CSU Single-Column Model Results and Quasi-Equilibrium Sensitivity Study

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Introduction

We participated in an intercomparison study using single-column models (SCMs) in which participants initialized and forced their respective SCMs with identical datasets; culled from the July 1995 Intensive Observation Period (IOP) at the Atmospheric Radiation Measurement (ARM) Southern Great Plains (SGP) Cloud and Radiation Testbed (CART) site. The SCMs were forced in three different fashions: 1) using total advective tendency or "revealed" forcing, 2) using observed horizontal advective tendencies and observed vertical motion or "vertical flux" forcing, and 3) using relaxation to the observed soundings and observed vertical motion. The Colorado State University (CSU) SCM was further tested in each of these forcing modes by the use of three different parameter settings, which control the tightness of quasiequilibrium in the SCM's cloud parameterization.

Results from SCM Intercomparison Study

As outlined by Krueger and Cederwall (1997), the rationale for conducting an SCM intercomparison study was to coordinate and unify the disparate efforts of several single-column modelers into a standardized approach with respect to both the datasets and methods used. Previously, members of the ARM SCM community shared their results by means of workshops conducted periodically at Lawrence Livermore National Laboratory (LLNL). However, in the interest of identifying potential individual model biases, it became evident that it would be beneficial to everyone involved with single-column modeling if identical datasets and prescription/forcing methods were used. Therefore, it was resolved that the July 1995 SGP CART IOP would serve as a suitable dataset for the study due to the quality of the data and the incidences of deep convection accompanied with precipitation, and that the three forcing methods mentioned above would provide a representative spectrum of the various modes in which an SCM may be forced (see paper by Cederwall et al. in this proceedings for full details on the Intercomparison Study itself). Additionally, the CSU SCM was run with three different "α parameter" settings, which control the quasi-equilibrium parameterization. We merely present a small sampling of the CSU SCM results compared to those of other participants as a means of setting the stage for the quasi-equilibrium discussion that follows (Figures 1 through 8). As can be seen, the CSU SCM relaxation forcing mode provided the best results compared to the observations while the revealed forcing mode generally showed the least amount of agreement with the observations.

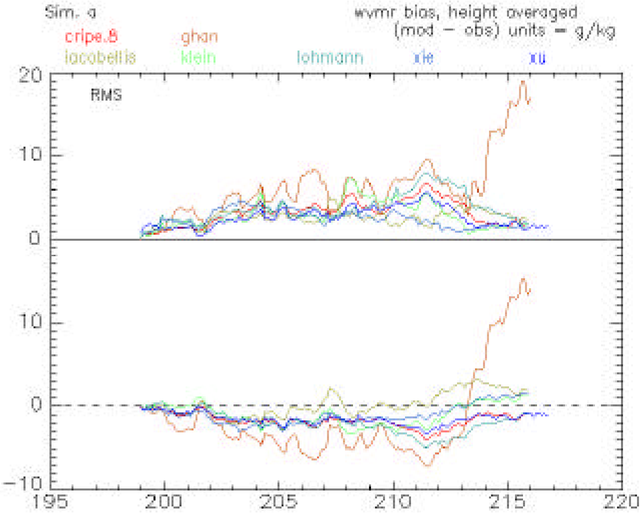


Figure 1. Height-averaged plot showing model-observation bias for water vapor mixing ratio during July 1995 IOP (00 UTC 18 July - 23 UTC 3 August 1995). Units are Julian day along x-axis and g kg^{-1} along y-axis. Revealed forcing (or total advective tendency) was used for driving all models, and CSU SCM run is in red. (For a color version of this figure, please see http://www/arm.gov/docs/documents/technical/conf_9803/cripe-98.pdf.)

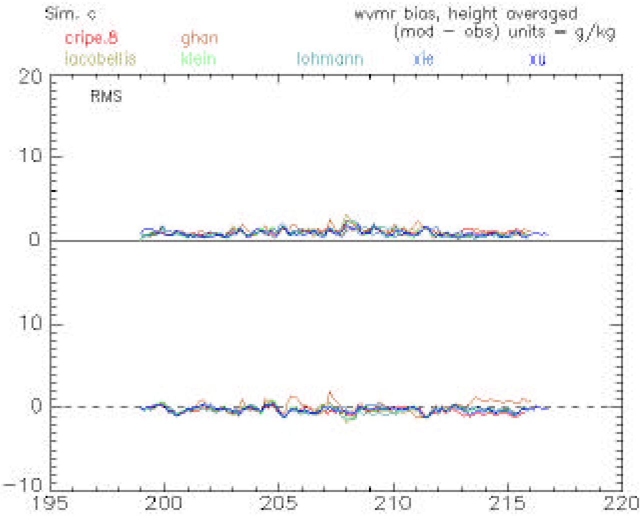


Figure 2. Same as Figure 1, only this time relaxation forcing was used for driving all models. CSU SCM run is in red. See poster by Cederwall et al. (1998) for details on each of the forcing modes used. In both plots above, the CSU SCM was run with the "α parameter" set to 10^8 M^4 kg^{-1}—see following discussion for explanation. (For a color version of this figure, please see *http://www/arm.gov/docs/documents/technical/conf_9803/cripe-98.pdf.)*

Quasi-Equilibrium Hypothesis

As a means of approximating the intensity of cumulus convection in numerical computations, Arakawa and Schubert (1974; hereafter, AS) proposed a cumulus parameterization featuring "quasi-equilibrium" of the cloud work function as a closure assumption. The cloud work function is defined as the vertical integral of the buoyancy of cloud air with respect to the large-scale environment, for a particular cumulus cloud subensemble. Thus, a positive value of the cloud work function indicates that potential energy of the mean state is available for conversion into convective kinetic energy. The cloud work function is hypothesized to be quasi-invariant as nonconvective ("large-scale") processes that destabilize the troposphere, such as horizontal and vertical advection of heat and moisture, or radiative heating and cooling, tend to be balanced by convective processes that restore atmospheric stability. AS found this to be especially true when the forcing time-scale of the nonconvective processes is considerably longer than the "adjustment time" over which cumulus convection acts. The quasi-equilibrium hypothesis has been tested and found to be valid by several people, including Lord and Arakawa (1980), Wang and Randall (1994), and Cripe (1994) using data from both the tropics and the mid-latitudes. For further discussion of quasi-equilibrium, its strengths, weaknesses, and related studies, the reader is directed to Randall et al. (1997).

A generalization of quasi-equilibrium led to the development of a prognostic closure by Randall and Pan (1993), Pan (1995), and Pan and Randall (1998). The prognostic closure includes a set of prognostic equations governing the vertically integrated cumulus kinetic energy (CKE) per unit area, for each convective cloud type. In particular, the cloud-base mass flux and cloud work function are used, along with the time derivative of the cloud work function for a given cloud-base mass flux, to predict the CKE. A problem arises, however, in that there are two equations and three unknowns in this scheme. In order to close this relationship, a parameter, α, with dimensions of length quadrupled per unit mass, was defined that would serve essentially as a conversion factor, relating cumulus mass flux to the CKE. The α parameter is further assumed to be a constant for simplicity; Randall and Pan (1993) have shown that a small value of α corresponds to a short adjustment time, and vice versa.

Quasi-Equilibrium Sensitivity Study Results

An examination of the results by Xu (1991) using a cumulus ensemble model (CEM) with GATE data suggests a setting of α ~10^8 M^4 kg^{-1} or larger. Indeed, statistical analyses of various fields such as temperature, as shown in our results below, indicates that a setting of α ~10^9 M^4 kg^{-1} appears to give the most satisfactory results using mid-latitude ARM CART IOP data, with the relaxation mode giving the closest agreement to observed conditions. Additionally, in an α parameter sensitivity study with the full CSU General Circulation Model (GCM), Randall et al. (1997) found that there was a general decrease in the cumulus precipitation rate accompanied by an increase in large-scale precipitation as the α parameter was increased from 10^7 M^4 kg^{-1} to 10^9 M^4 kg^{-1}, with a general decrease in overall precipitation. We obtained similar results with respect to cumulus and large-scale precipitation rates. Only the combined precipitation results are presented here in which the general decrease may be observed as the α parameter is increased. Note the improved agreement between model runs and observations in the α parameter setting of 10^9 M^4 kg^{-1}, as demonstrated in the statistical analyses.

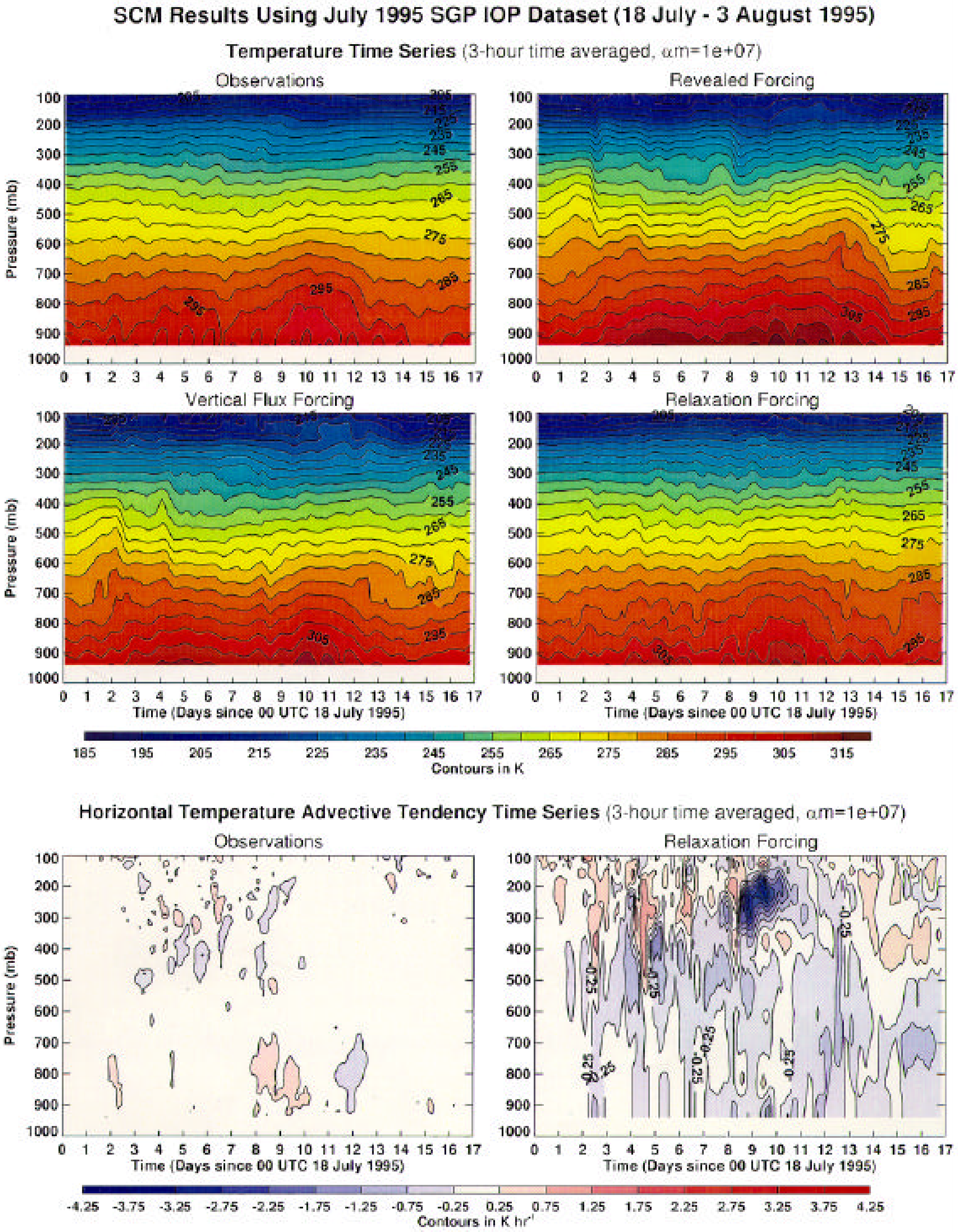
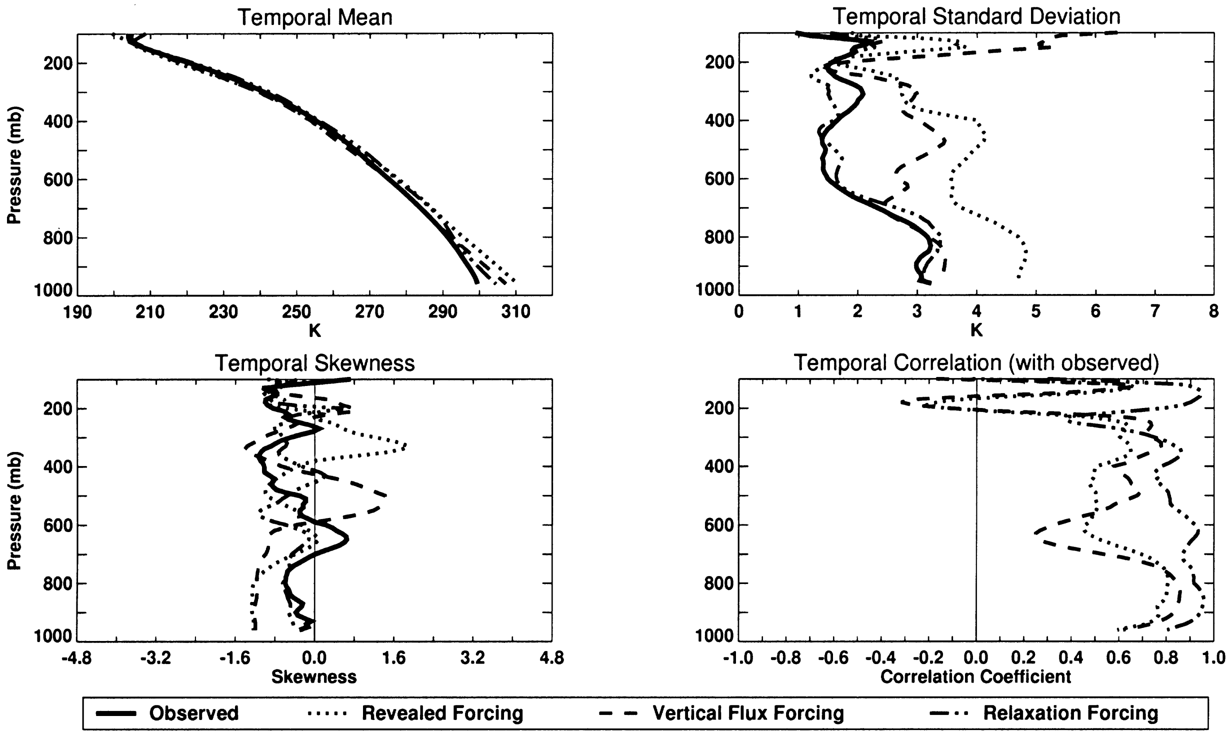


Figure 3. Time-height plot of observed temperature field and results from all three SCM forcing modes, for α parameter setting of 10^7 M^4 kg^{-1}. Horizontal temperature advective tendency results shown in lower panels. (For a color version of this figure, please see *http://www/arm.gov/docs/documents/technical/conf_9803/cripe-98.pdf*.)

SCM Results Using July 1995 SGP IOP Dataset (18 July - 3 August 1995)

Temperature Time Series (3-hr time-averaged, αm=1e+07)



Horizontal Temperature Advective Tendency Time Series (3-hr time-averaged, αm=1e+07)

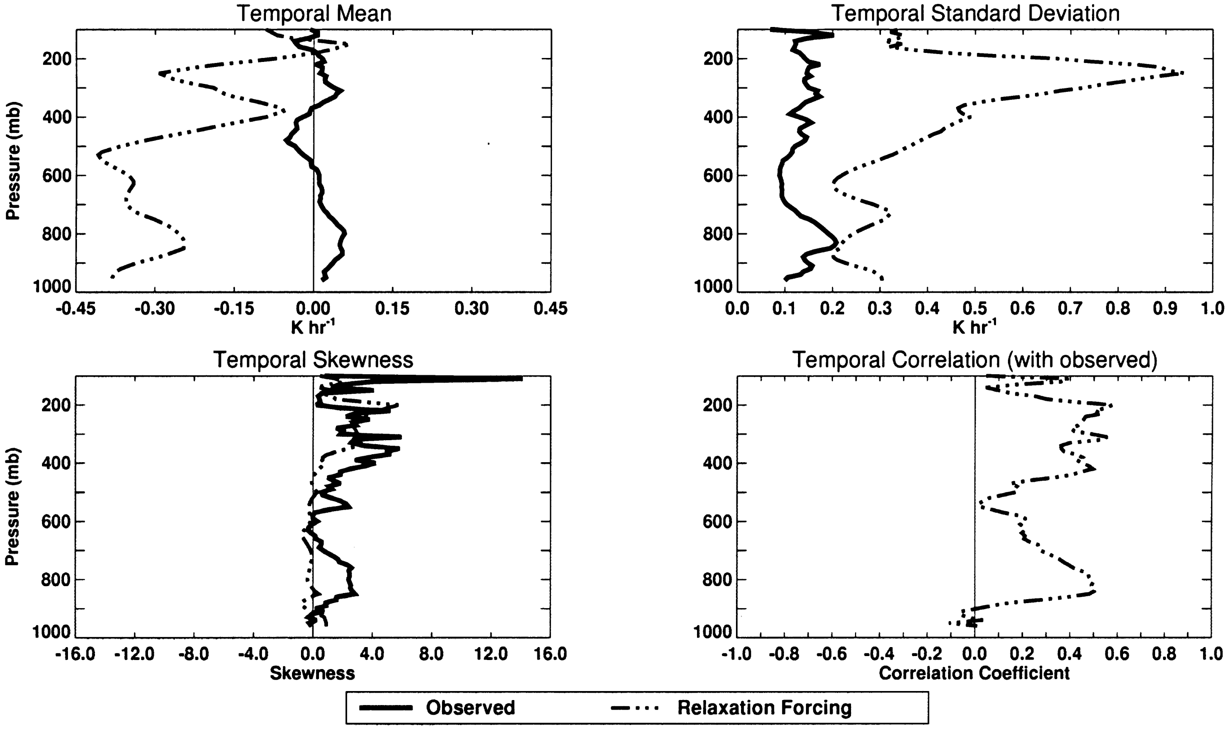


Figure 4. Statistical analysis (time-averaged) of results shown in plot above.

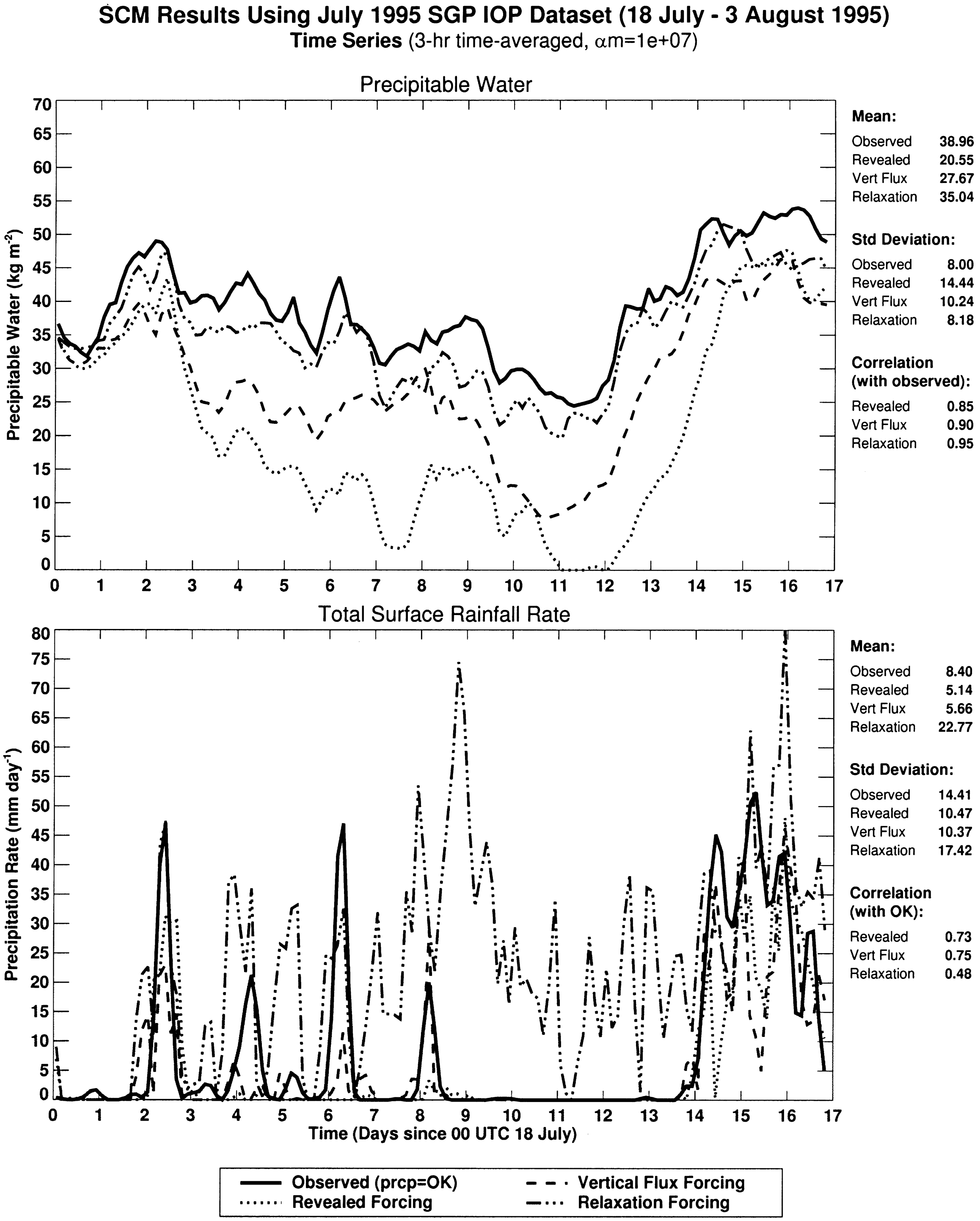


Figure 5. Plot of precipitable water and precipitation results (with statistical analysis in margin) from all three forcing modes, for α parameter setting of 10^7 M^4 kg^{-1}.

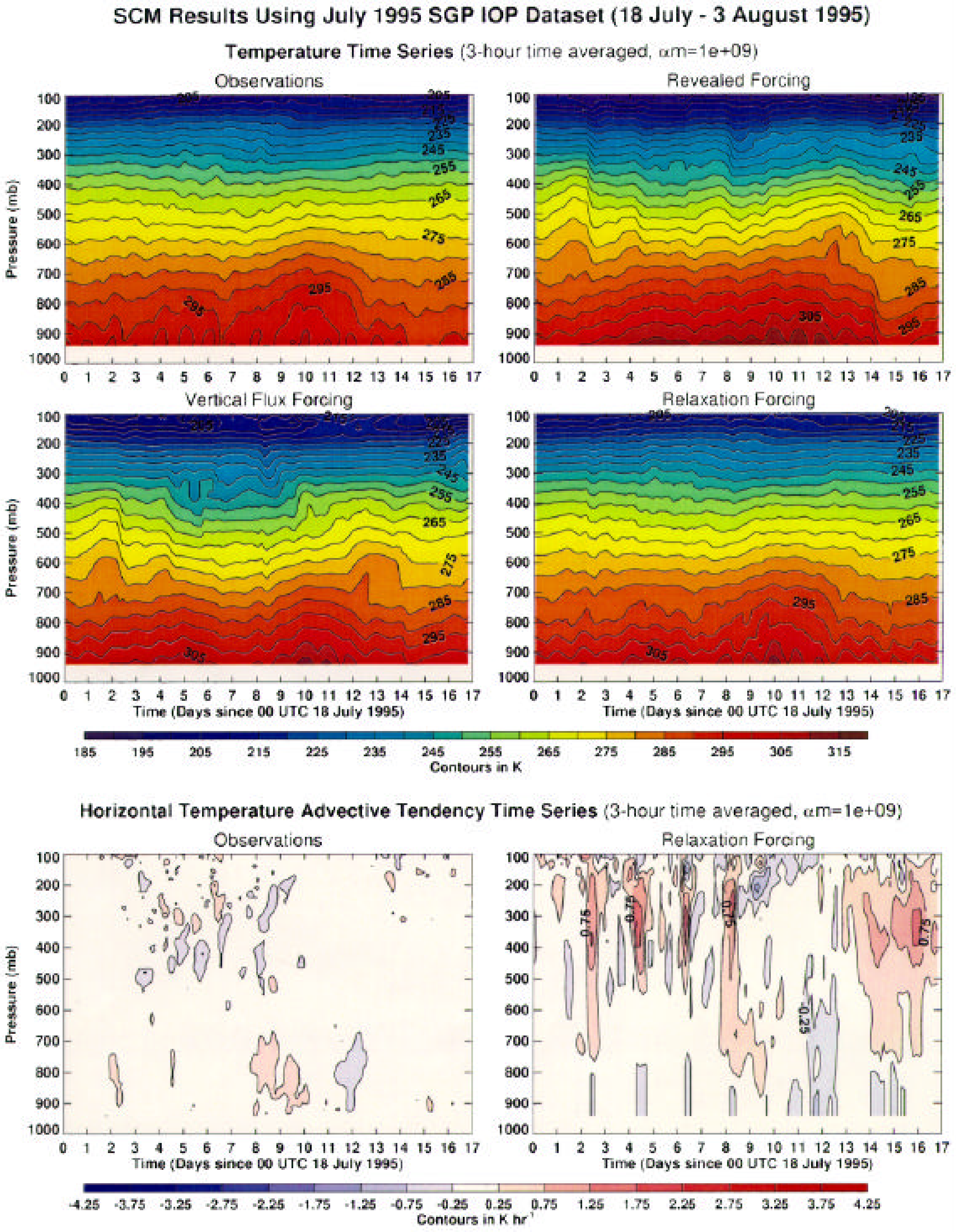
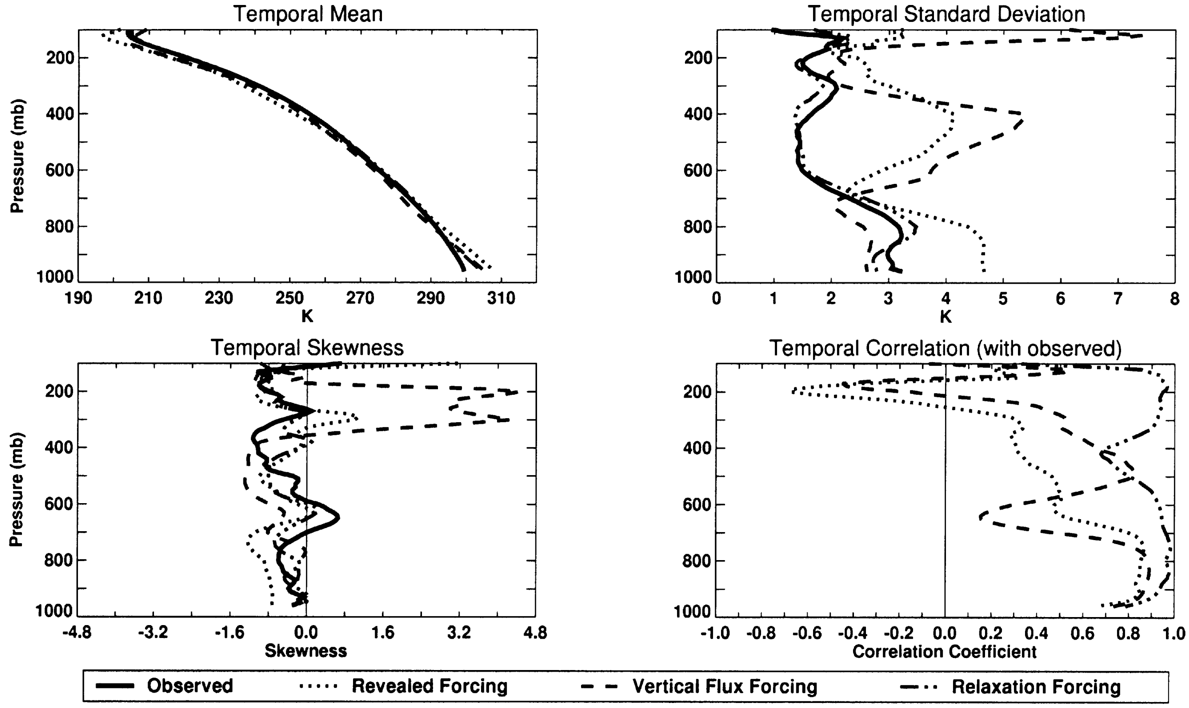


Figure 6. Time-height plot of observed temperature field and results from all three SCM forcing modes, for α parameter setting of 10^9 M^4 kg^{-1}. Horizontal temperature advective tendency results shown in lower panels. (For a color version of this figure, please see *http://www/ arm.gov/docs/documents/technical/conf_9803/cripe-98.pdf*.)

SCM Results Using July 1995 SGP IOP Dataset (18 July - 3 August 1995)

Temperature Time Series (3-hr time-averaged, αm=1e+09)



Horizontal Temperature Advective Tendency Time Series (3-hr time-averaged, αm=1e+09)

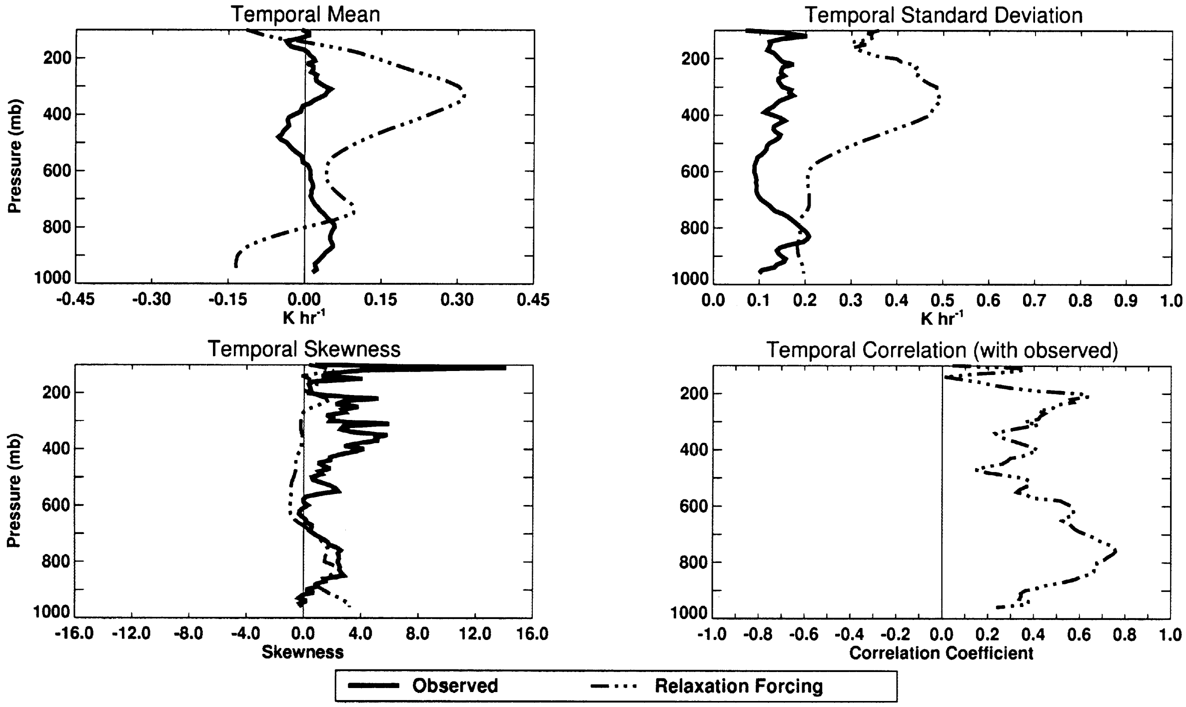


Figure 7. Statistical analysis (time-averaged) of results shown above. Note the improved agreement with observations as the α parameter is set to 10^9 M^4 kg^{-1}, compared to the 10^7 m^4 kg^{-1} case.

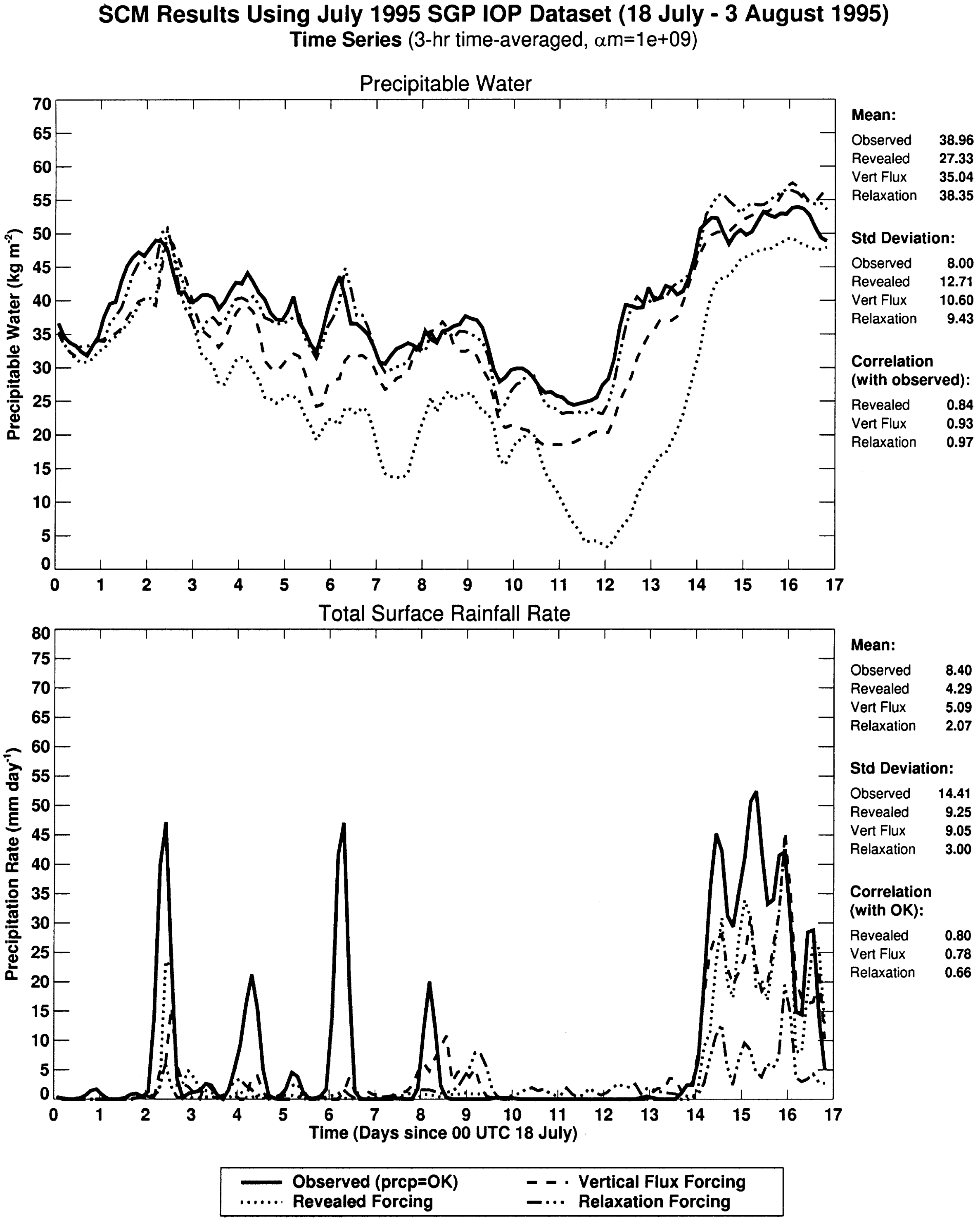


Figure 8. Plot of precipitable water and precipitation results (with statistical analysis in margin) from all three forcing modes, for α parameter setting of 10^9 M^4 kg^{-1}. Again, note improvements over previous case.

Conclusions

- The CSU SCM performed well relative to other participants in the SCM Intercomparison Study conducted earlier this year.

- The SCM Intercomparison Study served to illustrate, among other things, the improved performance across all participating SCMs using relaxation forcing. Depending on the intended use of an SCM, other forcing modes may be desirable.

- As Xu (1991) discovered with tropical data, we found that an α parameter setting of at least 10^8 M^4 kg^{-1} gives the most realistic results using mid-latitude ARM data. Indeed, a setting of 10^9 M^4 kg^{-1} gave even better results, indicating that, although treated as a constant, the α parameter may take different values depending on the type of atmospheric conditions and cumulus convection regimes being modeled.

- We also note the general decrease in cumulus precipitation and increase in large-scale precipitation, and combined precipitation rate decrease, that Randall et al. (1997) found with the full GCM as the α parameter went from lower to higher values.

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