12th WRF Users Workshop
21 June 2011

The real-time High Resolution Rapid Refresh (HRRR): Recent enhancements and evaluation activities during the 2011 convective season

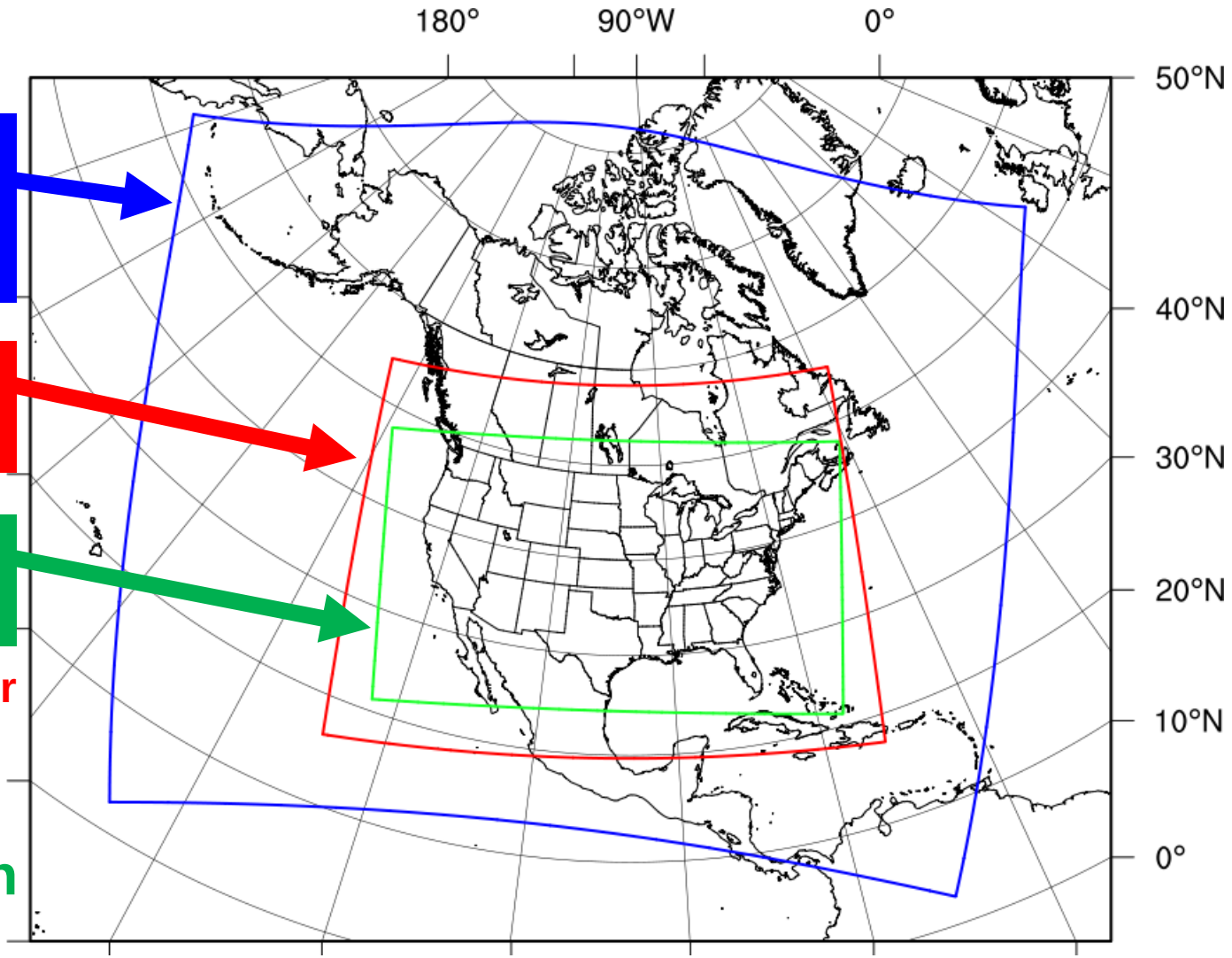
NOAA/ESRL/GSD
Curtis Alexander, Steve Weygandt, Tanya Smirnova, Stan Benjamin, John Brown, David Dowell, Patrick Hofmann, Eric James, Ming Hu, Kevin Brundage, Susan Sahm, and Brian Jamison

Hourly Updated NOAA NWP Models

Rapid Refresh (RR)

replaces RUC at NCEP in 2011

WRF, GSI with RUC features



13km Rapid Refresh (mesoscale)

13km RUC (mesoscale)

3km HRRR (storm-scale)

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

High-Resolution Rapid Refresh

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

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 from RUC to 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	2014
• Ensemble HRRR (HRRRE) at NCEP	2016

High Resolution Rapid Refresh

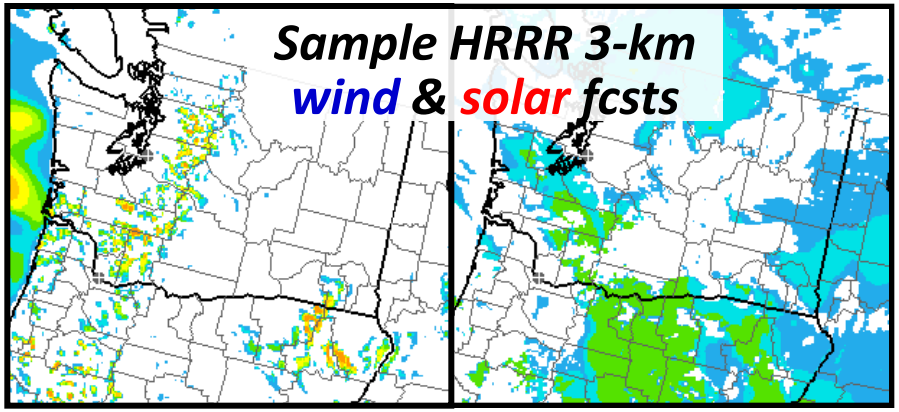
Real-time hourly updated 3-km 15-h CONUS storm-scale model

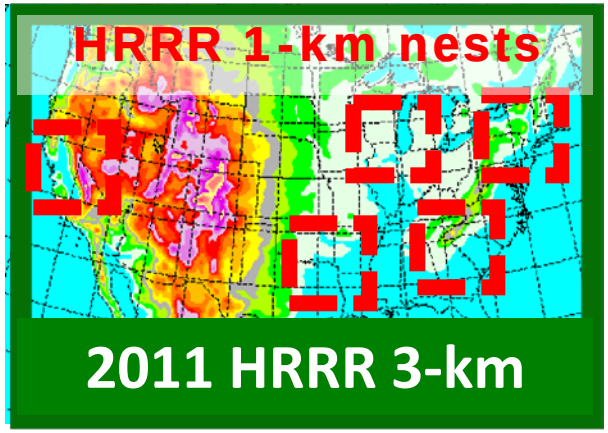
*HRRR provides key convective guidance for **NextGen** aviation*

HRRR essential component of Warn on Forecast development

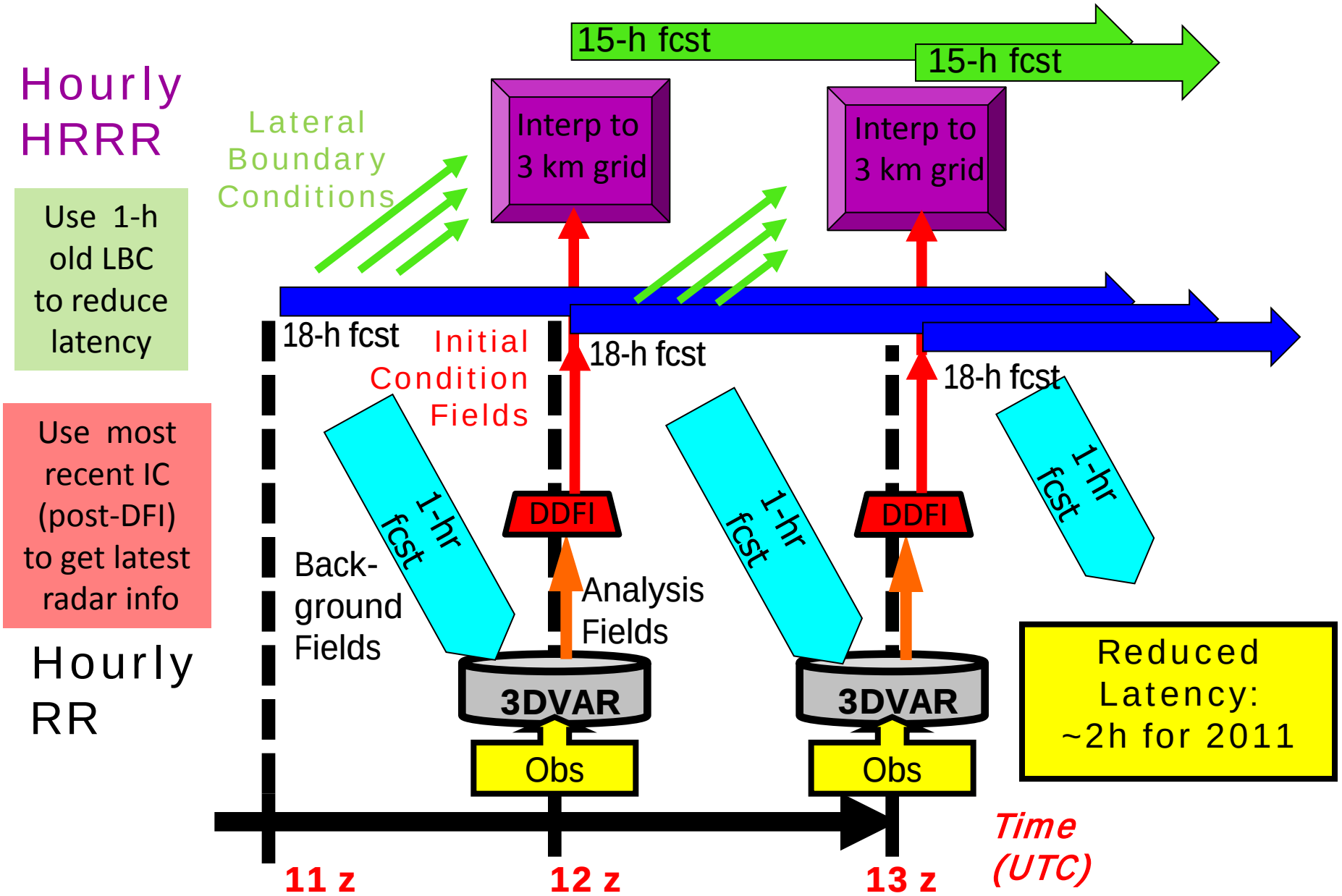
*HRRR fields provide surface detail needed for **Renewable Energy** demands*

Plans for 1-km nests within HRRR





Spring 2011 Hourly HRRR Initialization from RR



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+	15-20s	15 hrs	Hourly (no-cycle)	RUC	~50 min	1000

NOAA/ESRL/GSD/AMB Models

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HRRR	WRF-ARW v3.2+	Increased	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	G3	MYJ	RUC
RR	GSI	Yes - strong	Thompson	RRTM/Goddard	G3	MYJ	RUC
HRRR	None: RUC I.C.	No	Thompson	RRTM/Goddard	None	MYJ	RUC

Tanya Smirnova talk #3.4 on RUC LSM in WRF/RR at 2:15 p.m.

John Brown talk #4.1 on RR developments at 3:45 p.m.

NOAA/ESRL/GSD/AMB Models

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RR	GSI	Yes - strong	Thompson	RRTM/Goddard	G3	MYJ	RUC
HRRR	None: RR I.C.	No	Thompson	RRTM/Goddard	None	MYJ	RUC

Summary of 2011 Evaluation Activities

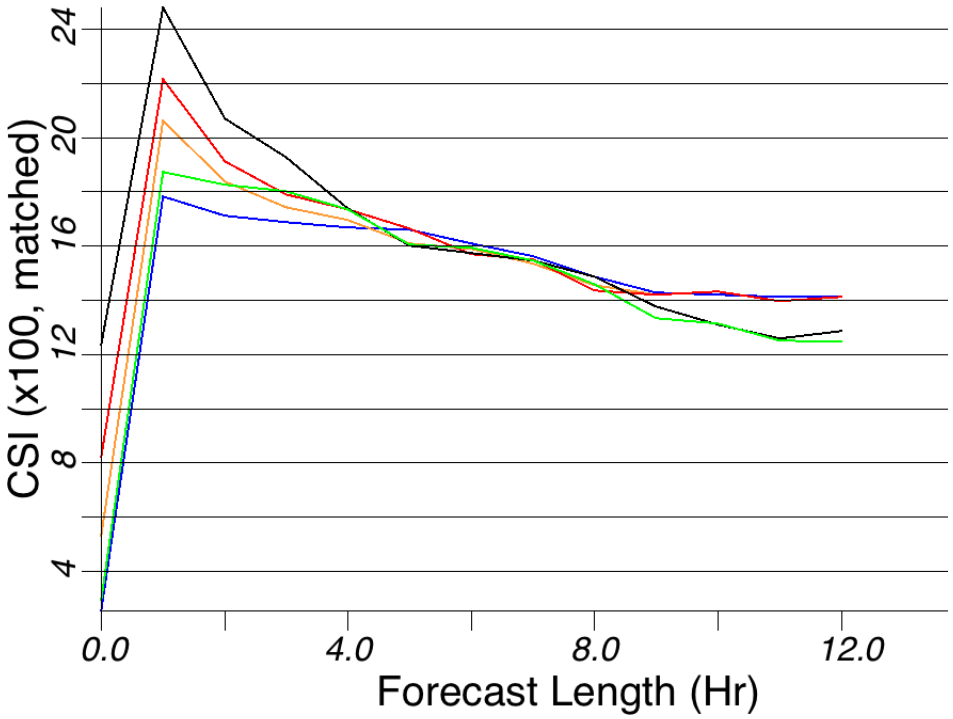
(1) RR initialization (parent model)
(2) Latent heating strength (radar data assimilation) in RR
(3) Reduced diffusion (no 6th order diffusion)
(4) Raised pressure top
(5) Increased min/max time step
(6) Thompson WRFv3.3 microphysics and reflectivity computations
(7) Radar reflectivity data assimilation in HRRR

25 dBZ Threshold
Eastern US
16-21 July 2010
48 Initialization Times

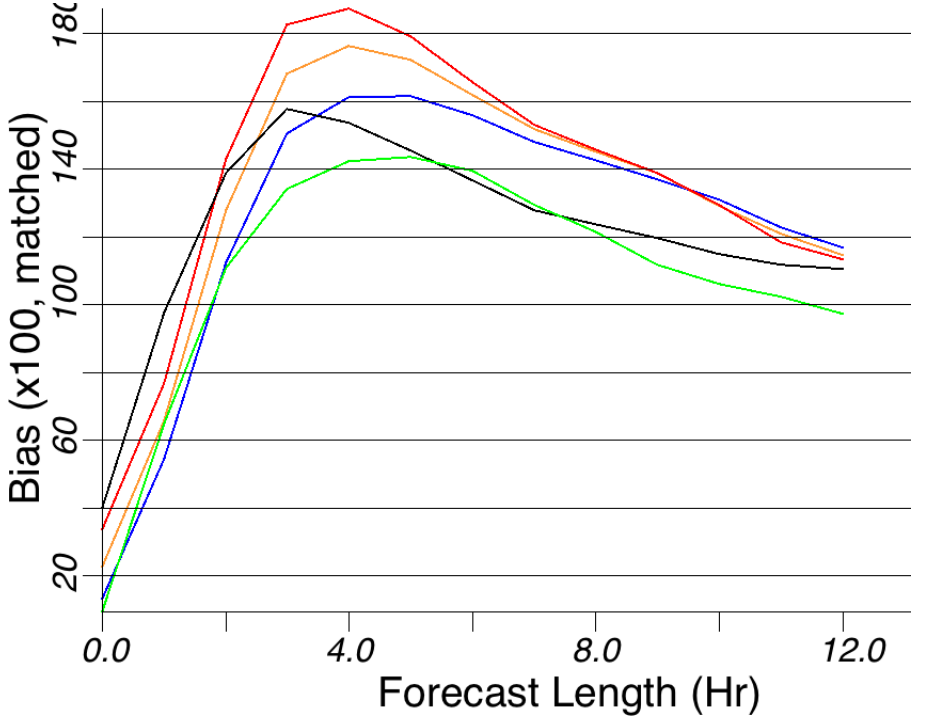
Multi-scale verification by Patrick Hofmann

- **RUC 1x latent heating**
- RR 1x latent heating
- RR 2x latent heating
- RUC 1/3x latent heating
- RR 1/3x latent heating

CSI 40 km



Bias 3 km

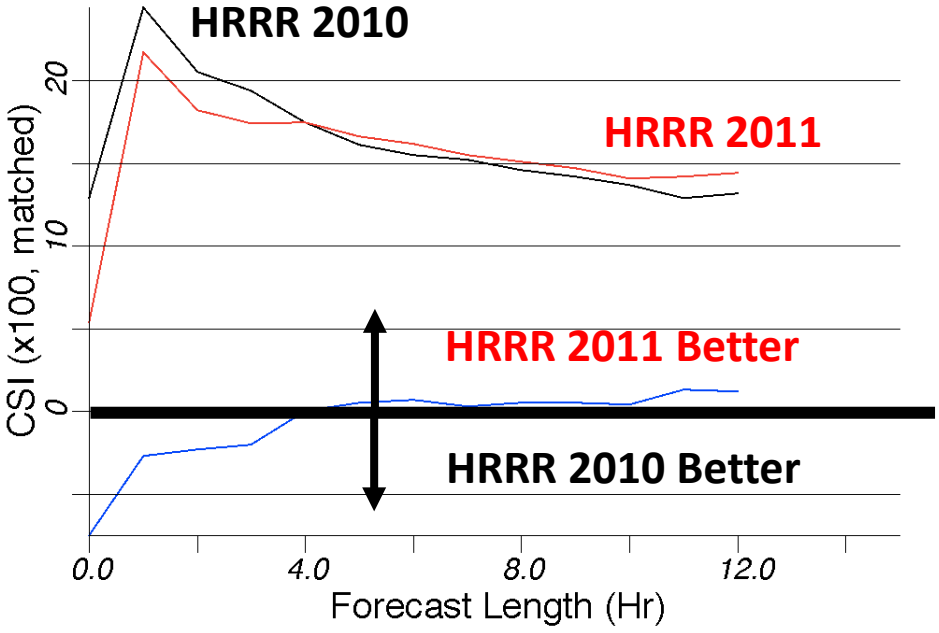


HRRR 2010
RUC Initial condition
1x latent heating
6th order diffusion

25 dBZ Threshold
Eastern US
16-19 July 2010
All Initialization Times

HRRR 2011
RR Initial condition
1x latent heating
No 6th order diffusion

CSI 40 km



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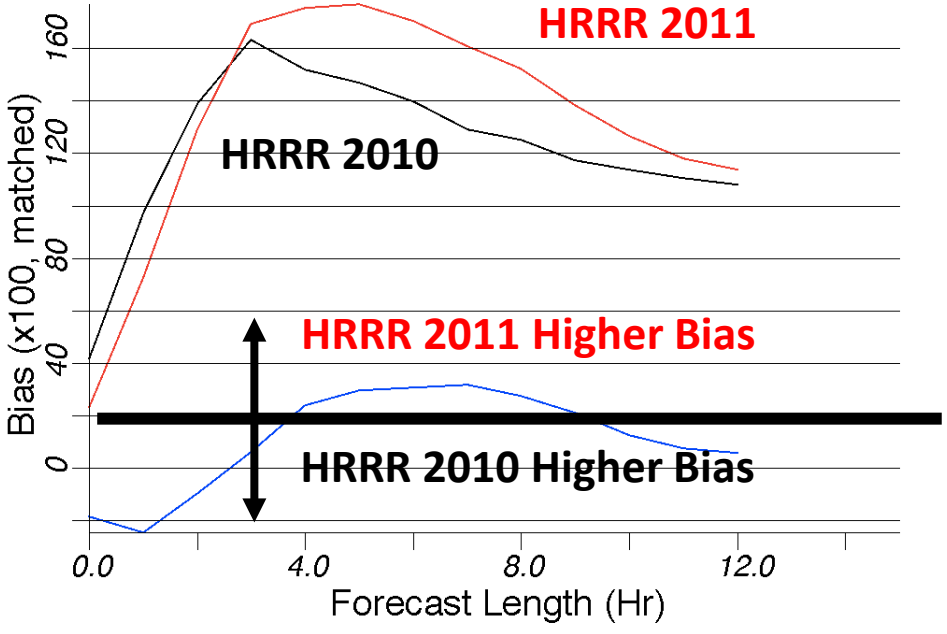

HRRR 2011 has more skill beyond forecast hour 4
HRRR 2011 has generally higher bias after hour 2

HRRR 2010
RUC Initial condition
1x latent heating
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Eastern US
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All Initialization Times

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RR Initial condition
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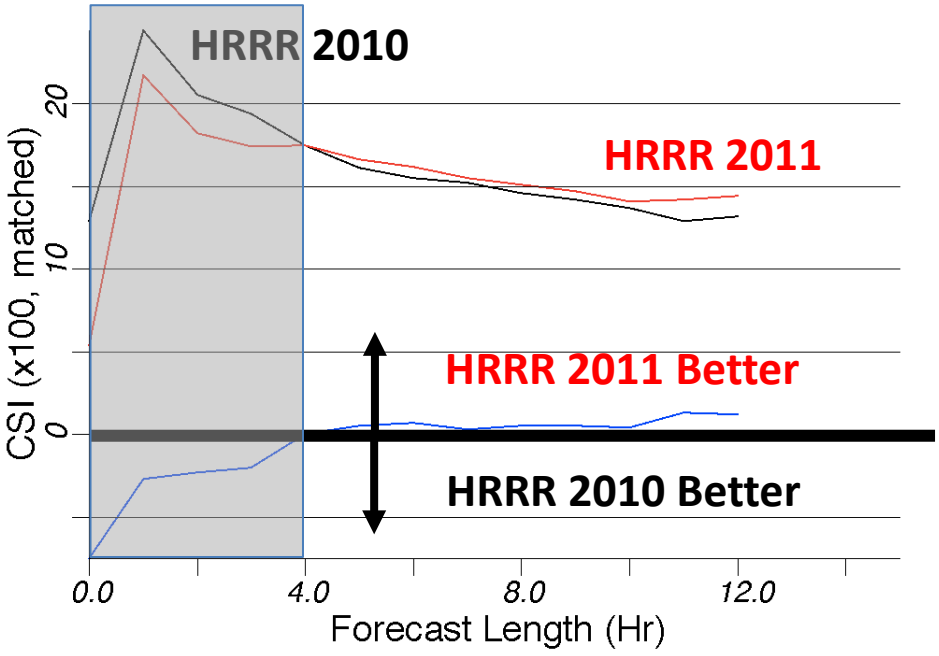

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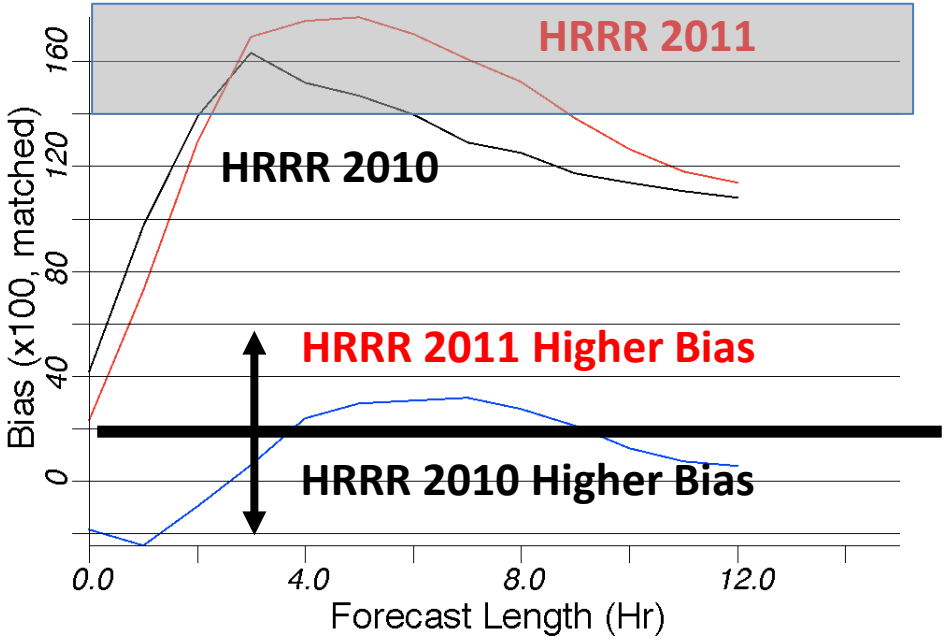

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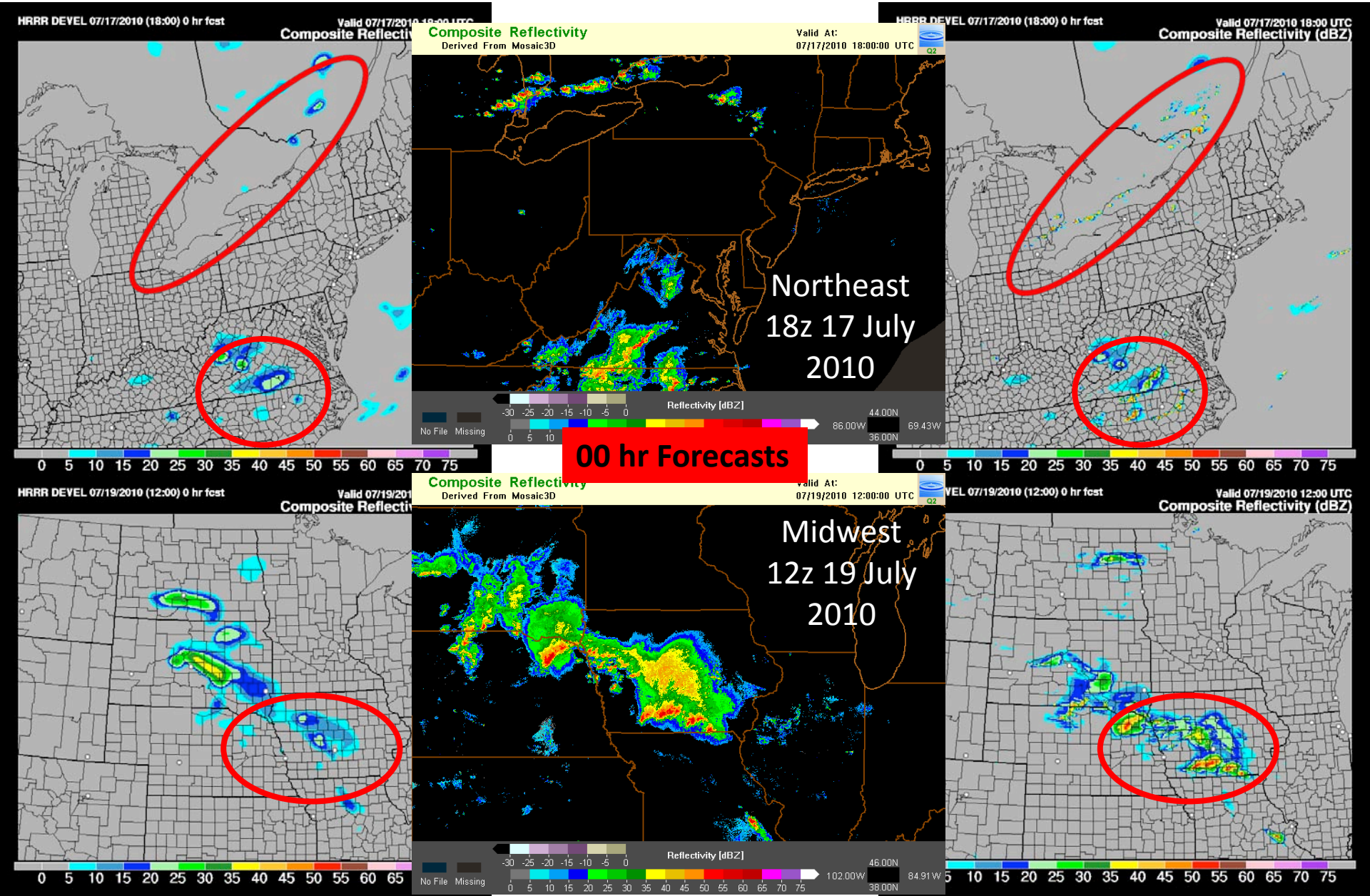
HRRR 2011 has generally higher bias after hour 2

HRRR
No 3-km radar assimilation

0-3 hr forecast deficiency:
HRRR 3-km radar assimilation

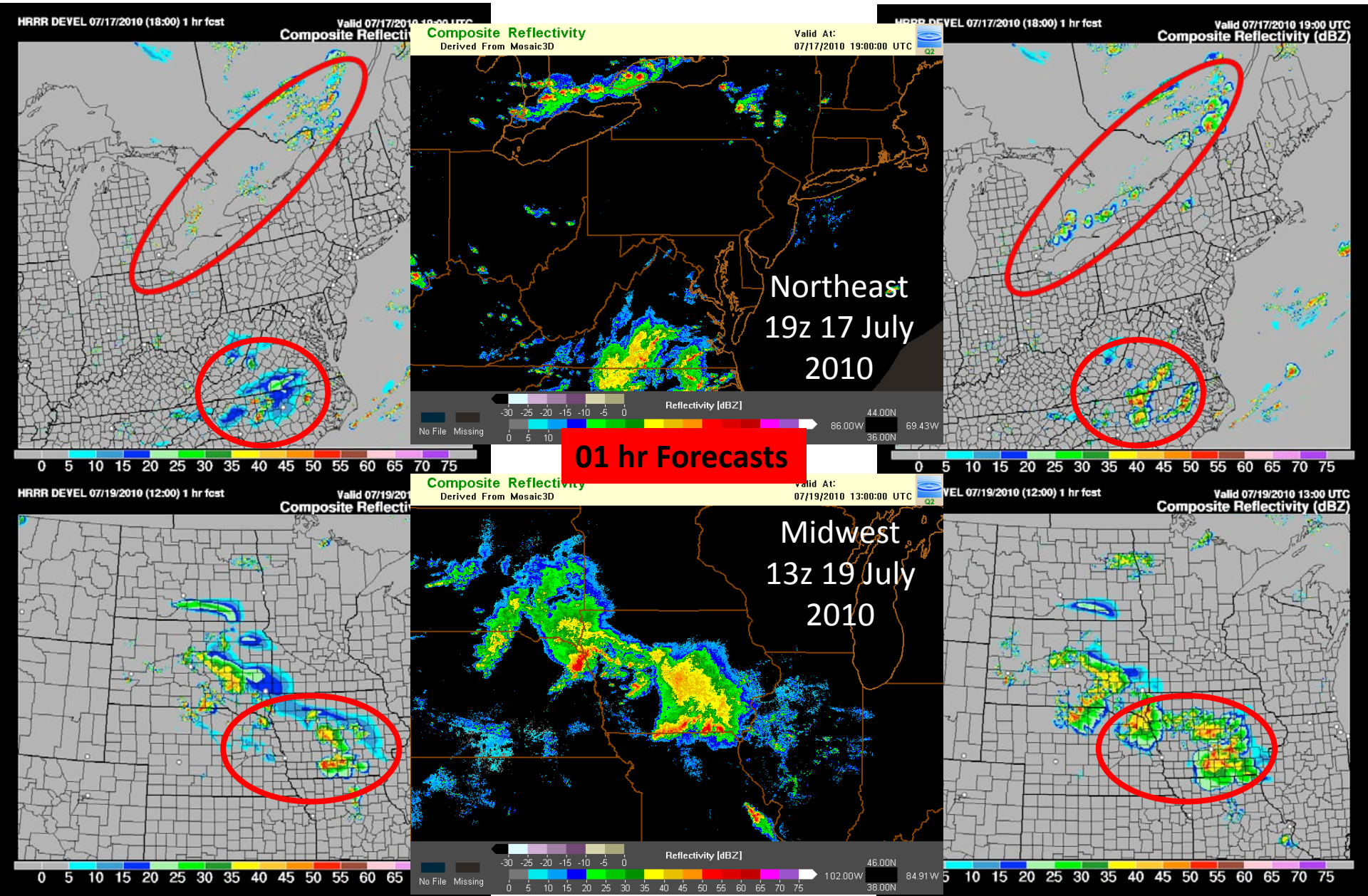
HRRR
With 3-km radar assimilation



HRRR
No 3-km radar assimilation

0-3 hr forecast deficiency:
HRRR 3-km radar assimilation

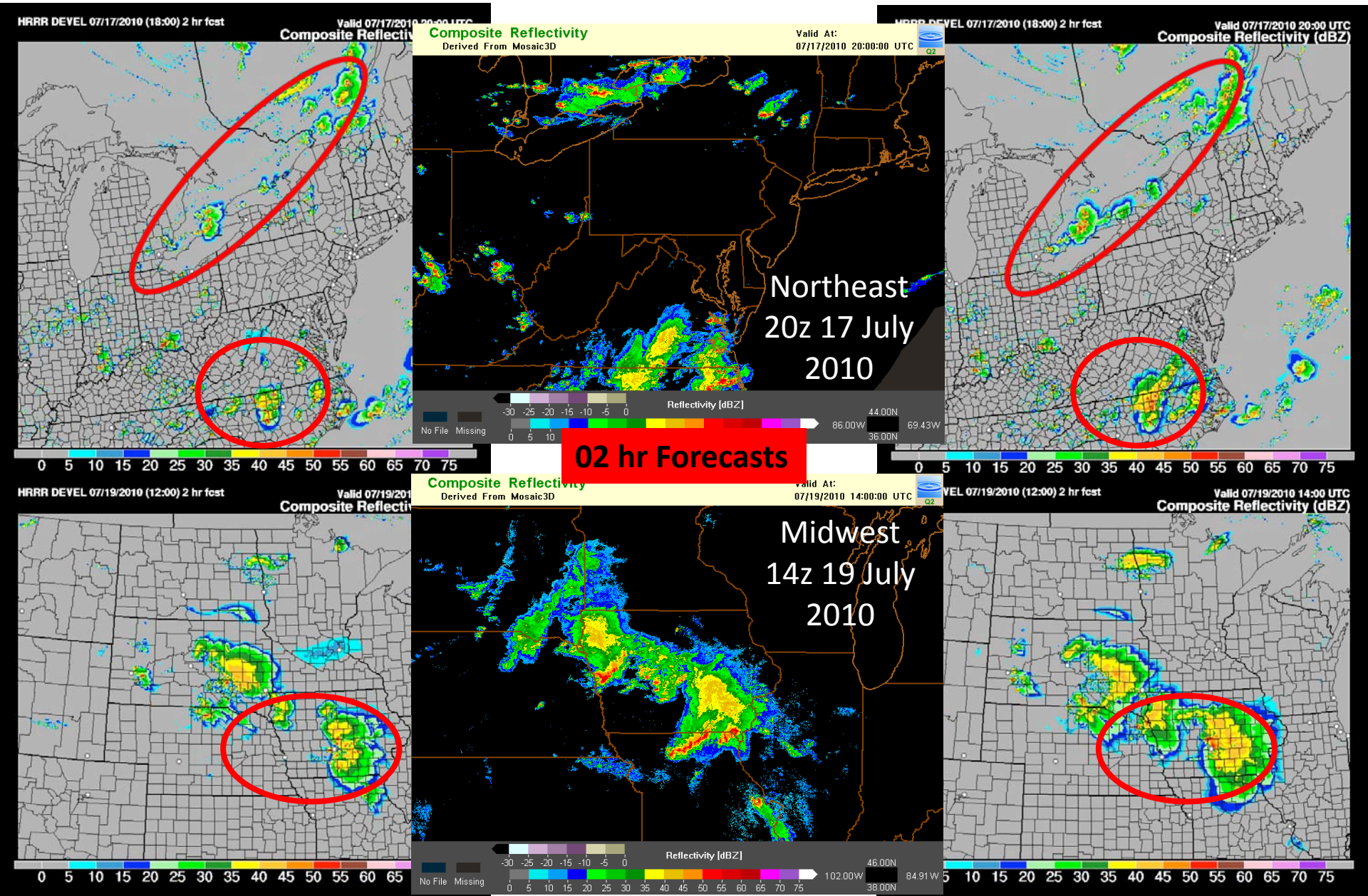
HRRR
With 3-km radar assimilation



HRRR
No 3-km radar assimilation

0-3 hr forecast deficiency:
HRRR 3-km radar assimilation

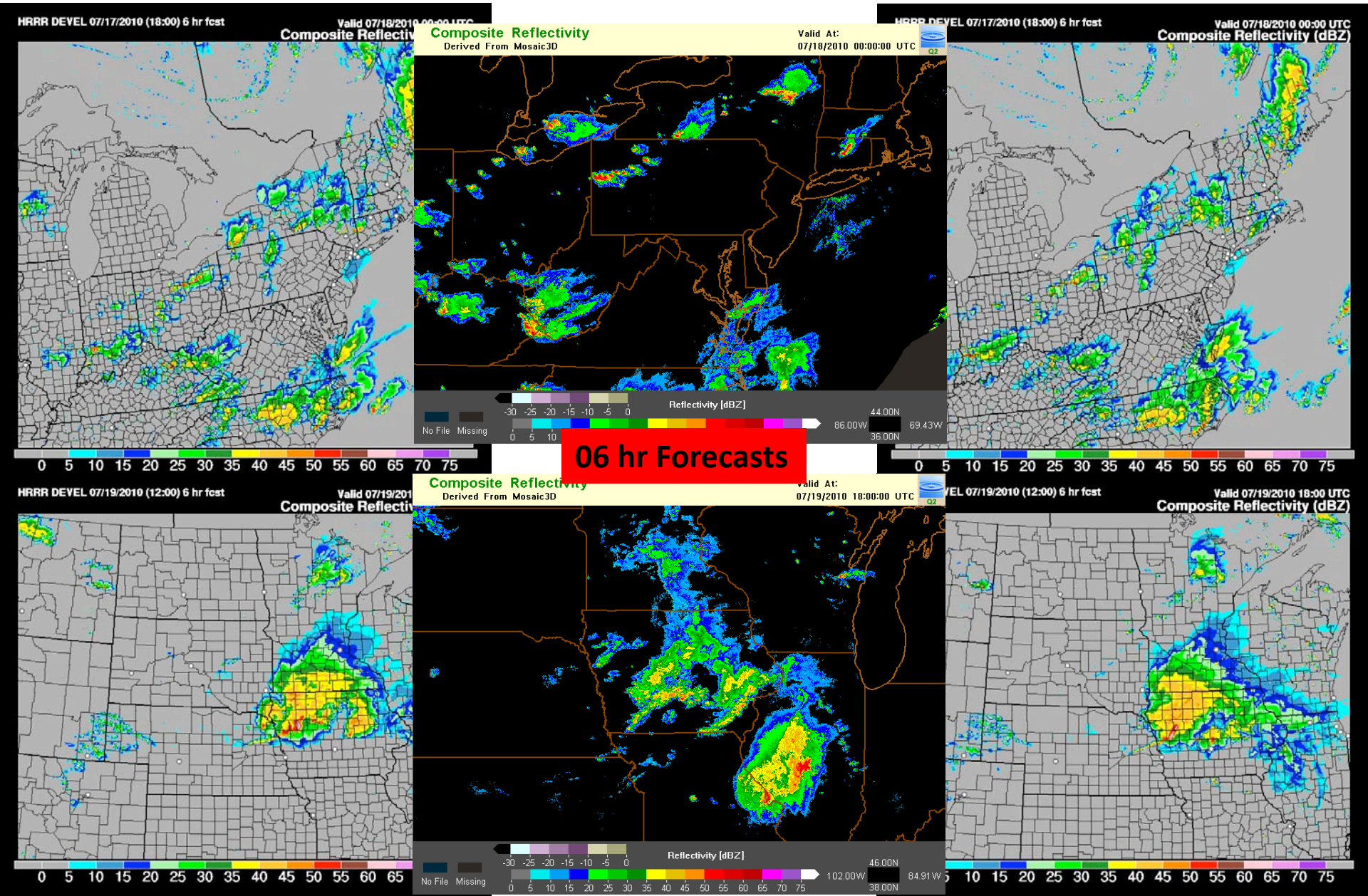
HRRR
With 3-km radar assimilation



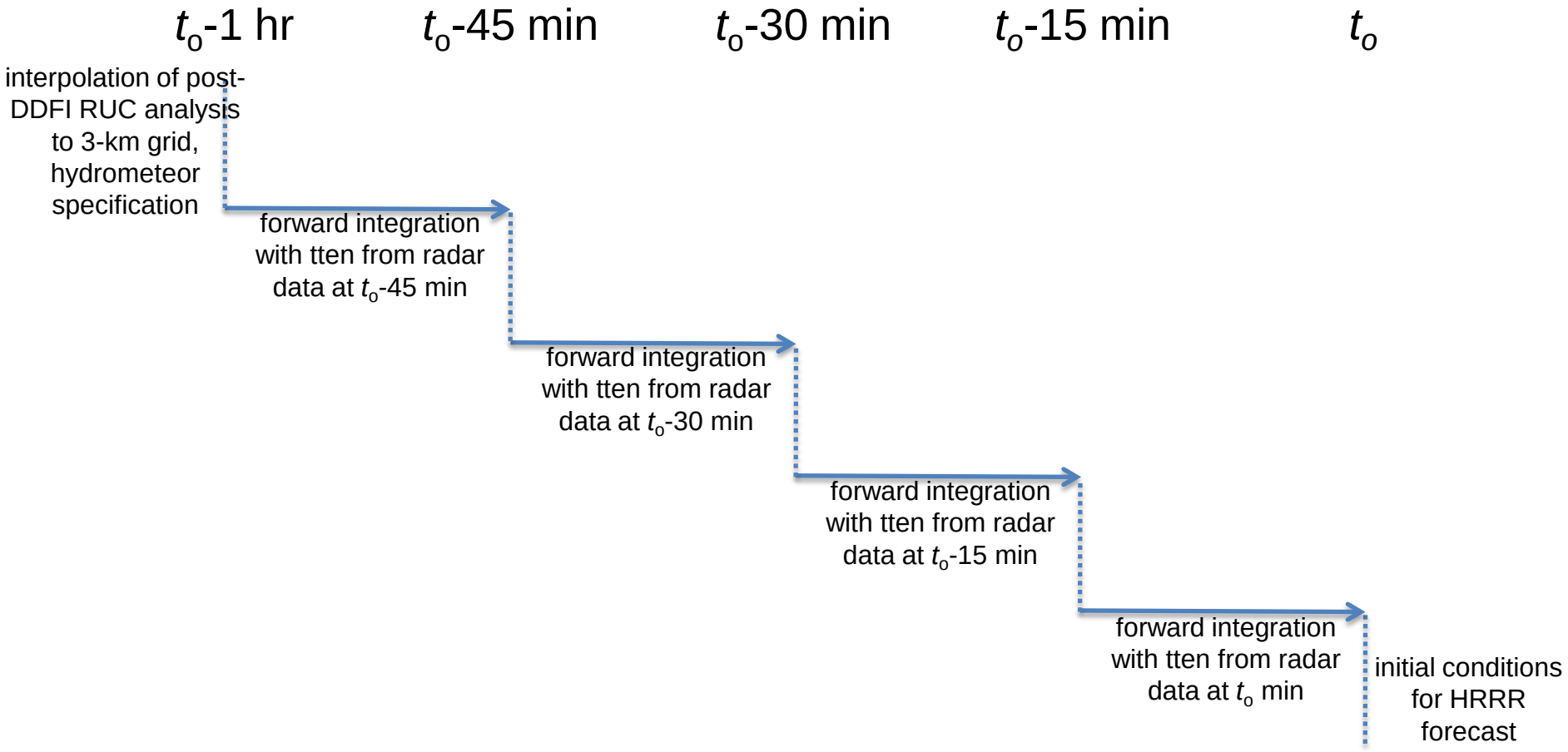
HRRR
No 3-km radar assimilation

0-3 hr forecast deficiency:
HRRR 3-km radar assimilation

HRRR
With 3-km radar assimilation



Reflectivity DA on 3-km Grid



Sub-hourly reflectivity DA in collaboration with David Dowell

Reflectivity DA: Specified Temp. Tendencies

Hydrometeors are specified by GSI on the 3-km grid only at t_0 - 1 h.

Reflectivity data are assimilated through specified temperature tendencies during four cycles of 15-min model integrations.

The temperature tendency at model levels 1-11 is not specified, so that cold pools can develop during the cycling.

The time scale for the specified temperature tendency is 10 min (“1x”).

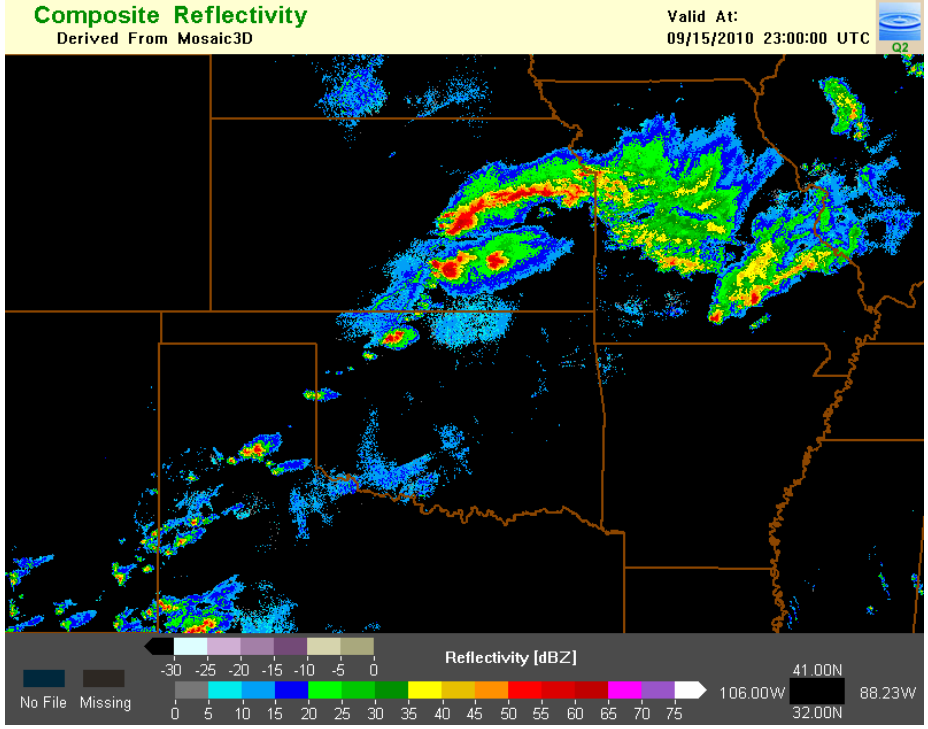
No digital filtering is employed on the 3-km grid.

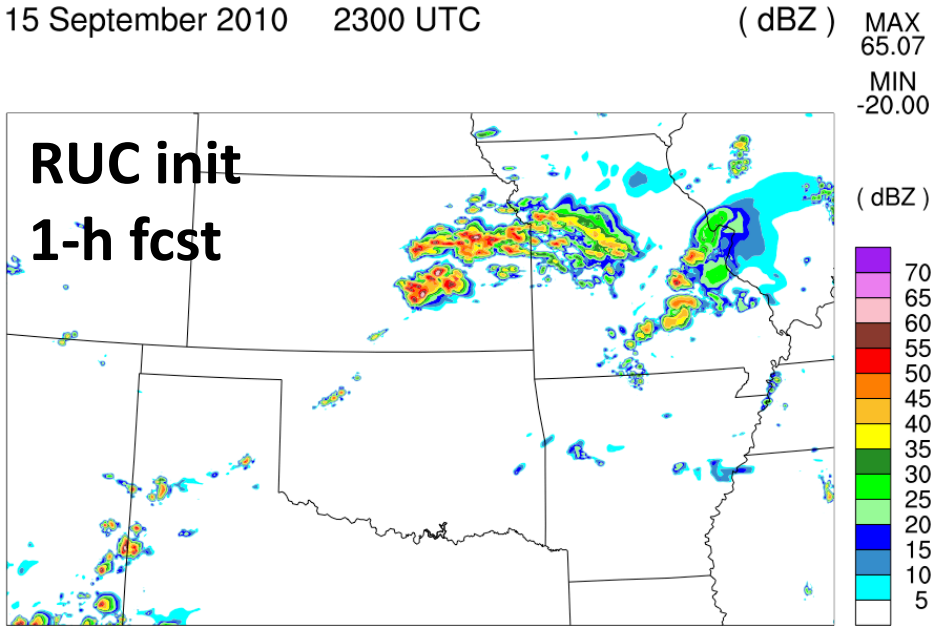
The Thompson 3.3 microphysics scheme with consistent reflectivity computation is used for all experiments.

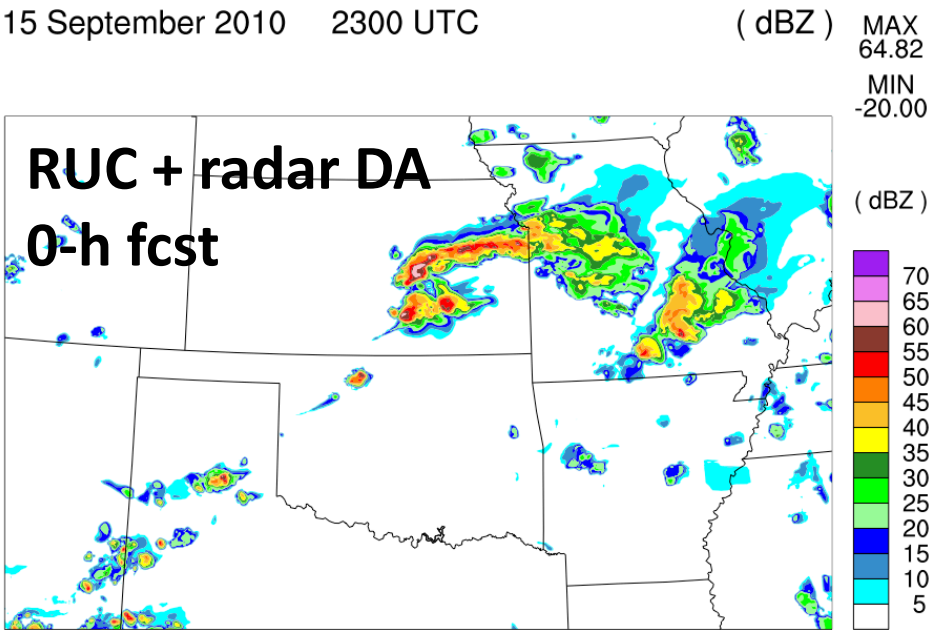
HRRR forecasts initialized as follows are compared in upcoming slides:

- RUC post-dfi analysis
- RUC post-dfi analysis + 3-km radar DA for 1 h

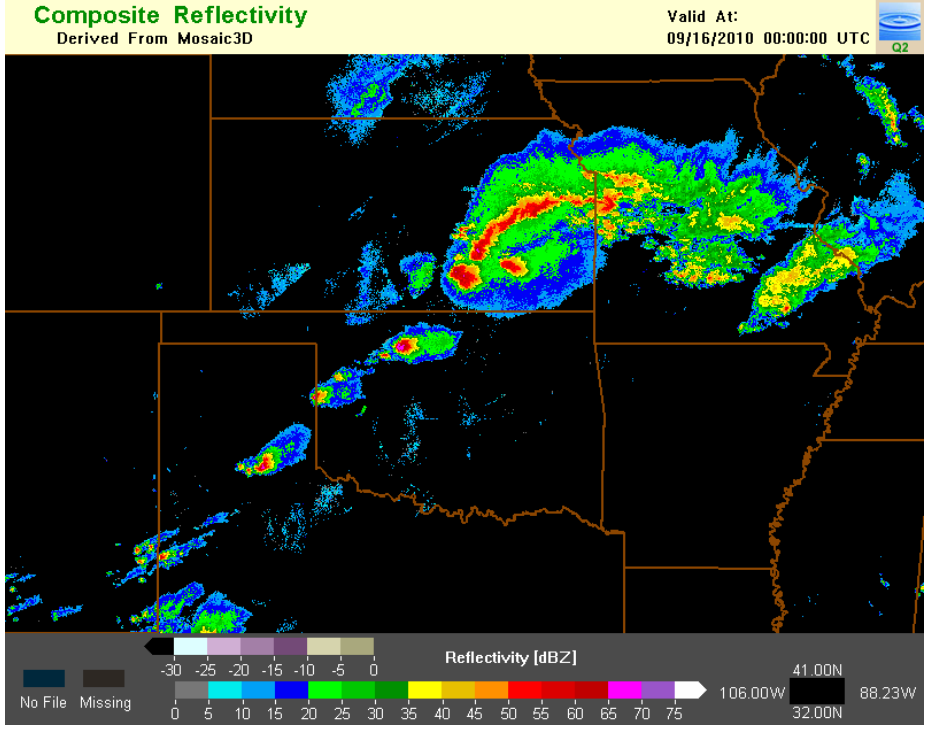
2300 UTC
16 Sep 2010

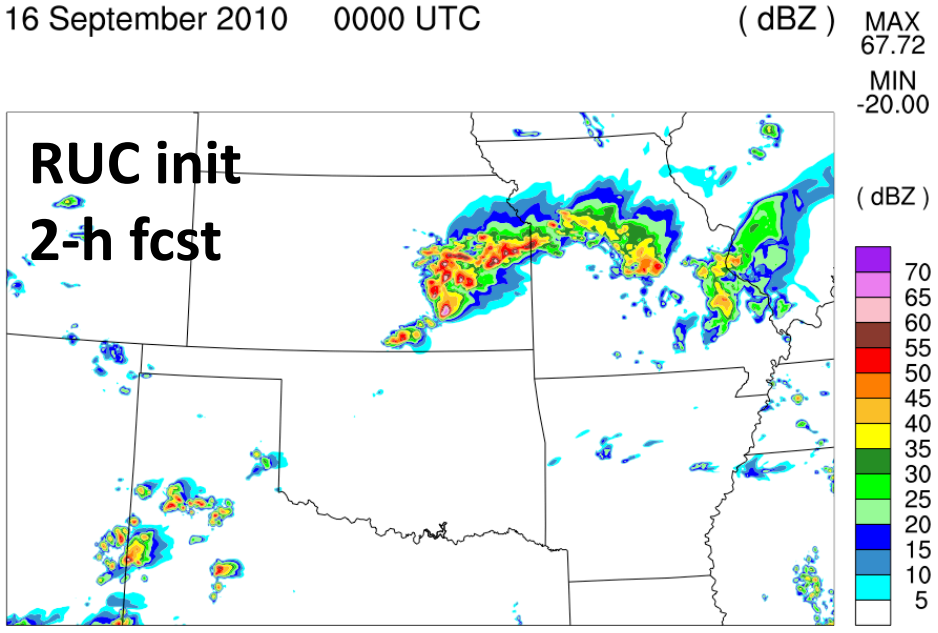


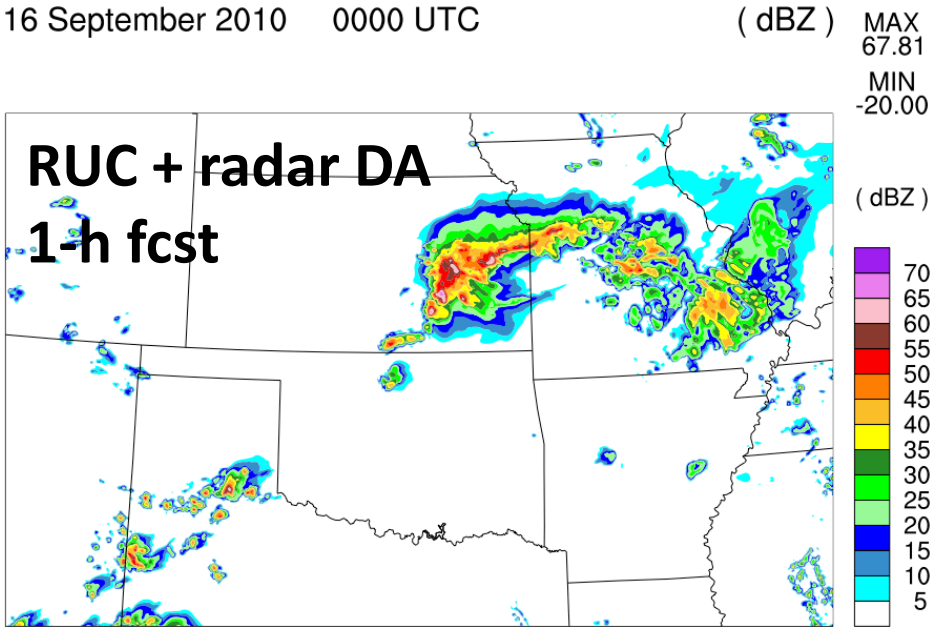




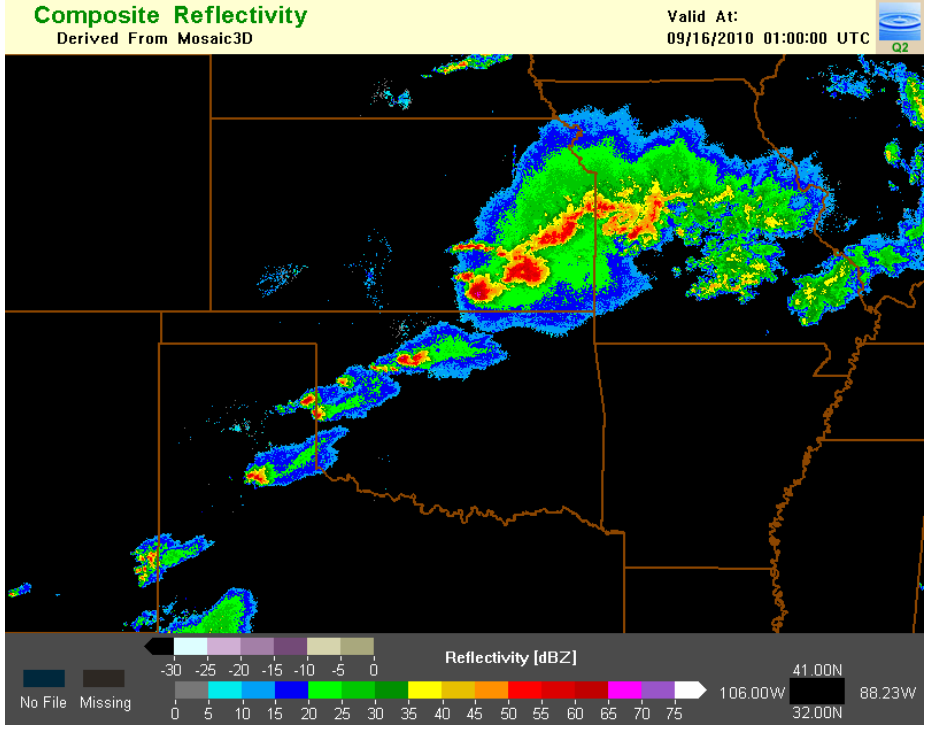
0000 UTC
16 Sep 2010

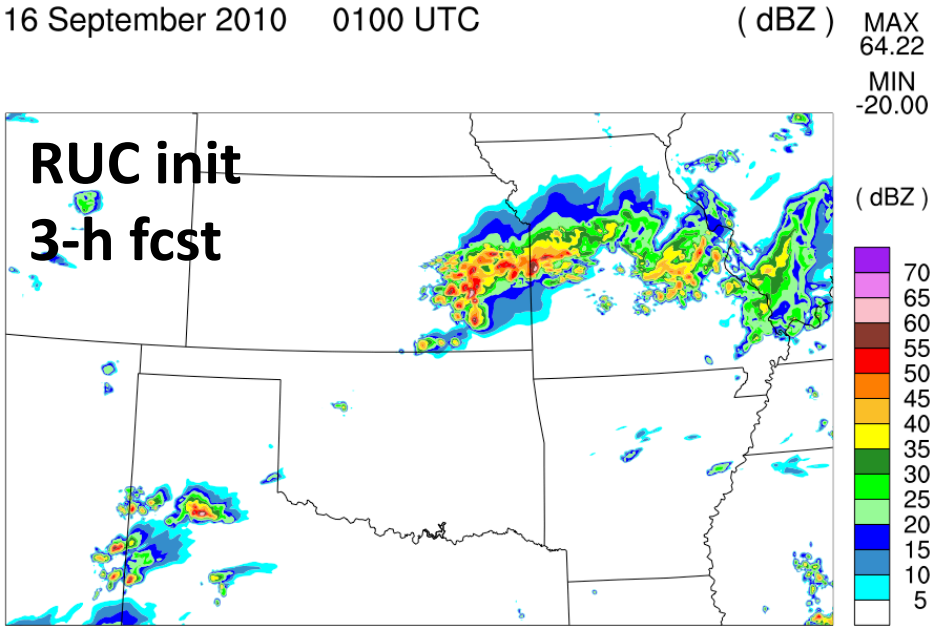


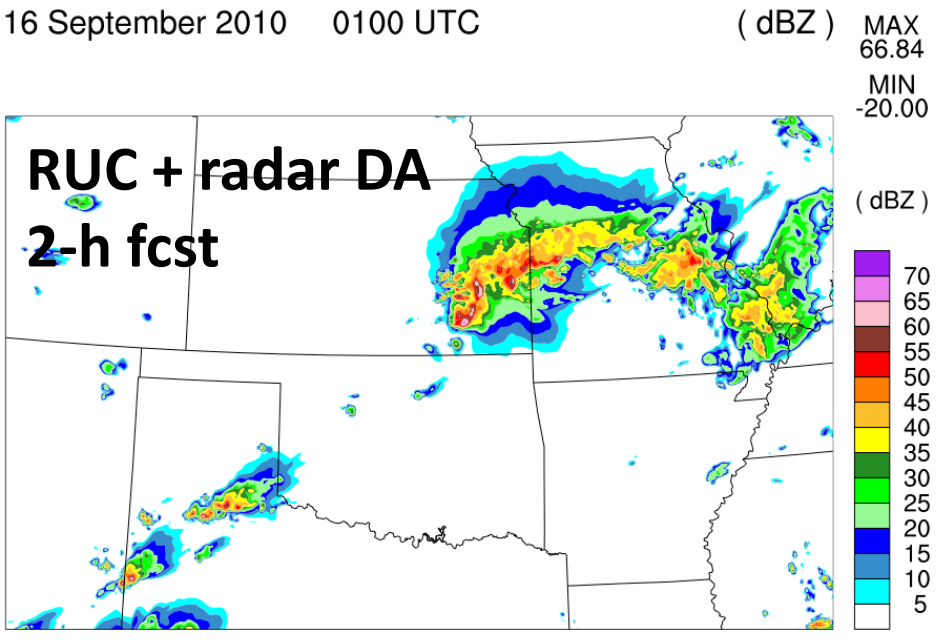




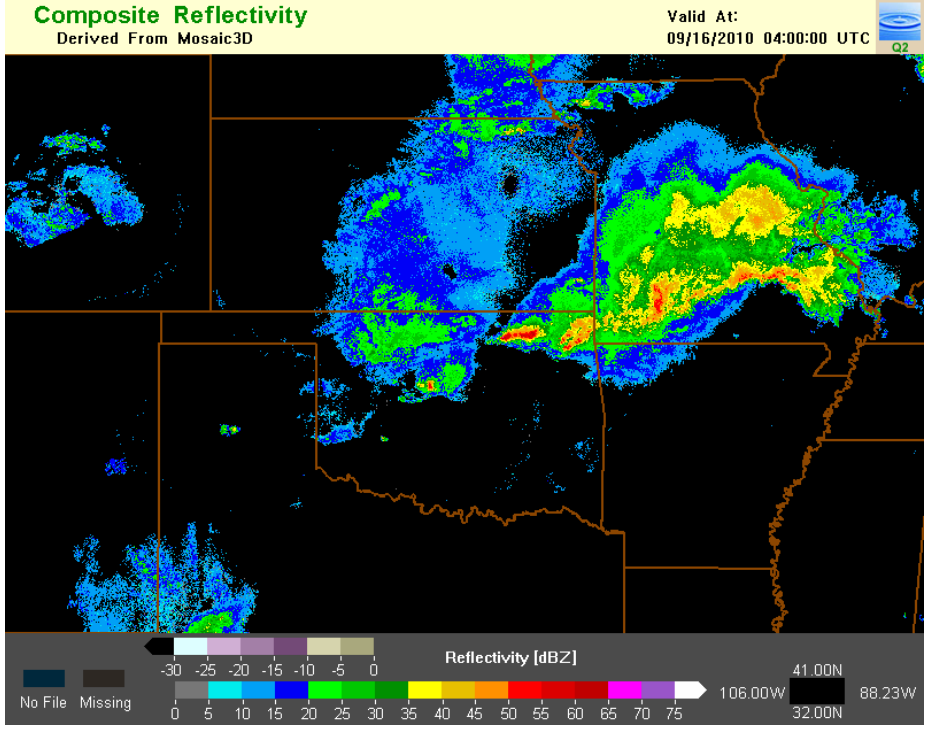
0100 UTC
16 Sep 2010

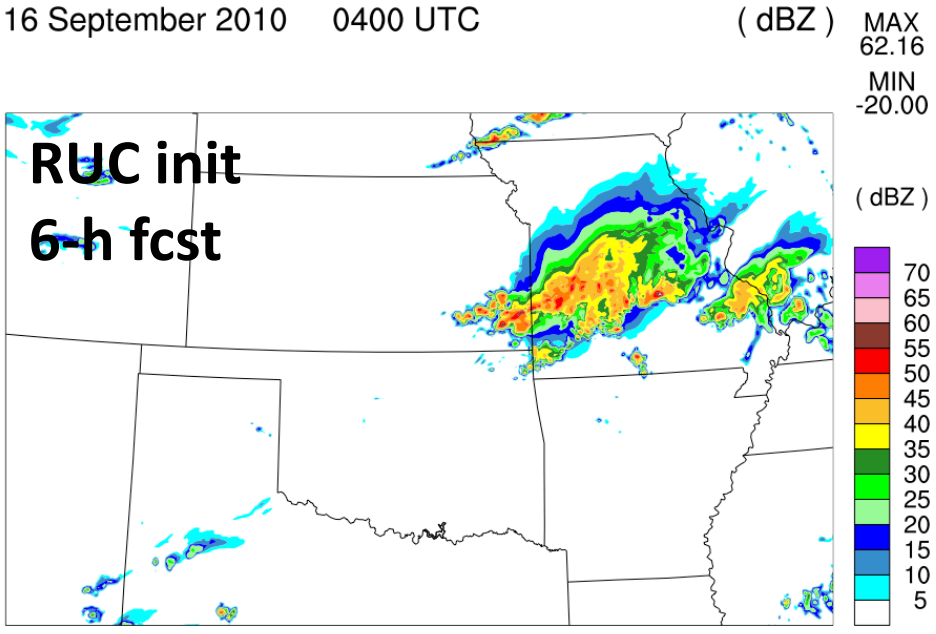


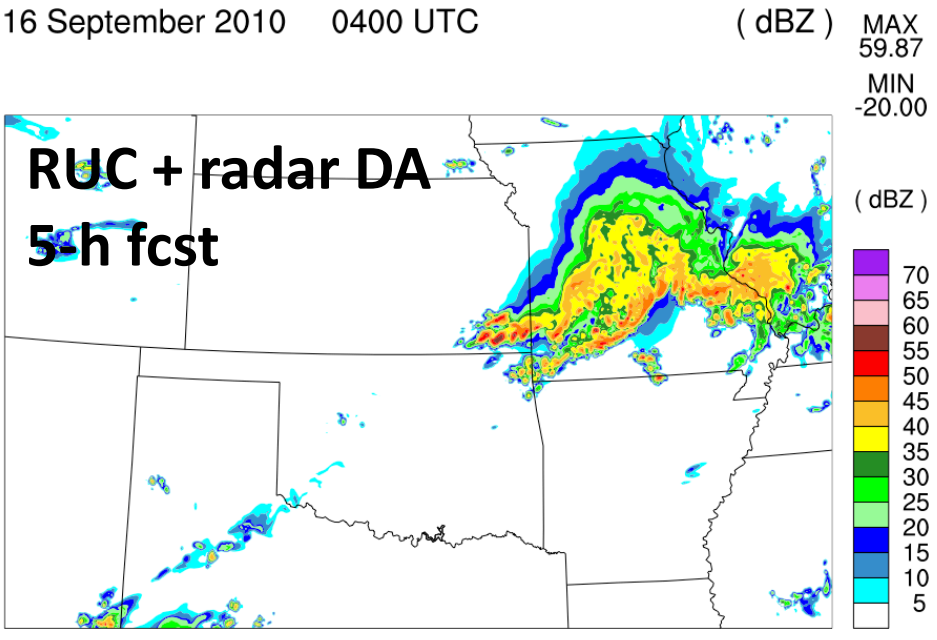




0400 UTC
16 Sep 2010







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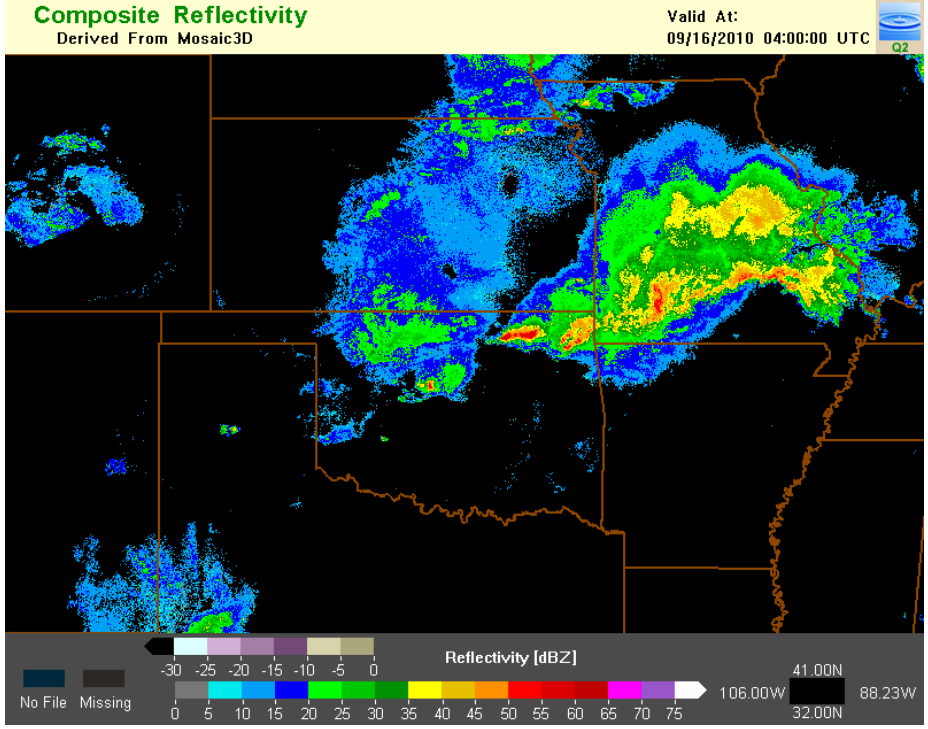
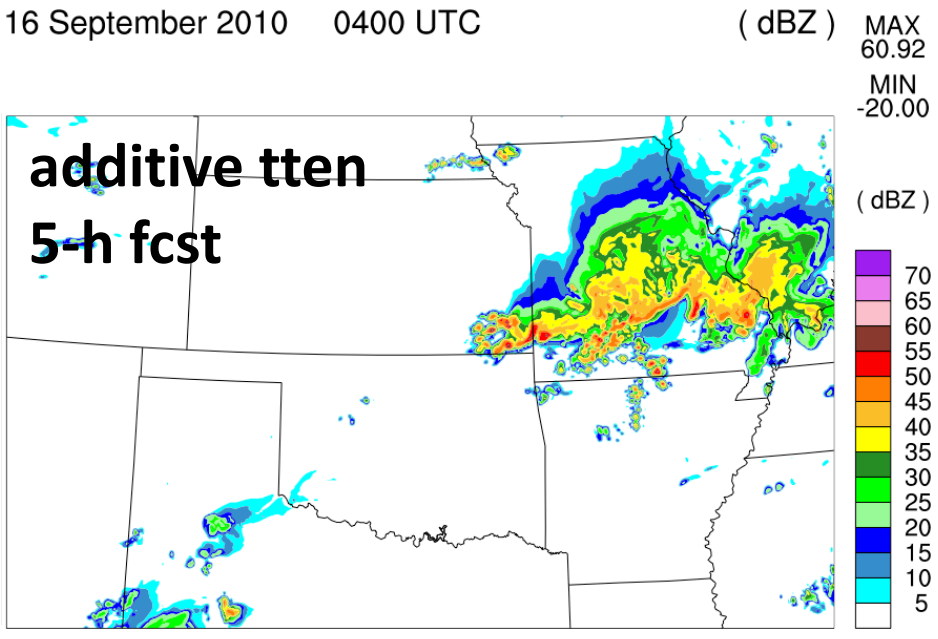
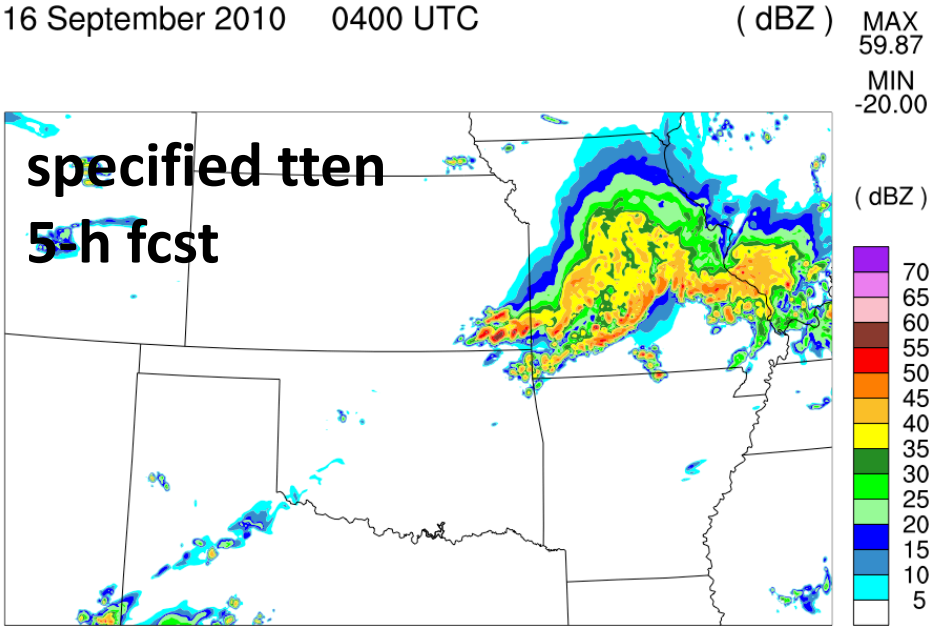


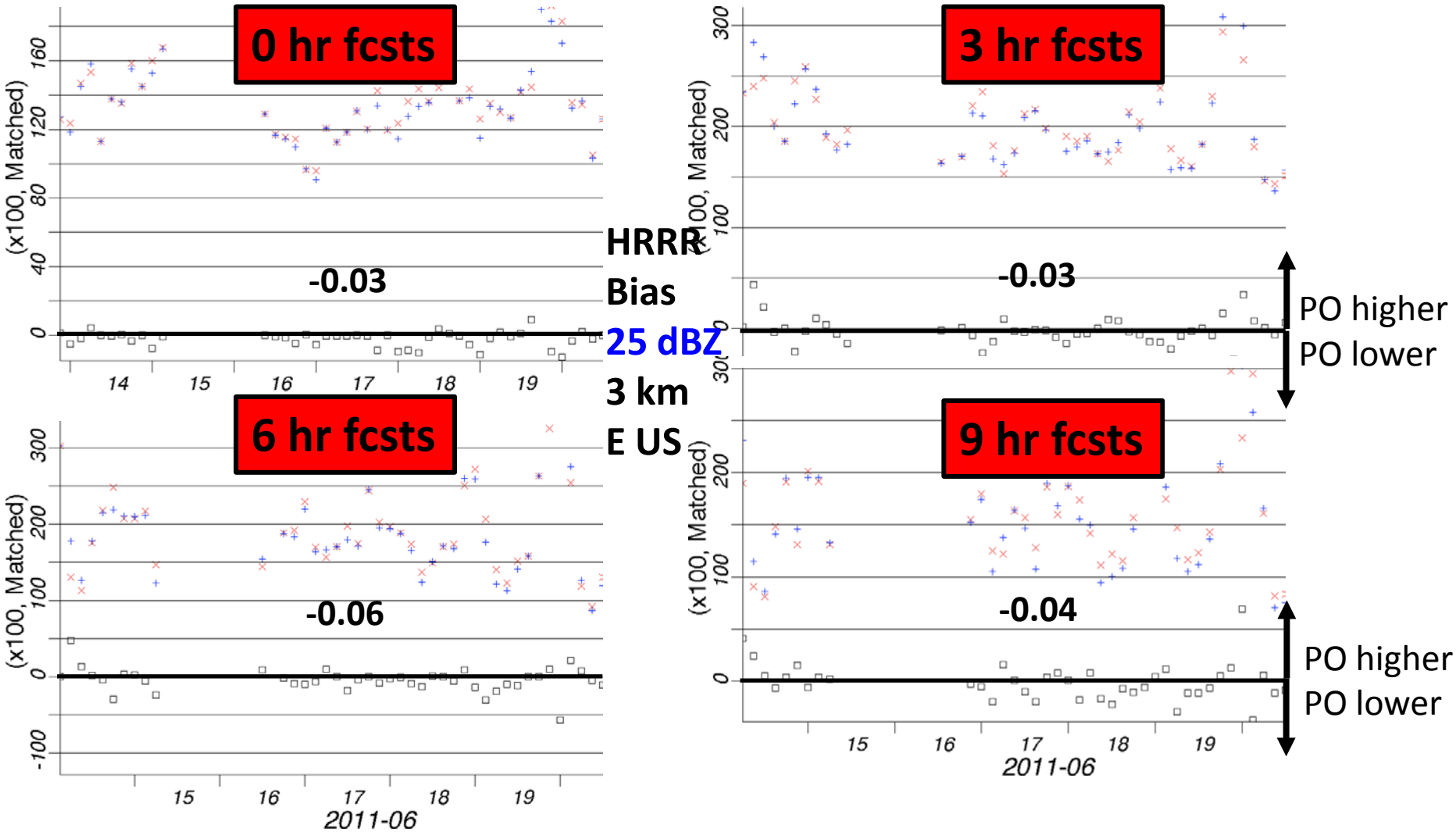




3+ hr forecast deficiency: High bias of convection in RR-HRRR forecasts

Introduction of PBL pseudo-observations (residuals) in GSI in RR only
Increases influence of surface observations in model PBL hourly analysis
Applied in 20 mb vertical increments through lowest 75% of model PBL

Implemented by Ming Hu, adapted from Stan Benjamin in the RUC formulation



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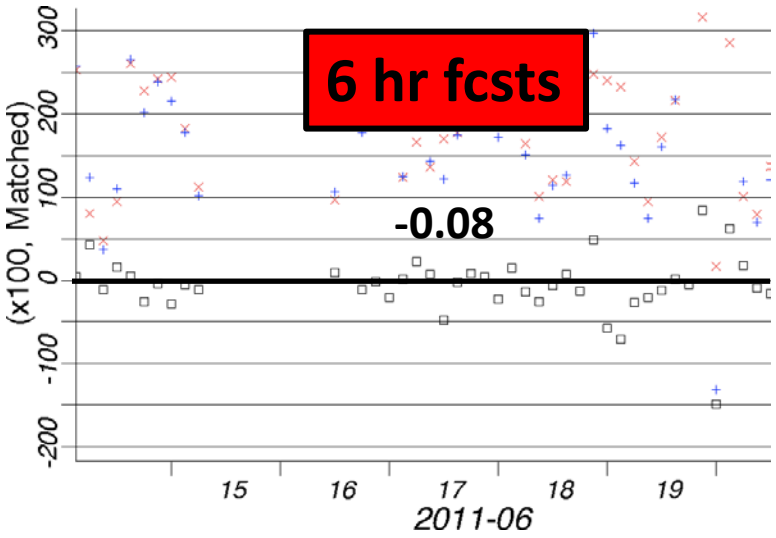
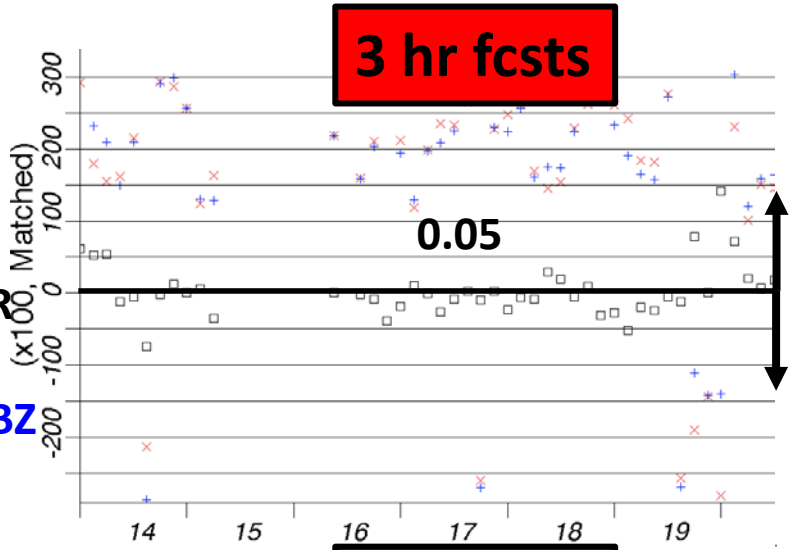
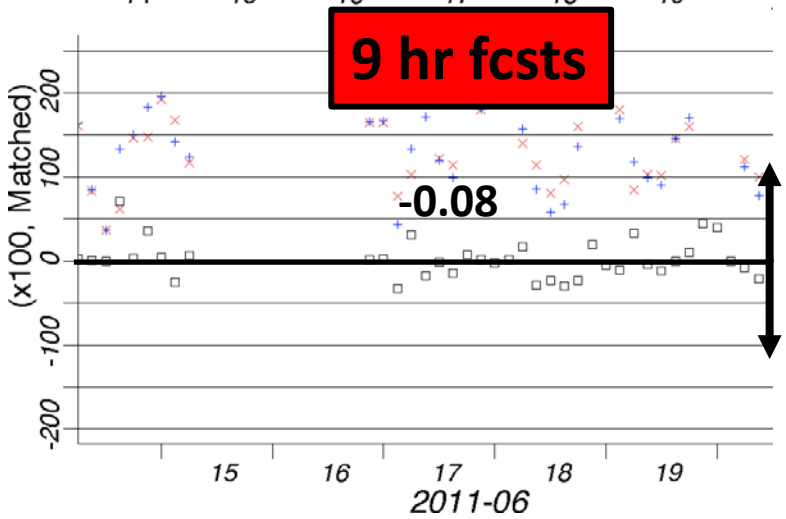
HRRR Bias
40 dBZ
3 km
E US







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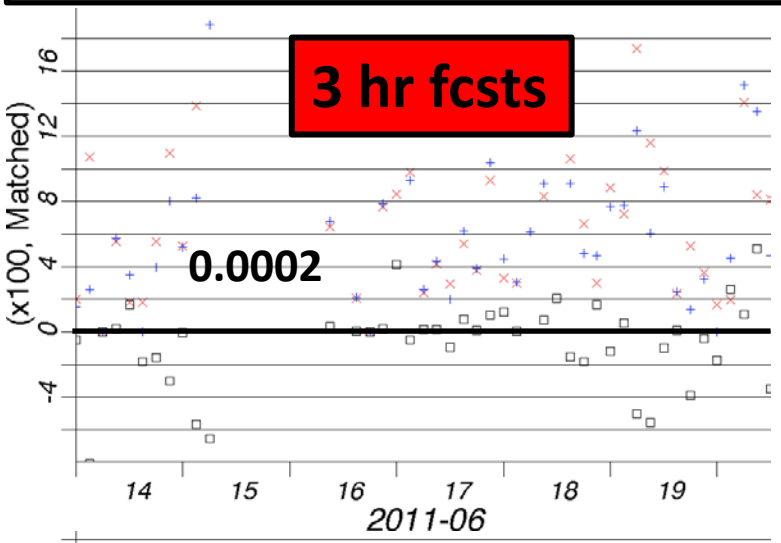
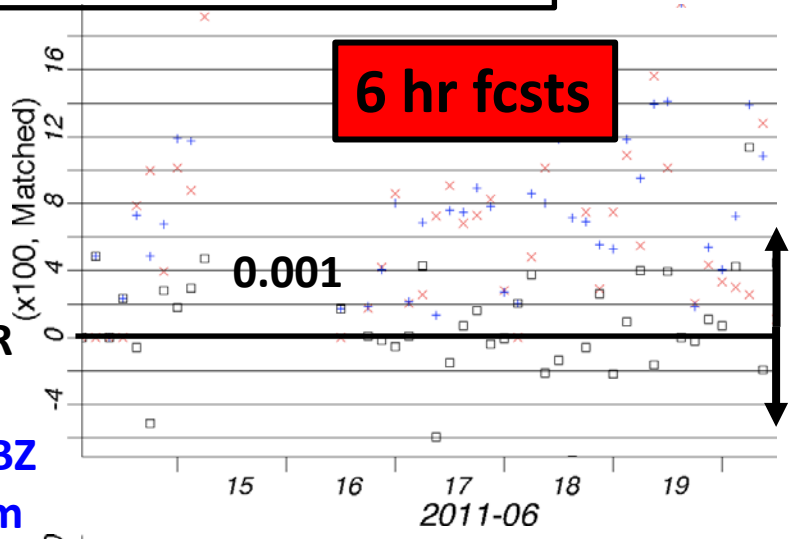
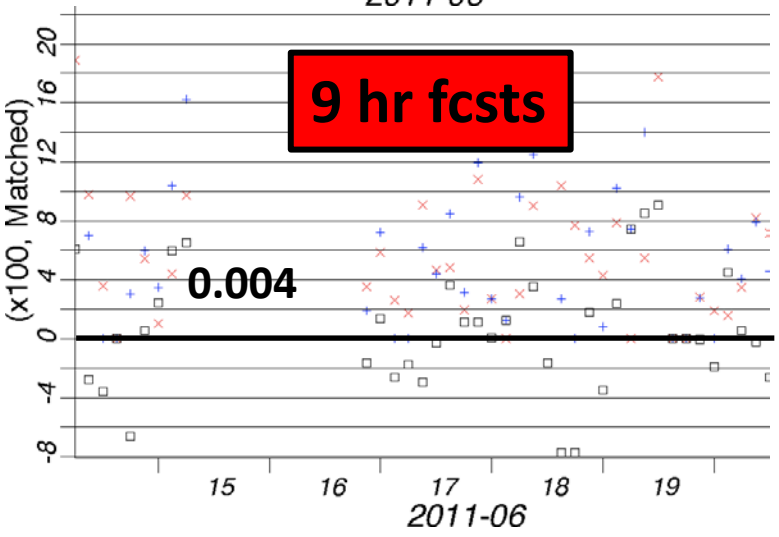
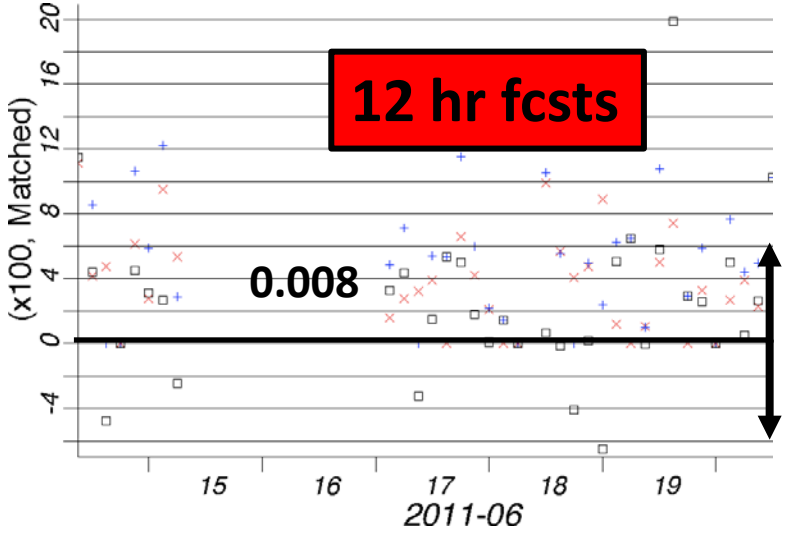




PO higher
PO lower

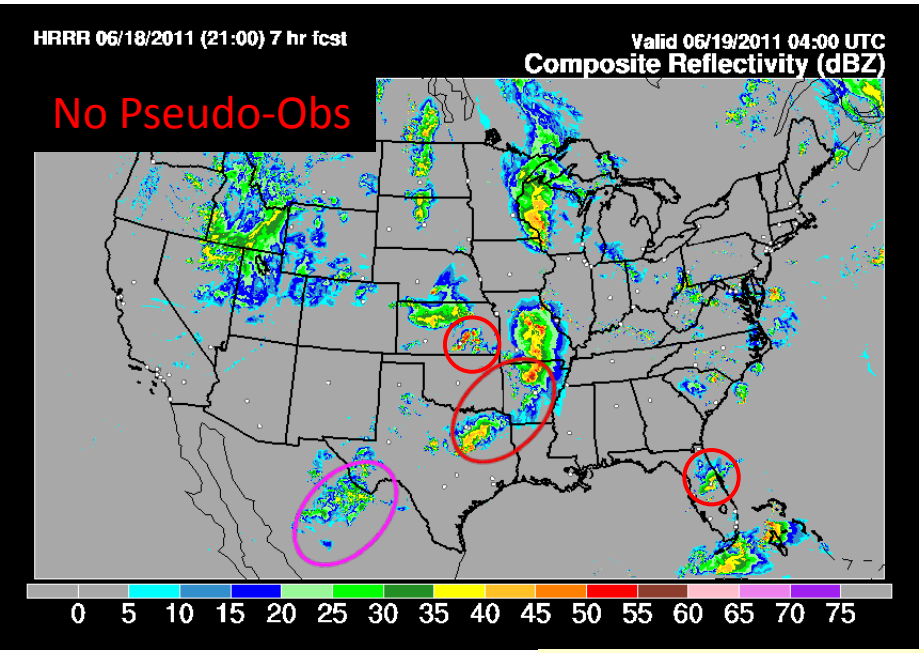
HRRR
CSI
40 dBZ
40 km
E US

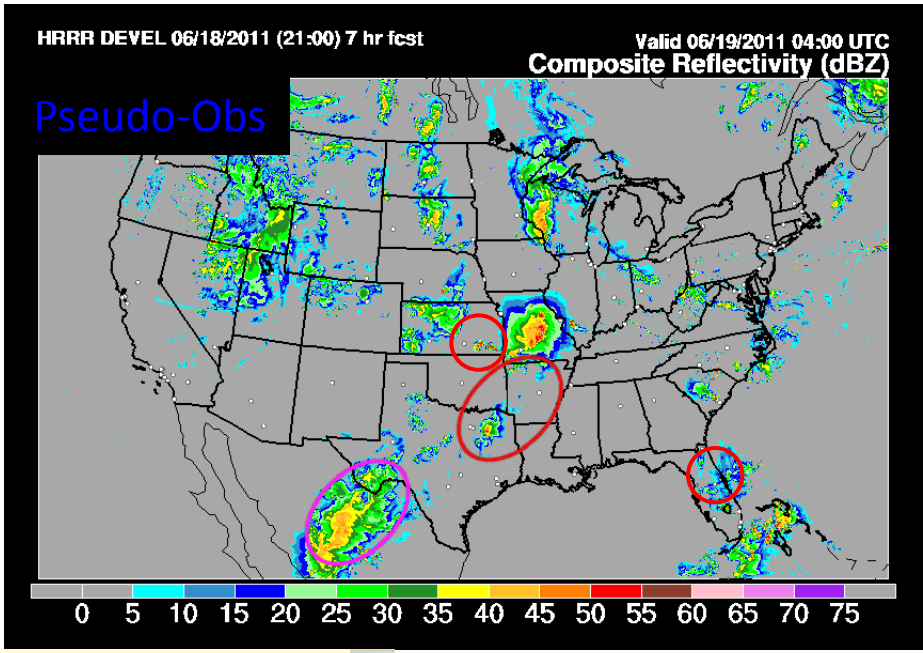




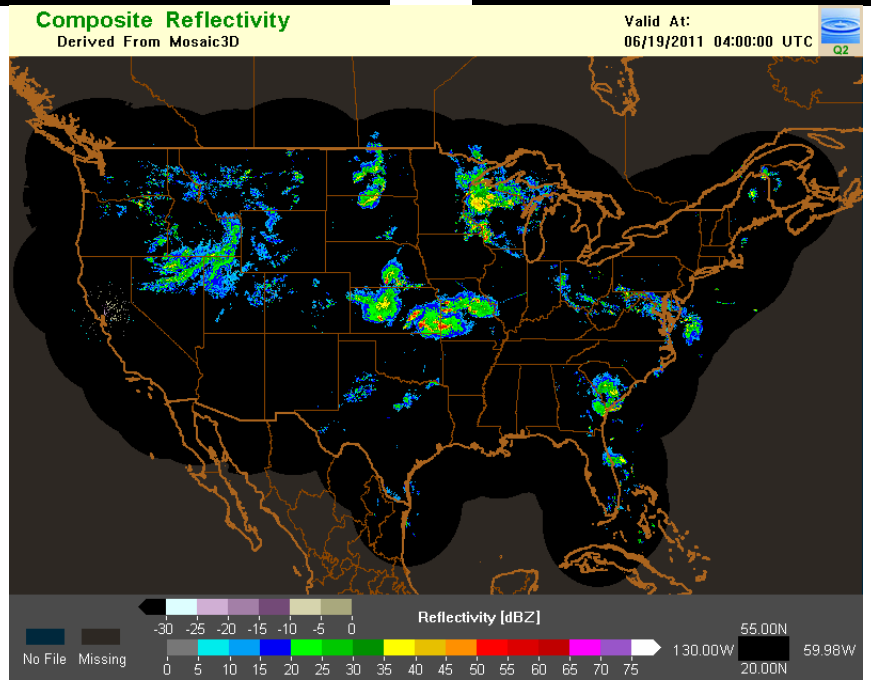
PO higher
PO lower

21 UTC 18 June 2011 init: 7 hr forecast valid 04 UTC 19 June 2011



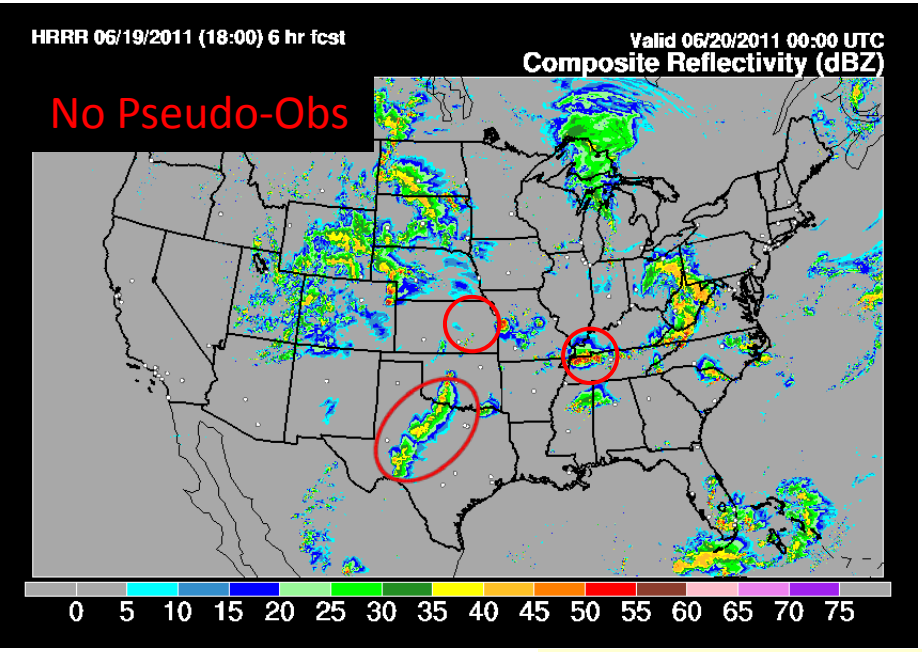


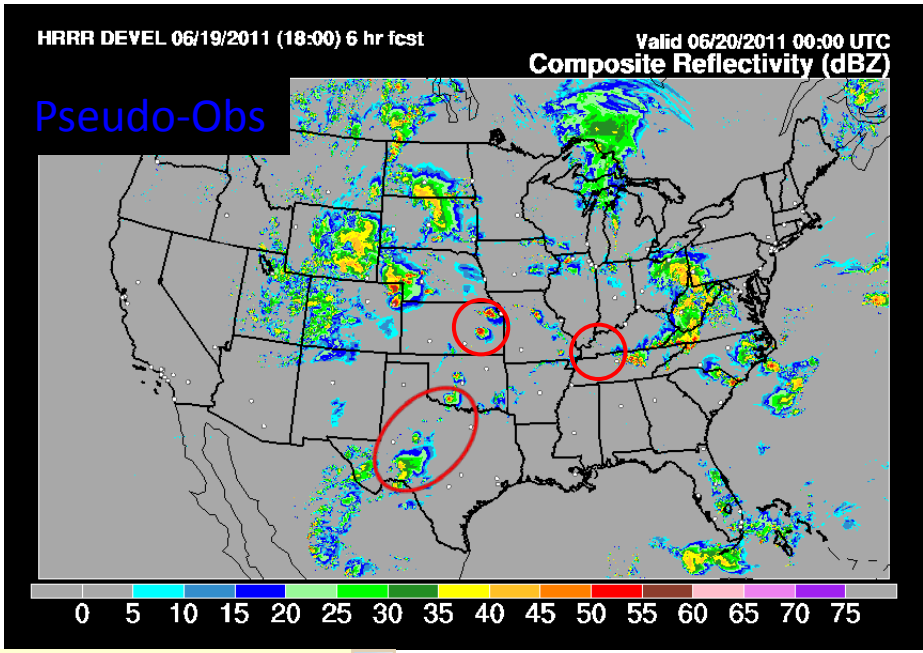
Observed Reflectivity



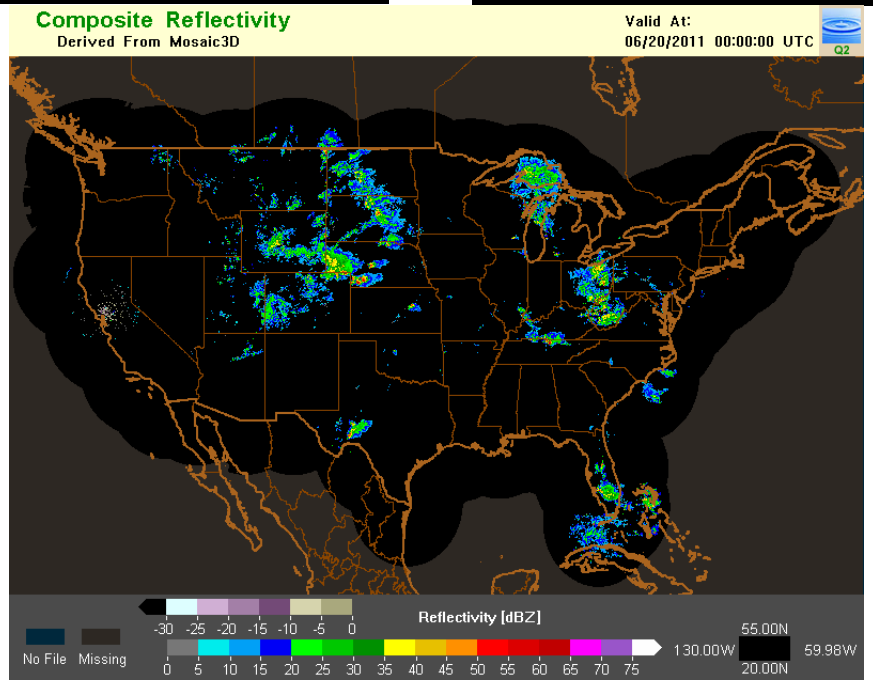
Parallel runs executed by Eric James

18 UTC 19 June 2011 init: 6 hr forecast valid 00 UTC 20 June 2011

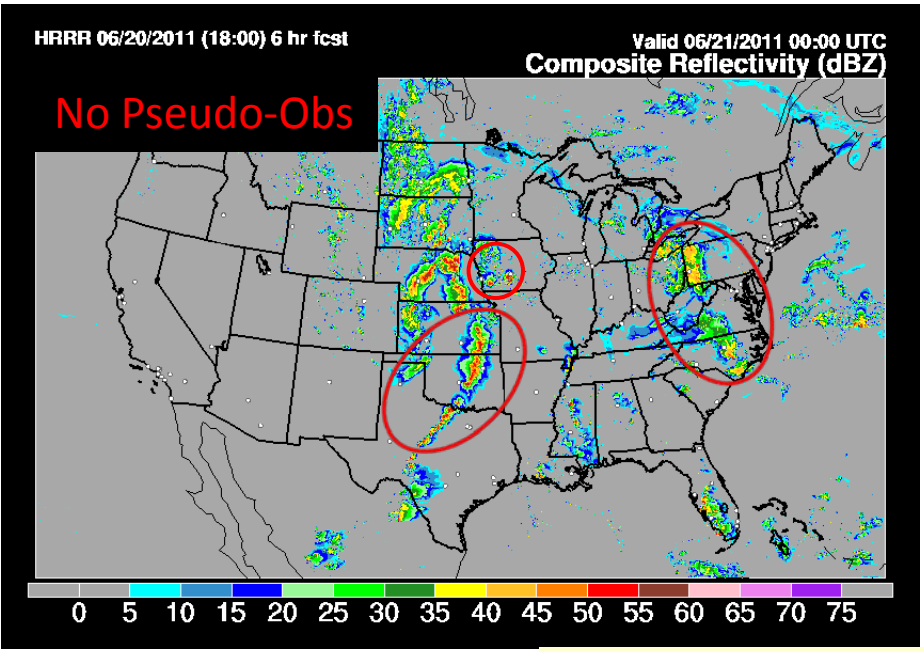


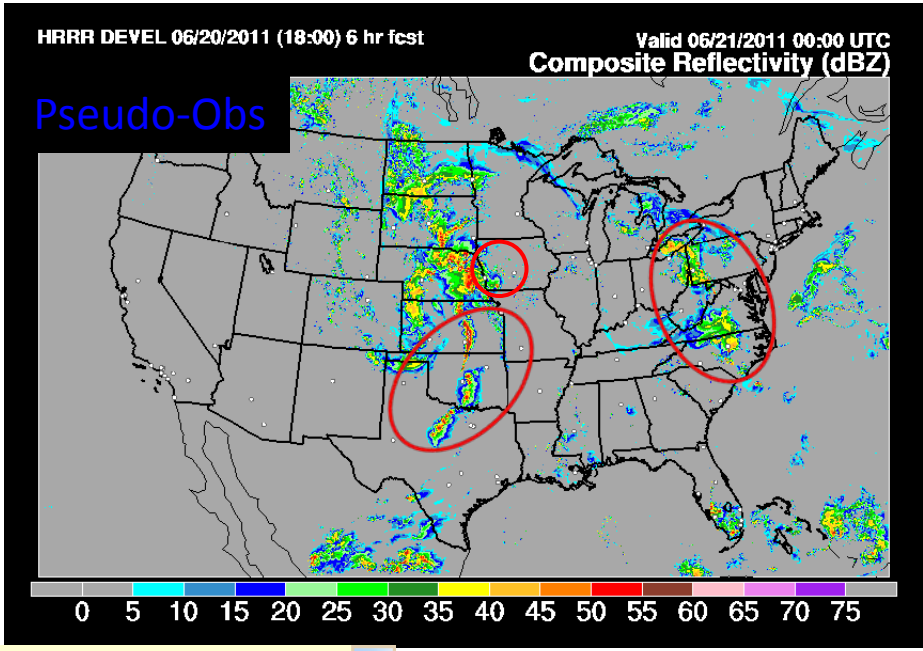


Observed Reflectivity

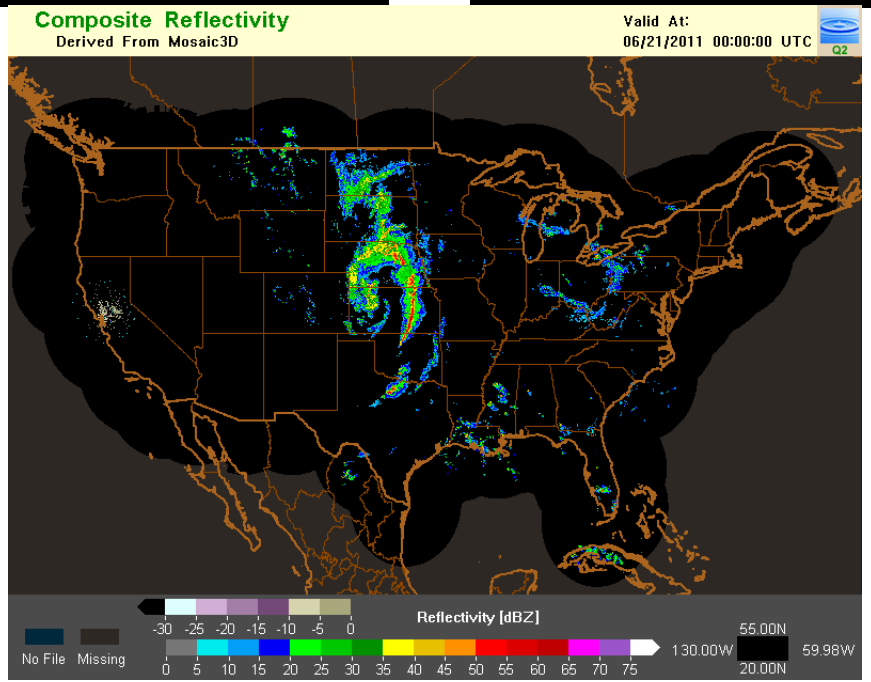


18 UTC 20 June 2011 init: 6 hr forecast valid 00 UTC 21 June 2011





Observed Reflectivity



General improvement of convective forecasts with fewer false alarms and more accurate evolution

Composite Reflectivity Diagnositic

Thompson v3.2+
Unipost reflectivity

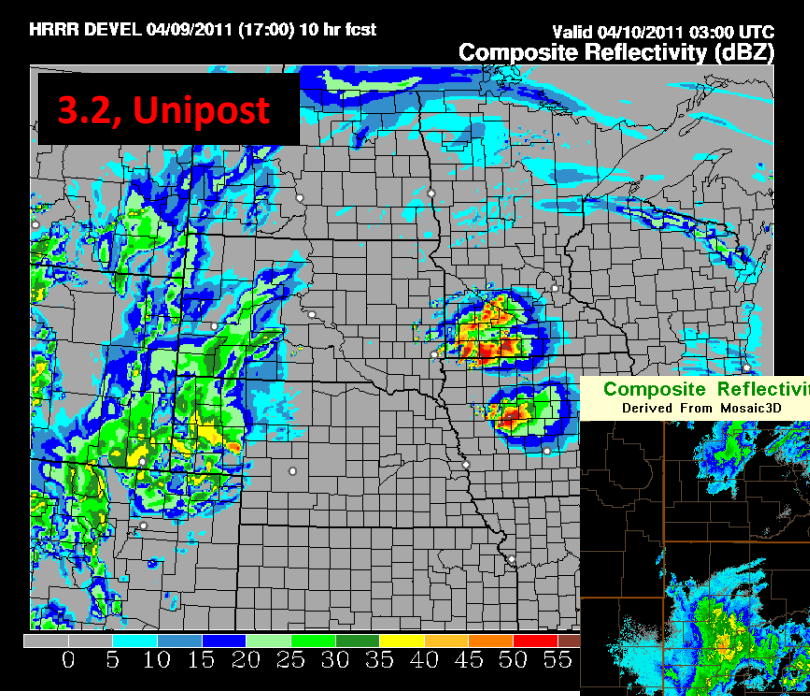
Thompson v3.2+
Thompson reflectivity
(consistent w/ microphysics scheme)

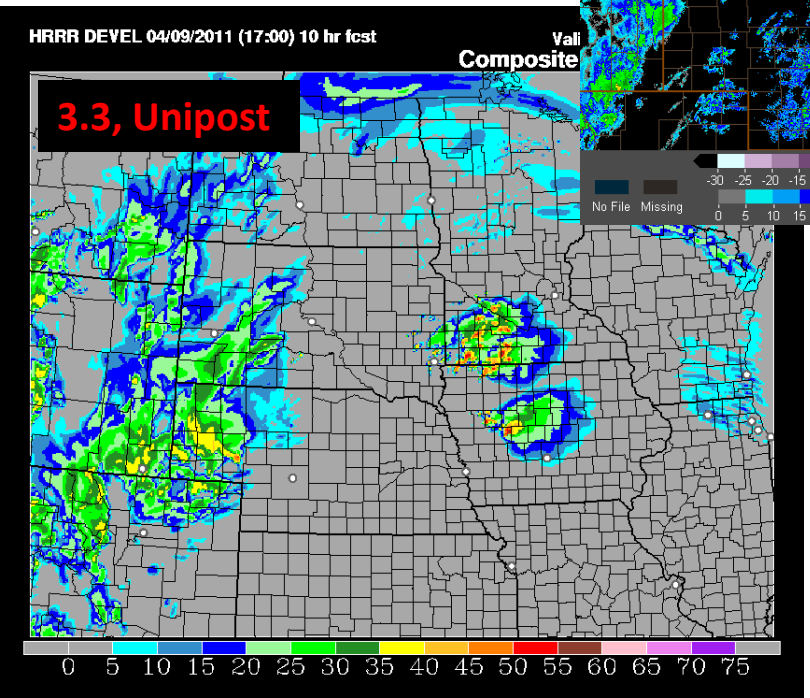
Observed Composite
Reflectivity

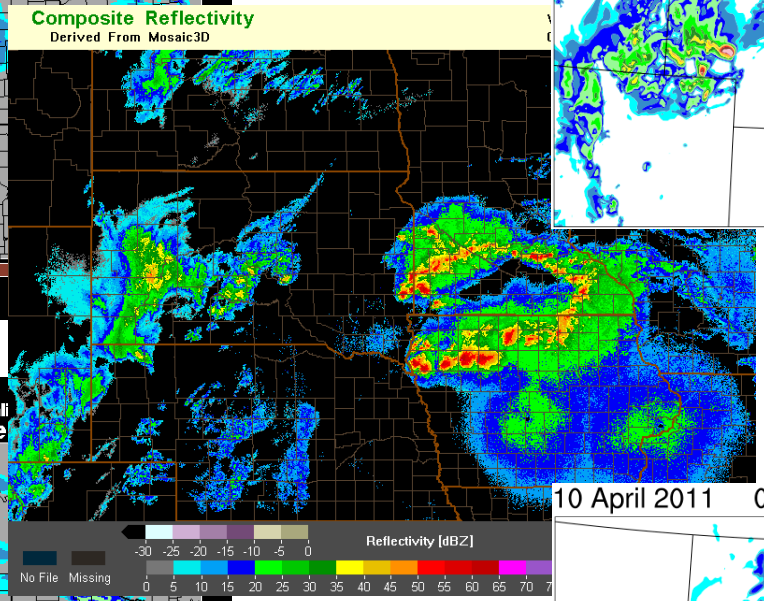
Thompson v3.3
Unipost reflectivity

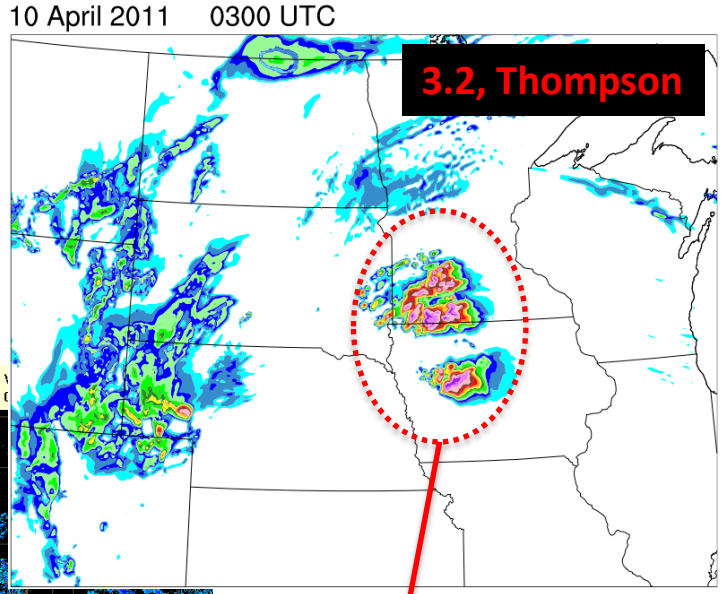
Thompson v3.3
Thompson reflectivity
(consistent w/ microphysics scheme)

Reflectivity comparison
by David Dowell

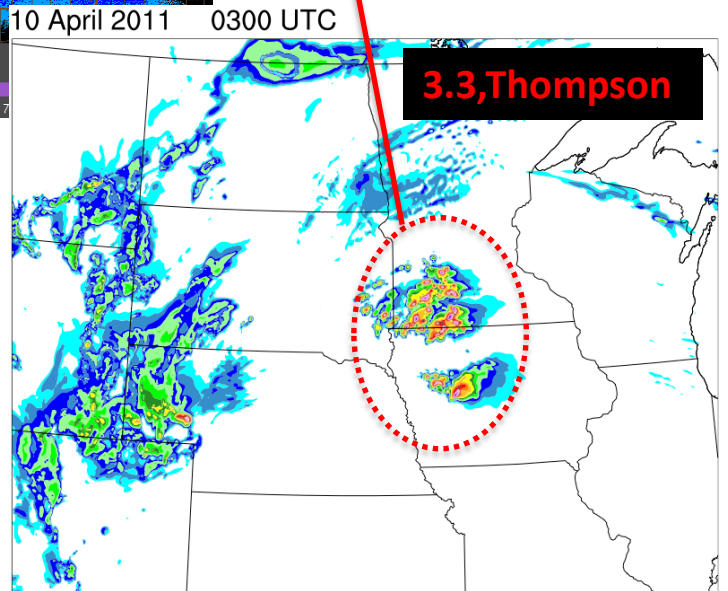


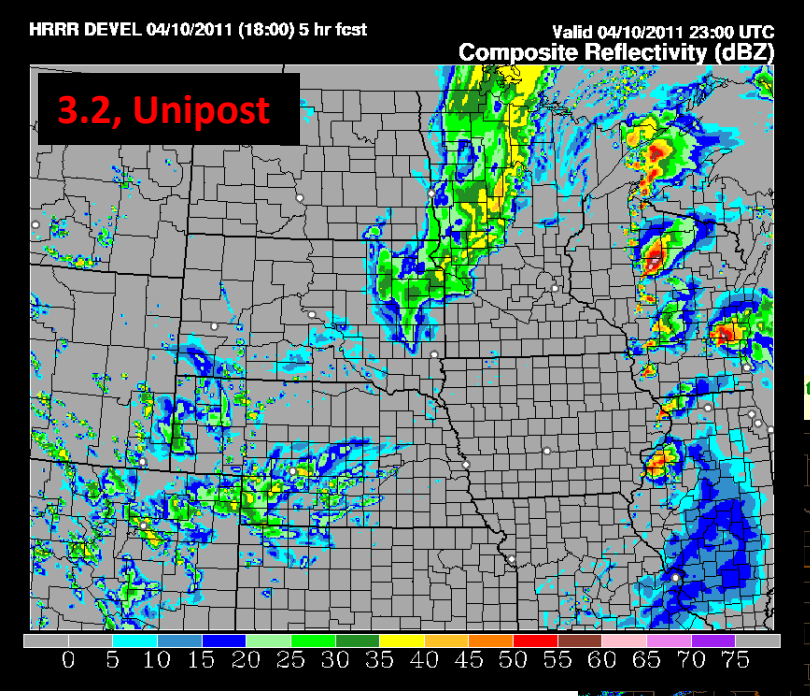


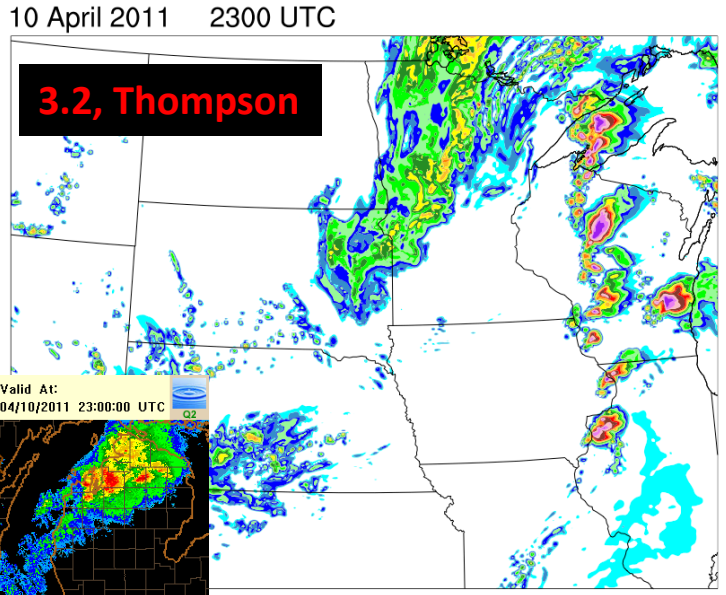


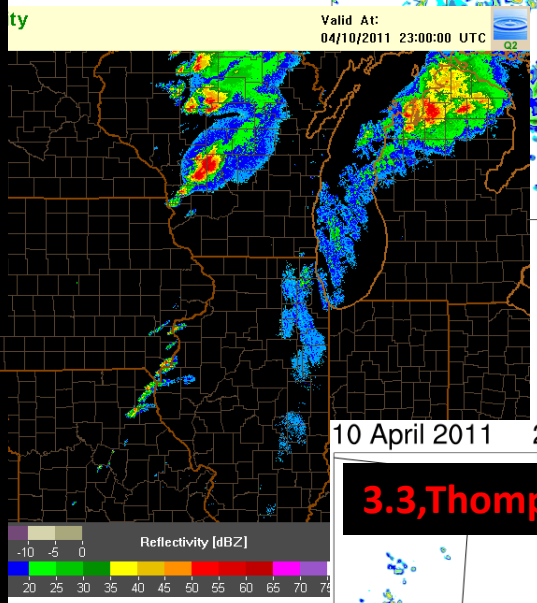


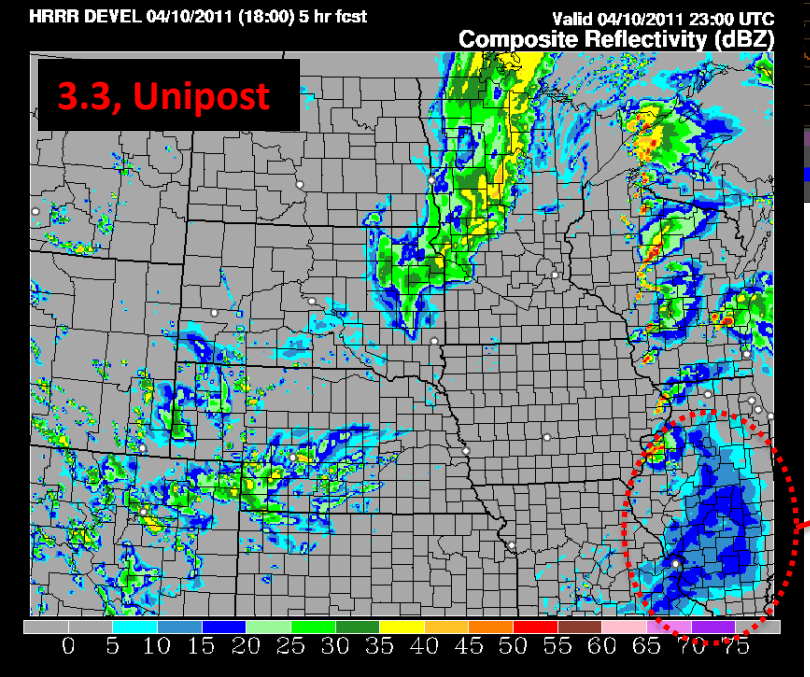
slightly smaller precipitation cores in Thompson v3.3

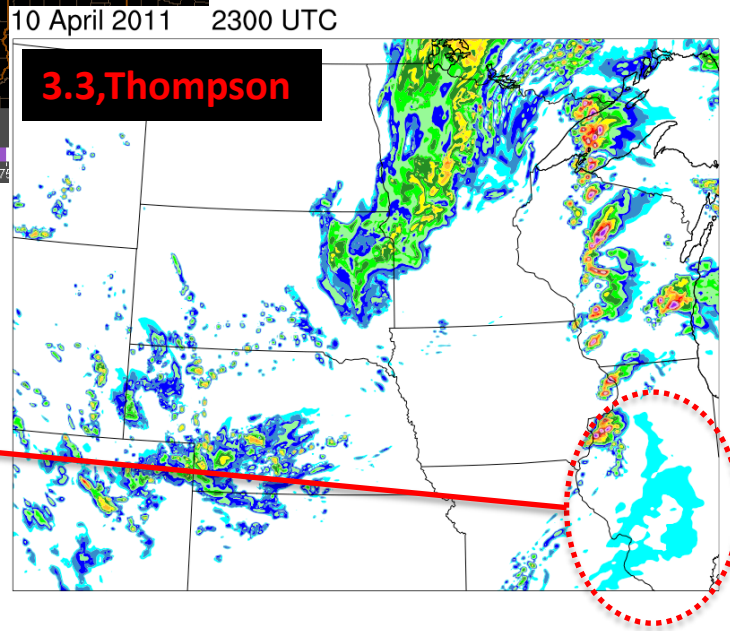












noticeable differences in lightly precipitating high clouds (snow)

High Resolution Rapid Refresh

Summary

Adopted Rapid Refresh for HRRR parent mesoscale model

HRRR model development proceeding through parallel real-time/retrospective studies using verification system for feedback

Recent and Current Focus on:

- **Retention of storm-scale features/evolution in first few forecast hours through sub-hourly radar/satellite DA**
- **Improvements in RR to reduce high bias in convective forecasts and maintain MCS structures**
- **Evaluation of WRFv3.3 and related diagnostic fields**
- **Ensembling of time-lagged HRRR runs for probabilistic guidance**