Evaluating a model of mixed-phase cloud processes using radar Doppler spectra

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Methodology

• Data (ISDAC - 8 April 2008 Golden case)
  – KAZR spectra
  – Model: DHARMA
    • Size resolved bin microphysics (drops, dendrites, aggregates): mass and fall speeds
    • Vertical velocity: mean and variance
  – Doppler spectrum simulator
    • Liquid/dendrites: small particle scattering theory
    • Aggregates: Generalize Multi-particle Mie (Botta et al.)
    • Adjusted for model/radar volume differences

– Processing
  • Reflectivity (dBZ)
  • Volume-mean air velocity ($w_{est}$)
  • Volume-mean Doppler velocity ($V_D$)
  • Hydrometeor fall speed ($V_{fs}$)
– Compare in-cloud histograms
  • One slice through model
  • One hour of KAZR data
Vertical velocity comparisons

- Velocity offset (a) depends on sub-volume turbulence and LWC
  - Model resolved $-0.02 \text{ m s}^{-1}$
  - Model retrieved $0.17 \text{ m s}^{-1}$ (bias expected)
  - Radar retrieved $0.40 \text{ m s}^{-1}$
- Model underestimation may be caused by
  - Underestimation of broadening (model)
  - Underestimation of LWC (model)
  - Shear across volume
  - Radar processor artifact
Radar moment comparisons

- Two simulations: high- and low density ice (dendrite & aggregates)
  - Low density:
    - Match precipitation dBZ
    - Cloud top dBZ high
    - Match $V_D$
    - Spectrum width too small
    - $V_{fs}$ too small
  - High density:
    - Precipitation dBZ low
    - Cloud top dBZ high
    - Match $V_D$
    - Spectrum width too small
    - $V_{fs}$ too small
  - Broadening?
  - Reflectivity weighting?
Turbulence:

\[ \sigma^2 = \sigma_w^2 + \sigma_s^2 + \sigma_d^2 + \sigma_B^2 \]

- Beamwidth (\(\sigma_B\)) no issue (narrow beam)
- Sub-volume turbulence width (\(\sigma_w\)) comparison OK (Shupe et al 2008)
- Discrepancy from
  - Shear (\(\sigma_s\)) [dynamical broadening]
  - PSD width (\(\sigma_d\)) [microphysical broadening]
- Microphysical broadening
  - No impact on air motion (also underestimated)
- Dynamical broadening
  - No good observations of vertical air motion
  - Increase (\(\sigma_s\)) by factor of three
  - Much better model/radar match
  - No physical basis: model physically consistent
Final comparisons

- With artificial dynamical broadening
  - Spectrum width comparison better
  - Mean fall speeds closer, but distribution off
  - PSD offsets? Reflectivity weighting offsets?

- What have we learned?
  - Using radars to evaluate models is deceptively easy
  - Must represent model ice characteristics in scattering model consistently
    (Must treat radar backscatter cross sections with care)
  - Must characterize ice better in observations (size, aspect ratio, mass, ice mass distribution in ice crystal)