Quantifying the Limits of Convective Parameterizations:

A Statistical Characterization of Simulated Cumulus Convection

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Background

The goal of cumulus cloud parameterization is to realize changes in the simulated large-scale environment as a function of the collective influence of multiple cumulus clouds. This is often accomplished by assumption of quasi-equilibrium (QE) whereby increases in convective available potential energy (CAPE) are assumed to be in near balance with CAPE-reducing processes.

The desire to create stochastic convective parameterizations (SCPs) has developed from the realization that QE-based (or otherwise diagnostic and deterministic) convective parameterizations fail to reproduce the full observational spectrum of convective variability. Such departures from QE are inherent to convection. The use of SCPs has the effect of interrupting QE and thereby corrects the variability of the convection.

Implementation of a complex, yet physically based, method requires an understanding of the nature of the deviation from QE to be able to direct convective variability in a more informed manner. We aim to gather such information from a CRM.

Objectives

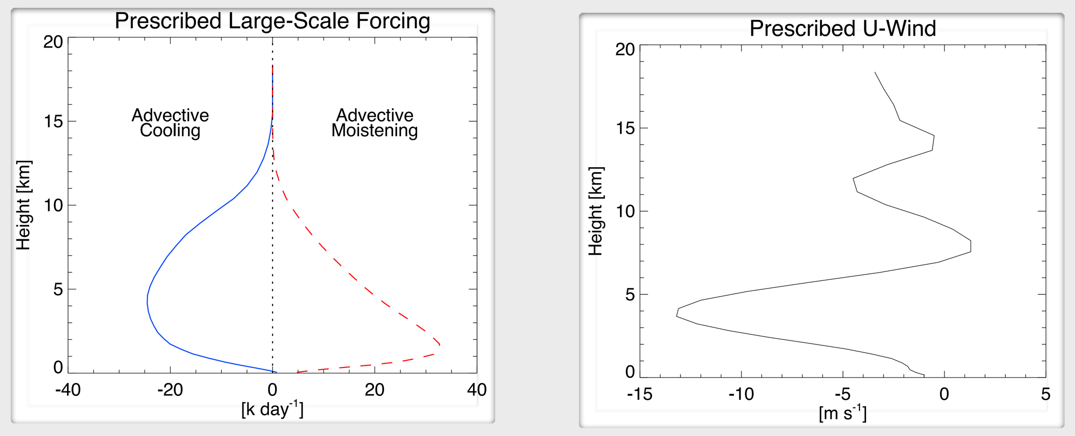
- What is the QE convective response under constant forcing?
- How does the convective response deviate from a variety of applied forcings compared to QE?
- At what grid size is QE no longer a good parameterization? How does the response vary across different domain sizes?

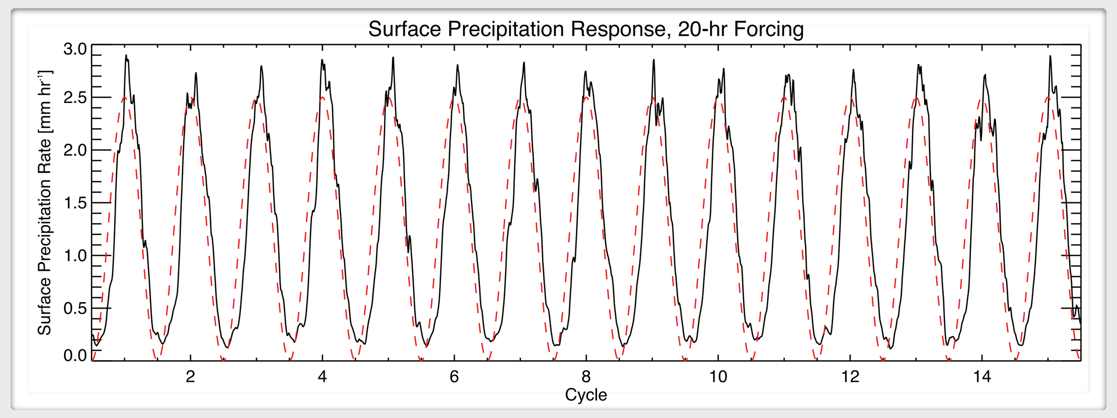
Methods

To obtain a characterization of 'true' convective variability at high resolution, the three-dimensional Jung-Arakawa anelastic CRM is used in this study (VVM). Convective statistics were compiled using the model with a 2-km horizontal resolution and a 35-level stretched vertical grid (to ~20 km). A doubly periodic grid covering the domain of (256 km)^2. The simulations were initialized with a GATE-III sounding containing moderate vertical wind shear (see next panel).

Following Xu et al. (1992), 13 simulations using cyclic large-scale forcings with periods ranging from 2 to 120 hours, using a series of constant forcing runs to act as a QE-like control to determine non-equilibrium effects. The dependence of the simulation on the size of the computational domain was investigated by sub-sampling the full domain to find non-deterministic effects of small sample size.

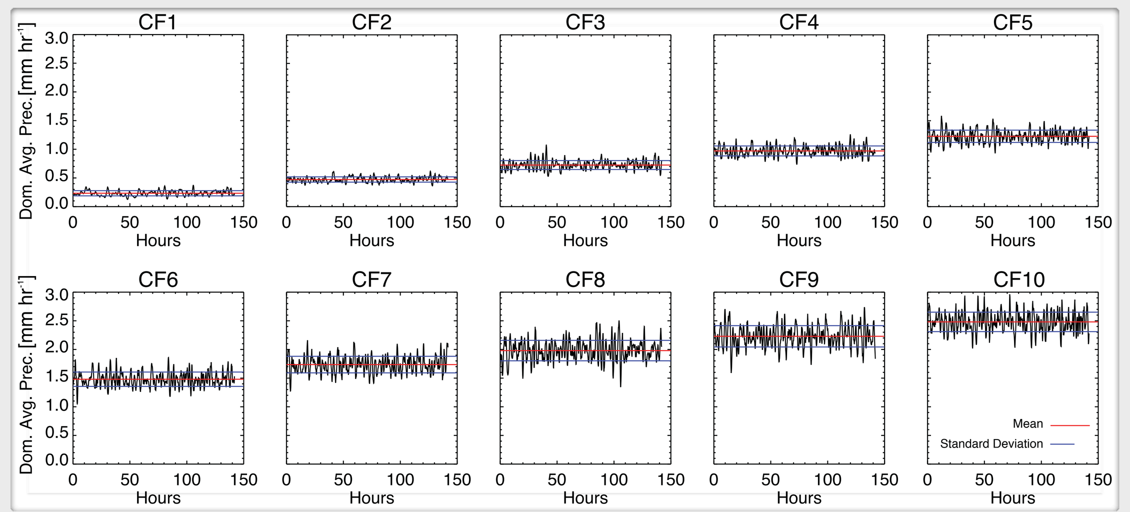
Model Initialization



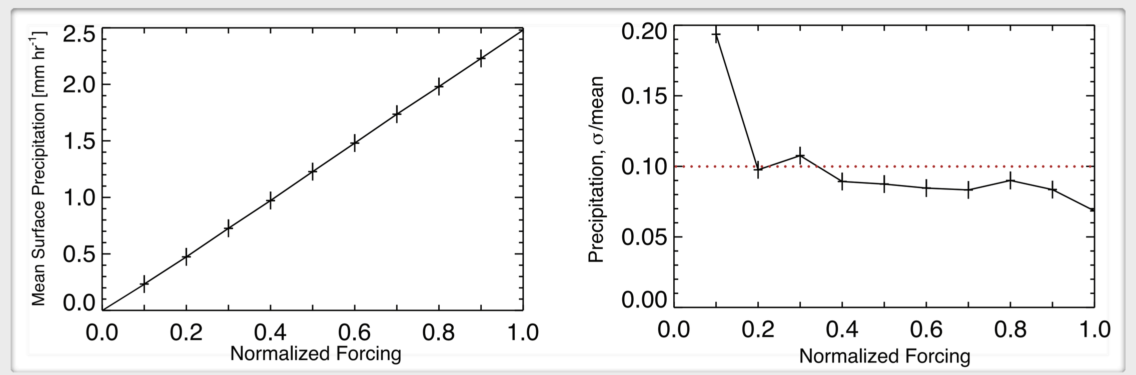


The precipitation response to the periodic forcing (*20-hour, black curve*). Due to the relatively short period of the forcing, the convective response lags the forcing. Also, the response has some scatter deviating from a smooth response, though less than Xu et al. (1992), since the VVM is 3D rather than 2D.

Constant Forcing

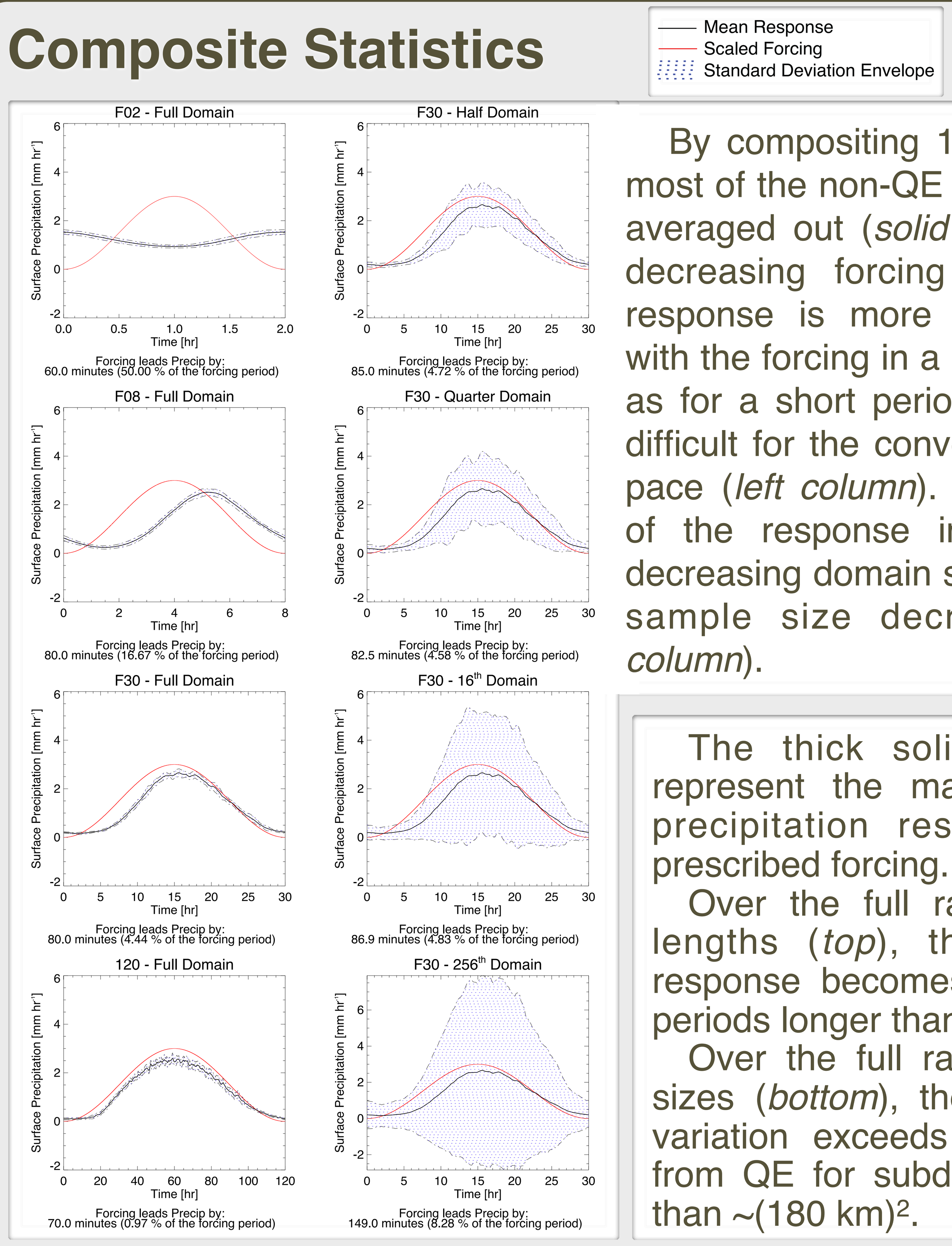


Numbers in the titles denote tens of a percent of the prescribed L-S forcing above. When the model is run at constant forcing, the response is a good approximation to this models representation of QE.



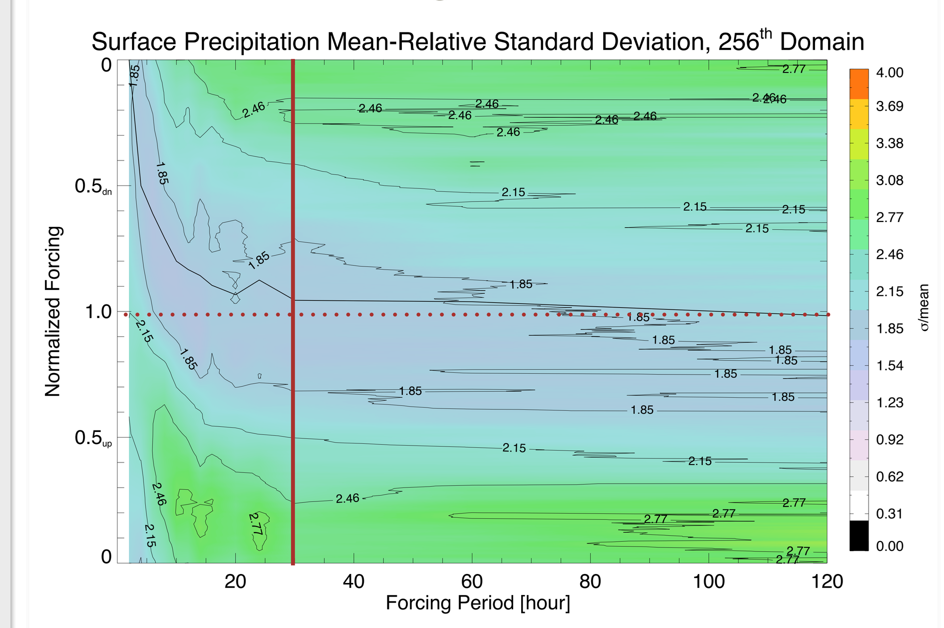
The response increases linearly with increasing constant forcing. The variability of the forcing scales with the mean convective response. This is in general agreement with conventional wisdom.

Composite Statistics

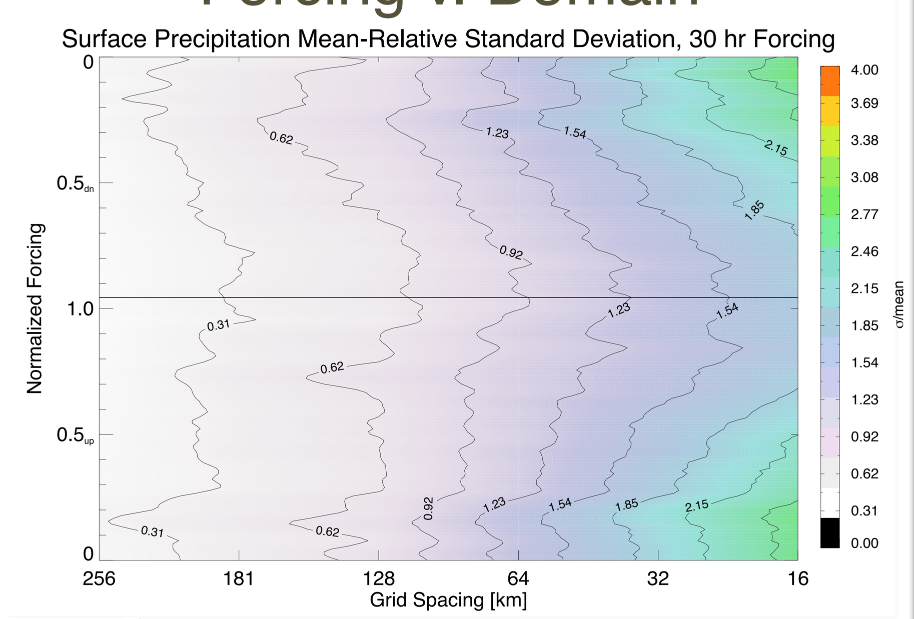


By compositing 15 realizations, most of the non-QE scatter can be averaged out (*solid black*). With decreasing forcing periods, the response is more out of phase with the forcing in a relative sense, as for a short period forcing, it is difficult for the convection to keep pace (*left column*). The variability of the response increases with decreasing domain size, that is, as sample size decreases (*right column*).

Forcing v. Period



Forcing v. Domain



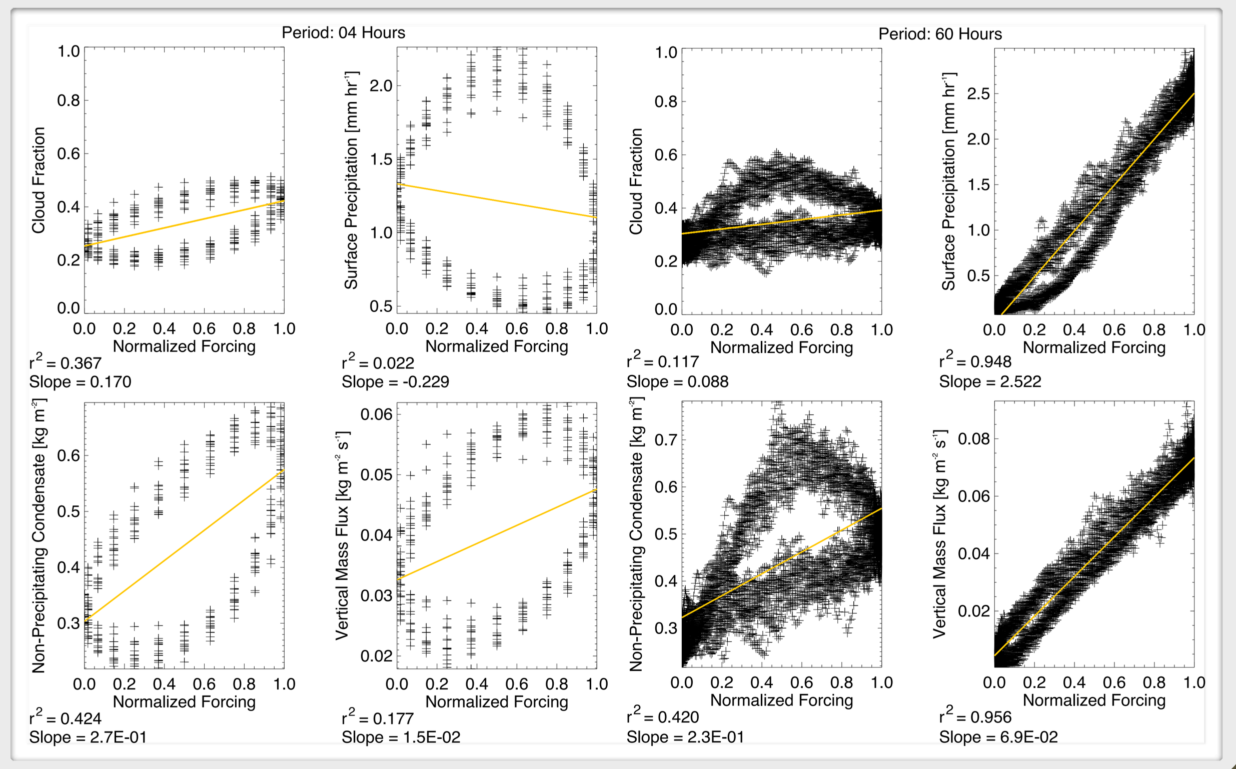
The thick solid black lines represent the maximum of the precipitation response to the prescribed forcing.

Over the full range of period lengths (*top*), the lag in the response becomes negligible for periods longer than ~30 hours.

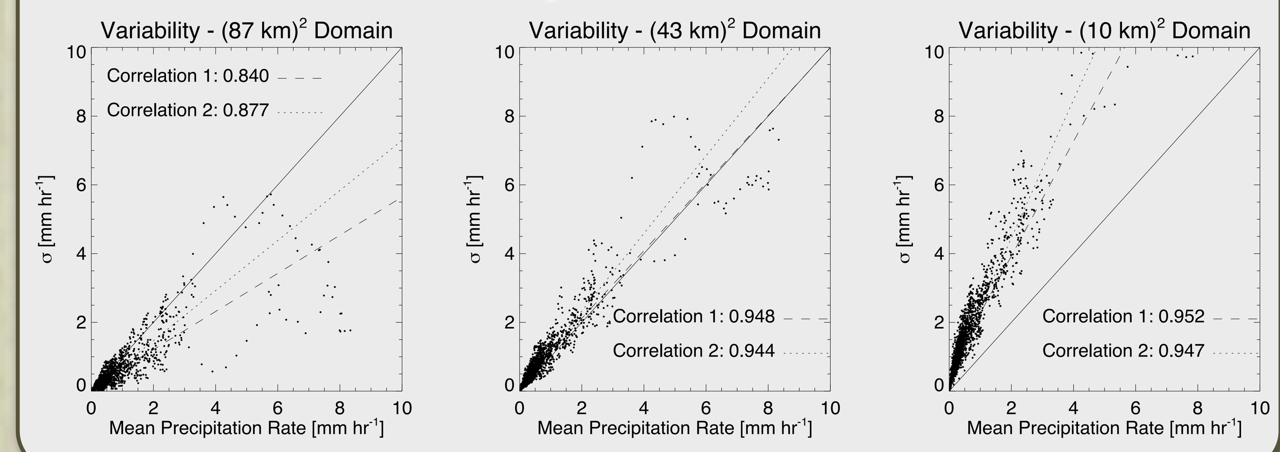
Over the full range of domain sizes (*bottom*), the coefficient of variation exceeds that expected from QE for subdomains smaller than ~(180 km)^2.

Correlation Analysis

The correlation coefficient improves dramatically for surface precipitation and vertical mass flux responses. The response more closely aligns with constant forcing results with longer forcing, regardless of whether the forcing is increasing or decreasing, though small deviations exist due to mesoscale modulation effects.



TWP-ICE Comparison



Conclusions

As models continue to employ equilibrium-based convective parameterizations, scientists need to be aware that there will be an **unrepresented lag** of convection from the timing of the forcing adding error to simulations for forcing timescales **less than 30 hours**.

Additionally, those same modelers should also be aware that **small-scale variability will be absent** from their solutions, adding to errors in components of the large-scale climate variability statistics when using grid spacing on the order of **(180 km)^2 or finer**.

Others have demonstrated that these missing elements can be incorporated into the model by adding a random part to the convective parameterization, alleviating model/observation discrepancies.

References:

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