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

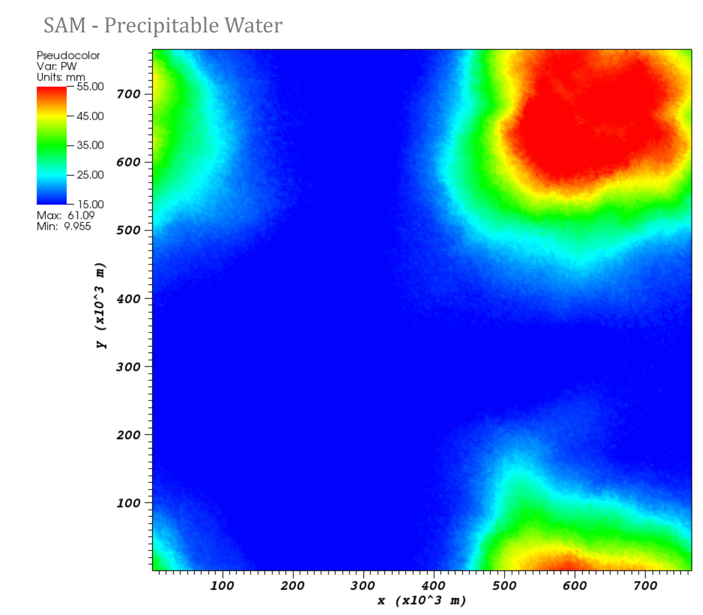
We hypothesize that the pulsation is associated with gravity waves that propagate across the model domain. The waves are excited by aggregated convection, and propagate away from it. Because of the periodic lateral boundary conditions, the waves "come back" to where they started, and modulate the same 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.

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.

Results



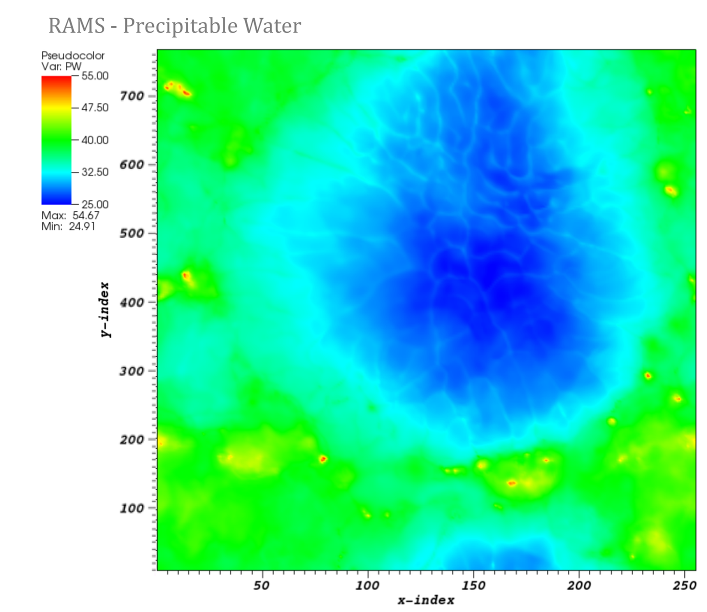
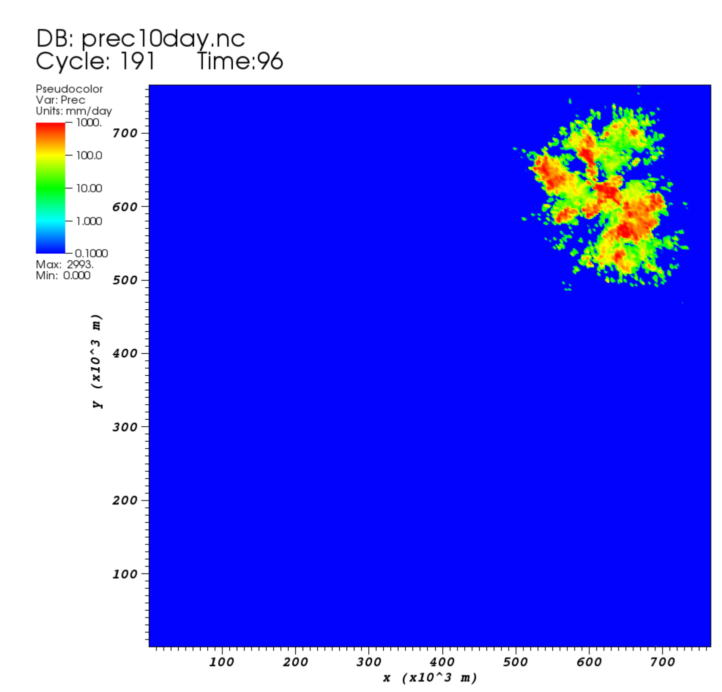


Figure 1. (Left) Large, expanding dry columns of air "crowd out" moisture into aggregated clouds. SAM shows strong aggregation and pulsation with stark differences between dry and moist areas.

Figure 2. (Right) Precipitable Water in RAMS shows weaker dry columns of air, making aggregation difficult. Contour maps show water columns on day 75.



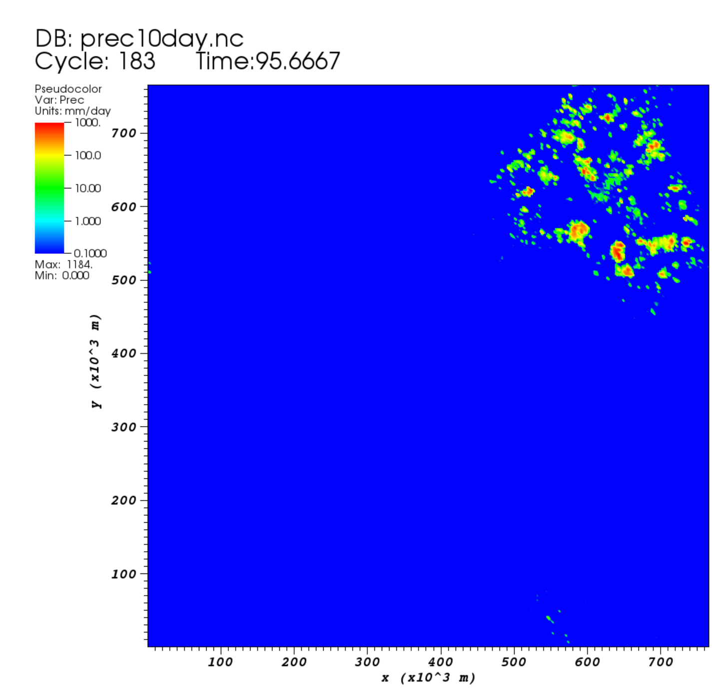
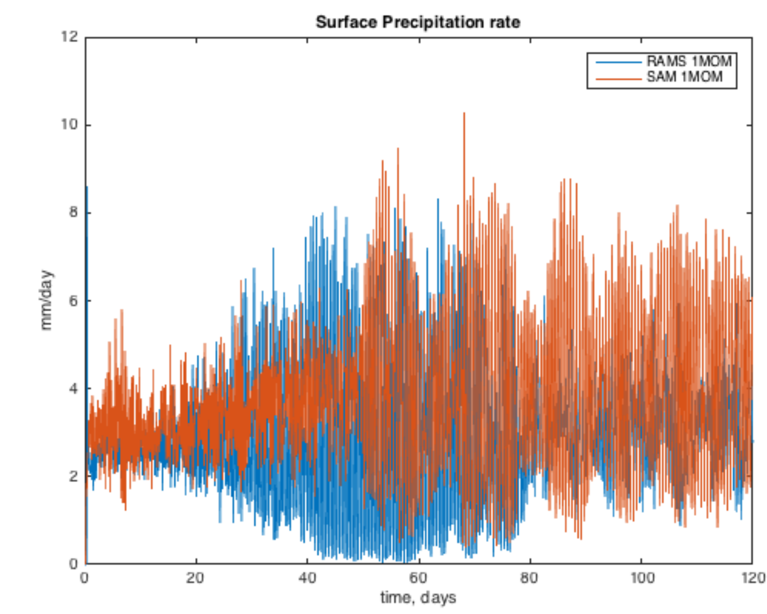


Figure 3. (Left) Regular pulsation is most evident in SAM after 95 days. Dramatic precipitation increase after 80 days in SAM indicates the formation of clouds. A strong aggregation is shown after Precipitable water in the model has dropped (as dry air columns expand).

Figure 4. (Right) The disappearance of intense aggregation that presents as oscillation. Precipitation is shown here to appear and disappear with periodicity of roughly 8 hours.



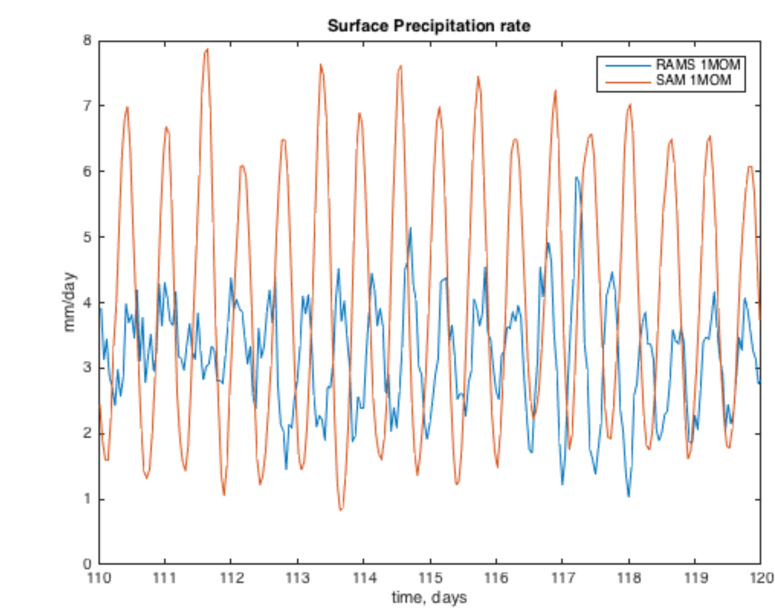
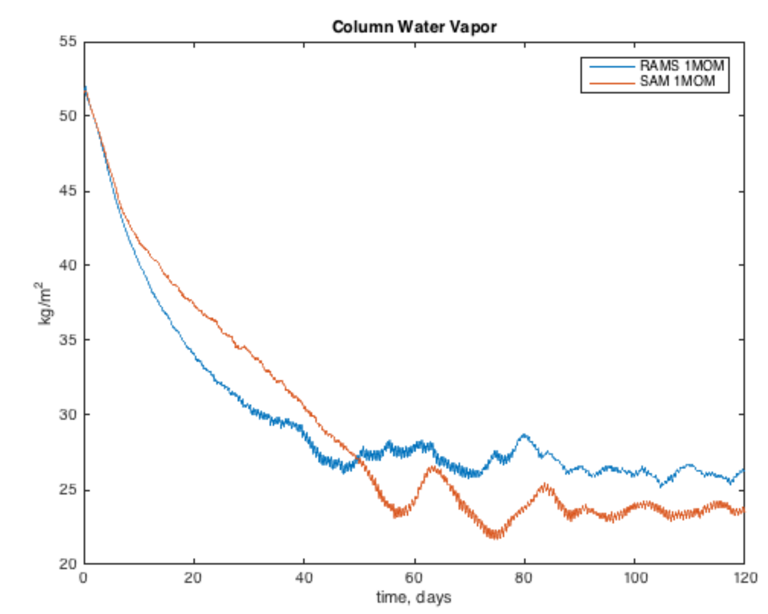


Figure 5. (Left) Surface Precipitation Rates from RAMS (blue) and SAM (red). The models show RAMS has a strong pulsation in the early days of the simulation, while SAM shows stronger pulsation after 50 days.

Figure 6. (Right) A sample of the full 120 day run is shown on the right to highlight the regularity of the pulsation.



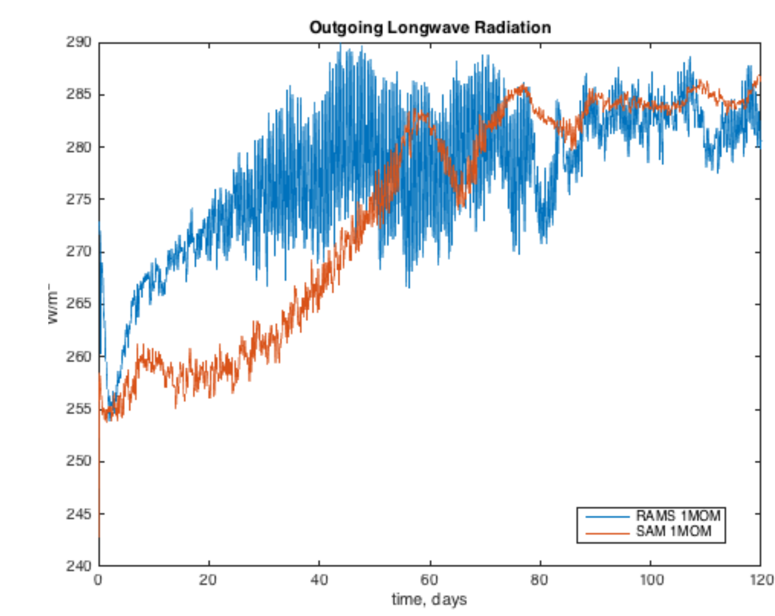


Figure 7. (Left) Given the same initial conditions in RAMS and SAM, precipitable water quickly drops considerably in both models as dry columns in the model domain expand and moisture in the air becomes precipitation (cloud aggregation). After 50 days, RAMS (blue) maintains a consistently higher level of precipitable water, but levels off at roughly the same time RAMS reaches stable PW levels. Pulsation can also be observed in both models.

Figure 8. (Right) Outgoing Longwave Radiation indicates a clear sky (or high clouds), with very little cloud cover blocking longwave radiation from the ocean surface. In RAMS, this means quick aggregation and strong pulsation, while SAM develops its large dry columns later and has a weaker pulsation.

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. We suspected that microphysical differences between the models are responsible for the different behaviors of SAM and RAMS.

Initial conditions were intended to be the same for both models, however, there were large differences in the initialization. SAM would consistently start with colder and dryer conditions. Because of the difference in moisture and temperature profile, the simulations also have different results. After changing the microphysics scheme to 1 moment, aggregation was found in both (but still weaker in the RAMS model).

Conclusions

- RAMS and SAM can create cloud aggregation and pulsation with similar initial conditions.
- The microphysics scheme used is critical for observing this aggregation.
- Cloud aggregation is found using the 1 moment microphysics scheme in both RAMS and SAM.
- Aggregation and Pulsation appears quickly in RAMS but requires a longer model run in SAM.
- SAM creates a stronger aggregation and pulsation.

References and Acknowledgements

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