Probabilistic Hazard Products Using a Time-Lagged HRRR Ensemble and RUA as a Necessary Validation Data Set

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NOAA/ESRL/GLOBAL SYSTEMS DIVISION

Research to Reduce Disasters and Enhance Resilience

Moore, OK Tornado
20 May 2013

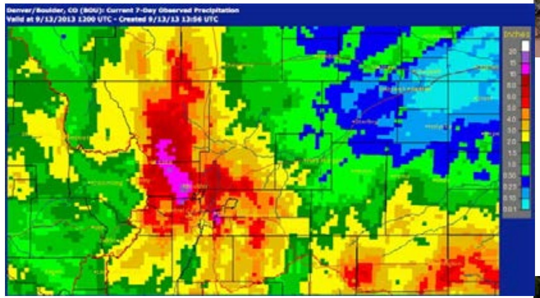
25 fatalities

1,150 homes destroyed

Yarnell, AZ Wildfire
30 June 2013

19 firefighter fatalities

Colorado Floods
9-15 September 2013



10,000 properties damaged or destroyed

$75 million in insurance claims

Atlanta, GA Snowstorm
28 January 2014

RAP/HRRR: Hourly-Updating Weather Forecast Models

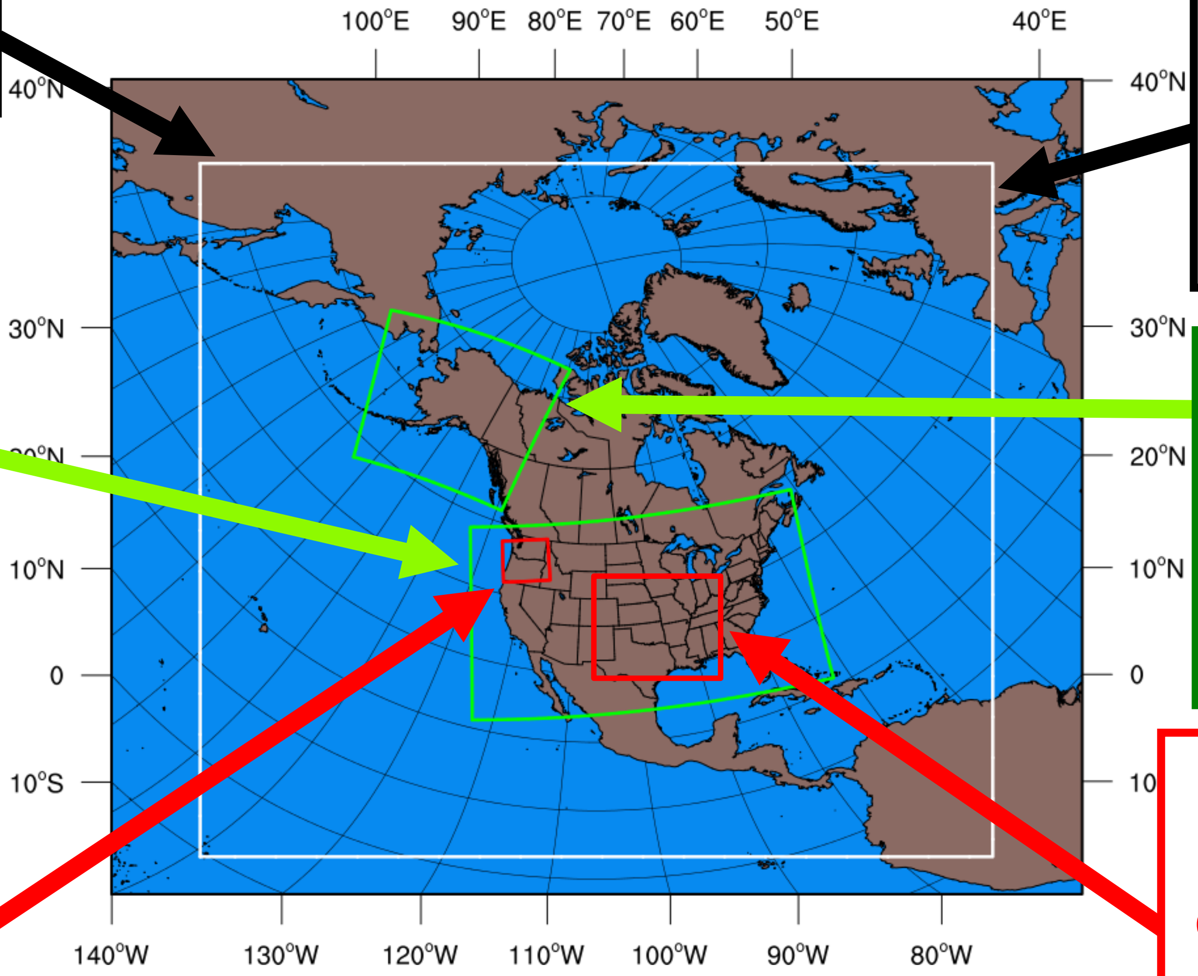
13-km Rapid Refresh (RAP) – to 21h (May 2016)

Initial & Lateral Boundary Conditions

3-km High-Resolution Rapid Refresh (HRRR) – to 18h (May 2016)

Initial & Lateral Boundary Conditions

750-m HRRR nest Wind Forecast Improvement Project Experiment (ongoing)



Expanded RAP to match NAM for SREF

(May 2016)

3-km High-Resolution Rapid Refresh Alaska Testing (HRRR-AK)

(Spring 2016)

Prototype 3-km storm-scale HRRR ensemble (HRRRE)

(Spring 2016)

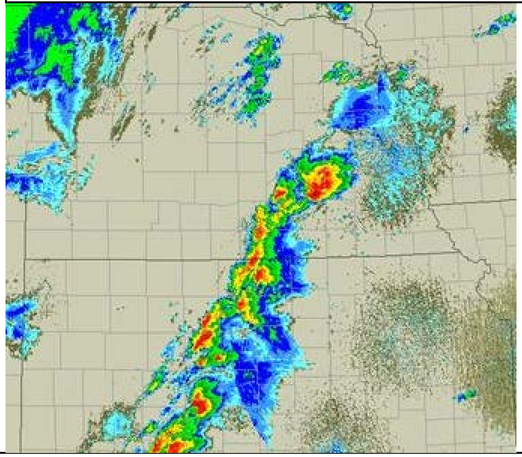
Project Overview

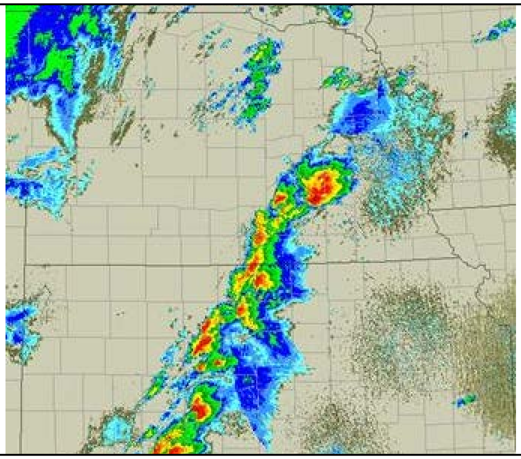
Multiple runs from the HRRR can provide additional forecast insight and can be grouped into categories:

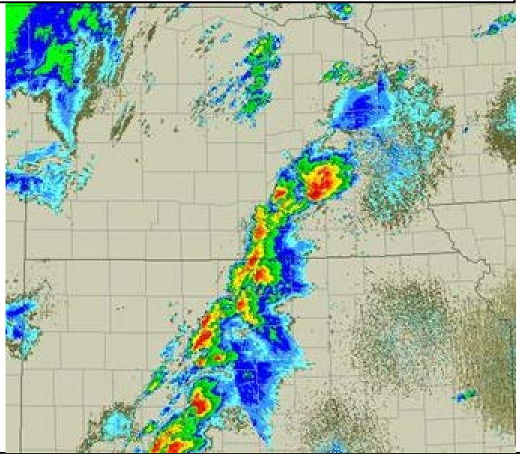
- **Run-to-run consistency (at least 3 consecutive runs)**
  - More common in strongly-forced events and can enhance forecast confidence
  - Solution, on limited occasions, could be erroneous, particularly in more weakly-forced events
- **Trend in guidance towards a particular solution (3 or more consecutive runs)**
  - Examples including increasing convective initiation/coverage
  - Forecasters should be judicious when extrapolating trends
- **Trend (at least 3 consecutive runs) then an abrupt change to a different solution/trend**
  - First run after convective initiation
  - First run assimilating new RAOB data (00/12 UTC)
  - Latest GFS cycle used (10/22 UTC)
- **No consistency and no trend with 3 or more consecutive runs with very different solutions**

HRRR Forecast Consistency Example

Radar Obs at 2200 UTC

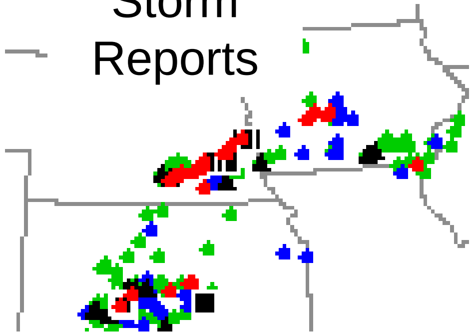




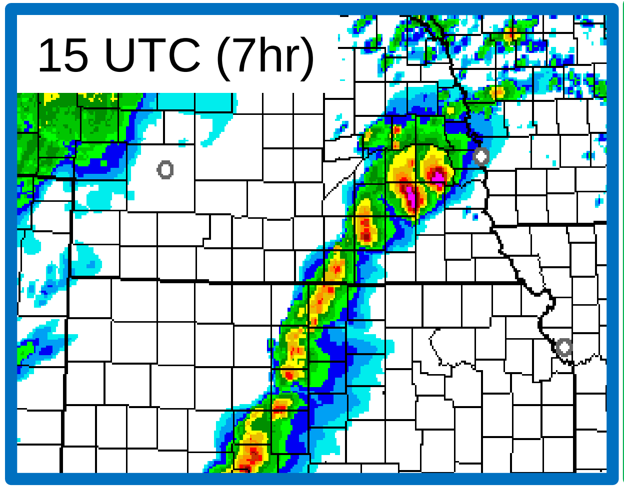


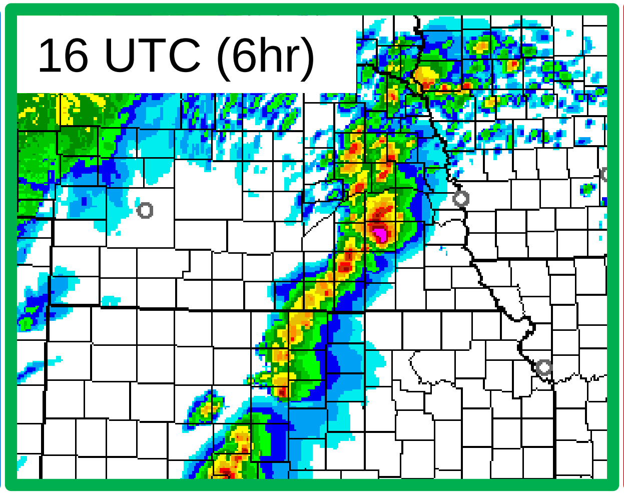
11 May 2014

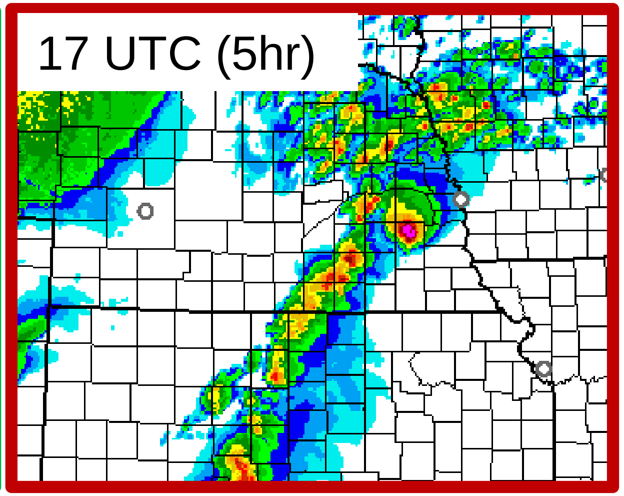
Storm Reports



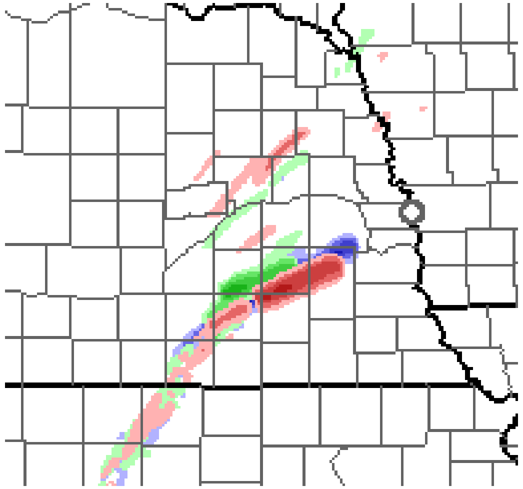
HRRR Forecasts valid at 2200 UTC







Updraft Helicity Time-Lagged Ensemble



Project Overview

Challenge:

- About 5 trillion bits of data from a single 15-hr HRRR forecast
- How to extract most useful information for forecasters?

Goal:

- Automated monitoring of hourly-updating model forecasts
- Measure run-to-run consistency/trends in forecasted hazards
- Provide *accurate* measure of confidence (uncertainty) for hazards

How:

- Post-process model output (computationally inexpensive)
- Create multi-run ensemble of HRRR (and other) forecasts
- Identify forecasted hazards (heavy rainfall, snow bands, severe storms)
- Form probabilistic gridded guidance of the hazards and bias correct for statistical reliability

HRRR Time-Lagged Ensemble (HRRR-TLE)

Deterministic HRRR:

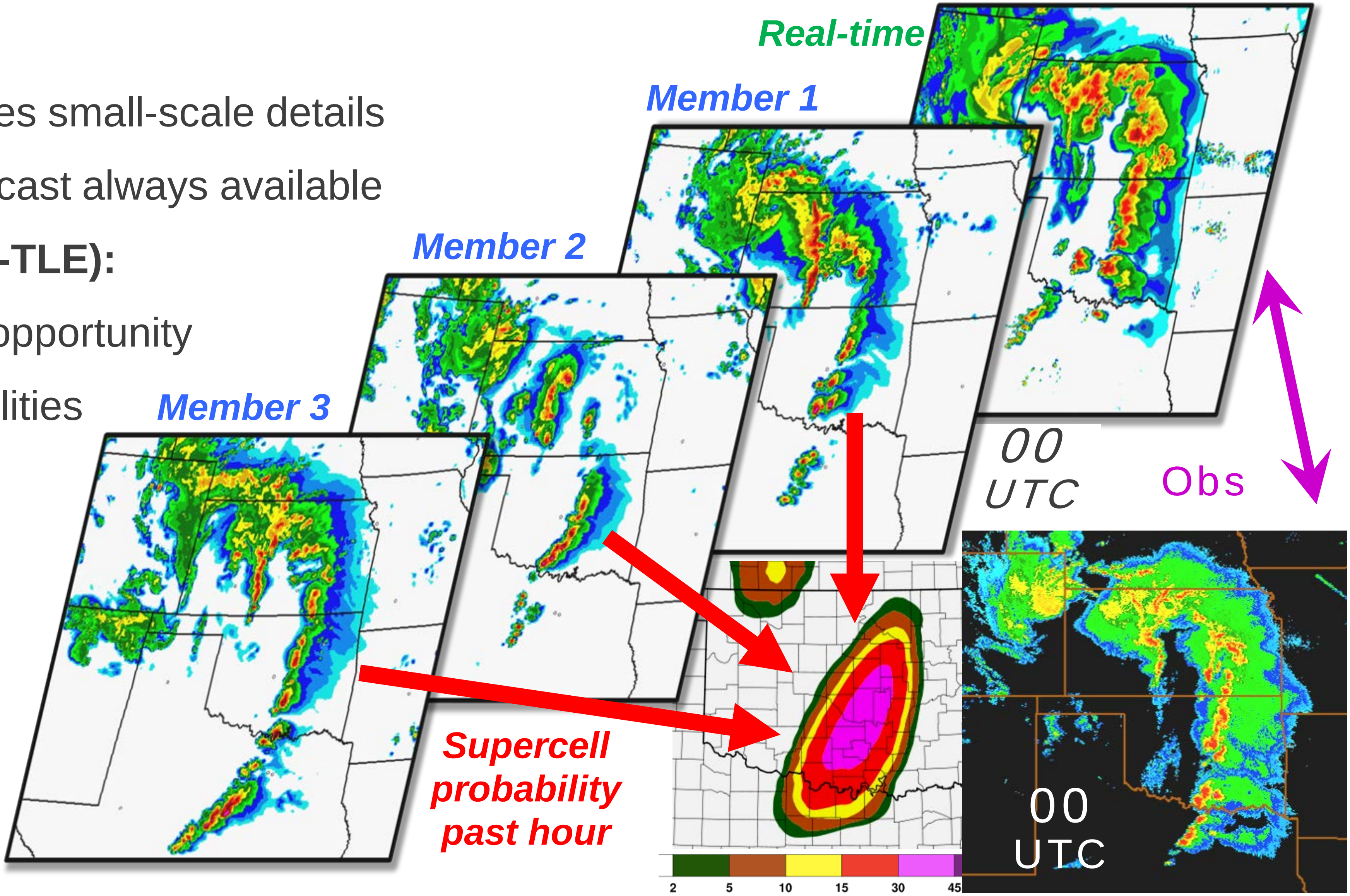
- High-resolution forecast provides small-scale details
- Hourly-updating with fresh forecast always available

Time-Lagged Ensemble (HRRR-TLE):

- Leverage runs in ensemble of opportunity
- Form hazard likelihood probabilities
- Less small-scale detail
- Proxy for confidence/certainty
- Underdispersive

HRRR Ensemble (HRRRE):

- More expensive ensemble
- More spread/dispersive/skill



HRRR-TLE Severe Weather Example

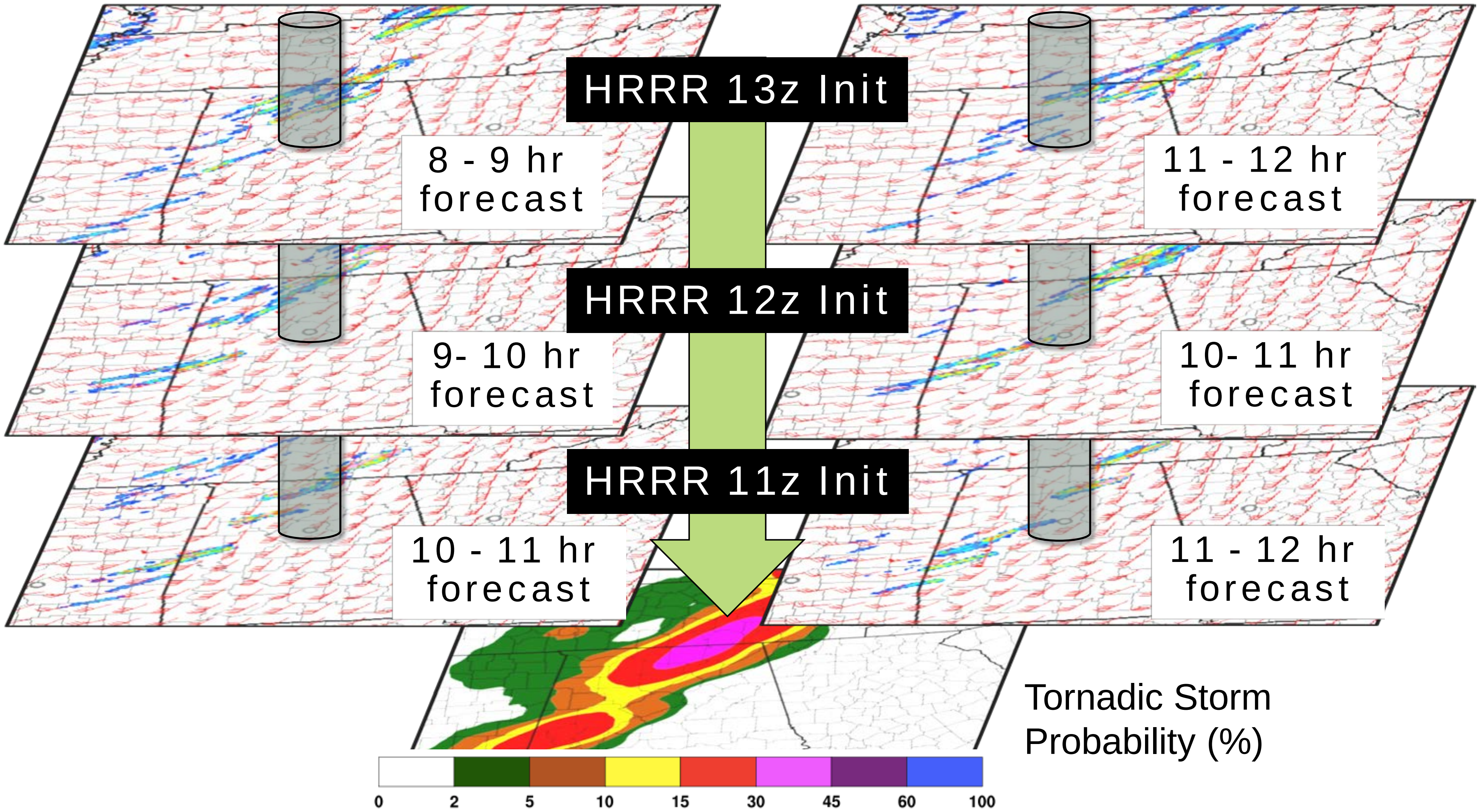
Forecasts valid 22-23z   Forecasts valid 23-00z

Neighborhood Search

Point Probability

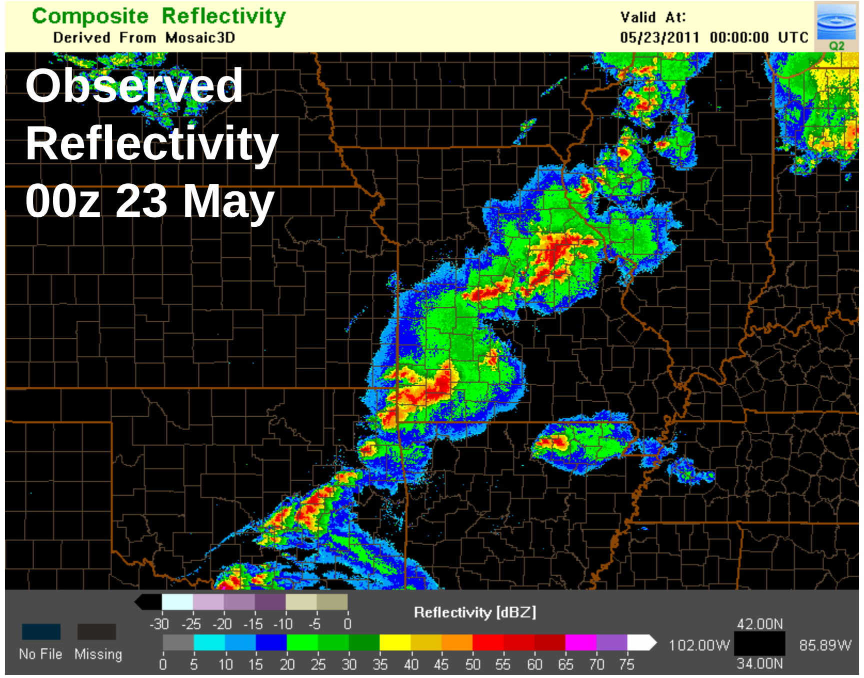
Spatial radius 45 km
Time radius 1 hr
UH threshold 25 m^2/s^2

All six forecasts combined to form probabilities valid 22z 27 April 2011

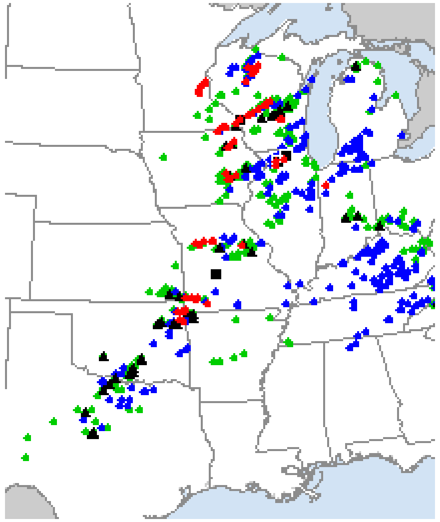


Tornadic Storm Probability (%)

HRRR-TLE Severe Weather Example

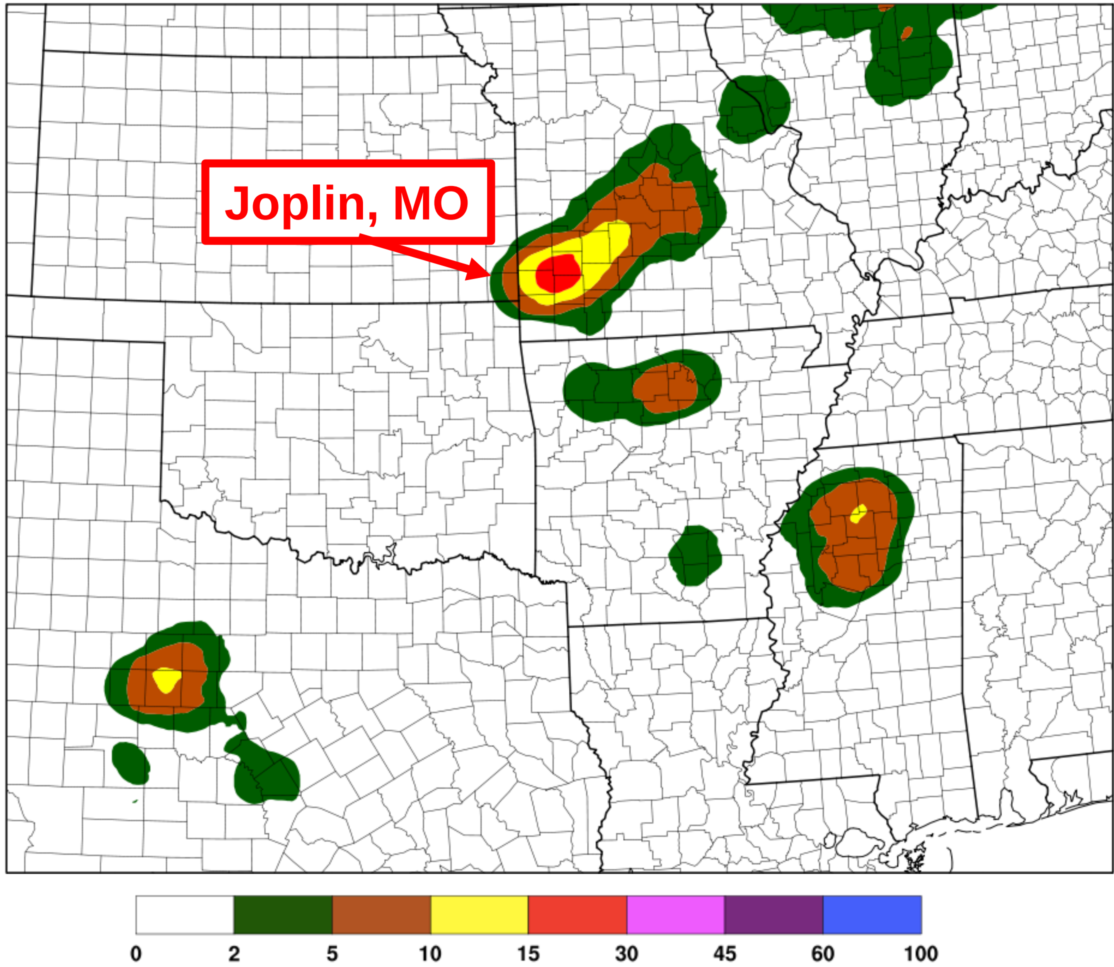


22 May 2011 Storm Reports



Tornado = Red Dots

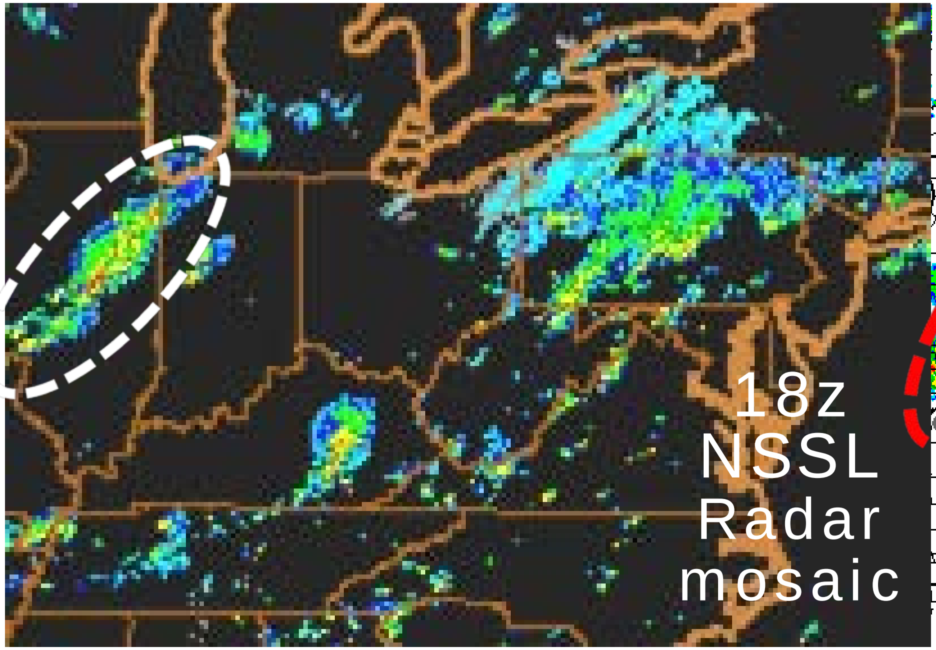
11 Hour Forecast Valid 00z 23 May 2011



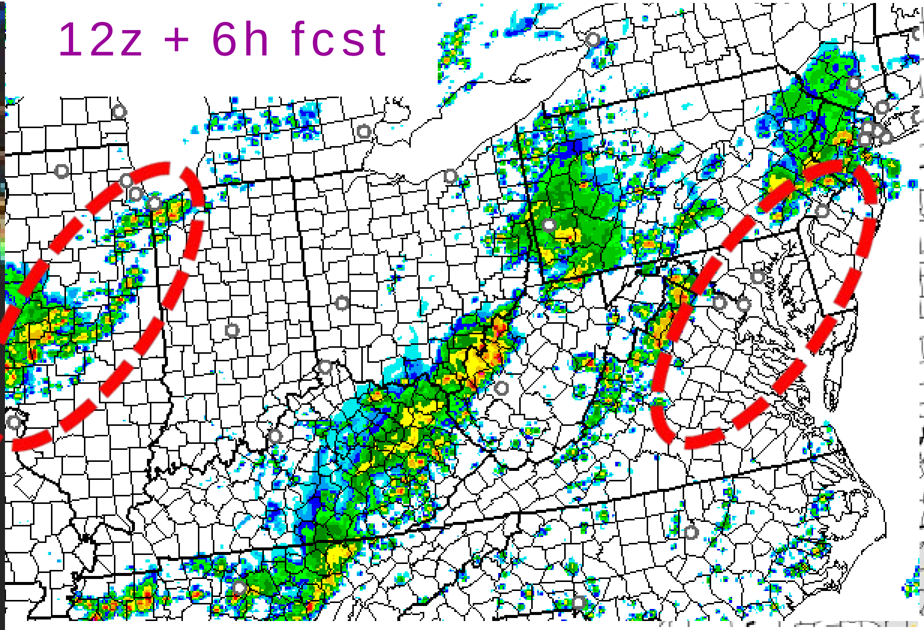
Tornadic Storm Probability (%)

HRRR-TLE Aviation Weather Example

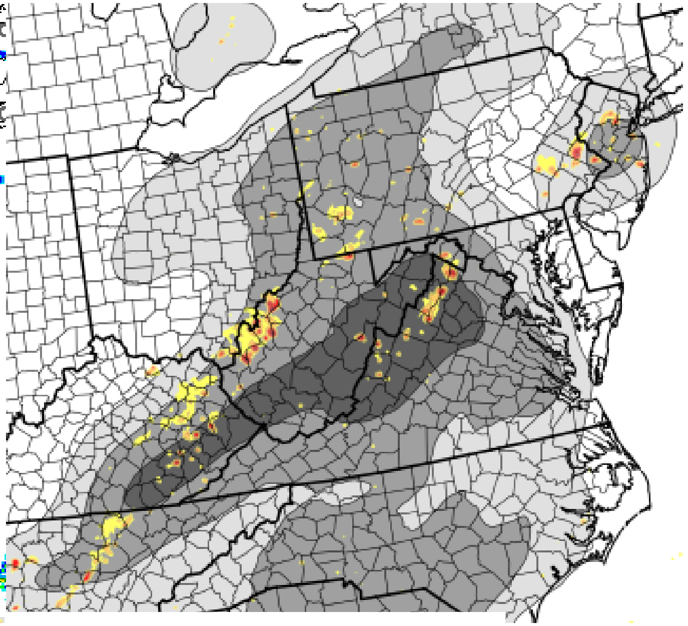
Observations 18z 14 July 2014

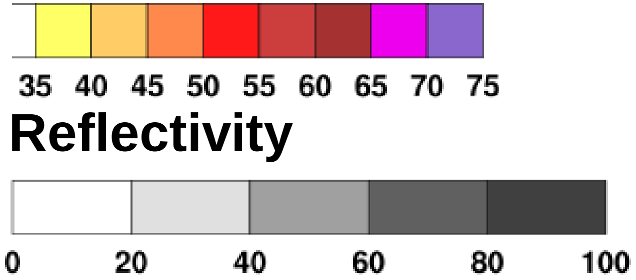


HRRR forecast radar



HRRR-TLE probability





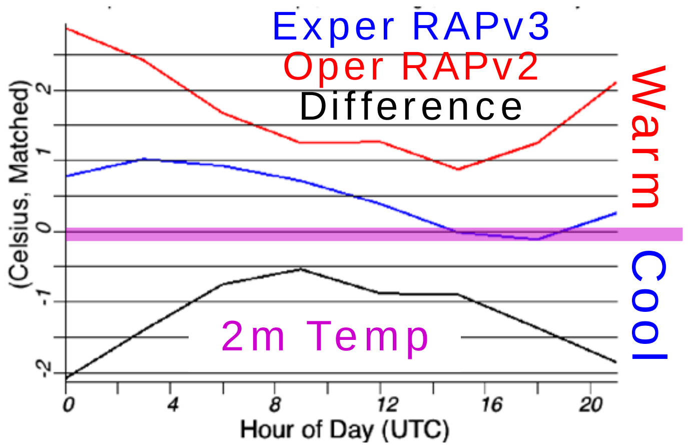
General convection problem (aviation application)
90 km search radius
≥ 1 m/s upward vertical motion in model column
≤ 2K best lifted index
HRRR Convective Probability Forecast (HCPF) → HRRR-TLE product

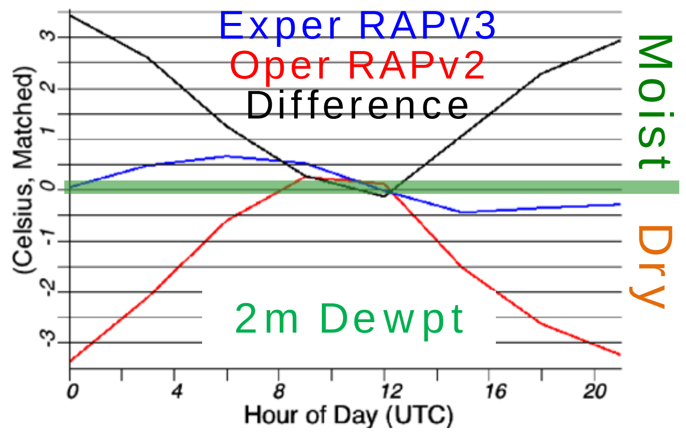
HRRR Model Improvements (HRRRv2)

HRRR component improvements to address warm/dry bias in RAPV2/HRRRv3

Component	Items
GSI Data Assimilation	Canopy water cycling Temp pseudo-innovations thru model boundary layer More consistent use of surface temp/dewpoint data
GFO Convective Parameterization	Shallow cumulus radiation attenuation Improved retention of stratification atop mixed layer
Thompson Microphysics	Aerosol awareness for resolved cloud production Attenuation of shortwave radiation
MYNN Boundary Layer	Mixing length parameter changed Thermal roughness in surface layer changed Coupling boundary layer clouds to RRTMG radiation
RUC Land Surface Model	Reduced wilting point for more transpiration Keep soil moisture in croplands above wilting point

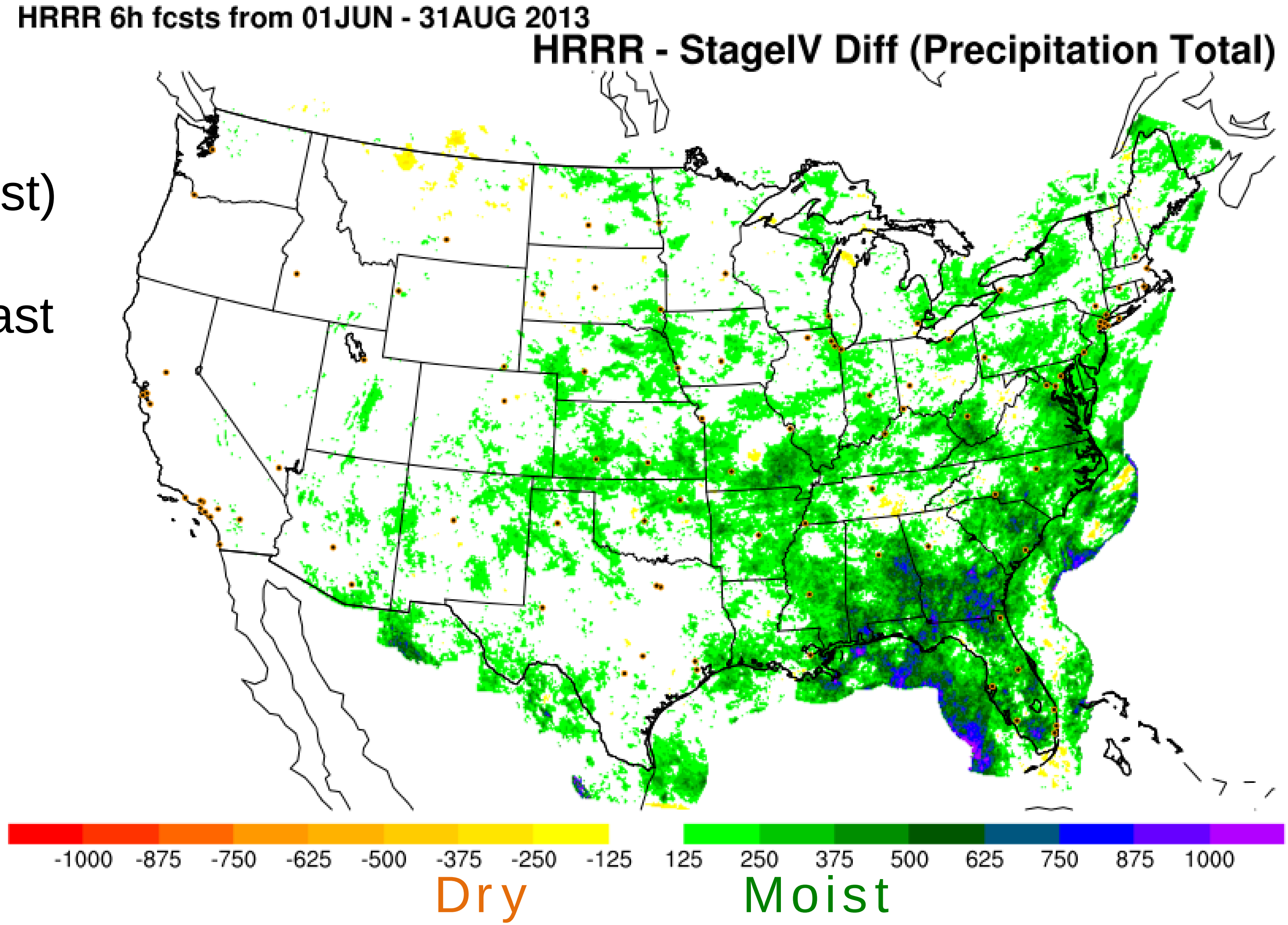
Reduced warm / dry bias





2013 Warm Season (June-August)

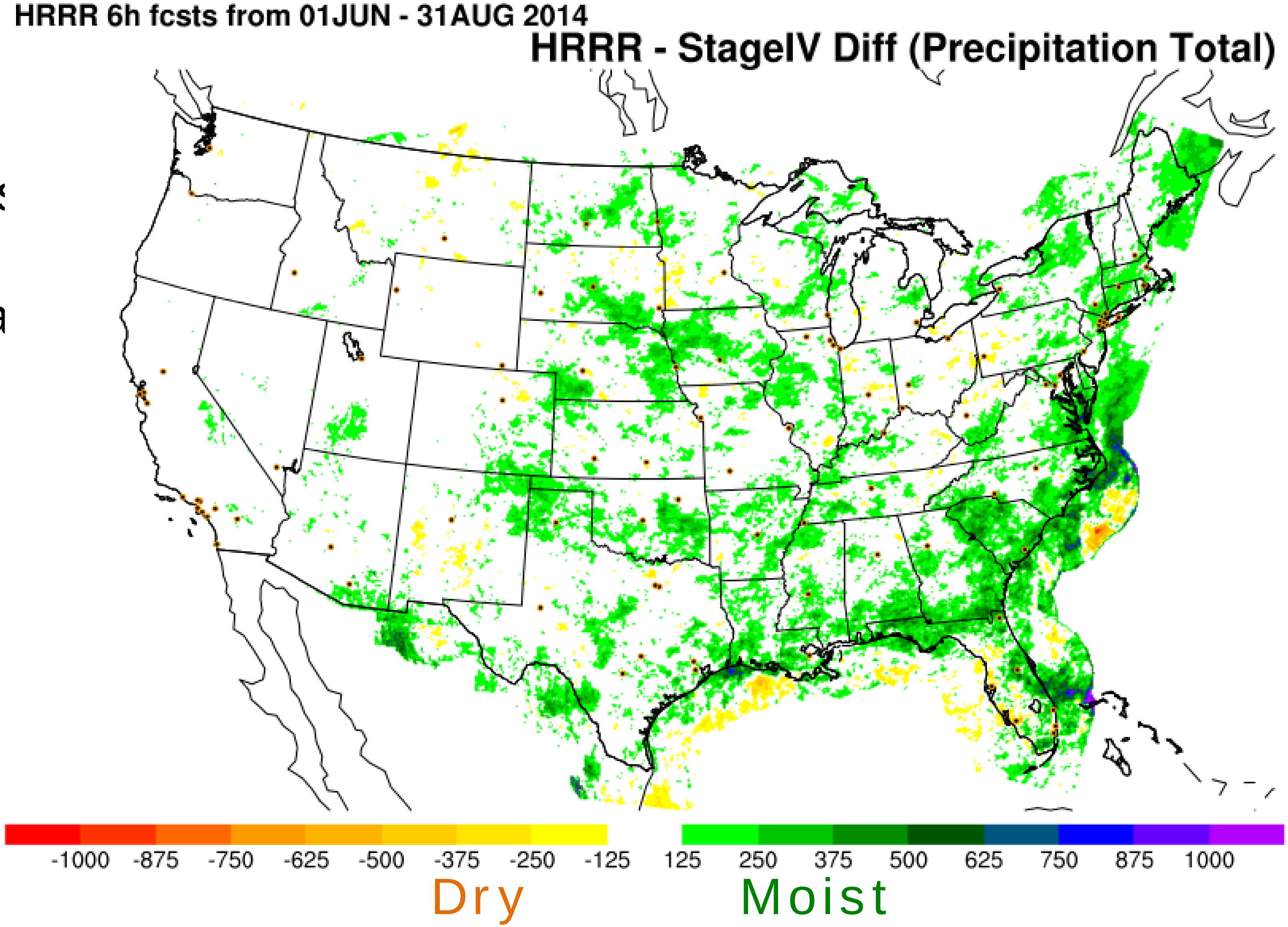
HRRR 0-6 hr precipitation forecast Difference against Stage IV



HRRR Model Improvements (HRRRv2)

2014 Warm Season (June-Augus

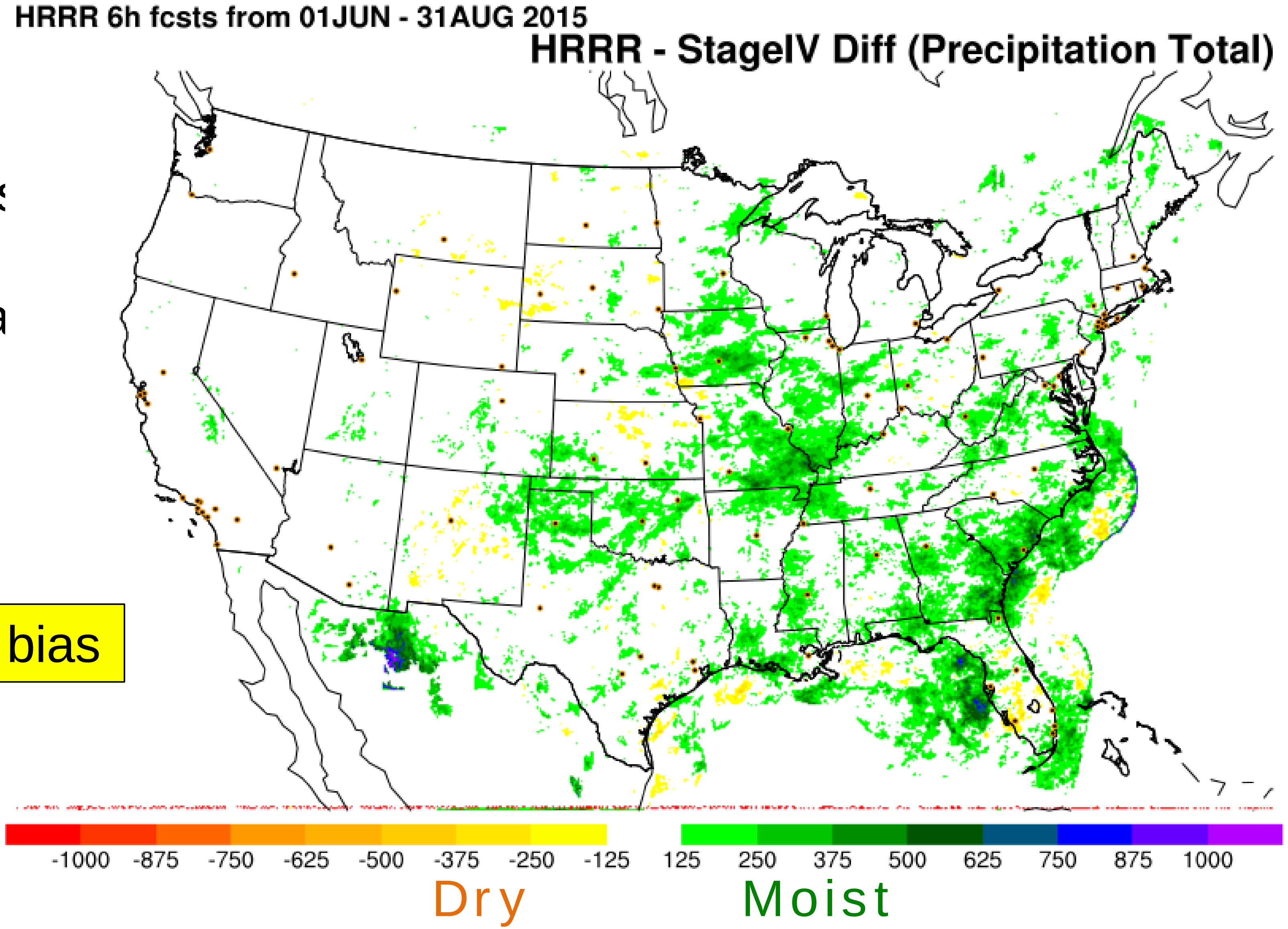
HRRR 0-6 hr precipitation foreca
Difference against Stage IV



2015 Warm Season (June-Augus

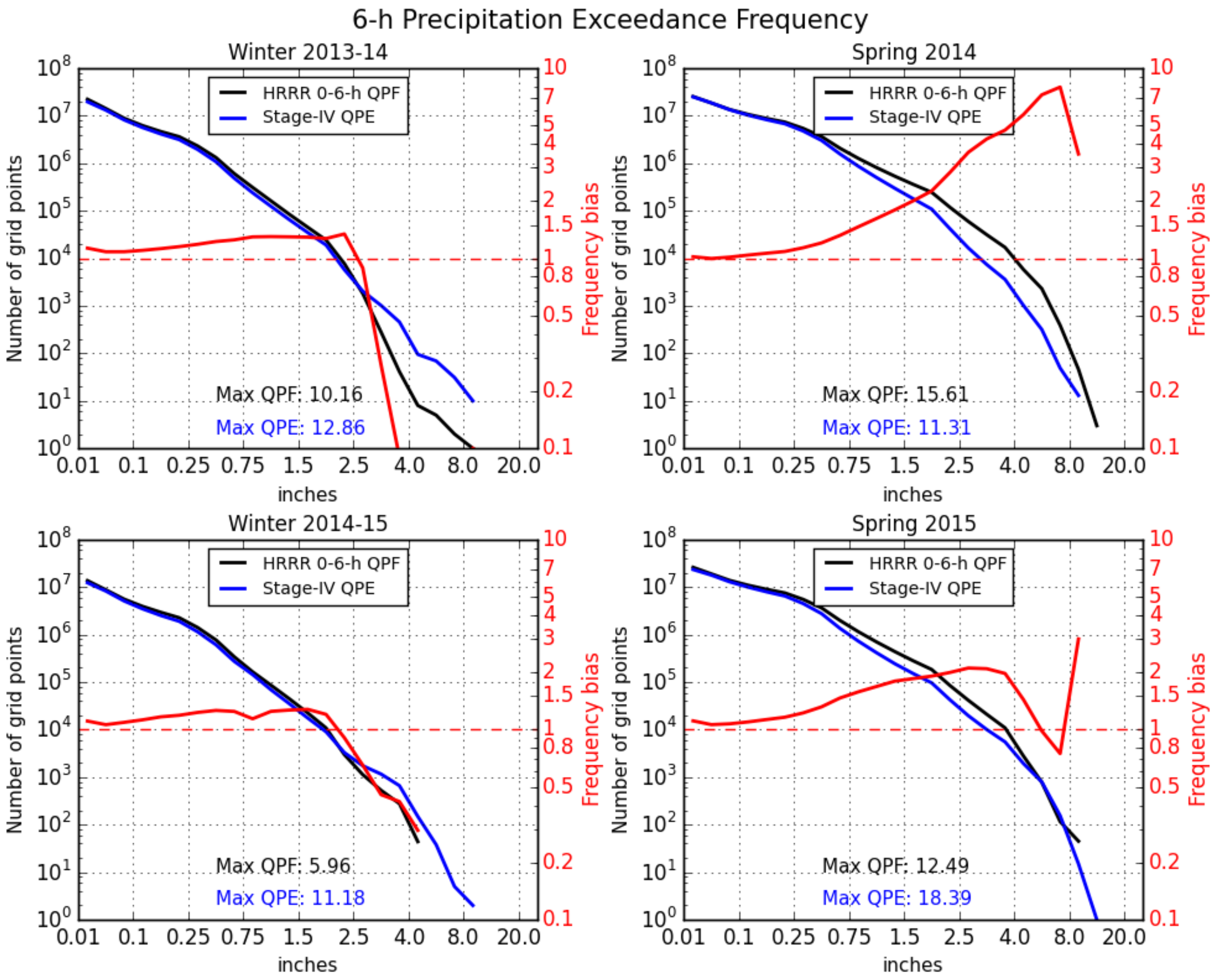
HRRR 0-6 hr precipitation foreca
Difference against Stage IV

Reduction in high precipitation bias



HRRR Model Improvements (HRRRv2)

Statistical Improvement in QPF skill
Reduction in bias from 2014 to 2015
Particularly at higher thresholds



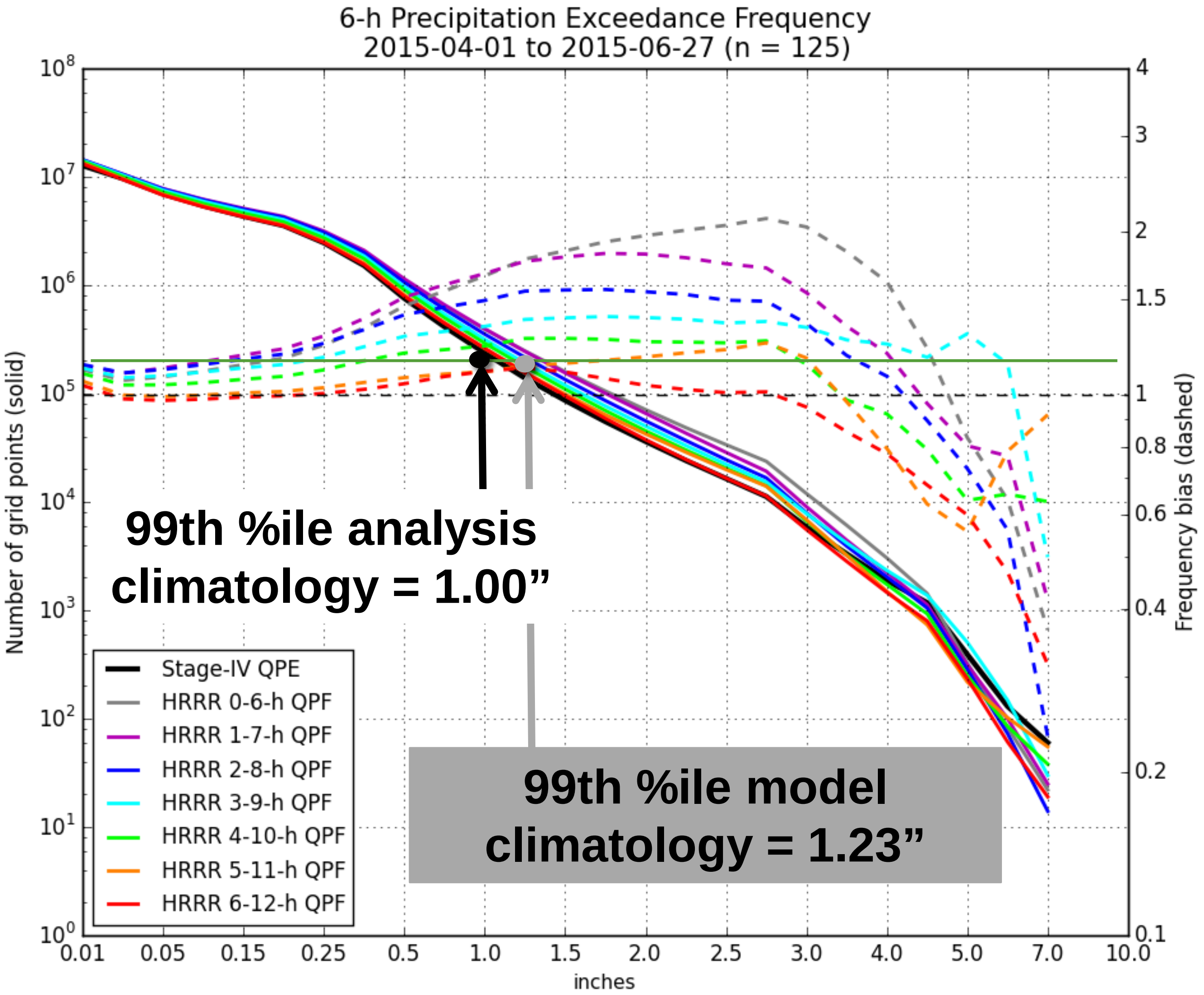
HRRR-TLE Development: Bias Correction

PQPF Product Development

Bias Correction

Frequency Bias Correction Using "Quantile Mapping"

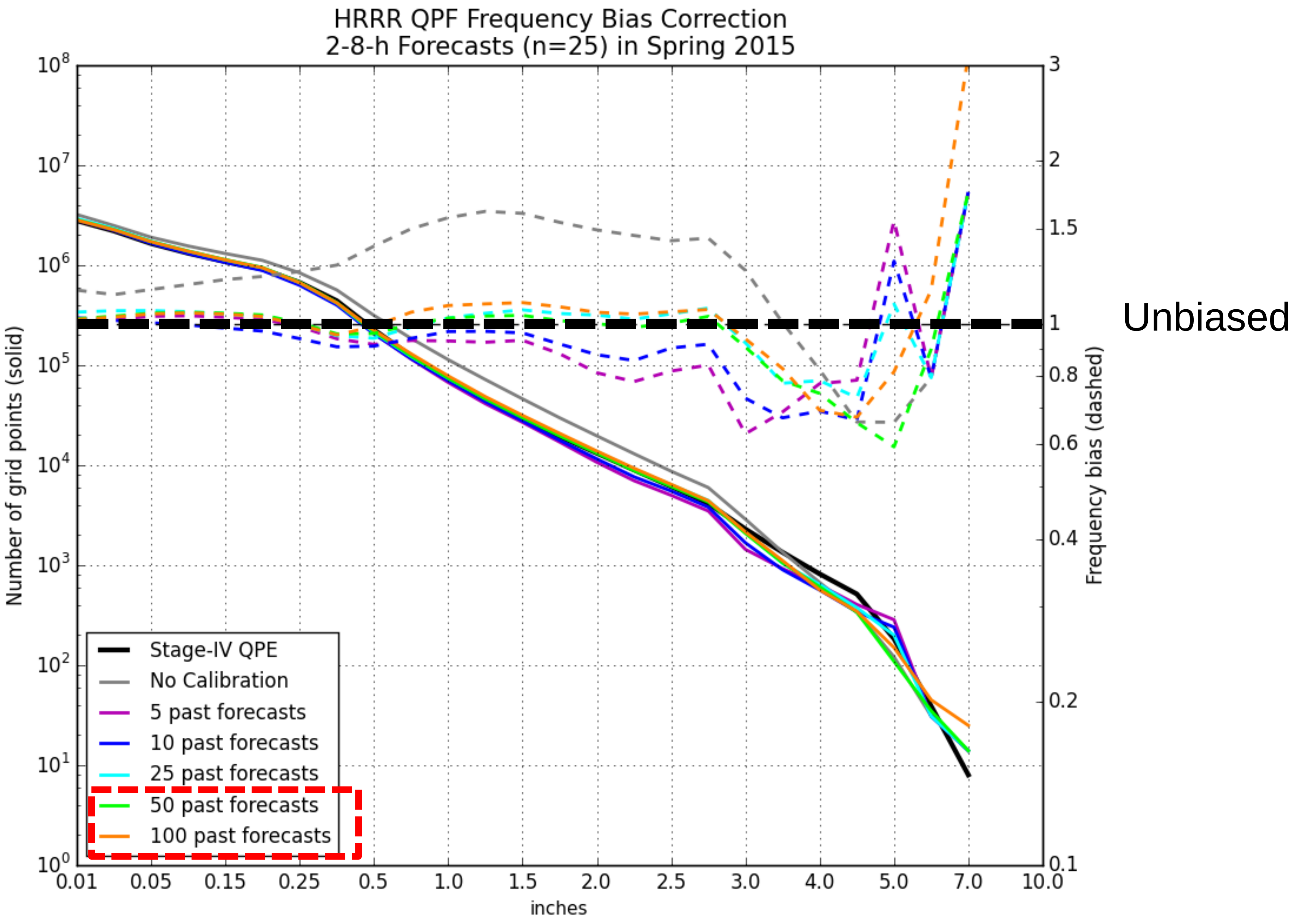
Adjust model forecast climatology to observation climatology for a particular threshold (1 in / 6 hrs)



HRRR-TLE: Real-Time Bias Correction

Efficient, real-time bias correction is possible with a small training dataset

Want to limit sample size to single season or even weather regime



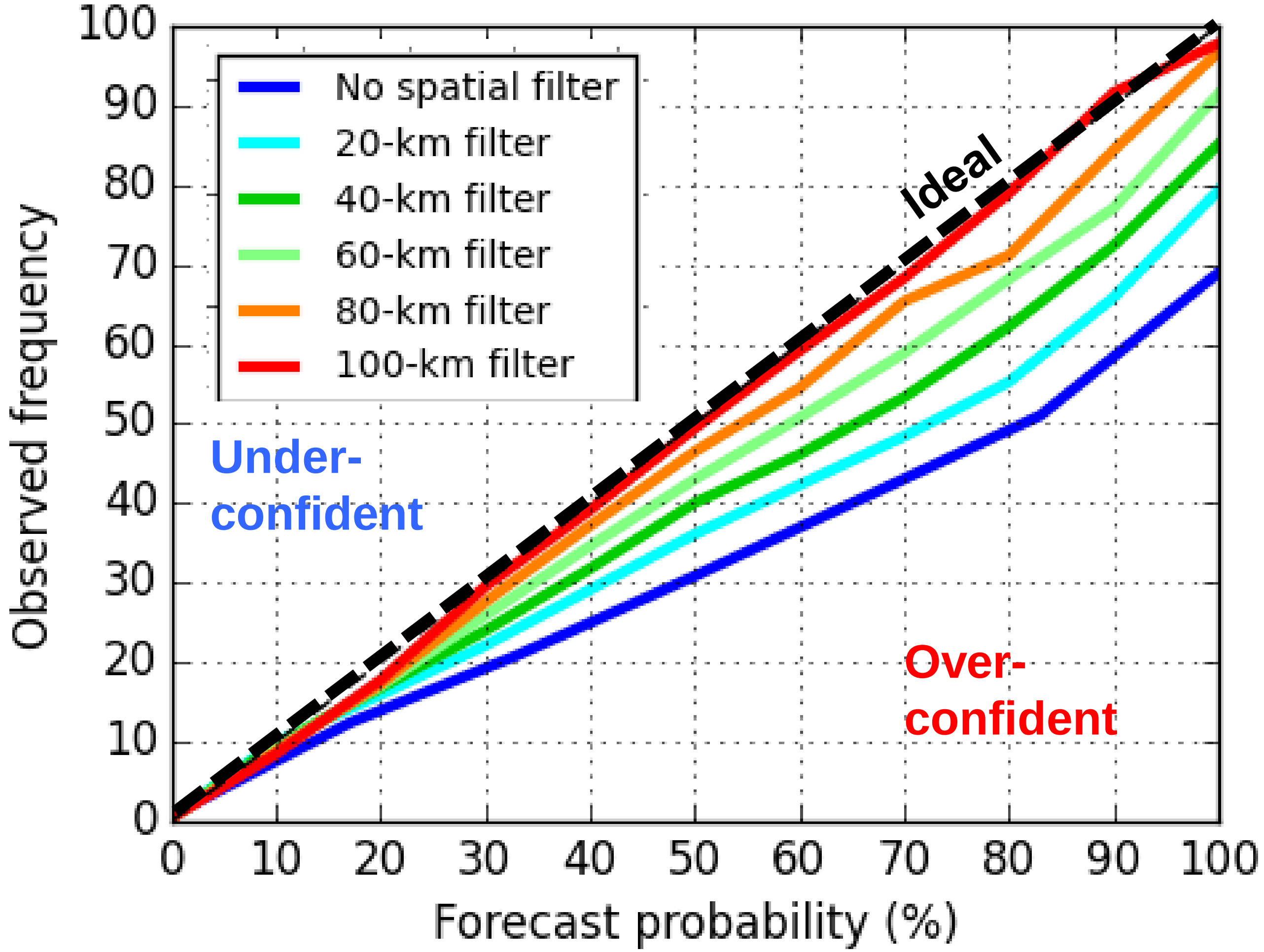
Spatial Filter Size

Minimize forecast phase error penalty (larger filter)

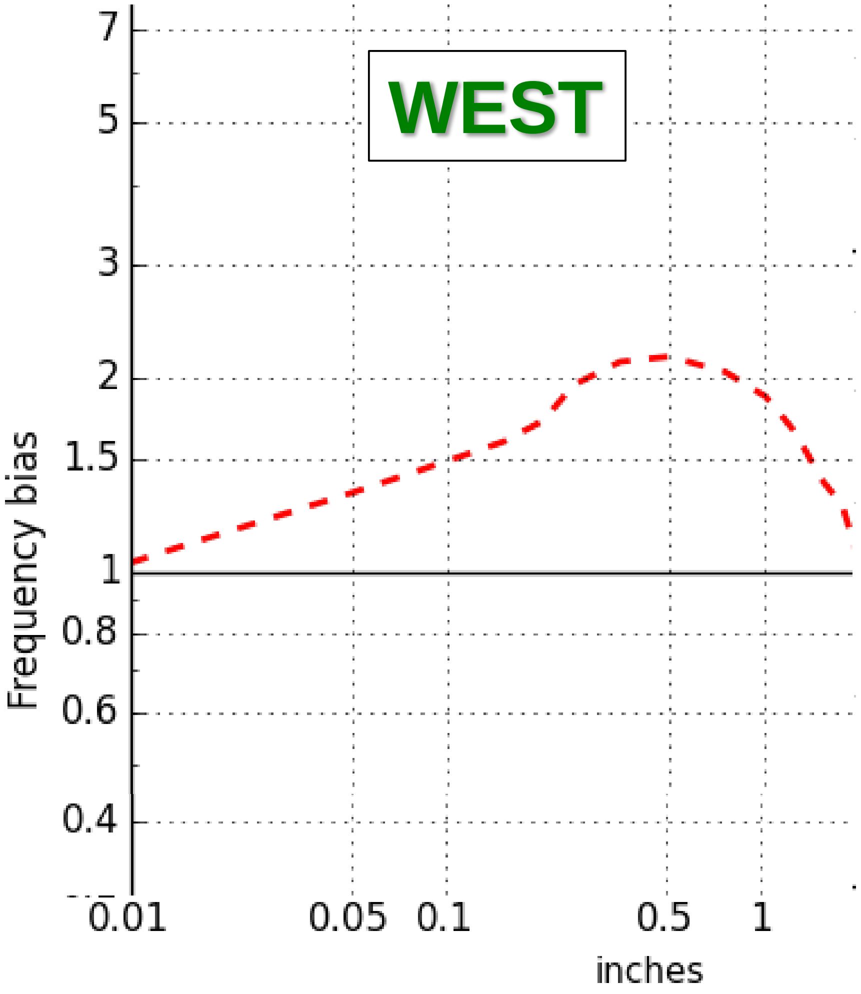
Minimize forecast forcing variability in complex terrain and different weather regimes (smaller filter)

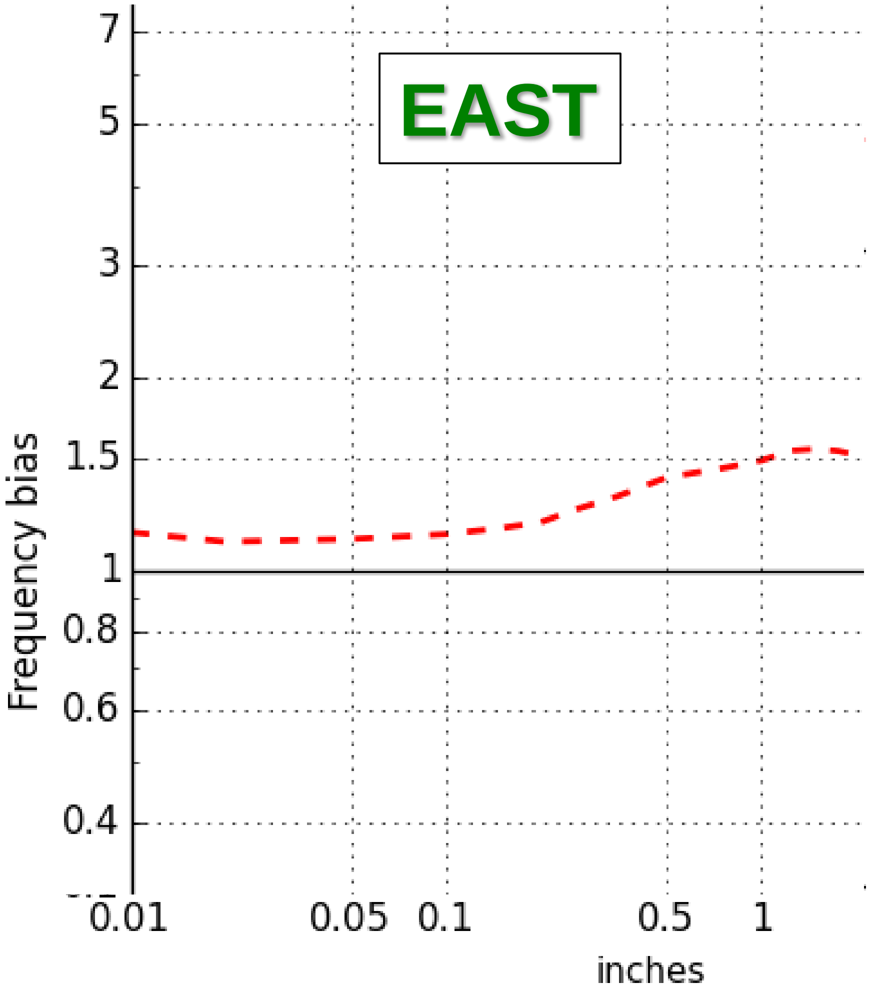
40-60 km appears sufficient
Note: Forecast valid at a point

Probability of 0.5” Precipitation in 6 hours

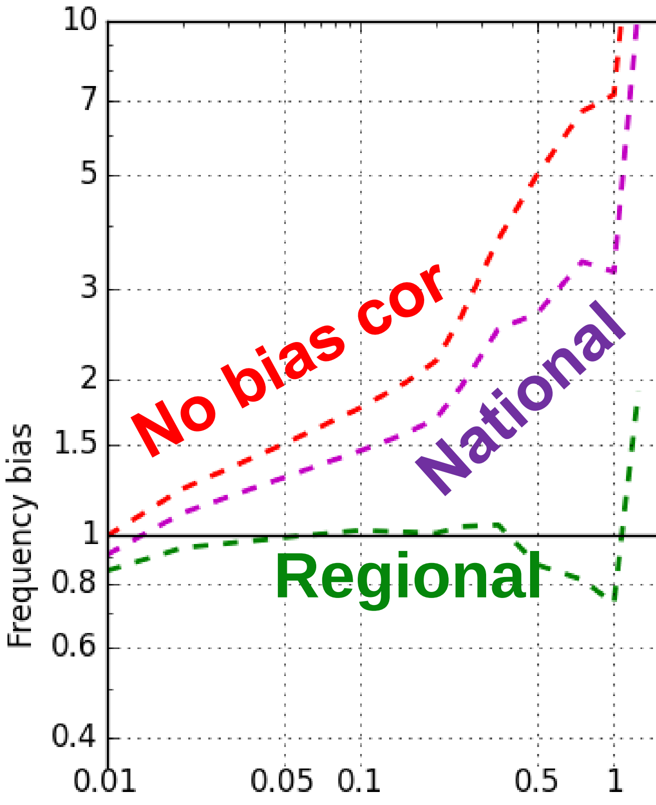


Spring 2015
HRRR 2-8-h QPF vs Stage-IV QPE





Western US Test Case



Real-Time Web Graphics

http://rapidrefresh.noaa.gov/hrrrtle/

Current Probability Products

6-hr QPF

1-hr snowfall rate

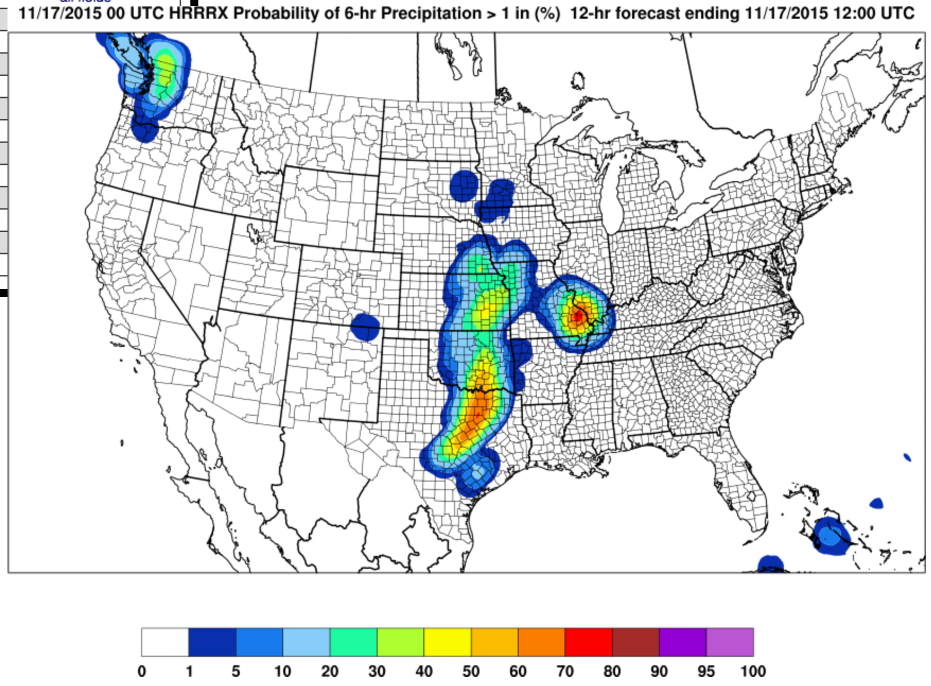
6-hr snowfall accumulation using variable-density model precipitating hydrometeor information

HRRR Time-Lagged Ensemble - Experimental

Model: HRRRX Probability (Experimental)   Area: Full   Date: 08 Jan 2016 - 19Z

Model: HRRRX Probability (Experimental) **Domain:** Full **Date:** 08 Jan 2016 - 19Z

	All times	Loop	Fri 19	Fri 20	Fri 21	Fri 22	Fri 23	Sat 00	Sat 01	Sat 02	Sat 03	Sat 04	Sat 05	Sat 06	Sat 07	
Forecast			00	01	02	03	04	05	06	07	08	09	10	11	12	
all fields			00	01	02	03	04	05	06	07	08	09	10	11	12	all fields
0.10" / 6 hr precip	✓	✓							06						12	
0.25" / 6 hr precip	✓	✓							06						12	
0.50" / 6 hr precip	✓	✓							06						12	
1.00" / 6 hr precip	✓	✓							06						12	
2.00" / 6 hr precip	✓	✓							06						12	
3.00" / 6 hr precip	✓	✓							06						12	
1.0" / 6 hr snowfall	✓	✓							06						12	
3.0" / 6 hr snowfall	✓	✓							06						12	
6.0" / 6 hr snowfall	✓	✓							06						12	
0.5"/hr snowfall rate	✓	✓	00	01	02	03	04	05	06	07	08	09	10	11	12	
1.0"/hr snowfall rate	✓	✓	00	01	02	03	04	05	06	07	08	09	10	11	12	
2.0"/hr snowfall rate	✓	✓	00	01	02	03	04	05	06	07	08	09	10	11	12	



HRRR-TLE: Project Timeline

Product Development Timeline

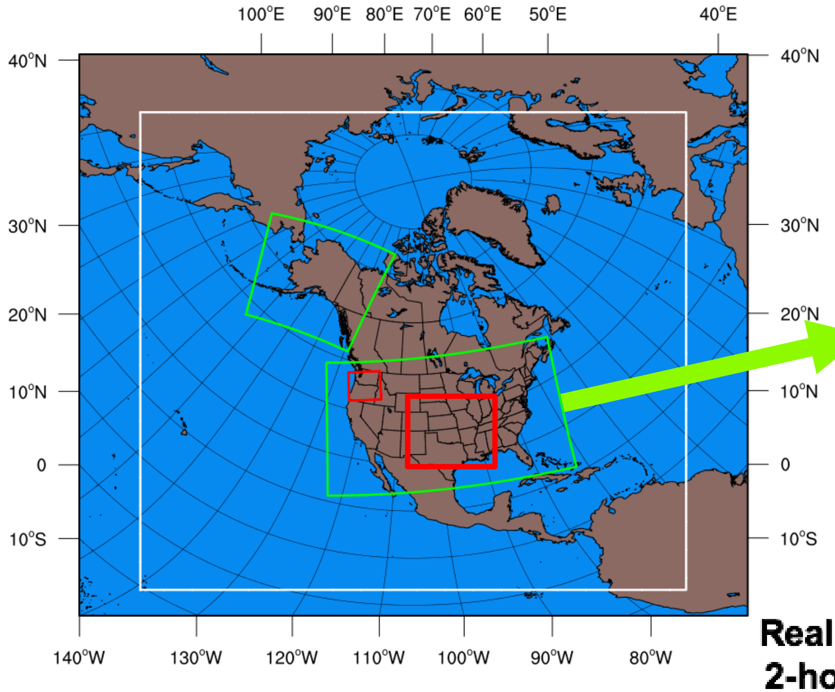
Engage National Center Testbeds

Organization/Experiment	Hazards	Platform	Timeline
WPC WWE	PQPF, Snowfall, Snow Rate	NAWIPS and web site	January 2016
NSSL/SPC EFP/EWP	Tornadoes, Hail, Wind	NAWIPS and AWIPSII	May 2016
WPC FFaIR	Refined PQPF and FF guidance	NAWIPS	June 2016
AWC Summer Experiment	Initial aviation hazards: ceiling, visibility, convection	NAWIPS	August 2016
WPC WWE	Refined winter hazards and PQPF	NAWIPS	January 2017
NSSL/SPC EFP/EWP	Refined severe weather guidance	NAWIPS and AWPSII	May 2017
WPC FFaIR	Refined FF guidance	NAWIPS	July 2017
AWC Summer Experiment/OPG	Refined aviation hazards	NAWIPS and AWPSII	August 2017
Initiate NCO ‘on-boarding”	All	IDP	September 2017

Product Development Methodology

Hazard	**Proxy**	**Truth**
Heavy rainfall	QPF	Stage-IV / MRMS
Snowfall rate	Microphysics-based	ASOS visibility
Precipitation type	Microphysics-based	ASOS type
Accum Snow	Explicit snow depth	Point observations
Severe wind	80-m hourly max wind or 10-m gust	METAR/mesonet observations
Large hail	Column graupel, updraft speed, ?	MESH
Tornado*	Updraft helicity	Post-processed MRMS rotation tracks
Visibility/Ceiling	Post-processed field in development	ASOS or future CIMSS technique

HRRR-TLE: Leading to HRRRE (HREF)



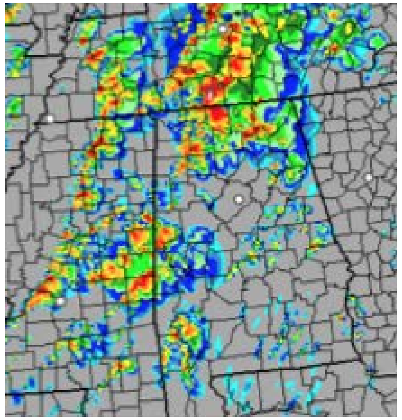
Prototype 3-km storm-scale HRRR ensemble domain

- **Single core (ARW)**
- **Ensemble DA**
- **Stochastic physics**

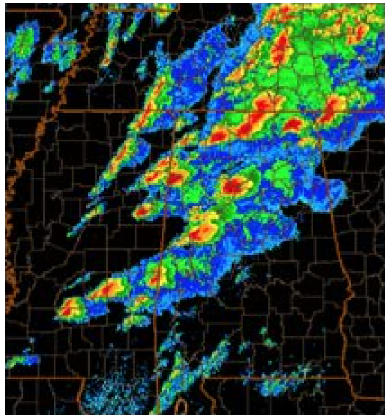
Assimilation	Forecast
40 members	**6 members**
1 hr forecast	**12-18 hr forecast**
24 fcsts / day	**4-8 fcsts / day**
2 nodes / member	**60 nodes / member**

Beginning development of formal 3-km data assimilation and forecast ensemble

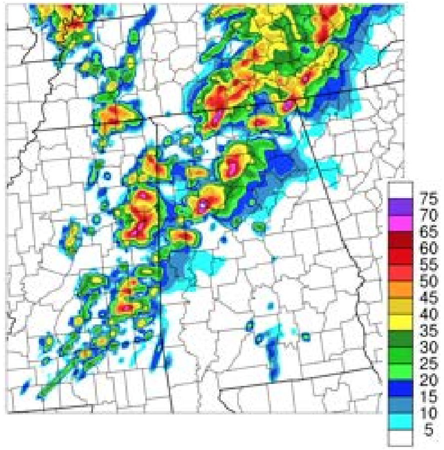
Real-Time HRRR 2-hour Forecast



MRMS Observations



2-hour Forecast Initialized with Ensemble DA

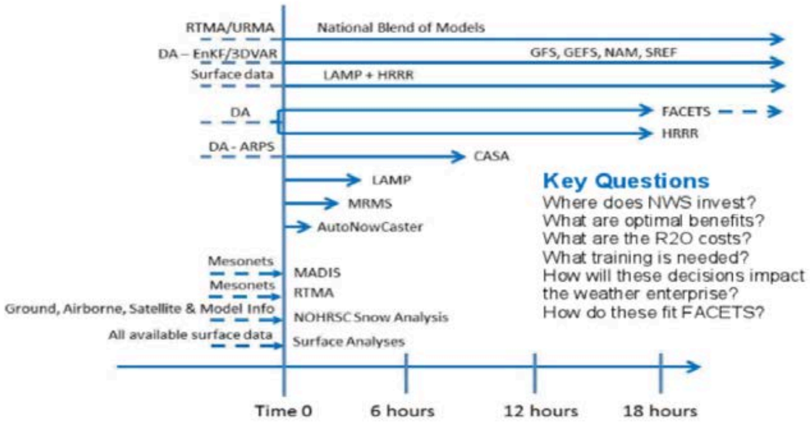


More accurate storm-details from ensemble data assimilation

HRRR-TLE: Summary

- Three-year USWRP-Funded HRRR Time-Lagged Ensemble Development
- Producing Probabilistic Hazard Prediction Guidance
- Ensuring Statistically Reliable Probabilities
- Engaging NCEP National Centers and Participating in Testbed Evaluations
- Transition to Operations Plan
- Experimental Real-Time GRIB2 LDM/FTP Feed Available
- Web Page Graphics Also Available
- An Evolutionary Step on the Path to Full 3-km Data Assimilation and Forecast Ensemble

RUA: Necessary Validation Data Set



Work to develop and implement a 3-D Rapidly Updating Analysis (RUA) to unify NOAA nowcasting capabilities to meet needs for situational awareness information and forecast verification.

- RUA unifies all nowcasting (0-h) components shown in the NWS figure, using observations from:
  - 3-D radar (via MRMS and CASA), including reflectivity and radial wind
  - surface observations (including mesonet via MADIS)
  - satellite observations including cloud and land-surface
  - all-sky cameras, including cloud fraction
  - all other observations assimilated by operational NWP systems, including
  - those used by the HRRR
- state-of-the-art 3-D data assimilation (DA) using GSI including a 3-D cloud/ hydrometeor analysis.
- background from very short-range HRRR model forecasts for IOC, to be replaced by a
- HRRR-related ensemble forecast representation for the Medium Operating Capability (MOC).