Updraft and Downdraft Statistics of Simulated Tropical and Midlatitude Cumulus Convection

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Introduction

The statistics of updrafts and downdrafts were substantially different between tropical/subtropical and midlatitude continental cumulus convection (LeMone and Zipser 1980; Lucas et al. 1994). The Thunderstorm Project (Byers and Braham 1949) provided the only statistics for midlatitude continental convection.

Recent aircraft observations over tropical oceans also suggested that the averaged thermal buoyancy of downdrafts was positive and similar to that of updrafts (Jorgensen and LeMone 1989; Lucas et al. 1994; Wei et al. 1998; Igau et al. 1999). Updrafts with negative buoyancies were also frequently observed. These observations revealed that "decelerating" drafts commonly occur within convective systems.

There have been only a few observational studies of the draft statistics of tropical and midlatitude cumulus convection. All aircraft observations were restricted to the lower and middle troposphere (Table 1). The lack of the complete draft statistics has diminished the values of these studies for improving cumulus parameterizations.

The objectives of this study are twofold: 1) to provide a complete set of the draft statistics for any height, and 2) to compare the similarities and to contrast the differences in the draft statistics between tropical and midlatitude cumulus convection. It is our hope that this study will motivate future field experimenters to examine many different aspects of the draft statistics in both midlatitudes and tropical oceans and provide some guidance for further improving cumulus parameterizations in large-scale numerical models.

The Approach

We use outputs generated from several cloud-resolving simulations of tropical and midlatitude cumulus convection, forced by observed large-scale advective tendencies during GATE (GARP [Global Atmospheric Research Program] Atlantic Tropical Experiment) and the July 1995 Intensive Operational Period (IOP) of the Atmospheric Radiation Measurement (ARM) Program (Xu and Randall 1996, 1999a). Because this study is mainly concerned with the statistics of simulated updrafts and downdrafts, the detailed descriptions of these simulations are beyond the scope of this study. Please refer to Xu and Randall (1996, 1999a).

Table 1. A list of draft statistics studies.

Study	Experiment	Number of Updraft Cores	Number of Downdraft Cores	Maximum Penetration Height (km)
Byers and Braham (1949)	Thunderstorm Project	206	95	7.9
Gray (1965)	Hurricanes	155	158	~5.0
LeMone and Zipser (1980)	GATE	253	159	8.1
Jorgensen et al. (1985)	Hurricane eyewalls and rainbands	1909	649	6.1
Jorgensen and LeMone (1989)	TAMEX (subtropics)	359	466	6.5
Lucas et al. (1994)	EMEX	511	259	5.8
Wei et al. (1998); Igau et al. (1999)	TOGA-COARE	185	147	5.8
This study	GATE	489,000	212,000	15.0
This study	ARM	478,000	372,000	15.0

EMEX—Equatorial Mesoscale Experiment
IAMEX—Taiwan Area Mesoscale Experiment
TOGA-COARE—Tropical Ocean Global Atmosphere-Coupled Atmosphere Response Experiment

The methodology used in this study is similar to that of LeMone and Zipser (1980) and subsequent studies used for aircraft measurements: strong convective cores with absolute vertical velocities over 1 m s^{-1} and total condensate mixing ratios over 0.1 g kg^{-1} are sampled for the statistical analysis. An average is taken if two or more adjacent grid points satisfy the criteria. After all draft cores are selected for a given height of the GATE and ARM simulations, respectively, the draft statistics are obtained separately for updrafts and downdrafts by ranking all the samples from the lowest to the highest values. Although the statistics obtained in this study should be compared to those of the cores from aircraft measurements, we still call them "draft statistics" for simplicity. The median value (the middle point of a probability distribution), the 10^{th} percentile (only 10% of the sample is smaller) and the 90^{th} percentile (only 10% of the sample is greater) will be shown in the section below.

Results

Sample sizes of updraft and downdraft cores in this study are a few order of magnitudes larger than those of any aircraft measurement (Table 1). It ranges from a few thousand to thirty thousand for a given height. The sample size is greatly dependent upon the height; bimodal for the GATE simulations and nearly unimodal for the ARM simulations (Figure 1). Such different distributions agree with those obtained from diagnostic studies (Ogura and Cho 1973; Lewis 1975).

Statistics of the draft velocities are comparable to observations from the recent tropical experiments (Figure 2), but much smaller than those of the Thunderstorm Project (not shown), which only sampled the growing convective towers. Figure 2 shows the 90^{th} percentiles of updraft velocities and 10^{th} percentiles of downdraft velocities for both the ARM and GATE simulations, as well as the corresponding GATE observations by LeMone and Zipser (1980). There is almost no difference in the median values (not shown) of updrafts and downdrafts. The difference between midlatitude and tropical

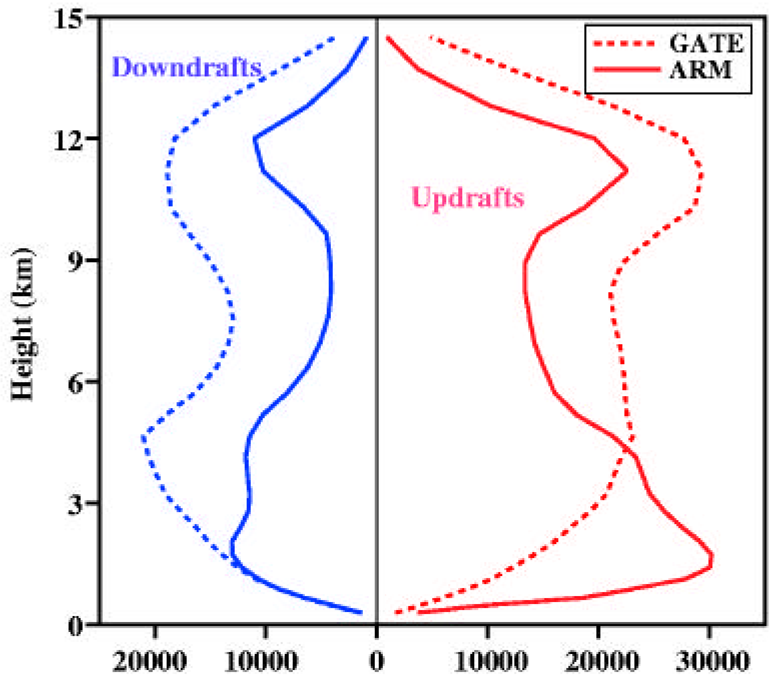

Figure 1. Vertical profiles of updraft and downdraft sample sizes for the GATE and ARM simulations.

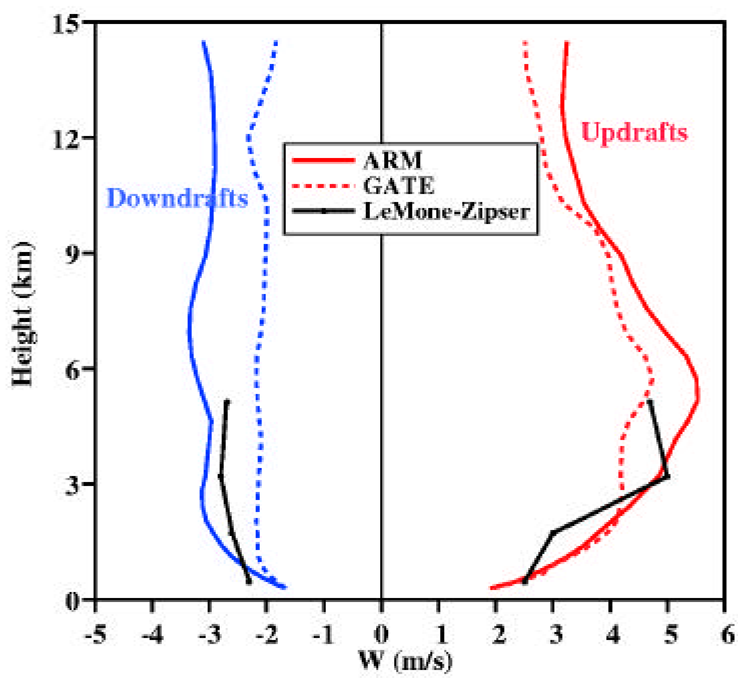

Figure 2. Vertical profiles of the 90th percentile (10th percentile) of updraft (downdraft) velocities for the ARM and GATE simulations and GATE observations (LeMone and Zipser 1980).

convection mainly occurs for the strongest 10% of the updrafts and downdrafts (Figure 2). This difference is expected because of significantly large differences in the large-scale environments. Large downdraft velocities are favored in drier environments and stronger updraft velocities are favored with larger convective instabilities over midlatitude continents.

The vertical profiles of the thermal buoyancy statistics (10^{th} percentile, median, and 90^{th} percentile) are rather similar between updrafts and downdrafts of either GATE or ARM simulations, except for smaller shifts in values (Figure 3). The median buoyancies of updrafts are approximately 0.5 K higher than

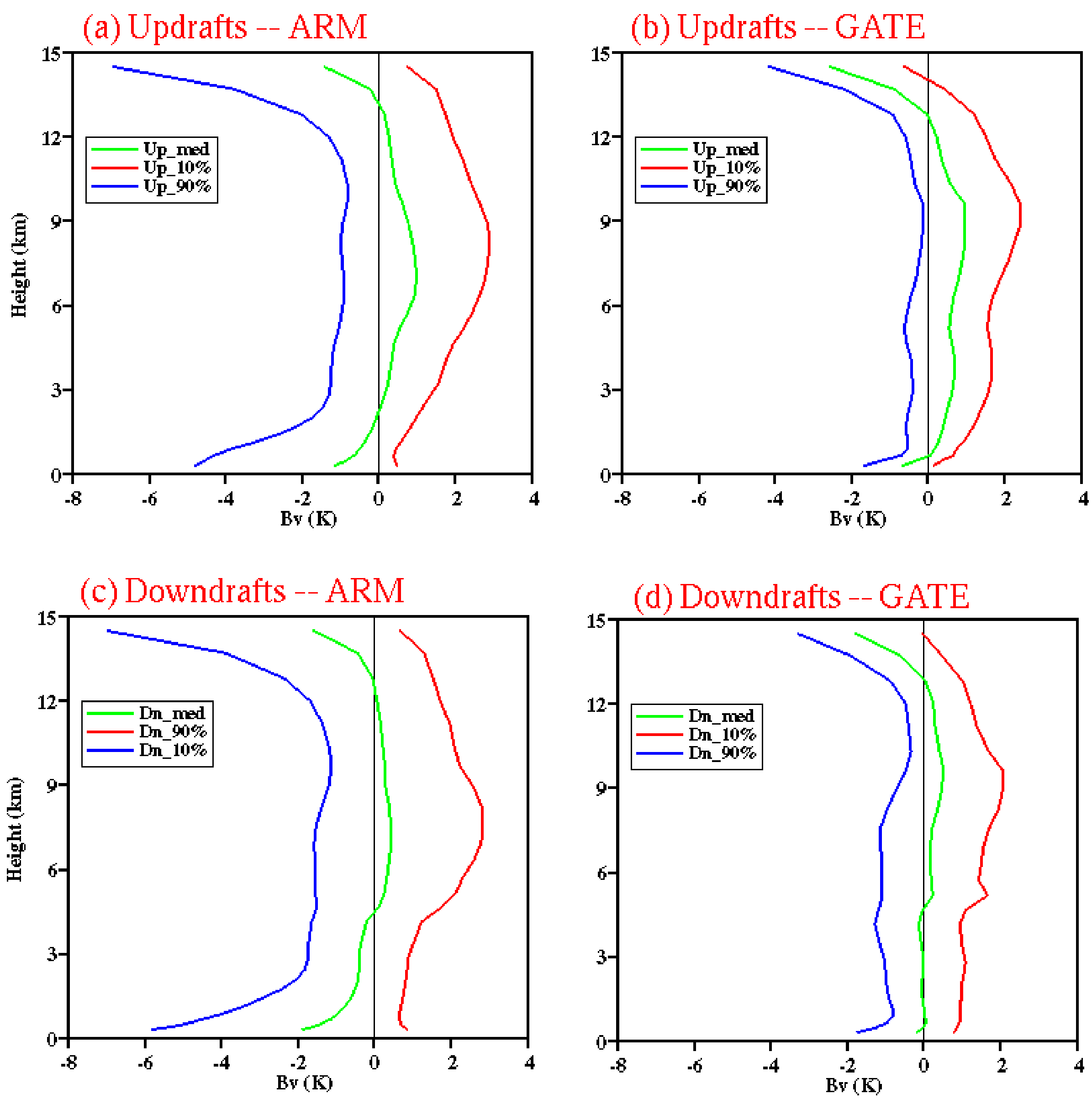

Figure 3. Vertical profiles of the median, 10^{th} percentile and 90^{th} percentile of the thermal buoyancy for updrafts and downdrafts of the GATE and ARM simulations.

those of downdrafts at most heights. As in aircraft measurements (Jorgensen and LeMone 1989; Lucas et al. 1994; Wei et al. 1998; Igau et al. 1999), positive buoyancies exist for more than half of downdrafts, and negative thermal buoyancies exist for significant number of updrafts. The nonhydrostatic pressure gradients can explain such a surprising result first obtained from aircraft measurements (Xu and Randall 1999b).

The vertical profiles of the total condensate mixing ratio statistics are rather different between updrafts and downdrafts. Figure 4 shows the 10th percentile, medium, and 90th percentile of the condensate mixing ratios for ARM simulations only. Results are similar for the GATE simulations (not shown). The vertical profile of the median condensate mixing ratio shows a maximum around 5 km and a secondary maximum at 3 km for updrafts. For downdrafts, the maximum occurs near the surface and a secondary maximum around 5 km. Another major feature of Figure 4 is that the median values are close to the 10th percentile, rather than the 90th percentile, especially in the middle and upper troposphere. This is related to the lognormal distribution of condensate mixing ratio (not shown).

The loading effects have the largest impact on the strongest updrafts. The vertically integrated (mass weighted) buoyancy reduction due to the loading effects is shown in Table 2. The vertically integrated thermal buoyancy values for updrafts are shown in the parenthesis of Table 2.

Another result of Table 2 is that the loading effects are slightly larger for the GATE drafts than for the ARM drafts, reflecting the more important role of the loading effects in oceanic convection. Overall, the loading effects are much larger for updrafts than for downdrafts.

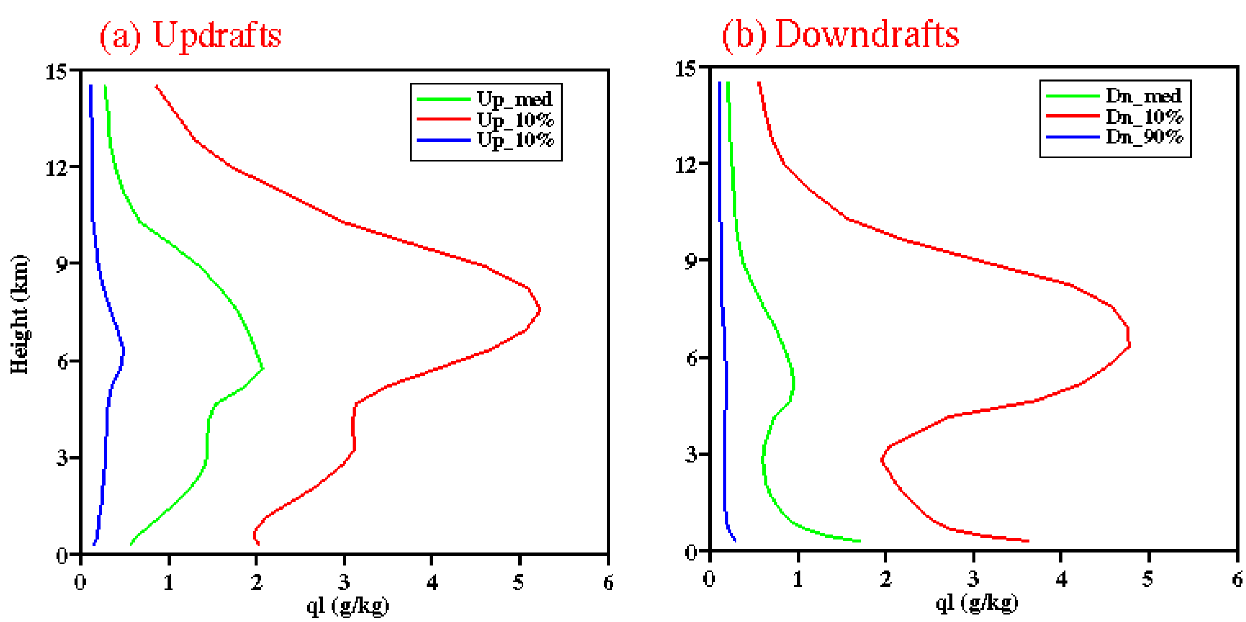

Figure 4. Vertical profiles of the median, 10th percentile, and 90th percentile of updraft and downdraft condensate mixing ratios for the ARM simulations.

Table 2. Vertically integrated loading effects for the 10th percentile, the median, the 90th percentile, and the mean of the sample. The vertically integrated thermal buoyancy for the median, the 90th percentile and the mean updrafts are shown in parenthesis. Unit is J kg^{-1}.

	10th Percentile	Median	90th Percentile	Mean
Updrafts – ARM	100	155 (209)	290 (1029)	181 (228)
Downdrafts – ARM	65	76	144	96
Updrafts – GATE	163	194 (252)	291 (787)	213 (272)
Downdrafts – GATE	100	100	160	119

The results shown above do not relate the thermodynamic properties of drafts with specific strengths of the drafts, although in some instances there are some connections. Therefore, we stratify the data sample according the magnitudes of draft velocities. The strongest 1% and 10% of the drafts show the large differences between tropical and midlatitude cumulus convection. Selected results are shown in Figure 5, which corresponds to the averages of the strongest 1% and 10% of the updrafts, respectively.

The magnitudes of the updraft velocities are obviously proportional to those of the thermal buoyancies (Figure 5b). The integrated thermal buoyancies are 905 J kg^{-1} (703 J kg^{-1}) and 1811 J kg^{-1} (1157 J kg^{-1}) for the strongest 10% and 1% of the ARM (GATE) updrafts, respectively. The vertical structures of the buoyancy are very different between tropical and midlatitude updrafts. The cloud bases are much higher in midlatitude continents, which is related to the much higher convective inhibition (CIN values of -77 J kg^{-1} and -123 J kg^{-1} for the strongest 10% and 1% of the ARM updrafts, respectively). Thus, the nonhydrostatic pressure gradients play a more important role in initiating cumulus convection in midlatitude continents.

The condensate mixing ratios for the strongest 1% of the updrafts are very close to the adiabatic values predicted from the parcel theory, but much smaller for the strongest 10% of the updrafts (Figure 5c). The moist static energy deviations from the domain-average (Figure 5d) show smaller differences between tropical and midlatitude convection, compared with other variables.

Finally, the comparison between drafts with diameters of 2 km and greater than 2 km shows the importance of less diluted, larger convective cores. Figure 6 shows the 90th percentiles of updraft and downdraft vertical velocities and the 10th percentile, the median and the 90th percentile of updraft buoyancies for wide (> 2 km) and narrow (2 km) updrafts of the ARM simulations. The buoyancies are much larger for the wide updrafts than for the narrow updrafts, especially in the middle and upper troposphere.

Conclusions

1. The median draft velocities are rather similar between tropical and midlatitude cumulus convection.

2. The strongest 10% of the midlatitude drafts, whose velocities strongly vary with height, are much stronger than their counterparts in the Tropics.

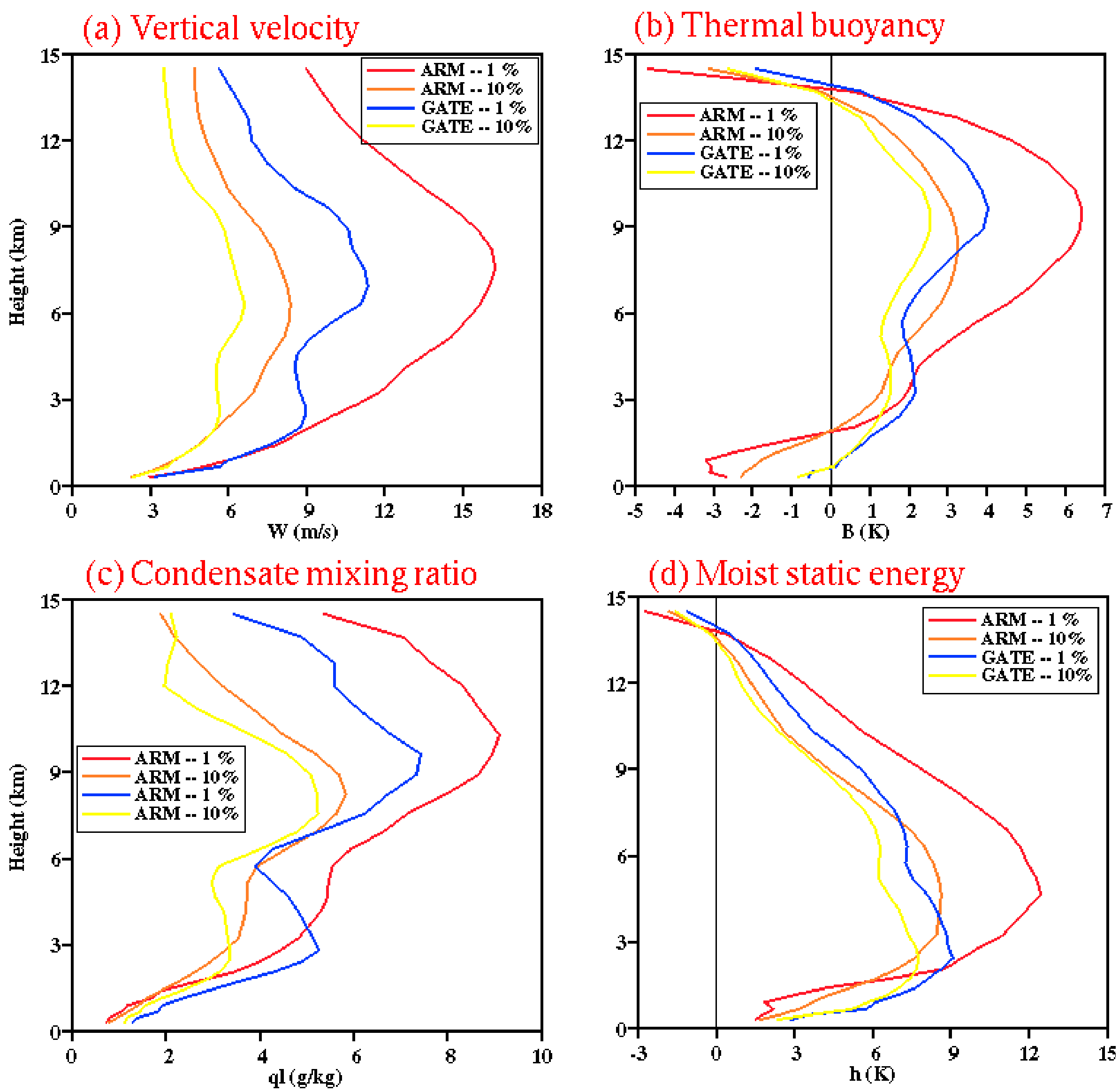

Figure 5. Vertical profiles of the averages over the top 1% and 10% of the updraft samples for the ARM and GATE simulations; (a) vertical velocity, (b) thermal buoyancy, (c) condensate mixing ratio, and (d) moist static energy deviation from the domain average.

3. “Decelerating” (based upon the sign of buoyancy) drafts are abundant in both the tropical and midlatitudes.

4. Wider drafts are much stronger than narrow drafts.

5. It is time for the ARM Program to conduct aircraft measurements of convective drafts to replace the only outdated, midlatitude draft statistics by Byers and Braham (1949).

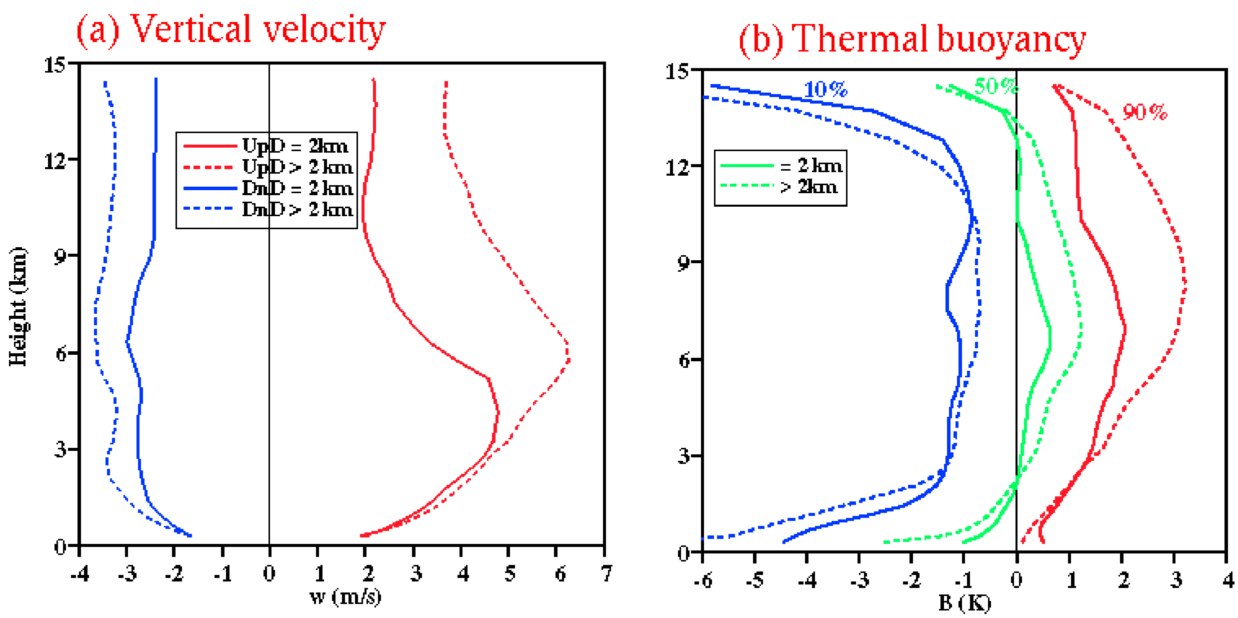

Figure 6. Vertical profiles of (a) the 90th percentile of updrafts and 10th percentile of downdrafts and (b) the median, the 10th percentile and 90th percentile of thermal buoyancies for updrafts of the ARM simulations.

Acknowledgments

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