RAPv2 webinar briefings to NWS FOs, Regions
18-19 February 2014

Rapid Refresh operational upgrade to version 2 at NCEP

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Rapid Refresh "version 2"

Scheduled implement 25 Feb 2014

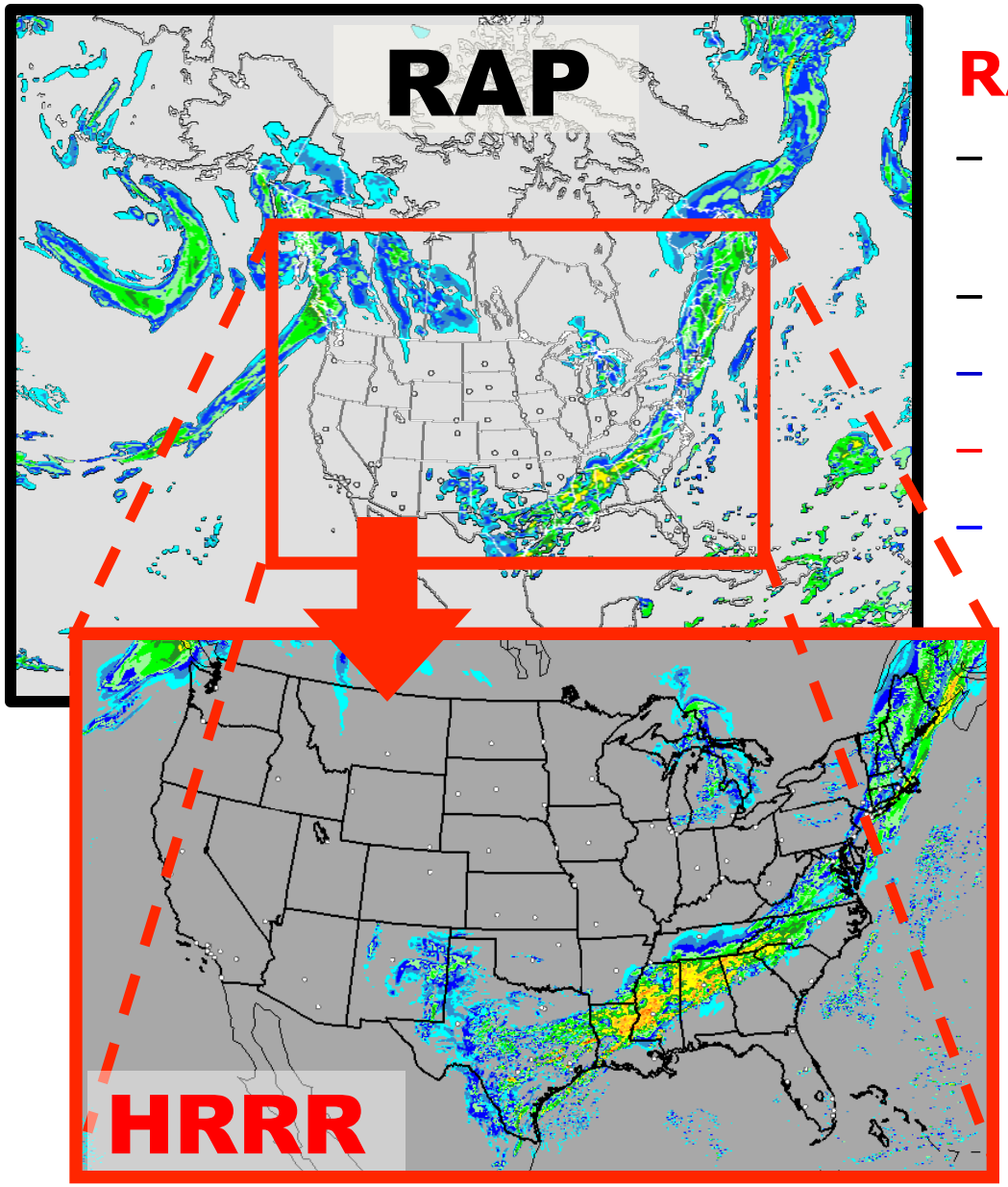
- Upgrades: **EnKF-3DVAR hybrid DA, MYNN PBL, 9-layer LSM, better cloud/precip anx**
- RAPv2 significant improvement over RAPv1
  Better winds, mid-level moisture, near- surface fields, convective environments

Rapid Refresh "version 3" – next year's story

GSD testing, NCEP implementation 2015

- **Grell-Freitas cum., MYNN PBL, hybrid DA upgrades**

NOAA Hourly Updated Models



RAP - Rapid Refresh

- NOAA "situational awareness" model for high-impact weather
- New 18-hour forecast each hour
- NOAA/NCEP operational – 1 May 2012
- RAPv2 implementation – 25 Feb 2014
- Hourly use by National Weather Service, SPC/AWC/WPC, FAA, private sector

HRRR – High-Resolution Rapid Refresh

- Storm/energy/aviation guidance
- Real-time *experimental* on ESRL supercomputer
- NCEP implementation planned for July 2014

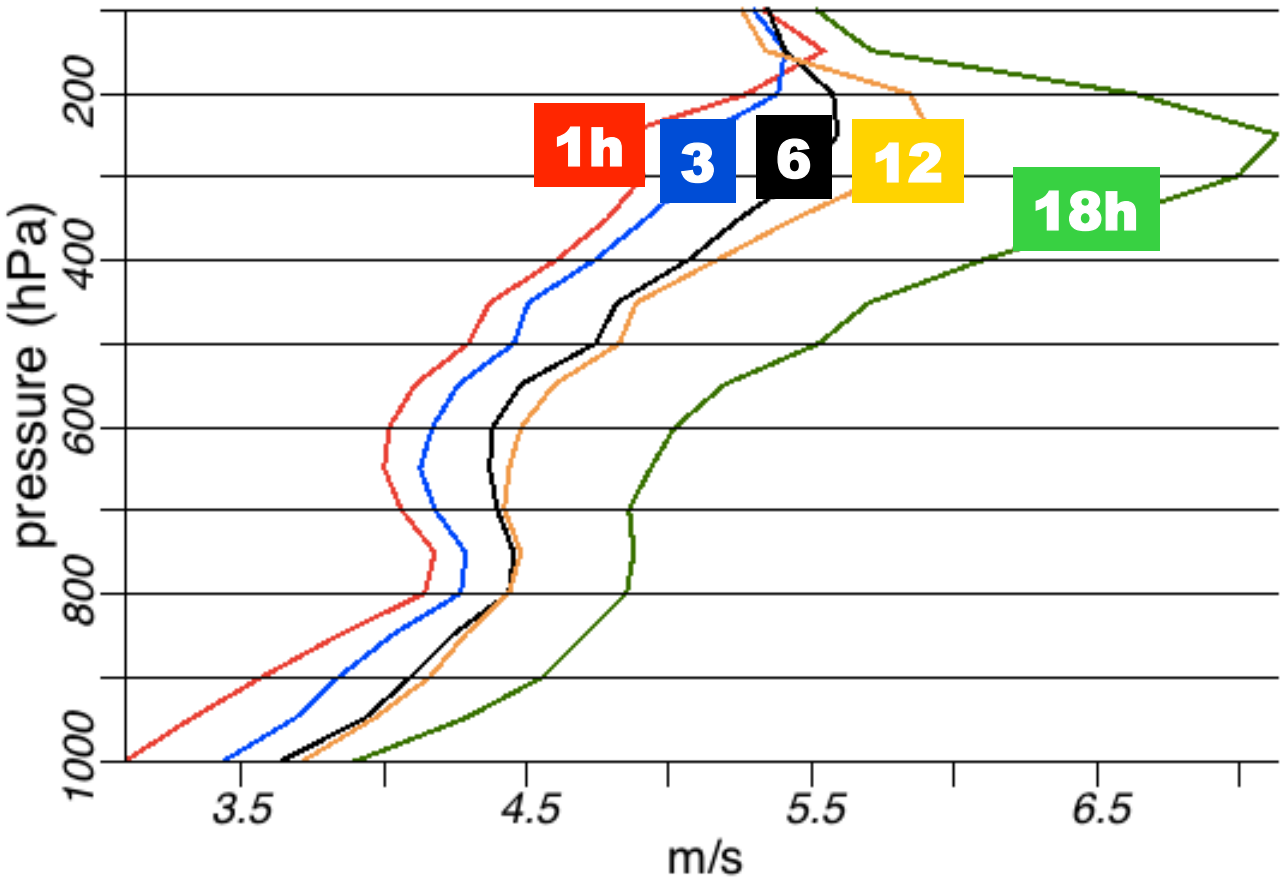
RAPv2 Prediction System Overview

- Hourly updated mesoscale analyses / forecasts
  - WRF-ARW model (Grell-3 cumulus param, Thompson microphysics, RUC-Smirnova land-surface, MYNN PBL scheme)
  - GSI hybrid analysis using 80-member global ensemble
  - 13-km, 50 levels, 24 cycles/day – each run out to 18 hours
  - 6-hour catch-up "partial" cycle run twice per day from GFS
  - Output grids: 13, 20, and 40 km CONUS, 32 km full domain, 11 km Alaska, 16 km Puerto Rico
- Use and downstream dependencies
  - Used by SPC, AWC, WPC, NWS FOs, FAA, energy industry, and others for short-range forecasts and hourly analyses
  - Downscaled RAP serves as first guess for RTMA
  - RAP serves as initial condition for SREF members
  - RAP will be used to initialize Hi-Res Rapid Refresh (HRRR, scheduled for implementation July 2014) and HRW runs

RAP error reduction to 1-h forecast

Rapid Refresh
Wind forecast accuracy vs. forecast length

1 Jan -
7 Mar 2012
- Verification against weather balloon data



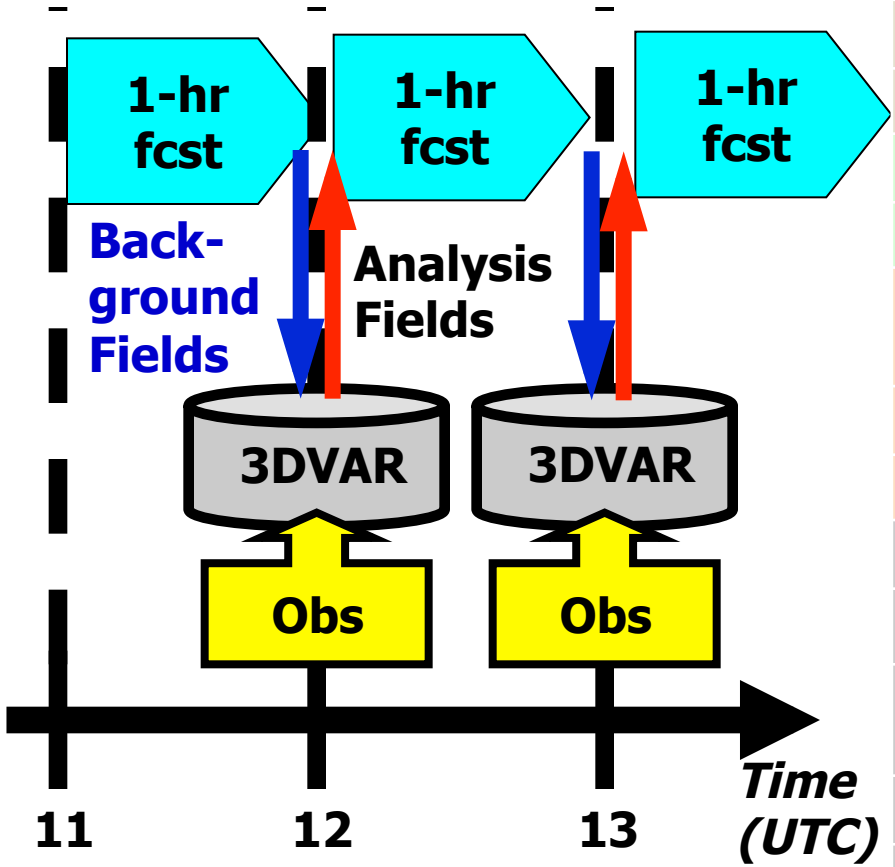
The Rapid Refresh is able to use recent obs to improve forecast skill down to 1-h projection

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)



Observations Used

Hourly Observations	RAP 2014 N. Amer
Rawinsonde (T,V,RH)	120
Profiler – NOAA Network (V)	Down to 9 (!)
Profiler – 915 MHz (V, Tv)	20-30
Radar – VAD (V)	125
Radar reflectivity - CONUS	1km
Lightning (proxy reflectivity)	NLDN (GLD360 later)
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	Flagged for now
GOES AMVs (V)	2000- 4000
AMSU/HIRS/MHS radiances	Used
GOES cloud-top press/temp	low-level (<1200m AGL) bldg added
GPS – Precipitable water	260
WindSat scatterometer	2-10K

RAPv2 enhancements over RAPv1

Data Assimilation	Assimilation Type	PBL Pseudo Innovations	Soil Adjustment	Low-Cloud Building	Snow Cover Building	Lightning Obs (radar refl proxy)
RAPv1	GSI 3D-VAR	No	No	No	No	No
RAPv2	GSI EnKF-3DVAR Hybrid + temp-dep radar-hydrometeor	Yes	Yes	Yes	Yes + revised trimming	Yes

Model	Version	Horiz/Vert Advection	Scalar Advection	Upper-Level Damping	SW Radiation Update	Land Use	Land-sfc model	PBL	Micro-physics	Radiation LW/SW
RAPv1	WRF-ARW V3.2+	$5^{th}/3^{rd}$	Monotonic	w-Rayleigh 0.02	30 min	USGS	RUC 6-lev	MYJ	Thompson V3.2	RRTM/ Goddard
RAPv2	WRF-ARW v3.4.1+	$5^{th}/5^{th}$	Positive-Definite	w-Rayleigh 0.2	10 min	MODIS Fractional	RUC 9-lev	MYNN	Thompson v3.4.1	RRTM/ Goddard w/ snow fix

Major changes for RAPv2

Assimilation

– hybrid ensemble assimilation, soil/PBL/surface/cloud assimilation

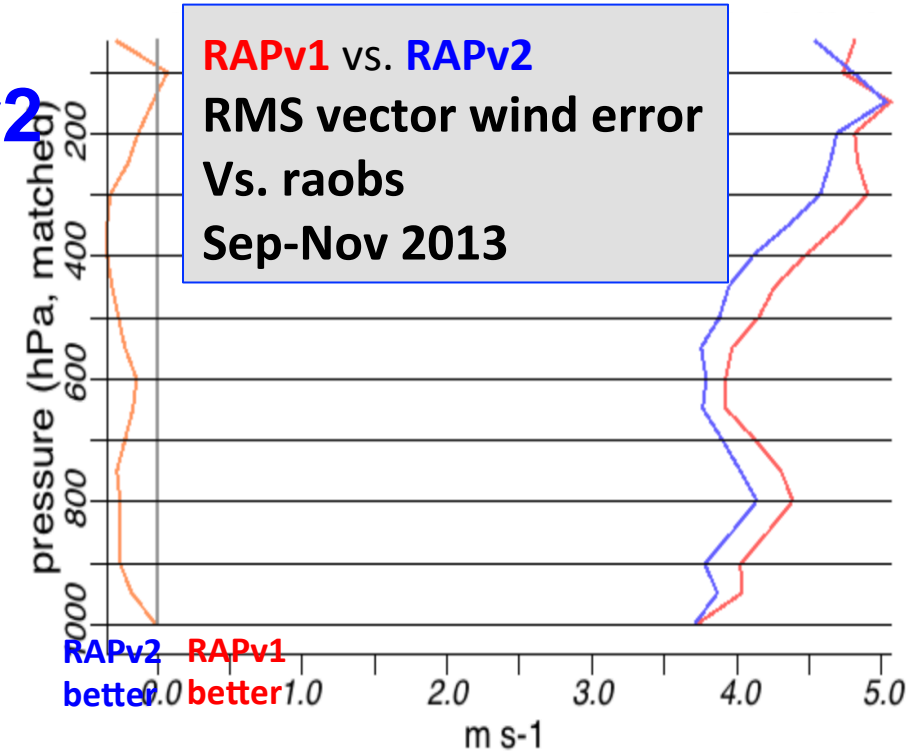
Model –

- land-surface, PBL, cloud physics

Forecast accuracy: RAPv2 vs RAPv1

Winds -- Consistent RAPv2 improvement, for both upper-air and surface

Moisture -- Improved RAPv2 RH forecasts aloft. Reduced RMS 2m dewpoint error, more so at night



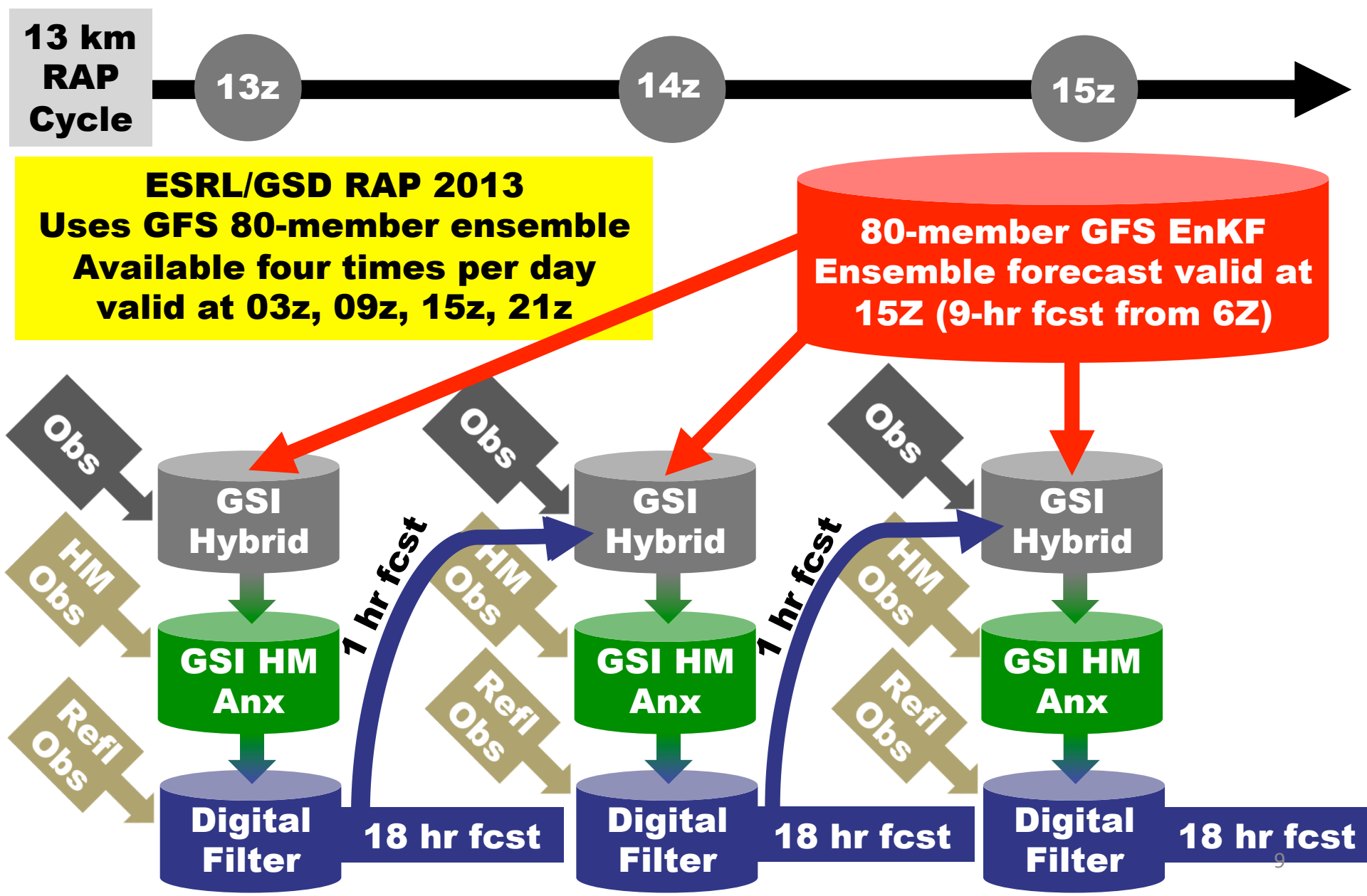
Temperature -- Similar RAPv2 skill for upper-air. **Improved skill for surface in warm season**

Precipitation and clouds – Improvement for precipitation, slight improvement for ceiling

RAP version 2 upgrades

Data Assimilation	Model
GFS EnKF-3DVAR hybrid data assimilation PBL-based 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	**Physics changes** MYJ → MYNN PBL scheme 9-layer RUC LSM (from 6-layer) MODIS land-use (fractional) Modified roughness length Revised Thompson cloud m-phys. **Higher-order numerics introduced** Positive definite scalar advection 5th-order vertical advection Update to WRFv3.4.1

RAPv2 Hybrid Data Assimilation

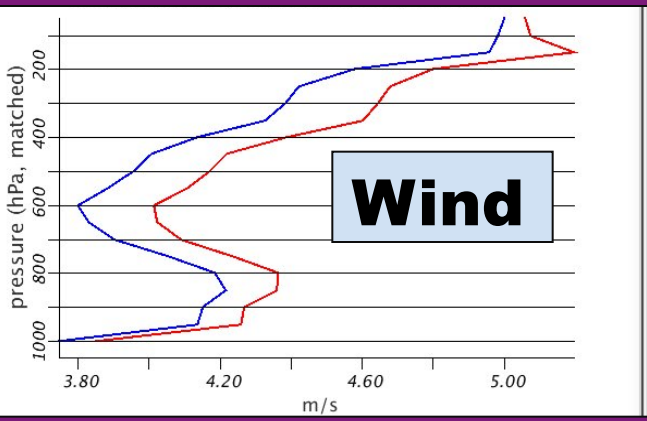


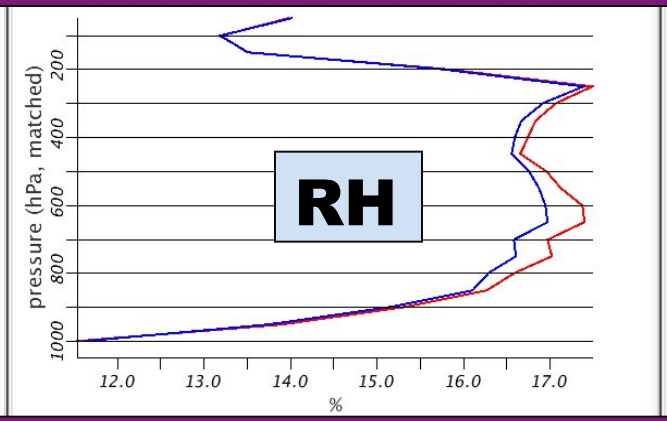
RAPv2 Hybrid Data Assimilation

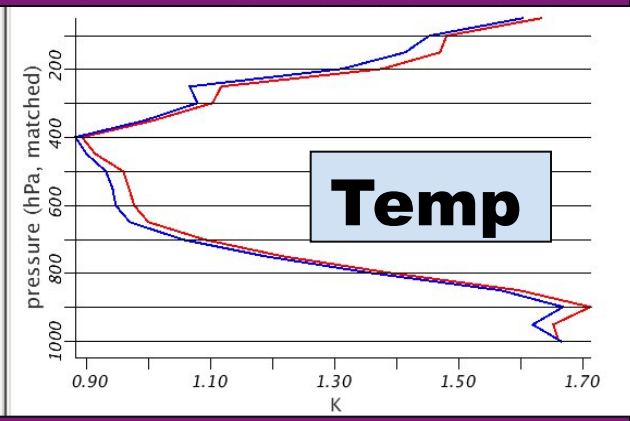
RMSE Vertical Profiles -- 22 Nov – 22 Dec 2012

RAPv2 Hybrid — RAPv1 No Hybrid (3D-VAR)

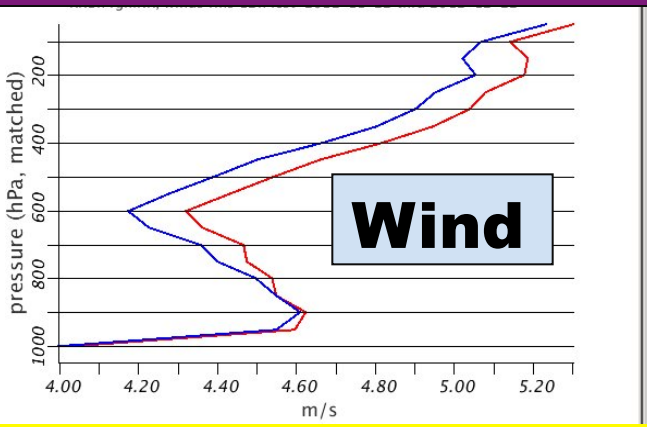
03-hr Forecast

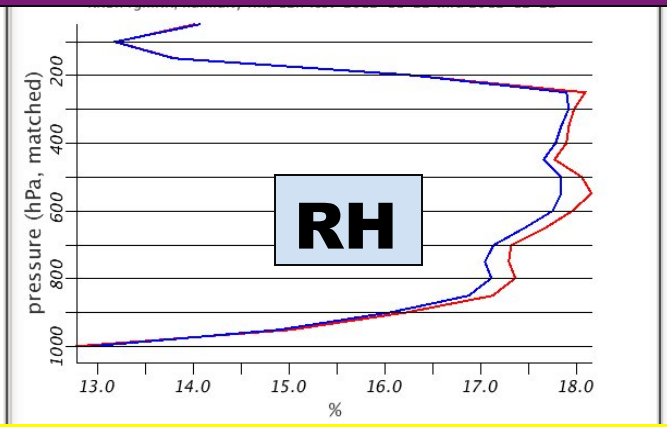


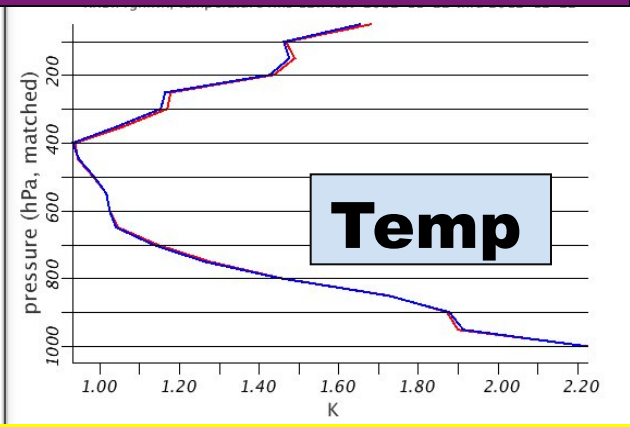




12-hr Forecast



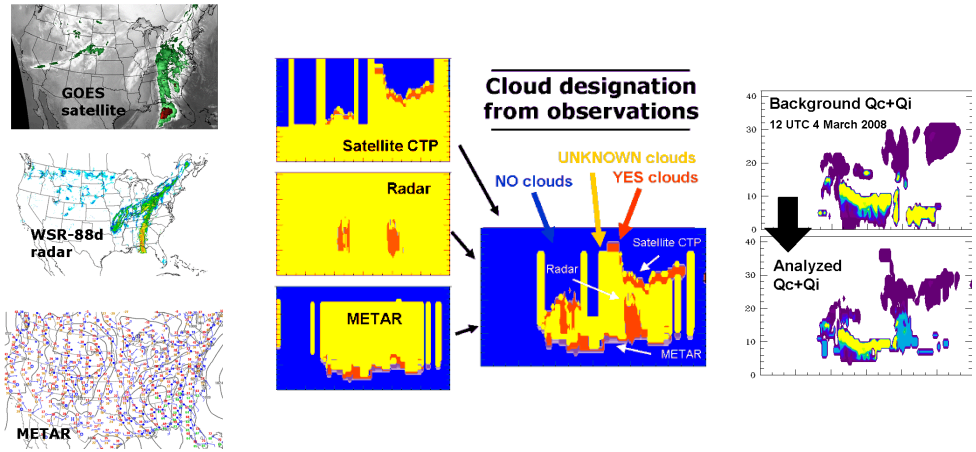




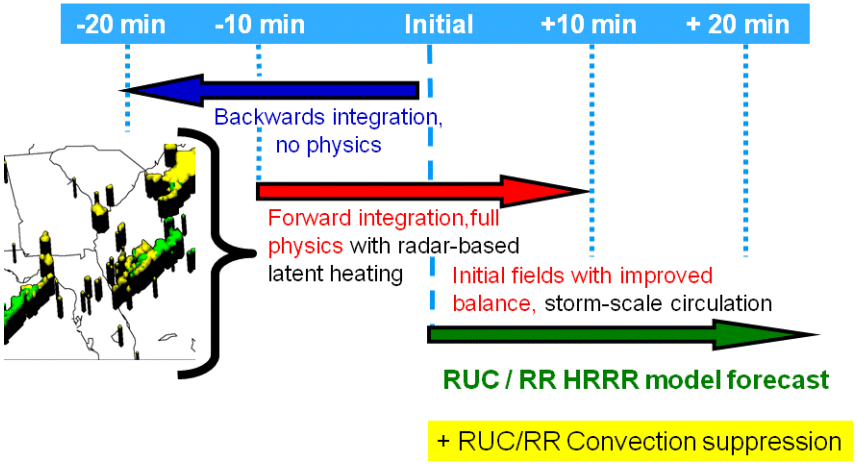
Improved upper-air environment

Rapid Refresh Specific Analysis Features

Cloud and hydrometeor analysis



Digital filter-based reflectivity assimilation (DDFI)



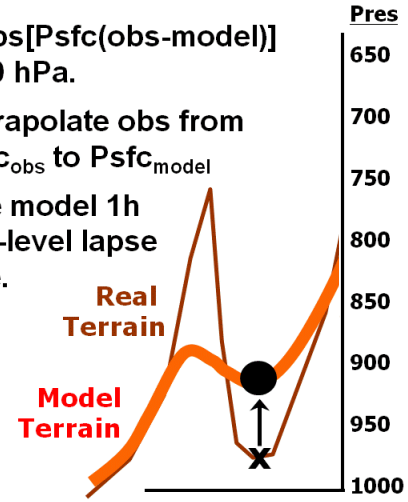
Special treatments for surface observations

Elevation correction

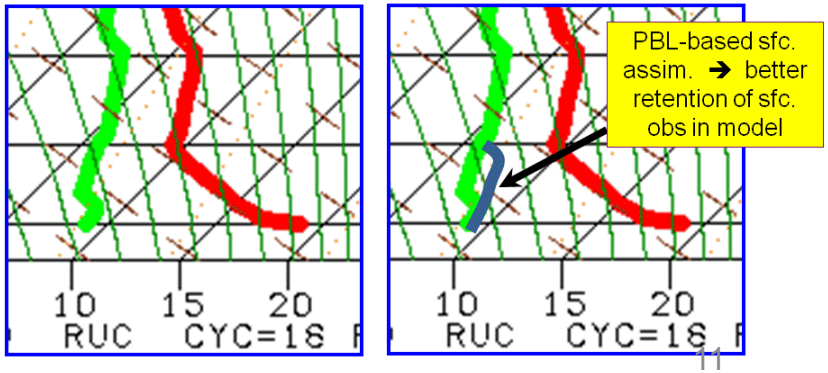
If abs[Psfc(obs-model)] < 70 hPa.

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

Use model 1h low-level lapse rate.

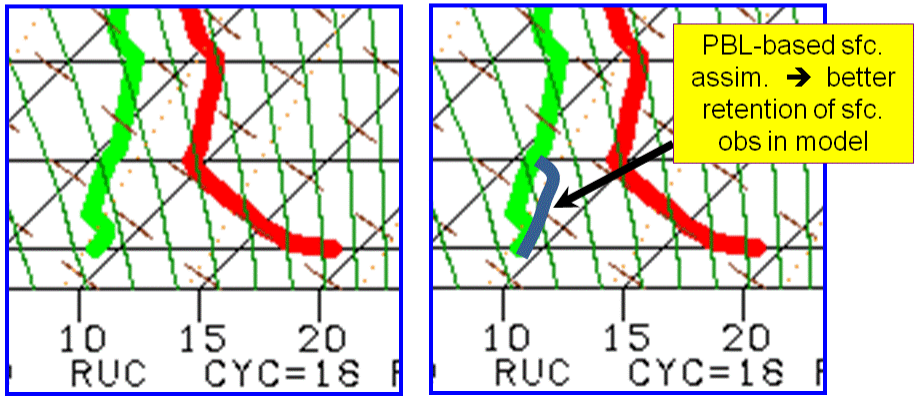


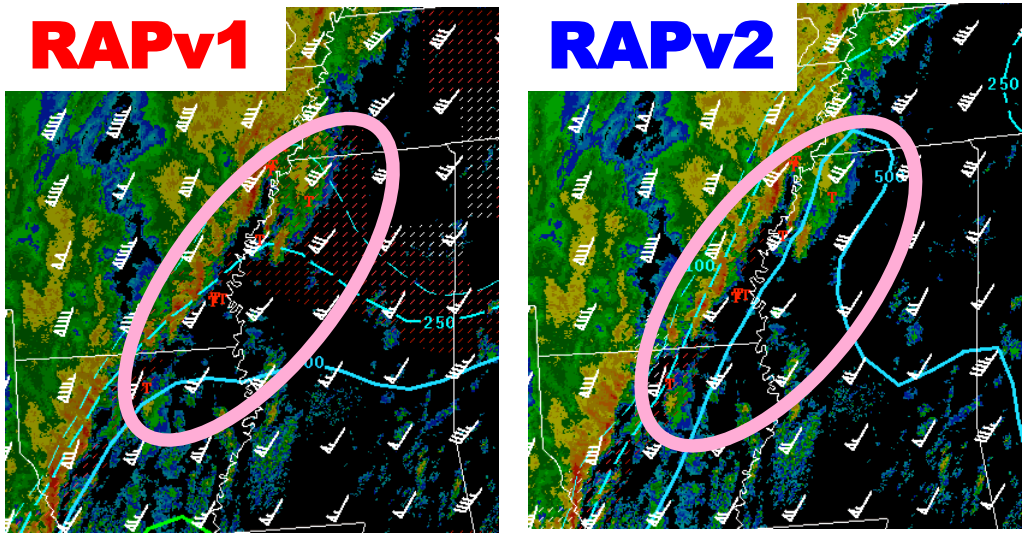
PBL-based pseudo-observations



RAPv2 PBL moisture pseudo-obs

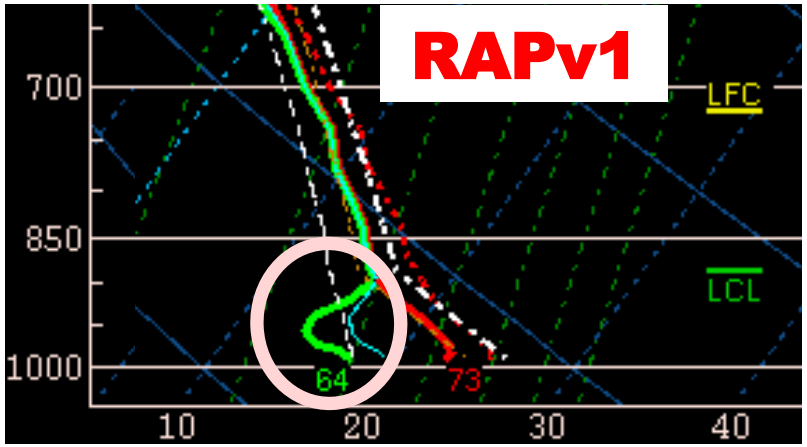
PBL-based pseudo-observations

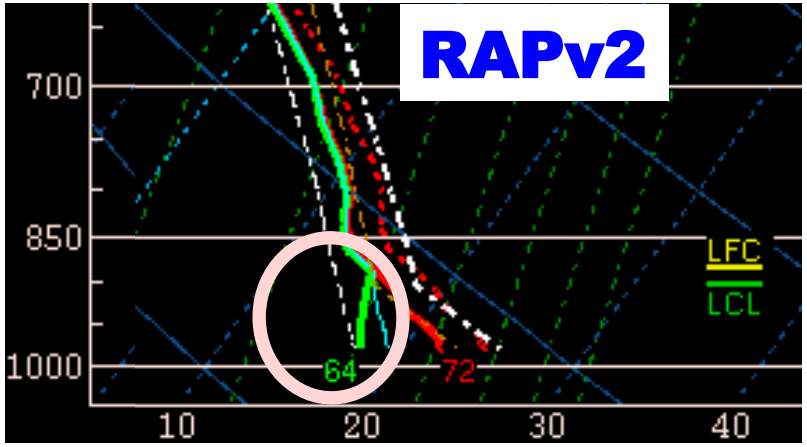




Model-based sfcOA MLCAPE/ CIN & EFF. SHEAR

MEM 21z 21 Dec 2013 Analyzed sounding





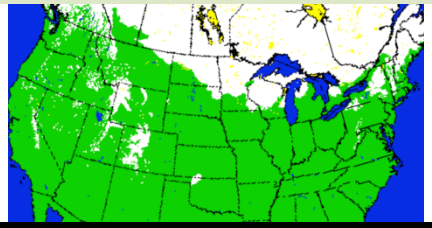
Images courtesy Israel Jirak, Steven Weiss, Phillip Bothwell, Andy Dean, Storm Prediction Center

Improved PBL moisture structure, crucial for RAP / HRRR

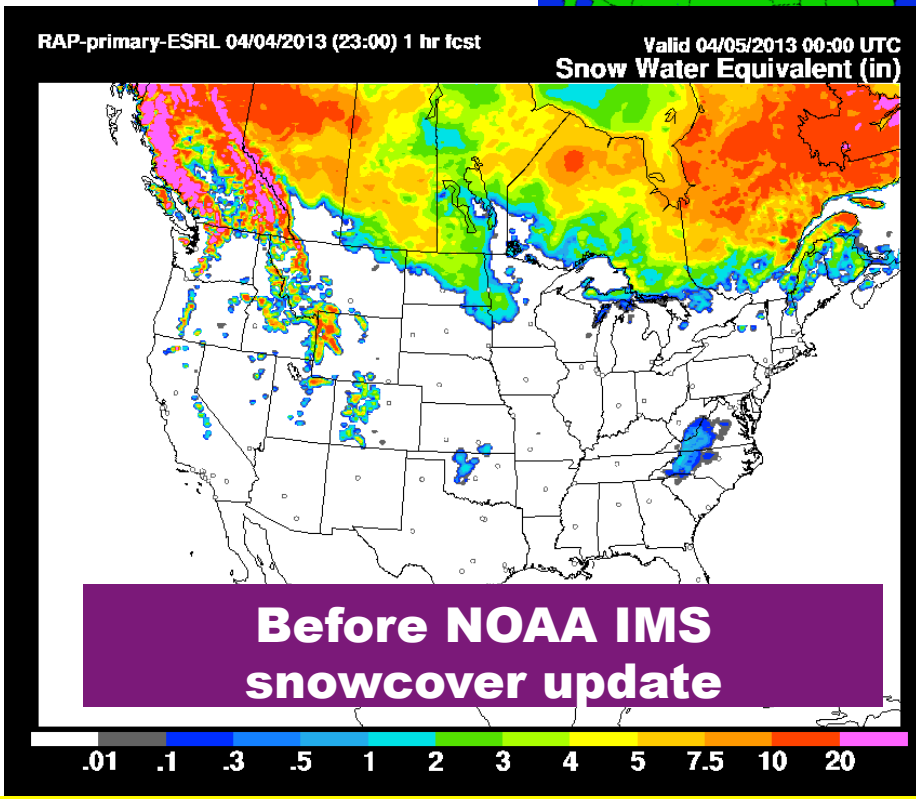
RAPv2 Snow Updating

Surface Snow Water Equivalent
Valid 00z 05 April 2013

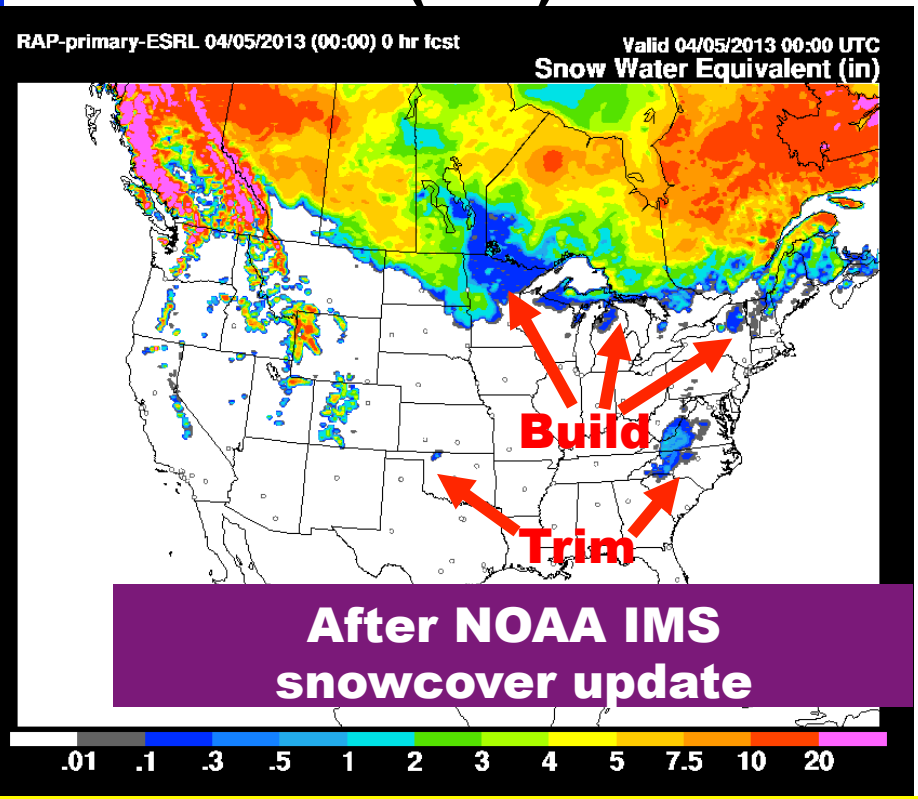
GSI Snow Cover Analysis (Run 00z Daily)



Using Interactive Multisensor Snow/Ice Mapping System (IMS)



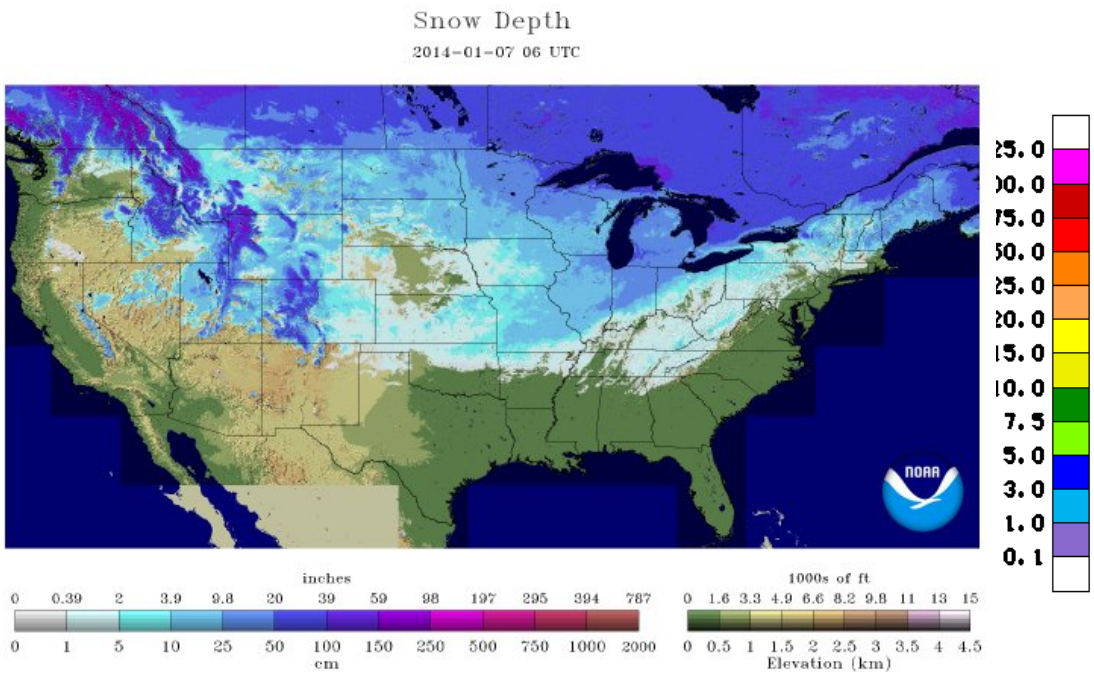
Before NOAA IMS snowcover update

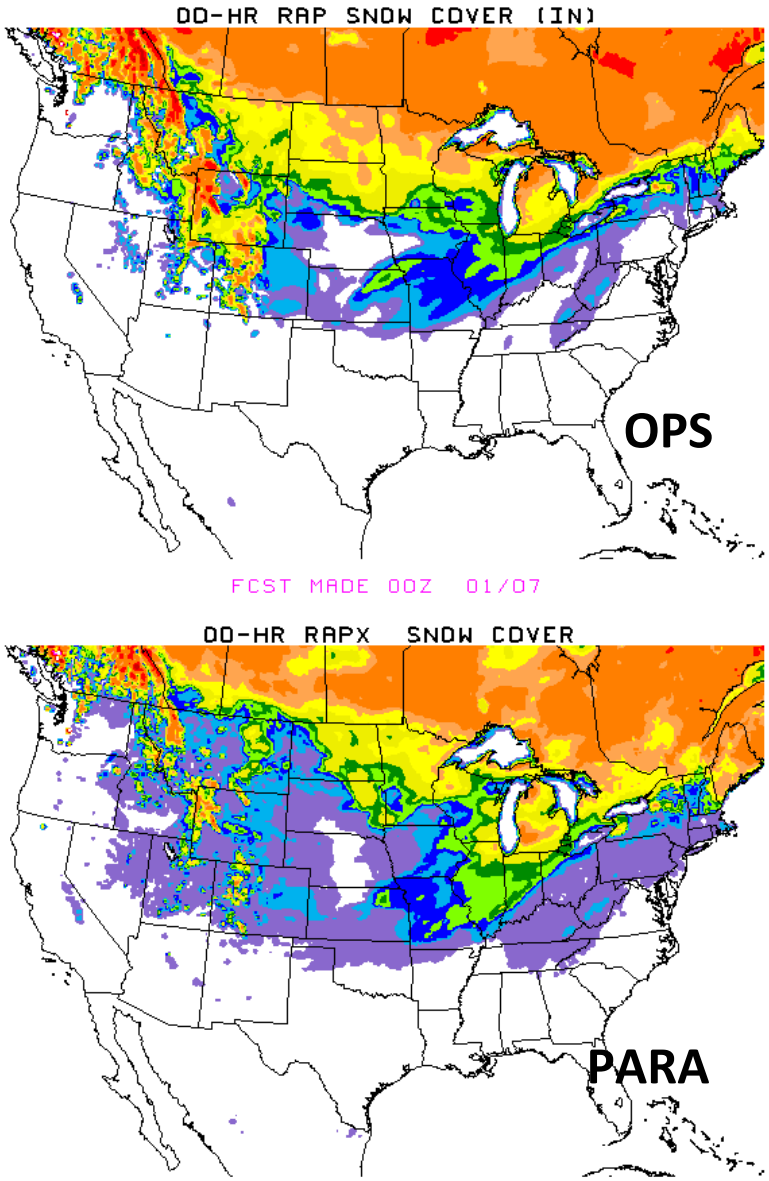


After NOAA IMS snowcover update

Improved snowcover

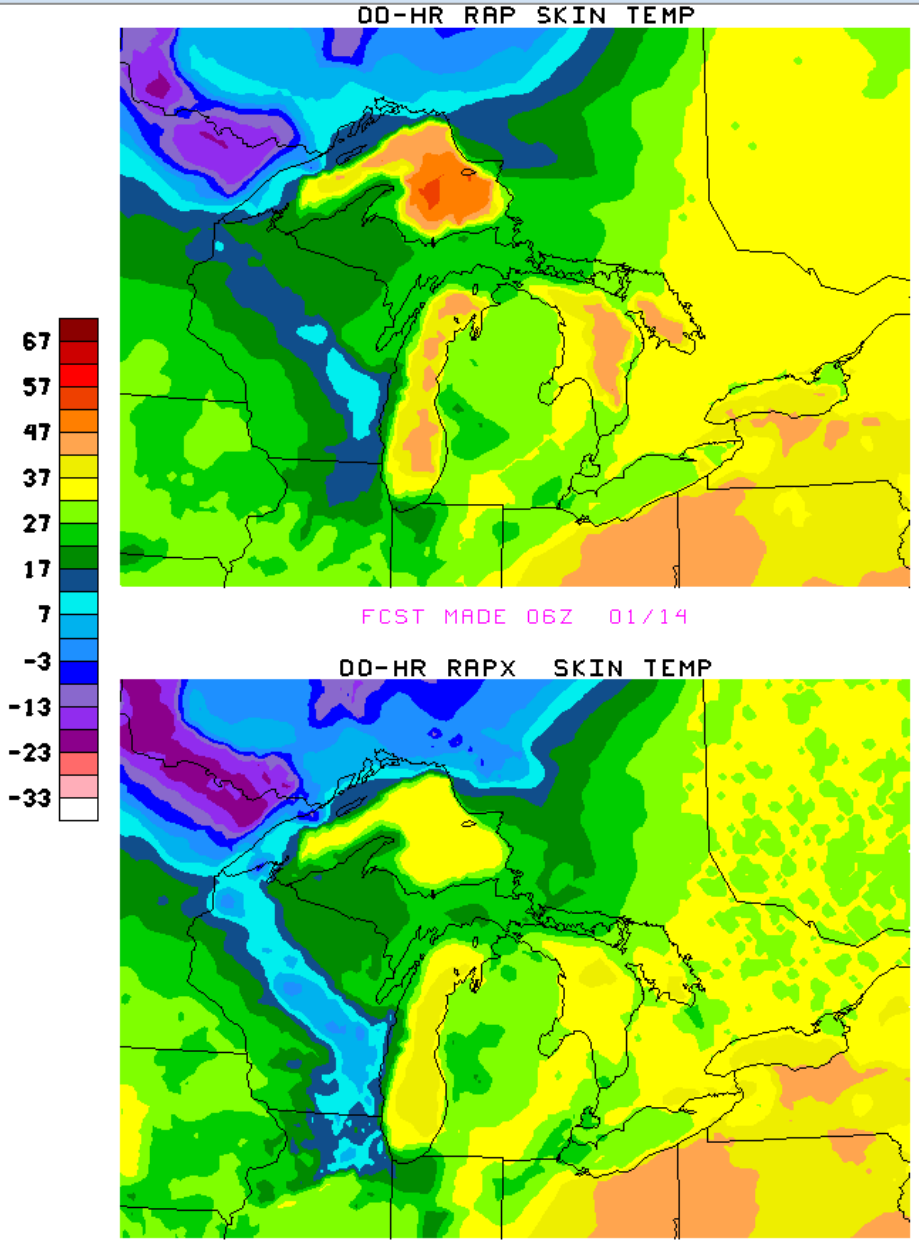
Snow Depth Analyses
00z 7 January 2014

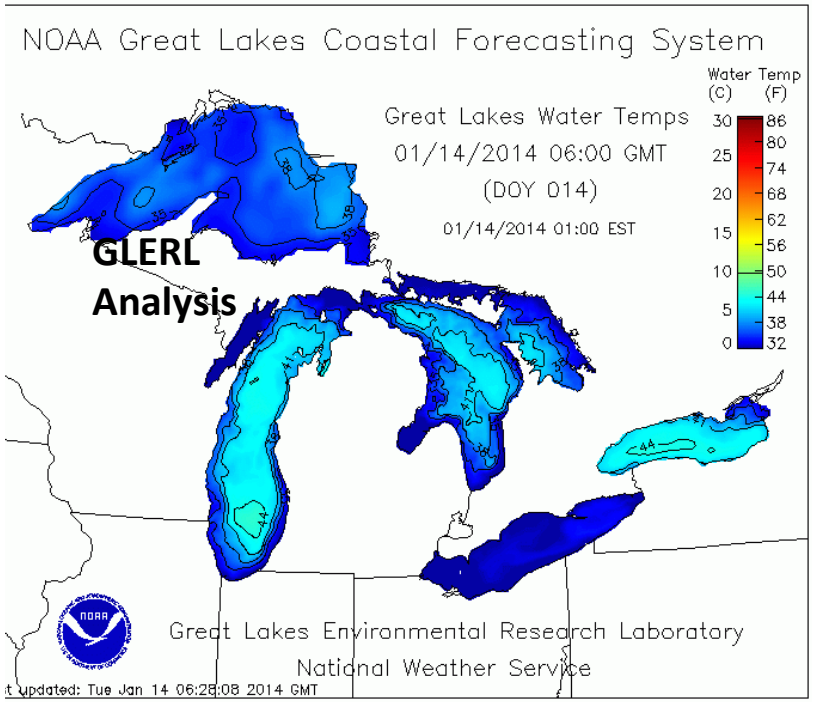




RAPv2 much better with snow depth initialization across KY/TN/OK/IL

Improved Lake Surface Temps - 06z 14 Jan 2014 Skin Temp





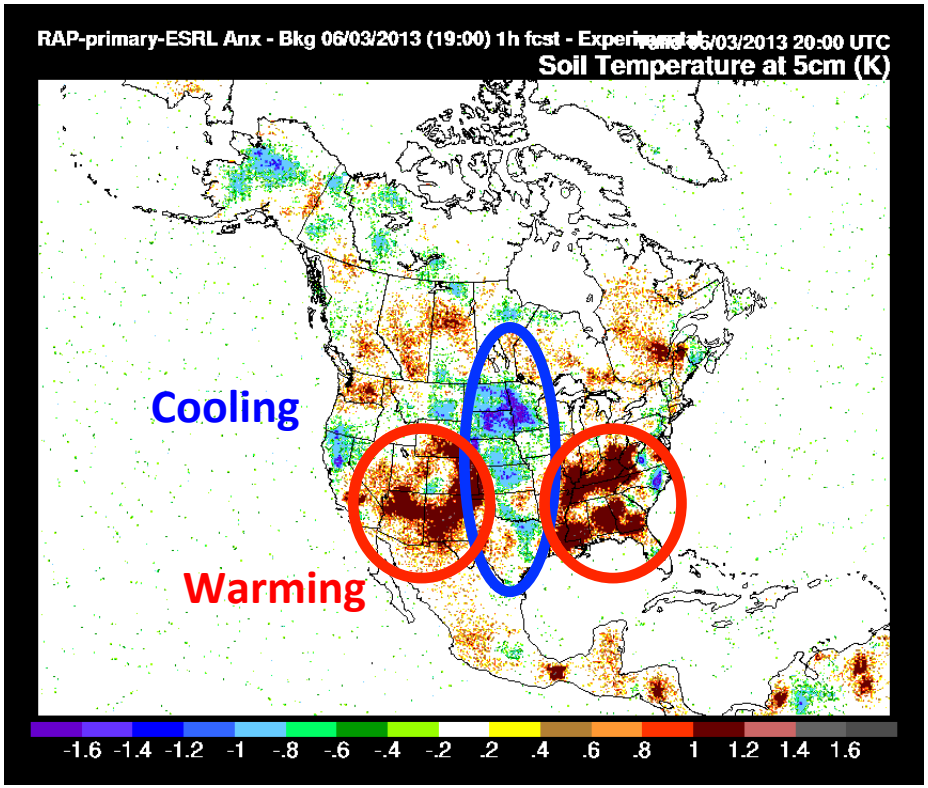
Para RAPv2 has moved to alternate handling of Great Lake temps; major improvement shown
(Also true for western US lakes)

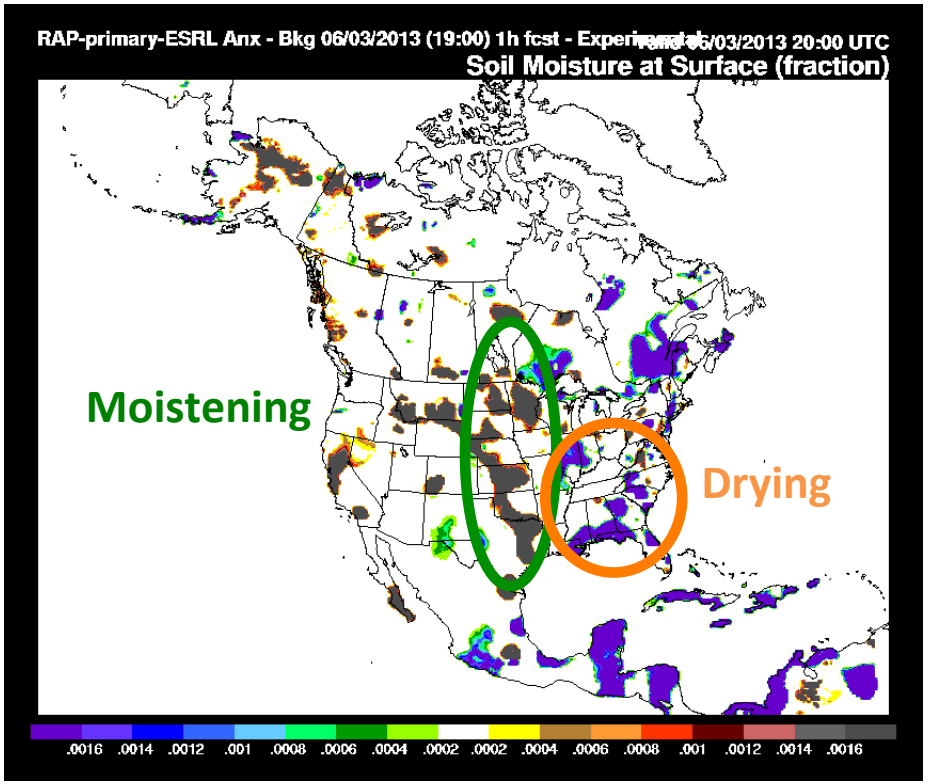
RAPv2 Soil Adjustment

Soil Temperature

Valid 20 UTC 03 June 2013

Soil Moisture



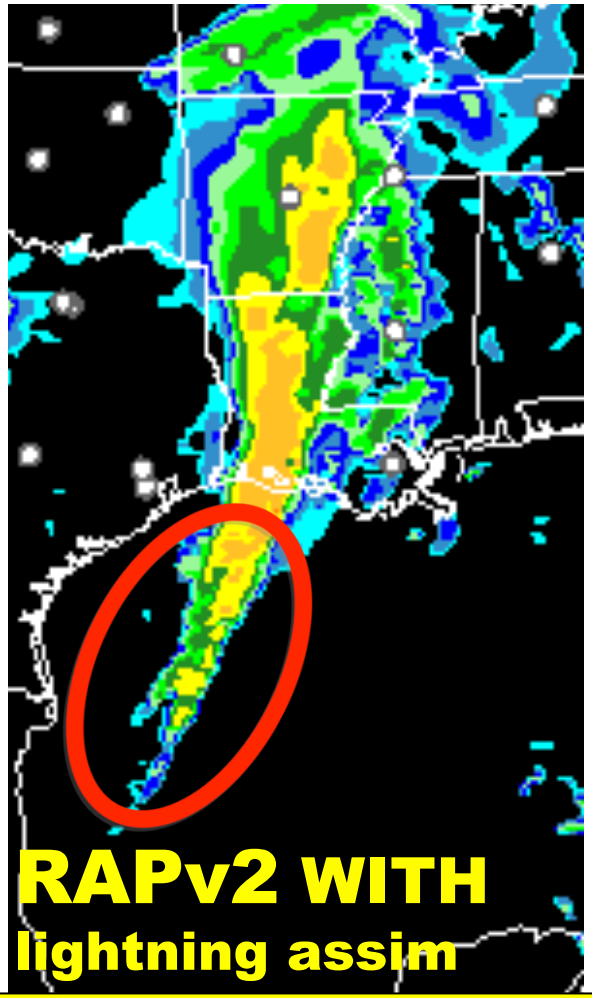


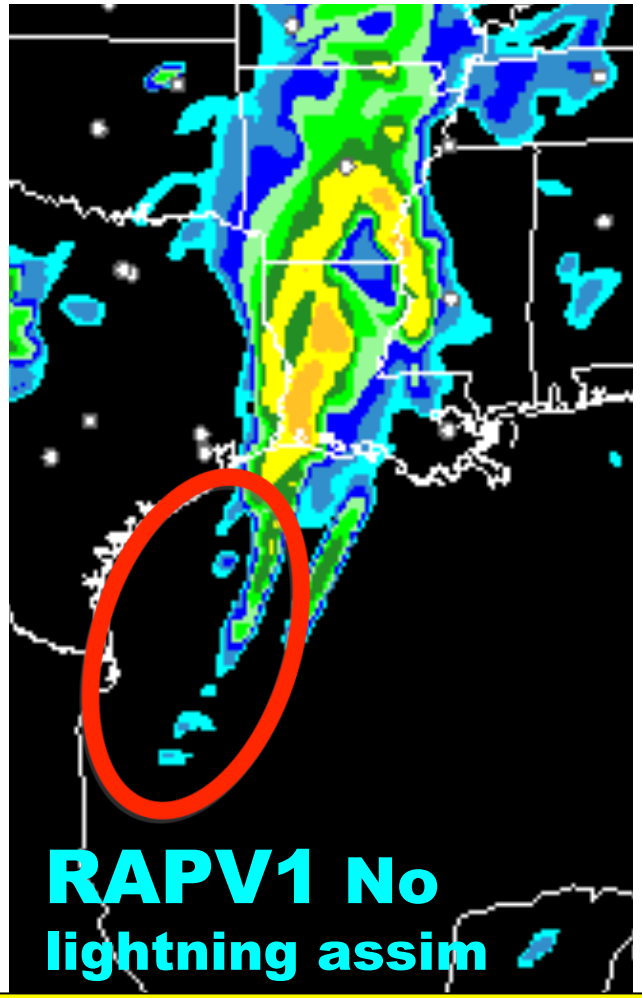
Based upon surface temperature and dewpoint analysis increments – new option within GSI. Critical also for HRRR

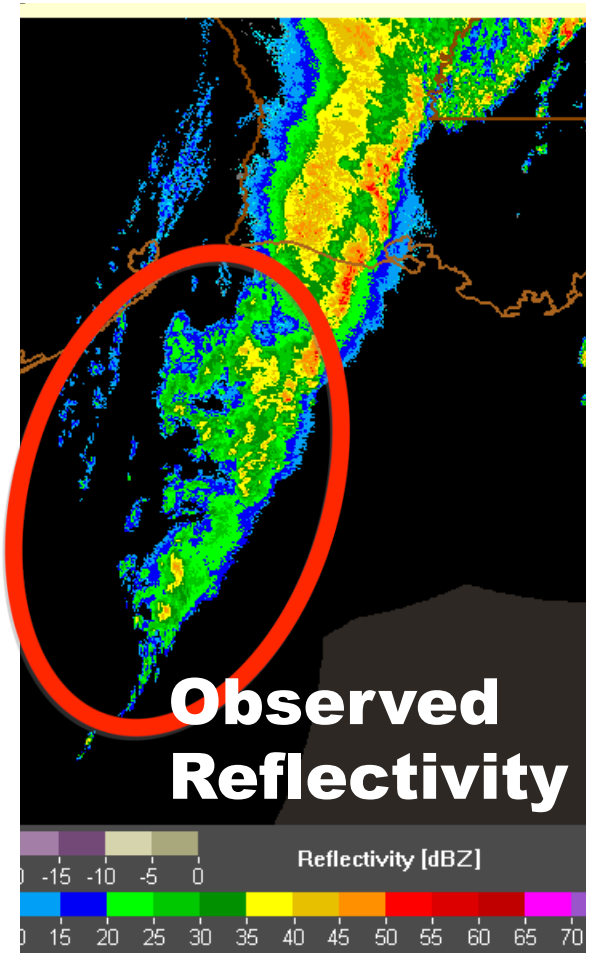
Improved soil, near-surface temperature, moisture

RAP Lightning Assimilation

Rapid Refresh – 0h valid 02z 26 Jan 2012







Improved convective coverage off the coast with lightning assimilation

RAP version 2 upgrades

Data Assimilation	Model
GFS EnKF-3DVAR hybrid data assimilation PBL-based 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	**Physics changes** MYJ → MYNN PBL scheme 9-layer RUC LSM (from 6-layer) MODIS land-use (fractional) Modified roughness length Revised Thompson cloud m-phys. **Higher-order numerics introduced** Positive definite scalar advection 5th-order vertical advection Update to WRFv3.4.1

Background on Mellor-Yamada-Nakanishi-Niino (MYNN) PBL Scheme

Joe Olson - GSD

- Implemented into WRF-ARW in 2009 (v3.1).
- Main features of the MYNN include:
  - Turbulent kinetic energy (TKE)-based local mixing scheme (like MYJ)
  - Option to run at level 2.5 or 3.0 closure.
  - Liquid water potential temperature, θ_l [$= \theta - (\theta/T)(L_v/c_p)q_l$], and total water content, q_w ($= q_v + q_l$), are used as thermodynamic variables.
  - Tuned to a database of LES simulations in order to overcome the typical biases associated with other MY-type schemes (insufficient growth of convective boundary layer and underestimated TKE).
  - More elaborate **mixing length formulations** to flexibly change behavior across the stability spectrum. **Major change by Olson (GSD).**
  - Initially adopted a very simple surface layer scheme, taken from an old version of the YSU surface layer scheme, **with very little customization to the PBL scheme**. **Major changes by Olson (GSD).**

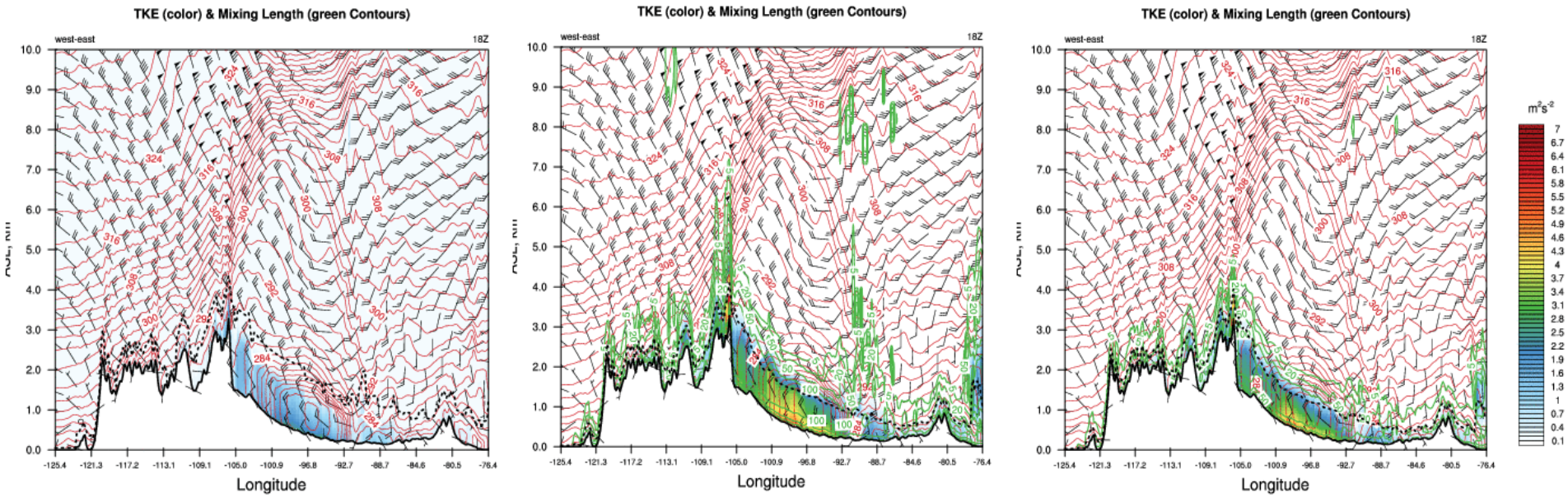
Example of Overall Impact on PBLH & TKE

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

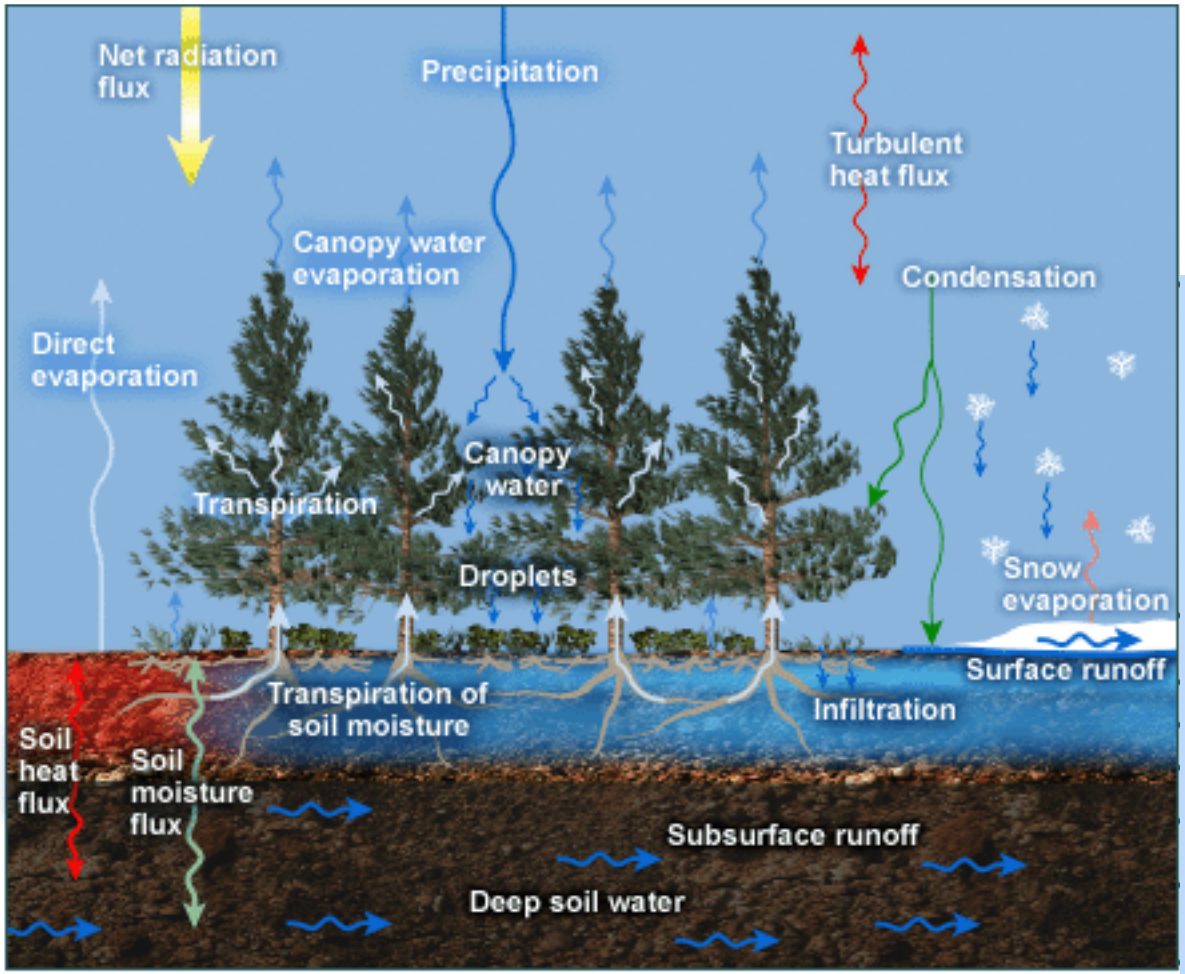
MYJ | **MYNN-original** | **MYNN-modified**



- 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 [$K_h = S_h l_m (TKE)^{1/2}$].

RAPv2 Model Update – 9-lev RUC LSM

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

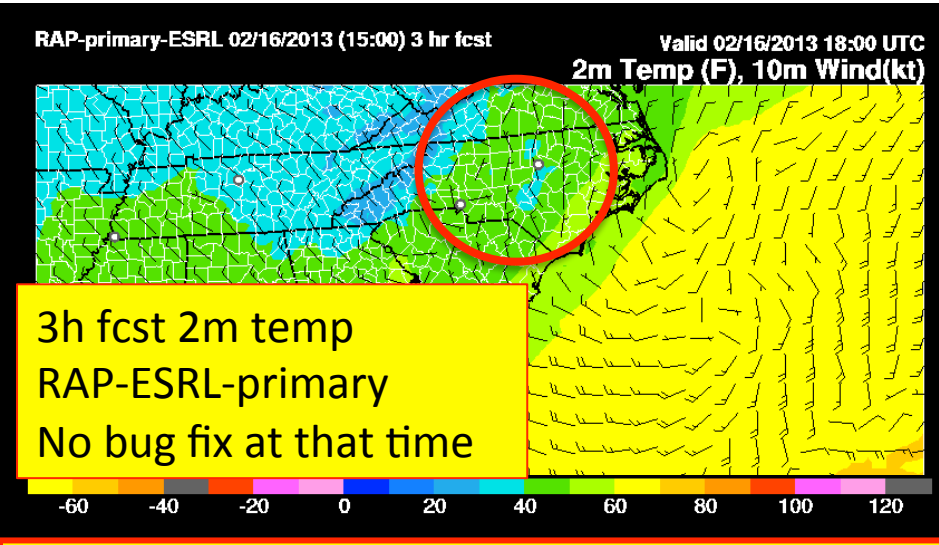


RUC Vegetation and Soil Model

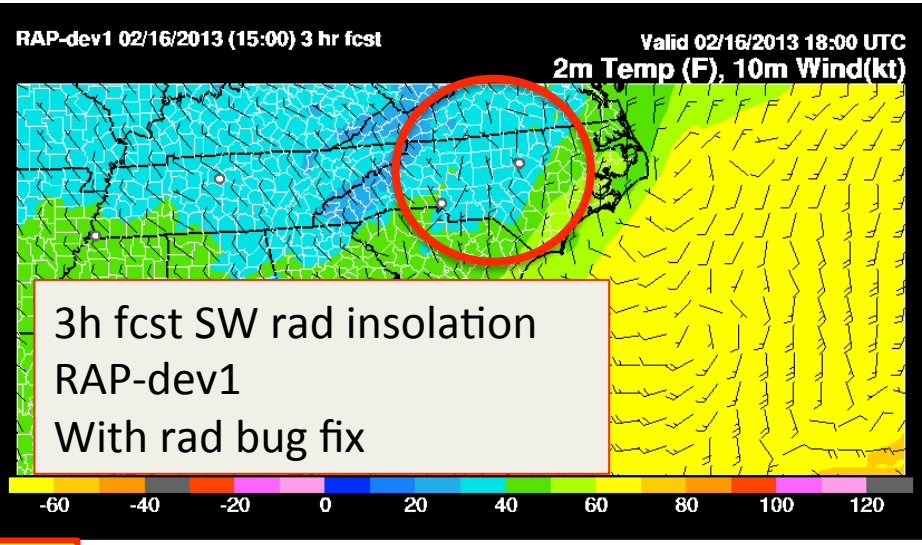
The COMET

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



3h fcst 2m temp
RAP-ESRL-primary
No bug fix at that time



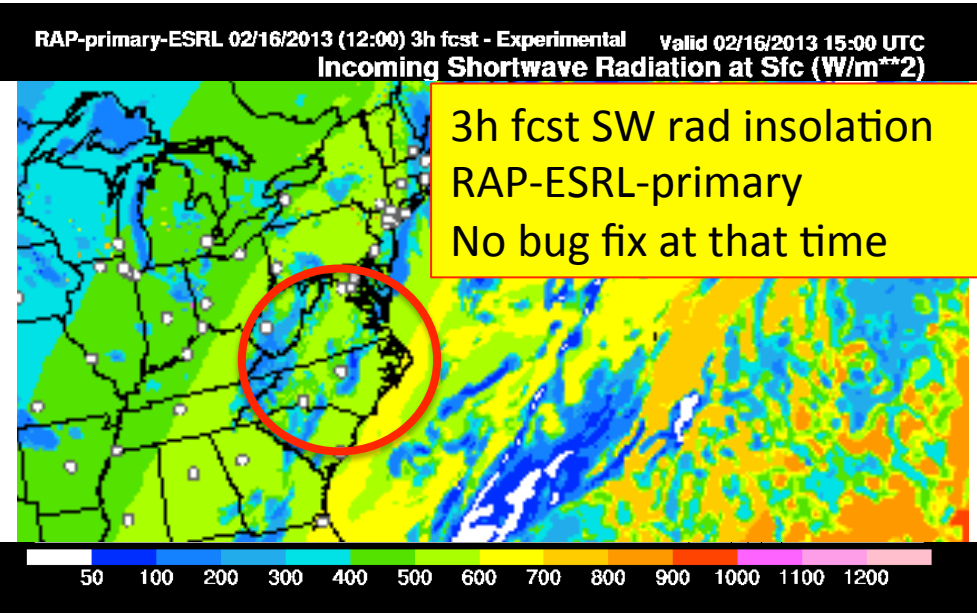
3h fcst SW rad insolation
RAP-dev1
With rad bug fix

RAP-NCEP 2m temp/ptype bust
Sat 16 February 2013

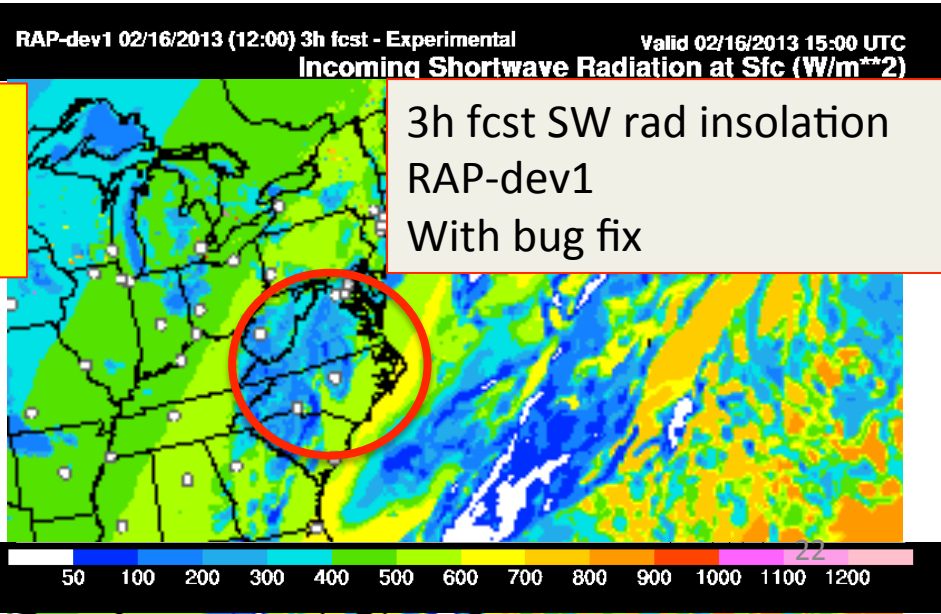
Courtesy - Jonathan Blaes – NWS Raleigh

Traced to WRF radiation bug – no attenuation for snow mixing ratio

Fixed in RAPv2



3h fcst SW rad insolation
RAP-ESRL-primary
No bug fix at that time



3h fcst SW rad insolation
RAP-dev1
With bug fix

Similar situation in recent Atlanta snow event 1/28/14

06z RAP

STN	YYMMDD/HHMM	2-m T T2MS	1-hr pcp P01I
722190	140128/1200	-1.90	0.00
722190	140128/1300	-1.30	0.00
722190	140128/1400	0.60	0.00
722190	140128/1500	3.10	0.00
722190	140128/1600	3.80	0.00
722190	140128/1700	2.40	0.01
722190	140128/1800	**2.40**	0.03
722190	140128/1900	**3.40**	0.07
722190	140128/2000	**3.90**	0.06
722190	140128/2100	**4.00**	0.04
722190	140128/2200	**2.60**	0.03
722190	140128/2300	0.20	0.04
722190	140129/0000	-0.90	0.02

06z RAPX (RAPv2)

STN	YYMMDD/HHMM	2-m T T2MS	1-hr pcp P01I
722190	140128/1200	-2.70	0.00
722190	140128/1300	-2.10	0.00
722190	140128/1400	-0.20	0.00
722190	140128/1500	1.10	0.00
722190	140128/1600	1.70	0.00
722190	140128/1700	2.00	0.00
722190	140128/1800	1.10	0.00
722190	140128/1900	-1.60	0.02
722190	140128/2000	-2.00	0.05
722190	140128/2100	-1.90	0.04
722190	140128/2200	-1.30	0.04
722190	140128/2300	-1.60	0.01
722190	140129/0000	-2.40	0.01

Ops RAP showing temperatures well above freezing during snow; colder in RAPX

28 January 2014 Birmingham, AL snow

06z RAP

STN	YYMMDD/HHMM	2-m T T2MS	1-hr pcp P01I
722280	140128/1200	-4.80	0.00
722280	140128/1300	-4.80	0.00
722280	140128/1400	-3.90	0.00
722280	140128/1500	-3.30	0.00
722280	140128/1600	-3.70	0.03
722280	140128/1700	**-2.50**	0.05
722280	140128/1800	**-2.00**	0.06
722280	140128/1900	-2.10	0.04
722280	140128/2000	-2.10	0.03
722280	140128/2100	-2.30	0.02
722280	140128/2200	-3.60	0.00
722280	140128/2300	-4.20	0.00

06z RAPX (RAPv2)

STN	YYMMDD/HHMM	2-m T T2MS	1-hr pcp P03I
722280	140128/1200	-5.70	0.00
722280	140128/1300	-5.60	0.00
722280	140128/1400	-5.50	0.00
722280	140128/1500	-5.10	0.00
722280	140128/1600	-5.70	0.00
722280	140128/1700	**-6.80**	0.02
722280	140128/1800	**-6.40**	0.04
722280	140128/1900	-4.50	0.04
722280	140128/2000	-3.30	0.01
722280	140128/2100	-3.30	0.00
722280	140128/2200	-2.70	0.00
722280	140128/2300	-3.20	0.00

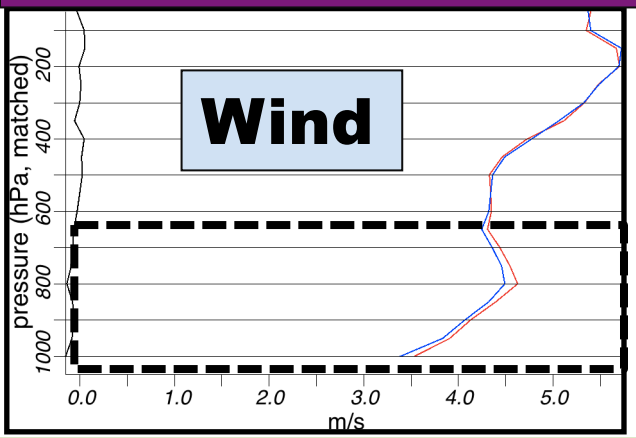
RAPv1 too warm with sfc temperatures which were in the -7C range during the snow

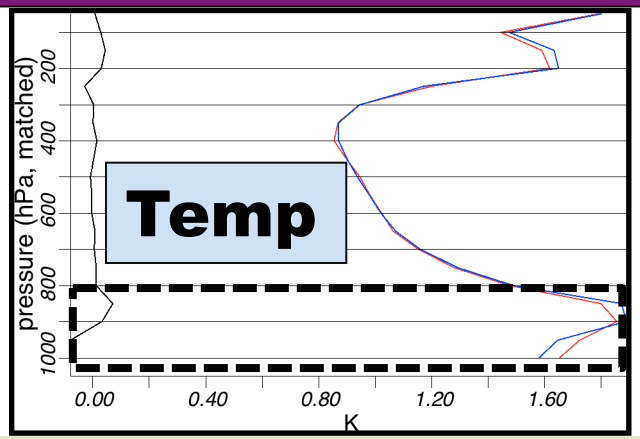
Verification - RAPv2 Model Update

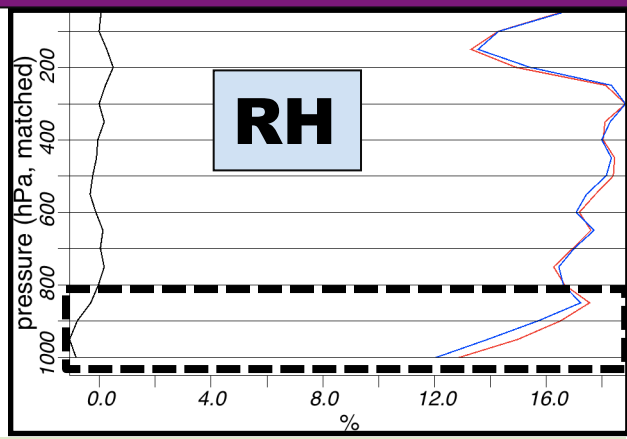
RMSE Vertical Profiles: Soundings 14 Jan – 11 Feb 2013

V2-MYNN, 9-level RUC LSM — **v1-MYJ, 6-level RUC LSM**

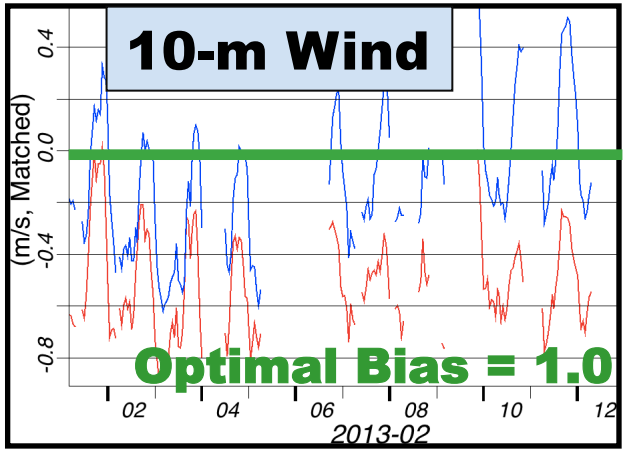
06-hr Forecast

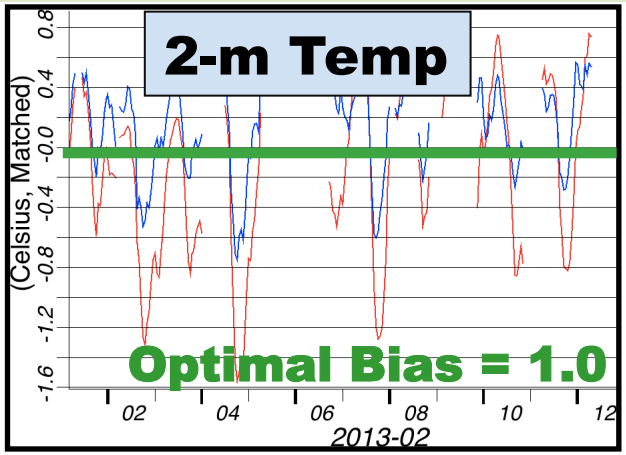


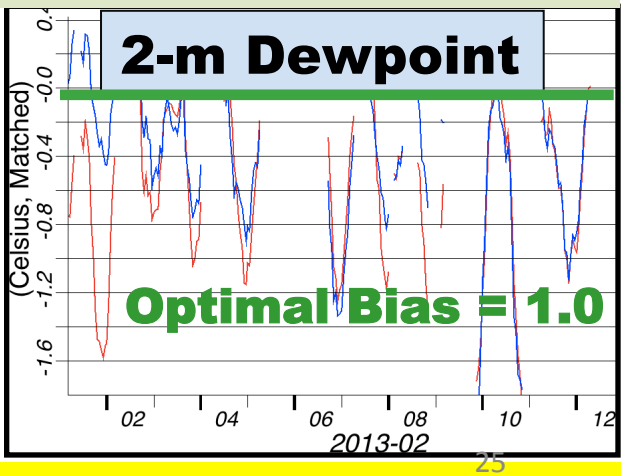




BIAS (Observed – Forecast) 01 Feb – 11 Feb 2013

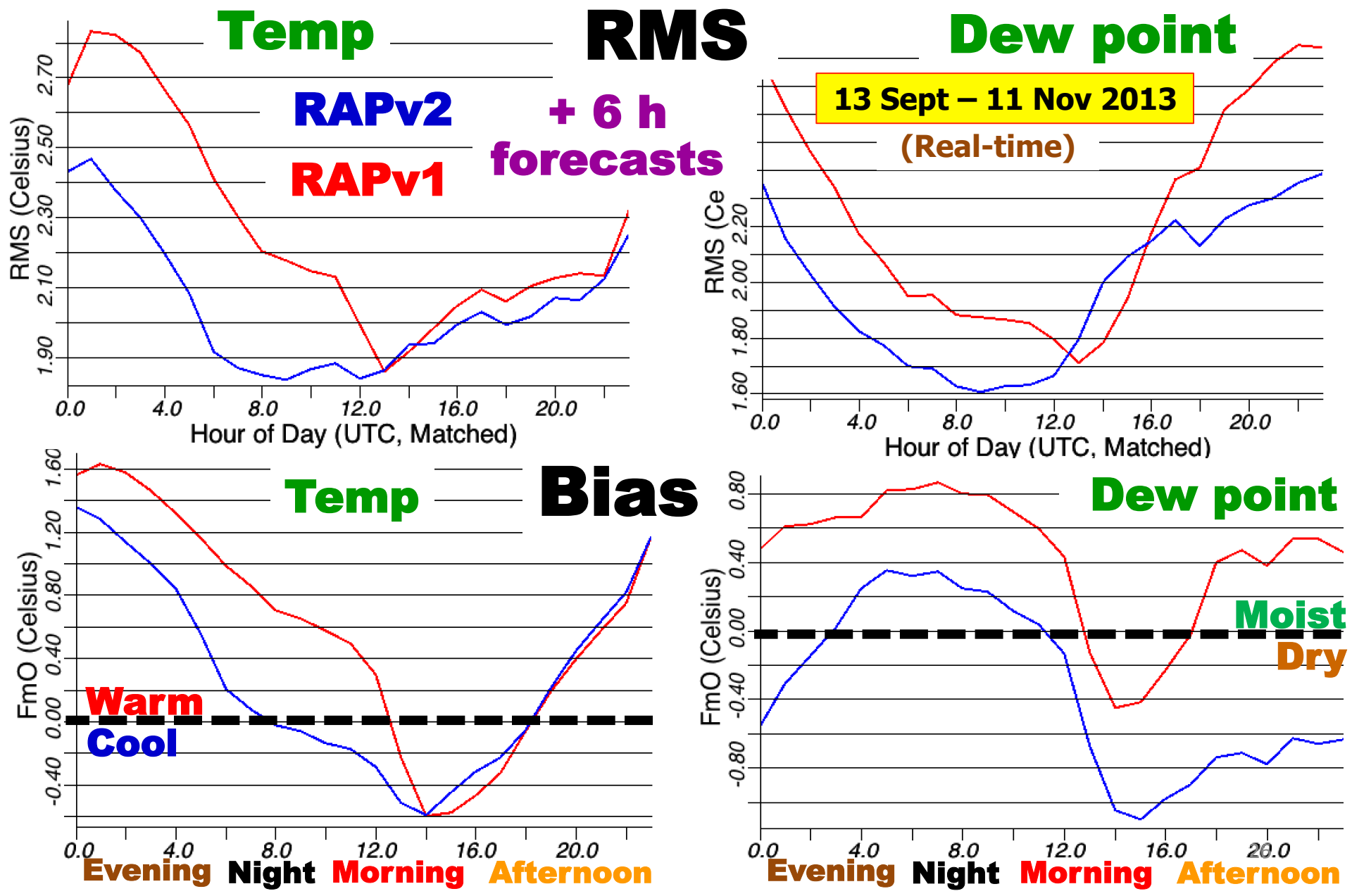






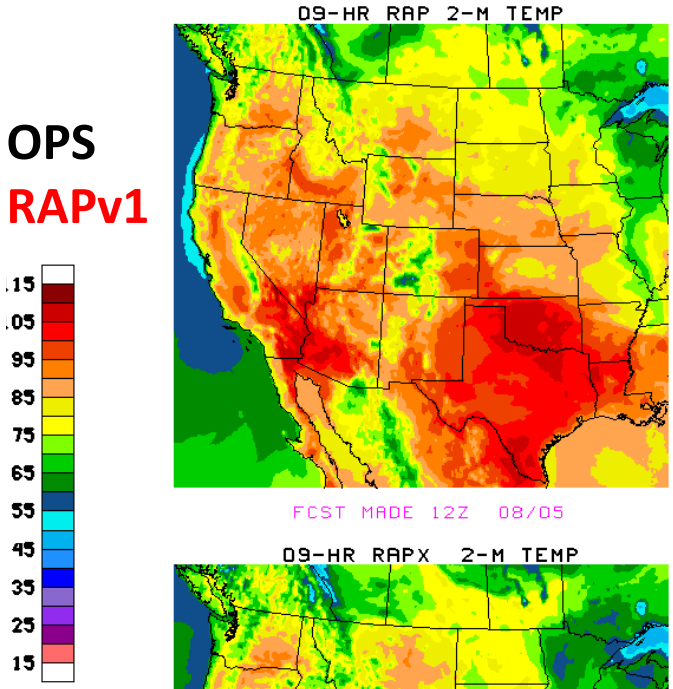
Improved near-surface environment

2m T and Td: RAPv2 vs. oper RAPv1

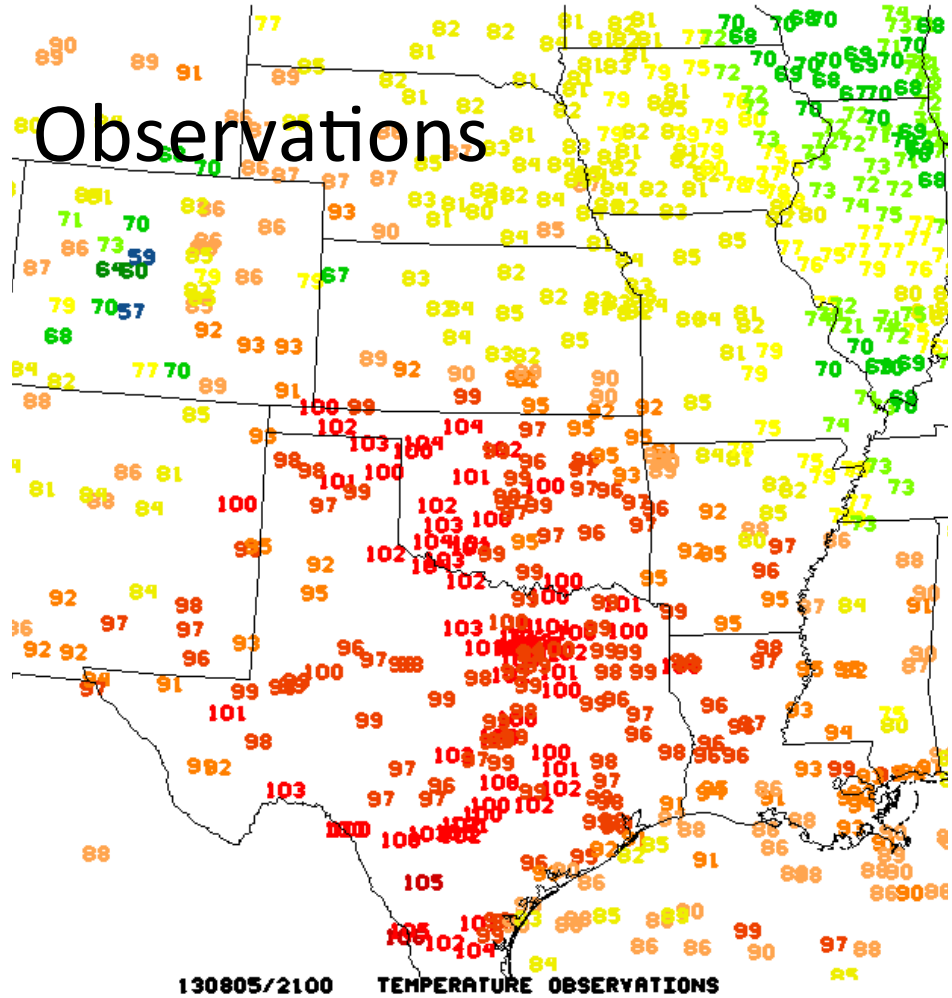


9-hr 2m Temp Forecasts 12z 5 August 2013

OPS
RAPv1

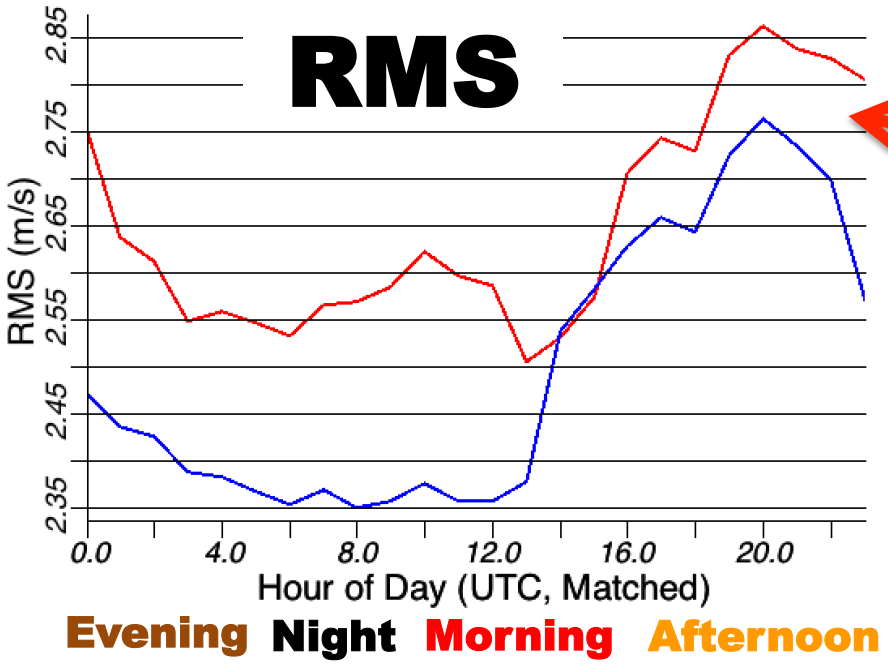


PARA
RAPv2



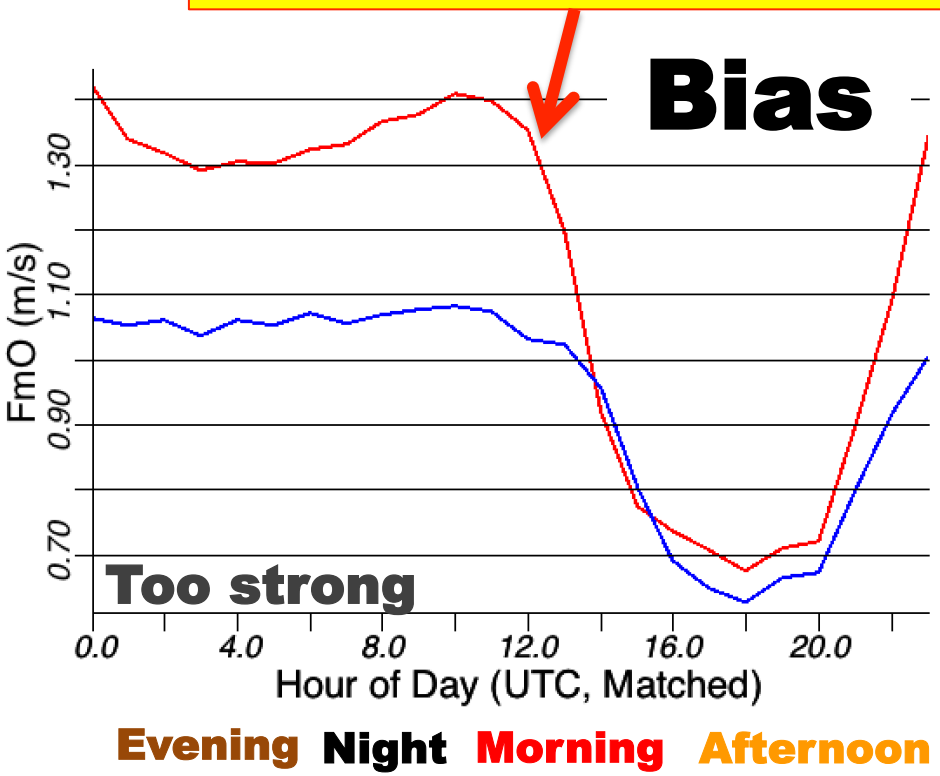
RAPv1 too warm across OK, much improved with RAPv2

10m winds: RAPv2 vs. oper RAPv1



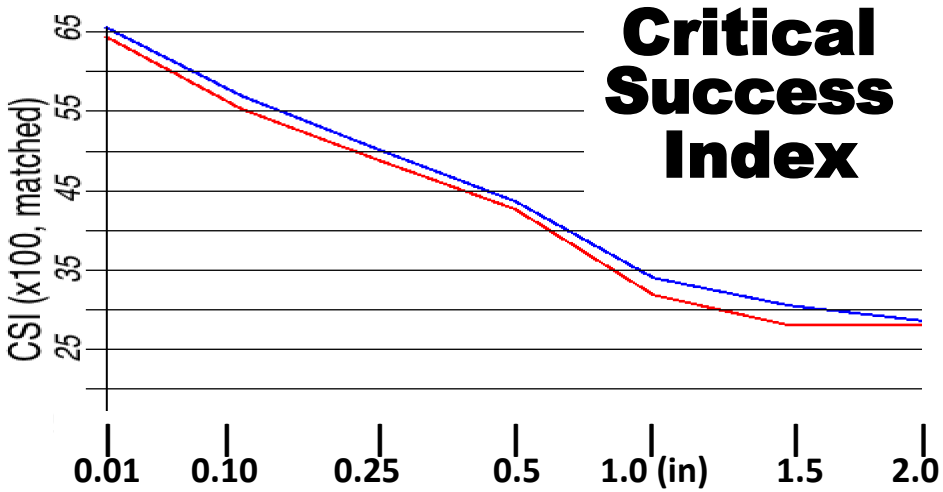
RAPv2 has lower **RMS** vector 10m wind errors than RAPv1 at all times of day.

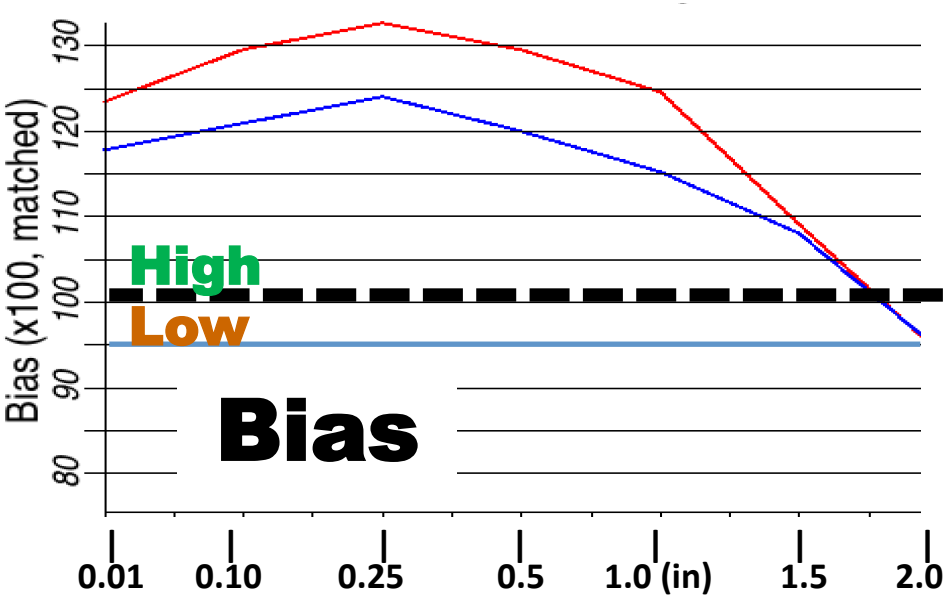
RAPv2 has lower (better) positive 10m wind speed **bias (F-O)** than RAPv1 at all times of day



6h <u>10m wind</u> forecasts
Eastern/Central US
12 Sept – 11 Nov 2013
RAPv1 vs. **RAPv2**

12-h precip: RAPv2 vs. oper RAPv1





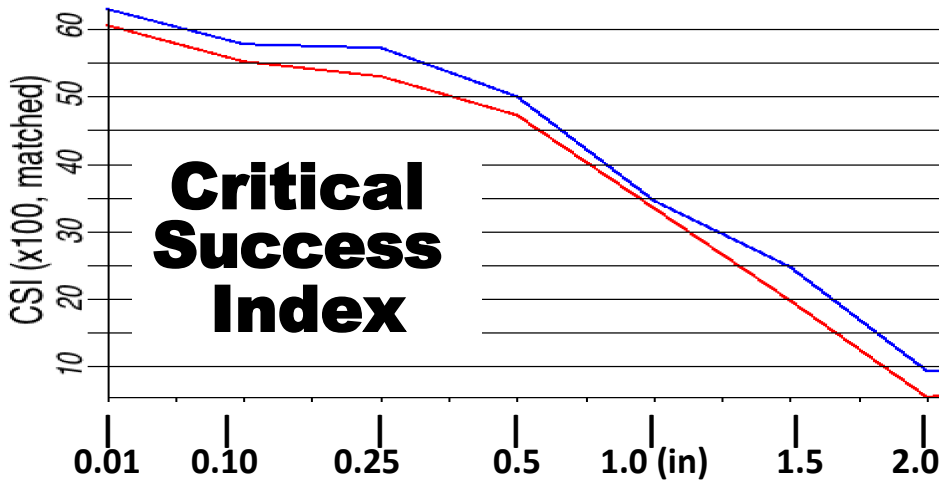
RAPv2
vs.
RAPv1
24-h precip. verification

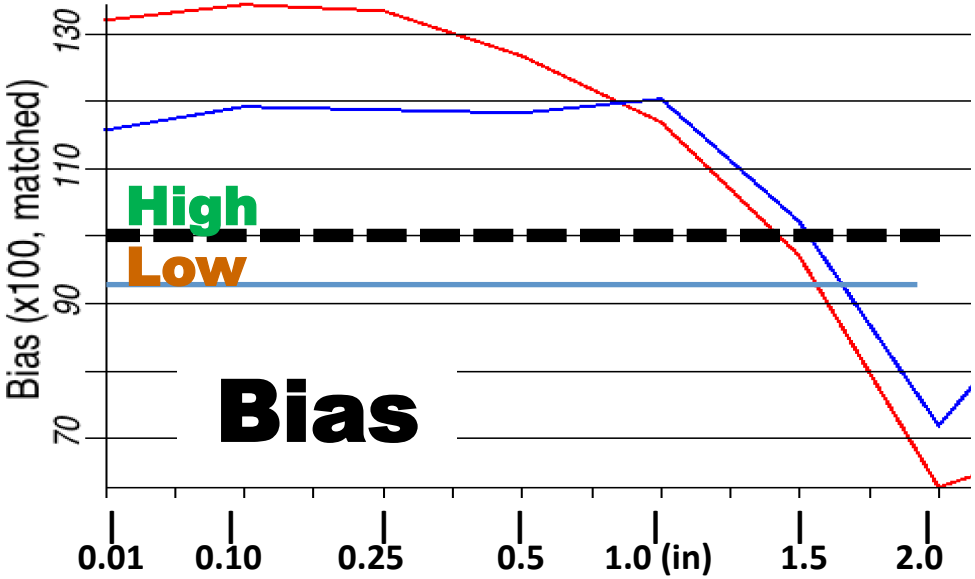
Fall 2013

2 x 12h fcst
13 Oct – 11 Nov 2013

Interpolated to 40-km grid

12-h precip: RAPv2 vs. oper RAPv1





RAPv2
vs.
RAPv1
24-h precip. verification

Winter 13-14

2 x 12h fcst
28 Dec 13 – 6 Feb 14
Interpolated to 40-km grid

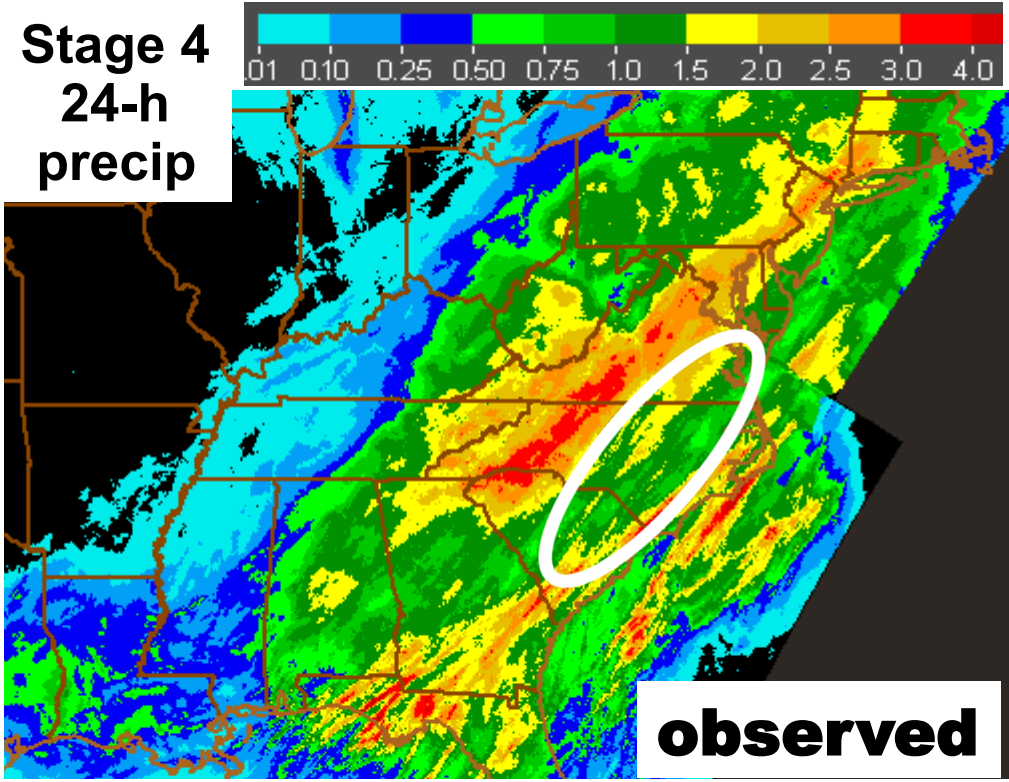
Precipitation forecasts –

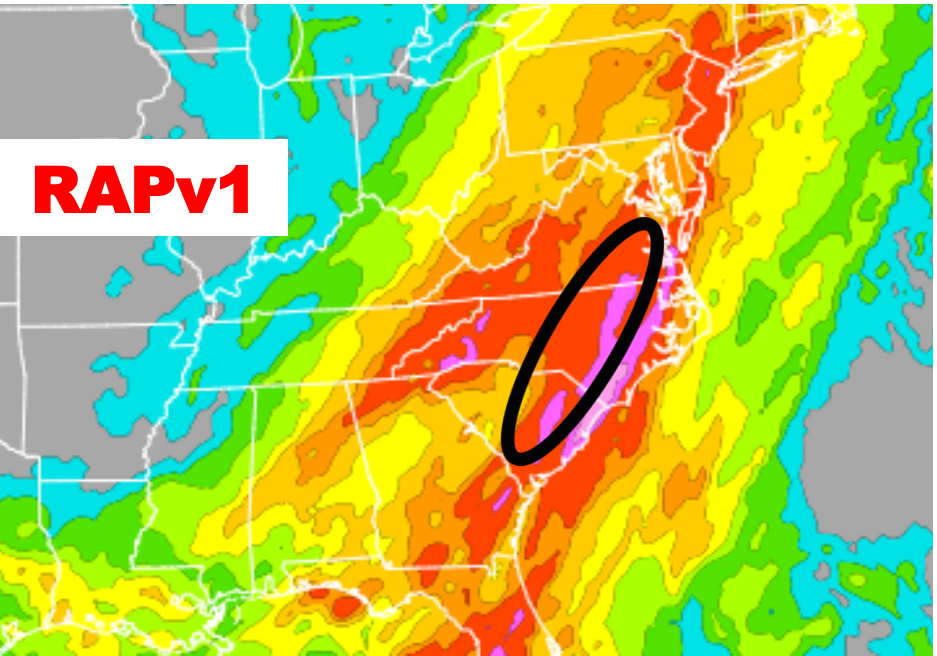
- RAPv2 better CSI than RAPv1
- RAPv2 bias closer to 1.0 at almost every threshold

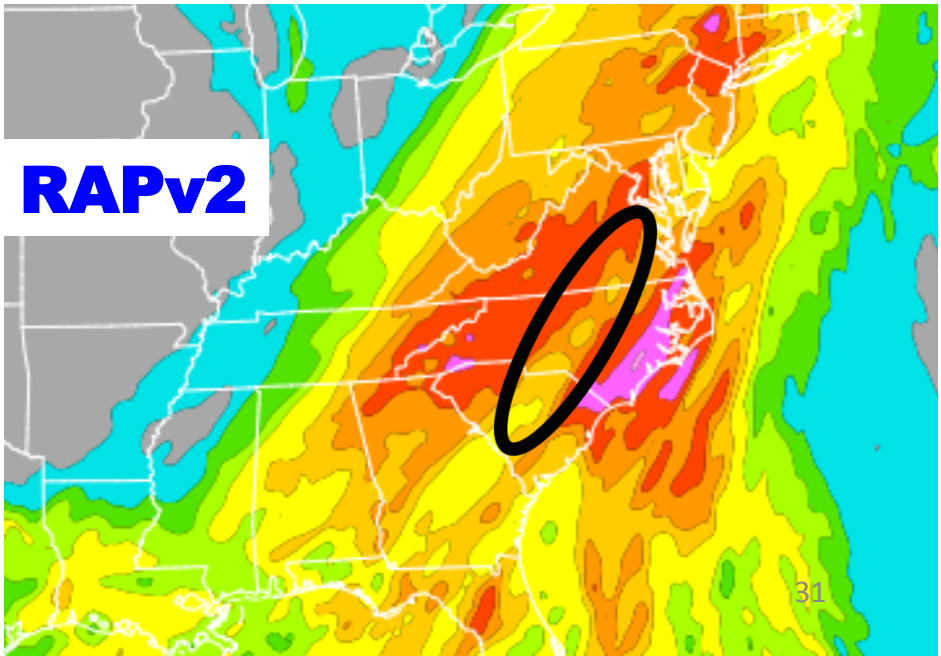
Precipitation Forecasts

RAPv2
vs.
RAPv1

2 x 12h fcst
ending 12z
27 Nov 2013



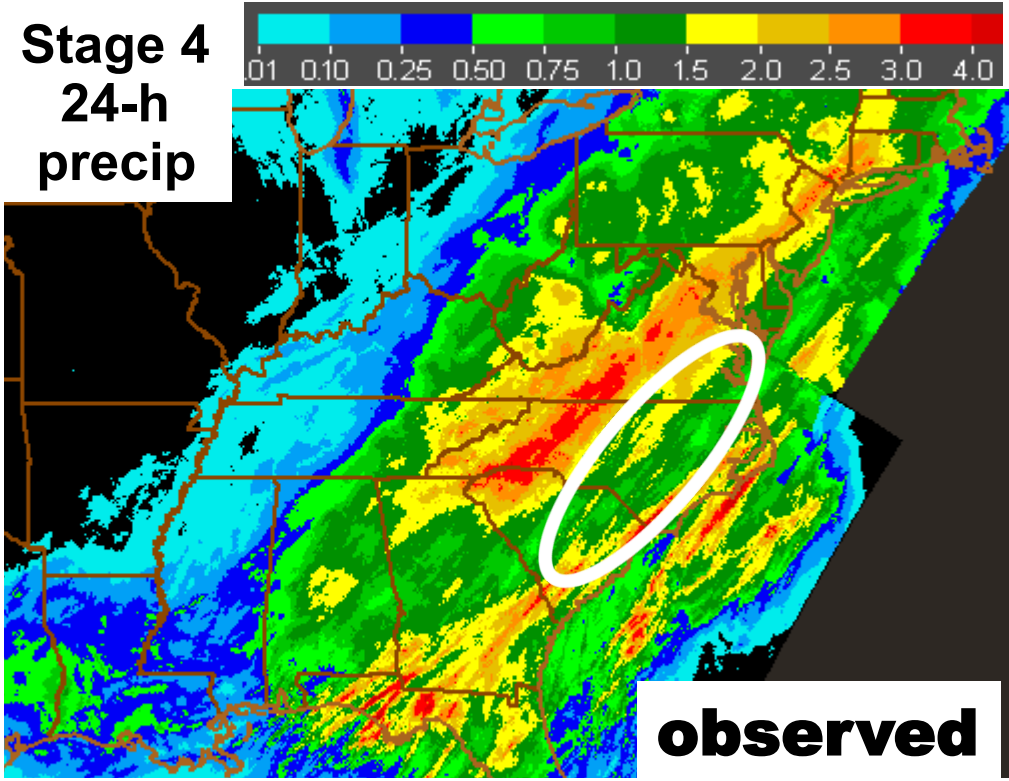


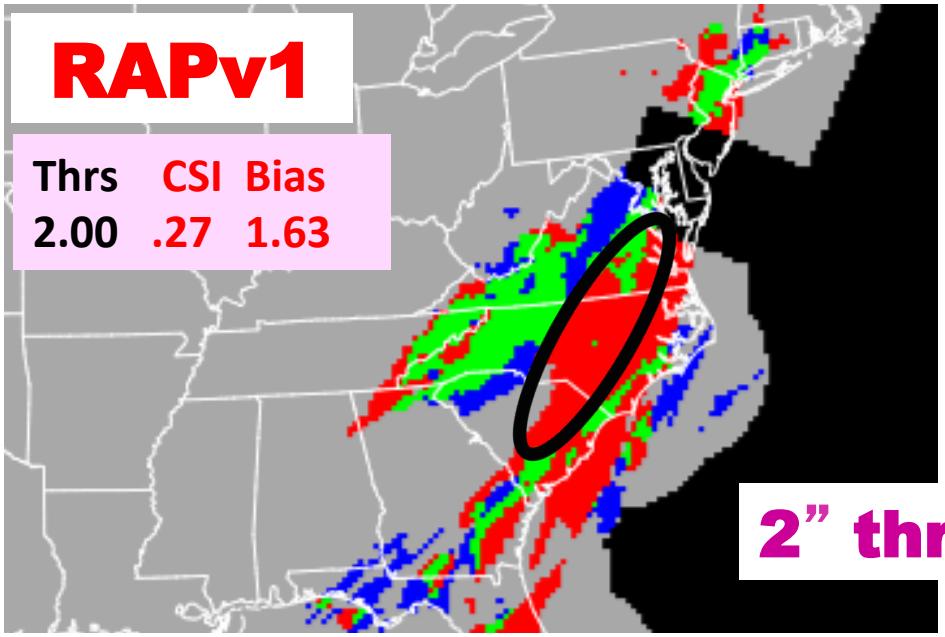


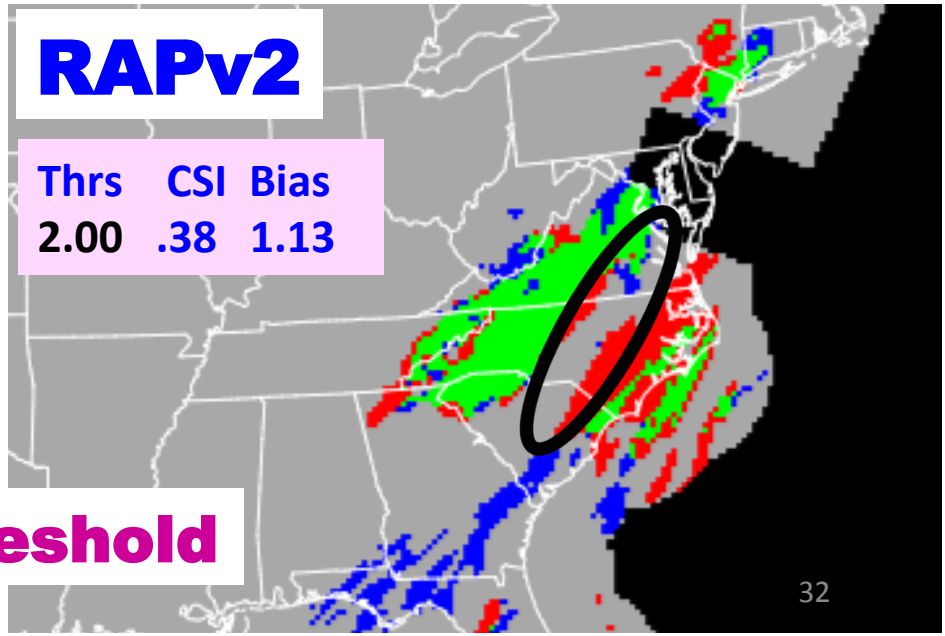
Precipitation Forecasts

RAPv2 vs. RAPv1

2 x 12h fcst ending 12z 27 Nov 2013







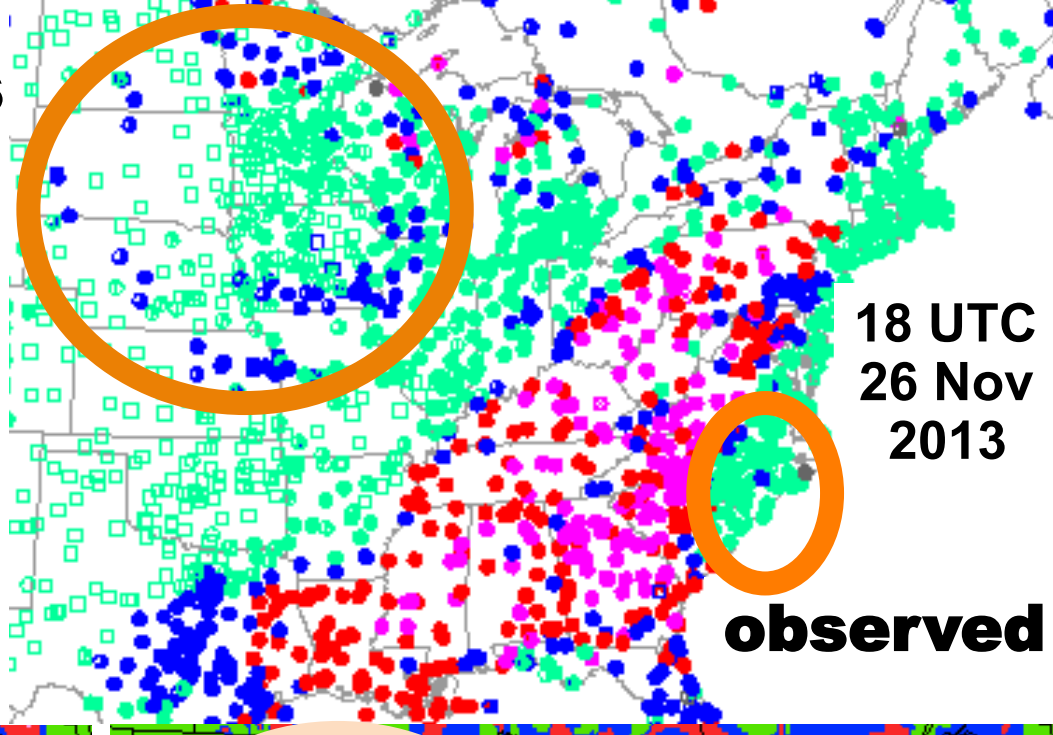
2" threshold

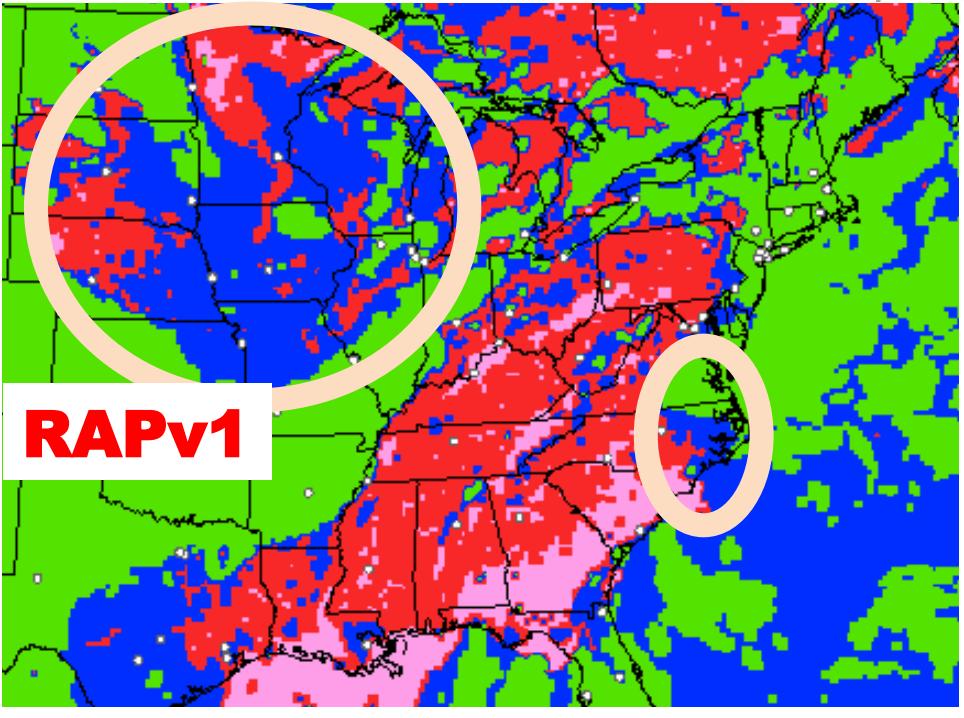
Aviation Flight Rules (ceiling and visibility)

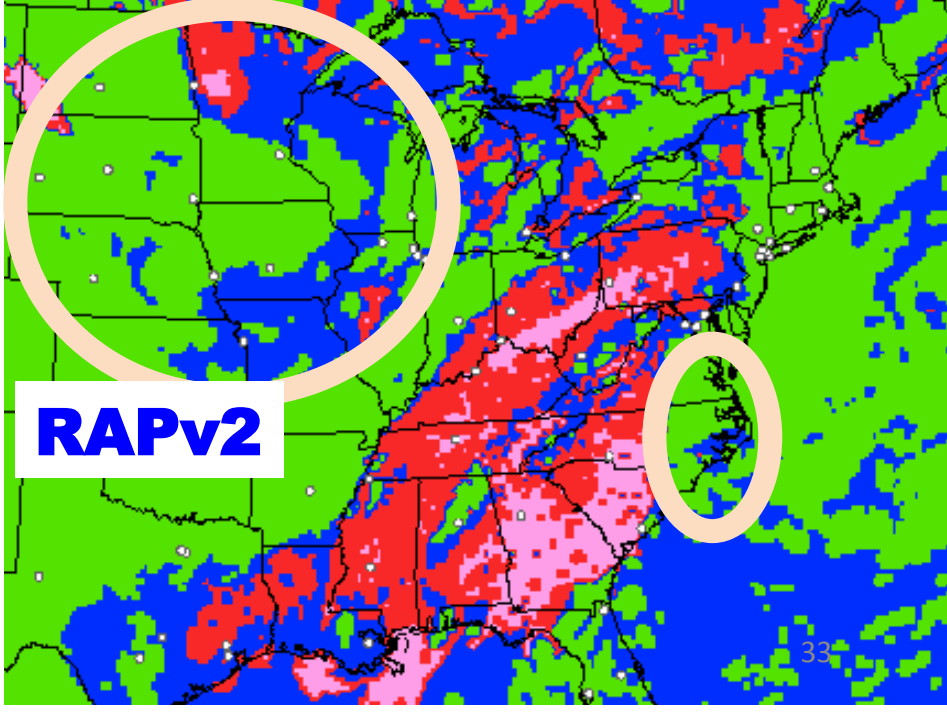
RAPv2 vs. RAPv1

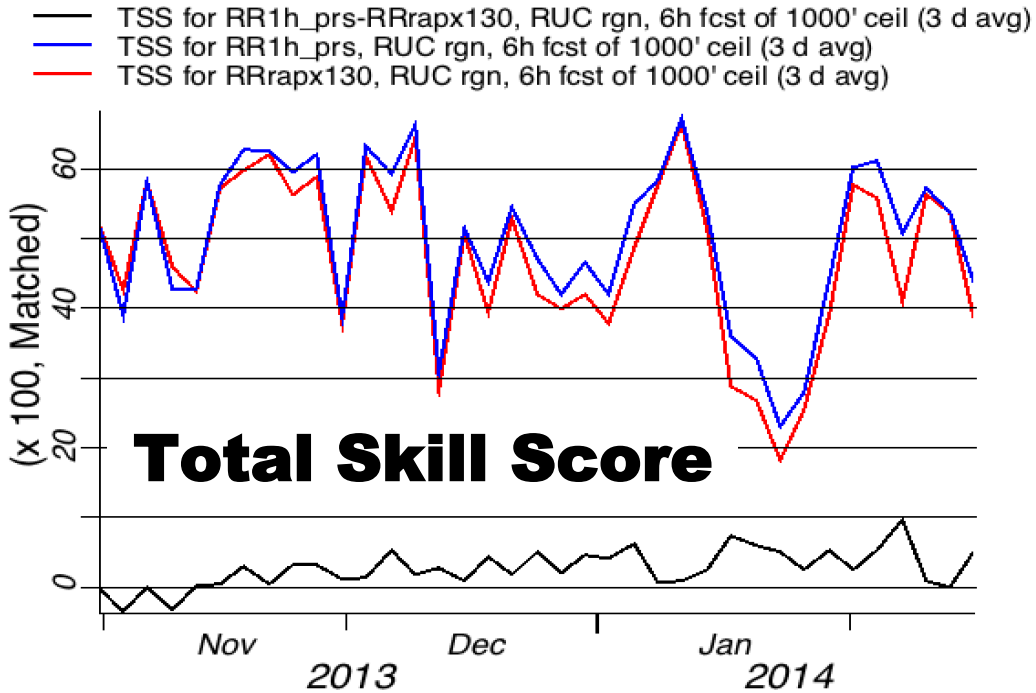
06 UTC
+ 12h fcst

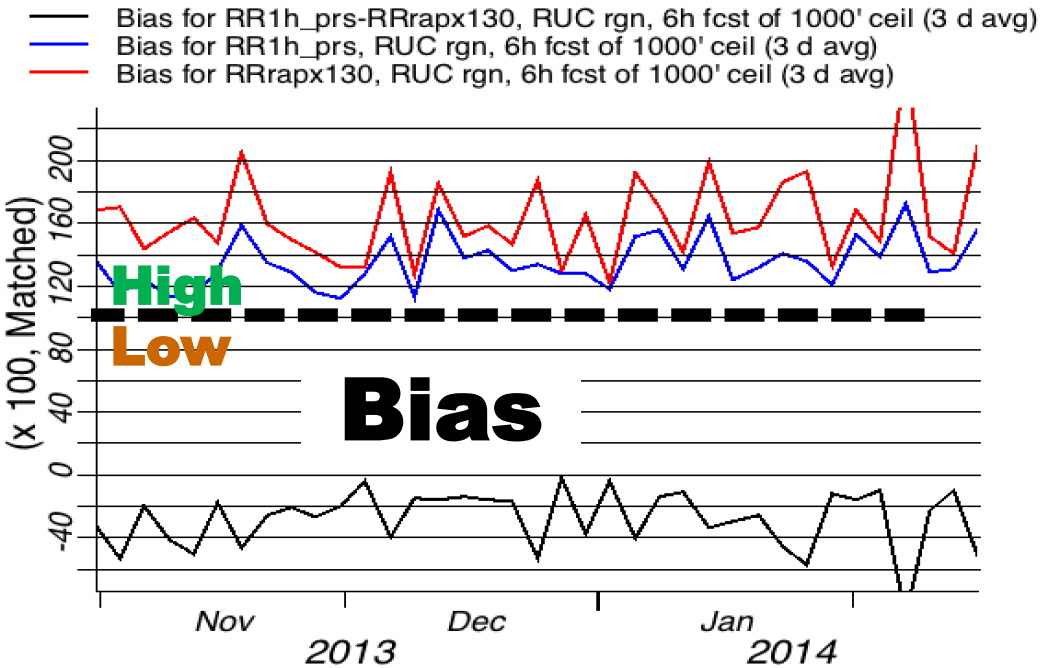
LIFR IFR MVFR VFR











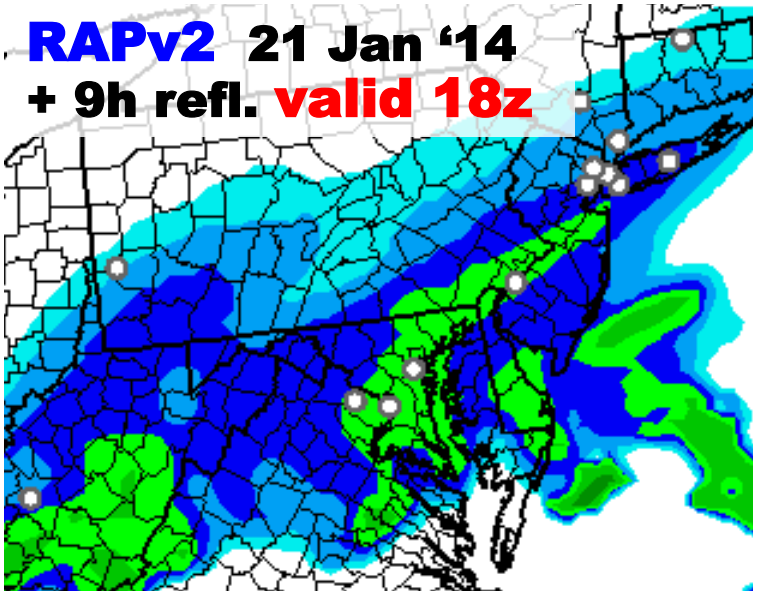
IFR conditions 1000-ft ceiling 6h forecasts

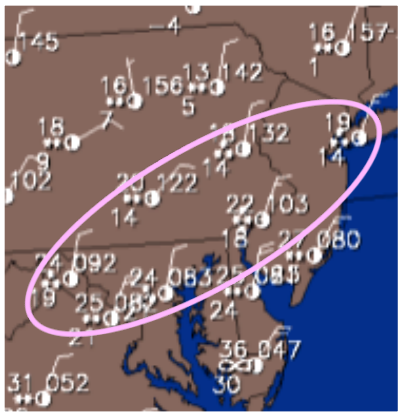
RAPv2
vs.
RAPv1

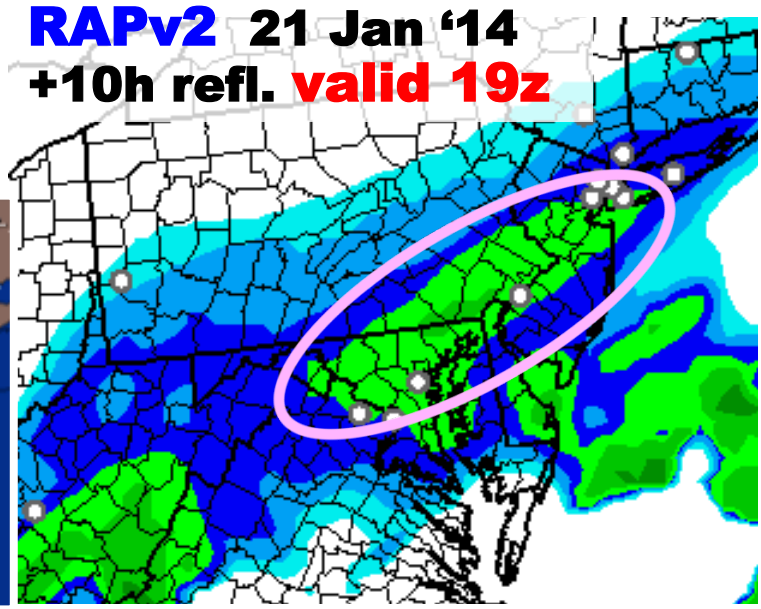
Ceiling forecasts –

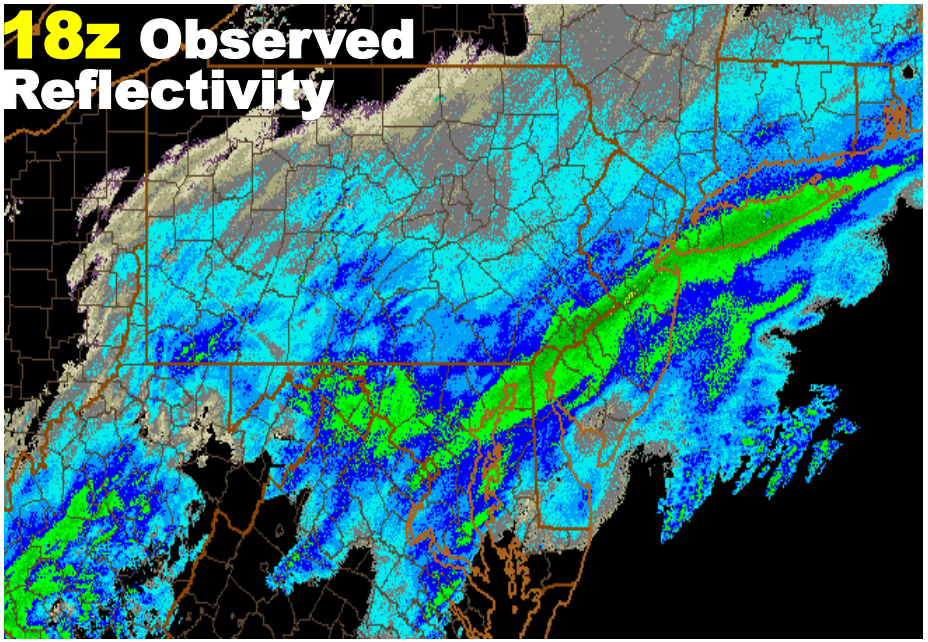
- RAPv2 better TSS than RAPv1
- Less overforecasting of IFR ceiling with RAPv2

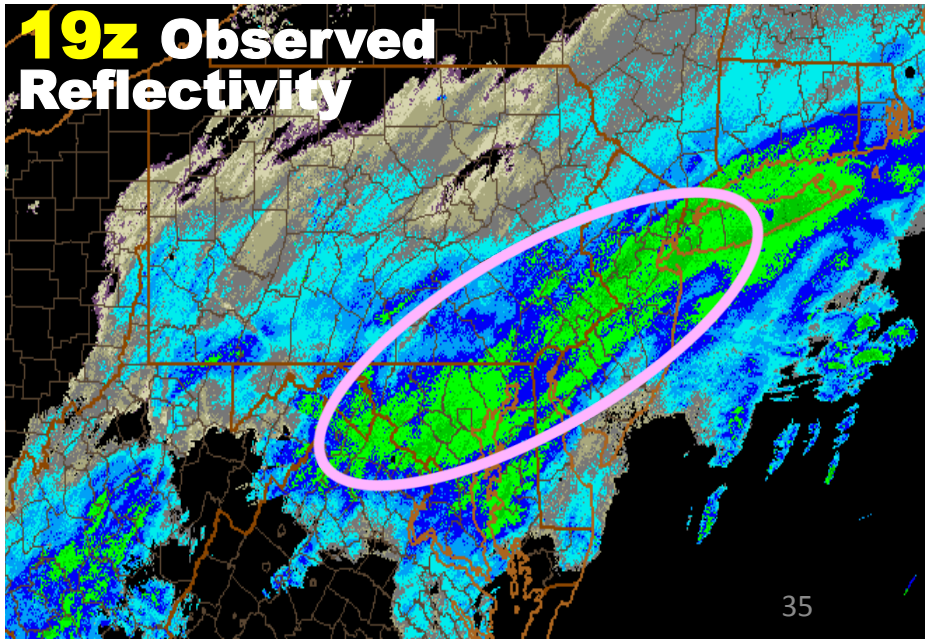
RAP mesoscale heavy snow predictions





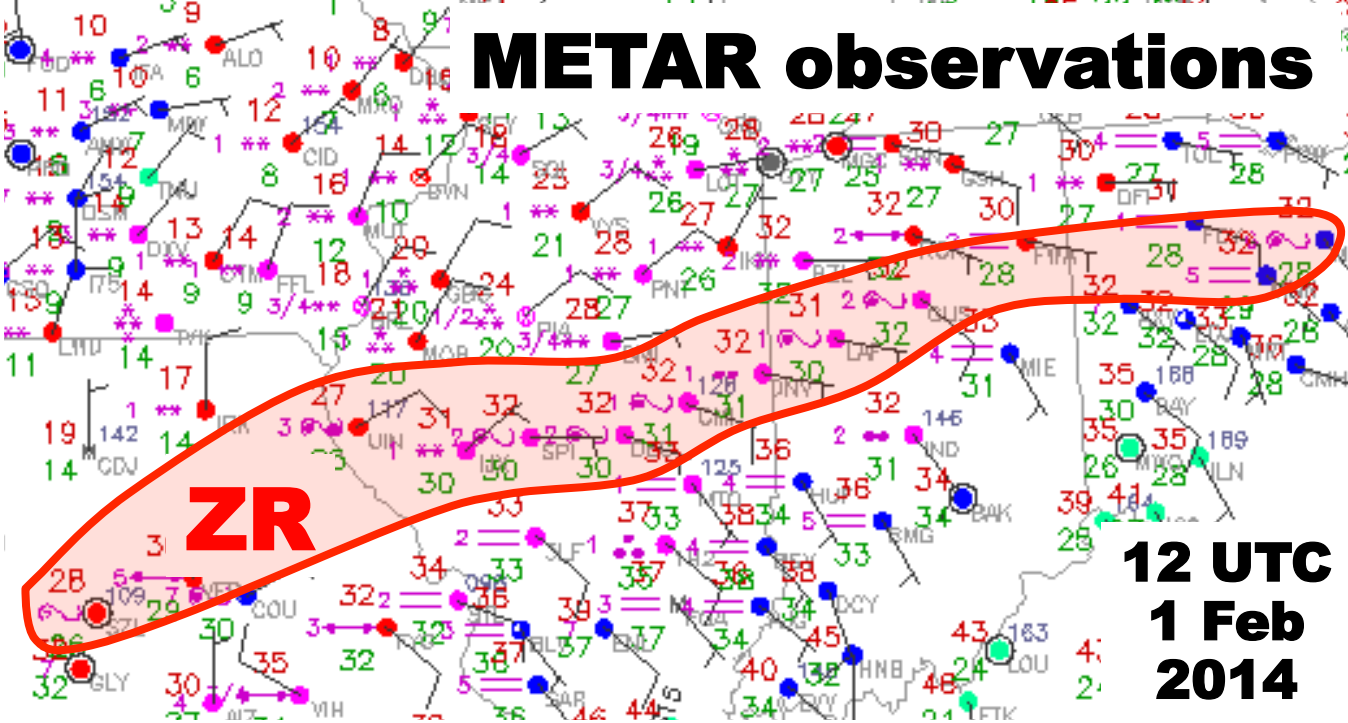




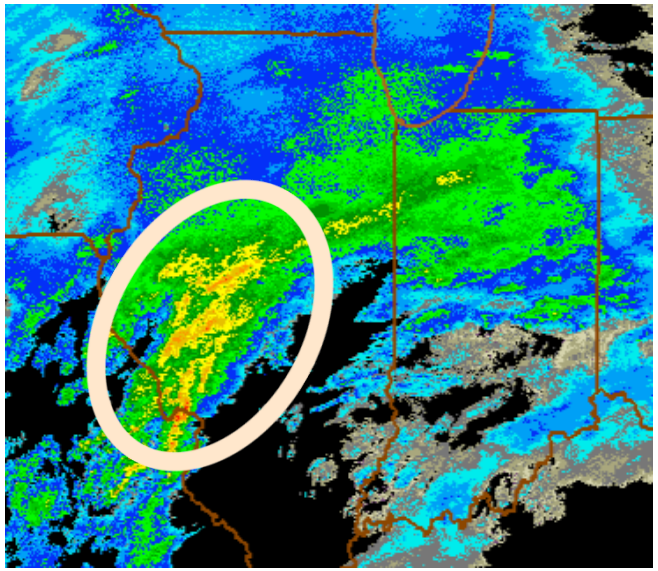


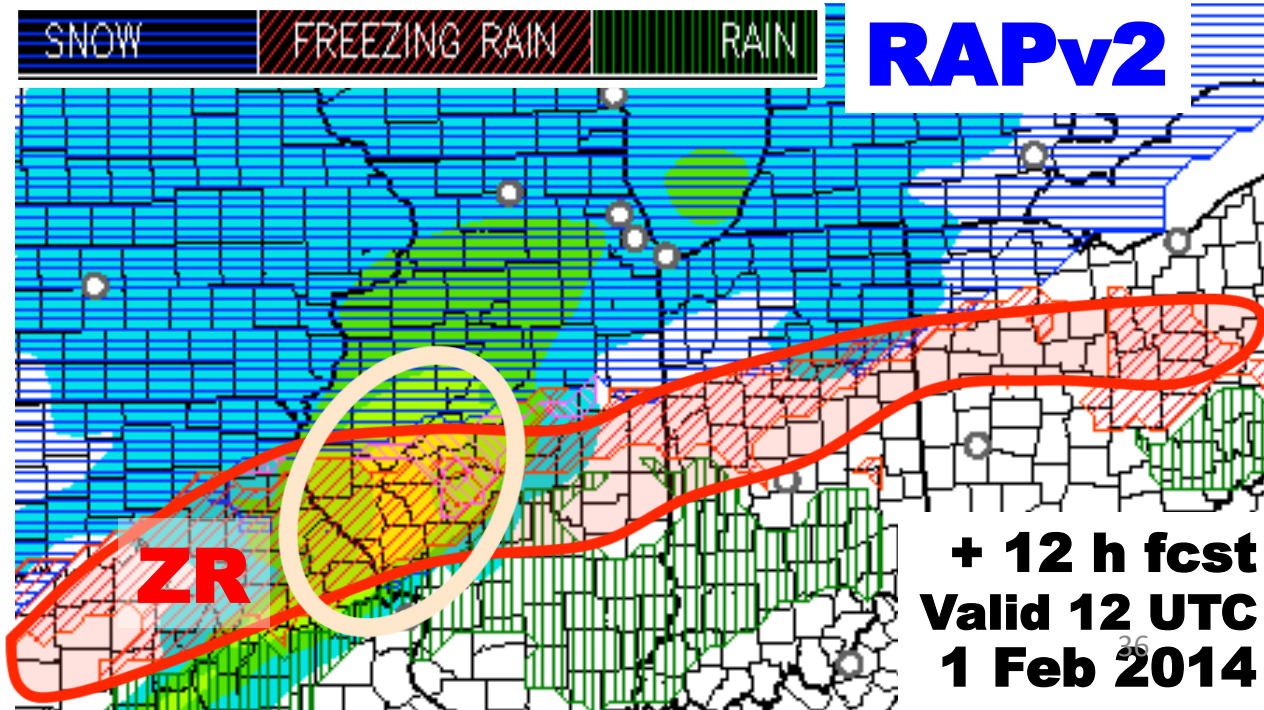
RAPv2

Sample mesoscale precipitation type and intensity



Radar obs

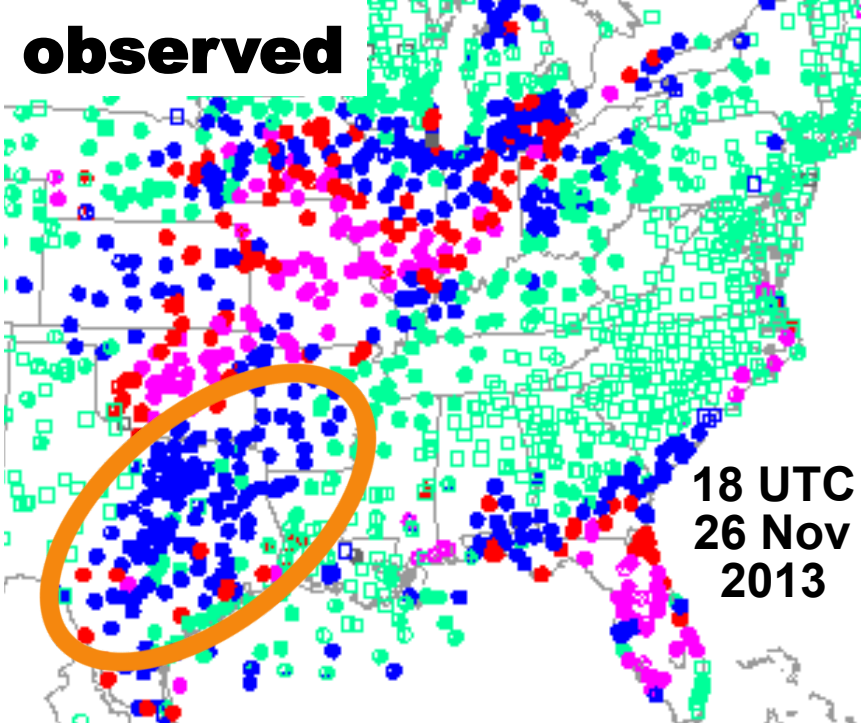


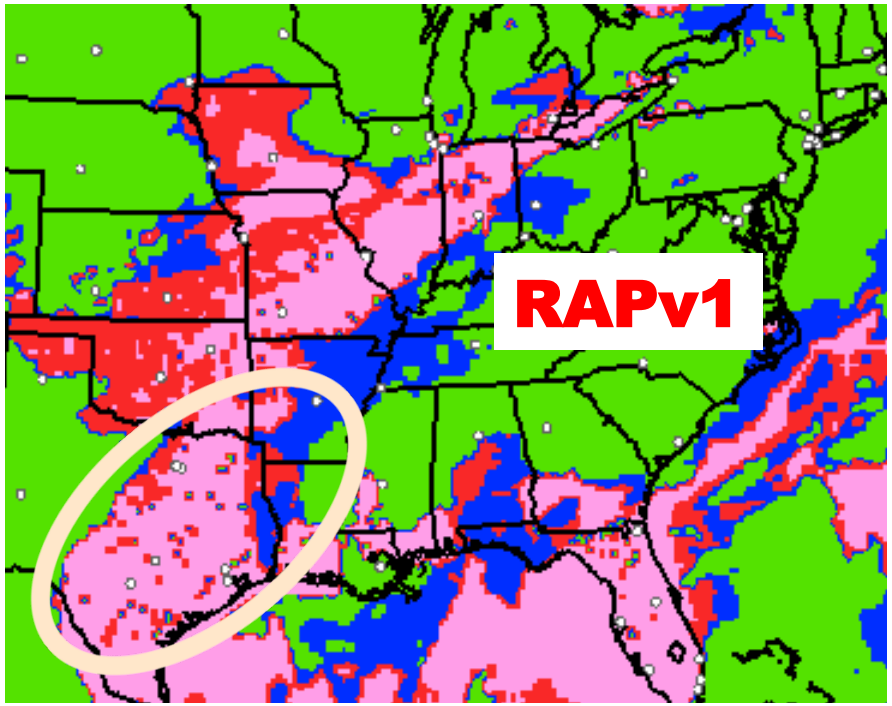


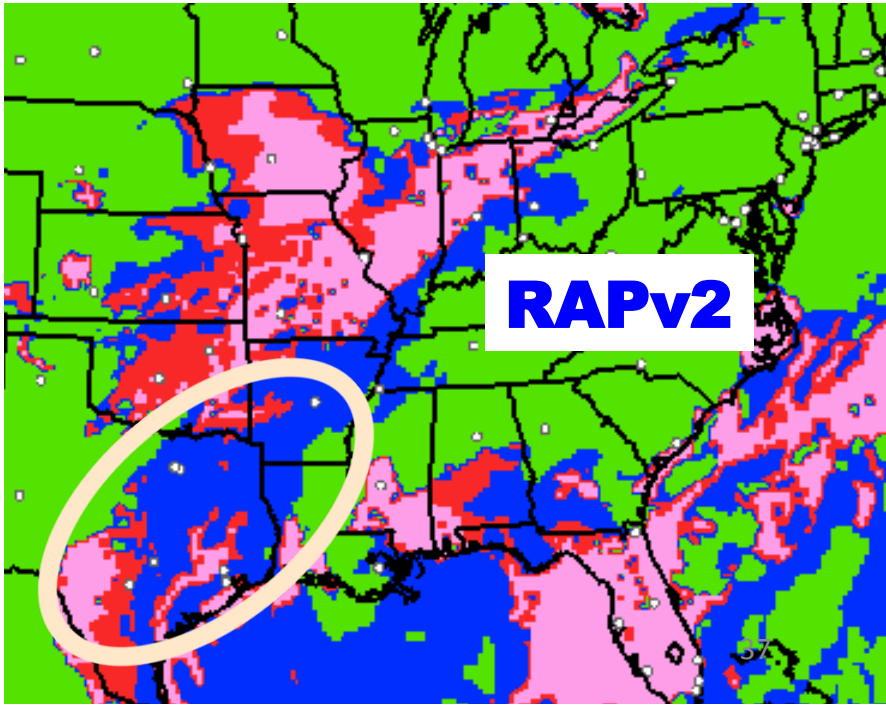
Aviation Flight Rules (ceiling and visibility)

RAPv2
vs.
RAPv1

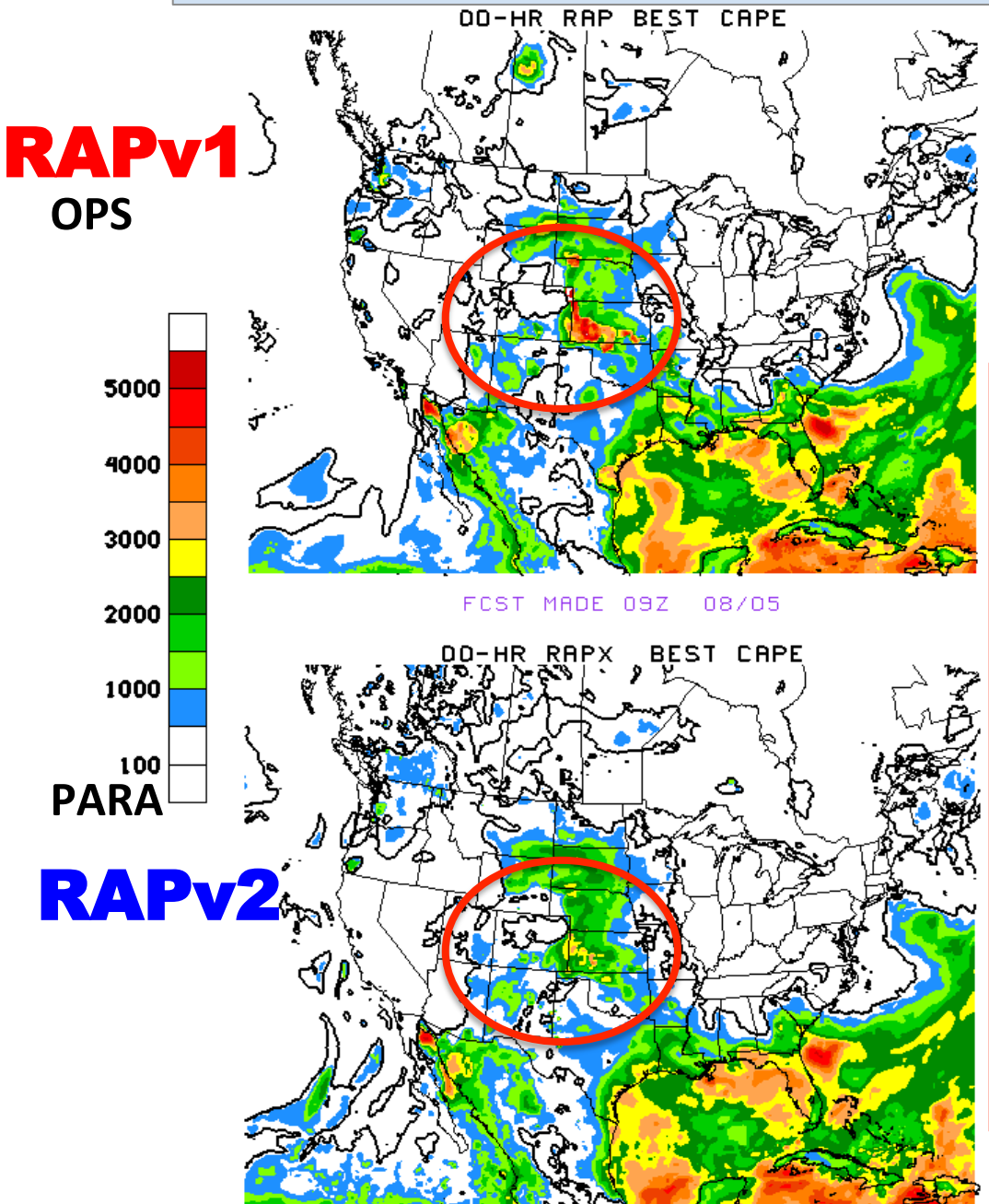
+ 6 h fcst
valid 9 UTC
1 Feb 2014







00-hr Best CAPE Forecasts 9z 5 August 2013



RAPv1 showing unlikely excessive analysis CAPE values over Midwest exceeding 5000 J/kg.

Improved cloud analysis in **RAPv2** conserving θ_v with addition of water vapor in cloud building

RAPv2 enhancements over RAPv1

Data Assimilation	Assimilation Type	PBL Pseudo Innovations	Soil Adjustment	Low-Cloud Building	Snow Cover Building	Lightning Obs (radar refl proxy)
RAPv1	GSI 3D-VAR	No	No	No	No	No
RAPv2	GSI EnKF-3DVAR Hybrid + temp-dep radar-hydrometeor	Yes	Yes	Yes	Yes + revised trimming	Yes

Model	Version	Horiz/Vert Advection	Scalar Advection	Upper-Level Damping	SW Radiation Update	Land Use	Land-sfc model	PBL	Micro-physics	Radiation LW/SW
RAPv1	WRF-ARW V3.2+	$5^{th}/3^{rd}$	Monotonic	w-Rayleigh 0.02	30 min	USGS	RUC 6-lev	MYJ	Thompson V3.1	RRTM/ Goddard
RAPv2	WRF-ARW v3.4.1+	$5^{th}/5^{th}$	Positive-Definite	w-Rayleigh 0.2	10 min	MODIS Fractional	RUC 9-lev	MYNN	Thompson v3.4.1	RRTM/ Goddard w/ snow fix

Major changes for RAPv2

Assimilation

– hybrid ensemble assimilation, soil/PBL/surface/cloud assimilation

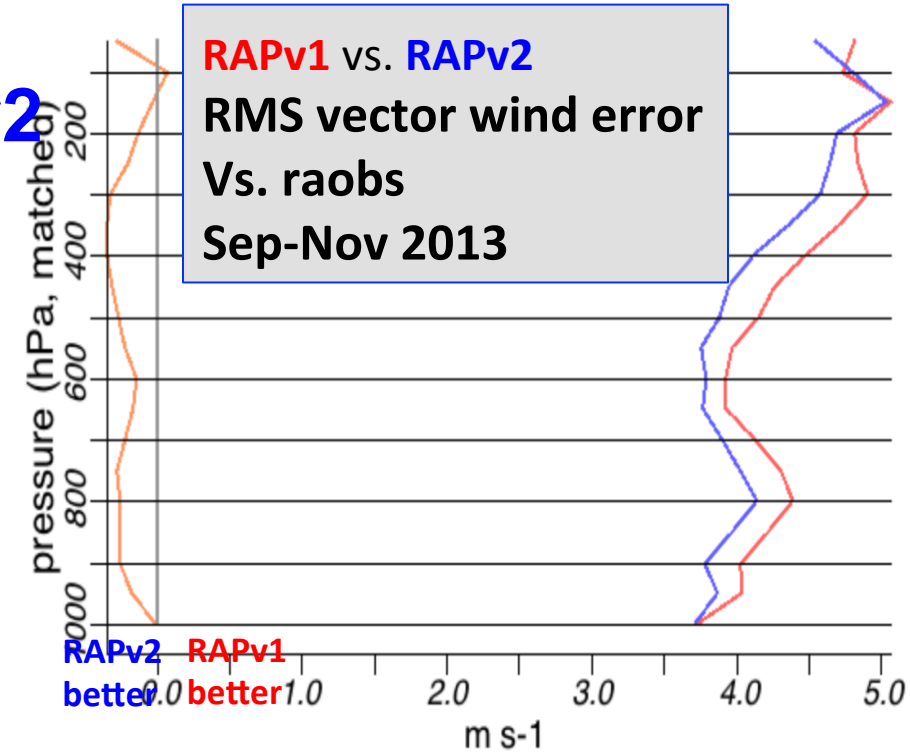
Model –

- land-surface, PBL, cloud physics

Summary: RAPv2 vs. RAPv1

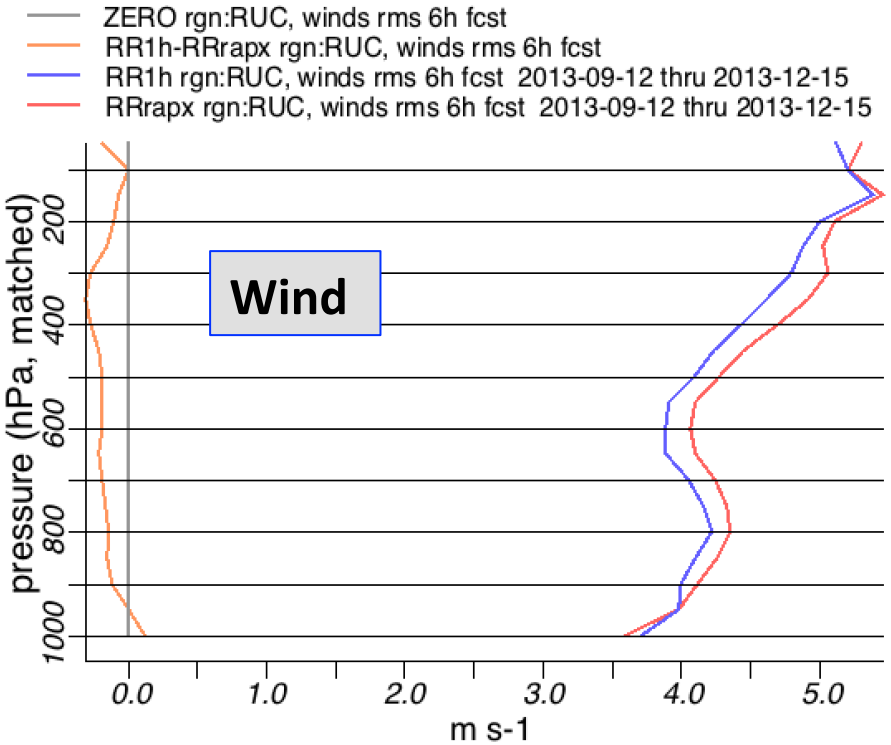
Winds -- Consistent RAPv2 improvement, for both upper-air and surface

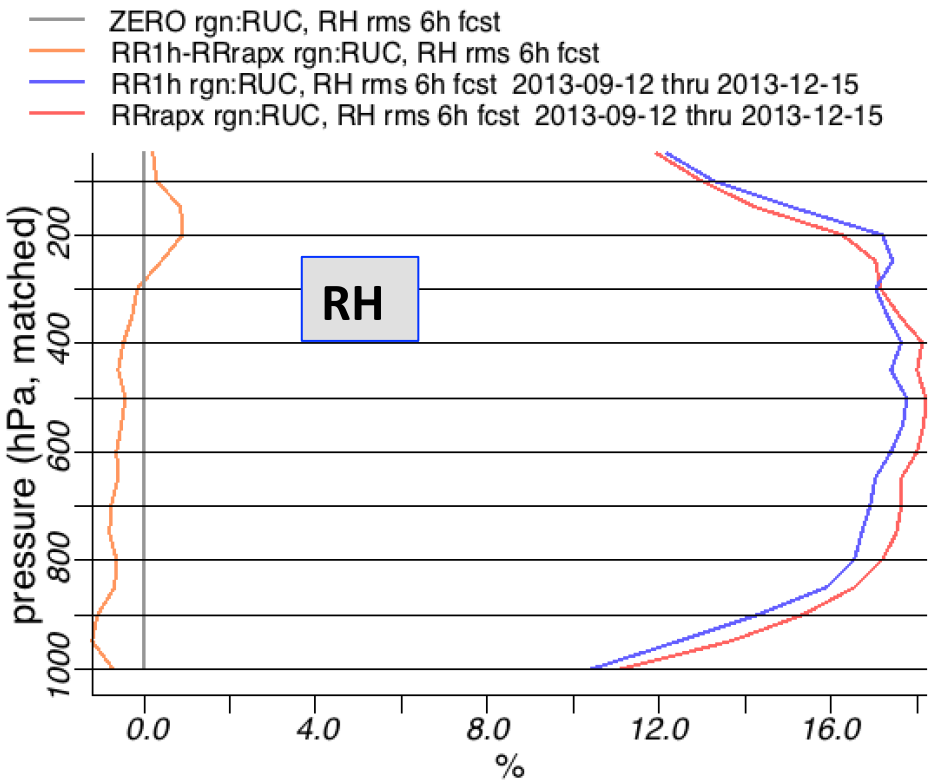
Moisture -- Improved RAPv2 RH forecasts aloft. Reduced RMS 2m dewpoint error, more so at night

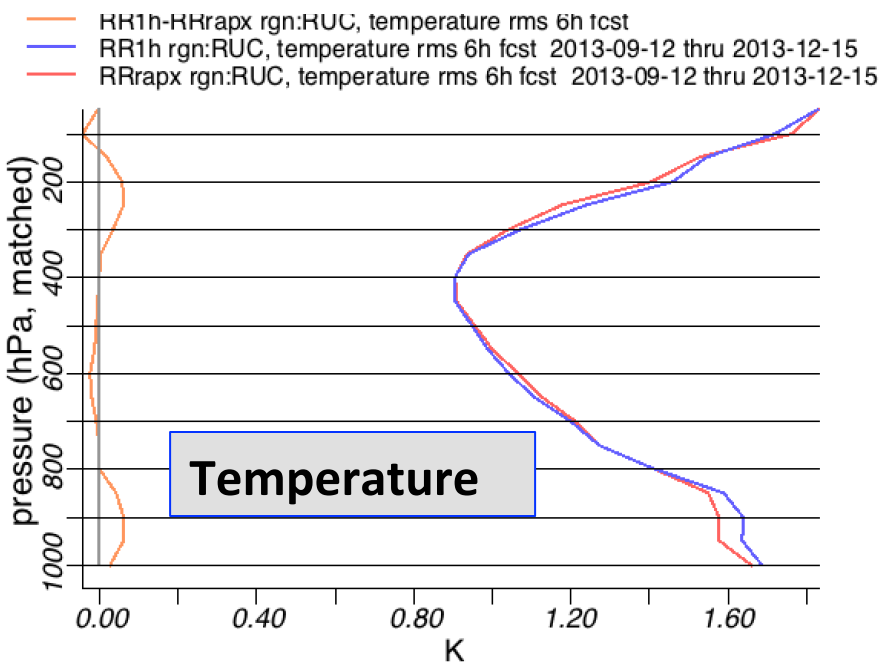


Temperature -- Similar RAPv2 skill for upper-air. **Improved skill for surface in warm season**

Precipitation and clouds – Improvement for precipitation, slight improvement for ceiling







6h forecast – **upper-air** - RMS
12 Sept –15 Dec 2013 **(recent)**

RAPv1 vs. **RAPv2**

Wind, RH

- Somewhat lower error with RAPv2

Temp

- Similar with RAPv2 (diff < 0.1K)

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 surface DA, hybrid DA, radar	• RAPv2 - implemented **scheduled on 25 Feb 2014** running in NCEP/NCO testing now
• HRRR – 2012 – Major improvement over 2011 (storm bias, 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 – Implementation **scheduled for July 2014** HRRR testing on WCOSS with real-time end-to-end runs underway

Look ahead - 2015 RAPv3/HRRRv2 Changes

	Model	Data Assimilation
RAP-ESRL (13 km)	WRFv3.5.1+ incl. physics changes Physics changes: Grell-Freitas convective scheme MYNN PBL scheme - Olson version RUC LSM update Thompson microphysics w/ aerosols RRTMG radiation scheme	Increase ensemble weight in hybrid DA Improved surface obs assimilation Radial velocity assimilation Full-column cloud assimilation Radiance bias correction
HRRR (3 km)	WRFv3.5.1+ incl. physics changes Physics changes: MYNN PBL scheme - Olson version RUC LSM update Thompson microphysics w/aerosols RRTMG radiation scheme Shallow cumulus parameterization Numerics changes: 6th order diffusion in flat terrain	3-km hybrid assimilation Improved surface obs assimilation Radial velocity assimilation Changes with high/ medium importance for *overall* forecast skill

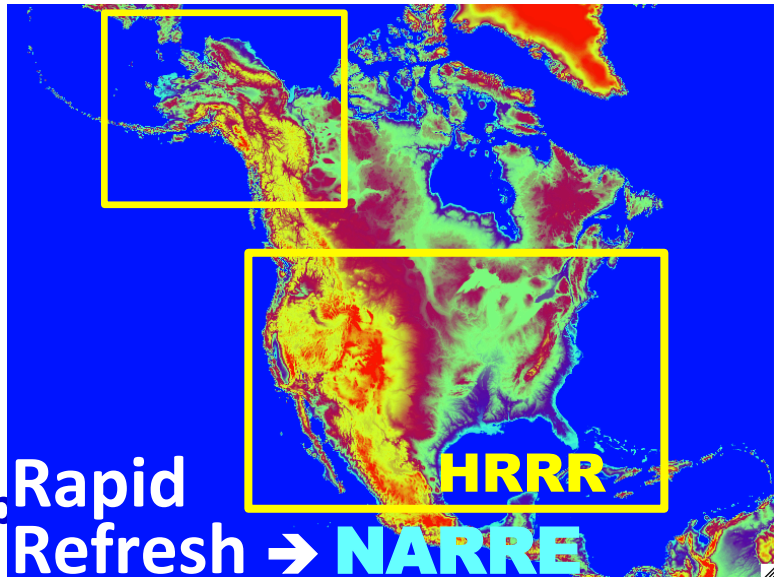
Evolution of hourly updated NOAA modeling

25 Feb 14 Rapid Refresh v2 –NCEP oper

- PBL/soil/radar assimilation enhancements
  - ➔ **Improved surface forecasts, convective environment fields**
- Hybrid ensemble-variational GSI assimilation
- Model – improved cloud / PBL / LSM, numerics improvements, updated WRF

July 2014 – HRRR (3km) - planned NCEP op with 3km/15min radar refl. assimilation

2015 – RAPv3 / HRRRv2 updates



North American Rapid Refresh Ensemble (NARRE) ~2017

- **NMM, ARW cores**
- **Hourly updating with regional ens data assim**
- **Initially 6 members, 3 each core, physics diversity (stochastic only or with RAP/ NAM/NCAR suites)**
- **Hourly forecasts to 24-h**
- **NMMB +ARW members to 84-h 4x/day**

NARRE / HRRRE at NCEP

2017 – Ensemble Rapid Refresh/NAM – NARRE (w/ hybrid 4d-ens/var DA)

2019? – Ensemble HRRR – HRRRE – (ultimately with hourly ~3km ensemble DA)