Macroscopic Properties of Boundary-Layer Clouds at the SGP CART Site During 1996

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Introduction

Stratus and stratocumulus clouds are important in the regulation of the earth's radiation budget and so play an important role in climate over both the land and ocean (Ramanathan et al. 1989). Consequently, there is a great need to have the most accurate boundary-layer cloud parameterizations input into global climate models (Slingo 1990). Therefore, it is necessary that adequate observational databases exist for both continental and maritime boundary-layer cloudiness. Currently our observational and modeling understanding for marine stratus is much more advanced than that for continental clouds (Albrecht et al. 1988; Albrecht et al. 1995). Data from the Atmospheric Radiation Measurement (ARM) Southern Great Plains (SGP) site can be used to add to our observational continental stratus database and so improve cloud parameterizations in climate models by providing statistical descriptions of cloud and boundary-layer properties.

In an attempt to effectively and efficiently use the ARM data for boundary-layer cloud studies, we have focused on techniques to 1) identify and classify periods (of 4 hours or more) when boundary-layer clouds were observed over the SGP site, 2) analyze ARM SGP data to describe cloud and boundary layer properties during these cloudy periods, and 3) develop statistical and composite descriptions of cloud and boundary-layer characteristics for a variety of synoptic conditions. Statistics based on hourly averaged data have been produced for average cloud-base height, fractional cloudiness, surface energy budget fluxes, lifting condensation level (LCL), and sub-cloud stability defined from conventional rawinsondes and a Radio Acoustic Sounding System (RASS). In addition, rawinsonde data, surface weather maps, and numerical weather forecast model initialization data have been subjectively analyzed to classify the large-scale synoptic conditions associated with each cloud event. These individual stratus cloud cases have been organized into a Continental Stratus Archive (CSA) located at *http://gizo.rsmas.miami.edu/~jgottsch/arm.html*. The archive provides a subset of data for investigators who want to focus on stratus clouds for both process and modeling studies without having to search through all of the ARM data.

Cloud Base Height

Table 1 shows the summary information for data from the entire year of 1996. A greater number of stratus cloud hours were observed by the Belfort ceilometer (BLC) primarily because of a substantial data void that existed for the micropulse lidar (MPL) data during the months of February through April. Stratus cloud hours were defined as any hour, included in a group of at least 4 consecutive hours, that had at least 60% zenith cloud fraction.

Table 1. Summary of data used to determine cloud statistics for both the BLC and the MPL for all synoptic classifications.

Synoptic Classification	Number of Hours		Percent of Total Hours	
	Belfort	Lidar	Belfort	Lidar
Overruning/stationary front	173	120	14.7	16.9
Warm sector/flow from Gulf	302	152	25.6	21.4
Cold front	166	100	14.1	14.1
Building high pressure	215	165	18.2	23.2
Miscellaneous	323	173	27.4	24.4
Total BLC hours:	1179			
Total MPL hours:	710			

Figure 1 shows a comparison plot between observed cloud base height and the calculated LCL for both the ceilometer and lidar for two synoptic classifications. The BLC observed cloud base height systematically higher than both its MPL counterpart and the calculated LCL. A similar bias has also been documented by other research groups.[a] Other synoptic classifications also show this bias as

(a) Clothiaux, E., 1998: Personal communication. Department of Meteorology, The Pennsylvania State University, March 1998.

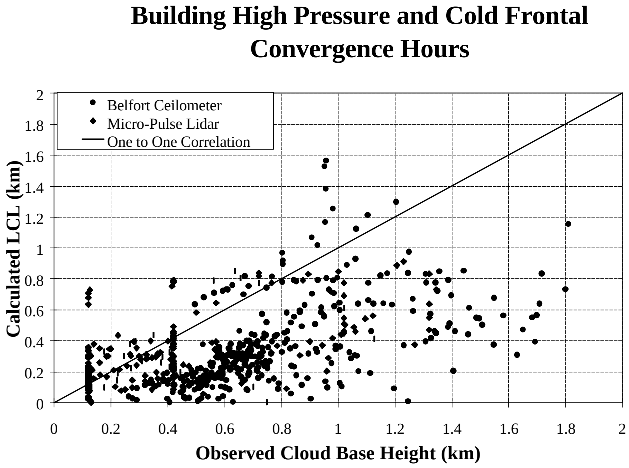

Figure 1. Correlation of the BLC and MPL cloud base height with calculated LCL values for the building high pressure and cold frontal convergence hours.

illustrated by Figure 2, which shows the breakdown of average cloud base height, standard deviation of cloud base height, and zenith cloud fraction for the five synoptic classifications. Similar values were observed by Thomas (1996) during the fall 1994 Continental Stratus Experiment.

Boundary-Layer Coupling

It is important not only to identify the macroscopic properties of boundary-layer cloudiness (i.e., cloud base height, etc.) but also to understand to what degree they are coupled to surface processes. One measure of the coupling is the difference between the observed cloud base and the LCL of the air near the surface.

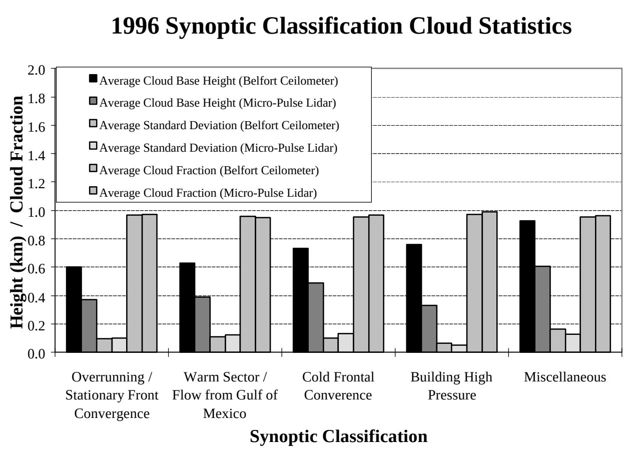

Figure 2. Statistics for hourly averaged cloud base height, standard deviation of cloud base height, and zenith cloud fraction for both the BLC and MPL for all synoptic classifications.

Figure 3 illustrates boundary-layer coupling statistics for the five synoptic classifications. The large discrepancy between the cloud base heights of the two observing instruments and the calculated LCL is clearly evident. The values of the cloud base and LCL differences for the BLC ranged from 2 to 3 times greater than that for the lidar. The synoptic conditions that produced the greatest coupling between the observed cloud base height and the calculated LCL were during the building high-pressure hours when winds increased after a cold frontal passage that allowed mixing in the moist boundary layer to form low-level clouds. For the high-pressure cases, the cloud base-LCL differences on average were 0.37 km and 0.04 km for the ceilometer and lidar, respectively.

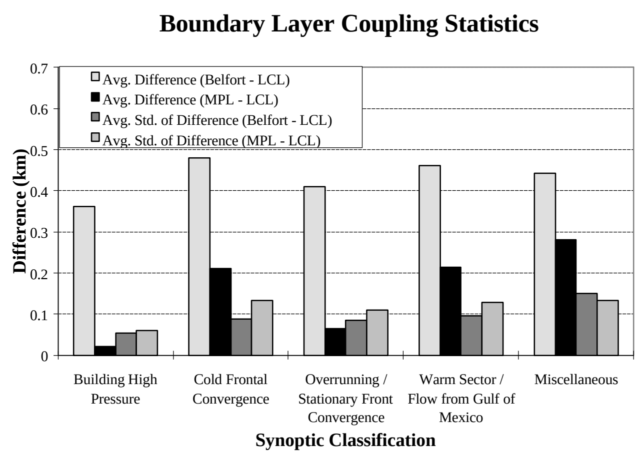

Figure 3. The hourly averaged difference between the observed cloud base height and the calculated LCL for both the BLC and MPL for all synoptic classifications.

Sub-Cloud Stability

The sub-cloud stability is also closely related to cloud development and the degree of vertical coupling. In this study, the Belfort ceilometer was used to obtain cloud base for all times that both conventional rawinsondes and RASS measurements were available.

A linear fit to dry static energy ($S_v = C_pT + gz$) as a function of height was then applied to the sub-cloud layer from just below cloud base to the lowest RASS level (127 m) to obtain the dry static energy gradient (dS_v/dz). Figure 4

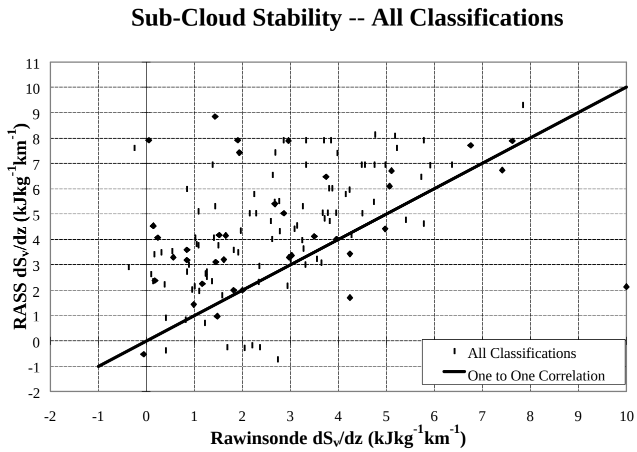

Figure 4. Sub-cloud stability for rawinsonde and RASS data via the calculation of the gradient in dry static energy below cloud base.

shows a comparison for dS_v/dz for data from both rawinsondes and RASS. The figure indicates that only during a few times is there good correlation between the stability obtained for these two observing systems. The RASS shows a bias towards higher sub-cloud stability than that for rawinsondes.

Figure 5 shows the average sub-cloud virtual temperature from both observing systems for identical times. The RASS sub-cloud average temperature is biased to higher values with the largest bias (~ 4K) occurring at higher temperatures.

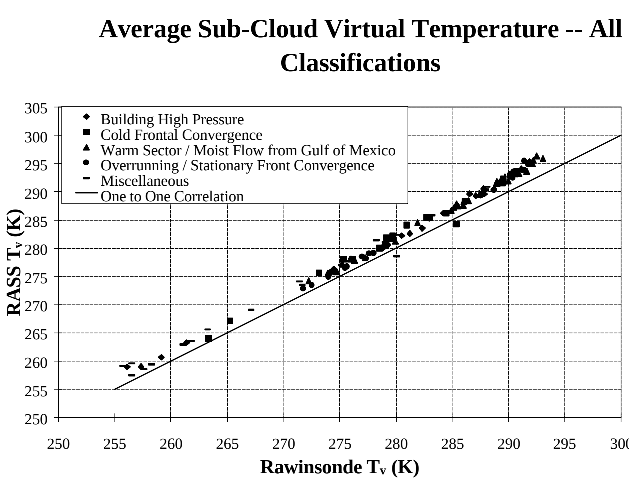

Figure 5. Comparison of rawinsonde and RASS average sub-cloud virtual temperature for all synoptic classifications.

Discussion

The SGP ARM dataset is a rich source for studies of continental stratus clouds. Nearly 1200 hours of low-cloud data were observed in 1996. Cloud coupling and boundary-layer stability were examined in some detail to better understand the mechanisms responsible for cloud formation and maintenance. Uncertainties in some of the observations have complicated these studies. The statistics from the SGP site indicate a substantial bias of the BLC to higher observed values of cloud base height compared with the MPL and calculated LCL. Moreover, this difference exists under all synoptic categories. An evaluation of the BLC base heights is ongoing and uncertainty still exists as to the accuracy of the BLC data. The uncertainties in ceilometer cloud base height present problems for other analyses such as calculating sub-cloud stability. The dS_v/dz values may be biased high because data from the inversion level may be included in the calculation of the gradient if the ceilometer cloud base height is higher than the actual cloud base height.

Biases in the RASS virtual temperature retrievals also are potentially detrimental to boundary-layer studies because small changes in stability can be critical to cloud development. Efforts to minimize the ceilometer and RASS biases will greatly improve the utility of the SGP ARM data.

Acknowledgments

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References

Albrecht, B. A., D. A. Randall, and S. Nicholls, 1988: Observations of marine stratocumulus clouds during FIRE. *Bull. Amer. Meteor. Soc.*, **69**, 618-626.

Albrecht, B. A., C. S. Bretherton, D. Johnson, W. H. Schubert, and A. S. Frisch, 1995: The Atlantic stratocumulus transition experiment--ASTEX. *Bull. Amer. Meteor. Soc.*, **76**, 889-904.

Ramanathan, V., R. D. Cess, E. F. Harrison, P. Minnis, B. R. Barkstrom, E. Ahmad, and D. Hartmann, 1989: Cloud-radiative forcing and climate: Results from the Earth radiation budget experiment. *Science*, **243**, 57-63.

Slingo, A., 1990: Sensitivity of the Earth's radiation budget to changes in low clouds. *Nature*, **343**, 49-51.

Thomas, D., 1996: Characteristics of continental stratus clouds determined from a suite of surface-based remote sensing systems. M. S. Thesis, The Pennsylvania State University, 150 pp.