DPR Algorithm Development

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Outline

- This talk provides a review/overview of work by various groups on dual-frequency radar algorithms
- The presentation covers the following areas:
  - The need for dual-frequency (DF) measurements
  - History of the DF approach
  - Recent DF algorithms
  - Stochastic versus deterministic approaches
  - Other algorithm differences and research issues

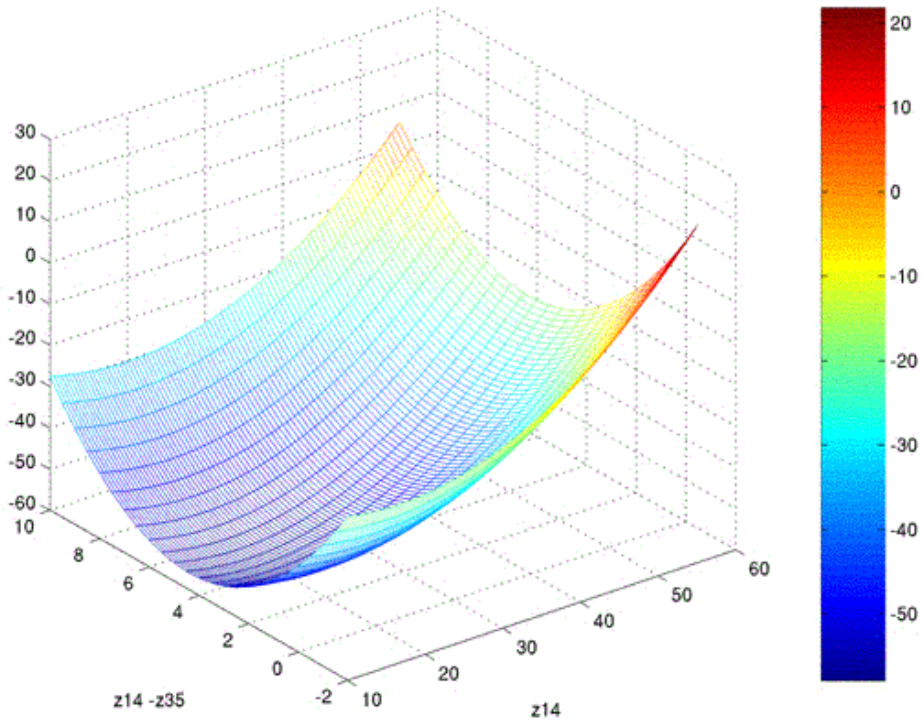
Why Do We Need Multi-Parameter Radar?

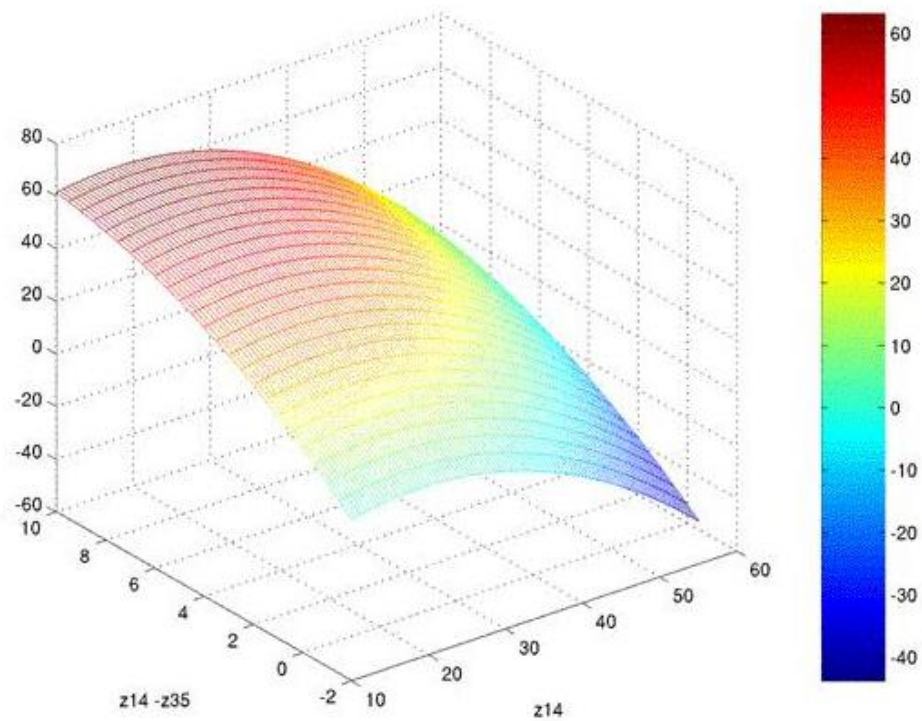
- Radar retrieval of rainfall is inherently ambiguous: a single reflectivity can correspond to multiple rainrates
  - More generally multiple DSDs can yield the same reflectivity
- Situation further complicated by use of attenuating frequencies
  - e.g, 5 km path, 2 mm/h: 0.5 dB 2-way PIA at 14 GHz
  - Hitchfeld and Bordan (1954) developed single-frequency profiling algorithm and showed need for additional information (constraint)
- From space we are limited in ways to gain additional parameters and reduce ambiguities
  - Doppler measurements challenging due to platform motion, although feasible
  - No differential reflectivity at nadir

  $\Rightarrow$ Multiple frequencies can provide independent measurements

COARE and KWAJEX DSDs

- Horizontal axes are calculated Z14 and DFR
- Vertical axis is relative difference in % (KWAJEX-COARE) in rain rate (left) and mean diameter (right)
- KWAJEX DSDs tended to have larger D_m





(figures courtesy Z. Haddad)

Dual-Frequency Algorithm History

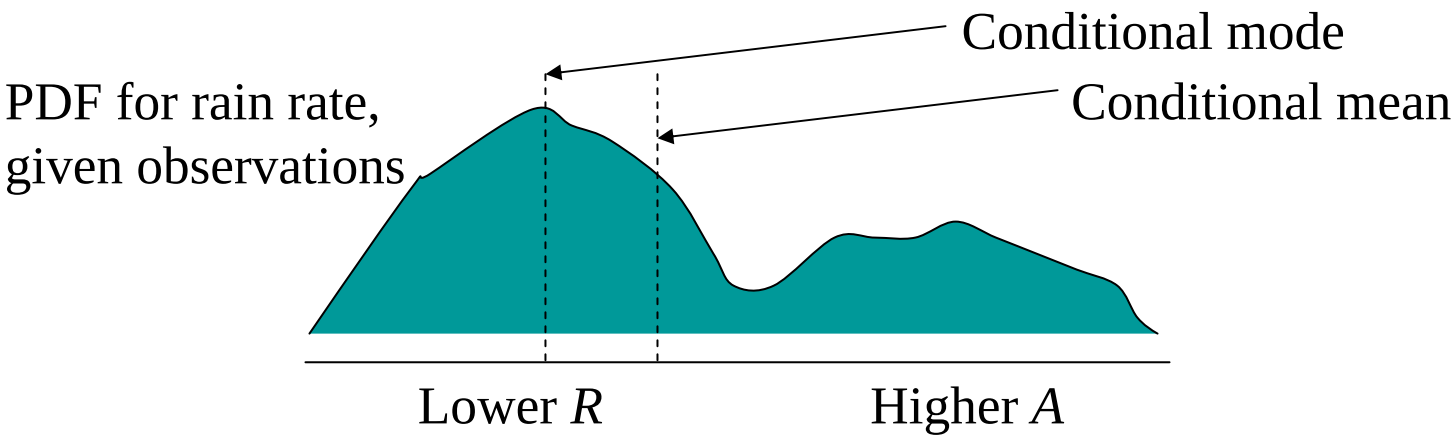
- Use of dual-frequency radar has been contemplated since the 1950's (Atlas, J. Meteorol., 1954)
- Eccles and Mueller, JAM (1971) proposed use of attenuating (X-band) and non-attenuating (S-band)
  - Apparent reflectivity difference provides attenuation
  - Attenuation can be converted to liquid water profile
  - Assumes Rayleigh scattering at both frequencies
- Fujita (1983) developed an algorithm that uses nonlinear least-squares to fit a k-R and Z-R -based model to dual-frequency data
- Coupled differential or integral equations for DSD parameters used by Meneghini et al. (1992) and subsequent authors.
- Stochastic approaches used by L'Ecuyer and Stephens (2002), Haddad et al. (2005)

Deterministic Coupled Equation Approaches

- Rose and Chandrasekar (2005) classify algorithms
  - Upward or downward recursion
  - SRT/non-iterative (Meneghini et al. 1997) or non-SRT/iterative (Mardiana et al. 2004)
    - (SRT is the surface-reference path attenuation)
- Non-Rayleigh scattering at second frequency is exploited to retrieve DSD information
  - Assume gamma size distribution
  - Use pre-computed table of dual-frequency reflectivity ratios versus mean size and altitude
  - Measured reflectivity ratios are converted to “true” reflectivity ratios using attenuation correction
  - Initial attenuation is provided by SRT in non-iterative case or set to some nominal value in iterative case

Stochastic Approaches

- Assume DSD parameters are random variables or random processes
- MAP estimate is conditional mode: R, D_o maximize conditional density(L'Ecuyer and Stephens 2002)
- MMSE estimate is conditional mean, using nonlinear filtering approach (Haddad 1996, 2005)
  - Model bin-to-bin variation as a Markov random process
  - Apply extended Kalman filter, particle filter, grid filter



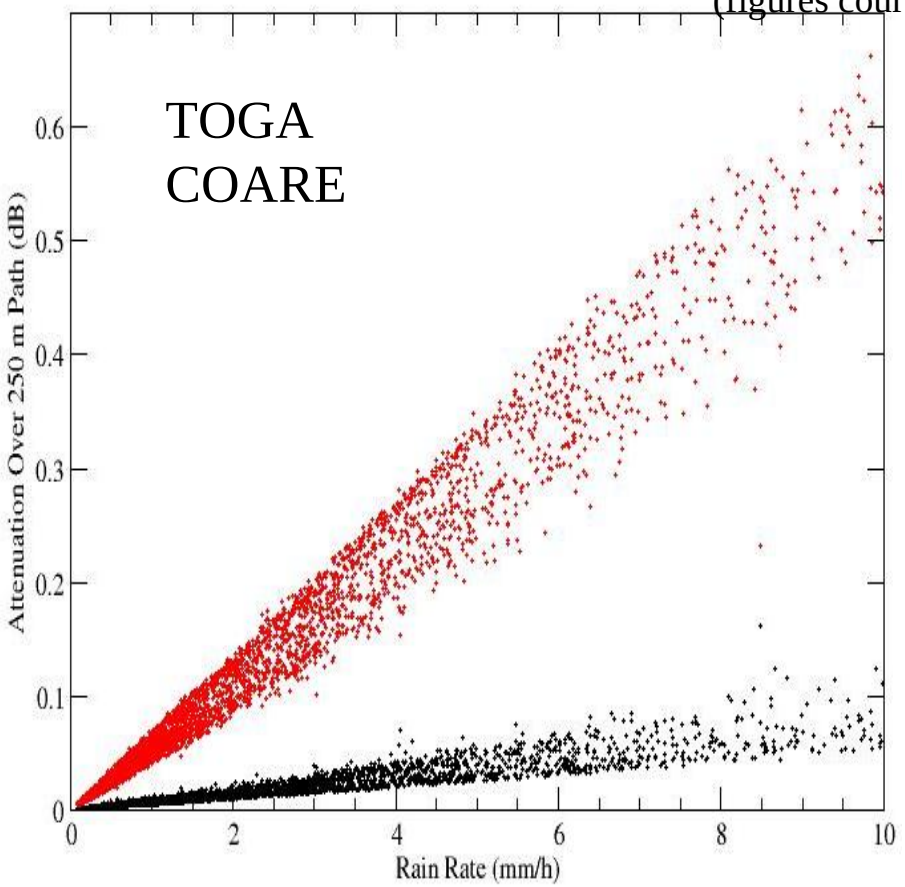
Additional Algorithm Differences/Issues

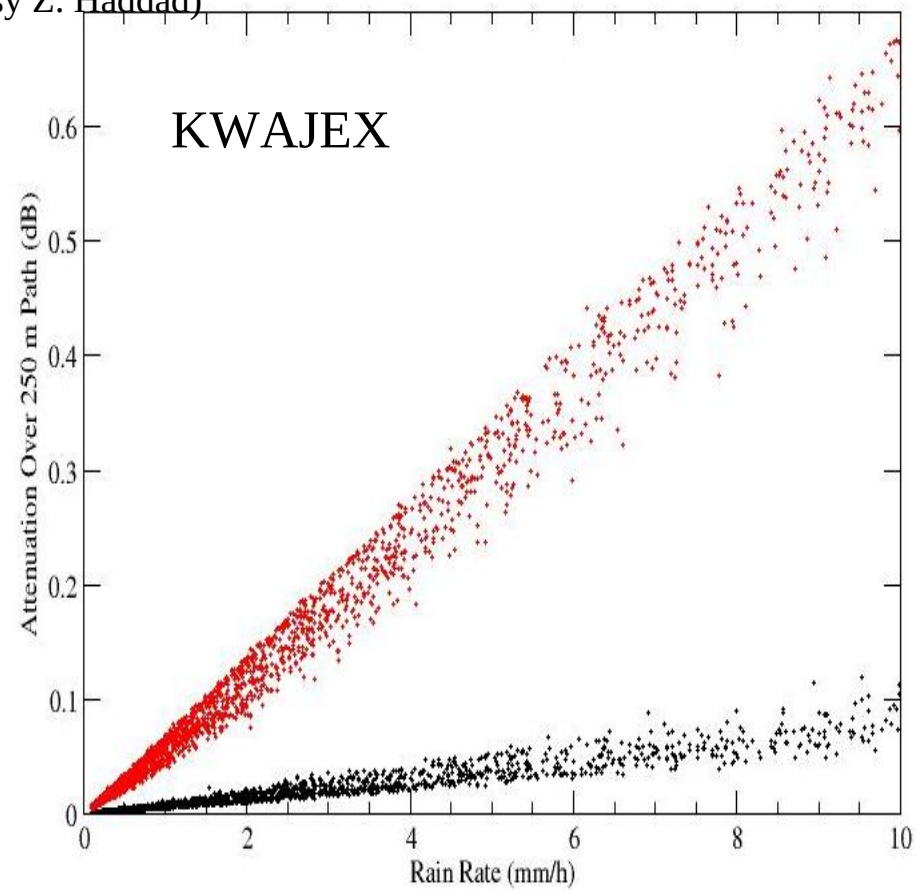
- Numerical implementation details
  - may affect accuracy and possibly stability
  - e.g., how do we handle discretization effects?
- Boundary conditions
  - Use PIA from SRT as a constraint?
  - If so, how is it best estimated?
- Microphysics
  - DSD description
    - How many parameters, and are they independent?
    - More or less effective to use DSD samples database?
    - How do we handle ambiguities?
  - Frozen and mixed-phase regions
  - Presence of cloud liquid water
- Algorithm output

Dual-Frequency Attenuation Over 250 m

- Attenuation within range bin computed directly from DSDs

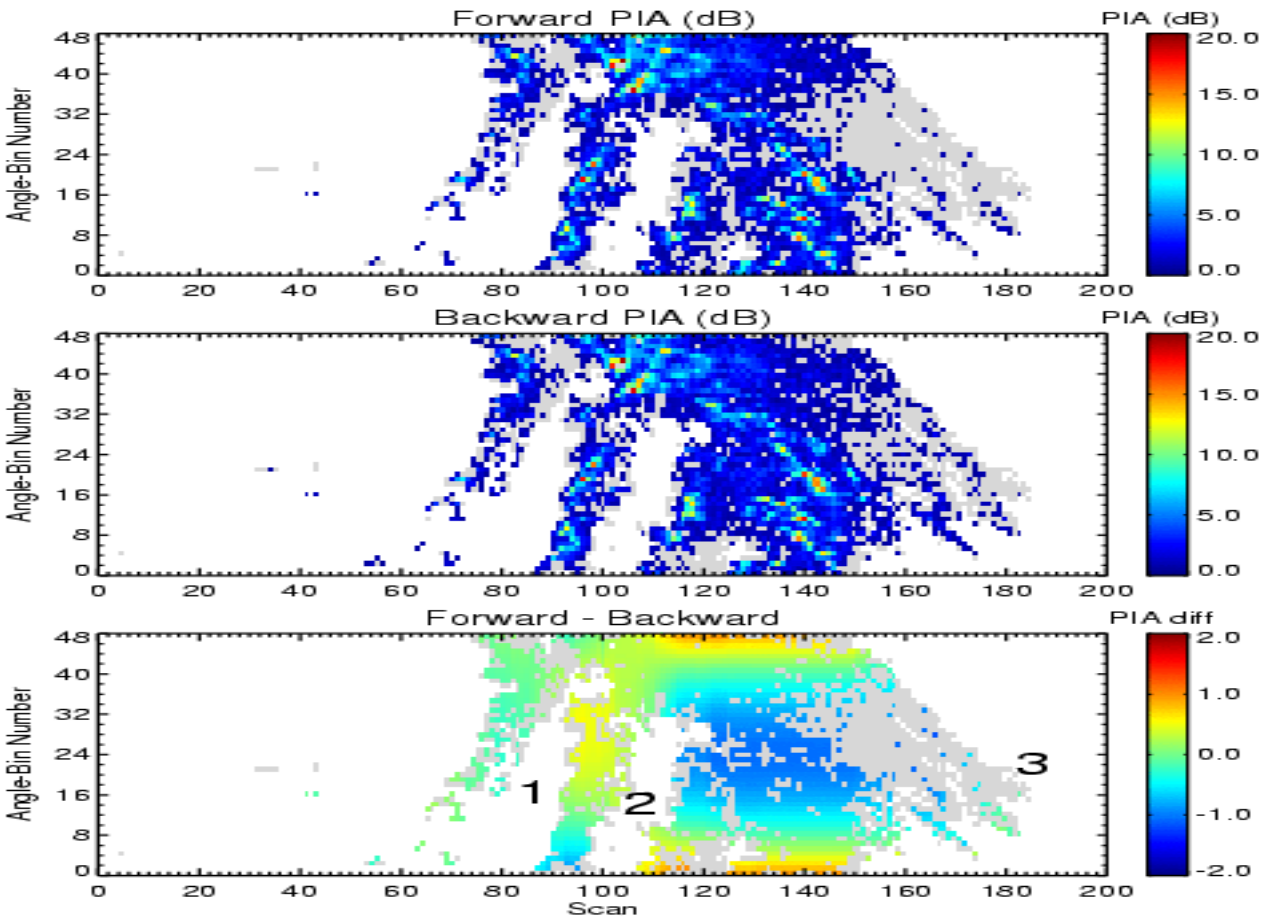
(figures courtesy Z. Haddad)





- At large rain rates, attenuation is large, especially 35 GHz
- For light rain within-bin attenuations are same order as bin-to-bin reflectivity variation due to noise

PIA Estimation

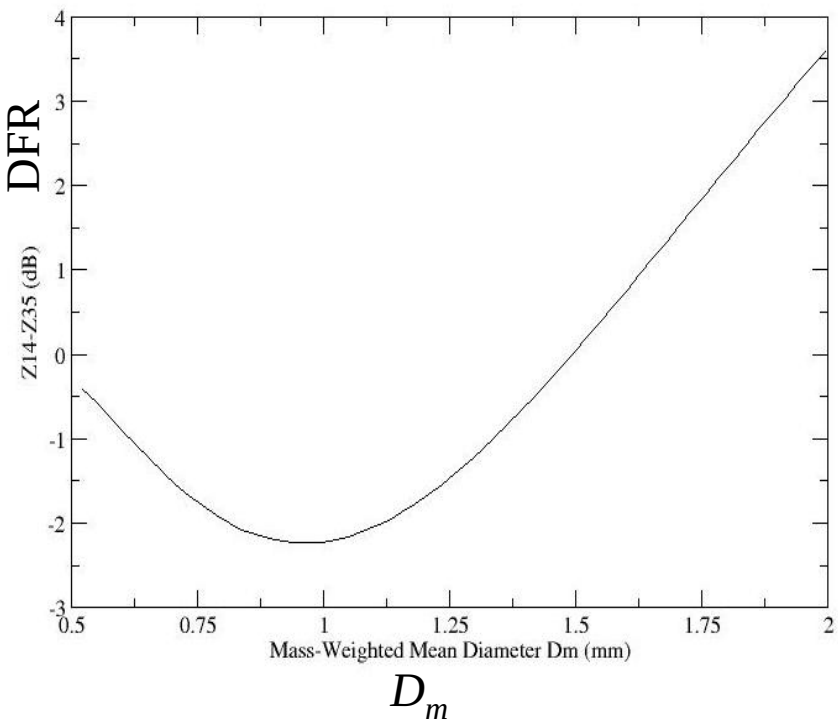


PIA obtained by moving forward differs from moving backward, likely due to wind gradients

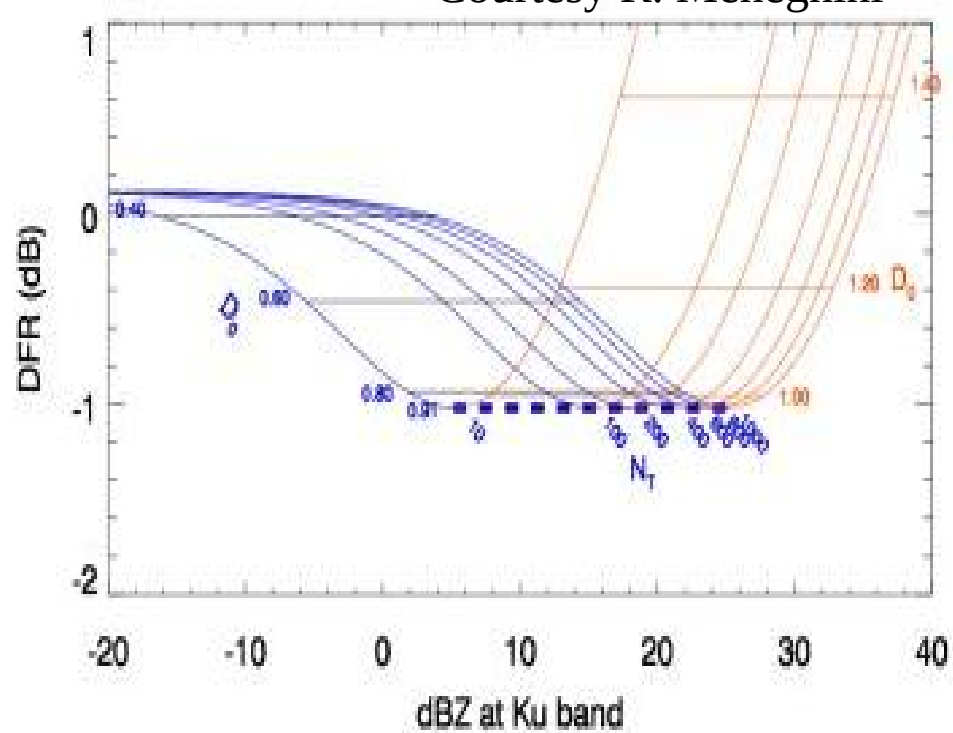
(courtesy R. Meneghini)

Dual-Frequency Ambiguity

- Dual-frequency ratio versus D_m is double-valued
  - Hence, DFR does not provide good estimate of D_m at low D_m
  - Z-14 can help with choice of D_m, although choice may be sensitive to noise



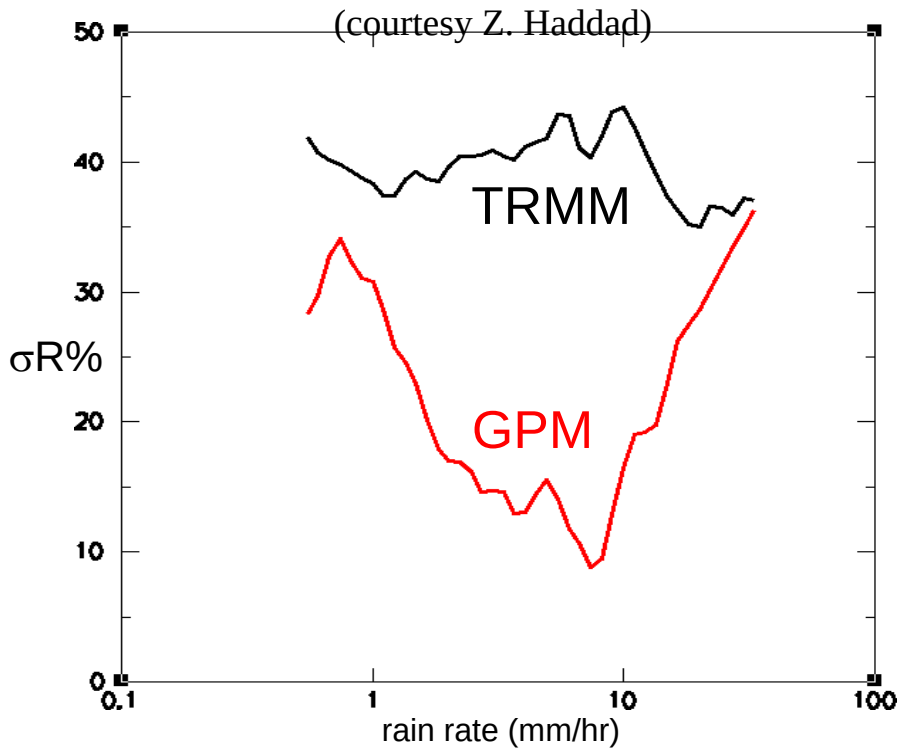
Courtesy R. Meneghini



Dual-Frequency Ambiguity (II)

- Ambiguity can result in larger uncertainty in retrieved *R* at low *R* (example simulation from Hurricane Bonnie)
- Dual-frequency approach still better than single even at low rain rate due to use of both Z-14 and DFR

(courtesy Z. Haddad)



Frozen and Mixed Phase Regions

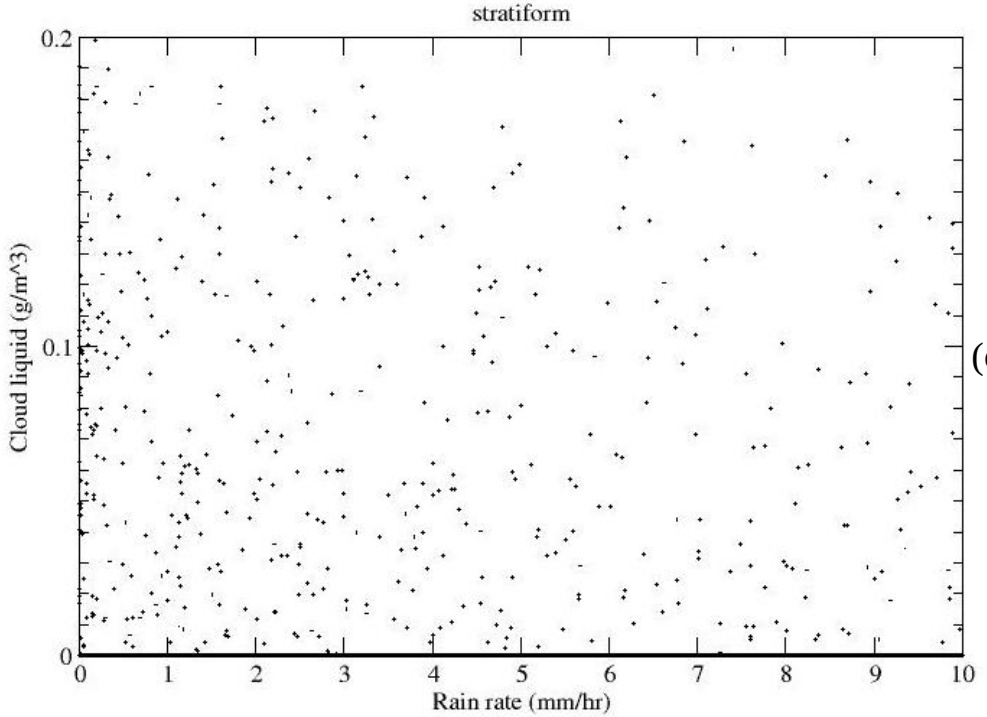
- Algorithms already have capability to handle frozen and mixed phase regions
  - e.g., D_o versus Z ratio tables are computed as a function of altitude, with calculations performed for mixed phase or frozen particles above freezing level
- Problem is to correctly model radar properties of partially-frozen, inhomogeneous, irregular particles
  - Numerical approaches for irregular particles exist
  - Rigorous theory for randomly inhomogenous particles also exists - dense medium multiple scattering theory
    - Application requires knowledge of internal particle structure, such as size distribution of water inclusions
  - In lieu of such information, use simpler mixing formula; e.g., Meneghini & Liao (2000), Liao & Meneghini (2005)

Cloud Liquid Water

- Cloud liquid water in the form of small droplets attenuates but provides little backscatter
  - 1 g/m^3 yields attenuation of 0.1 dB/km at Ku-band and 0.9 dB/km at Ka-band but reflectivity only 8 dBZ
- How can this additional attenuation be included in the retrieval algorithms?
  - Use climatological or typical values in certain conditions (e.g., stratiform versus convective)
  - Parameterize cloud liquid water in terms of precipitation
  - Other?

Correlation of Cloud and Precipitation

- Cloud *C* and rain *R* liquid water in a given bin in model output are not correlated

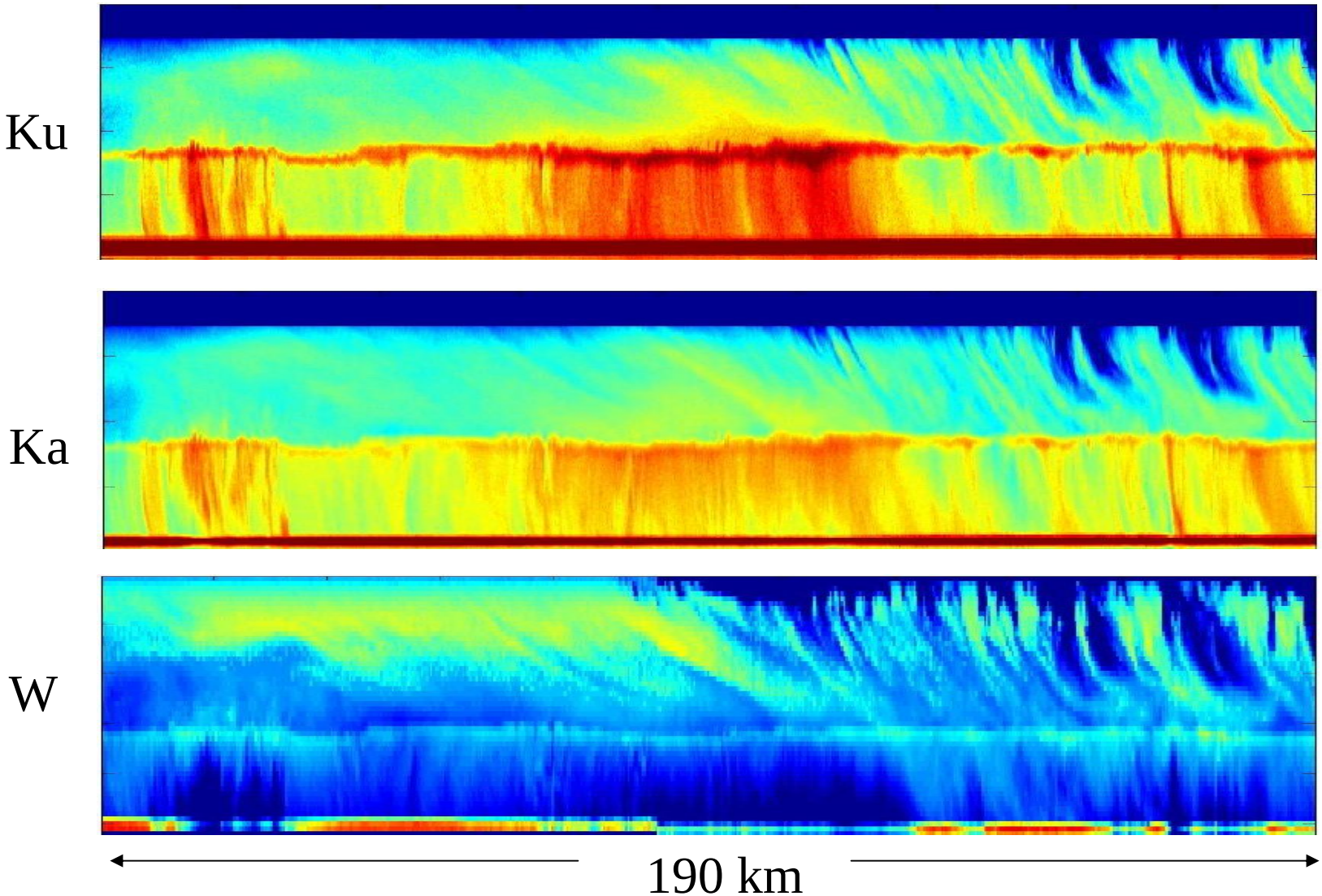


(courtesy Z. Haddad)

- However, preliminary results indicate vertical behavior of *C/R* can be characterized to first order by one number

Summary

- Basic concepts of dual-frequency precipitation measurements were developed many years ago
- Recent algorithms use attenuating frequencies and non-Rayleigh scattering to estimate DSD parameters
- Algorithm differences include
  - Viewpoint: stochastic or deterministic
  - Numerical implementation
  - Boundary conditions
  - Outputs
- Microphysics, including vertical behavior of DSD, cloud/rain water relationship, and melting particle representation, are likely key areas for DPR algorithm improvements

Triple-Frequency Data

- Wakasa Bay, AMSR Validation, Jan 23, 2003