Atmospheric ice shape and orientation effects in sub-mm dual-polarization observations

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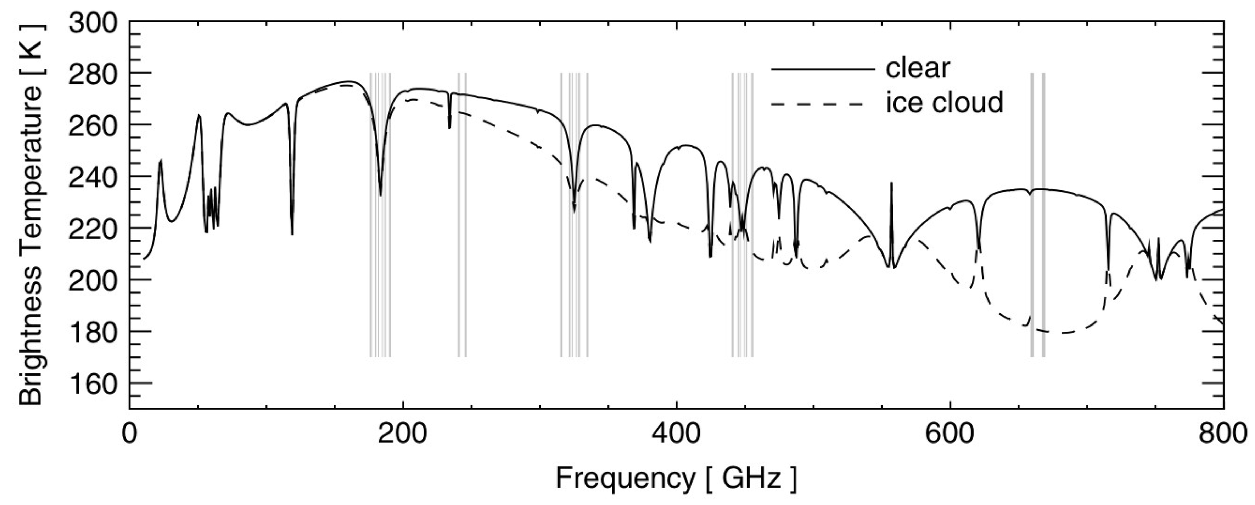
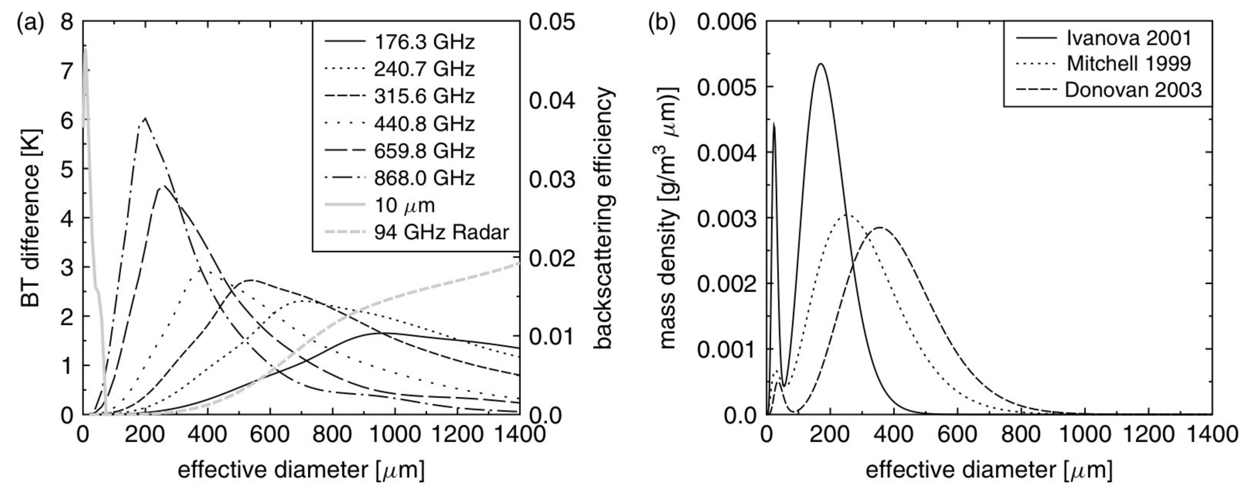
1. Motivation & Aim

- MetOp-SG to carry the Ice Cloud Imager (ICI) with 11 channels at 183 to 664GHz incl. dual-polarization at 243 & 664GHz. [Kangas14]
- Airborne sub-mm demonstrators with dual-polarization exist: ISMAR, [Fox16] CoSSIR. [Evans05]
- Ice mass and size estimate derived from intensity signal. [Buehler07]
- Polarization signal expected to additionally provide information about shape and orientation of particles.
- Here, analyzing possible range of polarization signatures in ICI/ISMAR dual-polarization channels.
- Using radiative transfer modeling. Considering randomly oriented and horizontally aligned particles of a range of shapes.
- Case study on FAAM flight 895 (COSMICS campaign) with background atmospheric data from sonde measurements, lidar-derived IWC profile and corresponding ISMAR measurement.

2. Submm ice measurement: The principle

- Main mass mode of ice (De of few 100um) strongly scatters at sub-mm frequencies.
- Leads to signal decrease compared to clearsky case (top right fig.).
- Ice signal frequency pattern strong correlates with mean particle size (bottom right fig.).
- Hence, mass inferred from intensity, particle size (and improved mass) from multi-spectral intensity signature. Altitude information through signal gradients around strong gas absorption lines. [Buehler10]





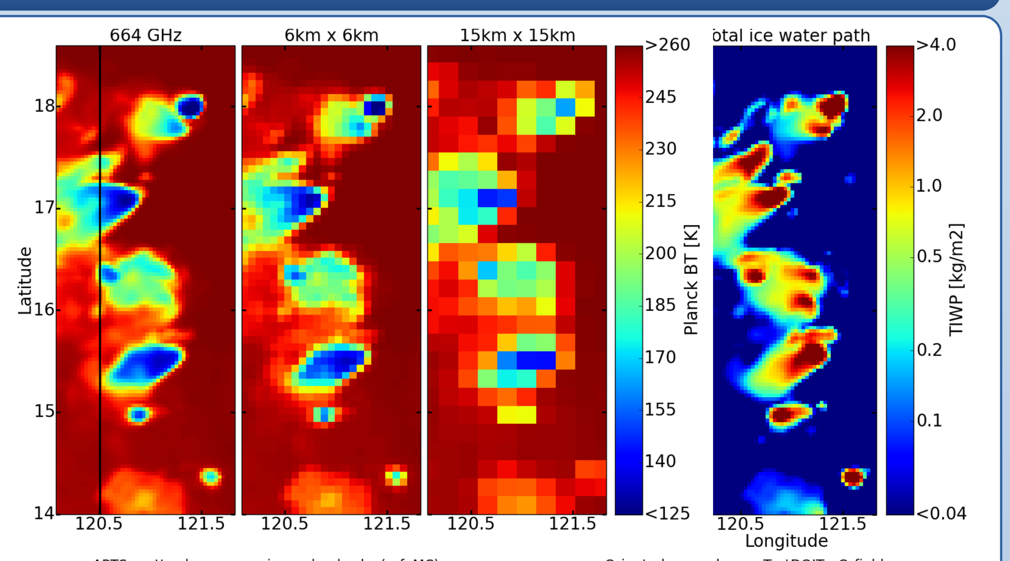
3. Radiative Transfer: ARTS and RT4 interface

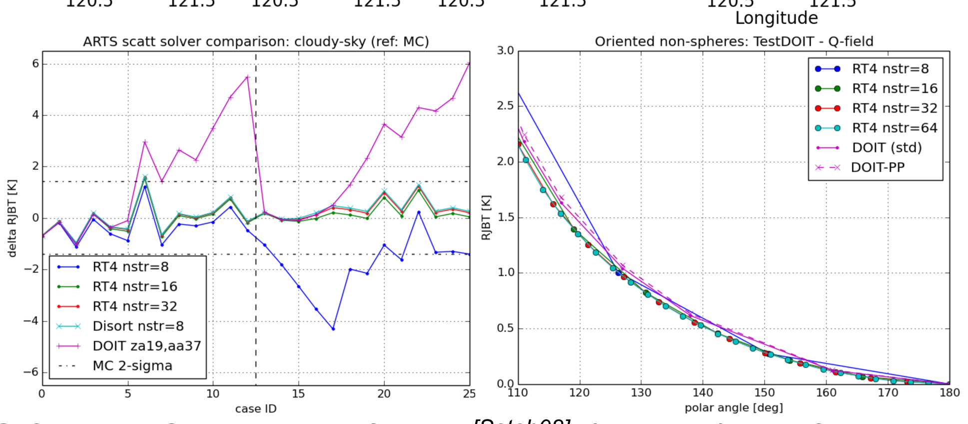
ARTS [Eriksson11] is a versatile RT model:

- Thermal radiation polarized RT in 3D spheroidal systems.
- Scattering models: 3 proprietary + DISORT&RT4 interfaces.
- All-sky Jacobians.
- Easy to apply GCM/NWP fields, sensor characteristics, ...

Here, RT4 scattering module used:

- H & V radiation components. Plane-parallel in cloudbox.
- So far, Lambertian surface only.
- Good agreement with ARTS-MC, -DOIT, -DISORT (bottom fig), degrading at thick clouds (DOIT and MC issues).
- Very stable regarding choice of vertical grid, quadrature type and stream number.





(top fig) 664GHz signal at sensor resolution 3,6,15km modeled with ARTS from NICAM atmo. fields. [Satoh08] (bottom) Verification of RT4 interface: (right) ISMAR channel intensity dev. to ARTS-MC at nadir and 50deg views for IFS atm. case. [Chevallier01] (left) 230GHz Q component for artifical ~150g/m2 cloud at ~13km.

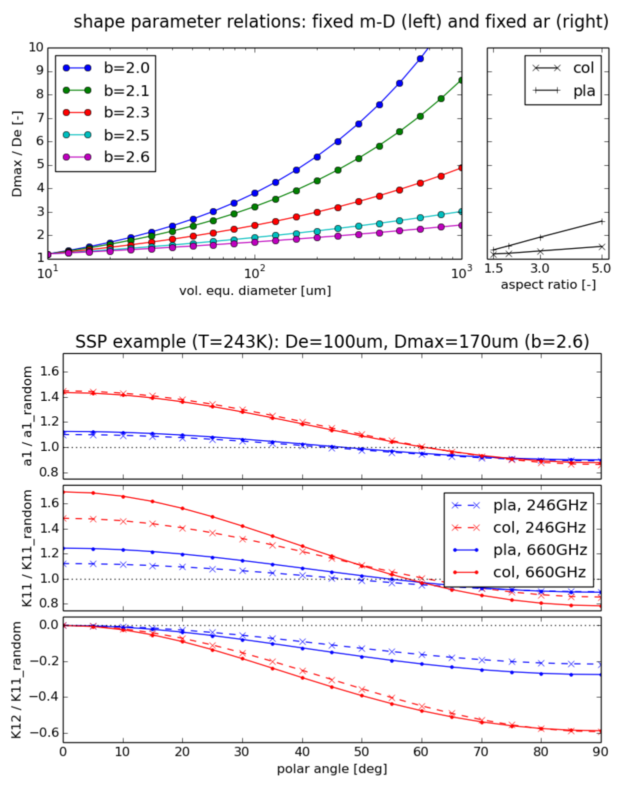
4. Single Scattering Data

Sets of randomly oriented and horizontally aligned columns and plates from T-Matrix [Mishchenko98,00] with De=10-1000um (top fig):

(a) fixed m-Dmax relation

(b) fixed aspect ratios (2 plates: $ar^{pla}=1/ar^{col}$ and $Dmax^{pla}=Dmax^{col}$)

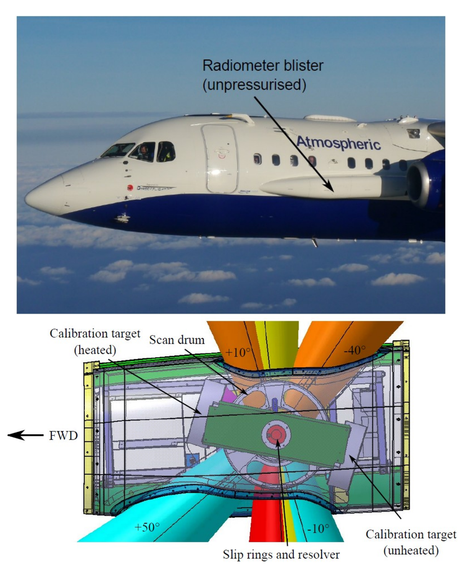
Fails for large D and large ar (columns with larger issues), hence not all SSD populated



- Scalar extinction (and abs./scat.) of aligned particles significantly larger at nadir, smaller in limb. Polarization coeff. always negative and largest in limb. (bottom fig.)
- Columns with stronger orientation features than plates.

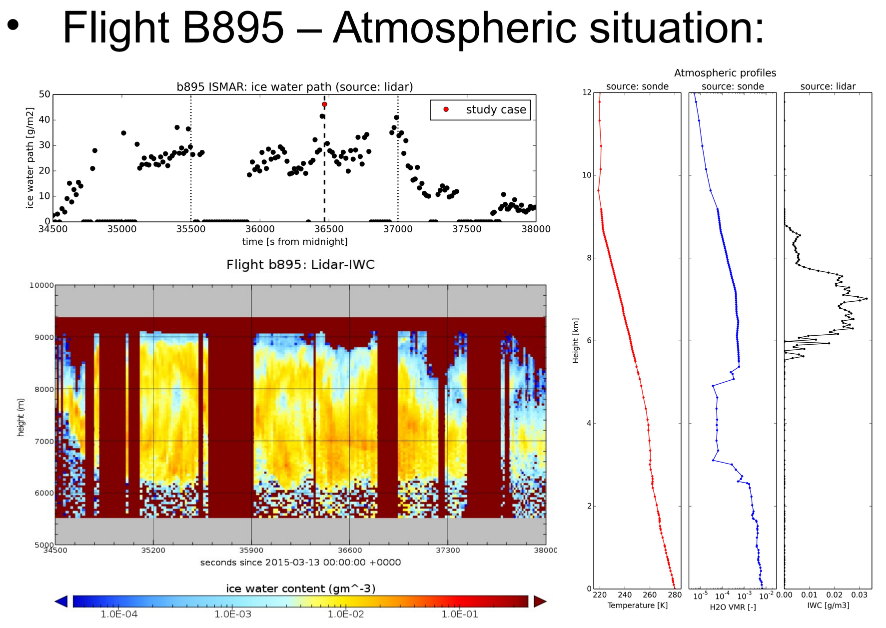
5. ISMAR: Instrument & flight B895

- The instrument: [Fox16]

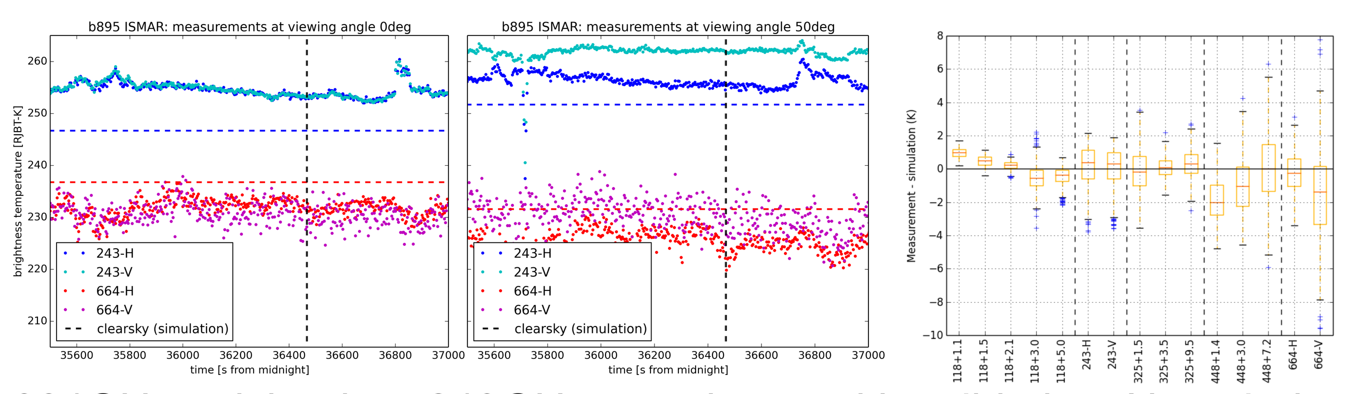


Centre frequency (GHz)	Frequency offset (GHz)	IF Bandwidth (GHz)	Polarisation (at +50° downwards view)
118.75	±1.1	0.4	V
	±1.5	0.4	
	±2.1	0.8	
	±3.0	1.0	
	±5.0	2.0	
243.2	±2.5	3.0	V & H
325.15	±1.5	1.6	V
	±3.5	2.4	
	±9.5	3.0	
424.7	±1.0	0.4	V
	±1.5	0.6	
	±4.0	1.0	
448.0	±1.4	1.2	V
	±3.0	2.0	
	±7.2	3.0	
664.0	±4.2	5.0	V & H
874.4	±6.0	3.0	V & H

- Flight B895 – Atmospheric situation:



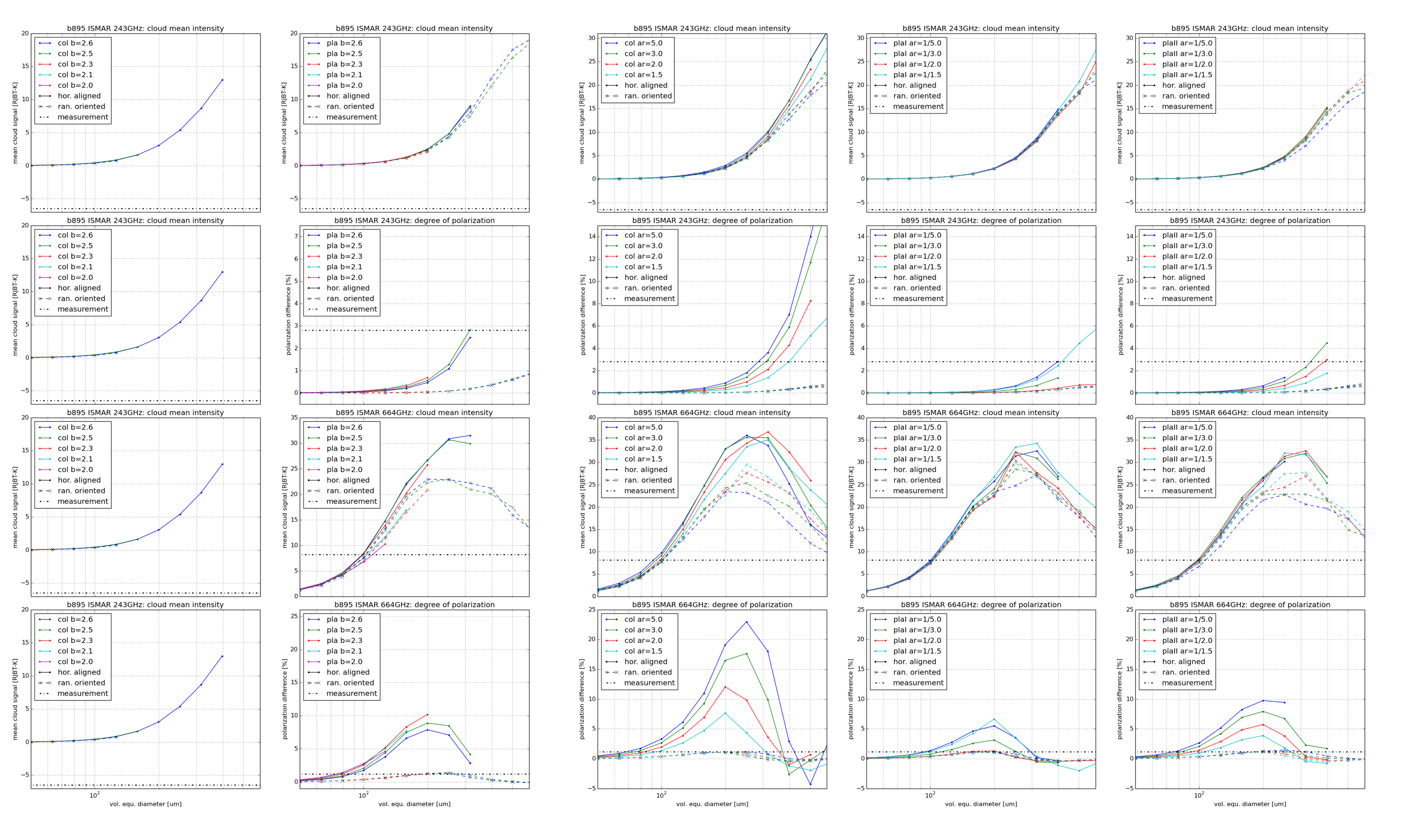
- Flight B895 – ISMAR measurements:



664GHz noisier than 243GHz, consistent with validation. No polarization in 0deg as expected, 50deg with clear signal: due to surface at 243GHz (not in simu. yet). Validation indicates V-664GHz unreliable.

(left) ISMAR measurements around case study location. (right) Validation measurements: B952 clearsky high-level nadir over ocean.

6. Shape & orientation polarization signatures



Mean cloud signals (Ic=V+H-Iclear) and degree of polarization (p=(V-H)/(V+H)) at 243 and 664GHz for (left-to-right) m-Dmax columns and plates, ar columns, ar-Dmax/De and 1/ar plates of monodispersions for atm. case shown above.

- Several K orientation signal in p, shape info more complex.
- Ic of random orientation lower than Ic aligned, particularly at 243GHz.
- Both, Ic and p of aligned particles peak at x~2 (p at slightly lower x).
- Ic and, particularly, p of m-Dmax particles seem less shape dependent than ar particles.
- Negative p for large x. Real or T-Matrix artifact?

7. Outlook

- Continue study with DDA particles (see Ekelund et al., **P1.49**) with more realistic shapes at higher De and complete SSP sets. Consider size distributions.
- For comparison to measurements, specular surface model is necessary for 243GHz; 664GHz needs more analysis of sensor behaviour (correction possible?).

Acknowledgements

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