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Southern Great Plains (SGP) Three-Dimensional Observations of Fair-Weather Cumuli Field Campaign Report

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Acronyms and Abbreviations

2D	two-dimensional
3D	three-dimensional
ARM	Atmospheric Radiation Measurement
CF	Central Facility
CM4	Coupling Mechanistically the Convective Motions and Cloud Macrophysics in a Climate Model
CMDV	Climate Model Development and Validation
DOE	U.S. Department of Energy
FWC	fair-weather cumuli
IOP	Intensive Operational Period
LES	large-eddy simulation
PCCP	Point Cloud of Cloud Points
PI	Principal Investigator
PPI	plan position indicator
RHI	range height indicator
SGP	Southern Great Plains
SGP3DOBS	Southern Great Plains Three-Dimensional Observations of Fair-Weather Cumuli

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1.0 Summary

The U.S. Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) user facility Southern Great Plains (SGP) Three-Dimensional (3D) Observations of Fair-Weather Cumuli (SGP3DOBS) experiment employed scanning Doppler lidar and the recently installed stereo camera ring to conduct a one-month intensive operational period (IOP) of fair-weather cumuli in a 3D domain at the ARM SGP Central Facility (CF). The SGP3DOBS is part of the Climate Model Development and Validation (CMDV) "Coupling Mechanistically the Convective Motions and Cloud Macrophysics in a Climate Model" (CM4) project and provides advanced observational analyses for improving physical understanding of shallow cumulus and supporting model parameterization evaluation. For the CM4 project, cloud macroscale and dynamical properties are determined using vertically pointing active remote-sensing measurements (e.g., lidar and radar), which provide a 2D view of fair-weather cumuli (FWC). It is critical to evaluate how well the 2D observations represent 3D cloud fields. The objectives of SGP3DOBS include: 1) evaluate the 3D gridded cloud field from stereo photogrammetry with scanning Doppler lidar measurements; 2) retrieve sub-cloud-layer turbulence (vertical velocity and mass flux) in a 3D domain; 3) estimate shallow cumulus lateral entrainment rate and its relation to environment conditions.

The SGP3DOBS IOP was held at the SGP Central Facility from August 31 to September 30, 2017, as the fair-weather nonprecipitating shallow cumuli are prevalent during summertime over land (Lamer and Kollias, 2015). A weather forecast team conducted a short-range forecast of weather conditions in the early morning each day to determine whether it was favorable for FWC. For each IOP day, the Doppler lidar at the SGP Central Facility ran under the range height indicator (RHI) scanning mode in the cross-wind direction. Occasionally, plan position indicator (PPI) scanning mode was run for updated wind directions. During each RHI scanning, the Doppler lidar run continuously between 30- and 150-degree elevation angles. The scanning rate was approximately 10 degree/s, corresponding to a transverse resolution of 111 m at 2 km of a typical FWC height. The newly established three pairs of stereo cameras ran concurrently during the IOP.

2.0 Results

During the one-month IOP, data were acquired for multiple shallow convection days including four golden FWC days: August 31 and September 10, 20, and 22. Some shallow cumuli were also observed on September 15, 18, and 21. The stereo cameras worked well except that one camera's fuse blew on September 15 and the ARM system failed to detect the data flow problem. Losing data on one camera does not have dramatic impacts on our comparisons since we are still able to do 3D reconstruction from the other two pairs.

Figure 1 shows a case of observed FWC with Doppler lidar cross-wind RHI scan on September 20, 2017. From the figure, several FWC were observed at the height of ~ 1.6 km above the ground. Continuous cross-wind RHI scans thus provide cloud field in a 3D domain.

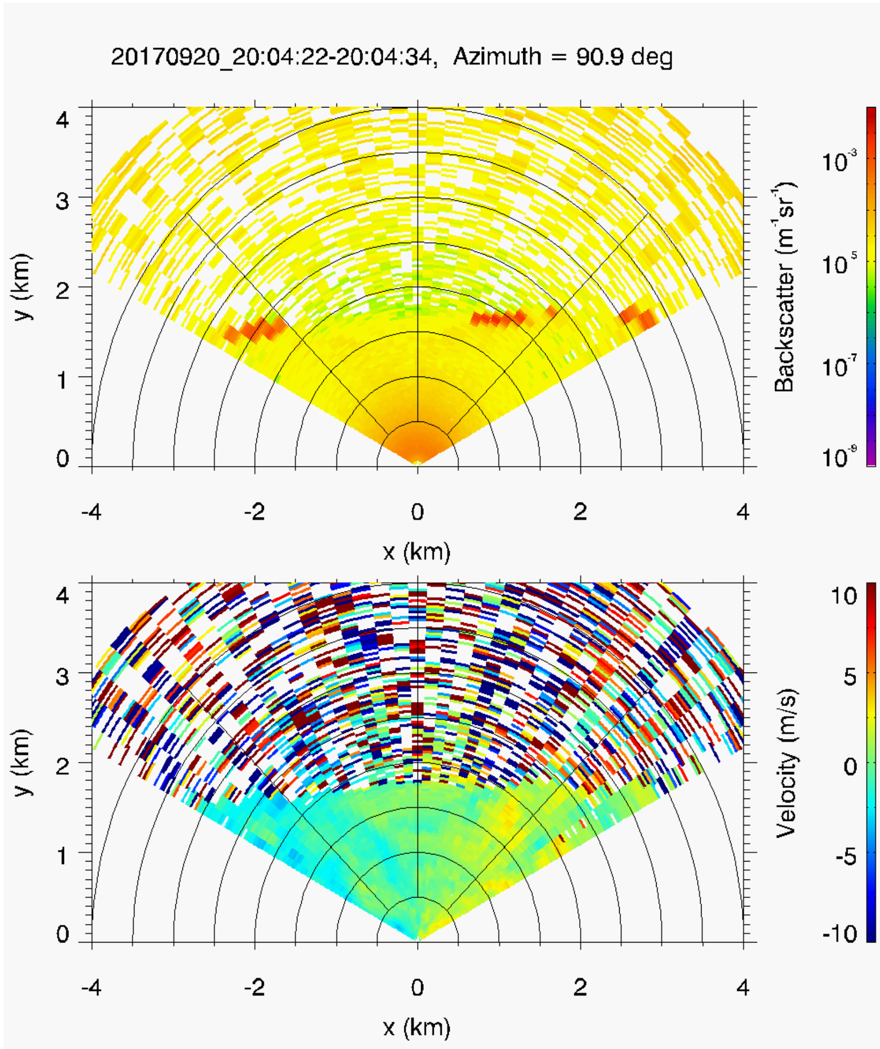

Figure 1. Observed FWC with Doppler lidar cross-wind RHI scan on September 20, 2017. Upper panel: Doppler lidar backscatter. Lower panel: Doppler lidar radial velocity.

After data were collected, cloud fields were retrieved from Doppler lidar measurements with methods described in Lamer and Kollias (2015). Figure 2 shows a case of FWC horizontal distributions observed with a 30-minute Doppler lidar cross-wind RHI scan on September 20, 2017.

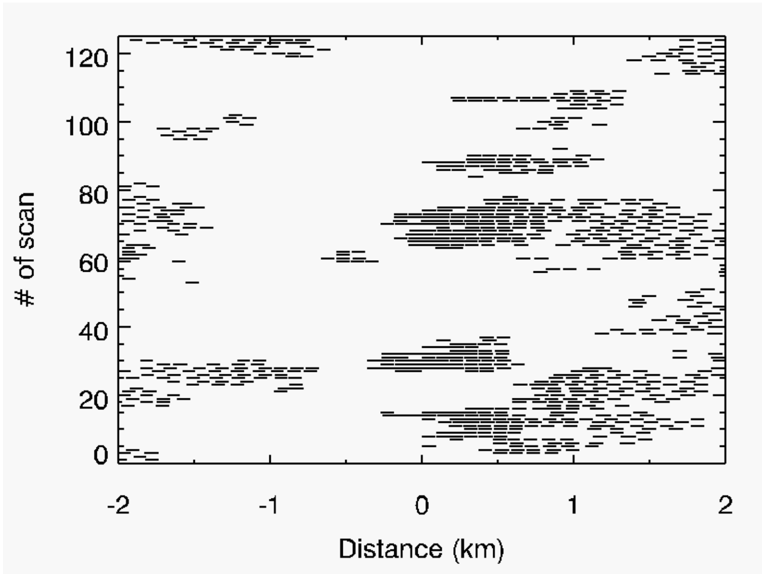

Figure 2. FWC horizontal distributions observed with Doppler lidar cross-wind RHI scan on September 20, 2017. The y axis is time in terms of the scan number, where each scan takes 12 s, so the plot represents 25 minutes of observing time.

The 3D gridded cloud field was retrieved from stereo photogrammetry using a method developed by Oktem and Romps (2015). Preliminary validation of Point Cloud of Cloud Points (PCCP) from stereo photogrammetry against scanning Doppler lidar during the SGP3DOBS IOP is shown in Figure 3.

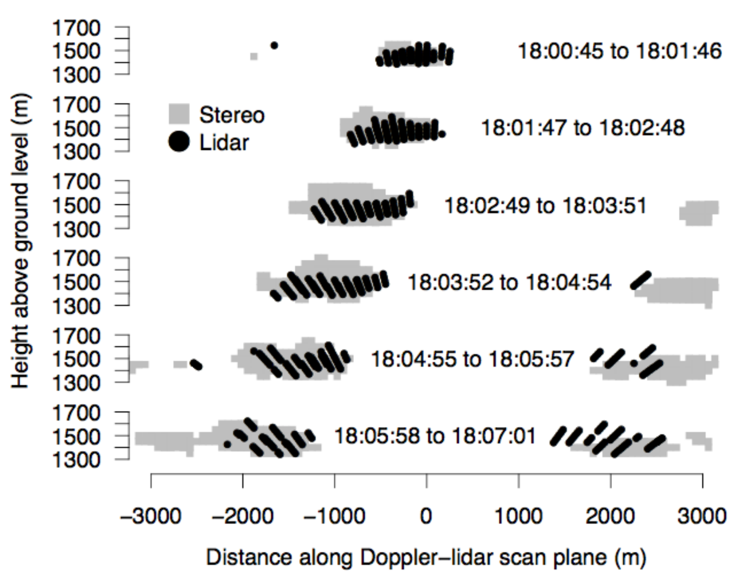

Figure 3. A comparison of scanning Doppler lidar cloud detections and stereo camera cloud points in the same plane as the Doppler lidar scan on August 31, 2017.

Work is in progress to retrieve the vertical velocity from the radial velocity measurements (e.g., bottom of Figure 1). Work is also in progress to retrieve sub-cloud-layer turbulence in the 3D domain from scanning

Doppler lidar measurements that will be used to investigate the representation of vertical structures of shallow cumuli in large-eddy simulations (LES).

In addition, a collaboration was initiated with an ARM team led by Jessica Kleiss (Assistant Professor of Environment Studies, Lewis and Clark College) to use the SGP3DOBS IOP observations to evaluate their total sky imager (TSI)-estimated cloud size products of cloud area and cloud chord length.

3.0 Publications and References

Analyses of the SGP3DOBS data have begun and publications are currently in preparation.

Lamer, K., and P Kollias. 2015. “Observations of fair-weather cumuli over land: Dynamical factors controlling cloud size and cover.” *Geophysical Research Letters* 42(20): 8693–8701, https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/2015GL064534

Romps, DM, and R Öktem. 2015. “Stereo photogrammetry reveals substantial drag on cloud thermals.” *Geophysical Research Letters* 42(12): 5051–5057. https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/2015GL064009

4.0 Lessons Learned

The Doppler lidar mentor Rob Newsome at Pacific Northwest National Laboratory provided excellent support for the SGP3DOBS IOP. We are thankful for the support received.

During the IOP, we tried to set up the Doppler lidar scanning in the cross-wind direction at the beginning of each IOP day. However, post-processing of Doppler lidar measurements showed that sometimes the Doppler lidar were scanning in the along-wind direction, probably because wind direction changed later on. A lesson learned is that near-real-time updates on wind directions are necessary to adjust the lidar scanning in the cross-wind direction.

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