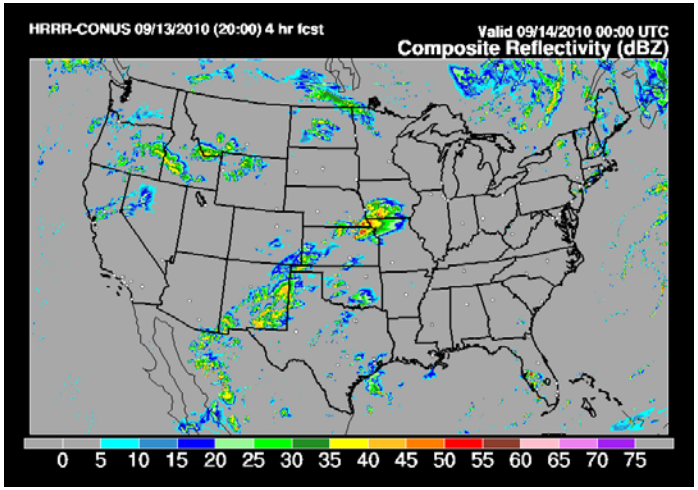
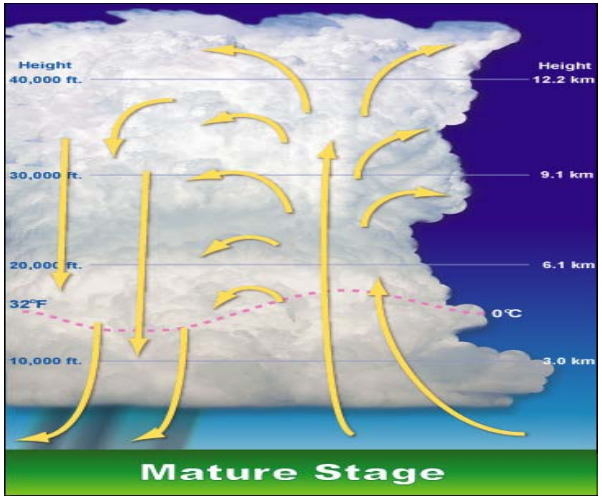
AMS 25th Conference On Severe Local Storms
12 October 2010

High resolution rapid refresh (HRRR): Recent enhancements and evaluation during the 2010 convective season

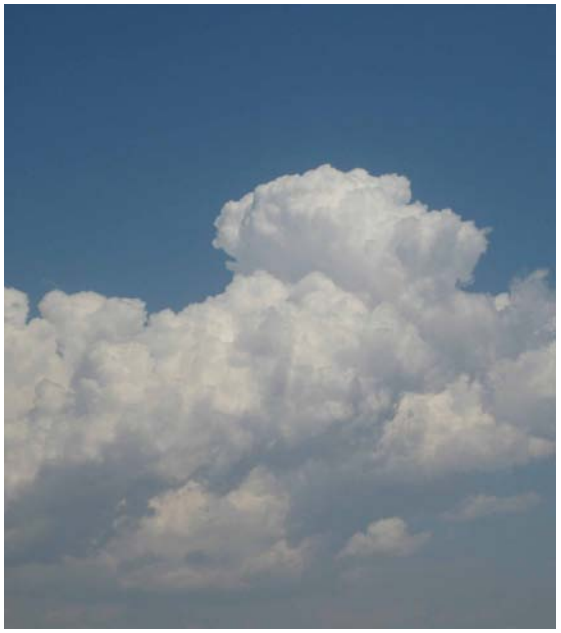
NOAA/ESRL/GSD
Curtis Alexander, Steve Weygandt, Tanya Smirnova, Stan Benjamin, Patrick Hofmann, Eric James and Doug Koch



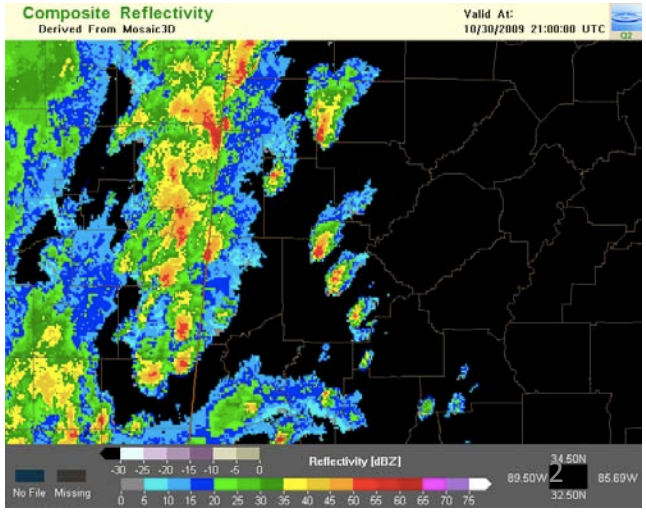


Very High Resolution Forecasts

- Deep moist convection has low predictability, partly because it occurs on small spatial and temporal scales



- Convective parameterization in RUC and RR not sufficient to reproduce convective-scale structures and evolution



- Need hourly-updating convection-resolving model that can assimilate convective-scale observations such as radar given sufficient computing resources

Models at NOAA/ESRL/GSD/AMB

Model	Domain	Grid Points	Grid Spacing	Vertical Levels	Vertical Coordinate	Height Lowest Level	Pressure Top
RUC	CONUS	451 x 337	13.5 km	50	Sigma/ Isentropic	5 m	~50 mb
RR	North America		13.5 km	50	Sigma	8 m	10 mb
HRRR	CONUS	1799 x 1059	3.0 km	50	Sigma	8 m	85 mb

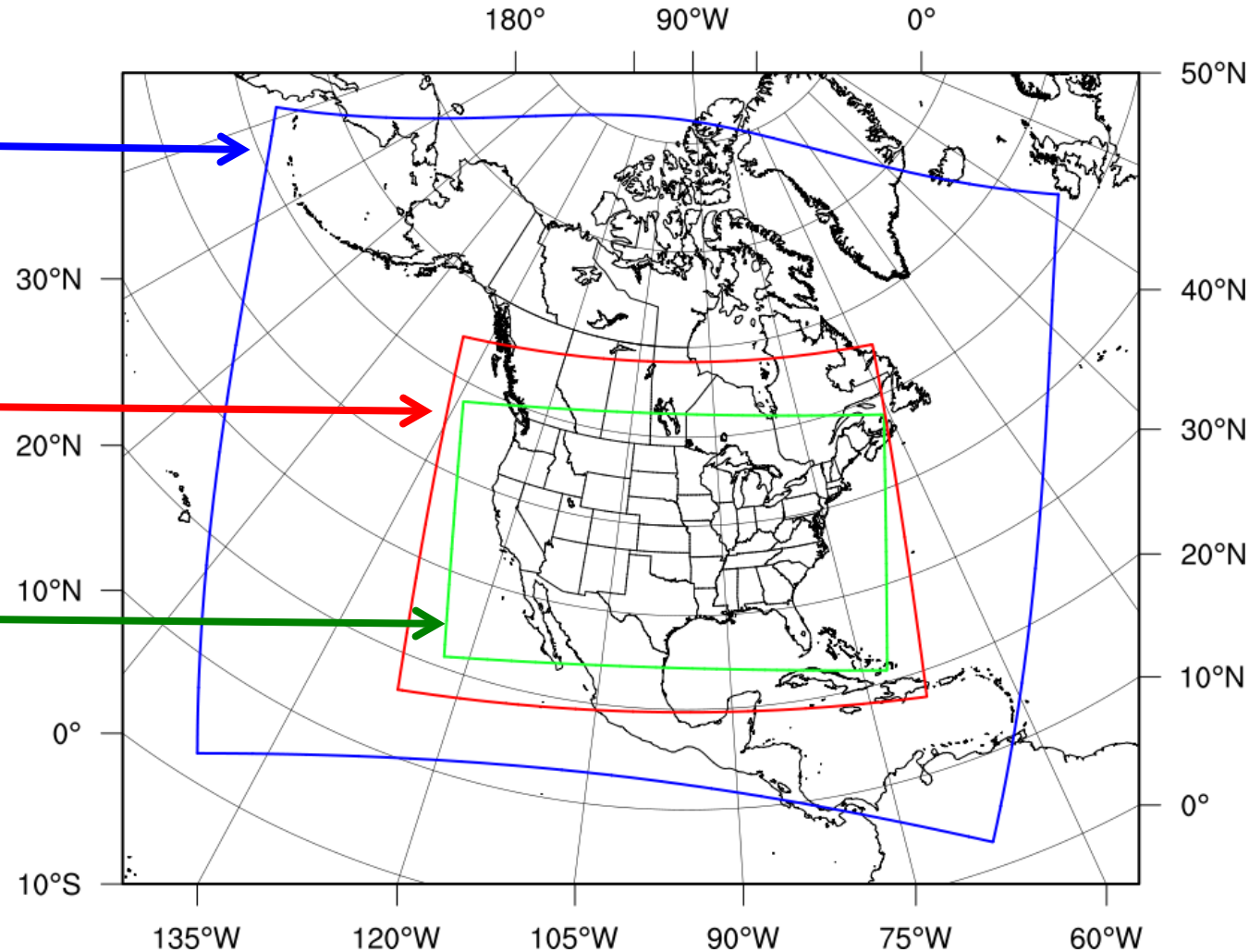
Model	Version	Time-Step	Forecast Period	Initialized	Boundary Conditions	Run Time	# of CPUs
RUC	N/A	18 s	24 hrs (18 @ NCEP)	Hourly (cycled)	NAM	45 min	36
RR	WRF-ARW 3.2	60 s	15 hrs (18 hrs soon)	Hourly (cycled)	GFS	25 min	160
HRRR	WRF-ARW 3.2	15-20s	15 hrs	Hourly (no-cycle)	RUC	50 min	1000

Current RR/RUC/HRRR Model Domains

RR (13 km)
758 x 567

RUC (13 km)
451 x 337

HRRR (3 km)
1799 x 1059



Models at NOAA/ESRL/GSD/AMB

Model	Assimilation	DFI	Microphysics	Radiation	Convection	PBL	LSM
RUC	RUC-3DVAR	Yes w/radar	Thompson	RRTM/Dudhia	Grell-Devenyi	MYJ	RUC
RR	GSI	Yes w/radar	Thompson	RRTM/Dudhia	Grell-Devenyi	MYJ	RUC
HRRR	None: RUC I.C.	No	Thompson	RRTM/Dudhia	None	MYJ	RUC

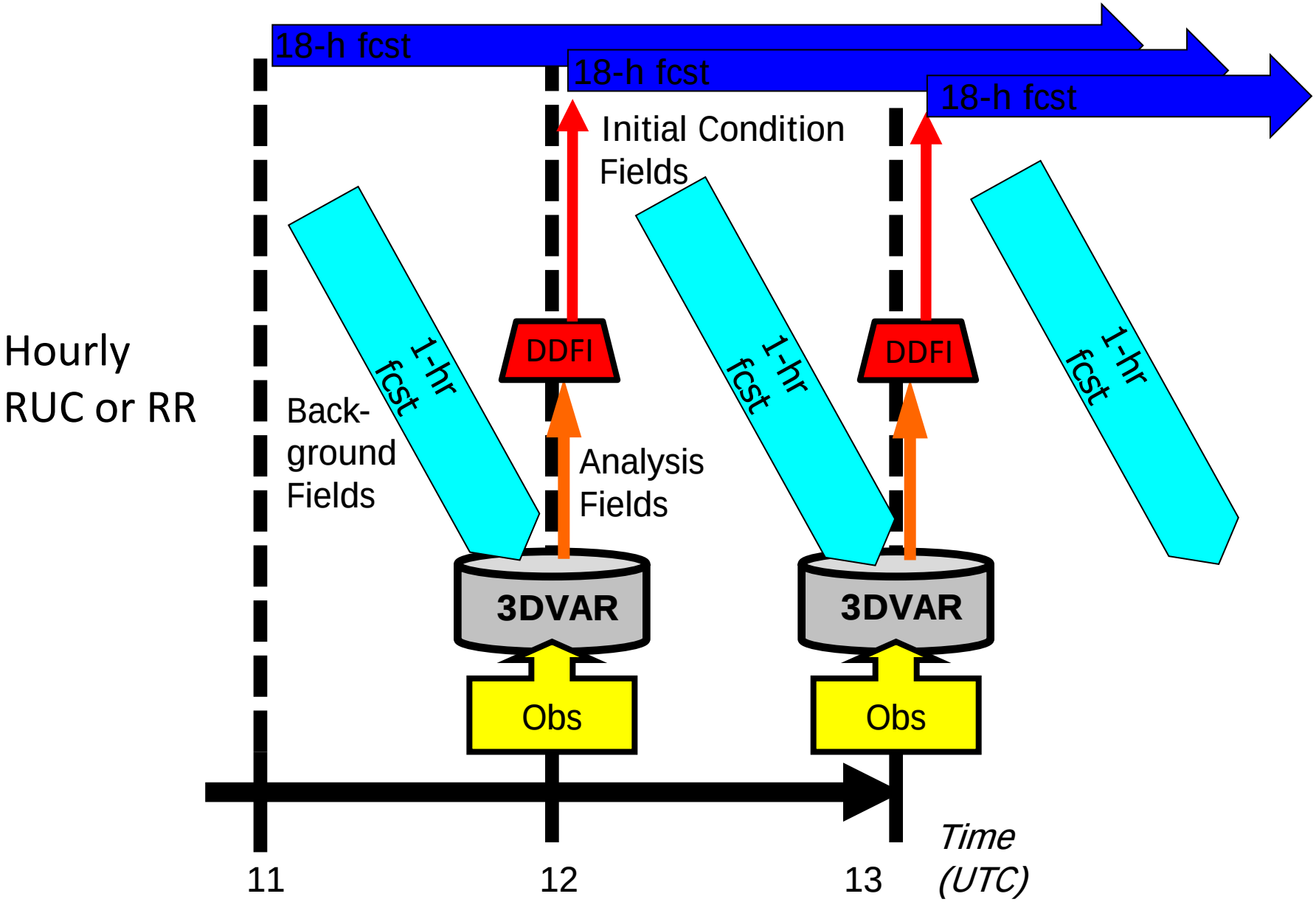
HRRR modifications starting in Fall 2010:

1) Change initial/boundary conditions from RUC to RR

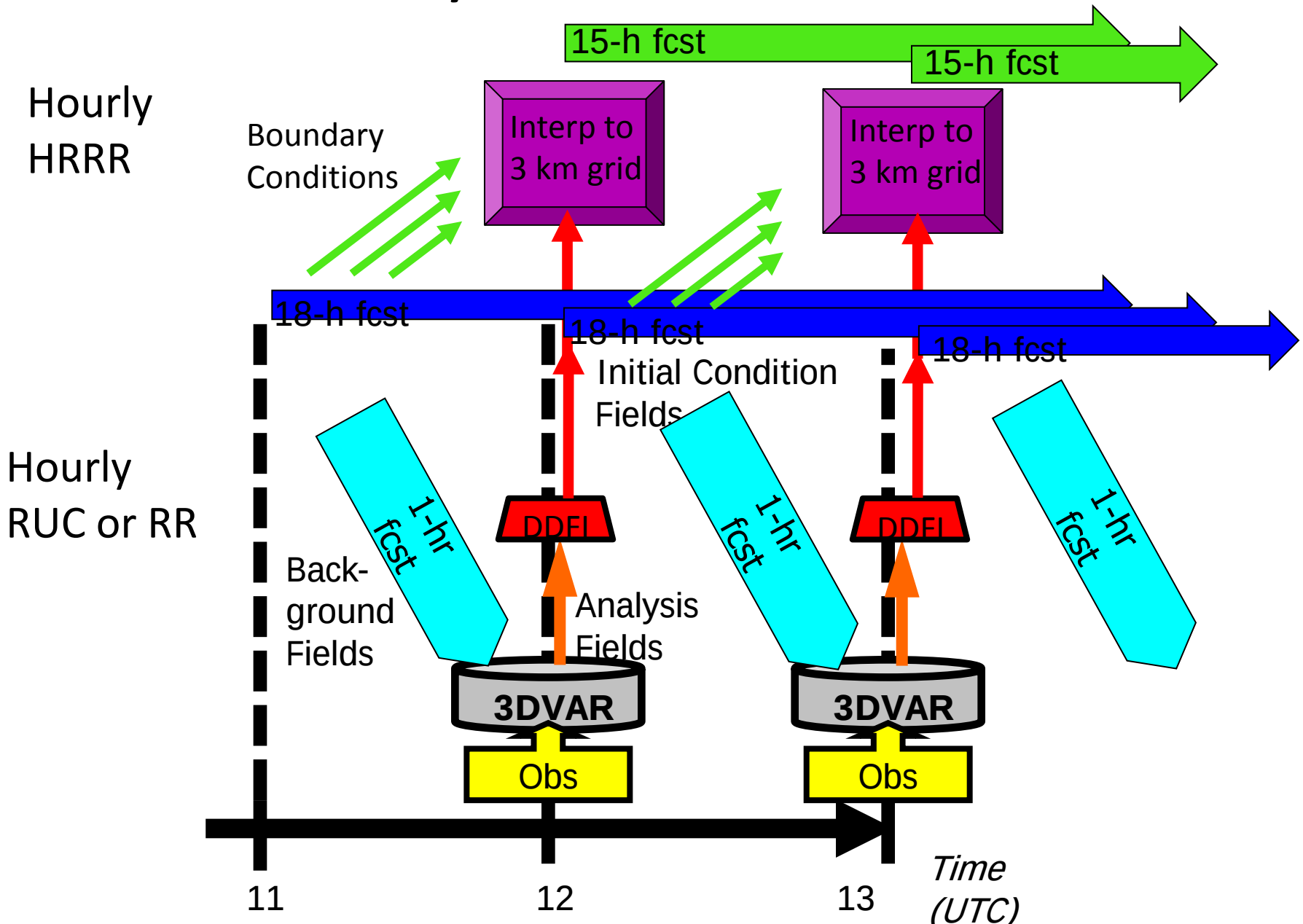
2) Assimilation of radar reflectivity in HRRR @ 3km to:

- Specify/clear hydrometeors (rain, snow, graupel)
- Establish 3-D radar temperature tendency (latent heating)
- Apply diabatic digital filter initialization (DDFI)

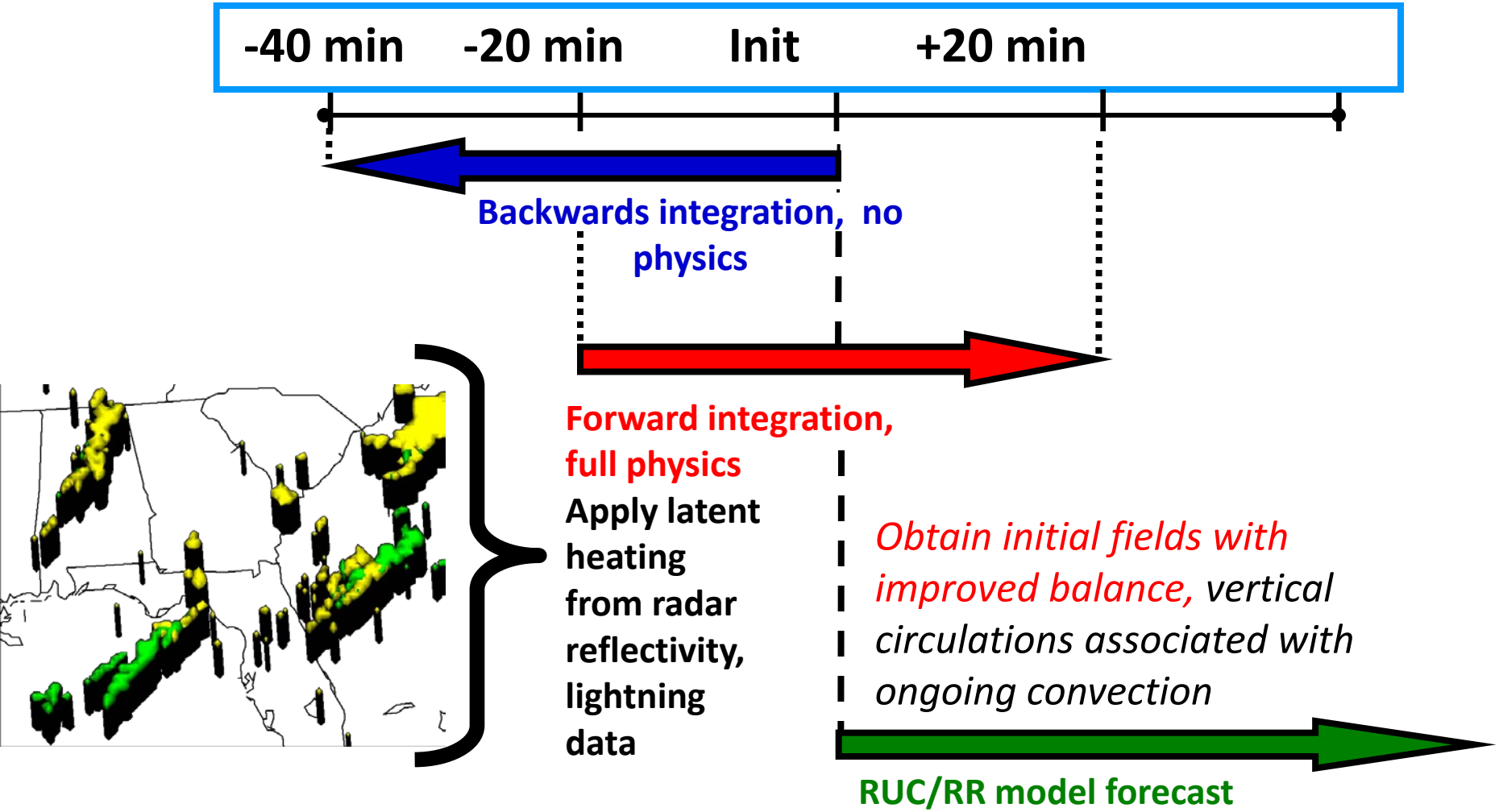
Hourly HRRR Initialization



Hourly HRRR Initialization



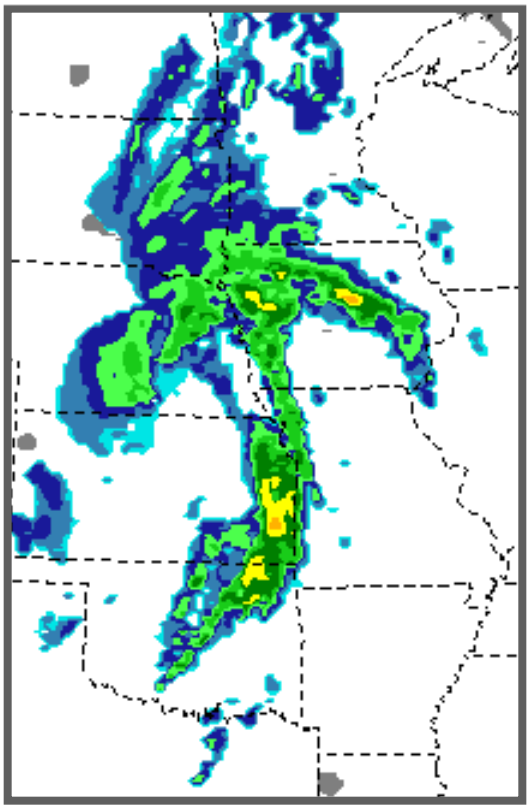
Diabatic Digital Filter Initialization (DDFI)



Radar reflectivity assimilation in RUC and Rapid Refresh

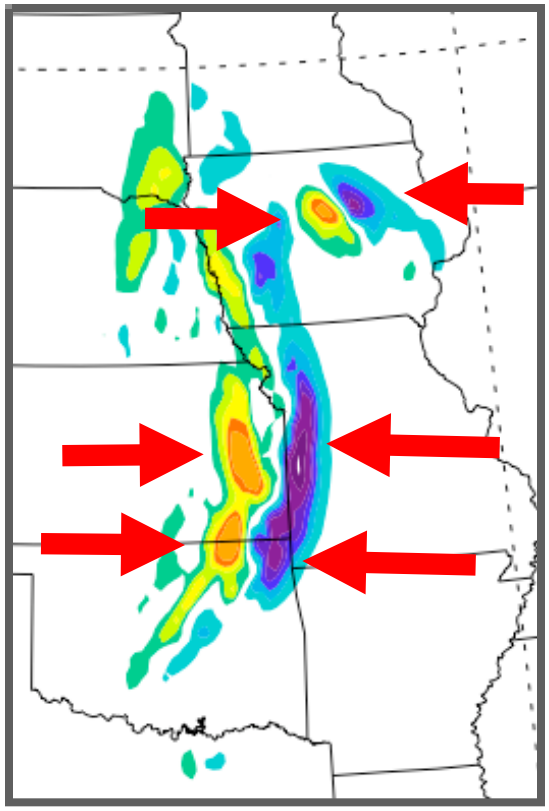
Rapid Refresh (GSI + ARW)
reflectivity assimilation example

NSSL radar reflectivity (dBZ)



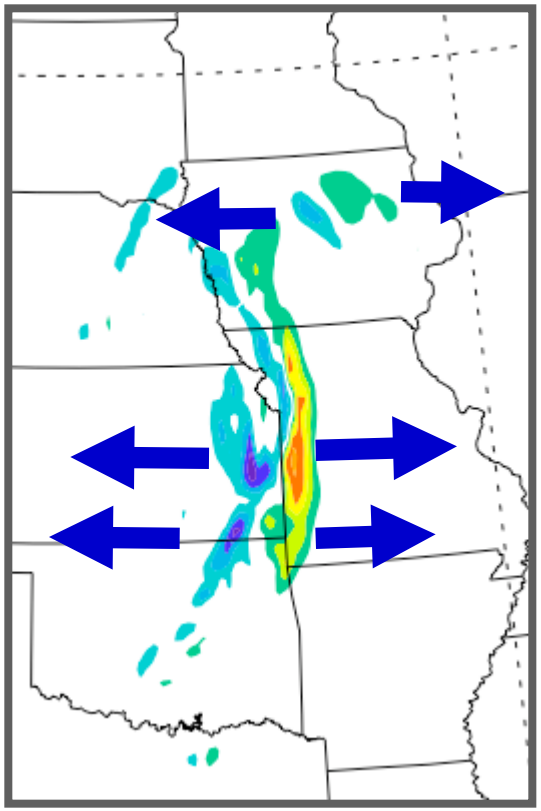
14z 22 Oct 2008
Z = 3 km

Low-level Convergence

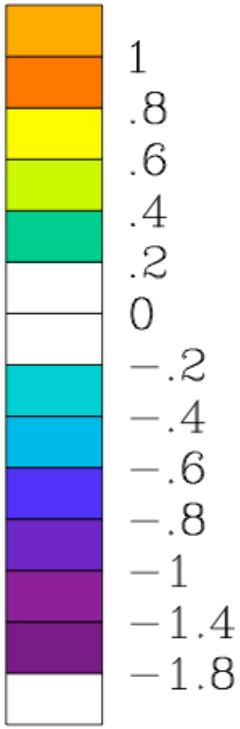


K=4 U-comp. diff
(radar - norad)

Upper-level Divergence



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



Some HRRR users and applications

Storm Prediction Center (SPC): 2-D grids
- Operational severe weather forecasting and evaluation

National Severe Storms Laboratory (NSSL): 2-D, 3-D and 15-min grids
- Mesoscale analysis, Short-term precipitation forecasts

National Centers for Environmental Prediction (NCEP): 15-min grids
- Real Time Mesoscale Analysis (RTMA)

Severe Weather

National Center for Atmospheric Research (NCAR): 2-D, 3-D, 15-min grids
- Operational evaluation in Consolidated Storm Prediction for Aviation

Aviation

Bonneville Power Administration (BPA): 3-D grids
- Real-time forecasts of turbine-level wind and solar irradiance

Colorado State University (CSU/CIRA): 2-D grids
- Verification of solar irradiance forecasts at SURFRAD sites

Renewable Energy

Air Resources Laboratory (ARL): Tiled 3-D HRRR grids
- Dispersion forecasts, Local wind forecasts in complex terrain

National Weather Service (NWS): 2-D and 3-D grids
- Operational weather forecasting

United States Air Force (USAF): 2-D grids
- Operational weather forecasting

Forecasting

Currently Available HRRR Fields

GRIB2 Hourly Output (24x a day out to 15 forecast hrs) – LDM or FTP

2-D Grid Sizes
File/Run/Day
70 MB / 1.1 GB / 26 GB

2-D fields

Surface pressure, MSLP

2-m temperature, dewpoint, relative humidity, specific humidity

Mixed-layer temperature, dewpoint, relative humidity, potential temperature

10-m u-wind, v-wind

Composite reflectivity, 1km AGL reflectivity

Updraft velocity, Downdraft velocity, Mean vertical velocity

Updraft helicity, Vertically integrated graupel, 10-m wind, 10-m wind gust

Surface, Boundary-Layer, Mixed-Layer, Most-Unstable CAPE/CIN, surface and most-unstable LI

0-1 km/0-3 km storm-relative helicity and storm motion, 0-1 km/0-6 km wind shear vector

LCL, Pressure-level of most unstable parcel, PBL height

Surface Visibility, Cloud base height (ceiling), Cloud top height

80-m u-wind, v-wind, 80-m wind generation potential, surface incoming shortwave radiation

Sensible, latent, ground heat flux

Surface and 5-soil level temperatures

Surface and 5-layer volumetric soil moisture content

Run-total precipitation, hourly precipitation, water equivalent of accumulated snow depth

Precipitable water, Outgoing long-wave radiation at the top of the atmosphere

Categorical snow, ice-pellets, freezing rain, rain

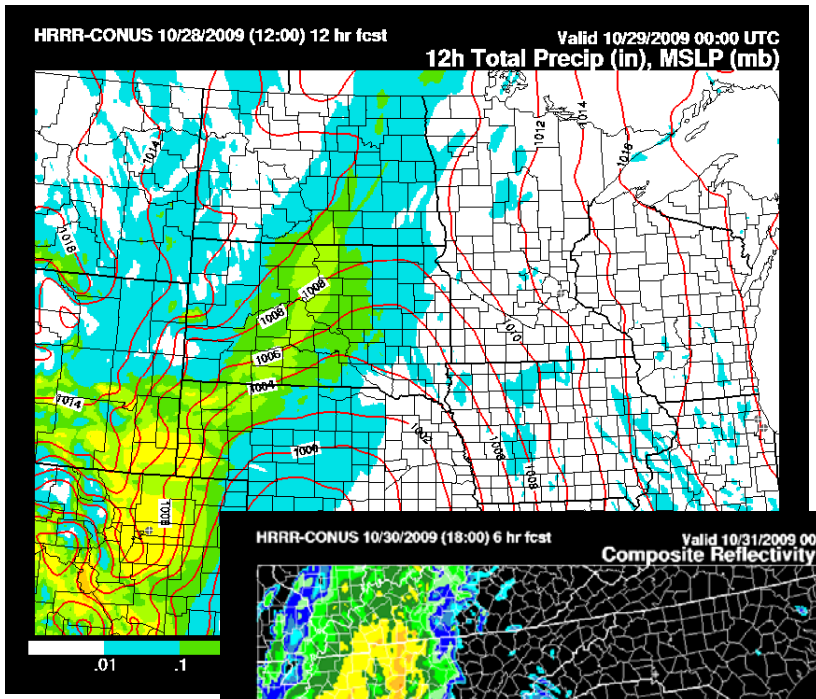
Real-Time HRRR

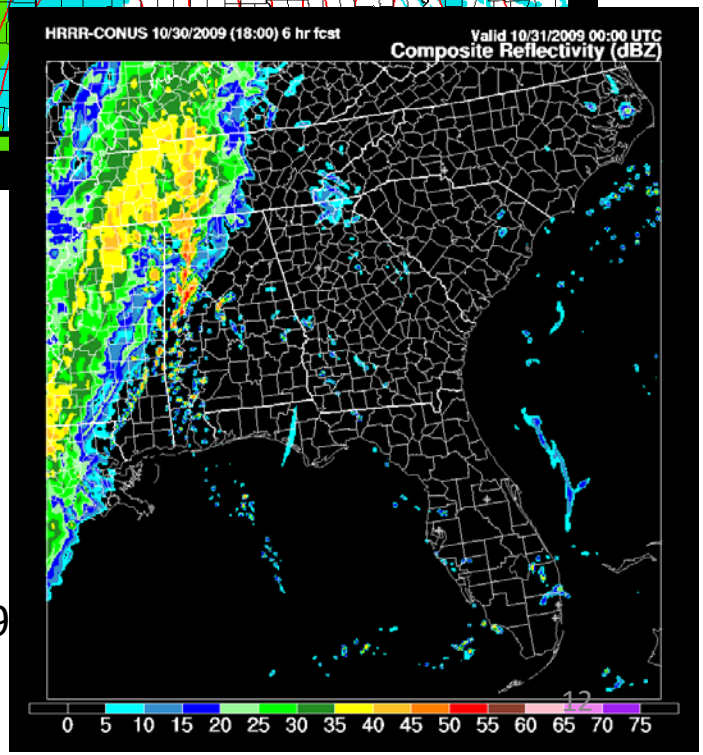
Front Range Winter Storm
12 hr fcst valid 00z 29 Oct 2009

http://rapidrefresh.noaa.gov/hrrrconus/

	All times	Loop	Valid Time													
			Fri 18	Fri 19	Fri 20	Fri 21	Fri 22	Fri 23	Sat 00	Sat 01	Sat 02	Sat 03	Sat 04	Sat 05	Sat 06	
			Forecast Duration													
			00	01	02	03	04	05	06	07	08	09	10	11	12	
all fields			18	19	20	21	22	23	00	01	02	03	04	05	06	all fields
1 km agl reflectivity	✔	✔	18	19	20	21	22	23	00	01	02	03	04	05	06	1 km agl reflectivity
reflectivity	✔	✔	18	19	20	21	22	23	00	01	02	03	04	05	06	reflectivity
max reflectivity	✔	✔		19	20	21	22	23	00	01	02	03	04	05	06	max reflectivity
surface CAPE	✔	✔	18	19	20	21	22	23	00	01	02	03	04	05	06	surface CAPE
surface CIN	✔	✔	18	19	20	21	22	23	00	01	02	03	04	05	06	surface CIN
mixed CAPE	✔	✔	18	19	20	21	22	23	00	01	02	03	04	05	06	mixed CAPE
most unstable CAPE	✔	✔	18	19	20	21	22	23	00	01	02	03	04	05	06	most unstable CAPE
best LI	✔	✔	18	19	20	21	22	23	00	01	02	03	04	05	06	best LI
LCL	✔	✔	18	19	20	21	22	23	00	01	02	03	04	05	06	LCL
0-1 km shear	✔	✔	18	19	20	21	22	23	00	01	02	03	04	05	06	0-1 km shear
0-6 km shear	✔	✔	18	19	20	21	22	23	00	01	02	03	04	05	06	0-6 km shear
0-1 km helicity, storm motion	✔	✔	18	19	20	21	22	23	00	01	02	03	04	05	06	0-1 km helicity, storm motion
0-3 km helicity, storm motion	✔	✔	18	19	20	21	22	23	00	01	02	03	04	05	06	0-3 km helicity, storm motion
max updraft helicity	✔	✔		19	20	21	22	23	00	01	02	03	04	05	06	max updraft helicity
max vert int graupel	✔	✔		19	20	21	22	23	00	01	02	03	04	05	06	max vert int graupel
max 10m wind	✔	✔		19	20	21	22	23	00	01	02	03	04	05	06	max 10m wind
10m wind	✔	✔	18	19	20	21	22	23	00	01	02	03	04	05	06	10m wind
skin temp	✔	✔	18	19	20	21	22	23	00	01	02	03	04	05	06	skin temp
2m temp	✔	✔	18	19	20	21	22	23	00	01	02	03	04	05	06	2m temp
2m temp - skin temp	✔	✔	18	19	20	21	22	23	00	01	02	03	04	05	06	2m temp - skin temp
2m dew point	✔	✔	18	19	20	21	22	23	00	01	02	03	04	05	06	2m dew point
precipitable water	✔	✔	18	19	20	21	22	23	00	01	02	03	04	05	06	precipitable water
1h acc precip	✔	✔		19	20	21	22	23	00	01	02	03	04	05	06	1h acc precip
total acc precip	✔	✔		19	20	21	22	23	00	01	02	03	04	05	06	total acc precip
snow water equiv	✔	✔	18	19	20	21	22	23	00	01	02	03	04	05	06	snow water equiv
precip type	✔	✔	18	19	20	21	22	23	00	01	02	03	04	05	06	precip type
850mb temp	✔	✔	18	19	20	21	22	23	00	01	02	03	04	05	06	850mb temp
850mb wind	✔	✔	18	19	20	21	22	23	00	01	02	03	04	05	06	850mb wind
850mb rh	✔	✔	18	19	20	21	22	23	00	01	02	03	04	05	06	850mb rh
850-500mb mean rh	✔	✔	18	19	20	21	22	23	00	01	02	03	04	05	06	850-500mb mean rh
700mb temp	✔	✔	18	19	20	21	22	23	00	01	02	03	04	05	06	700mb temp
700mb wind	✔	✔		19	20	21	22	23	00	01	02	03	04	05	06	700mb wind

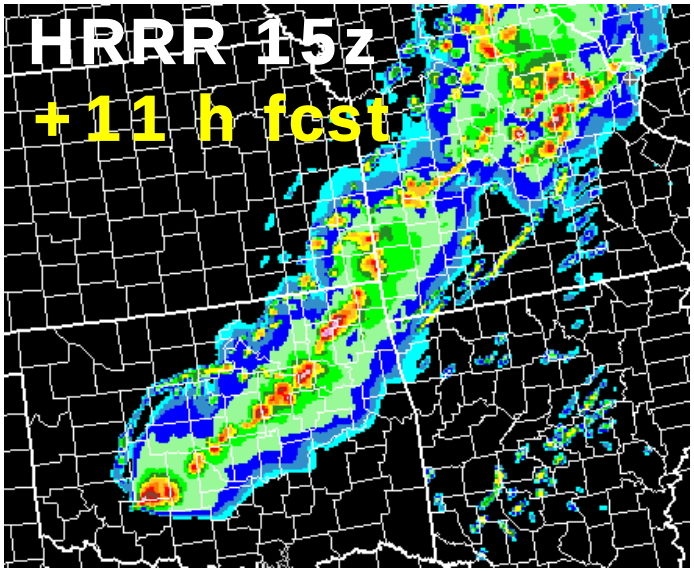
Diversity of forecast fields

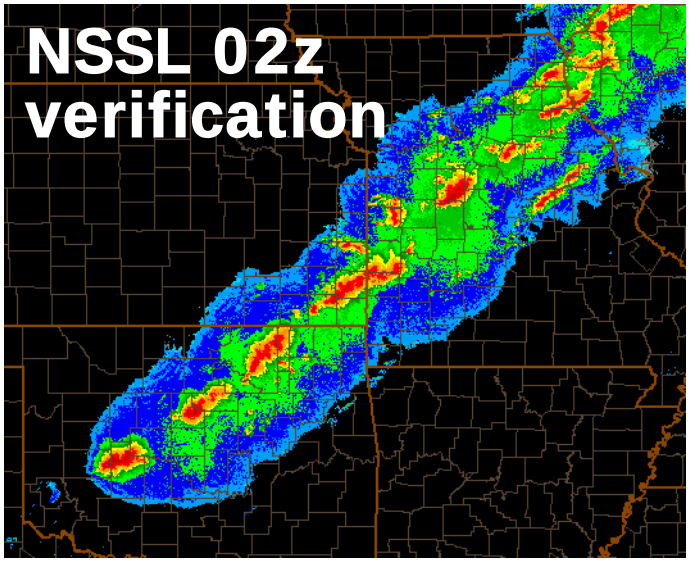


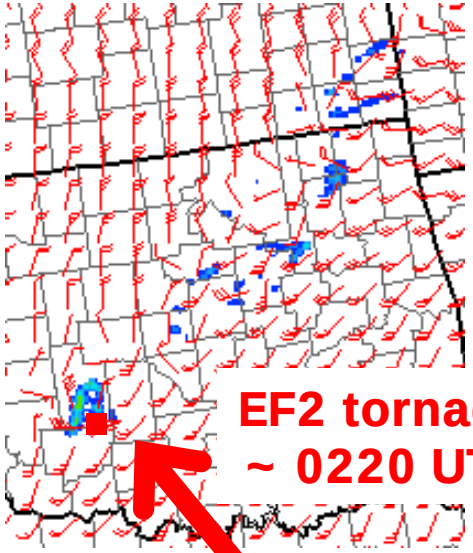


Squall-line with leading supercells
6 hr fcst valid 00z 31 Oct 2009

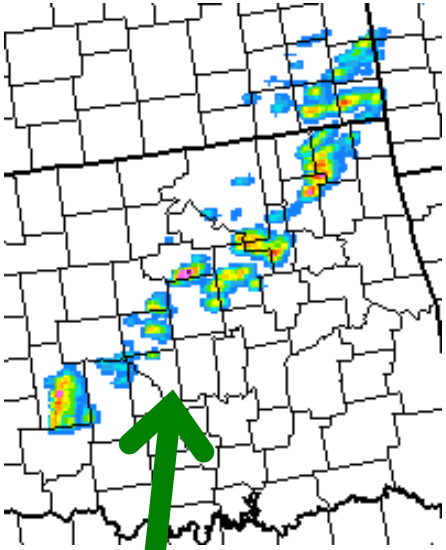
HRRR Severe Weather Forecasts







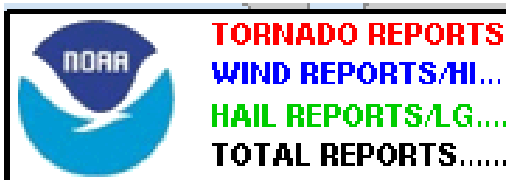
EF2 tornado
~ 0220 UTC

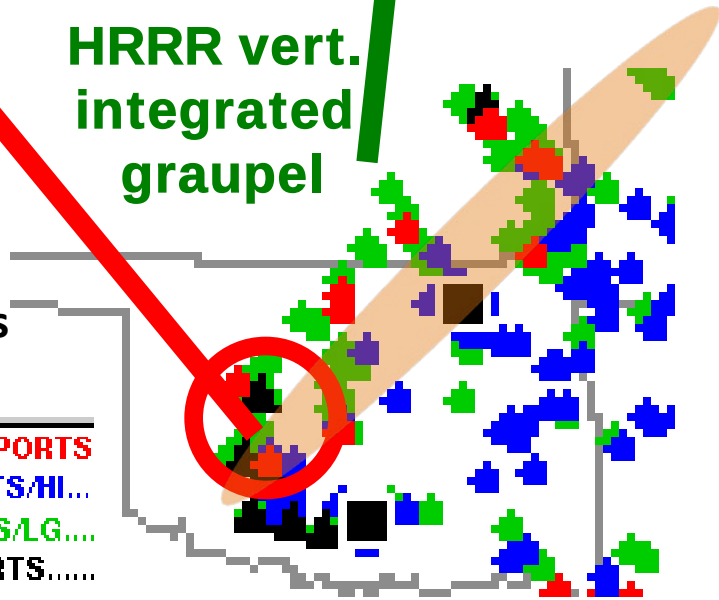


HRRR vert. integrated graupel

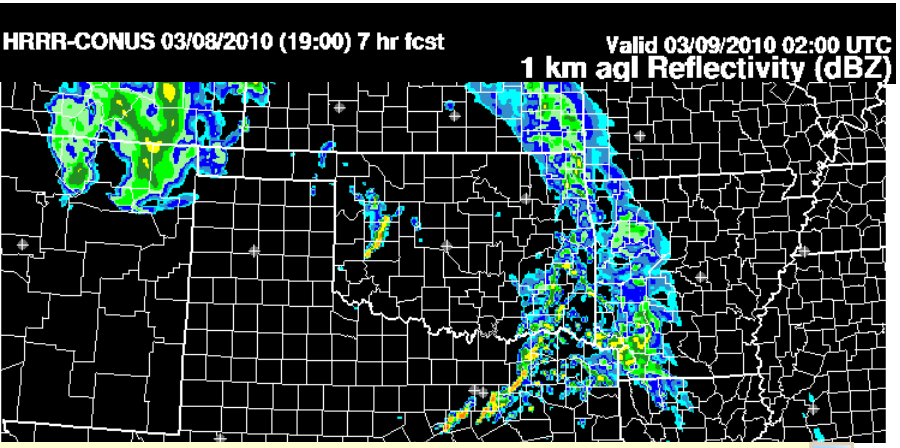
HRRR updraft helicity

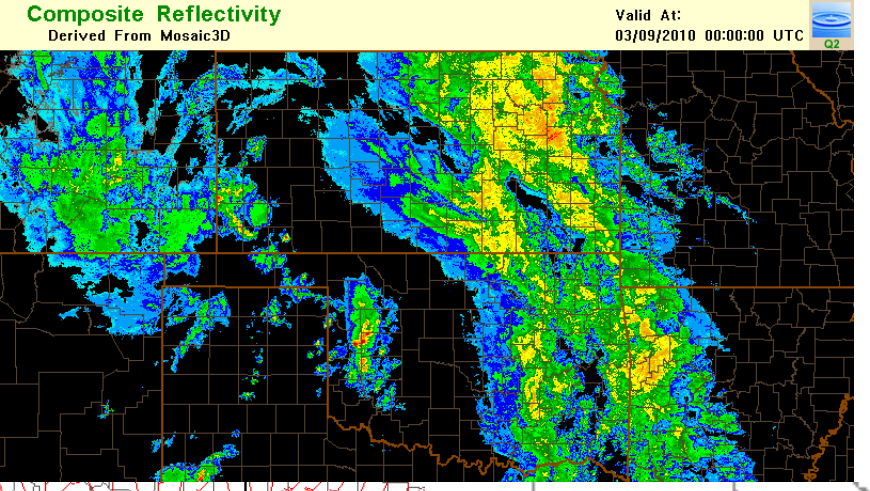
Severe diagnostics code from NSSL

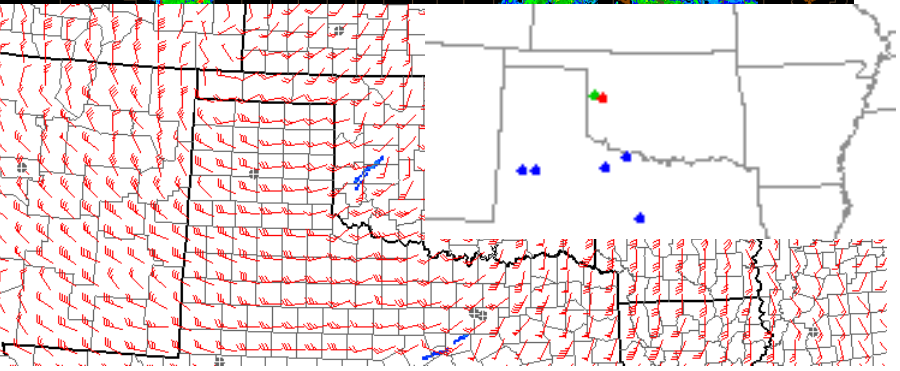


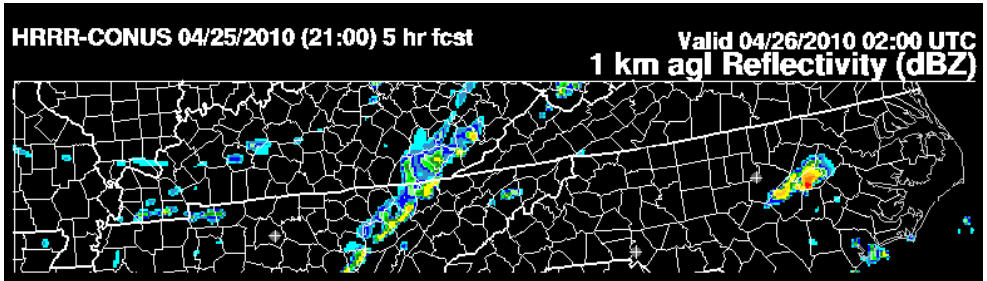


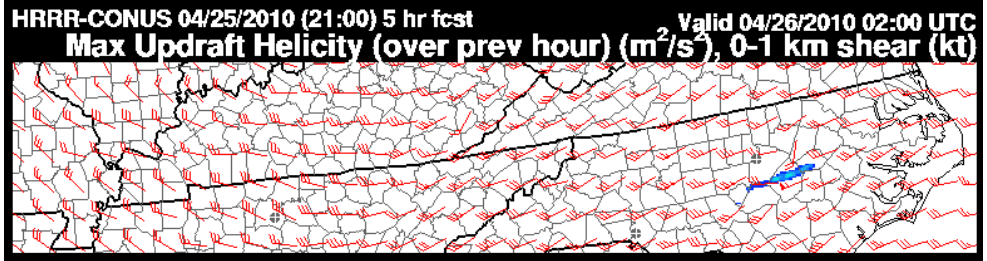
HRRR Severe Weather Forecasts

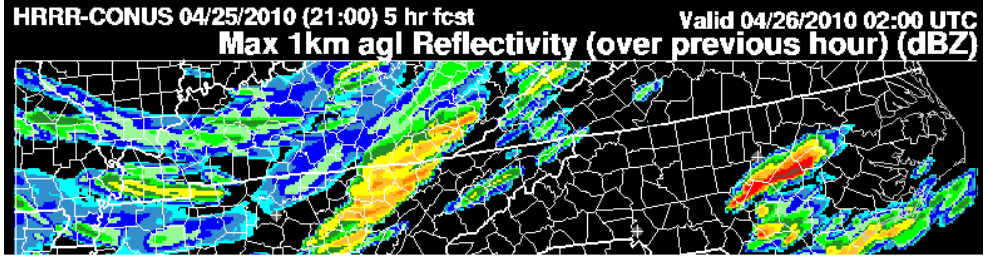




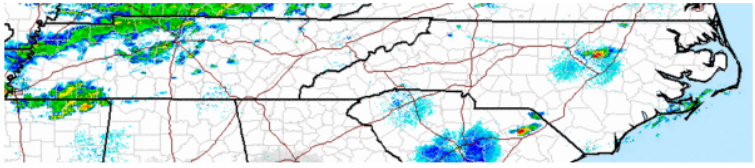








Observed Regional Reflectivity at 2358 UTC 04/25/2010



April 25, 2010 Zebulon Tornado Track

HRRR Severe Weather Forecasts

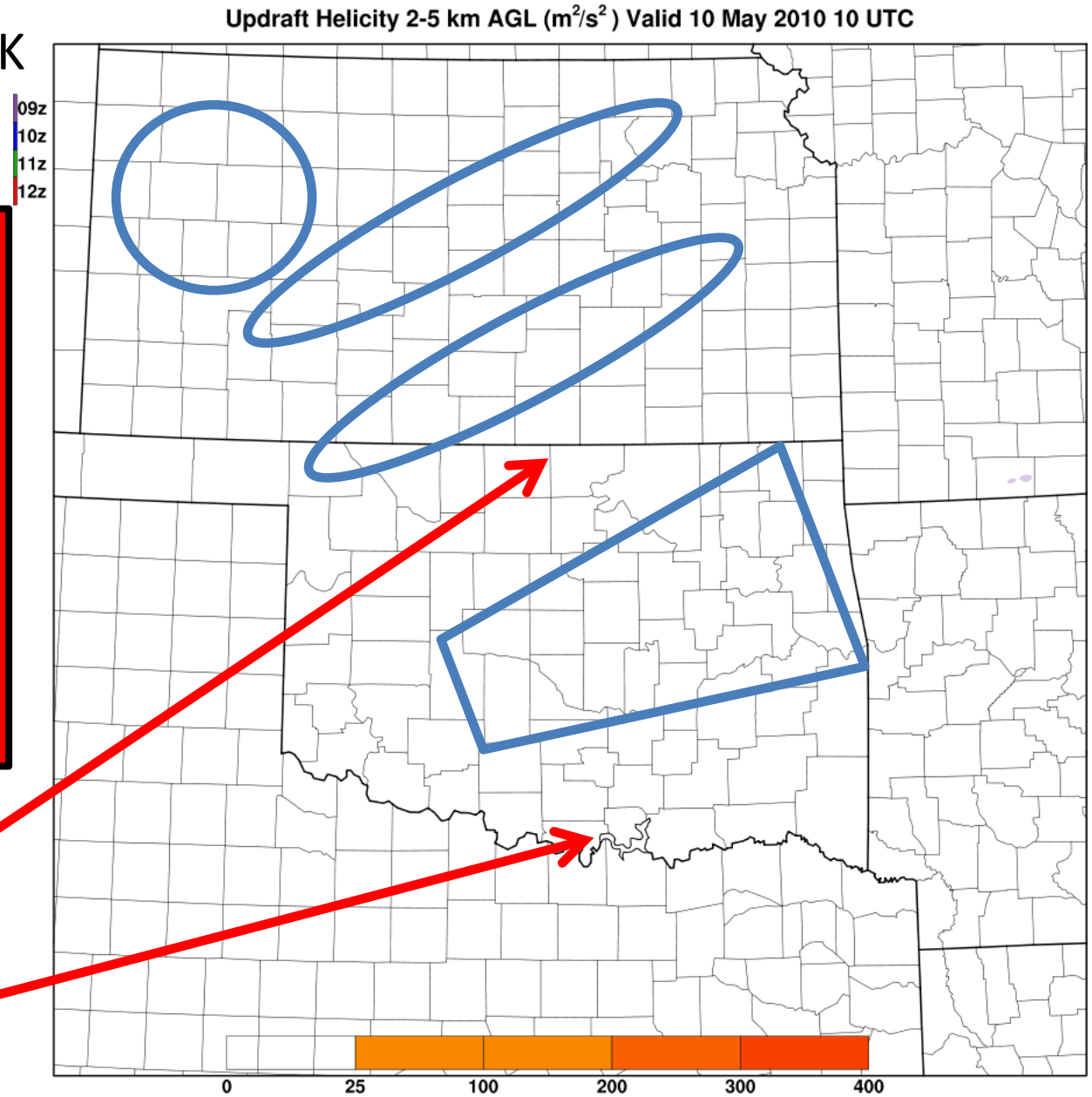
Tornado Outbreak KS/OK
10 May 2010

Updraft helicity from four consecutive HRRR runs 09-12 UTC (color coded by run)

Tornado Reports Up to valid time (red dots)

No organized convection forecasted near storm track

No organized convection Forecasted near Red River

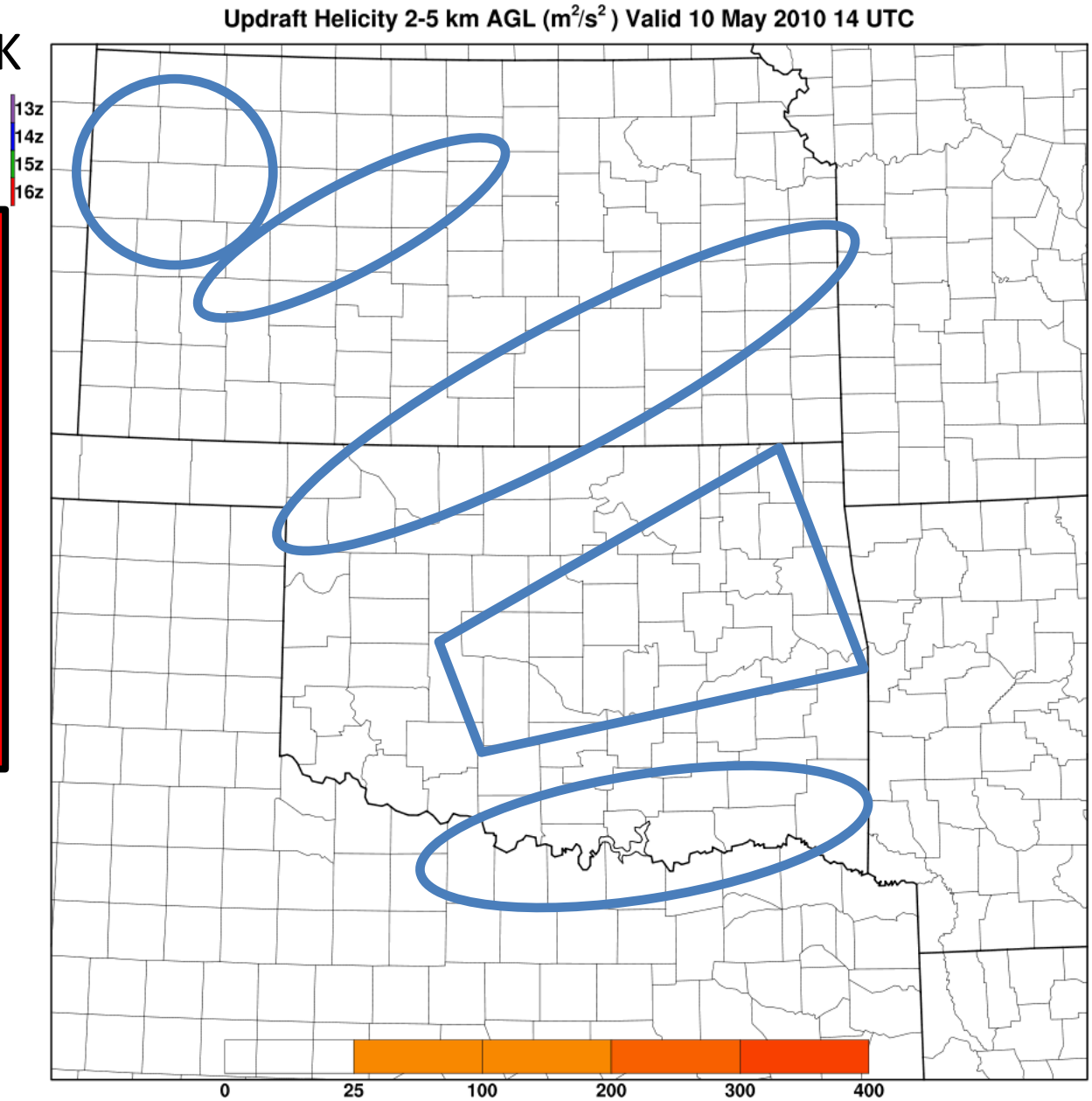


HRRR Severe Weather Forecasts

Tornado Outbreak KS/OK
10 May 2010

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

Tornado Reports Up to valid time (red dots)



The HCPF

HRRR Convective Probabilistic Forecast (HCPF)

Uses time-lagged ensemble to estimate liklihood of convection

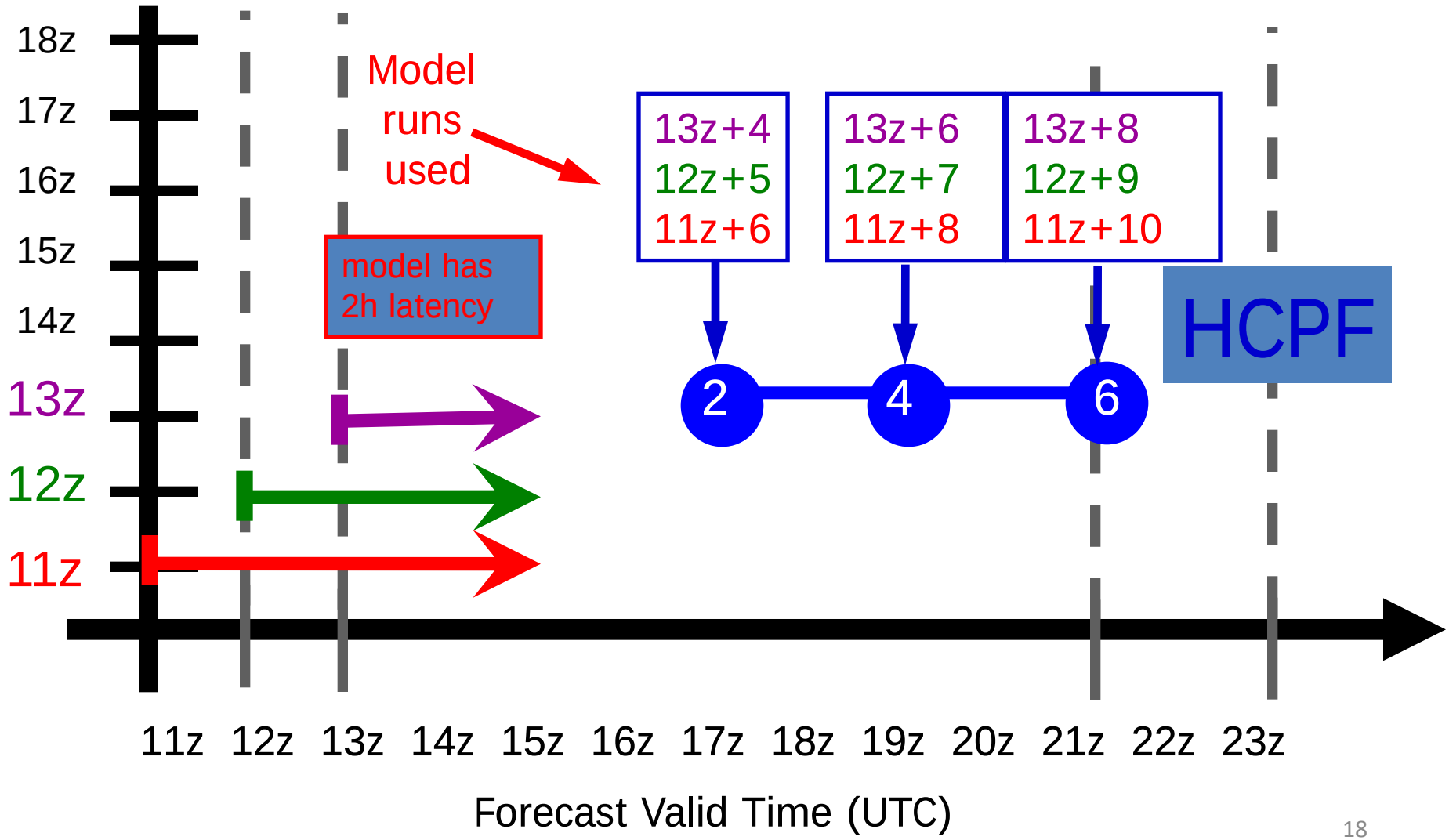
Identification of moist convection using model forecast fields:

- Stability – Surface lifted index < +2 C (neutral to unstable)
- Intensity – Model reflectivity > 30 dBZ or updraft > 1 m s^{-1}
- Time – 2 hr search window centered on valid times
- Location – Stability and intensity criteria searched within 30 points (radius of ~90 km) of each point for each member

$$\text{HCPF} = \frac{\text{\# grid points matching criteria over all members}}{\text{total \# grid points searched over all members}}$$

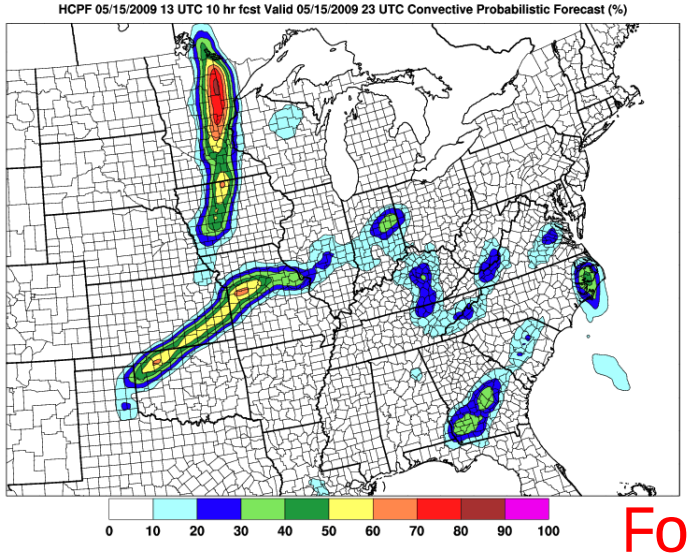
Time-lagged ensemble

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

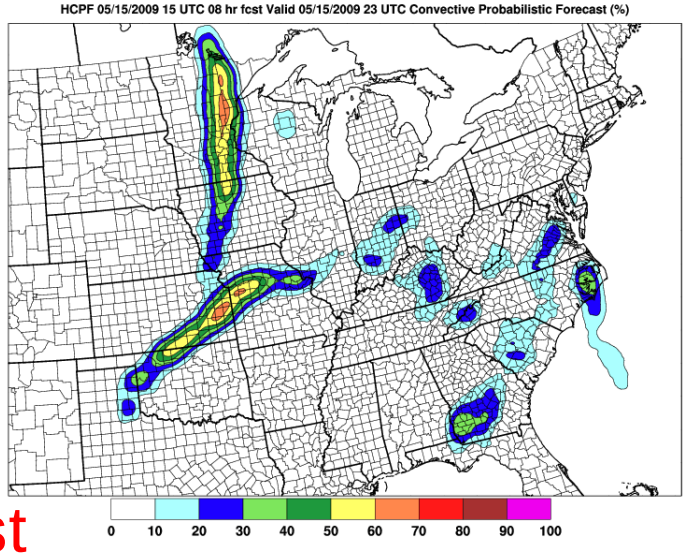


HCPF Example: 23 UTC 15 May 2009

10 hr forecast

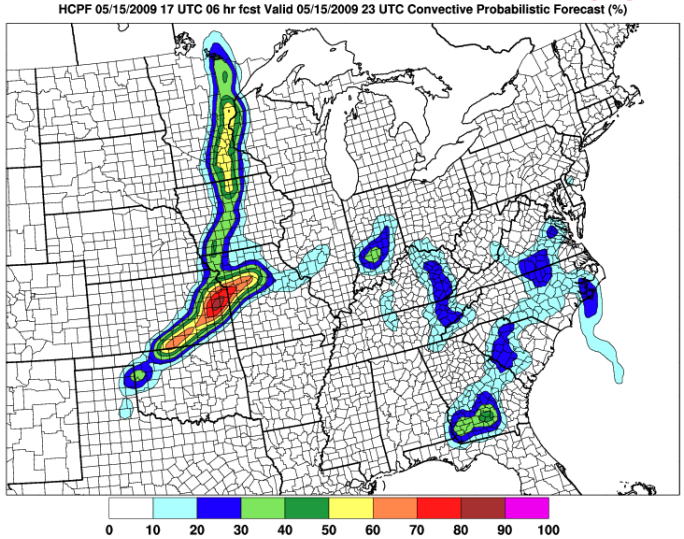


08 hr forecast

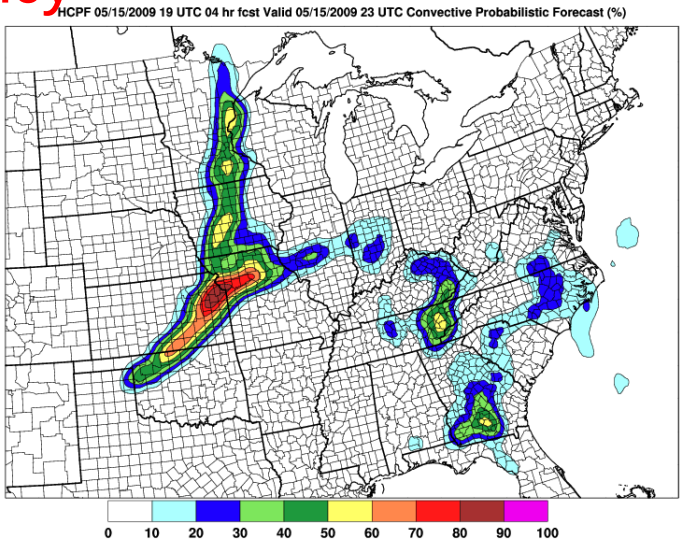


Forecast Consistency

06 hr forecast

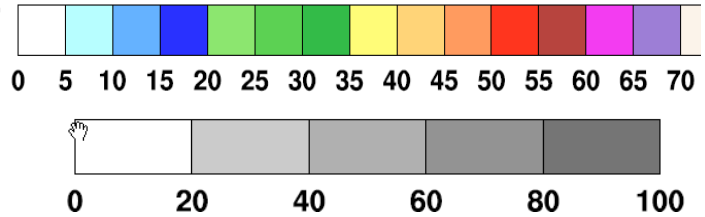


04 hr forecast



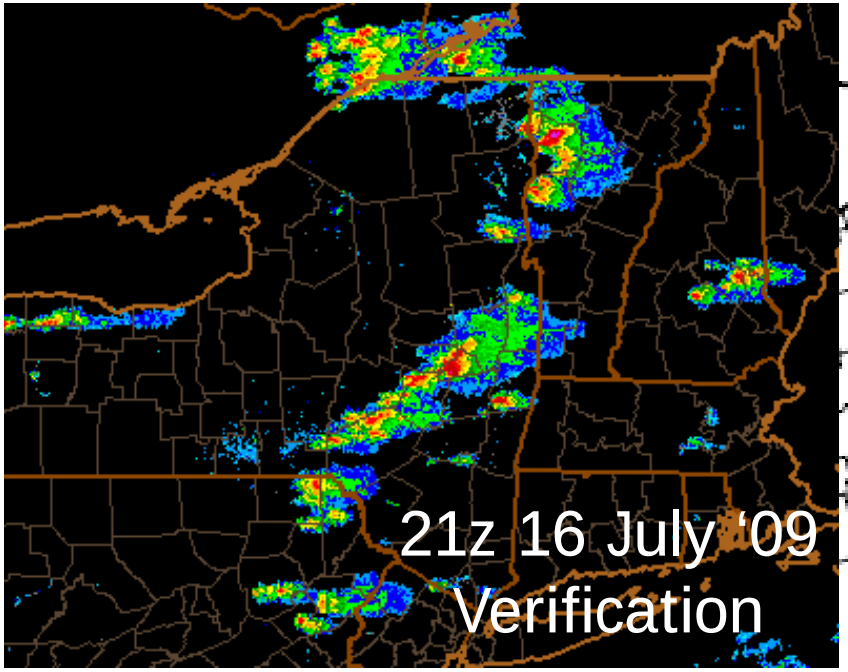
Convective probability forecasts from HRRR time-lagged ensemble

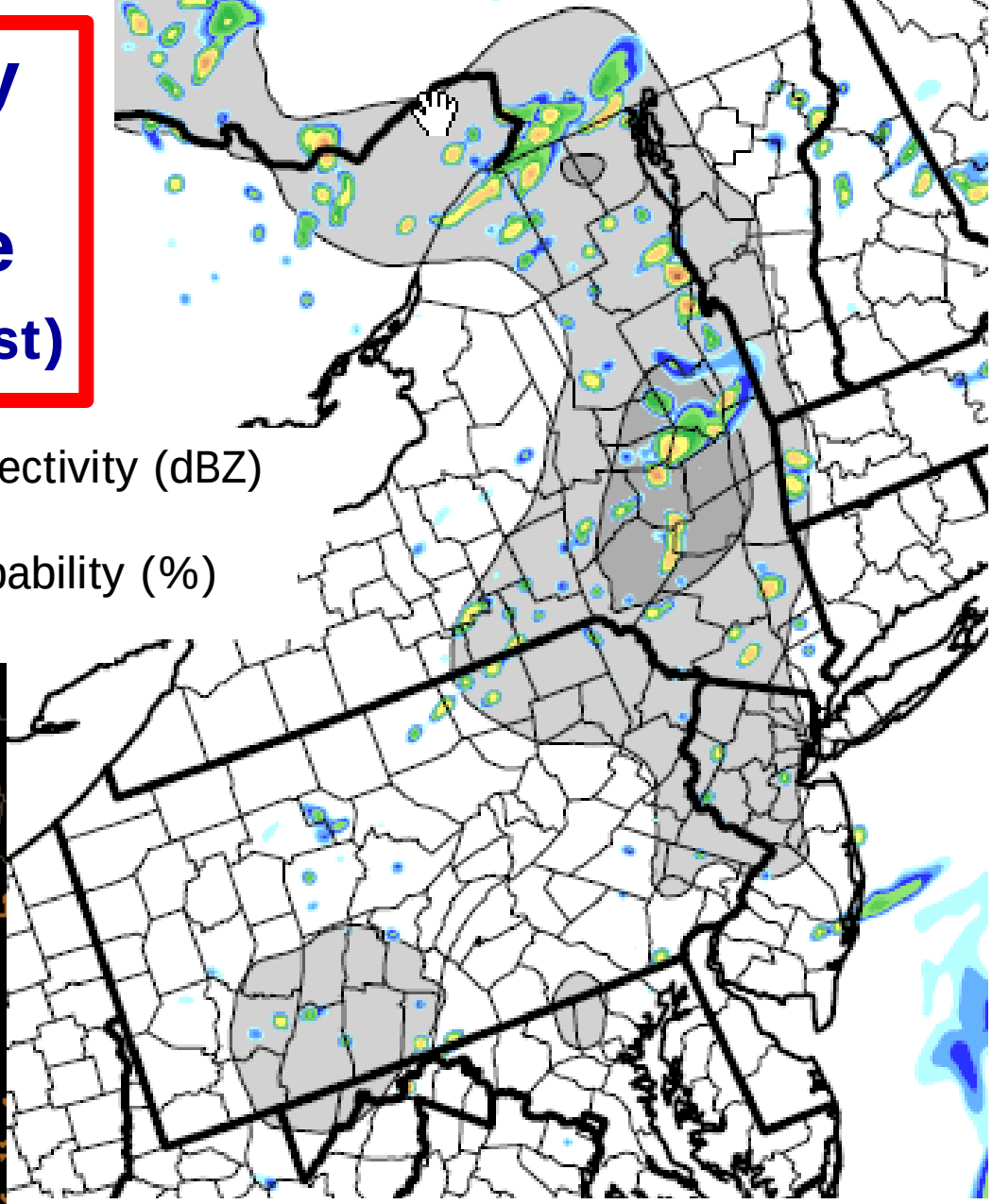
(show with deterministic fcst)



Reflectivity (dBZ)

Probability (%)





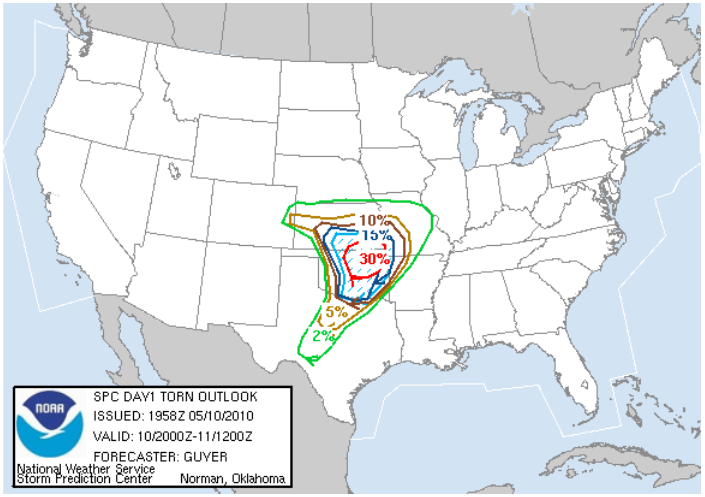
15z + 6h HRRR and HCPF

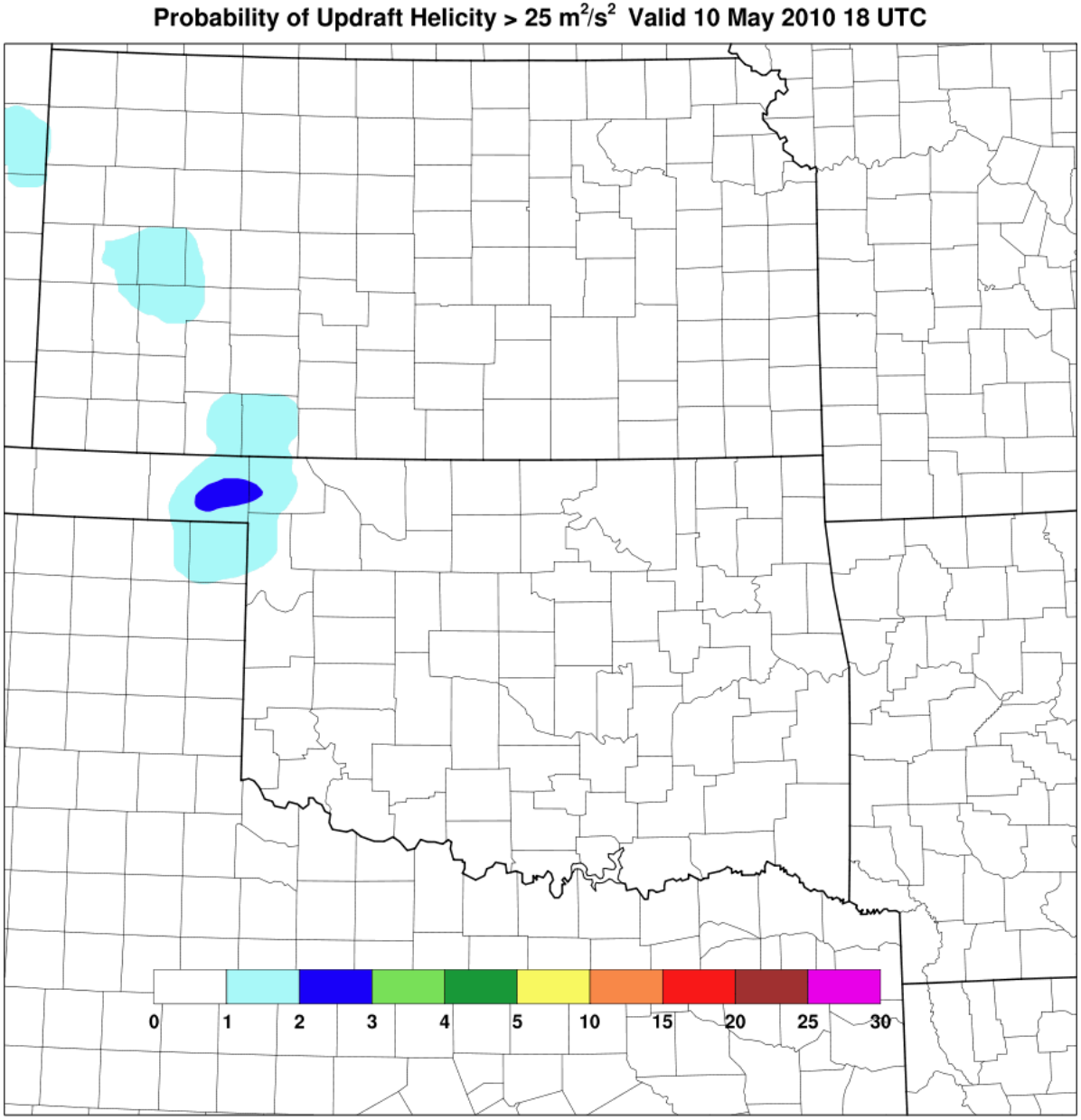
HRRR use for Warn on Forecast

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



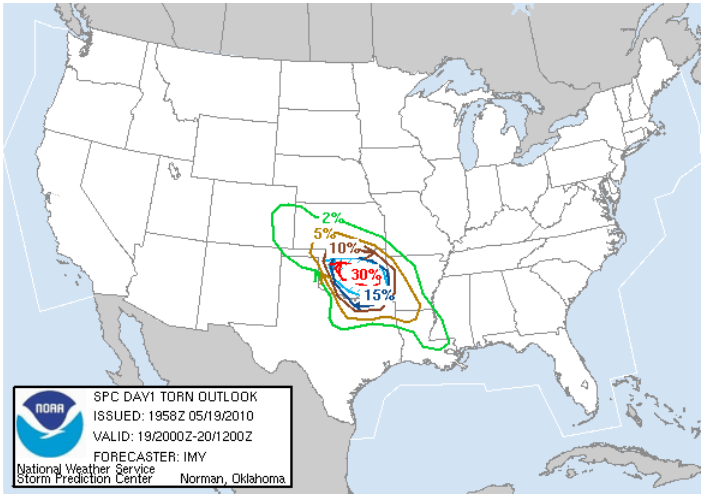


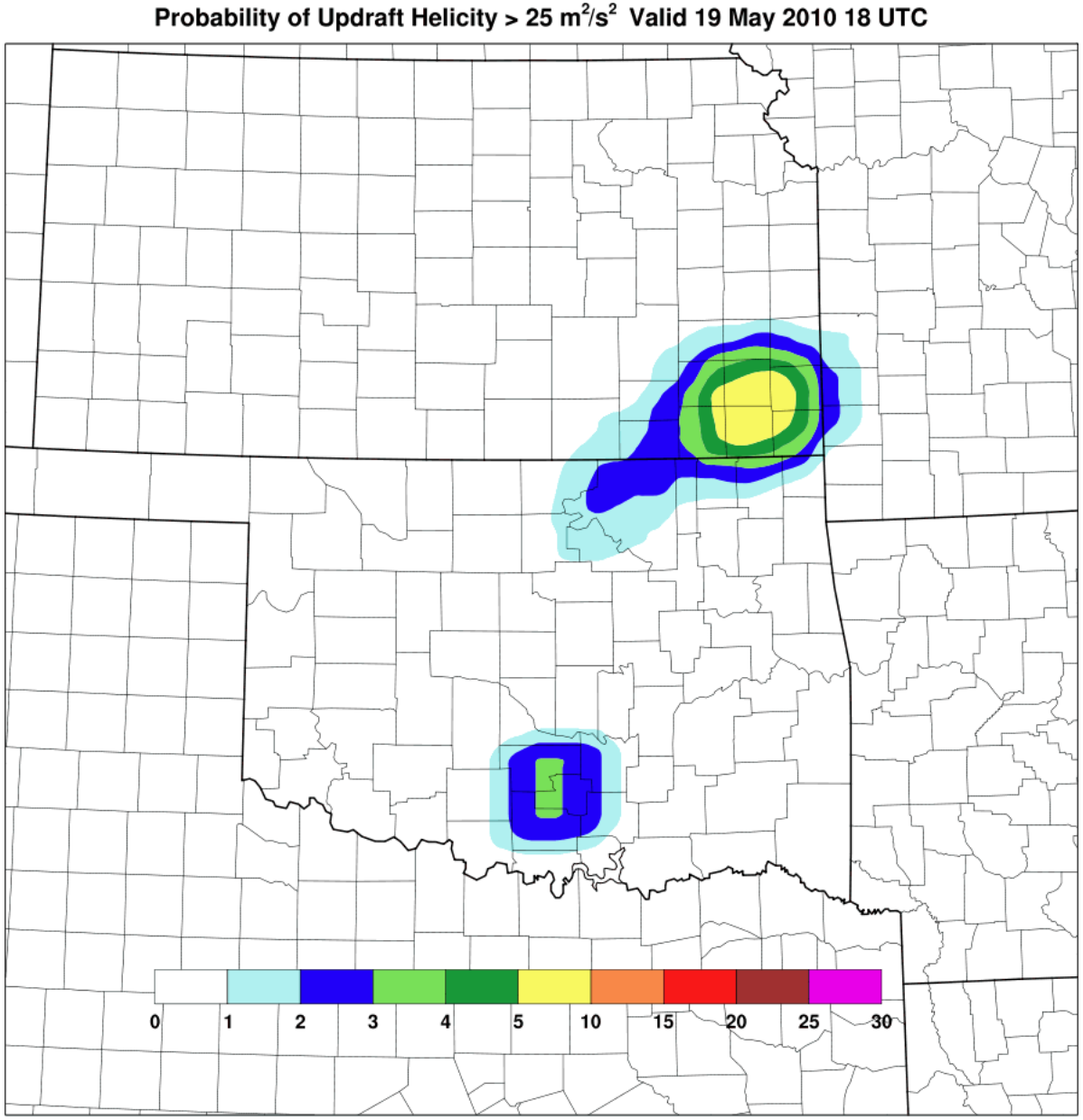
HRRR use for Warn on Forecast

Tornadoes KS/OK
19 May 2010

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

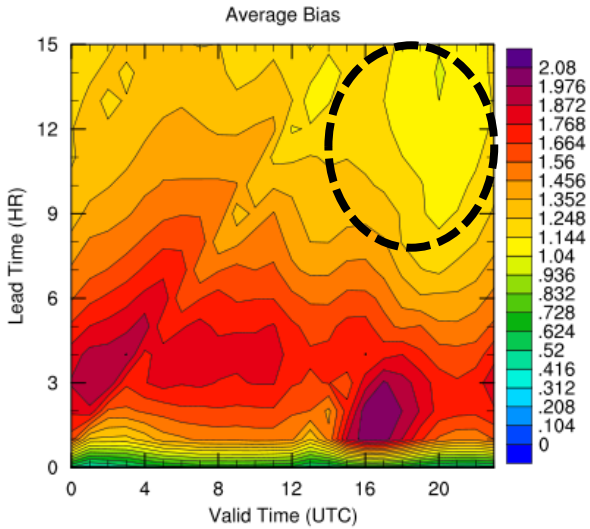
Time-bracket of 2-hrs
45 km search radius

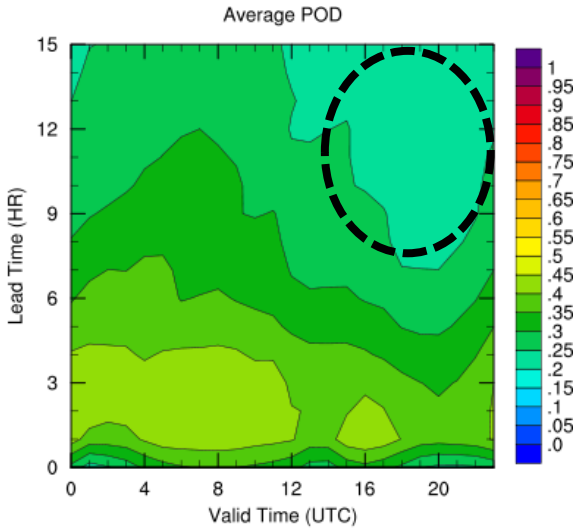




HRRR Multi-Scale Reflectivity Verification
10 June 2010 – 26 September 2010

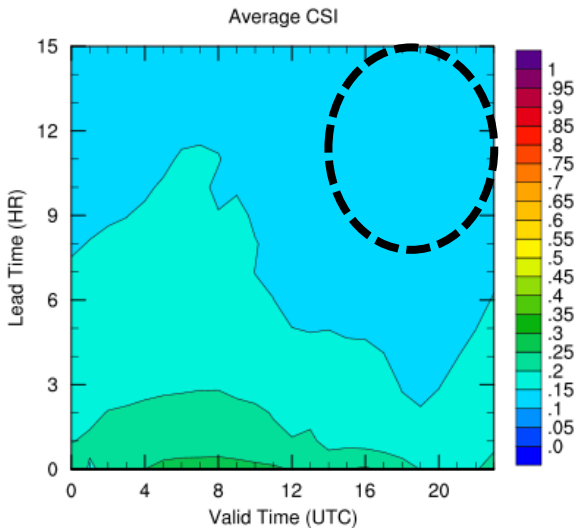
3 km verification
20 dBZ threshold
NSSL composite reflectivity mosaic

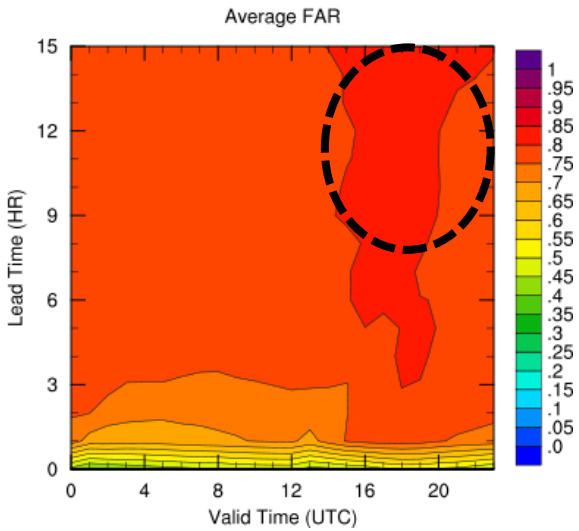




The convective initiation (CI) “challenge”

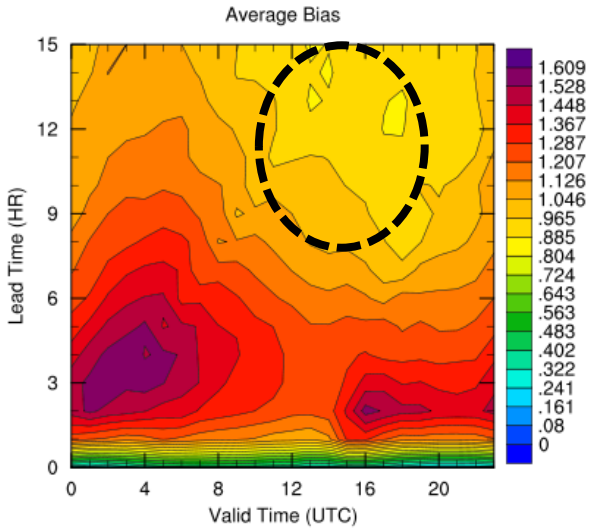
Missing exact location of small-scale convection around climatological CI time especially at longer lead times

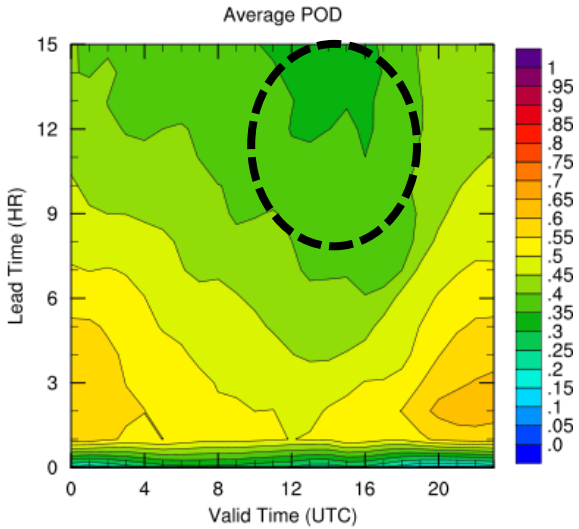




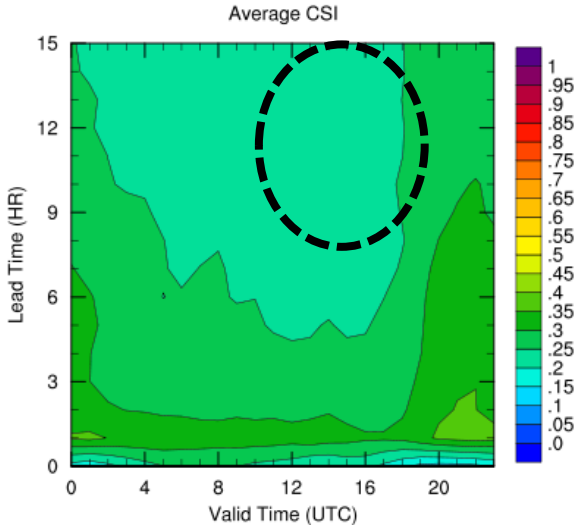
HRRR Multi-Scale Reflectivity Verification
10 June 2010 – 26 September 2010

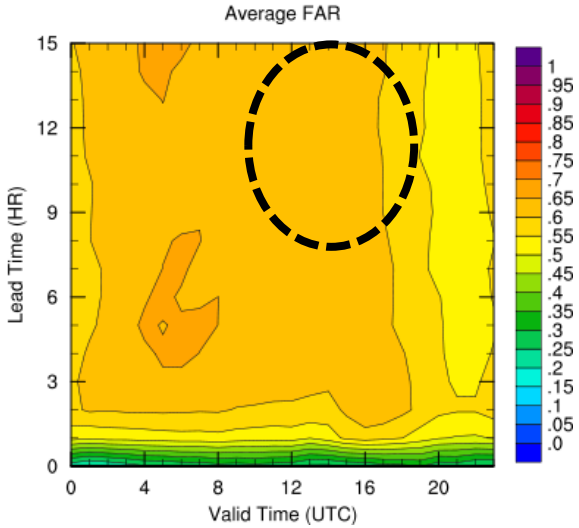
80 km verification
20 dBZ threshold
NSSL composite reflectivity mosaic





Not maintaining nocturnal/morning MCSs at longer lead times

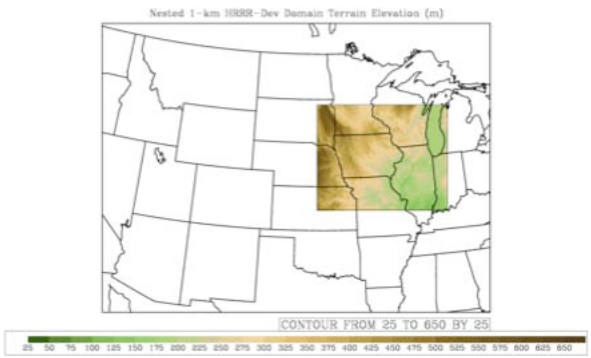




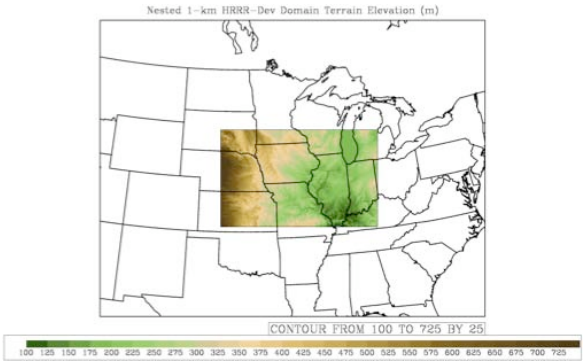
HRRR Nested Grid Experiments

Initial conditions from the RUC, same as operational HRRR
Two-way nested inner 1-km domain defined in vicinity of MCS
All other settings identical to operational HRRR

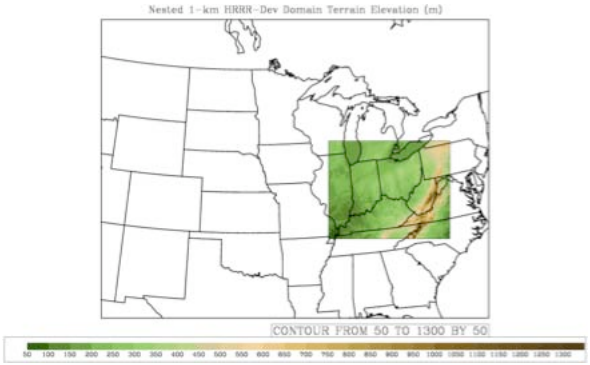
18 June 2010



19 July 2010

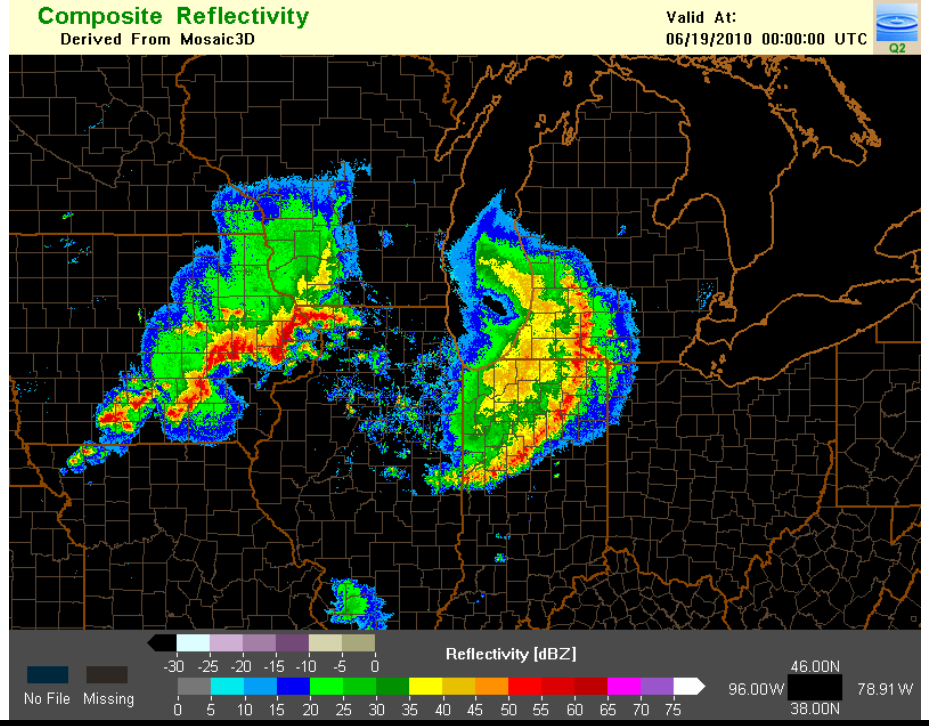


4 August 2010



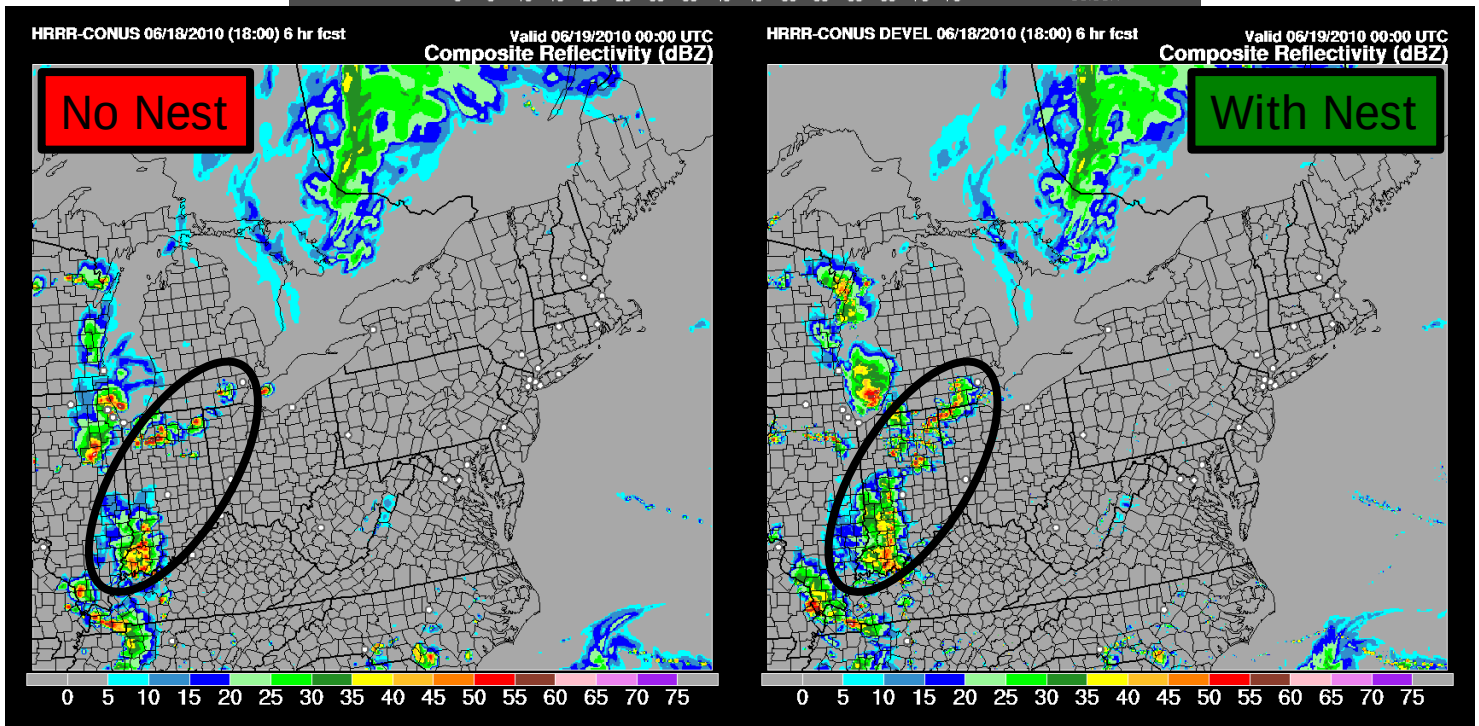
~2x run-time

00 UTC
19 June 2010

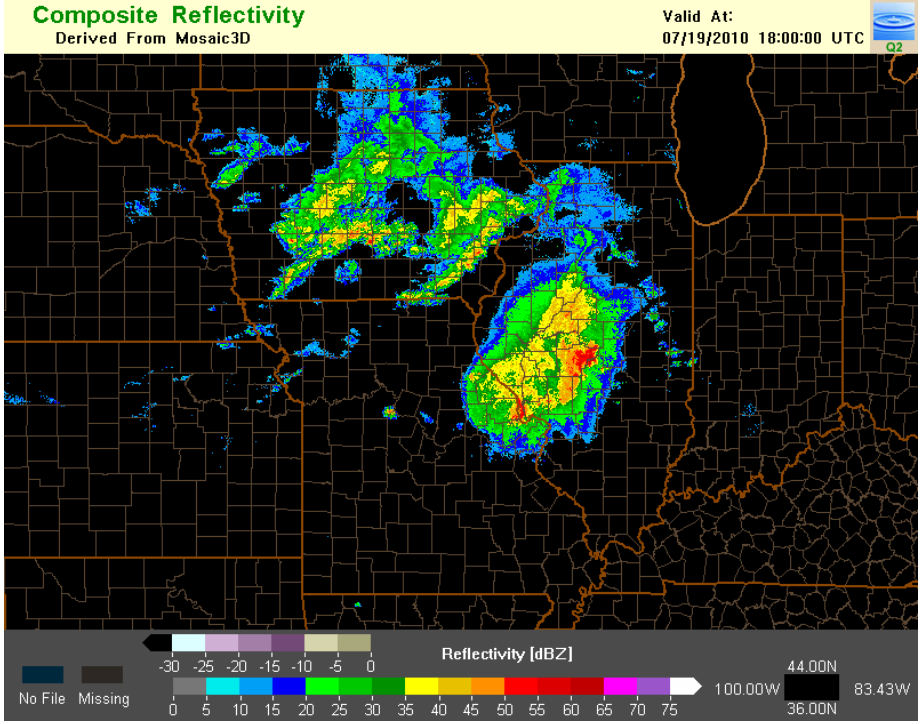


Some Improvement MCS maintenance

(6-h forecasts)

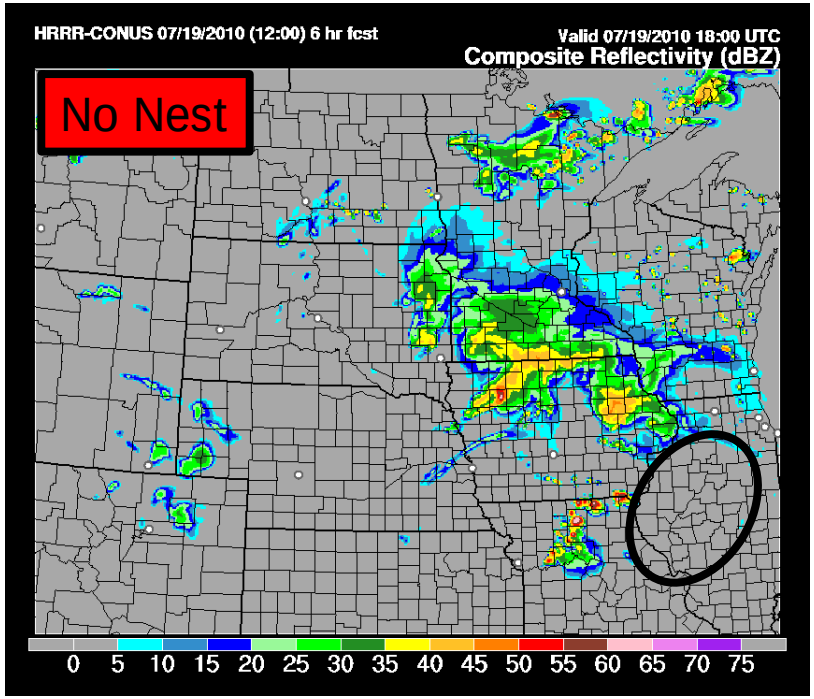


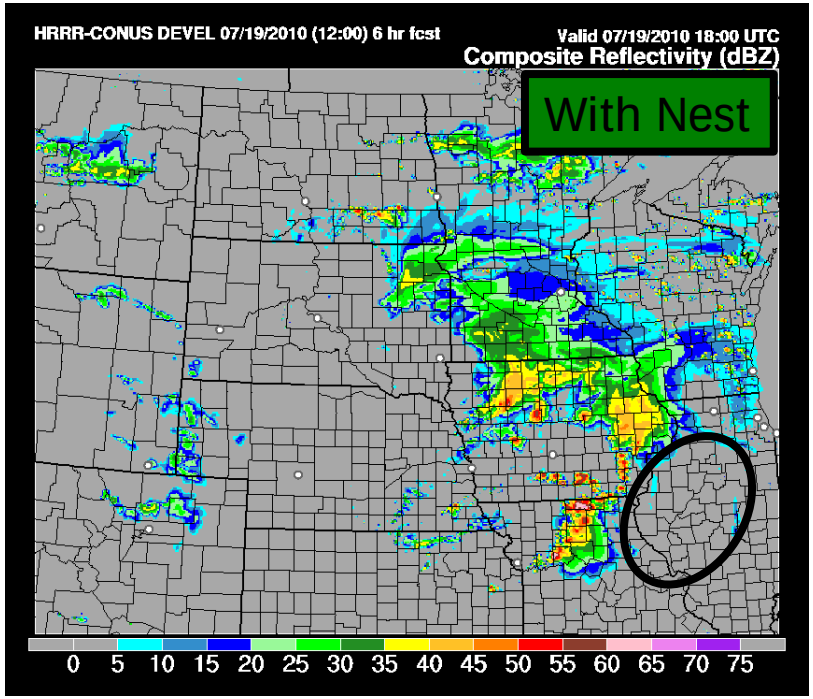
18 UTC
19 July 2010



No Improvement MCS maintenance

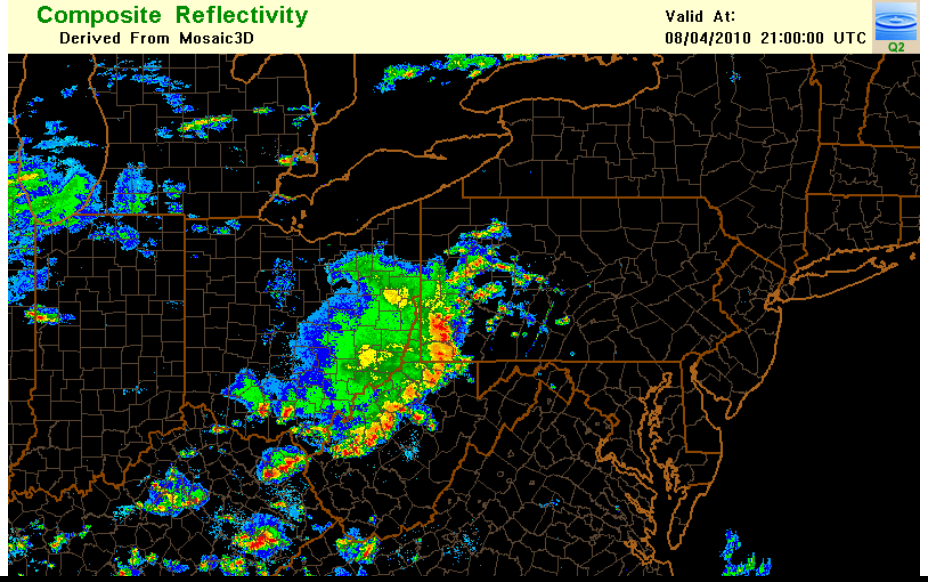
(6-h forecasts)



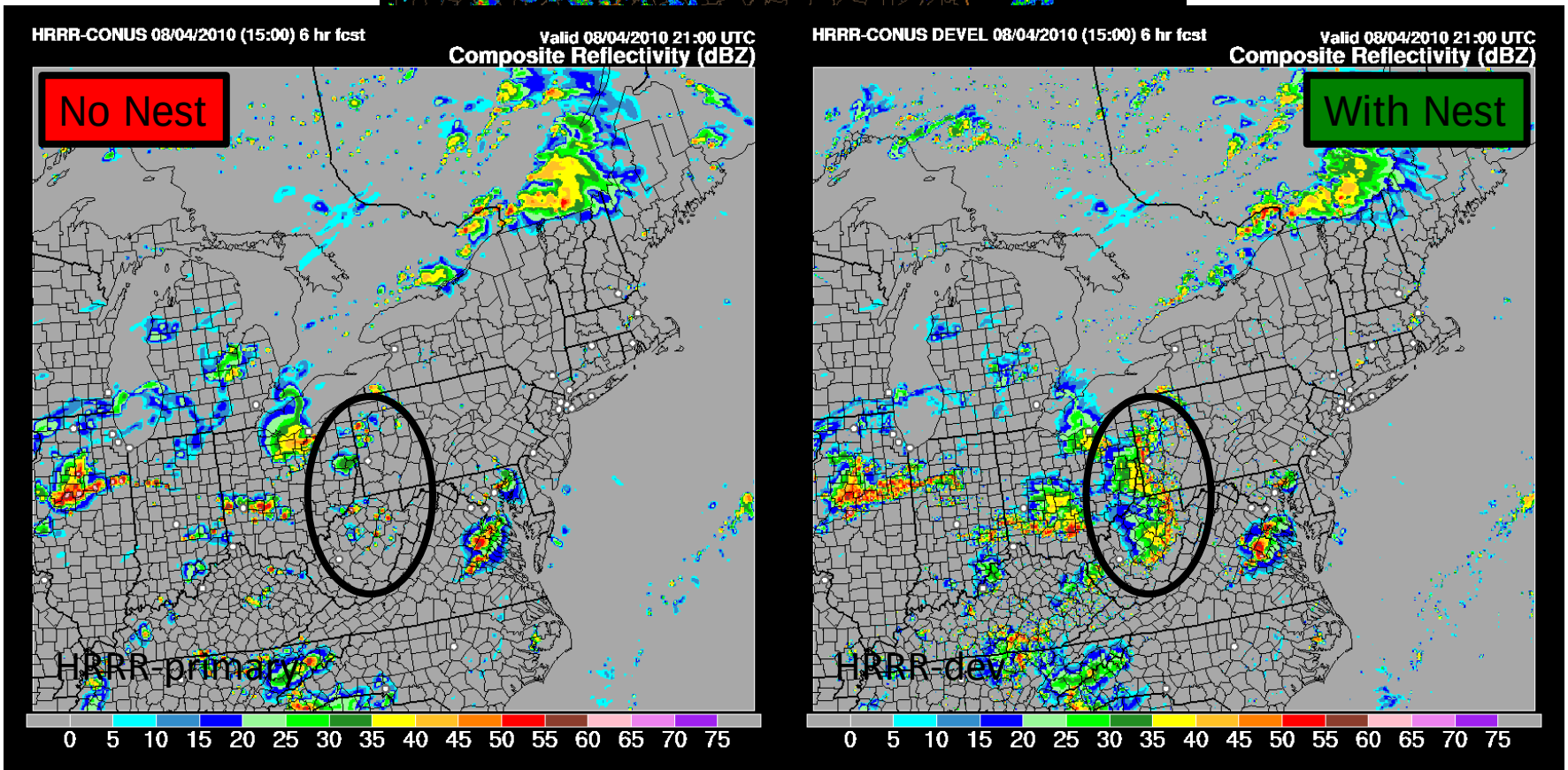


21 UTC
4 August 2010

(6-h forecasts)



Significant Improvement MCS maintenance



Upcoming HRRR Changes

Fall/Winter 2010

Transition 15-min NetCDF fields to GRIB2 format
Provide 15-min fields in hourly files (4 valid times per file)
Reduce model latency by ~30 min to attain ~2 hr latency

Winter/Spring 2011

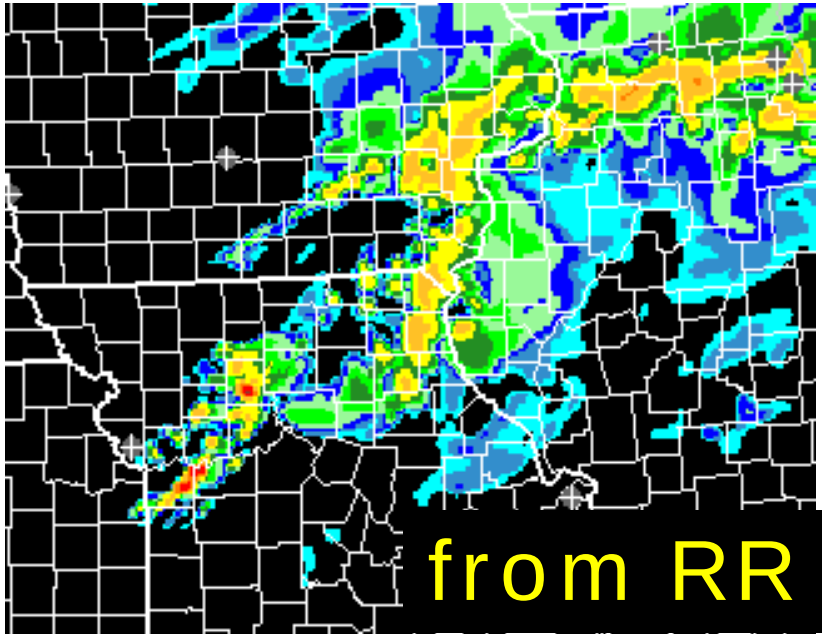
Switch parent model from RUC to RR
Assimilate radar reflectivity at 3-km (hydrometeors and temperature tendency)

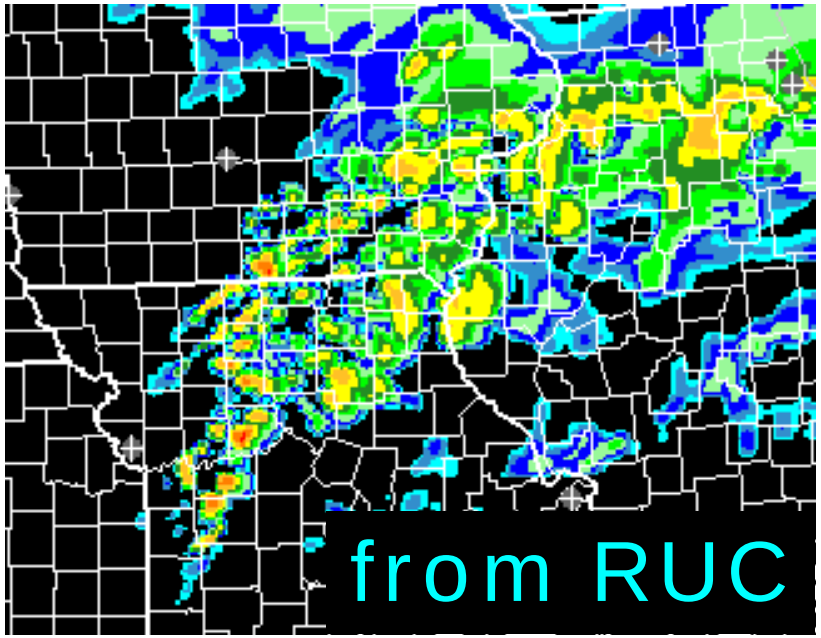
Spring 2011+

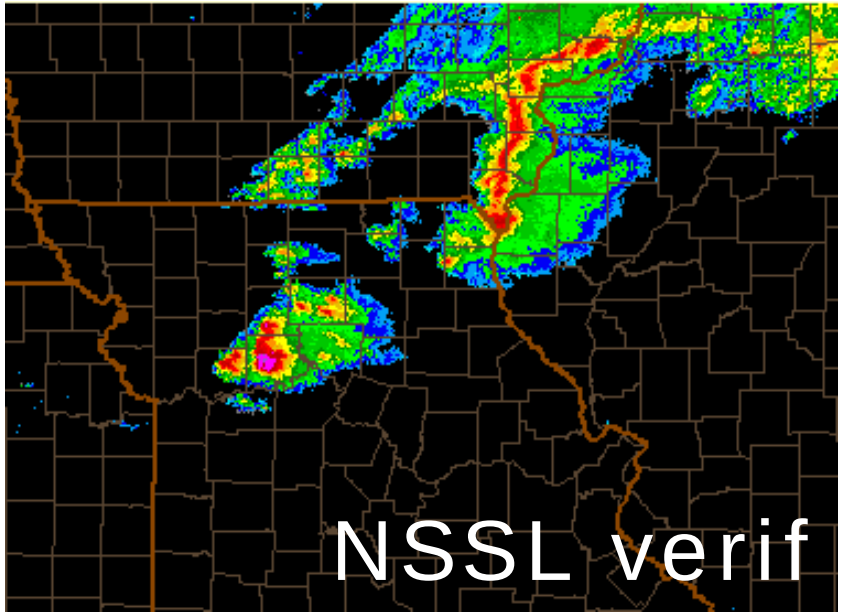
Add 2-way 1 km nests?
Domain expansion?
Parallel HRRR with different dynamic core and/or physics (the HIMM)?

HRRR Enhancement: Switch from RUC to RR initial/boundary conditions

1-h HRRR forecasts Valid 23z April 4, 2010

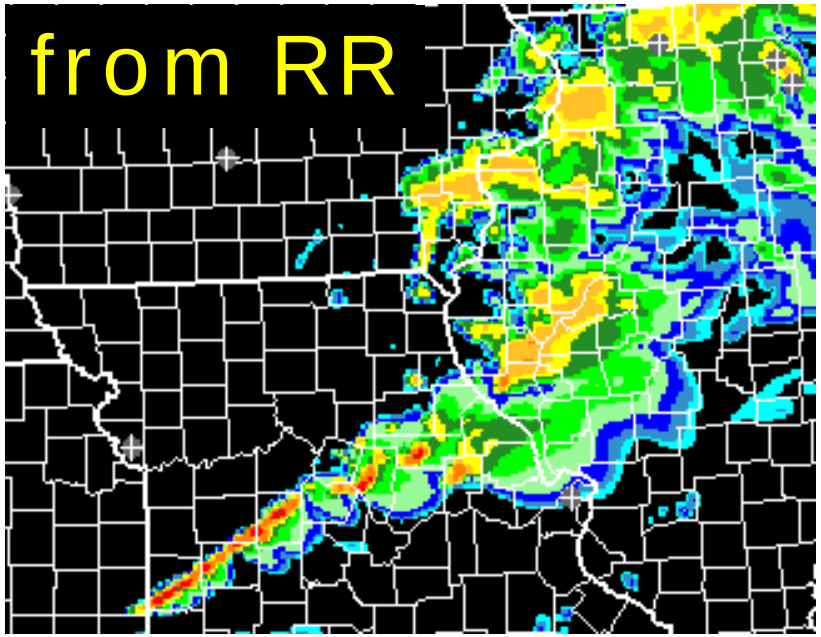


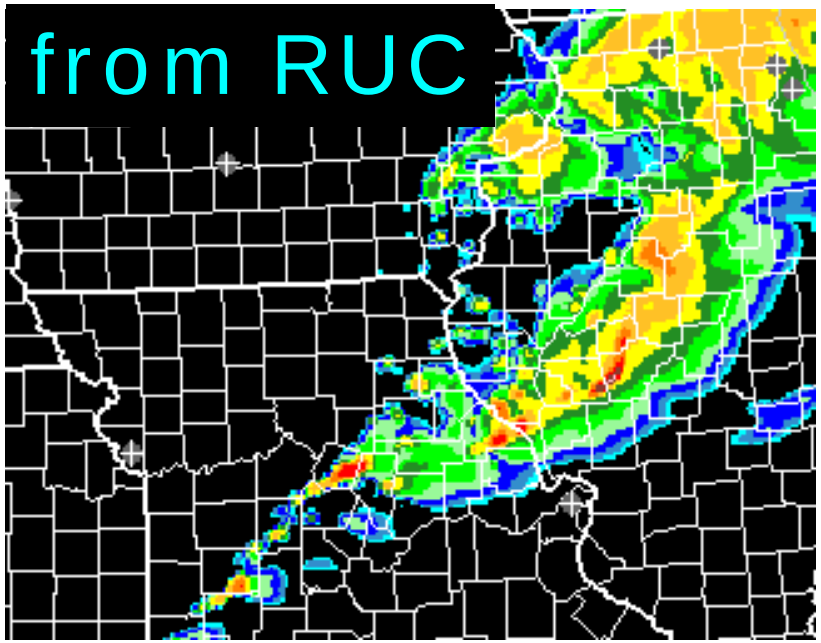


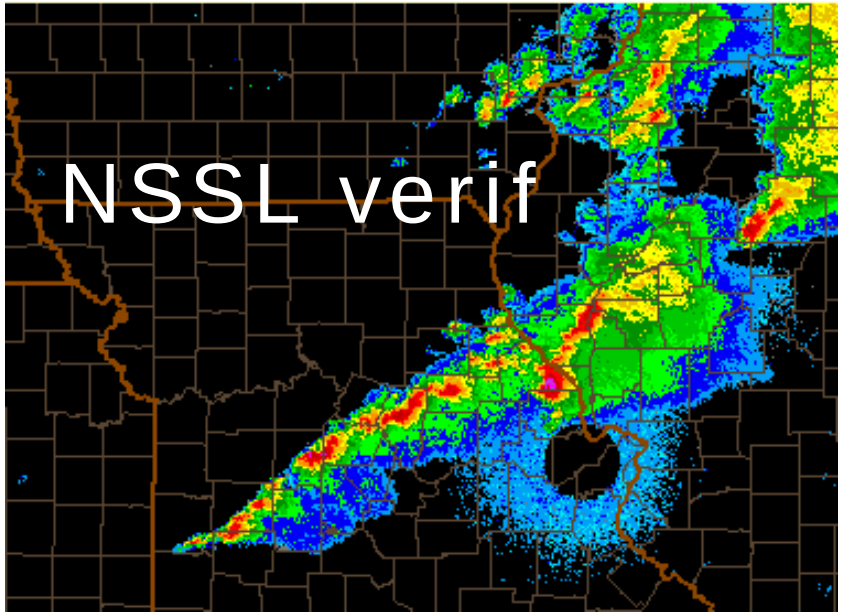


HRRR Enhancement: Switch from RUC to RR initial/boundary conditions

4-h HRRR forecasts Valid 02z April 5, 2010

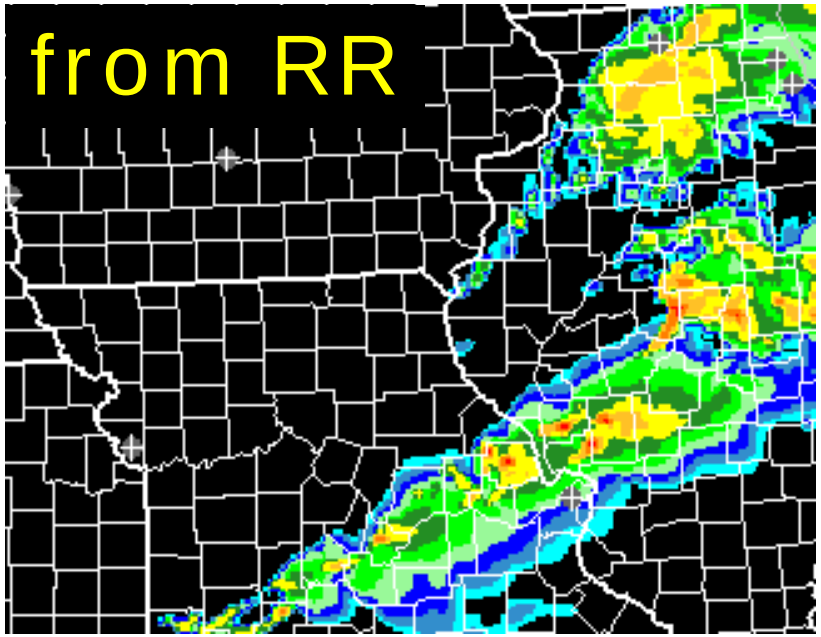


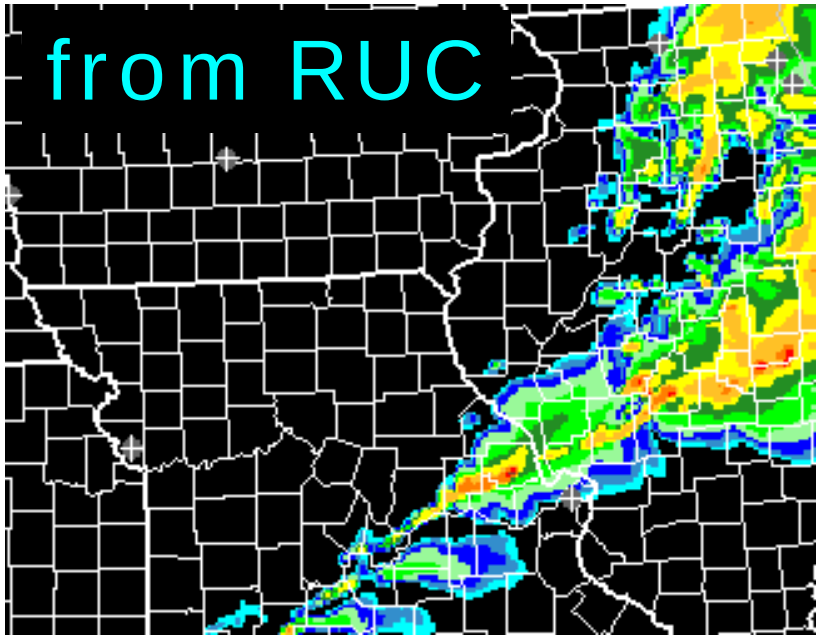


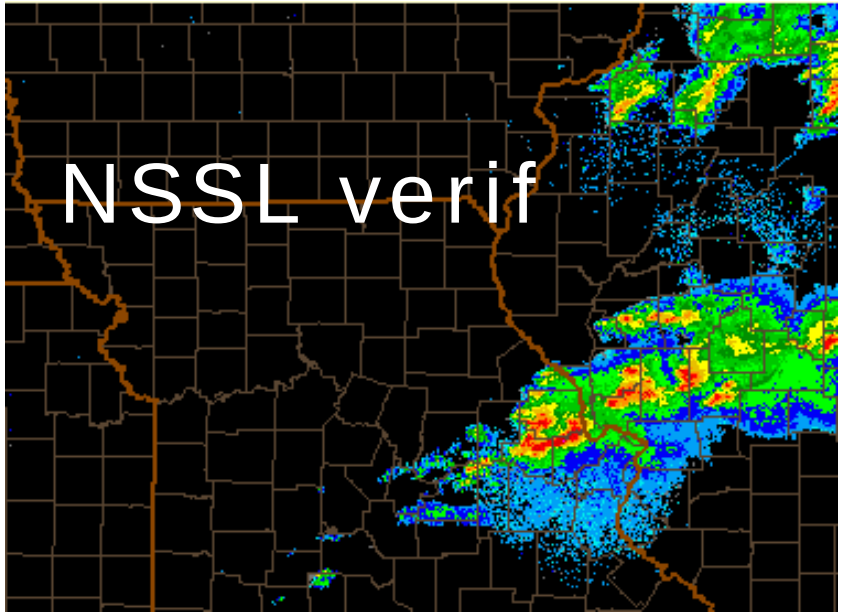


HRRR Enhancement: Switch from RUC to RR initial/boundary conditions

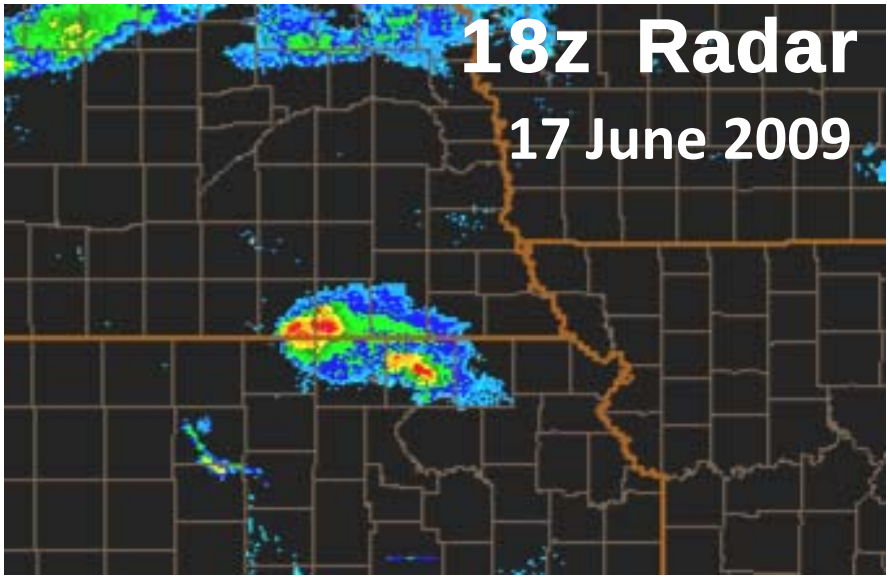
6-h HRRR forecasts Valid 04z April 5, 2010

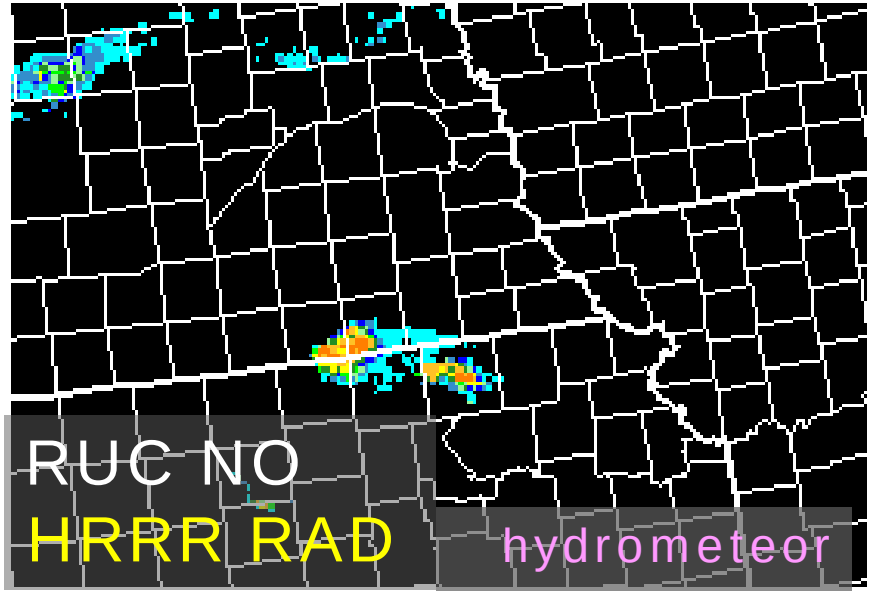




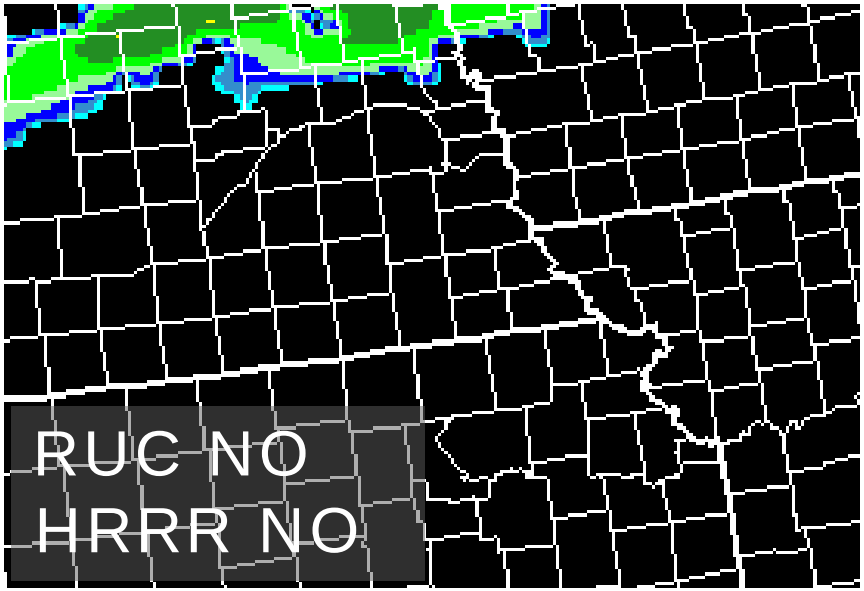


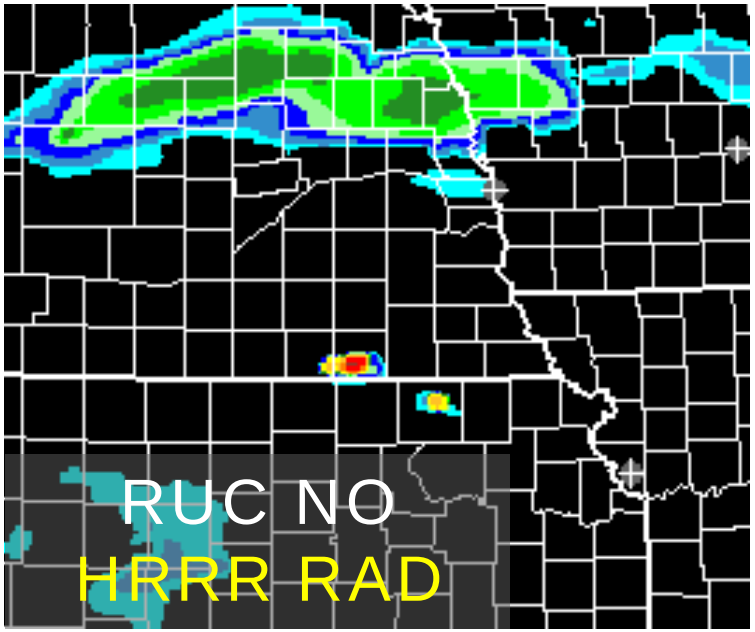
HRRR with RDA only on 3-km domain vs. no RDA



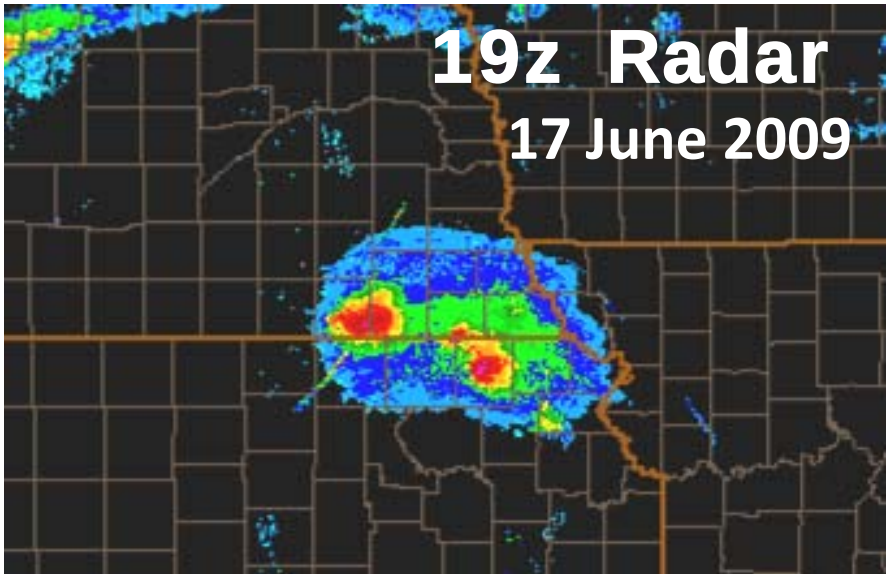


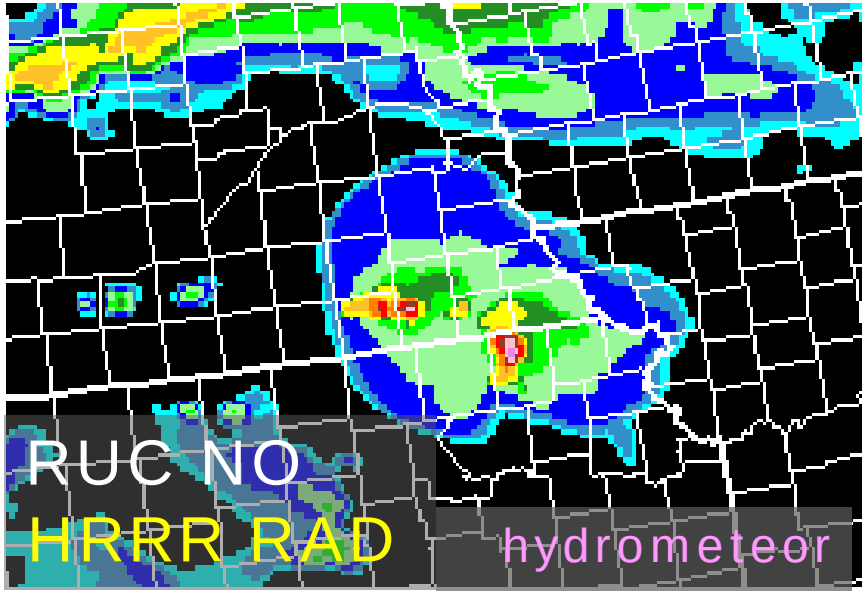
+ 0h fcsts



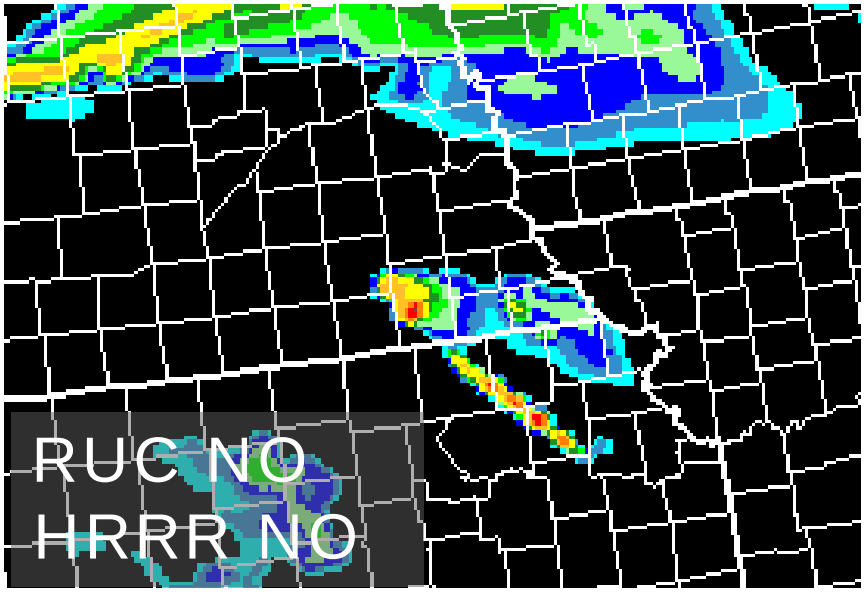


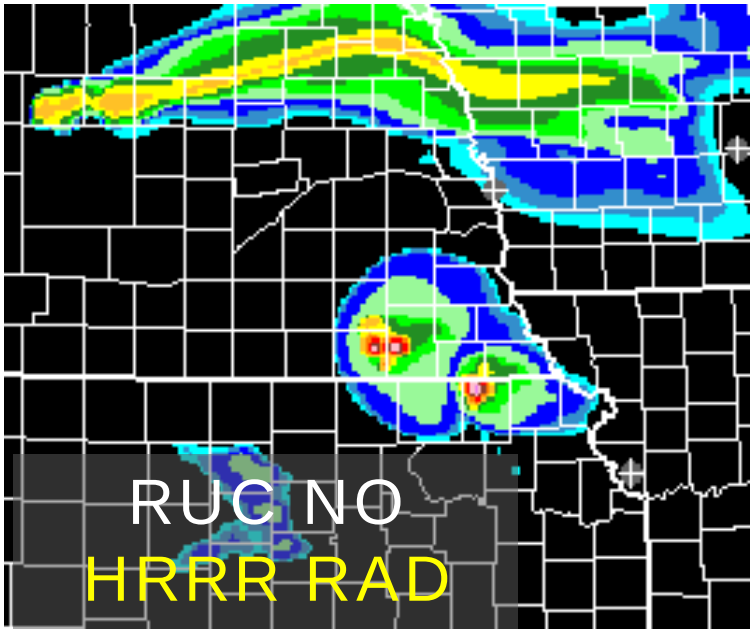
HRRR with RDA only on 3-km domain vs. no RDA



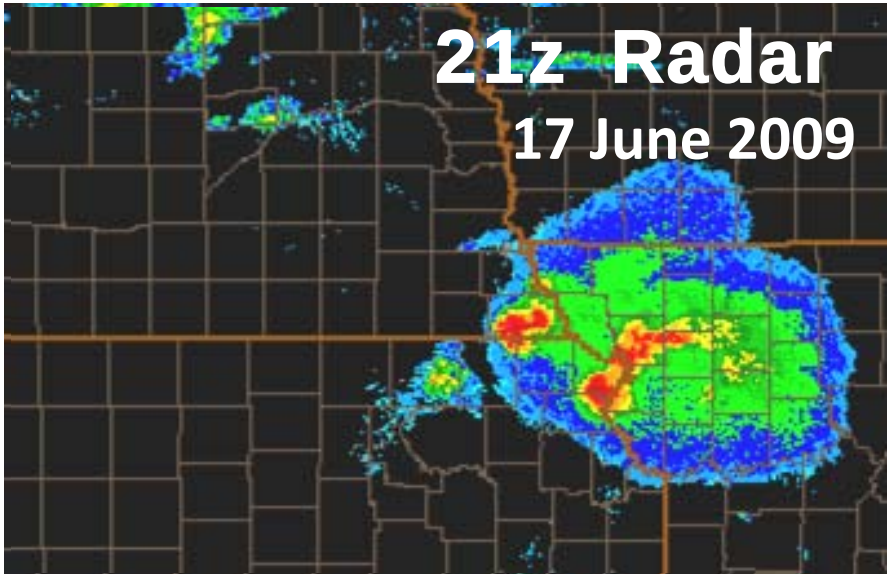


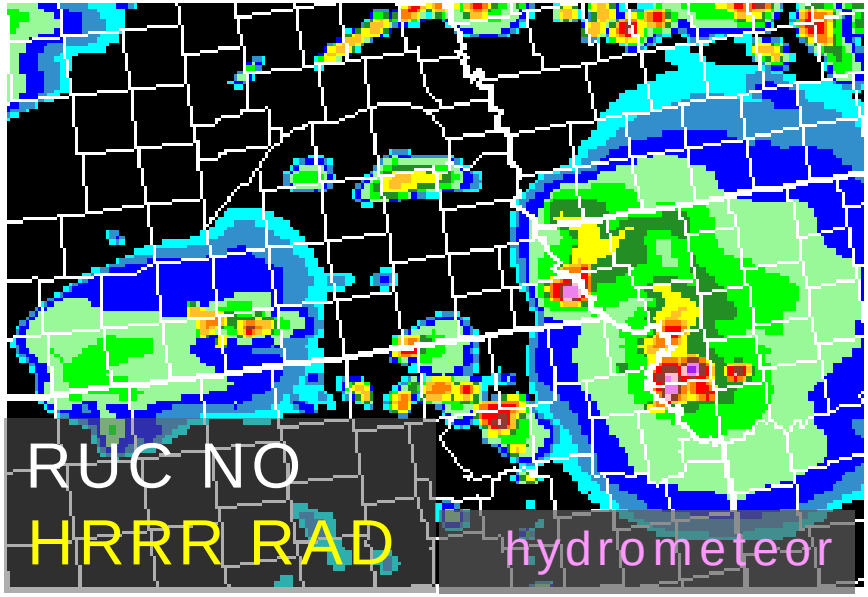
+ 1h fcsts





HRRR with RDA only on 3-km domain vs. no RDA





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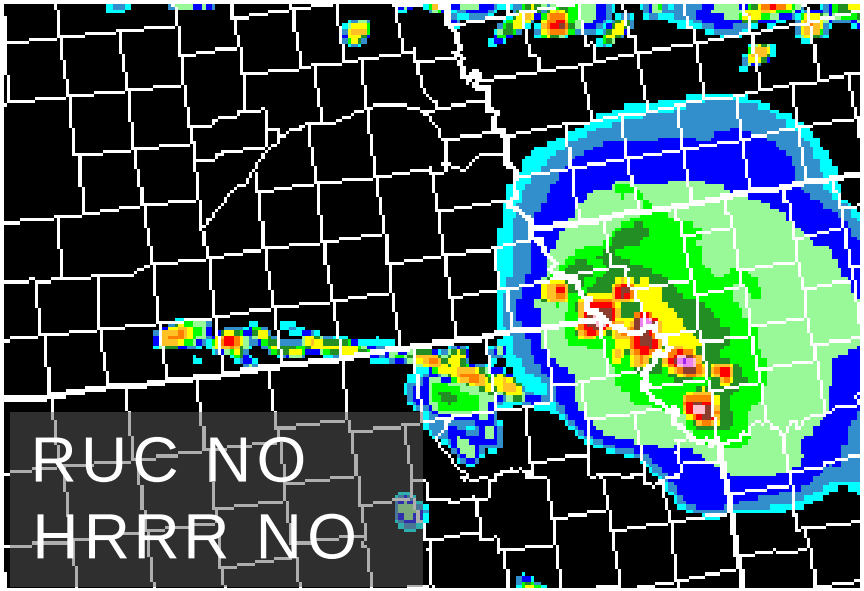

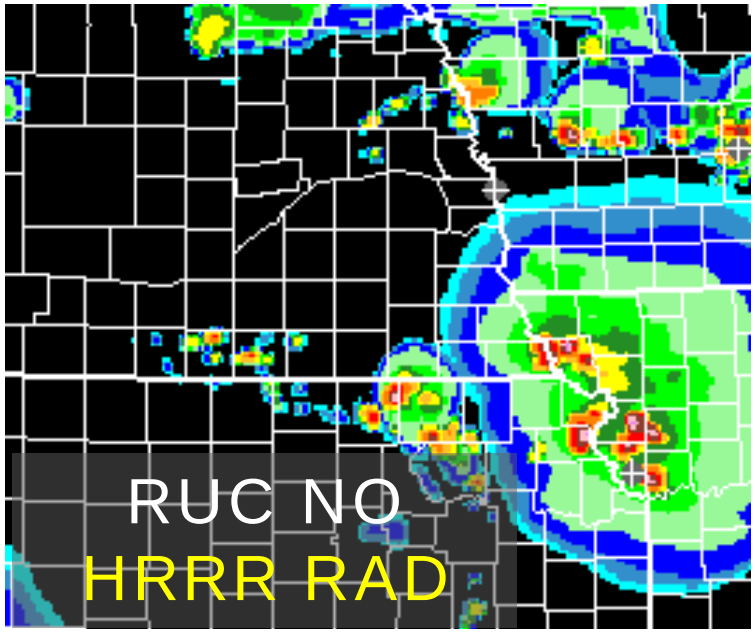

Summary

- Hourly-updating convection-resolving HRRR expanded to provide CONUS-wide forecasts at 3 km scale with a variety of users and applications in (severe) weather forecast, aviation, and renewable energy sectors

- HRRR forecasts shown to provide information of convective-scale structure and evolution not represented by lower-resolution models using parameterization

- HRRR scale-dependent forecast skill has improved through use of radar-assimilation from diabatic digital filter initialization via the RUC and soon RR

- HRRR can provide an estimate of the likelihood (probability), timing, and location of convection and other phenomena through a time-lagged "ensemble-of-opportunity"

- The implementation of 1-km two-way nesting will provide terminal-scale information for NextGen requirements and improve forecasts of convective evolution

- Additional convective forecast skill can be achieved through assimilation of radar and satellite observations within the HRRR at 3 km scale

Questions

Web Sites:

http://rapidrefresh.noaa.gov/hrrrconus/
http://ruc.noaa.gov/hcpf/hcpf.cgi

Curtis.Alexander@noaa.gov