

# Impact of the P3 Cloud Microphysics on Simulation of Mesoscale Convective Systems in E3SM Regionally Refined Model (RRM)

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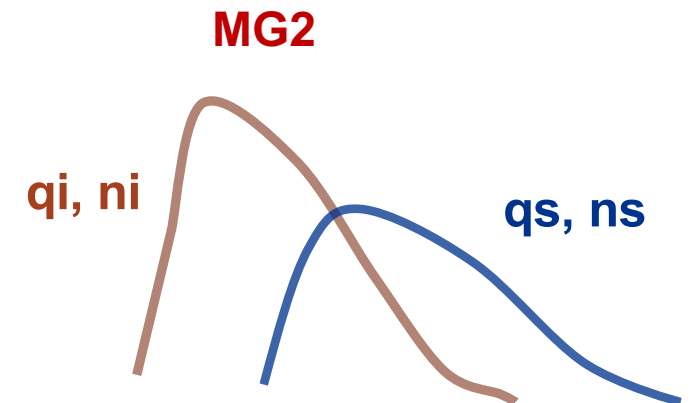
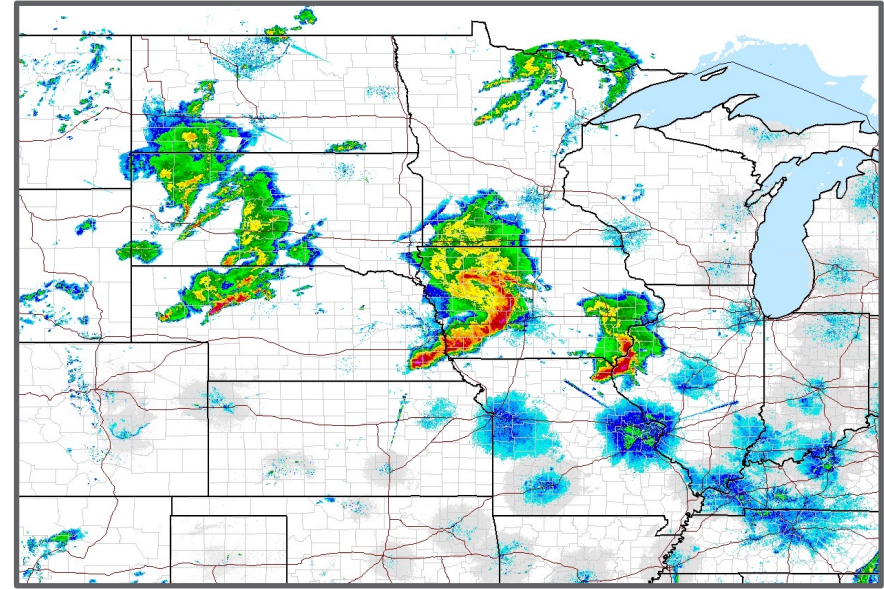
Acknowledgement:

- DOE CMDV and E3SM Programs

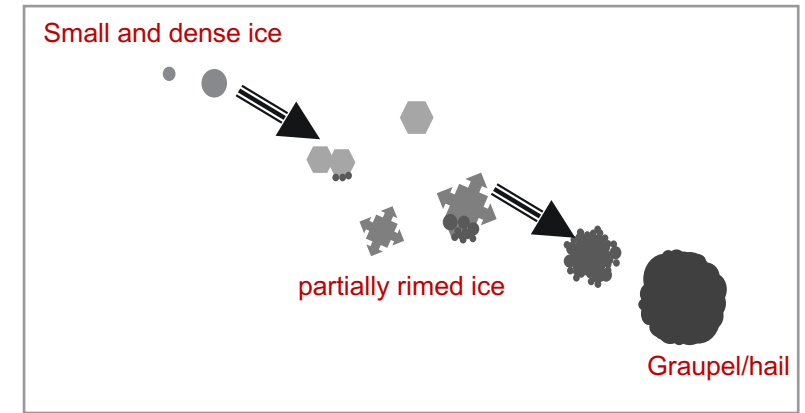
# Motivation

- ▶ Mesoscale Convective Systems (MCSs) play important roles in global hydrological cycle, radiative budget, and circulation. It is difficult to simulate in GCMs because of coarse resolutions. The regionally refined model (RRM) at  $1/4^\circ$  makes the simulation of MCSs possible.
- ▶ Cloud microphysics is one of the most poorly represented physics in GCMs. Microphysics parameterization in the released E3SM follows MG2 (Gettelman & Morrison, 2015). Limitations:
  - The artificial conversion from ice to snow
  - Neglects the rimed particles that are important hydrometeors in convective systems.

Mesoscale Convective Systems (MCSs)



- ▶ The Predicted Particle Properties (P3) scheme (Morrison & Milbrandt, 2015) addresses both limitations
- Ice particles are predicted and evolved locally, removing the artificial conversion (also means less predefined parameter and thresholds).
- Rimed particles are considered by predicting rimed mass and volume
- 8 prognostic variables ( $Q_c$ ,  $N_c$ ,  $Q_r$ ,  $N_r$ ,  $Q_i$ ,  $N_i$ ,  $Q_{rim}$ ,  $B_{vrim}$ ) same as MG2 ( $Q_c$ ,  $N_c$ ,  $Q_r$ ,  $N_r$ ,  $Q_i$ ,  $N_i$ ,  $Q_s$ ,  $N_s$ )





## P3 in E3SM

Implementation of P3 into E3SM: (a) subgrid variability in microphysical process rates, (b) cloud fraction, and (c) scaling some tendency terms.

- ▶ The initial implementation of P3 into E3SM was under CMDV-MCS project (done by K. Zhang).
- ▶ Later, SCREAM team refactored P3 and implemented into E3SM.
- ▶ Under NGD project, we merged with the refactored P3 to have a single P3 code base, then debugged and evaluated it (by K. Shpund). The code is being used for the convective assessment task and being evaluated for v3 release.
- ▶ This study still used the version developed under CMDV-MCS project. A couple of bugs found from the NGD project were applicable to this version and were fixed.

Some features about the E3SM-P3 we used in this study

- Heterogenous ice nucleation still follows original P3 – Bigg 1953 for immersion freezing and Cooper (1986) for deposition nucleation, **different from CNT used in our P3 under NGD project.**
- Homogenous aerosol freezing for cirrus clouds (Liu and Penner (2005))
- Corrected the aqueous chemistry bug: total condensate mass was changed to liquid water content, leading to smaller aerosol loading

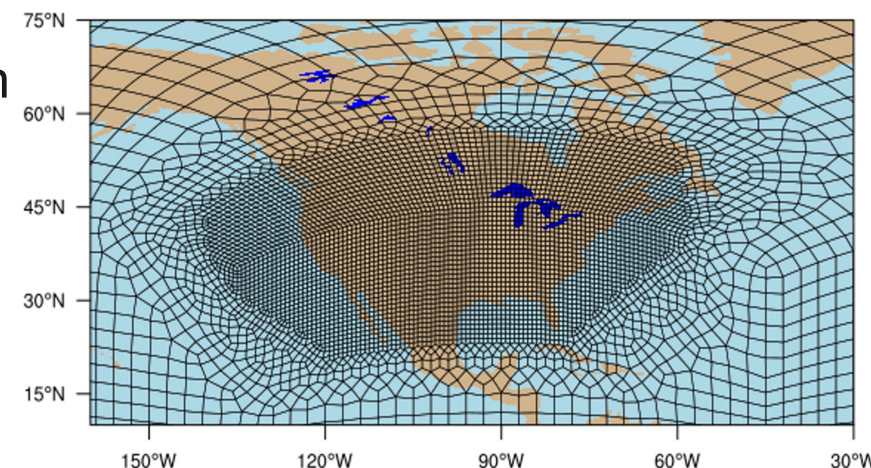
# Simulations and Analysis Methods

## ► CONUS RRM 1/4 deg

- E3SM v1 with some updates of v2; Nudged simulation with linear nudging of winds from ERA-Interim
- Ran from Jan. 01 to Sep. 30, 2011

## ► Analysis Methods

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

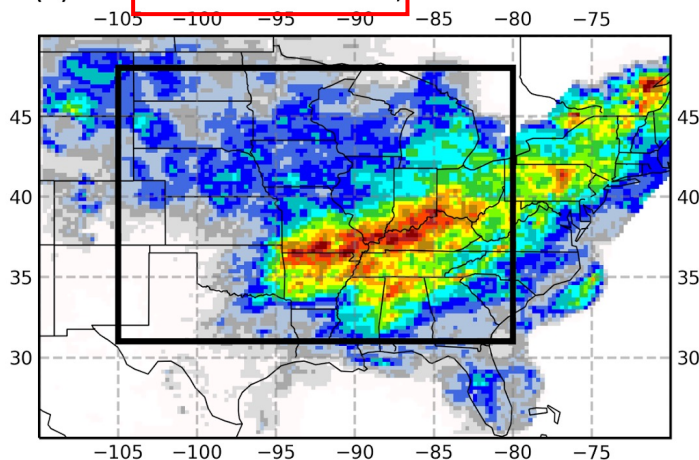


# P3 improves precipitation and PDF of rain rate

Central US (Mar-May, 2011)

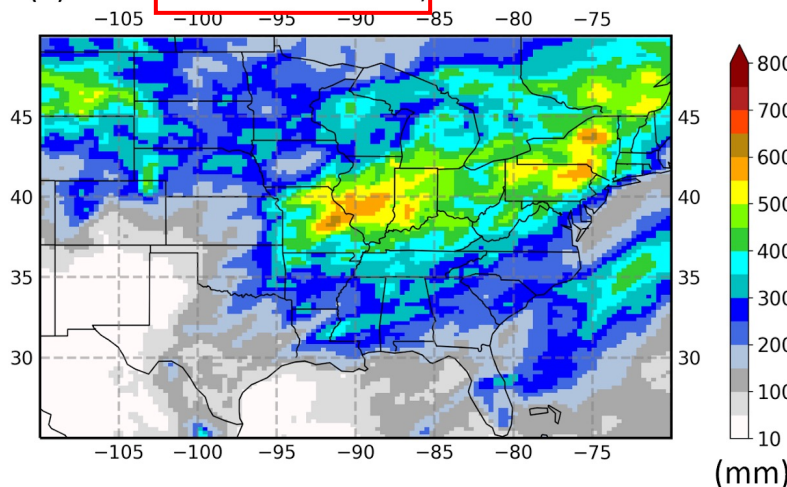
**OBS**

(a) Ob: Mean = 270.5 mm, STD = 171.1 mm



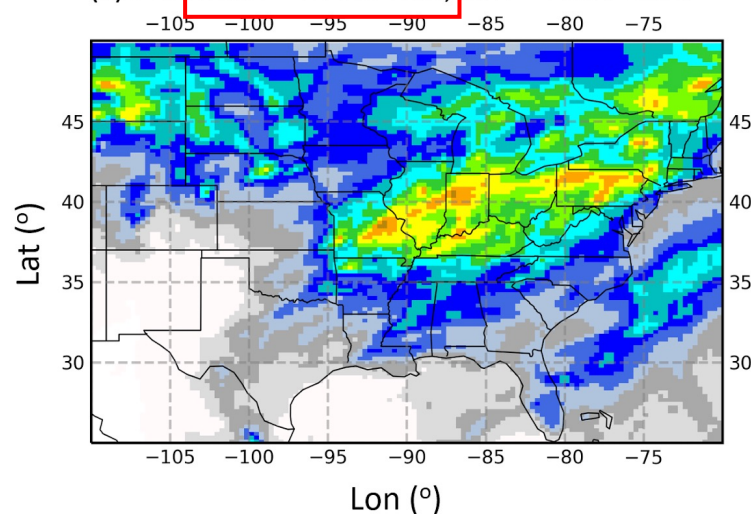
**MG2**

(b) MG2: Mean = 286.0 mm, STD = 119.8 mm

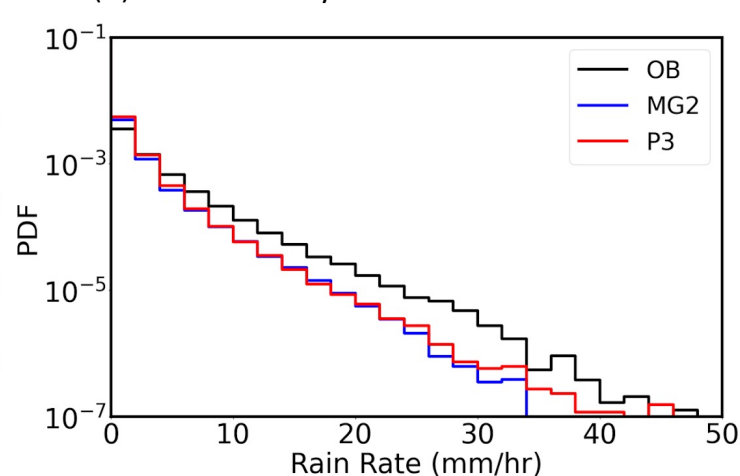


**P3**

(c) P3: Mean = 279.6 mm, STD = 130.1 mm



(d) PDF of Hourly Rain Rate



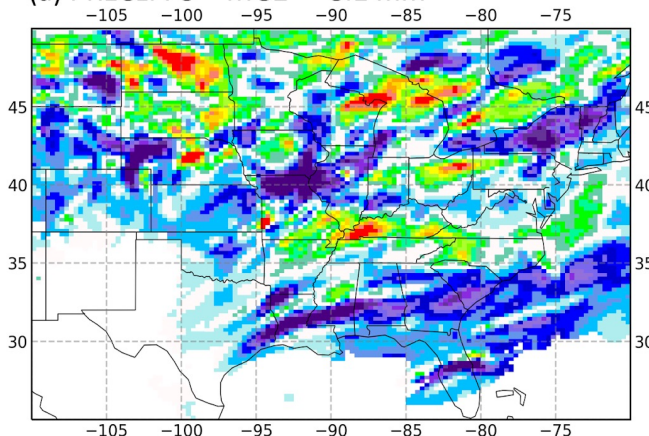
- Both P3 and MG2 overestimate the mean precipitation but P3 has lower biases
- P3 improves PDF of rain rate significantly by predicting higher frequencies of large rain rates (> 30 mm/h). Capture rain rates larger than 45 mm/h



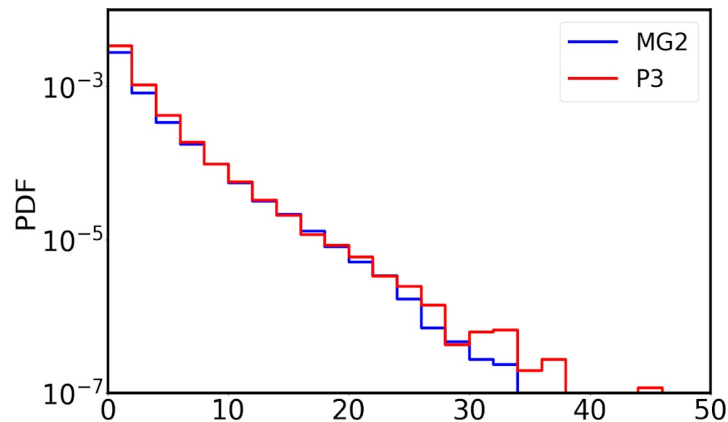
# The improvement mainly comes from the large-scale precipitation

## Large-scale Precipitation

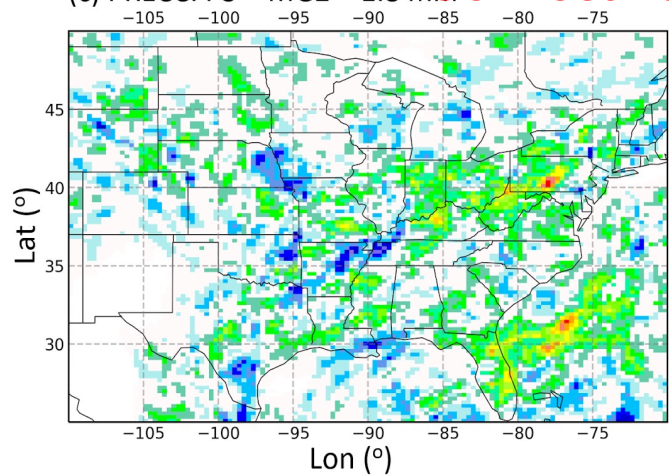
(a) PRECL: P3 – MG2 = -8.1 mm



(b) PDF of Hourly PRECL Rain Rate

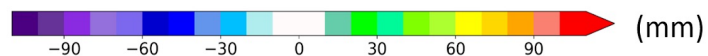
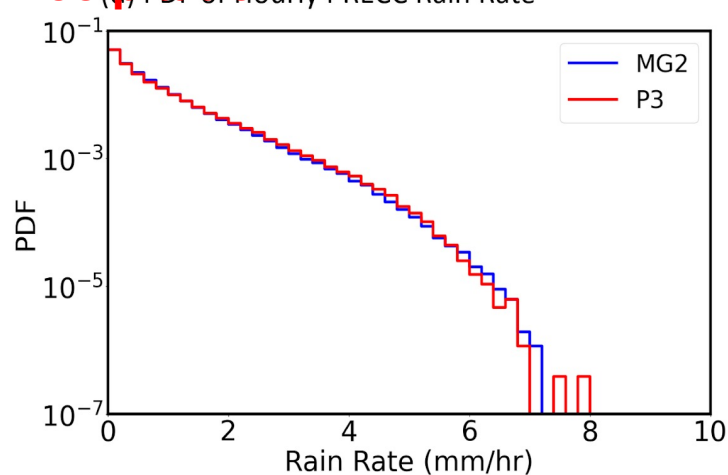


(c) PRECC: P3 – MG2 = 1.8 mm

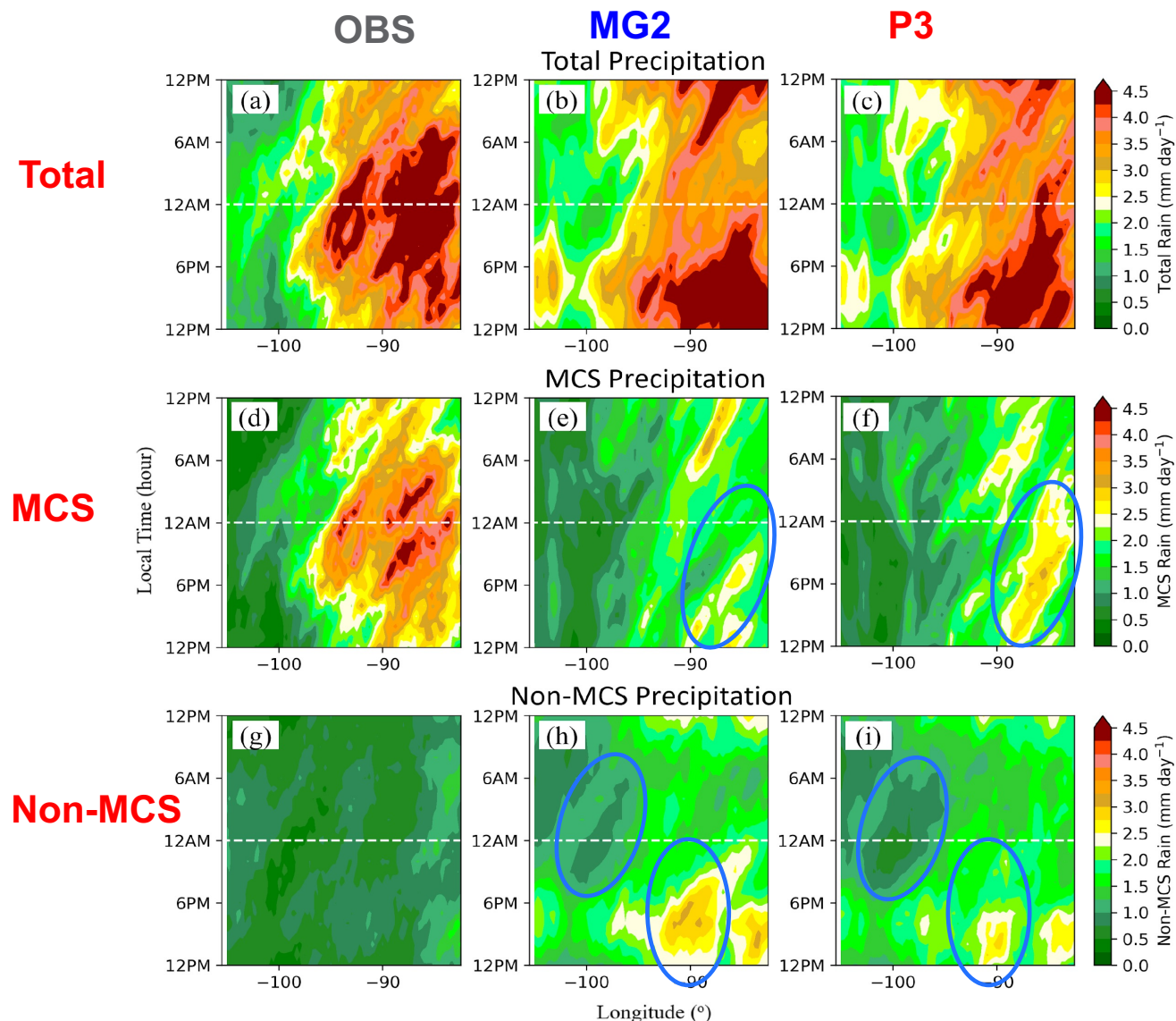


## Convective Precipitation

(d) PDF of Hourly PRECC Rain Rate



# P3 improves MCS precipitation but does not improve the diurnal cycle



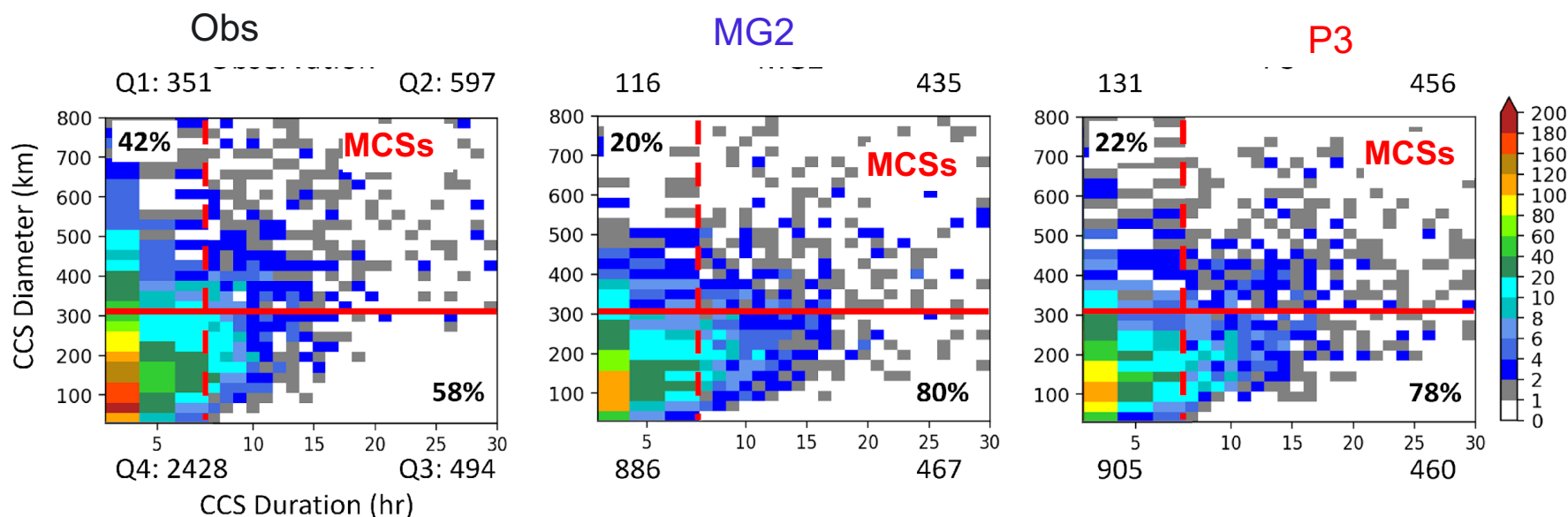
- P3 predicts less morning and afternoon precipitation but more nighttime precipitation, closer to obs.
- P3 simulates more MCS precipitation (over 20% in some locations) and less non-MCS precipitation; improves both.
- The changes are encouraging but not large enough to shift the phase of diurnal cycle.



# P3 improves MCS number but still has a large low bias

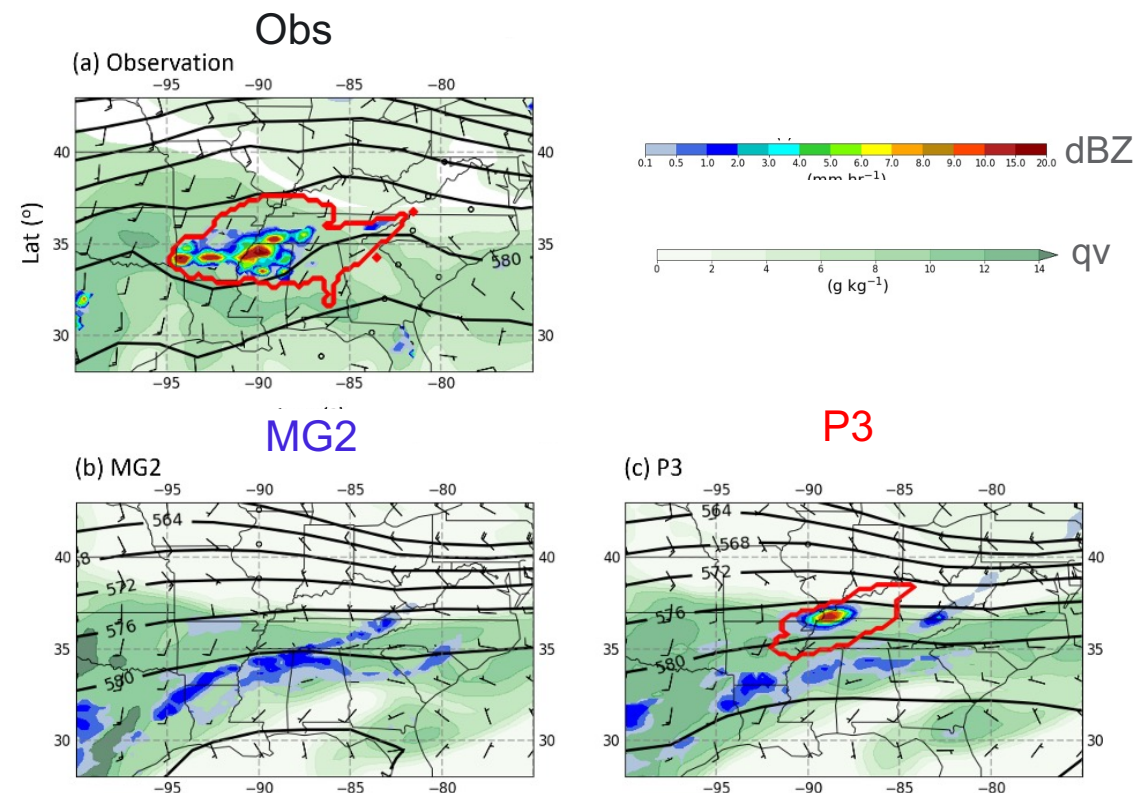
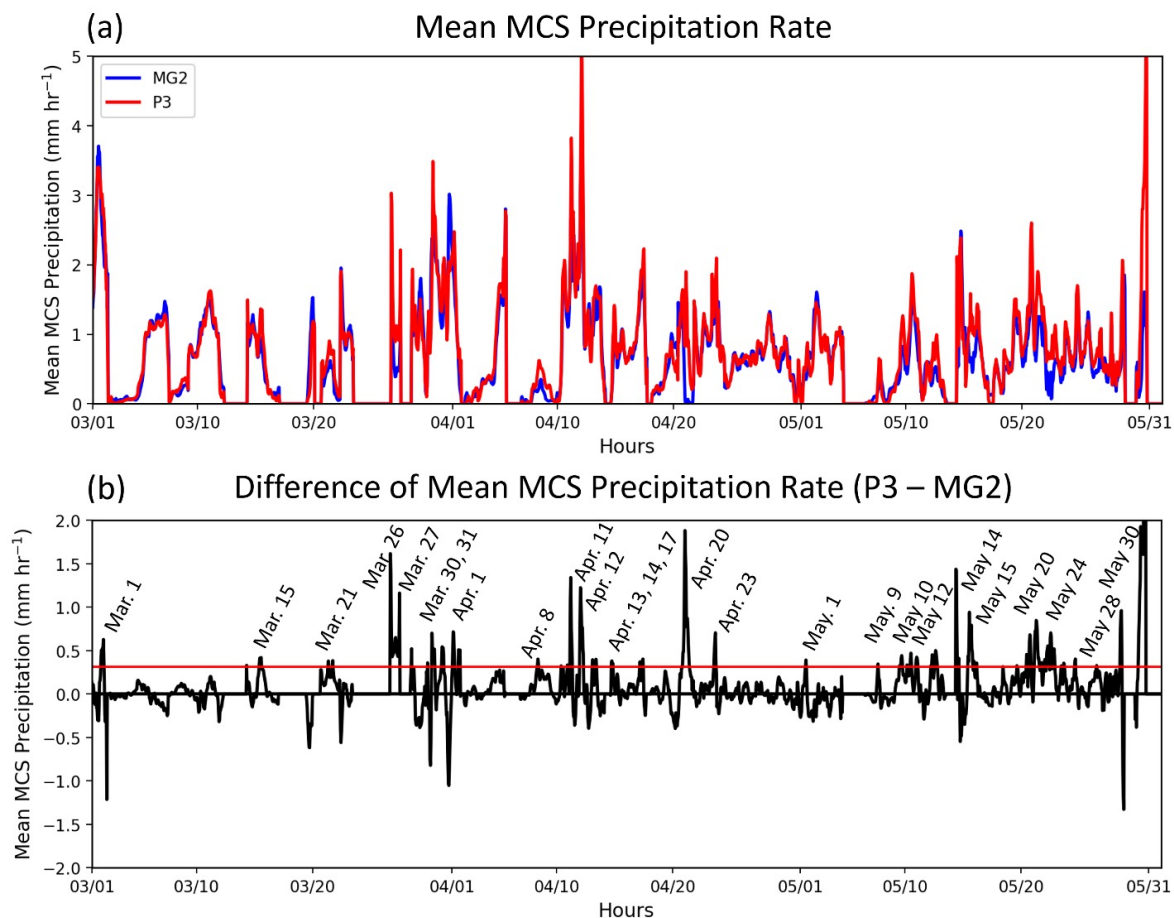
- The model (either MG2 or P3) underestimates MCS number drastically, mainly because simulated systems are too small in size
- P3 predicts 11 more MCSs than MG2 due to higher rain rate. This is significant for one spring season.

	Obs.	MG2	P3
Number of MCS	122	56	67
Duration (hr)	28.6	44.6	39.1
MCS Diameter (km)	625.1	597.2	577.2



# P3 simulates higher precipitation rates thereby more MCSs

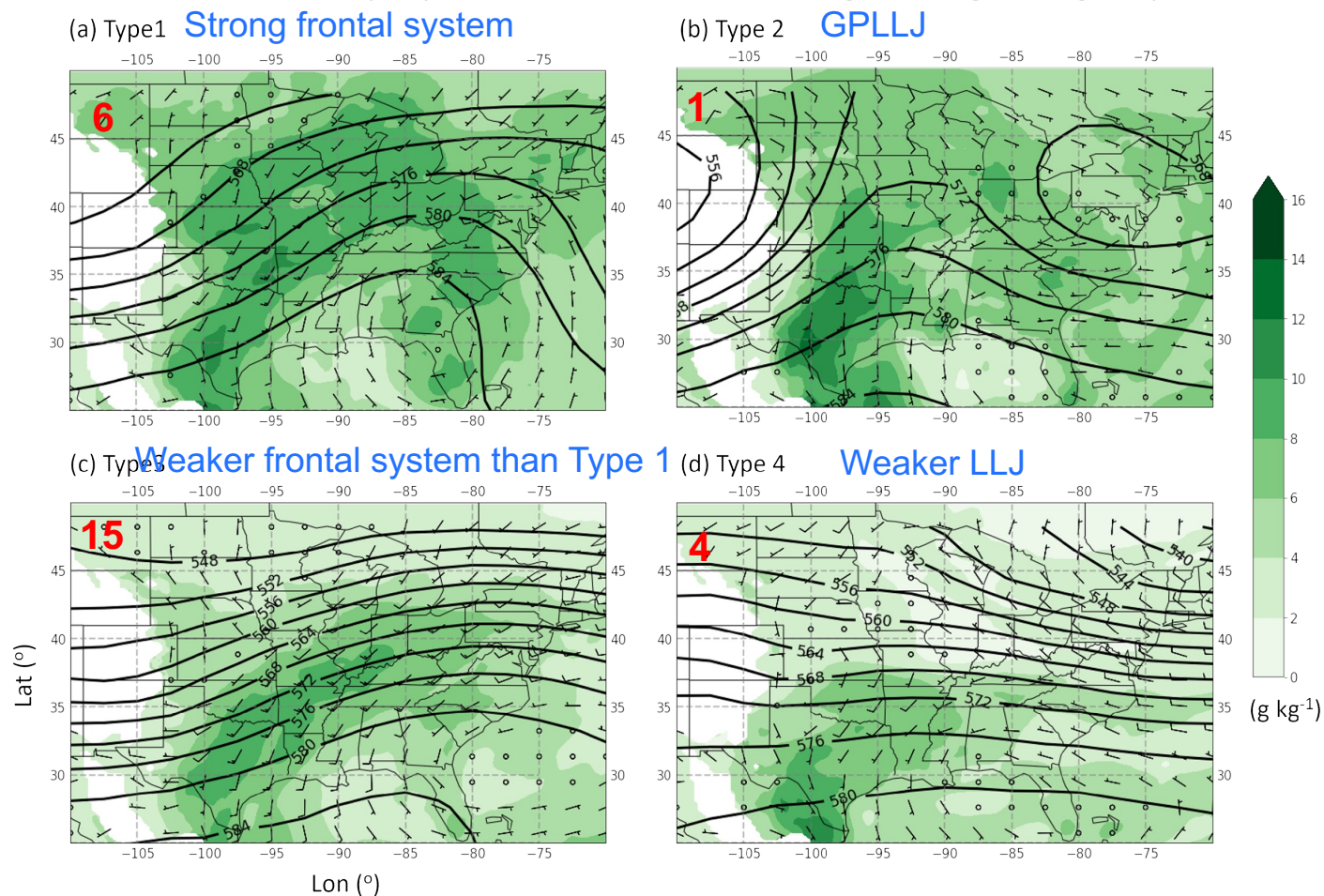
Example of MCS Simulation on 21 April 2011, 00:00 UTC



# Missed MCSs by MG2 are mainly from large frontal systems with broad stratiform precipitation area

- There are 26 time periods when MG2 has drastic lower MCS precipitation.
- From the long-term (2004-2016) self-organizing maps (SOMs, Song et al., 2019) analysis, four major types of synoptic patterns of MCS initiation are identified.
- The majority of the MG2-missed events occur under Type 1 and Type 3, which are associated with large frontal systems featuring broad stratiform precipitation.

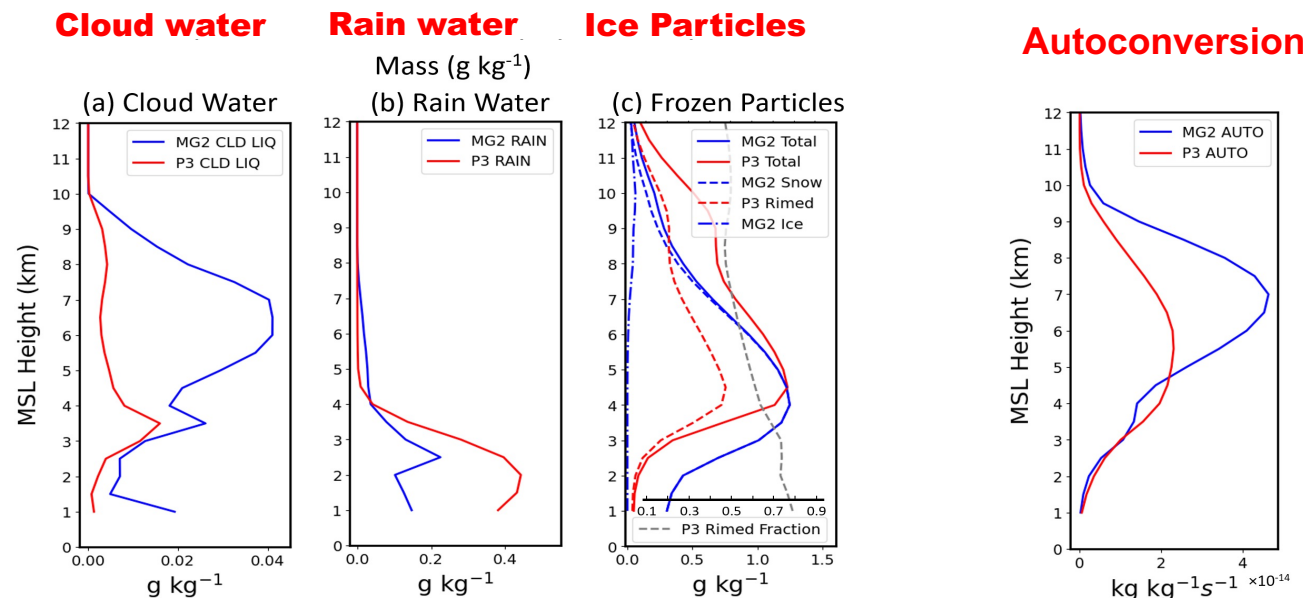
MCS-related Synoptic Patterns Extracted Using Self-organizing Map



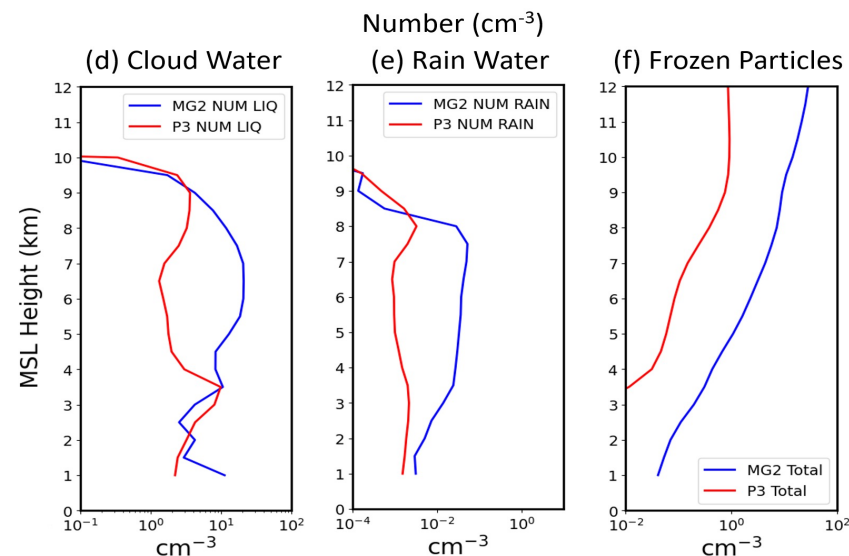


# Reasons for larger precipitation rates by P3

**Mass for rain  
rate >10 mm/hr**



**Number (cm<sup>-3</sup>)**

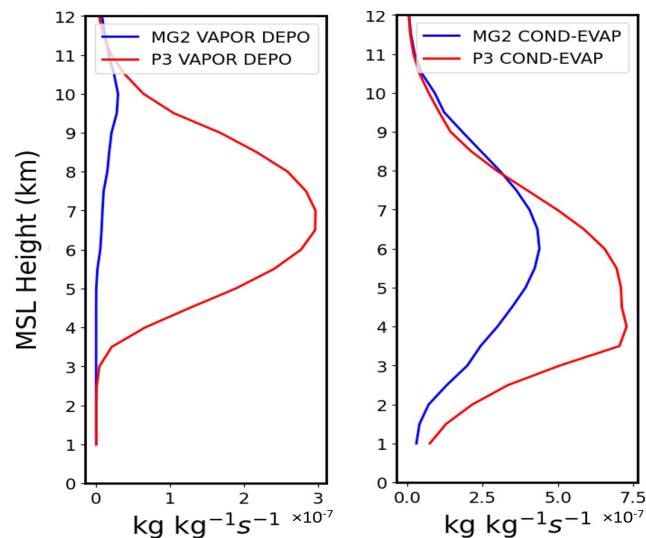


- P3 simulates much larger rain mass and lower raindrop number, explaining larger precipitation rates.
- This is because of much larger ice particle mass content (40%) with decreased ice particle number, since warm rain formation rates are much smaller in P3.
- Rimed ice mass contributes to ~50-60% of the total ice mass, indicating deposition growth contributes to increased non-rimed ice mass.

# Stronger feedback of microphysics to dynamics

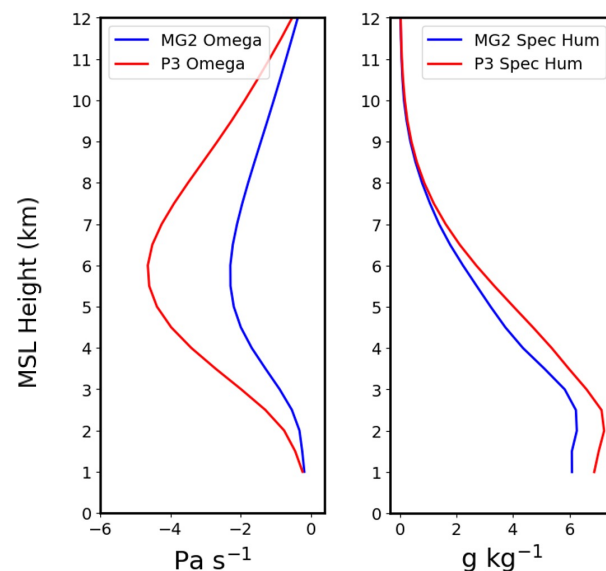
## Deposition

## Condensation+evaporation



## Subsidence

## Specific humidity



- The deposition rates are several times larger in P3, mainly because the deposition in P3 is treated for total ice whereas is only treated for cloud ice not snow in MG2
- Added riming and enhanced deposition release more latent heat and feedback to circulation, enhancing large-scale convergence, further enhancing condensation and deposition.

## Summary

- ▶ The new microphysics P3 employed in E3SM improves the simulation of precipitation particularly PDF of precipitation rates
- ▶ P3 improves the simulation of MCS number and precipitation by predicting higher frequencies of large rain rates, which mainly comes from increased ice mass due to added riming and enhanced deposition
- ▶ Notable microphysics-dynamics feedback is shown: the latent heat from added riming and enhanced deposition induces strong convergence.
- ▶ The missed MCSs by MG2 but captured by P3 are mainly associated with large frontal systems with broad stratiform precipitation area.

## Current work

- Under NGD, we are evaluating aerosol forcing particularly aerosol-cloud interaction forcing for the latest E3SM with P3 (E3SM v2 + P3 + aqueous chemistry bug fix + ZM\_micro)