UNCERTAINTIES IN PRODUCTS DERIVED FROM RADAR

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Uncertainty in Radar Retrievals, Model Parameterizations, Assimilated Data and In-situ Observations: Implications for the Predictability of Weather
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Layout of the talk

• Polarimetric microphysical retrievals in rain

• Polarimetric microphysical retrievals in ice / snow

• Multifrequency polarimetric radar retrievals
Two possible ways to optimize microphysical parameterization of NWP models

• Radar microphysical retrievals
• Forward radar operators

Two sources of errors in radar microphysical retrievals

• Errors due to natural variability of microphysical properties of hydrometeors
• Radar measurement errors
Polarimetric microphysical retrievals in rain
Estimation of liquid water content (LWC)
Estimation of rain rate (R)  
S band

- The estimates of LWC and R from specific attenuation $A$ are much less affected by the DSD variability than the $Z$- or $K_{dp}$-based estimates.
- The $A$-based estimates are immune to radar miscalibration, attenuation, partial beam blockage, and impact of wet radome.
- Cloud modeling community should utilize specific attenuation for estimation of LWC and R following its successful use for the WSR-88D QPE. $R(A)$ and $LWC(A)$ can be made a routine products on the WSR-88D network.
The accuracy of the LWC estimate is a function of LWC varying between 15 and 25% for lower LWC and not exceeding 40% for larger LWC.

- The accuracy of the LWC(A) estimator is 4 – 5 times better than the one for the R(Z) estimator for lower LWC.
Estimation of the median diameter of raindrops $D_0$

- Differential reflectivity $Z_{DR}$ is commonly used for estimation of $D_0$.
- FSD of the estimate related to the DSD variability is 10 – 12 %.
- Measurement errors of $Z_{DR}$ (as low as 0.1 – 0.2 dB) may produce much larger impact on the accuracy of the $D_0$ estimate than the DSD variability, especially for lower values of $D_0$.
- Combined use $Z$ and $A$ may offer a very attractive alternative to the $Z_{DR}$ – based estimator. This requires further exploration.
Polarimetric microphysical retrievals in ice / snow
Ice microphysical retrievals

- All existing ice microphysical retrievals are based on the use of radar reflectivity $Z$ measured at a single or multiple radar frequencies.

- The $IWC(Z)$ relations are notoriously inaccurate because they are strongly parameterized by (a) mass-weighted diameter $D_m$, (b) total concentration $N_t$, and (c) density (or degree of riming).

$$N(D) = N_{0s} \exp(-\Lambda_s D) \quad \rho(D) = \alpha D^{-1} \quad \Lambda_s = 4 / D_m$$

$$IWC = 3.81 \times 10^{-4} \alpha^{-0.2} N_{0s}^{0.4} Z^{0.6} \quad IWC = 3.09 \times 10^{-3} \frac{Z}{\alpha D_m^2}$$

- $D_m$ varies 2 orders of magnitude
- $N_t$ varies 4 orders of magnitude
- $\alpha$ changes at least by a factor of 4
Variability of the intercept in the IWC(Z) power-law relation as a function of $N_{0s}$ (Bukovcic et al. 2018)

Disdrometer snow measurements in Oklahoma
Basic formulas for polarimetric ice retrievals

\[
Z = \frac{|K_i|^2}{|K_w|^2} \frac{1}{\rho_i^2} \int \rho_s^2 (D) D^6 N(D) dD
\]

\[
K_{DP} = \frac{0.27 \pi}{\lambda \rho_i^2} \left( \frac{\varepsilon_i - 1}{\varepsilon_i + 2} \right)^2 \int F_{\text{shape}} F_{\text{orient}} \rho_s^2 (D) D^3 N(D) dD
\]

*Z is proportional to the 4th moment of snow SD whereas*  
*K_{DP} is proportional to its 1st moment*

**Exponential size distribution**

\[
Z = 5.30 \times 10^{-3} \alpha^2 N_{0s} D_m^5
\]

\[
K_{DP} = 1.02 \times 10^{-2} F_{\text{shape}} F_{\text{orient}} \frac{\alpha^2 N_{0s}}{\lambda} D_m^2
\]

\[
\frac{Z}{K_{DP} \lambda} = 0.520 \frac{D_m^3}{F_{\text{shape}} F_{\text{orient}}}
\]
Median volume diameter as a function of $[Z/(K_{DP}\lambda)]^{1/3}$

The width of the canting angle distribution $\sigma$ in ice typically varies between 10° and 40°. This is a serious source of uncertainty.

$$\sigma = \frac{180}{\pi} \frac{L_{dr}^{1/2}}{(1 + Z_{dr}^{-1} - 2\rho_{hv}Z_{dr}^{-1/2})^{1/2}}$$
Utilization of the $Z_{DP}/K_{DP}$ ratio for estimation of $D_m$

$Z_{DP} = Z_h - Z_v$

$$h = cL^d$$

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<th>c</th>
<th>d</th>
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<td>1. Hollow bullets (L &gt; 0.3 mm)</td>
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<td>1. Elementary needles</td>
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<td>0.611</td>
</tr>
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</table>

$D_m = -0.1 + 2.0 \eta$

$$\eta = \left( \frac{Z_{DP}}{K_{DP} \lambda} \right)^{1/2}$$

$$\gamma = \alpha D_m^2 \approx 0.78 \eta^2 = 0.78 \frac{Z_{DP}}{K_{DP} \lambda}$$

$$\log(N_t) = 0.1Z(dBZ) - 2 \log(\gamma) - 1.33$$

$IWC \approx 4.010^{-2} \frac{K_{DP} \lambda}{1 - Z^{-1}}$

The $Z_{DP}/K_{DP}$ ratio provides estimate of $D_m$ which is immune to the particles shape and orientation.
Sensitivity to the microphysical variability of ice hydrometeors

- The suggested estimates of IWC and $D_m$ are not sensitive to the variability of number concentration.
- The suggested relations have been optimized for exponential size distribution of ice, hence they may need to be adjusted for gamma SD (particularly for negative shape factor $\mu$).
- The FSD of the IWC and $D_m$ estimates is within 20% if $-1 < \mu < 1$.
- IWC tends to be overestimated and $D_m$ - underestimated for $\mu < -1$.
- The $D_m(K_{DP},Z)$ estimate is immune to the variations of ice density (or $m$ – $D$ relations) but is sensitive to the shape and orientations of ice particles.
- The $D_m(K_{DP},Z_{DP})$ relation is immune to the variability of shapes and orientations but is sensitive to ice density (or degree of riming).
General dependencies of the shape factor $\mu$

- Factor $\mu$ tends to be negative as a result of aggregation
- Average factor $\mu$ is close to 0 (exponential SD) within the DGL
The impact of measurements errors of $K_{DP}$ and $Z_{DR}$ ($Z_{DP}$)

- Statistical errors of the point measurements of $K_{DP}$ and $Z_{DR}$ are prohibitively large. SD($D_m$) > 70% if $K_{DP} < 0.05$ deg/km; SD($D_m$) > 25% if $Z_{DR} < 0.2$ dB
- Aggressive spatial averaging of $K_{DP}$ and $Z_{DR}$ is required to obtain their meaningful values which is inevitably results in the degradation of spatial resolution
- Various techniques for processing and presentation of polarimetric radar data have been developed recently (QVP, range-defined QVP, CVP, 4D-grid) to reveal polarimetric signatures in ice / snow, to reduce statistical errors in polarimetric radar variables, and improve their vertical resolution
- The best results are achieved in the dendritic growth layer and the worst are just above the freezing level where $K_{DP}$ and $Z_{DR}$ signatures almost vanish as a result of strong aggregation of dry snowflakes
QVP example for stratiform rain
QVP example for snow
Midlatitude vs. Tropical MCSs

\(D_m: \text{Midlatitude}\)

\(D_m: \text{Tropical}\)
Midlatitude vs. Tropical MCSs

log(N): Midlatitude

log(N): Tropical

(a) [Image of log(N) for Midlatitude]

(b) [Image of log(N) for Midlatitude]

(c) [Image of log(N) for Midlatitude]

(d) [Image of log(N) for Tropical]

(e) [Image of log(N) for Tropical]

(f) [Image of log(N) for Tropical]
Dual-frequency polarimetric radar measurements with Ka-band and S-band radars

Courtesy of Pavlos Kollias and Mariko Oue

KASPR

WSR-88D

SBU – Stony Brook University

KASPR – Ka-band scanning polarimetric radar
KOKX and KASPR Kdps are almost perfectly matched.
The difference between \(Z(Ka)\) and \(Z(S)\) are related to (1) resonance scattering, (2) attenuation, and (3) differences in sensitivities and sampling volumes.
Comparison of Z and Kdp measured by KASPR and KOKX at 1 km altitude

The dual-wavelength ratio is high when large snow aggregates are measured by the Parsivel disdrometer - Mie scattering
Dual-frequency polarimetric radar measurements from satellite and ground-based radars (Matrosov 2018)

CloudSat
W band

WSR-88D
S band

KDLH
Conclusions

• The quality of microphysical retrievals can be significantly improved if multiparameter (particularly polarimetric) radar measurements are used instead of a sole reflectivity factor.
• It is strongly recommended to use specific attenuation A for microphysical retrievals in rain.
• Novel polarimetric algorithms for microphysical retrievals in ice/snow show great promise and outperform conventional techniques based on reflectivity.
• Recently developed techniques for processing and displaying polarimetric radar variables (e.g., QVP) allow to recognize “fingerprints” of individual microphysical processes and to improve the quality of radar estimates and retrievals.
• The network of WSR-88D radars provides tremendous resource for cloud modelers, particularly if complemented with higher-frequency cloud radars operated on the ground or from space.