Use of single-column models to constrain and investigate climate model physical processes and comparison with global tuning

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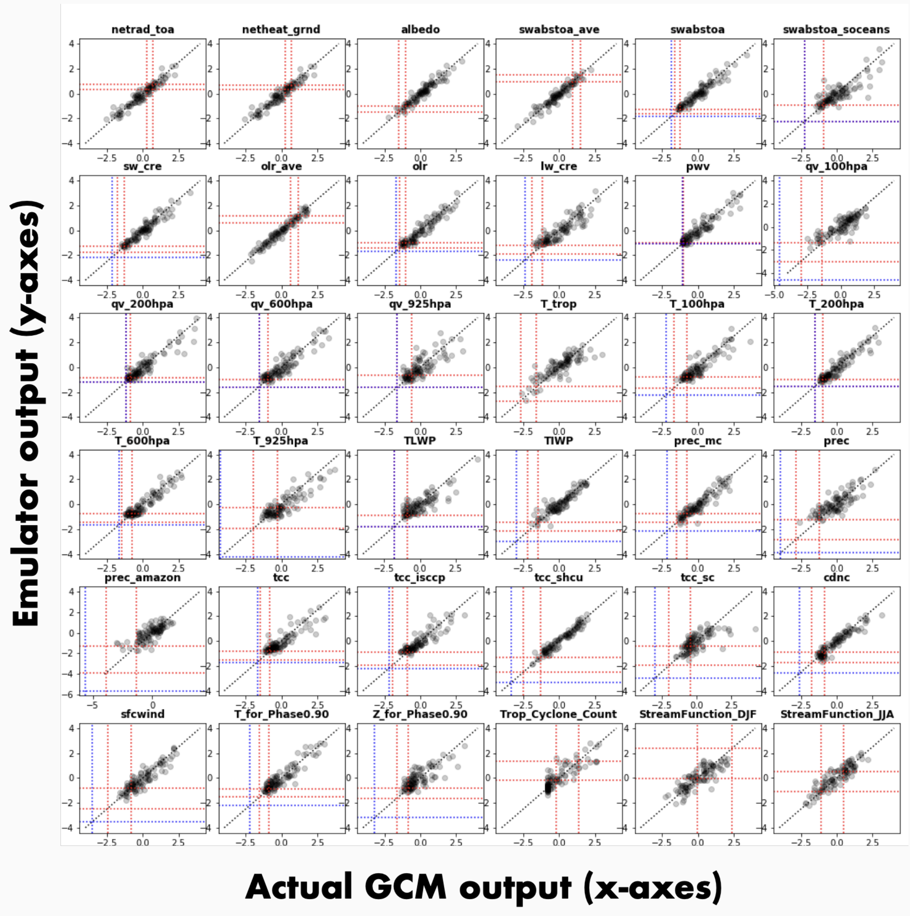
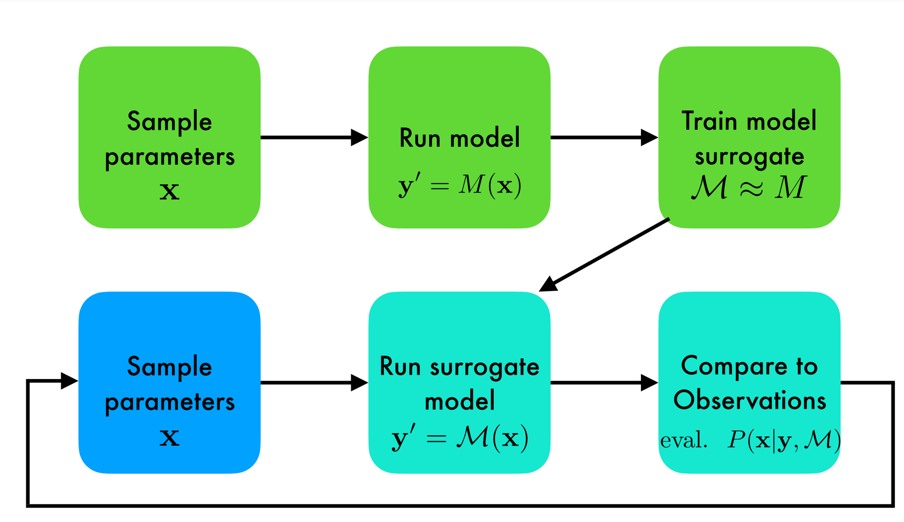
GCM PPE tuning

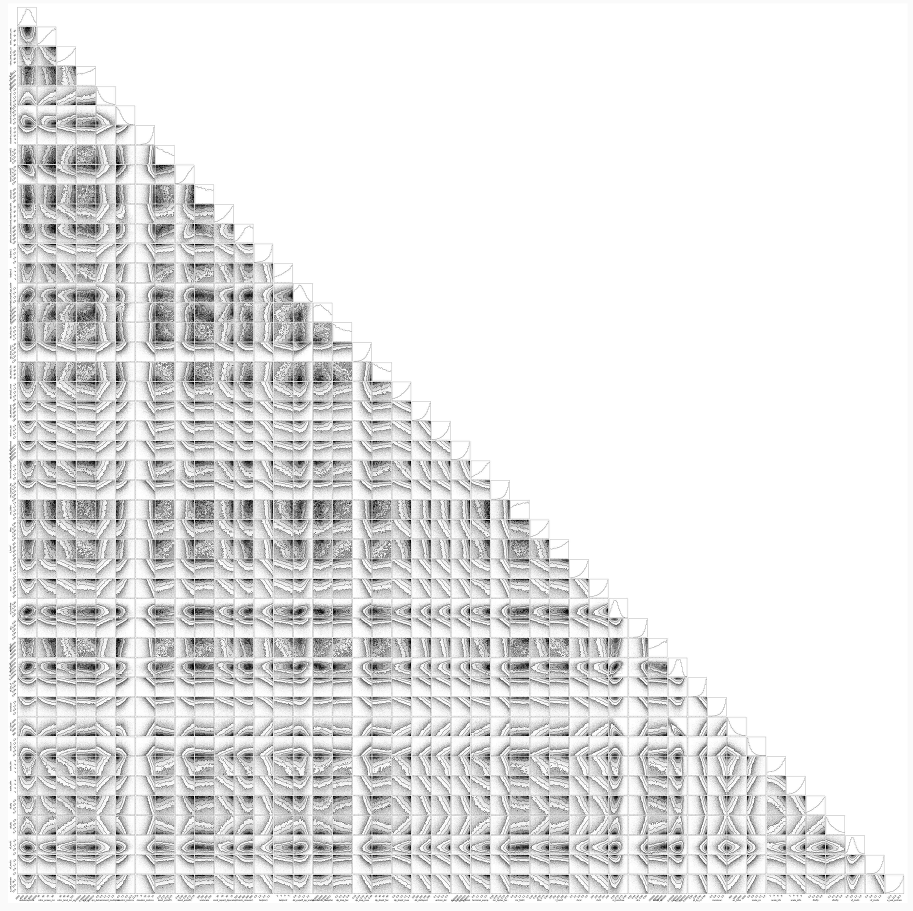
One-at-a-time and ad-hoc tuning is not sufficient to optimize model performance and reduce uncertainty in GCM parameters; simultaneous exploration of parameters is necessary. An perturbed-parameter ensemble of 1-year atmosphere-only ModelE global simulations with parameters sampled via LHS from a 45-dimensional parameter space is used to train a emulator or "surrogate" model. Outputs are 36 observable variables and satellite-based error metrics.



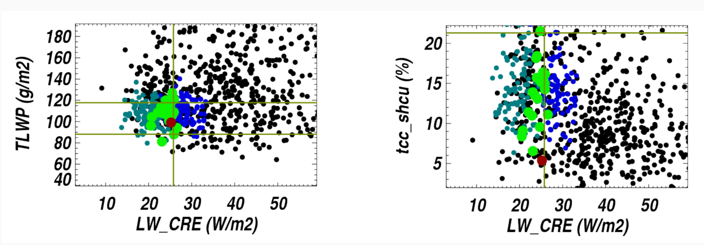
The emulator allows for tractable estimation of parameters using Bayesian tools such as Markov Chain Monte Carlo: the emulator acts a surrogate for the GCM output sensitivity to parameter variations.



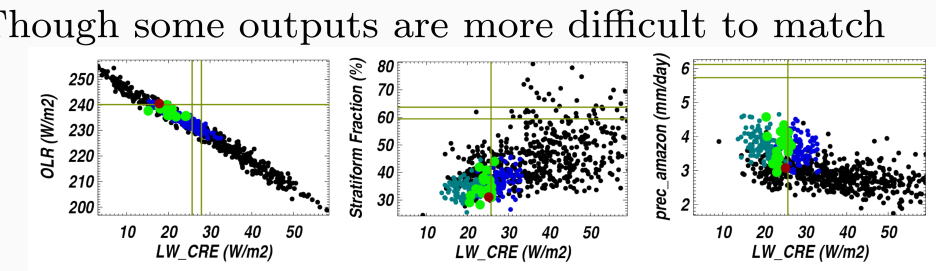
Despite an inexact neural-network emulator, this procedure results in a useful posterior distribution over uncertain model parameters (below).



Posterior samples (bright green) are generally closer to targets (crosshairs) than prior (black)



Though some outputs are more difficult to match



Methodology for SCM tuning experiments

Our aim is to investigate whether single-column model runs can be used to aid in constraint of GCMs/ESMs. GCM tuning is very expensive, and the relatively small ensemble (500 members) impairs the ability to find optimal parameter choices. SCMs may help in the following ways:

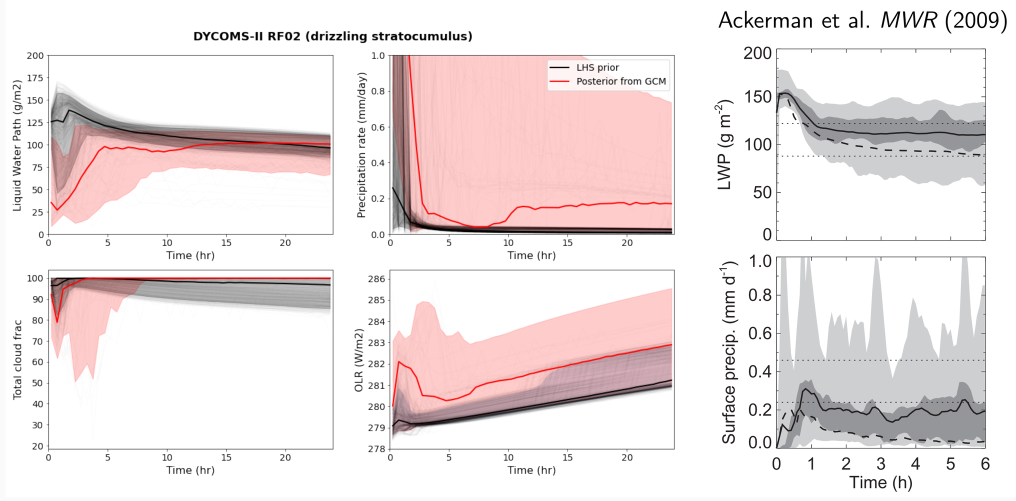
1. SCMs are computationally cheaper than GCMs, allowing for more robust exploration
2. SCMs may allow for targeting important process regimes
3. SCM tuning may provide a (Bayesian) *prior* that can be refined in GCM tuning, making GCM tuning more efficient

Here, we present a preliminary proof-of-concept, demonstrating how SCMs may serve to narrow the space of possible parameter values. Our initial methodology is as follows:

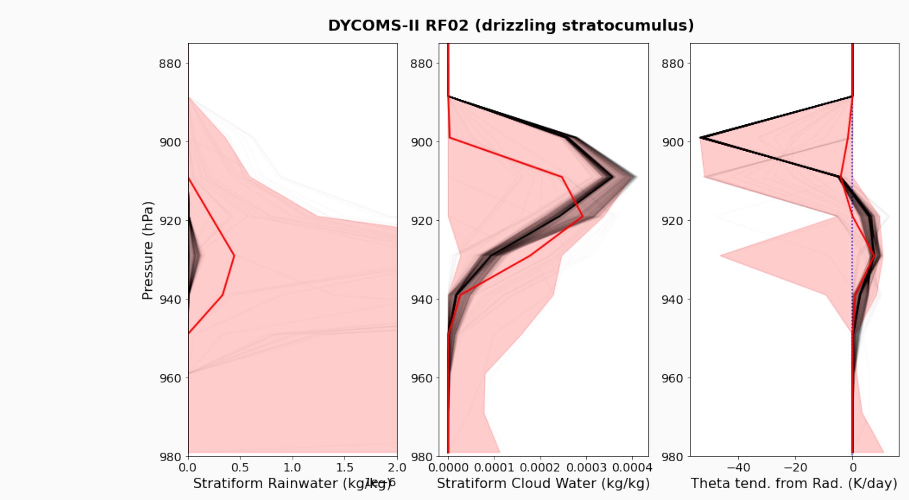
1. Sample from the *prior* distribution of parameters using LHS, run numerous SCM cases with these parameter values
2. Sample from the *posterior* distribution of parameters that was created in GCM tuning, run SCM cases with these parameter values
3. Compare to Large-Eddy Simulation (LES) and observational values for each SCM case.

SCM case: DYCOMS-II RF02

Case described in Ackerman et al. (2009), drizzling stratocumulus observed off the coast of southern California and Baja California during the second research flight of DYCOMS-II (Stevens et al. 2003).



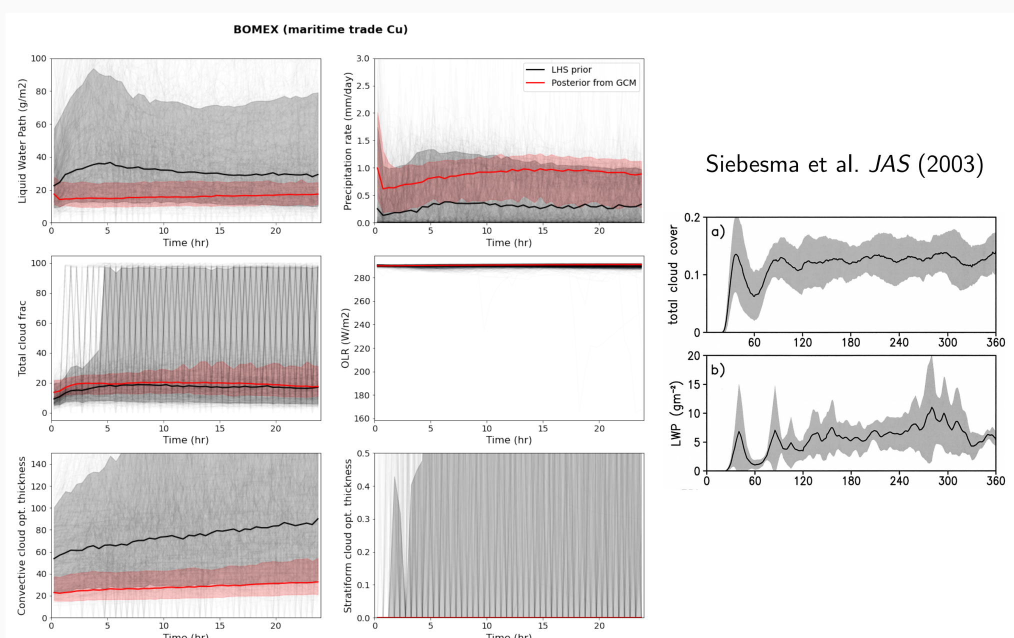
LWP is generally comparable to LES for both prior & GCM posterior, all are within observed ranges (dotted lines on right figures). Precipitation is underestimated in prior; GCM posterior better matches models and observed ranges.



Prior and GCM posterior profiles show very different behaviors, with much thinner clouds for for the posterior, with higher precipitation concentration and greatly decreased cloud-top radiative cooling. Further diagnostics (e.g. cloud thickness, precip. at cloud base) are needed.

SCM case: BOMEX

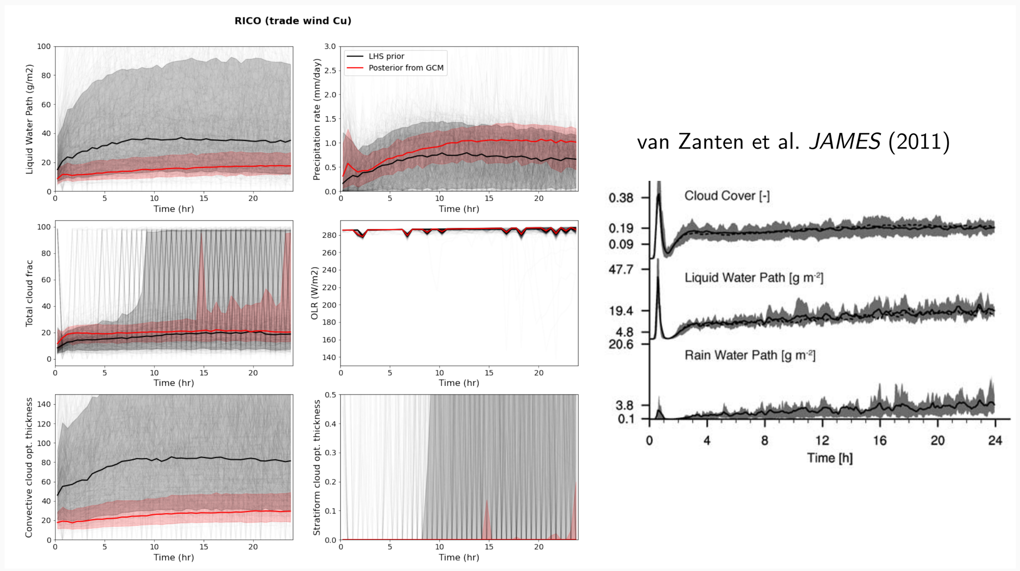
Case described in Siebesma et al. (2003) of trade wind cumulus observed during the Barbados Oceanographic and Meteorological Experiment (BOMEX).



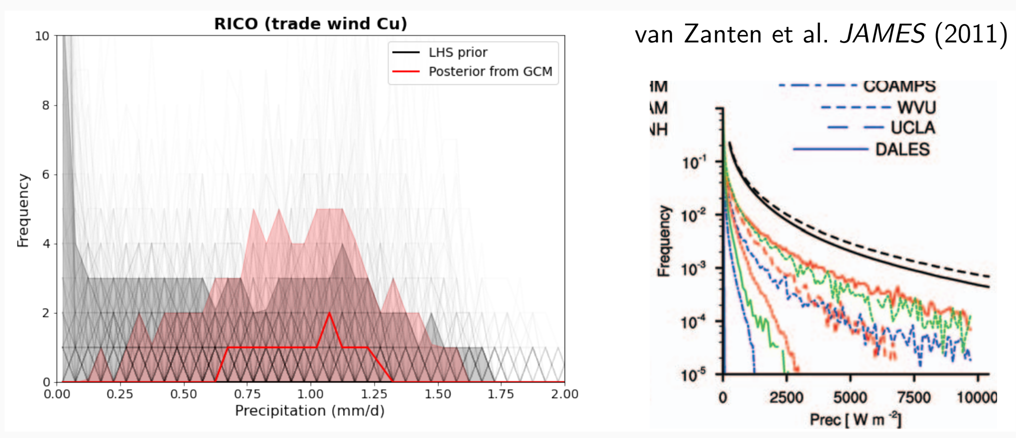
GCM posterior does not overestimate LWP as much as LHS ensemble, cloud fractions are generally closer to the Siebesma LES intercomparison. Also, few/none of the GCM posterior samples produce stratiform clouds (which is good).

SCM case: RICO

Case described in van Zanten et al. (2011) of precipitating trade wind cumulus observed during the Rain in Cumulus over the Ocean (RICO) campaign.



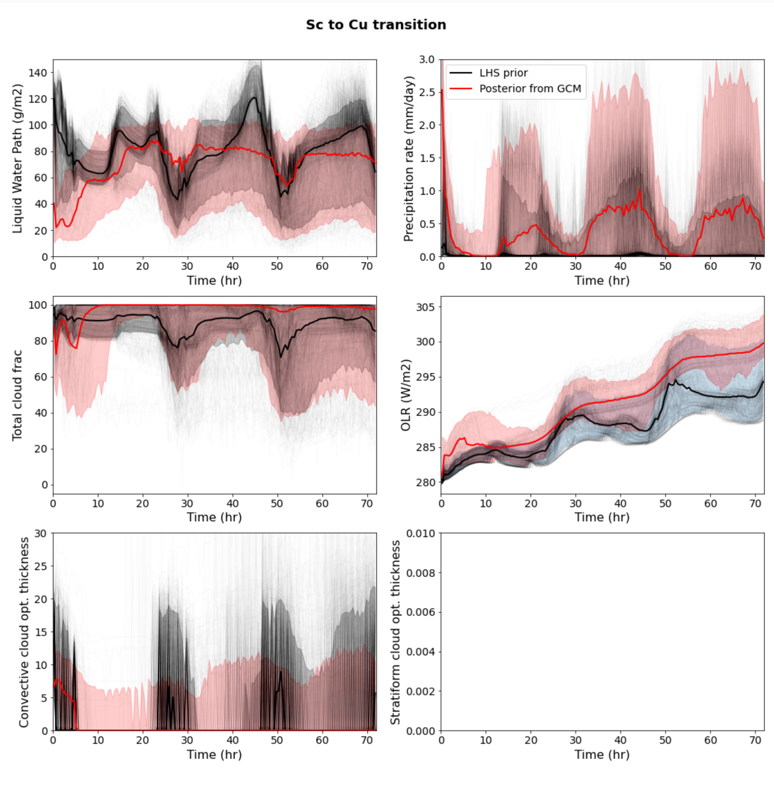
The GCM posterior does not overestimate LWP as much as the LHS prior. As in the BOMEX case, the GCM produces little to no stratiform cloud, unlike the LHS prior ensemble.



The GCM posterior generally produces greater precipitation rates than the LHS prior samples.

SCM case: SCT

This case simulates stratocumulus-to-cumulus transition and is under evaluation at NASA-GISS.



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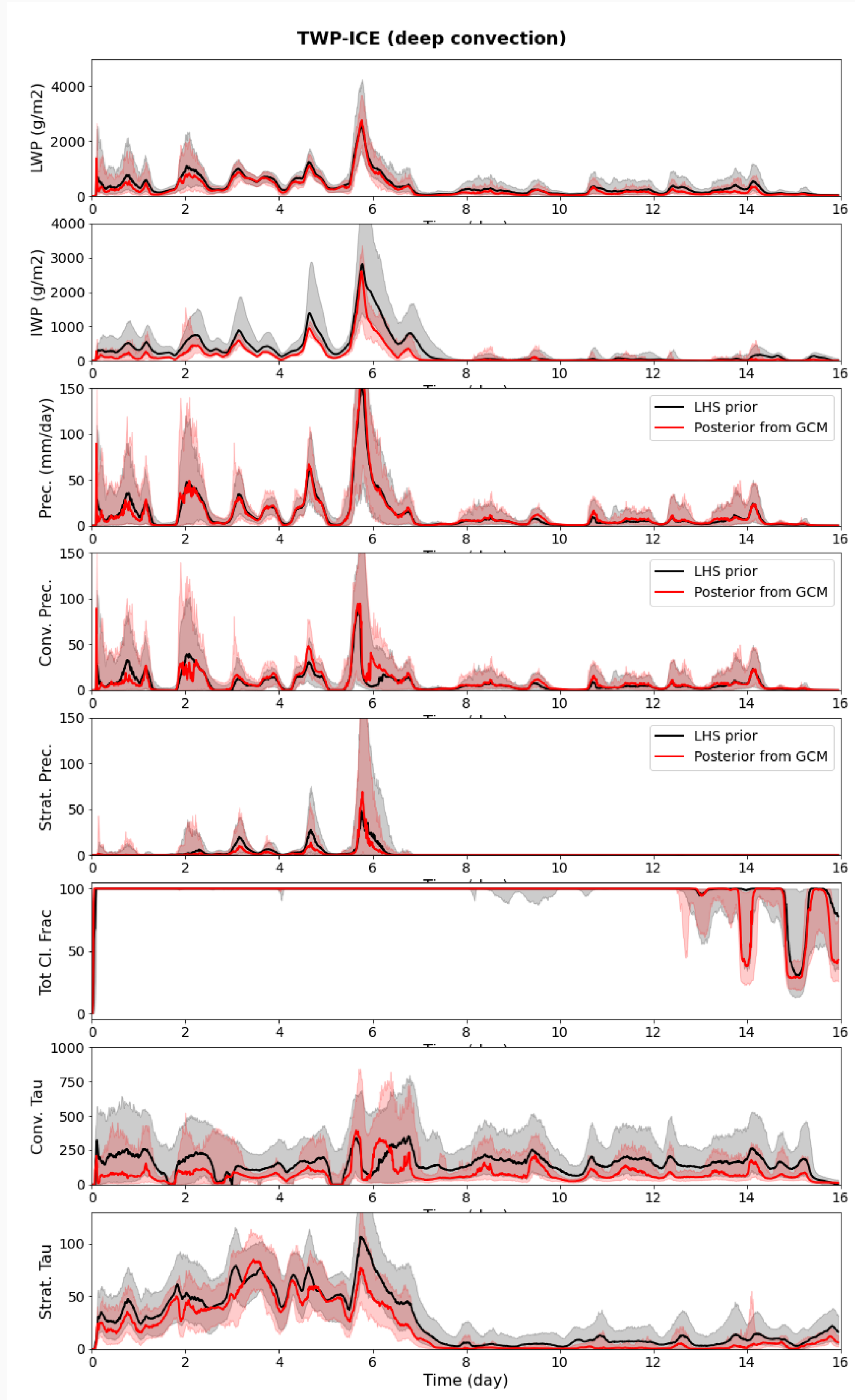
SCM case: TWP-ICE

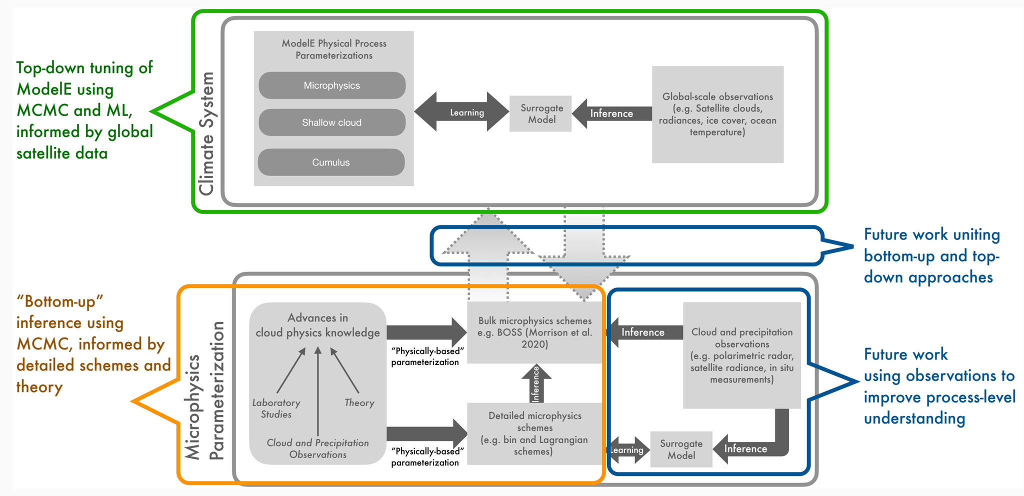
Case described in Fridlind et al. (2012) of tropical deep convection observed near Darwin, Australia during the Tropical Warm Pool-International Cloud Experiment (TWP-ICE). Two meteorological phases occurred: "active" (first 6-7 hours shown here) and "suppressed" (last 6-7 hours).



Differences between ensembles are primarily visible in reduced IWP and lower optical thickness. Detailed analysis needed.

Conclusions & Big Picture

This work is part of a broader effort to systematically improve parameterized components of weather and climate models. Global tuning is one of the best targets for systematic inference, but is extremely expensive. SCM simulations may help target processes and speed identification of probable parameter combinations. Bottom-up constraints (see Sean P. Santos poster) can also be incorporated when learning is Bayesian.



Next steps include:

- Identify SCM outputs to use as targets for inference
- Test whether constraint using the GCM posterior outputs yeilds parameter combinations consistent that ensemble
- Formulate a pre-GCM tuning methodology using SCMs to accelerate parameter estimation
- Test SCMs from CESM, GEOS, E3SM models
- Use SCM PPE tuning methodology as a testbed to benchmark parameter tuning methodologies (e.g. ensemble size, LHS ensemble vs. Gaussian, etc.)