In this response to reviewer comments, the reviewer comments are italicized, and our responses are not.

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This paper describes the implementation of a new subcolumn generator which can include correlations between state variables and between columns in the vertical. I believe there is great need for the kind of tool developed here and I think the paper does a great job of describing a complex topic. I have several suggestions for clarity and a couple questions about methodology, so I suggest acceptance with minor revisions.

Thank you for your review.

*Major Comments: 1. I don't like your methodology for computing vertical correlations. While the methodology of sampling from a uniform distribution of width 2*vert_corr centered on the sample drawn for the cell above gives the right behavior when vert_corr is 0 or 1, it isn't clear to me that values for the 2 cells will have correlation = vert_corr for intermediate values of vert_corr.*

They don't have correlation vert_corr. This was unclear in the original manuscript. SILHS does not prescribe the vertical correlation directly. Instead, vert_corr is merely a quantity that is related to the vertical correlation. The new manuscript explains "Here $vert\_corr$ is not the correlation itself between points in the vertical, but $vert\_corr$ does increase with increasing correlation, as will become clear momentarily."

Further, I don't think "folding back" preserves the desired correlation structure. Here's an example: suppose vert_corr=0.95. If X_u(K) = 1, then X_u(k+1) unif(0.95,1.05) so half of the time samples will be >1 and will be folded back to 2 – X_u(k+1) => values will be between 0 and 0.05.

Using the formulas proposed in the manuscript, the values between (1.0, 1.05) will be folded back to 2 - (1.0, 1.05) = (0.95, 1).

If we were to plot X_u(k) vs X_u(k+1) on a scatter plot, this would correspond to a value very far away from the 1:1 line expected for a good correlation.

Since the points will be folded only from (1.0, 1.05) to (0.95, 1.0), the correlation will still be close to the 1:1 line, which corresponds to good correlation.

Minor Comments:

1. p. 2138 L 24: I suggest rewriting as "parameterizations are usually based on understanding of physical processes at a point in space, while models are typically formulated in terms of grid-box means. "

We have rewritten the sentence as "A typical physical parameterization estimates the rate of a process at a point in space, whereas a coarse-resolution model instead needs the process rate averaged over a grid-box scale."

2. P. 2141 L 10: I think the biggest benefit of subcolumns is commonly thought to be the ability to handle any kind of vertical overlap. You should mention this!

The manuscript now mentions that "Another advantage of some Monte Carlo integrators is that they allow a variety of assumptions about the correlation of sample points in the vertical, including both random and maximal overlap of vertical points. Flexibility of the vertical correlations is useful for driving radiative transfer parameterizations and diagnostic parameterizations of precipitation."

3. P. 2143 L1: The 2-component normal mixture terminology threw me for a loop. Is this typical terminology in some other community? If not, why not just call it a double Gaussian?

Yes, the normal mixture terminology is what statisticians use. They have developed a wide body of results that readers might want to search. Since the most useful search keyword is "normal mixture", I have kept the terminology and added the sentence "The normal mixture terminology is widely used in statistics."

4. P. 2143 L 27: Maybe change to "using a weighted mean if needed (described further below)": : : I was initially confused why you'd ever want to use a weighted mean.

The new manuscript adds the phrase "(described further below)".

5. P. 2148 L 4: Can't you say "we start by creating a vector of independent samples drawn from a uniform PDF on (0,1), where each element of the vector corresponds to a variable needed by the routines using the subcolumn."

The new manuscript clarifies by stating "Once the starting grid level is chosen, SILHS generates for that level an uncorrelated, multivariate sample. The distribution lies between $(0,1)$ and is uniform except for weightings discussed below. Stated differently, SILHS generates a vector of independent, uniformly distributed sample points, each element of which corresponds to a separate variate, such as w, et cetera."

6. P. 2148 L 7: It took me a really long time to understand this paragraph (partly because of confusion about the normal mixture terminology). I think what you're saying is that drawing a sample from a double-Gaussian is equivalent to drawing a sample from one or the other of the component standard Gaussians, with the probability of choosing one standard Gaussian or the other given by the weighting parameter of the double Gaussian. So you select 2 random #s to represent the 2 standard Gaussians, then choose a 3rd random # to choose between the choices? If so, then the paragraph on P. 2151 L20 saying that all sample points are later converted to normal mixture distributions doesn't make sense to me.

We think that the passage was unclear because it didn't make obvious that we start with a uniform distribution and only later transform to a normal distribution. To make this clearer, we now write: "(The uncorrelated, uniformly distributed samples are transformed to correlated, normally distributed ones in task 4 below.)

Care must be taken in sampling the variates that have two mixture components…"

7. A follow-on question to the above: Do you always sort the initial pair of random variables in increasing order so the 3rd # chooses between big and small values? Otherwise, wouldn't you get the same distribution by just choosing a single random variable for position in the PDF and using another more random variable + double-Gaussian weighting parameter to say how to convert the first value to a Gaussian w/ the correct mean and sigma?

What you describe in the latter sentence is what SILHS does. I.e., we don't choose 3 random numbers per variate.

8. A general question/comment is that if you're using this sampling for microphysics, you'd want to only sample in the cloudy or precipitating region, since microphysical rates are 0 outside cloud/precip. Thus your inclusion of clear-sky samples confused me for most of the paper. I think you do so in order to keep your sampler general, so it could also be used for radiation (for example). You should clarify this.

The revised manuscript now clarifies: "When liquid cloud fraction lies between 0.001 and 0.5, SILHS chooses half the sample points within liquid cloud. If one were interested only in within-cloud processes, such as autoconversion and accretion, one could choose all points within cloud. However, some interesting processes do occur outside of cloud, such as evaporation of raindrops falling alongside sheared cumulus clouds and clear-sky radiative transfer. Therefore, SILHS chooses some sample points outside of cloud."

*9. P. 2149 L 1: I think sample weighting for in-cloud points would be cldfrac/(0.5*ncols) and clear-sky points would get weight (1-cldfrac)/(0.5*ncols). If so, you might want to*

say this. If not: : : well, then I don't understand.

We have added these formulas.

10. P. 2152 L 13: Why don't you just say "For each hydrometeor x, we assume a normal PDF for y=ln(x)"?

The sentence has been reworded and the formula for a lognormal PDF included for reference.

11. P. 2152 L 23: I think you mean "all variates" instead of "all hydrometeors"?

"All variates" consists of all hydrometeors plus w, rt, and theta_l.

12. P. 2153 L 11: change "in the prior step we have" to "we previously" to avoid confusion about whether "prior step" means prior timestep.

In the revised manuscript, "in the prior step" has been changed to "previously".

13. P. 2153 L 24-P2154 L2: I'm confused – these 2 sentences seem to contradict each other.

The revised manuscript distinguishes more clearly between the sedimentation *term* and the sedimentation *velocity* that appears in that term: "One could compute the sedimentation \textit{term} in the rain budget equation separately for each subcolumn, but for simplicity, this paper computes the sedimentation term only once using grid-box mean profiles. However, the grid-mean sedimentation \textit{velocity}, which is used in sedimentation term, is obtained by averaging sedimentation velocities computed separately for each subcolumn."

14. P. 2155 L 18: why the square brackets?

The square brackets denote what is being isolated from what, so that the reader does not get lost in the pronouns. We borrowed the idea of using square brackets from Reif's textbook on Statistical Mechanics.

15. P. 2155 L 22-27: I suggest replacing these sentences with something like "Rain is created entirely within SILHS subcolumns, while subcolumn microphysics is only one of several terms contributing to LWP. As a result, subcolumn noise is felt more strongly by rain than LWP."

We have revised the passage as follows: "The time series of rain simulated by CLUBB-SILHS shows considerable noise, but the noise is reduced in liquid water path (LWP) (see Fig.~\ref{fig:rico_time_series} and Fig.~\ref{fig:dycoms2_rf02_time_series}). Rain exhibits

substantial noise in part because it is updated directly by SILHS' microphysical tendencies, and this injection of noise at each time step is not overcome by negative feedbacks and diffusion of rain. Liquid water, on the other hand, is influenced only indirectly by noise from subcolumns. As a result, subcolumn noise is felt more strongly by rain than liquid water."

16. P2158 L 10: This section made me uncomfortable because 12 hr averaging time is long enough to destroy the diurnal cycle. Will this have a big effect on the simulations? I suspect not and I guess you could get around this by compositing over similar times for many days, but the 12 hr suggestion without worrying about diurnal sampling seemed kind of cavalier.

We have added a caveat about the diurnal cycle: "We did not use longer averaging periods because longer periods would span too much of the diurnal cycle."

17. P. 2158 L 16: I think most climate models already break grid cells into clear and cloudy portions and compute radiation and microphysics separately for each, then do a cloud-fraction weighted average of the result. In this context, 2-sample SILHS differs from the default treatment only by choosing properties randomly instead of by using layer averages. I expect the massive noise injection from this would outweigh the benefit of subgrid sampling: : : So I need more convincing that 2 sample SILHS is a good idea. Additionally, isn't there a good probability for cldfrac>0.5 that all SILHS samples will be from cloudy conditions, so clear-sky conditions wouldn't be sampled at all? This seems distinctly worse for both radiation and microphysics than what's currently done.

Unfortunately, it is infeasible for SILHS to replicate how a typical climate model handles subgrid microphysics. One feasible modification to SILHS, however, is to choose all samples as usual, except choose the average value of cloud water and/or rain in a deterministic way, rather than sampling from the full distribution. The results are shown in a figure in the revised manuscript. The upshot is that treating liquid deterministically still leads to sampling noise in the rain, and treating both liquid and rain deterministically underpredicts rain. The underprediction in rain is understandable, given that accretion is boosted by positive covariance between rain and cloud water, and if only the mean of rain is kept, the covariance is zero.

18. P 2160 L 12: "of PDF of": something's wrong here.

Thanks. The typo has been fixed.

19. P 2160 L 19: "may be a suitable problem" -> "is a suitable problem": subcolumns are perfectly parallel so there's no question that we can speed them up w/ more processors (or with GPUs!)

Yes, parallelization can surely speed up the calculation of microphysics per se in the subcolumns, but the generation of multivariate sample points is not embarrassingly parallel. The revised manuscript clarifies as follows: “Although SILHS is expensive, its computational burden may be blunted by the use of massively parallel computers. It is true that there is computational overhead associated with choosing multivariate sample points that is not embarrassingly parallel. However, computing microphysics and other physical processes in multiple subcolumns may be a suitable problem for parallelization because, in our formulation, the subcolumns do not communicate information with each other.”