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High Resolution Airborne FMCW Radar Reveals the Well-Known Puzzle of Warm Rain Formation in a Small Cumulus

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1. Introduction

To investigate dynamics and microphysics in shallow precipitating cumulus clouds, an upward facing airborne W-band FMCW radar with range resolution as high as 10 meters was employed in field experiment conducted in Key West of Florida in May 2012. After removing aircraft motion, the Mie notch technique is applied to radar observed Doppler spectra to retrieve vertical profiles of vertical air velocity in clouds. It has been realized for decades that turbulence may play a significant role in warm rain formation, but it is lack of observational evidence. With the aid of FMCW radar, this study investigates the features of vertical air velocity in cumuli. Observed detailed fine structures in both Doppler spectra and retrieved velocity profiles reveal for the first time that vertical air velocity structures in the precipitating areas of cumuli with cloud depths of about 1.5 km are not spatially uniform and exhibit changes with height.

2. FMCW radar parameters

Center frequency (GHz)	94.2
Peak power (dBm)	30
Transmit duty cycle (%)	6.25
PRF (Hz)	63.145
Chirp pulse bandwidth (MHz)	up to 20
Maximum range (m)	3962.5
Maximum velocity (m s^{-1})	12
Range Resolution (m)	10
Receiver noise figure (dB)	7.0
Antenna Diameter (cm)	30
Antenna Gain (dB)	46
Antenna Beam width (degrees)	0.7
FFT Number	64

3. Removal of contaminations of motions

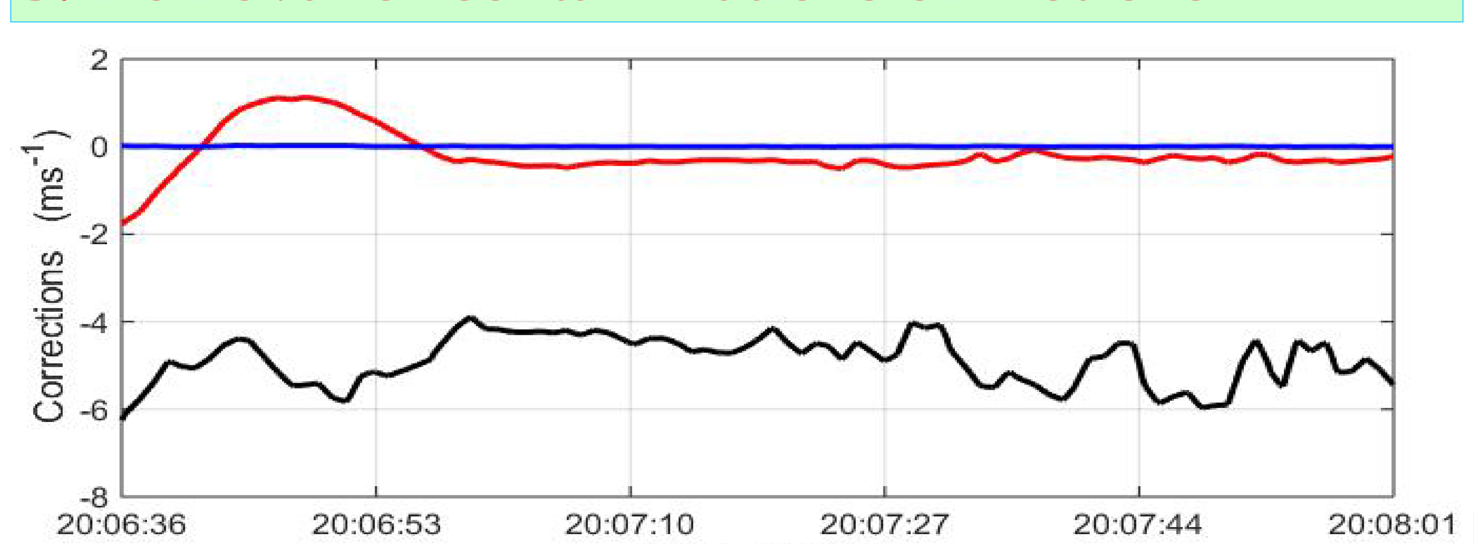

Fig. 1 Correction terms related to aircraft motion (black), horizontal wind (red) and apparent velocity (blue).

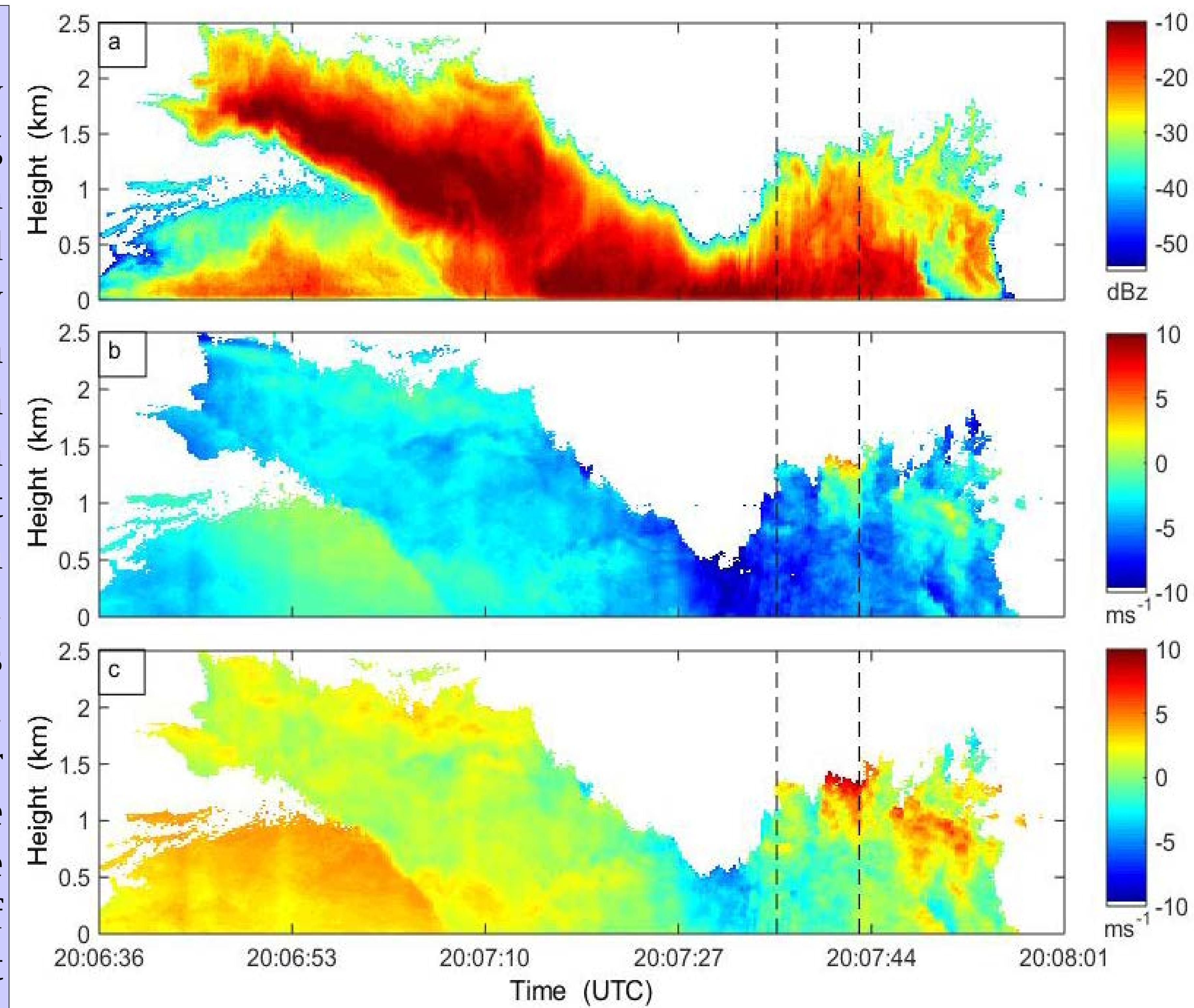

Fig. 2 Reflectivity factor (a), corrected Doppler velocity (b) and uncorrected Doppler velocity (c), 05/22/2012, Key West

4. Air density correction

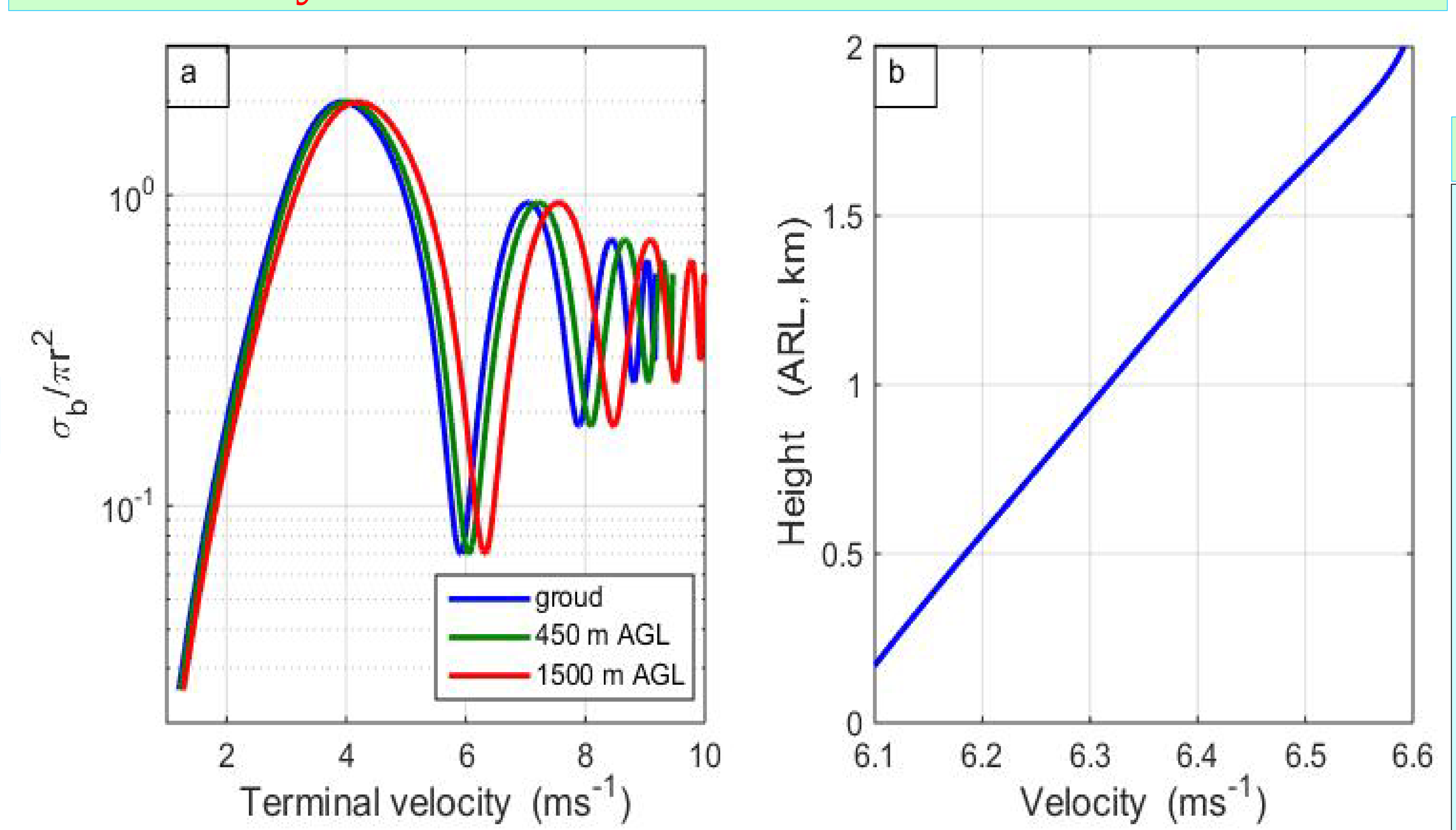

Fig. 3 (a)Simulated spectra with or w/o air-density correction at ground, 450 m and 1500 m AGL, 22 May 2012 in Key West, Florida; (b) air-density-corrected terminal speed profile AFL for 1.69 mm raindrop.

5. Observed results

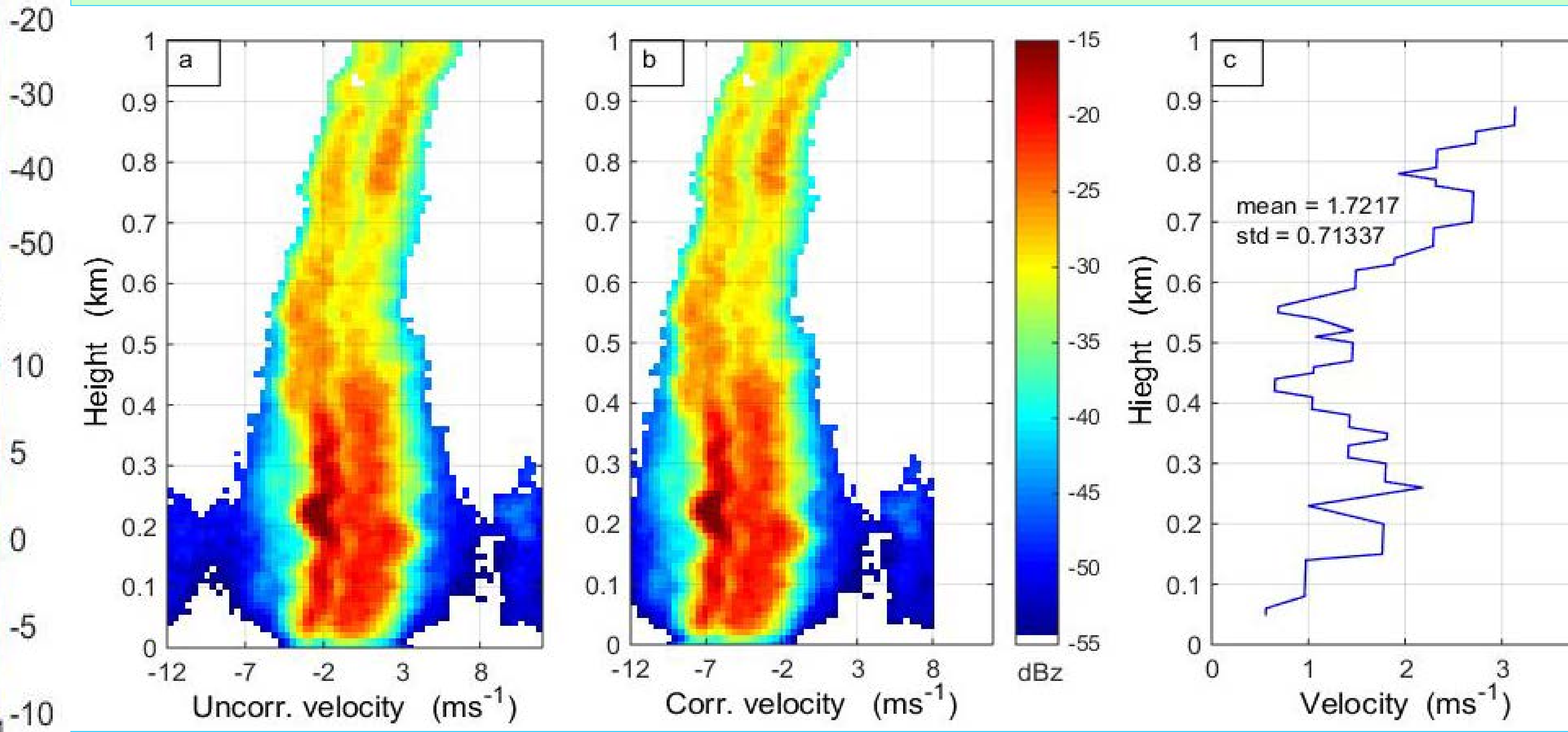

Fig. 4 Corrected (b) and uncorrected (c) spectrogram, and vertical air velocity profile at 20:06:42 UTC, 22 May 2012 in Key West, Florida.

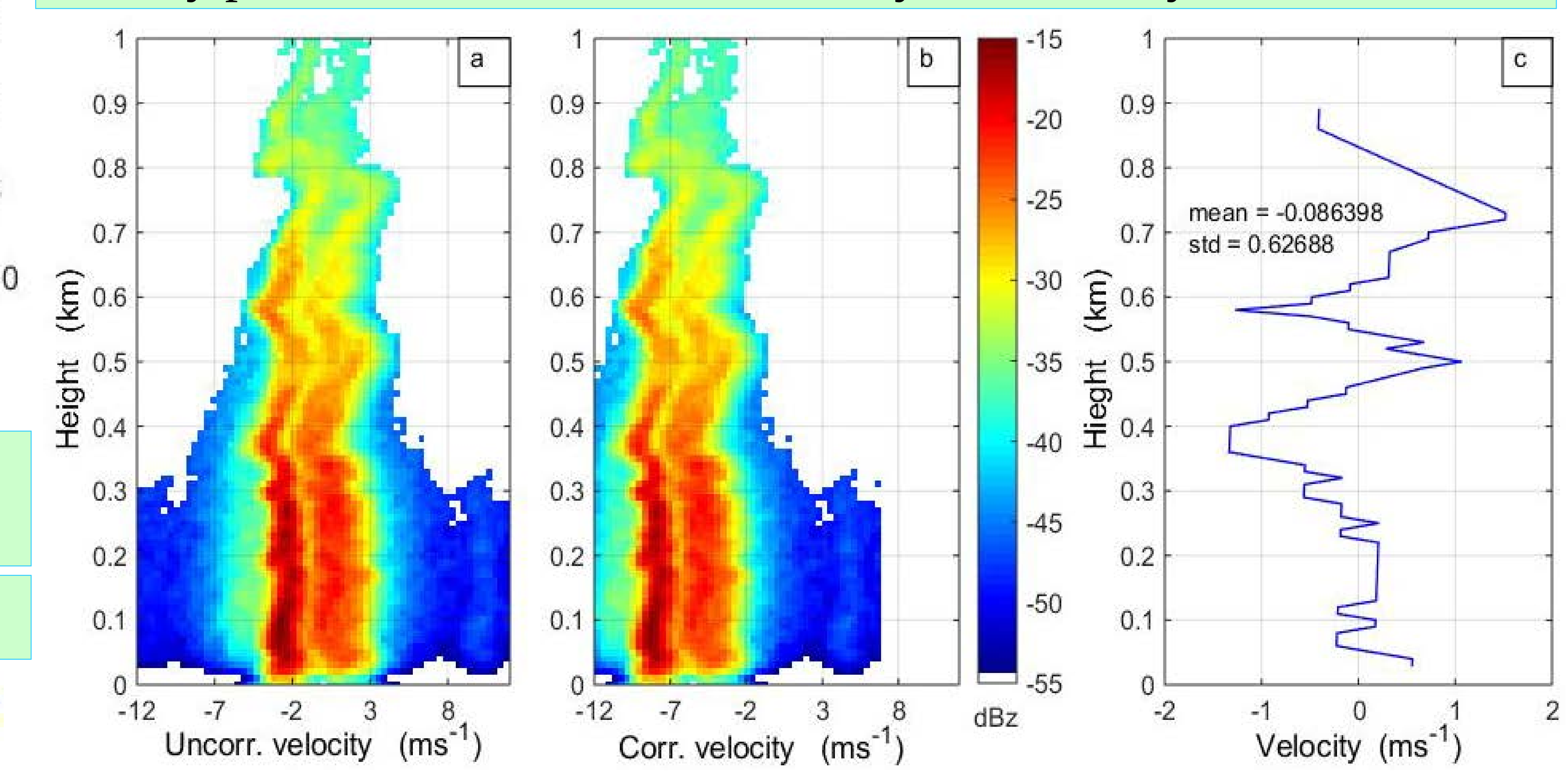

Fig. 5 Similar to Fig. 3 but at 20:06:35 UTC

6. Summary

Multiple layers were observed where the vertical air velocity decreases in the upper portion and increases in the lower portion. The local convergence may contribute to an enhancement of the collision-coalescence between hydrometers. This process could repeat in each of the multiple layers and may help account for the relatively heavy precipitation falling out of these shallow clouds. This study, for the first time, shows observational evidence that the collision-coalescence associated with turbulence or oscillations in the vertical air velocity may be an important process in the formation of warm rain precipitation.

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