A Climatology of Fair-Weather Cloud Statistics at the Atmospheric Radiation Measurement Program Southern Great Plains Site: Temporal and Spatial Variability

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Motivation

In previous work, Berg and Stull (2005) developed a new parameterization for Fair-Weather Cumuli (FWC). Preliminary testing of the new scheme used data collected during a field experiment conducted during the summer of 1996. This campaign included a few research flights conducted over three locations within the Atmospheric Radiation Measurement (ARM) Climate Research Facility (ACRF) Southern Great Plains (SGP) site. A more comprehensive verification of the new scheme requires a detailed climatology of FWC. Several cloud climatologies have been completed for the ACRF SGP, but these efforts have focused on either broad categories of clouds grouped by height and season (e.g., Lazarus et al. 1999) or height and time of day (e.g., Dong et al. 2005). In these two examples, the low clouds were not separated by the type of cloud, either stratiform or cumuliform, nor were the horizontal chord length (the length of the cloud slice that passed directly overhead) or cloud aspect ratio (defined as the ratio of the cloud thickness to the cloud chord length) reported. Lane et al. (2002) presented distributions of cloud chord length, but only for one year. The work presented here addresses these shortcomings by looking explicitly at cases with FWC over five summers. Specifically, we will address the following questions:

- Do the cloud fraction (CF), cloud-base height (CBH), and cloud-top height (CTH) of FWC change with the time of day or the year?
- What is the distribution of FWC chord lengths?
- Is there a relationship between the cloud chord length and the cloud thickness?

Data Analysis Methods

Three different ARM data streams form the basis of our analysis. First, periods with fair-weather clouds were determined from the Active Remotely Sensed Clouds Locations (ARSCL) Value-Added Product (VAP) for the summers of 2000 through 2004, inclusive. An initial set of days that might have fair-weather clouds was determined by eye from the ARSCL time series. We looked for cases in which there was little or no CF early in the day, the CBH was between 1 and 3 km, and the CTH was less then 6 km. After this preliminary list was compiled, movies were created from the total sky imager (TSI) images, and these movies were checked to confirm that there were FWC on those days. This check removed days on which agricultural burning occurred near the SGP Central Facility, days in which the clouds appeared to be stratocumuli, and days in which there were large amounts of mid-level or high clouds.

Hourly averages of the CBH, CTH, and CF were computed from the ARSCL VAP using data from those days that were identified to have FWC. CBH and CTH were taken directly from the ARSCL VAP. CF was defined to be the fraction of the total time that FWC were observed in the ARSCL VAP. The cloud chord length is defined as the slice of cloud that passes through the cloud radar beam. This value is the product of the length of time that a cloud is intercepted by the radar beam and the wind speed at which the cloud is moving over the cloud radar. The length of time over the sensors was simply computed by the number of sequential ARSCL observations that showed a cloud overhead. No adjustment was applied to account for short breaks that might occur for an irregular cloud boundary. The wind speed at CBH was determined from the 915-MHz radar wind profiler operated at the Central Facility. The measured wind speed in the range gate that contained the observed CBH was used. Once the cloud chord length was determined, the cloud aspect ratio was computed by taking the ratio of the cloud thickness to the cloud chord length.

Hourly Variations of Cloud Macroscale Properties

Observations of the CF, CBH, and CTH from the days with FWC have been combined to form hour average composites (Figure 1). There seems to be little year-to-year variability in any of these variables, particularly the CF and the CTH. There is a weak tendency for the relatively dry years (2003 and 2001) to have slightly higher CBHs. As one would expect, there is some diurnal variation to the cloud properties. The CBH increases throughout the entire day. The CTH increases through the morning, but remains nearly constant or decreases in the afternoon. This behavior indicates that the cloud thickness decreases throughout the day (not shown). The CF quickly increases in the morning, reaches a peak between 12 and 14 CST and then decreases.

Similar to the observations of the CF, CBH, and CTH, observations of the cloud-chord length and the cloud aspect ratio were combined to form hourly average composites (Figure 2). The composite cloud chord length increases some between 10 and 12 CST, but remains nearly constant throughout the afternoon. This behavior is expected because the FWC are associated with convective thermals in the boundary layer. These boundary-layer thermals scale with the mixed-layer depth, which increases in the morning and is often nearly constant throughout the early afternoon. The cloud aspect ratio decreases some throughout the day, which is related to a general decrease in cloud thickness throughout the day (not shown).

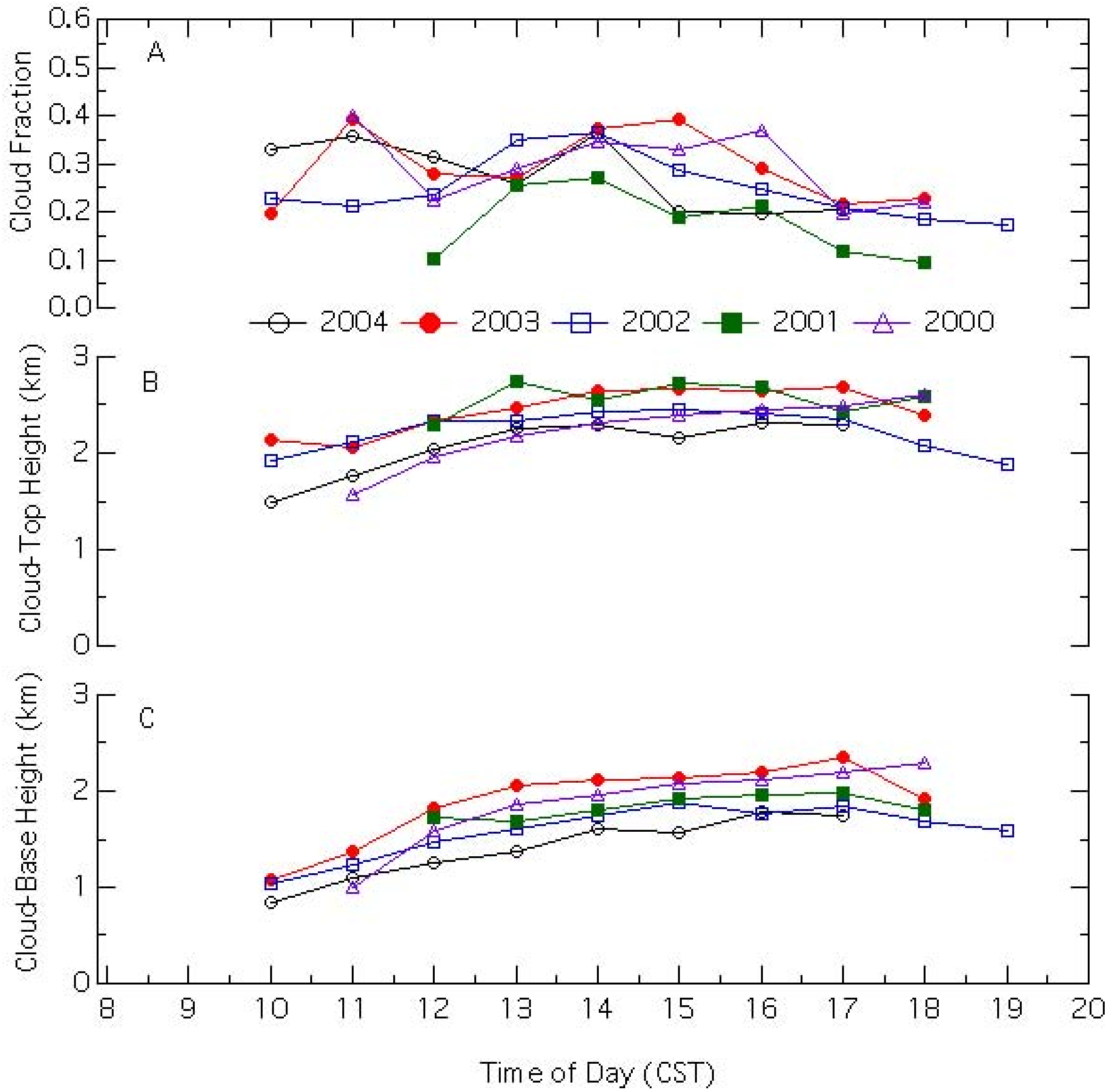

Figure 1. Composite average CF (A), CTH (B), and CBH (C) for the summers of 2000 and 2004.

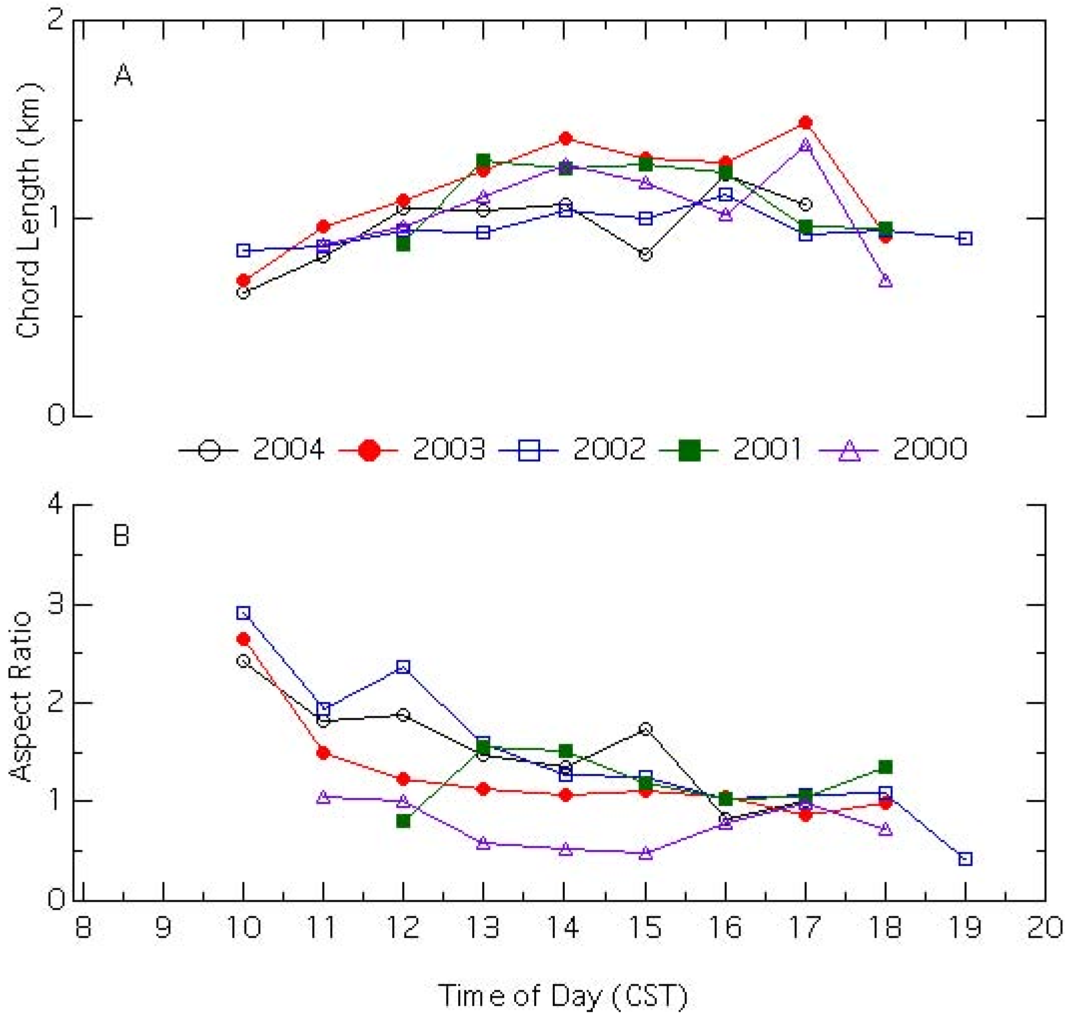

Figure 2. Composite average cloud chord length (A) and composite average cloud aspect ratio (B) for the summers of 2000 through 2004.

Cloud Chord Lengths

It is informative to look more closely at the distributions of cloud chord length. The distributions for each year are similar, with relatively small changes in the mean cloud chord length (Figure 3). Similar to the work presented by Plank (1969), we fit an exponential distribution, $F = Aexp(-Bl)$, where F is the frequency, l is the chord length, and A and B are fit-parameters used to fit to the observed distributions. The value of B determines how quickly the distribution decreases, and both A and B determine the mean of the distribution following the expression A/B^2. In this study, $A \approx B$, so that B^{-1} represents approximately the mean cloud chord length. A remarkable amount of agreement exists between the distributions computed for the separate years. In addition, the values of A and B do not change much from year to year. The values of B are consistent with the results of analysis of photographs by

Plank (1969) and Hozumi et al. (1982) who reported values ranging between 1 and 14 km^{-1}. Other authors have suggested either a single power law (Machado and Rossow 1993) or a double power law (Cahalan and Joseph 1989; Benner and Curry 1998; Sengupta et al. 1990), and we will address this future work.

Table 1. Best-fit statistics for exponential fits to the cloud chord length distributions.

Year	A	σ_A	B (km^{-1})	σ_B (km^{-1})
2000	0.99	0.034	0.95	0.046
2001	0.95	0.033	0.97	0.051
2002	1.1	0.018	1.1	0.025
2003	0.97	0.030	0.93	0.040
2004	1.0	0.040	1.0	0.054

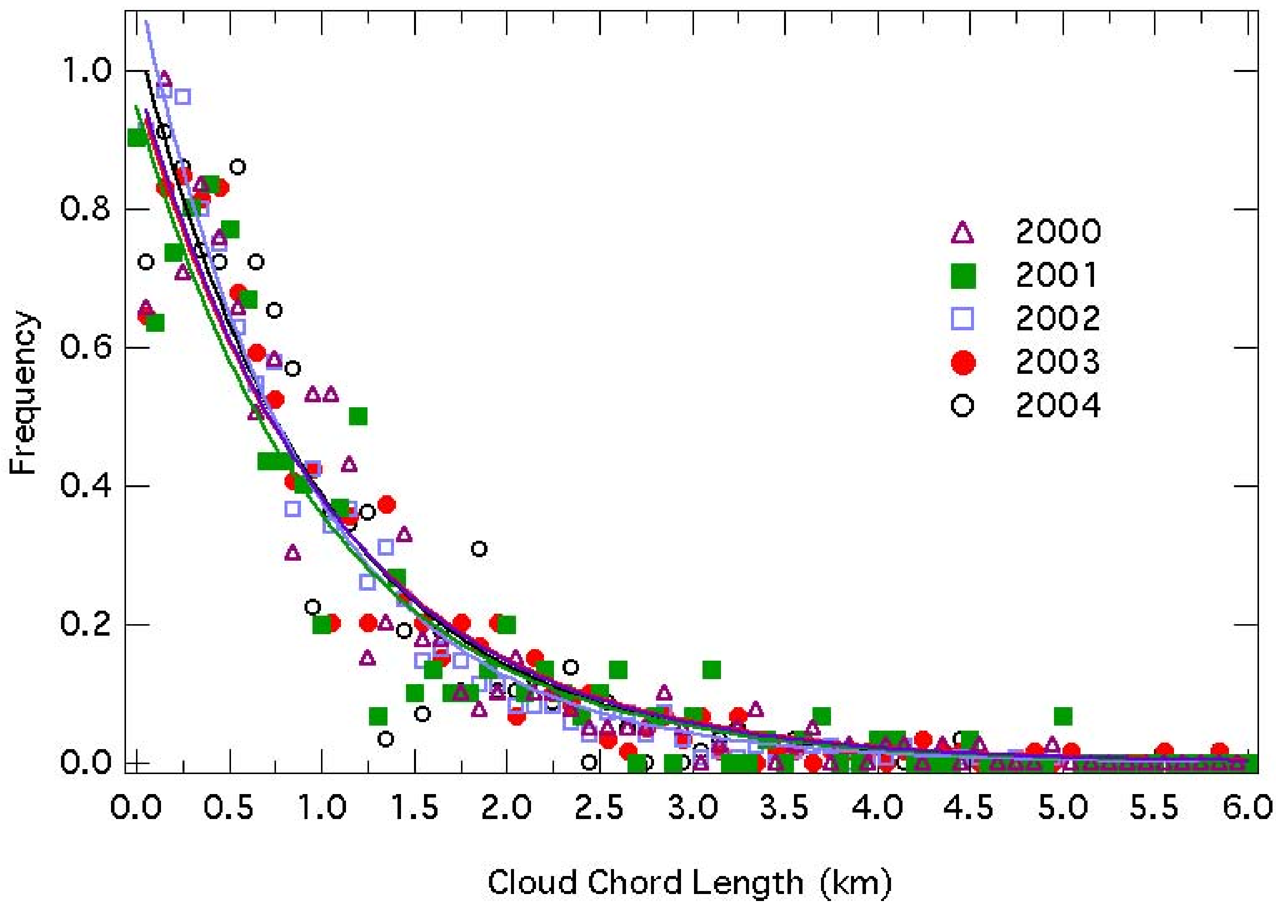

Figure 3. Observed (symbols) and best-bit exponential distributions (lines) for the summers of 2000 through 2004. Best-fit parameters are listed in Table 1.

Cloud Aspect Ratio

Cloud aspect ratio, which was defined to be the cloud thickness divided by the cloud chord length, was determined for our case study days. Large values of cloud aspect ratio indicate tall narrow clouds, while smaller values indicate short wide clouds. We found a larger range of values than suggested by other authors (e.g., Benner and Curry 1998). Most of the observed values of aspect ratio were between 0.25 and 2, which is reasonable for FWC (Figure 4).

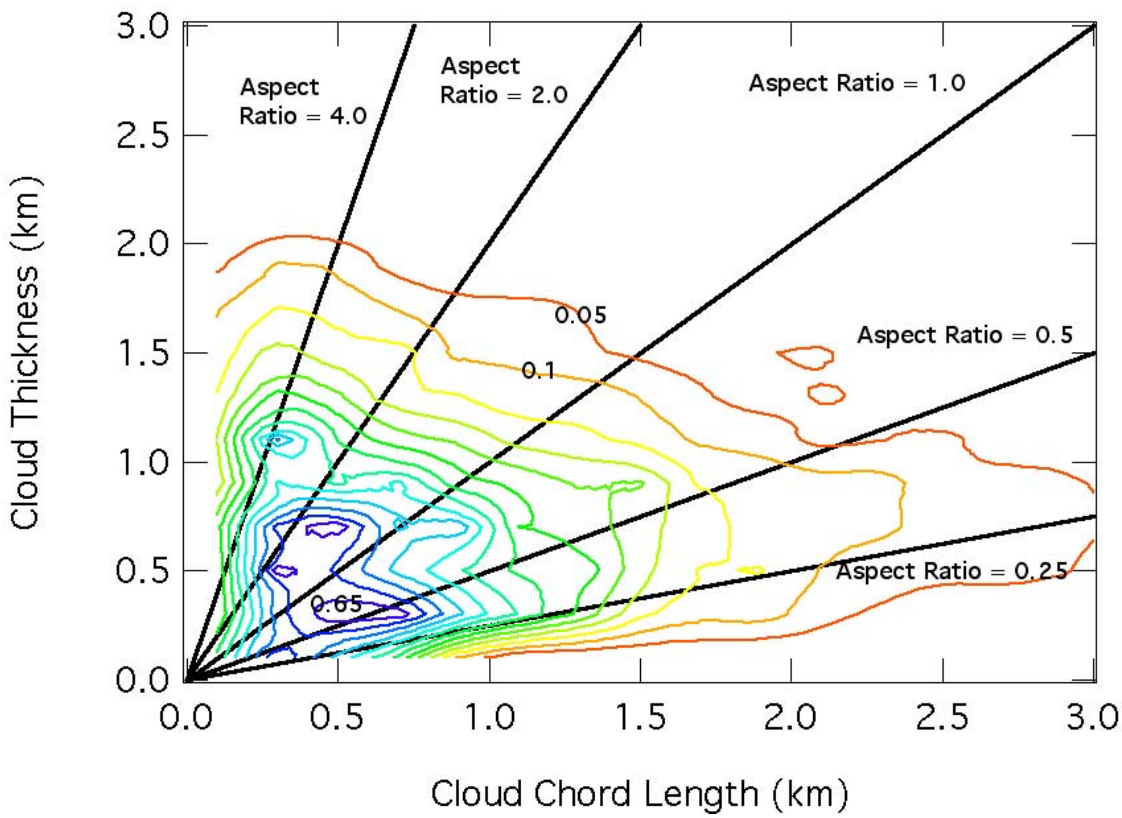

Figure 4. Joint Frequency Distribution of cloud chord length vs. cloud thickness for the summers of 2000 through 2004. The first contour indicates a frequency of 0.05, and the contour interval is 0.05. Solid lines indicate various cloud aspect ratios.

Cloud aspect ratio can also be computed from the TSI data using methods suggested by Kassianov and Long (2005). Their method compares the TSI images for both large and small fields of view to obtain an estimate of the cloud aspect ratio. If a cloud field is spatially homogeneous, then we expect that the cloud aspect ratio measured from the ARSCL data stream and wind profiler measurements would be in good agreement with the TSI estimate. For the case that we have examined, 27 July 2004, we see that there is good agreement between the two methods (not shown), suggesting that the cloud field is homogeneous.

Conclusions

A unique five-year cloud climatology for the ACRF SGP has been presented. The CBH, CTH, and CF all varied as a function of time of day. In general, the composite hourly averaged CBH, CTH, CF, cloud chord lengths and cloud aspect ratios did not vary much from year to year. The distribution of cloud chord lengths followed an exponential distribution that also did not change much from year-to-year. We did not find a single exclusive relationship between the cloud chord length and the cloud thickness; instead, we found that the cloud aspect ratio ranged between 0.25 and 2 for the FWC.

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