UCRL-JC-131824
PREPRINT

# An ARM SCM Intercomparison Study-Overview and Preliminary Results for Case 1

R.T. Cederwall
J.J. Yio
S.K. Krueger

This paper was prepared for submittal to the
*Eighth Atmospheric Radiation Measurement (ARM) Science Team Meeting*
*Tucson, AZ*
*March 23-27, 1998*

**September 1998**

Lawrence Livermore National Laboratory

# The ARM SCM Intercomparison Study - - Overview and Preliminary Results for Case 1

*R.T. Cederwall and J.J. Yio*
*Atmospheric Science Division*
*Lawrence Livermore National Laboratory*
*Livermore, California*

*S.K. Krueger*
*Department of Meteorology*
*University of Utah*
*Salt Lake City, Utah*

## Introduction

The Single-Column Model (SCM) Working Group in the Atmospheric Radiation Measurement (ARM) Program has begun a series of SCM Intercomparison case studies to evaluate the adequacy of the forcing data sets and the progress of SCM formulations. There are nine modeling groups paticipating, which include eight SCMs: Ghan (PNNL), Randall/Cripe (CSU), Somerville/Iacobellis (Scripps/UCSD), Klein (NOAA/GFDL), Lohmann (Dalhousie), Stenchikov/Robock (Maryland, Rutgers), Zhang/Xie (SUNY Stony Brook), Sud/Wlaker (NASA/GSFC), and one 2-D cloud-resolving model: Xu (CSU). The first case study addresses the prescription of advective forcing, the methods used to derive SCM forcing terms, and the methods used to estimate surface flux forcing. Details of the SCM Intercomparison procedures are given elsewhere (Cederwall, et al., 1998).

## Approach

A critical issue in single-column modeling is the prescription of advective forcing, required for the SCMs since the information usually provided by neighboring cells in a GCM is not available in the single-column formulation. The SCM large-scale (L.S.) advective forcing is comprised of horizontal and vertical advection, given here for water vapor mixing ratio $(q)$ as an example:

$$\left(\frac{\partial \bar{q}}{\partial t}\right)_{L.S.} \equiv -\bar{v}\cdot\nabla\bar{q} - \bar{\omega}\frac{\partial \bar{q}}{\partial p}$$

Three methods for specifying the advecting forcing were tested, defined by the following expressions (given for $q$) :
(1) observed total advective tendency,

$$\left(\frac{\partial \bar{q}}{\partial t}\right)_{L.S.} = \left(\frac{\partial \bar{q}}{\partial t}\right)_{L.S.T.}$$

(2) observed horizontal advective tendency plus vertical advective tendency estimated using observed large-scale vertical motion and the model-predicted vertical gradient,

$$\left(\frac{\partial \bar{q}}{\partial t}\right)_{L.S.} = \left(\frac{\partial \bar{q}}{\partial t}\right)_{L.S.H.} - \bar{\omega}\frac{\partial \bar{q}_m}{\partial p}$$

(3) horizontal advective tendency estimated using a relaxation toward upstream values, plus vertical advective tendency estimated as in (2)

$$\left(\frac{\partial \bar{q}}{\partial t}\right)_{L.S.} = -\frac{\bar{q}_m - \bar{q}_u}{\tau_{adv}} - \bar{\omega}\frac{\partial \bar{q}_m}{\partial p}$$

SCM advective tendency terms were obtained in two ways: (a) Barnes objective analysis using ARM sounding and NOAA wind profiler data, and (b) variational analysis (provided by Zhang) that uses ARM sounding and NOAA wind profiler data and then additional data to adjust the advective tendencies in order to match the observed column-integrated tendencies of mass, moisture, static energy, and momentum (Zhang and Lin, 1997).

Surface forcing was prescribed from two methods of heat and moisture flux estimates:
(i) area-averaged SiB2 model output (from a 6.25-km grid) that uses ARM observations as input (Doran, et al., 1998), and
(ii) area-averaged observations from Energy Balance Bowen Ratio (EBBR) stations.

The EBBR stations are located only in non-cropland areas, and therefore sample just a part of the SCM bottom surface. The SiB2 model approach incorporates all surface types in the SCM domain. The difference in estimates of heat and moisture flux is most pronounced in clear-sky daytime periods, when the harvested wheat fields (the dominant cropland) are *hotter and drier* than the non-cropland (Shaw, et al., 1998). This illustrated in Figure 1, where Julian days 208-211 have clear skies.

The SCM Intercomparison involved an abbreviated 3 x 2 x 2 matrix of runs to evaluate the 3 methods of prescribing the advective forcing, the 2 methods of deriving the SCM forcing terms, and the 2 methods of estimating the surface forcing. This matrix and associated simulation notation is given in Table 1.

## Meteorological Conditions

The first case study is based on data from the Summer 1995 SCM Intensive Observation Period (IOP), July 18 - August 3, 1995. The first half of the period was characterized by variable cloudiness and precipitation every other day associated with a stationary, large-scale upper level trough over North America. In the second half of the period, upper-level ridging led to clear days and hot, dry conditions. An upper-level trough replaced the ridge, with increasing cloudiness, thunderstorms, and occasional intense precipitation toward the end of the study period. Hence, a wide range of summertime weather conditions occurred for testing SCMs, including hot, clear days, variable cloudiness and local convection, and synoptic forcing with increased cloudiness, precipitation, and occasional severe weather. Inspection of an animation of the satellite images for the IOP reveals the importance of cloud advection through the study area. Cloud processes are not governed simply by local convection

## Results

Several comparisons between simulated and observed values were made for such quantities as temperature and moisture profiles, surface and top-of-atmosphere radiative fluxes, column-integrated cloud-liquid water, precipitable water, and rainfall rate. A few of these comparison are illustrated next.

A comparison is made to evaluate the benefit of deriving SCM forcing terms with variational analysis over those derived from traditional Barnes objective analysis. Profiles of model bias (model - observed values) for water vapor mixing ratio are shown for seven of the participating models using Barnes analysis (simulation B) and variational analysis (simulation E). For simulation B, there is clearly a dry bias in the lower troposphere (see Figure 2a). This bias is removed in simulation E (see Figure 2b). The use of integrated water vapor from the ARM microwave radiometers in the variational analysis helps adjust the analyzed values to the state of the atmosphere and provides more representative advective forcing for the SCMs.

The ability of the model to simulate the state of the atmosphere and the radiative interactions is indicated by the outgoing longwave radiation. A comparison is made for variational-analysis derived SCM terms between the ‘total advective tendency’ prescription of advective forcing and the ‘relaxation toward upwind values’ prescription. An illustration of this comparison is given in Figure 3 for three of the SCMs. Generally, the ‘relaxation’ mode gives slightly better simulations than the ‘total’ mode (see Figure 3c vs Figure 3b). In clear-sky conditions (Julian days 208-211), both advection prescriptions produce simulations with reduced model bias compared to those in cloudy-sky condtions. This is not surprising, and confirms the challenges that remain for improving parameterizations of clouds and their radiative interactions.

## Preliminary Conclusions

Based on the preliminary analyses for the Case 1 simulations, we have drawn the following, tentative conclusions:

(1) simulations are improved with forcing terms derived by the *variational analysis*,
(2) simulations match observations better in *clear-sky* conditions than in *cloudy* conditions,
(3) the *relaxation* toward upstream values is the preferred prescription for advective tendency when evaluating *process parameterizations*, especially those for clouds, and
(4) in general, the *2-D CRM* performs better than the SCMs.
The results were mixed for simulations using the two different estimates of surface forcing. This is under further study by a subgroup of participants.

## Future Efforts

The SCM Working Group is conducting more SCM Intercomparison case studies. Another summertime case is planned, in collaboration with the GEWEX Cloud System Study Working Group 4, studying deep convection. Data from the Summer 1997 SCM IOP will be used. A fall case, using the Fall 1997 SCM IOP, is also planned to take advantage of the five other ARM IOPs that were conducted at that time.

*Acknowledgments:* This work was performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under contract number W-7405-Eng-48.

## References

Cederwall, R.T., and S.K. Krueger, 1998: ARM Single-Column Model (SCM) Intercomparison Procedures for Case 1: Summer 1995 SCM IOP. LLNL Report UCRL-ID-130561, Livermore, CA, 21pp.

Doran, J.C., J.M. Hubbe, J.C. Liljegren, W.J. Shaw, G.J. Collatz, D.R. Cook, and R.L. Hart, 1998. A Technique for Determining the Spatial and Temporal Distributions of Surface Fluxes of Heat and Moisture over the Southern Great Plains Cloud and Radiation Testbed. *J. Geophys. Res.*, **103**, 6109-6121.

Shaw, W.J., J.C. Doran, J.M. Hubbe, and J.C. Liljegren, 1998: Comparison of EBBR and SiB2 Model Sensible and Latent Heat Fluxes. *Proceedings of the Seventh ARM Science Team Meeting*, 187-189.

Zhang, M.H., and J.L. Lin, 1997: Constrained Variational Analysis of Sounding Data Based on Column-Integrated Budgets of Mass, Heat, Moisture, and Momentum: Approach and Application to ARM Measurements. *J. Atmos. Sci.*, **54**, 1503-1524.

**Table 1**. SCM Intercomparison Simulations

| | Barnes analysis (LLNL) | variational analysis (SUNY-SB) |
|---|---|---|
| observed total advective tendency | A * | D * |
| observed horizontal advective tendency | B | E * |
| relaxation toward upstream values | C | F * |

* *simulations made with both surface forcing methods*

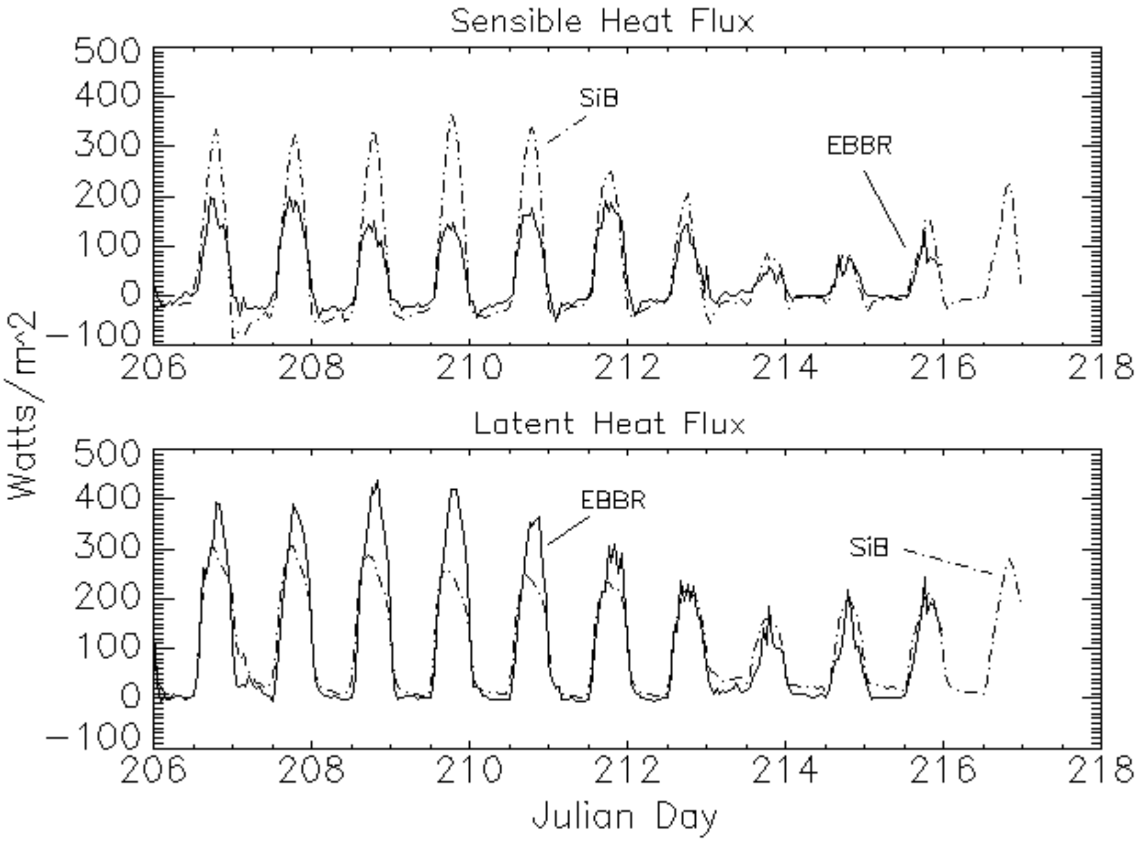

**Figure 1.** Estimates of (a) sensible and (b) latent heat flux from average EBBR data (solid lines) and SiB2 model output (dashed-dot lines). Clear skies occurred on Julian days 208-211.

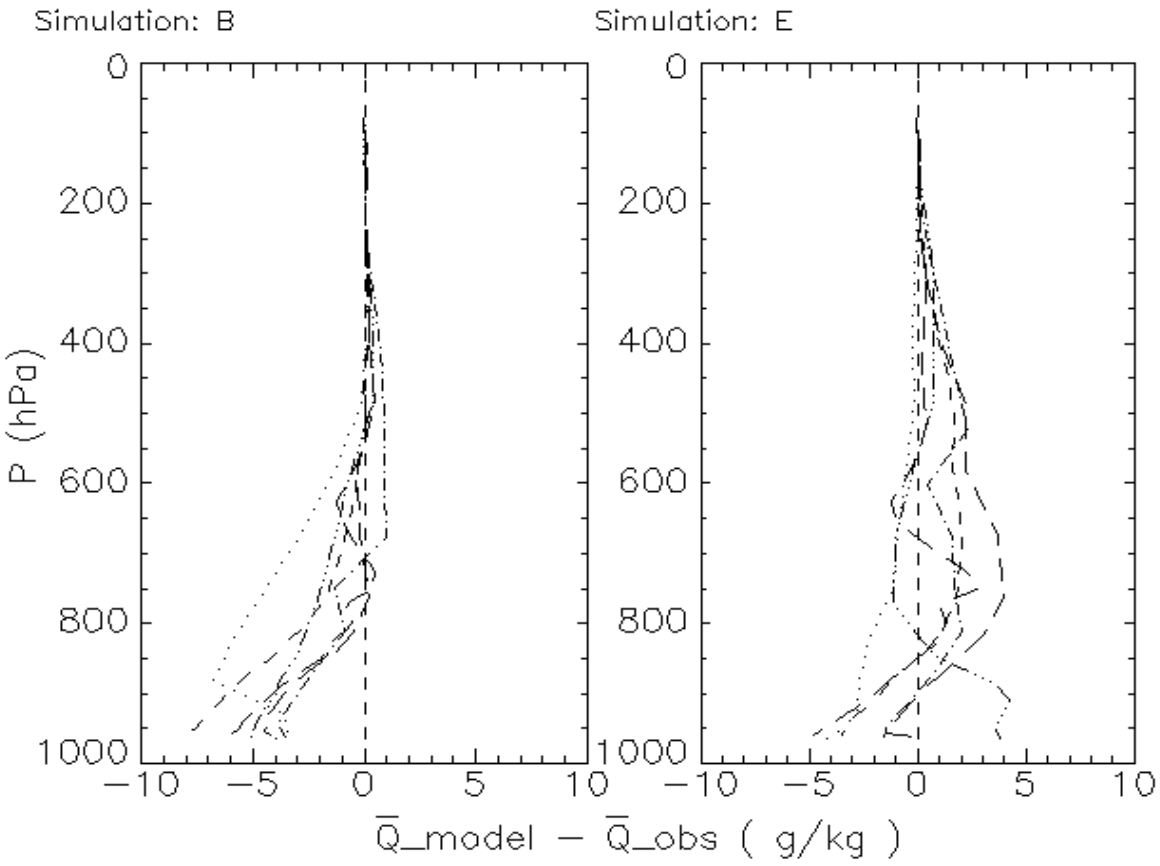

**Figure 2**. Vertical profiles of model bias of simulated water vapor mixing ratio for seven models using (a) Barnes objective analysis in simulation B, and (b) variational analysis in simulation E.

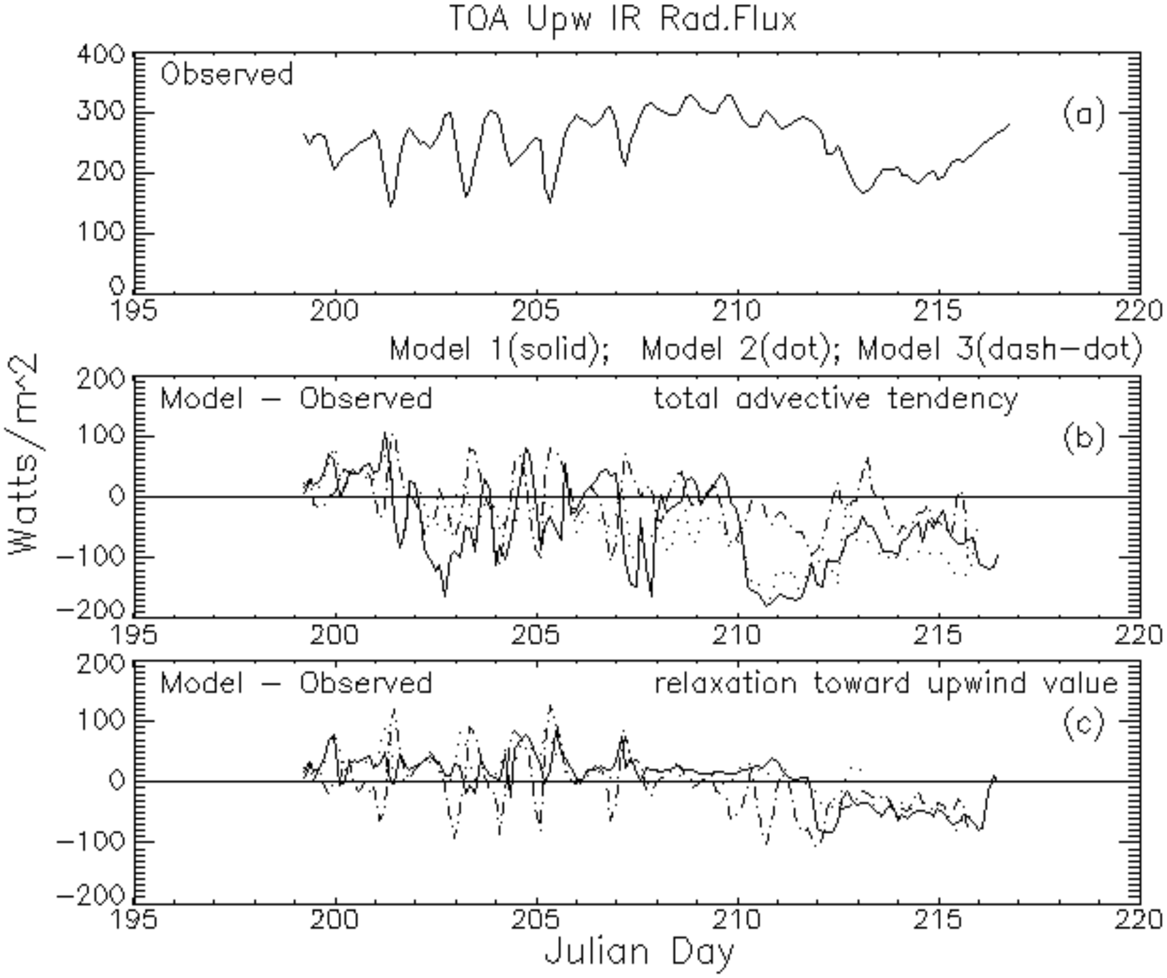

**Figure 3**. Time series of outgoing longwave radiation (W/m$^2$) from (a) satellite-based observations, (b) model bias for simulation D -- ‘total advective tendency’, and (c) model bias for simulation F -- ‘relaxation toward upwind value’. Model results are for three SCMs.