Evaluating ice and snow water contents in the global NWP model GME with CloudSat

Eikenberg[1], **S.**, K. Fröhlich[2], A. Seifert[2], S. Crewell[1] and M. Mech[1]

[1] Institute of Geophysics and Meteorology, University of Cologne, [2] German Weather Service DWD

1. Motivation

Microphysical parameterizations in atmospheric models are under continuous development as the correct representation of ice clouds and snow is a precondition for describing radiation budget and surface precipitation. CloudSat observations are used to assess model performance on the example of GME, the global hydrostatic NWP model of DWD:

- 4 hydrometeor classes: cloud ice, snow, cloud water, and rain
- Icosaheder grid with horizontal resolution of 40 km
- 40 hybrid level
- Forecasts every 6 h in hourly resolution

Two versions are compared:

GME → diagnostic precipitation scheme
GME1007 → new prognostic precipitation scheme
(without the advection of snow and rain)
→ new temperature-dependent drop size
distribution for snow after *Field et al. [2005]*

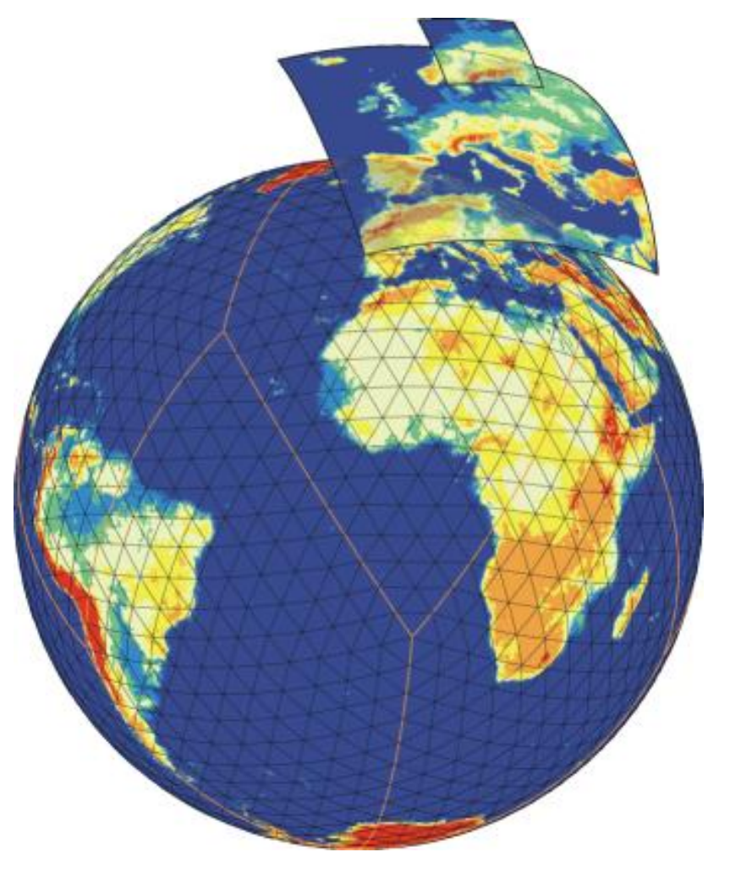

***Fig. 1:** Modelchain at DWD.*

2. CloudSat

- Operational since June 2006
- Part of the A-Train
- Polar-orbiting in 705 km height
- Orbiting time: 1.5 h
- Payload: CPR

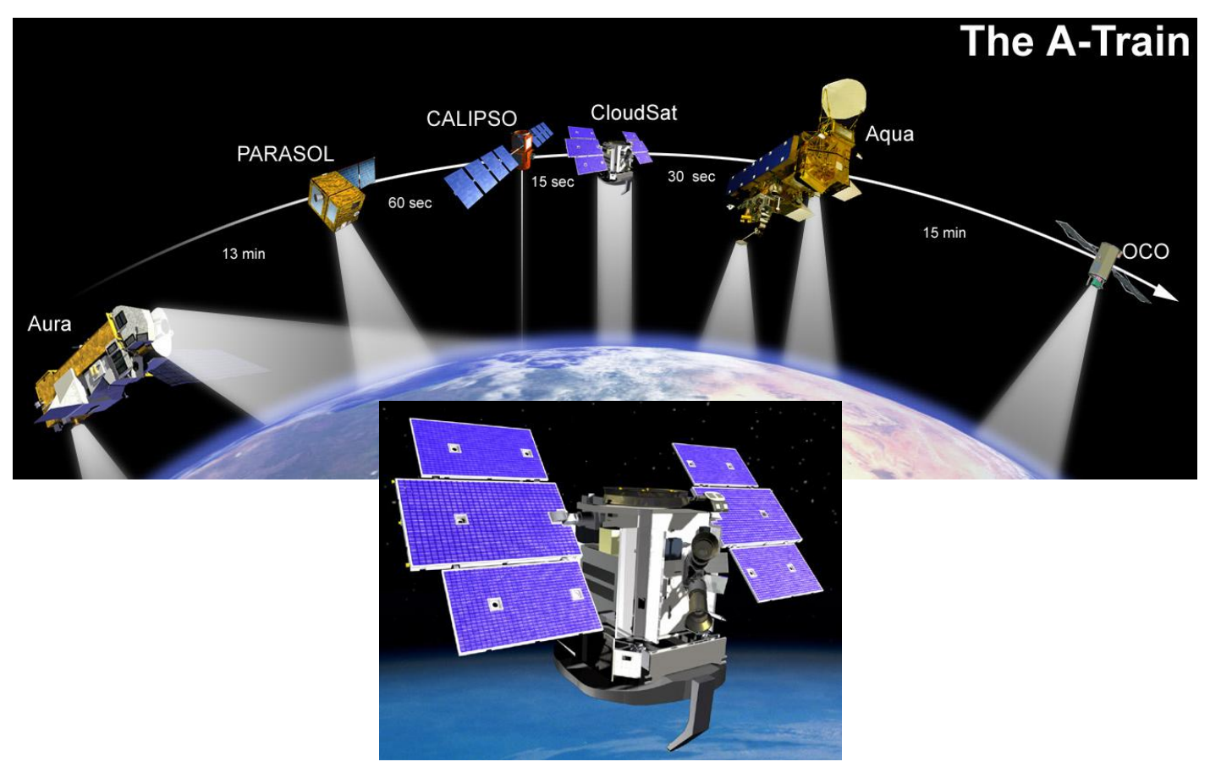

***Fig. 2:** CloudSat and the A-Train. [http://www.nasa.gov/mission_pages/cloudsat/].*

Cloud Profiling Radar (CPR):

- 94 GHz nadir-viewing radar
- Detection limits: -27 dBz and +29 dBz
- Footprint: 1.8 km x 1.4 km
- Vertical resolution: 500 m
- 0.16 s averaging interval = 1.1 km horizontal resolution

Version 5.1 IWC retrieval (*Austin et al. [2009]*; contained in release R04):

- Optimal estimation approach after *Rodgers [1976]*
- Smallest detectable IWC: 0.001 g m^{-3} (underestimation of cirrus)

3. Methodology

a) <u>Model output sampling</u>

- Use forecast time (of 0 UTC run) closest to mean time of each CloudSat orbit
- Vertically: linear interpolation onto regular levels of 500 m height
- Horizontally: Nearest neighbour interpolation of GME onto CloudSat grid
- Running mean applied to CloudSat data

b) <u>Two approaches</u>

Observation-to-model: Version 5.1 IWC retrieval of CloudSat	Model-to-observation: QuickBeam v1.1a from Haynes et al. [2007]
+ Easy computation	+ Avoids retrieval uncertainties
+ Close to model physics	+ Close to actual physics
– Retrieval uncertainties (e. g., linear scaling between liquid and ice phase)	– Ice crystals modelled as soft spheres, not as actual particle habit of GME

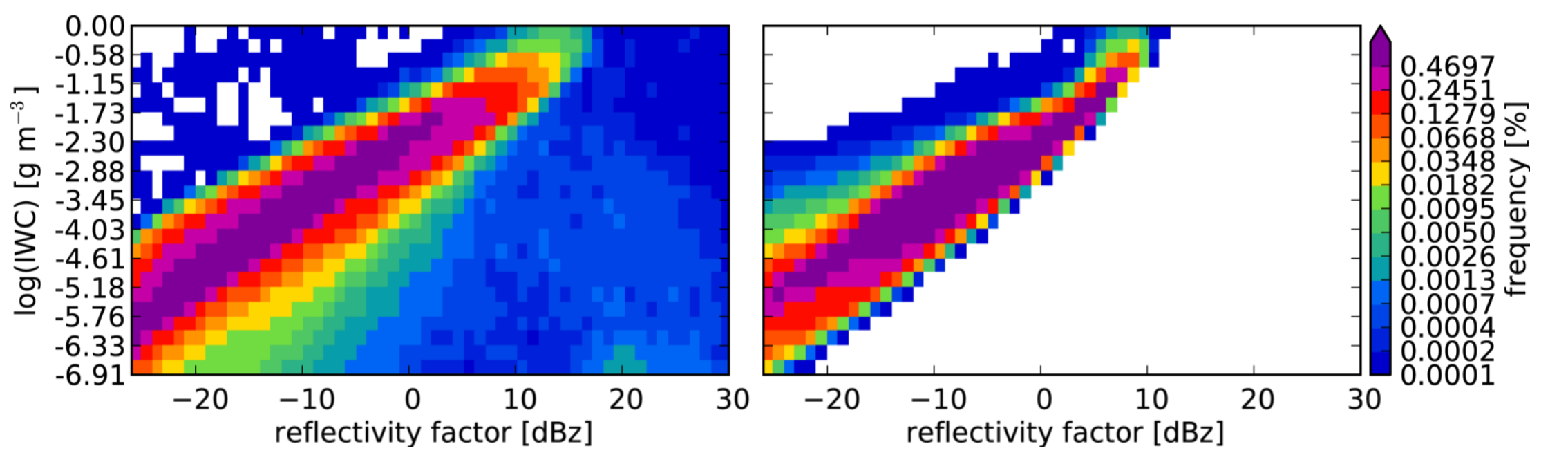

***Fig. 3:** Z-IWC relations as frequency distributions. Period: 1 July 2009 to 31 October 2009. Left: From observation-to-model approach. Right: From model-to-observation approach.*

c) <u>Criteria</u>

- Temperature ≤ -10°C
- Cloud cover ≥ 50 %
- Height of top of convection ≤ 1 km
- Total column attenuation ≤ 3 dBz

References:

Austin, R. T., A. J. Heymsfield, and G. L. Stephens (2009), Retrieval of ice cloud microphysical parameters using the CloudSat millimeter-wave radar and temperature, J. Geophys. Res., 114, D00A23, doi:10.1029/2008JD010049.

Field, P., R. Hogan, P. Brown, A. Illingworth, T. Choulartona, and R. Cotton (2005), Parameterization of ice-particle size distributions for mid-latitude stratiform cloud, Quart. J. Roy. Met. Soc., 131, 1997-2017.

Haynes, J. M., R. T. Marchand, Z. Luo, A. Bodas-Salcedo, and G. L. Stephens (2007), A mulitipurpose radar simulator package: QuickBeam, Bull. Am. Met. Soc., 11/2007, 1723-1727.

Rodgers, C. D. (1976), Retrieval of atmospheric temperature and composition from remote measurements of thermal radiation, Rev. Geophys., 14 (4), 609-624.

4. Results

a) <u>Global frequency distributions</u>

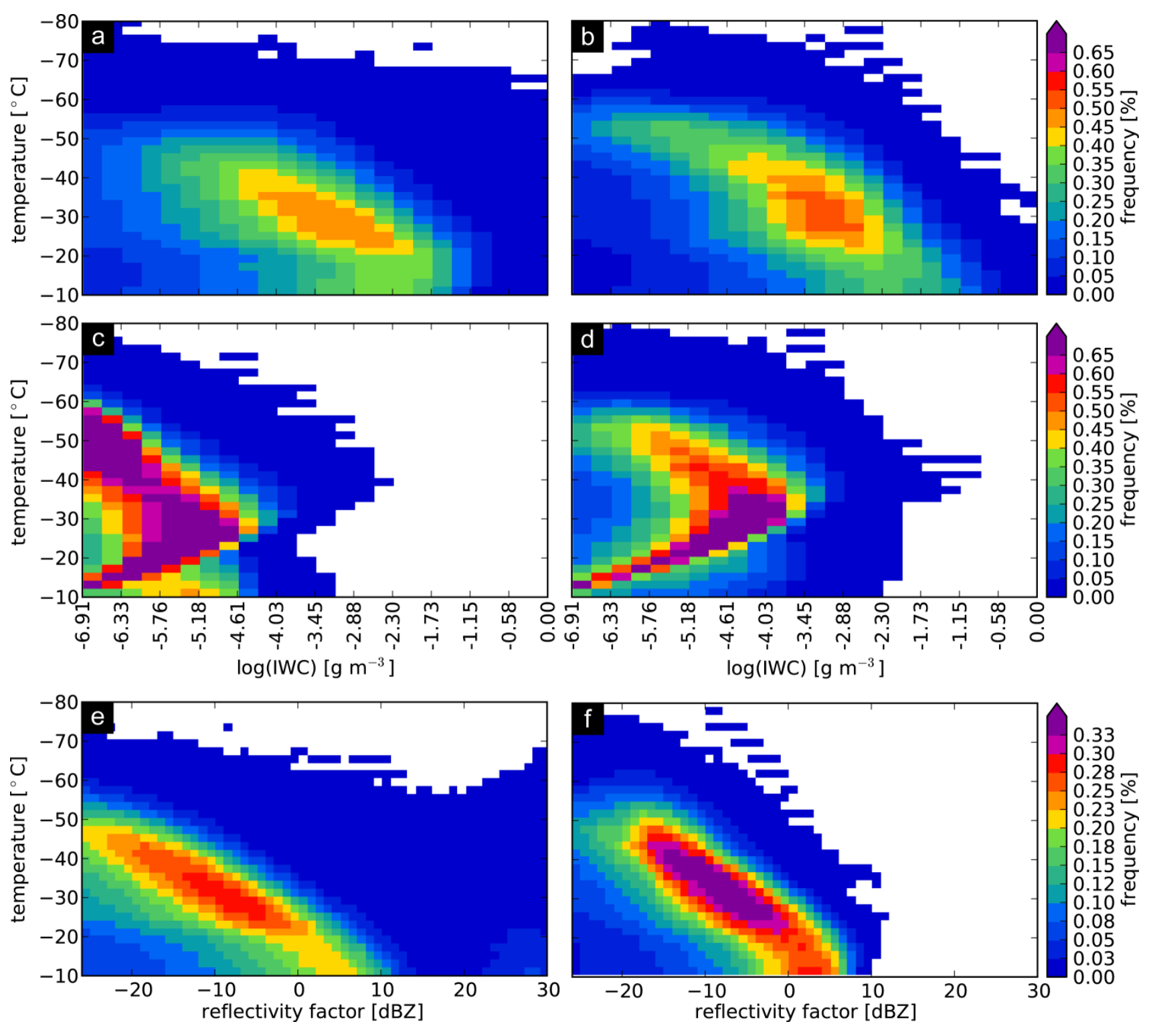

***Fig. 4:** Frequency distributions for 1 July 2009 to 31 October 2009. a) CloudSat IWC, b) GME1007 IWC, c) GME IWC, d) GME1007 CIWC, e) CloudSat reflectivity factor, and f) GME1007 reflectivity factor. GME reflectivity factor not displayed because out of range.*

- GME1007 captures CloudSat T-IWC distribution well in contrast to GME which does not produce large IWCs
- Except: Maximum reaches up to colder temperature regimes in GME1007 than in CloudSat
- GME1007 CIWC > GME IWC

- GME1007 also captures CloudSat T-reflectivity factor distribution well
- Except: GME1007 distribution is
  - steeper
  - more narrow
- CloudSat only sees model SWC

b) <u>Zonally averaged IWP</u>

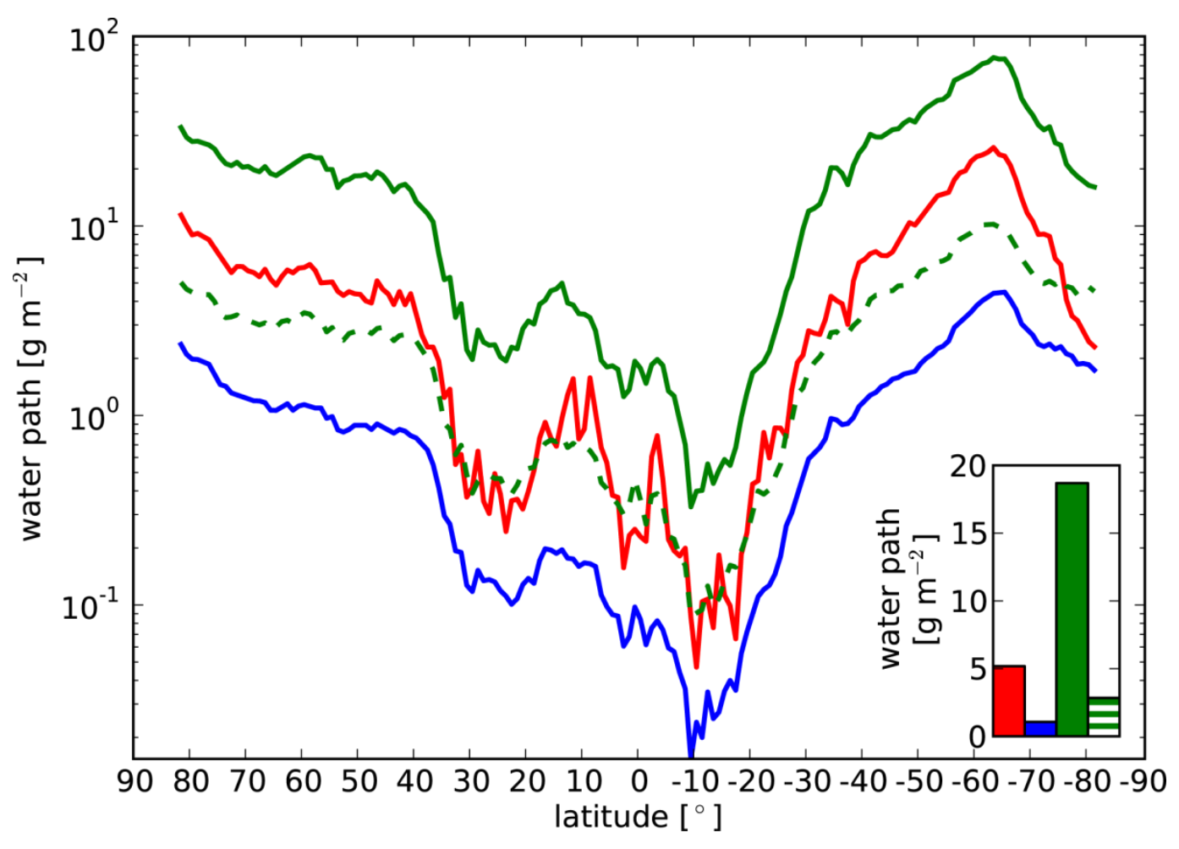

***Fig. 5:** Zonally averaged IWP for 1 July 2009 to 31 October 2009. Inlet: Globally averaged IWP.*

- Due to convection and cloud cover criterion the IWP maximum in the Tropics is filtered out
- General characteristics captured by both model versions
- GME produces too small IWP
- GME1007 produces too large IWP, especially in the mid-latitudes
- Globally: GME1007 IWP~4xCloudSat ÍWP
- SWP dominant contributor to IWP

c) <u>Frequency distributions for 3 temperature and 3 latitudinal regimes</u>

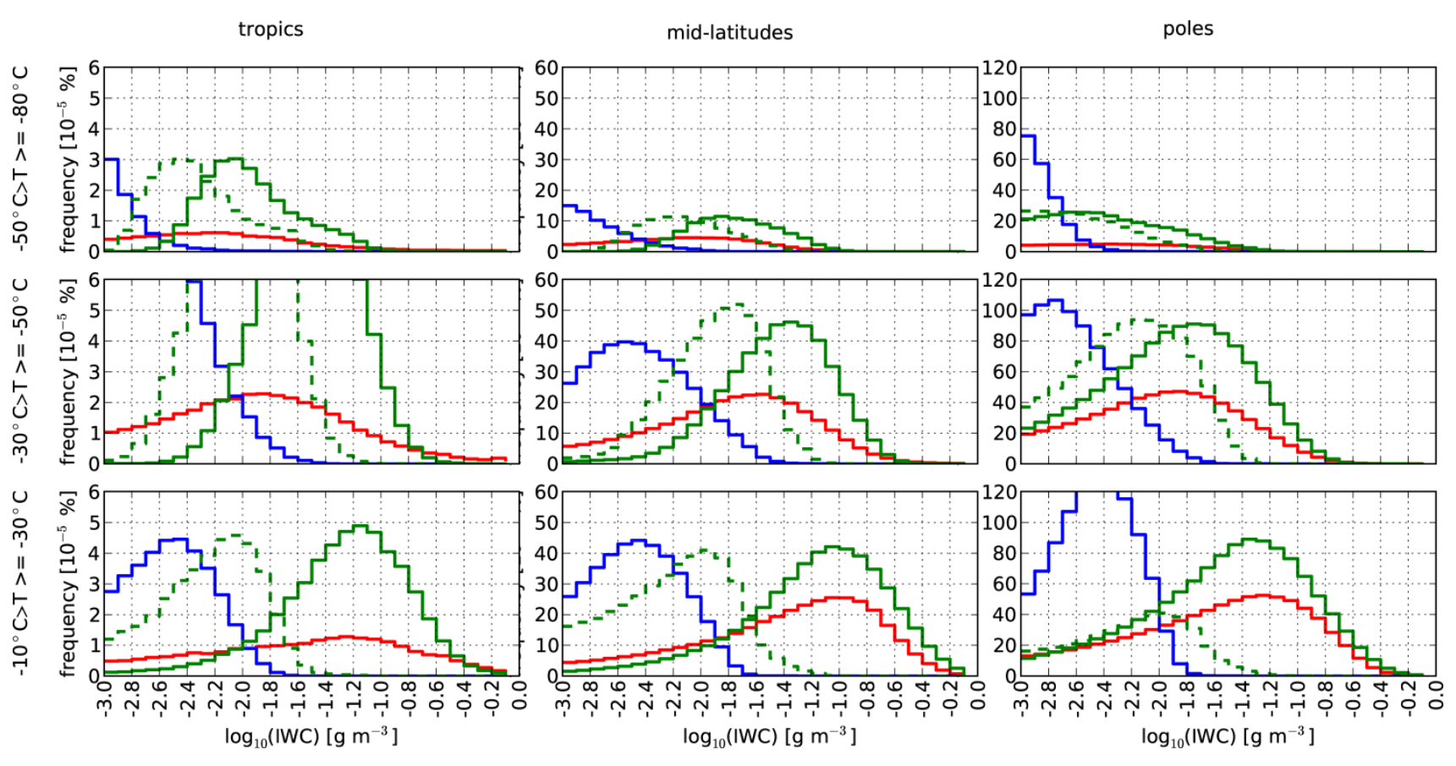

***Fig. 6:** IWC frequency distributions for 1 July 2009 to 31 October 2009. Dashed: CIWC.*

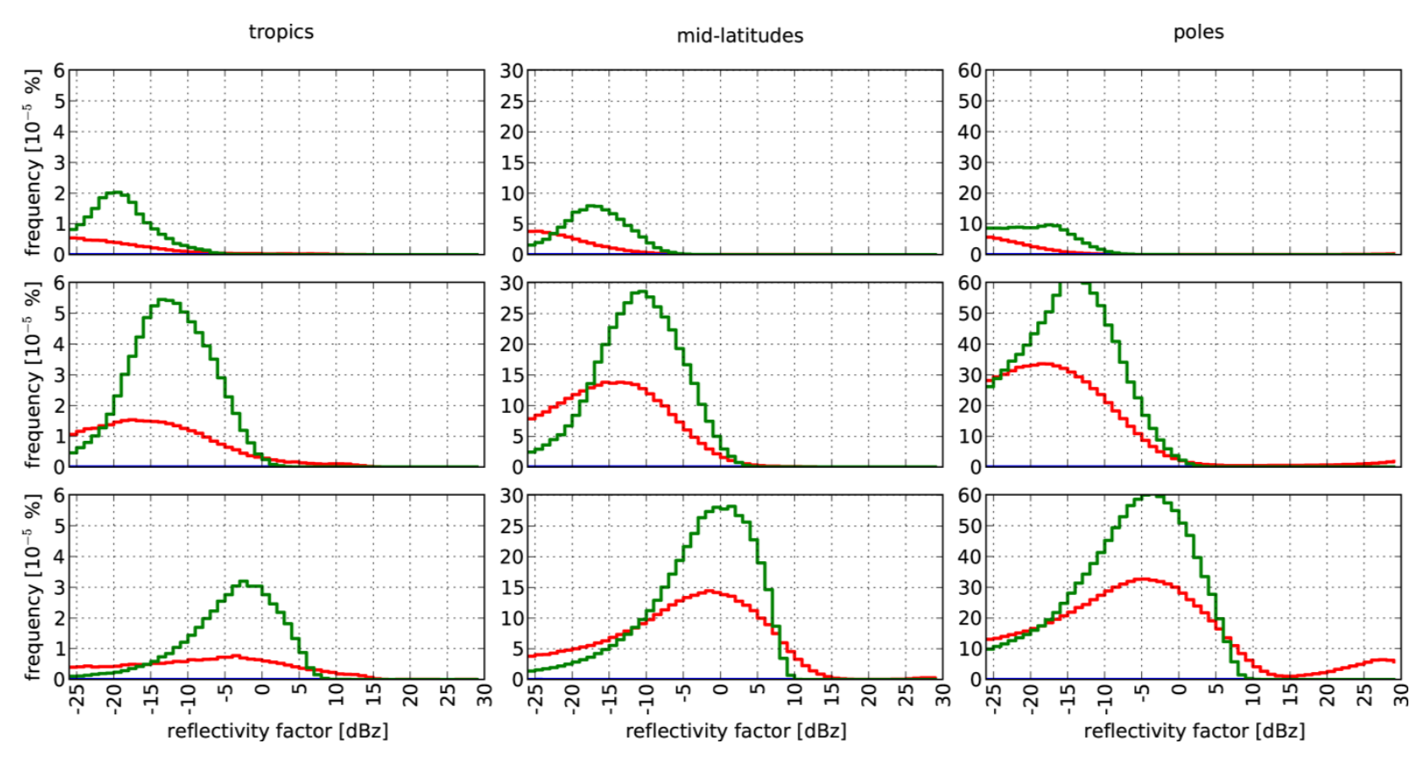

***Fig. 7:** Reflectivity factor frequency distributions for 1 July 2009 to 31 October 2009. GME not displayed because out of range.*

Shape of frequency distribution and position of peak captured well by GME1007

- Peak overestimated by GME1007, and even more with decreasing temperature → snow suspended too long - problem with snow fall speed?
- Large IWCs in tropics underestimated by GME1007
- Small IWCs generally underestimated by GME1007

d) <u>Sensitivity tests for snow fall speed</u>

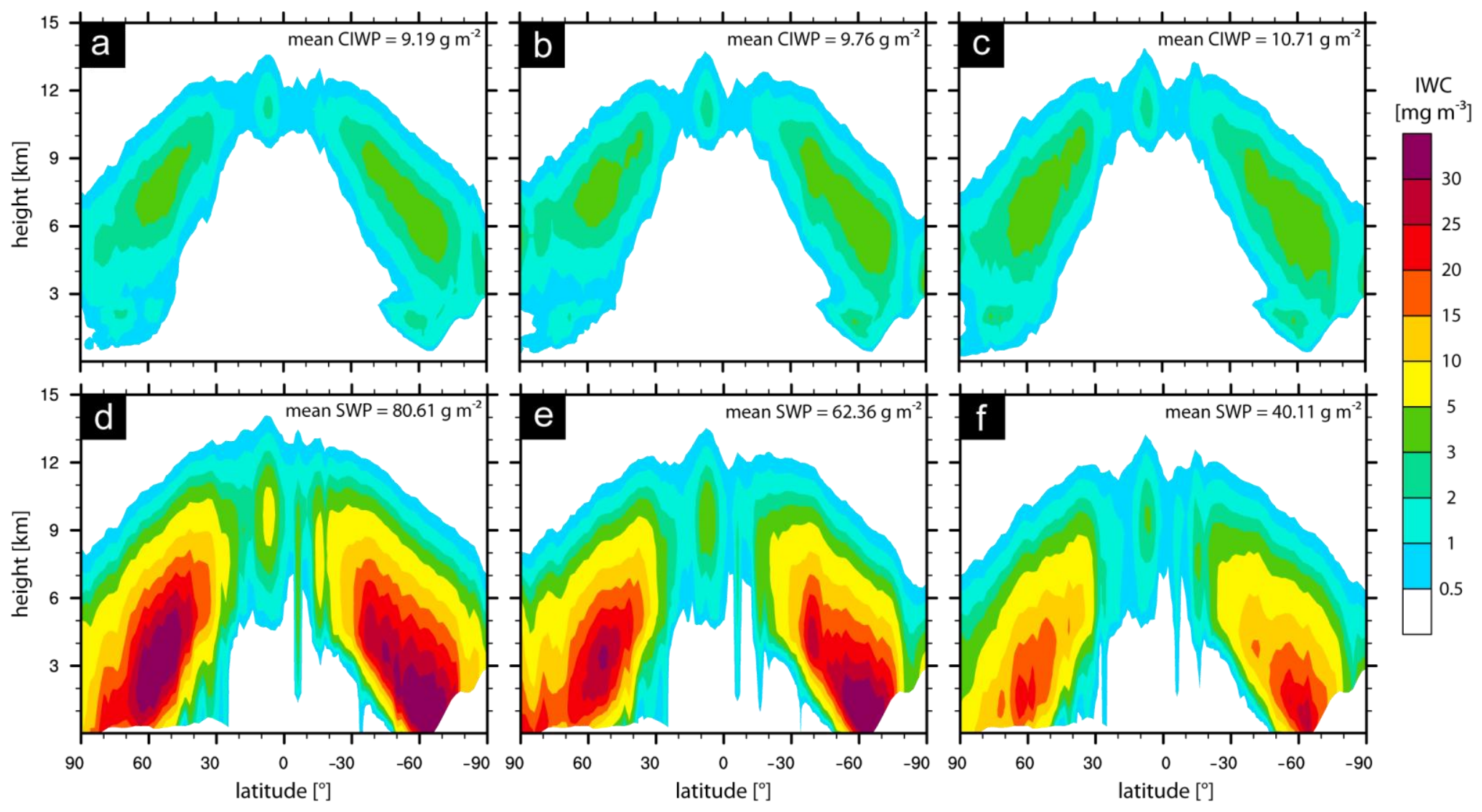

***Fig. 7:** Zonal averages of GME1007 for a 25-day period. Top row: CIWC, bottom row: SWC. Left column: GME1007, middle column: GME1007 Exp1, right column: GME1007 Exp2.*

Exp1: density-corrected fall speed of snow
Exp2: + increased fall speed of snow

- SWC is continuously reduced, CIWC increases only marginally
- Globally averaged, changes in snow fall speed reduce SWP by 25 % / 50 %

5. Conclusions

- GME1007 operational since February 2010
- Exp1 operational since December 2010
- CloudSat suitable for continuous model evaluation
- SWC dominant contributor to IWC in model
- Results robust: both approaches deliver the same general picture
  → For the general picture it does not matter which approach is applied
  → For details the model-to-observation approach is to be preferred, because the uncertainties are better estimated

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