Improvement of Convective/Severe Weather Prediction through an Integrative Analysis of WRF Simulations and NEXRAD/GOES Observations over the CONUS

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2 August 2017 – NGGPS PI Meeting

Improvement of Convective/Severe Weather Prediction:

Proposed Objectives

- **Objective 1: Evaluation of WRF simulated convection and precipitation**
  - At SGP and NGP using Stage IV data
  - At SGP and NGP by Meteorological Regimes.

- **Objective 2: Develop and determine best practices for a WRF microphysics ensemble**
  - Improve severe wx forecasting, through determining
    - biases in WRF microphysics schemes
    - best performing WRF microphysics scheme

Improvement of Convective/Severe Weather Prediction:

Supported Following Graduate Students

Ph.D students at University of Arizona

- **Jingyu Wang: Using Stage-IV to evaluate WRF simulated precipitation**
- **Ted McHardy: Using GOES satellite data to evaluate WRF simulated convective cloud properties.**

MS students at University of North Dakota

- **David Goines: Using Stage-IV to evaluate NSSL and NCEP WRF simulated precipitation (working at Valparaiso University)**
- **Brooke Hagenhoff: Using SOMs to evaluate WRF simulated precipitation (graduating, will work at NWS IA)**
- **Joshua Markel: Determining best WRF microphysics scheme (working at Mission Support Alliance)**

Improvement of Convective/Severe Weather Prediction:

Publications

Papers Submitted:

- **Wang, J., X. Dong, B. Xi, B. Hagenhoff, and A. Kennedy, 2017: Statistical comparisons of warm season convective rain properties and diurnal cycle between SGP and NGP regions. Submitted to J. Hydrometeo**.
- **McHardy, T.M., X. Dong, B. Xi, M. M. Thieman, and P. Minnis, 2017: Comparison of Daytime Low-Level Cloud Properties Derived from GOES and ARM SGP Measurements. Submitted to JGR.**
- **Goines, D. and A. Kennedy, 2017: Precipitation from a Multi-Year Database of Convection-Allowing WRF Simulations. Submitted to JGR.**

Papers in Preparation

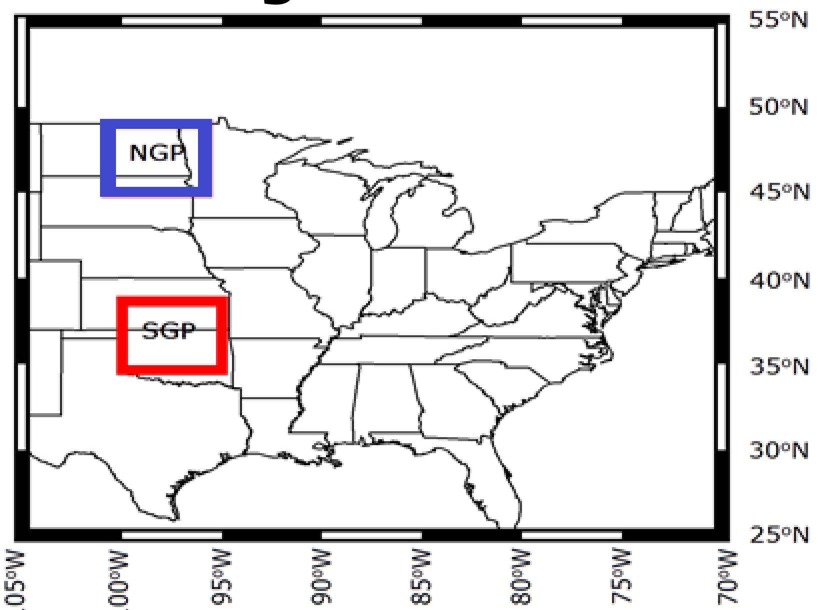
- **Wang, J. X. Dong et al. 2017: Quantitative diagnosis the NSSL WRF simulated warm season convective rain over SGP and NGP. Will submit to J. Hydrometeo**.
- **Mchardy, T.M. X. Dong et al., 2017: Evaluation of WRM simulated convective cloud properties using GOES satellite results. Will submit to JGR.**
- **Hagenhoff, B., A. Kennedy etc, 2017: Assessment of WRF Simulated Precipitation over the Northern and Southern Great Plains by Meteorological Regimes. Will submit to Weather and Forecasting.**
- **Markel, J. M. Gilmore etc 2017: Precipitation biases in severe convective storms revealed within a WRF cloud microphysics ensemble. Will submit to Weather and Forecasting.**

Improvement of Convective/Severe Weather Prediction:

Objective I

Evaluation of WRF simulated Warm Season (4-9) Convective Rain (CR, >5 mm/hr) at SGP and NGP using Stage IV data (by Wang and Dong)

Study Domain



SGP and NGP are chosen for their marginal locations within mid-latitudes (30° – 60° N)

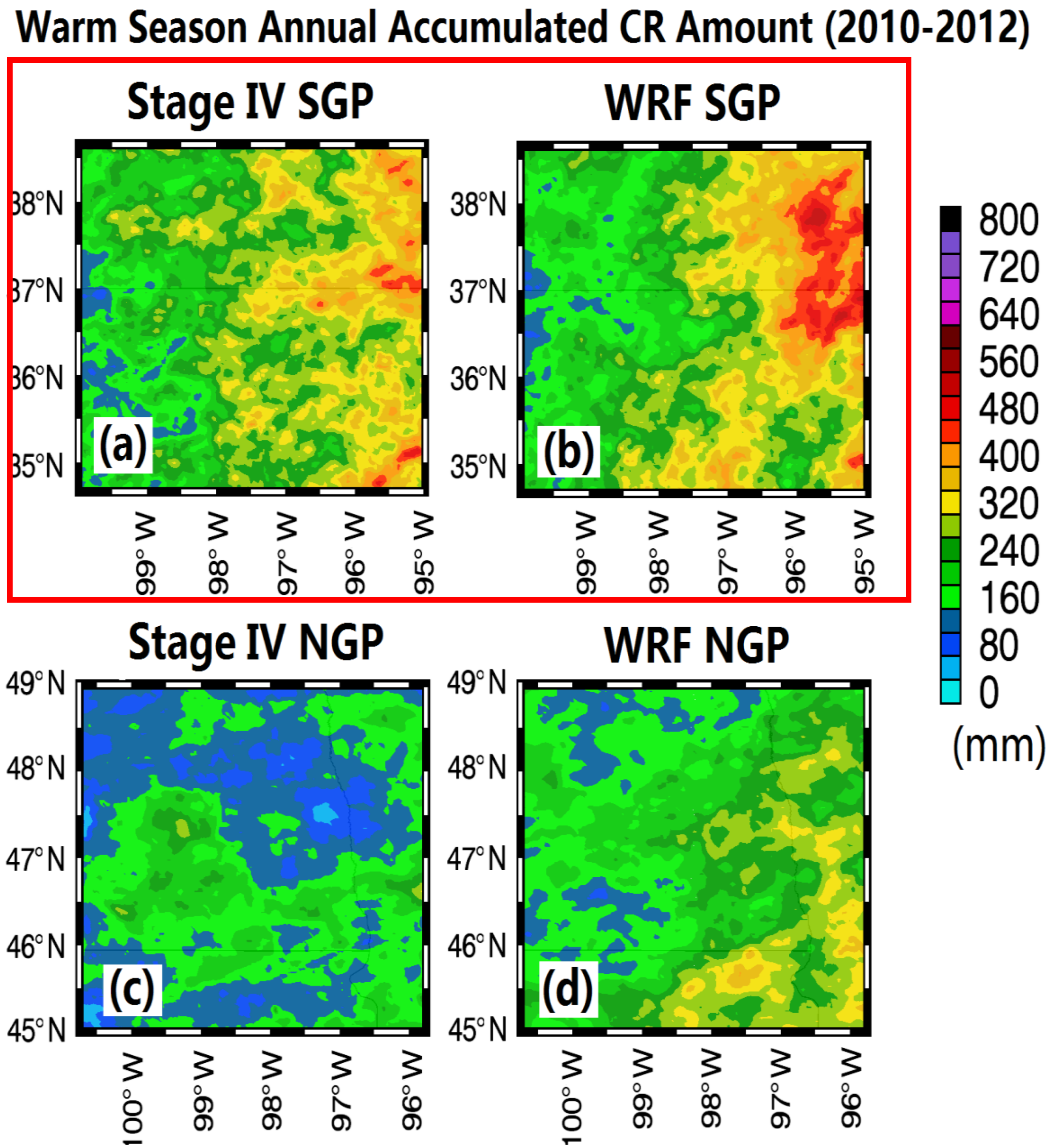
	CAPE ($J\ Kg^{-1}$)	Vapor Flux ($Kg\ m^{-1}\ s^{-1}$)
NGP	473.90	72.26
SGP	817.73	318.45

SGP features much larger CAPE and vapor availability ➔ higher CR intensity.

Issue: Current WRF model using one precip. parameterization from 30 to 60°N. Does it work well for both SGP and NGP?

Spatially Averaged Annual CR Amount

(mm)	Stage IV	NSSL WRF
SGP	276	289
NGP	164	231



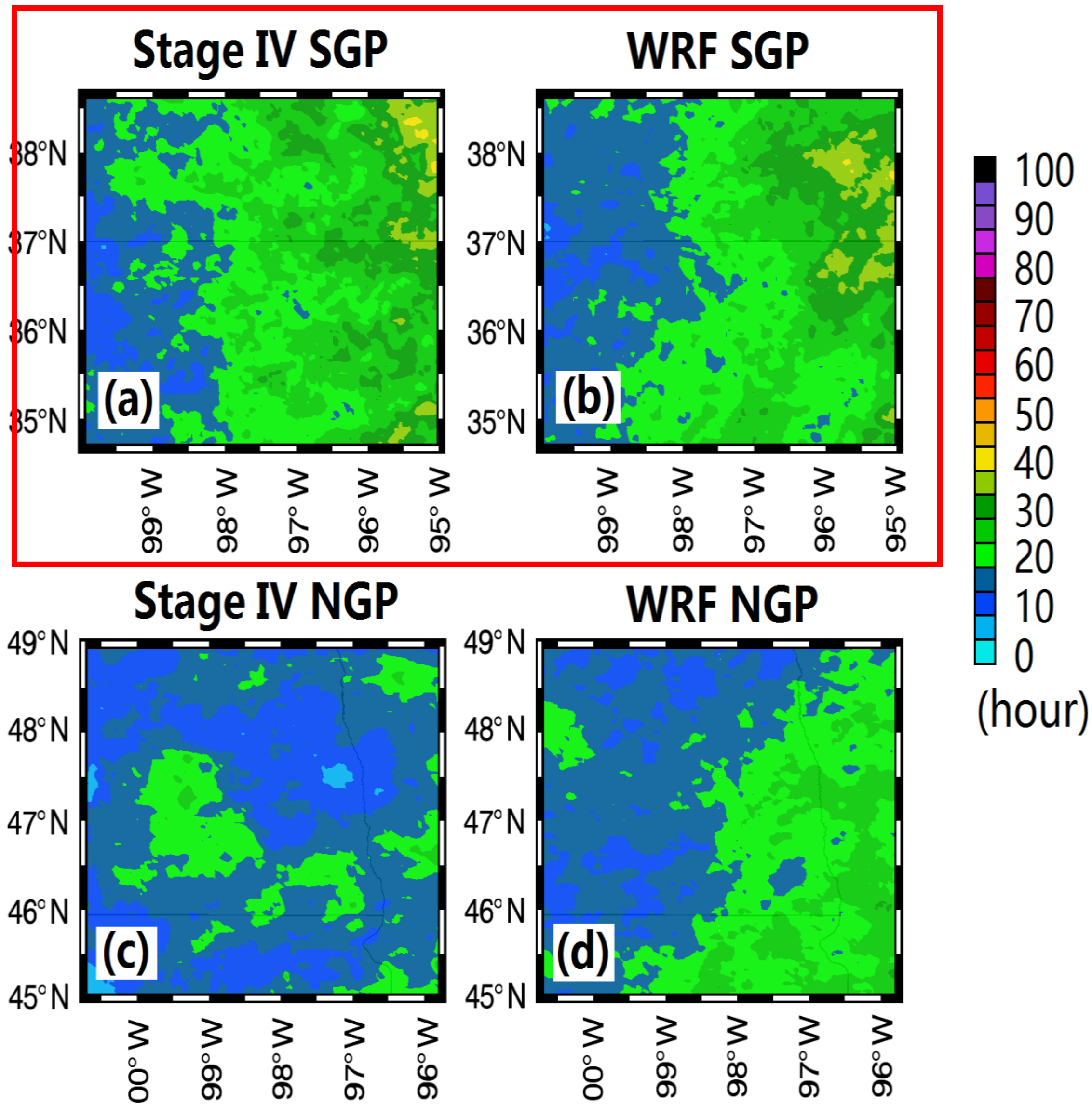
Conclusion:
From annual total and spatial distribution, WRF agrees well with Stage IV at SGP but over-simulates at NGP.

Spatially Averaged Annual CR Hour

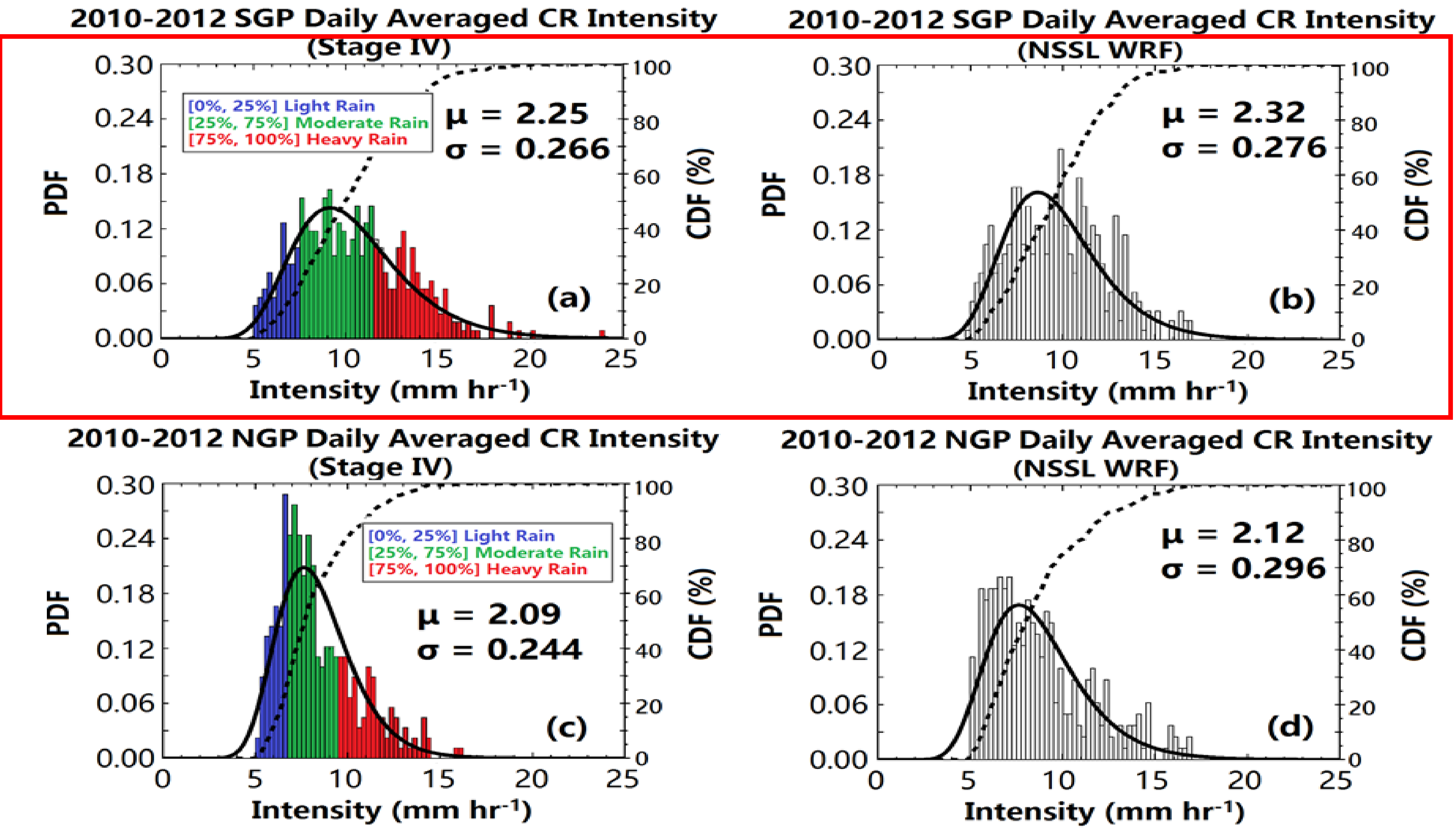
(Hour)	Stage IV	NSSL WRF
SGP	24	23
NGP	17	20

Conclusion:
Again, WRF simulated precipitation hours agree better with Stage IV at SGP than at NGP.

Warm Season Annual Accumulated CR Duration (2010-2012)



Comparison on daily averaged CR intensity



1) **Stage IV: Location parameter μ = 2.25 vs μ = 2.09. Dispersion σ = 0.266 vs. σ = 0.244. Larger and wider at SGP than at NGP**
2) **WRF: Better at SGP, but NGP greatly skewed to the right.**

Hourly total CR amount over the entire study domain for each CR intensity category

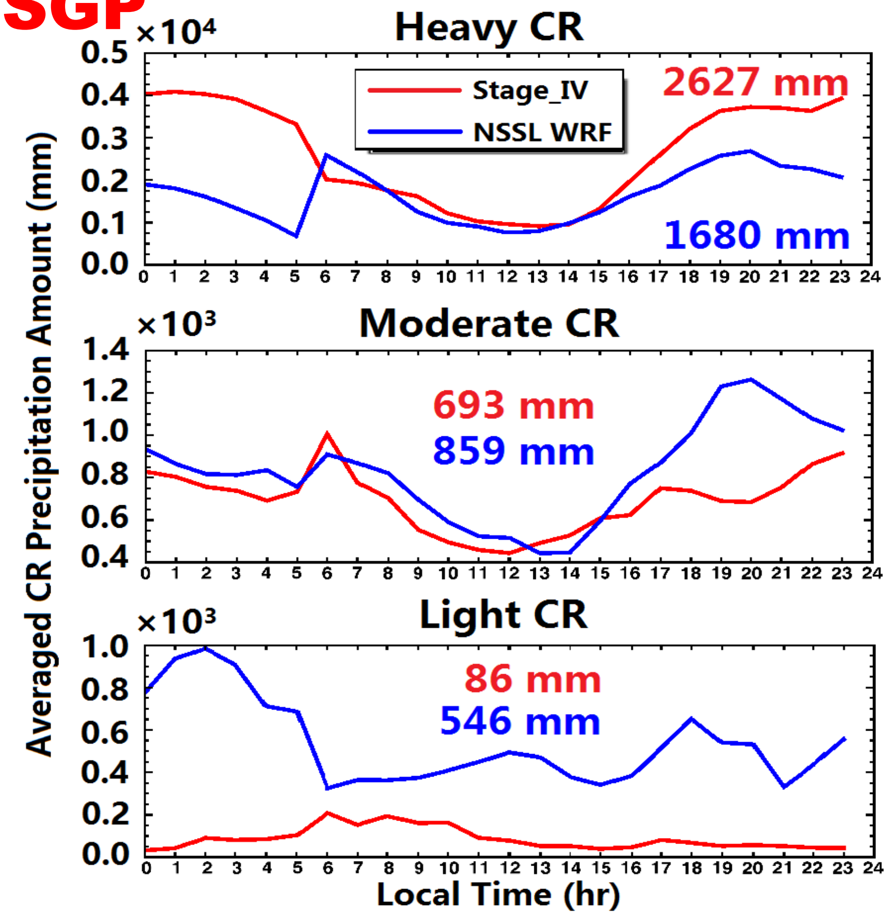
(Light< 25%, 25%<Moderate<75%, Heavy>75%)

		All CR	Heavy	Moderate	Light
SGP 388 cases (98/216/86)	Stage IV	1065 mm 0.77 %	2627 mm 1.70 %	693 mm 0.57 %	86 mm 0.10 %
	WRF	1007 mm 0.72 %	1680 mm 1.15 %	859 mm 0.62 %	546 mm 0.44 %
NGP 340 cases (96/181/63)	Stage IV	520 mm 0.62 %	1213 mm 1.26 %	314 mm 0.46 %	57 mm 0.10 %
	WRF	720 mm 0.64 %	1045 mm 0.83 %	668 mm 0.62 %	371 mm 0.40 %

Conclusion: WRF agrees with Stage IV from 700-1200 mm, but undersimulates for heavy and oversimulates for light cases.
Suggestion: Was WRF precip para developed from CR=700-1200 mm? So it under for CR>1200 mm and over for CR< 700? Need new para?

Diurnal Variations of CR amounts at SGP and NGP

SGP

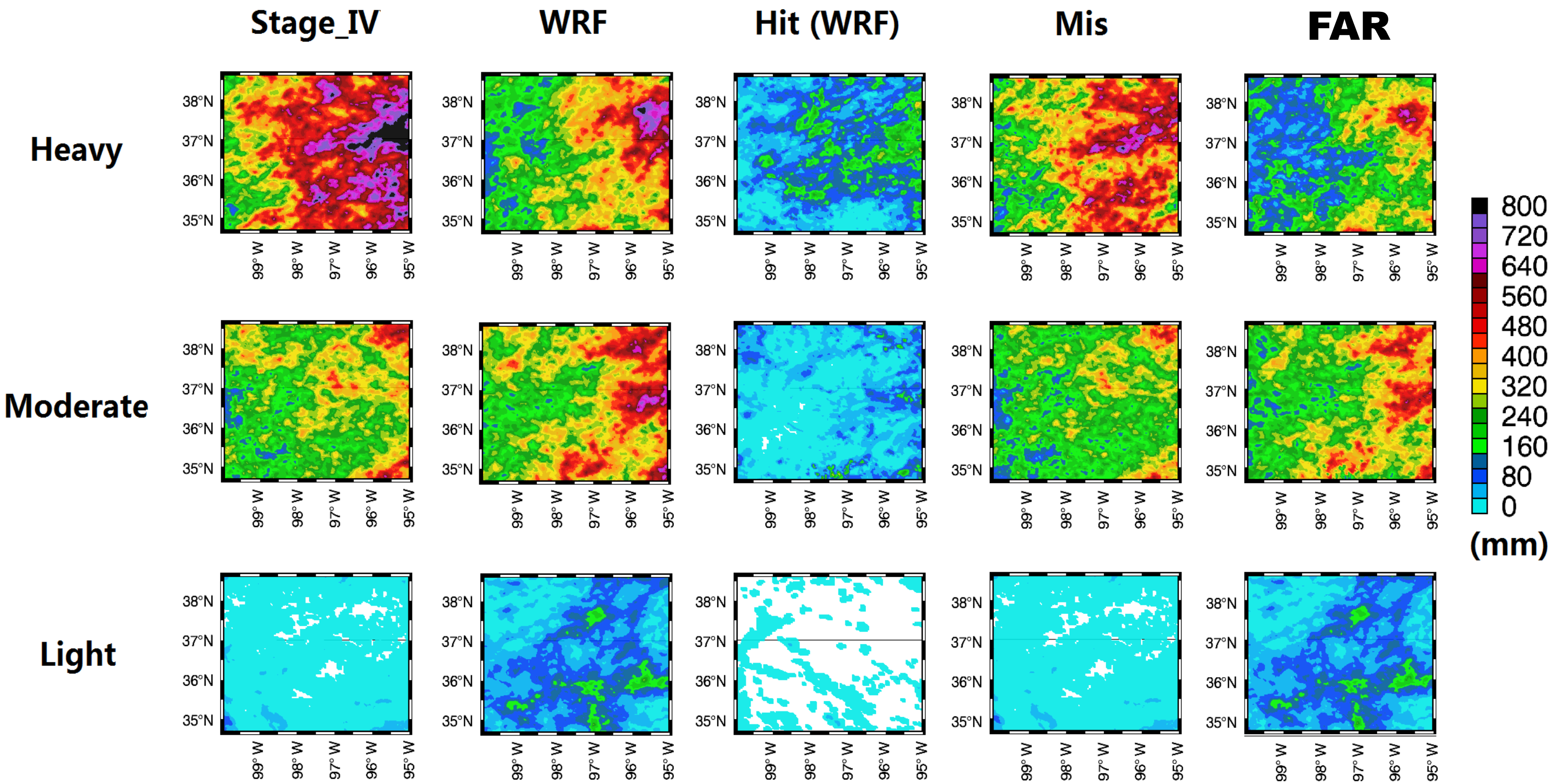


NGP

SGP

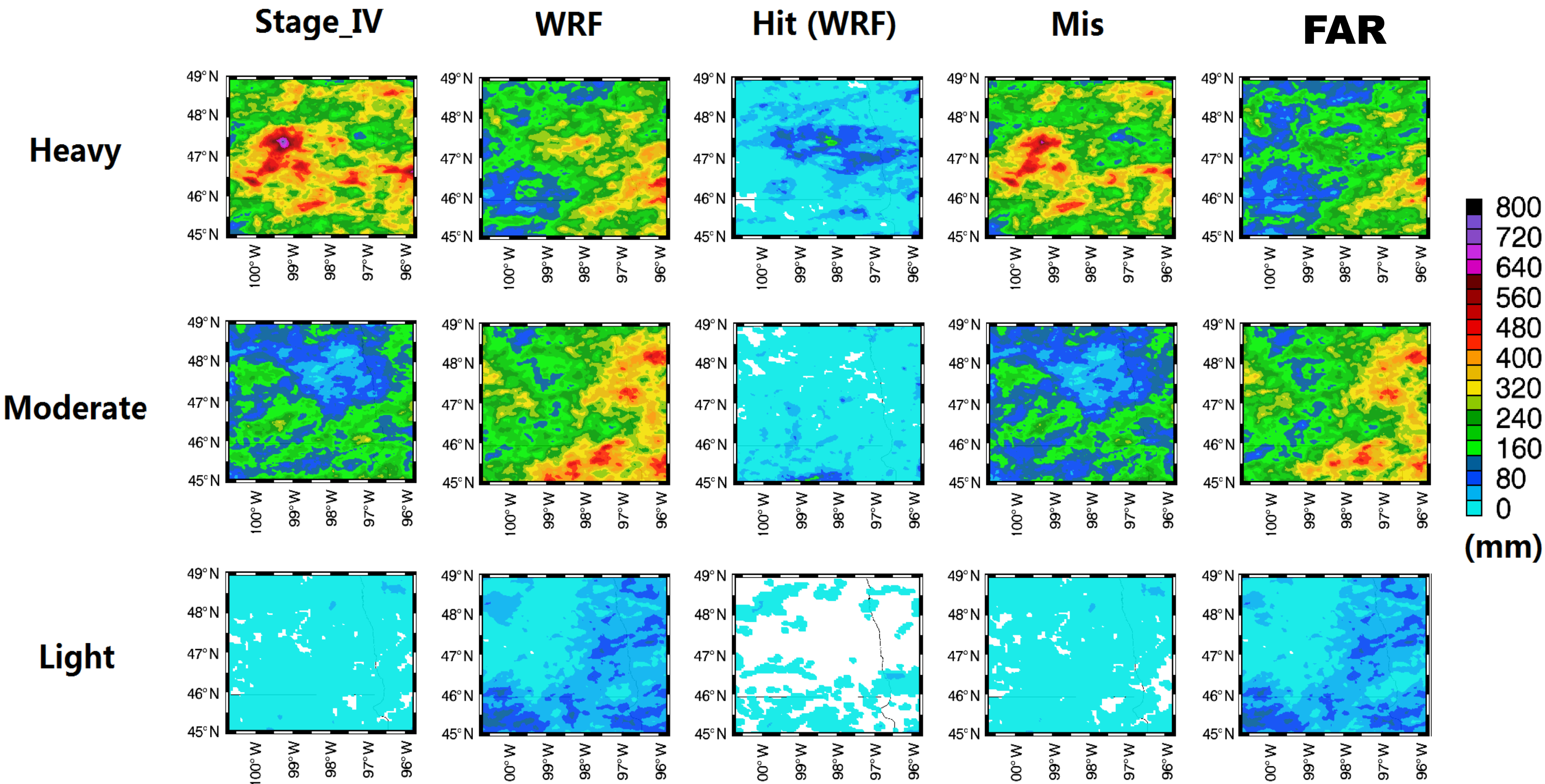
1. For heavy cases, WRF agrees with Stage IV from 06-16 LT, but undersimulates from 16-06 LT.
2. For moderate cases, best match until 15 LT, then deviate.
3. For light cases, WRF oversimulates entire day.

SGP Categorical Scores for WRF-simulated 24-hr precip.



SGP	POD (%)	FAR (%)	CSI (%)
Heavy	14.18	82.83	5.02
Moderate	14.03	85.13	4.96
Light	12.51	83.93	1.20

NGP Categorical Scores for WRF-simulated 24-hr precip.



NGP	POD (%)	FAR (%)	CSI (%)
Heavy	10.55	90.78	2.48
Moderate	11.09	90.79	2.73
Light	6.35	94.67	1.71

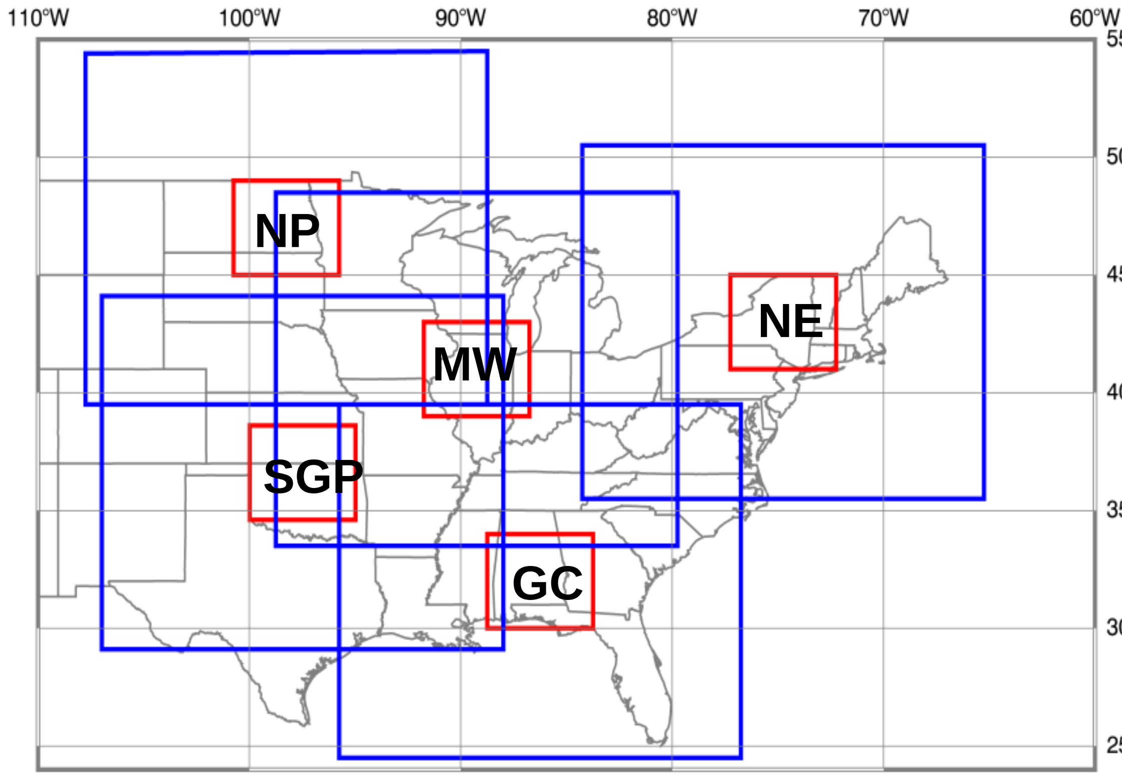
Compared to SGP, NGP POD and CSI are lower, FAR is higher

Improvement of Convective/Severe Weather Prediction:

Objective I

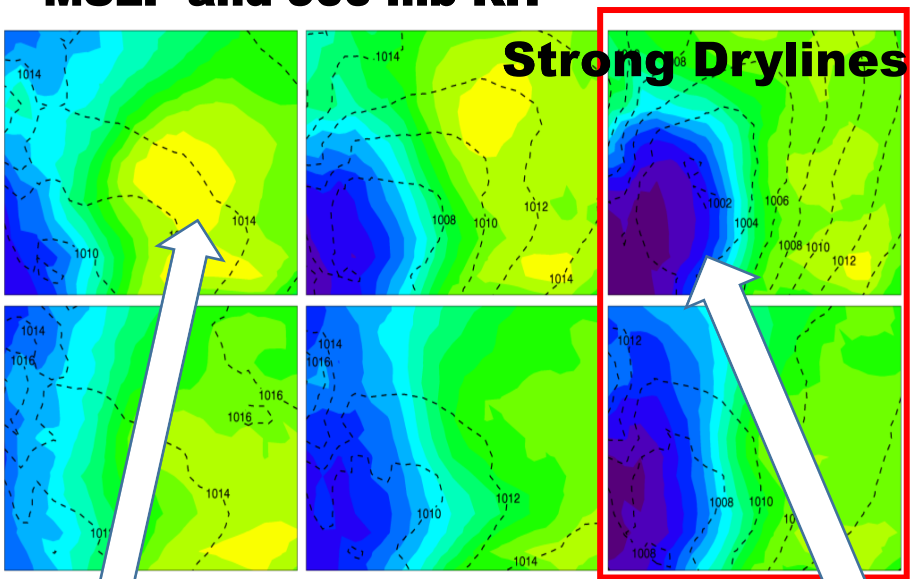
Assessment of WRF Simulated Precipitation over the Northern and Southern Great Plains by Meteorological Regimes (Hagenhoff and Kennedy)

- Patterns classified using data from NARR
- Self Organizing Maps (SOMs) a type of competitive neural network used for the classifications
  - Red boxes: Precipitation analysis
  - Blue Boxes: NARR domain used for SOMs



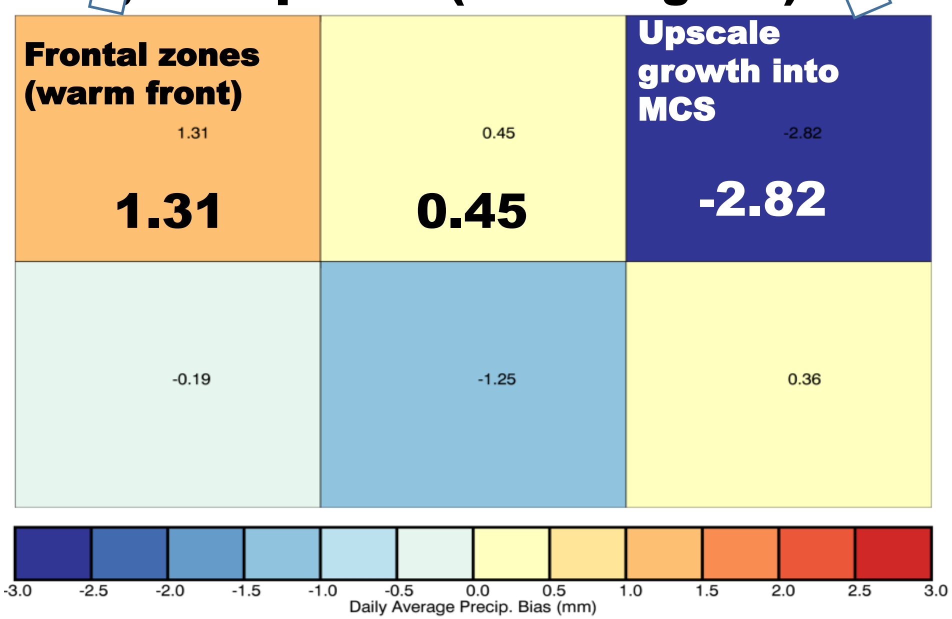
SGP – Precipitation Statistical Analysis

MSLP and 900 mb RH



Light	Moderate	Heavy
86 mm 0.10 %	693 mm 0.57 %	2627 mm 1.70 %
546 mm 0.44 %	859 mm 0.62 %	1680 mm 1.15 %

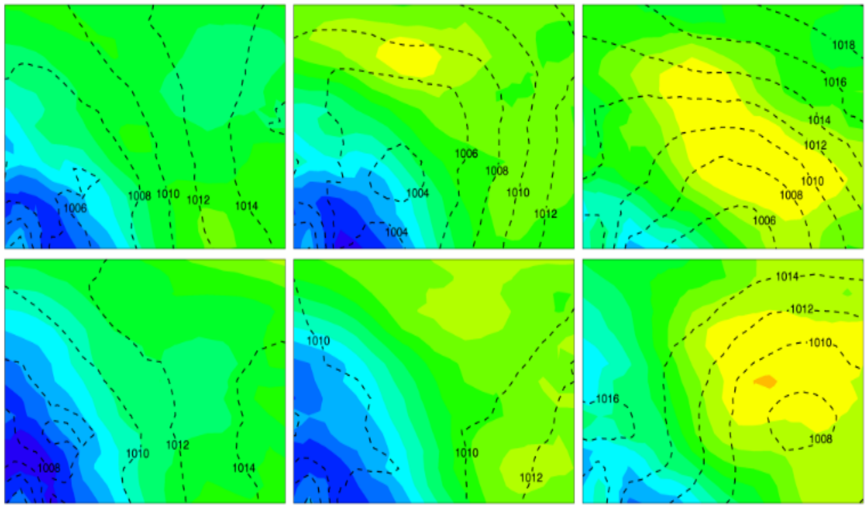
Daily Precip. Bias (WRF-Stage IV)



- **Light CR associated with frontal systems, WRF oversimulates**
- **Heavy CR associated with strong drylines, WRF undersimulates**

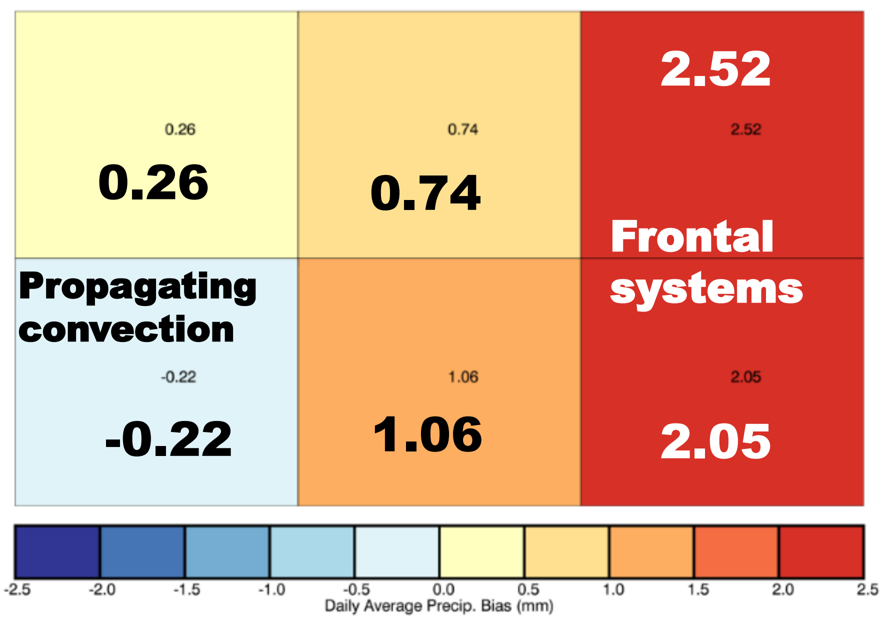
NGP – Precipitation Statistical Analysis

MSLP and 900 mb RH



Heavy	Moderate	Light
1213 mm **1.26 %**	**314 mm** **0.46 %**	**57 mm** **0.10 %**
1045 mm **0.83 %**	**668 mm** **0.62 %**	**371 mm** **0.40 %**

Daily Precip. Bias



Positive precipitation bias dominates the region

- **Precipitation is driven by strong forcing events and is more often less convective in nature compared to SGP (light CR)**
- **Negative trend is associated with propagating convection although it is less freq. (Heavy CR)**

Improvement of Convective/Severe Weather Prediction:

Objective 1: Priorities, Milestones, and Challenges

Conclusions:

1. **SGP features larger CR amount, duration and coverage than those at NGP**
2. **WRF simulations agree with Stage IV better at SGP than at NGP.**
3. **Negative bias associated with strong drylines, while positive bias associated with frontal systems at Great Plains.**

Priorities/Milestones (Will finish following 3 papers)

1. **Evaluating SGP and NGP WRF simulated precipitation using Stage IV data (Wang)**
2. **Evaluating SGP and NGP WRF simulated convective cloud properties using GOES data (McHardy)**
3. **Assessment of WRF simulations at SGP and NGP by Meteorological regimes (Hagenhoff)**

Challenges

1. **As demonstrated in this study, SGP and NGP CR amounts, duration and coverages are significantly different, should we modify the current WRF CR parameterization in the middle latitudes in the future?**
2. **Even though the overall simulations are optimal, WRF still has trouble distributing CR precipitation into heavy, moderate and light categories?**
3. **How can we incorporate the synoptic patterns into weather forecasting?**

Objective II

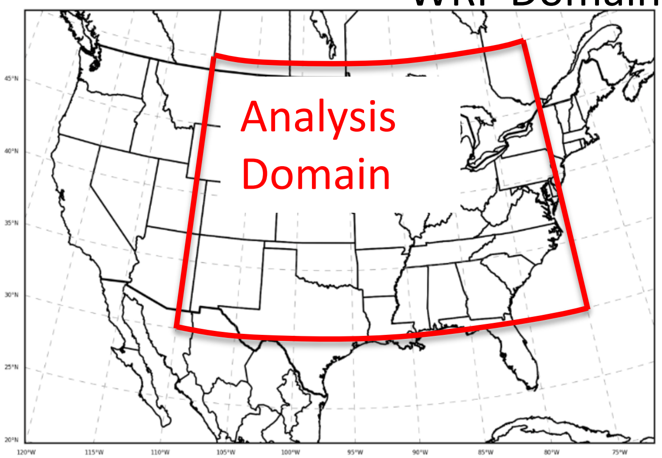
Detailed analysis of a WRF Microphysics Ensemble (By Markel and Gilmore)

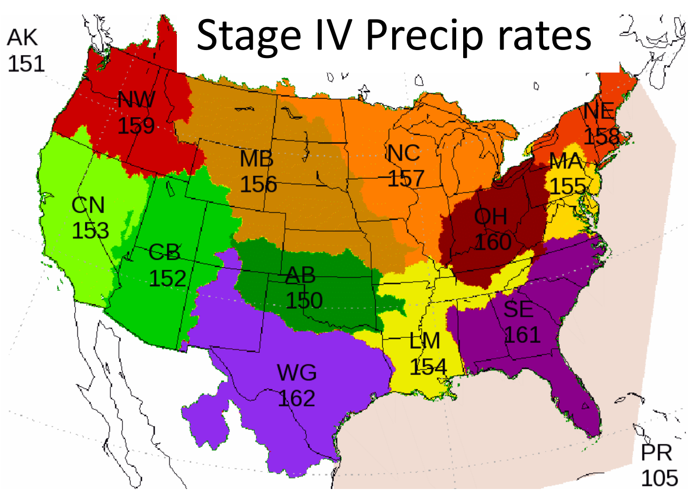
Goal: Improving severe wx forecasting, through determining

- **biases in WRF microphysics schemes**
- **best performing WRF microphysics scheme**

Detailed analysis of a WRF Microphysics Ensemble

WRF Domain





- 77 case dates
  - 46 retro: Apr-Sep 2010-'12
  - 31 real-time: Apr-Jun 2016
- 3 km grid spacing
- MODE-TD analysis
- Compared to Stage IV obs

Markel et al. (2017)

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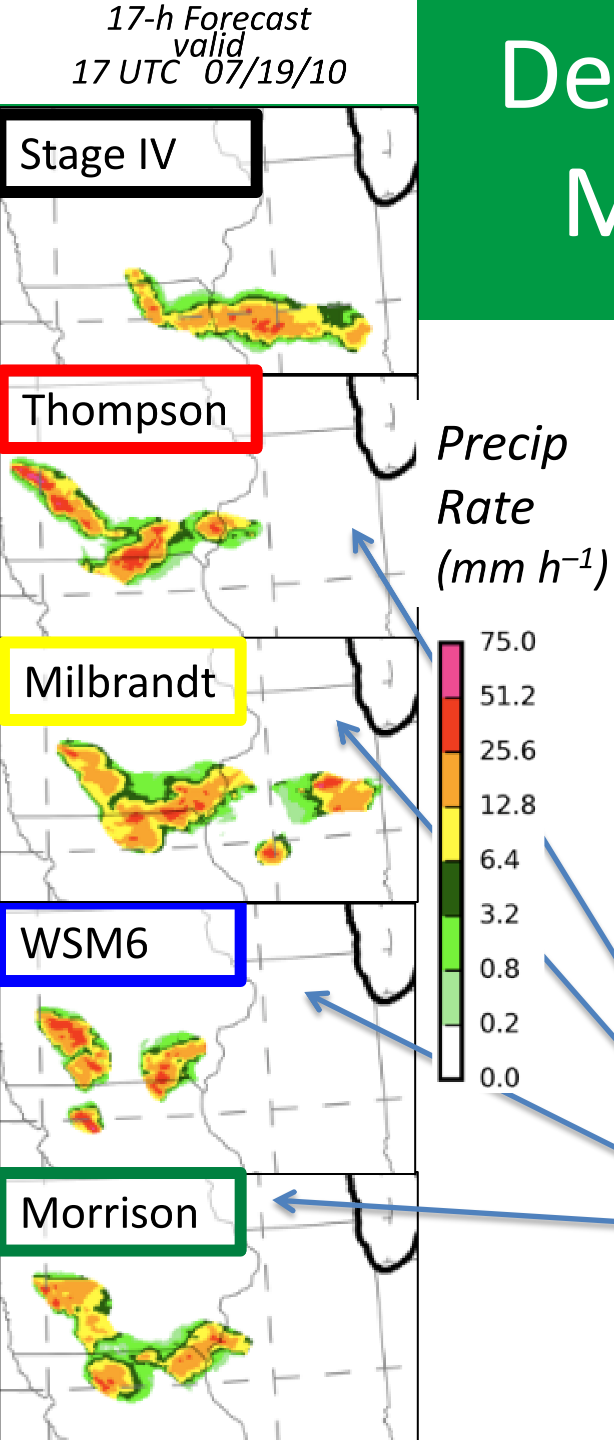
Detailed analysis of a WRF Microphysics Ensemble



- 77 case dates
  - 46 retro: Apr-Sep 2010-’12
  - 31 real-time: Apr-Jun 2016
- 3 km grid spacing
- MODE-TD analysis
- Compared to Stage IV obs
- Four micro schemes

Example at hour 17

Markel et al. (2017)

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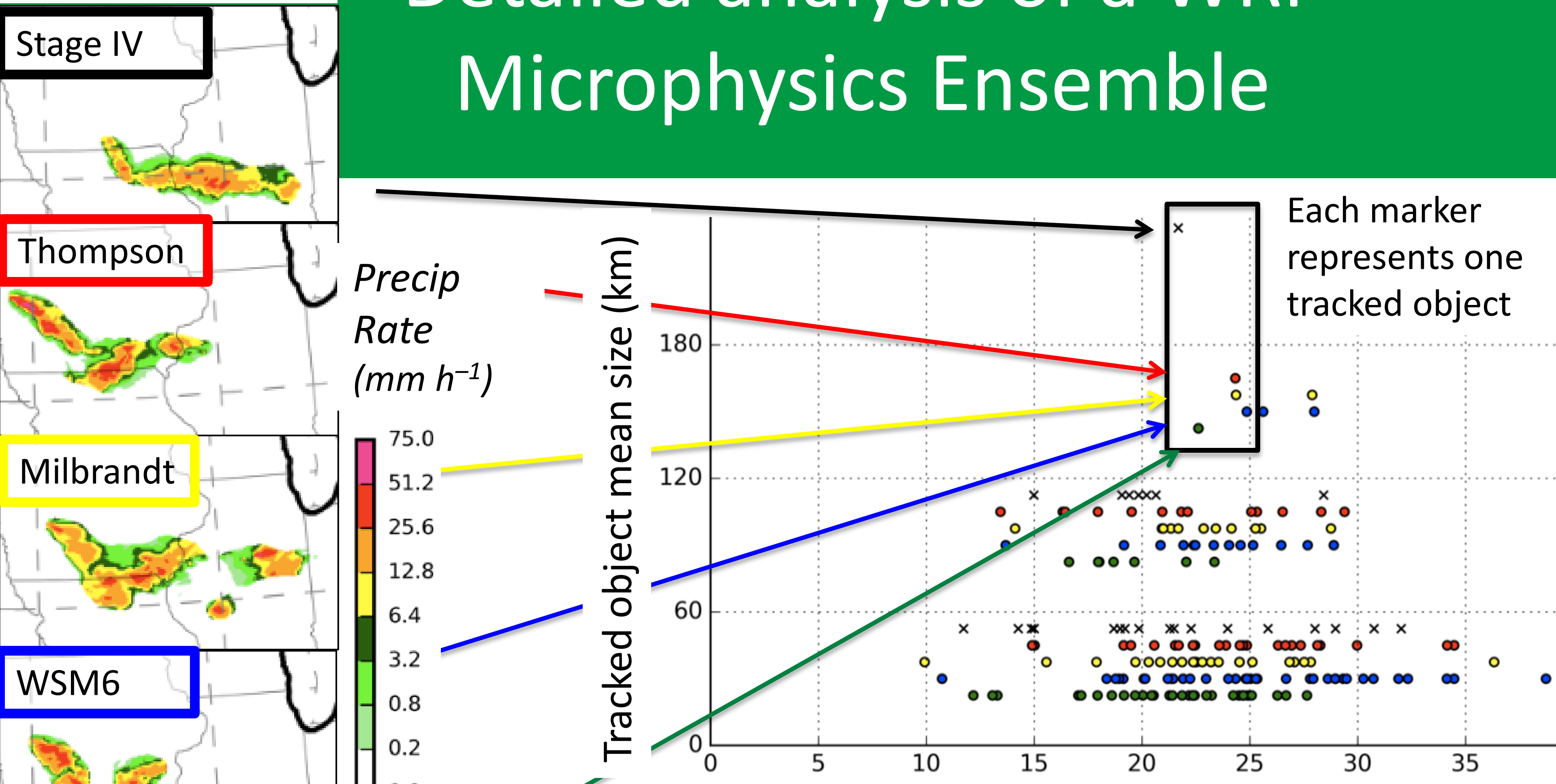
Detailed analysis of a WRF Microphysics Ensemble

17-h Forecast valid 17 UTC 07/19/10



90th Percentile Precip. Rate (mm h^{-1})

for tracked objects occurring within a 24 hour period beginning 12 UTC 07/19/10

Markel et al. (2017)

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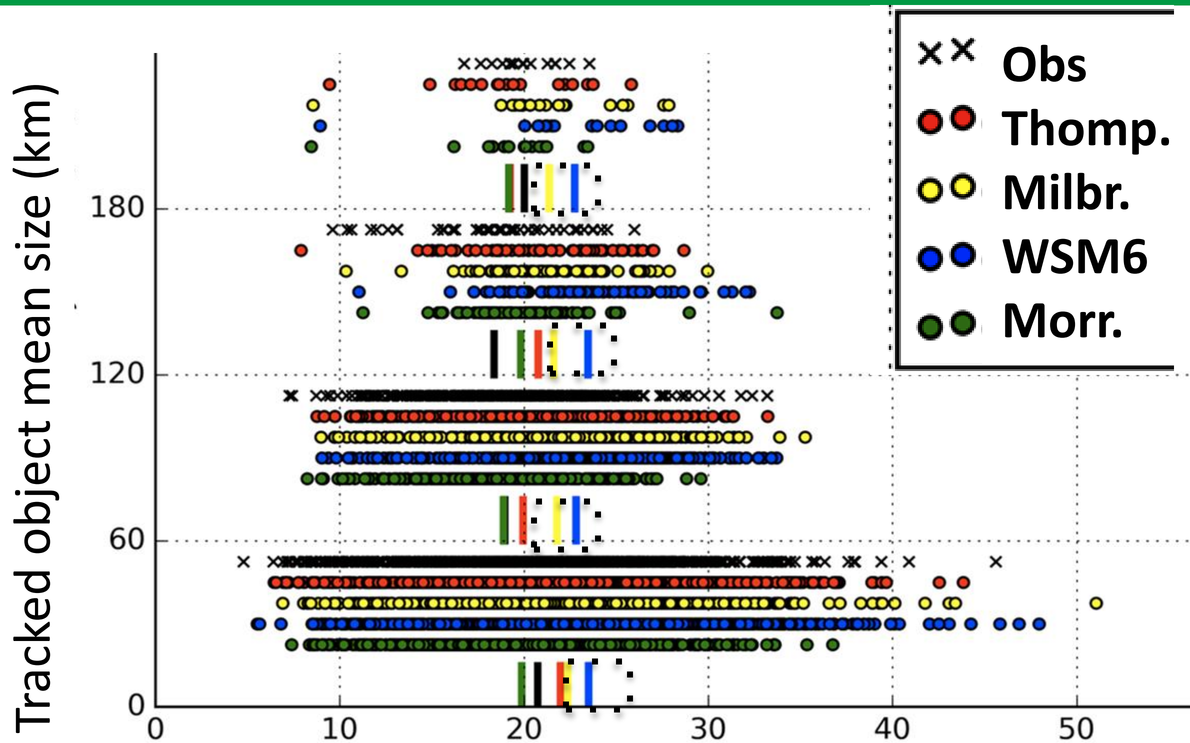
Detailed analysis of a WRF Microphysics Ensemble

- **Consider all case days**
- **Vertical bars: average of 90th percentile over all tracked objects**
- **WSM6 and Milbrandt schemes have heaviest precip. rate bias**



90th Percentile Precip. Rate (mm h^{-1})
for tracked objects occurring within a 24 hour period beginning 12 UTC **for all 77 case days**

Markel et al. (2017)

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Detailed analysis of a WRF Microphysics Ensemble

FAR

MODE-TD	Thomp-son	Mil-brandt	WSM-6	Morr-ison
Total # detected objects	T			T
# detected objects w/ time (#)				✓
% detected objects w/ time (%)				✓
Size distribution (#)	T			T
Size distribution (%)	–	–	–	–
Size with time		✓		
# Initiated (#)	T			T
% Initiated (%)		T		T
Dissipated (#)	T			T
Dissipated (%)		T	T	T
Duration (#)	T			T
Duration (%)			✓	
10th Percentile average				✓
25th Percentile average				✓
50th Percentile average			✓	
75th Percentile average	✓			
90th Percentile average				✓
Object velocity	–	–	–	–

Method for Object-Based Diagnostic Evaluation-Time Domain (MODE-TD).

✓ Best (closest to Stage IV obs)
T Tie for best
– No clear best

Note that all schemes…

- **Overpredict # of small objects**
- **initiate & dissipate too early**

Overall: Morrison microphysics preforms best

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Finished:

- **Overall: Morrison microphysics preforms best**

Priorities/Milestones (Will finish following paper)

- **Precipitation biases in severe convective storms revealed within a WRF cloud microphysics ensemble. Will submit to Weather and Forecasting (by Markel)**

Challenges (same as Obj. 1)

All WRF microphysics schemes…

- **Overpredict # of small objects**
- **initiate & dissipate too early**

Backup

Accuracy analysis on 6-hr interval (comparing WRF and Stage IV based on 6-hr accumulated CR)

SGP		POD (%)	FAR (%)	CSI (%)
Heavy	0000-0005 LT	4.14	90.40	1.21
	0600-1100 LT	1.39	96.34	0.72
	1200-1700 LT	5.66	95.67	0.75
	1800-2300 LT	3.42	95.57	0.99
Moderate	0000-0005 LT	2.77	94.30	0.78
	0600-1100 LT	3.89	95.85	0.75
	1200-1700 LT	4.74	96.53	0.78
	1800-2300 LT	3.89	95.13	1.02
Light	0000-0005 LT	3.13	93.55	0.63
	0600-1100 LT	0.67	96.92	0.36
	1200-1700 LT	4.79	96.04	0.41
	1800-2300 LT	2.84	98.18	0.69

NGP		POD (%)	FAR (%)	CSI (%)
Heavy	0000-0005 LT	3.33	98.26	0.32
	0600-1100 LT	0.18	99.97	0.00
	1200-1700 LT	2.07	98.74	0.27
	1800-2300 LT	0.97	99.31	0.18
Moderate	0000-0005 LT	2.15	98.42	0.34
	0600-1100 LT	0.24	99.81	0.05
	1200-1700 LT	2.50	99.01	0.29
	1800-2300 LT	1.30	98.17	0.38
Light	0000-0005 LT	1.27	99.57	0.15
	0600-1100 LT	0.27	99.98	0.00
	1200-1700 LT	1.66	98.49	0.21
	1800-2300 LT	1.30	99.65	0.18

Conclusion:

1. For SGP POD, best performance is found at the third quarter of the day
2. For NGP POD, best H at first quarter, best M and L at third quarter

Hit: an coincidence of Stage_IV and WRF
Mis: Stage_IV observation without collocated WRF simulation
Fal: WRF simulation without collocated Stage_IV observation.

POD: probability of detection

$$\mathrm{POD} = \frac{\# \, of \, Hit}{\# \, of \, Hit + \# \, of \, mis}$$

FAR: false alar

$$\mathrm{FAR} = \frac{\# \, of \, fal}{\# \, of \, Hit + \# \, of \, fal}$$

CSI: critical suc

$$\mathrm{CSI} = \frac{\# \, of \, Hit}{\# \, of \, Hit + \# \, of \, mis + \# \, of \, fal}$$

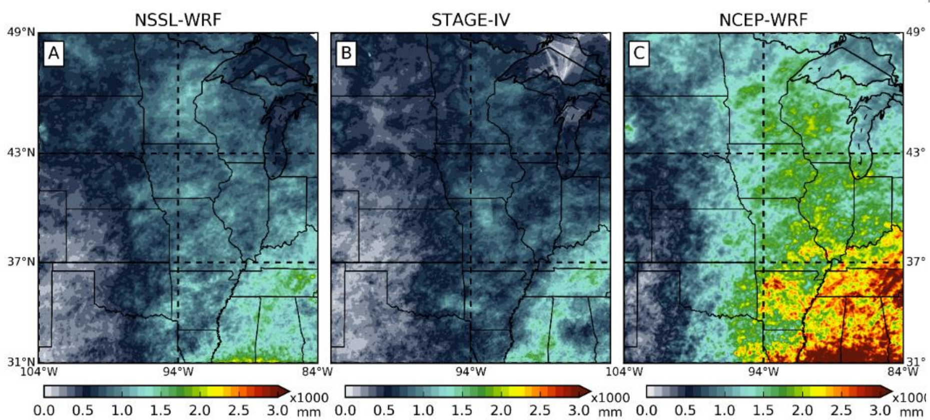
Strategy: Objective 1

- **Datasets**
  - NSSL WRF HWT simulations (4km, 2007-2014)
  - NCEP WRF NMM simulations (4km, 2010-2012)
  - NCEP Stage-IV precipitation
  - UND Hybrid classification product (2010-2013)
    - NEXRAD/GOES data
    - Define convective core / stratiform areas (radar) and anvil regions (satellite)
- **Strategy**
  - Climatological assessment (biases/Hovmöllers/object tracking)
  - Utilize Self Organizing Maps (SOMs) to classify synoptic patterns (both climatology and for precipitation cases)
  - Develop a historical database of cases for use in Ob. 2

Summary of Precipitation Biases

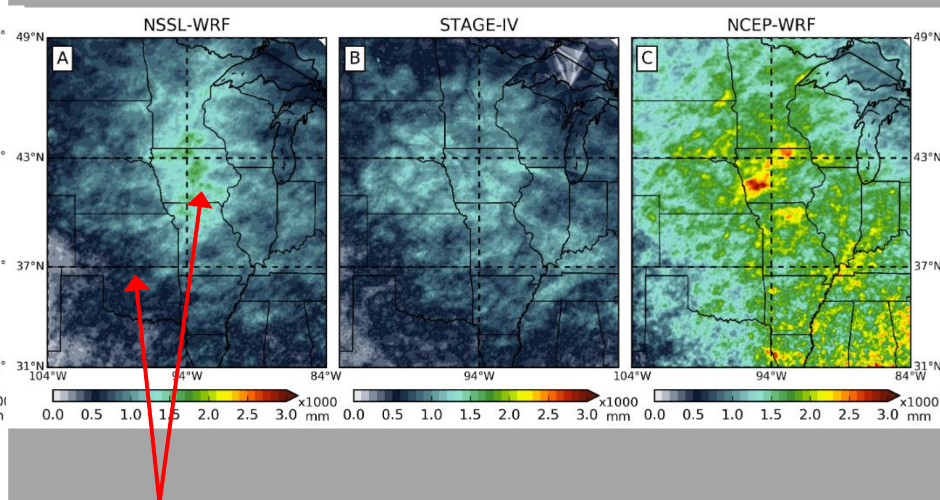
- NSSL/NCEP 4 km deterministic runs, April-Sept 2010-2012
- Goines and Kennedy (2017), rev. submitted to JGR Atmospheres
- *Note, NCEP runs were NMM core, now replaced with NMMB.
- Discussion limited to NSSL runs

Daytime (12-00 UTC)



Positive bias over entire domain

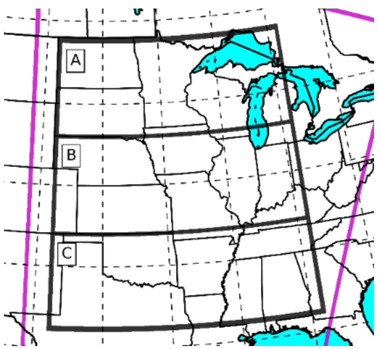
Nighttime (00-12 UTC)



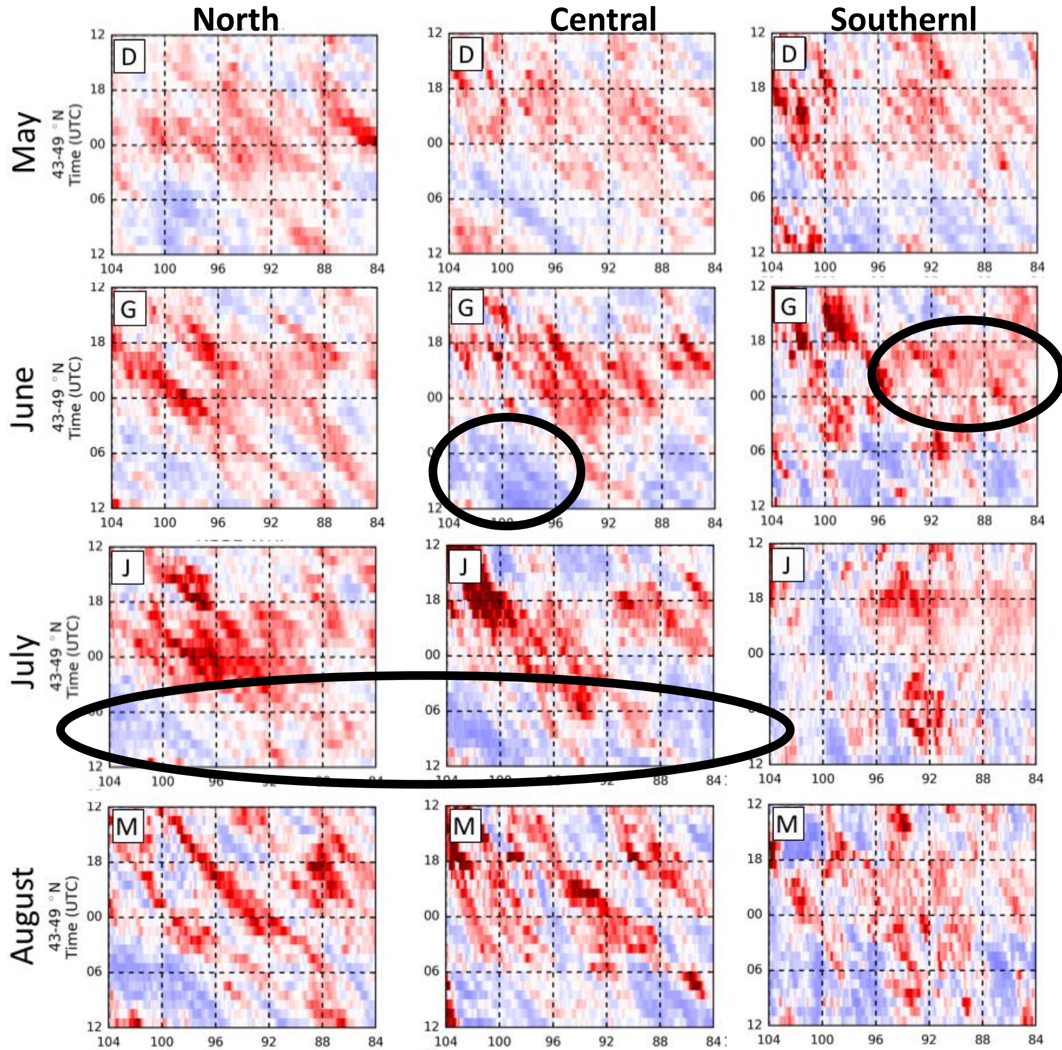
Slight negative bias over plains
Higher positive bias over Midwest/N. Plains

Monthly Hovmöller Diagrams of Precip.

- Separated into three latitude regions
- Bias plotted (blue colors = model deficit)



- Persistent deficit in western half of domain during overnight hours (propagating MCS)
- Positive bias from 18-00 UTC (diurnal signal) over eastern half of domain
- I



Improvement of Convective/Severe Weather Prediction:

FY2017 Deliverables and Beyond

- **Deliverables:**
  - Real time/Retrospective MP ensemble
- **Fundamental question: How to transition gained knowledge to operational forecasting**
  - Forecaster usage?
  - On-demand ensembles. How to make choices on the fly (and how does this relate to ensembles that vary I.C./B.C.)?
  - Some offices run nested deterministic runs for localized forecasting… utility for picking best physics?
- What can be implemented by the 2017 HWT SFE? How does this knowledge transfer to other products (i.e. NSSL probabilistic severe wx hazards)?

Questions?