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

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Co-I: Drs. Aaron Kennedy and Matt Gilmore

NOAA Collaborator: Adam Clark, NSSL (HWT)

2 August 2016 – NGGPS PI Meeting

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- **Overreaching question: Why do model precipitation biases exist in convection allowing simulations and how is this tied to:**
  - Large-scale atmospheric patterns
  - Microphysics

- **Deliverables**
  - Real-time microphysics ensemble
  - Characteristics of deterministic/ensemble simulations

- NWS R2O Initiative (NSSL/SPC Spring Forecast Experiment HWT)
  - What WRF configurations are most beneficial for convective forecasting?
  - Does this configuration vary by synoptic state
  - Potential for on-demand ensembles or selected deterministic/ensemble runs (i.e. pick members based on pattern of the day)

Proposed Objectives

- **Objective 1: Evaluation of WRF simulated convection/precipitation**
  - How does performance vary with synoptic state?
  - Investigate WRF ability to capture formation/dissipation of convective complexes

- **Objective 2: Develop and determine best practices for a WRF microphysics ensemble**
  - Combination of real-time/ retrospective runs
  - How do the schemes perform by synoptic pattern?

Improvement of Convective/Severe Weather Prediction:

Updated Team

PI: Xiquan Dong

- Radiation / Cloud Physics / Retrievals
- R2O Role
  - Satellite Retrievals
  - Stratiform/convective classification

Jingyu Wang

CO-I: Matt Gilmore

- Modeling / Microphysics Parameterizations
- R2O Role
  - WRF Microphysics Ensemble

Joshua Markel

CO-I: Aaron Kennedy

- Remote Sensing / Modeling / Synoptic Typing
- R2O Role
  - Performance of prior HWT simulations
  - Database of convective events
  - Synoptic classification

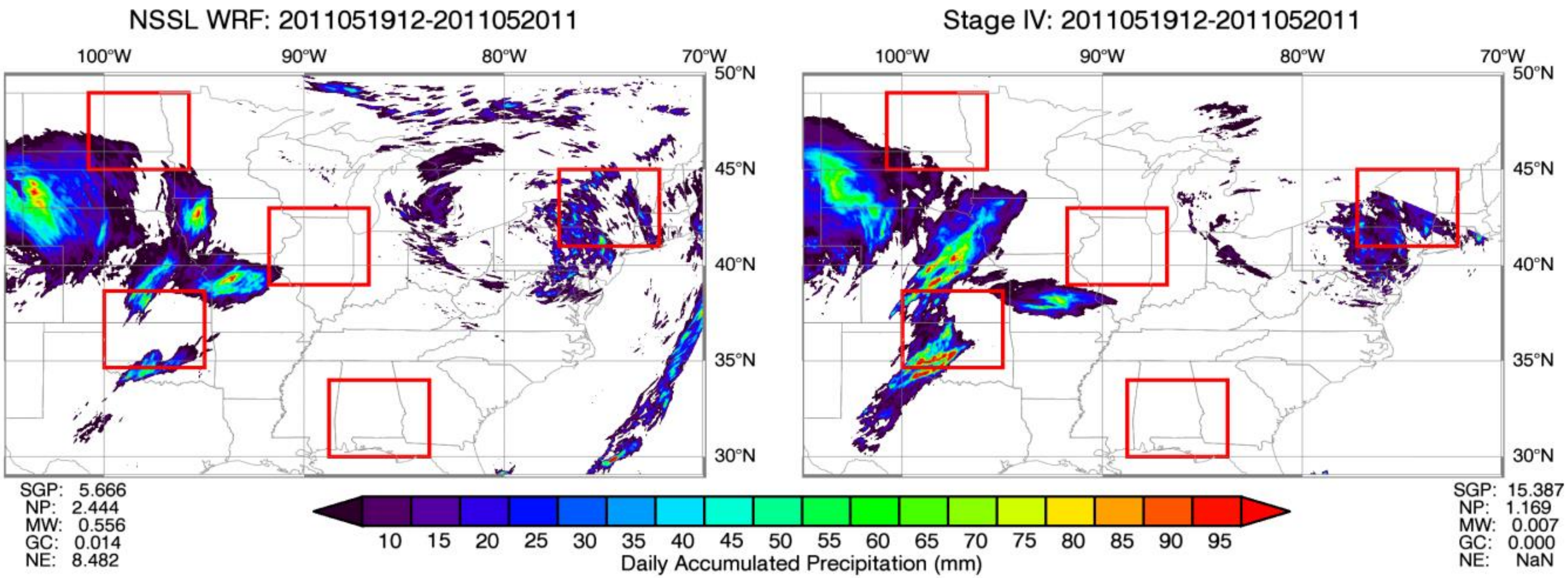
Brooke Hagenhoff
David Goines

Strategy: Objective 1

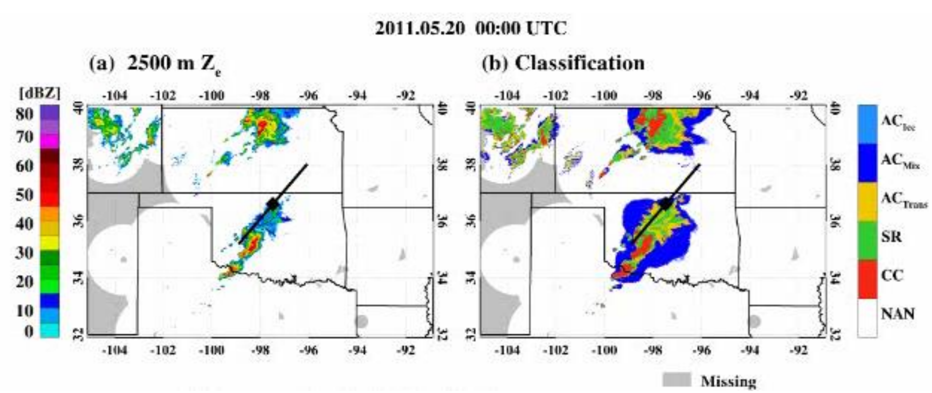
- **Datasets**
  - NSSL WRF ARW simulations (4km, 2007-2014)
  - NCEP WRF NMM simulations (4km, 2010-2012)
  - NCEP Stage-IV precipitation
  - UND Hybrid classification product (2010-2013)
    - NEXRAD/GOES data
    - Define convective core / stratiform areas (radar) and anvil regions (satellite)
- **Strategy**
  - 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

Improvement of Convective/Severe Weather Prediction:

Strategy: Objective 1



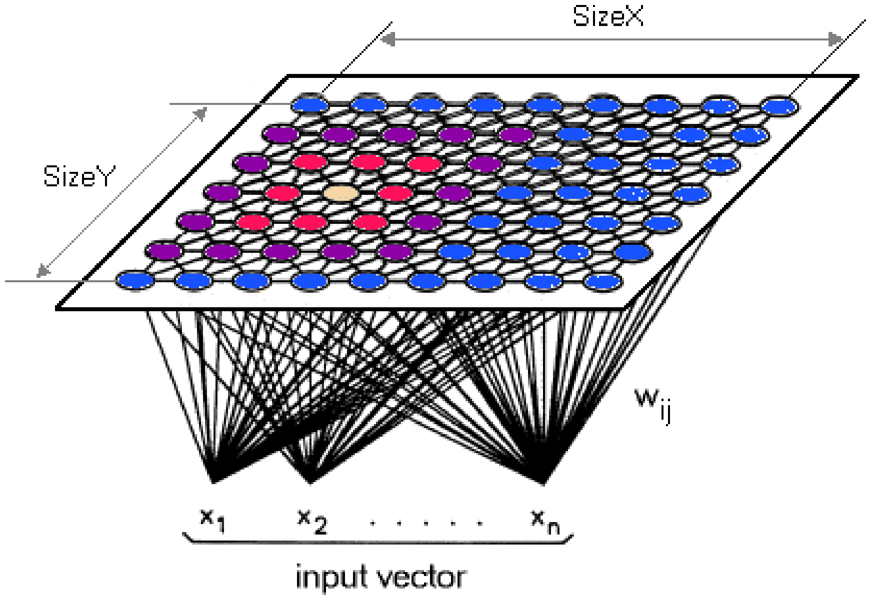
- **Defined 5 focus regions (red boxes)**
- **Example Case: May 19-20 2011**
- **Criteria:**
  - **Intensity > 40 dBZ**
  - **Duration > 3 hr**
  - **Must pass through domain**



Improvement of Convective/Severe Weather Prediction:

Strategy: Objective 1 (SOMs)

- **Kohonen (1995)**
- **Competitive neural network**
- **Unlike other techniques, classes are related to each other in a 2-dimensional matrix (feature map)**
- **If you remove the neighborhood function, the SOM is reduced to a k-means clustering technique *(vectors compared using Euclidean distance)***



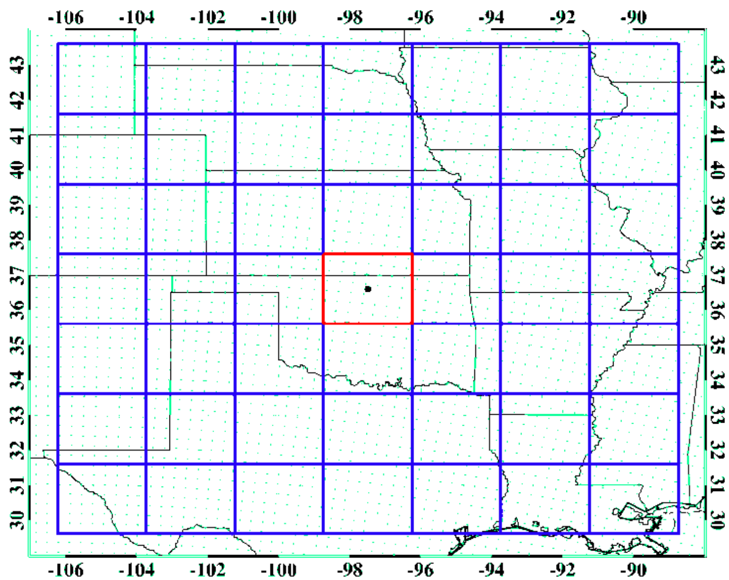
From *http://www.lohninger.com*

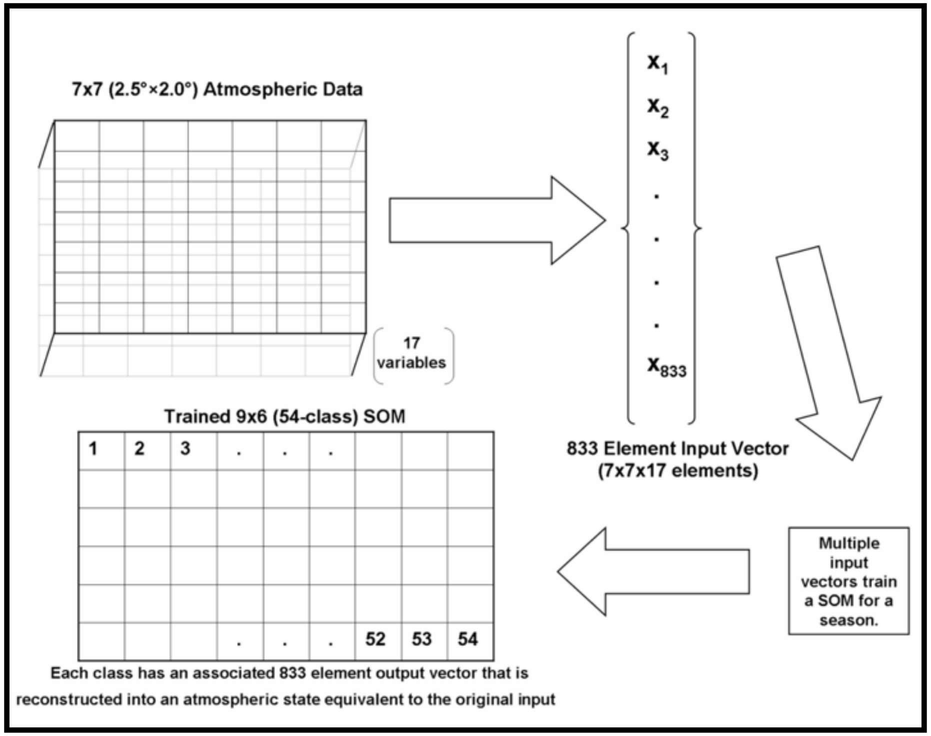
Public domain software: SOM_PAK
http://www.cis.hut.fi/research/som-research/nnrc-programs.shtml

Routines in Matlab, Python Packages: PyMVPA, SOMpy, etc.

Improvement of Convective/Severe Weather Prediction:

Strategy: Objective 1 (SOMs)





Kennedy, A., X. Dong, and B. Xi, 2016: Cloud Fraction at the ARM SGP Site: Reducing uncertainty with Self Organizing Maps. *Theor. Appl. Climatol.*, DOI:10.1007/s00704-015-1384-3

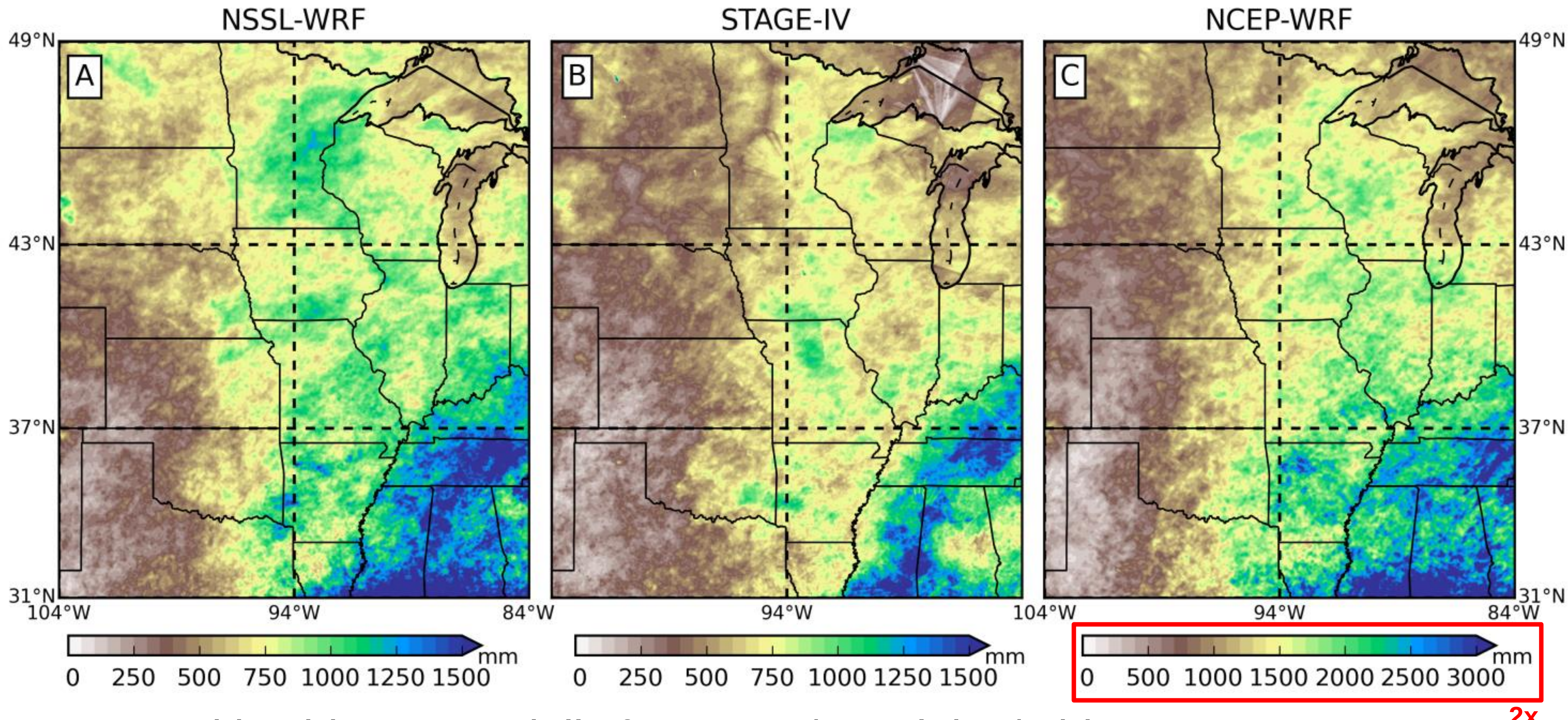
- **Variables typically used for classification:**
  - **MSLP**
  - **900, 700, 500, 300 hPa: Φ, RH, U, V**
  - **From the North American Regional Reanalysis (NARR)**
  - **Data normalized to contribute equally to SOMs**

SOM patterns typically have strong link to precipitation. Possible tool for 3-4wk forecasting?

Improvement of Convective/Severe Weather Prediction:

Strategy: Objective 1 (Climatology)

2010-2012 Warm Season Daytime (12–00 UTC)



- Positive bias, especially for NCEP/ N. Plains/Midwest
- Larger during nocturnal hours over the latter regions

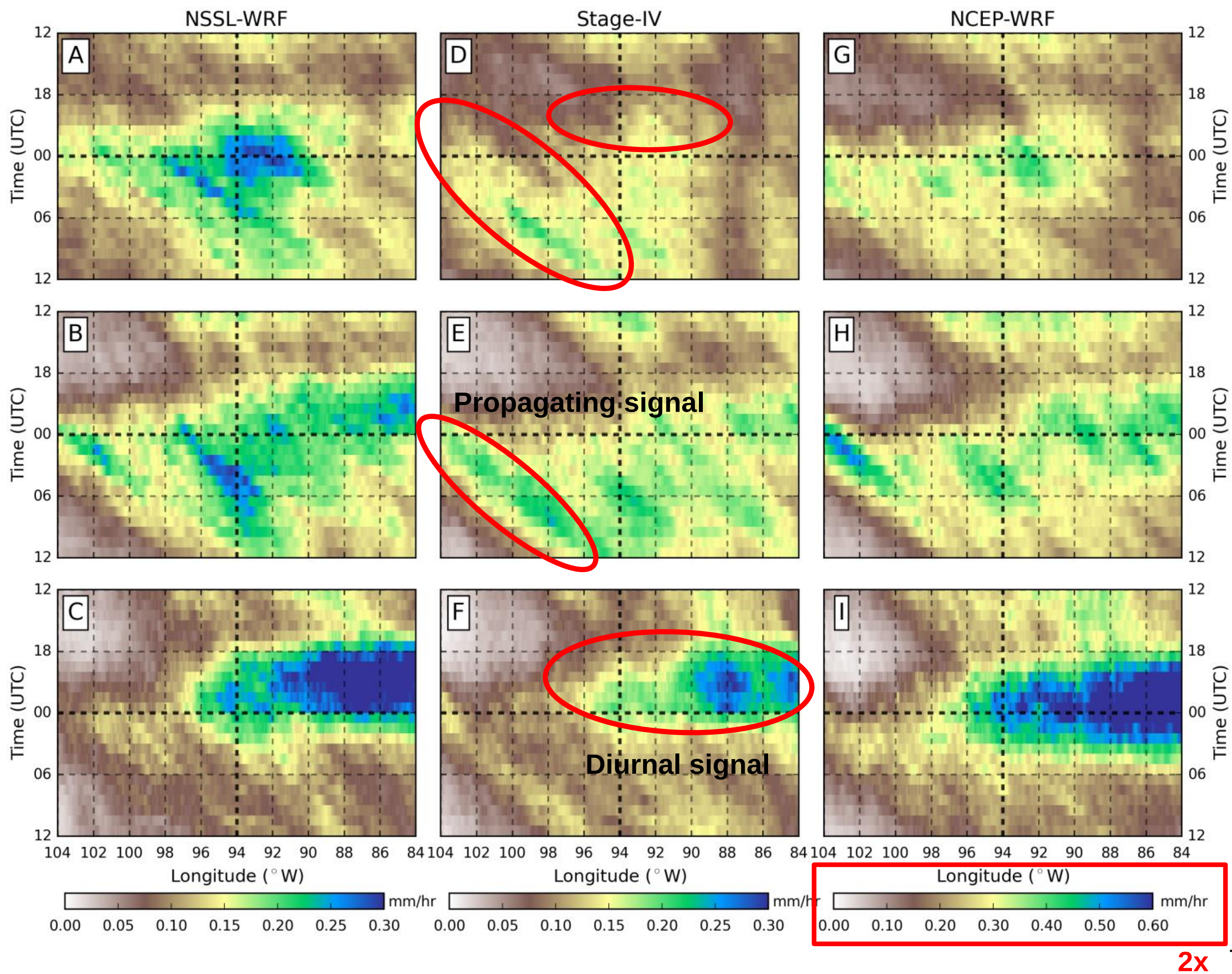
Improvement of Convective/Severe Weather Prediction:

Strategy: Objective 1 (Climatology - Hovmöllers)

Northern Plains / Great Lakes

Central Plains / Midwest

Southern Plains / Gulf Coast

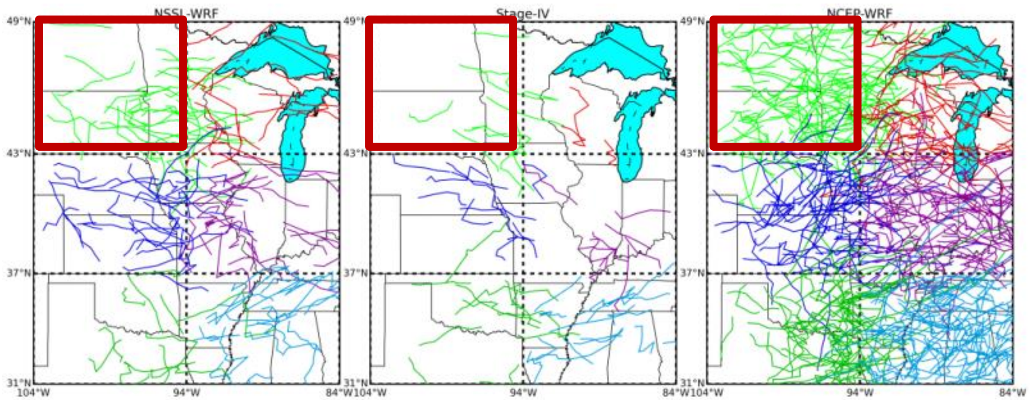


Strategy: Objective 1 (Climatology - Tracked Objects)

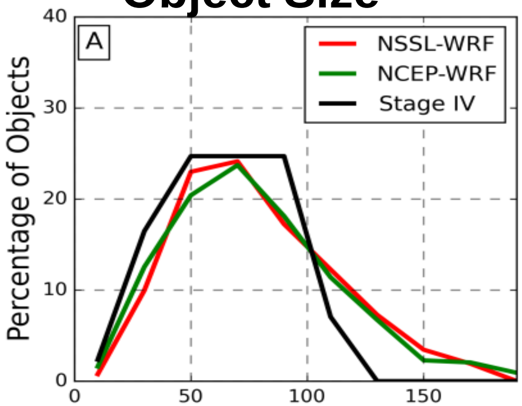
MCS Objects: Duration >= 6hr, Distance >= 250km

NSSL **Obs** **NCEP**

Objects identified using a beta version of Method for Object-based Diagnostic Evaluation Time Domain (MODE-TD) from NCAR DTC

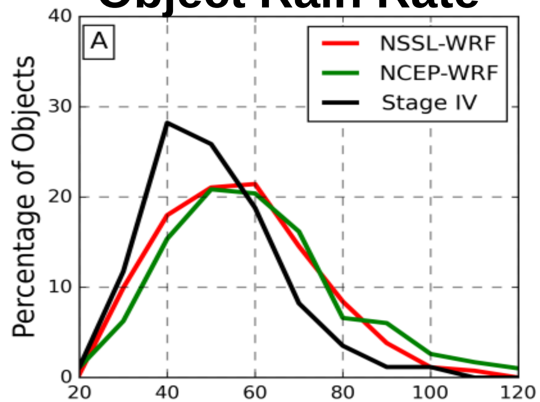


Object Size



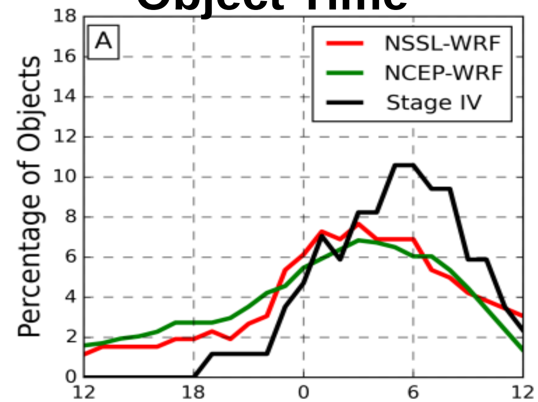
$\sqrt{Area}\ (km)$

Object Rain Rate



Max. Rain rate (mm/hr)

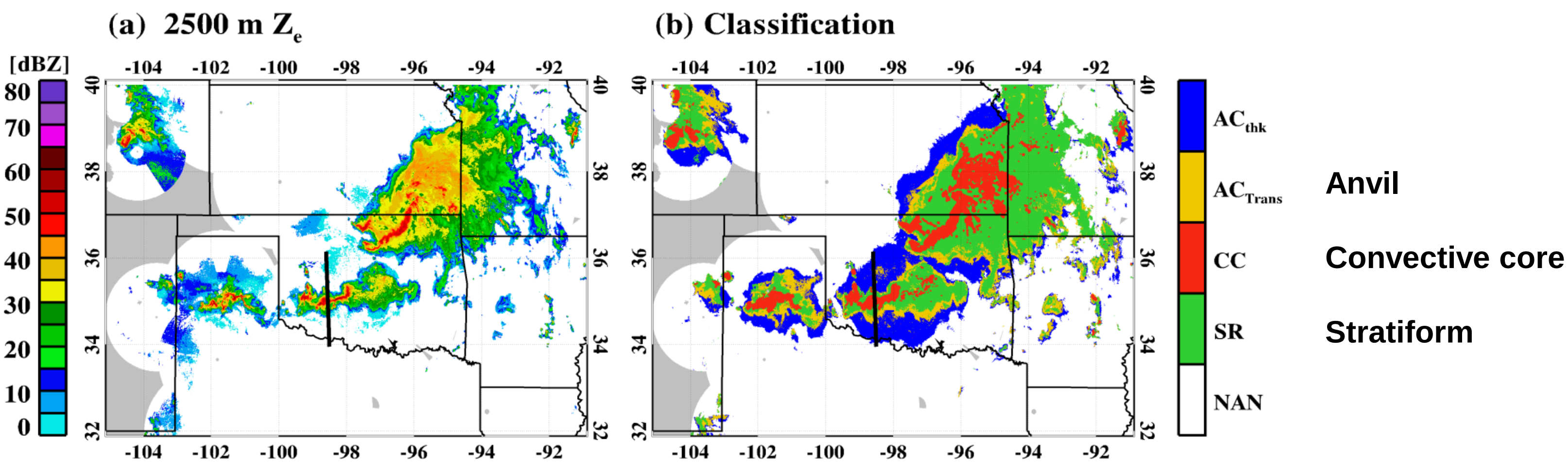
Object Time

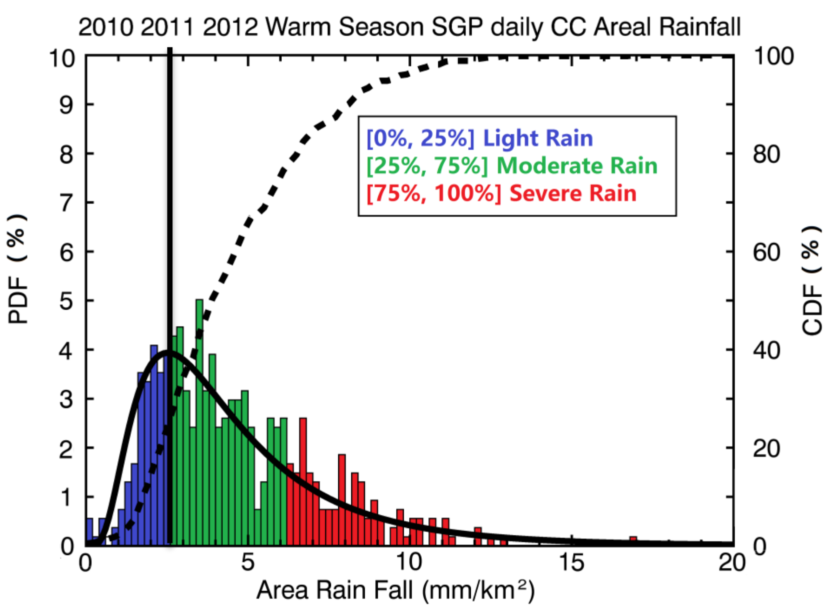


Time (UTC)

Improvement of Convective/Severe Weather Prediction:

Strategy: Obj. 1 (Radar Objects and Classification)

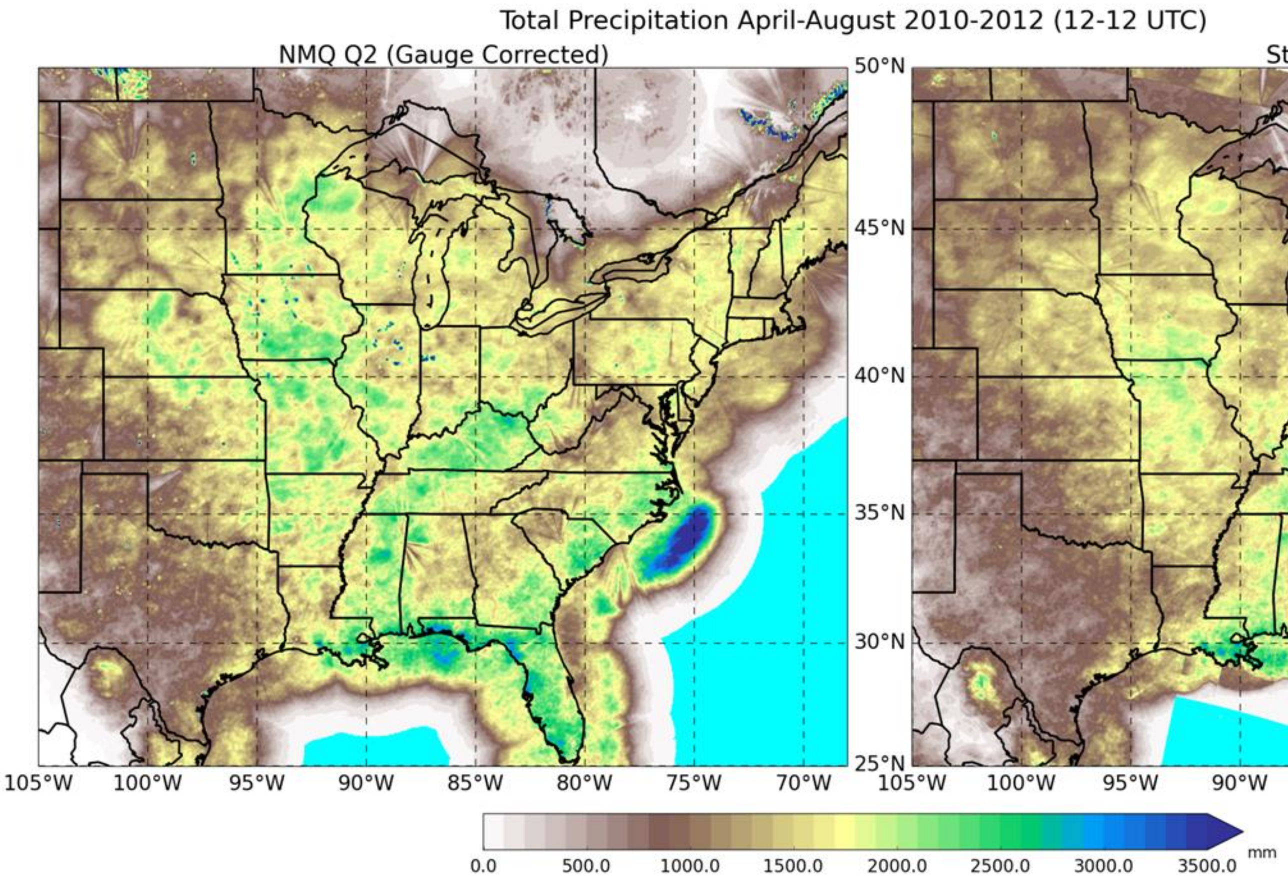




- **Use area rainfall**
  - Total rainfall within region / area
  - Allows for intense or large coverage events
- **Pick convective cases (CC) for upper 75% of CDF**
  - Avoids issues with radar artifacts (i.e. wind farms)
  - Isolated events
  - *Looking into similarity with Stage IV*

Improvement of Convective/Severe Weather Prediction:

Strategy: Obj. 1 (Q2 vs. Stage IV)

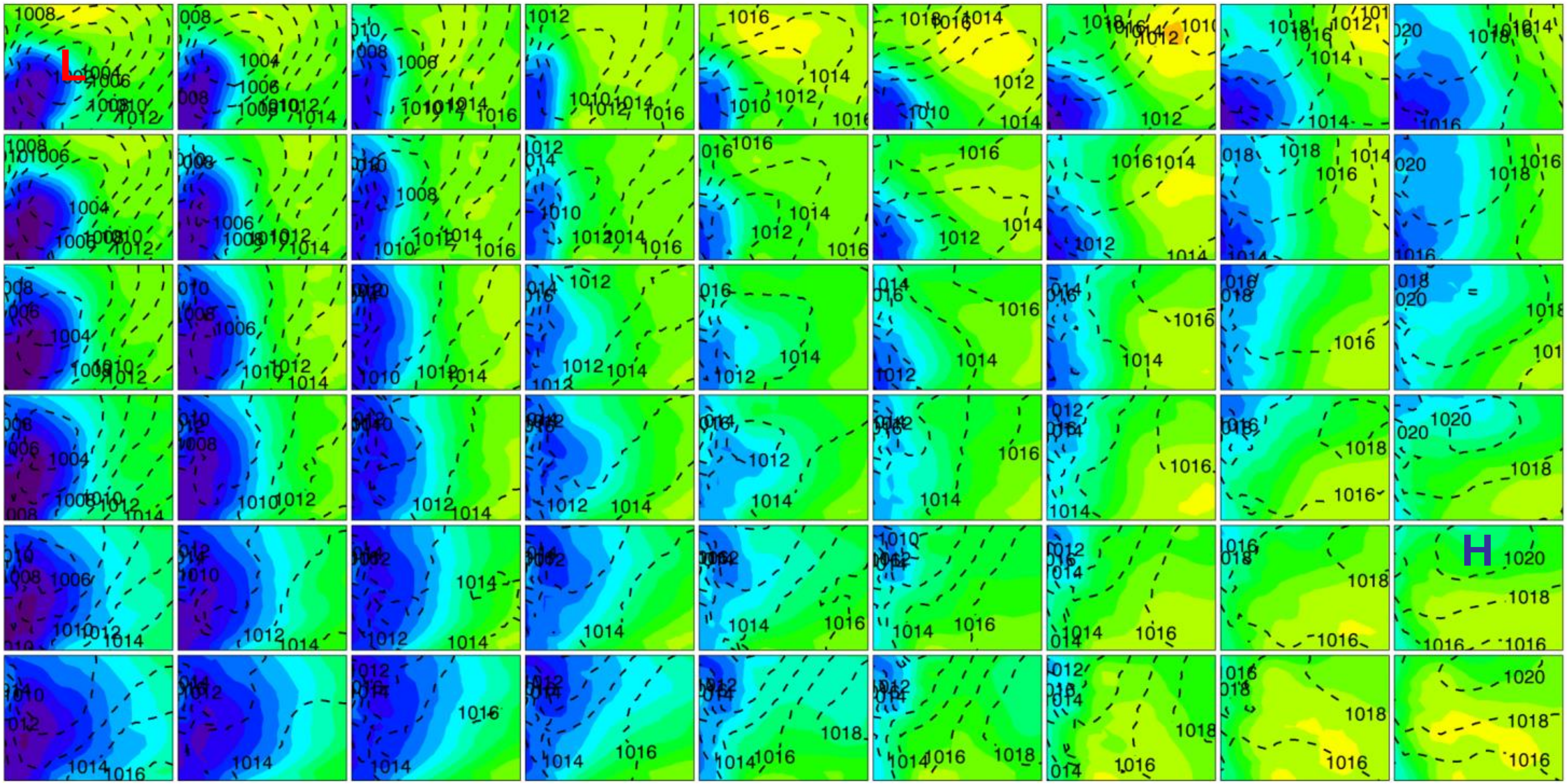


- Note the number artifacts in Q2 NMQ: wind farms, beam blockage, etc.

- **SOM general guidelines**
  - Climatological (look at all times)
  - Convective events (generate from list of cases)
- **End goal: pattern recognition**
  - Create ‘simple’ SOMs based on either near-sfc or upper air properties
    - MSLP/900 hPa (winds, humidity)
    - 500 hPa (heights, winds, humidity)

Improvement of Convective/Severe Weather Prediction:

Strategy: Climatological SOMs (Southern Plains)

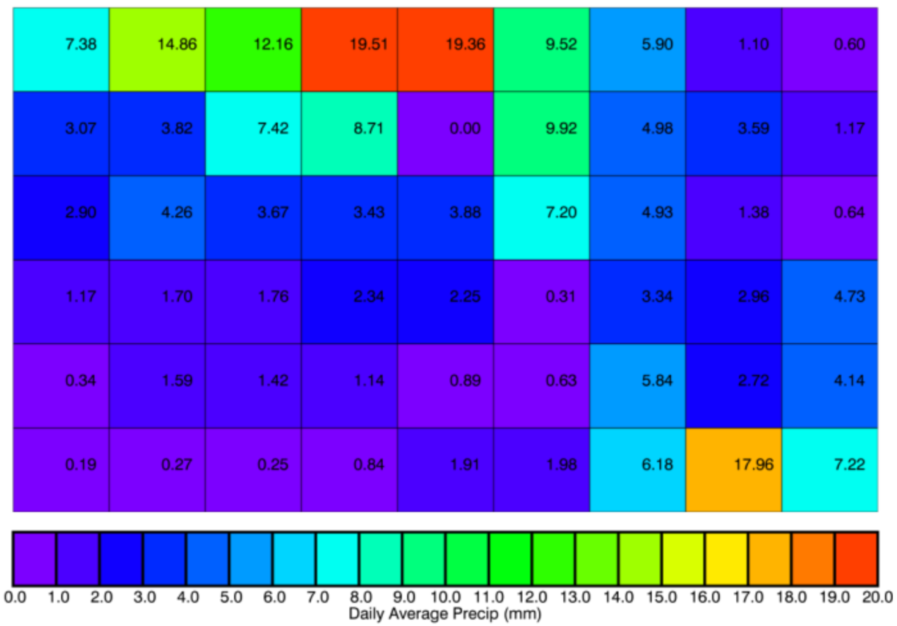


- Warm Season 2007-2014 MSLP/900 hPa
- Note number of dryline cases (cooler colors, lower humidity)

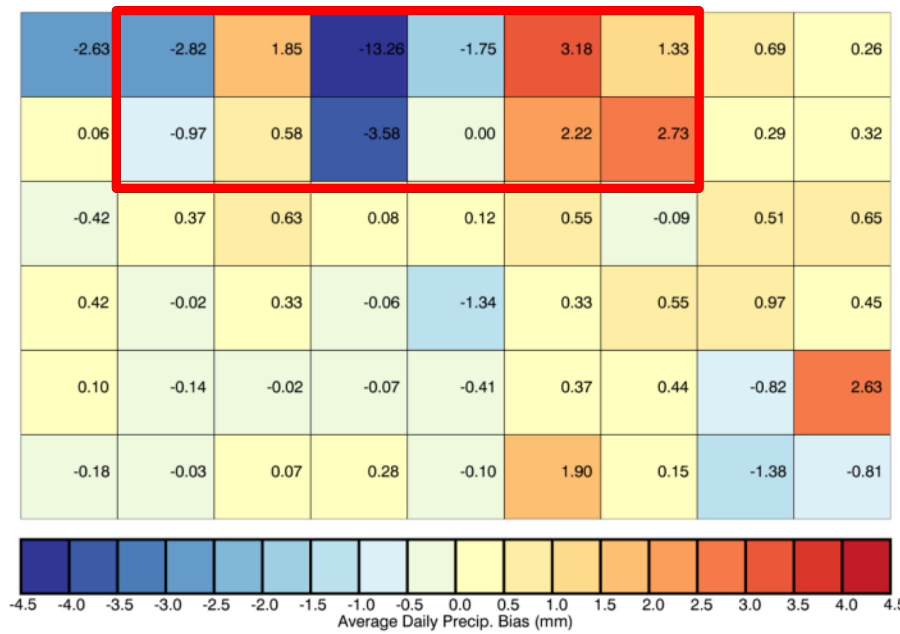
Improvement of Convective/Severe Weather Prediction:

Strategy: Climatological SOMs (Southern Plains)

Stage IV Precipitation



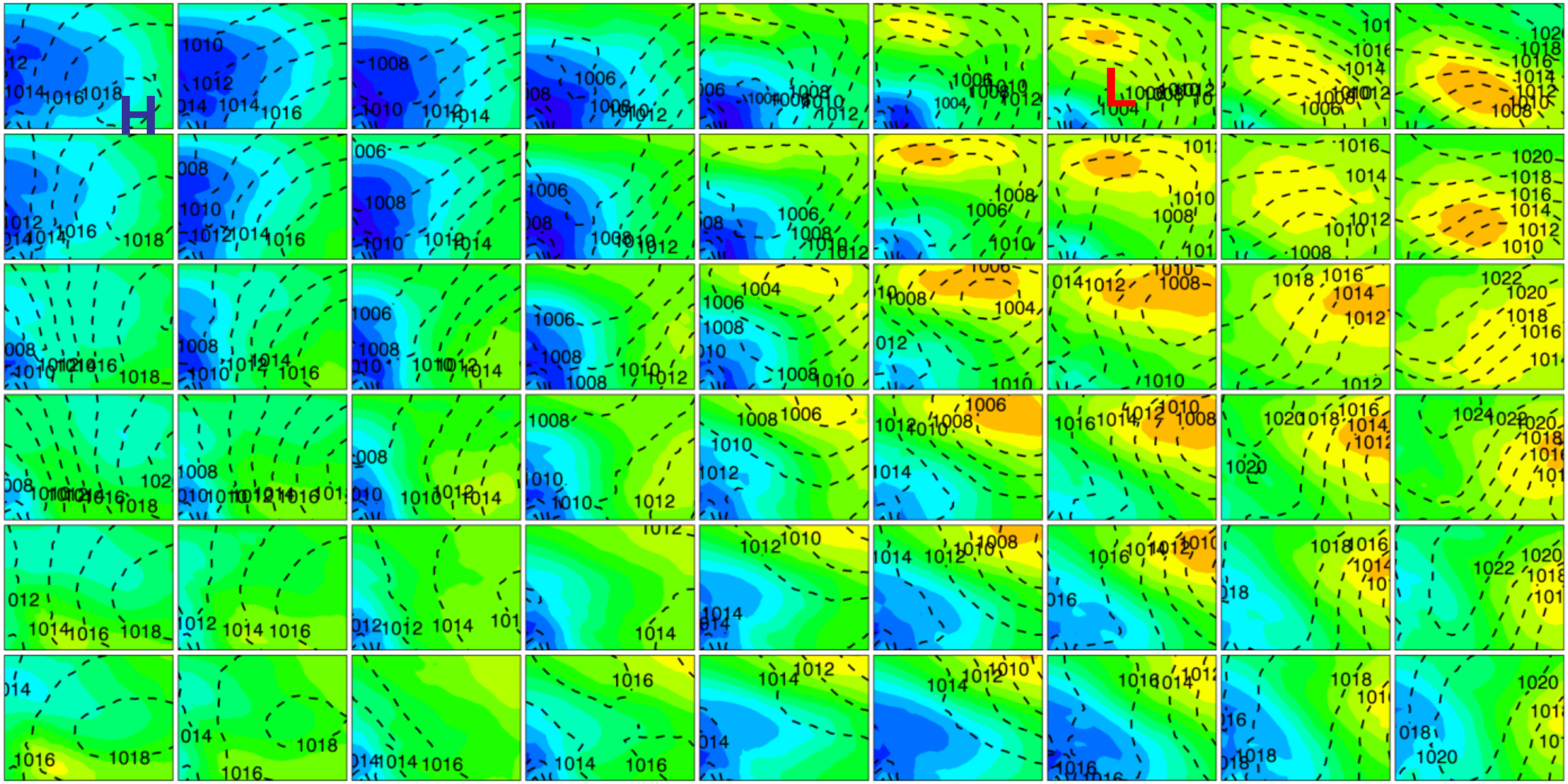
NSSL WRF Bias



- Higher precipitation generally associated with higher humidity (moisture transport) and/or mid-latitude cyclones
- Biases with WRF are inconclusive- noise suggests some sampling issues although there appears to be more positive biases on RHS of SOM. Why?
- Impacts of deterministic runs (hit/miss storms) and/or morning convection?

Improvement of Convective/Severe Weather Prediction:

Strategy: Climatological SOMs (Northern Plains)

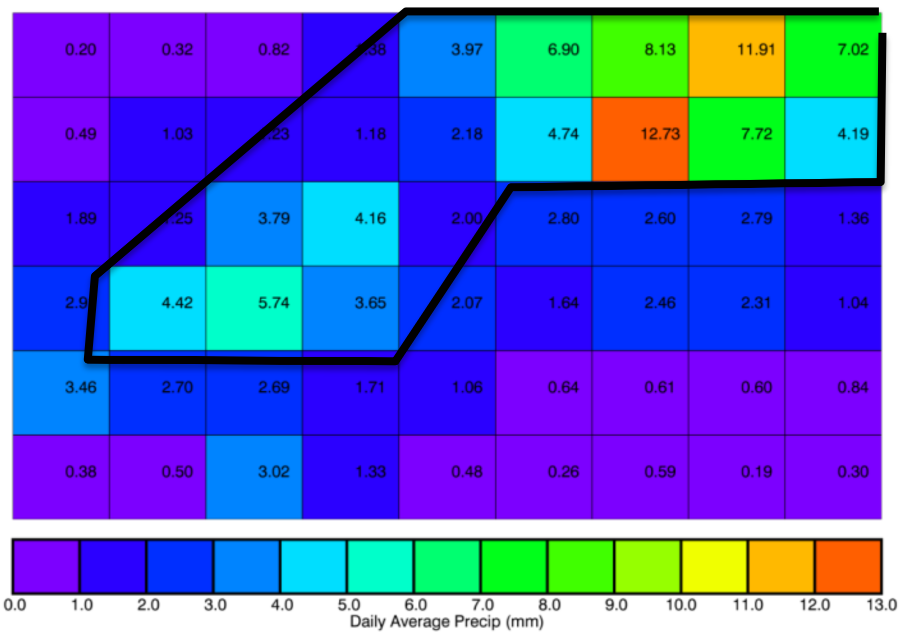


- Warm Season 2007-2014 MSLP/900 hPa
- Note differences compared to S. Plains. More strongly forced events (RHS)

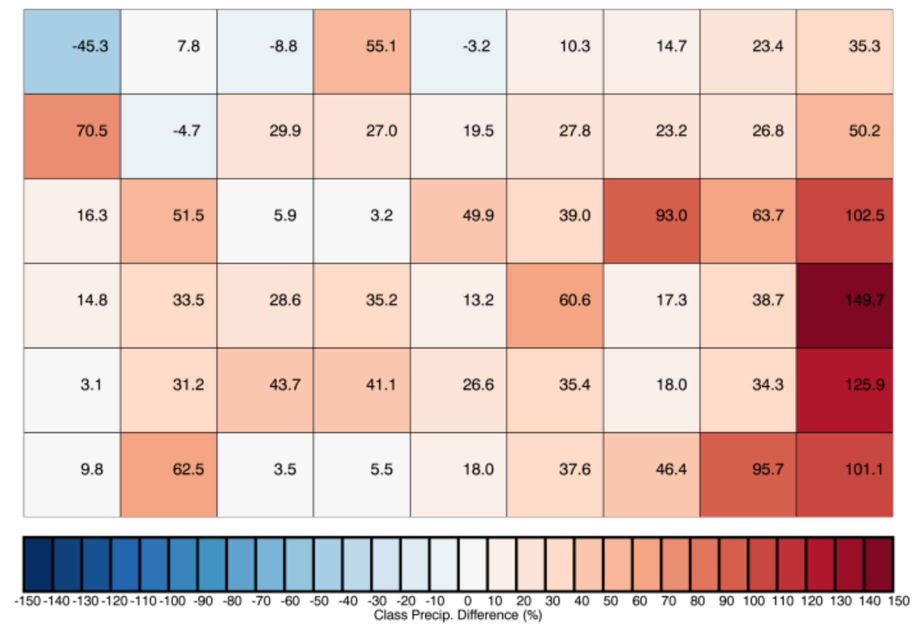
Improvement of Convective/Severe Weather Prediction:

Strategy: Climatological SOMs (Northern Plains)

Stage IV Precipitation



NSSL WRF Bias

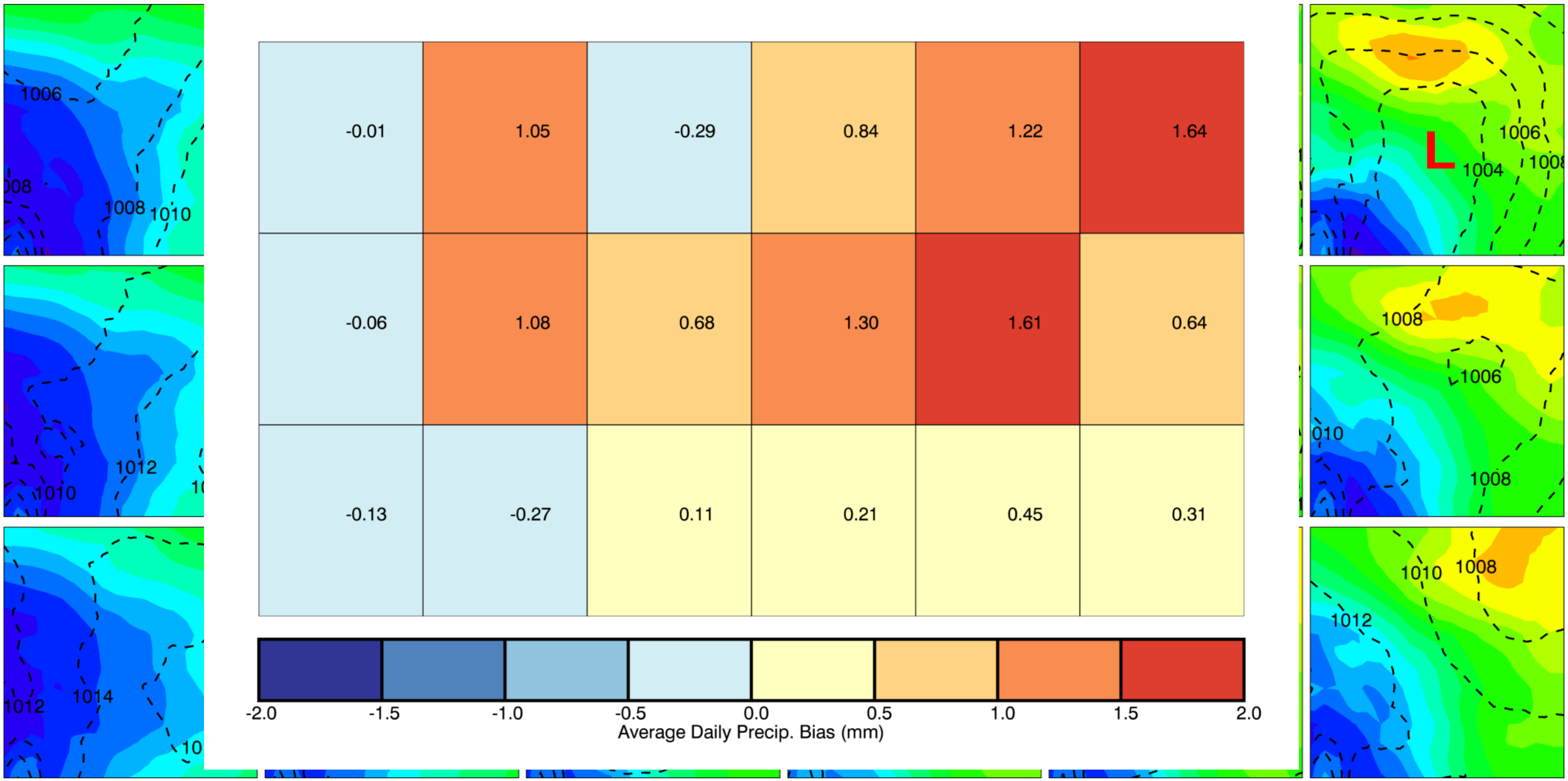


- Positive biases for almost all patterns
- Relative differences highest in lower right (patterns with more southerly flow)

- What if SOMs are created based on precipitation days?

Improvement of Convective/Severe Weather Prediction:

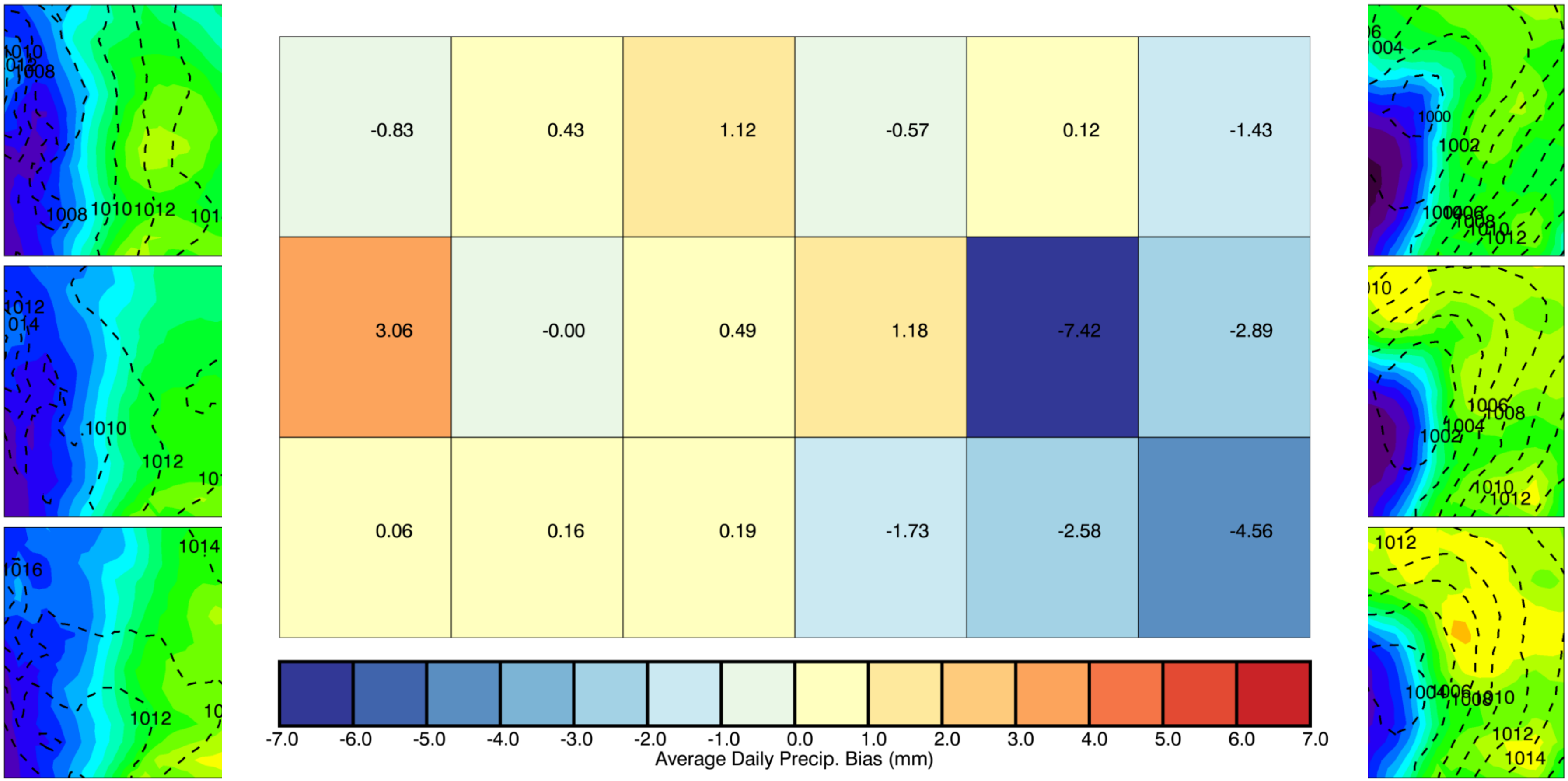
Strategy: Convective SOMs (Northern Plains)



- Warm Season 2007-2014 MSLP/900 hPa
- Strongly forced cases on RHS

Improvement of Convective/Severe Weather Prediction:

Strategy: Convective SOMs (Southern Plains)



- Warm Season 2007-2014 MSLP/900 hPa, high precipitation cases
- Negative bias for strongly forced cases.
- Opposite of Northern Plains… Need to look at convective properties

Objective 1: Priorities, Milestones, and Challenges

- **Finished:**
  - Baseline climatology for NSSL/NCEP WRF (Goines 2016, Goines et al. 2016)
  - Climatological SOMs for the five regions
  - Processing of hybrid classification for NP/SGP
  - Case identification for the microphysics ensemble

- **Priorities/Milestones**
  - Finish case-based SOMs (Fall)
    - Statistical significance for all SOMs
    - Analysis of hybrid classification
  - Comparison of Q2 to Stage IV (eliminate non-meteorological cases, Fall)
  - Process hybrid classification for other regions, include GOES data (Spring)

- **Challenges**
  - Balance between sampling / statistical significance / detail in patterns
  - Personnel transition (new grad students) delayed progress to some extent
  - Transitioning knowledge to operational setting

Strategy: Objective 2 (Microphysics Ensemble)

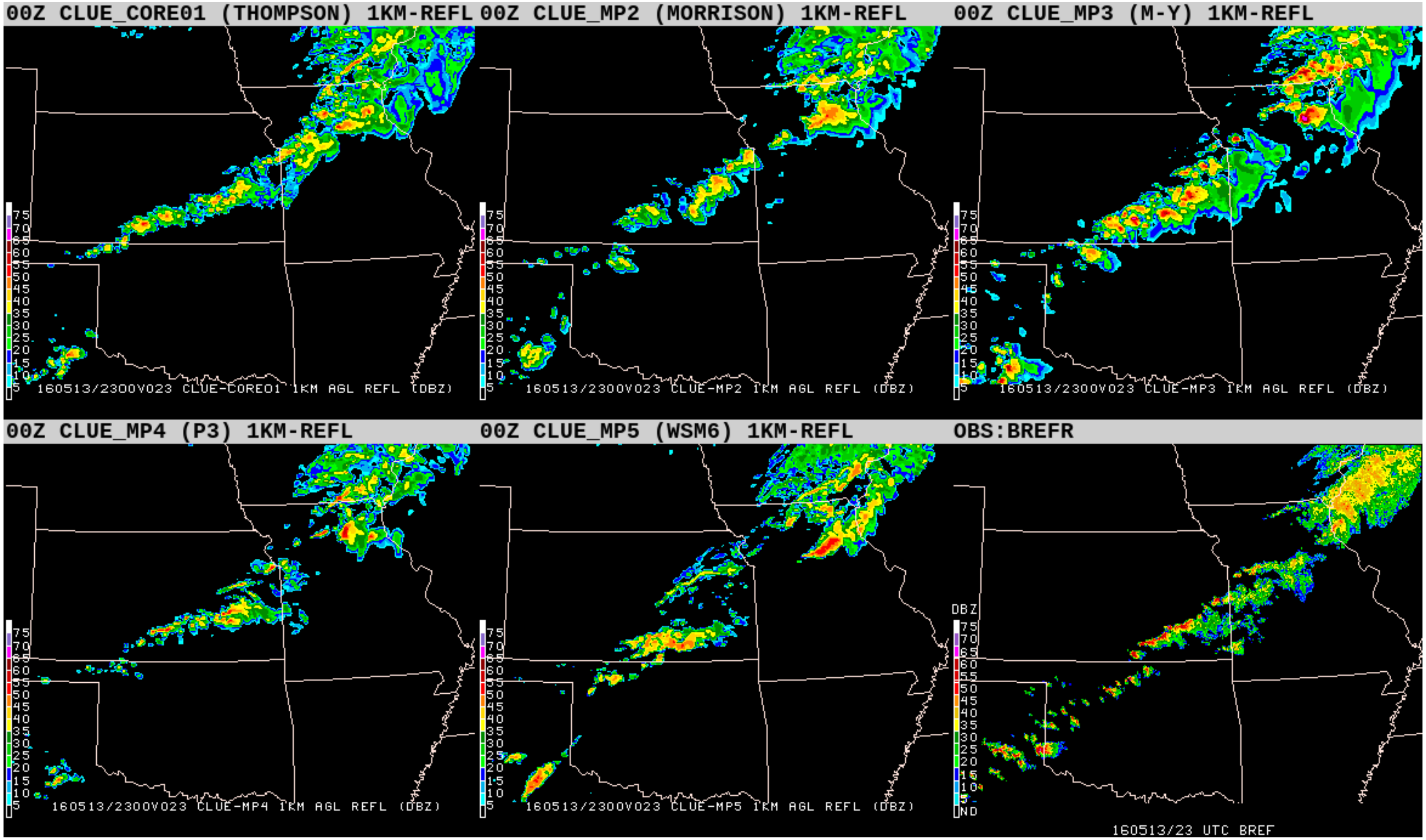
- Summary:
  - Developed microphysics ensemble for both real-time and retrospective case
- Run for 2016 Spring HWT, retrospective cases ongoing

Microphysics Scheme	Moments Predicted/Features	Original Reference
Ens 1. WSM6	Qc, Qr, Qi, Qs, Qg	Hong and Lim (2006)
Ens 2. Thompson	+Ni, Nr	Thompson et al. (2008)
Ens 3. Morrison	+Ns, Ng	Morrison et al. (2009)
Ens 4. Milbrandt	+Qh, Nc, Nh	Milbrandt and Yau (2005)
Ens 5. P3	Qc, Qr, Nc, Nr, Q*(free ice category)	Morrison and Milbrandt (2015)

- Number of schemes reduced from 9 to 5 due to computational demand
- Running with Community Leveraged Unified Ensemble config. (CONUS) instead of nested setup

Improvement of Convective/Severe Weather Prediction:

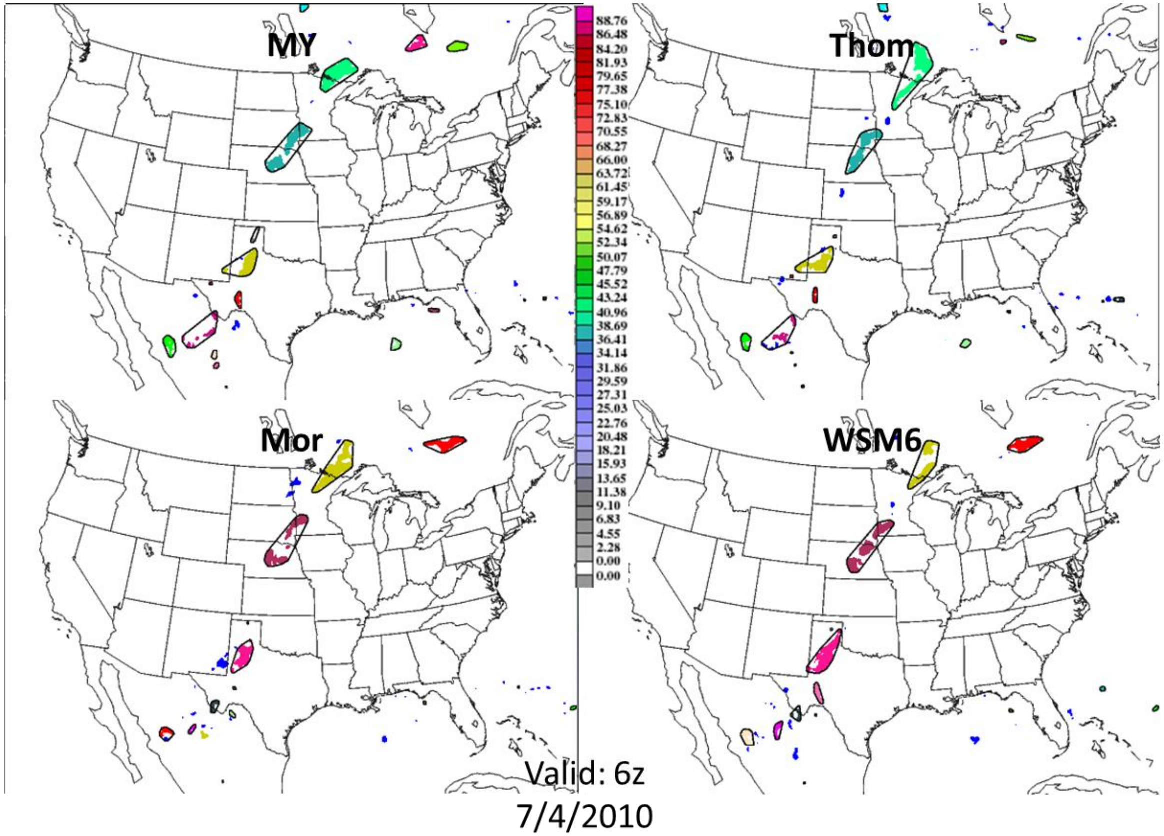
Strategy: Microphysics Ensemble (Example)



- Subjective notes during HWT:
- Milbrandt consistently simulated more/stronger convection (higher reflectivity)
- Morrison tended to simulate less convection

Improvement of Convective/Severe Weather Prediction:

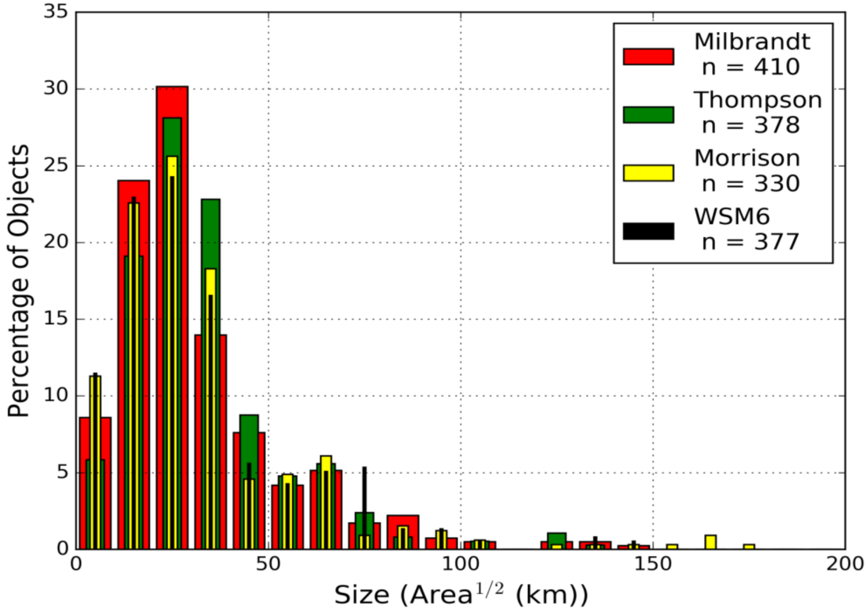
Strategy: Microphysics Ensemble (Objects)

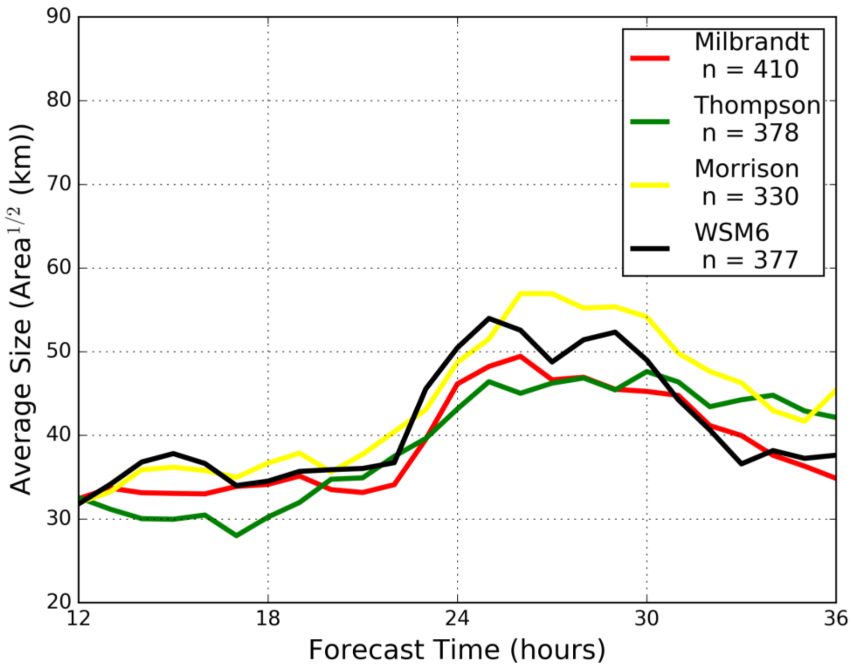


- Using MODE TD (now released) to classify and track objects
- Thresholds:
  - Convolution radius - 5 grid squares (15 km)
  - Convolution threshold - >= 2.54 mm (0.1 in)

Improvement of Convective/Severe Weather Prediction:

Strategy: Microphysics ensemble (Case Statistics)





- Results for one day
- Currently running MODE-TD for all of the retrospective/real-time cases.

Strategy: Microphysics Ensemble (Progress)

	Thompson	Morrison	Milbrandt	WSM6	P3
Real Time	33	33	31	33	23
Retrospective	46	46	46	46	16

Real Time Cases: 4/20/2016 – 6/3/2016

Retrospective Cases: April – September (2010-2013)

Strategy: Microphysics Ensemble (Challenges)

- **P3 Stability**
  - CLUE vertical grid spacing led to stability issues using 18s timestep (updrafts too strong)
  - Reduced timestep to 15s for failed runs (still fail on occasion)
  - Limited computing resources so significantly less P3 runs

- **Computing time**
  - Real time runs + testing ate up more time than expected
  - Will be applying for additional time from XCEDE to finish retrospective runs (100+).

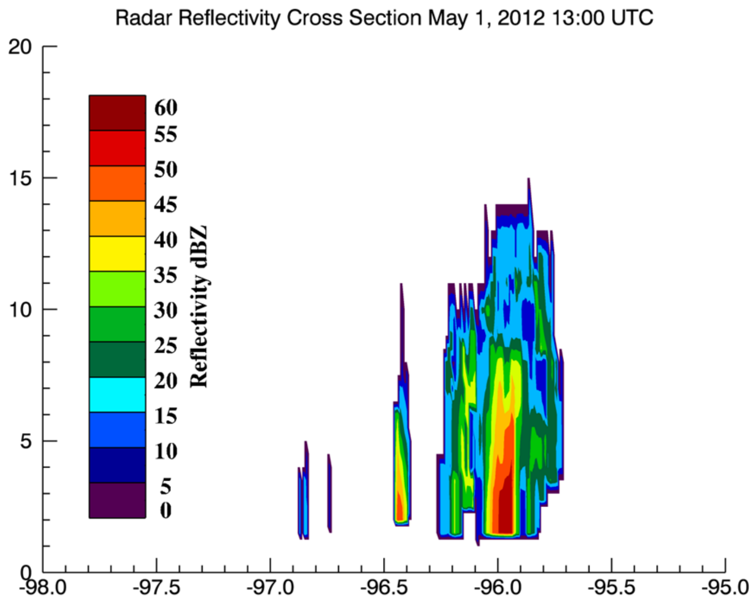
- Priorities
  - Finish retrospective runs (Fall)
  - Run and analyze MODE-TD for all cases (Fall)
  - Analyze results based off SOMs from Obj. 1 (Spring)

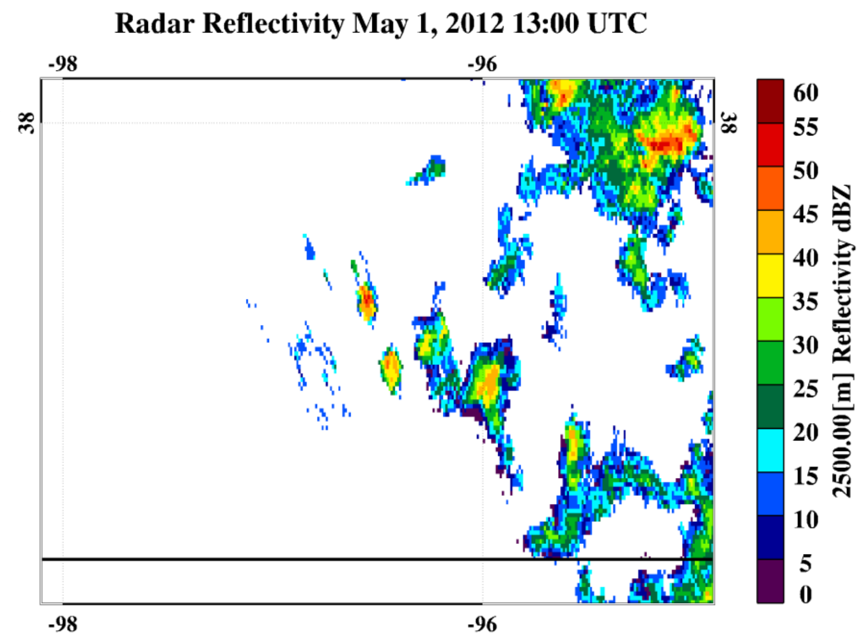
- **Deliverables:**
  - Real time/Retrospective MP ensemble
- **Fundamental question: How to transition gained knowledge to operational forecasting**
  - Forecaster usage?
  - On-demand ensembles. How to make choices on the fly (and how does this relate to ensembles that vary I.C./B.C.)?
  - Some offices 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?

Improvement of Convective/Severe Weather Prediction:

Backup Slide: Ground Clutter Example



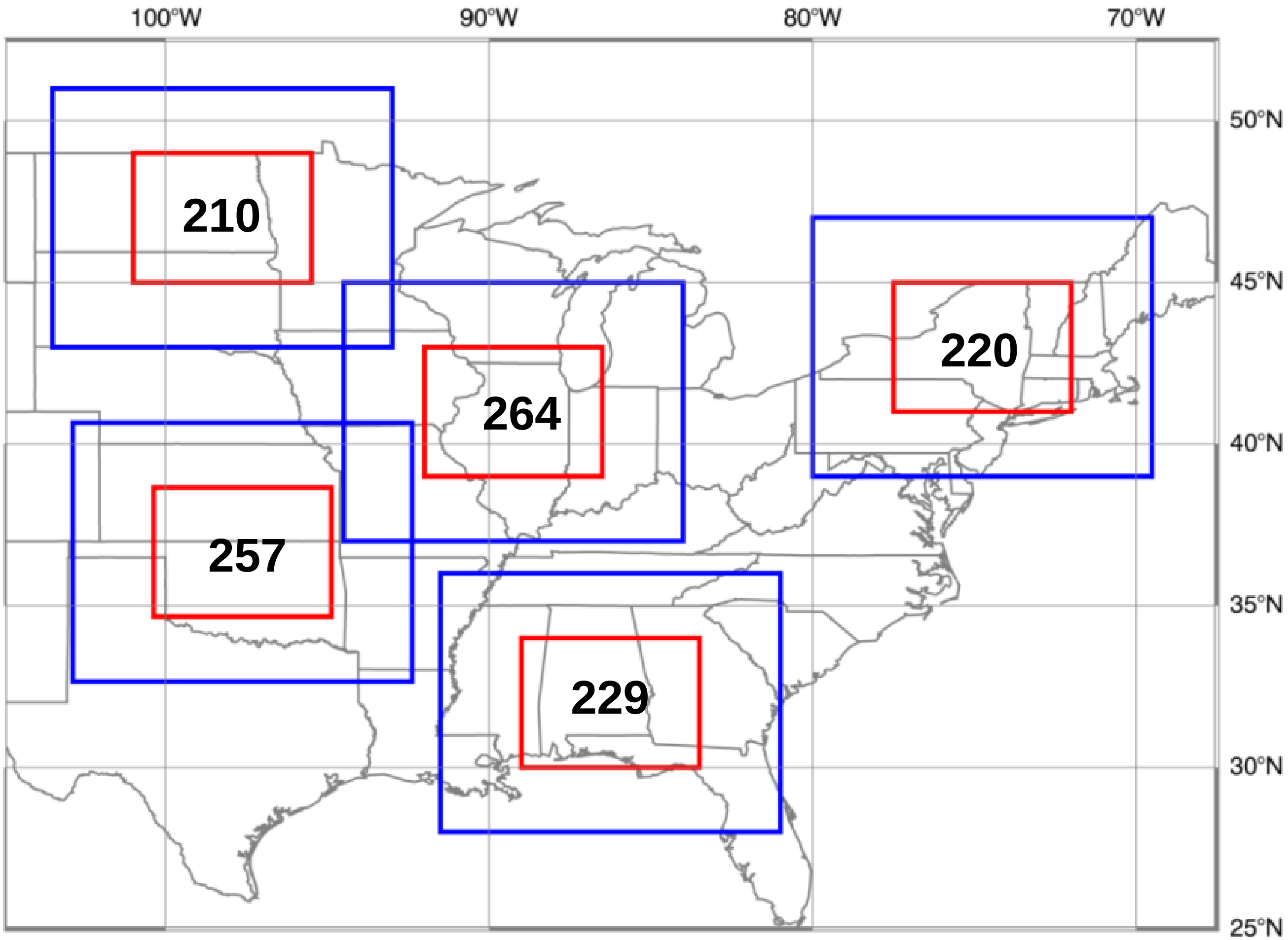


- **Merged radar products can contain storm-like reflectivity objects that are actually clutter**

Improvement of Convective/Severe Weather Prediction:

Strategy: Selecting Cases (Subjective 2007-2014)

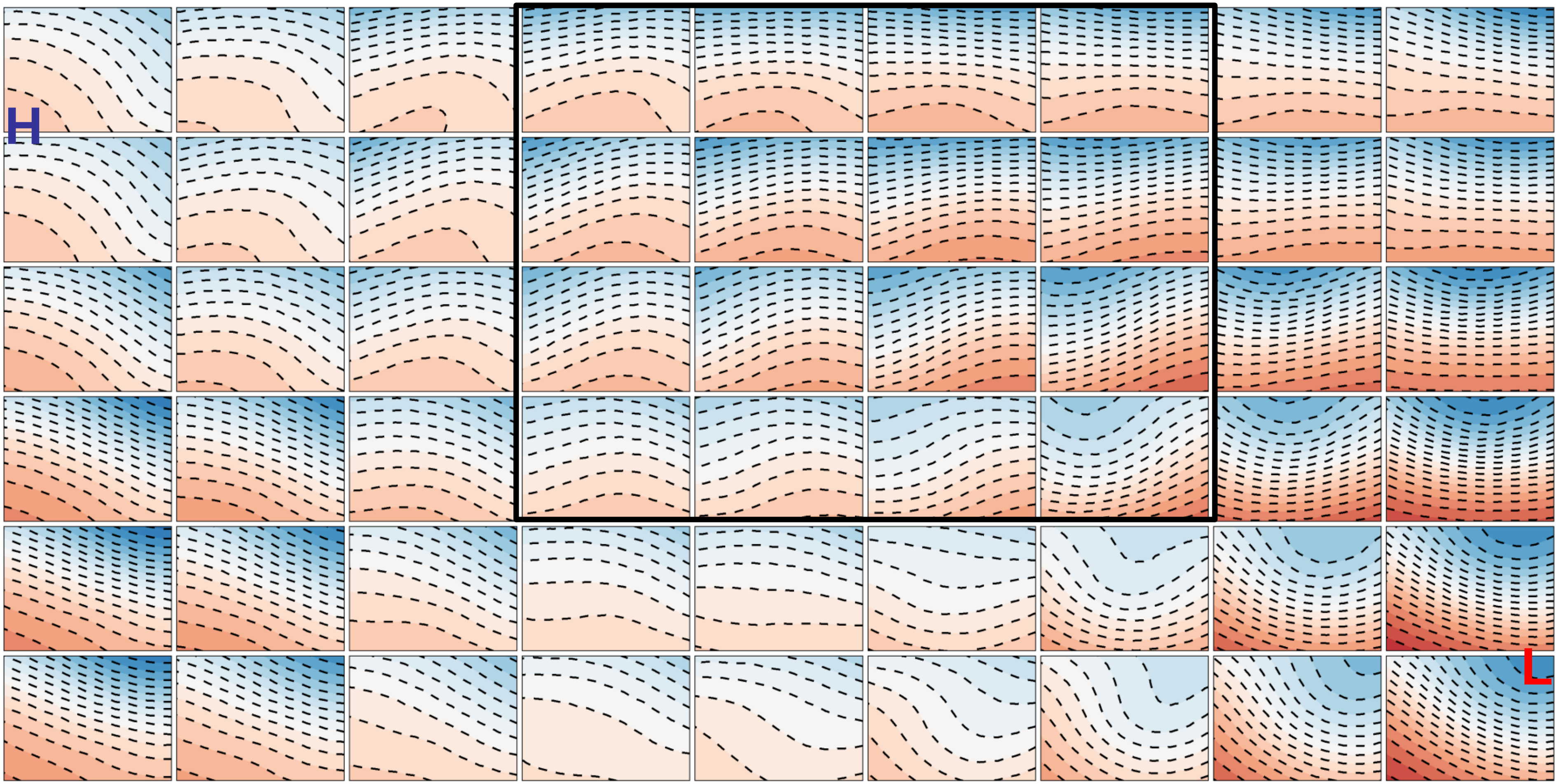
Warm Season Cases 2007-2014



Red: focus region Blue: area for pattern classification (from NCEP North American Regional Reanalysis)

Improvement of Convective/Severe Weather Prediction:

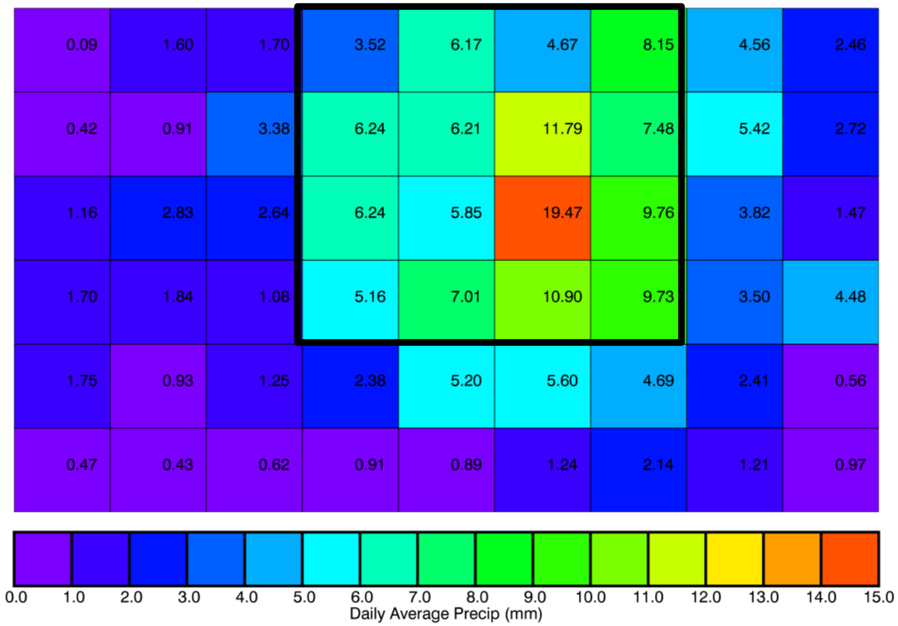
Strategy: Climatological SOMs (Midwest)



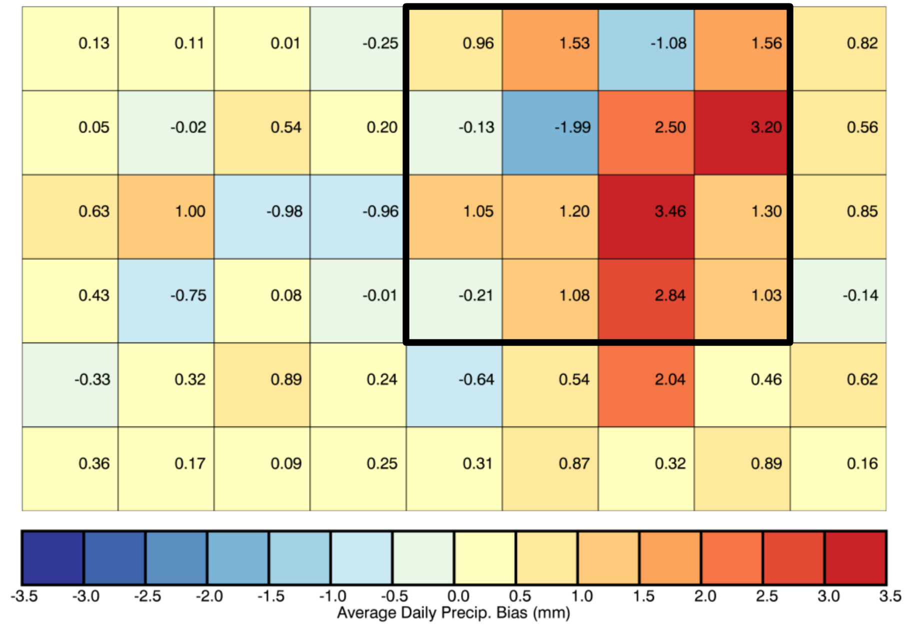
- Warm Season 2007-2014 500 hPa variables (only height anomalies plotted)

Strategy: Climatological SOMs (Midwest)

Stage IV Precipitation



NSSL WRF Bias



- Large variability in neighboring classes (both for observations and model)
- Statistically significant? ~1-3 dozen cases per class