Effects of Horizontal Resolution on Cumulus Cloud Simulations

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1. Introduction

The horizontal resolution of cumulus cloud simulations not only affects the computational cost of running a cloud resolving model (CRM), but it affects the results of the model as well. It is necessary to find the coarsest resolution that can be used without compromising the accuracy of the results.

2. Model and data

This study was carried out using the System for Atmospheric Modeling (SAM), a three-dimensional cloud resolving model. The forcing data used for the model came from two different field campaigns, the GARP (Global Atmospheric Research Program) Atlantic Tropical Experiment (GATE) and Atmospheric Radiation Measurement Program (ARM) at the Southern Great Plains site. GATE took place during the summer of 1974 over the tropical Atlantic Ocean extending from Africa to South America. The ARM field campaign took place during the summer of 1997.

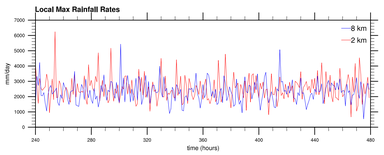
A constant large scale forcing was applied to the temperature and moisture fields for the GATE case. The model was run until the atmospheric water content stabilized. With the ARM forcing data, a diurnal cycle of solar insolation was applied. The model was run until the soil moisture adjusted. For both GATE and ARM simulations a 20-day period was analyzed.

3. Rainfall Rates

Fig. 1

Fig. 1 illustrates the local maximum rainfall rates in the domain at a given time. There is no discernable difference between the resolutions for local rainfall maxima for the GATE runs (Fig. 1a) do not have a significant difference in the local rainfall rates. ARM runs have an increasing local rainfall rate with increased resolution.

(a) GATE



(b) ARM

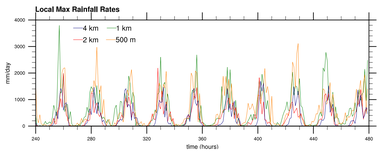
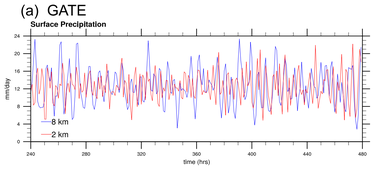
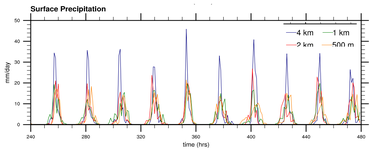


Fig. 2

(a) GATE



(b) ARM



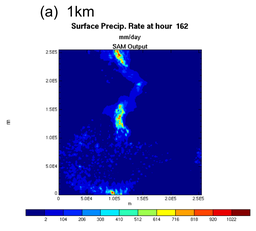
Domain averaged surface precipitation rates are displayed to the left in Fig. 2. The horizontal resolution does not have a significant effect on the surface precipitation rate for the GATE runs. Coarser resolutions have a higher precipitation rate in the ARM runs. This means that the coarse resolution is raining more over a larger area, but has milder local rainfall rates, which can be seen in Fig. 3.

4. Surface Precipitation Map

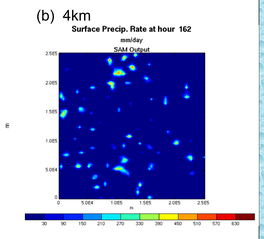
Fig. 3

Contour maps of surface precipitation for the 1 km and 4 km ARM runs are given to the right (Fig. 3). The 1 km run displays more intense rainfall rates and the 4 km run shows smaller rates over a larger area. The finer resolution appears to have more organization.

(a) 1km



(b) 4km

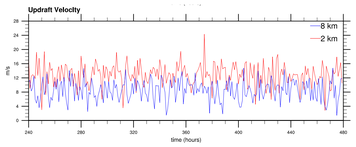


5. Updrafts & Downdrafts

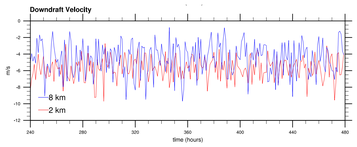
The graphs below (Fig. 4) illustrate the local maximum updraft velocities and minimum downdraft velocities. It is evident that for both GATE and ARM cases the higher resolutions have stronger updrafts and downdrafts. The finer grid spacings (1 km and 500 m) in the ARM runs converge.

Fig. 4

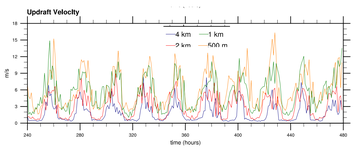
(a) GATE



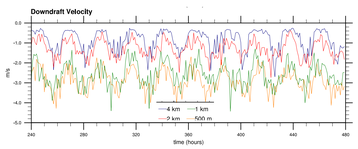
(b) GATE



(c) ARM



(d) ARM

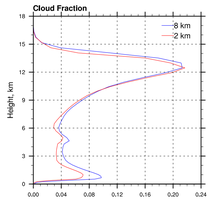


6. Cloud Fraction

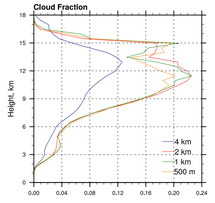
The cloud cover fraction is displayed in the plots to the right (Fig. 5). Cloud fraction values were averaged over time and the domain and plotted against the height. GATE runs (Fig. 5a) do not display a significant difference in cloud fraction from the 8 km to 2 km grid spacing. The coarser resolution for the ARM case is substantially different than the higher resolutions which are all converged.

Fig. 5

(a) GATE



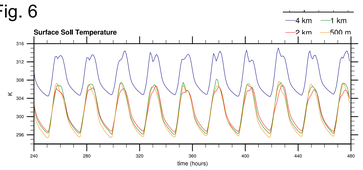
(b) ARM



7. Further Investigation of ARM runs: Soil Temperature and Moisture

Fig. 6

Fig. 6 illustrates the surface soil temperature in K. A substantial difference is noted in the 4 km grid spacing, which has a greater temperature than the higher resolutions.

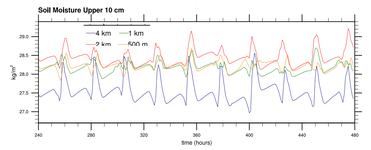


7. Further Investigation of ARM runs: Soil Temperature and Moisture continued…

Fig. 6

The soil moisture in the upper 10 cm of the ground is depicted in the plot to the right (Fig. 6). The coarse resolution run is significantly drier than all other resolutions which are, again, converged.

Evaporation from the soil (not pictured) is also greater in the coarse resolution. This results in a moister and warmer atmosphere.



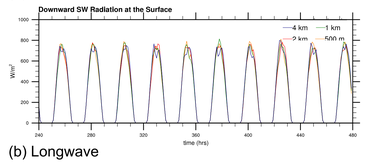
8. Further Investigation of the ARM runs: Downward Radiation

Fig. 8

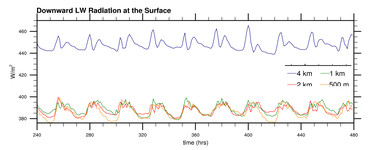
The incoming shortwave solar radiation and the downward longwave radiation are plotted in Fig. 8. The incoming solar radiation (Fig. 8a) is the same for all resolutions despite the much lower cloud cover in the 4 km grid spacing. This could be explained by optically thin clouds in the higher resolution runs, where shortwave radiation can easily pass through.

The downward longwave radiation, on the other hand, is substantially higher for the coarse resolution. This is explained by a warmer and moister atmosphere.

(a) Shortwave



(b) Longwave



9. Conclusions

For the GATE runs, resolution does not have a great impact on rainfall rates. A more radical effect is seen on updrafts and downdrafts, which intensify with higher resolutions. Cloud cover for the GATE are not considerably different for the different grid spacings studied.

The ARM runs are more sensitive to horizontal resolution than the GATE runs. Domain averaged rainfall rates decrease with increased resolution. Local rainfall rates, on the contrary, increase with increased resolution. In the ARM runs updrafts and downdrafts intensify with increased resolution. Cloud cover decreases with increased resolution. Grid spacings larger than 4 km were not used for the ARM case because they gave unrealistically high values for the precipitable water and the tropospheric temperature. The coarse, 4 km grid spacing for the ARM runs showed warmer and drier surface conditions. These differences corresponded to a moister atmosphere and more downward longwave radiation. Further study is needed to understand these resolution sensitivities.

10. Acknowledgements

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11. References

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