Modeling the Distribution of Sub-Grid Moisture Variability for Cloud Parameterizations in Large Scale Models

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Statistical Cloud Schemes

Large Scale Models (LSM) with statistical sub-grid cloud parameterizations require realistic parametric forms for the distribution of sub-grid moisture. A vertical column of such distributions, together with vertical overlap assumptions, can be used to generate an ensemble of sub-column cloud fields for each LSM grid-column. These can then be operated on by Independent Column Approximation (ICA) radiative transfer to yield more accurate radiative averages for each grid-column.

Key Questions

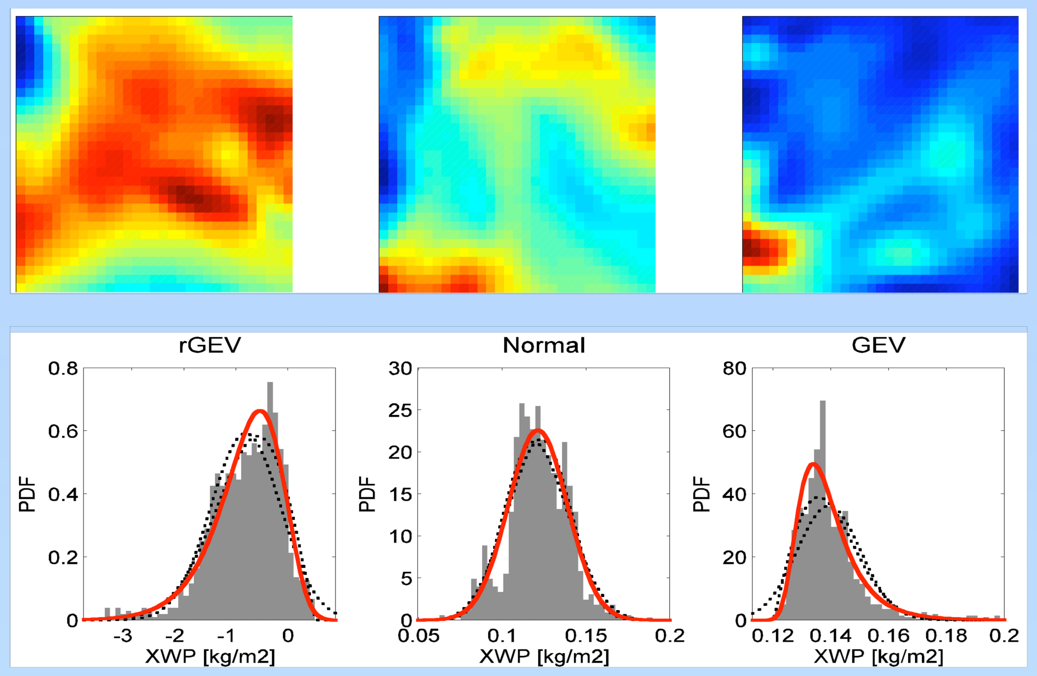
- Which simple probability density function (PDF) is most realistic for describing the subgrid-scale variability of total moisture on scales smaller than an LSM grid-box?
- What effect do large-scale moisture trends have on the form of these subgrid-scale PDFs?

Methodology

We examine various candidate layer probability density functions (PDFs) for modeling total moisture content from a 20 day Cloud Resolving Model (CRM) simulation over the ARM SGP site (Zeng *et al.*, JAS v64, 2007). We include both symmetric (Gaussian) and skewed (Generalized Extreme Value) distributions (see Norris *et al.*, QJRMS v134, 2008 — the GEV distribution, with its exponential-type tails, tends to be more realistic than say the Beta distribution, with its polynomial-type tails). A maximum likelihood (ML) method chooses which PDF and set of parameters most likely produces the observations. The results shown are for 1-km resolution and 32 x 32 subsets of the full domain, mimicking a $\frac{1}{4}°$ LSM.

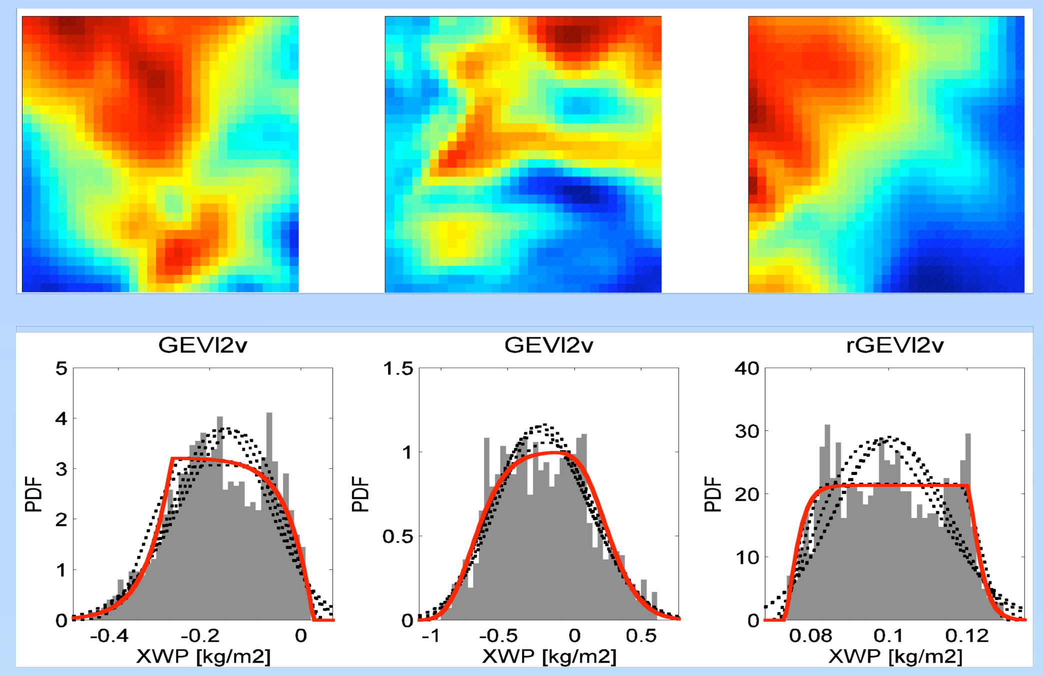
We also consider the effect of grid-scale trends on these PDFs. Such trends can sometimes dominate subgrid small-scale variability, particularly outside the boundary layer. We consider a 2D linear trend, whose PDF must be convolved with the subgrid-scale PDF on the assumption that the subgrid- and grid-scale variability are not correlated.

Symmetrical vs. Skewed PDFs



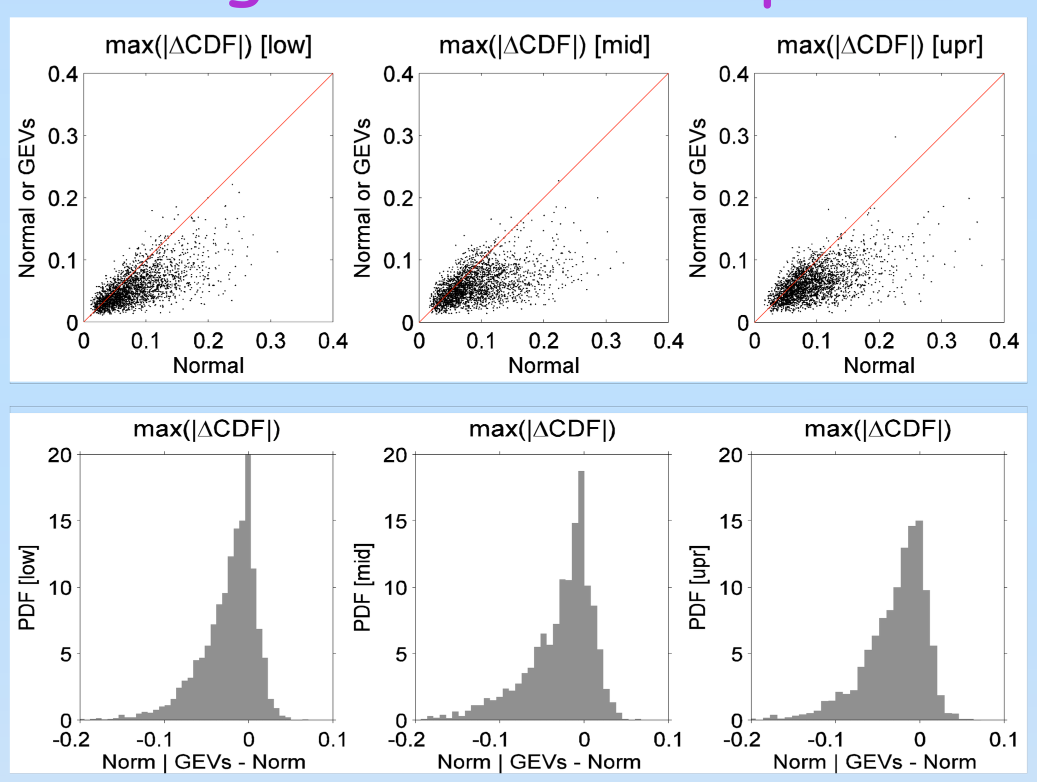
Examples of 3 horizontal layers of excess water path (XWP = total minus saturation) and the corresponding distribution densities (PDFs) in grey. The red lines are maximum likelihood (ML) fits of the normal distribution and the standard (GEV) & reverse (rGEV) Generalized Extreme Value distributions (3 params). Marked skewness (of both signs) is evident.

Trend vs. No Trend

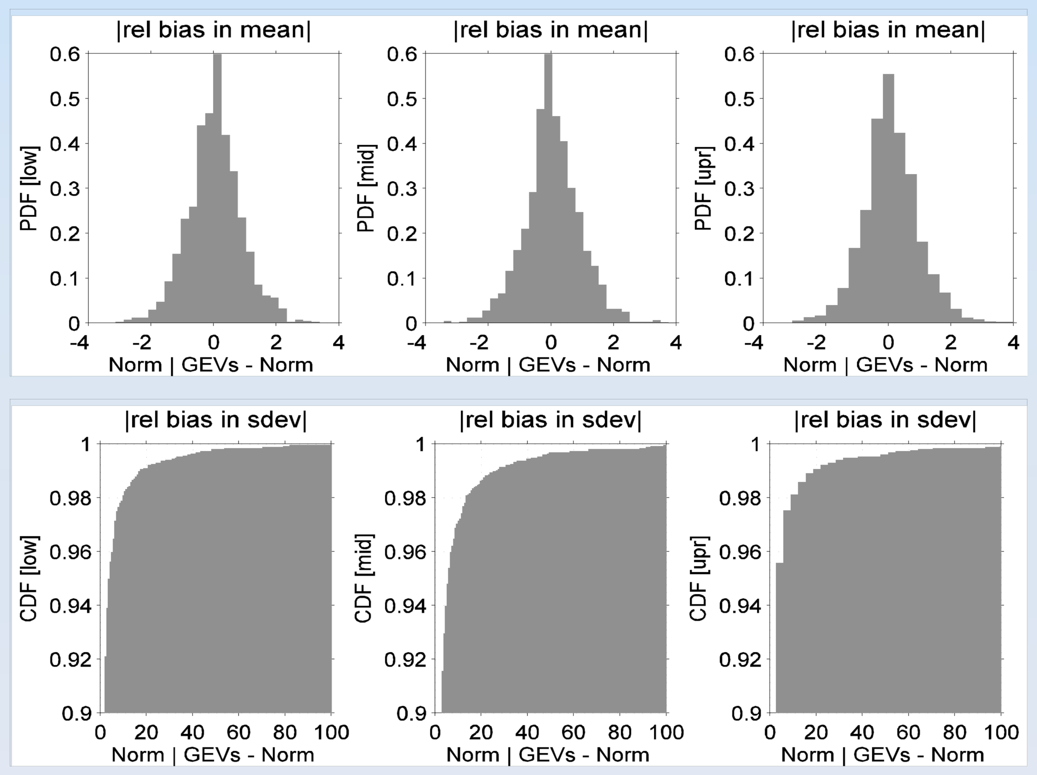


Three more horizontal layers of water path and their empirical PDFs. Notice the grid-scale trends in the layers. The red lines are maximum likelihood fits for the PDF of a 2D linear trend convolved with the PDFs of the reverse & regular GEV distributions. The trends tend to flatten the PDF top (a pure trend yields a truncated triangular distribution).

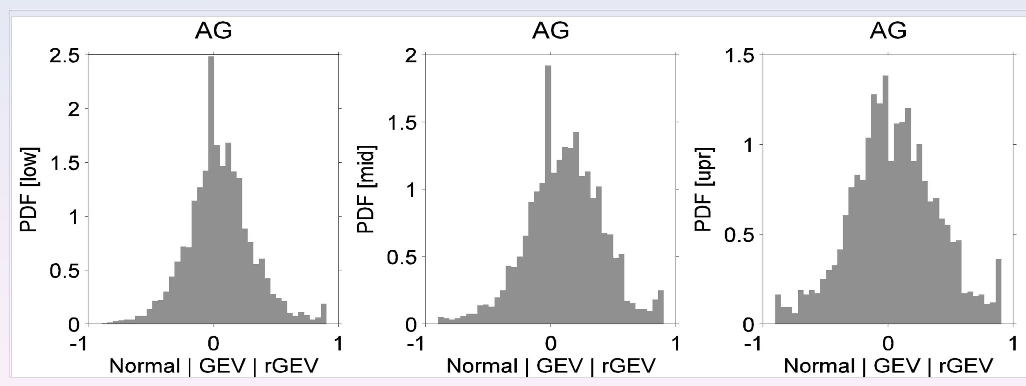
Adding Skewness Improves the Fit



Every 3 hours during the 20 day simulation, an ML fit was performed for 3 pressure bands (edges @ 400, 700 hPa). The better the fit, the lower the maximum absolute CDF difference between the empirical and fitted PDFs. Allowing maximum likelihood selection between normal, GEV and rGEV distributions tends to produce a better fit (sometimes much bet-ter) than using the nor-mal distribution alone.

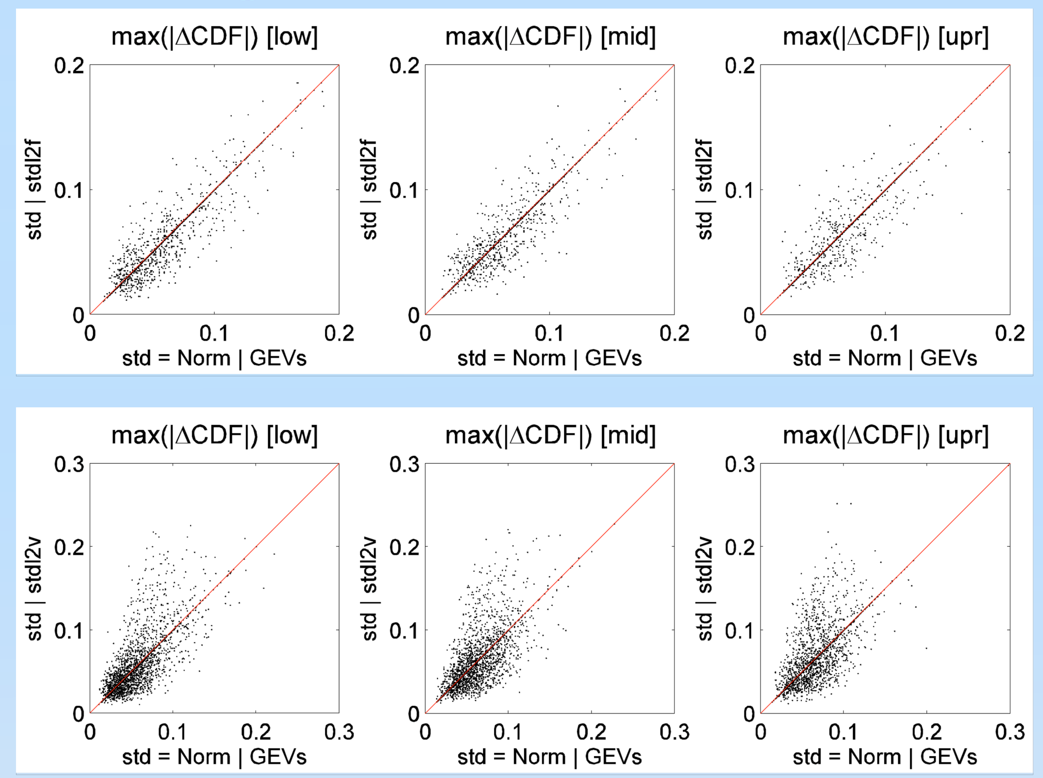


Bias in the mean XWP is scaled by the standard error in the mean. The absolute value of that bias is not significantly impacted by including GEVs in the fit. Conversely, absolute bias in the standard deviation (scaled by its standard error) becomes larger. This is a potential problem with the GEV distributions — the extended tails may produce some very large values which will need to be limited in an LSM implementation.

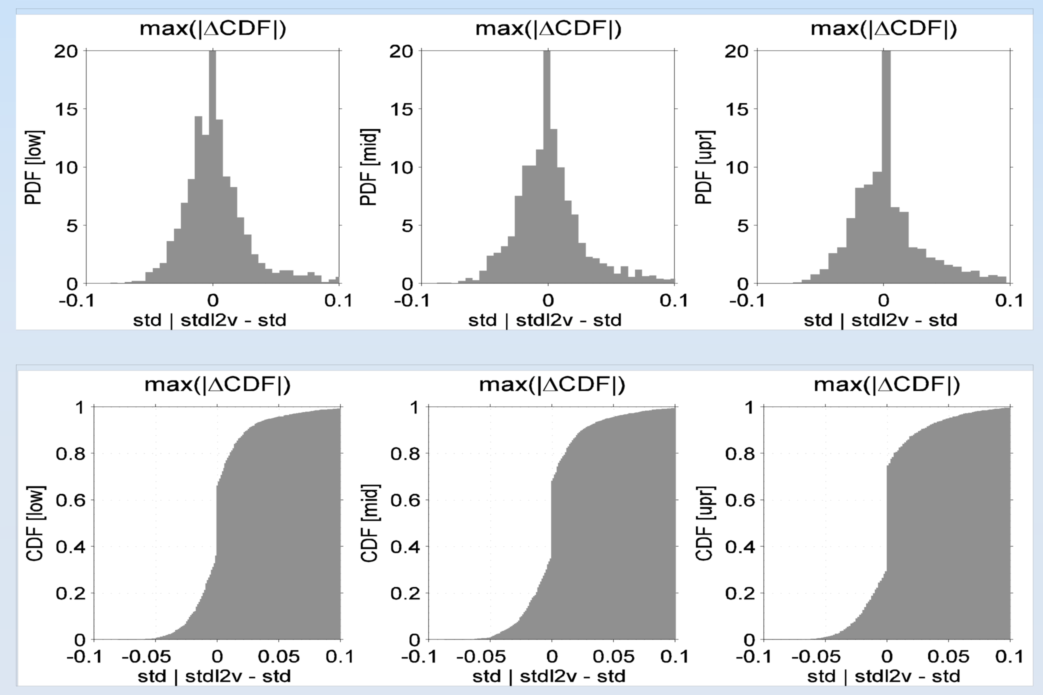


Distribution of Arnold & Groeneveld (AG) skewness measure for the ML fits. Mid- and upper-level regions have a broader distribution of skewness. Mid-levels are especially skewed in the positive direction.

Adding Trends is Near Neutral



First we add a 2D linear trend, but fixed by the large scale trends between LSM gridboxes. As expected, it has very little effect on the overall goodness of fit, since large-scale trends tend to smear out features at the gridbox scale. Next we let trend slopes enter the ML fit (as in the 3 examples at the top). This seems to worsen the fit on some occasions.



More precisely, although close to half the cases improve and half deteriorate, the deteriorations can be 2x the magnitude of the improvements (i.e., the change in max(|ΔCDF|) is in the range -0.05 to 0.1. The ML fitting procedures for the combined trend + small-scale need more work, and maybe quadratic trends should be tried. But so far, the inclusion of trends is not particularly beneficial.

Conclusions

(1) The GEV should be further tested as a suitable PDF for statistical cloud parameterizations. It is able to capture quite well the frequently observed positively and negatively skewed PDFs of moisture, although it may lead to positive biases in variance unless tail-limited. (2) So far, adding linear trends seem not to be particularly important.

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