RAP/HRRR: Hourly-Updating Weather Forecast Models

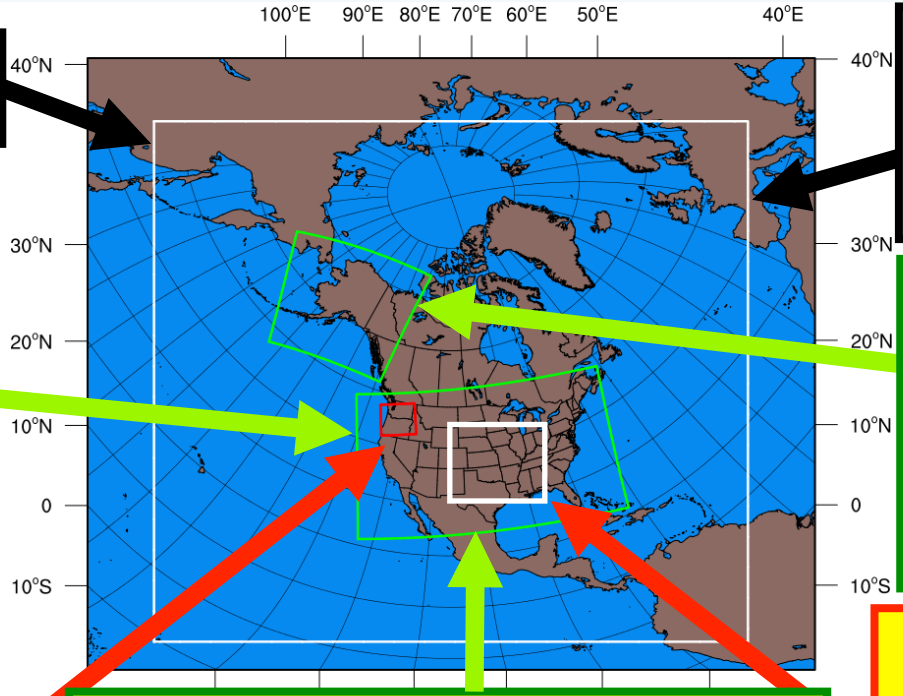
13-km Rapid Refresh (RAPv3) – to 21h (Aug 2016)

Initial & Lateral Boundary Conditions

3-km High-Resolution Rapid Refresh (HRRRv2) – to 18h (Aug 2016)

Initial & Lateral Boundary Conditions

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



Expanded RAP to match NAM for SREF

(July 2016)

3-km High-Resolution Rapid Refresh Alaska Testing (HRRR-AK) w/MRMS radar data

(Spring 2016)

3-km High-Resolution Time Lagged Ensemble (HRRR-TLE)

3-km HRRR-Smoke (VIIRS fire data)

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

(Spring 2016)

RAP/HRRR Implementation History

Operational Implementations

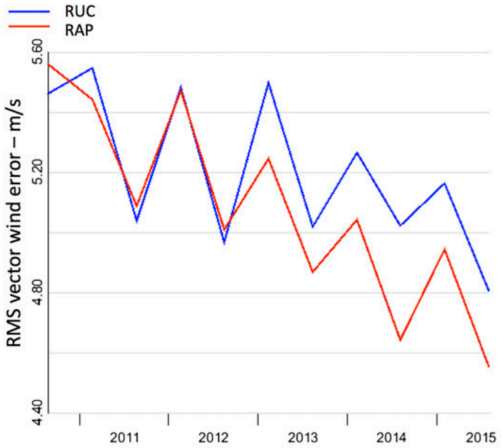
01 May 2012
- **RAPv1**: Adoption of GSI, WRF-ARW and unified post
- Enabled use of community-developed software

25 Feb 2014
- **RAPv2**: Hybrid EnKF-3DVar data assimilation
- Significant improvement in upper-air forecasts

30 Sep 2014
- **HRRRv1**: 3-km Radar DA in WRF-ARW
- Significant improvement in convective forecasts

August 2016
- **RAPv3/HRRRv2 (a.k.a. RAPX/HRRRX)**: Aerosol Thompson MP, improvements to
- MYNN PBL, RUC LSM, RRTMG Rad, Grell-Freitas cumulus
- Significant improvement in surface forecasts

Benjamin et al. 2016, A North American Hourly Assimilation and Model Forecast Cycle: The Rapid Refresh. *Mon. Wea. Rev.*, **144**, 1669-1694.



250 mb
6-hr
Vector Wind
RMSE

RUC
RAP

RAP/HRRR Summary of Changes

Pre-Operational RAP/HRRR 2010 Starting Point

Model	Run at:	Domain	Grid Points	Grid Spacing	Vertical Levels	Pressure Top	Boundary Conditions	Initialized
RAP	GSD	North America	758 x 567	13 km	50	10 mb	GFS	Hourly (cycled)
HRRR	GSD	CONUS	1799 x 1059	3 km	50	20 mb	RAP	RAP I.C.

Model	Version	Assimilation	Radar DA	Radiation LW/SW	Microphysics	Cumulus Param	PBL	LSM
RAP	WRF-ARW v3.1.1+	GSI 3D-VAR	13-km DFI	RRTM/ Goddard	Thompson v3.1.1	G3 + Shallow	MYJ	RUC 6-lev
HRRR	WRF-ARW v3.1.1+	None	None	RRTM/ Goddard	Thompson v3.1.1	None	MYJ	RUC 6-lev

Model	Horiz/Vert Advection	Scalar Advection	Upper-Level Damping	6th Order Diffusion	SW Radiation Update	Land Use	MP Tend Limit	Time-Step
RAP	5th/3rd	Monotonic	Diffusive 0.2	Yes 0.25	30 min	USGS	0.01 K/s	60 s
HRRR	5th/3rd	Monotonic	Diffiusive 0.2	No	30 min	USGS	0.01 K/s	18-23 s

RAPv3/HRRRv2 Summary of Changes

Operational RAPv2/HRRRv1

Model	Run at:	Domain	Grid Points	Grid Spacing	Vertical Levels	Pressure Top	Boundary Conditions	Initialized
RAP	GSD, NCO	North America	758 x 567	13 km	50	10 mb	GFS	Hourly (cycled)
HRRR	GSD, NCO	CONUS	1799 x 1059	3 km	50	20 mb	RAP	Hourly (pre-forecast hour cycle)

Model	Version	Assimilation	Radar DA	Radiation LW/SW	Microphysics	Cumulus Param	PBL	LSM
RAP	WRF-ARW v3.4.1+	GSI Hybrid 3D-VAR/Ensemble	13-km DFI	RRTM/ Goddard	Thompson v3.4.1	G3 + Shallow	MYNN	RUC 9-lev
HRRR	WRF-ARW v3.4.1+	GSI 3D-VAR	3-km 15-min LH	RRTM/ Goddard	Thompson v3.4.1	None	MYNN	RUC 9-lev

Model	Horiz/Vert Advection	Scalar Advection	Upper-Level Damping	6th Order Diffusion	SW Radiation Update	Land Use	MP Tend Limit	Time-Step
RAP	$5^{th}/5^{th}$	Positive-Definite	w-Rayleigh 0.2	Yes 0.12	10 min	MODIS Fractional	0.01 K/s	60 s
HRRR	$5^{th}/5^{th}$	Positive-Definite	w-Rayleigh 0.2	No	5 min	MODIS Fractional	0.07 K/s	20 s

RAPv3/HRRRv2 Summary of Changes

Implementation RAPv3/HRRRv2

Larger RAP Domain

Newer Model Version
More Ensemble Weight
Advanced Physics

Seasonal Vegetation Fraction/Leaf Area Index

Model	Run at:	Domain	Grid Points	Grid Spacing	Vertical Levels	Pressure Top	Boundary Conditions	Initialized
RAP	GSD, NCO	North America	953 x 834	13 km	50	10 mb	GFS	Hourly (cycled)
HRRR	GSD, NCO	CONUS	1799 x 1059	3 km	50	20 mb	RAP	Hourly (pre-forecast hour cycle)

Model	Version	Assimilation	Radar DA	Radiation LW/SW	Microphysics	Cumulus Param	PBL	LSM
RAP	WRF-ARW v3.6+	GSI Hybrid Ensemble to 0.75	13-km DFI	RRTMG/ RRTMG	Thompson Aerosol v3.6	GF + Shallow	MYNN v3.6	RUC v3.6
HRRR	WRF-ARW v3.6+	GSI Hybrid Ensemble to 0.75	3-km 15-min LH	RRTMG/ RRTMG	Thompson Aerosol v3.6	None	MYNN v3.6	RUC v3.6

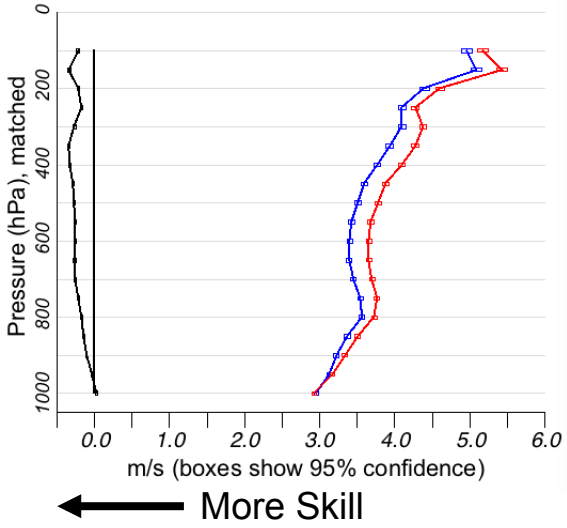
Model	Horiz/Vert Advection	Scalar Advection	Upper-Level Damping	6th Order Diffusion	SW Radiation Update	Land Use	MP Tend Limit	Time-Step
RAP	5th/5th	Positive-Definite	w-Rayleigh 0.2	Yes 0.12	20 min	MODIS Seasonal	0.01 K/s	60 s
HRRR	5th/5th	Positive-Definite	w-Rayleigh 0.2	Yes 0.25 (flat terr)	15 min with SW-dt	MODIS Seasonal	0.07 K/s	20 s

RAP/HRRR Performance History

RAPv1
RAPv2
RAPv2 - RAPv1

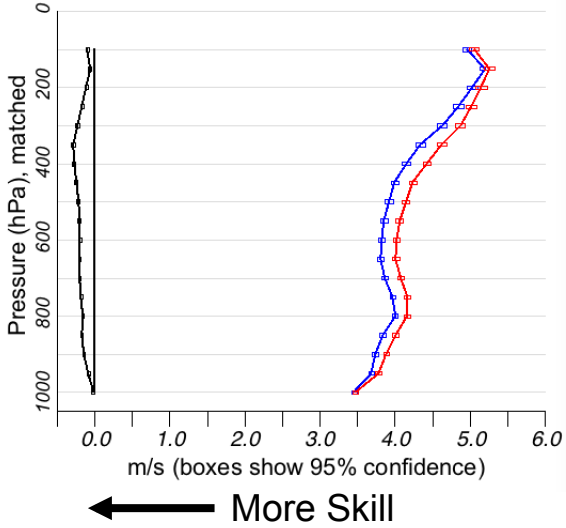
RAP RMSE Vector Winds (~ 1 year of matched data)
Improvement with inclusion of ensemble (flow-dependent) DA

1 hr Forecasts



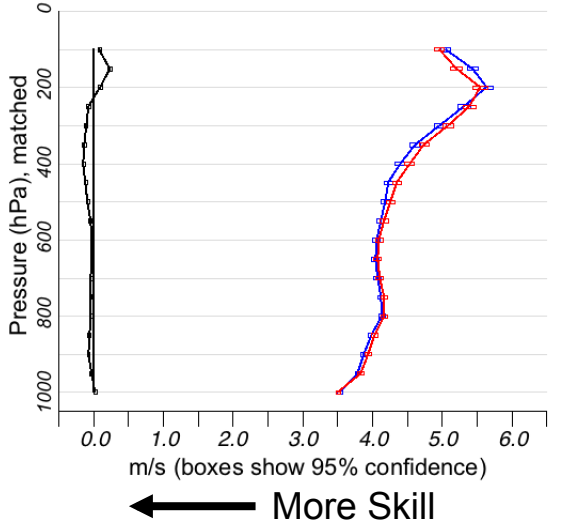
More Skill

6 hr Forecasts



More Skill

12 hr Forecasts



More Skill

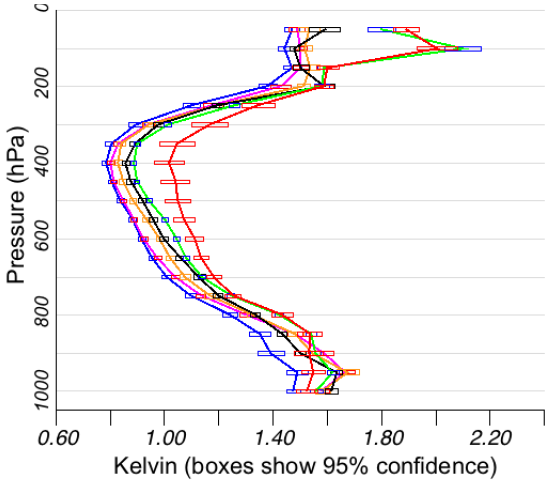
RAP/HRRR Performance History

- 2010
- 2011 (v1)
- 2012
- 2013 (v2)
- 2014
- 2015 (v3)

Experimental RAP RMSE 6-hr Forecasts

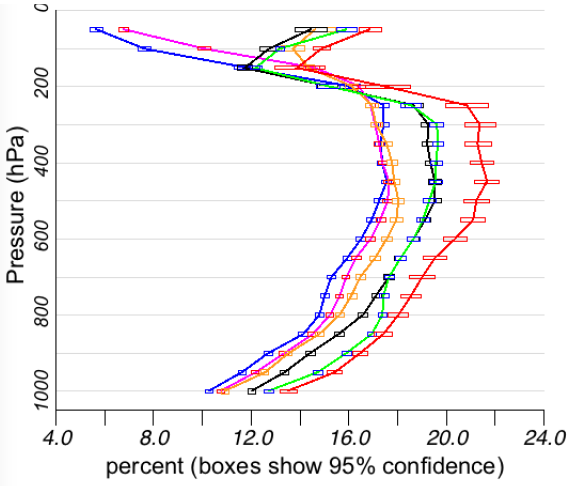
~25% RMSE Reduction in 5 years

Temperature



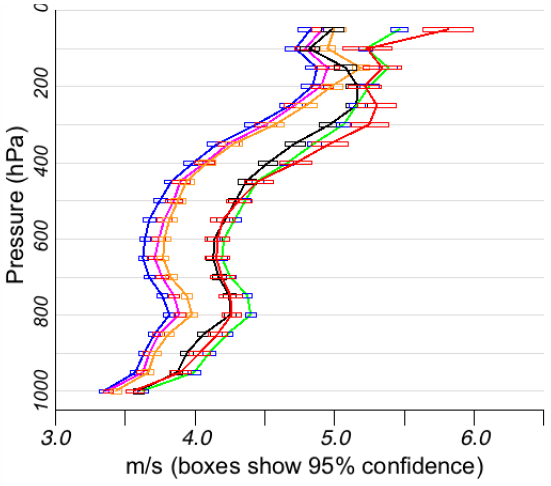
More Skill

Humidity



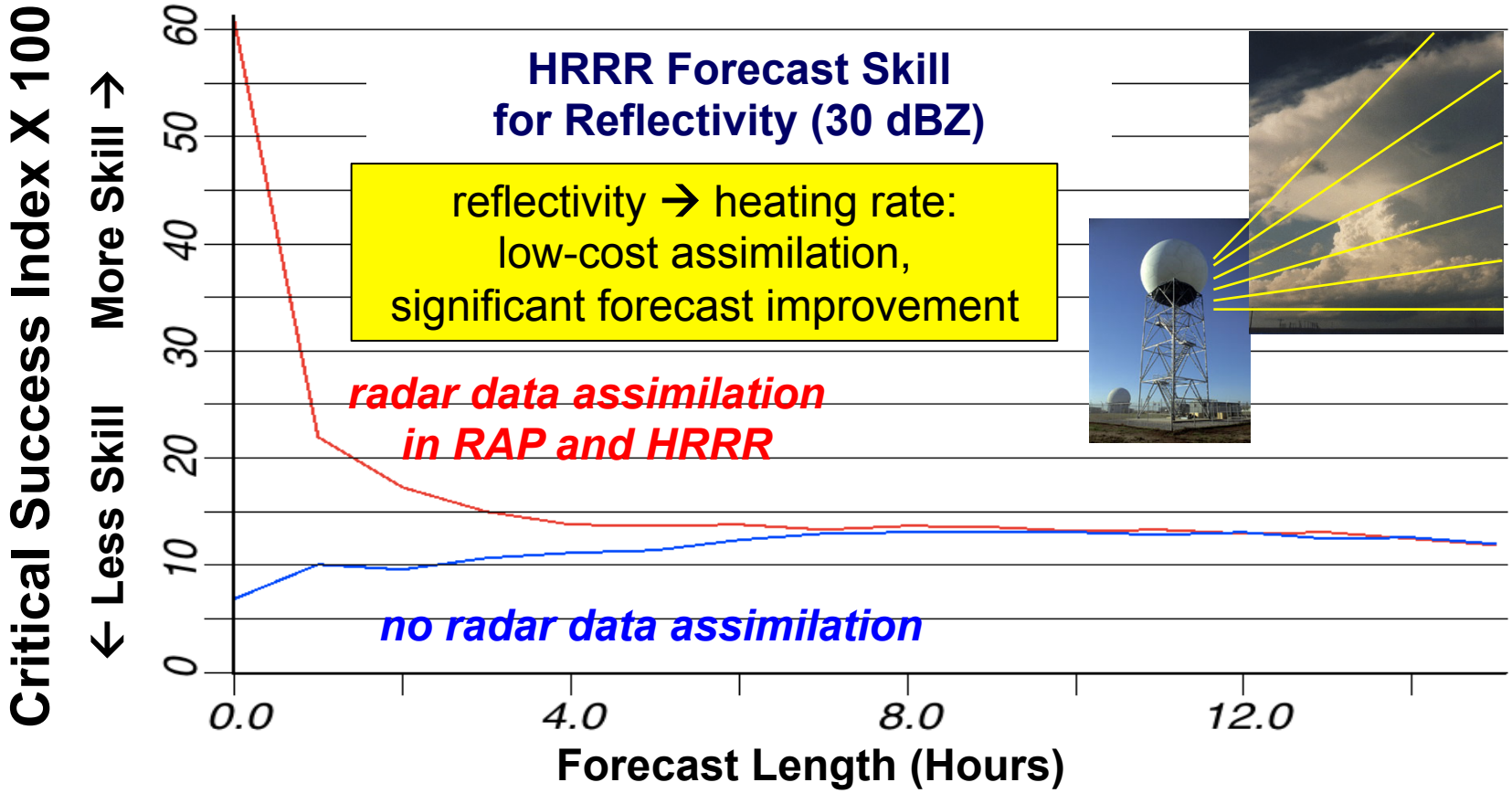
More Skill

Wind



More Skill

RAP/HRRR: Improving Forecast Skill

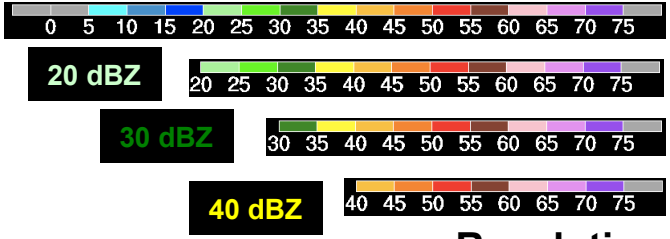


RAP/HRRR Gridded Verification System Using MRMS

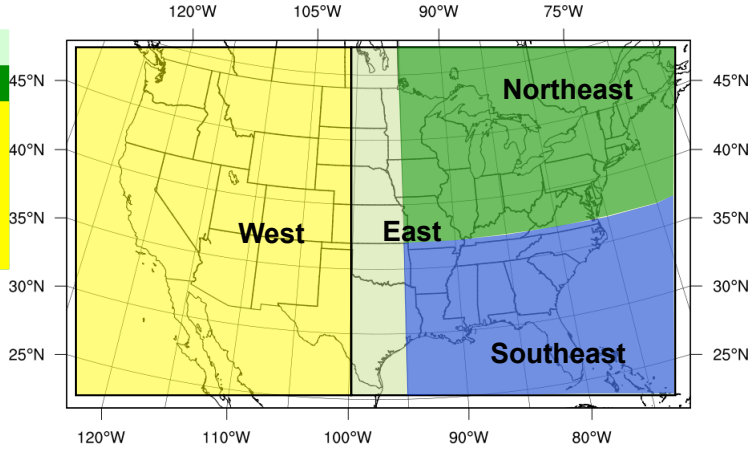
Intensity Threshold

VIP** Level	Echo Intensity	Precipitation Intensity	Rainfall Rate (in/hr) Stratiform	Rainfall Rate (in/hr) Convective	Reflectivity in (dBZ)
1	Weak	Light	Less Than 0.1	Less Than 0.2	Min. Signal - 30
2	Moderate	Moderate	0.1 - 0.5	0.2 - 1.1	31 - 40
3	Strong	Heavy	0.5 - 1.0	1.1 - 2.2	41 - 45
4	Very Strong	Very Heavy	1.0 - 2.0	2.2 - 4.5	46 - 50
5	Intense	Intense	2.0 - 5.0	4.5 - 7.1	51 - 57
6	Extreme	Extreme	More Than 5.0	More Than 7.1	> 57

Highest precipitation top in area in hundreds of feet MSL (45,000 feet MSL).



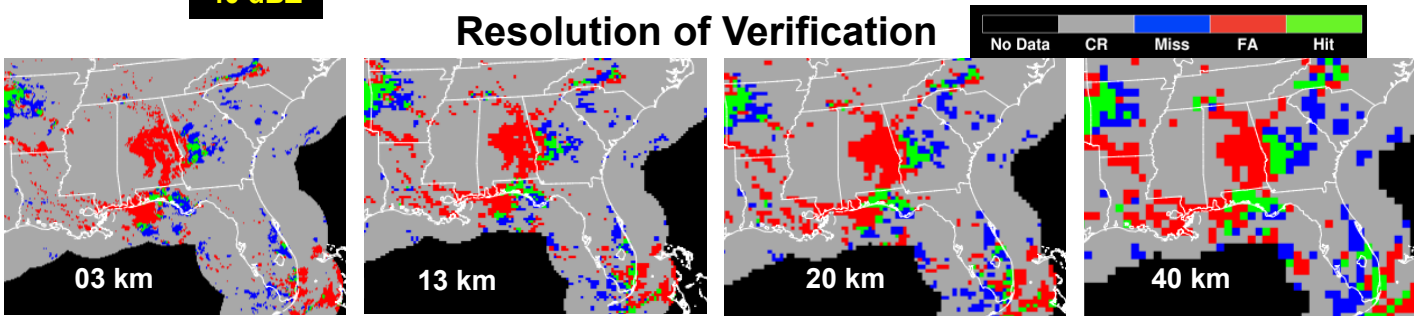
Domain



Gridded Fields

- Composite Reflect
- Stage IV Precip
- Echo Top Heights
- VIL

Resolution of Verification



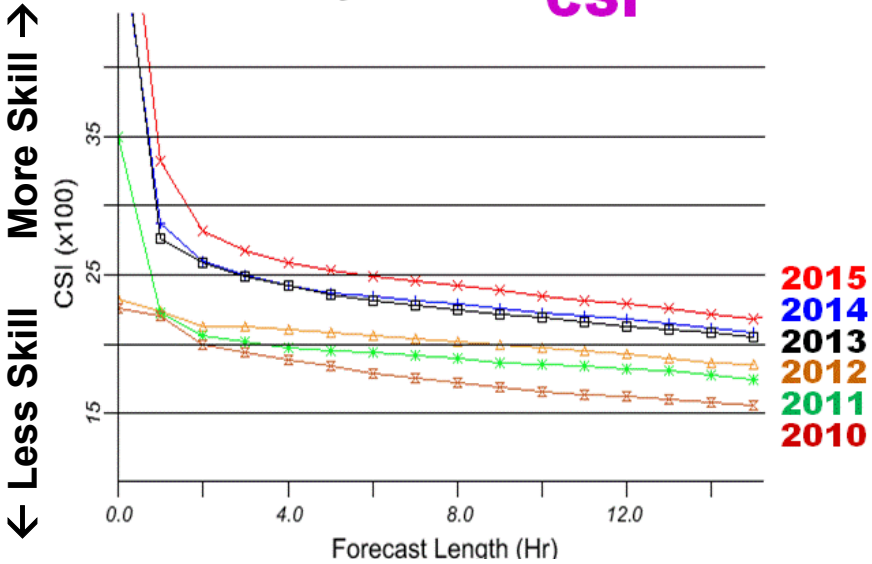
HRRR Performance History

HRRR reflectivity verification by year

CONUS
1 Jan – 31 Dec
Each year

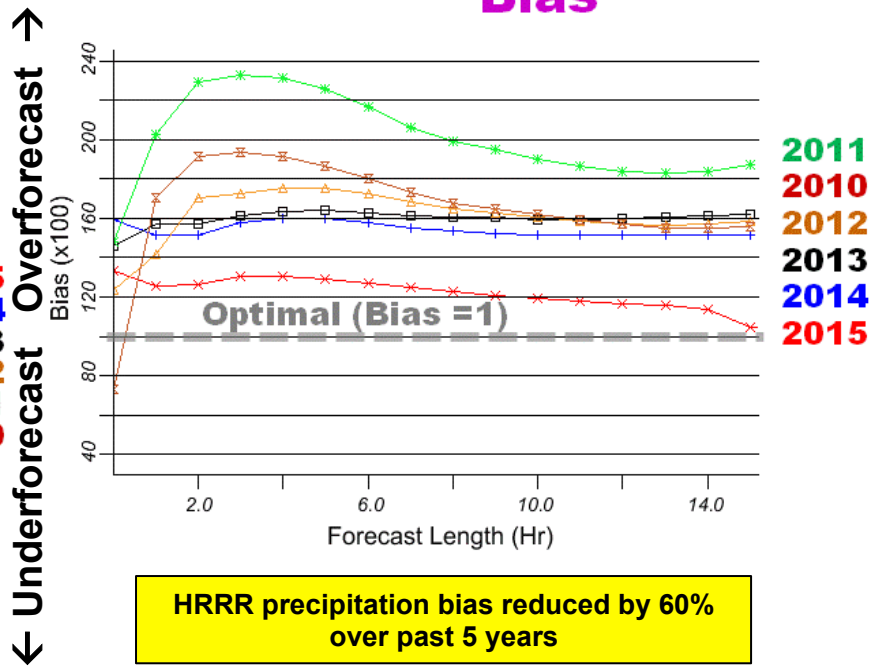
20 dbz 20 km -- score vs. forecast length

CSI



HRRR precipitation location skill improves by 50% over past 5 years

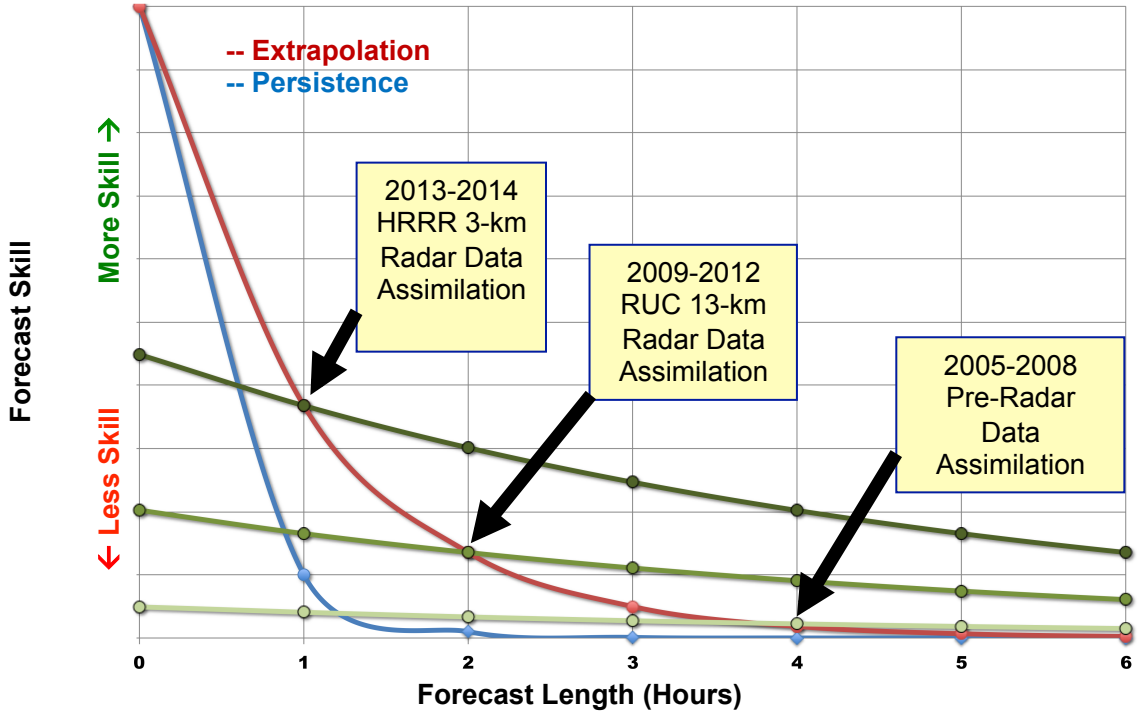
Bias



HRRR precipitation bias reduced by 60% over past 5 years

RUC/RAP/HRRR: Improving Forecast Skill

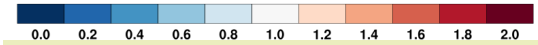
Crossover in forecast skill between Nowcasting/Extrapolation vs Numerical Weather Prediction



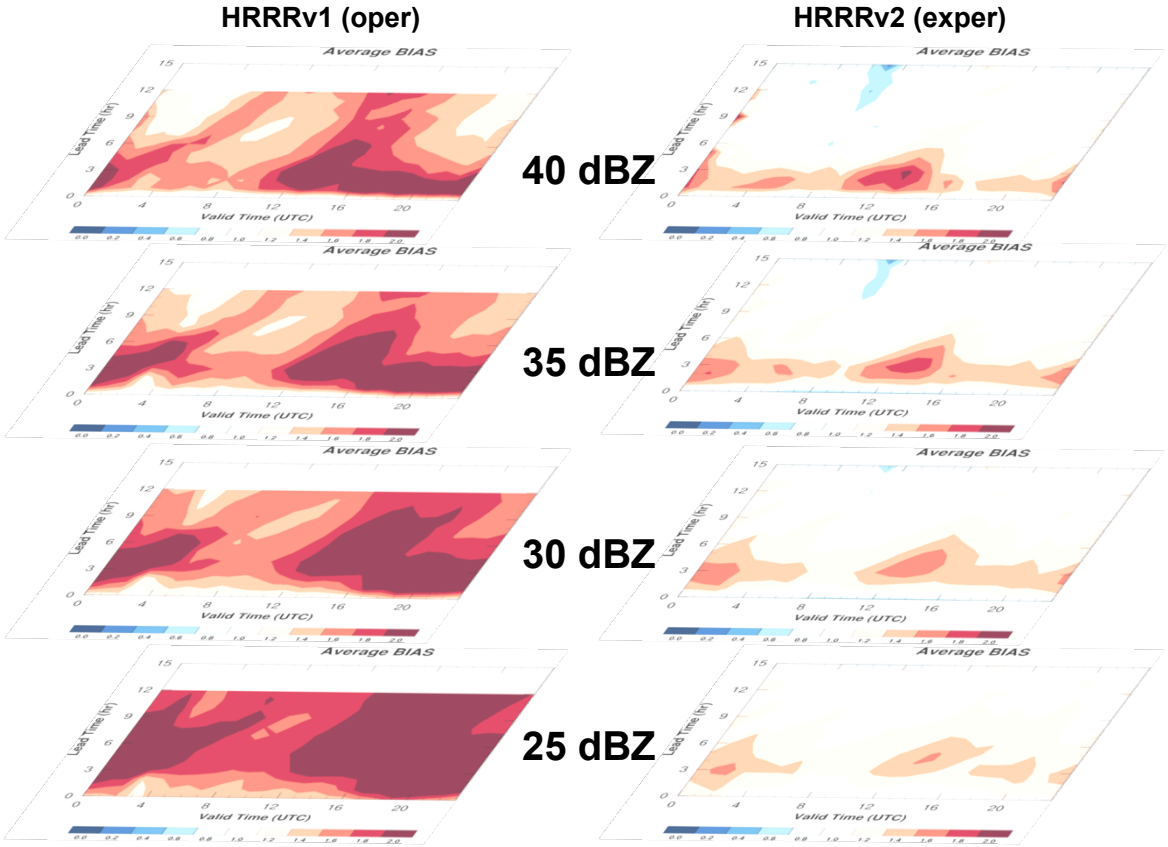
Improving forecast skill and halving crossover period every ~3-4 years

HRRRv2 Real-Time Evaluation: Reflectivity

Eastern US
May – June 2015



High afternoon bias in HRRRv1 improved in HRRRv2

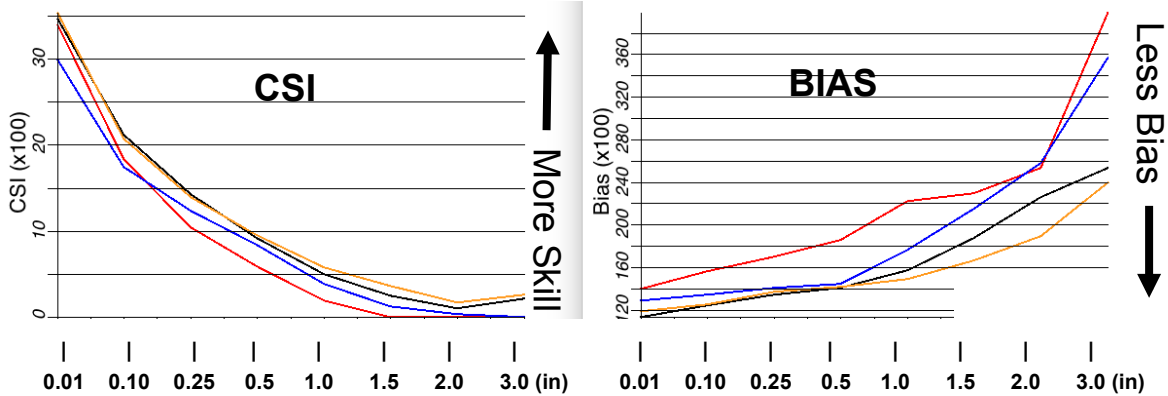


RAP/HRRR Implementation History

Western US 40km Grid

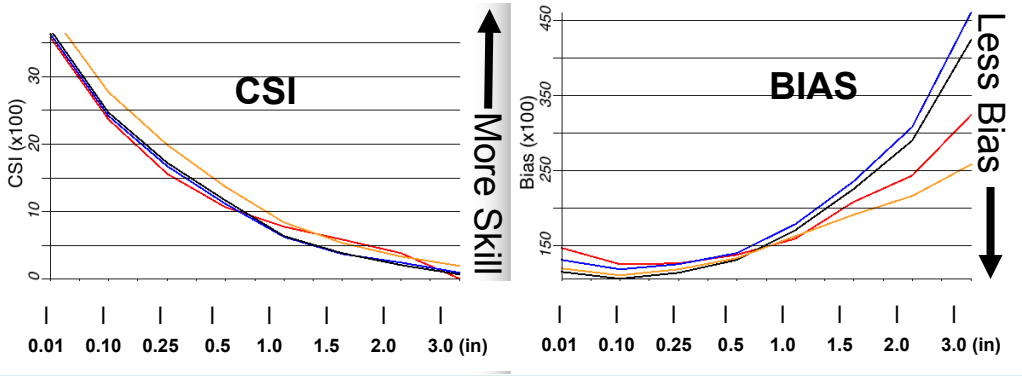
3hr Precipitation

- 2012
- 2013 (v1)
- 2014
- 2015 (v2)

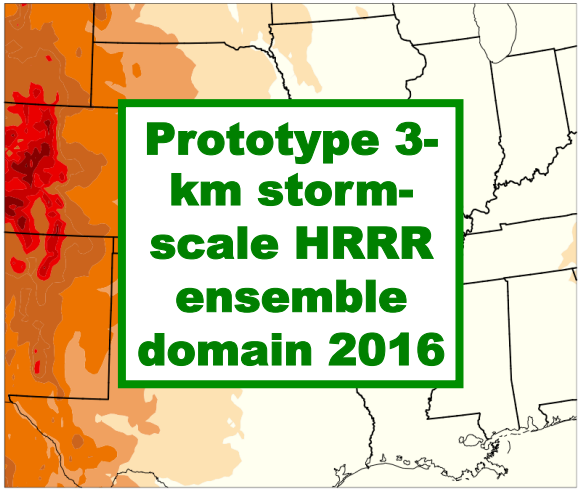


25% (East) to 50% (West) increase in skill over 3 years

Eastern US 40km Grid



HRRRE



Proof-of-concept
Real-time demonstration
With NSSL Experimental
WoF System for ensembles
“NEWS-e”

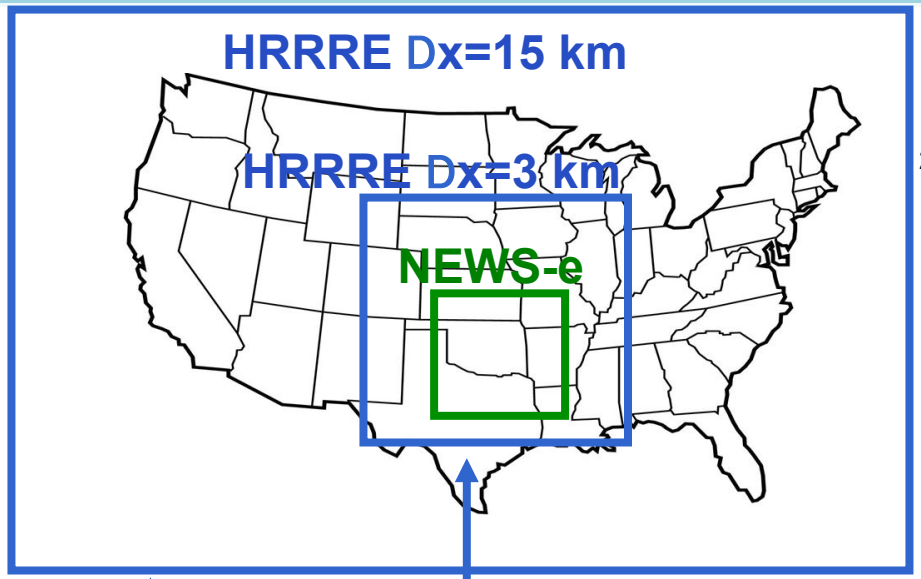
Real-Time Web Graphics

http://rapidrefresh.noaa.gov/HRRRE

- Single core (ARW)
- Ensemble DA (GSI-EnKF)
- RAP mean + GDAS (GFS) perturbations
- Conventional observations only (no radar data)

Assimilation	Forecast
20 members	00z - Three mem to 30 hr
1 hr cycling	03z - Three mem to 27 hr
21 fcsts / day	12z - Six mem to 18 hr
Start 21z day zero	15z - Eighteen mem to 15 hr
End 18z day one	18z - Eighteen mem to 12 hr

HRRRE and NEWS-e Workflows



BC from GFS

Soil state from RAP
Initial atmospheric mean from RAP
Atmospheric perturbations
from GDAS ensemble

HRRRE
1-hr cycling
21z to 18z

21Z 0Z 3Z 6Z 9Z 12Z 15Z 18Z

HRRRE ensemble forecasts
(3-18 mem to 06z)

6Z

15z handoff at ~17z

NEWS-e
15-min cycling
18z to 03z

NEWS-e ensemble forecasts
36 mem
1.5 – 3 hr forecasts

HRRRE Resources

HRRRE Real-Time System on NOAA R&D "Jet"
2 May - 20 June 2016 (testing in March/April)
HRRRE ~650x550 = 357,500 grdpts
HRRR 1800x1060 = 1,908,000 grdpts
HRRRE ~ 20% HRRR (1/5th)

Ensemble Pre-Processing

LBC	64 cores	~ 15 min
IC	120 cores	~ 30 min

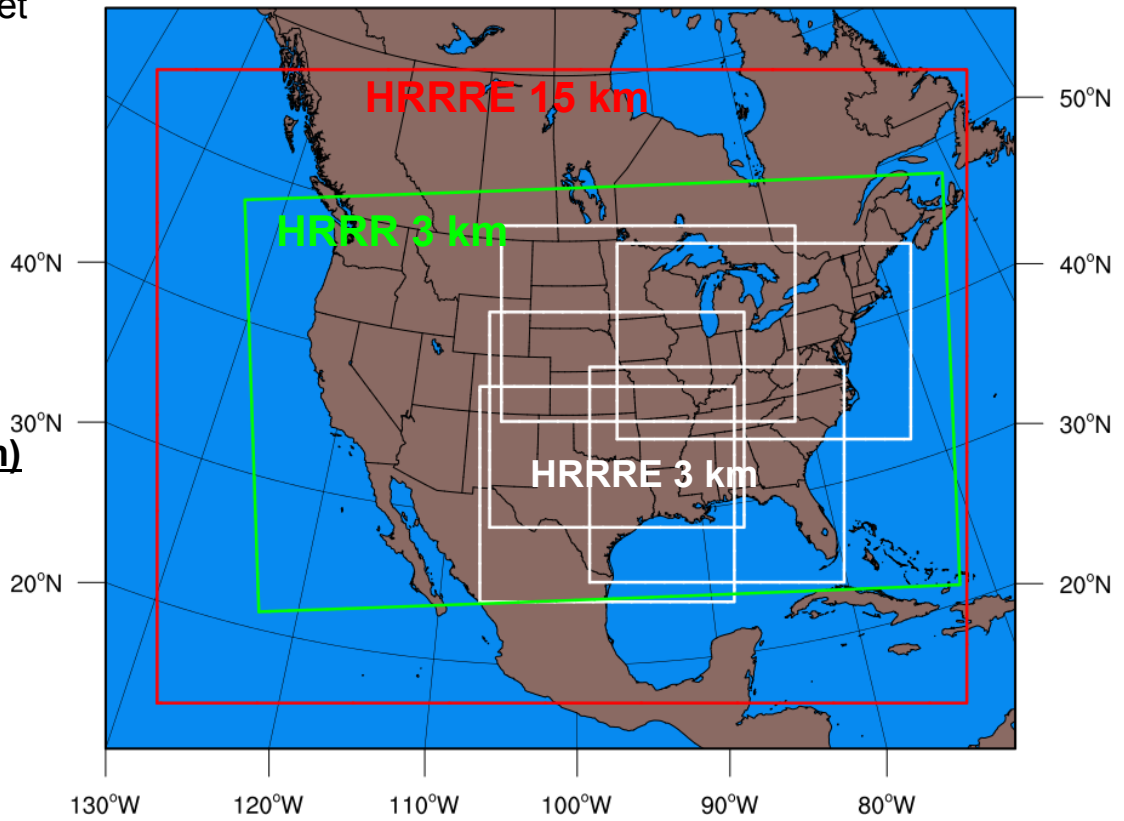
Ensemble 3-km Data Assimilation (20 mem)

WRF 1-hr cycle	72 cores/mem	~ 20 min
GSI-EnKF	240 cores	~ 25 min

Ensemble 3-km Forecast (3-18 mem)

WRF 18-hr fcst	180 cores/mem	~120 min
Post-processing	16 cores/mem	~5 min

DA + FCST = ~5,000 cores (18 fcst mem)



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Ensemble 3-km Data Assimilation (40 mem)

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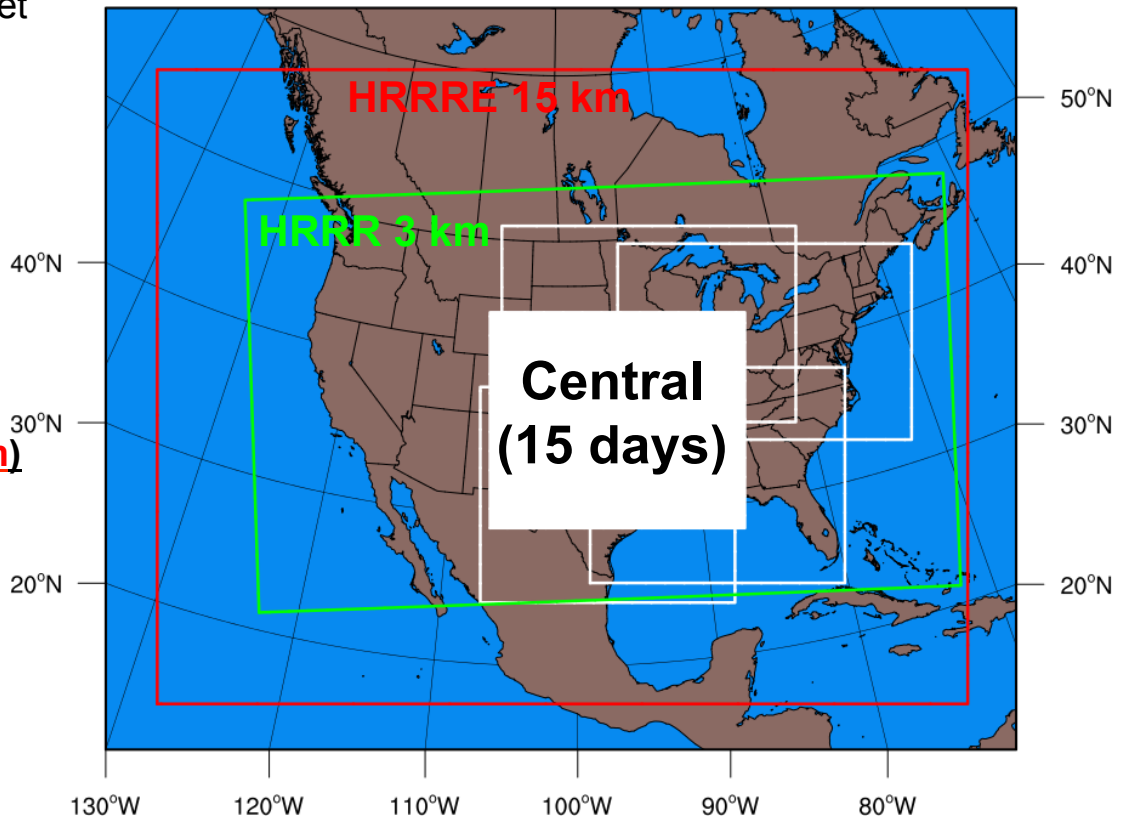
DA + FCST = ~6,500 cores (18 fcst mem)



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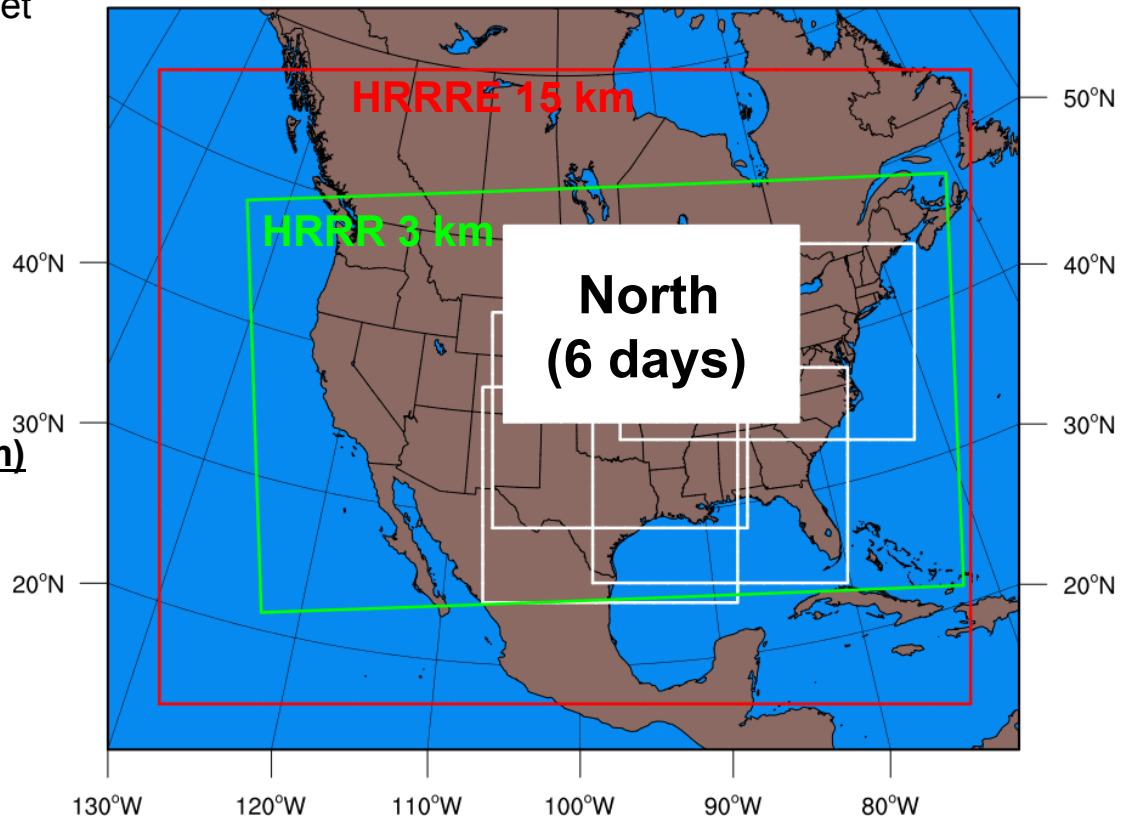
DA + FCST = ~4,500 cores (9 fcst mem)



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Ensemble 3-km Forecast (3-18 mem)

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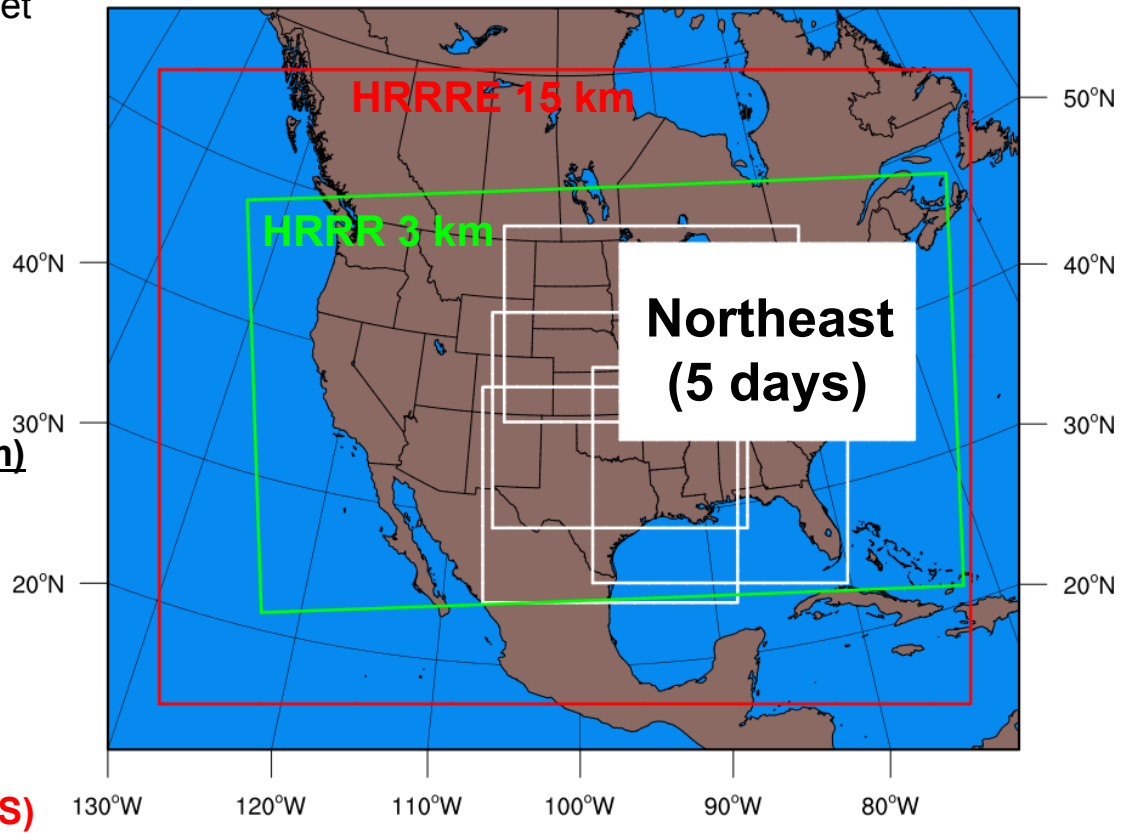
Post-processing	16 cores/mem	~5 min

DA + FCST = ~22,000 cores (9 mem CONUS)



HRRRE Resources

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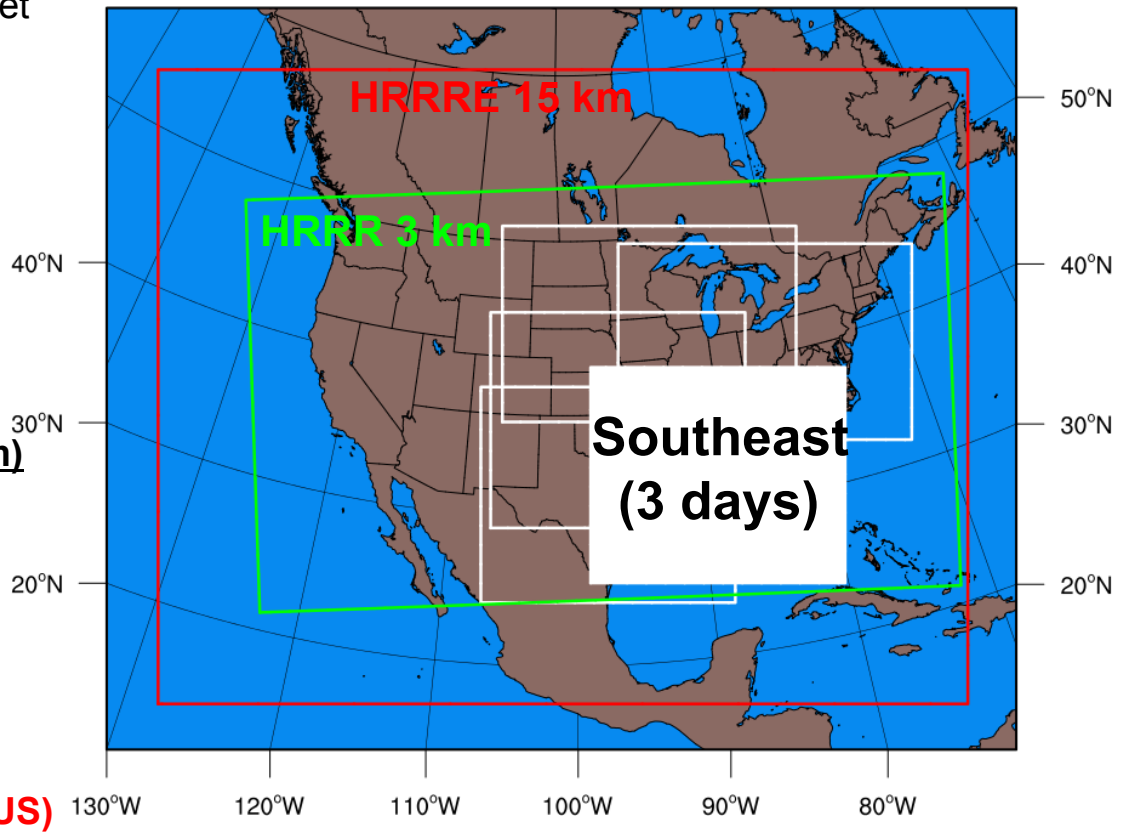

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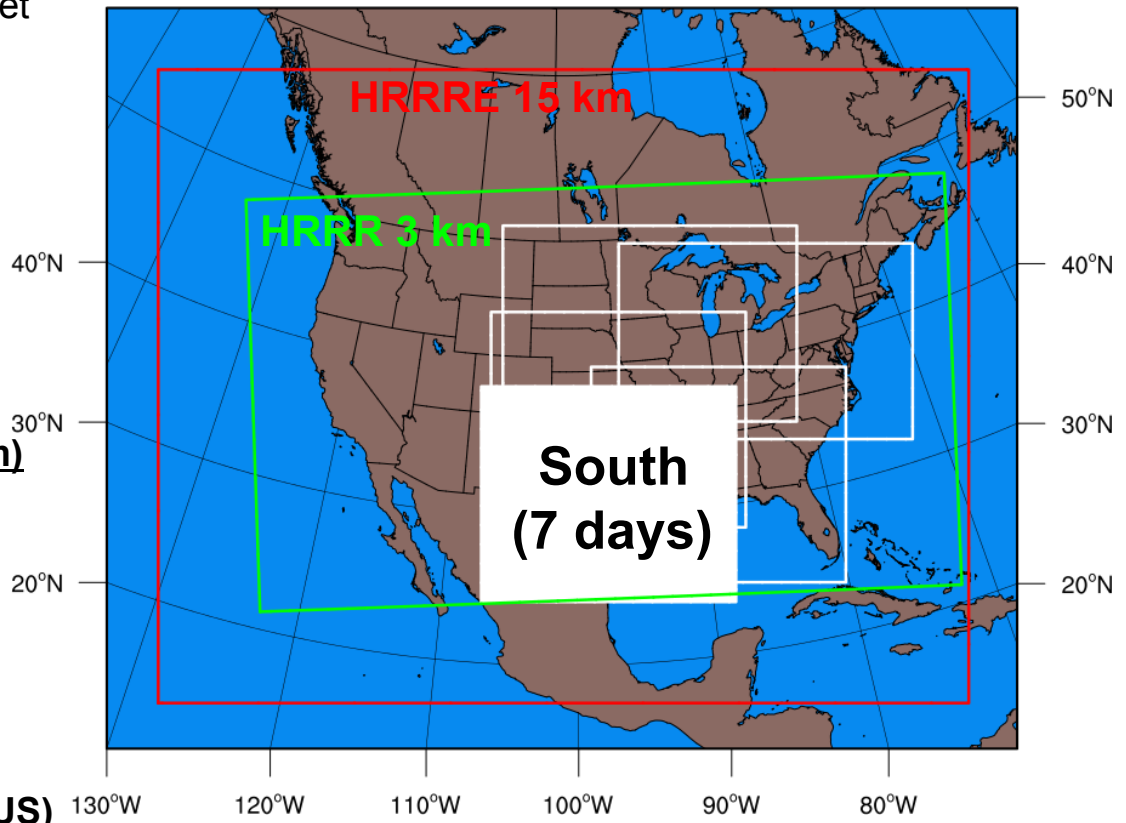
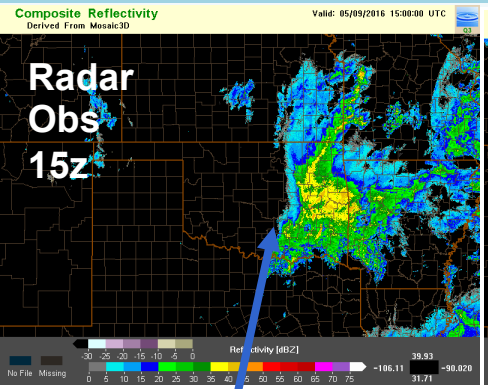
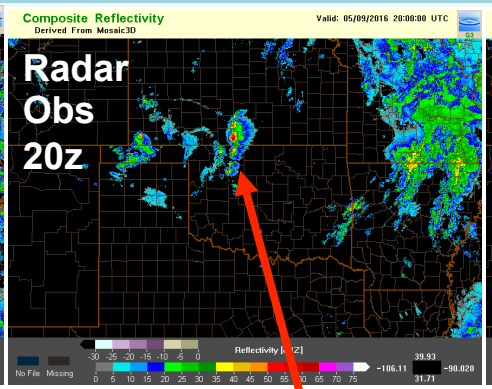
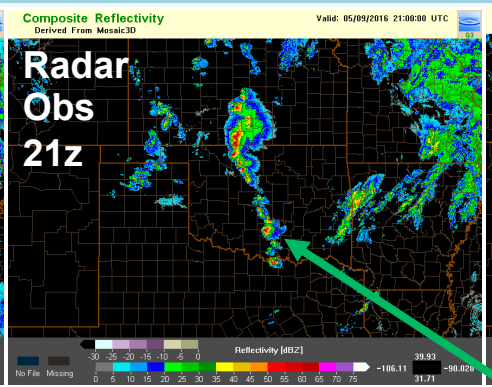
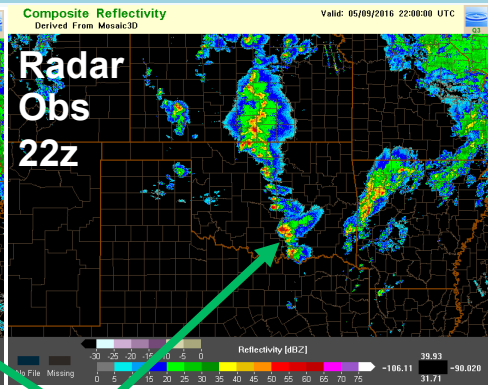


HRRRE: Case Study 09 May 2016





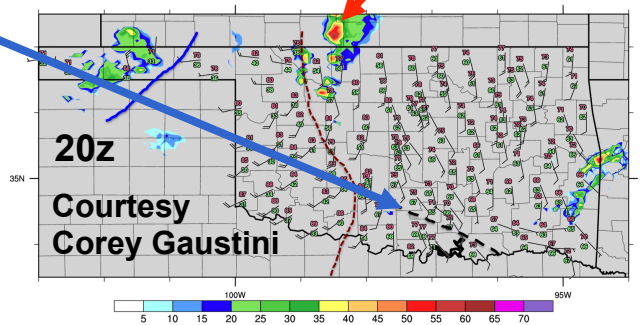


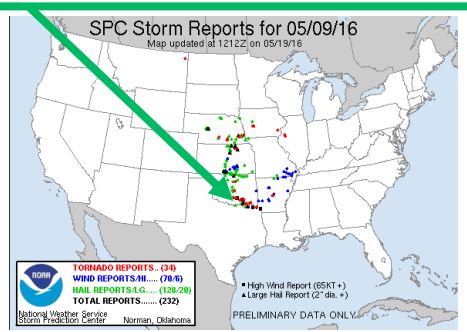


Rain-cooled Boundary

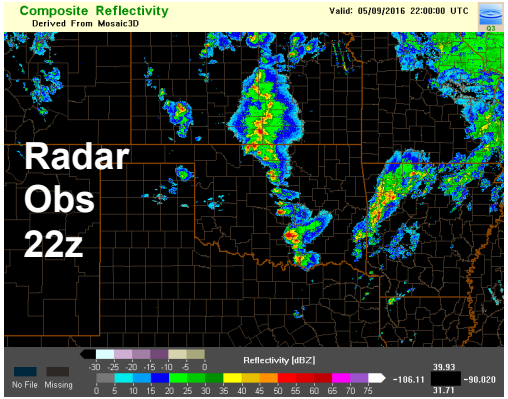
Convective initiation along dryline

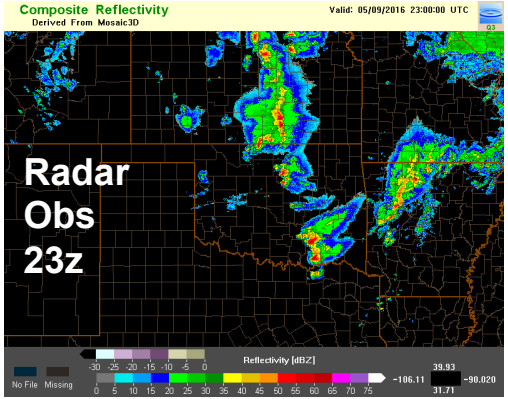
Tornadic supercell development near residual outflow boundary intersection





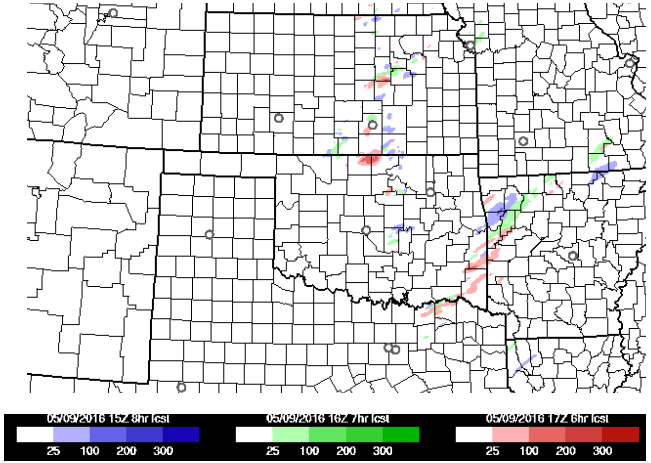
HRRRE: Case Study 09 May 2016



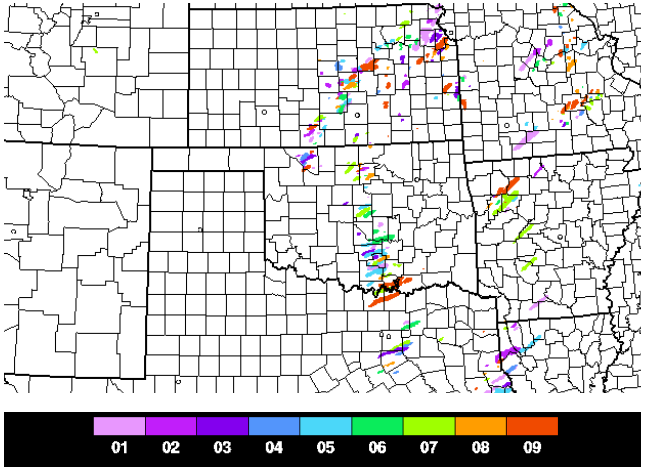


1-hr Maximum Updraft Helicity Valid 22z
(colors > 25 m^2/s^2)

HRRRX 15z-17z initializations
Time-Lagged Ensemble



HRRRE 15z + 7hr fcst valid 22z



Effective use of the boundary observations in storm-scale ensemble data assimilation

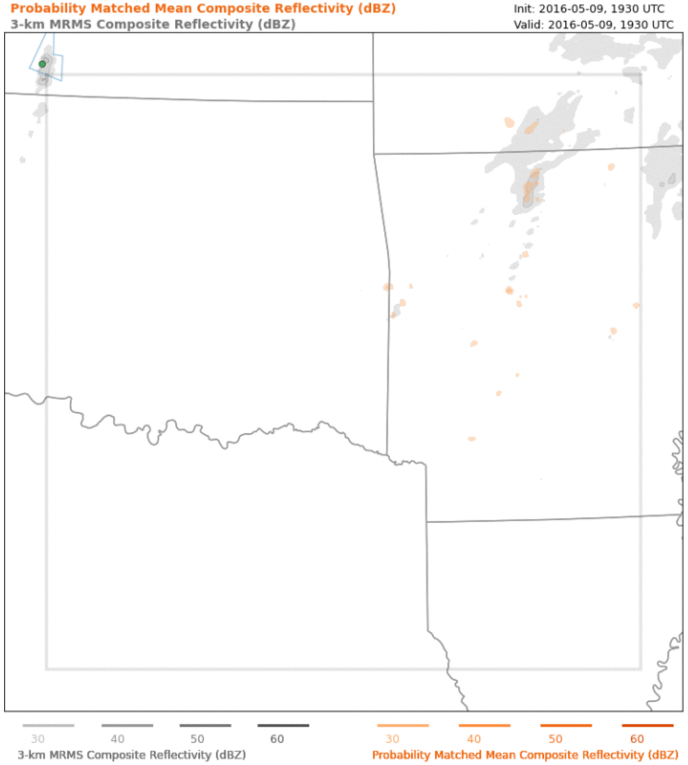
HRRRE to NEWSe: Case Study 09 May 2016

T+90 min from 18z HRRRE initial conditions

NEWSe initialized 1930z on 9 May 2016
90 Minute Forecast

Probability Matched Mean Composite Reflectivity (orange)
MRMS Composite Reflectivity Obs (grey)

- Forecasts central OK storm prior to storm initiation
- Indicates scatted nature of storms moving across OK/AR
- Misses KS storms near the edge of the domain

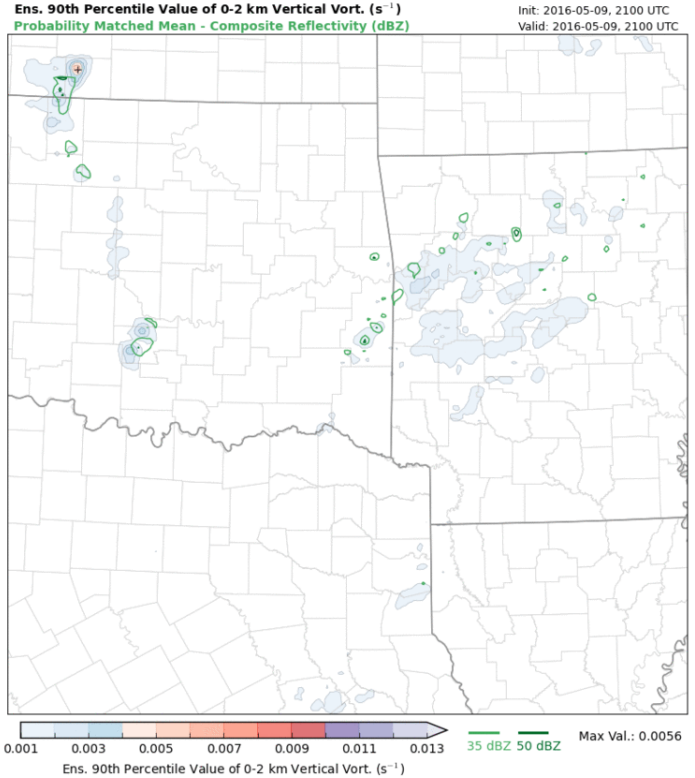


HRRRE to NEWSe: Case Study 09 May 2016

T+180 min from 18z HRRRE initial conditions

NEWSe initialized 2100z on 9 May 2016
90 Minute Forecast

Probability Matched Mean Composite Reflectivity (green)
90th Percentile Value of 0-2km Vertical Vorticity (colors)



- Vertical Vorticity forecast aligns with observed tornadoes in south central OK

- Overforecast in KS
- Underforecast in OK

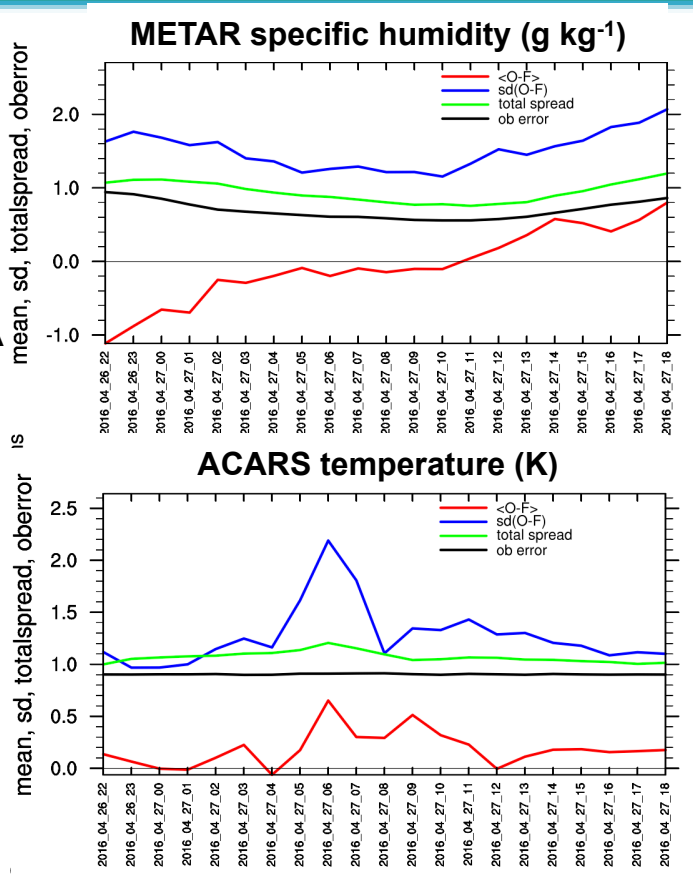
HRRRE Observation Space Diagnostics: 1-hr cycling

Black = Observation Error
Red = Ens Bias (mean obs innovation)
Green = Total Spread (ensemble standard deviation + ob error)
Blue = Ens Forecast Error (innovation standard deviation)

Need accurate specification of observation error
Ensemble spread << Observation error → Not drawn towards obs in DA
Based on results observation errors reduced for some datasets

Want total spread to track with forecast errors of the day
Ensemble spread < Forecast error (green < blue) → Underdispersive
Ensemble spread > Forecast error (green > blue) → Overdispersive
Ensemble generally underdispersive

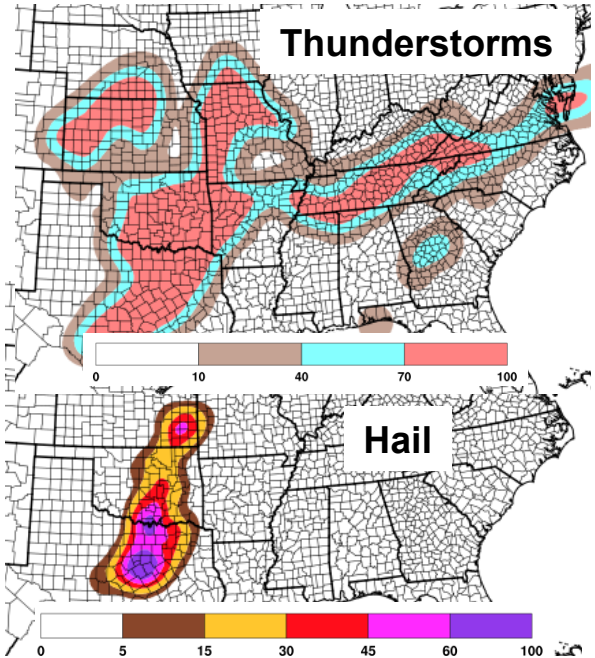
Ensemble design refinements planned including…
statistical post-processing



HRRR Time-Lagged Ensemble (HRRR-TLE)

Current Experimental Probability Products:

- **Based on 3 HRRRX runs (equal weight)**
- **Starting with forecast hour two**
- **40-km neighborhood probabilities**
- **120-km spatial filter applied *after* identifying neighborhood hazard exceedance**



Real-Time Web Graphics (and grids via LDM/FTP)

http://rapidrefresh.noaa.gov/hrrrtle

HRRR Time-Lagged Ensemble - Experimental

Model: HRRRX Neighborhood Probability (Experimental) Area: Full Date: 07 Jun 2016 - 22Z

Model: HRRRX Neighborhood Probability (Experimental) Domain: Full Date: 07 Jun 2016 - 22Z

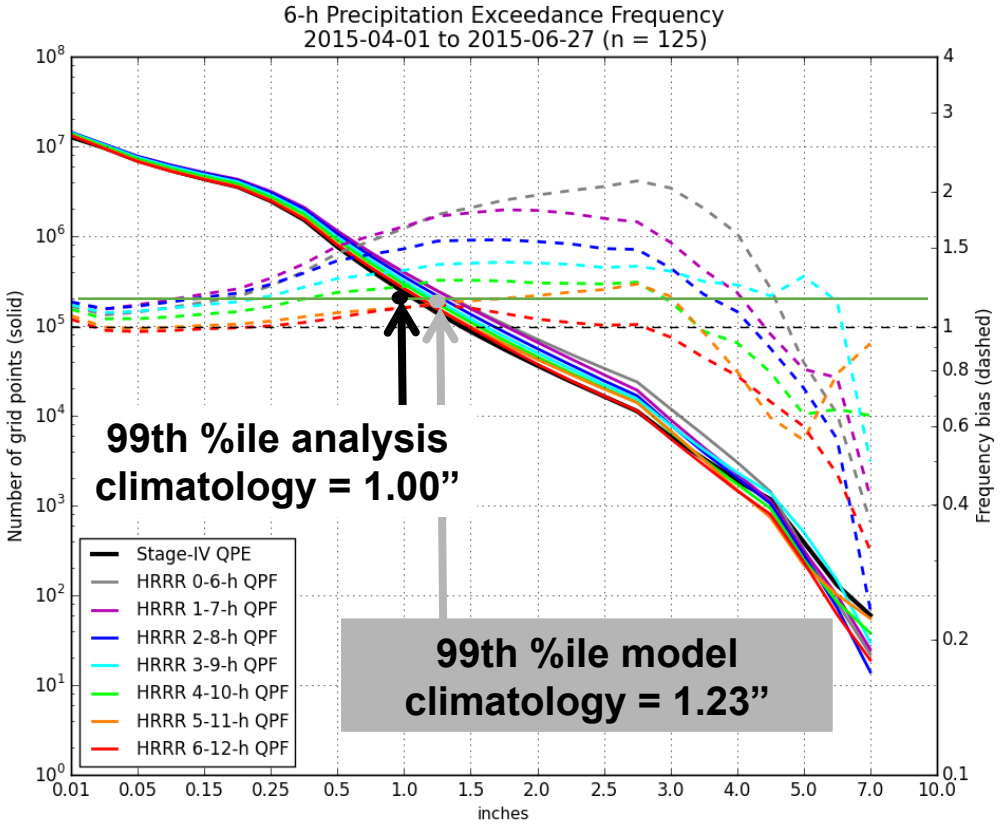
			Valid Time																												
			Tue 22	Tue 23	Wed 00	Wed 01	Wed 02	Wed 03	Wed 04	Wed 05	Wed 06	Wed 07	Wed 08	Wed 09	Wed 10	Wed 11	Wed 12	Wed 13	Wed 14	Wed 15	Wed 16	Wed 17	Wed 18	Wed 19	Wed 20	Wed 21	Wed 22					
	All times	Loop	Forecast																												
			00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24				
QPF	all fields			00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24				
	0.50" / 1 hr precip	✓	✓		01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24				
	1.00" / 1 hr precip	✓	✓		01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24				
	2.00" / 1 hr precip	✓	✓		01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24				
	0.50" / 3 hr precip	✓	✓				03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24				
	1.00" / 3 hr precip	✓	✓				03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24				
	2.00" / 3 hr precip	✓	✓				03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24				
	3.00" / 3 hr precip	✓	✓				03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24				
	0.50" / 6 hr precip	✓	✓							06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24				
	1.00" / 6 hr precip	✓	✓							06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24				
	2.00" / 6 hr precip	✓	✓							06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24				
	3.00" / 6 hr precip	✓	✓							06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24				
	6.00" / 6 hr precip	✓	✓							06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24				
	6 hr precip > 100-yr recurrence	✓	✓							06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24				
	1.00" / 3 hr runoff	✓	✓				03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24				
	2.00" / 3 hr runoff	✓	✓				03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24				
	3.00" / 3 hr runoff	✓	✓				03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24				
Winter	0.50" / 1 hr snowfall	✓	✓		01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24				
	1.00" / 1 hr snowfall	✓	✓		01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24				
	2.00" / 1 hr snowfall	✓	✓		01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24				
	1.00" / 6 hr snowfall	✓	✓							06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24				
	3.00" / 6 hr snowfall	✓	✓							06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24				
Severe	Thunderstorm	✓	✓	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24				
	Wind > 50 kt in last 4 hr	✓	✓				04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24				
	Hail > 1" in last 4 hr	✓	✓				04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24				
	Tornado in last 4 hr	✓	✓				04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24				
Aviation	Visibility < 3 mi	✓	✓	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24				
	Visibility < 1 mi	✓	✓	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24				
	Ceiling < 3000 ft	✓	✓	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24				
	Ceiling < 1000 ft	✓	✓	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24				
	Ceiling < 500 ft	✓	✓	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24				
	IFR conditions	✓	✓	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24				
	Echo Tops > 25 kft	✓	✓	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24				
	Echo Tops > 30 kft	✓	✓	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24				
	Echo Tops > 35 kft	✓	✓	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24				

HRRR-TLE Development: Bias Correction

Frequency Bias Correction Using "Quantile Mapping"

Model forecast climatology adjusted to observation climatology for a particular threshold (1 inch / 6 hrs)

Exploring modified gamma distribution for additional refinement in bias correction



HRRR-TLE Precipitation Products

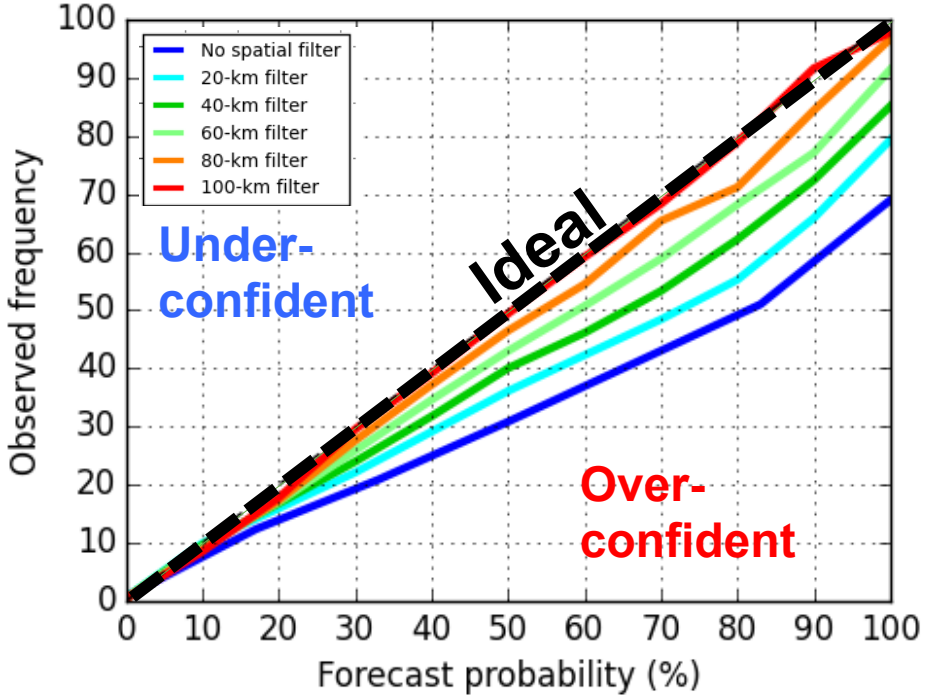
Results: Probability of 0.5” Precipitation in 6 hours
May-Aug 2015

With relatively small sample size (~50 forecasts)

Produce statistically reliable probabilities
60% forecasts observed 60% of the time

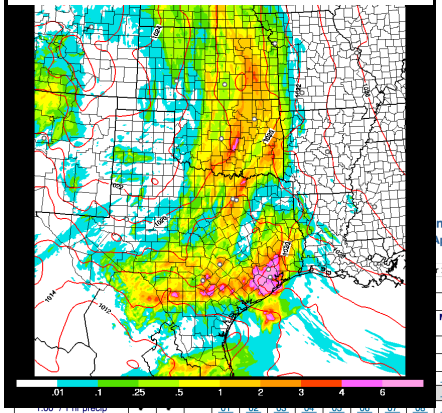
Produce probabilities with sufficient resolution/sharpness
Large dynamic range to probabilities including extremes

Still fundamentally underdispersive (overconfident)

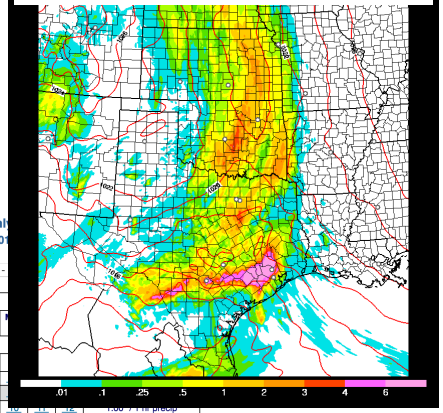


HRRR-TLE Case Study: 12 UTC 18 April 2016

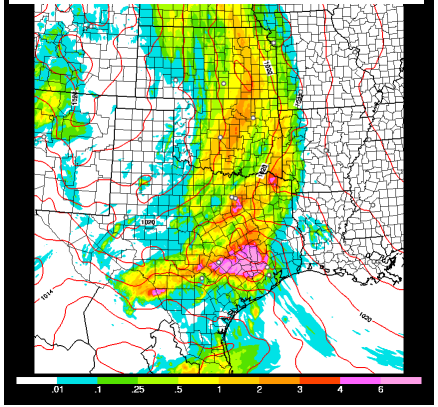
HRRR 23z 13hr pcp fcst

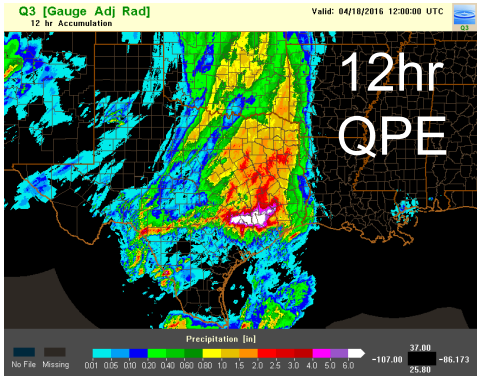


HRRR 00z 12 hr pcp fcst



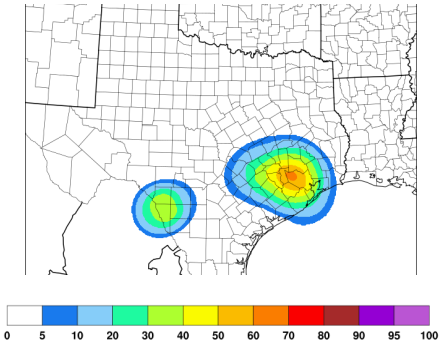
HRRR 01z 11 hr pcp fcst





2.00" / 1 hr precip	✓	✓		01	02	03	04	05	06	07	08	09	10	11	12	2.00" / 1 hr precip
0.50" / 3 hr precip	✓	✓				03			06			09			12	0.50" / 3 hr precip
1.00" / 3 hr precip	✓	✓				03			06			09			12	1.00" / 3 hr precip
2.00" / 3 hr precip	✓	✓				03			06			09			12	2.00" / 3 hr precip
3.00" / 3 hr precip	✓	✓				03			06			09			12	3.00" / 3 hr precip
0.50" / 6 hr precip	✓	✓							06			09			12	0.50" / 6 hr precip
1.00" / 6 hr precip	✓	✓							06			09			12	1.00" / 6 hr precip
2.00" / 6 hr precip	✓	✓							06			09			12	2.00" / 6 hr precip
3.00" / 6 hr precip	✓	✓							06			09			12	3.00" / 6 hr precip
6.00" / 6 hr precip	✓	✓							06			09			12	6.00" / 6 hr precip
6 hr precip > 100-yr recurrence	✓	✓							06			09			12	6 hr precip > 100-yr recurrence
1.00" / 3 hr runoff	✓	✓				03			06			09			12	1.00" / 3 hr runoff
2.00" / 3 hr runoff	✓	✓				03			06			09			12	2.00" / 3 hr runoff
3.00" / 3 hr runoff	✓	✓				03			06			09			12	3.00" / 3 hr runoff
0.50" / 1 hr snowfall	✓	✓		01	02	03	04	05	06	07	08	09	10	11	12	0.50" / 1 hr snowfall
1.00" / 1 hr snowfall	✓	✓		01	02	03	04	05	06	07	08	09	10	11	12	1.00" / 1 hr snowfall
2.00" / 1 hr snowfall	✓	✓		01	02	03	04	05	06	07	08	09	10	11	12	2.00" / 1 hr snowfall
1.00" / 6 hr snowfall	✓	✓							06			09			12	1.00" / 6 hr snowfall
3.00" / 6 hr snowfall	✓	✓							06			09			12	3.00" / 6 hr snowfall
6.00" / 6 hr snowfall	✓	✓							06			09			12	6.00" / 6 hr snowfall
Thunderstorm	✓	✓	00	01	02	03	04	05	06	07	08	09	10	11	12	Thunderstorm
Wind > 50 kt in last 4 hr	✓	✓					04	05	06	07	08	09	10	11	12	Wind > 50 kt in last 4 hr
Hail > 1" in last 4 hr	✓	✓					04	05	06	07	08	09	10	11	12	Hail > 1" in last 4 hr
Tornado in last 4 hr	✓	✓					04	05	06	07	08	09	10	11	12	Tornado in last 4 hr

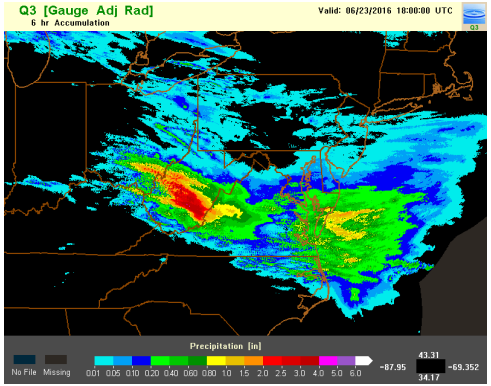
HRRR-TLE 03z 09 hr fcst



HRRR-TLE forecasts > 60% probability of 6hr QPF exceeding 100 year average return interval (ARI) in Houston,TX area based on ATLAS14

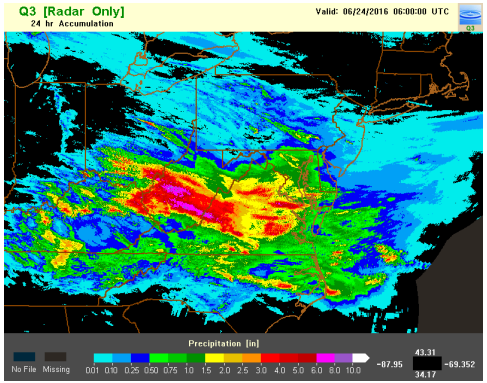
HRRR-TLE Case Study: 12 UTC 23 June 2016

6 hr QPE Valid 18z 23 June 2016



3+” observed

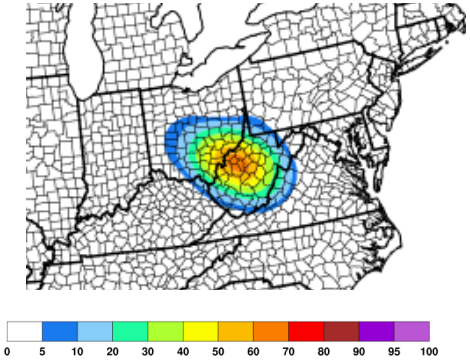
24 hr QPE Valid 06z 24 June 2016



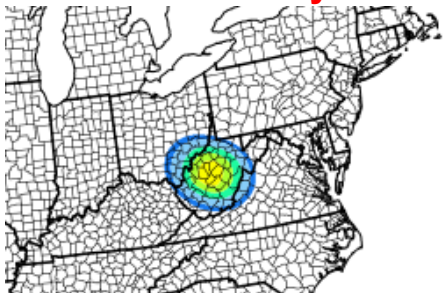
10+” observed

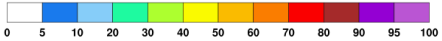
HRRR-TLE 15 hr fcst valid 15z 23 June 2015

6 hr PQPF > 3”



6 hr PQPF > 100 year ARI





HRRR-TLE forecasts > 40% probability of 6hr QPF exceeding 100 year average return interval (ARI) in West Virginia area based on ATLAS14

HRRR-TLE: Product Development

Product Development Methodology

Hazard	Proxy	Truth
Heavy rainfall	QPF	Stage-IV / MRMS
Snowfall rate	Microphysics-based	ASOS visibility
Precipitation type	Microphysics-based	ASOS type
Accumulating 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 Threat*	Updraft helicity	Post-processed MRMS rotation tracks
Lightning	Lightning flash algorithm	GLD360/NLDN
Visibility/Ceiling	Post-processed field in development	ASOS or future CIMSS technique
General Convection	Vertical motion, stability, reflectivity	MRMS reflectivity

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
AWC Winter Experiment	Ceiling and visibility	NAWIPS	February 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	Late 2017 or 2018

HRRRE Future Work

Objective HRRRE verification underway

- Membership comparison against deterministic forecasts (HRRRX)
- Ensemble diagnostics like spread/skill

Refine ensemble data assimilation

- Install radar reflectivity data assimilation
- Stochastic physics (parameter perturbation, tendencies)
- Apply HRRR-TLE statistical post-processing
- Include lagged members?

Real-Time Status

Resume real-time HRRRE runs in Oct/Nov 2016 after ending 20 June 2016
HRRR-TLE runs continually available

RAPv4/HRRRv3 ESRL Development 39/36 hr Runs

	Model	Data Assimilation
RAPv4 (13 km)	WRF-ARW v3.8+ incl. physics changes **Physics changes:** Thompson microphysics – improved upper-level clouds MYNN PBL update – better sub-grid clouds, meso env LSM update – 15" MODIS data – better lower boundary Thomp. aerosols + MYNN cloud-fraction – improved C&V VIIRS-based real-time greenness vegetation fraction **Numerics changes:** Improved terrain (cell avg) – reduced noise, better turb Hybrid vertical coordinate from NCAR (upcoming)	Merge with GSI trunk – last updated in Jan 2016 **New Observations for assimilation:** NCEP new VAD wind retrievals Add AMVs over land and TAMDAR GOES-R lightning mapper – convection proxy **Assimilation Methods:** Revised PBL pseudo-obs – reduce RH bias More ensemble weight in hybrid DA (.9/.1) METAR and GOES cloud building now consistent Aircraft temperature bias correction
HRRRv3 (3 km)	WRF-ARW v3.8+ incl. physics changes **Physics changes:** Thompson microphysics – improved upper-level clouds MYNN PBL update – better sub-grid clouds, meso env LSM update – 15" MODIS data – better lower boundary Thomp. aerosols + MYNN cloud-fraction – improved C&V VIIRS-based real-time greenness vegetation fraction **Numerics changes:** Hybrid vertical coordinate from NCAR (upcoming)	**New Observations for assimilation:** GOES cloud-top cooling rates – convection proxy Add new VAD wind, AMVs over land and TAMDAR GOES-R lightning mapper – convection proxy Radar radial velocity at 3km – better convection **DA Methods:** More ens weight in hybrid DA (.9/.1) – better winds Full atmospheric cycling – better 0-4 hr convection Variational/hybrid cloud analysis – better C/V

RAPv4/HRRRv3 ESRL/GSD Development Talks

6.6	Wed 11:45	Joseph Olson	Updates to the MYNN PBL and surface layer scheme for RAP/HRRR
7A.2	Thu 8:45	Ravan Ahmadov	Development of the HRRR-Smoke air quality modeling system with the VIIRS real- time fire products
7B.3	Thu 9:00	Jaymes Kenyon	Case Studies of improved HRRR low-level wind forecasts from the Wind Forecast Improvement Project II
9.2	Thu 1:45	Isidora Jankov	A performance comparison between multi-physics and stochastic approaches within a North American RAP ensemble