Characteristics of Convective Clouds Observed During the Ice in Clouds Experiment – Tropical (ICE-T) Field Campaign

Lindsey J. Hayden[1], Amanda M. Sheffield[2], and Susan C. van den Heever[2]
[1]Dept. of Earth and Atmospheric Sciences, Metropolitan State University of Denver, Denver, CO
[2]Dept. of Atmospheric Science, Colorado State University, Fort Collins, CO

Abstract

Convective clouds are an important source of weather throughout the tropics and the globe. Convection in the tropics significantly impacts precipitation over this region, is trimodally distributed, and influences the general circulation (Johnson et al. 1999). It is therefore important to better understand and correctly represent these types of clouds in global and regional models. In-situ observations are very useful to compare with models in order to evaluate how accurately clouds are being represented. This study examines growing cumulus and cumulus congestus clouds sampled during the Ice in Clouds Experiment – Tropical (ICE-T) field campaign. Clouds were selected for this study by using the aircraft forward camera used during the experiment flights, and a definition of cloud, based on liquid water content. Penetrations through stratus clouds and cloud edges were not included, in order to specifically isolate cumulus and cumulus congestus. Statistics include the mean, standard deviation, minimum, and maximum values of several variables per penetration, per level above cloud base, and per day.

The specific variables examined in this study are cloud droplet number concentration and diameter, rain droplet number concentration and diameter, updraft speed, and liquid water content. The vertical profile of each variable above cloud base was examined, as well as the relationships between the variables. Rain drop number concentration and diameter, updraft speed, liquid water content, and cloud droplet diameter are found to increase with height, while cloud droplet number concentration is shown to decrease. Liquid water content is also compared to predicted adiabatic values. Finally, the statistical results of the study are compared to cloud resolving model output of similar congestus clouds.

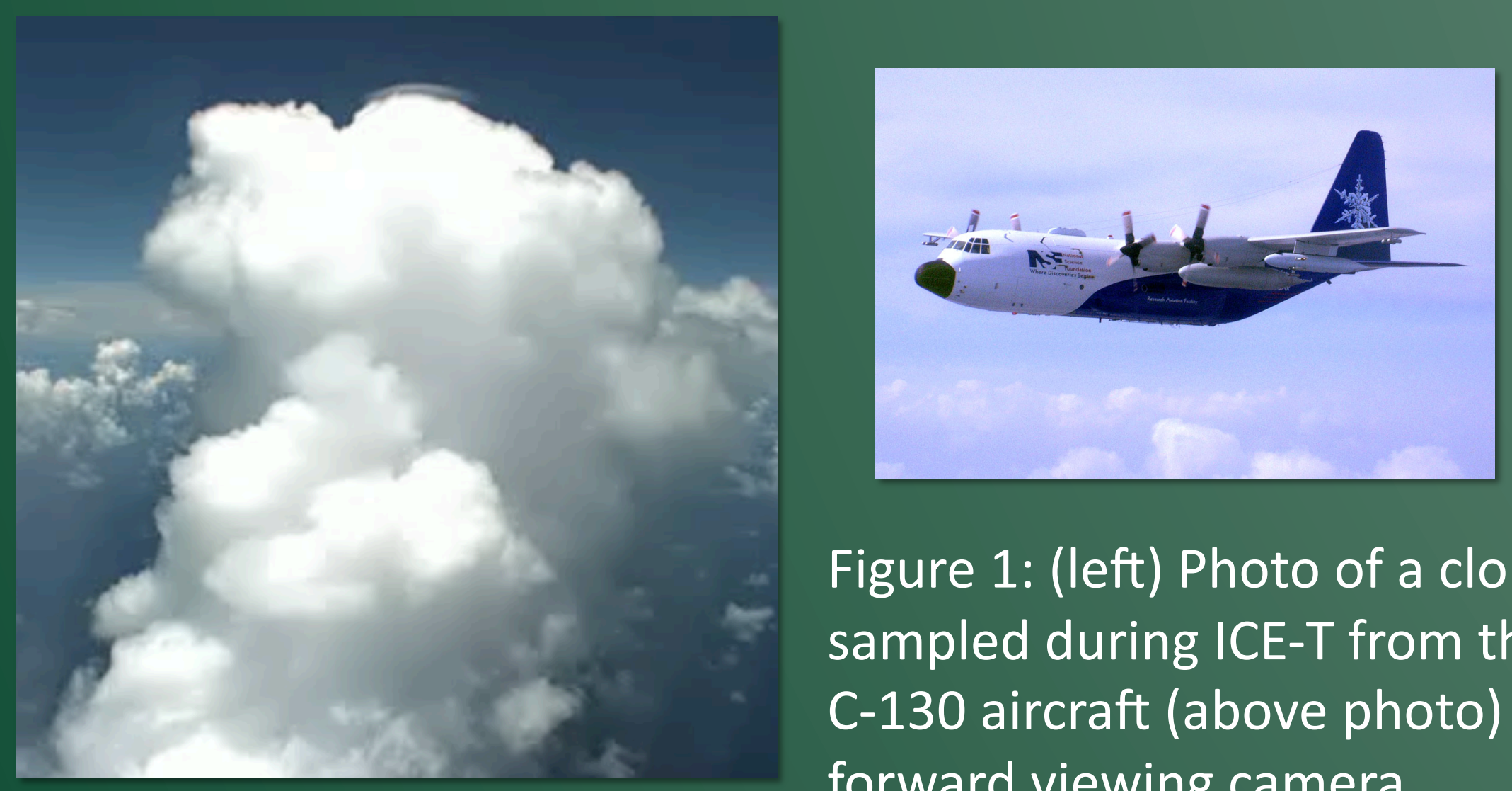


Figure 1: (left) Photo of a cloud sampled during ICE-T from the C-130 aircraft (above photo) forward viewing camera.

1. Ice in Clouds Experiment-Tropical (ICE-T)

The objective of the ICE-T mission was to statistically sample trade wind cumulus and cumulus congestus clouds during their growth. These clouds make up the smallest two sizes of the trimodal size distribution of tropical convection (Johnson et al. 1999). The campaign also observed the conditions leading to the formation of ice in clouds, as well as observe the aerosol concentrations and variety in the area. The experiment occurred from July 1 to July 30, 2011 in the Caribbean Sea near St. Croix (USVI). The dataset used here was collected on the National Science Foundation/National Center for Atmospheric Research's C-130 research aircraft. More information on the campaign can be found at http://www.eol.ucar.edu/projects/ice-t/.

2. Methodology

Analysis of these clouds began with an examination of clouds from the forward camera onboard the C-130 aircraft. With this, the time of each convective cloud penetration was identified. Edges of clouds and stratus type clouds were not included in order to isolate cumulus type clouds. Using a requirement of liquid water content greater than 0.01 gm^{-3}, the portion of the identified penetrations as 'cloud' was examined. The data was then analyzed by altitude and by research flight. The data used was collected from the Forward Scattering Spectrometer Probe (FSSP-100), the 2-Dimensional Precipitation probe (2DP), and the PMS-King liquid water content probe. GPS corrected wind velocity was also used.

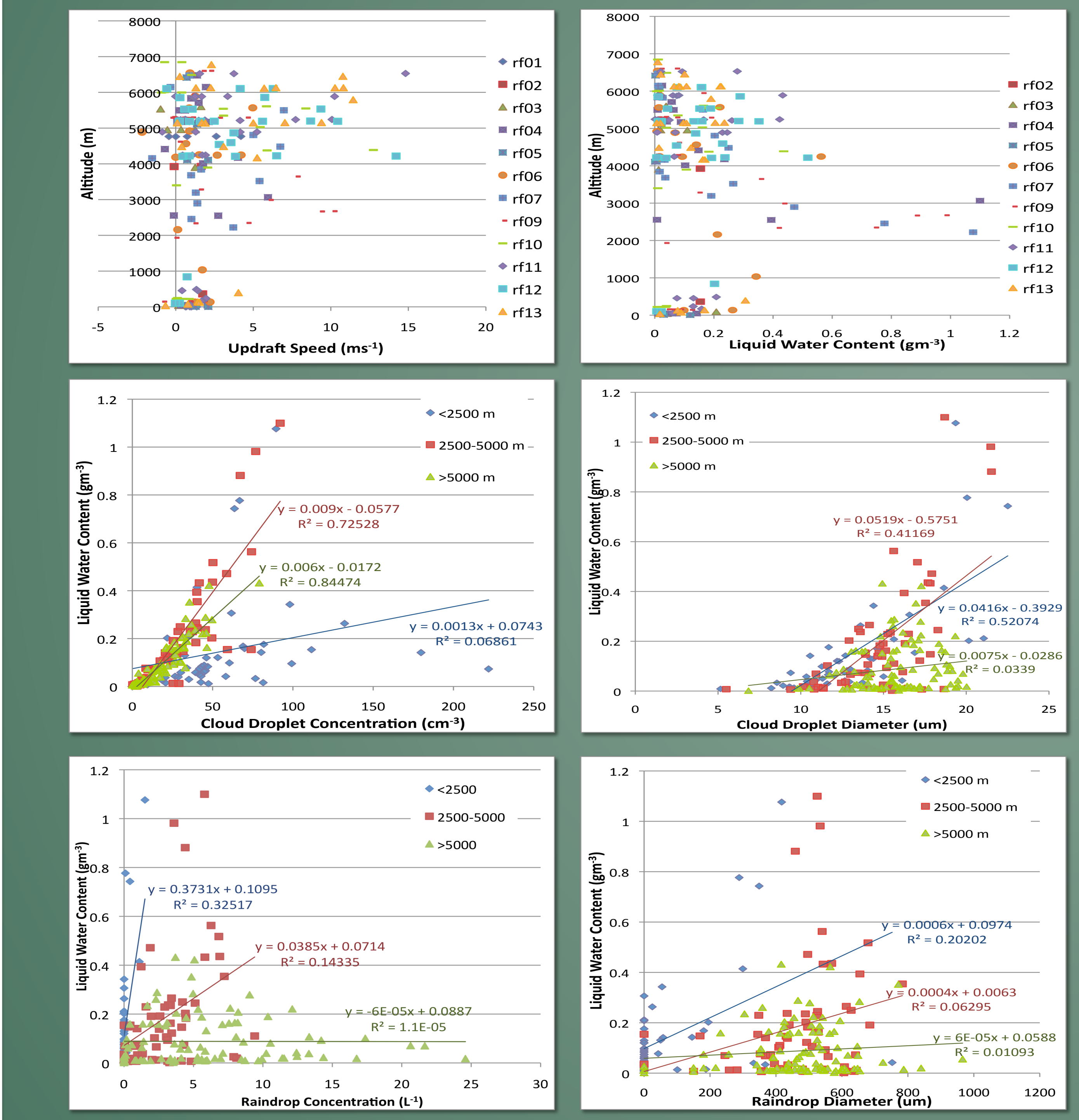


Figure 3: Values of a) updraft speed and b) LWC with altitude above cloud base for each research flight. Separated by 3 altitudes bins, c) cloud drop concentration vs. LWC, d) cloud drop diameter vs. LWC, e) rain drop concentration vs. LWC, and f) rain drop diameter vs. LWC.

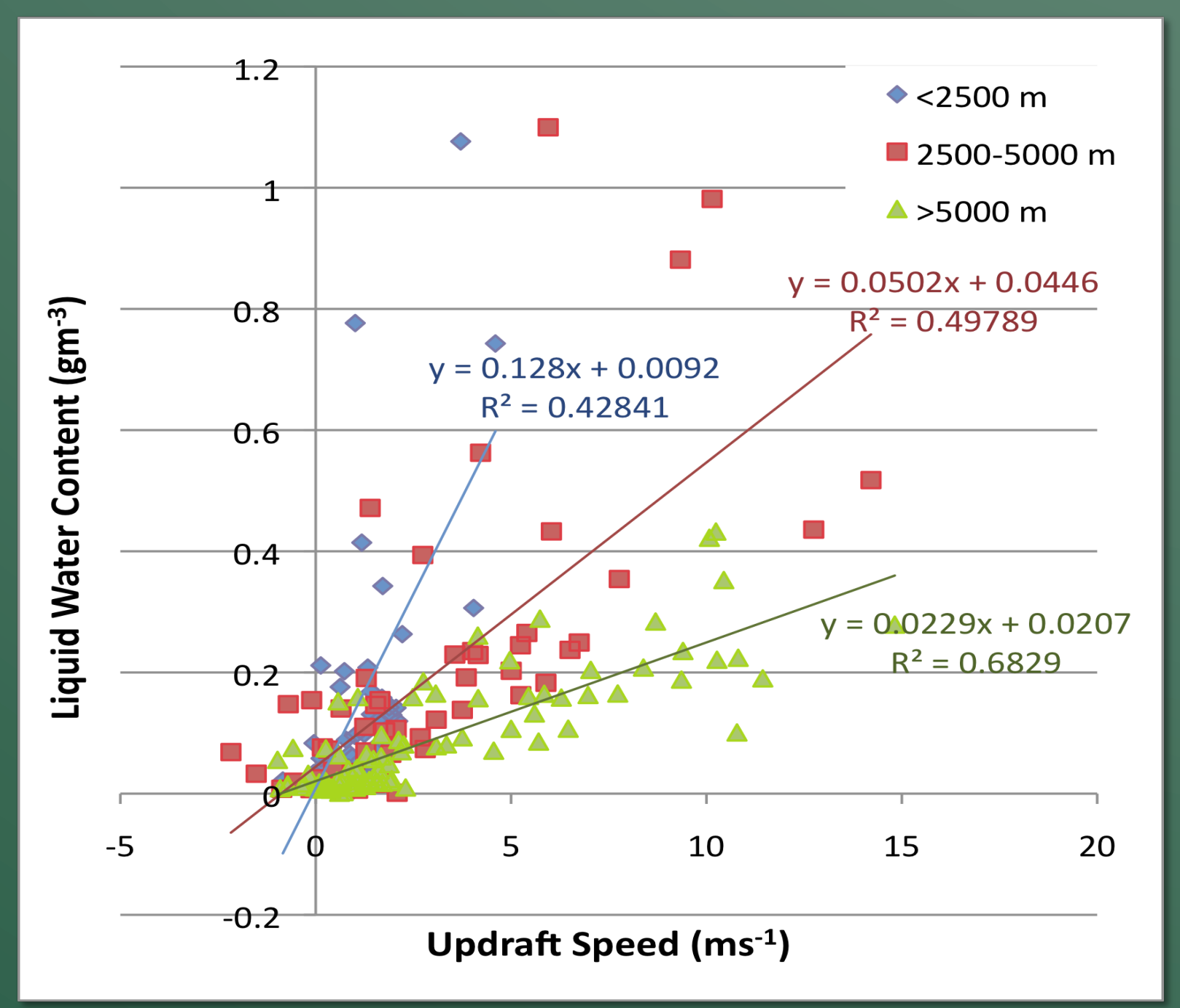


Figure 4 (left): Relationship between updraft speed and LWC.

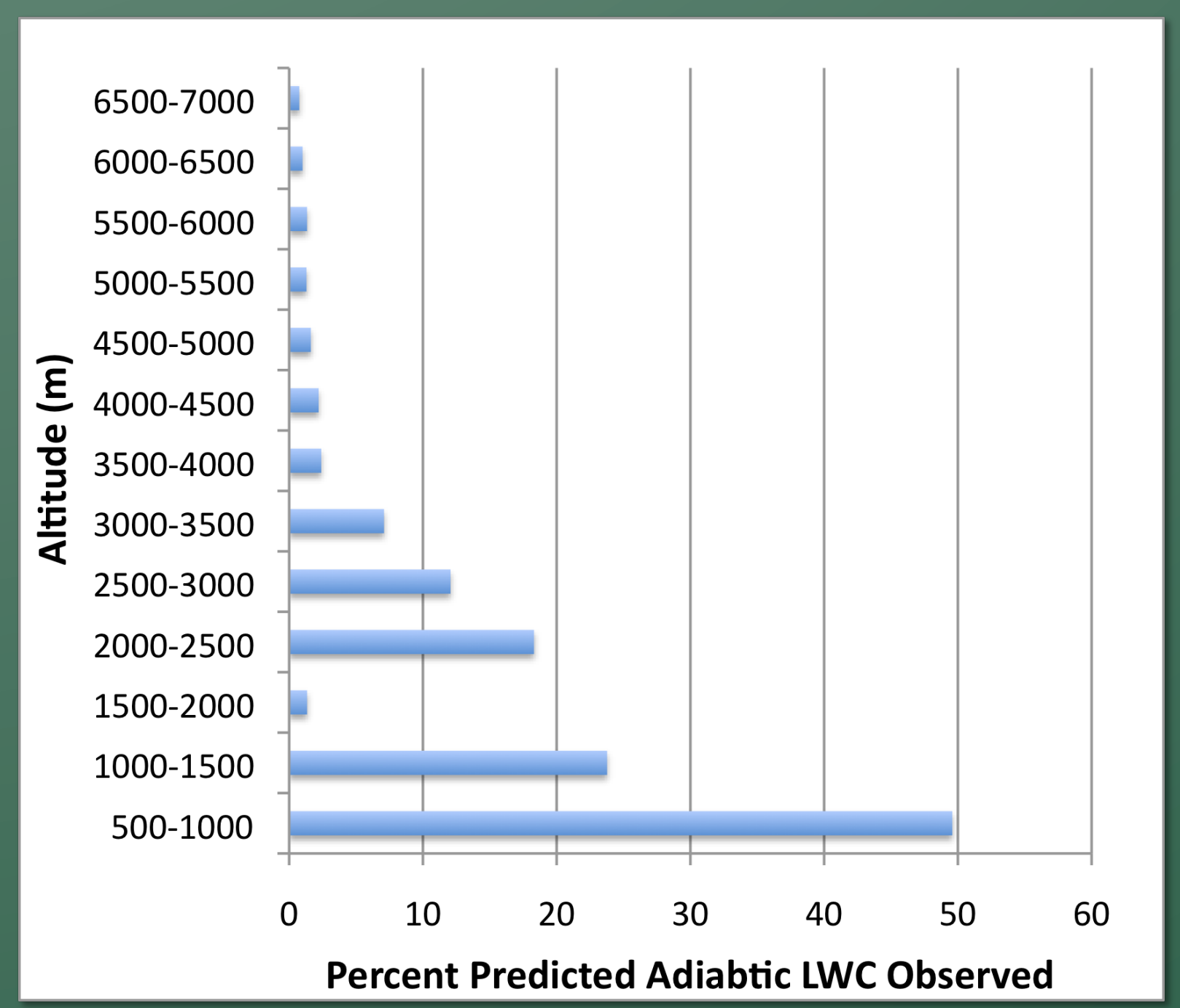
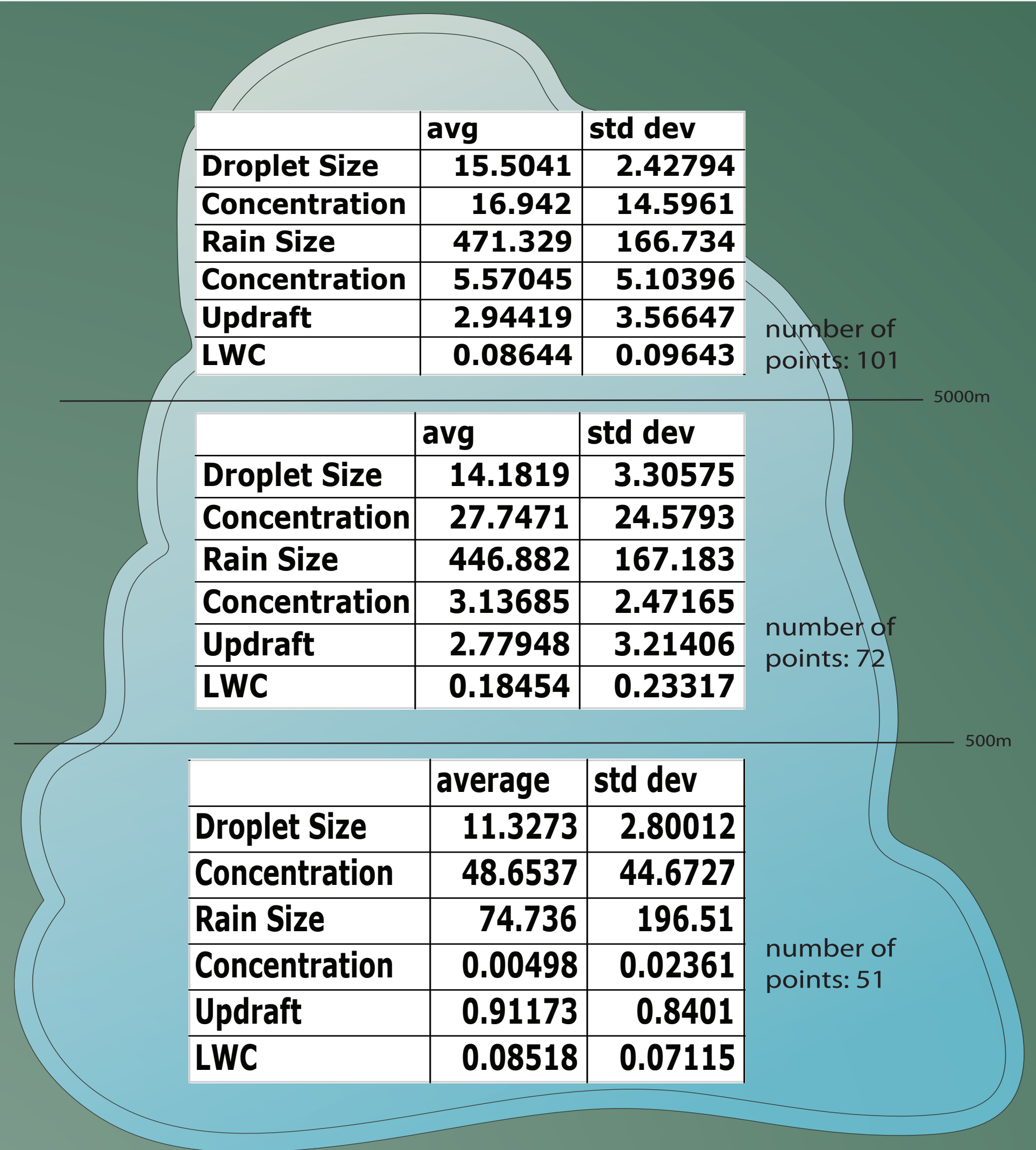


Figure 5 (right) : Ratio of the measured LWC to the predicted adiabatic LWC by altitude above cloud base.



	avg	std dev
Droplet Size	15.5041	2.42794
Concentration	16.942	14.5961
Rain Size	471.329	166.734
Concentration	5.57045	5.10396
Updraft	2.94419	3.56647
LWC	0.08644	0.09643

number of points: 101

	avg	std dev
Droplet Size	14.1819	3.30575
Concentration	27.7471	24.5793
Rain Size	446.882	167.183
Concentration	3.13685	2.47165
Updraft	2.77948	3.21406
LWC	0.18454	0.23317

number of points: 72

	average	std dev
Droplet Size	11.3273	2.80012
Concentration	48.6537	44.6727
Rain Size	74.736	196.51
Concentration	0.00498	0.02361
Updraft	0.91173	0.8401
LWC	0.08518	0.07115

number of points: 51

Figure 2: Average and standard deviation values over several altitudes of the 6 variables considered in this study.

3. Results

Six variables were considered in this study: *cloud droplet size (μm) and number concentration (cm^{-3}) (FSSP-100 data), rain droplet size (μm) and number concentration (L^{-1}) (2DP data), updraft speed (m s^{-1}), and liquid water content (LWC, g m^{-3}) (PMS-King data).*

A. Among these variables, all tended to increase with height except for cloud droplet number concentration (Fig. 2). The standard deviation per level for each variable was large, with the exception of cloud droplet size. Entrainment is an important process in creating this variability.

B. Increasing updraft speeds with height are associated with an increase in LWC with height through increased supersaturation values (Fig. 3a-b). This may make it easier to form cloud droplets that may eventually become rain. However, this study found no statistically significant correlation between these variables, especially liquid water content and rain droplet size or number concentration (Fig. 3c-f).

	Model Data		
	<2500	2500-5000	>5000
Droplet Size (um)	22.4636	22.3813	16.1281
Concentration (cm-3)	71.2603	72.1382	46.3911
Rain Size (um)	568.685	304.166	173.899
Concentration (L-1)	40.8217	40.5399	20.2765
LWC (gm-3)	1.30242	1.00957	0.428465
Updraft > 0 (ms-1)	0.334699	0.393491	0.306542
Updraft > 1 (ms-1)	1.71728	1.97252	1.53343

Table 1: Similar values to those found in this study from cumulus congestus clouds in cloud resolving model simulations.

3. Results (continued)

C. The relationship between LWC and updraft speed due to supersaturation is shown (Fig. 4). The correlation between these two variables is relatively consistent throughout the cloud.

D. The LWC found in these clouds is much smaller than the predicted adiabatic value, with the highest percent of predicted LWC being less than 50% (Fig. 5).

E. The results found here can be compared to cumulus congestus clouds from recent cloud resolving model simulations (CRM) (Sheffield et al. 2012) (Table 1). In the model simulations, cloud droplet size and concentration, as well as rain droplet concentration, LWC, and updraft speed are relatively constant from the lower to the middle portion of the cloud then decrease to the top, as a general trend. Rain droplet size tends to decrease at a more constant rate per level with increasing height. While it is not expected that the observed and modeled values should closely compare, as the simulations are conducted for a different environment using different soundings, it is useful to note that they are similar in magnitude.

4. Conclusions

- Congestus cloud properties are inter-related in complex ways that are not yet completely understood and thus is an area of ongoing research.
- Observational research into the interaction and variability of these properties is important for the development and validation of cloud microphysical parameterization schemes.
- Correct representation of the various cloud properties observed in this study in CRMs is important so that the models can better represent cloud processes.

References

Johnson, R. H., T. M. Rickenbach, S.A. Rutledge, P. E. Ciesielelki, and W. H. Shubert, 1999: Trimodal characteristics of tropical convection. *J. Climate*, 12, 2397-2418

Sheffield, Amanda M, S.C. van den Heever, and S. M. Saleeby, 2012: Growth of cumulus congestus clouds when impacted by aerosols. *In preparation.*

Acknowledgements

This work has been supported by the National Science Foundation Science and Technology Center for Multi-Scale Modeling of Atmospheric Processes (CMMAP), managed by Colorado State University under cooperative agreement No. ATM-042524. The data used in this study was collected as part of the Ice in Clouds Experiment – Tropical (ICE-T). The primary sponsor of ICE-T is the US National Science Foundation (NSF). The involvement of the NSF-sponsored Lower Atmospheric Observing Facilities, managed and operated by the National Center for Atmospheric Research (NCAR) Earth Observing Laboratory (EOL), is acknowledged. The data was downloaded from the ICE-T Data Archive, which is maintained by NCAR EOL.