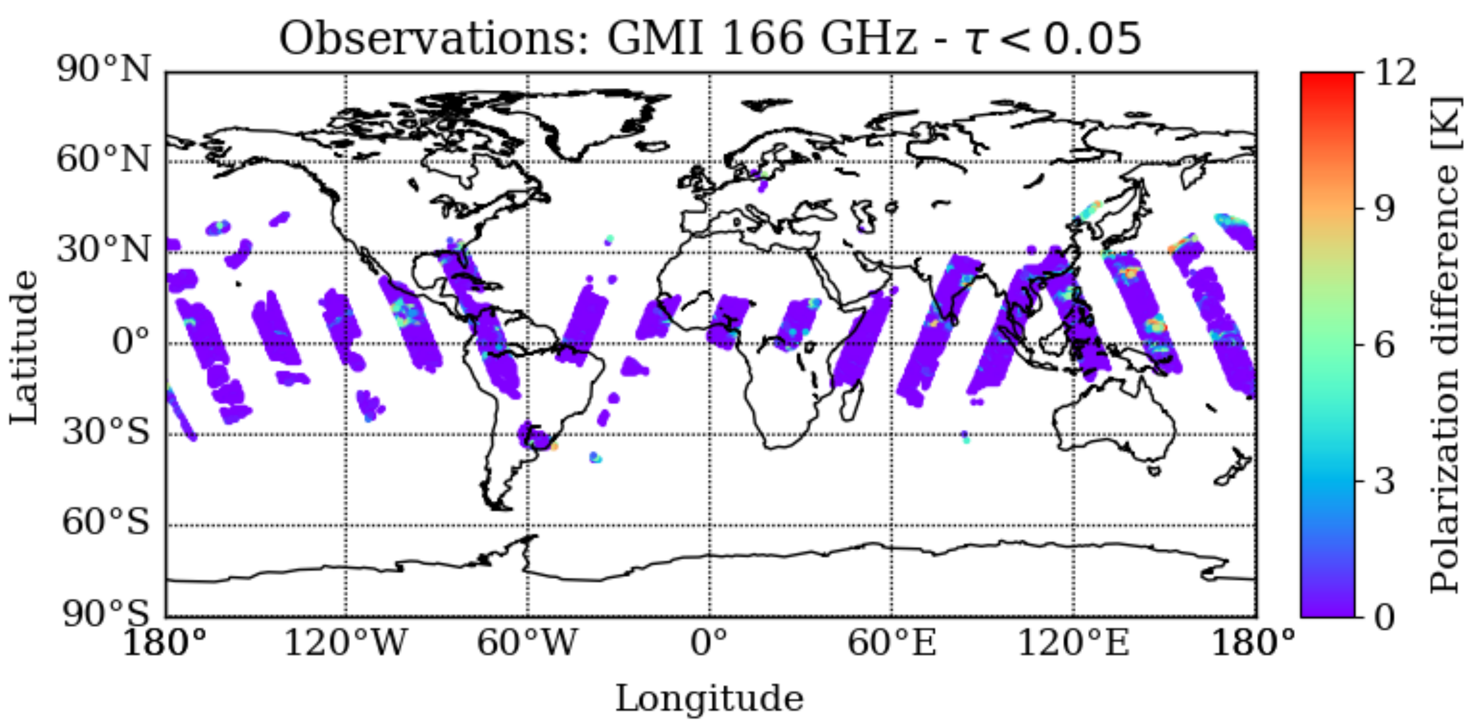
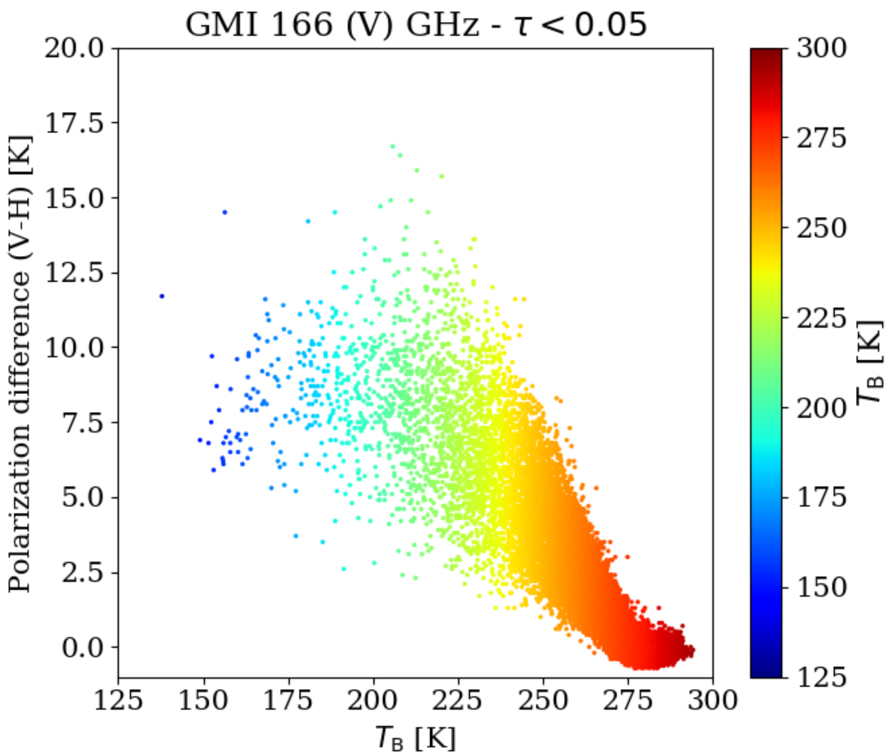
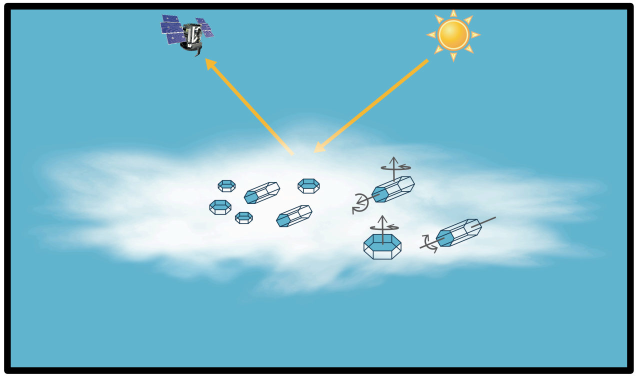


Polarization differences (PDs) at 166 GHz

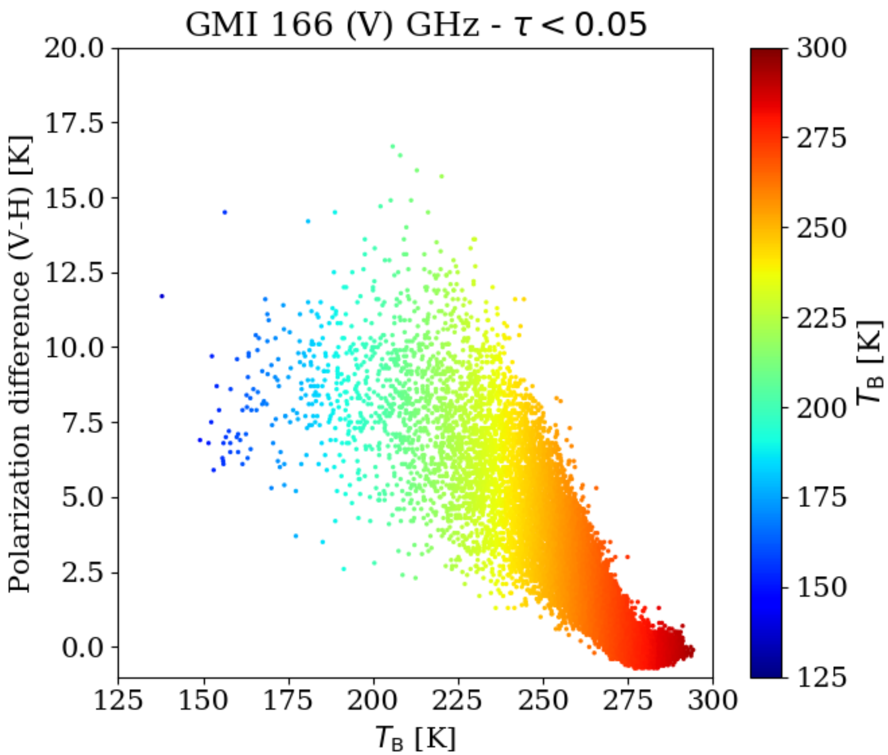


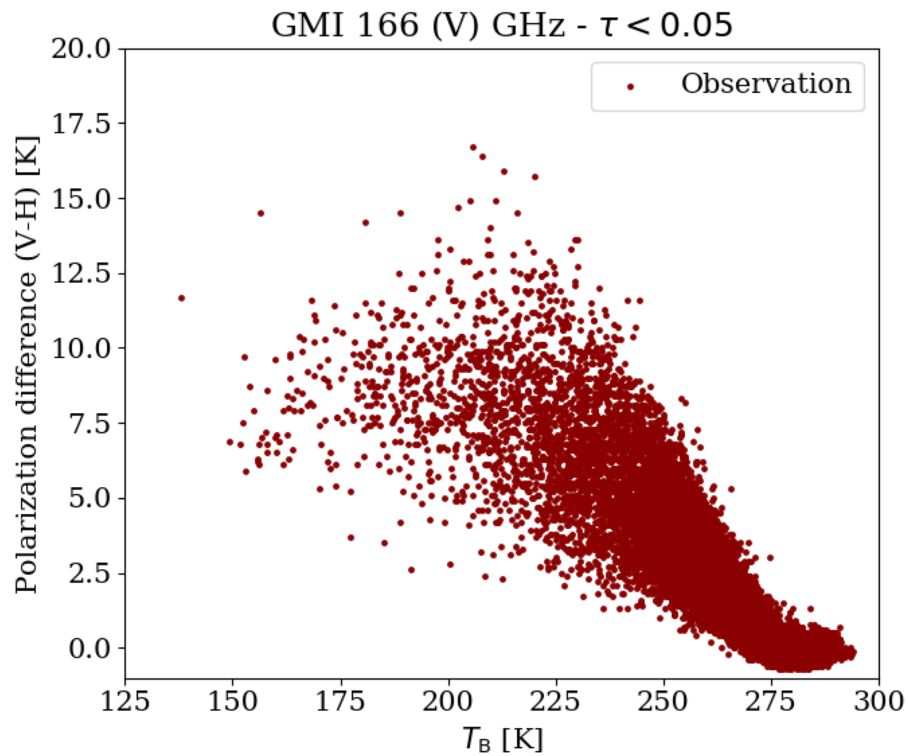


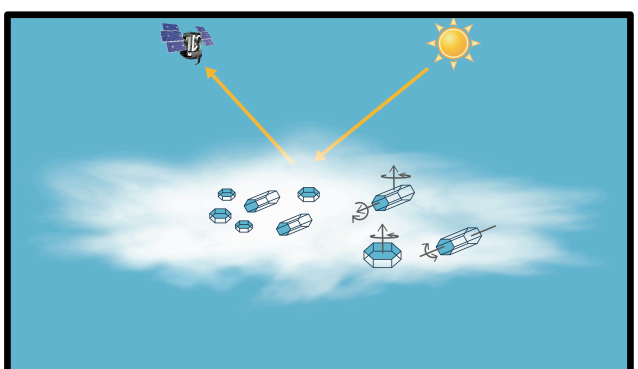
Results: 1 week only, ρ = 1.22

Particle orientation – Preliminary results

Polarization differences (PDs) at 166 GHz



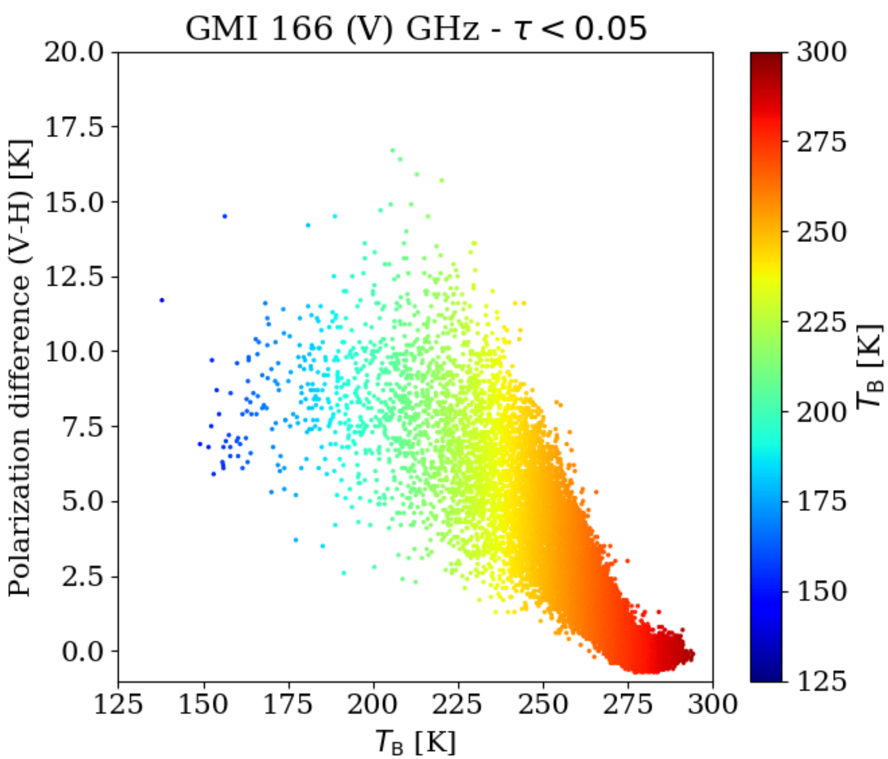


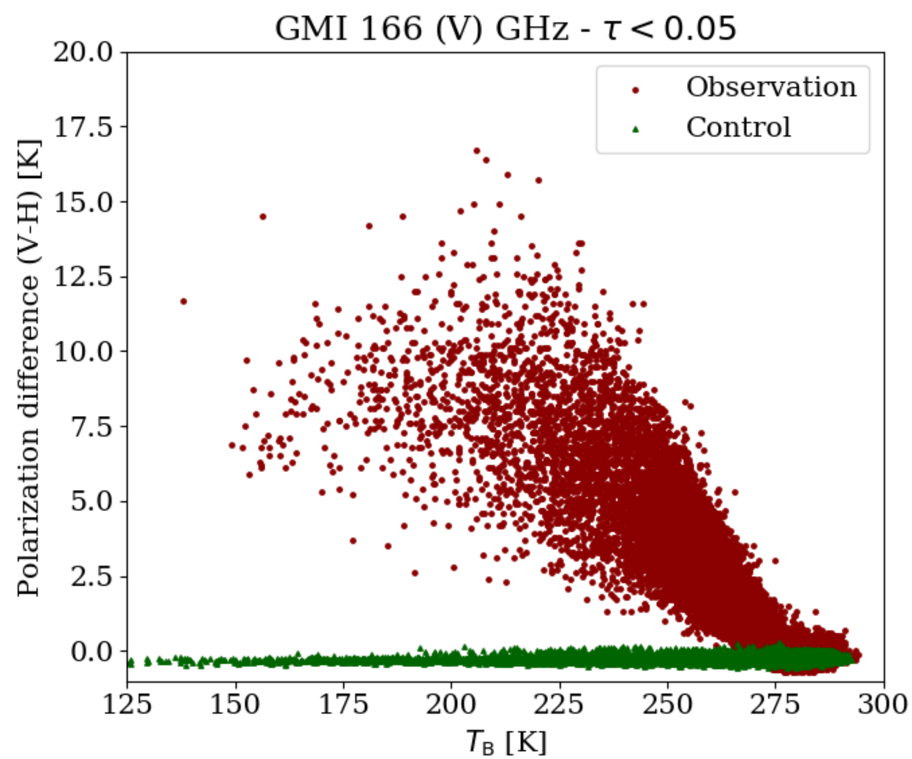


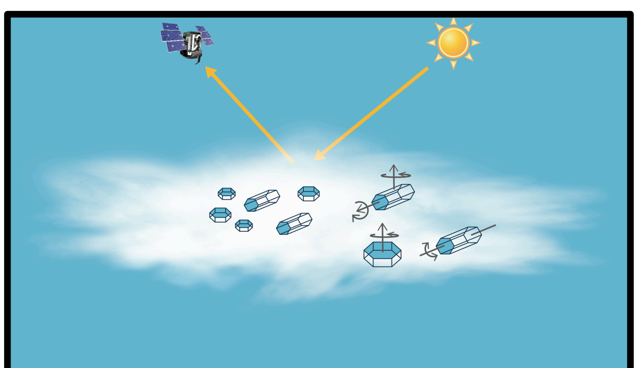
Results: 1 week only, ρ = 1.22

Particle orientation – Preliminary results

Polarization differences (PDs) at 166 GHz







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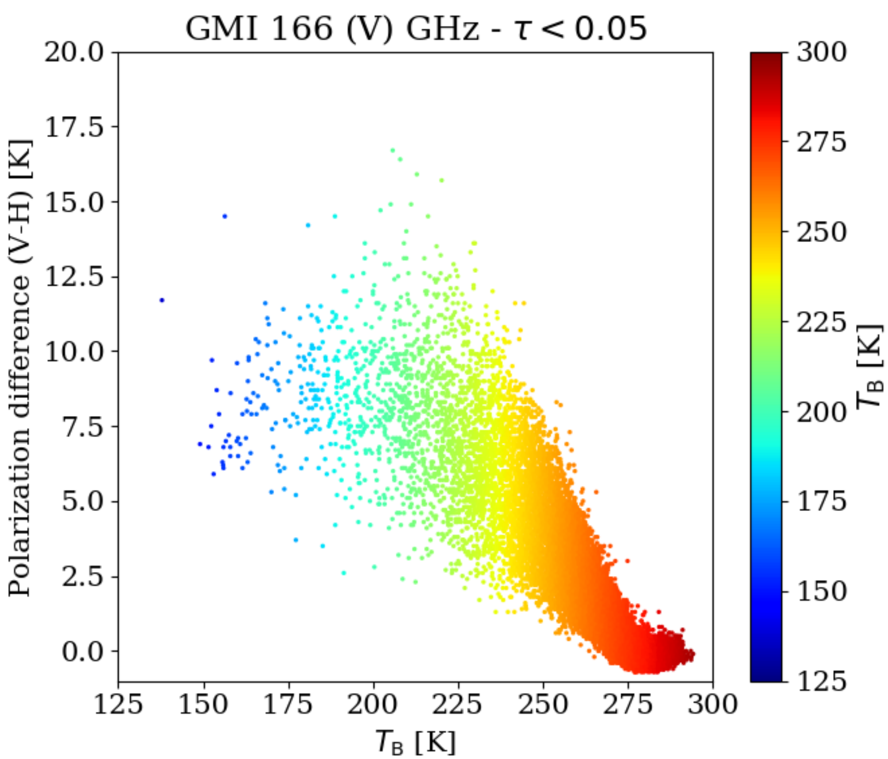
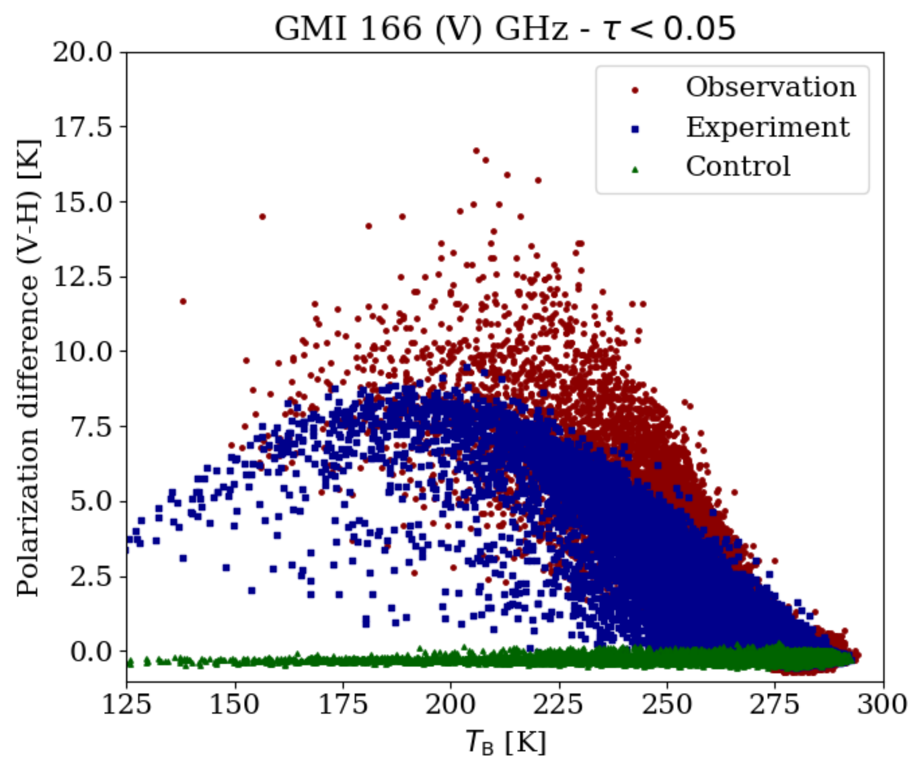
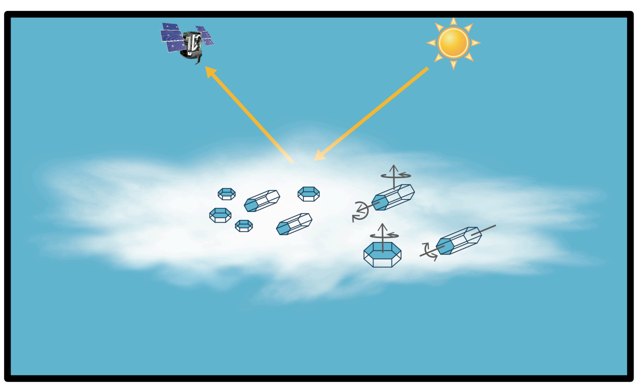
Particle orientation – Preliminary results

Polarization differences (PDs) at 166 GHz

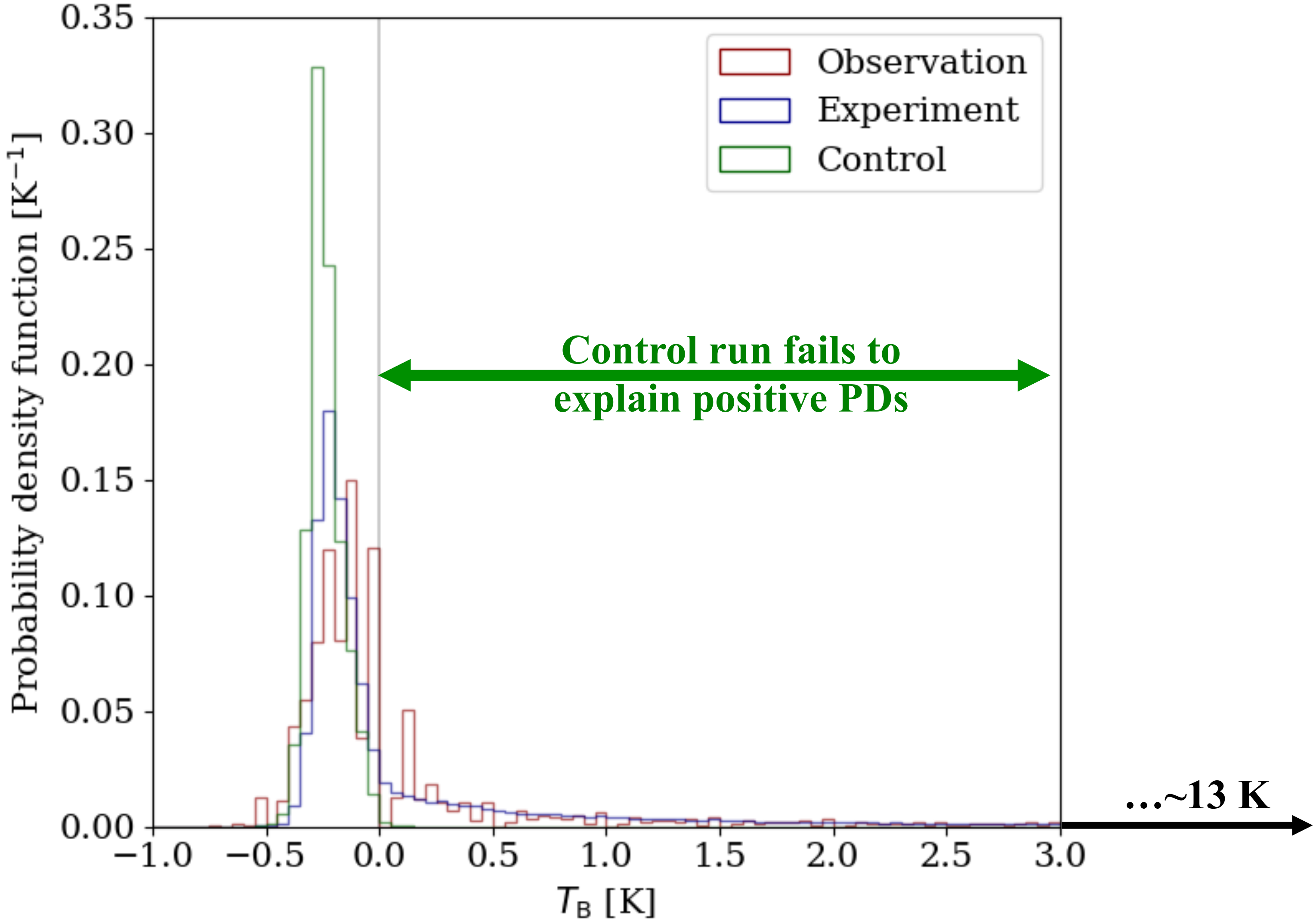






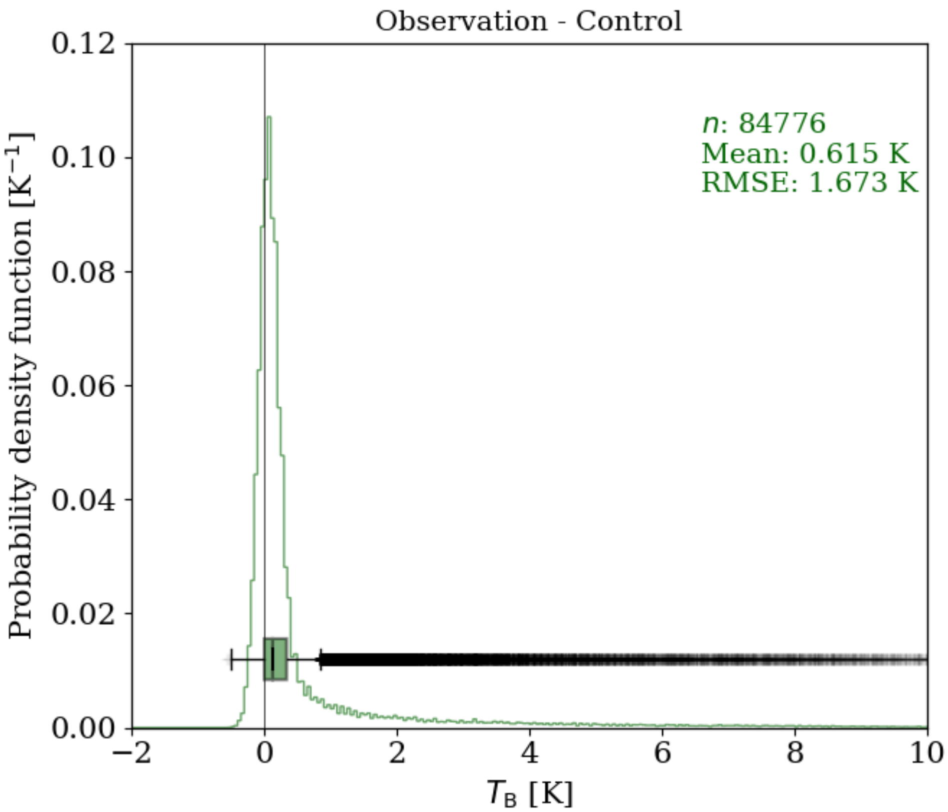
Results: 1 week only, $\rho = 1.22$

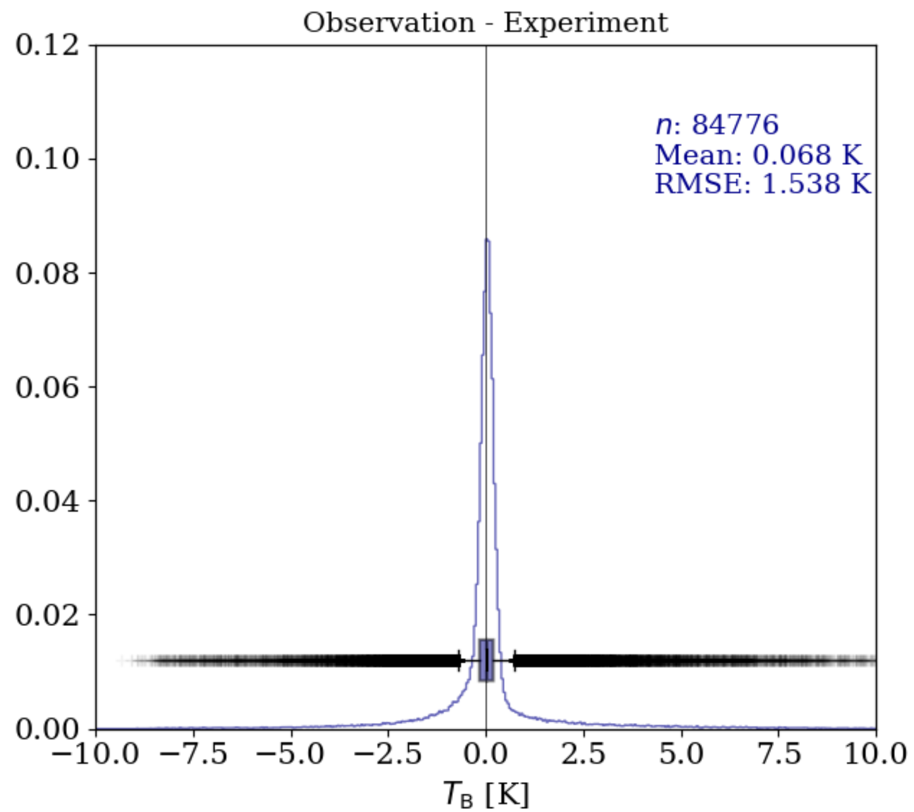
- **Histograms of PDs at 166 GHz**



Results: 1 week only, ρ = 1.22

Histograms of differences in PDs at 166 GHz





Results: 1 week only, ρ = 1.22

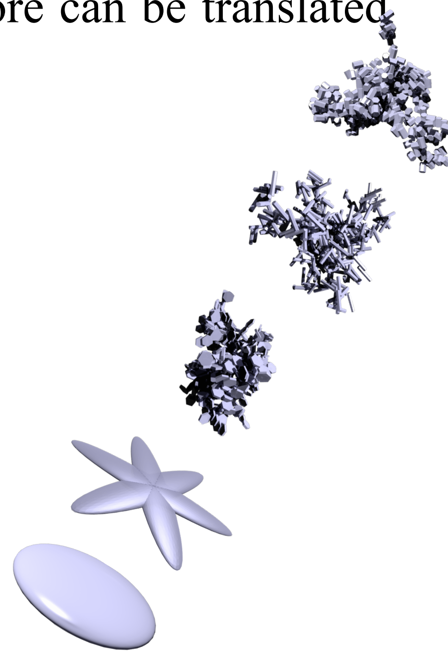
Summary

- The current modeling framework fails to identify the measured polarization.
- A simple modeling framework was developed to account for particle orientation.
- Scaling the cloud optical thickness in V– and H–polarization by ρ =1.22 diminishes the differences in the observerd polarization differences by an order of magnitude.
- Snow is found to induce the observed polarization differences.
- The observed polarization difference value range in this study therefore can be translated into a 12% ice water path retrieval error if polarization is neglected.

Outlook

- Increase the robustness of the statistics.
- Sensitivity study of the scaling factor ρ.
- Make use of a more realistic particle habits; ARTS scattering database
- Improve current scattering database:

Azimuthally randomly oriented ice hydrometeors (Brath et al., 2019)



Three-dimensional effects in retrievals

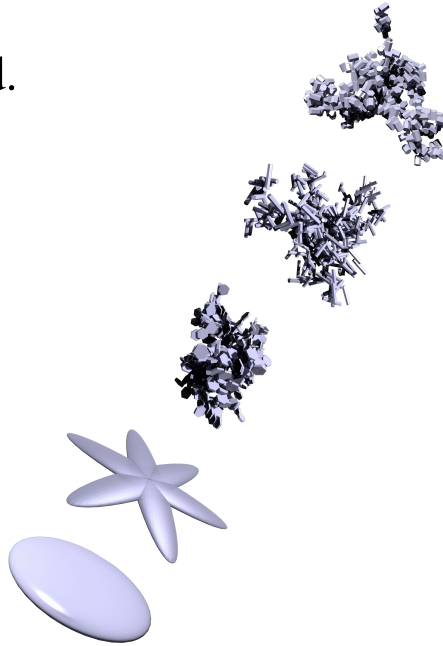
- Explore the use or the development of correction schemes for the BF effect at mm/sub-mm.
- Particle orientation and 3D effects including polarization.

Intercomparison study

- Further explore the discrepancies between ARTS and RTTOV–SCATT: optical properties.
- It applies a two-stream approximation.
- Data is extracted column-wise and maximum cloud overlap is assumed.
- Three-dimensional effects are neglected.

Particle orientation

- Increase the robustness of the statistics.
- Sensitivity study of the scaling factor ρ.
- Make use of a more realistic particle habits; ARTS scattering database
- Improve current scattering database:



Azimuthally randomly oriented ice hydrometeors (Brath et al., 2019)