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Modeling Mesoscale Convective Systems and their Large-Scale Environments

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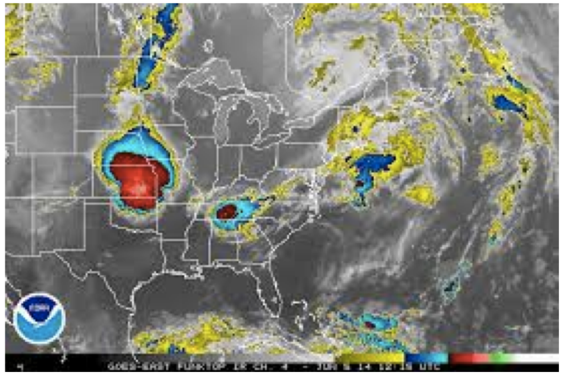
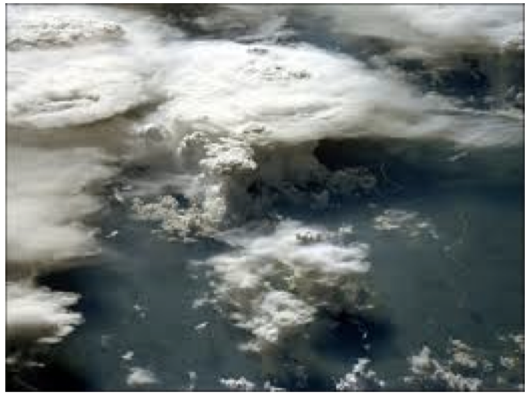
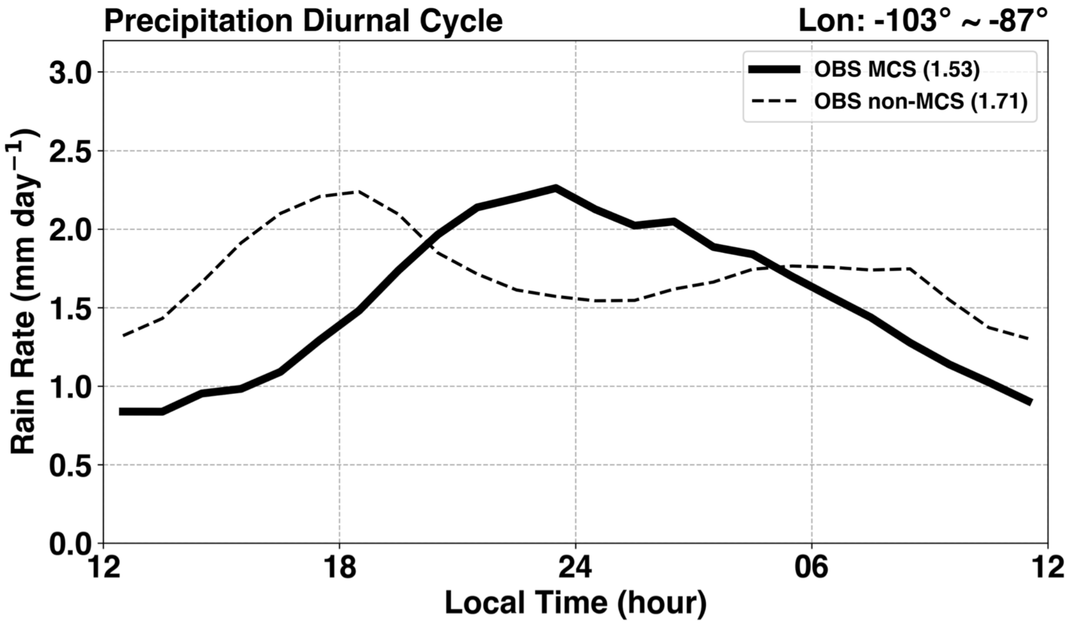
U.S. DEPARTMENT OF ENERGY

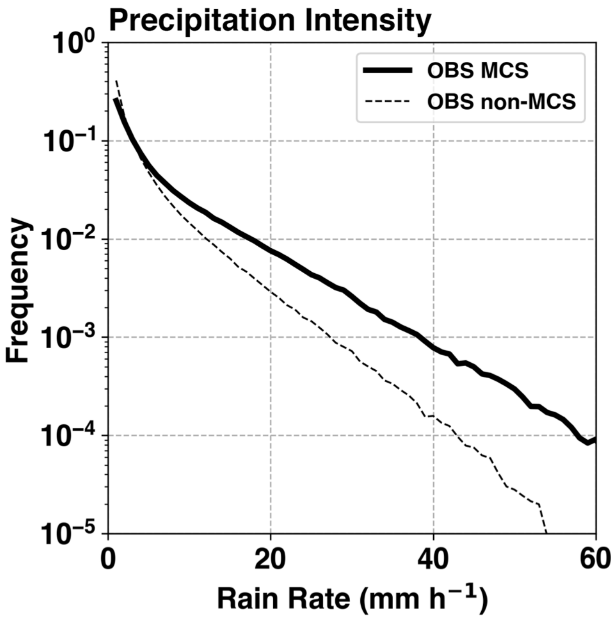
Characteristics of mesoscale convective systems

- A mesoscale convective system (MCS) is a contiguous cumulonimbus cloud complex with horizontal dimensions of 100s to 1000s km and lasts up to ~10-24 h
- MCSs have distinct characteristics compared to non-MCS precipitation events
- Past (Feng et al. 2016) and projected future (Prein et al. 2017) changes motivated more efforts to model MCSs





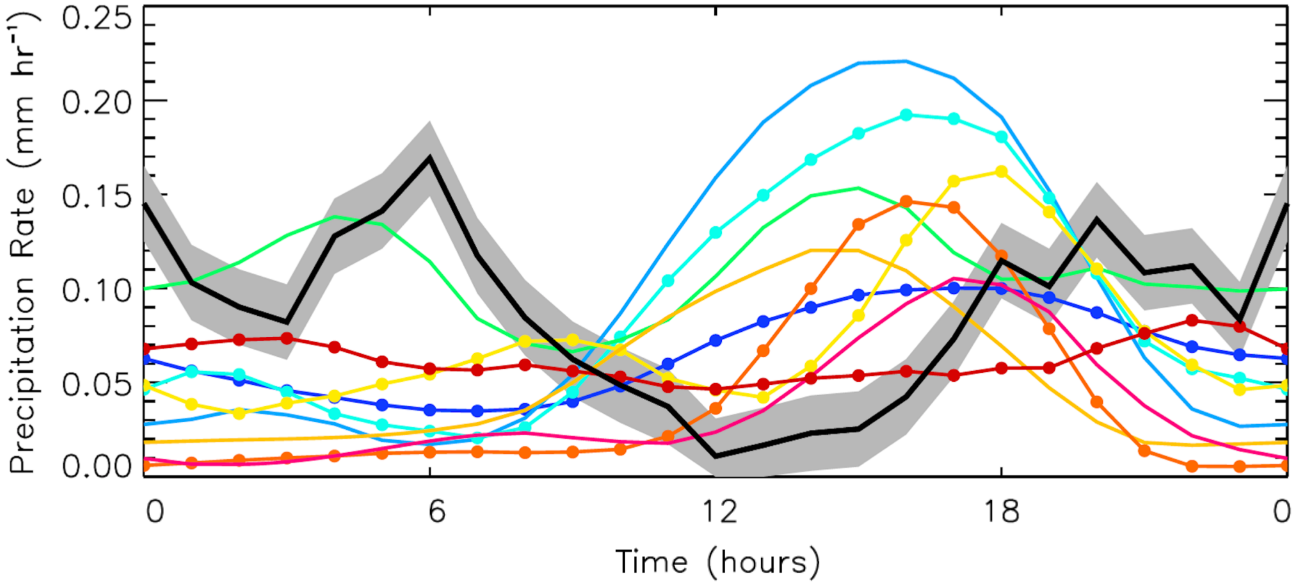




Challenges for climate modeling

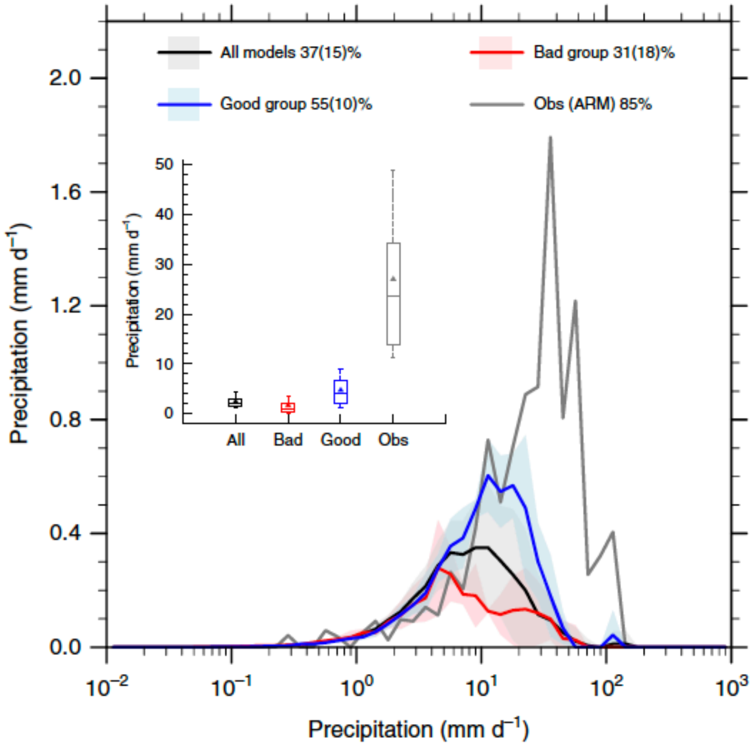
- Climate models with parameterized convection exhibit significant biases in simulating precipitation (mean, diurnal cycle, intensity) and surface temperature

Diurnal cycle of precipitation in central U.S.



(VanWeverberg et al. 2017 *JGR-A*)

Daily precipitation distribution

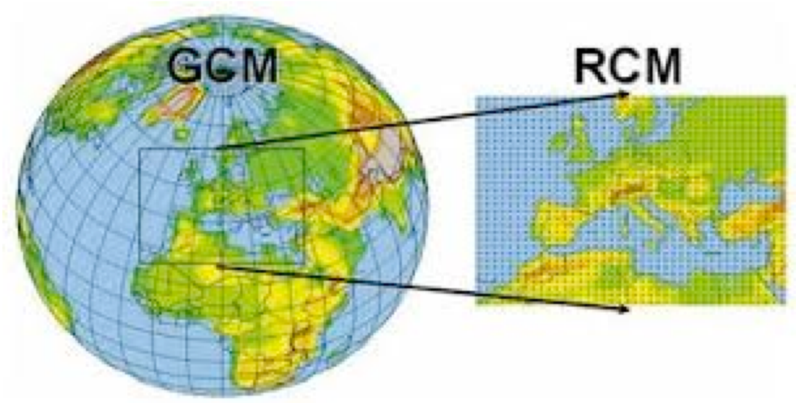


(Lin et al. 2017 *Nat. Commun.*)

Modeling MCSs in climate models

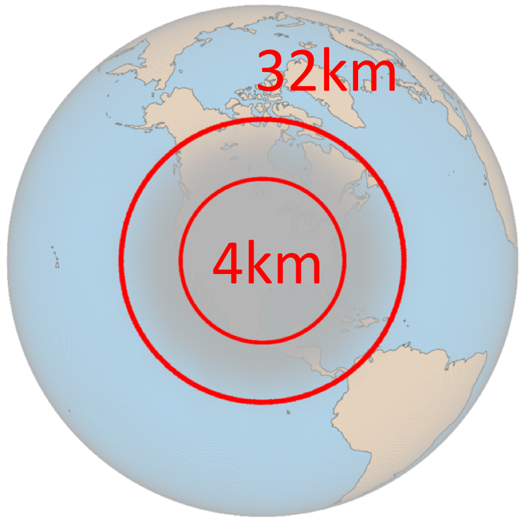
- Three modeling approaches with computational requirements within reach for climate simulations:

Limited area models



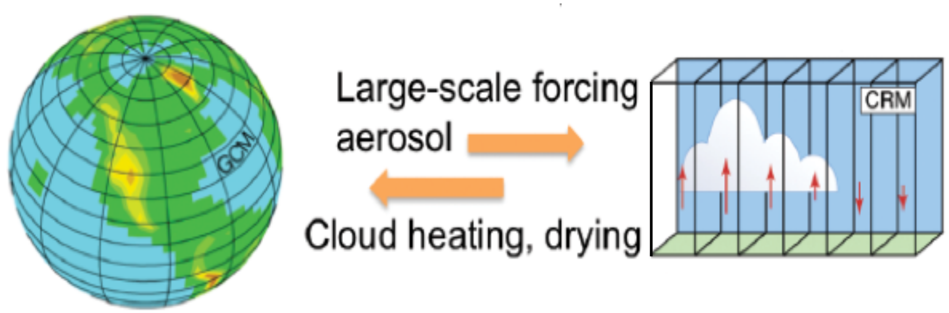
Weather Research and Forecasting (WRF)

Global variable resolution models



Model for Prediction Across Scales (MPAS)

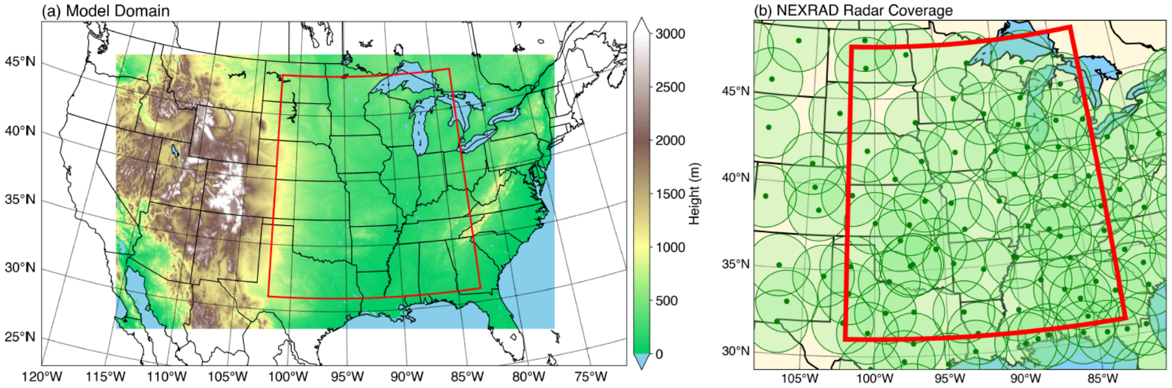
Multiscale Modeling Framework



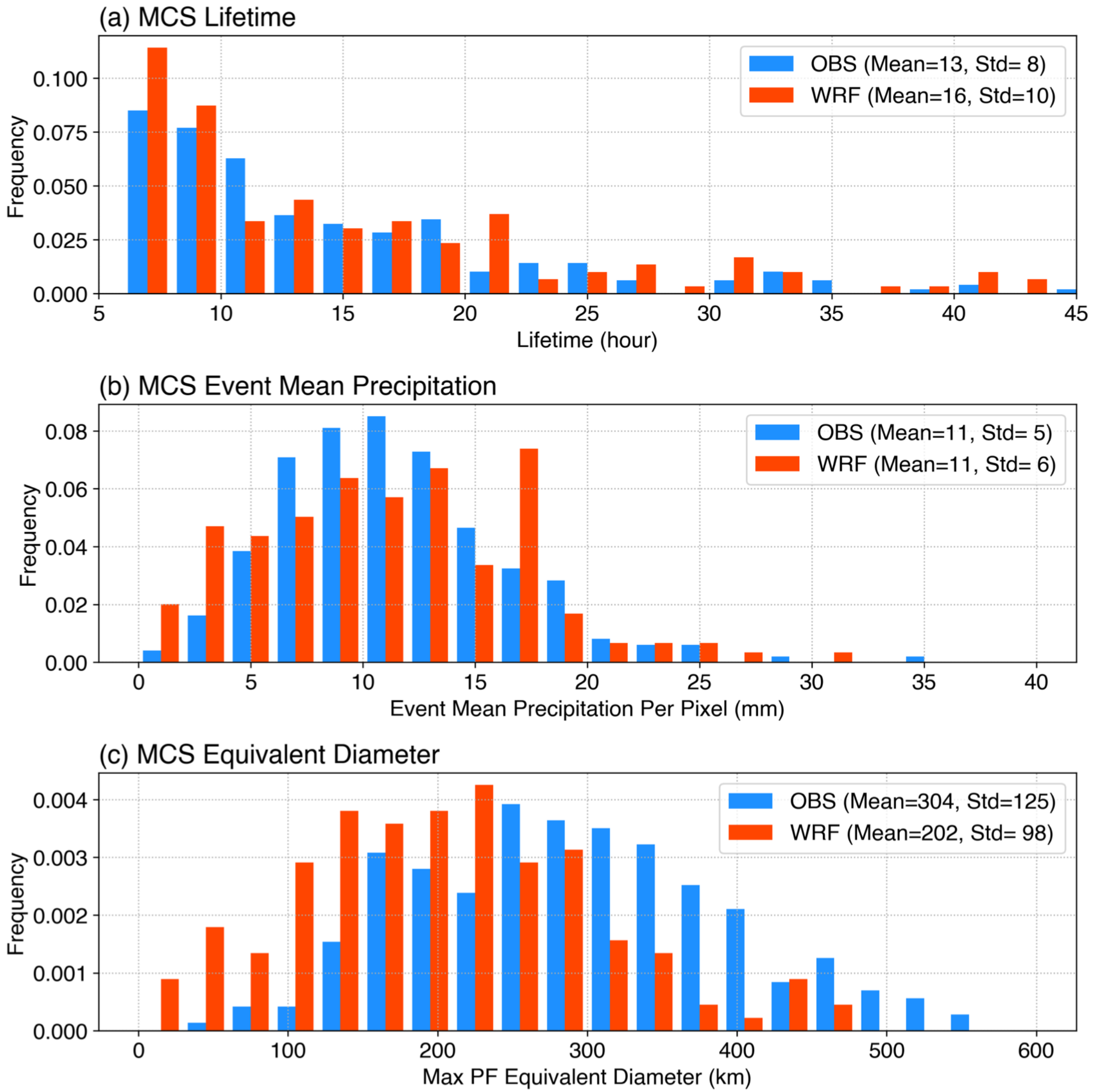
Superparameterized Energy Exascale Earth System Model (SP-E3SM)

MCS characteristics reasonably simulated

- WRF convection permitting simulations at 4 km grid spacing for two warm seasons without convection parameterization
- Simulations reproduced observed MCS statistics



(Yang et al. 2017 *JGR*)



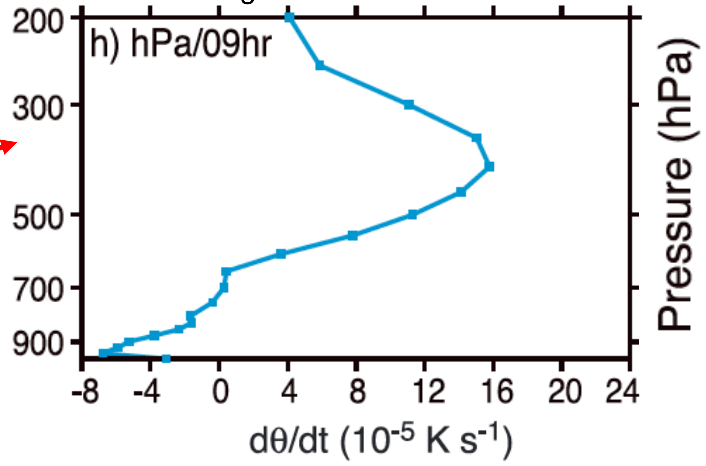
Positive feedback from long-lived MCSs to the environment supports their longevity

- Long-lived MCSs produce a midlevel circulation anomaly that maintains the MCSs and strengthens the environmental trough

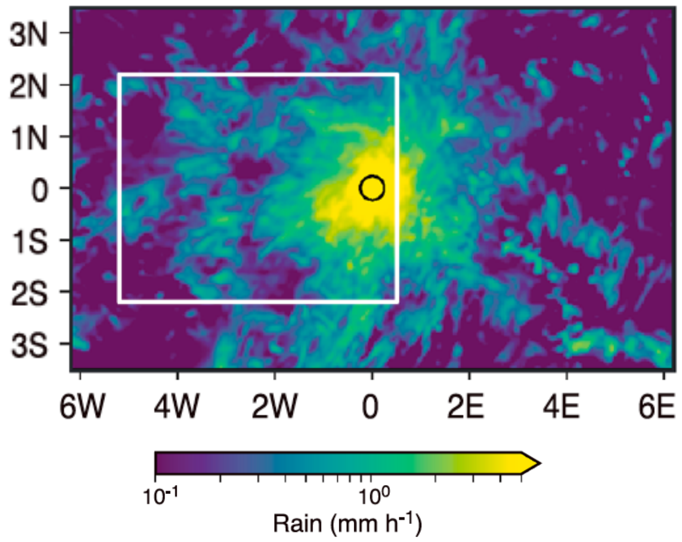
Interactions between MCSs and their large-scale environment

MCS precipitation generates top-heavy heating profile

MCS Heating

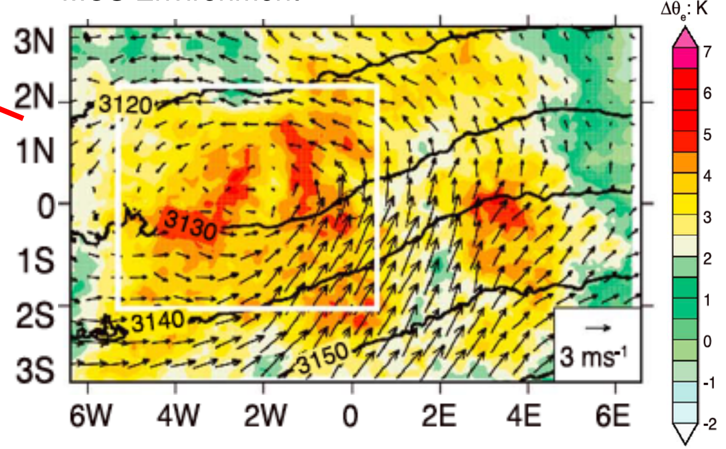


MCS Rainfall



Top-heavy heating strengthens the mesoscale vortex

MCS Environment



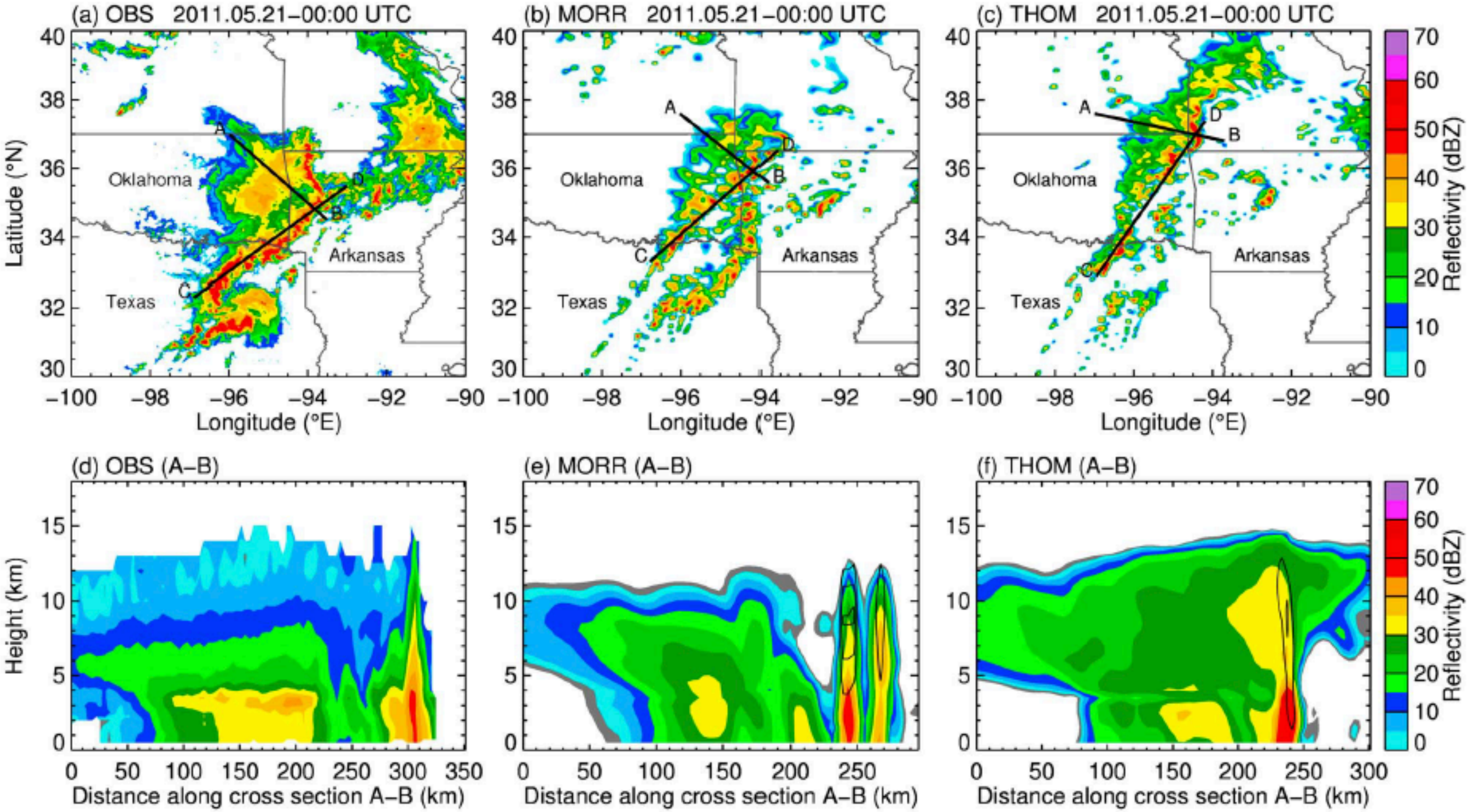
Mesoscale vortex feeds dry, cooler air that enhances evaporative cooling and prolongs the lifetime of MCS

(Yang et al. 2017 *JGR*)

Sensitivity to microphysics parameterizations

- Model simulates convective and stratiform aspects of MCS with varying level of details

OBS **MORR** **THOM**



Morrison (MORR) vs. Thompson (THOM) schemes

(Feng et al. 2018 *JAMES*)

Microphysical influence on MCS evolution

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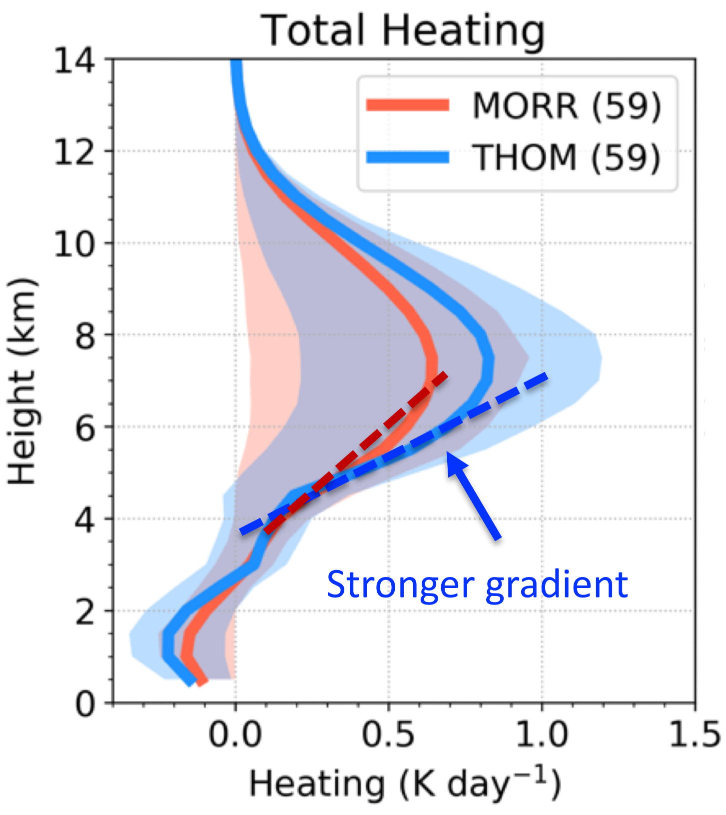
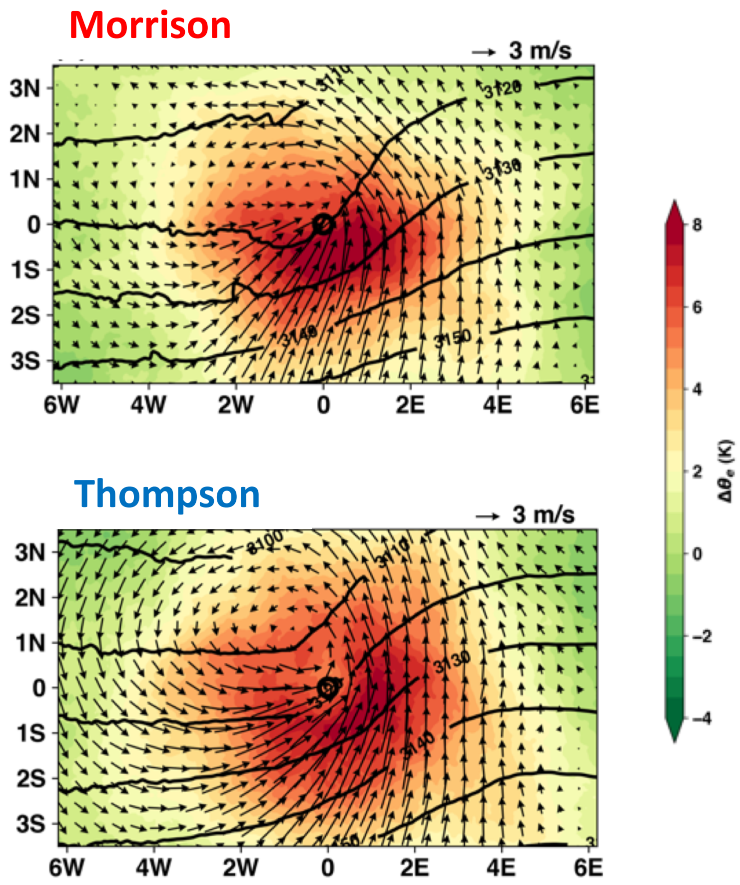
- Comparing WRF convection permitting simulations with Morrison vs. Thompson microphysics schemes

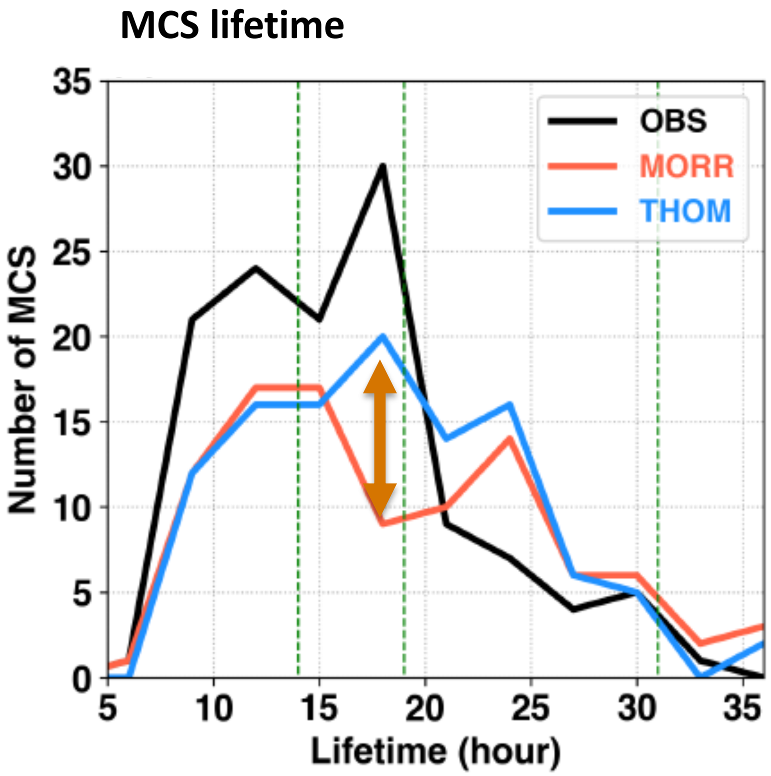


(Feng et al. 2018 *JAMES*)



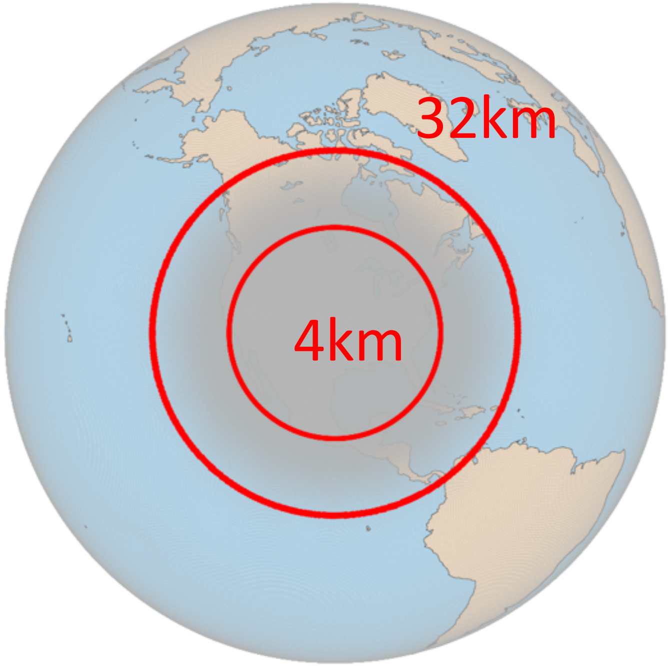
700 hPa winds and equivalent potential temperature anomalies

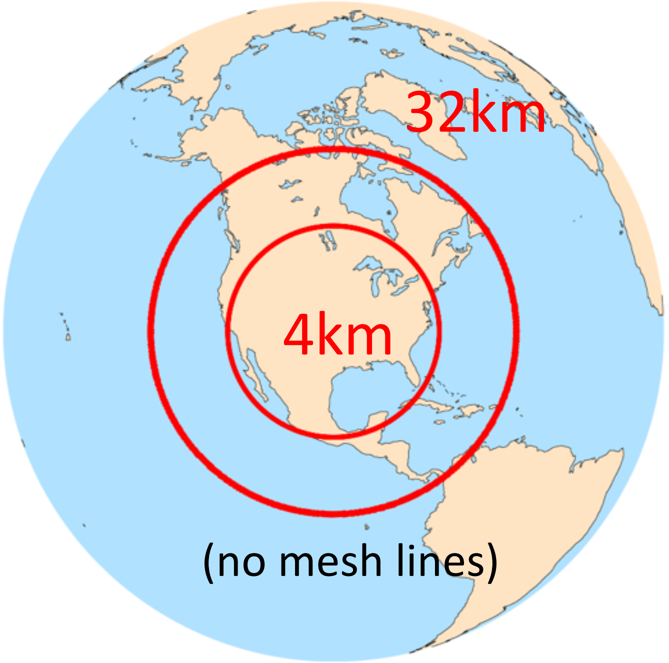
Thompson produced more longer-lived MCSs that produced more precipitation



Global variable resolution modeling

- Given the important interactions between MCSs and the circulation, a global modeling approach may offer some advantages in modeling MCSs
- Model for Prediction Across Scales (MPAS) coupled with CAM physics
  - Finite volume scheme on the spherical centroidal Voronoi tessellation (SCVT) grid
  - C-grid staggering for better representation of mesoscale, divergent flow (Skamarock 2011)





MCSs in April

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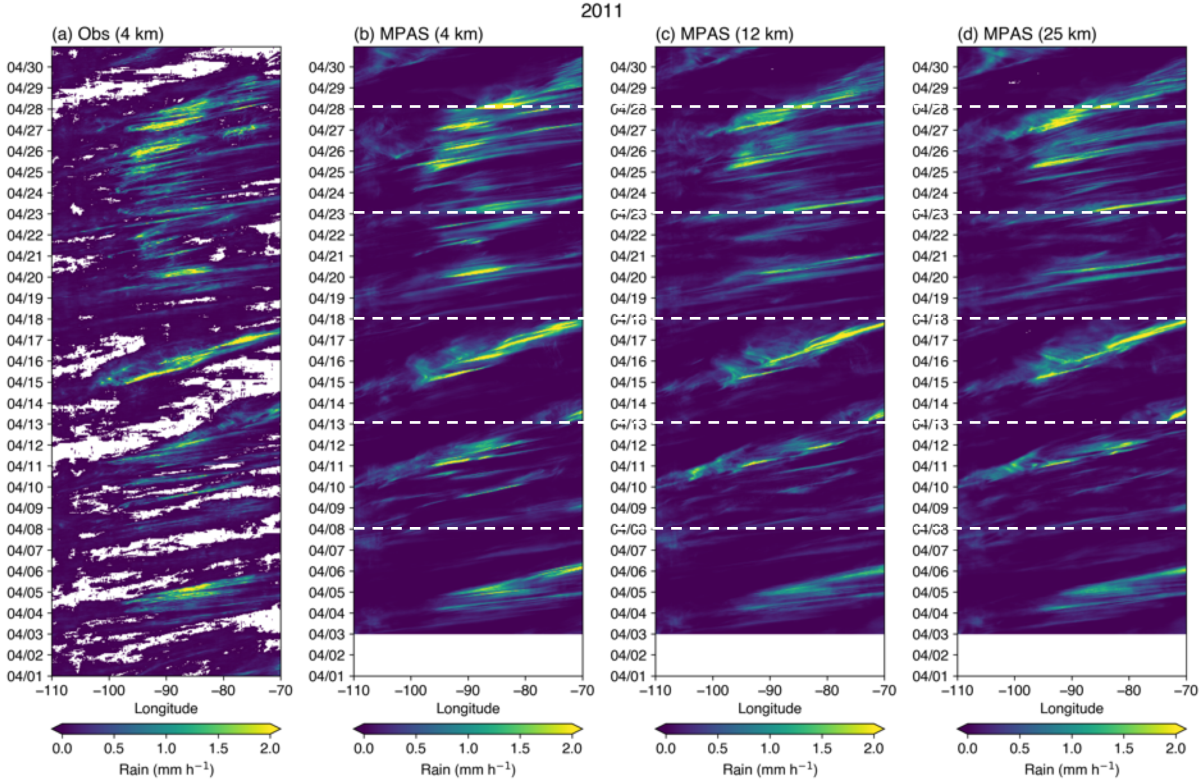
- Model evaluation using initialized forecasts: 4 km (no CP), 12 and 25 km (with CP)
- Large precipitation events and some embedded MCSs are well captured even at 12 km and 25 km resolution

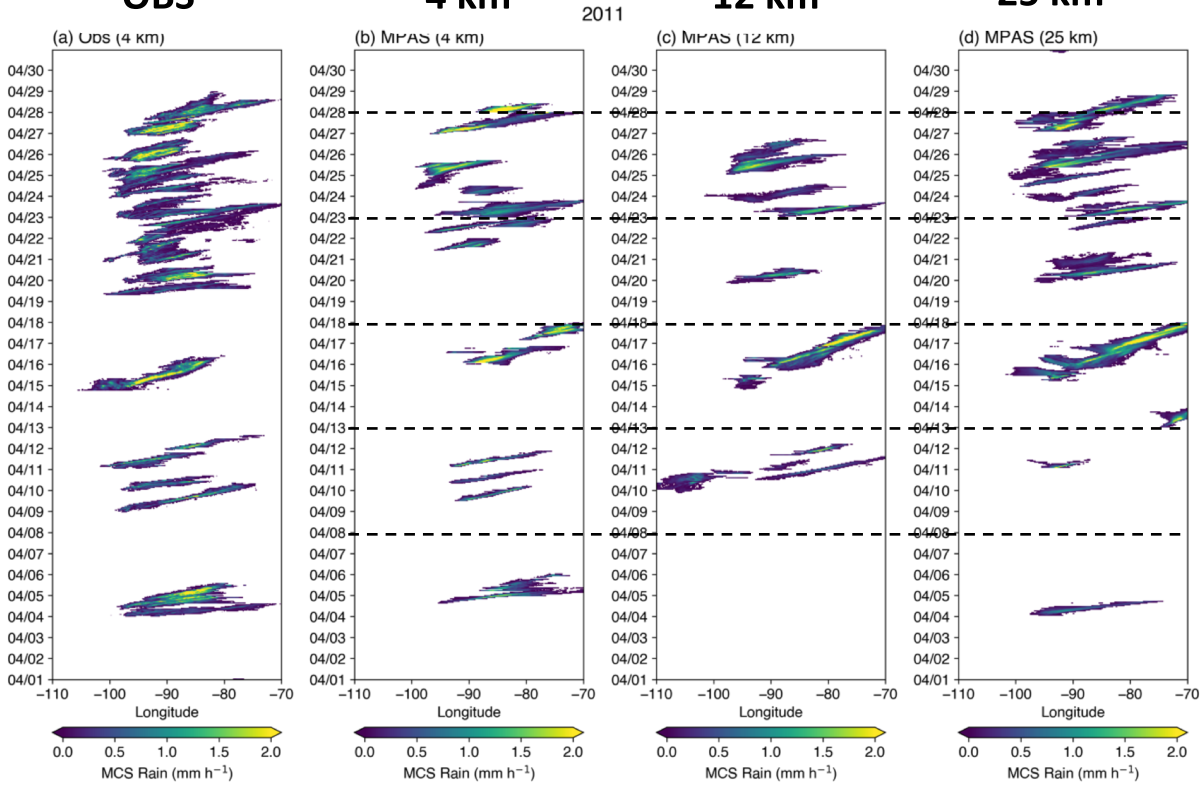
Total precipitation

OBS | 4 km | 12 km | 25 km



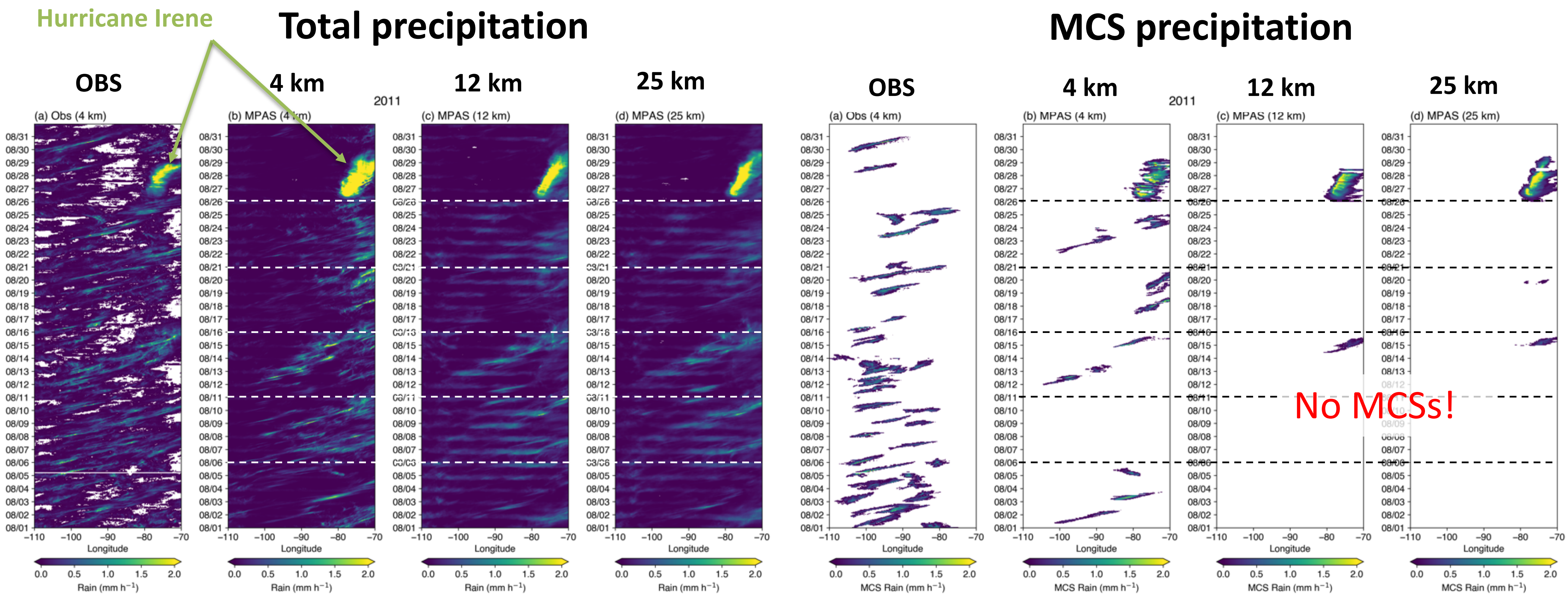
MCS precipitation

OBS | 4 km | 12 km | 25 km



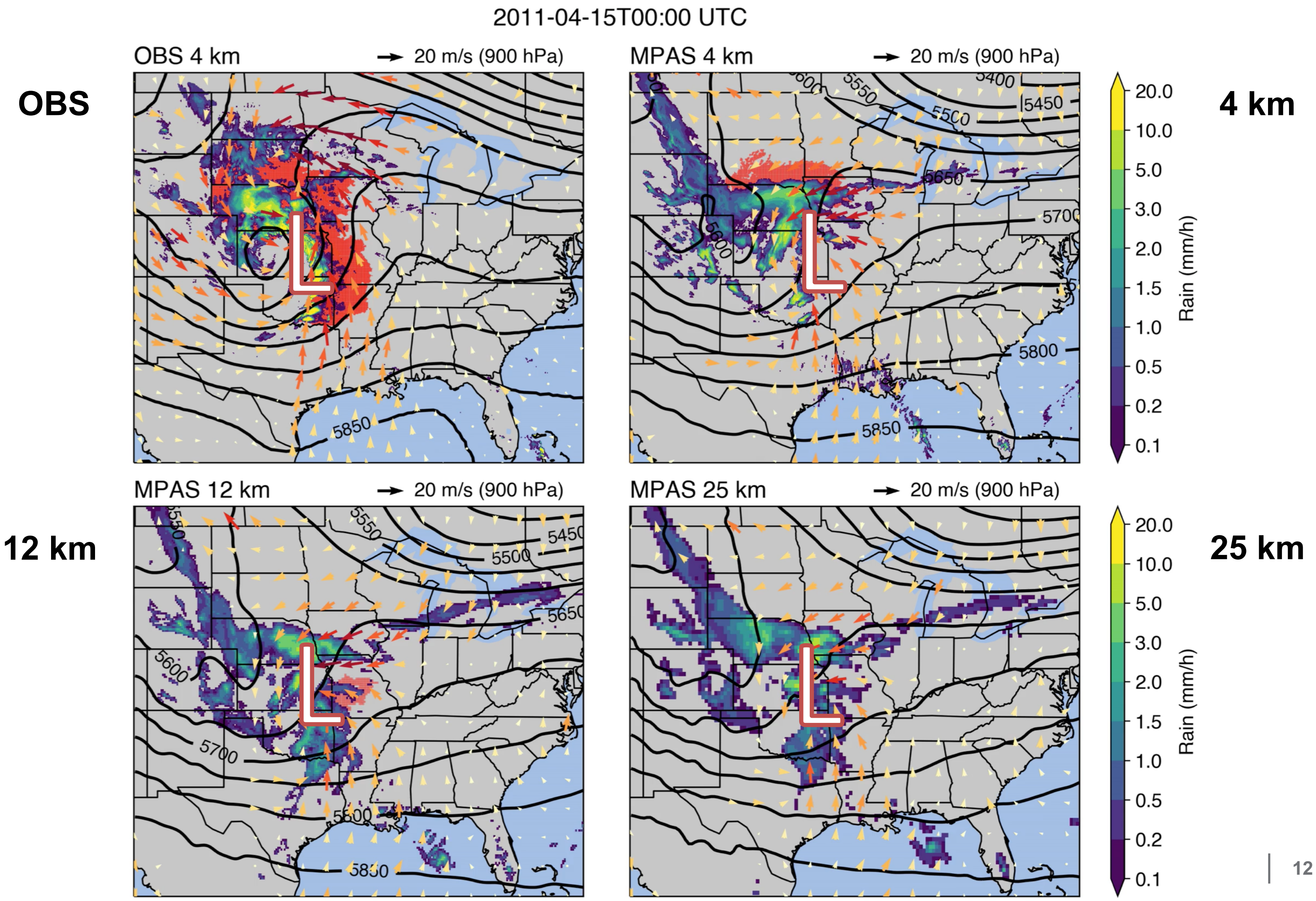
MCSs in August

- MCSs are much weaker in August; simulations at 4 km are significantly better in capturing the propagating events than simulations at 12 km and 25 km resolution



An MCS event in April

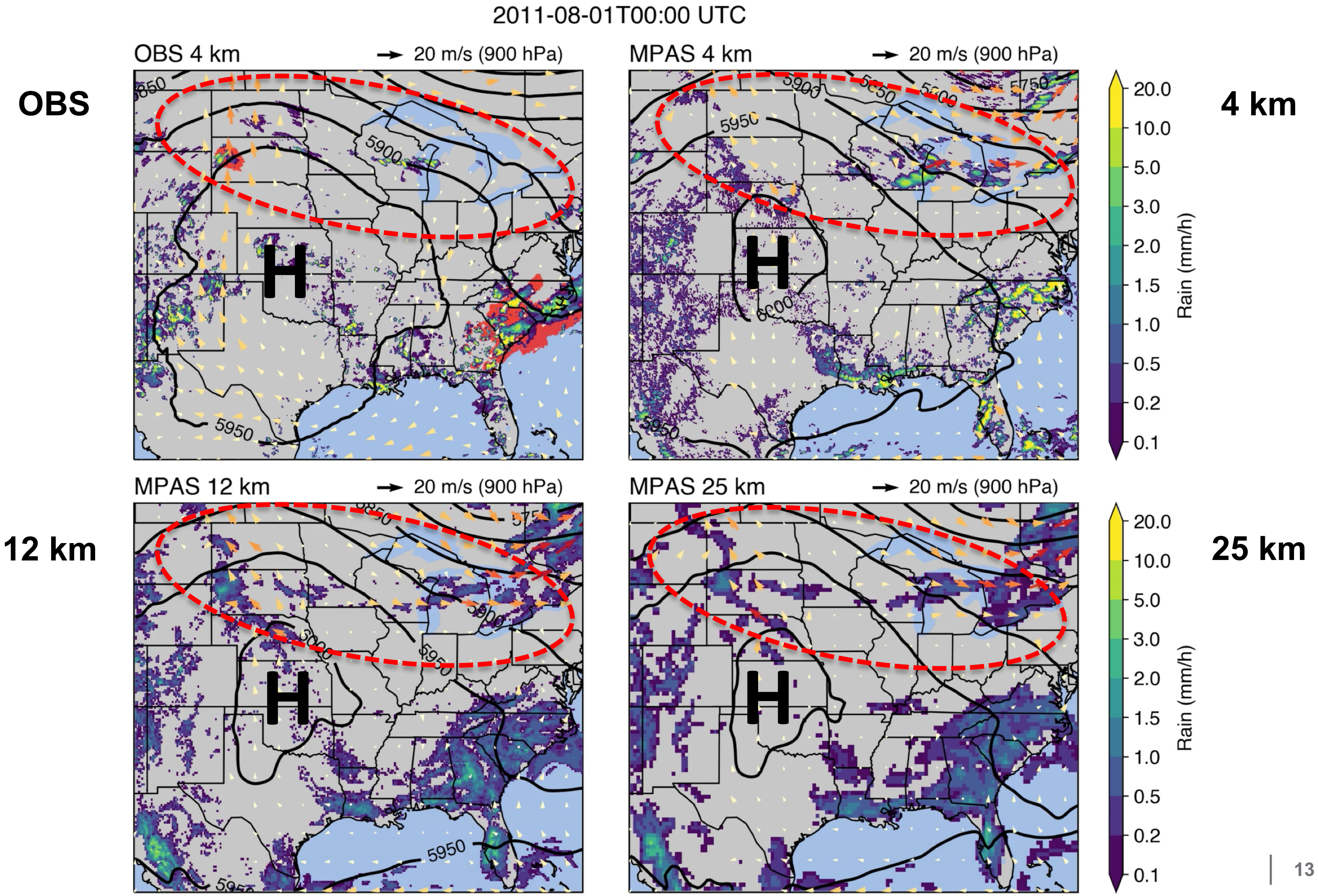
- Strong synoptic scale forcing associated with baroclinic waves, strong LLJ and moisture supply from the Gulf



Contour: 500 hPa geopotential
Vector: 900 hPa wind
Red shading: MCS cloud shield
Color shading: precipitation

An MCS event in August

- High pressure over the Great Plains
- Weaker nocturnal LLJ
- Convection initiates ahead of shortwave trough, feeding from LLJ and propagate along the ridge

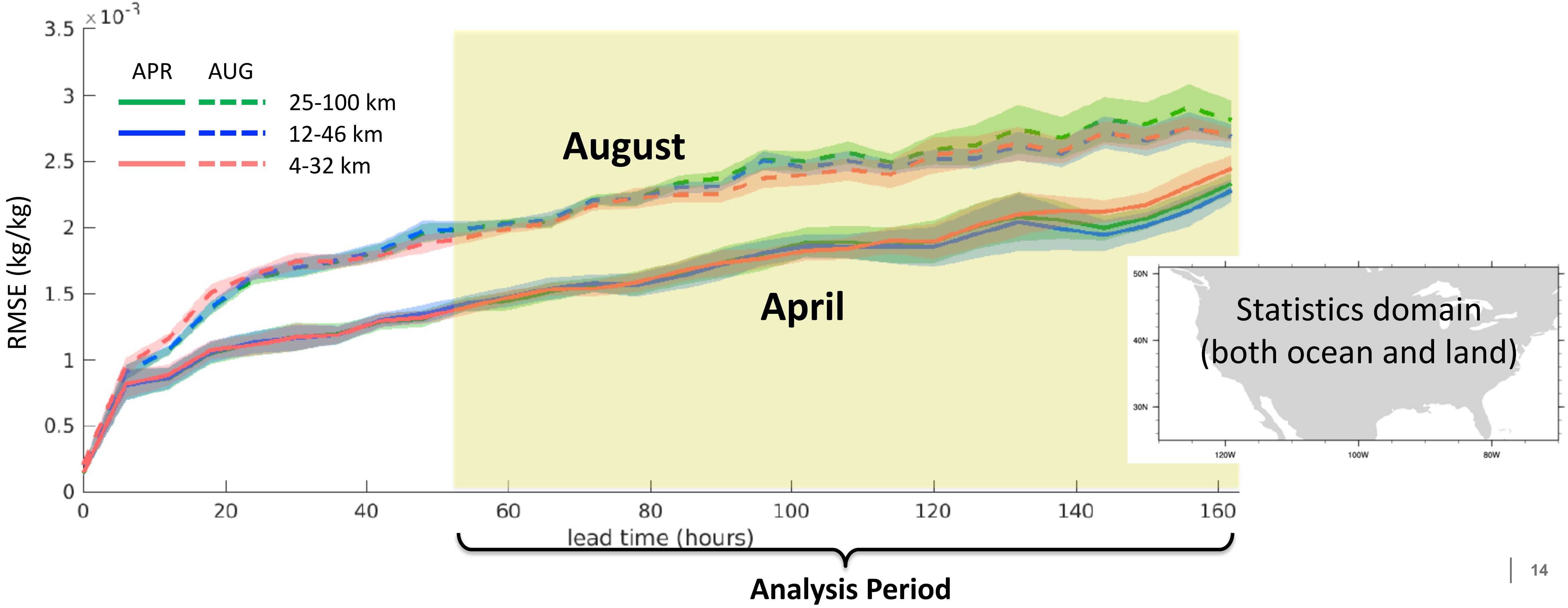


Contour: 500 hPa geopotential
Vector: 900 hPa wind
Red shading: MCS cloud shield
Color shading: precipitation

Predictability of large-scale environment

- Lower predictability of the large-scale environment in August than April for the first 5 days

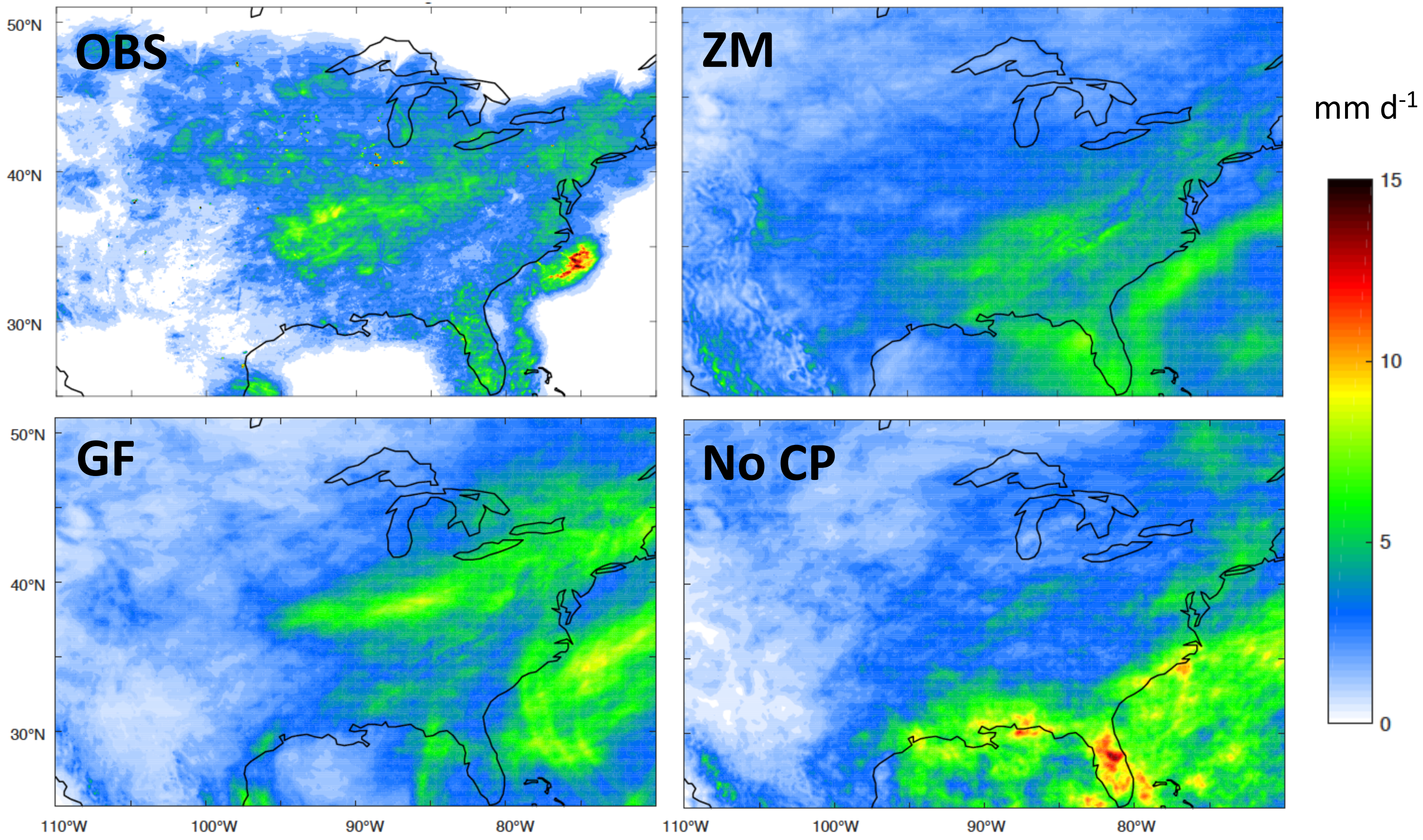
RMSE of 850 hPa humidity comparing MPAS with ERAI



Exploring MPAS simulations at gray zone resolution

- Compare simulations with Zhang-McFarlane (ZM), Grell-Freitas (GF), and no (no CP) convection parameterizations

Mean precipitation (April – August 2011)



Promising skill at the gray zone with a scale-aware parameterization

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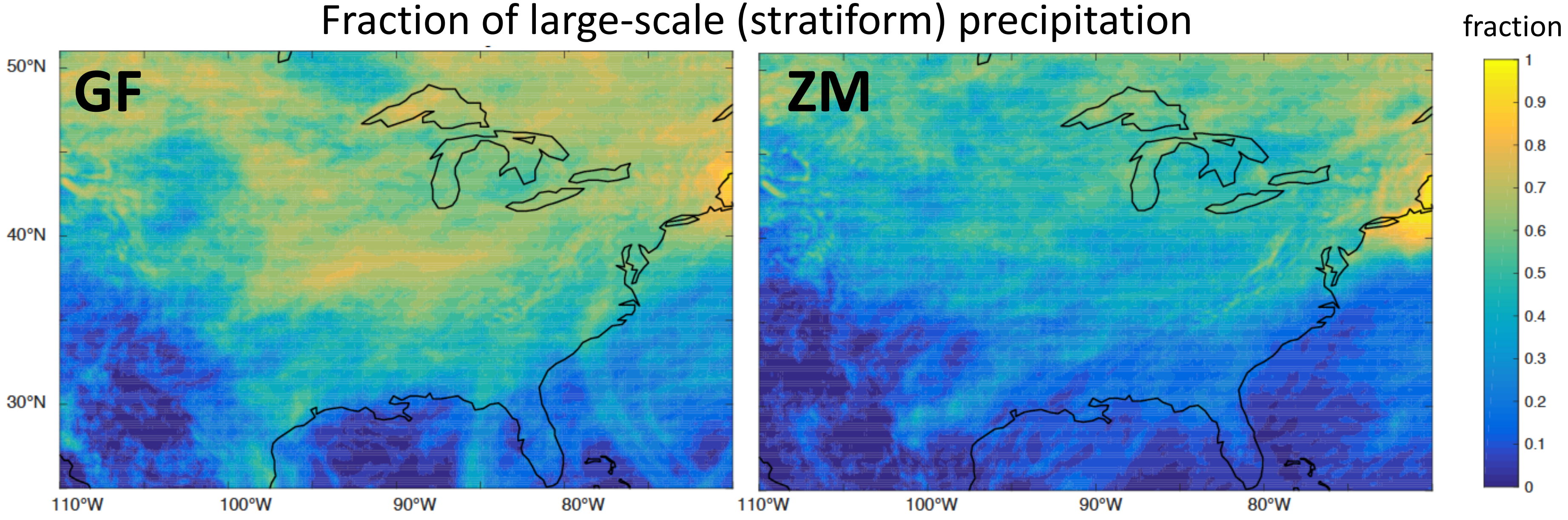
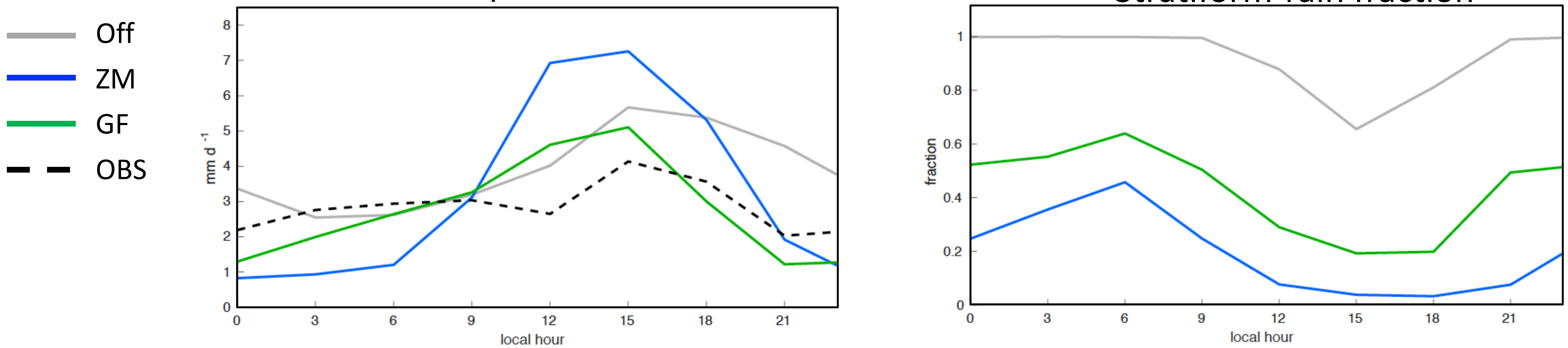
Fraction of large-scale (stratiform) precipitation



Precipitation

Stratiform-rain fraction



Summary

- Regional convection permitting simulations can capture many aspects of MCSs
- Positive feedback from long-lived MCSs to the circulation through diabatic heating is important for MCS longevity
- Global variable resolution modeling offers a viable approach for convection permitting modeling of MCSs in the global context
  - Simulations at 4 km with no CP are more skillful than simulations at 12 km and 25 km with the ZM scheme
  - At gray zone resolution (12 km), the GF scheme shows some promises as a scale-aware parameterization
- Models are more skillful in simulating MCSs during spring, but they are much less skillful in summer with weak synoptic forcing