15th Annual WRF Users' Workshop
24 June 2014

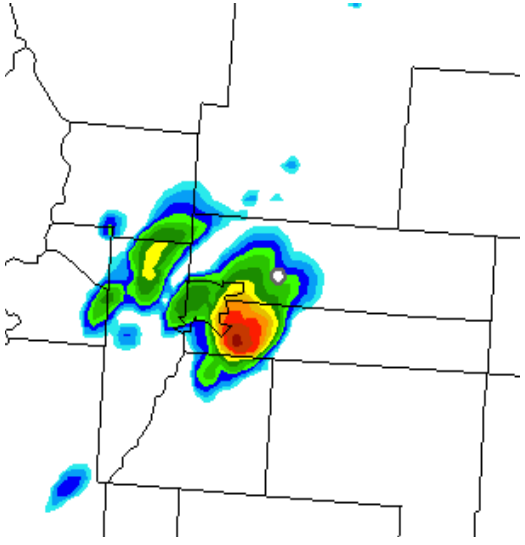
Recent Improvements in WRF-based Rapid Refresh and HRRR Forecast Systems and transition to NCEP Operations

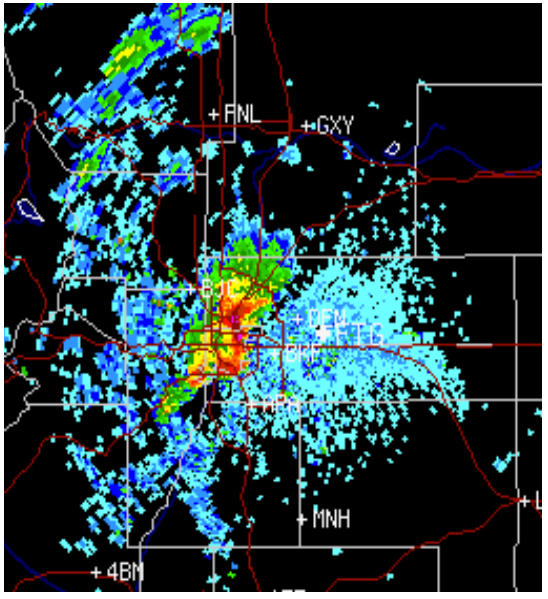
Steve Weygandt
NOAA/ESRL/GSD/AMB

Curtis Alexander, Ming Hu, Tanya Smirnova, Joe Olson, David Dowell, Stan Benjamin, Eric James, John Brown, Haidao Lin, Steve Peckham, Georg Grell, Brian Jamison, Kevin Brundage, Tracy Smith

Denver supercell 20z May21, 2014

HRRR 13Z+7h fcst **Observed**





Rapid Refresh and HRRR
NOAA hourly updated models

13km Rapid Refresh (RAP)

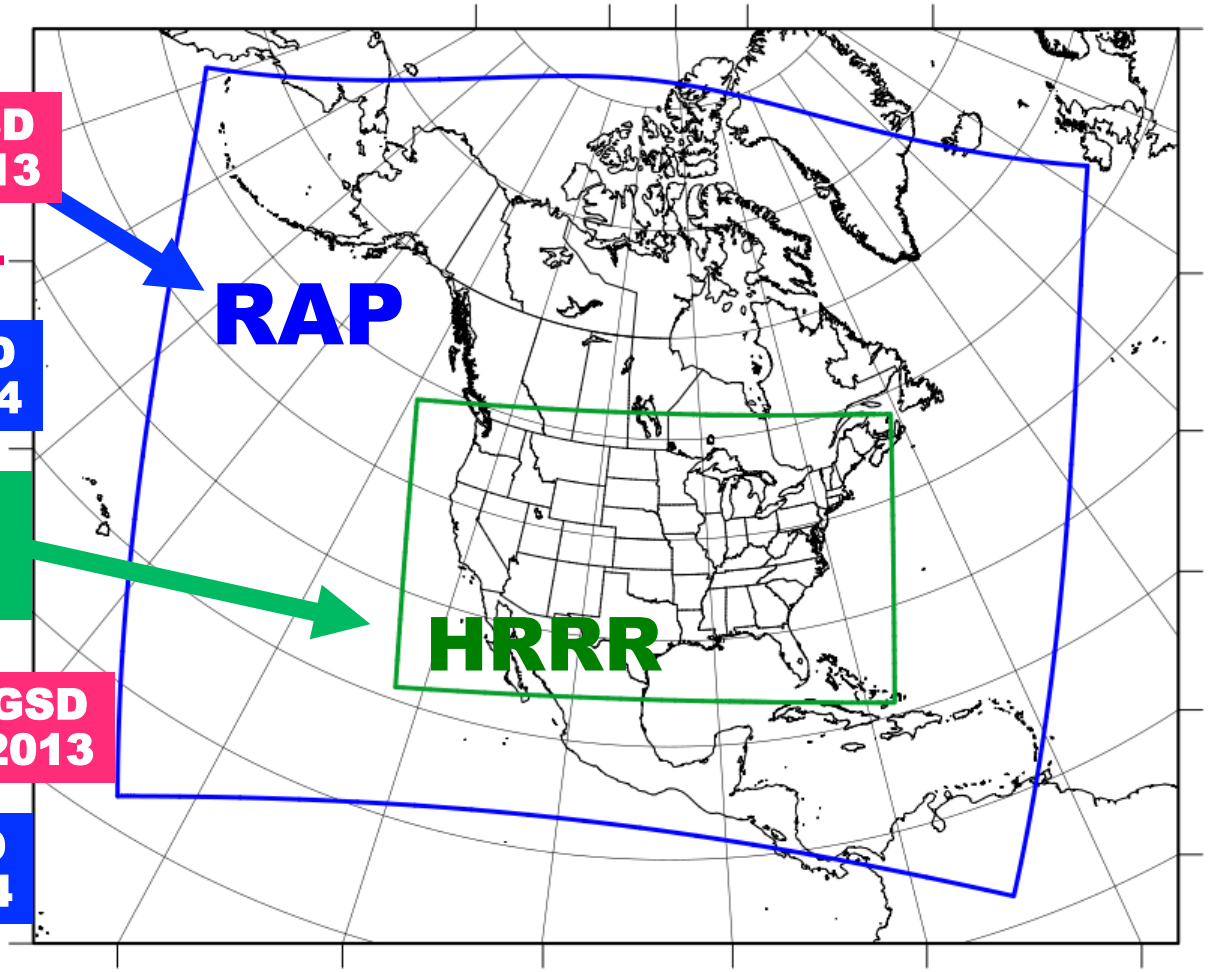
Version 2 -- NCEP GSD 2013
implement 25 Feb 2014

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



NCEP RAP v2 (GSD 2013) upgrades

Data Assimilation

GFS EnKF-3DVAR hybrid data assimilation

PBL-based moisture pseudo-innovations

Surface-obs-based soil moisture/temp adjustment

Low cloud building / other cloud enhancements

Temp-dependent radar hydrometeor building

Lightning data assimilation

GSI trunk update

Model

Physics changes

MYJ → MYNN PBL scheme

6 → 9-layer RUC LSM

MODIS land-use (fractional)

Modified roughness length

Revised Thompson cloud m-phys.

Higher-order numerics

Positive definite scalar advection

5th-order vertical advection

Update to WRFv3.4.1

RAP / HRRR use of MYNN PBL scheme

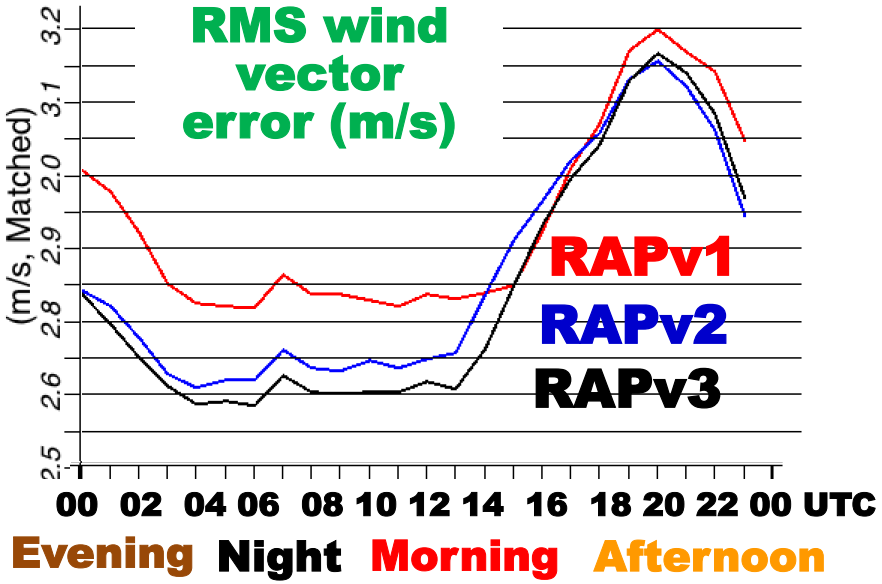
First implemented with RAPv2 / HRRR 2013

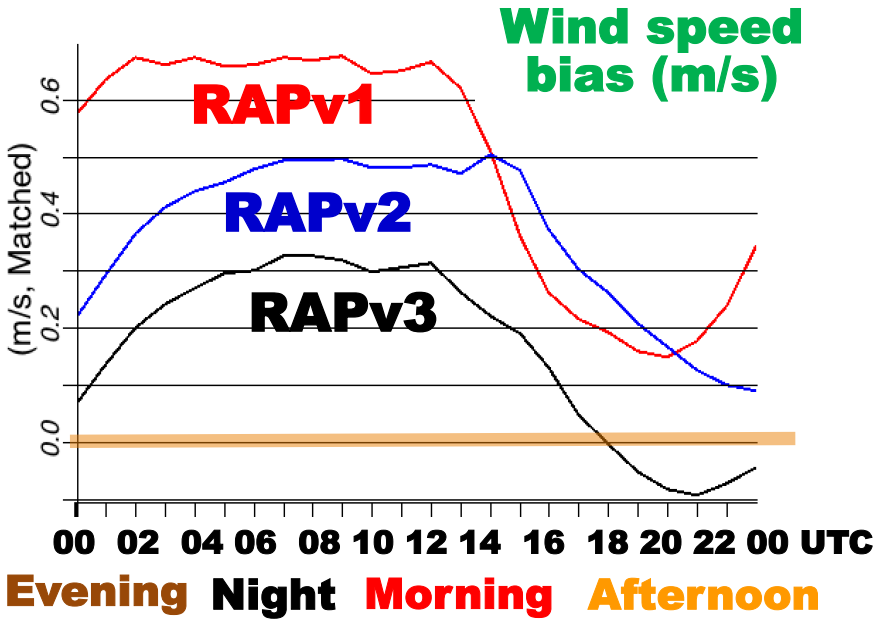
Joe Olson talk, Thurs 1:30

Improved mixing length formulations to flexibly change behavior across the stability spectrum

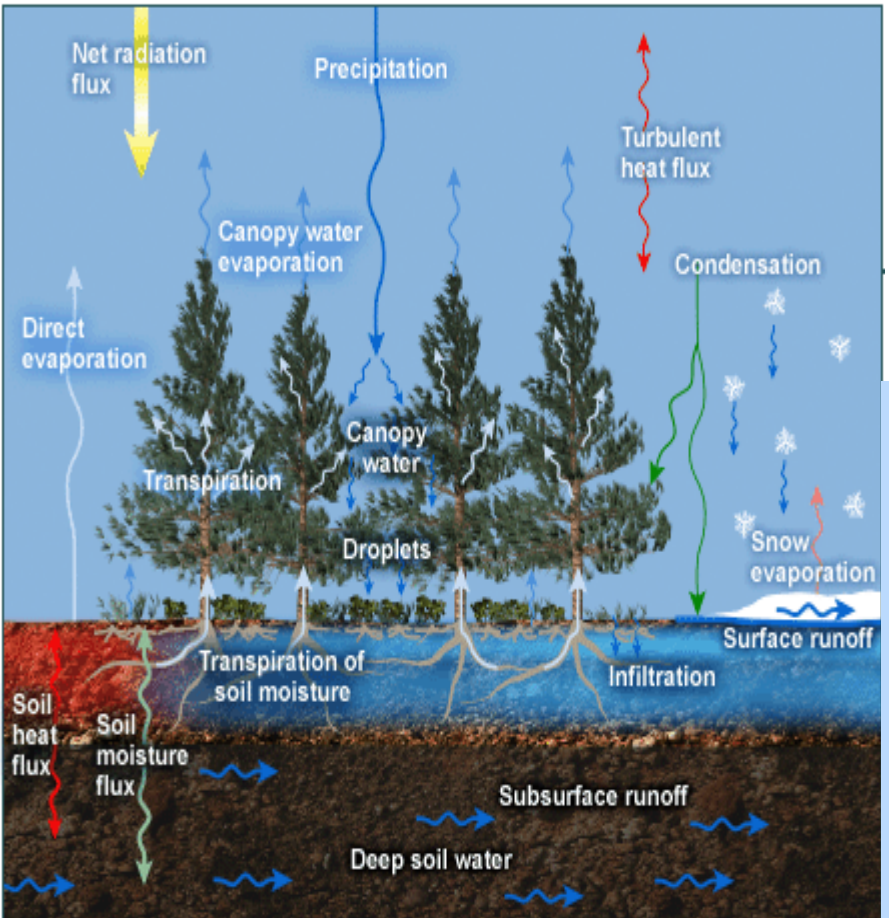
Improved surface layer scheme with customization to PBL scheme

Further enhancements for RAP v3 / HRRR 2014 -- cloud mixing, refined closure constants, coupling to different shallow cu schemes





Updates to RUC Land Surface Model



RAP v2 Updates

Tanya Smirnova talk, LSM Workshop – Thurs 10:30

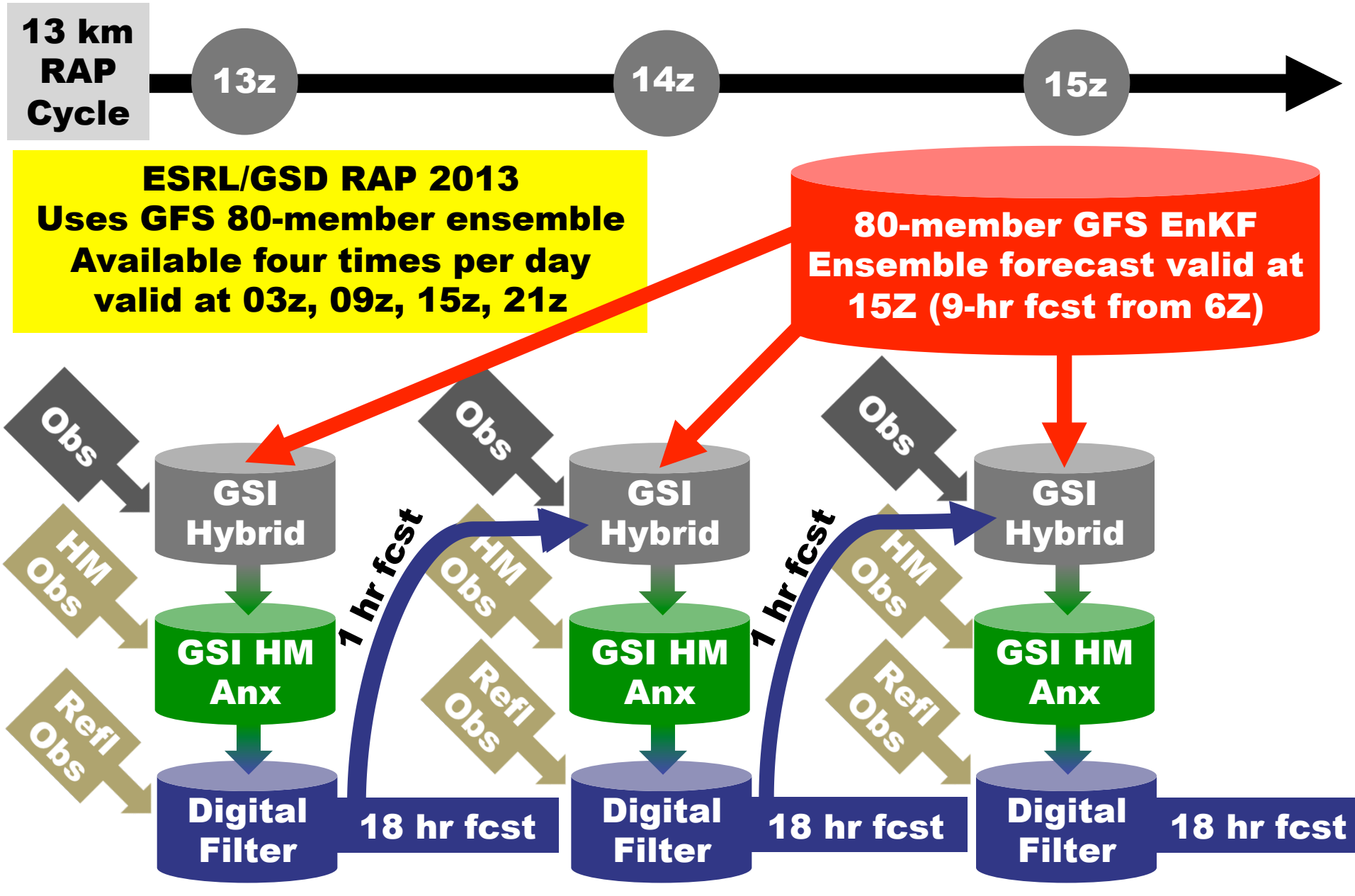
Increased number of levels in soil domain – 9 levels

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

- Increased roughness Z_0 for forests, cropland, urban
- New formulation to compute effective roughness length Z_{0eff} in the grid box (exponential)
- Seasonal variations of Z_0 for MODIS cropland category
- Seasonal variations of LAI based on the current vegetation fraction and variability of this parameter for different vegetation types

Thinner soil layer in energy / moisture budgets
Potential for increased near-surface diurnal cycle
Reduced warm bias at night, cold bias in day

RAPv2 Hybrid Data Assimilation

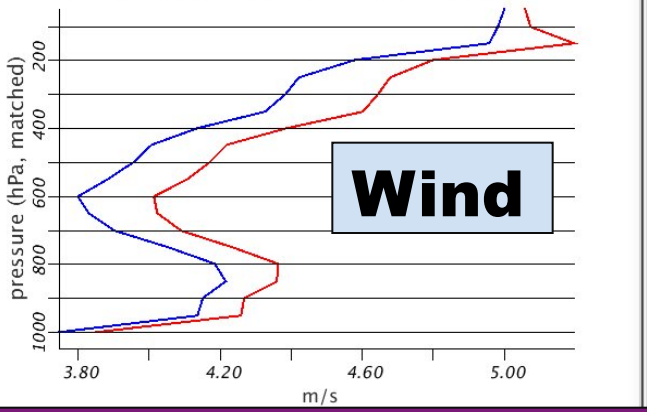


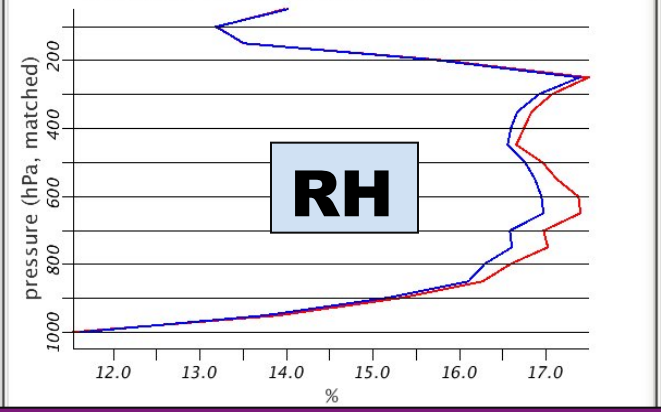
RAP Hybrid Data Assimilation

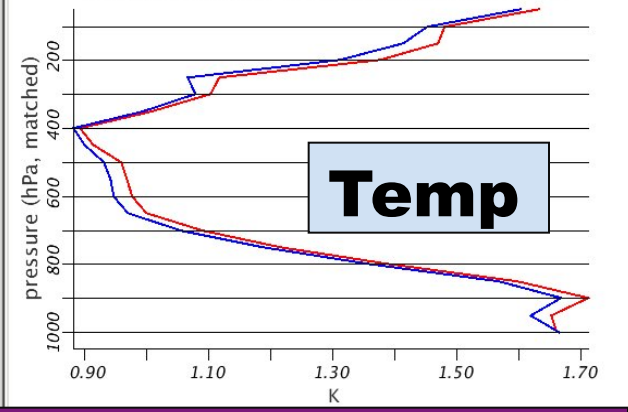
RMSE Vertical Profiles -- 22 Nov – 22 Dec 2012

RAP Hybrid RAP No Hybrid (3D-VAR)

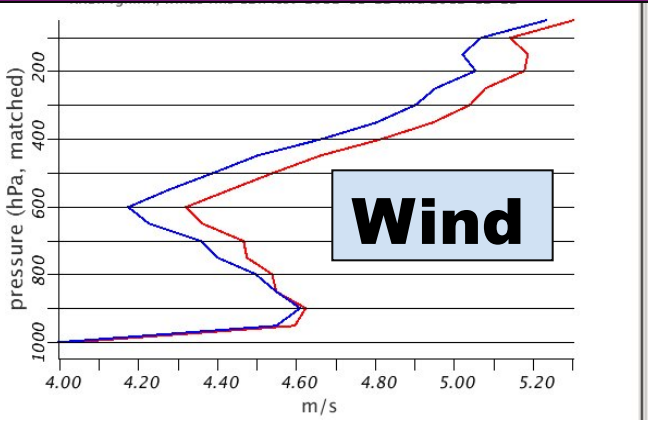
03-hr Forecast

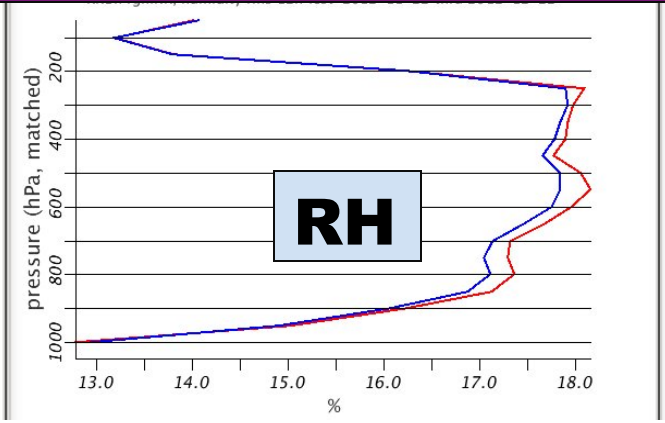


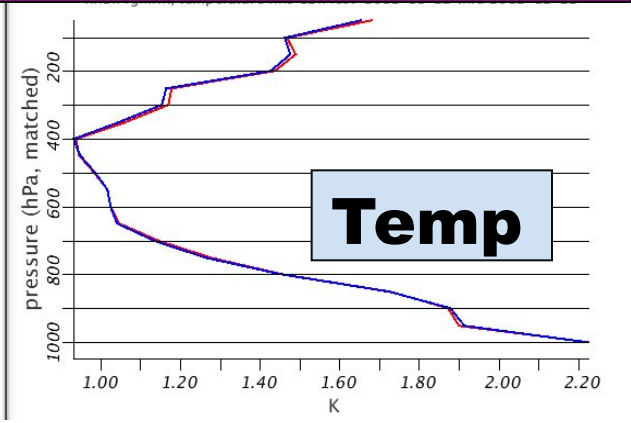




12-hr Forecast



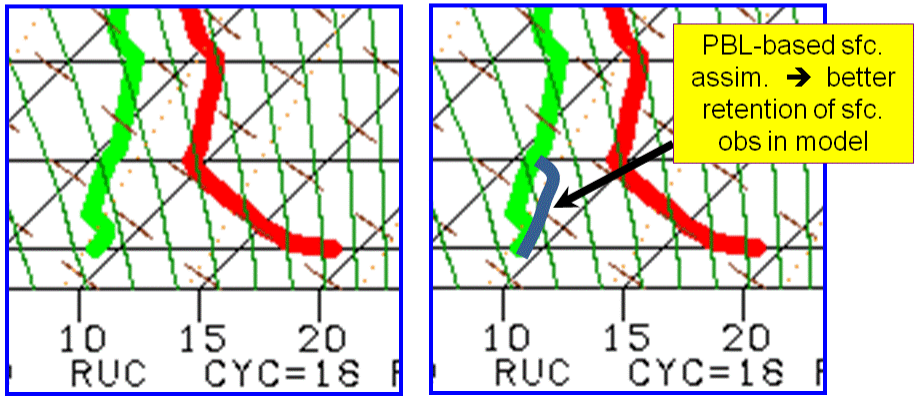




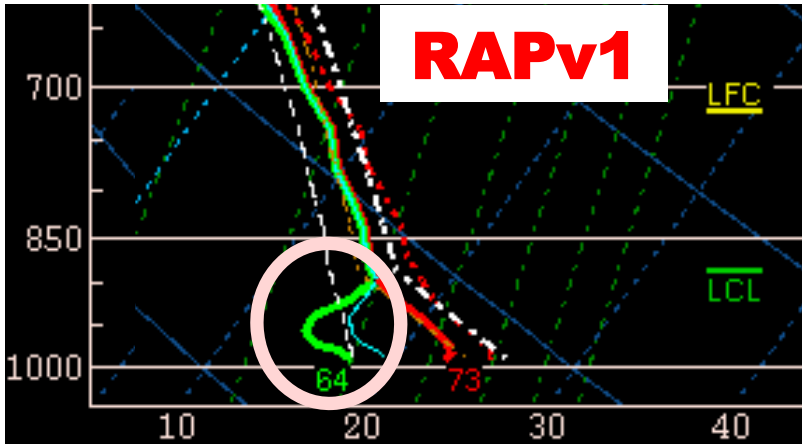
Improved upper-air fields, crucial for RAP / HRRR

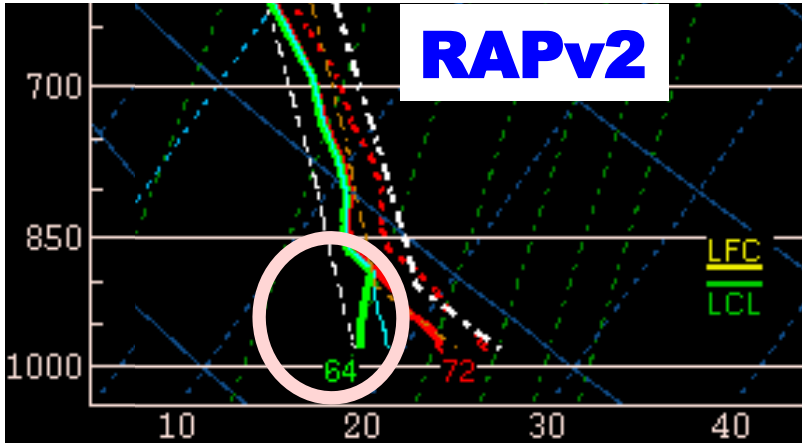
RAPv2 PBL moisture pseudo-obs

PBL-based pseudo-observations

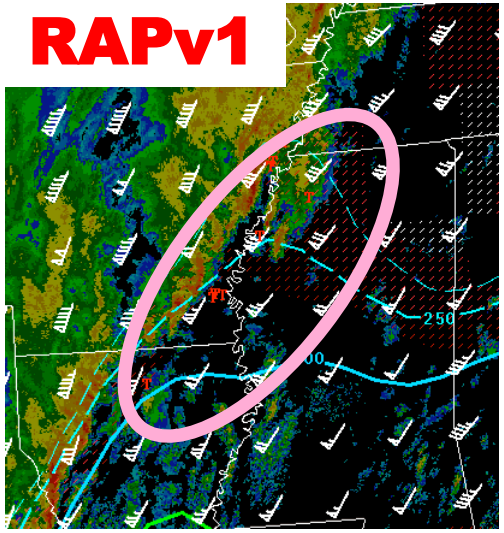


MEM 21z 21 Dec 2013 Analyzed sounding

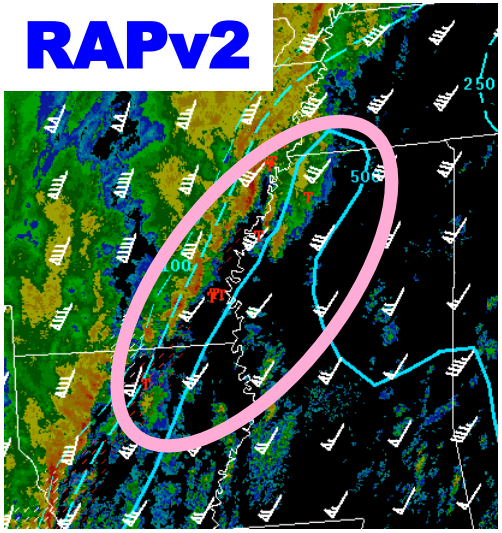




RAPv1



RAPv2

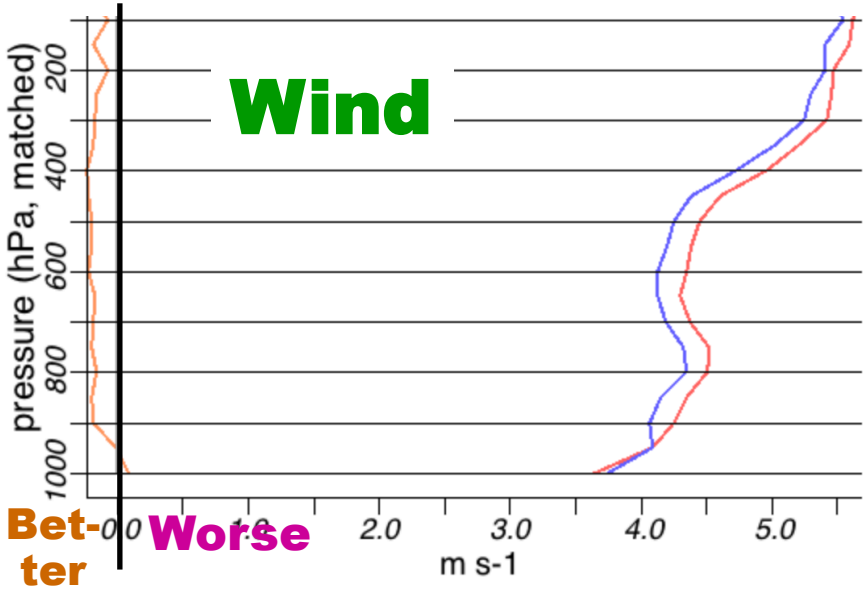


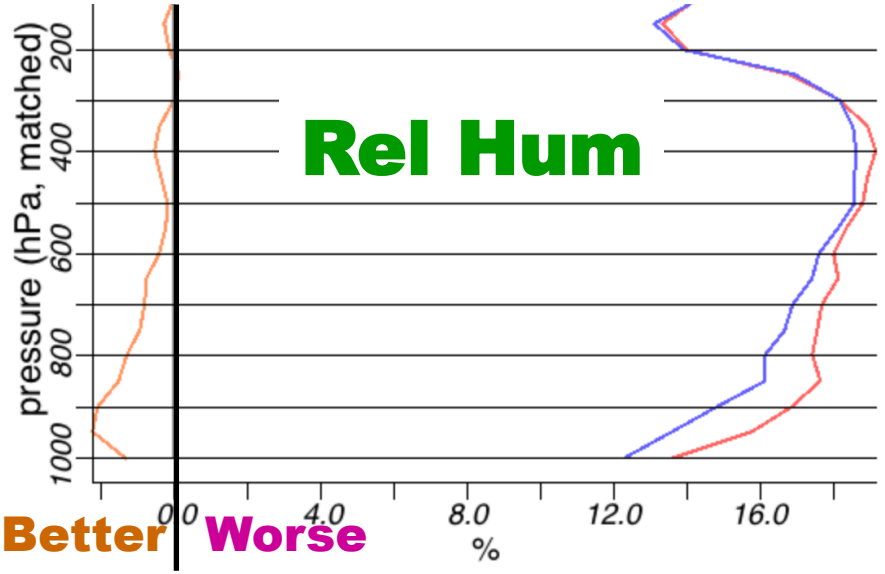
Model-based sfcOA MLCAPE/ CIN & EFF. SHEAR

Images courtesy Israel Jirak, Steven Weiss, Phillip Bothwell, Andy Dean, Storm Prediction Center

Improved PBL moisture structure, crucial for RAP / HRRR

Upper-air: RAPv2 vs. oper RAPv1





RAPv2 **RAPv1**

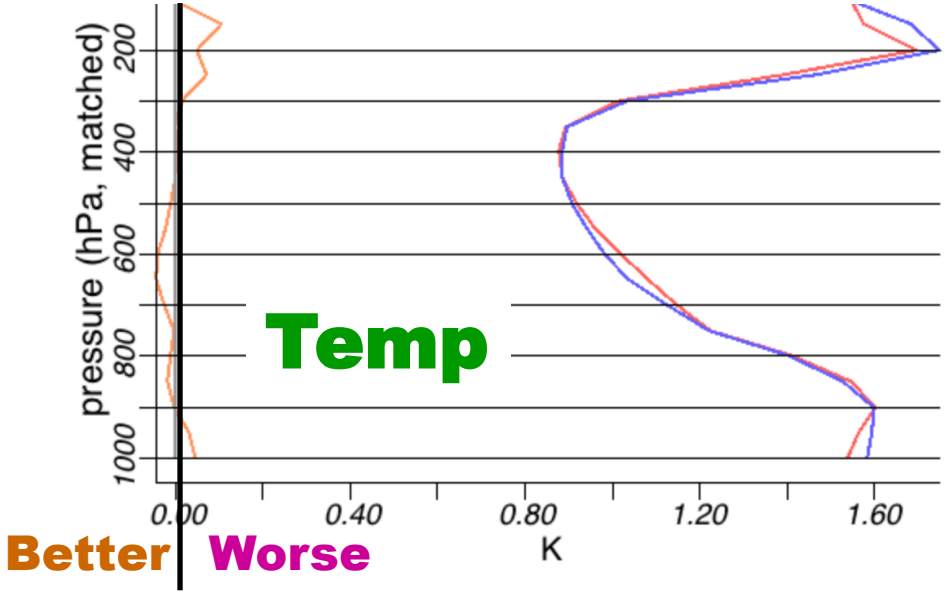
upper-air verification

+ 6 h forecast

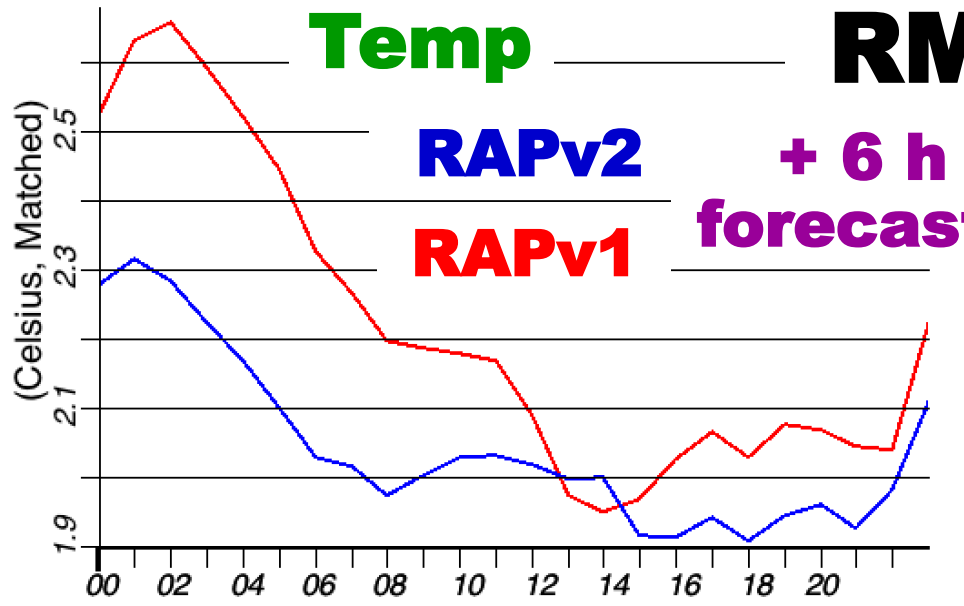
RMS Error

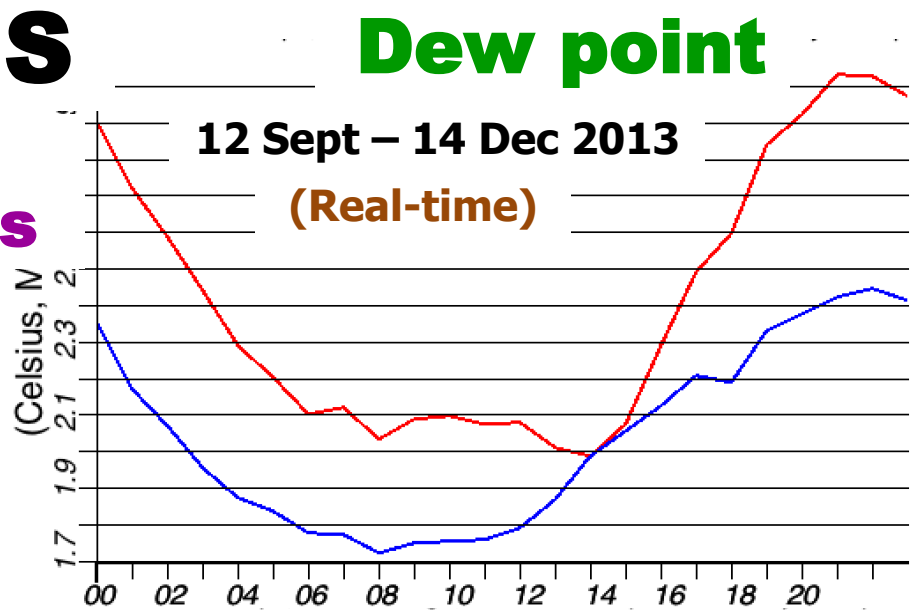
25 Jan – 25 Feb 2013

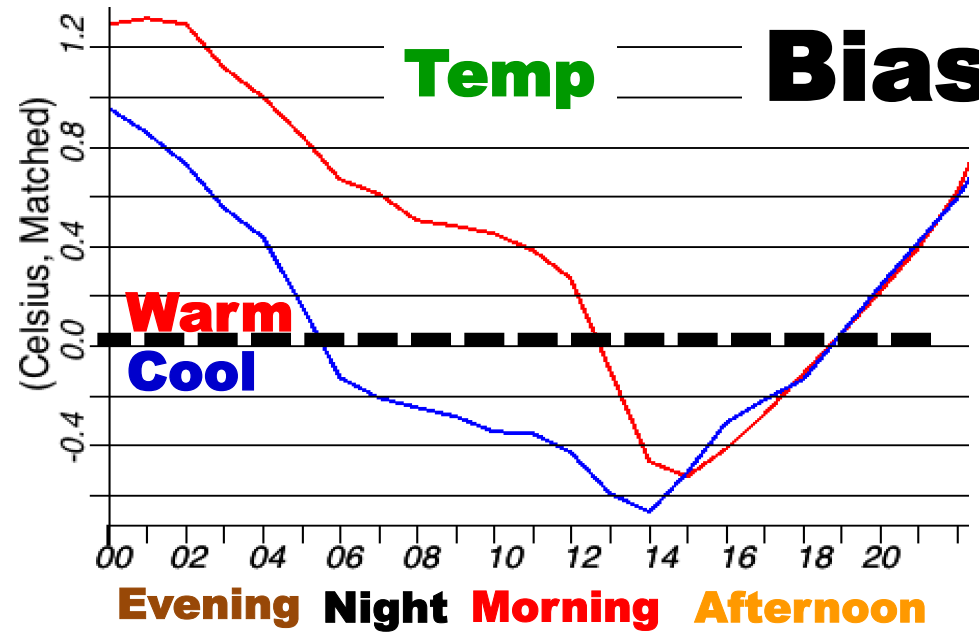
(Winter Retro)

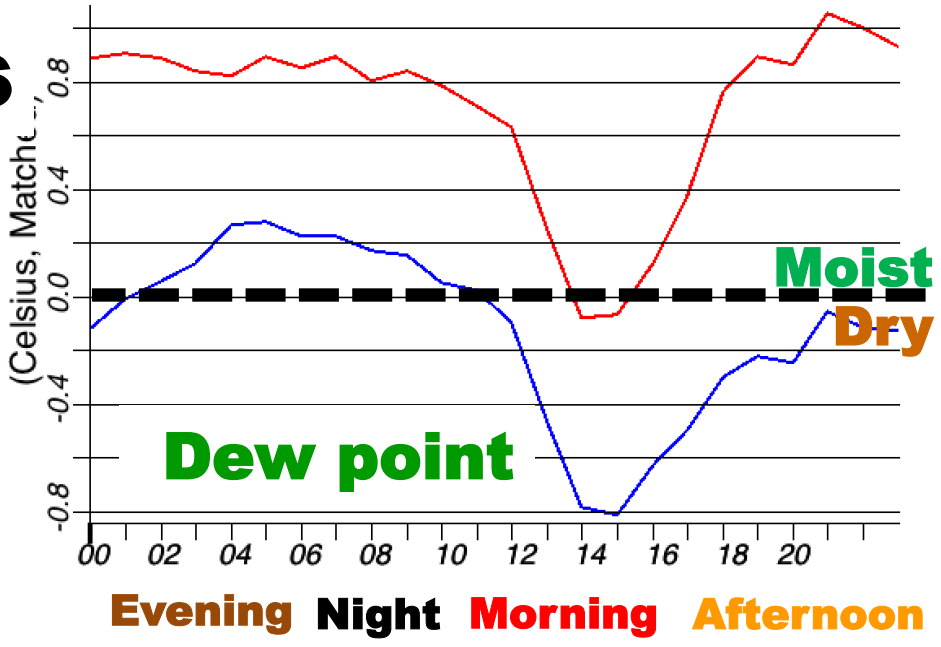


2m T and Td: RAPv2 vs. oper RAPv1

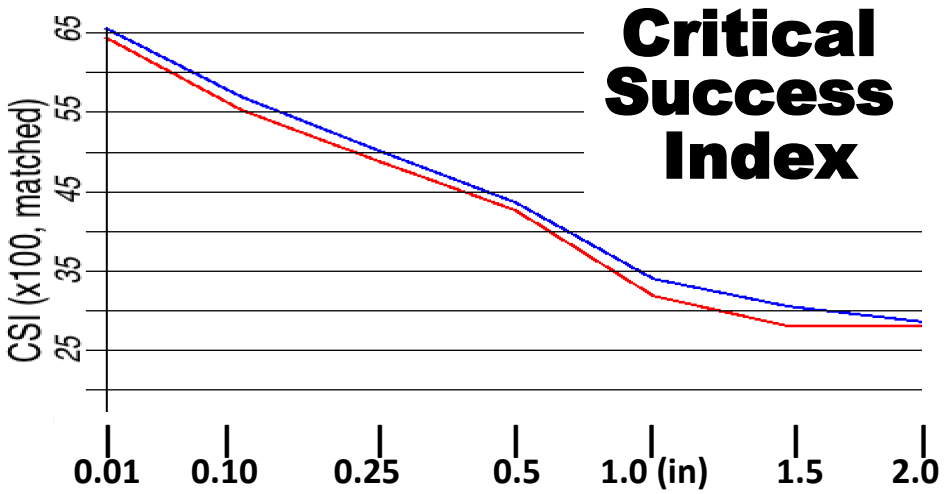


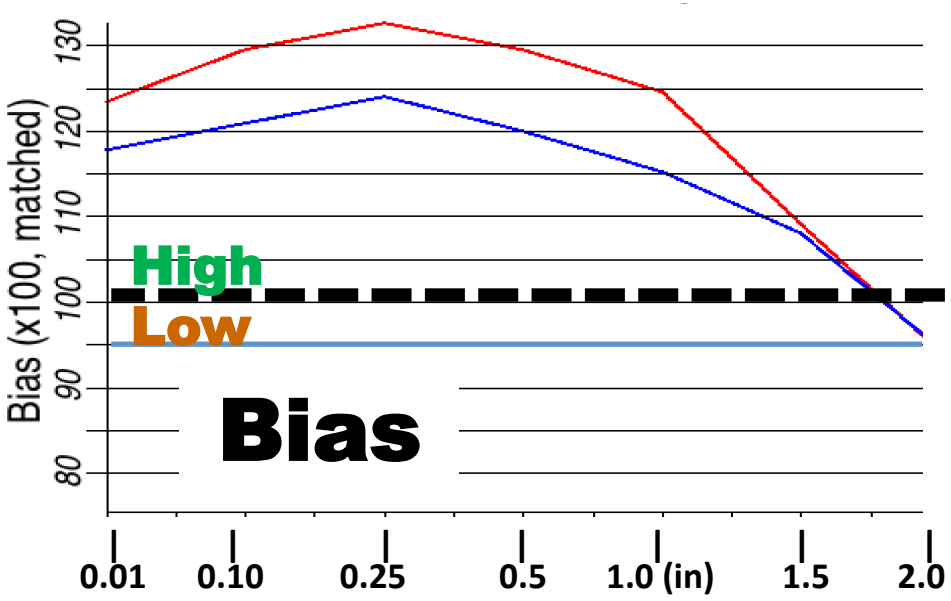






12 h precip: RAPv2 vs. oper RAPv1



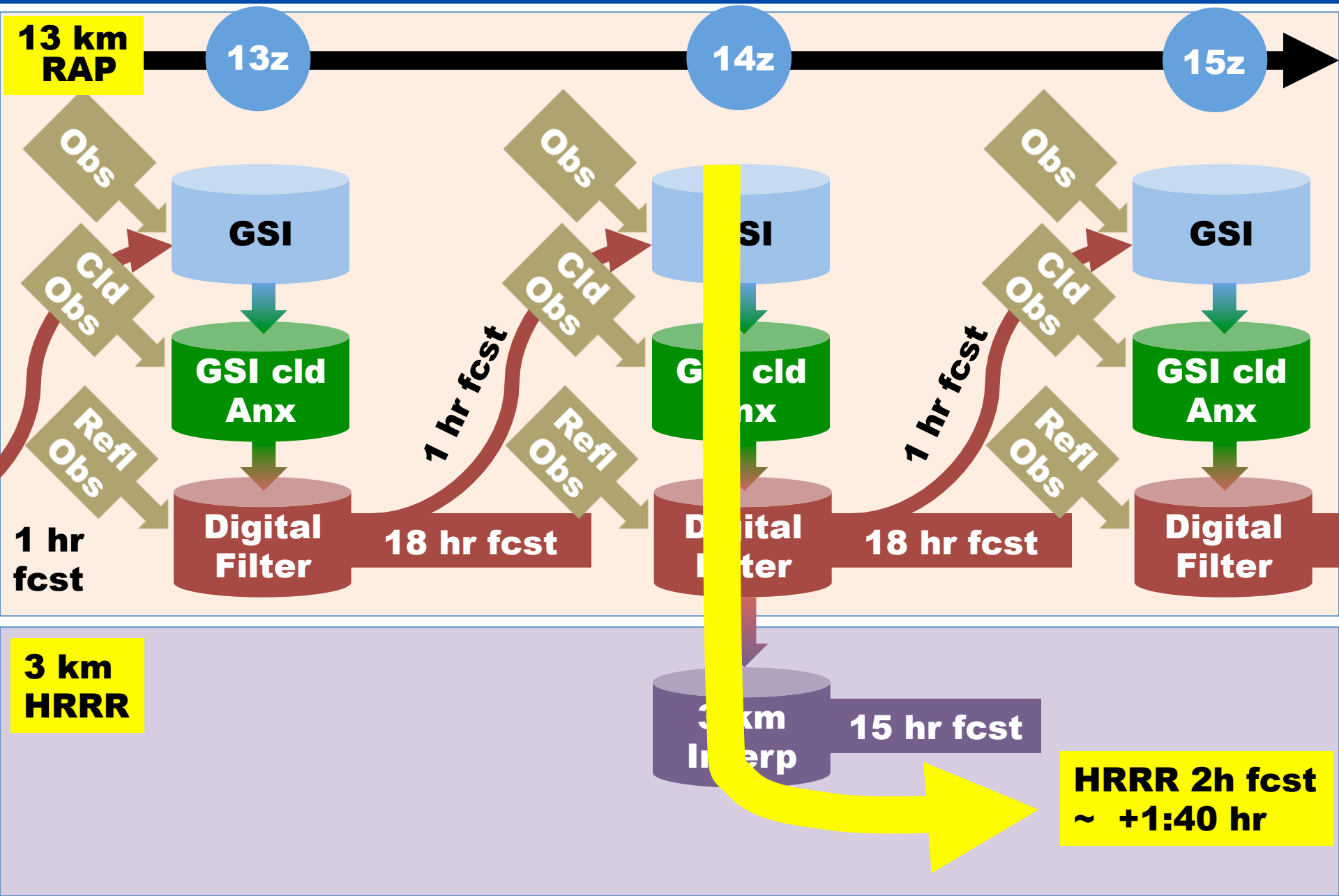


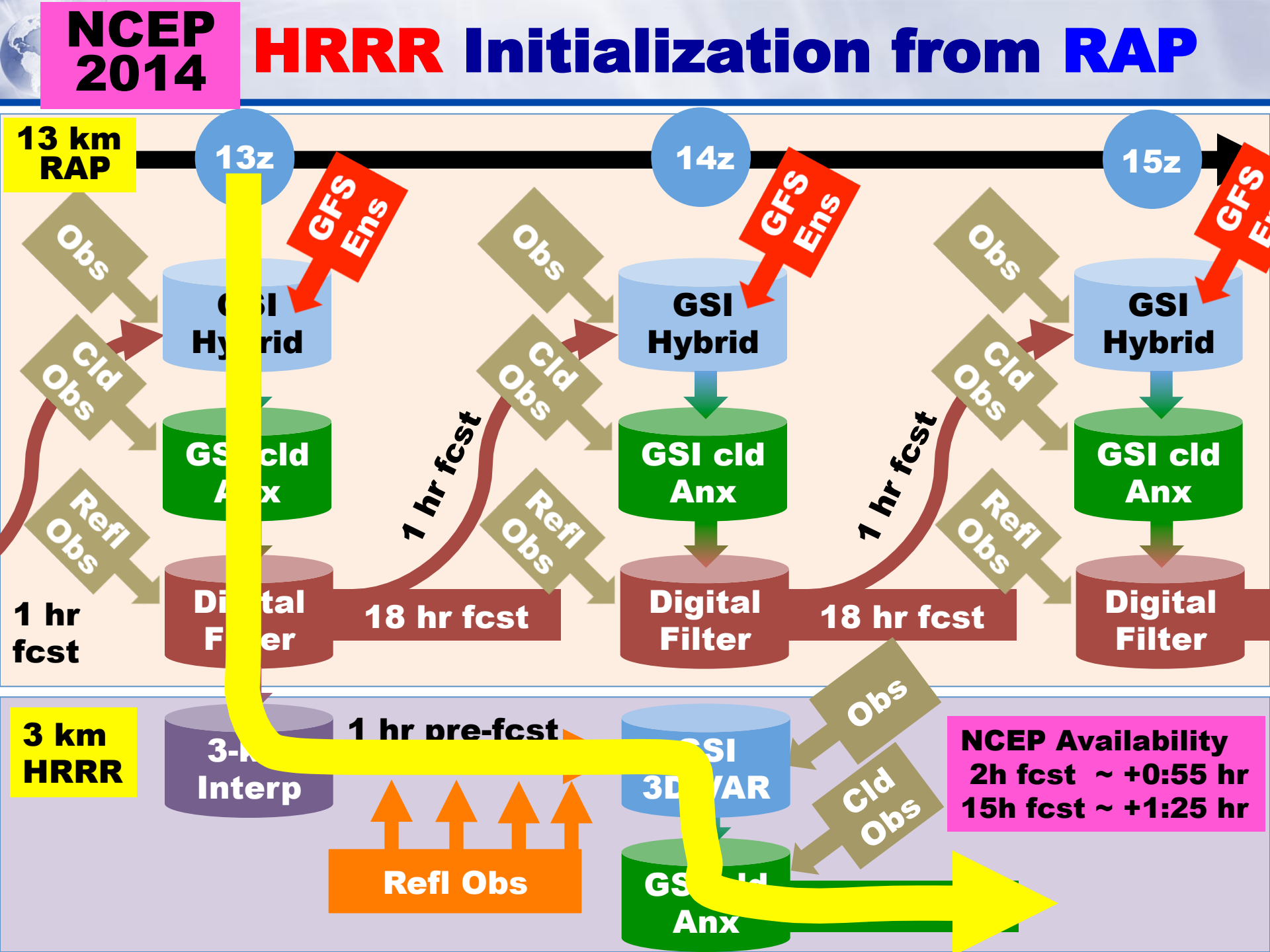
RAPv2
vs.
RAPv1
24-h precip. verification

2 x 12h fcst
13 Oct – 11 Nov 2013

Interpolated to 40-km grid

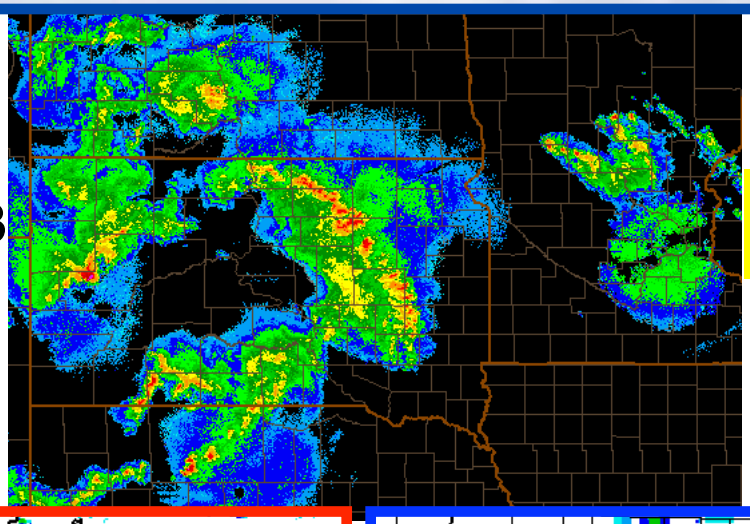
2012 HRRR Initialization from RAP



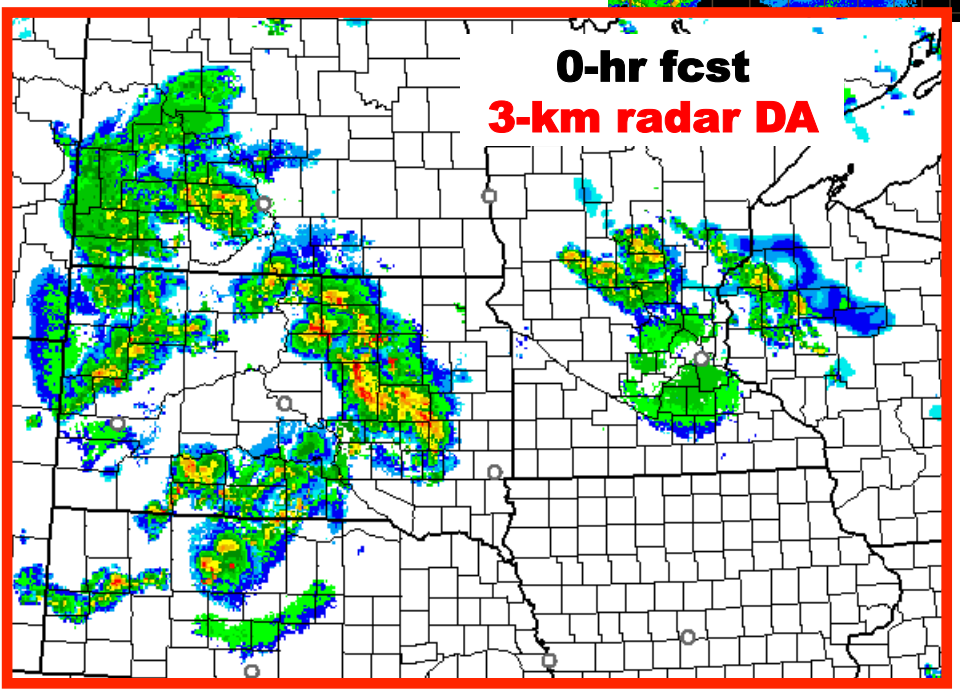

NCEP 2014
HRRR Initialization from RAP
13 km RAP
13z
14z
15z
GFS Ens
Obs
Cld Obs
Refl Obs
GSI Hybrid
GSI cld Anx
Digital Filter
1 hr fcst
18 hr fcst
1 hr fcst
3 km HRRR
3-h Interp
1 hr pre-fcst
GSI 3DVAR
Refl Obs
NCEP Availability
2h fcst ~ +0:55 hr
15h fcst ~ +1:25 hr

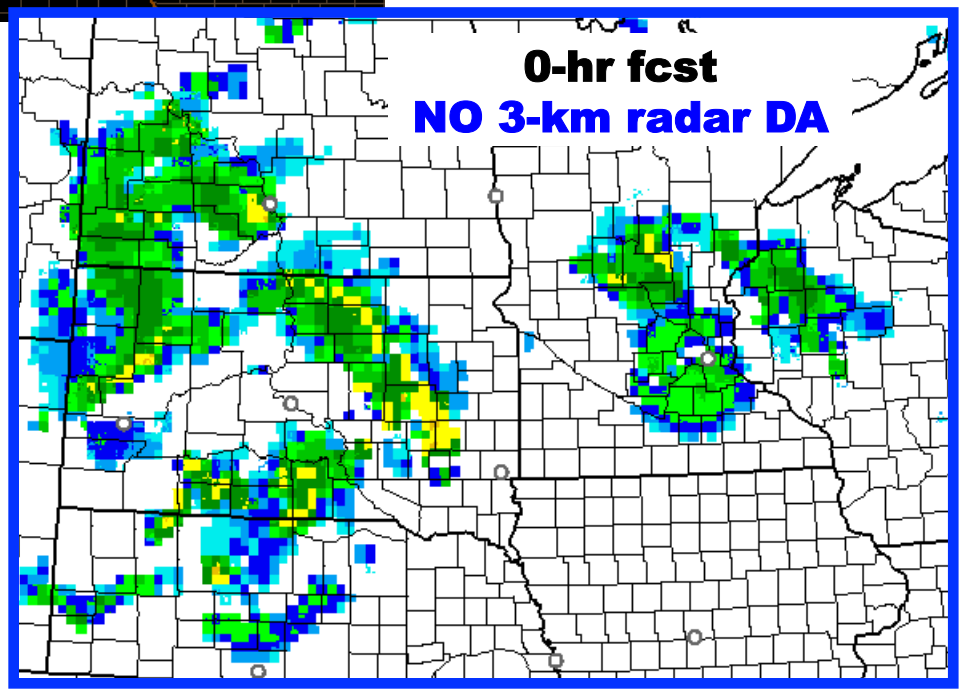
Improved 0-2 hr Convective Fcsts

Radar Obs
05:00z 18 May 2013



05z + 0 min





Improved 0-2 hr Convective Fcsts

Radar Obs
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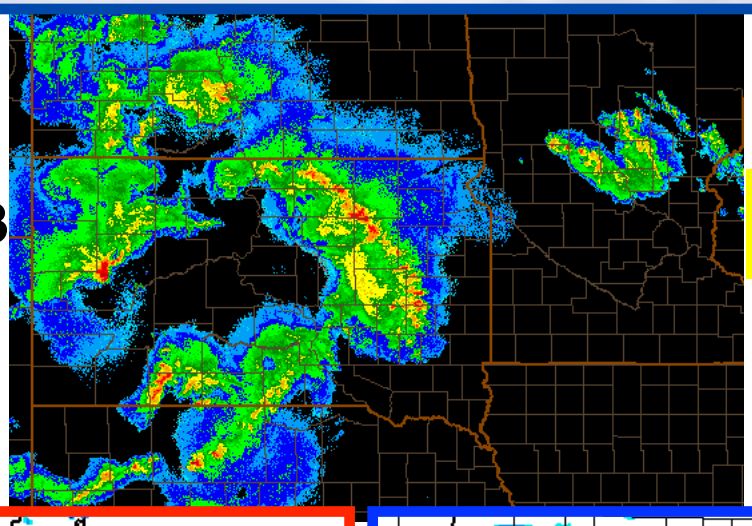
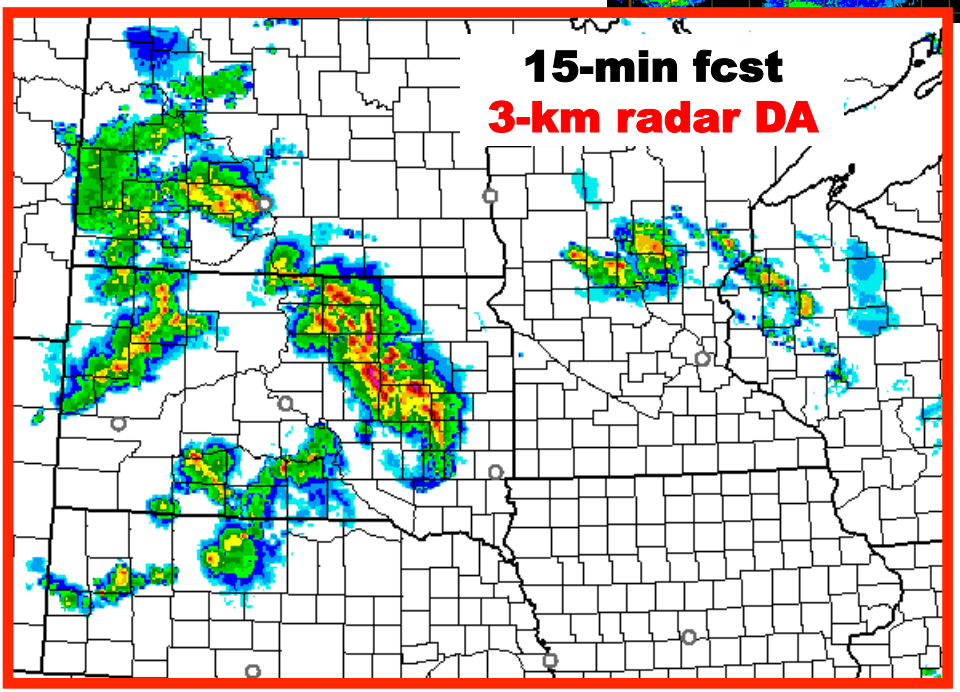
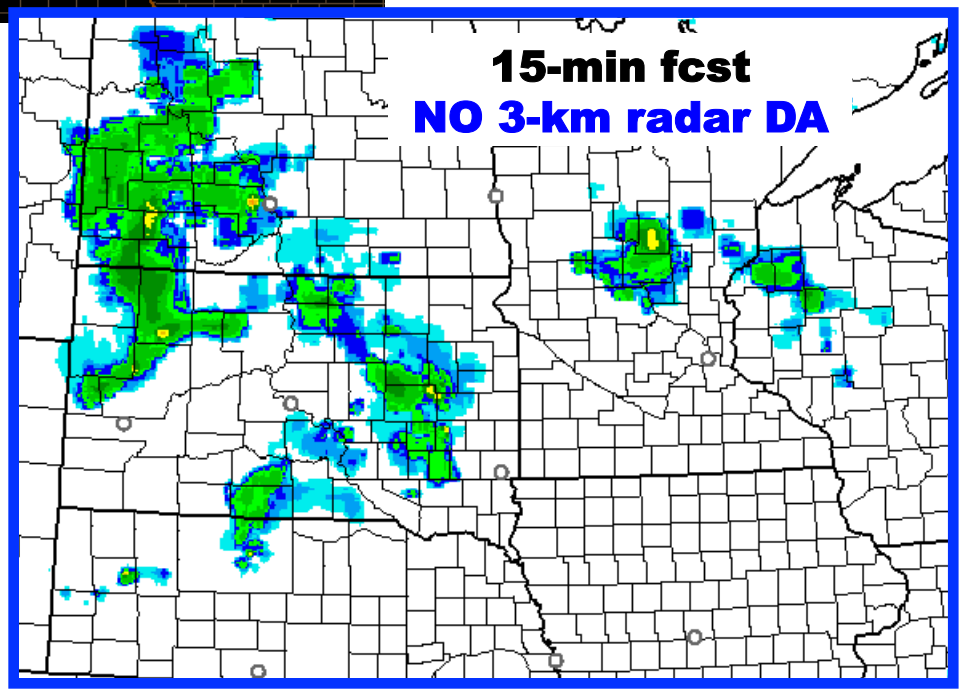


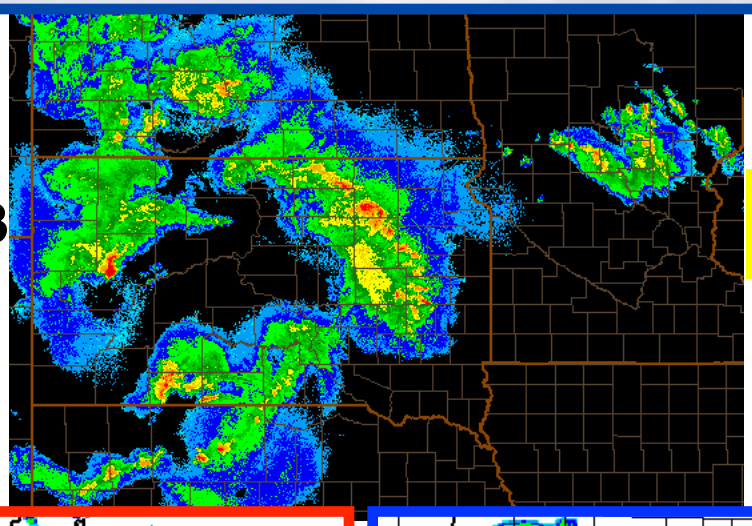
05z + 15 min



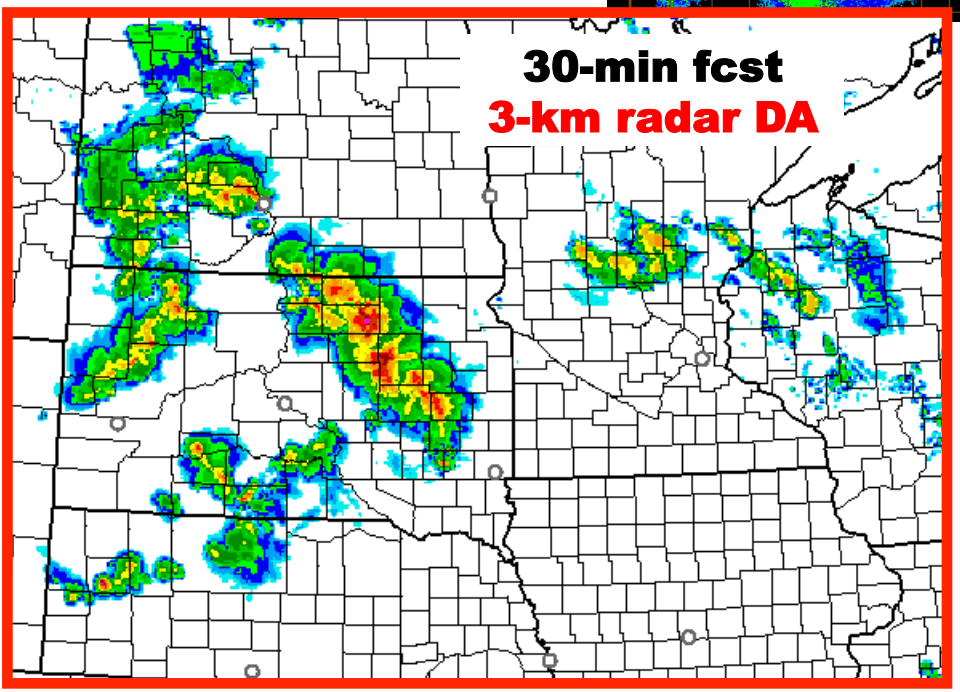


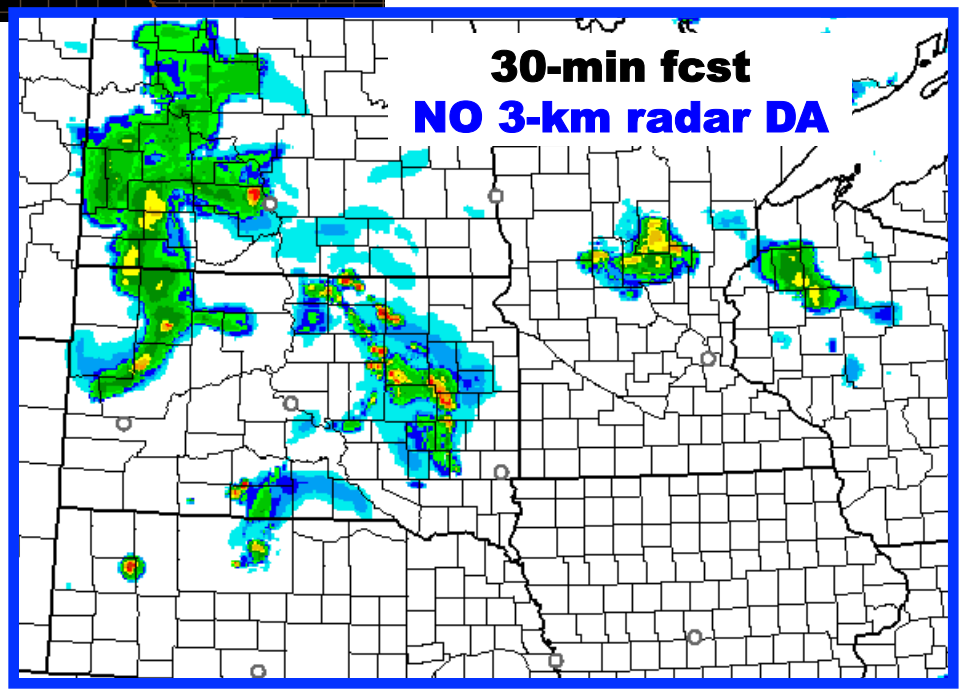
Improved 0-2 hr Convective Fcsts

Radar Obs
05:30z 18 May 2013



05z + 30 min





Improved 0-2 hr Convective Fcsts

Radar Obs
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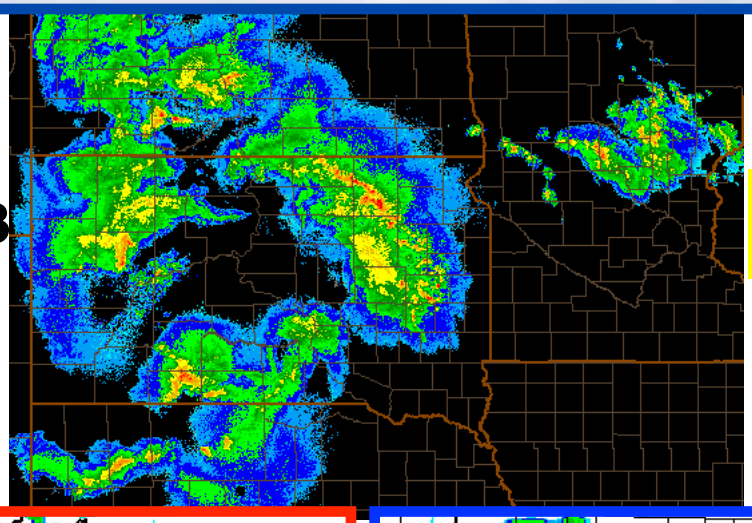
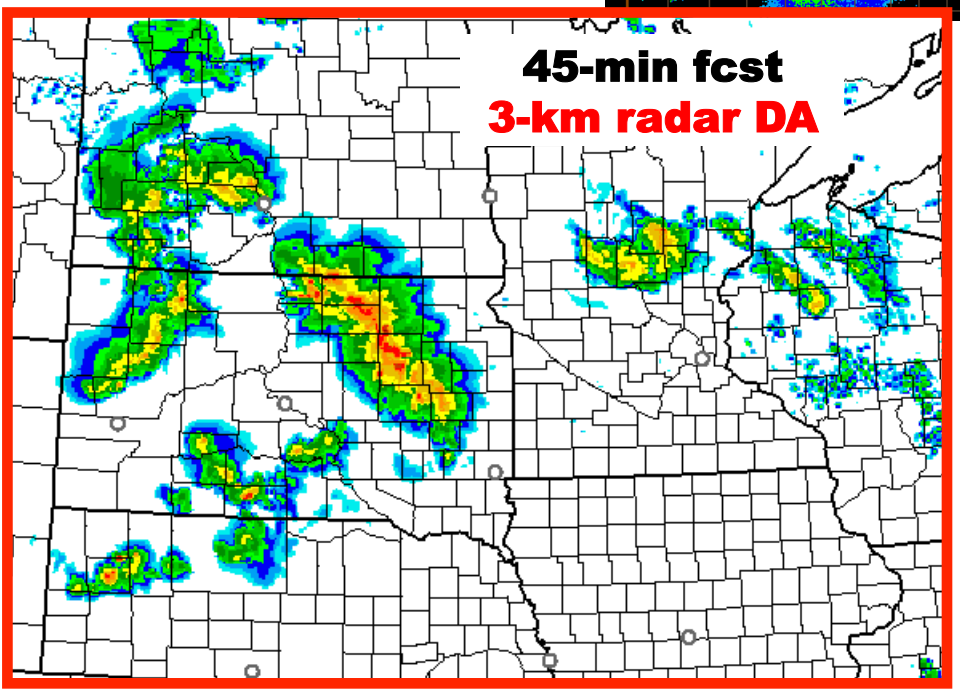
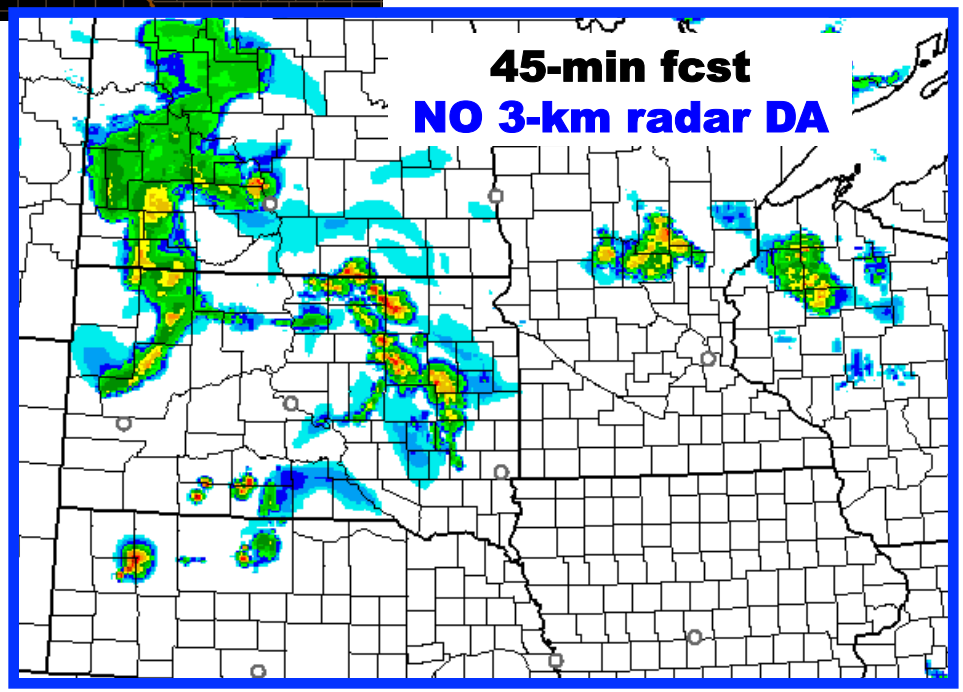


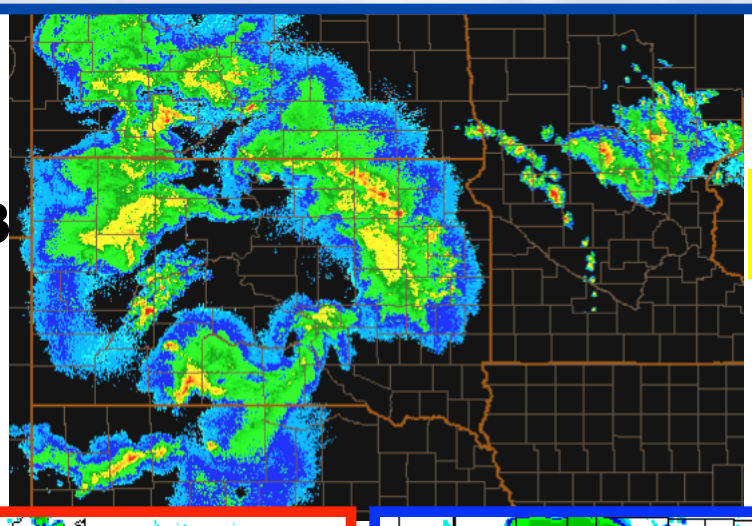
05z + 45 min



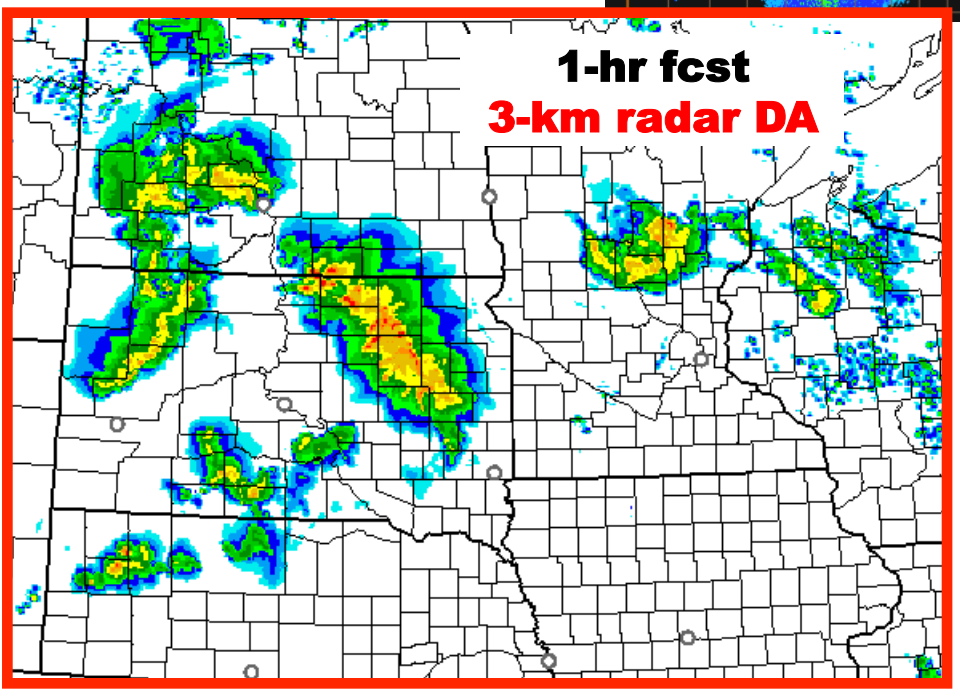


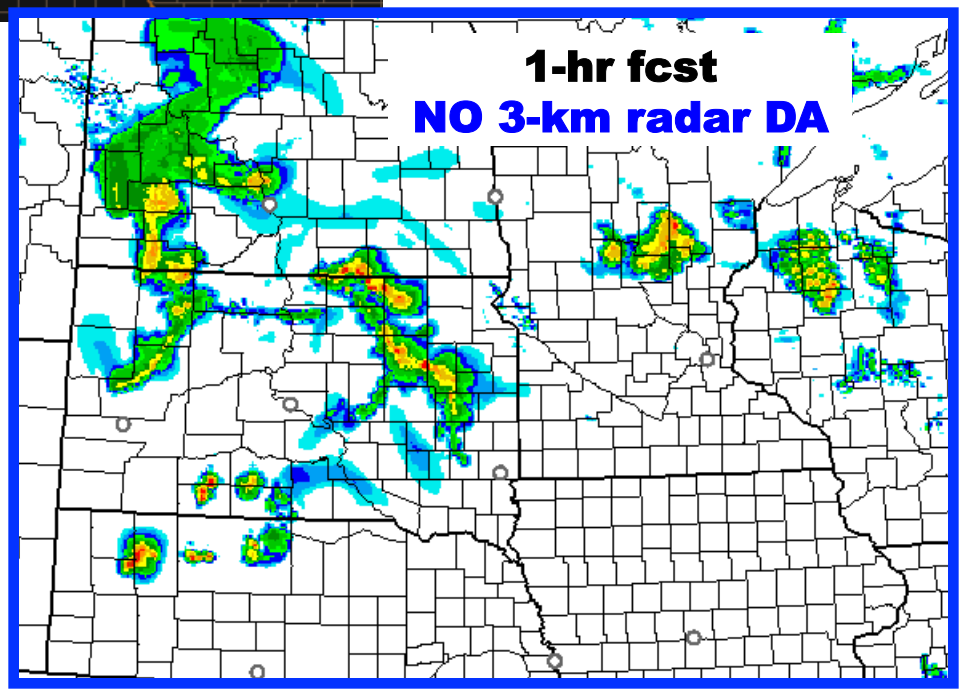
Improved 0-2 hr Convective Fcsts

Radar Obs
06:00z 18 May 2013



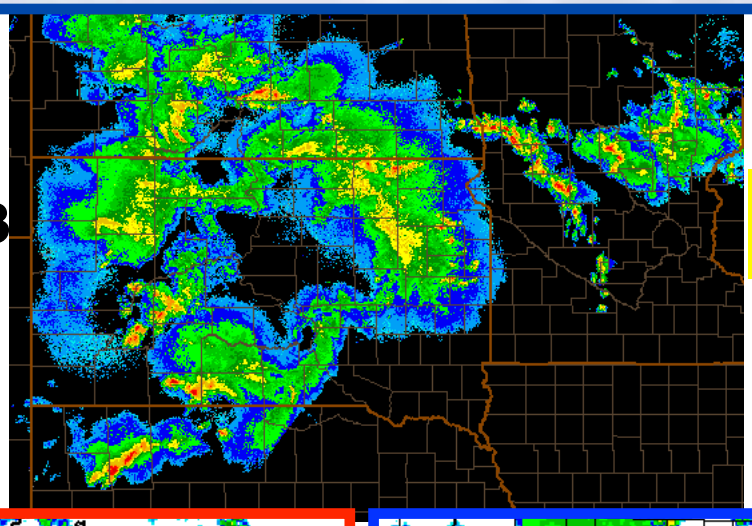
05z + 1 hour



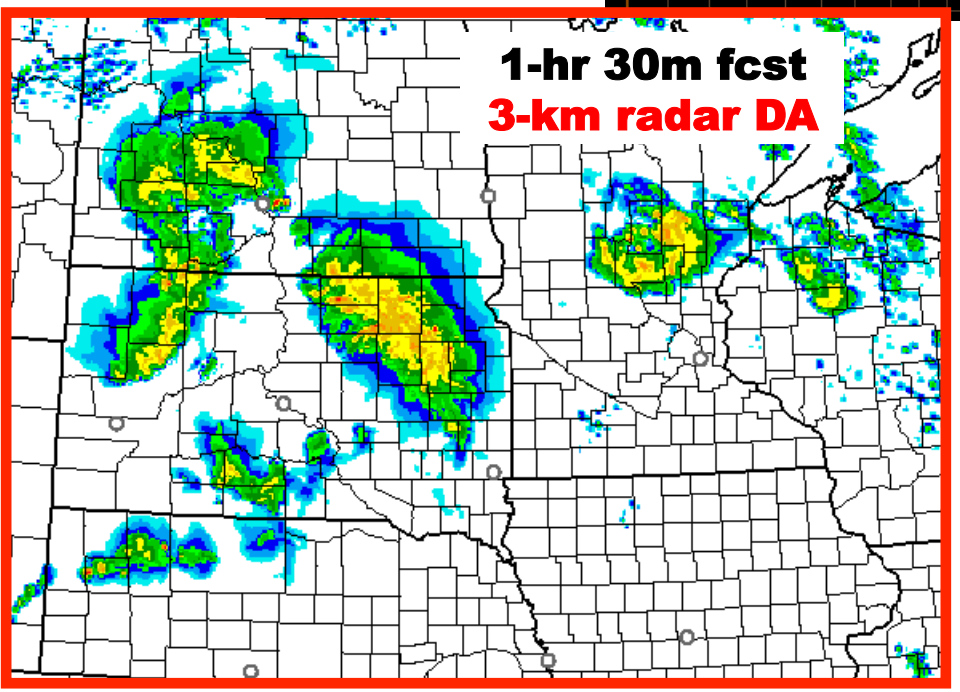


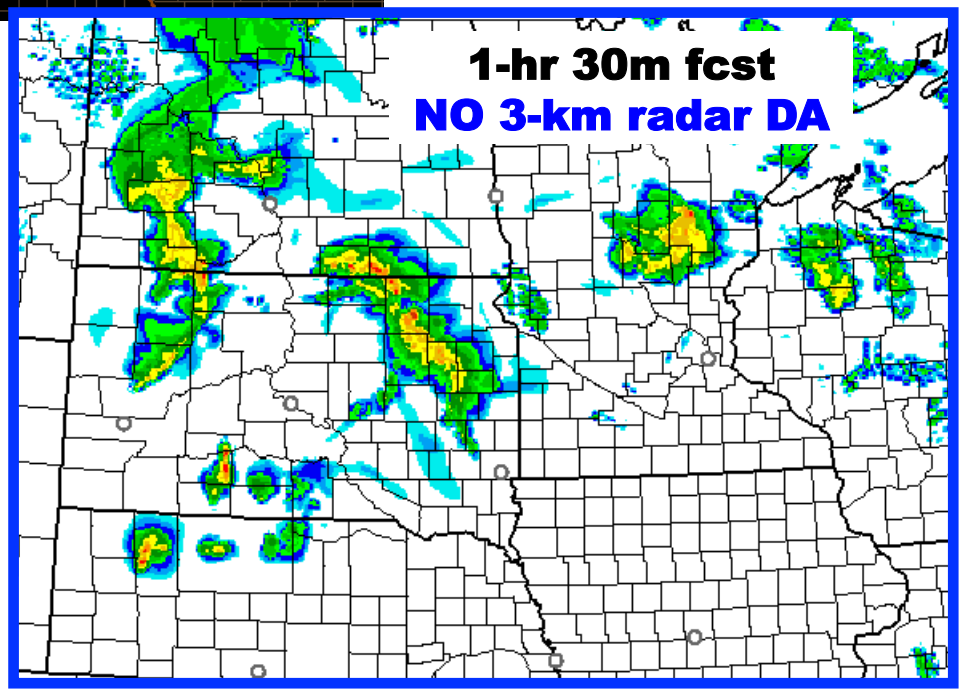
Improved 0-2 hr Convective Fcsts

Radar Obs
06:30z 18 May 2013



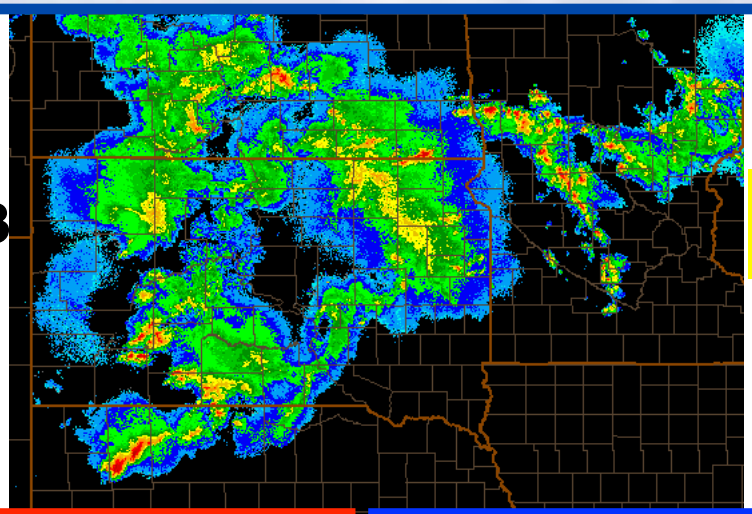
05z + 1:30 mi



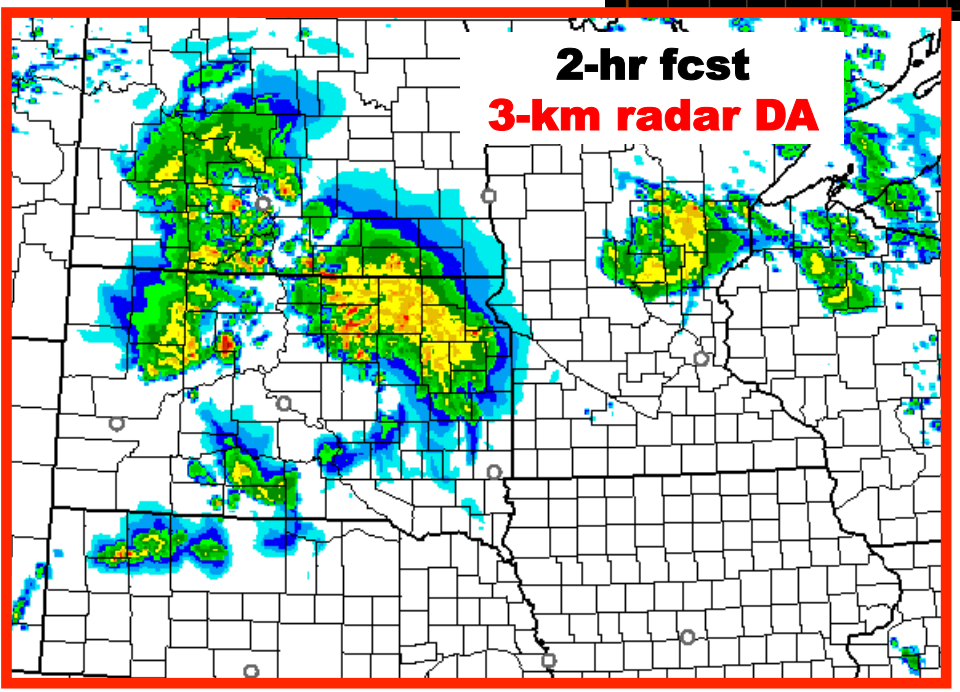


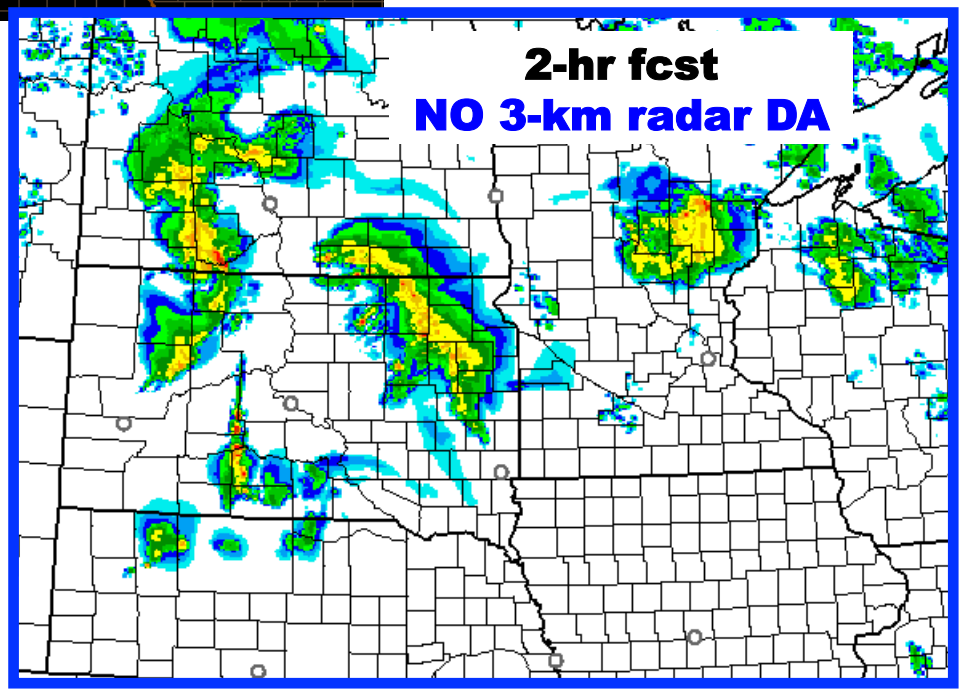
Improved 0-2 hr Convective Fcsts

Radar Obs
07:00z 18 May 2013



05z + 2hr min



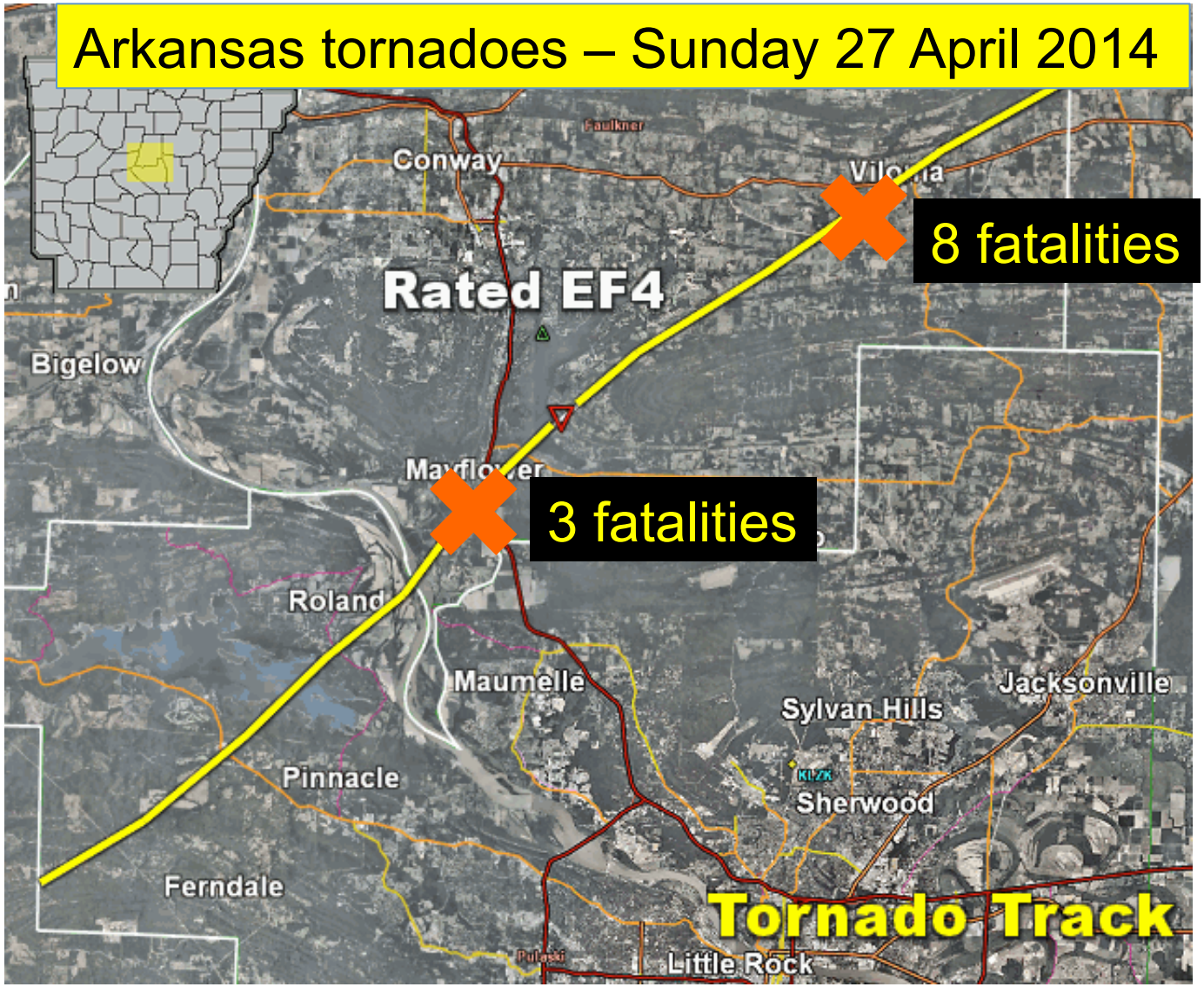


ESRL RAPv3/HRRR-2014 Changes

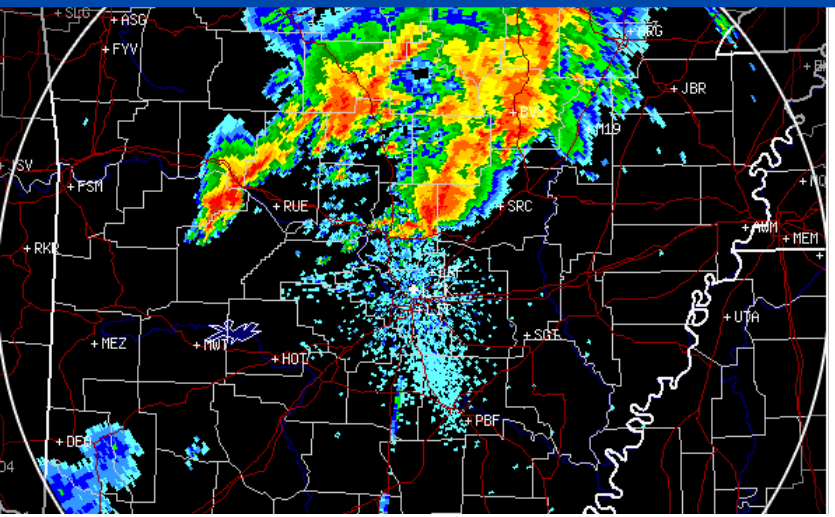
	Model	Data Assimilation
RAP-ESRL (13 km)	WRFv3.5.1+ incl. physics changes Physics changes: Grell-Freitas convective scheme MYNN PBL update - Olson RUC LSM update - Smirnova Thompson microphysics – v3.5.1 RRTMG radiation scheme Shallow cumulus parm w/ rad feed MODIS veg fraction/leaf area index	Merge with GSI trunk Increase ensemble weight in hybrid DA 8m→2m bkg for sfc Td assim Radiance bias correction New sat assimilation (NOAA-19, METOP-B, GOES, direct readout – RARS)
HRRR (3 km)	WRFv3.5.1+ incl. physics changes Physics changes: MYNN PBL update - Olson version RUC LSM update Thompson microphysics – v3.5.1 RRTMG radiation scheme MODIS veg fraction/leaf area index Numerics changes: 6th order diffusion in flat terrain Smooth terrain @lat BC	3-km hybrid ens/var assimilation (var-only in 2013) 8m→2m bkg for sfc Td assim Radar LH – 4x less intense than 2013 (2x less intense than RAP but more local)

Changes with high/medium importance *overall* forecast skill

Arkansas Tornadoes Background

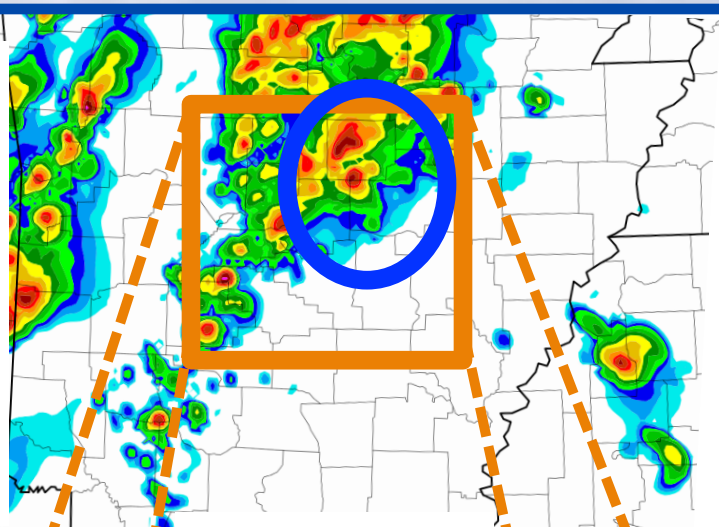


HRRR Supercell Forecast Arkansas

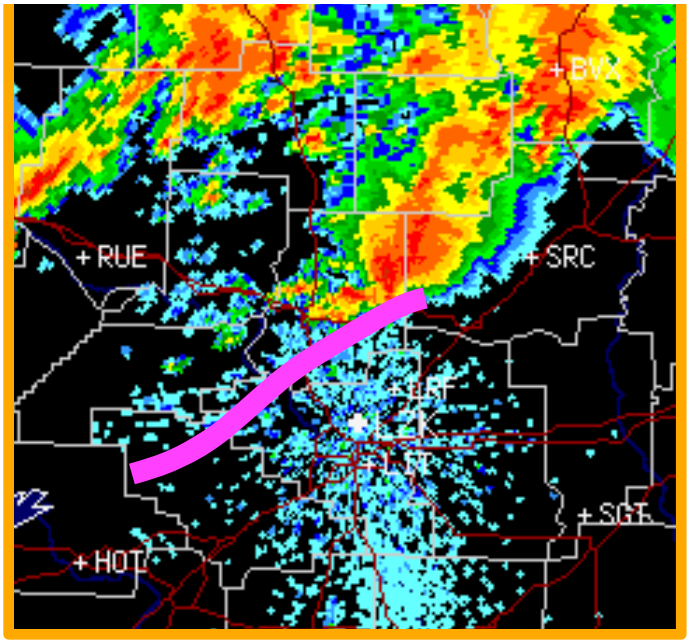


Observed radar

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



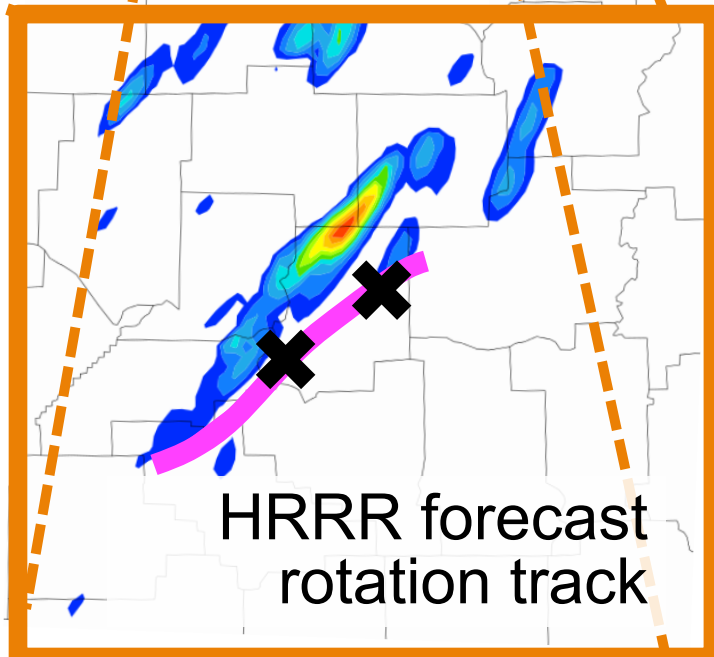
HRRR



Tornadic thunderstorm

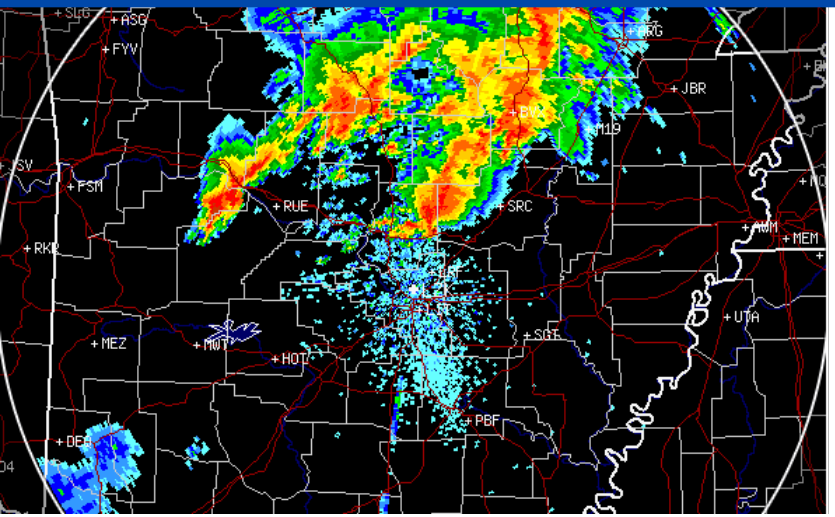
Actual tornado path

Fatalities



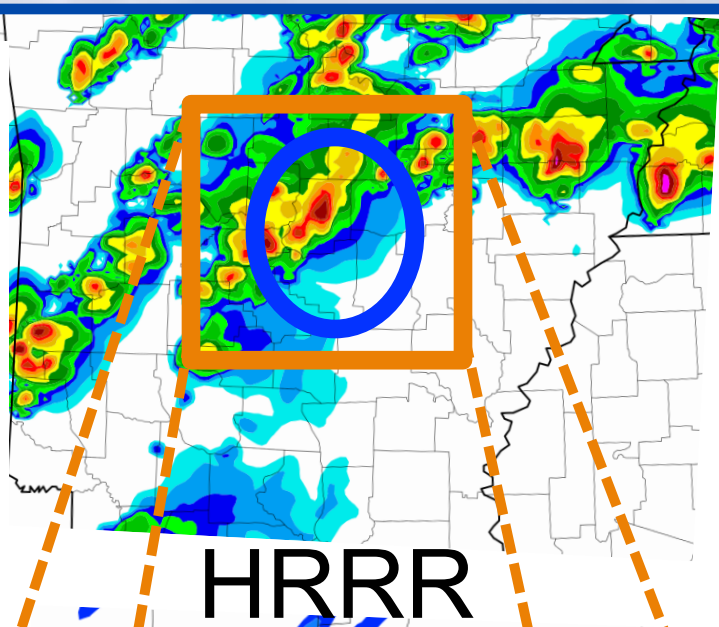
HRRR forecast rotation track

HRRR Supercell Forecast Arkansas

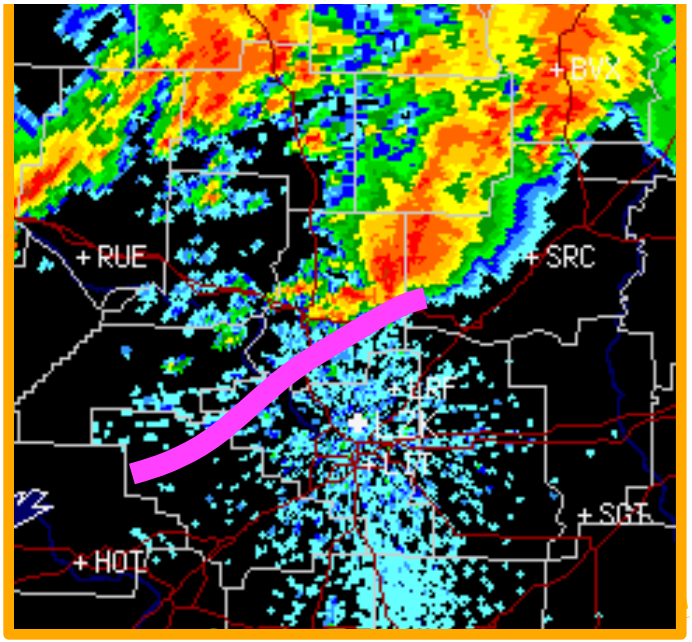


Observed radar

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



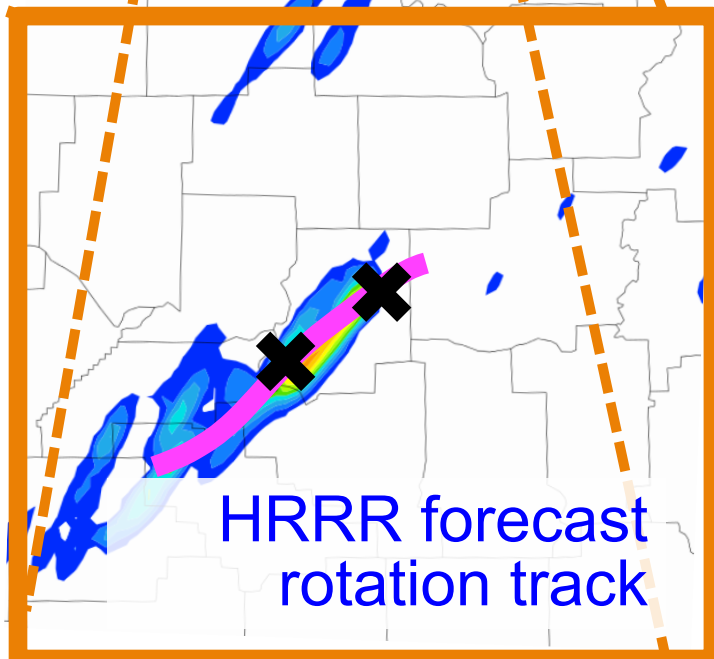
HRRR



Tornadic thunderstorm

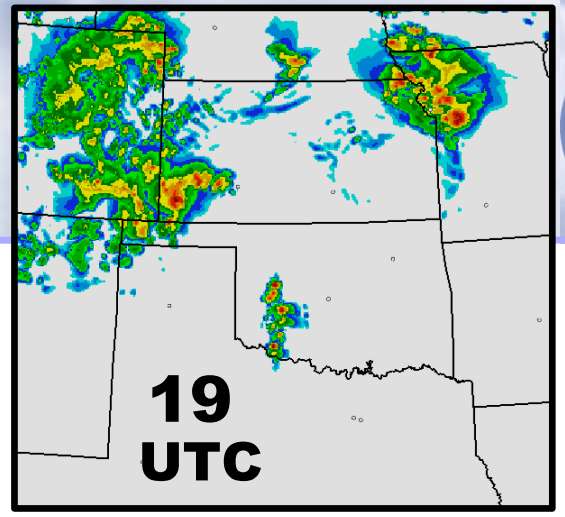
Actual tornado path

Fatalities



HRRR forecast rotation track

HRRR ensembles (TL or trad): Assess likelihood of hazards



Real-time

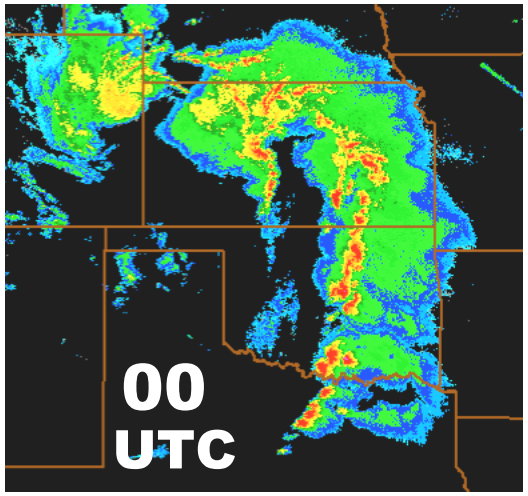
Member 1

Member 2

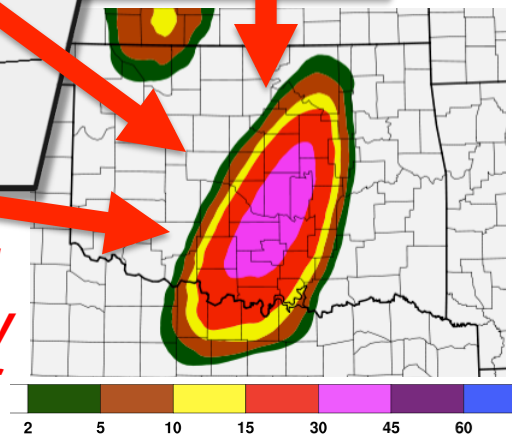
Member 3

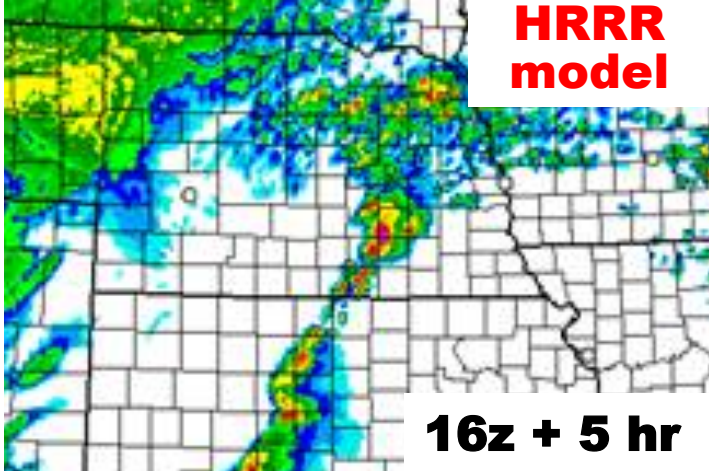
00
UTC

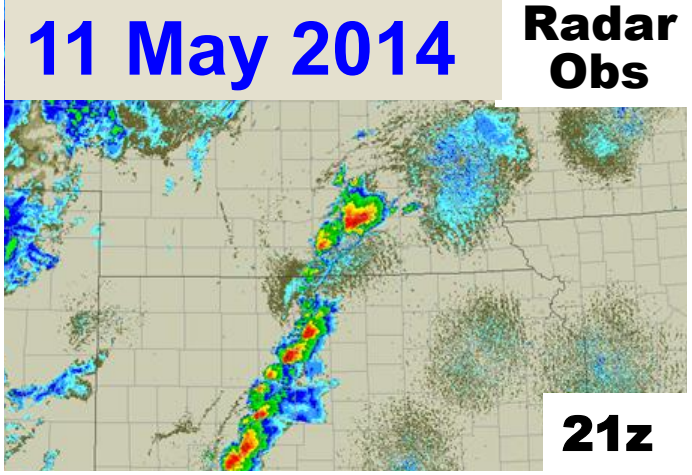
Observations

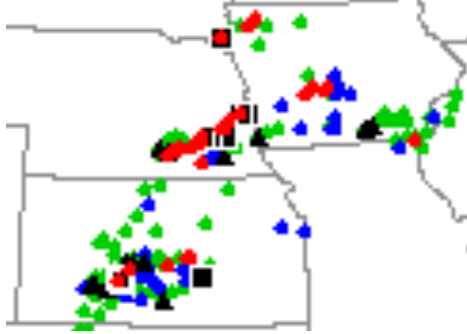


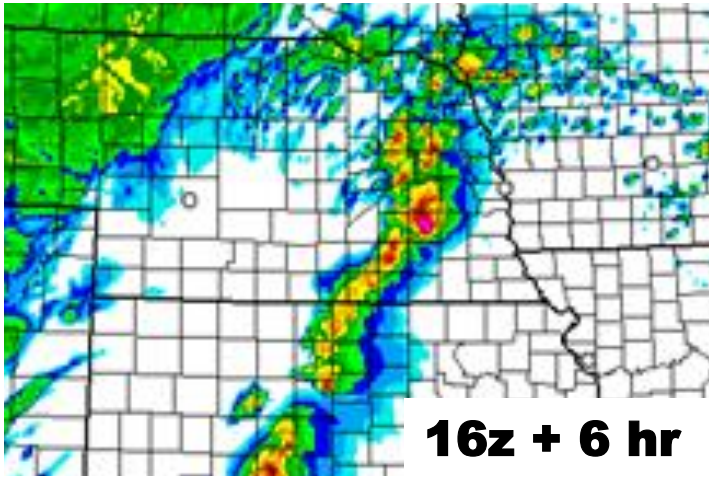
Supercell probability past hour

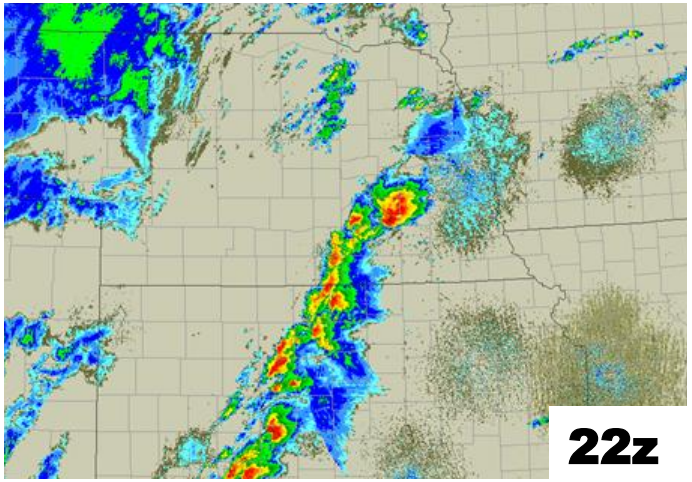


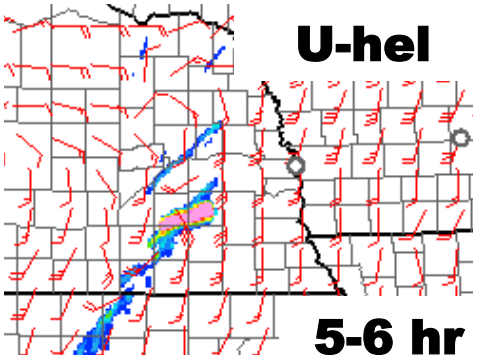

HRRR
model
16z + 5 hr

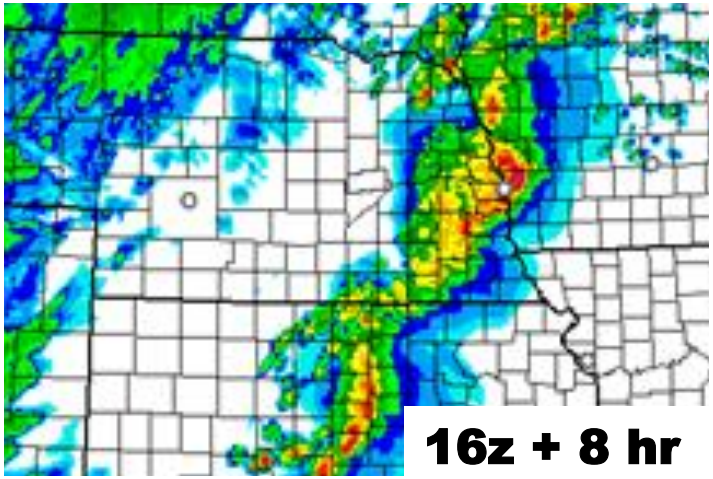

11 May 2014
Radar
Obs
21z

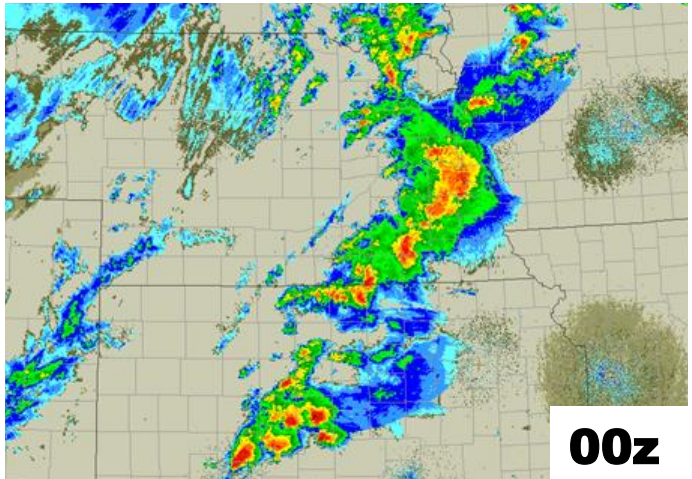


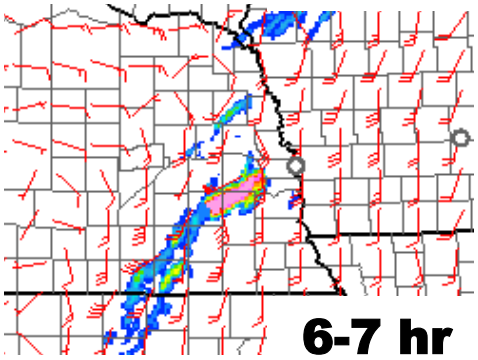

16z + 6 hr

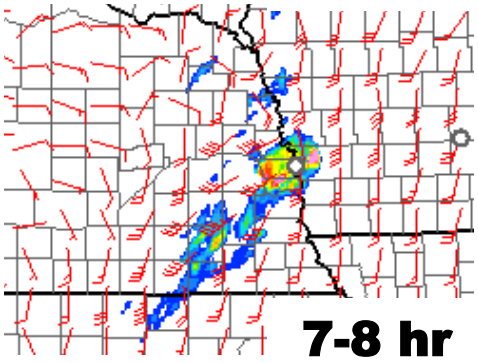

22z


U-hel
5-6 hr


16z + 8 hr


00z


6-7 hr

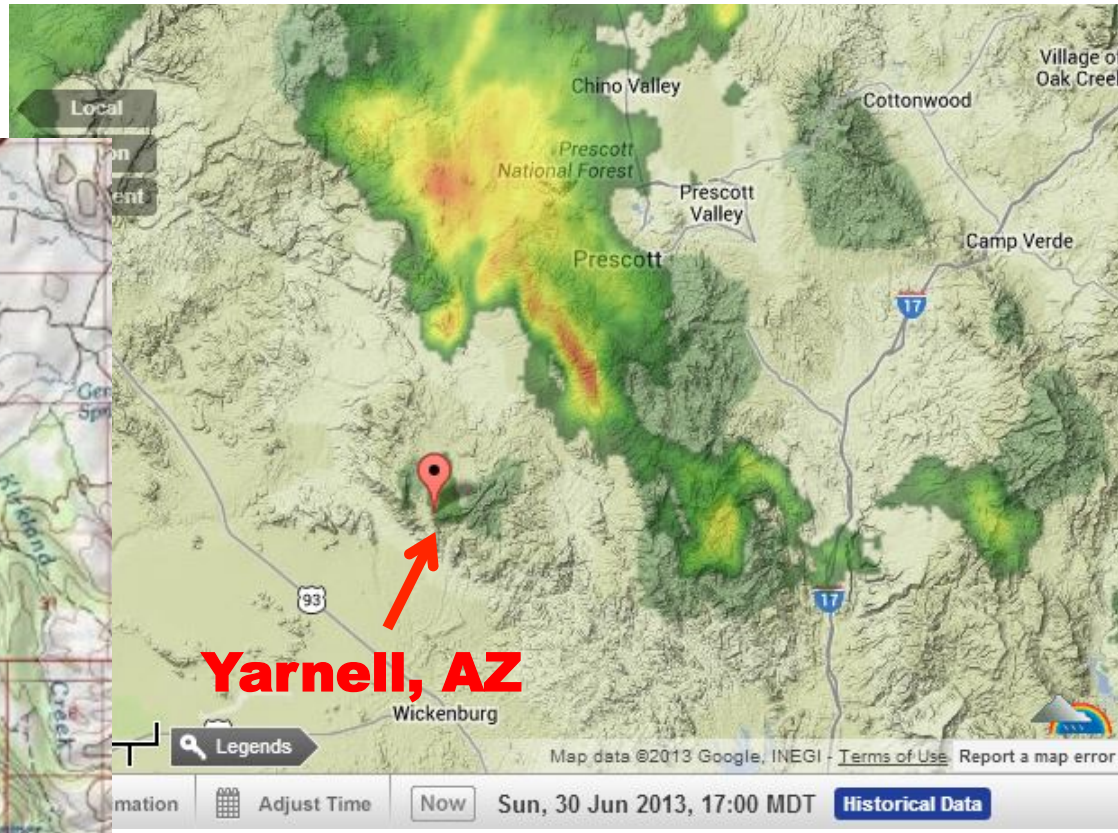

7-8 hr

Yarnell, AZ Wildfire Background

Wildfire Driven by thunderstorm outflow , 30 June 2013

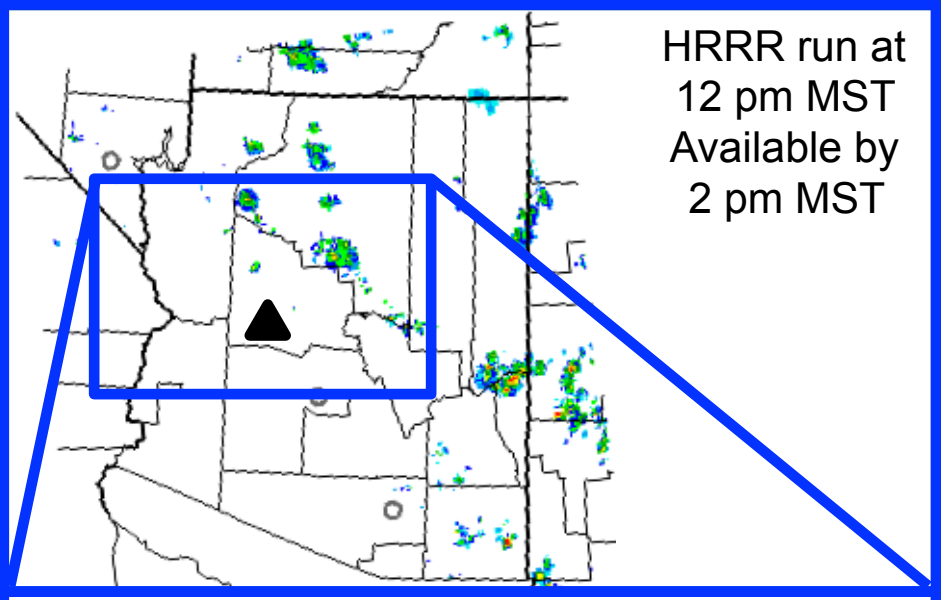
Radar Reflectivity
4 PM MST June 30, 2013

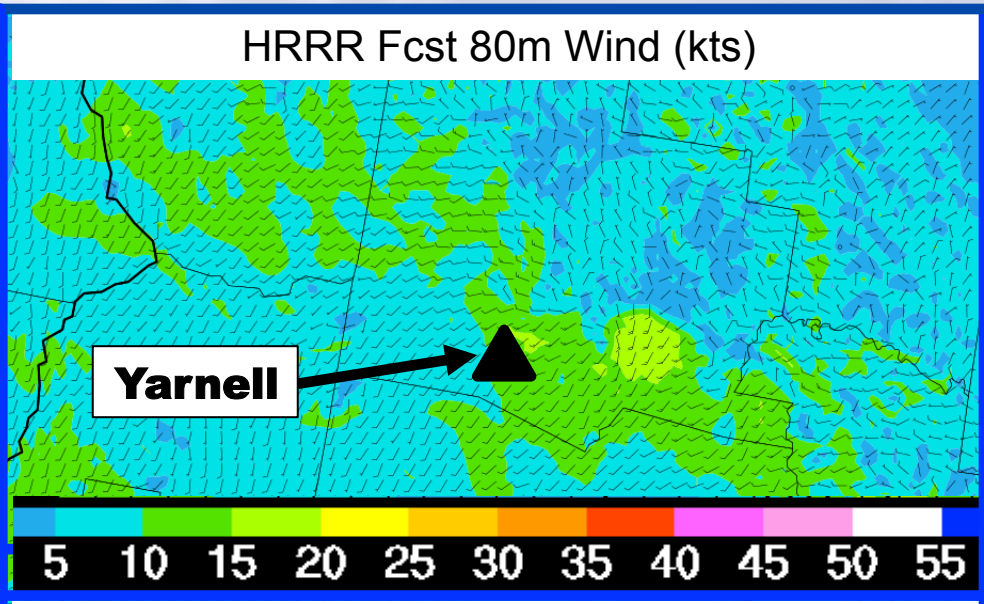
July 2, 2013 Yarnell, AZ
Wildfire Perimeter

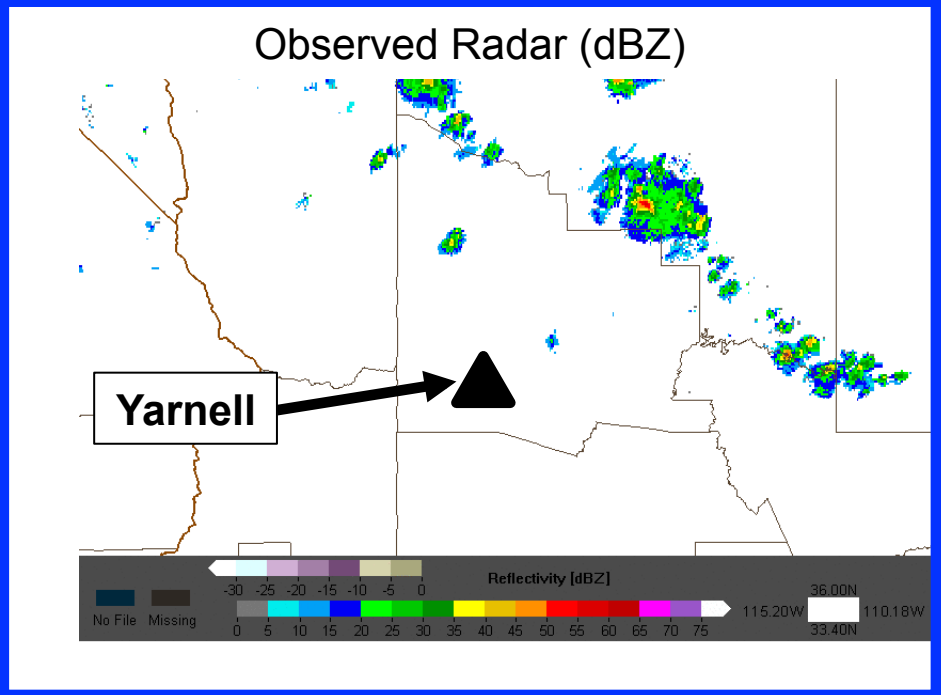


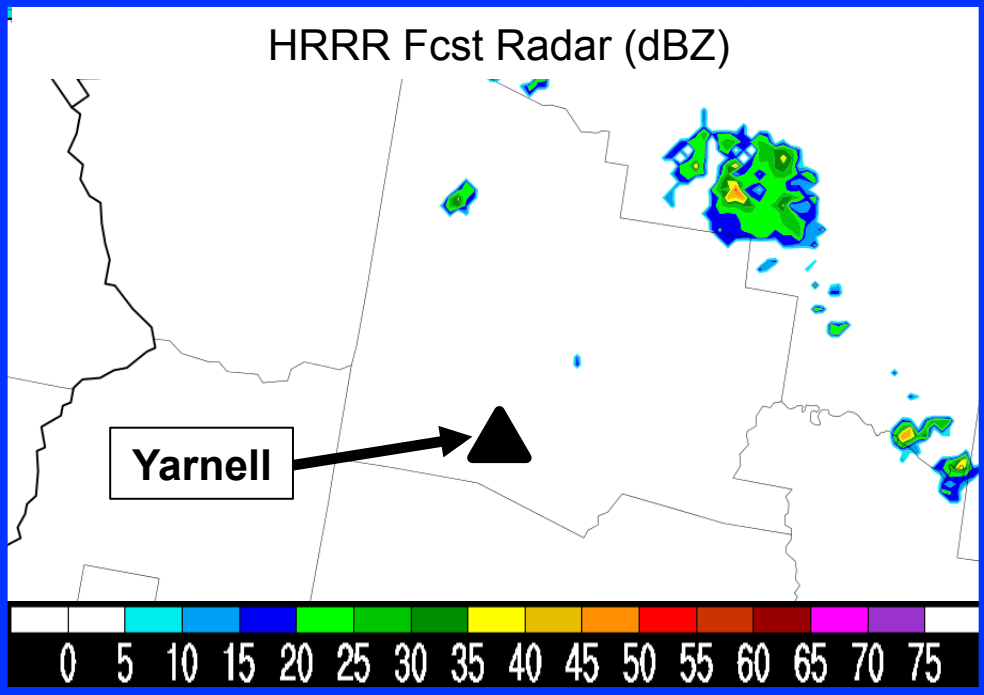
Last contact with fire crew
~ 4:30 PM MST
(2330 UTC) Sun. 30 June, 2013

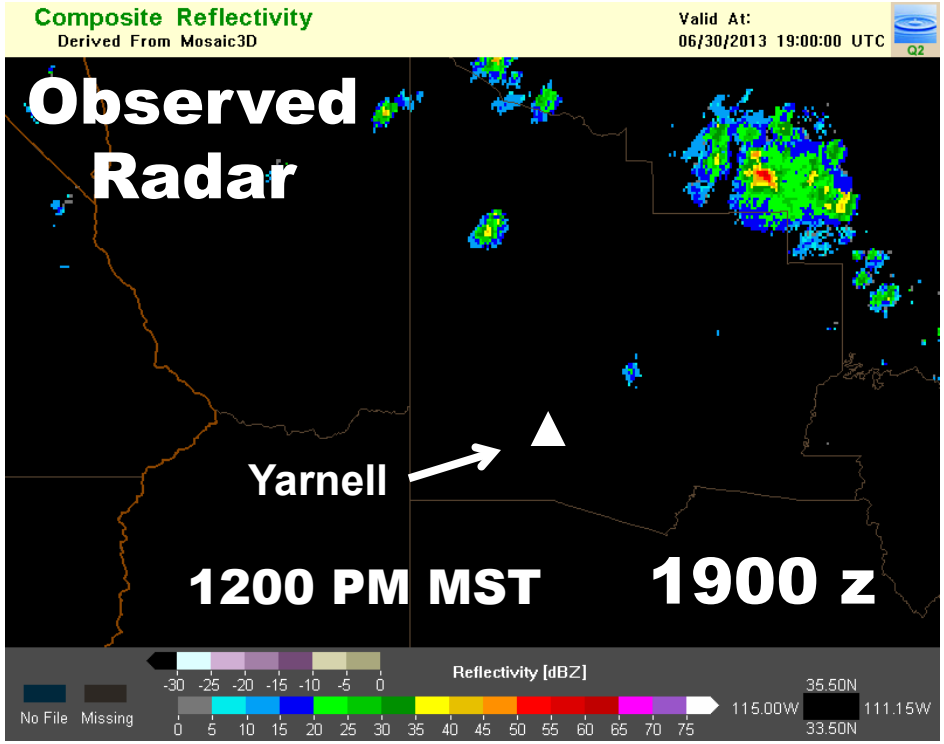
HRRR Wind Forecast Yarnell, AZ





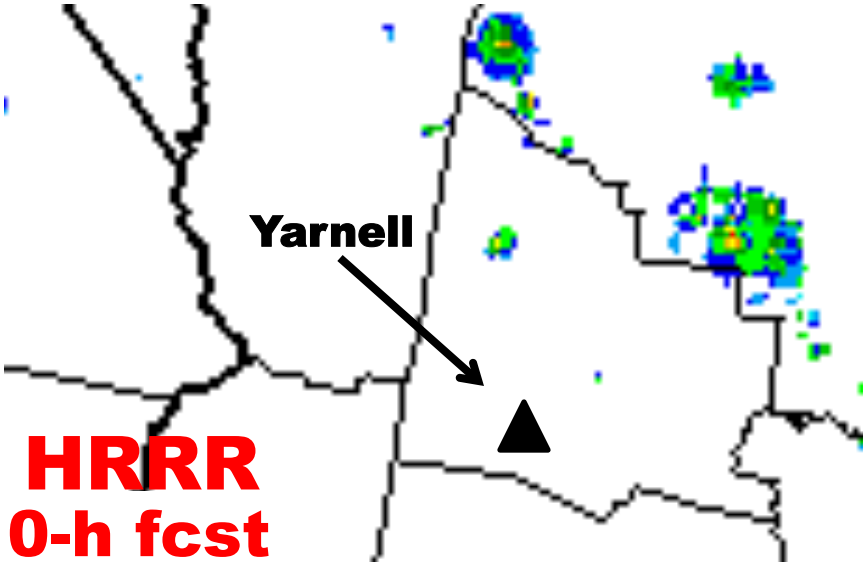




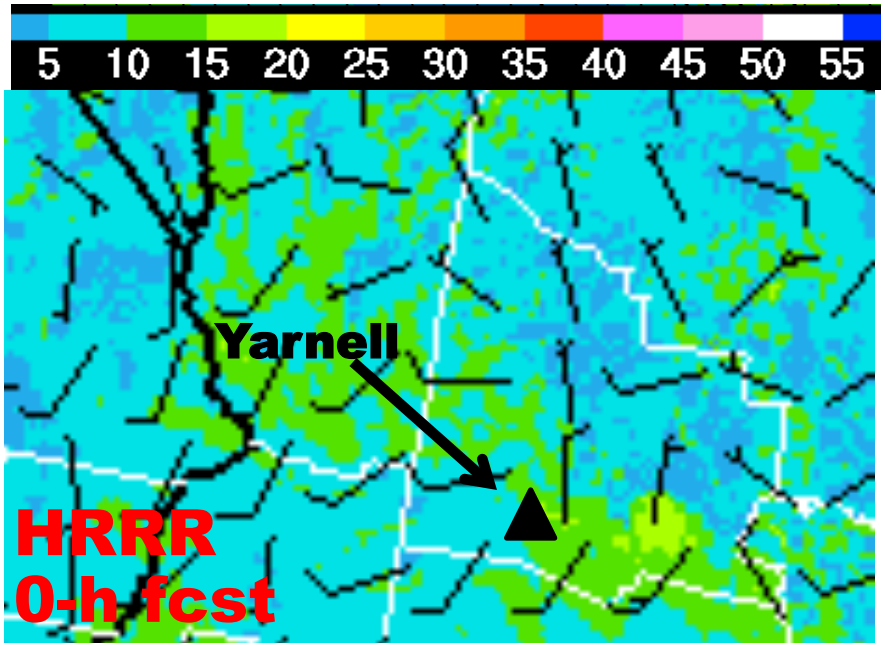


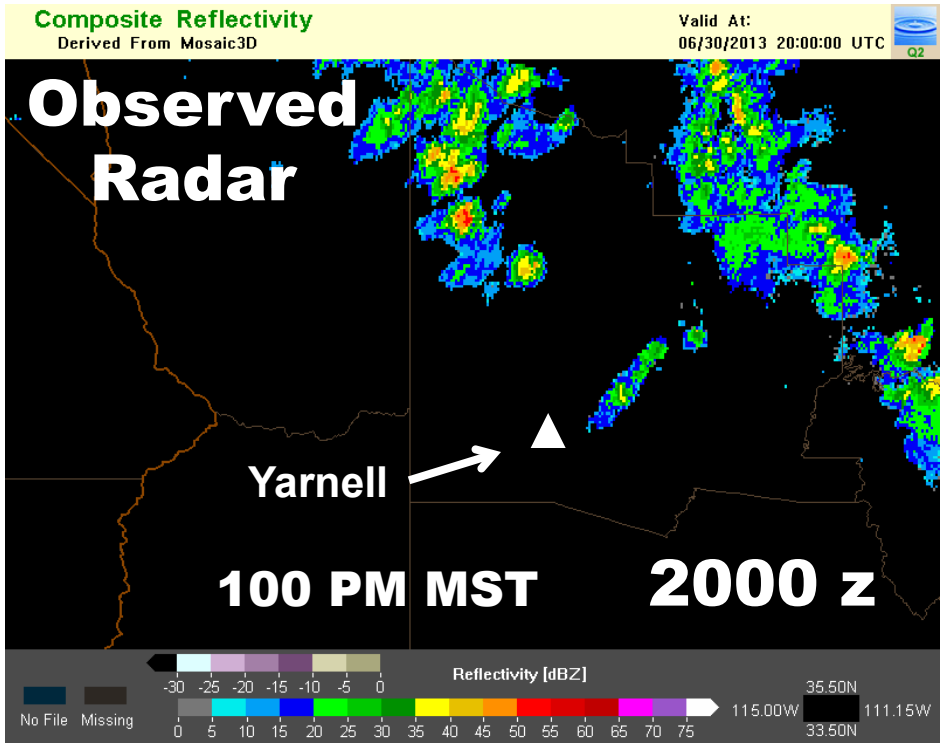
HRRR forecast from 1900 UTC (noon MST) model run, which is available by 2 PM MST

HRRR forecast radar reflectivity



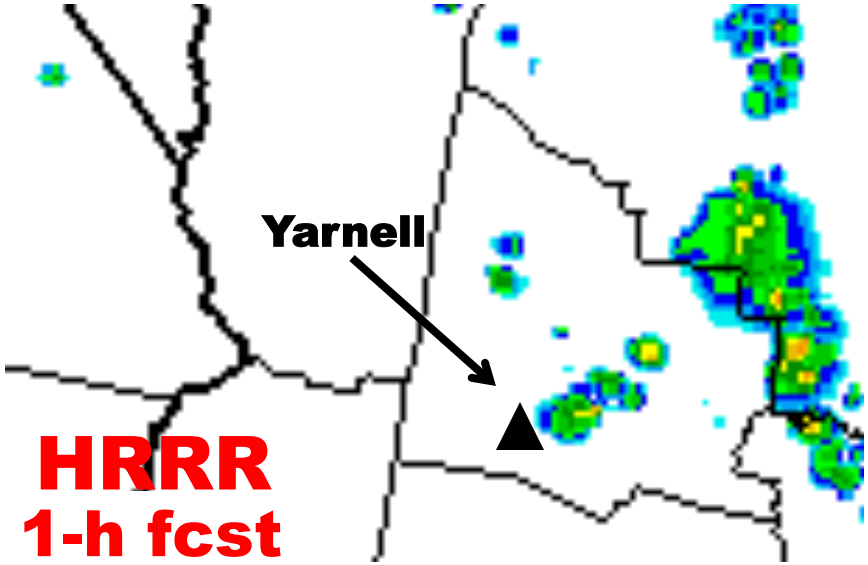
0-h HRRR forecast 80 m AGL wind speed (kts) and direction (barbs)



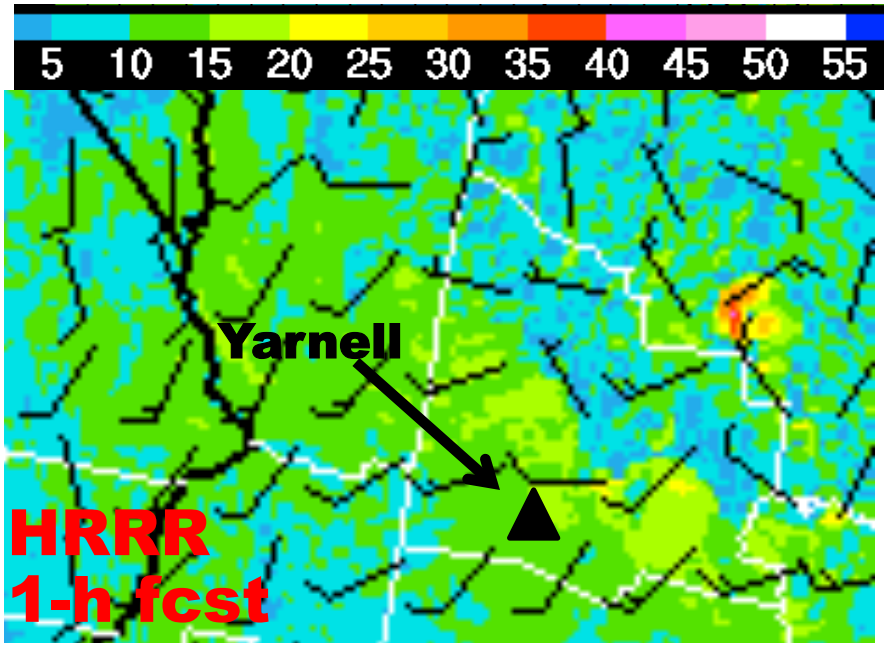


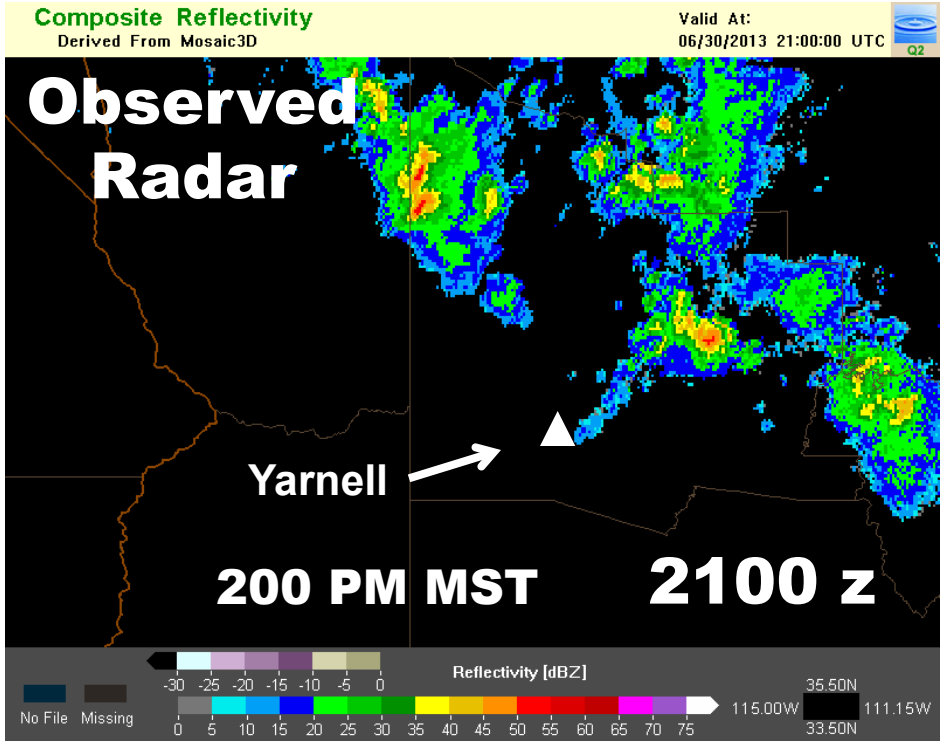
HRRR forecast from 1900 UTC (noon MST) model run, which is available by 2 PM MST

HRRR forecast radar reflectivity



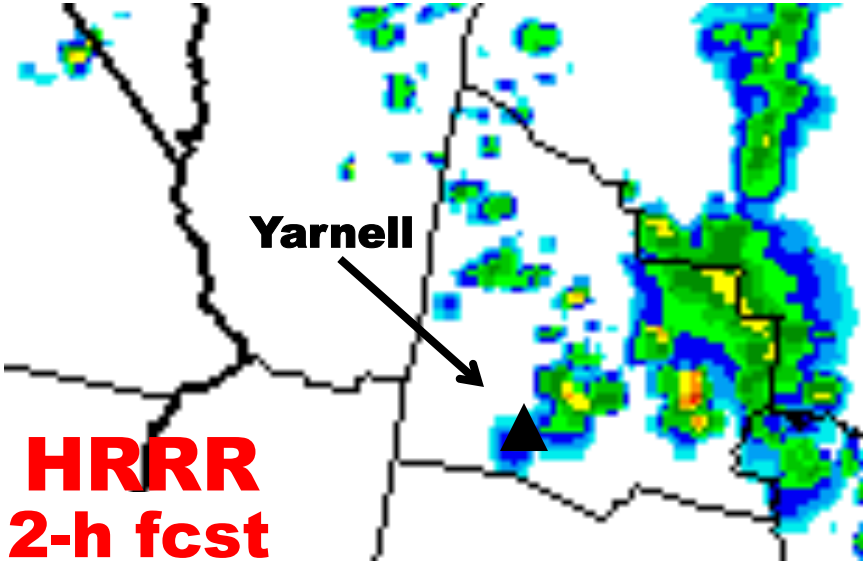
1-h HRRR forecast for 1 PM 80 m AGL wind speed (kts) and direction (barbs)



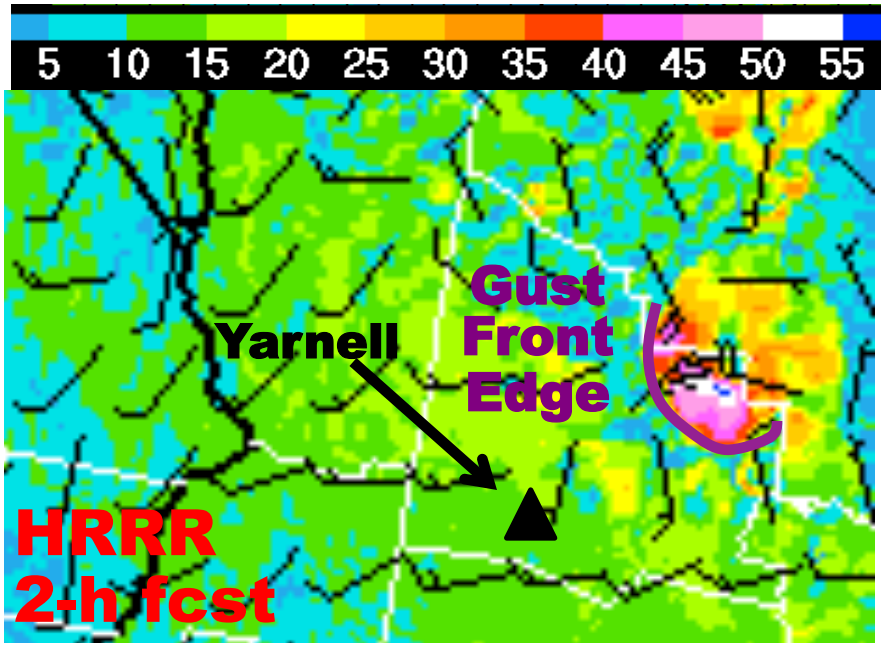


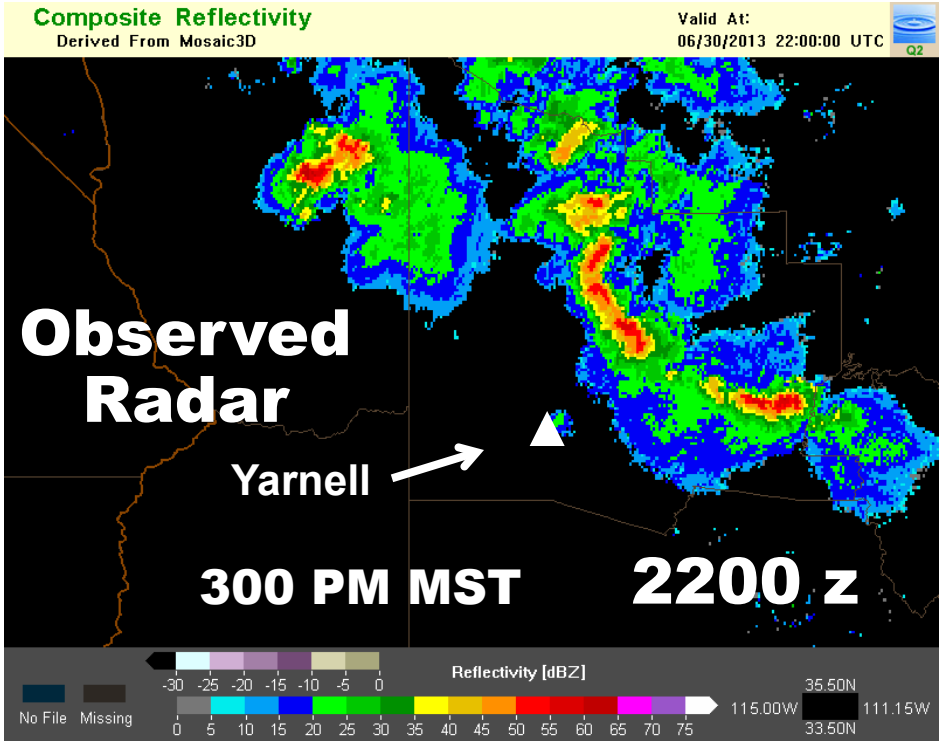
HRRR forecast from 1900 UTC (noon MST) model run, which is available by 2 PM MST

HRRR forecast radar reflectivity



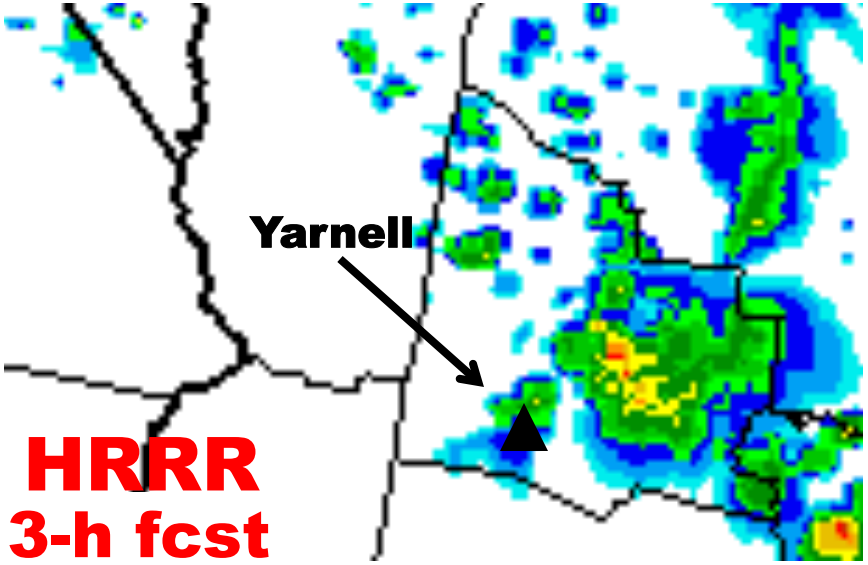
2-h HRRR forecast for 2 PM 80 m AGL wind speed (kts) and direction (barbs)



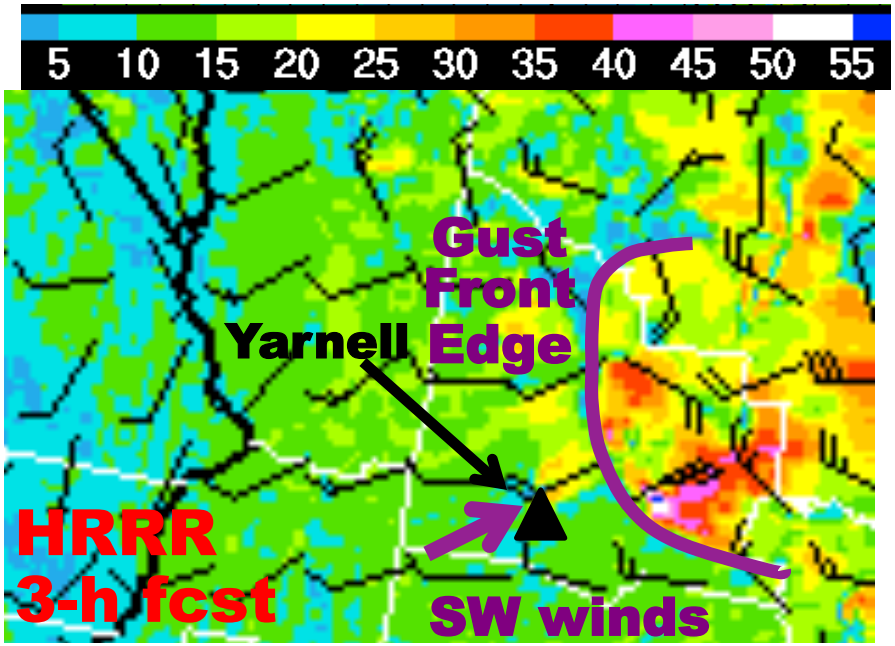


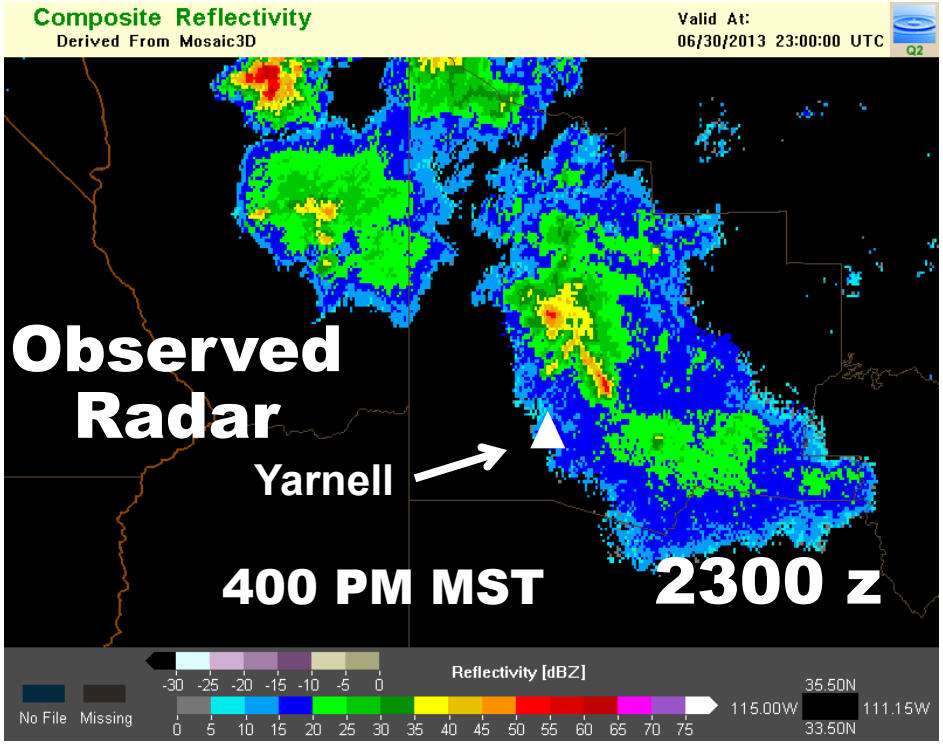
HRRR forecast from 1900 UTC (noon MST) model run, which is available by 2 PM MST

HRRR forecast radar reflectivity



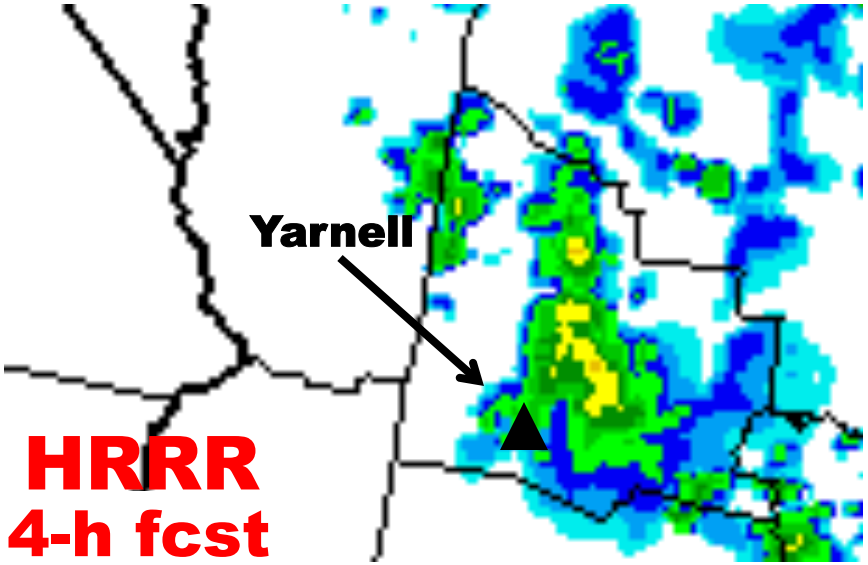
3-h HRRR forecast for 3 PM 80 m AGL wind speed (kts) and direction (barbs)



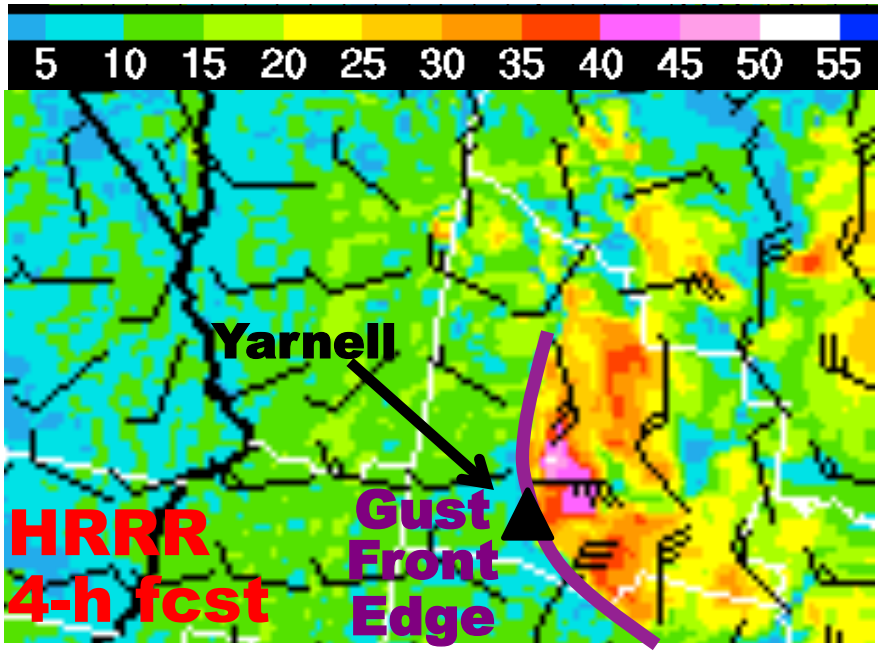


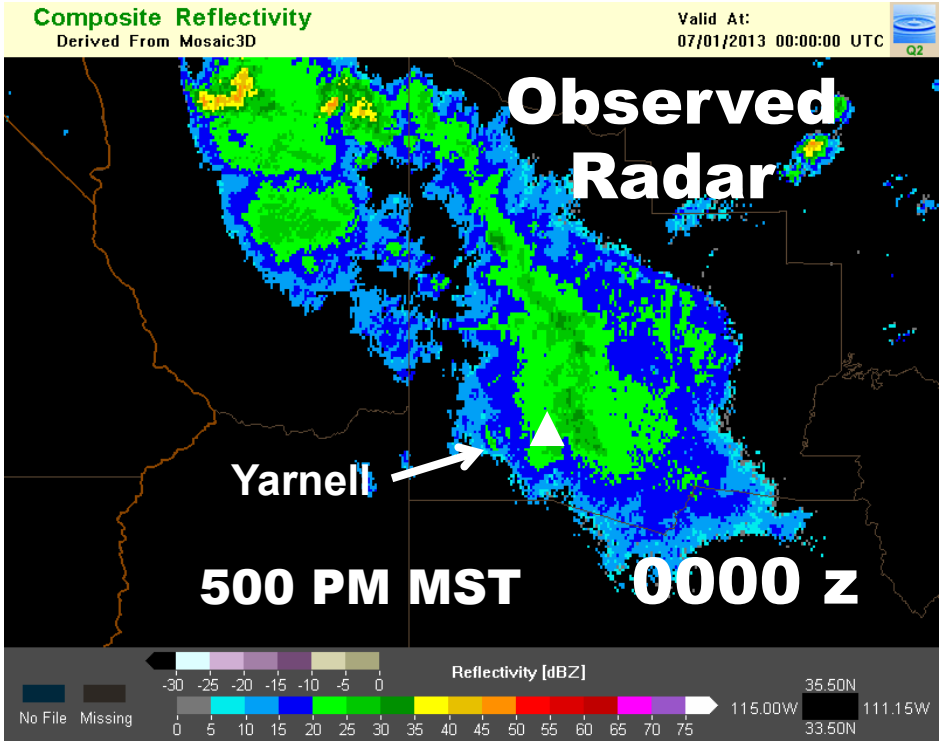
HRRR forecast from 1900 UTC (noon MST) model run, which is available by 2 PM MST

HRRR forecast radar reflectivity



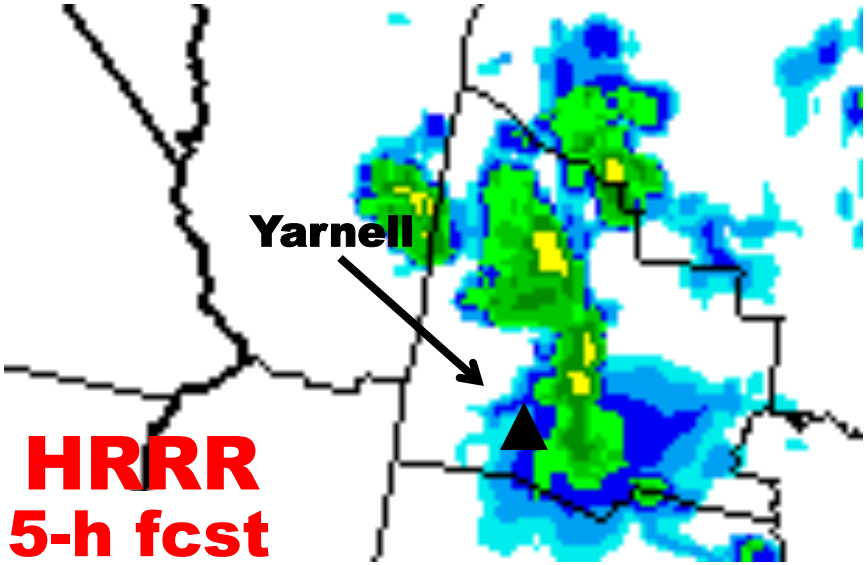
4-h HRRR forecast for 4 PM 80 m AGL wind speed (kts) and direction (barbs)



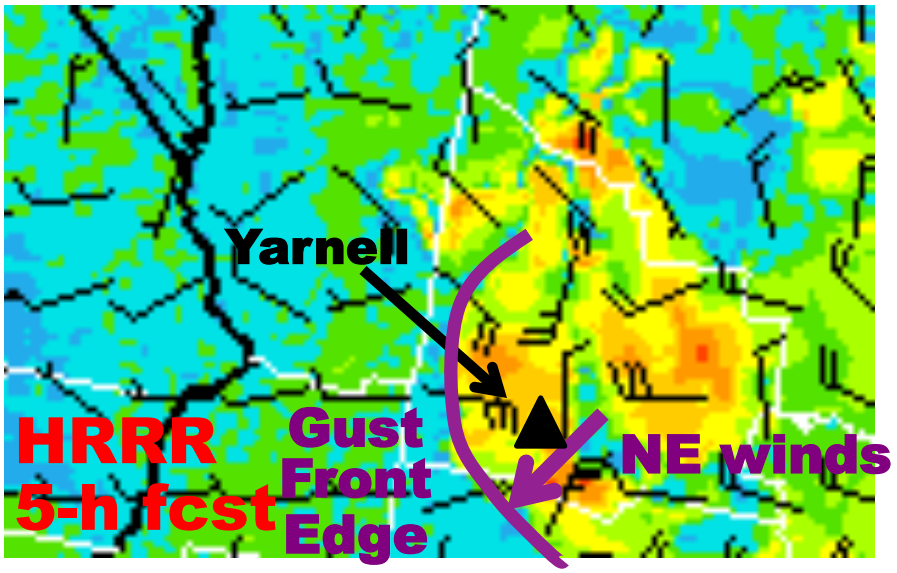


HRRR forecast from 1900 UTC (noon MST) model run, which is available by 2 PM MST

HRRR forecast radar reflectivity



5-h HRRR forecast for 5 PM 80 m AGL wind speed (kts) and direction (barbs)



RAP/HRRR Implementation Map

ESRL – experimental version	NWS-NCEP - operational
• RAPv1 – used in 2011 – Initialized 2011 HRRR	→ • 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**

  → Implement early 2015

- **HRRRv2 – GSD testing in 2014**
  - **Initialized by 2014 RAP (v3)**
  - **Improved radar assimilation, hybrid assimilation, PBL/cloud physics**

  → Implement early 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

HRRR Evolution

HPC	2013	Sept 2014	2015
NCEP WCOSS		HRRRv1 Operational Implementation	HRRRv2 Operational Implementation April 2015?
NOAA JET	HRRR Primary	HRRR-2014 Backup/ Development	HRRR Backup/ Development
NOAA ZEUS	HRRR Backup/ Development	HRRR Limited-Area Ensemble Retros	HRRR Limited-Area Ensemble Testing
NREL PEREGRINE		36-48 hr Extended Runs 1-2x per day	36-48 hr Extended Runs 2-4x per day? Model update

RAP and HRRR Update Summary

- **RAP/HRRR Model Updates**
  - Enhanced RUC LSM, ongoing improvements
  - MYNN PBL scheme, ongoing enhancements
  - Work toward scale-aware physics
- **RAP Data Assimilation Updates**
  - Transitioned to hybrid EnKF-3DVar
  - Improved satellite radiance assimilation
  - Improved hydrometeor assimilation
- **HRRR Data Assimilation Updates**
  - 3-km pre-forecast cycle with radar DA (reduced spin-up)
  - 3-km hybrid assimilation for conventional observations
  - 3-km non-variational hydrometeor analysis
  - Significantly reduced model latency