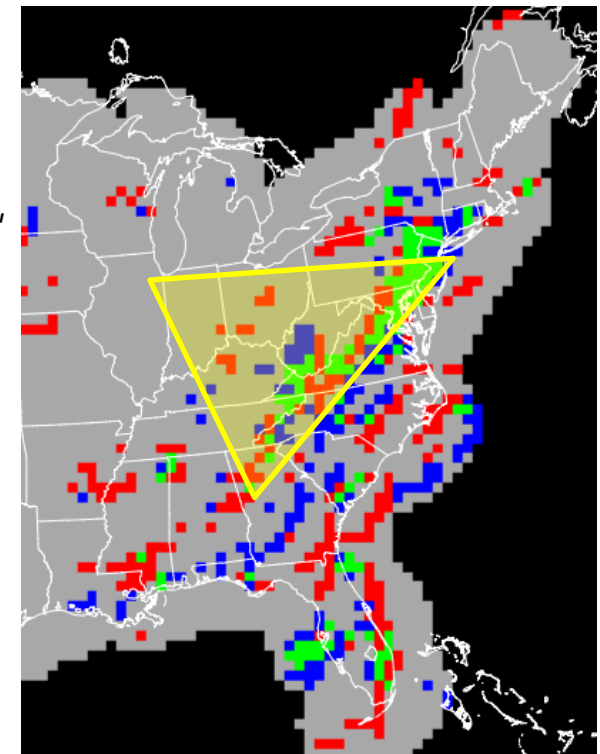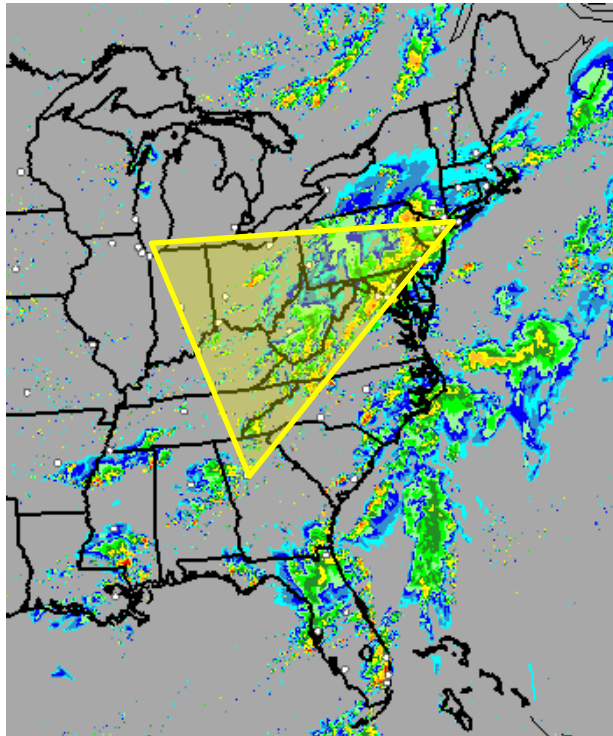# NOAA Weather Modeling with the RAP/HRRR

24 October 2013

**Curtis Alexander,
Stan Benjamin,
Steve Weygandt, David Dowell,
Tanya Smirnova, Eric James,
Patrick Hofmann, Ming Hu,
John Brown, Joe Olson
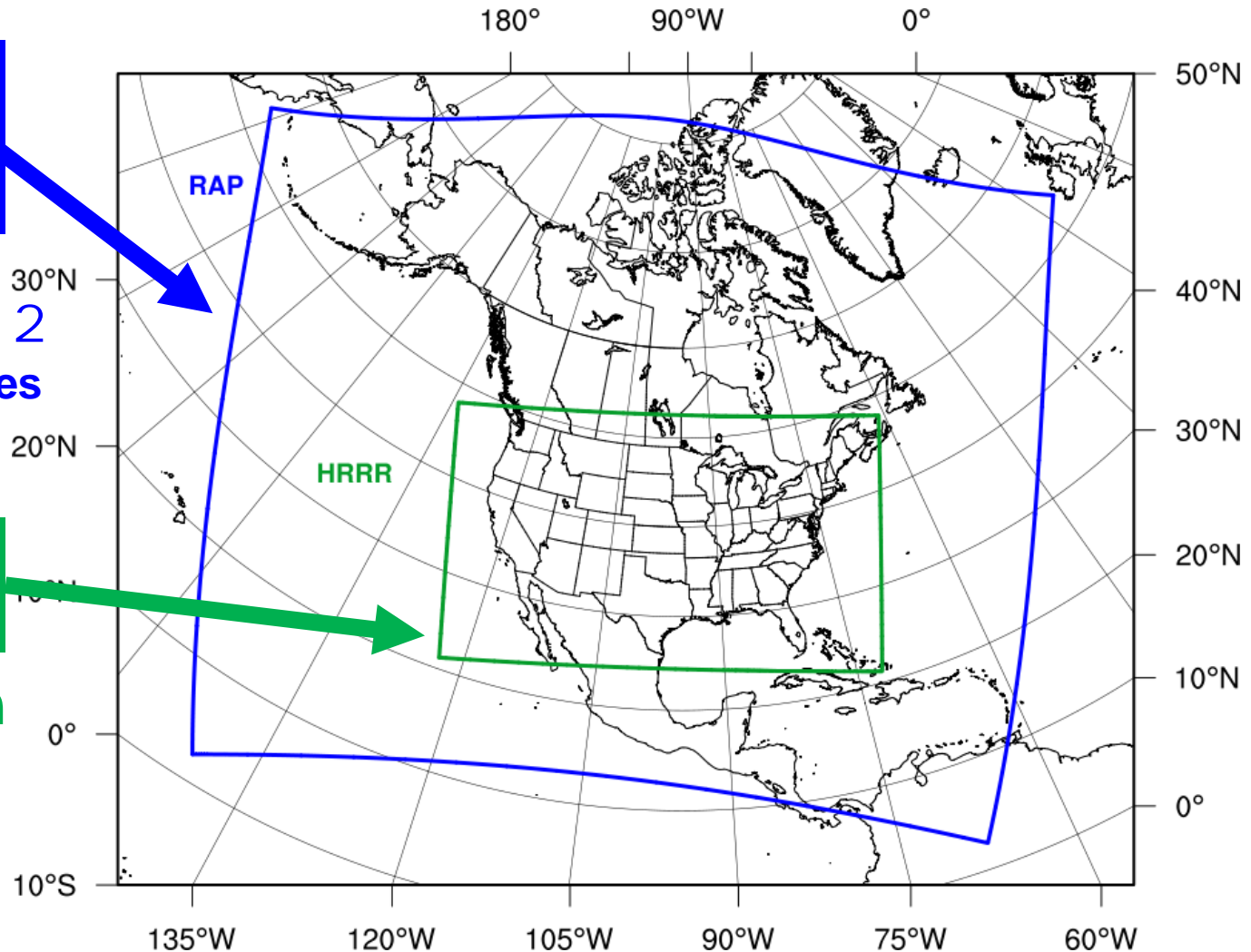and Georg Grell**

**NOAA Earth System
Research Laboratory
Boulder, CO**

Hourly Updated NWP Models

13km Rapid Refresh (RAP) (mesoscale)

Replaced RUC at NCEP 05/01/12

WRF, GSI, RUC features

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

Aviation

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

Department of Energy/NOAA Wind Forecast Improvement Project (WFIP)
    ~12 energy private sector companies via WFIP (WindLogics, 3Tier,
    AWS Truepower, Iberdrola, 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

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
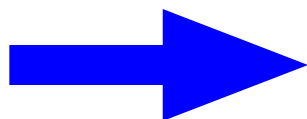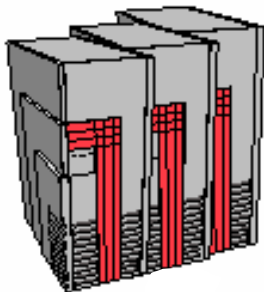   Operational weather forecasting

Forecasting

Hourly cycling model
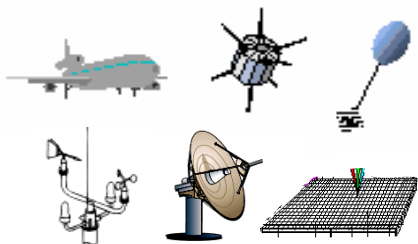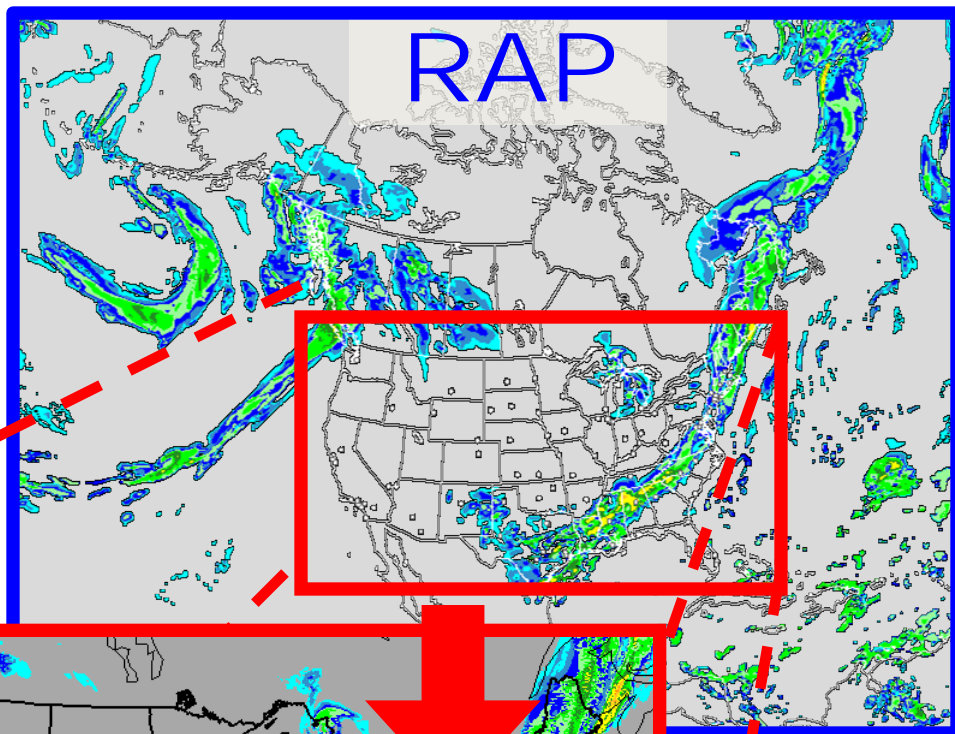
Data
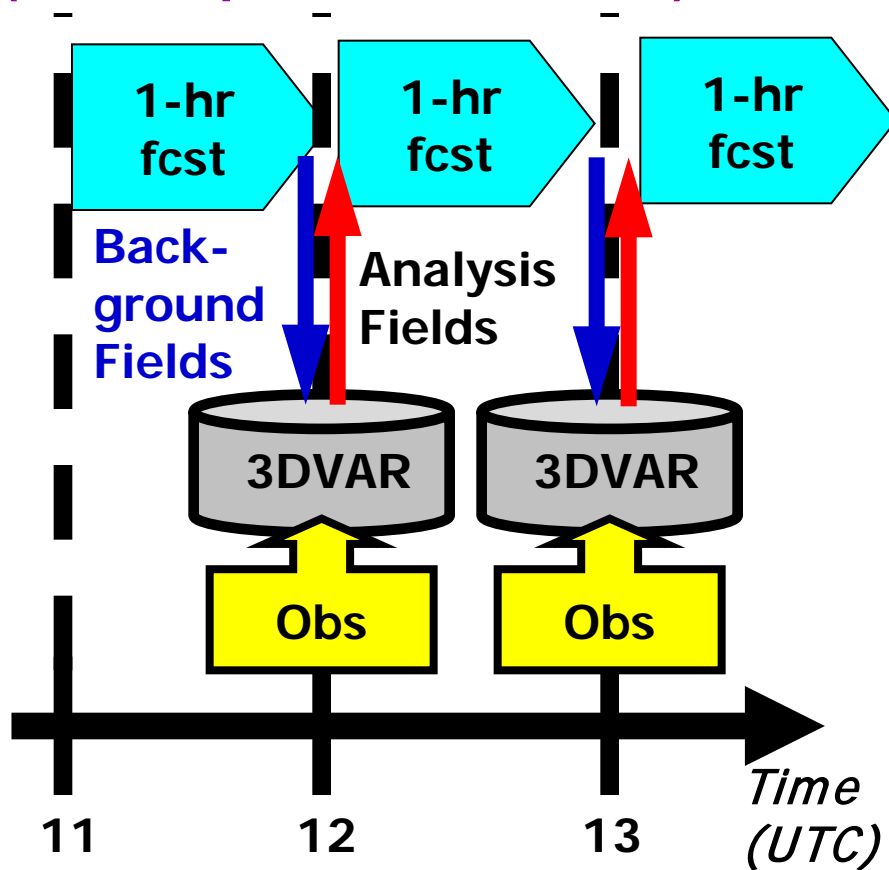Assimilation
cycle

Observations

RAP

HRRR
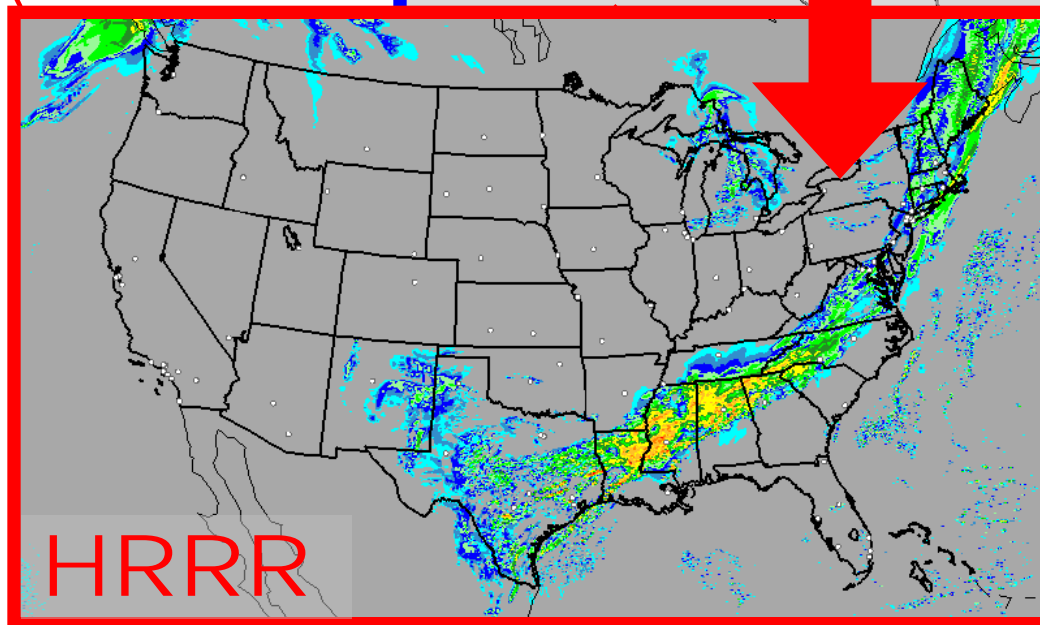
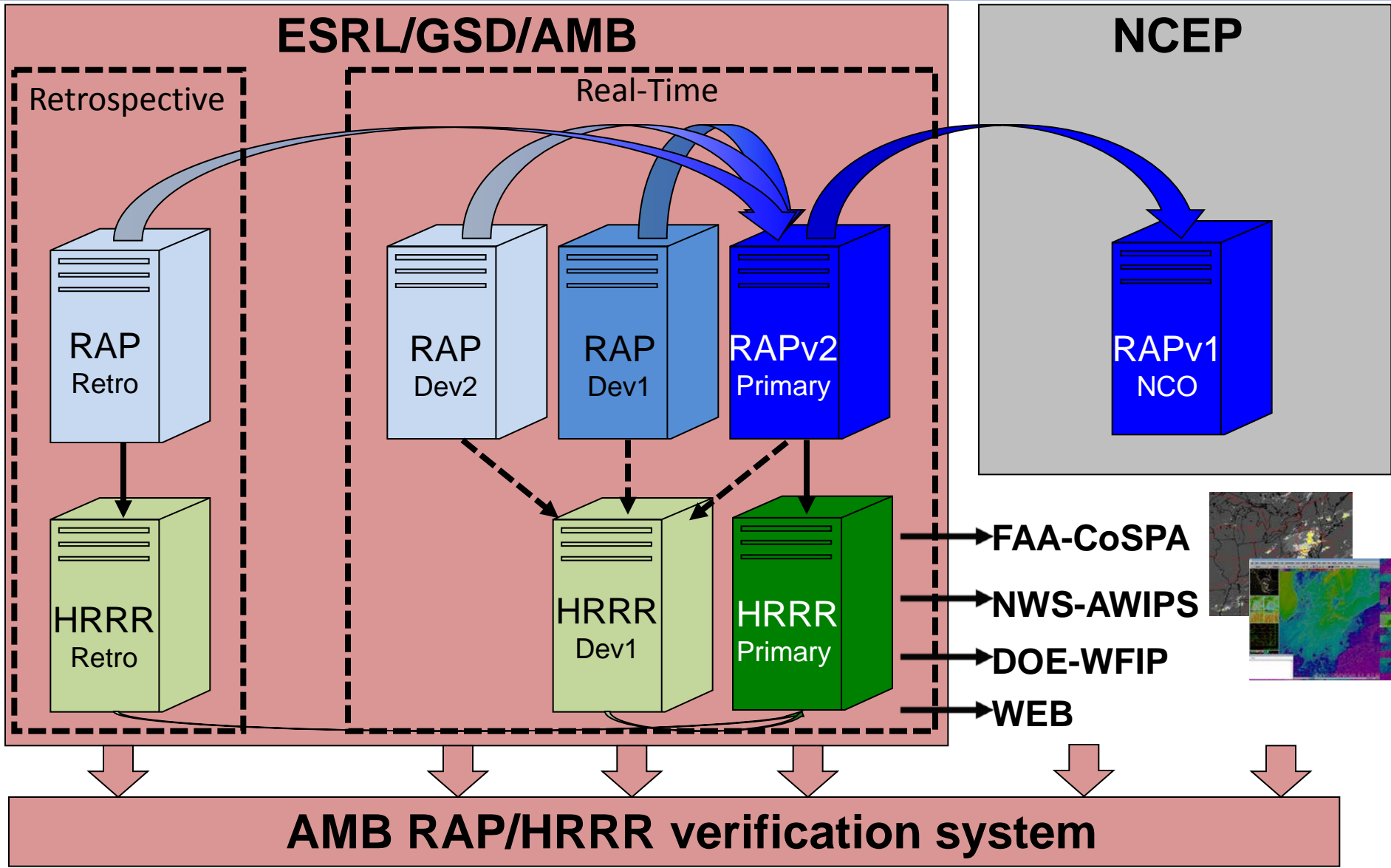# Rapid Refresh
Hourly Update Cycle

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

Cycle hydrometeors

Fully cycle all land-sfc fields (soil temp, moisture, snow)

Hourly Observations	RAP 2013 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	1km
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 press/temp	13km
GPS – Precipitable water	260
WindSat scatterometer	2-10K
Nacelle/Tower/Sodar	20/100/10

AMB Model Development and Eval

ESRL/GSD/AMB

NCEP

Retrospective

Real-Time

RAP
Retro

RAP
Dev2

RAP
Dev1

RAPv2
Primary

RAPv1
NCO

HRRR
Retro

HRRR
Dev1

HRRR
Primary

FAA-CoSPA

NWS-AWIPS

DOE-WFIP

WEB

AMB RAP/HRRR verification system
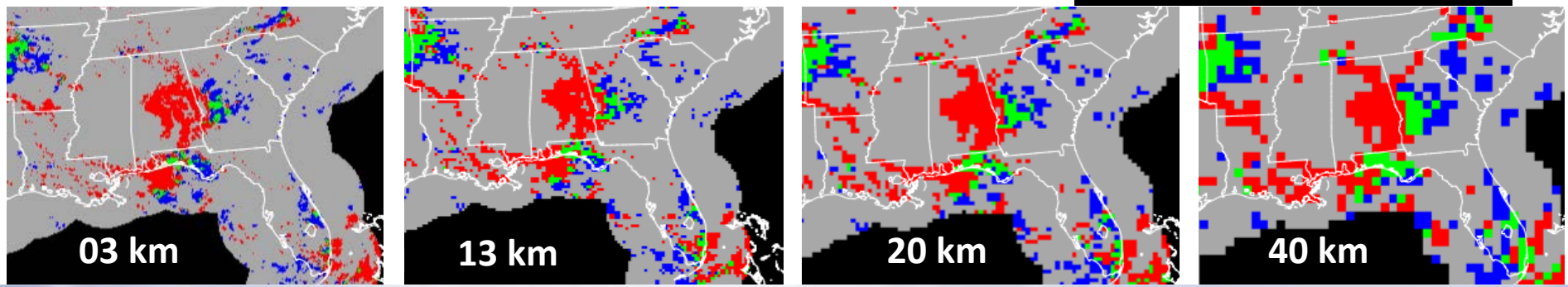
RAP/HRRR Verification System

Intensity Threshold

VIP** Level	Echo Intensity	Precipitation Intensity	Rainfall Rate (in/hr) Stratiform	Rainfall Rate (in/hr) Convective	Reflectivity in (dBZ)
1	Weak	Light	Less Than 0.1	Less Than 0.2	Min. Signal - 30
2	Moderate	Moderate	0.1 - 0.5	0.2 - 1.1	31 - 40
3	Strong	Heavy	0.5 - 1.0	1.1 - 2.2	41 - 45
4	Very Strong	Very Heavy	1.0 - 2.0	2.2 - 4.5	46 - 50
5	Intense	Intense	2.0 - 5.0	4.5 - 7.1	51 - 57
6	Extreme	Extreme	More Than 5.0	More Than 7.1	> 57

Highest precipitation top in area in hundreds of feet MSL (45,000 feet MSL).

20 dBZ

30 dBZ

40 dBZ

Domain

Northeast

West   East

Southeast
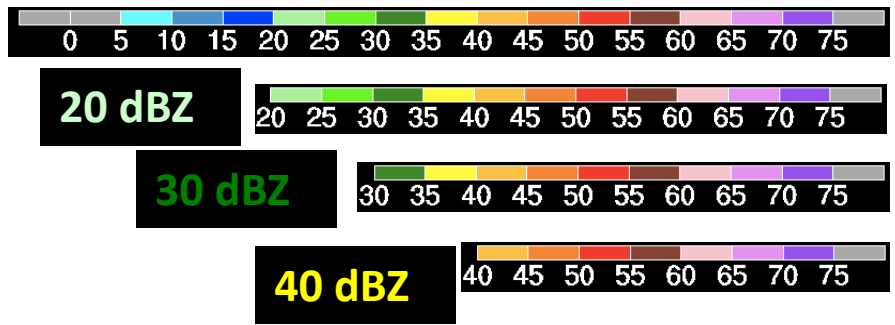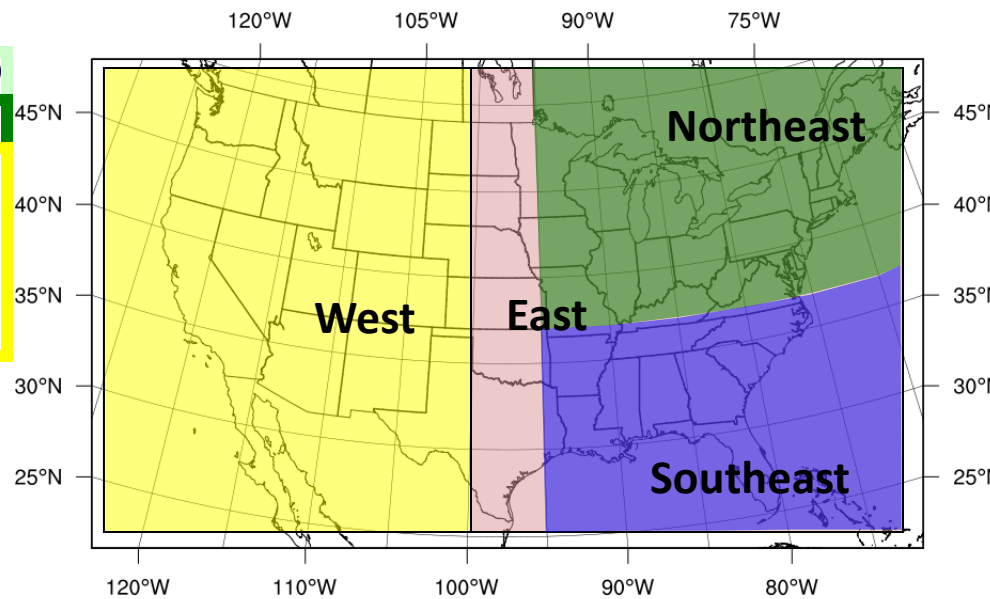
Resolution of Verification

No Data | CR | Miss | FA | Hit

03 km

13 km

20 km

40 km

HRRR Availability – "We want it"

HRRR 12 hr fcst availability
Includes all missed/incomplete runs
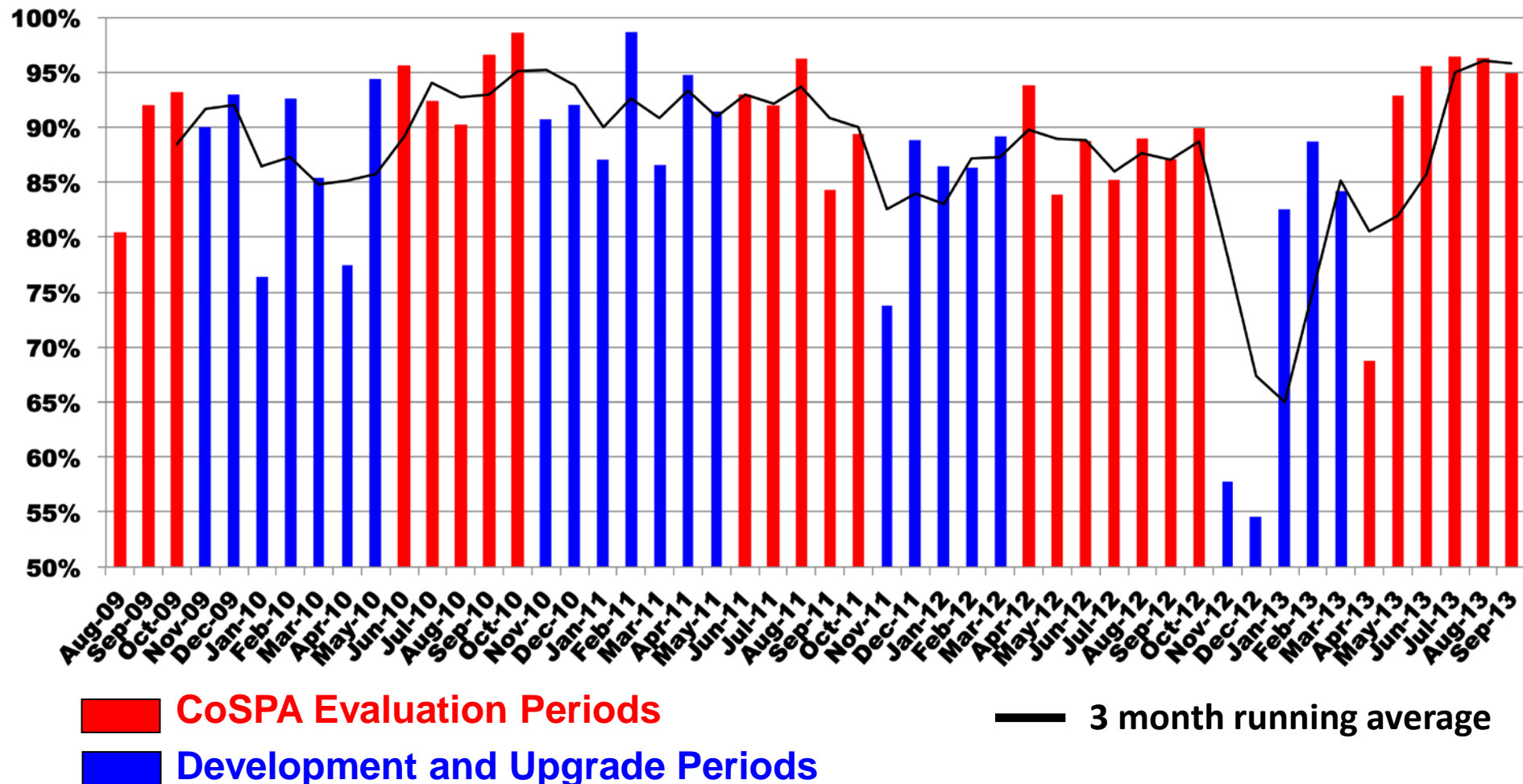
CoSPA Evaluation Periods

Development and Upgrade Periods

3 month running average

HRRR Dual-Computer Availability

HRRR 12 hr fcst availability
Includes all missed/incomplete runs

Jet (HRRR primary) — Zeus (HRRR backup) — Jet or Zeus (union)
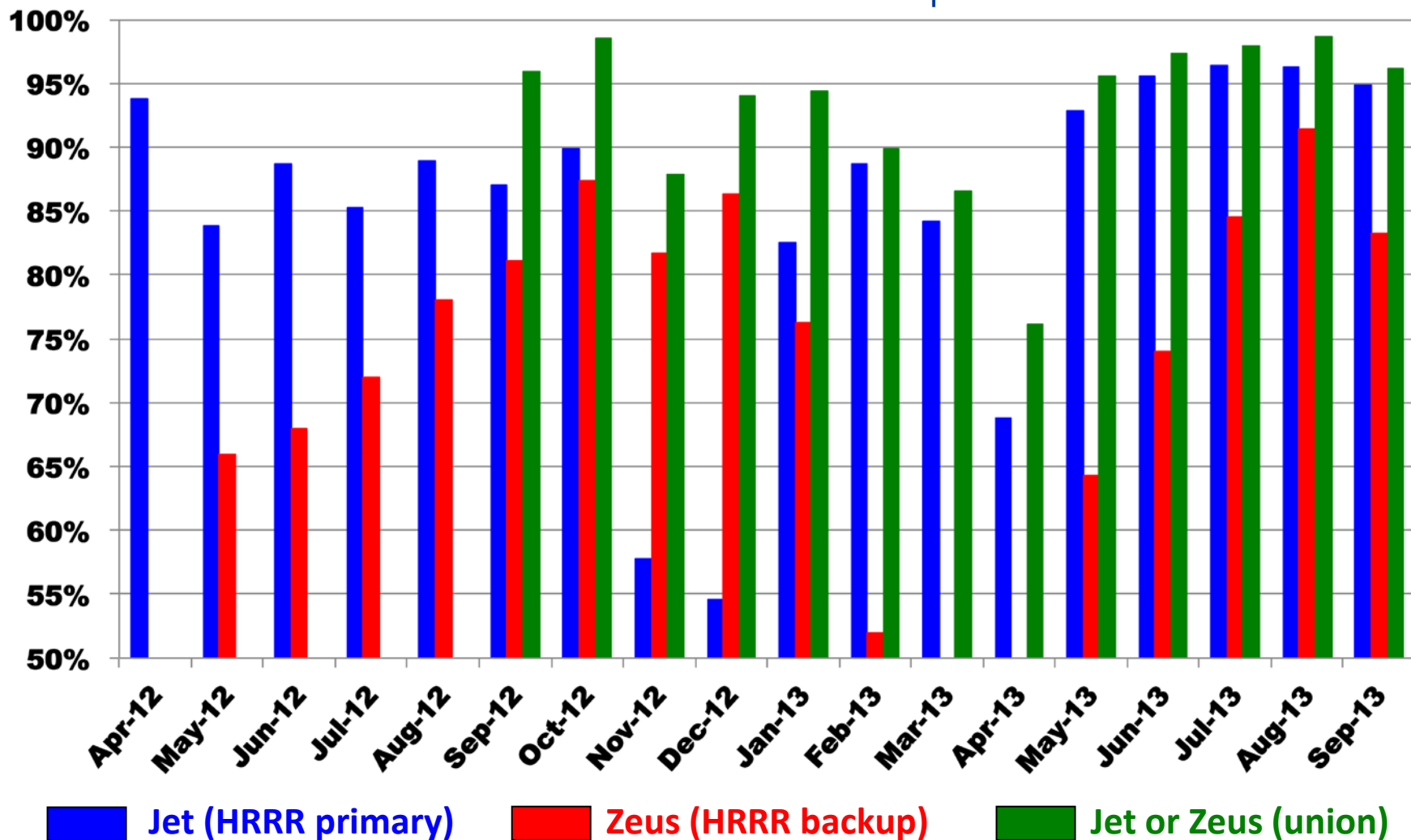
HRRR Dual-Computer Availability

HRRR 12 hr fcst availability
Excludes two (or fewer) consecutive missed/incomplete runs

Legend: Jet (HRRR primary) · Zeus (HRRR backup) · Jet or Zeus (union)
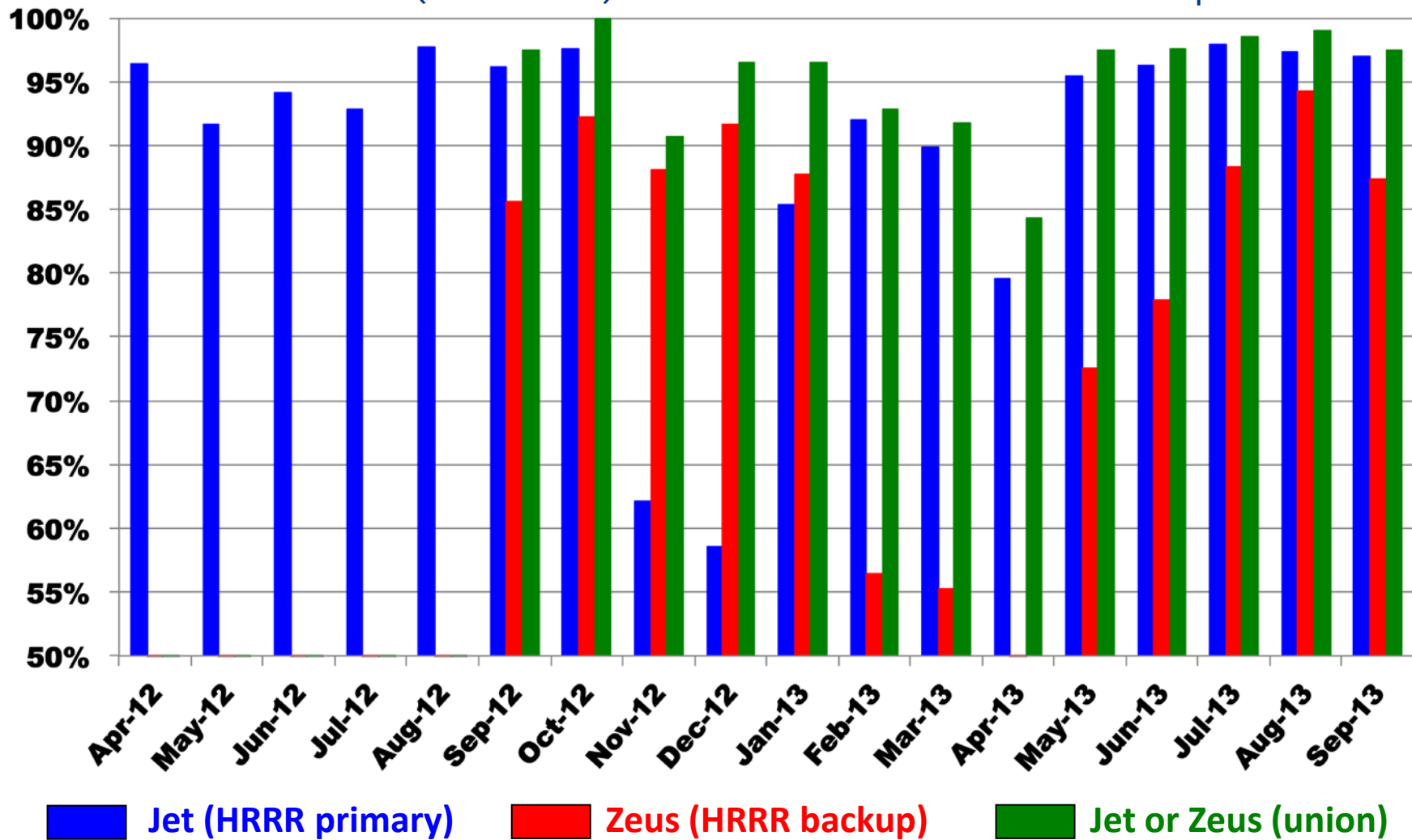
HRRR Dual-Computer Availability

HRRR 12 hr fcst availability
Excludes three (or fewer) consecutive missed/incomplete runs

Jet (HRRR primary)　　**Zeus (HRRR backup)**　　**Jet or Zeus (union)**
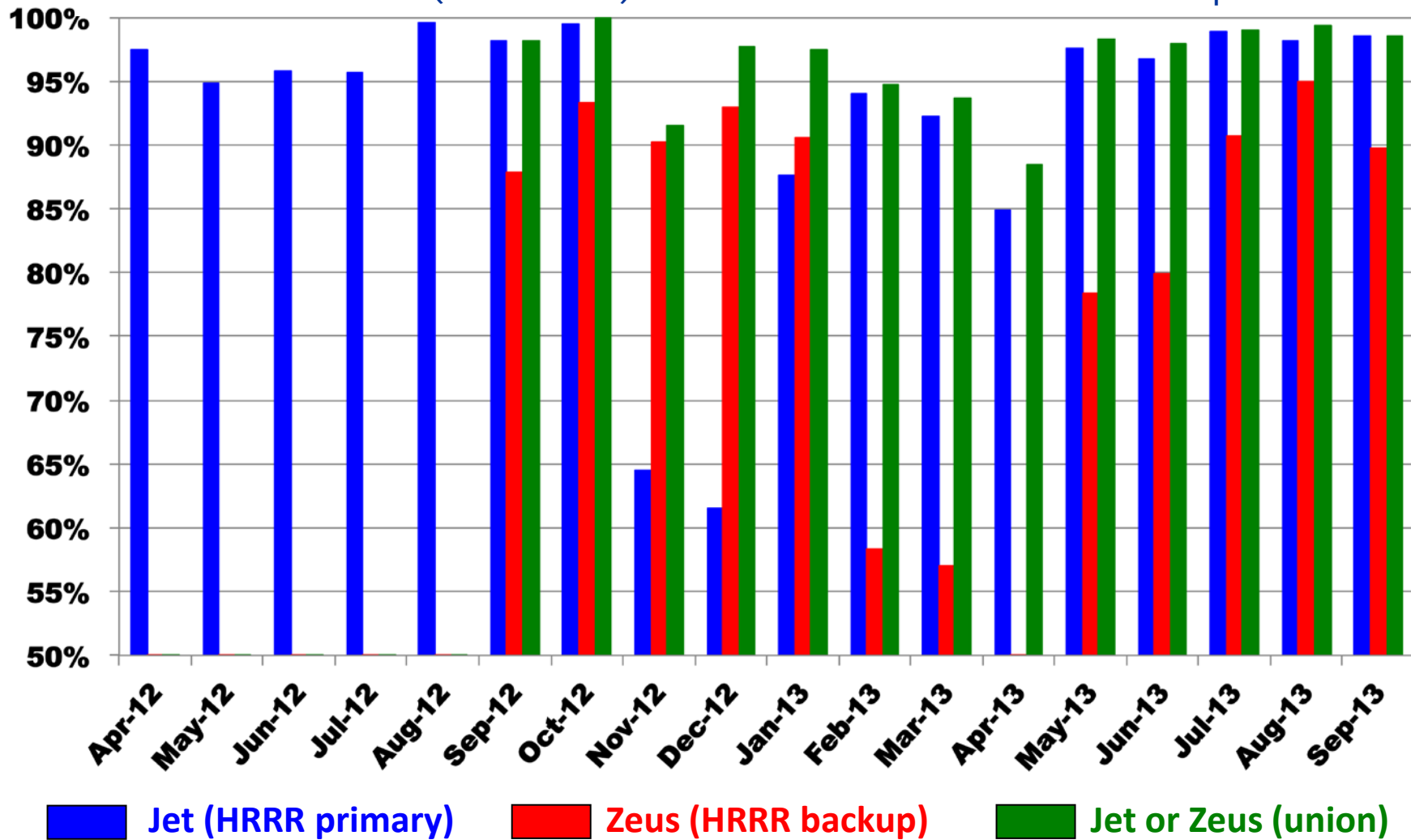
HRRR Dual-Computer Availability

HRRR 12 hr fcst availability
Excludes four (or fewer) consecutive missed/incomplete runs

Jet (HRRR primary)   Zeus (HRRR backup)   Jet or Zeus (union)
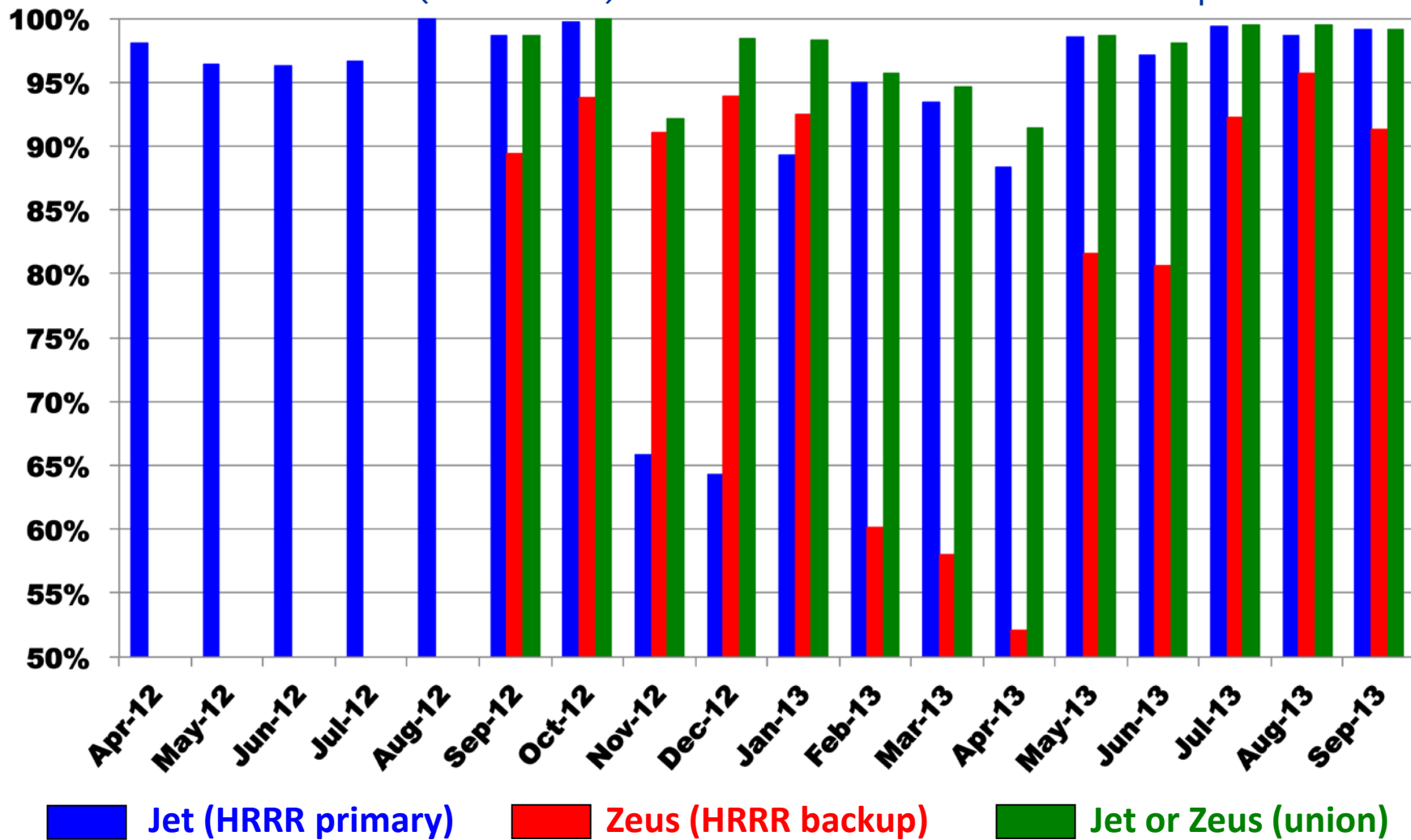
HRRR Latency – "We want it now"

2013 HRRR changes permitted ~45 min reduction in latency

12-hr HRRR Forecast Latency
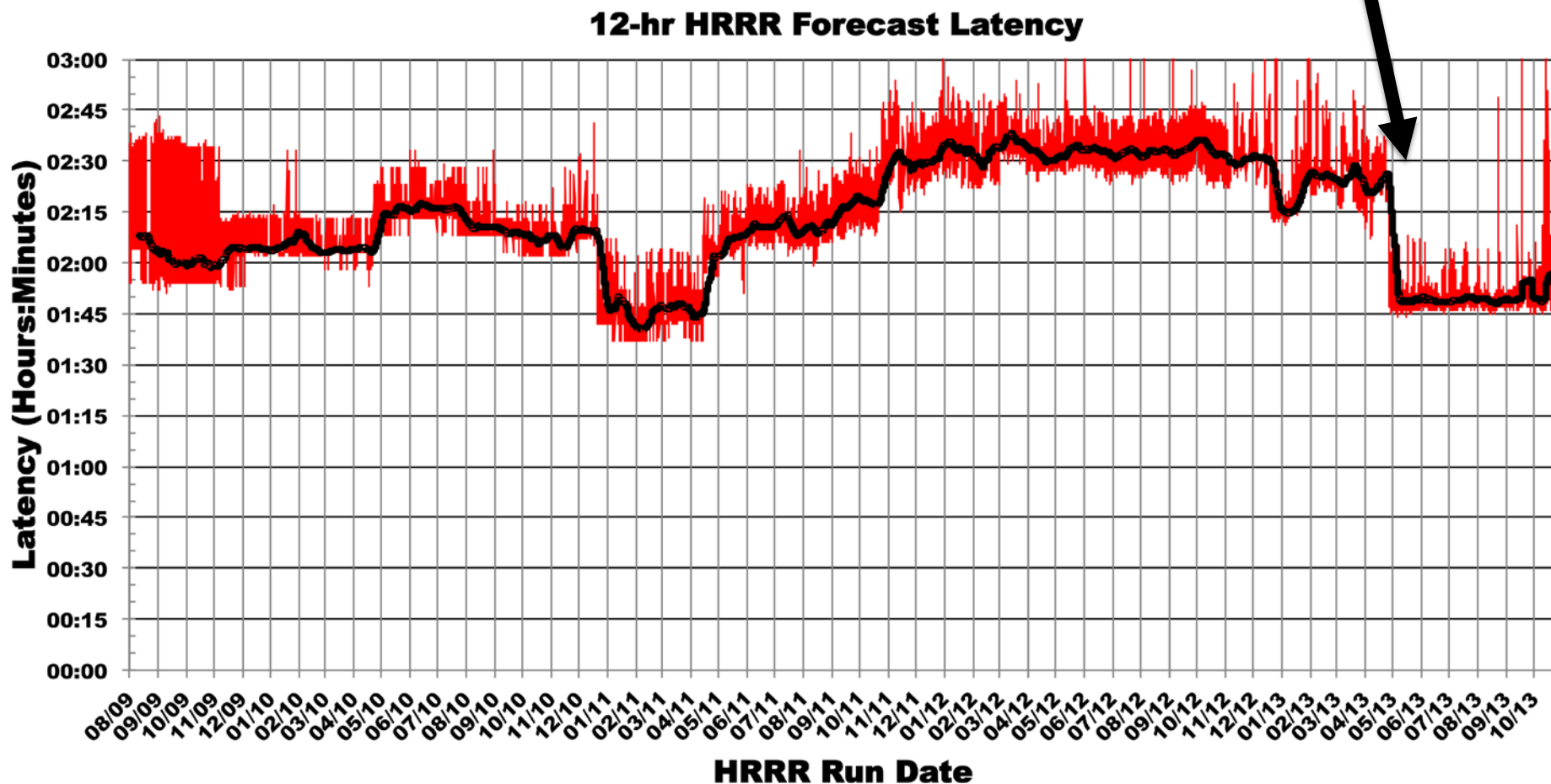
RAP/HRRR Implementation Map

ESRL – experimental version

NWS-NCEP - operational

- RAPv1 – used in 2011
  - Initialized 2011 HRRR
  - effective but too many storms

  → • Implemented 1 May 2012

- RAPv2 – used in 2012-2013
  - Initialized 2012-2013 HRRR
  - Better use of surface obs / radar, storm bias eliminated, Hybrid DA

  → • RAPv2 - Scheduled to be implemented in Dec 2013

- HRRR – 2012
  - Major improvement over 2011 HRRR, storm coverage/accuracy

- **HRRR – 2013**
  - **3km/15min radar assimilation**
  - **Initialized from RAPv2-2013**
  - **Available 45 min earlier, much more accurate 0-15h storm forecasts, more reliable 2-computer**

  → • HRRRv1 – Scheduled to be implemented in 2014

HRRR Forecast Behavior

2012

(1) **Coarse** 00-hr **analysis**

(2) Convective **"spin-up"** **during forecast** period

(3) **Low** echo top **bias**

(4) Latency of **2-3 hrs**

(5) **Single HPCS** reliability

RAP/HRRR Model Development and Evaluation

2013 Targets

(1) **3-km scale** at 00-hr

(2) **Reduced "spin-up"** during forecast period

(3) **Optimal** echo top **bias**

(4) Reduced latency of **1-2 hrs**

(5) **Dual HPCS** reliability

Key Advantage of 3-km HRRR

13-km 6hr forecast

HRRR 6hr forecast

13-km
Resolution

Parameterized
Convection

3-km
Resolution

Explicit
Convection

07 June
2012

5 PM EDT
observed
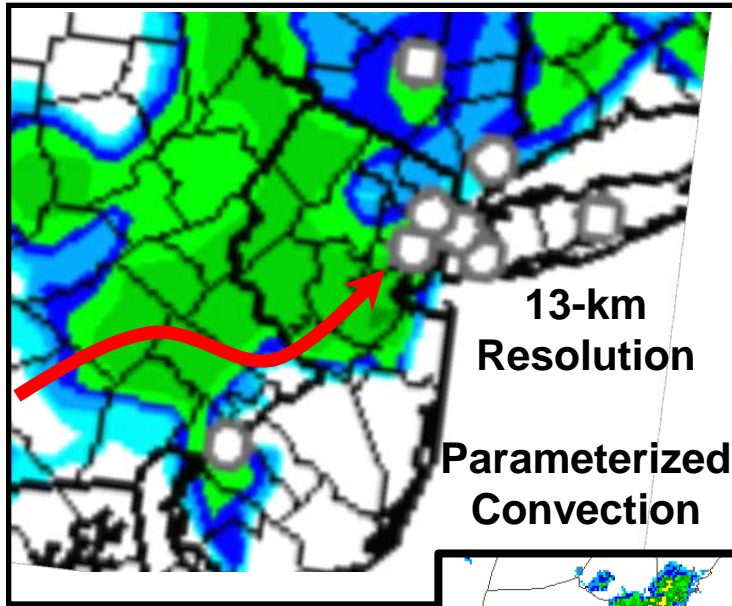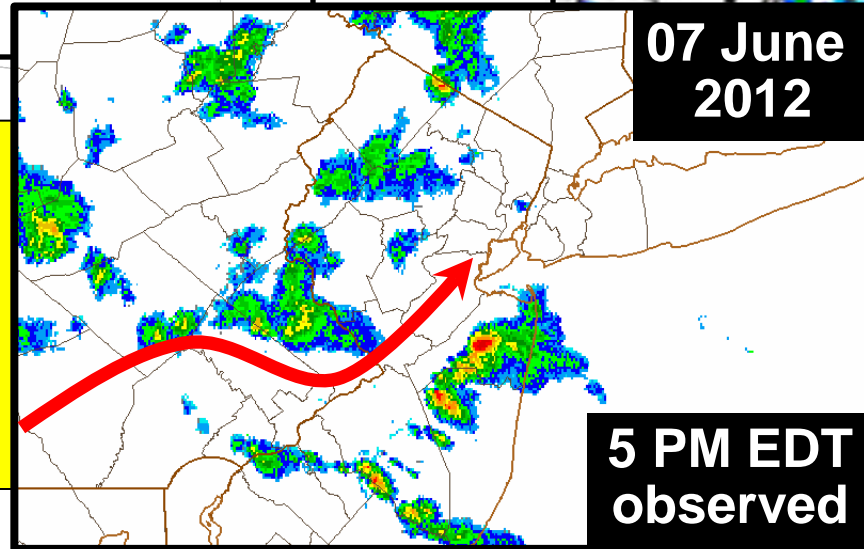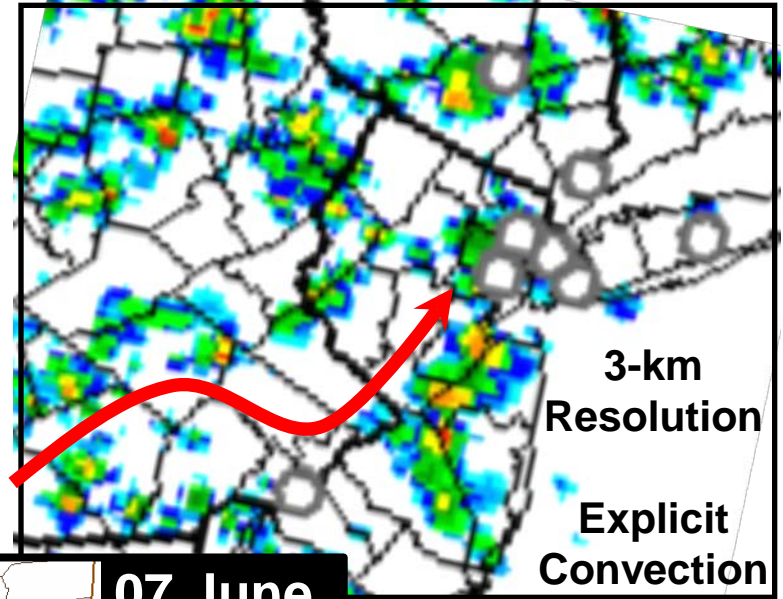
**NO
STORM
STRUCTURE**

**NO ESTIMATE OF
PERMEABILITY**

**ACCURATE
STORM
STRUCTURE**

**ACCURATE
ESTIMATE OF
PERMABILITY**

HRRR Forecasts for Aviation

CoSPA: Collaborative effort: ESRL/GSD, NCAR/RAL, MIT/LL

Provide 0-8 hr thunderstorm intensity and echo top guidance to aviation community

HRRR 15 UTC 08 July 2011
6 hr forecast valid 21 UTC
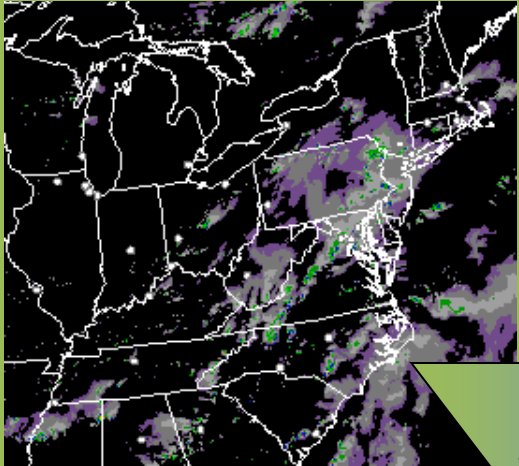
CoSPA 17 UTC 08 July 2011
4 hr forecast valid 21 UTC
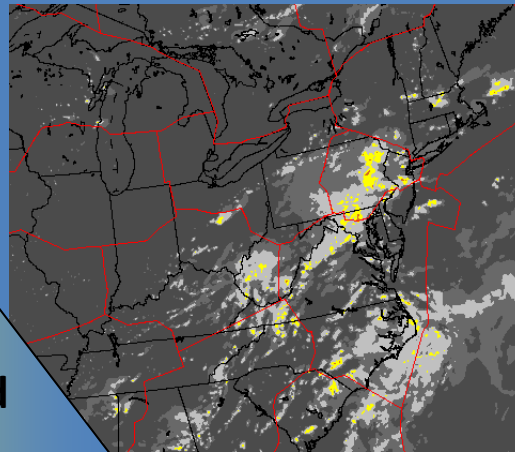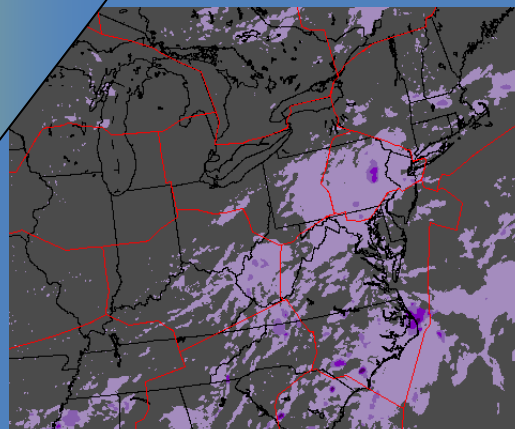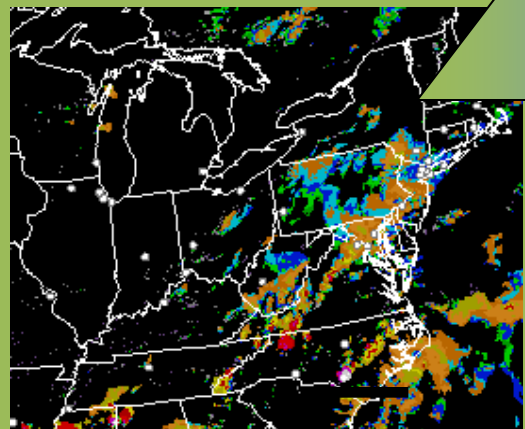
Observation
Valid 21 UTC 08 July 2011

Blend with CIWS

VIL

Echo Top

HRRR Aviation Websites

http://rapidrefresh.noaa.gov/hrrraviation/ (hourly output)

Feedback from AWC

Aviation specific forecast fields:

Convection (intensity and depth)
Ceiling and Visibility
Flight Rules
Surface Wind
Precip Type
Snowfall

http://rapidrefresh.noaa.gov/hrrraviation15min/ (sub-hourly output)

New HRRR ET Diagnostic

**Observation
01z 21 June 2012**

**HRRR 4 hr
forecast**

Echo Tops (kft)

Old
2012

2012 low bias in echo tops

New HRRR ET Diagnostic

**Observation
01z 21 June 2012**
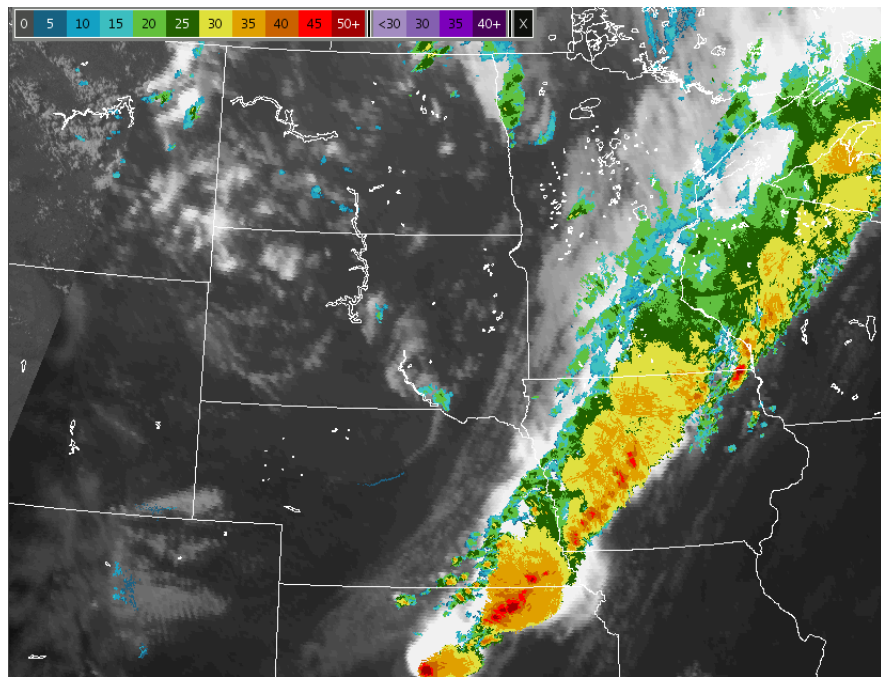
**HRRR 4 hr
forecast**
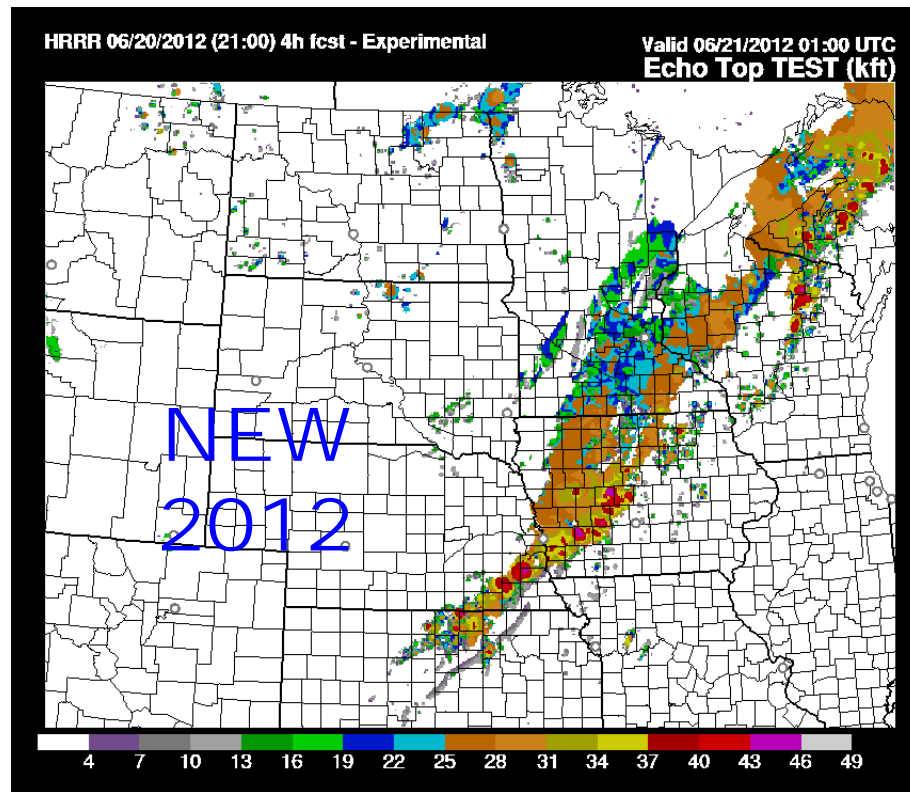
Echo Tops (kft)

Calibration of echo tops to produce improved bias

Eastern US 03-km **BIAS** 344 runs 08-25 July 2012
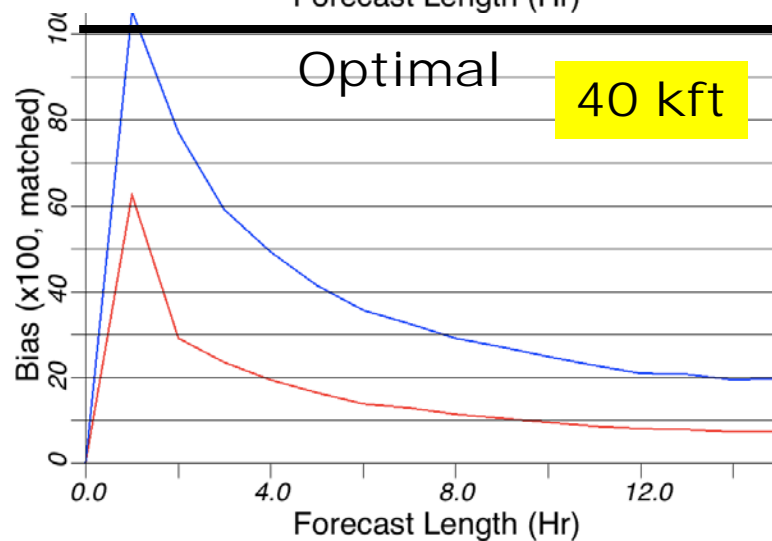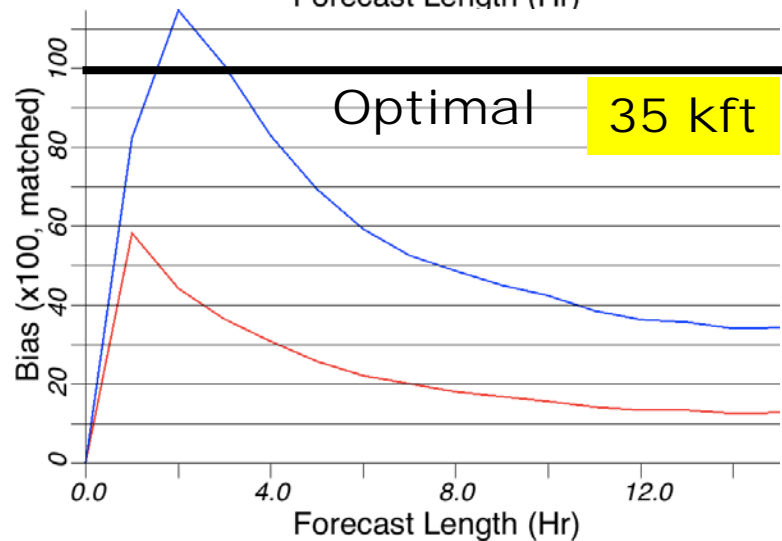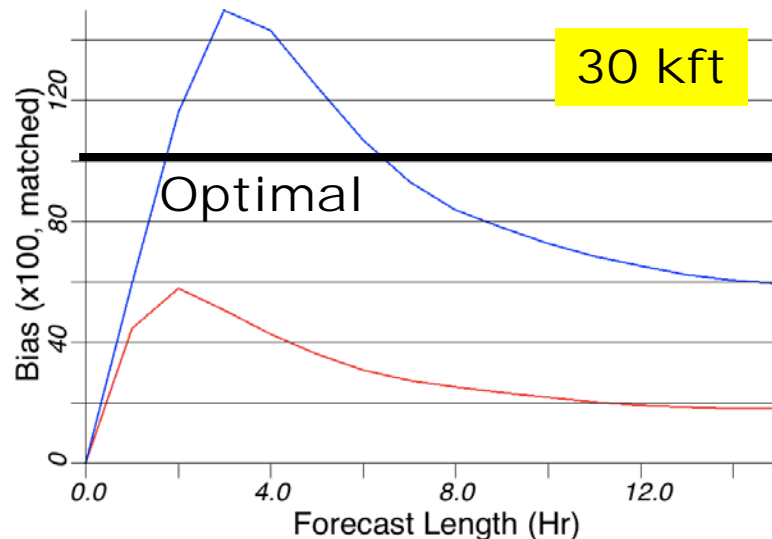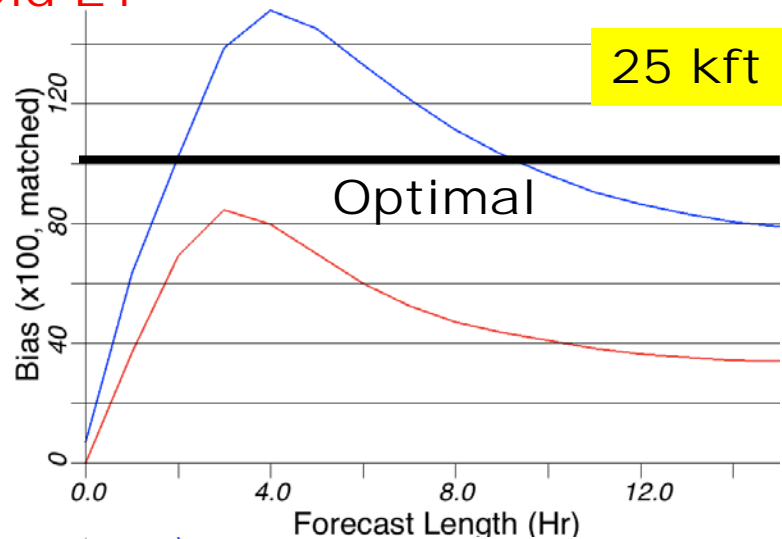
New ET
Old ET
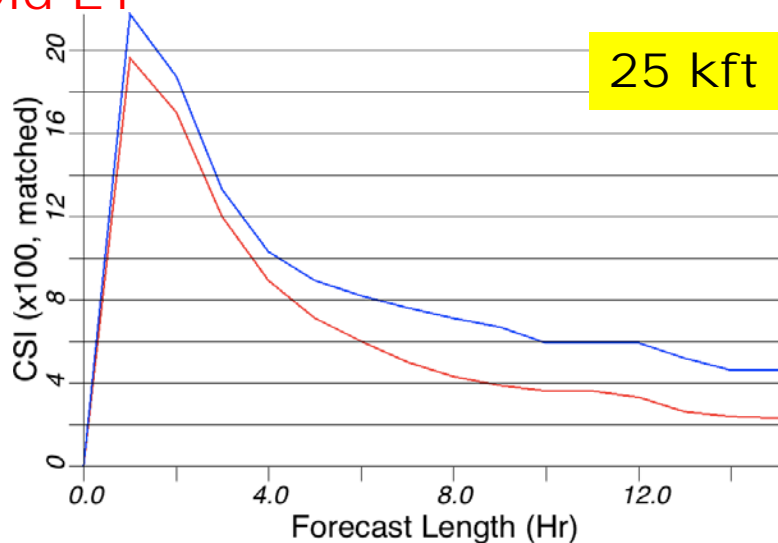
HRRR ET Diagnostic Verification

New ET
Old ET

Eastern US 40-km CSI 344 runs 08-25 July 2012

25 kft

30 kft

35 kft

40 kft
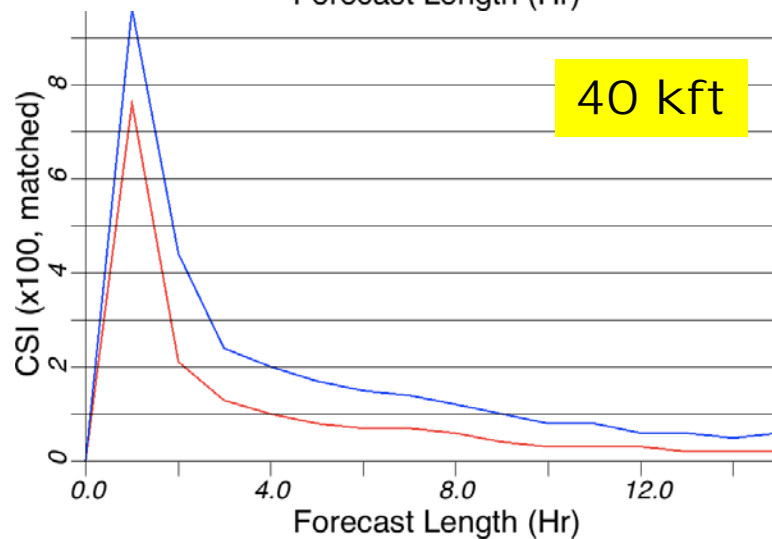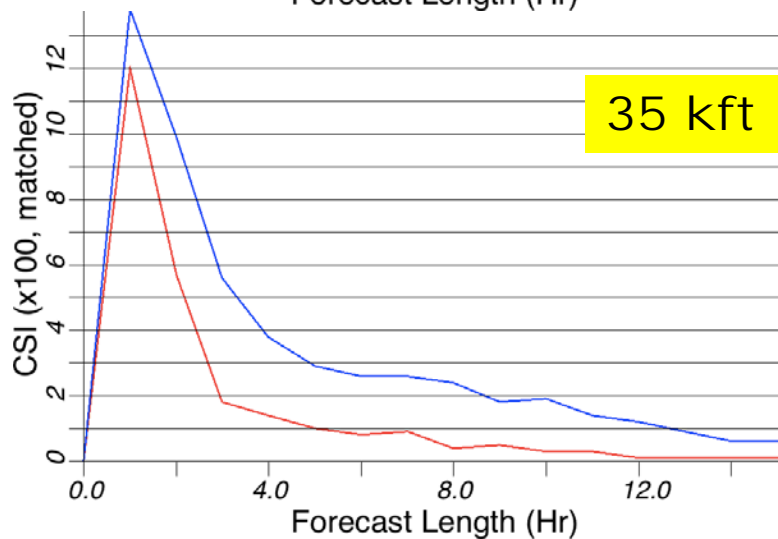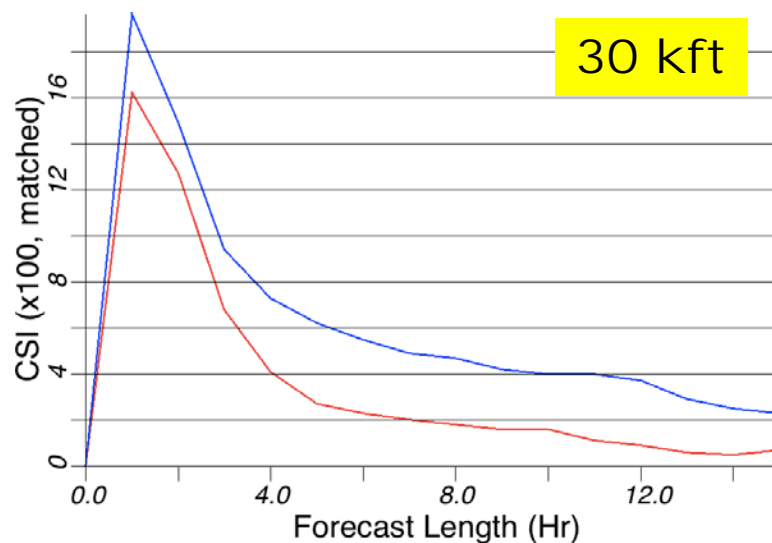
2012 HRRR Initialization from RAP
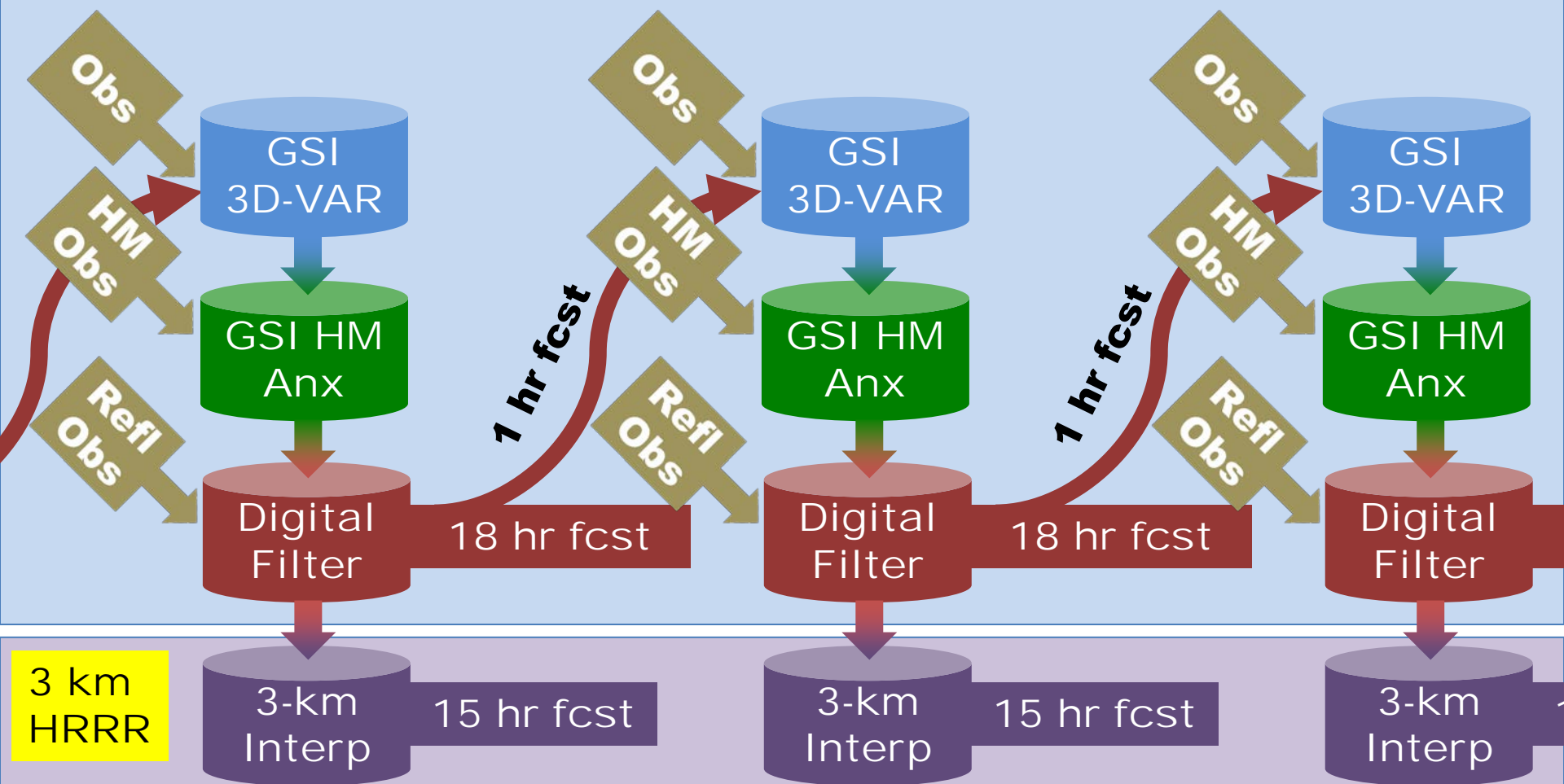
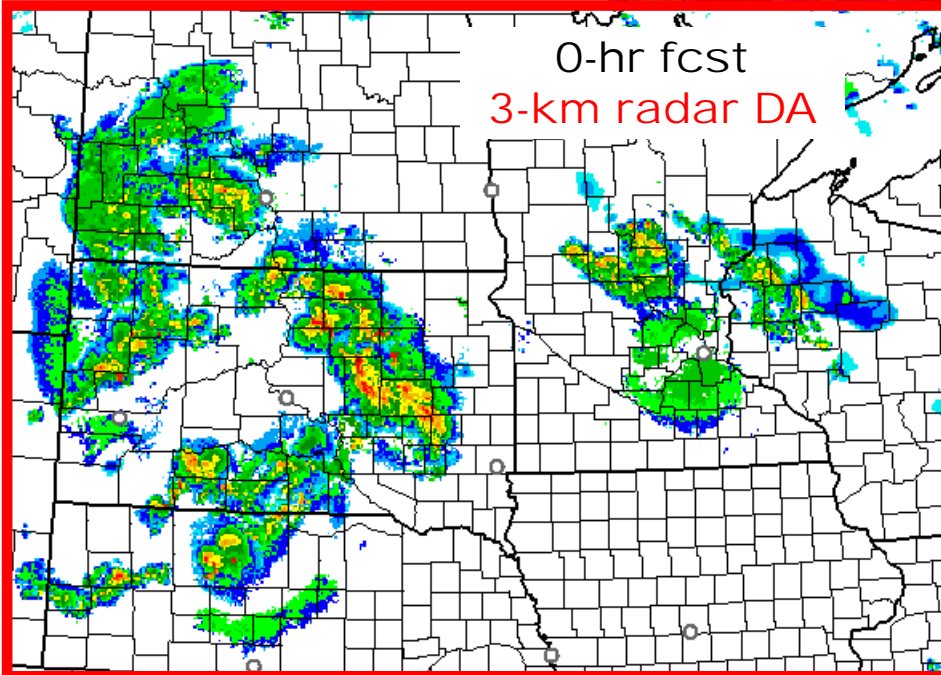# 2013 HRRR Initialization from RAP
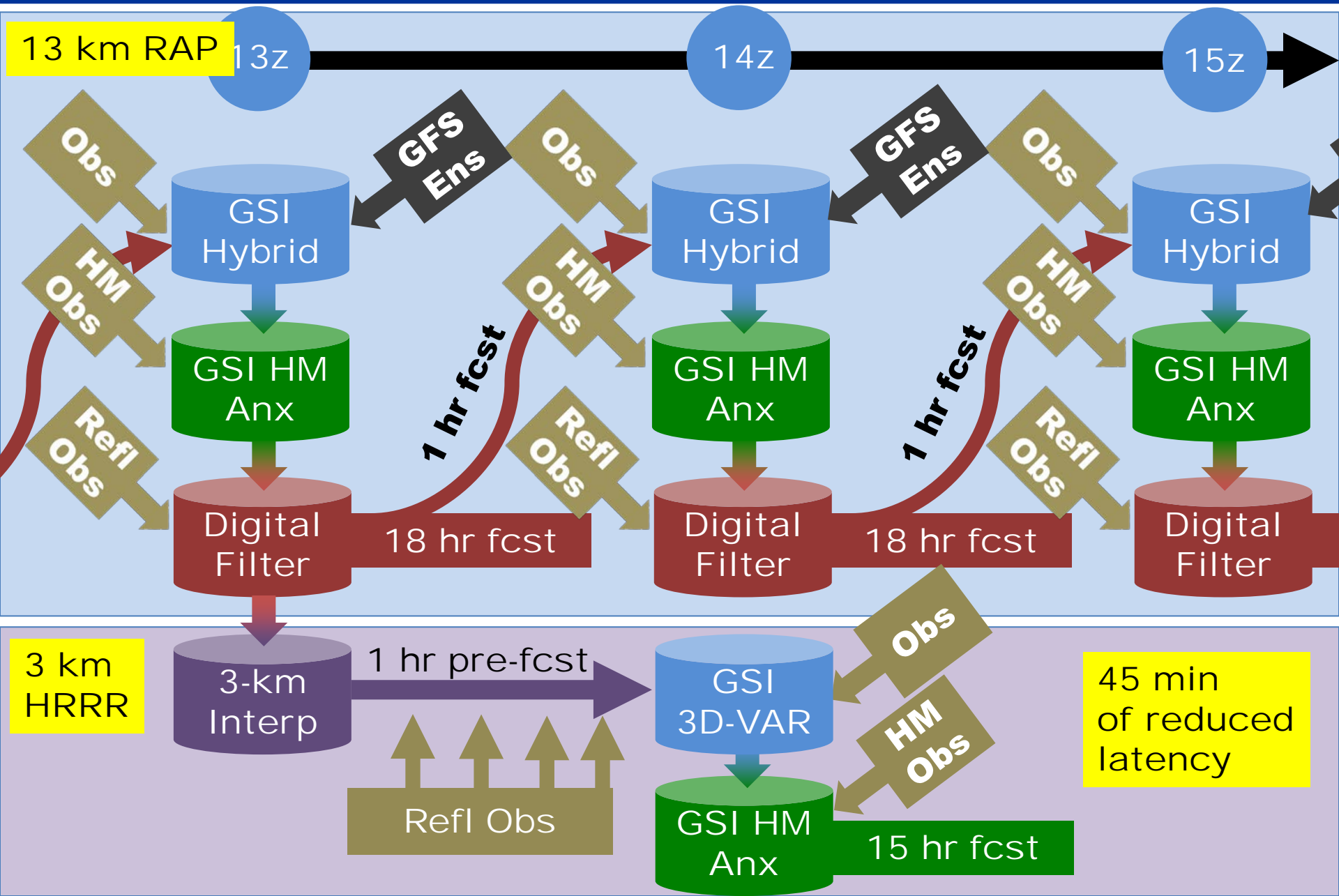
Improved 0-2 hr Convective Fcsts

**Radar Obs
05:00z 18 May 2013**

05z + 0 min
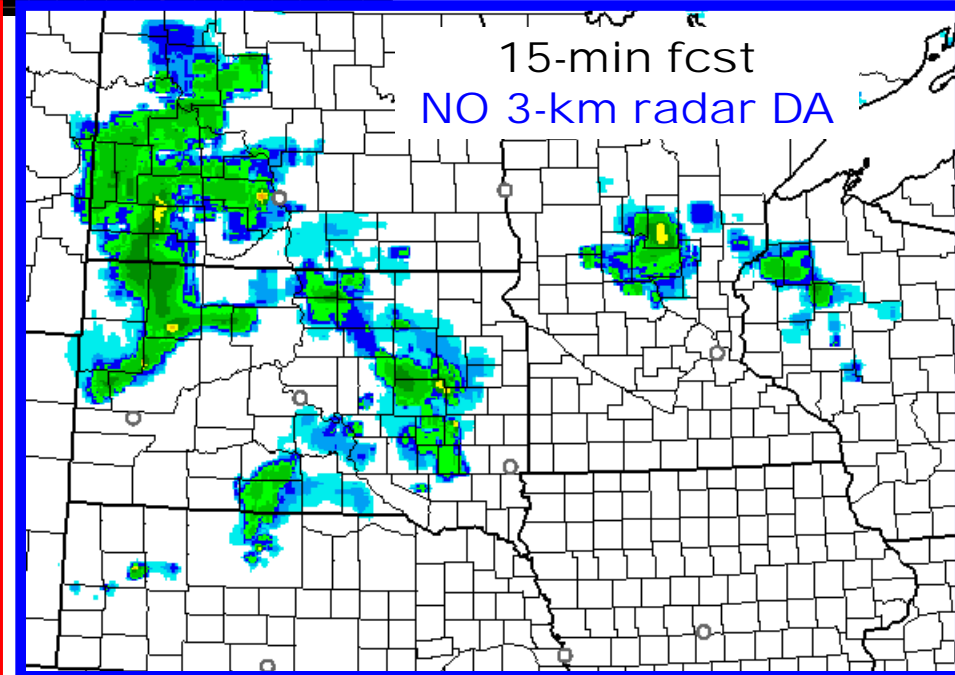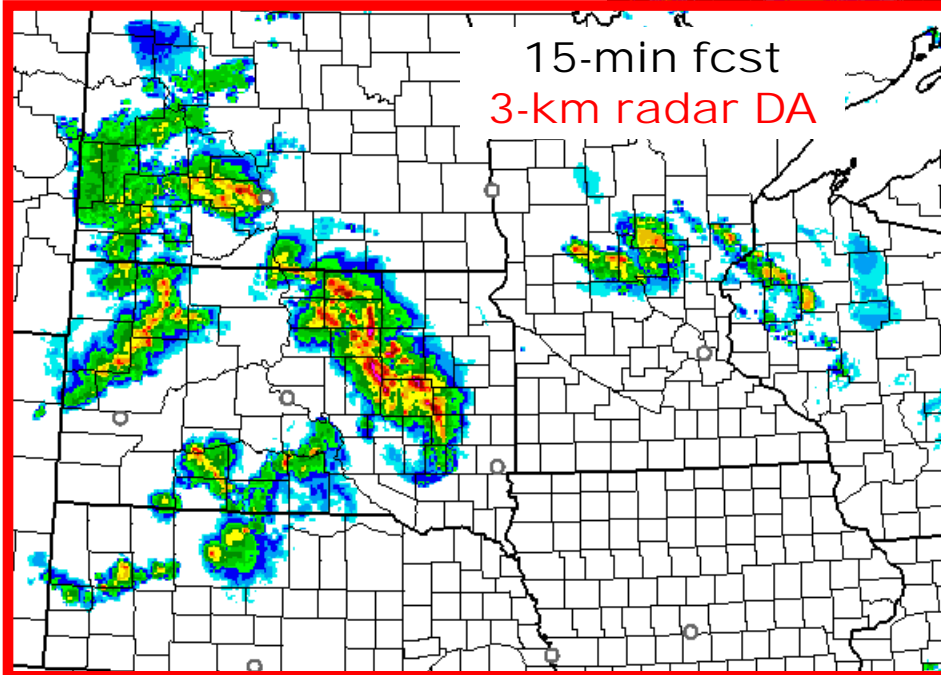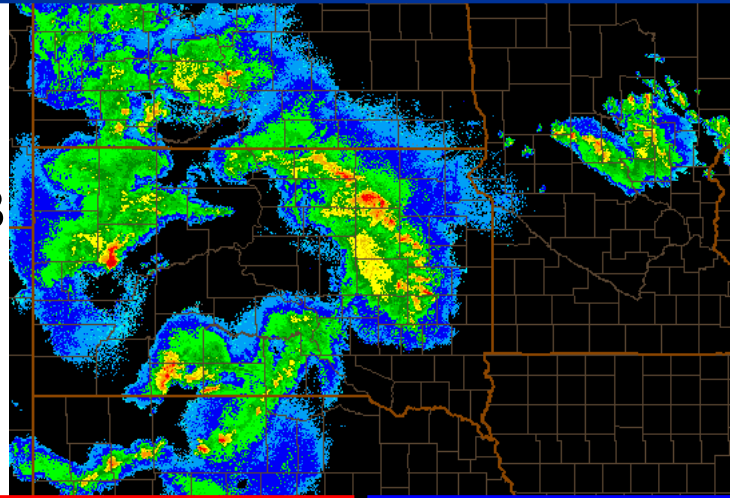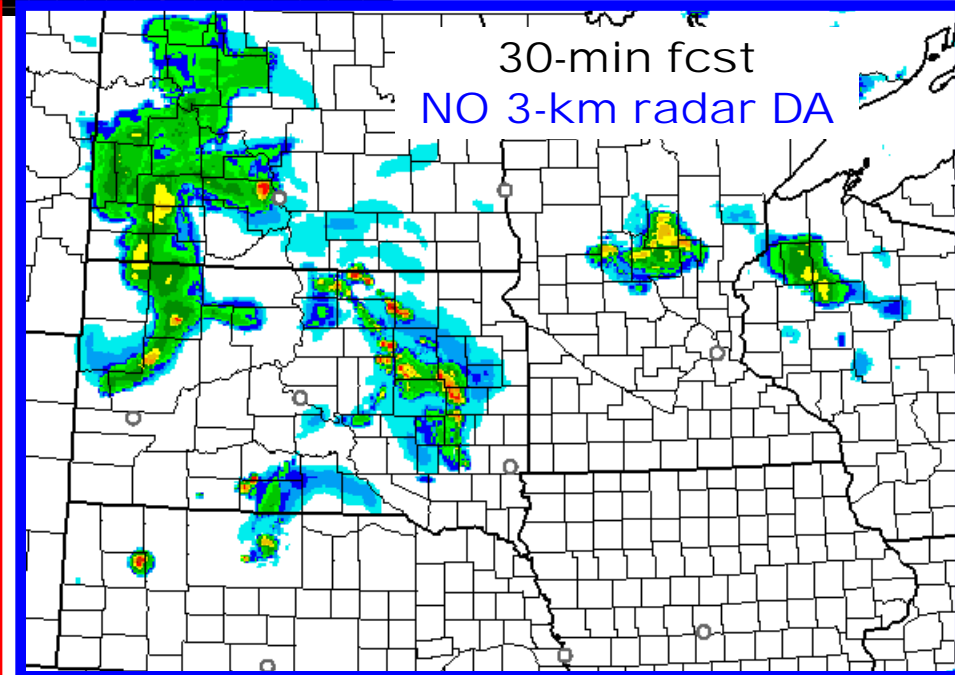
**0-hr fcst
3-km radar DA**

**0-hr fcst
NO 3-km radar DA**
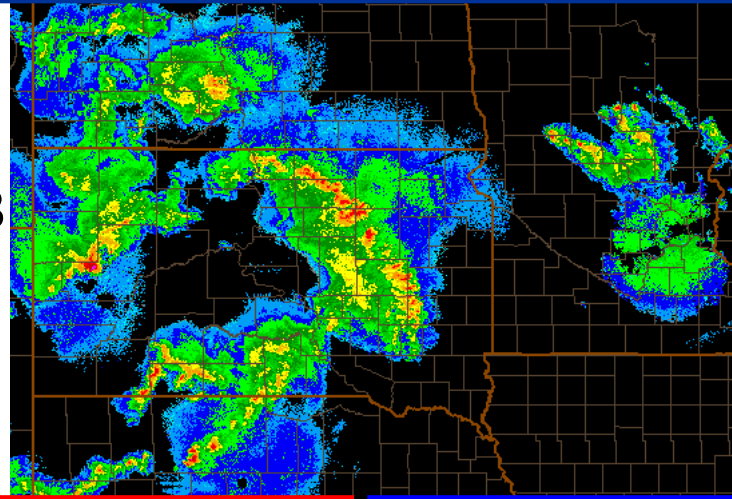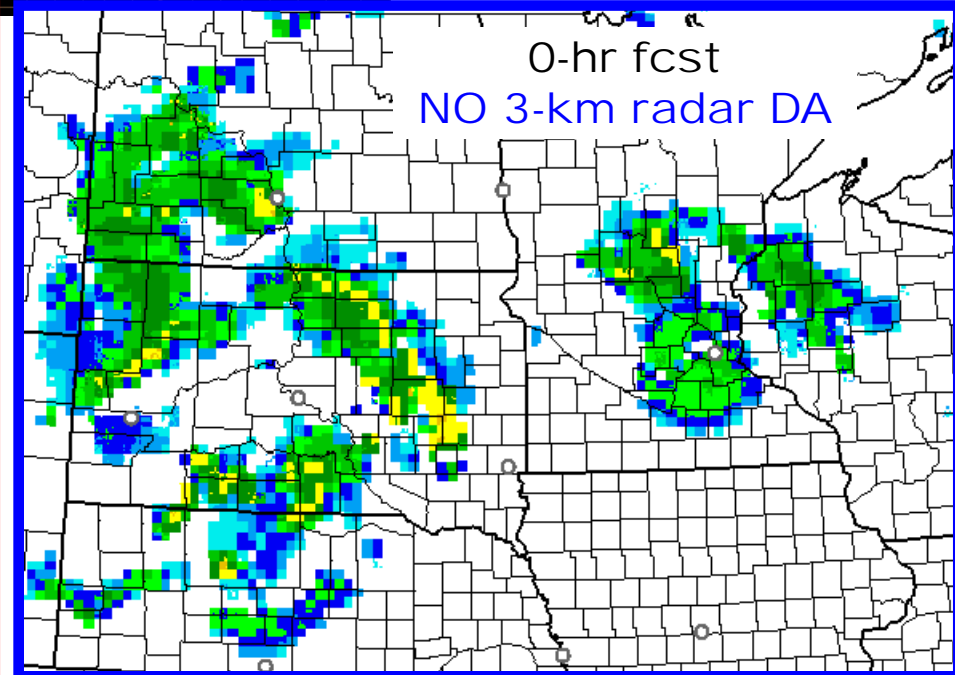
Improved 0-2 hr Convective Fcsts

Radar Obs
05:15z 18 May 2013

05z + 15 min

15-min fcst
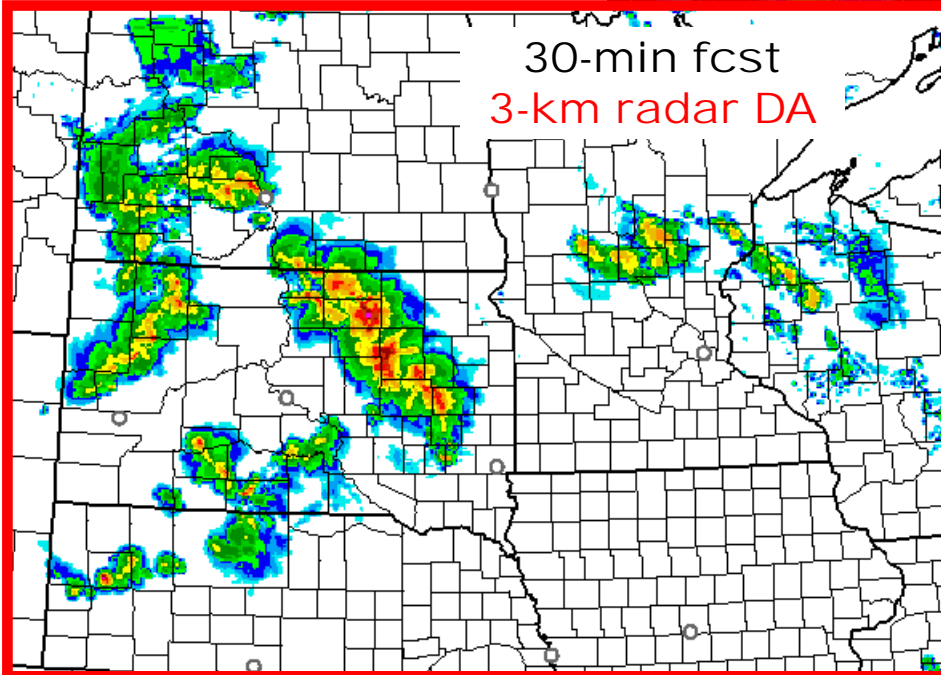**3-km radar DA**

15-min fcst
NO 3-km radar DA
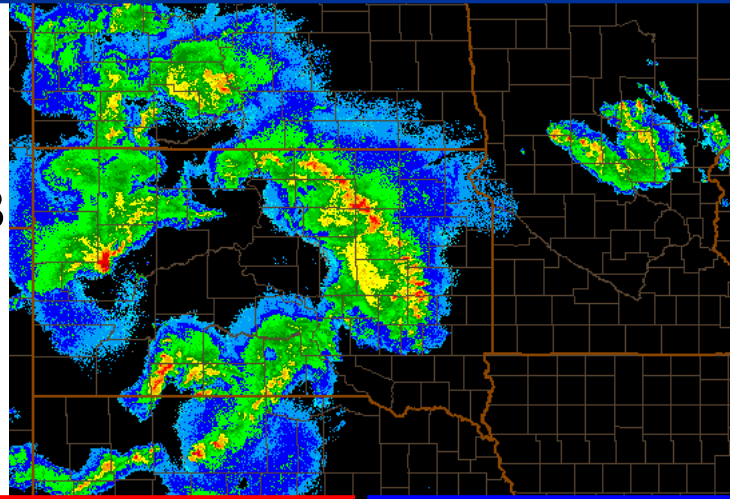
Improved 0-2 hr Convective Fcsts

**Radar Obs
05:30z 18 May 2013**

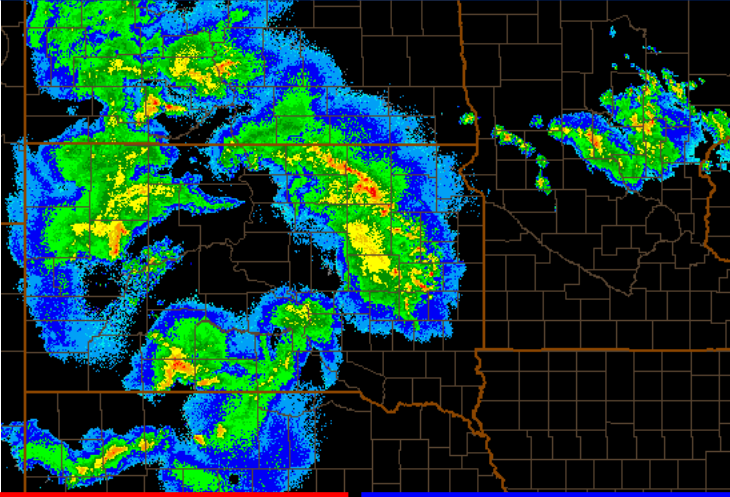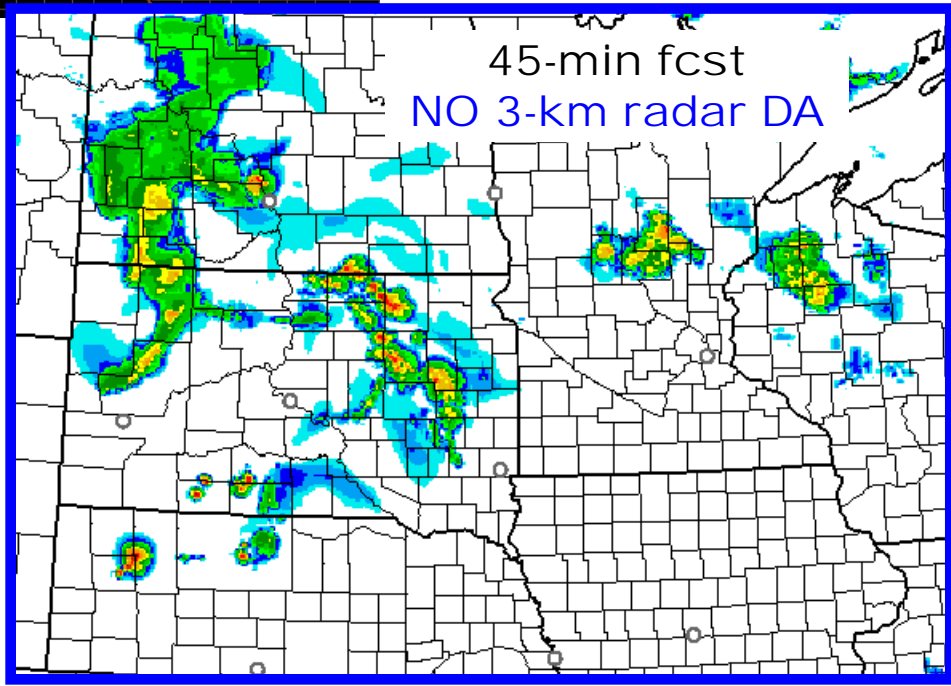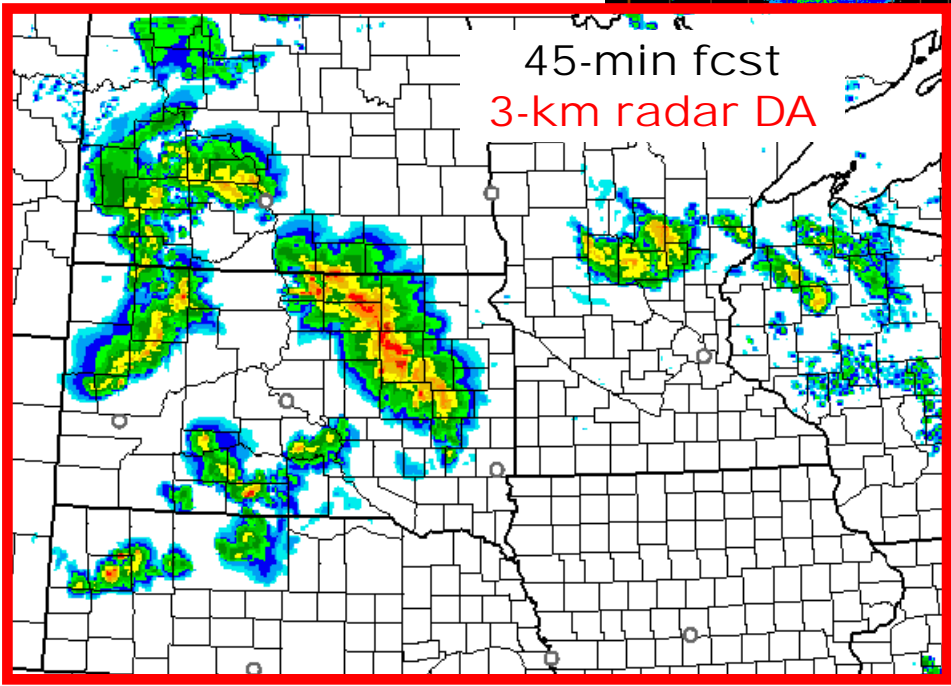**05z + 30 min**

**30-min fcst
3-km radar DA**

**30-min fcst
NO 3-km radar DA**

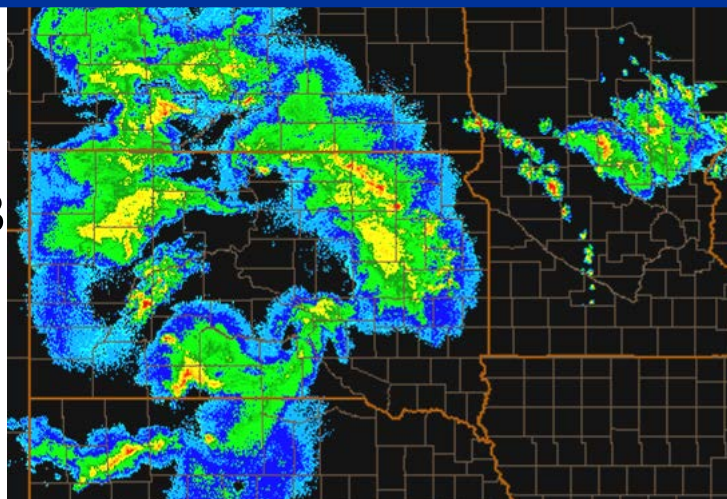# Improved 0-2 hr Convective Fcsts

**Radar Obs
05:45z 18 May 2013**

05z + 45 min

45-min fcst
3-km radar DA
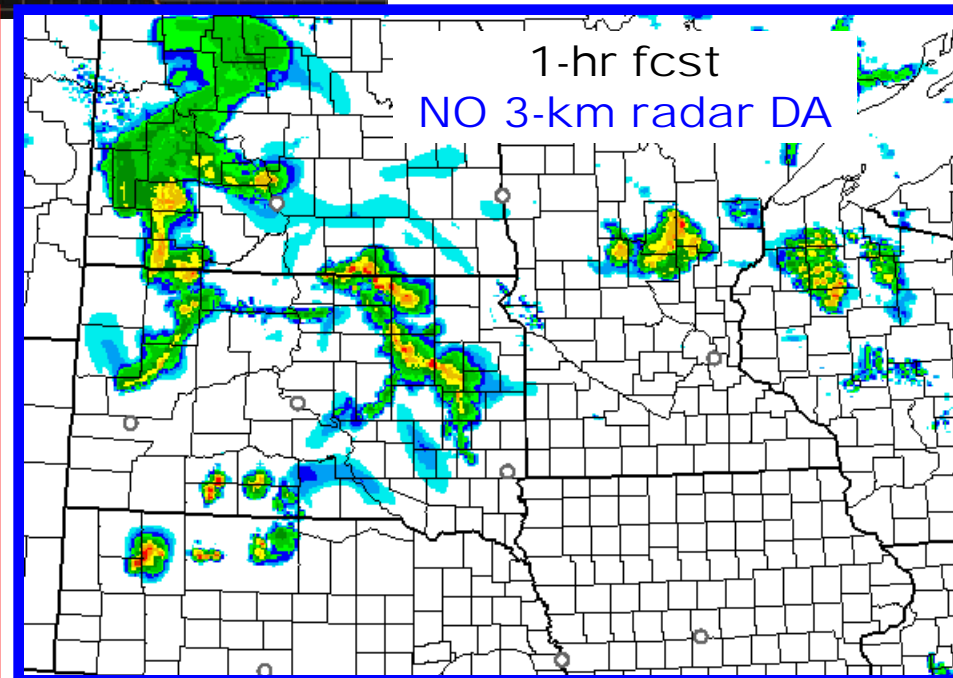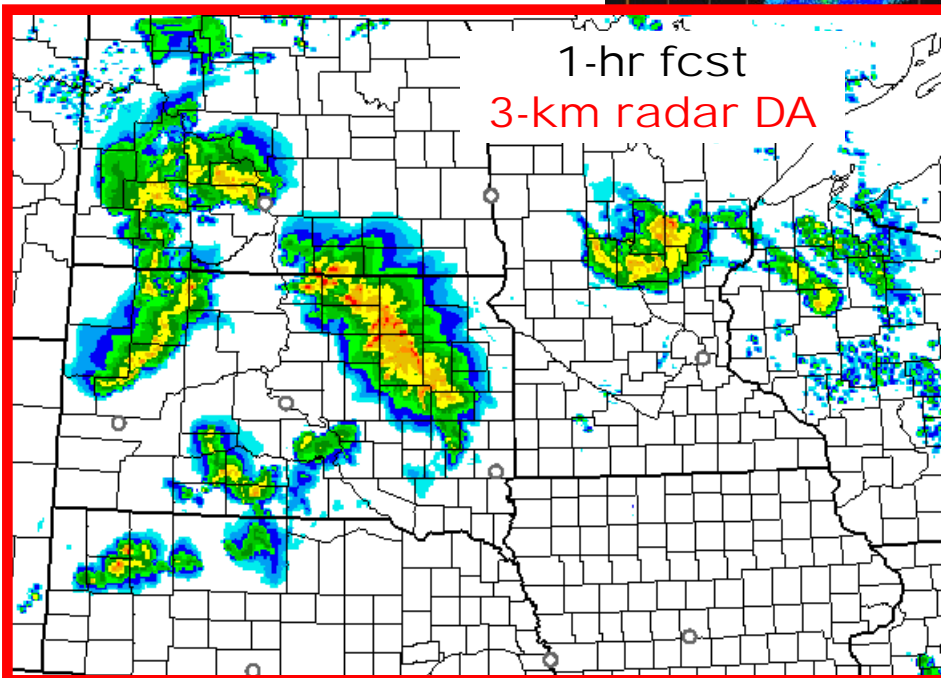
45-min fcst
NO 3-km radar DA

Improved 0-2 hr Convective Fcsts

**Radar Obs
06:00z 18 May 2013**

05z + 1 hour

1-hr fcst
3-km radar DA

1-hr fcst
NO 3-km radar DA

Improved 0-2 hr Convective Fcsts

**Radar Obs
06:30z 18 May 2013**

05z + 1:30 min

1-hr 30m fcst
3-km radar DA

1-hr 30m fcst
NO 3-km radar DA

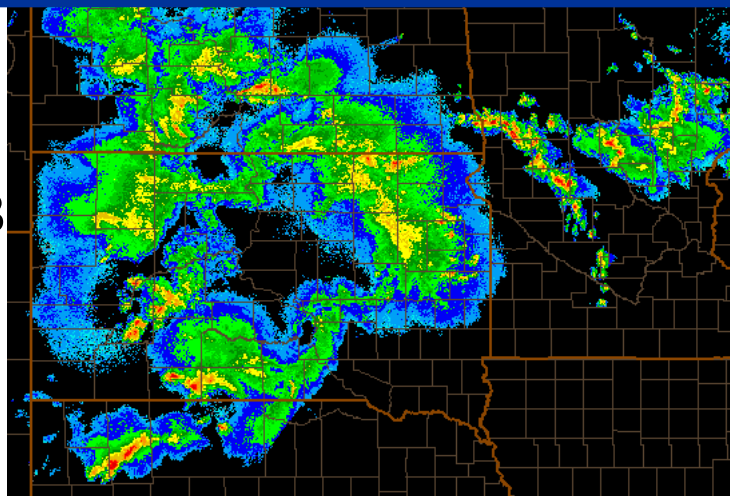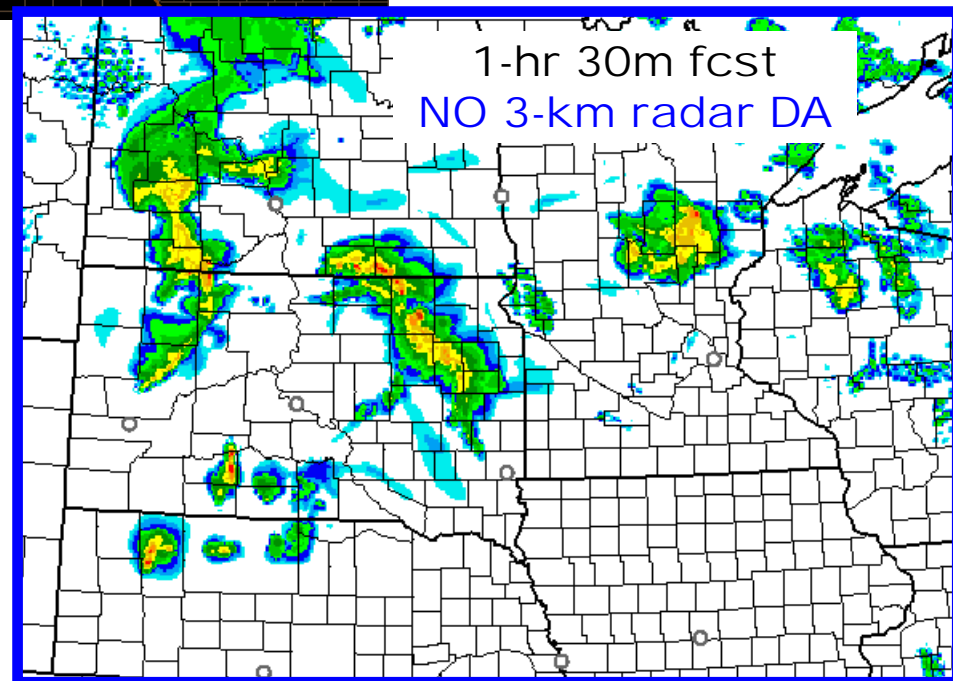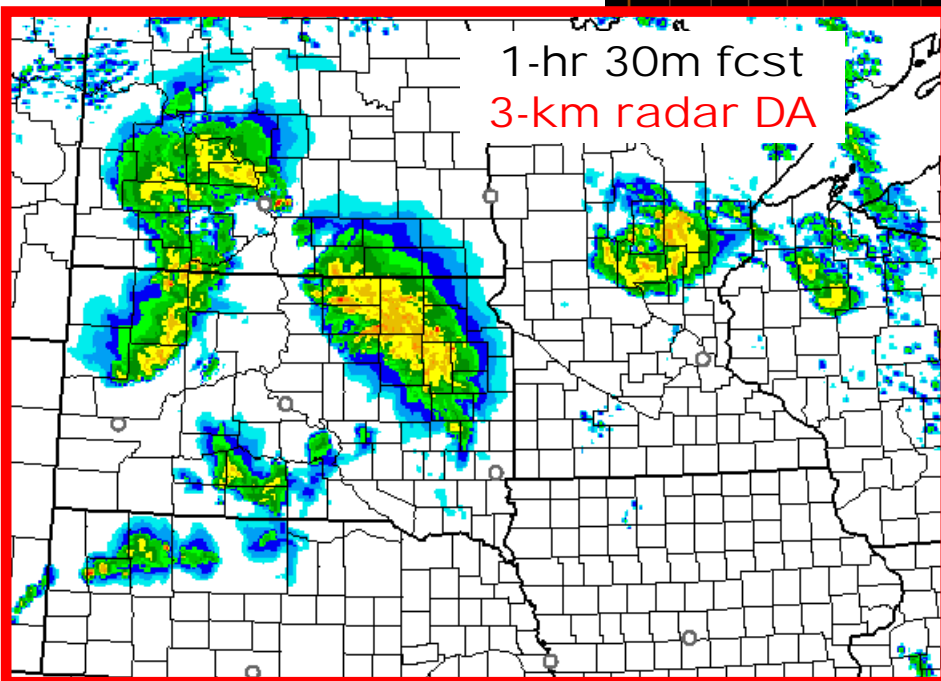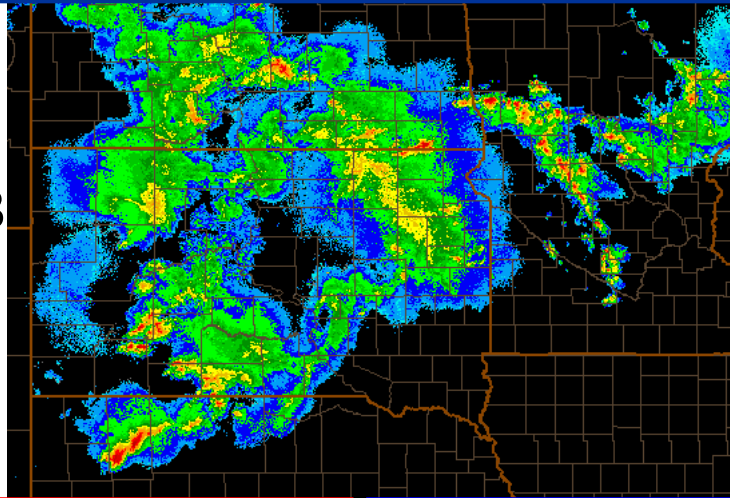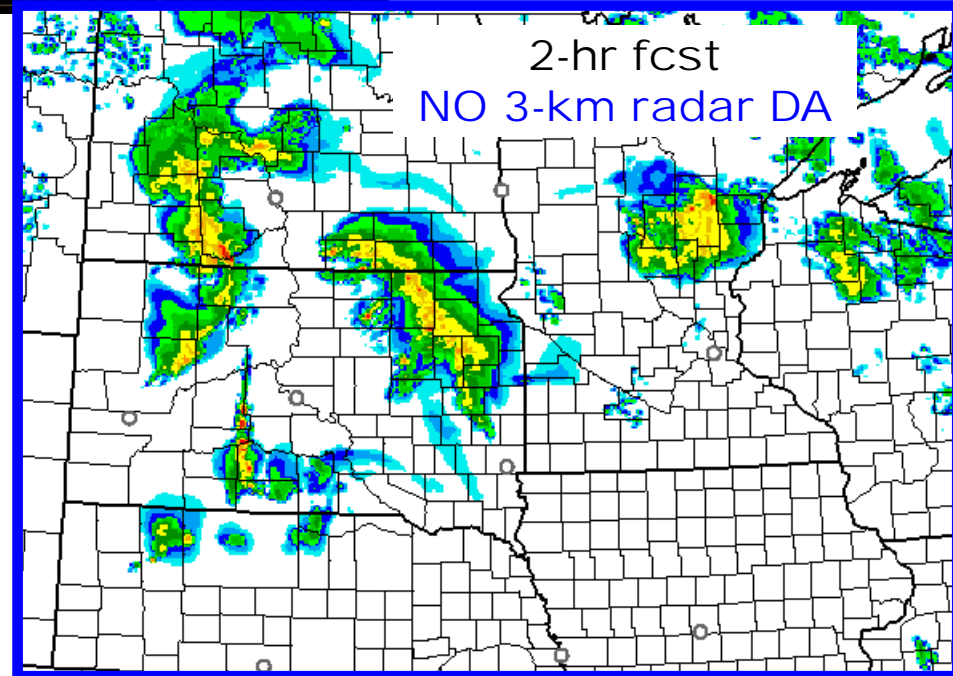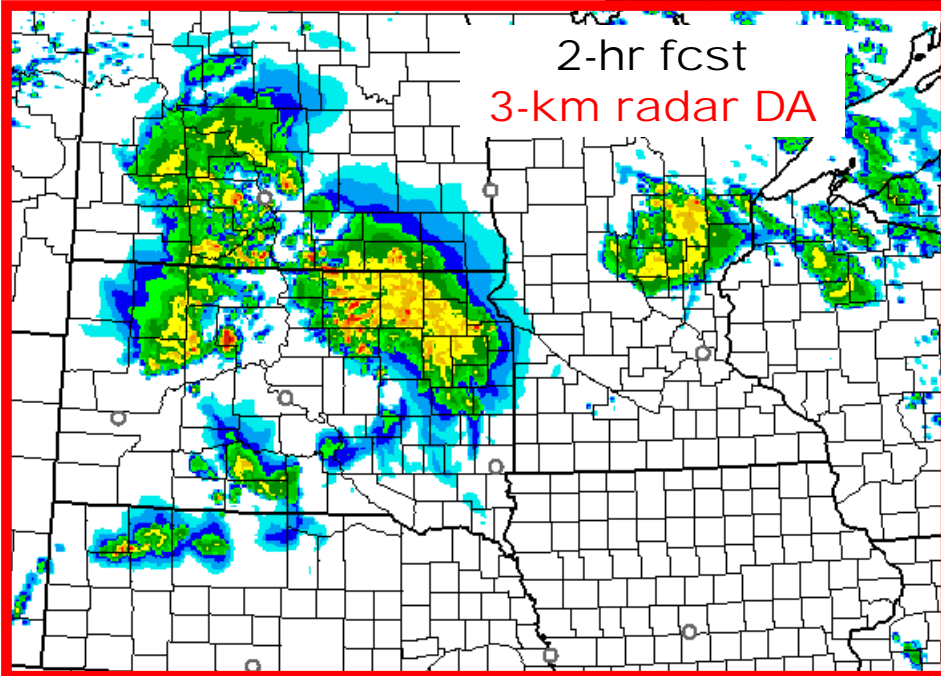# Improved 0-2 hr Convective Fcsts

**Radar Obs
07:00z 18 May 2013**

05z + 2hr min

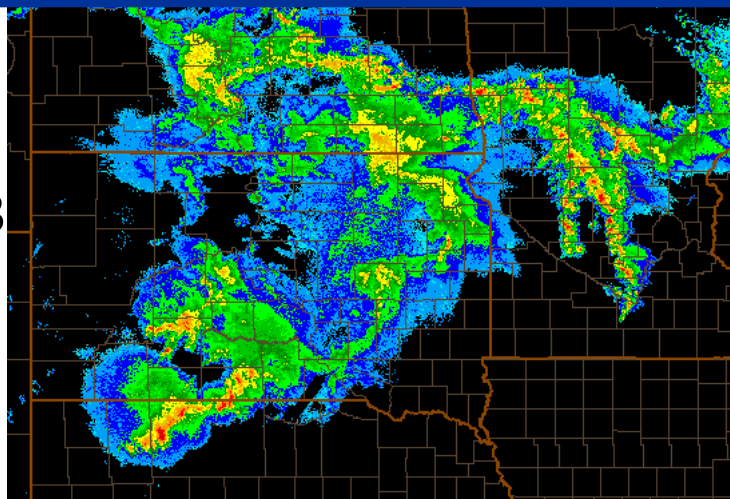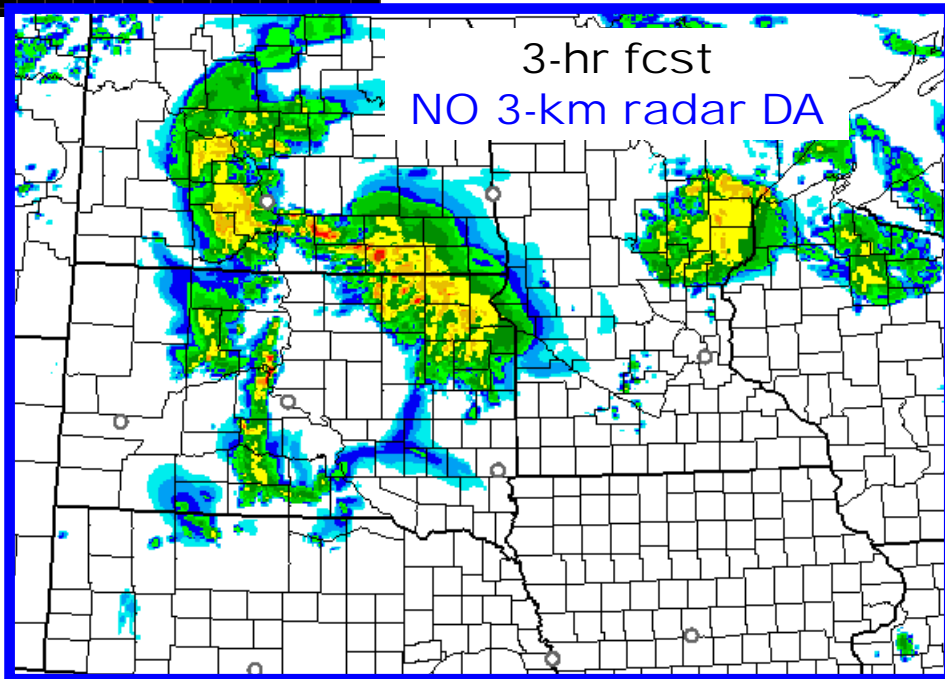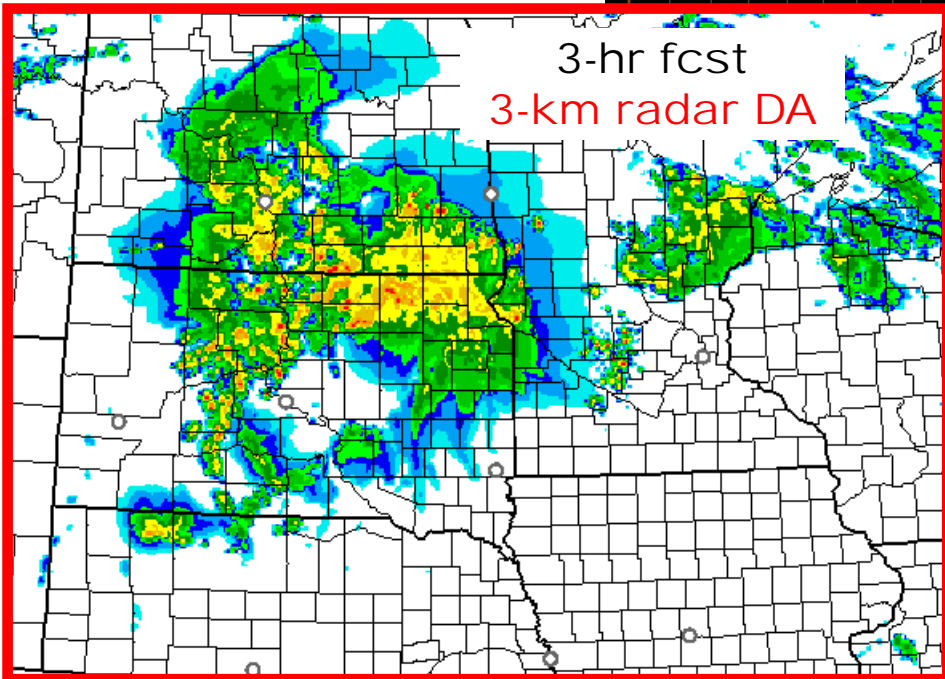**2-hr fcst
3-km radar DA**

**2-hr fcst
NO 3-km radar DA**

Improved 0-2 hr Convective Fcsts

Radar Obs
08:00z 18 May 2013

05z + 3hr

3-hr fcst
3-km radar DA

3-hr fcst
NO 3-km radar DA

Lead-Time vs Valid Time

Spring (Apr-June)

Summer (July-Sept)

2012

2013

20-45 dBZ Average
3-km Grid East US

Up to 2x convection in 2013

Easier Forecasts?

Lead-Time vs Valid Time

Spring (Apr-June) — Average CSI — 2012 / 2013
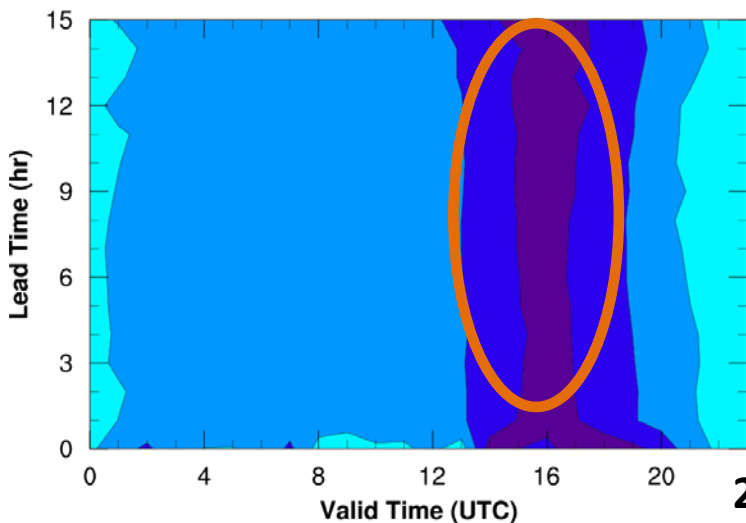
Summer (July-Sept) — Average CSI — 2012 / 2013
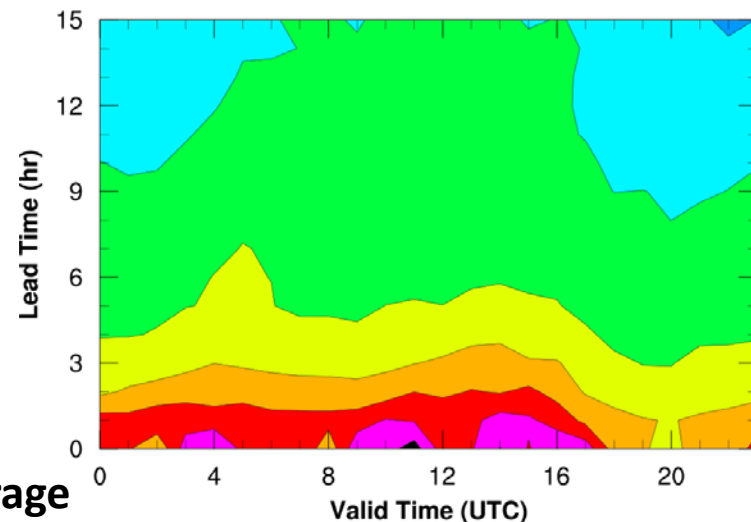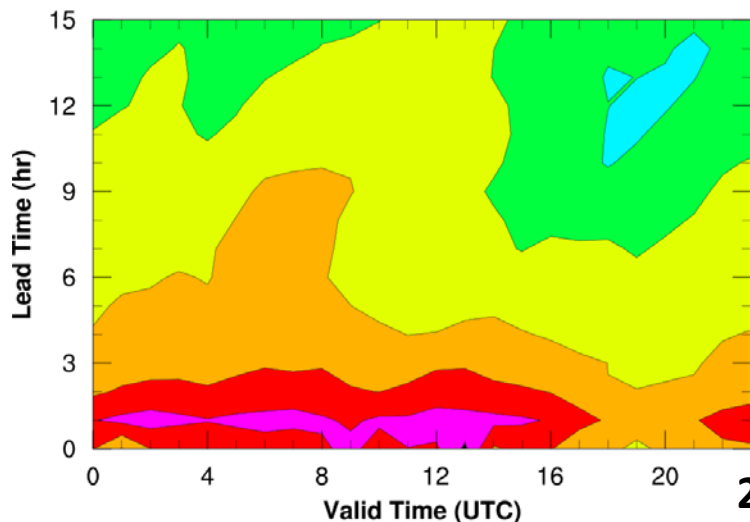
20-45 dBZ Average
3-km Grid East US
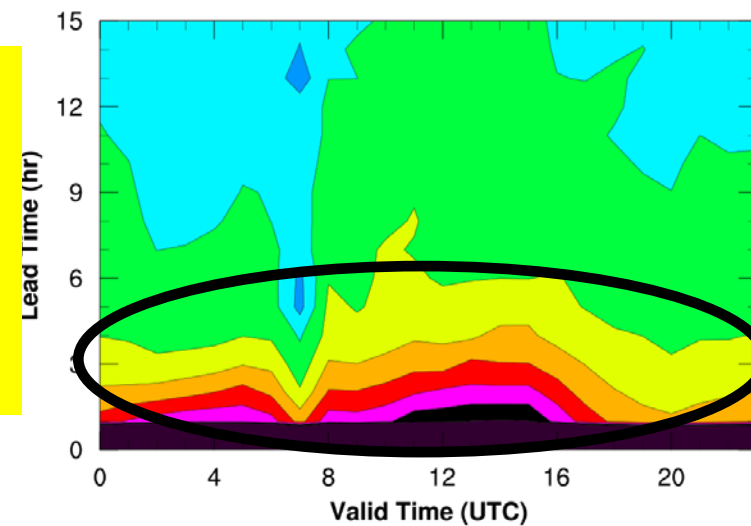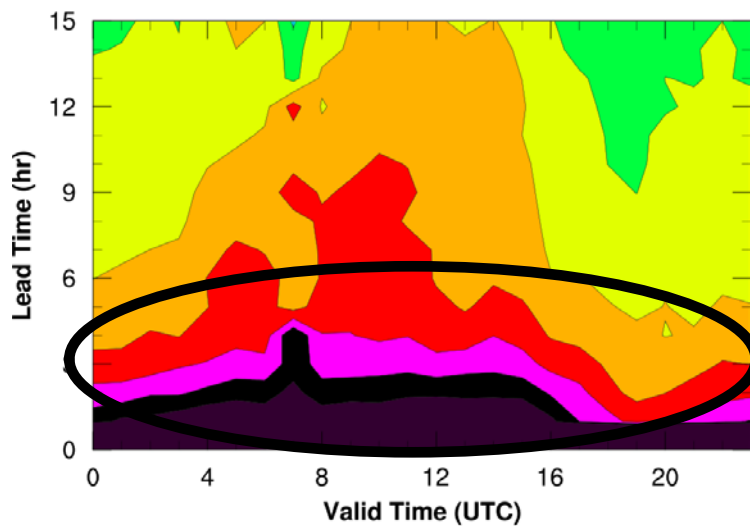
Significant skill increase at short lead times with 3-km DA

Lead-Time vs Valid Time

Spring (Apr-June)

Summer (July-Sept)

20-45 dBZ Average
3-km Grid NE US
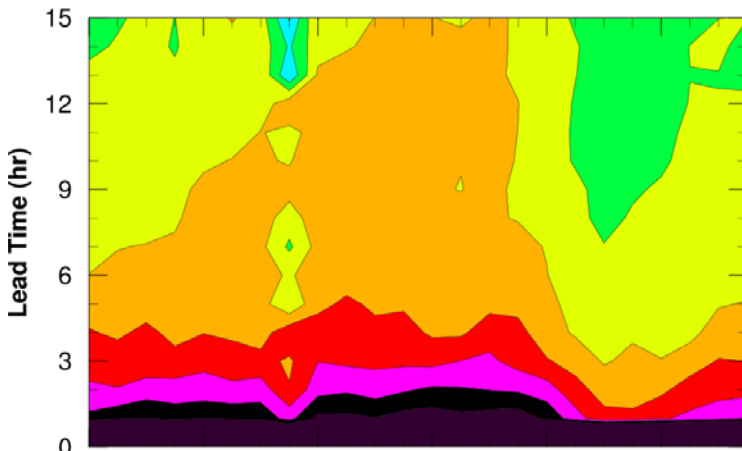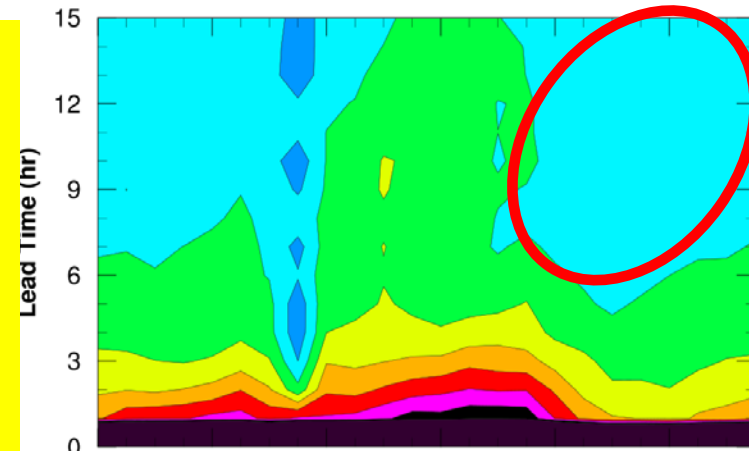
Late afternoon, long-lead times in summer have lowest skill in NE

Lead-Time vs Valid Time

Spring (Apr-June)

Summer (July-Sept)
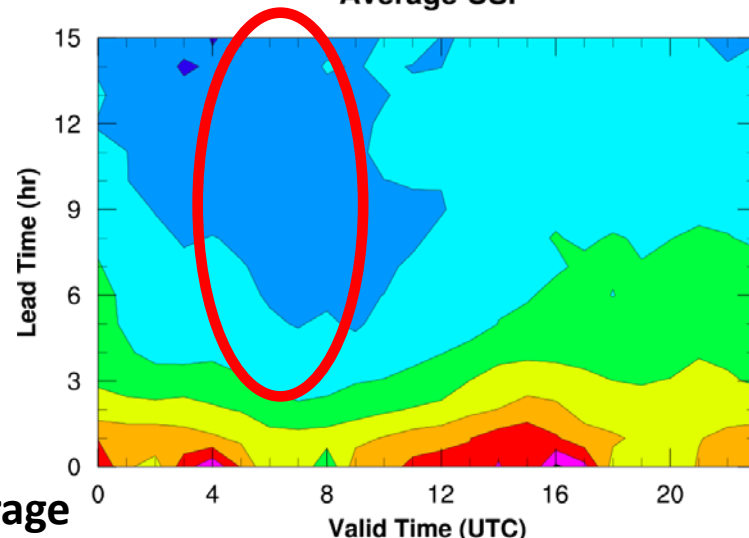
2012

2013

20-45 dBZ Average
3-km Grid SE US
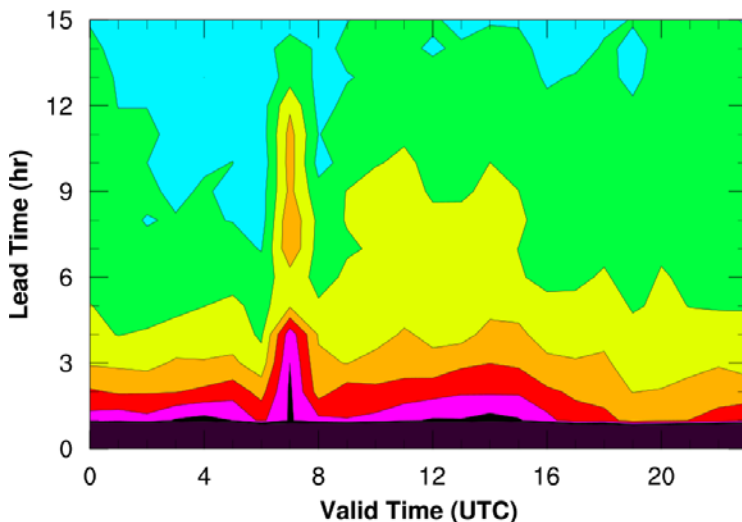
Early morning, long-lead times in summer have lowest skill in SE
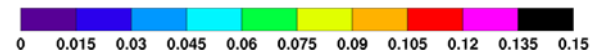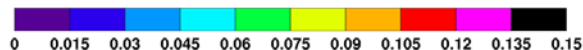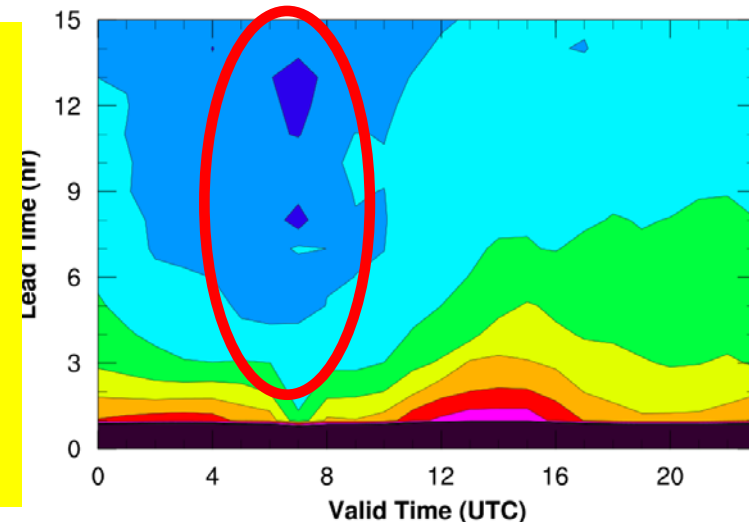
HRRR Real-Time Exper Products

|	Background	Dimensionality	Updated
2012 HRRR model initialization	13-km RAP	3-D	Hourly
2013 HRRR model initialization	13-km RAP	3-D	Hourly
Rapidly Updating Analysis (RUA-HRRR)	3-km HRRR 1 hr fcst	3-D	Hourly
Real-Time Meso Analysis (RTMA-HRRR)	3-km HRRR 1 hr fcst	2-D	**Hourly (15 min planned)**
Time-Lagged HRRR (HCPF)	3-km HRRR Fcsts	2-D	Hourly

Time-lagged Ensemble

Forecasts valid 21-22z 27 April 2011   Forecasts valid 22-23z 27 April 2011

10-11 hr fcst   11-12 hr fcst

HRRR 11z Init

09-10 hr fcst   10-11 hr fcst

HRRR 12z Init

08-09 hr fcst   09-10 hr fcst

HRRR 13z Init
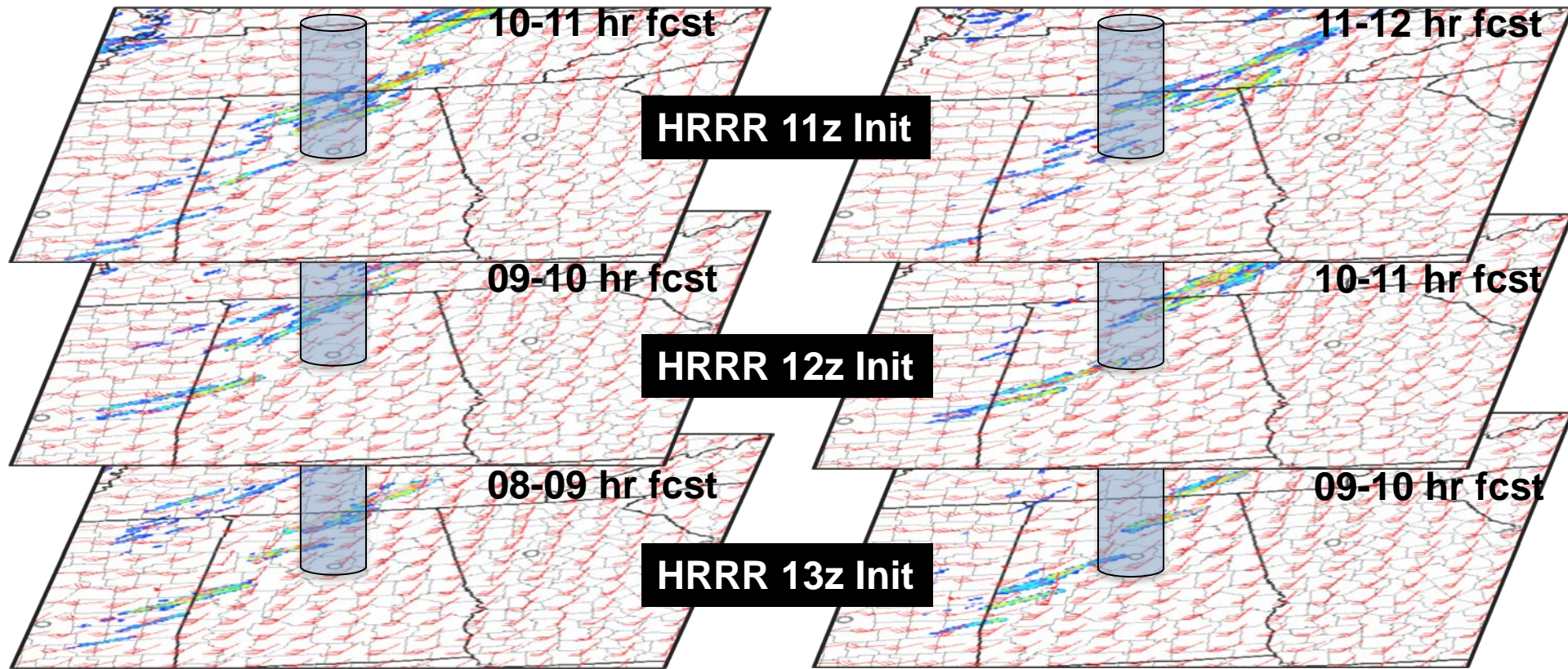
All six forecasts combined to form probabilities valid 22z 27 April 2011

Spatial radius 45 km
Time radius 1 hr
UH threshold 25 m²/s²

0   2   5   10   15   30   45   60   100
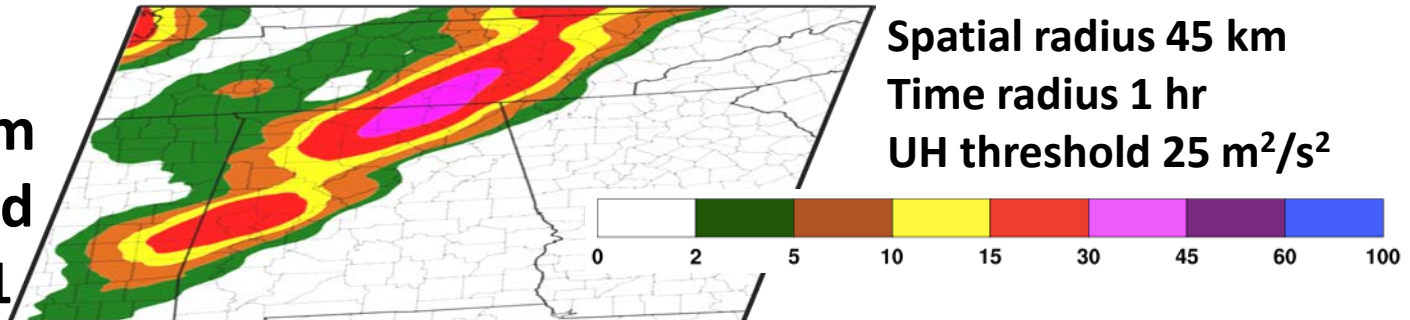
Example: 28 August 2013

Atypical summer convection embedded in NW flow with "back-door" cold front in New England

Composite Reflectivity
Derived From Mosaic3D

Valid: 08/28/2013 06:00:00 UTC
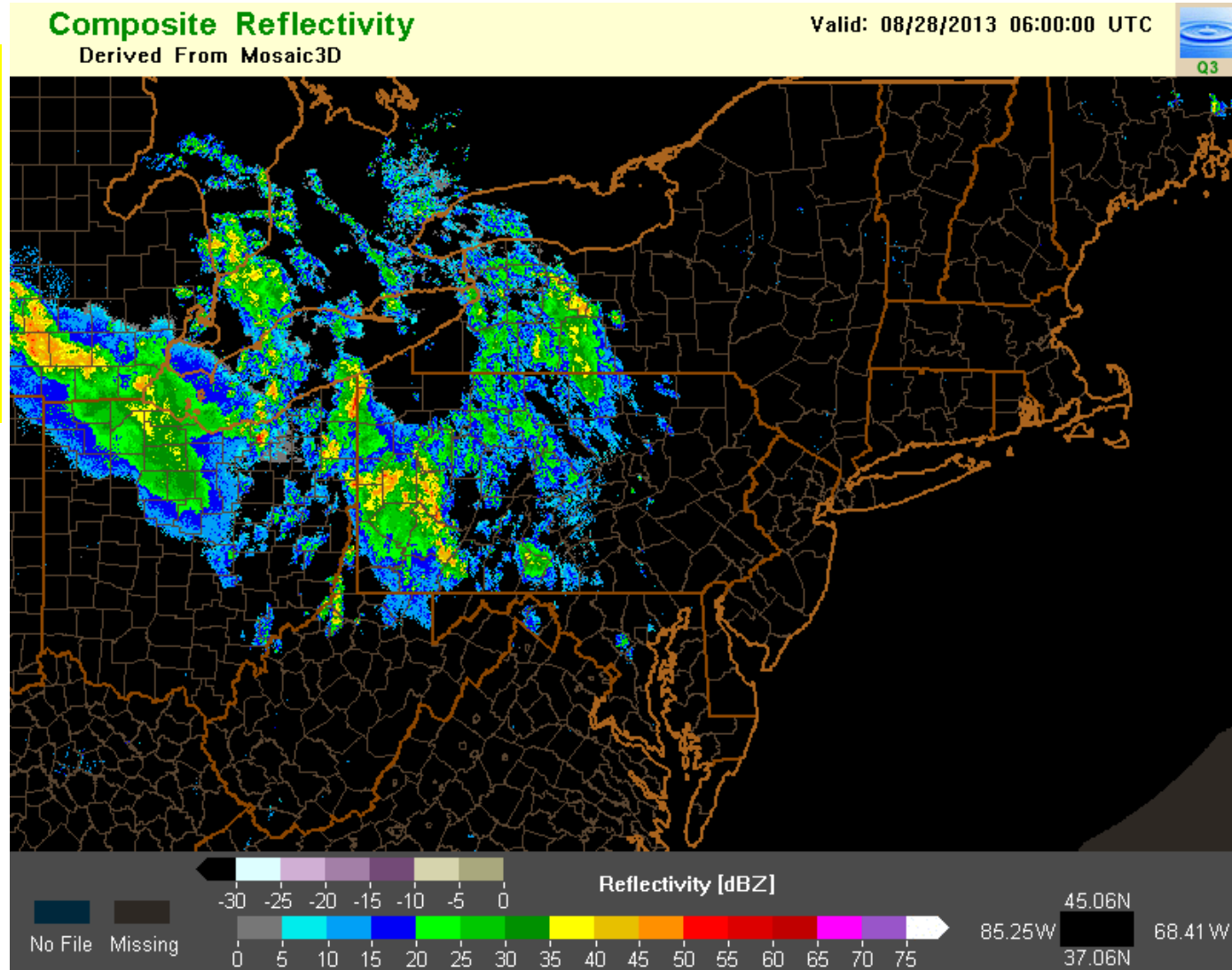
Convection develops in NYC terminal areas around 16 UTC

Composite Reflectivity Derived From Mosaic3D — Valid: 08/28/2013 16:00:00 UTC
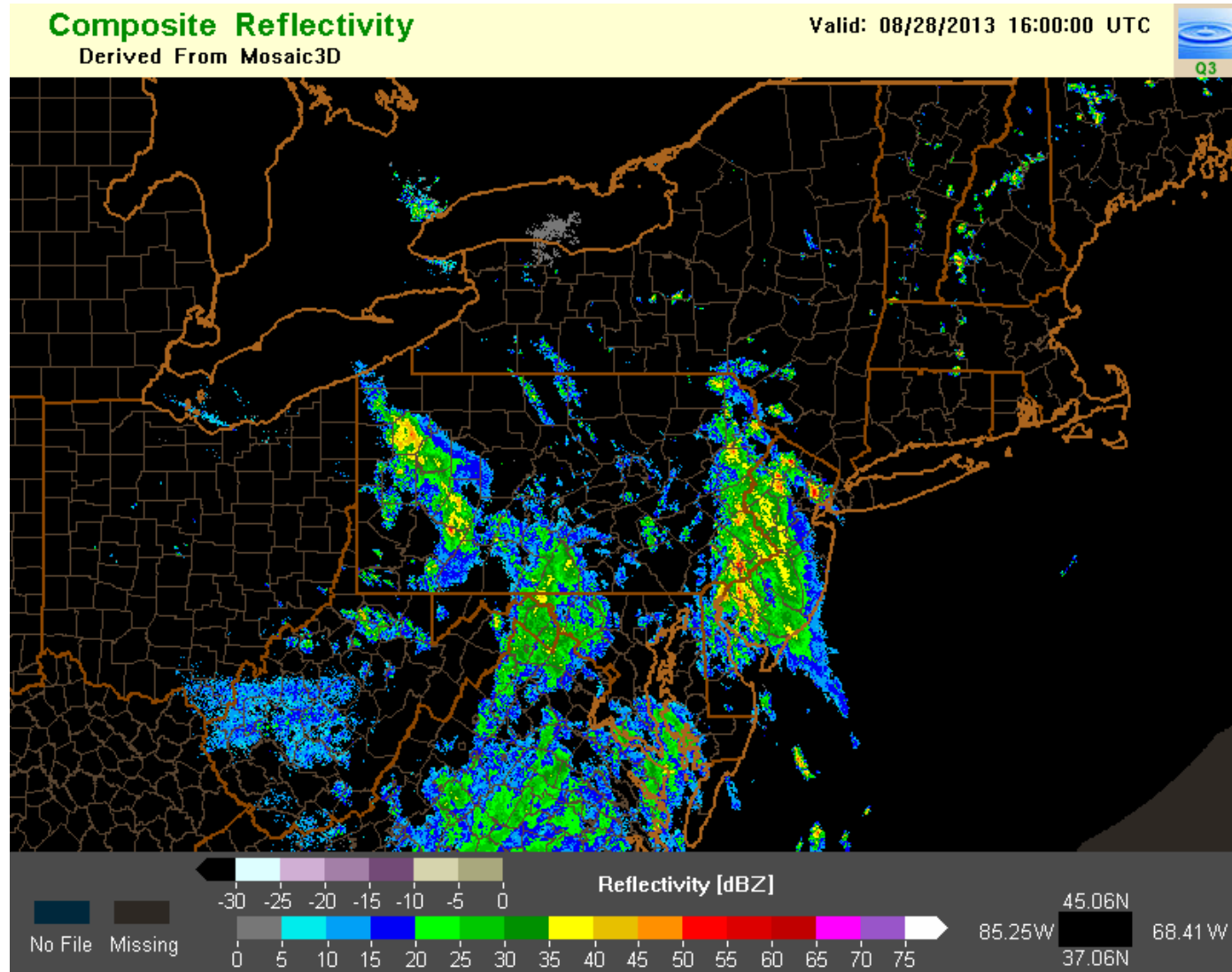
HRRR Conv Prob Fcst (HCPF)

HCPF - HRRR deterministic forecasts (reflect > 35 dBZ) overlaid on convective probability

Attempt to capture uncertainty through measure of hourly forecast consistency

AWC beginning evaluation of product

06 hr fcst valid 16z 28 Aug 2013

First hints of convection in NE PA

HRRR Convective Probability Forecast (%) and Reflectivity (dBz) 06 hr fcst valid 08/28/2013 16 UTC

Obs valid 16z 28 Aug 2013

Composite Reflectivity
Derived From Mosaic3D

Valid: 08/28/2013 16:00:00 UTC

HRRR Conv Prob Fcst (HCPF)

04 hr fcst valid 16z 28 Aug 2013

Increasing convective intensity and coverage in NE PA and N NJ
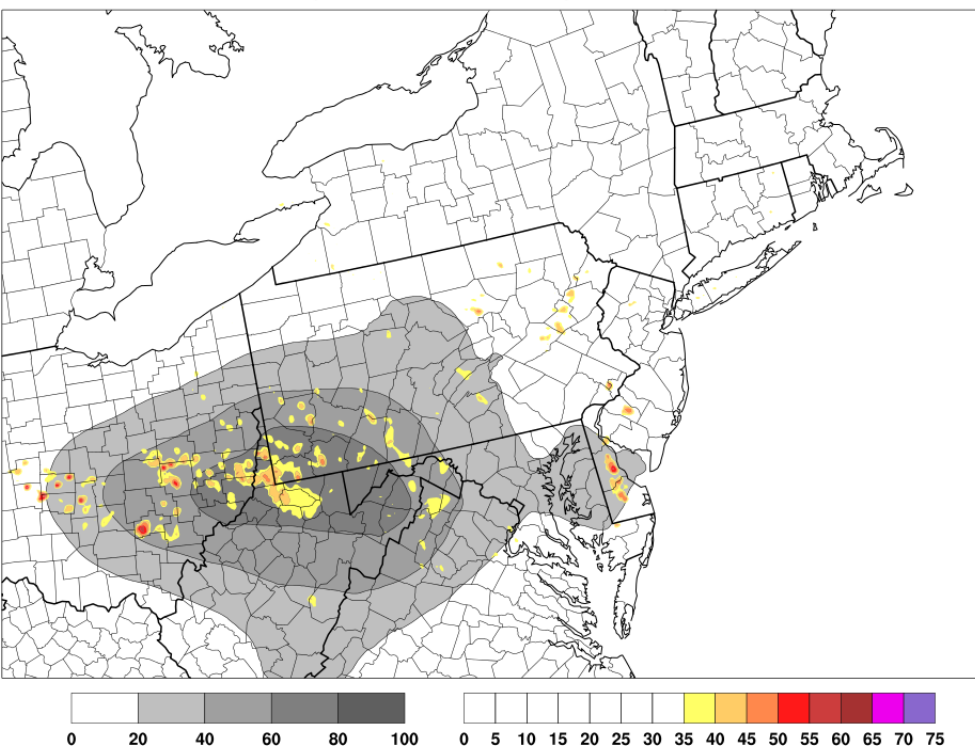
Probability exceeds 20%

HRRR Convective Probability Forecast (%) and Reflectivity (dBz) 04 hr fcst valid 08/28/2013 16 UTC

Composite Reflectivity
Derived From Mosaic3D

Valid: 08/28/2013 16:00:00 UTC

Obs valid 16z 28 Aug 2013

HRRR Conv Prob Fcst (HCPF)

Convective coverage now over much of extreme E PA and NJ

Probability exceeds 40%

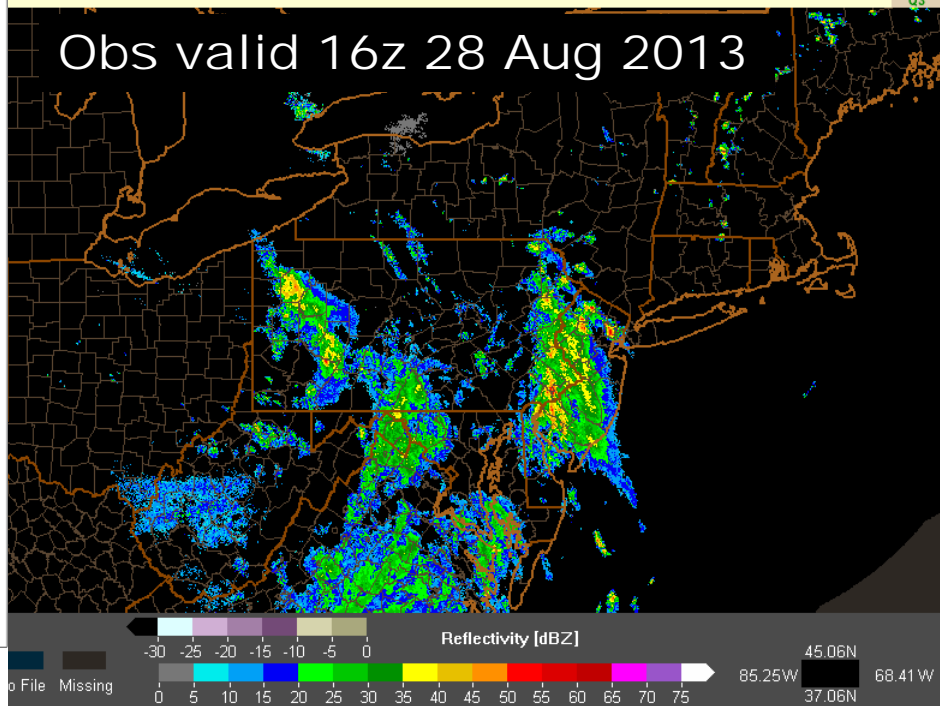HRRR Convective Probability Forecast (%) and Reflectivity (dBz) 02 hr fcst valid 08/28/2013 16 UTC

Composite Reflectivity
Derived From Mosaic3D
Valid: 08/28/2013 16:00:00 UTC

Obs valid 16z 28 Aug 2013

HRRR Conv Prob Fcst (HCPF)

HRRR Convective Probability Forecast (%) and Reflectivity (dBz) 00 hr fcst valid 08/28/2013 16 UTC

Composite Reflectivity
Derived From Mosaic3D

Valid: 08/28/2013 16:00:00 UTC
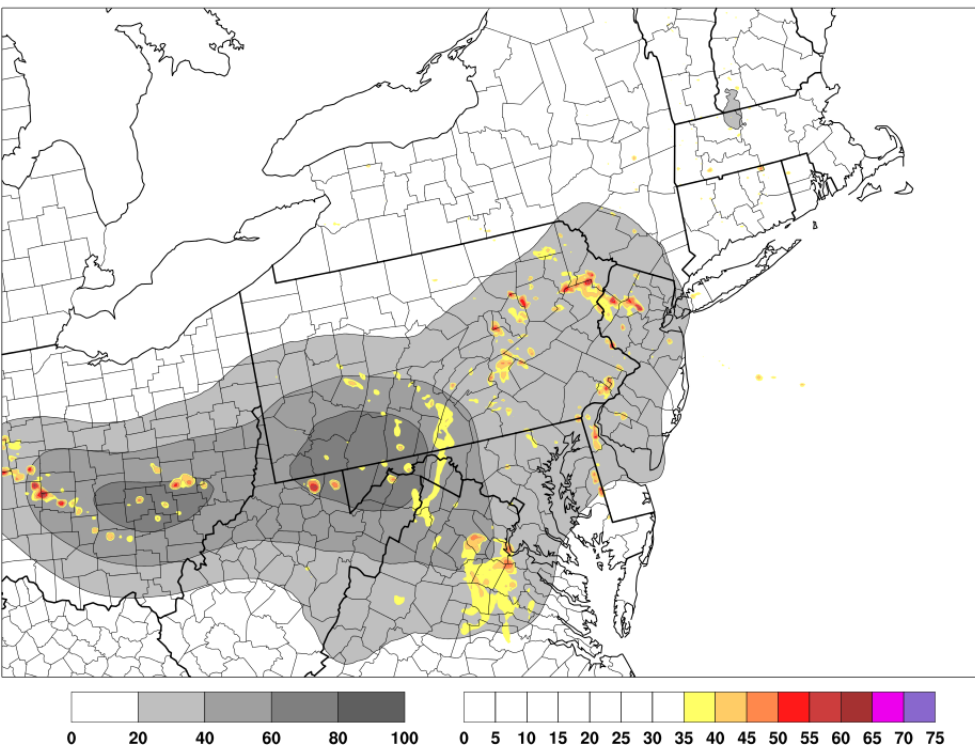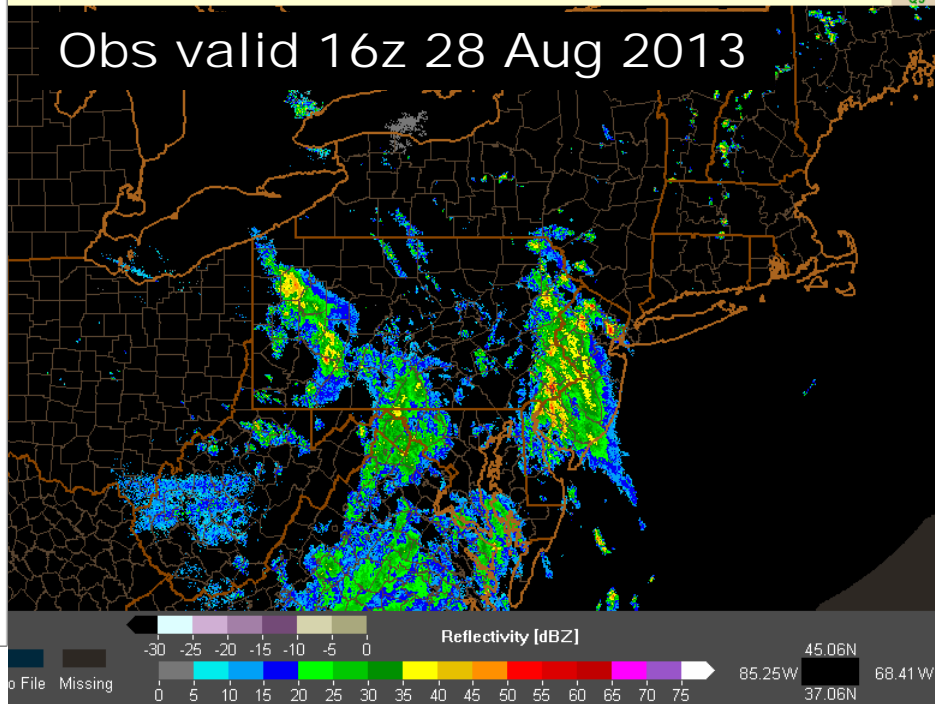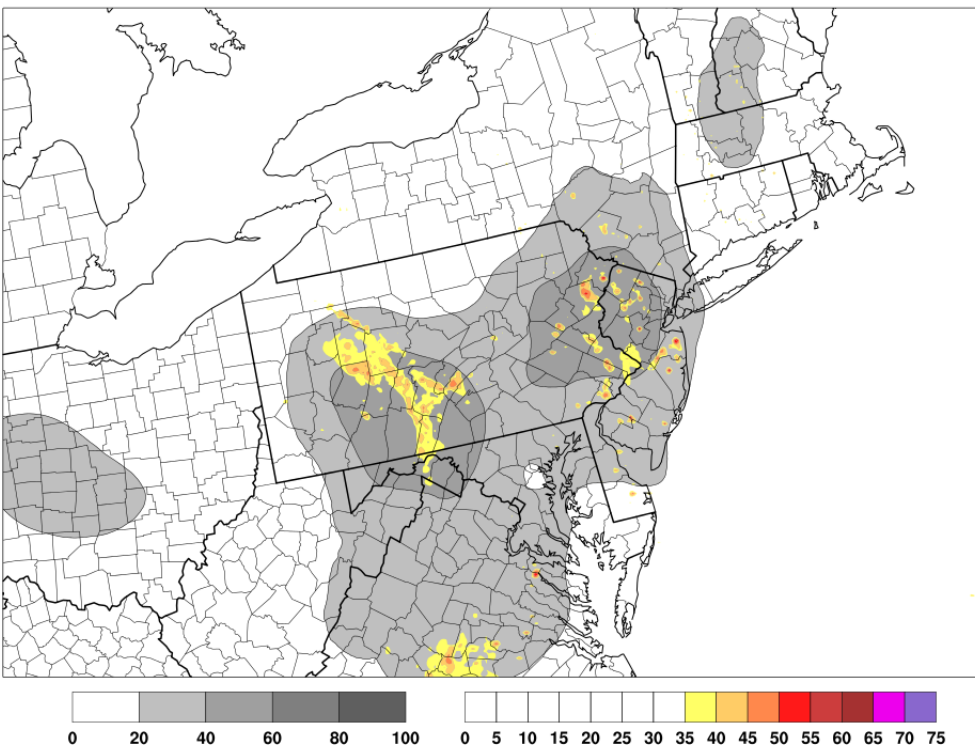
Obs valid 16z 28 Aug 2013

Reflectivity [dBZ]

HRRR Conv Prob Fcst (HCPF)

Probabilities slowly evolve providing identifiable run-to-run trends

Convective structure (permeability etc...) still accessible

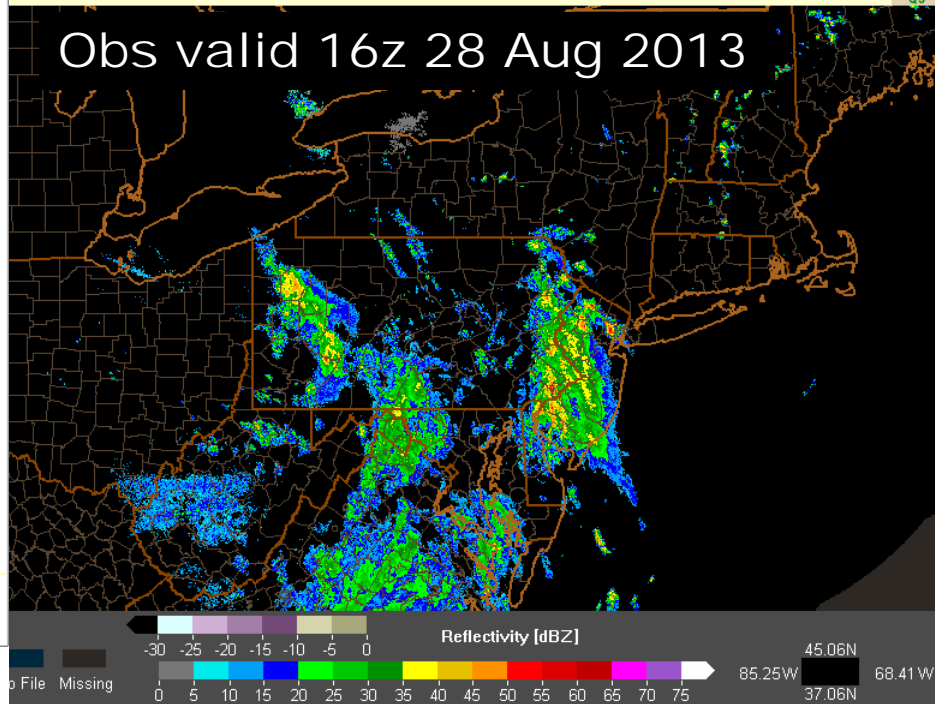HRRR Convective Probability Forecast (%) and Reflectivity (dBz) 10 hr fcst valid 08/28/2013 16 UTC

Composite Reflectivity
Derived From Mosaic3D
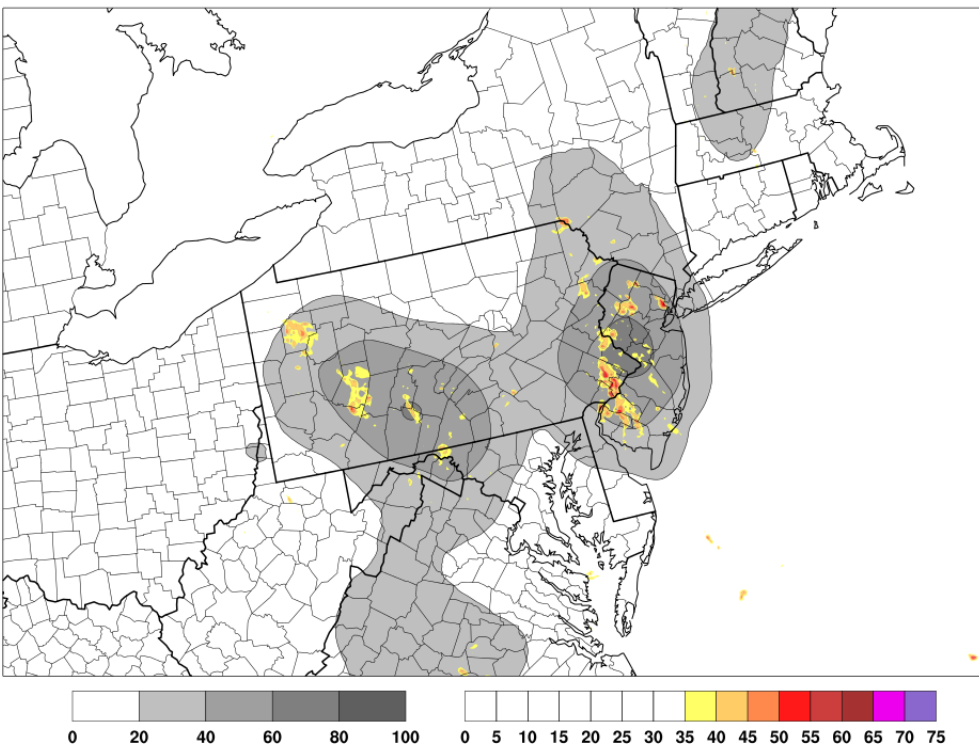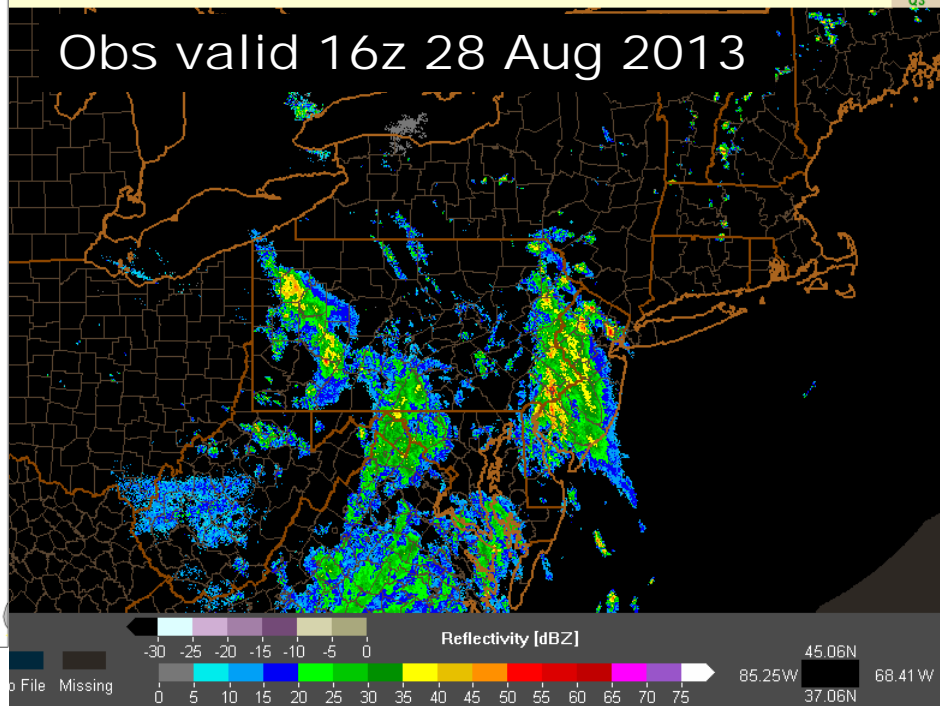Valid: 08/28/2013 16:00:00 UTC
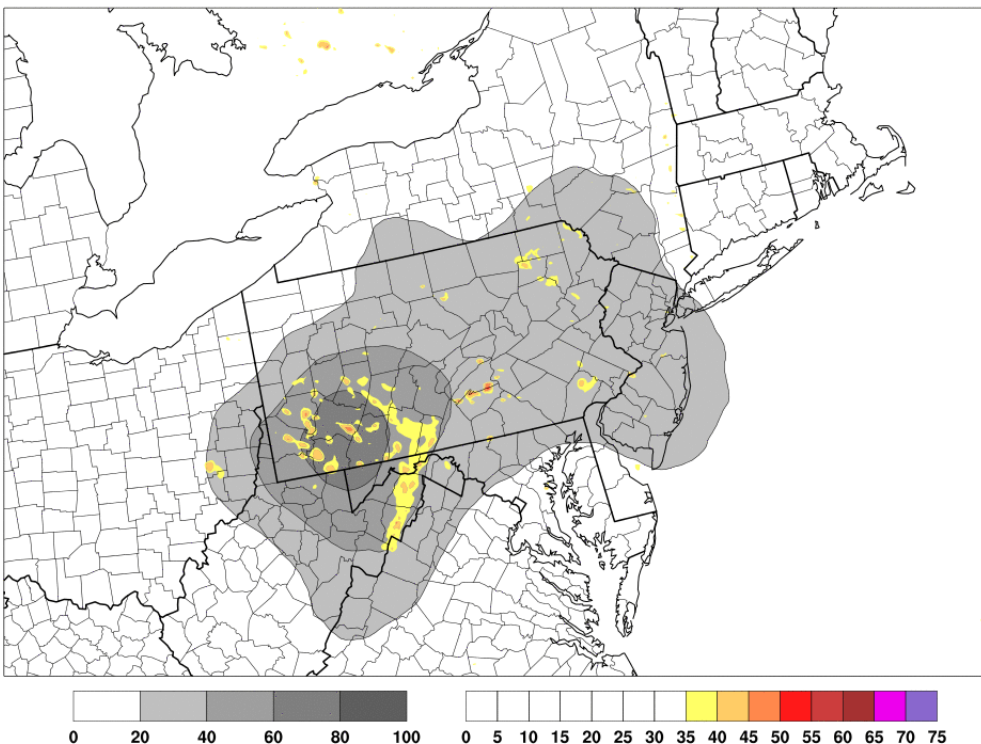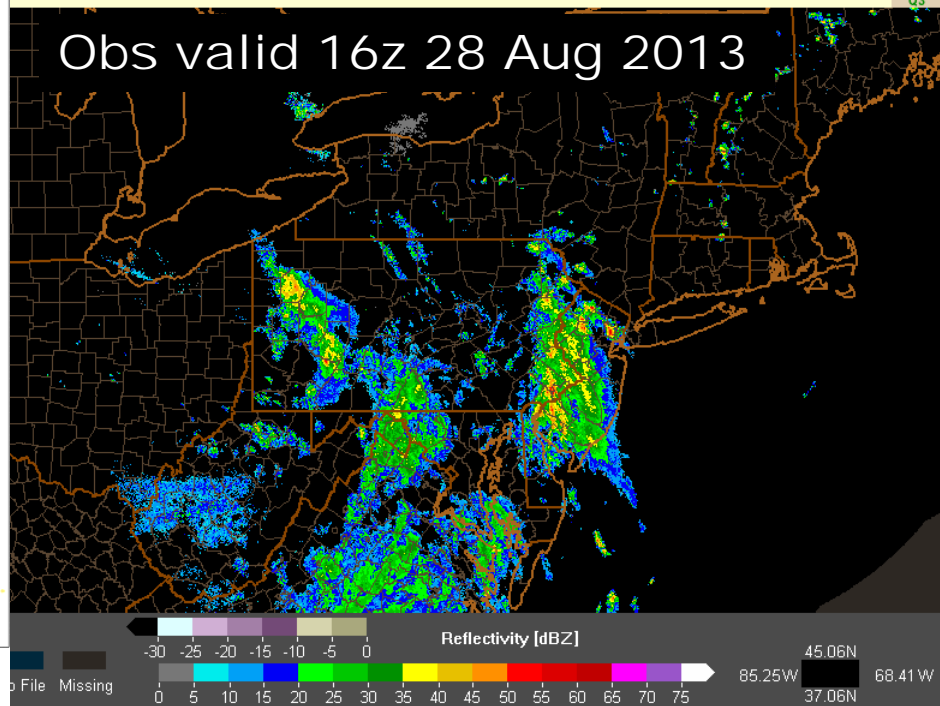
Obs valid 16z 28 Aug 2013
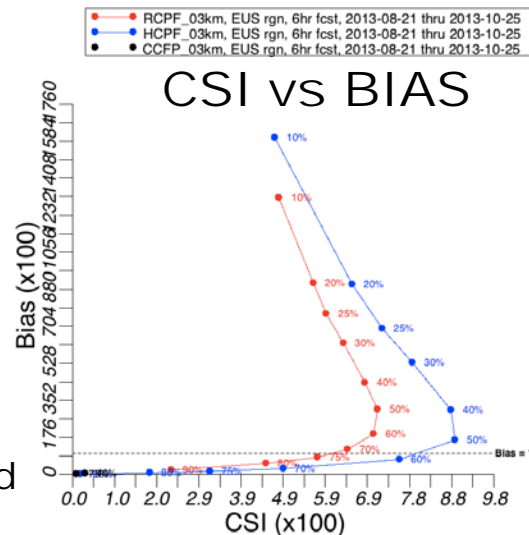
HRRR Conv Prob Fcst (HCPF)

HCPF (blue) being developed to replace legacy RUC conv prob fcst (RCPF in red)

HCPF more statistically reliable in eastern US but over forecasts (no calibration yet)
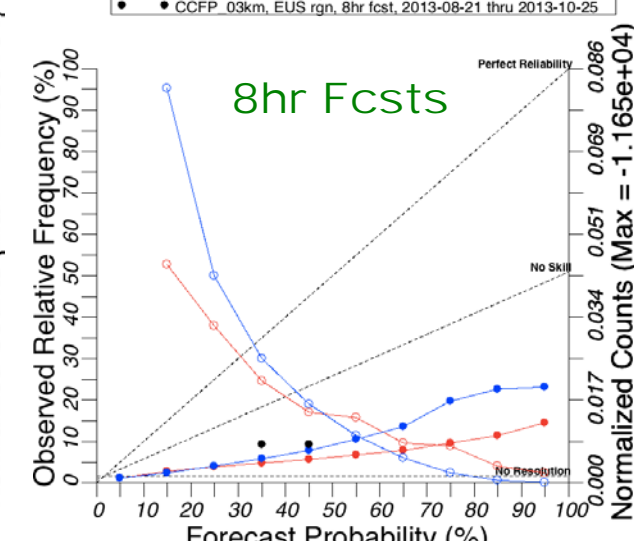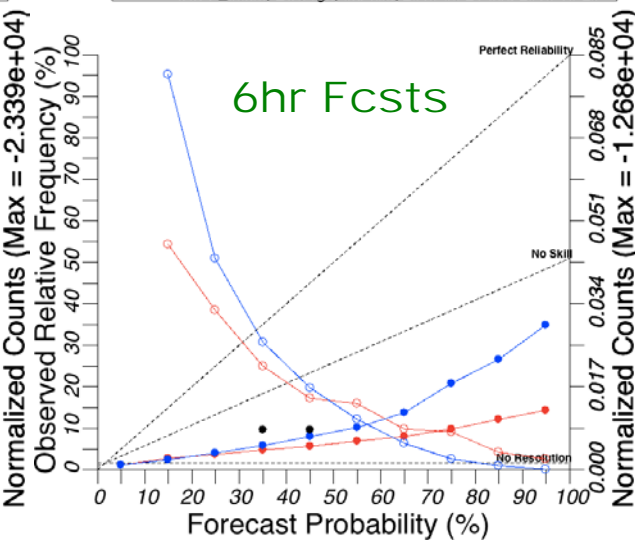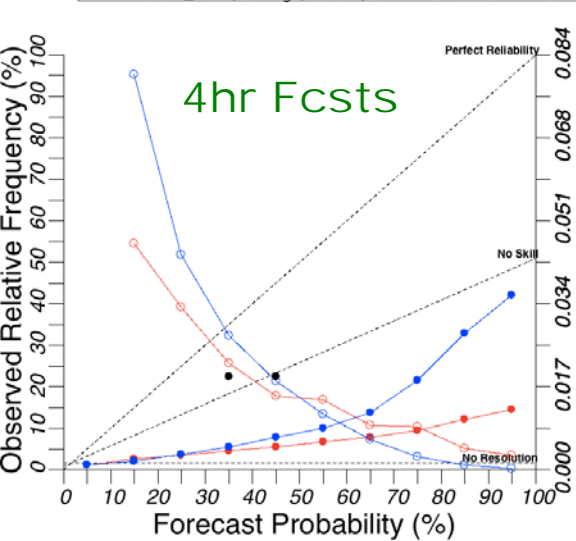
HCPF max CSI @ 50% with BIAS ~1.7

CSI vs BIAS

Reliability Diagrams using 35 dBZ NSSL threshold on 3-km grid Aug-Oct 2013 Eastern US

4hr Fcsts

6hr Fcsts

8hr Fcsts

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**

- **Science: Focus on 3-km assimilation for 2013**
  - **3-km variational analysis**
  - **3-km non-variational cloud analysis**
  - **3-km radar reflectivity data assimilation**

- **Technical: Reduced latency for 2013 (2-3 hrs now)**
  - **Approximate 1-hr reduction in execution time (1-2 hrs)**
  - **Faster post-processing with parallelization**
  - **Direct GRIB2 generation**

HRRR Transition to NCEP

- **2013 - early 2014 – 2 computers running identical HRRR (and RAPv2) – interim solution**
  - Boulder – computer 1
  - Fairmont, WV – computer 2
  - Expected reliability at 98.5-99% via coordination of downtimes for Boulder vs. Fairmont computers

- **2014 – NCEP running RAPv2 (FYQ1) and HRRR (FYQ2)**
  - RAPv2 running in NCEP/NCO testing now
  - Effort underway to begin testing HRRR at NCEP

- Conclusion: *Interim HRRR computing for 2013 on 2 sites to provide "real-time experimental" HRRR from NOAA for NWS, FAA, DOE/energy users until HRRR impl @NCEP*