Confronting MCS Simulations with ARM Observations Across the Convective Gray Zone

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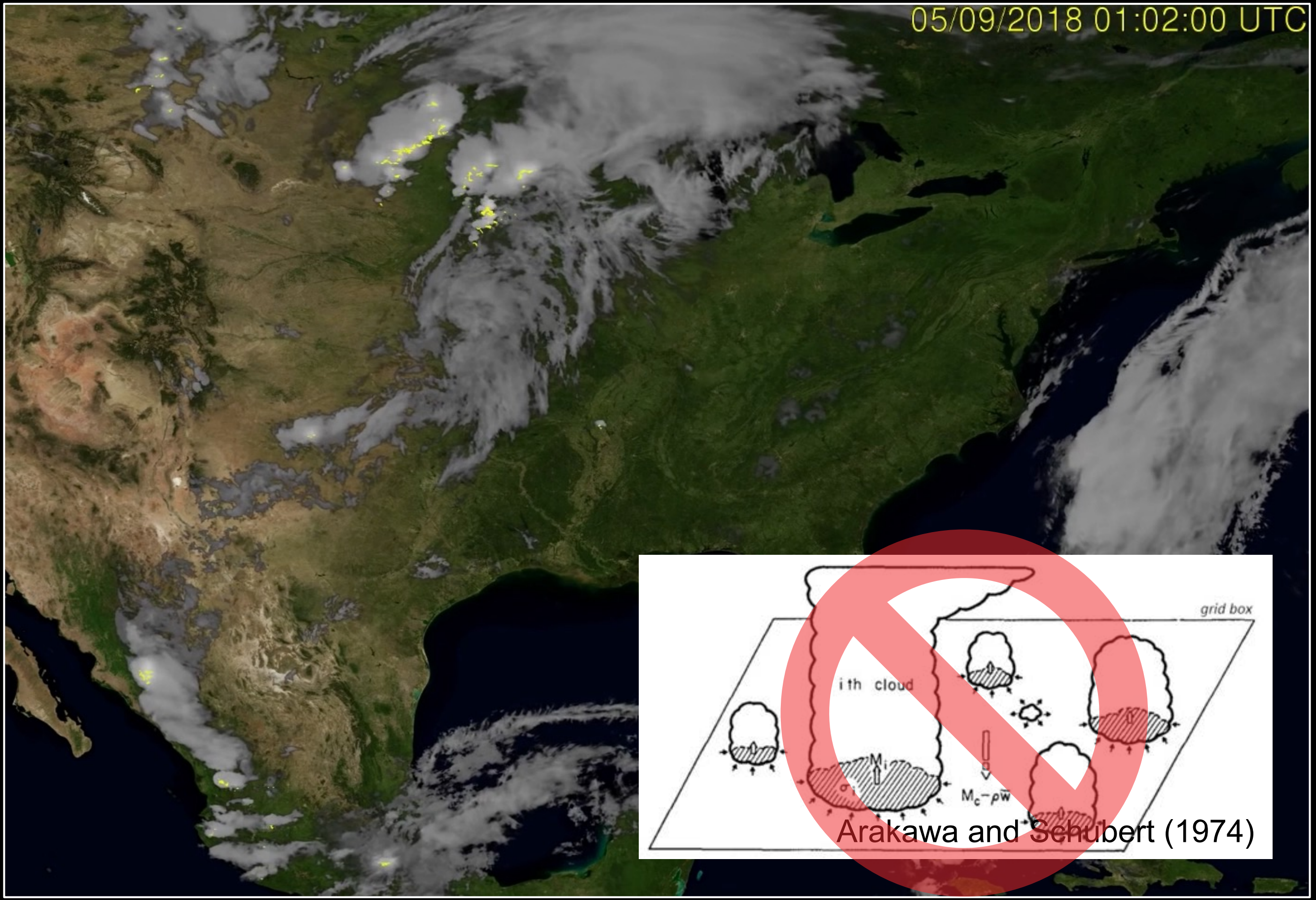
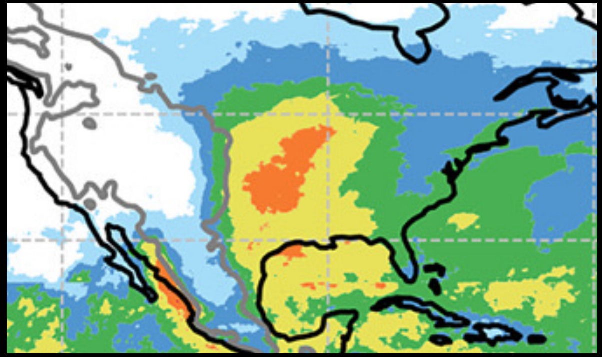
Mitch Dobrowner for The New York Times

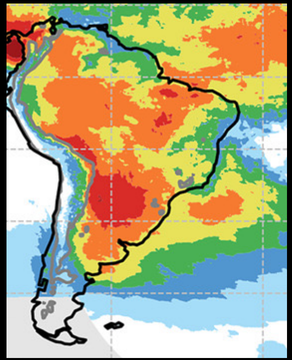
The Importance of Mesoscale Convective Systems in Weather and Climate

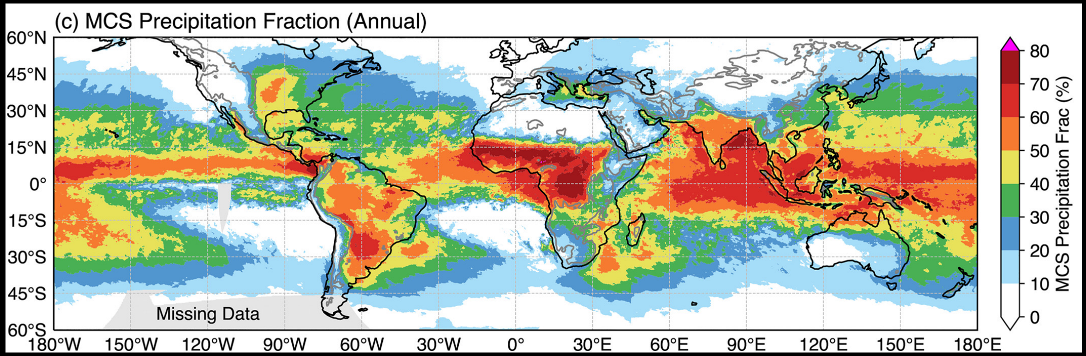


NOAA - https://www.youtube.com/watch?v=QFTrwqhEaKE

Fritsch et al. 1986:
"MCSs contribute between 30—70% to the warm season precipitation (April—September) in region between the Rocky mountains and the Mississippi River."







[Feng et al. 2021]

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MCS in 3 atmospheric regimes

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Research

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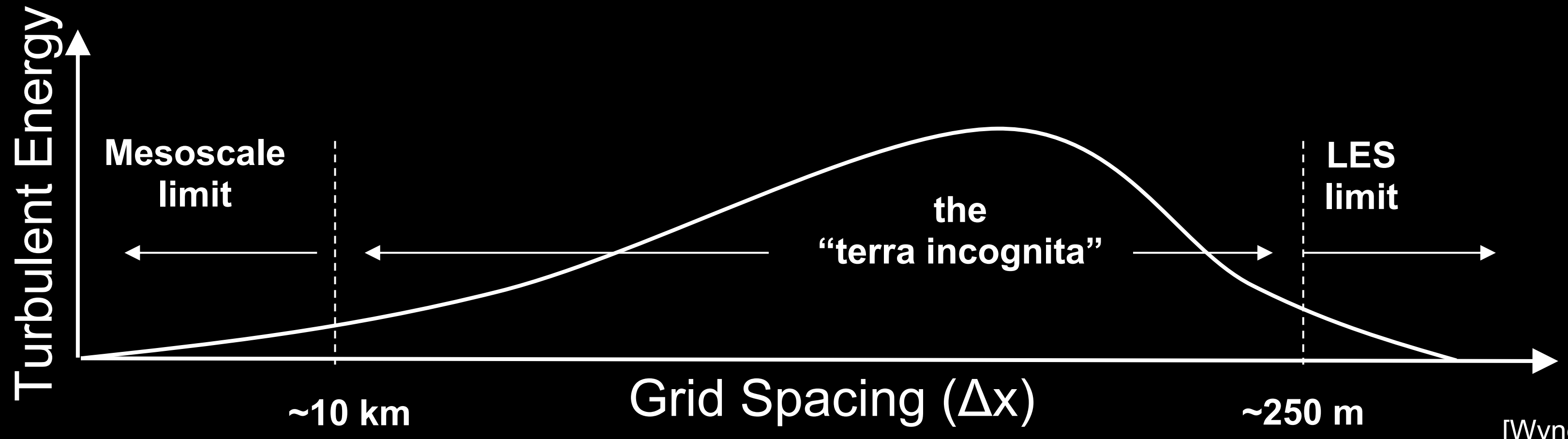
Sensitivity of organized convective storms to model grid spacing in current and future climates

A. F. Prein[1], R. M. Rasmussen[1], D. Wang[2] and S. E. Giangrande[2]

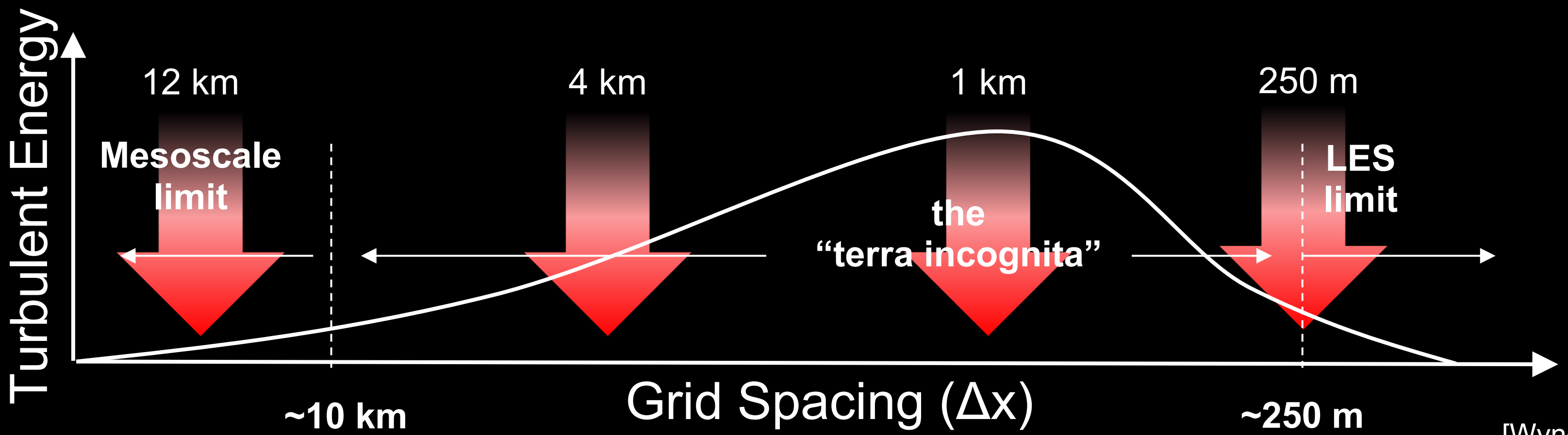
[1]National Center for Atmospheric Research, 3090 Center Green Drive, Boulder, CO 80301, USA
[2]Environmental and Climate Sciences Department, Brookhaven National Laboratory, 98 Rochester St, Upton, NY 11973, USA



[Wyngaard 2004, JAS]

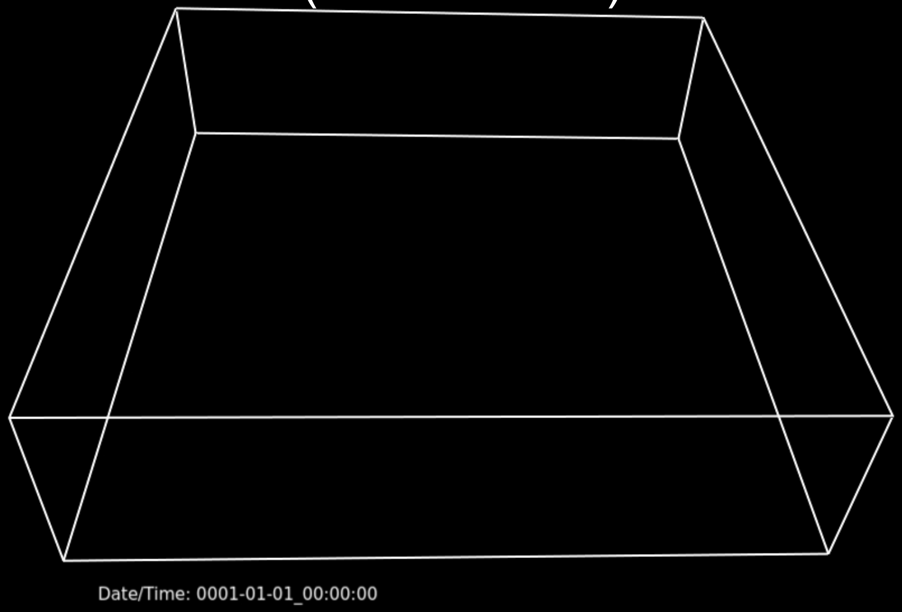
Prein et al. 2021

MCS in 3 atmospheric regimes

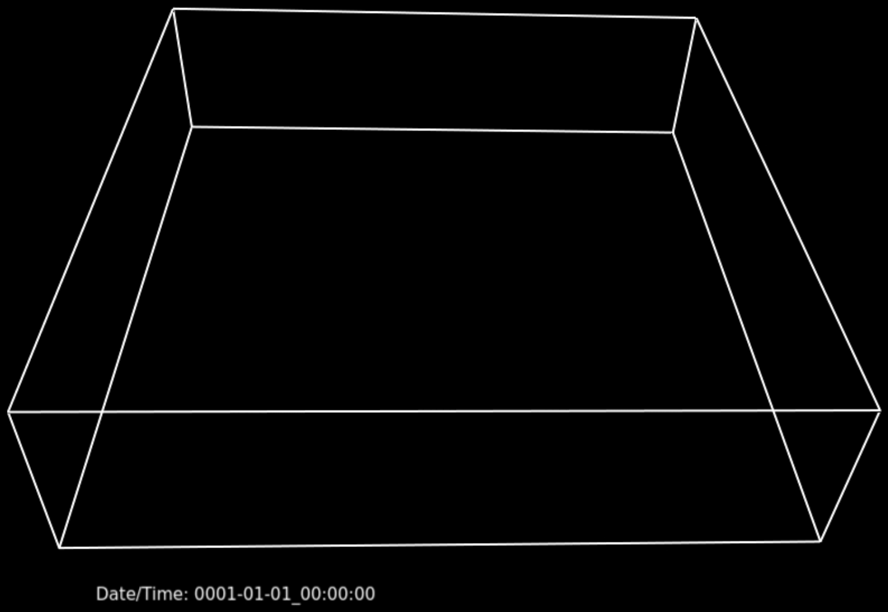


[Wyngaard 2004, JAS]

Δx = 12 km
(K-F scheme)

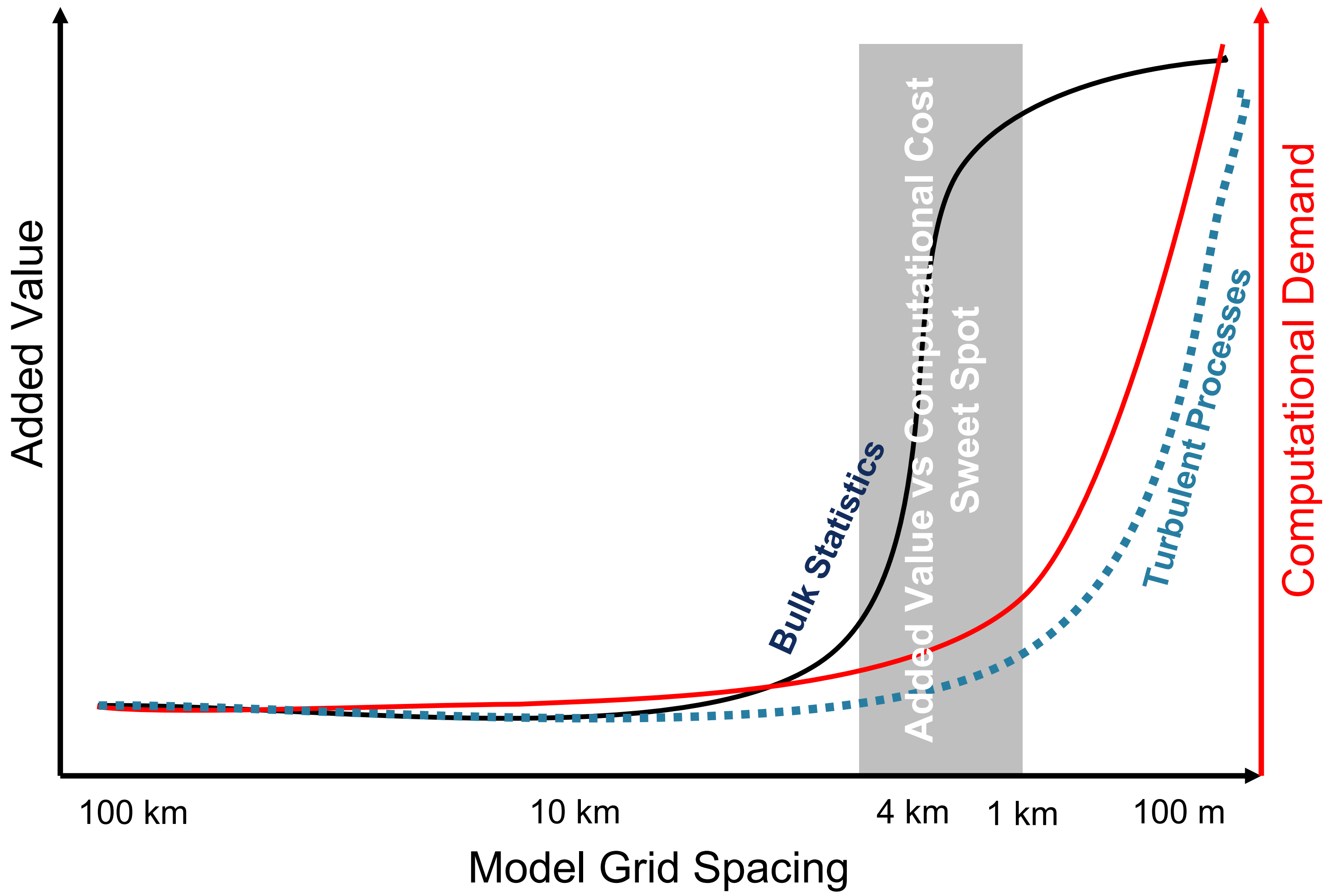


Δx = 4 km



Prein et al. 2021

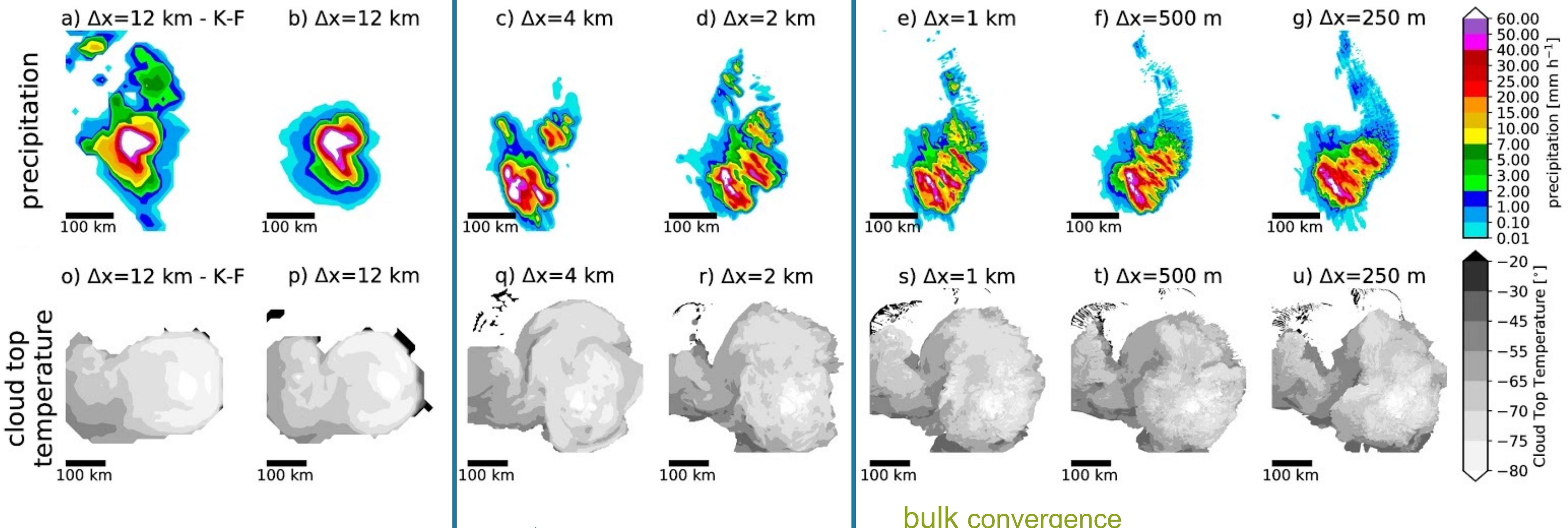
Why Kilometer-Scale Modeling?



Kilometer-Scale Models have large benefits in Simulation

- extreme precipitation
- tropical cyclones
- orographic processes
- coastal processes
- urban effects
- frequency, intensity, amount and phase of precipitation
- Land-atmosphere coupling

Example MCSs Features



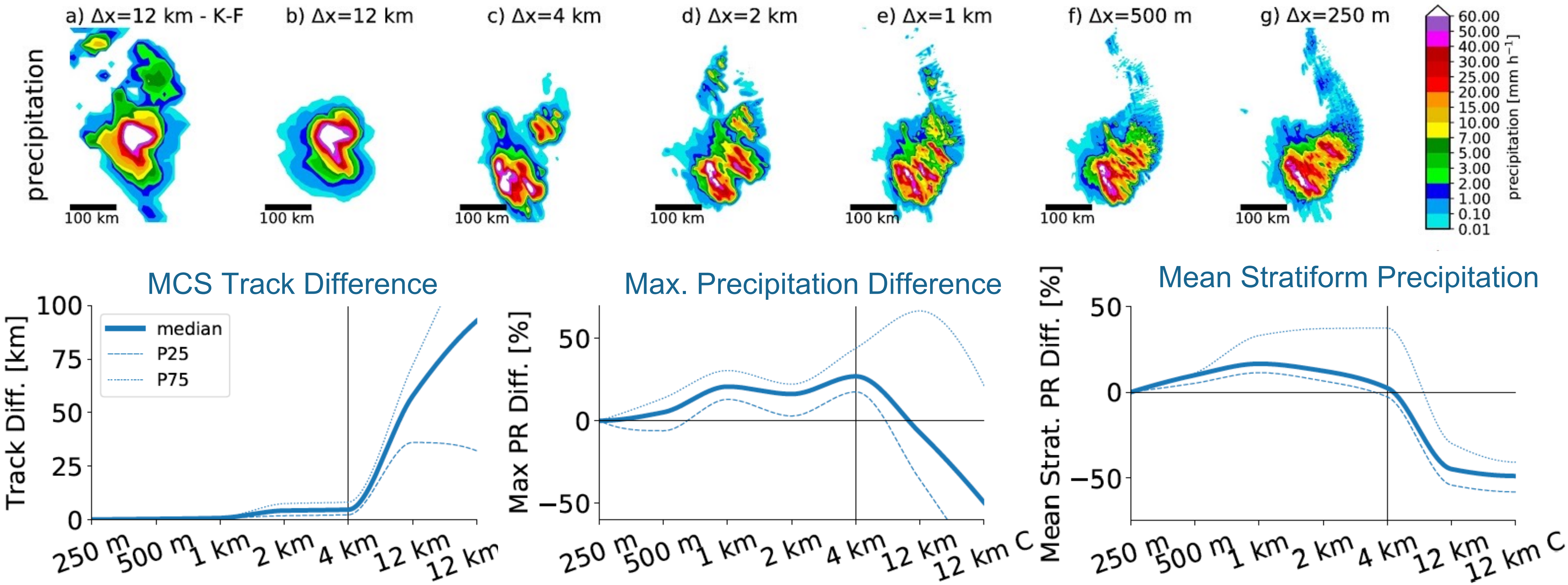
bulk convergence

step improvement
from Δx=12 km to Δx=4 km

further structural improvements from
Δx=4 km to Δx=1 km

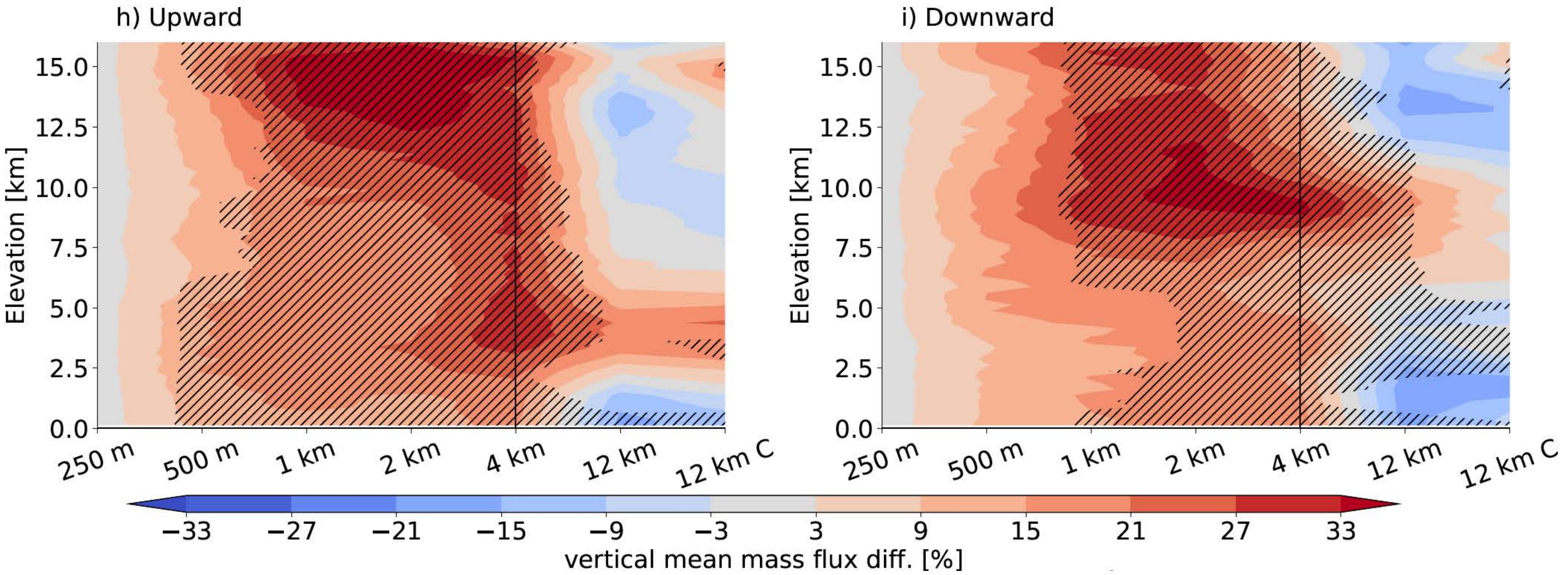
[Prein et al. 2021]

MCS Precipitation



[Prein et al. 2021]

MCS Mean Vertical Mass Flux



[Prein et al. 2021]

Evaluating Convective Drafts with Radar Wind Profiler (RWP) Observations

JGR Atmospheres

RESEARCH ARTICLE

10.1029/2019JD031774

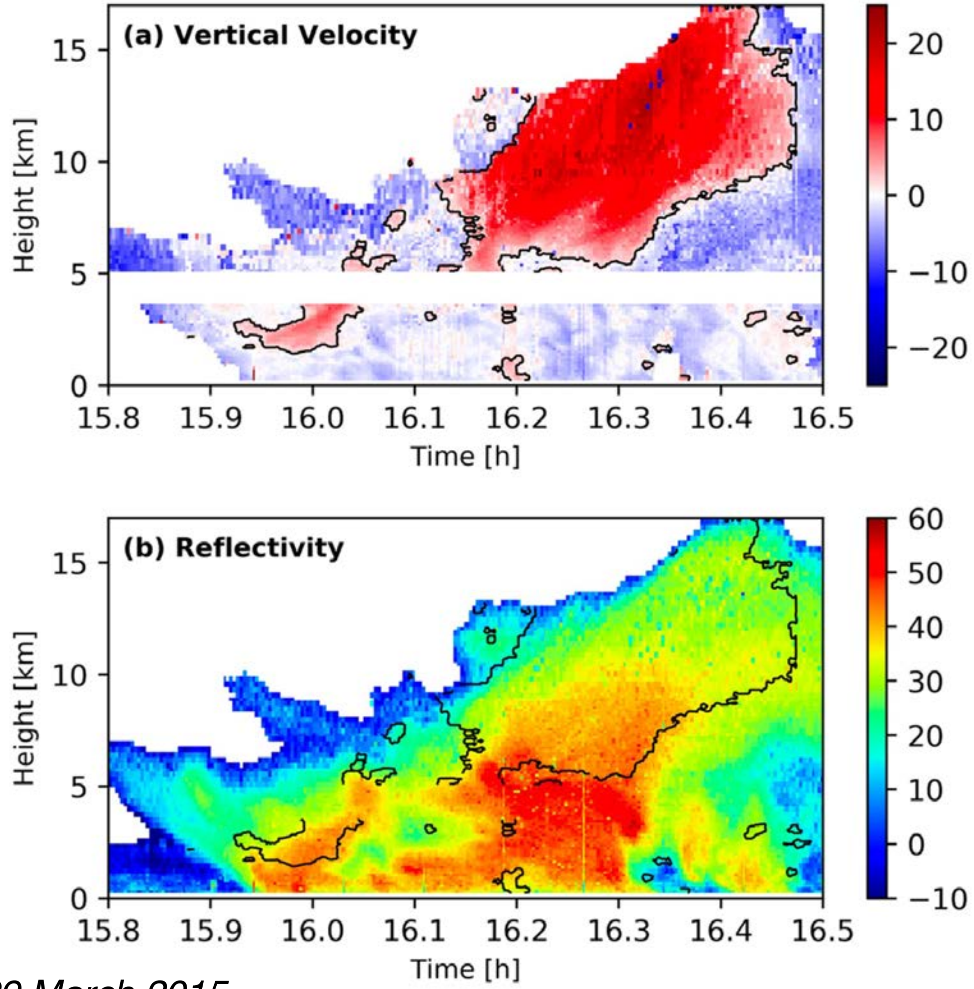
Key Points:

- Mature Oklahoma mesoscale convective systems exhibit more intense, wider convective drafts than Amazon systems
- Drafts intensity increases with core width and with altitude

Updraft and Downdraft Core Size and Intensity as Revealed by Radar Wind Profilers: MCS Observations and Idealized Model Comparisons

Dié Wang[1], Scott E. Giangrande[1], Zhe Feng[2], Joseph C. Hardin[2], and Andreas F. Prein[3]

Radar Wind Profiler (RWP)



29 March 2015

MCS event during GoAmazon2014/15 field campaign

Wang et al. 2020

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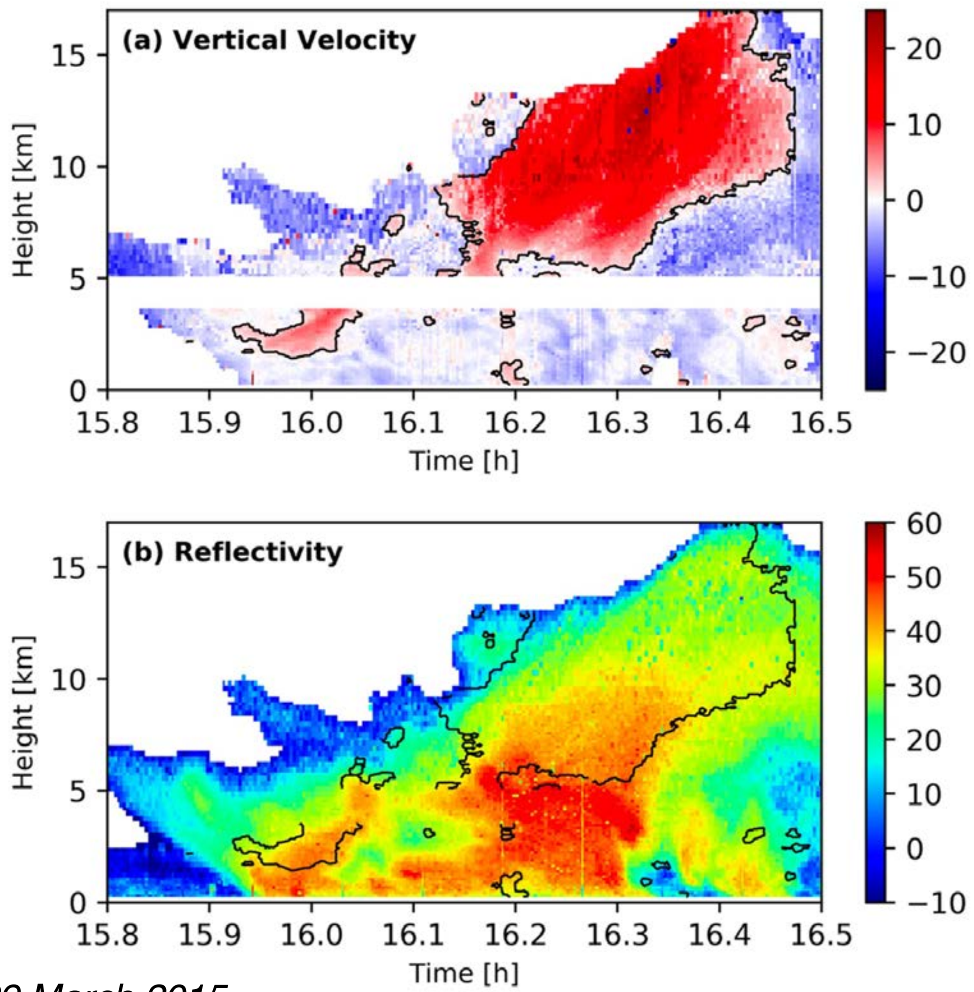
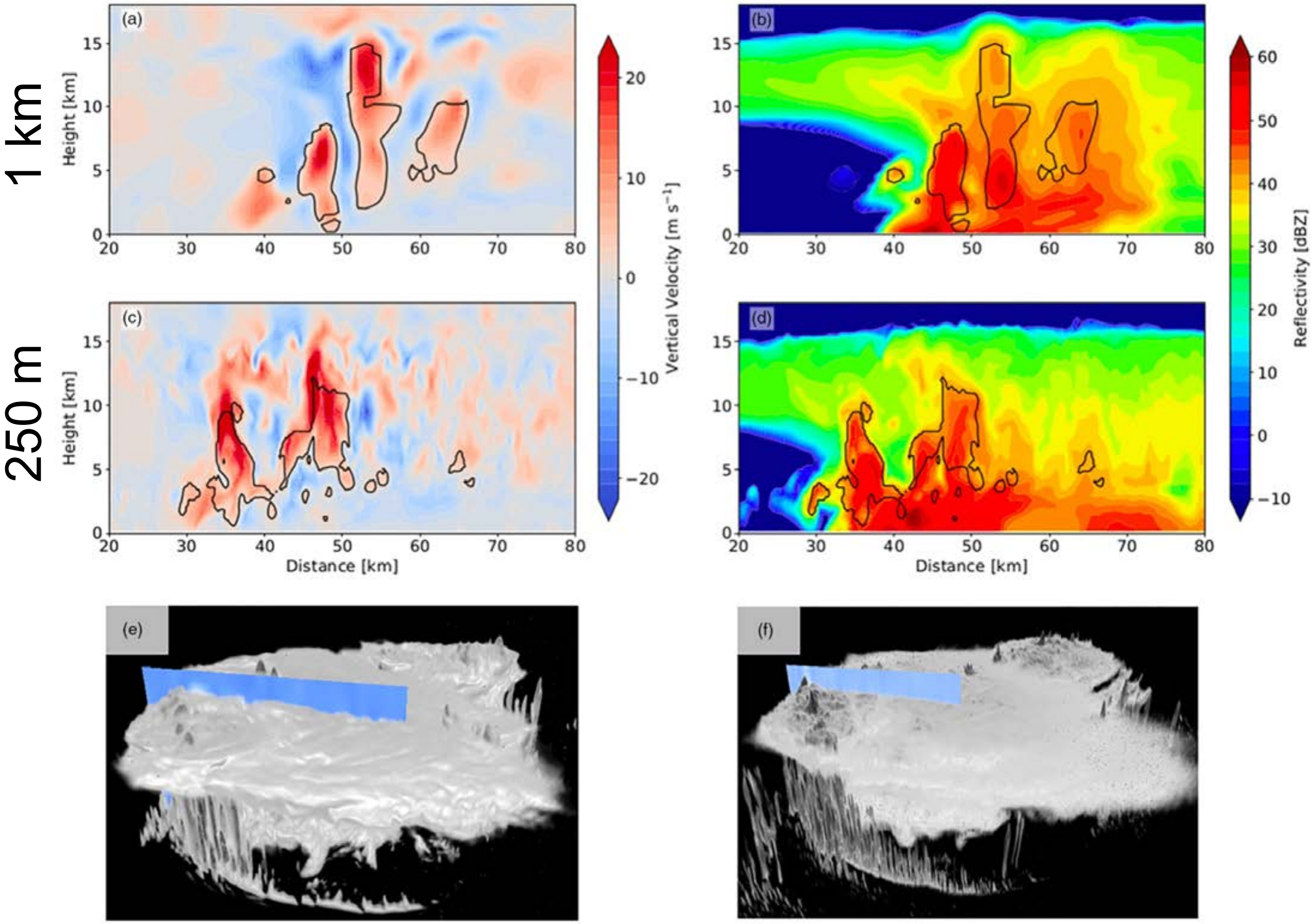
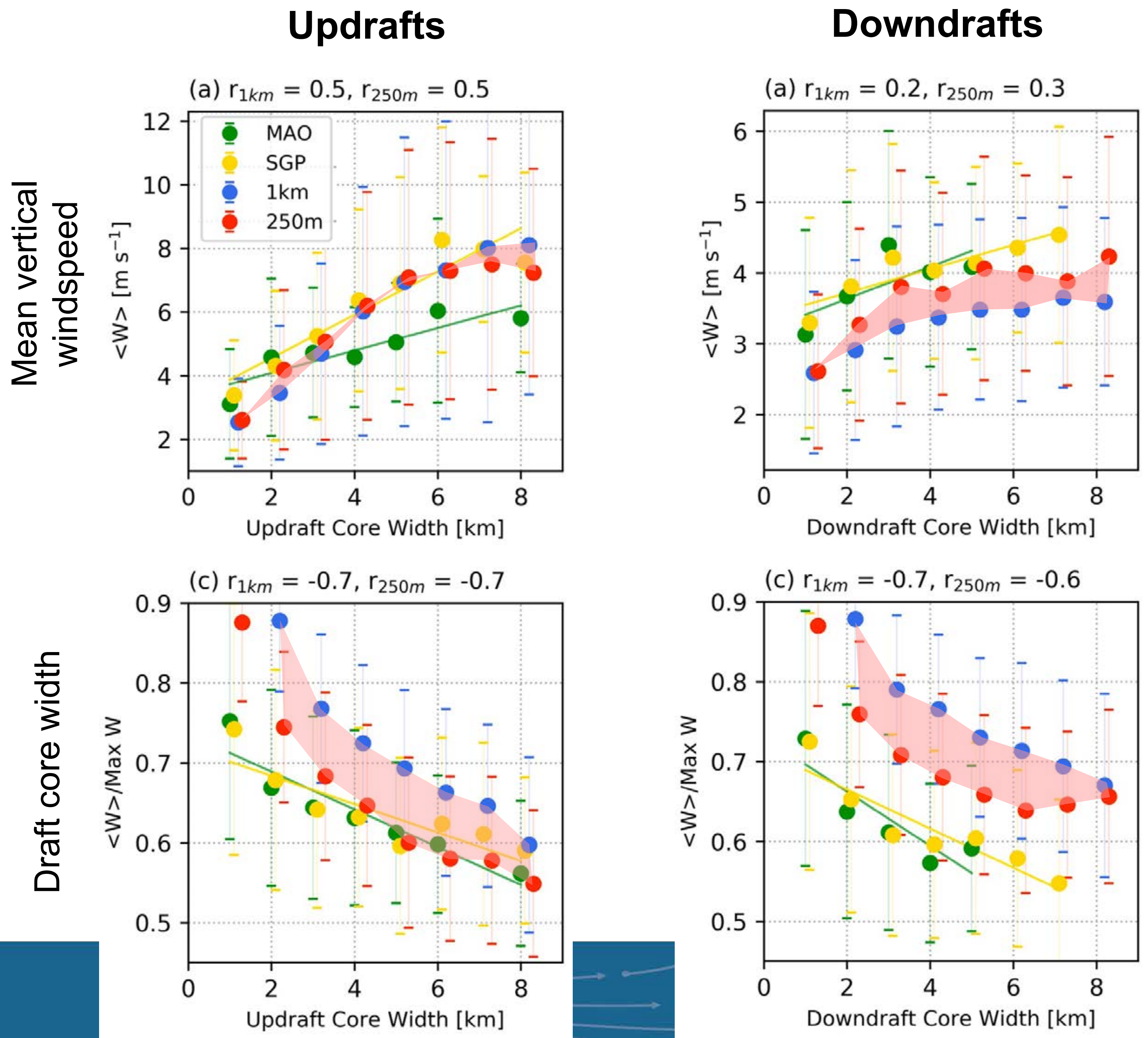




29 March 2015
MCS event during GoAmazon2014/15 field campaign
Wang et al. 2020

Convective Core Properties as a Function of Core Width

- Km-scale models have to large cores
- 1 km model draft statistics are better than expected
- 250 m simulations show improvements
- At 250 m – updrafts start to converge but downdrafts do not



Wang et al. 2020

Simulate MCS Overpasses over the SGP and MAO ARM Site Across the Convective Gray Zone

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).

AGU ADVANCING EARTH AND SPACE SCIENCE

Earth and Space Science

RESEARCH ARTICLE

10.1029/2022EA002295

Key Points:

- Simulated US and Amazonian mesoscale convective systems (MCSs) are evaluated accounting for spatiotemporal and rotational errors

Towards a Unified Setup to Simulate Mid-Latitude and Tropical Mesoscale Convective Systems at Kilometer-Scales

Andreas F. Prein[1], Ming Ge[1], Alexandra Ramos Valle[1], Dié Wang[2], and Scott E. Giangrande[2]

[1]National Center for Atmospheric Research, Boulder, CO, USA, [2]Brookhaven National Laboratory, Upton, NY, USA

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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).

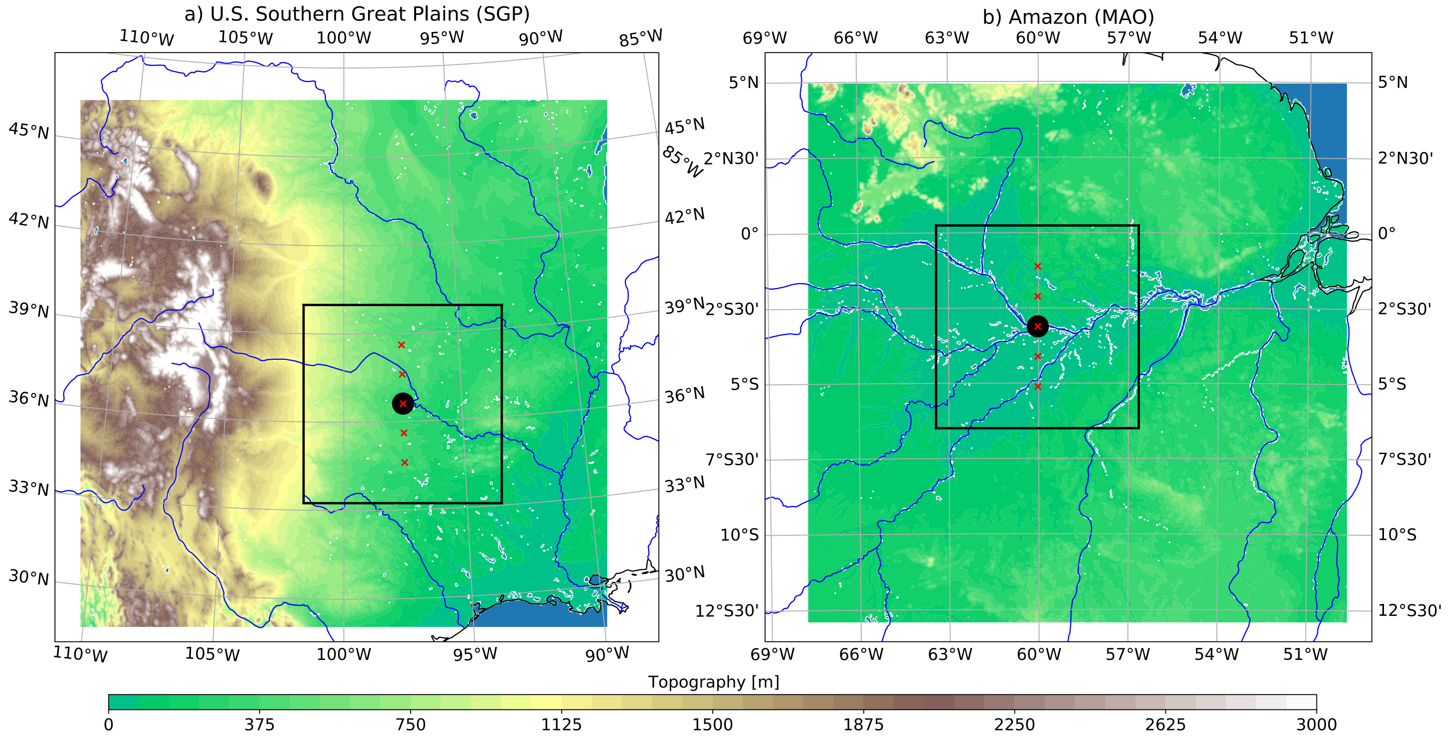
Simulated Cases

Main Physics Setting for 12 km, 4 km, 2 km & 1 km simulations

- ERA5 downscaling (36-hour runtime)
- Thompson Microphysics (Morrison & P3 tested at 4 km)
- YSU PBL scheme (MYJ and MYNN tested at 4 km)
- RRTNG radiation scheme
- Noah-MP land surface scheme
- One 12 km simulation ensemble was ran using the KF deep convection scheme

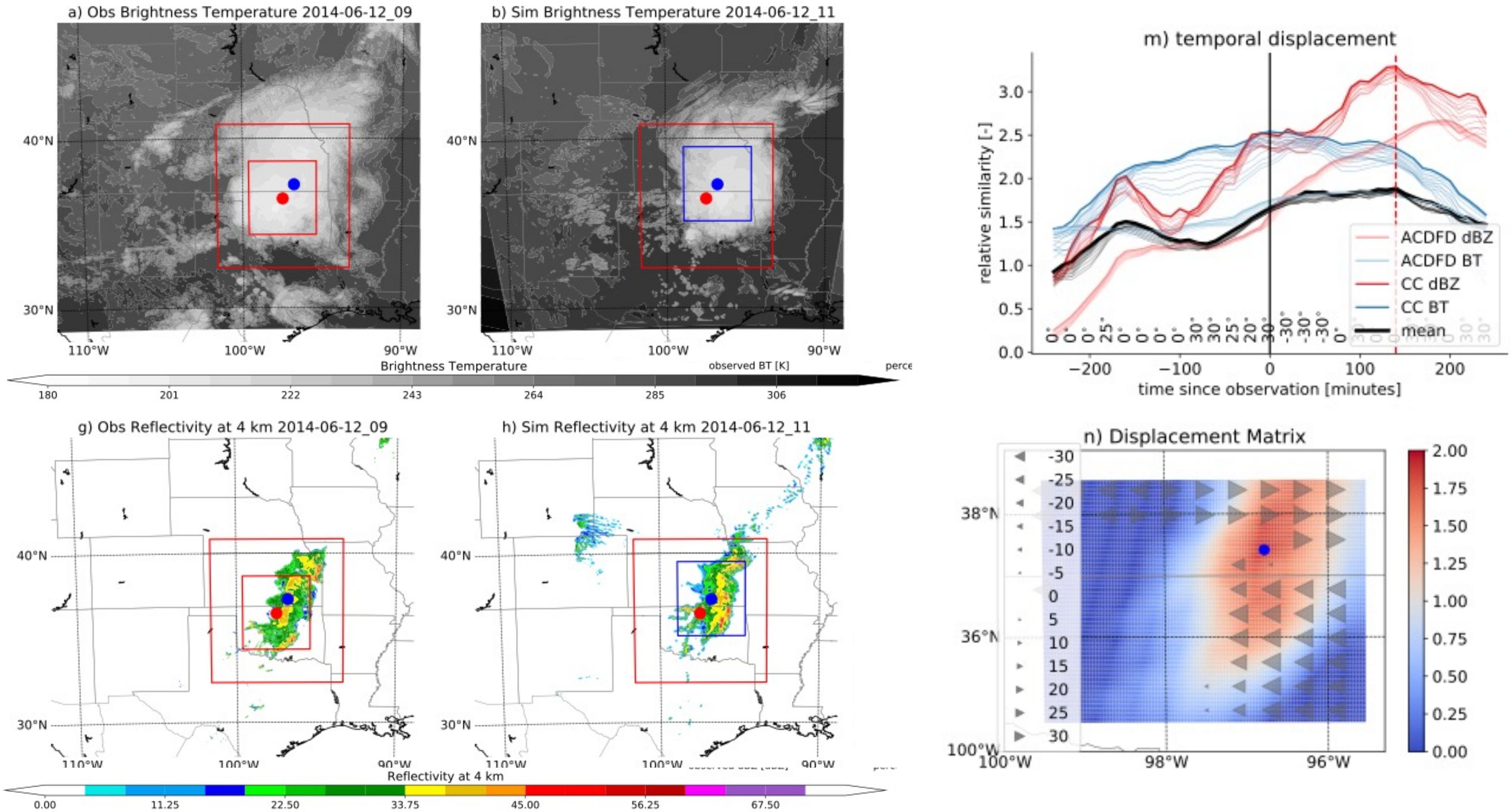
Changes for 500 m, 250 m, and 125 m runs

- No PBL, diff_opt=2 and km_opt =2 (1.5 order 3D TKE closure)
- 12 hours runtime online nested in 1 km run



Evaluating MCS Simulations in Spite of Spatiotemporal Displacements

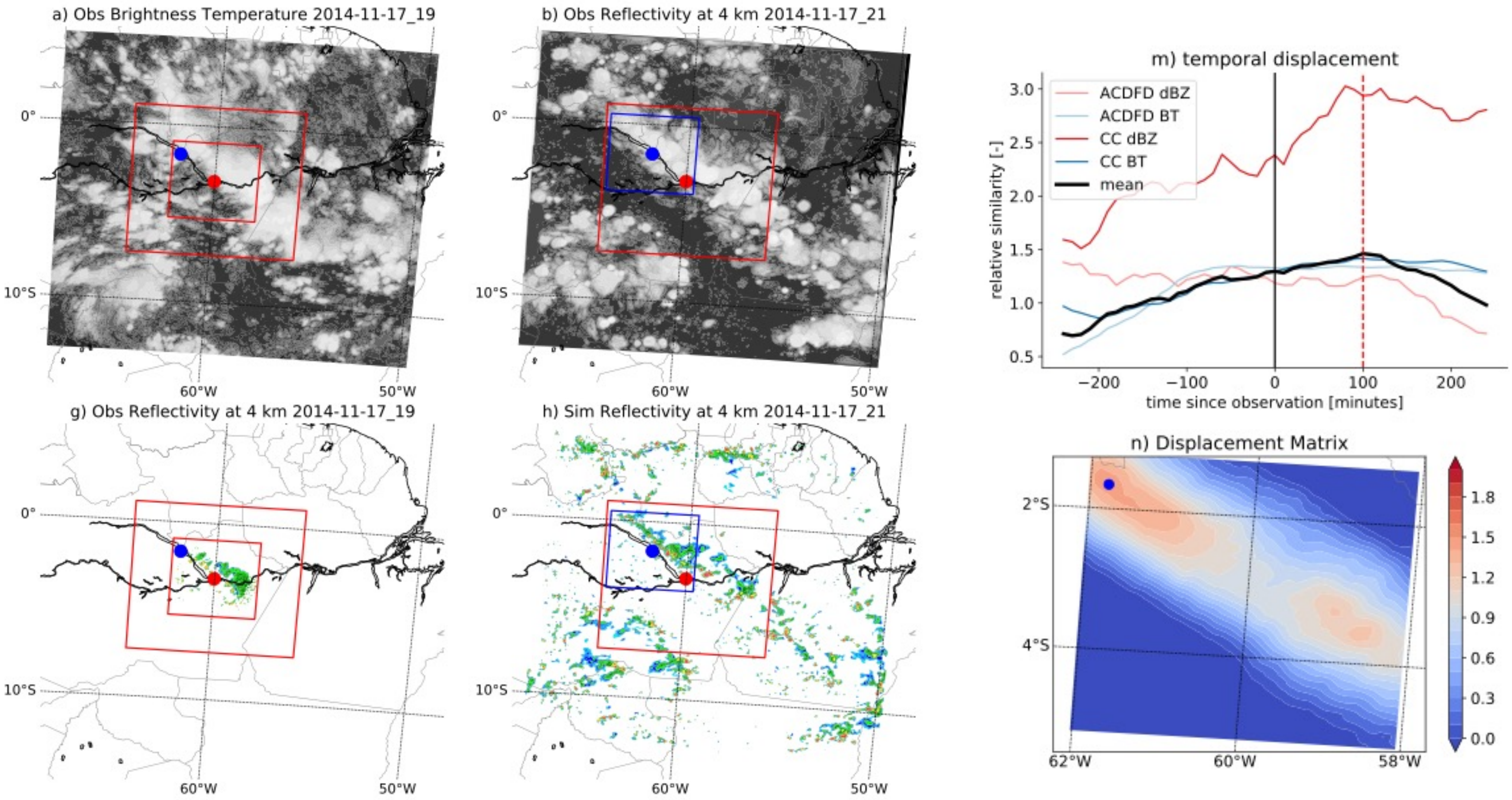
12 June 2014, 9 UTC



Prein et al. (2022)

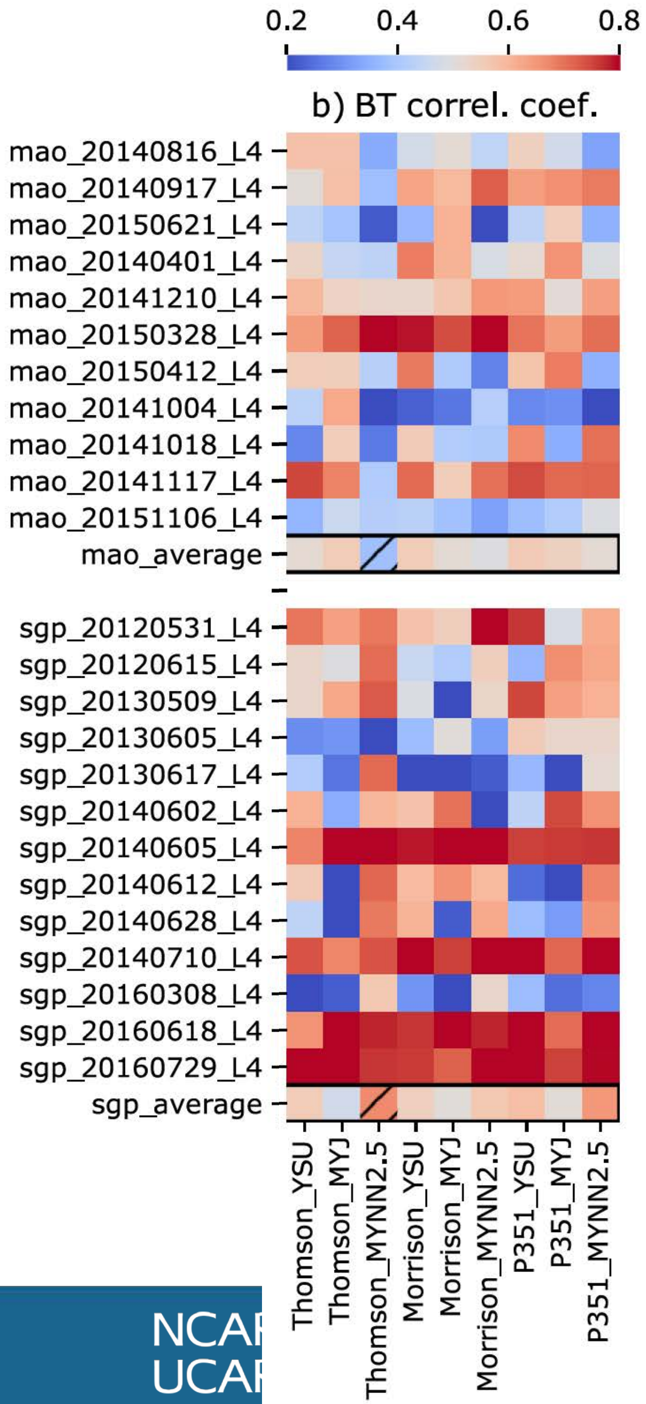
Evaluating MCS Simulations in Spite of Spatiotemporal Displacements

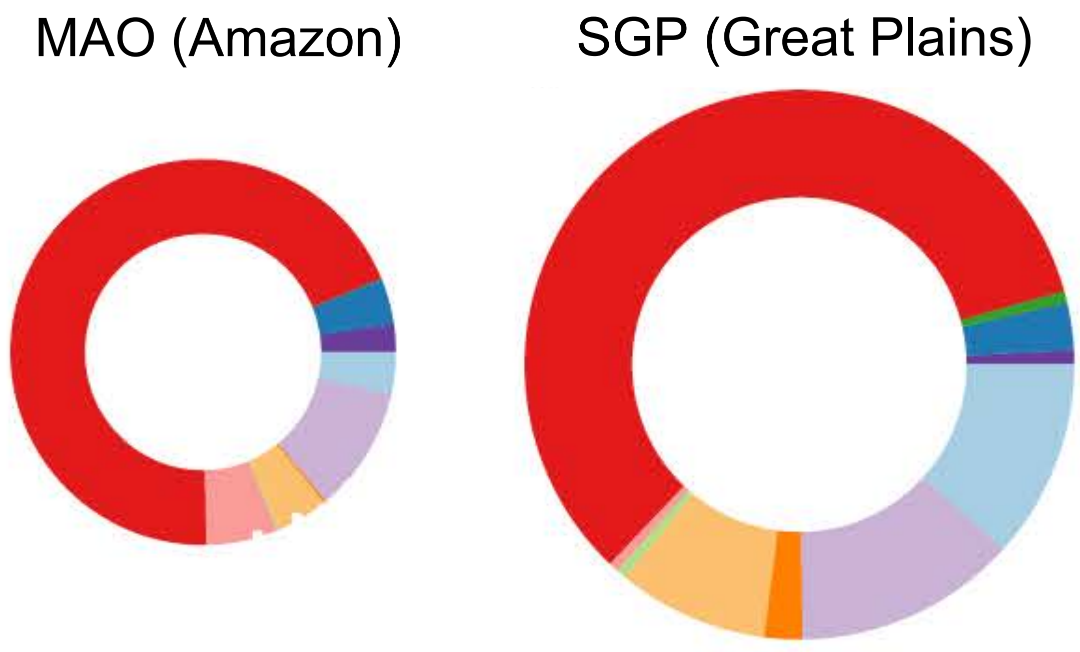
17 November 2014, 21 UTC



Prein et al. (2022)

Uncertainty Sources
Brightness Temperature Correlation Coefficients

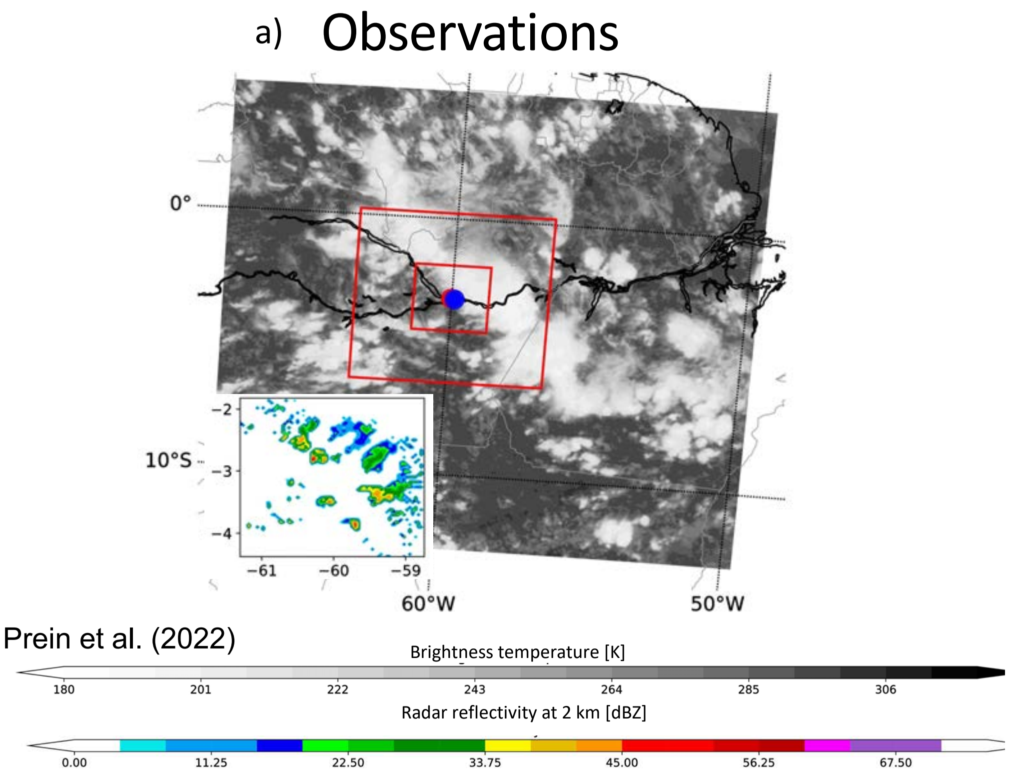




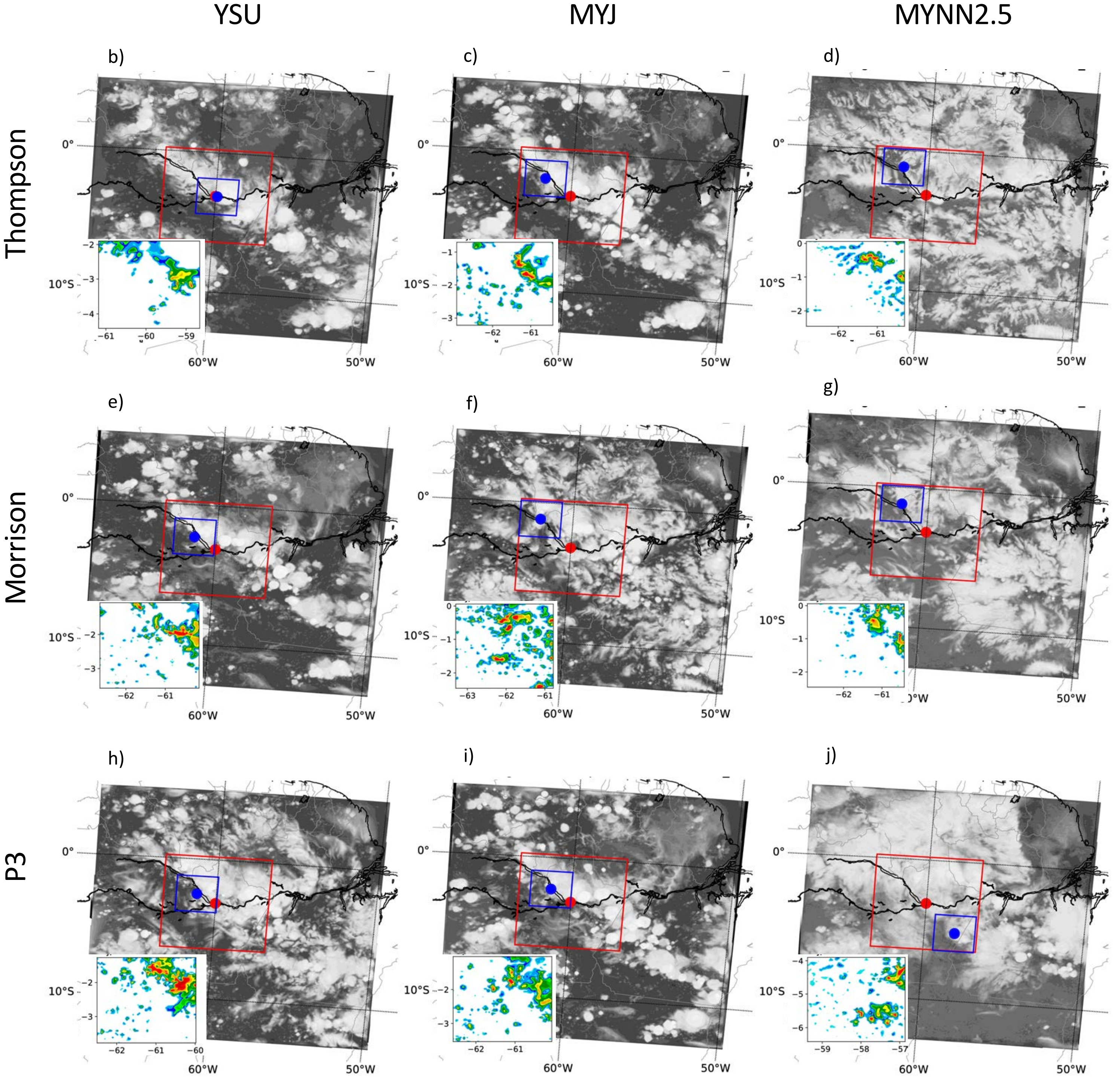
The major source of model evaluation uncertainty comes from case-to-case variability

Prein et al. (2022)

Example Physics Sensitivities



Prein et al. (2022)



- Simulations using MYNN2.5 perform well in SGP but poor in MAO
- Large Case to Case variability
- Thompson and YSU performed well in both locations

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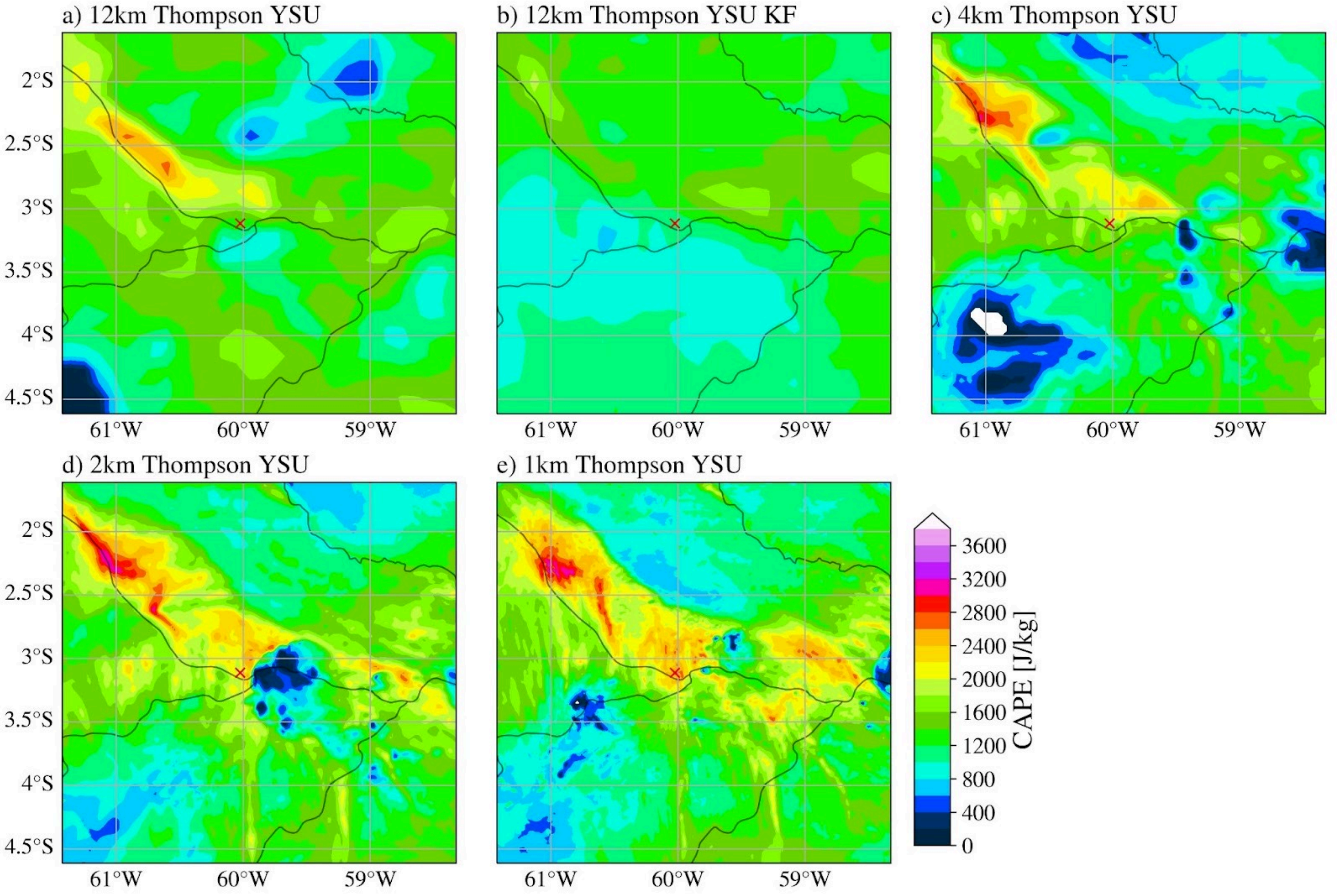
Representativeness of Point/Column Observations

- Many fields are highly variable in space and time
- “Infrequent” point observations such as with radiosonde soundings might be non-representative for case studies

Simulated mixed layer CAPE
April 1, 2014 at 11:40 UTC | 3.5 hours before MCS overpass



Ramos-Valle et al. (in review)

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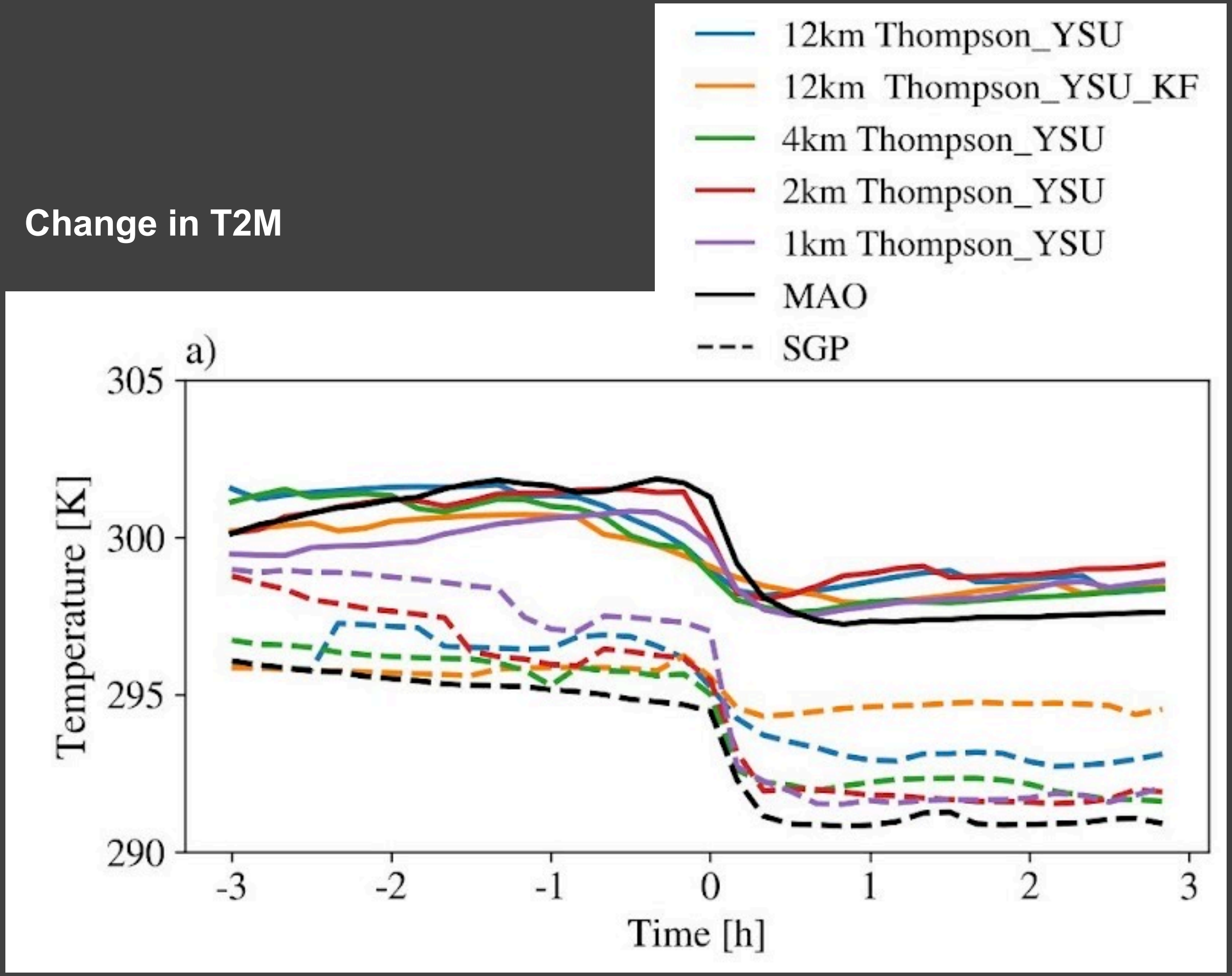
Evaluation with Surface Observations

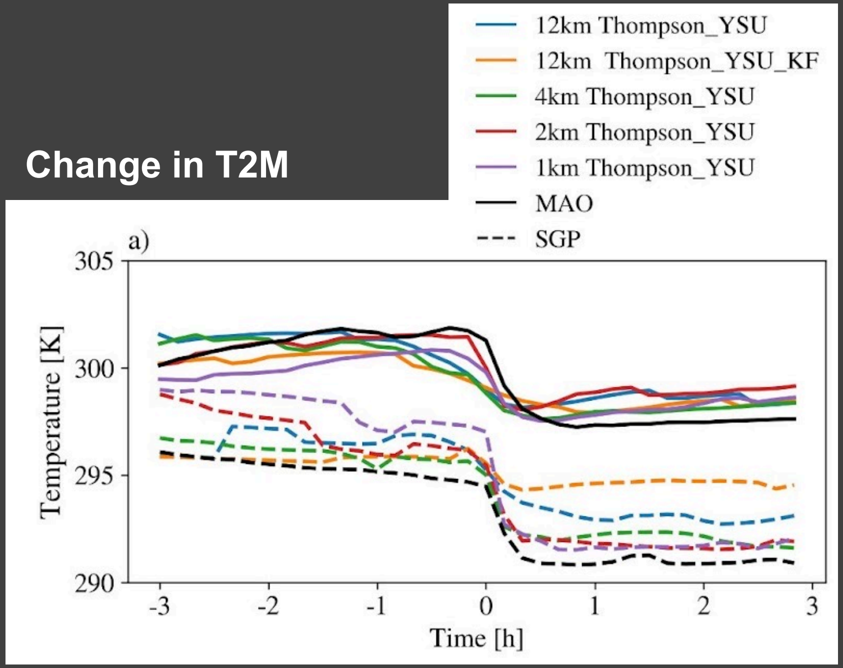
Change in T2M



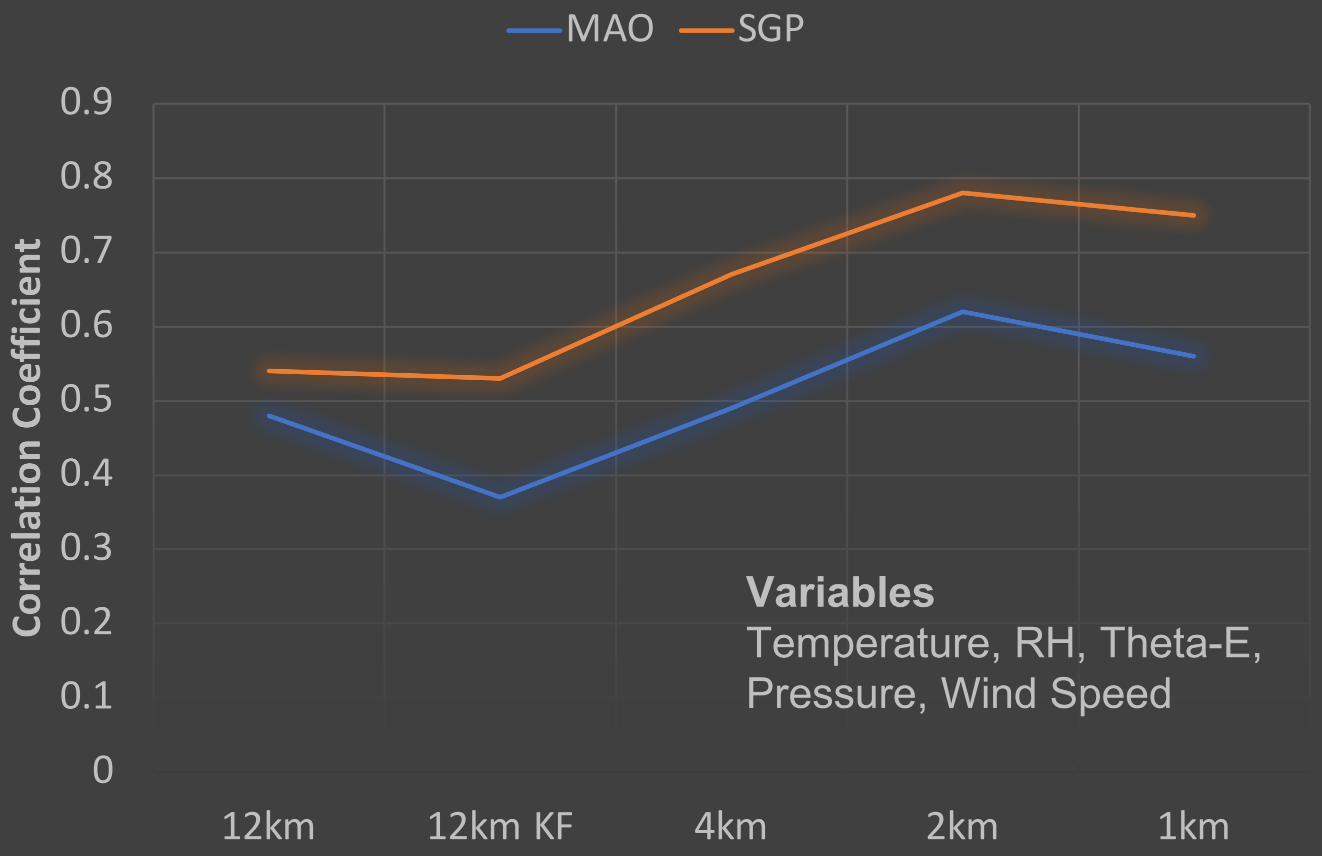
Ramos-Valle et al. (in review)

Evaluation with Surface Observations

Change in T2M



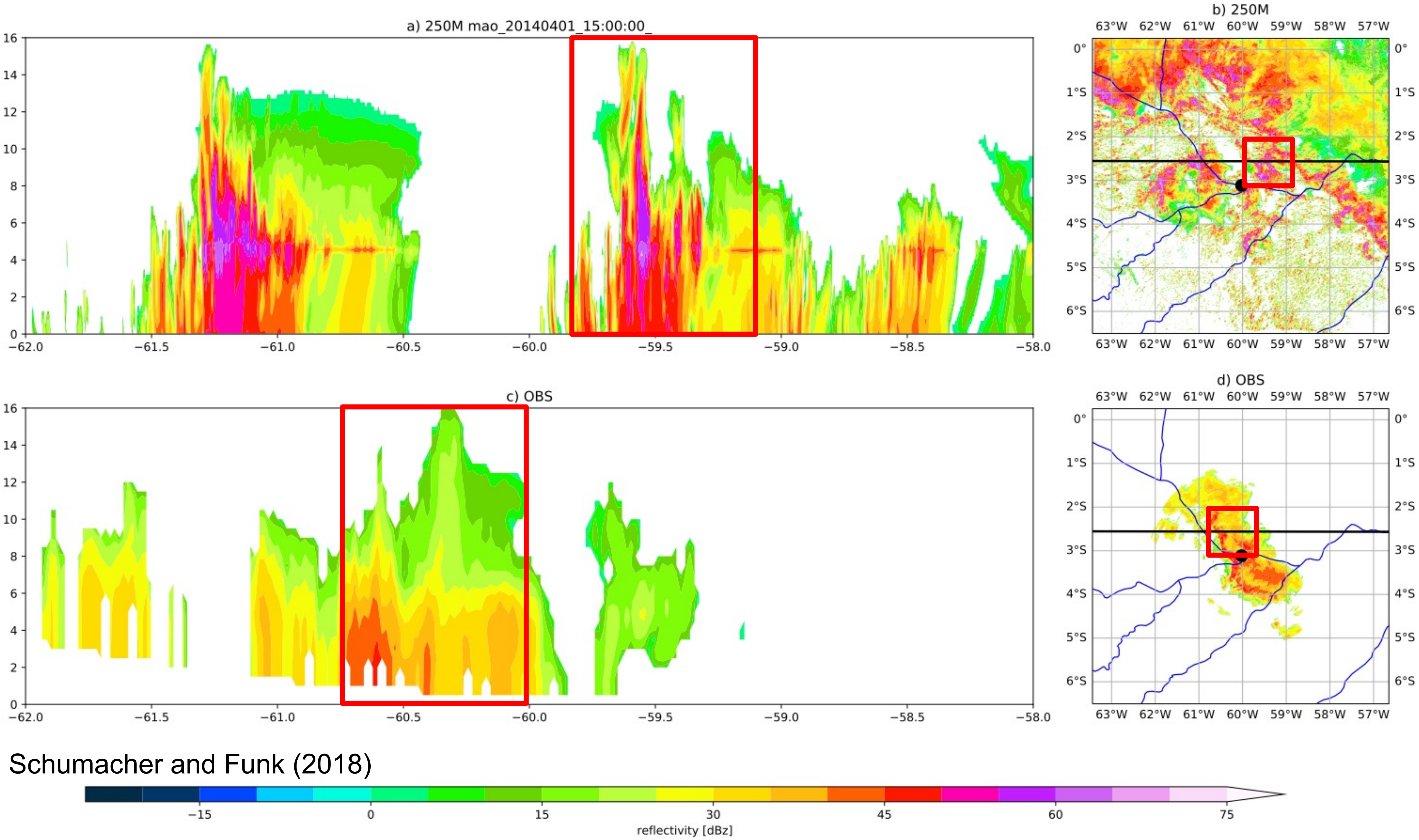
Correlation Coefficient of Near Surface Changes During MCS Overpass



Ramos-Valle et al. (in review)

Improving km-Scale Models by Using LESs and ARM Observations

MAO on April 1 2014, 15 UTC



Schumacher and Funk (2018)

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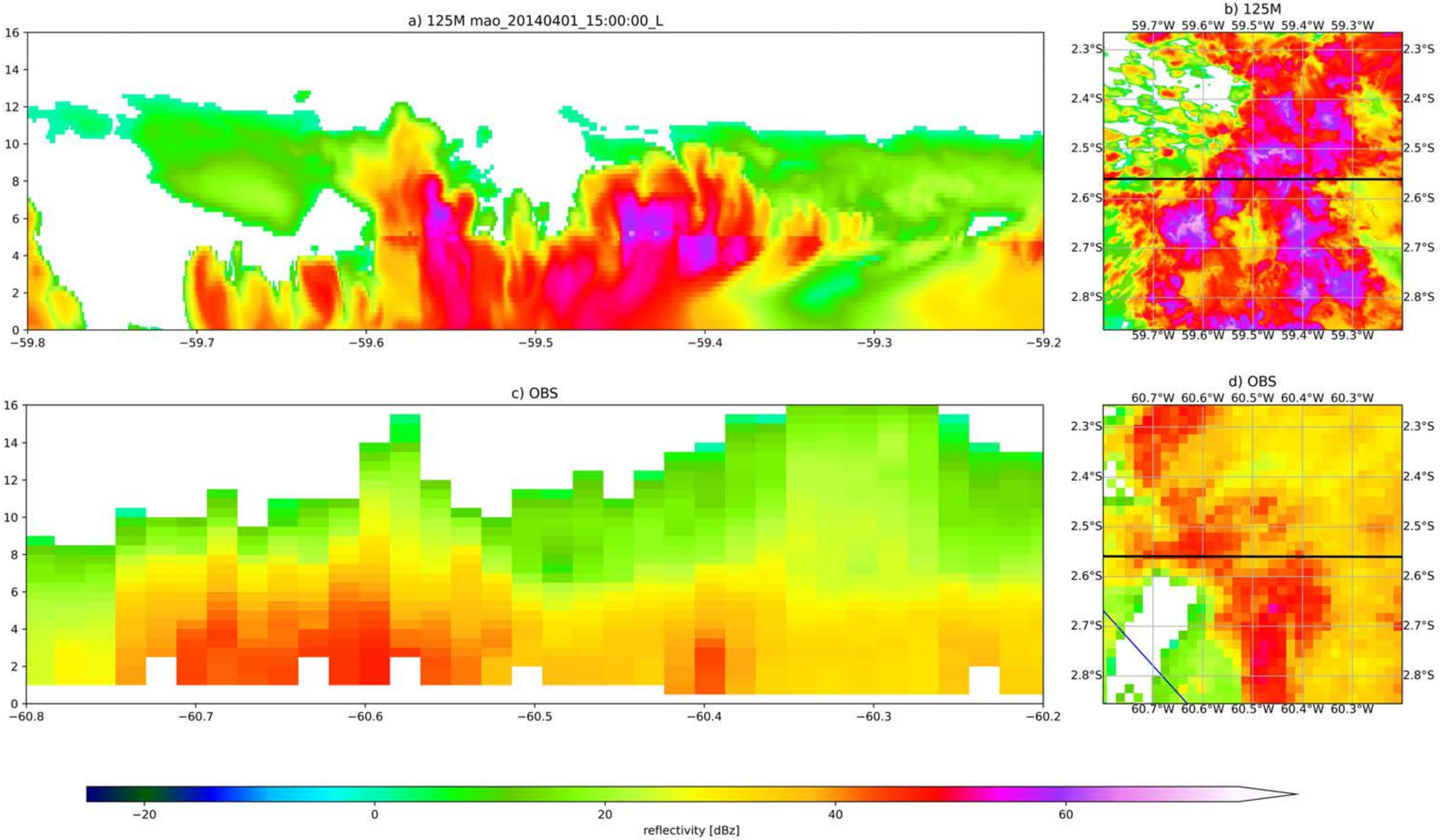
Learning from LESs and ARM Observations

MAO on April 1 2014, 15 UTC



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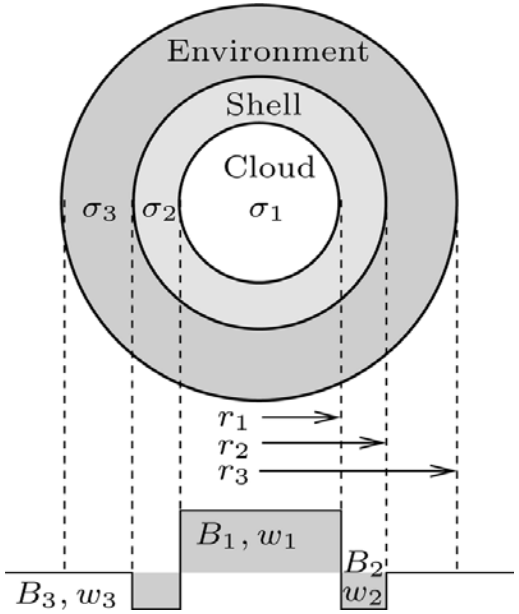
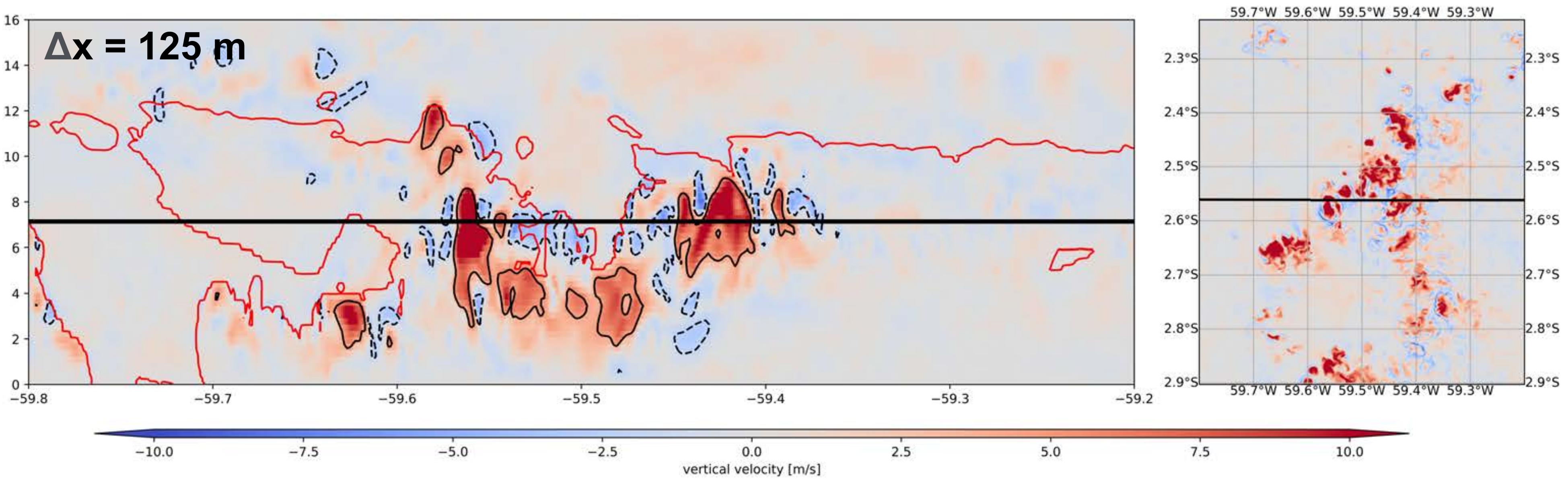
Learning from LESs and ARM Observations

MAO on April 1 2014, 15 UTC



Heus and Jonker (2008)



Learning from LESs and ARM Observations

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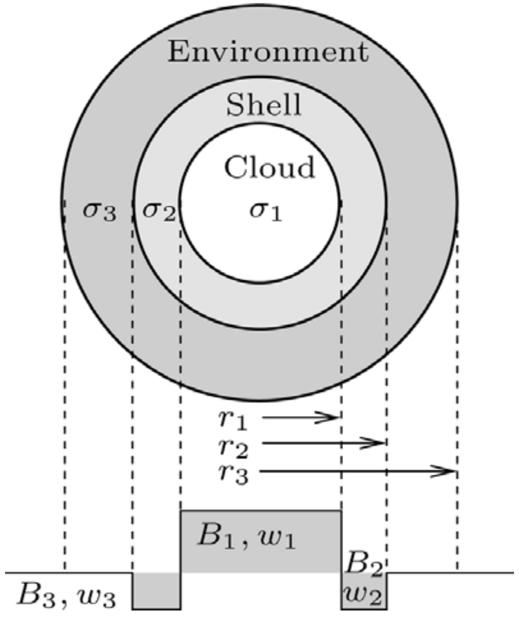

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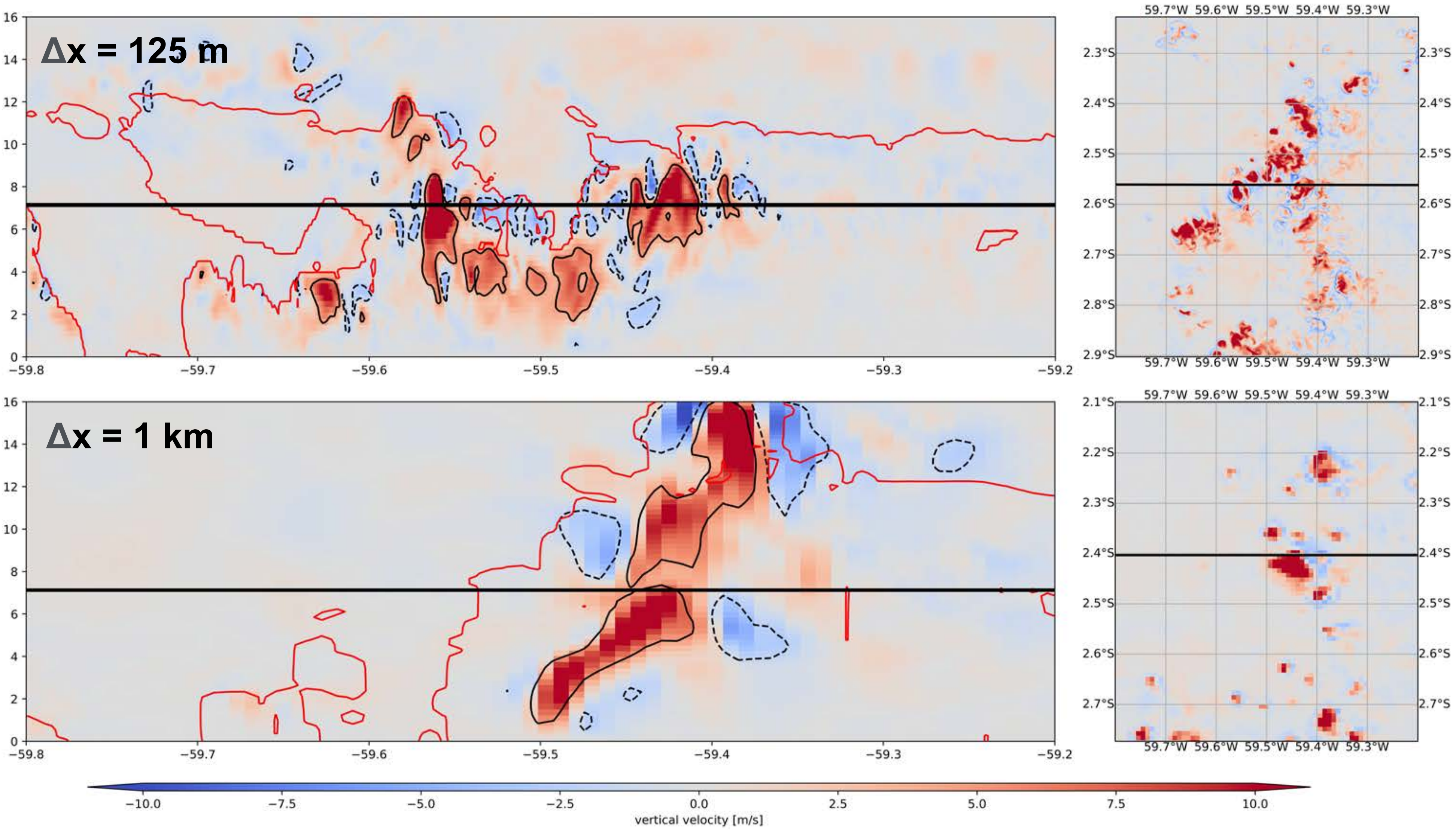

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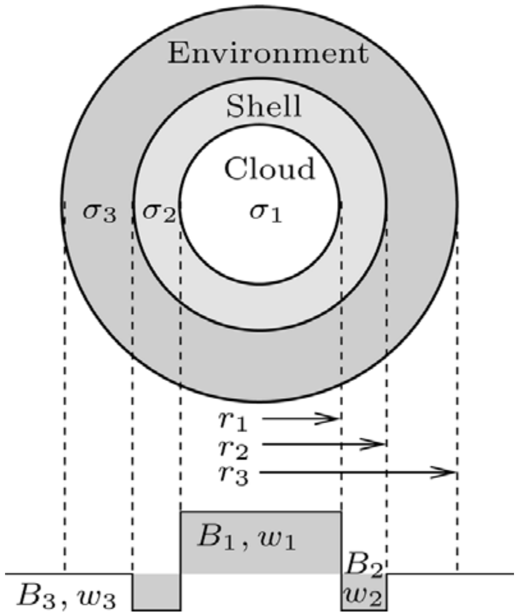

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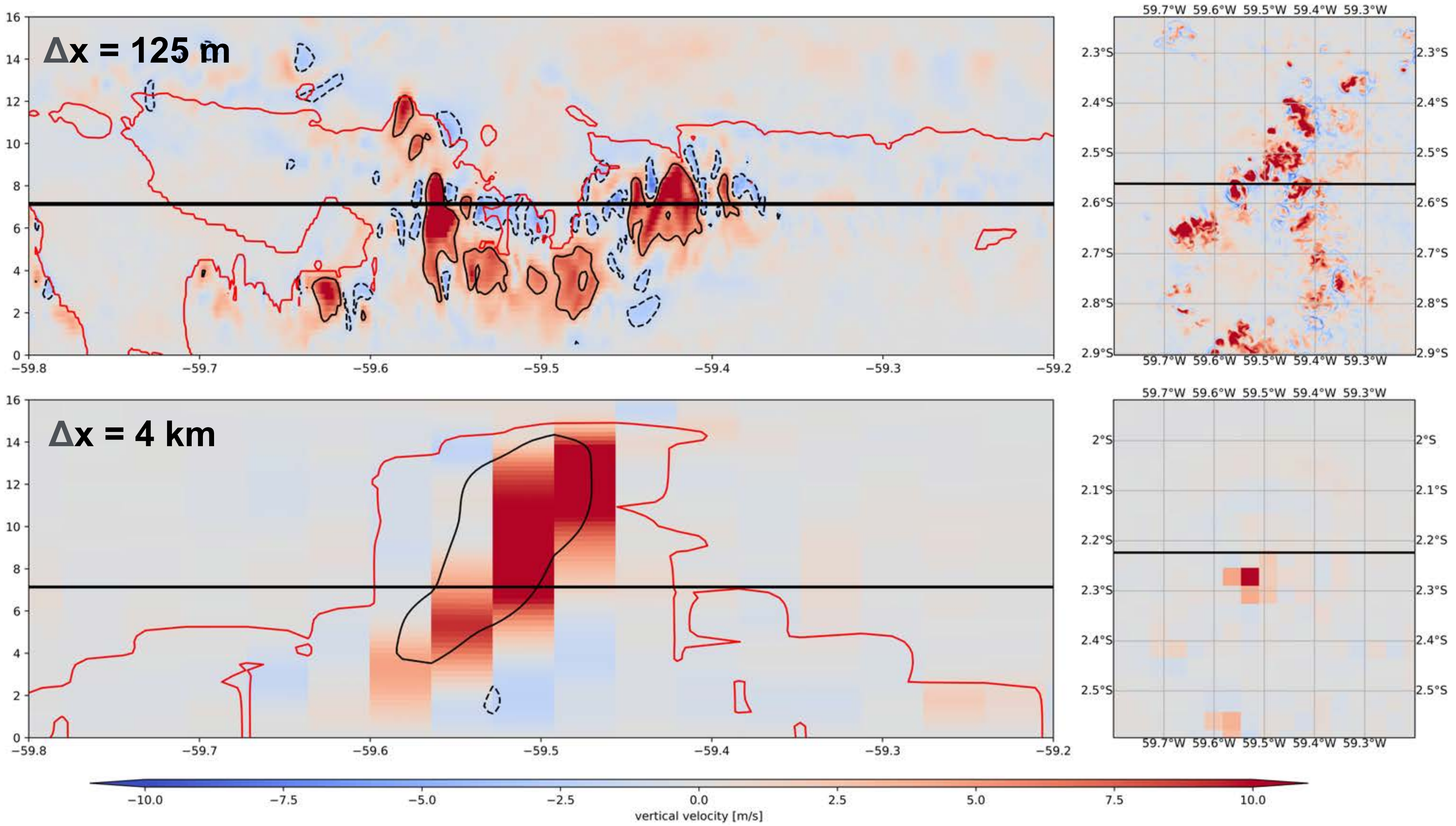
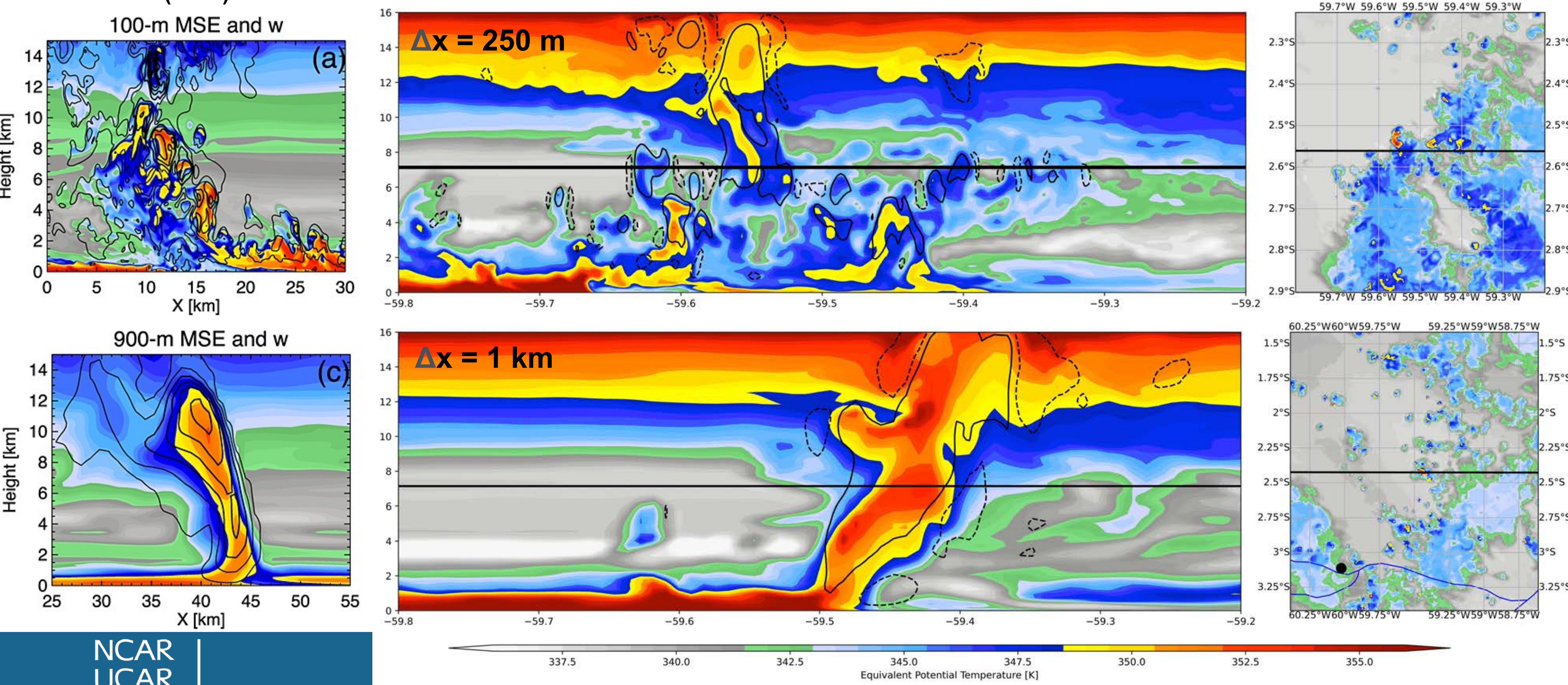


Stanford et al. (2020) show that the undermixing of updrafts at km-scales is difficult to improve.

Learning from LESs and ARM Observations

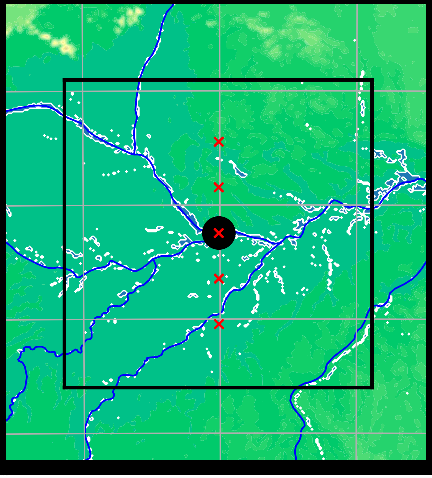
MAO on April 1 2014, 15 UTC

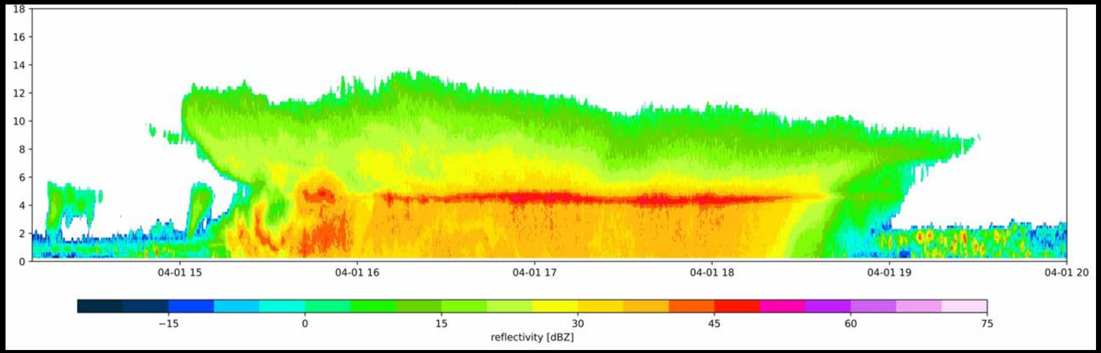
Varbel et al. (2014)

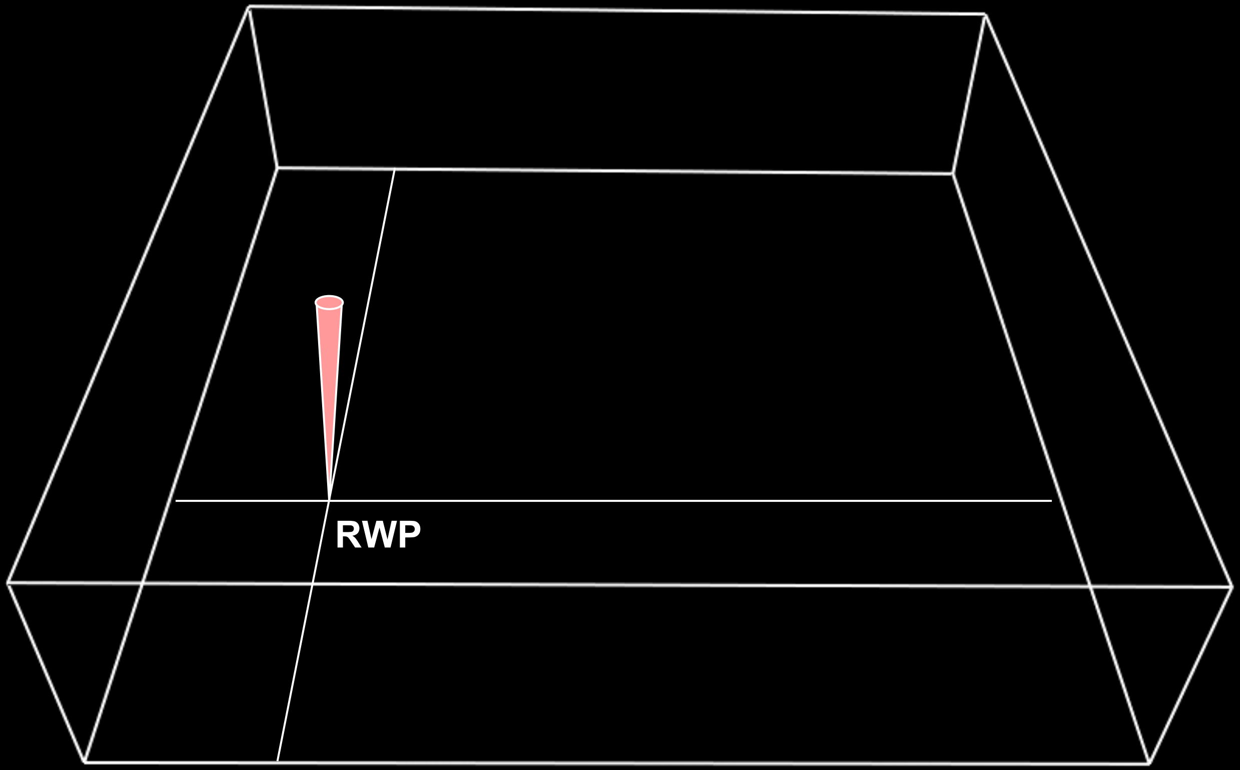


RADAR WIND PROFILER (RWP)

Virtual RWPs



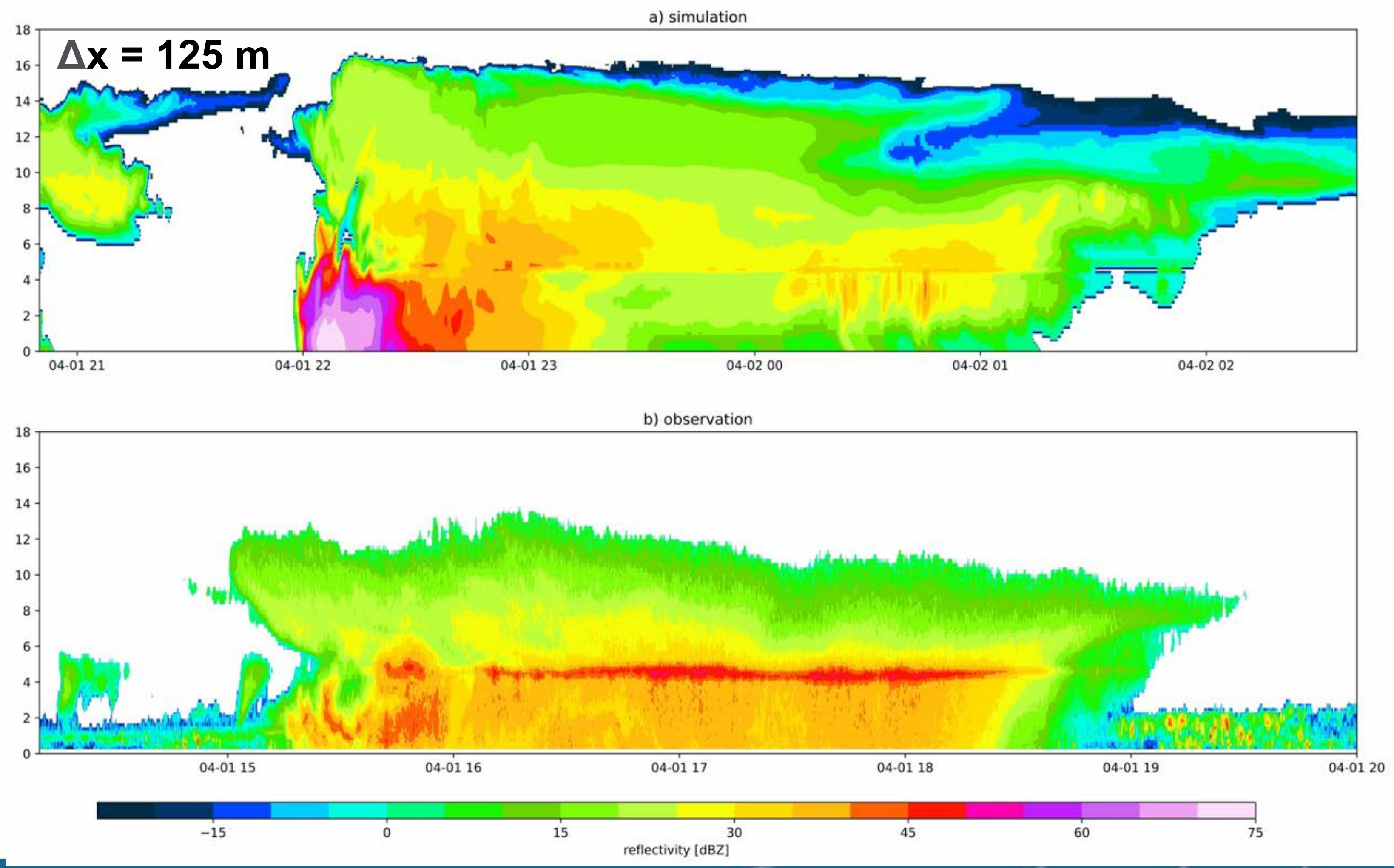




Date/Time: 0001-01-01_00:00:00

Learning from LESs and ARM Observations

MAO on April 1 2014, 15 UTC



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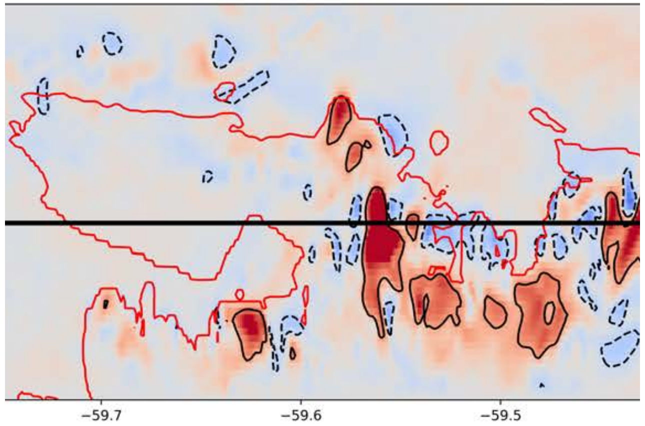

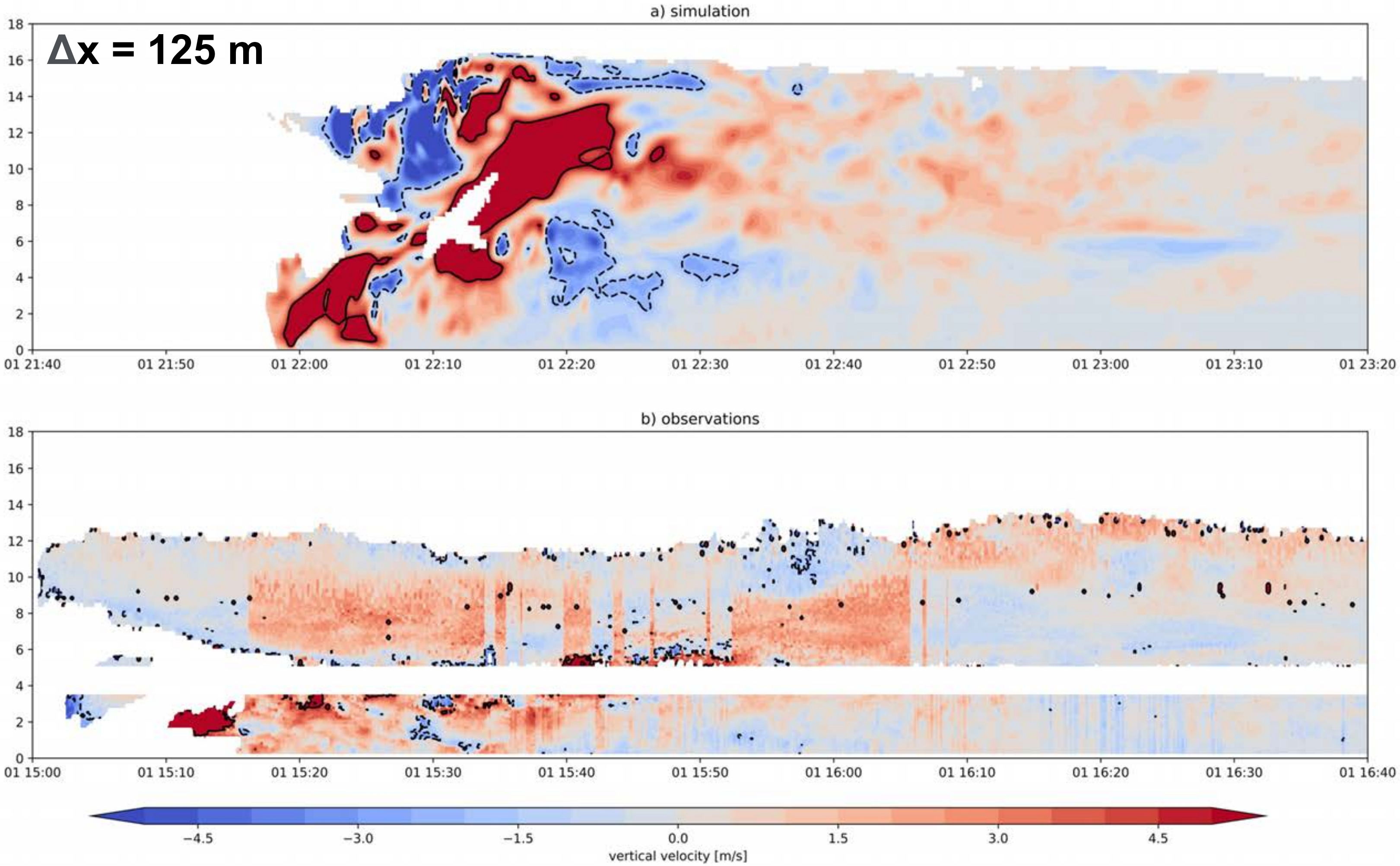

- 3D model snapshots are hard to compare with Virtual RWP output
- MCS movement speed is similar to updraft core-width and updraft speed

Learning from LESs and ARM Observations

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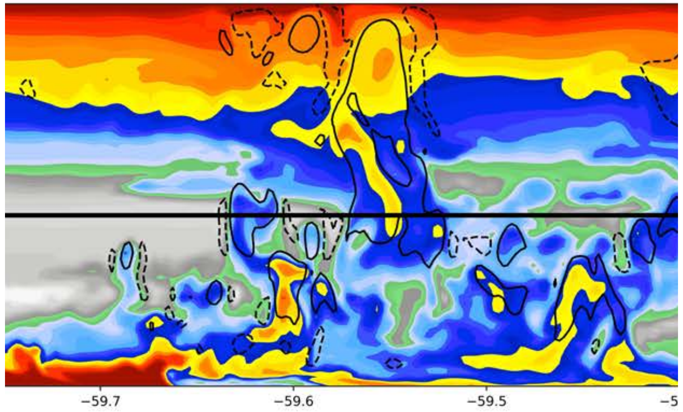

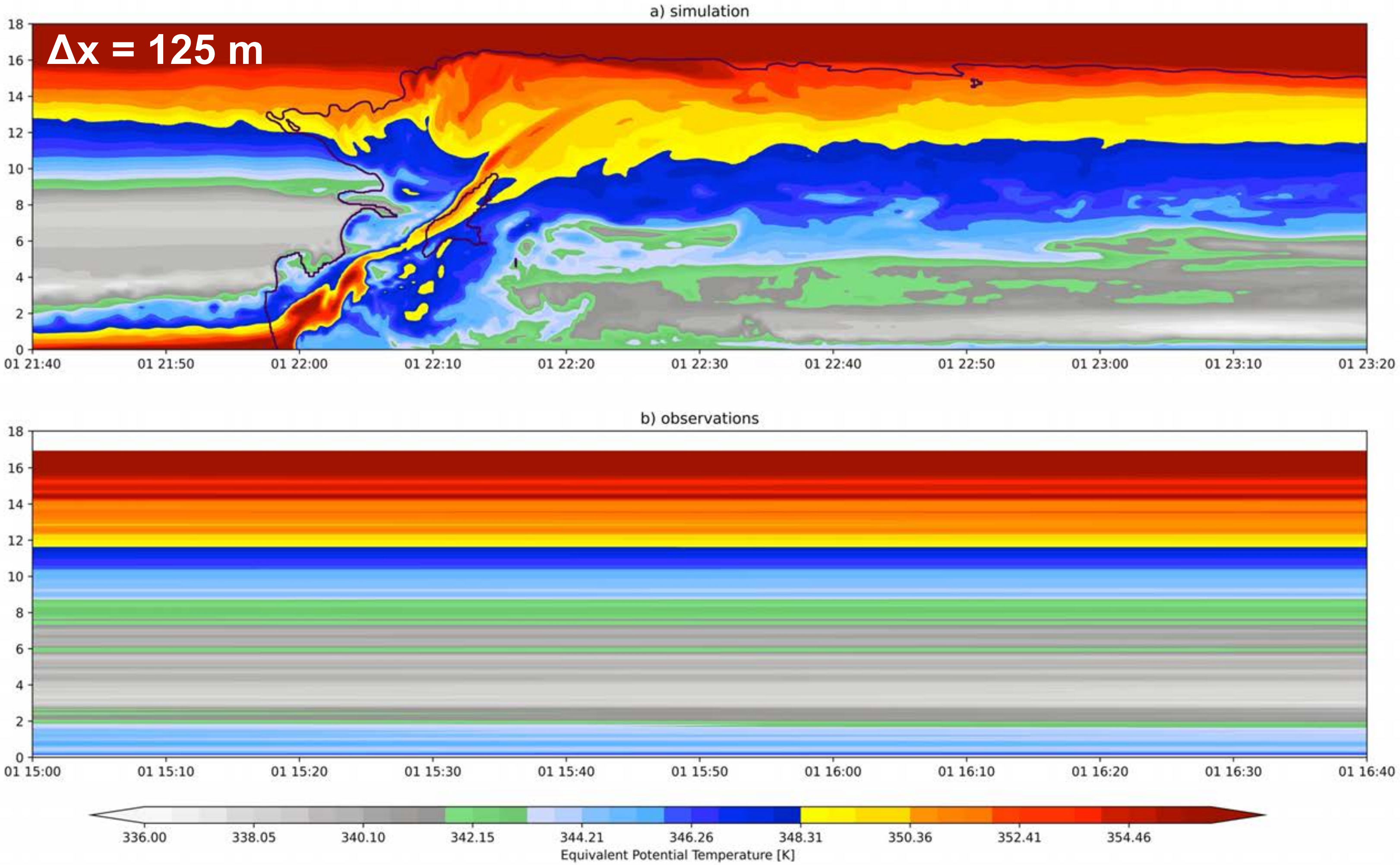

- 3D model snapshots are hard to compare with Virtual RWP output
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Final Remarks

- Evaluating (MCS) simulations with ARM observations is difficult and demands close, long-term collaborations

- Key challenges in evaluating MCS simulations
  - Spatiotemporal displacements
  - Large case-to-case variability
  - Model sensitivity tests on large LES domains are extremely expensive
  - Evaluation of model diagnostics (e.g., dBZ, Tb) rather than prognostics

- How can we improve Deep Convection in km-Scale Models
  - Main difficulty is parameterizing sub-grid-scale turbulence
  - Need better strategy to test model setup sensitivities
    e.g., by using the piggybagging methodology (Grabowski 2019)

SAAG

South American Affinity Group

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CONICET	Universidade Federal de Santa Maria	Hong Kong Baptist University	U. of Illinois
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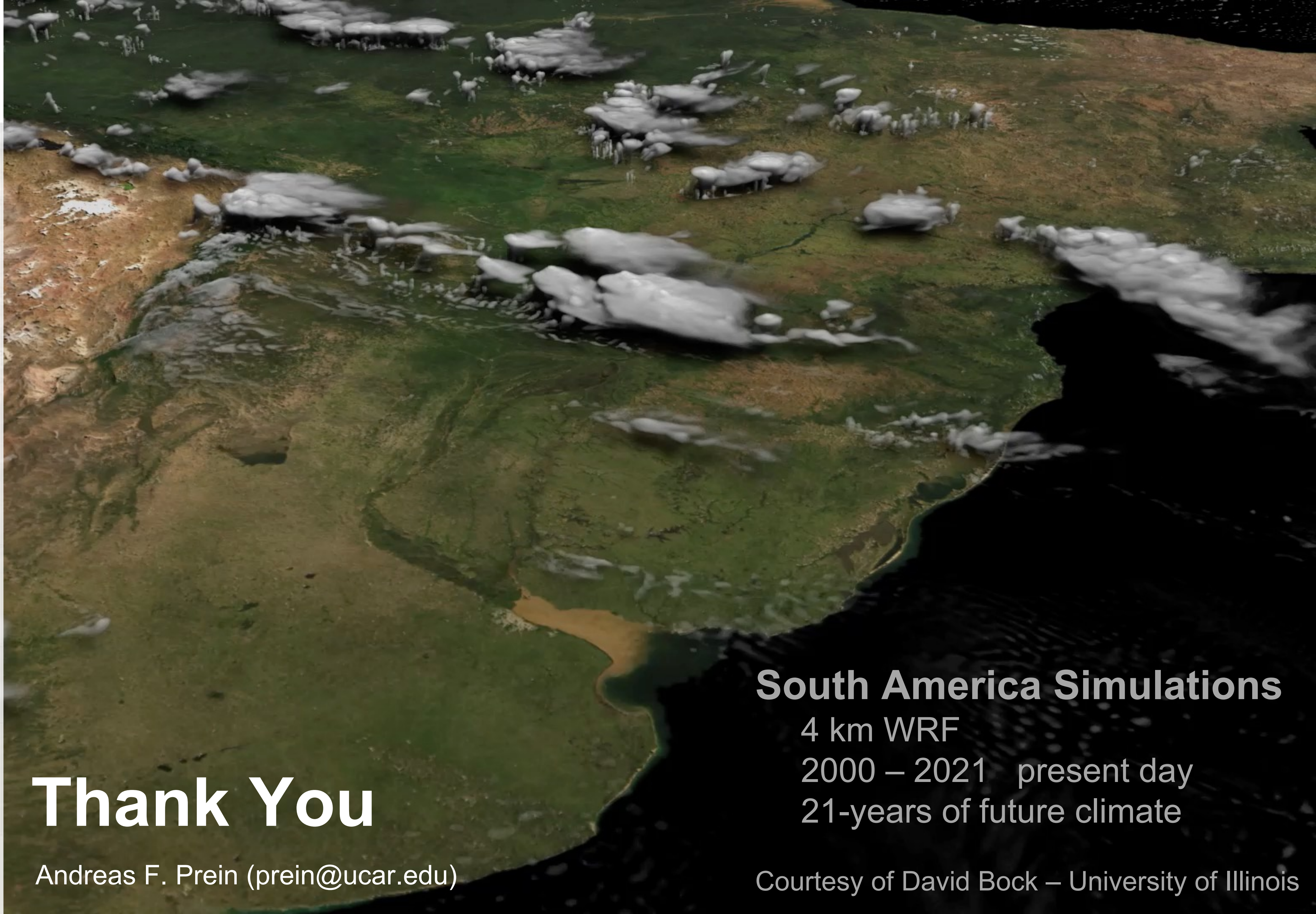
University of Manchester	Universidade de São Paulo	University of Arizona	UC Santa Barbara
UC Los Angeles	UFSM Universidade Federal de Santa Maria	Universidad de Buenos Aires	Universidad Nacional de Colombia
Universidad de la Frontera	University of Oklahoma	University of Richmond	University of Saskatchewan
University of Utah	Universidad de Santiago de Compostela	University Grenoble Alpes	Instituto de Astronomia, Geofísica e Ciências Atmosféricas
Center for Climate and Resilience Research	Universidad de Chile		



Thank You

Andreas F. Prein (prein@ucar.edu)

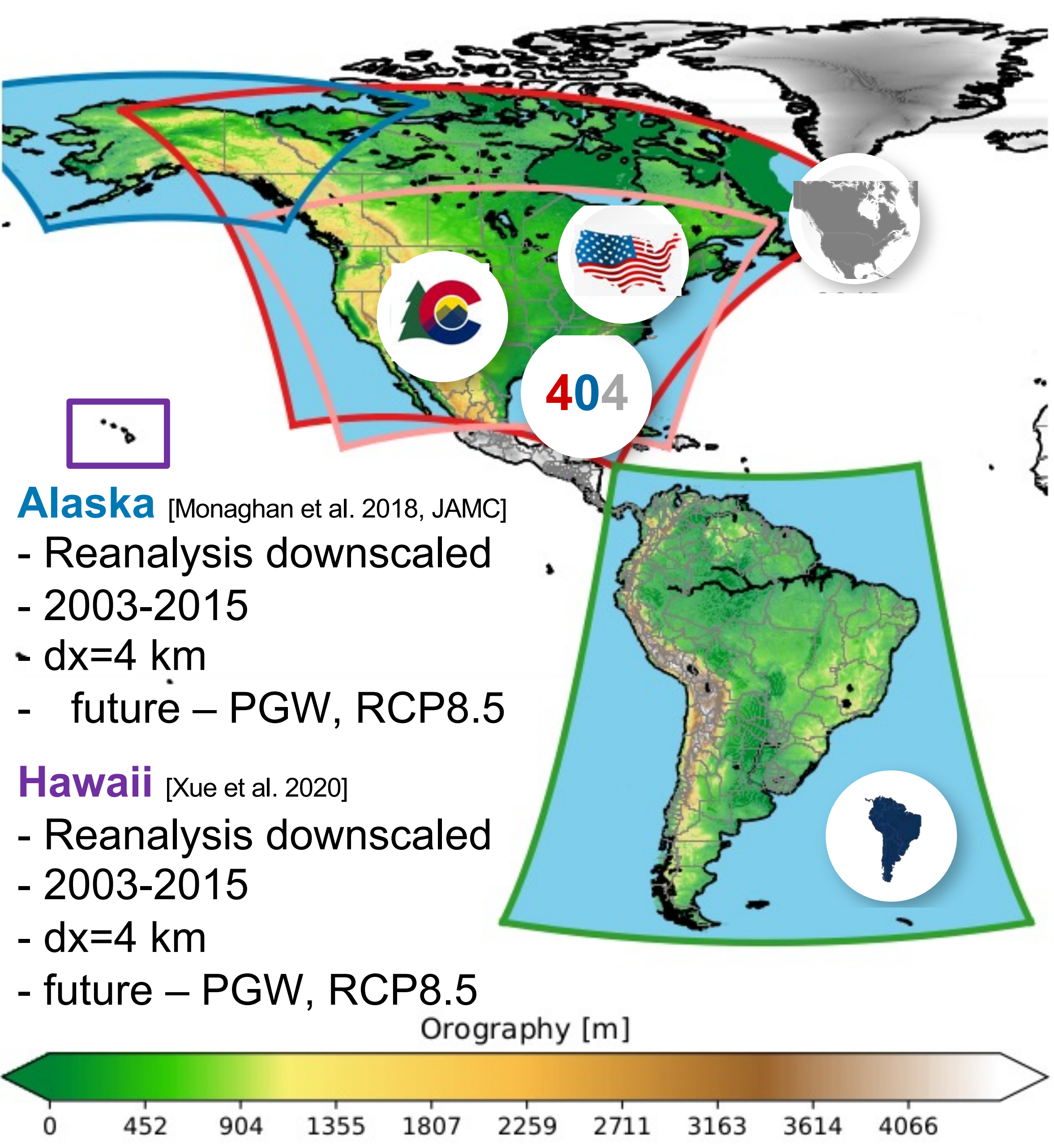
South America Simulations

4 km WRF

2000 – 2021 present day

21-years of future climate

Courtesy of David Bock – University of Illinois



Alaska [Monaghan et al. 2018, JAMC]
- Reanalysis downscaled
- 2003-2015
- dx=4 km
- future – PGW, RCP8.5

Hawaii [Xue et al. 2020]
- Reanalysis downscaled
- 2003-2015
- dx=4 km
- future – PGW, RCP8.5

NCAR/RAL Kilometer-Scale Climate Simulations

CO-Headwaters [Rasmussen et al. 2014]
- Reanalysis downscaled
- 2001-2008
- dx=4 km
- future – PGW, RCP8.5

CONUS-1 [Liu et al. 2017, Clim Dyn]
- Reanalysis downscaled
- 2001-2013
- dx=4 km
- future – PGW, RCP8.5

CONUS-2 [in progress]
- GCM downscaled
- 1995-2014
- dx=4 km

CONUS404 [finished]
- Reanalysis downscaled
- 1979-2019
- dx=4 km

South America [in progress]
- Reanalysis downscaled
- 20-years
- dx=4 km
- future – PGW, RCP8.5