Evaluating the Effective Stability and Springtime Clouds Simulated in the CAM at the ARM SGP

Atmospheric System Research

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1. Introduction

Biases of simulated clouds in climate models can arise from either physical processes directly, or large-scale atmospheric circulation indirectly (dynamical processes, such as the propagation speed of cyclones) that could be initially caused by physics biases. Here we present an analysis of cloud biases in the simulation with the Community Climate Model (CAM3) during the ARM 2000 cloud IOP that were caused by dynamical biases; we then trace the dynamical biases to physical processes.

2. The case

The case is for the March 1-4 2000 frontal system that was studied in Xie et al. (2005) using Single-Column Models (SCM) and Cloud Resolving Models (CRM). A cyclone passed through the ARM SGP; associated with it is the typical comma shaped cloud shield as in Figure 1a. The vertical cross section of cloud amount from ARM ARSCL is shown in Figure 1b.

Different from Xie et al. (2005) in which large-scale dynamical forcing was prescribed from the ARM variational analysis, here we initialize the CAM with reanalysis at 00 March 1 and integrate the model with interactive dynamics. The location of the cyclone as shown in Figure 2a (the 700 hpa geopotential height) is similar to observation in Figure 1a.

The time-pressure cross section of simulated clouds is shown in Figure 2b. Compared with Figure 1b, the model missed the cloud break at 00Z March 3rd due to the lack of dry air intrusion; this is expected since the model cannot resolve this feature. The model however also missed the middle and high clouds on March 4th; the cloud dissipation is much earlier than in observation. Why?

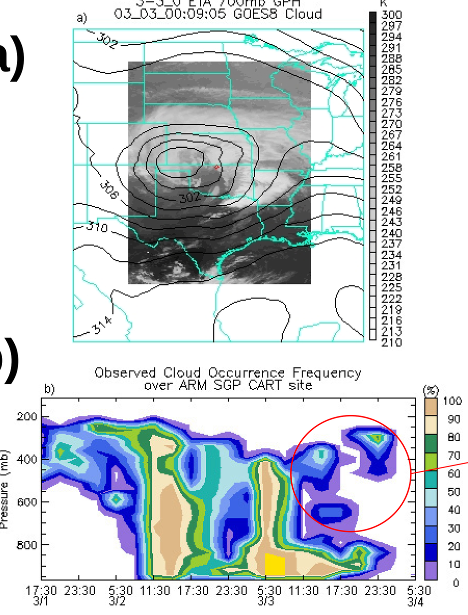

Figure 1

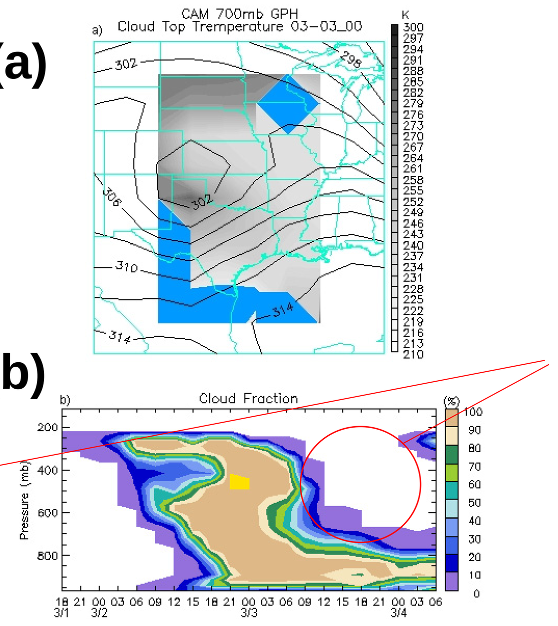

Figure 2

3. The cause of cloud biases

The top row of Figure 3 shows the propagation of the of the 500 hpa geopotential height associated with the cyclone trough and the high pressure ridge on March 1 and March 4 in observation.

The second row of Figure 3 shows the simulated trough and ridge in the CAM. The ridge propagated faster in the CAM; this caused the dissipation of clouds on March 4.

The third row shows the simulation of the WRF with the same horizontal resolution as the CAM. The ridge also propagated faster than in observation.

The last row shows WRF simulation when the horizontal resolution is reduced to 48 km; the propagation speed is improved.

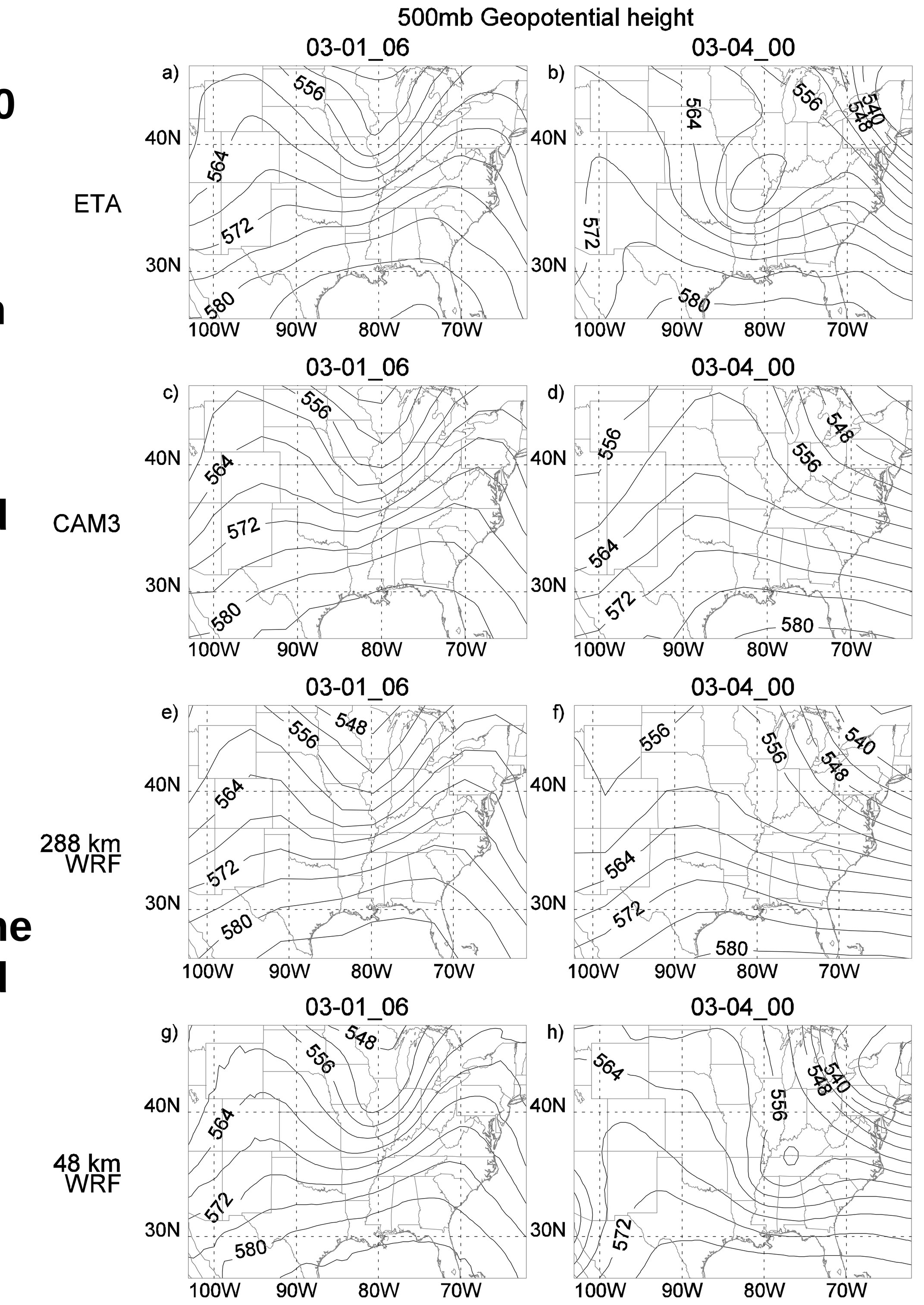

Figure 3

4. The cause of the propagation biases

When we define an effective atmospheric vertical stability as the dry stability compensated by adiabatic heating (Q1), we found that the compensation is more complete in the coarse resolution models than in observation for this case. This causes faster propagation of the synoptic wave, thus earlier dissipation of clouds.

$$\sigma_e = \sigma - \left(-\frac{R_d}{pC_p\omega}Q_1\right) = -\frac{R_d T}{p}\frac{d\ln\theta}{dp} + \frac{R_d}{pC_p\omega}Q_1$$

$$\left(\frac{\partial}{\partial t} + v\cdot\nabla\right)\left[\nabla^2\psi + \frac{\partial}{\partial p}\left(\frac{f_0^2}{\sigma_e}\frac{\partial\psi}{\partial p}\right)\right] = -\frac{\partial\psi}{\partial x}\beta.$$

$$c_p = \bar{u} - \frac{\beta}{k_x^2 + \frac{f_0^2}{\sigma_e}k_p^2}$$

References

S. Xie, et al. (2005), Simulations of midlatitude frontal clouds by single-column and cloud-resolving models during the Atmospheric Radiation Measurement March 2000 cloud intensive operational period, *J. Geophys. Res.*, 110, D15S03, doi:10.1029/2004JD005119.

5. Summary

Clouds in the coarse resolution model dissipated earlier than observation. This is caused by faster propagation of the synoptic wave, which is in turn caused by a larger compensation of diabatic heating with the dry atmospheric vertical stability.