CIRES

Earth System Research Laboratory
SCIENCE, SERVICE & STEWARDSHIP

NCEP

The High-Resolution Rapid Refresh (HRRR): A maturation of frequently updating convection-allowing numerical weather prediction

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Global Systems Division

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Rapid Refresh and HRRR
NOAA hourly updated models

13km Rapid Refresh (RAP)

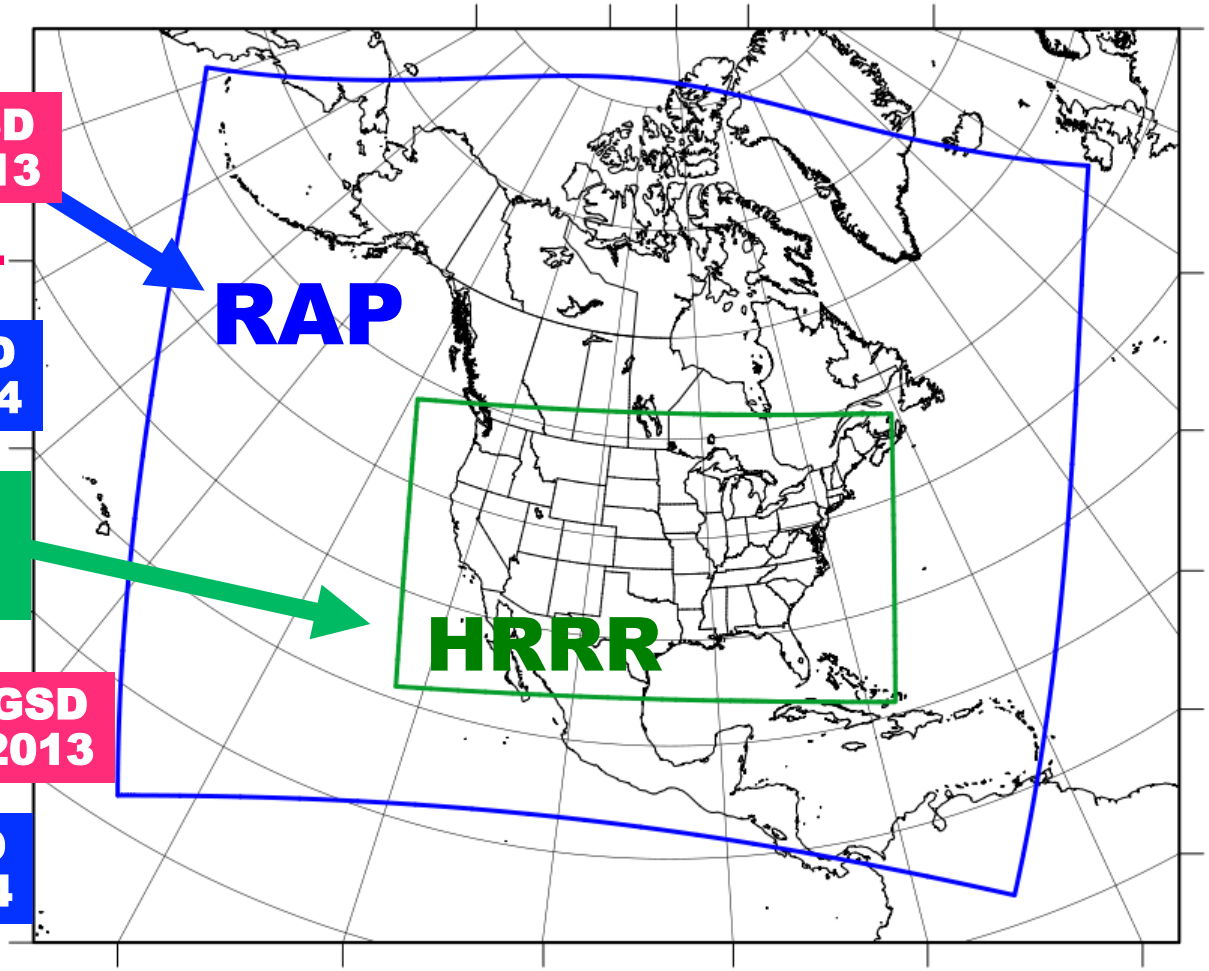
Version 2 -- NCEP GSD 2013
implement 25 Feb 2014

Version 3 – GSD GSD 2014
freeze April 2014

3km High Resolution Rapid Refresh (HRRR)

Initial – plan NCEP GSD 2013
implement Sept 2014

Version 2 – GSD GSD 2014
freeze April 2014

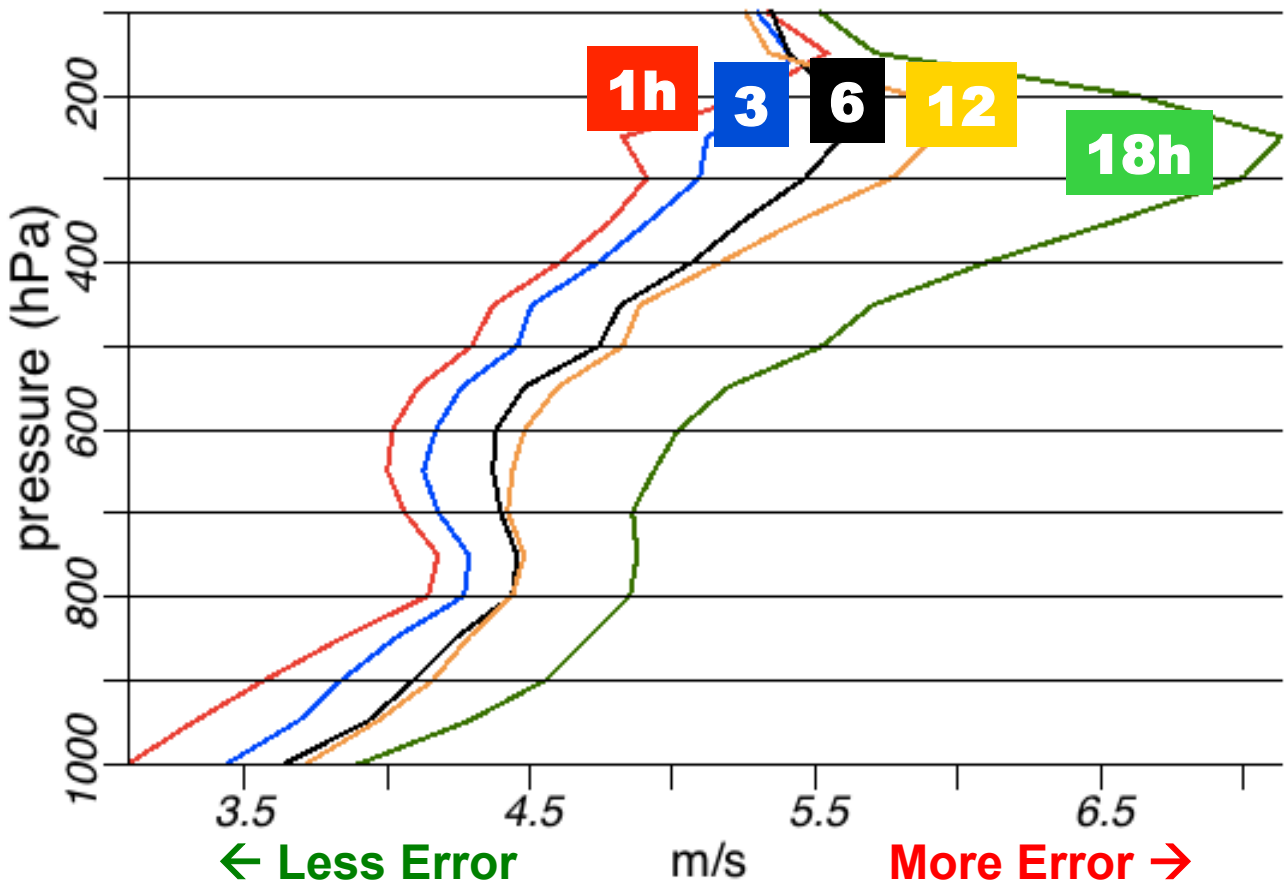


High Impact Prediction Needs: Advanced Obs Assimilation

Wind Forecast Accuracy vs Forecast Length

Like most numerical weather prediction the forecast errors increase with the forecast length

Motivation to use observations with very short term forecasts as first guess
→ **Hourly Cycling**

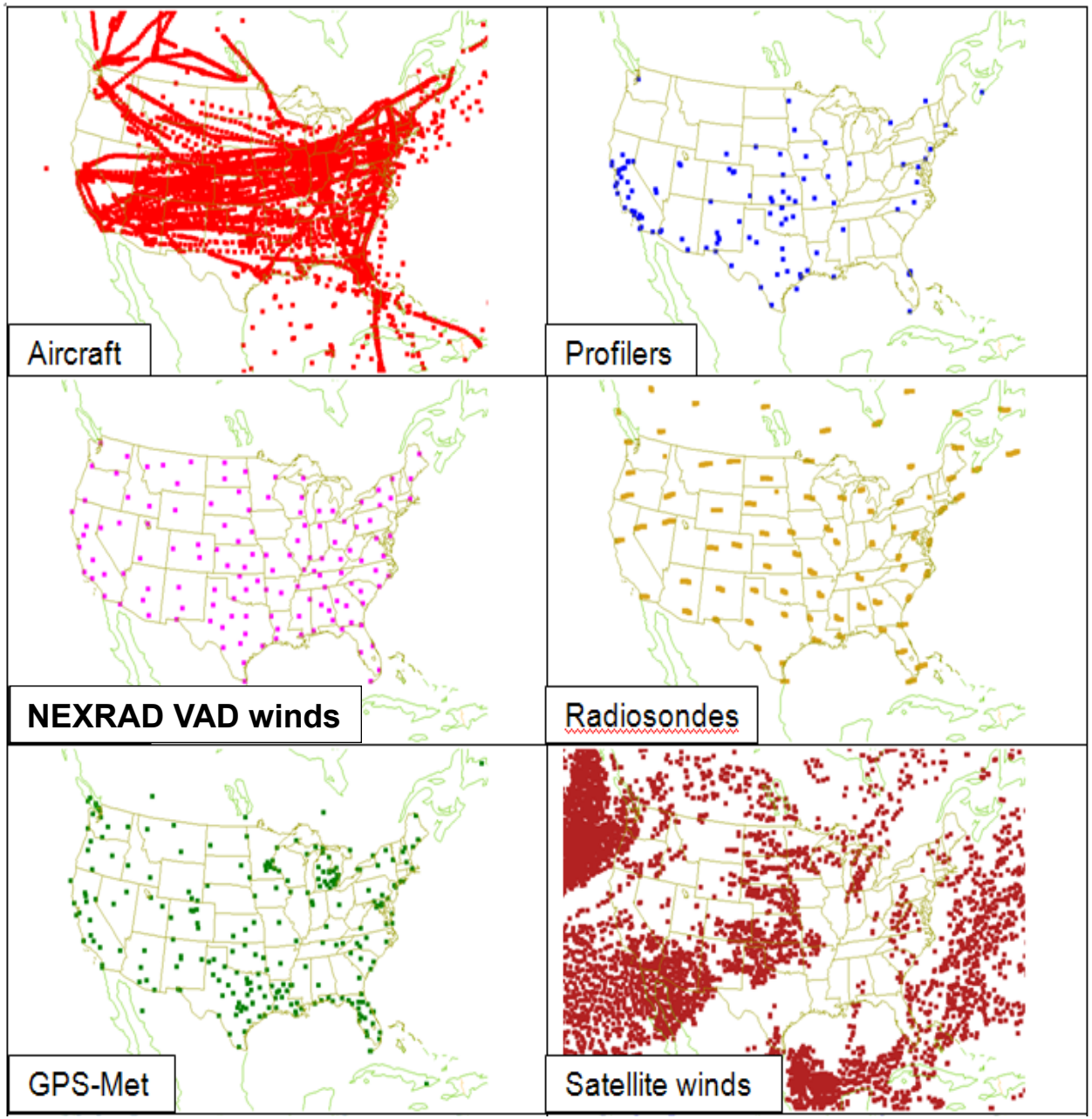


Wind Root Mean Square Error Verified Against RAOBS
Jan 1 – March 7, 2012

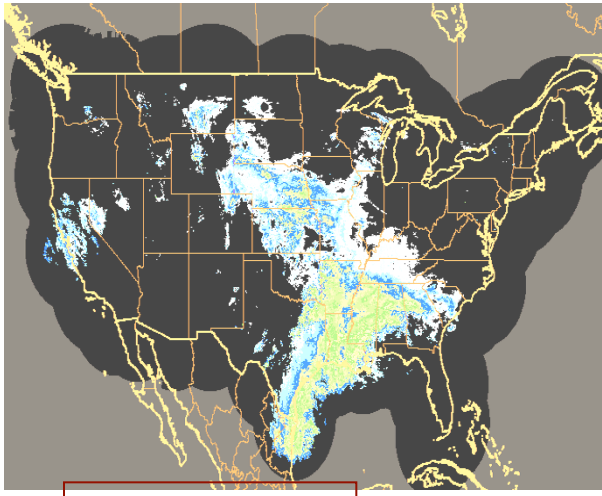
High Impact Prediction Needs: High Density Observations

Observations Used in 2014 RAP/HRRR

Hourly Observation Type	Variables Observed	Observation Count
Rawinsonde	Temperature, Humidity, Wind, Pressure	120
Profiler – NOAA Network	Wind	Down to 9 (!)
Profiler – 915 MHz	Wind, Virtual Temperature	20-30
Radar – VAD	Wind	125
Radar reflectivity – CONUS	Rain, Snow, Hail	1,500,000
Lightning – GLD360	(proxy reflectivity)	5,000
Aircraft	Wind, Temperature	2,000 -15,000
Aircraft - WVSS	Humidity	0 - 800
Surface/METAR	Temperature, Moisture, Wind, Pressure, Clouds, Visibility, Weather	2200 - 2500
Buoys/ships	Wind, Pressure	200 - 400
GOES AMVs	Wind	2000 - 4000
AMSU/HIRS/MHS	Radiances	5,000
GOES cloud-top press/temp	Cloud Top Height	100,000
GPS – Precipitable water	Humidity	260
WindSat Scatterometer	Winds	2,000 – 10,000

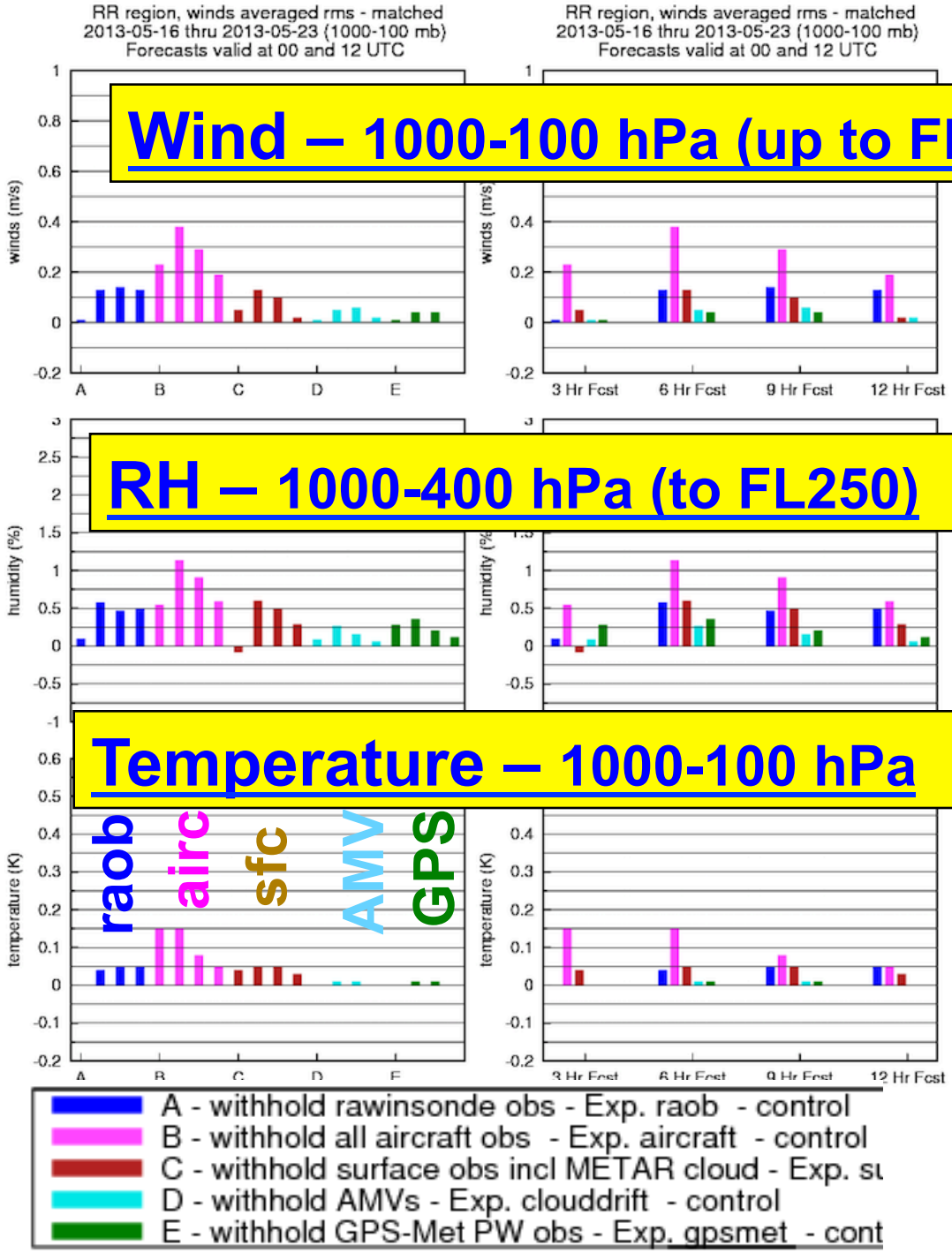


Observations assimilated in hourly update models (RUC, Rapid Refresh)



Radar reflectivity

RAP 2013



Wind – 1000-100 hPa (up to FL500+)

RH – 1000-400 hPa (to FL250)

Temperature – 1000-100 hPa

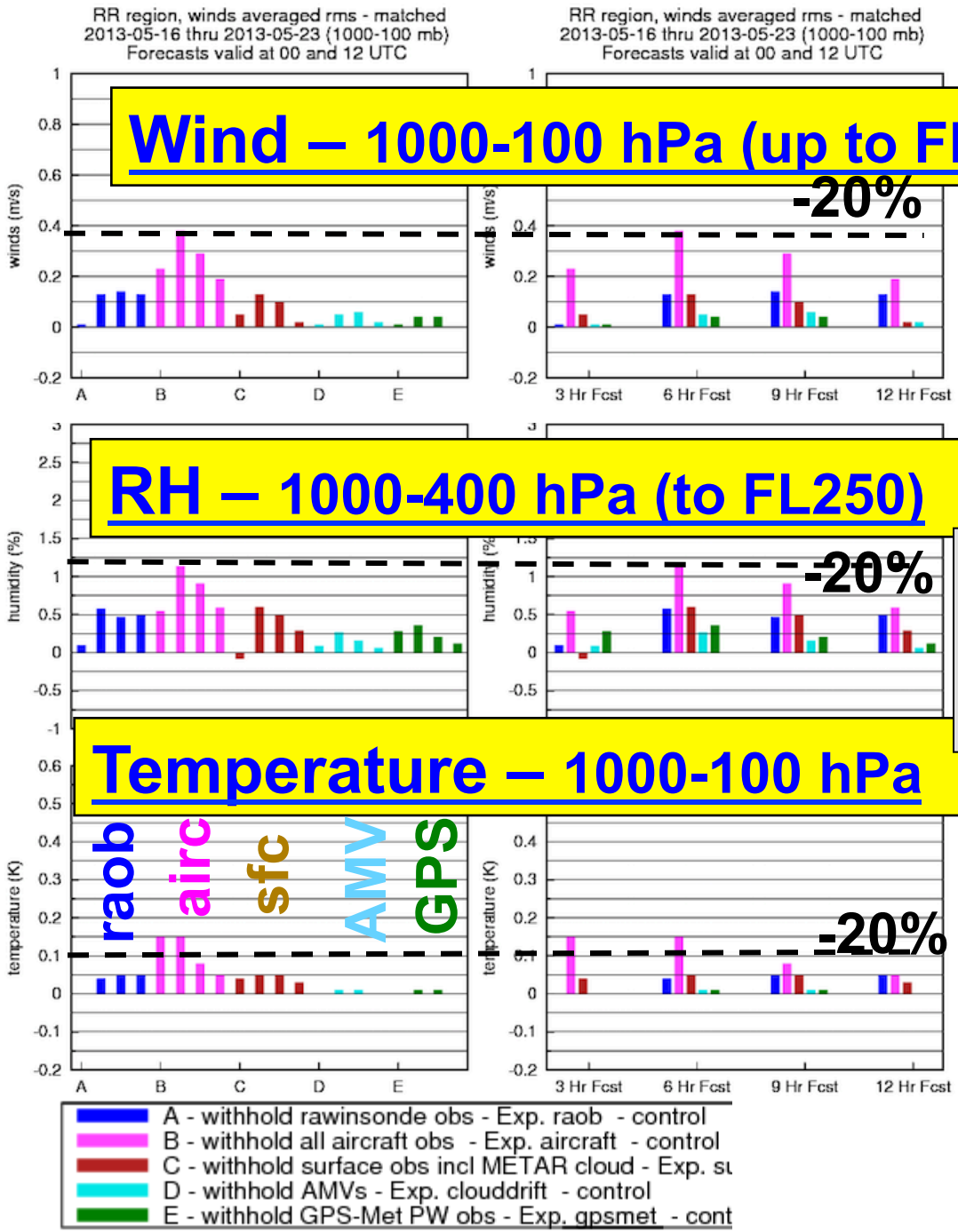
Summary

N.American data impact for RAP
– May 2013 experiments
-12z and 00z combined

Aircraft – largest impact

for all variables.
Following in importance:
Raob, surface, GPS-Met, AMVs (no exps yet for other obs assim in RAP)

RAP 2013 obs impact



Summary

N.Am data impact- RAP – May 2013 experiments -12z and 00z combined

6h F – 0h A for normalizing

V – 1.8 m/s, T – 0.5K

RH – 6%

Aircraft – largest impact

for wind/RH/temp – up to 20% reduction of forecast error, especially for 6h-9h forecasts

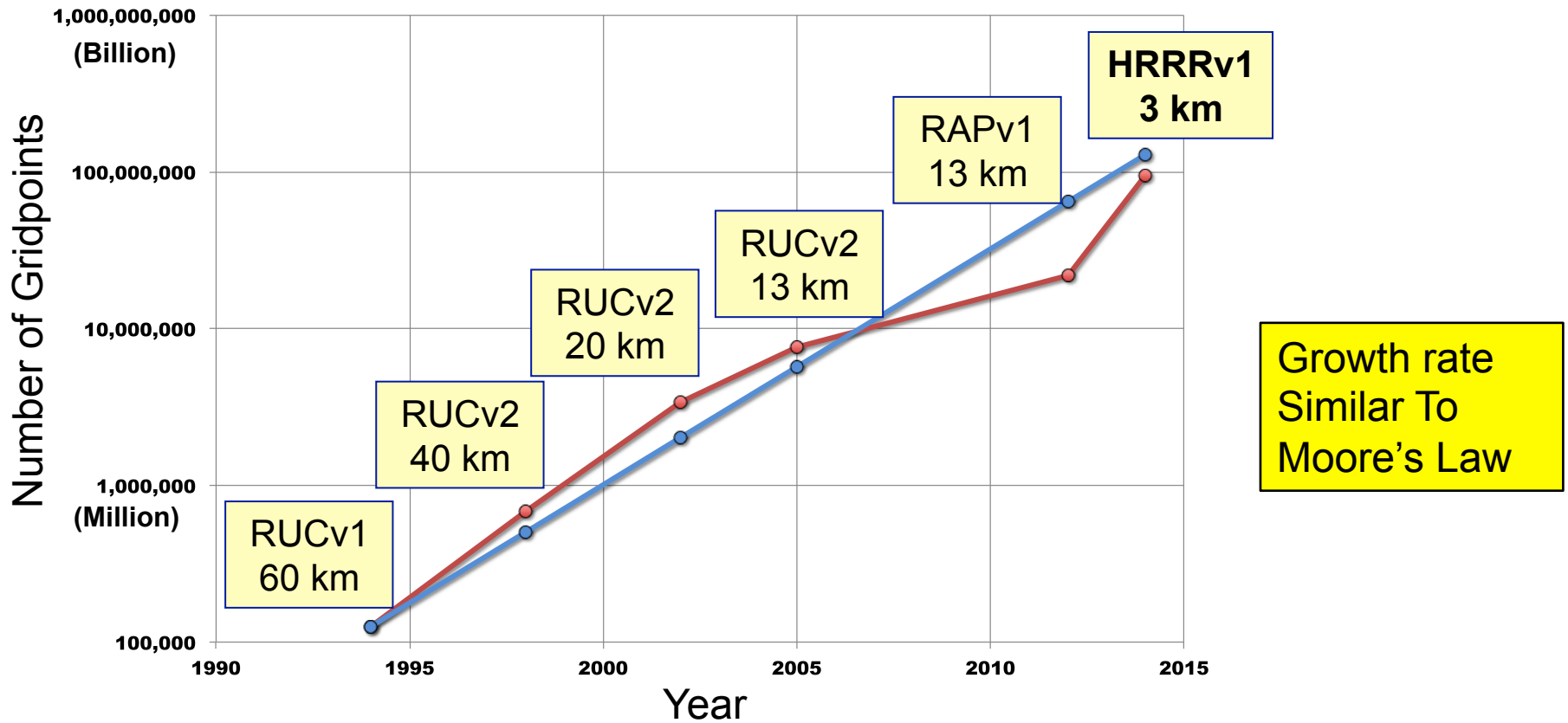
Following in importance:

Raob, surface, GPS-Met, AMVs

High Impact Prediction Needs: High Performance Computing

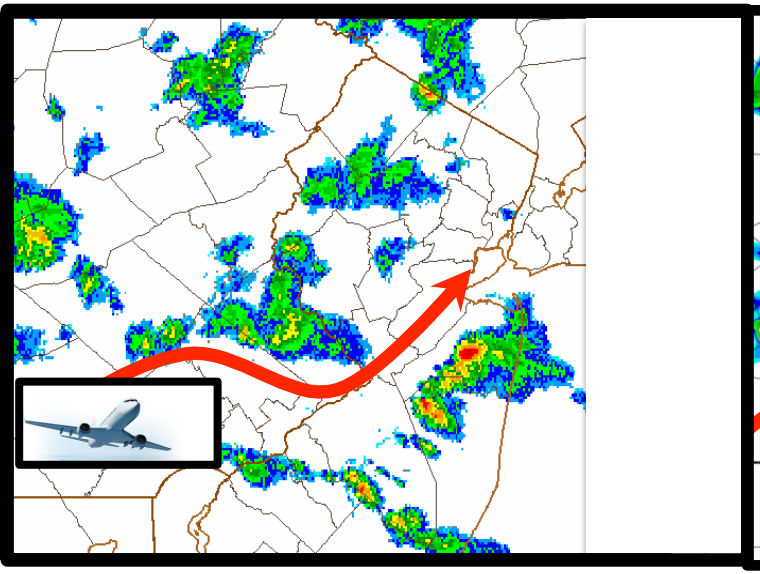
Growth of NOAA Frequently Updating Numerical Weather Guidance:
Rapid Update Cycle (RUC), Rapid Refresh (RAP) and
High-Resolution Rapid Refresh (HRRR)

Moore's Law: Number of transistors or integrated circuits doubles every two years



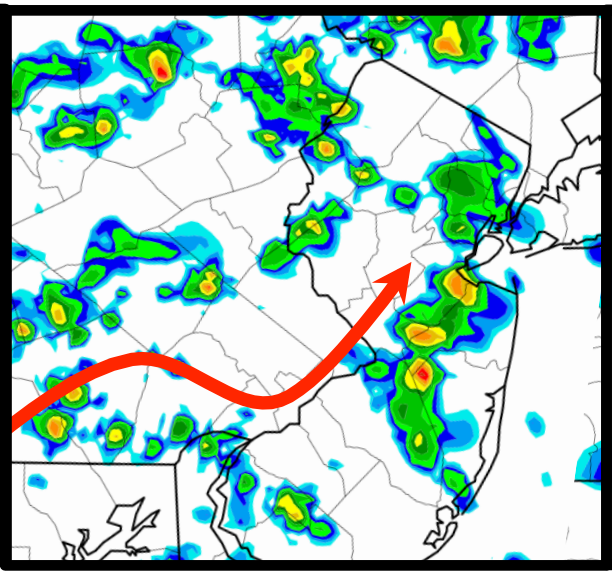
High Impact Prediction Needs: Advanced NWP Model

07 June 2012 5 PM EDT
Reality



Aircraft must Navigate Around Thunderstorms

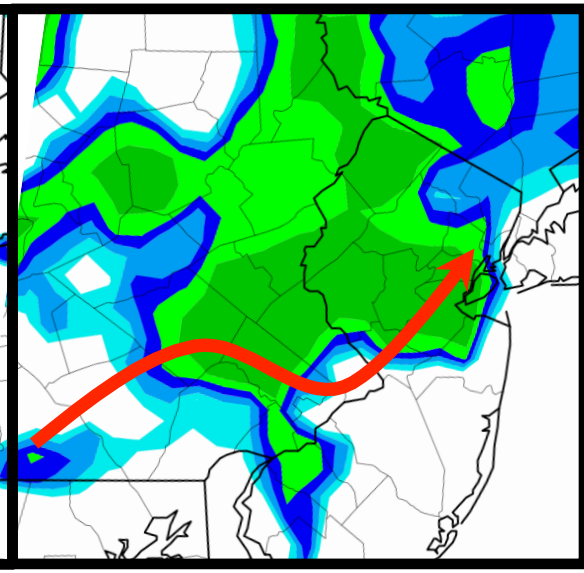
3-km HRRR
Explicit
Convection 6 hr forecast



Accurate Storm Structure

Accurate Estimate of Permeability

13-km RAP
Parameterized
Convection 6 hr forecast



No Storm Structure

No Estimate of Permeability

ESRL RAPv1+ and HRRR 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 DA	Radiation LW/SW	Microphysics	Cumulus Param	PBL	LSM
RAP	WRF-ARW v3.3.1+	GSI 3D-VAR	13-km DFI	RRTM/ Goddard	Thompson v3.3.1	G3 + Shallow	MYJ	RUC 6-lev
HRRR	WRF-ARW v3.3.1+	None: RAP I.C.	None	RRTM/ Dudhia	Thompson v3.3.1	None	MYJ	RUC 6-lev

Model	Horiz/Vert Advection	Scalar Advection	Upper-Level Damping	6th Order Diffusion	SW Radiation Update	Land Use	MP Tend Limit	Time-Step
RAP	5th/5th	Positive-Definite	w-Rayleigh 0.2	Yes 0.12	10 min	MODIS Fractional	0.01 K/s	60 s
HRRR	5th/5th	Positive-Definite	w-Rayleigh 0.2	No	5 min	MODIS Fractional	0.07 K/s	20-23 s

ESRL RAPv2 and HRRR 2013

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 DA	Radiation LW/SW	Microphysics	Cumulus Param	PBL	LSM
RAP	WRF-ARW v3.4.1+	GSI Hybrid 3D-VAR/Ensemble	13-km DFI	RRTM/ Goddard	Thompson v3.4.1	G3 + Shallow	MYNN	RUC 9-lev
HRRR	WRF-ARW v3.4.1+	GSI 3D-VAR	3-km 15-min LH	RRTM/ Goddard	Thompson v3.4.1	None	MYNN	RUC 9-lev

Model	Horiz/Vert Advection	Scalar Advection	Upper-Level Damping	6th Order Diffusion	SW Radiation Update	Land Use	MP Tend Limit	Time-Step
RAP	5th/5th	Positive-Definite	w-Rayleigh 0.2	Yes 0.12	10 min	MODIS Fractional	0.01 K/s	60 s
HRRR	5th/5th	Positive-Definite	w-Rayleigh 0.2	No	5 min	MODIS Fractional	0.07 K/s	20 s

ESRL RAPv3 and HRRR 2014

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 DA	Radiation LW/SW	Microphysics	Cumulus Param	PBL	LSM
RAP	WRF-ARW v3.5.1+	GSI Hybrid 3D-VAR/Ensemble	13-km DFI	RRTMG/ RRTMG	Thompson v3.5.1	GF	MYNN	RUC 9-lev
HRRR	WRF-ARW v3.5.1+	GSI 3D-VAR/ Ensemble	3-km 15-min LH	RRTMG/ RRTMG	Thompson v3.5.1	None	MYNN	RUC 9-lev

Model	Horiz/Vert Advection	Scalar Advection	Upper-Level Damping	6th Order Diffusion	SW Radiation Update	Land Use	MP Tend Limit	Time-Step
RAP	5th/5th	Positive-Definite	w-Rayleigh 0.2	Yes 0.12	20 min	MODIS Fractional	0.01 K/s	60 s
HRRR	5th/5th	Positive-Definite	w-Rayleigh 0.2	Yes 0.25 (flat terr)	5 min	MODIS Fractional	0.07 K/s	20 s

ESRL RAPv4 and HRRRv2 2015

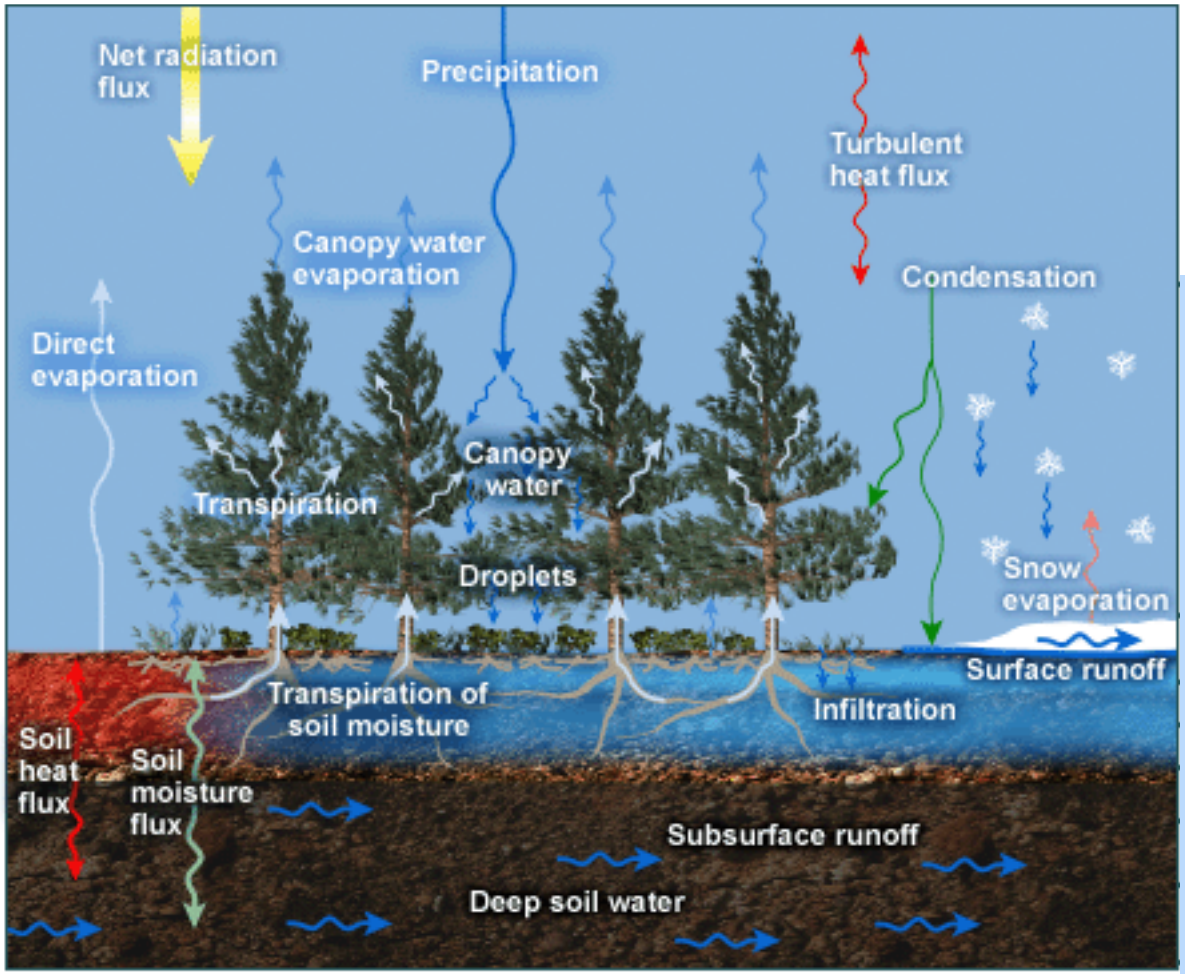
Model	Run at:	Domain	Grid Points	Grid Spacing	Vertical Levels	Pressure Top	Boundary Conditions	Initialized
RAP	GSD, NCO	North America	758 x 567	13 km	50	10 mb	GFS	Hourly (cycled)
HRRR	GSD	CONUS	1799 x 1059	3 km	50	20 mb	RAP	Hourly - RAP (no-cycle)

Model	Version	Assimilation	Radar DA	Radiation LW/SW	Microphysics	Cumulus Param	PBL	LSM
RAP	WRF-ARW v3.6.1+	GSI Hybrid 3D-VAR/Ensemble	13-km DFI	RRTMG/ RRTMG	Thompson – aerosol-aware v3.6.1	GF – v3.6.1	MYNN v3.6.1	RUC 9-lev v3.6.1
HRRR	WRF-ARW V3.6.1+	GSI 3D-VAR/ Ensemble	3-km 15-min LH	RRTMG/ RRTMG	Thompson – Aerosol-aware v3.6.1	None	MYNN	RUC 9-lev v3.6.1

Model	Horiz/Vert Advection	Scalar Advection	Upper-Level Damping	6th Order Diffusion	SW Radiation Update	Land Use	MP Tend Limit	Time-Step
RAP	5th/5th	Positive-Definite	w-Rayleigh 0.2	Yes 0.12	20 min	MODIS Fractional	0.01 K/s	60 s
HRRR	5th/5th	Positive-Definite	w-Rayleigh 0.2	Yes 0.25 (flat terr)	15 min with SW-dt (Ruiz-Arias)	MODIS Fractional	0.07 K/s	20 s

RAP/HRRR 2013 Model Update

RUC Land Surface Model (LSM) increased from 6 to 9 levels
Changed PBL scheme from MYJ (Mellor-Yamada-Janjic) to MYNN (Mellor-Yamada-Nakanishi-Niino)
Increased surface roughness lengths



RUC Vegetation and Soil Model

The COMET

OLD ~ 8 m	NEW ~ 8 m
0 (cm)	0 (cm)
	1
	4
5	
	10
20	
	30
40	
	60
	100
160	160
300	300

Thinner soil layer in the energy and moisture budgets – potential for increased diurnal cycle near surface: reduced warm bias at night and cold bias during the day

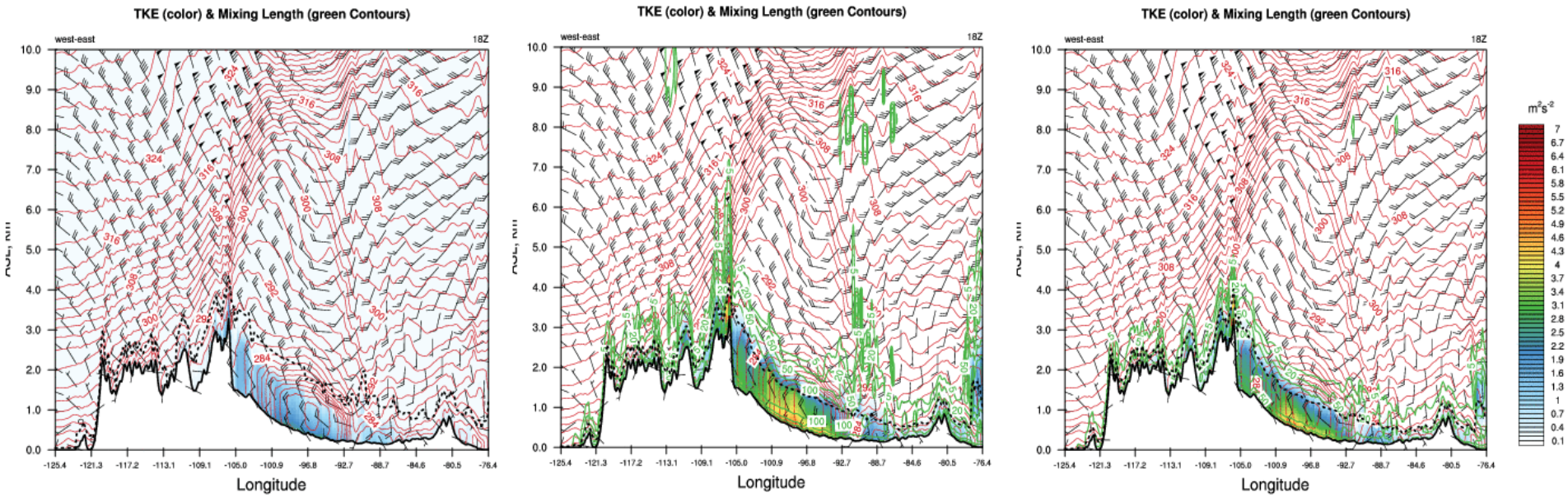
Example of Overall Impact on PBLH & TKE

TKE (colors; $m^2 s^{-2}$) and mixing lengths (green) for 18 UTC 12 December 2011.

Cross section taken at ~37° latitude across U.S.

Joe Olson - GSD

MYJ | **MYNN-original** | **MYNN-modified**

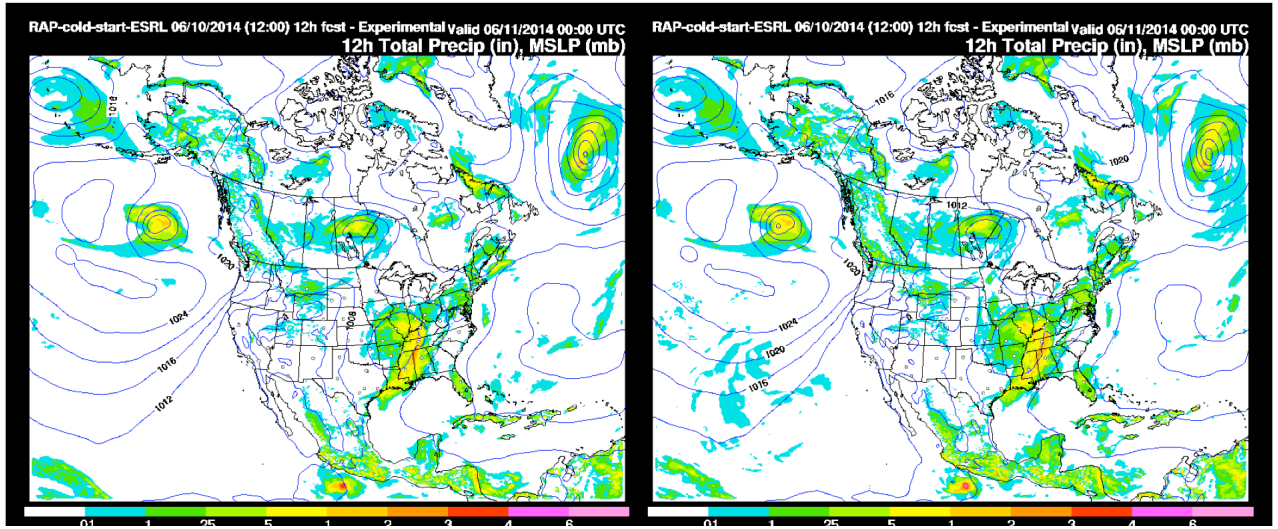


- MYJ's PBLH (dotted line) is a TKE-based diagnostic, whereas MYNN's is θ-based, so a direct comparison is not advised. Modified MYNN has slightly smaller PBLHs (2-5% reduction).
- **Mixing lengths (l_m, green contours) are generally about 30-50% smaller in the modified MYNN compared to the original version.**
- **MYJ produces much less TKE than either version of the MYNN, but the modifications to the mixing lengths reduce the TKE by about 20% (right panel) compared to original (center).**
- Combined reduction in l_m and TKE reduce the eddy diffusivity [$K_h = S_h l_m (TKE)^{1/2}$].

ESRL RAPv4/HRRRv2-2015 Changes

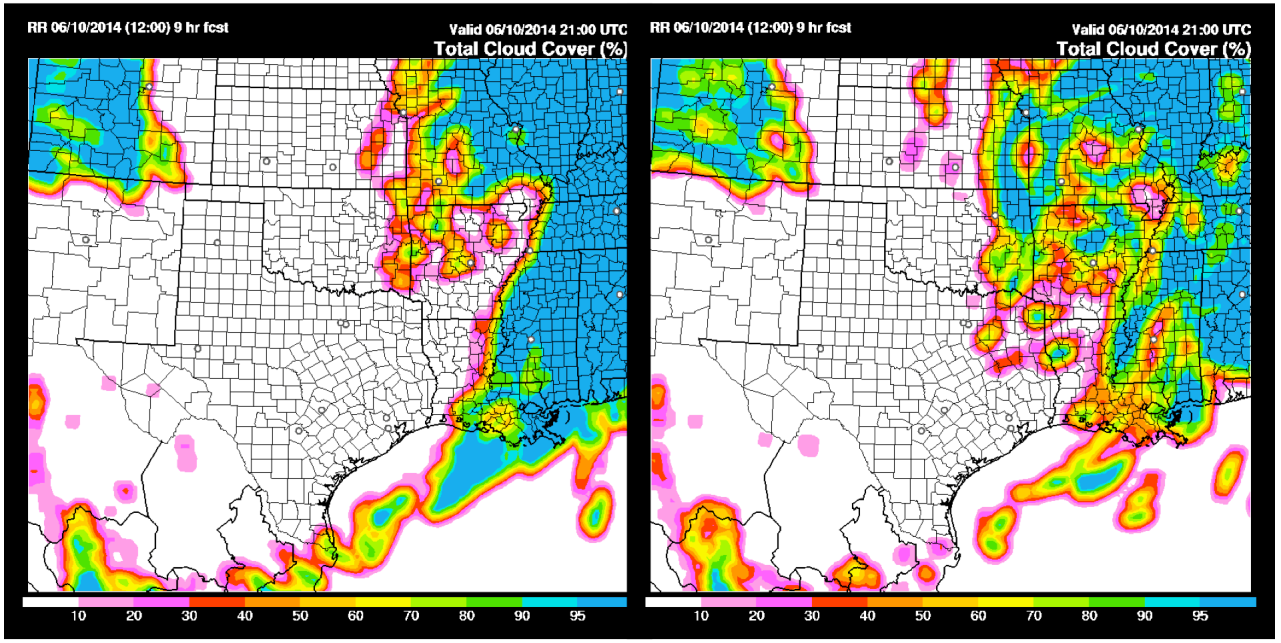
WRFv3.5.1 Aerosol unaware

WRFv3.6 Aerosol-aware



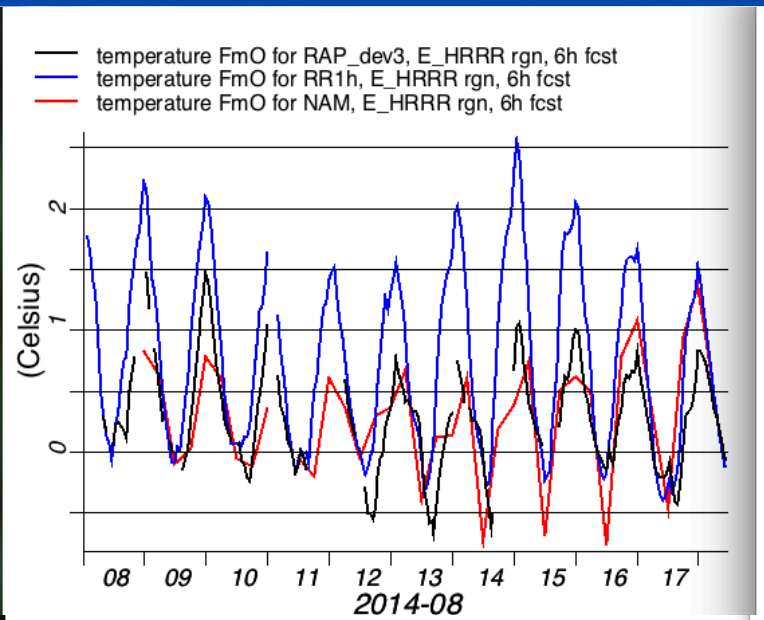
WRFv3.5.1 aerosol unaware

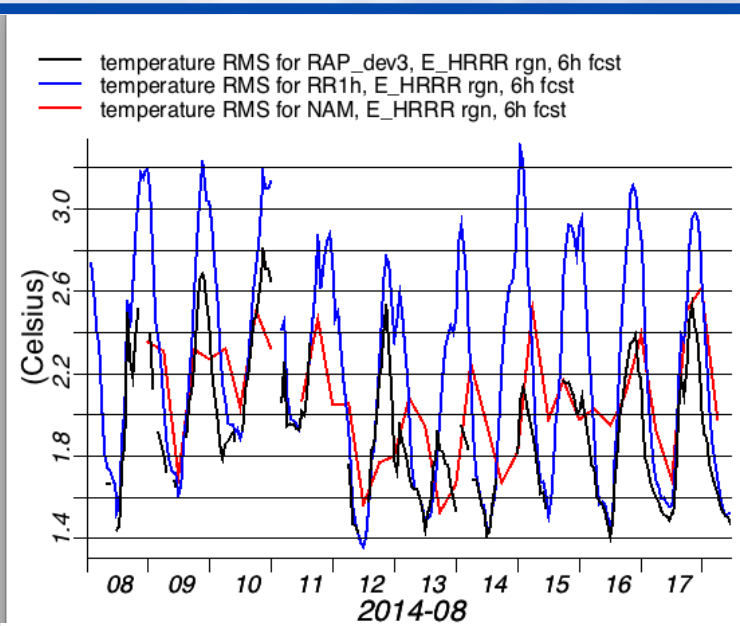
WRFv3.6 Aerosol-aware



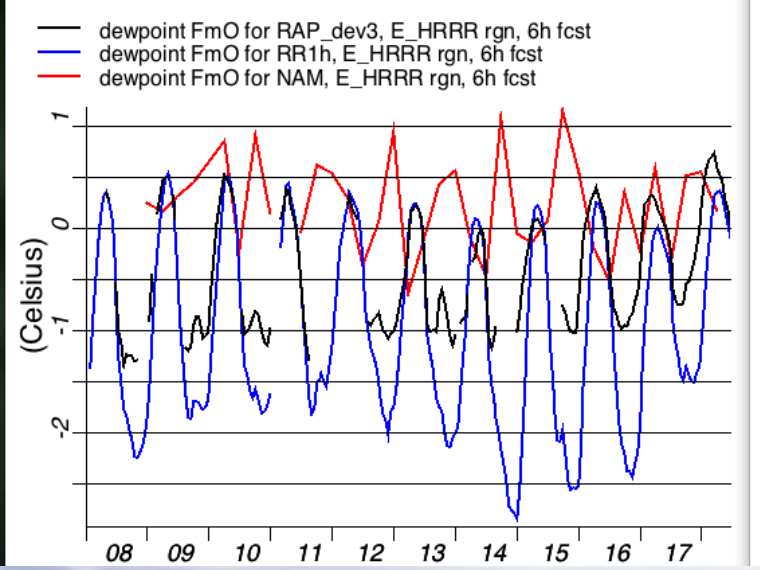
RAP cold-start tests without/with aerosol-aware cloud microphysics

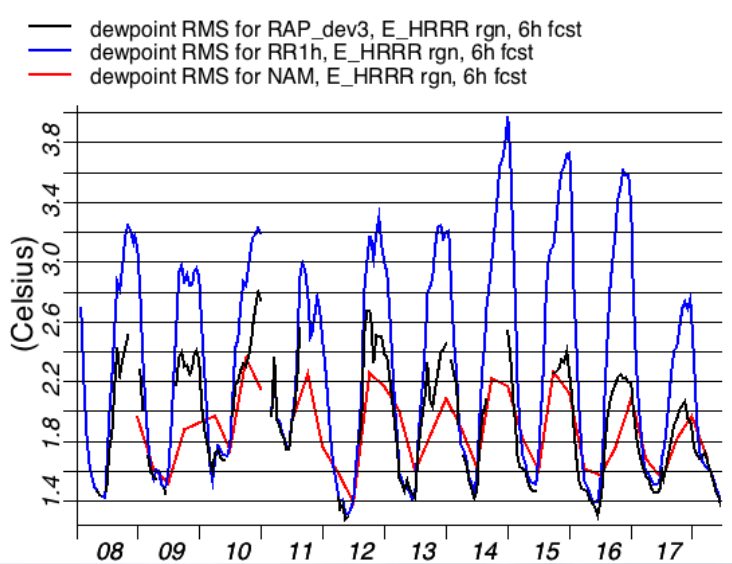
ESRL RAPv4/HRRRv2-2015 Changes





RAP-dev3 is close to NAM





RAP-dev3 log:
8 Aug.2014 – reduced wilt. point

13 Aug. 2014 – change for cropland soil moisture

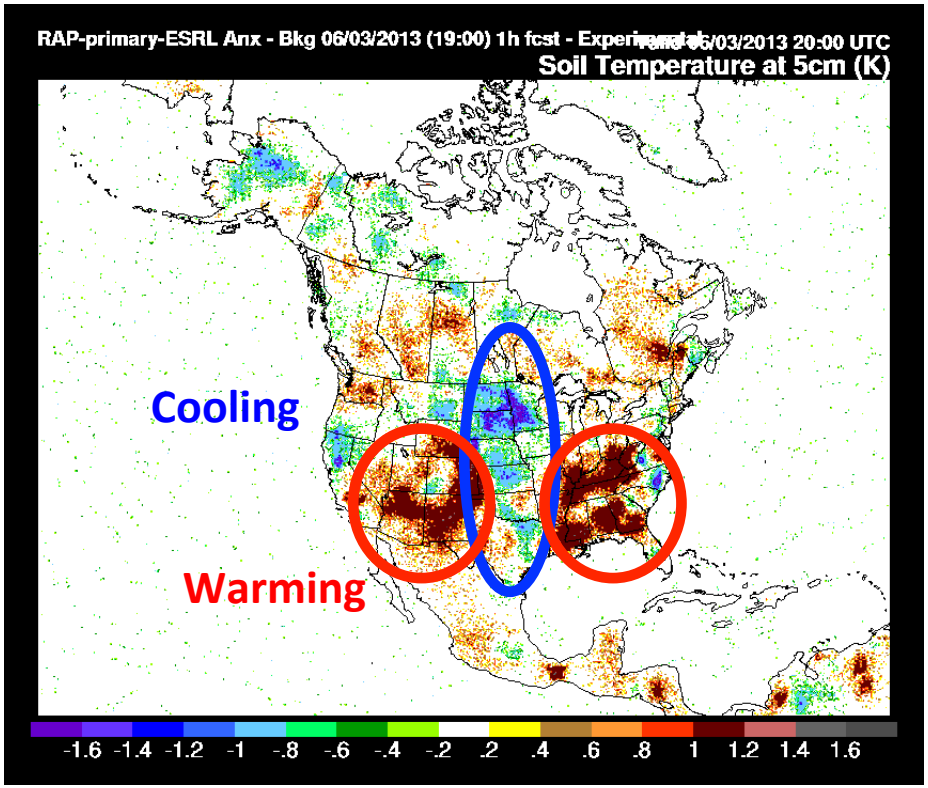
15 Aug. 2014 – Q2 diagnostics

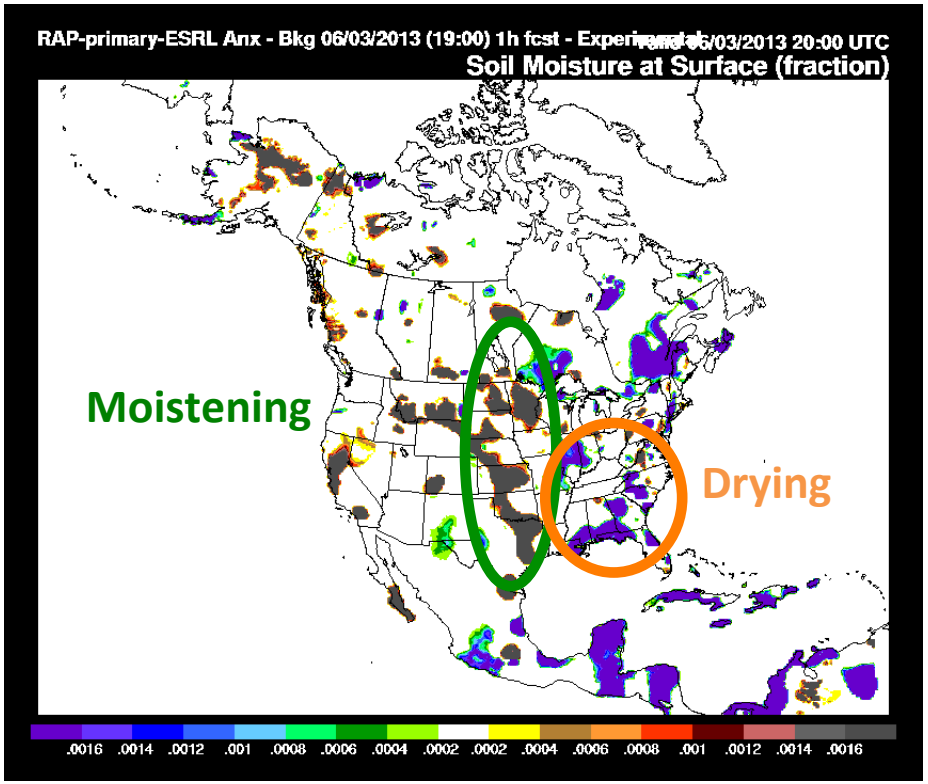
RAP/HRRR Soil Adjustment

Soil Temperature

Valid
20 UTC
03 June 2013

Soil Moisture

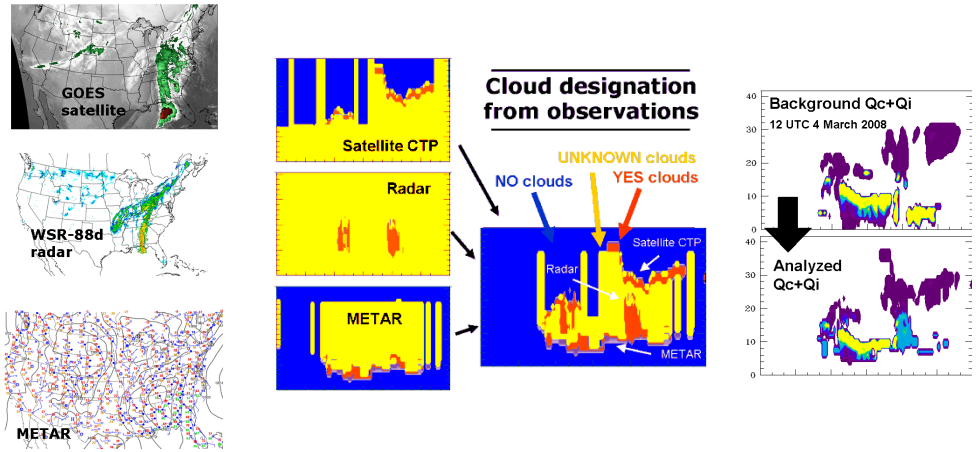




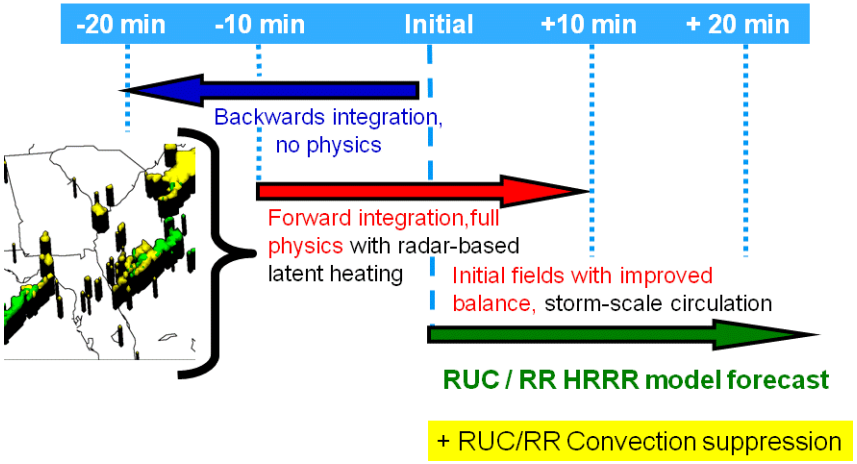
Based upon 2m temperature and dewpoint analysis increments

Rapid Refresh Specific Analysis Features

Cloud and hydrometeor analysis



Digital filter-based reflectivity assimilation (DDFI)



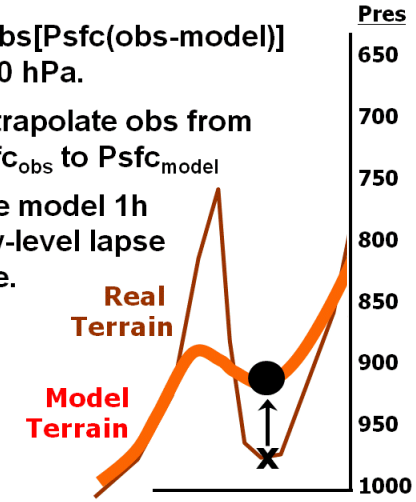
Special treatments for surface observations

Elevation correction

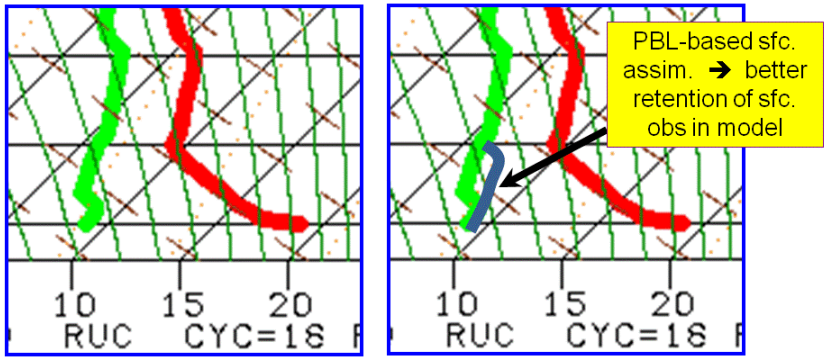
If abs[Psfc(obs-model)] < 70 hPa.

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

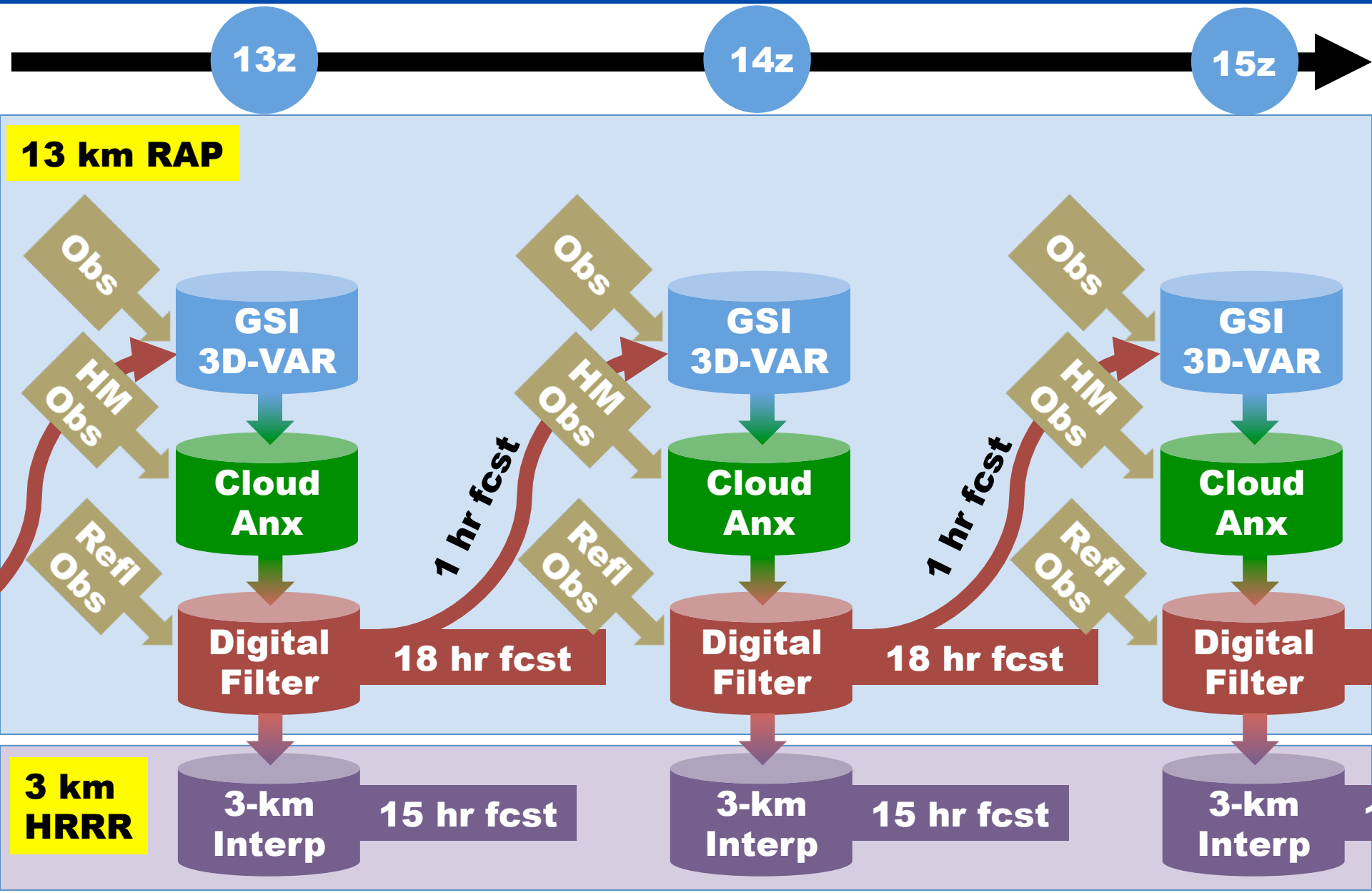
Use model 1h low-level lapse rate.



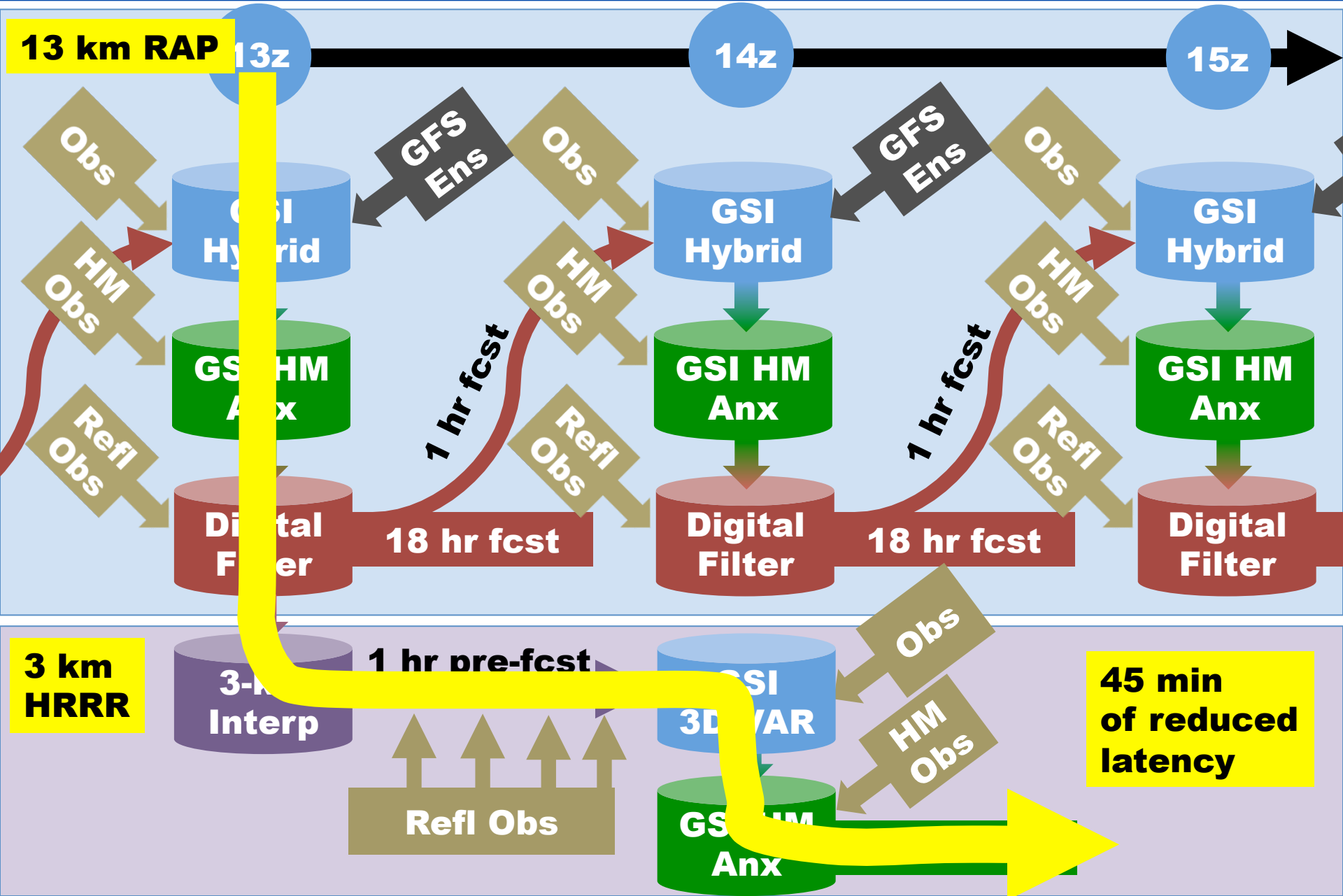
PBL-based pseudo-observations



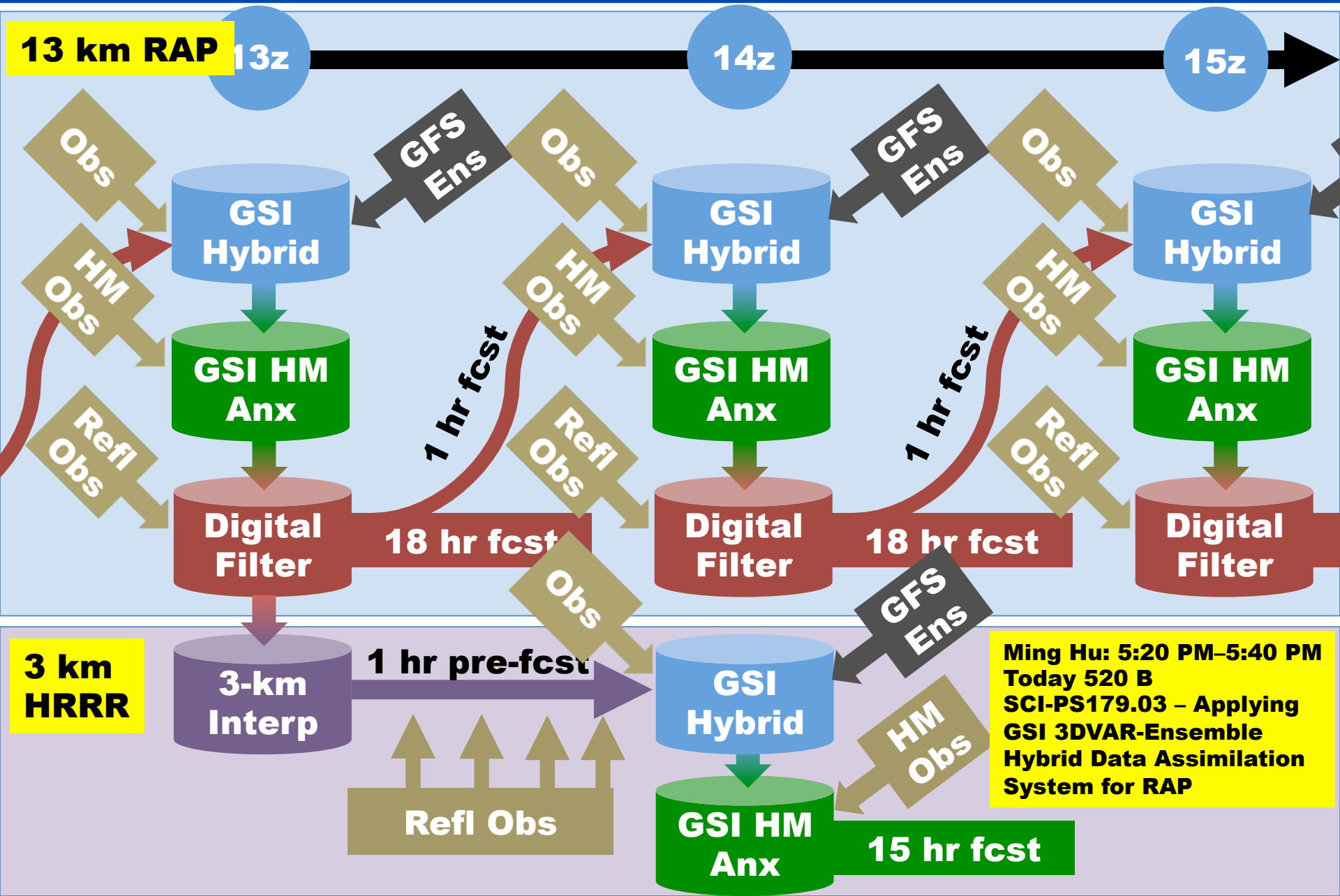
2012 HRRR Initialization from RAP



2013 HRRR Initialization from RAPv2



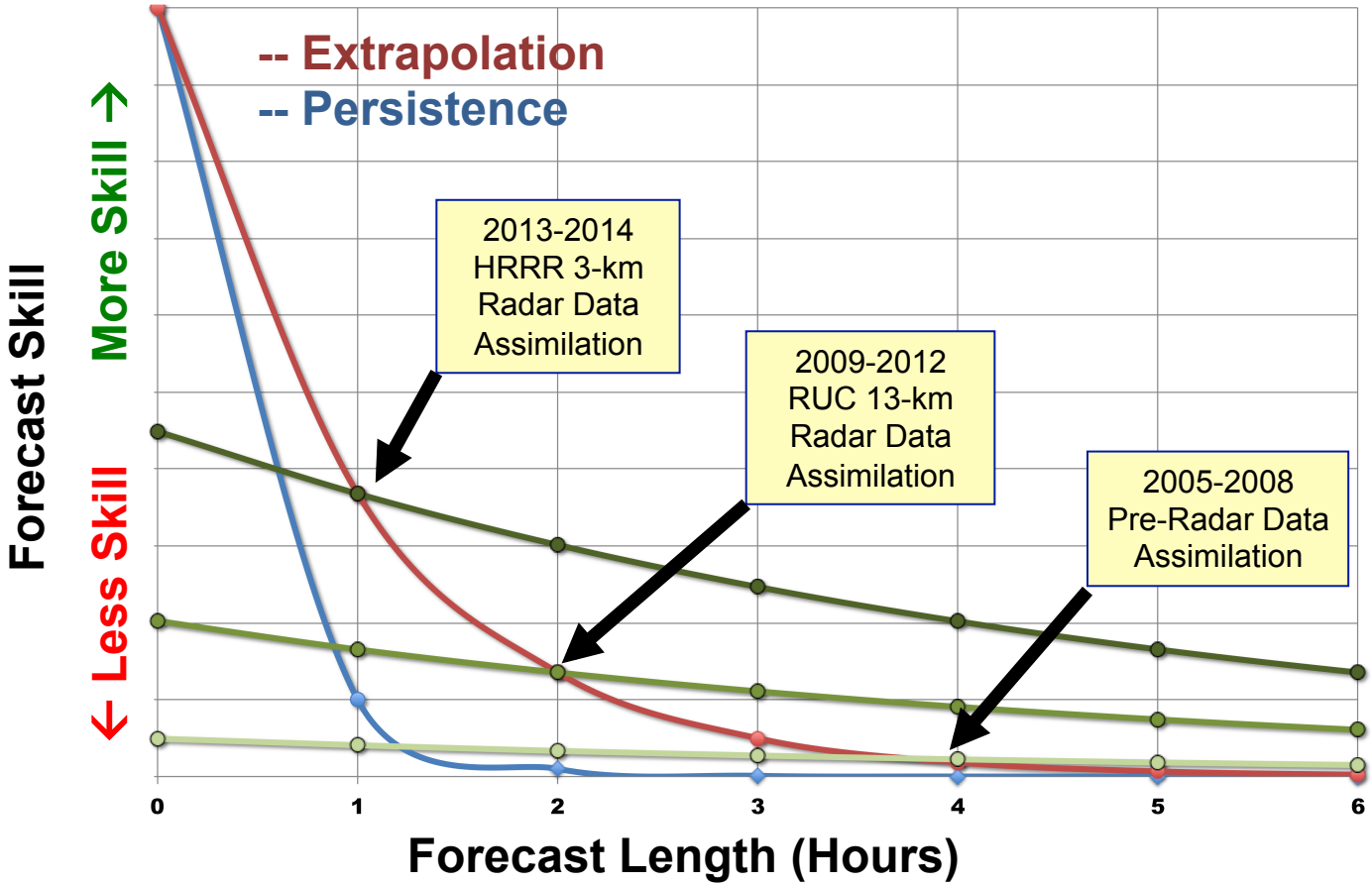
2014 HRRR Initialization from RAPv3



Ming Hu: 5:20 PM–5:40 PM
Today 520 B
SCI-PS179.03 – Applying GSI 3DVAR-Ensemble Hybrid Data Assimilation System for RAP

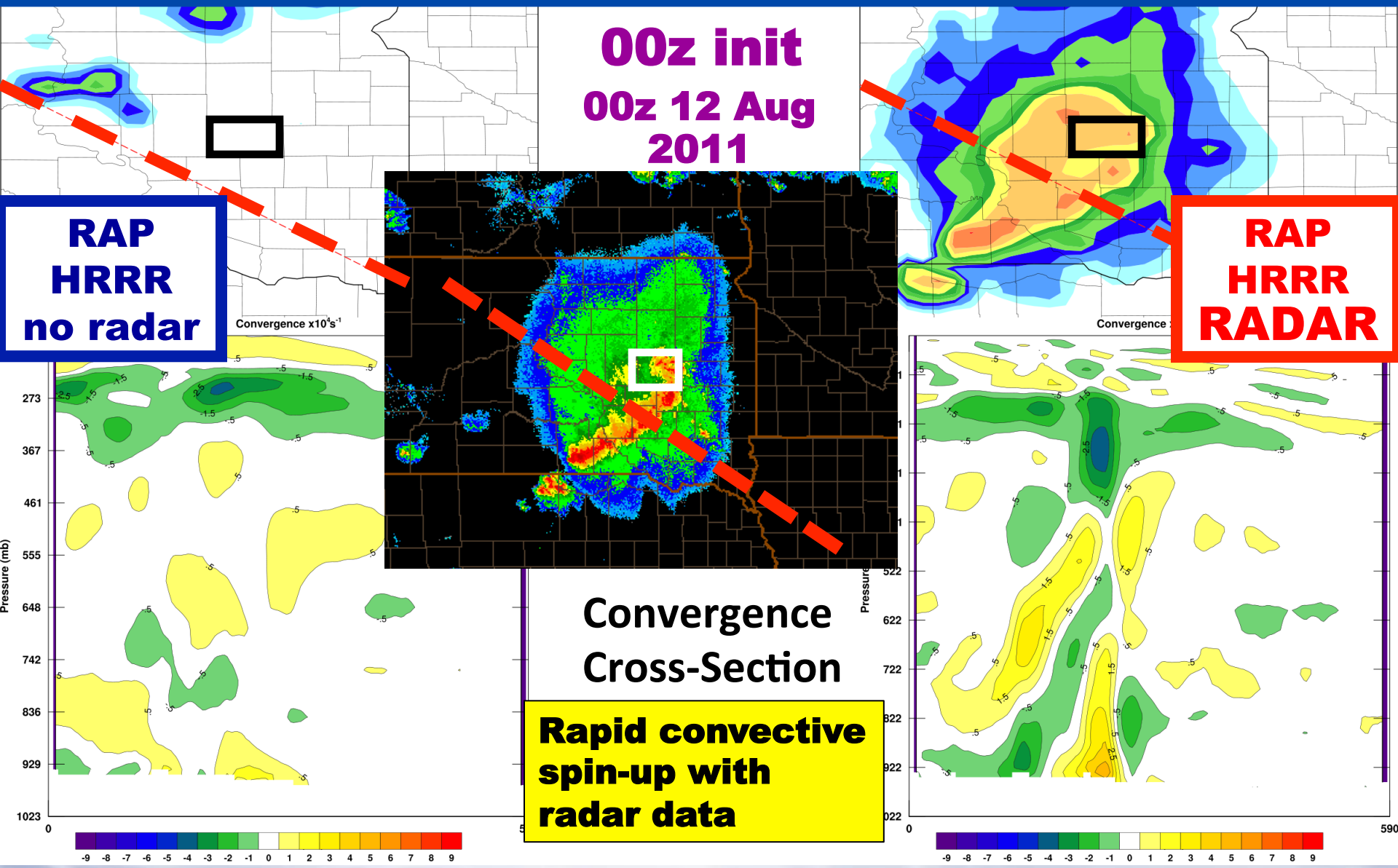
HRRR: Improving Forecast Skill

Crossover in forecast skill between Nowcasting/Extrapolation vs Numerical Weather Prediction

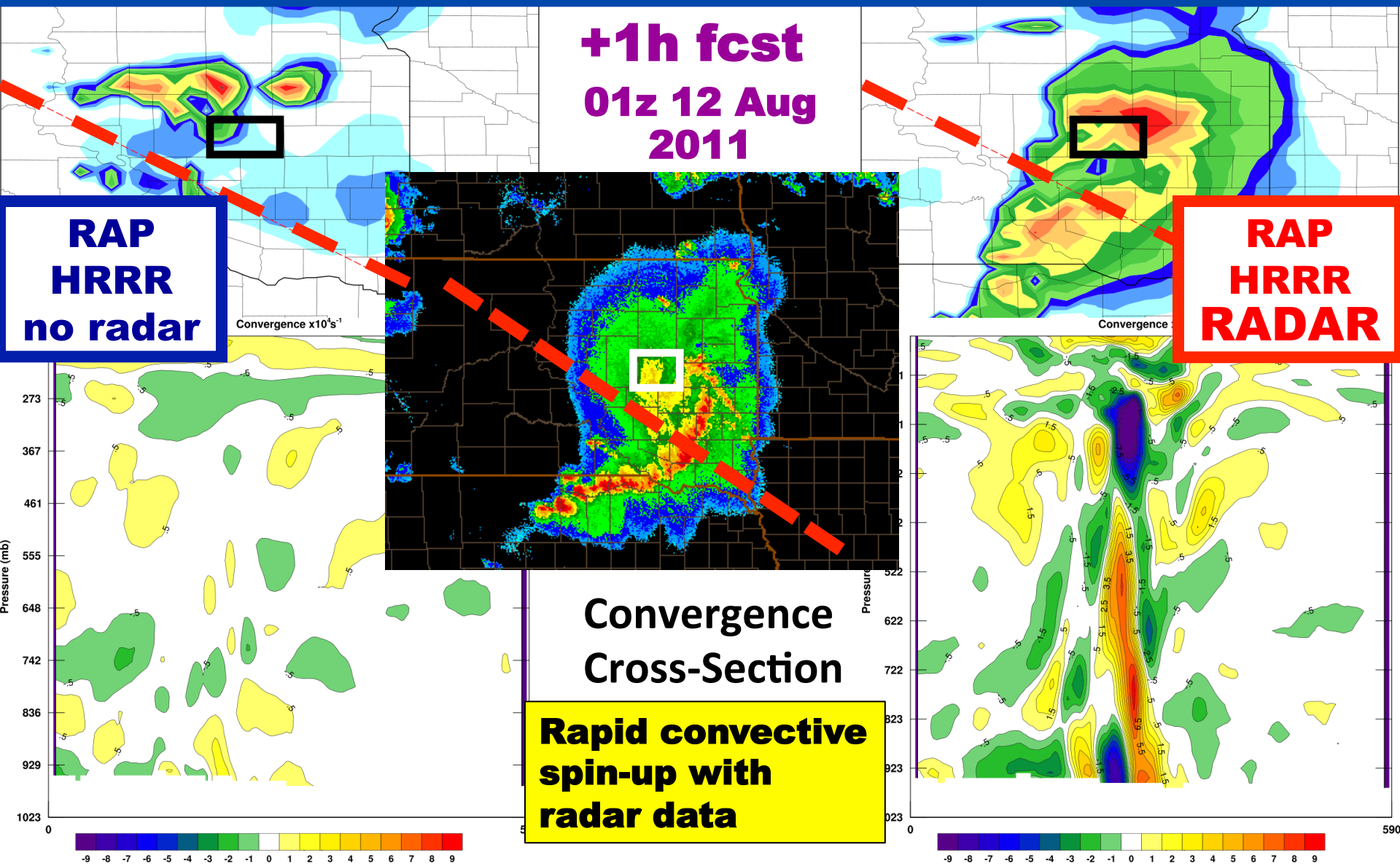


Improving forecast skill and halving crossover period every ~3-4 years

Radar Reflectivity Assimilation

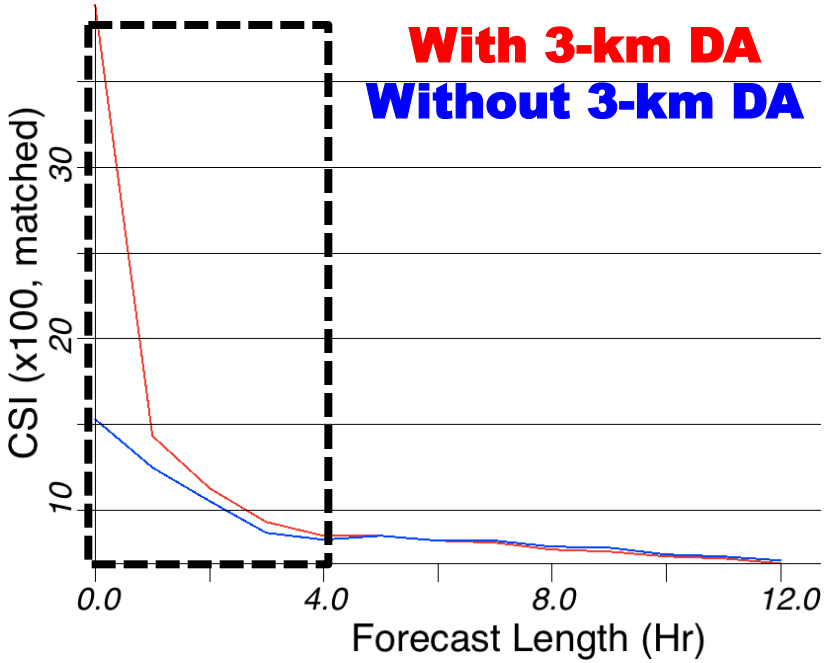


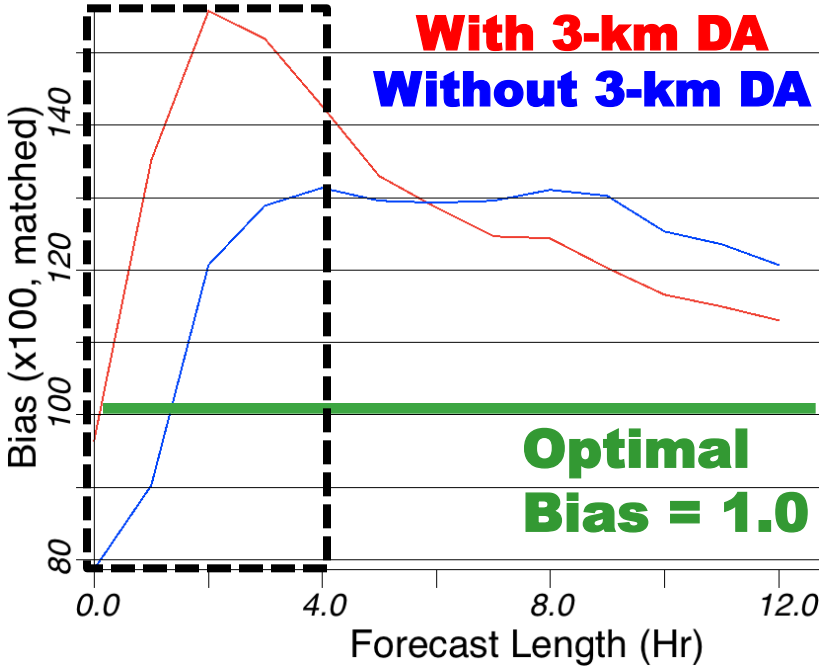
Radar Reflectivity Assimilation



HRRR 2013 3-km GSI Data Assim

Statistical Retrospective Comparison
30 May - 04 June 2012 (55 matched runs)
3-km grid ≥ 35 dBZ
Eastern US





Improved 0-2 hr convection

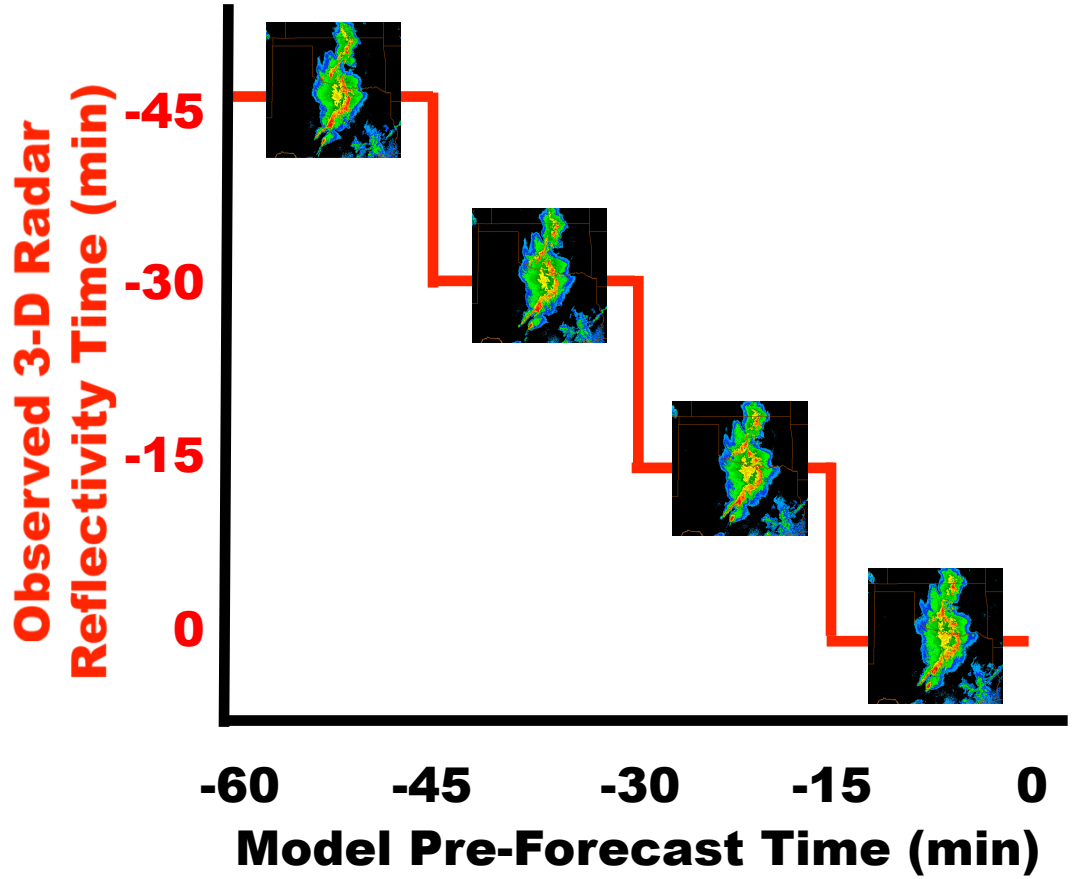
HRRR 2014 Pre-Forecast Hour

Temperature Tendency (i.e. Latent Heating) = f(Observed Reflectivity)
LH specified from reflectivity observations applied in four 15-min periods
NO digital filtering at 3-km
Reflectivity observations used to specify latent heating in previous 15-min period as follows:

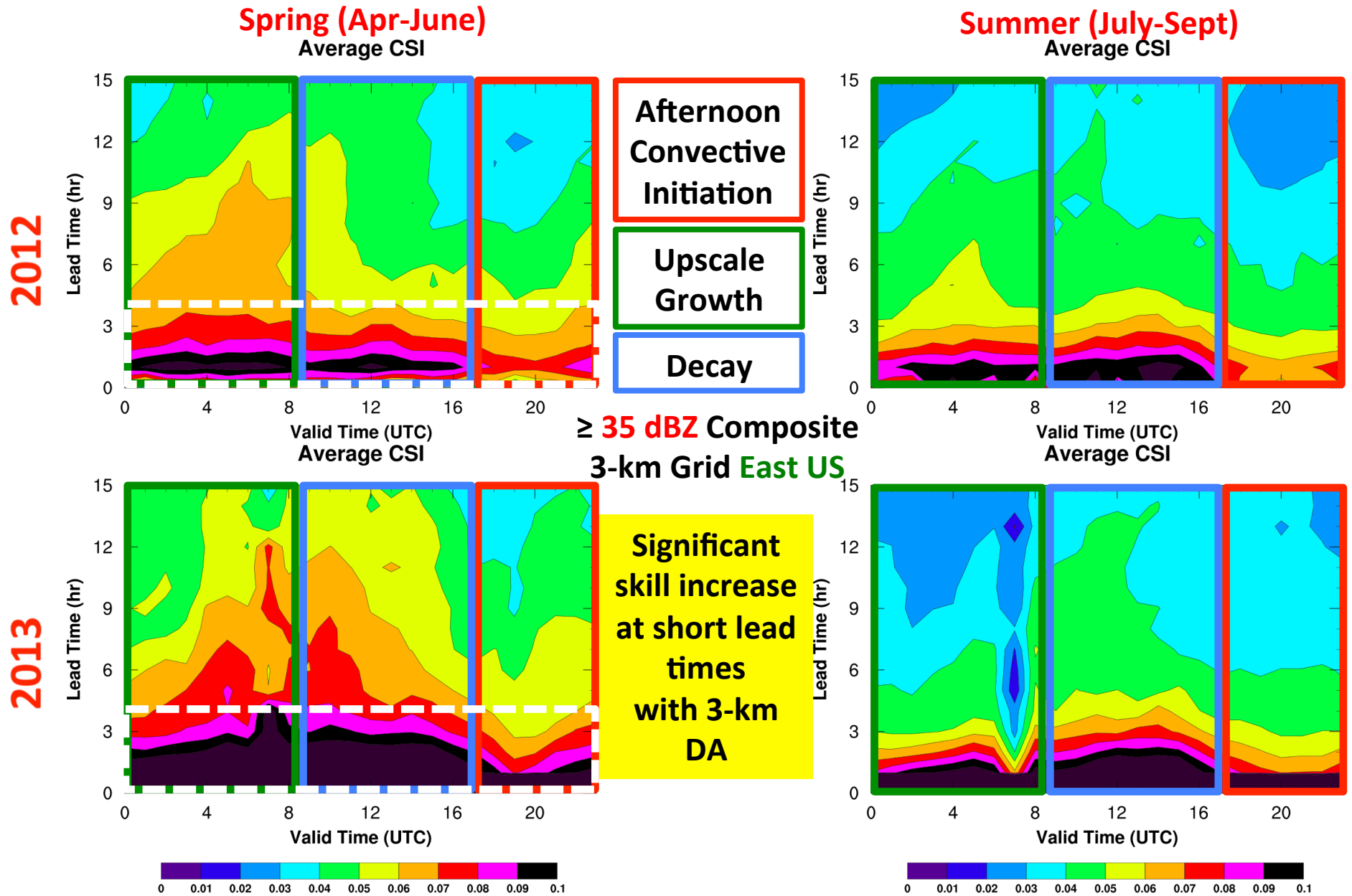
- **Positive heating rate where obs reflectivity ≥ 28 dBZ over depth ≥ 200 mb (avoids bright banding)**
- **Zero heating rate where obs reflectivity ≤ 0 dBZ**
- **Model microphysics heating rate preserved elsewhere**

$$LH(i,j,k) = \left(\frac{1000}{p}\right)^{R_d/c_p} \frac{(L_v + L_f)(f[Z_e])}{t * c_p}$$

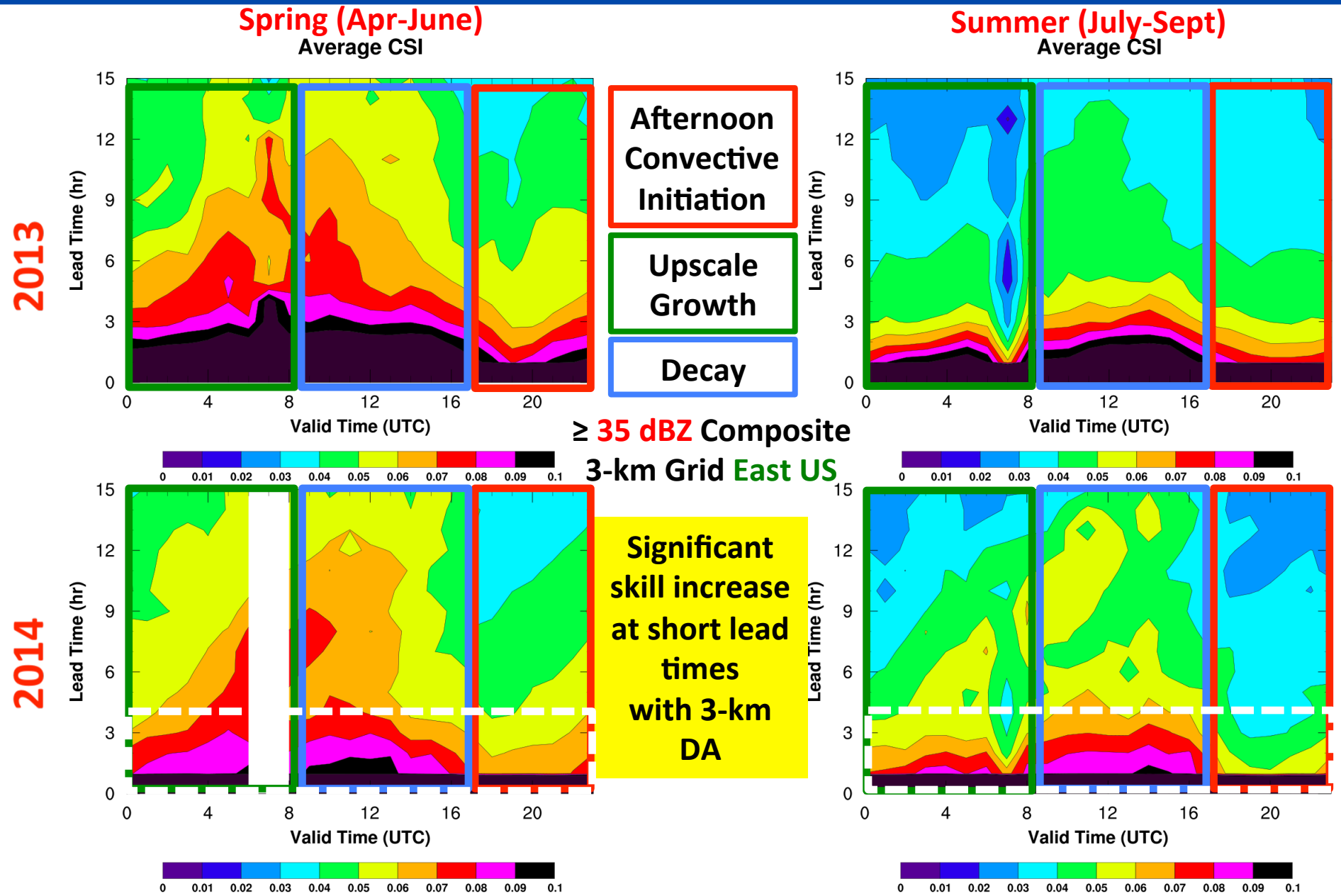
LH = Latent Heating Rate (K/s)
p = Pressure
L_v = Latent heat of vaporization
L_f = Latent heat of fusion
R_d = Dry gas constant
c_p = Specific heat of dry air at constant p
$f[Z_e]$ = Reflectivity factor converted to rain/snow condensate
t = Time period of condensate formation (20 min)



Lead Time vs Valid Time

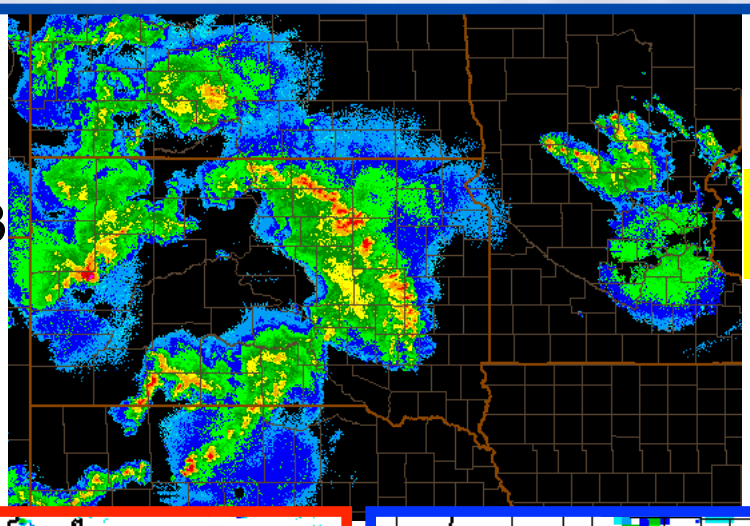


Lead Time vs Valid Time



Improved 0-2 hr Convective Fcsts

Radar Obs
05:00z 18 May 2013



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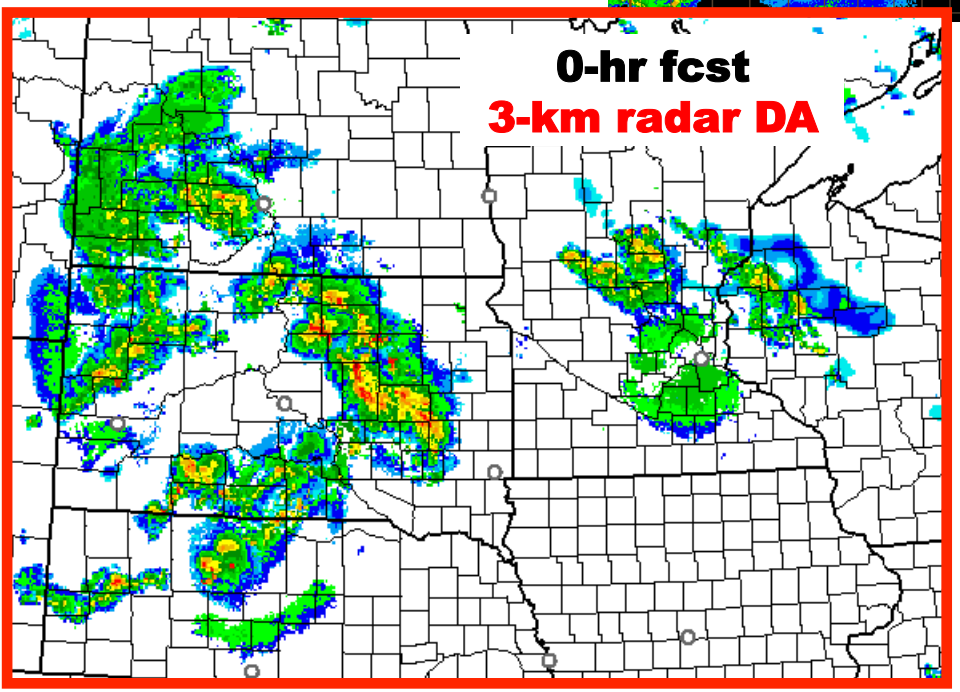

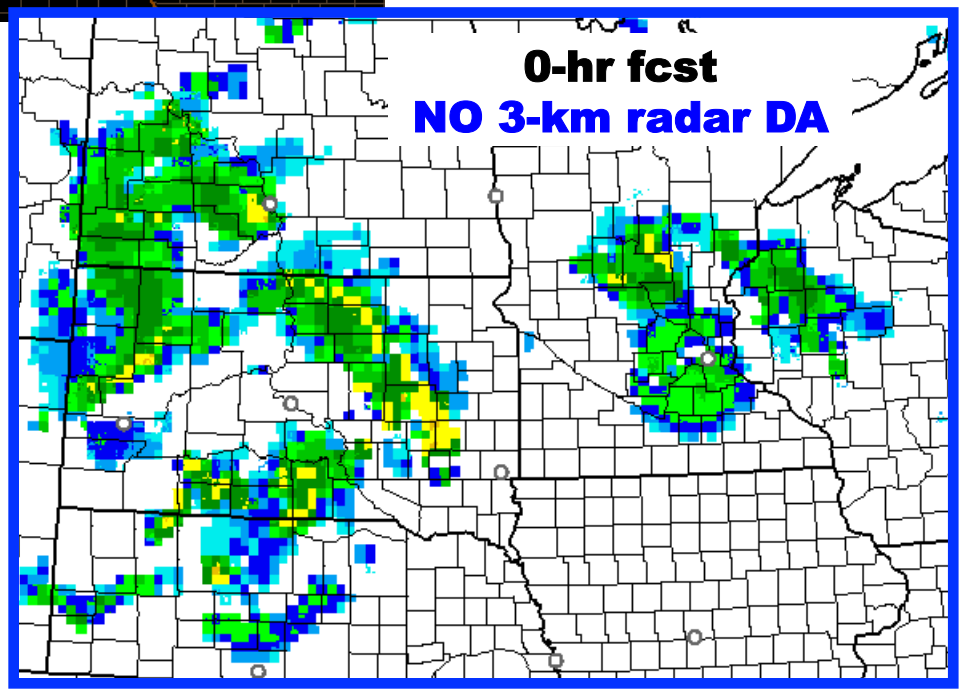

Improved 0-2 hr Convective Fcsts

Radar Obs
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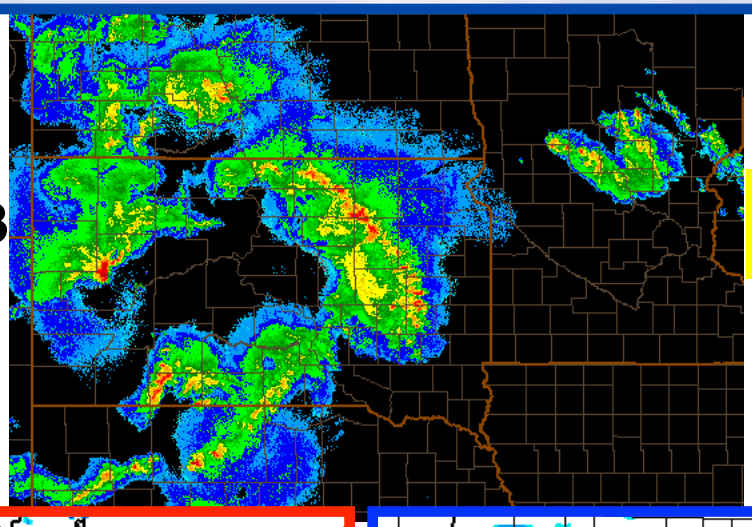
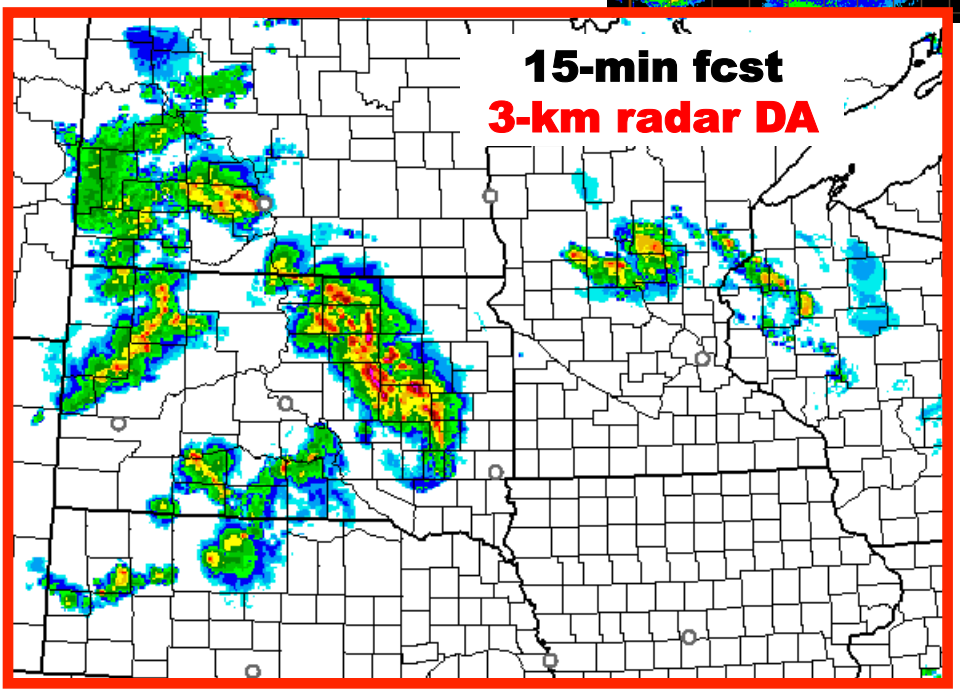
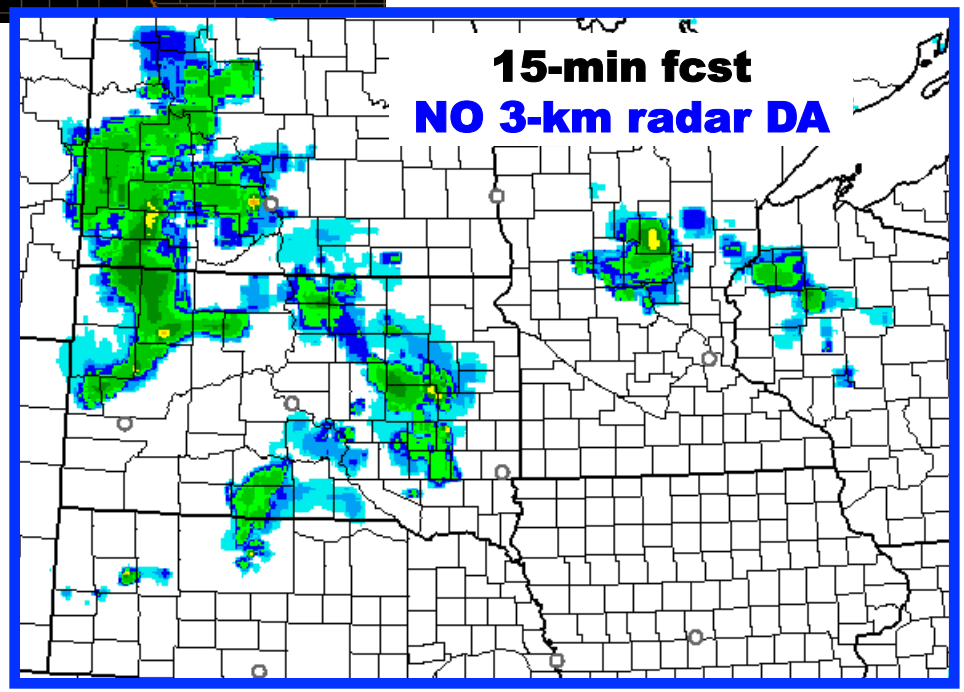


05z + 15 min





Improved 0-2 hr Convective Fcsts

Radar Obs
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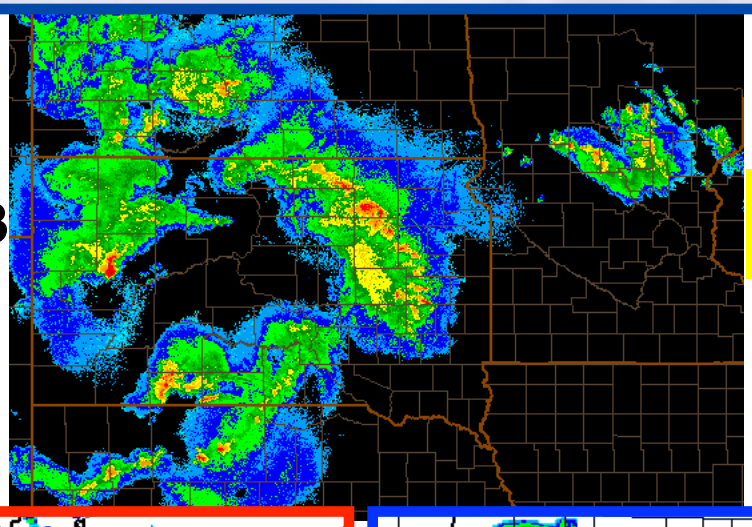
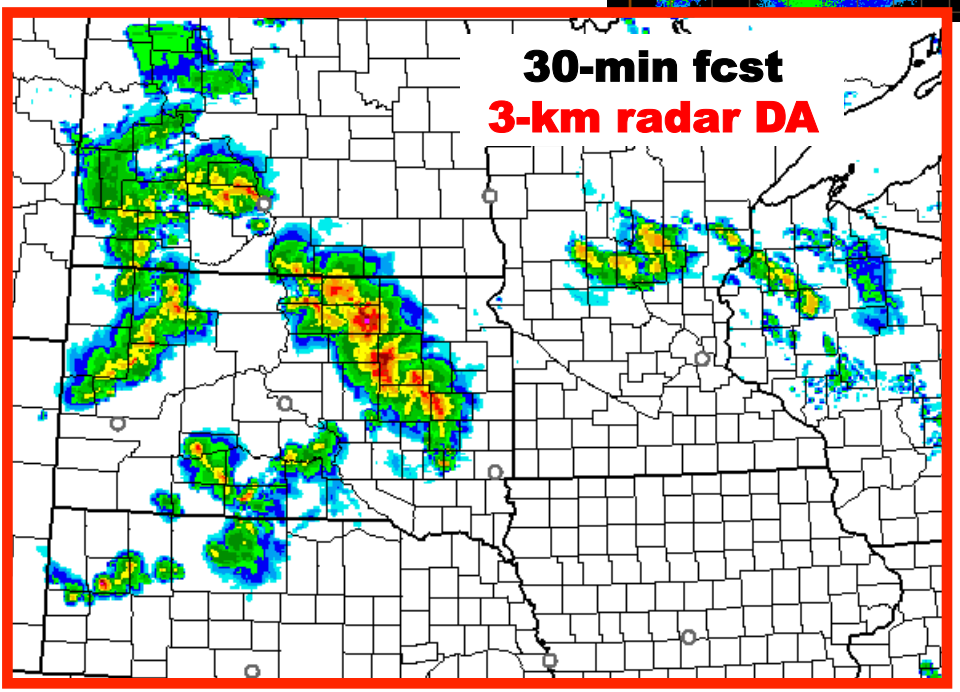
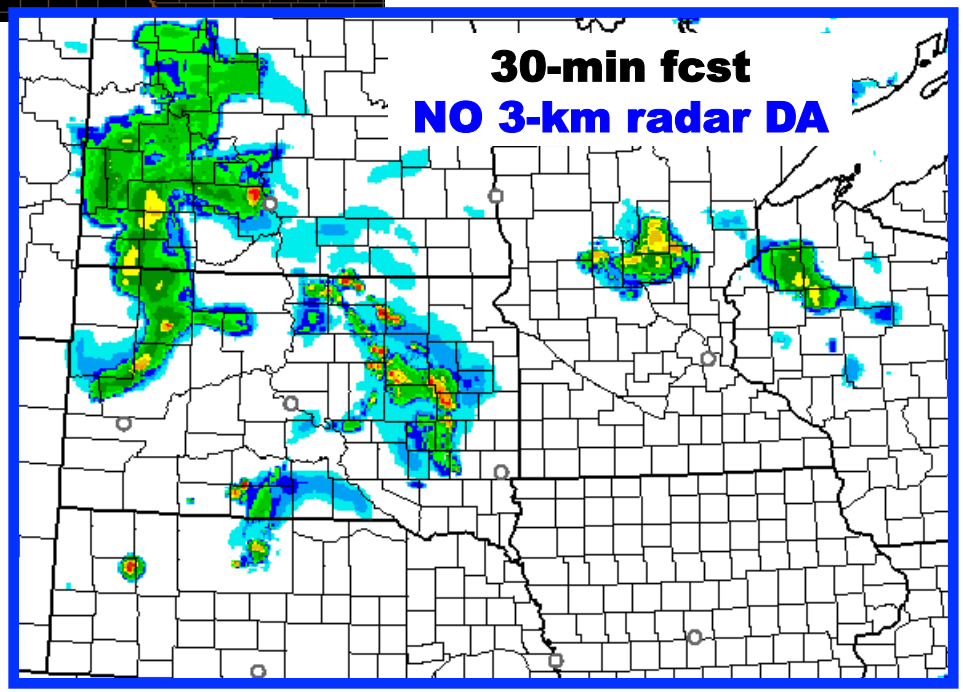


05z + 30 min





Improved 0-2 hr Convective Fcsts

Radar Obs
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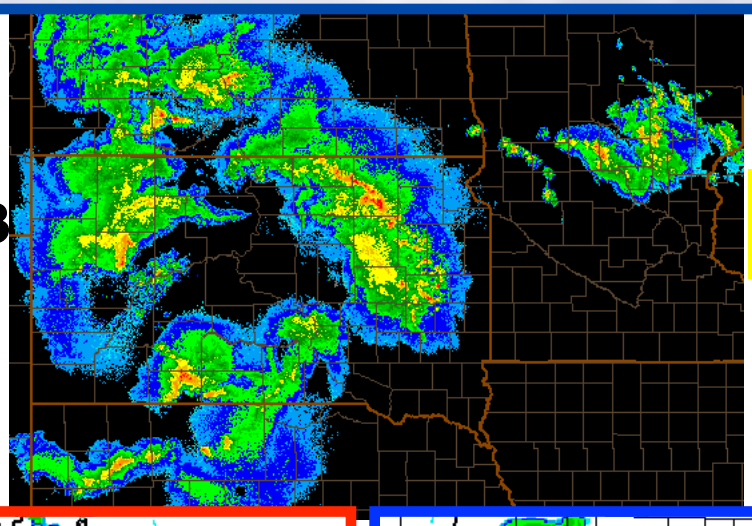
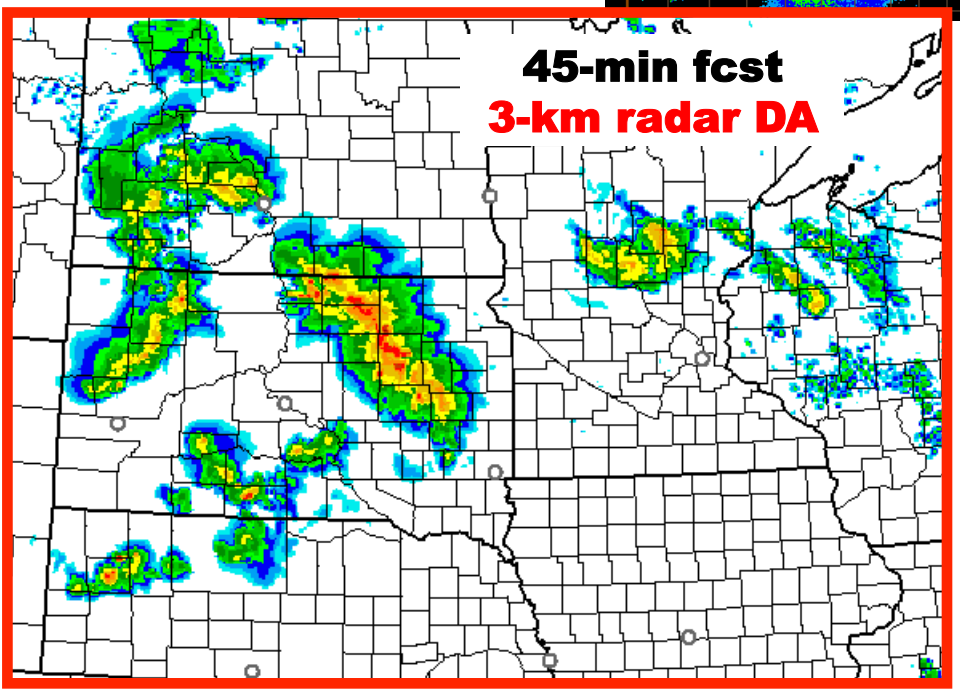
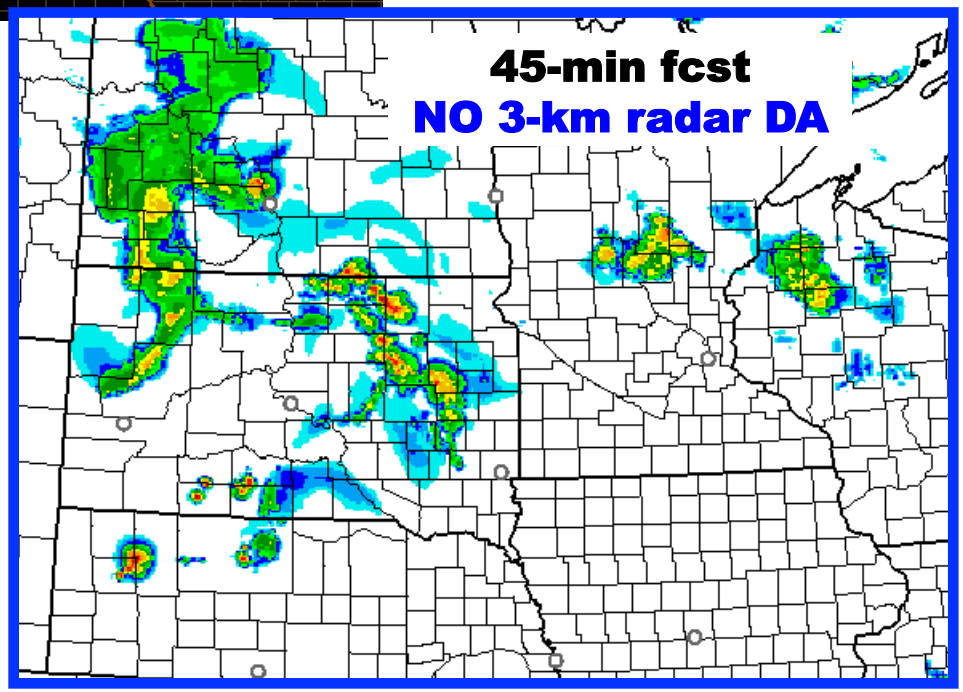


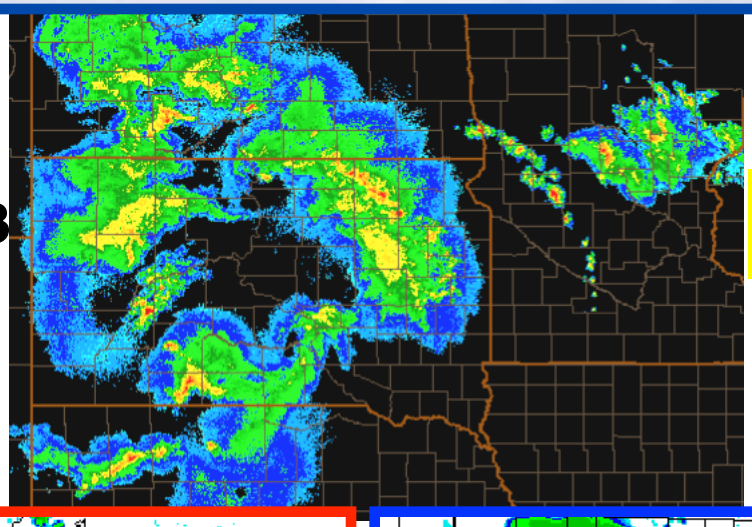
05z + 45 min



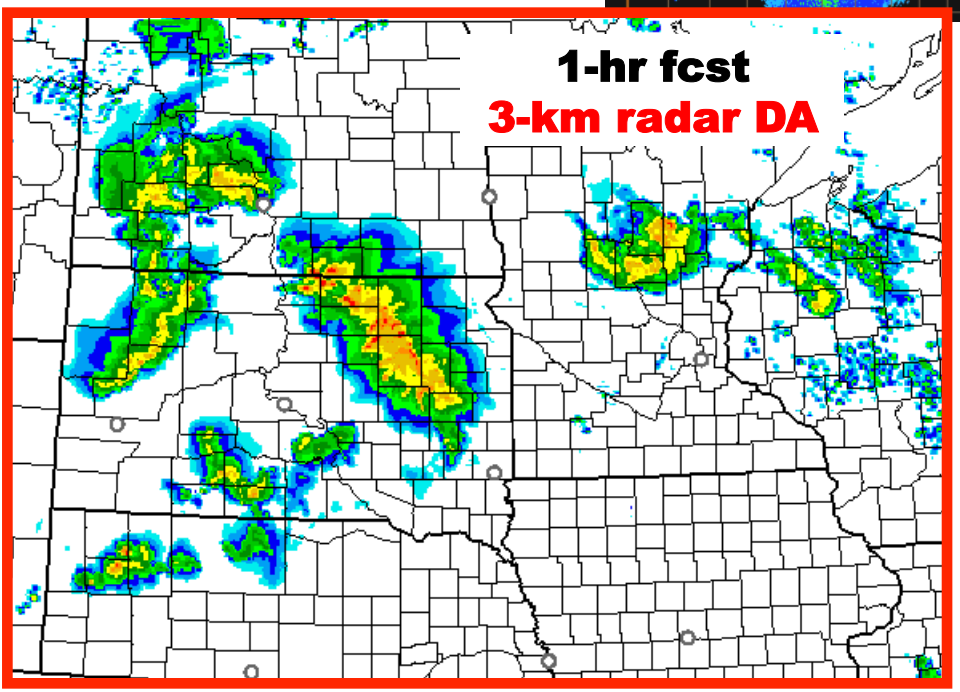


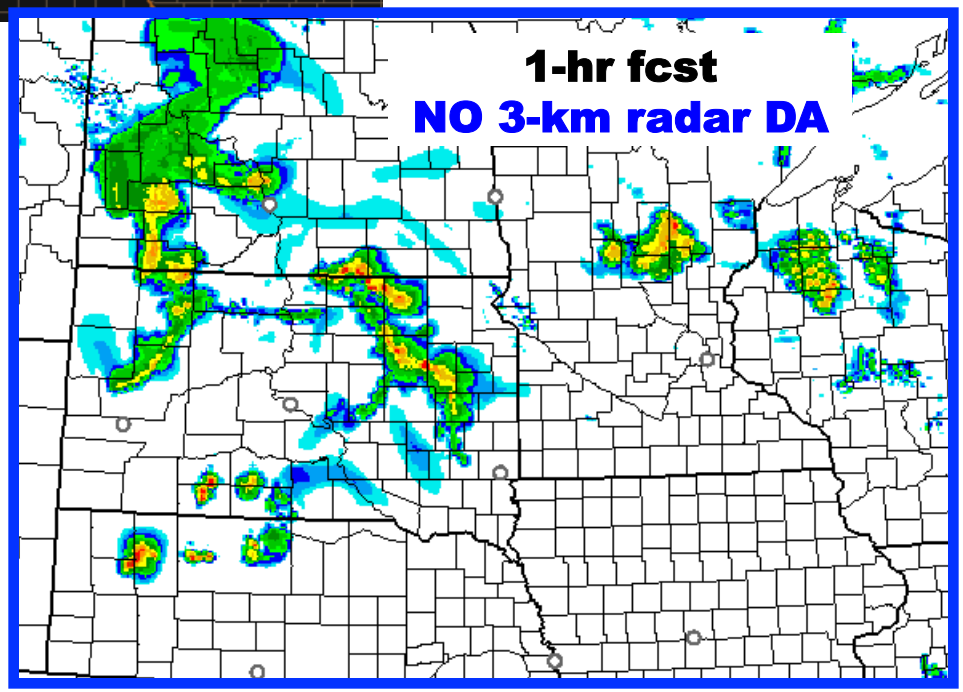
Improved 0-2 hr Convective Fcsts

Radar Obs
06:00z 18 May 2013



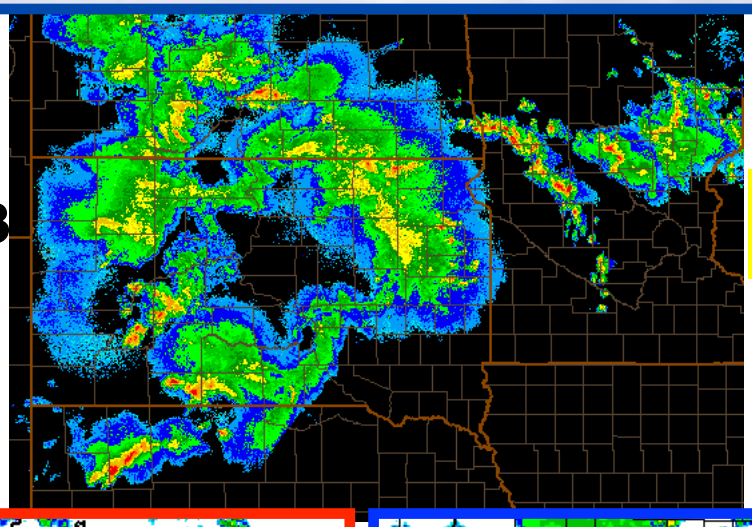
05z + 1 hour



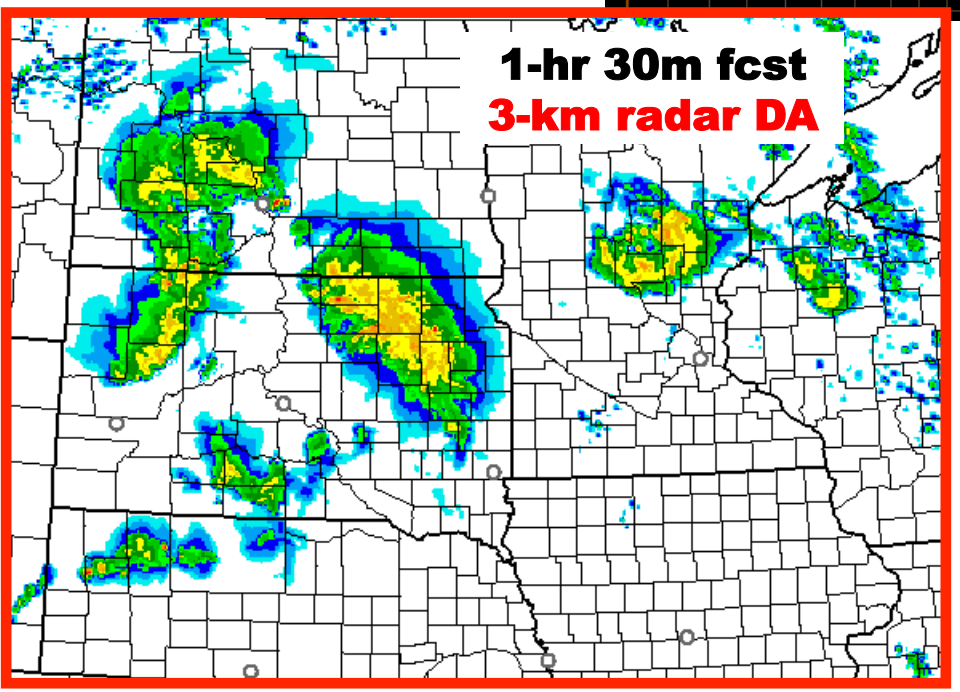


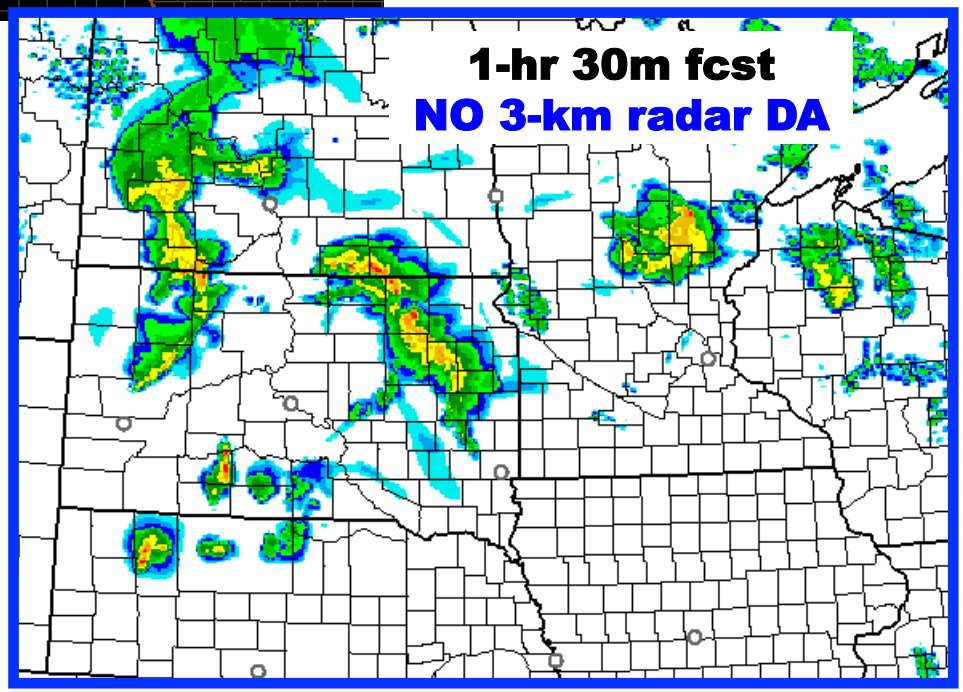
Improved 0-2 hr Convective Fcsts

Radar Obs
06:30z 18 May 2013



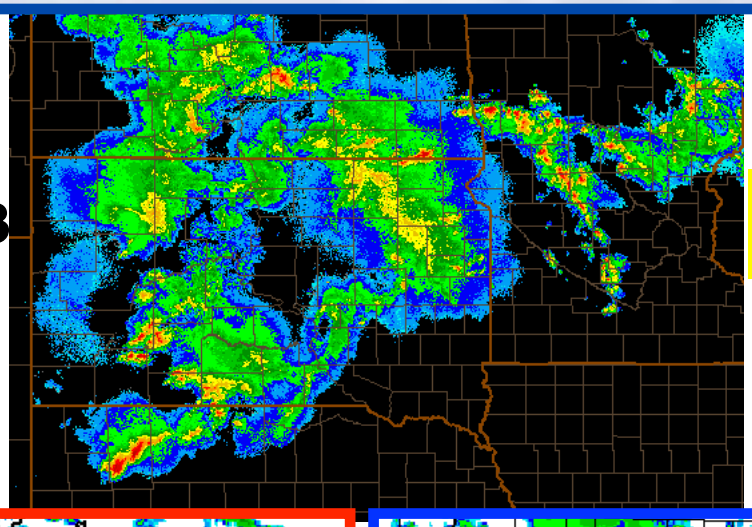
05z + 1:30 min



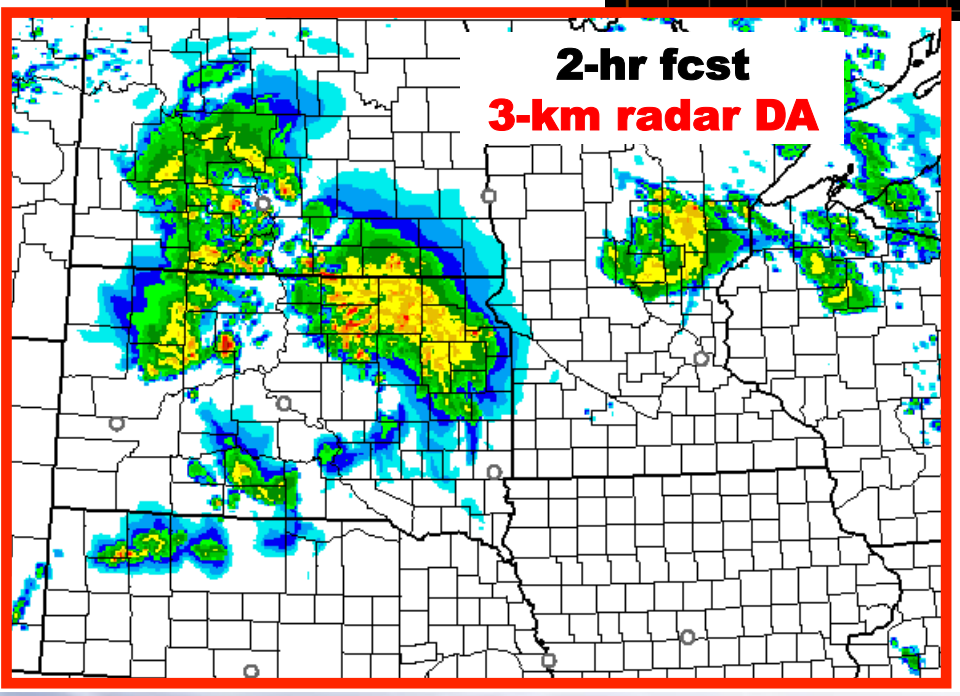


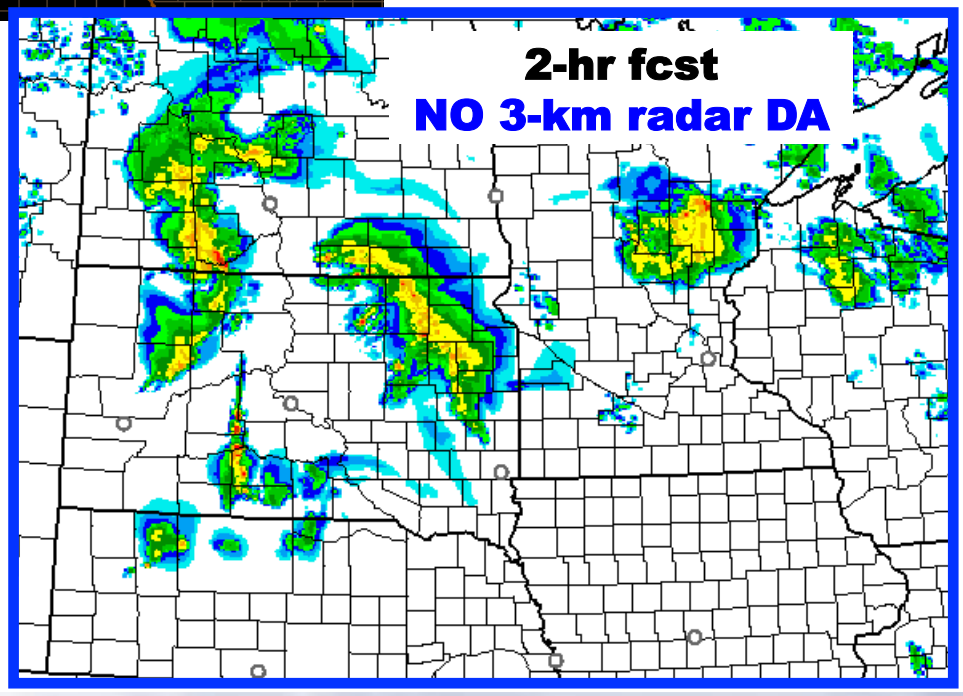
Improved 0-2 hr Convective Fcsts

Radar Obs
07:00z 18 May 2013



05z + 2hr min

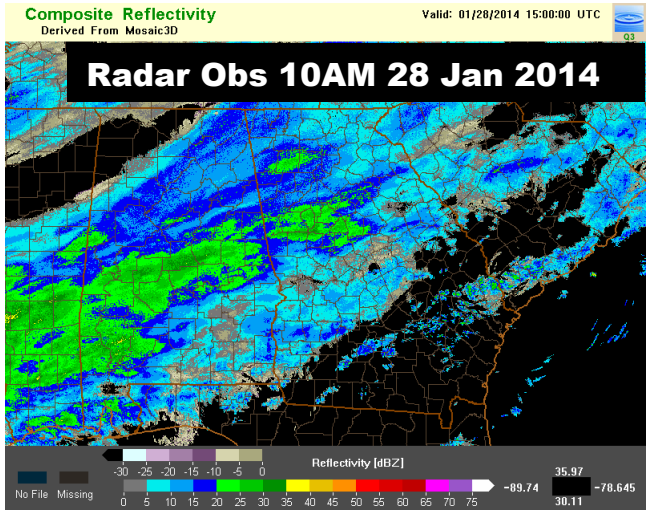


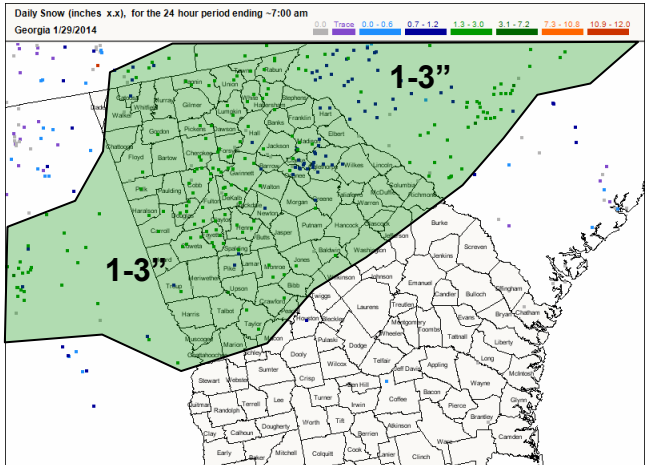


HRRR Snow Forecast Atlanta, GA

28 Jan 2014

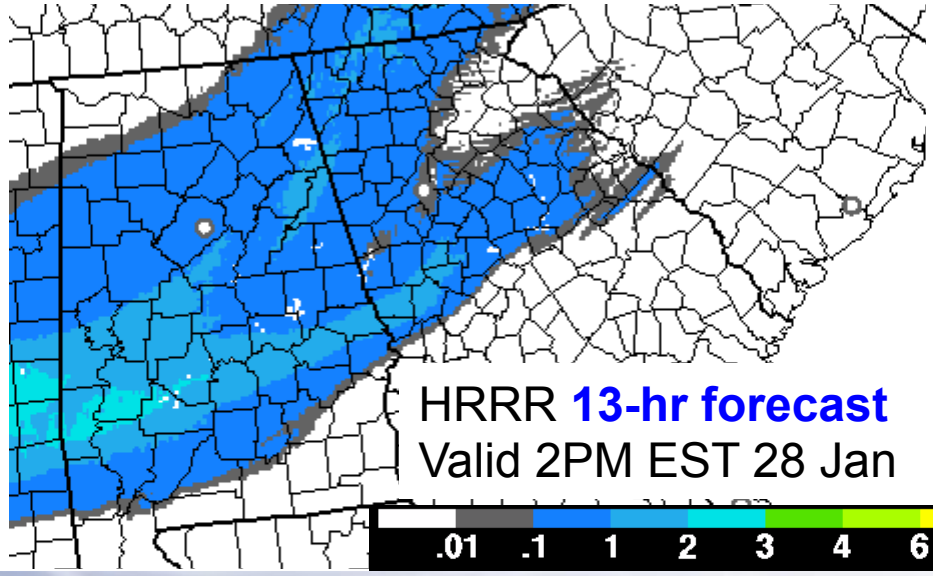
Atlanta Metro Snow Reports of 2.7”



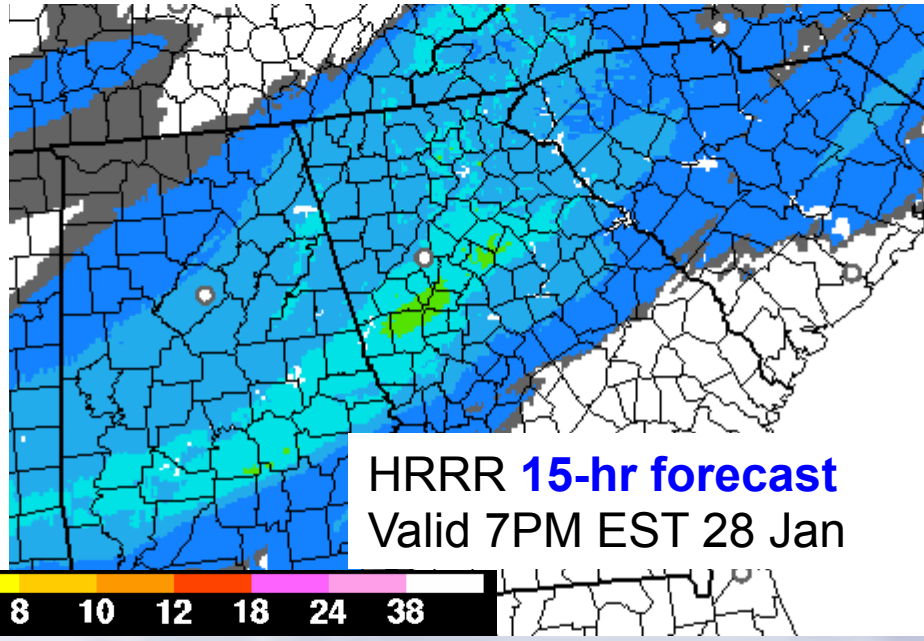


24 Hr Snow Valid 7AM EST 29 Jan 2014

HRRR Snowfall Forecasts (assuming 10:1)



HRRR **13-hr forecast**
Valid 2PM EST 28 Jan



HRRR **15-hr forecast**
Valid 7PM EST 28 Jan

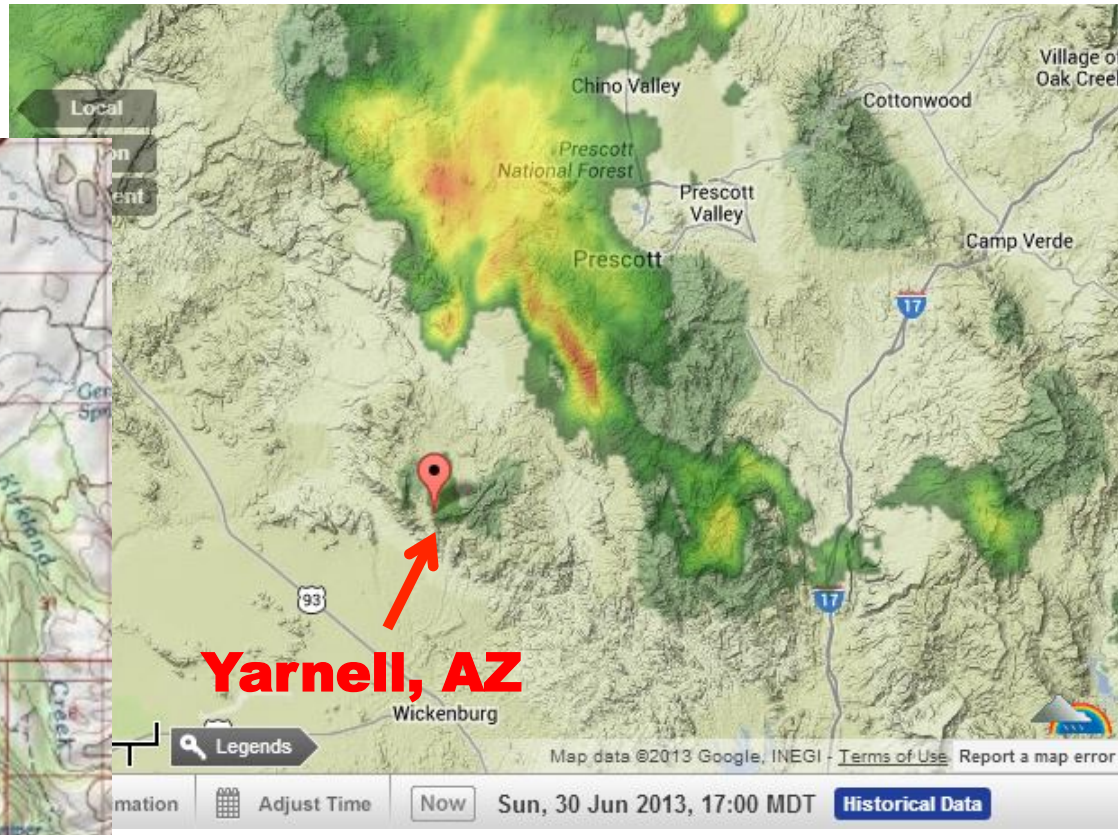
.01 .1 1 2 3 4 6 8 10 12 18 24 38

Yarnell, AZ Wildfire Background

Yarnell, AZ Wildfire Driven by
Thunderstorm Outflow 30 June 2013

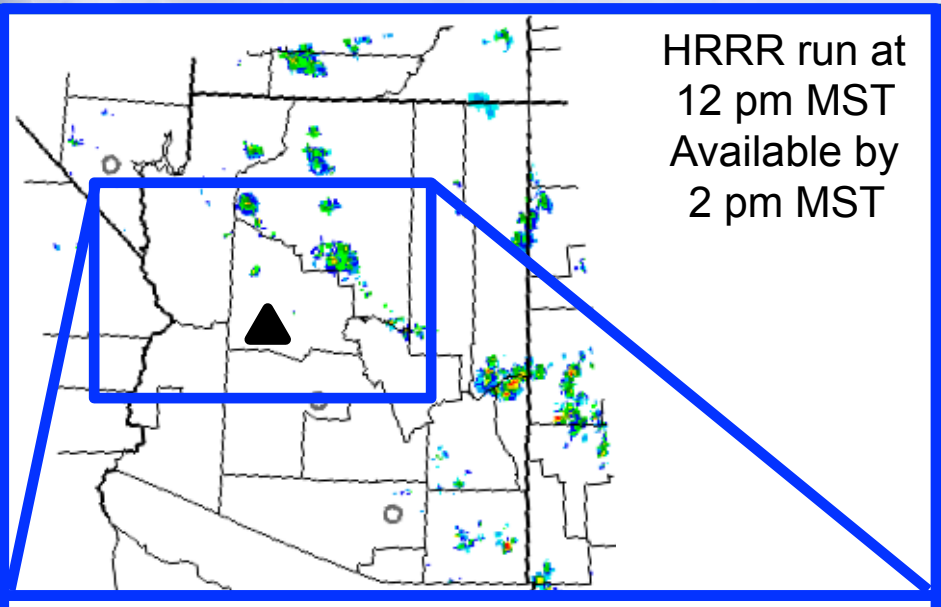
Radar Reflectivity
4 PM MST 30 June 2013

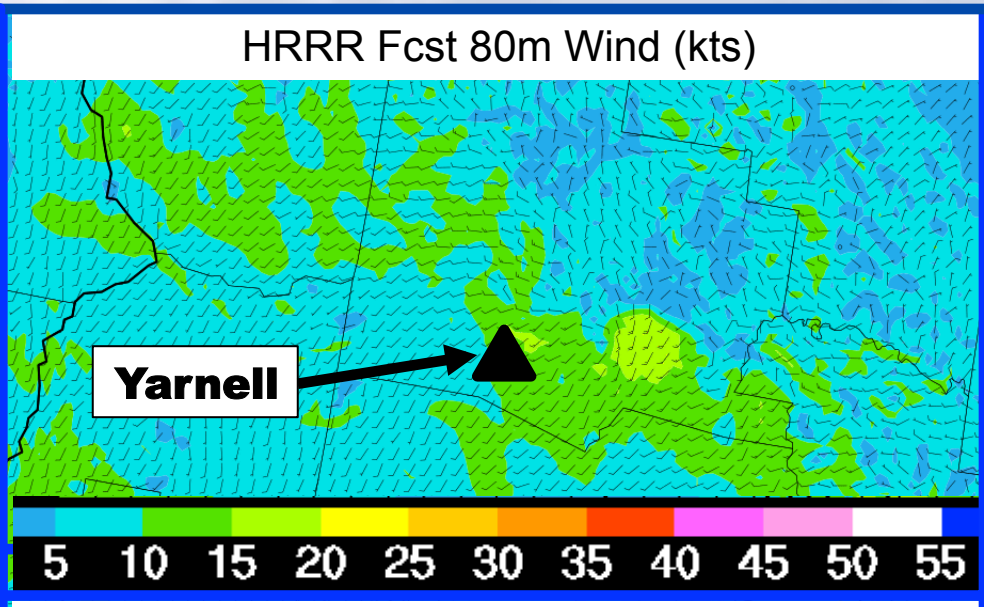
2 July 2013 Yarnell, AZ
Wildfire Perimeter

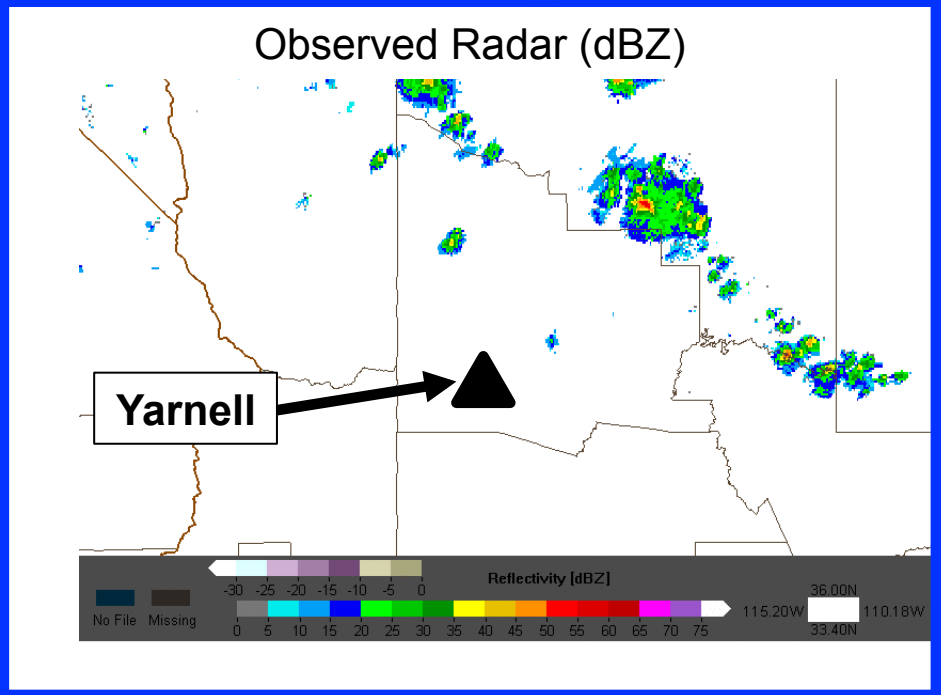


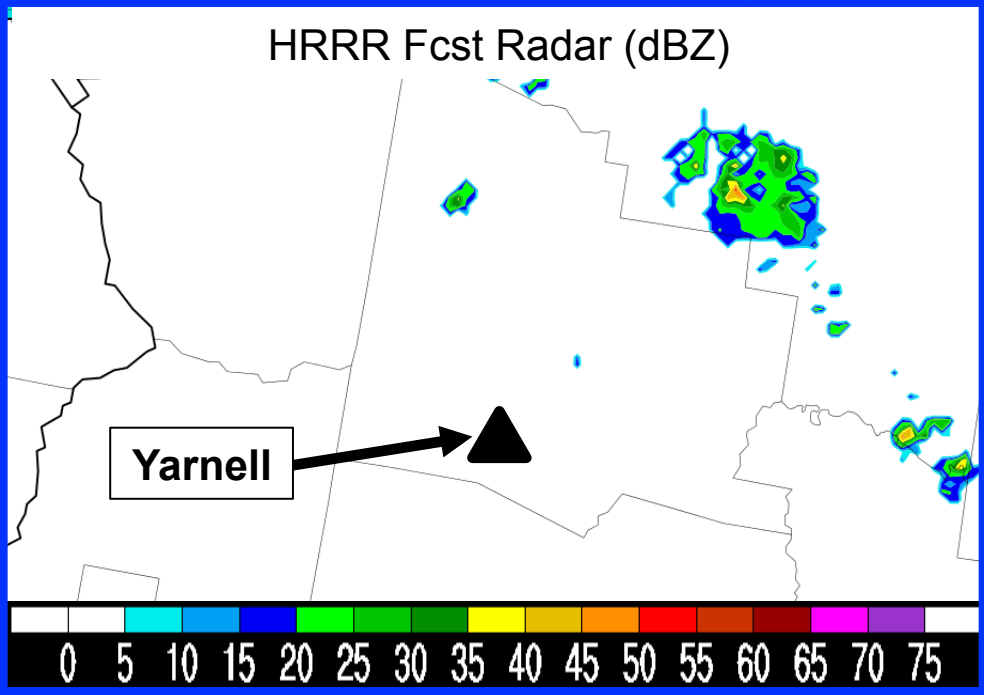
Last contact with fire crew
~ 4:30 PM MST
(2330 UTC) Sun. 30 June 2013

HRRR Wind Forecast Yarnell, AZ

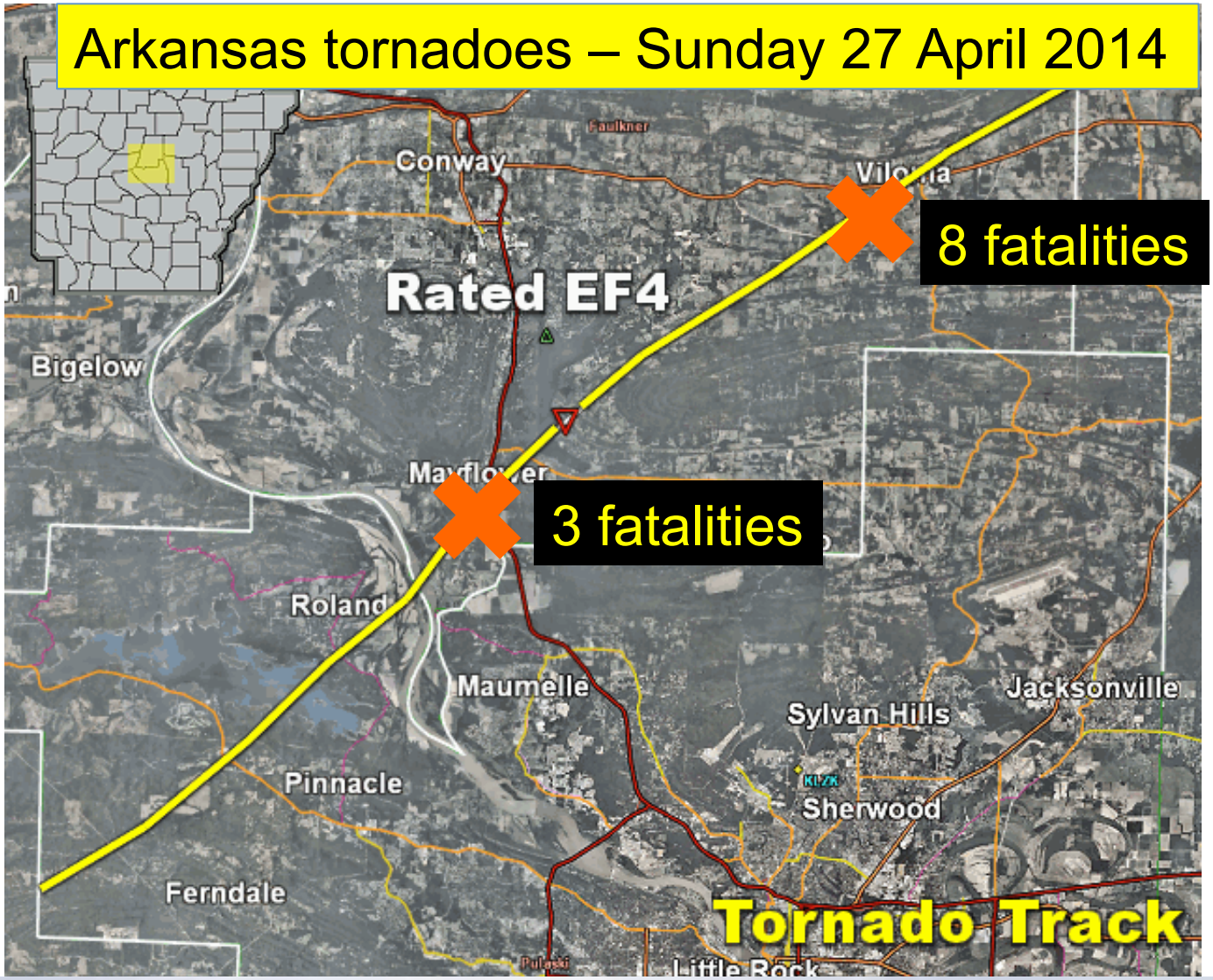




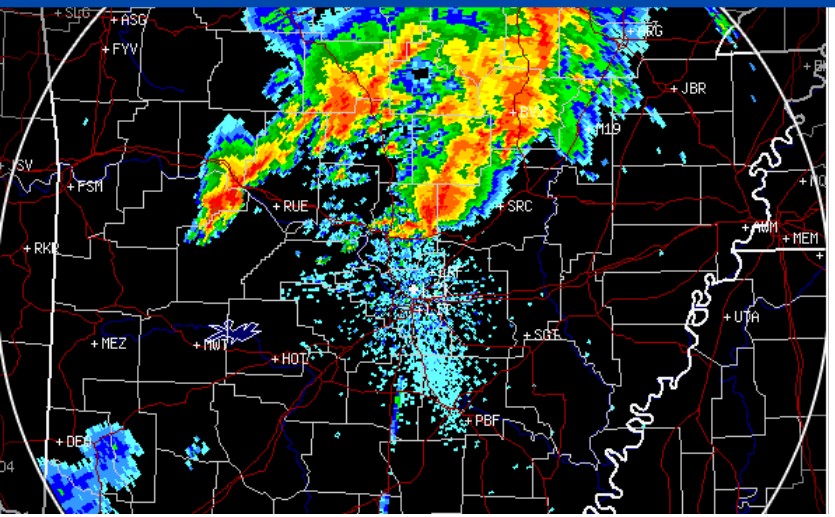




Arkansas Tornadoes Background

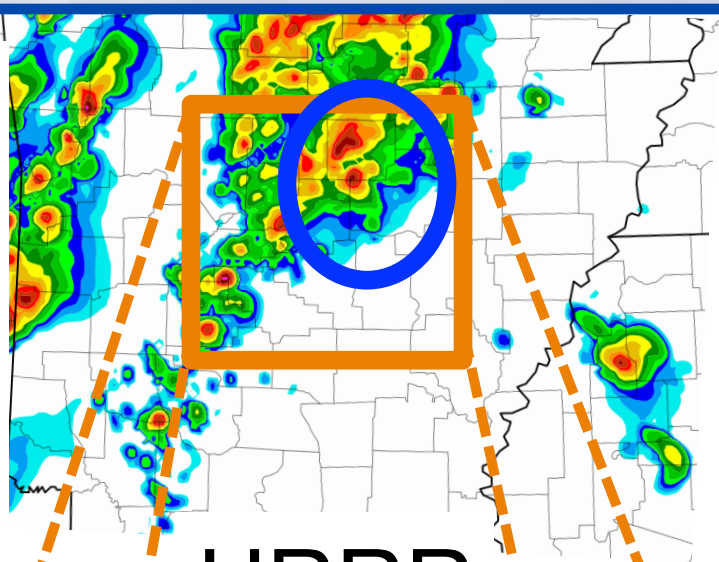


HRRR Supercell Forecast Arkansas

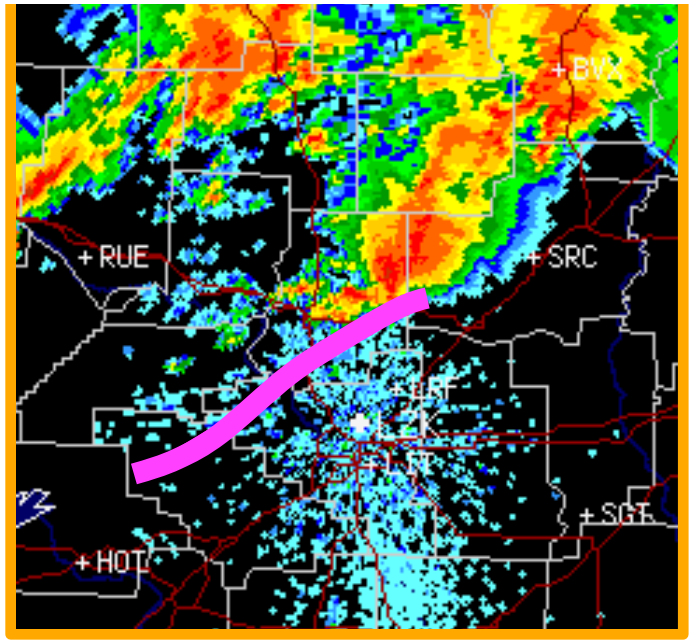


Observed radar

HRRR
6-hr fcst
made
at 2 PM
for 8 PM
27 April



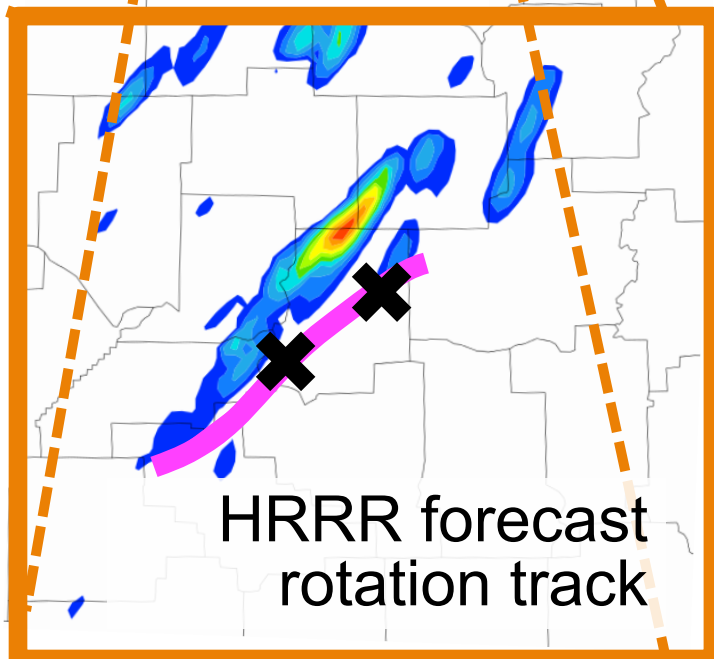
HRRR



Tornadic thunderstorm

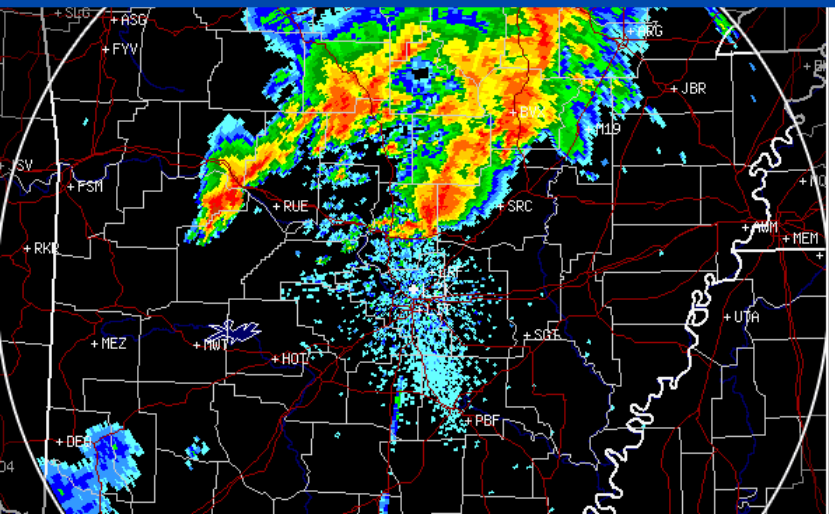
Actual tornado path

Fatalities



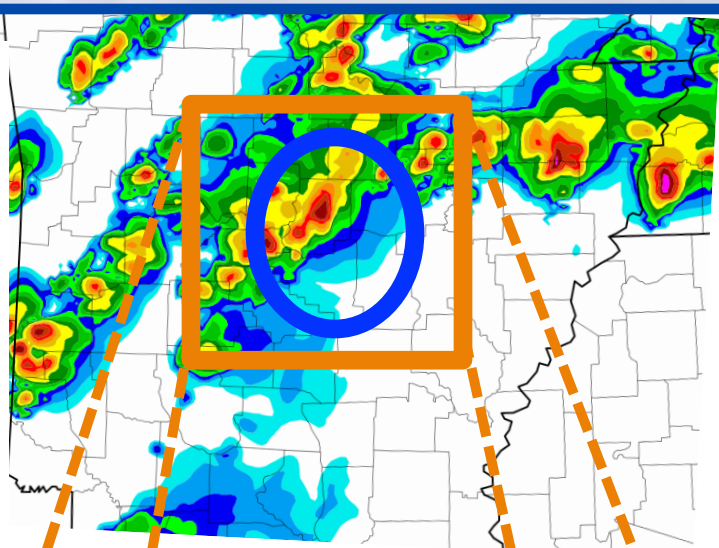
HRRR forecast rotation track

HRRR Supercell Forecast Arkansas

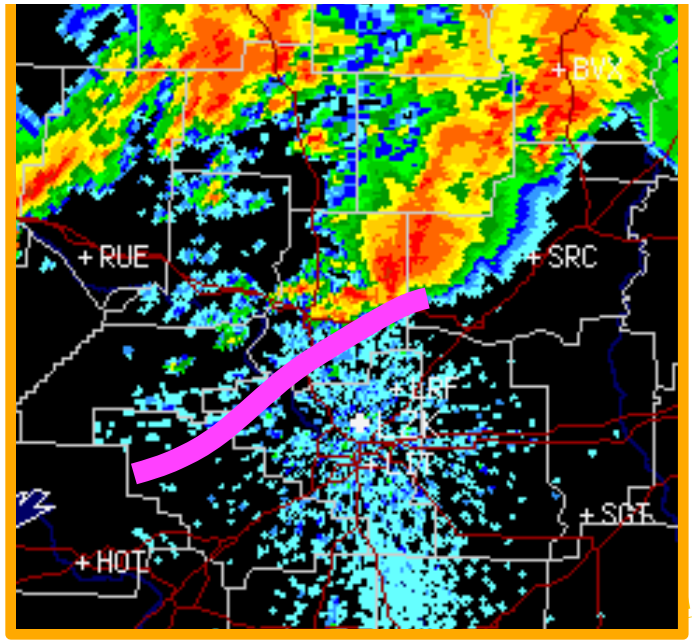


Observed radar

HRRR
10-hr fcst
made
at 10 AM
for 8 PM
27 April



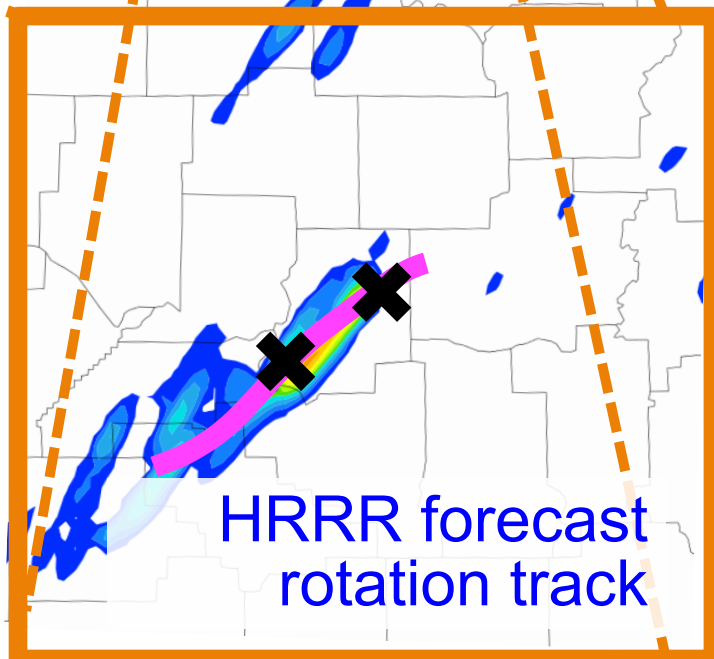
HRRR



Tornadic thunderstorm

Actual tornado path

✖ Fatalities



HRRR forecast rotation track

ESRL RAPv4/HRRRv2-2015 Changes

	Model	Data Assimilation
RAP-ESRL (13 km)	WRFv3.6.1+ incl. physics changes Physics changes: Aerosol-aware Thompson cloud microphysics WRF (CLM) lake model Updated MYNN PBL – cloud mixing and non-local mixing Shallow cumulus parm w/ rad feed SW Rad output by dt (Ruiz-Arias) Updated GF convective scheme	Merge with GSI trunk Use of T1534-GFS ens members Other observations to be considered - Mesonet - SCAT Add pseudo-PBL obs for temps Radar assim – reinstate beam blockage
HRRR (3 km)	WRFv3.6.1+ incl. physics changes Physics changes: Same as for RAP except no convective parameterization	Same as RAP, plus, Radial wind assimilation Subhourly spin-up data assimilation - Add lightning - Add full cloud/hydrometeor assimilation

RAP/HRRR Implementation Map

ESRL – experimental version

- RAPv1 – used in 2011
  - Initialized 2011 HRRR

→ **NWS-NCEP - operational**

- Implemented 1 May 2012

- **RAPv2 – used in 2012-2013**
  - **Initialized 2012-2013 HRRR**
  - **MYNN PBL, 9-layer LSM**
  - **Hybrid DA, Better surface DA**

→

- **RAPv2 – implemented on 25 Feb 2014**

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

→

- **HRRR – Implementation scheduled for Sept 2014**

HRRR testing on WCOSS with real-time end-to-end runs

Important operational storm-scale application of WRF-ARW model

RAP/HRRR Implementation Map

ESRL – experimental version	NWS-NCEP - operational
• **RAPv3 – GSD testing in 2014** – Will initialize 2014 ESRL-HRRR(v2) – Improved PBL, LSM, cu-parm, DA – WRFv3.5.1 or WRFv3.6.1 w/ Thompson/ NCAR aerosol-aware microphysics	→ • Implement 2015
• **HRRRv2 – GSD testing in 2014** – Initialized by 2014 RAP (v3) – Improved radar assimilation, hybrid assimilation, PBL/cloud physics	→ • Implement 2015
• **RAPv4 – GSD testing in 2015** – Target: WRFv3.6.1, improved physics (including aerosol-aware microphysics from NCAR/Thompson) – Hourly RAP ensemble data assimilation	→ • Implement 2016
• **HRRRv3 – GSD testing in 2015** – Target: Improved 3km physics + improved data assimilation	→ • Implement 2016