16th Annual WRF Users' Workshop
16 June 2015

The 2015 Operational Upgrades to the Rapid Refresh (RAP) and High-Resolution Rapid Refresh (HRRR)

NOAA/ESRL/GSD/EMB

Curtis Alexander, Steve Weygandt, Stan Benjamin, David Dowell, Ming Hu, Tanya Smirnova, Joe Olson, Jaymes Kenyon, Georg Grell, Eric James, Haidao Lin and John Brown

And other collaborators…

Geoff Manikin, Jianbin Yang, John Michalakes, Jim Abeles, Jim Taft, Justin Cooke, Becky Cosgrove, Geoff DiMego

Rapid Refresh and HRRR
NOAA hourly updated models

13km Rapid Refresh (RAP)

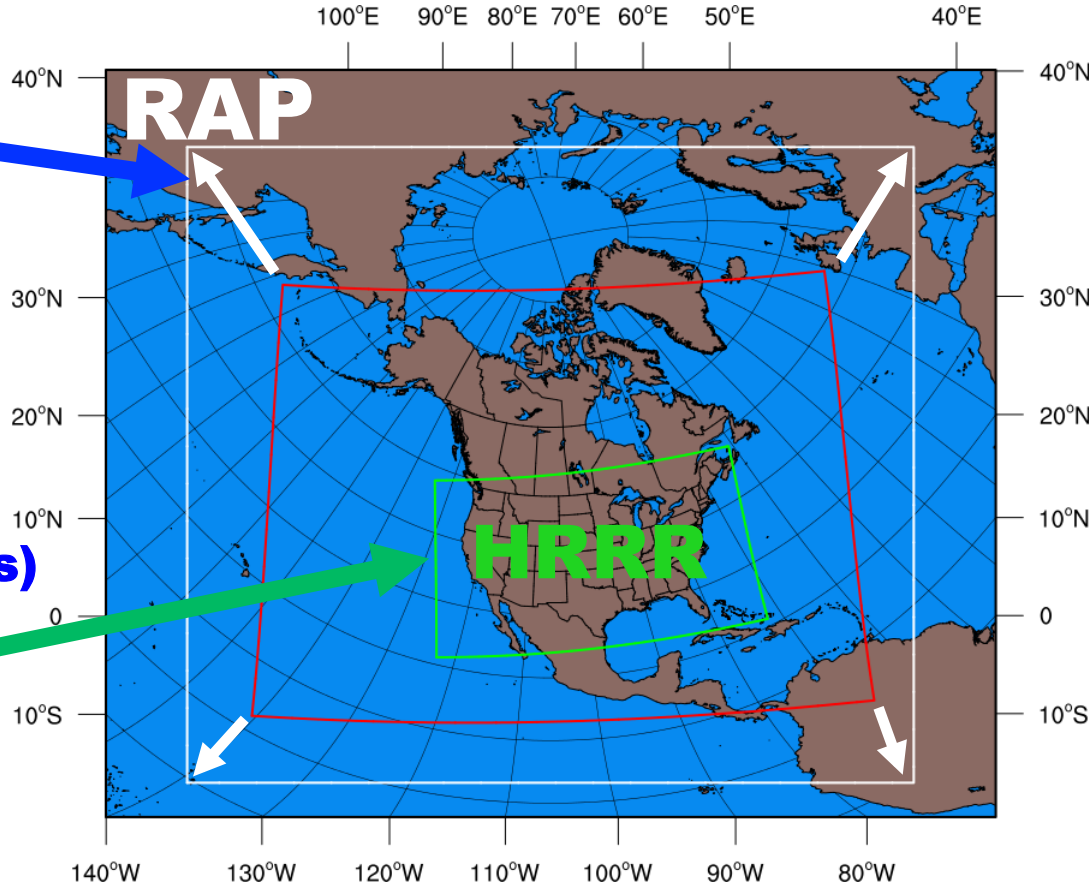
Version 2 -- NCEP
implement 25 Feb 2014

Version 3 – GSD
Planned NCEP – Late 2015
Larger Domain (red → white)
Longer Forecasts (18 → 30? hrs)

3km High Resolution Rapid Refresh (HRRR)

Initial – NCEP
implement 30 Sept 2014

Version 2 – GSD
Planned NCEP – Late 2015
Longer Forecasts (15 → 24? hrs)



RAP and HRRR R2O Schedule

Operational Implementations

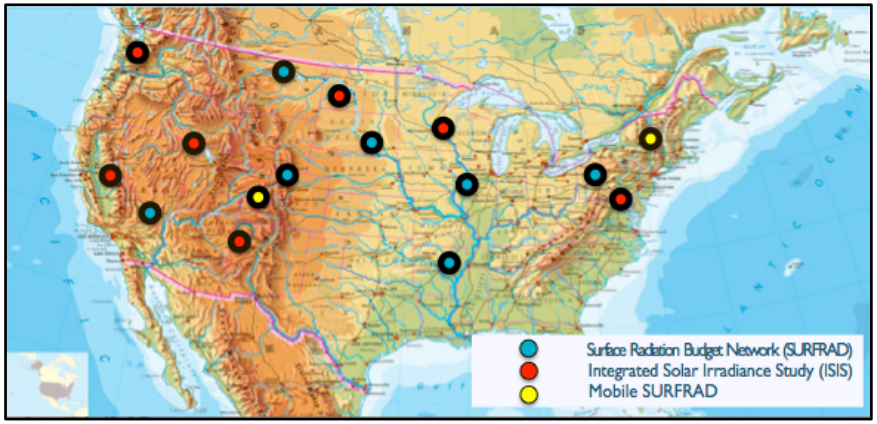
May 2012 — RAPv1: Adoption of GSI, WRF-ARW and unified post
Enabled use of community-developed software

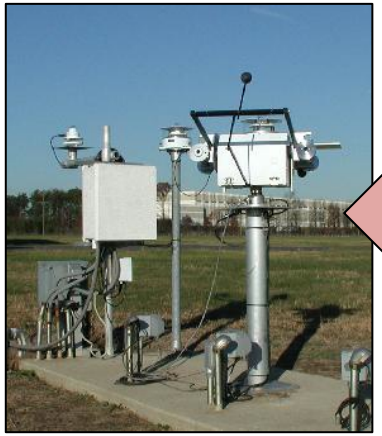
Feb 2014 — RAPv2: Hybrid DA
Significant Improvement in Upper-Air Forecasts

Sep 2014 — HRRRv1: 3-km Radar DA in WRF-ARW
Significant Improvement in Convective Forecasts
Another milestone thanks to the WRF-ARW community

Oct-Nov 2015 — RAPv3/HRRRv2:
Aerosol Thompson MP, MYNN PBL, RUC LSM, RRTMG Rad, GF Cu
Significant Improvement in Surface Forecasts

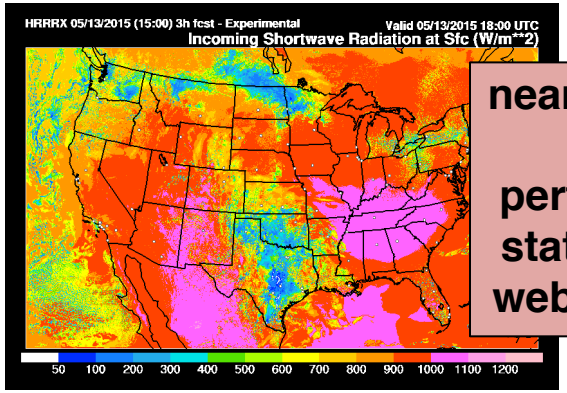
RAP / HRRR Irradiance Verification (SURFRAD / ISIS)



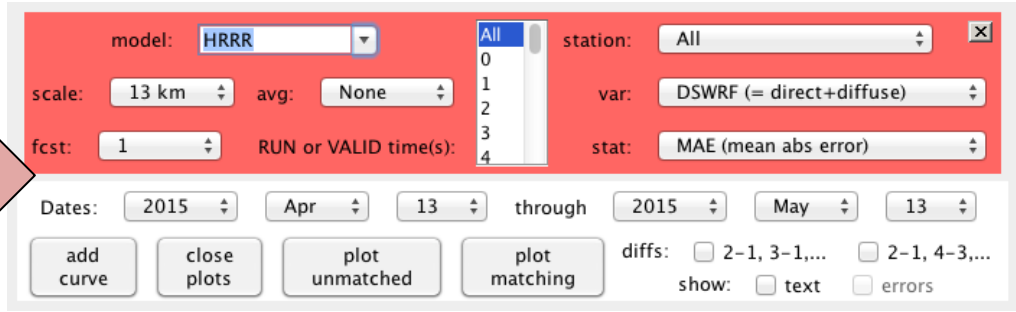


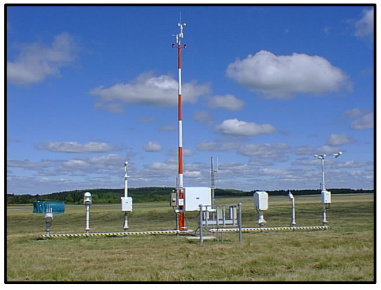
14 SURFRAD / ISIS sites

near-real-time data processing



near-real-time model performance statistics via web interface





- **GMD's SURFRAD / ISIS measurements provide a unique model assessment capability:**

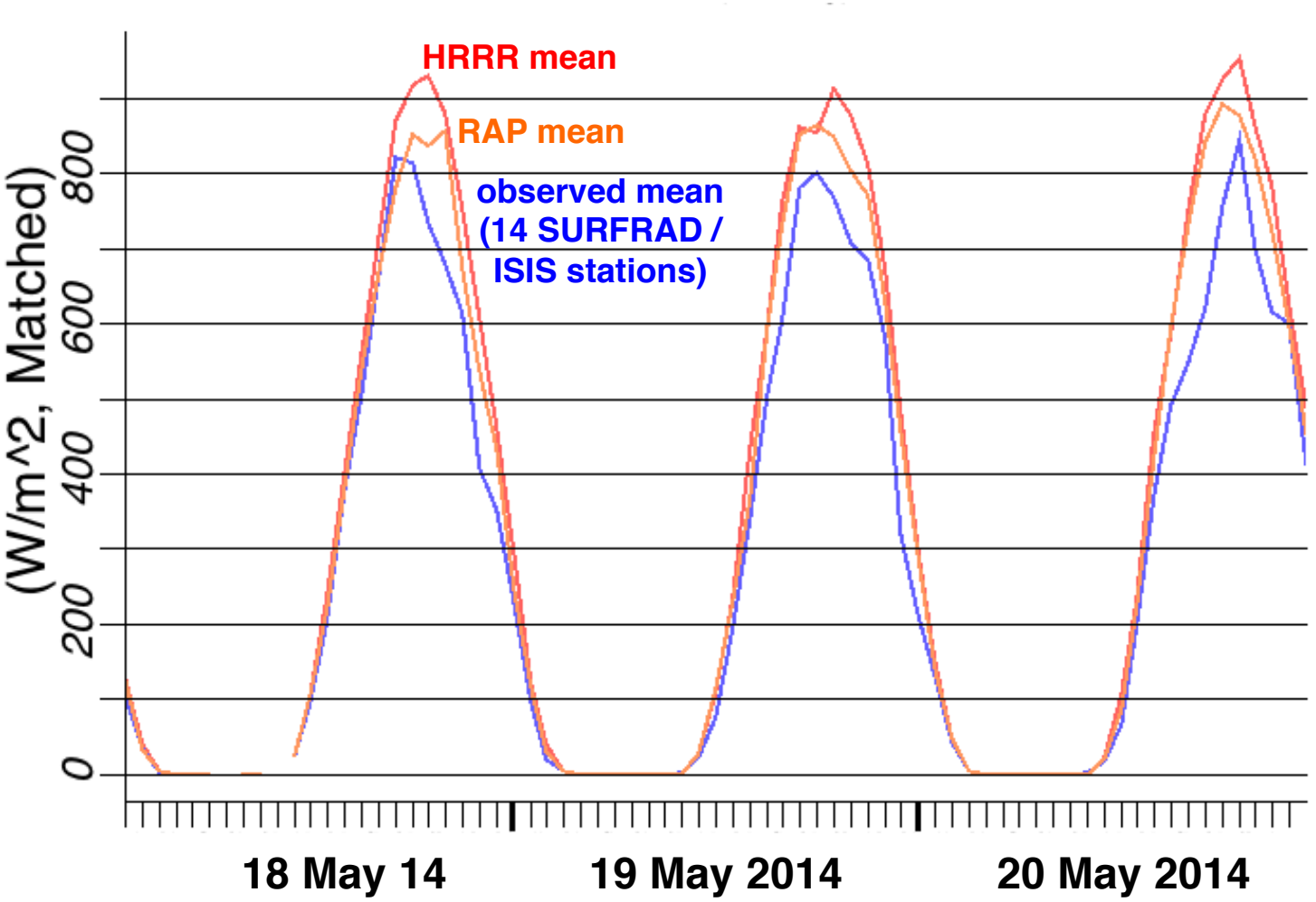
  (1) Directly quantify **surface energy budget** issues

  (2) Conventional "surface" variables (e.g., 2-m temperature) are **diagnosed** in the model

  (3) "Upper-air" variables verified against **twice-daily** radiosondes

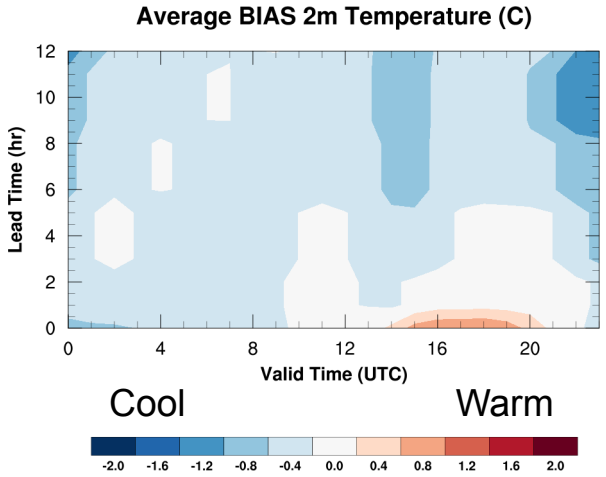
Cloud Deficiency in RAP and HRRR
- A problem for convection/ceiling/terminal forecasts

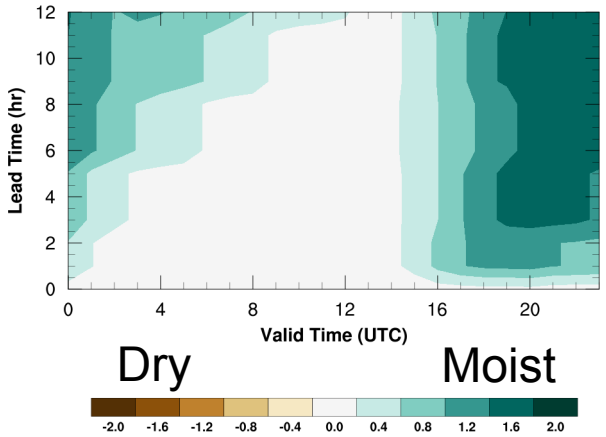
12-h forecasts of downward shortwave flux at surface



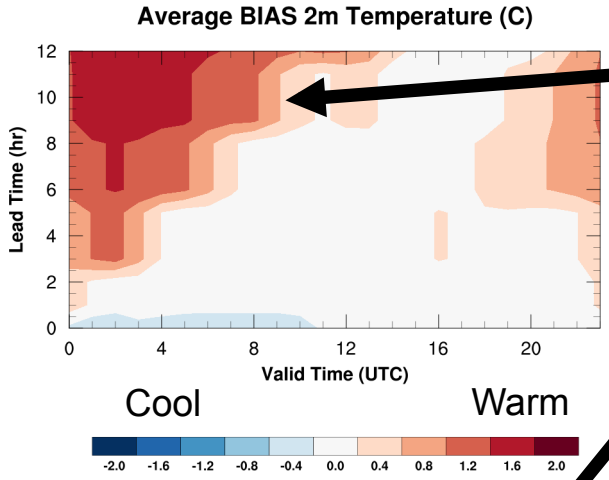
RAPv2/HRRRv1 Forecast Biases

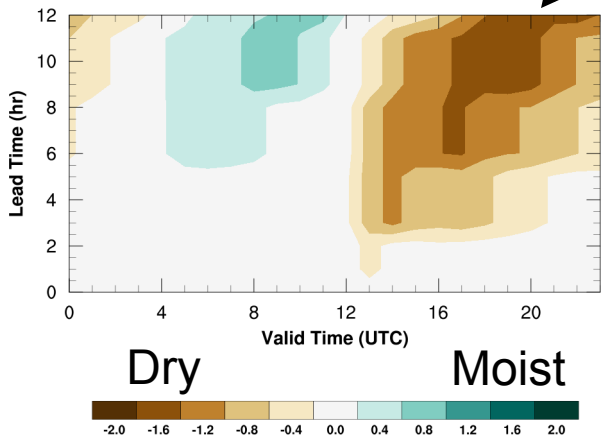
Winter (Jan-Mar)





Summer (Jul-Sep)





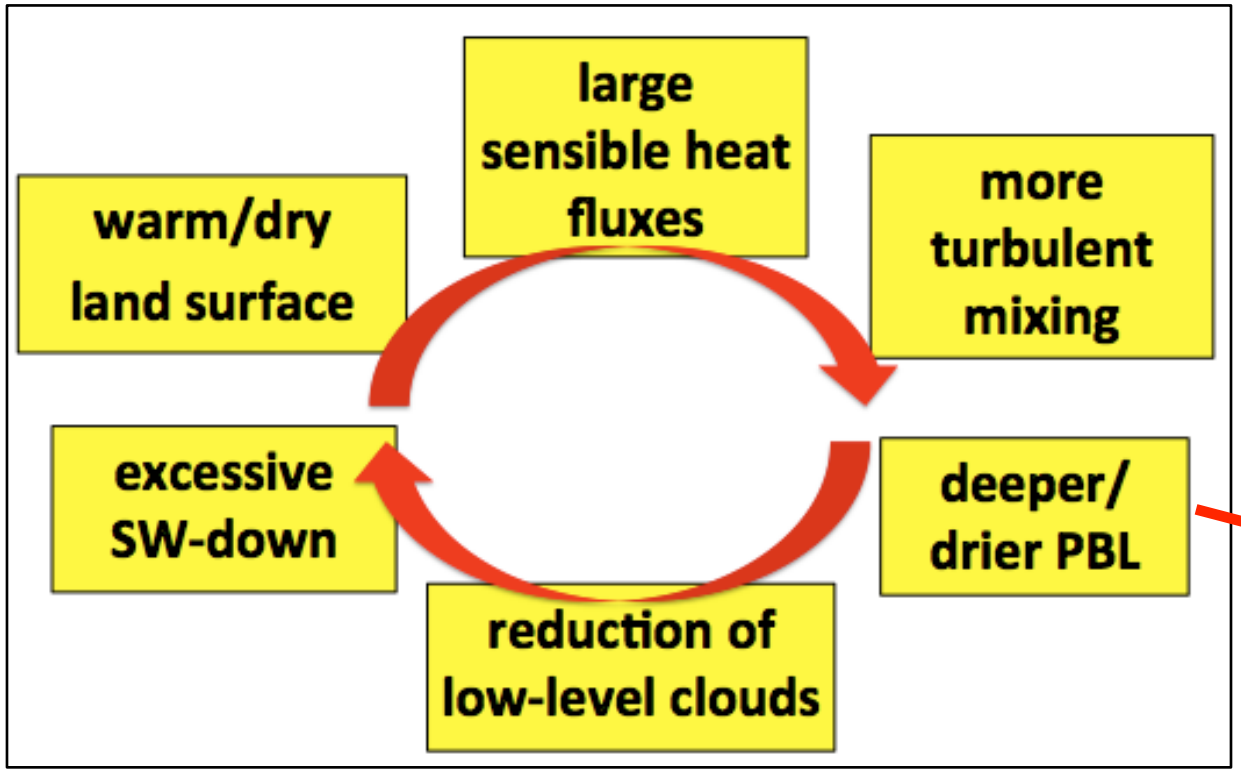
The HRRR has a daytime warm bias in the warm season.

The HRRR has a daytime dry bias in the warm season.

Experimental improvements to the model to remove bias have been made and will be implemented in HRRRv2.

RAPv2/HRRRv1 Model Bias Feedback

Conceptual Model of Positive Feedback Model Bias

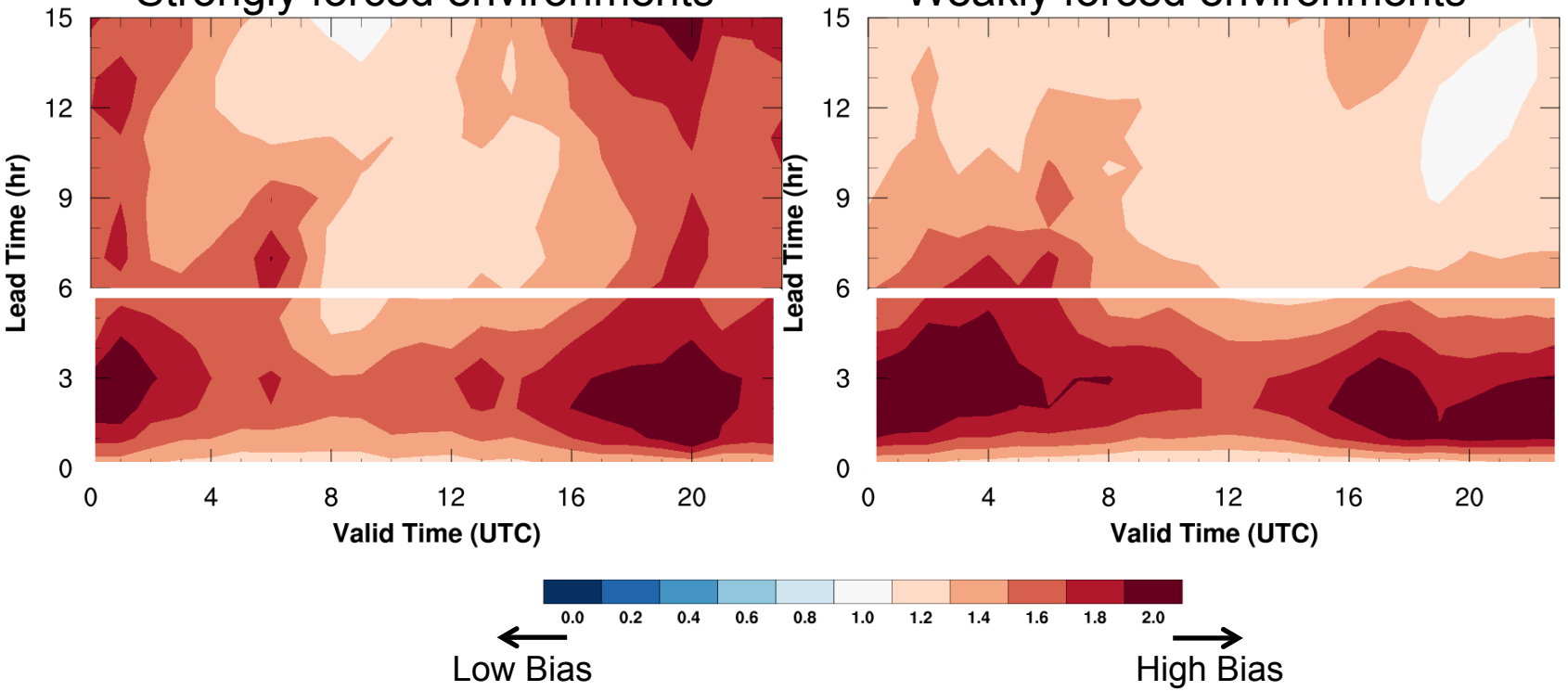


Led to occasional spurious high-based convective initiation in more weakly-forced diurnally-driven events

Summary of HRRRv1 Forecast Skill

Average BIAS for Reflectivity ≥ 35 dBZ

Stats for east of 100°W longitude (good radar coverage for verification)



Higher bias at early lead times

RAPv3/HRRRv2 Warm/Dry Bias Mitigation

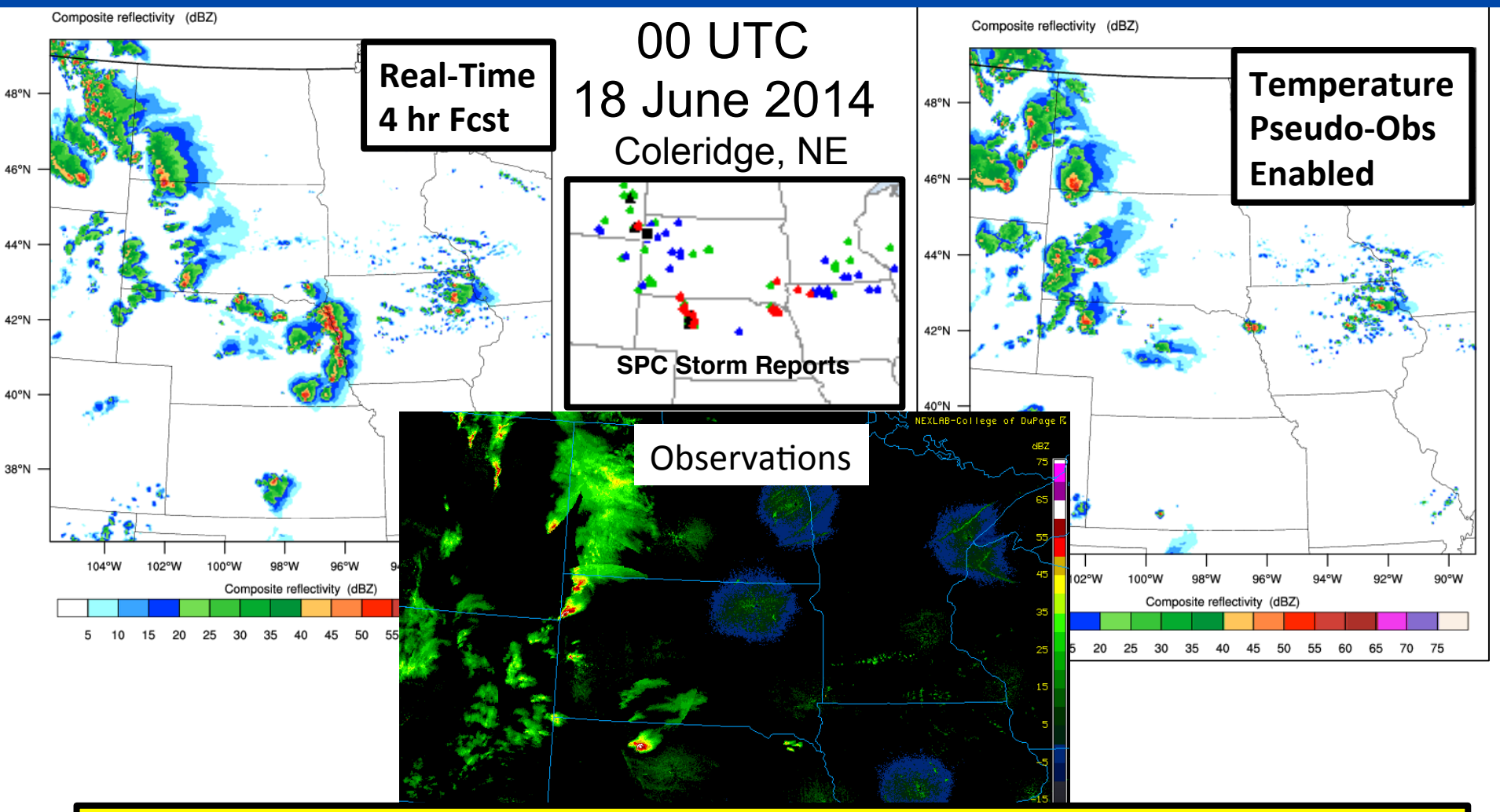
Component	Mitigating Items
GSI Data Assimilation	Canopy water cycling Temp pseudo-innovations thru model boundary layer More consistent use of surface temp/dewpoint data
GFO Convective Parameterization	Shallow cumulus radiation attenuation Improved retention of stratification atop mixed layer
Thompson Microphysics	Aerosol awareness for resolved cloud production Attenuation of shortwave radiation
MYNN Boundary Layer	Mixing length parameter changed Thermal roughness in surface layer changed Coupling boundary layer clouds to RRTMG radiation
RUC Land Surface Model	Reduced wilting point for more transpiration Keep soil moisture in croplands above wilting point

Talk 7.5: Georg Grell Thu 2:30
Poster P54: Pallavi Marrapu

Talk 5.3: Joe Olson Wed 11:30
Poster P31: Jaymes Kenyon

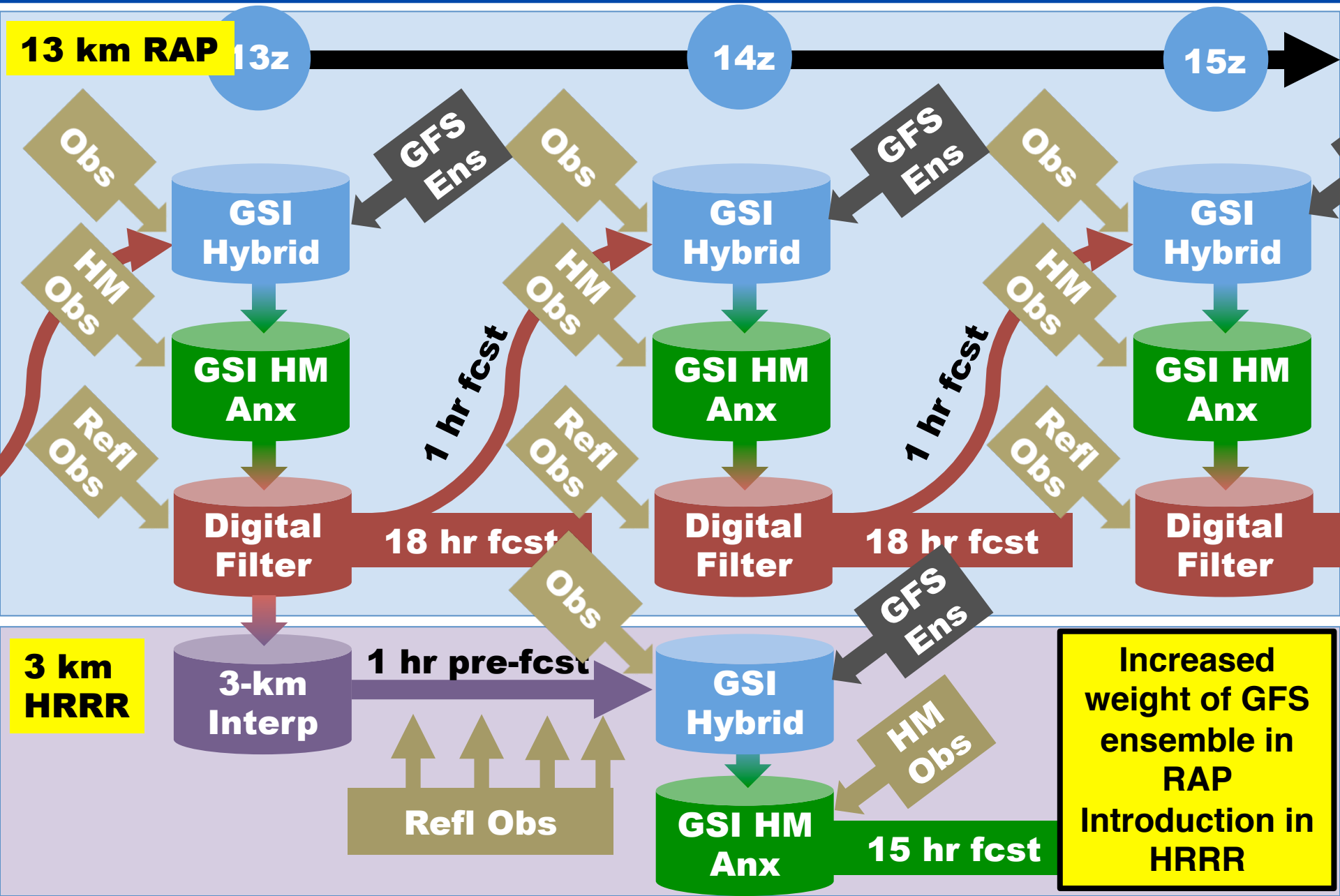
Poster P33: Tanya Smirnova

HRRR Convective Case Study



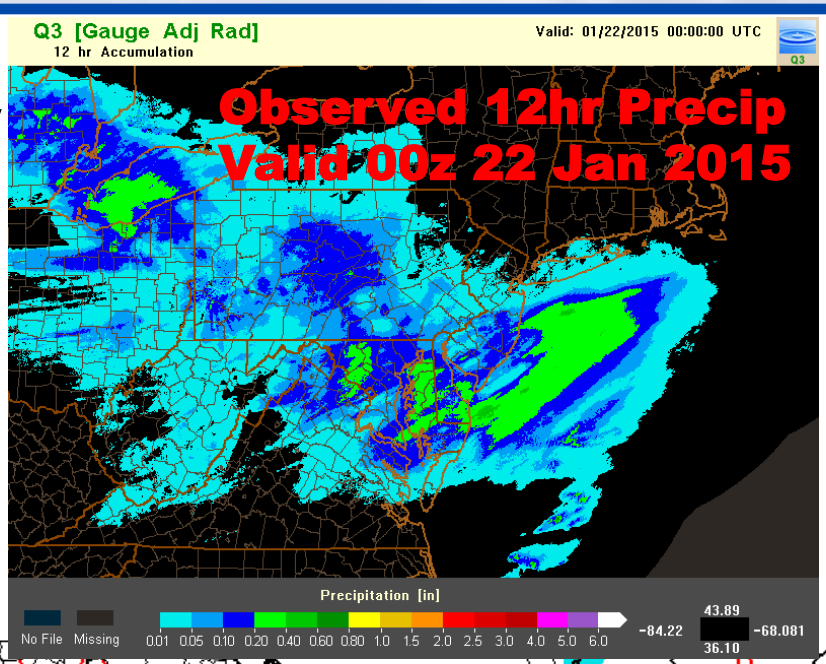
Control run develops too much high-based convection that grows upscale
Data assimilation change improves timing and evolution of convection

HRRRv2 Initialization from RAPv3



HRRR Winter Case Study

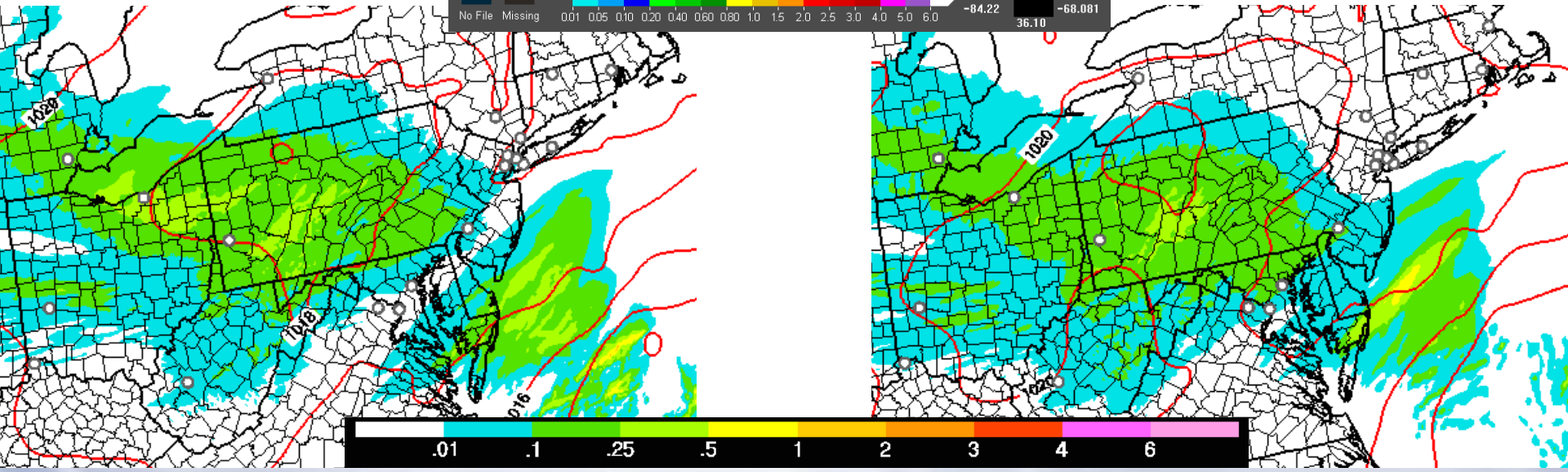
"Clipper" System Produced 1-2" snow D.C. Metro 21 Jan 2015



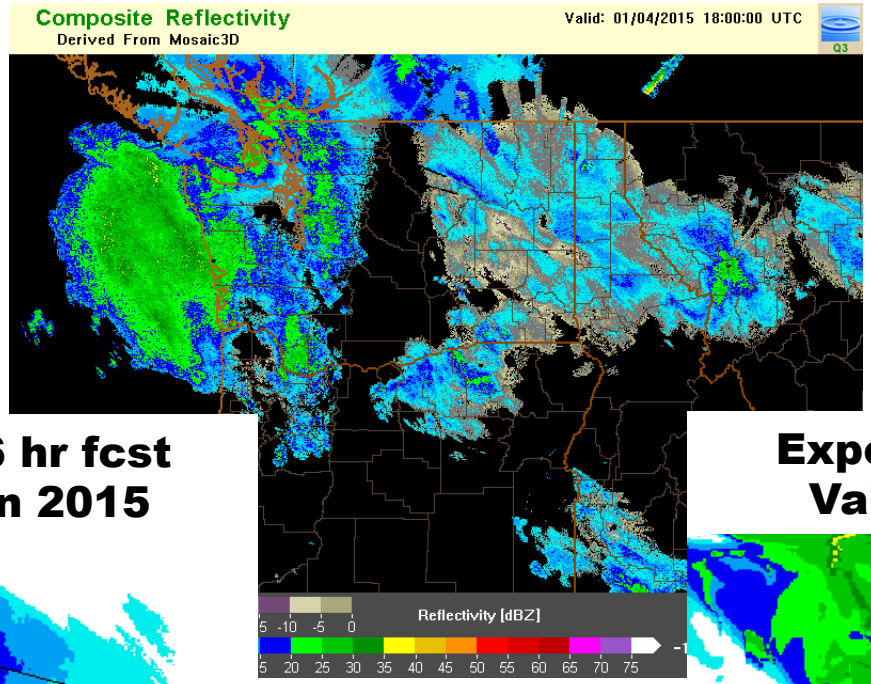
More precipitation produced in D.C. and northern suburbs

Oper HRRR 12 hr fcst Valid 00z 22 Jan 2015

Exper HRRR 12 hr fcst Valid 00z 22 Jan 2015

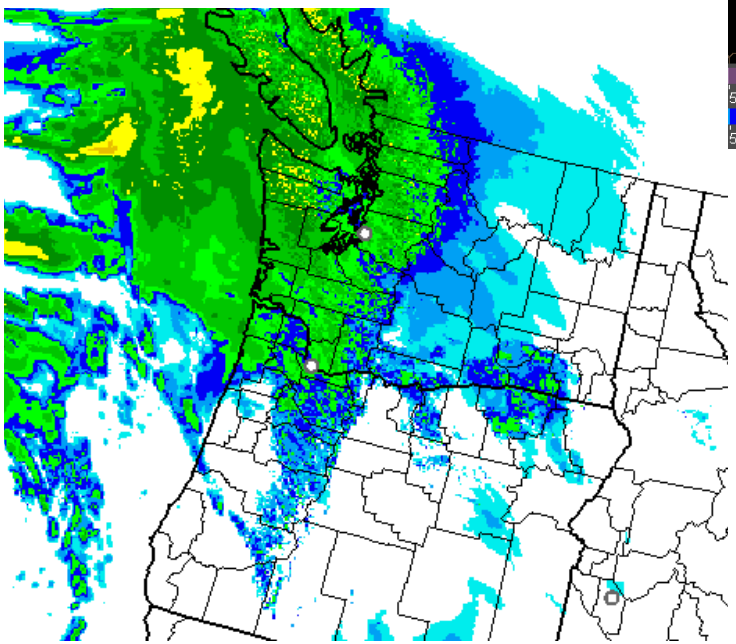


HRRR Winter Case Study

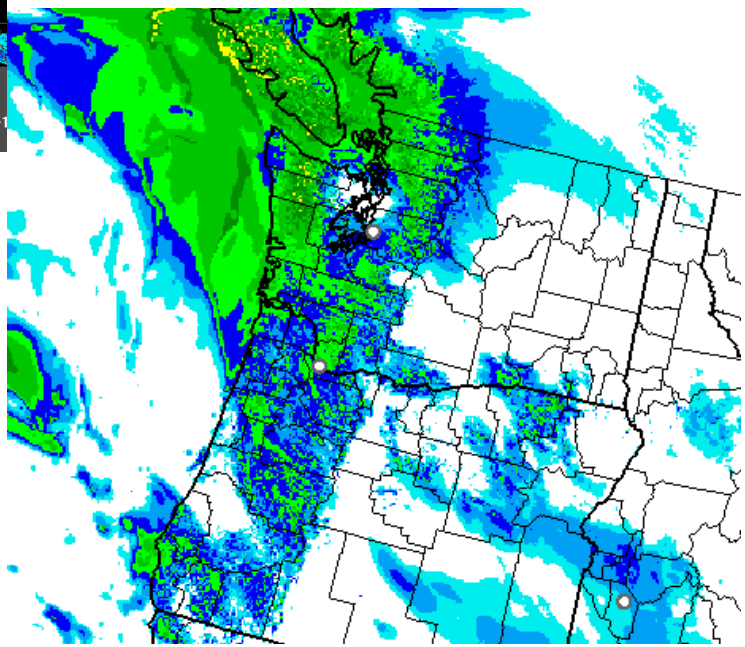


More rain shadow apparent in lee of Olympic Mountains

Oper HRRRv1 06 hr fcst
Valid 18z 04 Jan 2015



Exper HRRRv2 06 hr fcst
Valid 18z 04 Jan 2015



RAPv3: Observations used (new 2015)

HRRRv2 – similar into 3km GSI assimilation

Hourly Observation Type	Variables Observed	Observation Count
Rawinsonde	Temperature, Humidity, Wind, Pressure	120
Profiler – 915 MHz	Wind, Virtual Temperature	20-30
Radar – VAD	Wind	125
Radar	**Radial Velocity**	**125 radars**
Radar reflectivity – CONUS	3-d refl ➔Rain, Snow, Graupel	1,500,000
Lightning	**(proxy reflectivity)**	**NLDN**
Aircraft	Wind, Temperature	2,000 -15,000
Aircraft - WVSS	Humidity	0 - 800
Surface/METAR	Temperature, Moisture, Wind, Pressure, Clouds, Visibility, Weather	2200 - 2500
Surface/Mesonet	**Temperature, Moisture, Wind**	**~5K-12K**
Buoys/ships	Wind, Pressure	200 - 400
GOES AMVs	Wind	2000 - 4000
AMSU/HIRS/MHS **(RARS)**	Radiances	1K-10K
GOES	**Radiances**	**large**
GOES cloud-top press/temp	Cloud Top Height	100,000
GPS – Precipitable water	Humidity	260
WindSat Scatterometer	Winds	2,000 – 10,000

NCEP RAPv2 and HRRRv1

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, NCO	CONUS	1799 x 1059	3 km	50	20 mb	RAP	Hourly (pre-forecast hour 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
HRRR	WRF-ARW v3.4.1+	GSI 3D-VAR	3-km 15-min LH	RRTM/ Goddard	Thompson v3.4.1	None	MYNN	RUC

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

NCEP RAPv3 / HRRRv2 – 2015 Changes

Model	Run at:	Domain	Grid Points	Grid Spacing	Vertical Levels	Pressure Top	Boundary Conditions	Initialized
RAP	GSD, NCEP	North America	953 x 834	13 km	50	10 mb	GFS	Hourly (cycled)
HRRR	GSD, NCEP	CONUS	1799 x 1059	3 km	50	20 mb	RAP	Hourly (pre-forecast hour cycle, LSM full)

Model	Version	Assimilation	Radar DA	Radiation LW/SW	Microphysics	Cumulus Param	PBL	LSM
RAP	WRF-ARW v3.6+	GSI Hybrid 3D-VAR/ Ensemble to 0.75	13-km DFI + low reflect	RRTMG/ RRTMG	Thompson – aerosol v3.6.1	GFO v3.6+	MYNN v3.6+	RUC v3.6+
HRRR	WRF-ARW v3.6+	3km: GSI Hybrid 3D-VAR/Ensemble to 0.75	3-km 15-min LH +low reflect	RRTMG/ RRTMG	Thompson – aerosol v3.6.1	MYNN PBL Clouds	MYNN v3.6+	RUC v3.6+

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

NCEP RAPv3/HRRRv2-2015 Changes

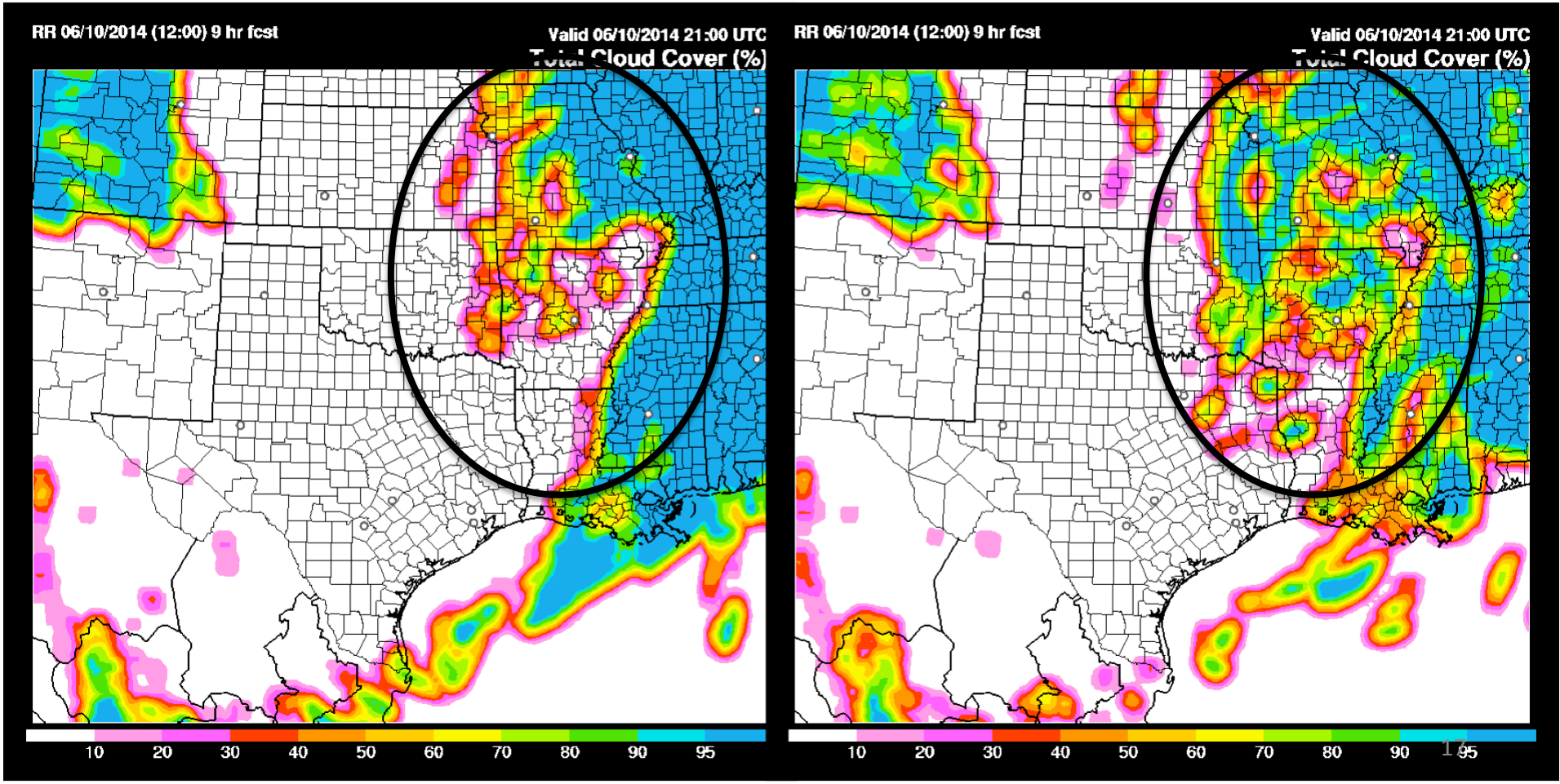
Use of forecast aerosol fields to have prognostic cloud-condensation nuclei (CCN).

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

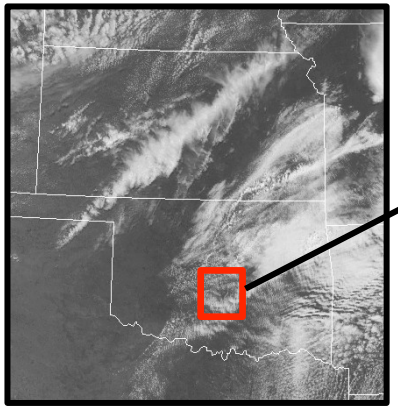
More small-scale cloud with more CCN over land.

WRFv3.5.1 aerosol unaware

WRFv3.6 Aerosol-aware



RAPv3/HRRRv2 Warm/Dry Bias Mitigation



area mean (437 grid points)

8-h forecasts valid 1700 UTC 20 May

Control

Subgrid Cloud

Subgrid Cloud + LSM

Water Vapor Mixing Ratio (g kg^{-1})

Potential Temperature (K)

Pressure (hPa)

750

800

850

900

950

1000

Moistening

Drying

Parameterized Shallow Cumulus

Cooling

Warming

Increased Stratification

{ PBL }

Δ ≤ 0.6 g kg^{-1}

Δ ≤ 0.9 K

4 6 8 10 12 14 16

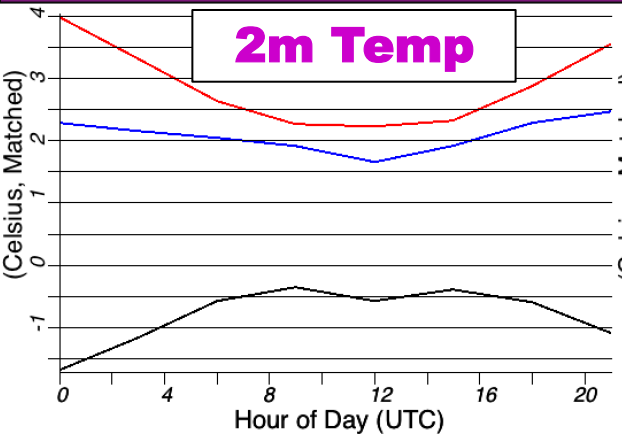
304.0 306.0 308.0 310.0 312.0

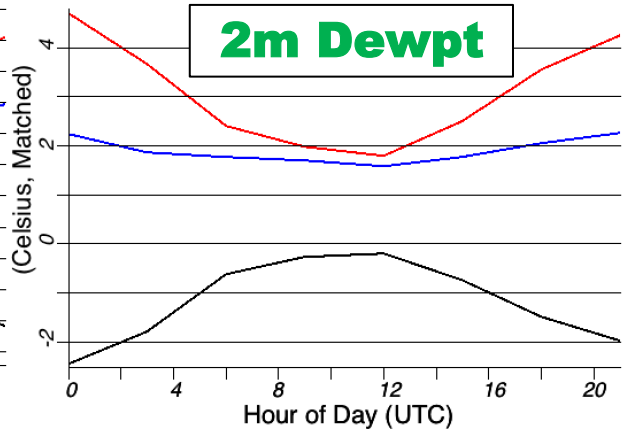
RAPv3 Retrospective Verification

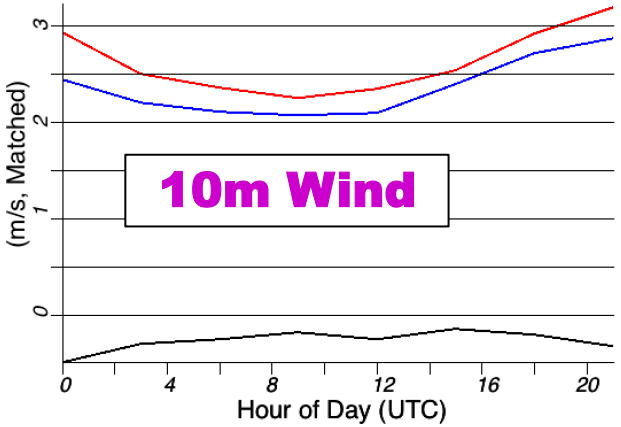
Eastern US 15 Jul – 15 Aug 2014

Exper RAPv3 **Oper RAPv2** **RAPv3 - RAPv2 Difference**

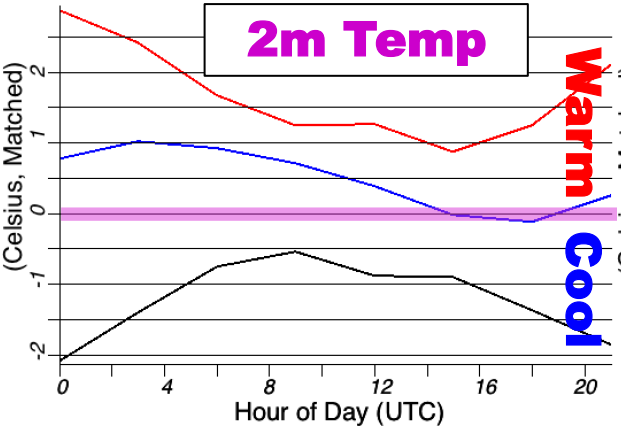
RAP Surface 12-hr Forecast RMSE

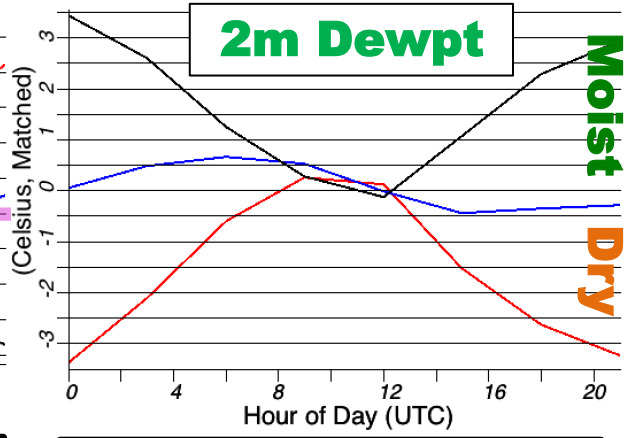


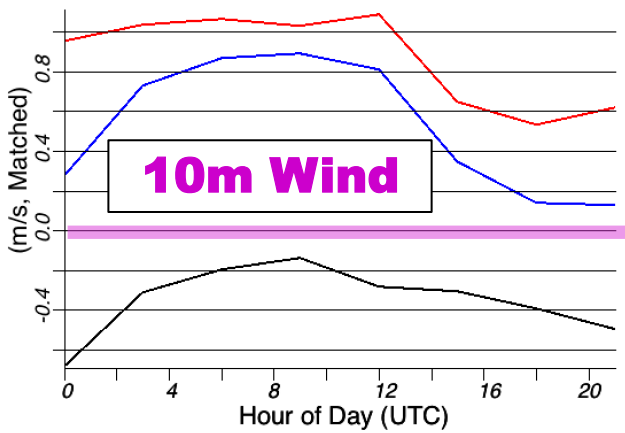




RAP Surface 12-hr Forecast Bias







Reduced warm bias

Reduced dry bias

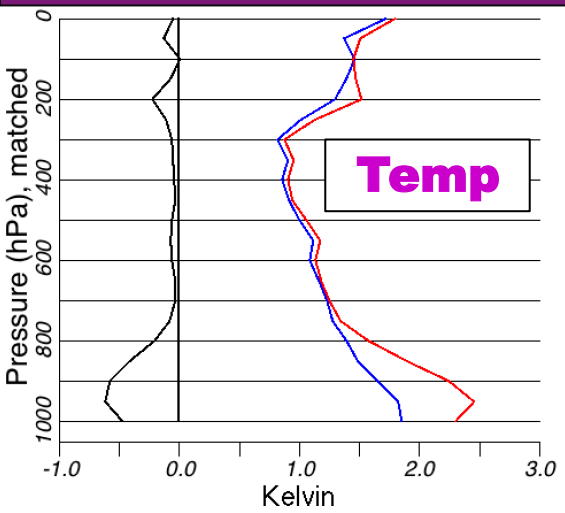
Reduced fast bias

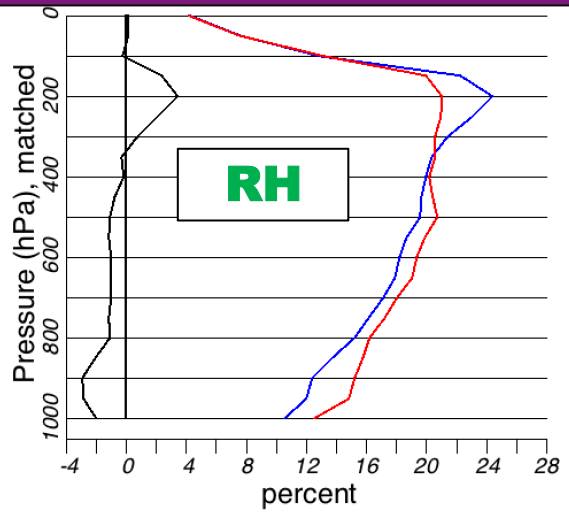
RAPv3 Retrospective Verification

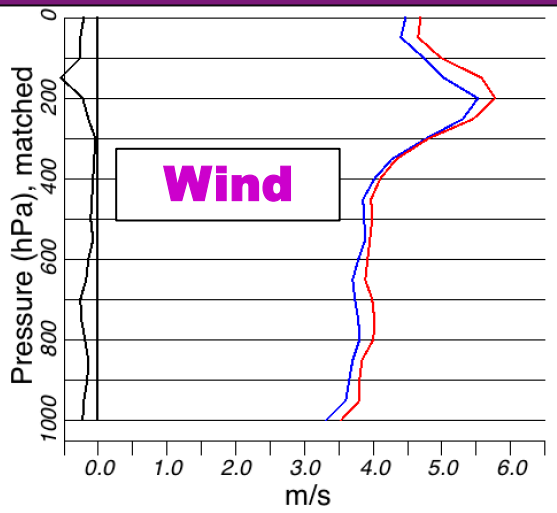
US 15 Jul – 15 Aug 2014

Exper RAPv3 **Oper RAPv2** **RAPv3 - RAPv2 Difference**

RAP Upper-Air 12-hr Forecast RMSE





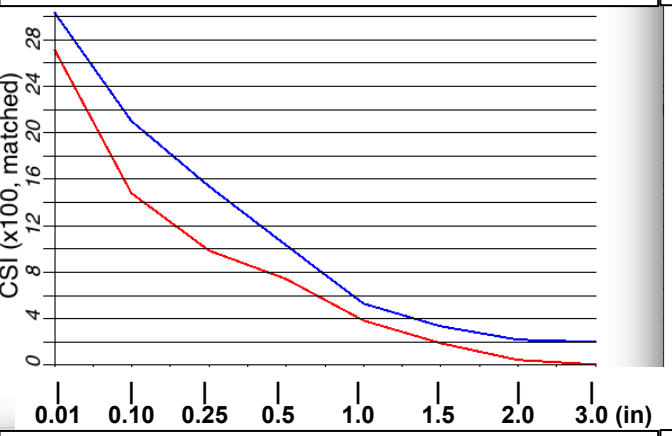


RAPv3 Retrospective Verification

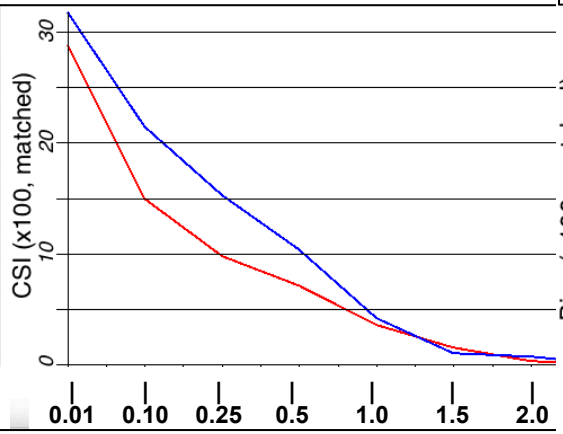
Eastern US 15 Jul – 15 Aug 2014 Exper RAPv3 Oper RAPv2

RAP Eastern US Precipitation 6-hr Forecast

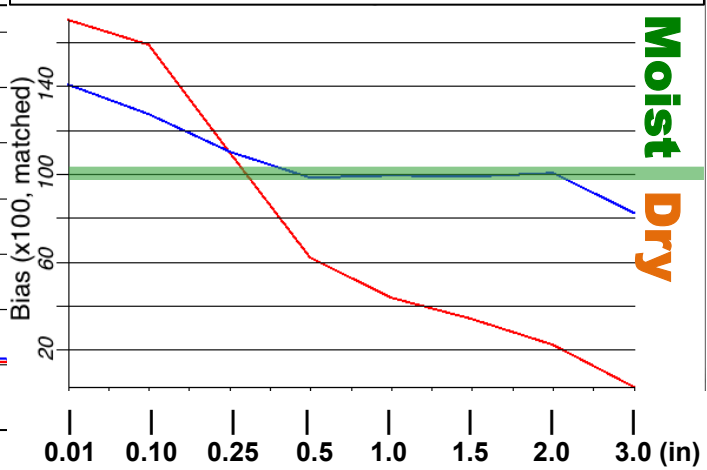
CSI 13-km



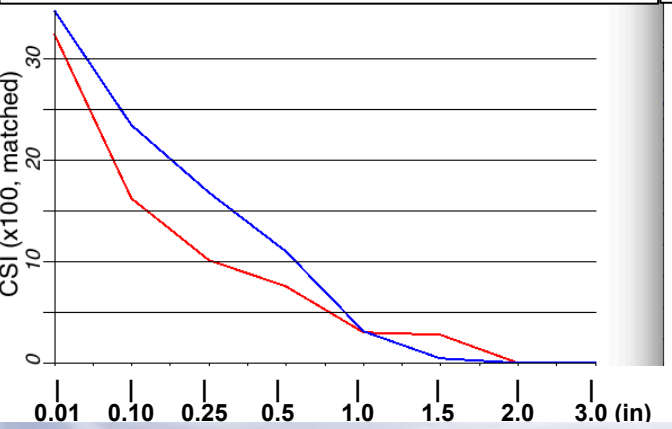
CSI 20-km



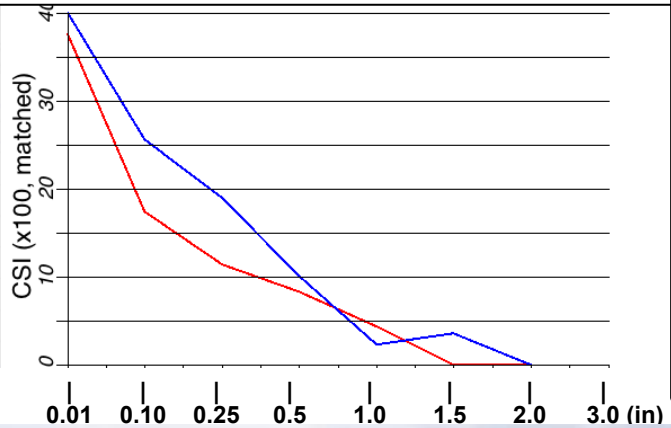
BIAS 13-km



CSI 40-km



CSI 80-km



Reduced moist bias at low precip thresholds

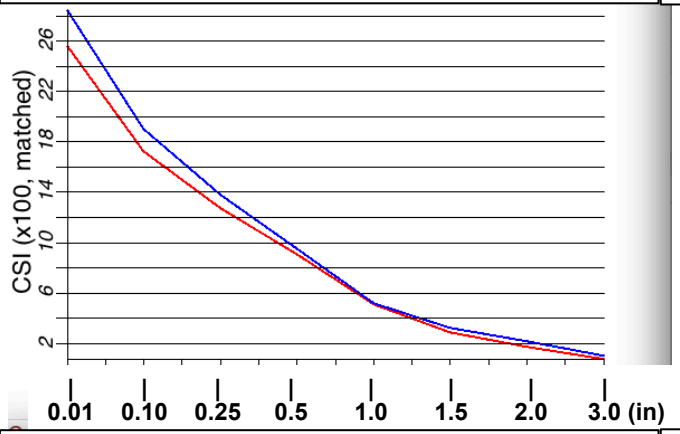
Reduced dry bias at high precip thresholds

HRRRv2 Retrospective Verification

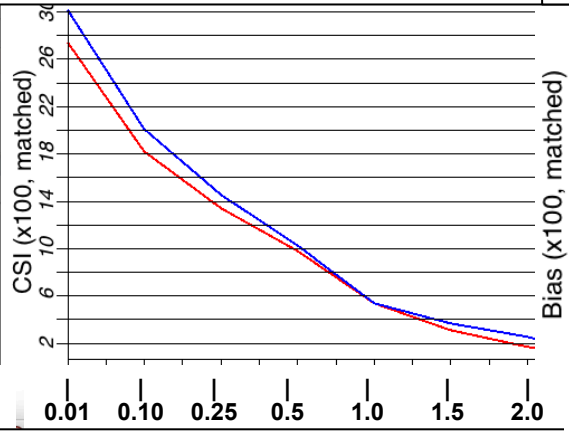
15 Jul – 15 Aug 2014 Exper HRRRv2 Real-time HRRR

HRRR Eastern US Precipitation 6-hr Forecast

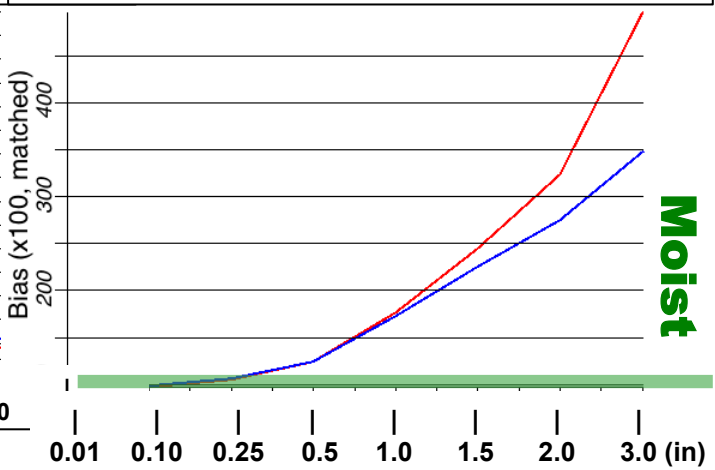
CSI 3-km



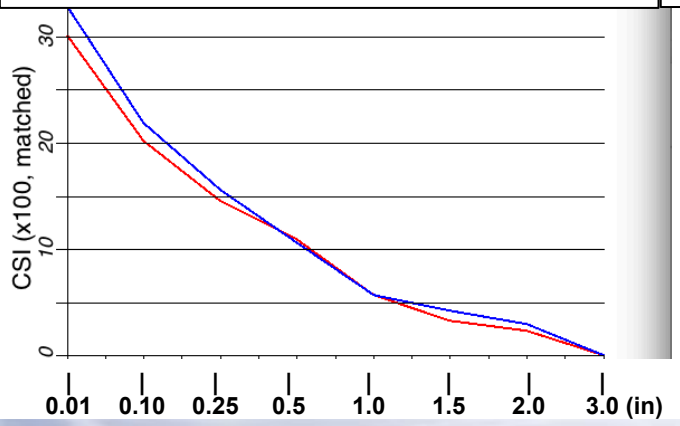
CSI 20-km



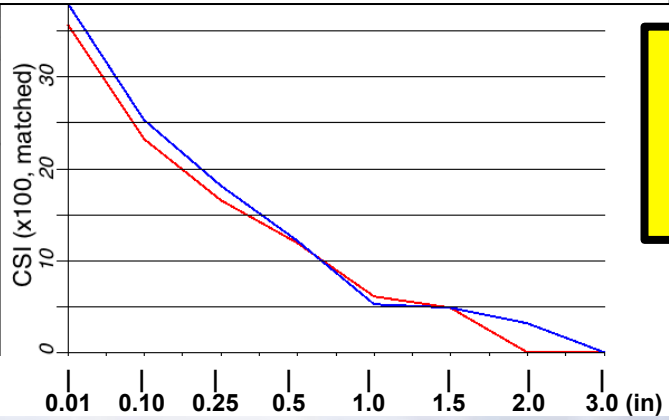
BIAS 3-km



CSI 40-km

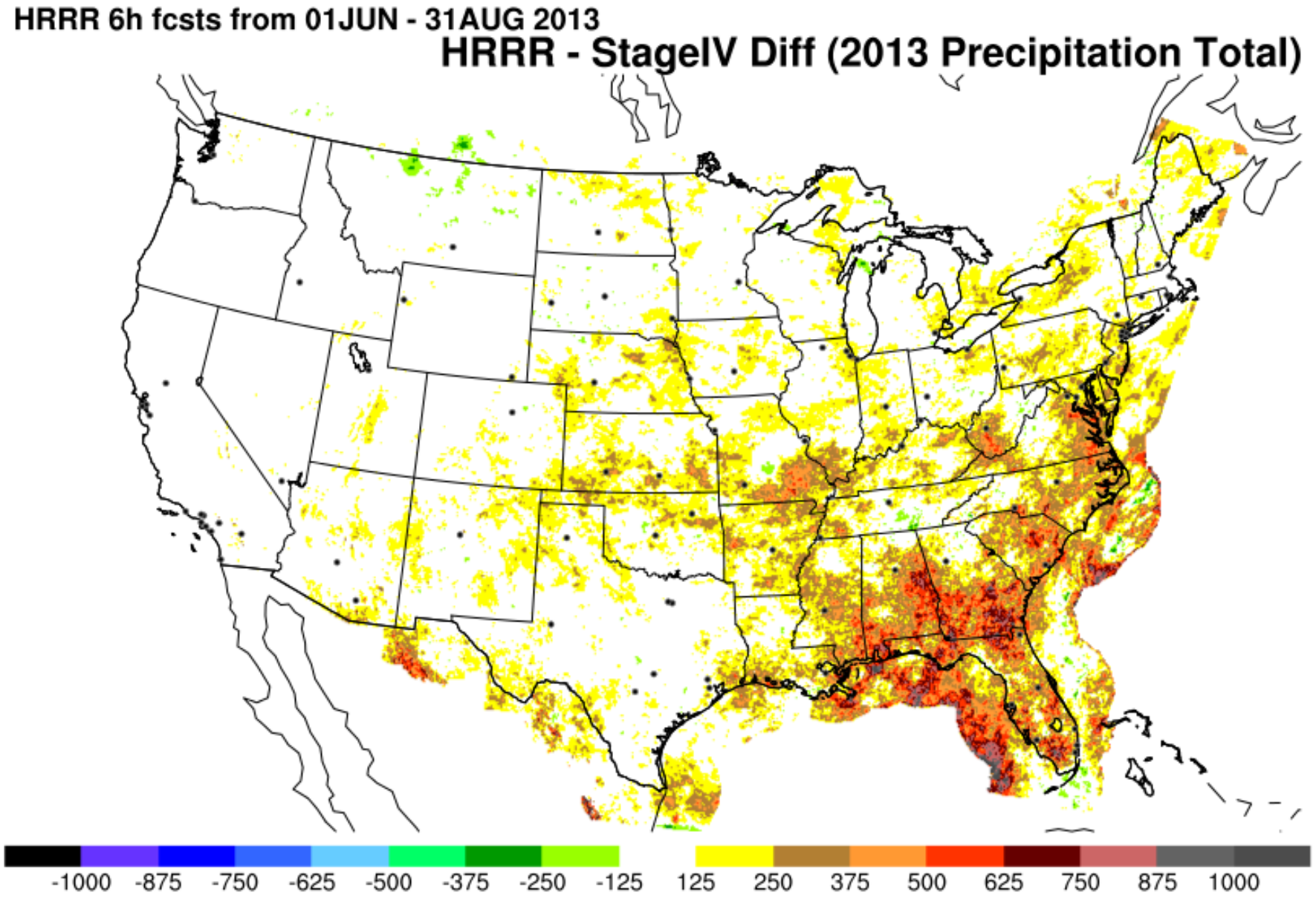


CSI 80-km

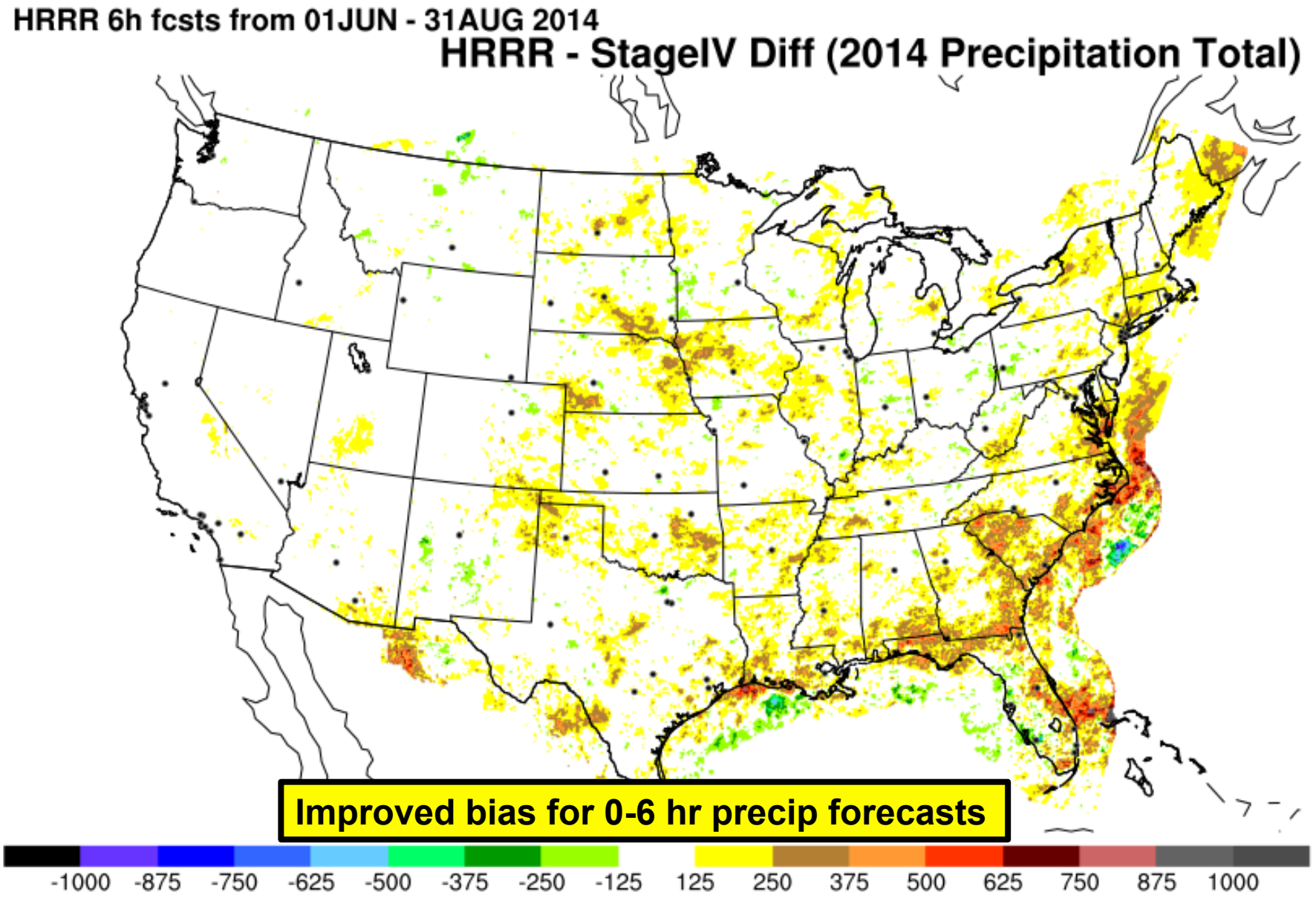


Reduced moist bias at high precip thresholds

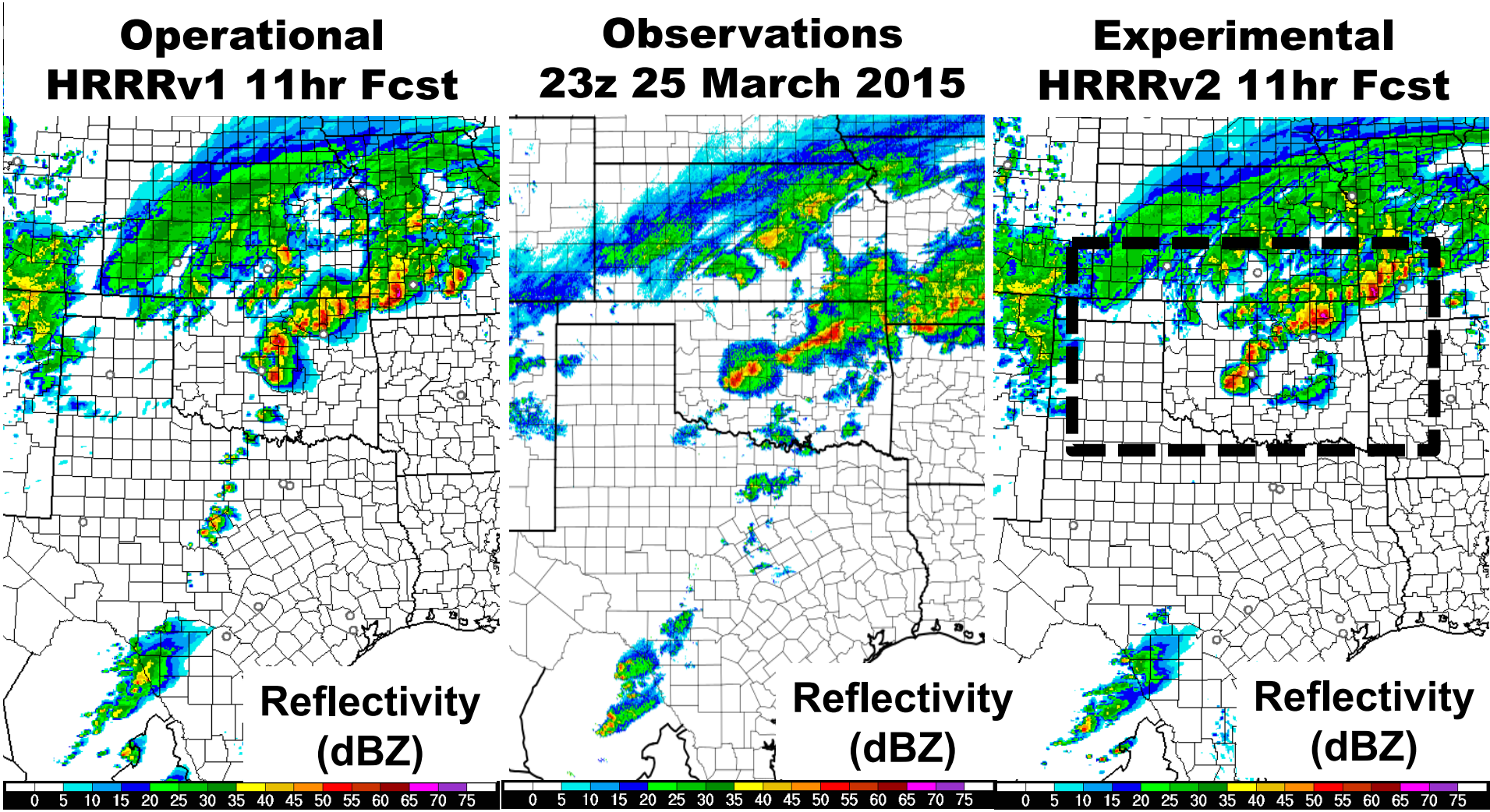
HRRR Precipitation Bias 2013 (v1)



HRRR Precipitation Bias 2014 (v2)



HRRR Convective Case Study



Reduction in false-alarm Texas dryline convection

HRRR 11-hr Convective Case Study

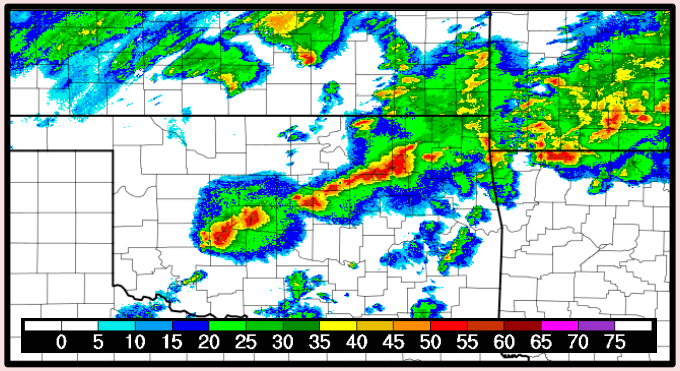
23z 25 March 2015

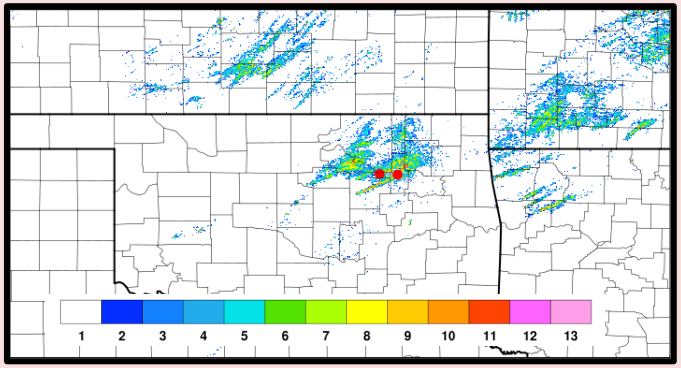
22z-23z 25 March 2015

Composite Reflectivity (dBZ)

Rotation Tracks (s^{-1})

Weather Radar Observations

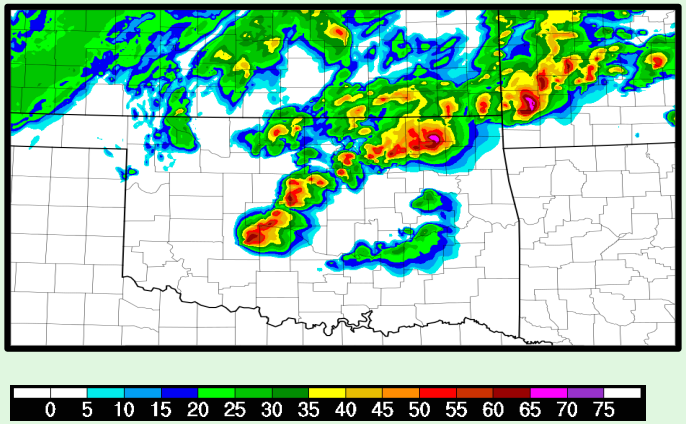


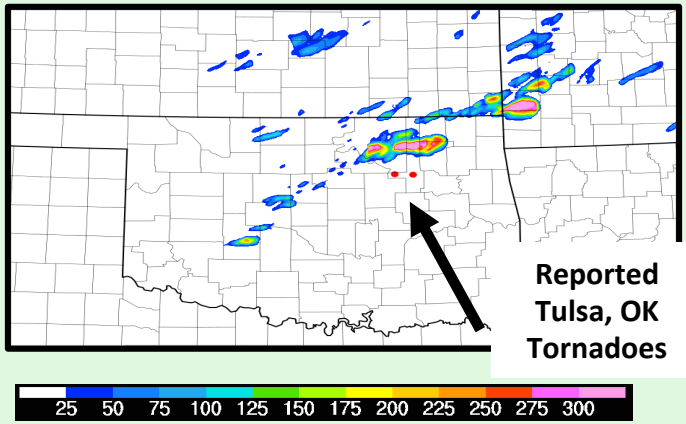


Composite Reflectivity (dBZ)

Updraft Helicity (m^2 s^{-2})

Real-Time 11 hr HRRRX Forecast

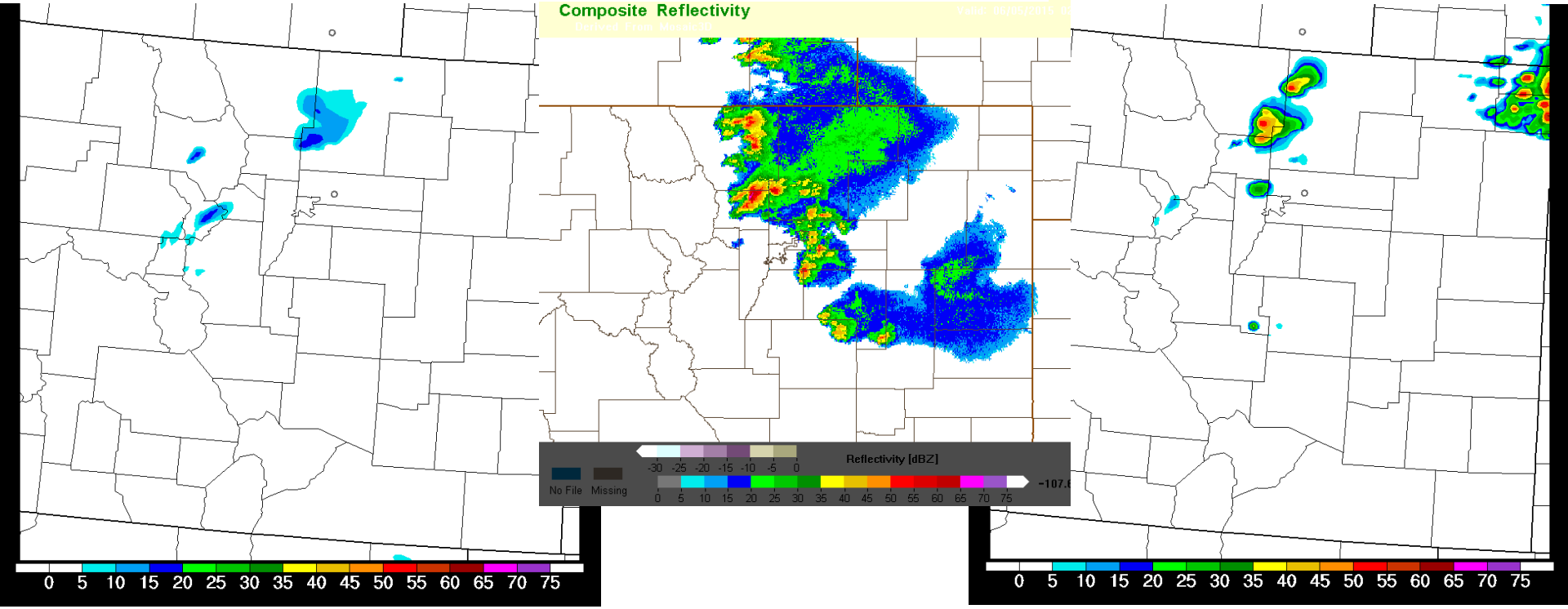




More accurate location of convection in Oklahoma

HRRR Convective Case Study

Operational HRRRv1 11hr Fcst | **Observations 02z 05 June 2015** | **Experimental HRRRv2 11hr Fcst**



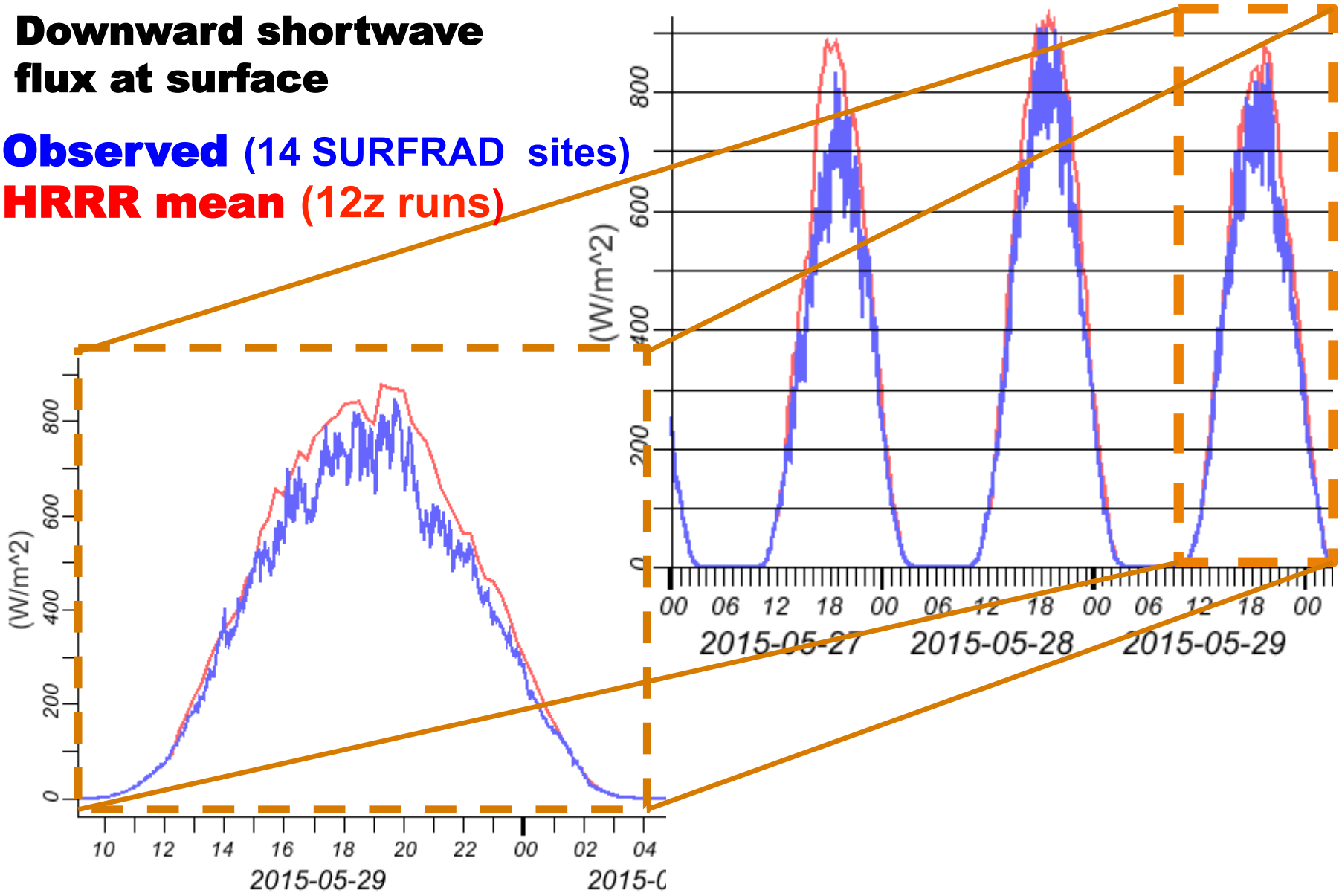
Improved convective evolution in NE CO that included tornadic supercells

15-min Validation of HRRR forecasts

Downward shortwave flux at surface

Observed (14 SURFRAD sites)

HRRR mean (12z runs)

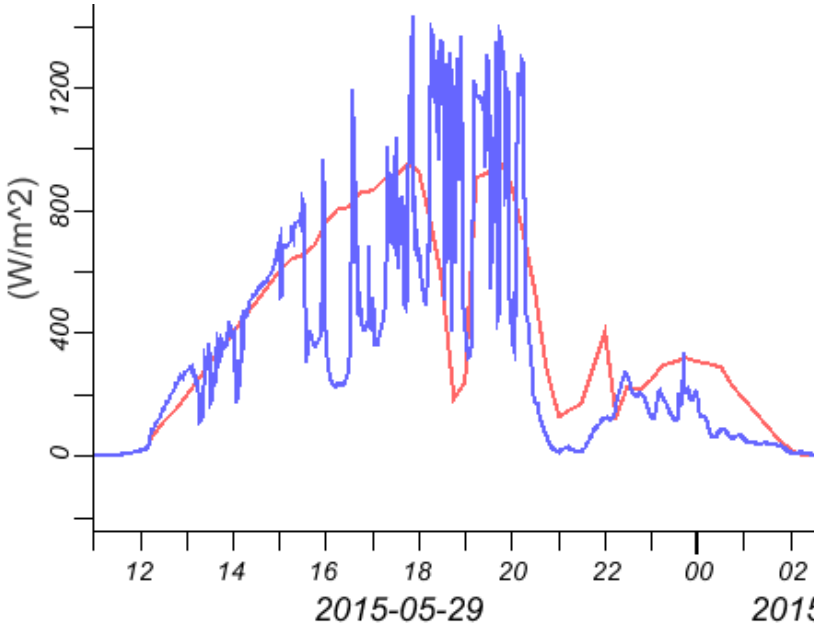


15-min Validation of HRRR forecasts

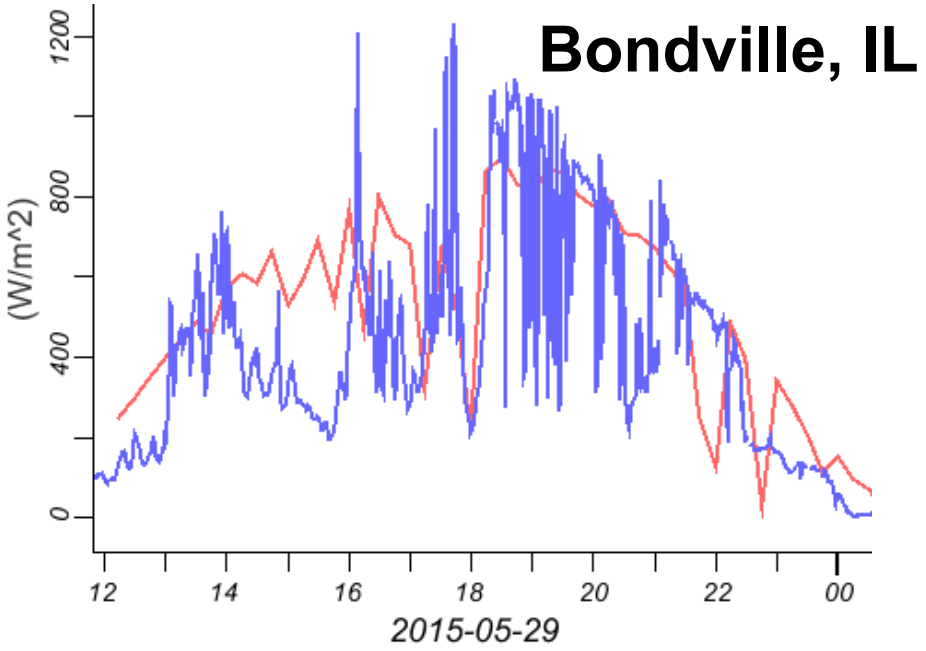
Downward shortwave flux at surface
29 May 2015

Observed (individual sites)
HRRRv2 mean (12z run)

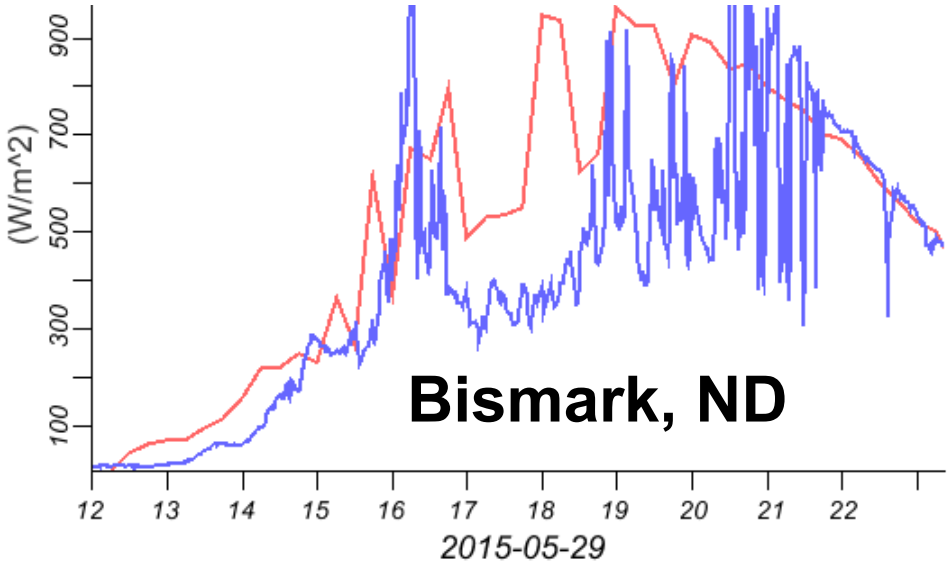
Table Mtn, CO



Bondville, IL



Bismark, ND



RAPv3/HRRRv2 vs. RAPv2/HRRRv1

Winds -- Consistent RAPv3 improvement for both upper-air and surface, for all seasons

Temperature – Reduced low-level warm bias for warm season afternoon / evening. Improved upper-level temperature forecasts

Moisture – Reduced low-level dry bias for warm season afternoon / evening. Improved upper-level relative humidity forecast

Precipitation – Slight improvement, reduced low thresh high bias / increased high thresh low bias

RAP/HRRR Implementation Map

ESRL – experimental version	NWS-NCEP - operational
• **RAPv3 – GSD testing in 2014-15** – Is initializing 2015 ESRL-HRRR(v2) – Improved PBL, LSM, cu-parm, DA – WRFv3.6.1 w/ Thompson/NCAR aerosol-aware microphysics	→ • Implement late 2015
• **HRRRv2 – GSD testing in 2014-15** – Initialized by 2015 RAP (v3) – Improved radar assimilation, hybrid assimilation, PBL/cloud physics	→ • Implement late 2015
• **RAPv4 – GSD testing in 2015** – Hourly RAP ensemble data assimilation – See Poster P36 Isidora Jankov/Jeff Beck	→ • Implement 2016
• **HRRRv3 – GSD testing in 2015** – Improved 3km physics – Full 3-km hourly cycling w/radial vel – Cycling of aerosols with fire/emissions	→ • Implement 2016