# Applications of Uncertainty Quantification to Multiscale Processes in the Atmosphere

SciDAC Scientific Discovery through Advanced Computing

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MULTISCALE

## Regionally-Refined Framework for Multiscale Atmospheric Uncertainty Quantification

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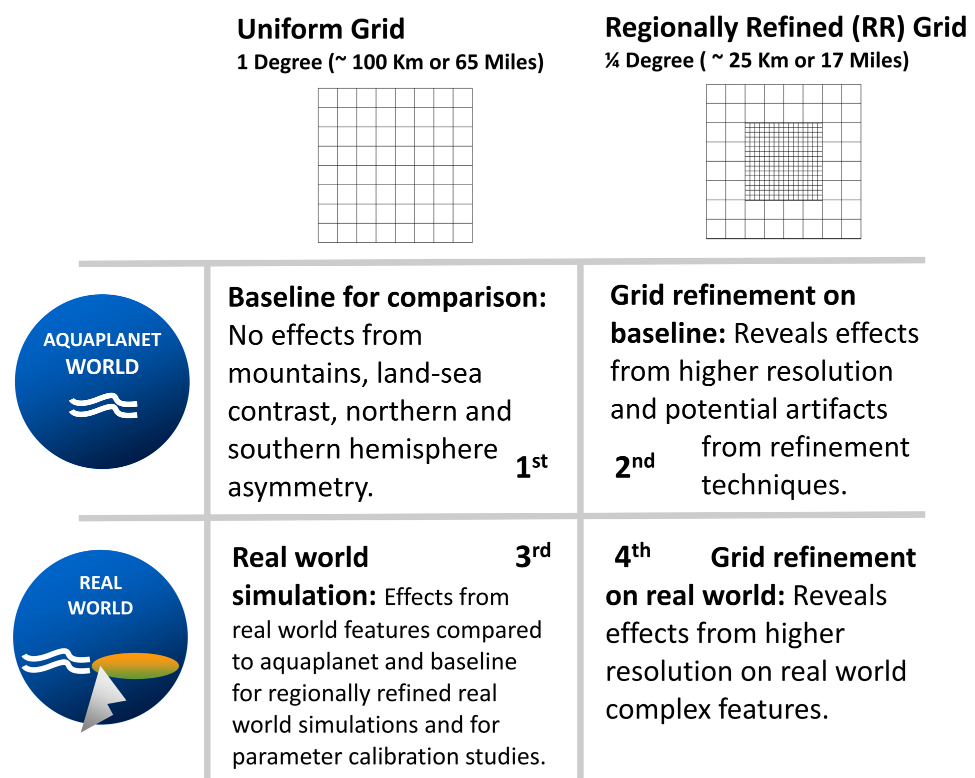
- **SciDAC Multiscale** is in collaboration with **ACME** (Accelerated Climate Modeling for Energy) to gain insights into the fidelity of new and revised treatments of cloud convection which plays a key role in determining the variability of climate from regional to global scales.
- The study region is the **Tropical West Pacific** (TWP), the heat engine of the atmosphere. Simulating time mean precipitation, shallow-to-deep convection transition, intra-seasonal and inter-annual climate variability (MJO and El Niño phenomena), and cyclone genesis in this region remains a challenge.
- SciDAC Multiscale will study the behavior of convection schemes at high resolution using ACME's **Regional Refinement** capability. This saves time and computational resource while targeting regions of interest and, by focusing on TWP, complements ACME work on evaluating convection.
- Final recommendations from SciDAC Multiscale on up to 4 different treatments of convection. Efforts will focus first on one treatment.

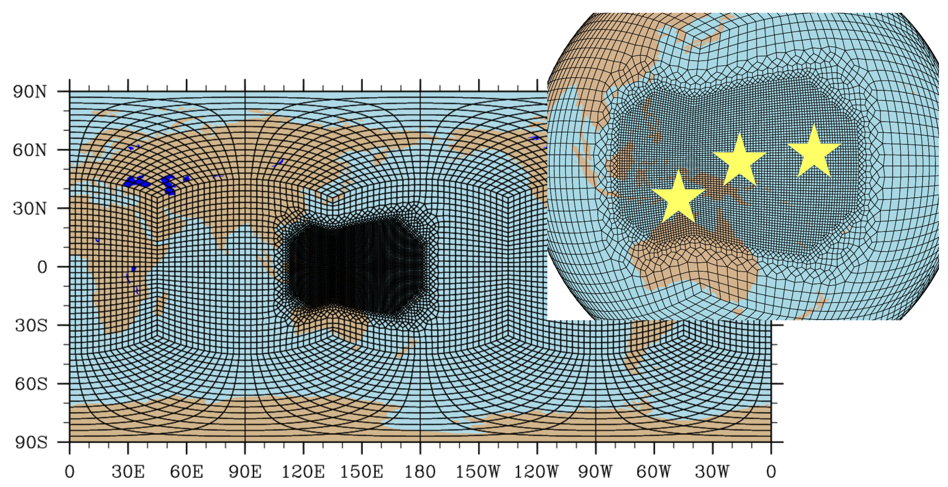
**Simulation Framework for evaluating convection:**




**Regional Refinement**

- RR uses the Multiscale developed tensor hyper viscosity operator which provides a resolution-aware dissipation mechanism and removes mesh transition artifacts [1]
- RR can capture physics sensitivity to resolution [2]
- Global circulation not affected by RR [3]
- Use of ¼ degree RR in Tropical West Pacific reduces by 8 times computational resources compared to global uniform ¼ degree

***Spectral Element Mesh used for the Tropical West Pacific Region.*** *Simulated data will be compared with observational data from the sites indicated with stars: from left to right, Darwin, Manus, and Nauru.*




**References:**
[1] Guba, O., Taylor, M. A., Ullrich, P. A., Overfelt, J. R., and Levy, M. N.: The spectral element method (SEM) on variable-resolution grids: evaluating grid sensitivity and resolution-aware numerical viscosity, Geosci. Model Dev., 7, 2803-2816, doi:10.5194/gmd-7-2803-2014, 2014.
[2] Colin M. Zarzycki, Michael N. Levy, Christiane Jablonowski, James R. Overfelt, Mark A. Taylor, and Paul A. Ullrich, 2014: Aquaplanet Experiments Using CAM's Variable-Resolution Dynamical Core. J. Climate, 27, 5481–5503.
[3] Colin M. Zarzycki, Christiane Jablonowski, Diana R. Thatcher, and Mark A. Taylor, 2015: Effects of Localized Grid Refinement on the General Circulation and Climatology in the Community Atmosphere Model. J. Climate, 28, 2777–2803.

## Reducing Simulation Time to Isolate Parameter Sensitivity

Steve Ghan, Guangxing Lin, Yun Qian, Hui Wan, Kai Zhang [all PNNL]

**Motivation:**

The atmosphere is chaotic, so internal variability often obscures the atmospheric response to changes in parameter values, so long simulations are used to isolate the sensitivity. For high resolution models with many parameters, this becomes computationally impractical. To reduce simulation time, we perform 12 10-day simulations initialized from selected snapshots from a common 4-year baseline simulation. Alternatively, we also nudged all simulations to winds and temperature or to winds alone from a common baseline simulation. Here we test whether these two methods bias the sensitivity of simulations to the value of model parameters.

**Ensemble Short Simulations**

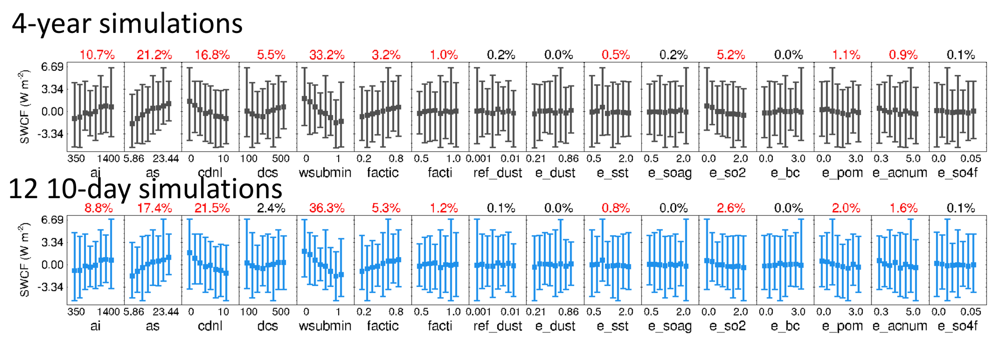
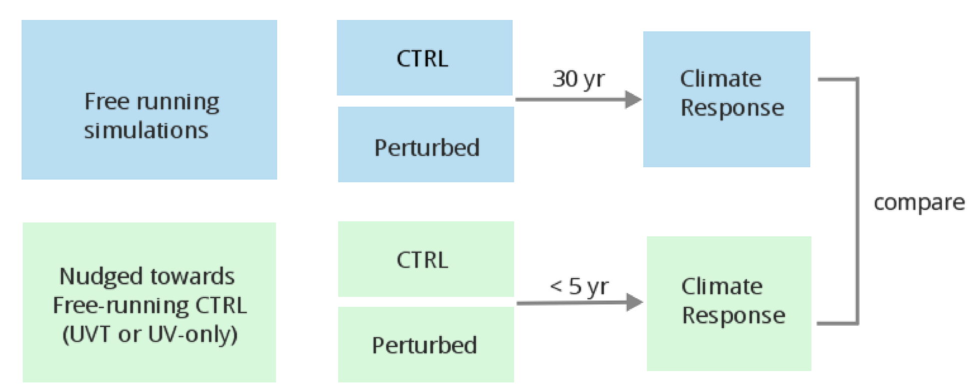



*Figure 1. Use of ensemble short simulations to study shortwave cloud radiative forcing sensitivity to model parameters.*

Wan, H., P. J. Rasch, K. Zhang, Y. Qian, H. Yan, and C. Zhao (2014), Short ensembles: An efficient method for discerning climate-relevant sen-sitivities in atmospheric general circulation models, Geosci. Model Dev., 7, 1961–1977, doi:10.5194/gmd-7-1961-2014.

**Nudging Simulations**



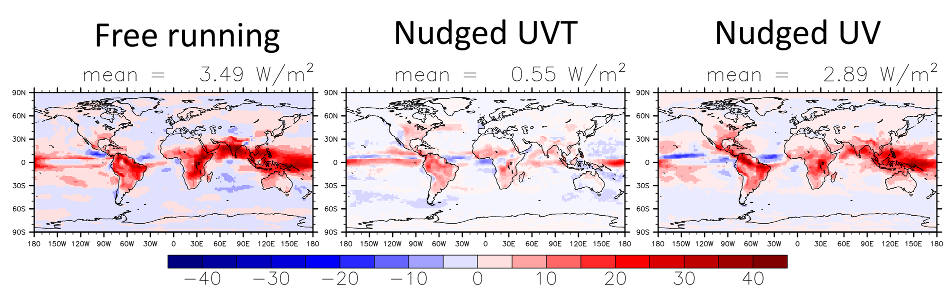




*Figure 2. Use of nudging simulations to investigate the sensitivity of shortwave cloud forcing to the value of the cumulus cloud adjustment timescale (tau) (tau=8 hours vs. tau= 1 hour)*

**Lessons Learned**

- A subset of short simulations can reproduce the same sensitivity as one long continuous simulation, a 15-fold reduction in CPU time.
- The ensemble of short simulations can be performed in parallel, yielding a 200-fold reduction in wall-clock time.
- Simulation length must be long enough for processes to respond to parameter differences.
- Response of winds to parameters can be important.
- Nudging toward common winds and temperature suppresses interaction of clouds with meteorological filelds, inhibiting response of moisture convergence and precipitation to changes in parameter values.
- Nudging toward winds alone more effectively captures the climate response to the tau perturbation.
- Nudging simulations can reduce the CPU time by more than a factor of 6.

## Quadrature Methods Applied to Microphysics Subgrid Variability

Kenny Chowdhary (SNL), Bert Debusschere (SNL), Vince Larson (UWM), Kyo-Sun Lim (PNNL)

### Summary of Past Work

- We have shown that deterministic quadrature approaches can achieve better accuracy and greater efficiency for the calculation of sub-grid microphysics moments, e.g., autoconversion and accretion, compared to traditional random sampling methods, such as Latin Hypercube sampling (see Figs 1 and 2).
- We have developed an open source Fortran library, ForQInt v1.0, to make quadrature routines easily available to CLUBB and CAM.

### Summary of Current Work

- We are in the process of integrating quadrature into the new MG2 microphysics scheme with CLUBB.
- This will allow us to study the full impact of using quadrature for sub-grid microphysics in CLUBB, with the goal of improving both the efficiency and accuracy of microphysics quantities.

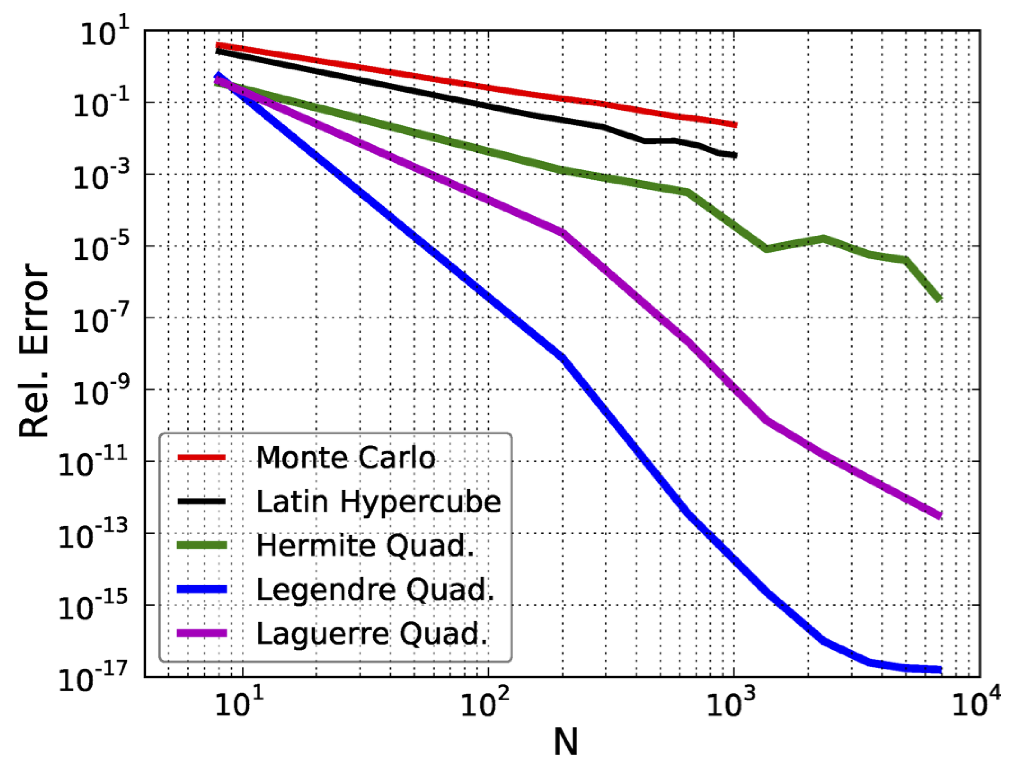



*Figure 1: Convergence plot for the autoconversion rate. Quadrature uniformly beats out Monte Carlo and Latin Hypercube sampling.*

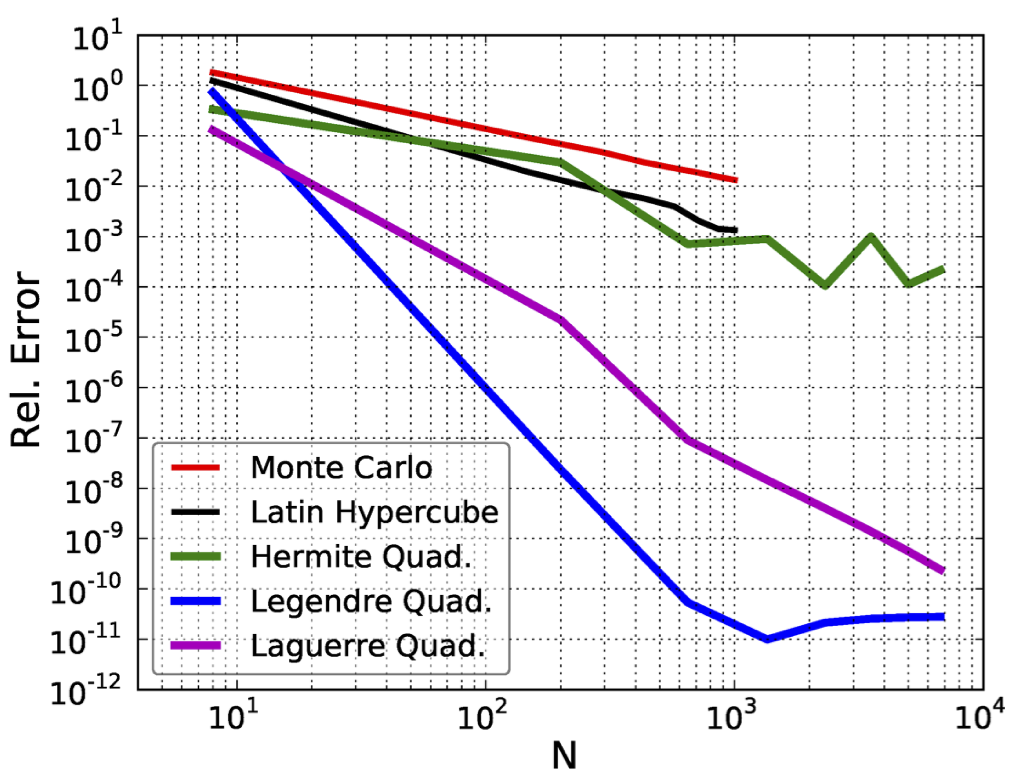



*Figure 2: Convergence plot for the accretion rate. Quadrature uniformly beats out Monte Carlo and Latin Hypercube sampling.*

## Multifidelity Calibration of Multiscale Physics Parameters in Atmospheric Models

Vera Bulaevskaya (LLNL), Donald Lucas (LLNL)

### Goal

Use multi-resolution ensemble with many "low" resolution simulations and few "high" resolution simulations to calibrate physics parameters in a "high" resolution version of a climate model (ACME or Community Atmosphere Model CAM5).

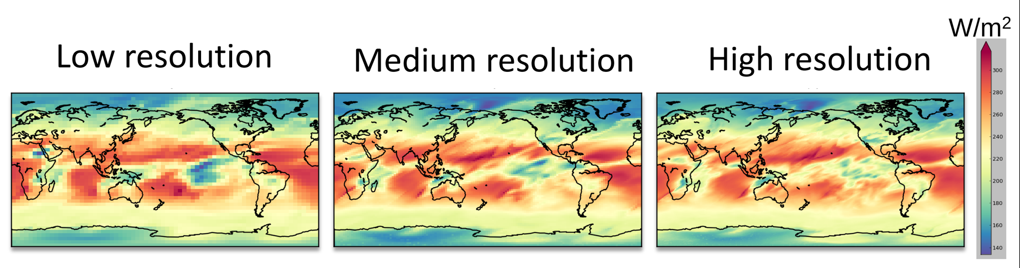



*Figure: outgoing longwave radiation in CAM5 (Dec 2011 monthly mean). Large scale patterns and features are similar at different resolutions. This suggests that we may be able to leverage low-fidelity simulations to calibrate a high-fidelity model.*

### Approach

1. Design climate model ensemble that samples uncertain physical parameters at different resolutions.
   - Applied to 11 parameters and 3 resolutions in CAM5.
   - Ran 503 simulations at 4° resolution, 263 simulations at 2° resolution, and 143 simulations at 1° resolution.
2. Train statistical models on ensemble data to predict the model response as a function of parameter values and resolution.
   - Fit outgoing energy fluxes (longwave, shortwave, net) using Gaussian process models (GPMs) and gradient boosting regression (GBR).
3. Use statistical models to optimize parameter values given observational targets. Likelihoods of the predicted output measure the degree of match between predictions and observations.
   - Tested methodology on *model-generated synthetic* observations and applied to NASA *satellite observations* of Earth's radiation fluxes.

**Verification test on model-generated "observations"**

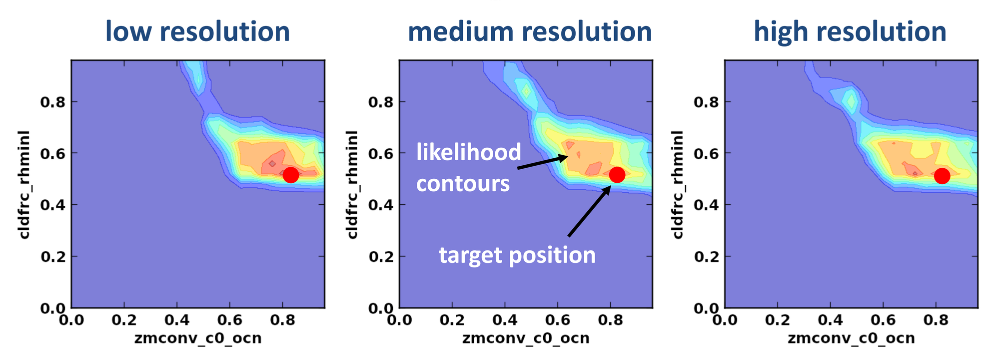



*Figure: GBR statistical model determines correct values of key parameters used to generate the target observations at the three different resolutions.*

**Application to satellite observations**

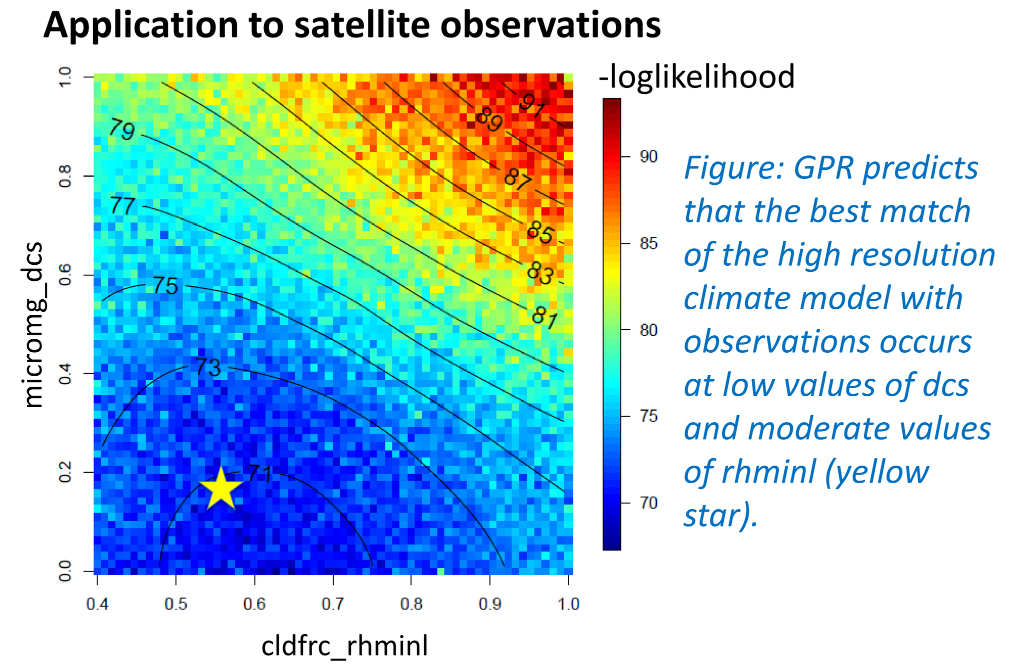



*Figure: GPR predicts that the best match of the high resolution climate model with observations occurs at low values of dcs and moderate values of rhminl (yellow star).*

### Key Results

- Climate model resolution can be incorporated as a dimension in statistical models used for parameter estimation and calibration studies.
- We used a resolution-aware statistical model to optimize climate model parameter values at three resolutions.
- We determined parameter values in CAM5 that are predicted to better match satellite data than any of our existing ensemble simulations.

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