Observational Studies of Continental Stratus—Implications for Modeling

B. A. Albrecht
University of Miami
Miami, Florida

G. G. Mace
University of Utah
Salt Lake City, Utah

H. Verlinde and T. P. Ackerman
Pennsylvania State University
University Park, Pennsylvania

Introduction

Data from the Atmospheric Radiation Measurement (ARM) Program Southern Great Plains (SGP) site have tremendous potential for providing statistical descriptions of cloud and boundary layer properties associated with continental stratus. But blind application of these statistics may not be the most prudent approach for the development of physically based-cloud and boundary-layer parameterizations. In this study, we are using observations from two case studies of continental stratus to identify issues that may challenge efforts to model and parameterize continental clouds. Because our understanding of continental stratus is relatively immature, we also attempt to make comparisons with marine stratocumulus, an area where our current observational and modeling understanding is more advanced. Work in progress will take advantage of the continuous monitoring offered by the ARM SGP site to develop an extensive data base on continental stratus.

The two stratus cloud systems described in this study formed under similar synoptic conditions. Both were associated with cold-air advection on the southwest side of midlatitude cyclones. One system was observed at the ARM SGP site on 9 September 1995 and the other at a site over central Pennsylvania on 24 October 1996. The capping inversion in both cases was at about 1500 meters (Figure 1). Temperatures during the SGP case are about 2-3° C higher than the Penn State case, and the water vapor mixing ratio near the surface is about 4 g/kg higher. The instrumentation used in these two case studies is similar. The Penn State 94-GHz radar was operated at the ARM site in support of an intensive observing period in September 1995. Other data used in

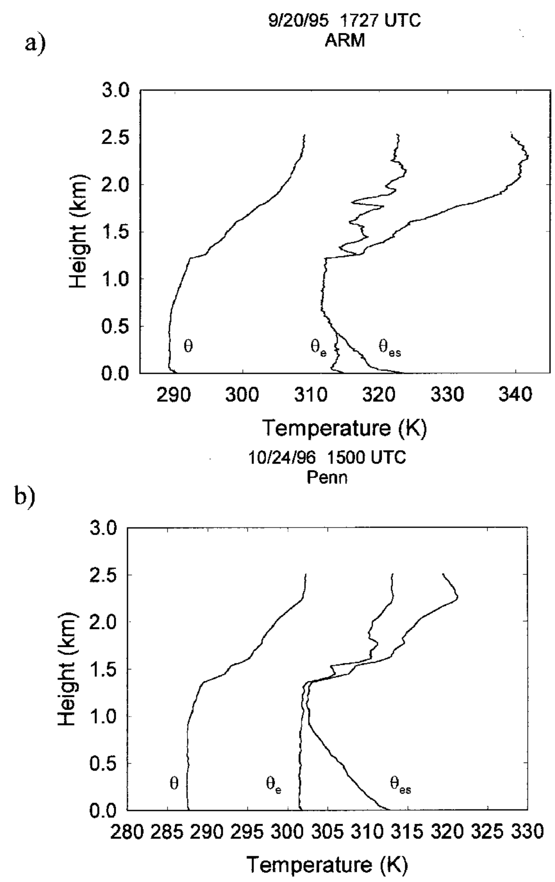

Figure 1. Potential temperature, equivalent potential temperature, and saturation equivalent potential temperature for a) the decoupled boundary-layer observed over the ARM SGP site and b) the well-mixed boundary-layer observed over central Pennsylvania.

this study are from instruments that operate routinely at the SGP site. The cloud radar was also in operation for the Penn State case. In addition, the Wyoming King Air made a comprehensive set of in-cloud measurements over the central Pennsylvania site.

Issues Important for Modeling

Boundary-Layer Decoupling

Despite the similarity in the synoptic conditions that are operating in the two cases under study, the cloud and boundary-layer structures differ substantially. The ARM cloud system (Figure 1a) is associated with a decoupled boundary-layer with cumulus rising into and feeding a stratus layer in a fashion similar to that of systems that are observed frequently over the oceans (Albrecht et al. 1995a,b). The Penn State cloud system is associated with a classic well-mixed boundary-layer and a relatively uniform cloud base (Figure 1b). The decoupling in the ARM case is also clearly indicated by differences between the lifting condensation levels (LCL) calculated from surface temperature and moisture measurements and the cloud base height from a laser ceilometer (Figure 2). The 915-MHZ radio acoustic sounding system (RASS) operating at the ARM SGP site is a very useful tool for documenting decoupling and boundary-layer stability. In Figure 3, we show hourly profiles of virtual dry static energy ($s_v=c_pT_v+gz$) for a 6-hour period of the ARM stratus case

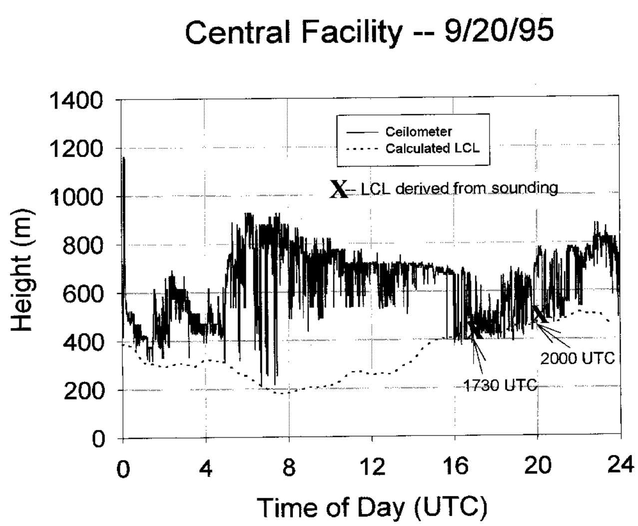

Figure 2. Cloud base height from the Belfort ceilometer and the LCL calculated from surface observations of temperature and moisture made from the Central Facilities (CF) at the ARM SGP site. LCLs from the soundings were calculated from air in the 100-200 m layer.

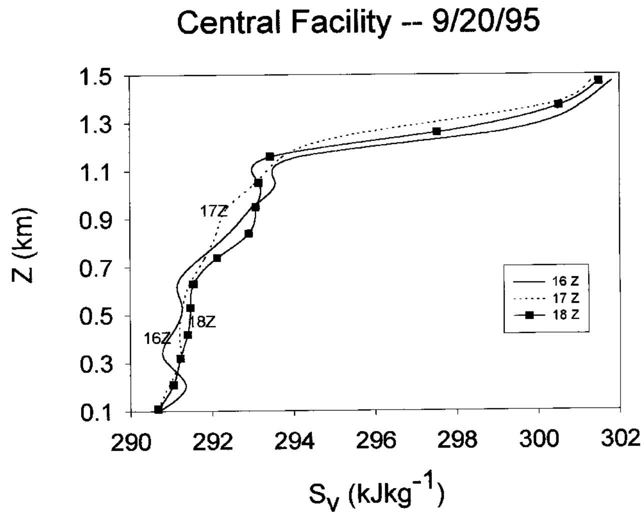

Figure 3. Virtual dry static energy profiles calculated using virtual temperature from the SGB CF 915 MHz radio acoustic sounding system (RASS).

calculated using RASS virtual temperatures. The capping inversion is well defined in these profiles, and the stable layer below this inversion near 700 meters is consistent with decoupling.

Feedbacks with Surface Processes

Unlike their marine counterparts, continental stratus clouds are involved in a two-way connection to the surface energy and moisture budgets on time scales of hours. Heating during the day can force mixing that can increase cloudiness, which in turn diminishes the surface solar radiation. The ARM case, for example, shows an inverse correlation between the net radiation at the surface and the cloud liquid water path on a time scale of hours (Figure 4).

Mesoscale Structure

Returns from the 94-GHz radar for the ARM case indicate cloud variability on the order of hours. Likewise, a collection of four soundings taken within about a 100-mile radius of the SGP Central Facility (Figure 5) indicate substantial mesoscale variability in the boundary-layer structure. Mesoscale variability in decoupled boundary-layers associated with cumulus rising into stratus is frequently observed with marine clouds (Miller and Albrecht 1995). It is unclear, however, if the mechanisms that give rise to mesoscale variability in the marine stratocumulus are similar to those operating in continental stratus.

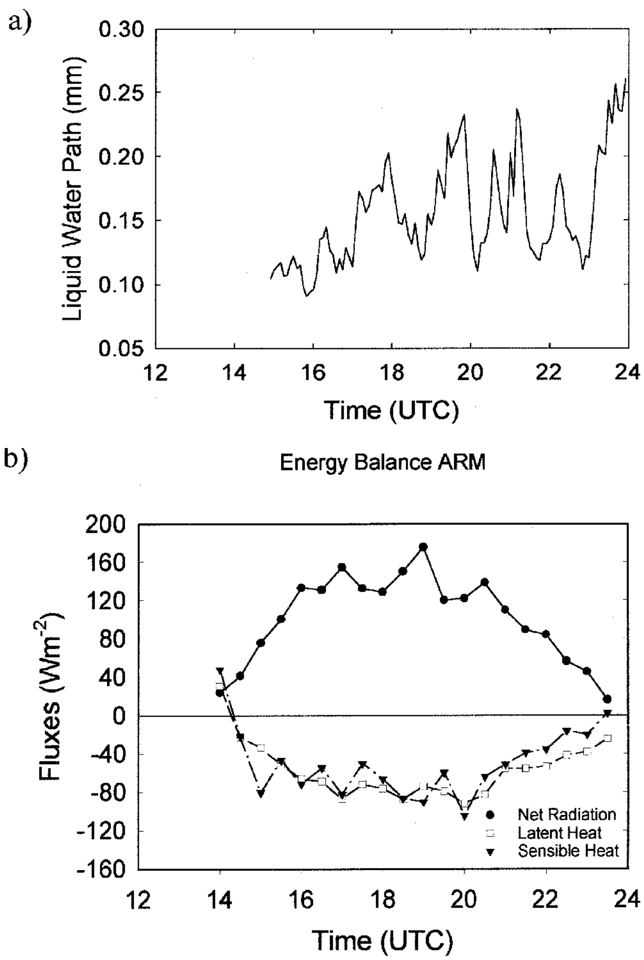

Figure 4. Observations on 20 September 1995 of a) liquid water path from the microwave radiometer and b) surface energy balance for the ARM case.

Cloud Microphysics

The Wyoming King Air was used to make in situ cloud microphysical measurements in the Penn State cloud system. Although small-drop concentrations in this system are typical of continental clouds with concentrations between 500 to 700 cm^{-3} with mean diameters of about 8 mm, there were still 10-30 liter^{-1} drops at 20-200 mm and a few drops at 200-800 µm even though the cloud is only about 500 meters thick. Although the large-drop production in continental stratus may not be as extensive as in marine stratus, it may still be important in regulating cloud properties.

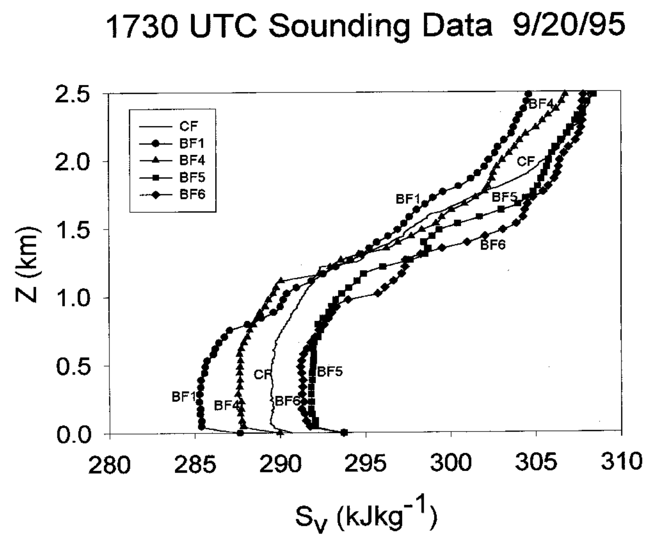

Figure 5. Virtual dry static energy profiles from soundings made from the central facility and the boundary facilities.

Discussion

We have used observations from the ARM SGP site and from a site over central Pennsylvania to identify issues that are relevant to the modeling of continental stratus clouds. At the same time, these issues should be considered carefully as observing tools and strategies are further developed and refined for use at the ARM SGP site.

References

Albrecht, B. A., C. S. Bretherton, D. Johnson, W. H. Schubert, and A. S. Frisch, 1995a: The Atlantic stratocumulus transition experiment—ASTEX. *Bull. Amer. Meteor. Soc.*, **76**, 889-903.

Albrecht, B. A., M. P. Jensen, and W. J. Syrett, 1995b: Marine boundary layer structures and fractional cloudiness. *J. Geophys. Res.*, **100**, 14209-14222.

Miller, M., and B. A. Albrecht, 1995: Surface-based observations of mesoscale cumulus-stratocumulus interactions during ASTEX. *J. Atmos. Sci.*, **52**, 2809-2826.