From Model Output to Virtual Observation: Generation and Application

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Cloud Resolving Model Radar SIMulator (CR-SIM)

Cloud model data (e.g., WRF, DHARMA) with various microphysics scheme

- 2-moment (Morrison et al., 2005, 2009, Milbrandt and Yau, 2005a,b, and Thompson et al. 2007)
- The spectral bin microphysics (Fan et al., 2012)

CR-SIM

Radar (scanning/profiling) simulator

1) T-matrix scattering calculation
   - For cloud water, cloud ice, rain, snow, graupel and hail for each size.
   - A fixed orientation for every elevation angles (0° -90°)
   - 3, 5.5, 9.5, 35, and 94 GHz
2) Calculate particle size distributions according to a selected microphysics scheme for each model hydrometeor type
3) Resample data to radar coordinate **Update!**

Zhh, DV, SW, Zvv, Zdr, Kdp, Ah, Av, LDRh for each model hydrometeor type

Ceilometer simulator

1) Calculate droplet size distribution
2) Compute single particle extinction and backscattering cross sections for spherical droplets at a wavelength of 905 nm.
3) Estimate first cloud base height at each column

Backscatter (including attenuation), extinction, lidar ratio, first cloud base

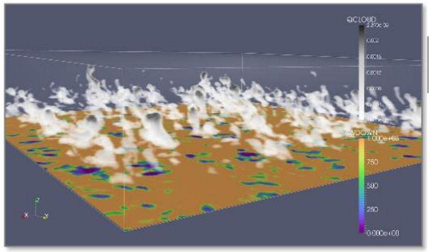
Micro Pulse Lidar (MPL) simulator — Update!

1) Calculate droplet and cloud ice size distributions
2) Compute particle extinction and backscattering cross sections for spherical droplets and ice at a wavelength of 353 or 532 nm.
3) Calibrate by aerosol and molecule backscattering

Backscatter (including attenuation), extinction, lidar ratio

CR-SIM Applications

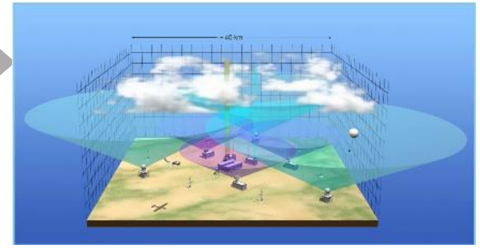
Cloud Model Output



CR-SIM

1

Virtual Observational Products



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Real Observational Data

1. Compare with the original model output to address potential uncertainties in observational products.
2. Compare with real observational product for LES evaluation.

Multi sensor product	Single radar product	Multi radar product
• Virtual ARSCL, MWR LWP	• Best estimates of cloud properties (cloud fraction) • Polarimetric observables	• 3DVAR Wind retrieval • Polarimetric observables

LASSO shallow convection

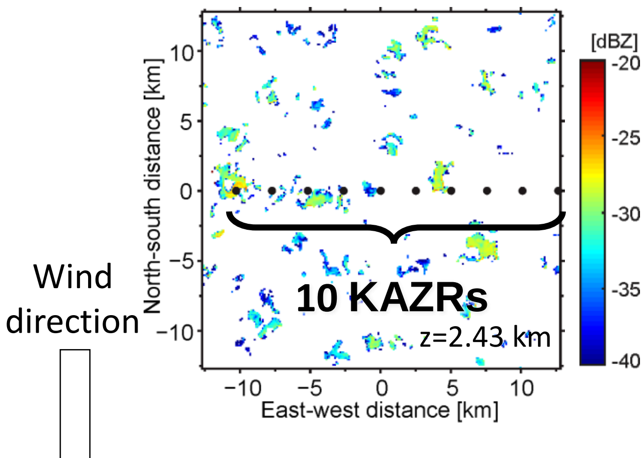
- Addressing observation uncertainties for cloud fraction
- Best estimates of cloud fraction
- Virtual ARSCL and Virtual MWR LWP

MC3E deep convection

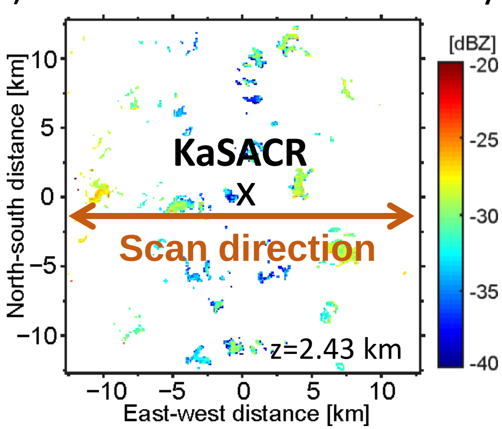
- Addressing observation uncertainties for wind retrieval

Cloud Fraction Using Single Profiling and Scanning Cloud Radars

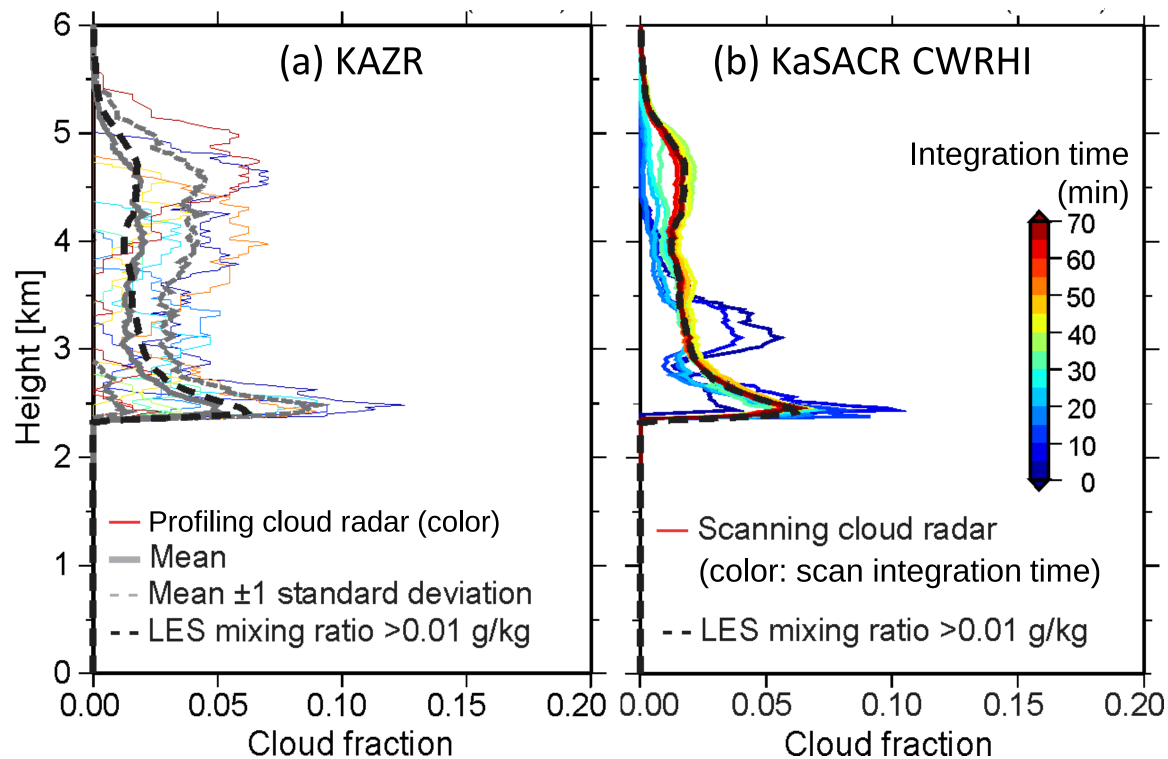
(a) KAZR Reflectivity



(b) KaSACR CWRHI Reflectivity



Domain-Averaged Cloud Fraction Profiles (CFPs)

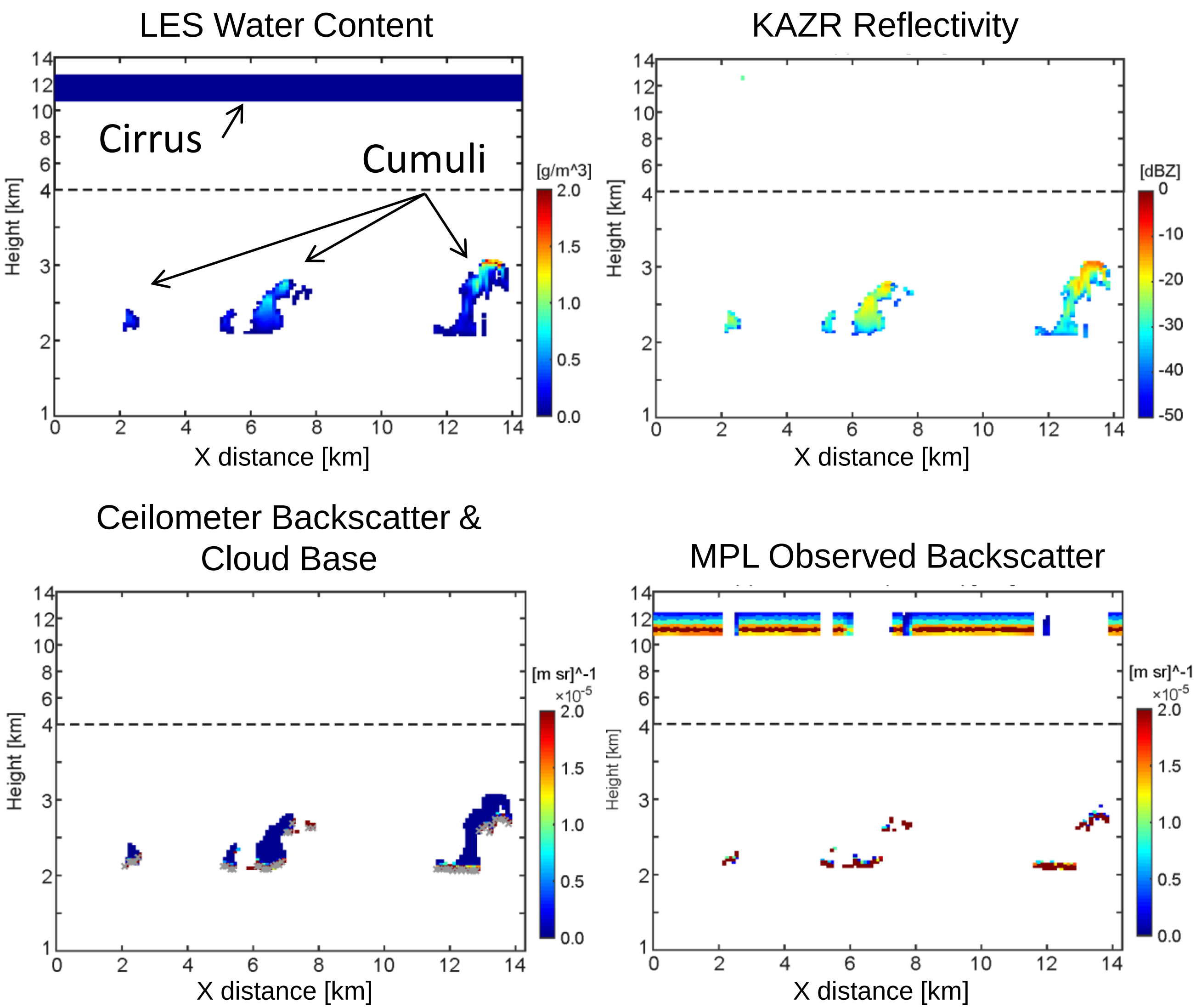


(a) Even 10 KAZR zenith pointing dwells cannot capture the domain averaged CFP.

(b) Estimate domain is optimized using reflectivity probability density at each height. 35 min or more CWRHI scans can capture the domain averaged CFP.

WRF LES for 2015/06/09 at SGP

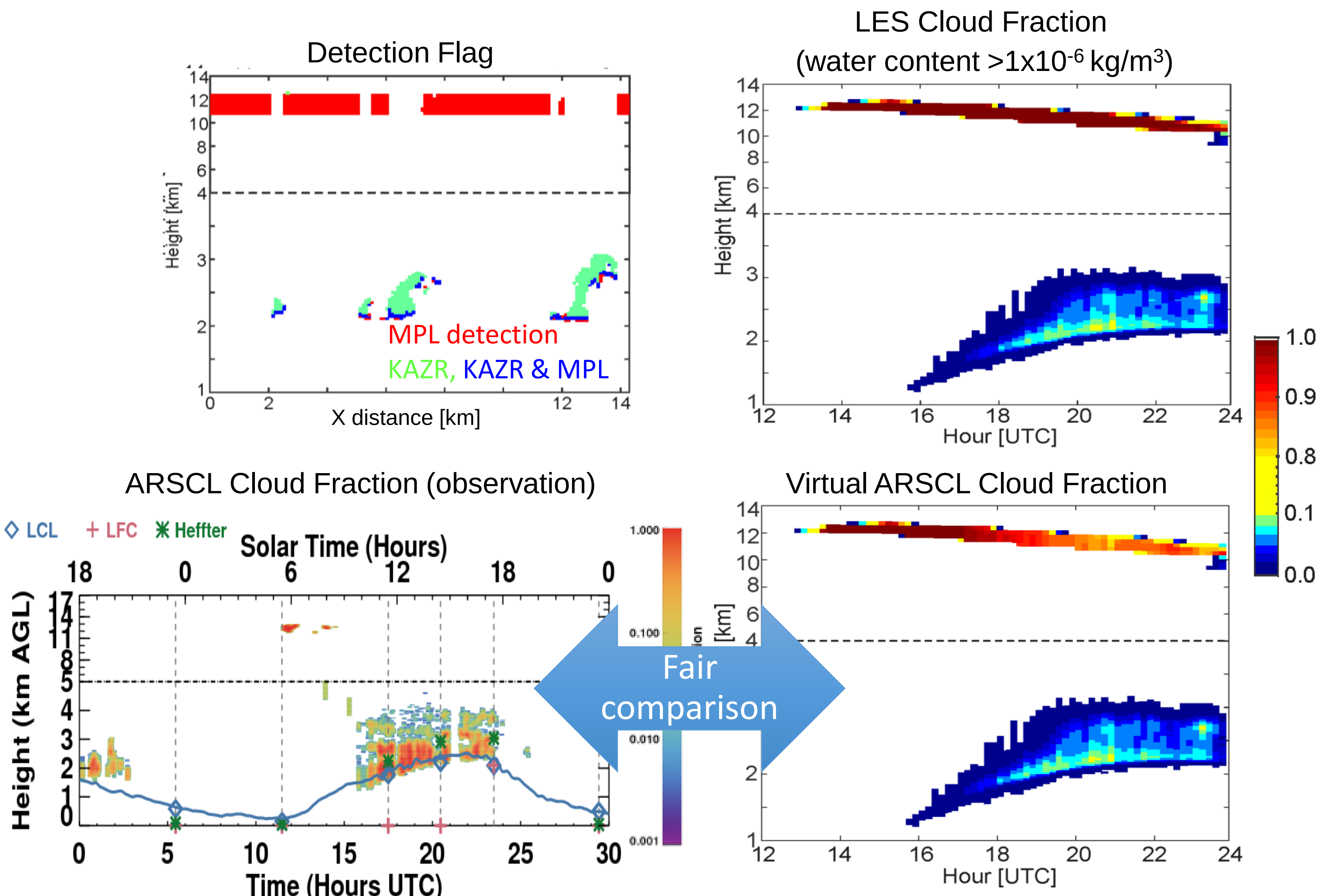
Virtual ARSCL from Multi Sensor Simulations



- KAZR can not detect cirrus clouds due to sensitivity issue.
- Ceilometer can well capture cloud base heights of cumulus convections.
- MPL can capture cumulus cloud bases and cirrus clouds, but not detect cirrus when cumulus cloud existed at lower altitudes due to attenuation.

LASSO LES for 2015/06/27 at SGP

Virtual ARSCL from Multi Sensor Simulations



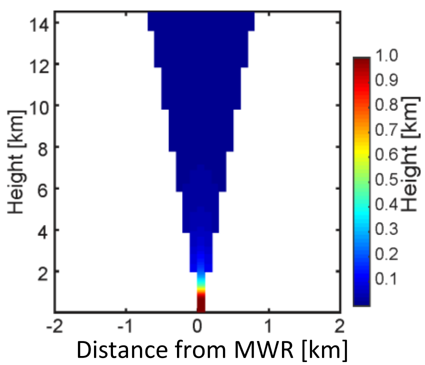
Virtual ARSCL cirrus cloud fraction decreased by ~20%.

LASSO LES for 2015/06/27 at SGP

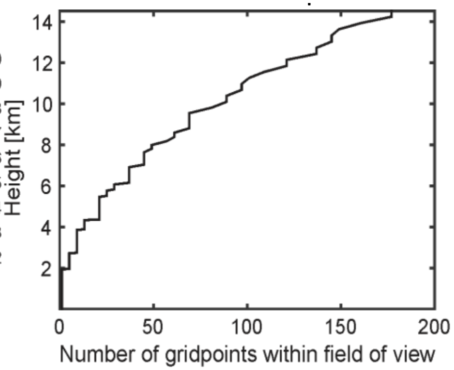
Virtual Microwave Radiometer LWP

Microwave radiometer (MWR) field of view: 5.9° (23 GHz channel)

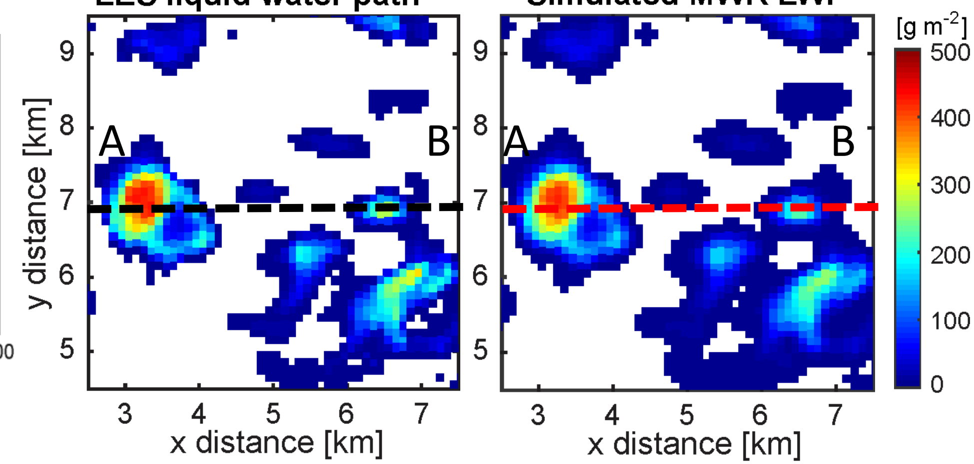
Gaussian Weighting



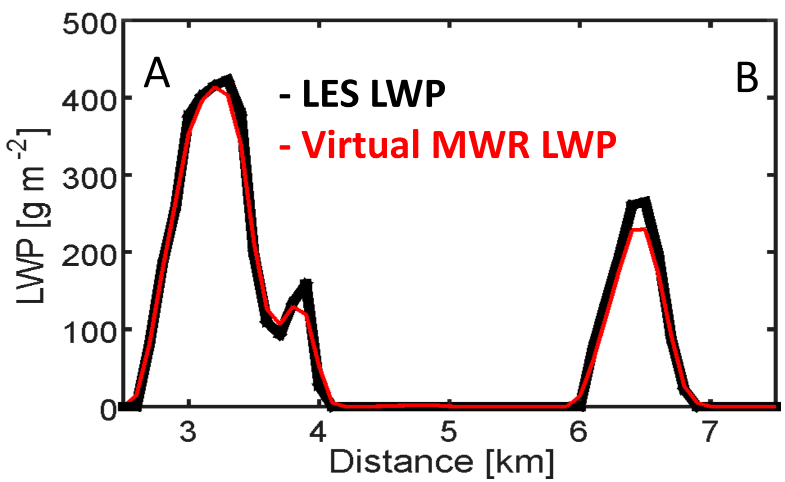
Number of Samples within Field of View



Liquid Water Path



LWP are distance-weighted averaged over the field of view of 5.9° using a Gaussian weighting.

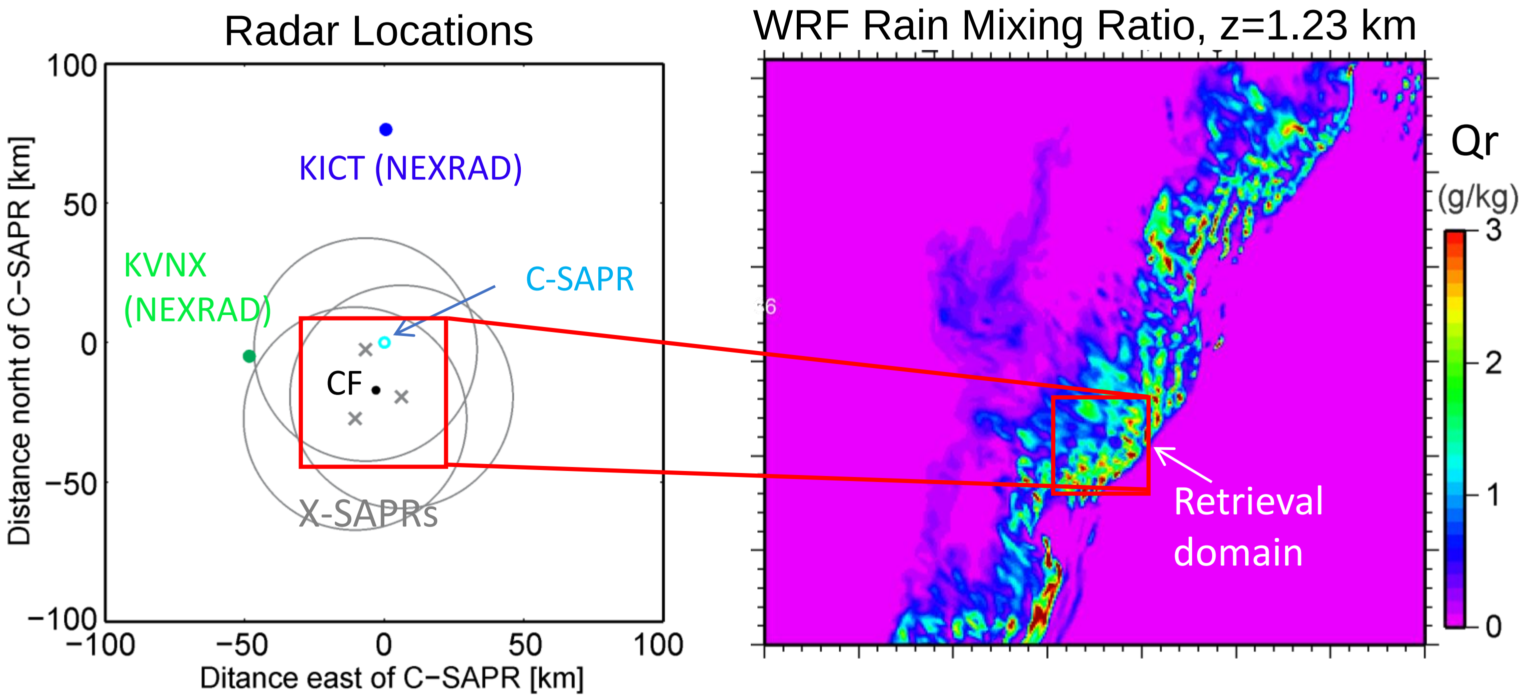


For larger-size clouds, MWR's field of view does not produce significant error in LES LWP evaluation.
For smaller-size clouds (<1-km diameter), MWR can over sample and underestimate peak values of LWP.

LASSO LES for 2015/06/27 at SGP

Multi Doppler Radar Wind Retrieval

WRF: MC3E of 2011/05/20 09:30:00, DX=DY=1 km
Radars: C-SAPR, NEXRAD, and X-SAPR
Radar grid resolutions: 250 m in horizontal and vertical
Method: Gridding each radar data from radar coordinate →3DVAR wind retrieval



Potential errors in:

- Smoothing and interpolation for gridding due to few observation points and/or large sampling volume.

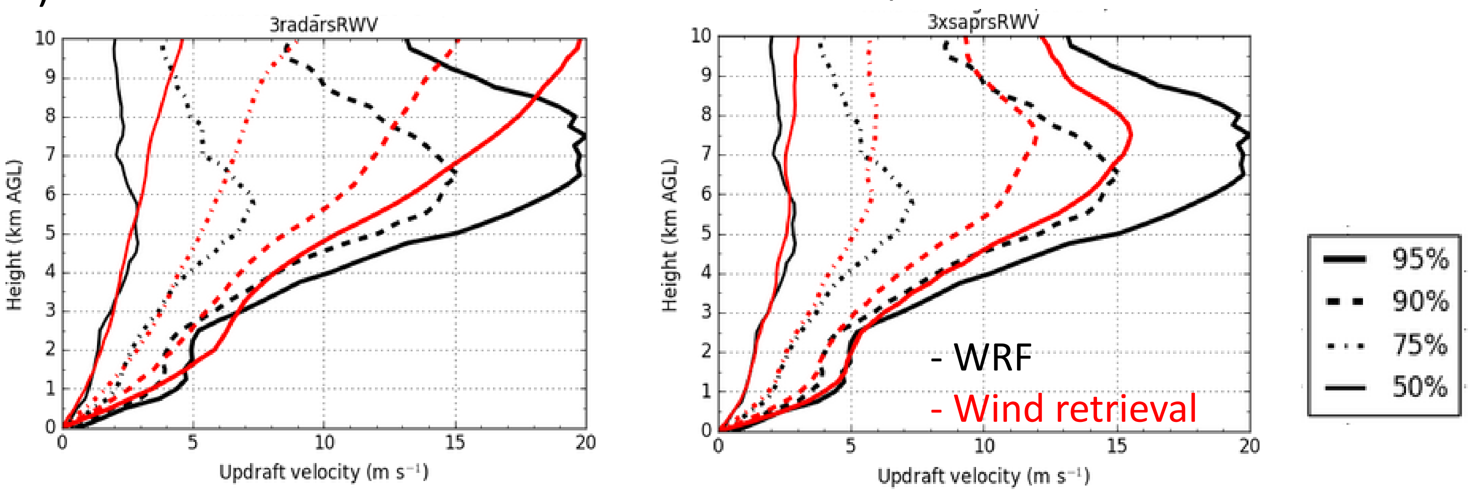
Assess potential observation errors in wind retrievals:

1) Use of C-SAPR and 2 NEXRAD radars
2) Use of 3 X-SAPRs

Multi Doppler Radar Wind Retrieval

PDF percentiles of updraft

1) C-SAPR and 2 NEXRAD radars 2) 3 X-SAPRs



- The uncertainty increases above 4 km altitude. Particularly, C-SAPR and NEXRAD retrieval can not resolve hook-like characteristics at ~7 km.
- Observations can be trusted quantitatively below 4-5 km altitude, but just qualitative characteristics can be trusted for upper levels.

- These uncertainties can be caused by:
  - Few observation points at high altitudes.
  - Larger radar sampling volume at higher altitudes.
  - Larger radial component of hydrometeor fall speed at higher altitudes (error in hydrometeor fall speed estimates can impact on retrievals).

Summary

- Virtual observational products were simulated from LES outputs using CR-SIM (e.g., Virtual-ARSCL, Virtual-MWR LWP, and Radar cloud fraction).
- The virtual observation products can be useful to address observation uncertainties.
  - Radar cloud fraction profiles (CFP)
    - KAZR zenith pointing dwells cannot capture the domain averaged CFP.
    - 35 min or more Ka-SACR CWRHI observations that use an optimized sampling strategy can much better capture the domain-averaged CFP.
  - Virtual ARSCL
    - Radar sensitivity and lidar attenuation can cause missing of cloud locations.
  - MWR LWP
    - MWR field of view can over sample and underestimate peak values for small size clouds.
  - Wind retrieval
    - Uncertainty increases with height above 4 km, because of errors in smoothing and gridding of radar data.
- The virtual observation products can help for evaluation of LES output with real observations.

Future Work

- Implement interfaces to various CRMs & different microphysics schemes
  - Predicted particle properties (P3) microphysics scheme (Morrison and Milbrandt, 2015)
  - RAMS with double moment (Walko et al., 1995; Meyers et al., 1997; Saleeby and Cotton, 2004; Saleeby and van den Heever, 2013)
  - SAM with double moment

- Code optimization to incorporate into real-time LES
- Latest packages are available at:
  - CR-SIM: ftp://ftp.radar.bnl.gov/outgoing/moue/crsim/src/crsim2.2.1_beta.tar.gz
  - Radar resampling: ftp://ftp.radar.bnl.gov/outgoing/moue/crsim/src/radar_filter_v1.2.tar.gz