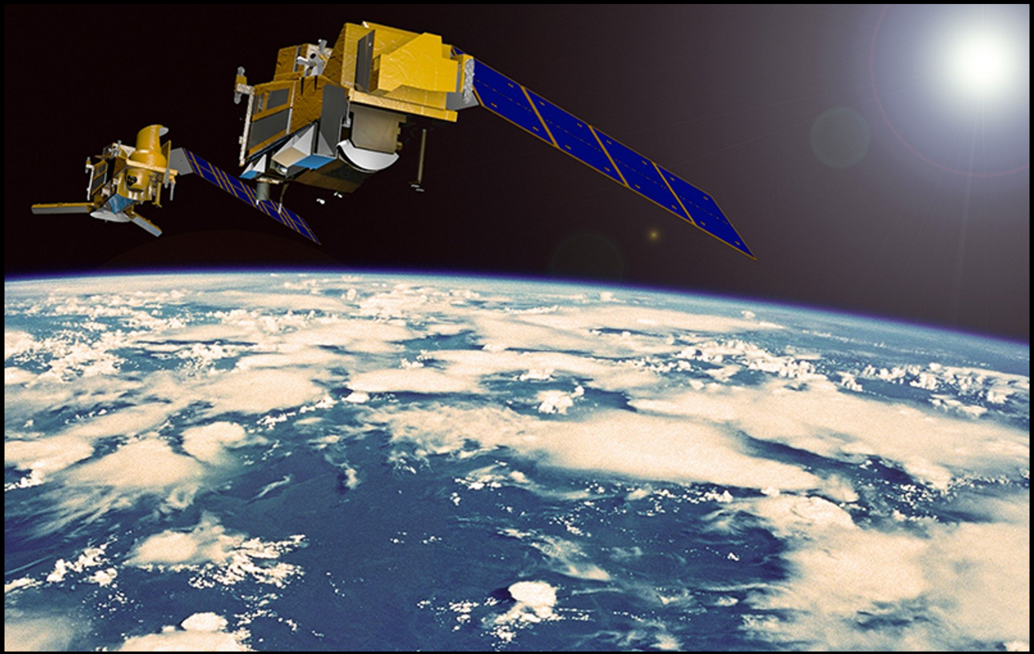
CHALMERS
UNIVERSITY OF TECHNOLOGY

Characterising and reducing uncertainties in all-sky radiative transfer

Vasileios Barlakas

Annual Fellow Day
01.03.2021



ECMWF

EUMETSAT

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

Sensors

- Sensors with frequencies up to ~183 GHz
- Ice Cloud Imager (ICI): 183.31 – 664 GHz

Applications

- Stand–alone retrievals
- Data assimilation (DA)

Open issues

- Three-dimensional radiative transfer is ingored
- Hydrometeor orientation and polarization are ignored
- RTTOV-SCATT accuracy
  - Two-stream delta-Eddington approximation
  - Sub-grid variability and cloud overlap scheme

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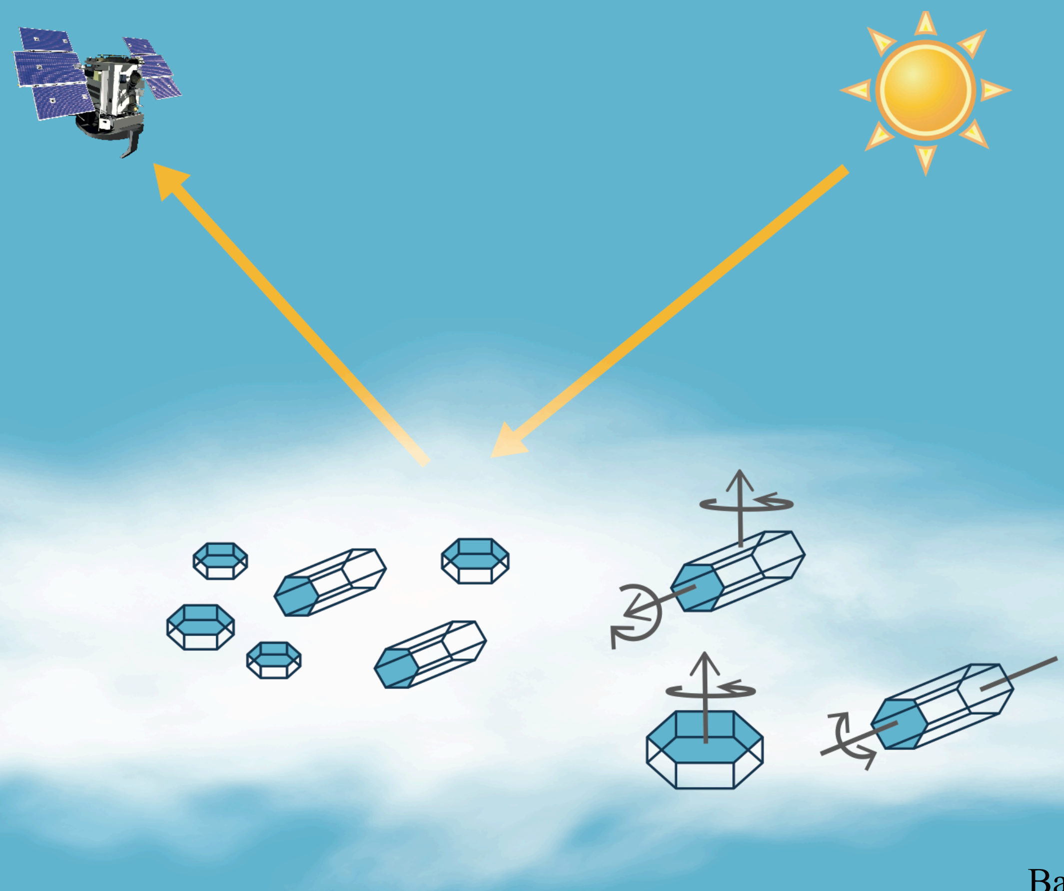
- ☑ Three-dimensional radiative transfer is ingored — 1st year[1]
- ☑ Hydrometeor orientation and polarization are ignored — 1st & 2nd year[2]
- RTTOV-SCATT accuracy — 1st & 2nd year[2]
  - Two-stream delta-Eddington approximation
  - Sub-grid variability and cloud overlap scheme

[1]Barlakas and Eriksson., *Remote Sens.*, 2020

[2]Barlakas et al., *AMTD*, 2020
[2]Geer, Barlakas et al., *to be submitted to GMD*, 2021
[2]Barlakas et al., *in preparation, JQSRT*, 2021

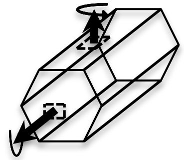
Introducing hydrometeor orientation into all-sky millimeter/sub-millimeter assimilation



Barlakas et al., *AMTD*, 2020
Geer, Barlakas et al., *to be submitted to GMD*, 2021

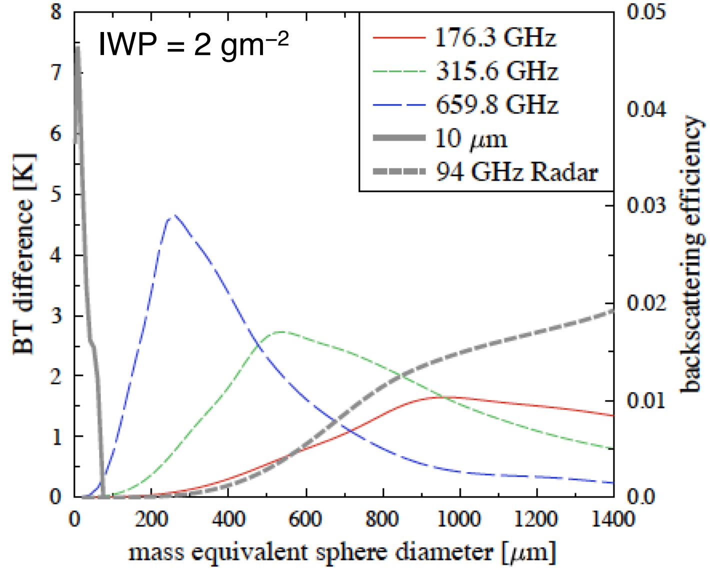
Motivation

Why ice clouds?



- Model uncertainties (**shape** and **orientation**).

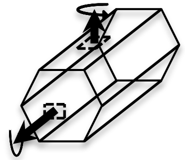
Why MW and sub-mm?



- Sensitive to **large** and **small** ice hydrometeors
- **Ice Cloud Imager (ICI)**
  - 183–664 GHz + dual polarization
  - Improved ice retrievals + extend data assimilation

Motivation

- **Why ice clouds?**



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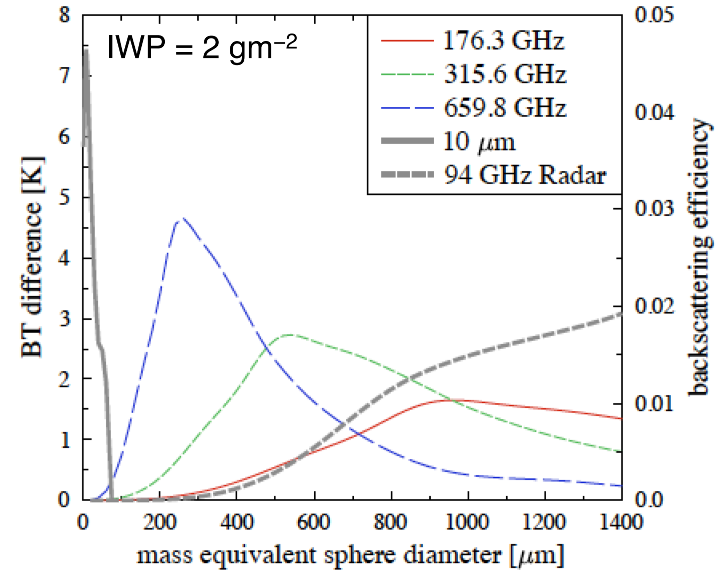

- **Why MW and sub-mm?**
  - Sensitive to **large** and **small** ice hydrometeors
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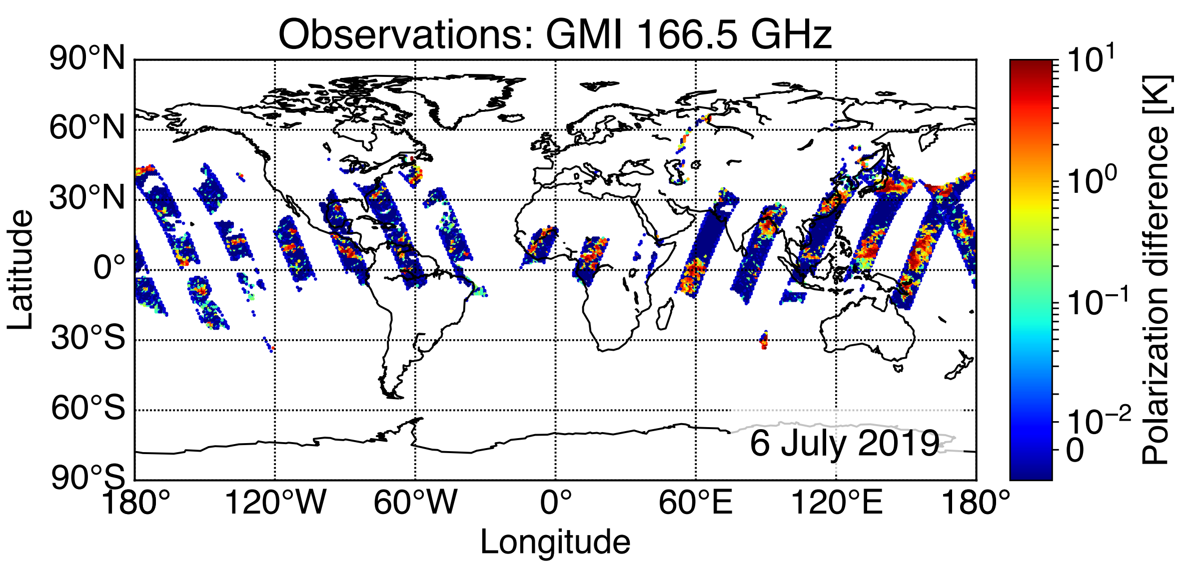
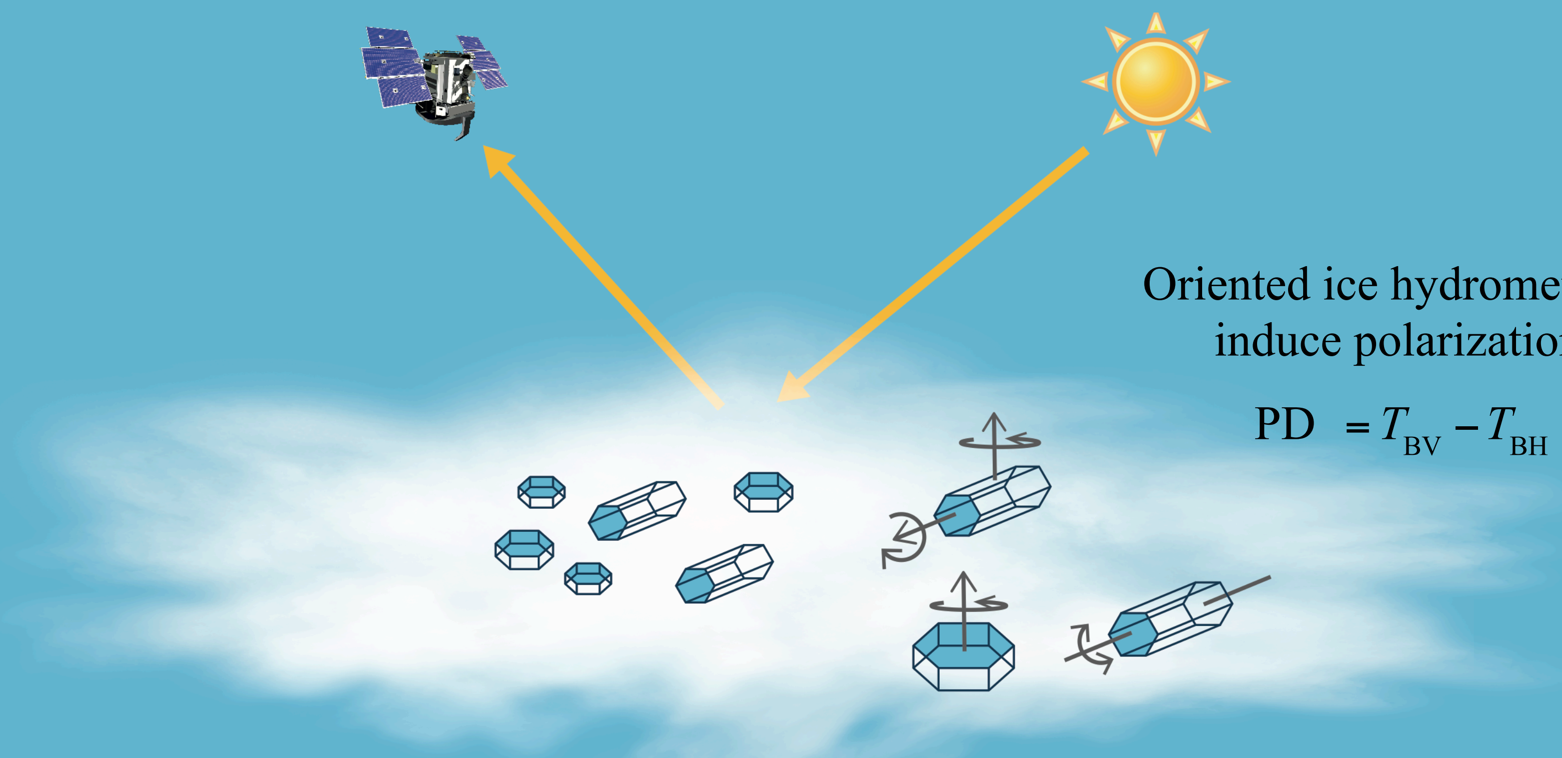
\+ **Polarization**



Assumptions in DA

- Totally randomly oriented (TRO) hydrometeors only
- “Scalar” simulations, i.e., V– or H–polarization
- Invariant scattering properties between V– and H–simulations



Oriented ice hydrometeors induce polarization

$$PD = T_{BV} - T_{BH}$$

Hydrometeor orientation

- Attenuation driven by the extinction matrix

$$K = \begin{pmatrix} K_{11} & K_{12} & K_{13} & K_{14} \\ K_{21} & K_{22} & K_{23} & K_{24} \\ K_{31} & K_{32} & K_{33} & K_{34} \\ K_{41} & K_{42} & K_{43} & K_{44} \end{pmatrix}$$

✓ incident direction
✓ orientation

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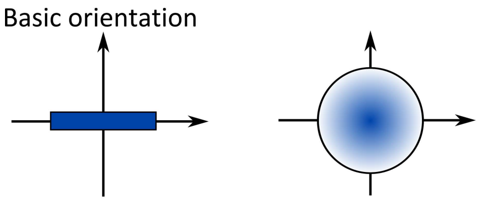
- Total random orientation (TRO)

✗ favored direction
✗ orientation

$$K = \begin{pmatrix} K_{11} & 0 & 0 & 0 \\ 0 & K_{11} & 0 & 0 \\ 0 & 0 & K_{11} & 0 \\ 0 & 0 & 0 & K_{11} \end{pmatrix}$$

K_{11}, extinction cross section



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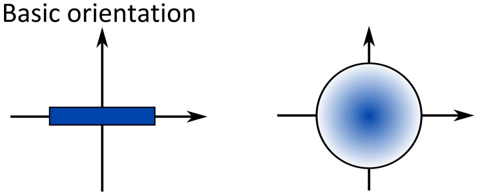
K_{11}, extinction cross section

Basic orientation



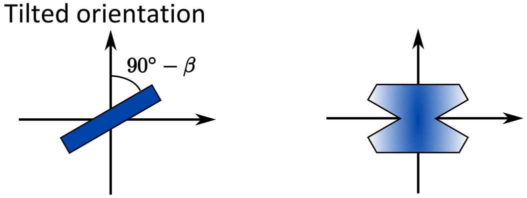
- Azimuthal random orientation (ARO)

✓ orientation based on tilt angle β
✗ orientation in the azimuth

$$K = \begin{pmatrix} K_{11} & K_{12} & 0 & 0 \\ K_{12} & K_{11} & 0 & 0 \\ 0 & 0 & K_{11} & K_{34} \\ 0 & 0 & -K_{34} & K_{11} \end{pmatrix}$$

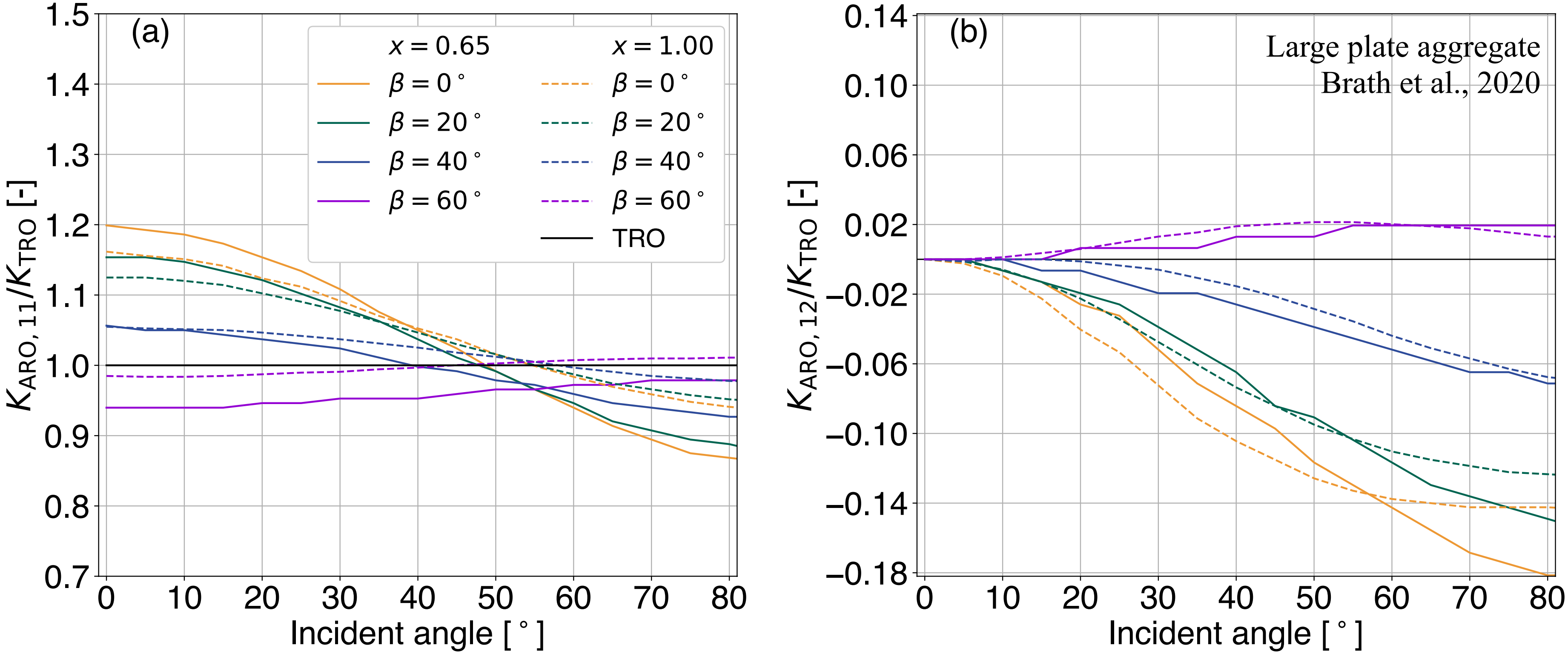
K_{12}, cross section for linear polarisation
K_{34}, cross section for circular polarisation

Tilted orientation



Extinction at 166.9 GHz

TRO vs ARO



Barlakas et al., *AMTD*, 2020

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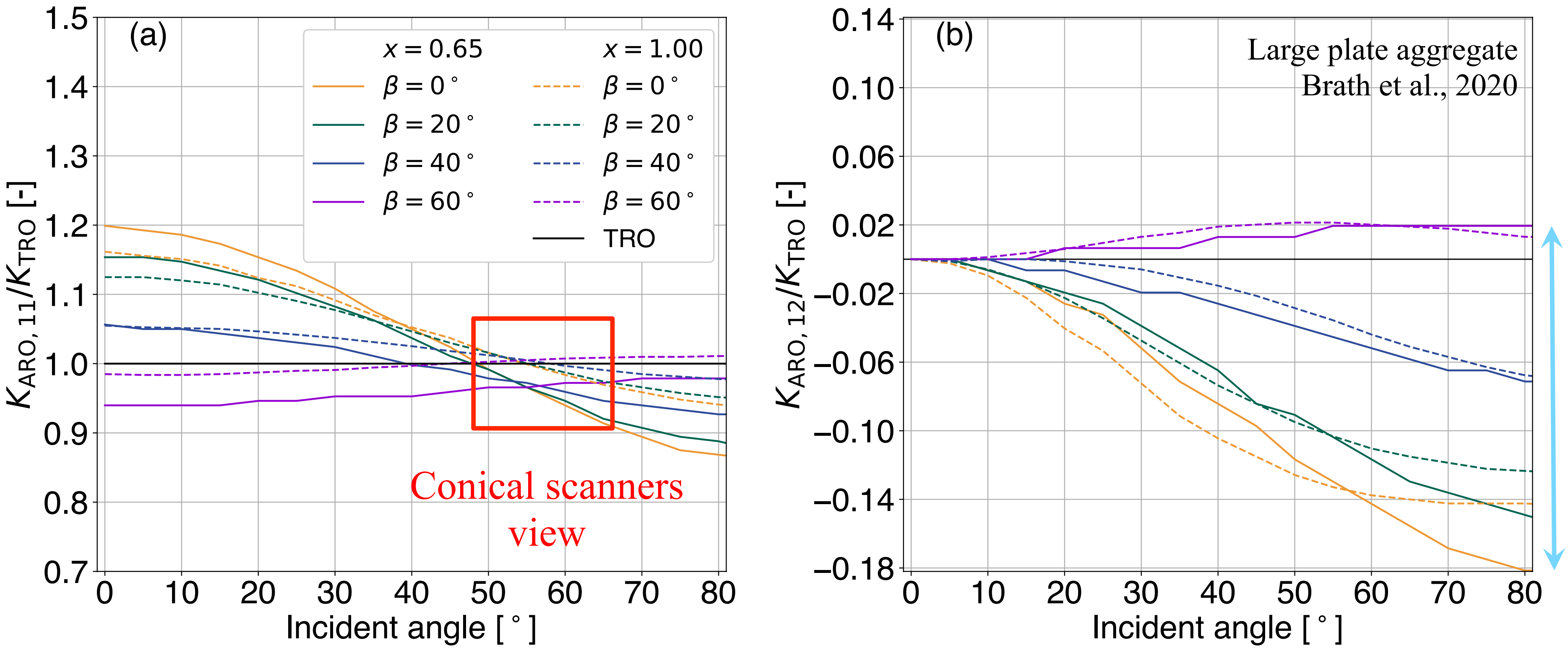


- Extinction cross section, K_{11} => At $\theta_{inc} \sim 55^o$, the differences are close to 0.
- Linear polarization cross section, K_{12} => Large differences up to 18 % between V & H

Barlakas et al., *AMTD*, 2020

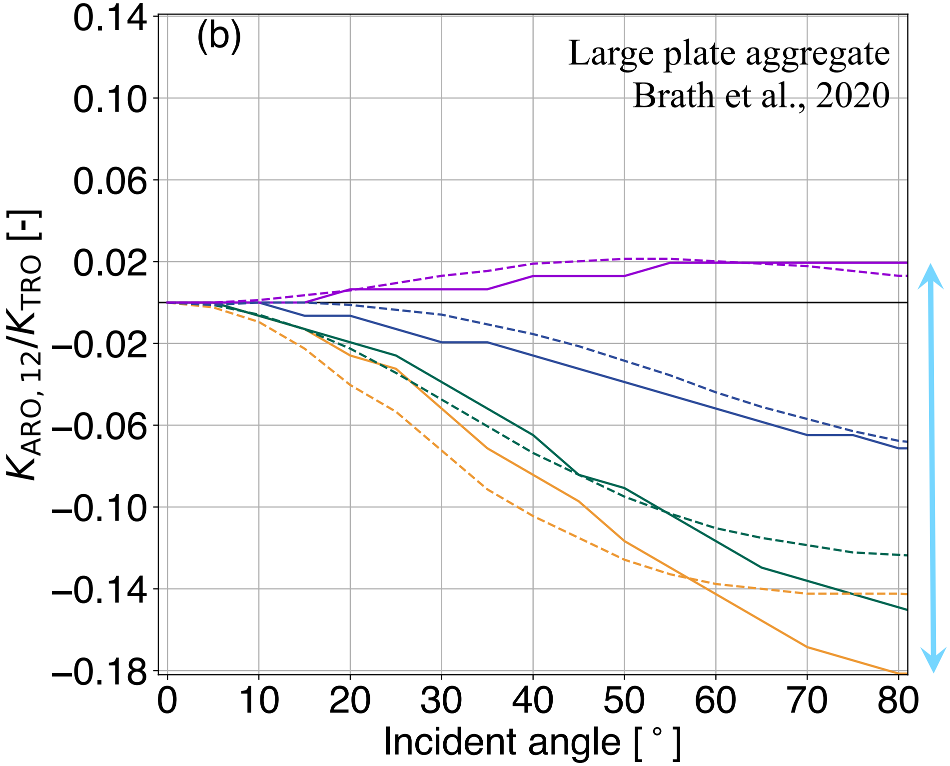
Orientation approximation

- The parameterization is governed by the polarization ratio ρ:

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

α is a correction factor approximating the cross section for linear polarization, i.e., K_{12}

* Control (current framework):
$\rho\ (\alpha = 0) = 1$



Barlakas et al., *AMTD*, 2020
Geer, Barlakas et al., *to be submitted to GMD*, 2021

- **Based on the IFS[1] of ECMWF[2]**

1) Passive monitoring experiments
   - Sensors: GMI[3]
   - Duration: Jun. – Jul. 2019

➡ Which is the best ρ?

2) Cycled DA experiments
   - Sensors: AMSR-2[4], GMI[3], SSMIS[5]
   - Duration: Febr. – May 2019 & Jun. – Aug. 2019

➡ What is impact of ρ on the forecast?

- Microphysical setup following:

Geer, *to be submitted to AMT*, 2021

[1]Integrated Forecast System
[2]European Centre for Medium-Range Weather Forecasts
[3]Global Precipitation Mission microwave imager
[4]Advanced Microwave Scanning Radiometer-2
[5]Special Sensor Microwave Imager/Sounder

Barlakas et al., *AMTD*, 2020
Geer, Barlakas et al., *to be submitted to GMD*, 2021

Choosing the best ρ

Polarization differences (PD)

- Observed (o): $\mathrm{PD}^{\mathrm{o}} = T^{\mathrm{o}}_{\mathrm{BV}} - T^{\mathrm{o}}_{\mathrm{BH}}$
- Simulated (b): $\mathrm{PD}^{\mathrm{b}} = T^{\mathrm{b}}_{\mathrm{BV}} - T^{\mathrm{b}}_{\mathrm{BH}}$

→ $\mathrm{PD}^{\mathrm{o}} - \mathrm{PD}^{\mathrm{b}}$!

* Careful cloud screening method

Barlakas et al., *AMTD*, 2020

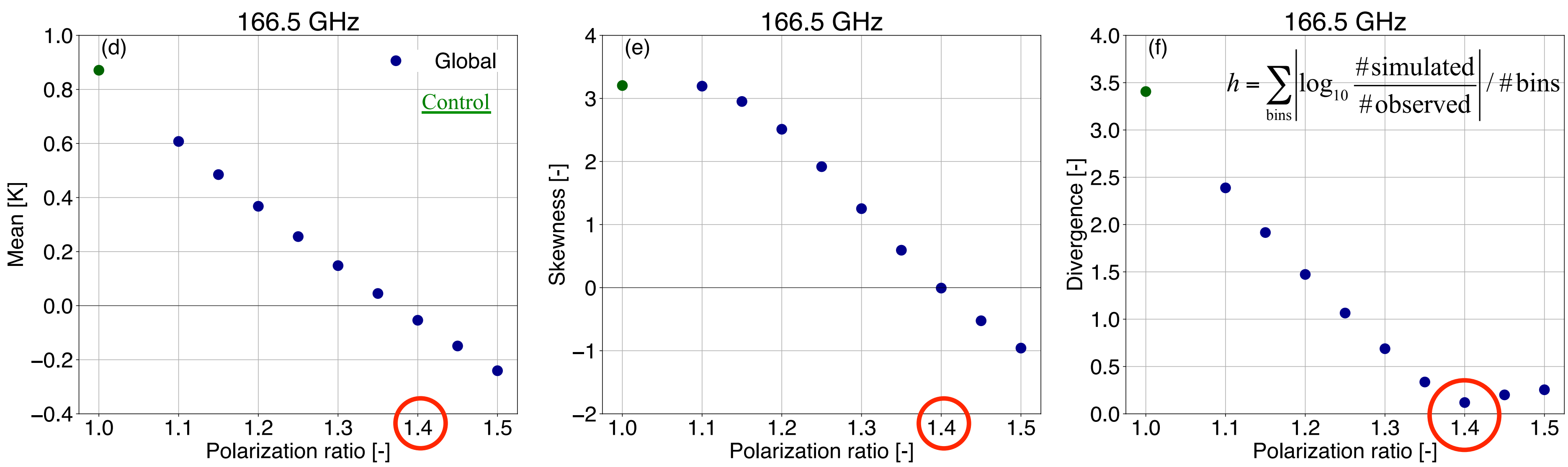
Choosing the best ρ

Polarization differences (PD)

- Observed (o): $PD^o = T_{BV}^o - T_{BH}^o$
- Simulated (b): $PD^b = T_{BV}^b - T_{BH}^b$

$\Rightarrow$ $\boxed{PD^o - PD^b}$!

* Careful cloud screening method

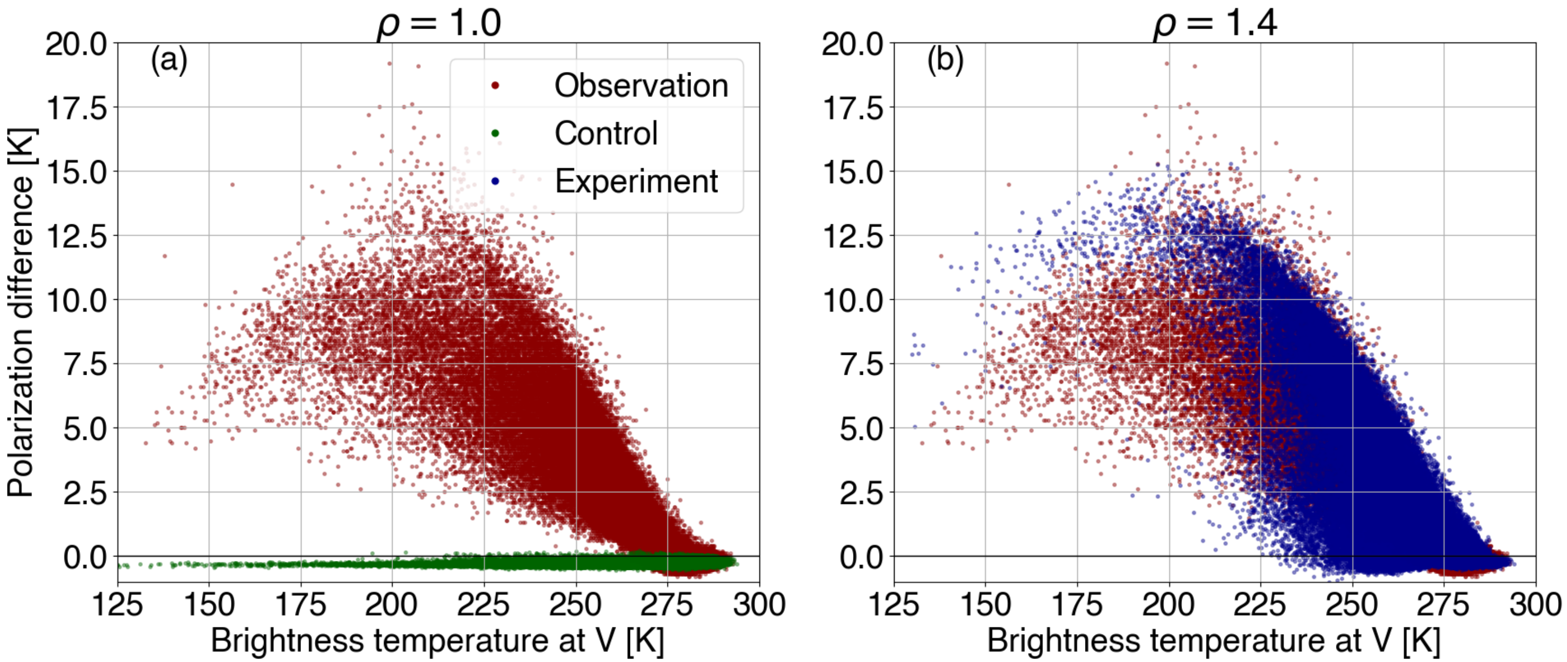


- Best fit:

166.5 GHz, $\rho = 1.4$ ($\alpha = 0.167$)
89.0 GHz, $\rho = 1.5$ ($\alpha = 0.2$)

Barlakas et al., *AMTD*, 2020

Global performance of $\rho = 1.4$



- Universal arch-like shape of relation
- Control run completely fails to reproduce it
- A ρ of 1.4 gives a reasonable representation of such relation

Barlakas et al., *AMTD*, 2020

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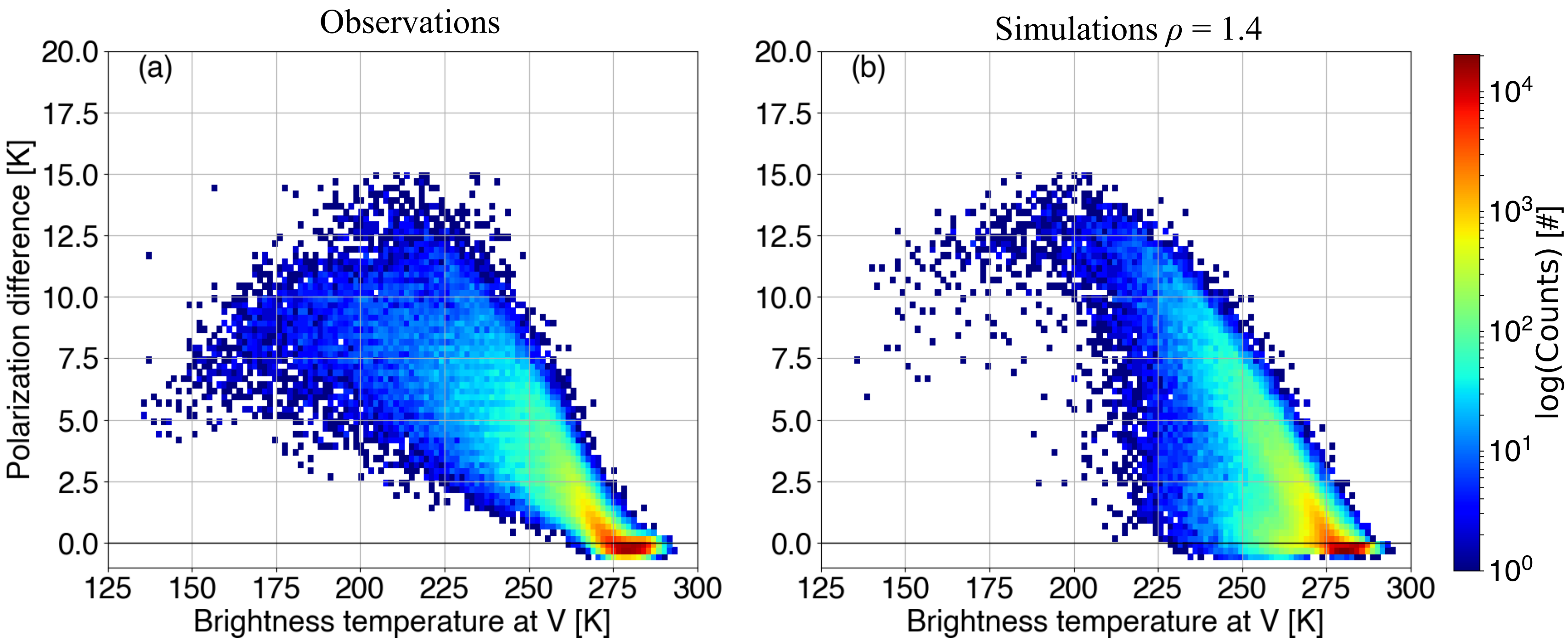

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Barlakas et al., *AMTD*, 2020

Forecast quality – $\rho = 1.4$

Equal & opposite
$\alpha = 0.167$

Unilateral in V
$\gamma = 0.286$

$$\rho = \frac{\tau_{\mathrm{H}}}{\tau_{\mathrm{V}}} = \frac{\tau_{\mathrm{TRO}}(1+\alpha)}{\tau_{\mathrm{TRO}}(1-\alpha)} = \frac{\tau_{\mathrm{TRO}}(1+\beta)}{\tau_{\mathrm{TRO}}(1)} = \frac{\tau_{\mathrm{TRO}}(1)}{\tau_{\mathrm{TRO}}(1-\gamma)} = 1.4$$

Unilateral in H
$\beta = 0.4$

[1]Advanced Technology Microwave Sounder
[2]Winds at 850 hPa, AMSUA (53.7H GHz), geostationary H_2O radiances

Barlakas et al., *AMTD*, 2020

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Validation

- Independent: ATMS[1] & conventional[2] data
  - ☑ Neutral impact

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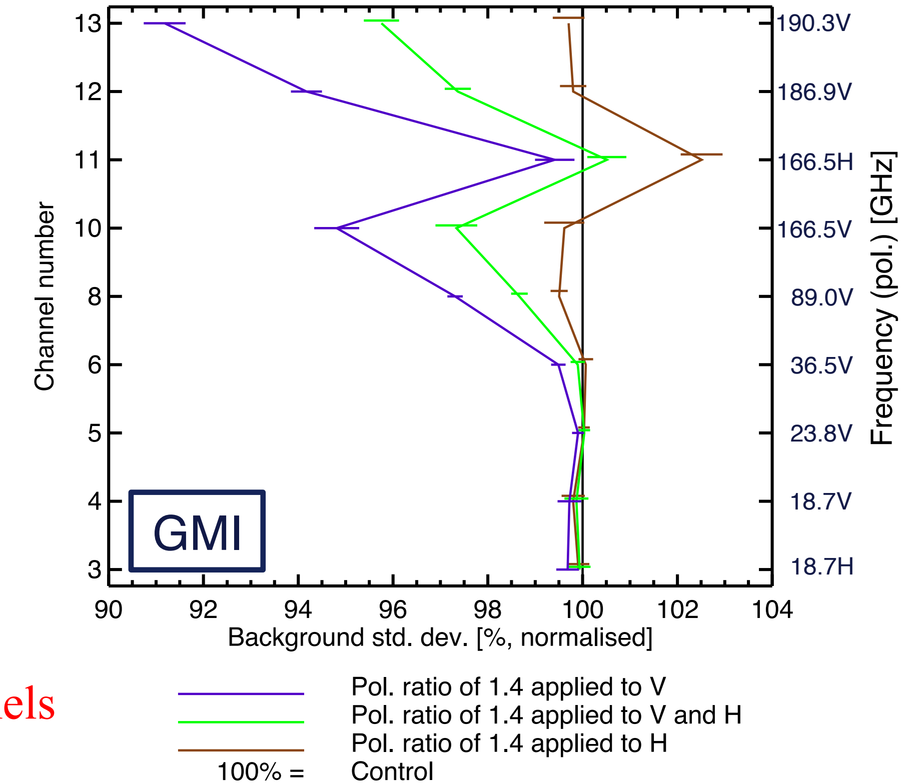


Validation

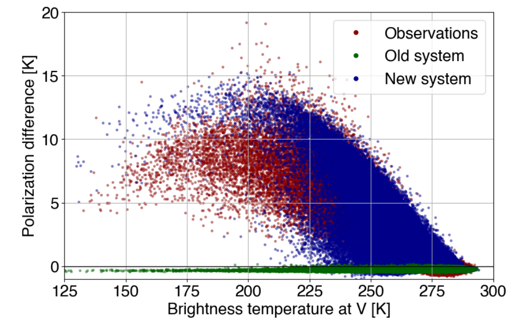
- Independent: ATMS[1] & conventional[2] data
  - ☑ Neutral impact
- Dependent: AMSR-2, GMI, SSMIS
  - ☑ Increased consistency between V & H channels
  - ☑ Increased consistency between instruments

+ Tuning the overall level of scattering

[1]Advanced Technology Microwave Sounder
[2]Winds at 850 hPa, AMSUA (53.7H GHz), geostationary H_2O radiances

Barlakas et al., *AMTD*, 2020

Final configuration of RTTOV-SCATT v13.0



- Minor software adaption and no calculation burdens
- Maximum modeling errors are reduced by 10–15 K
- Errors are now ~ symmetrical
- Neutral forecast impact, with increasing consistency between instruments
- Polarization ratio of 1.4 in RTTOV-SCATT v13.0 + future IFS cycle

Outlook

- Polarization correction scheme
  - Cross-track sounders
  - Radar backscattering
  - Ice retrievals, e.g., in GMI

3rd year

- Frequencies above 183 GHz, i.e., Ice Cloud Imager

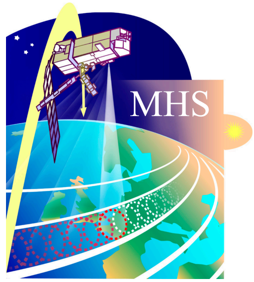


Photo: esa.int

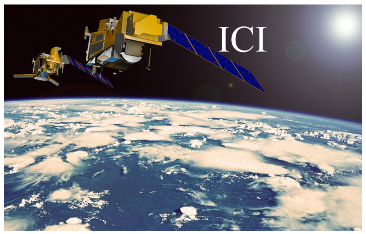


Photo: Airbus

Barlakas et al., *AMTD*, 2020
Geer, Barlakas et al., *to be submitted to GMD*, 2021

Model inter-comparison in all-sky millimeter/sub-millimeter radiative transfer

Barlakas et al., *in preparation*, *JQSRT,* 2021

Objectives:

- Are there any systematic or random errors?
- Where does the two-stream delta-Eddington “falls apart”?
- Most studies focus on clear-sky or frequencies below ~90 GHz
- Prepare RTTOV–SCATT for ICI

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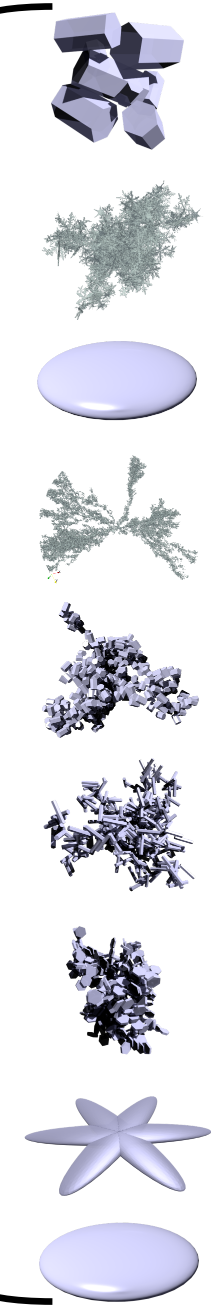
ARTS vs RRTOV (–SCATT):
- Clear–sky
- All–sky (i.e. snow, ice, rain)

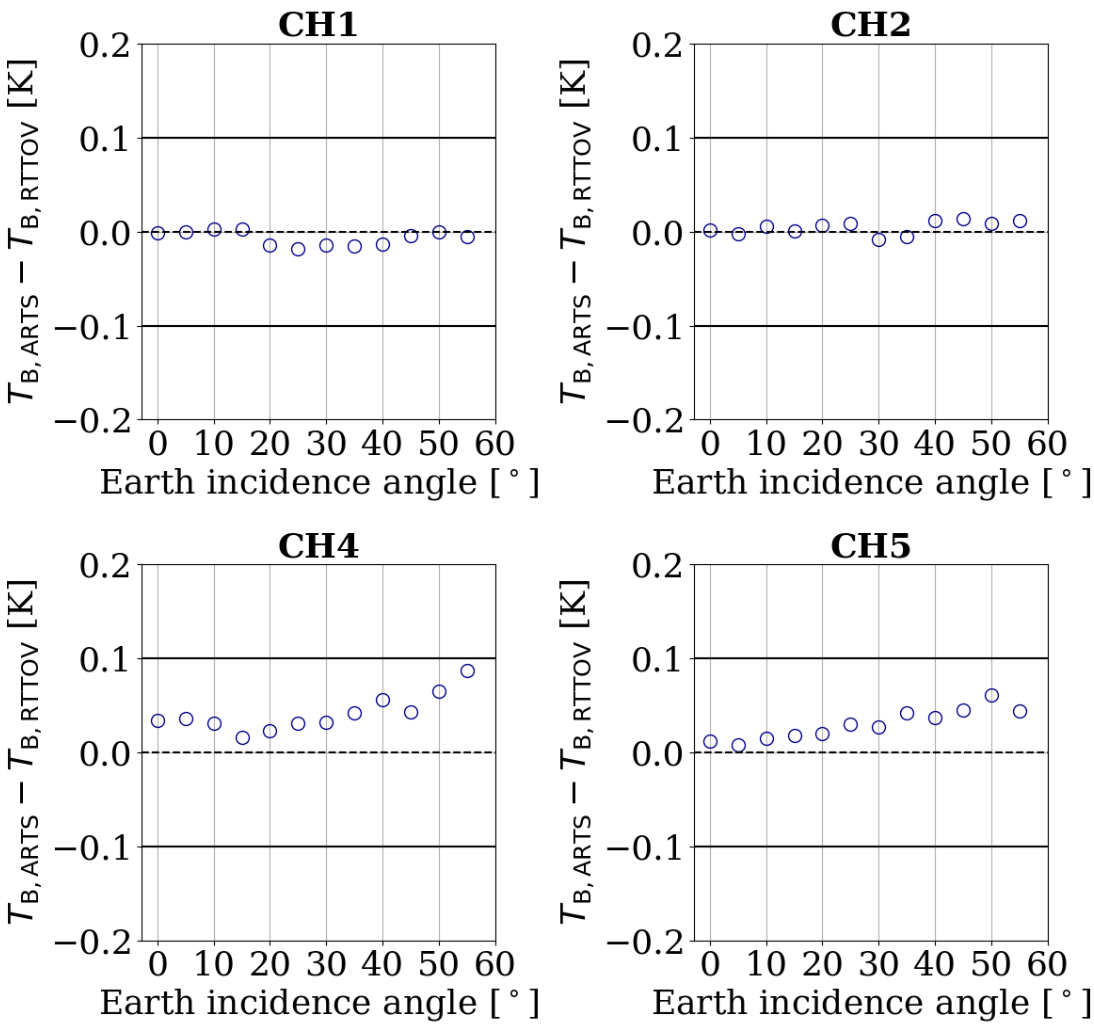
Sensors:
- Advanced Microwave Sounding Unit A (AMSUA)
- Microwave Humidity Sounder (MHS)
- Ice Cloud Imager (ICI)

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

Eriksson et al., *ESSD*, 2018



MHS: Clear–sky comparison



Settings:

- US standard atmosphere
- Surface emissivity = 1

- An excellent agreement is found ± 0.1 K
- Exceptions: ICI at 243.2 GHz (~0.2 K) and 448 GHz (~0.4 K)

Correct spectroscopy!

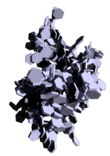
Ongoing by Met Office

Barlakas et al., *in preparation*, *JQSRT*, 2021

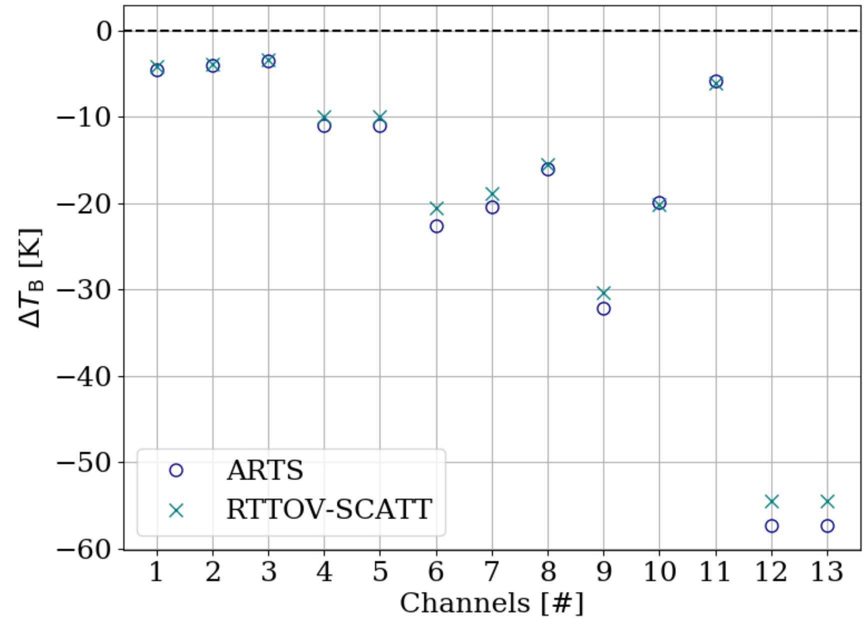
ICI: Ice–only comparison

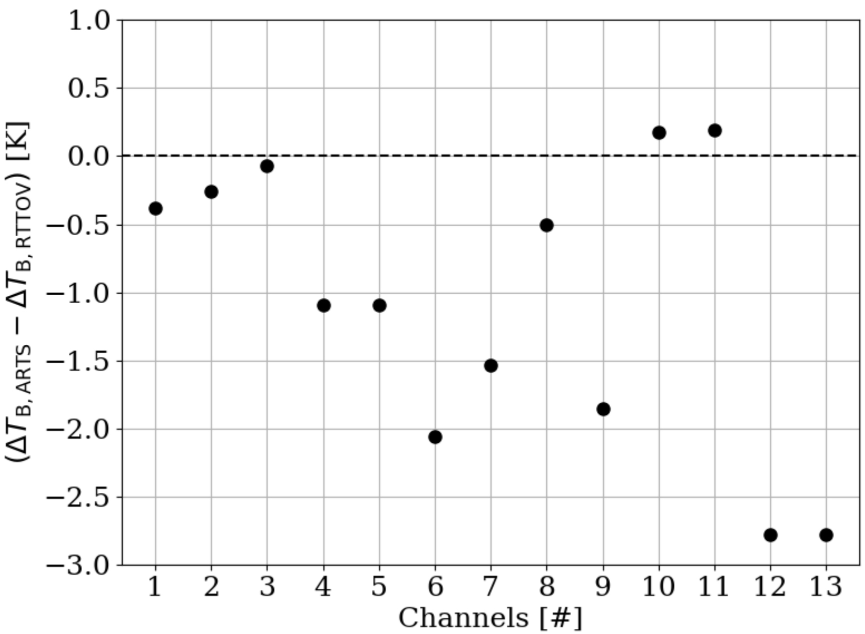
Settings:

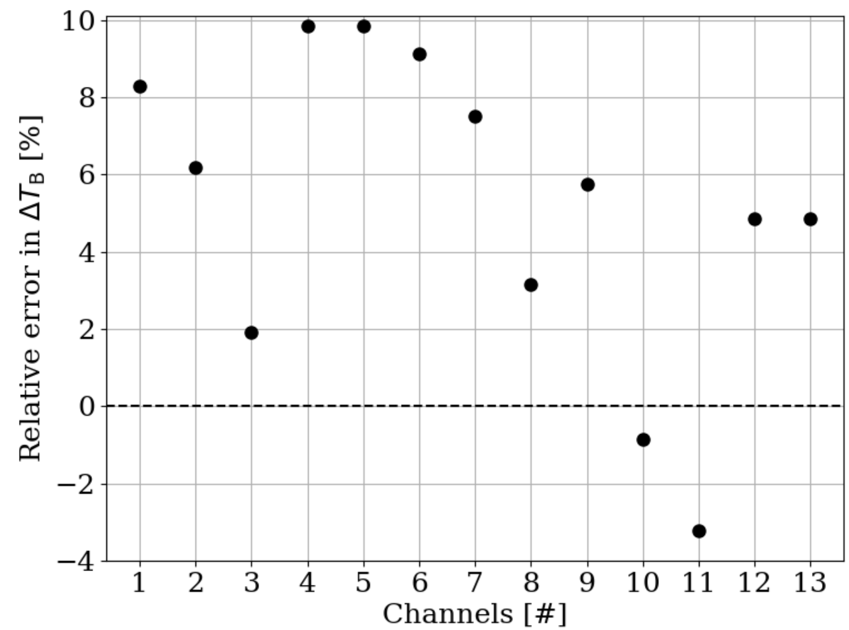
- Gaussian cloud: 9-11 km
- Large plate aggregate habit
- Field et al., 2007 PSD



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







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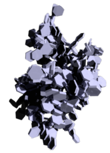

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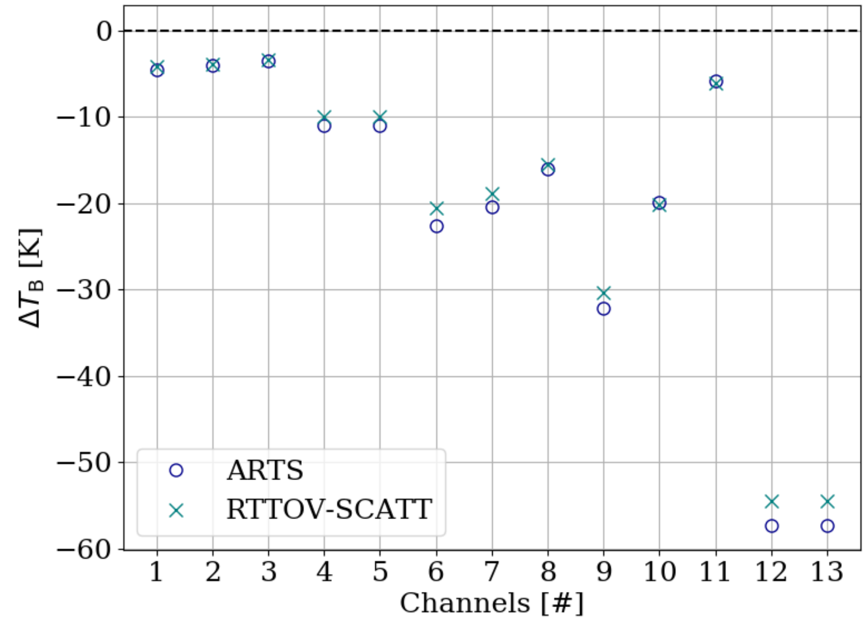
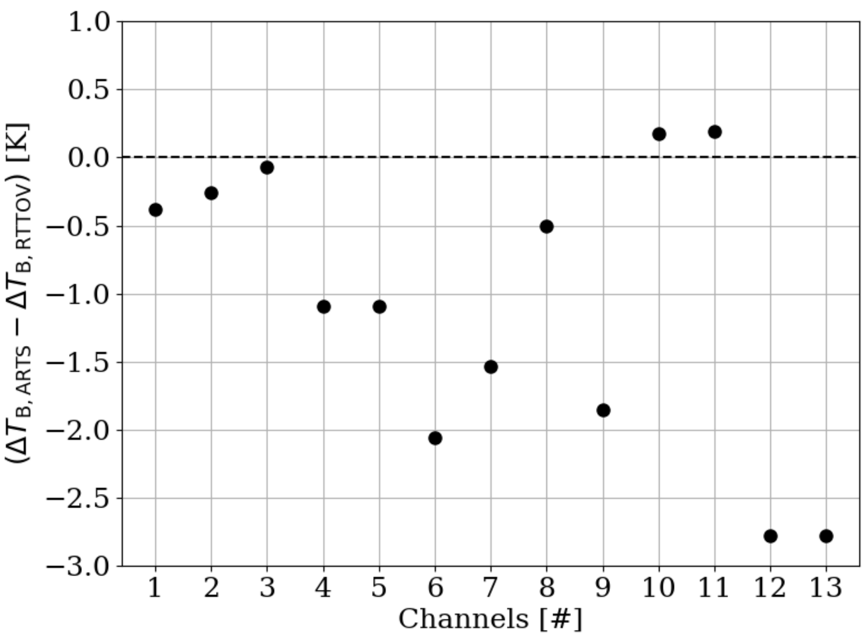
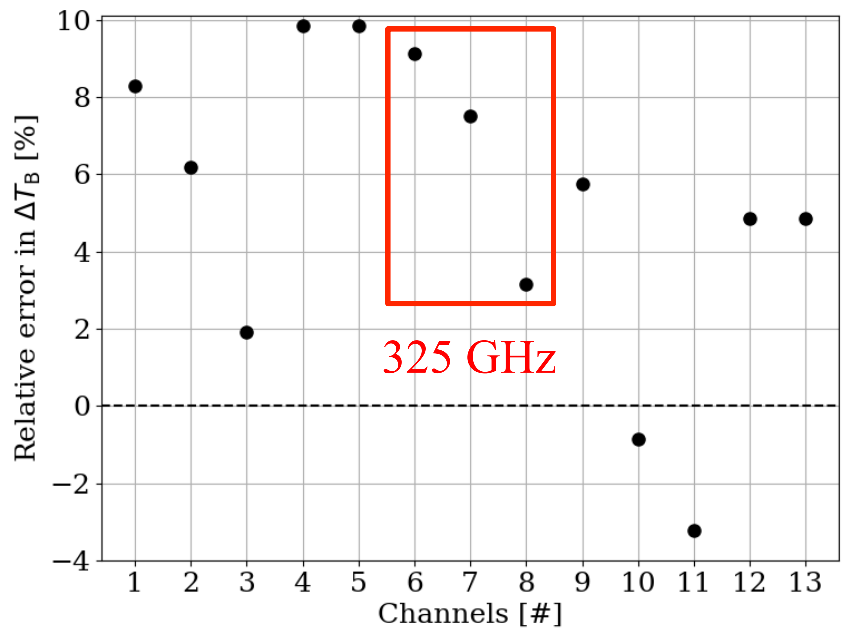






Barlakas et al., *in preparation*, *JQSRT*, 2021

Summary & Outlook

Performance of RTTOV-SCATT

- Clear–sky conditions
  - An excellent agreement is found (±0.1 K). For ICI, there is still some ongoing work.
- All–sky conditions
  - ICI: $\Delta T_B \sim 3$ K, with a relative error up to $\Delta T_B \sim 10$ %
  - MHS and AMSUA: $\Delta T_B \sim 7$ K, with a relative error up to $\Delta T_B \sim 15$ %

Outlook

- Where does the two-stream delta-Eddington "falls apart"?
- Finalize the manuscript

3rd year

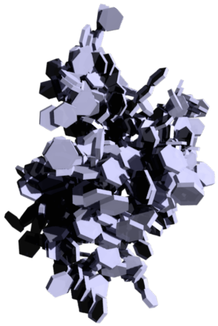
- Sub-grid variability and cloud overlap scheme.

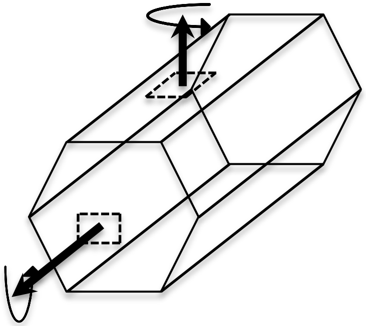
Barlakas et al., *in preparation*, *JQSRT*, 2021

Polarized correction scheme

- Cross-track sounders
- Radar backscattering
- Ice cloud retrievals (ongoing)

Photo: esa.int





Performance of RTTOV-SCATT

- Finalize the intercomparison (ongoing)
- Sub-grid variability and cloud overlap scheme.

Thank you for your attention !