A Cloud Climatology of the ARM CART Site

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Introduction

The Atmospheric Radiation and Measurement (ARM) Program (Stokes and Schwartz 1994) Southern Great Plains (SGP) Cloud and Radiation Testbed (CART) is host to a bevy of radiometric and cloud observing instruments dedicated to assisting ARM in reaching its objective to develop and improve cloud and radiative parameterizations for use in general circulation models (GCMs). Because clouds are a major component of the climate system, quality cloud observations are essential.

General cloud characteristics can be obtained from climatologies composited from a variety of observation types (e.g., Newell et al. 1970). Inherent biases in any one data source make this particularly attractive. For example, data collected via satellite is a natural complement to that obtained by a surface observer as the former (latter) yields relatively accurate estimates of high (low) cloud amounts. A potential contributor to a CART I site climatology is the millimeter-wavelength cloud radar (MMCR), which has the capability to provide cloud information throughout the entire troposphere. Unfortunately, the operation of the MMCR has been of too short duration to contribute to a climatology. Surface-based remote sensors such as the micropulse lidar (MPL, Spinhirne 1993) and the Belfort laser ceilometer (BLC), however, have operated side-by-side since 1993 at the ARM CART site. Herein, we present a regional cloud climatology of the ARM CART site produced from three different sources: human, satellite, and surface-based lidars. These sources and their characteristics are described in Section 2, while in Section 3 the statistics for low, middle, high, and total clouds are presented for each of the three data sets.

Data Sets Description

Edited Cloud Report

Hahn et al. (1994) have developed a cloud data set from synoptic weather reports over the globe for the 10-year period from December 1981 to November 1991. The data set was constructed to facilitate cloud analysis by removing or correcting inconsistent and erroneous reports, and including only information from the synoptic weather report pertaining directly to clouds. Corrections are encoded in the Edited Cloud Report (ECR) such that the original report can be reconstructed.

While the amount of low-level cloud is specified directly in the synoptic code, upper cloud amount is often ambiguous. Under certain conditions, however, a quantity referred to as the amount-when-present (AWP) can be estimated at all levels. Whether visible or not, upper-level cloud amount can be determined by utilizing the random overlap assumption, i.e.,

$$(1 - A_T) = (1 - A_L)\ (1 - A_U)$$

where A_T, A_L, and A_U are the fractional amounts (0-1 in oktas) of total, lower, and upper cloud amount, respectively. Eq. (1) can be used to determine the upper level AWP if there are 2 cloud layers. If there are no low clouds, the AWP for upper- (middle- or high-) level clouds can sometimes be obtained directly from the synoptic report. Estimates of A_U are restricted to values of A_L less than 7/8 to avoid infinite values. If clouds are present at all three levels, Eq. (1) contains two unknowns and cannot be solved. Eq. (1) has no observation basis, and its accuracy will likely depend on the cloud distribution (Tian and Curry 1989).

We choose a method to estimate cloud cover that attempts to determine, as closely as possible, the average cloud amount (i.e., the fractional coverage of a particular cloud type over a given time interval) as opposed to the cloud occurrence frequency (COF) or the amount that is visible from below. With this in mind, we calculate the time-averaged cloud amount (TCA) for total cloud cover, and low, middle, and high cloud genera defined by the World Meteorological Organization (WMO) Code Handbook No. 2 (1969). The TCA is computed by multiplying the COF by the AWP (Warren et al. 1988), where the COF is defined as the number of reports of a particular cloud type divided by the total number of synoptic weather reports with encoded information about that cloud type (assuming the COF for middle and high clouds is the same whether the clouds are visible or not). We sample two reporting stations within the SGP CART site: Oklahoma City, Oklahoma and Wichita, Kansas.

Micropulse Lidar and Belfort Laser Ceilometer

The lidar data consist of a combination of cloud base records from the MPL and BLC. (The processing of raw signal to determine cloud base height is presented in more detail in Clothiaux et al. 1998.) In tandem, the two instruments generate a more complete record of cloud base as the BLC yields better estimates of cloud base occurrence in the lowest few kilometers due to short-range detection ambiguities of the MPL. The data sets are combined in such a way as to match the coarser temporal resolution of the MPL. If the BLC does not observe clouds below 3 km, the MPL data are inspected for clouds above 3 km. Both the MPL and BLC accurately record only the occurrence of the lowest opaque cloud in a vertical column directly above the instrument. As a result, cloud occurrence probabilities obtained from the MPL and BLC may vary substantially from the “truth,” i.e., measured by an instrument that could sense clouds at all levels (e.g., MMCR) or from an observer with a full-sky view. We assume that, for the MPL/BLC, the AWP is either 0 (no clouds) or 1 (clouds). Consequently, based on these assumptions, the COF can be taken to be equivalent to the TCA. Over one million observations from a 12-month period beginning April 1994 are used to compile the joint MPL/BLC climatology. The cloud occurrence frequency (COF or TCA) is calculated by taking the number of reports where clouds are reported (cloudy) and dividing them by total number of reports (clear + cloudy). Low, middle, and high cloud categories are delineated by the International Cloud Atlas cloud stage temperate classification (1929). The top of the middle stage is reduced from 7 km to 5 km to avoid overlap with the high cloud stage.

International Satellite Cloud Climatology Project

We use 8 years (1983-1991) of the International Satellite Cloud Climatology Project (ISCCP) spectral radiance data [0.6 μm visible (VIS) and 11 μm infrared (IR)] referred to as Stage C2. The C2 data are monthly summaries of the global data (Stage CI) that are reported every 3 hours. The C2 data are averaged over the month at three hourly increments to preserve information concerning the diurnal variability. Because of the diurnal bias associated with measuring nocturnal low-level clouds using IR radiances alone, the data have been modified such that nighttime measurements of total cloud amount are adjusted using the mean differences between the VIS/IR and IR only results measured during the daytime. The cloud genera are defined by cloud top pressures determined from IR radiances with low clouds classified between 1000 mb and 680 mb, middle clouds between 680 mb and 440 mb, and high clouds between 440 mb and 50 mb.

The C2 data were sampled for an equal-area grid cell containing the CART SGP site. Each map grid cell is defined by a 2.5° latitude increment and variable longitude increment.

Cloud amount is defined by the ratio of the number of cloudy pixels to the total number of image pixels in the specified map grid cell (Rossow and Schiffer 1991). Because the C2 data include both clear sky and cloudy sky data that are averaged at constant diurnal phase, the ISCCP cloud amount is equivalent to the TCA.

Results

In an attempt to mitigate any diurnal bias, we first average all observations for a particular reporting hour (regardless of year) and then average these together to produce an average for the month or season. We apply this averaging procedure to both the ECR and MPL/BLC data, while the ISCCP Stage C2 data have been processed similarly.

Monthly Means

The monthly mean TCA was calculated for the ECR data and is compared with the TCA of both the satellite and MPL/BLC data for total, low, middle, and high clouds (Figures la-1d). The error bars represent one standard deviation and indicate the interannual variability present in the monthly averages of the 10-year ECR record. The solid, dashed, and dotted lines represent the TCA from the ECR, ISCCP, and MPL/BLC data sets, respectively. The cycle depicted by the total cloud amount (Figure 1a) is determined primarily by the low cloud signature which registers a July/August minimum and a March maximum. The summer minimum may come as somewhat of a surprise as cumulus frequencies (Cu) tend to be a maximum over the SGP during this time of year. However, the peak in summer Cu is offset by a minimum in Stratus (St) and Stratocumulus (Sc) during the summer months. The summer cloud cover minimum is consistent with the seasonal variation in continental cloud cover observed in other cloud climatologies (e.g., van Loon 1972). Both the ECR and ISCCP data sets indicate a second peak in the total cloud amount in May and a relatively significant decrease (~10%) in the total cloud amount from December to January. The trends in the MPL/BLC data agree well with those of the ECR and ISCCP albeit 8 months that lie outside the single standard deviation of the ECR climatology. These outliers might be a result of the limited nature of ECR climatology, whose standard deviations have been constructed using only ten

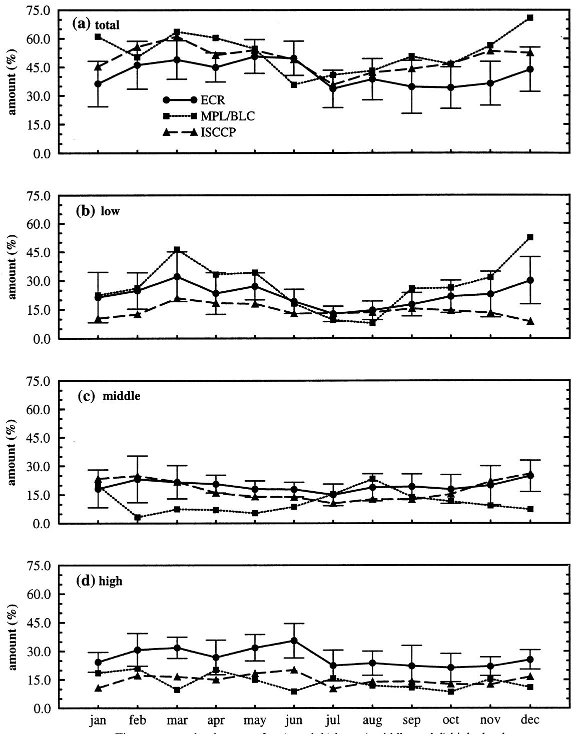

Figure 1. Time average cloud amount for a) total, b) low, c) middle, and d) high clouds.

data points (i.e., 10 years). Differences in the lidar climatology may be a result of diurnal contamination due to the effects of background solar noise (Spinhirne 1993), or that, in the presence of clouds, an AWP equal to one overestimates the actual cloud amount (note that seven of eight lidar outliers are greater than the ECR TCA).

There are systematic differences between the ECR and ISCCP total TCA with the ISCCP TCA larger than the ECR in all but the summer (where there is near perfect agreement). ISCCP image pixels that are labeled “cloudy” are considered to be completely overcast which in turn can, in the presence of low resolution data, lead to an overestimate of cloud amount (Coakley and Bretherton 1982). One might expect to find this especially problematic in the presence of increased cloud cover.

In Figures lb-ld, three features are particularly evident:

1. ISCCP data appear to under-report low cloud frequency when compared to the ECR and MPL/BLC data.

2. ECR data appear to over-report high cloud amount when compared to the ISCCP and MPL/BLC data.

3. There is excellent agreement between the ECR and ISCCP midlevel cloud amounts.

When viewed from above, low clouds are often obscured by higher clouds. Furthermore, ISCCP low, middle, and high TCA are determined from the retrieved cloud top pressures obtained from IR radiances only. IR threshold techniques (used to identify pixels as clear or cloudy) have difficulty “seeing” low clouds when the emitted radiance of the overcast pixels is virtually indistinguishable from the cloud-free background (Rossow et al. 1985). This is especially problematic in the case of broken low cloud decks (e.g., Sc, Cu) over cold surfaces.

In reference to the second point above, we note that, despite the 10% to 15% difference between the ISCCP and ECR high TCA, the trends are quite similar. Assuming the ISCCP high TCA is more accurate—the systematic overprediction of the ECR high TCA may be a result of errors in the random overlap assumption Eq. (1). It is also possible that the ISCCP data under-report (or misreport as a lower cloud deck) the high TCA due to the optically thin nature of cirriform clouds. Although the MPL/BLC data agree well with the ISCCP high cloud amount, the lidar climatology excludes measurement of all but the lowest occurrence of cloud in the vertical column. Consequently, MPL/BLC data will also tend to underestimate the actual frequency of high-level clouds. As an example, the MPL/BLC midlevel TCA is significantly lower than that obtained from the ECR and ISCCP data in all but the summer months. That the MPL/BLC TCA is more in line with that from the ECR and ISCCP during the summer may be a result of the summertime minimum in low cloud amount.

The third point is related to the first two as observations taken by a human are typically best in the low levels while satellites generally yield more accurate estimates of high cloud amount. Thus, comparison of the cloud statistics between these two datasets is likely to be best in the middle levels. Here, the agreement is surprisingly good with differences generally less than 5%. Also, note that the ECR standard deviation contains all 12 months of the satellite monthly mean TCA. That the midlevel TCA for the MPL/BLC data are generally lower than they are for the ISCCP and ECR may be a result of the lidar sampling methodology discussed previously (note that the maximum in MPL/BLC midlevel TCA corresponds to a minimum in the MPL/BLC low-level TCA).

Summary

Cloud data statistics were calculated for an intercomparison of synoptic cloud reports (from two stations), satellite radiances, and lidar data over the ARM CART site. Results presented include monthly means of the time-averaged cloud amount. Caution should be exercised when comparing climatologies derived from different sources as the statistics are likely sensitive to both the spatial and temporal sampling of the measurements. Satellite data represent a different field-of-view than that of a human observer while the MPL and BLC sample only small segment of sky directly overhead but do so continuously. However, in some cases the observations are complementary, as with the ECR and ISCCP data sets. Highlights of the intercomparison are as follows:

- Trends for all three data sets compare favorably for total cloud amount.
- There is relatively good agreement in the trends of the monthly low cloud amount for the ECR and MPL/BLC data.
- There is excellent agreement for the midlevel cloud amount of the ISCCP and ECR data.
- ECR high cloud amount estimates are typically 5% to 10% greater than that obtained from either the ISCCP or MPL/BLC data sets.
- There is a possible high cloud lidar detection problem resulting from solar noise.

Otherwise, expected diurnal and seasonal variations in low clouds are evident.

The regional climatology presented herein was designed to provide an estimate of cloud type and amount over the ARM CART site while evaluating the differences in three observing platforms. This study represents a first attempt to produce a CART site climatology. Additional climatologies can also be constructed from the millimeter cloud radar and whole sky imager data as extended time observations become available.

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