Objective Synoptic Classification of Stratus: Impact on Macroscopic Cloud Statistics

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Introduction

Stratus 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. Therefore, it is necessary that adequate observational databases exist for both continental and maritime boundary layer clouds. Stratus cloud and environmental properties may vary as a function of the large-scale synoptic regime. These differences can have a significant impact on radiative transfer and cloud microphysics and therefore on cloud, boundary layer, and climate modeling. A number of subjective synoptic classification schemes have been performed, but vary in their selection criteria. This creates difficulty in consistently applying statistical descriptions of clouds in model parameterizations. Objective methods need to be evaluated in order to consistently and accurately parameterize cloud properties in numerical model simulations.

Background

Stratus clouds observed at the Atmospheric Radiation Measurement (ARM) Program's Southern Great Plains (SGP) Cloud and Radiation Testbed (CART) site during 1997 were subjectively classified into four synoptic categories (Table 1) by analyzing surface weather maps, numerical model initialization data, surface meteorology data, and rawinsonde data (Gottschalck and Albrecht 2000).

Table 1. The number of stratus hours for each synoptic classification.

Category	Number of Hours
Post-Cold Frontal	721
Pre-Warm Frontal	135
Southerly Flow Regime	382
Miscellaneous	225

The results from this research indicate some significant variations in cloud macroscopic and boundary layer statistics, such as for the diurnal distribution of cloud base height (Figure 1). Differences were also evident in cloud base height and mean vertical profiles of potential temperature, mixing ratio, wind speed, and wind direction (not shown).

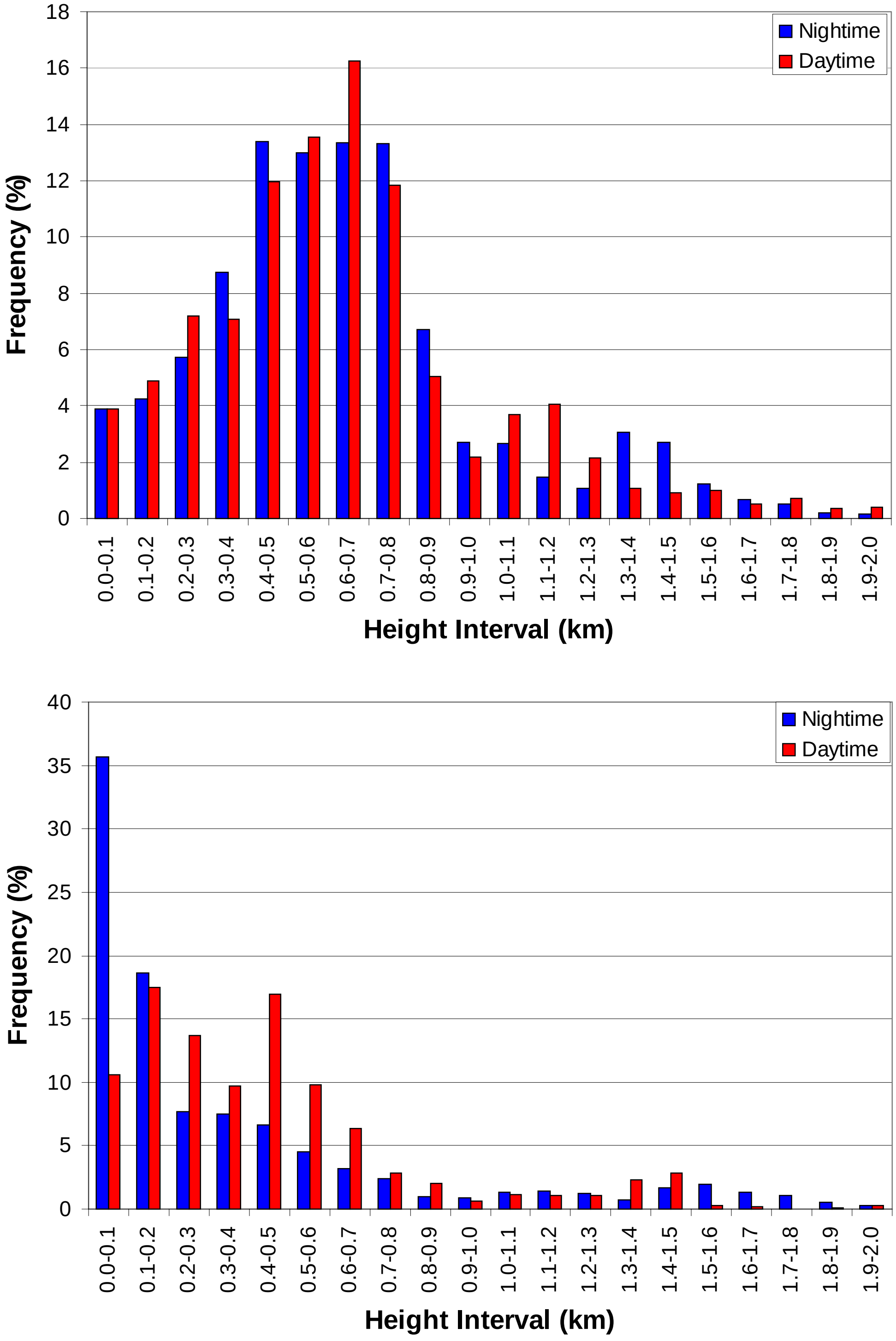

Figure 1. Diurnal distribution of cloud base height for the post-cold frontal and pre-warm frontal stratus hours.

Methodology

Because of questions of consistency in classification and available time resources, subjective classification techniques make comparisons difficult. Objective classification provides a more consistent method of grouping the data and may highlight important differences in the cloud macroscopic and boundary layer statistics not captured by subjective classification.

We use a principal component analysis (PCA) approach to classify stratus clouds observed during 1997 into distinct synoptic weather regimes. The technique organizes rawinsonde data into groups having similar thermodynamic and wind structures, thus allowing cloud cases that occur under a similar synoptic environment to be grouped together. The objective composite descriptions developed here can be used to further build upon the current continental stratus climatology and aid in modeling efforts.

Of the 1463 total hours of stratus used in the subjective classification, 265 soundings were available for the PCA. The weather regimes were defined objectively by using cluster analysis similar to the procedure outlined by Zivkovic and Louis (1992), which consists of two stages: PCA of the basic variables and clustering of their loading scores. First, the principal components of the analyzed profiles must be identified. Each analyzed profile consisted of 57 components: surface pressure (P_s), 14 levels of potential temperature (θ), mixing ratio (w), zonal wind (u), and meridional wind (v). Levels included: surface, 950, 925, 900, 875, 850, 825, 800, 750, 700, 650, 600, 550, and 500 mb. An environmental profile at a single point *i* can be defined as a vector such as:

$$x^i = (P_s, \theta_1, \ldots, \theta_{14}, w_1, \ldots, w_{14}, u_1, \ldots, u_{14}, v_1 \ldots, v_{14})$$

This is a large number of components to represent the environment at a single point, and it contains much redundant information. The number can be reduced by expressing the profiles in terms of PCs. For legitimate comparison of all fields, the data must first be normalized by subtracting the mean of the profiles and dividing each component by the standard deviation.

The second stage of the procedure is to expand the original data in terms of the PC as given below:

$$X^i = \sum_{1}^{57} a^i_j P_j$$

Where x^i is the i_{th} profile, P_j the PC corresponding to the j-th eigen value and a^i_j are the component loading scores for the i_{th} profile. Similar profiles have similar a^i_j so the weather categories can be defined by clustering of the PC loading scores. Each cluster will define a weather regime and the profiles are clustered according to the similarity of their loading score vectors. Mean profiles of θ, w, u, and v were computed and these are shown as a function of cluster in Figure 2.

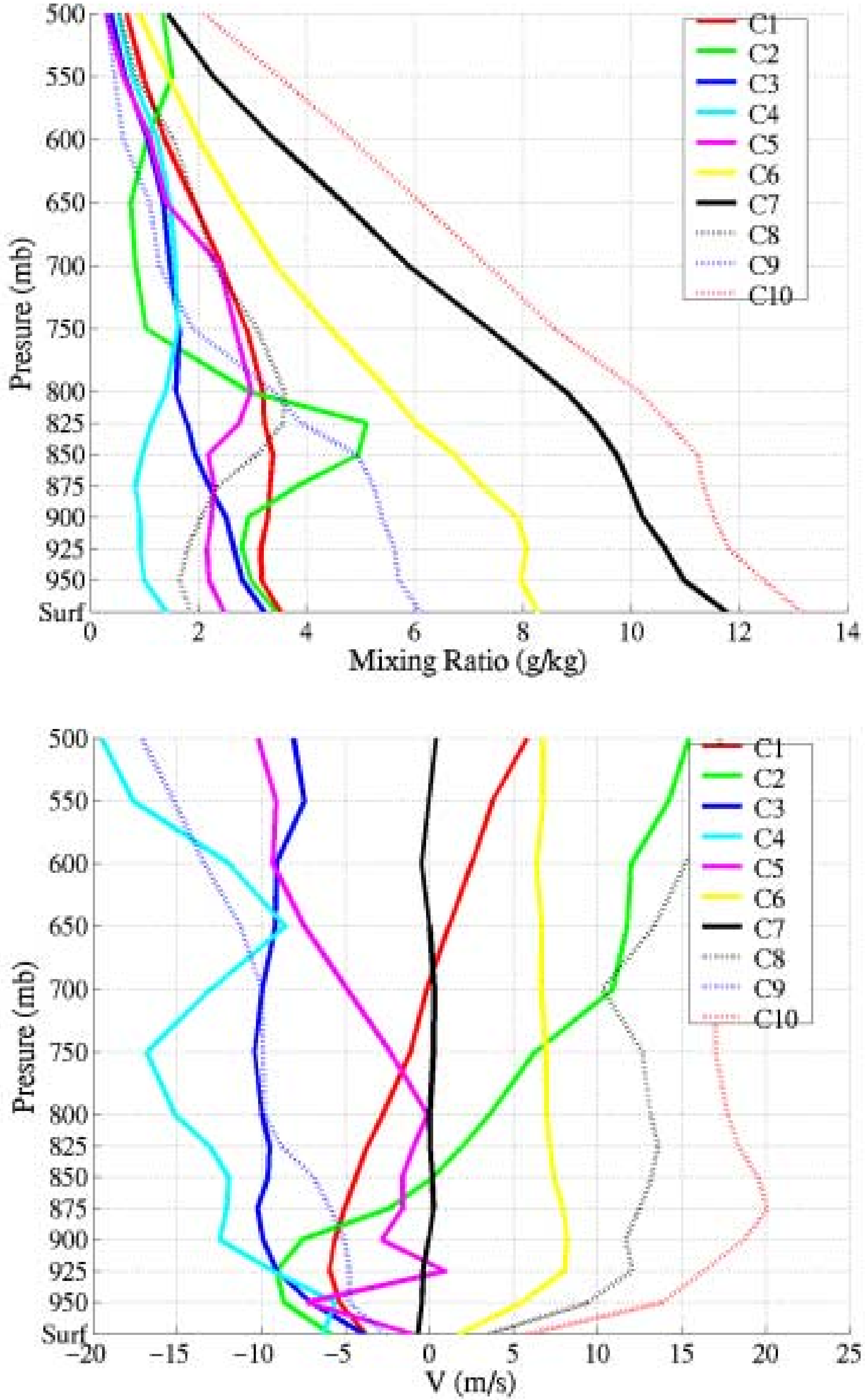

Figure 2. Mean profiles of mixing ratio (w) and meridional wind (v) for all ten clusters.

Results

Based on the cluster analysis, mean profiles of mixing ratio (w) and meridional wind (v) were computed (Figure 2) for the ten clusters. Focusing on clusters 1, 6, and 7 (clusters with the greatest number of soundings), it is clear that distinct differences exist. Also, it is evident that cluster 1 is drier than the other two clusters with significant cold advection likely in the lower levels as v is negative. On the other hand, cluster 6 is more moist with warm advection.

The primary objective of this work was to determine whether applying a more objective methodology to synoptic classification would result in less or more variability in cloud macroscopic and boundary layer properties under differing synoptic weather conditions. Figure 3 illustrates mean cloud base height, cloud top height, and cloud thickness as calculated from rawinsonde data for the ten clusters. It shows significant differences between the ten clusters with cloud base height varying from 0.4 km to 1.7 km, cloud top height from 0.9 km to 1.8 km, and cloud thickness from 0.1 km to 1.0 km. The three main clusters show only modest differences. These ideas are corroborated by using the Belfort laser ceilometer to calculate mean hourly averaged cloud base height, standard deviation, and zenith cloud fraction (not shown). In addition, a cluster comparison for both sub-cloud and in-cloud stability (not shown) indicate there are substantial differences between the ten clusters in both parameters with sub-cloud and in-cloud values ranging from 0 $\mathrm{kJkg^{-1}km^{-1}}$ to 11 $\mathrm{kJkg^{-1}km^{-1}}$ and 4 $\mathrm{kJkg^{-1}km^{-1}}$ to 17 $\mathrm{kJkg^{-1}km^{-1}}$, respectively. Clusters that contain the greatest post cold frontal soundings (1, 3, and 9) indicate results consistent with those obtained in the subjective analysis; that is, a more well mixed sub-cloud layer and strong inversion at cloud top.

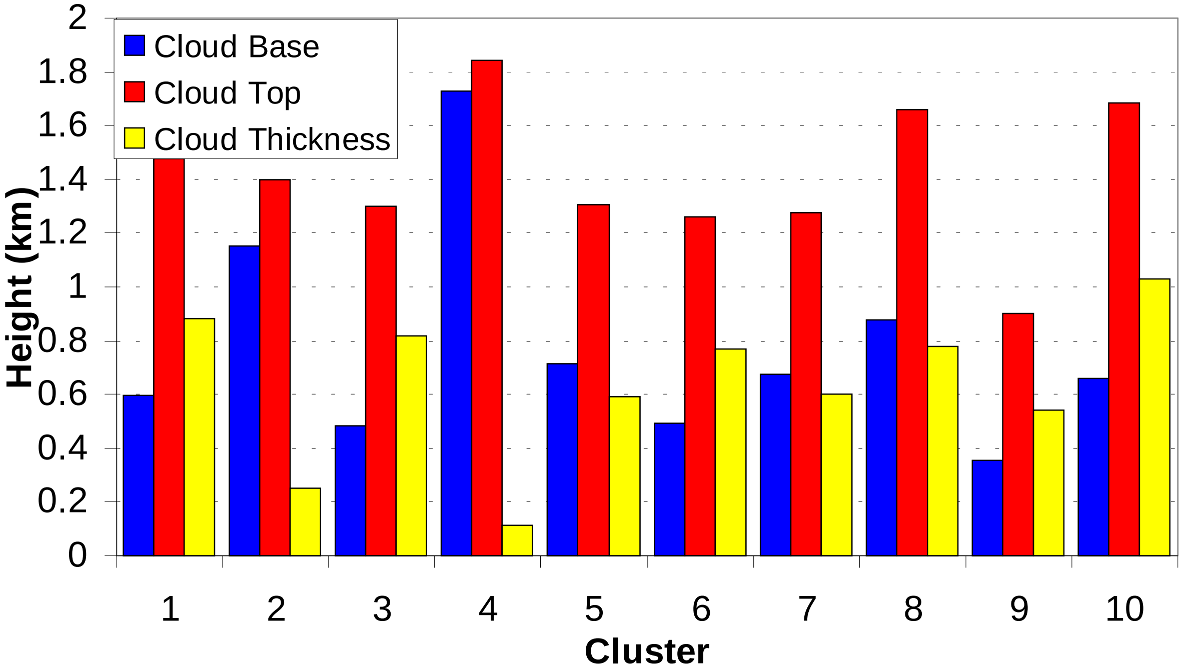

Figure 3. Average cloud base height, cloud top height, and cloud thickness derived from rawinsonde data for all ten clusters.

Summary

Stratus clouds observed during 1997 were objectively classified into ten different weather regimes, and the cloud macroscopic and boundary layer properties were calculated and compared with equivalent statistics assembled from a subjective classification. The findings presented here illustrate three main points:

(1) The objective mean profiles show substantial variation in four important parameters, θ, w, u, and v as well as surface pressure (substitution of surface pressure tendency (dP_s/dt) for P_s did not significantly alter the findings of the cluster analysis).

(2) The cluster analysis was unable to completely differentiate the soundings into the four subjective synoptic categories described earlier as a number of clusters contained soundings from all four of these categories. Clusters 1 and 6 were the only weather regimes that could realistically be compared with a subjective classification (post cold frontal and southerly flow regime, respectively) as greater than 50% of the total soundings were from these subjective categories.

(3) Despite the results of (2), cloud macroscopic and stability properties still showed substantial variation in their statistics across the range of clusters, although the three main clusters (1, 6, and 7) showed smaller differences.

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References

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