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# THE VARIABILITY OF CIRRUS CLOUDS DERIVED FROM 4 YEARS OF ARM DATA; RELATIONSHIPS TO THE LARGE-SCALE METEOROLOGY.

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## 1. INTRODUCTION

Previous studies have shown that the climate feedbacks associated with cirrus clouds on the results of general circulation models (GCM) are significant (*Cess et al., 1996*). Cirrus cloud feedback can either be positive or negative depending on the cloud microphysical and macro scale properties (*Stephens et al., 1990*). One method of improving a GCM's representation of cirrus is to limit the number of parameters by which a radiative balance in the model can be artificially imposed (*Del Genio, 2001*). In order to limit the number of these so-called tuning parameters more accurate cloud property statistics on the temporal and spatial scales used by climate models need to be obtained.

Until recently cirrus cloud properties could only be measured using aircraft, and other in-situ instruments. Unfortunately the short time span, and small area sampled by aircraft may not result in representative cloud property statistics useful on seasonal or yearly time scales. In an effort to obtain large temporal and spatial scale cloud property statistics the Atmospheric Radiation Measurement (ARM) program has deployed cloud remote sensing instruments, such as the millimeter cloud radar (MMCR). From data collected by the MMCR and the atmospheric emittance radiance interferometer, cloud microphysical properties are derived using the algorithm described in *Mace et al*. (1998). Since the MMCR is a continuously operating instrument there is now more than four-years of effective radius ($r_e$), ice water path (IWP), emissivity ($\varepsilon$), and optical thickness ($\tau$) statistics that will aid in improving cirrus parameterizations in GCM's.

In this paper we show the distributions of these cloud properties over a four-year period. Using data obtained from the ARM site, we also explore the seasonal and inter-annual variability of the observed and derived properties of clouds. Also, since cloud properties are sensitive to the mechanisms that generate them, there needs to be a better understanding of the large-scale meteorology occurring during cirrus events. Currently we are using the NCAR/NCEP reanalysis data to represent the mean large-scale meteorology occurring during cirrus events. Reanalysis data is used to determine the difference between the mean meteorology during days with cirrus events from the seasonal and inter-annual means. Results of this analysis and implications for the parameterization of cirrus in climate models will be discussed in this paper.

## 2. CLOUD PROPERTIES

According to the method described by *Mace et al.* (*1998*), our study is limited to optically thin cirrus events with no lower cloud layers. Using all the cloud observations during a cirrus event we derive event-averaged layer-mean values for IWP, $r_e$, $\varepsilon$, and $\tau$. Variability of these properties are shown as the average standard deviation ($\sigma$) within each event, and the standard deviation ($\Sigma$) of the event means.

### 2.1 Frequency of Occurrence

The frequency of occurrence distributions in figure 1 display cirrus cloud property statistics from 1997 to 2000. Histograms of IWP, $\varepsilon$, and $\tau$ show a logarithmic distribution, while the $r_e$ histogram has more of a gaussian form. The frequencies of the smallest IWP, $\varepsilon$, and $\tau$ bins are skewed somewhat toward larger values, by the difficulty of detecting very thin cirrus with the MMCR.

The mean, standard deviation ($\Sigma$), and median values of the event-averaged properties from

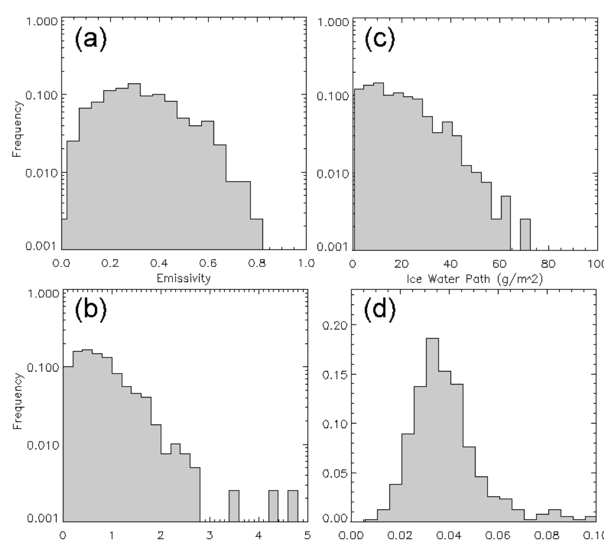


*Fig. 1. Cloud property frequency of occurrence distributions with their corresponding moments. (a) Emissivity (b) optical thickness (c) ice water path [g/m$^2$] (d) effective radius [mm]*

these distributions are 1.01 ± 1.53 and 0.69 for τ, 0.32 ± .16 and 0.30 for ε, 19.16 ± 15.16 and 16.50 *g/m²* for IWP, and 0.044 ± .030 and 0.037 mm for $r_e$. Values for ε and τ agree well with those obtained using the LIRAD method in *Sassen and Comstock* (2001), which are 0.75 ± 0.91 and 0.61 for τ, and 0.30 ± .22 and 0.25 for ε.

## 2.2 Yearly and Seasonal Variability

To find out if these cirrus property values are typical, we compared the mean of each event-averaged cirrus property for the years 1997 to 2000 (see Table 1). From this comparison we note that there are no significant changes from one year to the next. However, when each year is split into a warm and cold season a noticeable signal appears (see Figure 2). The warm and cold seasons are defined as the months from May to September and November to March, with an excluded transition month between the two seasons. During the cold season, $r_e$ is approximately 0.015-0.020mm smaller than during the warm season. Also, both the standard deviation of the events and the mean standard deviation within each event are smaller during the cold season. The seasonal variability that emerges from this data set might be related to the different cirrus cloud generating mechanisms occurring in one season more often than the other. We are continuing further analysis in this area in order to determine the sensitivity of the derived cloud properties to the specific large-scale generating mechanisms occurring in each season.

*Table 1. Mean values of the event averaged cloud properties, and the number of events each year.*

| | **1997** | **1998** | **1999** | **2000** |
|---|---|---|---|---|
| ε | 0.30 | 0.37 | 0.36 | 0.27 |
| **τ** | 0.87 | 1.43 | 0.99 | 0.83 |
| **IWP** | 18.27 | 21.36 | 20.97 | 16.06 |
| **$r_e$** | 0.047 | 0.042 | 0.045 | 0.037 |
| **Events** | 121 | 80 | 109 | 85 |

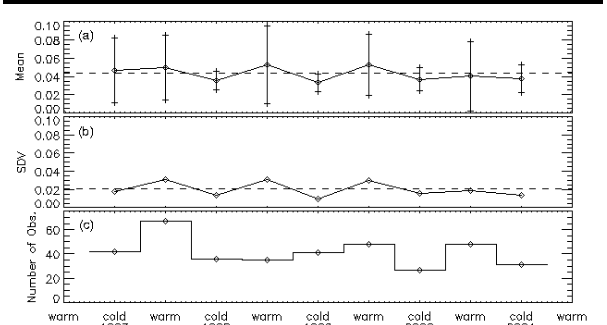


*Fig. 2. (a) Warm (May to September) and cold (November to March) season values for the mean event-averaged effective radius. Error bars represent the standard deviation (Σ) of all events. (b) The average intra-event standard deviation (σ). (c) The number of events for each season. Dashed lines represent the average value of all seasons.*

## 3. Large-Scale Meteorology

To show relationships between the cloud property statistics and the large-scale meteorology, the NCEP reanalysis product is used. From the reanalysis data we show the average anomalous meteorology that is present during all cirrus events, and during warm and cold season events. The average anomalous meteorology during cirrus events are determined by finding the mean meteorology on days with cirrus events, and then subtracting it from the mean meteorology for all days during the period. For example, during the cold season, reanalysis data is used to find the average geopotential heights, absolute vorticity, temperature, vertical velocity, and winds for all days in the cold seasons of 1997 to 2000. The average geopotential height, absolute vorticity, temperature, vertical velocity, and winds are calculated from the days when cold season events occurred and then subtracted from the cold season mean meteorology. The resulting large-scale cirrus anomalies are shown in figures 3 and 4.

On average there is an anomalous anticyclone over the SGP site during cirrus events (Figure 3a). Associated with the 250mb anticyclone are anomalous anti-cyclonic vorticity (Figure 3c) and slightly colder temperatures (Figure 3b). Grid-scale averaged vertical motion is slightly positive over and upstream of the ARM site (Figure 3d), with the largest values of rising motion existing

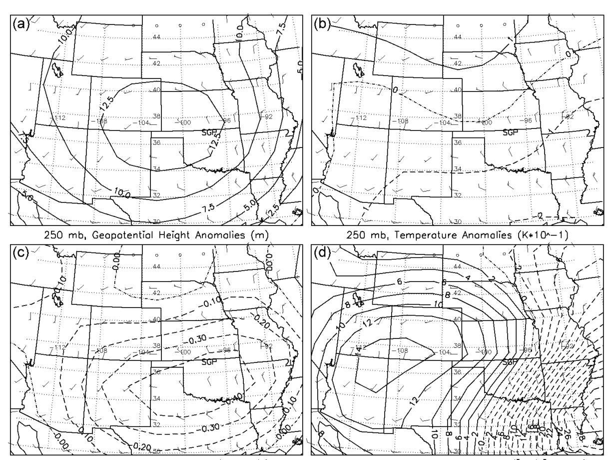


*Fig. 3. 250mb (a) height, (b) temperature, (c) absolute vorticity, and (d) vertical velocity event anomalies from the mean meteorology from 1997 thru 2000. Anomalous winds of* $10^{-1}$m/s *s are shown in all plots.*

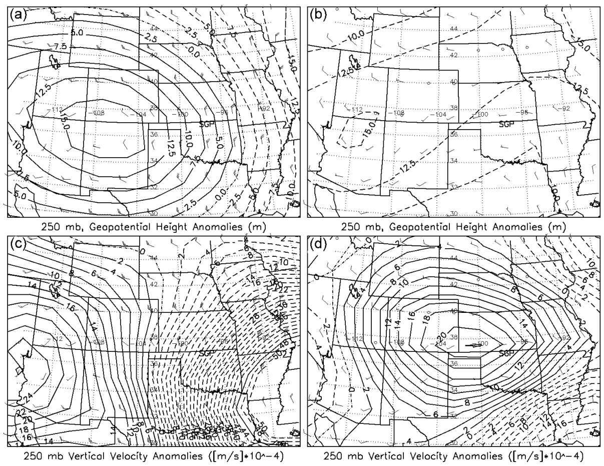


*Fig. 4. 250mb height and vertical velocity anomalies for (a) (c) cold, and (b) (d) warm seasons.*

over the four corners region.

During cold season events the height (figure 4a), temperature, and vorticity anomalies are similar to those of all cirrus events except for slightly larger amplitudes. Cold Season events tend to have anomalous large-scale subsidence of about $-20 \times 10^{-4}$m/s over the site, and rising motion upstream (figure 4c).

Considering the seasonal variation seen in the previous section, one would expect a difference in the large-scale meteorology for the warm and cold seasons. Large-scale patterns seen in the reanalysis data show this difference between the two seasons. Warm season 250mb heights are lower than normal over the entire region (figure 4b). The warm season also shows large-scale lifting over the ARM site, with the strongest rising motions slightly upstream in the Oklahoma panhandle (figure 4d). Also, the anomalous winds are an order of magnitude smaller than in the cold season. From the light winds and strong rising motion near the ARM site, we suspect that the warm season cirrus events are more likely to be generated near the site. While the strong winds and large-scale subsidence during the cold seasons suggests that the cirrus is generated upstream and advected over the ARM site.

These findings suggest that there is a relationship between the large-scale meteorology and the seasonal variability of cirrus cloud properties. However, specific relationships are still not well understood. To better understand these relationships future work will need to compare the large-scale meteorology with specific types of cirrus events (e.g. synoptic cirrus, anvil cirrus, orographic cirrus, etc.) Also, it is possible that the large-scale meteorology during the years 1997 to 2000 may be anomalous. Improved precision in the large-scale anomalies may result by using a 30-year climatology to better define the mean conditions.

## 4. Summary

In this paper we have shown preliminary results of our analysis of cirrus cloud property statistics. From the frequency distributions and comparison to similar results derived from LIRAD data (*Sassen and Comstock, 2001*) we find that even though the MMCR is not detecting the very thinnest cirrus layers, the overall results derived from MMCR-radiometer algorithms are similar to results derived from lidar-radiometer algorithms. During the four years we notice that the inter-annual variability of cloud properties is relatively small. This finding is significant because the period encompasses a major El Niño, La Niña cycle. It also suggests that the instruments do not drift significantly during this time.

The annual large-scale meteorology that tends to be associated with optically thin cirrus includes anomalously higher 250mb heights, slightly colder temperatures, and slighly positive vertical motions. During the cold season, these features are amplified compared to the warm season, suggesting that cold season cirrus is more closely coupled to the large-scale meteorology. We are working now to define specific relationships between the large-scale meteorology and cloud property statistics.

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