Multisensor Simulation and Retrieval of Ice-Phase Precipitation Observed During the 2003 Wakasa Bay Field Experiment

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Introduction

In recent years, the focus on weather and climate has intensified significantly. **Precipitation** provides a critical link between climate, weather, and human activity. However, the accurate measurement of precipitation on a global spatial scale and over long temporal scales remains a difficult prospect, even with the use of satellite-based remote sensing platforms.

Especially troublesome to precipitation retrievals are the middle and high latitudes, where the variety and complexity of precipitating cloud systems decreases our ability to accurately discern precipitation properties of interest, such as particle size distribution [PSD] and precipitation rate [R].

The present research contains two primary components:

- **Simulation:** Simulate the microphysical and radiative properties of ice-phase hydrometeors (e.g., snow, graupel, aggregates, sleet, etc.). Given these and other properties, simulate what a remote sensing instrument might observe. This is the goal of the **forward model**.
- **Retrieval:** Given a set of observations, infer information regarding the physical properties of precipitation-sized hydrometeors, while simultaneously "untangling" the desired information from other sources of noise. The forward model is, loosely speaking, "inverted" to provide the precipitation retrieval.

Retrieval Method Overview

(1) Dual Wavelength Ratio Technique [DWR] (see Meneghini, et al., 1997)

- *Key principle*: co-located radar observations of the same cloud at two wavelengths sees the same *number* of particles, whereas the reflectivity ratio is proportional to the size of the particles. (Fig. 1)

  Primary Unknowns: ice-phase hydrometeor density (❒), and cloud liquid water content [CLWC]
- Assumes spherical particles (Mie Theory)
- Assumes exponential particle size distribution [PSD]: $N(D) = N_0 \exp(-☹ D)$

(2) Brightness temperature (TB) constraint

- *Key principle*: For a given 1-D profile of DWR-retrieved PSD properties (N_0 and ☹), ❒, and CLWC; passive microwave TBs are simulated and compared to observed TBs.
- TB consistency is determined through RMSE (see examples below) comparison
- Process in Fig. 2 repeats for all variations in particle density and CLWC

Figure 1: Relationship between DWR and median volume diameter (D_0 = 3.67/☹) for various particle densities, (❒)

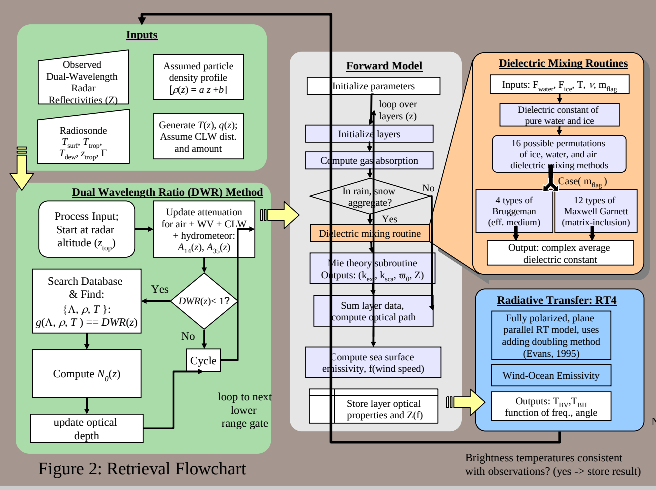

Figure 2: Retrieval Flowchart

Observations and Retrieval Results, 29 January 2003 Snowfall Case, Wakasa Bay, Japan

On 29 January 2003 around 0318 UTC during the Wakasa Bay 2003 Field experiment (WBAY03), observations of a convective snow storm over the ocean were made using the advanced precipitation radar [APR-2] (Ku- and Ka-band) and the Millimeter Wave Imaging Radiometer [MIR]. Figure 3 shows these observations.

Figure 4 shows an example 1-D profile retrieval (c,d) with the DWR retrieval technique applied. A 9-bin smoothing window has been applied to the reflectivity data to reduce noise.

However, there are a large number of solutions to the ill-posed DWR-only retrieval (fig. 5). The key unknowns are particle density and cloud liquid water content. TB constraints (black lines) provide a tighter set of retrieved profiles , and thus, provide ranges of possible densities/CLW parameters.

Figure 6 illustrates the best-fit TBs and the associated RMS error across the entire scan. Associated with these best fit values are the density profiles (fig. 7a) and CLW data (7b).

Figure 8 shows the TB constrained retrieved profiles of N_0 and D_0, with the derived precipitation rate (c) compared to a Z_{35}-R rate from Noh and Liu (2005) in panel (d).

Figure 3: Observed Radar reflectivities at (a) Ku-band (13.4 GHz) and (b) Ka-band (35.6 GHz). Co-located MIR passive observations at (c) 183+/-1,3,7 GHz and (d) 89, 150, 220, 340 GHz.

Figure 4: Example 1-D snow profile: (a) observed reflectivities (smoothed), (b) DWR, (c-d) retrieved N0 and D0 given a fixed linear particle density profile.

Figure 5: Range of unconstrained DWR-only retrievals (colors), black lines indicate the 20 best TB constrained quantities.

Figure 6: Observed and best-fit simulated TBs at (a) 89 GHz, (b) 150 GHz, and (c) 220 GHz. Panel (d) shows the TB RMSE [K].

Figure 7: (a) Particle densities providing "best fit" TB values, (b) Cloud liquid water content and distribution

Figure 8: (a) D0, (b) N0, (c) R (liq. Equiv.), (d) Z_{35}-R relationship (Noh & Liu, 2005).

Selected References:
Meneghini, R., H. Kumagai, J. Wang, T. Iguchi, and T. Kozu, 1997: Microphysical Retrievals over Stratiform Rain Using Measurements from an Airborne Dual-Wavelength Radar-Radiometer. IEEE Trans. Geosci. Rem. Sens., 35(3), 487– 506.
Petty, G. W., 2001: Physical and microwave radiative properties of precipitating clouds. Part I: Principal component analysis of observed multichannel microwave radiances in tropical stratiform rainfall. J. Appl. Meteorol., 40(12), 2105–2114.

Discussion and Conclusions

- The DWR retrieval method is ill-posed, requiring additional constraints
- Passive microwave TBs provide an additional constraint, but is more sensitive to environmental parameters (WV, CLW, SST, Wind Speed)
- Particle densities vary over a fairly wide range from scan-to-scan, also the TB constraint is less sensitive to particle density in optically dense clouds
- Additional validation data is needed from other field campaigns to assess the global applicability of the present retrieved microphysical properties
- Sensitivity analyses (not shown here) indicate that the largest sources of uncertainty in the retrieval arises from the noise term in the reflectivities (+/-1 dBZ at Ku and +/-2 dBZ at Ka).
- Current Work: realistic particle shapes (DDA), rainfall case w/ melting layer
- Future Work: over-land algorithm, GPM geometry/field of view considerations, robust error analysis (optimal estimation?)

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