# Assimilation of Lightning Data Using a Newtonian Nudging Method Involving Low-Level Warming

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Acknowledgements: Drs. I. M. Navon and R. Stefanescu, FSU and Joint Center for Satellite Data Assimilation (JCSDA)

# Past Lightning Data Assimilation

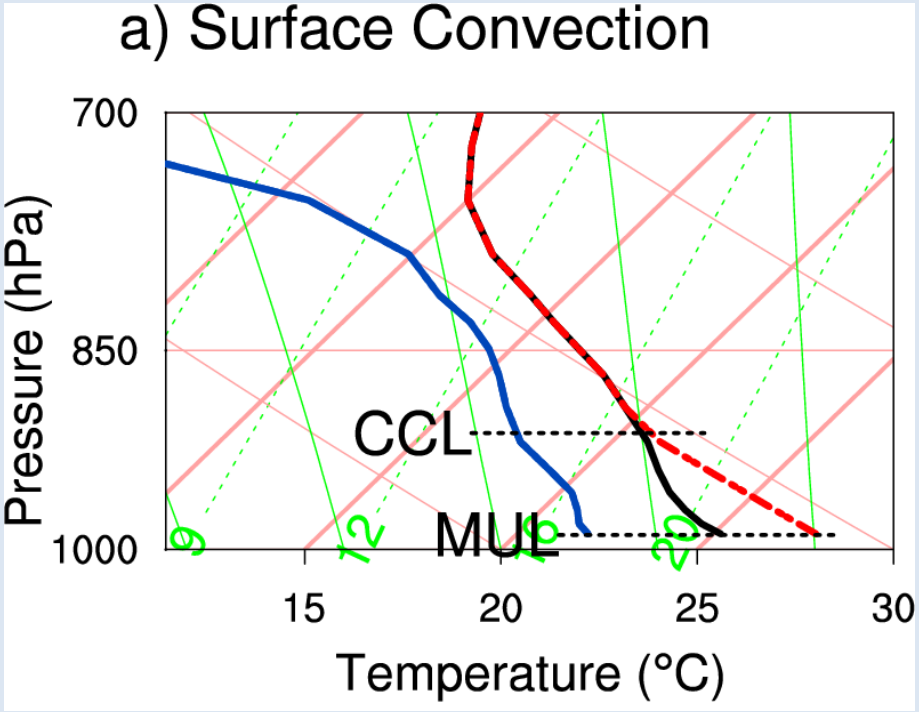
- Mostly nudging methods at coarse resolutions
- Generally two categories of nudging:
  - Modification of mid and upper-level convective heating rates (Alexander et al. 1999; Chang et al. 2001; Pessi and Businger 2009; Weygandt 2008)
  - Increasing humidity to initiate convection (Papadopoulos et al. 2005; Mansell et al. 2007; Fierro et al. 2012)

# Our New Warming Method

- Applicable for cloud-permitting scales (i.e., ≤ 4 km)
- Appropriate for forthcoming GOES-R Geostationary Lightning Mapper (i.e., ≈ 9 km grid spacing, total lightning)
- Instead of moistening, our method warms to initiate convection where lightning is observed
- Instead of warming mid to upper-levels and assimilating effects of the deep convection, low-levels are warmed
- Objective is to warm just enough to produce storms where observed
- Assume simulated temperature and humidity profiles are accurate, just need slight warming to produce storms

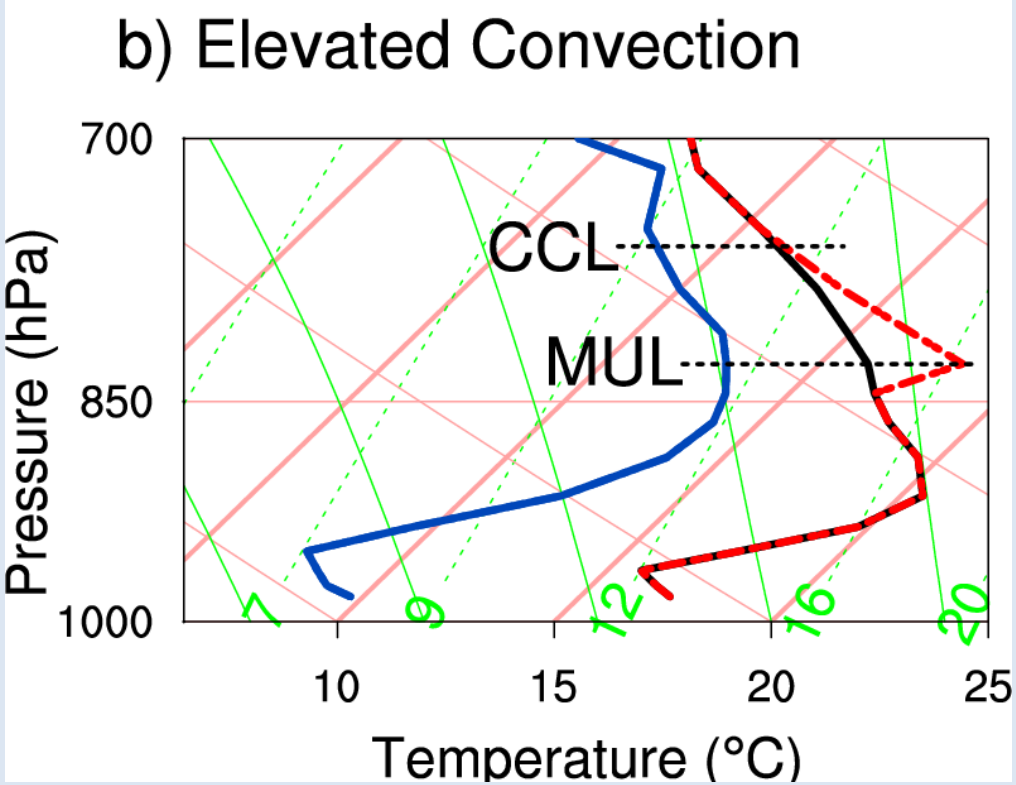
# Warming to Initiate Convection

- If maximum graupel mixing ratio < 1 g/kg, warming used to assimilate lightning data and initiate deep convection in cloud-resolving simulations
- Deep convection can initiate from surface warming to the convective temperature



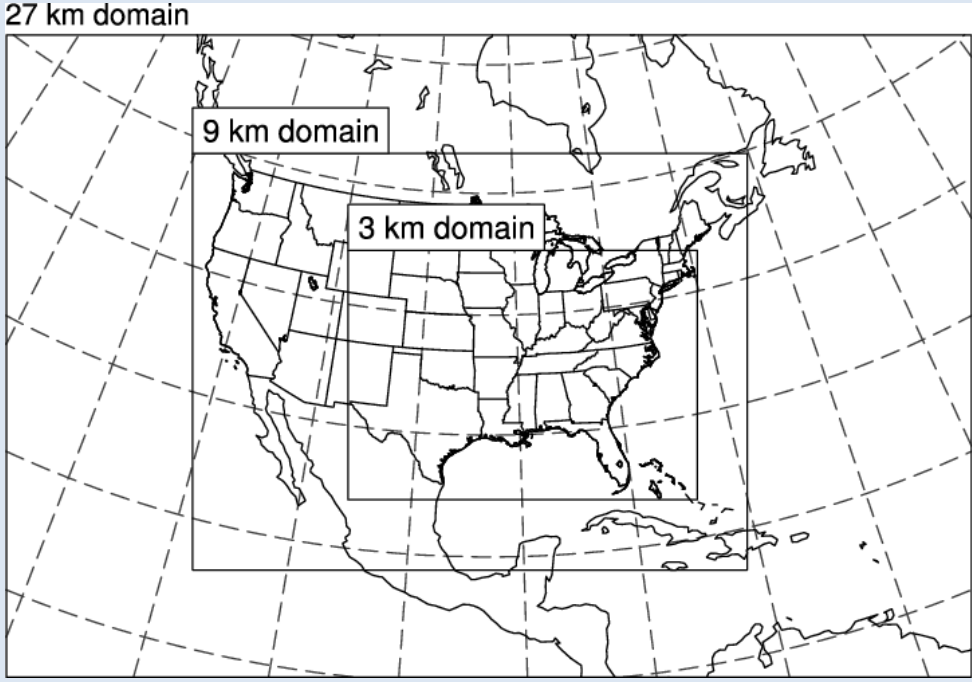
# Elevated Convection

- Warming done between the most unstable level (MUL) up to the CCL computed from the MUL



# Model Configuration

- WRF-ARW Version 3
- Nested approach with 3 domains (27, 9, and 3 km spacing), 60 vertical levels
- 2 way-nesting with WSM6 microphysics, Kain-Fritsch CPS in 27 km, no CPS in others




- Initial and boundary conditions: 1° x 1° FNL data
- 6-h spin-up (06-12 UTC), 12-h assimilation period (12-00 UTC) followed by a 12-h forecast (00-12 UTC)

# Case Studies and Lightning Data

- Simulations done for three cases:
  - Strong forcing: 27 April 2011
  - Weak forcing: 9 June 2011
  - Moderate forcing: 15 June 2011
- Among most electrically active days of 2011
- Earth Networks Total Lightning Network (ENTLN) data used– includes both IC and CG flashes
  - CG DE > 95%; IC DE 50-90% in 3 km domain
- To match GLM, lightning mapped on intermediate 9×9 km grid
- Each 3 km grid cell assigned value of the 9 km
- Lightning summed over 10 min intervals

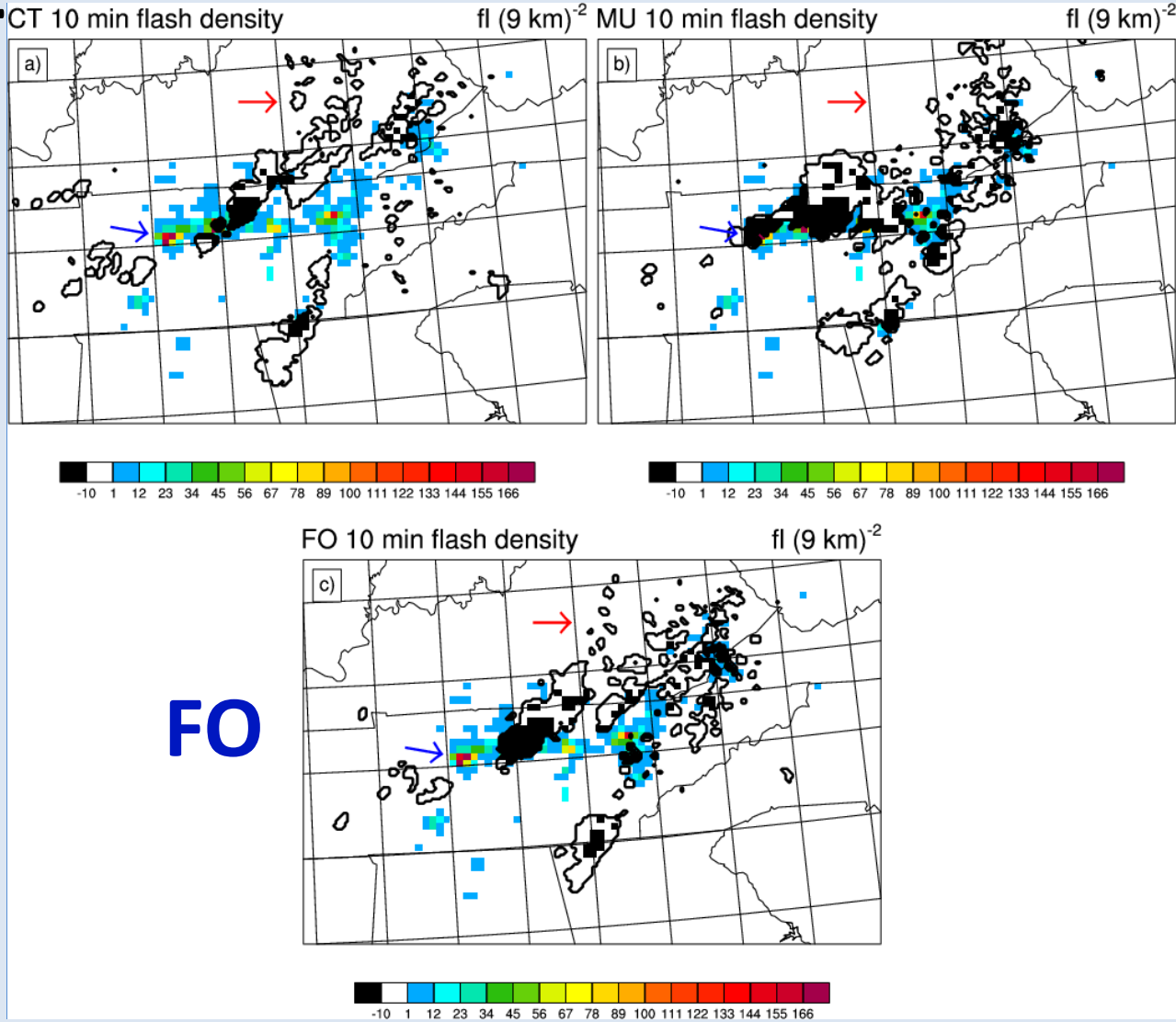
# Results Overview

- 3 Simulations for Each Case
  - CT: No assimilation
  - MU: Our warming method
  - FO: Moistening method of Fierro et al. (2012)
    - RH increased to 81%-101% in mixed phase region (0 to -20°C) if RH < 81% (Fierro et al. 2012)
    - 81-101% depending on observed flash rate and simulated graupel mixing ratio

- 3 Parts to Results
  - Demonstrating the assimilation methods
  - Objective comparison of precipitation fields
  - Advantage of using Newtonian nudging

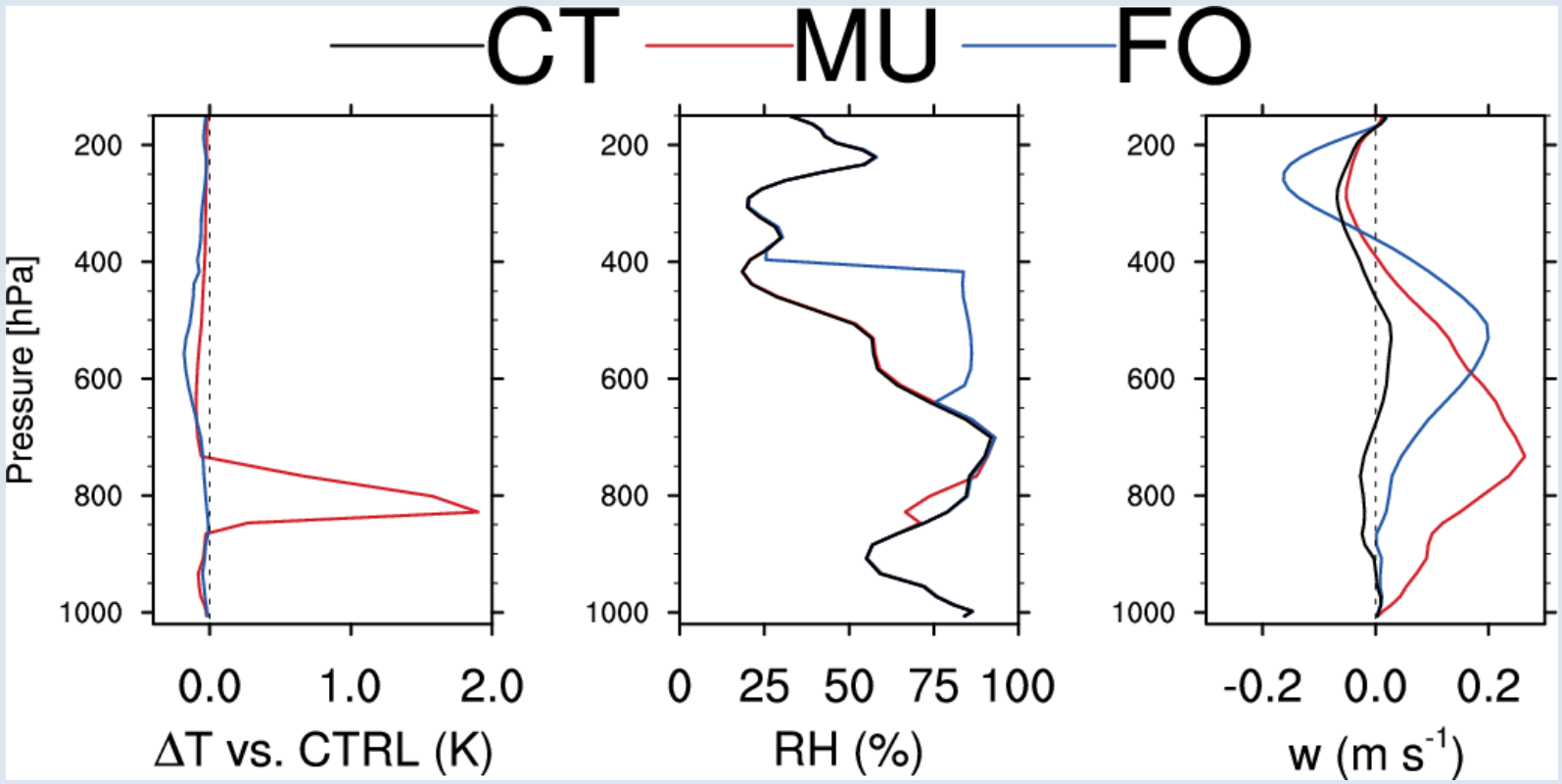
# Example of Performance: 6 h After Start of Assimilation (18Z 15 June)

- Contoured graupel mixing ratios > 1 g/kg
- Colored observed lightning quantities
- **Black** denotes model/ observation agreement



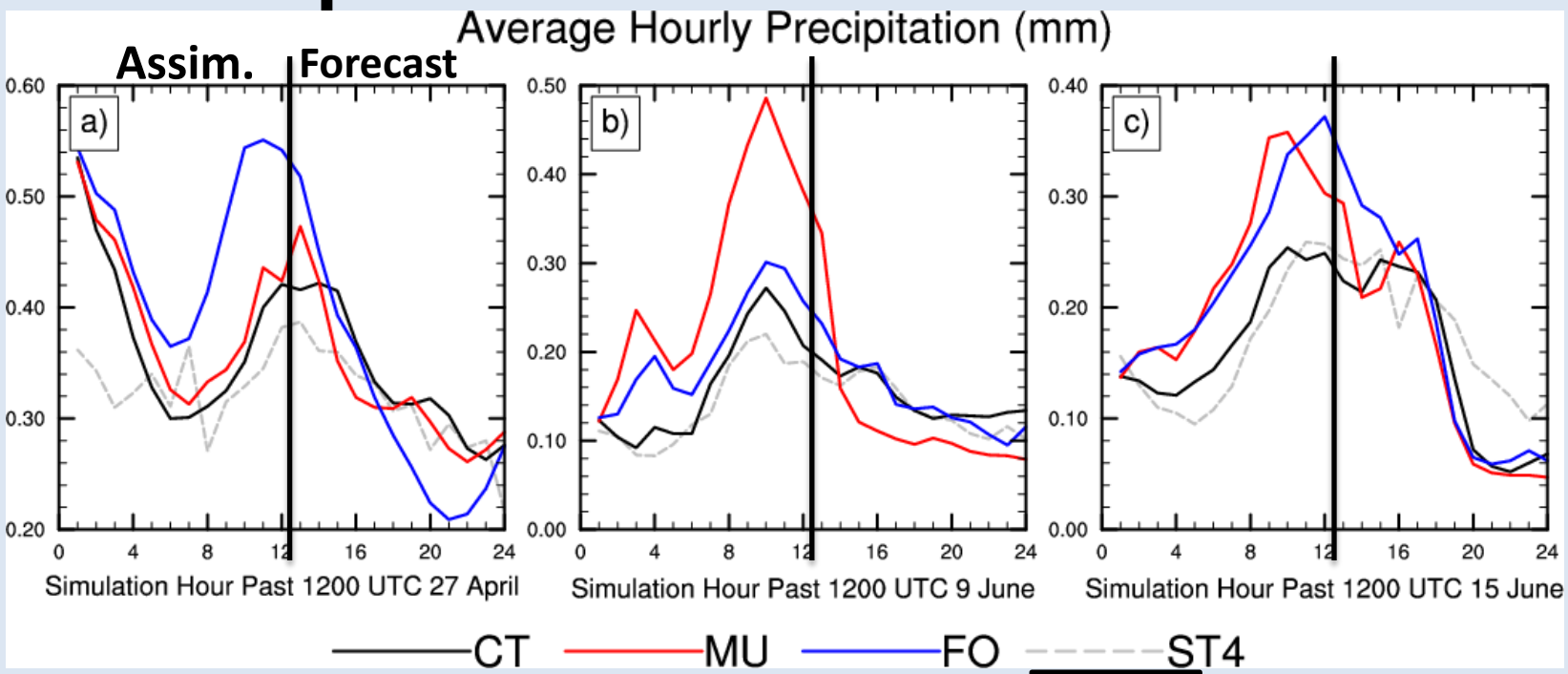
# Assimilation Effects on Vertical Velocity: 5 min into assimilation (1205 UTC 9 June)

- Assimilation methods induce a weak updraft
- MU peak updraft in low-levels; begins to saturate CCL
- FO in mid-levels near cooling



# Precipitation Bias

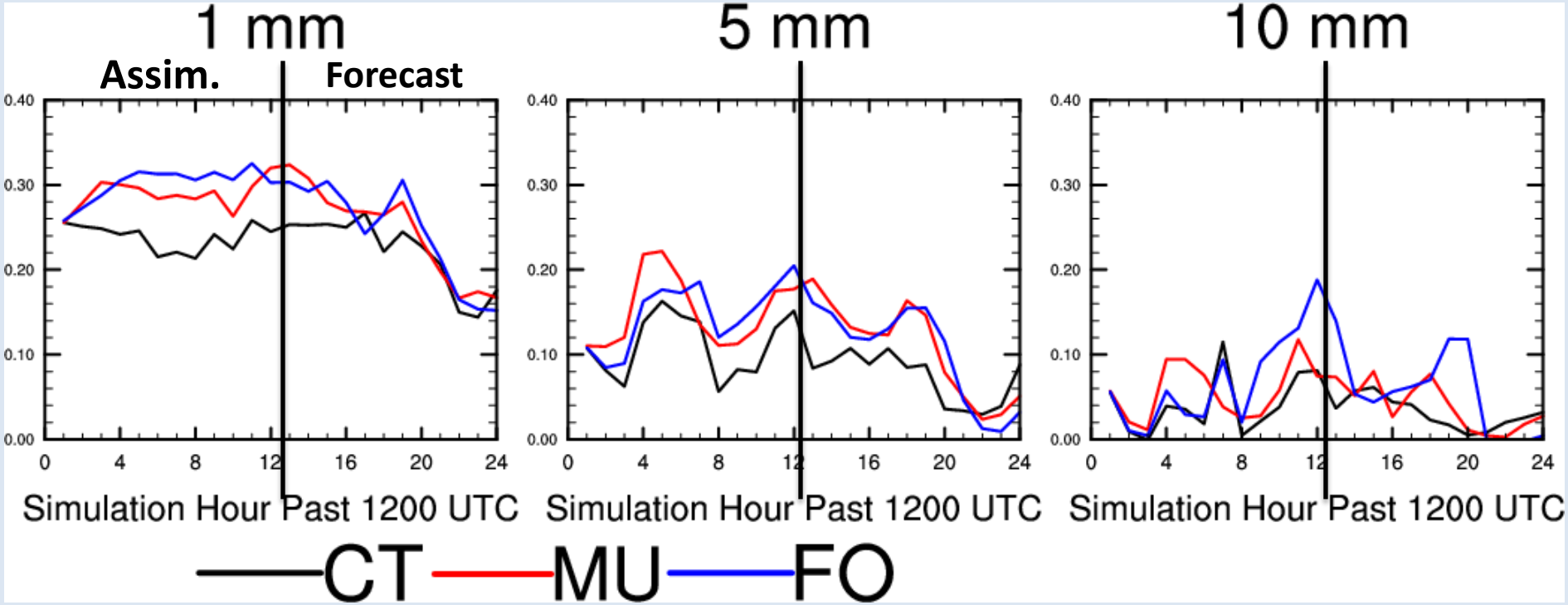
**27 Apr** **9 Jun** **15 Jun**




**CT** **MU** **FO** **ST4**

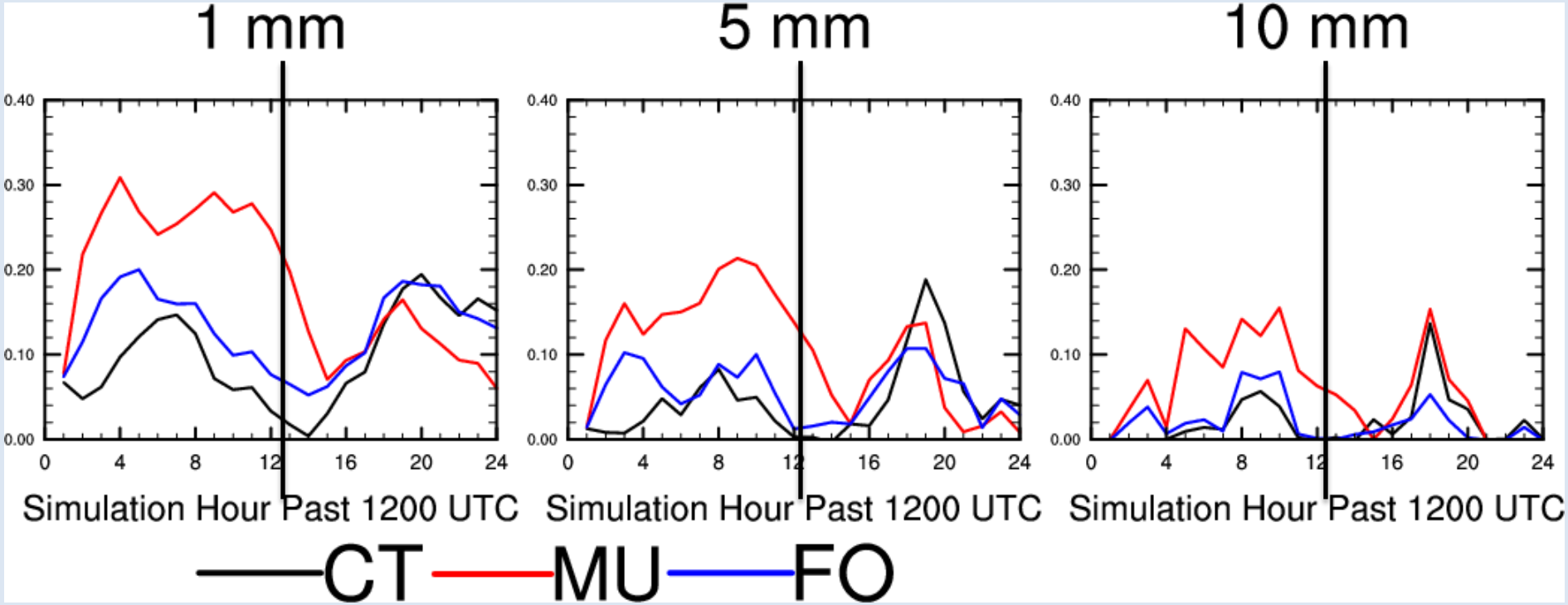
- Average hourly precip. of CT close to STAGE 4 (ST4)
- Methods do not suppress convection, so overprediction results during assimilation
- Tend to underpredict after assimilation ends
- Bias similar for both methods

# ETS: 27 April—Strong Forcing



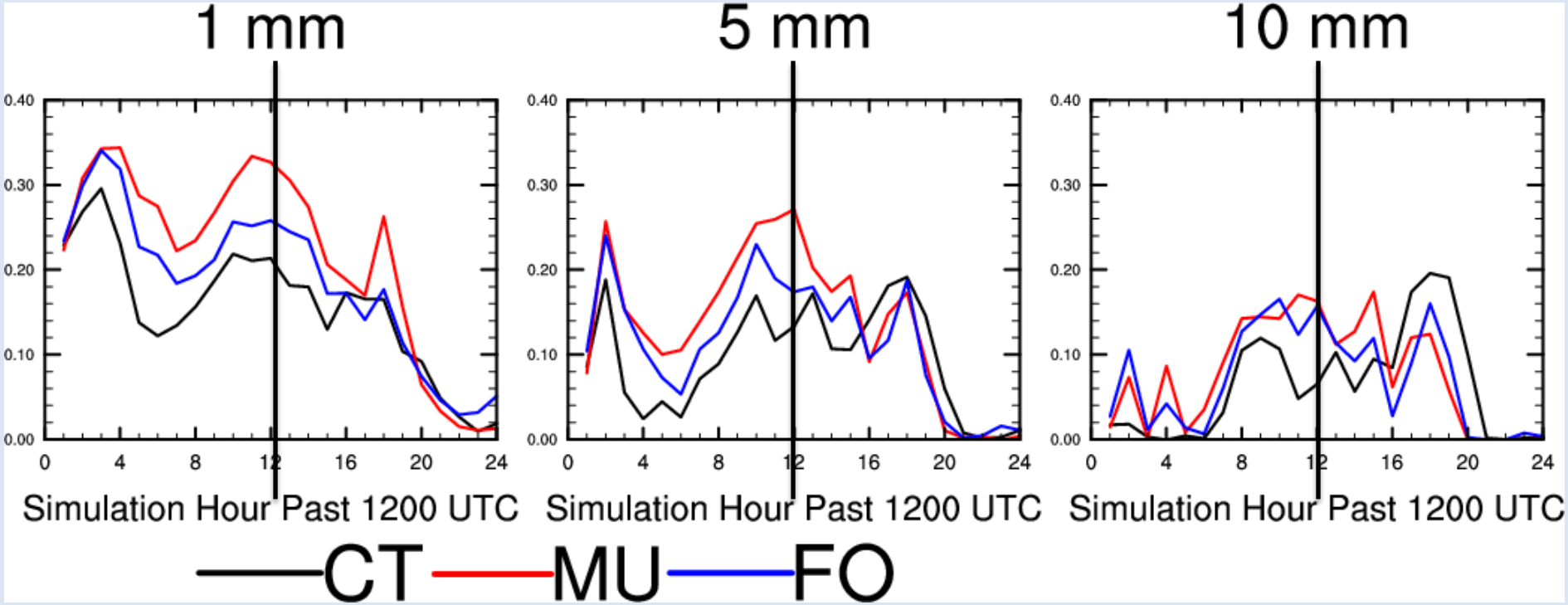

- FO ETS greater than MU
- MU greater than CT
- 10 mm more ambiguous

# ETS: 9 June—Weak Forcing




- MU ETS greater than FO, FO greater than CT
- CT has low skill

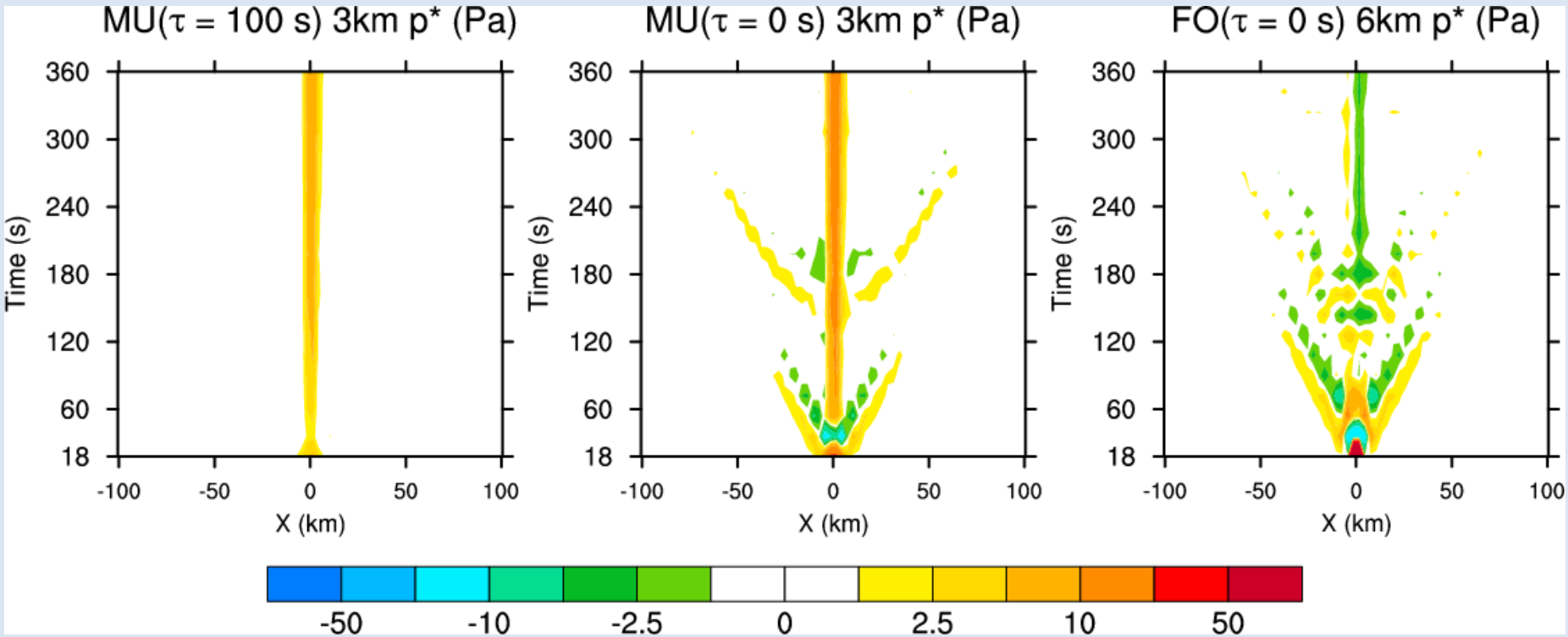
# ETS: 15 June—Mod. Forcing




- MU ETS greater than FO for 1 and 5 mm
- MU and FO similar for 10 mm
- Using Fuzzy/Neighborhood verification method (Fractions Skill Score) shows similar results

# Reducing Acoustic Waves

**Using Newtonian Relaxation** | **Not Using Newtonian Relaxation**



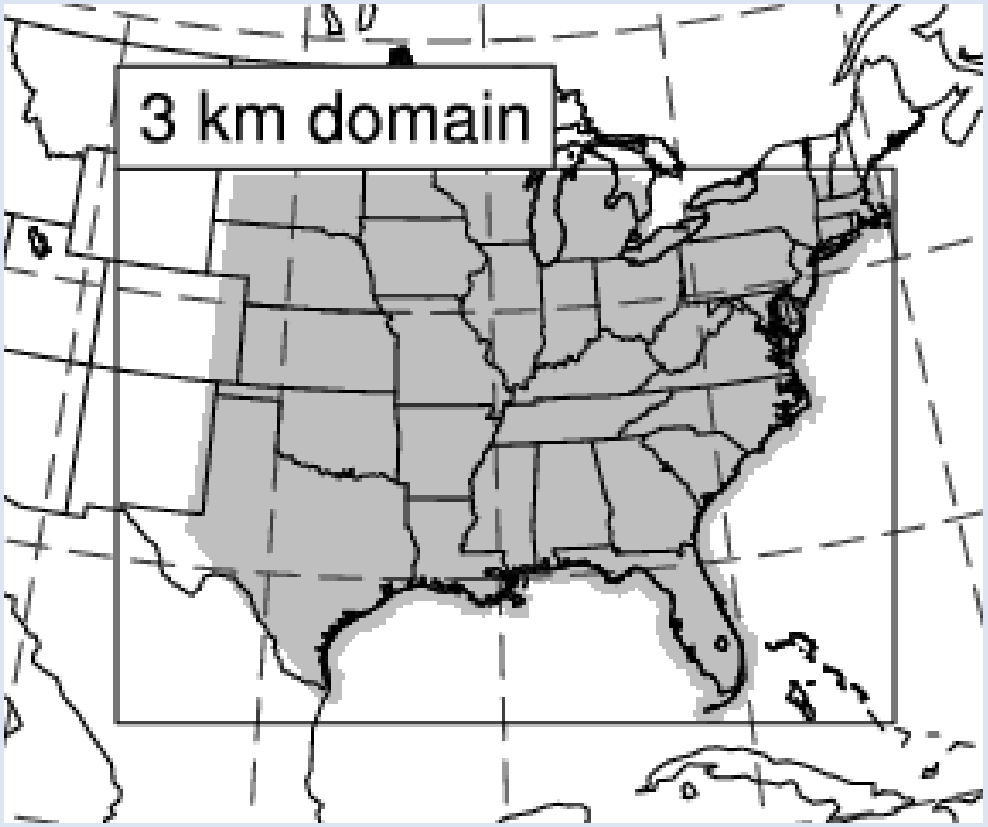

- Warming all in one time step produces sound wave signals in pressure field
- Moistening also produces sound wave signals
- Gradually warming prevents sound wave signals

# Conclusions

- Low-level warming used to assimilate lightning data and effectively initiate deep convection in a numerical model
- Improves precipitation simulations during assimilation, short forecast period
- Newtonian nudging reduces possible numerical instabilities when warming or moistening
- Produces surplus of precipitation, but methods could be combined with more observations and/or sophisticated methods (e.g., EnKF, 4DVAR)
- New, computationally inexpensive method creates a better analysis; expands the utility of forthcoming GOES-R GLM data source

# Precipitation Observations

- Hourly simulated precipitation compared with NCEP stage IV (ST4) radar and gauge observations (~4 km)
  - Human quality controlled by river forecast offices
- Verification domain (grey region) defined to ensure high quality precipitation data use for comparison with simulated precip.
  - Avoid poor radar coverage areas: sea, Rockies, non-U.S. land



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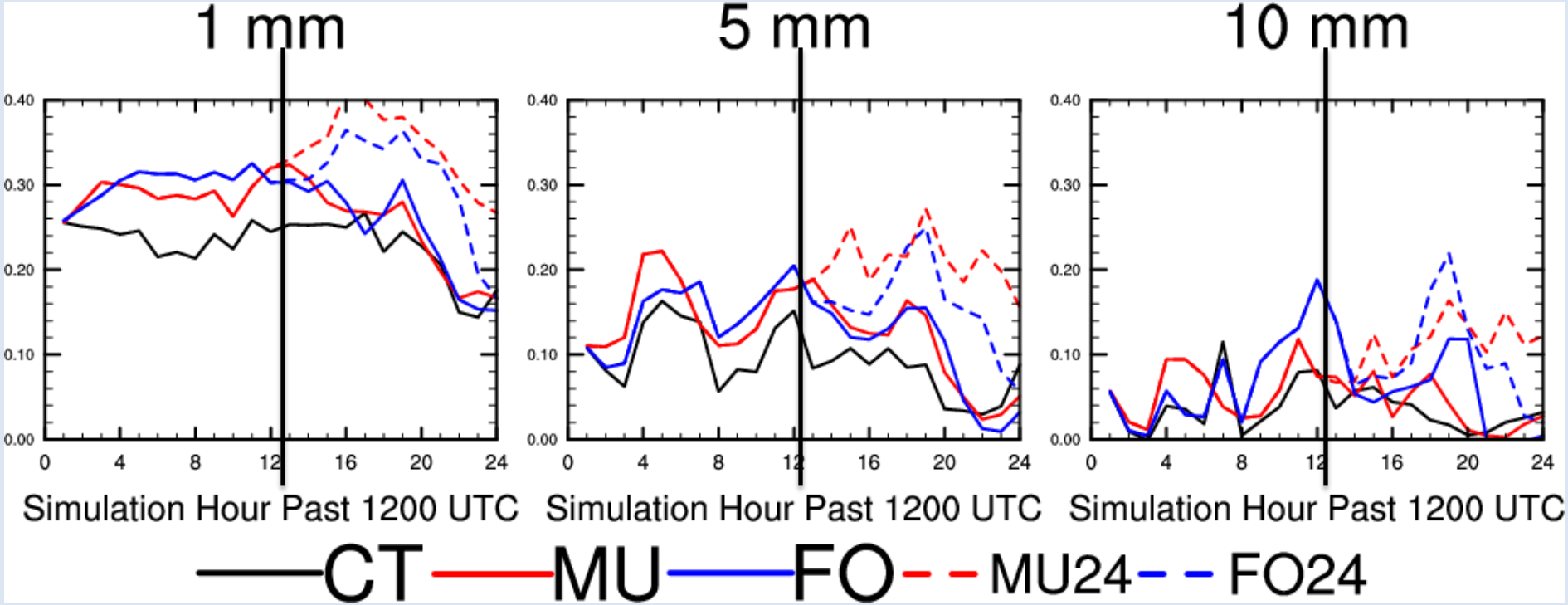


- FO ETS greater than MU, MU greater than CT
- 10 mm more ambiguous
- Greater ETS if assimilation continues (dashed lines)

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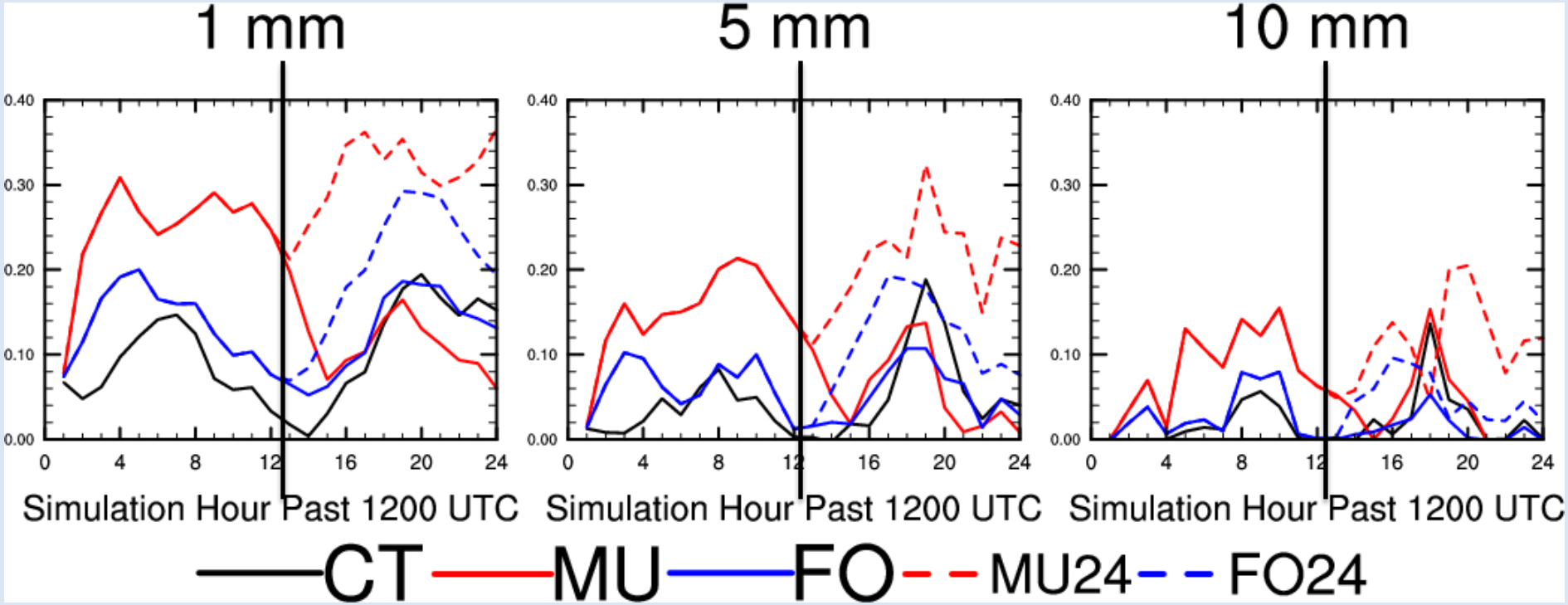


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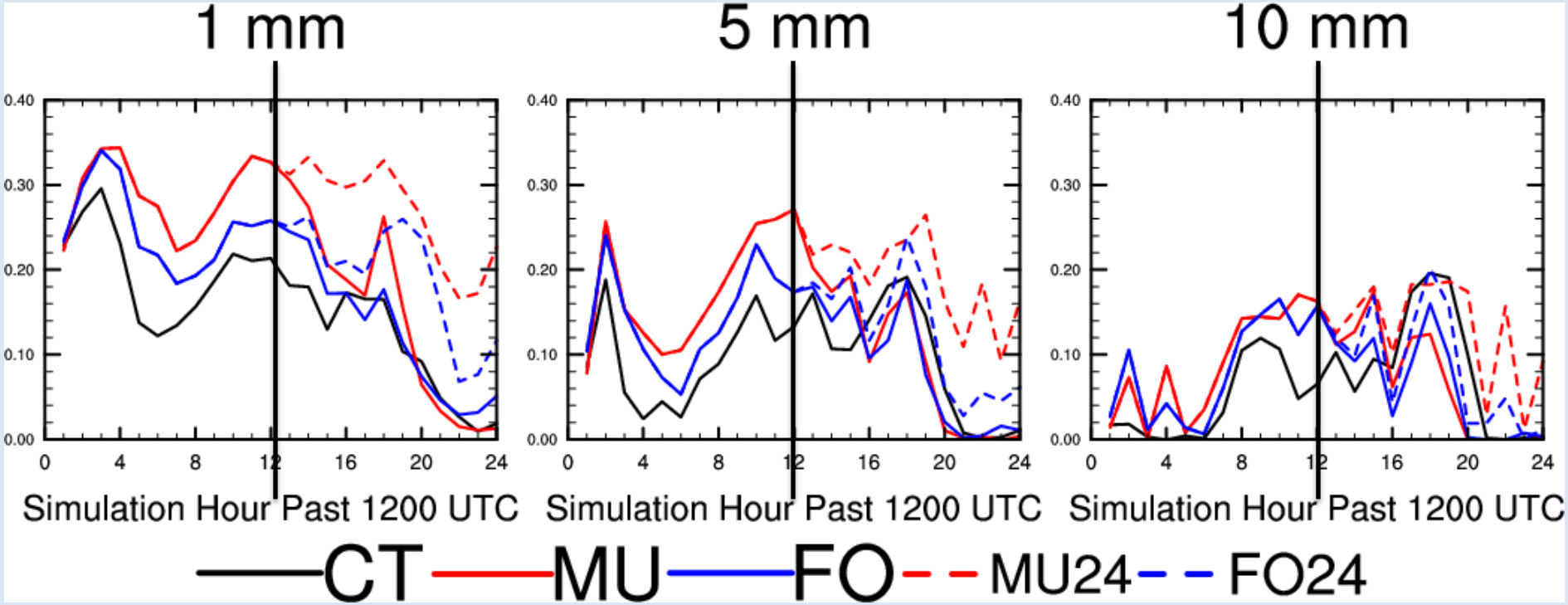


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