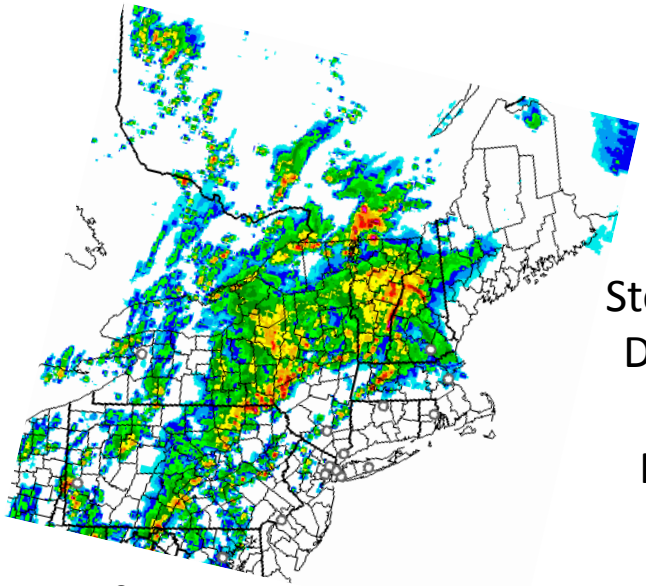
13th Annual WRF Users' Workshop
27 June 2012

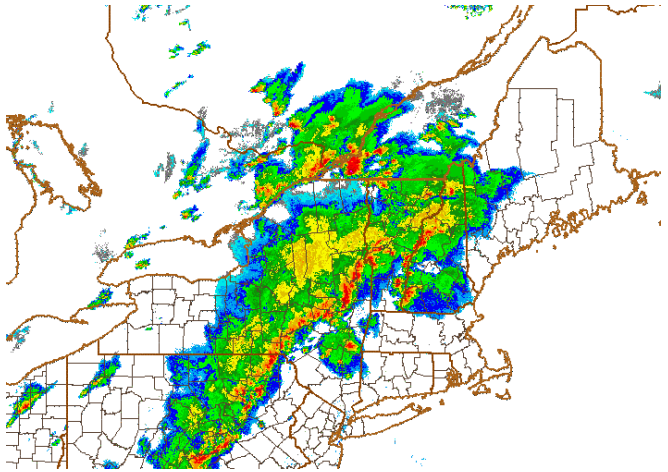
The 2012 High-Resolution Rapid Refresh (HRRR): WRF Enhancements and Challenges



5 hr fcst valid 21z 29 May 2012

NOAA/ESRL/GSD/AMB

Curtis Alexander,
Steve Weygandt, Stan Benjamin,
David Dowell, Tanya Smirnova,
Ming Hu, John Brown,
Patrick Hofmann, Eric James,
and Haidao Lin



Observations 21z 29 May 2012

Hourly Updated NWP Models

13km Rapid Refresh (RAP) (mesoscale)

Replaced RUC at NCEP 05/01/12

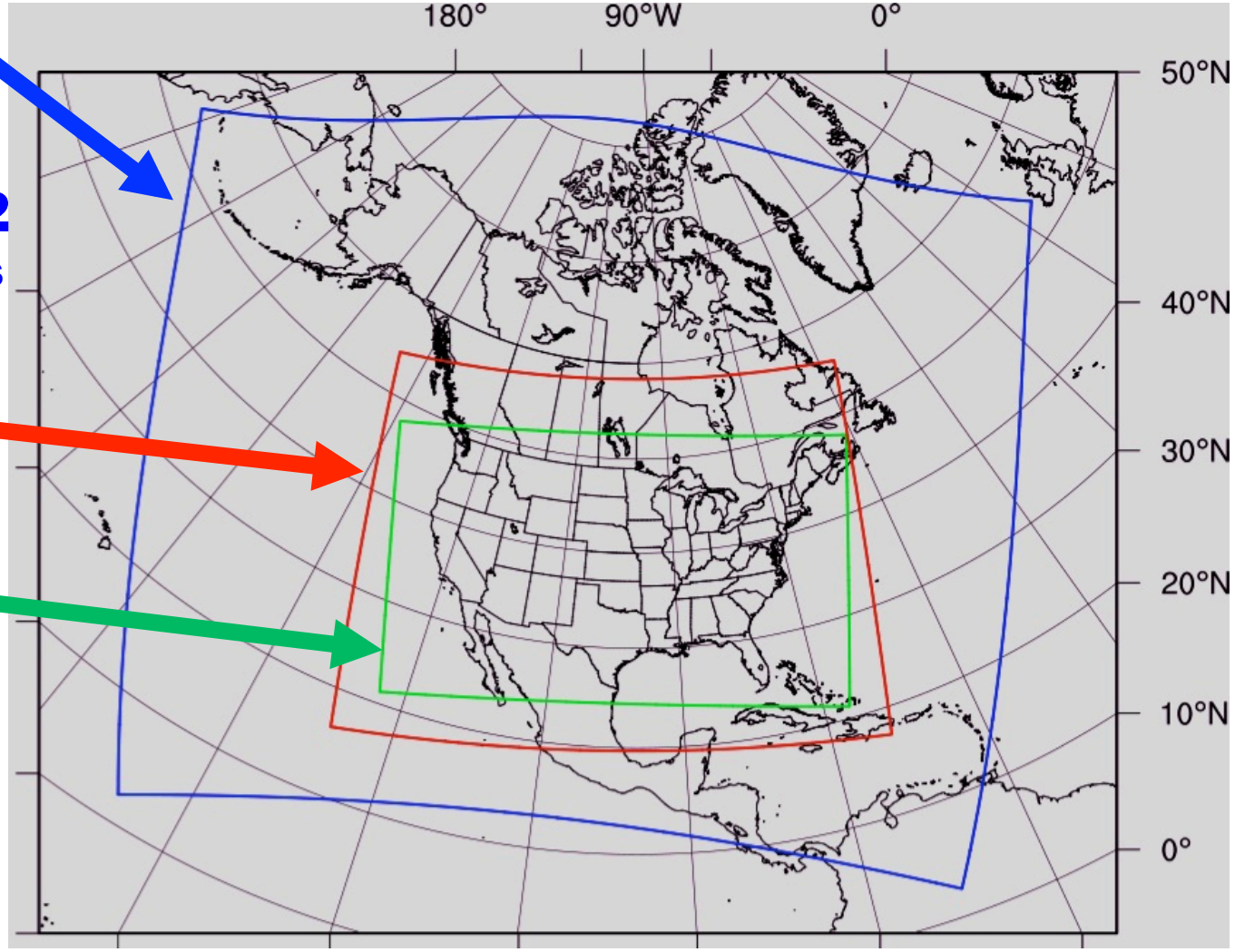
WRF, GSI, RUC features

13km RUC (mesoscale)

3km HRRR (storm-scale)

High-Resolution Rapid Refresh

Experimental 3km nest inside RAP, hourly 15-h fcst



HRRR Users and Applications

Aviation Weather Center (AWC): 2-D grids
Federal Aviation Administration (FAA) Command Center
National Center for Atmospheric Research (NCAR): 2-D, 3-D, 15-min grids
    Operational evaluation in CoSPA
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)
Department of Energy/NOAA Wind Forecast Improvement Project (WFIP)
    ~12 energy private sector companies via WFIP (WindLogics, 3Tier, AWS Truepower, Precision Wind, Weather Channel, etc.)
    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
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

Aviation

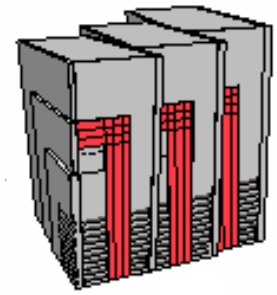
Severe Weather

Renewable Energy

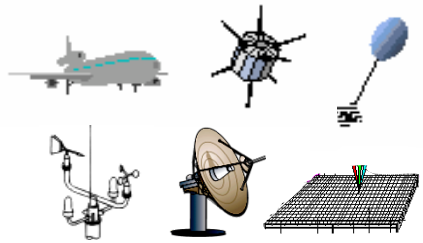
Forecasting

RAP: Data assimilation engine for HRRR

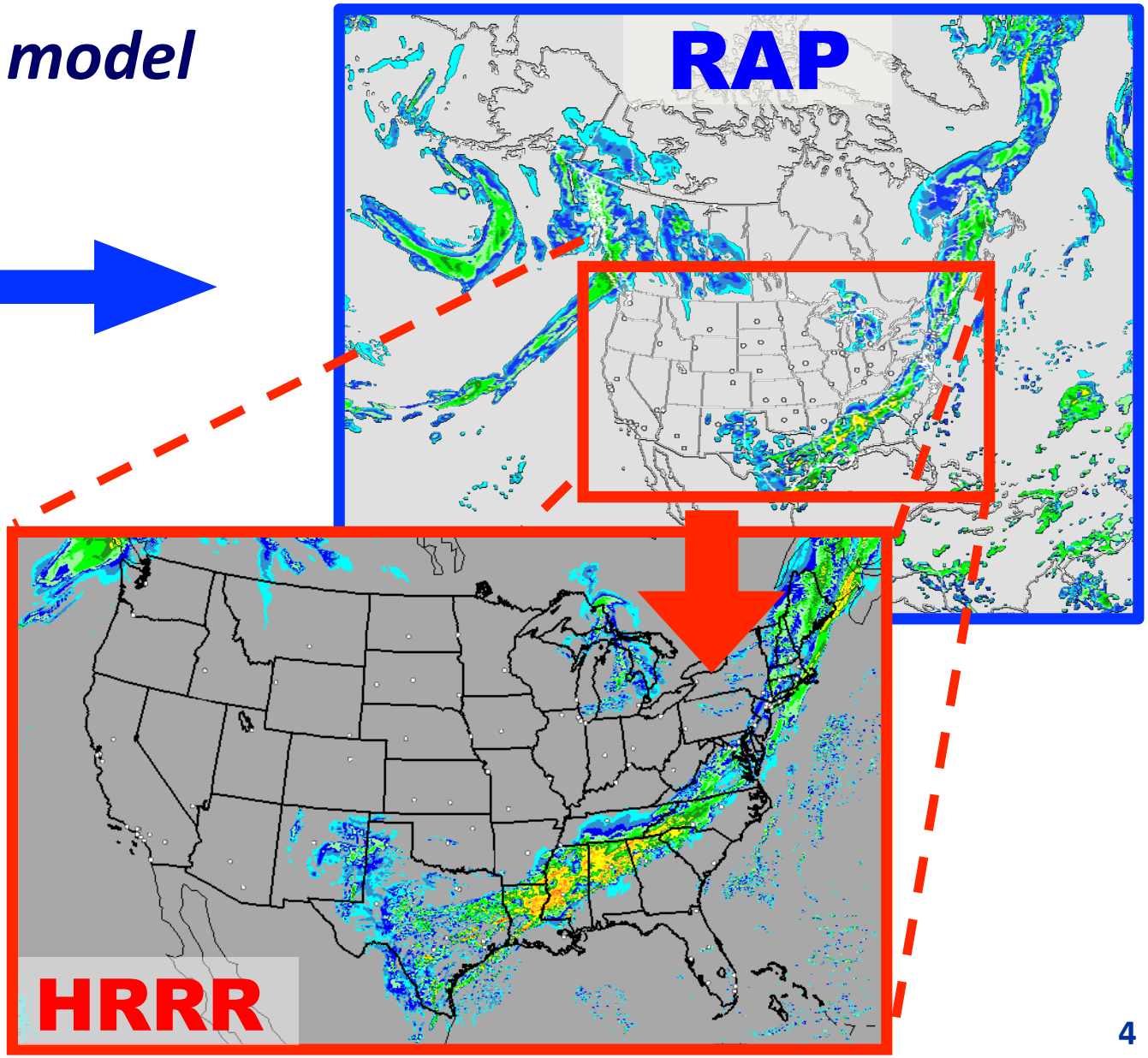
Hourly cycling model



Data Assimilation cycle



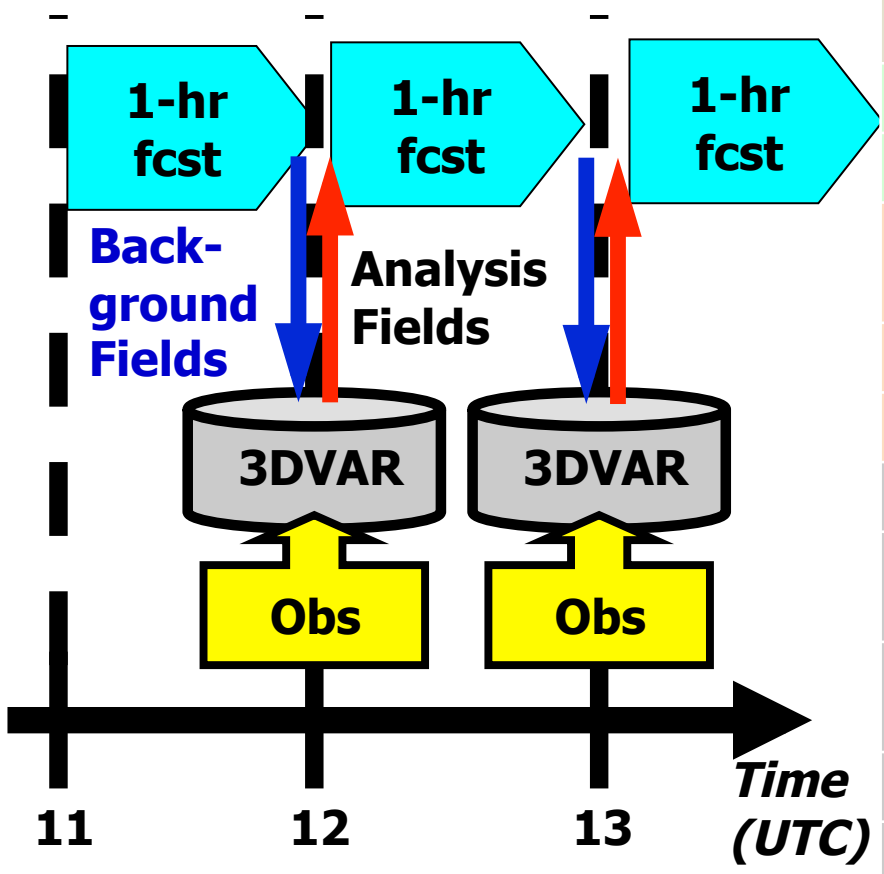
Observations



Rapid Refresh
Hourly Update Cycle

Partial cycle atmospheric fields – introduce GFS information 2x/day

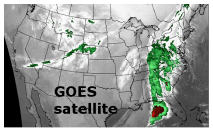
Fully cycle all land-sfc fields

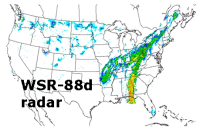


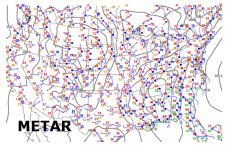
Hourly Observations	RAP 2012 N. Amer
Rawinsonde (T,V,RH)	120
Profiler – NOAA Network (V)	21
Profiler – 915 MHz (V, Tv)	25
Radar – VAD (V)	125
Radar reflectivity - CONUS	2km
Lightning (proxy reflectivity)	NLDN, GLD360
Aircraft (V,T)	2-15K
Aircraft - WVSS (RH)	0-800
Surface/METAR (T,Td,V,ps,cloud, vis, wx)	2200- 2500
Buoys/ships (V, ps)	200-400
Mesonet (T, Td, V, ps)	flagged
GOES AMVs (V)	2000- 4000
AMSU/HIRS/MHS radiances	Used
GOES cloud-top pressure/temp	13km
GPS – Precipitable water	
WindSat scatterometer	2-10K

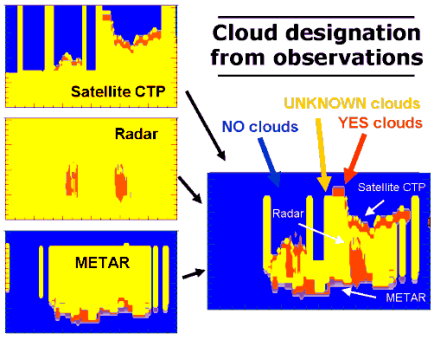
Rapid Refresh Specific Analysis Features

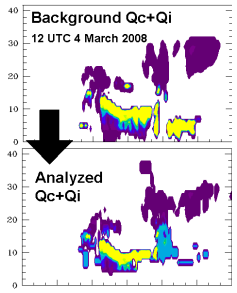
Cloud and hydrometeor analysis











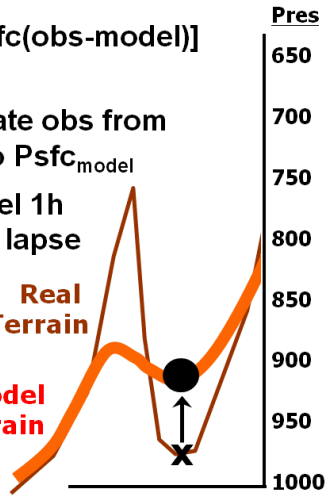
Special treatments for surface observations

Elevation correction

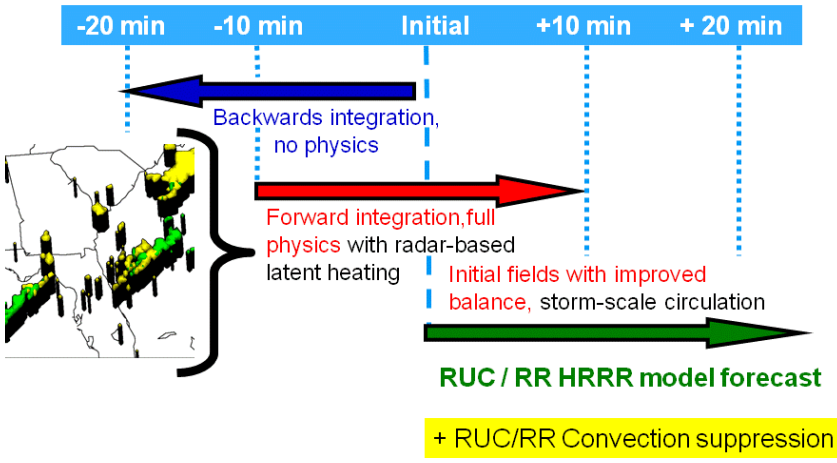
If abs[Psfc(obs-model)] < 70 hPa.

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

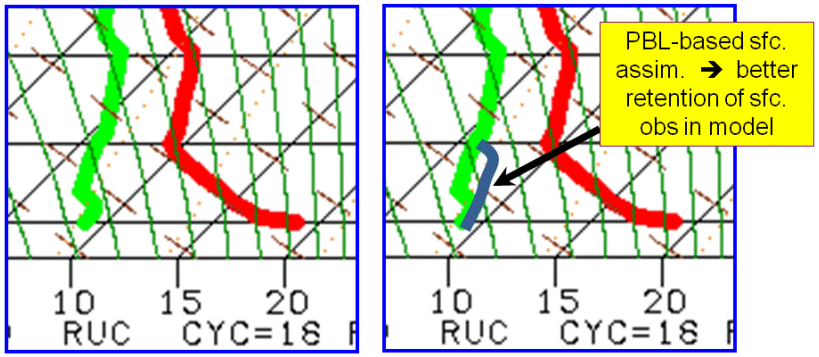
Use model 1h low-level lapse rate.



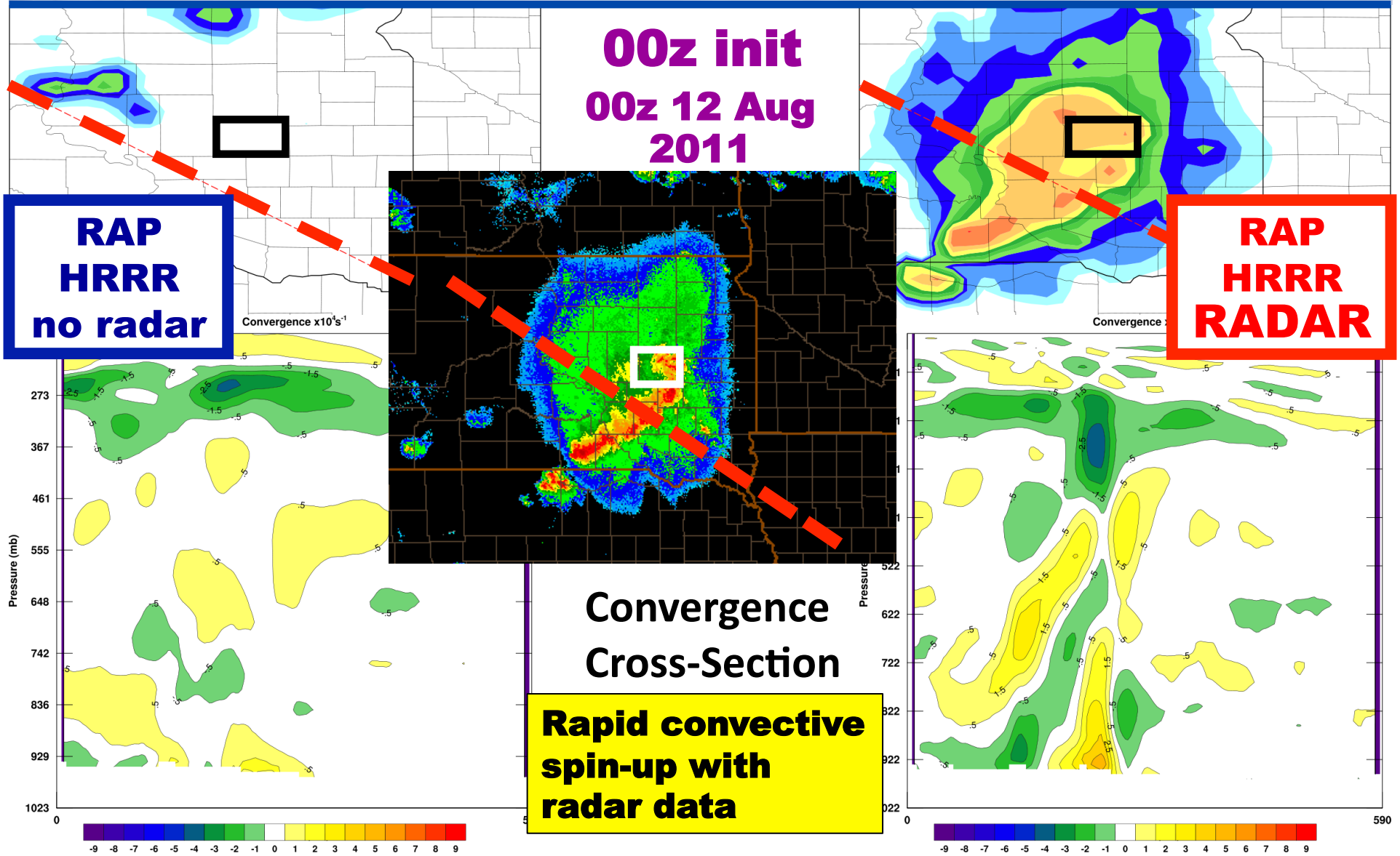
Digital filter-based reflectivity assimilation (DDFI)



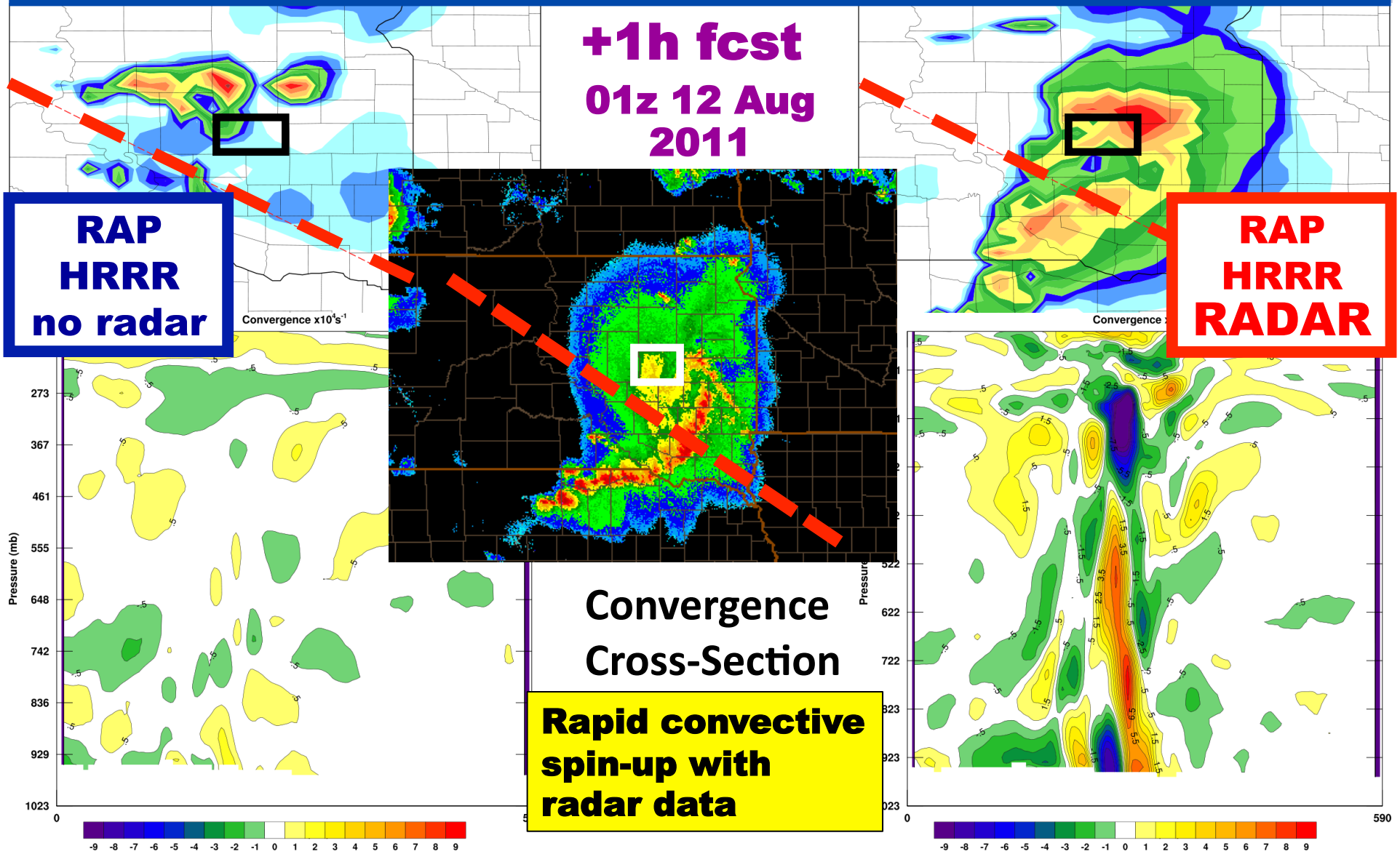
PBL-based pseudo-observations



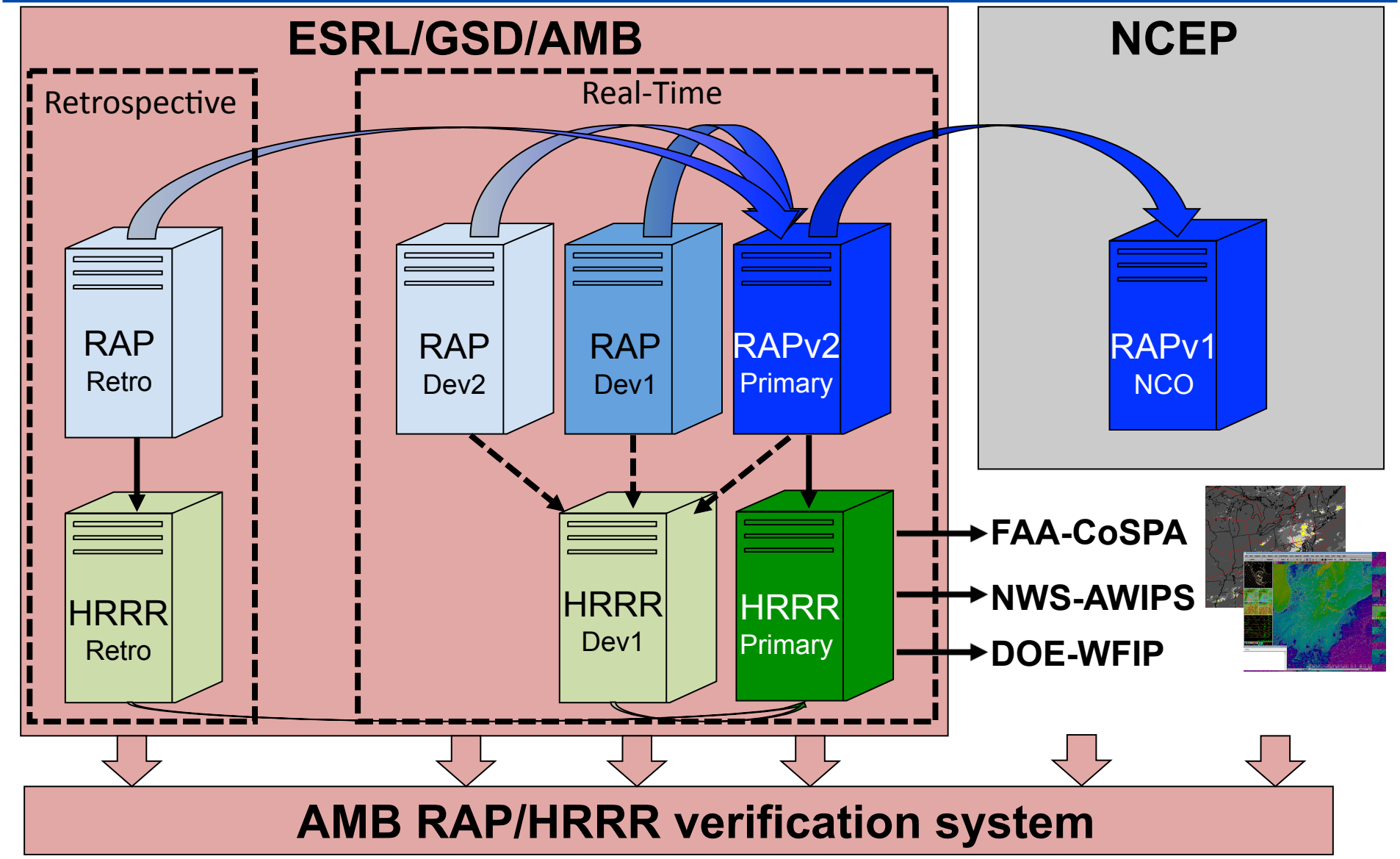
Radar Reflectivity Assimilation



Radar Reflectivity Assimilation



Model Configurations



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

HRRR (and RAP) Milestones

• Reduced latency to ~2 hrs	Dec 2010
• Conversion of all output to GRIB2 format	Apr 2011
• Transition from RUC to RAP parent model	Apr 2011
• DOE-funded HRRR FTP site for energy industry	May 2011
• Update to WRF-ARW v3.3.1	Feb 2012
• Rapid Refresh operational at NCEP	May 2012
• 3-km data assimilation and cycling	2012-2013
• HRRR operational at NCEP	2015?
• Ensemble Rapid Refresh (NARRE) at NCEP	2016?
• Ensemble HRRR (HRRRE) at NCEP	2017?

RAP/HRRR Changes for 2012

Red = Changes in current RAP/HRRR effective before 09 March 2012

	Model	Data Assimilation
RAP (13 km)	WRFv3.3.1+ Physics changes (convection, microphysics, land-surface, PBL) Numerics changes (w-damp upper bound conditions, 5th-order vertical advection) MODIS land use, fractional 30→10 min shortwave radiation New reflectivity diagnostic	Soil adjustment, Temp-dep radar-hydrometeor building PW assim mods Cloud assim mods Tower/nacelle/sodar observations GLD360 lightning GSI merge with trunk Radial wind assim
HRRR (3 km)	WRFv3.3.1+, Physics changes (microphysics, land-surface, PBL) Numerics changes (w-damp upper bound conditions, 5th-order vertical advection) MODIS land use, fractional 30→05 min shortwave radiation New reflectivity diagnostic	3 km/15 min reflect assim 3 km radial wind assim 3 km cloud cycling 3 km land-surface cycling

RAP and HRRR Config 2011

Model	Run at:	Domain	Grid Points	Grid Spacing	Vertical Levels	Pressure Top	Boundary Conditions	Initialized
RAP	GSD, NCO	North America	758 x 567	13 km	50	10 mb	GFS	Hourly (cycled)
HRRR	GSD	CONUS	1799 x 1059	3 km	50	20 mb	RAP	Hourly - RAP (no-cycle)

Model	Version	Assimilation	Radar DFI	Radiation	Microphysics	Cum Param	PBL	LSM
RAP	WRF-ARW v3.2.1+	GSI-3DVAR	Yes	RRTM/ Goddard	Thompson	G3 + Shallow	MYJ	RUC
HRRR	WRF-ARW V3.2.1+	None: RAP I.C.	No	RRTM/ Goddard	Thompson	None	MYJ	RUC

Model	Horiz/Vert Advection	Scalar Advection	Upper-Level Damping	SW Radiation Update	Land Use	MP Tend Limit	Time-Step
RAP	$5^{th}/3^{rd}$	Monotonic	Diffusive 0.02	30 min	USGS	0.01 K/s	60 s
HRRR	$5^{th}/3^{rd}$	Monotonic	Diffusive 0.02	30 min	USGS	0.10 K/s	18-23 s

RAP and HRRR Config 2012

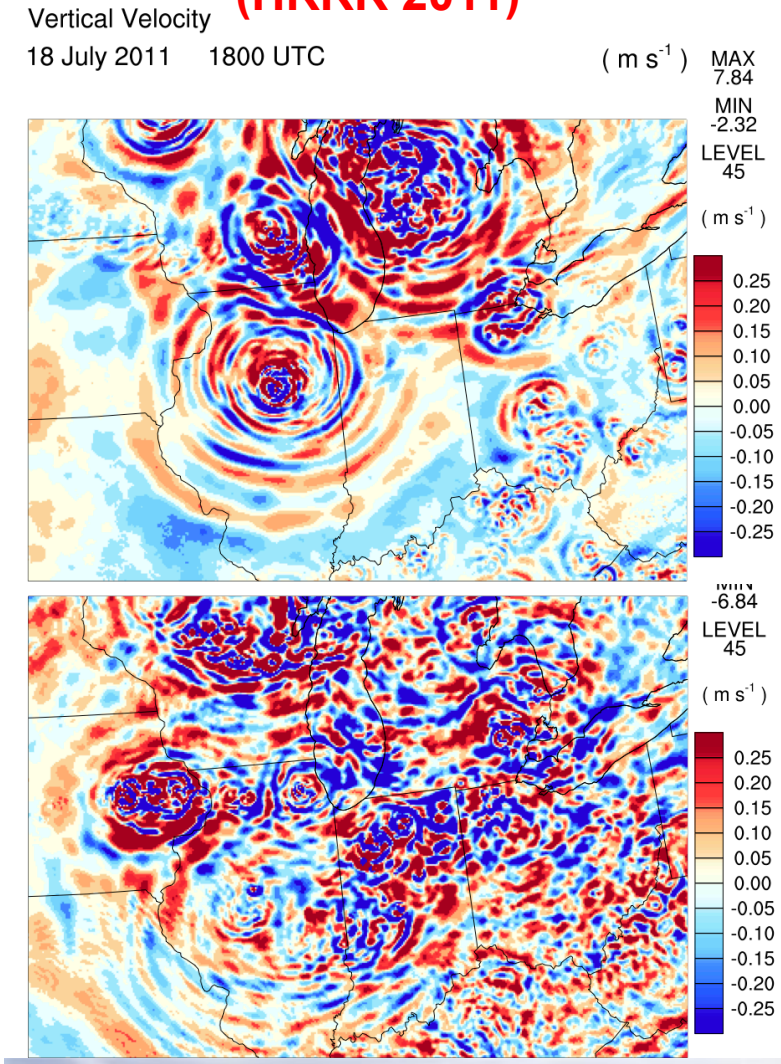
Model	Run at:	Domain	Grid Points	Grid Spacing	Vertical Levels	Pressure Top	Boundary Conditions	Initialized
RAP	GSD, NCO	North America	758 x 567	13 km	50	10 mb	GFS	Hourly (cycled)
HRRR	GSD	CONUS	1799 x 1059	3 km	50	20 mb	RAP	Hourly - RAP (no-cycle)

Model	Version	Assimilation	Radar DFI	Radiation	Microphysics	Cum Param	PBL	LSM
RAP	WRF-ARW v3.3.1+	GSI-3DVAR	Yes	RRTM/ Goddard	Thompson	G3 + Shallow	MYJ	RUC
HRRR	WRF-ARW v3.3.1+	None: RAP I.C.	No	RRTM/ Goddard	Thompson	None	MYJ	RUC

Model	Horiz/Vert Advection	Scalar Advection	Upper-Level Damping	SW Radiation Update	Land Use	MP Tend Limit	Time-Step
RAP	$5^{th}/5^{th}$	Positive-Definite	w-Rayleigh 0.2	10 min	MODIS Fractional	0.01 K/s	60 s
HRRR	$5^{th}/5^{th}$	Positive-Definite	w-Rayleigh 0.2	5 min	MODIS Fractional	0.07 K/s	20-23 s

Upper-Level Damping Upgrade

Diffusive Damping (HRRR 2011)

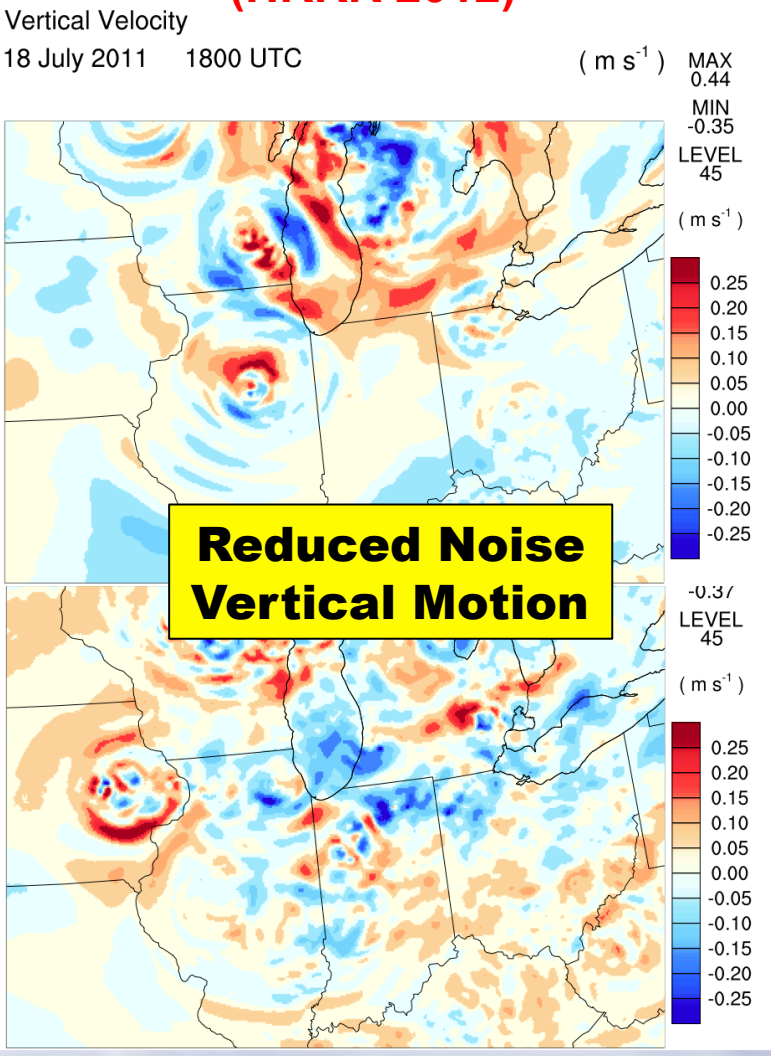


Vertical Velocity at Level 45 (~15 km MSL)

2 hr fcst
Valid 18z
18 July 2011

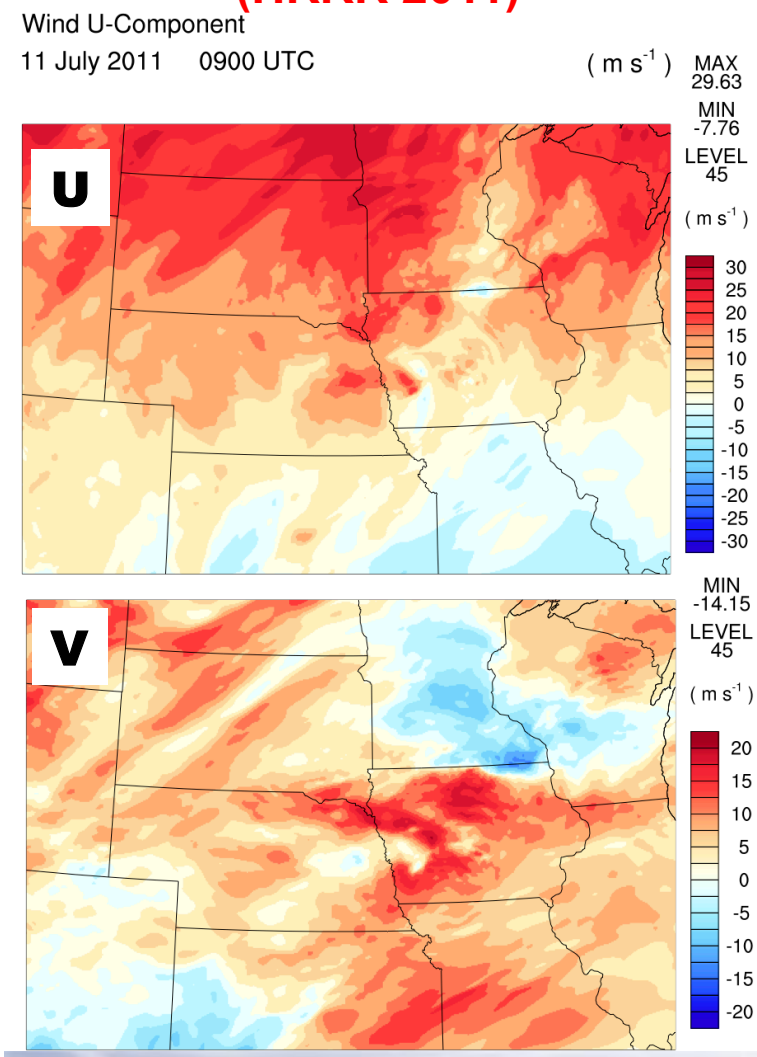
5 hr fcst
Valid 21z
18 July 2011

w-Rayleigh Damping (HRRR 2012)



Upper-Level Damping Upgrade

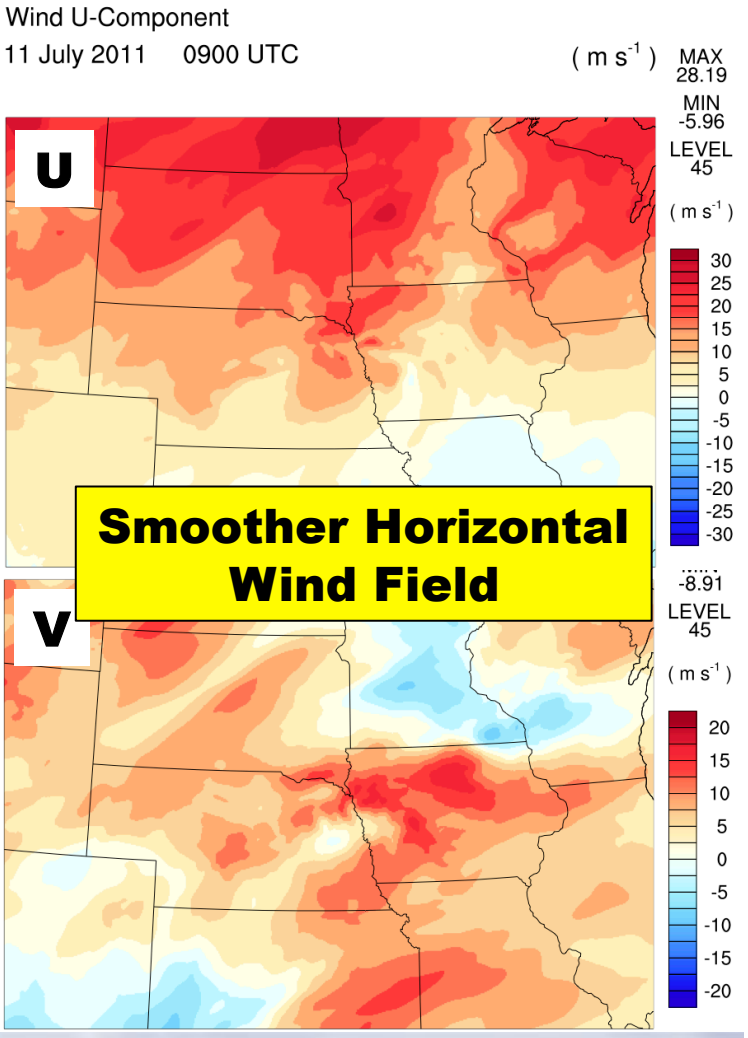
Diffusive Damping (HRRR 2011)



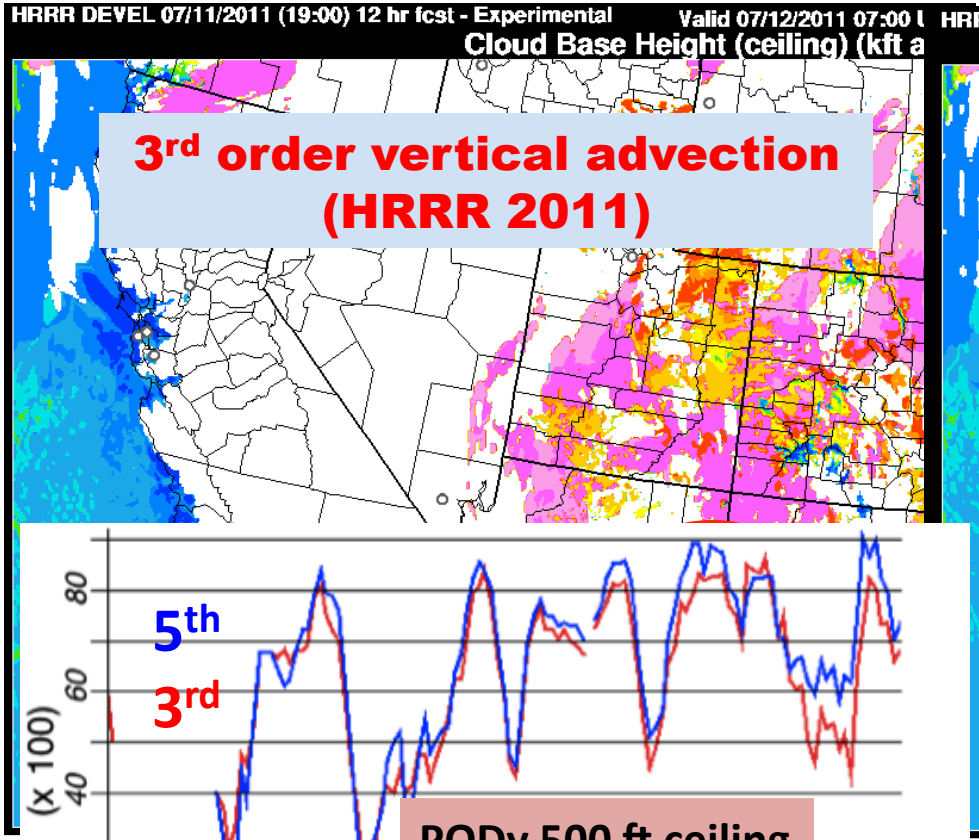
Horizontal Wind Components at Level 45 (~15 km MSL)

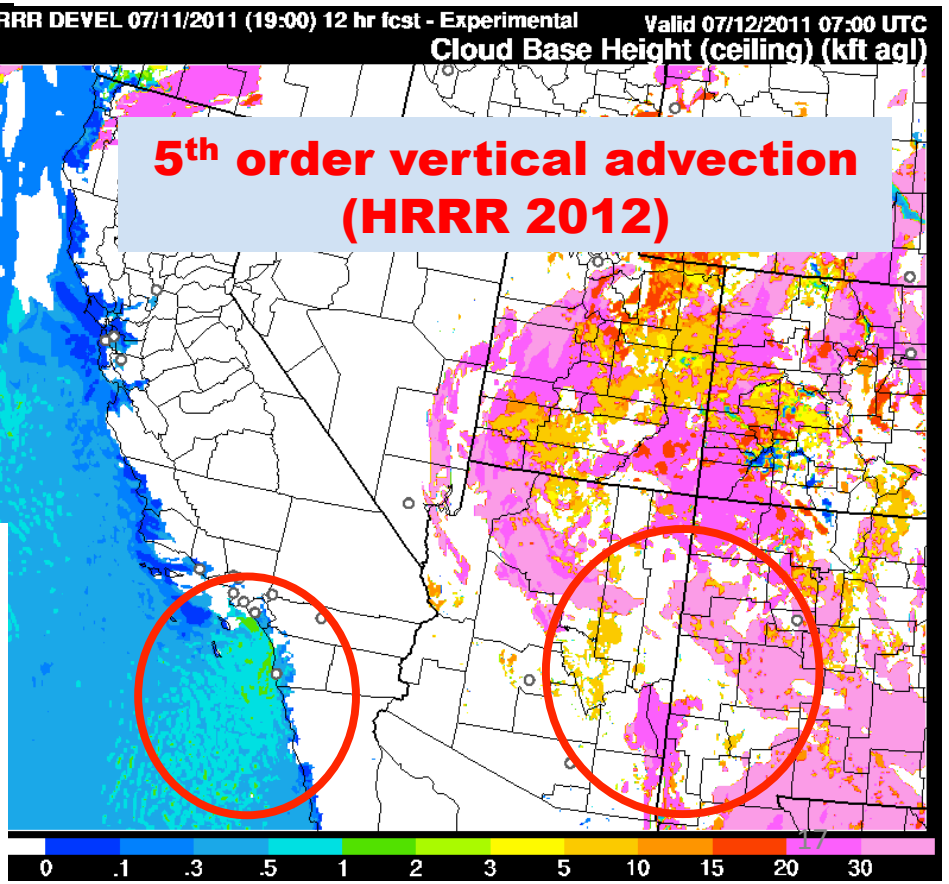
9 hr fcst
09z 11 July 2011

w-Rayleigh Damping (HRRR 2012)



Vertical Advection Upgrade





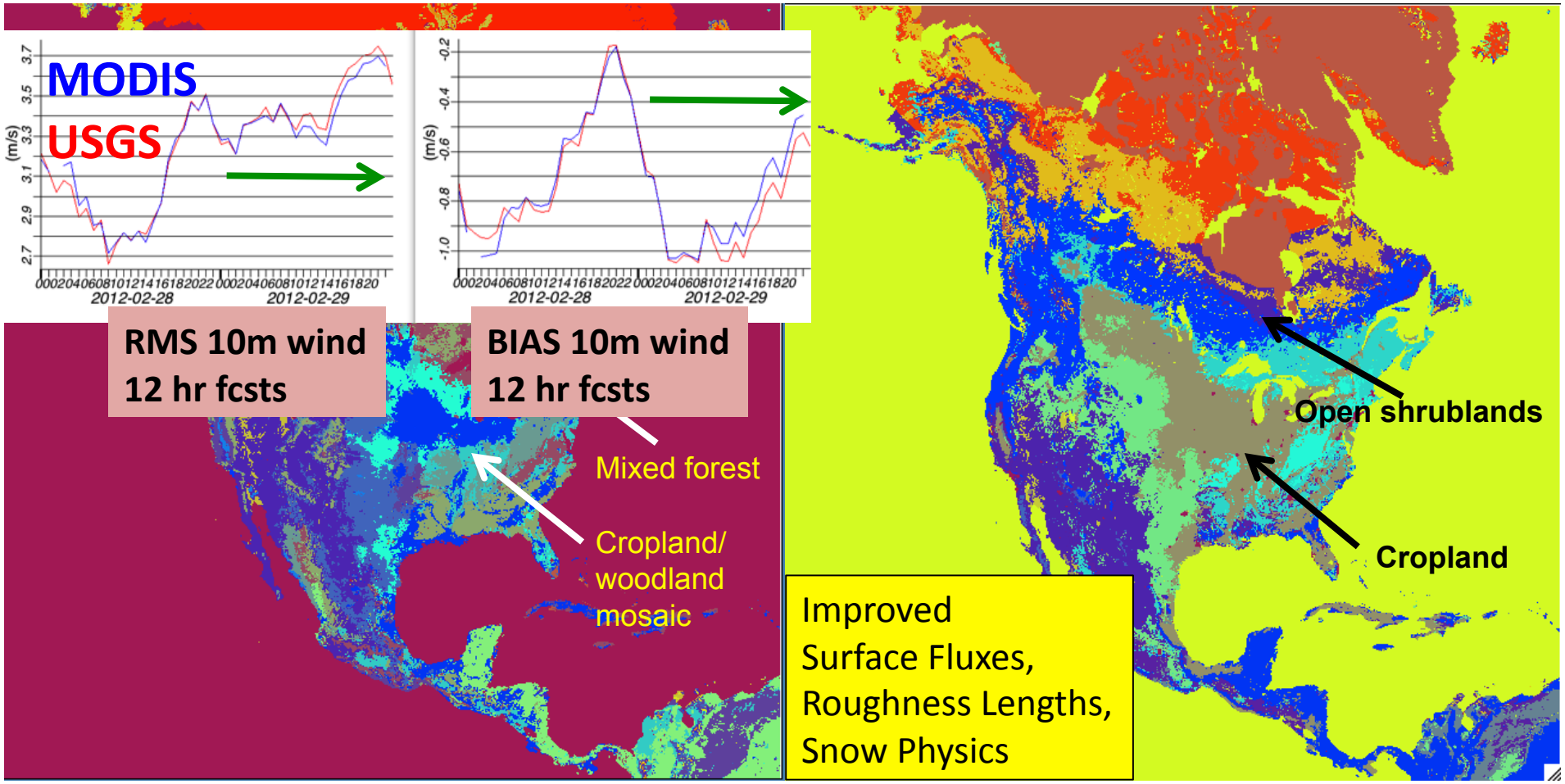
Slightly higher ceiling in marine stratocumulus, Less eroding of clouds

Land Use Upgrade

Capability to use MODIS land use categories with RUC LSM
Mosaic approach to specify land use properties

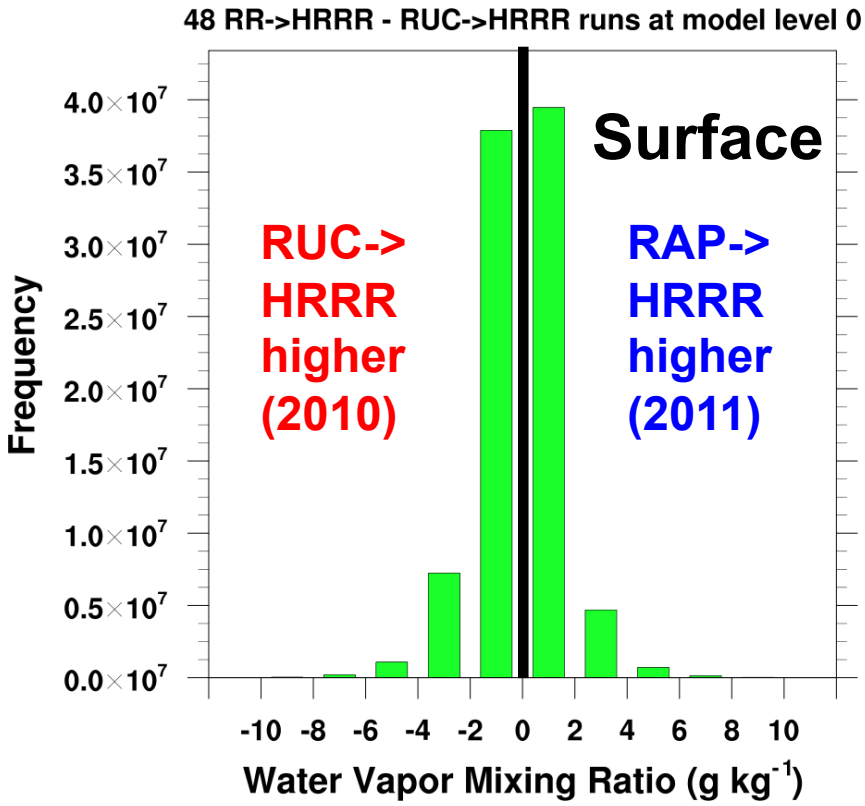
24 USGS category (RAP/HRRR 2011)

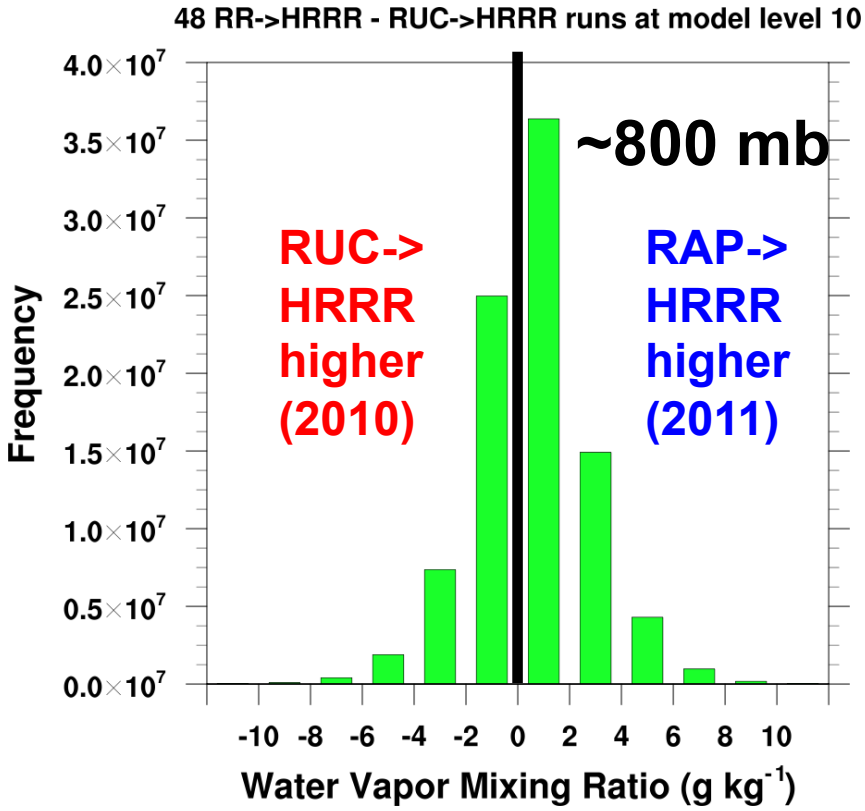
20 MODIS categories (RAP/HRRR 2012)



HRRR Water Vapor Histograms

CONUS
11-22 August 2011
0 hr Analysis on 3km grid





Moisture differences large enough to affect convective forecasts

HRRR Forecast Behavior

2011

(1) High bias in convection over eastern US

(2) False alarms

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

(4) Difficulty maintaining mesoscale convective systems

(5) Reflectivity biases in snow and convective storms

RAP/HRRR Model Development and Evaluation

2012 Targets

(1) Lower peak bias in convection over eastern US

(2) Fewer false alarms

(3) Improved timing of convective initiation

(4) More success maintaining mesoscale convective systems

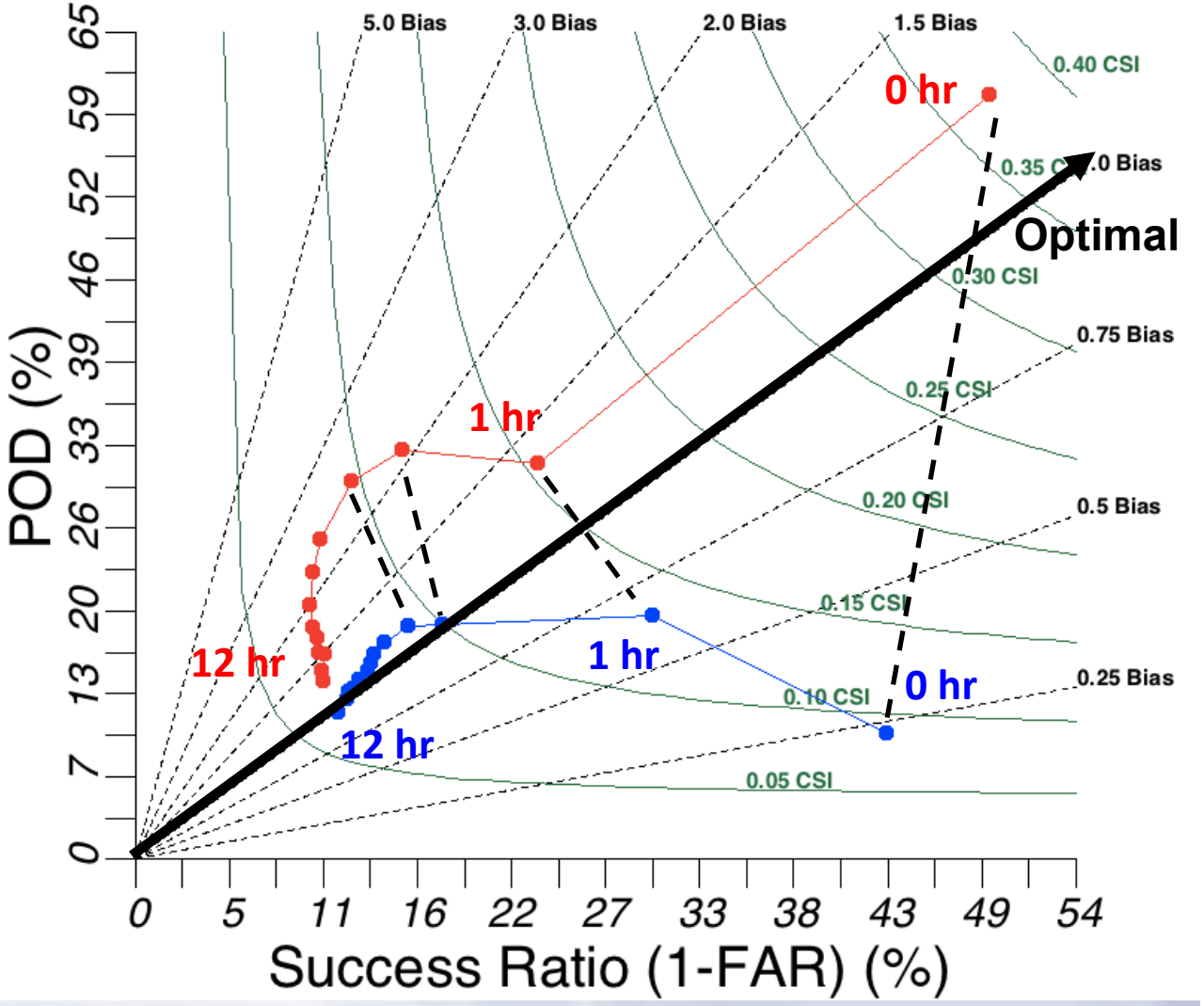
(5) More realistic reflectivity

HRRR June Retro Verification

Reflectivity ≥ 30 dBZ **03km** **Eastern US** **160 cases 29 May – 12 June 2011**

HRRR 2011 (real-time)
HRRR 2012 (retro)

Reduced high bias in first 6 hrs and improved CSI

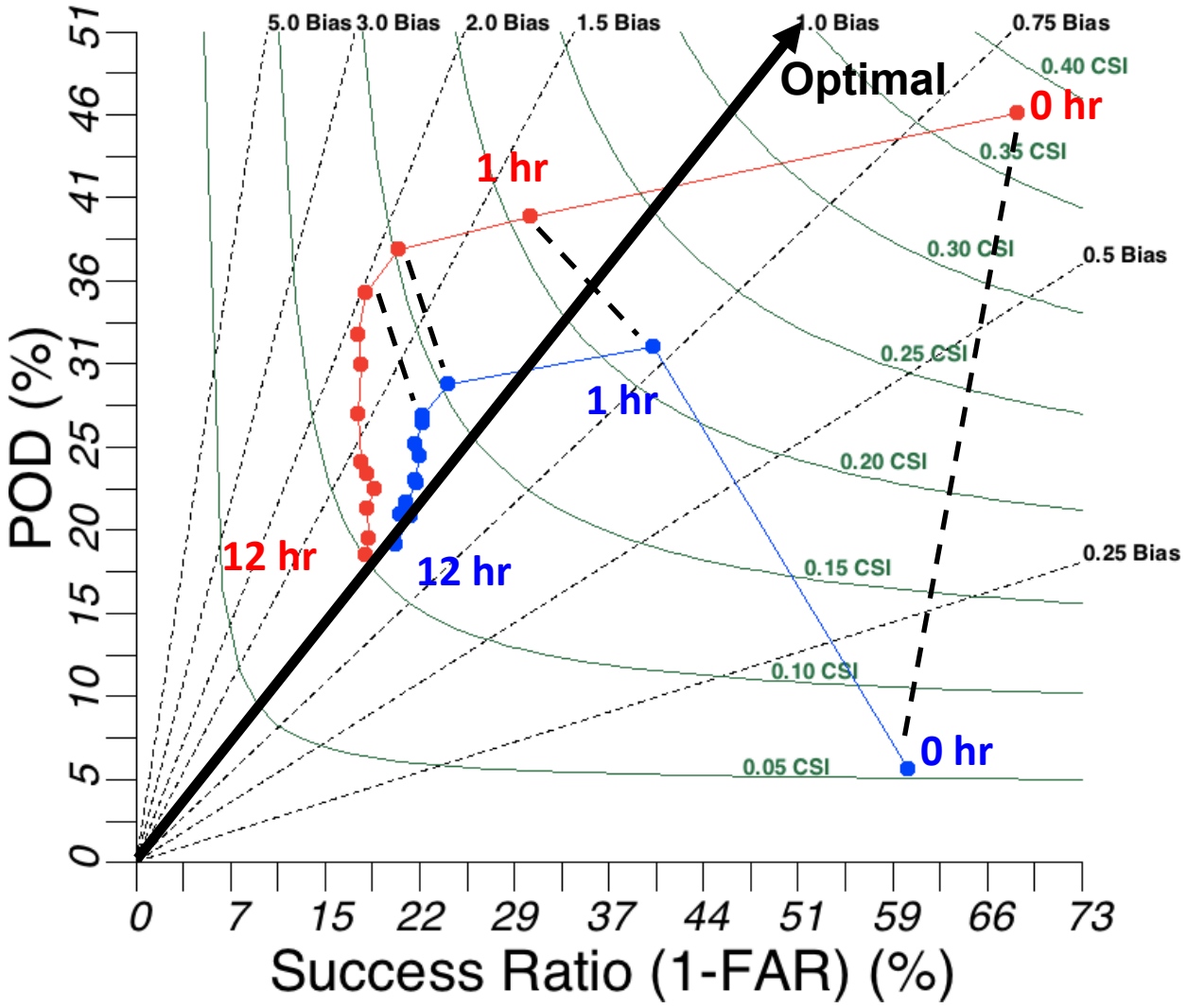


HRRR June Retro Verification

Reflectivity ≥ 30 dBZ **40km** **Eastern US** **160 cases 29 May – 12 June 2011**

HRRR 2011 (real-time)
HRRR 2012 (retro)

Reduced high bias in first 6 hrs and improved CSI

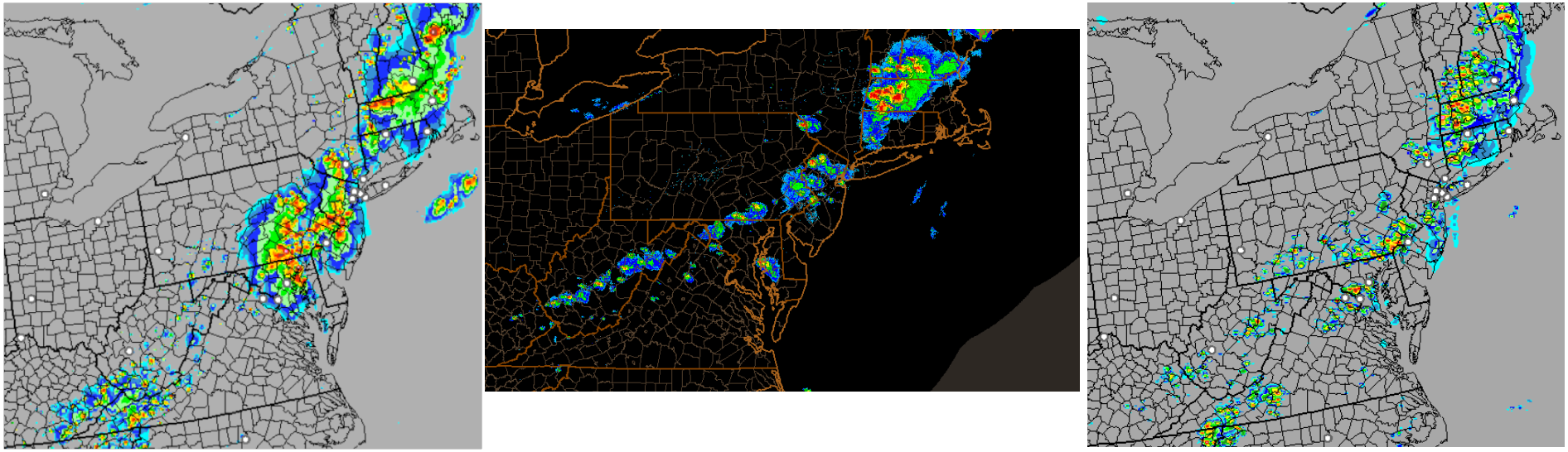


HRRR Retro Case Studies

HRRR 4hr fcst 2011 Real-Time

20z 01 June 2011 Observations

HRRR 4hr fcst 2012 Version



Composite Reflectivity (dBZ)

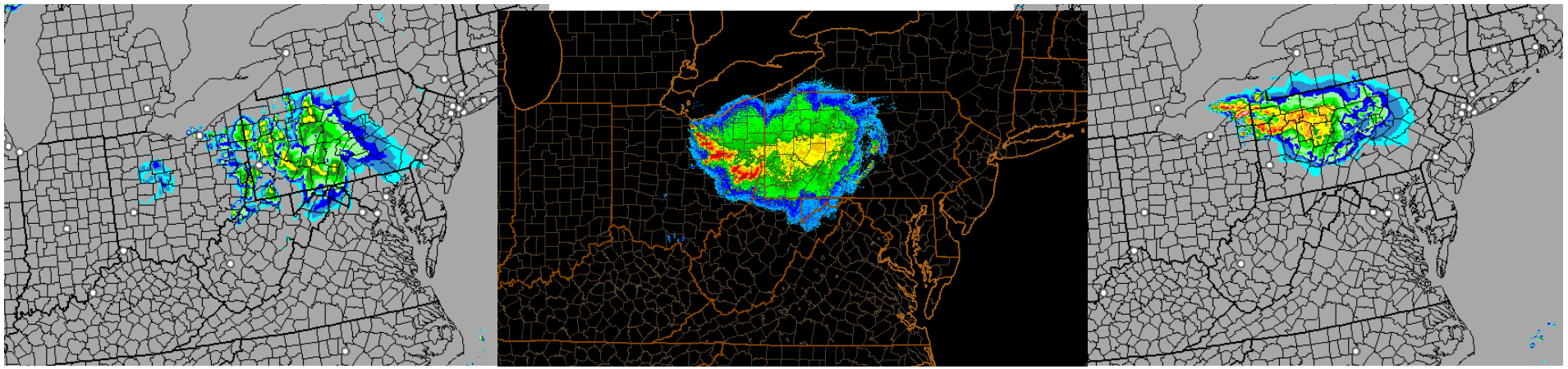
Large reduction in false alarm (excessive) convection
Improved structure to broken convective line

HRRR Retro Case Studies

HRRR 7hr fcst 2011 Real-Time

15z 07 June 2011 Observations

HRRR 7hr fcst 2012 Version



Composite Reflectivity (dBZ)

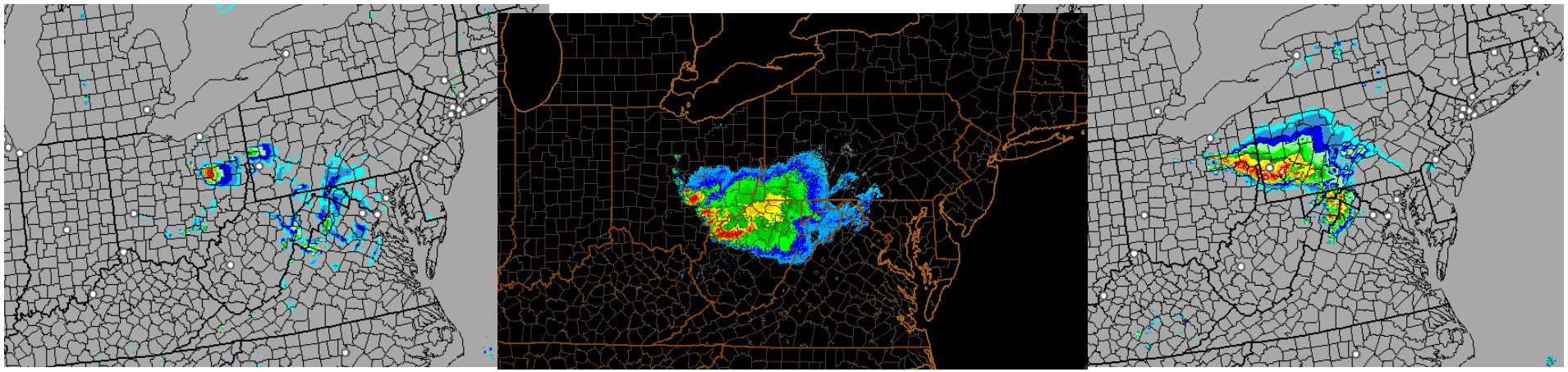
Improved mesoscale convective system (MCS) maintenance

HRRR Retro Case Studies

HRRR 10hr fcst 2011 Real-Time

18z 07 June 2011 Observations

HRRR 10hr fcst 2012 Version



Composite Reflectivity (dBZ)

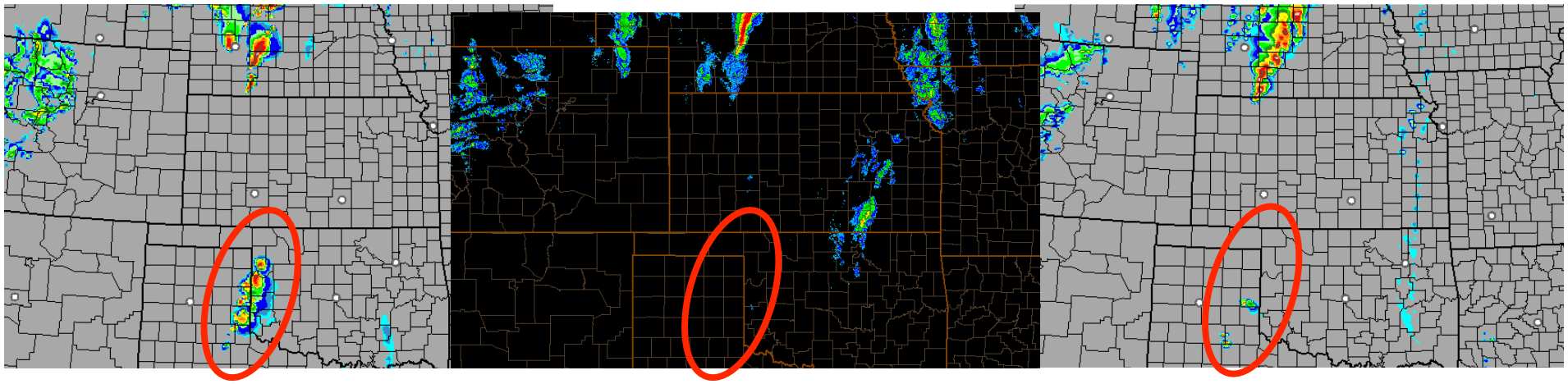
Improved mesoscale convective system (MCS) maintenance

HRRR Retro Case Studies

HRRR 8hr fcst 2011 Real-Time

00z 31 May 2011 Observations

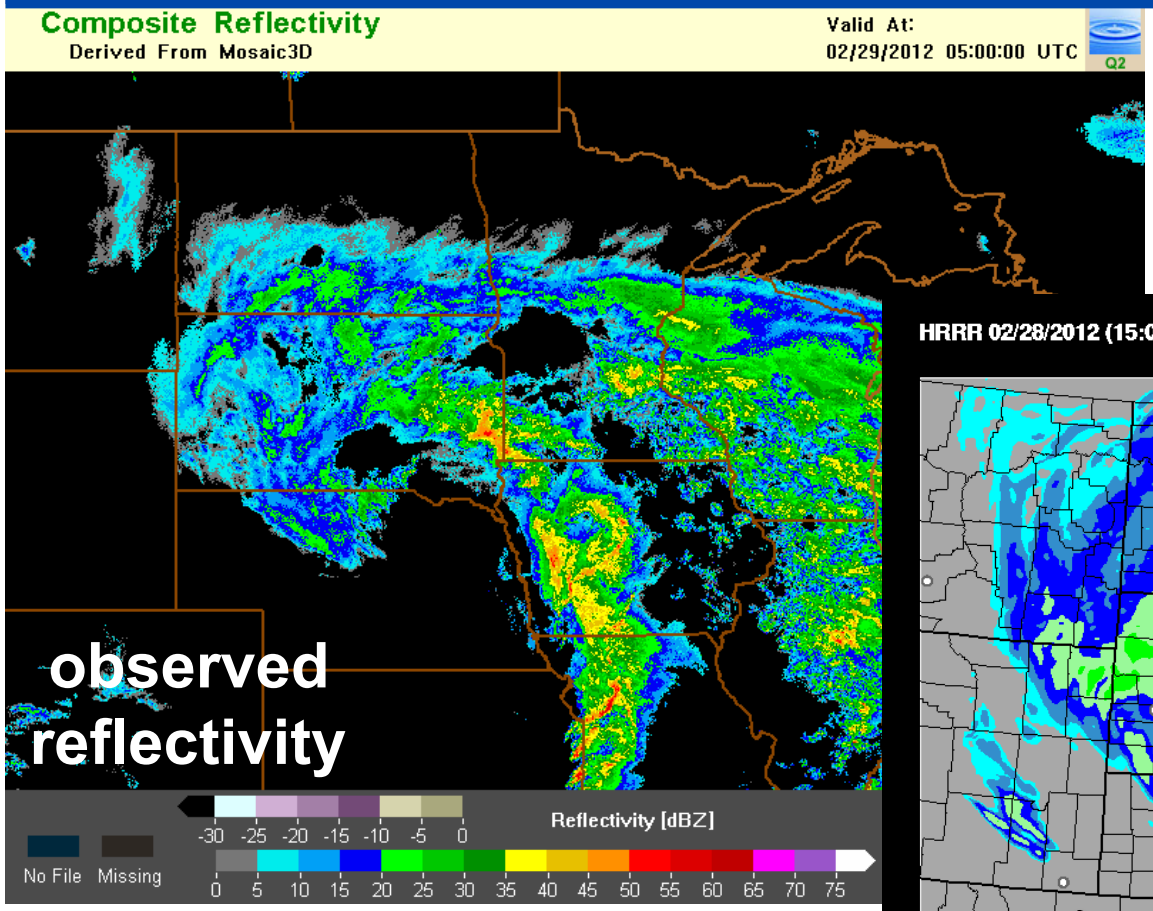
HRRR 8hr fcst 2012 Version

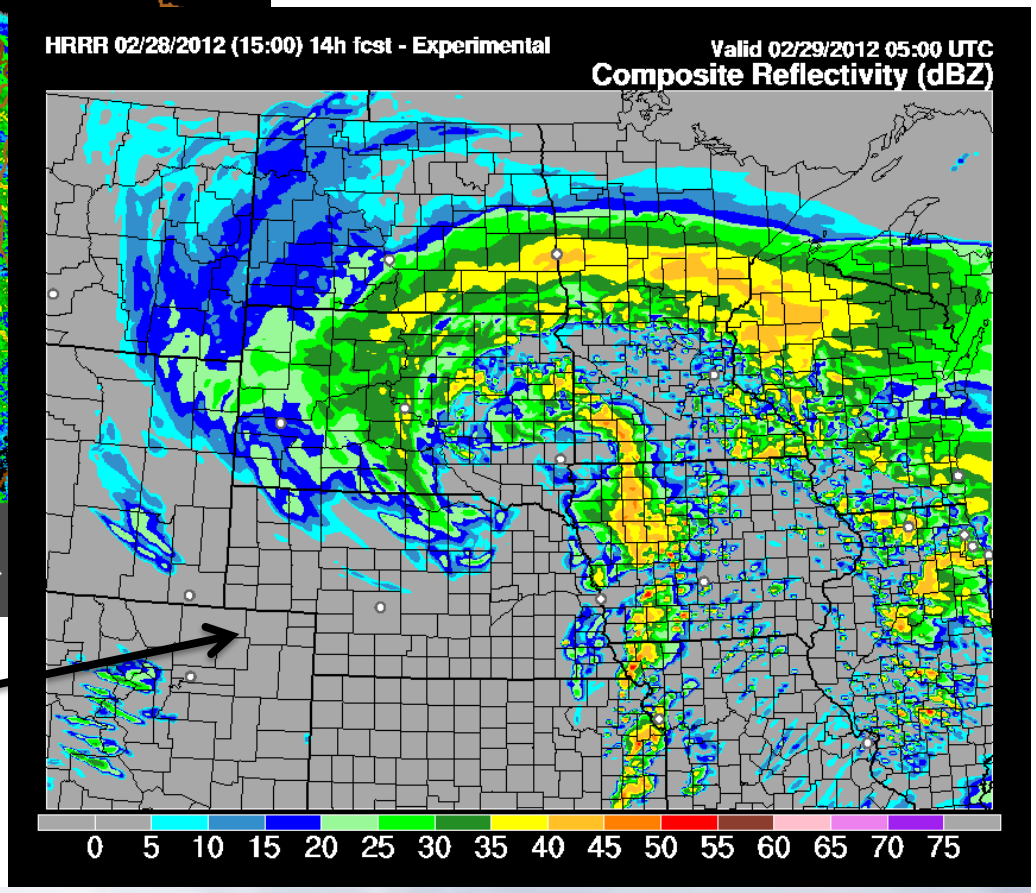


Composite Reflectivity (dBZ)

Reduction in false alarm convective initiation

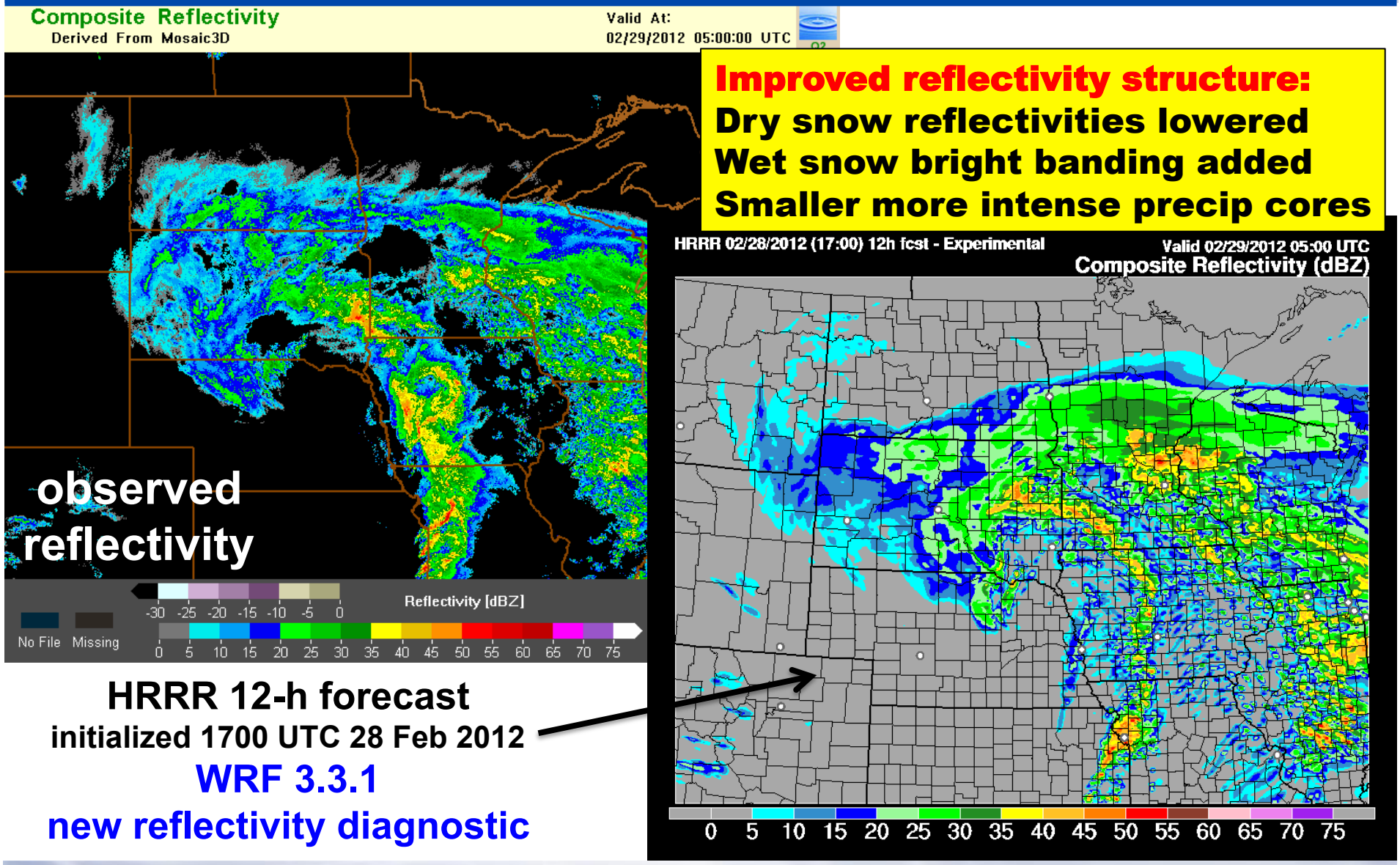
Reflectivity Diagnostic Upgrade





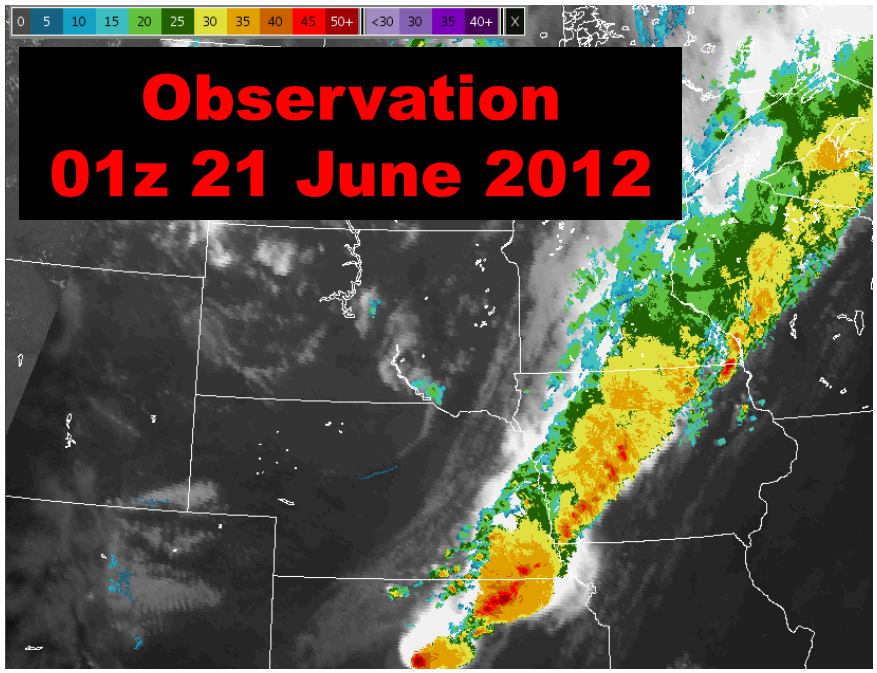
HRRR 14-h forecast
initialized 1500 UTC 28 Feb 2012
WRF 3.2
old reflectivity diagnostic

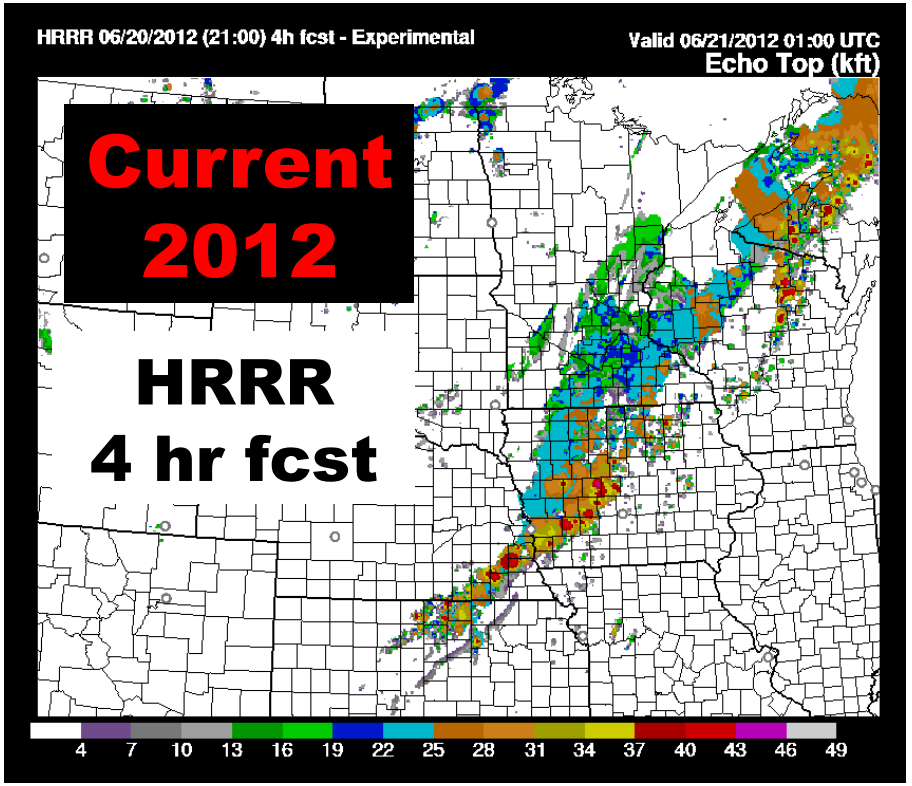
Reflectivity Diagnostic Upgrade

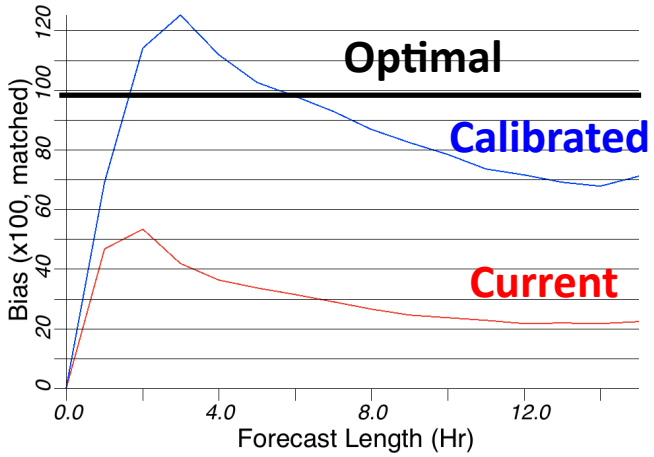


HRRR 12-h forecast
initialized 1700 UTC 28 Feb 2012
WRF 3.3.1
new reflectivity diagnostic

Echo Top Height Challenge



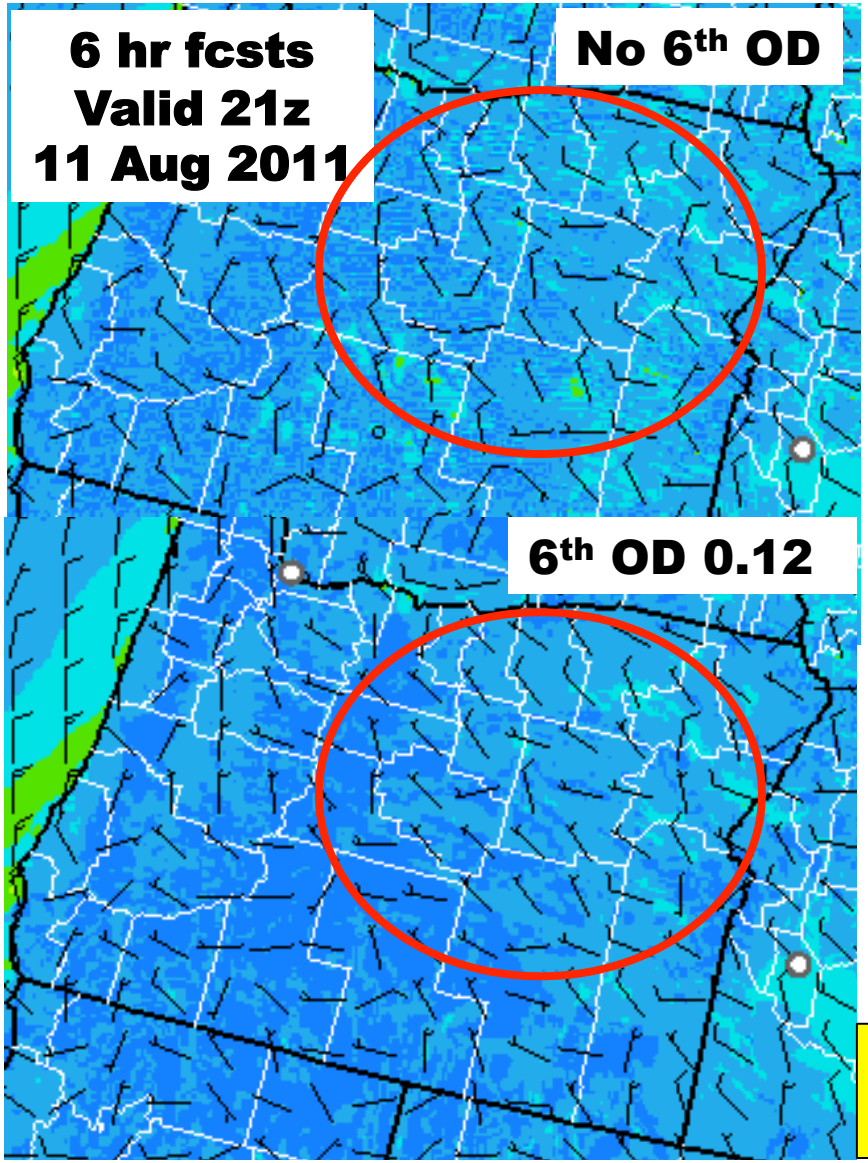




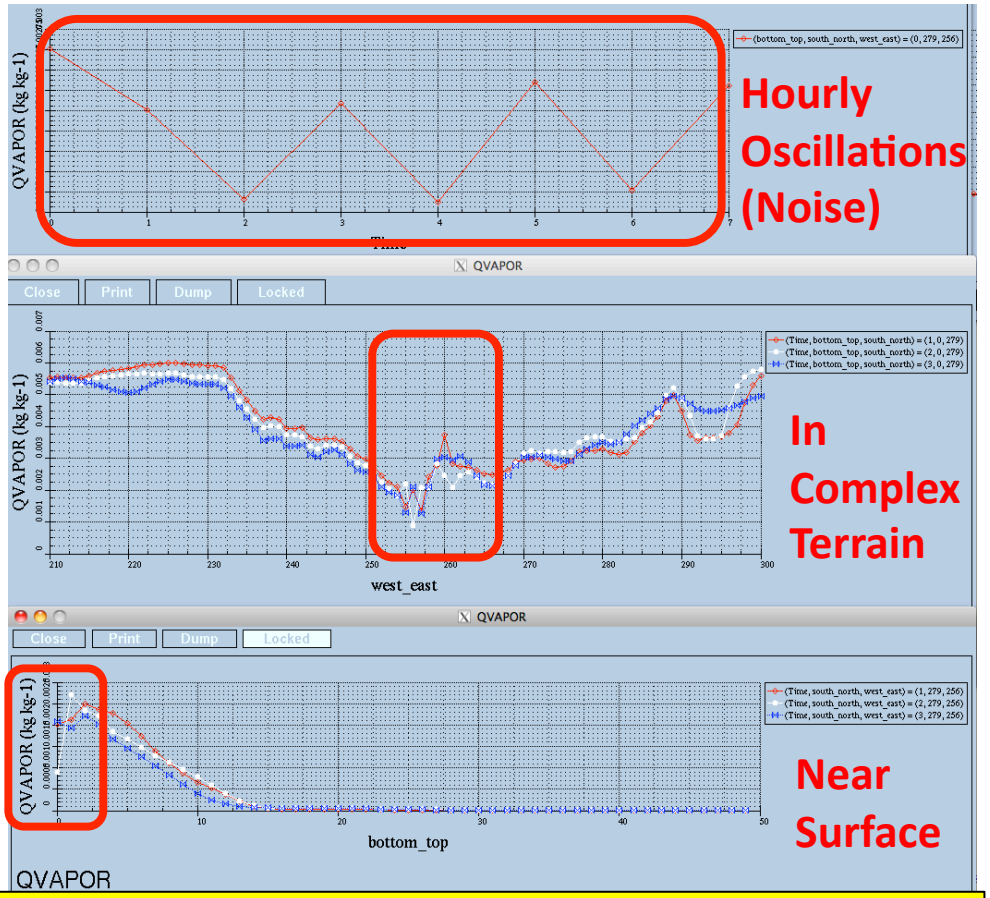
18 dBZ Echo Tops > 30 kft Eastern US
BIAS 03 km
10-28 June 2012

Current 2012 low bias in echo tops after reflectivity diagnostic made consistent with microphysics

6th Order Diffusion Challenge

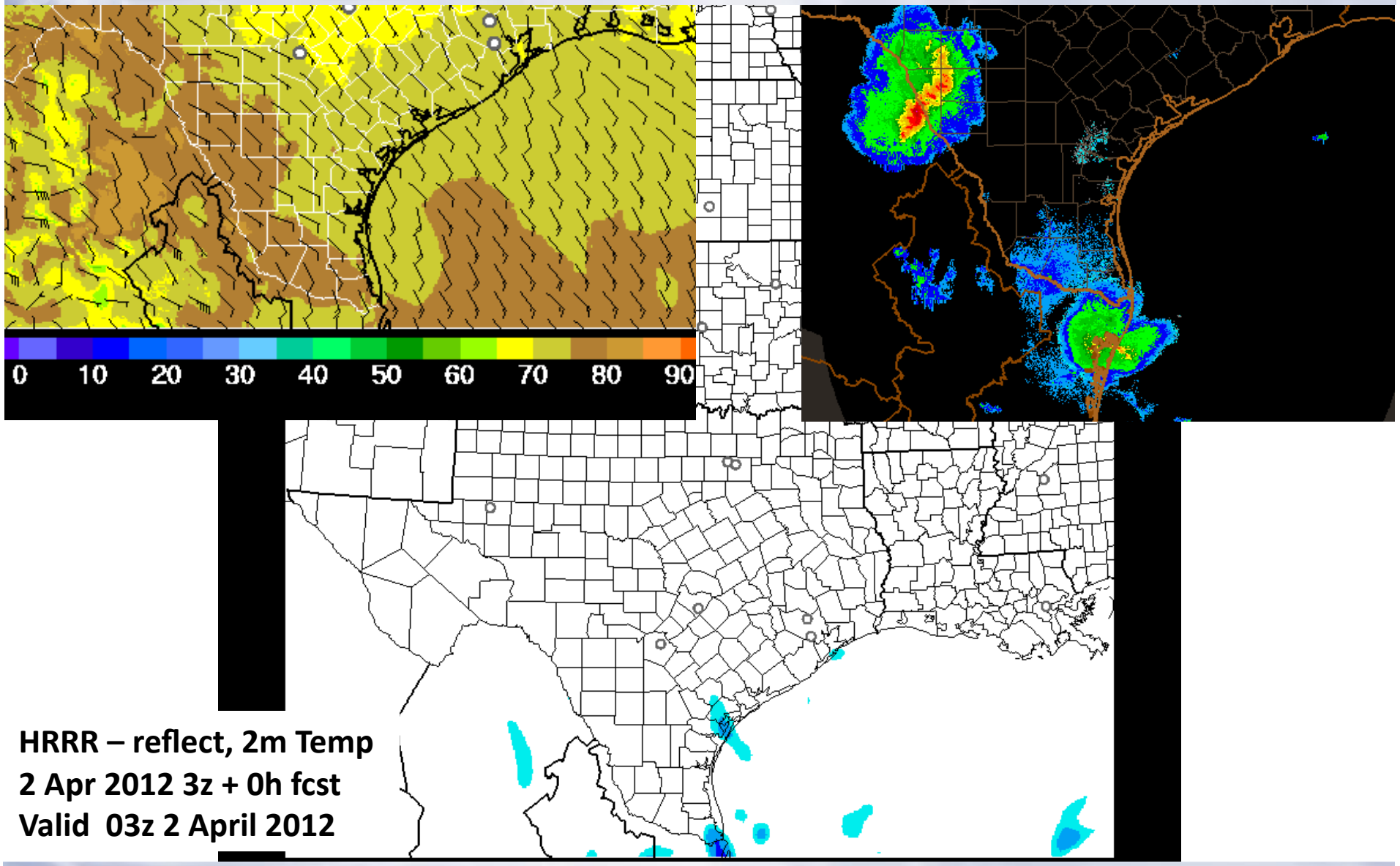


6th OD 0.03
Water Vapor (and other fields)



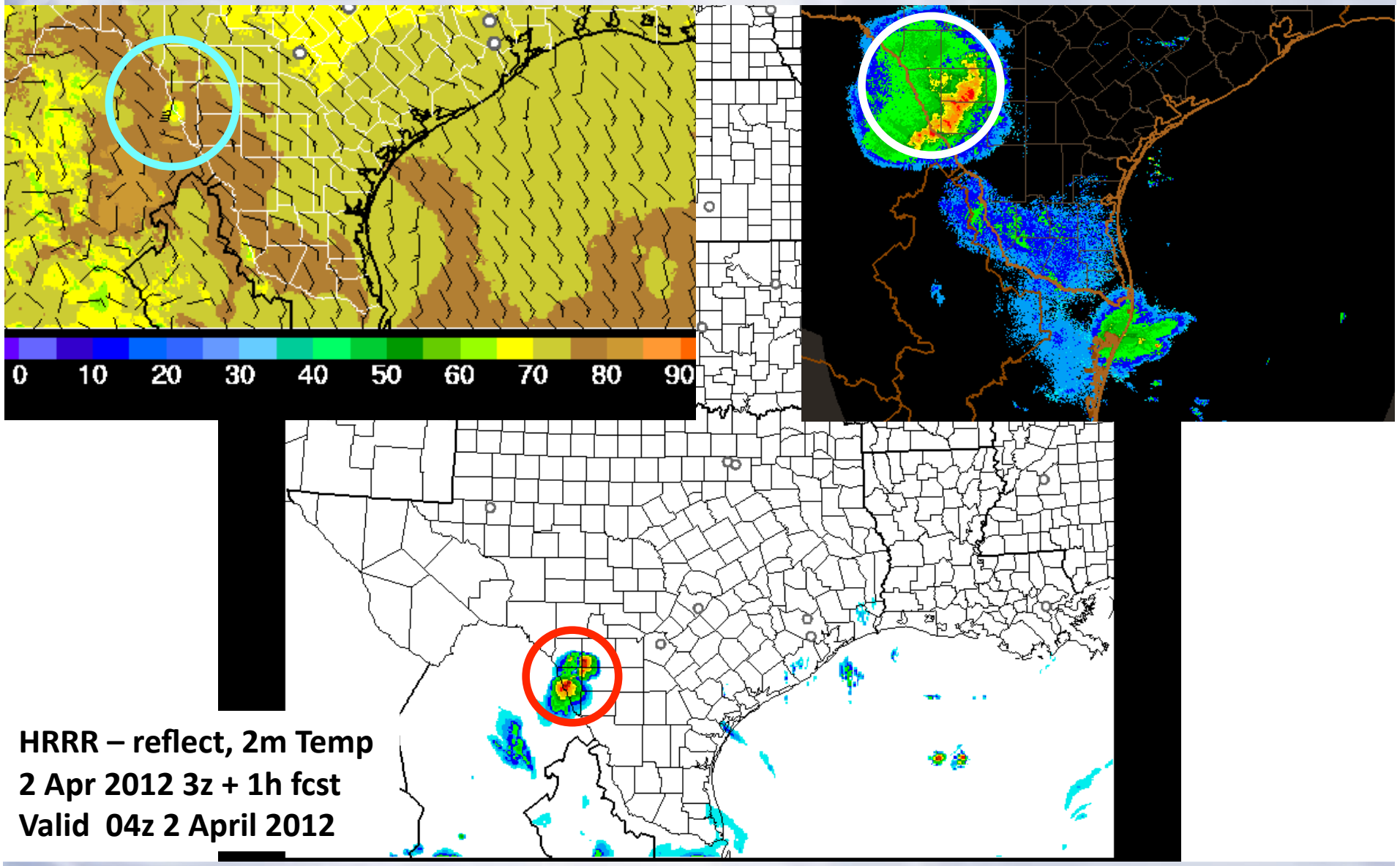
Noise increases with higher 6th OD
Detected with values as low as 0.001

Convective System Challenge



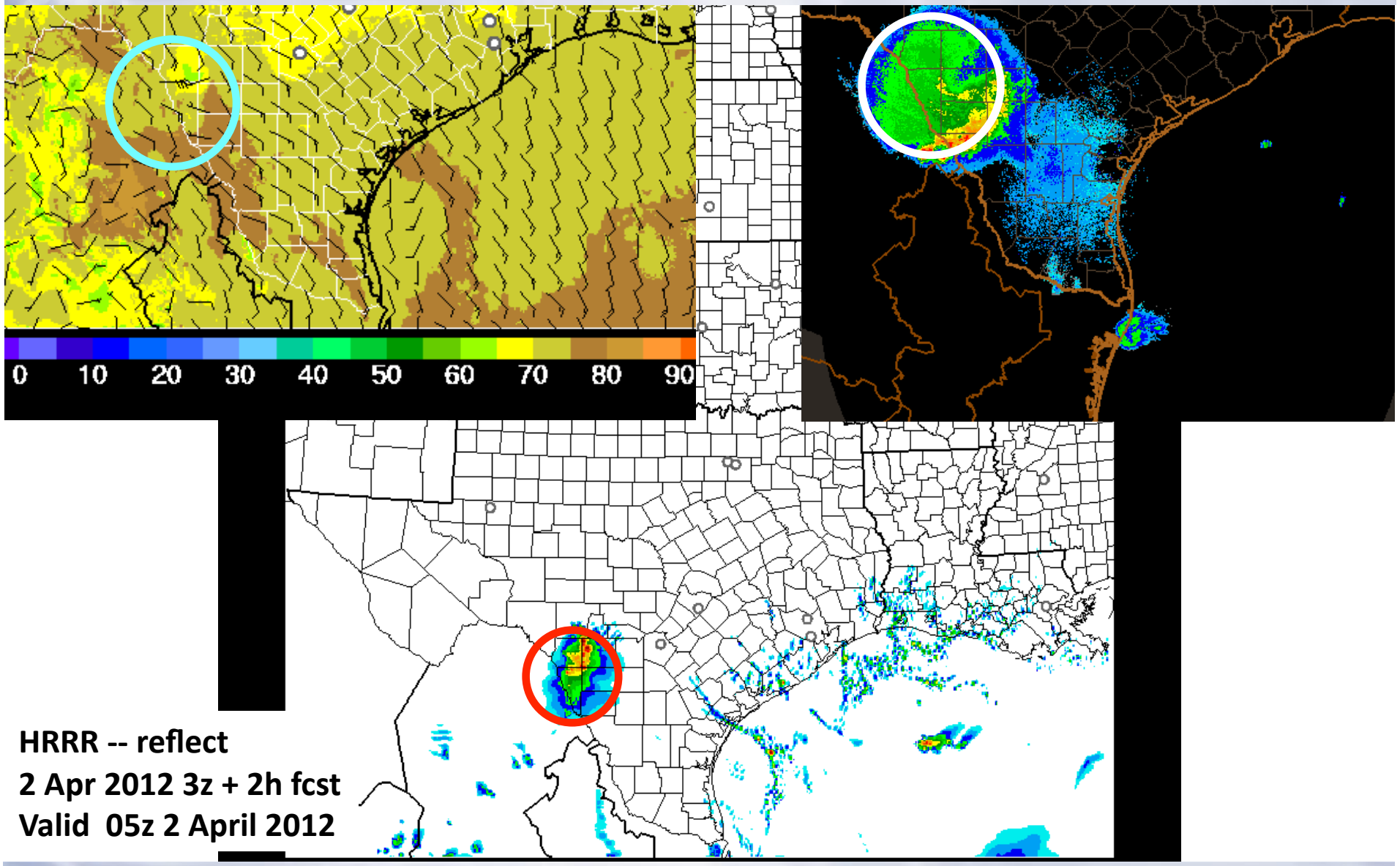
HRRR – reflect, 2m Temp
2 Apr 2012 3z + 0h fcst
Valid 03z 2 April 2012

Convective System Challenge



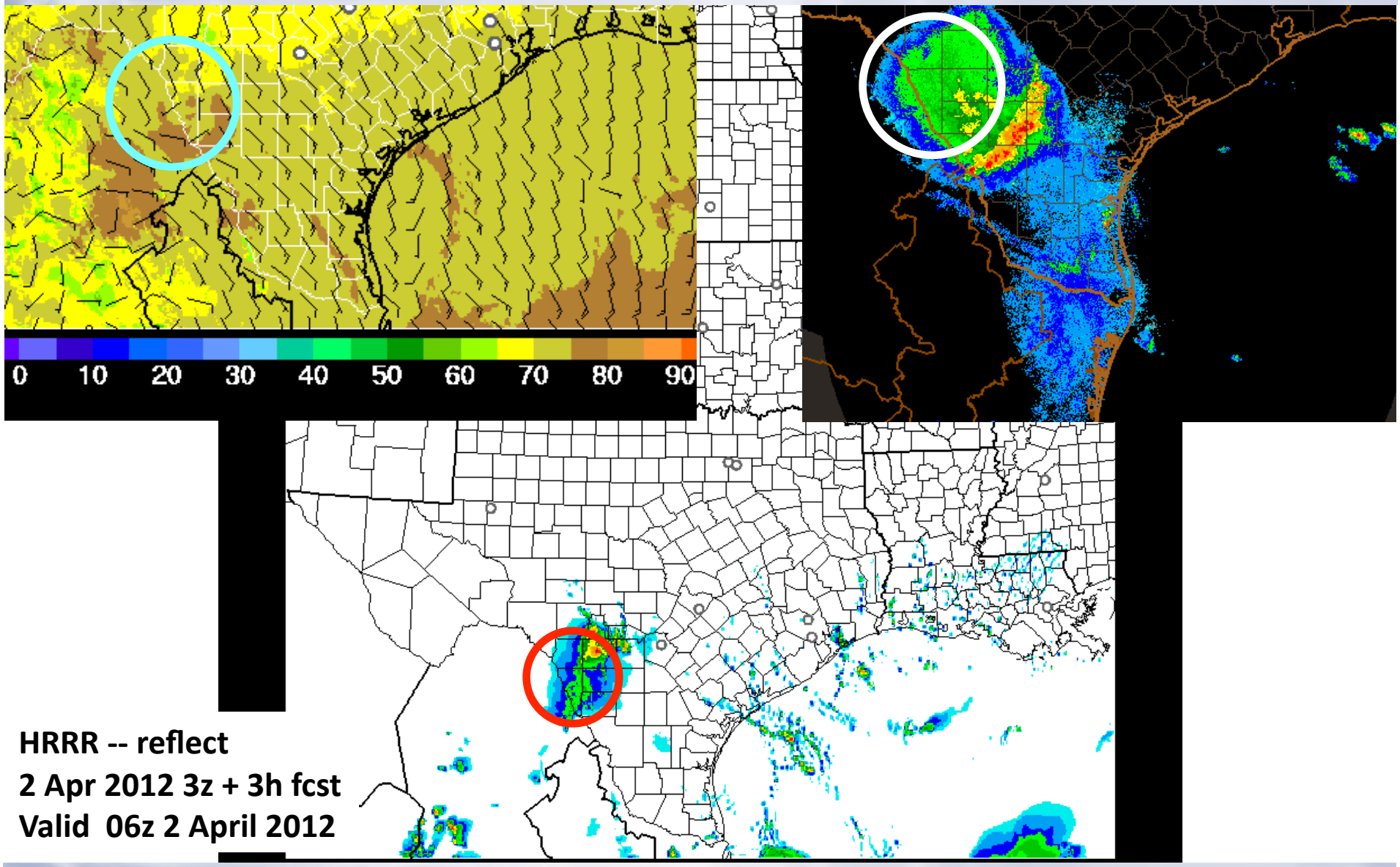
HRRR – reflect, 2m Temp
2 Apr 2012 3z + 1h fcst
Valid 04z 2 April 2012

Convective System Challenge



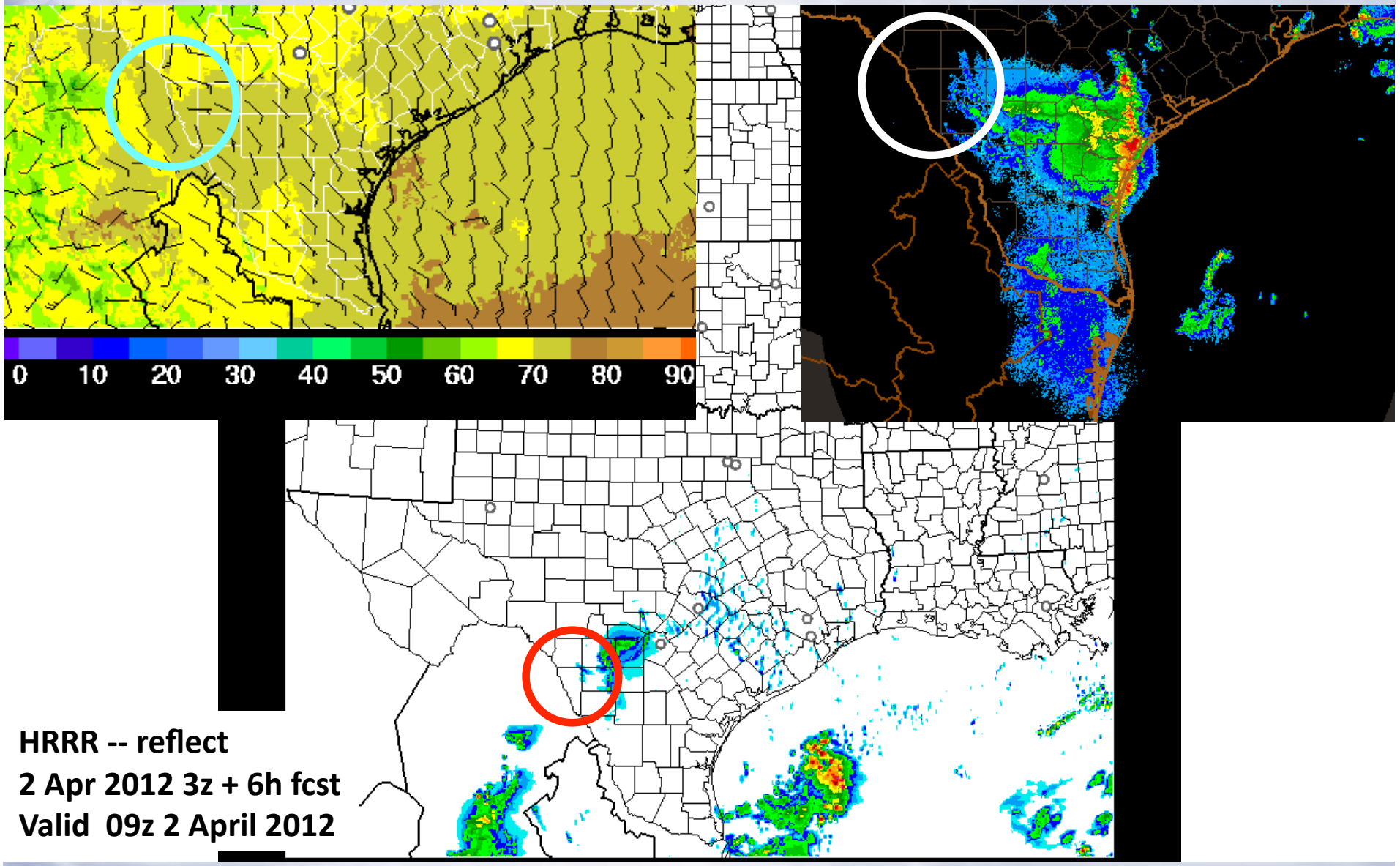
HRRR -- reflect
2 Apr 2012 3z + 2h fcst
Valid 05z 2 April 2012

Convective System Challenge



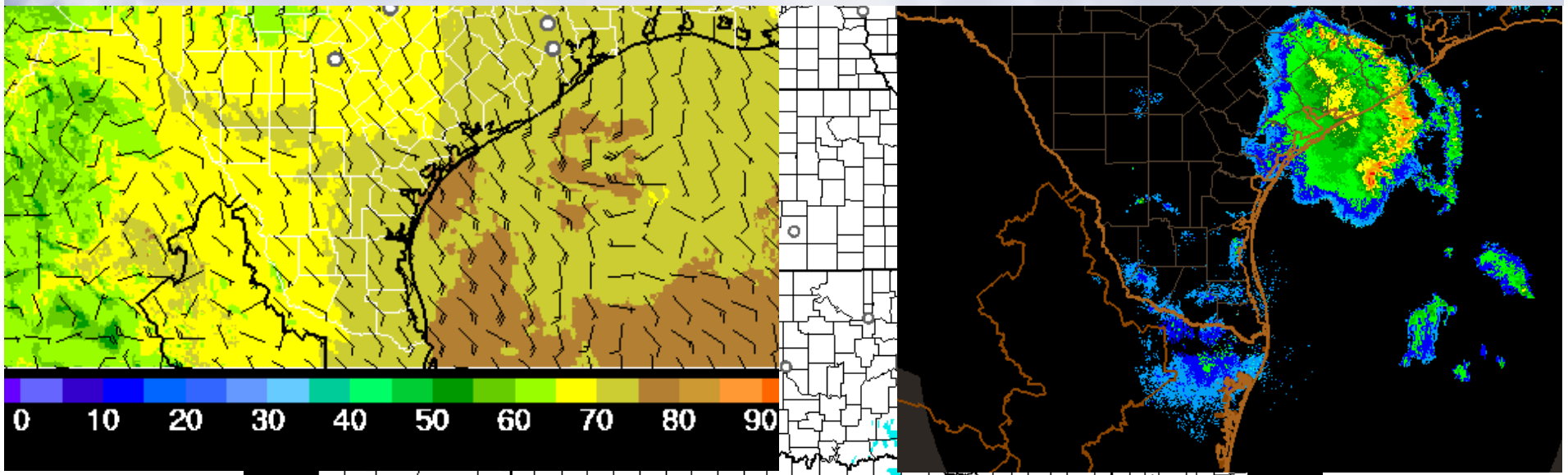
HRRR -- reflect
2 Apr 2012 3z + 3h fcst
Valid 06z 2 April 2012

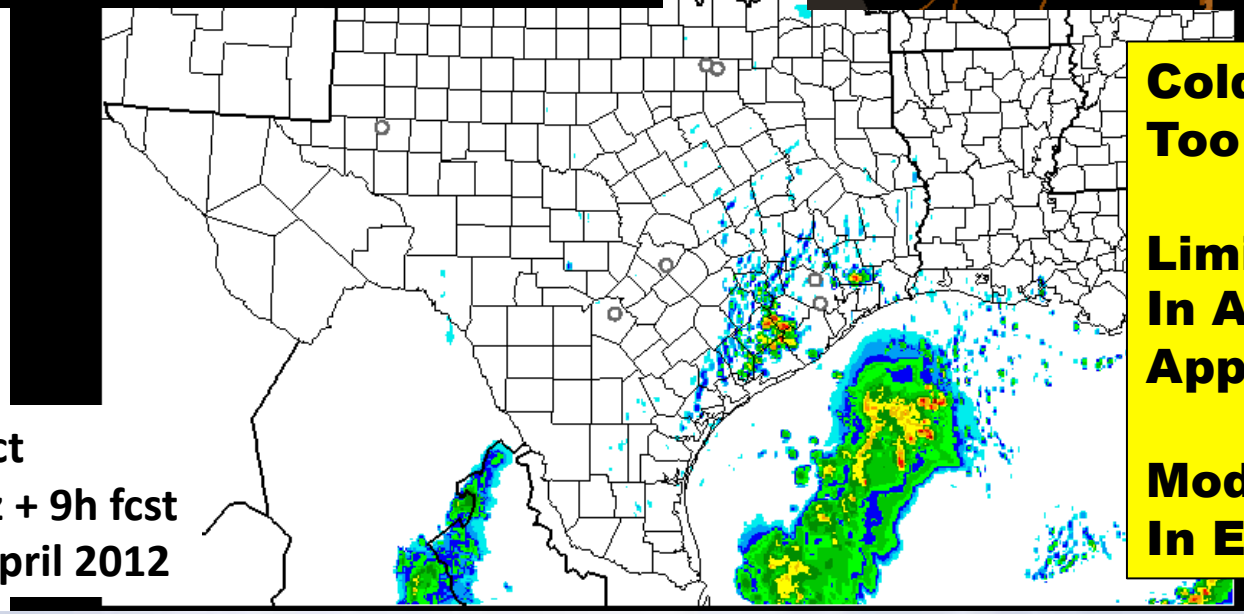
Convective System Challenge



HRRR -- reflect
2 Apr 2012 3z + 6h fcst
Valid 09z 2 April 2012

Convective System Challenge





HRRR -- reflect
2 Apr 2012 3z + 9h fcst
Valid 12z 2 April 2012

Cold Pool Too Weak?

Limitation In Assimilation Approach?

Model Error In Environment?

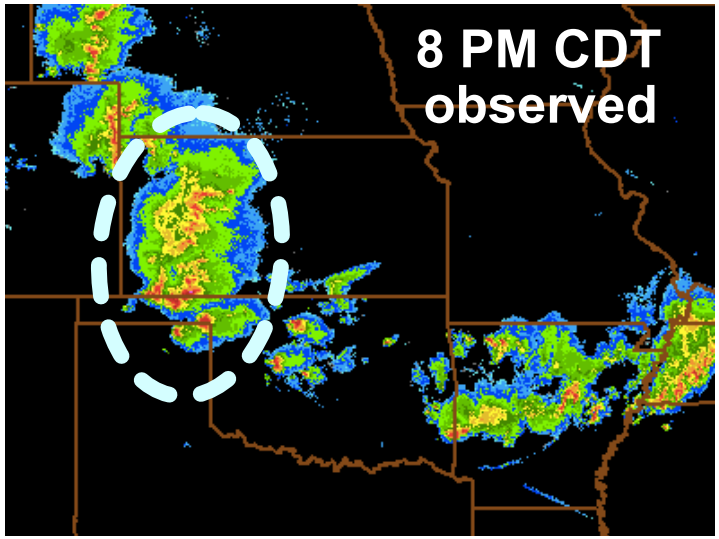
RAP and HRRR Resources

Model	Version	Initialized	Forecast Length	Run Time	# CPUs	Disk Space
RAP	WRFv3.3.1+	Hourly	18 hrs	~30 min	200	230 GB (per run)
HRRR	WRFv3.3.1+	Hourly	15 hrs	~50 min	1128	800 GB (per run)

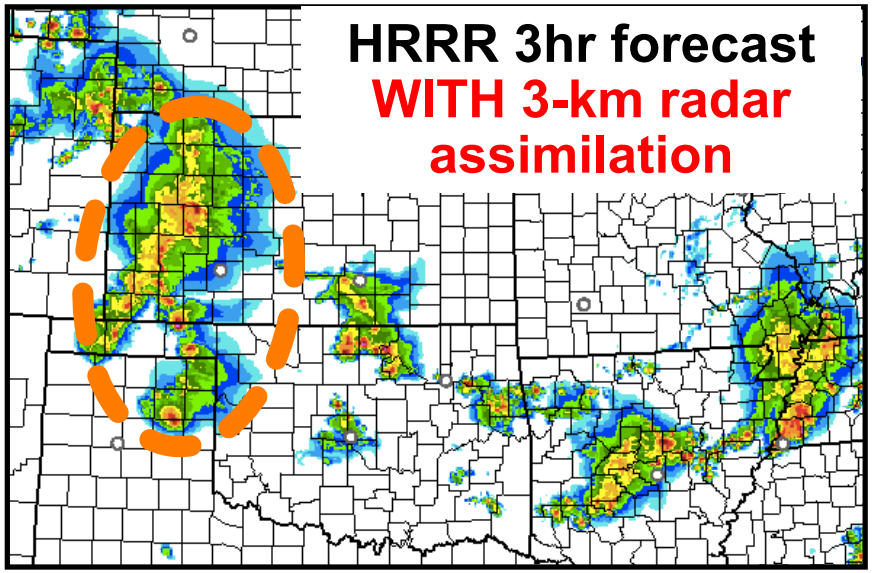
NOAA High-Performance Computer System	Number of Filesystems	Total Reserved Disk Space	CPU Type	Total Reserved CPUs	Performance Increase
Jet (current)	4	150 TB	Intel Nehalem	1736	-
Zeus (new)	2	230 TB	Intel Westmere	2000-4000	30%

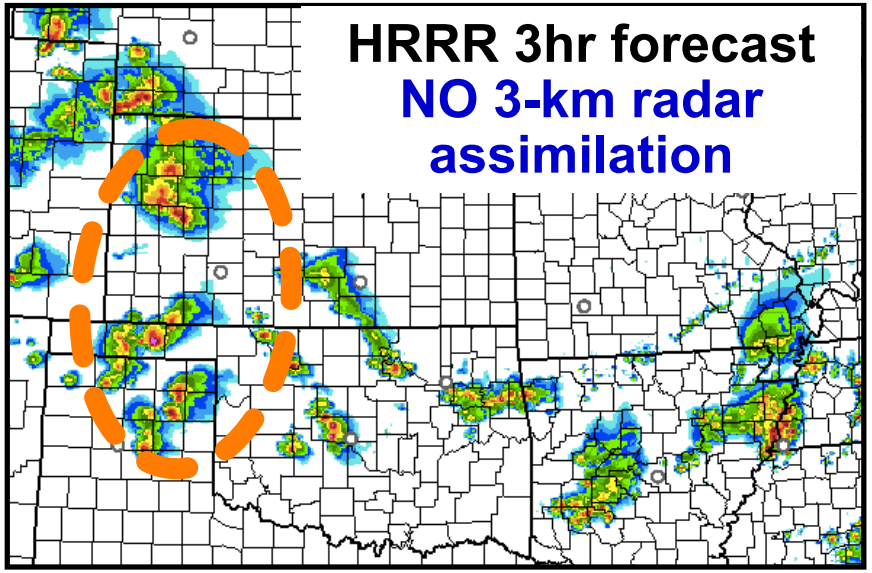
HRRR 2013 Upgrade

Sub-hourly 3-km HRRR radar assimilation



Better short-range forecasts storm details





HRRR Transition to NCEP

- **Current – 1 computer running HRRR**
  - NOAA/ESRL – Boulder
  - Current reliability: 97% for last 12h months (allowing up to 3h gaps)
- **2012-14 – 2 computers running HRRR – interim solution**
  - Boulder – computer 1
  - Fairmont, WV – computer 2
  - Expected reliability to increase further to 98.5-99% via coordination of downtimes for Boulder vs. Fairmont computers
- **2015 – NCEP running HRRR**
  - NOAA/NCEP computing budget – will allow no increase before 2015
- Conclusion***: Interim HRRR computing for 2012-14 on 2 sites to provide "research regular" HRRR from NOAA for NWS, FAA, DOE/energy users***

Summary and Plans

- **Moist bias reduced in 2012 RAP and HRRR**
  - Reduced false alarms, lower precipitation bias
  - GSI enhancements and WRF upgrade to v3.3.1
  - Reflectivity diagnostic consistent with microphysics
- **Focus on cycled 3-km assimilation for 2013**
  - 3-km variational analysis
  - 3-km non-variational cloud analysis
  - 3-km radar reflectivity data assimilation
- **Reduced latency for 2013 (currently 2-3 hrs)**
  - Approximate 1-hr reduction in execution time
  - Faster post-processing with parallelization
  - Direct GRIB2 generation