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Verification of LES warm rain microphysics and observational uncertainty

Yefim Kogan[1], *Danielle Corrao*[1] *and Hermann Gerber*[2]

[1]*The University of Oklahoma, Norman, Oklahoma, 73072*
[2] *Gerber Scientific Inc., 1643 Bentana Way, Reston, Virginia, 20190*

1. Introduction

Verifying model against observations is an important, however challenging task. The difficulties stem not only from lack of comprehensive integrated observations and uncertainties in measurement techniques, but also from large natural variability of atmospheric systems, such as clouds and precipitation. The objective of this study is to analyze this variability and to understand how best compare numerical model results with in-situ observations.

We use the data from the second Dynamics and Chemistry of Marine Stratocumulus (DYCOMS II) field study of marine stratocumulus off the coast of California (Stevens et al. 2005). Over the course of one month, the NCAR C130 airplane conducted nine research flights west-southwest of Los Angeles, CA. We analyzed variability of microphysical parameters in two research flights: RF01 conducted in a homogeneous, non-precipitating STBL and RF02 conducted in a drizzling layer.

The data sets consist of liquid water content and cloud drop concentration time series collected every 0.1-sec (10-Hz) over a little more than one hour. Given the airplane speed of about 100 m/s, the 0.1 s data samplings correspond approximately to a horizontal distance of 10 m. Liquid water content and drop concentration were obtained by integrating the cloud drop concentrations measured by the scattering spectrometer probe, or SPP-100. In both flights the airplane flew about 100-m below cloud top.

2. Results

2 .1. Variability of the whole data set

We first look at the variability of cloud parameters during the whole flight duration of about one hour. Fig. 1 depicts probability distribution functions (PDF) of liquid water content (LWC) and cloud droplet number concentration, N_c, illustrating the scope of variability of both parameters. The droplet concentration in the RF01 case varies in the range up to 300 cm^{-3}, with the mean of 156 cm^{-3} and standard deviation of 27 cm^{-3} resulting in a variance coefficient[1], *VC*, of about 18%. The liquid water content fluctuates from 0 to about 0.5 gm^{-3} with the mean of 0.2 gm^{-3} and standard deviation of 0.06 gm^{-3} (*VC* of ~30%).

[1] The variance coefficient is defined as the ratio of the standard deviation to the mean expressed in percents.

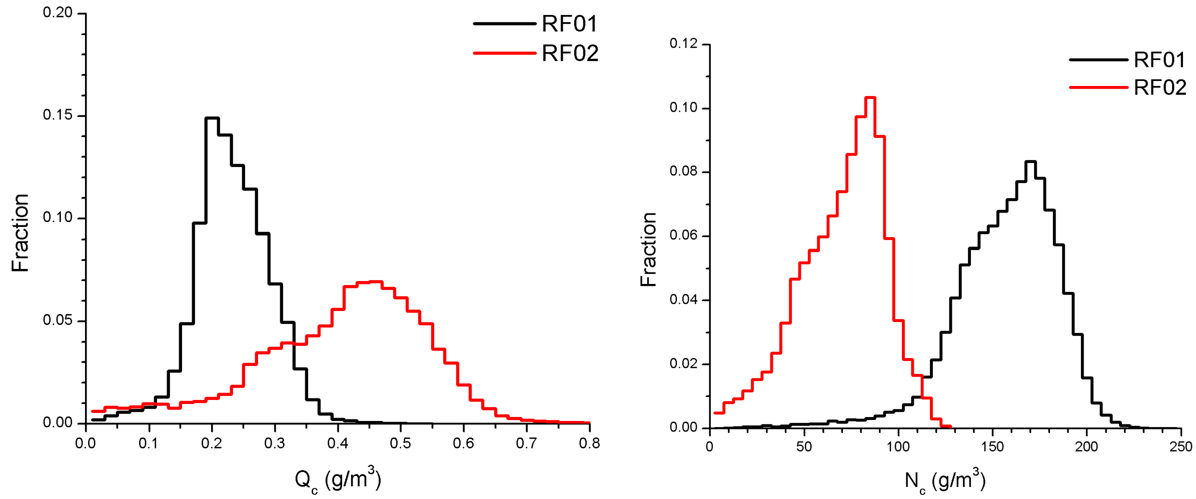


Figure 1. Histograms of liquid water content and cloud droplet concentration $\boldsymbol{N_c}$ for the RF01 and RF02 cases.

The variability in the precipitating case RF02 is larger. LWC varies in the range from 0 to 1.1 gm^{-3} with VC ~ 25%. The number concentration, N_c, is between 0 and 130 cm^{-3} with VC of about 34%. It is interesting that in the non-precipitating Sc, the concentration is more stable (VC ~ 20%) than LWC (VC ~ 30%). It should be noted that the histograms presented here reflect the variability of data at one particular cloud level (the airplane was flying at about 100 m below cloud top). As will be shown below based on LES model data, the variance coefficient changes significantly in the vertical.

It is interesting to note that concentration PDF in the RF01 case is negatively skewed, while the LWC PDF is positively skewed. In the RF02 case both PDFs are negatively skewed because of prevalence of evaporating drizzle. The skewness in both cases is rather significant, and as a result, a simple approximation of the probability distribution function (PDF) by a Gaussian distribution function may be problematic. The approximations based on three parameters, e.g., Gamma-type functions, will likely prove to be more accurate.

2 .2. Scale dependence of variability

While PDF in Fig 1 provide a general idea about the variability range of LWC and N_c, from the model verification point of view one needs to compare the means, as well as standard deviations taken over a time scale characteristic of a particular model. For an LES model these means and standard deviations (or *VCs*) is reasonable to calculate over a one minute (6 km) data subset.

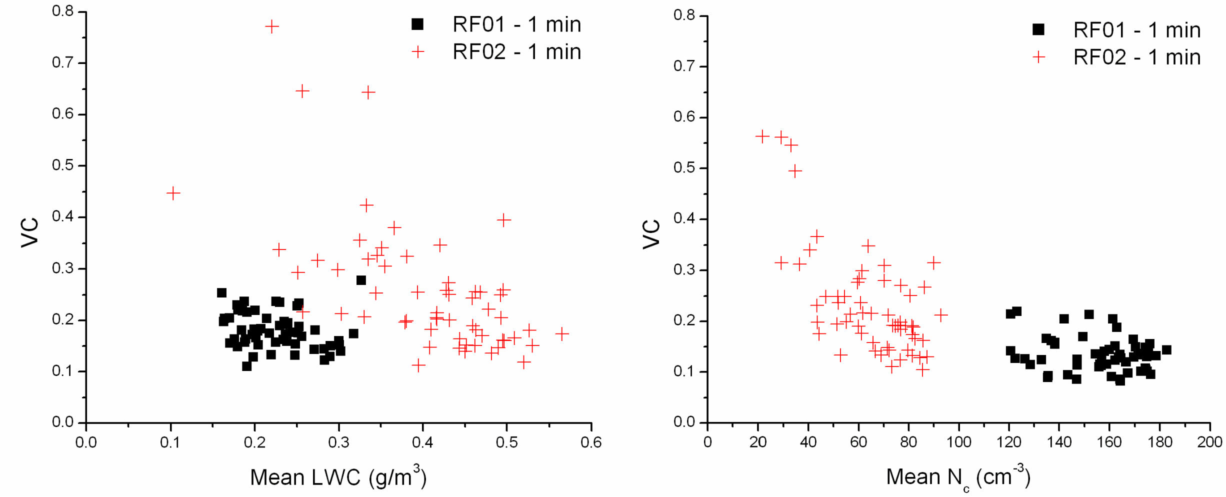


Figure 2. Variability coefficient vs mean LWC (left) and N_c (right). The black squares are RF01 and the red triangles are RF02.

Figure 2 shows *VC* and means calculated over the LES domain size, i.e., using the one-minute data segments (~600 data points). These "LES-domain" means and *VCs* have to be compared with the corresponding model parameters horizontally averaged over the LES integration domain. During the one hour flight about 60 observational "LES-means and *VCs*" can be obtained. As Figure 2 shows there is a rather large horizontal variability along the 60 km flight leg, even in the non-precipitating RF01 case which is generally considered to be relatively homogeneous. This variability in mean parameters reflects the effect of variation in mesoscale forcing which is clearly identifieable in Figure 3. The "LES-domain" mean values of LWC vary in the range from 0.16 to 0.33 gm^{-3}; the mean values for N_c vary in the range from 120 to 185 cm^{-3}.

The variation in the means essentially *define uncertainties*[2] in observational data used for LES model verification. For the RF01 case the uncertainty in the observational mean of LWC is ~30%, for the mean N_c it is slightly less ~ 20%. When in addition to the means one compares the standard deviation of the parameter (or its *VC*), then the uncertainty in the LWC variance coefficient is about 50% and the uncertainty in the N_c variance coefficient is about 30%.

As noted previously, in precipitating stratocumuli the range of variability and, consequently, the uncertainly in observational parameters is significantly increased. The mean LWC in the RF02 case varies in the range from 0.1 to 0.56 gm^{-3} with the mean of 0.40 resulting in the uncertainty of ~60%. N_c varies in the range from 22 to 93 cm^{-3} with the mean of 64.3 resulting in approximately the same value of uncertainty of ~60-70%. The uncertainties in the *VC* parameters are also of similar values. As expected, the uncertainties in the precipitation case are larger and the observational constraints are weaker.

[2] We use the term "uncertainty" to indicate data variability in the following sense. Although cloud parameters may, in principle, be measured, say each second with a 100% accuracy, the in-situ sounding profiles are usually collected during the airplane flight one hour or less frequently. As the result, the ambient thermodynamic state specified in the model cannot be linked to a specific one-minute mean data point and model output is compared to the whole range of data collected over the one hour time interval.

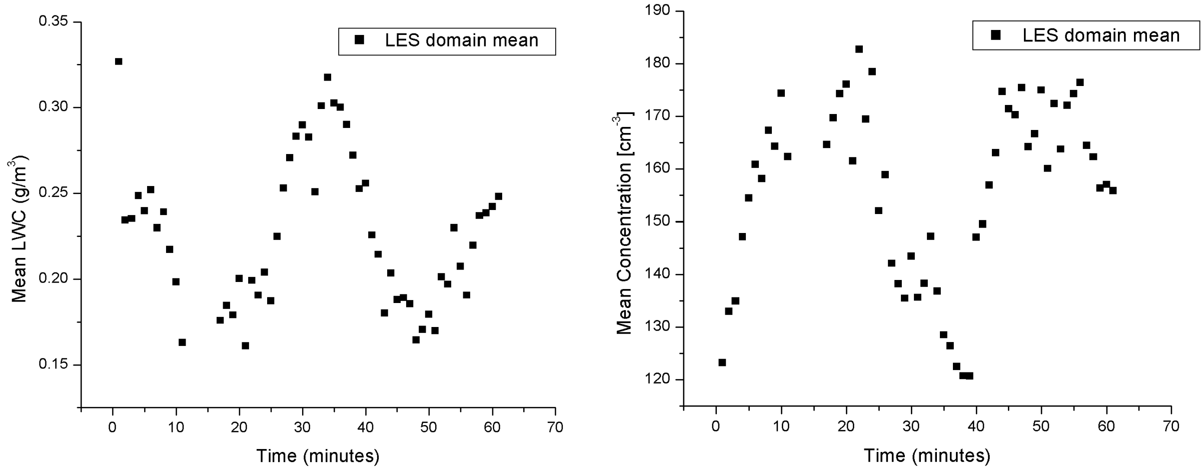


Figure 3. The mean LWC (left) and N_c (right) for the non-precipitating RF01 case calculated over the one-minute data subsets and displayed as a function of the time of data collection.

For more accurate comparision with observations, the sounding profiles have to be measured more frequently to identify conditions corresponding to a very specific position of the airplane in the Sc cloud layer. Obtaining such sounding characterizing a very specific antomosperic environment is a very challenging observational problem.

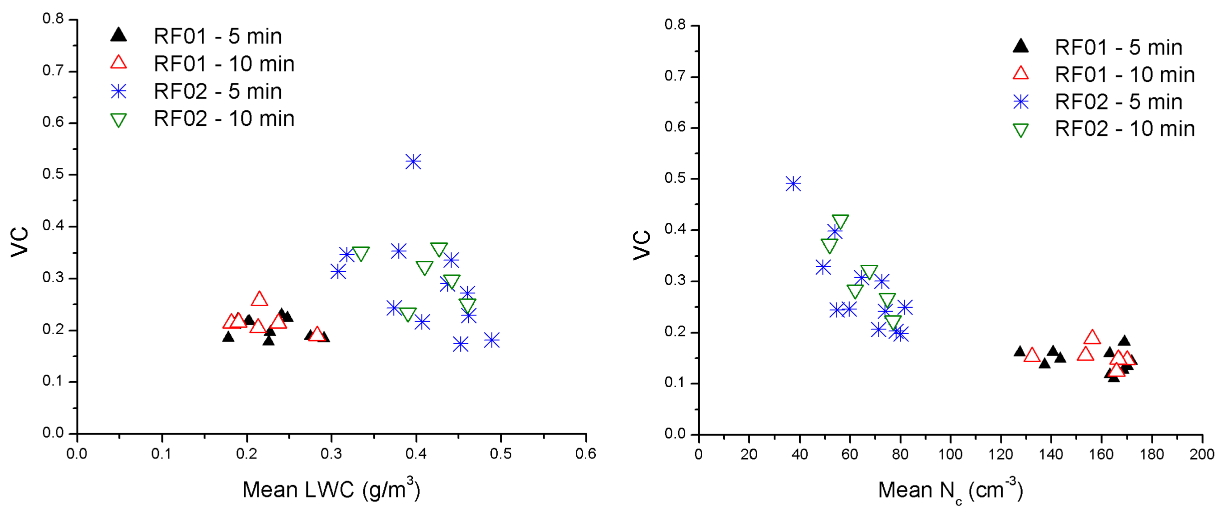


Figure 4. Variability coefficient vs mean LWC (left) and N_c (right)for time scales indicated in the plot.

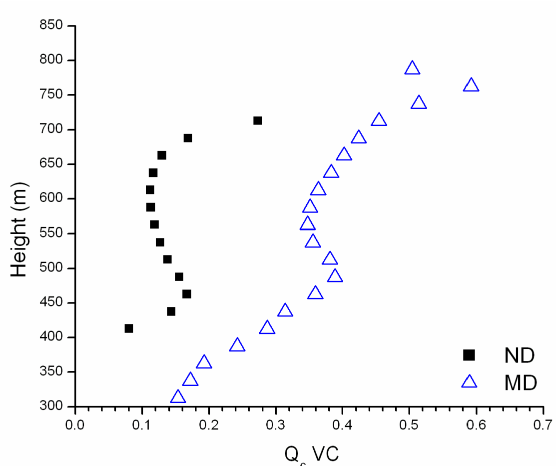
For comparison with numerical weather prediction model scales (grid sizes of 20-60 km), we examine variability of the means and VCs over the five minutes (about 30 km) and 10 minutes (about 60 km) subsets of data. When the timescale of the data segment (or domain size) is expanded (Fig. 4), the mean values are larger and vary less in the horizontal, i.e., with the time the data segment was taken. At a 10-minute scale, the variability of the mean and VC on the time when the sample was collected is even less. In general, the VC values increase with scale and become less sensitive to the time when the sampling is taken. Essentially, we may expect that for larger scale models, the observational constraints are somewhat stronger.

2.3. Variability of cloud parameters with height

The in-situ data is usually limited to level flights, therefore we will use data produced from two LES experiments conducted representing no drizzle (ND), and moderate drizzle (MD) conditions. The LES data was produced by the CIMMS LES model, which combines 3-D dynamics with an explicit formulation of liquid phase microphysical processes. A detailed description of the model can be found in Kogan et al (1995), and Khairoutdinov and Kogan (1999).

In both cases there is an increase in variability near cloud boundaries. For the ND case, *VC* for LWC changes from 0.1 in the middle of the cloud to 0.3 at the cloud top. The variability coefficient for drop concentration in the ND case is at maximum near cloud base. The same is true for the RF02 case, however the *VC* are twice as much compared to the non-drizzling case. As the horizontal legs are limited to a steady altitude in the cloud, applying the observational data for model comparison has to take into account the altitude of observations and model data.

In the precipitation case MD the mean LWC profile is affected by drizzle and sedimentation. High standard deviation values near cloud-top are products of both precipitation and entrainment effects. Concentration amounts in MD do not vary much, except near cloud base, where N_c is affected by falling drizzle. Standard deviation is also largest at these heights. The stronger observational constraints and more certain verification results may be obtained using observations made in the middle of the cloud away from cloud boudaries.



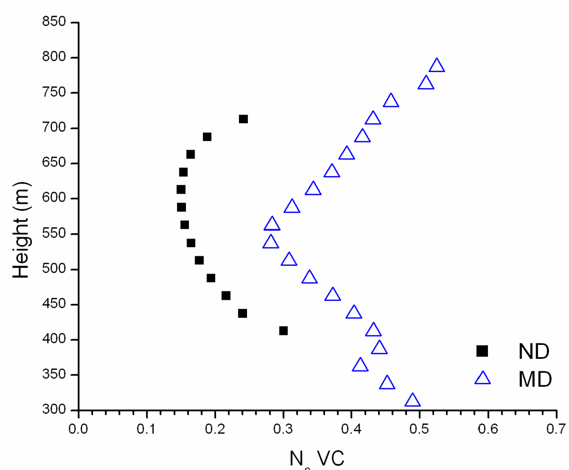


Figure 5. Variability coefficient vs height for non-drizzling (ND) and moderately drizzling (MD) cases. Left panel are standard deviation for LWC, and right panels are standard deviation for N_c.

3. Conclusions

The warm rain microphysics is considered a well established area of cloud physics, both in terms of physical formulations of its major processes, as well as accuracy of governing equations parameters. Nevertheless, precipitation forecasts given by most advanced explicit microphysics LES models are still subject to large, not well documented uncertainties. Neither do we know if further refinements of microphysical processes (e.g., accounting for turbulence effects on coagulation) will improve or deteriorate precipitation forecasts. Therefore finding methods to accurately verify model predictions against observations is quite important.

We have analyzed the variability of observations made during DYCOMS II field project and its possible effect on LES model verification. It is concluded that, in general, observations of individual cloud parameters do not provide stong enough constraints to verify the accuracy of model predictions. One of the reasons is the large uncertainties in observations due to natural variability of clouds; the latter usually are less in non-precipitating stratocumulus, however, even in this case the in observational uncertainties are about 30% both in LWC and N_c.

The verification of precipitation processes is even harder; it cannot be made with an accuracy better than 60-70%. In order to make conclusive predictions about the fidelity of the formulation of warm rain processes, multi-sensor, integrated observations are needed which may eventually lead to stronger constraints on model predictions.

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