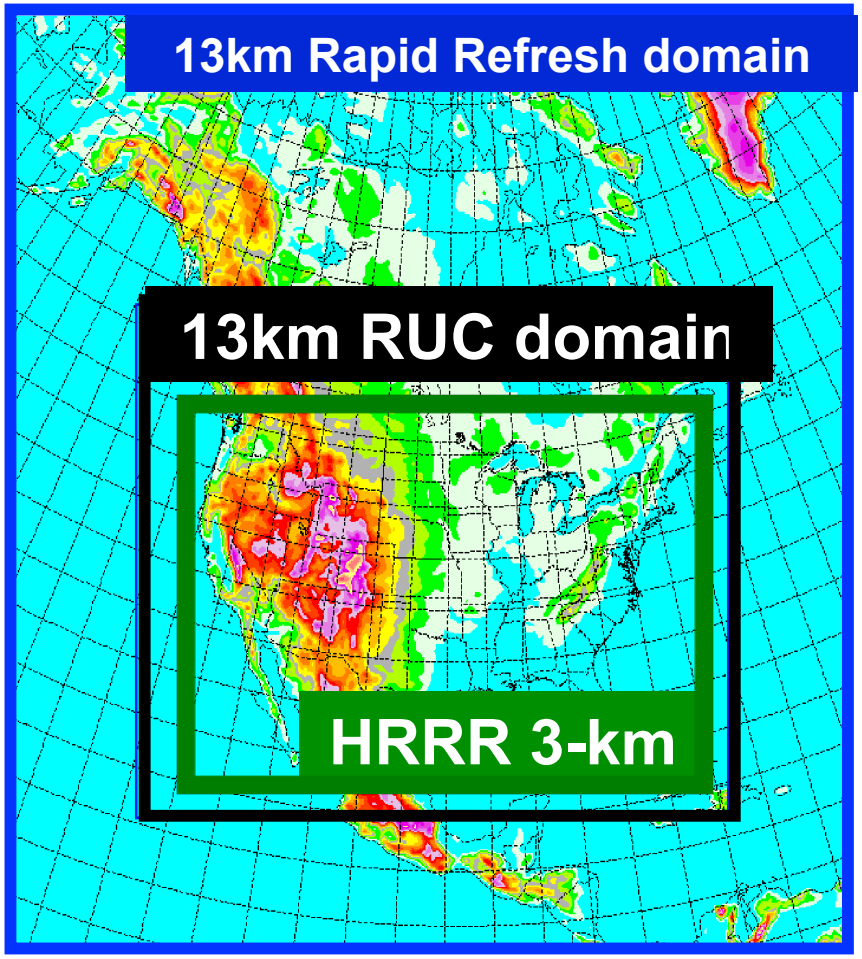
Latest on NOAA's hourly updated models: 13km Rapid Refresh, 3km HRRR



NWS Southern Region
Tuesday 16 August 2011, updated 8/23

Stan Benjamin +

Steve Weygandt, Tanya Smirnova
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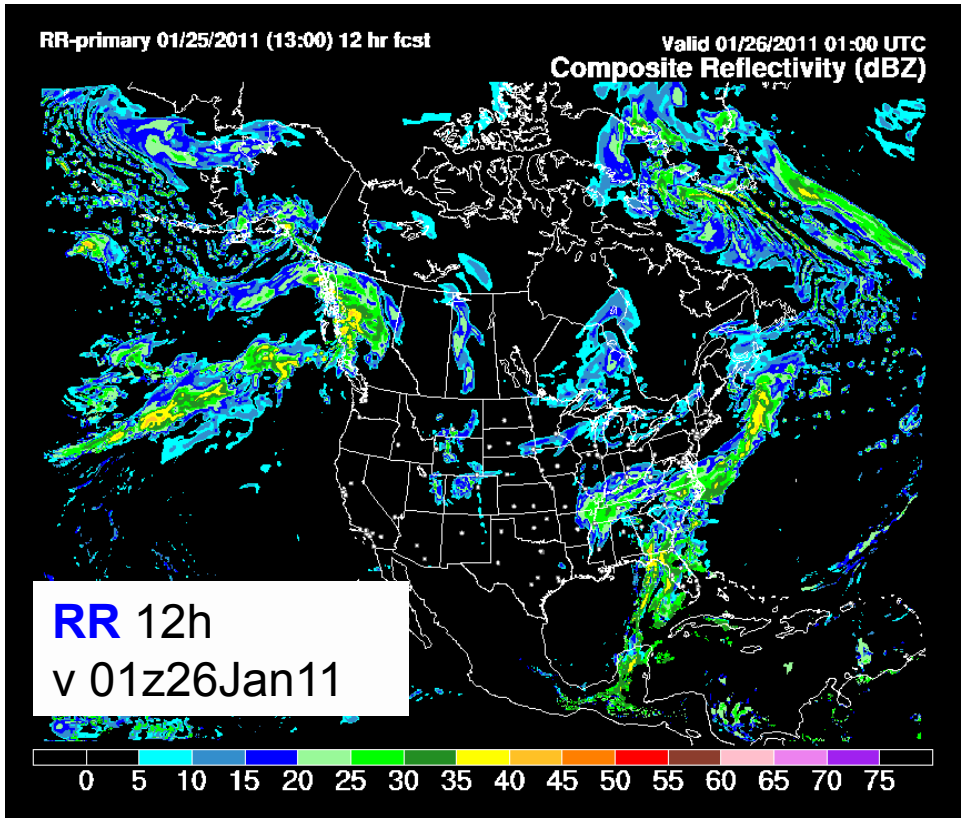
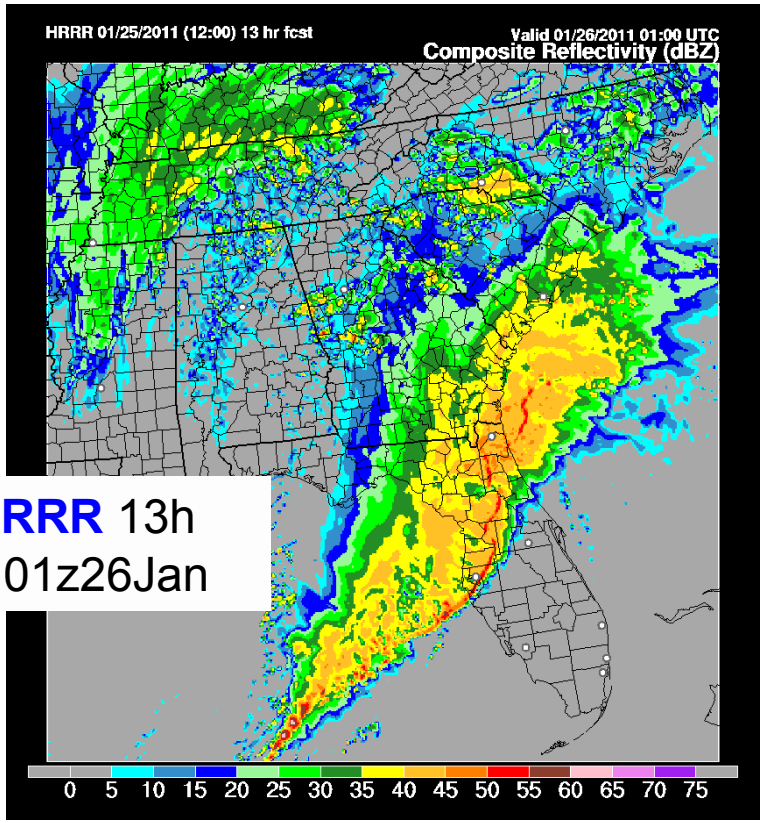
NOAA NCEP, Camp Springs, MD

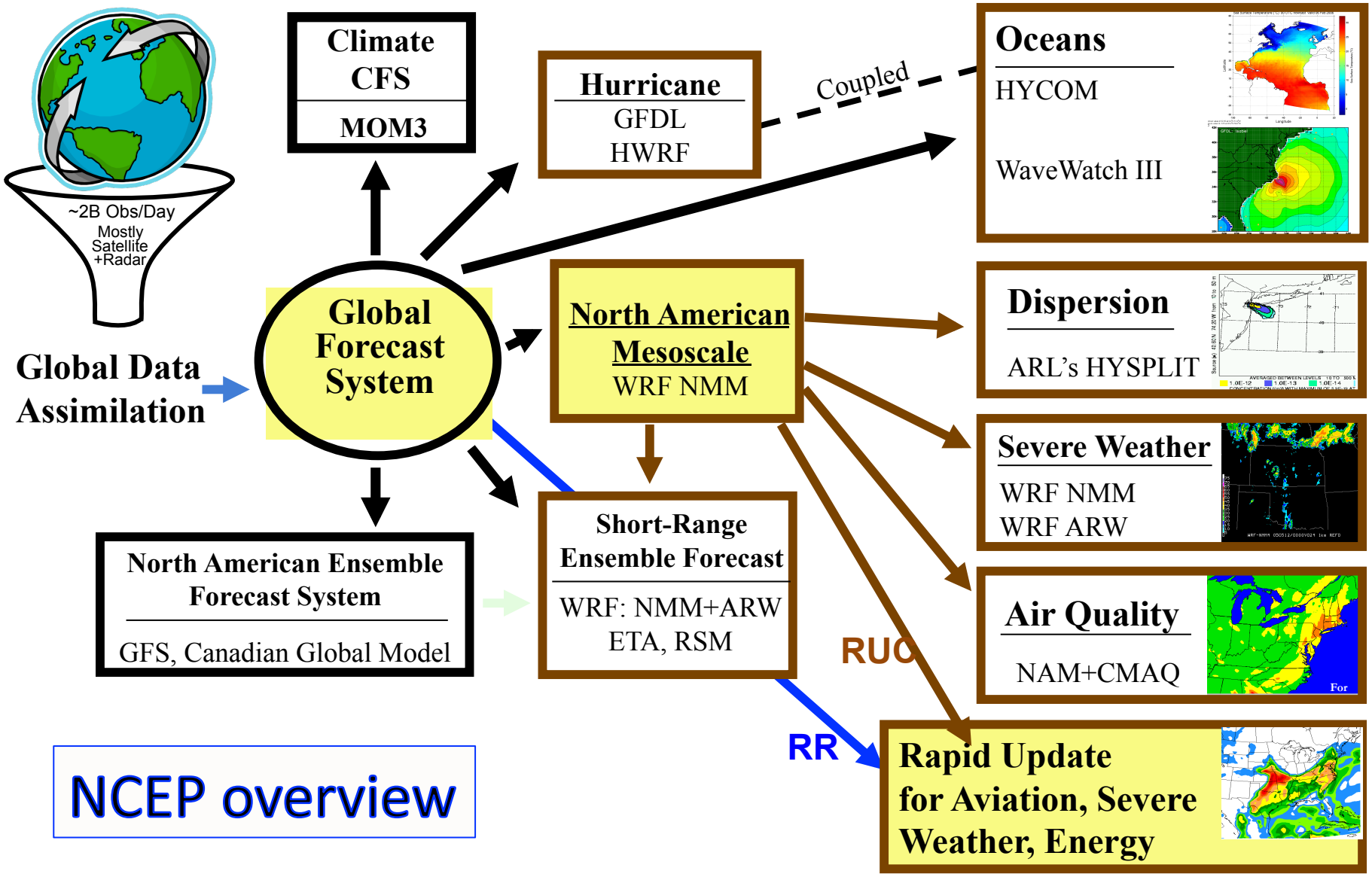
Outline

- **Rapid Refresh**
  - Implementation@NCEP planned Nov 2011, significant improvement over RUC
  - Replaced the RUC as parent model for the HRRR – 4/14/2011
- **HRRR**
  - Backbone for hourly updated storm-scale forecasting for US
  - Much improved evaluation environment for 2010➔2011
  - Improvements – assimilation (radar, cloud, surface), WRF configuration





NOAA's Current NWP Model Production Suite



NCEP overview

Hourly Updated NOAA NWP Models

Rapid Refresh (RR)

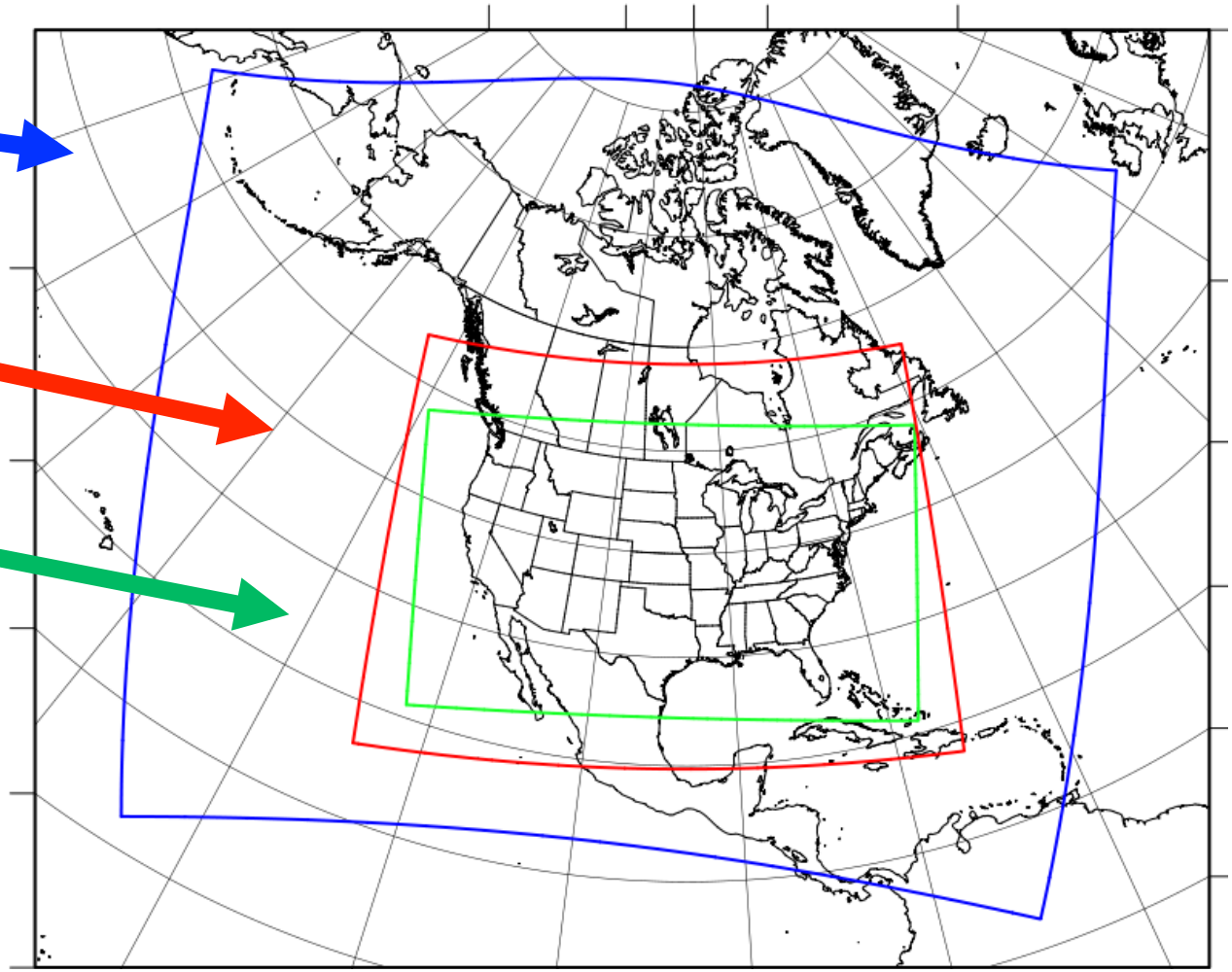
Code frozen, running at EMC

Operational implementation Planned Nov. 2011 (after NAM)

13km Rapid Refresh

13km RUC

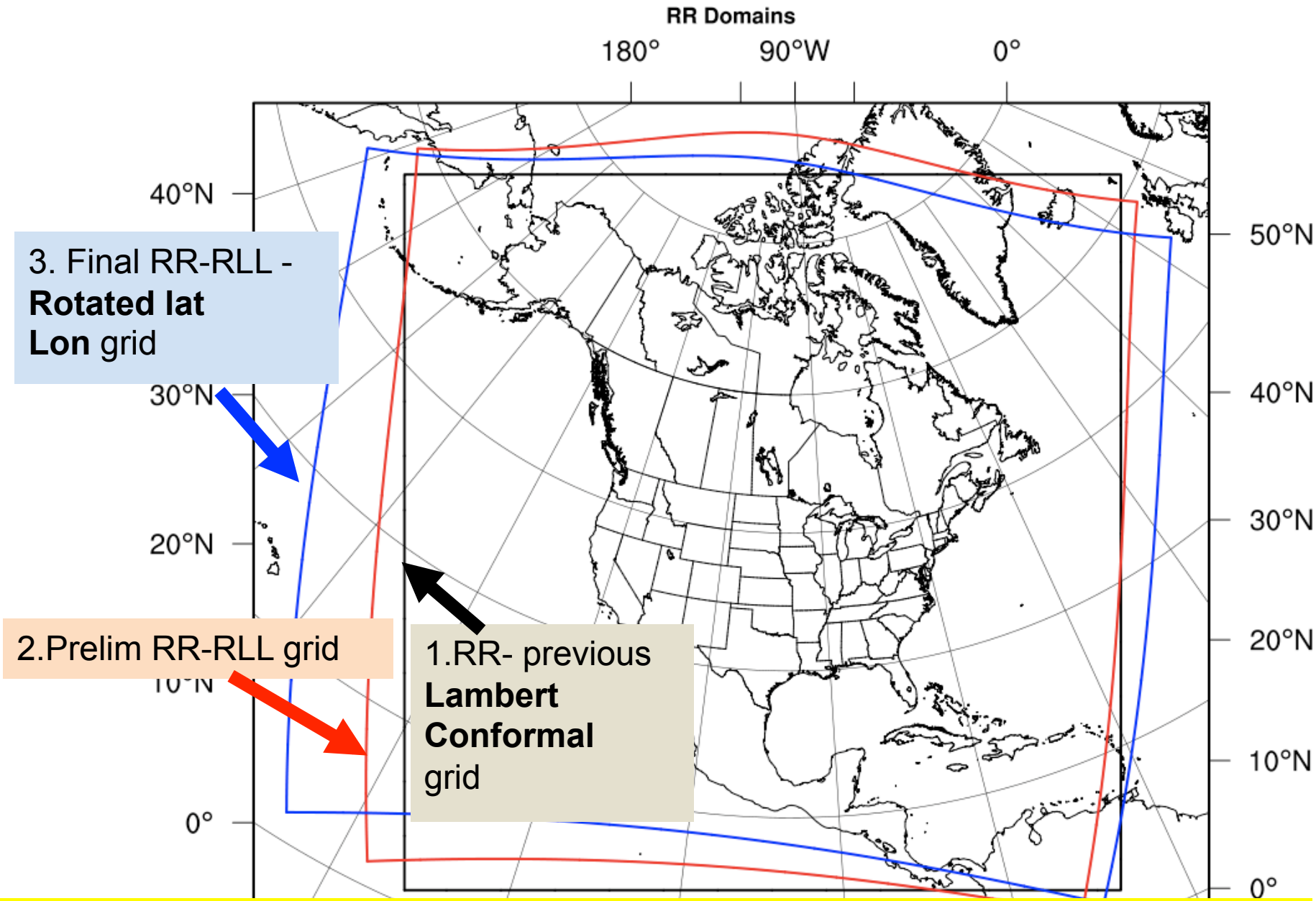
3km HRRR



RUC – current oper Model, new 18h fcst every hour

High-Resolution Rapid Refresh

Experimental 3km nest inside RUC or RR, new 15-h fcst every hour



June 2010 decision: switch RR to rot-lat-lon grid covering all of Aleutian Is. (per NWS-AR, AWC approval)

Key progress toward Rapid Refresh

- RUC cloud analysis incorporated into NCEP GSI (2008-10)
- Introduced partial cycling (via GFS) of atmospheric fields (2009)
- Enhanced RUC-Smirnova LSM with snow on ice (2009-10)
- Enhancements for surface obs assimilation (2009)
- Mods for 1-h cycling with 3-h LBCs update (2009)
- WRFPOST → UNIPOST with many additions (2009-10)
- Change to rotated lat-lon (RLL) grid (Summer-Fall 2010)
- ***Added corrections to RLL curvature terms (Fall 2010)***
- ***Corrections to radar/satellite processing (F 2010)***
- Adapted GFS BEC for optimal short-range skill (F 2010)
- Corrected height diagnostic in post-processing (F 2010)
- Frozen R/T code running at EMC, grids on ftp (Dec 2010)
- Fix to DFI to allow preservation of original RH, hydrometeors (Apr 11)
- PBL-based pseudo-obs (Jun-July 2011, ESRL version only)

Transition from RUC to Rapid Refresh

Provides hourly cycled guidance to all North America

Community-based advanced model and analysis

- **WRF-ARW:** advanced numerics, non-hydrostatic
- **GSI:** advanced satellite DA, 4DVAR/EnKF development

Model	Domain	Grid Points	Grid Spacing	Vertical Levels	Vertical Coordinate	Pressure Top	Boundary Conditions
RUC	CONUS	451 x 337	13 km	50	Sigma/ Isentropic	~50 mb	NAM
RR	North America	758 x 567	13 km	50	Sigma	10 mb	GFS

Model	Assimilation	DFI	Cloud Analysis	Micro-physics	Radiation LW/SW	Conv param	PBL	LSM
RUC	RUC-3DVAR	Yes w/radar	Yes	Thompson	RRTM/ Dudhia	Grell-Devenyi	Burk Thompson	RUC
RR	GSI w/ radiances	Yes w/radar	Yes	Thompson	RRTM/ Goddard	Grell-3d	MYJ	RUC

Rapid Refresh sigma levels (50)

1.0000, 0.9980, 0.9940, 0.9870, 0.9750, 0.9590,
0.9390, 0.9160, 0.8920, 0.8650, 0.8350, 0.8020, 0.7660,
0.7270, 0.6850, 0.6400, 0.5920, 0.5420, 0.4970, 0.4565,
0.4205, 0.3877, 0.3582, 0.3317, 0.3078, 0.2863, 0.2670,
0.2496, 0.2329, 0.2188, 0.2047, 0.1906, 0.1765, 0.1624,
0.1483, 0.1342, 0.1201, 0.1060, 0.0919, 0.0778, 0.0657,
0.0568, 0.0486, 0.0409, 0.0337, 0.0271, 0.0209, 0.0151,
0.0097, 0.0047, 0.0000,

4 layers in lowest 200m, lowest @ ~8m

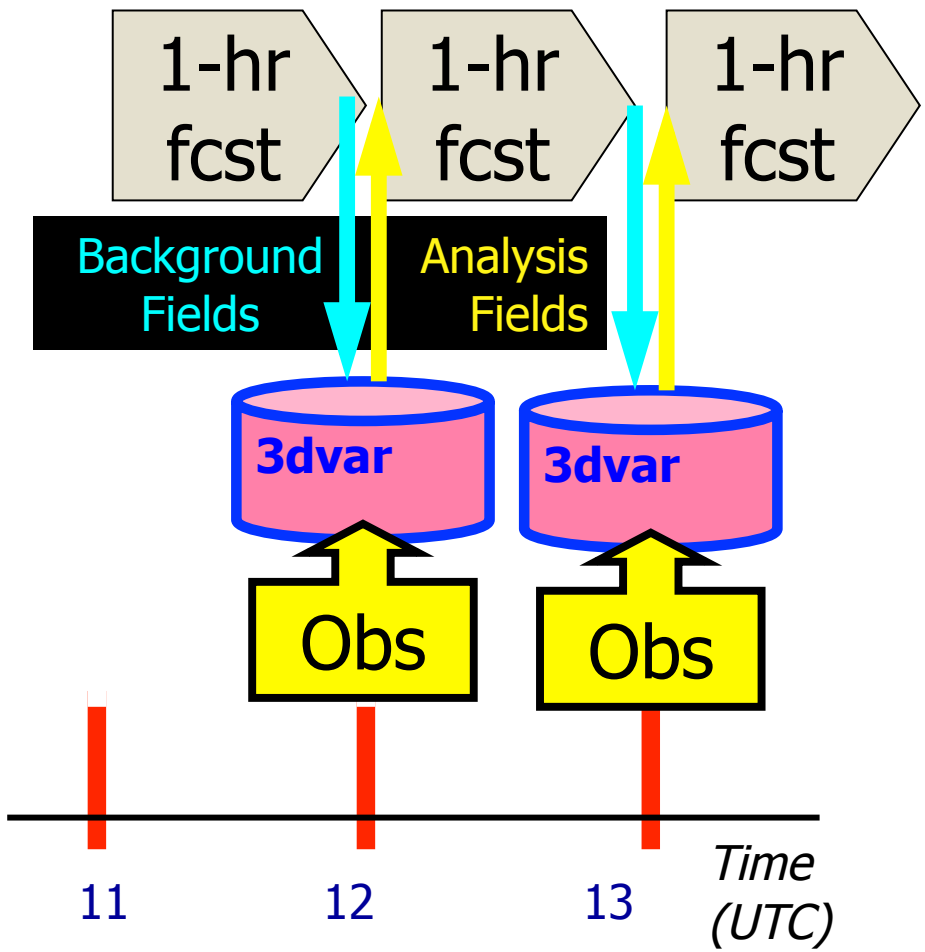
WRF default choices for sigma levels (35)

1.000, 0.993, 0.983, 0.970, 0.954, 0.934,
0.909, 0.880, 0.845, 0.807, 0.765, 0.719, 0.672,
0.622, 0.571, 0.520, 0.468, 0.420, 0.376, 0.335,
0.298, 0.263, 0.231, 0.202, 0.175, 0.150, 0.127,
0.106, 0.088, 0.070, 0.055, 0.040, 0.026, 0.013, 0.000

3 layers in lowest 200m, lowest @~50m

Rapid Refresh Hourly Assimilation Cycle

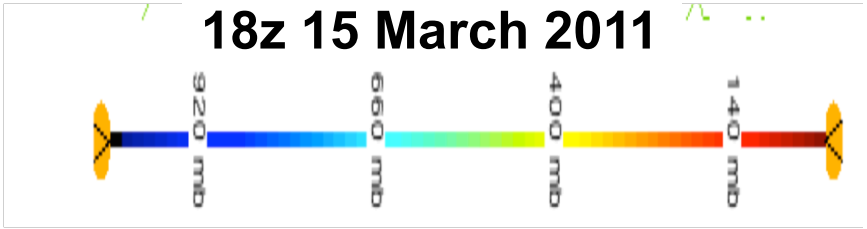
Cycle hydrometeor, soil temp/moisture/snow



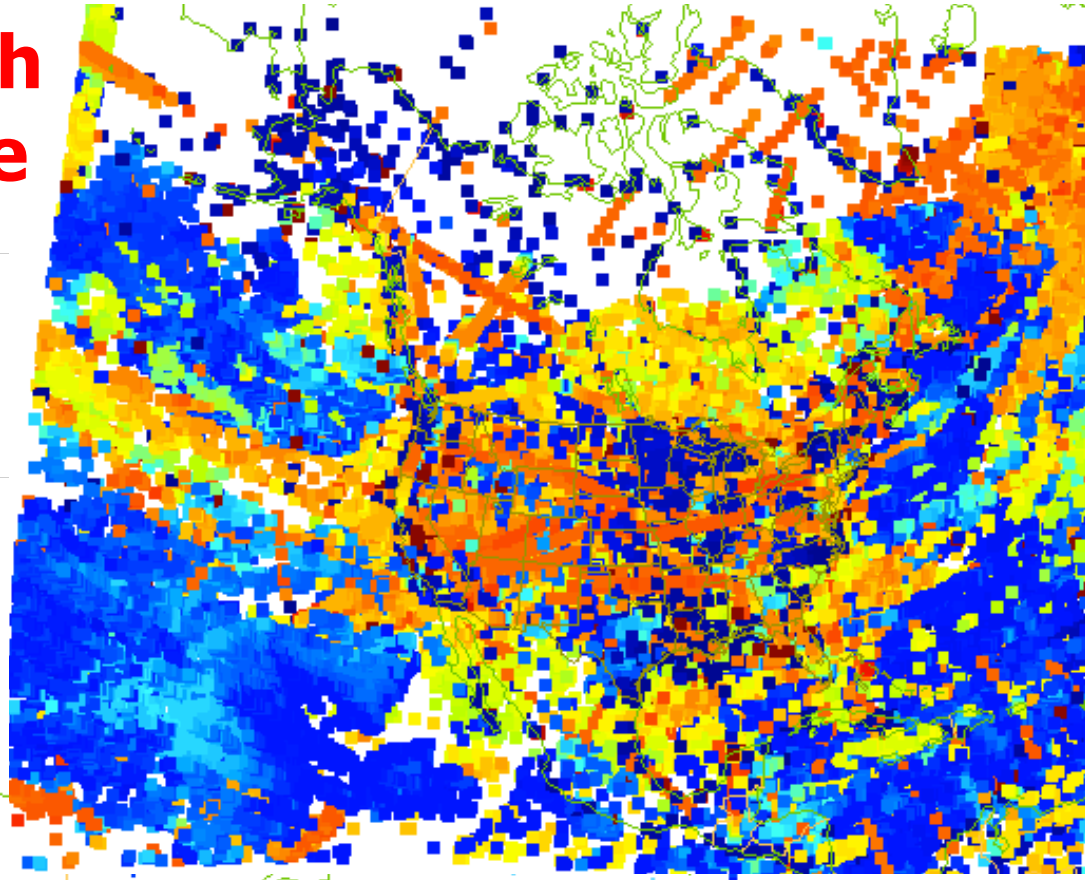
Hourly obs

Data Type	~Number/hr
Rawinsonde (12h)	~120
NOAA profilers	21
VAD winds	~125
PBL – profiler/RASS	~25
Aircraft (V,temp)	2K-15K(avg 7K)
TAMDAR/WVSS (V,T,RH)	0-160 (avg 40)
WVSS (RH)	0-800(avg 520)
Surface/METAR	~2500
Buoy/ship	200-400
GOES cloud winds	4000-8000
GOES cloud-top pres	10 km res
GPS precip water	~260
Mesonet (temp, dpt)	~8000 (RRv2)
Mesonet (wind)	~4000 (RRv2)
METAR-cloud-vis-wx	~2000
AMSU-A/B/GOES radiances – *RR only*	
Radar reflectivity/ lightning	1km
Radar radial wind	- tested, RRv2 imp
Nacelle/tower/sodar	(future)

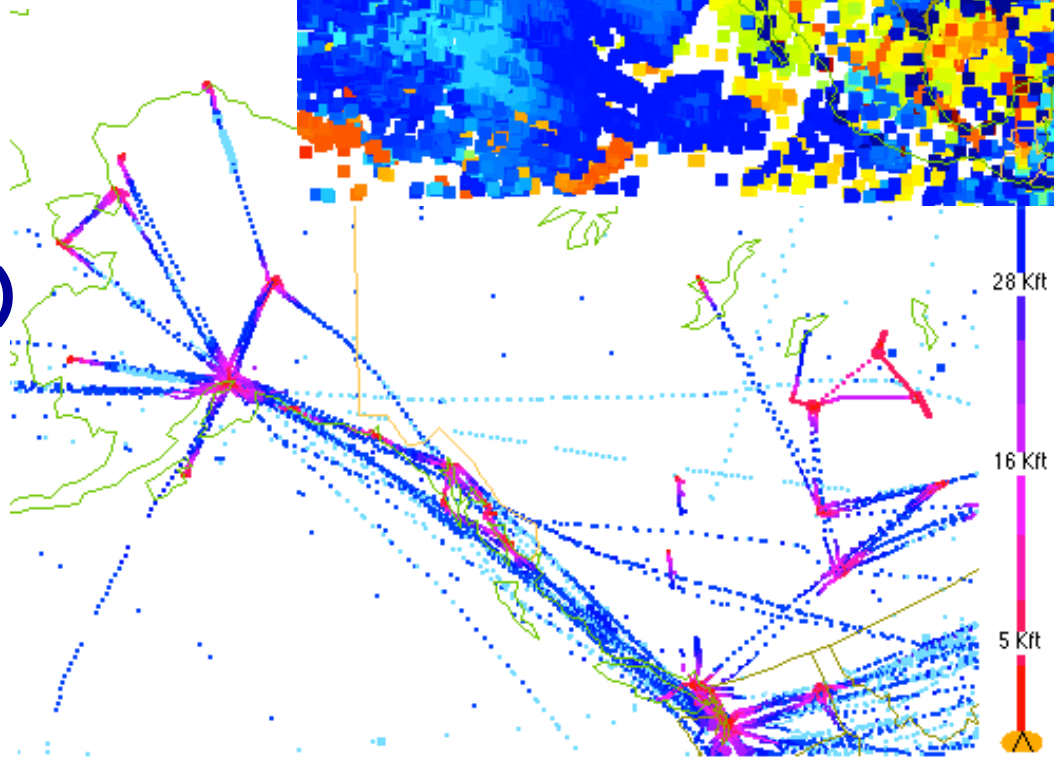
Sample Rapid Refresh observation coverage



920 660 400 140 mb

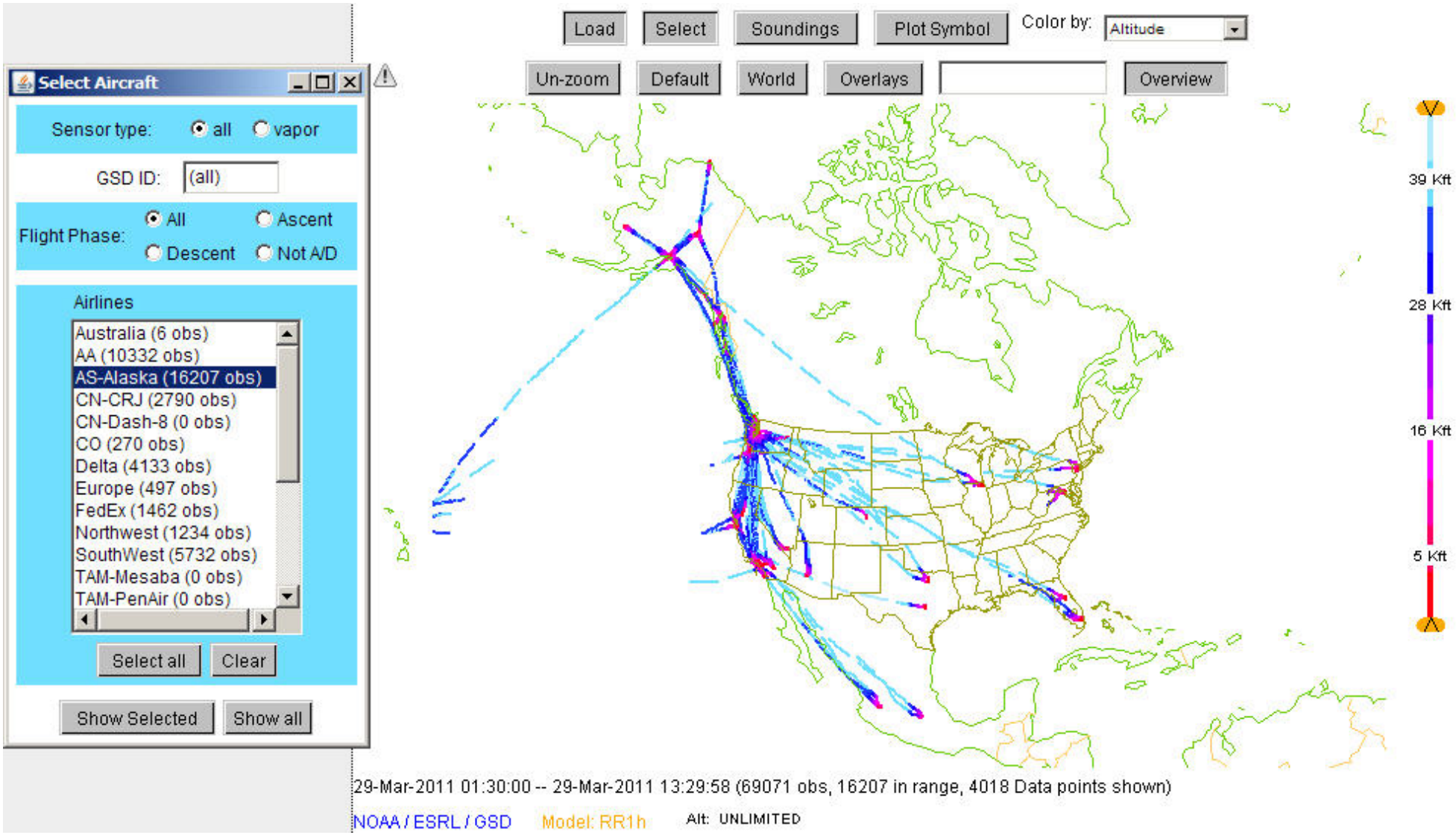


Additional aircraft obs (Alaska Airlines) beginning March 2011

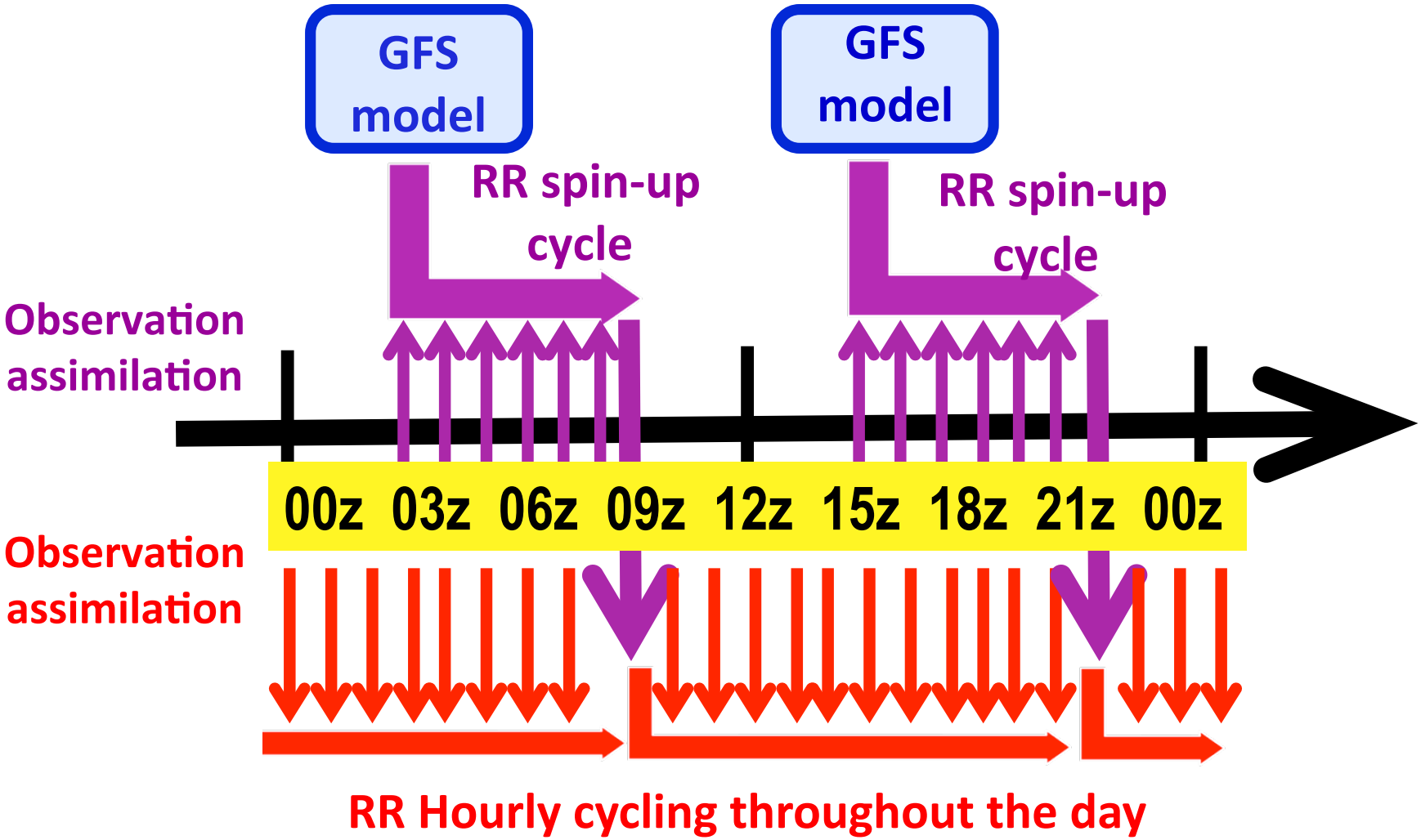


Sample from 18z 30 March 2011 – 05z 31 March 2011

Alaska Airlines obs



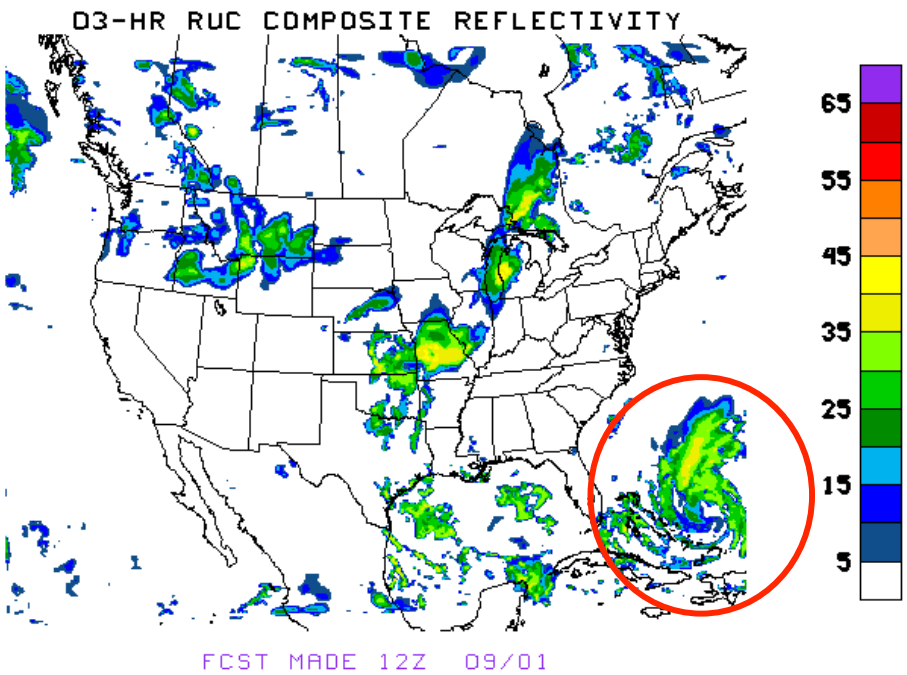
Rapid Refresh Partial Cycling



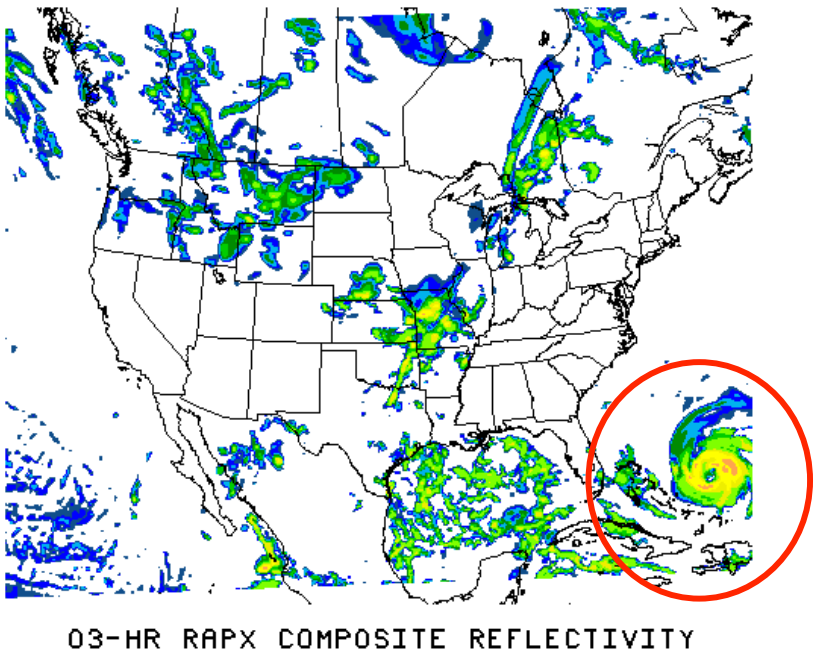
- Hourly cycling of land surface model fields
- 6 hour spin-up cycle for hydrometeors, surface fields
- Introduced in 2009

RUC / RR comparison from Geoff Manikin's parallel RR run

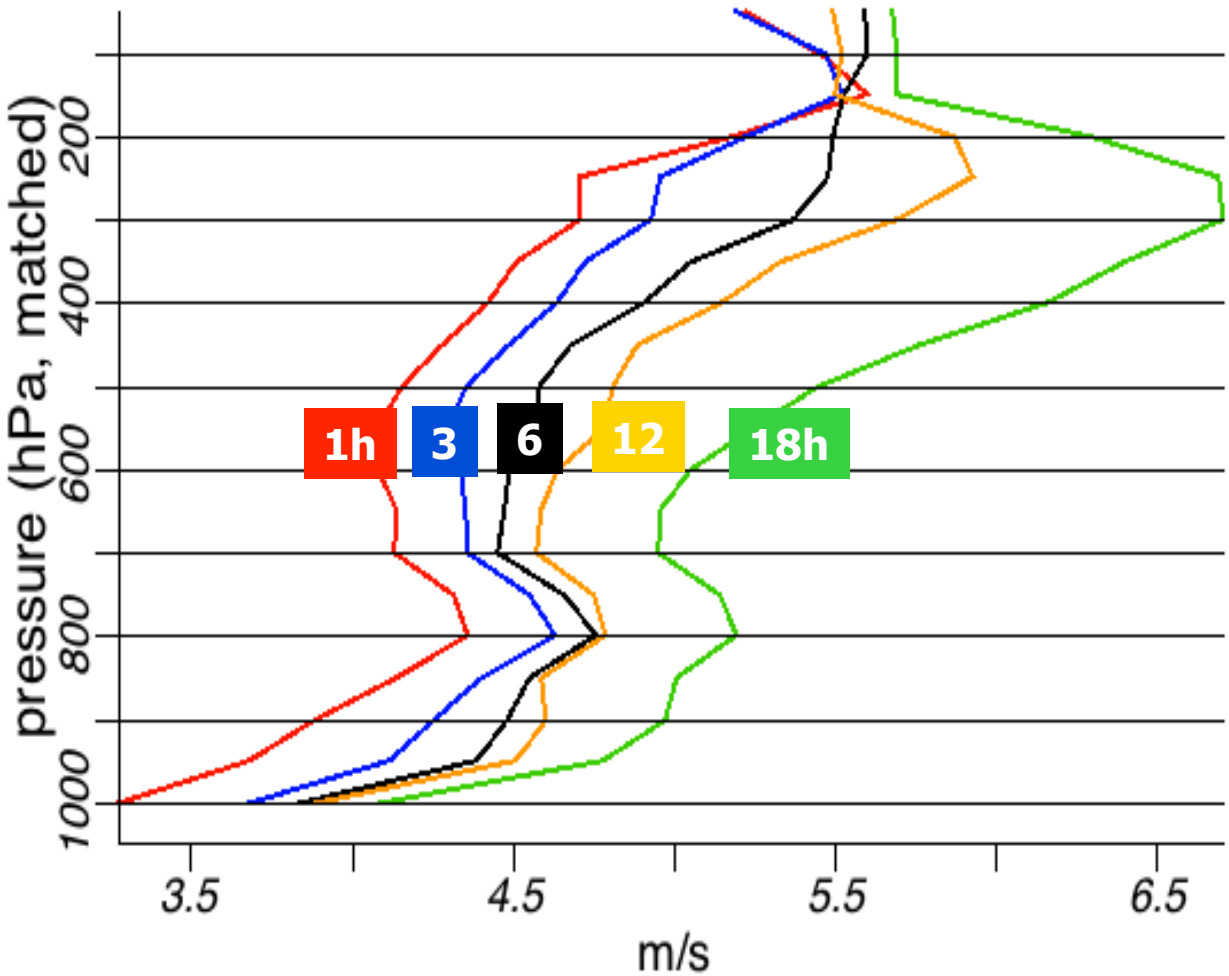
RUC



RR



www.emc.ncep.noaa.gov/mmb/gmanikin/rap/para/

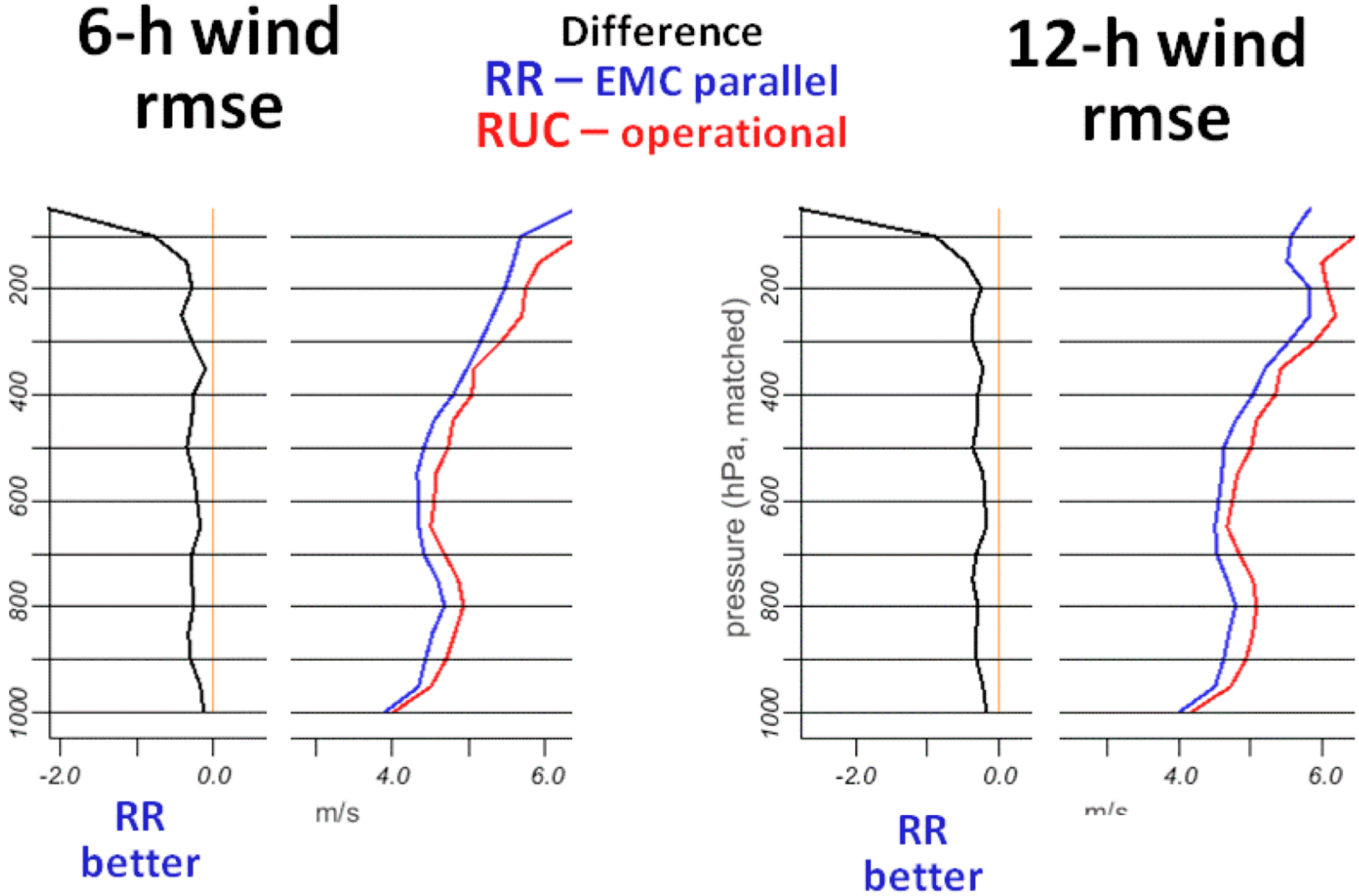


Rapid Refresh
Wind forecast accuracy vs. forecast length

March 2011

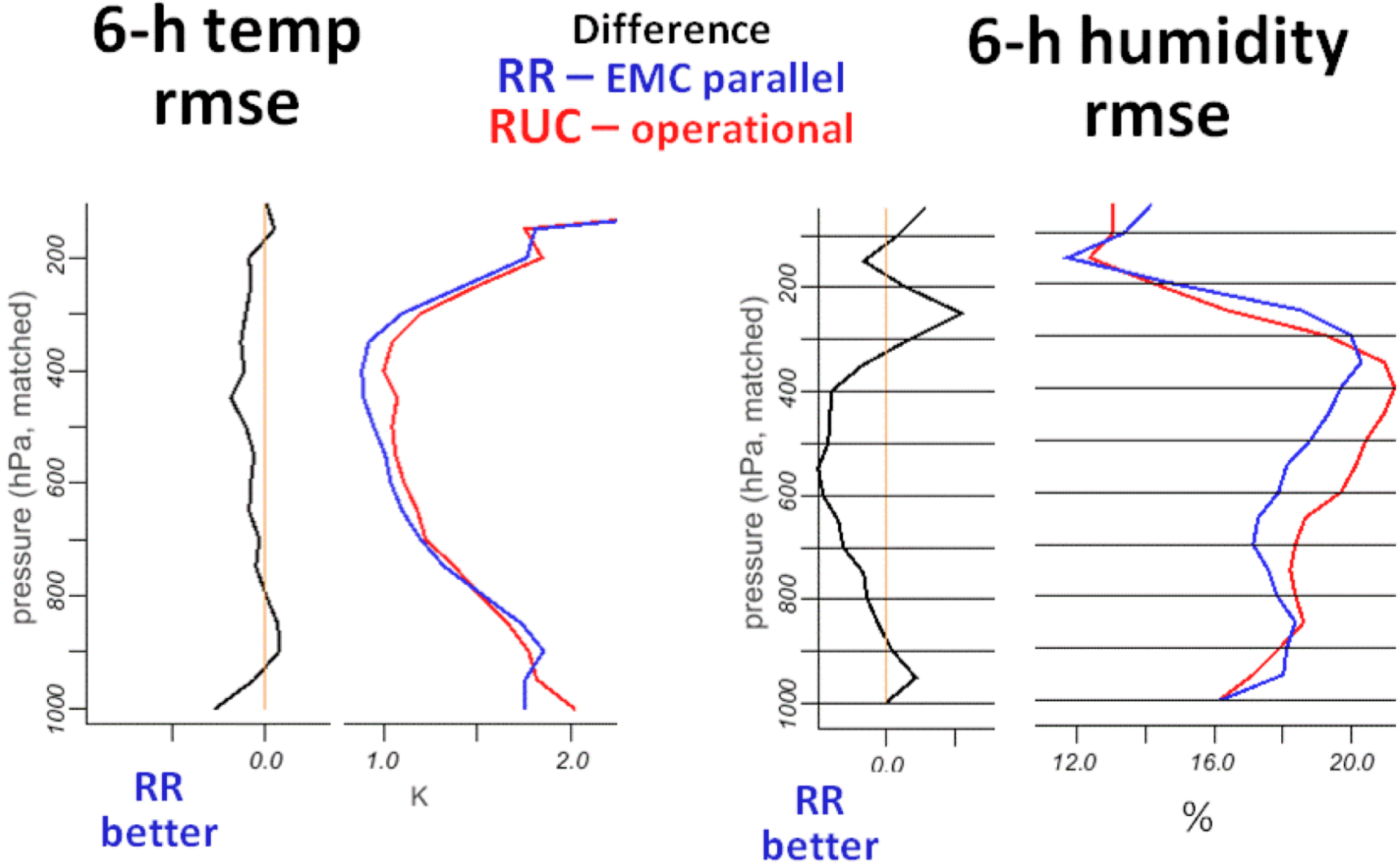
The Rapid Refresh is able to use recent obs to improve forecast skill down to 1-h projection

Rapid Refresh (EMC-para) vs. RUC (NCEP-oper) upper-air verification

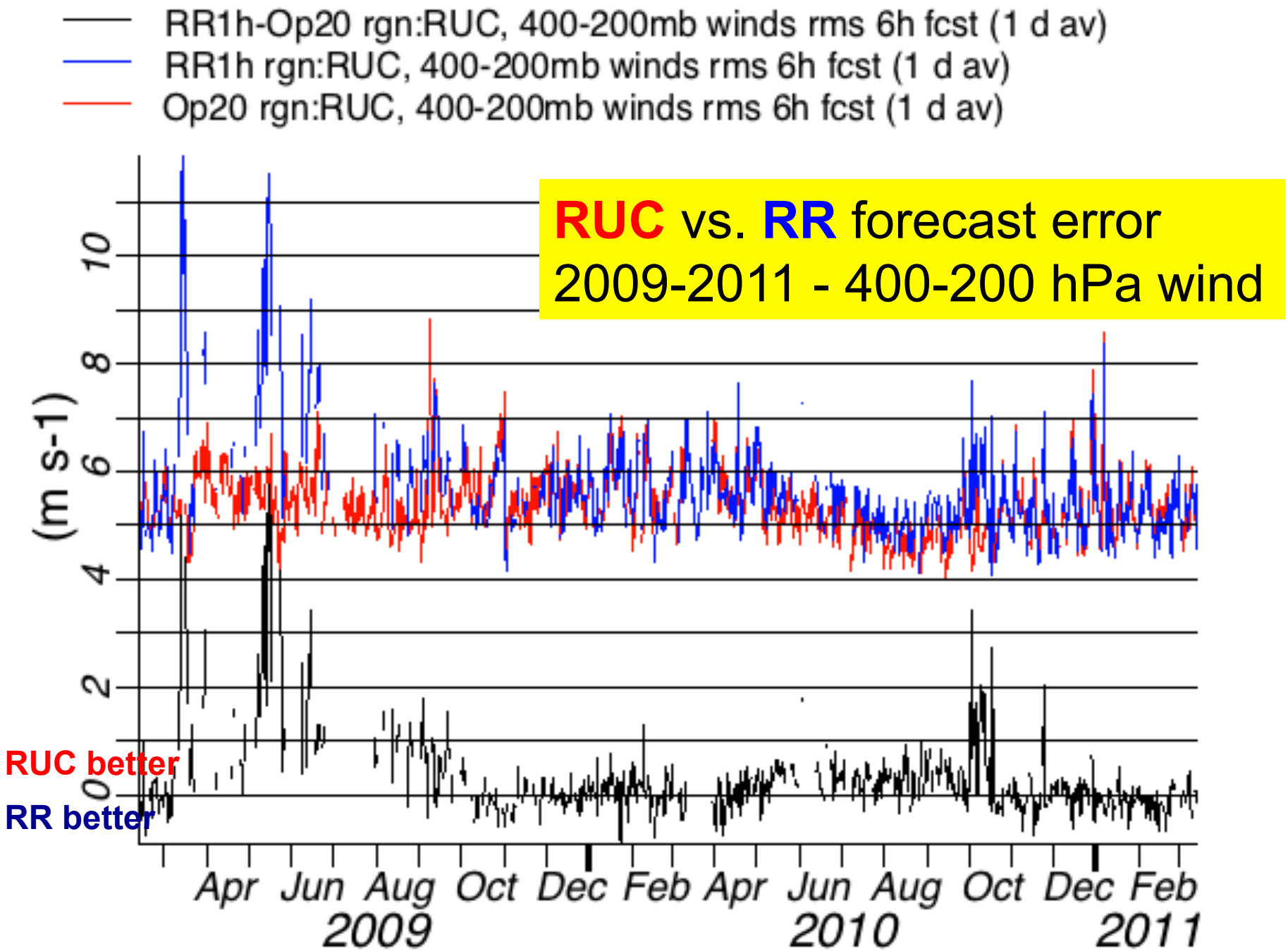


1 Feb – 11 March 2011

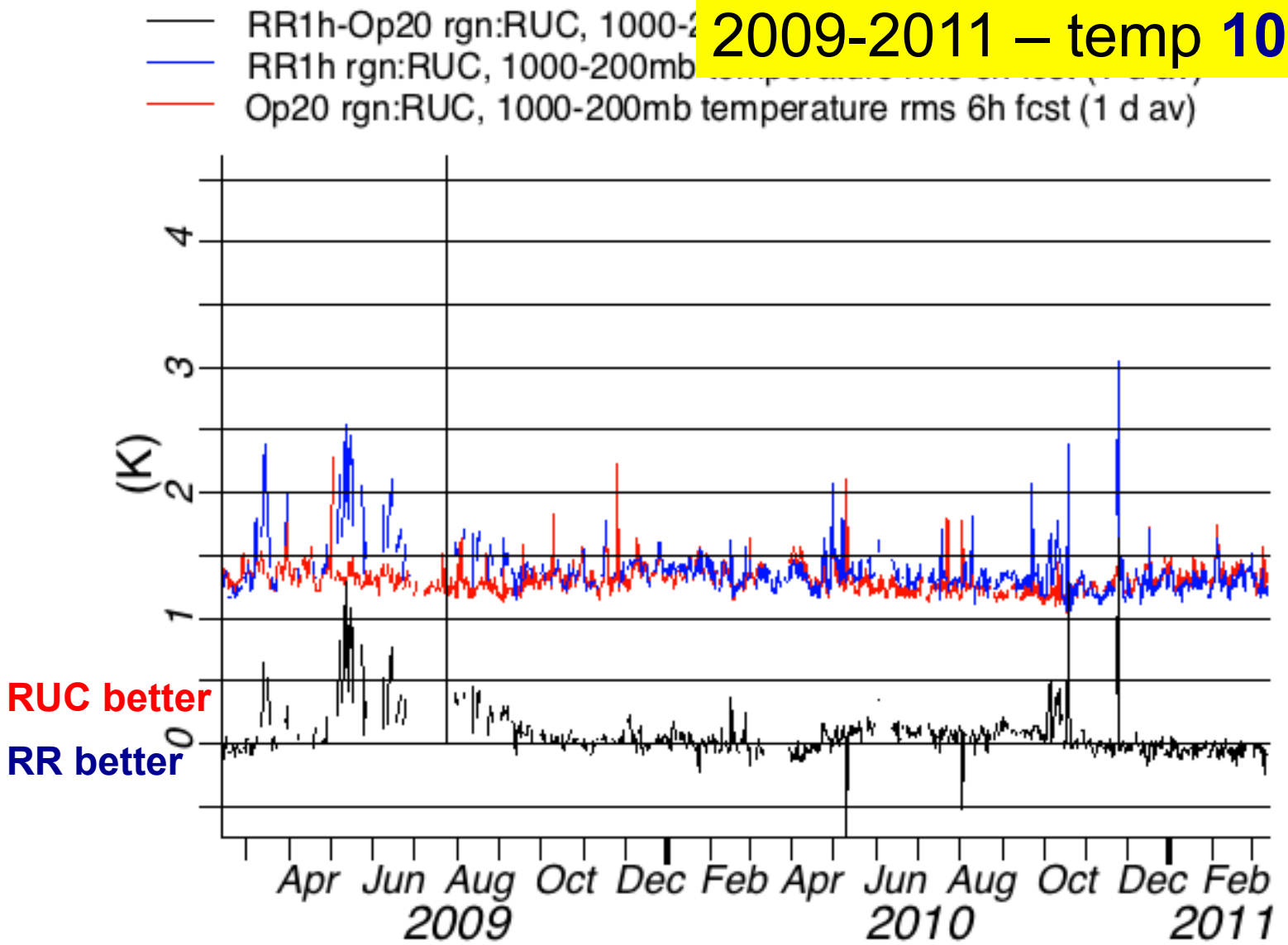
Rapid Refresh (EMC-para) vs. RUC (NCEP-oper) upper-air verification



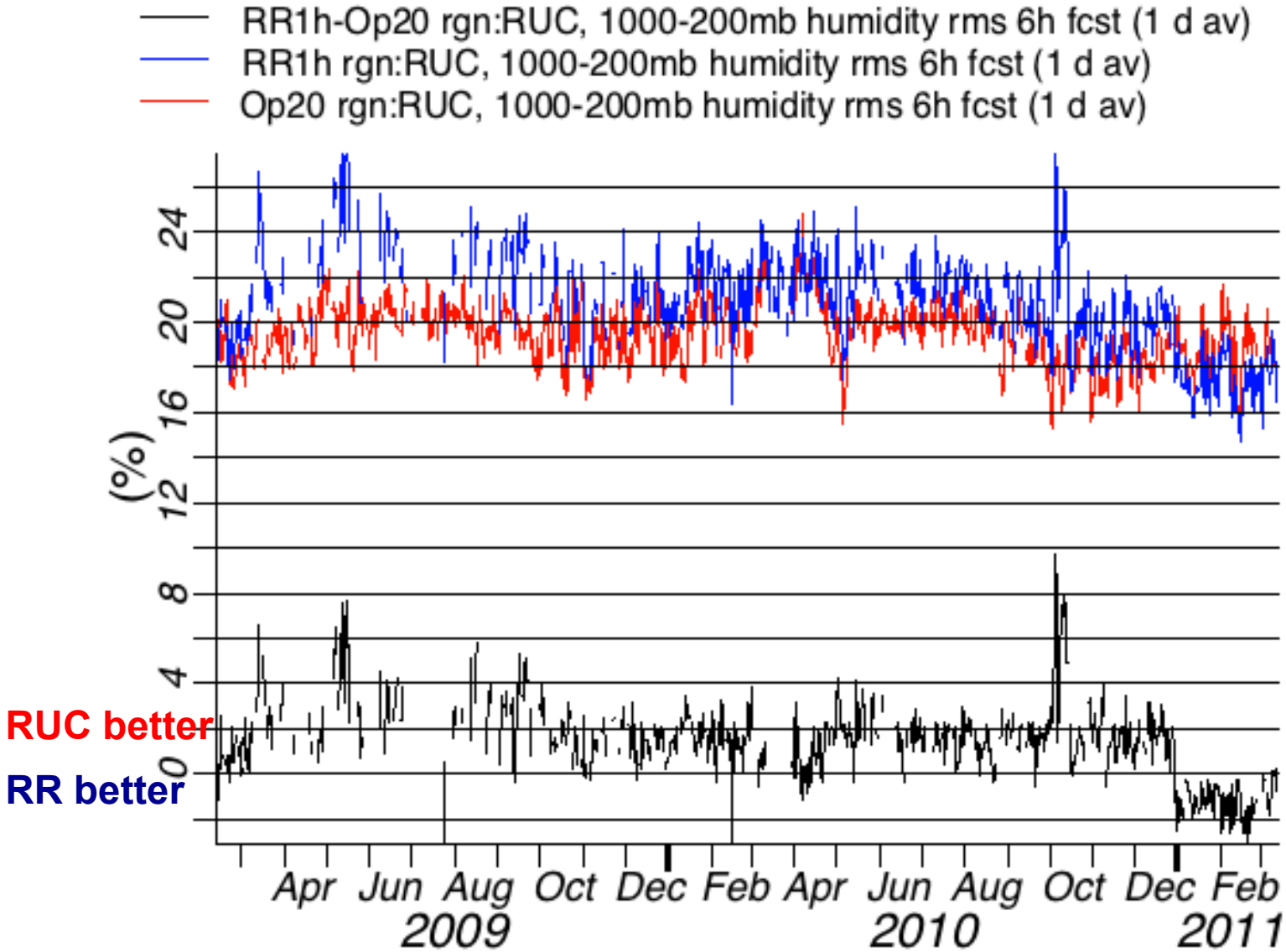
1 Feb – 11 March 2011


RR1h-Op20 rgn:RUC, 400-200mb winds rms 6h fcst (1 d av)
RR1h rgn:RUC, 400-200mb winds rms 6h fcst (1 d av)
Op20 rgn:RUC, 400-200mb winds rms 6h fcst (1 d av)
RUC vs. RR forecast error
2009-2011 - 400-200 hPa wind
(m s-1)
0
2
4
6
8
10
RUC better
RR better
Apr
Jun
Aug
Oct
Dec
Feb
Apr
Jun
Aug
Oct
Dec
Feb
2009
2010
2011

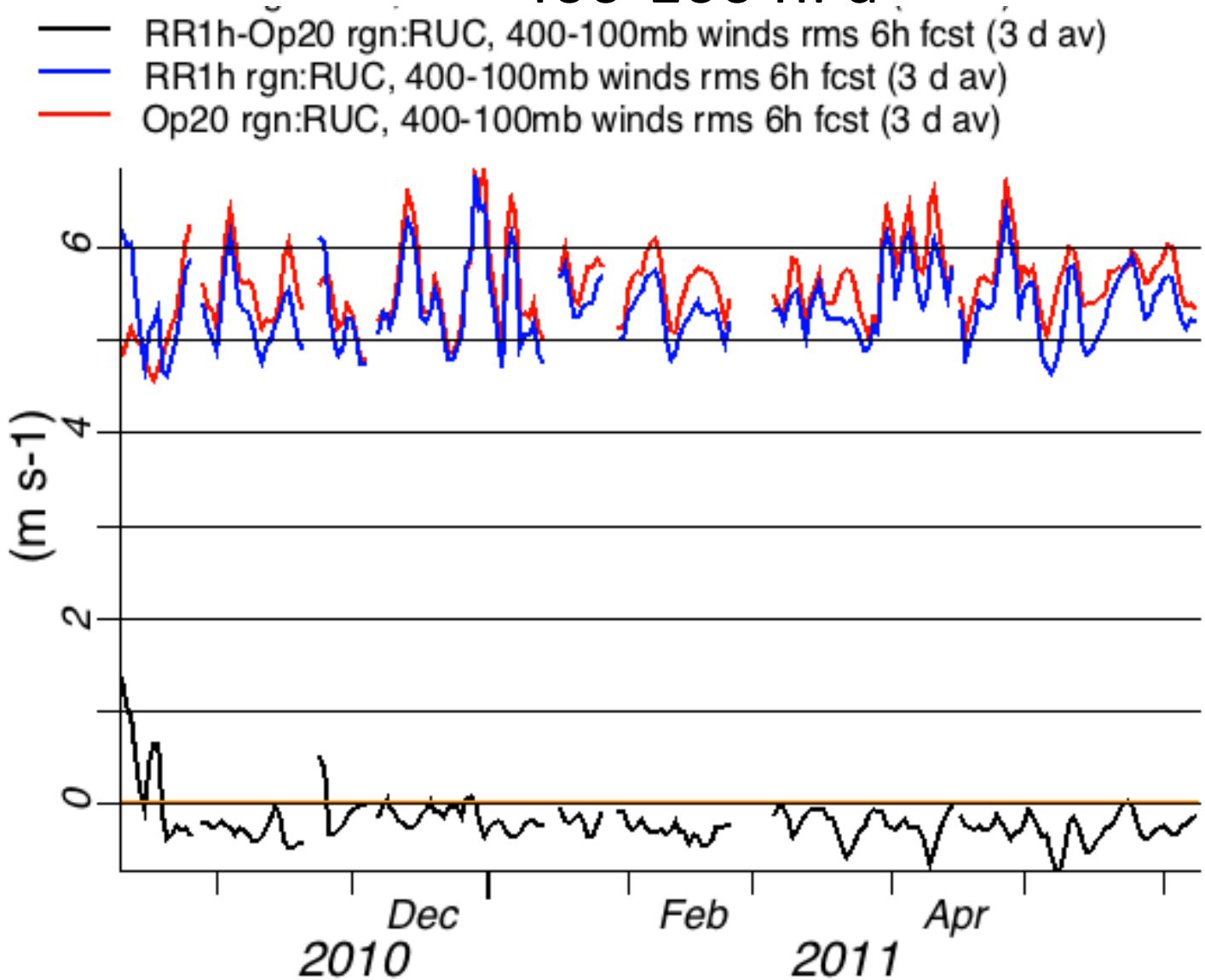
RUC vs. RR forecast error 2009-2011 – temp 1000-200



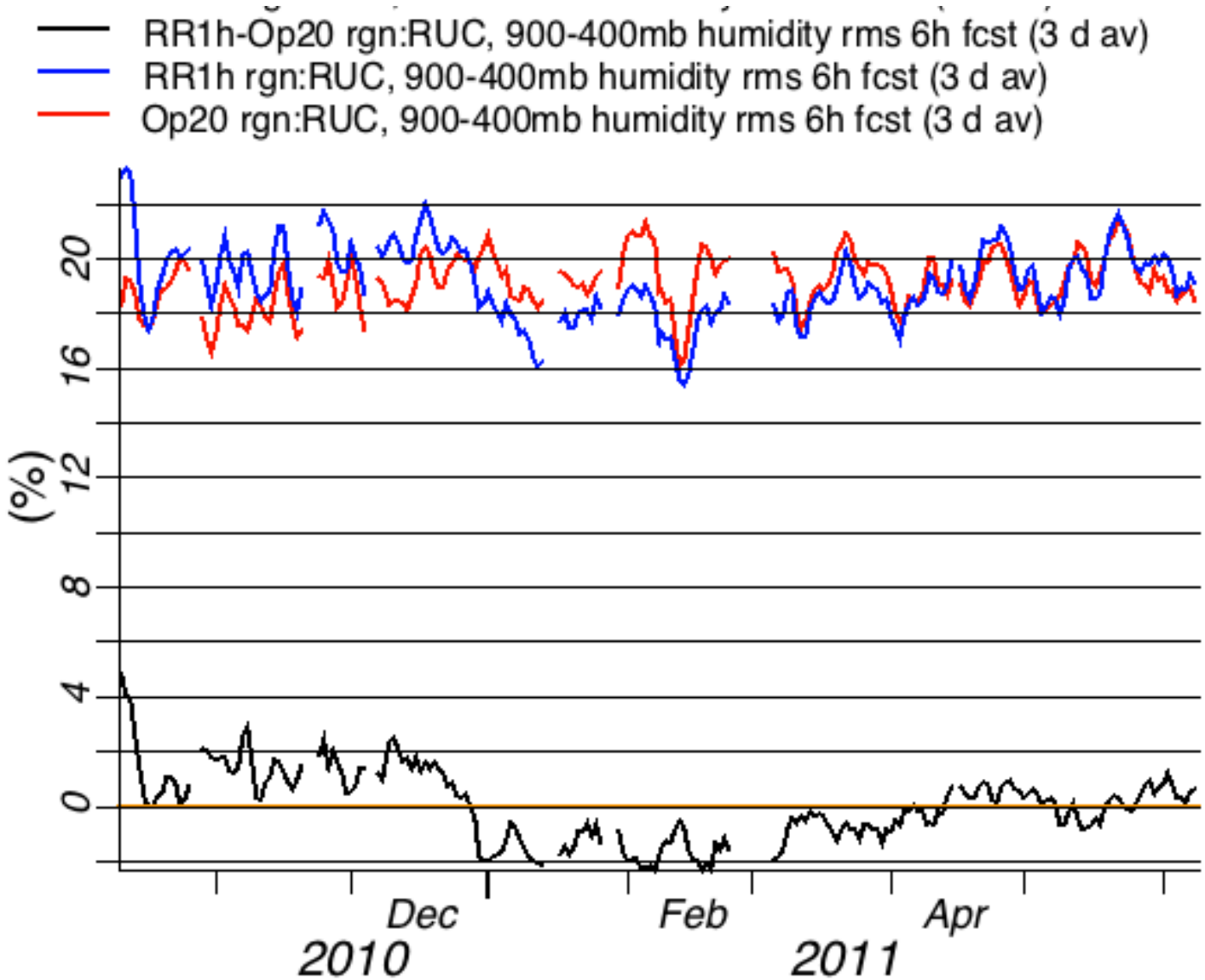
RUC vs. RR forecast error 2009-2011 - 1000-200 hPa RH



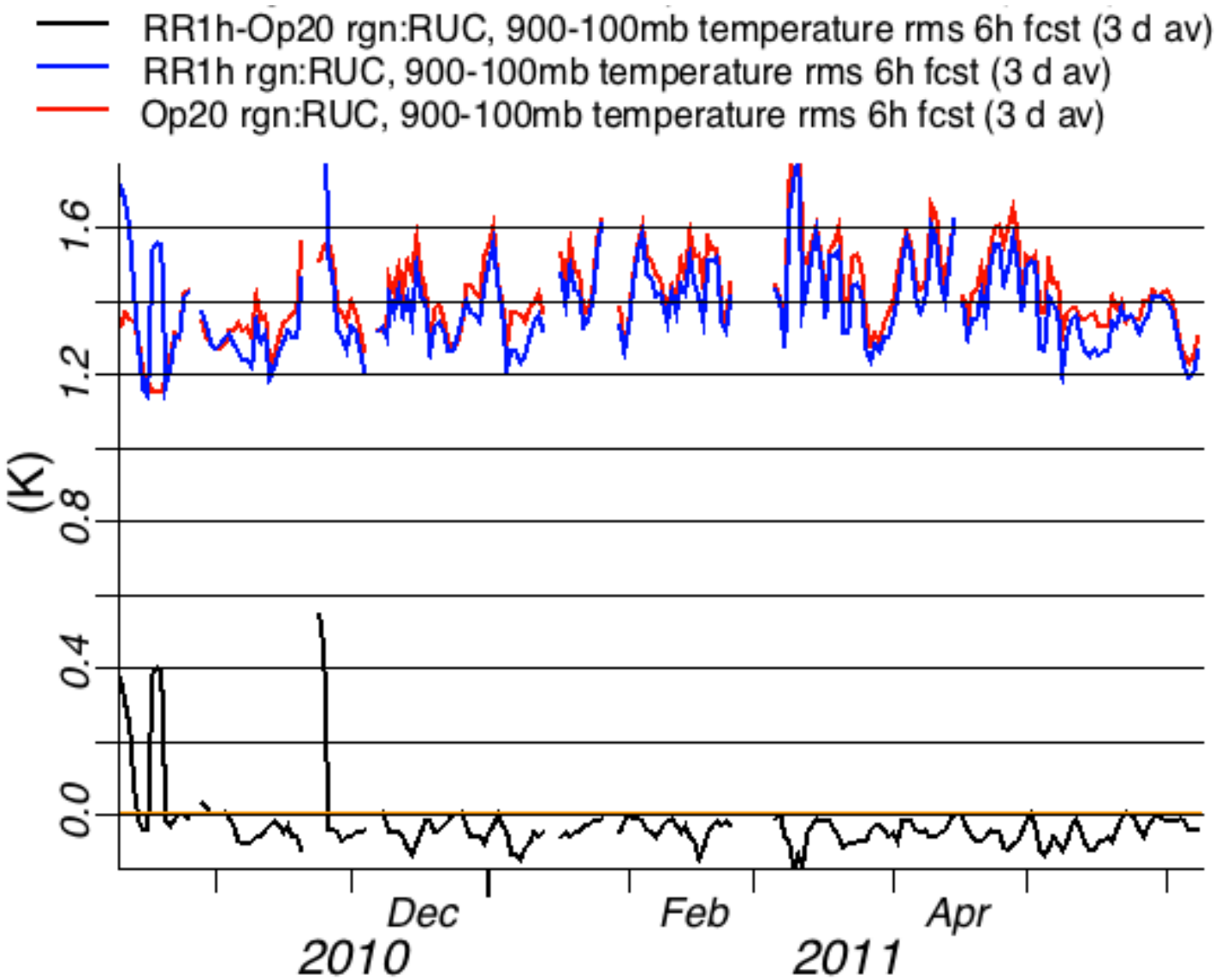
Update on RR vs. RUC – upper-level wind 400-100 hPa



Update on RR vs. RUC – 900-400 hPa RH

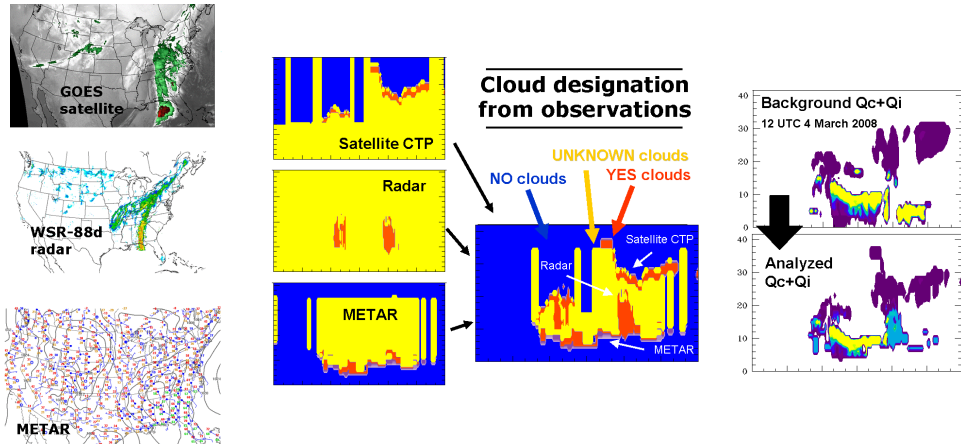


Update on RR vs. RUC – 900-100 hPa temp



Rapid Refresh – specific analysis features

Cloud and hydrometeor analysis



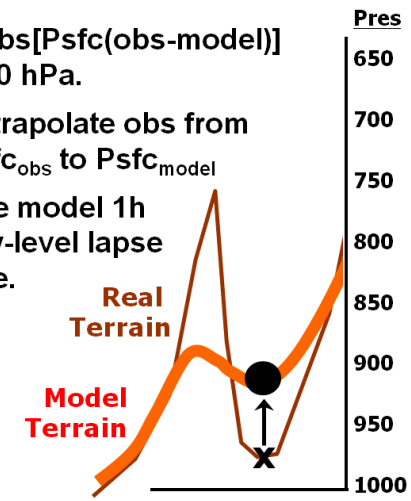
Special treatments for surface observations

Elevation correction

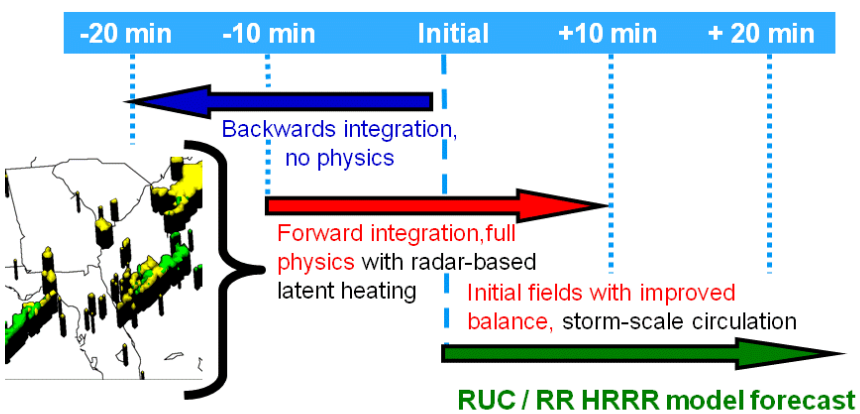
If abs[Psfc(obs-model)] < 70 hPa.

Extrapolate obs from $Psfc_{obs}$ to $Psfc_{model}$

Use model 1h low-level lapse rate.

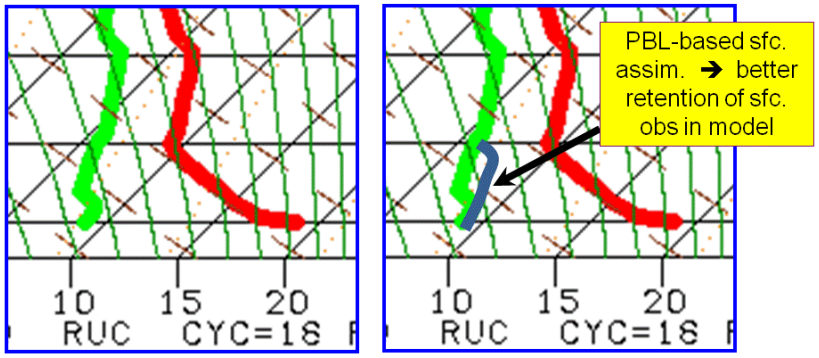


Digital filter-based reflectivity assimilation



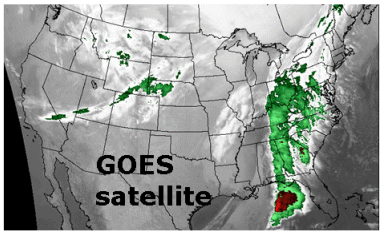
+ RUC/RR Convection suppression

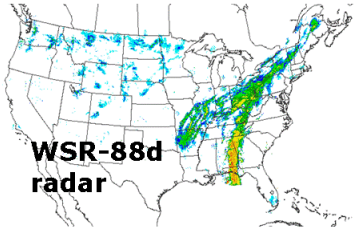
PBL-based pseudo-observations

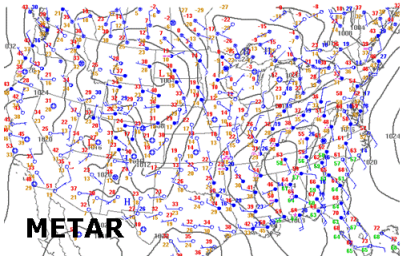


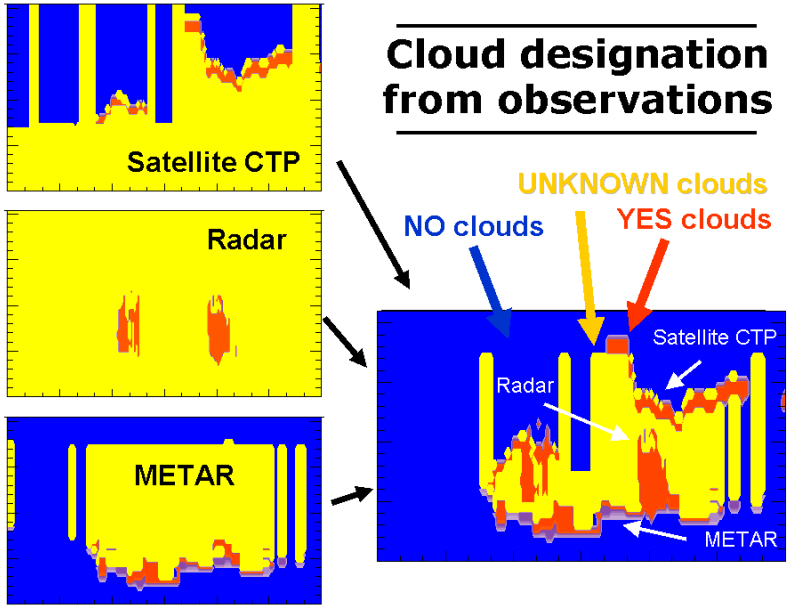
Rapid Refresh – specific analysis features

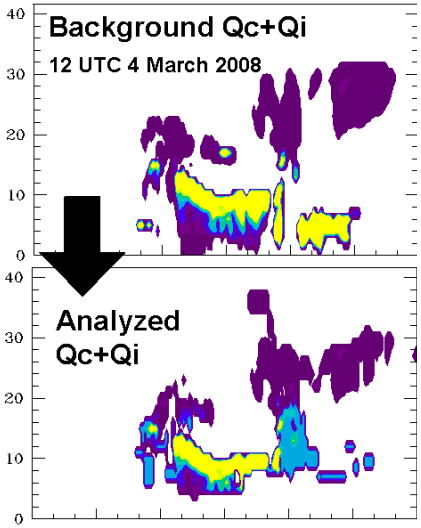
Cloud and hydrometeor analysis











UPDATE: No cloud building from NESDIS/ Langley cloud products in initial RR (RUC experiments, bring in with RR2)

RUC/RR cloud / radar assimilation flowchart

1-h fcst
qv, qc, qi,
qr, qs, qg

Sat cloud-top observations

METAR cloud observations

3D Radar reflectivity

Lightning

Analysis

RUC-3dvar
GSI-3dvar

Model

RUC
WRF

RUC/RR cloud / radar assimilation flowchart

1-h fcst
qv, qc, qi,
qr, qs, qg

Sat cloud-top observations

METAR cloud observations

3D Radar reflectivity

Lightning

Analysis

RUC-3dvar
GSI-3dvar

Merge observations → 3D arrays of precipitation and cloud information (observed Yes / No / Unknown)

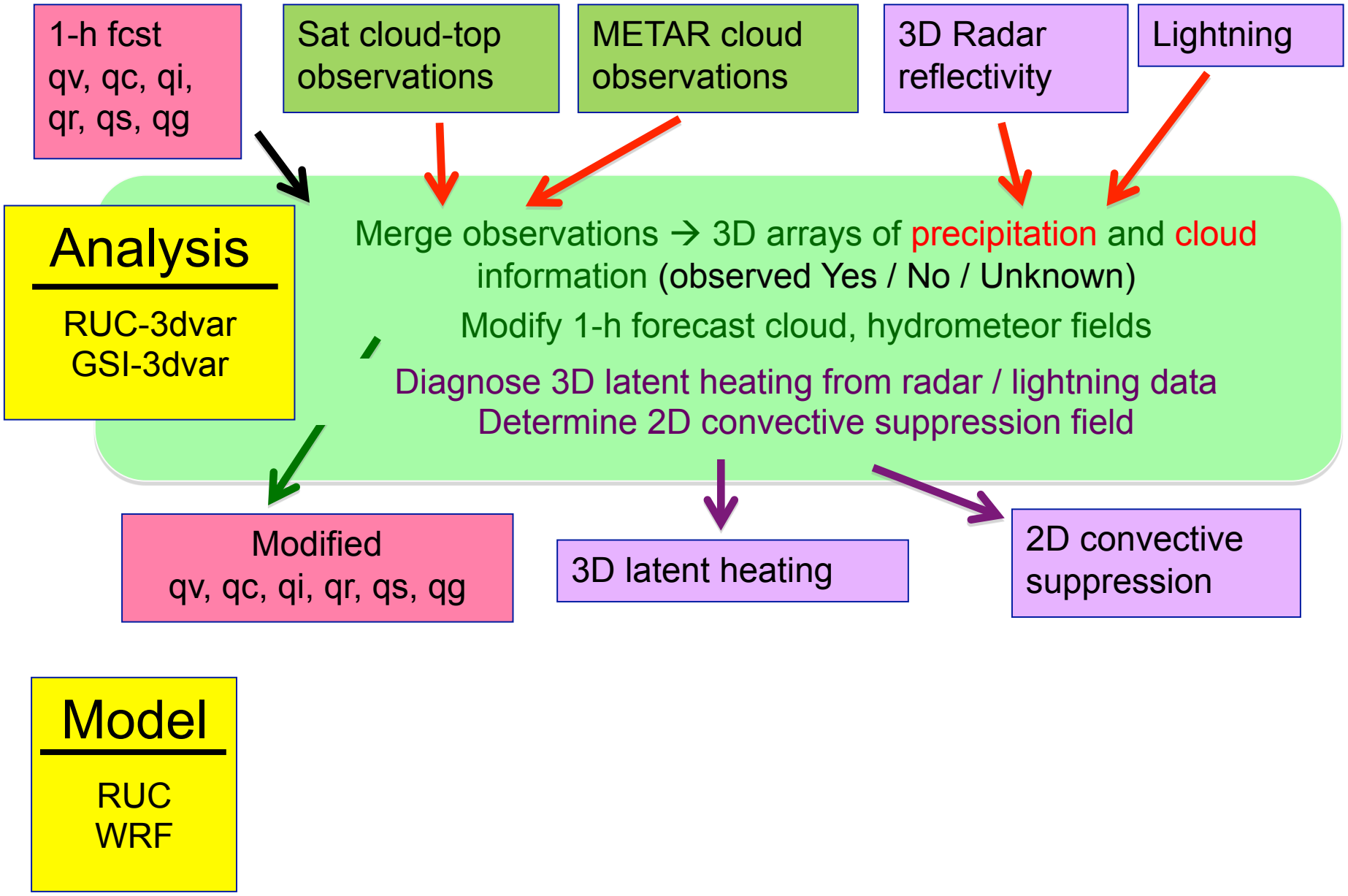
Modify 1-h forecast cloud, hydrometeor fields

Diagnose 3D latent heating from radar / lightning data
Determine 2D convective suppression field

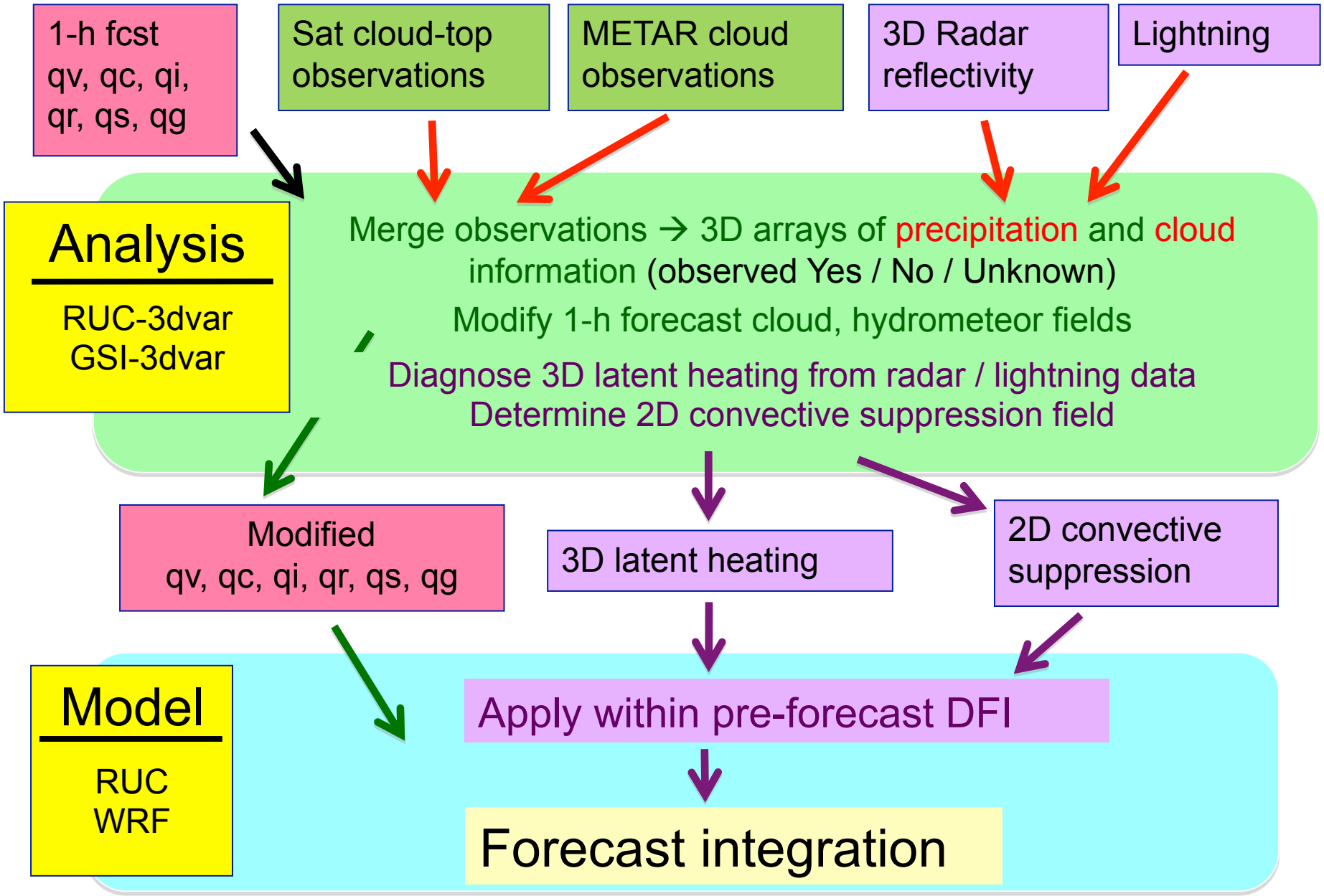
Model

RUC
WRF

RUC/RR cloud / radar assimilation flowchart



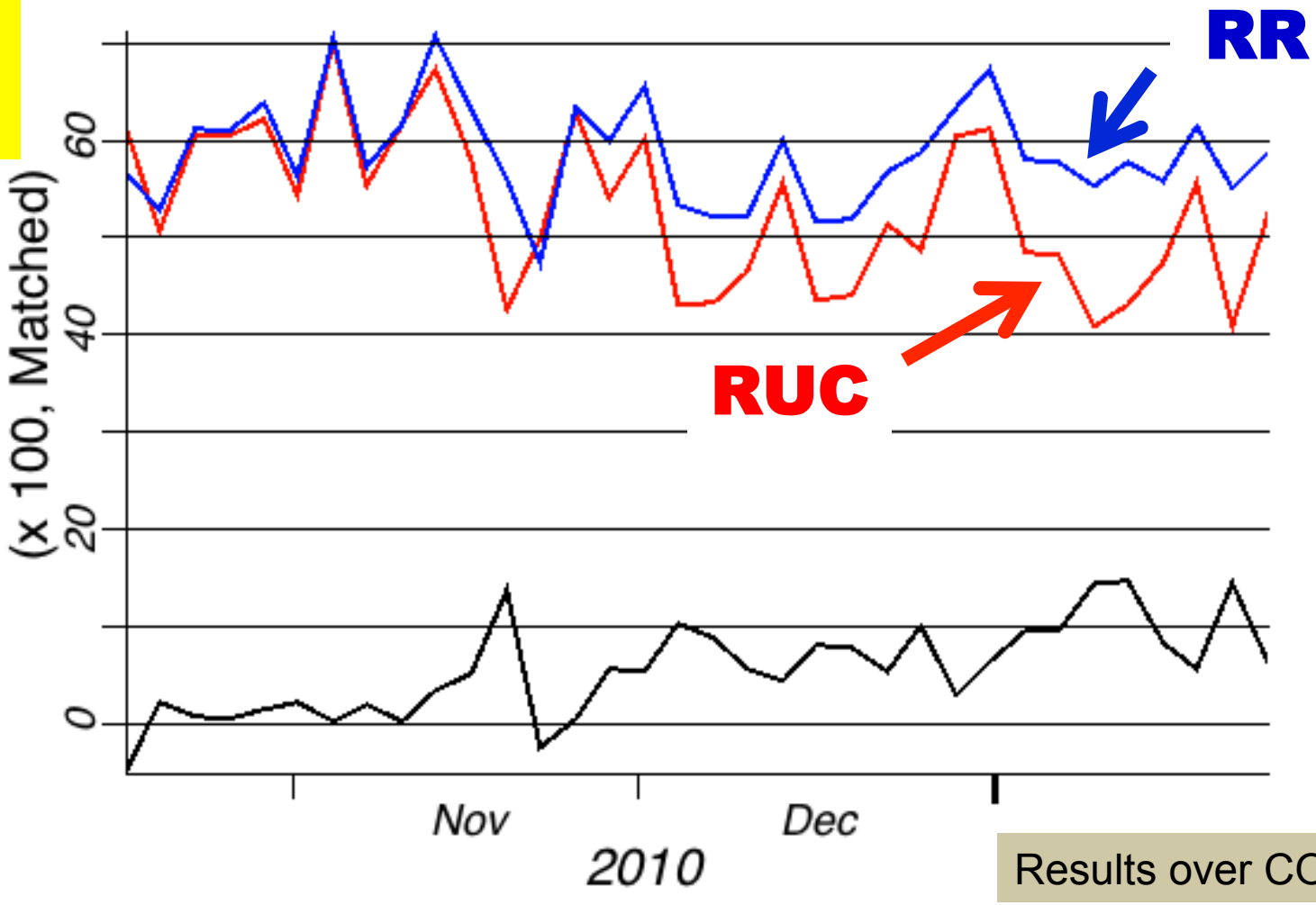
RUC/RR cloud / radar assimilation flowchart



Cloud and hydrometeor analysis

Rapid Refresh vs. RUC 3000' ceiling (MVFR) Verification (+3h forecasts)

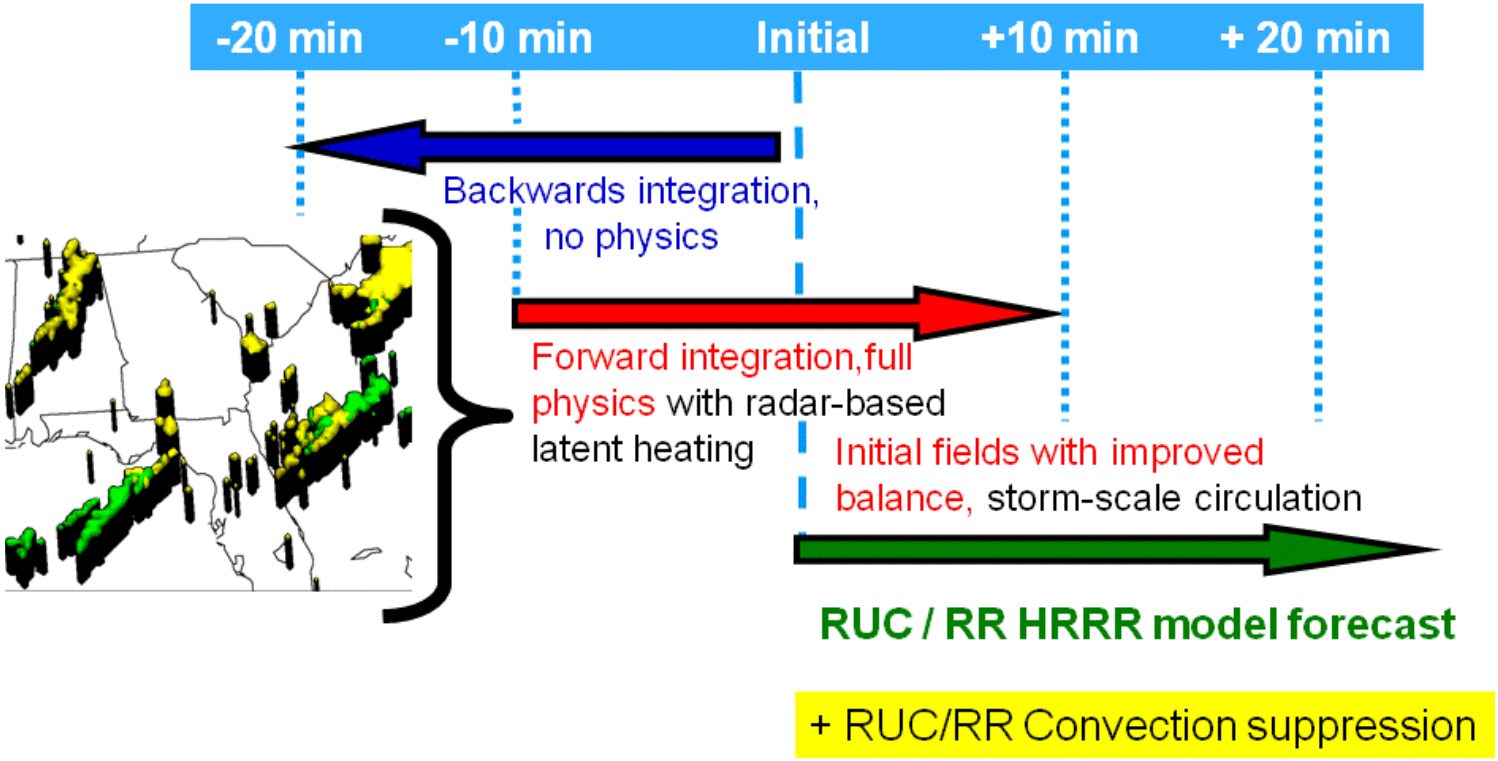
True Skill Score -- Higher is better



Results over CONUS

Rapid Refresh – specific analysis features

DFI-radar reflectivity assimilation



UPDATES: (1) Fix to DFI to allow preservation of original hydrometeors and relative humidity.

(2) Further study on specification of latent heating based temperature tendency (function of stability, storm history)

Radar reflectivity assimilation in RR and RUC

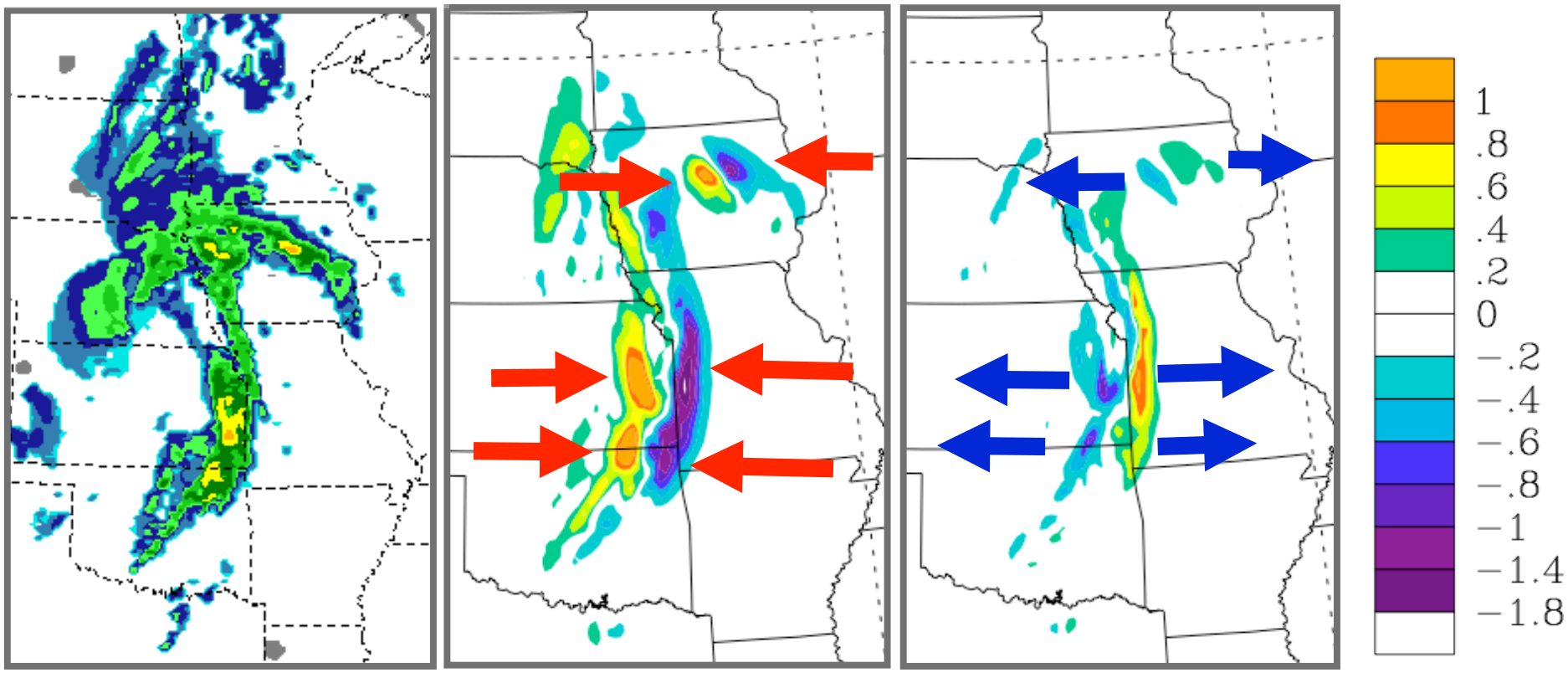
"DFI-radar" technique – reason for HRRR success

reflectivity assimilation example below – from RR

NSSL radar reflectivity (dBZ)

Low-level Convergence

Upper-level Divergence



14z 22 Oct 2008
Z = 3 km

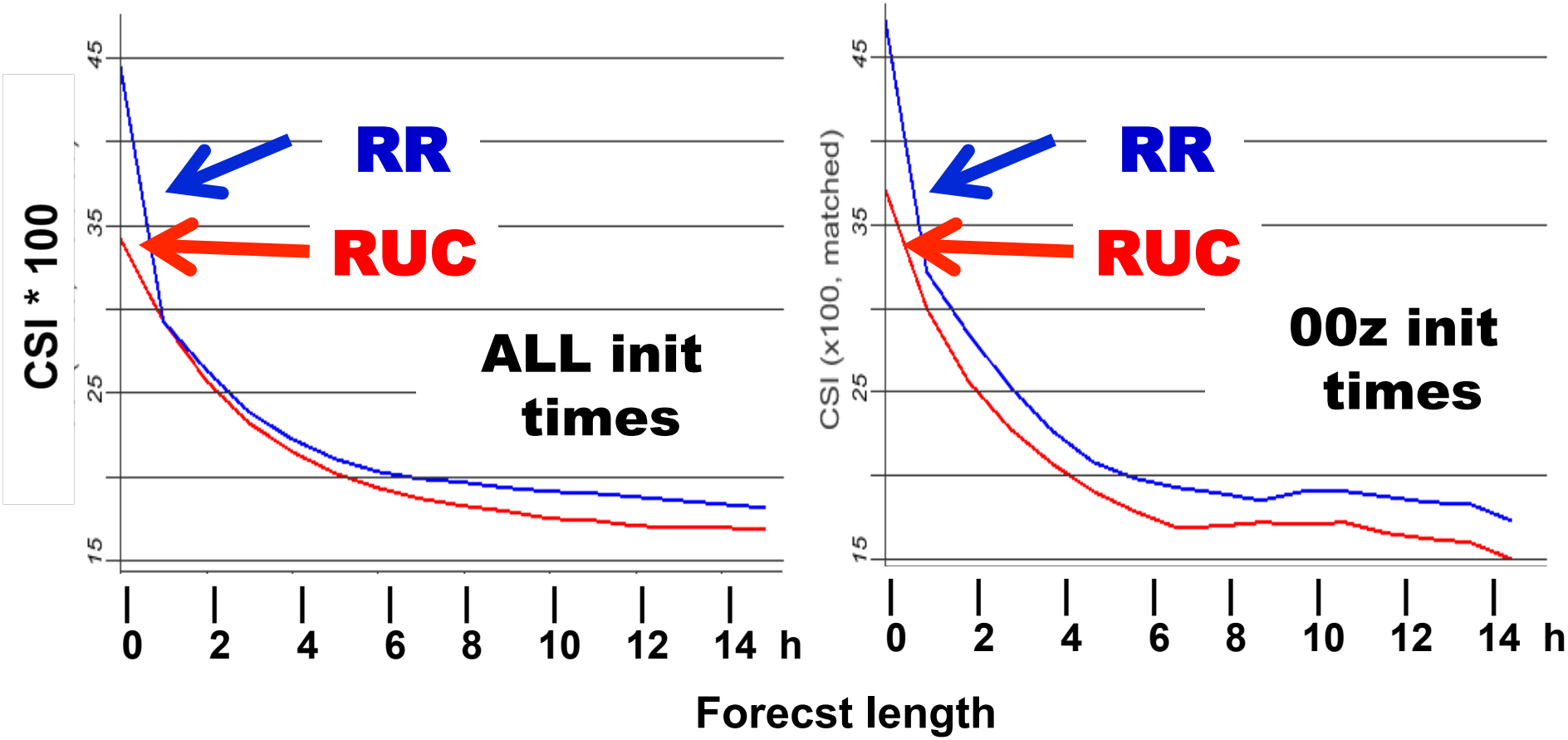
K=4 U-comp. diff
(radar - norad)

K=17 U-comp. diff
(radar - norad)

DFI-radar reflectivity assimilation

Rapid Refresh vs. RUC reflectivity skill vs. forecast length (CSI for 20 dBZ on 40-km grid)

DFI-radar → No "spin-up" in RUC or RR
RR better overall and at max convection time



RR vs. RUC Precipitation Verification

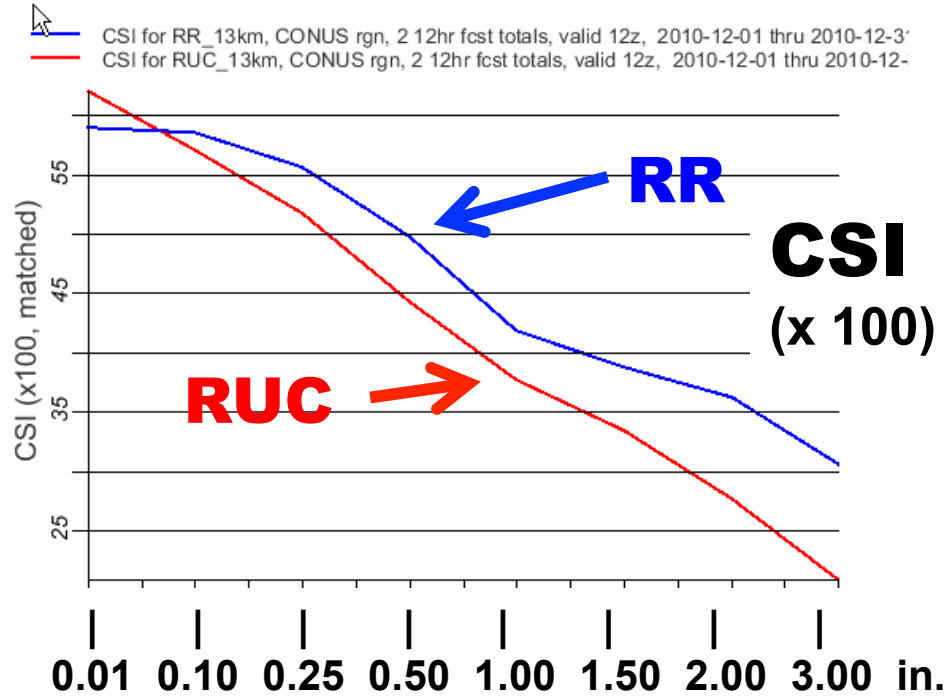
13-km CONUS

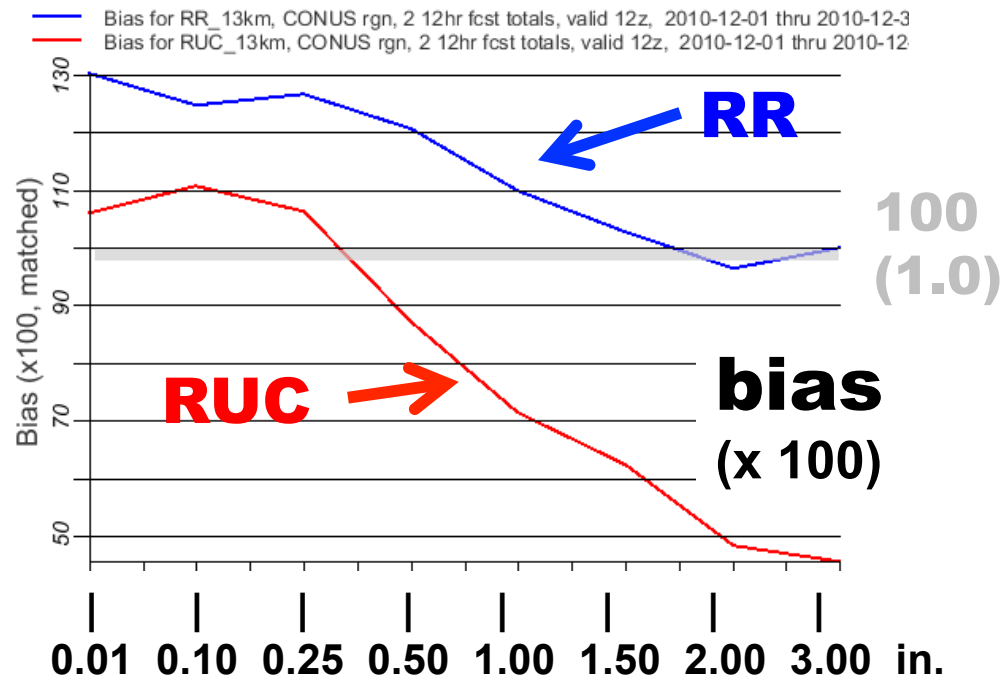
Comparison

2 X 12 hr fcst
vs. CPC 24-h analysis

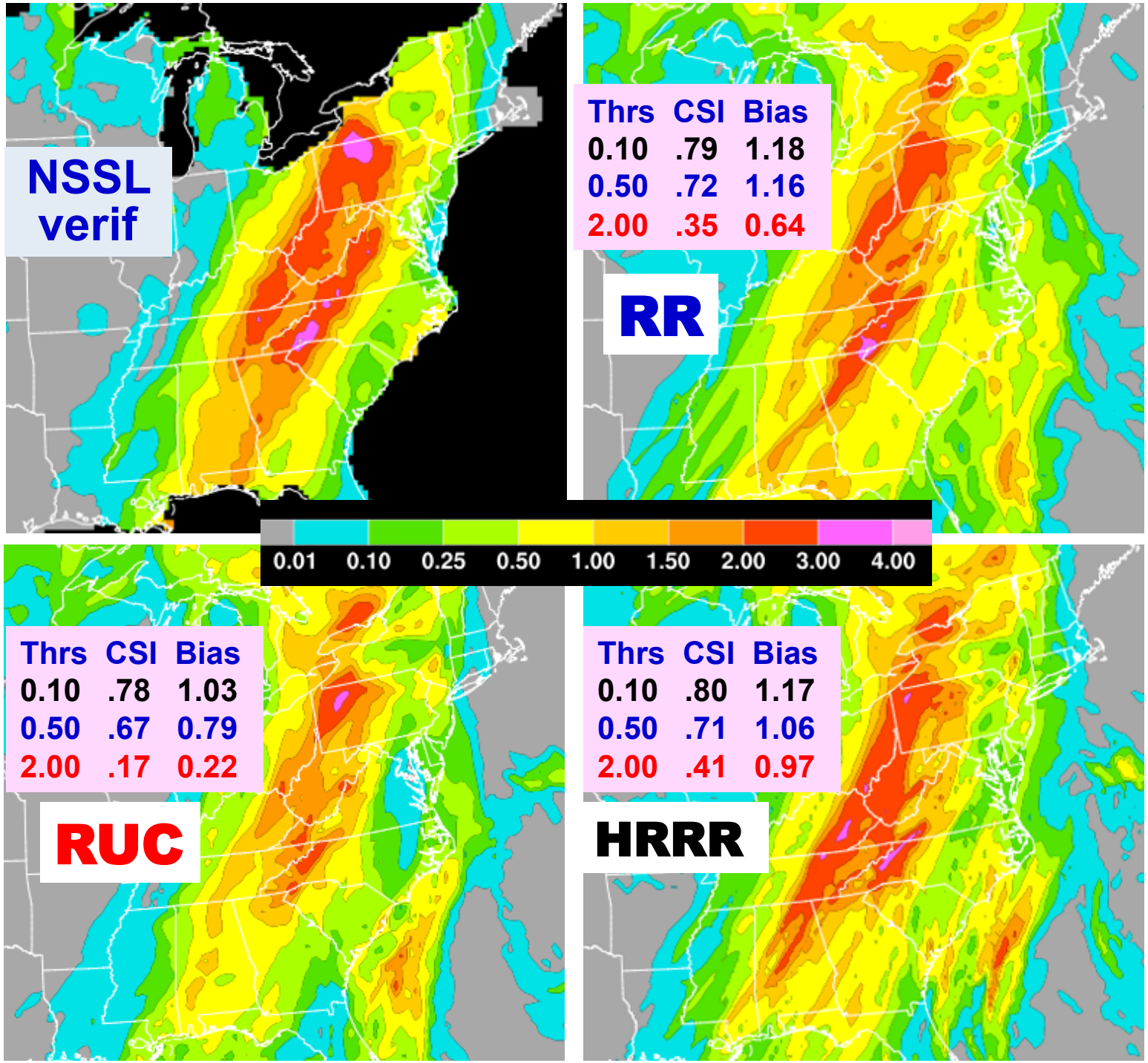
1 – 31 Dec 2010
Matched

WINTER





RUC, RR, HRRR 24-h fcst Precip



2 x 12-h forecasts Ending 12z 1 Dec 2010

RR vs. RUC Precipitation Verification

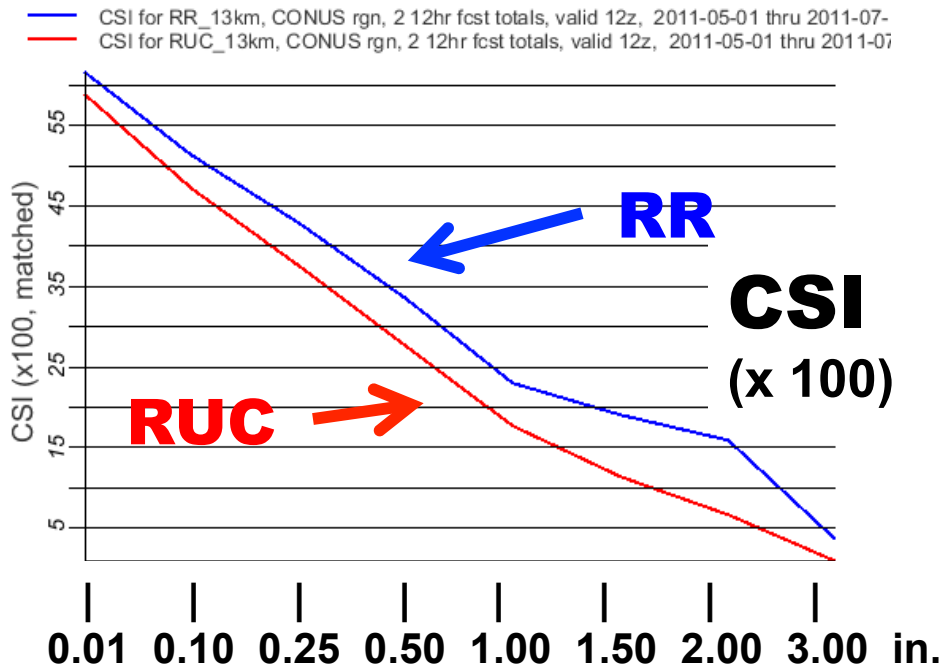
13-km CONUS

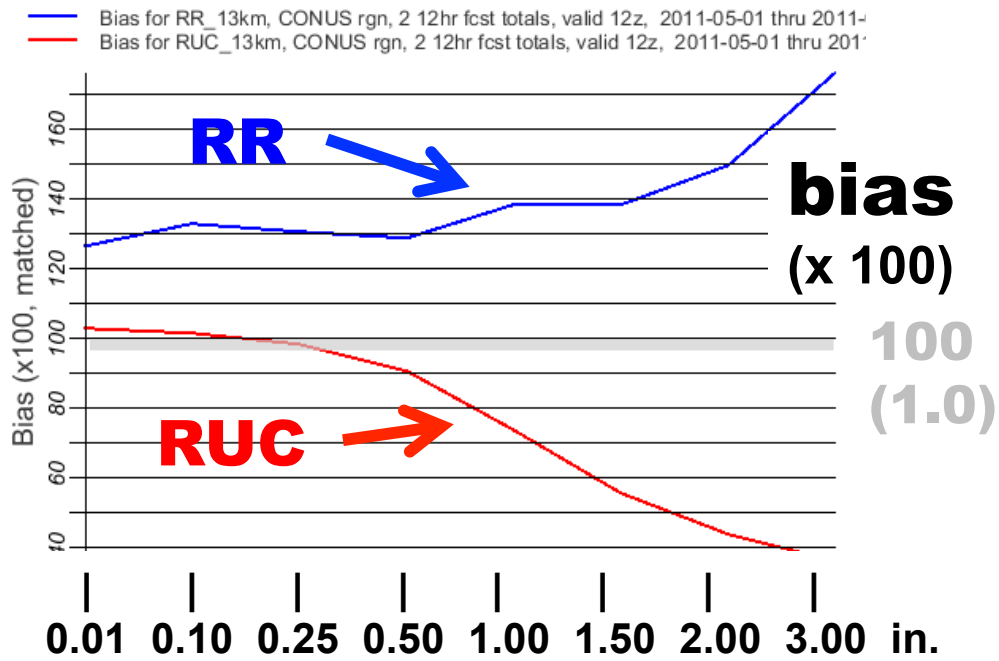
Comparison

2 X 12 hr fcst
vs. CPC 24-h analysis

1 May – 15 July 2011
Matched

SPRING/
SUMMER

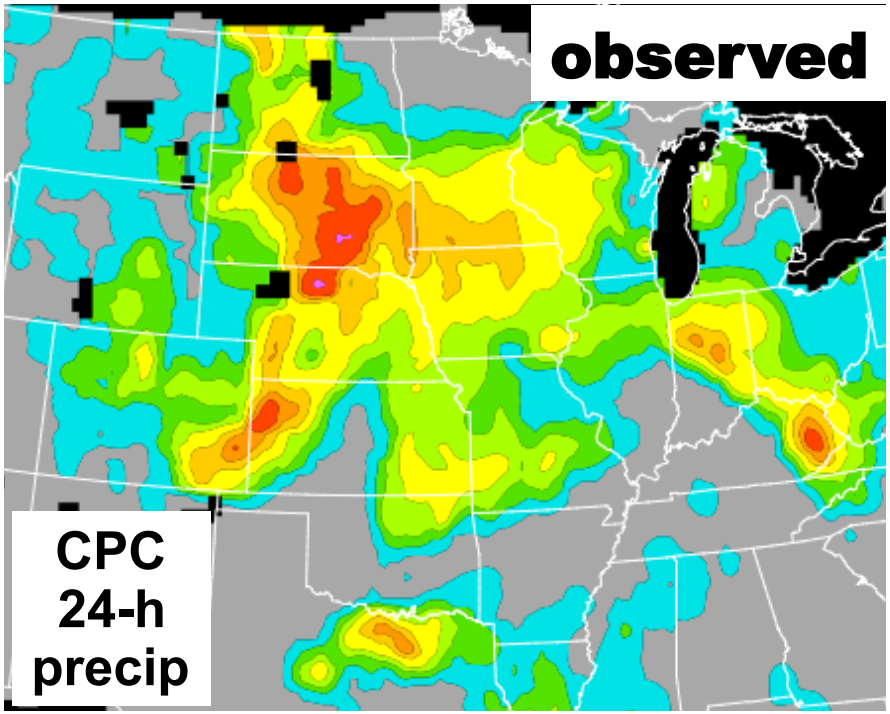


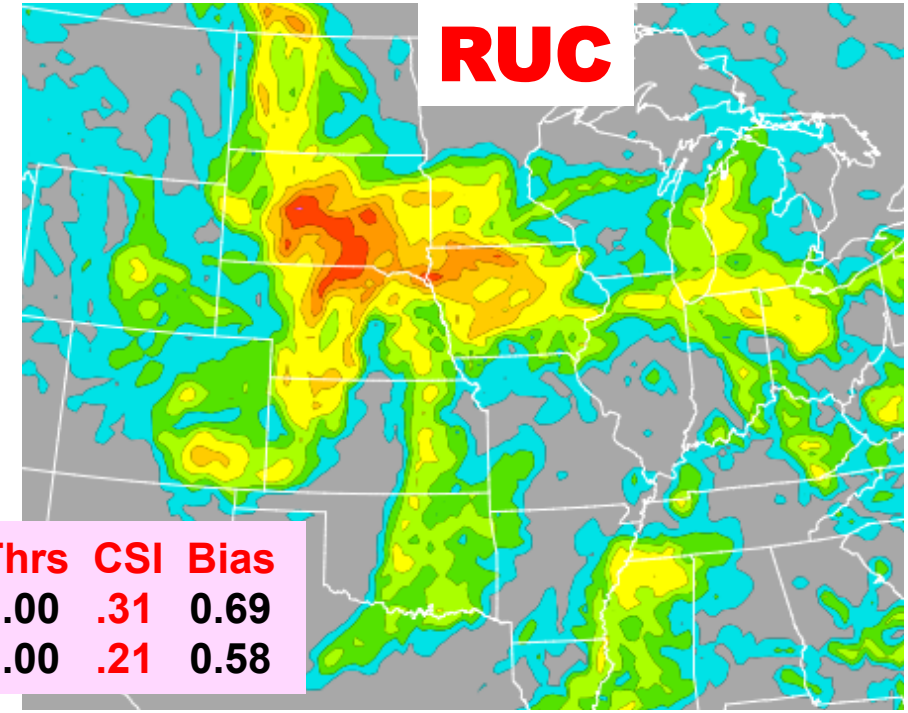


RR vs. RUC 24-h precip. verif

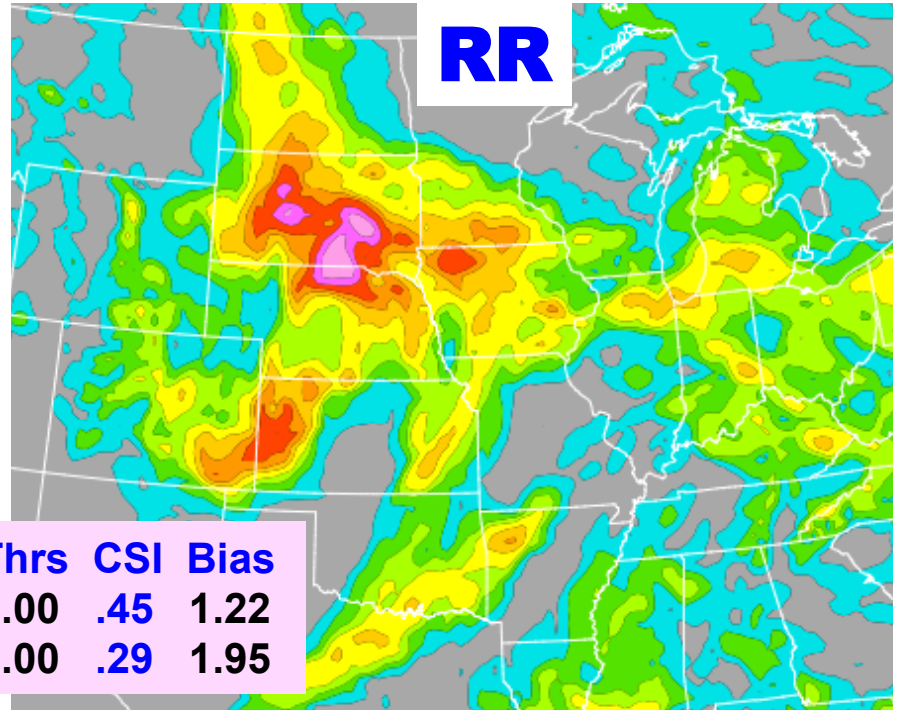
2 x 12h fcst
ending 12z
21 June 2011

Interpolated
to 20-km grid





Thrs	CSI	Bias
1.00	.31	0.69
2.00	.21	0.58

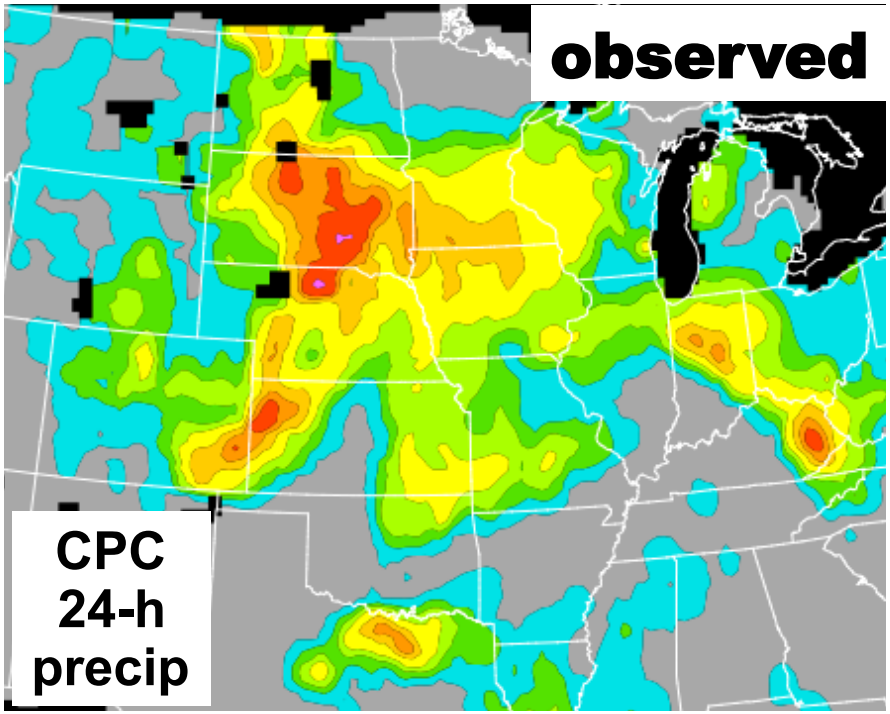


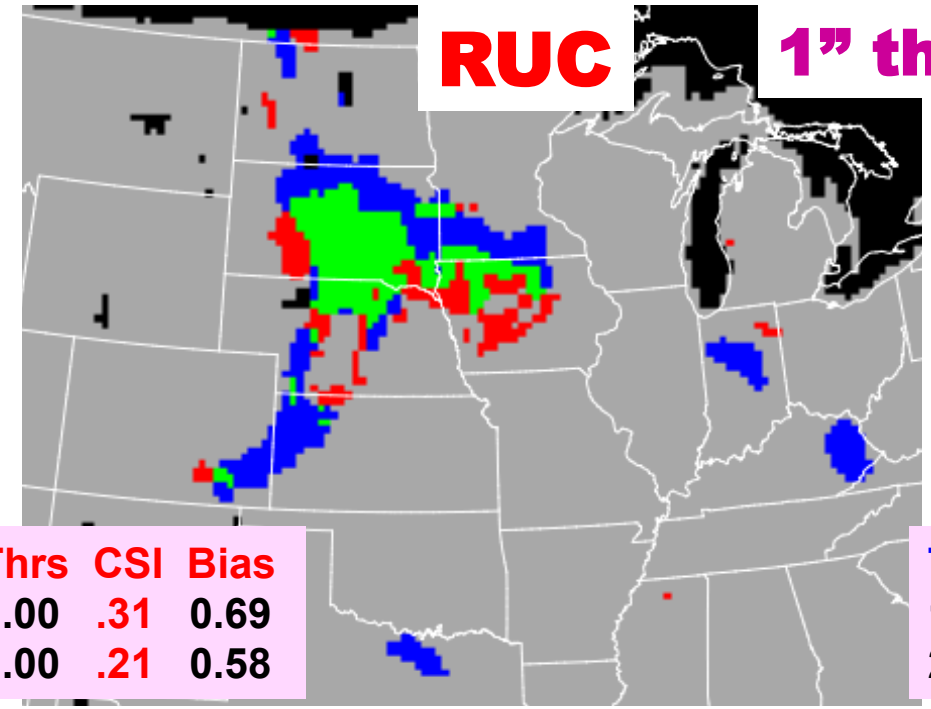
Thrs	CSI	Bias
1.00	.45	1.22
2.00	.29	1.95

RR vs. RUC 24-h precip. verif

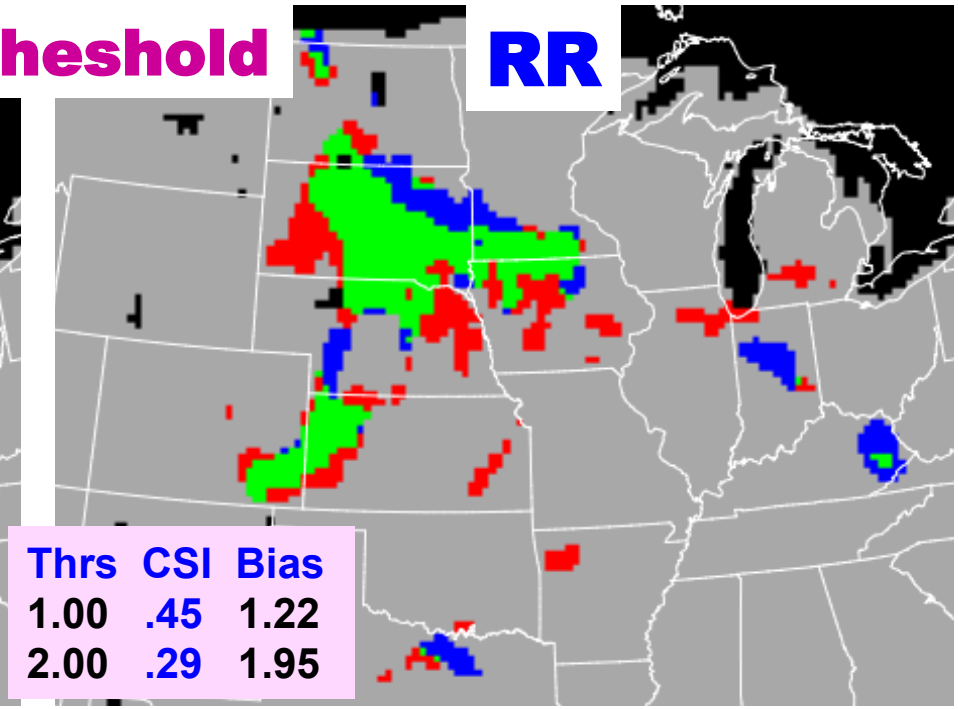
2 x 12h fcst
ending 12z
21 June 2011

Interpolated
to 20-km grid





Thrs	CSI	Bias
1.00	.31	0.69
2.00	.21	0.58

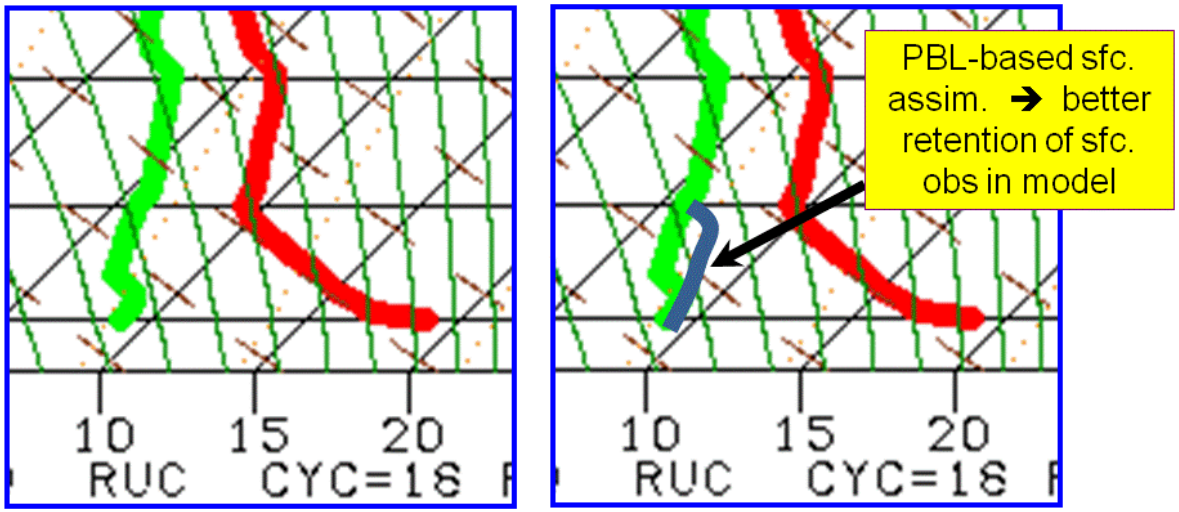


Thrs	CSI	Bias
1.00	.45	1.22
2.00	.29	1.95

Rapid Refresh – specific analysis features

Special treatment for surface observations

PBL-based pseudo-observations

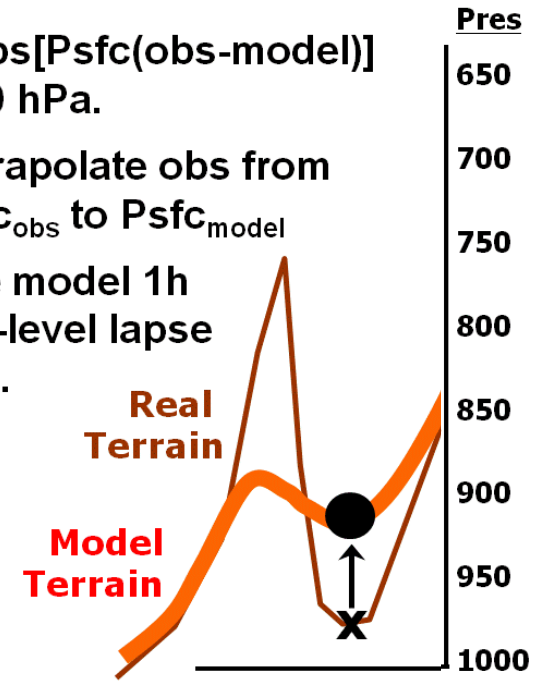


Elevation correction

If abs[Psfc(obs-model)] < 70 hPa.

Extrapolate obs from $Psfc_{obs}$ to $Psfc_{model}$

Use model 1h low-level lapse rate.



UPDATES: (1) Elevation correction in GSI repository, RR1

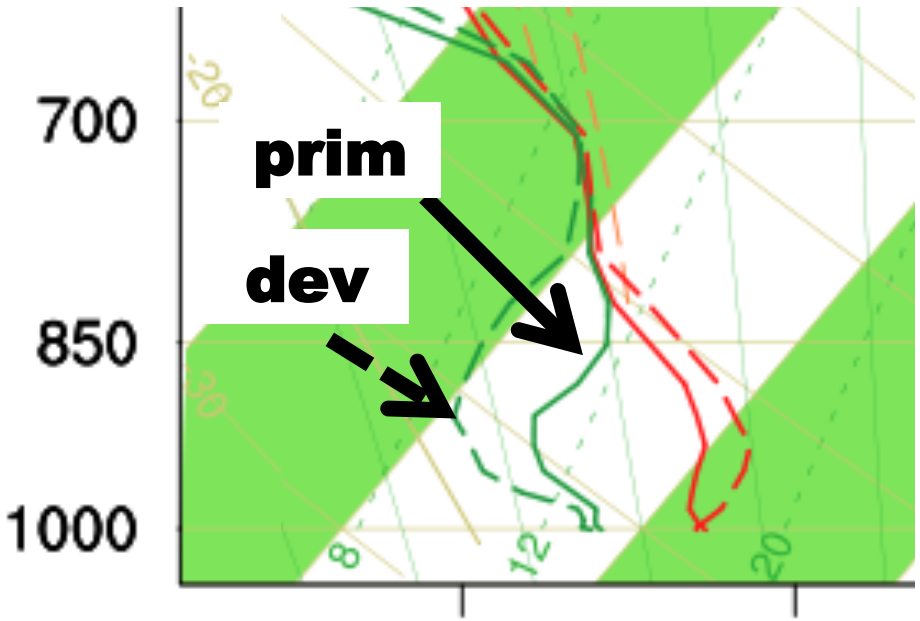
(2) Pseudo-obs in ESRL RR-primary (beneficial to HRRR) NOT in initial NCEP RR implementation (RR1)

(3) Nudge soil temperature /moisture from lowest level analysis increments (work ongoing for RR2)

Treatment of surface observations

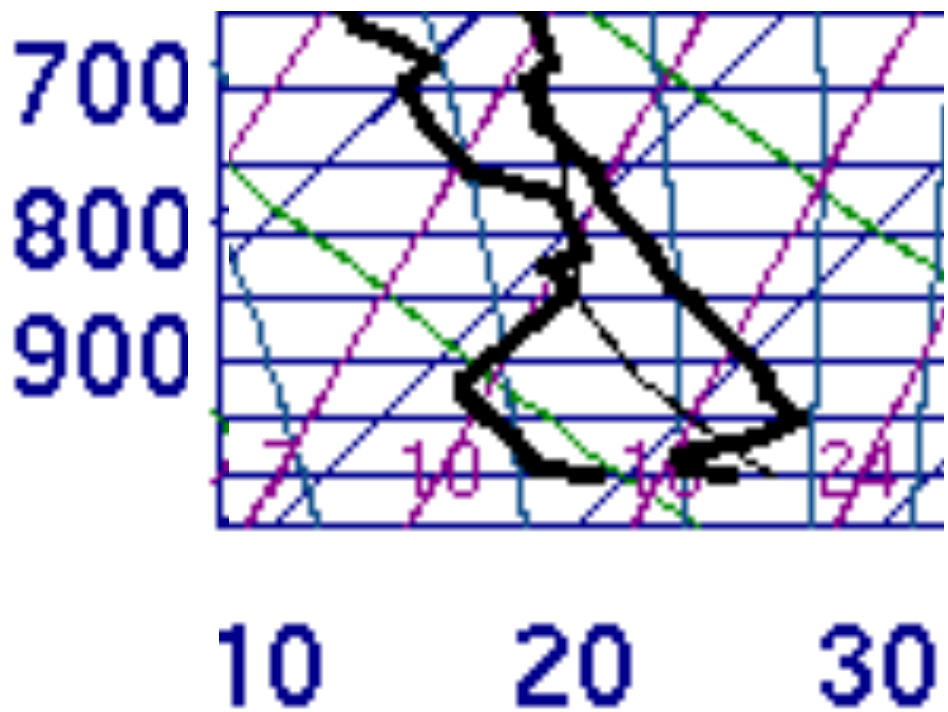
Rapid Refresh prim (——) vs. dev (----)
RR-dev has METAR-based pseudo-observations

Residual mixed layer better depicted in RR-dev (w/ PBL pseudo-obs)



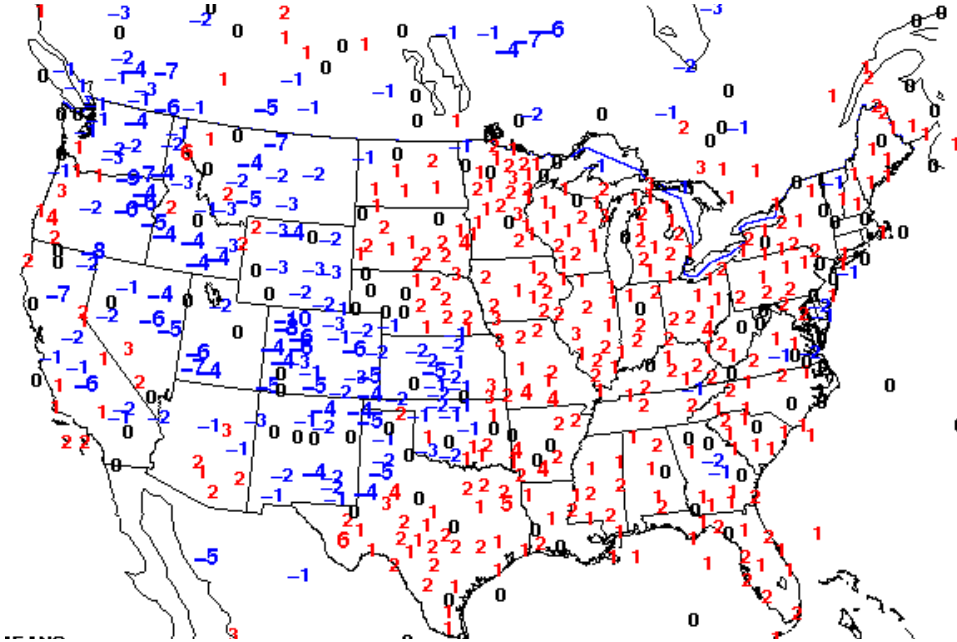
23z 6 July 2011
RR sounding

Observed
00z 7 July 2011
Albany, NY sounding

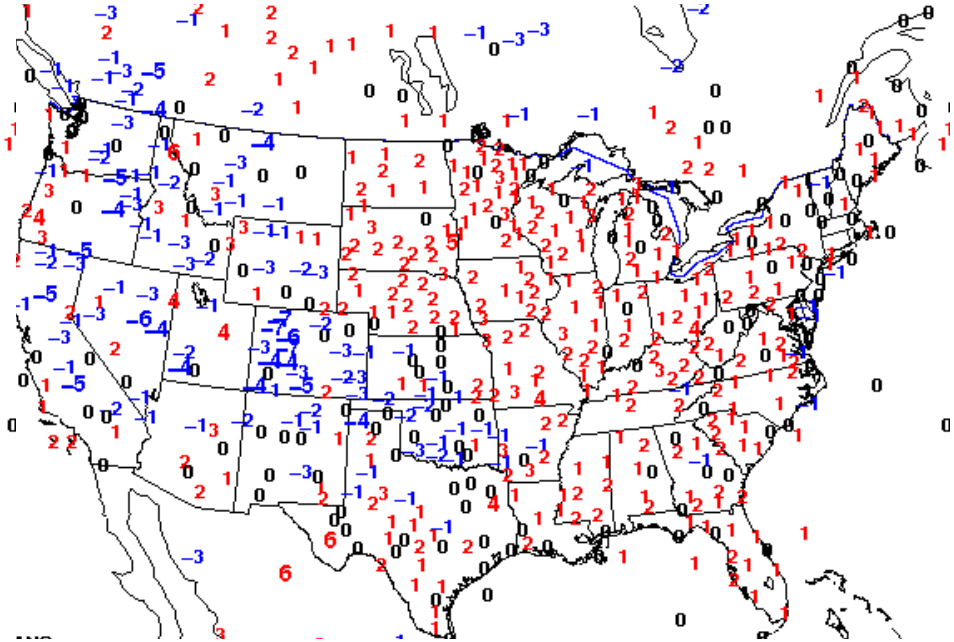


2m dewpoint verification – 00z+3h fcsts – 20-27 June 2011

	West US MAE	West US Bias	East US MAE	East US Bias
RR-primary	2.94	-1.40	1.87	0.84
RR-dev (w/ PBL pseudo-obs)	**2.45**	**-0.49**	**1.70**	1.00



RR-primary



RR-dev (w/ PLB pseudo-obs)

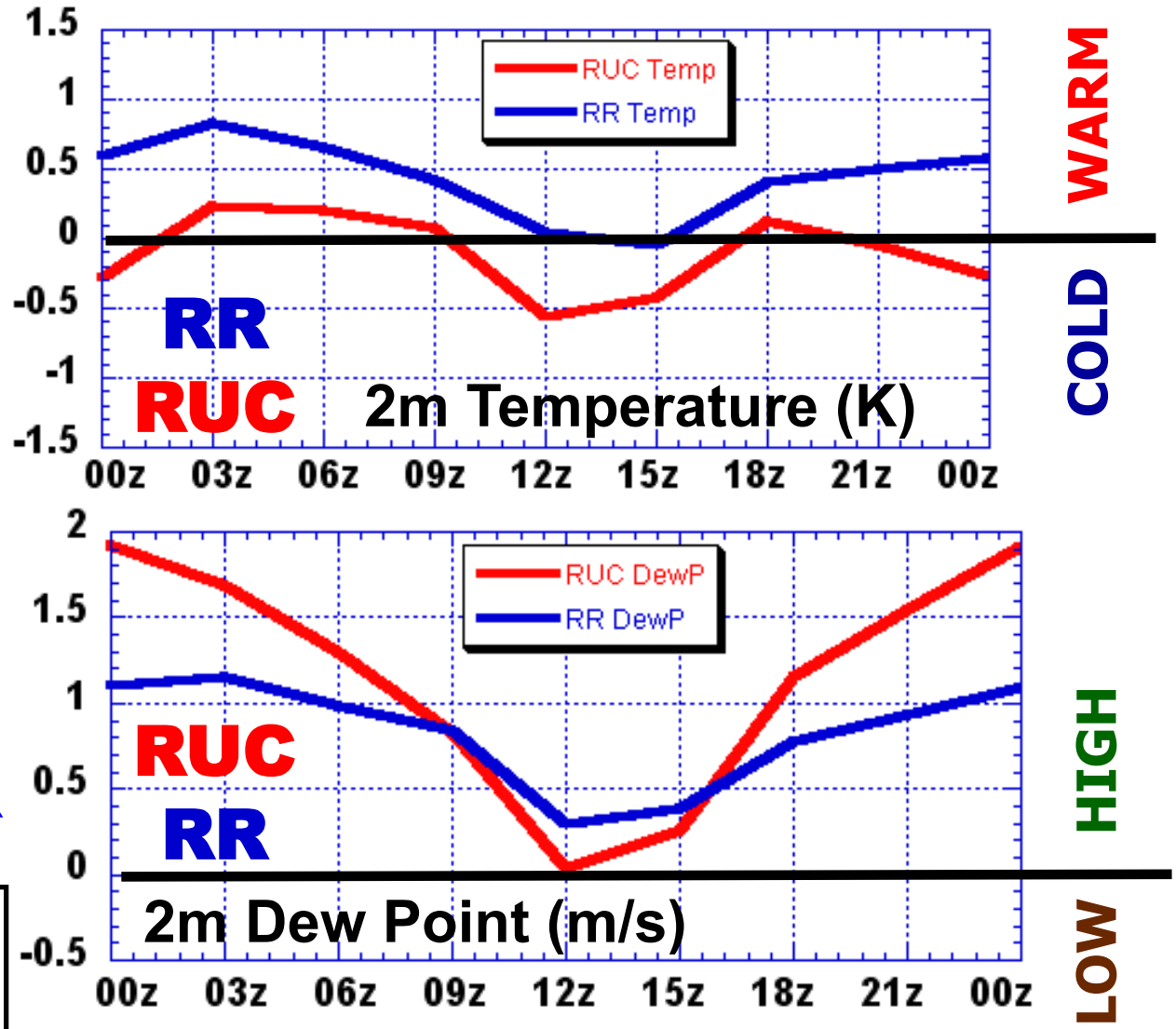
RR vs. RUC surface verification

Diurnal bias variation
6-h fcst

RUC daytime slightly cool, RR warm, esp. overnight

Both too moist, especially at night
RUC worse than RR

2-month comparison
20 April – 20 July 2011
Eastern US only



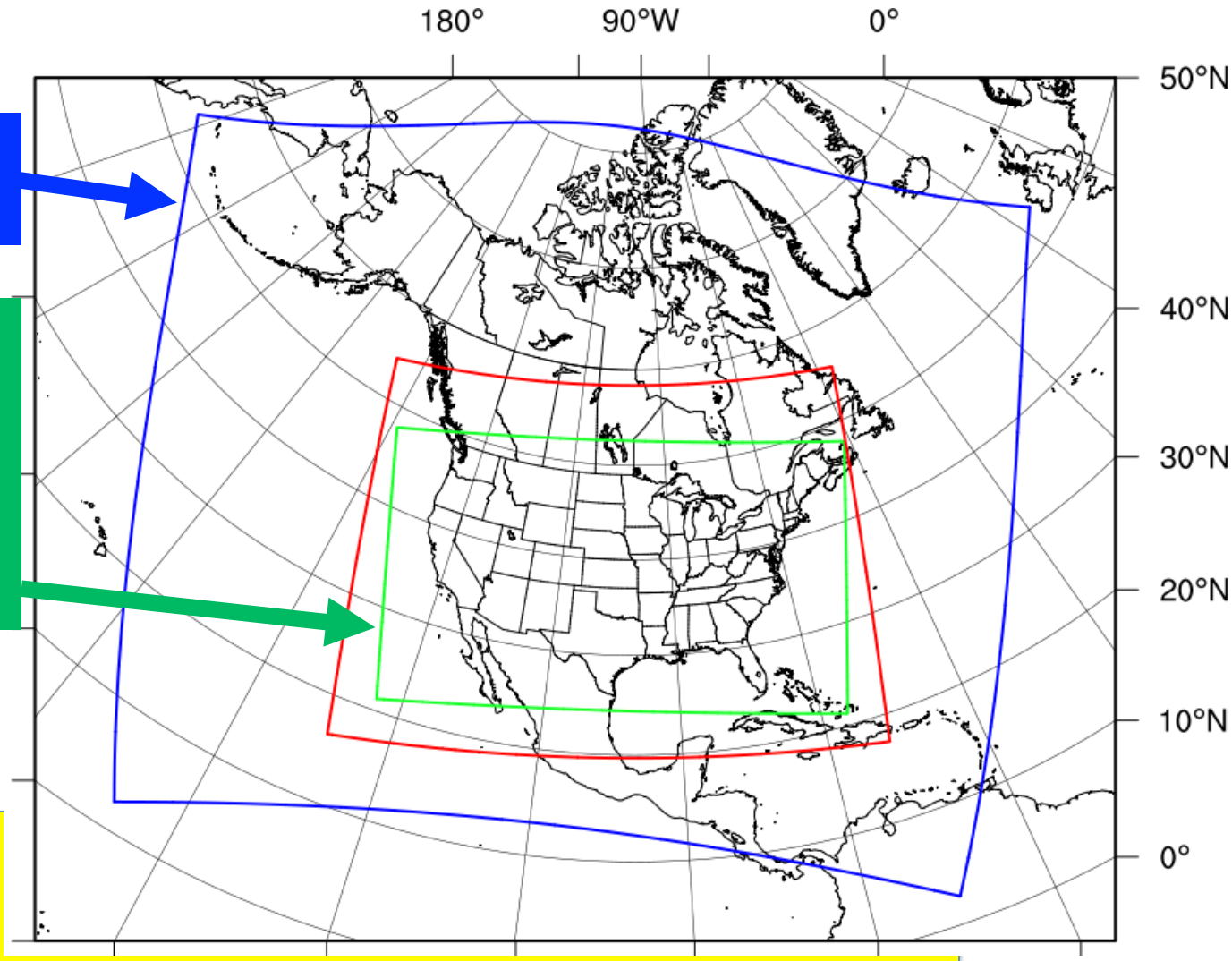
Hourly Updated NOAA NWP Models

Rapid Refresh (RR) replaces RUC at NCEP in 2011 - WRF, GSI with RUC-based enhancements

13km Rapid Refresh

3km HRRR

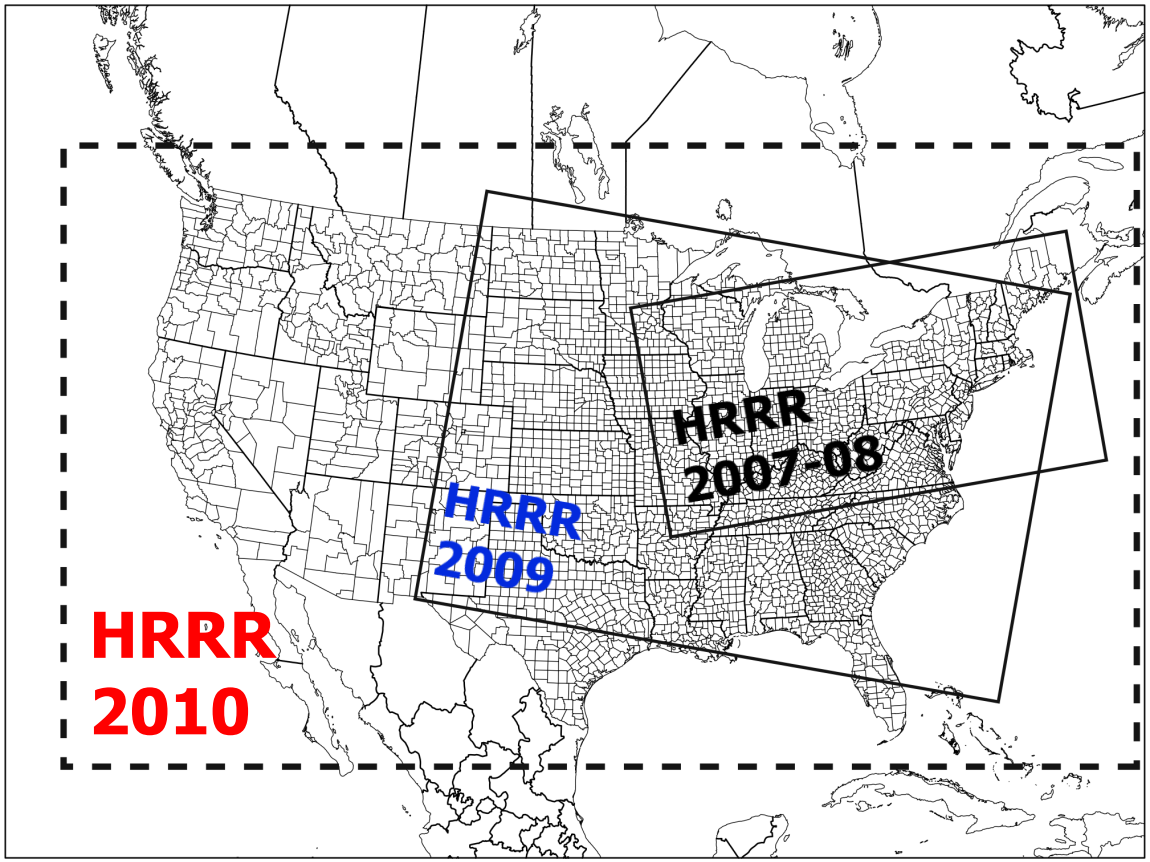
April 2011 – switch **to RapidRefresh** for hourly initial conditions



High-Resolution Rapid Refresh
Experimental 3km nest inside RUC or RR, new 15-h fcst every hour

Evolution of the HRRR Domain

RUC Domain



Hourly frequency maintained

September 2007
Initial HRRR domain:
northeastern United States
"aviation corridor"
745 x 383 grid points
200 processors

March 2009
Domain expansion:
Eastern 2/3 of the US
1000 x 700 grid points
568 processors

October 2009
Domain expandsion:
CONUS
1800 x 1060 grid points
15 hour forecasts
1000 processors

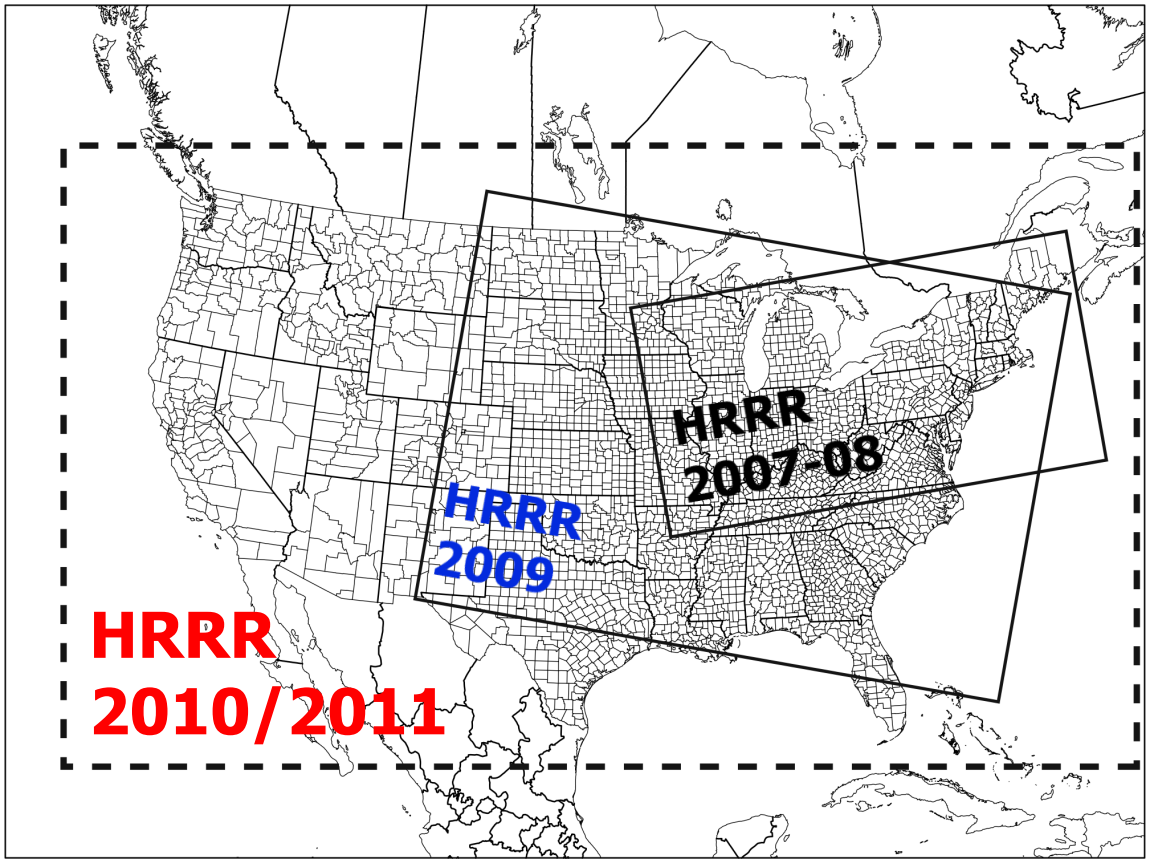
May – Oct 2010 HRRR run reliability

94.5% HRRR completion rate (including scheduled downtime)

Evolution of the HRRR Domain

Hourly frequency maintained

RUC Domain



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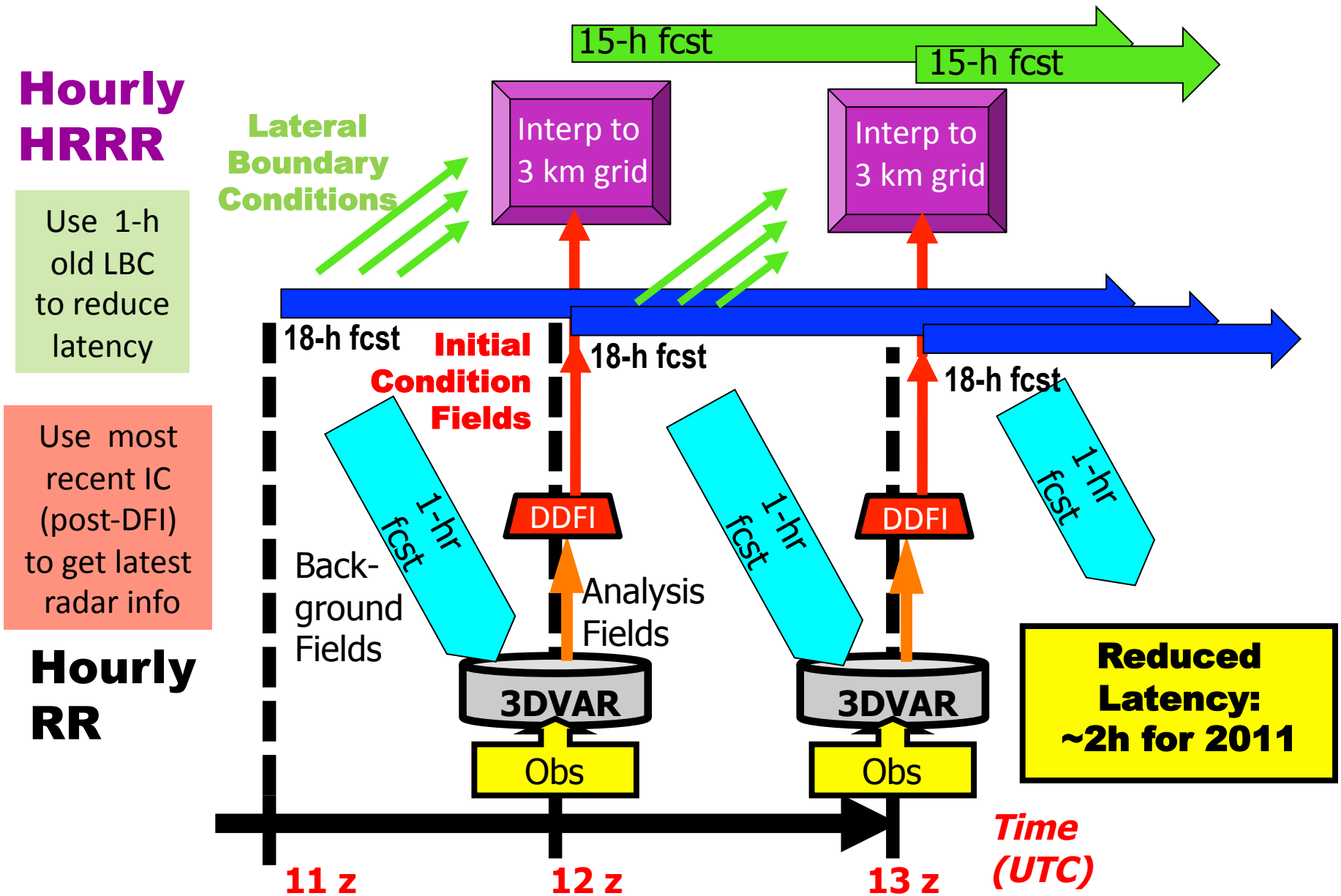
October 2009
Domain expansion:
CONUS
1800 x 1060 grid points
15 hour forecasts
1000 processors

May – Oct 2010 HRRR run reliability

94.5% HRRR completion rate (including scheduled downtime)

140 TB total reserved disk space
2088 total reserved CPUs

Spring 2011 Hourly HRRR Initialization from RR



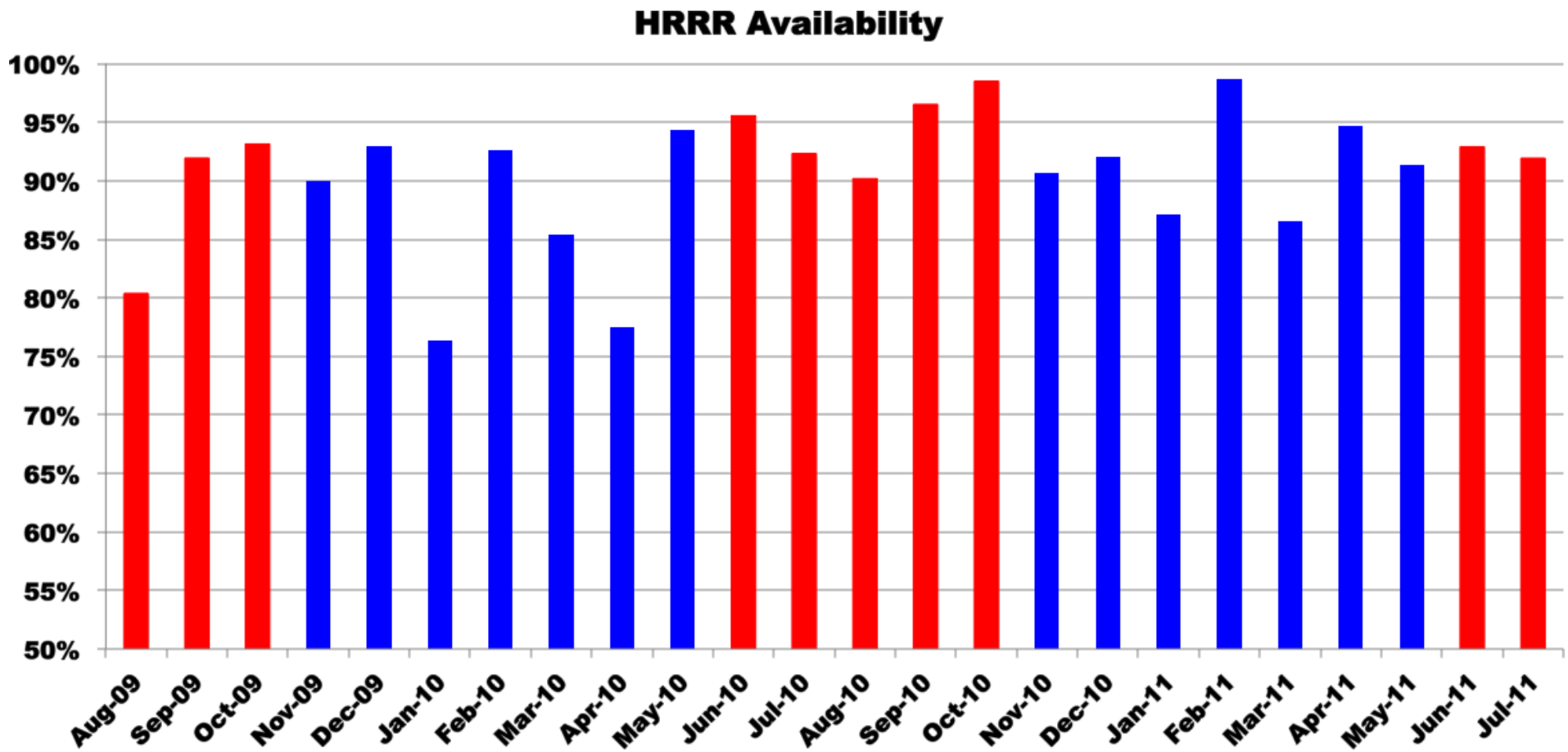
HRRR Milestones

• Inception over northeastern US	Sept 2007
• Integration into CoSPA: Aviation Users	Spring 2008
• Domain expansion to eastern US	Mar 2009
• HCPF time-lagged ensemble inception	May 2009
• HRRR WRF-ARW updated to v3.1.1	Oct 2009
• **Domain expansion to CONUS**	**Oct 2009**
• HRRR WRF-ARW updated to v3.2	Apr 2010
• Forecast period extended to 15 hrs	Apr 2010
• Real-time multi-scale reflect. verification	June 2010
• Parallel (shadow) retrospective system	Sept 2010
• Attained ~95% reliability	Jun 2010
• Reduced latency to ~2 hrs	Dec 2010

HRRR (and RR) Future Milestones

• Conversion of all output to GRIB2 format	Apr 2011
• **Transition: RUC → RR parent model**	**Apr 2011**
• DOE-funded HRRR FTP site for energy industry	May 2011
• Update to WRF-ARW v3.3.1	Oct 2011
• Reflectivity data assimilation at 3 km scale	2012
• Incorporate SatCast products at 3 km scale	2012
• Assimilate Radial Velocity at 3 km scale	2012
• HRRR demo @ESRL improves	2012-2014
• Rapid Refresh operational at NCEP	2011
• Ensemble Rapid Refresh (NARRE) at NCEP	2014
• HRRR operational at NCEP	2015?
• Ensemble HRRR (HRRRE) at NCEP	2016?

HRRR Hourly Reliability



CoSPA Operational Evaluation Periods

NOAA/ESRL/GSD/AMB Models

Model	Run at:	Domain	Grid Points	Grid Spacing	Vertical Levels	Vertical Coordinate	Lowest Level	Pressure Top
RUC	GSD, NCO	CONUS	451 x 337	13 km	50	Sigma/ Isentropic	5 m	~50 mb
RR	GSD, EMC	North America	758 x 567	13 km	50	Sigma	8 m	10 mb
HRRR	GSD	CONUS	1799 x 1059	3 km	50	Sigma	8 m	85 mb

Model	Version	Time-Step	Forecast Length	Initialized	Boundary Conditions	Run Time	# of CPUs
RUC	N/A	18 s	18 hrs	Hourly (cycled)	NAM	~25 min	36
RR	WRF-ARW v3.2+	60 s	18 hrs	Hourly (cycled)	GFS	~25 min	160
HRRR	WRF-ARW v3.2+	15-20 s	15 hrs	Hourly (no-cycle)	RUC	~50 min	1000

NOAA/ESRL/GSD/AMB Models

Model	Run at:	Domain	Grid Points	Grid Spacing	Vertical Levels	Vertical Coordinate	Lowest Level	Pressure Top
RUC	GSD, NCO	CONUS	451 x 337	13 km	50	Sigma/ Isentropic	5 m	~50 mb
RR	GSD, EMC	North America	758 x 567	13 km	50	Sigma	8 m	10 mb
HRRR	GSD	CONUS	1799 x 1059	3 km	50	Sigma	8 m	20 mb

Model	Version	Time-Step	Forecast Length	Initialized	Boundary Conditions	Run Time	# of CPUs
RUC	N/A	18 s	18 hrs	Hourly (cycled)	NAM	~25 min	36
RR	WRF-ARW v3.2+	60 s	18 hrs	Hourly (cycled)	GFS	~25 min	160
HRRR	WRF-ARW v3.2+	18-23 s	15 hrs	Hourly (no-cycle)	RR	~50 min	1064

NOAA/ESRL/GSD/AMB Models

Model	Assimilation	Radar DFI	Microphysics	Radiation	Cum Param	PBL	LSM
RUC	RUC-3DVAR	Yes - strong	Thompson	RRTM/Dudhia	Grell-Devenyi	Burk-Thompson	RUC
RR	GSI	Yes - strong	Thompson	RRTM/Goddard	G3 + Shallow	MYJ	RUC
HRRR	None: RUC I.C.	No	Thompson	RRTM/Goddard	None	MYJ	RUC

NOAA/ESRL/GSD/AMB Models

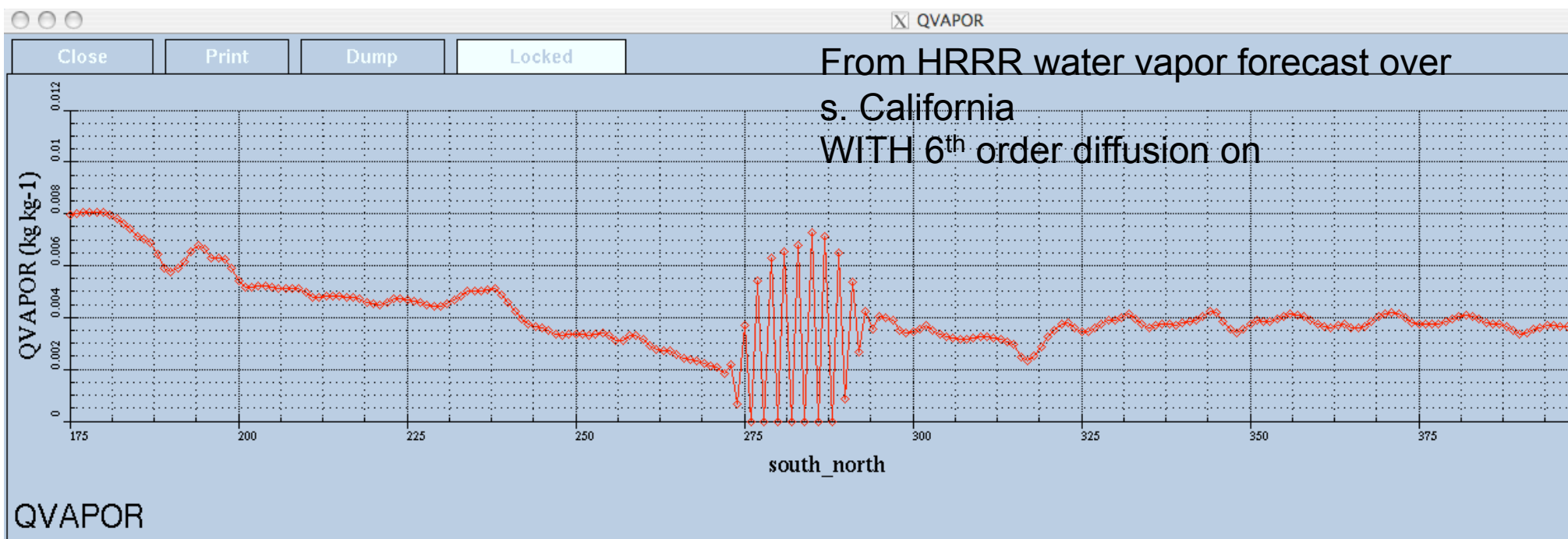
Model	Assimilation	Radar DFI	Microphysics	Radiation	Cum Param	PBL	LSM
RUC	RUC-3DVAR	Yes - strong	Thompson	RRTM/Dudhia	Grell-Devenyi	Burk-Thompson	RUC
RR	GSI	Yes - strong	Thompson	RRTM/Goddard	G3 + Shallow	MYJ	RUC
HRRR	None: RR I.C.	No	Thompson	RRTM/Goddard	None	MYJ	RUC

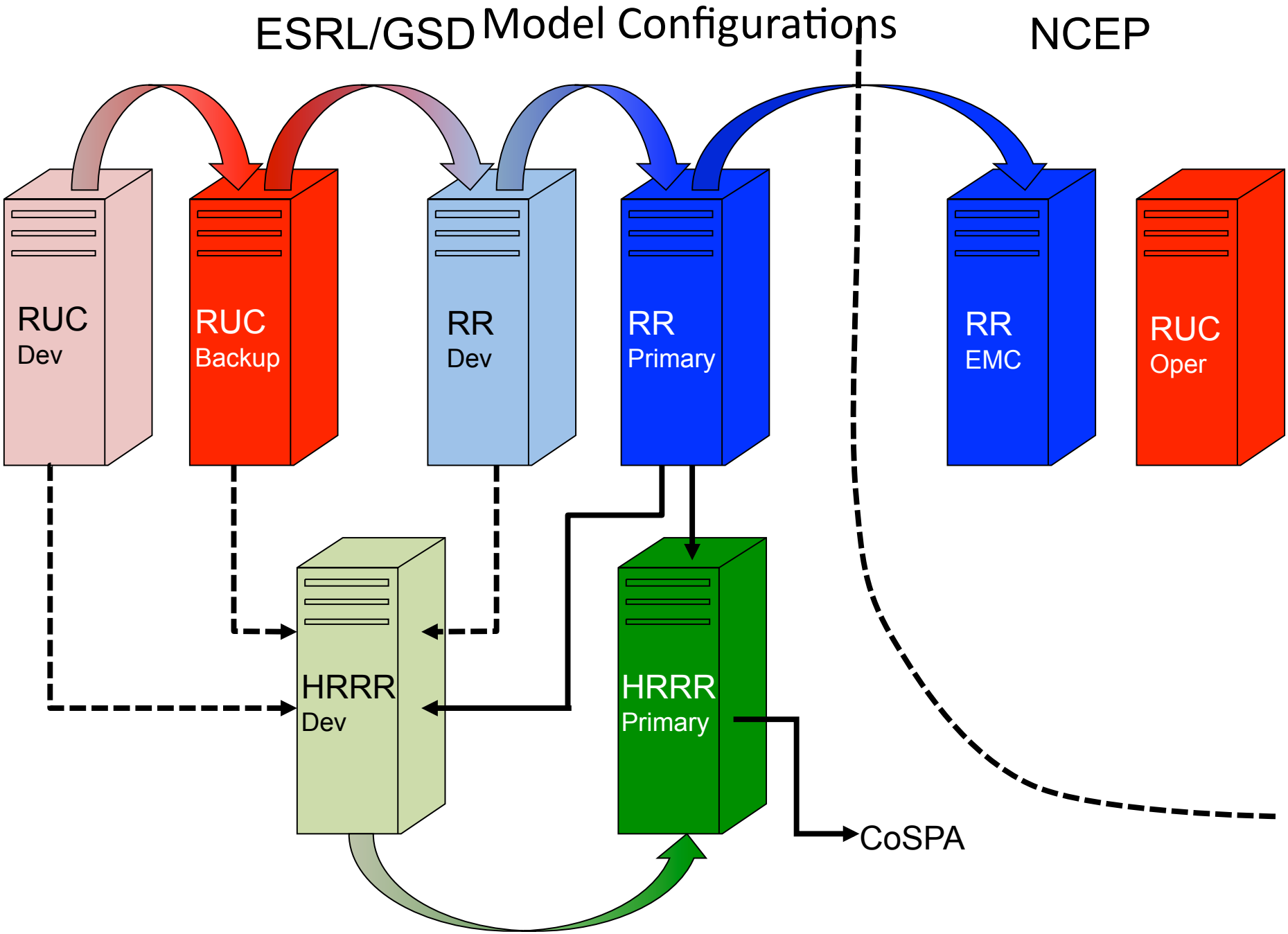
Summary of 2011
Changes & Evaluation Activities

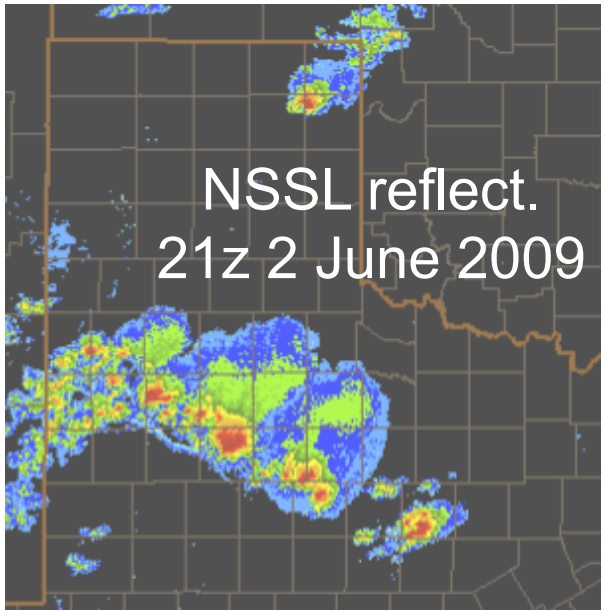
(1) RR initialization (parent model/assimilation)
(2) Latent heating strength (radar data assimilation) in RR
(3) Reduced diffusion (no 6th order diffusion)
(4) Raised pressure top
(5) Increased min/max time step
(6) Higher resolution SST data (0.083°)

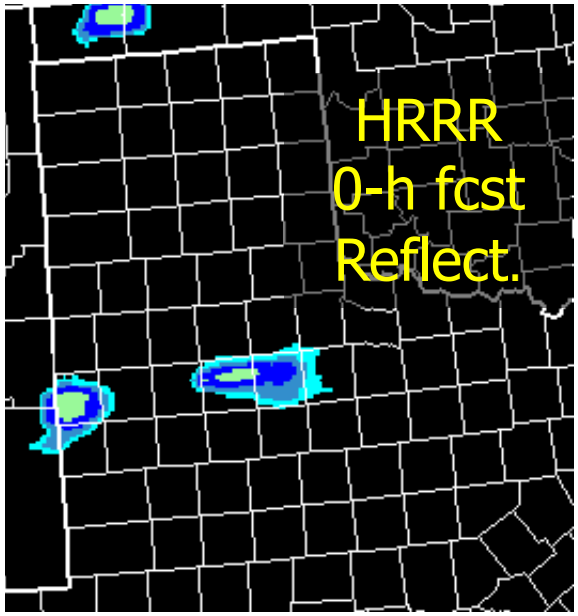
Turning off 6th order diffusion in HRRR/ARW

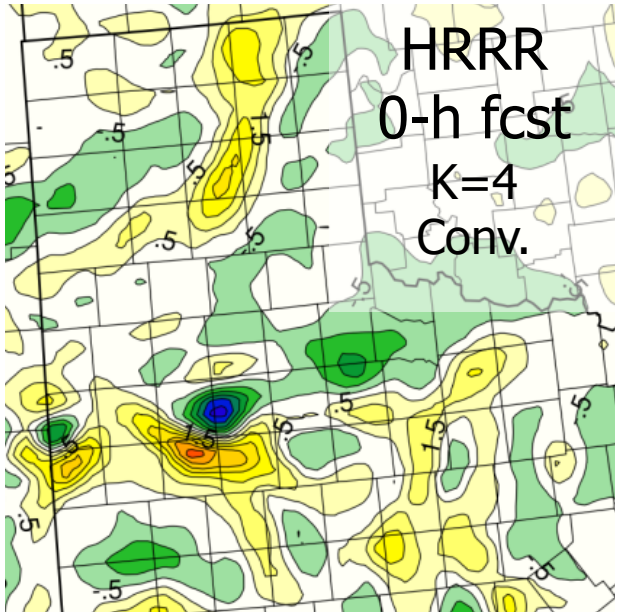
- Instability w/ flow over terrain noted by NWS Western Region in Dec 2010 – Jan 2011 – dewpoint - minus 80F in spots - "undesirable"
- Experiments showed problem was from numerical instability from 6th order diffusion
- 6th order diffusion turned off in HRRR on Friday 21 Jan 2011
- Removal also improves convection coverage and leads to earlier diurnal initiation time



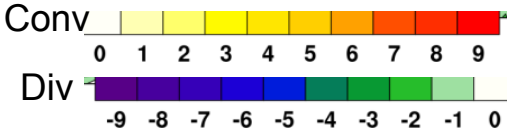

ESRL/GSD Model Configurations
NCEP
RUC
Dev
RUC
Backup
RR
Dev
RR
Primary
RR
EMC
RUC
Oper
HRRR
Dev
HRRR
Primary
CoSPA

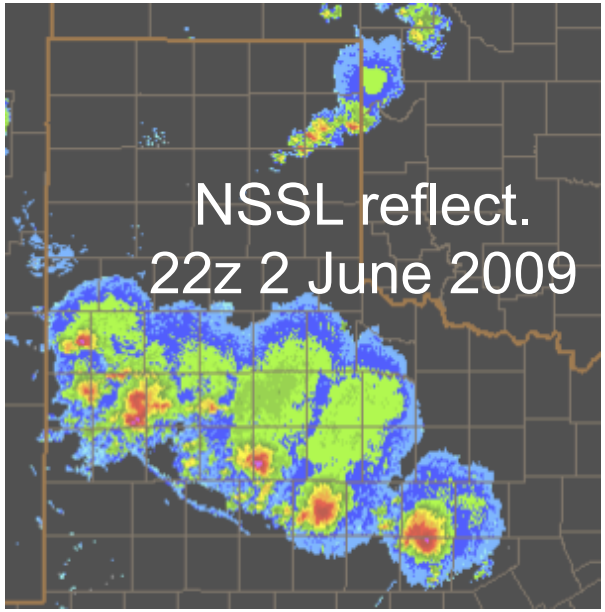


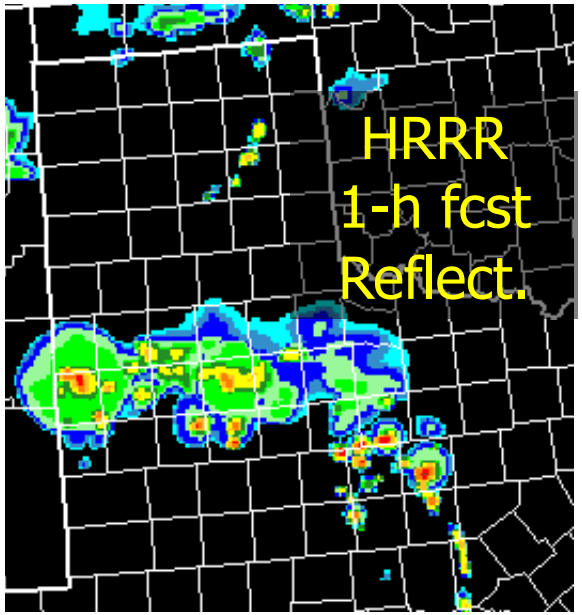


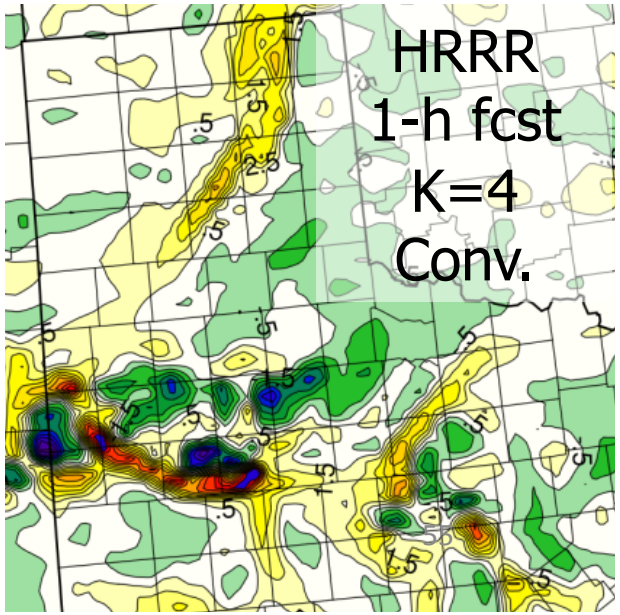


RUC DFI impact on HRRR fields

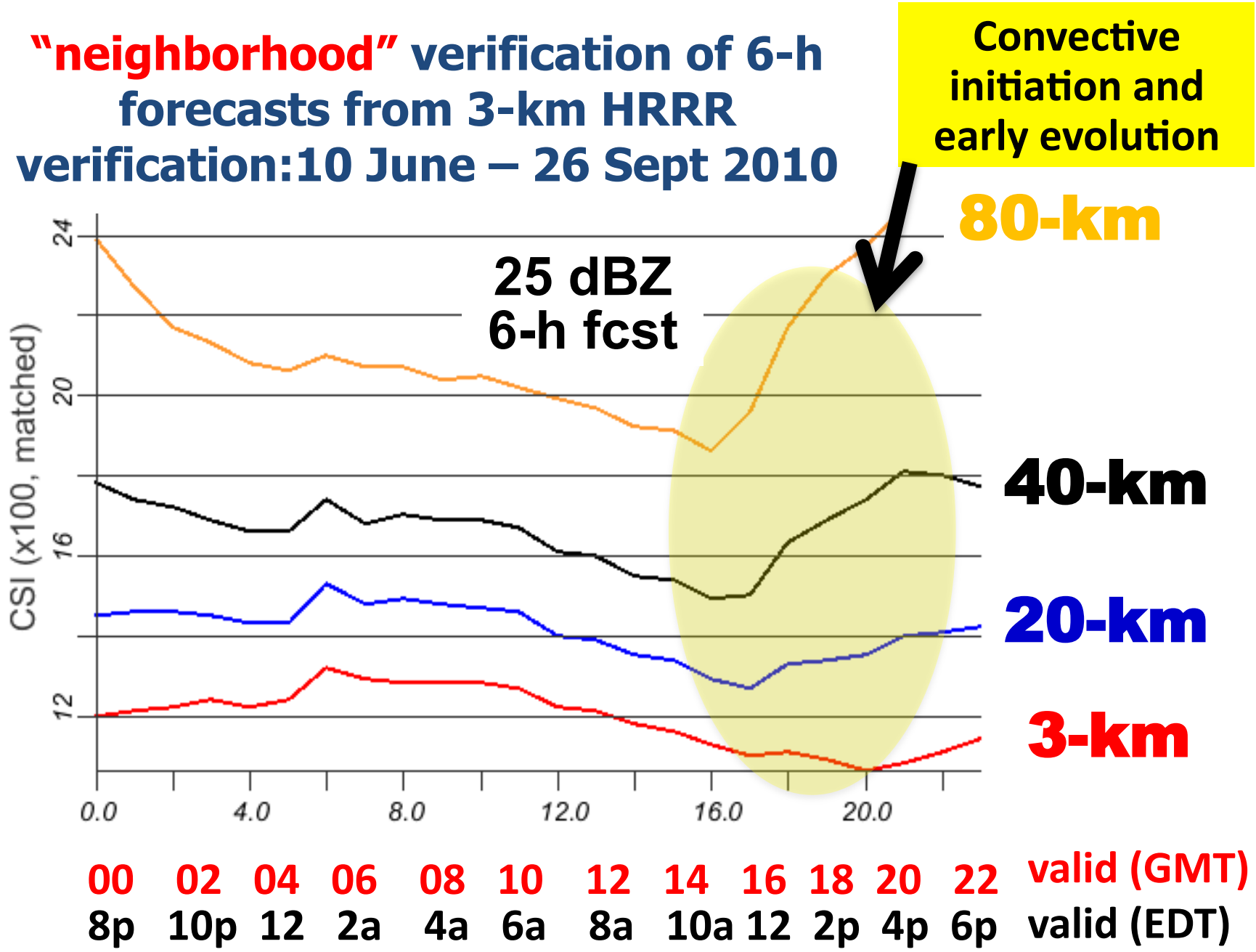




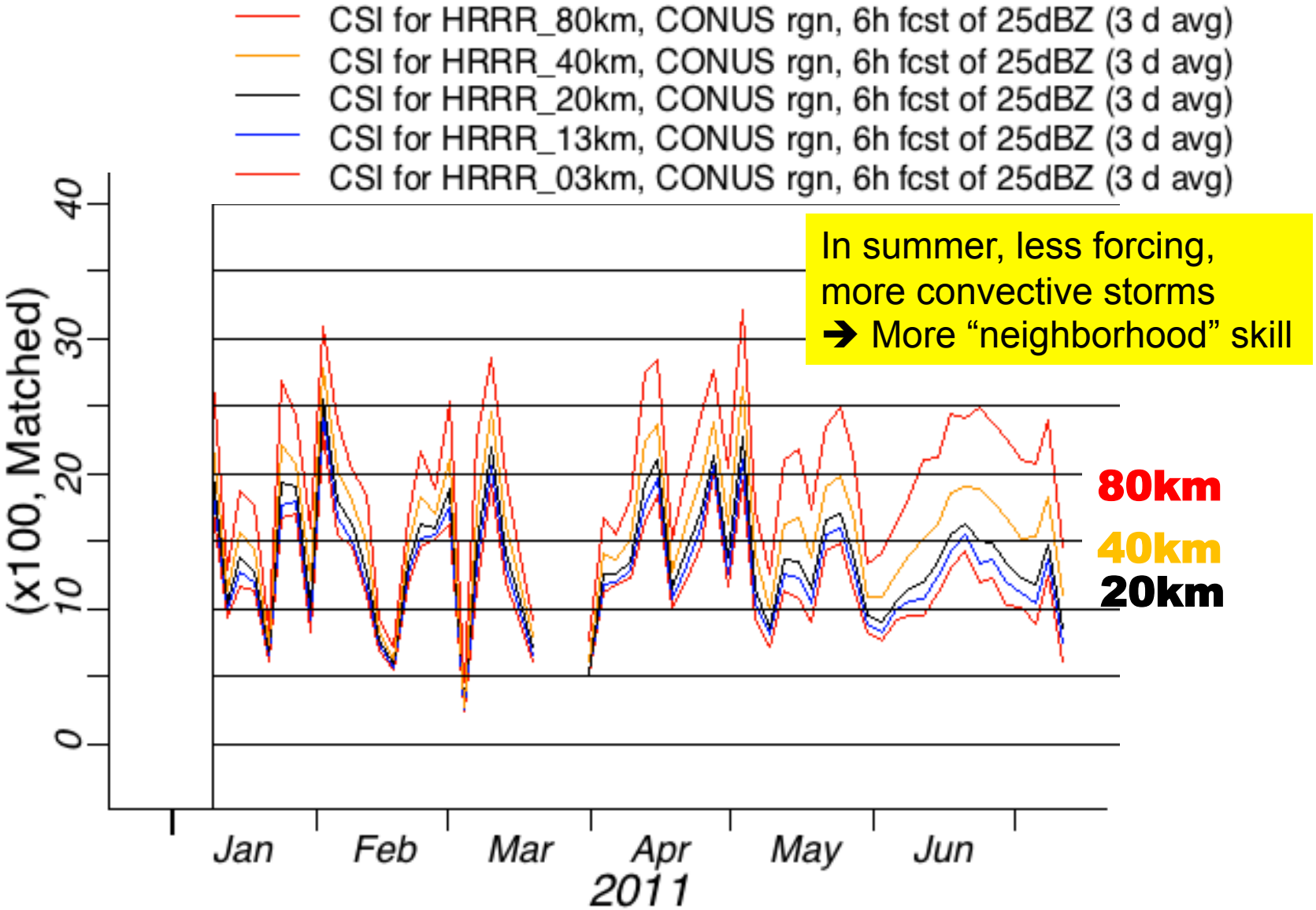




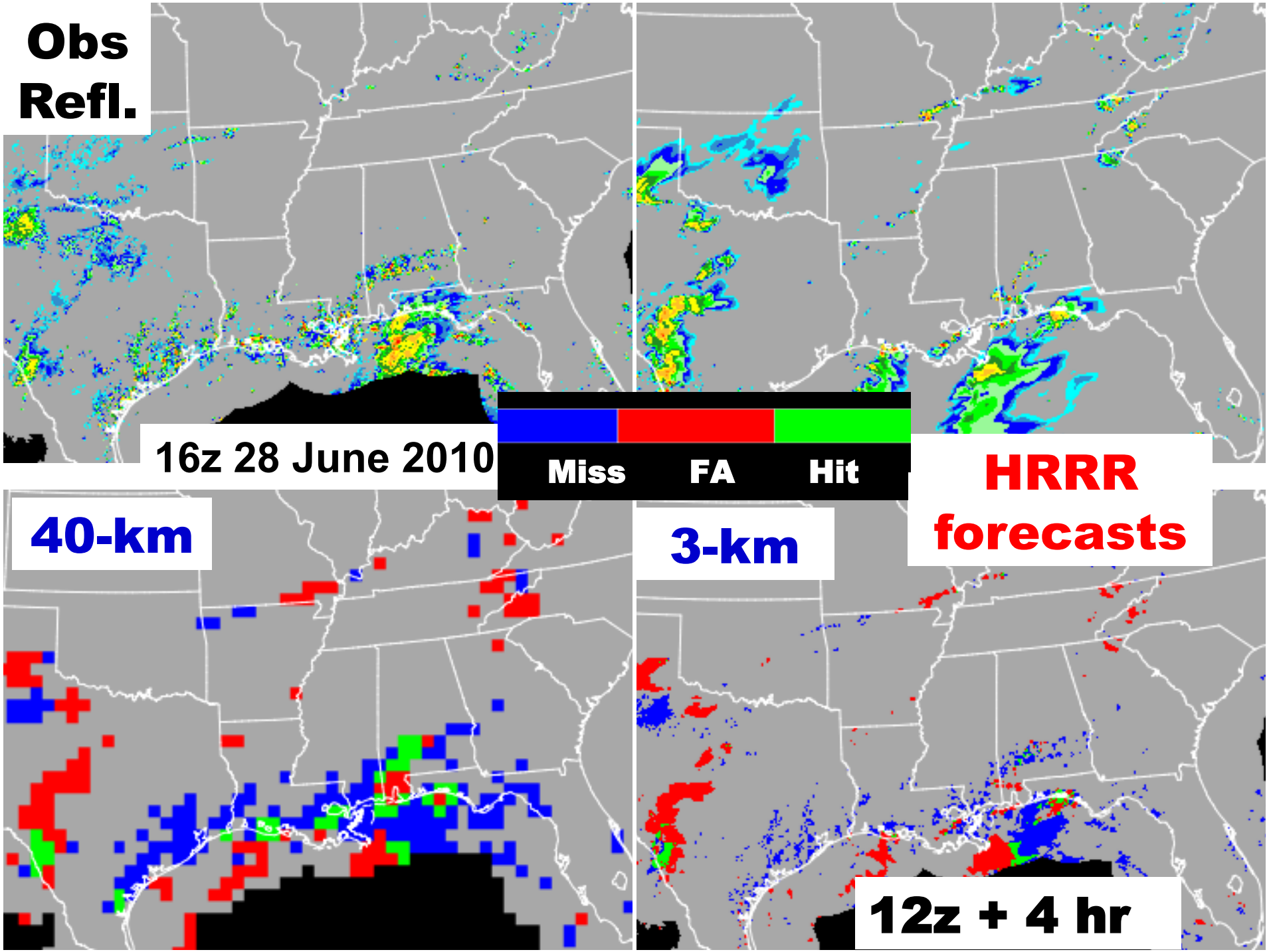
"neighborhood" verification of 6-h forecasts from 3-km HRRR verification:10 June – 26 Sept 2010

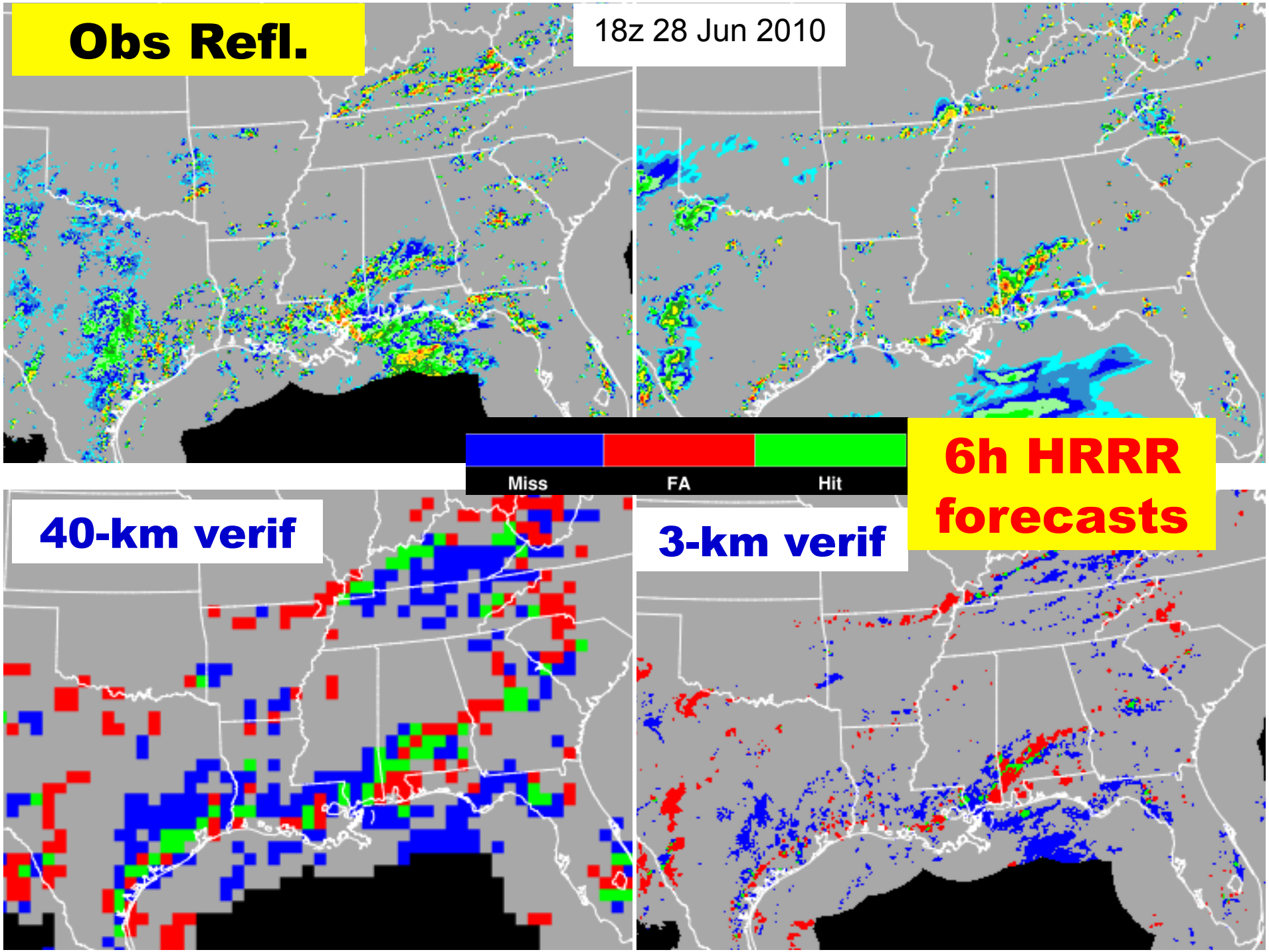


HRRR reflectivity skill – 25 dBZ – 6h
Aggregation to different scales



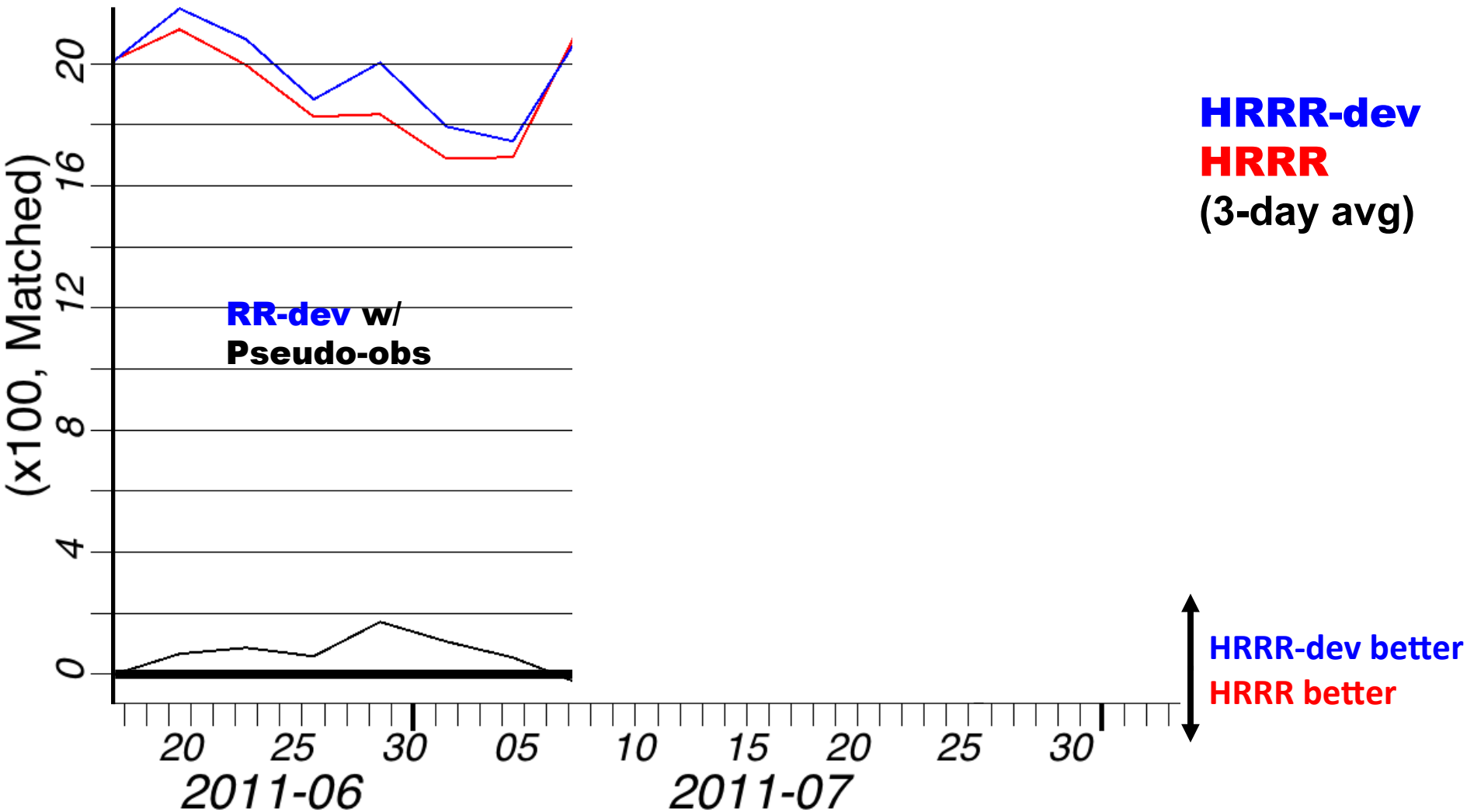
In summer, less forcing, more convective storms
➔ More "neighborhood" skill


Obs
Refl.
16z 28 June 2010
Miss
FA
Hit
HRRR
forecasts
40-km
3-km
12z + 4 hr


Obs Refl.
18z 28 Jun 2010
Miss
FA
Hit
6h HRRR forecasts
40-km verif
3-km verif

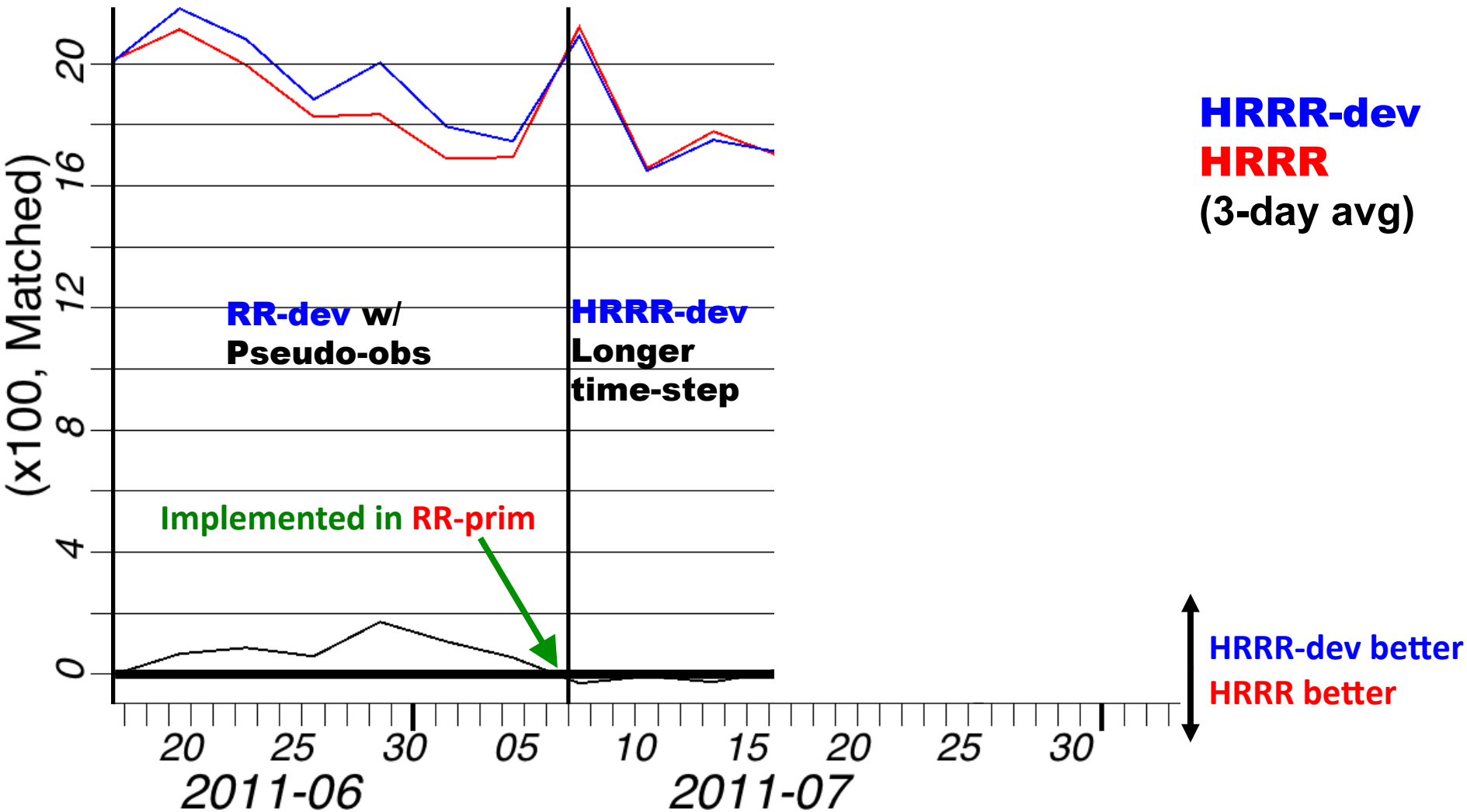
Real-Time Parallel HRRR Evaluation

Convection (> 25 dBZ)
CSI Eastern US on 40 km grid



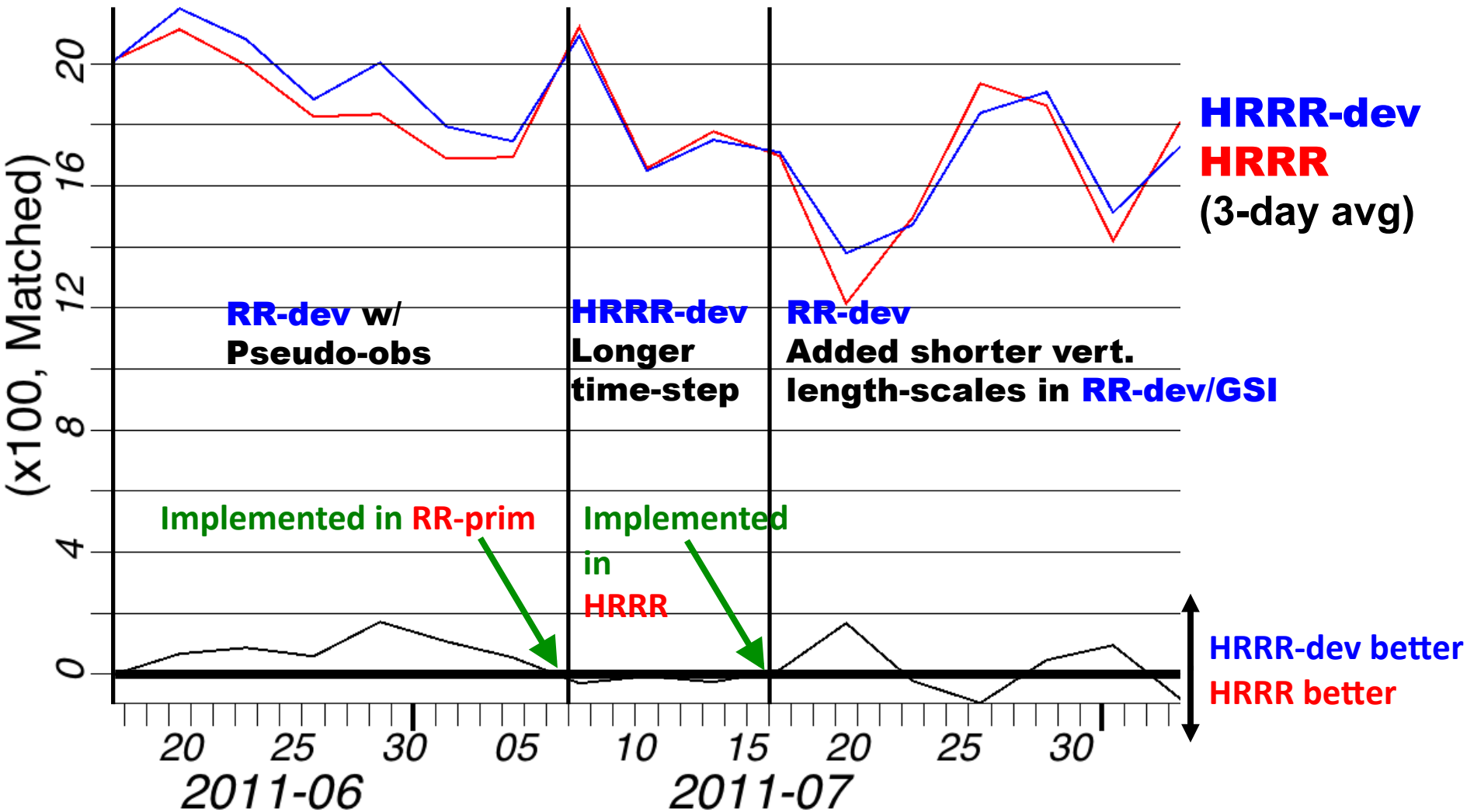
Real-Time Parallel HRRR Evaluation

Convection (> 25 dBZ)
CSI Eastern US on 40 km grid



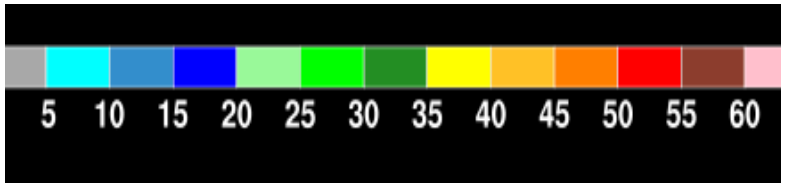
Real-Time Parallel HRRR Evaluation

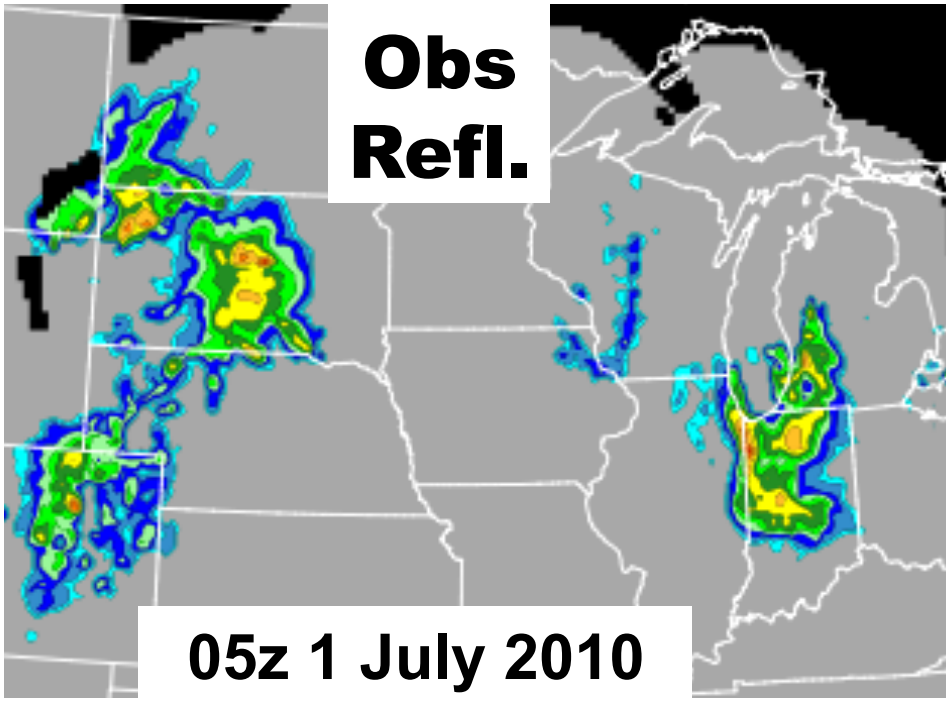
Convection (> 25 dBZ)
CSI Eastern US on 40 km grid

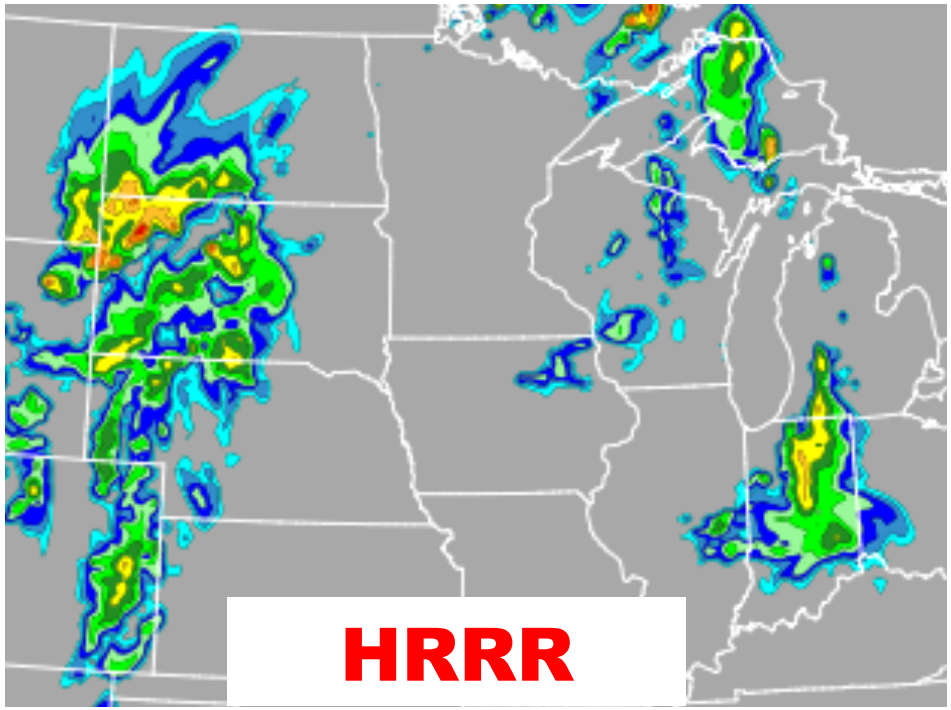


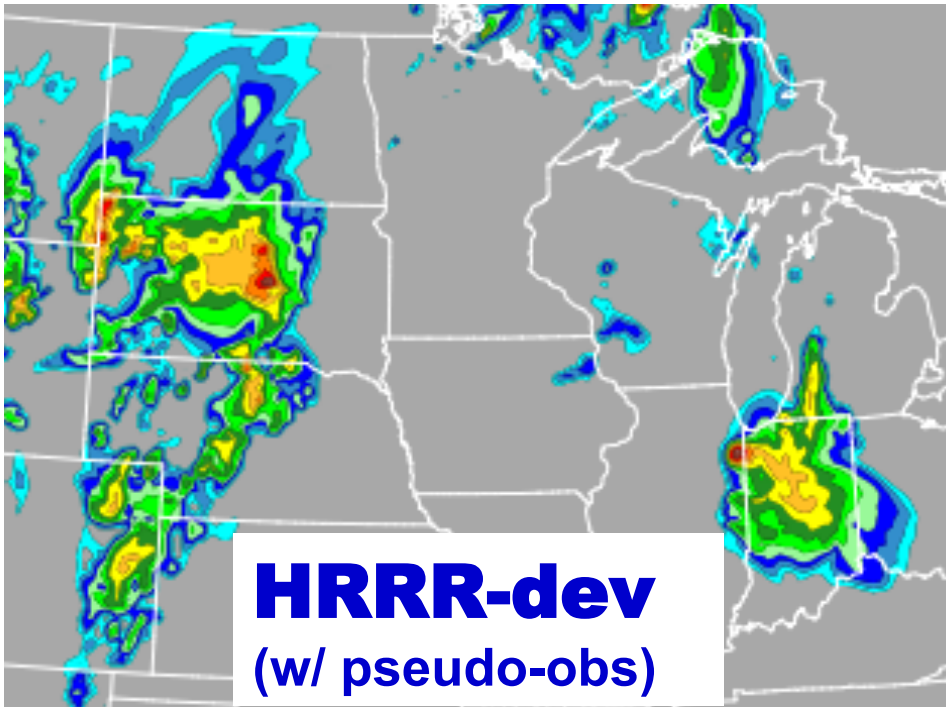
Impact of PBL pseudo-obs (in RR-dev) on HRRR-dev

3-km HRRR interpolated to
13-km verification grid
00z + 5h forecasts





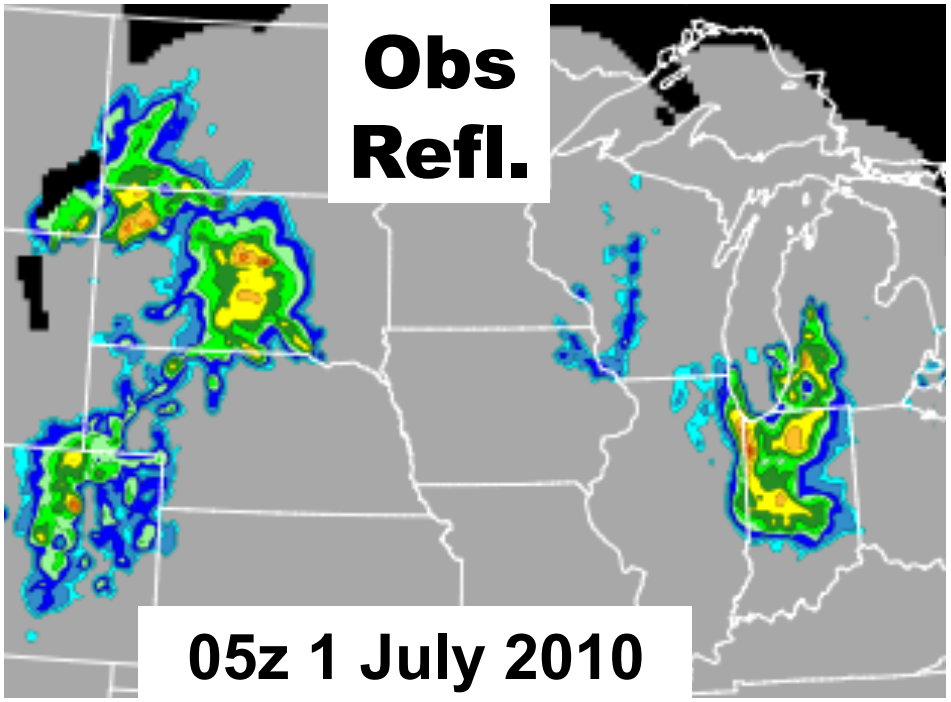


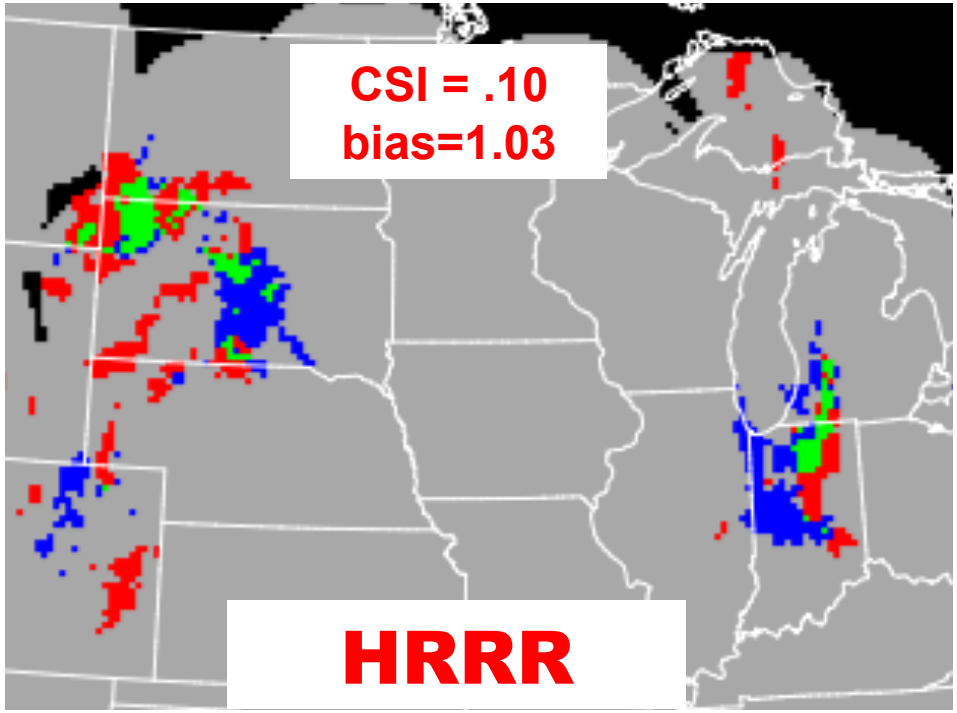


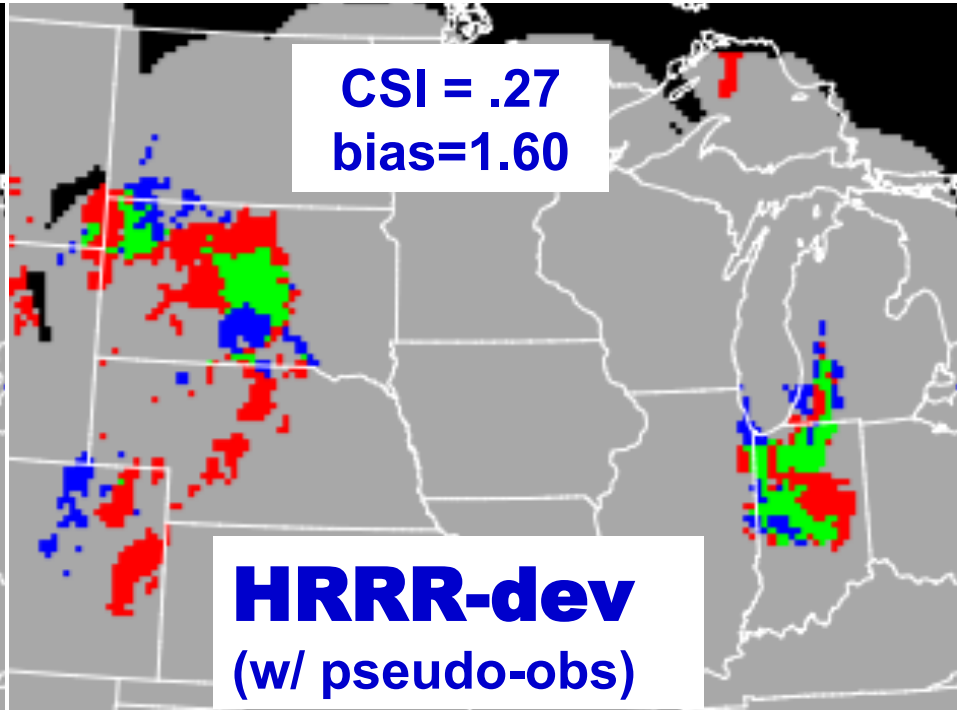
Impact of PBL pseudo-obs (in RR-dev) on HRRR-dev

3-km HRRR interpolated to
13-km verification grid
00z + 5h forecasts

30 dBZ

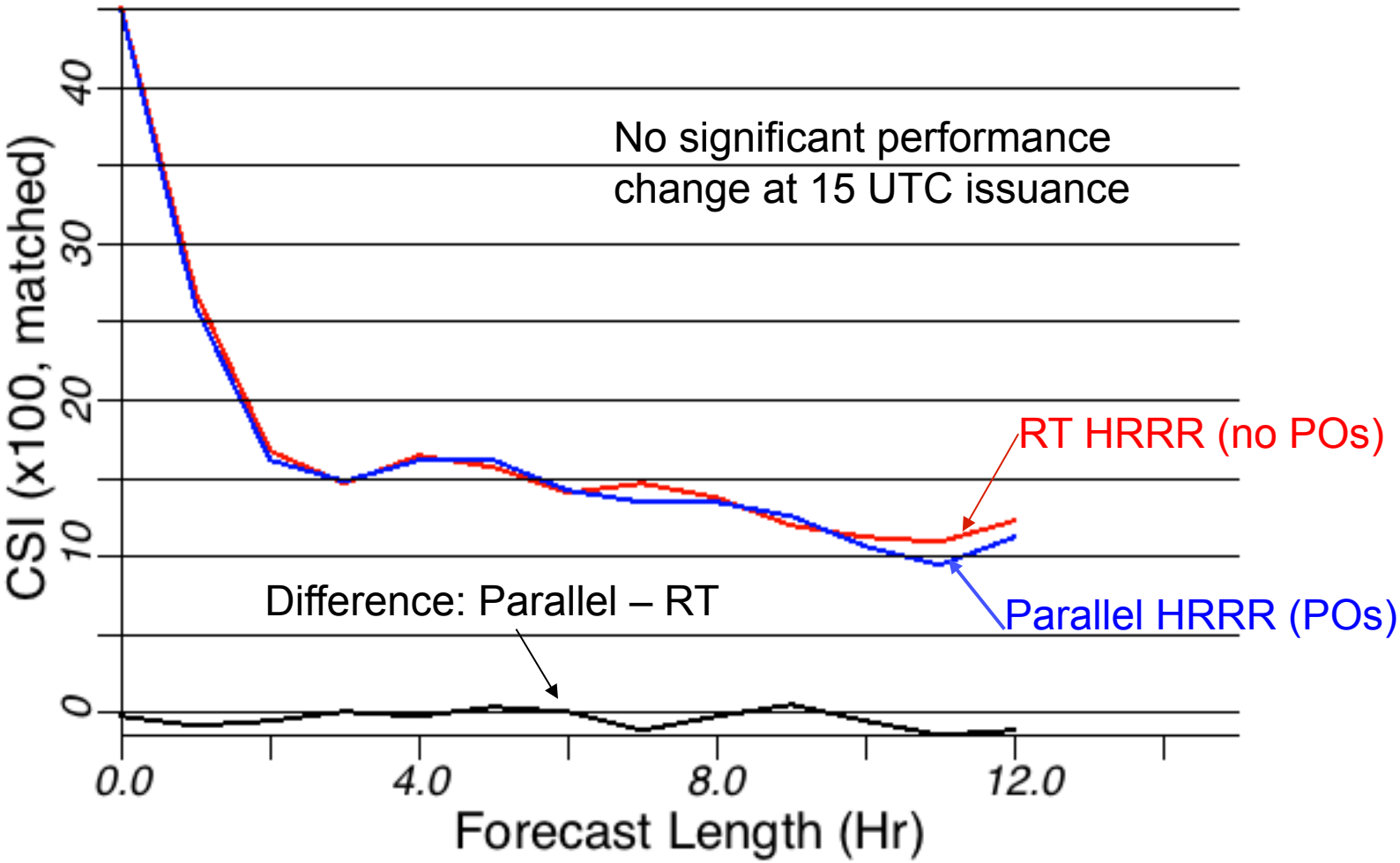






Northeast Performance, 15UTC Issuance

June 19 – July 5, 2011, 30 dBZ threshold, 40 km



Northeast Performance, 18UTC Issuance

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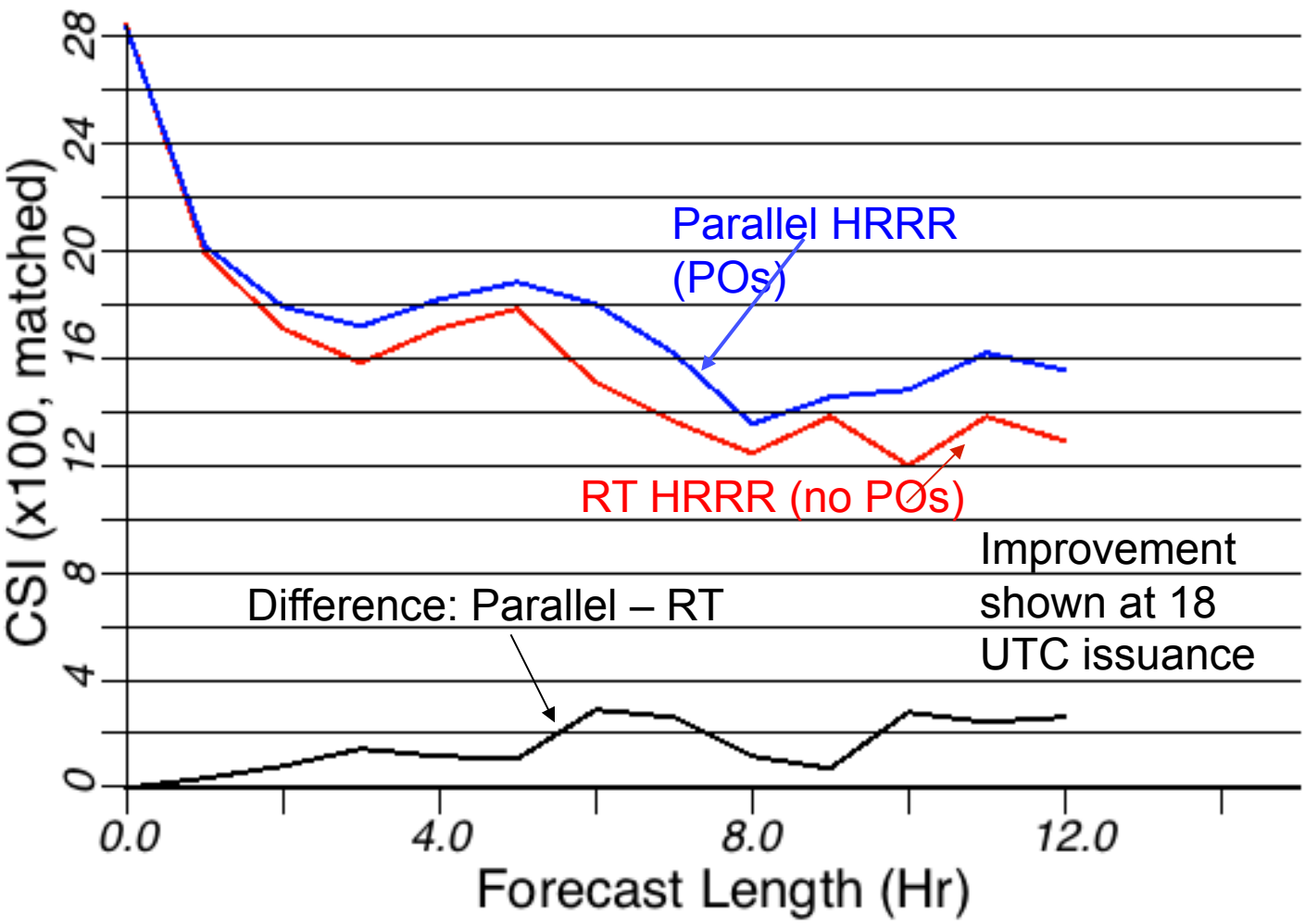

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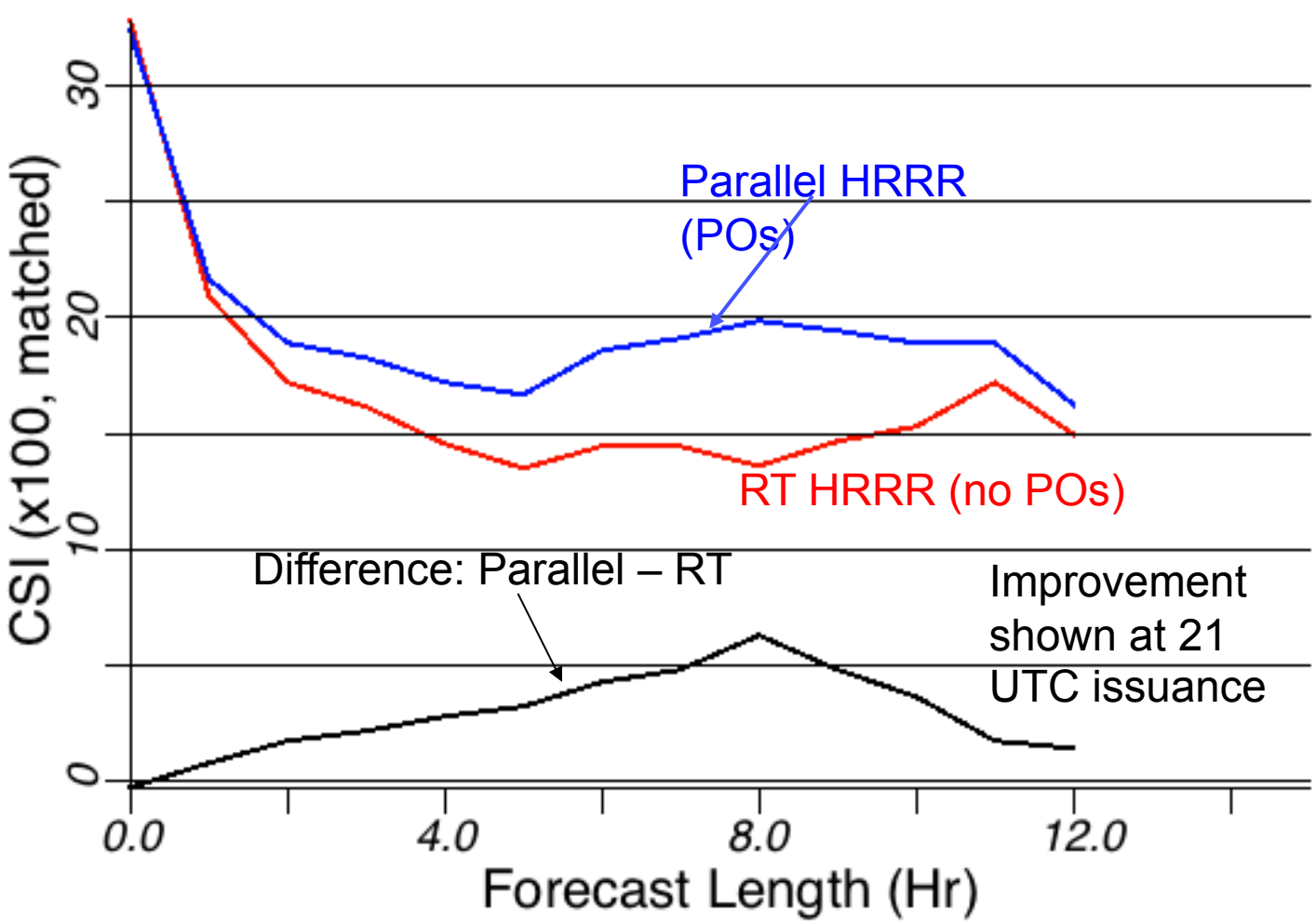

Northeast Performance, 00UTC Issuance

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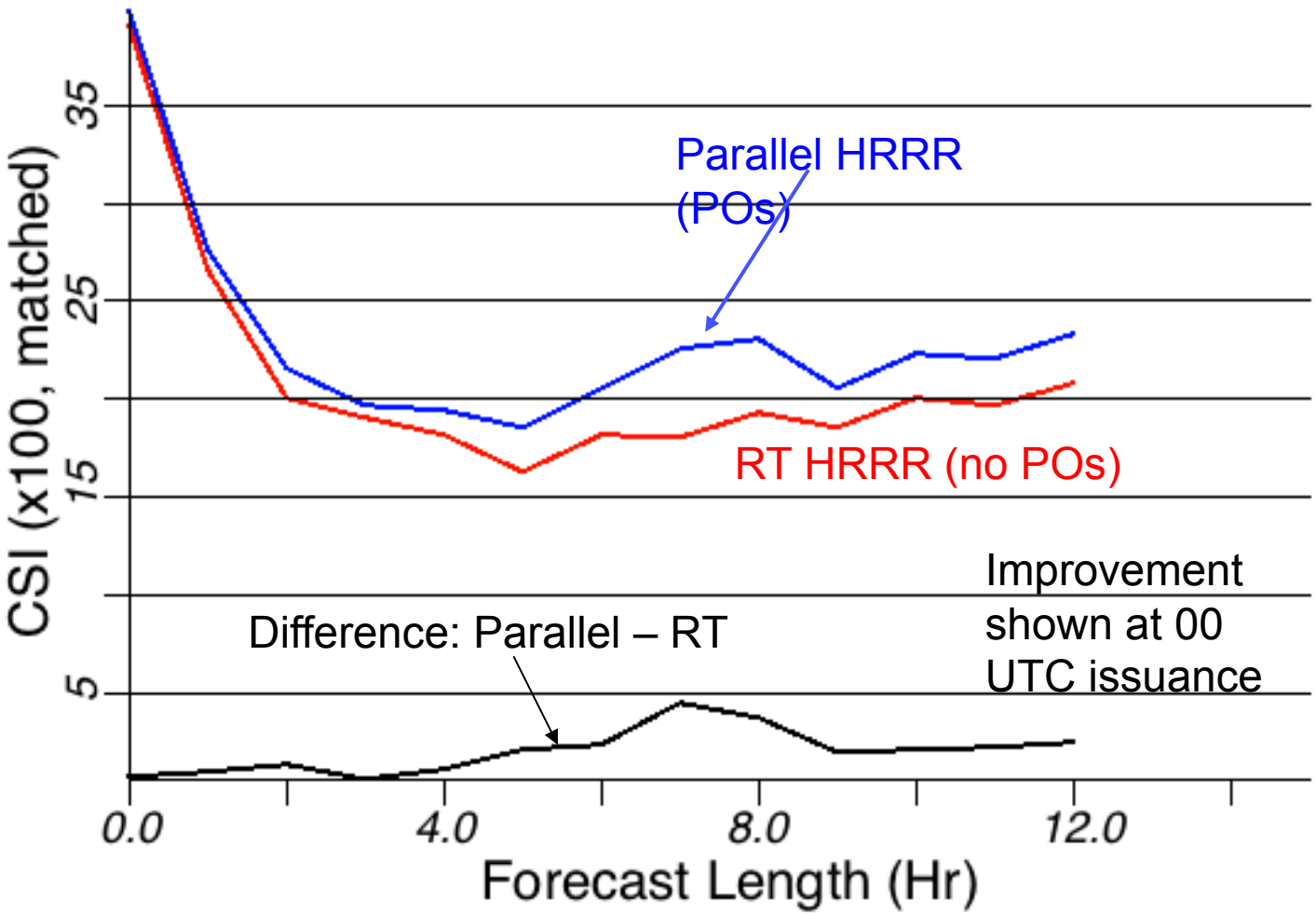


HRRR Forecast Behavior

2011

(1) Higher bias in convection over eastern US

(2) Difficulty propagating/ maintaining MCSs

(3) Lead in convective initiation (early AM runs)

(4) False alarm cases

RR/HRRR Model Development and Evaluation

2012 Targets

(1) Lower peak bias in convection over eastern US

(2) Less difficulty propagating/ maintaining MCSs

(3) Improve timing convective initiation (early AM runs)

(4) Fewer false alarm cases

"Simplistic" 13-km latent heating
WRFv3.2+ with old refl diagnostic
No 3-km data assimilation
No 3-km cloud analysis
MYJ PBL
No Shallow Cu Parameterization

Implement

"Smarter" 13-km latent heating
WRFv3.3.1 with new refl diagnostic
3-km radar data assimilation
3-km cloud analysis
MYNN PBL
Shallow Cu parameterization

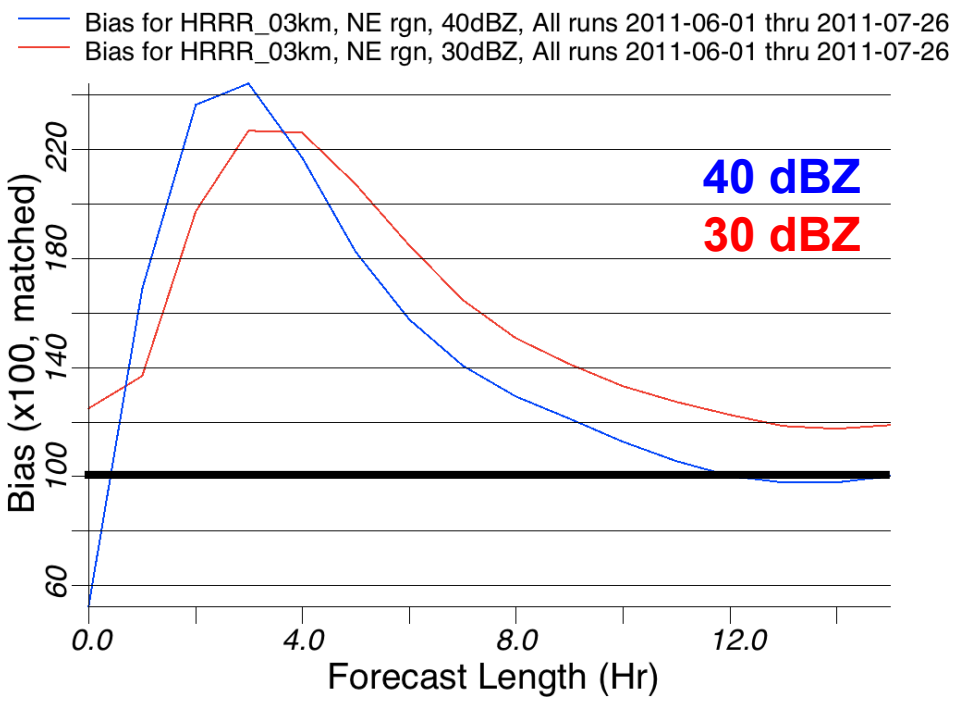
Higher Convective Bias

01 June – 26 July 2011

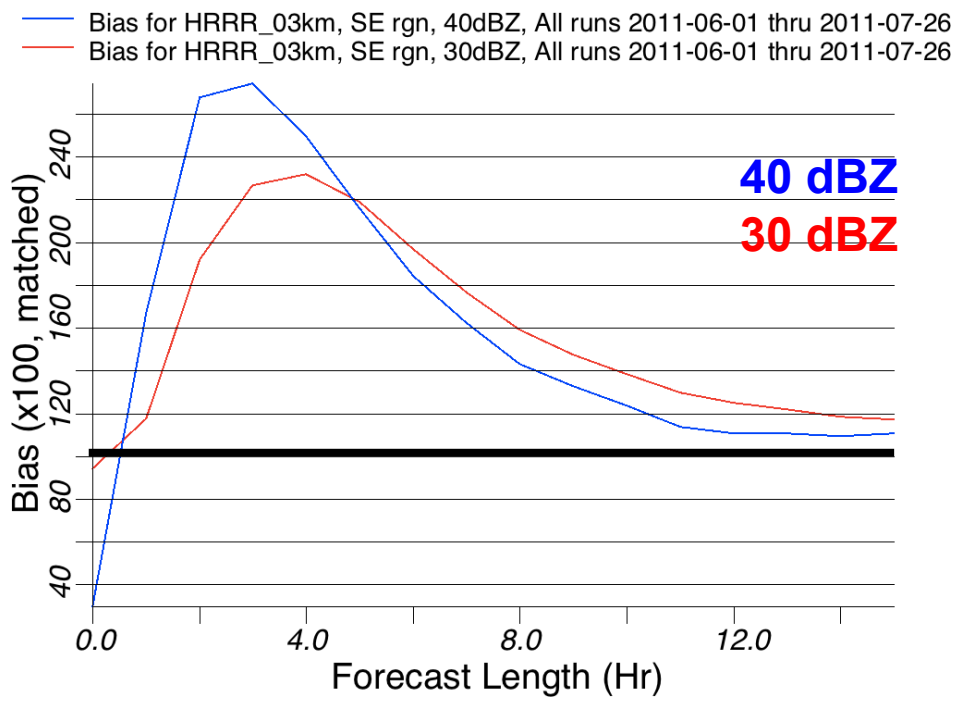
3 km Bias

All initialization times

NE

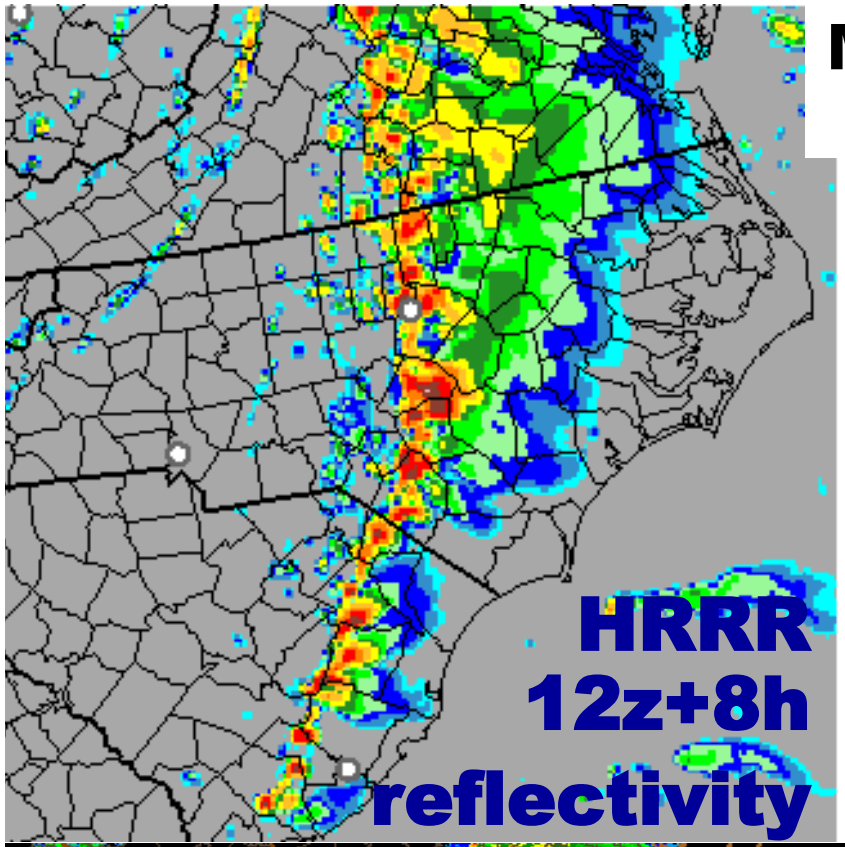


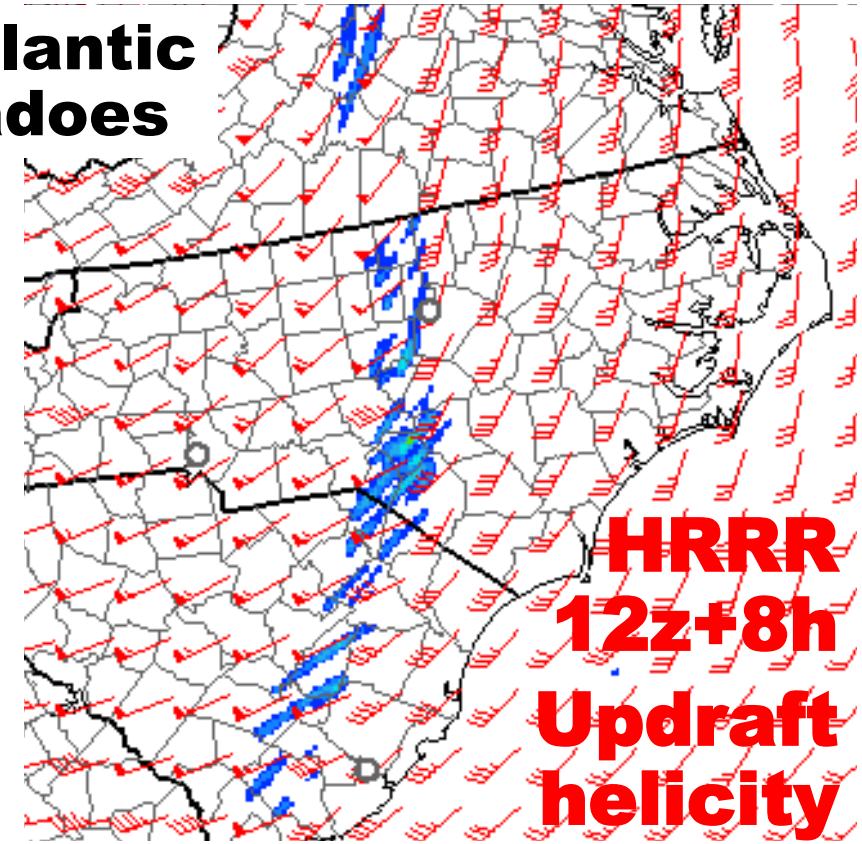
SE

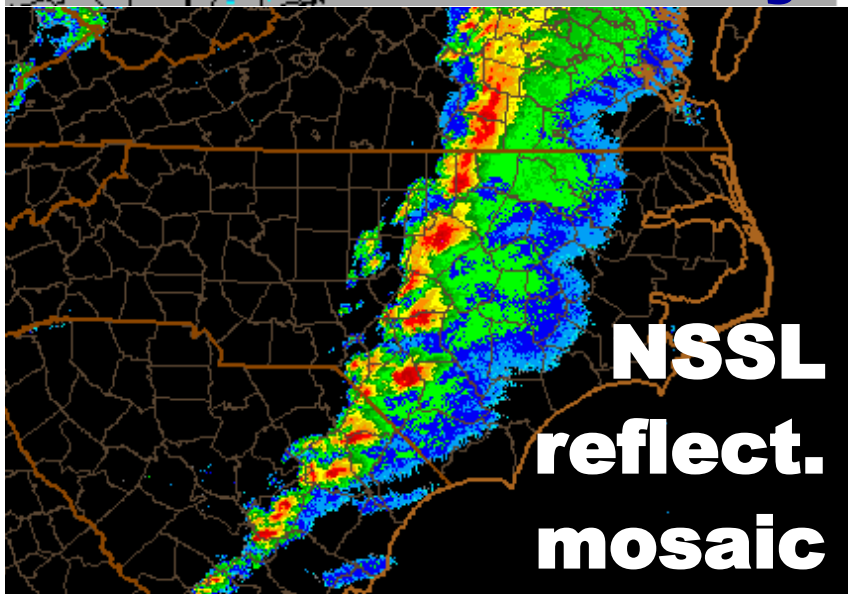


Multi-scale verification by Patrick Hofmann

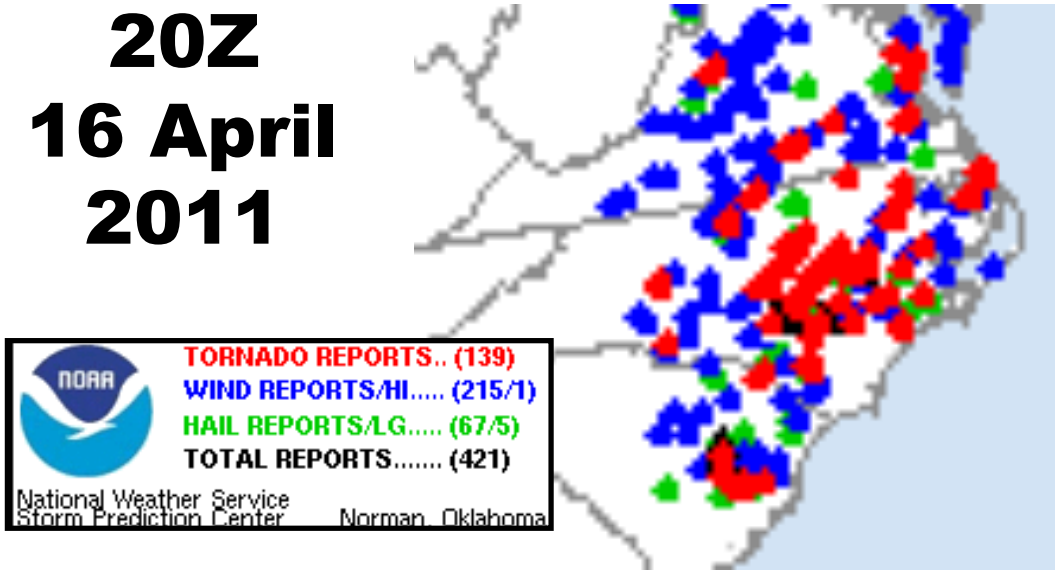
Mid-Atlantic Tornadoes





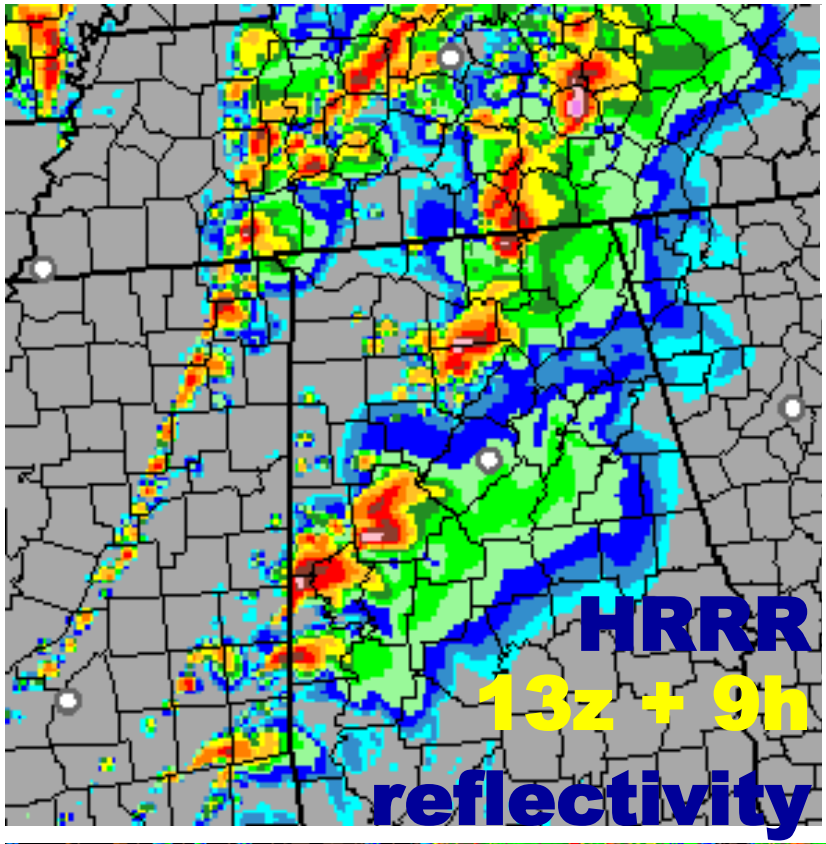


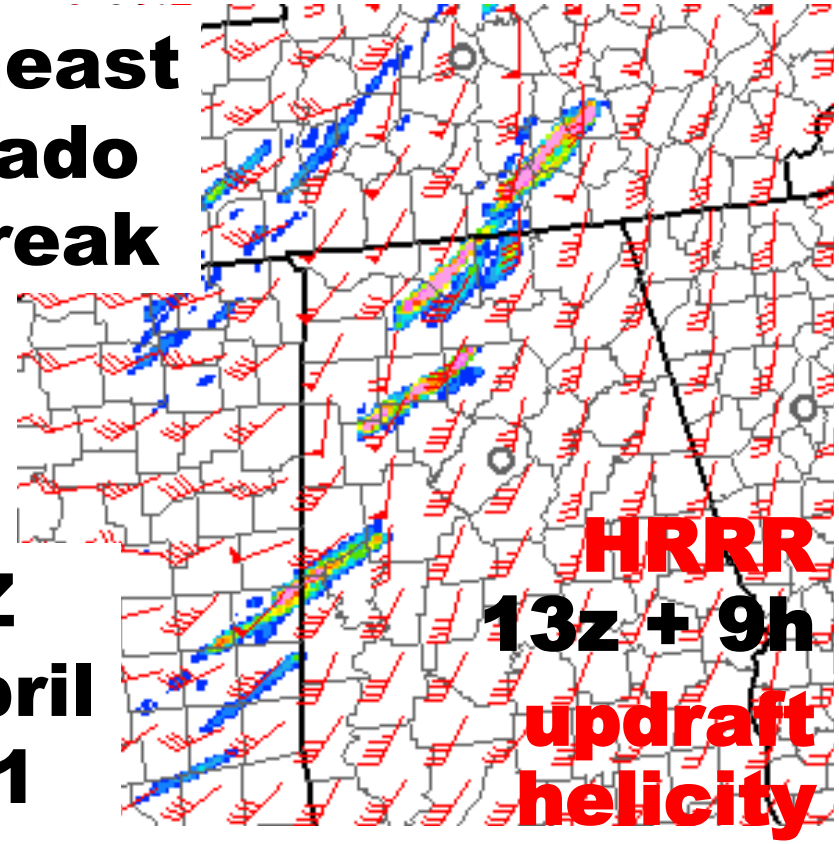
20Z
16 April
2011

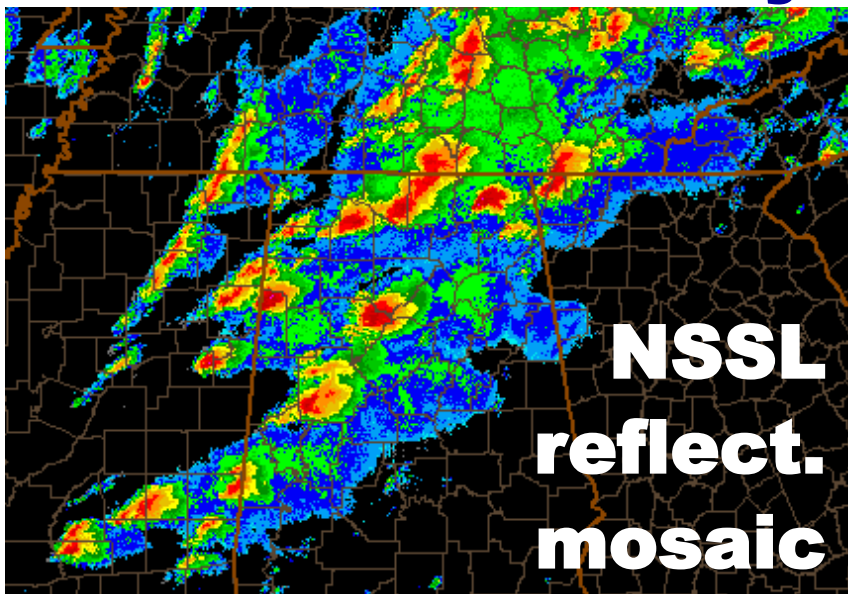


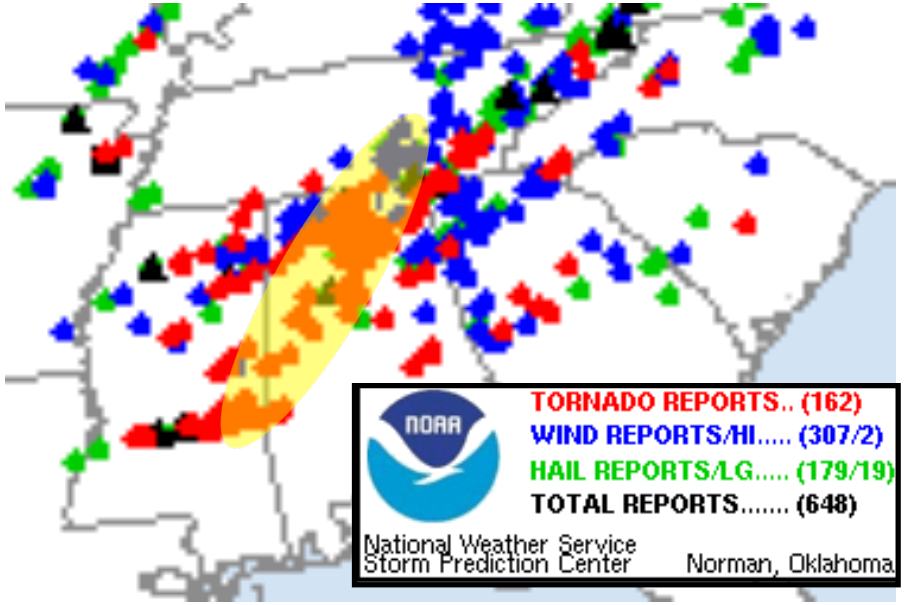
Southeast Tornado Outbreak

22Z
17 April
2011



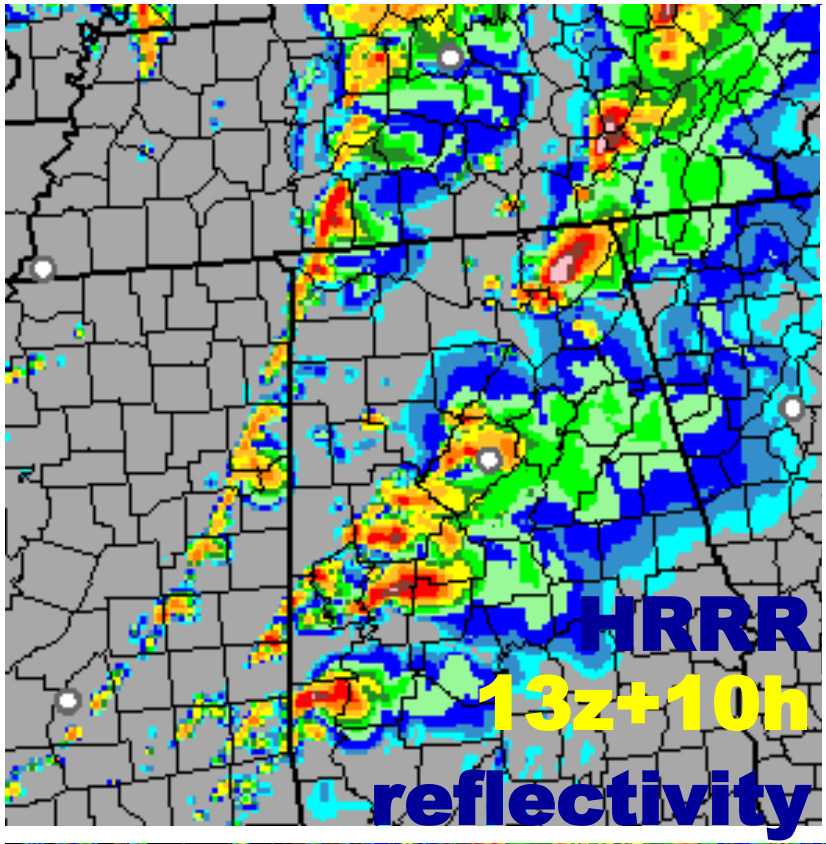


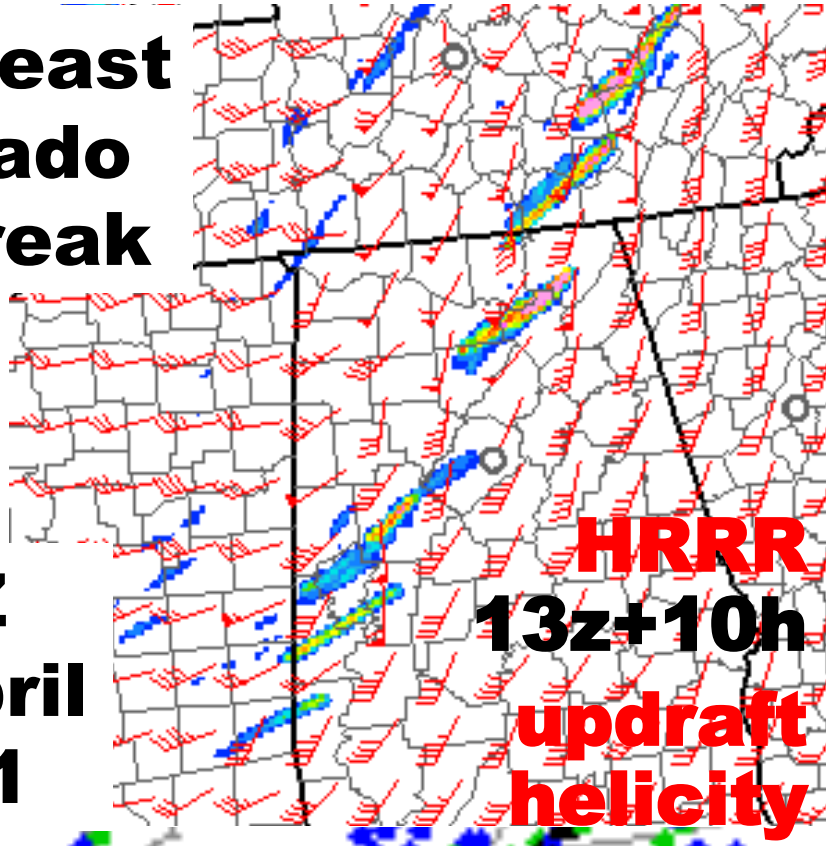


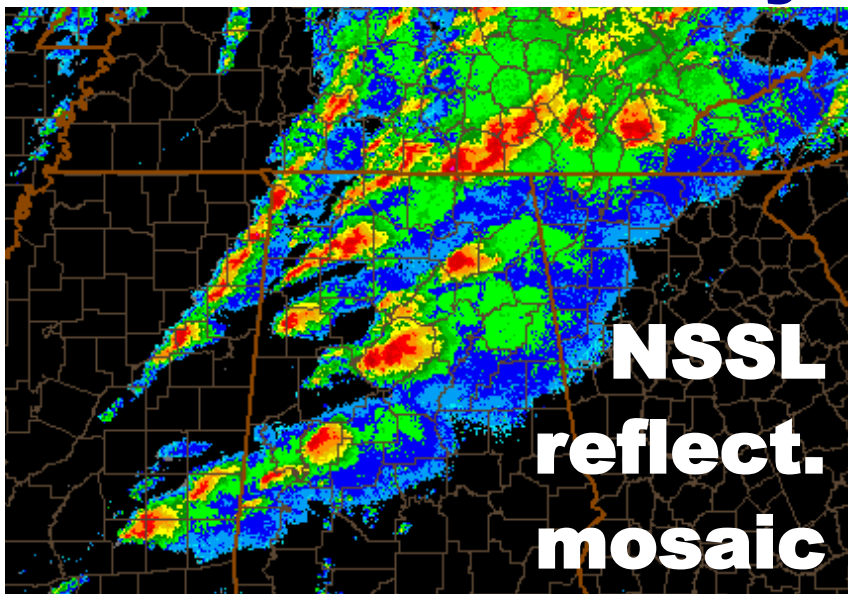


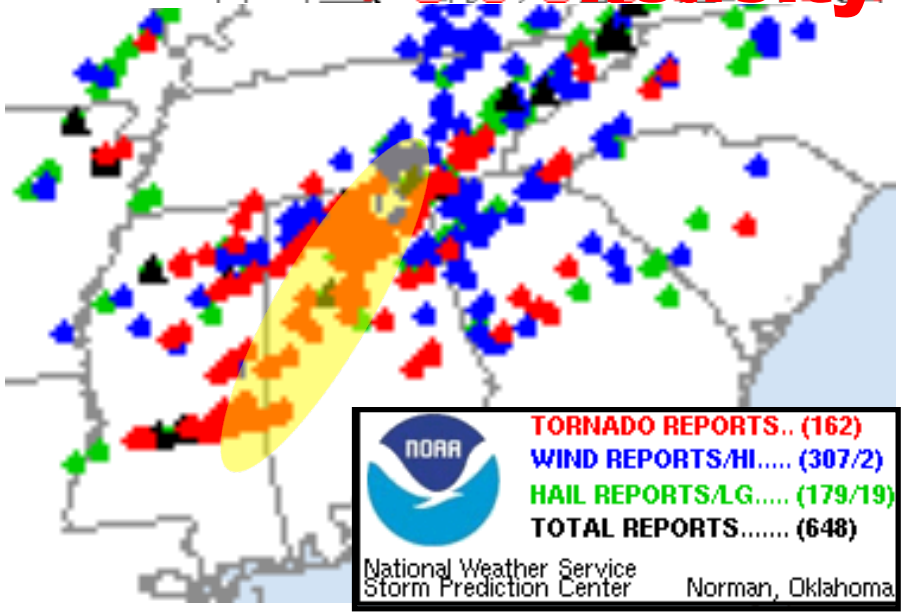
Southeast Tornado Outbreak

23Z
17 April
2011



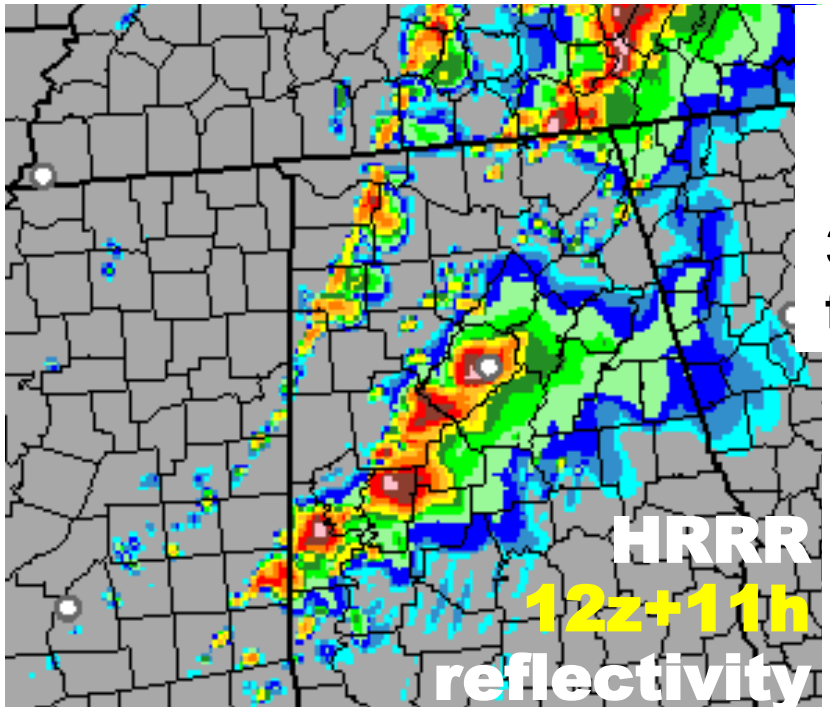


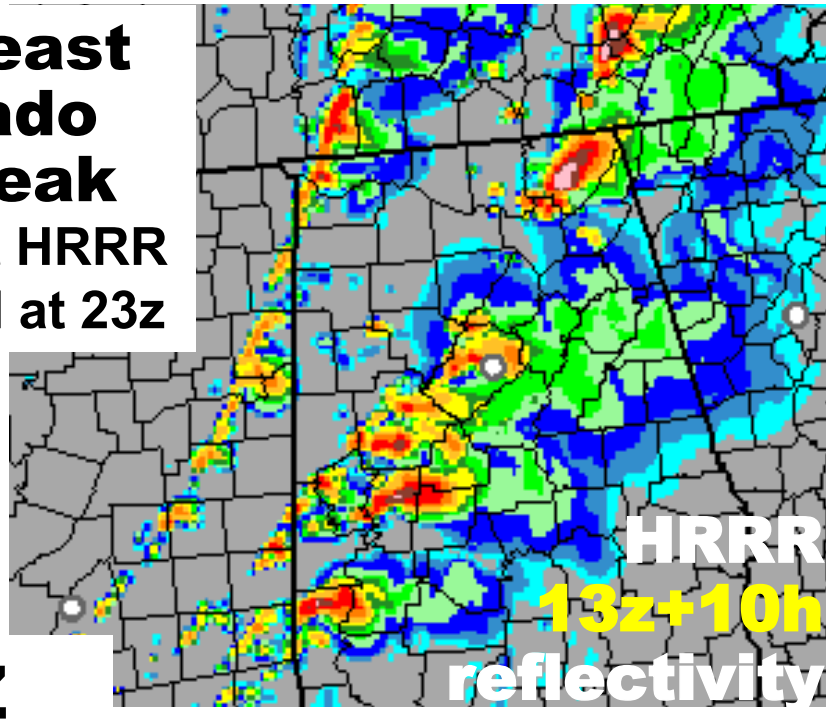




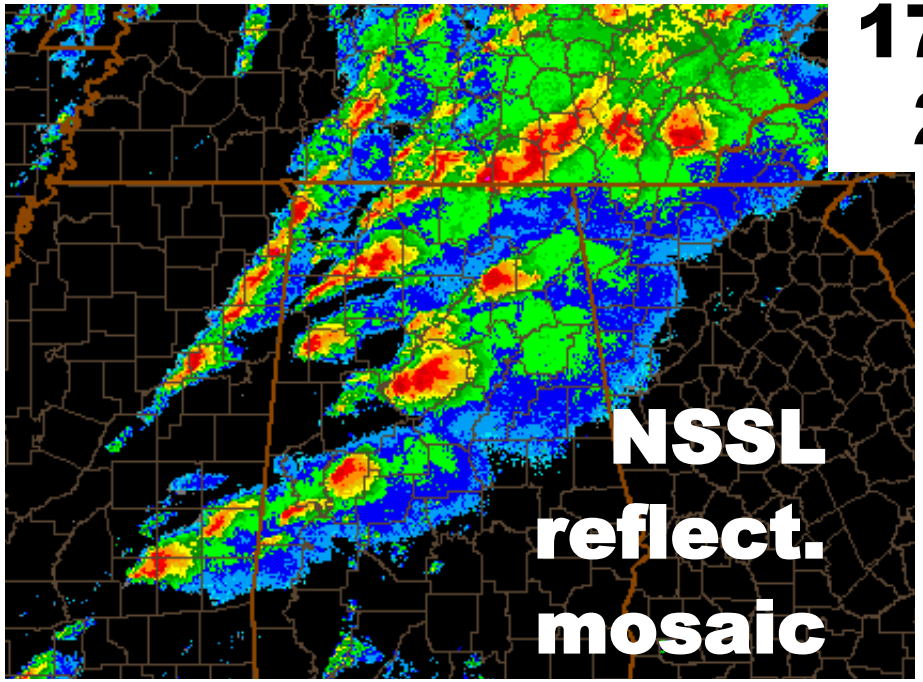
Southeast Tornado Outbreak

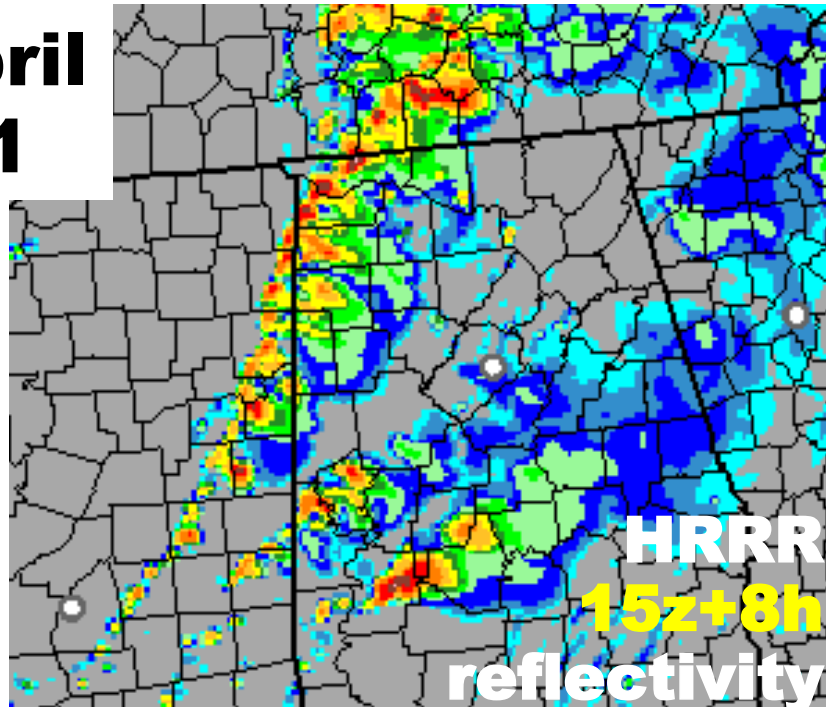
3 different HRRR fcsts valid at 23z





23Z
17 April
2011





HRRR forecasts a derecho – Improved MCS maintenance 11 Jul 2011

Confirmed Derecho From Storm Survey (7/11/2011)

PUBLIC INFORMATION STATEMENT
NATIONAL WEATHER SERVICE DES MOINES IA
458 PM CDT MON JUL 11 2011

...PRELIMINARY DAMAGE SURVEY RESULTS FOR STORY...MARSHALL AND TAMA
COUNTIES...

THIS STORM SURVEY INVESTIGATION IS STILL ONGOING AND SUBJECT TO
FURTHER COORDINATION WITH LOCAL EMERGENCY MANAGEMENT AGENCIES.

...WIDESPREAD AND EXTREME STRAIGHT LINE WIND EVENT...

THE FOLLOWING IS A PRELIMINARY ASSESSMENT FOR THE DAMAGE THAT OCCURRED OVER STORY...MARSHALL AND TAMA COUNTIES...OR FROM CENTRAL
INTO EAST CENTRAL IOWA...EARLY IN THE MORNING ON MONDAY...JULY 11...2011.

* EVENT DATE: 07/11/2011.

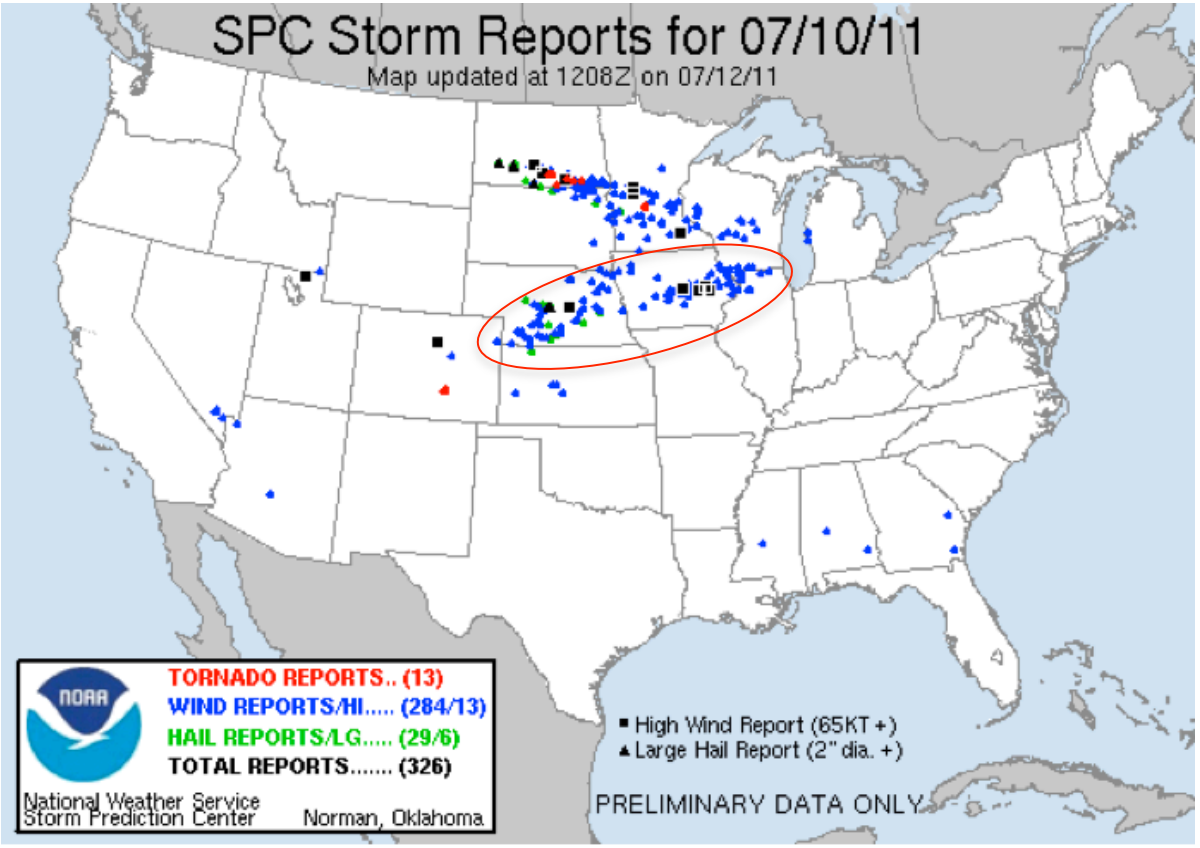
* ESTIMATED START TIME: APPROXIMATELY 320 AM CDT.

* EVENT TYPE: DERECHO. NO TORNADOES WERE INDICATED DURING THIS EVENT. THIS PARTICULAR DERECHO BEGAN IN CENTRAL IOWA AND TRAVELED ACROSS CENTRAL AND EASTERN IOWA...AS WELL AS ACROSS ILLINOIS...LAKE MICHIGAN...MICHIGAN...AND ENDED IN ONTARIO CANADA. THIS DERECHO TRAVELED FROM CENTRAL IOWA TO DETROIT MICHIGAN...OR A DISTANCE OF APPROXIMATELY 550 MILES...OVER THE TIME SPAN OF NINE HOURS. A DERECHO IS A LONG LIVED... WIDESPREAD...DAMAGING WIND STORM WHICH IS ASSOCIATED WITH RAPIDLY MOVING SHOWERS AND THUNDERSTORMS. DERECHOES ARE OFTEN CURVED OR BOWED IN THEIR SHAPE. WINDS IN DERECHOES CAN EXCEED 100 MPH. THE WINDS ASSOCIATED WITH DERECHOES ARE NOT CONSTANT AND MAY VARY CONSIDERABLY ALONG THEIR PATHS.

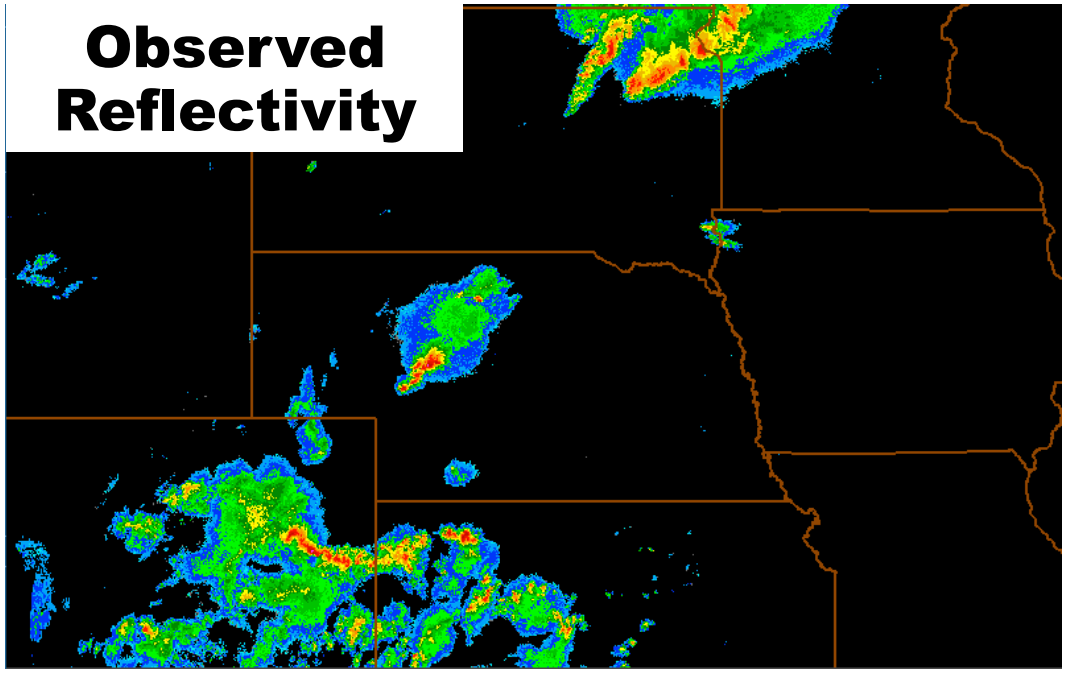
* EVENT LOCATION: BEGAN JUST WEST OF INTERSTATE 35 IN SOUTHERN STORY AND NORTHERN POLK COUNTIES. CONTINUED EASTWARD INTO MARSHALL AND TAMA COUNTIES.

* PEAK WIND: THE HIGHEST WINDS WERE AT LEAST 80 TO 105 MPH.

* PATH WIDTH: THE PATH WIDTH OF THE STRONGEST...HIGH-END WINDS WAS IN TAMA COUNTY AND WAS 5 MILES WIDE. IN ADDITION... THERE WAS A 10 MILE WIDE PATH OF WIND SPEEDS OF 70 TO 80 MPH.



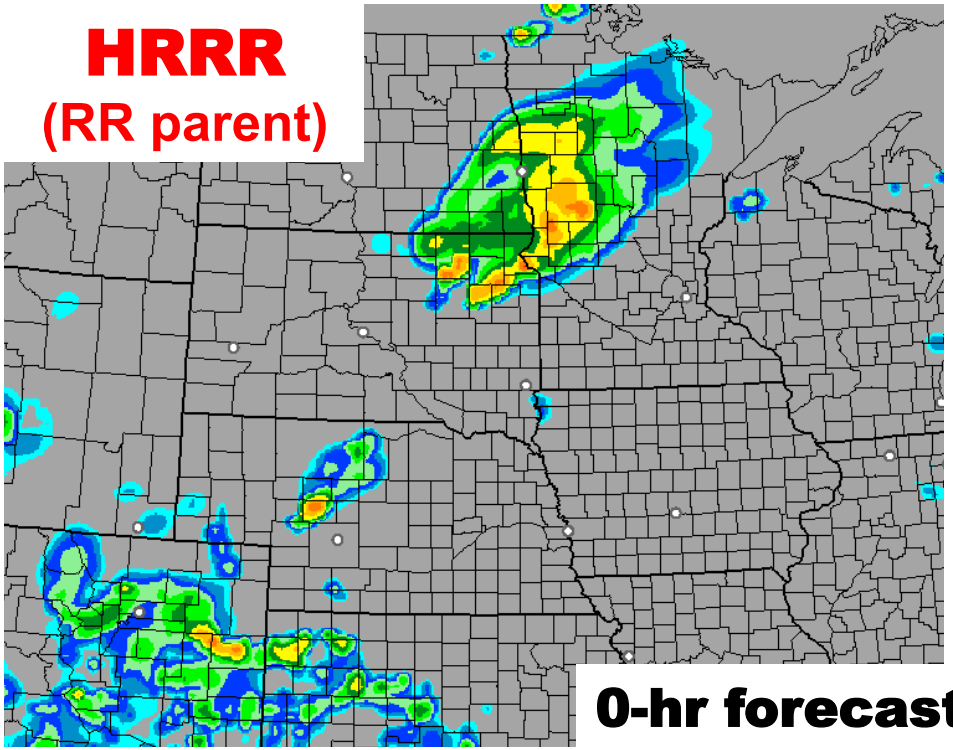
Note: damage swath continued east to the mid-Atlantic after 12z 11 Jul

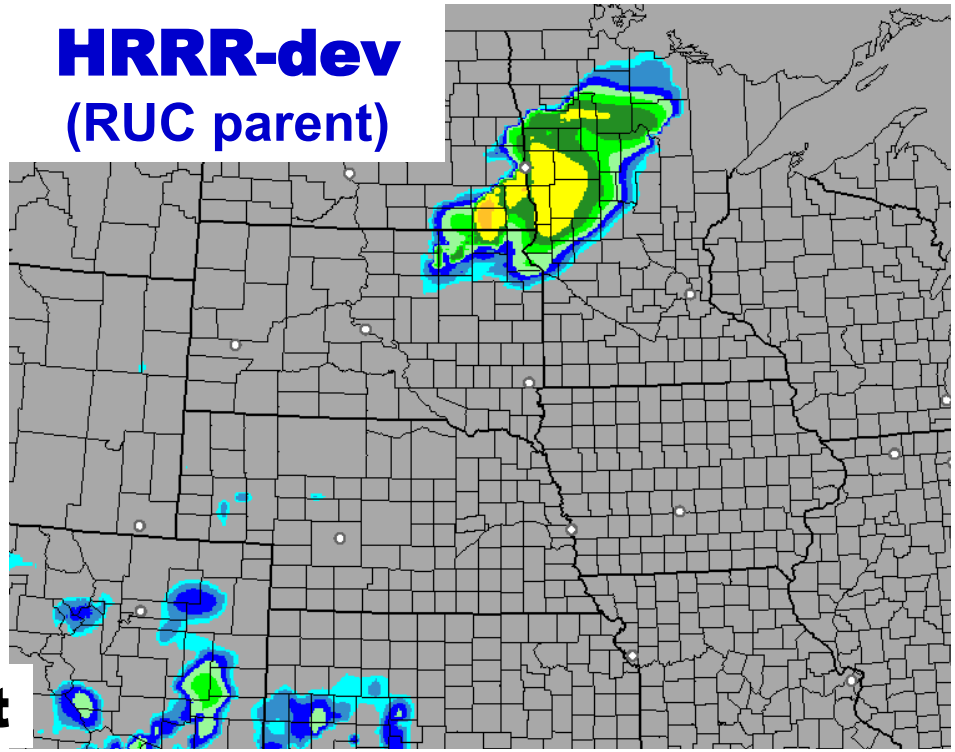


00Z 11 Jul 11

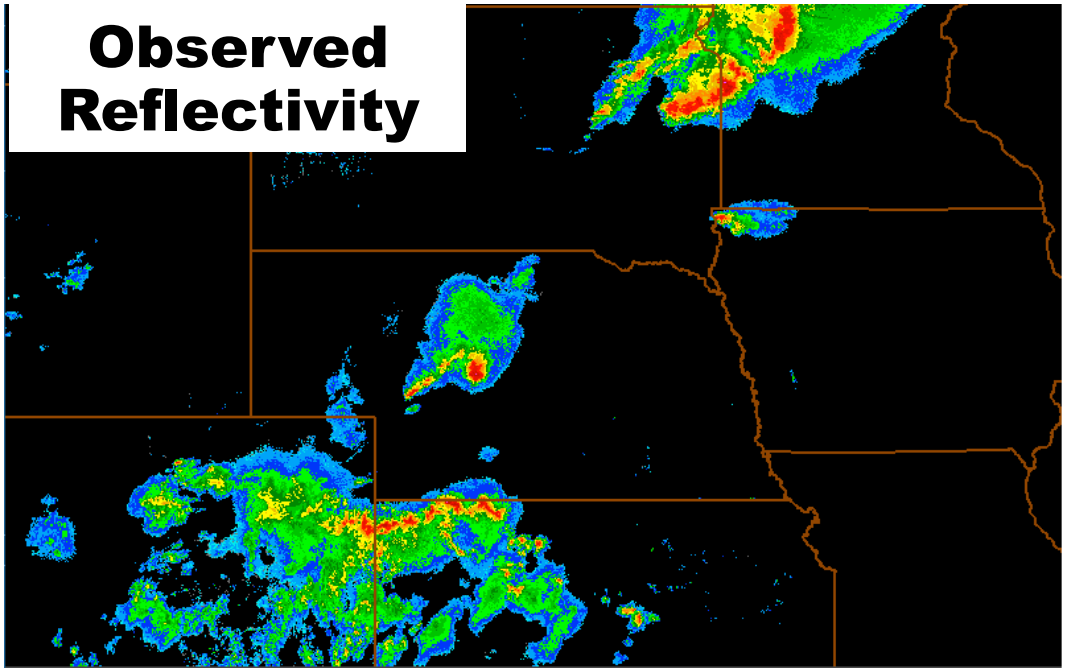
Real-time HRRR forecast
Initialized from RR
(2011 configuration)

HRRR-dev forecast
Initialized from RUC
(2010 configuration)





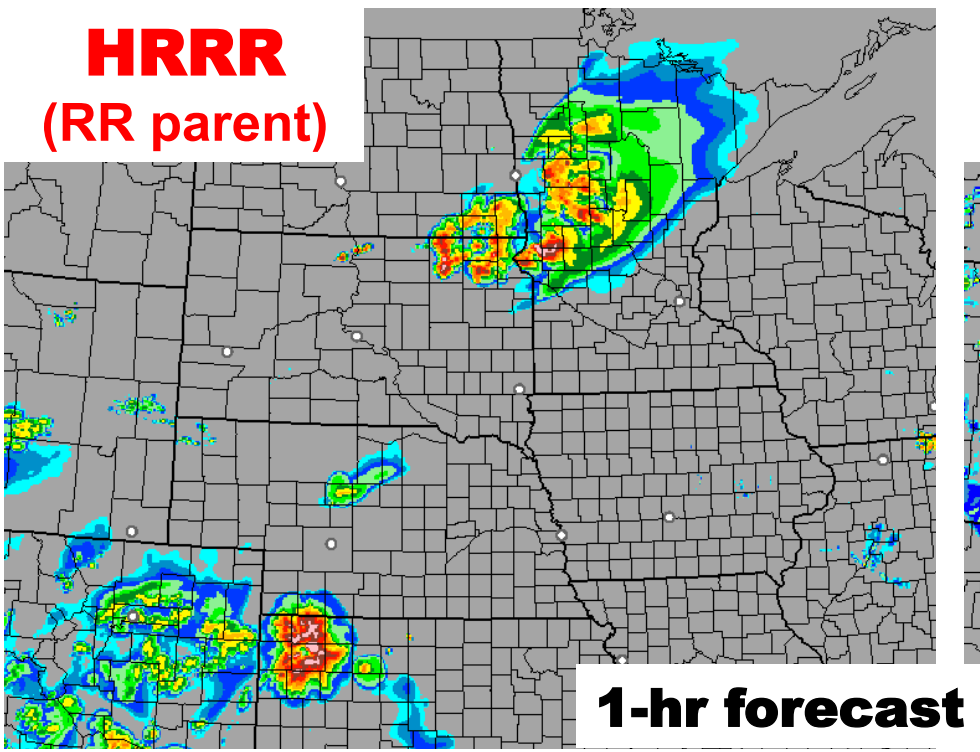
0-hr forecast

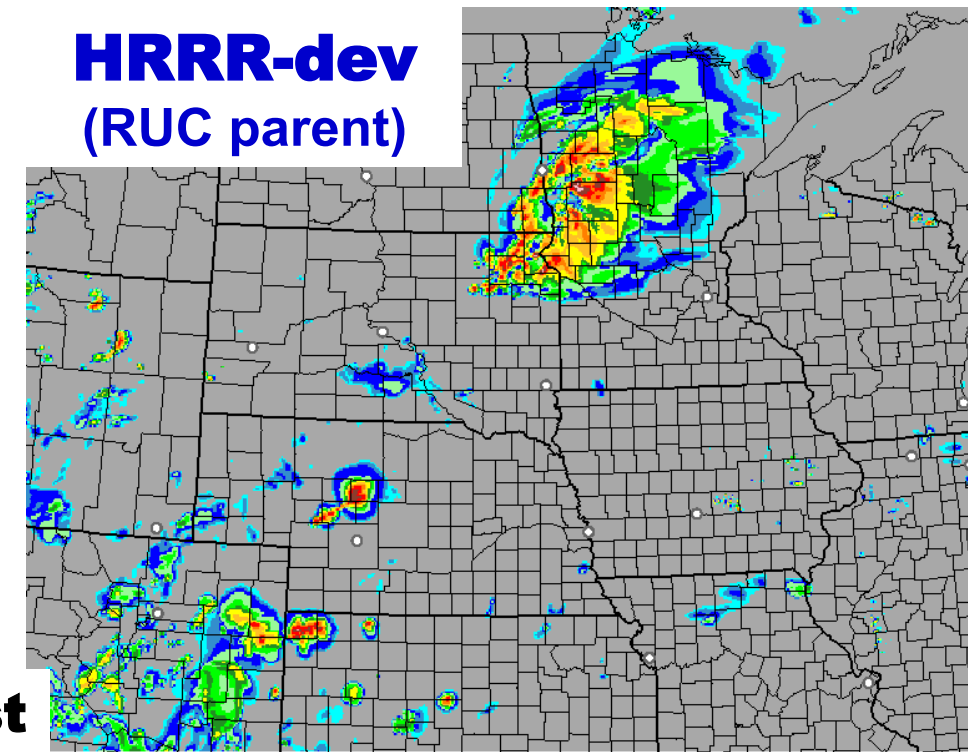


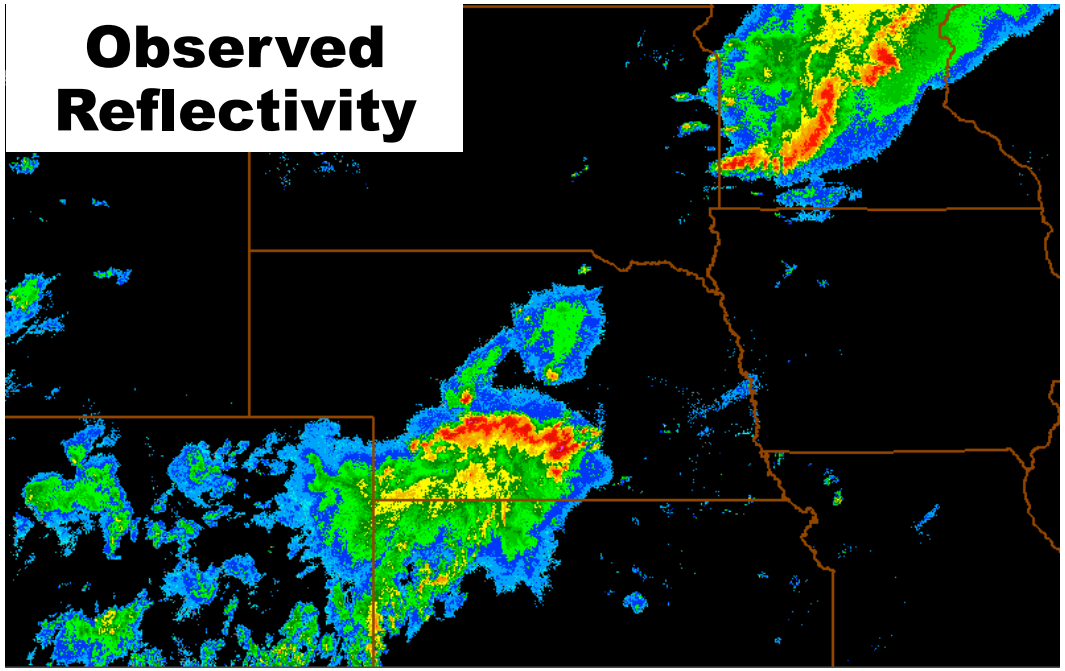
01Z 11 Jul 11

Real-time HRRR forecast
Initialized from RR
(2011 configuration)

HRRR-dev forecast
Initialized from RUC
(2010 configuration)







03Z 11 Jul 11

Real-time HRRR forecast
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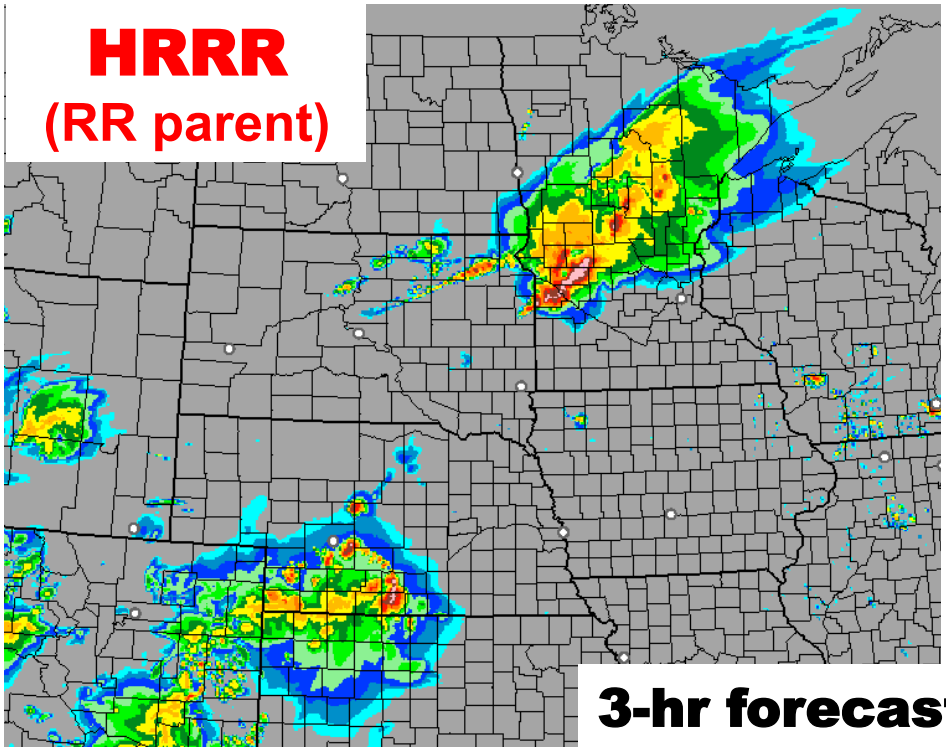
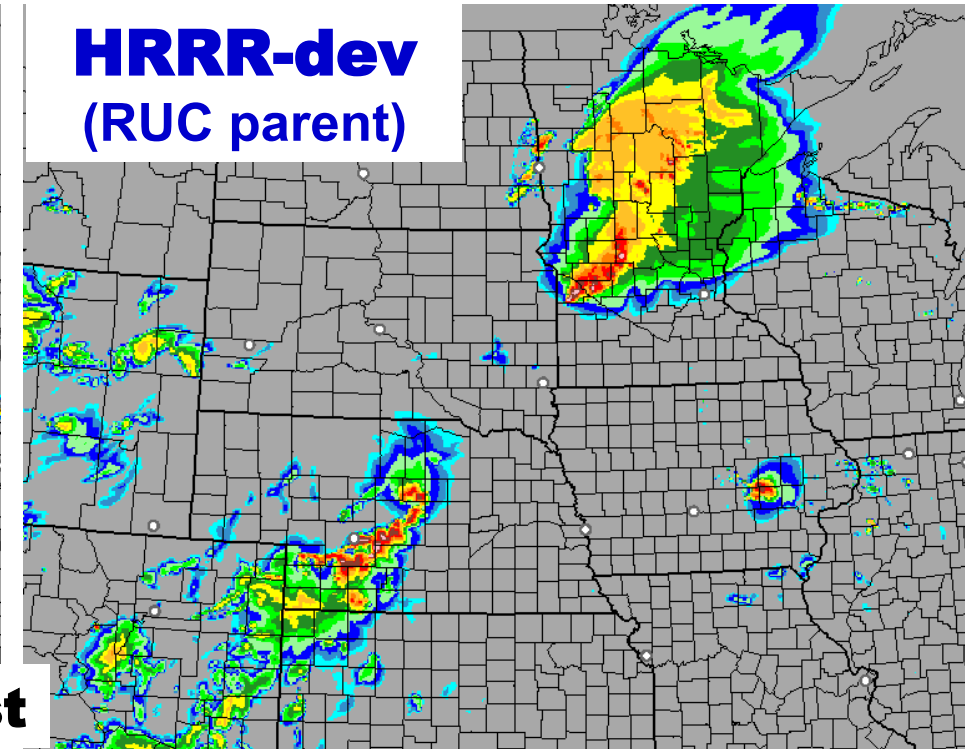
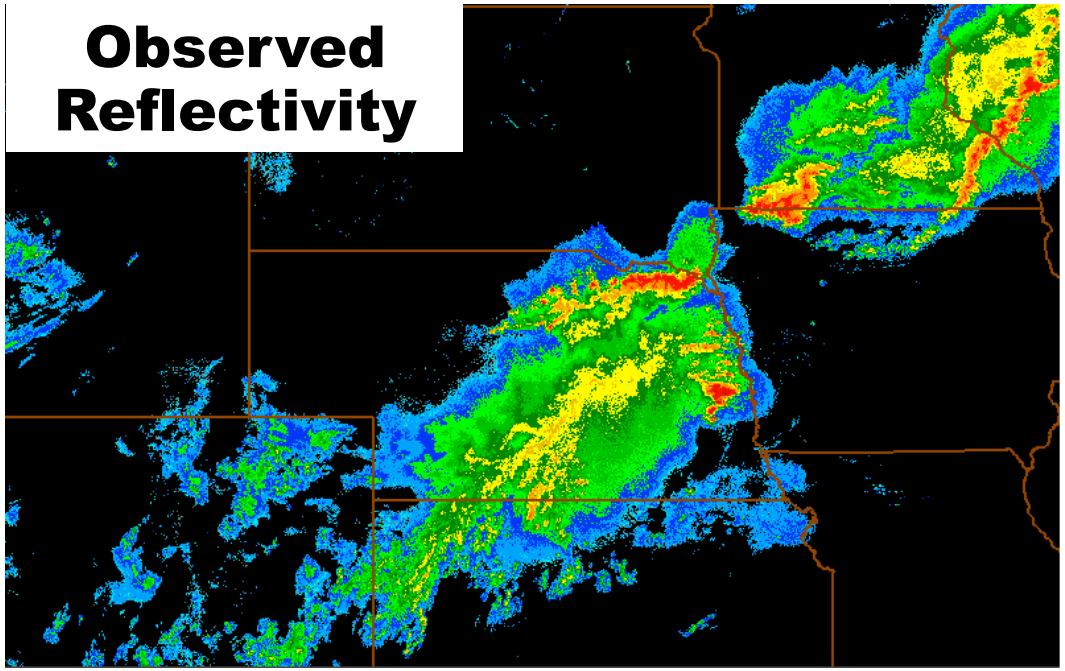
(2011 configuration)

HRRR-dev forecast
Initialized from RUC
(2010 configuration)





3-hr forecast



06Z 11 Jul 11

Real-time HRRR forecast
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(2011 configuration)

HRRR-dev forecast
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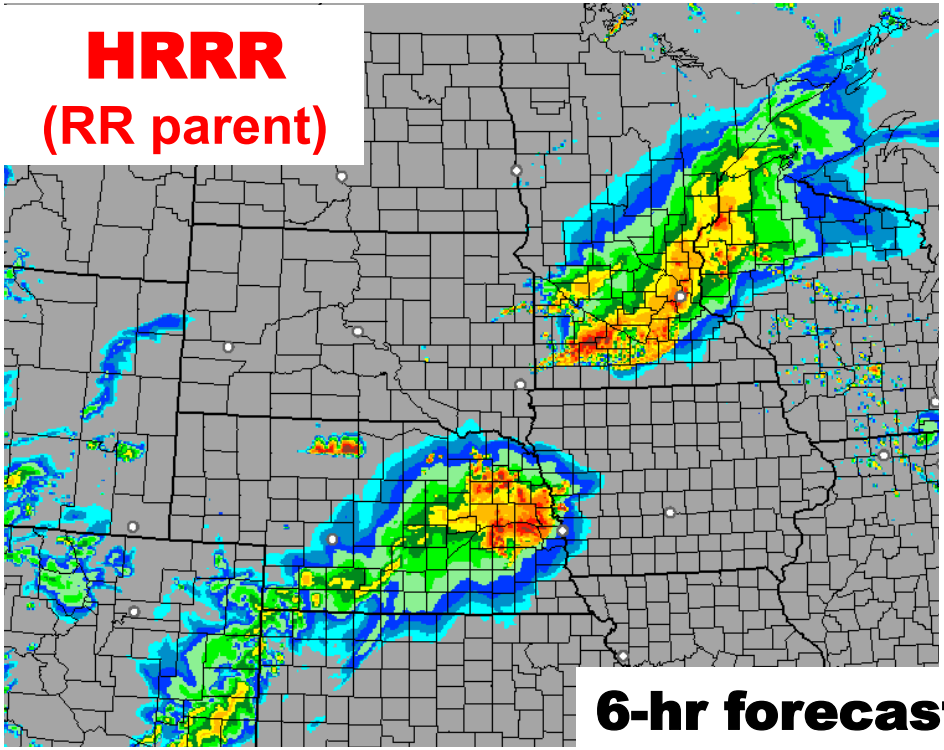
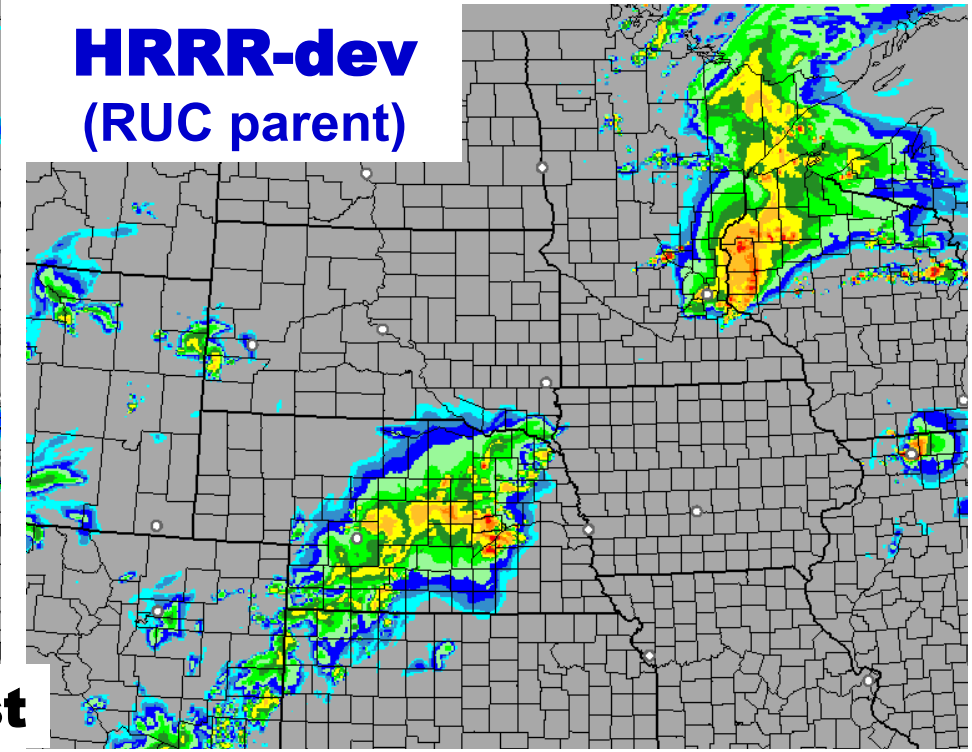
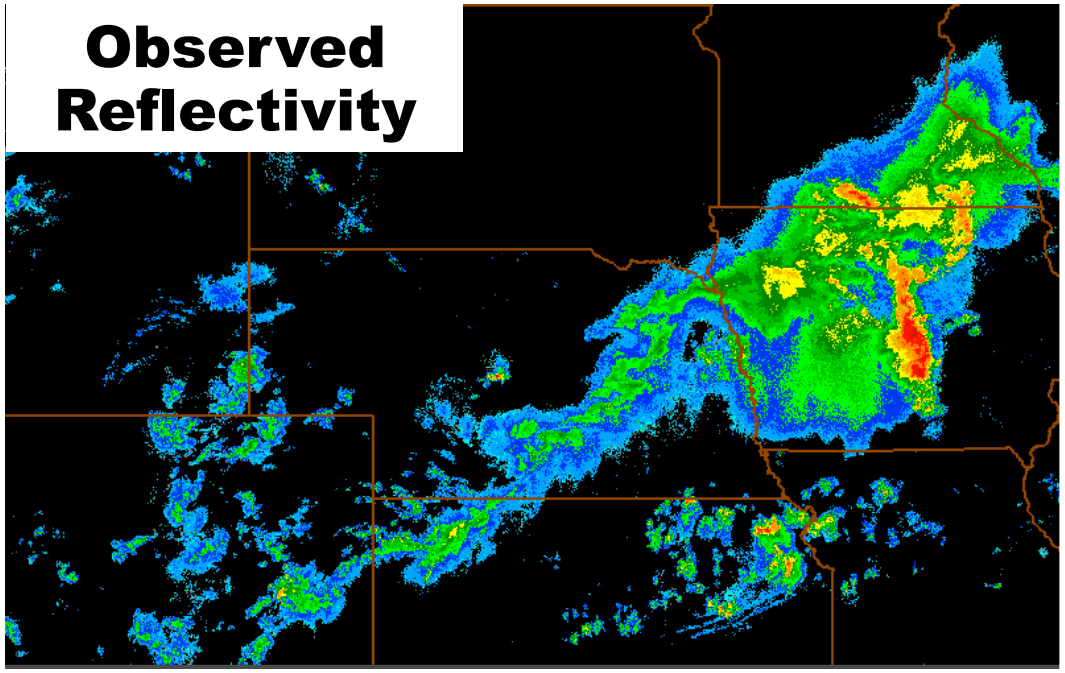
(2010 configuration)





6-hr forecast



09Z 11 Jul 11

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(2011 configuration)

HRRR-dev forecast
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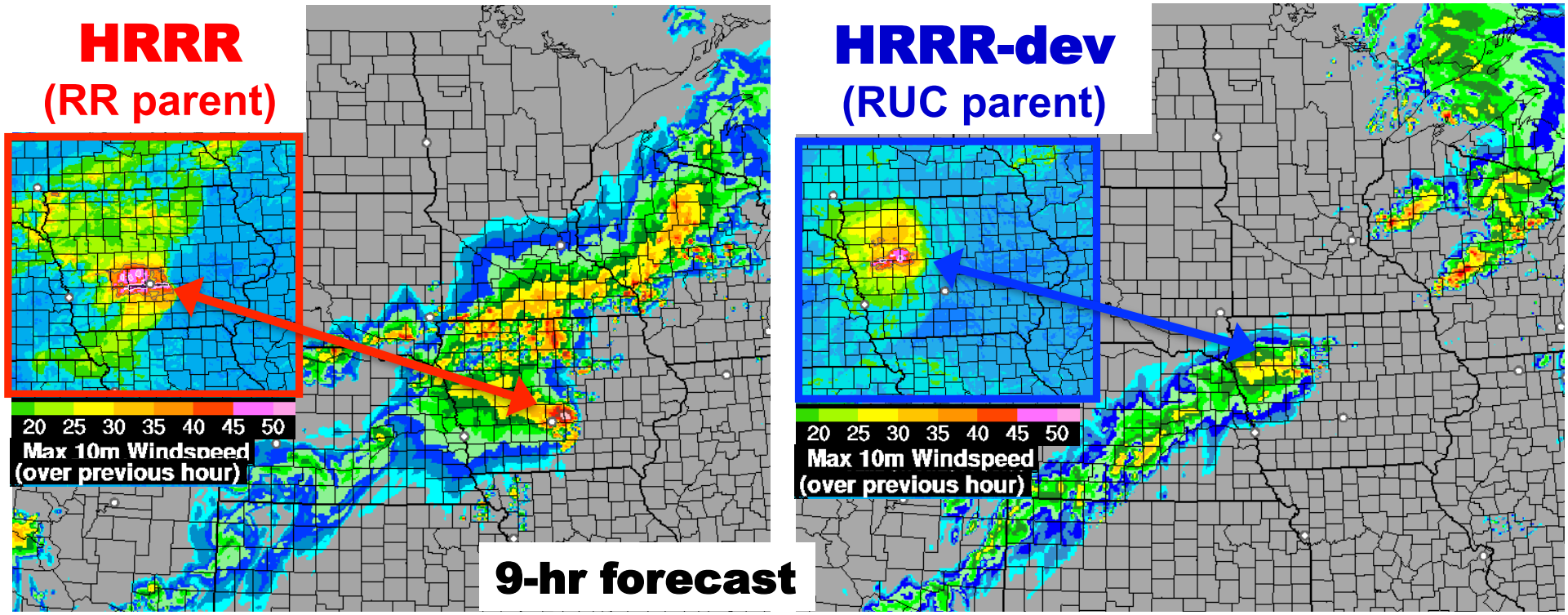
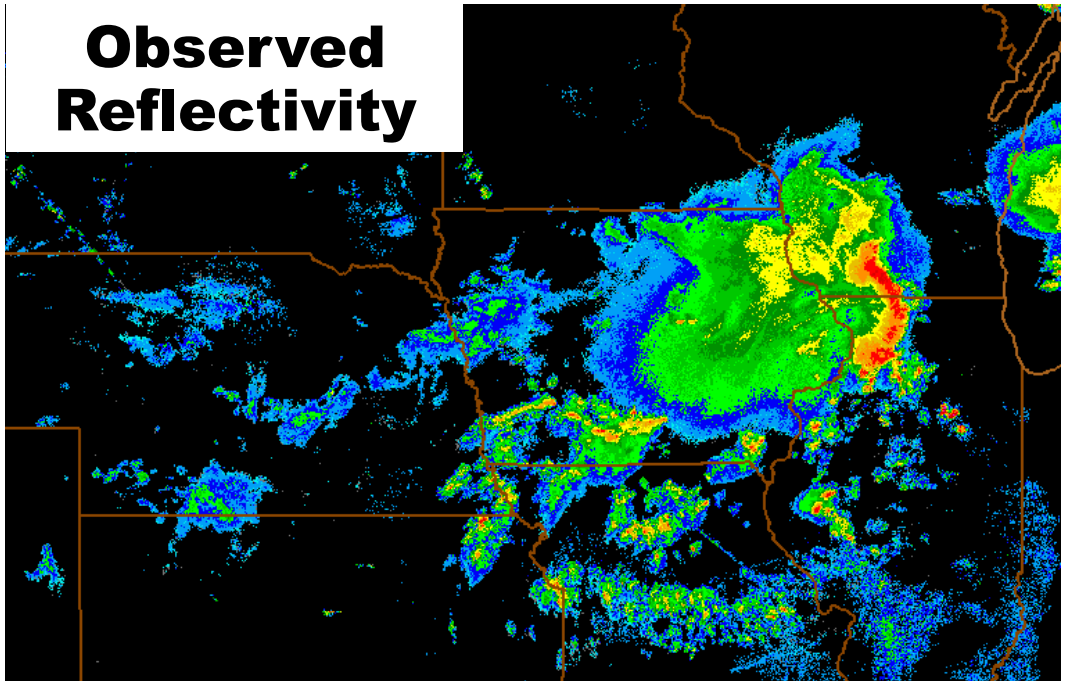
(2010 configuration)





12Z 11 Jul 11

Real-time HRRR forecast
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(2011 configuration)

HRRR-dev forecast
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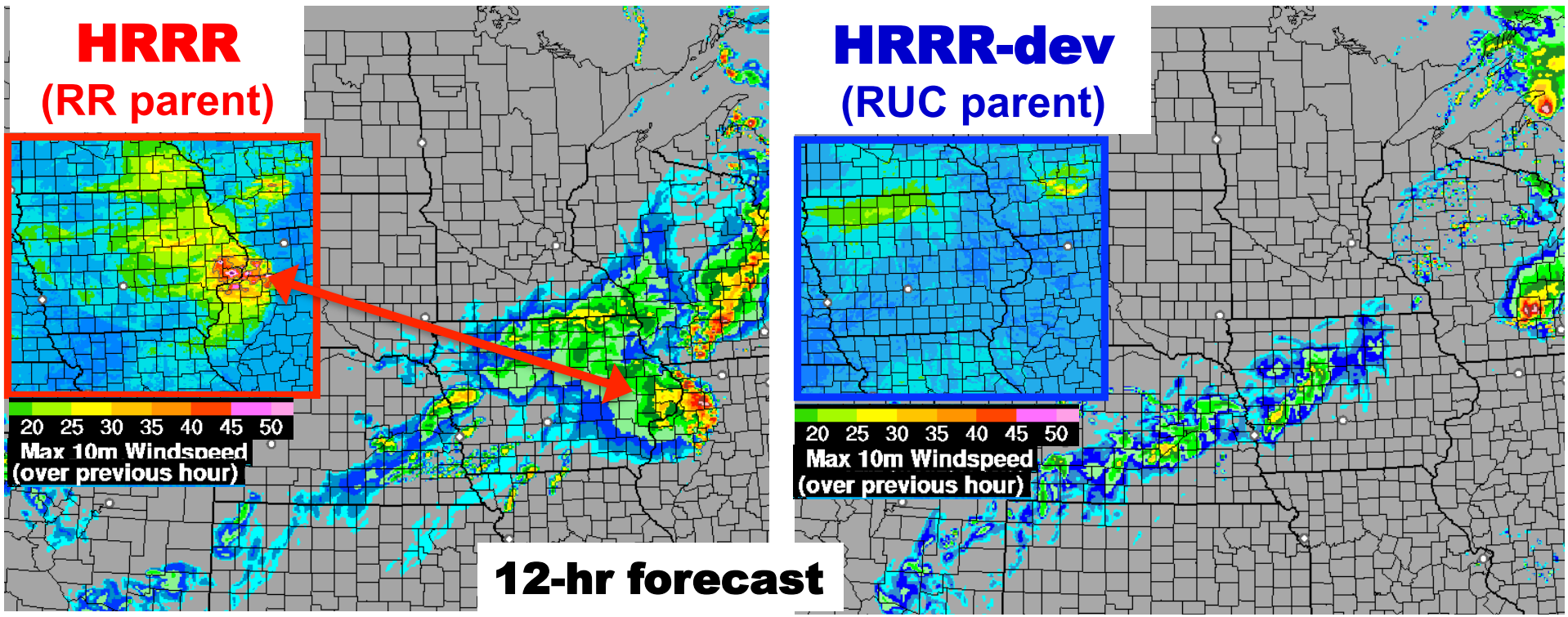
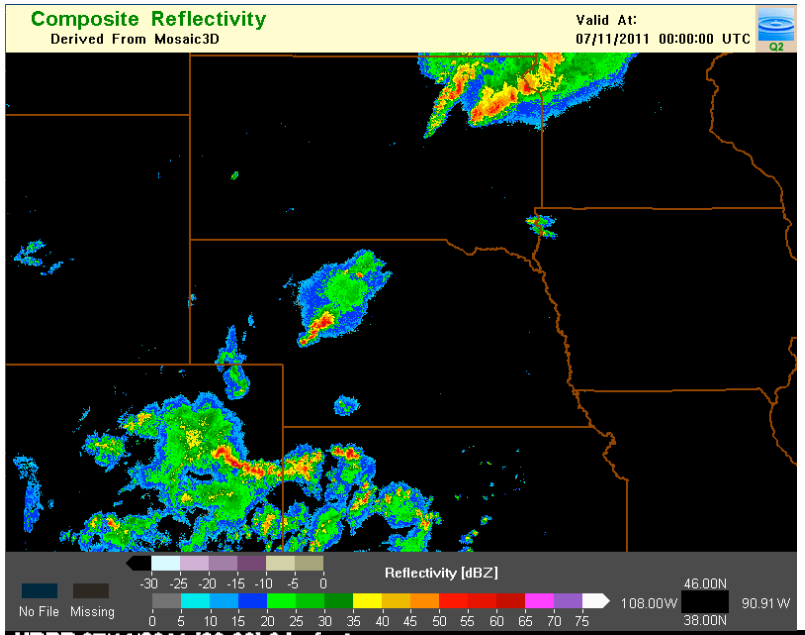
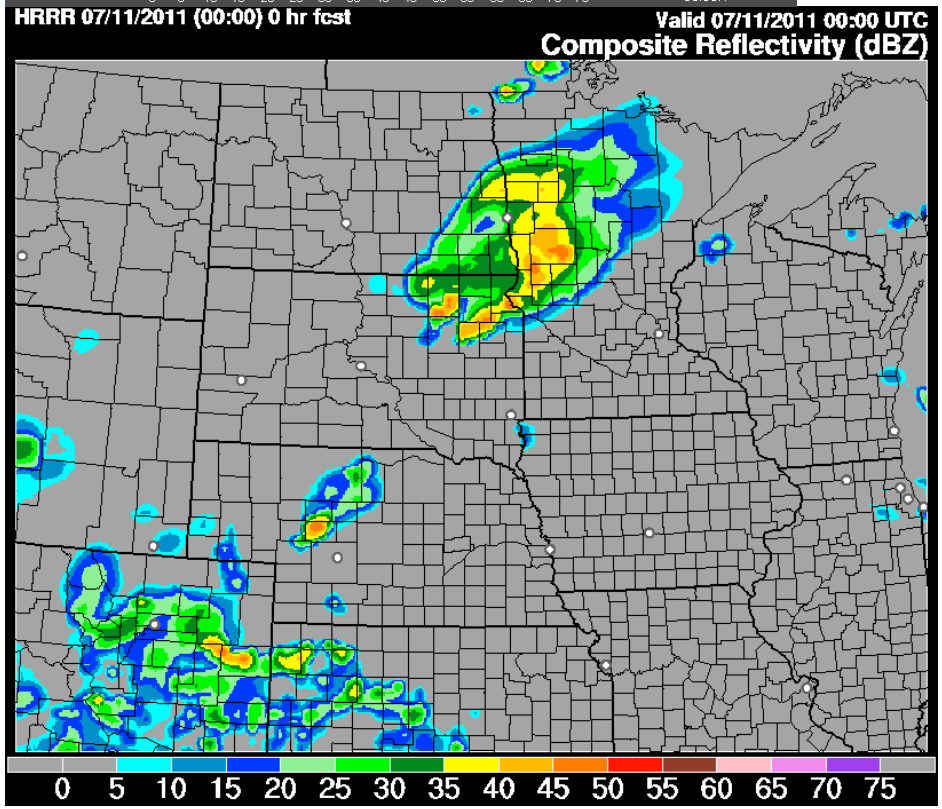


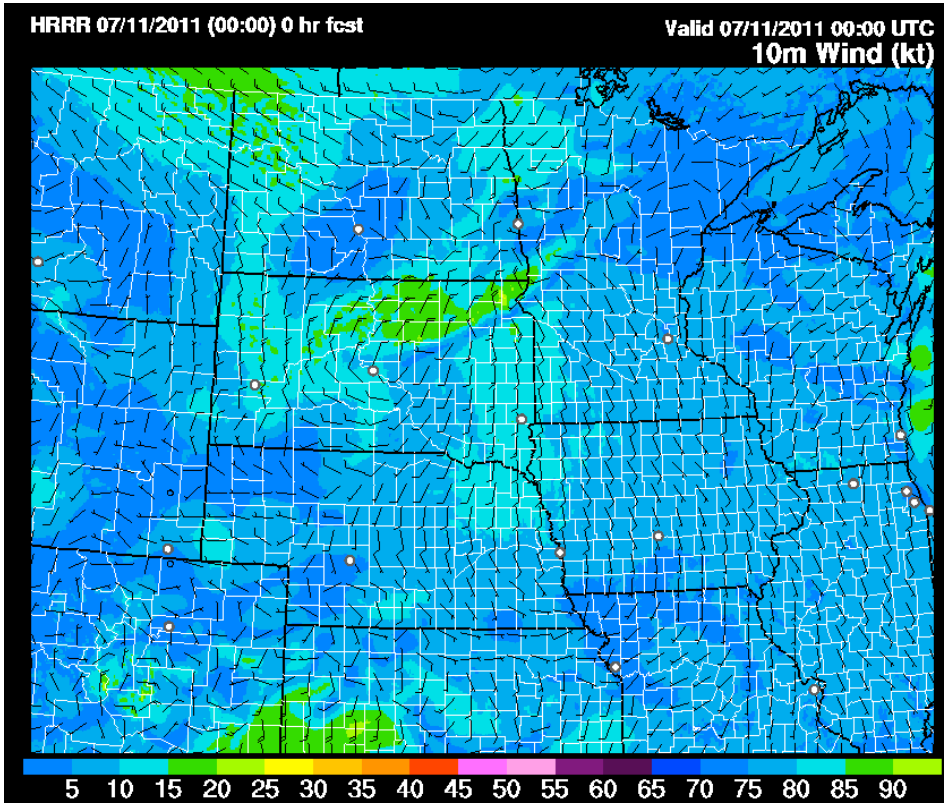


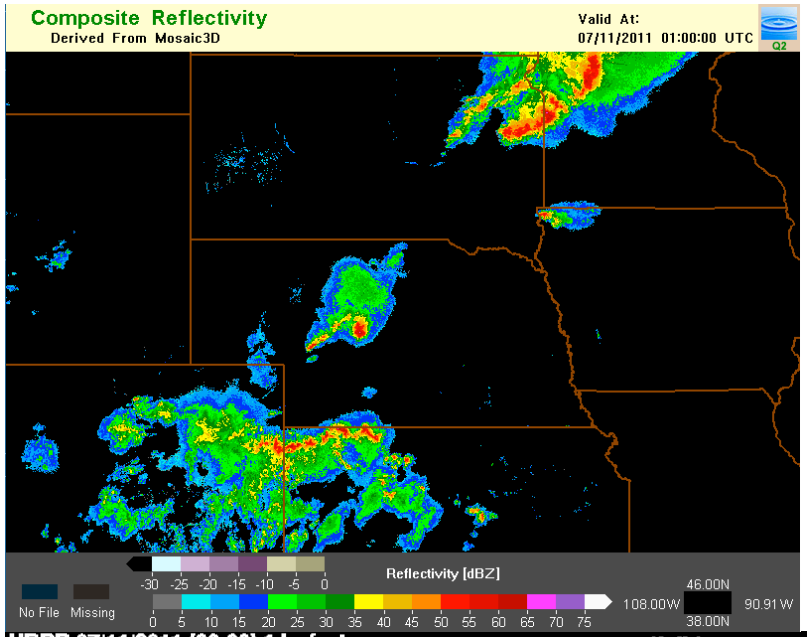
00Z 11 Jul 11

00Z 11 Jul 11 – run initial time

Real-time HRRR forecast
Initialized from RR
(2011 configuration)



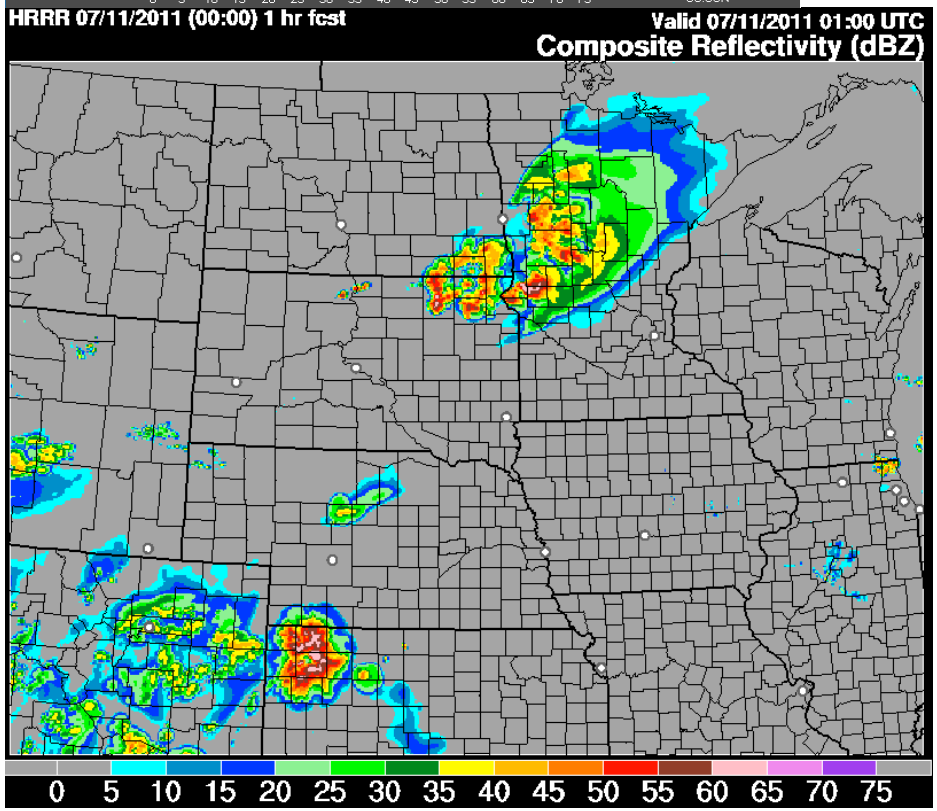


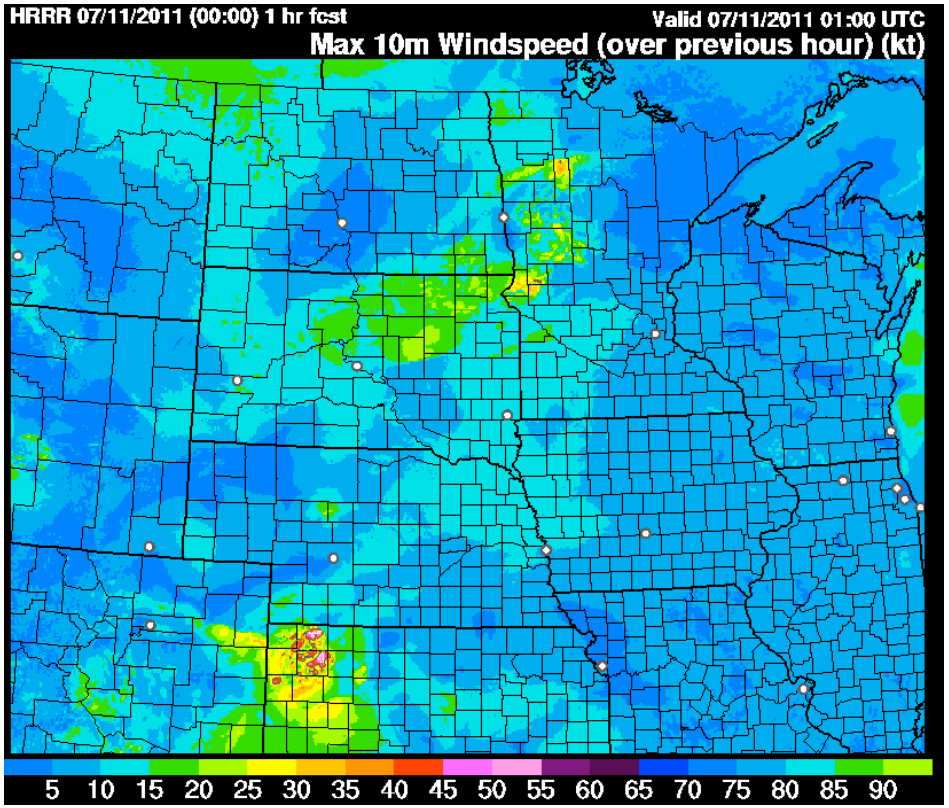


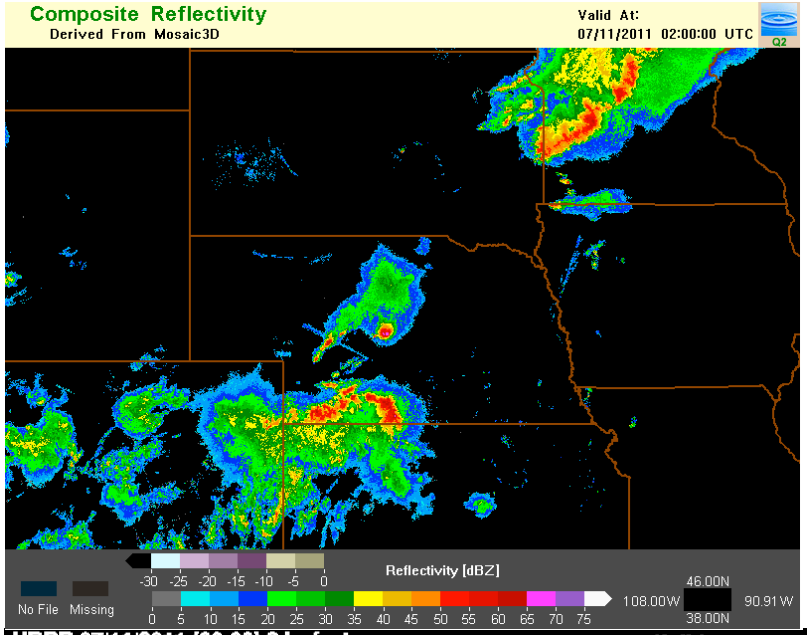
01Z 11 Jul 11

00Z 11 Jul 11 – run initial time

Real-time HRRR forecast
Initialized from RR
(2011 configuration)



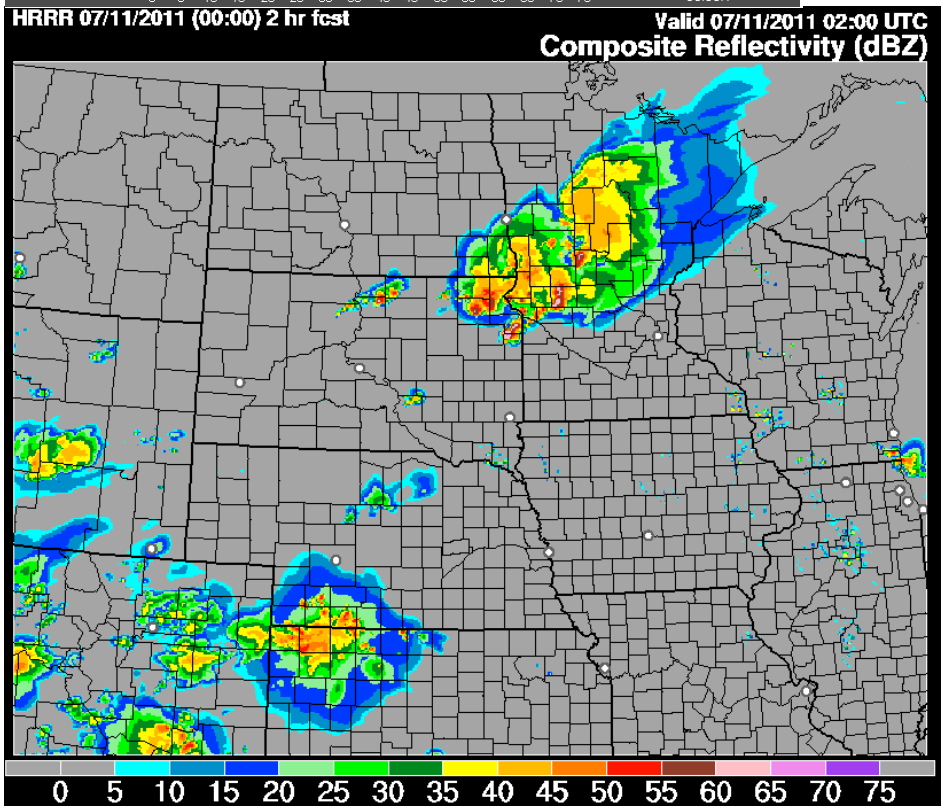


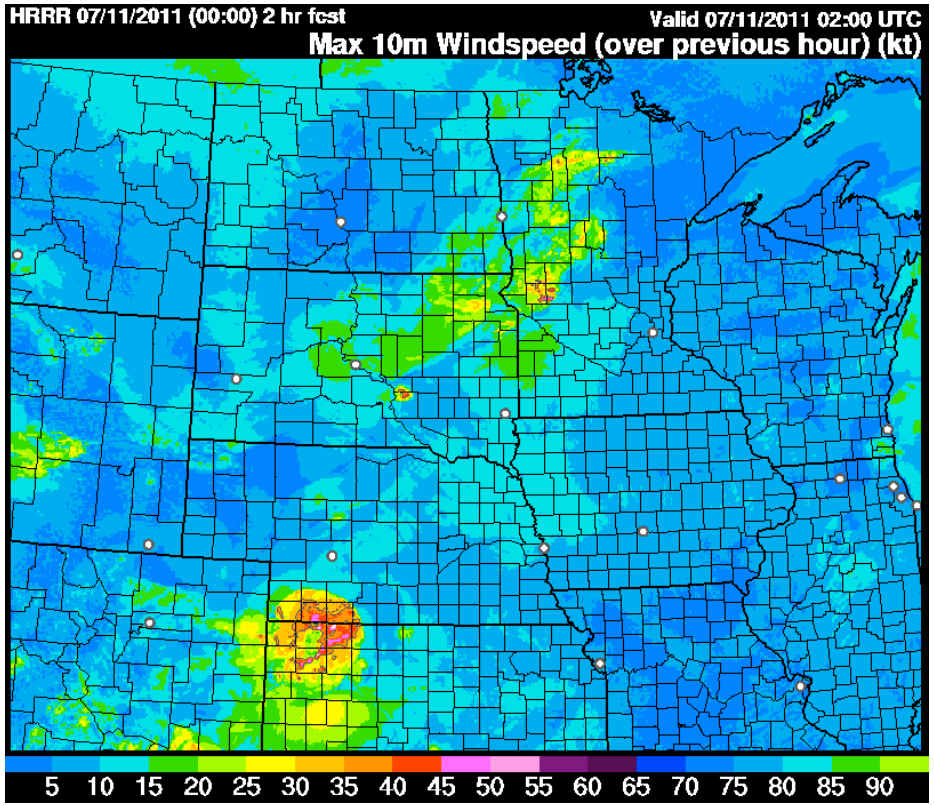


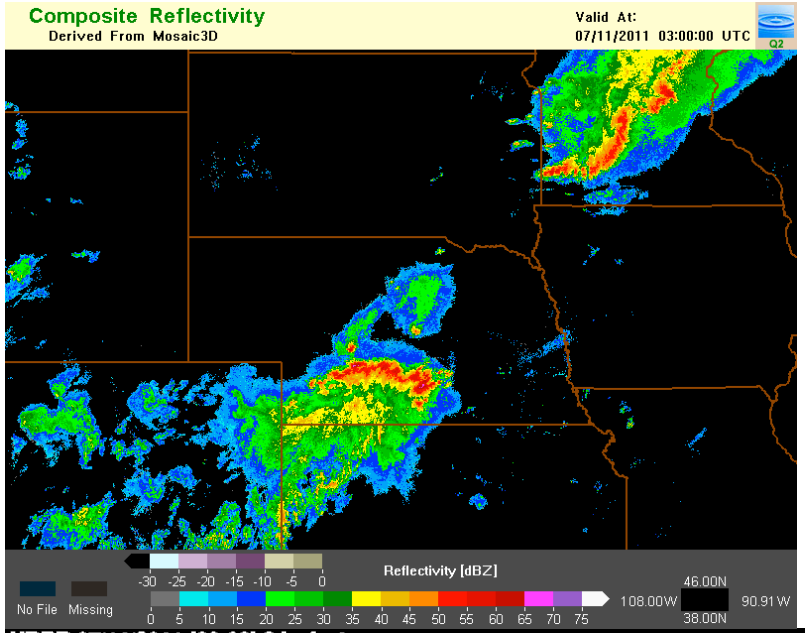
02Z 11 Jul 11

00Z 11 Jul 11 – run initial time

Real-time HRRR forecast
Initialized from RR
(2011 configuration)







03Z 11 Jul 11

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Real-time HRRR forecast
Initialized from RR
(2011 configuration)

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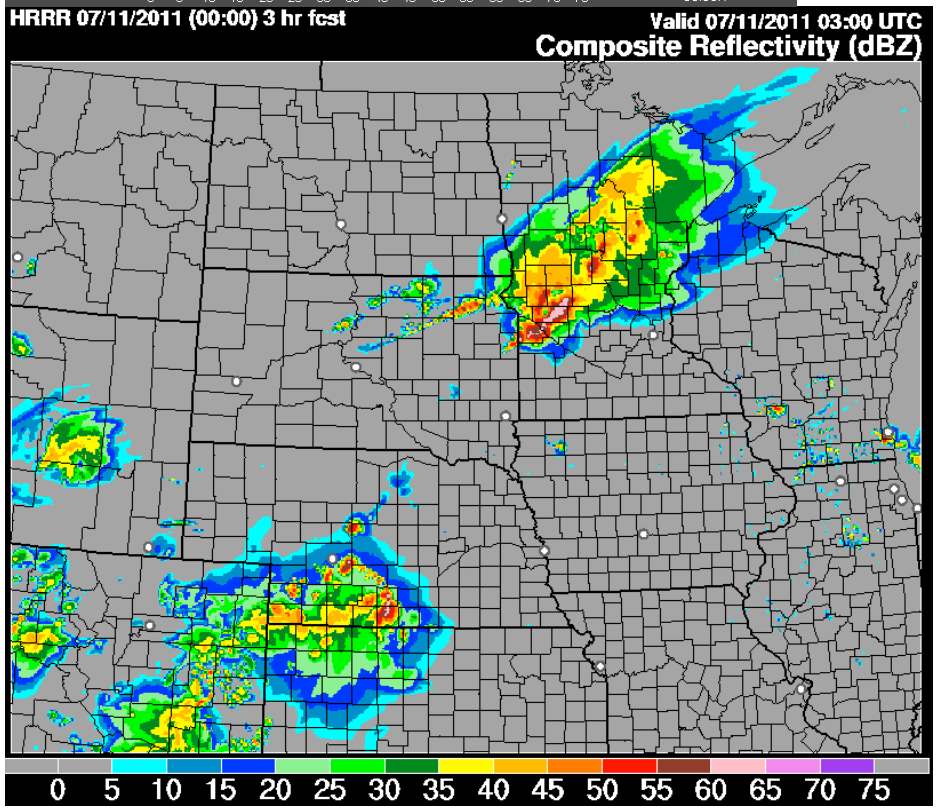

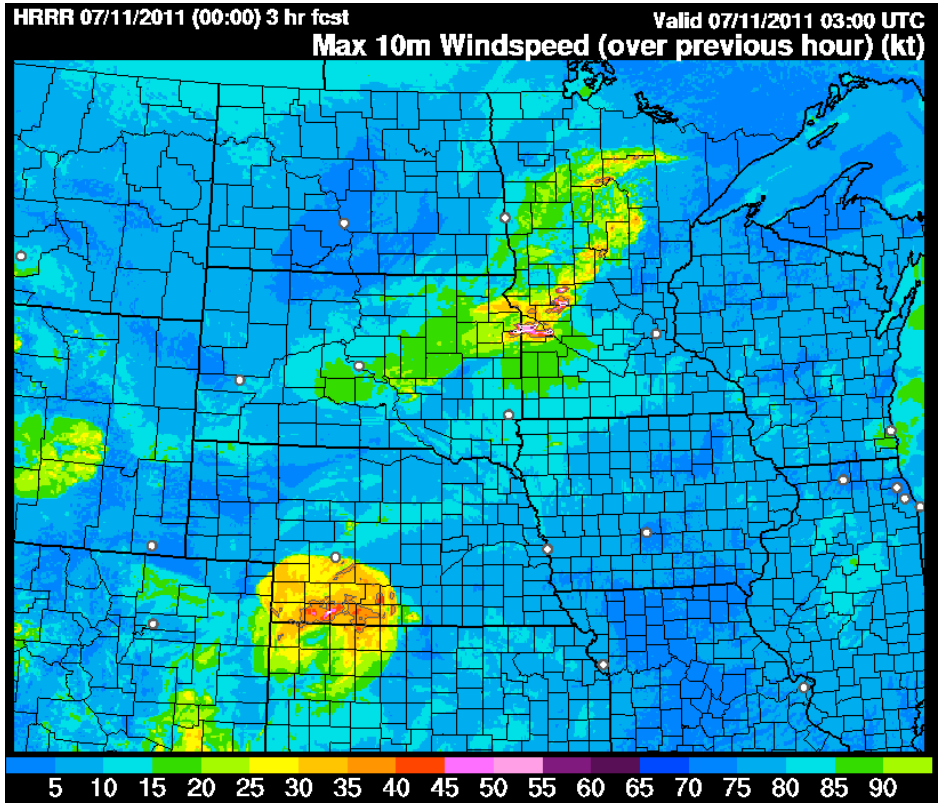

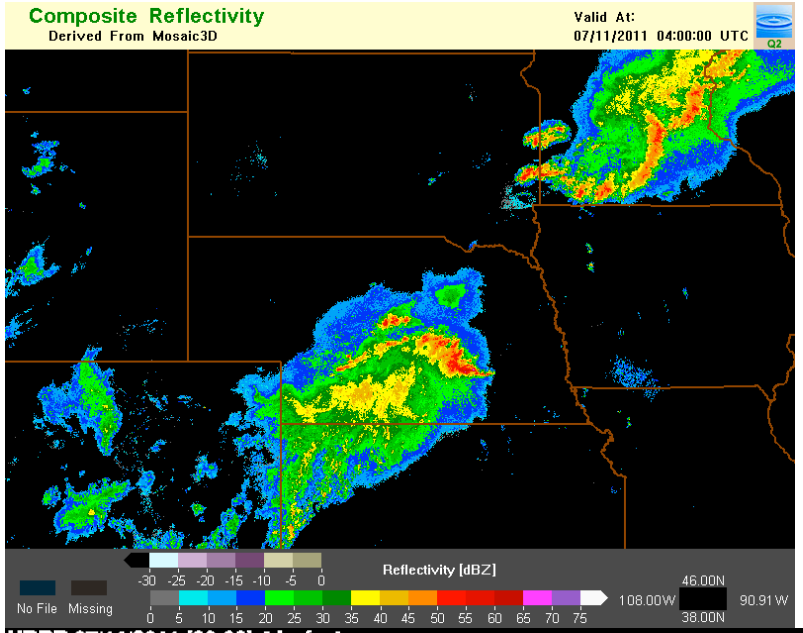

04Z 11 Jul 11

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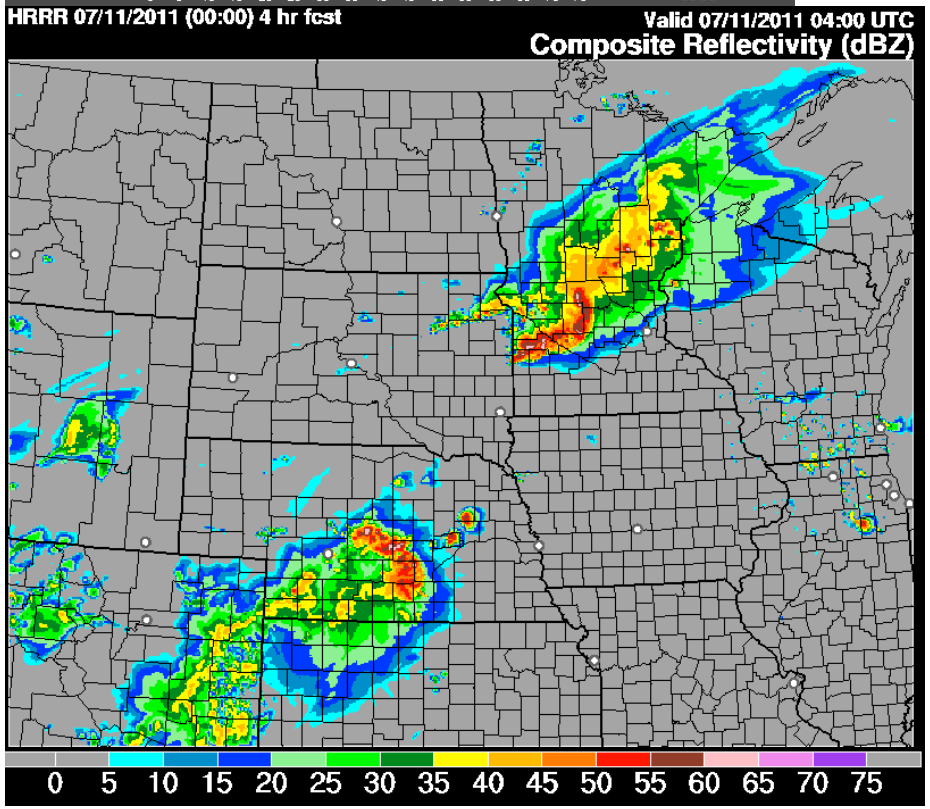
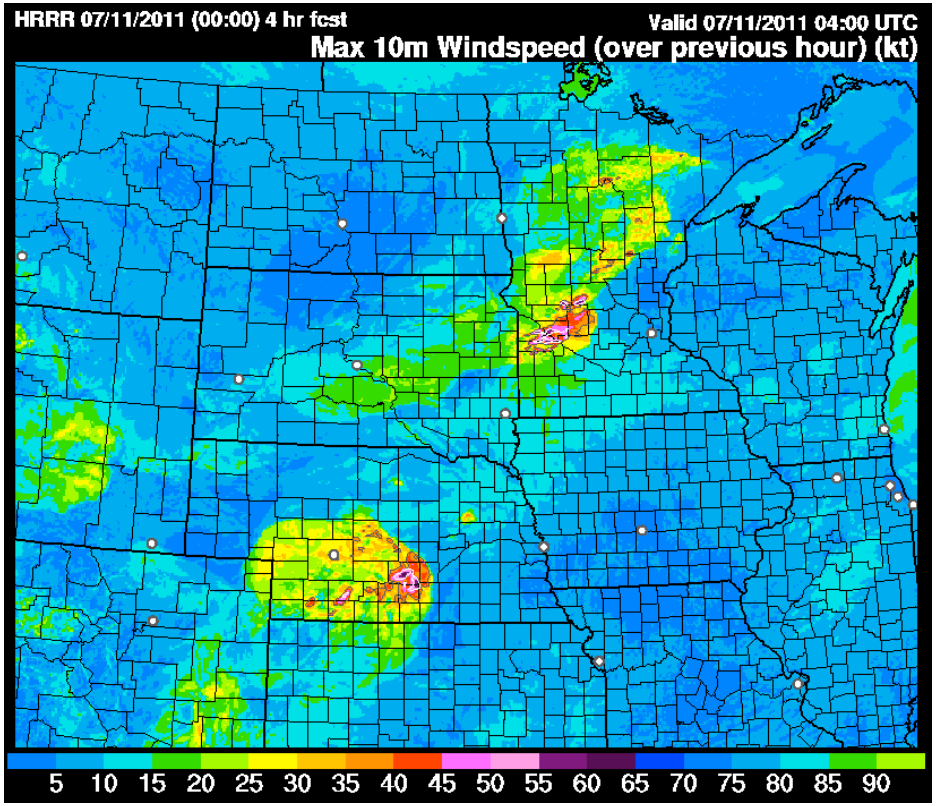
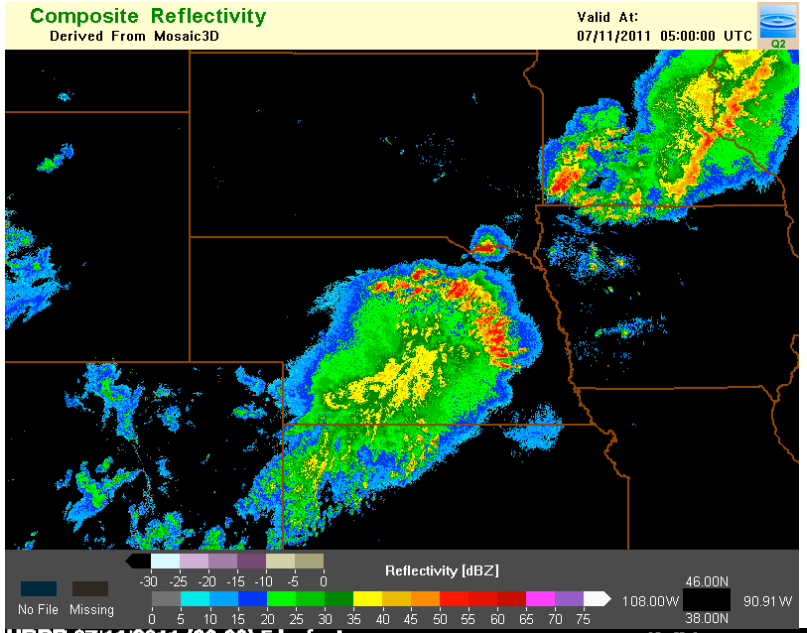
Real-time HRRR forecast
Initialized from RR
(2011 configuration)



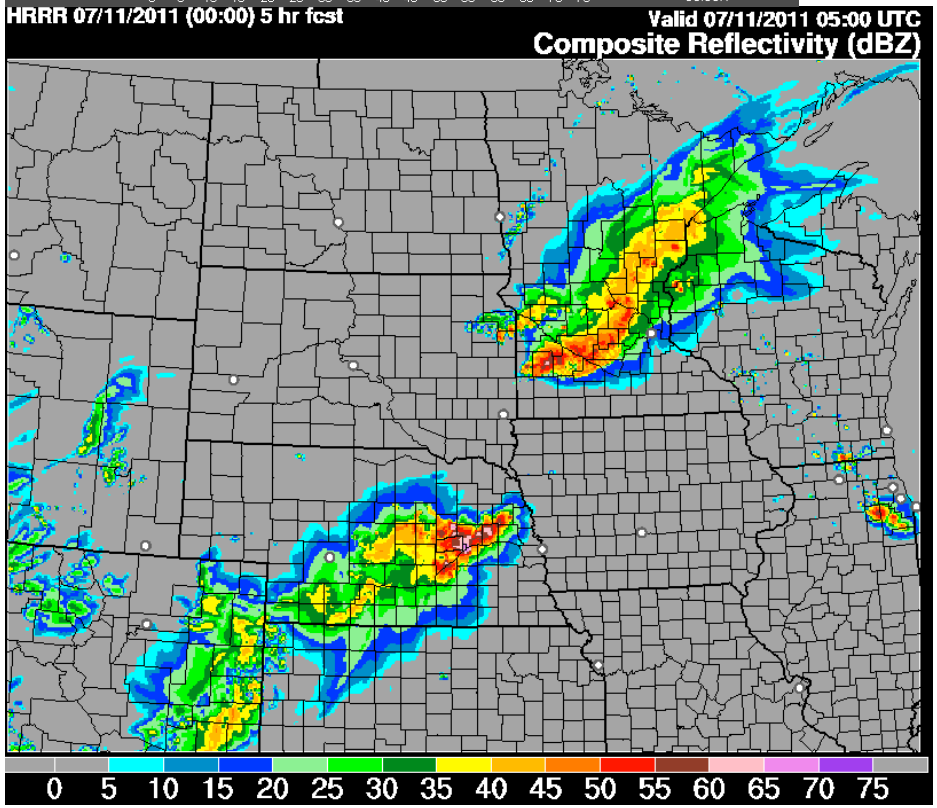


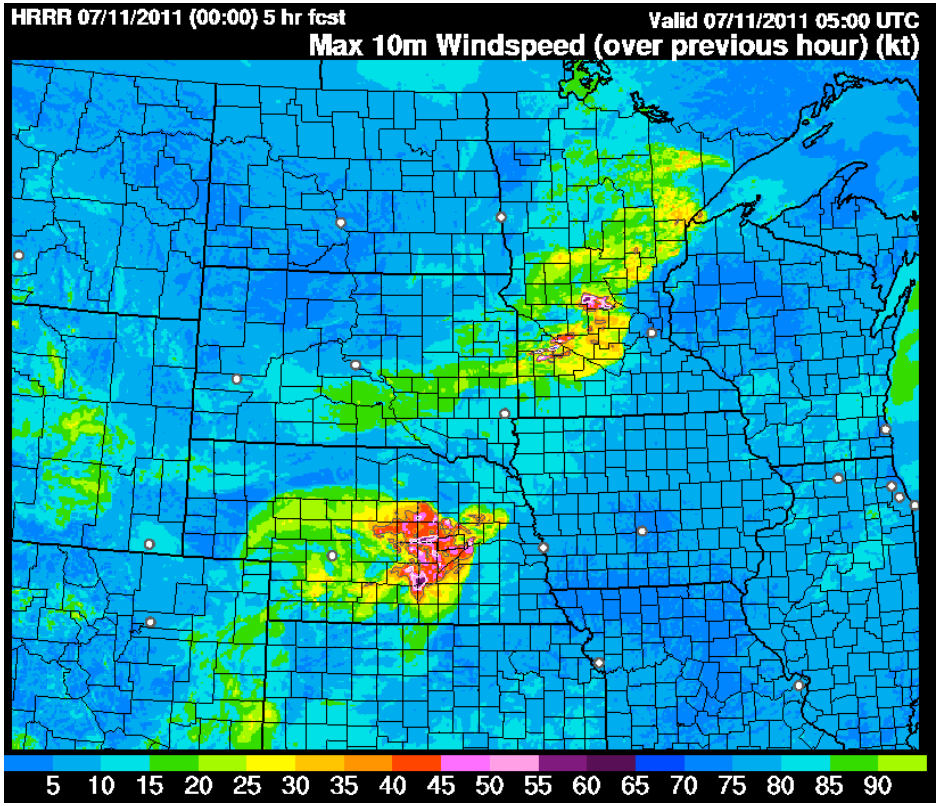


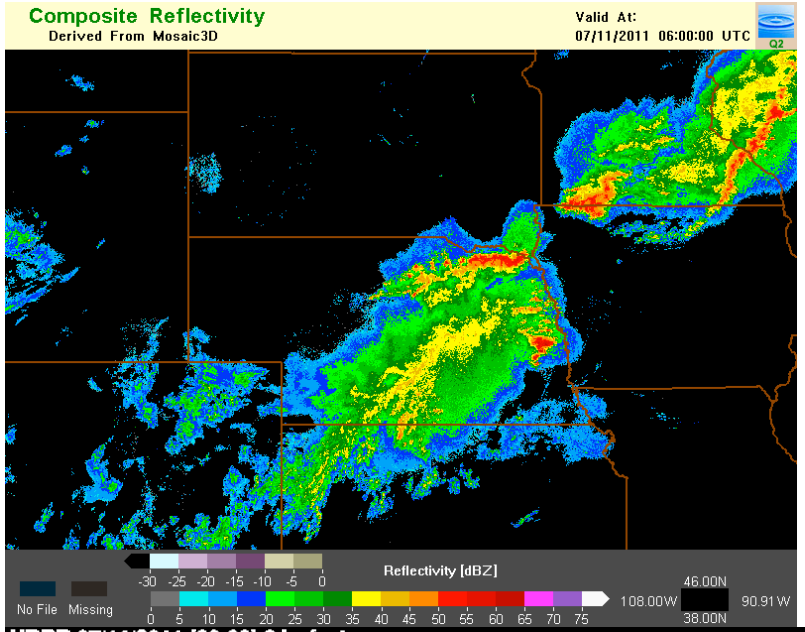
05Z 11 Jul 11

00Z 11 Jul 11 – run initial time

Real-time HRRR forecast
Initialized from RR
(2011 configuration)







06Z 11 Jul 11

00Z 11 Jul 11 – run initial time

Real-time HRRR forecast
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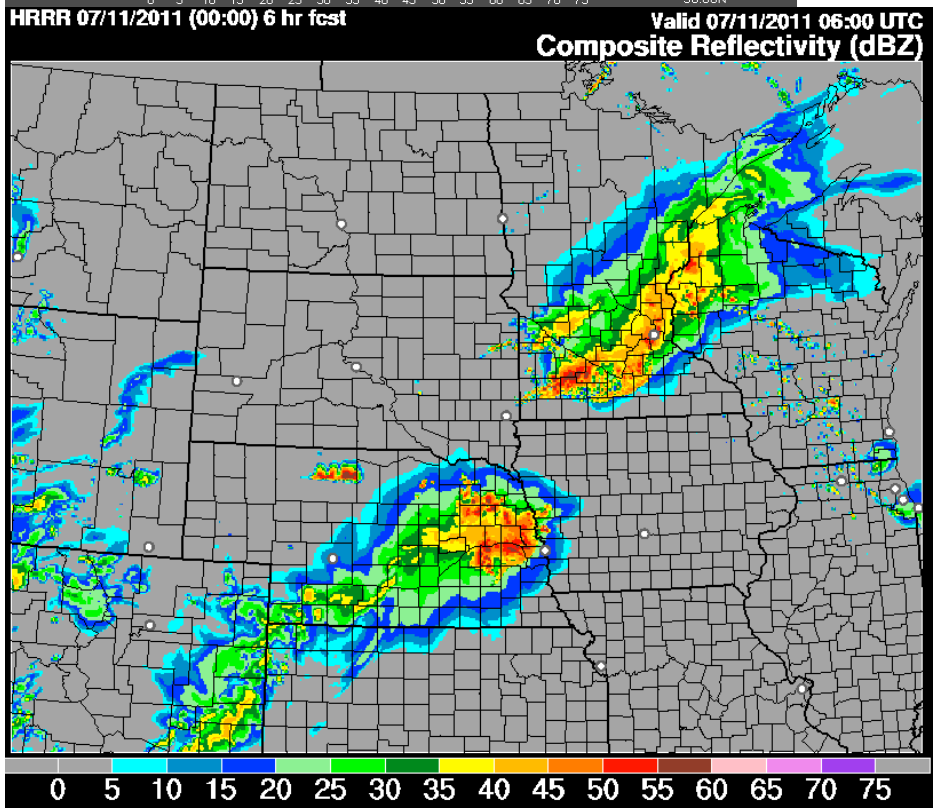
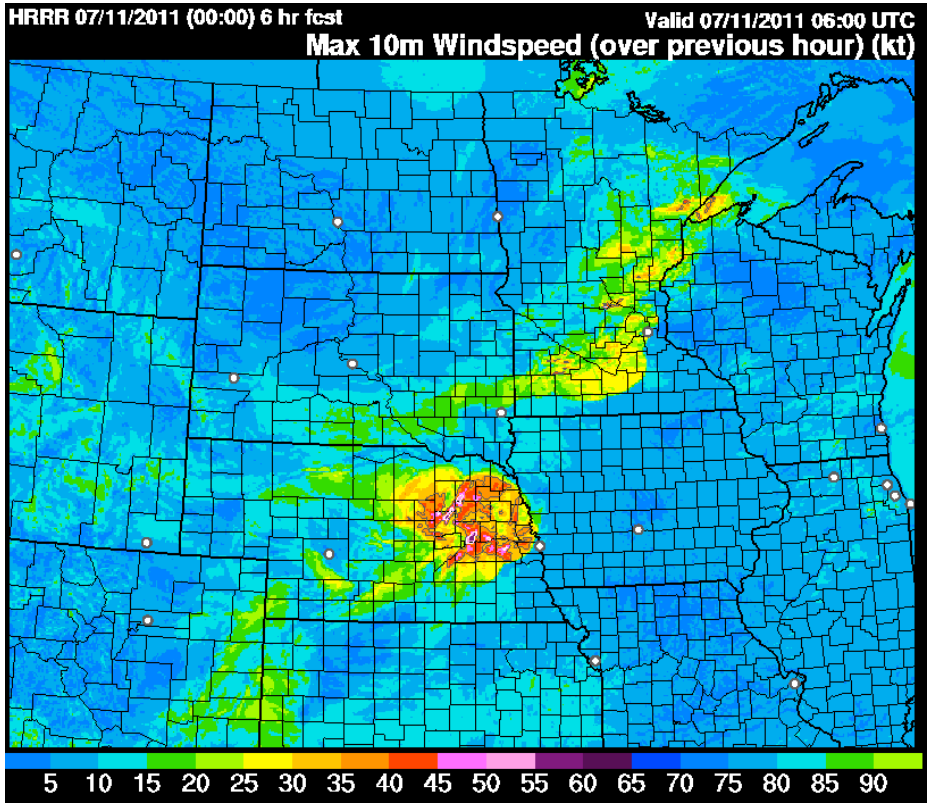
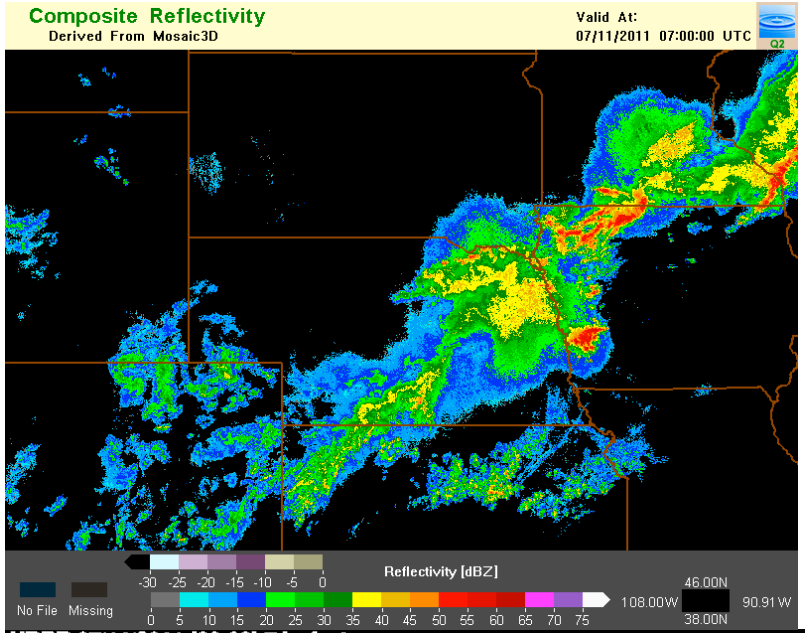
(2011 configuration)







07Z 11 Jul 11

00Z 11 Jul 11 – run initial time

Real-time HRRR forecast
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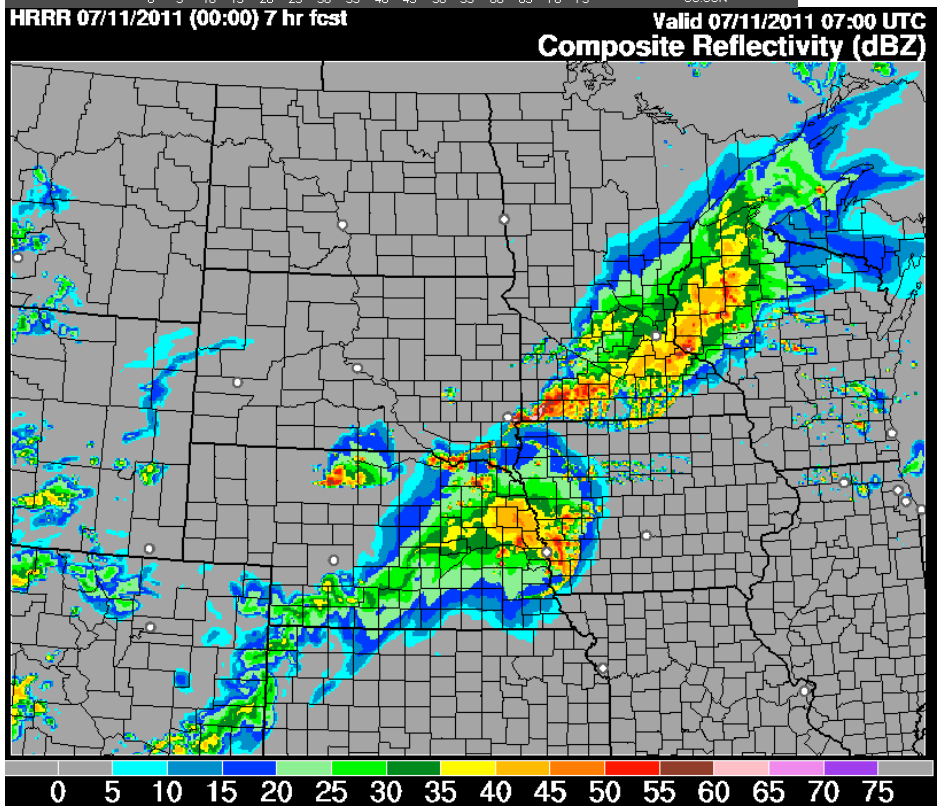
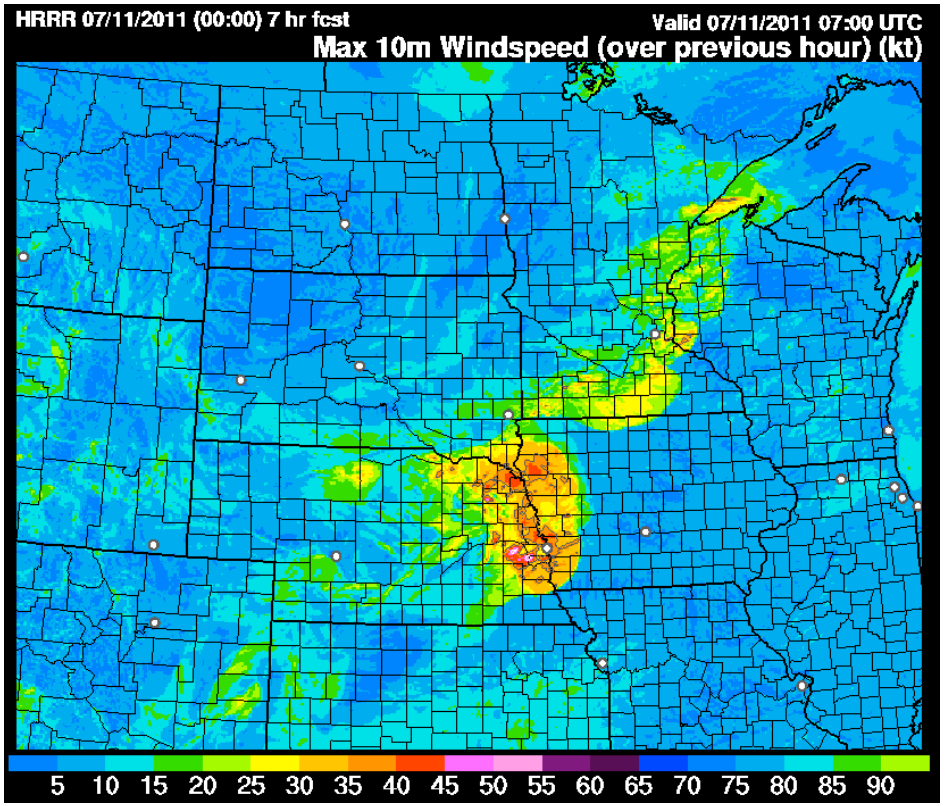
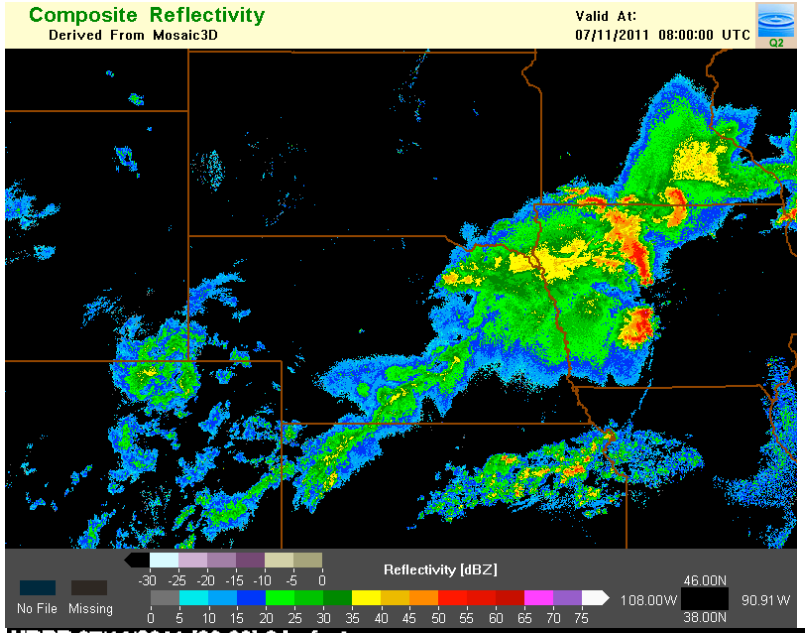
(2011 configuration)







08Z 11 Jul 11

00Z 11 Jul 11 – run initial time

Real-time HRRR forecast
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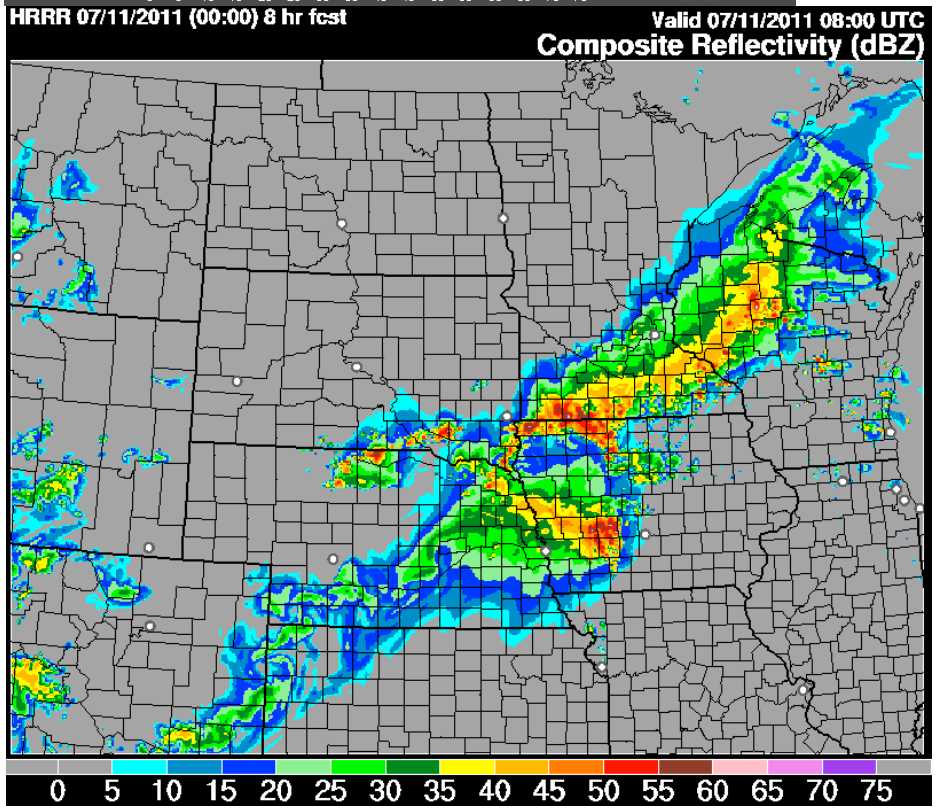
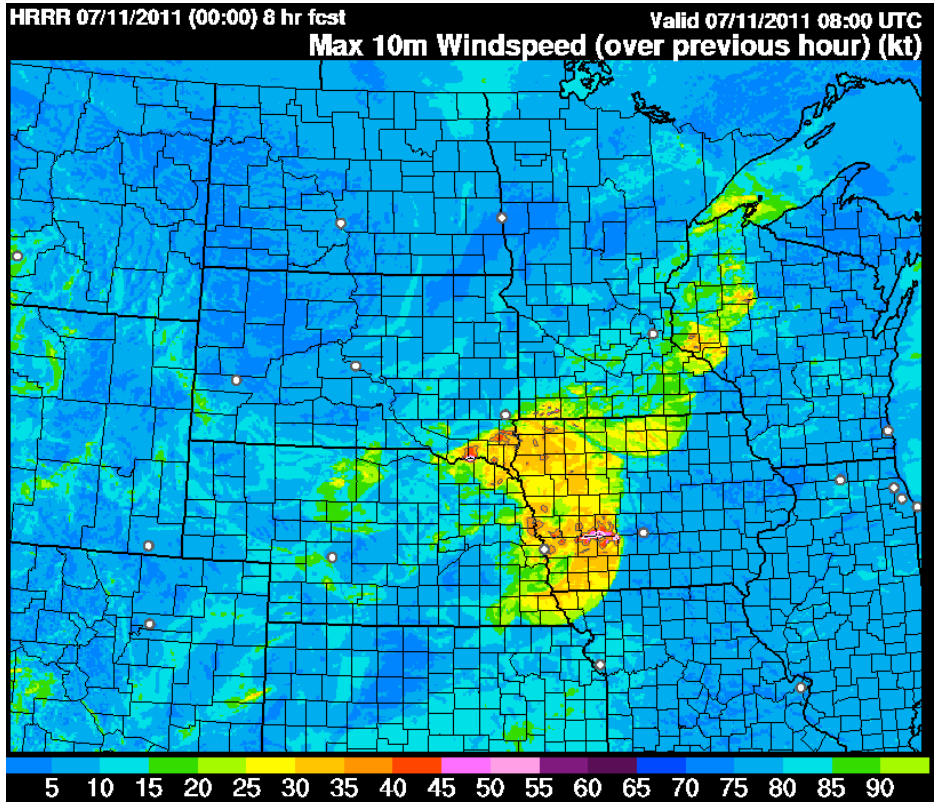
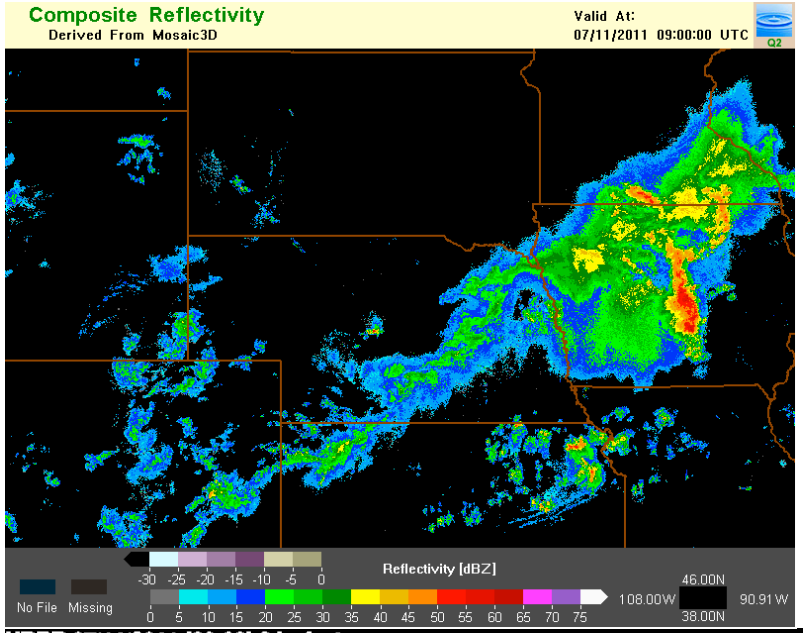
(2011 configuration)



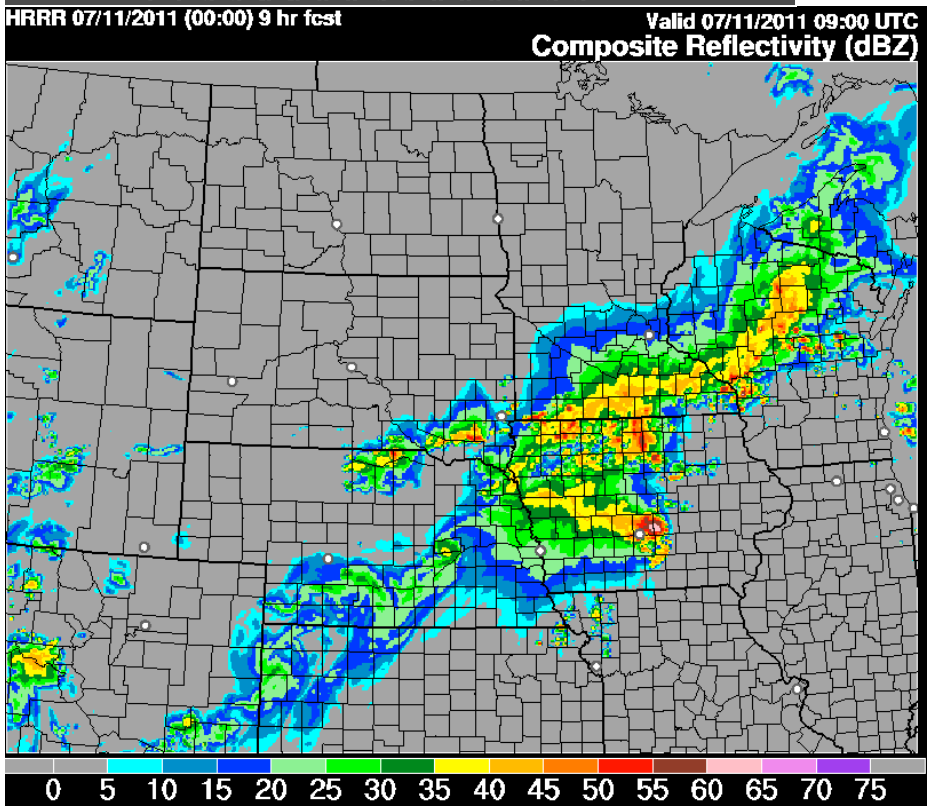


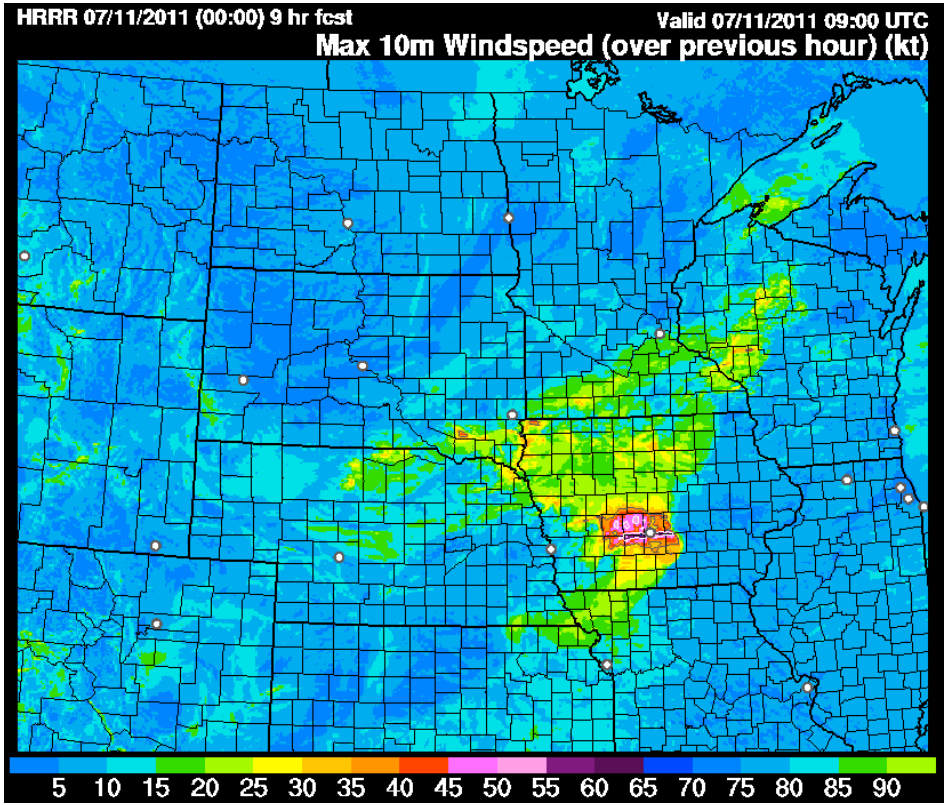


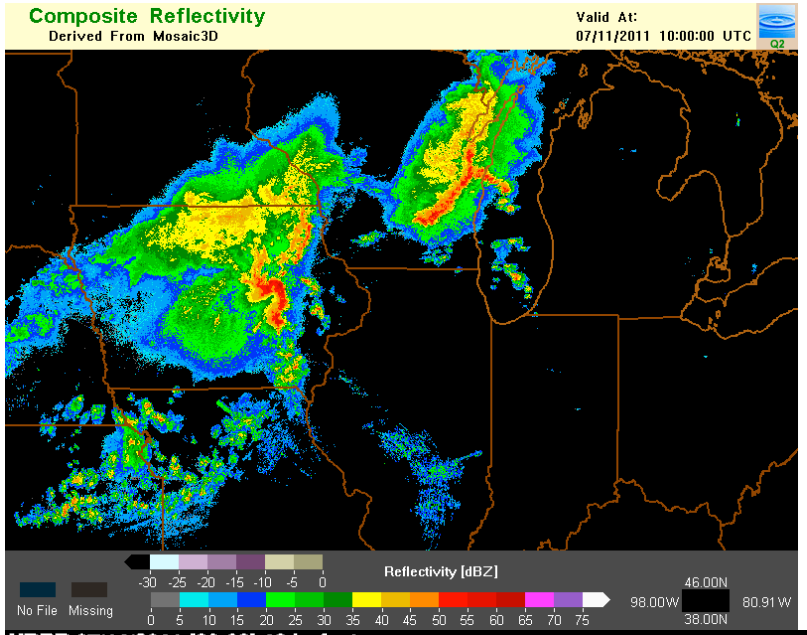
09Z 11 Jul 11

00Z 11 Jul 11 – run initial time

Real-time HRRR forecast
Initialized from RR
(2011 configuration)



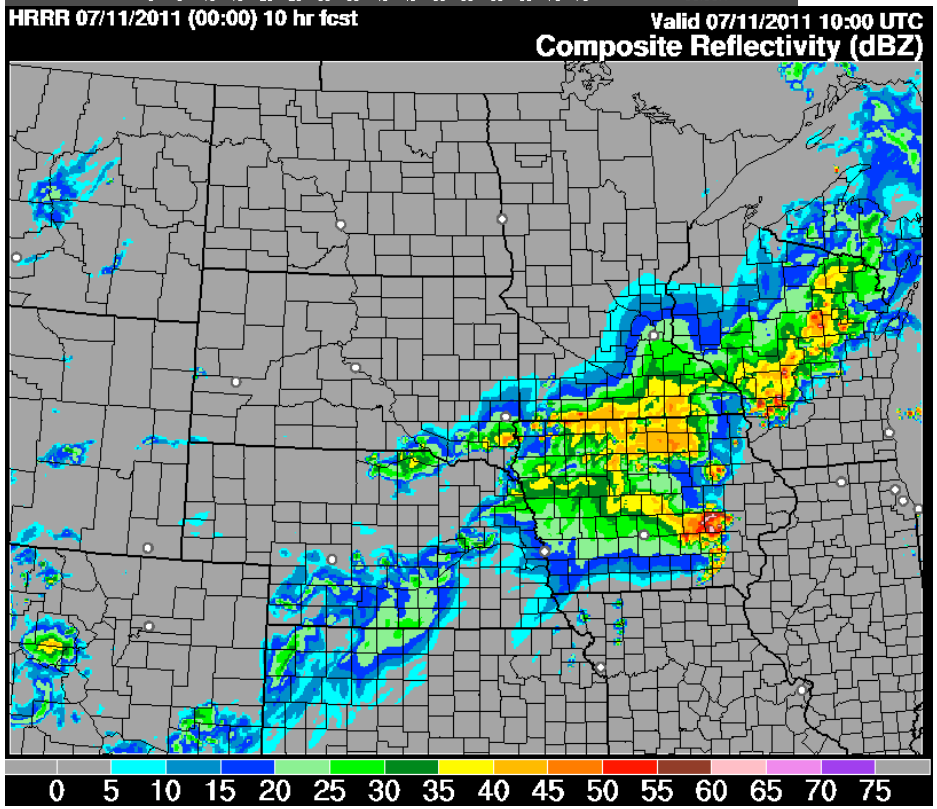


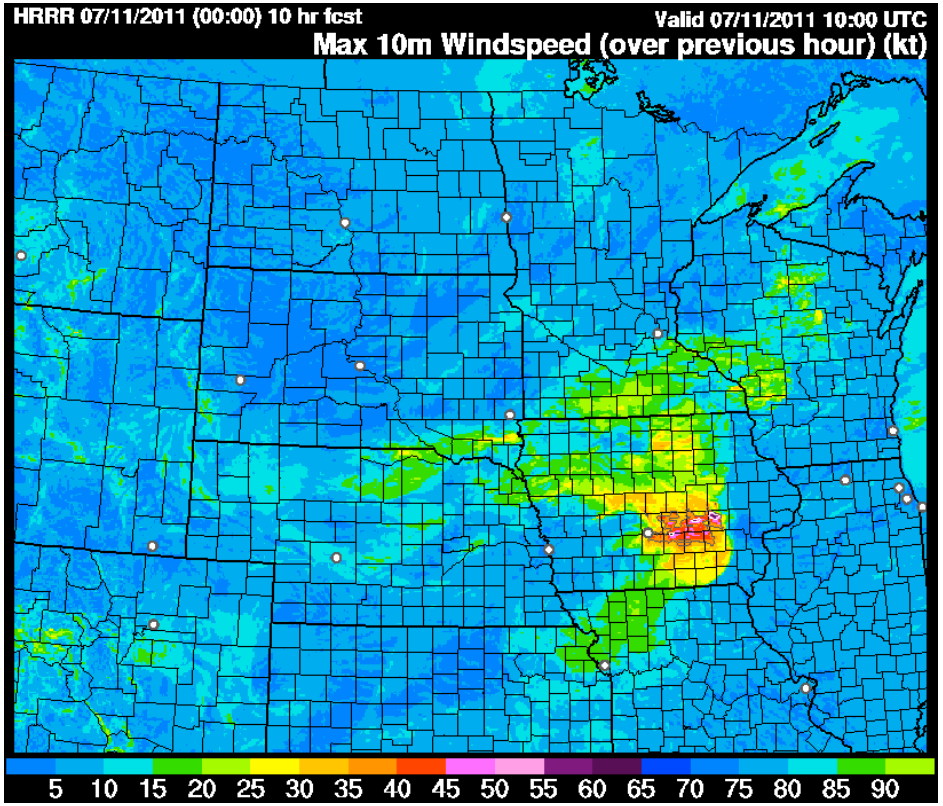


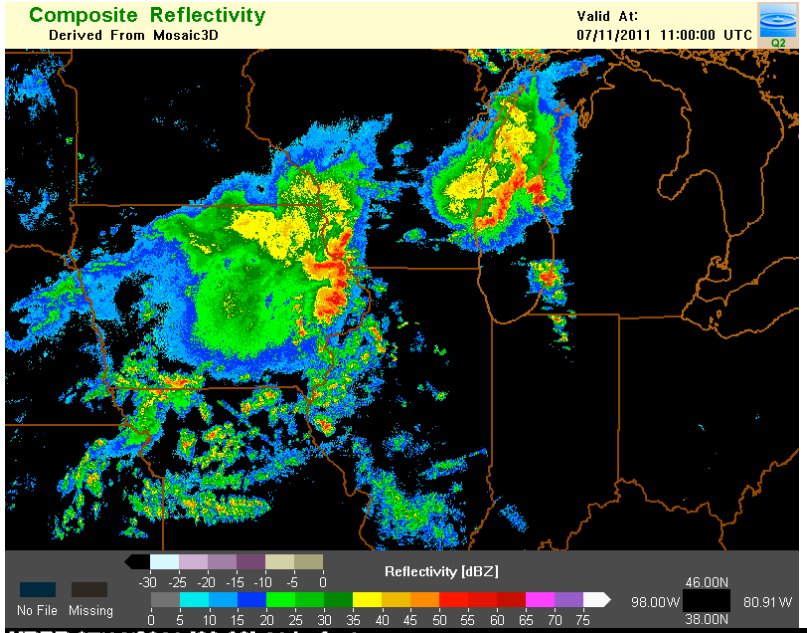
10Z 11 Jul 11

00Z 11 Jul 11 – run initial time

Real-time HRRR forecast
Initialized from RR
(2011 configuration)



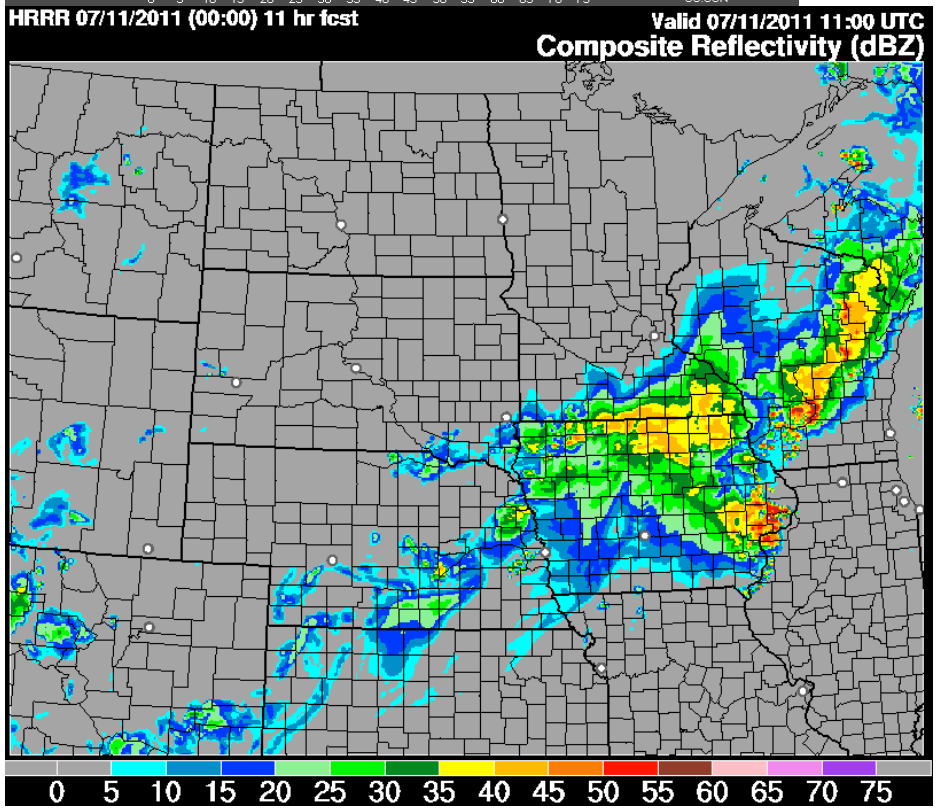


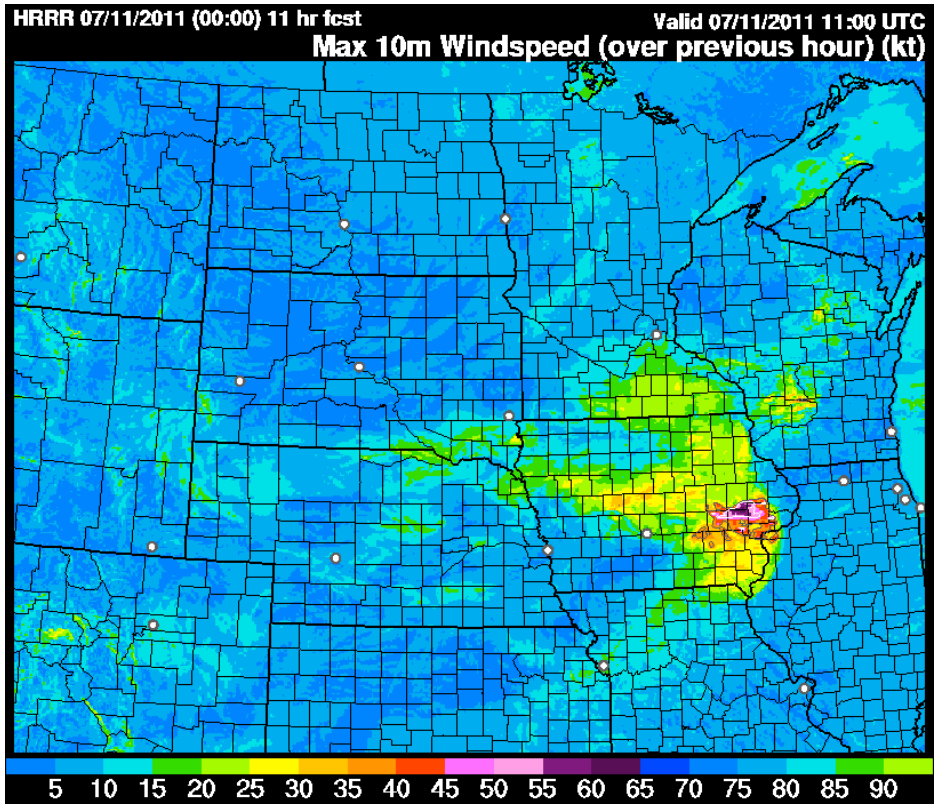


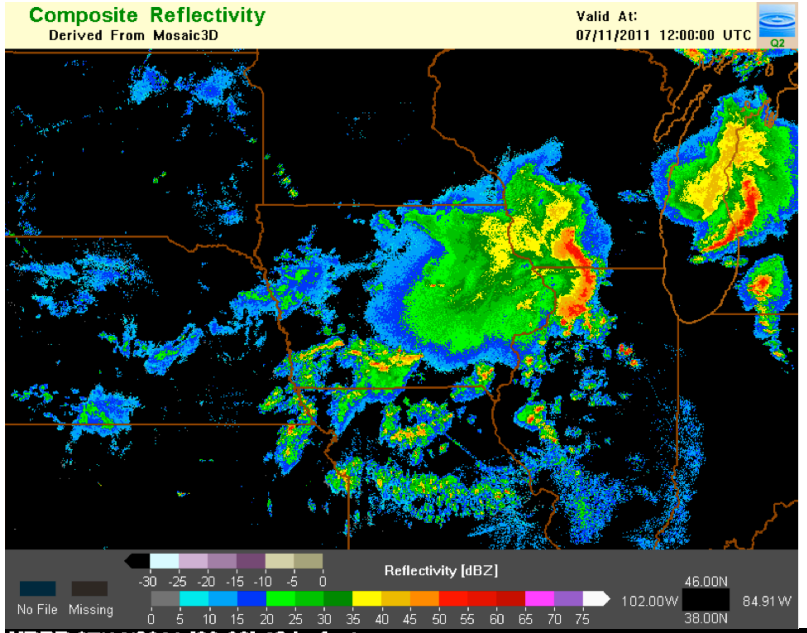
11Z 11 Jul 11

00Z 11 Jul 11 – run initial time

Real-time HRRR forecast
Initialized from RR
(2011 configuration)



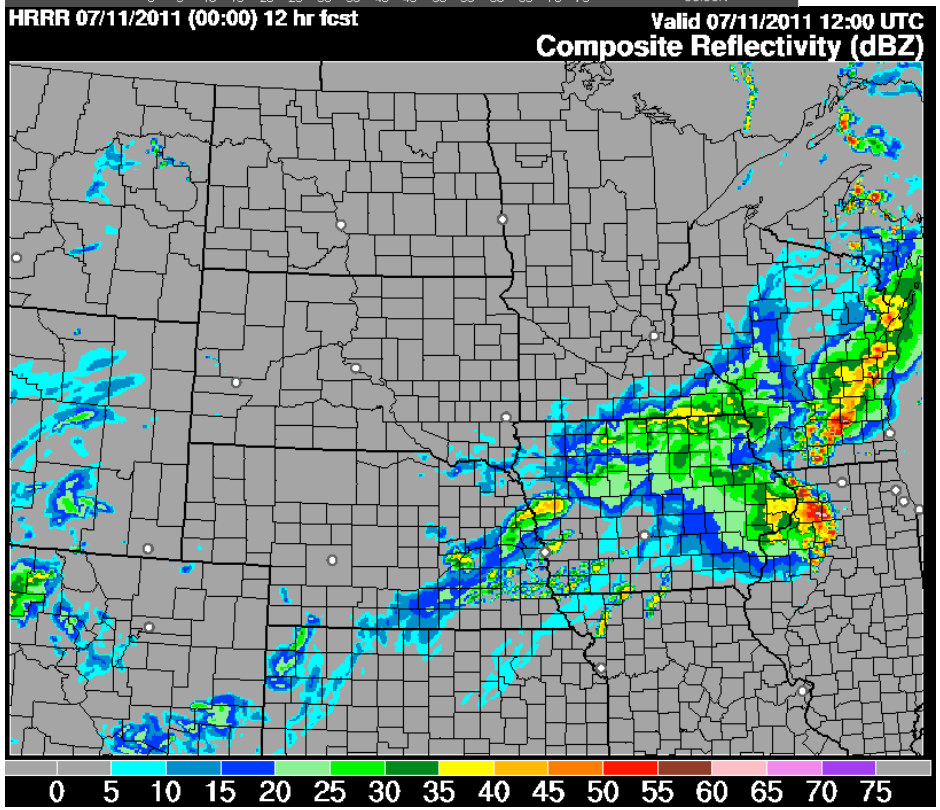


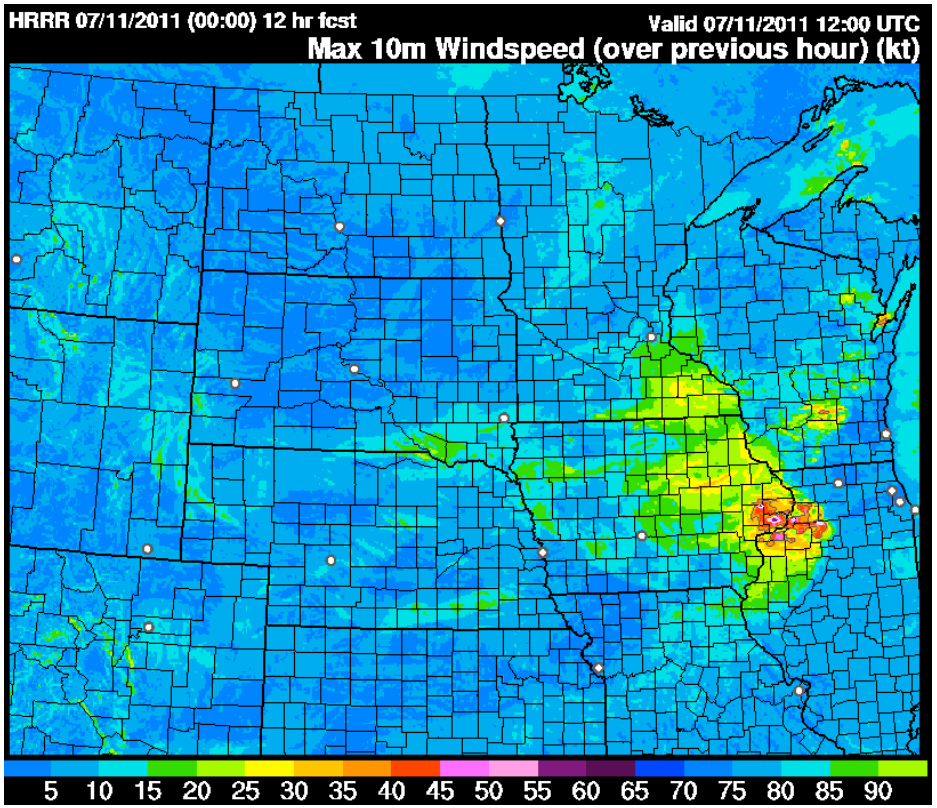


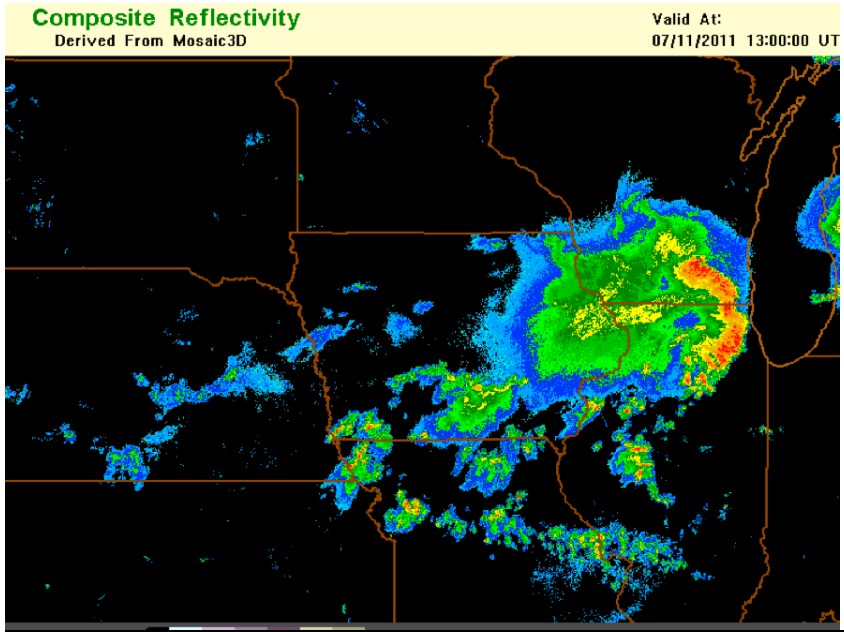
12Z 11 Jul 11

00Z 11 Jul 11 – run initial time

Real-time HRRR forecast
Initialized from RR
(2011 configuration)







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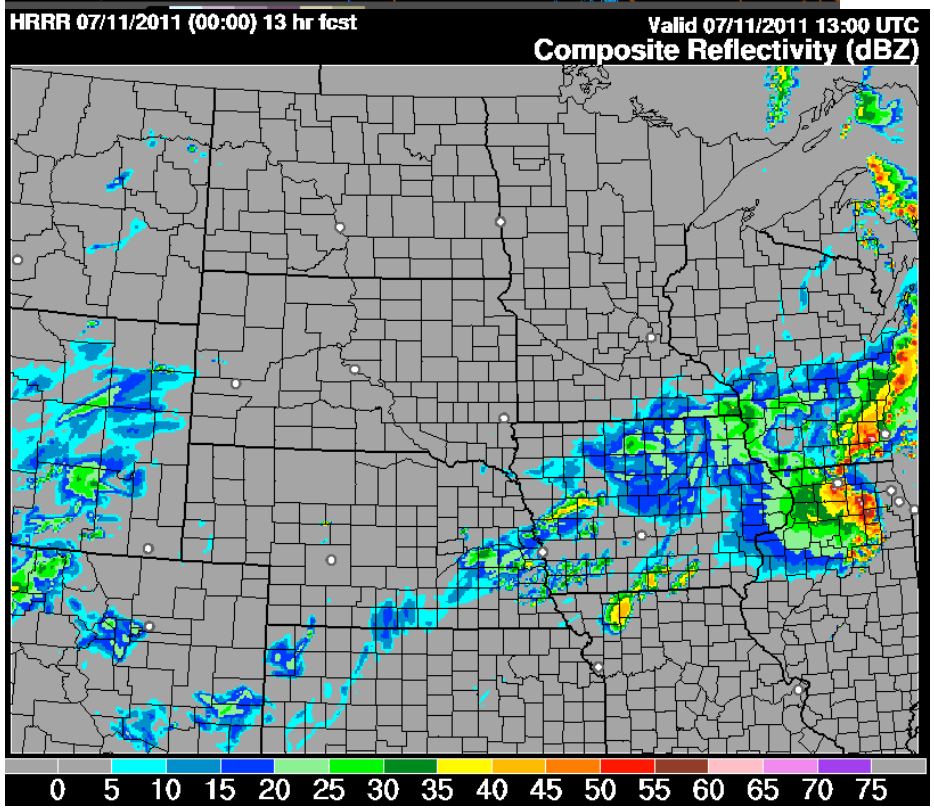
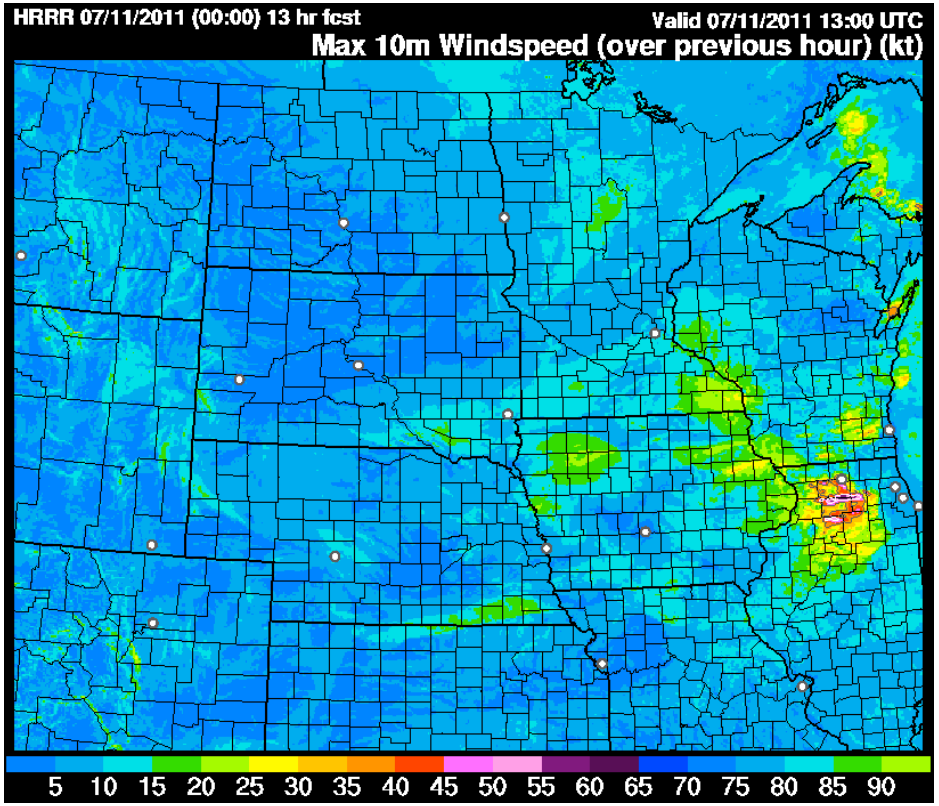
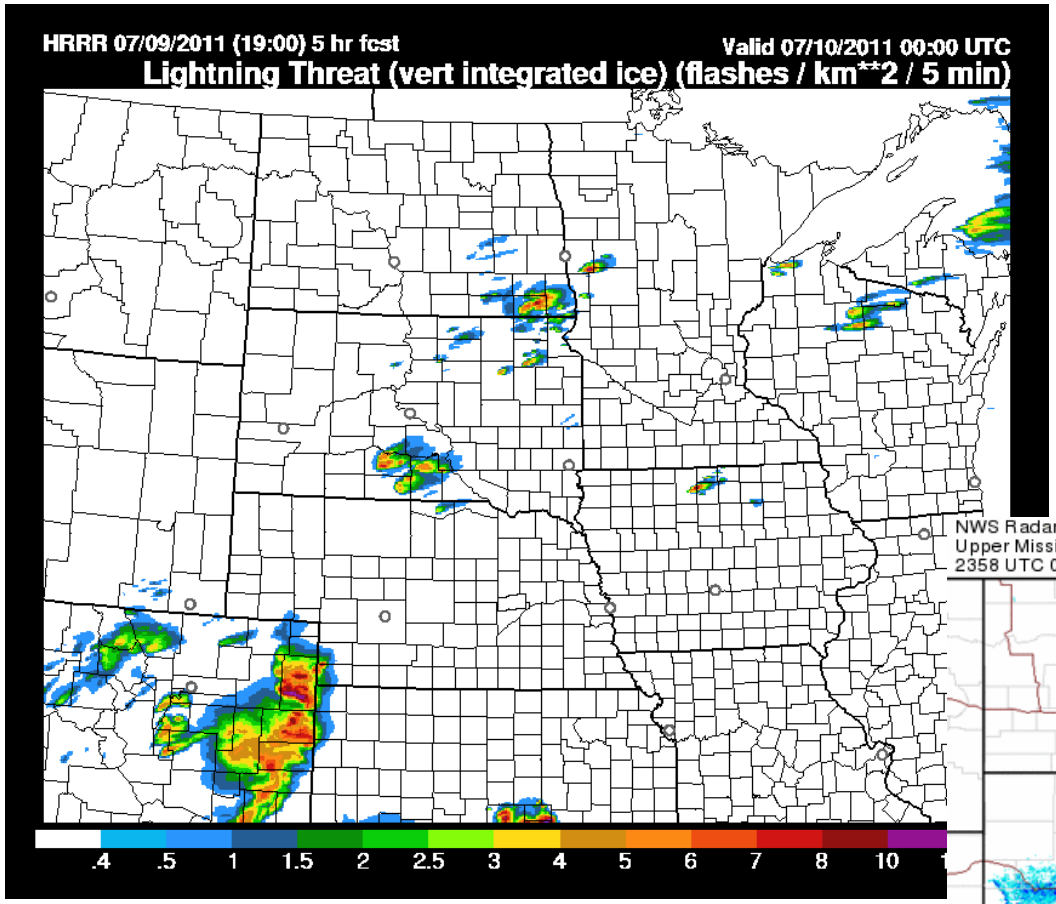
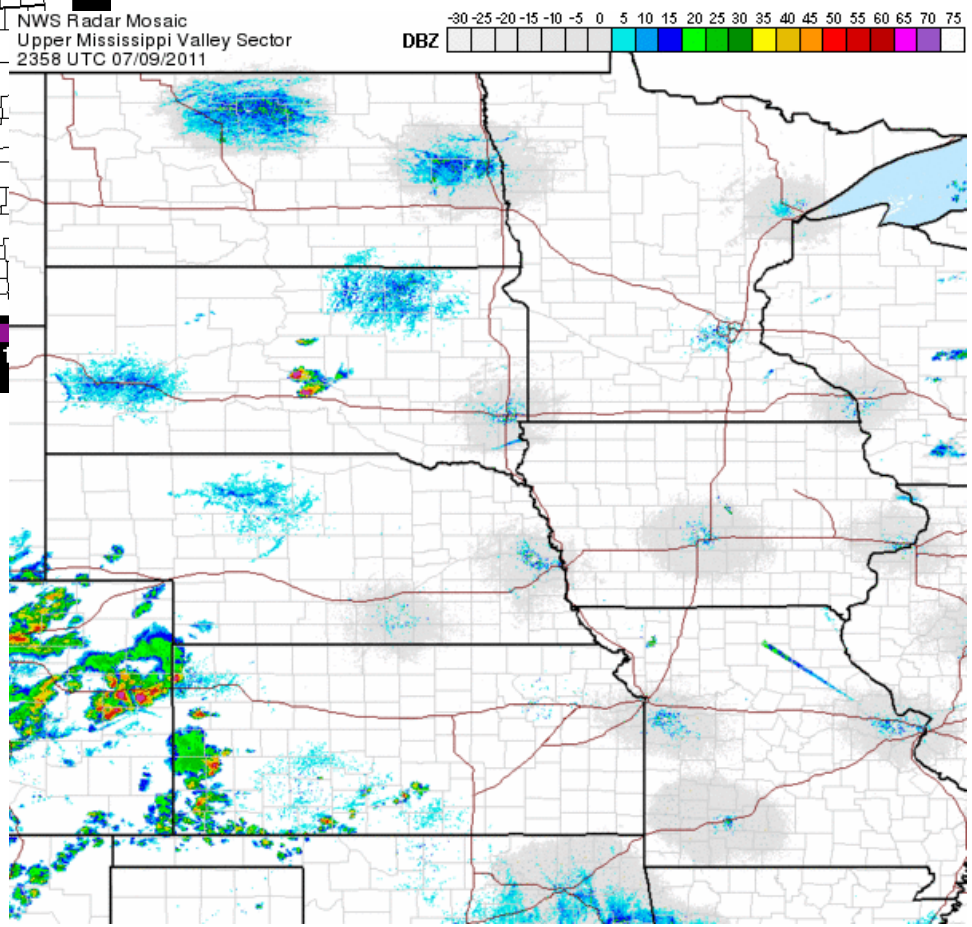
Real-time HRRR forecast
Initialized from RR
(2011 configuration)



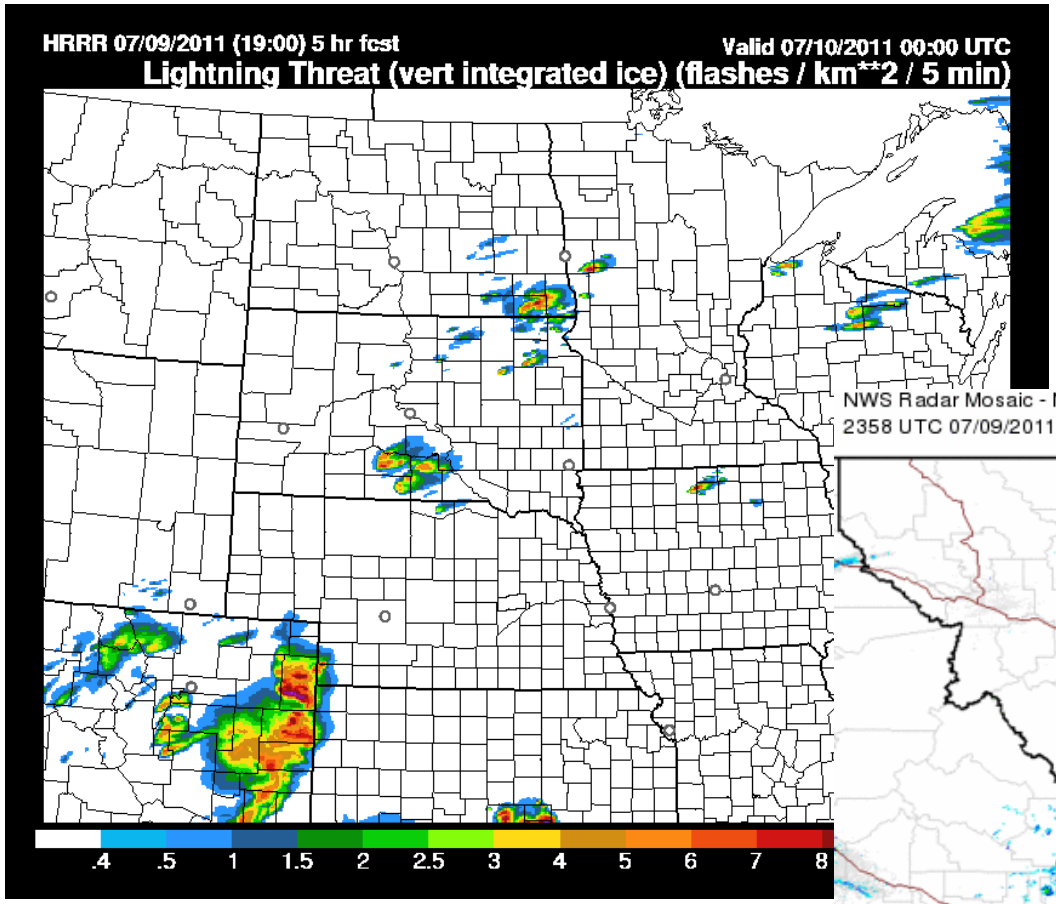


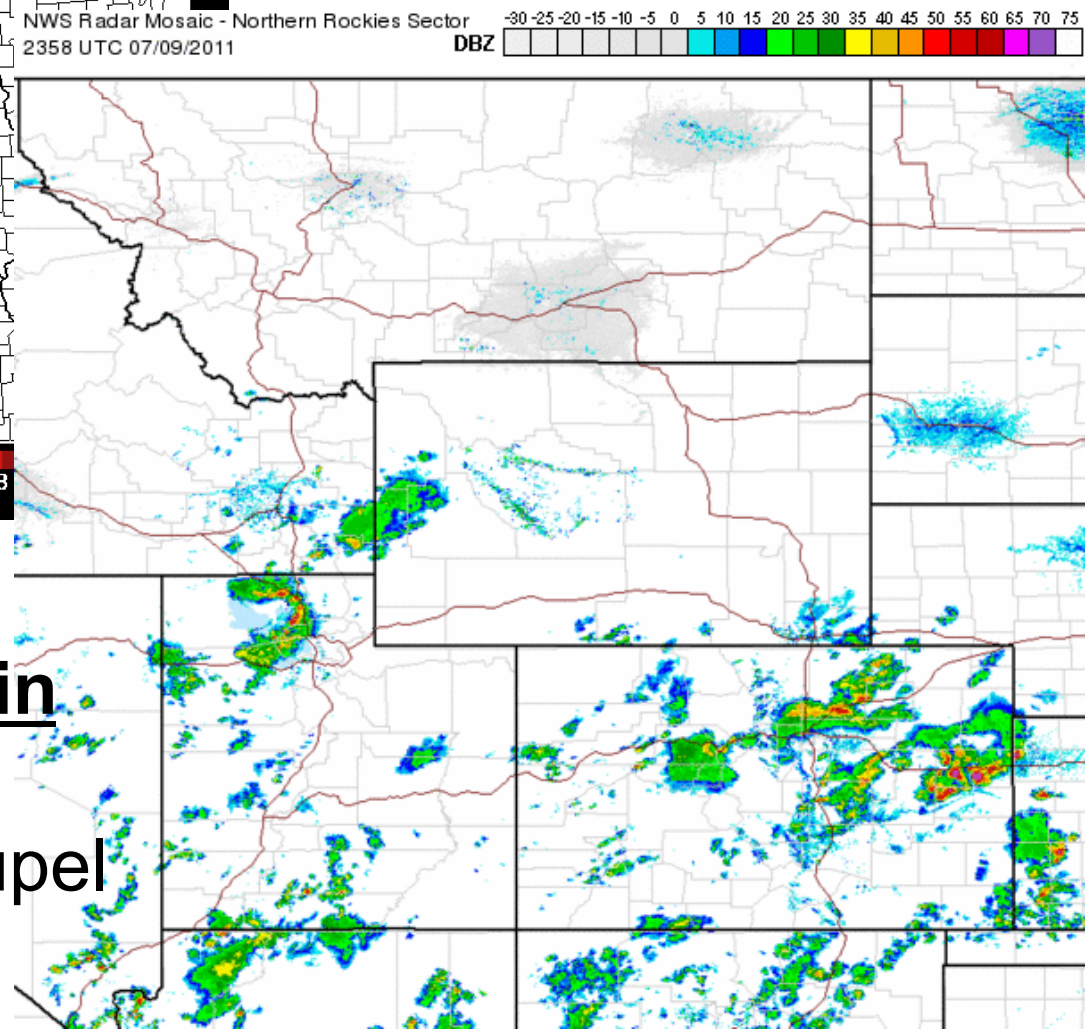




Lightning diagnostics in HRRR

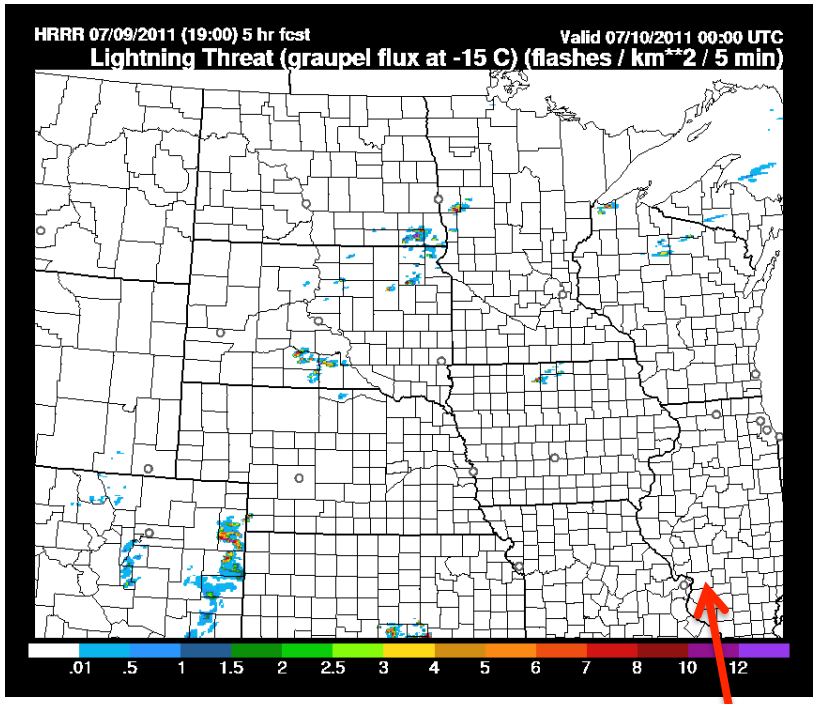
vertically integrated graupel

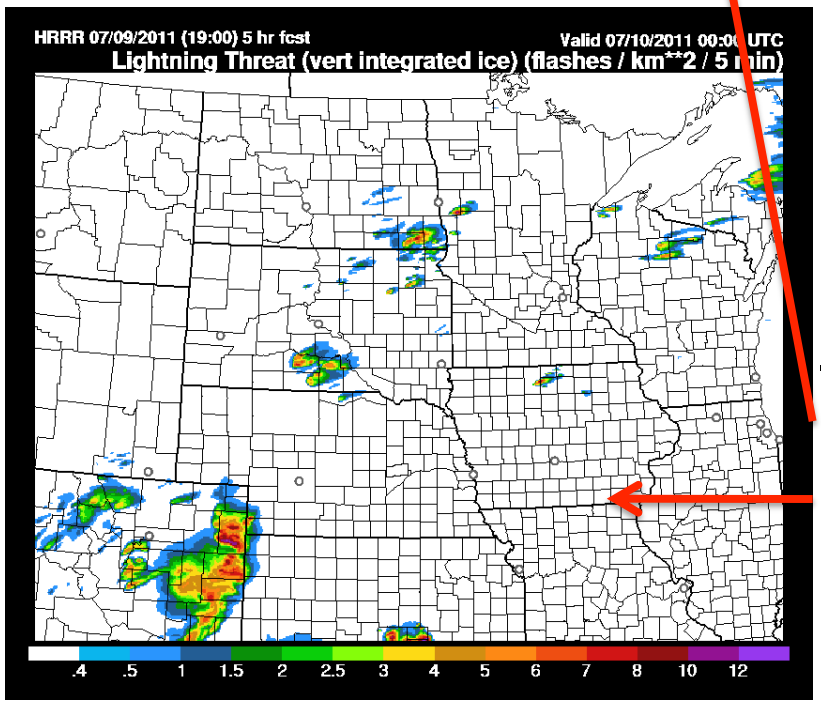


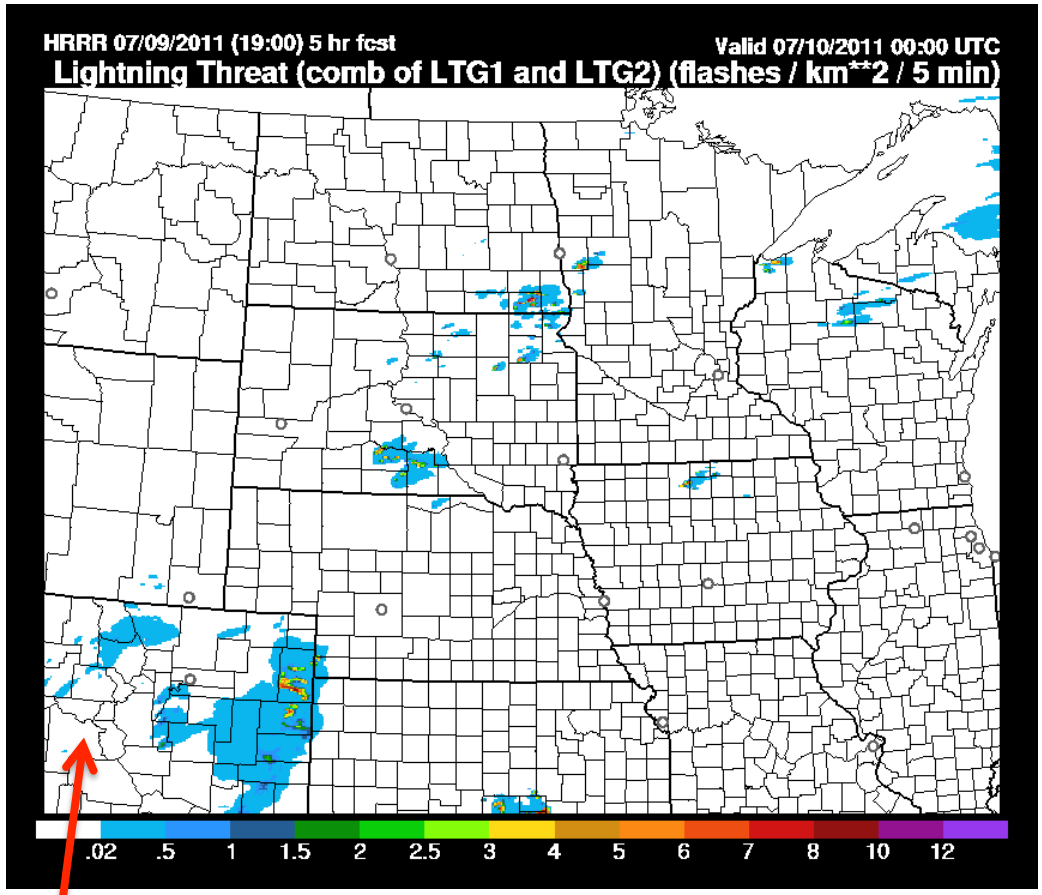


Lightning diagnostics in HRRR output fields

vertically integrated graupel

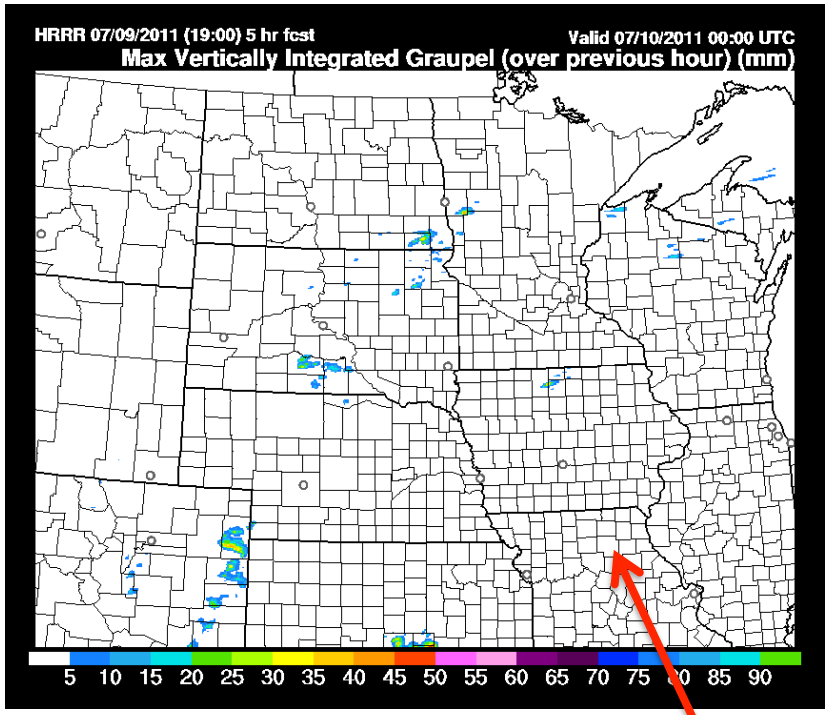


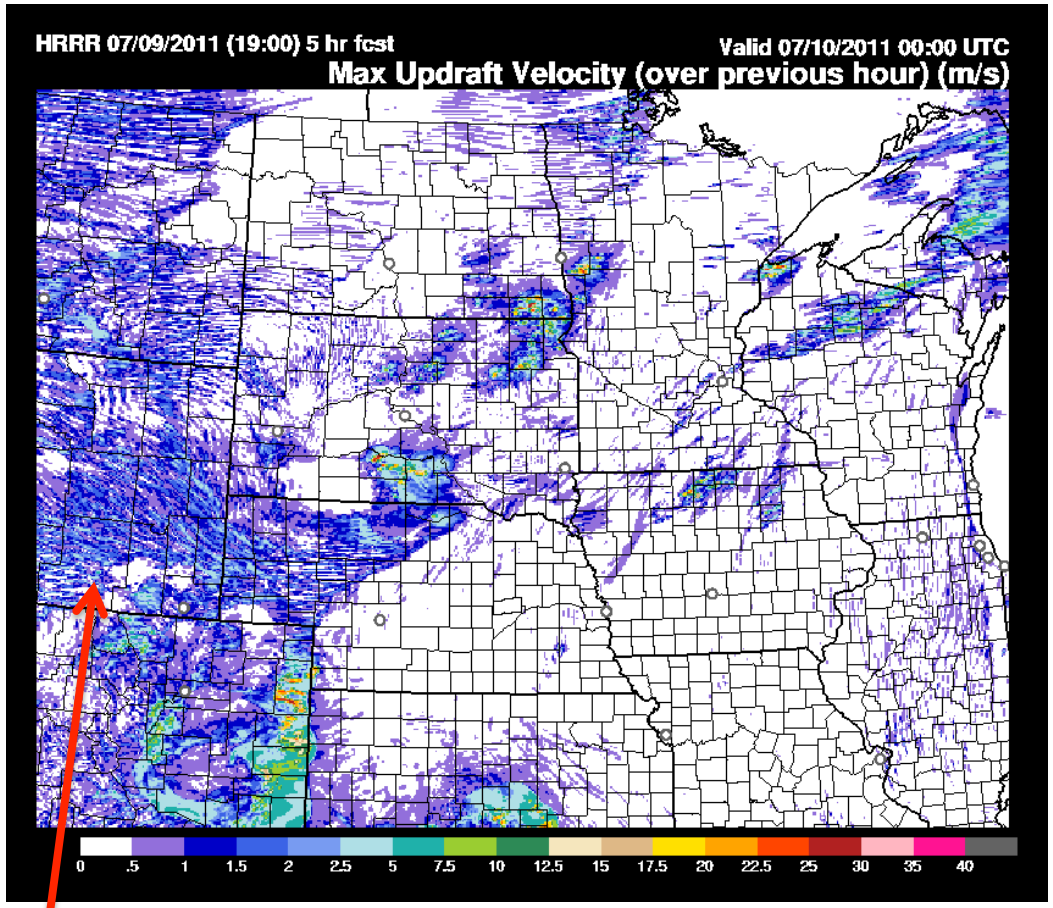


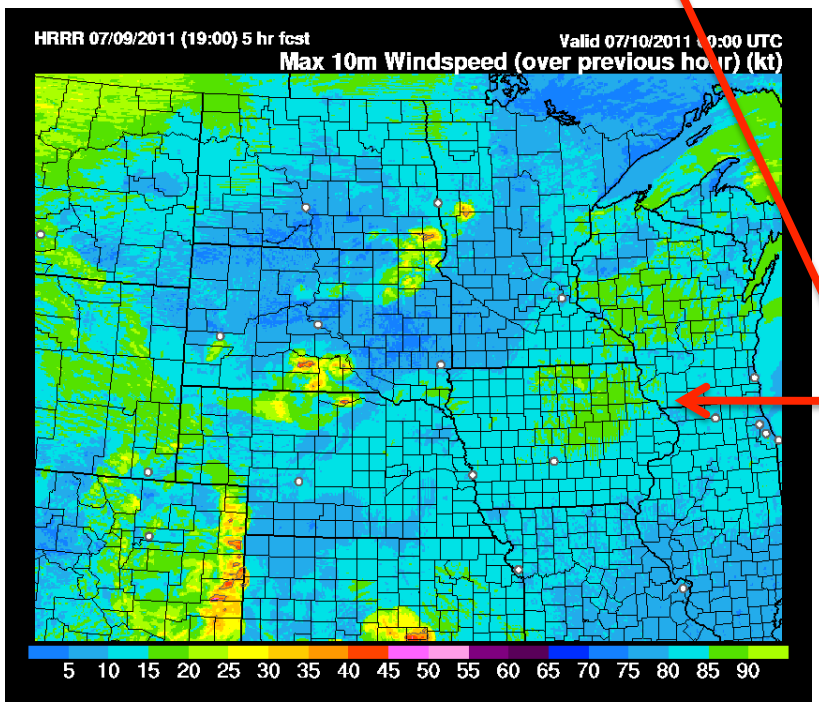


Lightning diagnostics in HRRR

1. qg (graupel) flux at -15C
2. vertically integrated qg
3. combination of 1 and 2

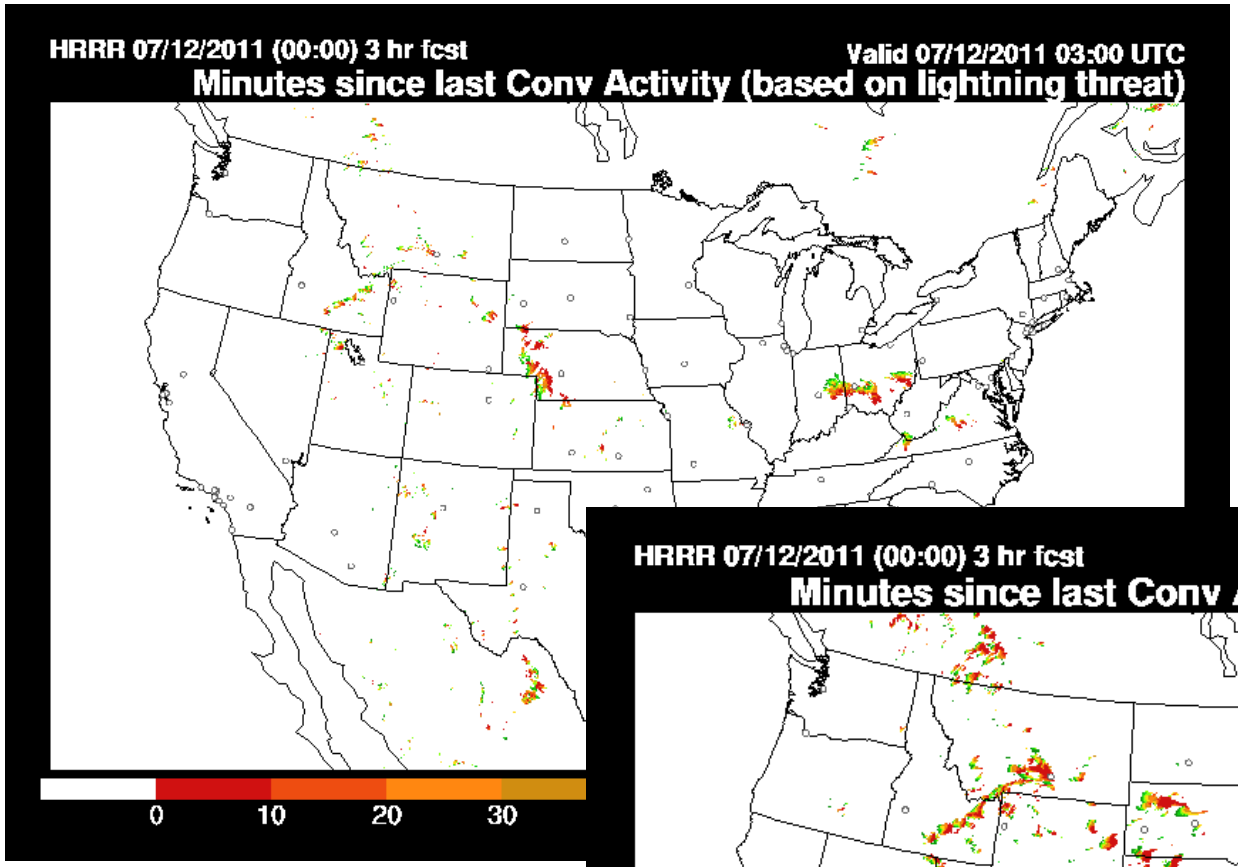


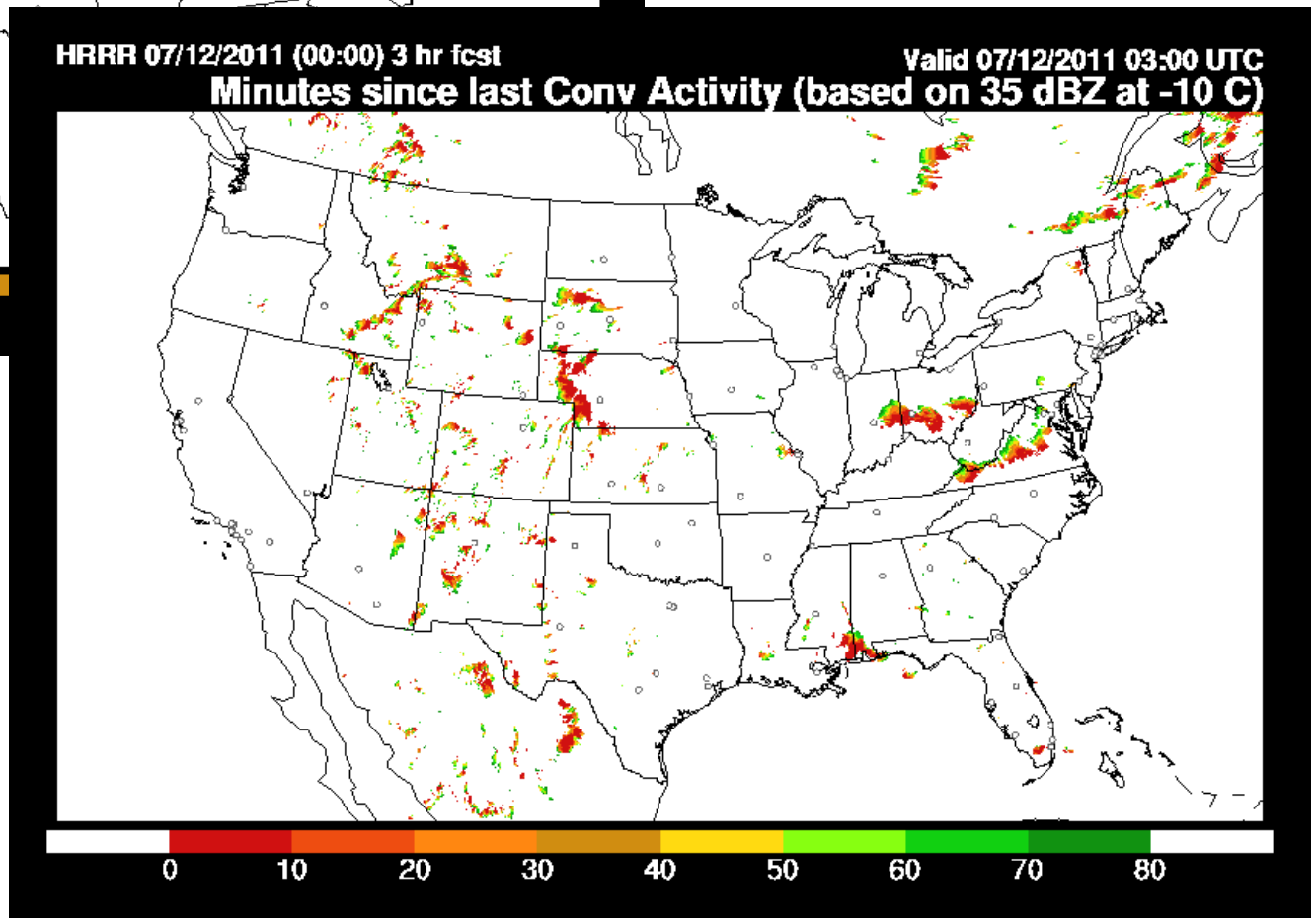




Max-over-last-hour **output fields**

- Max vertically integrated graupel (qg)
- Max 10m wind speed
- Max updraft velocity / downdraft velocity
- Max updraft helicity
- Max 1km AGL reflectivity

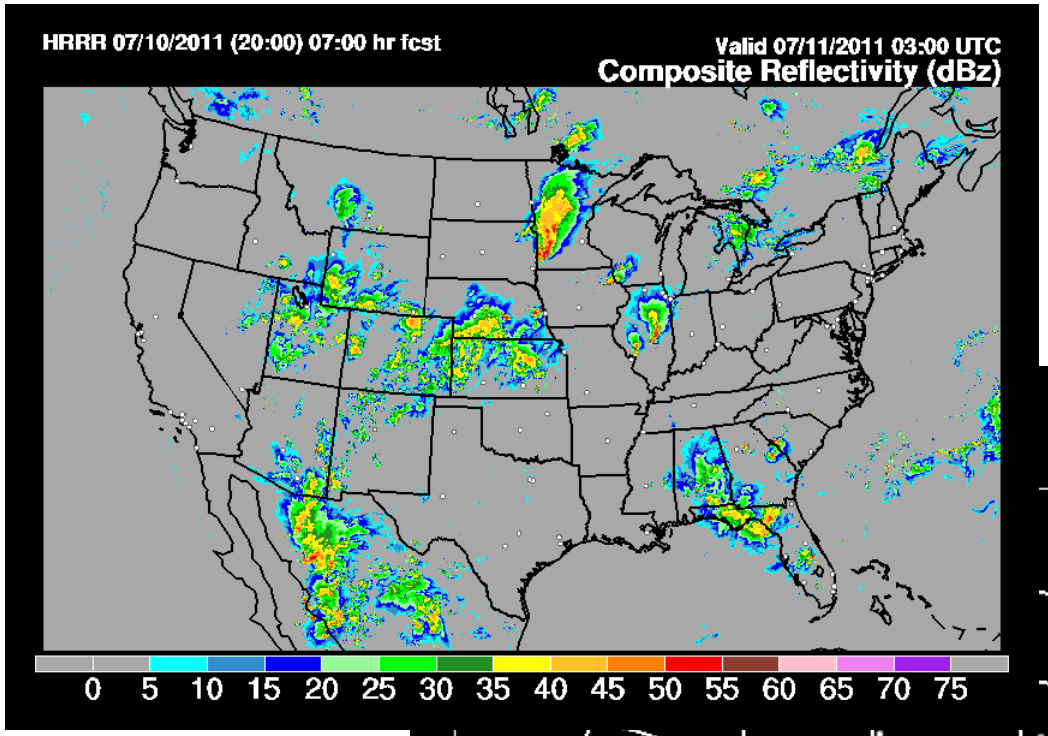


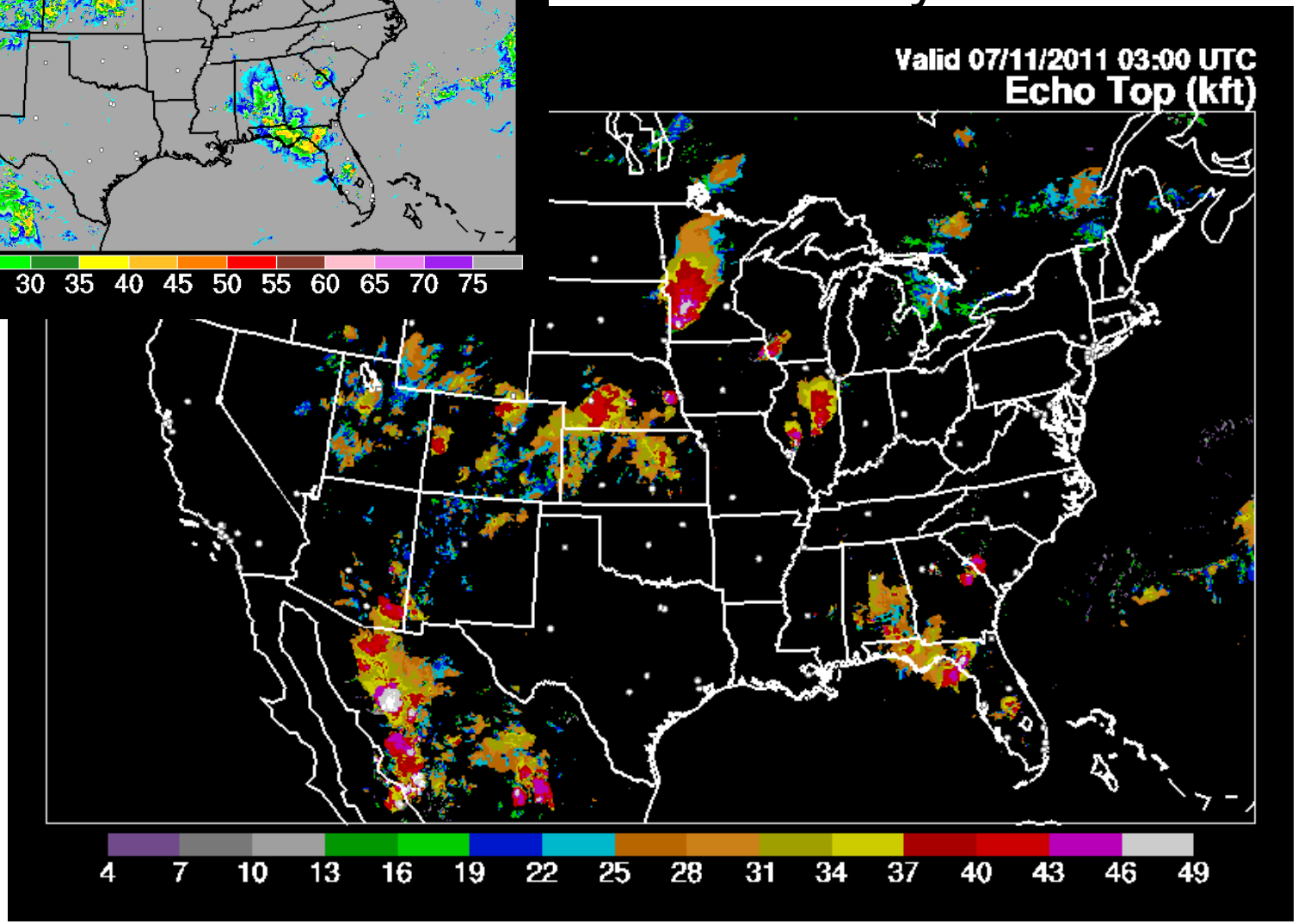


Convective initiation - new HRRR output fields

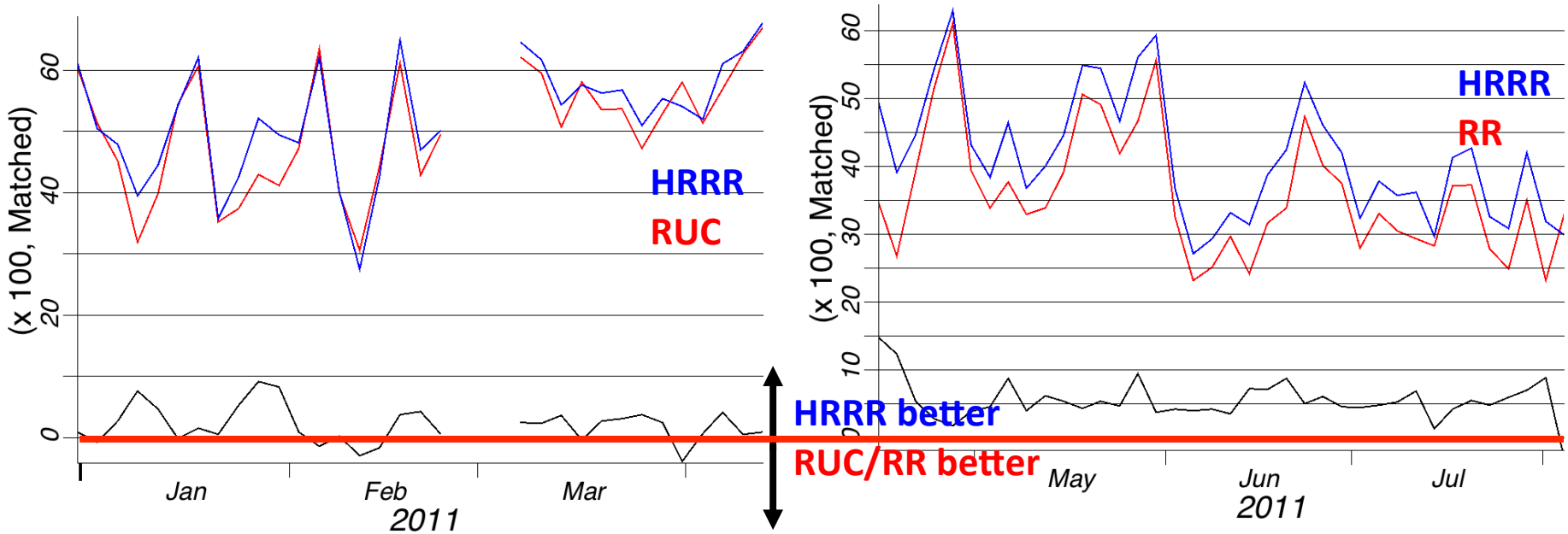
Echo top in HRRR output fields

Top level with 18 dBZ reflectivity





HRRR Verification
< 500 ft ceiling, 6-hr forecasts
TSS (3 day averages)



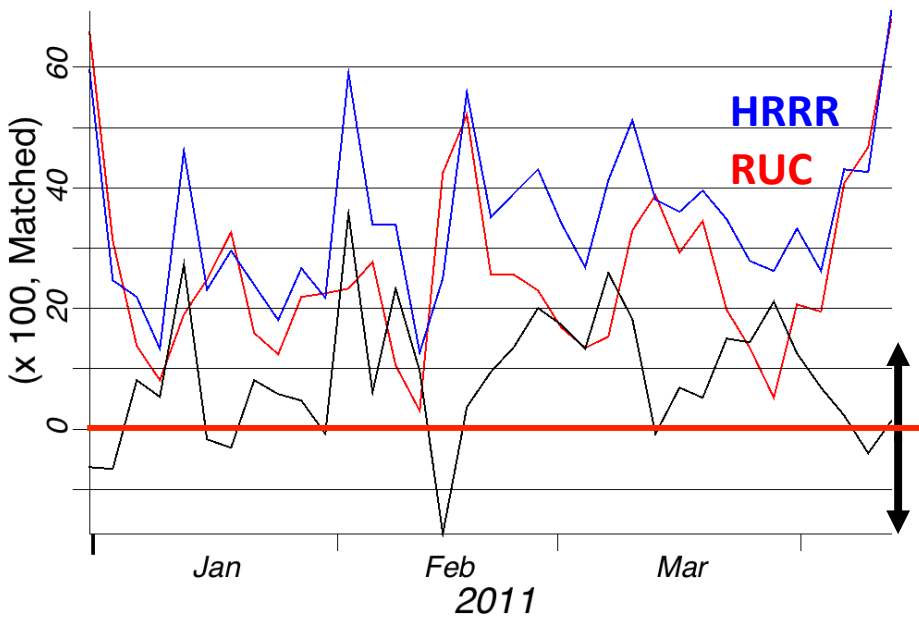
HRRR consistently beats the RUC

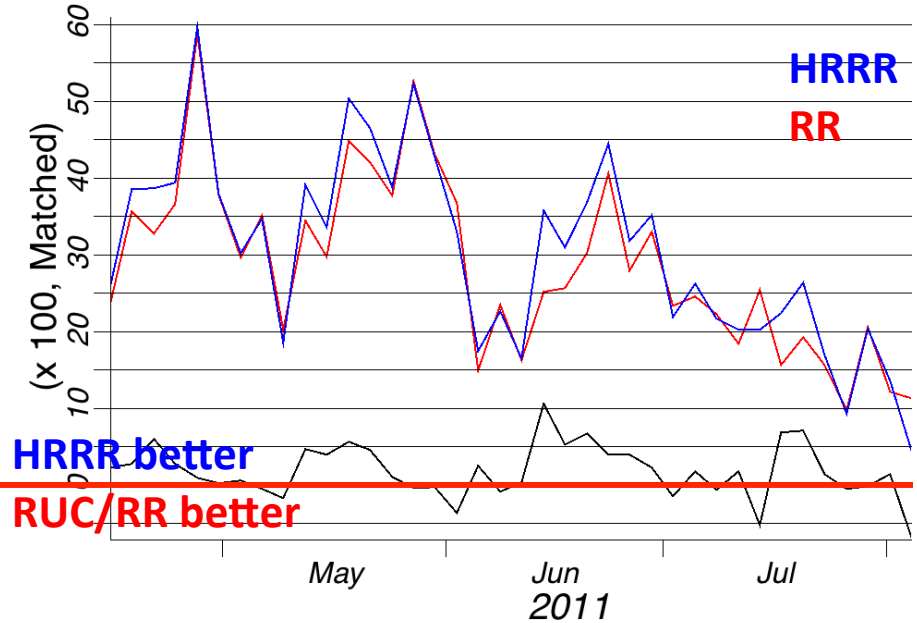
(cold season)

HRRR consistently beats the RR

(warm season)

HRRR Verification
< 0.5 mi visibility, 6-hr forecasts
TSS (3 day averages)





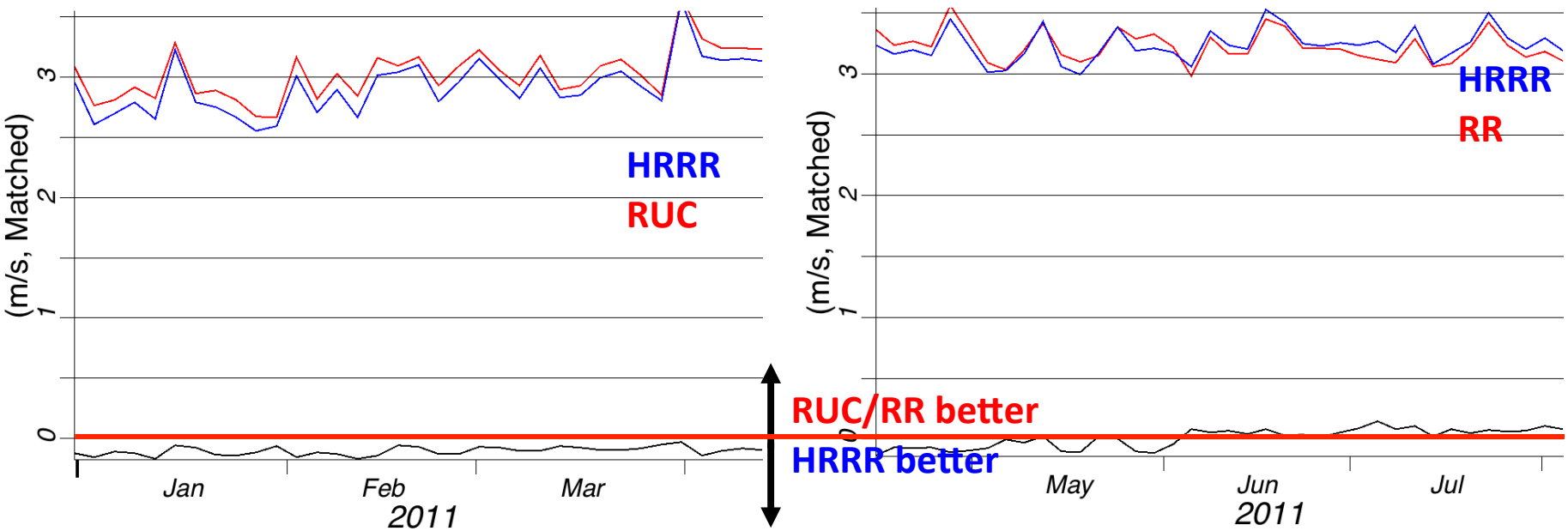
HRRR consistently beats the RUC

(cold season)

HRRR consistently beats the RR

(warm season)

HRRR Verification
10 m wind, 6-hr forecasts
RMS error (3 day averages)



HRRR consistently beats the RUC

(cold season)

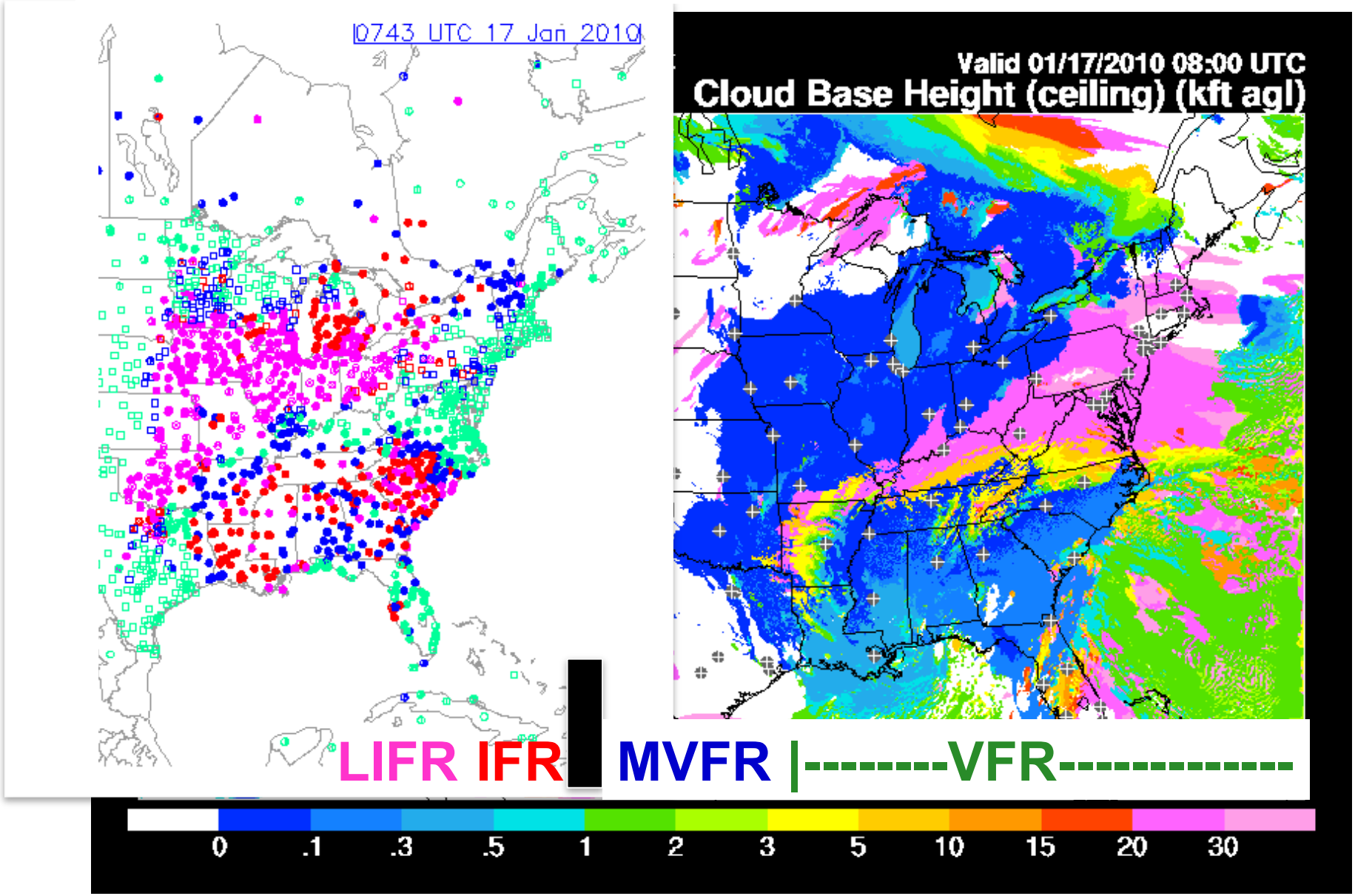
HRRR beats the RR in Apr/May,

Slight margin to RR in Jun/Jul

(warm season)

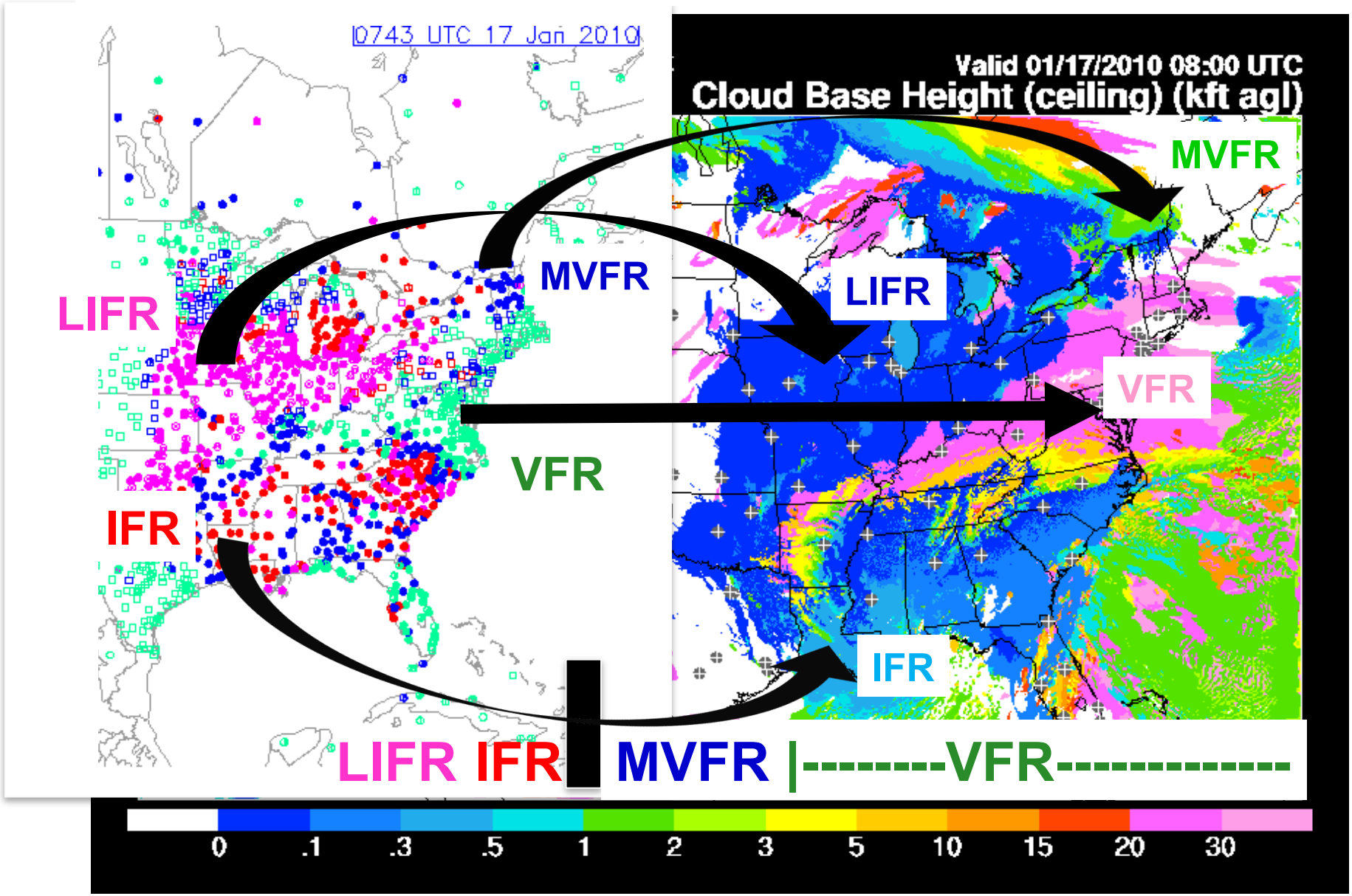
HRRR – wintertime forecast applications

Excellent skill for low ceiling / visibility

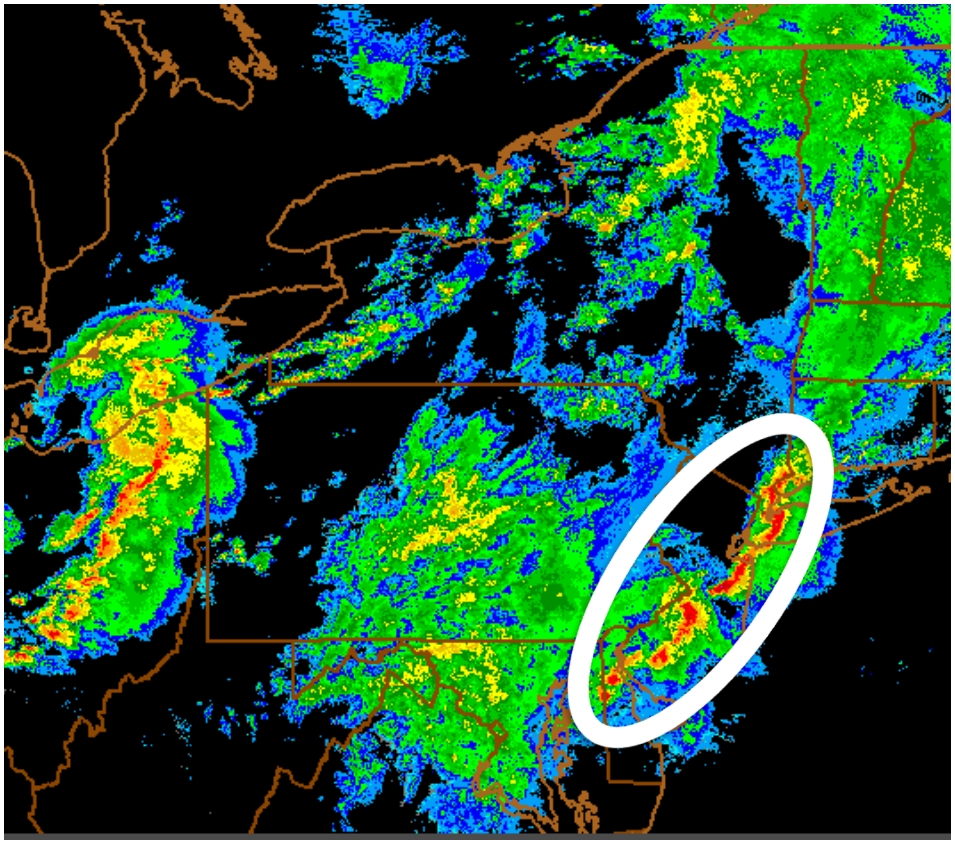


HRRR – wintertime forecast applications

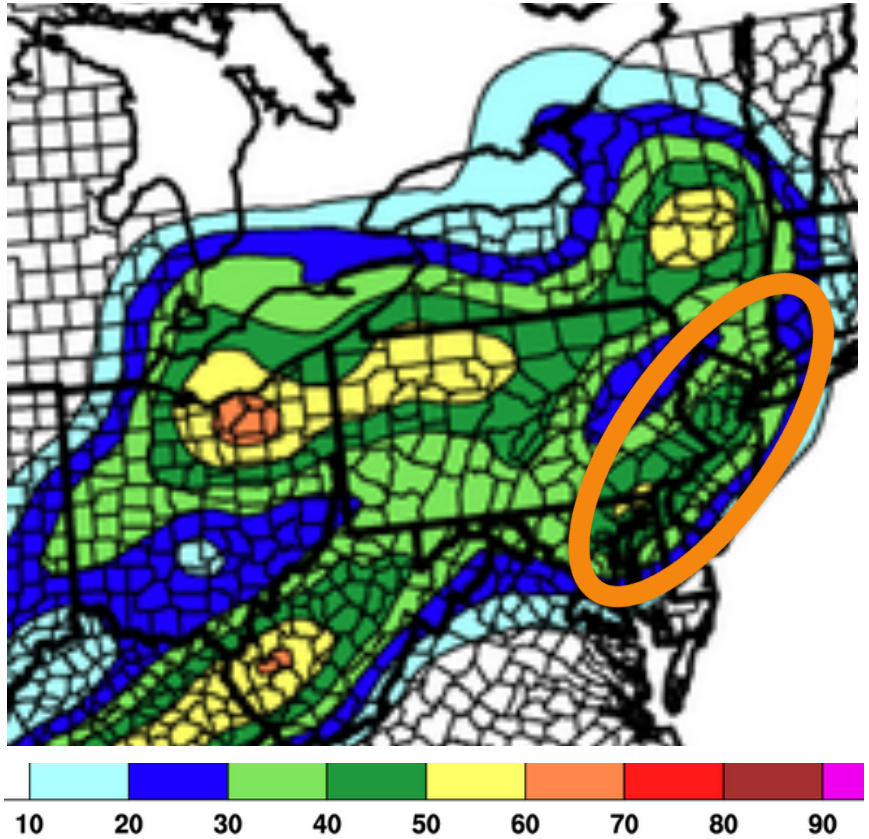
Excellent skill for low ceiling / visibility



HCPF - Convective probability forecasts from HRRR time-lagged ensemble



22z 16 Sept '10 Verification



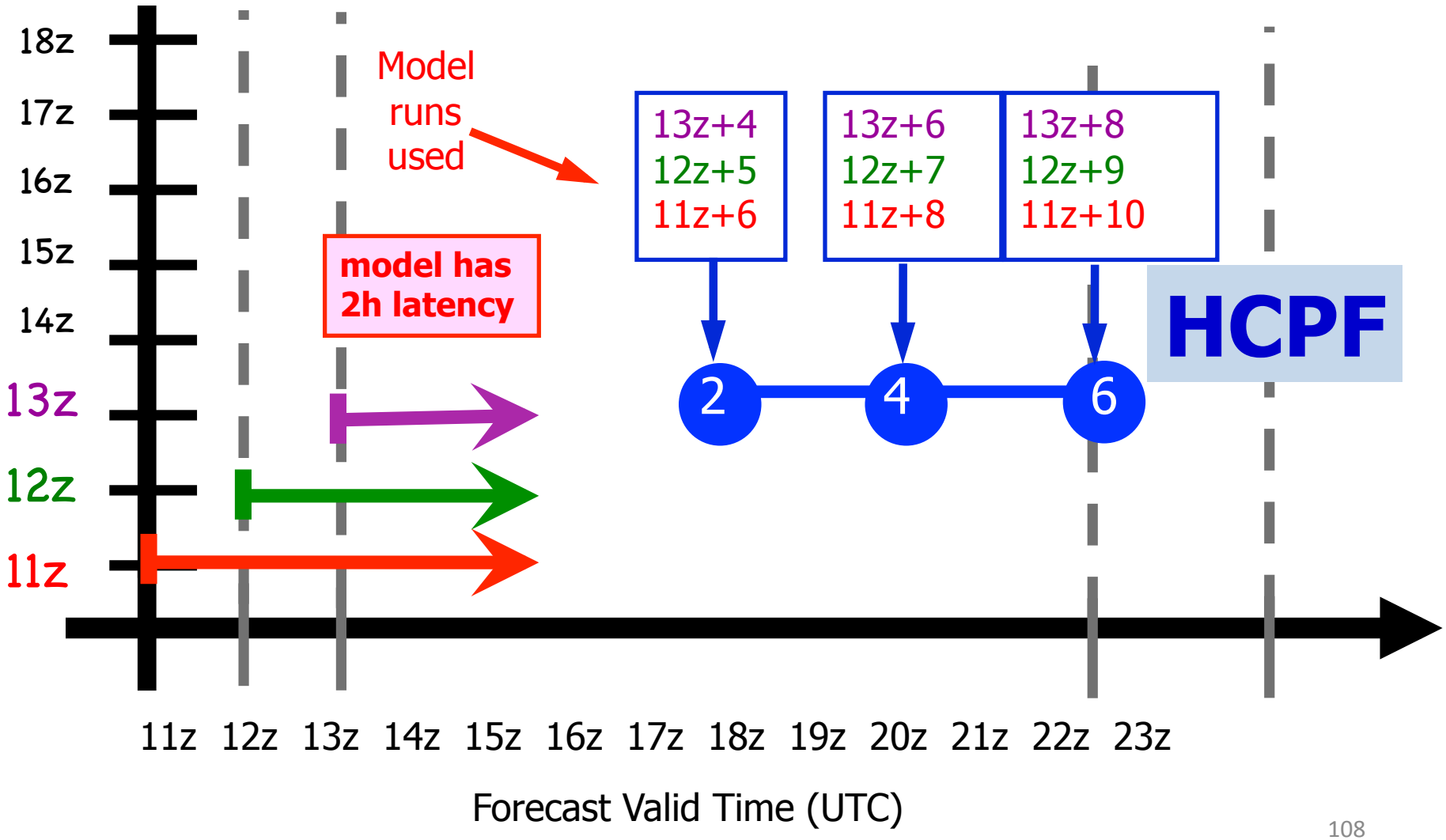
Probability (%)

09z + 13h HCPF valid 22z

Forecasts some risk for NYC development

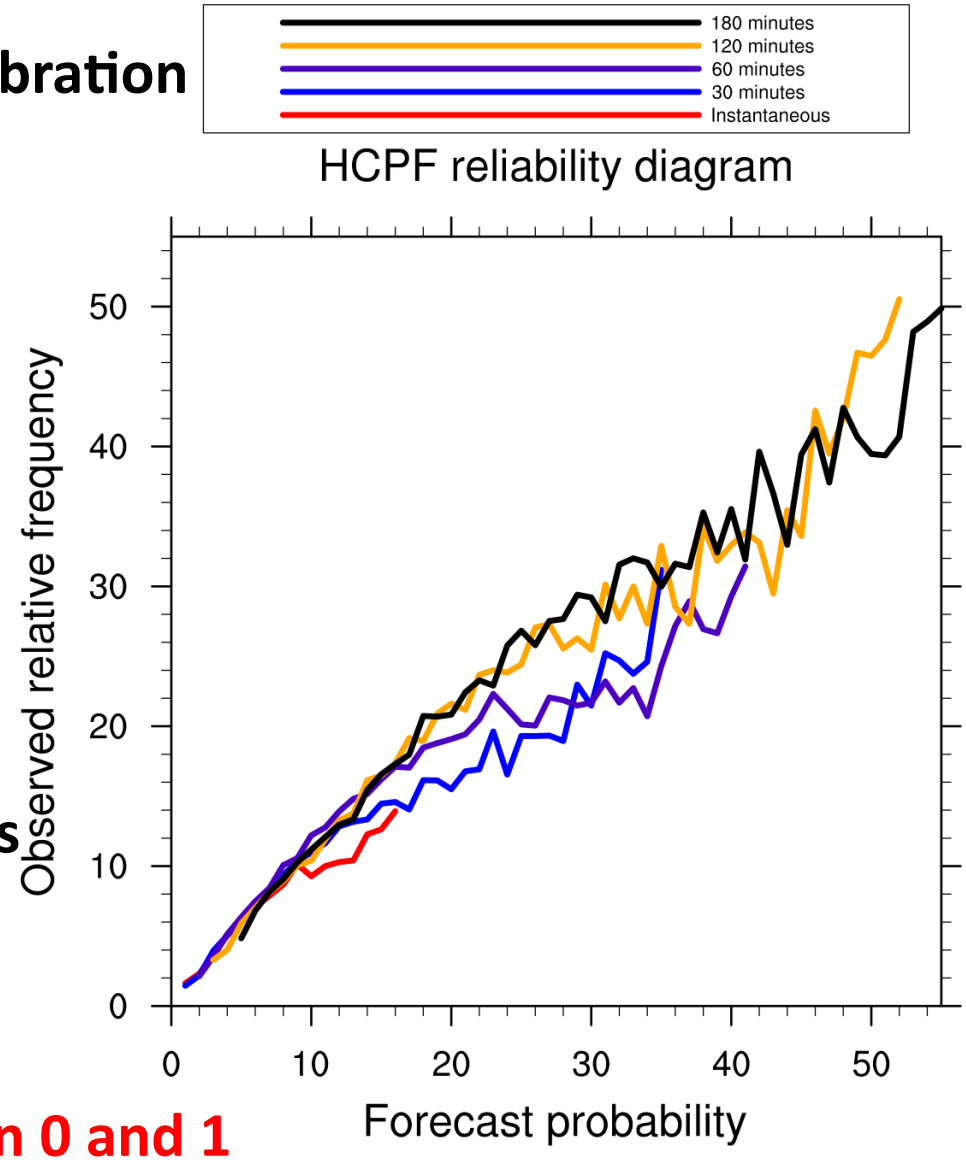
Time-lagged ensemble

Example: 15z + 2, 4, 6 hour HCPF



Reliability vs Resolution/Sharpness

Logistic regression using various observation time windows for calibration



Parameter choices:
3 members (2 hr lag youngest)
Fixed 2 hr time window
Fixed 60 km spatial filter
1.0 m/s updraft velocity

P(convection) = $[1 + \exp(-z)]^{-1}$
$z = B_0 + B_1x_1 + B_2x_2 + B_3x_3$
where B_i are the regressed weights and x_i are the predictors

Obtain reliability while preserving resolution → probabilities between 0 and 1

HRRR Time-lagged Ensemble

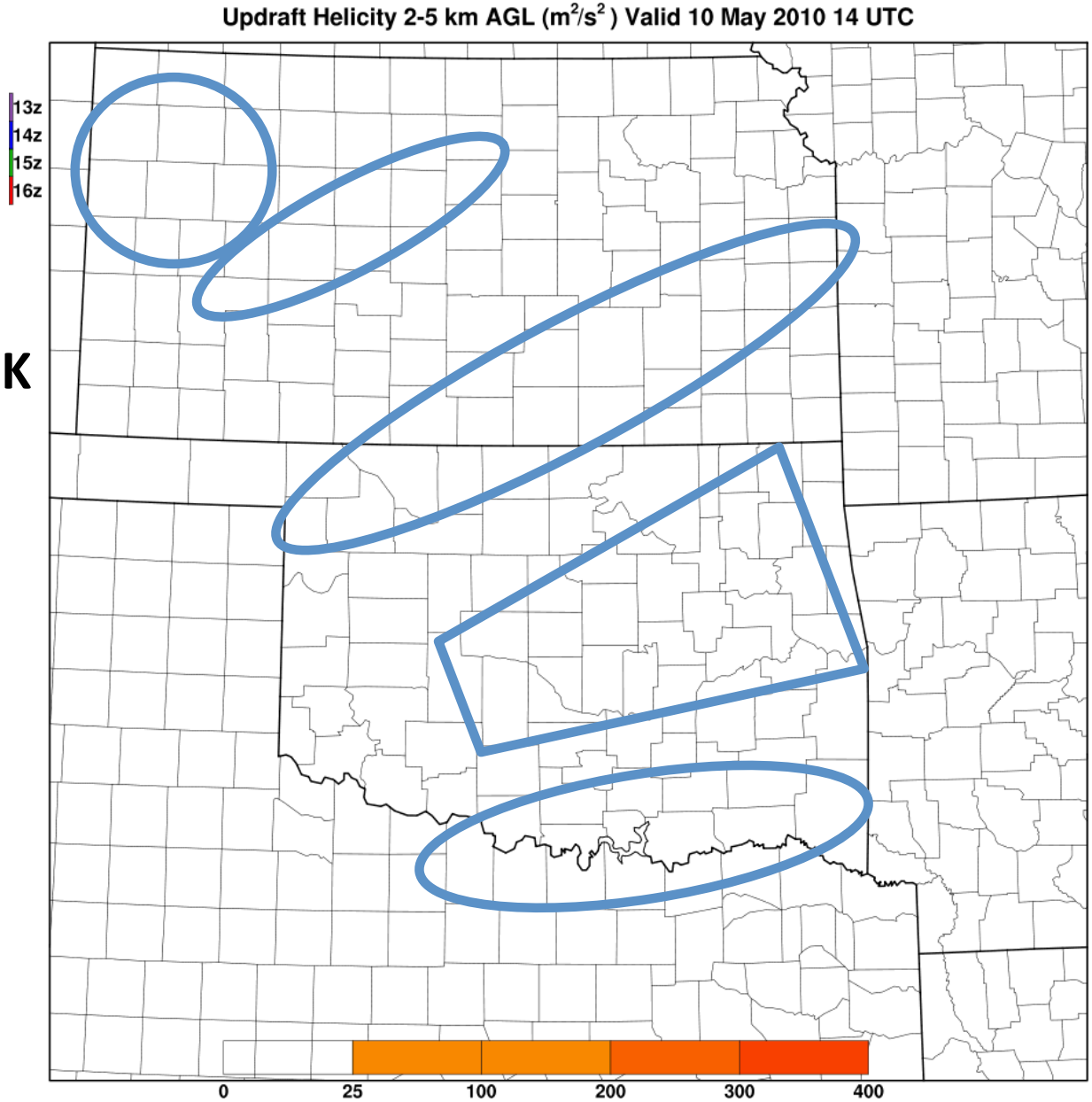
Severe Weather Application

Tornado Outbreak KS/OK
10 May 2010

Updraft helicity from four HRRR runs 13-16 z (color coded by run)

- 13z HRRR
- 14z HRRR
- 15z HRRR
- 16z HRRR

Tornado Reports ●

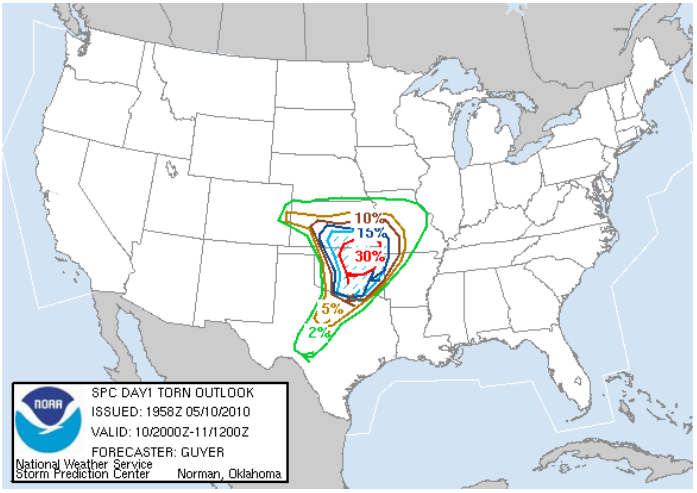


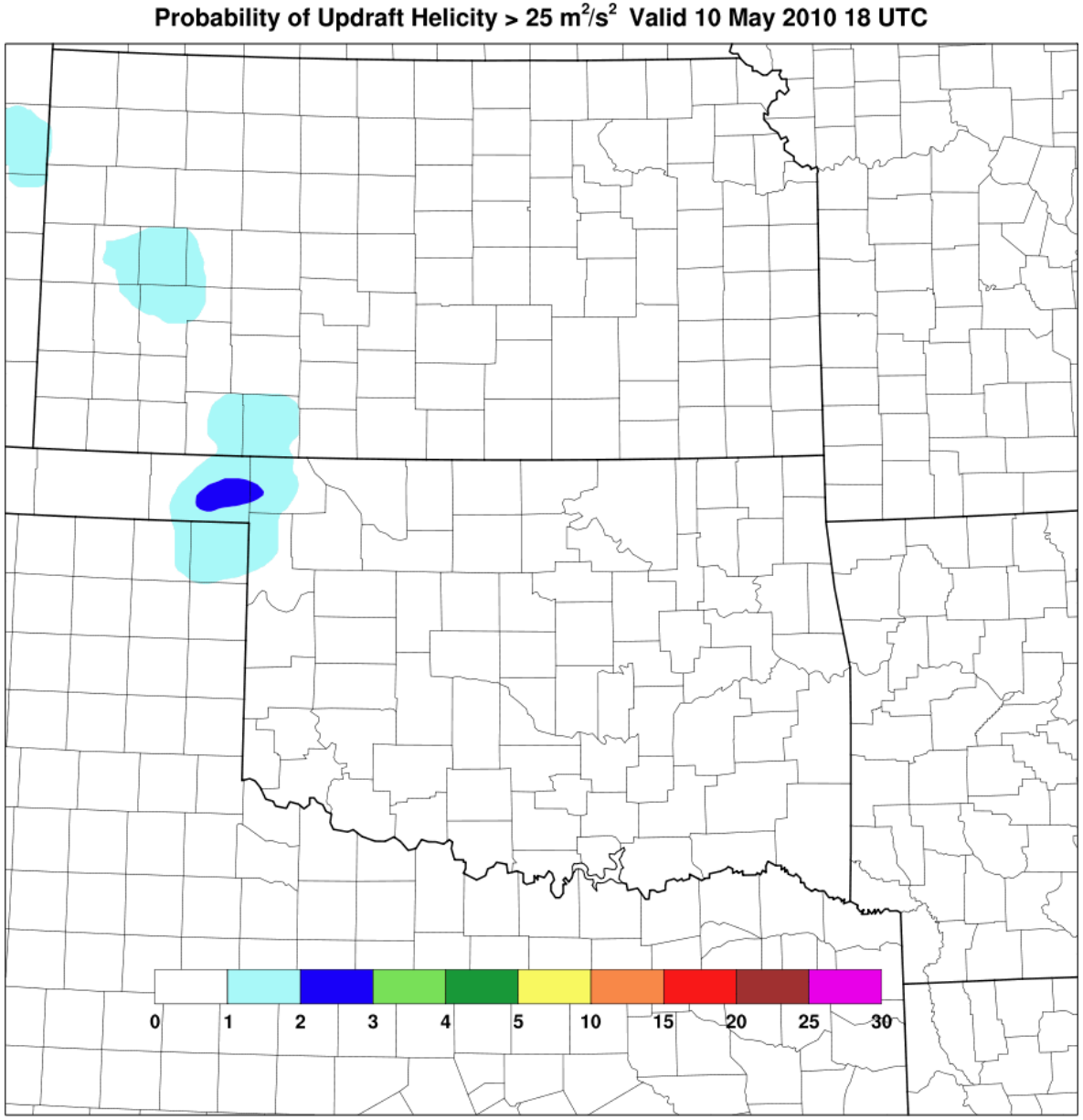
HRRR Severe Weather Forecasts

Tornado Outbreak KS/OK
10 May 2010

Updraft helicity probability
Four consecutive HRRR runs (13-16 UTC)

Time-bracket of 2-hrs
45 km search radius





Coordinated meso- and storm-scale ensembles

NARRE

North American Rapid Refresh Ensemble

- NEMS-based NMM-b and ARW model cores
- Hourly updating with Gridpoint Statistical Interpolation (GSI)
- Six members initially, 3 each + perturbations
- Hourly updating with forecasts to 24-h, NMM to 84-h 4x per day

HRRRE

High-Resolution Rapid Refresh Ensemble

- 3-km CONUS and Alaska nest run within each NARRE member
- Advanced assimilation with radar, lightning, and satellite data
- Key source for NextGen probabilistic guidance
- Enables 1-k terminal and Warn-on-forecast nests

VSREF – Very Short Range Ensemble Forecast

VSREF members

RR - hourly time-lagged (TL) ensemble members

NAM / NAM ensemble

~2014 – RR ensemble – NARRE

~2014 - 3km HRRR (TL ensemble)

~2016-7 - HRRR ensemble - HRRRE

GFS / GFS ensemble

SREF (updated every 6h)

VSREF

Hourly Updated

Probabilistic Forecasts

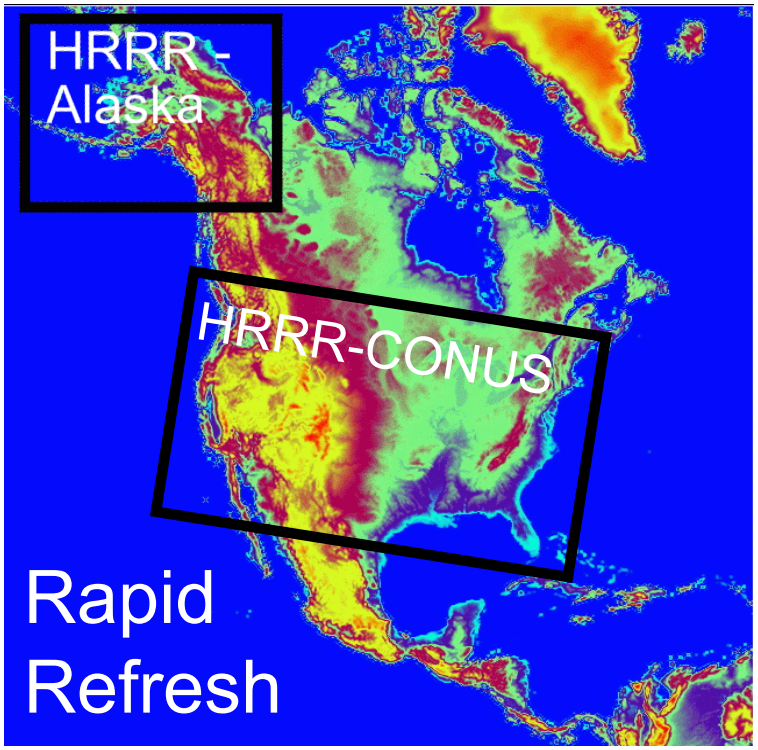
Future plans for advanced hourly NWP/DA

2011 Nov – RR operational at NCEP

2011-14 – HRRR demo @ESRL improves

2014? – Ensemble Rapid Refresh – NARRE

2015? – High-Resolution Rapid Refresh operational at NCEP for CONUS



North American Rapid Refresh Ensemble (NARRE)

- **NEMS-based NMM, ARW cores**
- **Hourly updating with GSI (hybrid-EnKF-GSI?)**
- **Initially 6 members, 3 each core**
- **Forecasts to 24-h**
- **NMM to 84-h 4x per day**

Other improvements

- **Add inline chem, chem DA**
- **Storm-scale radar assimilation**
- **Sub-hourly DA**