Triggering of Boundary Layer Cumulus Clouds Over a Heterogeneous Surface

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Complex multimodal joint frequency distributions of LCL height versus θ_v in surface-layer air over a large heterogeneous surface area are modeled as the superposition of simpler mono-modal distributions. These simpler distributions, which apply to quasi-homogeneous subdomains, are approximated with bivariate distribution models. The shape of each of these modeled distributions depends on variations of the Bowen ratio and heat input forcings. These forcings are a function of the landscape, insolation, surface albedo, cloud-shading, soil moisture, and other factors that either are known as imposed boundary conditions or can be resolved or parameterized on the coarse grid scale of a global climate forecast model (GCM).

This approach is motivated by the need to forecast subgrid-scale boundary-layer cumulus clouds in GCMs and in one-dimensional (single column) forecast models. The full distribution function, formed as a composite from the simpler models, can be combined with mean virtual temperature sounding information to forecast cloud onset time, cloud coverage, cloud base and heights, and cloud size distributions of an ensemble of subgrid clouds. Thus, land-use inventories or similar satellite-based observations of relative landscape amounts have the potential to be combined with distribution parameterizations such as those explored here to forecast subgrid clouds.

As a case study, we have analyzed aircraft data from the Hydrologic Atmospheric Pilot Experiment (HAPEX) field experiment in southwest France, which was designed to answer basic questions about GCM subgrid modeling within a horizontal grid area 100 km on a side. For this data set, we found that bivariate range-cut Gaussian or pq distribution models work equally well to approximate the simpler mono-modal distributions within quasi-homogeneous subdomains. The Gaussian distribution requires two fewer parameters than the pq distribution, and the parameters can be objectively determined with a relatively straightforward maximum-likelihood statistical fitting method.

For the whole grid-cell domain, however, we find that a simple model is not adequate to describe the complex multi-modal distributions. Instead, we recommend that these complex distributions be built as a composite from the simpler Gaussian distributions. The composite is formed by adding simple joint frequency distributions (JFDs) together in proportion to the relative abundance of their corresponding surfaces within a GCM grid cell. Figure 1 shows examples of modeled fits to composite observations from various flight tracks of data obtained in the surface layer during HAPEX.

The offsets of each simple JFD from the GCM cell average is quantified as a function of land use and mean weather conditions, thereby allowing it to be incorporated into GCM forecast models. An example of such offsets for the HAPEX data is shown in Figure 2.

These results have been submitted (Schrieber et al.)[(a)] as the first of a series of papers on parameterizing subgrid cumulus for GCMs. This first paper quantifies the joint frequency distributions. A second paper will describe the variable heterogeneity induced by cloud shadows. A third paper will use these previous results to describe a method for forecasting cumulus clouds. The fourth paper will explore the parameterization of cumulus population size parameters, cloud base height distributions, and similar matters. These results will then be extended to include the

(a) Schrieber, K., R. B. Stull, and Q. Zhang. Boundary-layer cumulus: Part 1 - Distributions of buoy-ancy versus LCL over a heterogeneous surface. Submitted to *J. Atmos. Sci.*

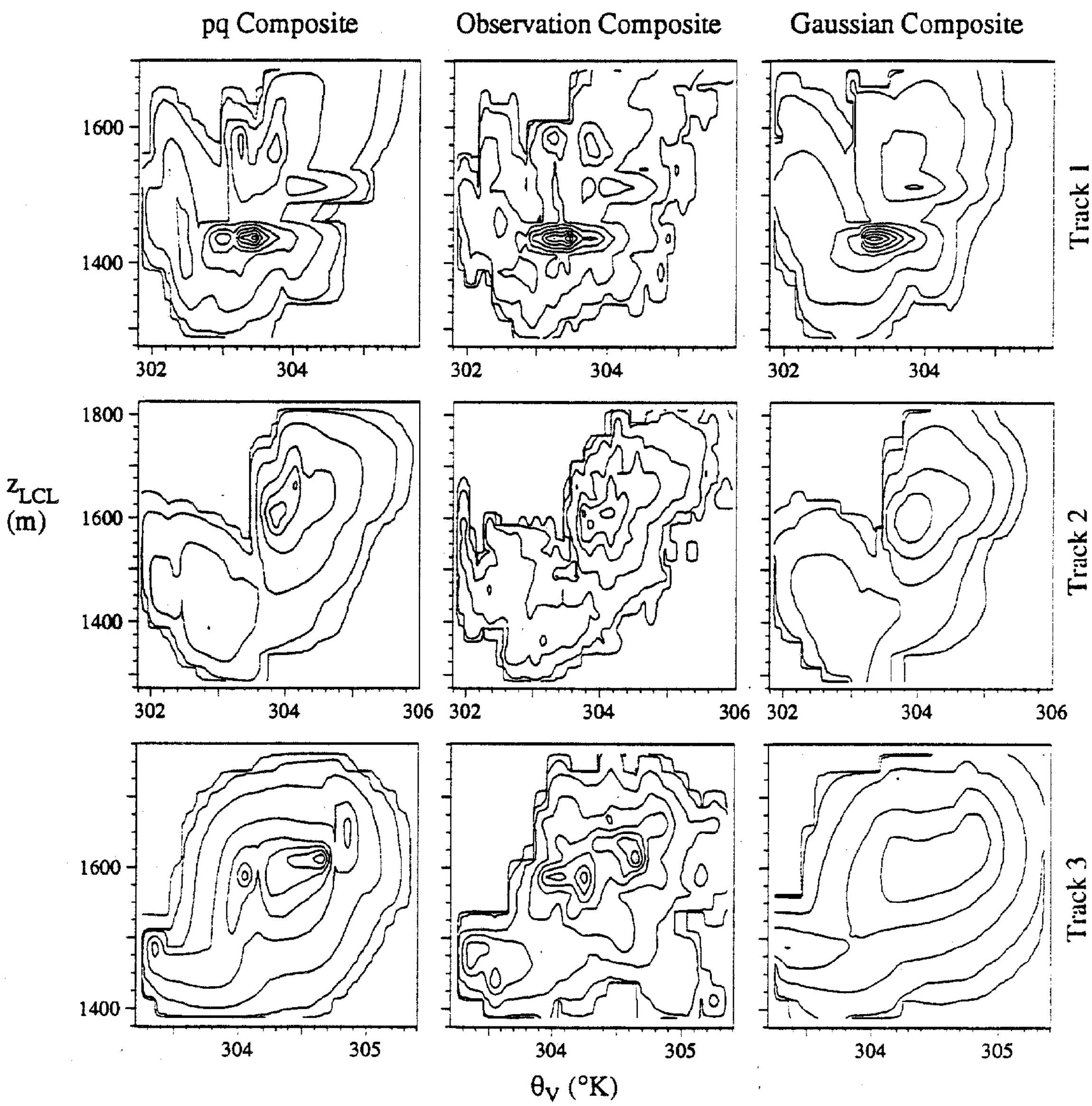

Figure 1. Example of modeled fits to composite observations from various flight tracks of surface layer data from HAPEX.

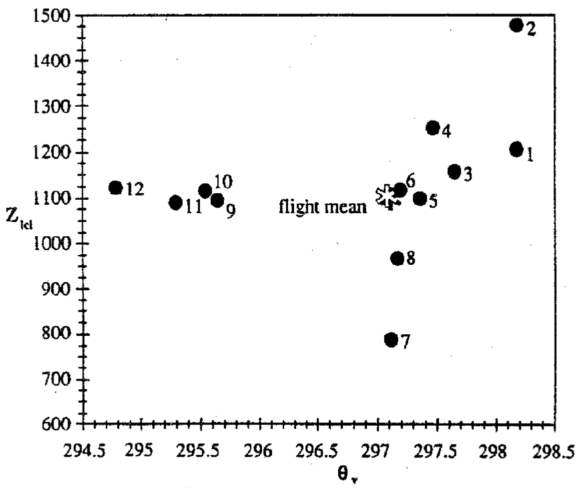

Figure 2. Offset of simple joint frequency distribution quantified as a function of land use and mean weather condition.

rich array of measurements from the Atmospheric Radiation Measurement (ARM) Cloud and Radiation Testbed (CART) site in the central plains.

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