The Importance of Grid Spacing in Simulating Organized Convective Storms

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1 - Introduction

Kilometer-scale models improve mesoscale convective system (MCS) simulations compare to coarser resolution weather and climate models. However, km-scale models operate in the convective gray zone and have deficiencies in simulating turbulent motions resulting in biases such as an underestimation of storm entrainment or an overestimation of peak rainfall rates. Here we use large-eddy simulations (LES) that can resolve turbulent motions to improve our understanding of deficiencies and the predictability of km-scale models.

2 - Objectives

We aim to better understand the interactions of processes in MCSs on multi-spatiotemporal scales.

The main project goals are to:

1) quantify the skill of LES simulations in capturing observed U.S. Southern Great Plains [SGP] and Amazon [MAO] MCSs at DOE ARM site,

2) analyze the convergence of MCSs processes (e.g., drafts, cold pools) with increasing model resolution, and

3) support the development of novel parameterizations of anvil clouds.

3 - Experiment Design

We simulate 11 SGP and 13 MAO MCSs (see Tab. 1) over the domains shown in Fig. 1 at 12 km, 4 km, 2 km, 1 km, 500 m, and 250 m grid spacing. 4 MCSs were simulated using 125 m.

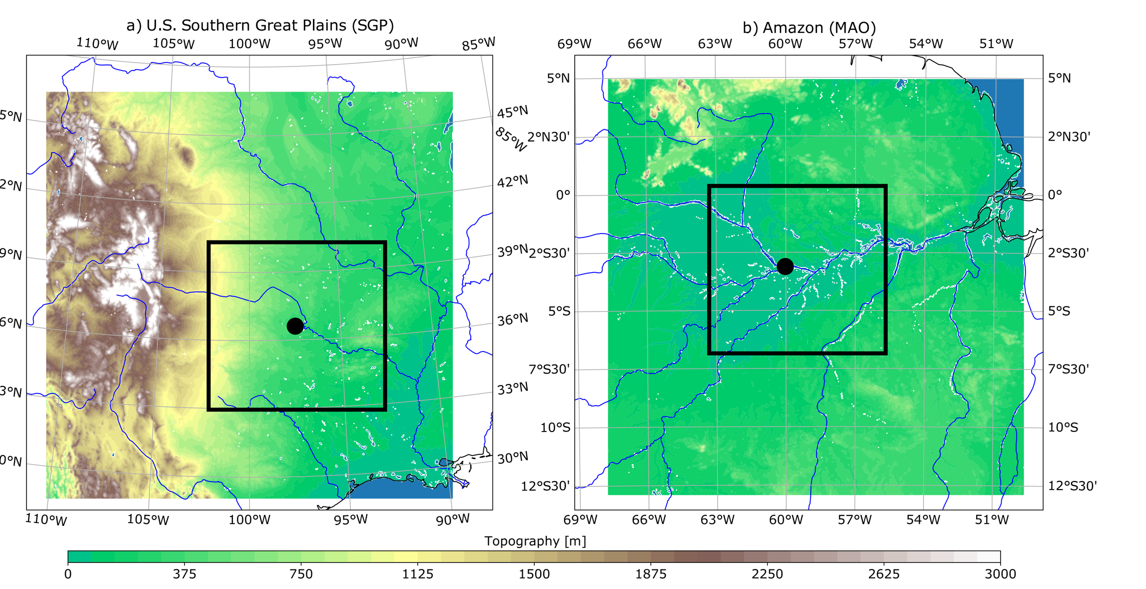

Fig. 1 - Computational WRF domains for simulating MCS cases in the US Southern Great Plains (SGP; a) and Amazon basin (MAO; b). The colored contours show the model topography. The black circle shows the location of the ARM SGP and MAO site and the black rectangle shows the location of the LES simulation domain.

Table 1
Selected MCS Cases in the US Central Great Plains (SGP) and Amazon Basin (MAO). Simulations in red boxes were ran wat 125 m grid spacing.

Region	Date and time [UTC]	Season	Morphology
SGP	2012.05.31 04:00	Spring	Squall line
SGP	2012.06.15 07:00	Spring	Squall line
SGP	2013.05.09 07:00	Spring	Squall line
SGP	2013.06.05 09:00	Spring	Bow echo
SGP	2013.06.17 07:00	Spring	Squall line
SGP	2014.06.02 04:00	Spring	Squall line
SGP	2014.06.05 12:00	Spring	Bow echo
SGP	2014.06.12 06:00	Spring	Squall line
SGP	2014.06.28 16:00	Spring	Weakly organized
SGP	2014.07.10 10:00	Summer	Training line
SGP	2016.03.08 15:00	Spring	Weak squall line
SGP	2016.06.18 10:00	Spring	Mesoscale convective complex
SGP	2016.07.29 09:00	Summer	Squall line
MAO	2014.08.16 14:00	Dry	Local, small system
MAO	2014.09.17 17:00	Dry	Squall line
MAO	2015.06.21 14:00	Dry	Squall line
MAO	2014.04.01 15:00	Wet	Training line
MAO	2014.12.10 14:00	Wet	Local, weakly organized
MAO	2015.03.28 15:00	Wet	Local, weakly organized
MAO	2015.04.12 12:00	Wet	Squall line
MAO	2014.10.04 13:00	Transition	Squall line
MAO	2014.10.18 14:00	Transition	Local, weakly organized
MAO	2014.11.17 18:00	Transition	Squall line
MAO	2015.11.06 12:00	Transition	Squall line

Note. The date and time indicates the overpass of the MCS over the corresponding ARM site as defined in Wang et al. (2019).

4 - Model Grid Spacing Sensitivity

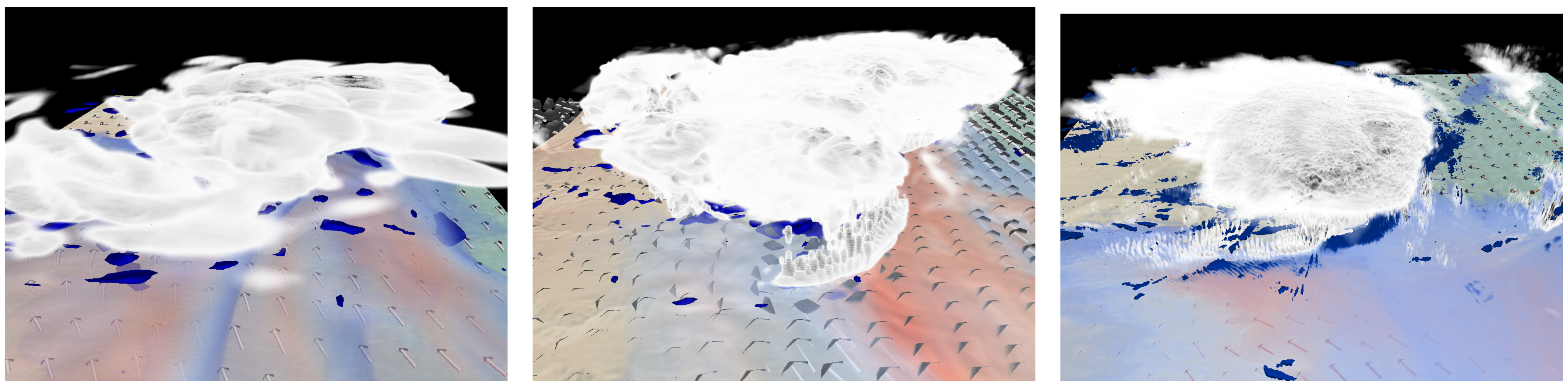

Fig. 2 - Visualization of the June 11, 2015, MCS over the SGP site during its mature phase as simulated using 12 km (left), 4 km (middle), and 125 m (right) grid spacing. Clouds are shown in gray, cold pools in blue, water vapor missing ratio in blue/red, and 10 m wind direction and speed in arrows.

5 - Physics Sensitivities

We tested the sensitivity of the 4 km WRF model to simulate MCSs over the SGP and MAO model microphysics and planetary boundary-layer scheme (Fig. 3). The Thompson and YSU scheme resulted in good performance in both environments and is selected for finer Δx simulations.

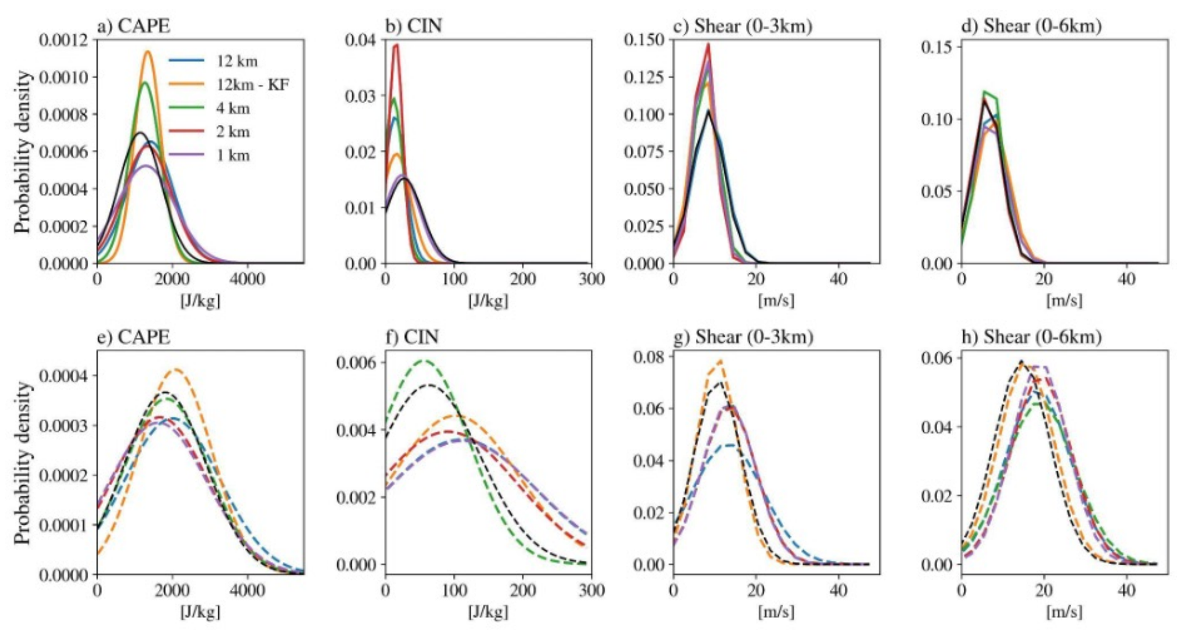

Fig. 4 - PDFs of observed (black) and simulated case ensemble mean (a,e) CAPE, (b,f) CIN and the (c,g) 0-3 km and (d,h) 0-6 km wind shear at the MAO (top) and SGP (bottom) site locations. Line colors identify the simulations with different Δx. Pre-MCS radiosonde observations are shown in black.

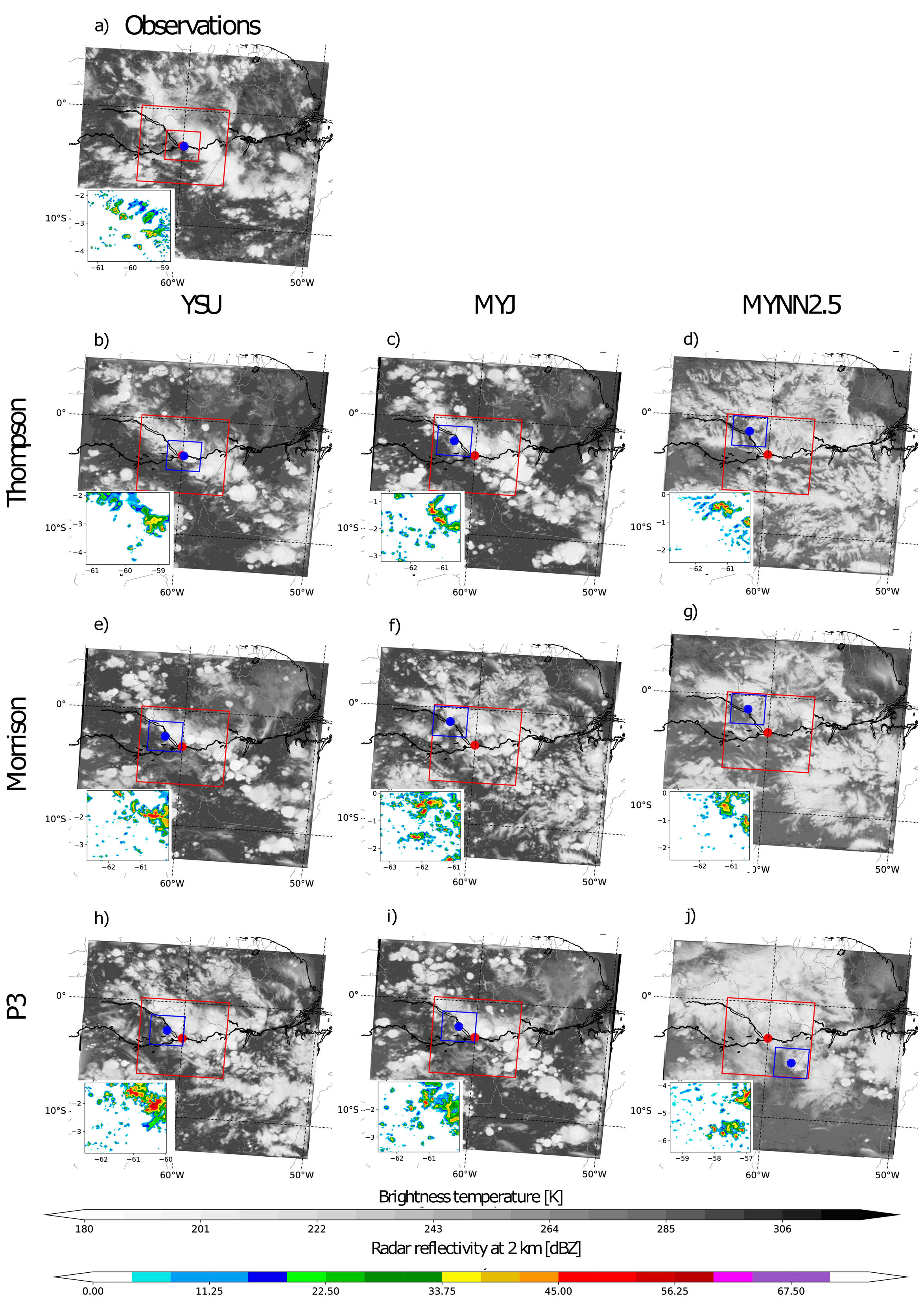

Fig. 3 - Example of the observed and (b–j) simulated BT (gray contorts) and radar reflectively (inlet in the lower left) at 2 km for the 17 November 2014, MCS casein the Amazon. Results using the Thompson, Morrison, and P3 microphysics scheme are shown top-down and YSU, MYJ, and MYNN2.5 planetary boundary layer (PBL) scheme from left to right.

6 - Environmental Conditions

Higher resolution results in an improved simulation of MCS environments over MAO but not necessarily over SGO (Fig. 4). Spatial gradients in MAO (Fig. 5) and SGP environments (not shown) are better resolved at higher Δx.

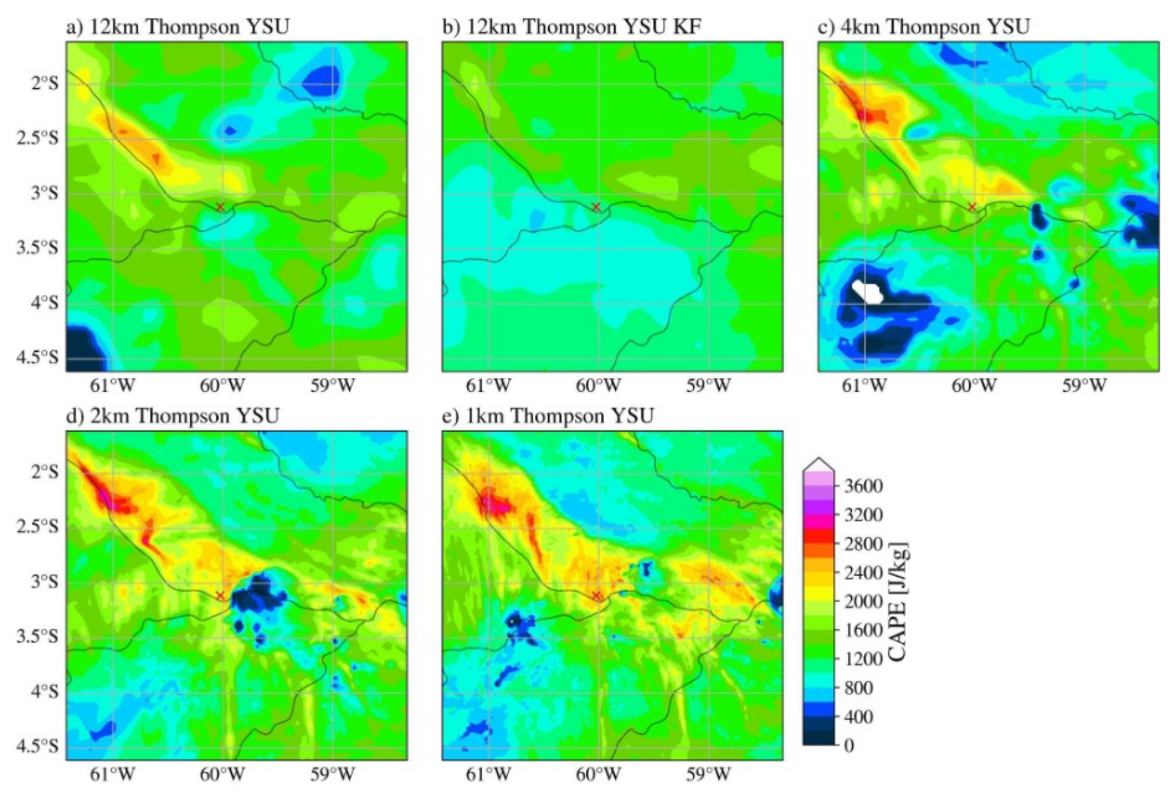

Fig. 5 - Example of the spatial distribution of simulated CAPE near the MAO site (marked in the red cross) for April 1, 2014, at 11:40 UTC, 3.5 hours before the MCS overpassed the site. Black contours represent river features.

7 - Key Results

We find clear improvements in simulating MCSs at **increasingly finer resolution** for:

- up-and downdraft geometriesstorm
- average draft dynamics
- cold-pool dynamics

Concerning the **model physic**s we find that:

- physics that work well in mid-latitudes might result in spurious results in the tropics
- microphysics play a larger role in simulating central U.S. MCSs while PBL scheme

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Literature

Prein, A.F., Ge, M., Valle, A.R., Wang, D. and Giangrande, S.E., 2022. Towards a Unified Setup to Simulate Mid-Latitude and Tropical Mesoscale Convective Systems at Kilometer-Scales. Earth and Space Science, p.e2022EA002295.

Ramos-Valle1 AN, Prein AF, Ge M, Wang D, and Giangrande SE (submitted) Grid spacing sensitivities of simulated mid-latitude and tropical mesoscale convective systems in the convective gray zone. JGR: Atmospheres
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