Final report for grant DE-FG02-06ER64182

Evaluation and Improvement of the Cloud Resolving Model Component of the Multi-Scale Modeling Framework

Robert Pincus, University of Colorado

This project was part of a larger collaborative effort involving collaborators at the University of Washington, NASA/Langley, and PCMDI. The overall aim was to evaluate and improve the cloud system resolving model (CSRM) at the heart of the multi-scale modeling framework (MMF). Our task at the University of Colorado our effort was to develop methods that would let us evaluate the performance of cloud-scale models at the ARM SGP site using ARM remote sensing products.

This grant funded three years of a post-doctoral appointment for Peter W. Henderson, who arrived after finishing his Ph.D. at the University of Reading under Dr. Tony Slingo. Unfortunately, Dr. Henderson was not well suited to the tasks at hand. He produced a single paper during his tenure in the US and has now left the field.

This paper elaborates on previous work (Jakob et al., 2004) that explored methods for using column measurements of cloud occurrence, such as those produced by the ARM ARSCL data product, to evaluate cloud forecasts. In the present work, long term forecasts of cloud occurrence at the ARM SGP site were made using System for Atmospheric Modeling (SAM; Khairoutdinov and Randall 2003) in several configurations of varying computational cost. The model was run for three years using warming and cooling tendencies from the ARM variational forcing data set (Xie et al., 2004). When the model is run freely it quickly develops large biases in temperature and moisture, so thermodynamic fields were nudged back to soundings on a 1-day time scale. We mimicked the observations that would be made by ARSCL by computing the radar and lidar reflectivity in each model column, then applying ARSCL-like logic to create a cloud mask. These three-year time series were then evaluated against ARSCL using both traditional metrics (RMSE and its components) and probabilistic measures that do not make assumptions about statistical stationarity.

When model thermodynamic fields are constrained by observations the model has significant skill at predicting the occurrence of clouds in both a column-integrated and layer-by-layer sense. The skill is comparable More surprisingly, the scores for each configuration are quite similar despite significant differences in computational costs. This is not due to a lack of sensitivity of the performance metrics, since large differences are seen in the seasonal performance of the models. While this result implies that almost all the benefit of the super-parameterization can be realized using a coarse, computationally efficient configuration, it may suggest that the cloud model's deficiencies are deeper than can be ameliorated by simple changes.

We also learned that the elaborate methods probabilistic evaluation methods, which we used to avoid equating temporally-averaged observations with spatially-averaged model fields, did not produce substantially different answers in this context. We expect that this is because the time series are very long.

Dr. Henderson did not excel at this task, but the results do lead to several interesting questions, and I have been contacted by investigators interested in pursuing them. These questions include

- How fast does forecast skill in cloud occurrence degrade when the model is not nudged towards thermodynamic observations?
- Can free-running forecasts starting from realistic (nudged) initial conditions provide insight as to the causes of the persistent temperature and humidity biases produced by the model?
- How many observations are required so that average-based metrics and probabilistic metrics provide the same results, and how does this depend on the spatial and temporal variability of the model fields and the observations?

References

Jakob, C., R. Pincus, C. Hannay, and K.-M. Xu (2004), Use of cloud radar observations for model evaluation: A probabilistic approach, J. Geophys. Res., **109**, D03202, doi: 10.1029/2003JD003473.

Khairoutdinov, M. F., and D.A. Randall, 2003: Cloud-resolving modeling of the ARM summer 1997 IOP: Model formulation, results, uncertainties and sensitivities. J. Atmos. Sci., **60**, 607-625.

Xie, S., R. T. Cederwall, and M. Zhang, 2004: Developing long-term single-column model/cloud system–resolving model forcing data using numerical weather prediction product constrained by surface and top of the atmosphere observations. *J. Geophys. Res.*, **109**, D01104, doi:10.1029/2003JD004045.

Publications

Henderson, P. W. and R. Pincus, 2009: Multi-year evaluations of a cloud model using ARM data. *J. Atmos. Sci.*, **66**, 2925-2936. doi:10.1175/2009JAS2957.1

Henderson, P. W. and R. Pincus, 2009. Multi-year Evaluations of a Cloud Model Using ARM Data. In *Proc. 19th ARM Science Team Meeting*, Lousiville KY.

Zhang, Y., Klein, S., Henderson, P., and Cheng, A., 2008. Diurnal Cycle of Clouds and Precipitation at the ACRF SGP Site. In *Proc. 18th ARM Science Team Meeting*, Norfolk VA.

Henderson, P. W. and R. Pincus, 2009. Multi-year Evaluations of a Cloud Model Using ARM Data. In *Proc. 18th ARM Science Team Meeting*, Norfolk VA.