Macroscopic Cloud and Boundary Layer Properties for Continental Stratus at the SGP CART Site During 1997

J. C. Gottschalck and B. A. Albrecht
University of Miami
Miami, Florida

Introduction

Stratus and stratocumulus clouds are important in the regulation of the earth's radiation budget and thus play an important role in climate over both the land and ocean (Ramanathan et al. 1989). Consequently, there is a great need for accurate boundary layer cloud parameterizations in climate models (Slingo 1990). Therefore, it is necessary that adequate observational data bases exist for both continental and maritime boundary layer clouds. 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 data base and thus improve cloud parameterizations in climate models by providing statistical descriptions of cloud and boundary layer properties.

In this paper, we use observations from the ARM SGP to add to the continental stratus data base and thus to improve cloud parameterizations in climate models. Central to this study are statistical descriptions of cloud and boundary layer properties. We have identified periods (four or more consecutive hours) when continental stratus were observed over the SGP site and have developed statistical descriptions of macroscopic cloud and boundary layer characteristics for differing synoptic conditions. Macroscopic cloud statistics based on hourly averaged data have been produced for cloud base height, cloud top height and cloud thickness (cold season only), fractional cloudiness, and liquid water path. Moreover, statistics of boundary layer characteristics have also been computed for lifting condensation level (LCL), wind speed and direction, surface energy budget fluxes, and boundary layer coupling.

All continental stratus hour statistics are classified into four synoptic categories by subjectively analyzing surface weather maps, numerical forecast model initialization analyses, and conventional rawinsonde data. These individual stratus cloud cases have been organized into a Continental Stratus Archive (CSA) located at *http://orca.rsmas.miami.edu/index.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. The composite descriptions developed here can be used to further build upon the current continental stratus climatology and aid in modeling efforts.

Cloud Base Height

Table 1 shows 1997 stratus cloud summary information obtained from the Belfort Laser Ceilometer (BLC) observations. Stratus cloud hours were defined as any hour, included in a group of at least four consecutive hours, that had at least 50% zenith cloud fraction. Since this classification also allows for fractional cloudiness less than 100%, some of the clouds identified as stratus may be associated with fair-weather cumulus fields with fractional cloudiness greater than 50%.

Table 1. Summary of data used to determine cloud statistics for all synoptic categories and months (from the BLC).

Synoptic Classification	Number of Hours	Percent of Total Hours
Post cold frontal	721	49.3
Pre warm frontal	135	9.2
Southerly flow regime	382	26.1
Miscellaneous	225	15.4
Month		
January	157	10.7
February	195	13.3
March	144	9.8
April	145	9.9
May	93	6.4
June	36	2.5
July	10	0.7
August	24	1.6
September	85	5.8
October	169	11.6
November	139	9.5
December	266	18.2

From the table it can be seen that the majority of stratus cloud events (nearly 50%) occurred after cold frontal passages as stronger winds maintained mixing in a moist boundary layer. Moreover, it is evident that stratus was infrequent during the summer months (June, July, and August) where the percentage was under 5%.

Figure 1 shows a comparison plot between observed cloud base height and the calculated LCL, using both the BLC and the Micro-Pulse Lidar (MPL), for all 1997 stratus hours. This figure indicates that the majority of the cloud observations are associated with bases below 1 km. Further, in general the BLC and MPL cloud base heights are strongly correlated. For higher cloud base heights, the observed cloud base height and the LCL diverge, indicating that the air near the surface is not well coupled to the cloud formation process.

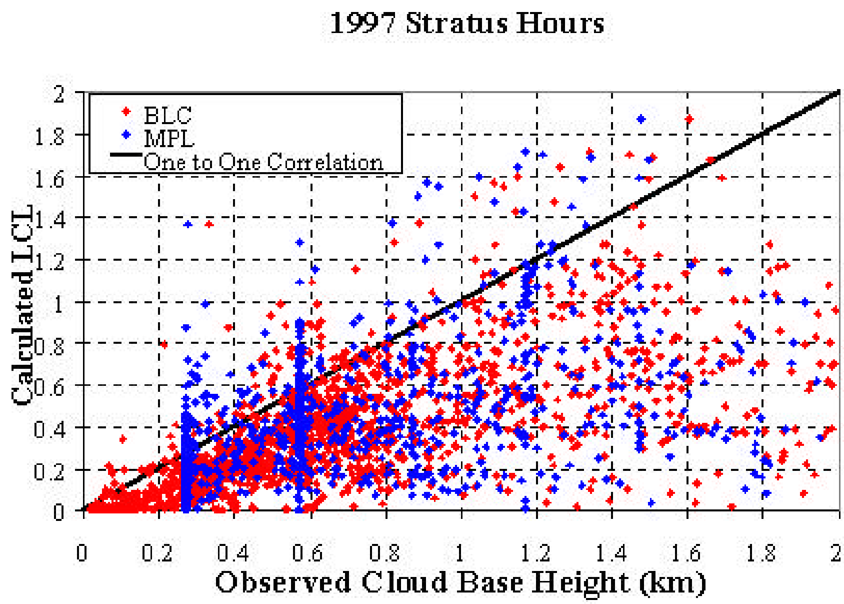

Figure 1. Correlation of the BLC and MPL cloud base height with calculated LCL values for all 1997 stratus hours.

Figure 2 shows the average cloud base height, standard deviation of cloud base height, and zenith cloud fraction for the four synoptic categories.

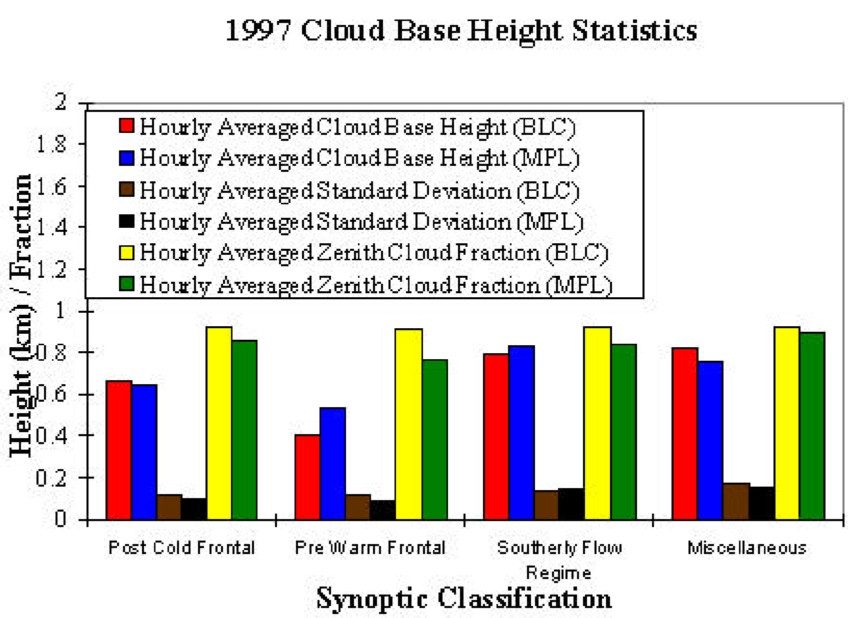

Figure 2. Hourly cloud statistics for both the BLC and MPL for all synoptic classifications.

Similar values were observed by Thomas (1996) during the fall 1994 Continental Stratus Experiment over central Pennsylvania. This figure shows that on average the cloud base heights and the associated standard deviations from the BLC and the MPL are in good agreement. The best agreement was during the post cold frontal hours, while the worst was during the pre-warm frontal stratus. In addition, the highest cloud base heights occurred during the miscellaneous and southerly flow classifications, while the lowest occurred during the pre-warm frontal hours.

Cloud Top Height and Thickness

Statistics on cloud top height were tabulated for 1997. The contamination of the 94-GHz cloud radar data by non-meteorological targets (mainly bugs) posed a great number of additional complications in the data. As a result, statistics presented here are only from the cold season taken to be from November to February. This figure illustrates some interesting features between these two synoptic categories. The first relative maximum frequency in cloud top height occurs 300 m lower under southerly flow conditions than in the post cold frontal clouds. This is most likely a result of lower cloud bases due to a more moist boundary layer and weaker surface fluxes resulting from lighter winds and less solar radiation. The post cold frontal clouds have a single maximum around 1.1 km to 1.2 km with a gradual and uniform decrease in frequency. On the other hand, the southerly flow regime clouds show three local maxima: 0.7 km to 0.8 km, 2.0 km to 2.1 km, and 2.6 km to 2.7 km. See Figure 3.

Boundary Layer Wind Speed

Mean low-level wind profiles (0.3 km to 3.0 km) were calculated from 915-MHz wind profiler observations for the four synoptic classifications (Figure 4). These wind profiles indicate substantial differences between synoptic categories. For example, the southerly flow regime stratus hours show a strong increase in wind speed from 0.3 km to 1 km, indicating the development of the low-level jet just above the surface that is not evident in the other categories.

Summary

The SGP ARM data set is a rich source for studies of continental stratus clouds. Nearly 1500 hours of low cloud data were observed in 1997. Hourly averaged statistics were calculated and studied for cloud base height, cloud top height, cloud thickness, liquid water path, surface energy budget fluxes, boundary layer coupling, and wind speed and direction. Some of these results were shown here.

The data shows that the MPL agrees best with calculated values of the LCL, even at higher cloud base heights. The BLC cloud base height data compares much better with the LCL values after the observed instrument bias (Gottschalck et al. 1998) was removed in the fall of 1997. The above relationships hold for all four synoptic classifications.

The data also show that the boundary layer coupling decreases as the hourly averaged cloud base height and the standard deviation of hourly averaged cloud base height increases. No clear relationship is evident between boundary layer coupling and cloud fraction or wind speed.

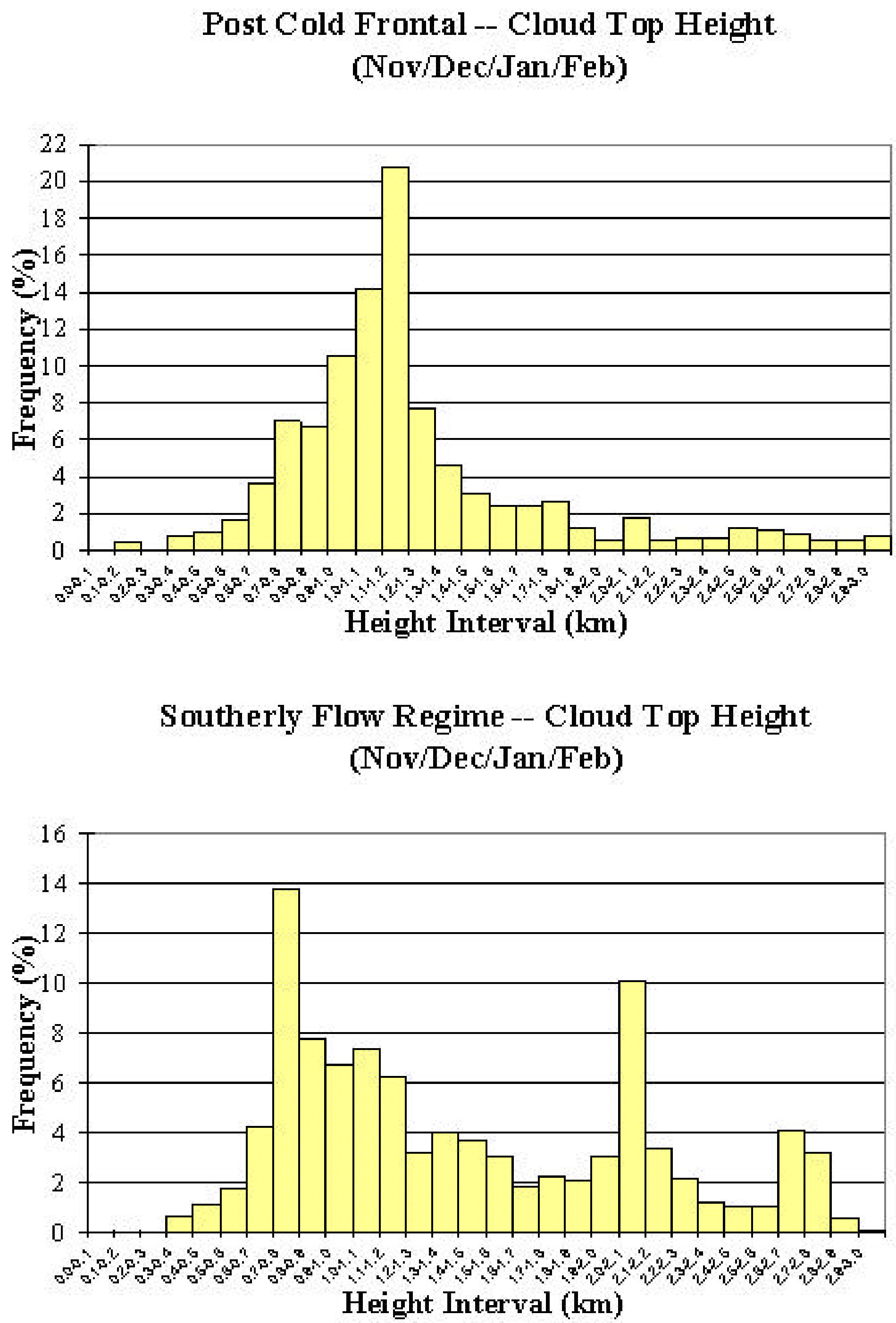

Figure 3. The frequency of cloud top height from the Millimeter Wave Cloud Radar (MMCR) for (a) the post cold frontal and (b) the southerly flow regime stratus hours.

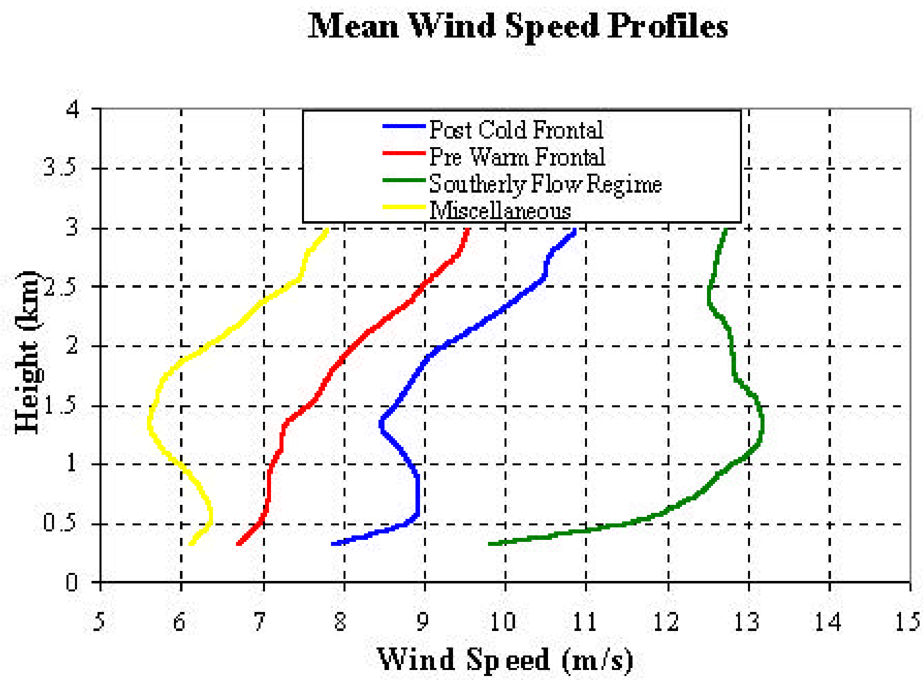

Figure 4. Mean wind speed profiles for the four synoptic classifications.

Cloud top and thickness data indicate significant variations between synoptic categories for cold season stratus. In addition, differences in the boundary layer mean wind speed profiles is clearly evident.

The differences between synoptic classifications noted above very clearly highlight the necessity to quantify and classify stratus cloud macroscopic properties (as observed by a suite of remote sensing systems) into distinct groups. The classification process must be performed objectively in order to assure that stratus cloud properties in differing synoptic regimes are correctly and *consistently* parameterized in numerical models so as not to erroneously impact the radiation field in global climate model simulations.

References

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.

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

Gottschalck, J. C., J. Pennington, and B. A. Albrecht, 1998: Macroscopic properties of boundary layer clouds at SGP CART site during 1996. In *Proceedings of the Eighth Atmospheric Radiation Measurement (ARM) Science Team Meeting*, DOE/ER-0738, pp. 287-290. U.S. Department of Energy, Washington, D.C.

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.