Feasibility of Reanalysis Derived Forcing for SCM/CRM Studies in the Mid-Latitudes

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1. Background

Despite recent advancements in global climate modeling, models produce a large range of climate sensitivities for the Earth. This range of sensitivities results in part from uncertainties in modeling clouds. To understand and improve cloud parameterizations in Global Climate Models (GCMs), simulations should be evaluated using observations of clouds. Detailed studies can be conducted at Atmospheric Radiation Measurements (ARM) sites which provide adequate observations and forcing for Single Column Model (SCM) or Cloud Resolving Model (CRM) studies. Unfortunately, forcing for SCM/CRMs is sparse and not available for many locations or times.

Potential Solution: Utilize reanalyses to develop forcing

- Advantage: Forcing could be developed for a variety of locations to address specific questions (i.e. snowstorms in North Dakota).
- Disadvantage: Underlying models used in reanalyses may propagate errors into the forcing limiting their usefulness.

Quality of reanalysis based forcing may vary by location due to the availability of observations. It is reasonable to assume this idea is most likely to work in regions such as the CONUS where reanalyses should be better constrained to the quantity of observations available.

We investigate this topic at the ARM Southern Great Plains (SGP) site located in north-central Oklahoma.

A variety of cloud/atmospheric observations allow us to evaluate reanalyses and compare derived forcing with the ARM continuous forcing product (Xie et al. 2004).

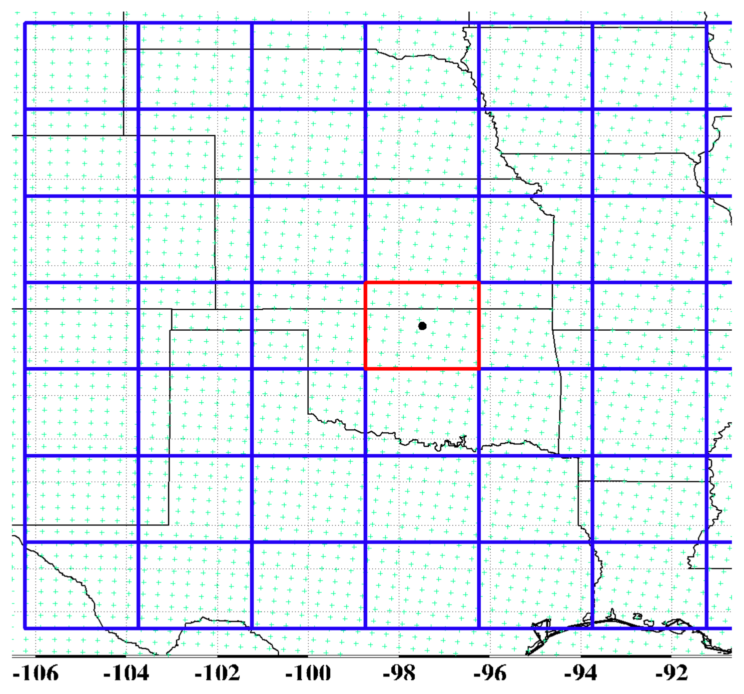


Figure 1. Domain of this study. The SCM is denoted by the red square in the middle of the blue grid which represents the averaged NARR data (green crosses) to a 2.5°×2° grid.

2. Quality of reanalyses at the ARM SGP Site

To determine the feasibility of reanalysis based forcing in the mid-latitudes, the North American Regional Renalysis (NARR) was first compared to ARM observations and forcing at the Southern Great Plains (SGP) site from 1999-2008. *See Kennedy et al. (2011) in the MERRA special collection of J. Climate for the initial study.*

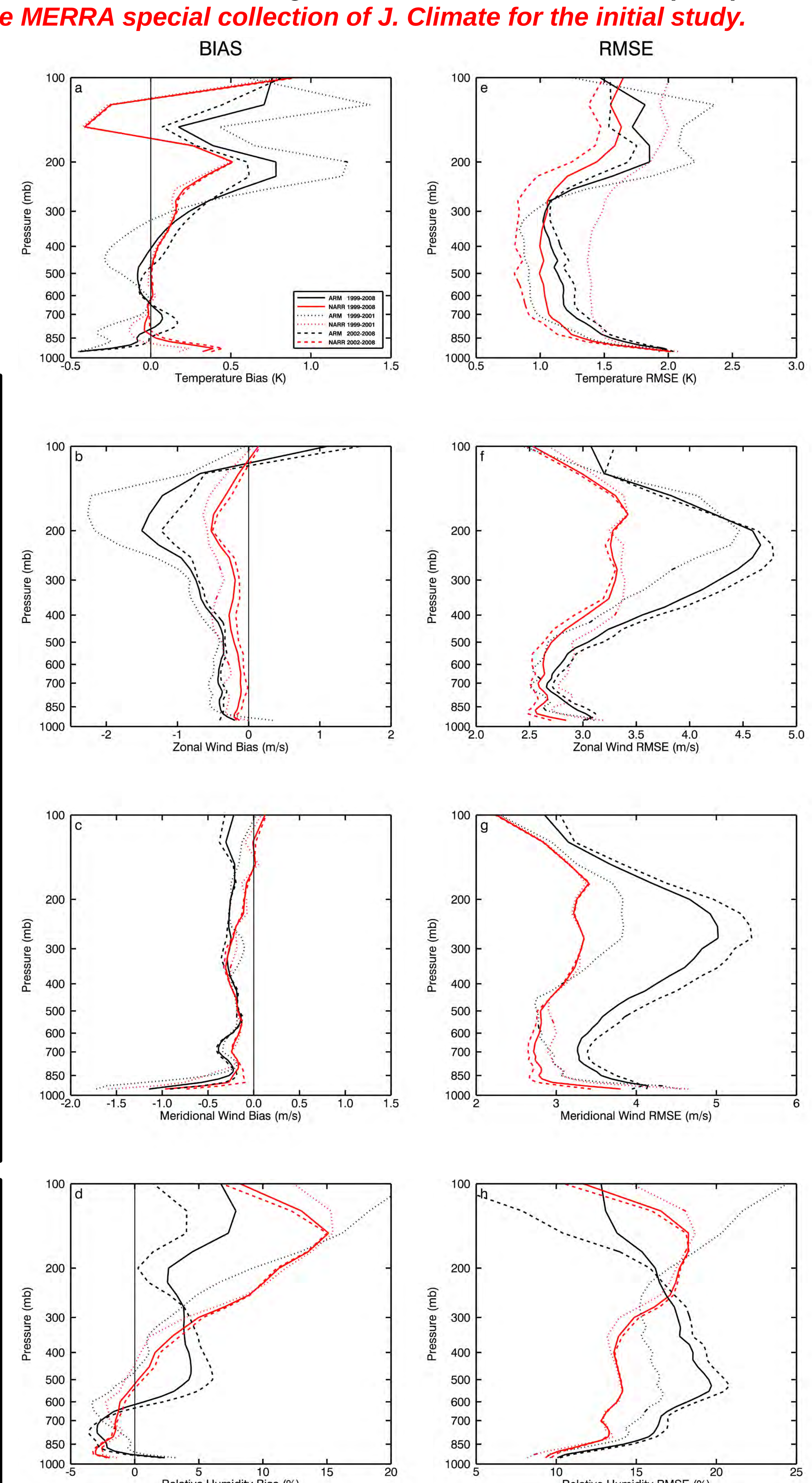


Figure 2. Biases of ARM continuous forcing (black), and NARR (red), relative to the ARM Cloud Modeling Best Estimate (CMBE) sounding profiles during the period 1999-2001 (dotted), 2002-2008 (dashed) and 1999-2008 (solid) for (a) temperature, (b) zonal wind, (c) meridional wind, and (d) relative humidity. (e)-(h) are the same as (a)-(d) except for the RMSE.

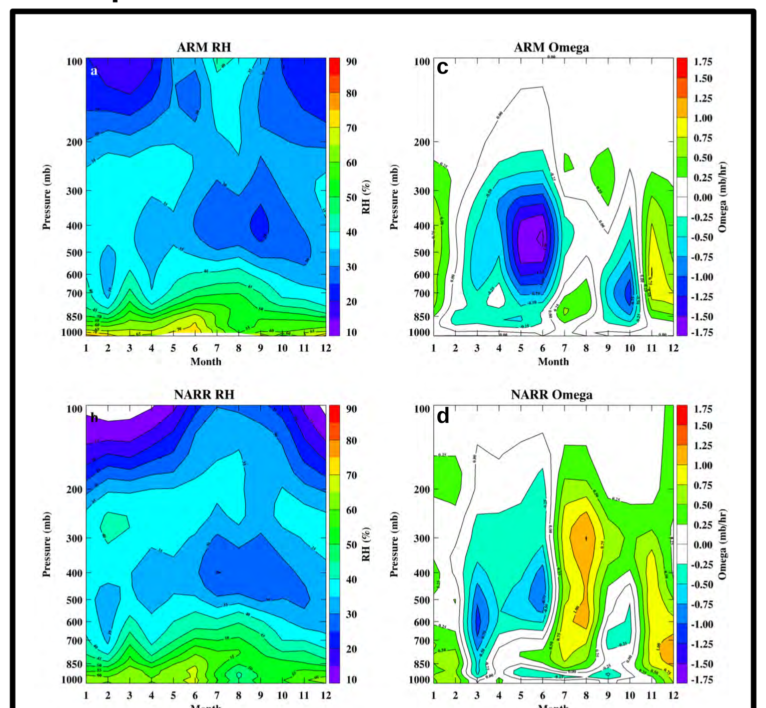


Figure 3. Monthly means of RH over the ARM SGP domain during the period 1999-2001 for (a) ARM continuous forcing, and b) NARR. (c)-(d) are the same as (a)-(b) except for the omega field. Figure adapted from Kennedy et al. (2011)

Summary

- NARR had many positive aspects w.r.t. ARM forcing.
- Biases/RMSE smaller in many cases
- Biggest disagreement:
  - Vertical velocities
  - Upper tropospheric humidity
  - Conclusion: NARR based forcing was a worthwhile endeavor

3. Development of Forcing

SCM/CRM forcing requires a number of variables, most notably the advective and vertical tendencies of temperature and humidity in the model grid box (Fig. 4 and Table 1).

Steps:

1. NARR variables were averaged to the 2.5°×2° grid in Fig. 1 (~50 points per box)
2. To match ARM forcing (hourly, 37x25hPa), variables were first interpolated in the vertical , then temporal dimensions.
3. Prior to generating the tendency terms using 4th order center finite differences, considerations were made regarding noise in the original multi-layer fields.
4. For certain versions of the forcing, a boxcar filter with a 9-hr window was used to smooth fields (ex. Fig. 5)

Final forcing:

- NARR NS (no fields smoothed)
- NARR AS (all fields smoothed)
- NARR OS (only omega smoothed)

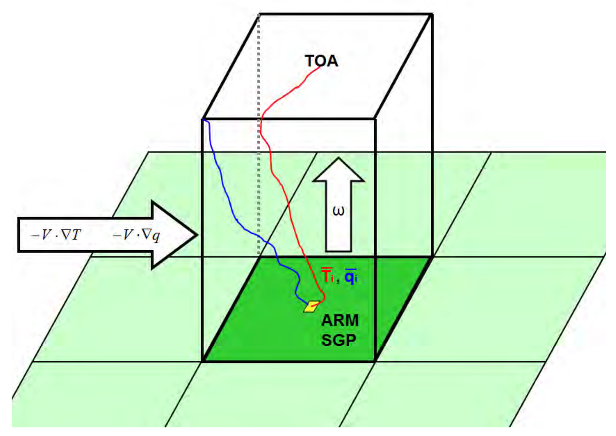


Figure 4. Schematic of a SCM centered on the ARM SGP site. The red and blue lines represent the grid-box mean temperature and humidity profile used as the initial conditions. The model is then iterated with use of large-scale advective and vertical velocity tendencies (white arrows).

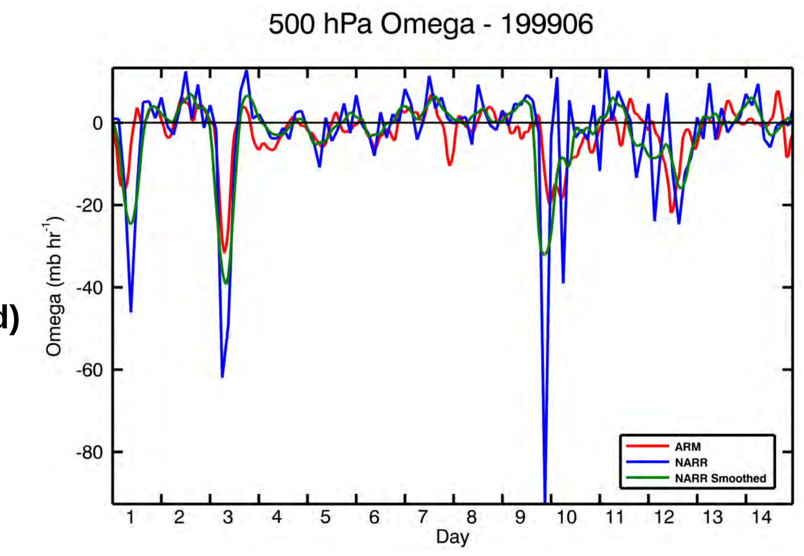


Figure 5. 500 hPa omega field for the first two weeks of June 1999.

Table 3. Variables required for SCM simulations. Italicized terms were calculated using center finite differences.

Variables (single-level)	Units
Surface latent heat flux	W m^{-2}
Surface sensible heat flux	W m^{-2}
Domain averaged surface pressure	mb
2m air temperature	°C
Skin temperature	°C
2m RH	%
10m wind speed	m s^{-1}
10m U component	m s^{-1}
10m V component	m s^{-1}
2m specific humidity	kg kg^{-1}
Variables (multi-layer)	**Units**
Temperature	K
Specific humidity	g kg^{-1}
Horizontal u-wind component	m s^{-1}
Horizontal v-wind component	m s^{-1}
Vertical pressure velocity (omega)	mb $hour^{-1}$
Horizontal wind divergence	s^{-1}
Horizontal temperature advection	K $hour^{-1}$
Horizontal water vapor advection	g kg^{-1} $hour^{-1}$
Vertical dry static energy tendency	K $hour^{-1}$
Vertical water vapor tendency	g kg^{-1} $hour^{-1}$

4. Results – General Properties

Vertical profiles of forcing terms (Fig. 6)

- Stronger winds in NARR lead to larger magnitudes for advective forcing
- Vertical tendency profiles generally follow ARM, but NARR is shifted due to weaker rising motion (see Fig. 3)

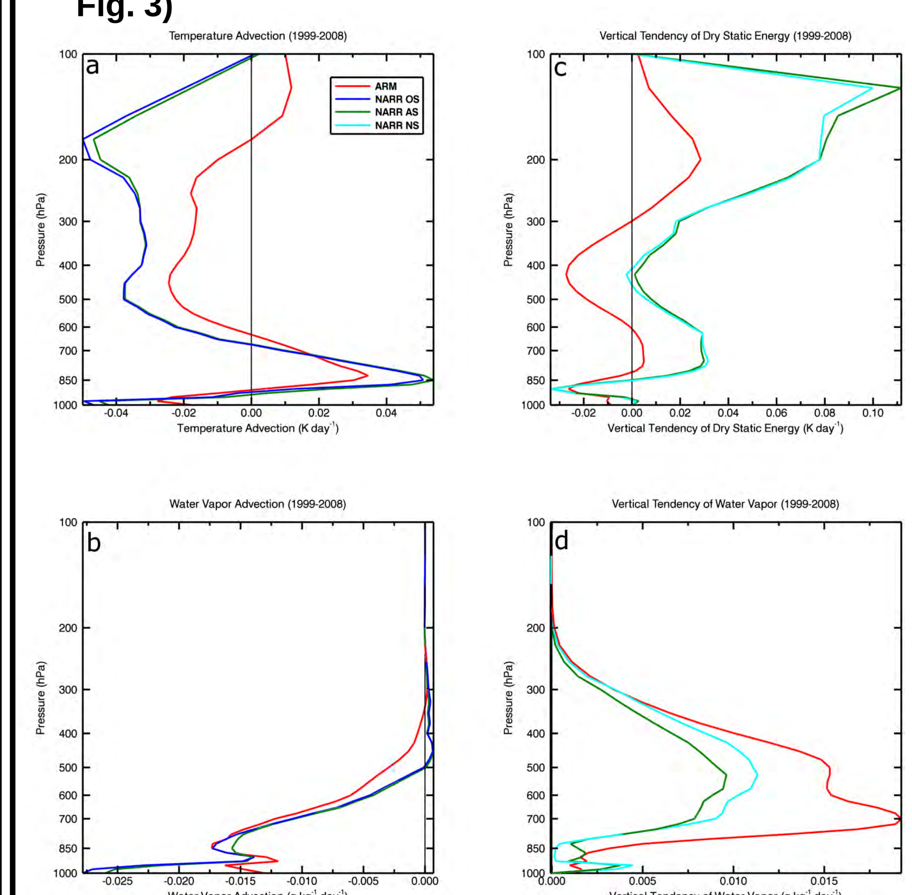
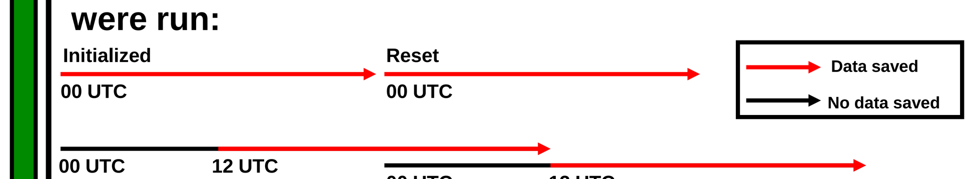


Figure 6. Vertical profiles of (a) temperature advection, (b) water vapor advection, (c) vertical tendency of dry static energy, and (d) vertical tendency of water vapor during the period 1999-2008.

Error Characteristics

To determine the stability of the forcing, model drift from the forcing was analyzed. Two sets of simulations were run:



- Drift was larger/smaller for NARR vs. ARM forcing depending on variable and height selected.
- 3-hourly oscillations were frequent in unsmoothed NARR forcings – AS provided the best error performance (Fig. 7).

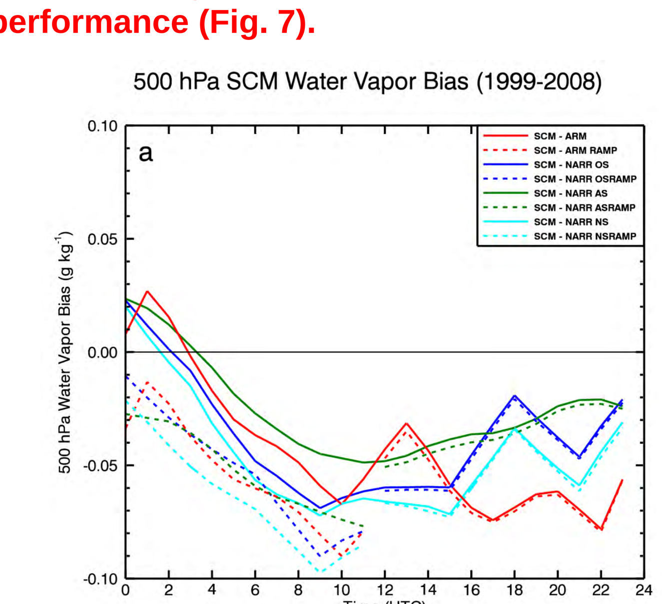


Figure 7. Error characteristics of 500 hPa water vapor for SCM simulations.

5. Results – Clouds/Precipitation

Precipitation

- Region receives majority of precipitation during the warm season due to convection (Fig. 8).
- Good agreement for all simulations during the cold season.
- Runs with ramping increase precipitation due to elimination of spin-up issues
- ARM forcing is in close agreement with observations, but with a caveat.
- Much of the gain above NARR is due to errors in the diurnal cycle (see peak at 16 UTC, Fig. 9)
- Smoothing NARR decreases precipitation to some extent – hourly convective signal will be washed out from a native 3-hr dataset (compared to the hourly RUC)
- NARR captures 75% of convective events during the month of June with near-zero FAR.

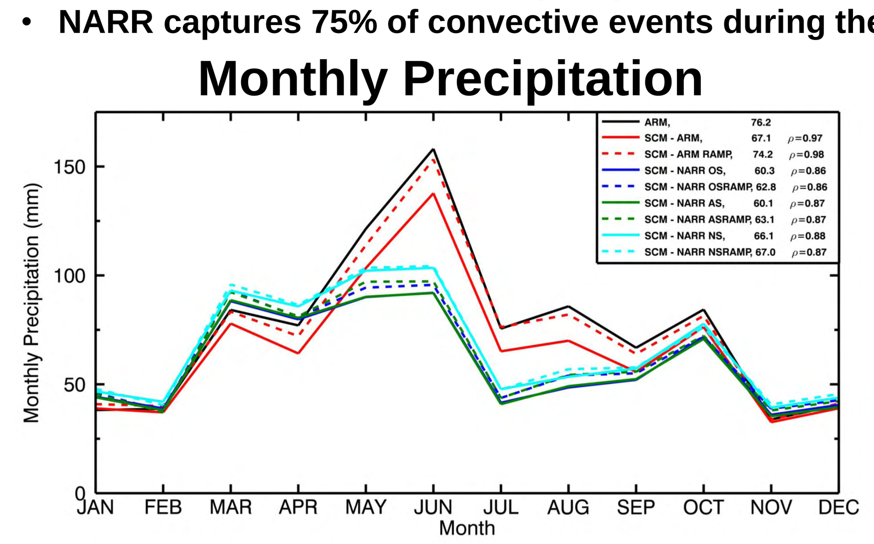


Figure 8. Monthly averaged precipitation observed by ARM and simulated by the different SCM runs during the period 1999-2008.

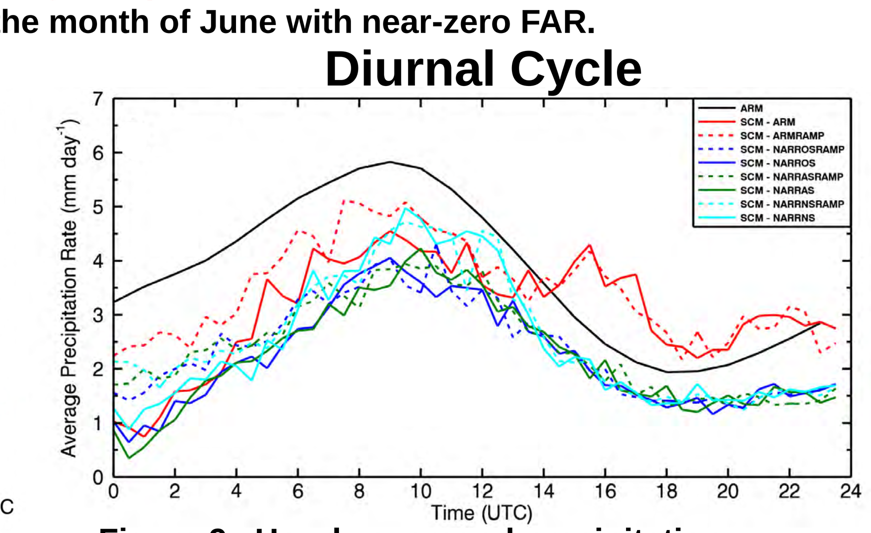


Figure 9. Hourly averaged precipitation observed by ARM and simulated by the different SCM runs during the MJJA period of 1999-2008.

Clouds

- Observations:
  - Bimodal distribution of clouds, with maxima for low/high clouds during spring/winter
  - Clouds were classified using an ISCCP like system (not shown)

	ARM Forcing	NARR Forcing
Advantage	High clouds	Low clouds
Disadvantage	Low clouds (+PBL humidity bias)	High clouds too high (convective param. issue?)

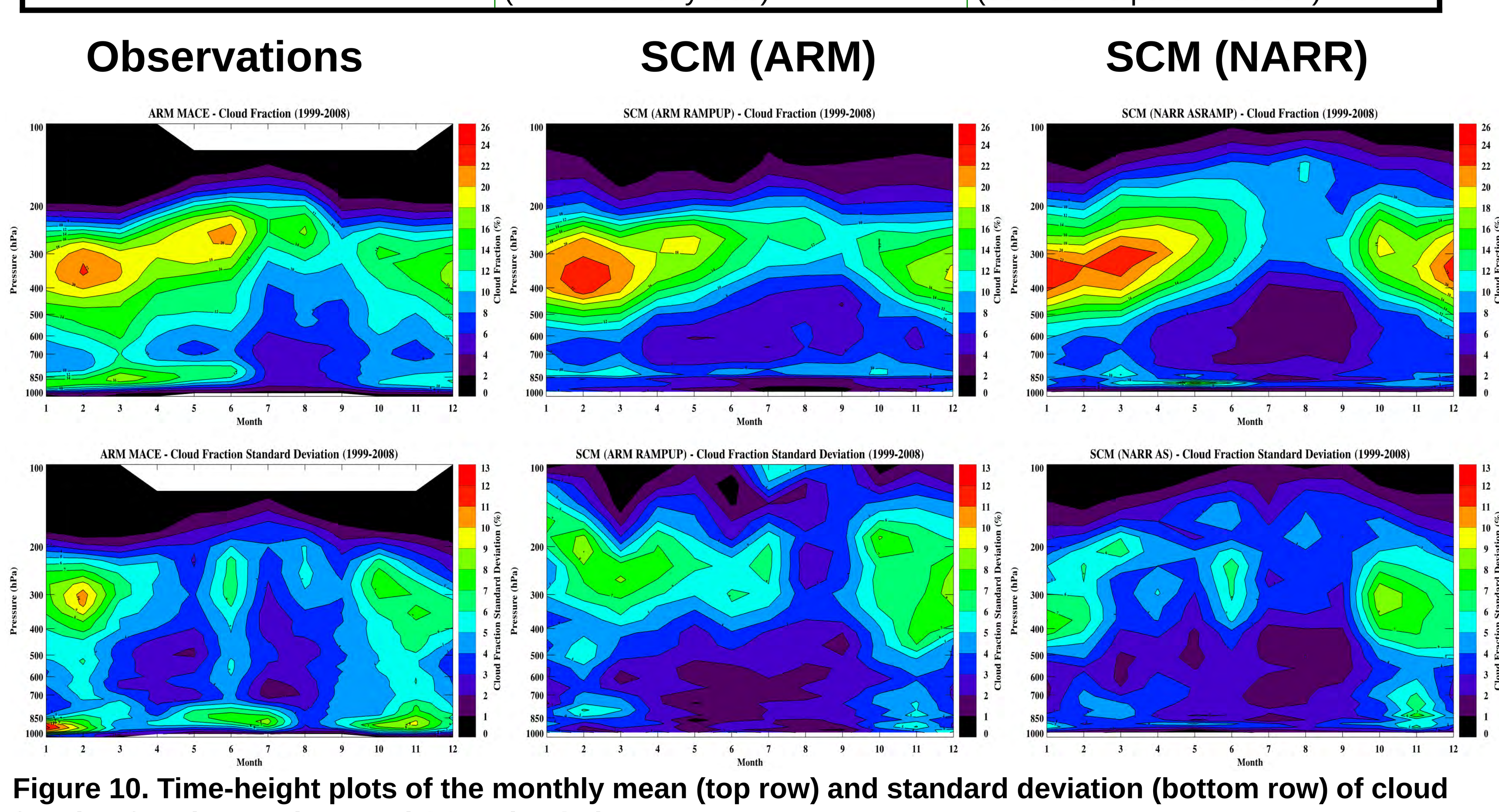


Figure 10. Time-height plots of the monthly mean (top row) and standard deviation (bottom row) of cloud fraction for observations and SCM simulations

Take home point: neither forcings are perfect - both have their own advantages. NARR may be a good alternative during time periods with little to no convection (i.e. snowstorms in more northern latitudes). More insight was gained by using BOTH forcings for this model.