State of 3D Convective Vertical Velocity Retrievals at the ARM Sites: Challenges, Uncertainties and Future Recommendations

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Introduction

The ARM fixed and mobile atmospheric observatories are heavily instrumented with active and passive remote sensors designed to provide 4D observations of clouds and precipitation. During the past 7-8 years, the ARM program has worked towards reliable radar-network based approaches for retrieving the 3D kinematic structure of convective clouds.

Dual- or multi-Doppler radar wind retrievals can provide spatial coverage and track storm evolution, but the retrievals still have large uncertainties owing to several sources of errors during radar data post processing (e.g., gridding, smoothing), selection of the parameters used in the minimization of the cost function (e.g., constraint, weight), and radar observation configurations and strategies (e.g., beam width, volume coverage pattern). These uncertainties are partially addressed by Observing System Simulation Experiments (OSSE) using WRF simulation and a radar simulator.

Application of Radar Forward Simulator

Cloud Resolving Model Radar SIMulator (CR-SIM)

Input

WRF simulation output

- MCS during MC3E (May 20, 2011), isolated convection in Houston (June 8, 2013)
- 500 m horizontal resolution
- 20-sec output
- Morrison 2-moment

Output

Radar observables

- Zhh, DV, SW, Zvv, Zdr, Kdp, Ah, Av, LDRh for each hydrometeor type, at each gridbox.
- Account for radar elevation angles

Convert simulated radar observables at WRF grid to CFRadial

- Account for scanning radar configurations and strategies
- MC3E case
  C-SAPR, X-SAPR, NEXRAD
- Houston case
  C-SAPR, DOW, NEXRAD

3DVAR wind retrieval

- First create Cartesian coordinate for each radar measurement
- Do 3DVAR wind retrievals for the following radar combinations:
  - MC3E case
    Set 1: C-SAPR and 2 NEXRAD radars, Set 2: 3 X-SAPRs
  - Houston case
    Set 1: C-SAPR and NEXRAD, Set 2: C-SAPR, DOW and NEXRAD

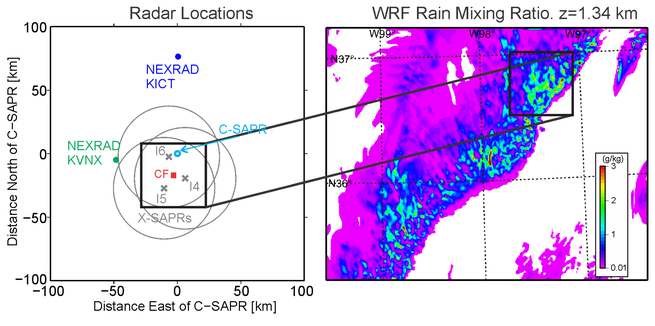
Compare simulated wind retrievals with WRF original wind

Investigate errors caused by:

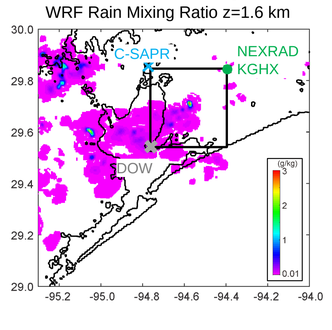
- 3DVAR algorithm
- Gridding (strength of smoothing)
- Radar characteristics (e.g., wavelength, beam width)
- Volume coverage pattern (VCP)
- Radar location
- Time to complete volume scan

Radar simulation settings

Mesoscale convective system (MC3E)



Isolated convection (Houston)

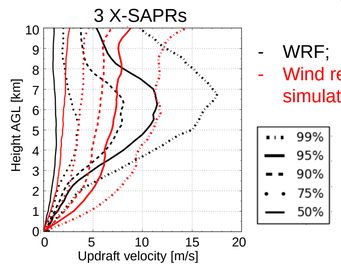


	NEXRAD	C-SAPR	X-SAPR, DOW
Beam width	0.93°	1.0°	1.0°
Range bin size	250 m	120 m	50-60 m
Azimuth spacing	0.5°	1.0°	1.0°
Maximum range	460 km	118 km	60 km
Elevation angles for PPI	14 angles (0.48,0.88,1.32,1.8,2.42,3.12,4.0,5.1,6.42,8.0,10.02,12.48,15.6,19.51°)	17 angles (0.75,1.2,1.9,2.6,3.5,4.4,5.3,6.4,7.8,9.6,11.7,14.3,17.5,21.4,26.1,33,42°)	22 angles (0.5,1.5,2.5,3.5,4.5,5.5,6.5,7.5,8.5,9.5,10.5,11.5,12.5,14,17,20,25,30,35,40,45,50°)
Scan rate	360°/20 sec	360°/20 sec	360°/20 sec (X-SAPR)

Results

Mesoscale convective system (MC3E)

Errors in observational retrievals



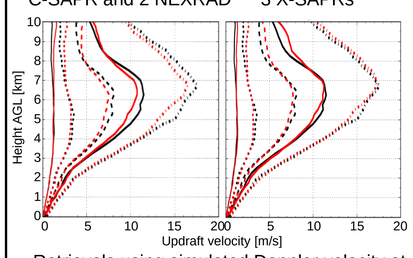
- WRF;
- Wind retrieval simulation

Retrievals using simulated 3 X-SAPR PPI measurements

Sources of the errors include:

- 3DVAR algorithm
- Time differences amongst PPI scans
- Gridding (e.g. smoothing strength)
- Radar characteristics (e.g. beam width)
- VCP (e.g., elevation angles, radar locations)
- Particle fall speed estimate

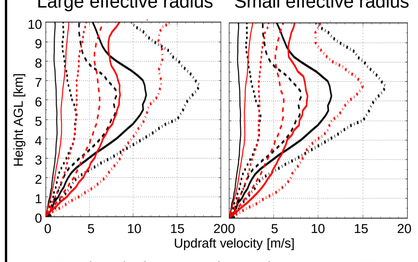
Errors from 3DVAR algorithm



Retrievals using simulated Doppler velocity at WRF grid (no resampling, smoothing, or gridding)

Uncertainty in the algorithm is small, as log as parameters used in the cost function and particle fall speeds are appropriately selected.

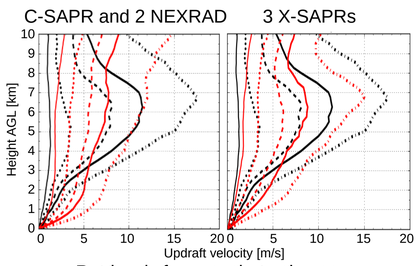
Errors from gridding process



Retrievals for snapshot using 3 X-SAPRs

Using strong smoothness (larger effective radius) can cause underestimation of larger updrafts.

Errors from time delays and VCP

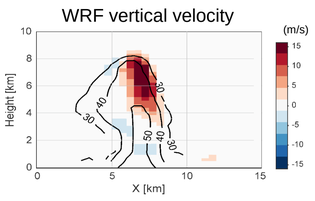


Retrievals for snapshot using same parameters as observation

The snapshot retrievals using 3 X-SAPRs can capture the peak at ~7 km altitude, but underestimate larger updrafts at 4-9 km altitudes.

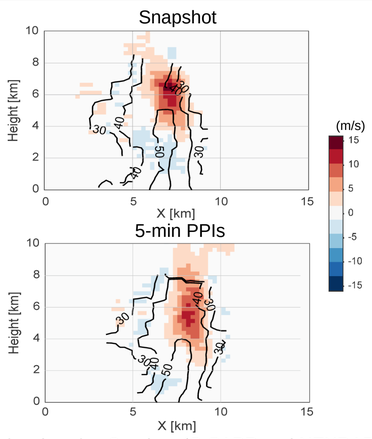
The retrieval using NEXRAD radars seems to be difficult to capture the peak. The difference between the two retrievals can be caused by locations of radars.

Isolated convective storm (Houston)



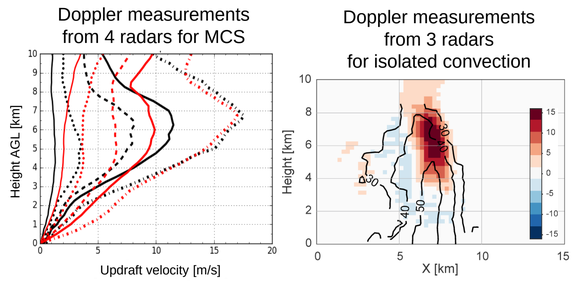
Contour: S-band reflectivity (dBZ)

- Time delay in PPI scans can cause underestimation of updrafts and tilted vertical structures of radar observables.
- Use of 2 radars may not enough to quantitatively capture the updraft core.



Retrievals using 2 radars (C-SAPR and NEXRAD)

Challenges and Recommendations



- Fast volume scans (< 1 min) by more than 2 radars (e.g., sector scans, phased array radars, DOW) at high spatial resolution can provide best performance for 3D vertical velocity retrievals.
- Reflectivity without attenuation (e.g., NEXRAD) should be used to estimate particle fall velocity.

Updates of CR-SIM

- Implement P3 microphysics option
- Accept RAMS and ICON model inputs and their microphysics
- Optimized for speed-up (e.g. using OpenMP)
- Implement automake configuration
- Latest packages are available at:
  - Web: https://www.bnl.gov/CMAS/cr-sim.php or
    https://you.stonybrook.edu/radar/research/radar-simulators/
  - CR-SIM: ftp://ftp.radar.bnl.gov/outgoing/moue/crsim/src/crsim-3.10.tar.gz
  - Scattering lookup tables: ftp://ftp.radar.bnl.gov/outgoing/moue/crsim/src/crsim3.1_LUTs.tar.gz
  - Documentation: ftp://ftp.radar.bnl.gov/outgoing/moue/crsim/docs/crsim-UserGuide-v3.1.pdf
  - Radar resampling: ftp://ftp.radar.bnl.gov/outgoing/moue/crsim/src/radar_filter_v1.2.tar.gz