Using CloudSat to generate ISMAR retrieval databases

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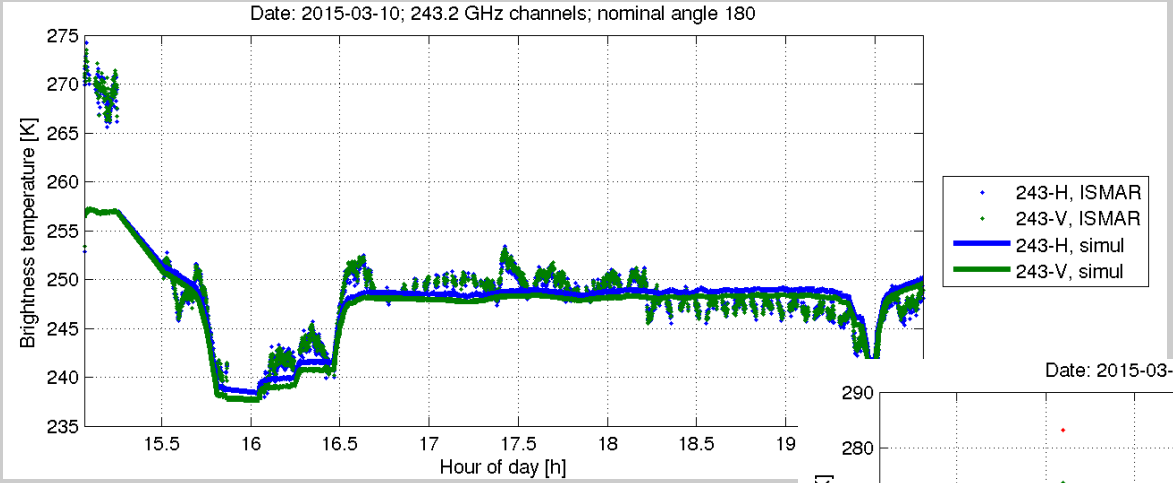
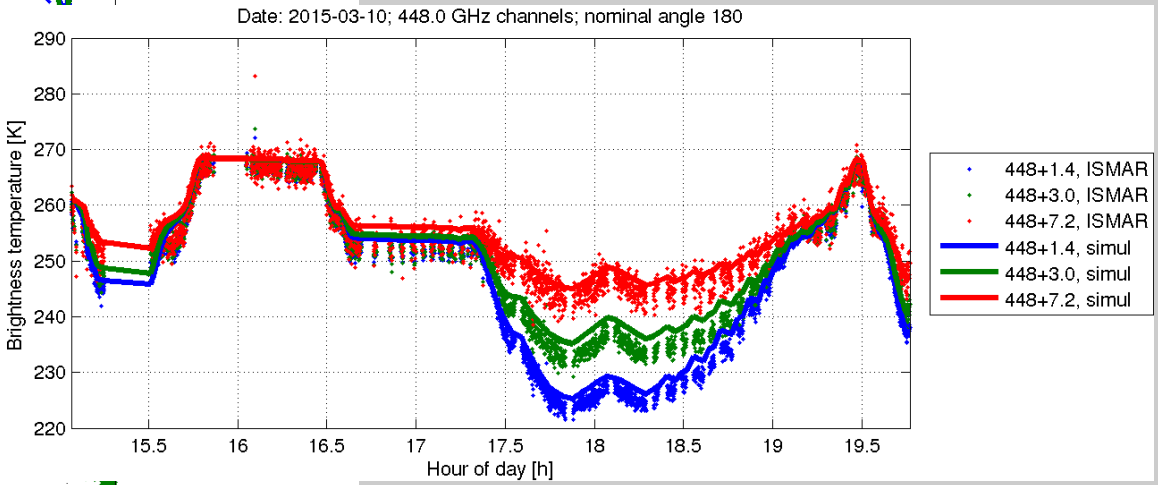
Outline

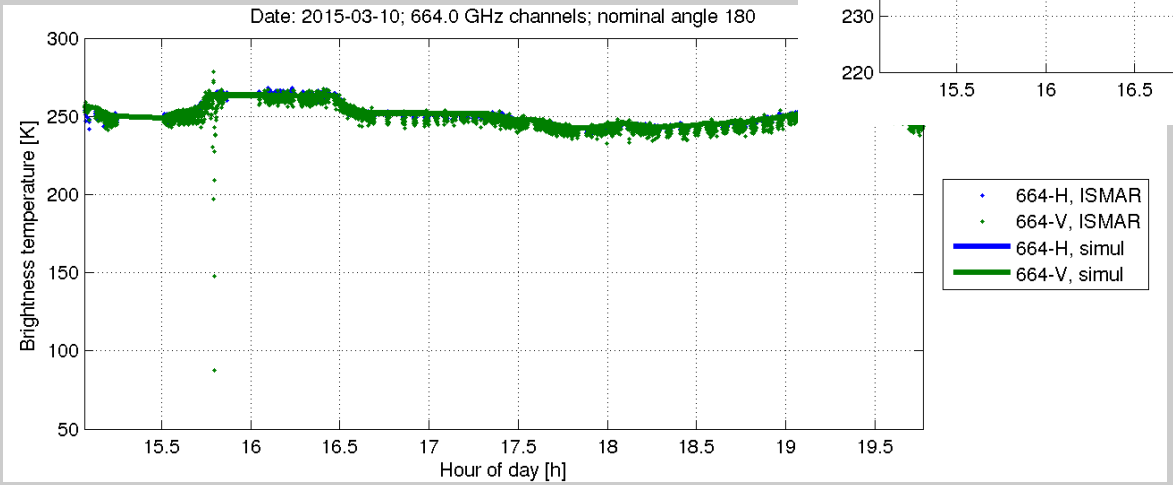
1. Introduction
2. Background data and assumptions
3. Using CloudSat 2B-CWC products
4. Using CloudSat dBZ

Some ISMAR “nadir” data from flight B893

Compared to ERA-Interim based non-scattering calculations

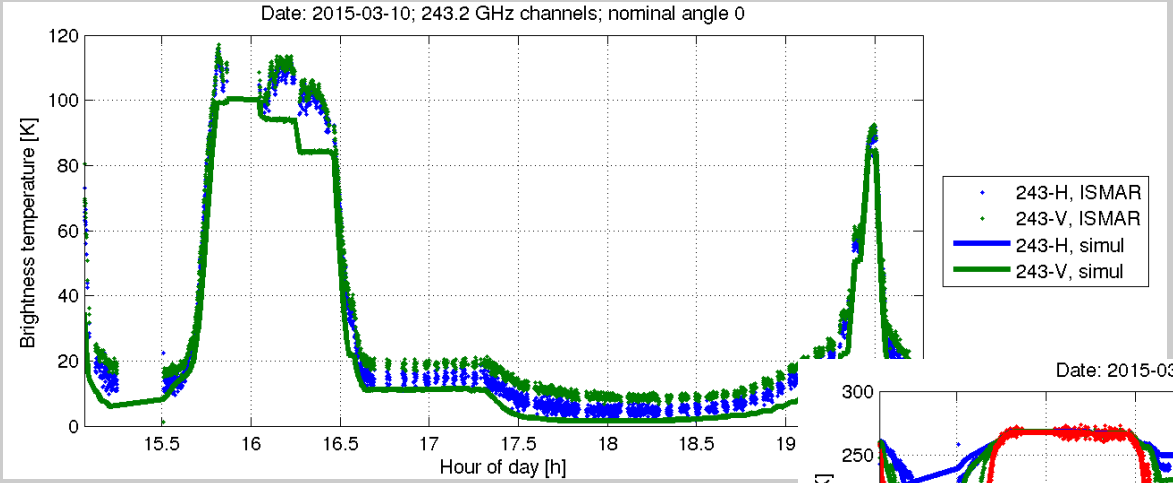


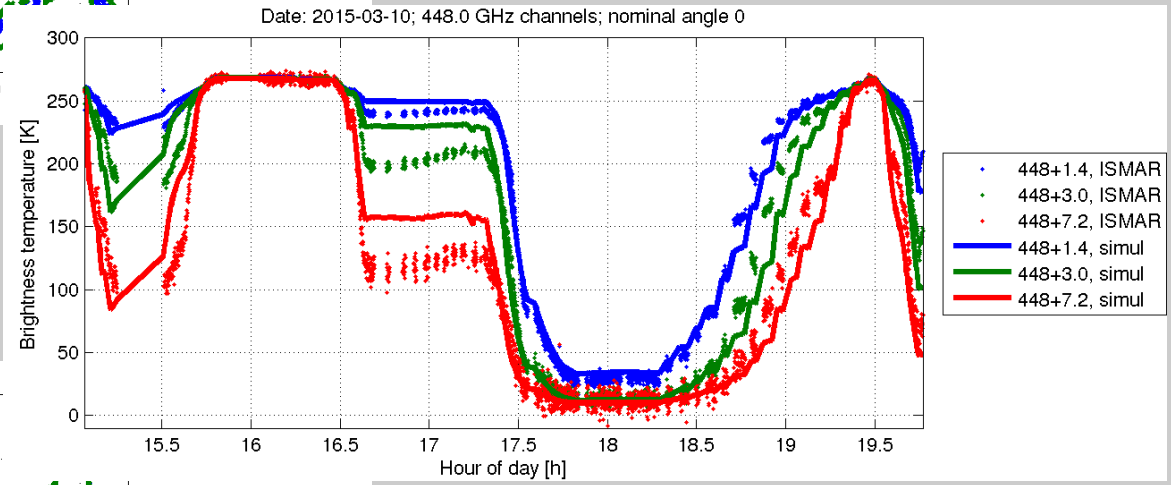


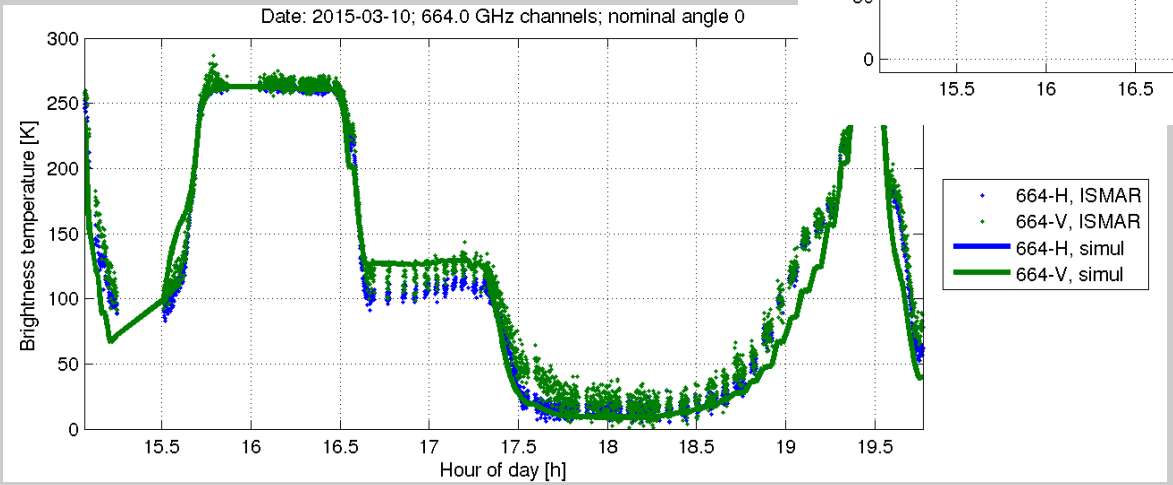


Some ISMAR “zenith” data from flight B893

Compared to ERA-Interim based non-scattering calculations

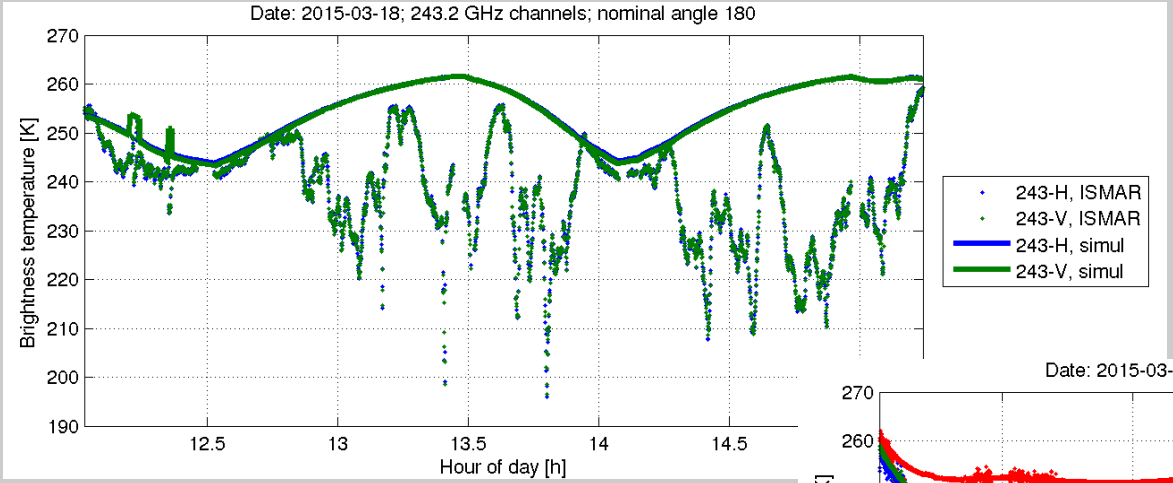


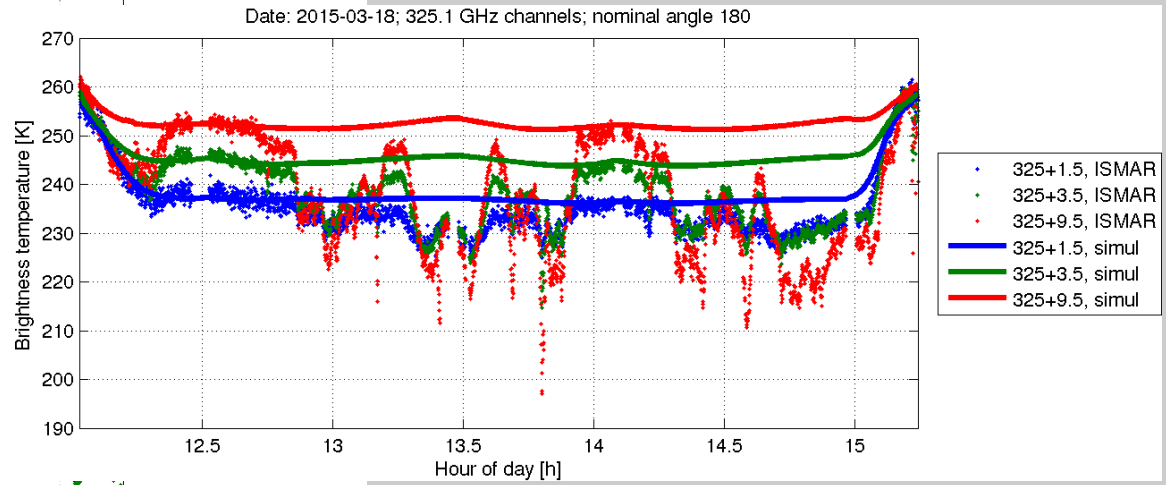


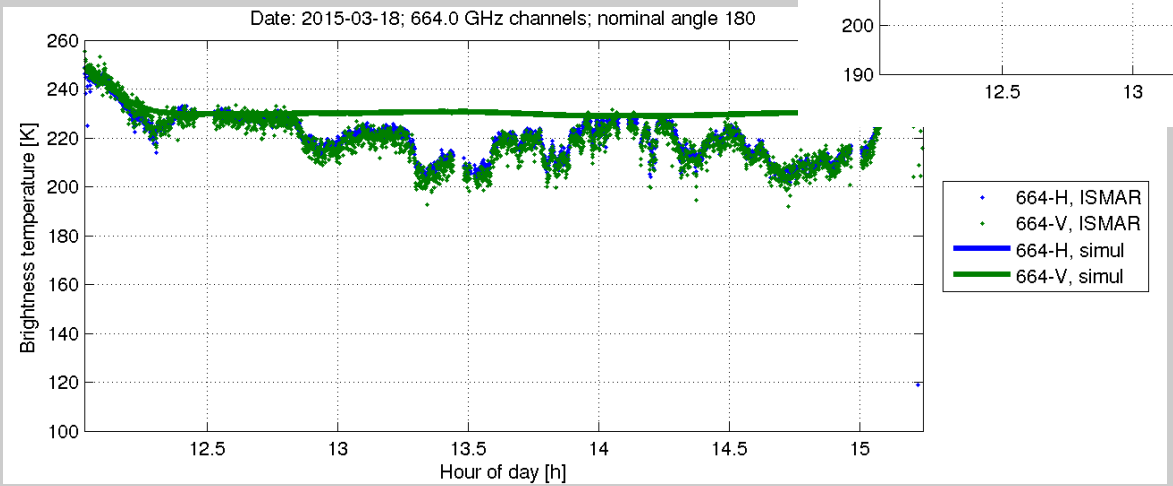


Some ISMAR data from flight B897

Compared to ERA-Interim based non-scattering calculations







The Bayesian Monte Carlo method

- Retrieved state is $\hat{\mathbf{x}} = \sum_i w_i \mathbf{x}_i / \sum_i w_i$
- with $w_i = exp\left(-0.5 \cdot [\mathbf{y} - \mathbf{y}_i]^T \mathbf{S}_\varepsilon^{-1} [\mathbf{y} - \mathbf{y}_i]\right)$
  - $\mathbf{y}$: measurement vector
  - $\mathbf{S}_\varepsilon$: covariance matrix of measurement errors
  - $\mathbf{x}_i$ and $\mathbf{y}_i$ realisations of $\mathbf{x}$ and $\mathbf{y}$
- The set of $[\mathbf{x}_i, \mathbf{y}_i]$ constitutes the "retrieval database"
- Basic requirements on the database
  - relationship between $\mathbf{x}_i$ and $\mathbf{y}_i$ must be "physically correct"
  - must cover all possible states
  - for a Bayesian solution, must follow a priori distribution
  - must be sufficiently dense ($\sim n^d$)
- Same issues apply when using neural nets
  - but database size appears less critical

Approaches to generate retrieval database

- Purely empirical
  - \+ does not require a forward model
  - \- hard to obtain required “ground-truth” data
- Based on an atmospheric model
  - \+ a fairly complete description of the atmosphere is provided
  - \- atmospheric and forward model errors/biases will be inherited
- “Observation-based”
  - \+ real observations used for most critical part(s)
    - here CloudSat used to obtain cloud structure information
    - successfully applied for Odin-SMR inversions
  - \- data from different sources have to be merged
  - \- at least forward model errors will be inherited

Options for radar-based databases

- Use external IWC and LWC retrieval
- Use basic observation, dBZ
  - results in an implicit retrieval

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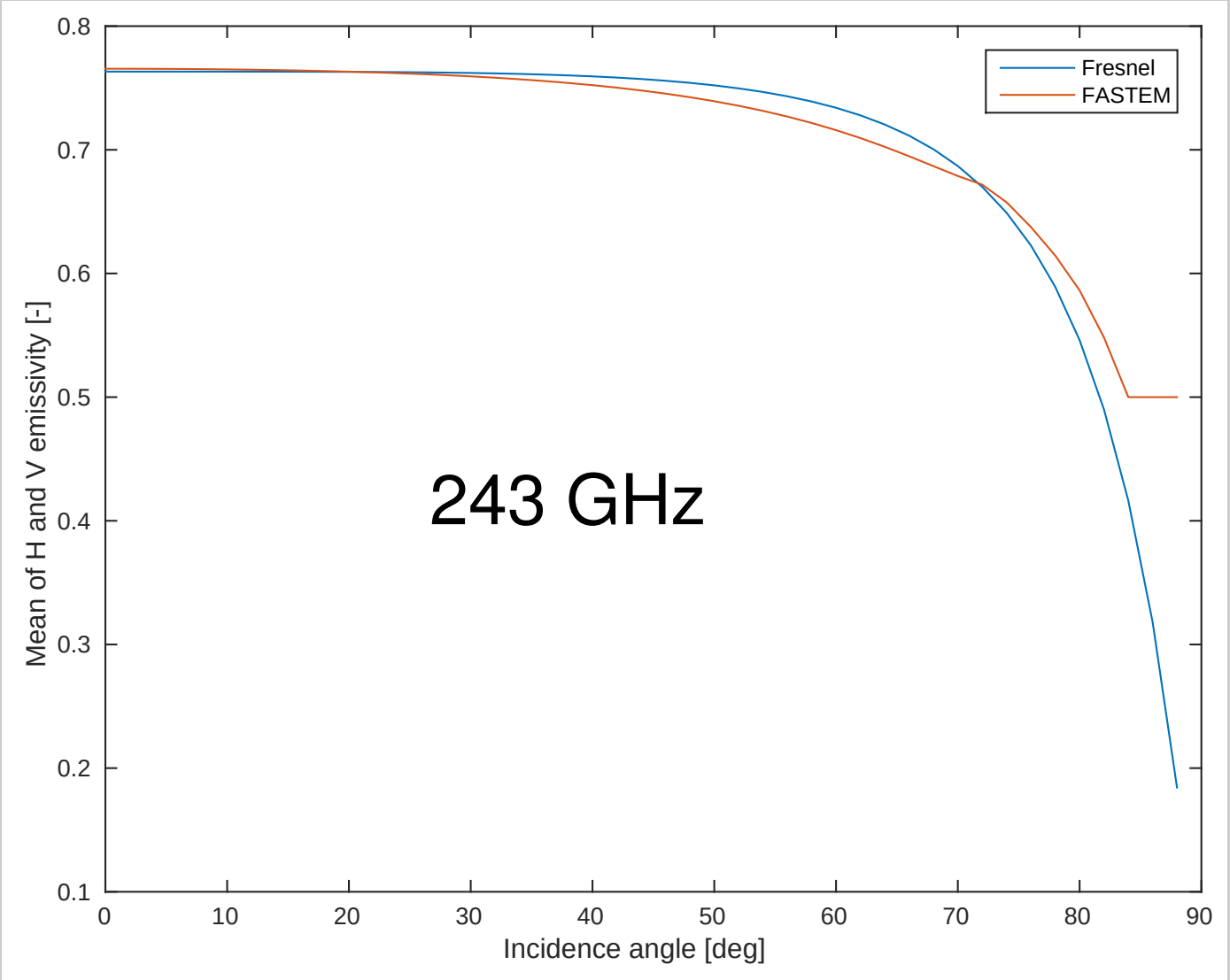
Clear-sky atmosphere and surface

- From ERA-Interim (0.7° resolution)
  - geopotential, temperature, water vapour, skin temperature
  - LWC, IWC, low and high cloud cover fraction
- Extracted for time and position of CloudSat measurements
- Only March 2008, lat 50°N to 70°N, lon -60°N to 0°N
- Surface: just ocean
  - winds not considered
  - Fresnel equations applied with n from MPM93

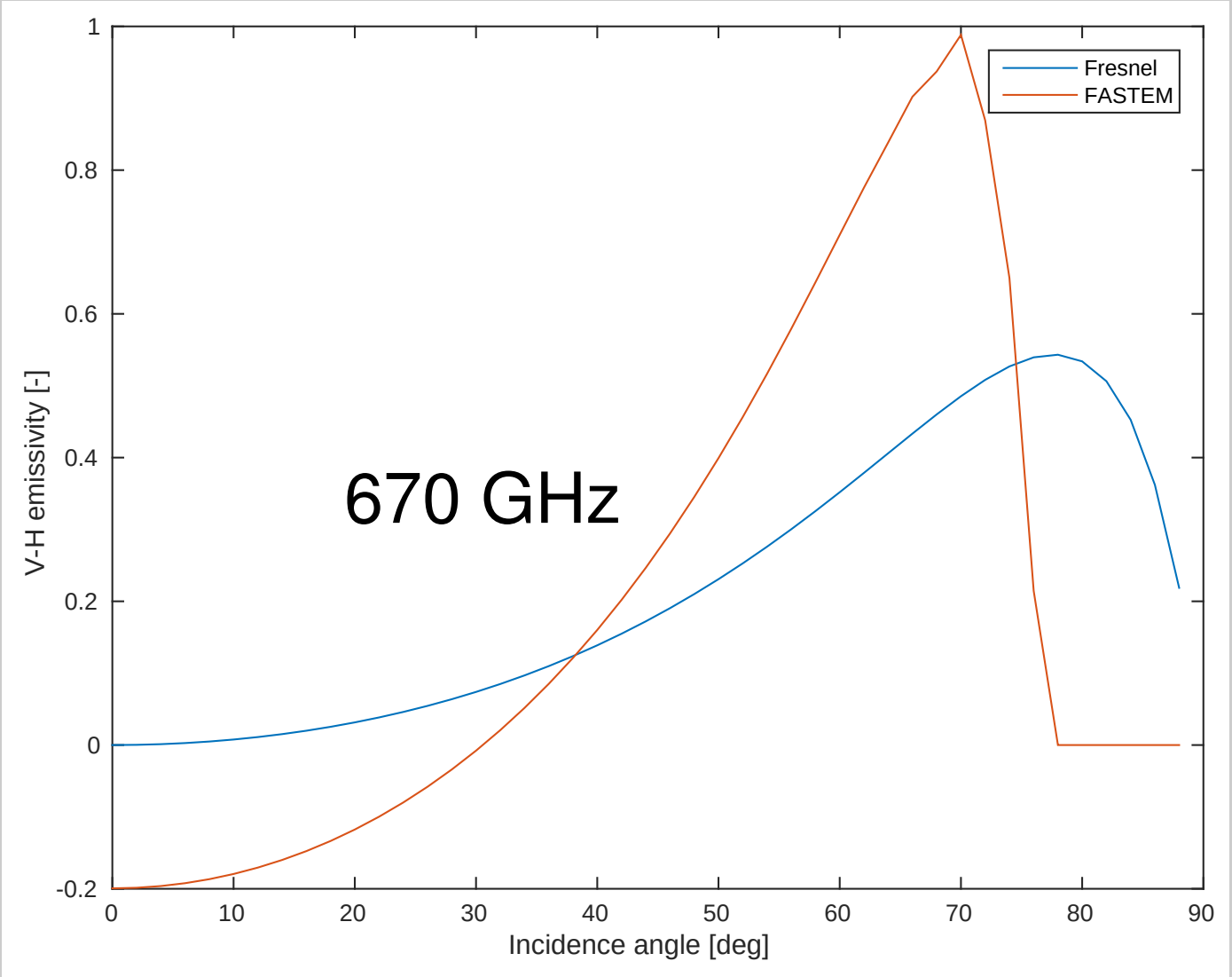
Why not use FASTEM?

Answer 1: don't work at high incidence angles



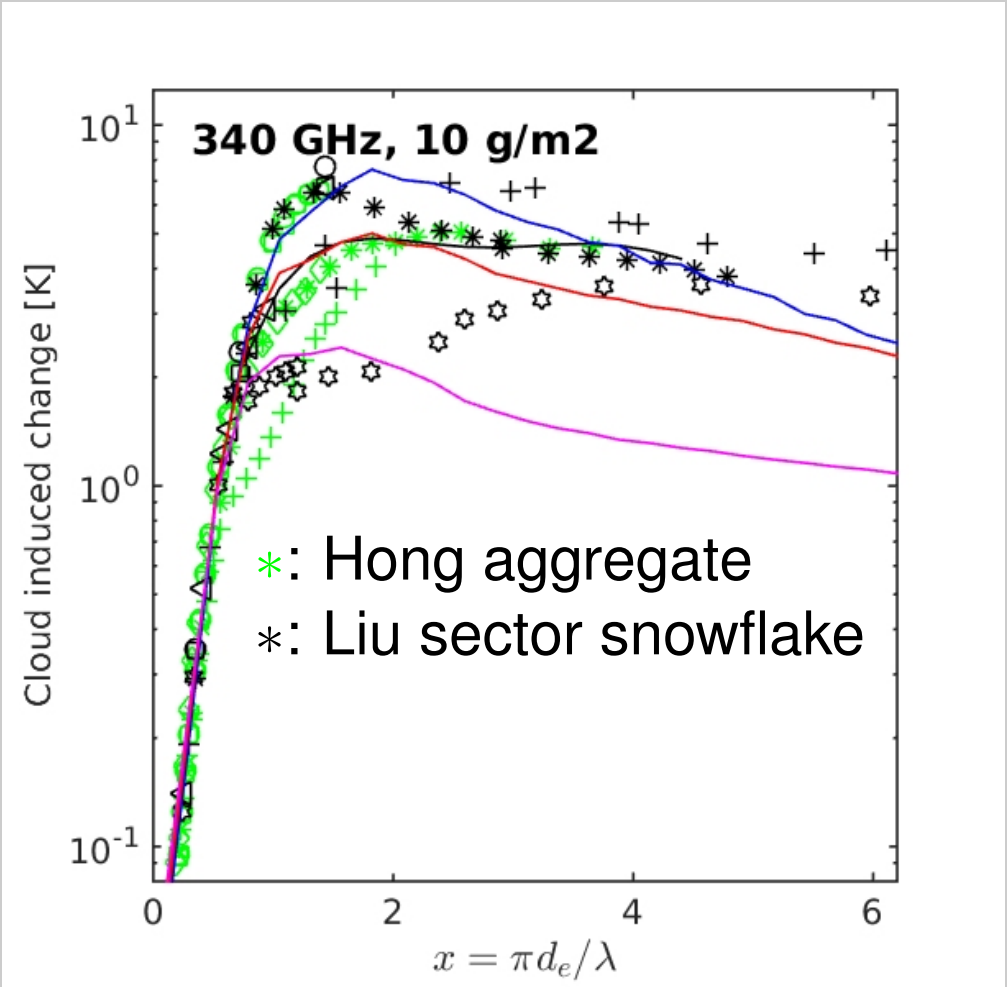
Why not use FASTEM?

Answer 2: don't work at all above $\sim$ 400 GHZ



Single scattering data

- The aggregate particle from the Hong database used
  - with a rough correction of absorption
- Some test calculations with “sector snowflake”

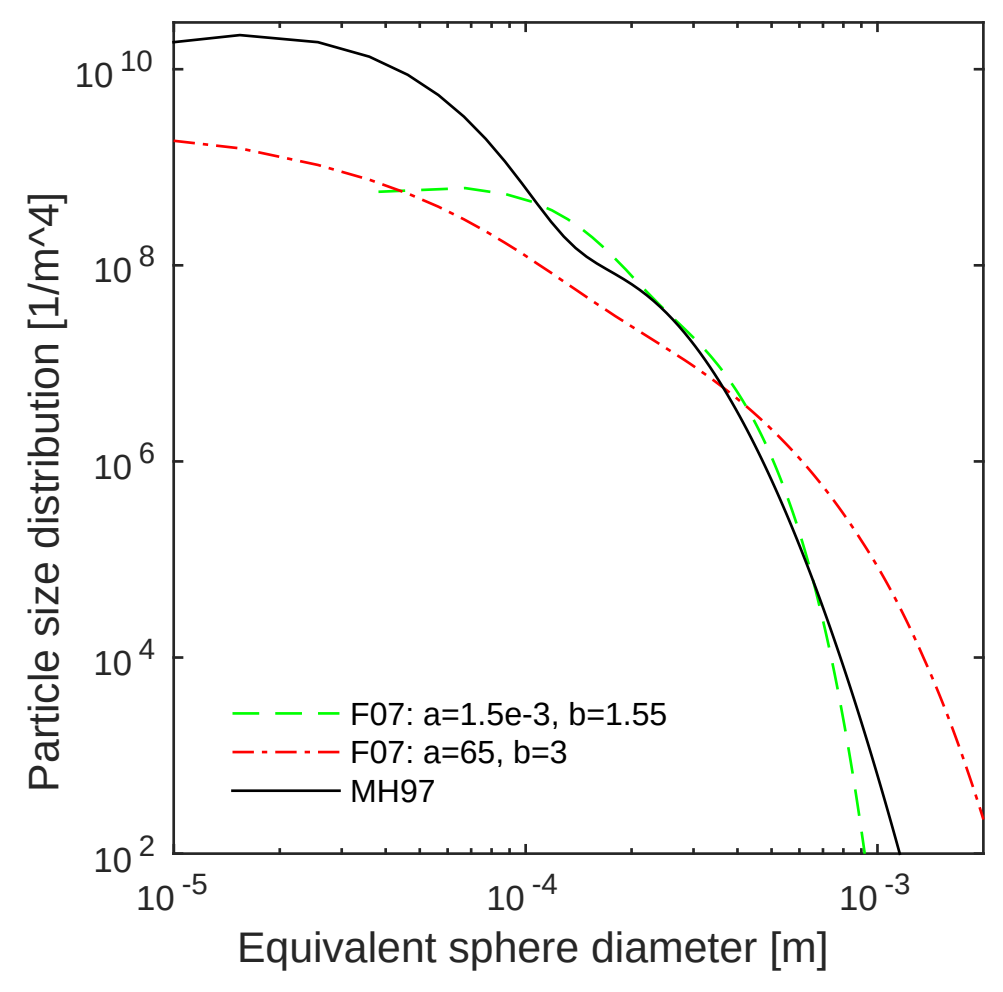


From Eriksson et al., AMT, 2015.

Particle size distributions (PSDs)

Exemplified for 0.1 g/m3 and 253 K

- MH97: McFarquhar and Heymsfield (1997) (MH97)
- F07t: Field et al. 2007, tropical version



$$m = aD_{max}^{b}$$

Radiative transfer

- ARTS used
  - "clear-sky" T_b calculated
  - 1D scattering calculations by DOIT
- DOIT provides the complete radiation field
  - all flight altitudes and view directions covered in one calculation
- MARSS and ISMAR channels between 183 to 664 GHz
- So far only total random orientation considered

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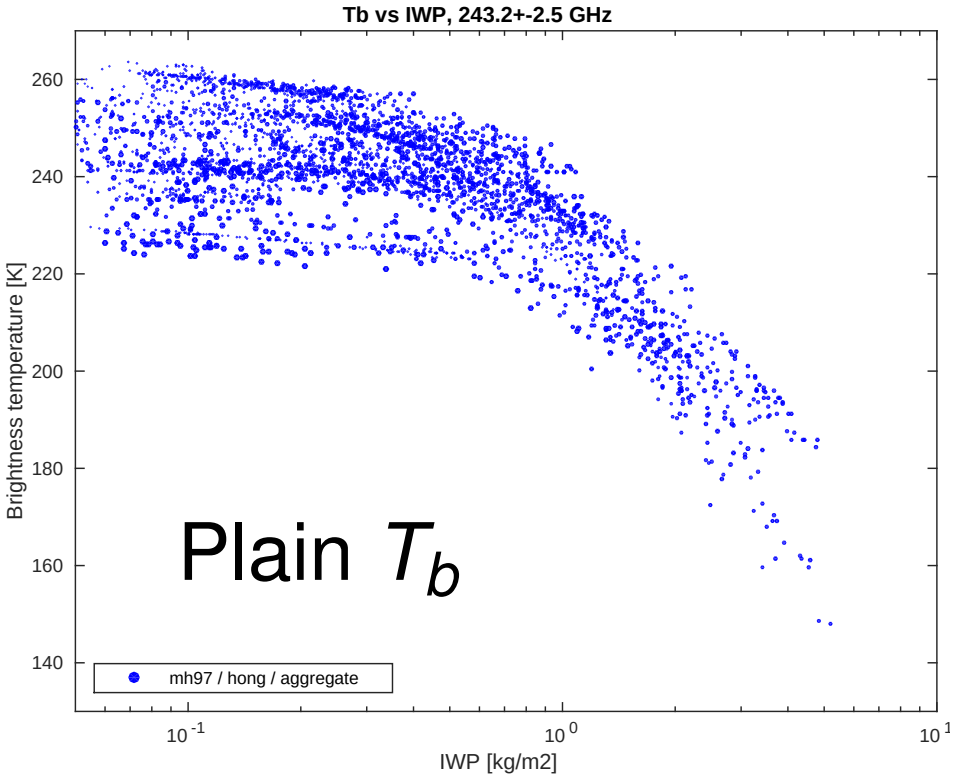
Setting of IWC and LWC

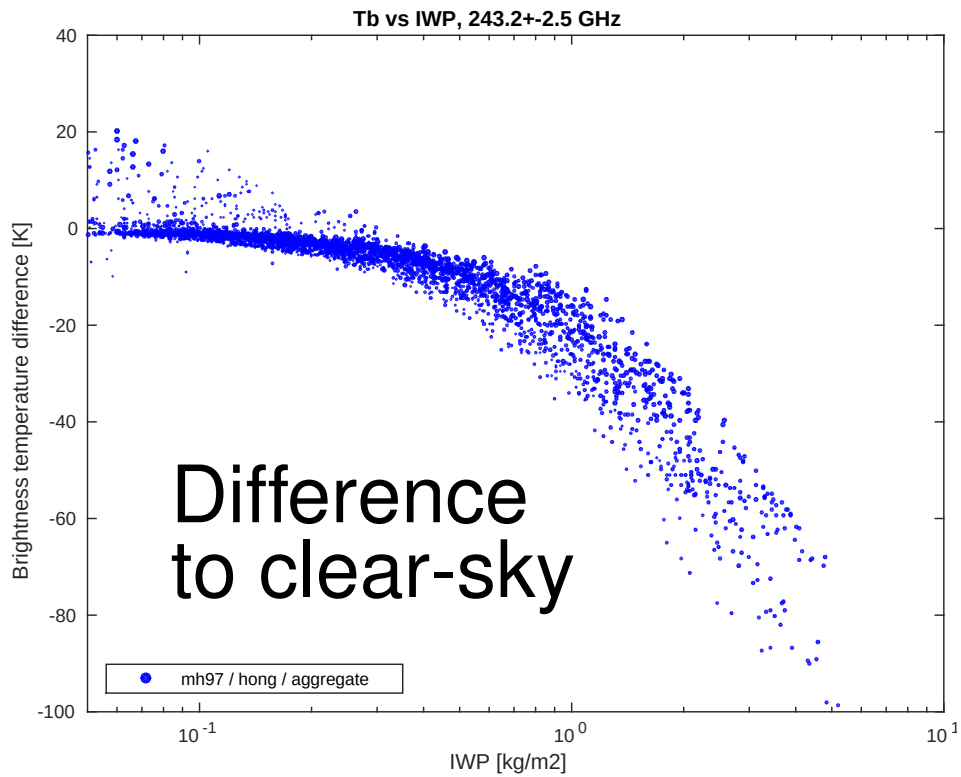
- Products used: `IO_RO_ice_water_content` and `LO_RO_liquid_water_content`
  - these products overlap in the “melting layer”
- The transition between liquid and ice selected randomly
  - a sharp transition applied, based on temperature
  - transition uniformly placed between 270 and 275 K

- IWC from ERA randomly forced to 0 based on high cloud fraction
- Final IWC set as max(IWC_{Csat},IWC_{ERA}),
- Same procedure for LWC, but low cloud fraction used

MH97 and Hong aggregates, 243 GHz

T_b as a function of IWP

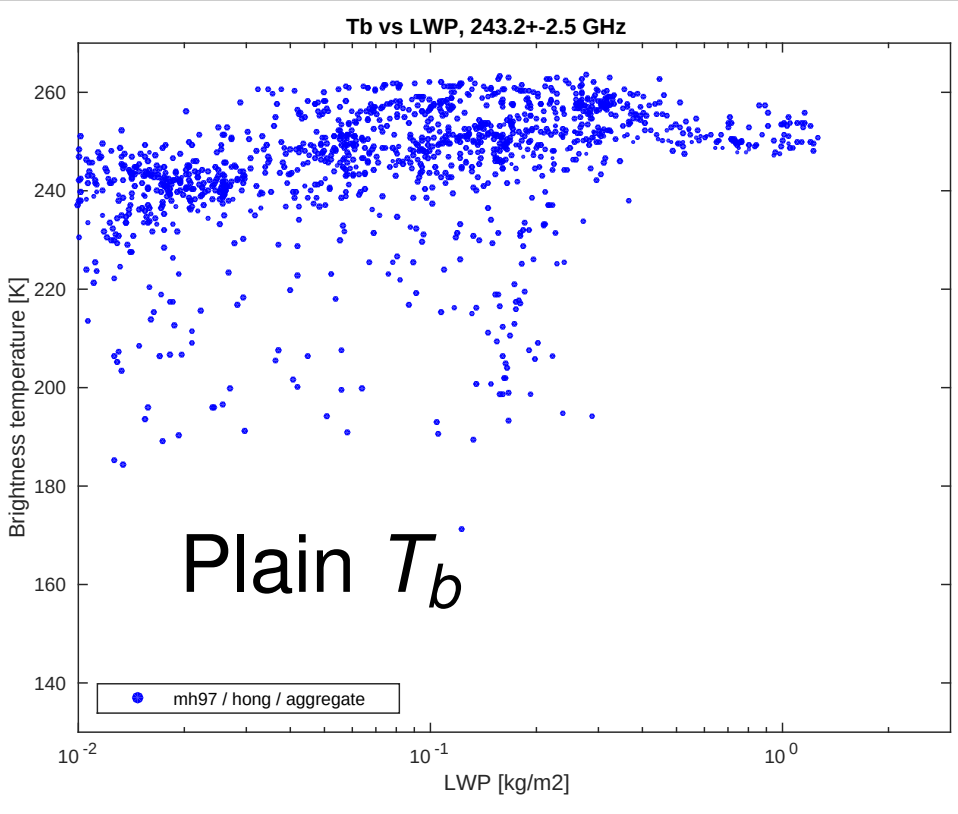


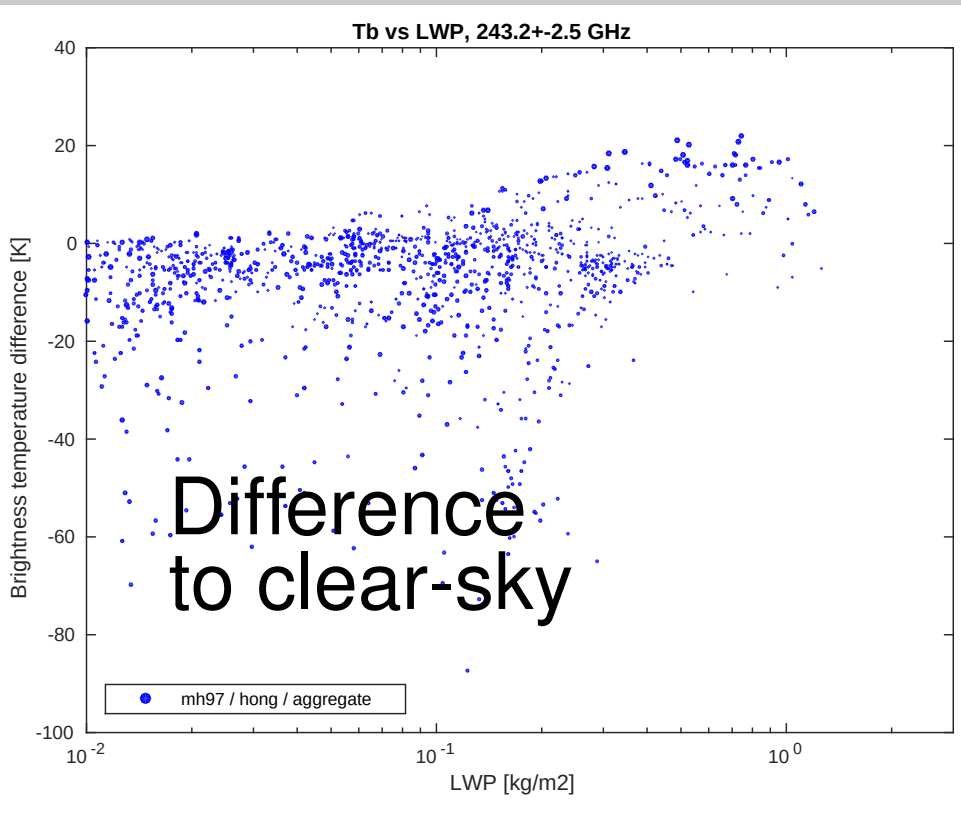


- Size of dot indicates median height for ice/liquid mass
- Mainly only data with `RO_ice_water_path` $> 50\ \mathrm{g/m^2}$

MH97 and Hong aggregates, 243 GHz

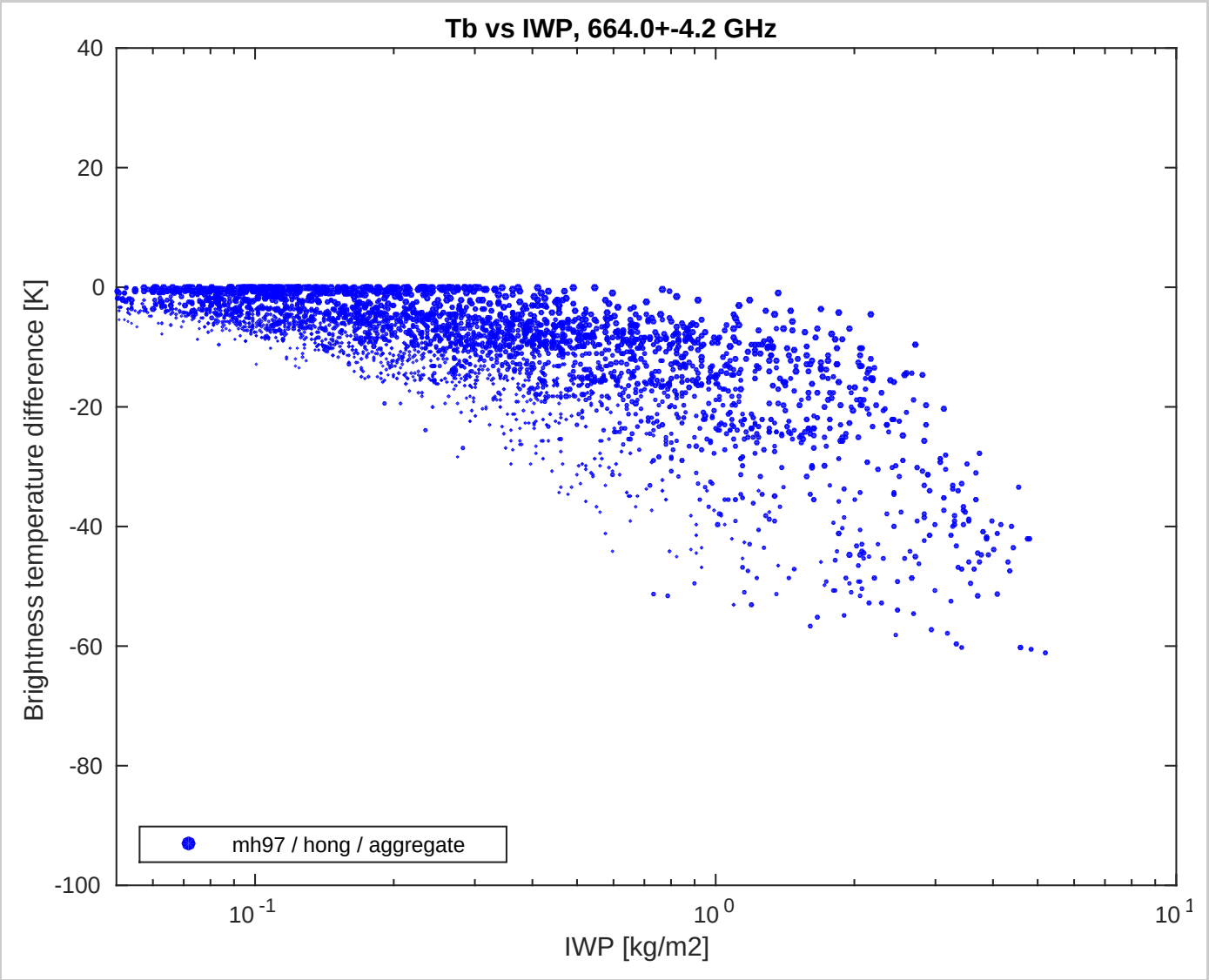
T_b as a function of LWP





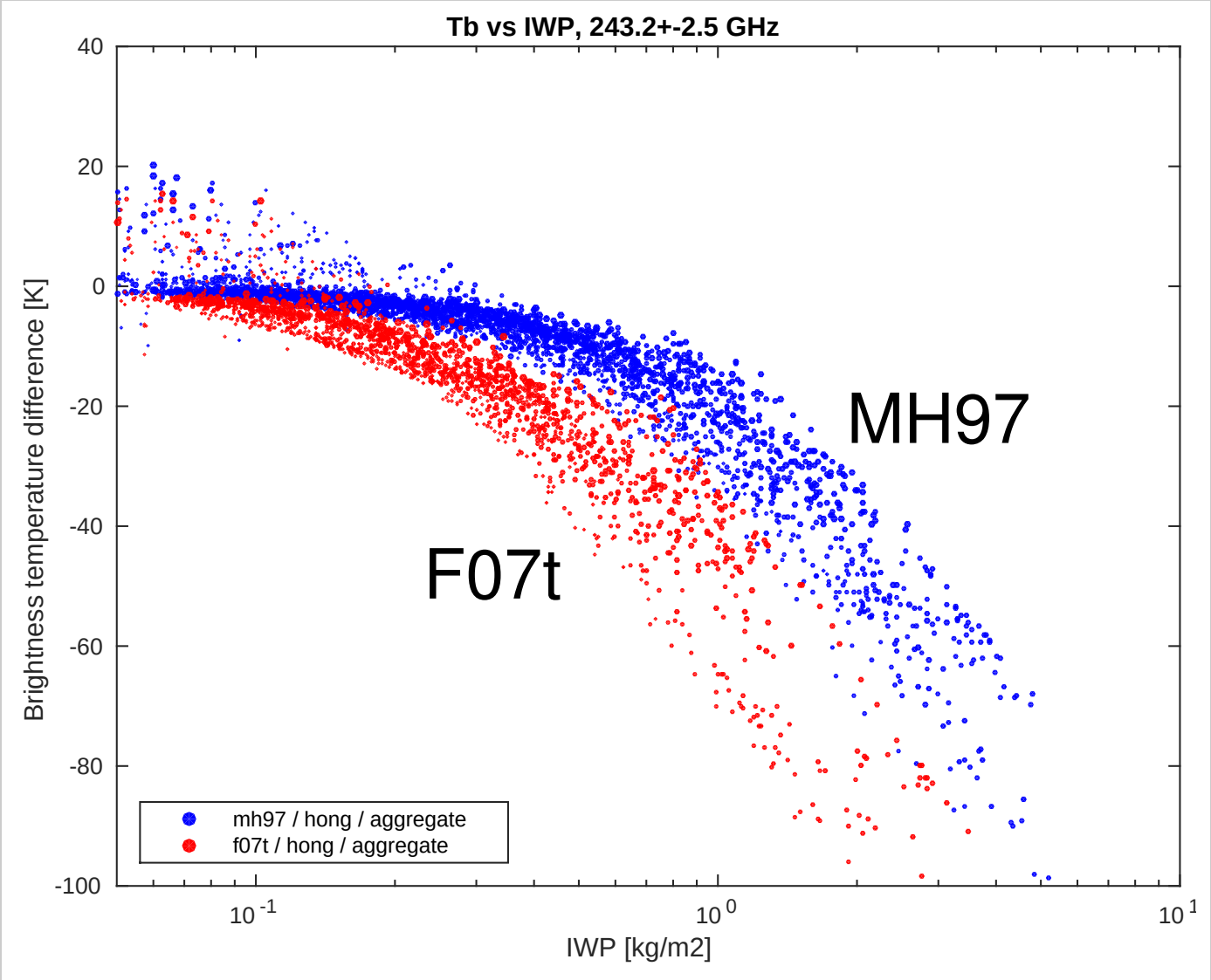
MH97 and Hong aggregates, 664 GHz

T_b as a function of IWP

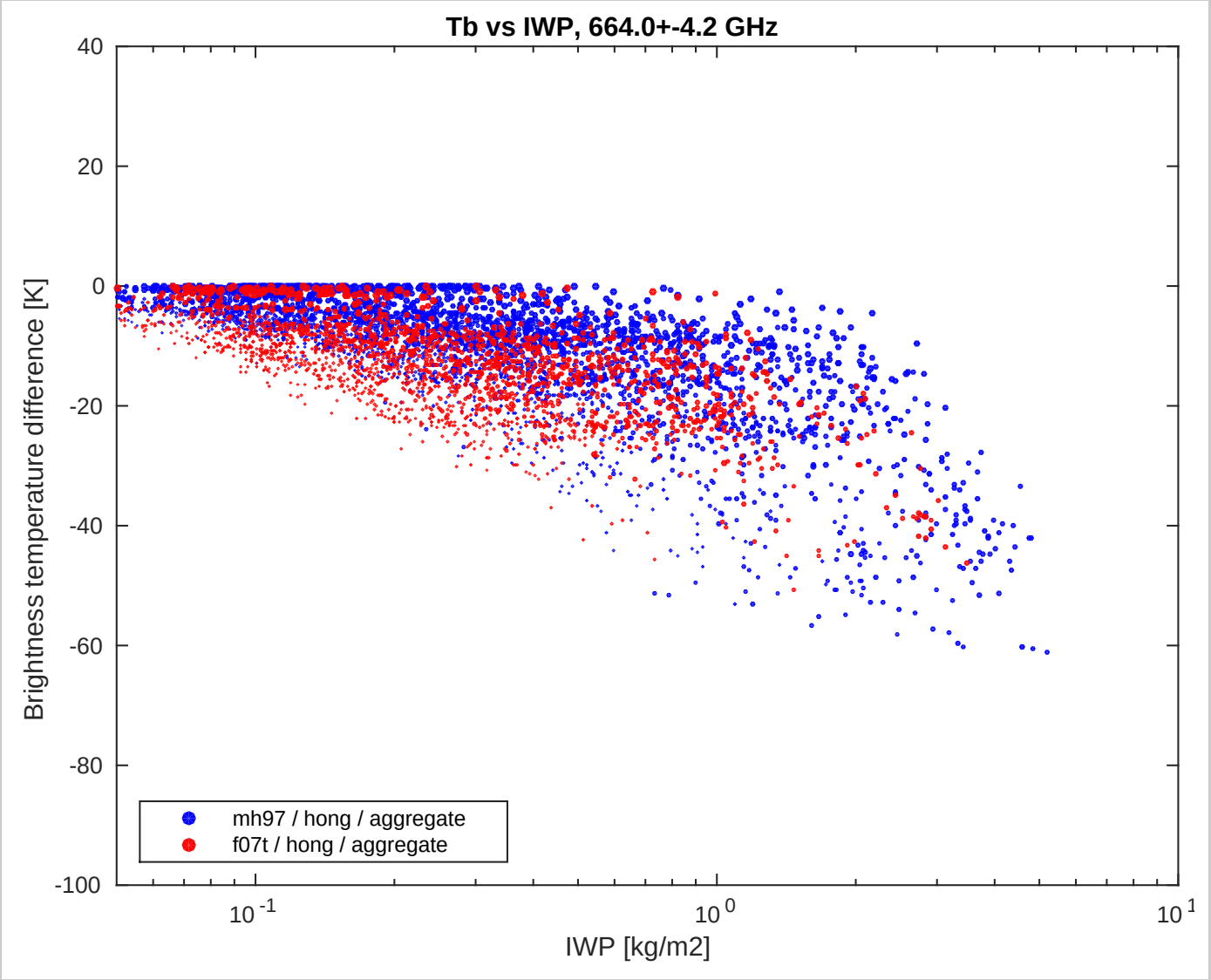


Particle size distribution matters!

243 GHz

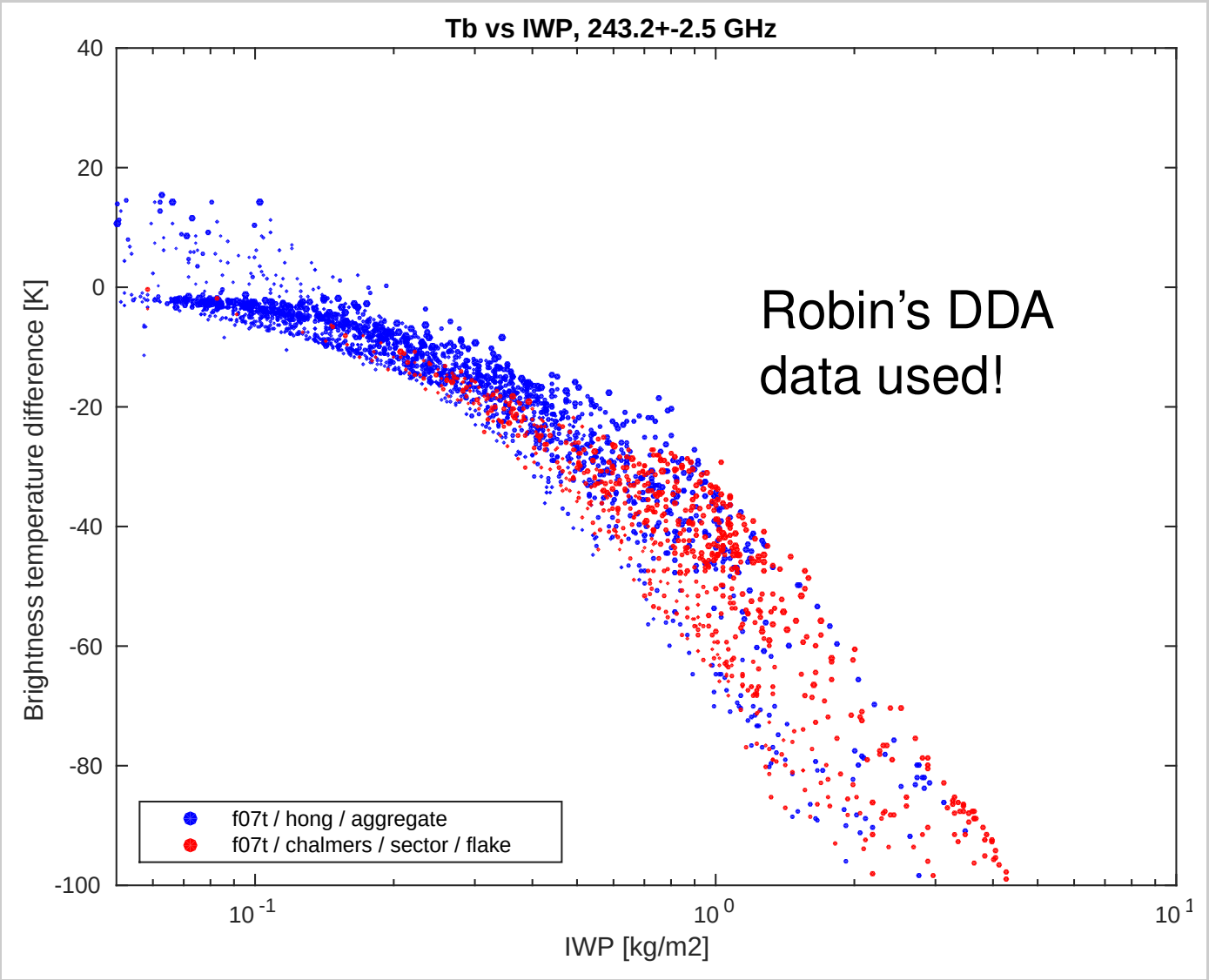


Same comparison at 664 GHz



Some calculations with sector snowflake

But particle shape still matters!



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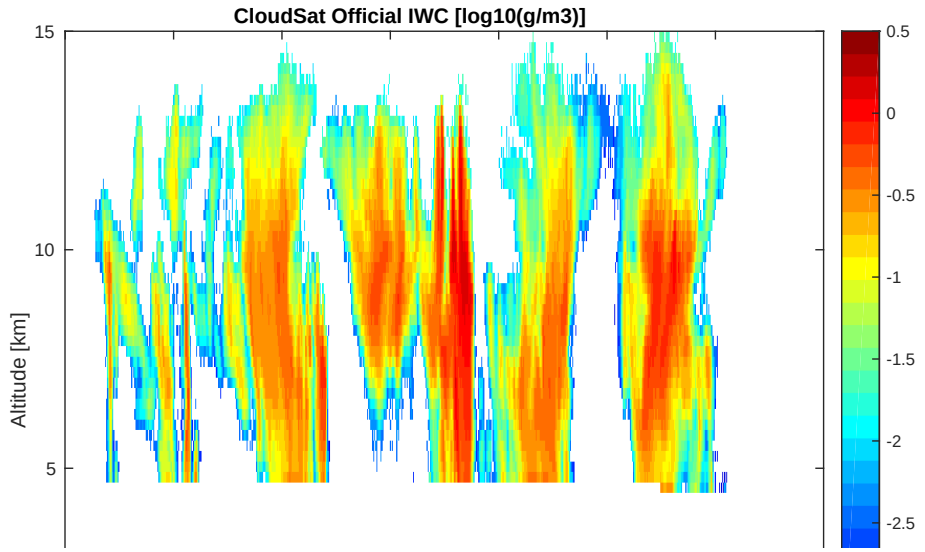
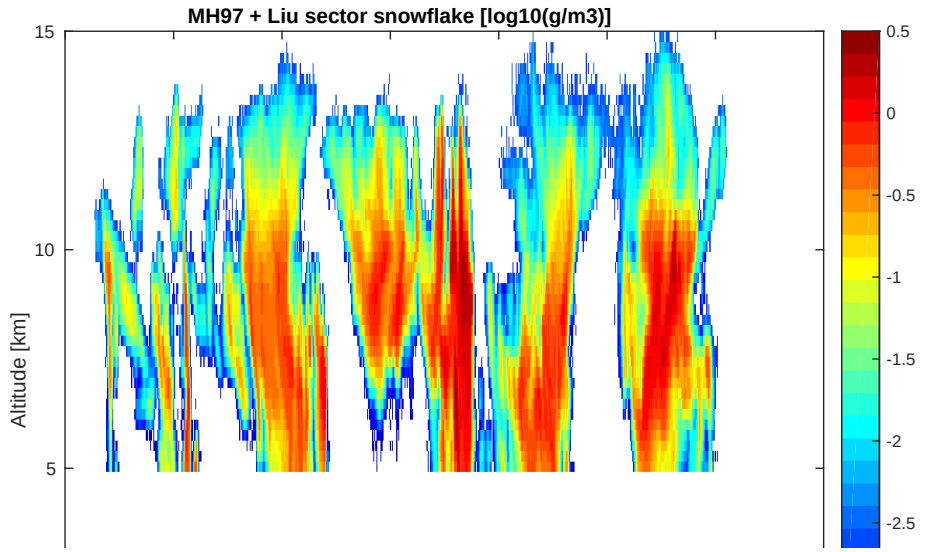
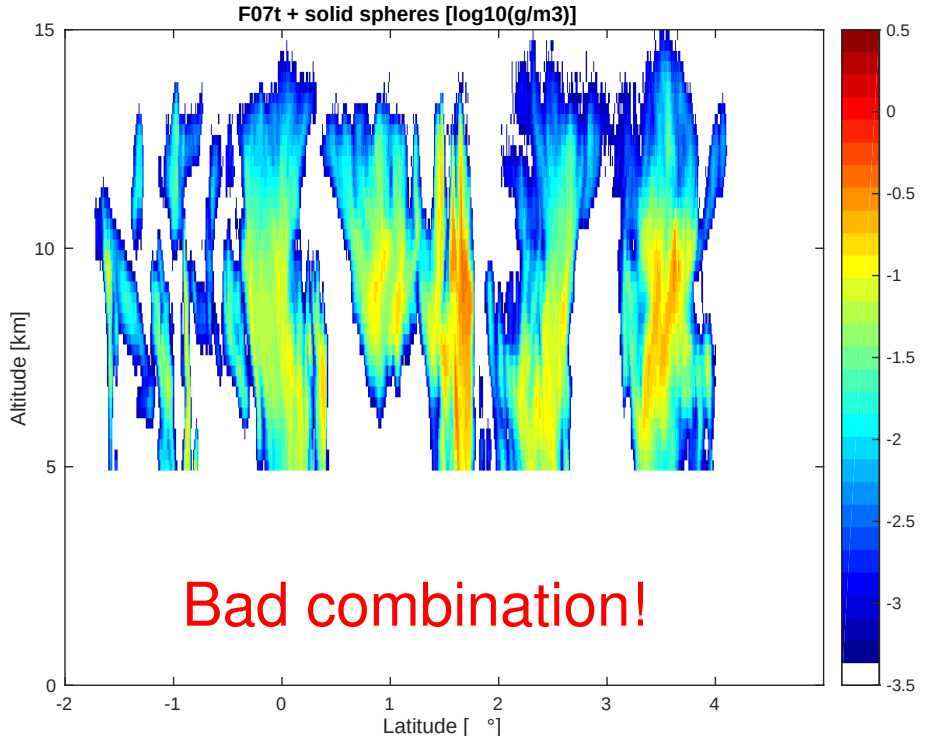
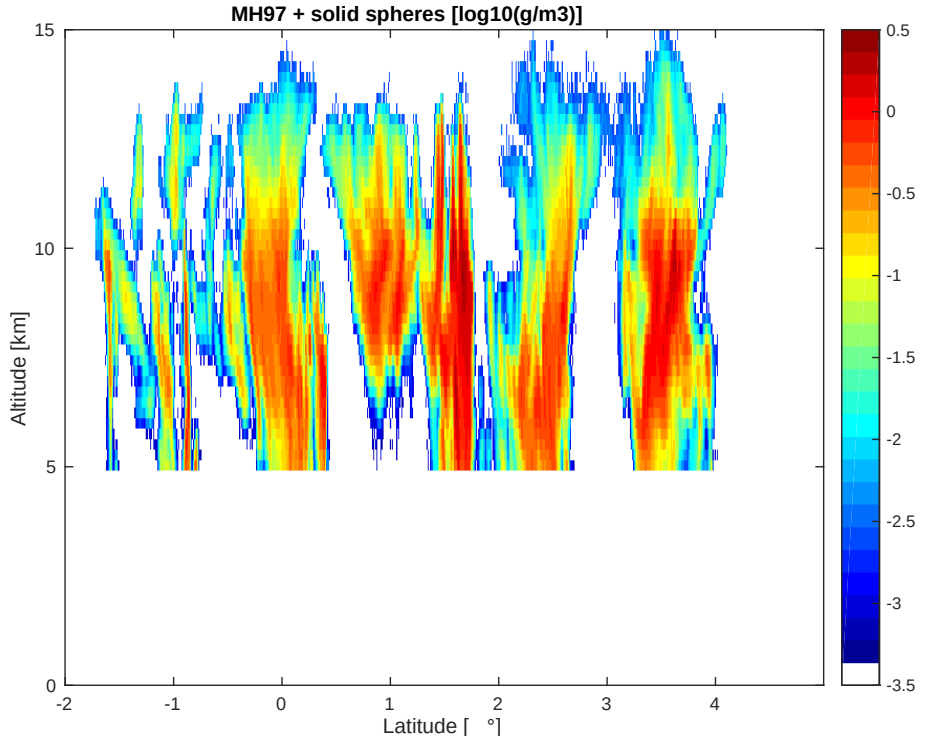
Comparison of resulting IWC



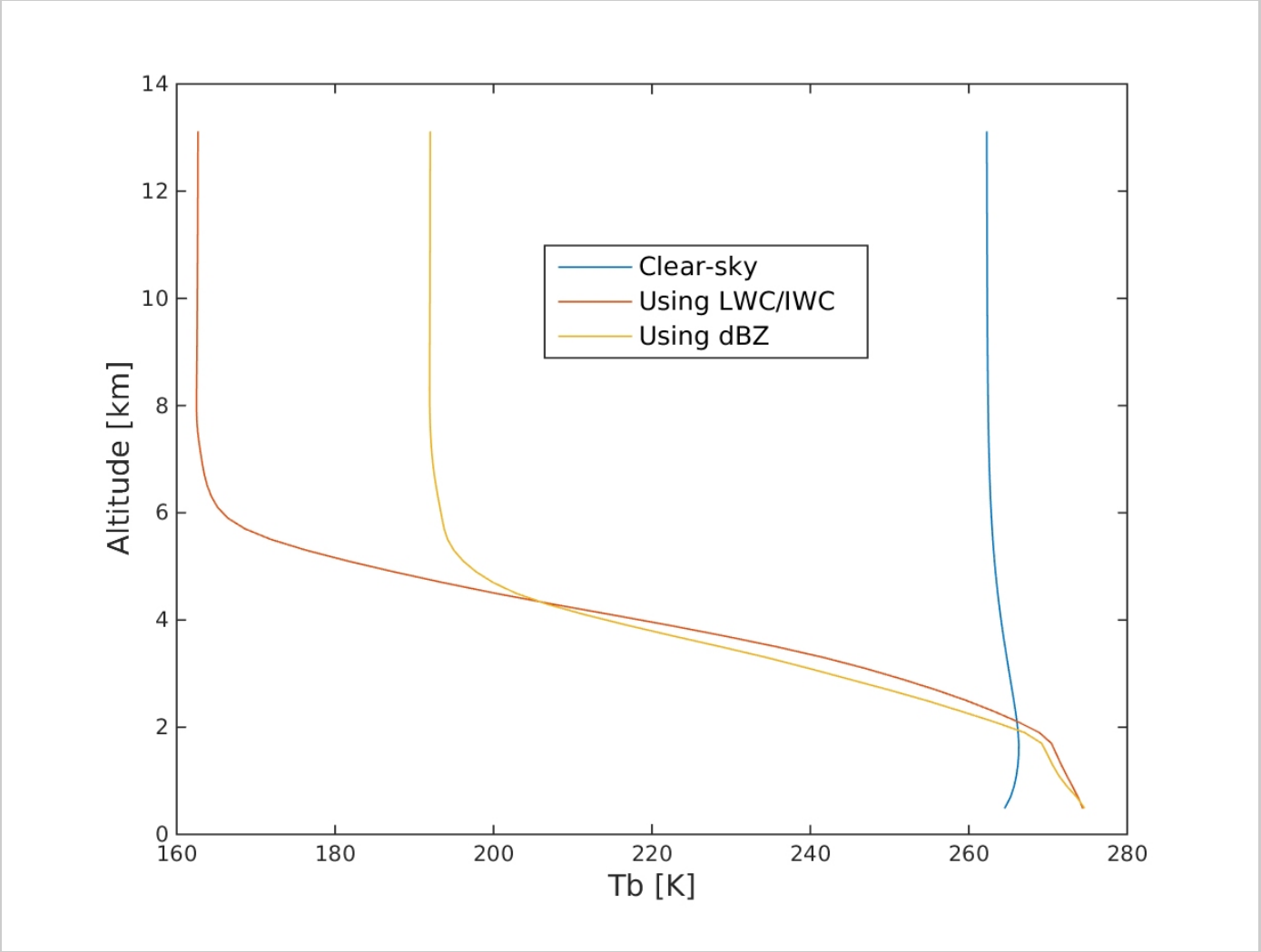




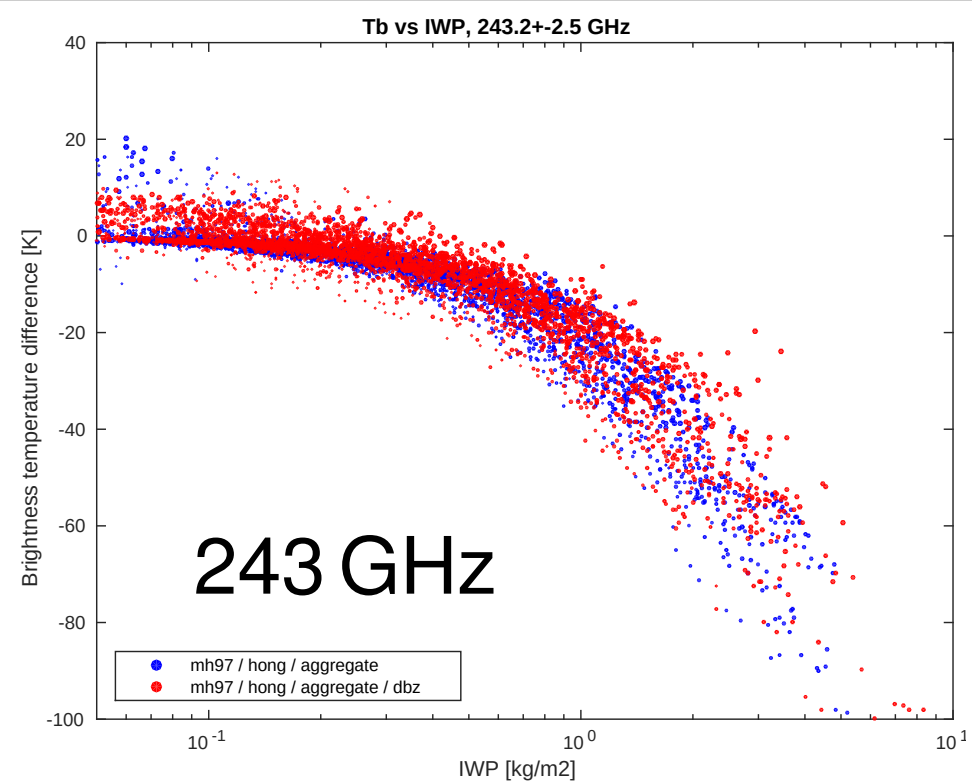


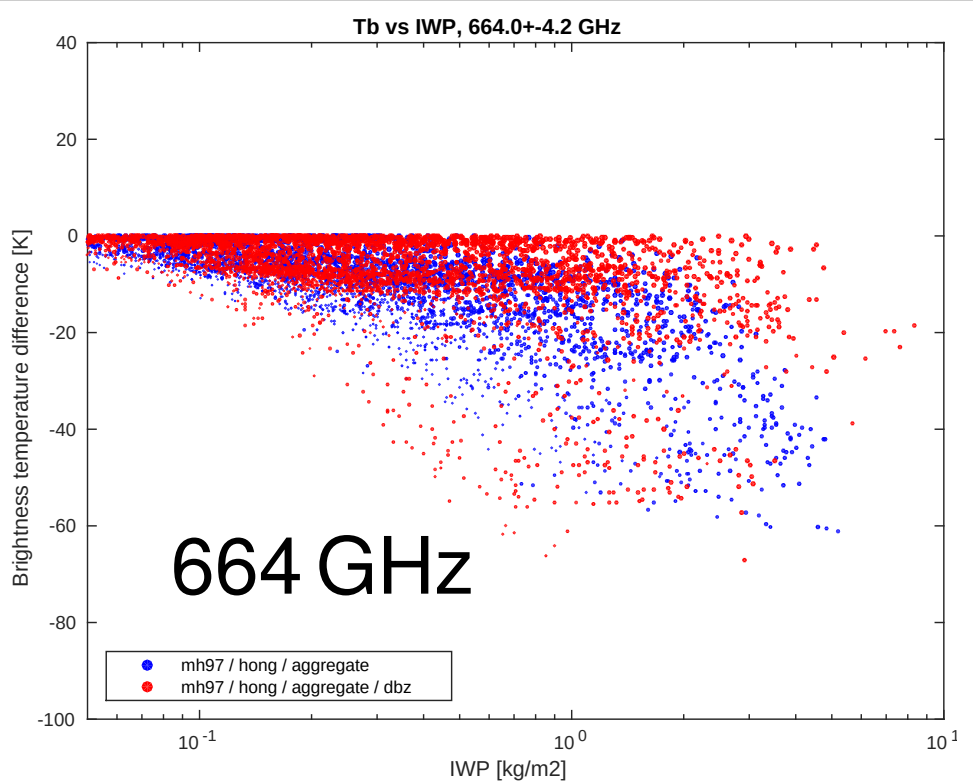
Impact on one individual DOIT calculation

243 GHz, nadir, F07t, aggregates, IWP $> 2\,\mathrm{kg/m^2}$, same “melting point”



Impact on database

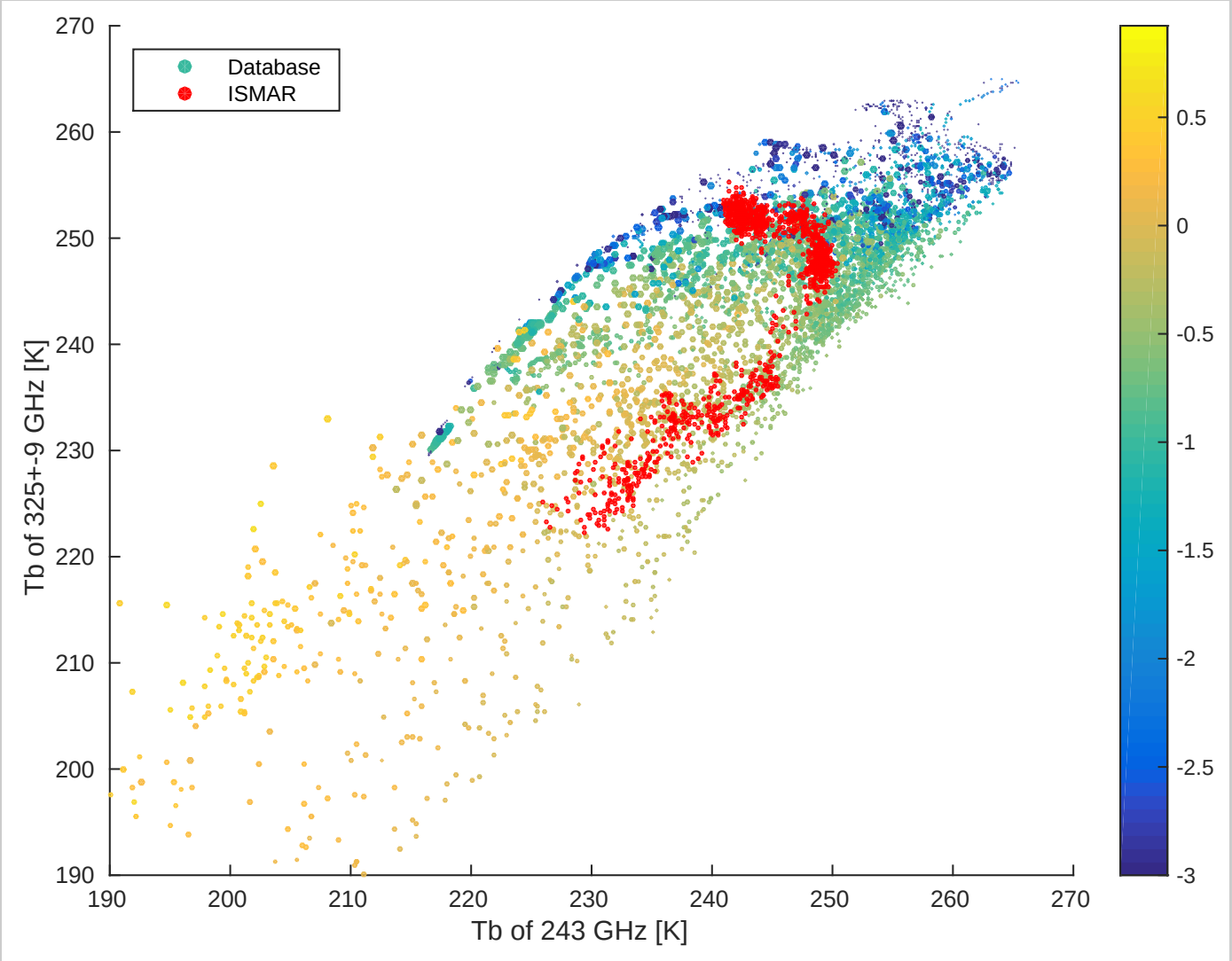




- Same patterns when using F07t

Correlation of T_b between channels

Red dots are some ISMAR data from B897



Conclusions / comments

- “Ensemble retrievals” of CloudSat can be performed
  - attenuation fully considered, but no multiple scattering
- 1D databases based on CloudSat can be generated
  - specified statistics of RH in cloudy regions will be added
  - non-random orientation will be considered
  - surface radiative properties so far simplistic
  - melting layer not properly represented
  - do we need 3D radiative transfer?
- EarthCARE should remove the need for adding model IWC