Variability of Low Stratiform Clouds Over ARM SGP CART Based on MMCR Data and LES Simulations

Z. N. Kogan, D. B. Mechem, and Y. L. Kogan
Cooperative Institute for Mesoscale Meteorological Studies
University of Oklahoma
Norman, Oklahoma

Introduction

The fidelity of a cloud parameterization depends on accurate formulation of cloud prognostic variable conversion rates, as well as on accurate description of sub-grid scale cloud variability and cloud fraction. The unique information on the latter parameters can be obtained using Atmospheric Radiation Measurement (ARM) observational platforms data, in particular cloud reflectivity data from the millimeter wave cloud radar (MMCR). The objective of the study is to define in terms of probability distribution functions (PDFs) and its moments the sub-grid variability of cloud parameters down to the smallest resolvable by the MMCR scale. The PDFs are shown to be important part of cloud physics and radiative parameterizations in meso- and large-scale models.

Description of the Dataset

We analyzed low-level stratiform clouds observed over the ARM Southern Great Plains (SGP) site during the three winter months from December 1997 until March 1998. The dataset included stratiform clouds with tops below 3 km continuously observed by MMCR for 30 min or longer. Assuming average advection velocity of 10 m/s, the minimum time constraint corresponds to model grids of larger than 18 km. As MMCR records data with a 10 s frequency, the minimum cloud segment of 30 min consists of 180 data points that is statistically significant for calculation of PDF. It has to be noted that 70% of data has duration of more than 0.8 (0.6) hours with the average duration of 1.9 (1.3) hours for non-precipitating (precipitating) cloud segments. The data also included low clouds that are overlaid by mid-level clouds and unaffected by precipitation from above.

Over the studied 3-months period, we selected 241 low-level stratiform cloud segments continuously lasting 0.5 hours and longer. The total duration of the dataset was about 489 hours, which is 23% of the 3-months observational period. The difference between this number and 39% estimated by Ackerman et al. (1998) and Dong et al. (2000) for all low clouds is, most likely, related to our constraints in cloud type selection.

The observational analysis was supplemented by large-eddy simulation(s) (LES) of a lightly and heavy precipitating stratus observed during intensive operational period (IOP) on March 3rd and 18th 2000, respectively.

Precipitating Versus Non-Precipitating Stratiform Clouds

Our analysis was based on about 489 hours of low stratiform clouds. One of the major microphysical properties influencing cloud variability is cloud precipitation. To study the effect of precipitation we partition the whole dataset into precipitating and non-precipitating cloud segments based on the commonly used radar reflectivity Z threshold: Z = -18 dBZ. The total number of non-precipitating cloud segments was 164 with the time duration about 358 hours (73%) and precipitating cloud segments was 77 with the time duration about 131 hours (27%) over the 3-month period.

In the present analysis, we considered for simplicity variability only within the middle one-third of the cloud, thus its vertical variation has not been investigated in this study. We described each cloud segment by its duration, mean, and standard deviation of radar reflectivity, as well as radar reflectivity PDF. Another useful parameter characterizing variability within the segment was the ratio of reflectivity standard deviation to its mean (ν).

During the analyzed 3-months period, the number of non-precipitating cloud segments was 2.1 times larger than the number of precipitating segments. The overall duration of non-precipitating cloud segments was 2.7 times larger compared to precipitating clouds. Most (90%) of the segments had duration of less than 4.6 and 3 hours (166 and 108 km in horizontal scale assuming mean velocity of 10 m/s) for non- precipitating and precipitating segments, respectively (see Figure 1a). The corresponding average duration was 1.9 hours (68 km) and 1.3 hours (47 km) with standard deviations of 1.6 and 1 hour for non-precipitating and precipitating segments, respectively. On average, the precipitating segments had a shorter life span (smaller horizontal scale): they lasted about 70% of the duration of non-precipitating segments.

Cloud Reflectivity Statistics

The average of all radar reflectivity means is -26.6 and -13.4 dBZ for non-precipitating and precipitating segments, respectively. For most segments (70%) the reflectivity means vary in the range from -29 to -22 dBZ for non-precipitating and from -16 to -9 dBZ for precipitating segments (see Figure 1b).

It is interesting to note that during the studied 3-month period there were no heavily precipitating segments with segment mean reflectivities greater than -4 dBZ. The distributions of reflectivity standard deviations (not shown) made clear that all segments have standard deviations less than 7 dBZ. Most of them (90%) have values less than 4.5 and 5 dBZ with the average of 3.1 and 3.5 dBZ for non-precipitating and precipitating segments, respectively. It appeared that reflectivity in non-precipitating segments was less scattered around its mean value compared to precipitating segments.

The horizontal variation of reflectivity is better characterized by the variability parameter ν. Figure 2 shows that in about 90% of cases the variability parameter is less than -0.2 (-0.5) with the average value of -0.1 (-0.3) for non-precipitating and precipitating segments, respectively. Thus, the variability within precipitating clouds is about 3 times larger than in non-precipitating clouds. The scatter plot shown in Figure 2 illustrates the dependence of segment variability on its mean reflectivity. Clearly, the amount

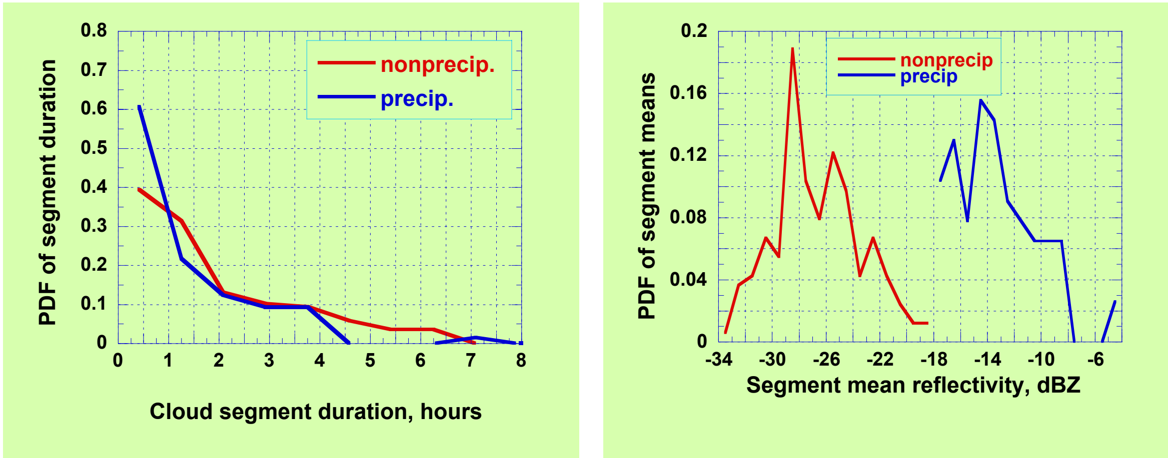

Figure 1. PDF of segment durations (a) and of segment reflectivity means (b) for all non-precipitating (red) and precipitating (blue) cloud segments.

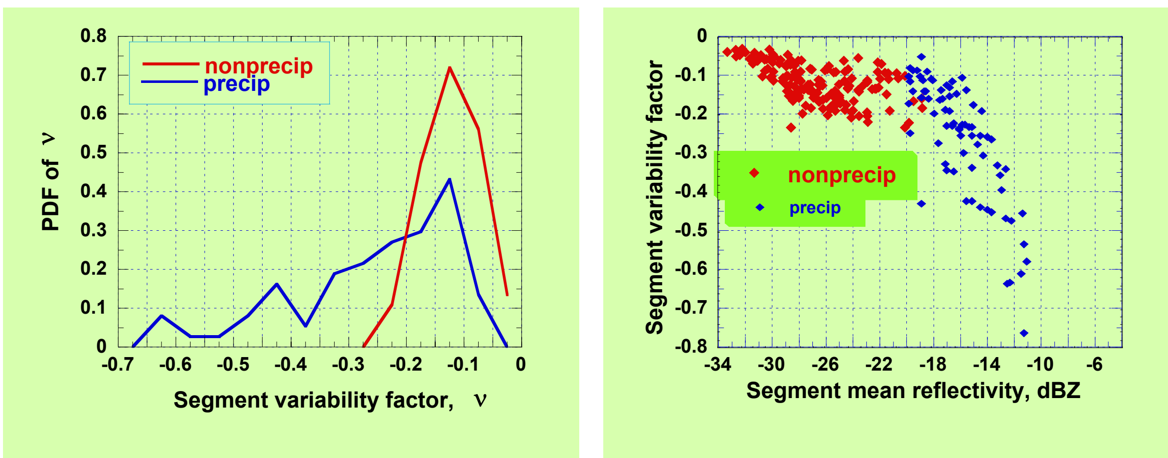

Figure 2. (a) PDF of variability parameter ν for non-precipitating (red) and precipitating (blue) cloud segments and (b) scattergram of ν versus mean reflectivity for each segment.

of variability increases with reflectivity; the increase is especially strong for precipitating segments. The heavier precipitating clouds seem to have significantly more variable structure.

On Figure 3, we see probability distribution function of reflectivity averaged over all non-precipitating or all precipitating segments, respectively. The averaged PDFs of radar reflectivity are very well approximated by Gamma type distribution:

$$P\,(Z_s) = a\,Z_s^{\,b}\,e^{-Z_s/c}$$

Here $Z_s = (Z + 57.8)/12.7$, $a = 282.3$, $b = 29.8$, $c = 0.079$ for non-precipitating and $Z_s = (Z + 34.6)/8.78$, $a = 387.5$, $b = 25.7$, $c = 0.089$ for precipitating segments. The average reflectivity for the whole 3-month period and its standard deviation, calculated using derived PDFs, yielded 26.0 and -13.2 dBZ with 4.2 and 4.3 dBZ for non-precipitating and precipitating clouds, respectively.

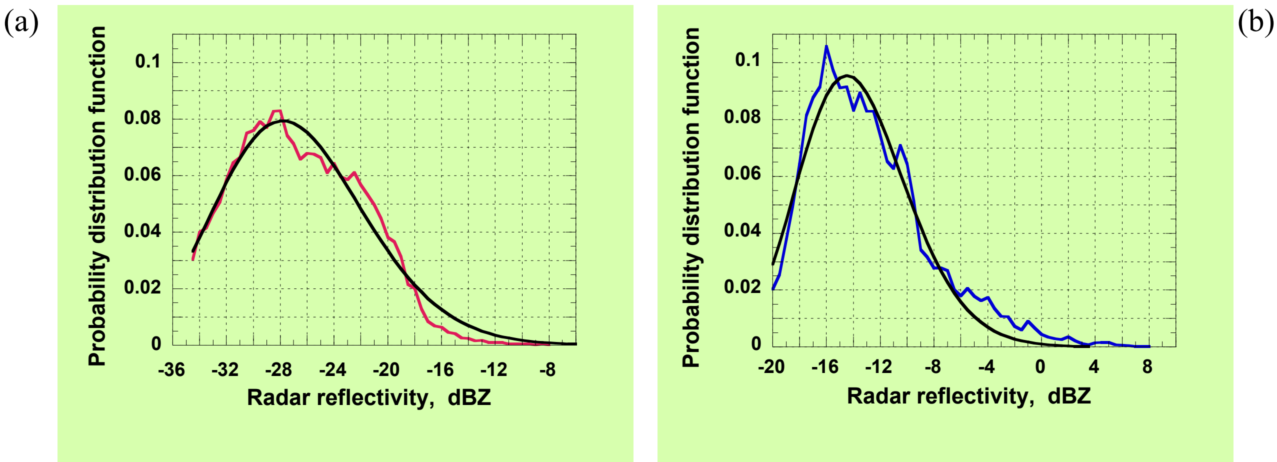

Figure 3. (a) PDF of reflectivity averaged over all non-precipitating and (b) precipitating segments. The corresponding Gamma fit distributions are shown by black curve.

The LES results confirm a good correlation between liquid water content (LWC) and reflectivity (Figure 4a) for almost non-precipitating case on March 3, 2000, and no correlation at all for the case of heavy precipitating stratus on March 18, 2000. Nevertheless, in the later case an excellent correlation existed between precipitation (Figure 4b) and precipitation flux (not shown here) which will enable us to derive PDFs of precipitation and its flux in the future for precipitating clouds.

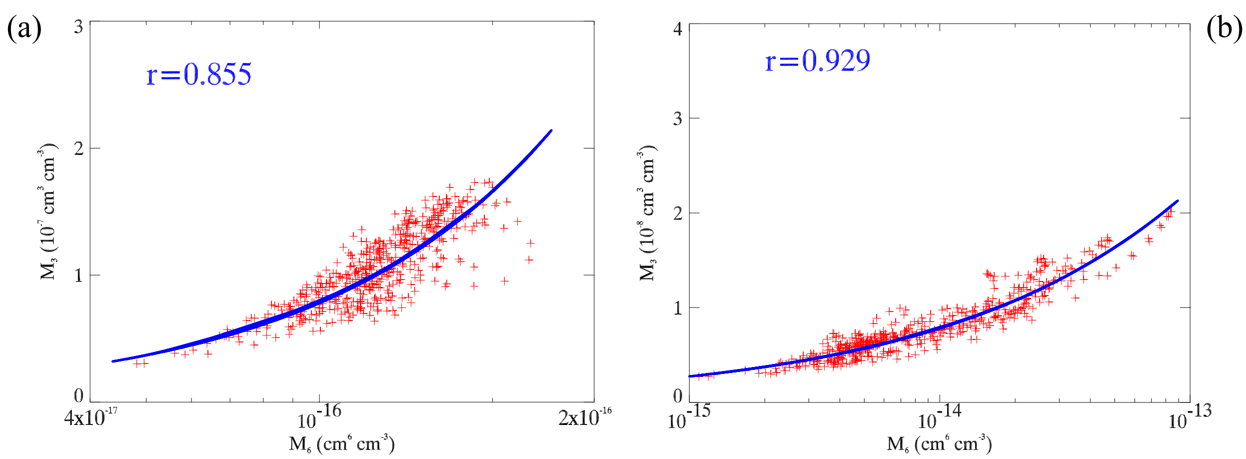

Figure 4. (a) The scattergram of 3 moment (LWC) vs. 6 moment (reflectivity) for non-precipitating stratus on March 3, 2000; and (b) partial 3 moment (drizzle) vs. 6 moment for heavy precipitating stratus on March 18, 2000.

Using lognormal assumption for drop size distributions, Frisch et al. (1995) suggested an algorithm for LWC retrieval in non-precipitating clouds, based on radar reflectivity. Figure 5 shows the average PDF of LWC derived from average PDF of reflectivity and assuming drop concentrations typical for winter months over the SGP site (Dong et al. 2000). Based on this PDF, the mean value of LWC is 0.24 g/m^3 with standard deviation of 0.016 g/m^3. All the above results characterize the middle 1/3 portion of the stratiform clouds because they are derived from reflectivity data contained within this portion.

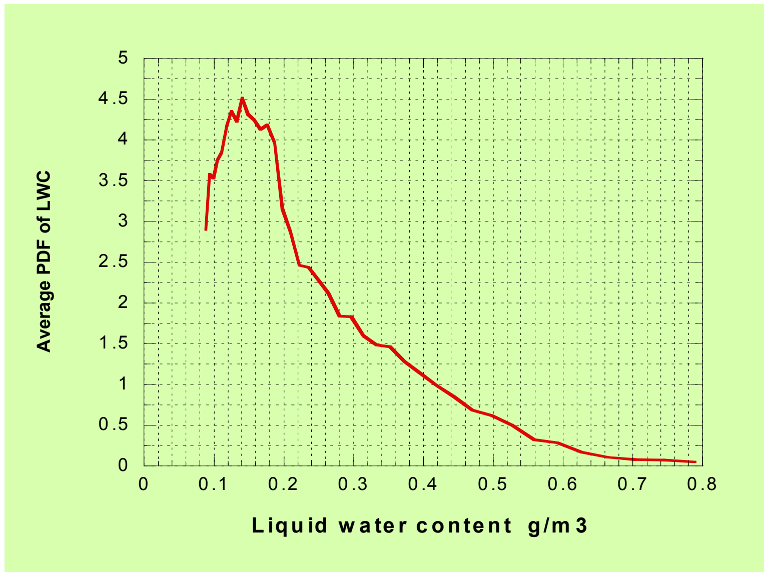

Figure 5. PDF of LWC averaged over all non-precipitating cloud segments.

Conclusions

We analyzed 241 low-level stratiform cloud segments that were observed over the ARM SGP site during the 3-winter months from December 1997 until March 1998. This amounts to approximately total 489 hours, which comprises about 23% of the whole period. Of the total 241 cloud segments, 164 were from non-precipitating clouds with total duration of 358 hours (about 73%) and 77 of precipitating clouds with total duration of 131 hours (about 27%). We conclude that over the studied period the number of non-precipitating cloud segments tends to be 2.1 times greater than the number of precipitating segments, with total duration of about 2.7 times longer than for precipitating segments. In other words, the non-precipitating cloud segments exist 2 times more often and cover the sky approximately 3 times larger over the observed 3-months period than precipitating segments.

We also conclude that the amount of horizontal variability (the ratio of standard deviation of reflectivity to its mean for each segment) for precipitating clouds segments is 3 times larger than for non-precipitating. There is a significant dependence of the segment variability on its mean reflectivity. Namely, the variability increases with reflectivity, especially for precipitating segments. Heavier precipitating clouds seem to have significantly more inhomogeneous structure.

Finally, the probability distribution functions for radar reflectivity averaged over all non-precipitating or precipitating cloud segments are very well approximated by Gamma type distribution. Those PDFs have means -26.0 and -13.2 dBZ with standard deviation 4.2 and 4.3 dBZ for non-precipitating and precipitating clouds, respectively. Based on PDF of radar refletivity, the PDF of LWC was obtained for non-precipitating cloud segments. This PDF is characterized by mean 0.24 g/m^3 and standard deviation 0.016 g/m^3 and related to middle levels within the cloud.

Acknowledgments

The research was supported by the Environmental Sciences Division of U.S. Department of Energy as part of the Atmospheric Radiation Measurement Program. Support for this research was also provided by the ONR Grant N00014-96-1-0687. Data was obtained from the Atmospheric Radiation Measurement (ARM) Program sponsored by the U.S. Department of Energy, Office of Science, Office of Biological and Environmental Research, Environmental Sciences Division.

Corresponding Author

Zena Kogan, zkogan@ou.edu, (405) 325-6076

References

Ackerman, T. P., R. T. Marchand, and E. E. Clothiaux, 1998: A one-year cloud climatology for the Southern Great Plains site. In *Proceedings of the Eighth Atmospheric Radiation Measurement (ARM) Science Team Meeting*, DOE/ER-0738, pp. 773-776. U.S. Department of Energy, Washington, D.C. Available URL: http://www.arm.gov/docs/documents/technical/conf_9803/ackerman-98.pdf

Xiquan, D., P. Minnis, T. P. Ackerman, E. E. Clothiaux, G. G. Mace, C. N. Long, and J. C. Liljegren, 2000: A 25-month database of stratus cloud properties generated from ground-based measurements at the Atmospheric Radiation Measurement Southern Great Plains site. *JGR,* **105**, 4529-4537.

Frisch, A. S., C. W. Fairall, and J. B. Snider, 1995: Measurements of stratus cloud and drizzle parameters in ASTEX with a Ka-band Doppler radar and a microwave radiometer. *JAS,* **52,** 2788-2799.