Integrated Framework for Retrievals in a Networked Radar Environment and Error Characterization of Retrievals

V. Chandrasekar1, Joseph C. Hardin2, Haonan Chen1, Michael P. Jensen2
1Colorado State University, 2Brookhaven National Laboratory

ABSTRACT

The Mid-Latitude Continental Convective Clouds Experiment (MC3E) (Jensen, et al., 2011), was a joint DOE Atmospheric Radiation Measurement (ARM) and NASA Global Precipitation Measurements (GPM) field campaign that took place from April - June 2011 in Central Oklahoma centered at the ARM Southern Great Plains site. The experiment was a collaborative effort between the U.S. Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) Climate Research Facility and the National Aeronautics and Space Administration (NASA) Global Precipitation Measurement (GPM) mission Ground Validation (GV) program. The field campaign involved a large suite of observing infrastructure currently available in the central United States, combined with an extensive sounding array, remote sensing and in-situ aircraft observatories, NASA GPM ground validation remote sensors, and new ARM instrumentation. This paper presents a comprehensive integrated retrieval methodology to obtain microphysical retrieval such as the drop size distribution for the complete MC3E network, for the ARM multi frequency radar systems.

Mid-Latitude Continental Convective Clouds Experiment

The Mid-Latitude Continental Convective Clouds Experiment was a multi-agency field campaign in northern Oklahoma during Summer 2011 with an emphasis on studying convective cloud activity at multiple scales. The campaign included multiple radars with overlapping fields of views as well as several other instruments. Shown in Fig. 1 is the layout of some of the primary instruments. In this coverage field are also several disdrometers that give us measurements of the drop shape distributions at ground level.

Radar Measurements: Governing Equations

The transformation of the covariance matrix $\mathbf{S}_y$ to the covariance matrix of the intrinsic field $\mathbf{S}_x$ takes the form

$$\mathbf{S}_x = \mathbf{F}^\top \mathbf{S}_y \mathbf{F}$$

By maximizing this distribution we get not only the optimal underlying field, we also get the likelihood of any other set of measurements allowing a more comprehensive error analysis on the returned parameters. In addition this framework allows us to incorporate different radar frequencies, as well as entire new instruments in a relatively straightforward manner.

### Network Formulation

Each radar is in a polar coordinate system. We can use the operator $\mathbf{T}$ to transform this to a Cartesian coordinate system giving us

$$\mathbf{p}(\mathbf{x}, \mathbf{y}) = N(\mathbf{x}, \mathbf{S}_x, \mathbf{S}_y)$$

where $\mathbf{x} = [\mathbf{X}_k, \Sigma_m]^\top$, and $\mathbf{S}_x = \mathbf{T} \mathbf{S}_y \mathbf{T}^\top$. A common choice of $\mathbf{T}$ operator is the nearest neighbor interpolation. While this step introduces errors related to gridding, it is necessary to integrate multiple radars to have them on a common coordinate system.

If we have a single frequency we can combine the distributions from each radar at each point in the Cartesian space by maximizing

$$p(\mathbf{x} | \mathbf{y}) = \prod_{k=1}^n p(\mathbf{x}_k | \mathbf{y})$$

for each of the $n$ radars. If we have multiple frequencies, we maximize

$$p(\mathbf{x} | \mathbf{y}) = \prod_{k=1}^n p(\mathbf{x}_k | \mathbf{y})$$

Over the entire set of $n$ radars. We incorporate the different frequencies both by the choice of the matrix $\mathbf{F}^*$, as well as in the covariance matrices in this step.

### Error Characterization

A critical and important step for error characterization is to have a formulation where all the errors can be accounted for. The sources of error can generally be divided into the following three categories:

- **Inaccuracies of Instrumental Precision (random error)**: Instrumental errors
- **Attenuation**: Beam Mismatch
- **Time Mismatch**: Instrumental errors
- **Transition Matrix**: Physical Assumption on Hydrometeors

### Hardware Errors

- Calibration errors represent a significant source of systematic bias in the retrieval process.
- Ideal calibration error: 1dBZ (Zdb) 0.2 dB (Zdr)
- In reality these can reach 3-5dBZ (Zdb) and 0.7dB (Zdr)
- This level of error can create 40%-60% error in the rainfall retrieval.

### Observation Errors

- **Beam Mismatch**: We are not measuring the same volume cells, so the measurements between two radar volumes is not 1-1.
- **Time Mismatch**: We are not guaranteed to see range cells at the exact same time.
- **Magnitude**: Notations T or T' are used to denote initial solution.

Algorithm Errors

Drop size distribution retrieval algorithm, and radar parameter estimation error, etc.

Example of error correlation structure.

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