DPR algorithm development status

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Increase of interest in DF radar algorithms

- Necessity of simultaneous measurements of precipitation, clouds, etc. with multiple radars and/or lidars.
  - cloud radar and lidar for cloud and aerosol measurements
  - wind profiler (VHF, P, L) and cloud radar (Ka, W) for precipitation measurements.
  - DF radar (X/Ku and Ka/W) for airborne precipitation measurements.
Groups/people interested in DF algorithms for spaceborne radar

• Japan
  – NICT (Iguchi, Takahashi, et al.)
    • CRL DF radar (X+Ka), (Windprofiler+Ku+W)
  – Nagoya U (Nakamura, et al.)
  – Shimane U (Kozu, et al.)
  – NIED (Iwanami, et al.)
    • Windprofiler+Ka+W

• US
  – NASA/GSFC (Meneghini, et al.)
    • EDOP (X) + Cloud radar (W)
  – JPL (Haddad, Durden, Meagher, et al.)
    • PR2 (Ku + Ka)
  – CSU (Rose, Chandrasekhar)

• Europe
Dual Frequency Precipitation Radar

Measure 3-D structure of rain as TRMM, but with better sensitivity
Accumulate climatological precipitation data continuously since TRMM

**Improve estimation accuracy with dual-frequency radar**

- Identification of hydrometeor type
- Estimation of one or two DSD parameters at each range bin

- Discrimination between snow and rain by attenuation difference
- Higher sensitivity at higher frequency
- Accurate rain estimation based on attenuation difference
- Detection limit in 35GHz channel
- Detection limit in 14GHz channel
Applicable Range of DF Algorithm

DF algorithm applicable in regions 2, 3, and 4.

- **Region 0**: No signal. Nothing can be done.
- **Region 1**: Snow, Ka only. Use $Z(Ka) - R$ relationship. No attention correction needed.
- **Region 2**: Snow, Ku and Ka. Use DF algo for snow. Attention by WV, CW.
- **Region 3**: Mixed, Ku and Ka. Use DF algo for mixed rain. Needs int. value at r3b or r3t.
- **Region 4**: Rain, Ku and Ka. Use DF algo for rain. Needs int. value at r4b or r4t.
- **Region 5**: Rain, Ku only. Use Ku SF algo for rain. Needs init. value at r5b or r5t.
- **Region 6**: Surface clutter. Use a model profile.

Applicable Range of DF Algorithm

- **Height**
- **Radar Reflectivity Factor**
  - **Region 0**: No signal
  - **Region 1**: Snow, Ka only
  - **Region 2**: Snow, Ku and Ka
  - **Region 3**: Mixed, Ku and Ka
  - **Region 4**: Rain, Ku and Ka
  - **Region 5**: Rain, Ku only
  - **Region 6**: Surface clutter

- **Noise level in 35GHz channel**
- **Noise level in 14GHz channel**

Ku Ze
Ku Zm (without noise)
Ku Zm (with noise)
Ka Ze
Ka Zm (without noise)
Ka Zm (with noise)

SRT gives attention at r6b.
Region 5 appears only when Ka attention is large.
Need for combining different algorithms

• Depending on the height,
  – the available information and the number of unknowns are different,
  – we need to use different DSD models (single-parameter or dual-parameter model),
  – the validity of assumptions are different,
• We need to combine retrieval algorithms with single- and dual-parameter DSD models.
  – The solutions must be continuous and consistent at the boundaries.
• We need to maximize the use of available information.
Dual Frequency Algorithms

• Difference between attenuation differences at two frequencies over a certain path (DAD-method)
  – $k$-$R$ relationship, path-averaged rain rate
  – independent of calibration
  – needs significant attenuation
  – assumes $Z_{e1}(r_1)/Z_{e2}(r_1)=Z_{e1}(r_2)/Z_{e2}(r_2)$

• Two independent measurements at each range bin (Ze-ratio method, RM method)
  – Estimate two DSD parameters at each range bin
    • Rainfall rate, precipitation water content
  – Needs initial conditions (e.g., surface reference)

• Other methods (e.g., DFHB-method)
  – E.g., combination of single frequency methods
Basic Idea of Meneghini’s DF Algorithm

• $2N$ observables ($Z_m$ at 2 freq.) to estimate RR at $N$ range gates.
  – If the relations among $Z, R$ and $k$ were constant, $R$ would be overdetermined. In fact, $Z, R$ and $k$ are functions of many parameters (DSD, phase, shape, temp., vertical air velocity, non-uniformity, etc.)

• Parameterize DSD with two variables.
  – E.g., $N_0$ and $D_0, N_0^*$ and $D_0$

• Estimate these two parameters at each gate.
  – $2N$ estimates from $2N$ observables

• All other parameters are fixed.
  – E.g. shape parameter in DSD, phase, temp, etc.

• Calculate $R$ with the estimated parameters.

• Needs 2 initial conditions
  – e.g., 2 PIA's, 2 $\Delta\sigma^0$'s (SRT), attenuations at the rain top, etc.
Combined H-B (DFHB) Method

- Hitschfeld-Bordan method applied to both bands of data.
  - **single-parameter DSD model**
    - Assume \( k_1 = \alpha_1 Z_{e1}^{\beta_1} \), \( k_2 = \alpha_2 Z_{e2}^{\beta_2} \), \( R_1 = a_1 Z_{e1}^{b_1} \), \( R_2 = a_2 Z_{e2}^{b_2} \)
  - \( 2N \) data to estimate \( N+2 \) unknowns (\( R, A_{b1}, A_{b2} \))

- Constraint: RR estimates at two channels must be the same.

\[
R_1(r; A_{b1}) = a_1 \frac{Z_{m1}^{b_1}(r)}{[A_{b1}^{\beta_1} - q\beta_1 \alpha_1 \int_{r_b}^r Z_{m1}^{\beta_1}(s) \, ds]^{b_1/\beta_1}}
\]

\[
R_2(r; A_{b2}) = a_2 \frac{Z_{m2}^{b_2}(r)}{[A_{b2}^{\beta_2} - q\beta_2 \alpha_2 \int_{r_b}^r Z_{m2}^{\beta_2}(s) \, ds]^{b_2/\beta_2}}
\]

- Minimize

\[
\int \left( \frac{R_1(s; A_{b1}) - R_2(s; A_{b2})}{R_1(s; A_{b1}) + R_2(s; A_{b2})} \right)^2 \, ds
\]

- Can estimate the unknown attenuations (\( A_{b1}, A_{b2} \)) to the boundary.
- Initial conditions (e.g., surface reference) not required.
- Applicable to any interval as long as attn. is significant.
- Performance depends on the assumed DSD model.
Once a two-parameter DSD model is selected, a Ze-R relation defines a relation between the two parameters (e.g. $N_0$ and $D_m$).

DF algorithms (e.g., RM method) without any constraint may give a(n) (unrealistic) solution outside the hatched region.

Some mechanism that limits the solutions within a reasonable bounds should be devised.

SF algorithms based on the Ze-R (or k-Ze) relation always give a solution in a realistic domain.
Error Analysis by C. Rose

\[ Y = f(X_1, X_2, \ldots, X_k) \]

\[ V = \sum_{i=1}^{k} V_i + \sum_{i}^{k} \sum_{j>i}^{k} V_{ij} + \ldots + V_{12\ldots k} \]

\[ \sum_{i=1}^{k} S_i + \sum_{i}^{k} \sum_{j>i}^{k} S_{ij} + \ldots + S_{12\ldots k} = 1 \]

SF algorithm

\[ R(r) = f(Z_m, \alpha, \beta, a, b, \Delta \sigma^0) \]

\[ R(r) = a \ Z_e^b (r) \]

\[ k(r) = \alpha \ Z_e^\beta (r) \]

DF algorithm

\[ R(r) = f\left(Z_{m1}, Z_{m2}\right) \]
Summary (1/2)

• Major uncertainties (DSD and calibration (attenuation to the first range gate)) in SF algorithm can be reduced with DF algorithms.
  – DF algorithm (RM method) can estimate two DSD parameters at each range bin.
  – DF algorithms may mitigate the issue with unreliable PIA, and unknown attenuation by CLW, H2O, BB, etc.
    • some attenuation can be estimated if the DSD model is constrained.
  – DFHB method can estimate the attenuation to the first range gate (DSD model with a single parameter is assumed. Needs enough attenuation over a path).

• Combination of single- and double-parameter DSD models is unavoidable.
  – Combination of different algorithms
    • Optimum weights and combination among $Z_m(Ku)$, $Z_m(Ka)$, SRT(Ka) and SRT(Ku) depend on region, height, rain rate, etc.
Summary (2/2)

• Even with DPR, we need to assume some profiles.
  – attenuation profile due to WV and Cloud
  – rain profile between the surface and the lowest data point
  – Models and GV measurements are of great value.

• Attenuation correction, DSD parameter retrievals, beam mismatching effect, and **NUBF corrections** are all entangled.
  – How to disentangle each effect is a challenge.
  – Denser samples of KaPR (than KuPR or TRMM PR) will provide better information of inhomogeneity, but its degree is yet to be examined.
  – More simulation studies are required to evaluate each effect and to reveal how they are coupled.

• More probabilistic or deterministic constraints from other data or models will help reduce the estimation error.
  – However, use of other data sources makes the validation of the algorithm more difficult. (better to keep at least one algorithm that is independent of the consensus algorithm.)
Future Issues and tasks

• Evaluate the errors in available information.
• Need to agree on how to use and combine all available information.
  – continuous or discrete parameter model
    • rain type classification, ice particle model, etc.
    • to what extent do we adopt Bayesian statistical method.
• Need to evaluate the performance by testing with simulated data which are created based on
  – airborne data (PR-2)
    • realistic data but with many unknown parameters (e.g., clouds)
  – model data
    • all parameters are available but many of them are calculated with unrealistic assumptions
  – purely synthetic data
    • can create any (unrealistic) extreme cases.