Comparison of Convective Aggregation in Cloud-Resolving Models

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Introduction

Clouds play an important role in the climate system, but many aspects of cloud processes are not well understood. Naegele (2016) used the high-resolution System for Atmospheric Modeling (SAM)[1] to simulate convective clouds in radiative-convective equilibrium in a square domain 768 km wide, with periodic lateral boundary conditions and no large scale forcing or rotation. A brief description of SAM is given in the Methods section below. In agreement with previous authors (e.g., Bretherton et. al., 2005), Naegele (2016) found that the clouds organized into "aggregations" with broad clear spaces in between. She also found that the aggregated cloud system pulsated with a period of ten simulated hours. This pulsation has not previously been discussed in the literature. The purpose of the present study is to investigate the mechanism that gives rise to the pulsation.

Hypothesis

We hypothesize that the pulsation is associated with gravity waves that propagate across the model domain. The waves are excited by aggregated convection, and propagate away from it. Because of the periodic lateral boundary conditions, the waves "come back" to where they started, and modulate the same convection that excited them in the first place. This synergistic interaction between the waves and the convection gives rise to the pulsation, and is only possible because of the periodic boundary conditions.

Methods

In addition to SAM, we have used the Regional Atmospheric Modeling System[2] (RAMS). Both SAM and RAMS are non-hydrostatic models that can be run with cloud-resolving resolution. SAM uses the anelastic system of equations, while RAMS uses the fully compressible system. Both models use finite differences on the staggered C grid, although they differ in the details of their numerical schemes. Both include parameterizations of turbulence, microphysics, and radiation, although these parameterizations differ between the models. SAM runs with periodic lateral boundary conditions, while RAMS can be run with a variety of lateral boundary conditions including both periodic and open.

Our plan was to first use RAMS, with periodic boundary conditions, to reproduce the pulsating aggregated cloud system simulated with SAM. Then we would continue the RAMS simulation with open boundary conditions, which would allow the gravity waves to "disappear" beyond the outer edges of the computational domain. If our hypothesis is correct, the pulsation should disappear with the open boundary conditions.

Discussion

For our initial run of the simulation, our goal was to replicate variables as closely as possible to the original SAM simulation that produced aggregation. When no aggregation was observed, we made adjustments with new conditions. Initially we increased surface winds from 1 m s^{-1} to 4 m s^{-1} to avoid a low surface wind value that would shut down surface fluxes (Latent heat flux in RAMS was only 50 W m^{-2}). Then we increased surface winds to 7 m s^{-1} and increased temperature perturbation from 0.2 K to 0.5 K, to increase convection at the beginning of the simulation. This produced stronger precipitation and somewhat more aggregated clouds, but not as strongly collected as in SAM (and no oscillation). We also tried decreasing the grid space for a finer resolution (2 km and 1 km) with surface winds at 4 m s^{-1}, with no changes.

Explorations

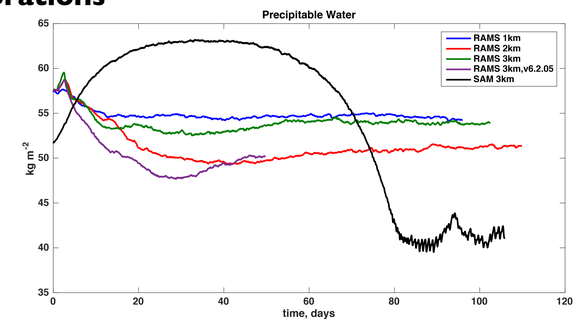

Figure 1. SAM gains a large amount of precipitable water as RAMS drops and maintains a similar level throughout. After 60 days, SAM's precipitable water drops as moisture in the air becomes precipitation (and cloud aggregation).

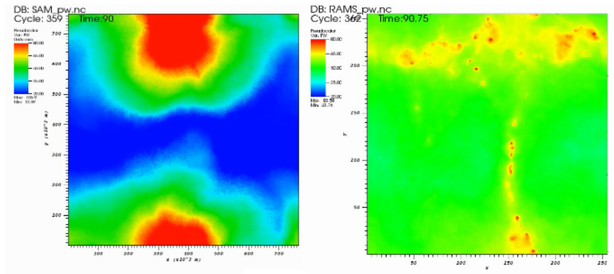

Figure 2. Precipitable Water (PW) in SAM (left) forms clear aggregation in contour plots. RAMS (right) begins to form bands of Precipitable Water after 90 days, but no strong organization.

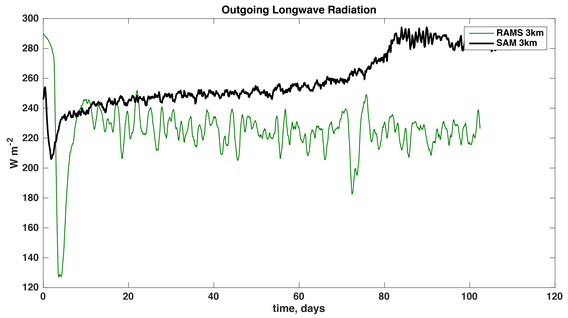

Figure 3. Outgoing Longwave Radiation indicates a clear sky (or high clouds), with very little cloud cover blocking longwave radiation from the ocean surface. In SAM, this means more aggregation and large dry columns.

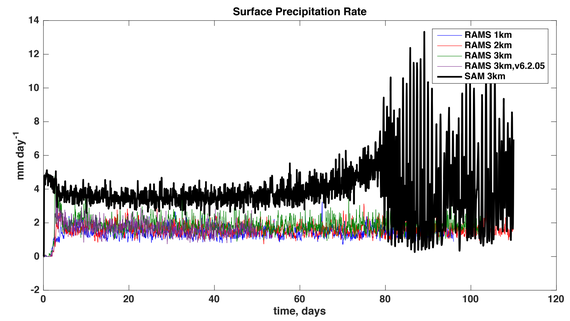

Figure 4. A dramatic Precipitation increase after 80 days in SAM indicates the formation of clouds which do not form in RAMS. The range of precipitation in SAM produces the intense aggregation and disappearance that presents as oscillation.

Preliminary Results

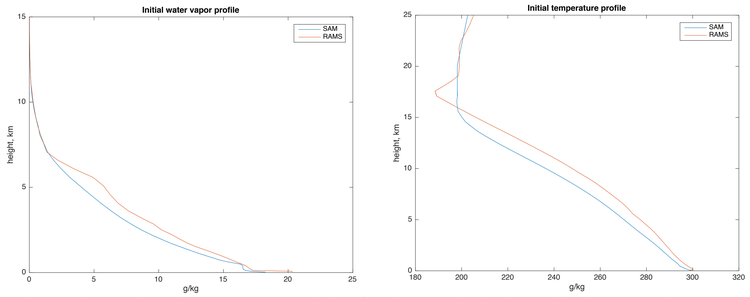

Figure 5. Initial conditions were intended to be the same for both models, however, there were large differences in the initialization (SAM – colder and dryer). Because of the difference in moisture and temperature profile, the simulations also have different results.

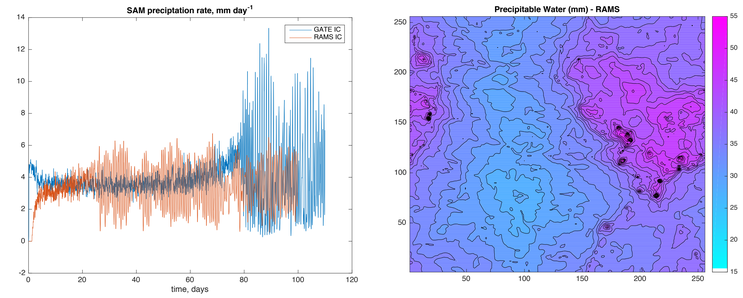

Figure 6. (Left) Using the initial conditions from RAMS in SAM (red), we see aggregation and pulsation similar to the original run (blue). Using SAM initial conditions in RAMS (right), we see weak aggregation and no pulsation.

Conclusions

- SAM goes to approximately the same pulsating, aggregated state from two different initial conditions.
- RAMS appears to be aggregating weakly, but does not show a pulsation yet.
- We suspect that microphysical differences between the models are responsible for the different behaviors of SAM and RAMS.

References and Acknowledgements

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