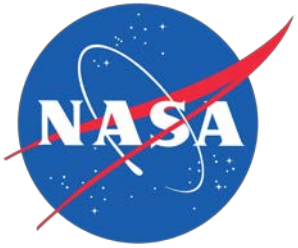


MCRadar: A Monte Carlo Solver for Cloud and Precipitation Radar

Ian Stuart Adams

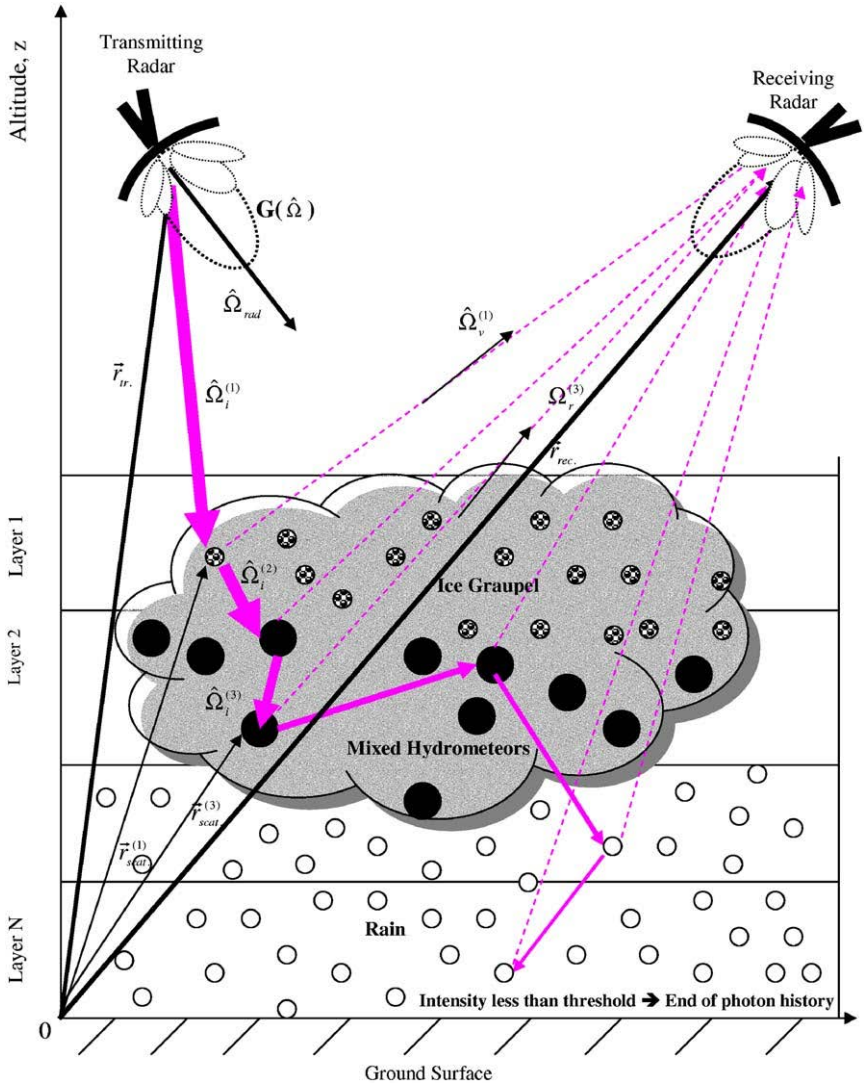
NASA Goddard Space Flight Center

with contributions from

Joe Munchak and Kwo-Sen Kuo

Multiple Scattering in Radar

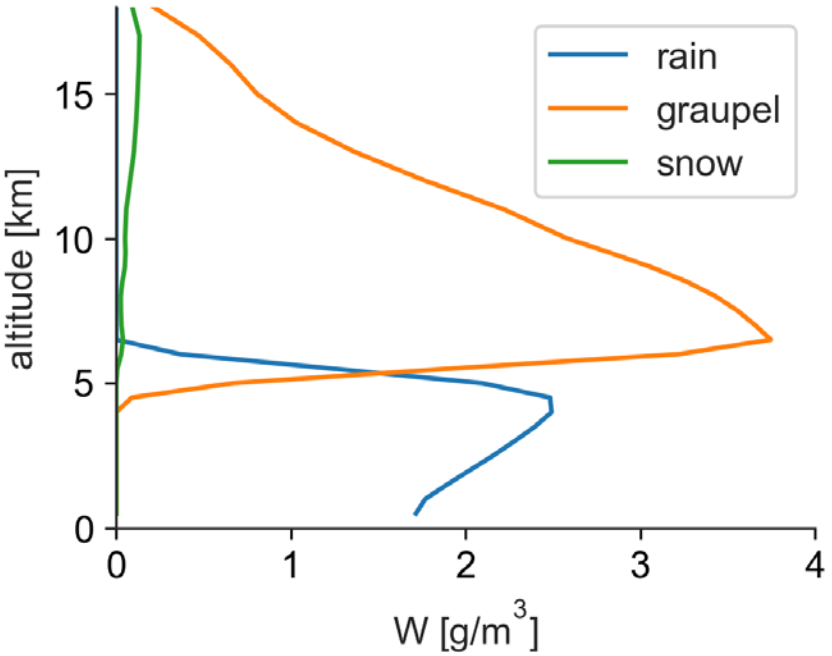
- Anomalous scattering contribution
  - High optical depth
  - High albedo
- Enhanced reflectivity down-range
  - Pulse stretching
- Overestimated by parallel-plane models



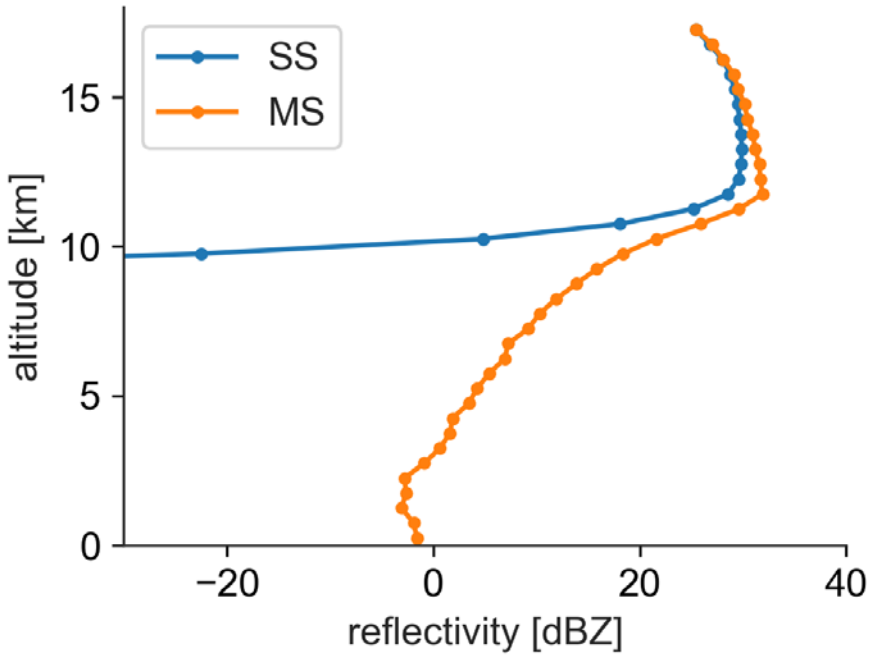
Battaglia et al. 2006

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

$$e^{kl} = RN$$

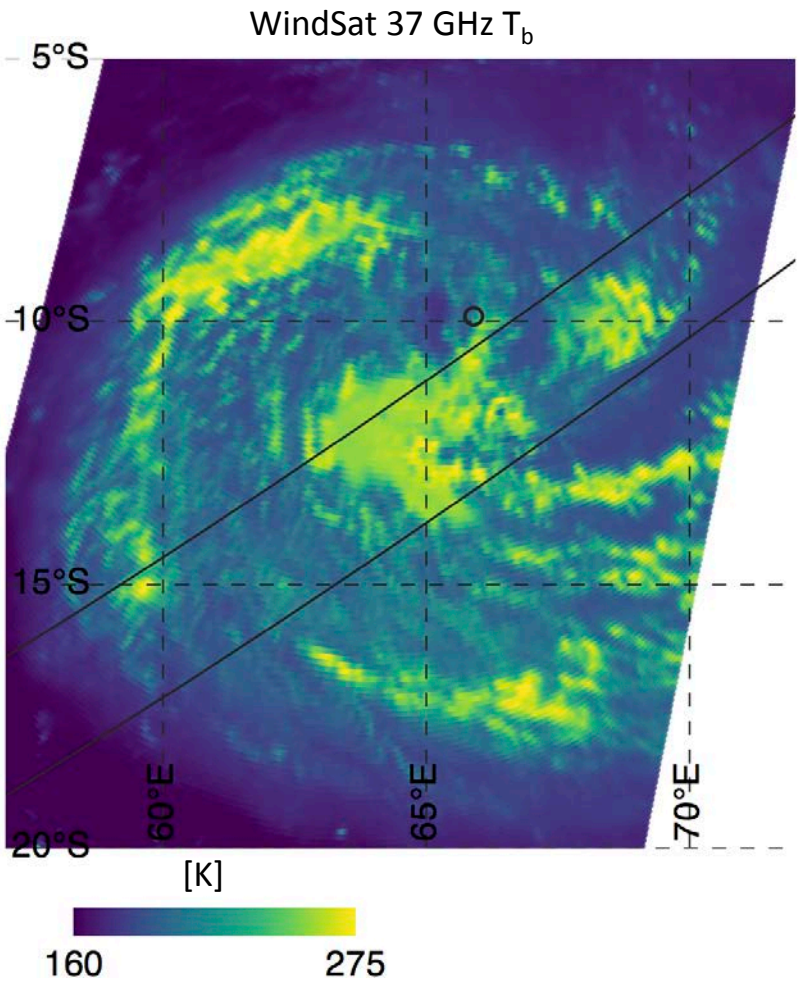
$$e^{k_1 l_1} e^{k_2 l_2} \ldots e^{k_n l_n}$$

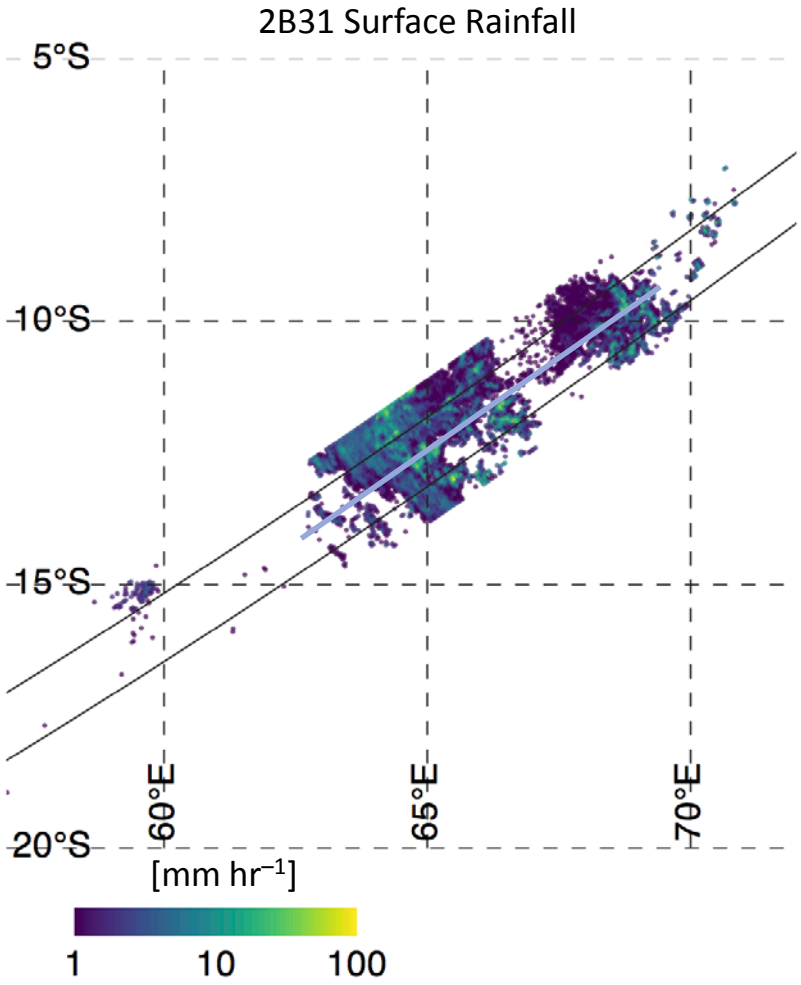
  - Azimuthally-random orientations (solved numerically)

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

- Draw RN to determine scattering or absorption
  - If RN > albedo, terminate (absorption), throw new photon
  - Else, add contribution to reflectivity based on distance
    - Randomly select new distance
    - Continue propagation until absorption

TRMM Example

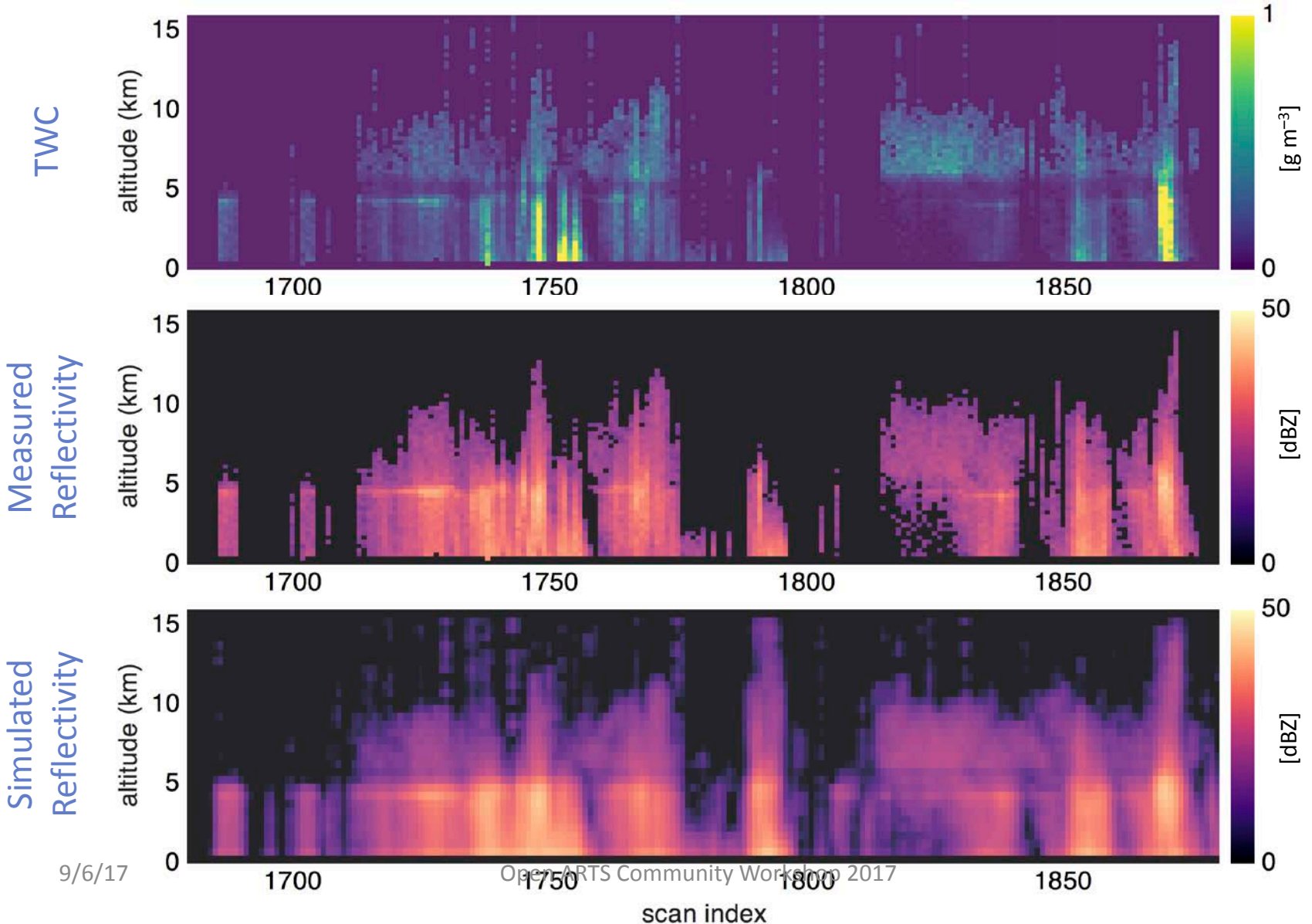




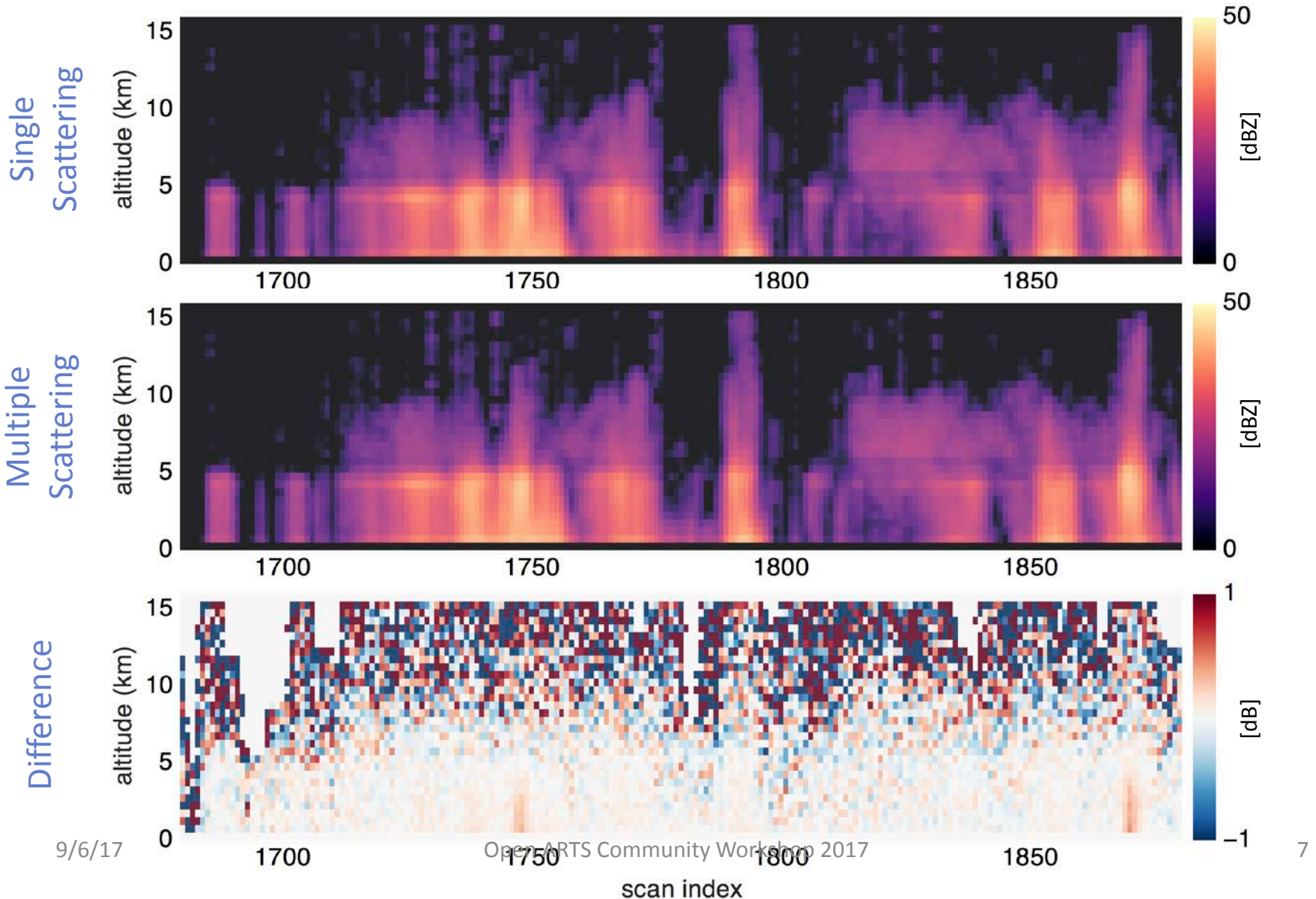
Moderate Tropical Storm Asma
19 October 2008 0129Z

Adams and Bettenhausen (2016)

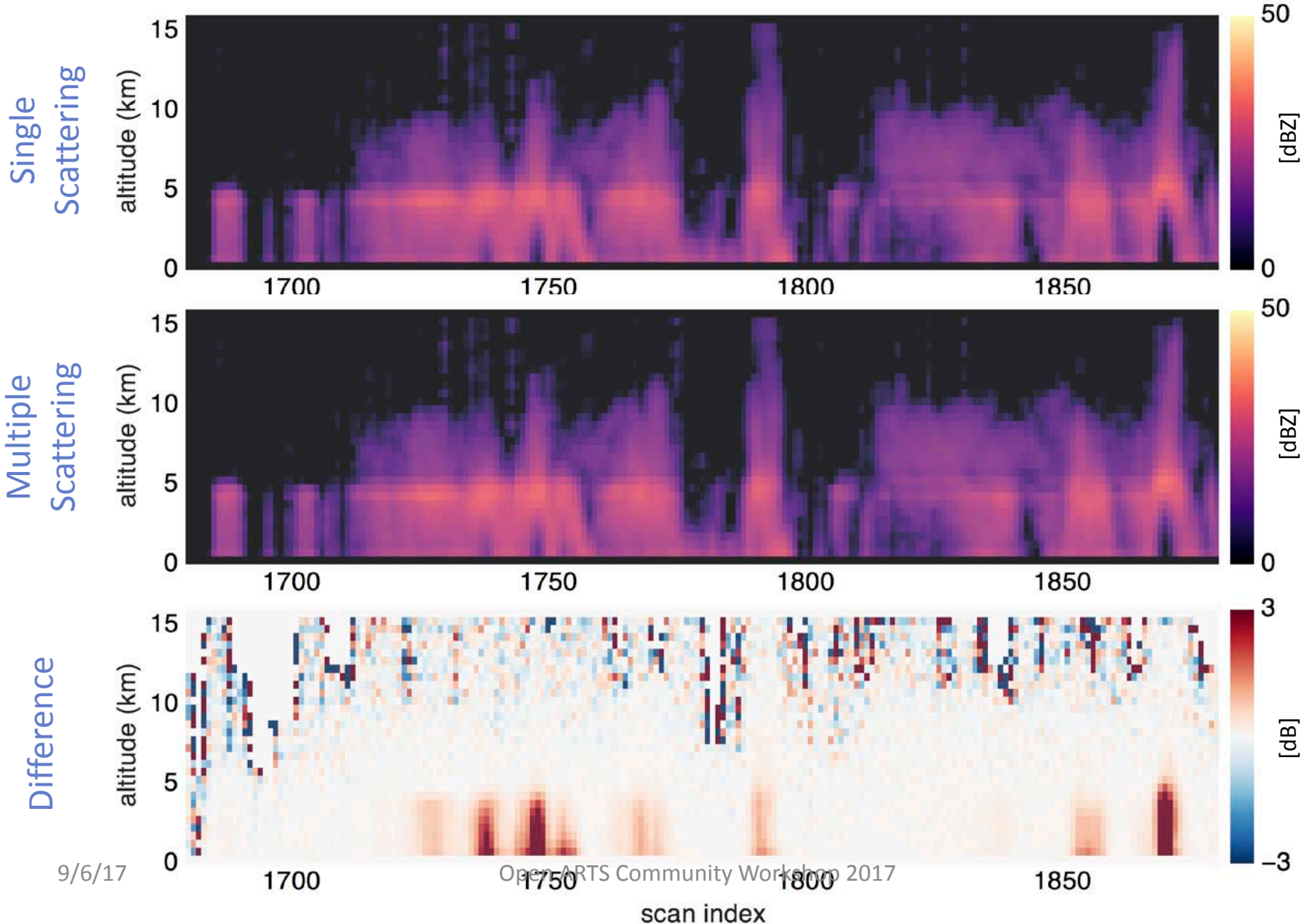
Measured and Simulated PR Reflectivity



Multiple Scattering Effects

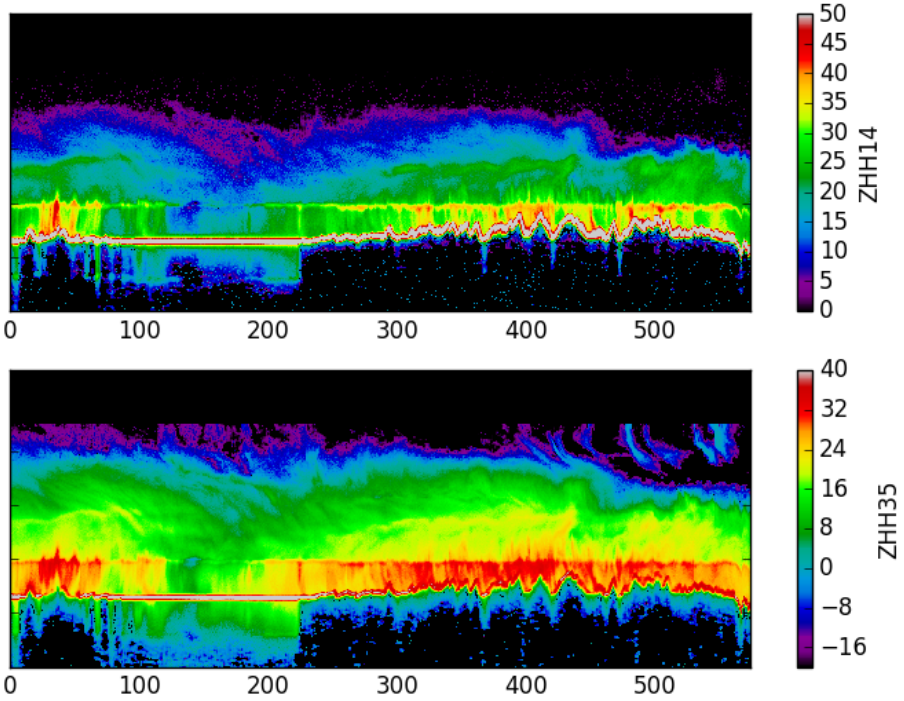


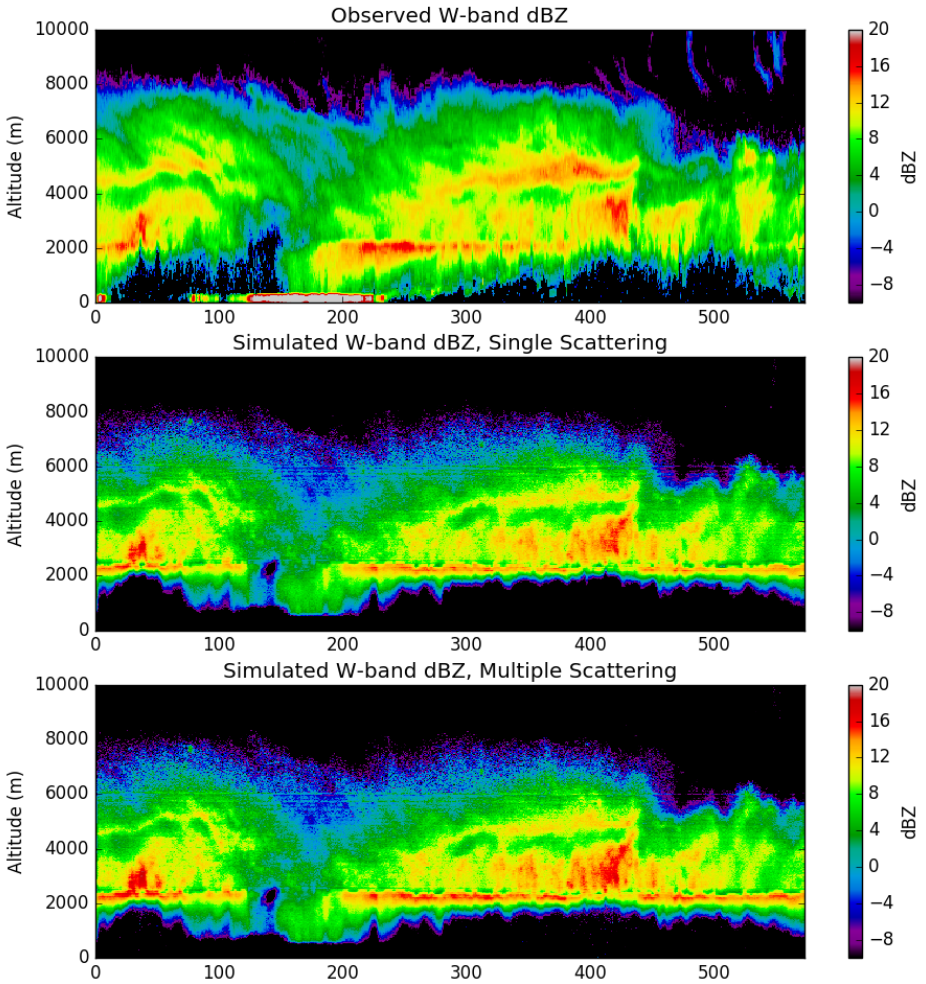
Multiple Scattering Effects (Contrived K_a band)



OLYMPEX 03 Dec 2015

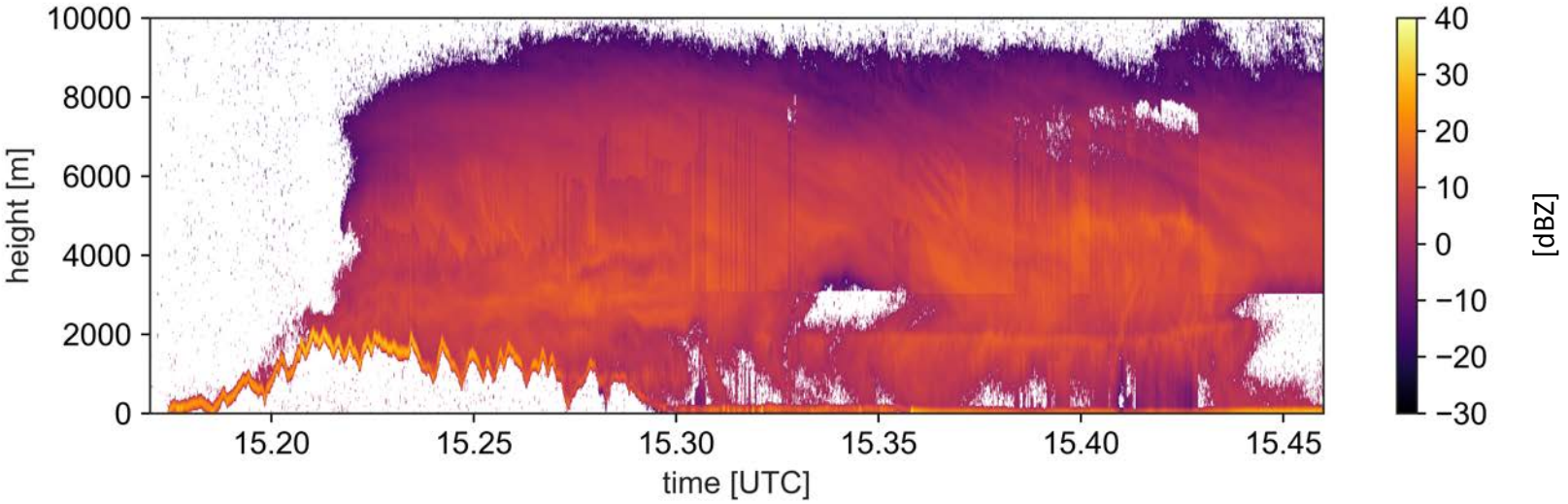
APR-3



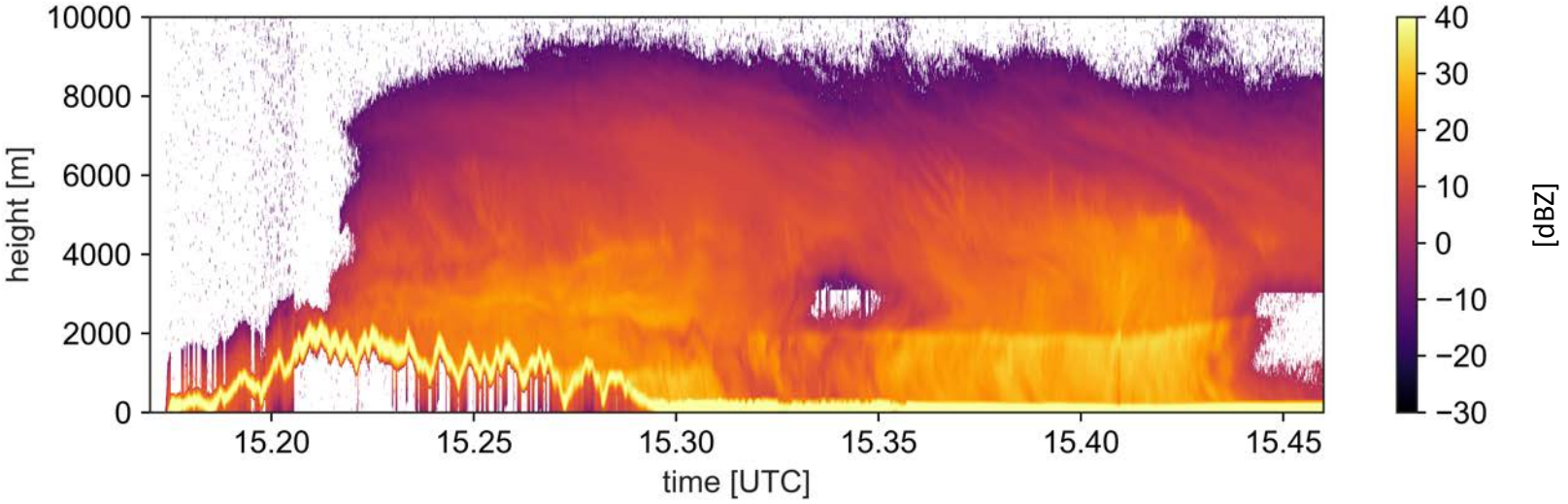


OLYMPEX/RADEX Case Study: 05 Dec 2015

CRS (W band)



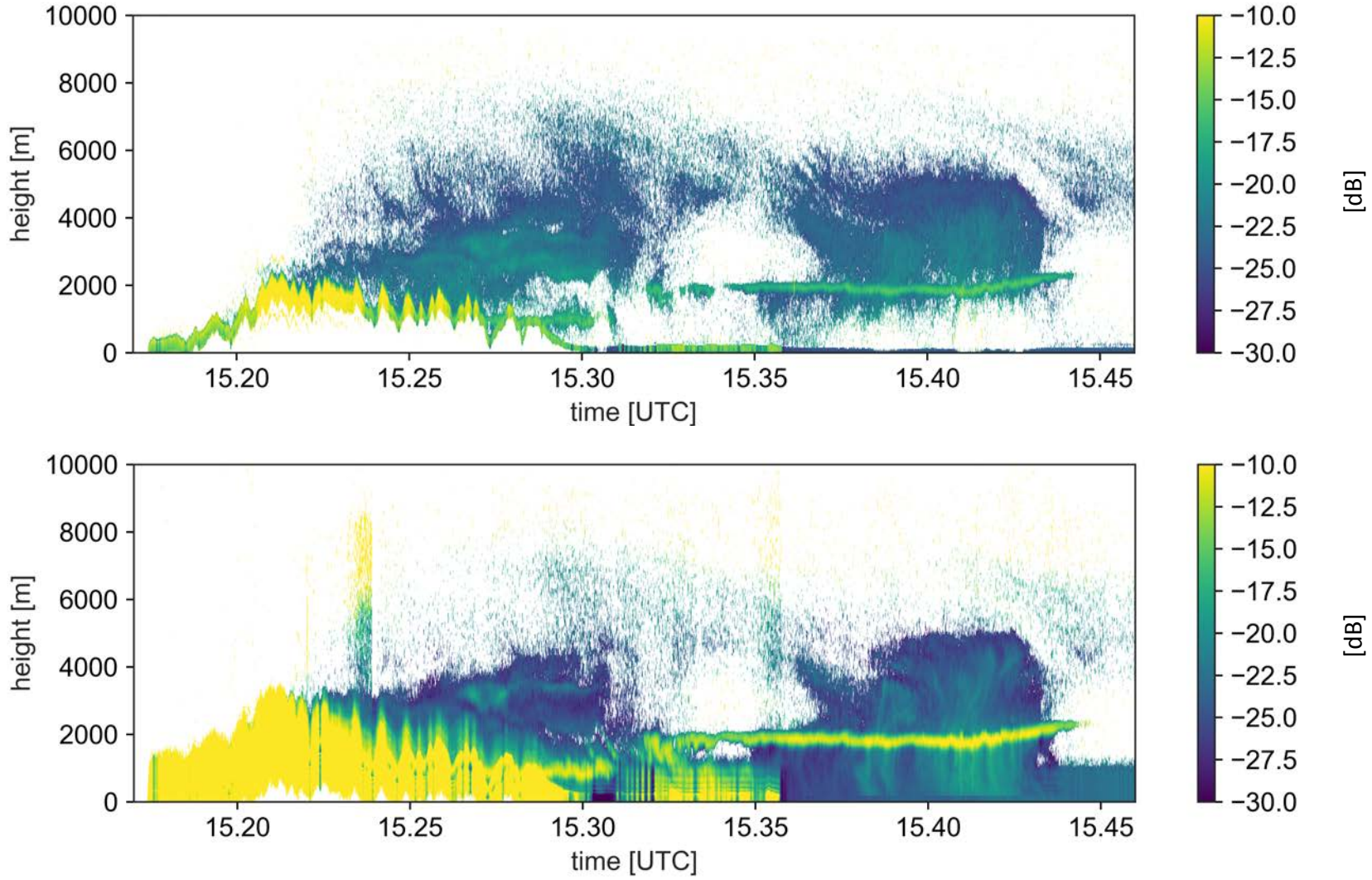
HIWRAP (Ka band)



Interesting LDR Features Above Melting Layer

CRS (W band)

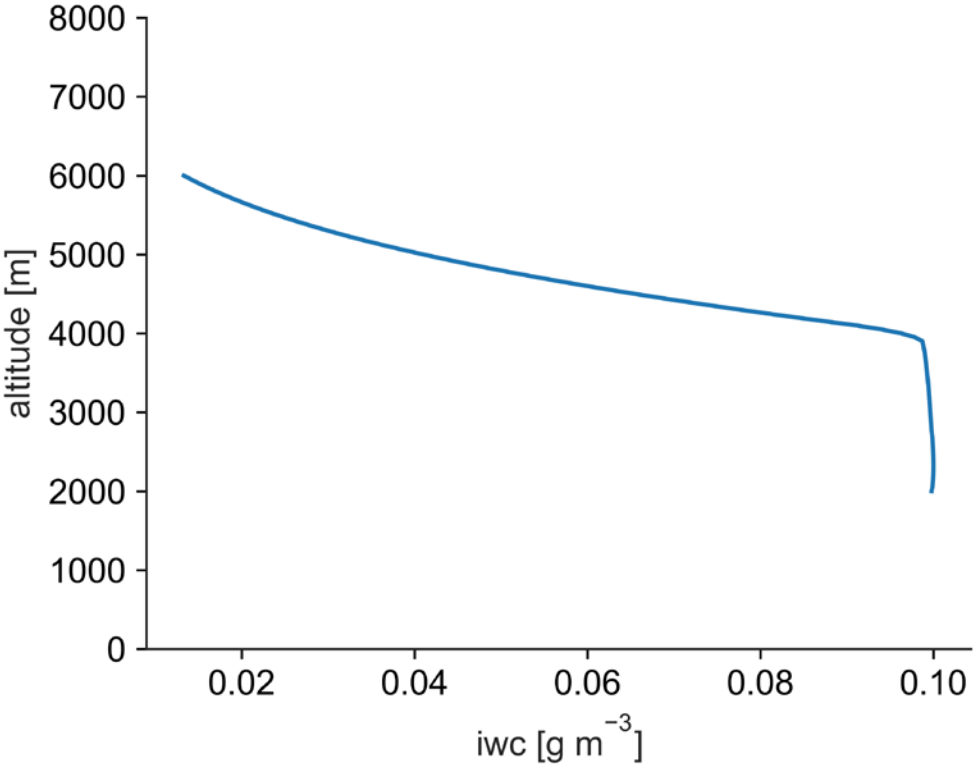
HIWRAP (Ka band)



Application of Idealized Profile

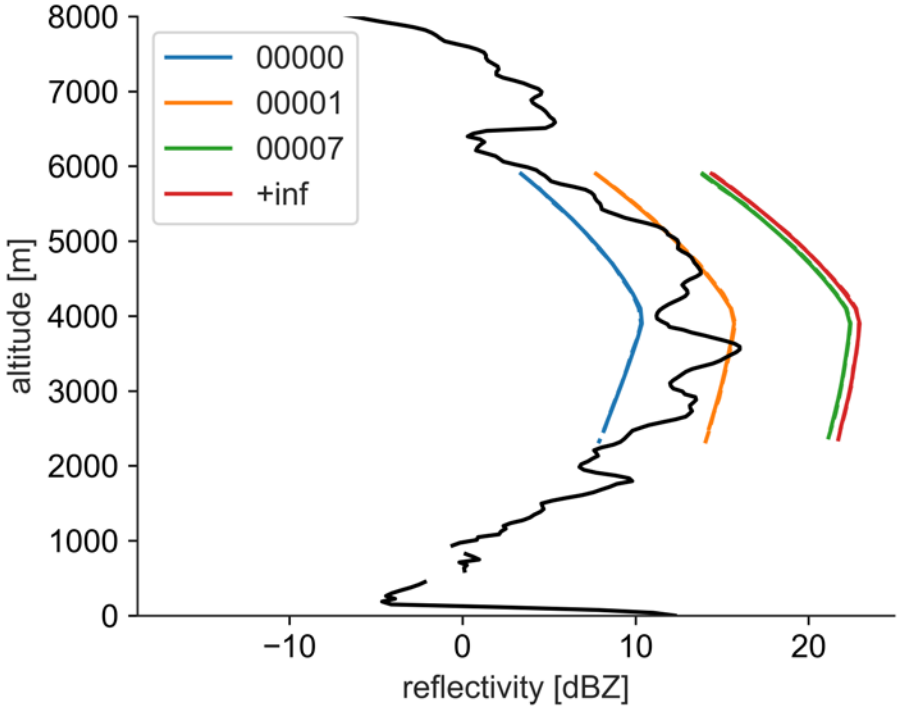
- Planar approximation
  - Based on Adams and Bettenhausen (2012)
  - ar = 7
  - Flutter σ = 38º
- Gamma distribution
  - Field et al (2005) temperature dependence

  ($N^*_{0,23} = M_2^4 / M_3^3$)

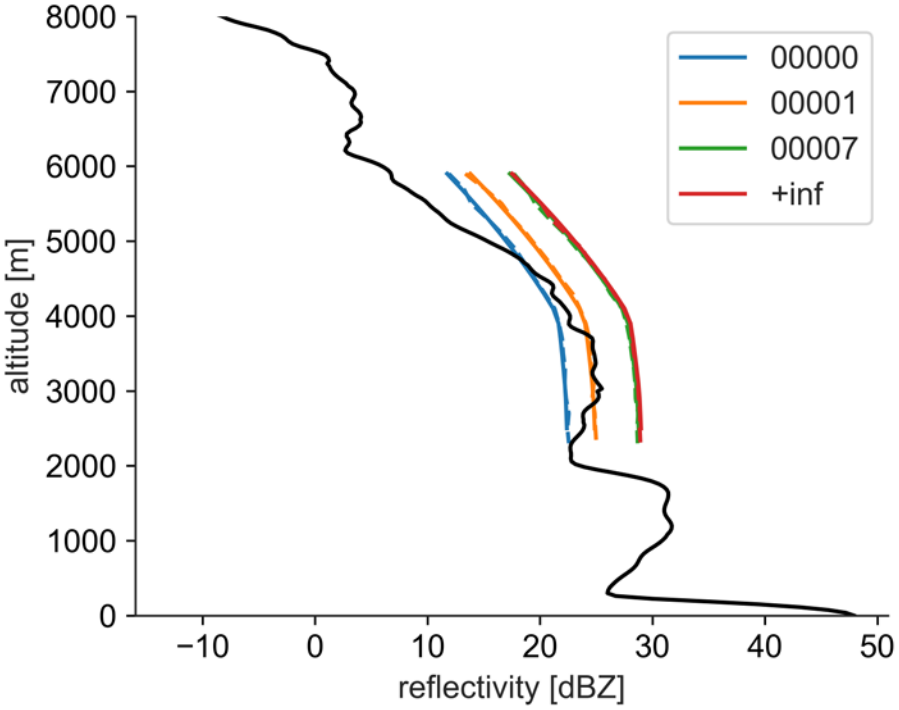


Reflectivity Profiles

CRS (W band)

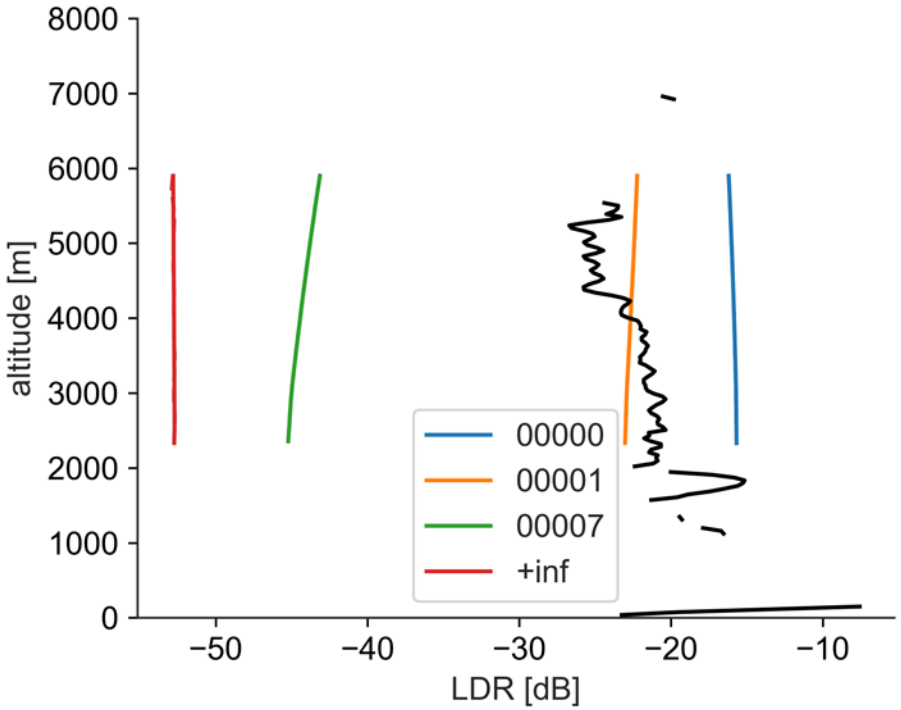


HIWRAP (K_a band)

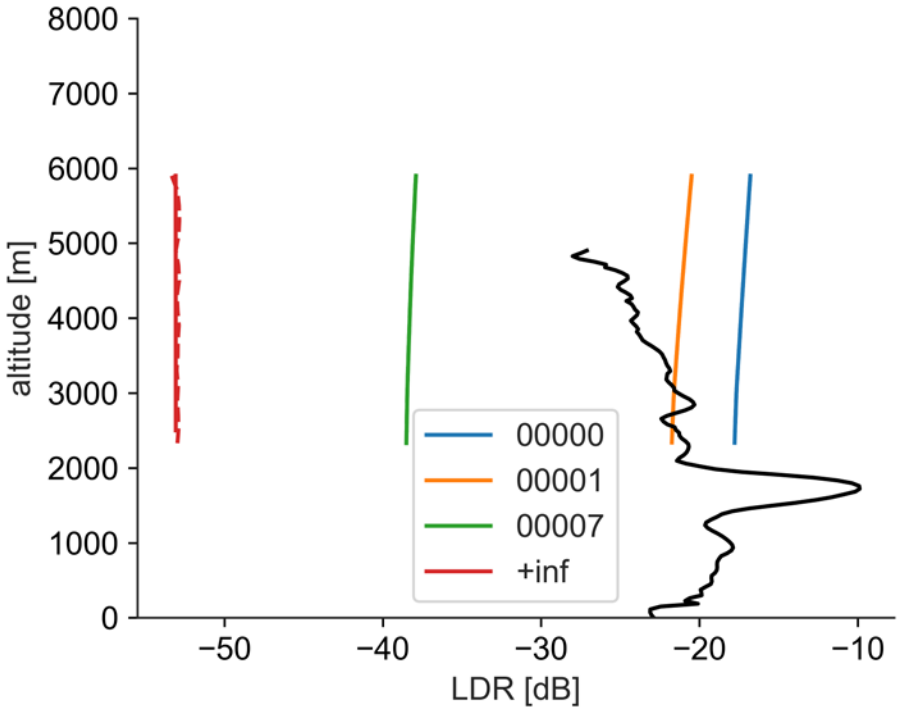


Linear Depolarization Ratio

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