11th WRF Users Workshop

24 June 2010

CIRES

The real-time Rapid Refresh (RR) and High Resolution Rapid Refresh (HRRR) forecast systems: Recent enhancements and evaluation activities

NOAA/ESRL/GSD

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Why have a Rapid UC or Rapid Refresh?

- Provide high-frequency (hourly) mesoscale analyses, short-range model forecasts
- Assimilate ("merge") all available observations into single, physically consistent 3-d grid such that forecasts are improved
- Initial focus on aviation enroute & surface weather:
  - Thunderstorms, severe weather, winter storms
  - Icing, ceiling and visibility, turbulence
  - Detailed surface temperature, dewpoint, winds
  - Upper-level winds
- Users:
  - aviation/transportation
  - severe weather forecasting
  - hydrology, renewable energy (load, availability)

"Situational Awareness Model"

Models at NOAA/ESRL/GSD/AMB

Model	Domain	Grid Points	Grid Spacing	Vertical Levels	Vertical Coordinate	Height Lowest Level	Pressure Top
RR	North America	648 x 647	13.5 km	50	Sigma	8 m	10 mb
RUC	CONUS	451 x 337	13.5 km	50	Sigma/ Isentropic	5 m	~50 mb
HRRR	CONUS	1799 x 1059	3.0 km	50	Sigma	8 m	85 mb

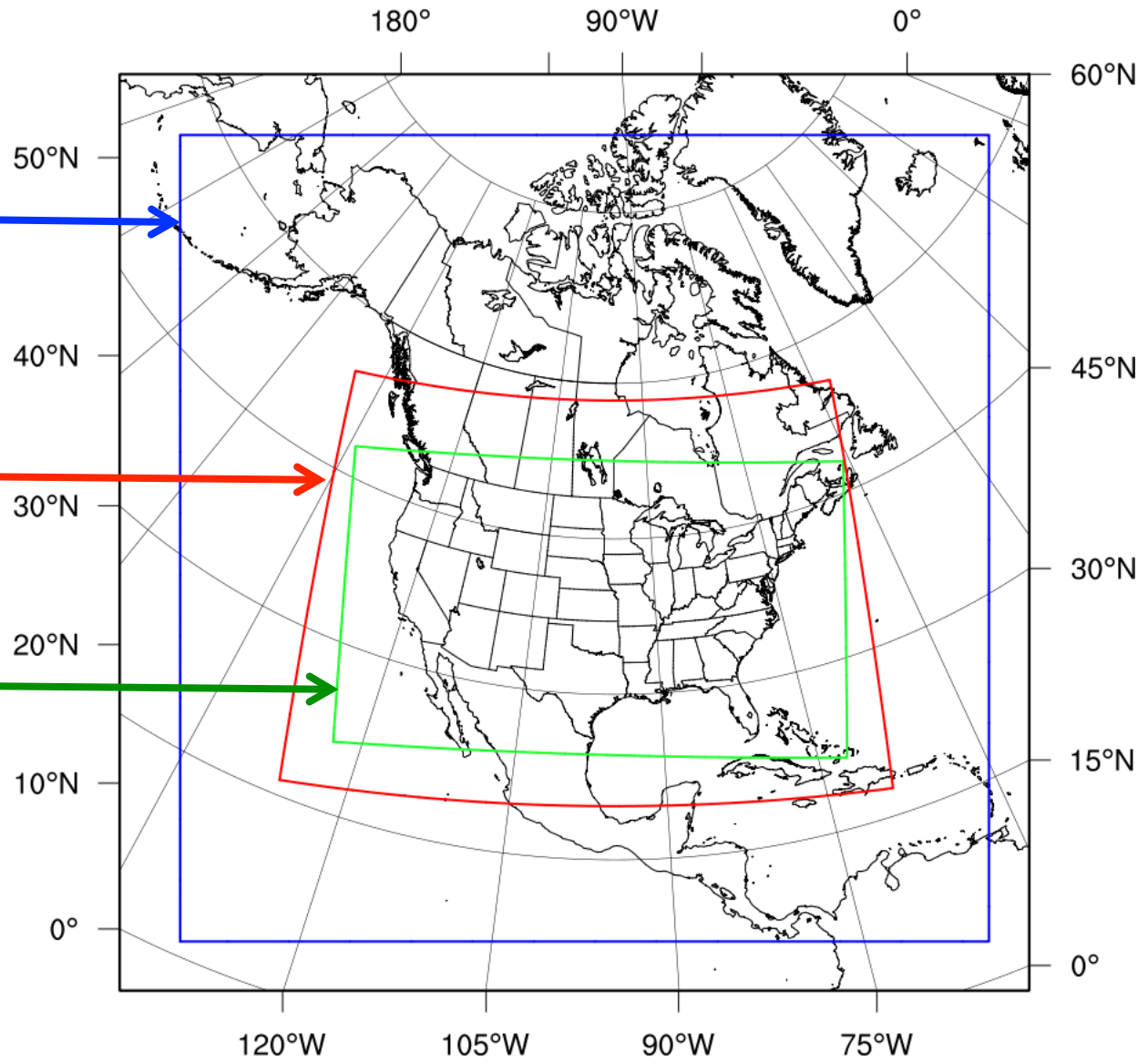
Model	Version	Time-Step	Forecast Period	Initialized	Boundary Conditions	Run Time	# of CPUs
RR	WRF-ARW 3.2	60 s	15 hrs (18 planned)	Hourly (cycled)	GFS	25 min	160
RUC	N/A	18 s	24 hrs (18 @NCEP)	Hourly (cycled)	NAM	50 min	32
HRRR	WRF-ARW 3.2	15-20s	15 hrs	Hourly (no-cycle)	RUC	50 min	1000

Current RR/RUC/HRRR Model Domains

RR (13 km)
648 x 647

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
RR	GSI	Yes w/radar	Thompson	RRTM/ Dudia	Grell-Devenyi	MYJ	RUC
RUC	RUC-3DVAR	Yes w/radar	Thompson	RRTM/ Dudia	Grell-Devenyi	MYJ	RUC
HRRR	None: RUC I.C.	No	Thompson	RRTM/ Dudia	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:

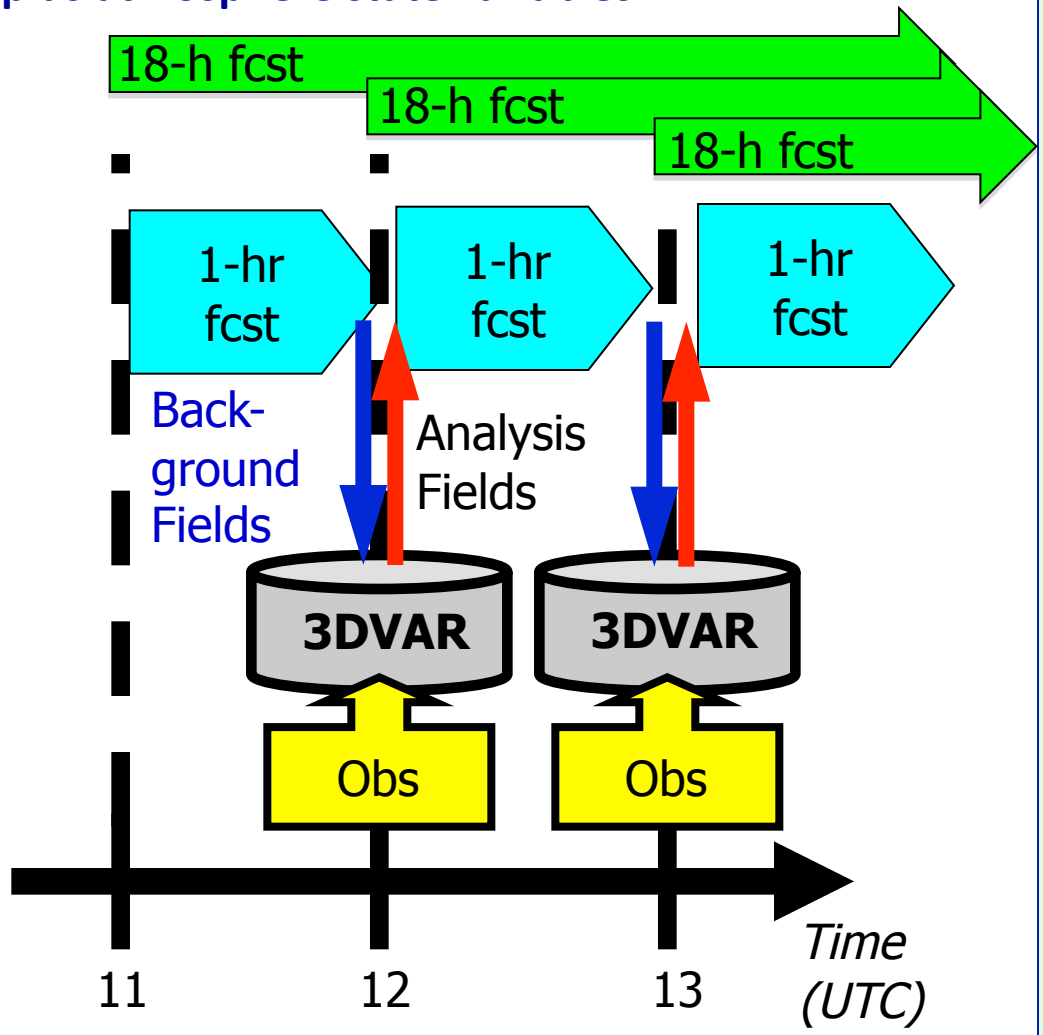
- Specify/clear hydrometeors (rain, snow, graupel)
- Establish 3-D radar temperature tendency (latent heating)
- Apply diabatic digital filter initialization (DDFI)

RUC to Rapid Refresh

- **CONUS domain (13km)** → **North American domain (13km)**
- **RUC 3DVAR** → **GSI (Gridpoint Statistical Interpolation)** (incl. RR enhancements)
- **RUC model + postprocessing** → **WRF-ARW model (RR version) + unipost (with enhancements)**

RUC/Rapid Refresh Hourly Assimilation Cycle

Cycle hydrometeor, soil temp/moisture/snow plus atmosphere state variables

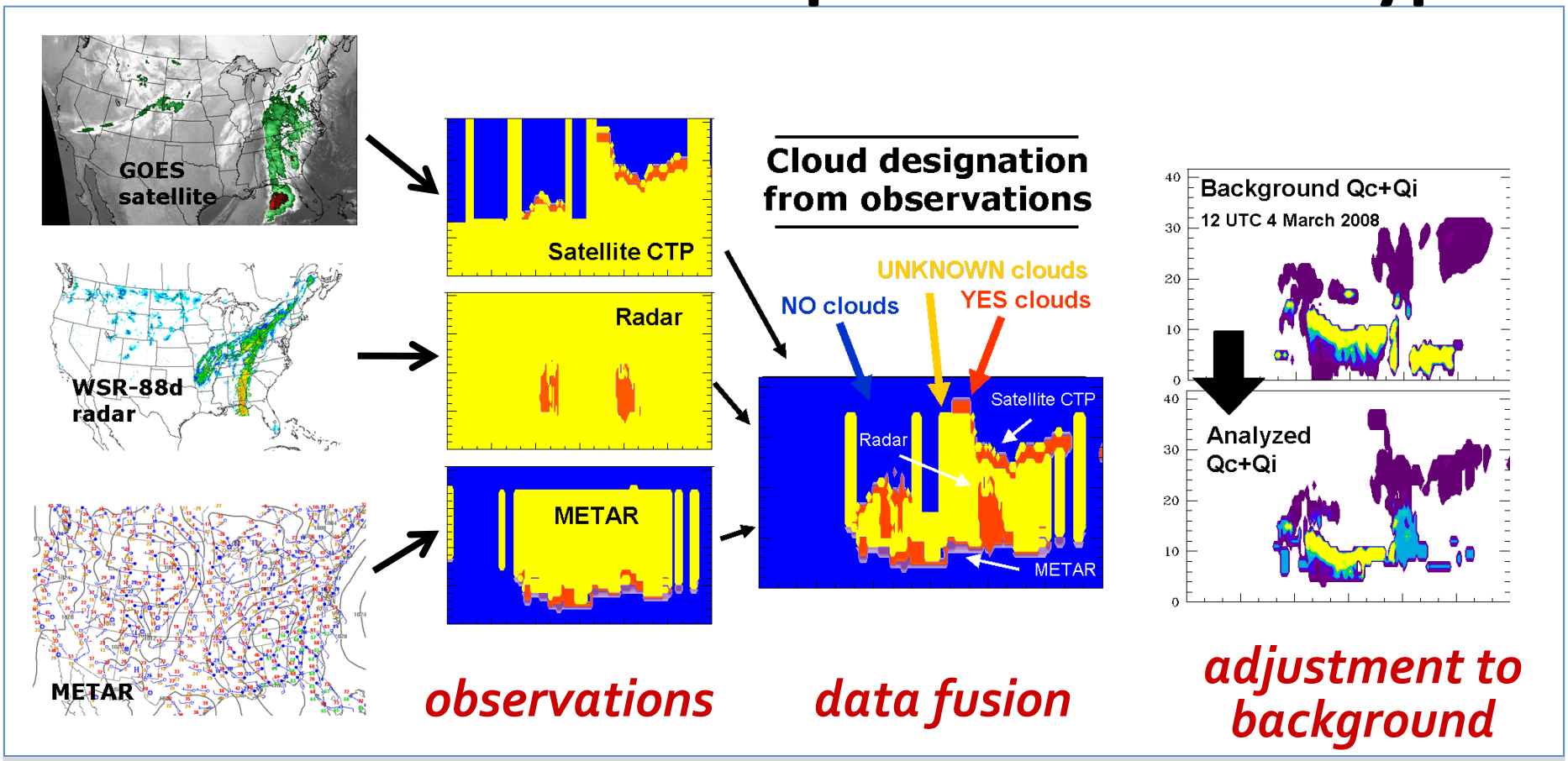


Hourly obs

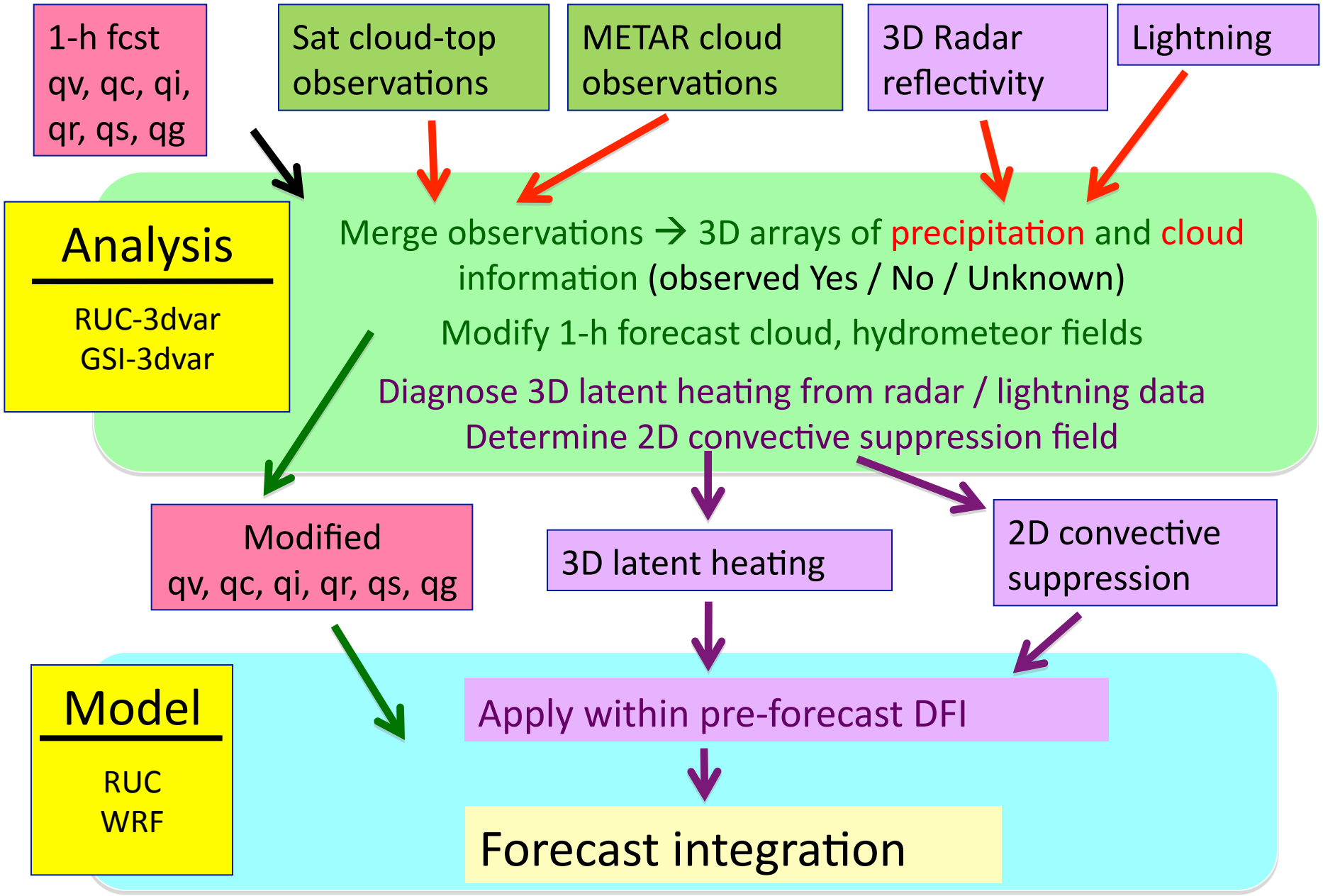
Data Type	~Number
Rawinsonde (12h)	150
NOAA profilers	35
VAD winds	120-140
PBL – prof/RASS	~25
Aircraft (V,temp)	3500-10000
TAMDAR (V,T,RH) *	200-3000
Surface/METAR	2000-2500
Buoy/ship	200-400
GOES cloud winds	4000-8000
GOES cloud-top pres	10 km res
GPS precip water	~300
Mesonet (temp, dpt)	~8000
Mesonet (wind)	~4000
METAR-cloud-vis-wx	~1800
AMSU-A/B/GOES radiances – *RR only*	
Radar reflectivity/ lightning 1km	

Cloud and Hydrometeor Analysis

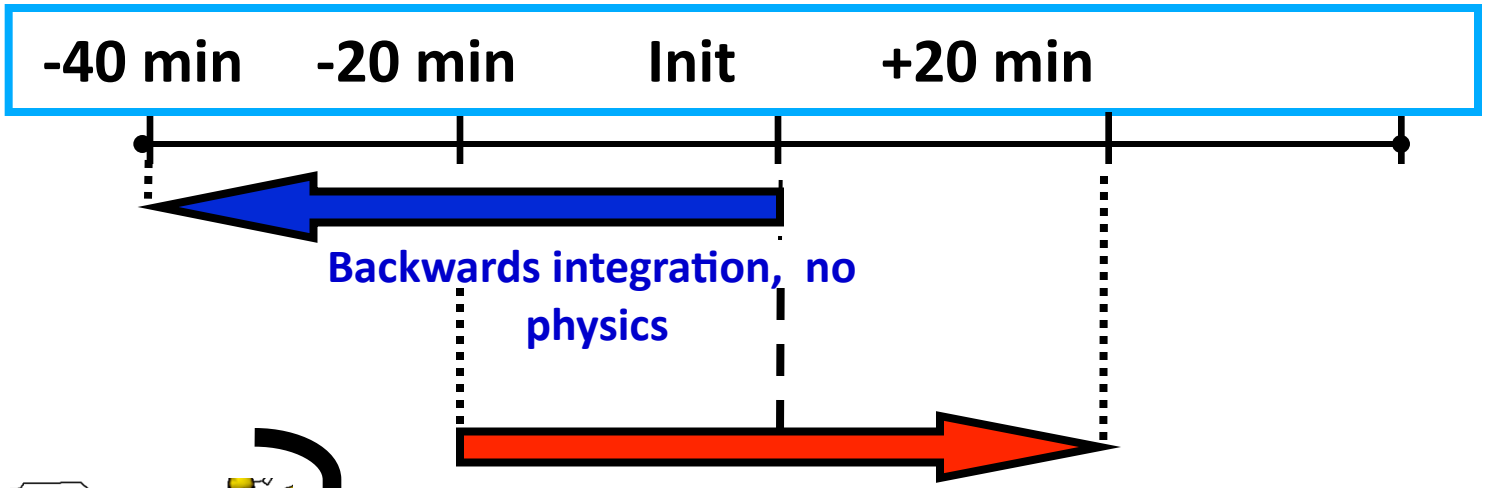
Incremental adjustment based on information from multiple observation types

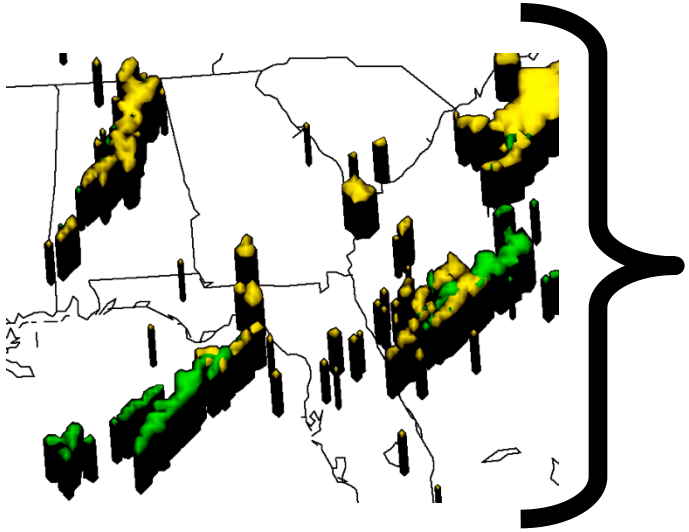


RUC/RR cloud / radar assimilation flowchart



Diabatic Digital Filter Initialization (DDFI)





Forward integration, full physics

Apply latent heating from radar reflectivity, lightning data

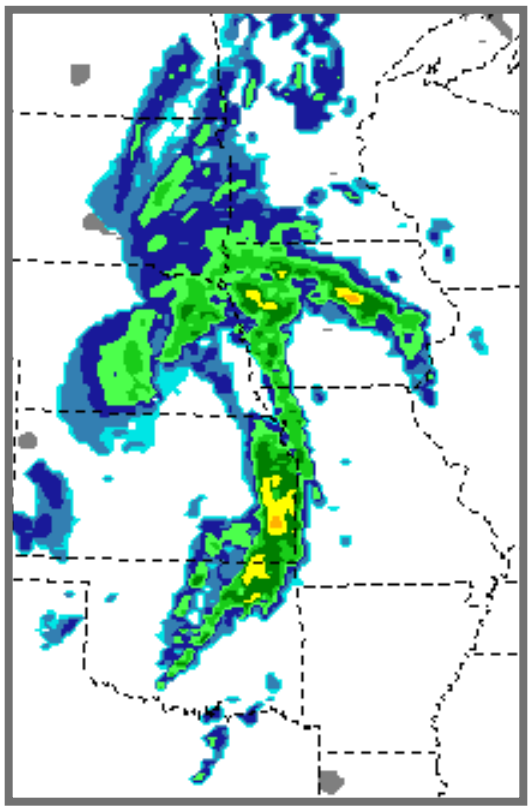
Obtain initial fields with improved balance, vertical circulations associated with ongoing convection

RUC/RR model forecast

Radar reflectivity assimilation in RUC and Rapid Refresh

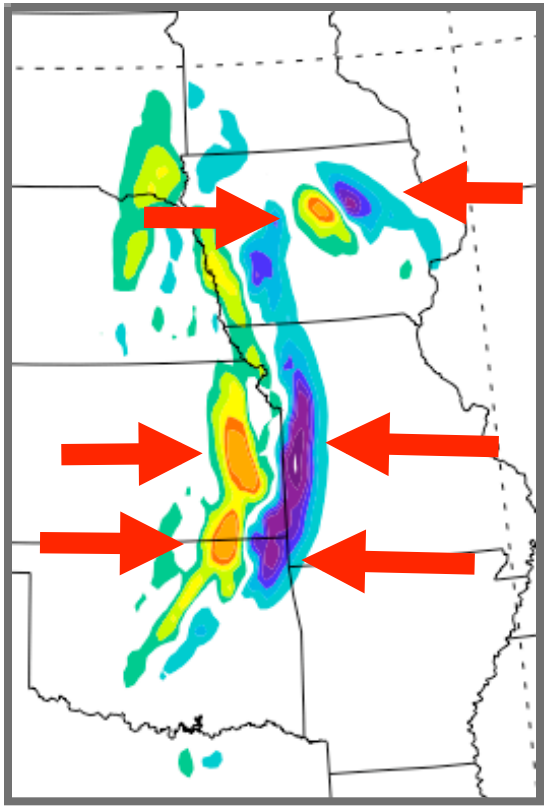
Rapid Refresh (GSI + ARW)
reflectivity assimilation example

NSSL radar reflectivity (dBZ)



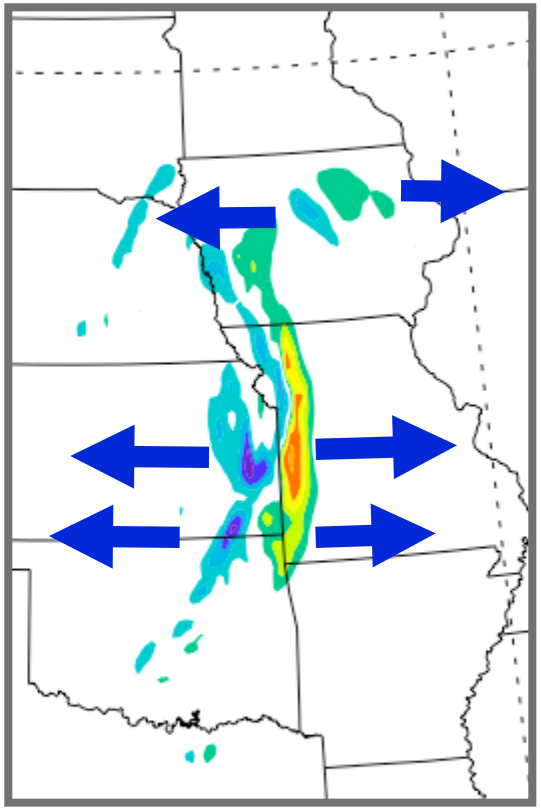
14z 22 Oct 2008
Z = 3 km

Low-level Convergence

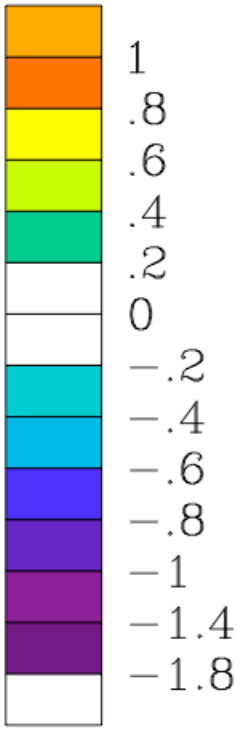


K=4 U-comp. diff
(radar - norad)

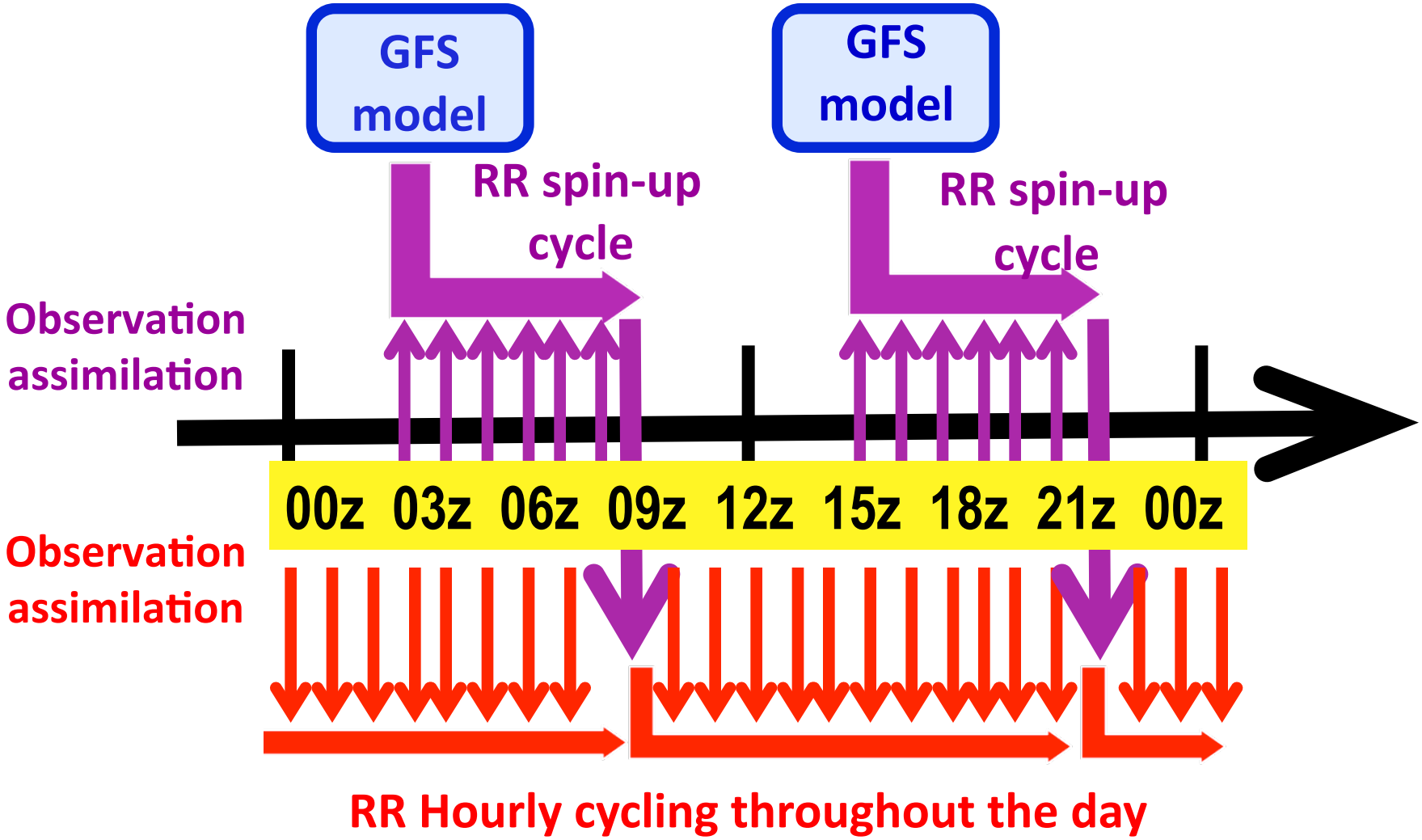
Upper-level Divergence



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



Rapid Refresh Partial Cycling



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

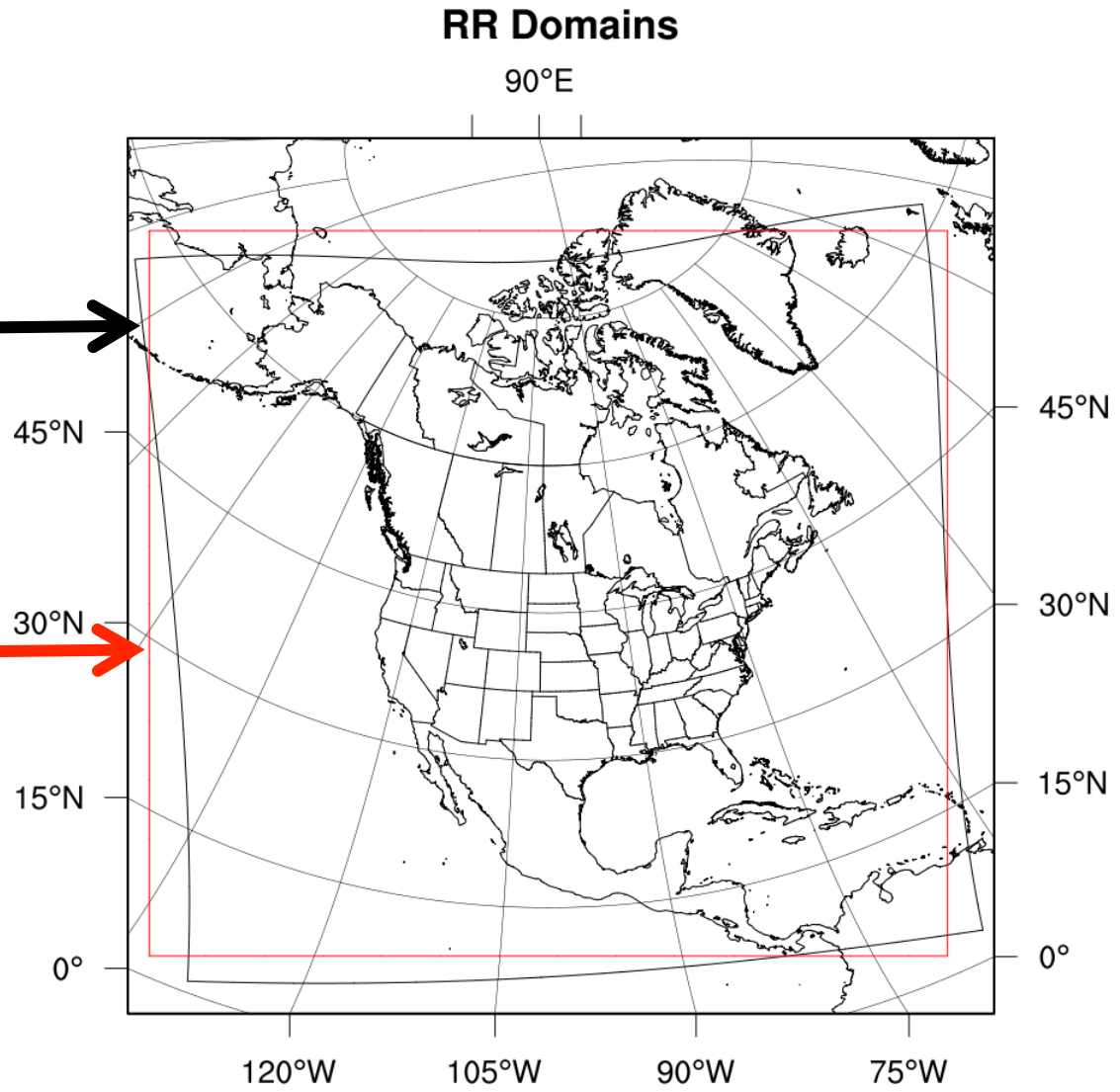
Domain

Horizontal coordinate / grid projection

- Current - Lambert Conformal - 649 x 648 grid points (420,552 pts)
- Likely switch to rotated lat-lon – 669 x 608 grid points (406,752 pts)

Current Lambert

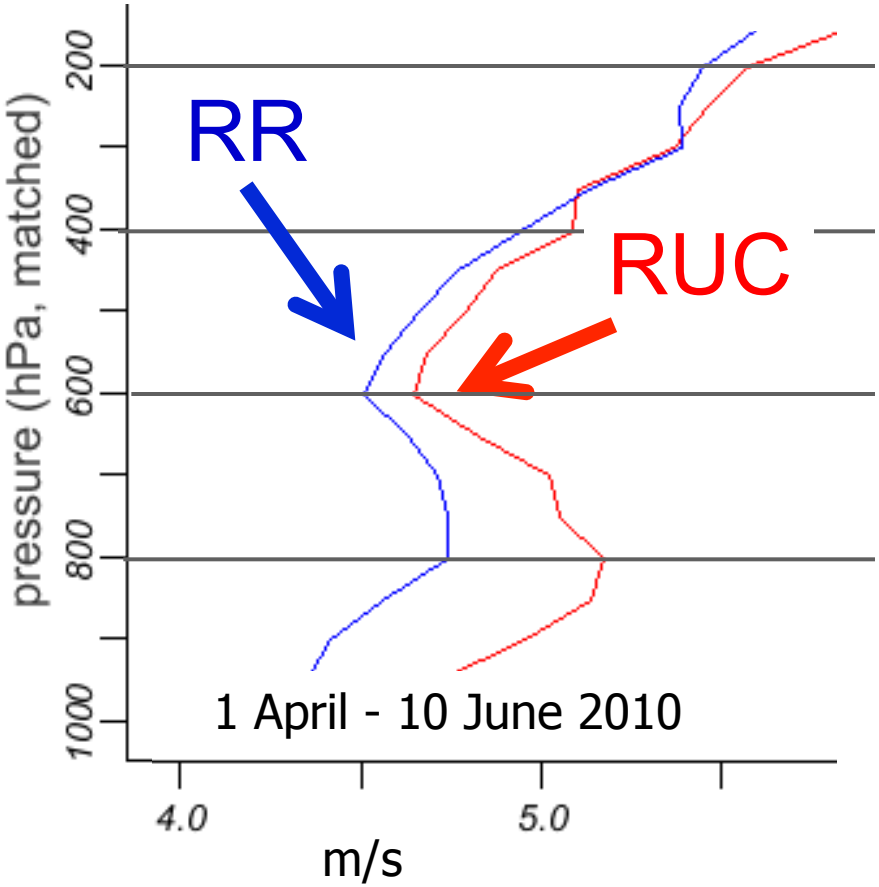
Future rotated lat-lon



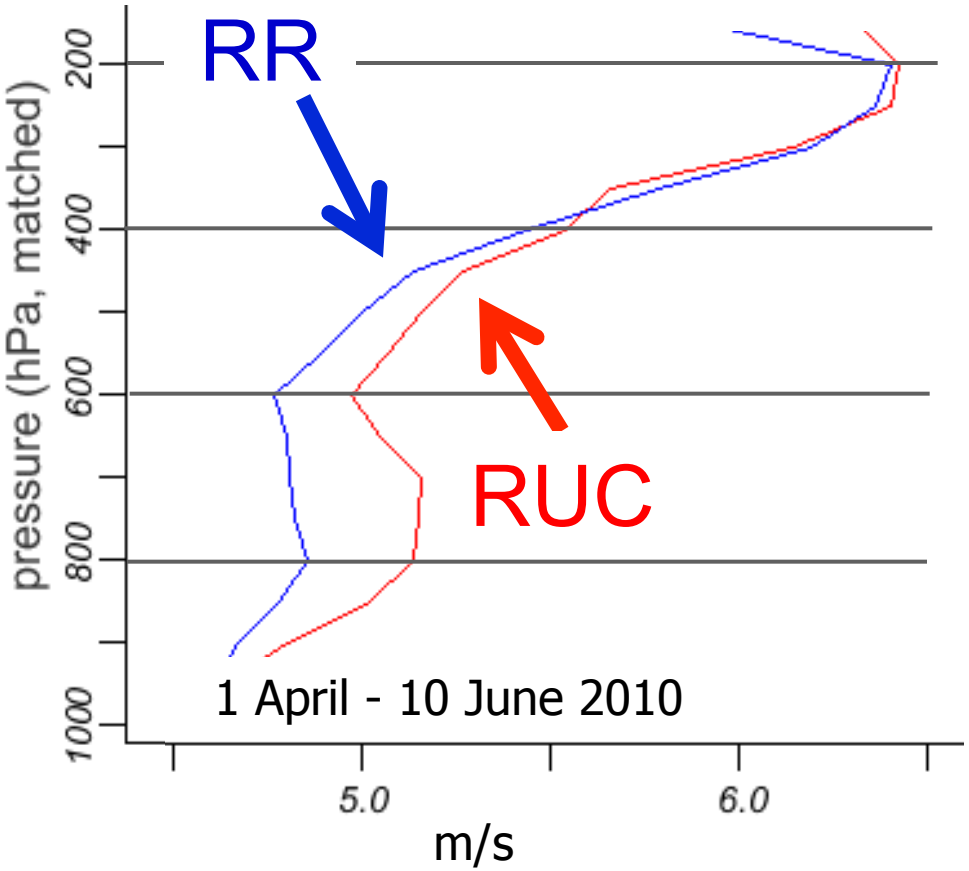
Rapid Refresh upper-air verification

vector wind RMS error

3-h fcst



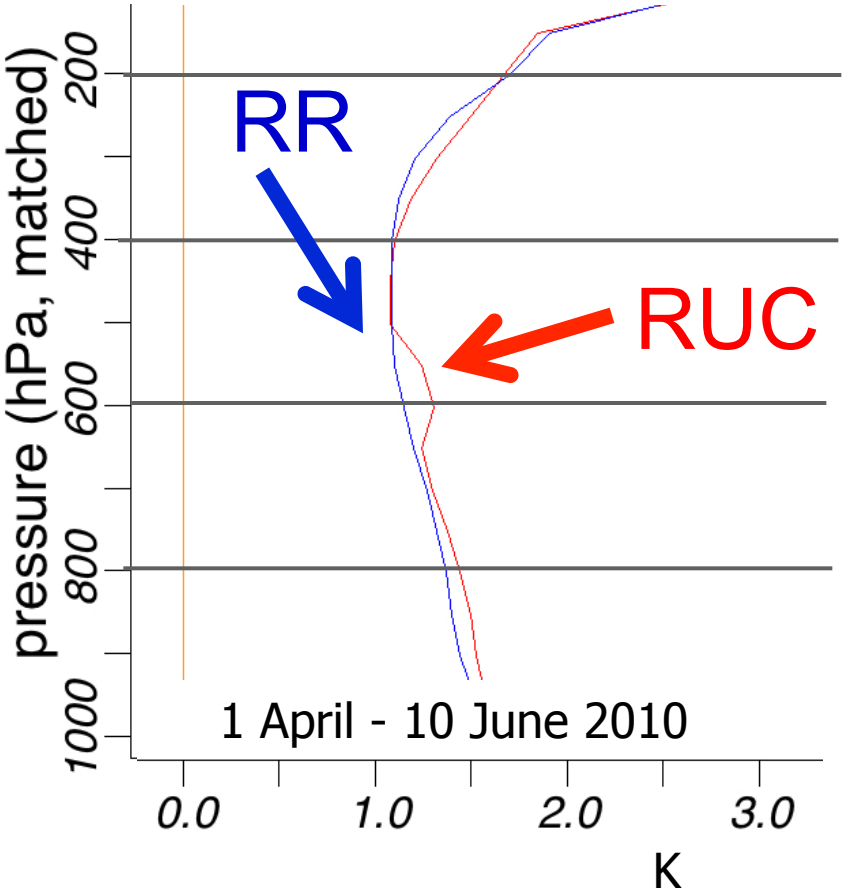
12-h fcst



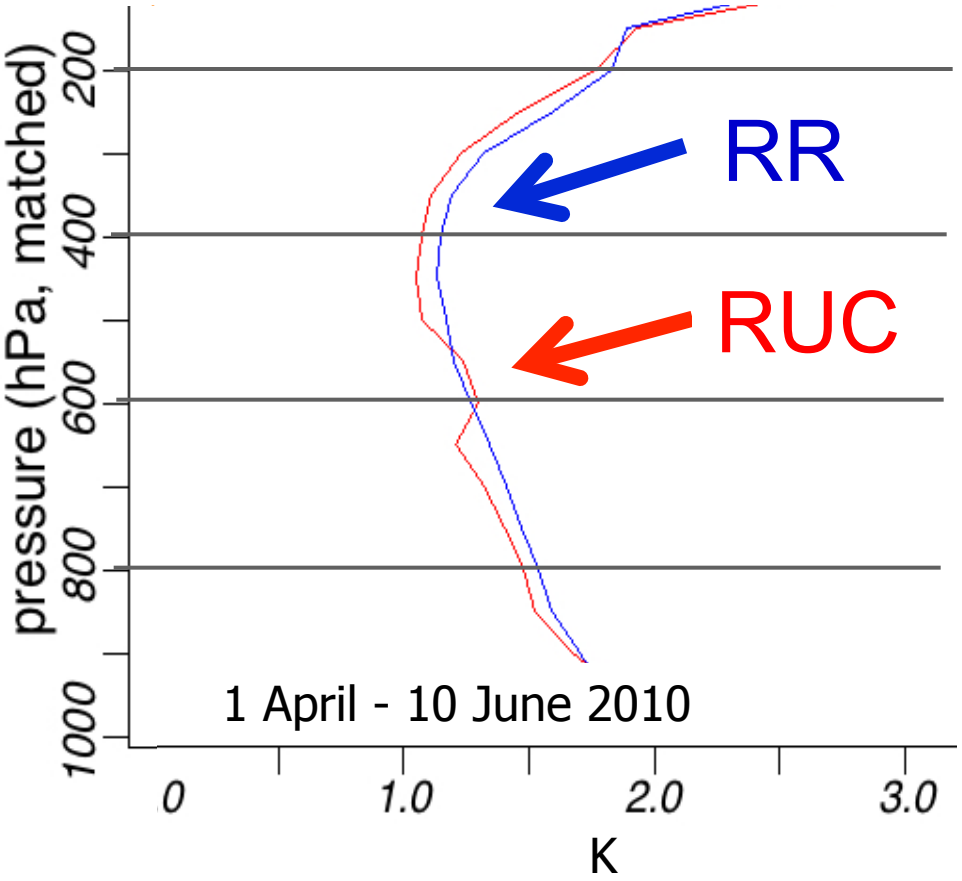
Rapid Refresh upper-air verification

Temperature RMS error

3-h fcst

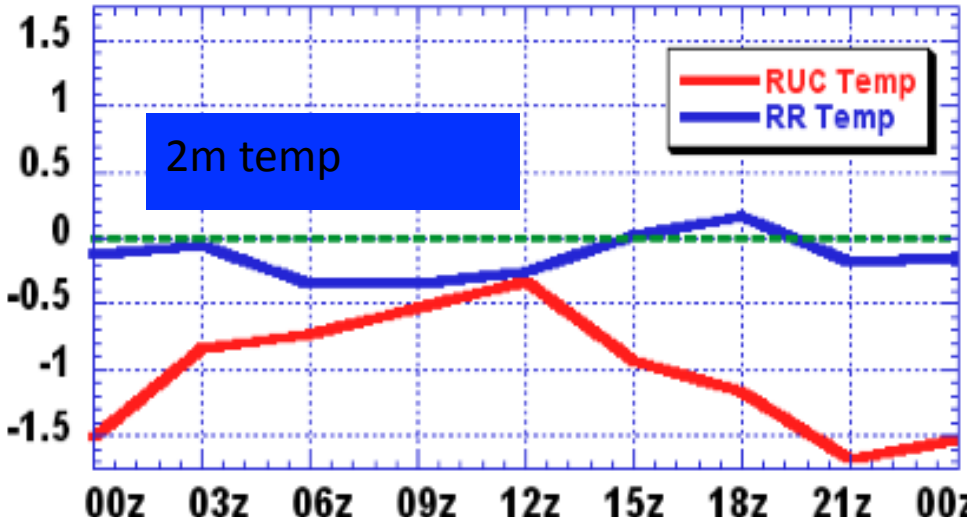


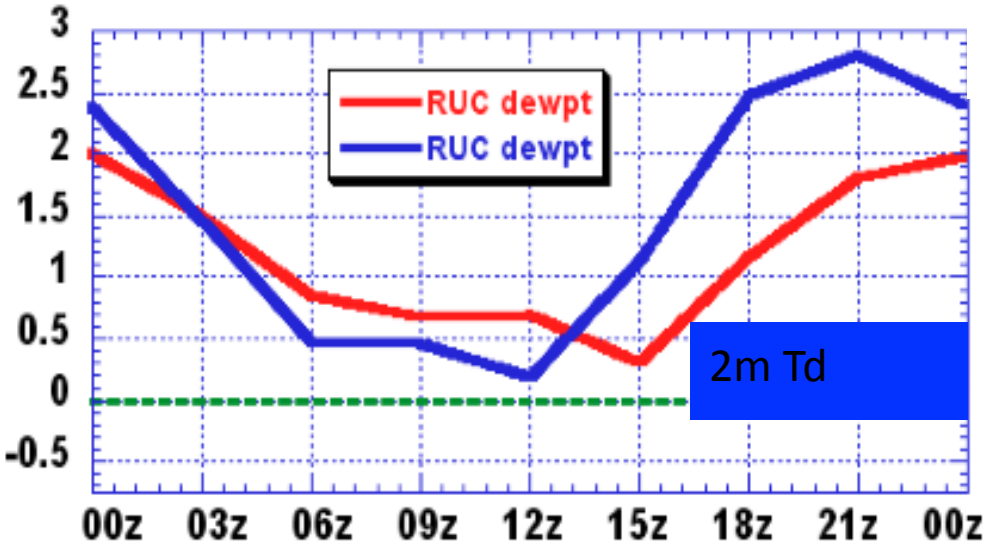
12-h fcst

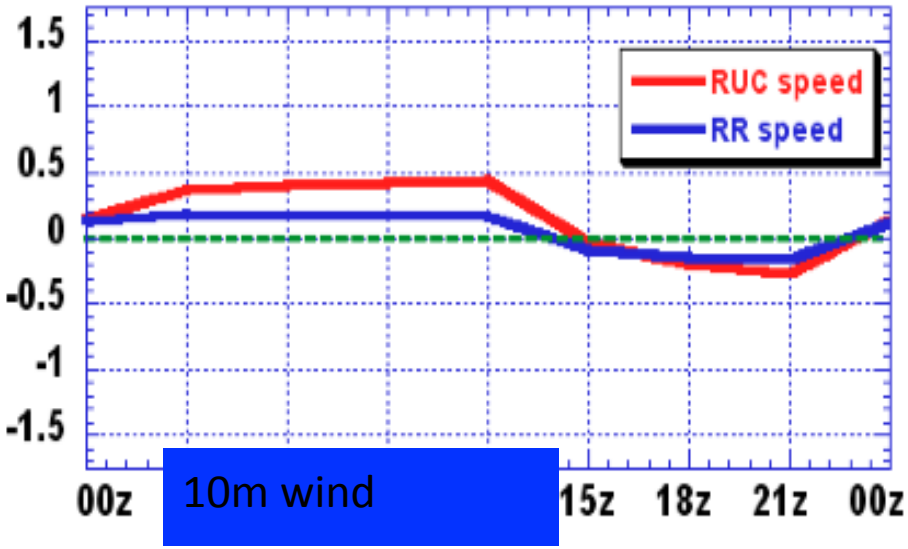


Surface bias – 6h fcst – RR vs. RUC

- March-April 2010







Warm 2m temp bias in RUC, none in RR

Daytime Td moist bias in both RR and RUC,
no bias in RR winds

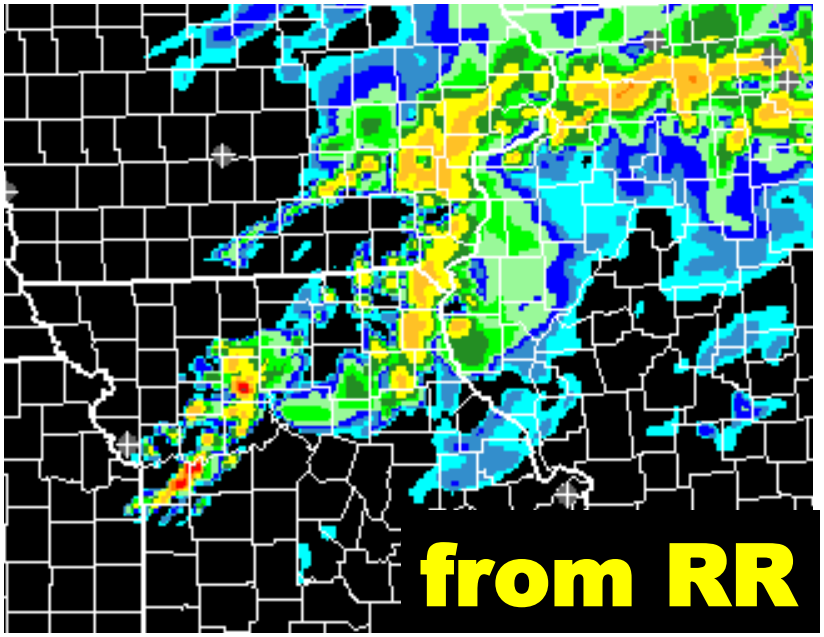
Rapid Refresh Implementation Update

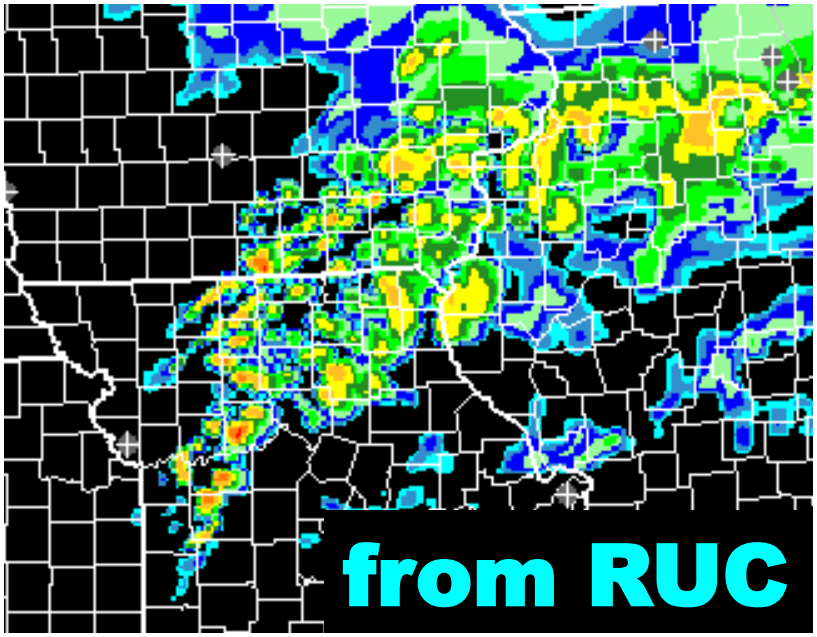
More updates to Rapid Refresh configuration

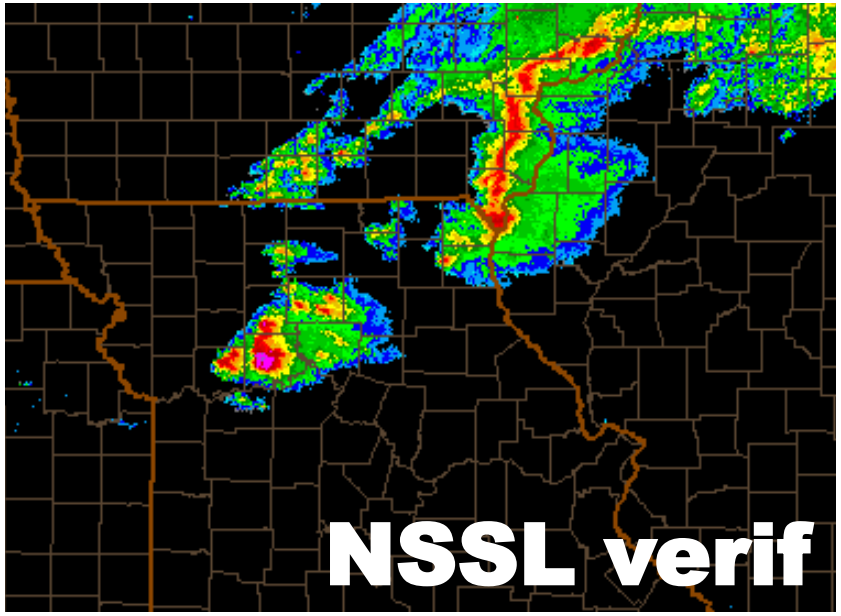
- Switch to unipost (NCEP post code to be used for all models) from WRFpost (similar code), change consistent with NCEP plans
- Updated RR to more detailed IMS snow/ice data (instead of coarser snow data via GFS)
- Testing of addition of shallow convection to G3 convective scheme, now using WRFv3.2 for Thompson microphysics
- Final modifications to GSI hydrometeor/cloud/radar treatment (e.g., remove radar-related moistening)
- Implementation at NCEP currently scheduled for Q2 2011

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

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

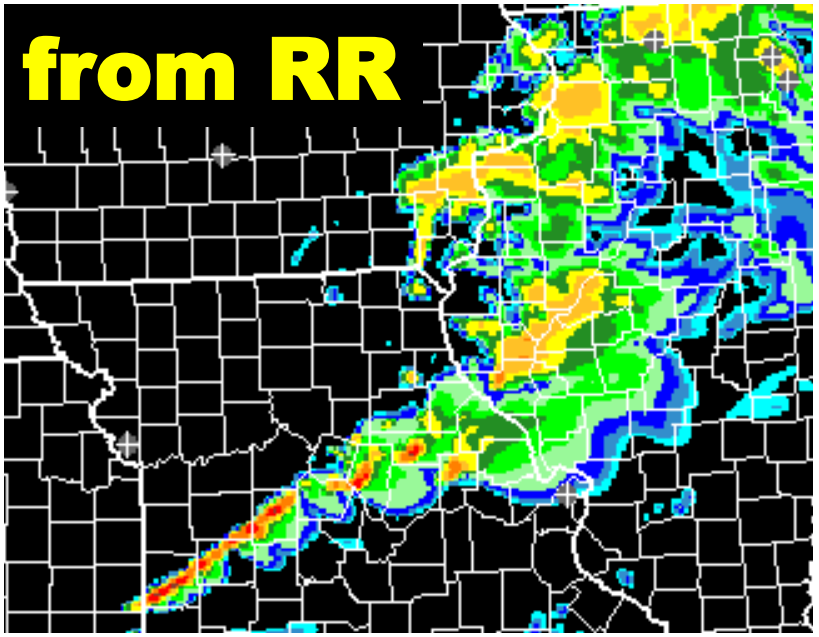


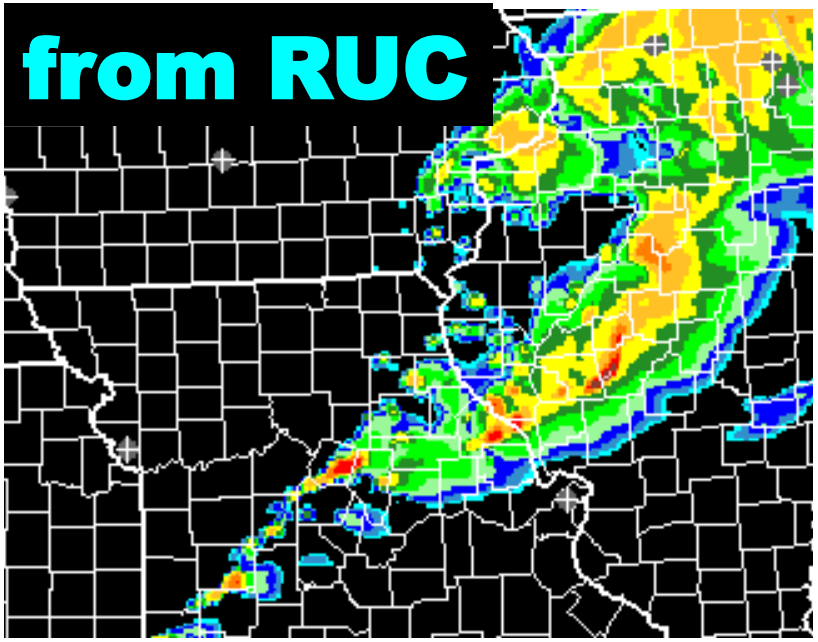


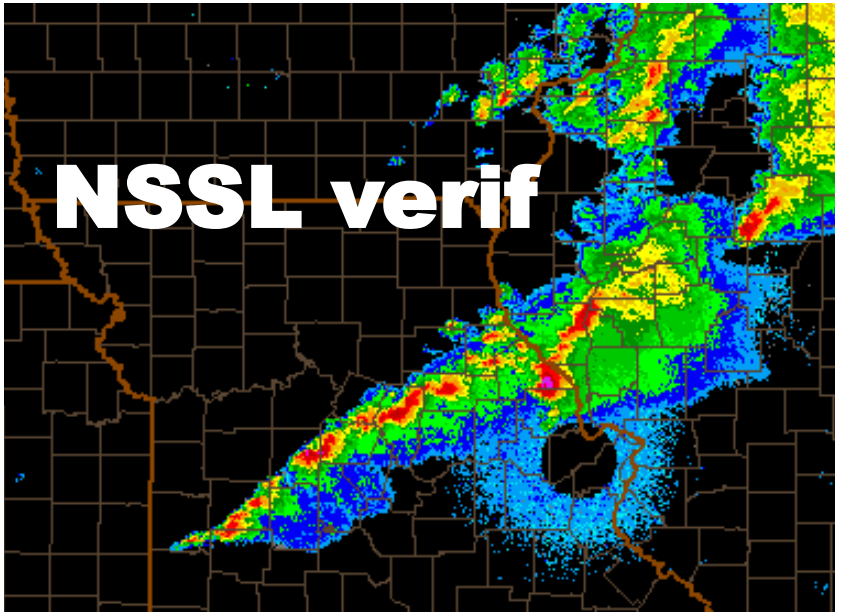


HRRR Enhancement: Switch from RUC to RR initial/boundary conditions

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

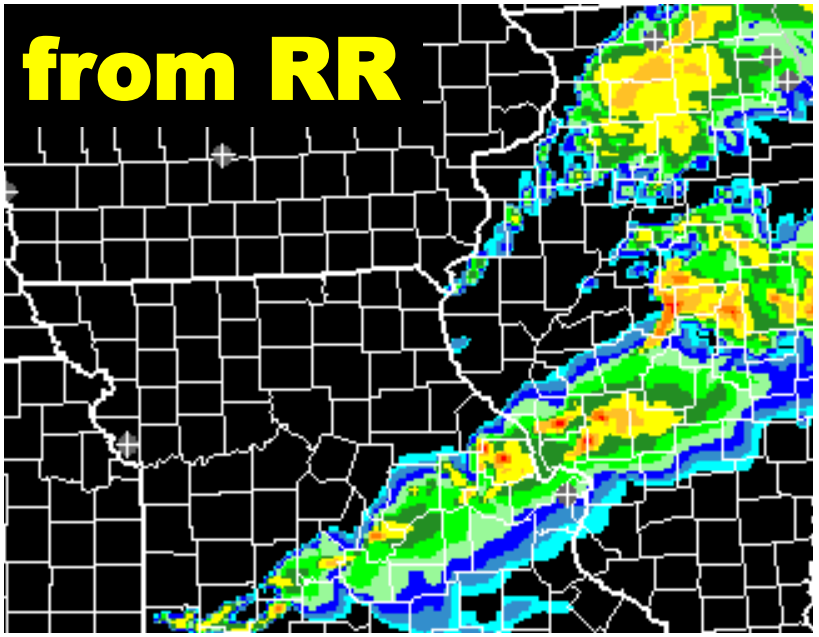


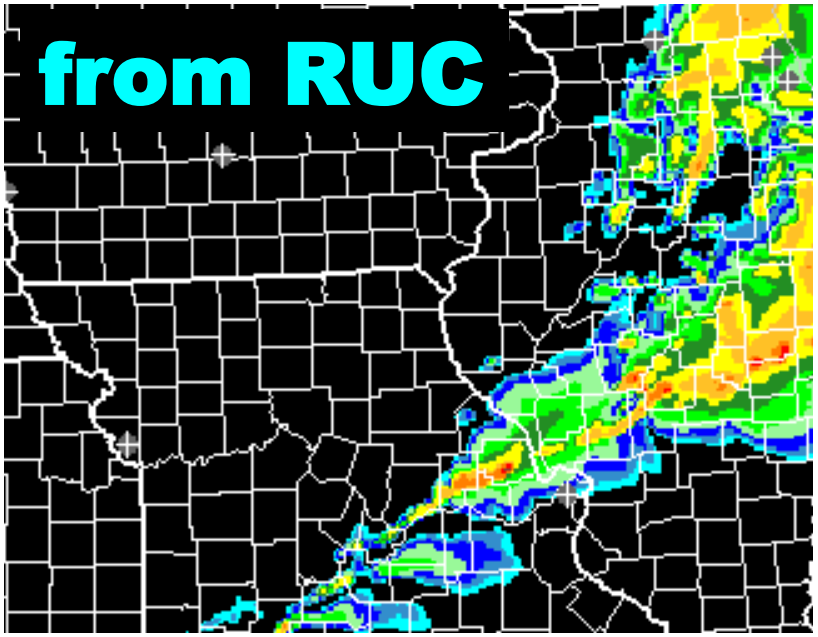


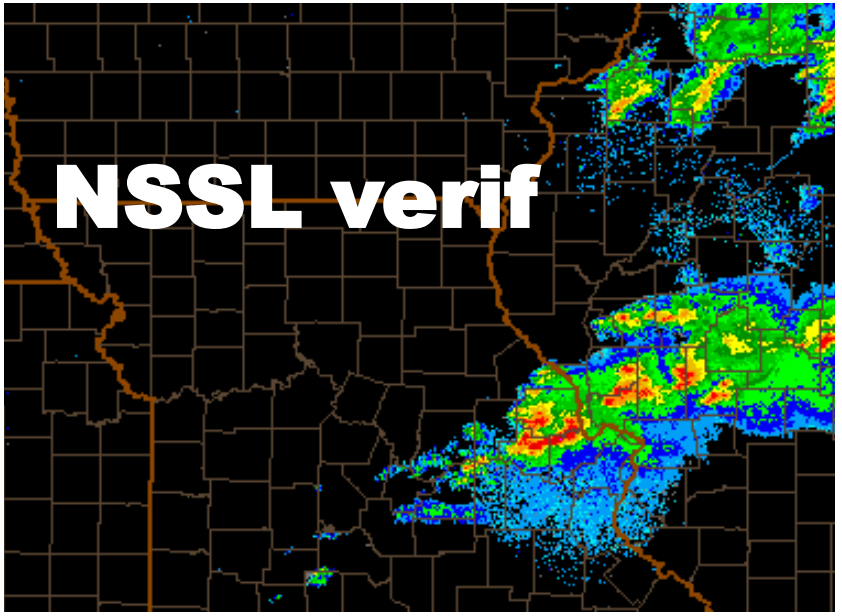


HRRR Enhancement: Switch from RUC to RR initial/boundary conditions

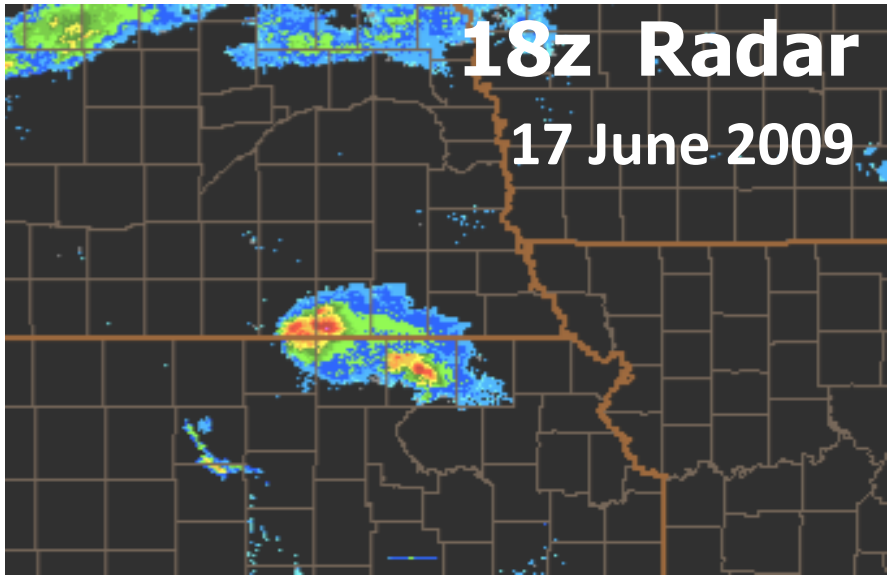
6-h HRRR forecasts Valid 04z April 5, 2010

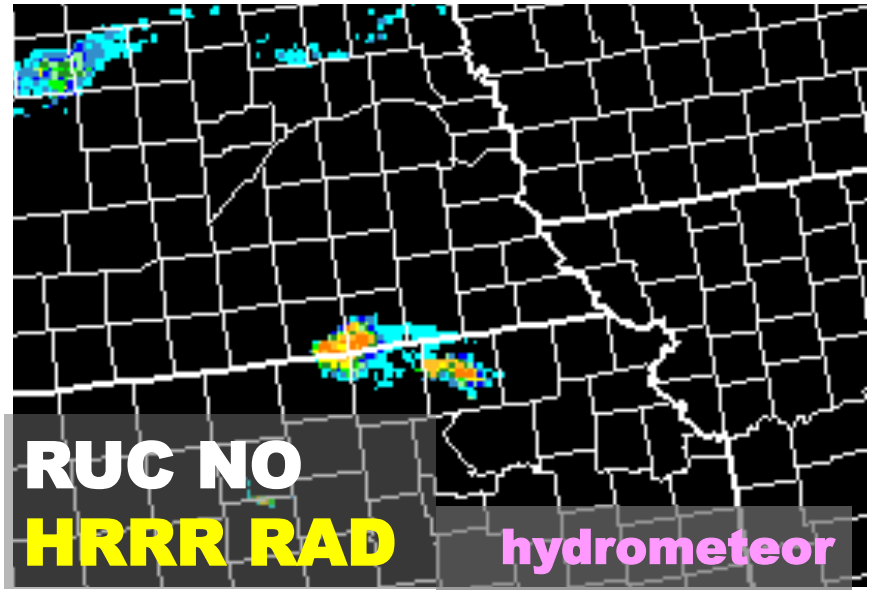






HRRR with RDA only on 3-km domain vs. no RDA





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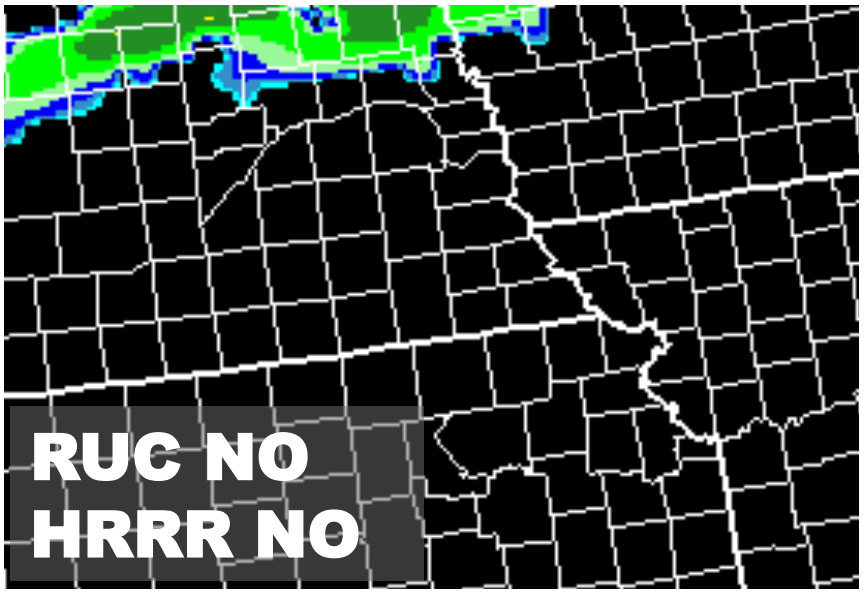
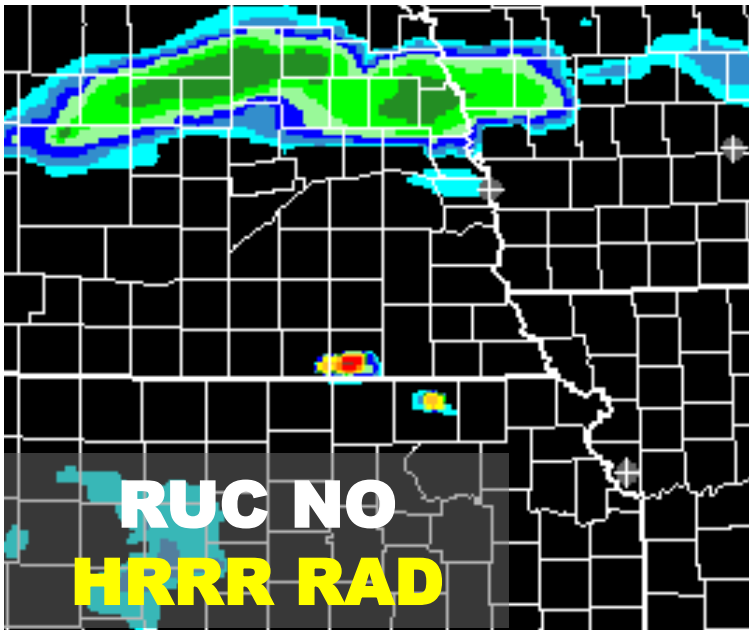
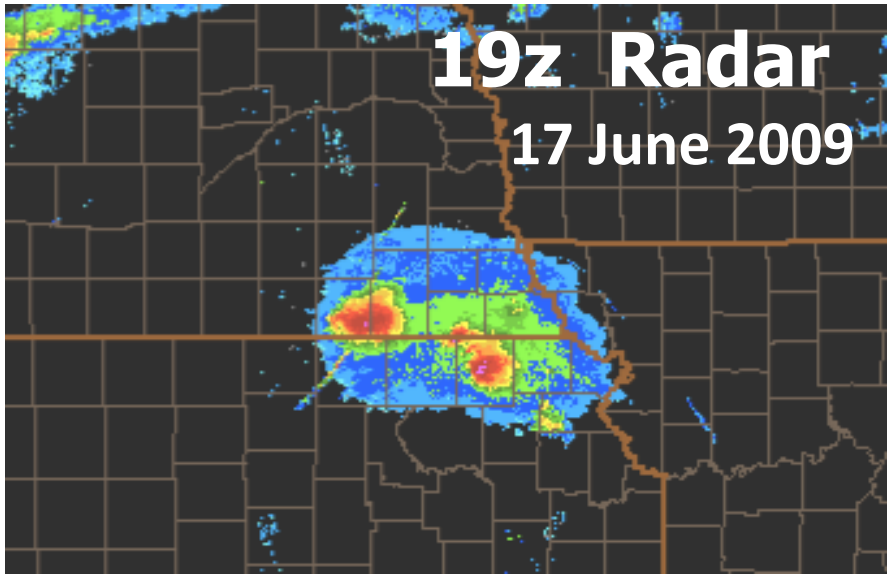
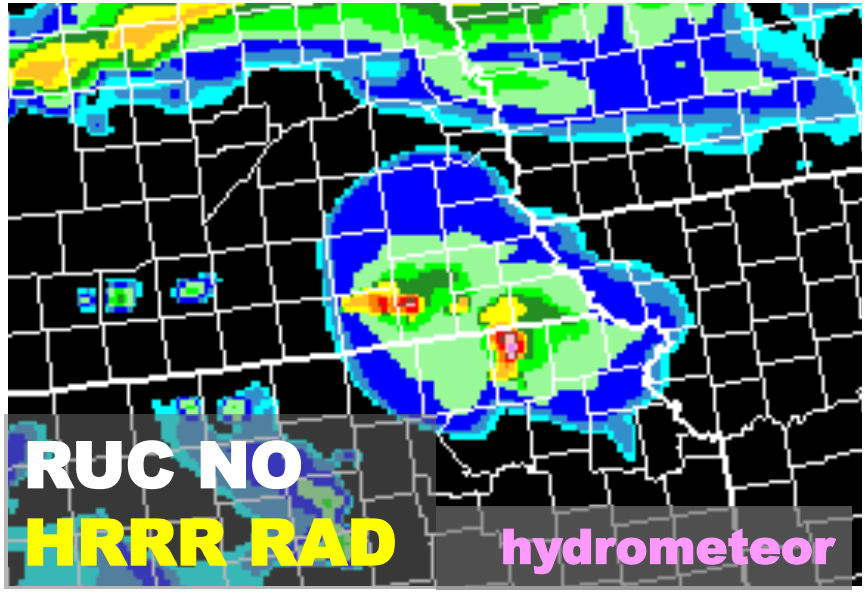




HRRR with RDA only on 3-km domain vs. no RDA





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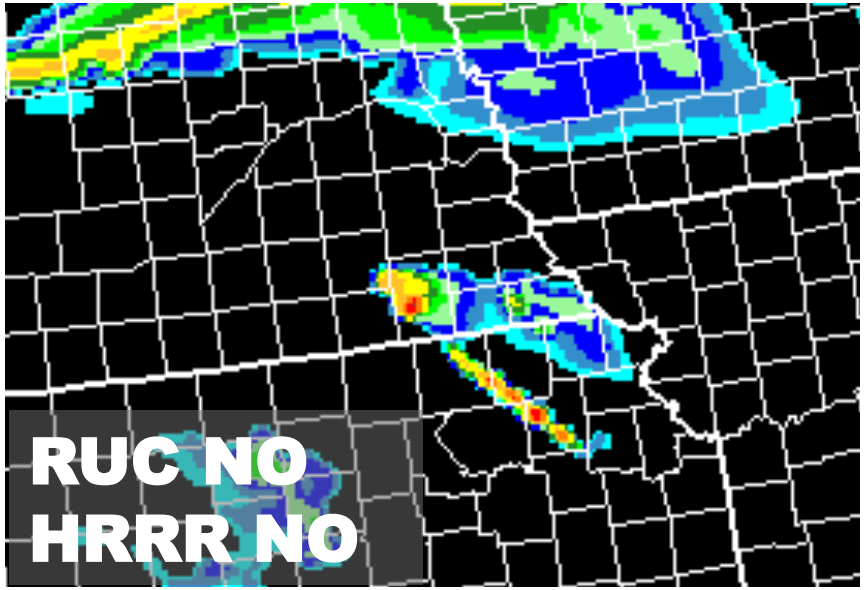
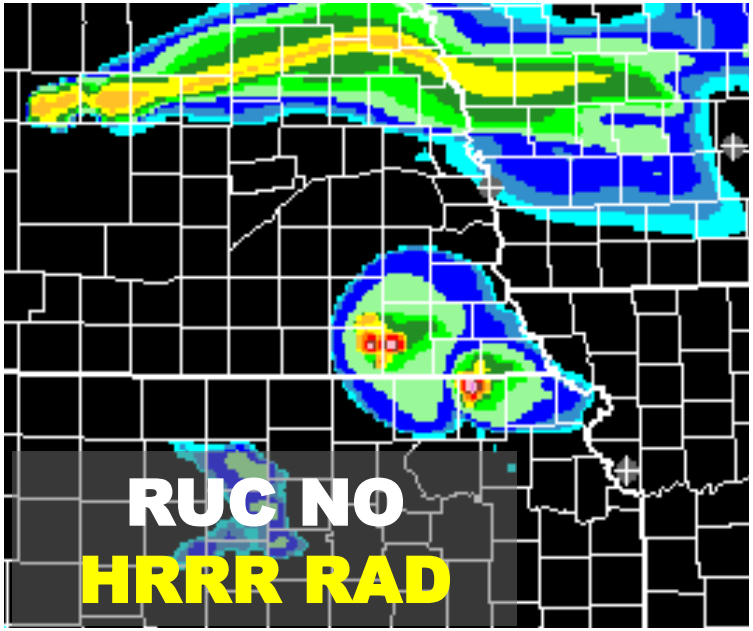
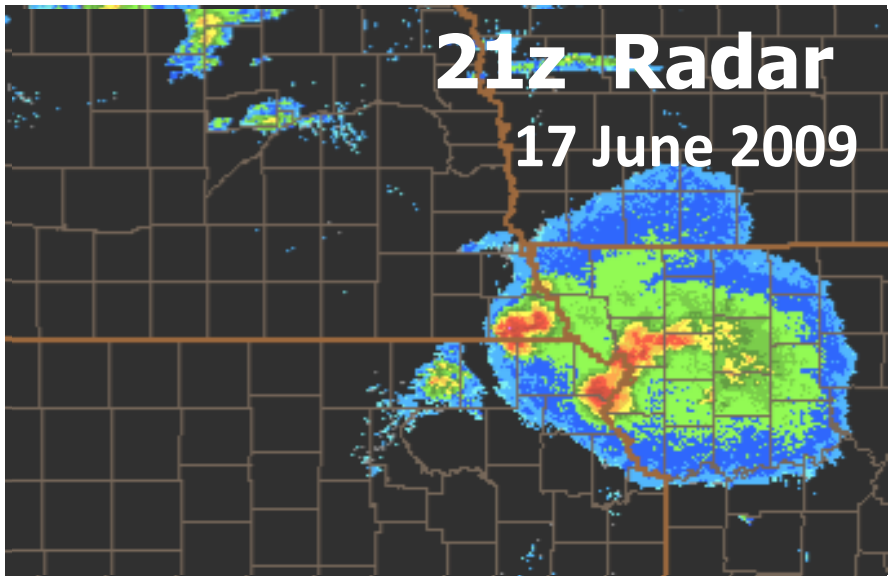
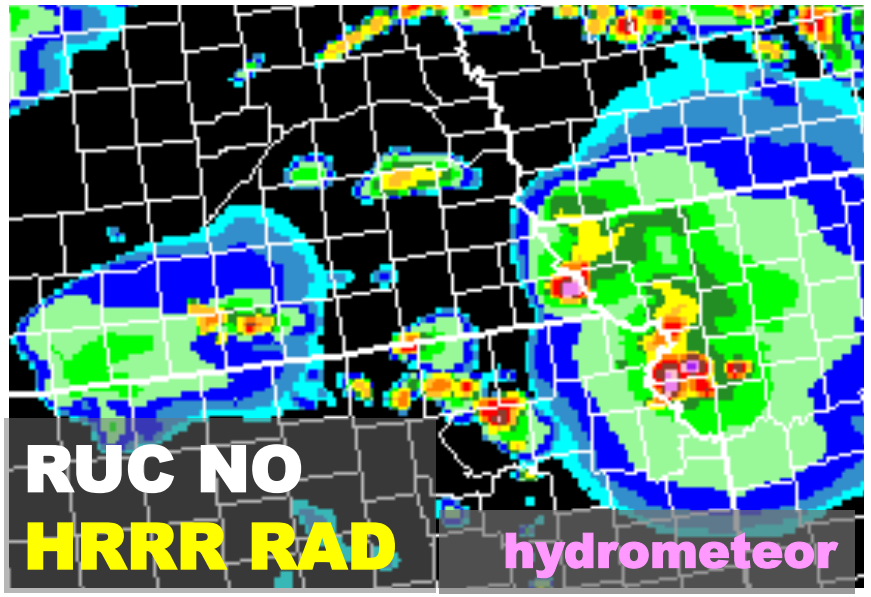


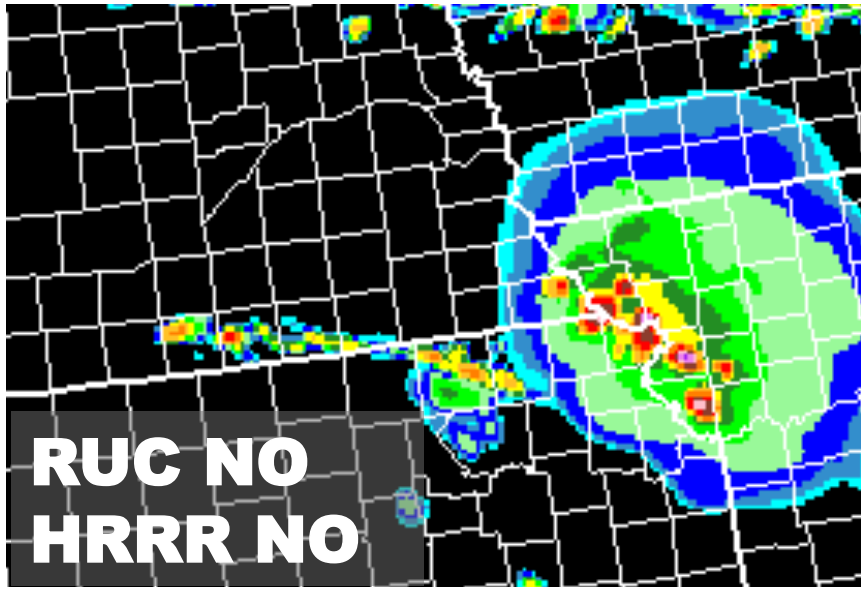


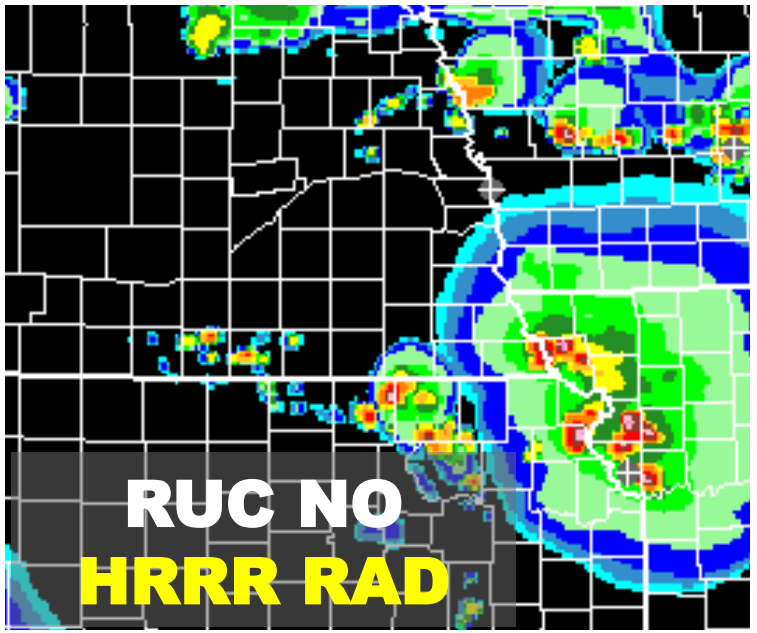
HRRR with RDA only on 3-km domain vs. no RDA



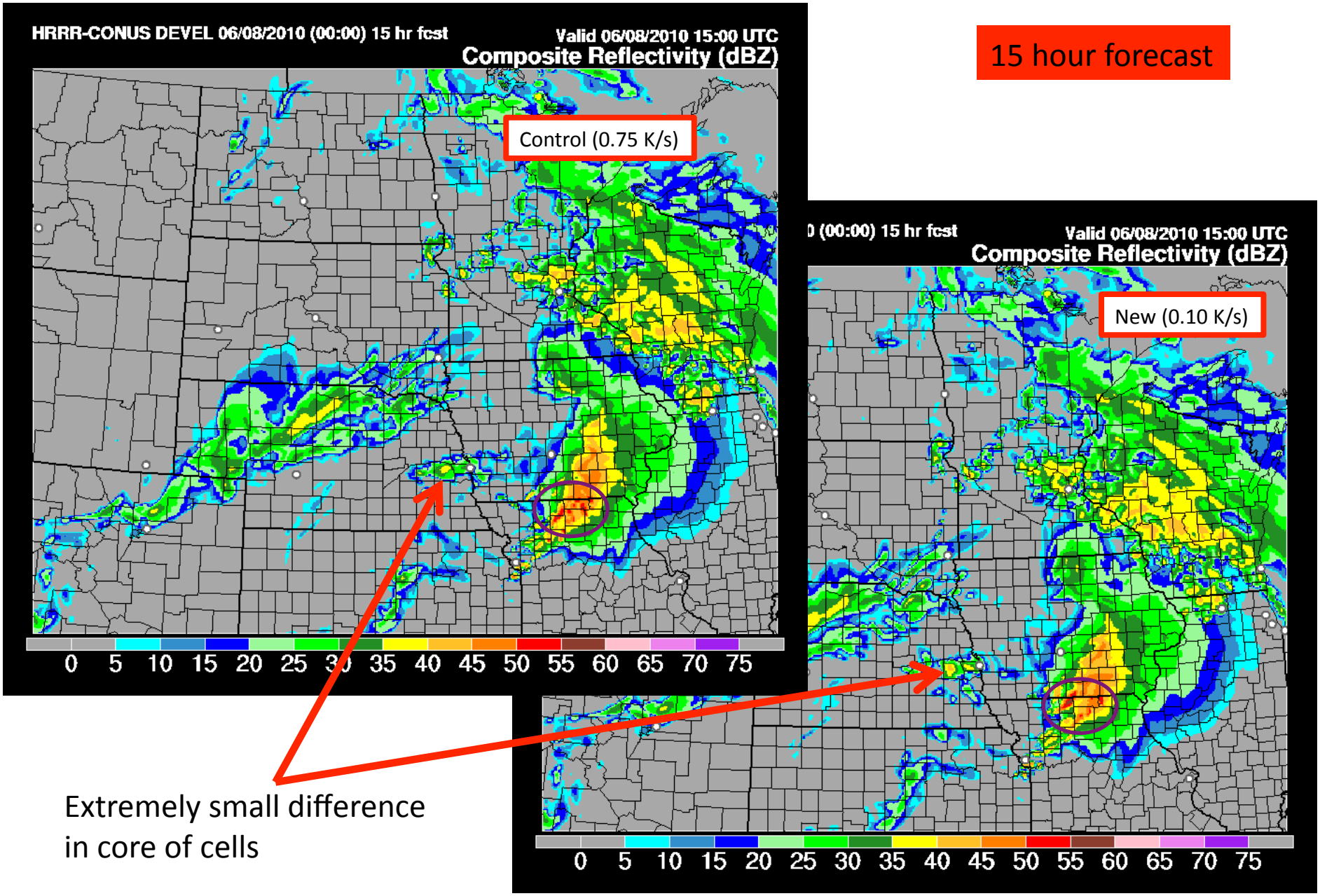


+ 3h fcsts





Difference in HRRR microphysics heating limit (mp_tend_lim)



15 hour forecast

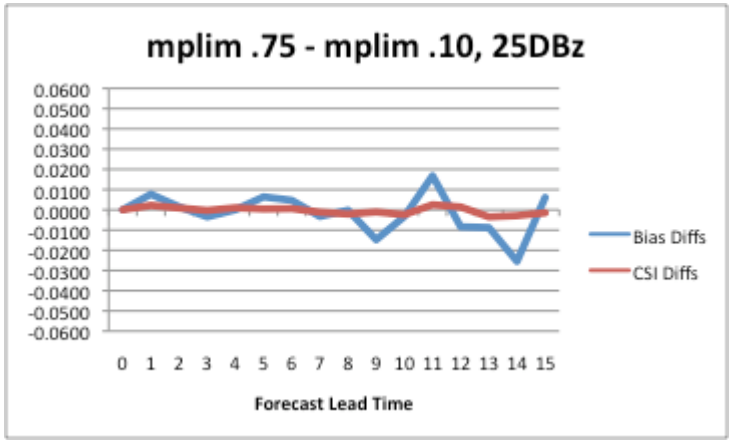
Extremely small difference in core of cells

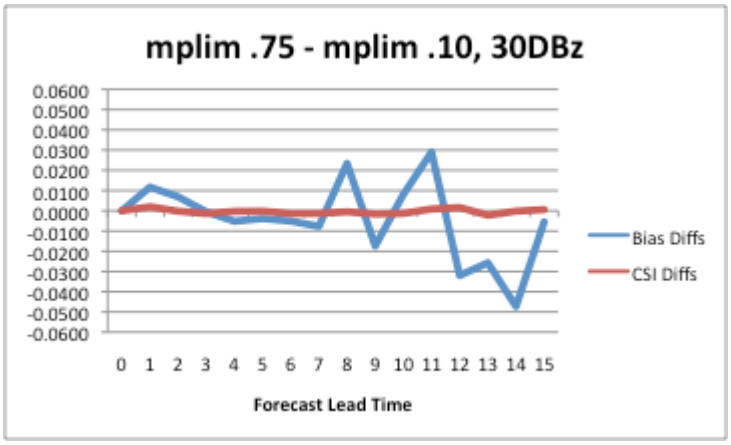
Difference in HRRR microphysics heating limit (mp_tend_lim)

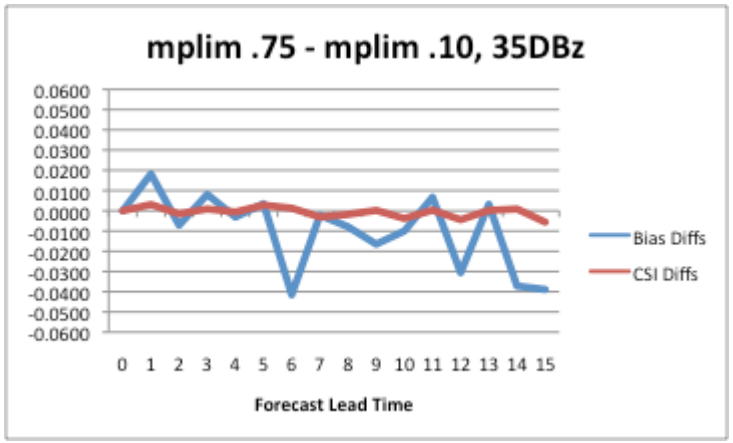
CONUS Domain Verification for 00 UTC 08 June 2010 run
On 10 km grid

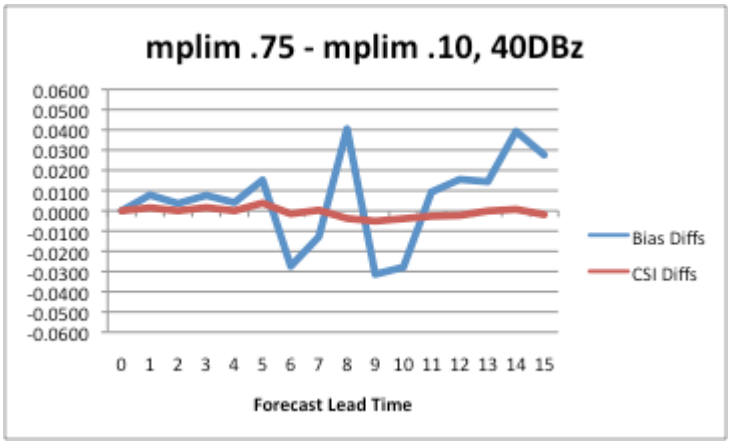
O(0) CSI difference
O(0.01) Bias difference

Allows for larger time-step
while avoiding CFL





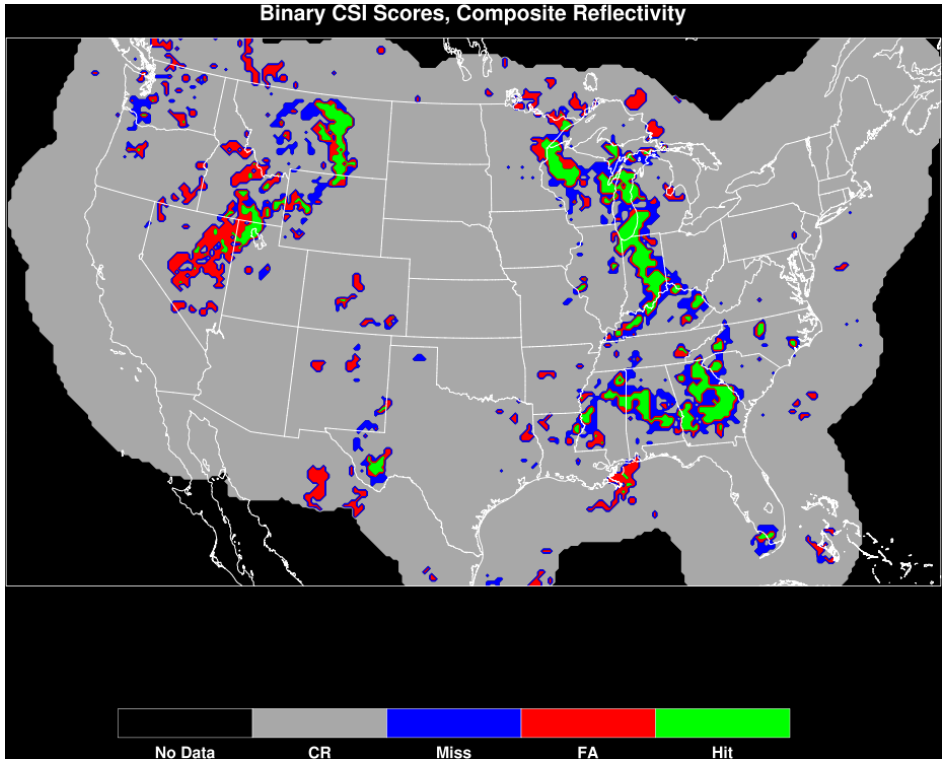




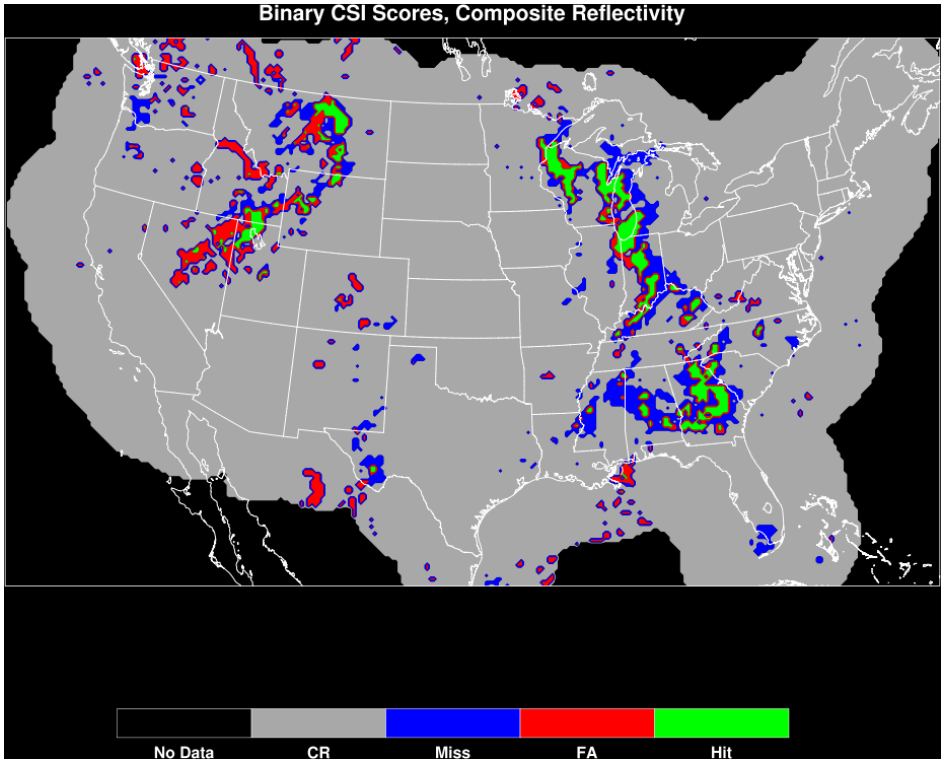
HRRR forecasts using various RUC DDFI initial conditions

1 hr forecasts
25 dBZ threshold
20 km verification
Valid 01 UTC 16 June 2010

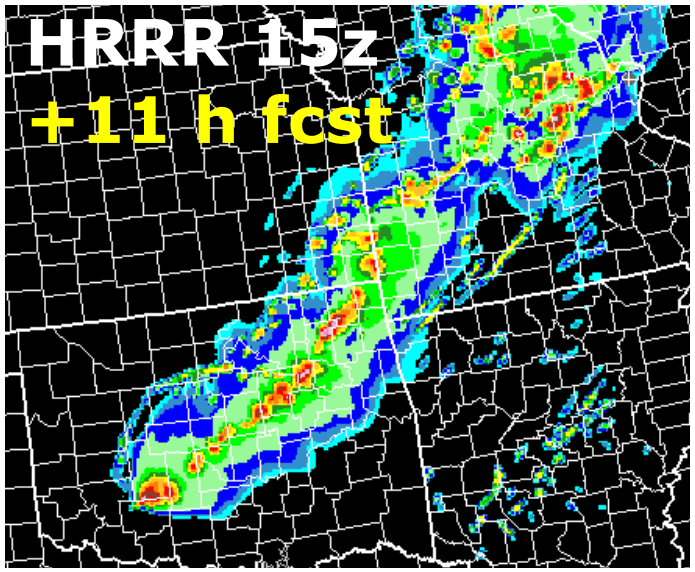
DDFI using 10 min condensation period
(stronger forcing – more hits and false alarms)

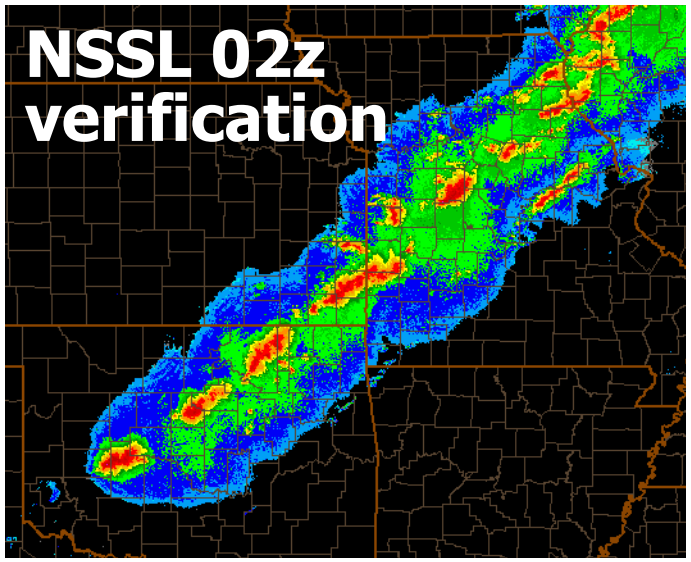


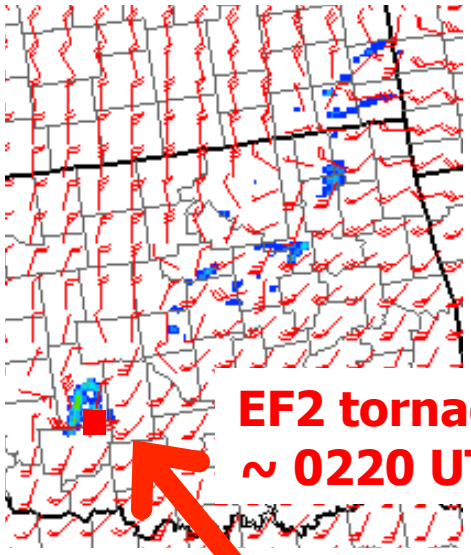
DDFI using 30 min condensation period
(weaker forcing – fewer hits and false alarms)

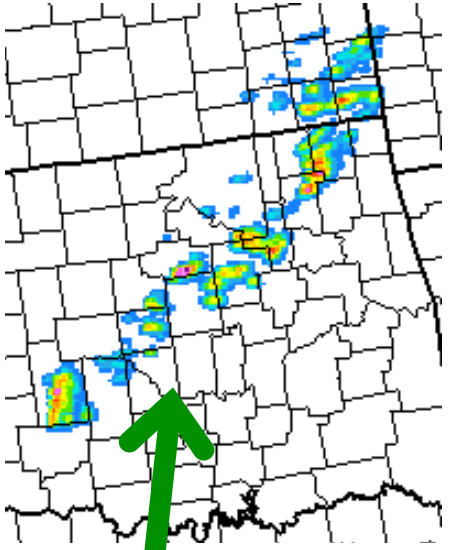


HRRR use for Warn on Forecast







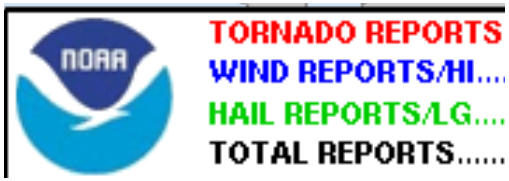


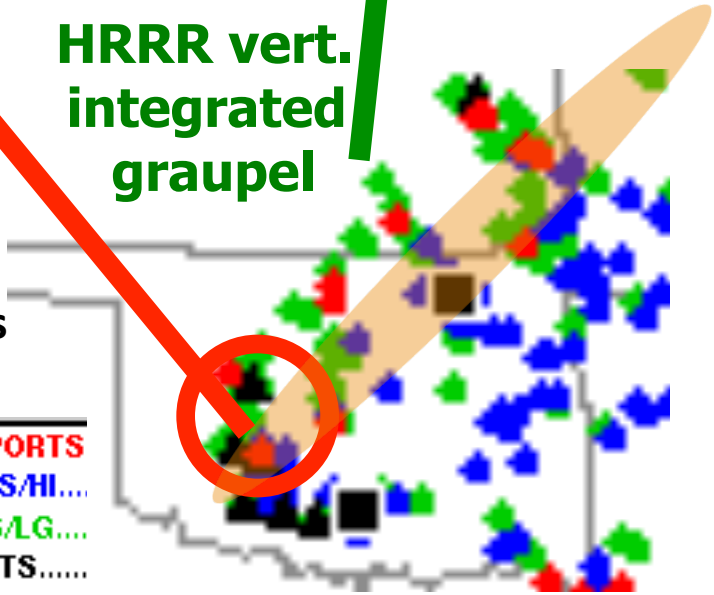
EF2 tornado
~ 0220 UTC

HRRR vert. integrated graupel

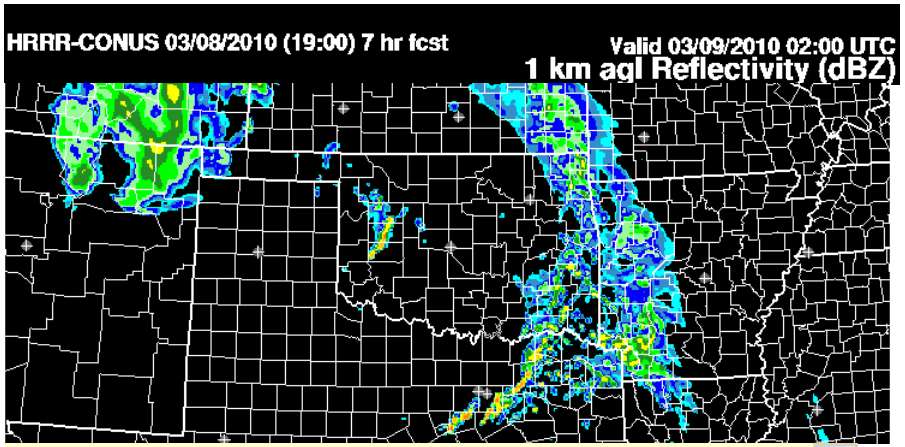
HRRR updraft helicity

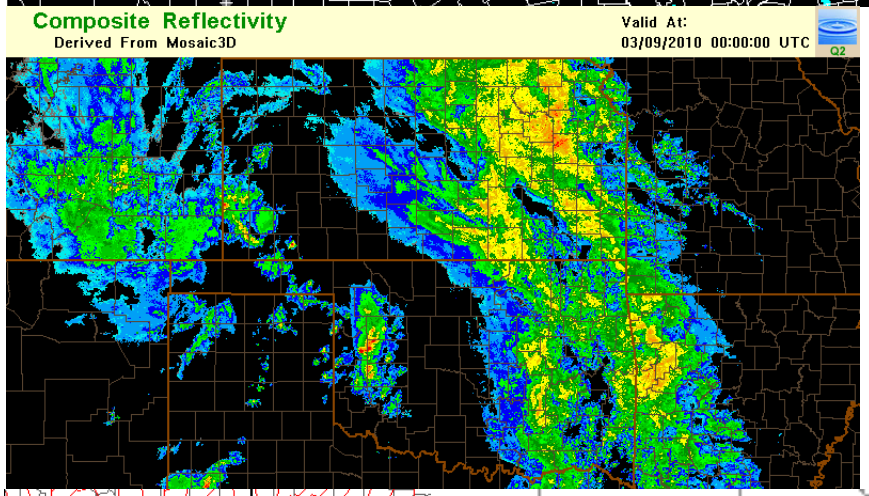
Severe diagnostics code from NSSL

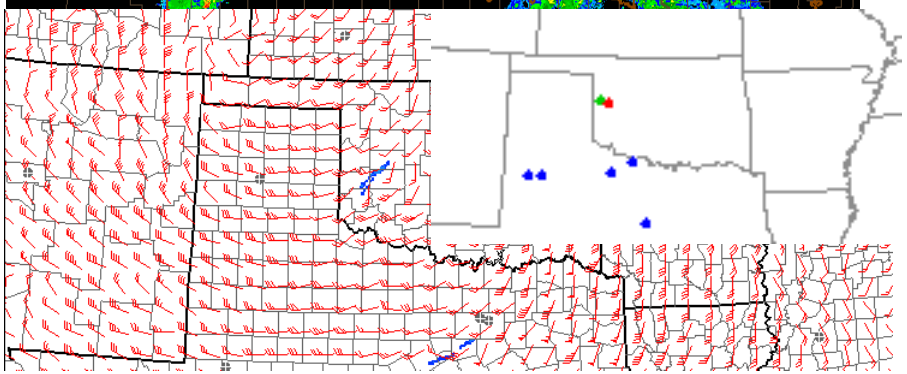


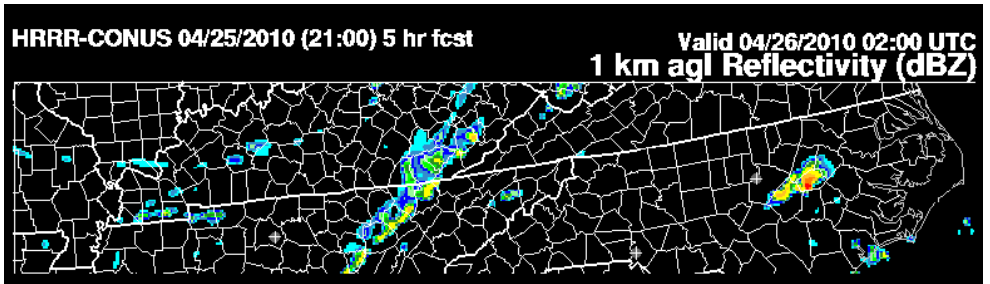


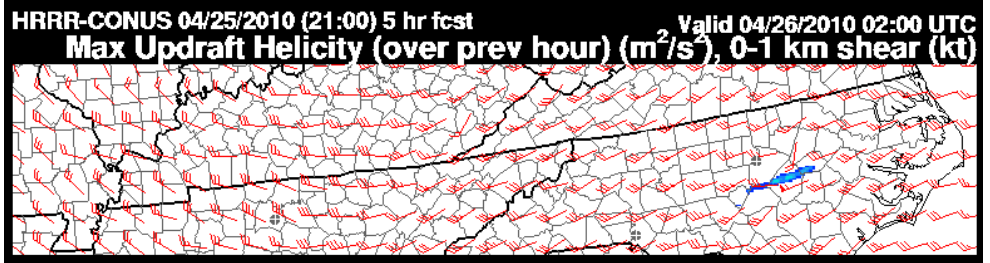
HRRR use for Warn on Forecast

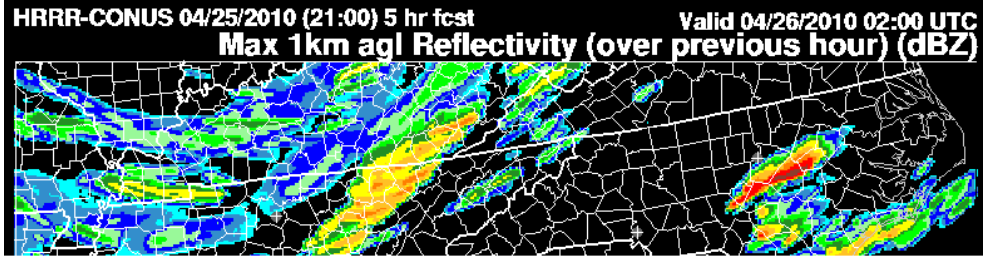




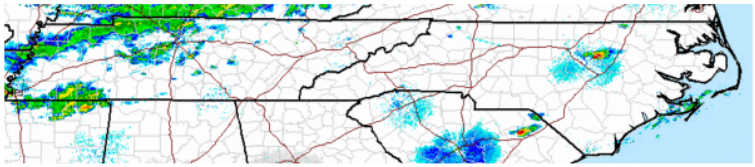








Observed Regional Reflectivity at 2358 UTC 04/25/2010



April 25, 2010 Zebulon Tornado Track

Tornado track

HRRR use for Warn on Forecast

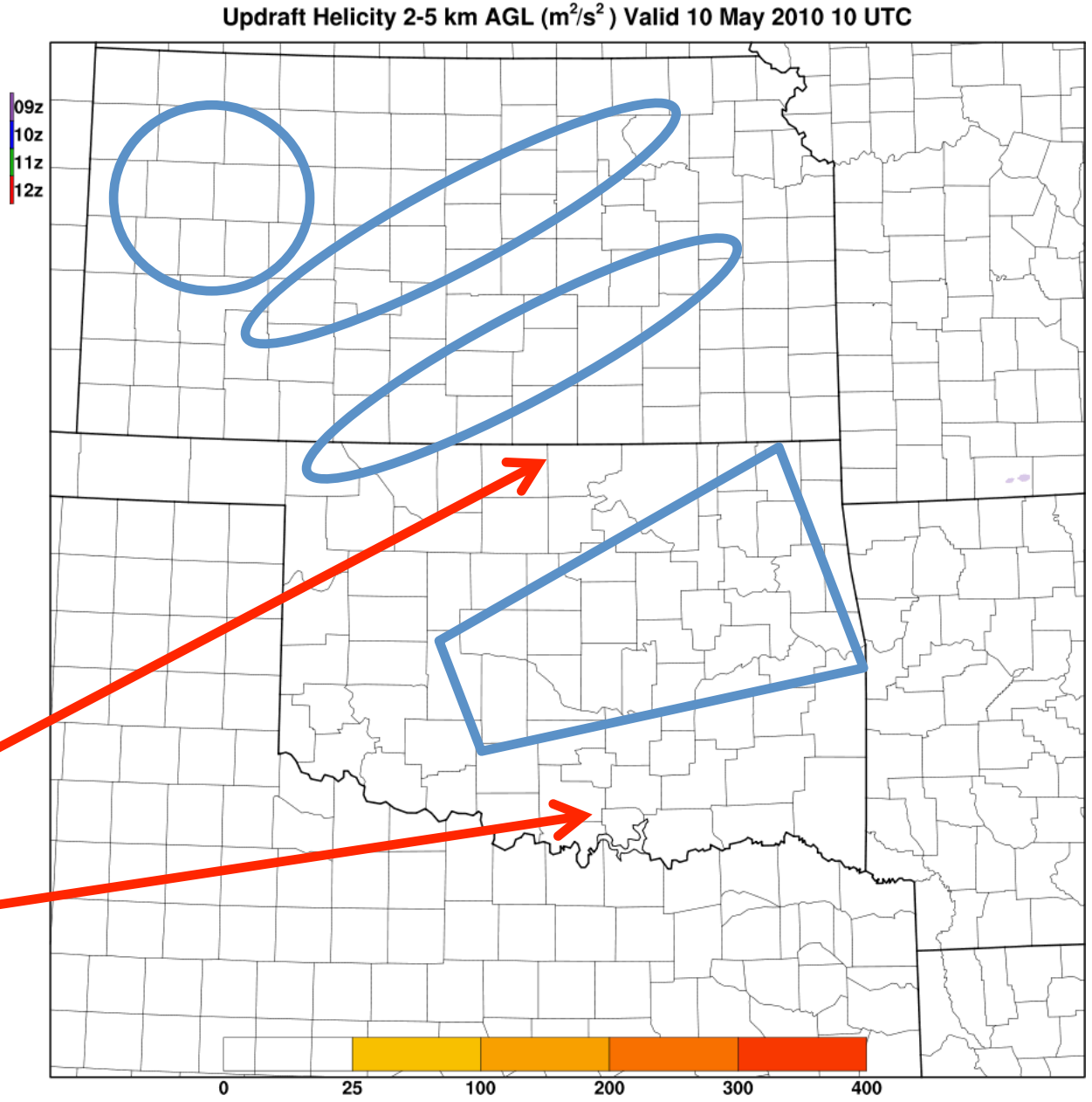
Tornado Outbreak KS/OK
10 May 2010

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

Tornado Reports
< 1 hr valid time (red dots)
Previous hours (blue dots)

No organized convection
forecasted near storm track

No organized convection
Forecasted near Red River

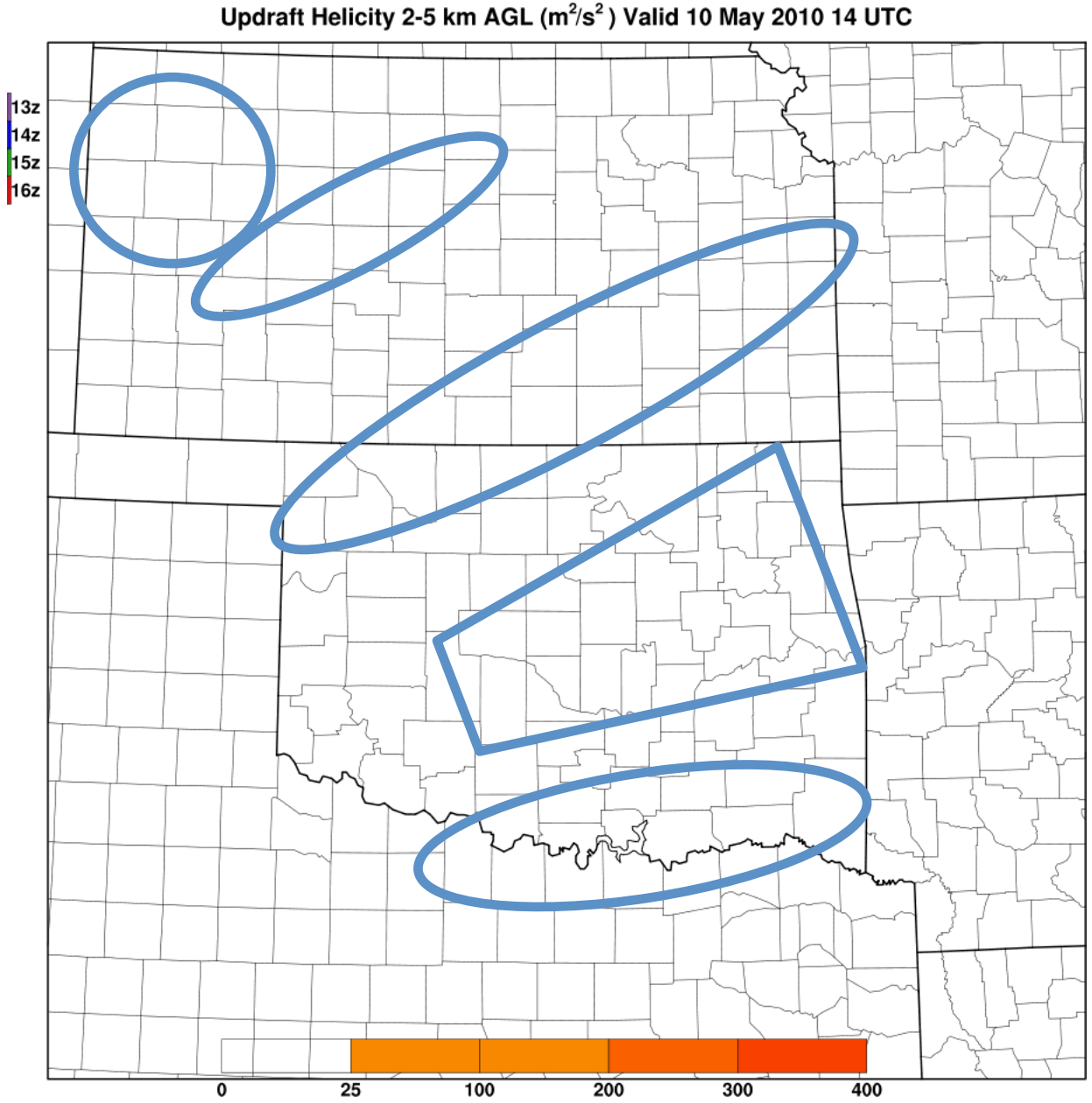


HRRR use for Warn on Forecast

Tornado Outbreak KS/OK
10 May 2010

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

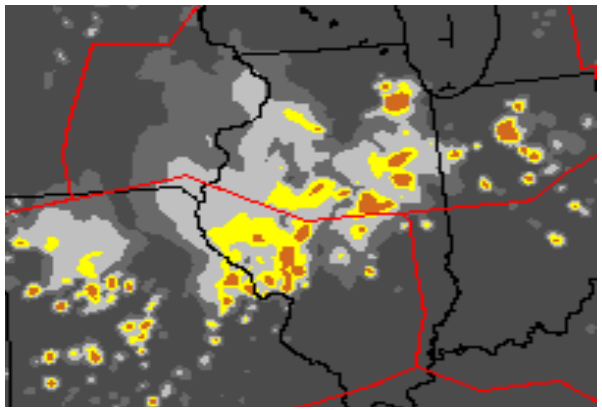
Tornado Reports
< 1 hr valid time (red dots)
Previous hours (blue dots)



Blending Model and Nowcasts for Aviation

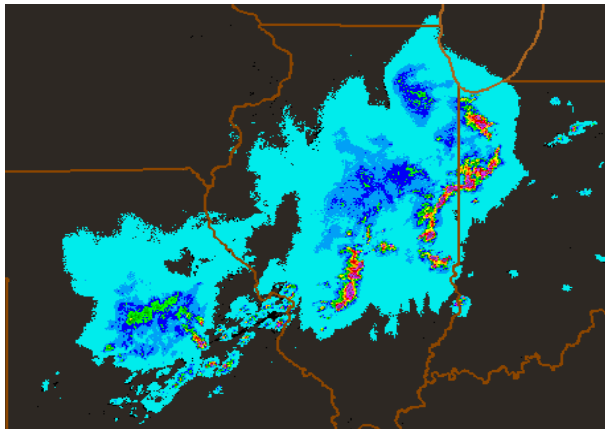
Consolidated Storm Prediction for Aviation

- Collaborative effort:
  - ESRL/GSD, NCAR/RAL, MIT/LL
- Provide 0-8 hr thunderstorm intensity / echo top guidance to aviation community
- Blend HRRR model forecasts with radar-based nowcasts
- Real-time demonstration ongoing!



CoSPA 7h VIL category forecast

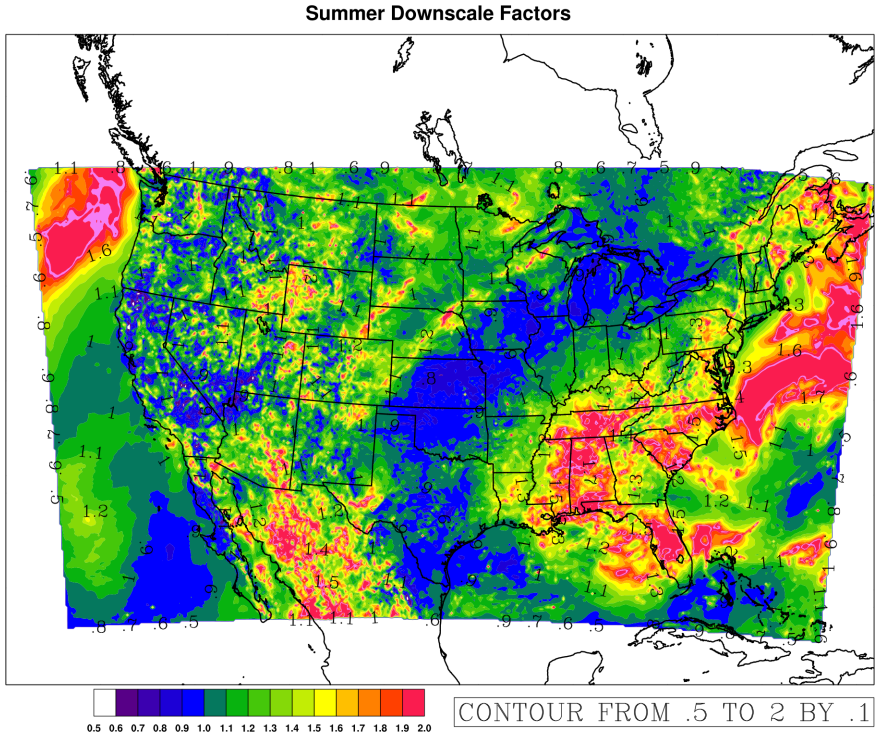
Observed radar VIL

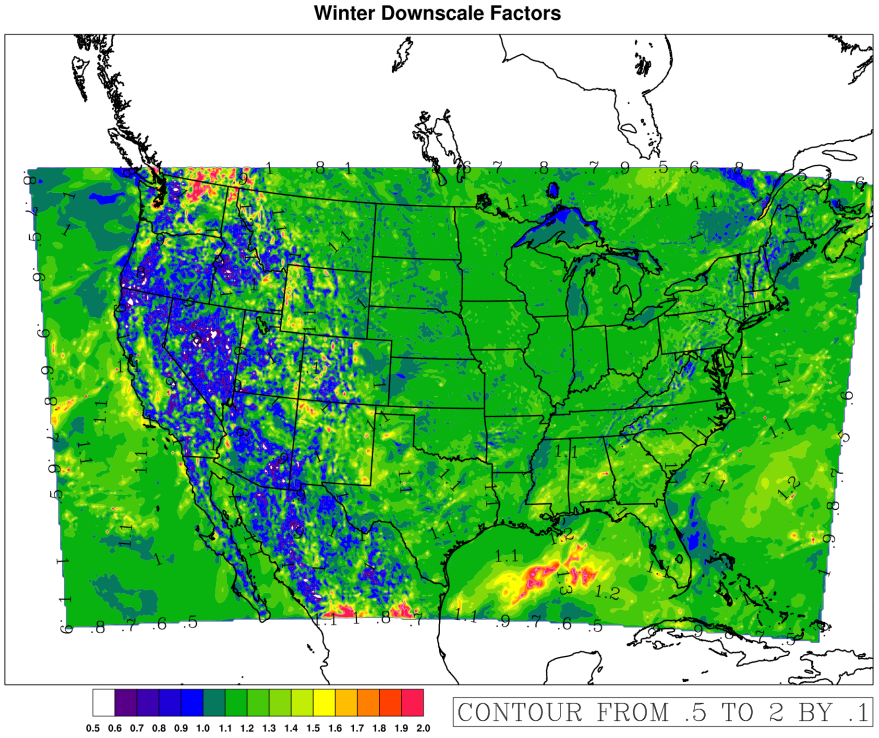


Renewable Energy

Renewable Energy - Scaling factors of wind speeds at turbine height (80 m AGL) from 42 RUC to HRRR fcsts in each season

HRRR faster winds (yellow-red) in low-terrain in summer
HRRR slower winds (purple-blue) in high-terrain in winter





High Resolution Rapid Refresh

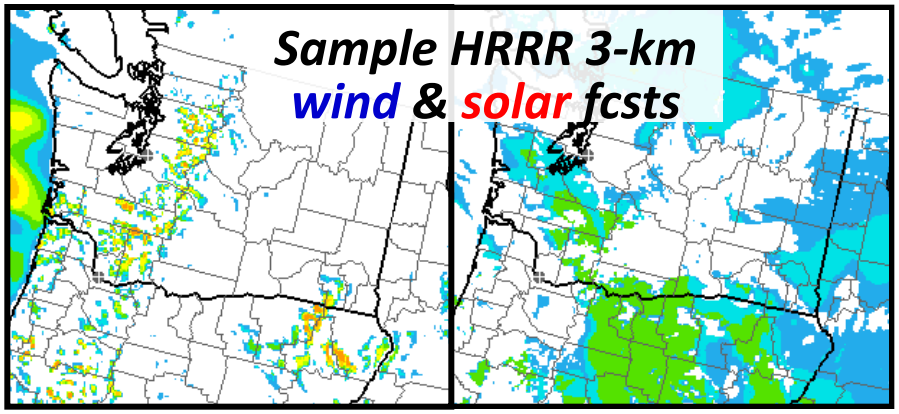
Real-time hourly updated 3-km 15-h CONUS storm-scale model

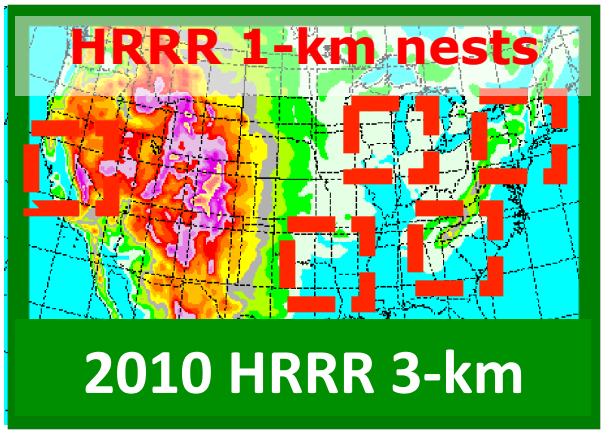
*HRRR provides key convective guidance for **NextGen** aviation*

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





The HCPF

HRRR Convective Probabilistic Forecast (HCPF)

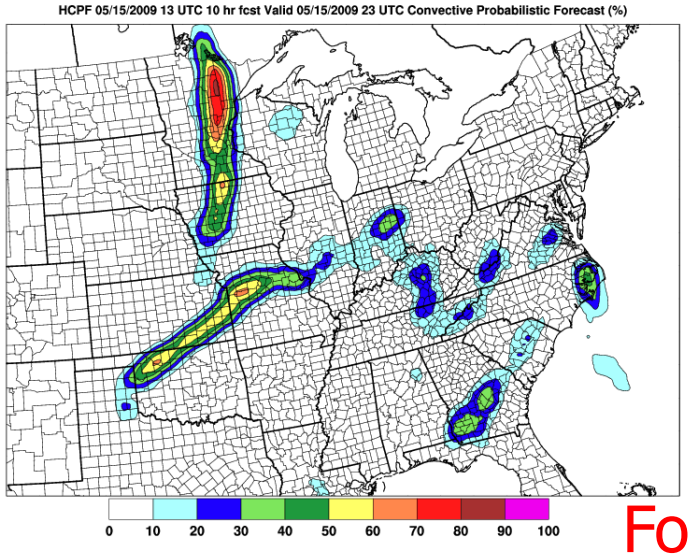
Identification of moist convection using model forecast fields:

- 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 25 points (radius of ~78 km) of each point for each member

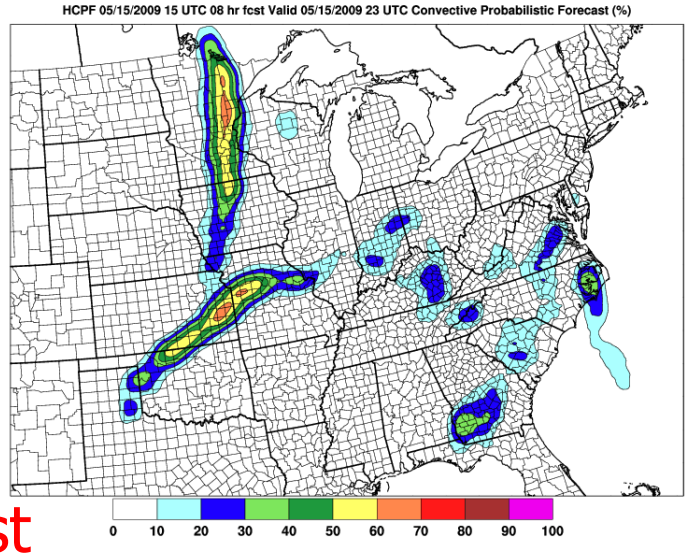
$$\text{HCPF} = \frac{\text{\# grid points matching criteria over all members}}{\text{total \# grid points searched over all members}}$$

HCPF Example: 23 UTC 15 May 2009

10 hr forecast

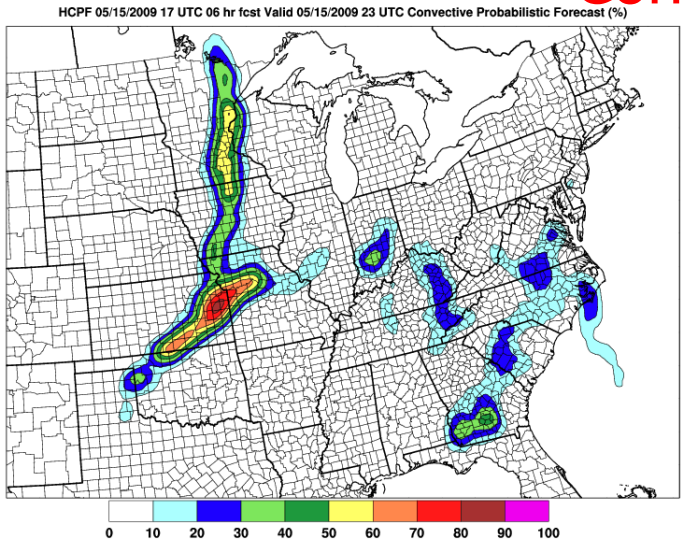


08 hr forecast

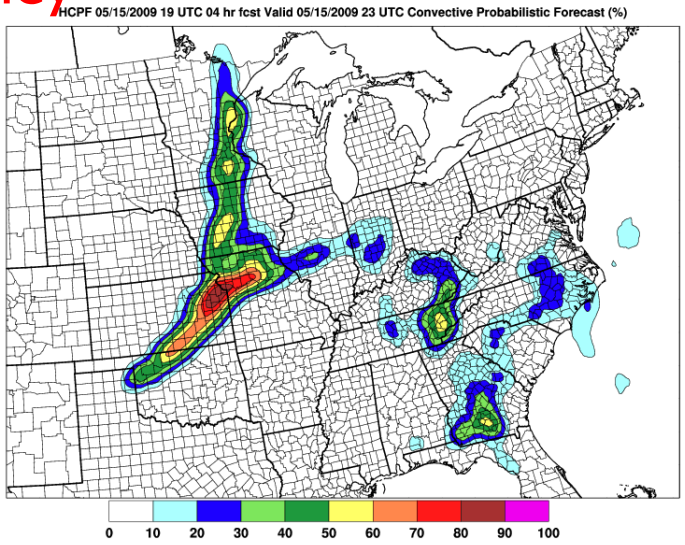


Forecast Consistency

06 hr forecast

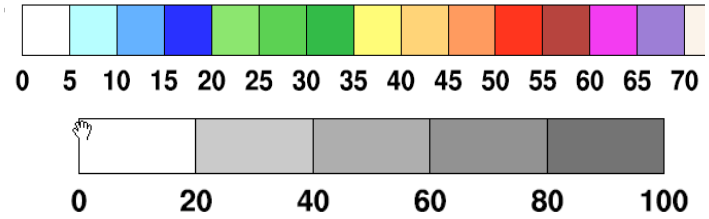


04 hr forecast



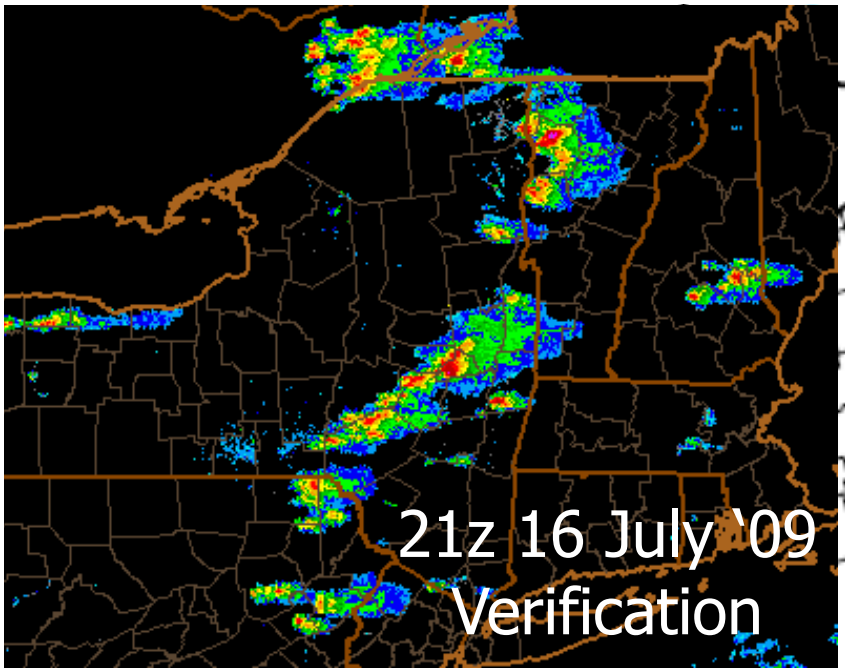
Convective probability forecasts from HRRR time-lagged ensemble

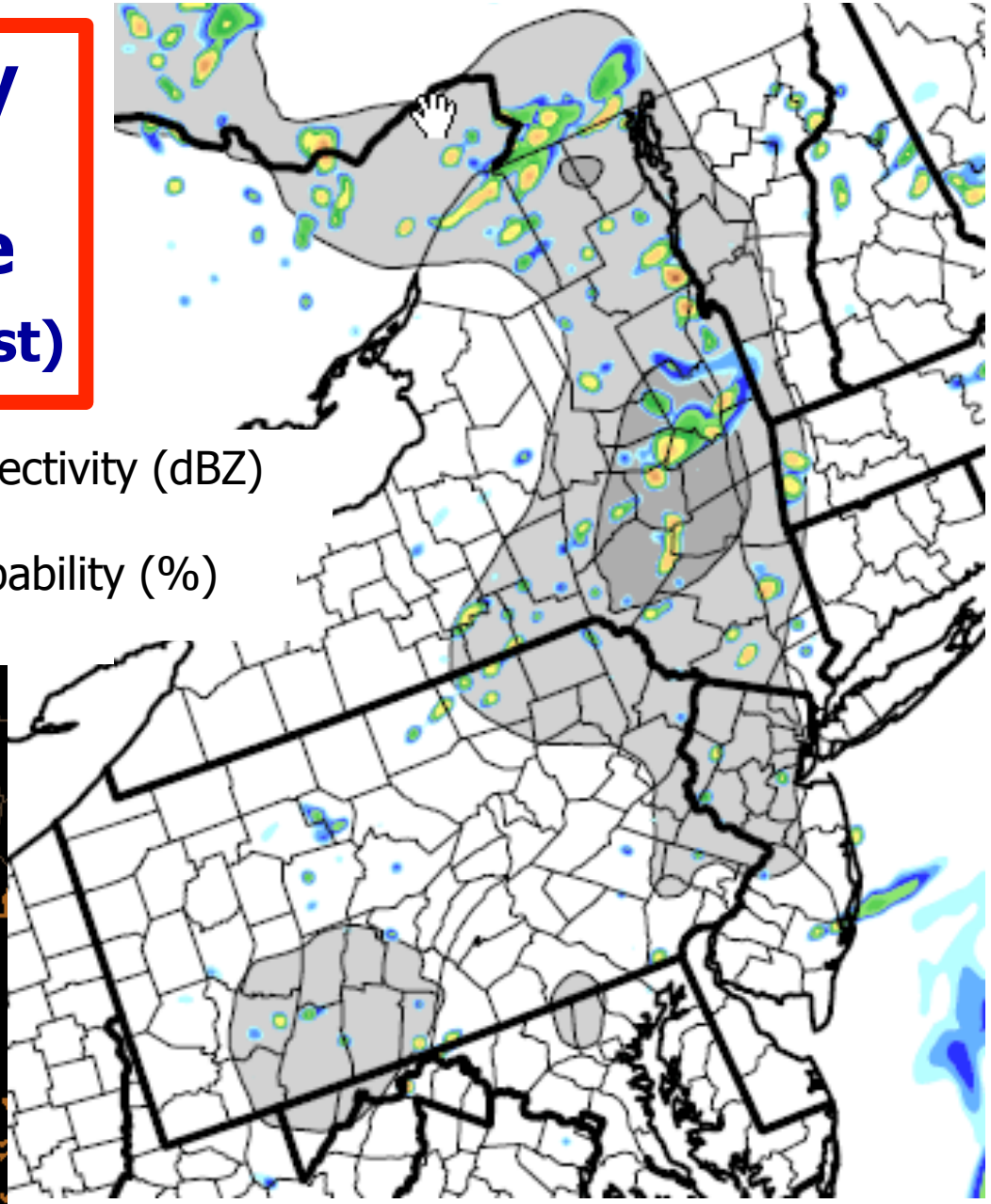
(show with deterministic fcst)



Reflectivity (dBZ)

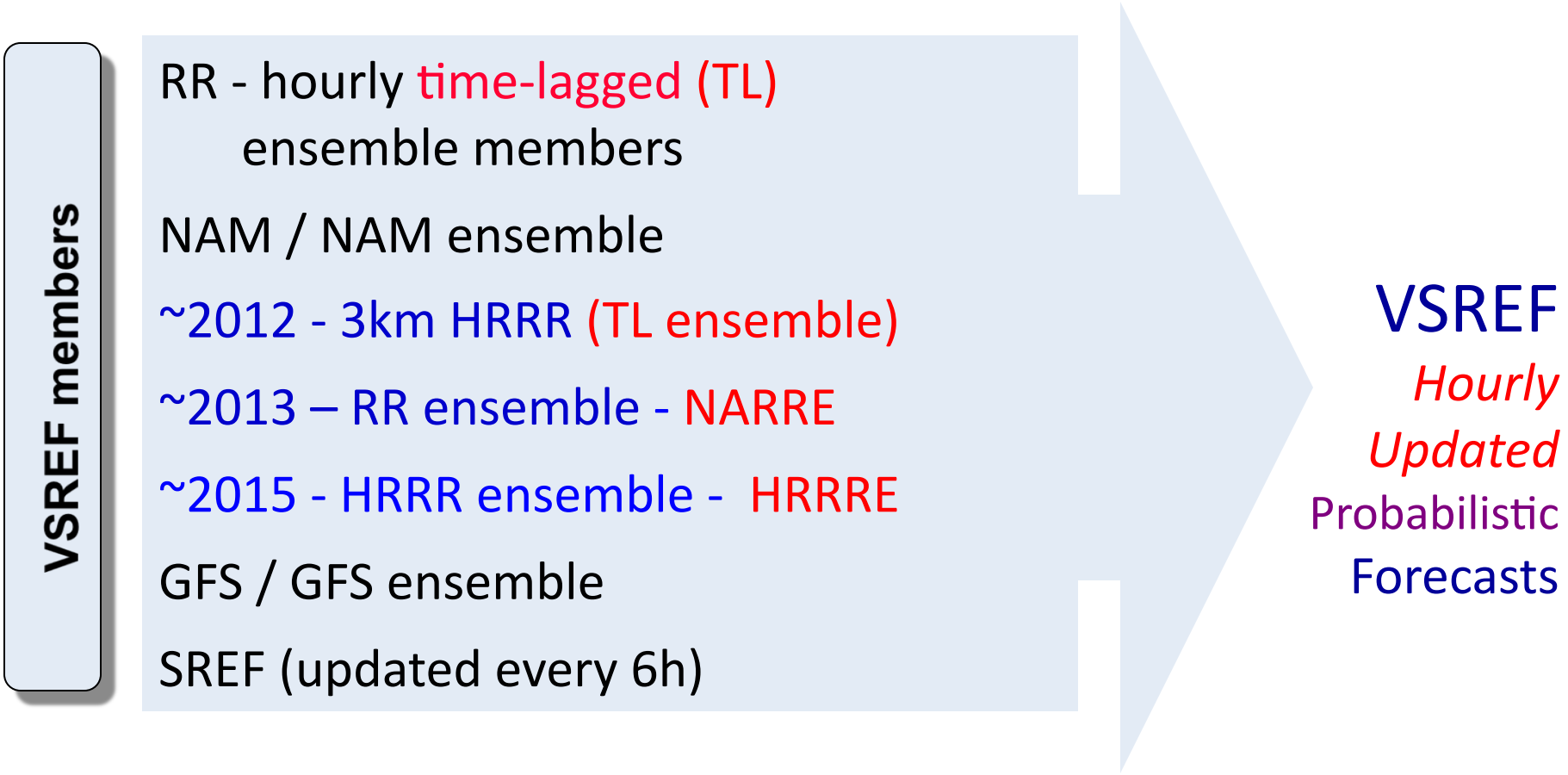
Probability (%)





15z + 6h HRRR and HCPF

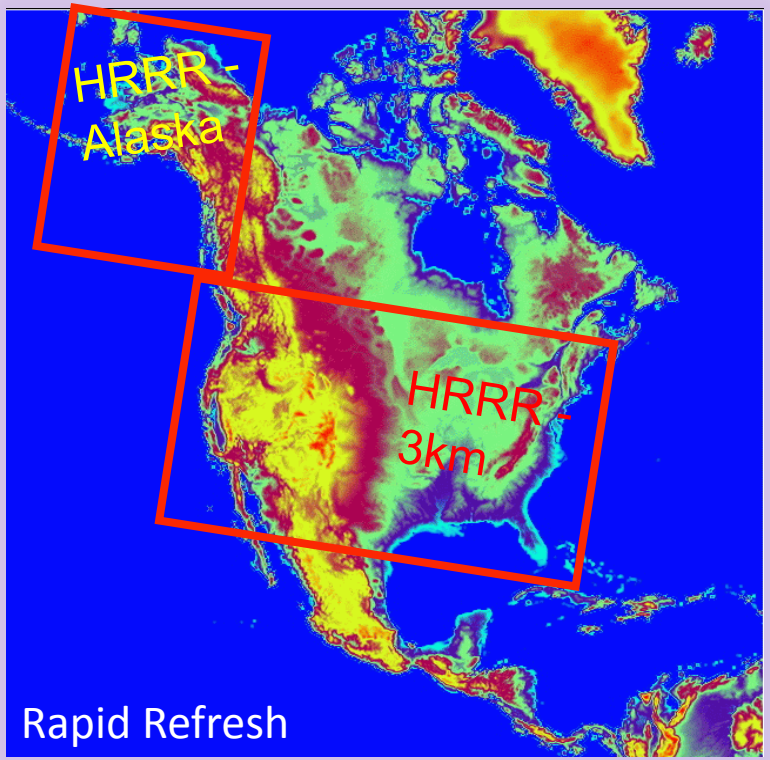
VSREF – Very Short Range Ensemble Forecast



Collaborative work EMC (Binbin Zhou), GSD

Future plans for ≤1h updated NWP

2011 – Rapid Refresh operational at NCEP
2012 – Operational (NCEP)
CONUS-wide High Resolution Rapid Refresh nested inside RR
2013 – Ensemble RR - NARRe (~6 members, ARW, NMM cores)
2014 – Add operational Alaska HRRR
2015 – Ensemble CONUS HRRR - HRRRe (6 members)
2017 – Global Rapid Refresh (GRR)



Incorporation of inline chemistry – 2012-15

- Assimilation of radial wind, new satellite, phased-array radar, CASA, new regional aircraft, chemistry obs…
- Frequency from 60min➔30➔15min
- 1h EnKF + 1h hybrid 4dvar/EnKF
- Improved nowcast/blend/NWP
- Ensemble-based post-processing

Applications:
Aviation, severe wx,
Hydrology, energy, air quality, fire weather, volcanoes/hazards, etc.

Firm NCEP plans

Plans in development