Six-Year Climatology of Boundary Layer Clouds at the ARM SGP Site

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Introduction

Low-level stratus clouds cover a large area of the world during all seasons (Klein and Hartmann, 1993). It is clear that these clouds have a large impact on the earth's radiation budget since they increase the surface albedo while having little effect on the longwave flux (Randall et al., 1984; Ramanathan et al. 1989; Harrison et al. 1990). The majority of these clouds are located over the world's oceans, and marine stratus clouds have long been an area of extensive research. There have, however, been only a few continental stratus cloud experiments and studies (Kollias and Albrecht, 2000; Sassen et al., 1999; Miles et al., 2000). Although the total coverage of continental stratus is significantly less than its maritime counterpart, they still undoubtedly impact the earth's radiation budget (Klein and Hartmann, 1993) and may have a substantial impact on diurnal temperature variations over land. Continental stratus may have different cloud properties, involve additional boundary layer feedbacks that impact their maintenance and dissipation, and exhibit greater diurnal variability than marine stratus.

Using data collected from 1998-2003 at the Southern Great Plains (SGP) site as part of the Atmospheric Radiation Measurement (ARM) Program, a 6-year boundary layer clouds climatology is developed. The analysis includes hourly estimates of cloud base height, cloud top height, cloud thickness, lifting condensation level (LCL), liquid water path for various cloud types, and boundary layer wind speed, direction, and static stability from atmospheric soundings. Furthermore, the European Center for Medium range Weather Forecasting (ECMWF) hourly averaged model output over the model domain 29 (e.g., [Lon: 261.7-263.0, Lat: 36.0-37.0]) around the ARM-SGP site is processed. The model output is compared to the cloud conditions observed by the vertically pointing active remote sensors at the SGP. Short time assessment of the ECMWF model cloudiness has been conducted in the past (e.g., Morcrette, 2002). Here a more time-extended assessment of the ability of ECMWF and other models to forecast cloud fields is attempted. Furthermore our objective is to relate the macroscopic properties of boundary layer clouds to ECMWF model predicted and diagnosed parameter.

Background

The basic dataset used in this study is the Active Remote Sensing Cloud product (ARSCL) (Clothiaux et al., 2000) that combines the Millimeter-wavelength Cloud Radar (MMCR), the Vaisala Ceilometer (CEILO) and the Micropulse Lidar (MPL) observations and provides the most accurate representation of clouds above the ARM SGP site with a temporal resolution of 10 sec and vertical resolution of 45 m. Using the ARSCL data from January 1998 to July of 2003 (5.5 years) a cloud climatology is developed with emphasis to the boundary layer clouds (BLC). Several different types of clouds are objectively classified according to their vertical extent, cloud base and precipitation stage (deep precipitating, shallow precipitating, non-precipitating, BLC, alto clouds, cirrus clouds). The clouds are classified (Figure 1) using the following criteria: a) deep convective, if the maximum dBZ in the column exceed 0 dBZ, the cloud top was higher than 2 km and there was measurable precipitation at the ground, b) cirrus, if the cloud base was higher than 6 km, c) alto if the cloud base was above 2 km height and below 6 km, d) boundary layer clouds if both the cloud top and base are below 2 km. Furthermore, the BLC were classified in sub-categories such as: d1) drizzling BLC, if the cloud base is at the lowest radar detectable height (100 m) or the maximum reflectivity in the column is larger than –10 dBZ and d2) non-precipitating BLC is the cloud base is higher than 100 m above the ground and the maximum reflectivity below –10 dBZ.

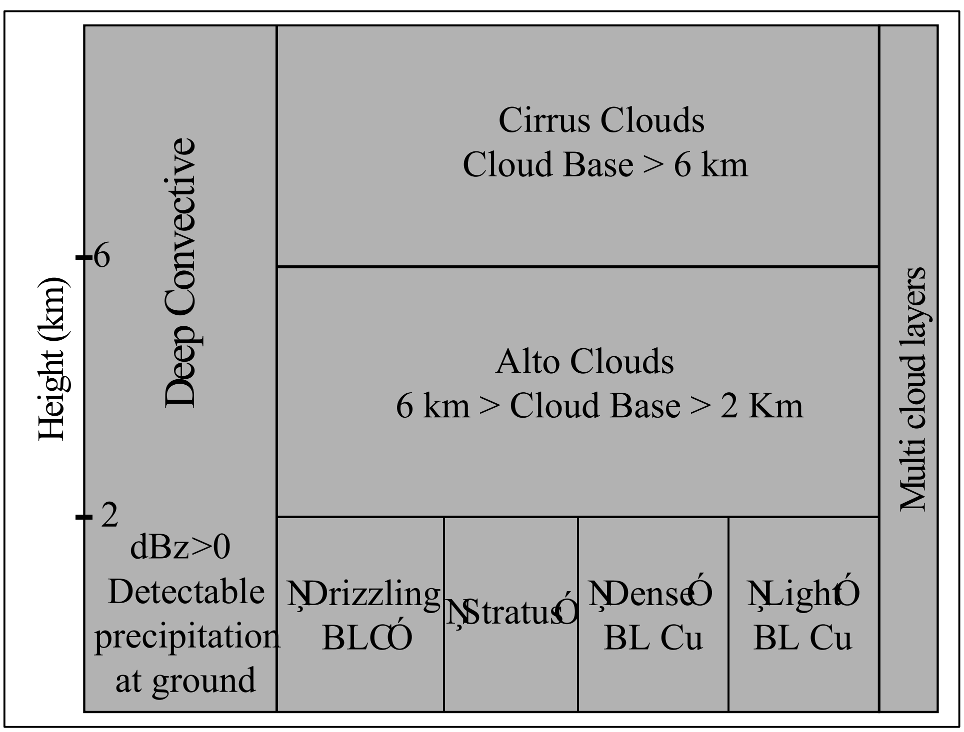
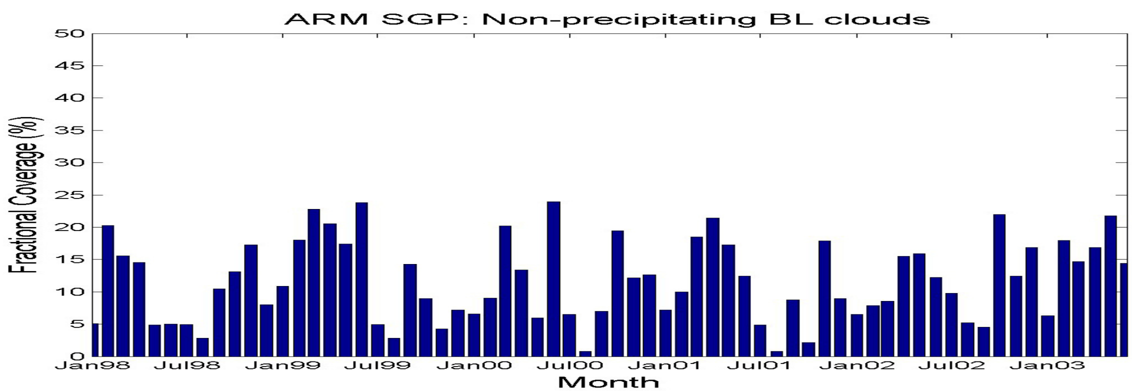


Figure 1. Cloud classification scheme

The non-precipitating BLC clouds were further classified according to their hourly averaged fractional coverage in the following categories: d1a) stratus BLC, if the hourly averaged fractional coverage is more than 0.75, d1b) dense BLC, if the hourly averaged fractional coverage is between 0.3 and 0.75 and d1c) light BLC if the hourly averaged fractional coverage is below 0.3.

BLC Climatology

The good MMCR operational health and stability at the SGP site (on average, 85% of the time the MMCR was operating) helped to developed the BLC climatology. During the March-October period every year, the presence of insects and bugs in the boundary layer results in strong non-cloud radar returns and thus make the BLC detection very difficult, especially the detection of the BLC top. Figure 2 shows the monthly averaged fractional coverage of non-precipitating BLC at the ARM SGP site. A strong annual cycle is observed with the maximum (20%) during the winter months and a minimum (5%) during the summer months.



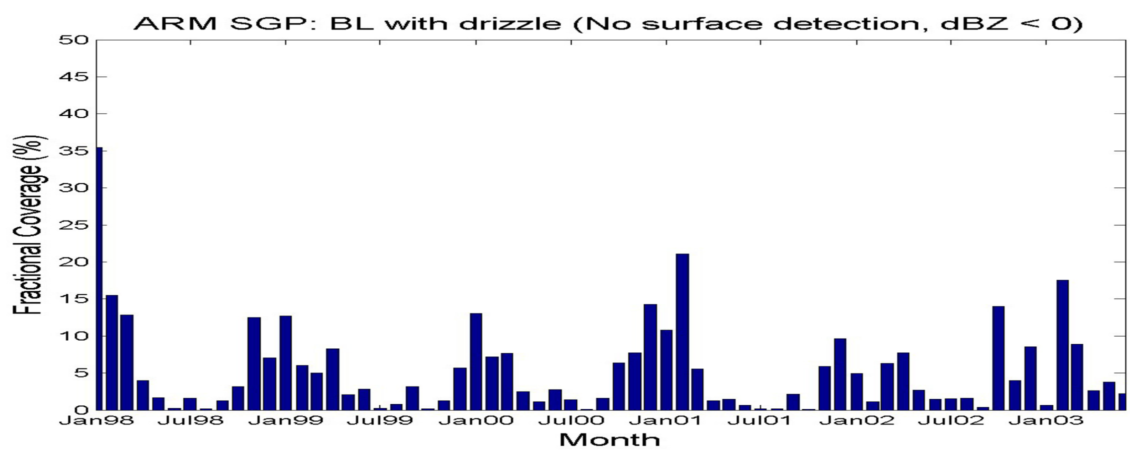


Figure 2. Monthly averaged fractional coverage of non-precipitating BLC at the ARM SGP site (top) and monthly averaged fractional coverage of BLC with drizzle or light precipitating (not measurable at the ground) conditions (bottom).

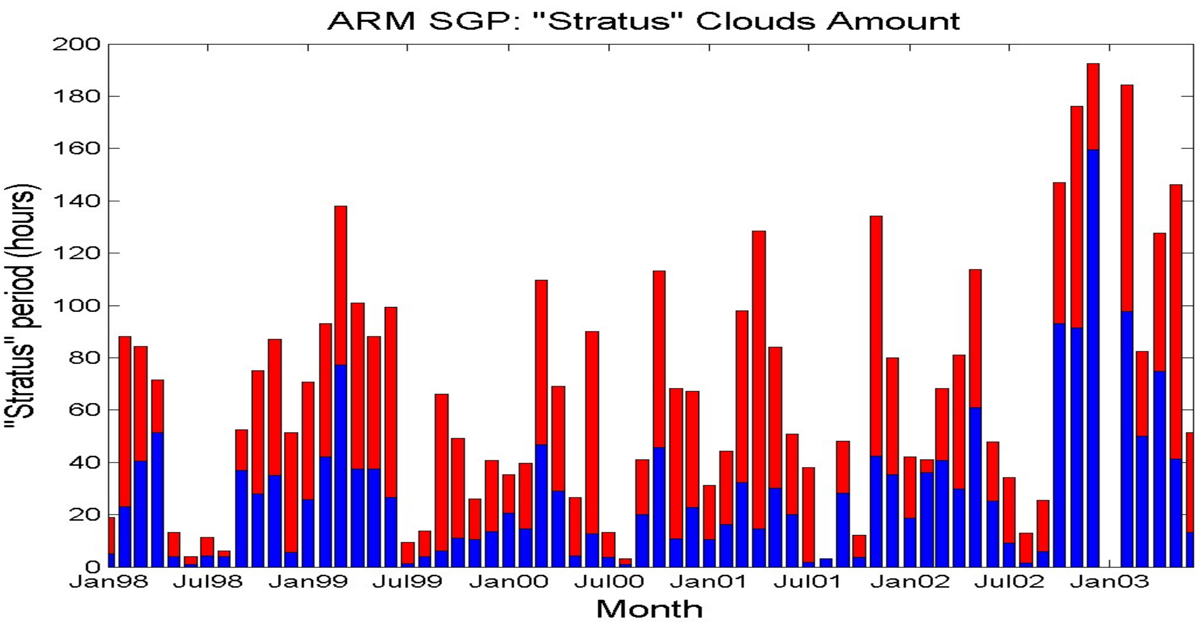


Figure 3. Monthly total of hours of stratus cloud observations at the SGP site. The blue color corresponds to stratus clouds observations without any other cloud type present.

The climatology of drizzling BLC exhibits similar annual cycle. Once the time periods with BLC were identified, the BLC were classified with respect their hourly averaged fractional coverage. Figure 3 shows the total number of hours in a month that “stratus” (BLC clouds with fractional coverage higher than 0.8) are observed. Furthermore, the portion of these hours where the stratus clouds were the only cloud type observed (Figure 3).

Observations and ECMWF Model Comparison

The ECMWF model output diagnostic data files are used to provide a comparison between model output and observations. The model output is hourly and averaged over a large area around the ARM SGP site. Using the cloud fraction model output for all pressure levels higher than 800 mb the layer averaged BLC fractional coverage in the ECMWF is derived. The pressure level with the highest model cloud fractional coverage from the surface to 800 mb, and adjunct pressure levels are used for the calculation of the model mean BLC fractional coverage. Figure 4 shows an example of ECMWF model output cloud fractional coverage and ARSCL derived cloud fractional coverage comparison.

There is good correspondence between the observed and model produced BLC field. The EMCWF accurately forecasts frontal passages and the associated with them precipitation and stratus clouds. However, the model often underestimates the amount of stratus clouds and their persistence. The ECMWF model ability to forecasting BLC is shown in Figure 5. It is apparent that ECMWF captures the annual cycle of stratus clouds. However, the amount of stratus clouds produced is small and for approximately 30% of the observed stratus clouds at the ARM SGP the model fails to produce any BLC. However, it is important to keep in mind that the model fractional coverage is averaged over a large domain area, while the ARSCL observations are point observations of clouds.

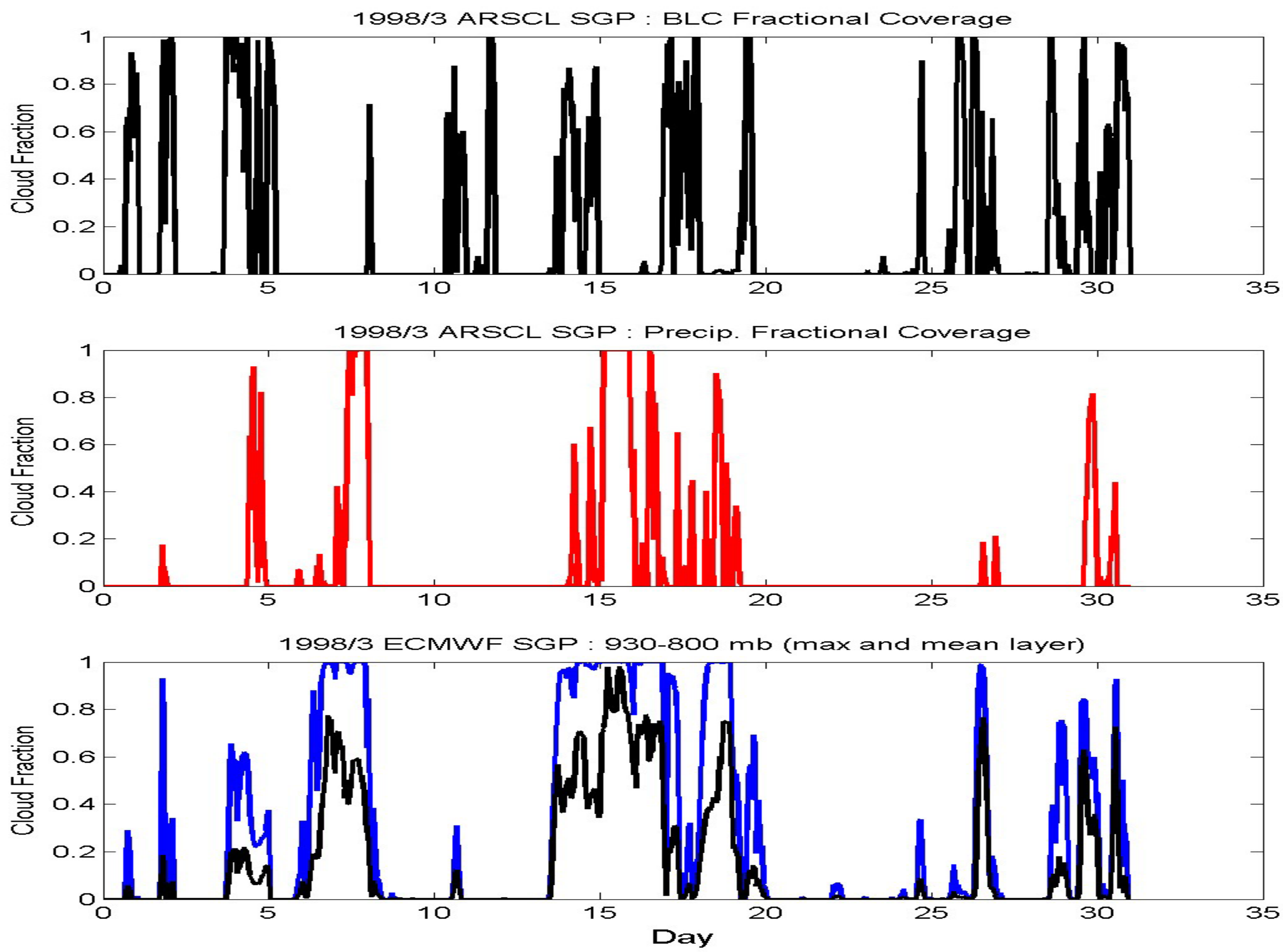


Figure 4. The top panel shows the ARSCL derived hourly averaged BLC fractional coverage, the middle panels shows the fractional coverage of "deep" precipitation and the bottom panel shows the ECMWF boundary layer averaged (black) and layer maximum (blue) cloud fractional coverage. The data cover the month of March 1998.

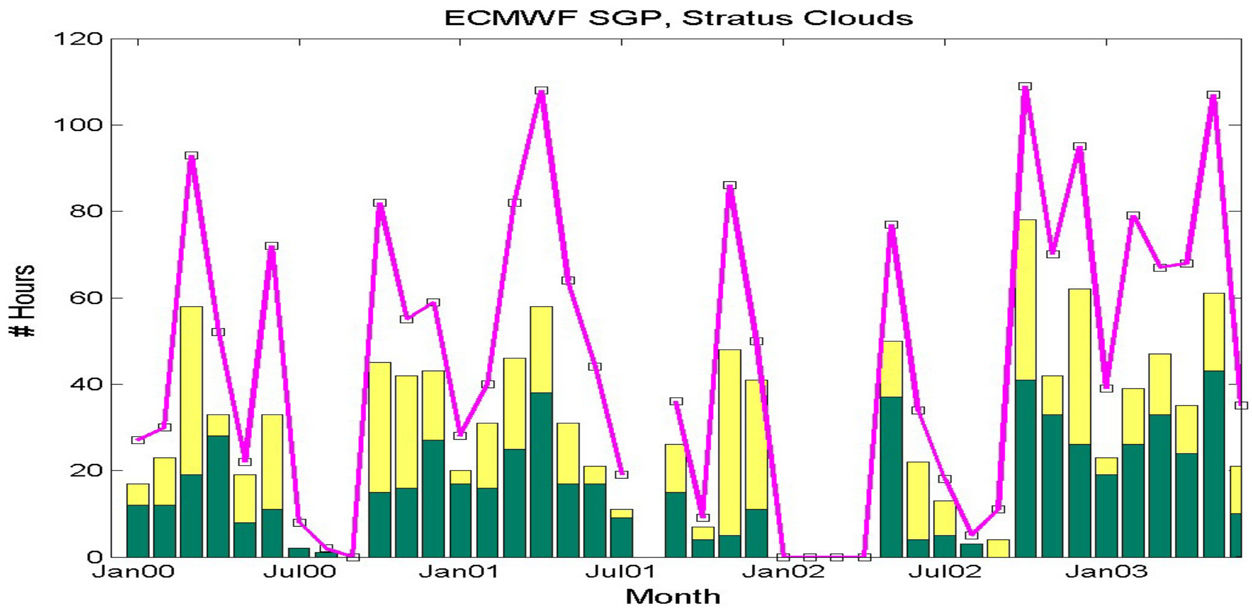


Figure 5. Monthly comparison of ECMWF model output and ARSCL observations of total stratus amount in hours. The line corresponds to the total number of stratus occurrence hours in a month derived by the ARSCL (observations) dataset. The green bar shows the number of hours that ECMWF fail to produce BLC in the domain (model diagnostic BLC fractional coverage = 0). The yellow bar (stacked above the green) shows the number of hours that ECMWF produced more than 50% layer averaged BLC fractional coverage.

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