



MCRadar: A Monte Carlo Solver for Cloud and Precipitation Radar

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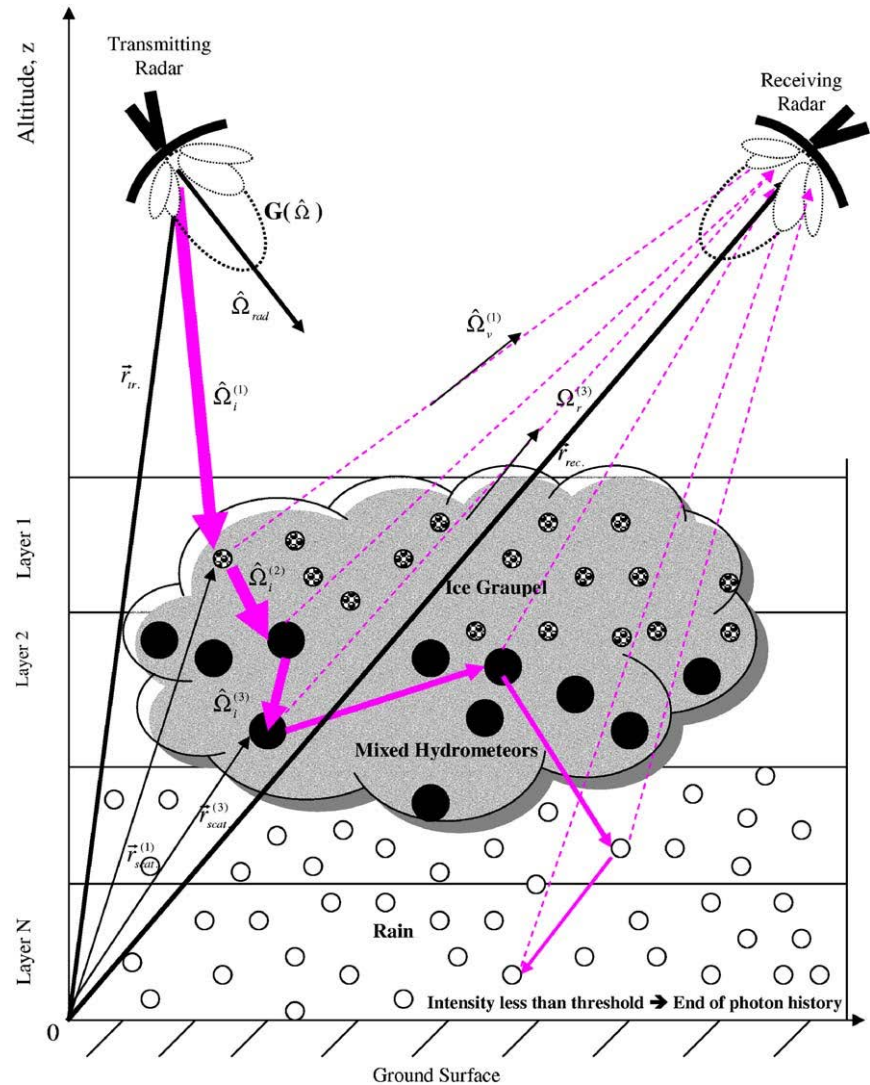
NASA Goddard Space Flight Center

with contributions from

Joe Munchak and Kwo-Sen Kuo

Multiple Scattering in Radar

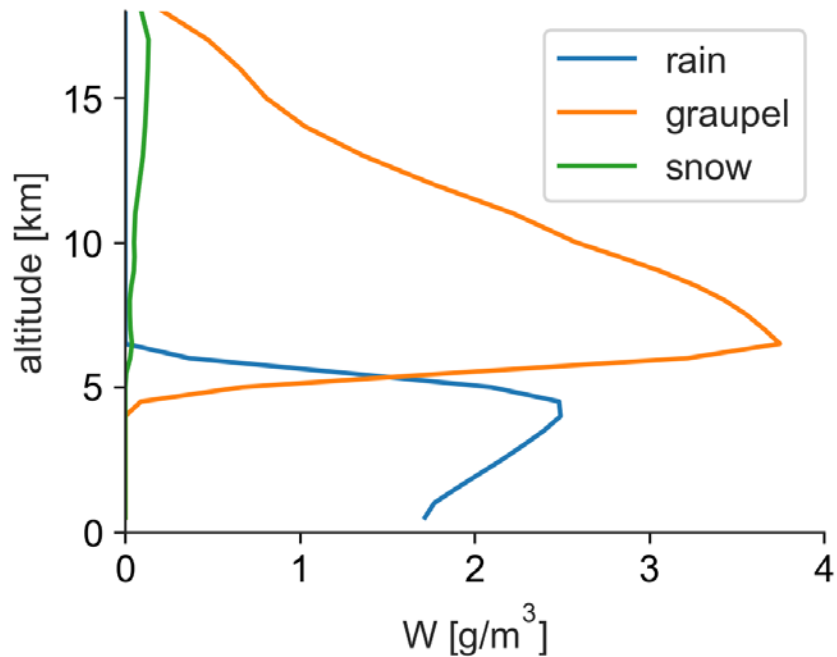
- Anomalous scattering contribution
 - High optical depth
 - High albedo
- Enhanced reflectivity down-range
 - Pulse stretching
- Overestimated by parallel-plane models



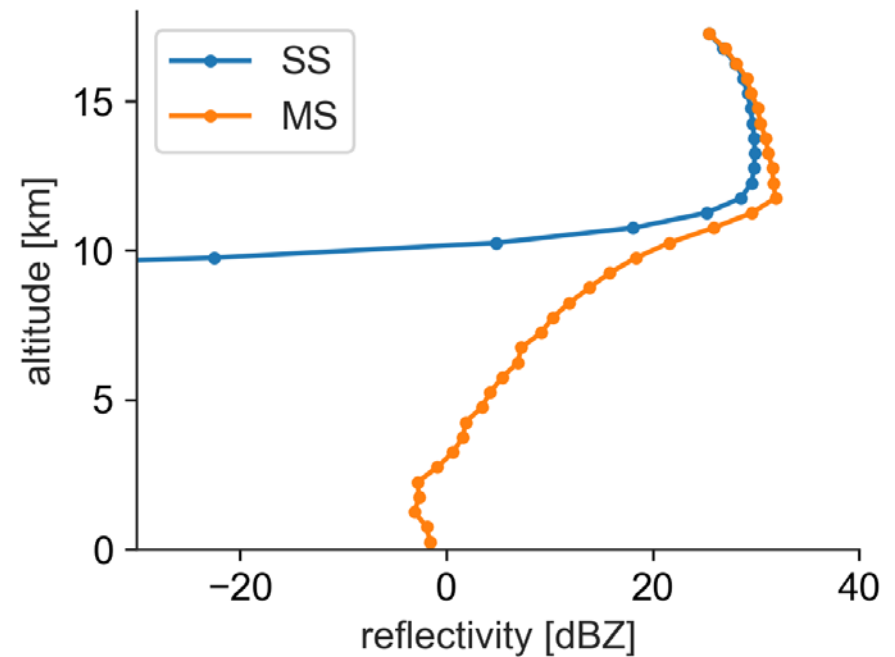
Battaglia et al. 2006

Multiple Scattering Example: Convection

TOGA COARE GCE Profile



Simulated Ka-band Reflectivity Factor



Photon Propagation

- Draw RN to determine propagation path length

- Completely random orientations

$$e^{kl} = RN$$
$$e^{k_1 l_1} e^{k_2 l_2} \dots e^{k_n l_n}$$

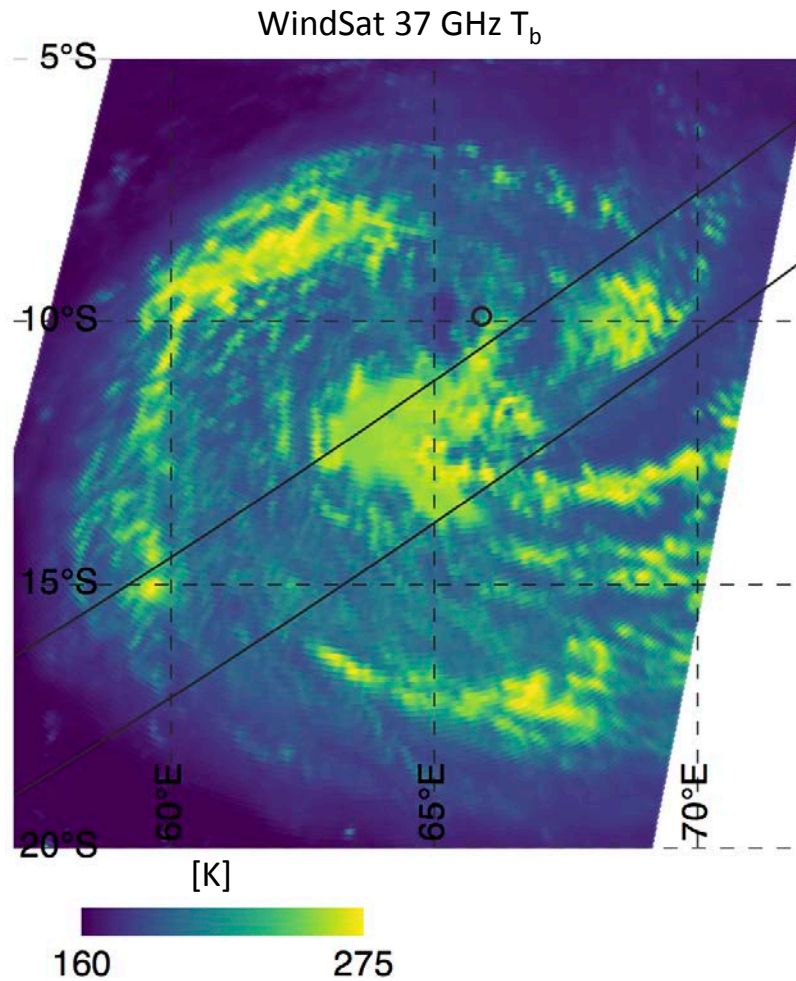
- Azimuthally-random orientations (solved numerically)

$$e^{k_I l} + \frac{Q}{I} e^{k_Q l} = RN$$

- Draw RN to determine scattering or absorption

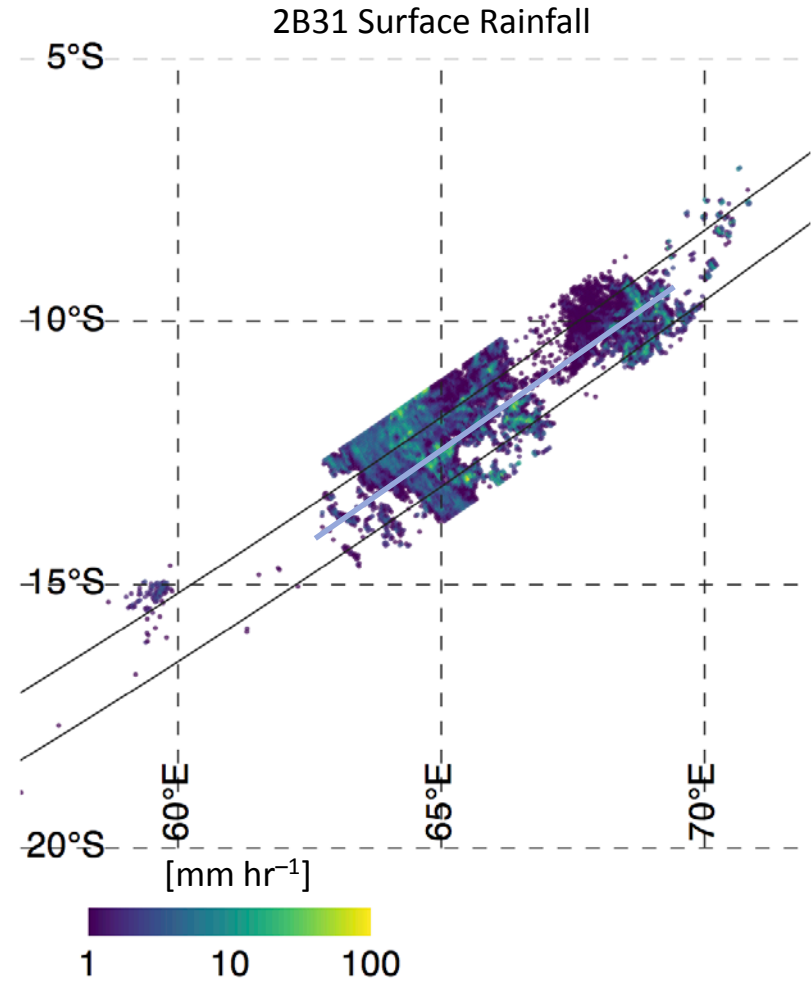
- If $RN > \text{albedo}$, terminate (absorption), throw new photon
- Else, add contribution to reflectivity based on distance
 - Randomly select new distance
 - Continue propagation until absorption

TRMM Example



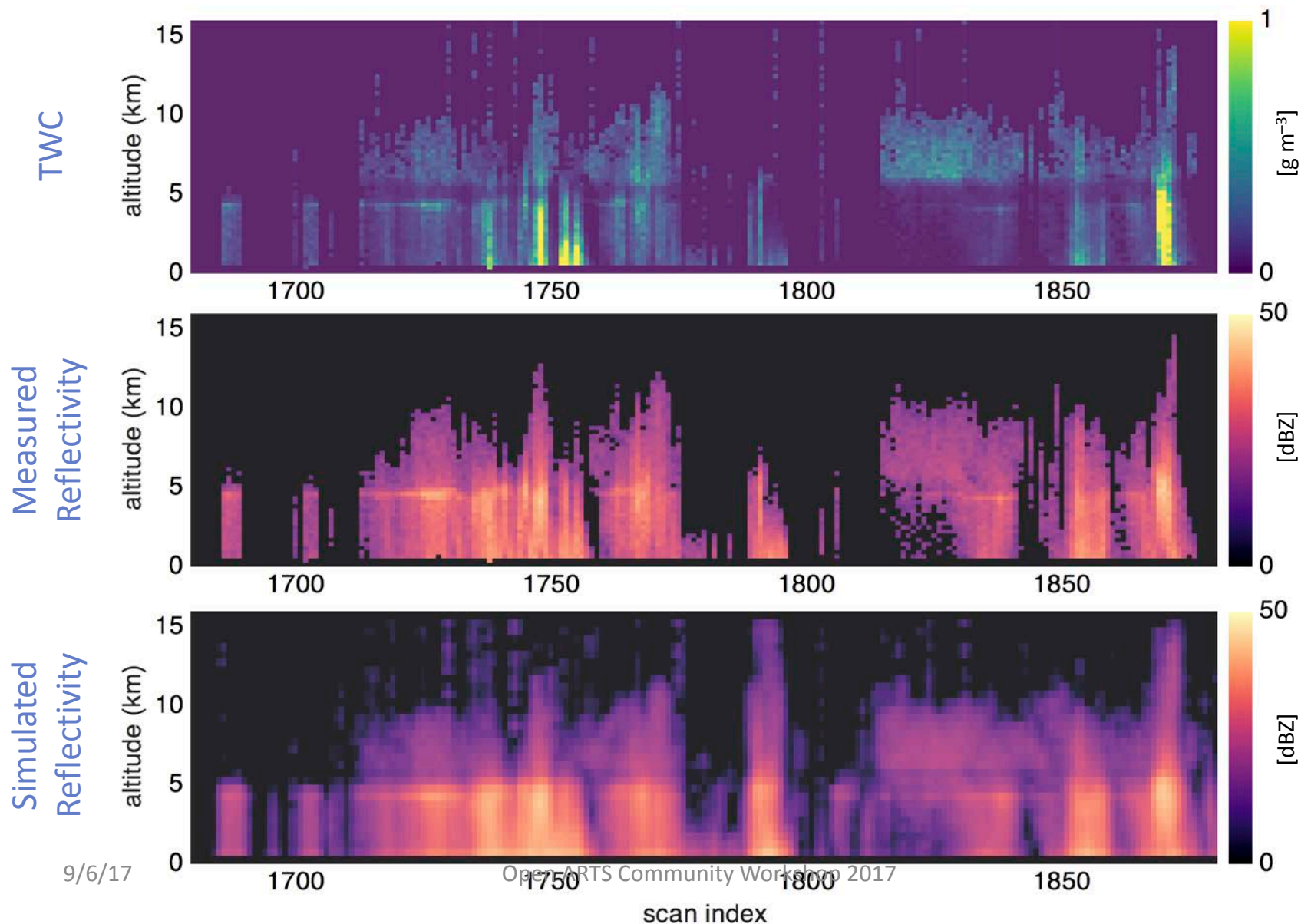
Moderate Tropical Storm Asma
19 October 2008 0129Z

9/6/17

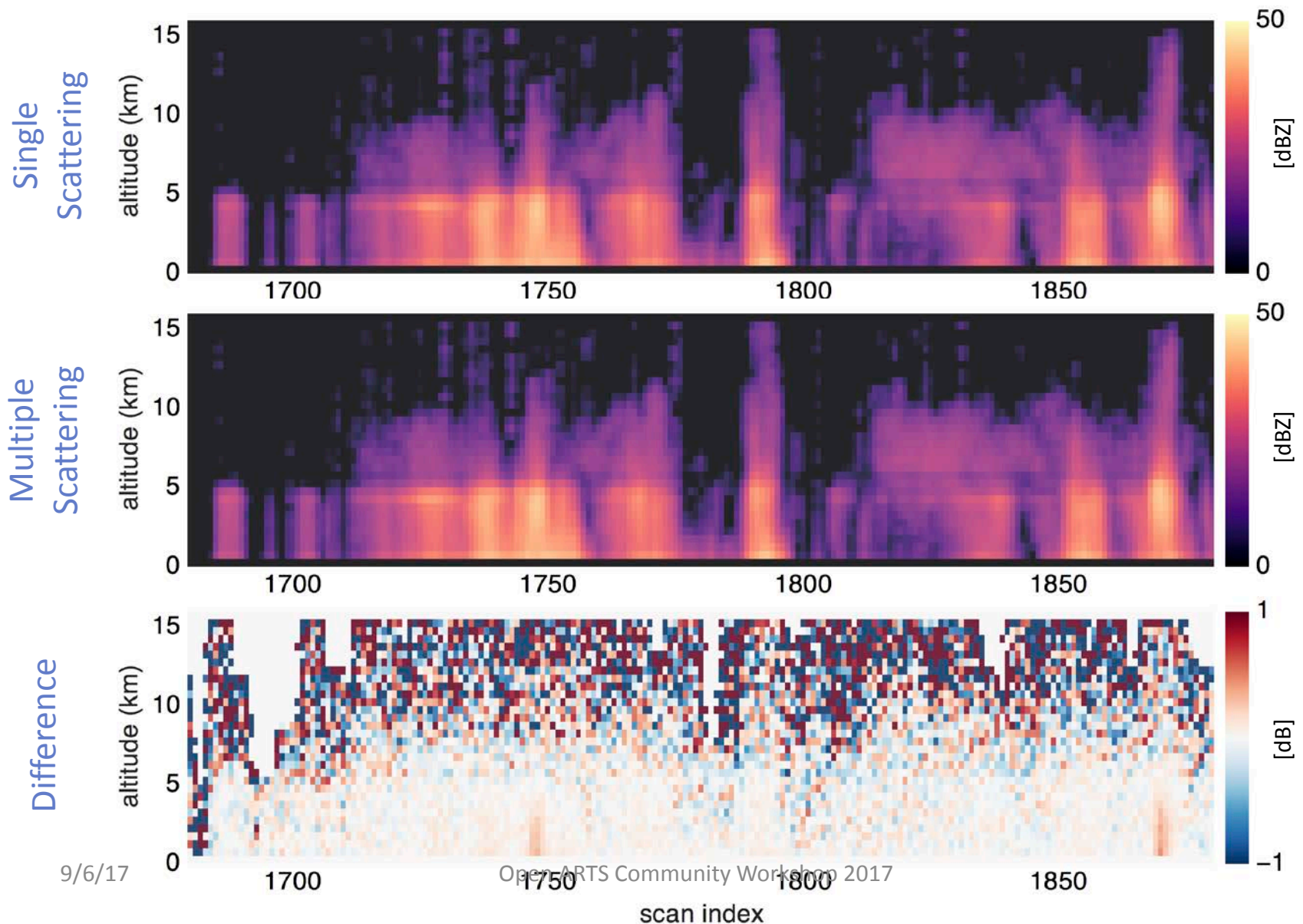


Adams and Bettenhausen (2016)

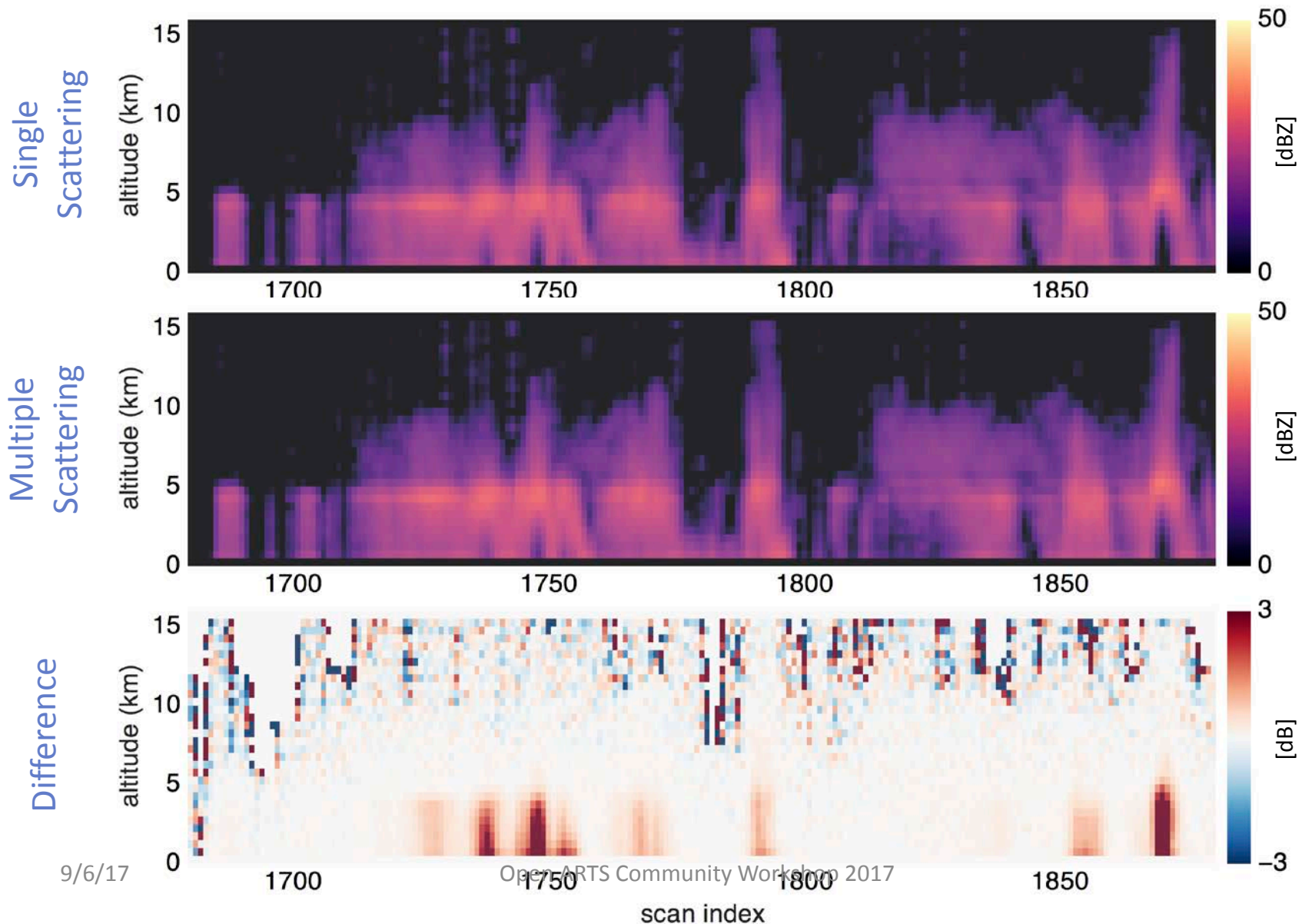
Measured and Simulated PR Reflectivity



Multiple Scattering Effects

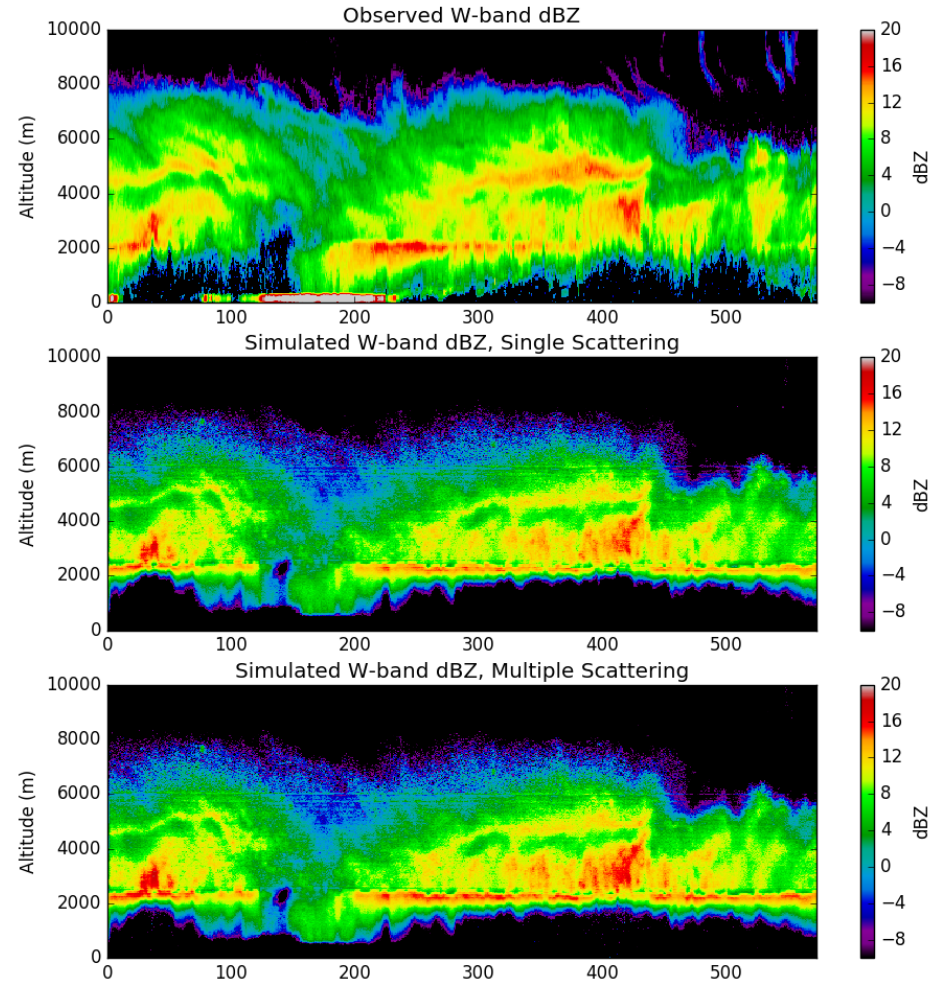
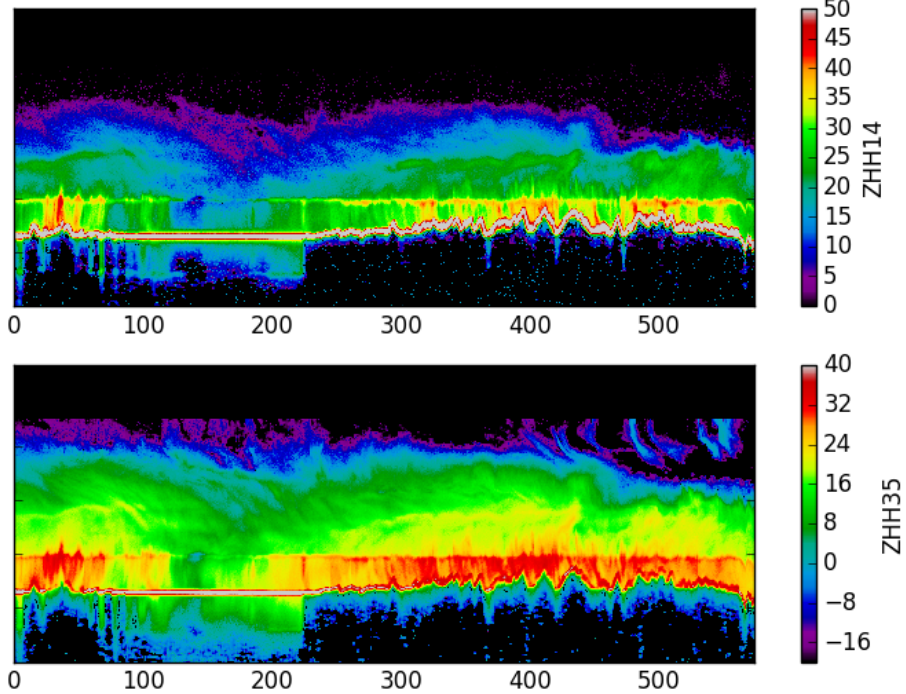


Multiple Scattering Effects (Contrived K_a band)



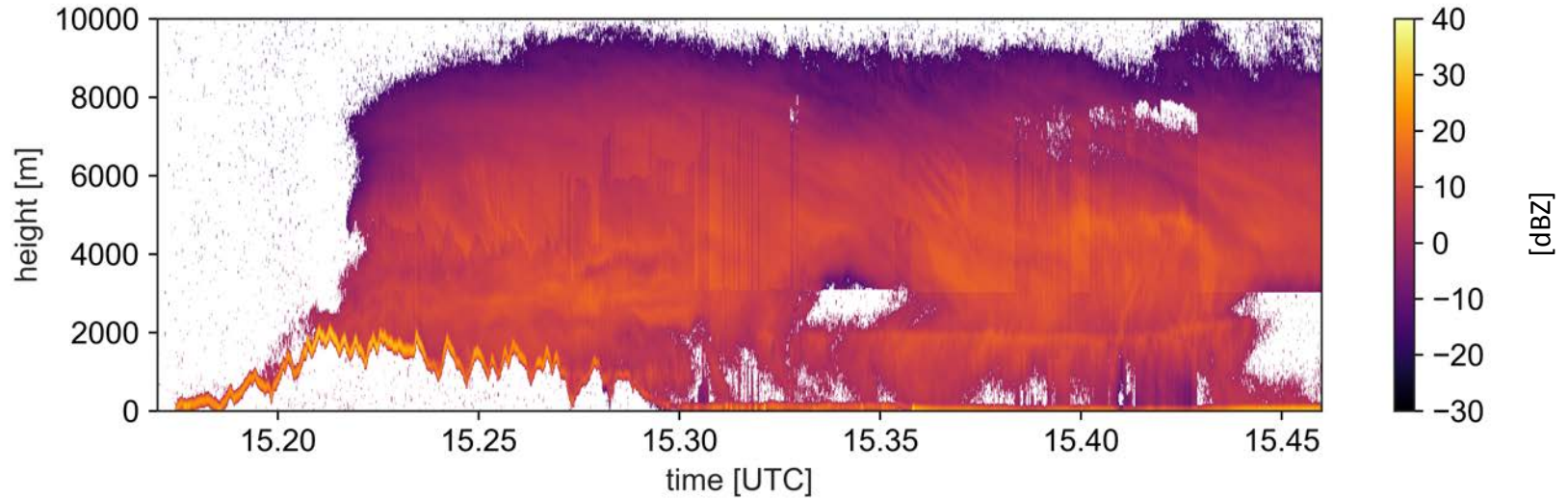
OLYMPEX 03 Dec 2015

APR-3

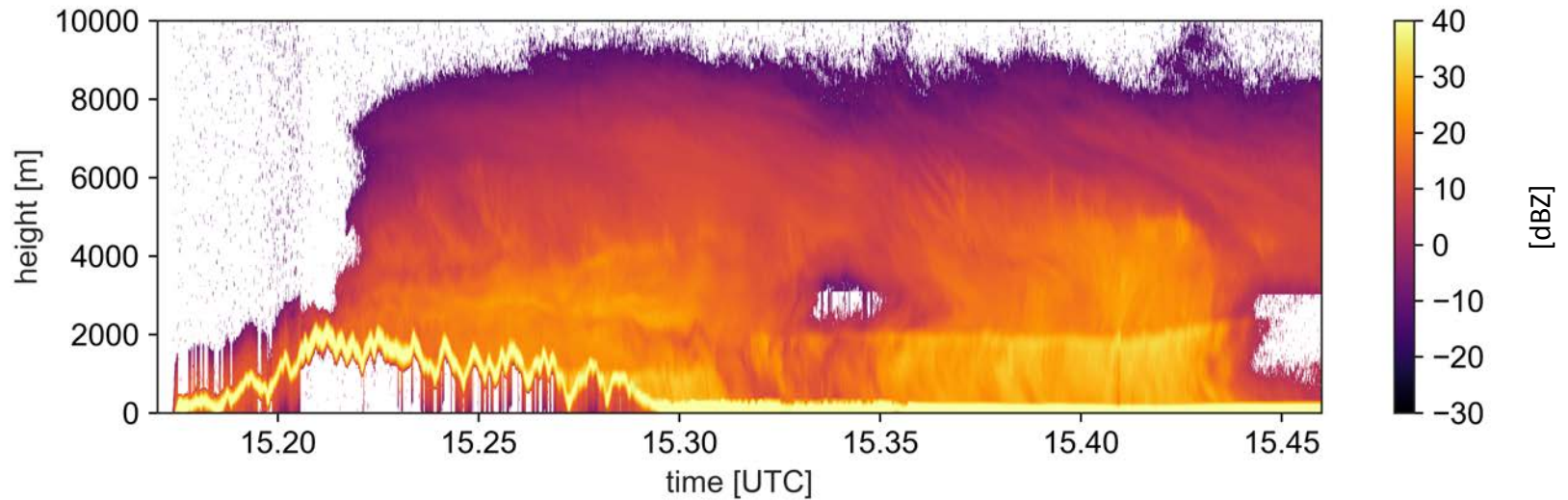


OLYMPEX/RADEX Case Study: 05 Dec 2015

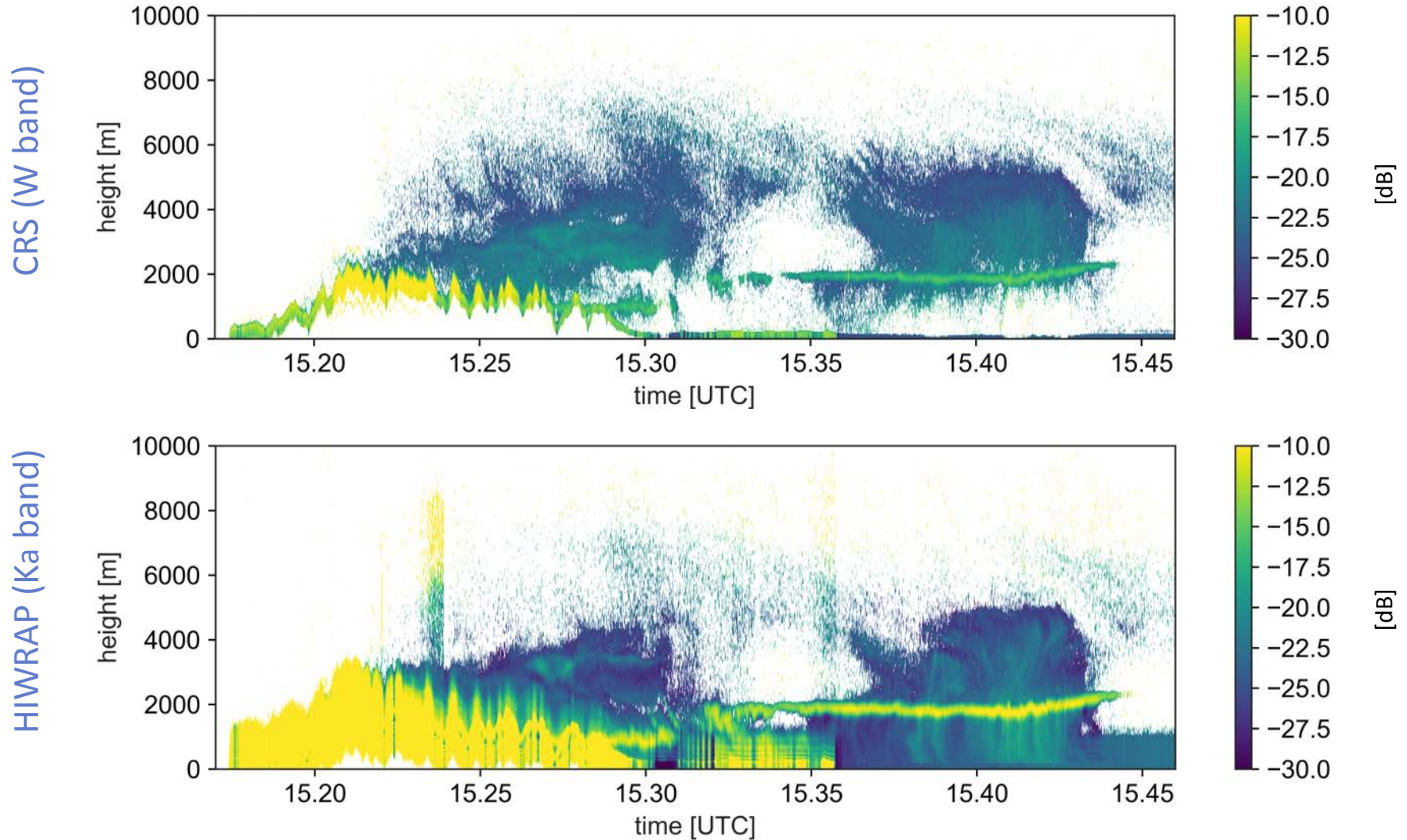
CRS (W band)



HIWRAP (Ka band)

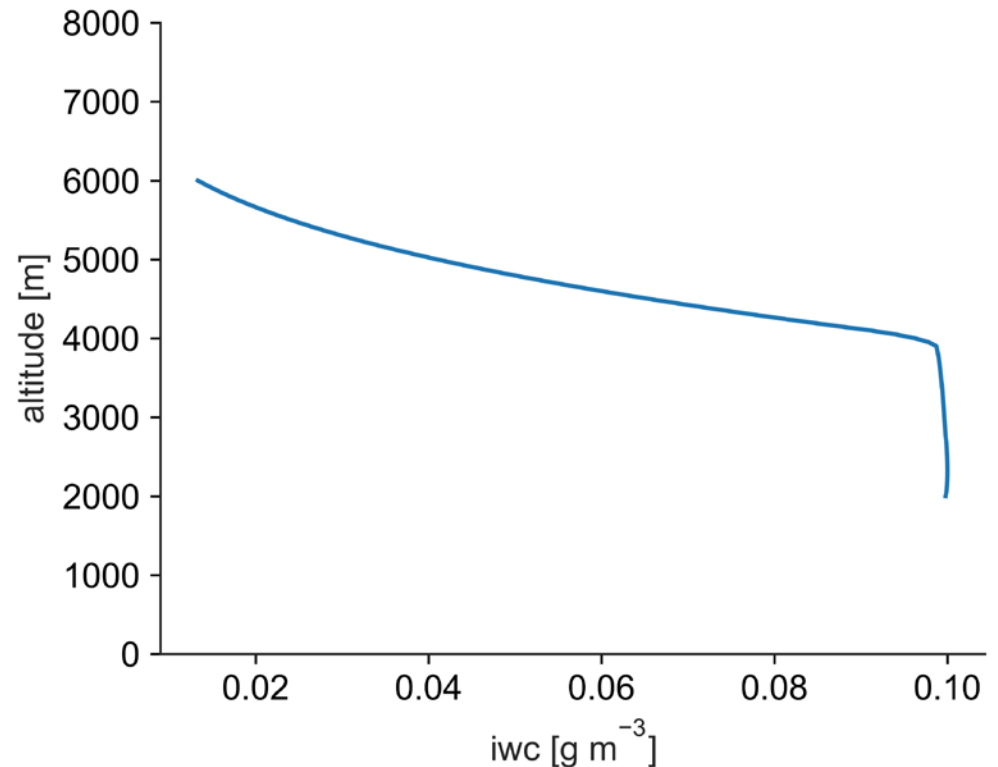


Interesting LDR Features Above Melting Layer



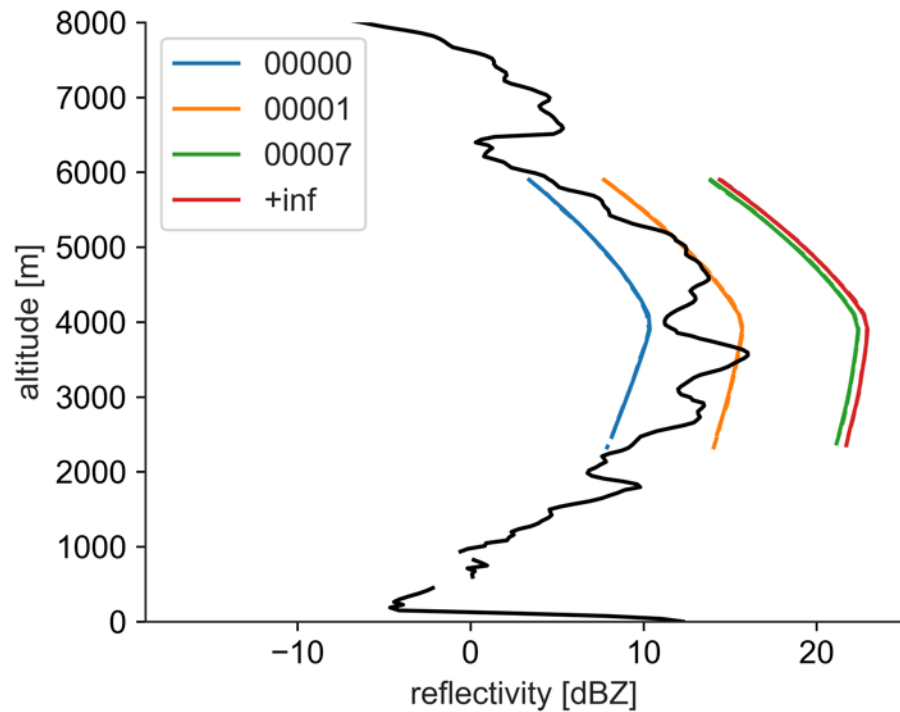
Application of Idealized Profile

- Planar approximation
 - Based on Adams and Bettenhausen (2012)
 - $ar = 7$
 - Flutter $\sigma = 38^\circ$
- Gamma distribution
 - Field et al (2005)
temperature
dependence
$$(N_{0,23}^* = M_2^4 / M_3^3)$$

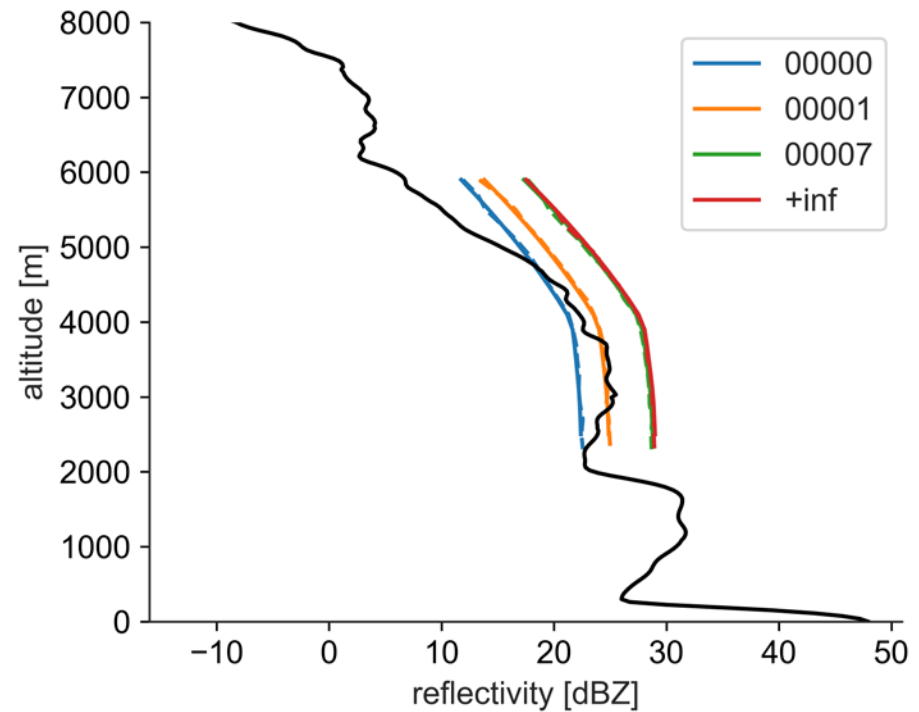


Reflectivity Profiles

CRS (W band)

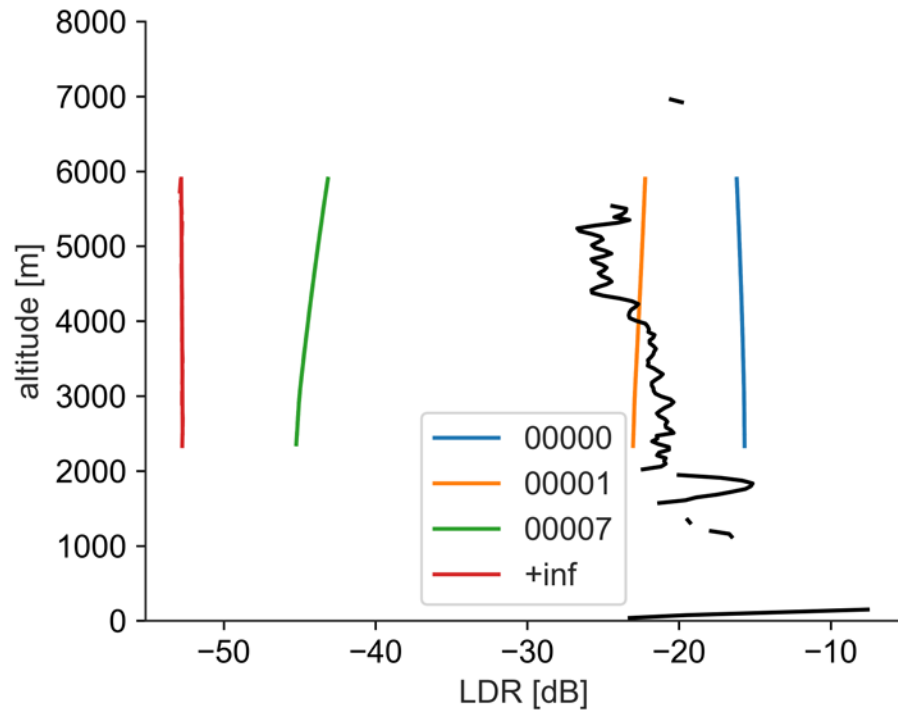


HIWRAP (K_a band)

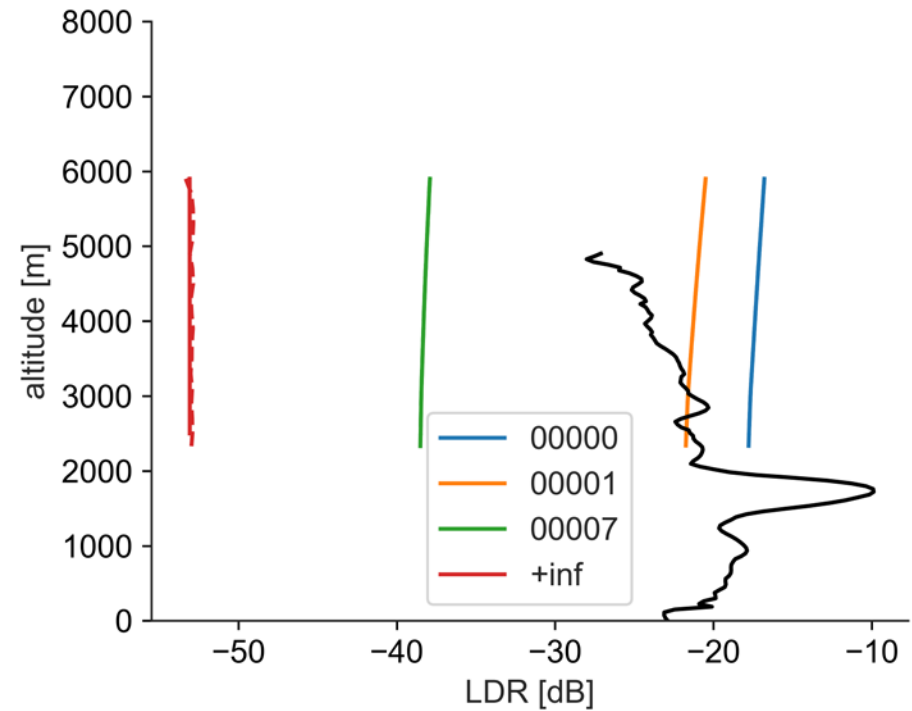


Linear Depolarization Ratio

CRS (W band)



HIWRAP (K_a band)



Conclusions and Future Work

- Monte Carlo integration to include multiple scattering
- Requires finite antenna response (Gaussian)
- Allows for polarimetric variables (LDR, ZDR)
 - K_{dp} , ρ_{hv} in development
- Available in development version of ARTS