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Impact of a New Cloud Microphysics Scheme on Simulation of Mesoscale Convective Systems in E3SM Regionally Refined Model (RRM)

Wang, J.[1] J. Fan[1,*], Z. Feng, K. Zhang[1], E. Roesler[2], B, Hillman[2], Jacob Shpund[1]

[1] PNNL, [2] SNL
* Presenting author

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E3SM Energy Exascale Earth System Model

Acknowledgement:
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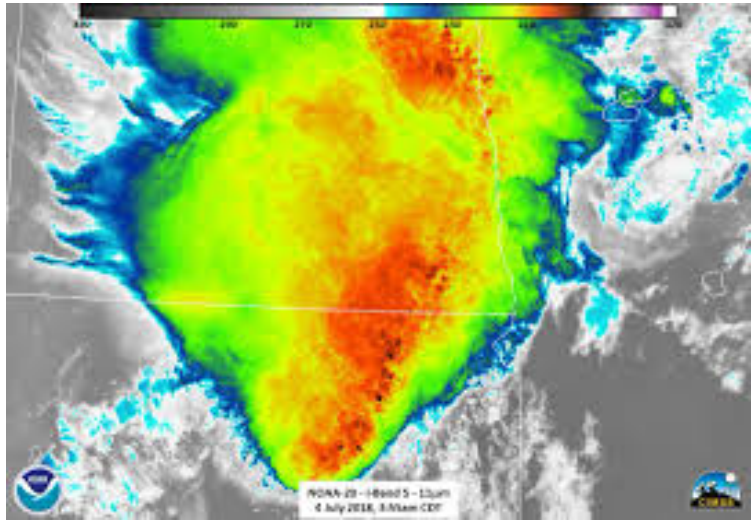
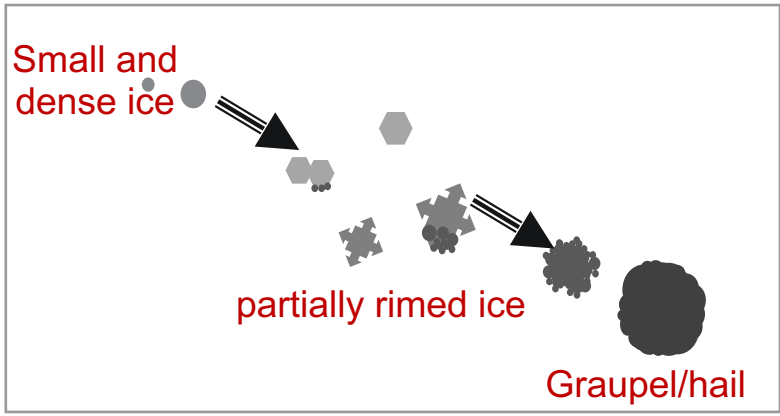
Motivation



- Mesoscale Convective Systems (MCSs) play important role in global hydrological cycle, radiative budget, and circulation. The E3SM regionally refined model (RRM) at 1/4^{o} makes the simulation of MCSs possible.
- E3SM's current cloud microphysics (MG2, Morrison and Gettelman, 2015) has artificial conversion from ice to snow and neglects the rimed particles, which is an important component of deep convection.
- The Predicted Particle Properties (P3) scheme allows for physical evolution of ice particles at local grids by predicting rimed mass and volume

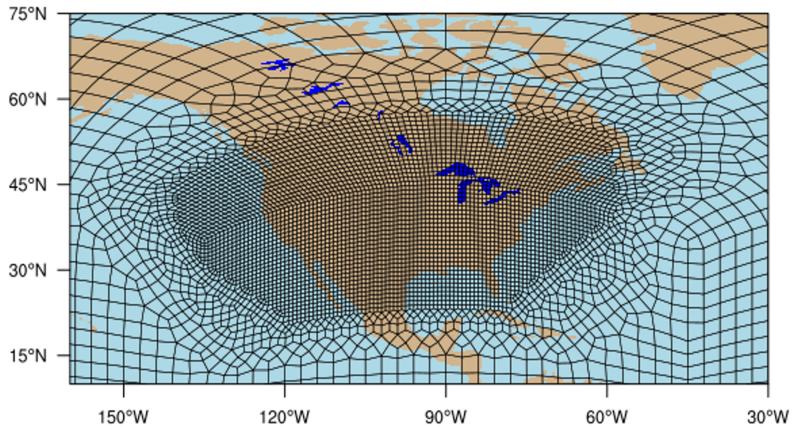
P3



Simulations and Analysis Methods

CONUS RRM ¼ deg

- E3SM v1; Nudged simulations with linear nudging of winds from ERA-Interim
- Ran from Jan. 01 to Sep. 30, 2011
- P3 with the most recent important bug fixes

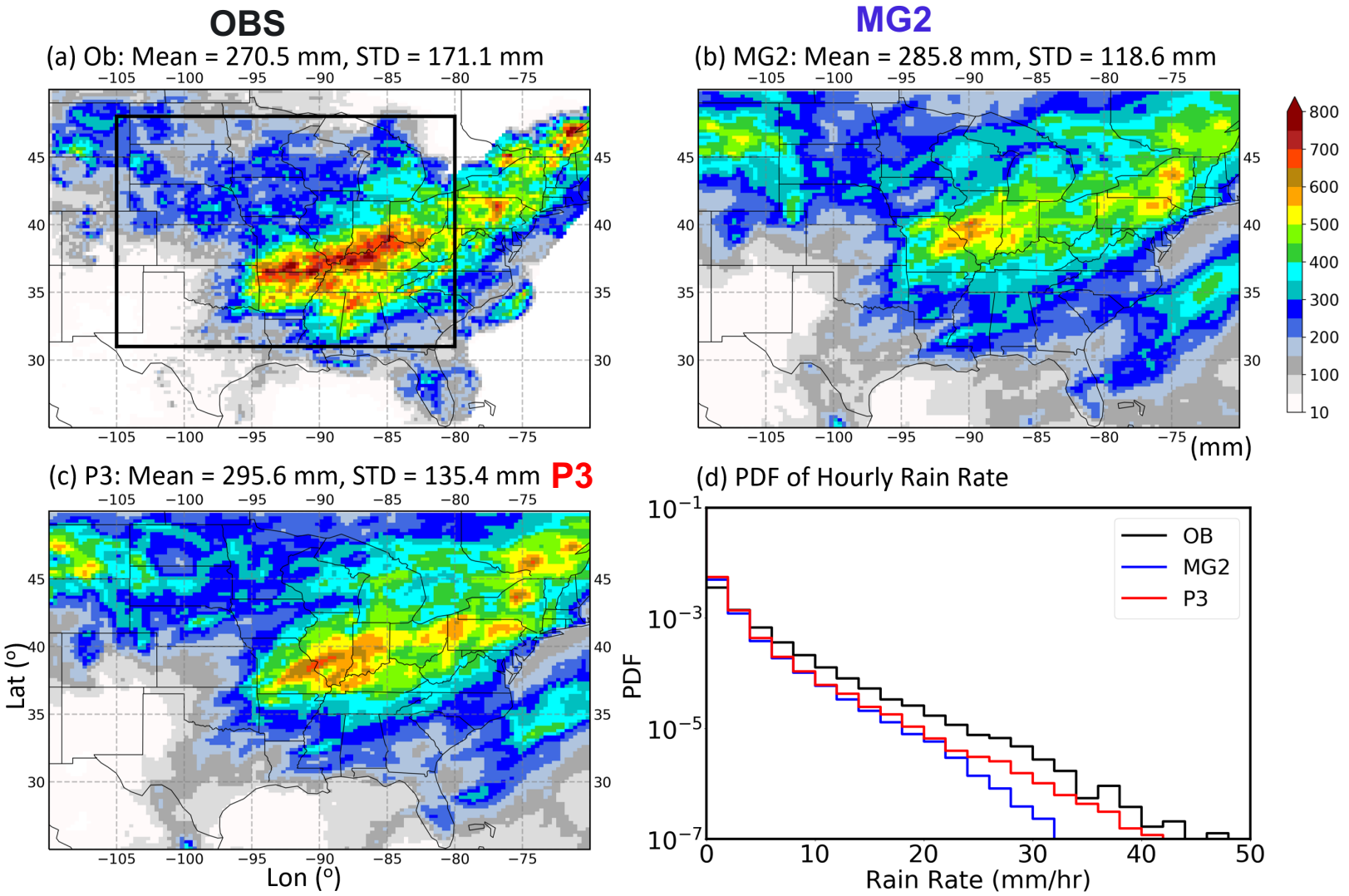


Analysis Methods

- Focused on spring 2011 over Central US.
- Observation data: Stage IV precipitation and MERGIR cloud brightness temperature, both are regridded to 1/4° resolution.
- MCS tracking at ¼ deg (FLEXTRKR, Feng et al. 2020) applied to both observation and model simulations
  - Cold cloud shield exceeds 6×10^4 km^2
  - Area, rain rate, and duration of precipitation features exceed certain thresholds

Total precipitation and PDF of precipitation rate

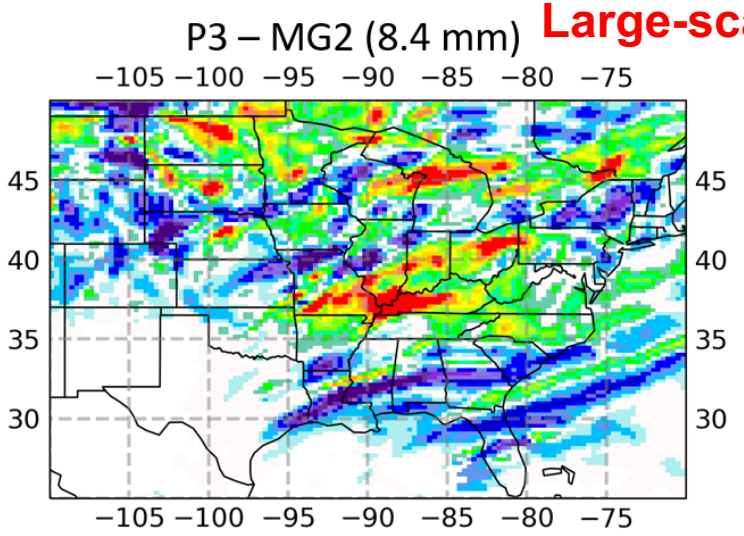
Central US (Mar-May, 2011)

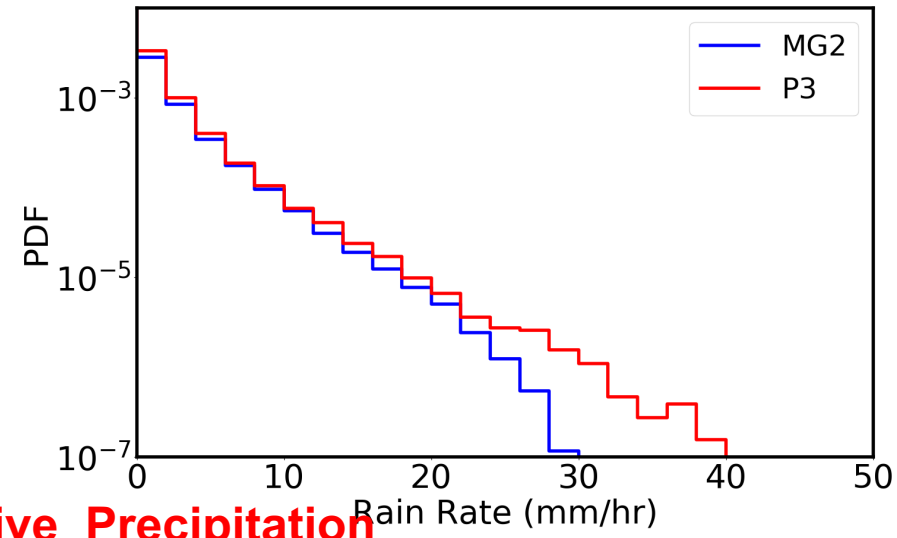


- P3 predicts larger precipitation amount compared with MG2, agreeing better with the Obs
- P3 improves PDF of rain rate significantly by predicting much higher frequencies of large rain rates (> 10 mm/hr).

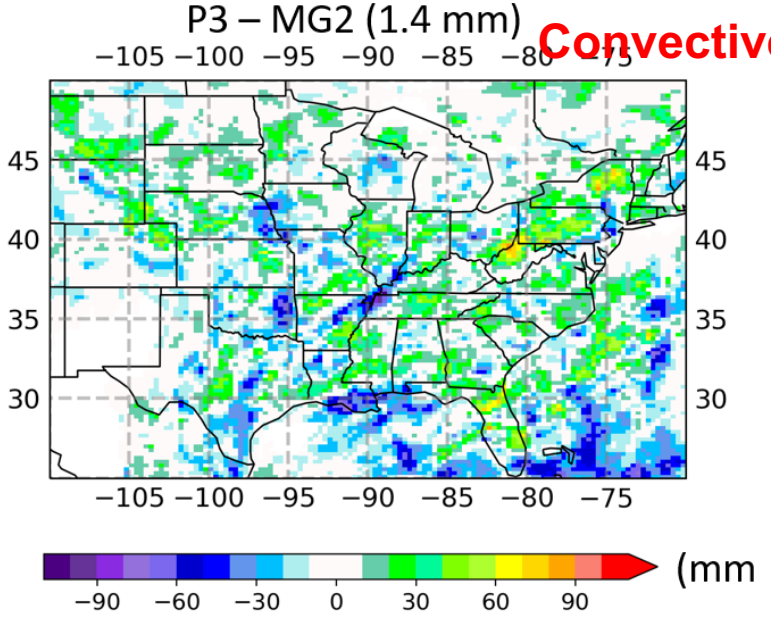
Convective and large-scale precipitation

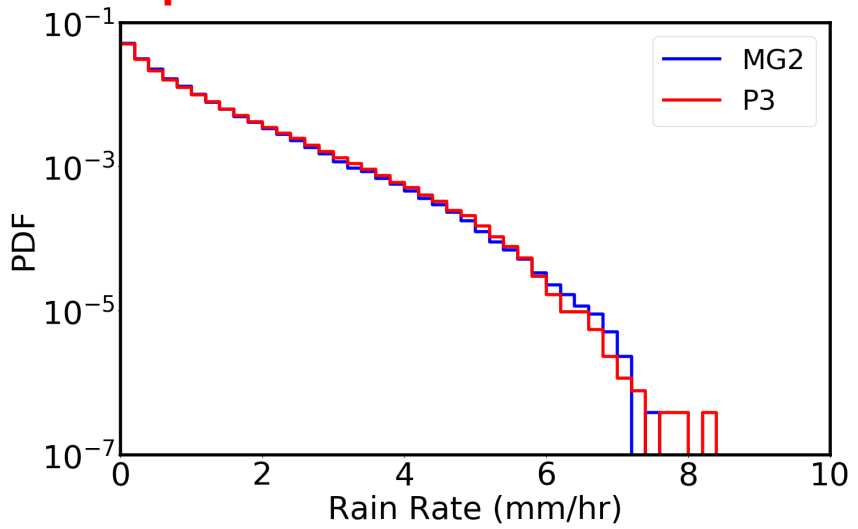
Large-scale Precipitation





Convective Precipitation





- The increase in precipitation and improved rain rate PDF in P3 is mainly in the large-scale precipitation (the resolved part)

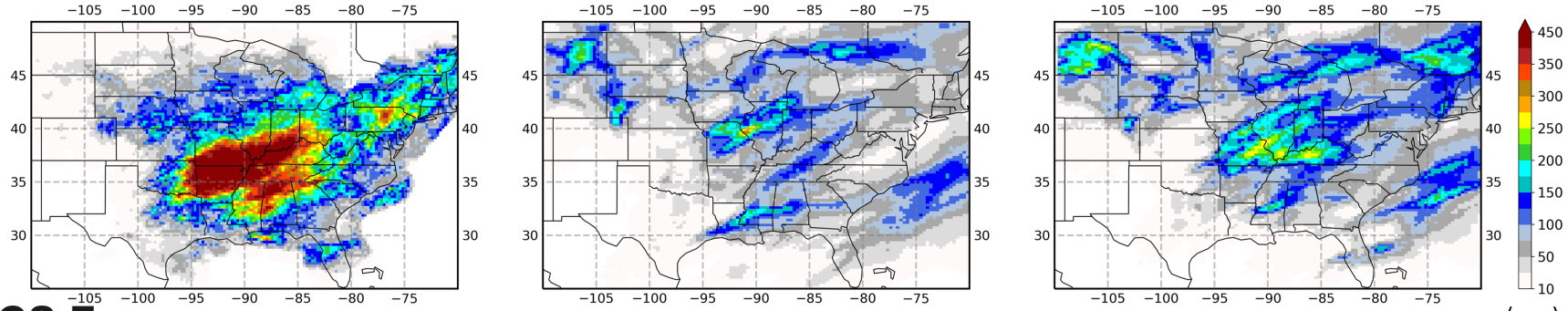
MCS properties

MCS Precipitation

OBS

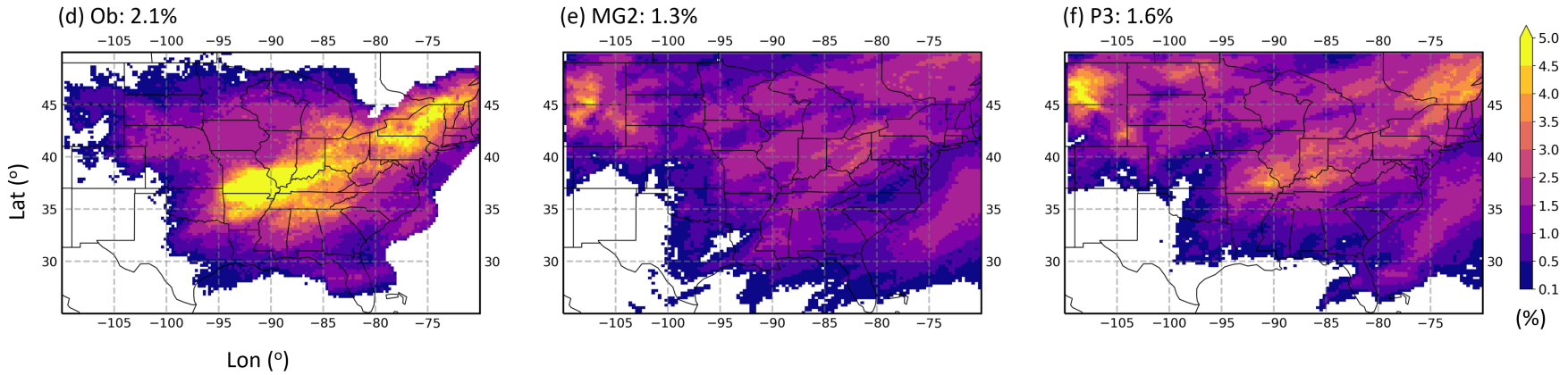
MG2

P3



MCS Frequency

2011 March-May MCS Occurrence Frequency

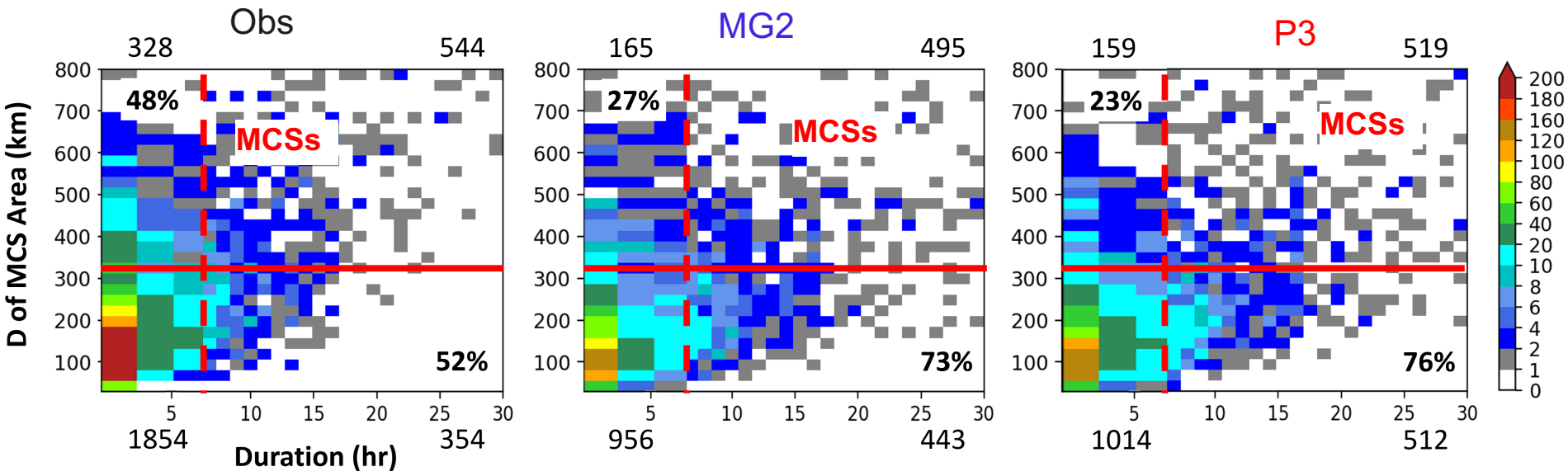


- The model (either MG2 or P3) underestimates MCS precipitation and frequency drastically
- P3 notably improves MCS precipitation and frequency but not large enough to close the gap.

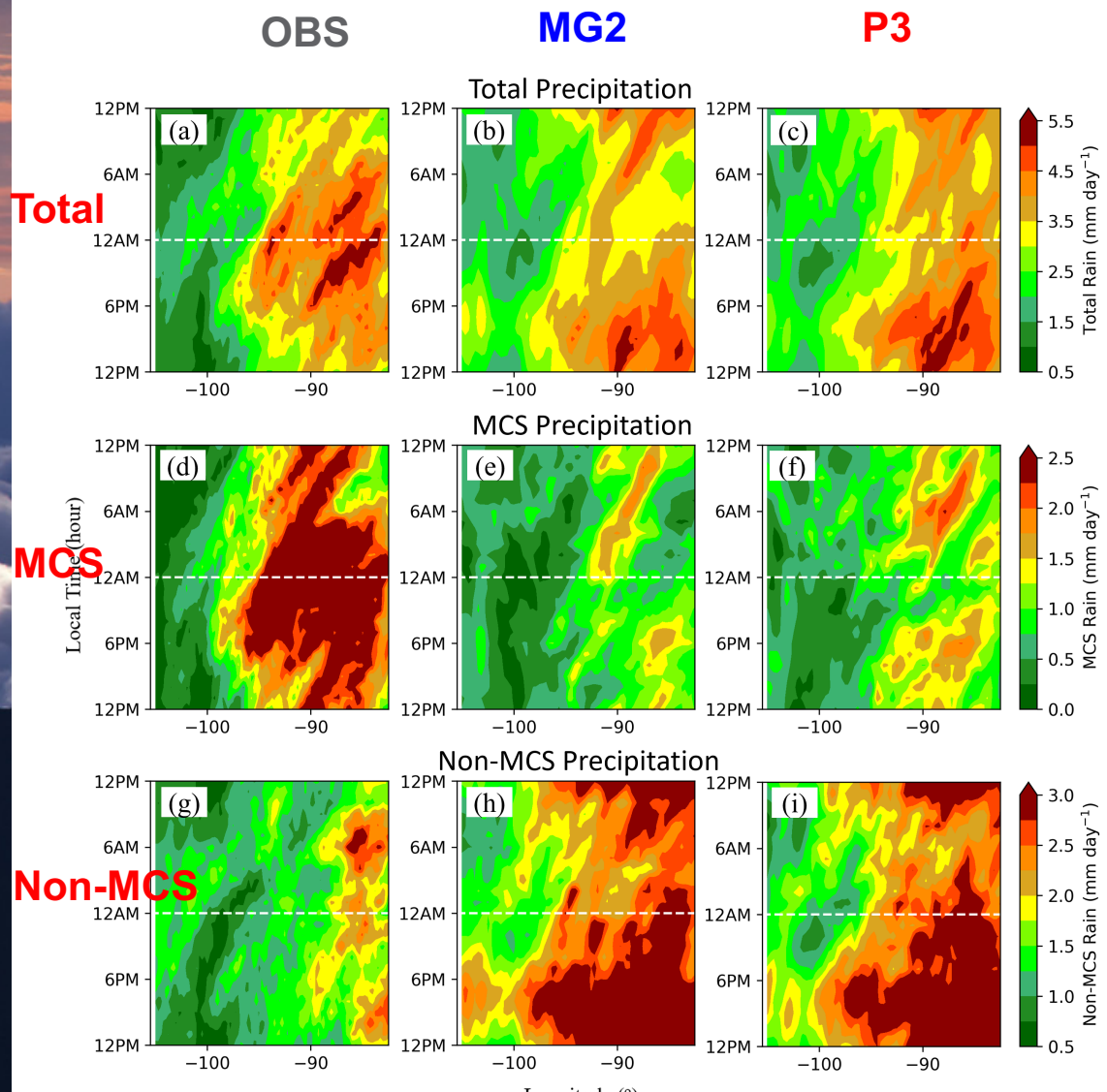
Underestimation of MCS number

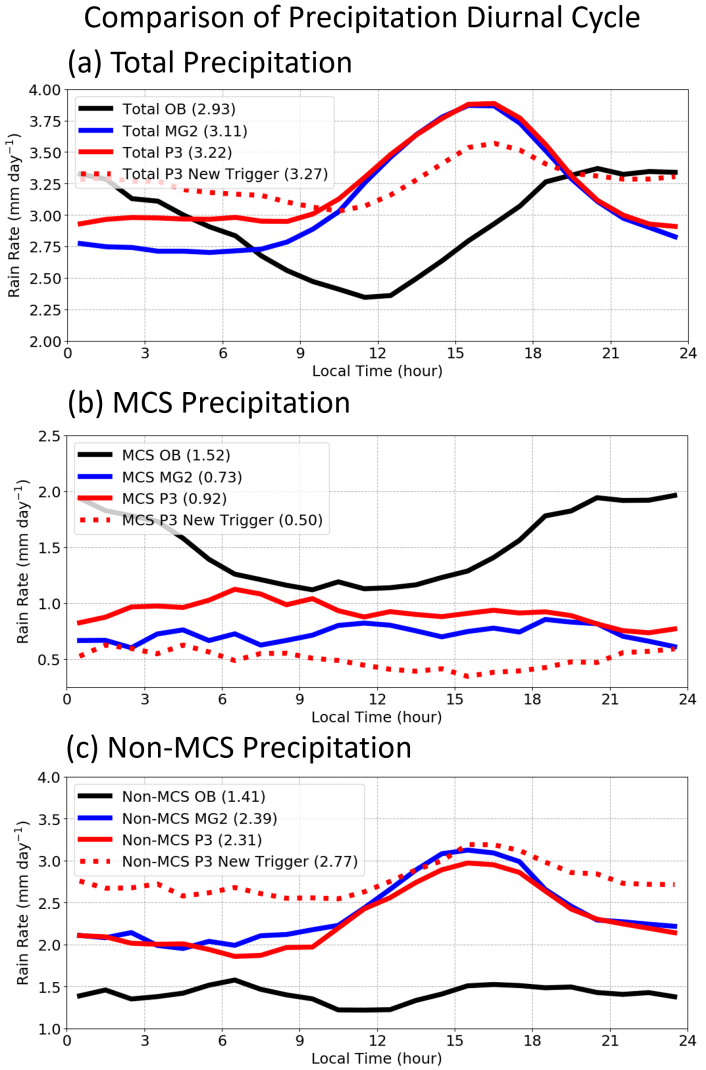
- The model (either MG2 or P3) underestimates MCS number drastically, mainly because simulated systems are too small in size (there are a lot of cases meeting with the duration criteria but failing to meet with the size criteria.
- P3 predicts 19 more MCSs than MG2 due to higher rain rate.

	Obs.	MG2	P3
Number of MCS	113	46	65
Duration (hr)	18.1	26.4	27.2
MCS Diameter (km)	307.8	339.9	333.0



Precipitation diurnal cycle

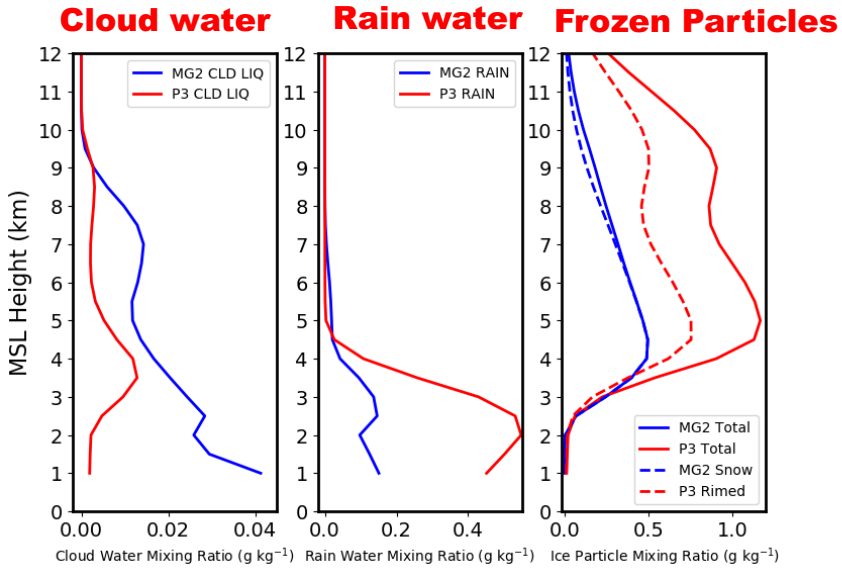




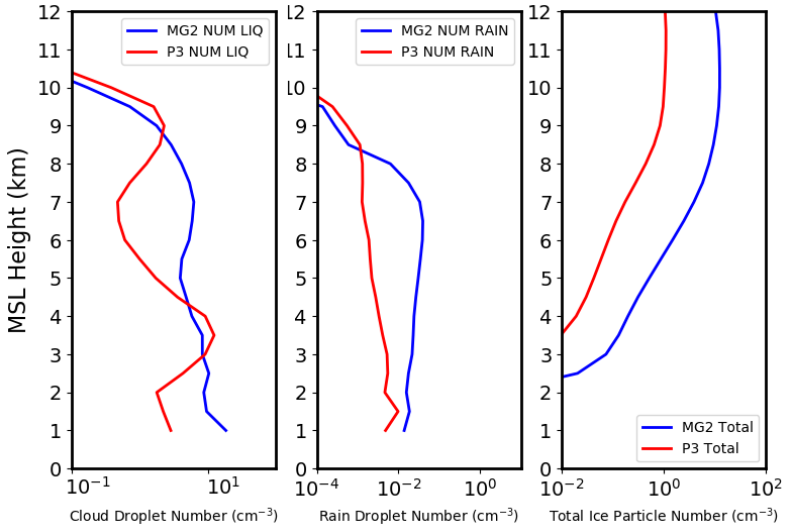
- A large gap still exists between modeled and observed diurnal cycle of precipitation. Might be related to the cumulus parameterization.
- P3 notably improves the nighttime precipitation.
- With the new triggering from Xie et al. (2019), the total precipitation is indeed improved over nighttime, but the MCS precipitation is more underestimated, because rain rates are weaker.

Reasons for improved MCS simulation by P3

Mass (g kg^{-1}) for rain rate >10 mm/hr

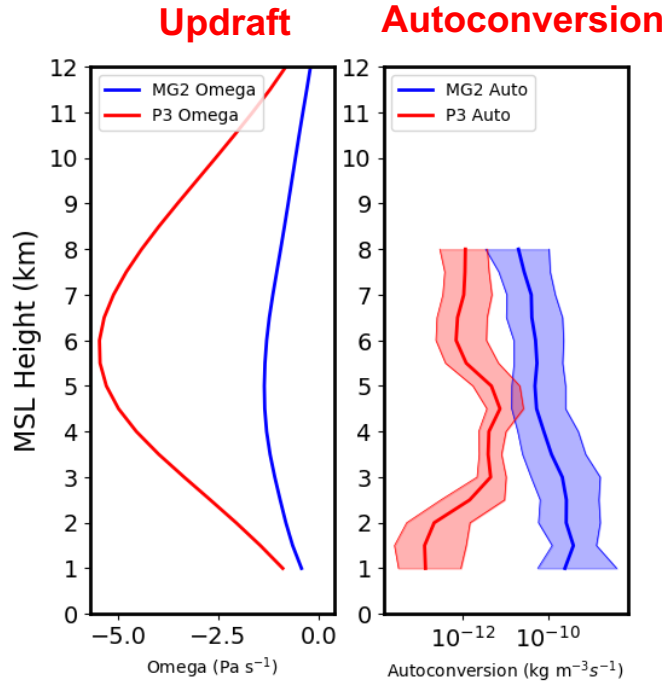


Number (cm^{-3})



- P3 simulates much larger rain mass and smaller raindrop number, thus a much larger mean raindrop size and larger rain rates.
- Larger rain mass is mainly due to much larger cloud ice mass and rimed mass, as a result of different deposition parameterization and added riming.
- Lower raindrop number in P3 is mainly due to smaller autoconversion rate.

- We see much larger upward and descending motions in P3, suggesting a strong feedback of the modified microphysics to dynamics in P3, which also leads to enhanced precipitation .



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Summary

- **With RRM ¼ deg, E3SM drastically underestimates the MCS precipitation, mainly because the convective system sizes are too small.**
- **The more physically advanced P3 scheme improves precipitation PDF, and MCS number and precipitation by predicting higher frequencies of large rain rates.**
- **The larger rain rates in P3 mainly comes from larger masses of precipitating ice (added riming process).**
- **The change in microphysics has a notable feedback to the dynamics, resulting in stronger vertical motions, leading to larger rain rates as well.**

Future work

Evaluate MCSs in E3SM v2 with P3 at the global uniform 25 km simulations