Overview of the Rapid Refresh
RAP

NOAA/ESRL/GSD/
Assimilation and Modeling Branch
RAP development scientists

Stan Benjamin
Steve Weygandt
Ming Hu / Tanya Smirnova
Curtis Alexander / John M. Brown
David Dowell / Joe Olson
Bill Moninger / Haidao Lin
Georg Grell / David Dowell
Patrick Hofmann / Eric James
Tracy Smith / Susan Sahm

NCEP – EMC/NCO
Geoff Manikin, Geoff DiMego,
Dennis Keyser, Julia Zhu,
Xiaoxue Wang, Thomas Pepe,
Becky Cosgrove, Chris Magee

Major topics:

- Rapid Refresh
  - NCEP implementation planned 20 Mar 12
    A totally complete new "chassis" for the hourly updated model/assimilation system with WRF-ARW and GSI
  - significant improvement over RUC

http://rapidrefresh.noaa.gov

NCEP

Earth System Research Laboratory
SCIENCE, SERVICE & STEWARDSHIP

Hourly Updated NOAA NWP Models

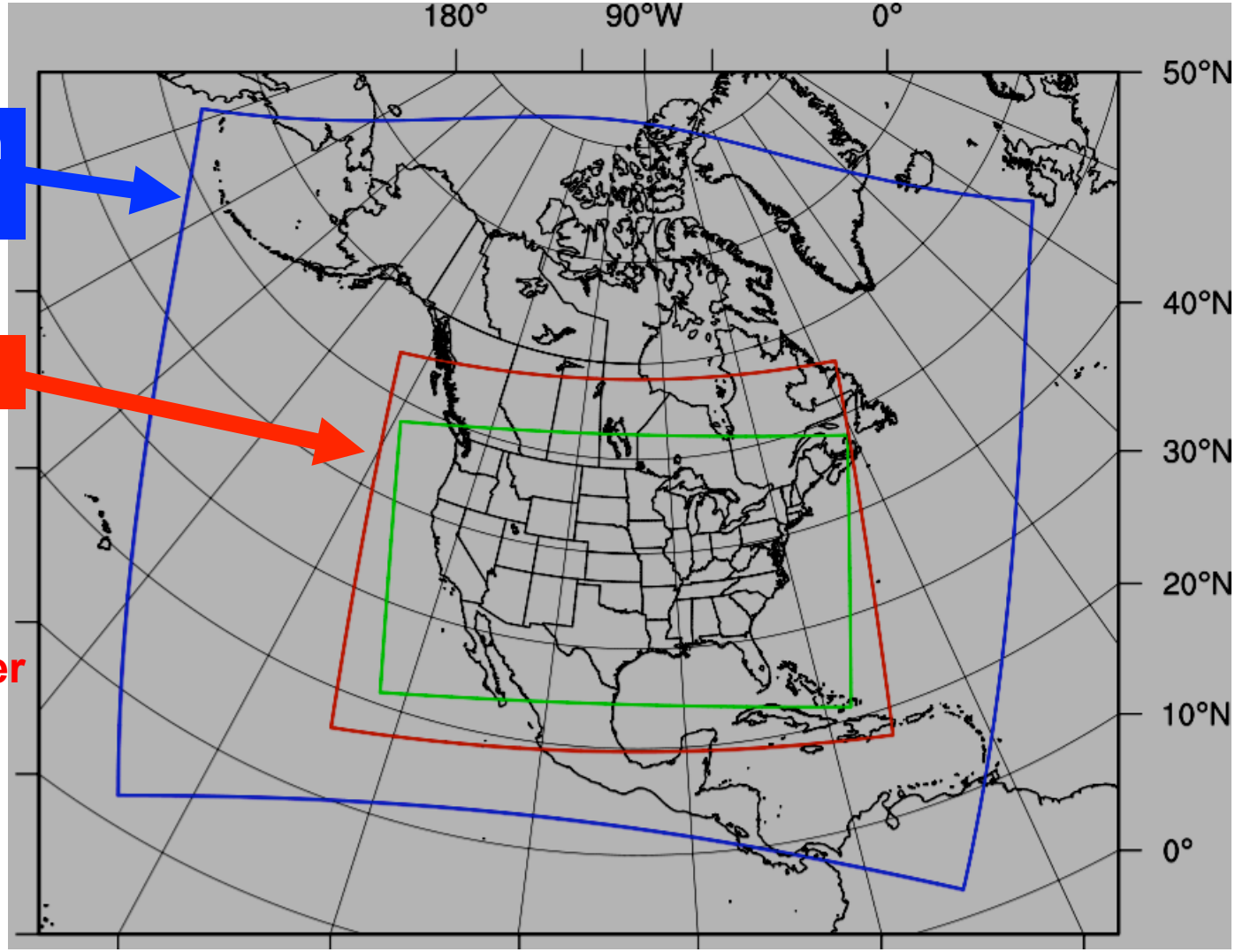
Rapid Refresh (RAP)

replaces RUC at NCEP

WRF, GSI with RUC features

13km Rapid Refresh

13km RUC



RUC – current oper model, new 18h fcst every hour

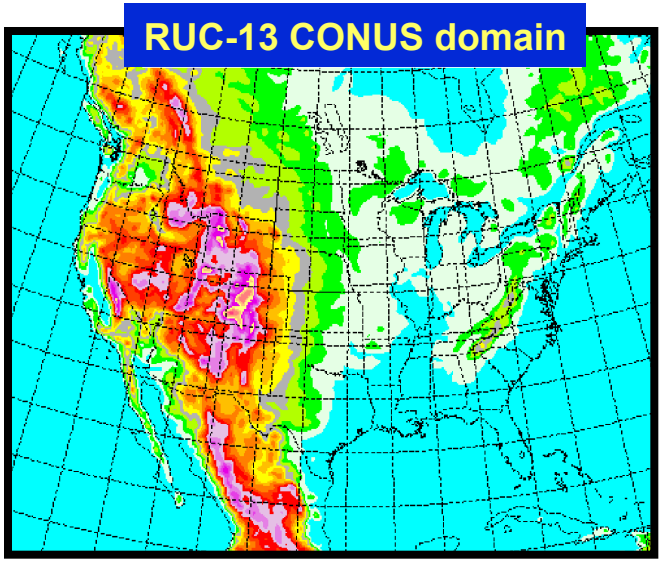
RUC Becomes Rapid Refresh

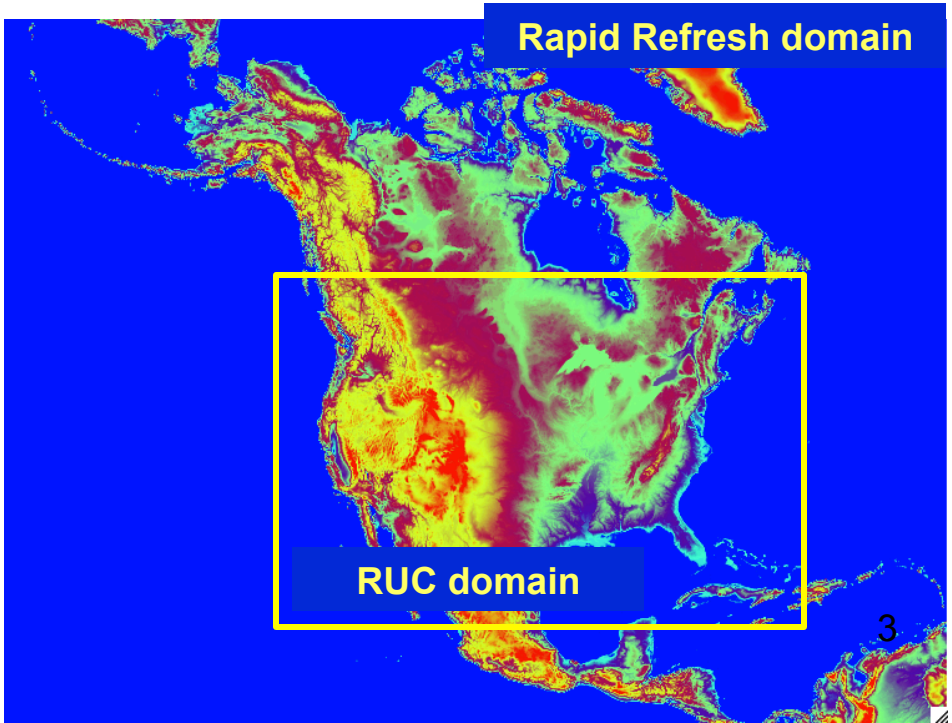
RUC

- Non-WRF RUC model
- RUC 3DVAR analysis
- 24/Day = hourly update
- Forecasts to 18 hours
- 13 km horizontal

Rapid Refresh

- WRF-based ARW
- GSI analysis
- Expanded 13 km Domain
  - ~2.8 times bigger
  - Includes Alaska
- Experimental 3 km HRRR runs ONLY at ESRL currently





Outline

- Model description for Rapid Refresh
- Data assimilation description for RAP
- Output from RAP (grids, Unipost mods, BUFR,downstream dependencies)
- Partial cycling for Rapid Refresh, SST, land-surface grids
- Verification statistics for RAP vs. RUC

WRF model enhancements for Rapid Refresh

- WRF - ARW - v3.2.1+ for initial RAP
  - WRF v3.3 issued too late in April 2011 – NCEP code freeze
- Benefited from ongoing community improvements to WRF
- GSD improvements –
  - Digital filter initialization (DFI - allows quiet 1h forecasts)
  - DFI-radar
  - Grell 3-d cumulus
  - RUC LSM (now with snow LSM cycling on sea ice)
- Use of rotated lat-lon grid - GSD was first to use ARW with RLL

Transition from RUC to Rapid Refresh

Provides hourly cycled guidance to all North America
Community-based advanced model and analysis

- **WRF-ARW: advanced numerics, non-hydrostatic**
- **GSI: advanced satellite data assimilation**

Model	Domain	Grid Points	Grid Spacing	Vertical Levels	Vertical Coordinate	Pressure Top	Boundary Conditions
RUC	CONUS	451 x 337	13 km	50	Sigma/ Isentropic	~50 mb	NAM
RAP	North America	758 x 567	13 km	50	Sigma	10 mb	GFS

Model	Assimilation	DFI	Cloud Analysis	Micro-physics	Radiation LW/SW	Conv param	PBL	LSM
RUC	RUC-3DVAR	Yes w/radar	Yes	Thompson (2003)	RRTM/ Dudhia	Grell-Devenyi	Burk Thompson	RUC 2003
RAP	GSI w/ radiances	Yes w/radar	Yes	Thompson (2008)	RRTM/ Goddard	Grell-3d	MYJ	RUC 2010

Model physics comparison

model	Shortwave Radiation	Cloud physics (# hydrometeor prog vars)	Cumulus parm	Boundary layer (PBL)	Shallow cumulus	Land-surface model
GFS	RRTM	Zhao-Carr (1)	Simplified Arakawa-Schubert	MRF – Troen-Mahrt	Jongil Han	Noah
NAM	GFDL	Ferrier (1)	Betts-Miller-Janjic	Mellor-Yamada-Janjic	BMJ	Noah
RUC	Dudhia	Thompson - 2004 - 1-moment rain (6)	Grell-Devenyi	Burk-Thompson	none	RUC (2003)
RAP	Goddard	Thompson - 2010 – 2-moment rain (7)	Grell-3D	Mellor-Yamada-Janjic	Grell	RUC – from WRFv3.3

Rapid Refresh sigma levels (50)

1.0000, 0.9980, 0.9940, 0.9870, 0.9750, 0.9590,
0.9390, 0.9160, 0.8920, 0.8650, 0.8350, 0.8020, 0.7660,
0.7270, 0.6850, 0.6400, 0.5920, 0.5420, 0.4970, 0.4565,
0.4205, 0.3877, 0.3582, 0.3317, 0.3078, 0.2863, 0.2670,
0.2496, 0.2329, 0.2188, 0.2047, 0.1906, 0.1765, 0.1624,
0.1483, 0.1342, 0.1201, 0.1060, 0.0919, 0.0778, 0.0657,
0.0568, 0.0486, 0.0409, 0.0337, 0.0271, 0.0209, 0.0151,
0.0097, 0.0047, 0.0000,

4 layers in lowest 200m, lowest @ ~8m

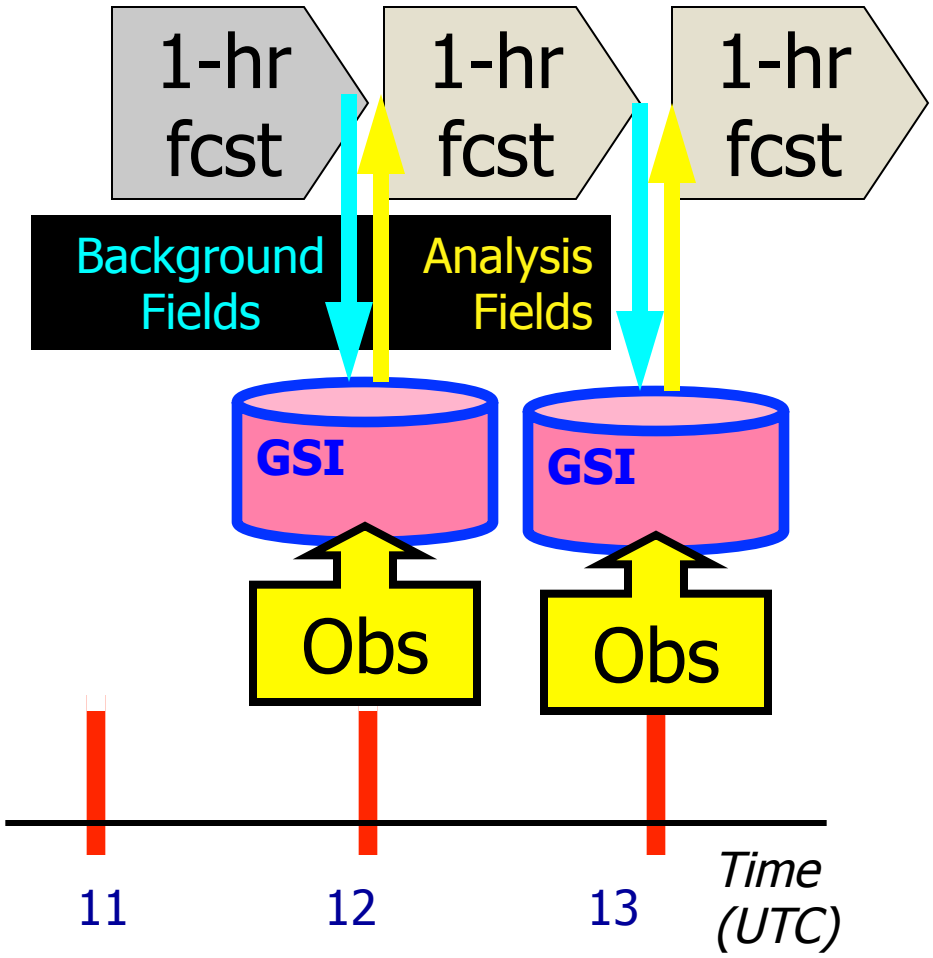
WRF default choices for sigma levels (35)

1.000, 0.993, 0.983, 0.970, 0.954, 0.934,
0.909, 0.880, 0.845, 0.807, 0.765, 0.719, 0.672,
0.622, 0.571, 0.520, 0.468, 0.420, 0.376, 0.335,
0.298, 0.263, 0.231, 0.202, 0.175, 0.150, 0.127,
0.106, 0.088, 0.070, 0.055, 0.040, 0.026, 0.013, 0.000

3 layers in lowest 200m, lowest @~50m

Rapid Refresh GSI-based Hourly Assimilation Cycle

Cycle hydrometeor, soil temp/moisture/snow



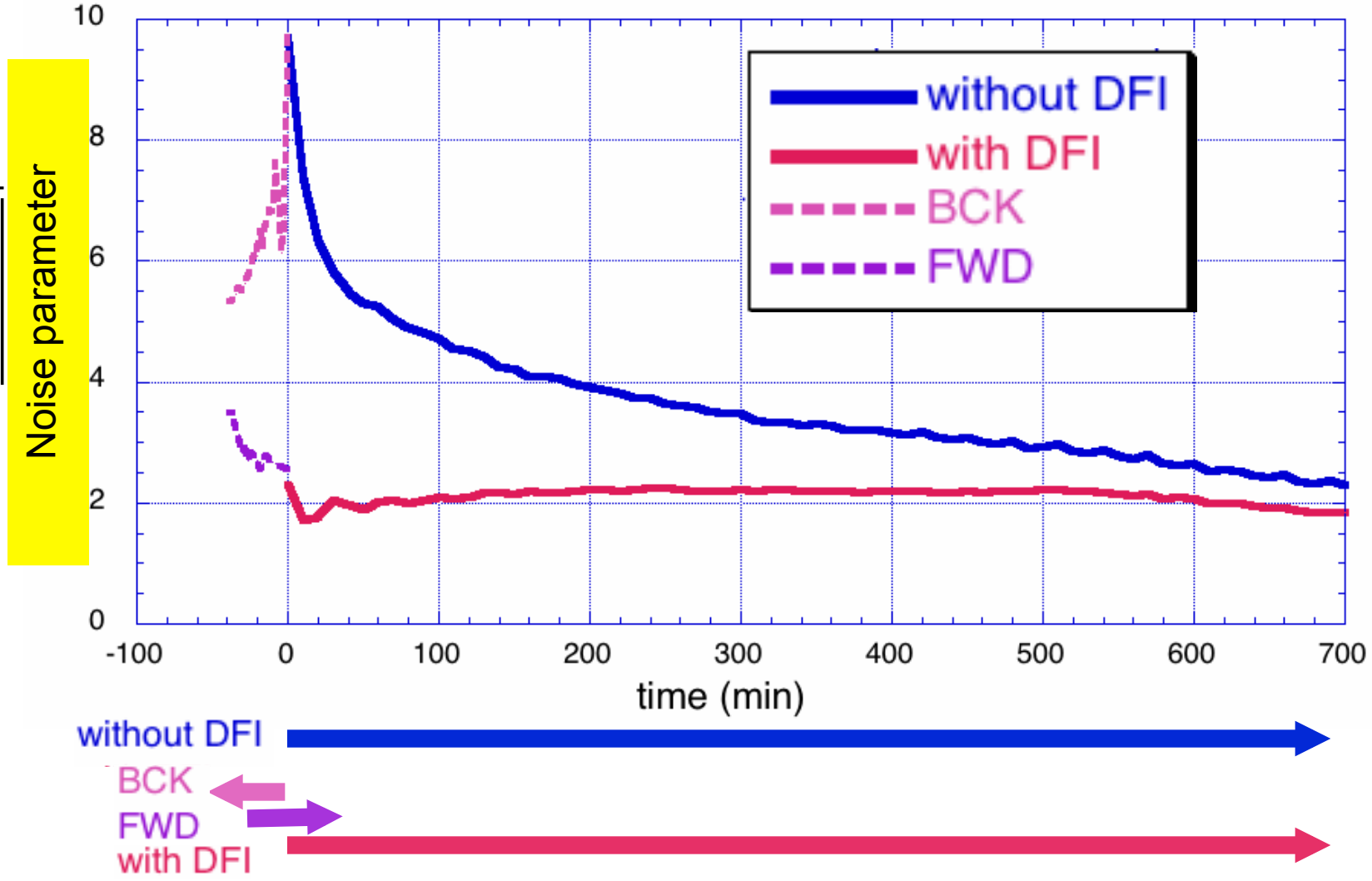
Hourly obs

Data Type	~Number/hr
Rawinsonde (12h)	120
NOAA profilers	21
VAD winds	~125
PBL – profiler/RASS	~25
Aircraft (V,temp)	2K-15K(avg 7K)
WVSS (RH)	0-800(avg 520)
Surface/METAR	~2500
Buoy/ship	200-400
GOES cloud winds	4000-8000
GOES cloud-top pres	10 km res
GPS precip water	~260
Mesonet (temp, dpt)	~8000 (RAPv2)
Mesonet (wind)	~4000 (RAPv2)
METAR-cloud-vis-wx	~2000
AMSU-A/B/HIRS/etc. radiances	
GOES radiances	*- testing – RAPv2*
Radar reflectivity	1km
Lightning (proxy refl) – *ready for RAPv2*	
Radar radial wind	*- ready for RAPv2*
Nacelle/tower/sodar – *ready for RAPv2*	

Diabatic Digital Filter Initialization

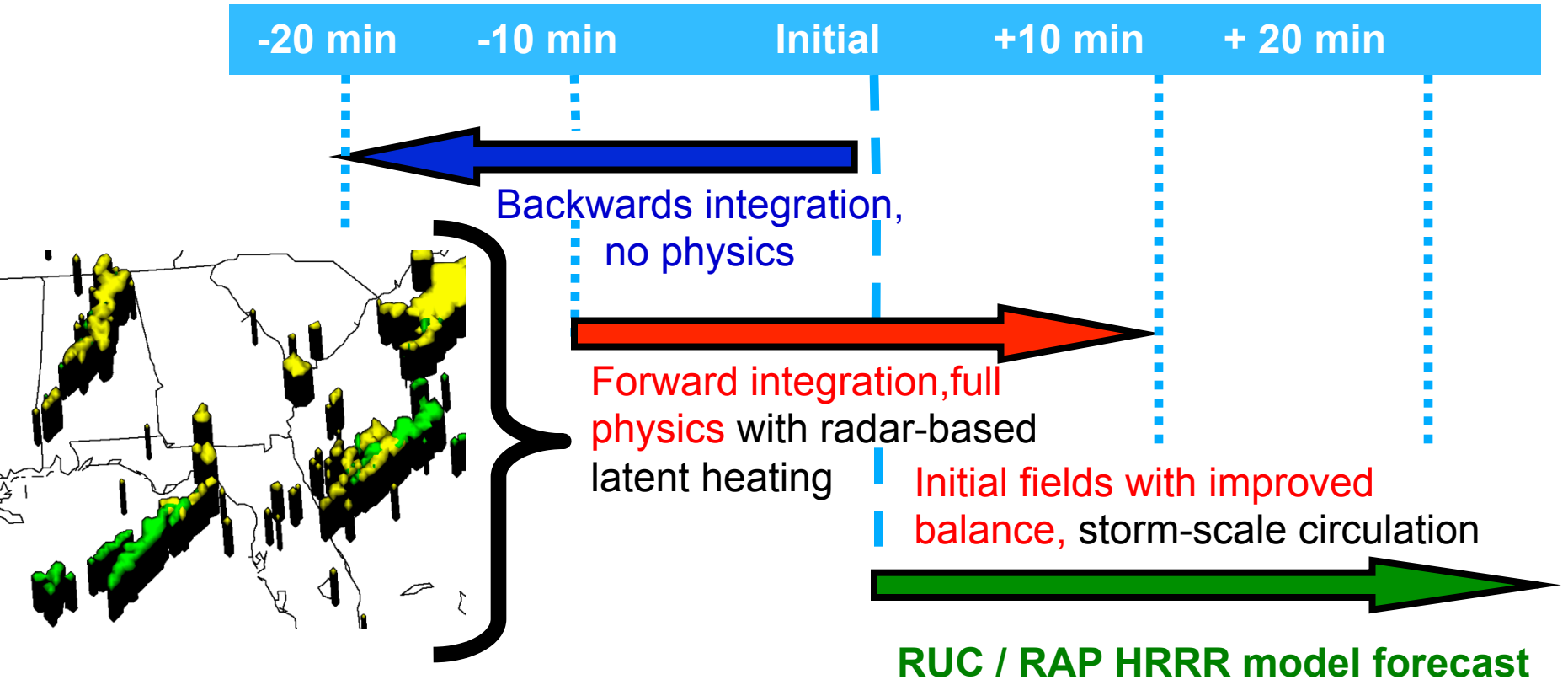
Reduce noise in RUC and Rapid Refresh

$$\left| \frac{\partial p_{sfc}}{\partial t} \right|$$



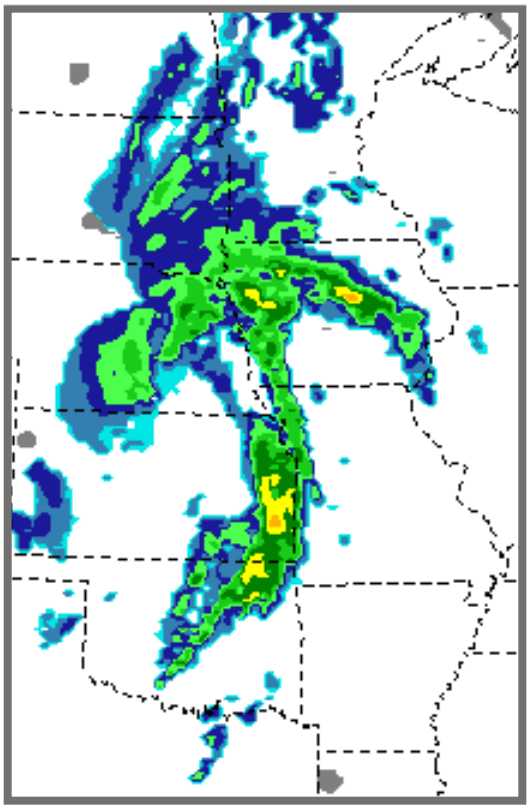
Radar reflectivity assimilation

Digital filter-based reflectivity assimilation initializes ongoing precipitation regions



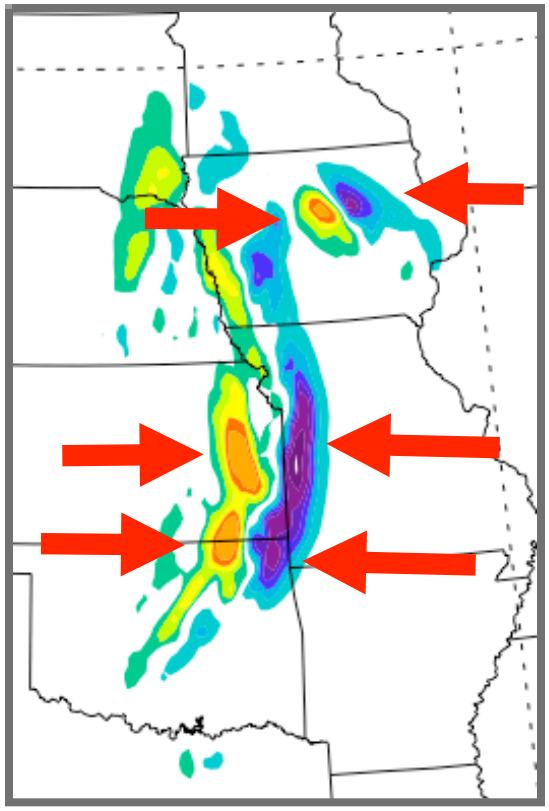
Rapid Refresh (GSI + ARW)
reflectivity assimilation example

NSSL radar reflectivity (dBZ)



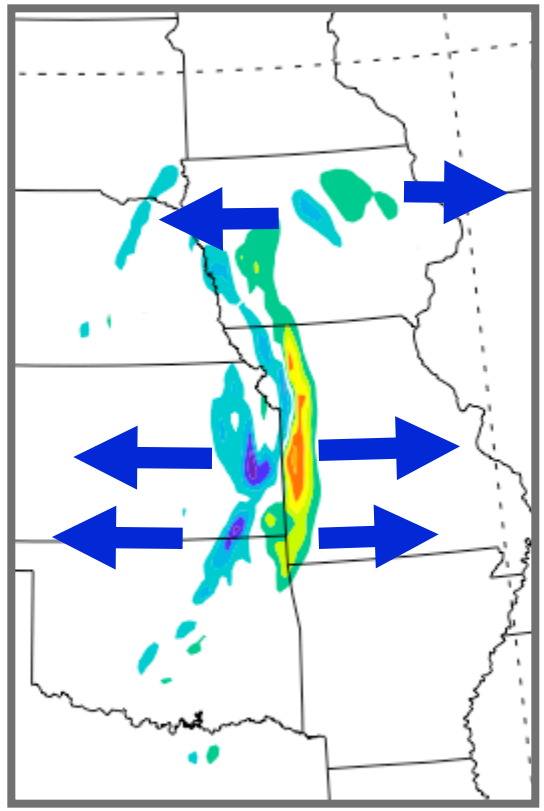
14z 22 Oct 2008
Z = 3 km

Low-level Convergence

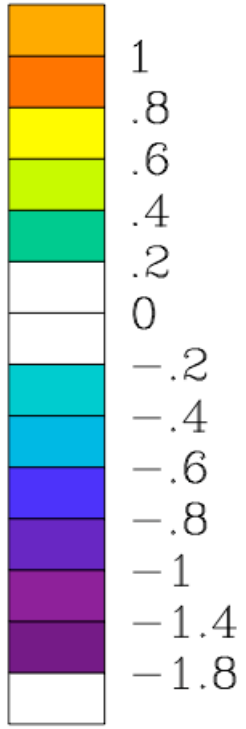


K=4 U-comp. diff
(radar - norad)

Upper-level Divergence

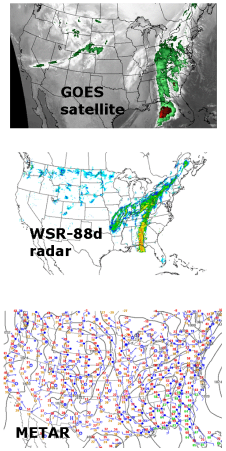


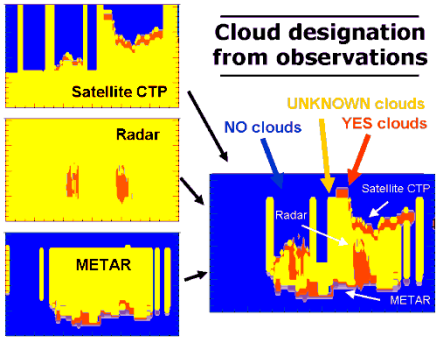
K=17 U-comp. diff
(radar - norad)

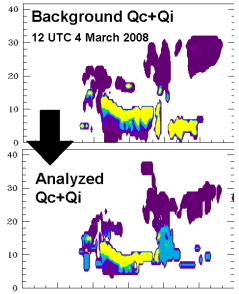


Rapid Refresh – specific analysis features

Cloud and hydrometeor analysis







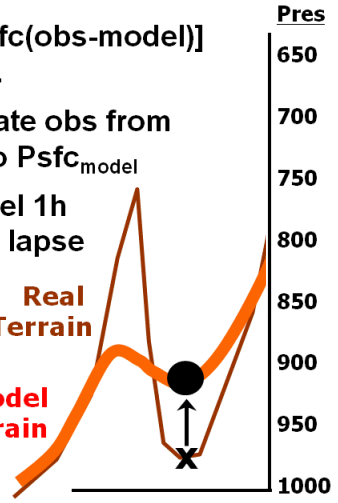
Special treatments for surface observations

Elevation correction

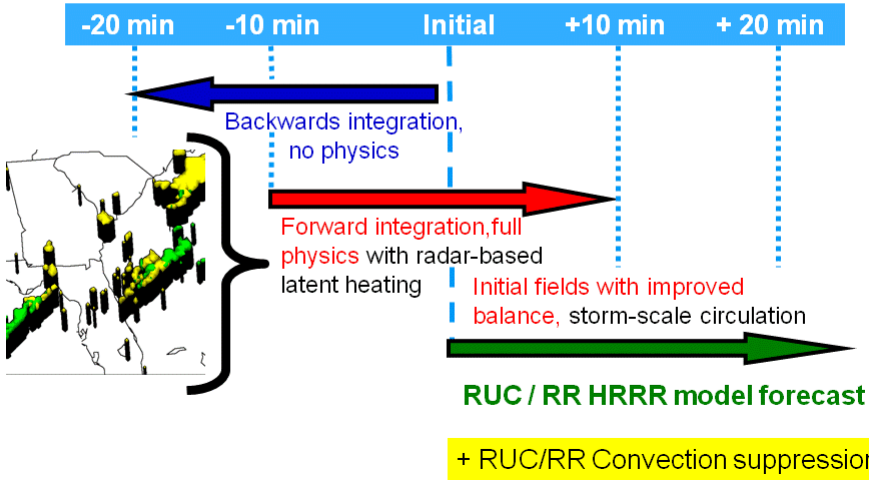
If abs[Psfc(obs-model)] < 70 hPa.

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

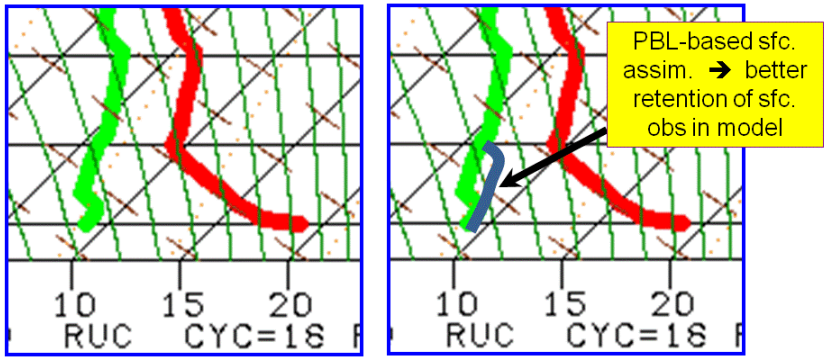
Use model 1h low-level lapse rate.



Digital filter-based reflectivity assimilation

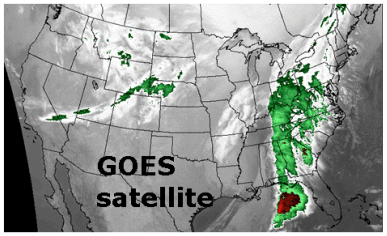


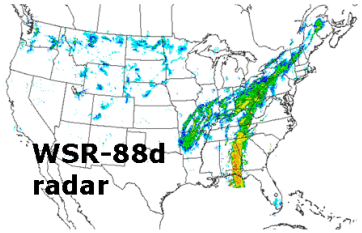
PBL-based pseudo-observations

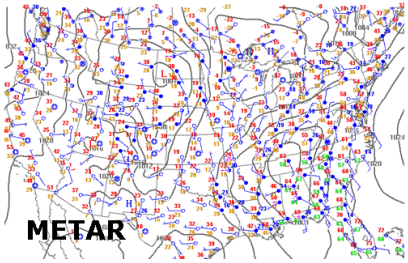


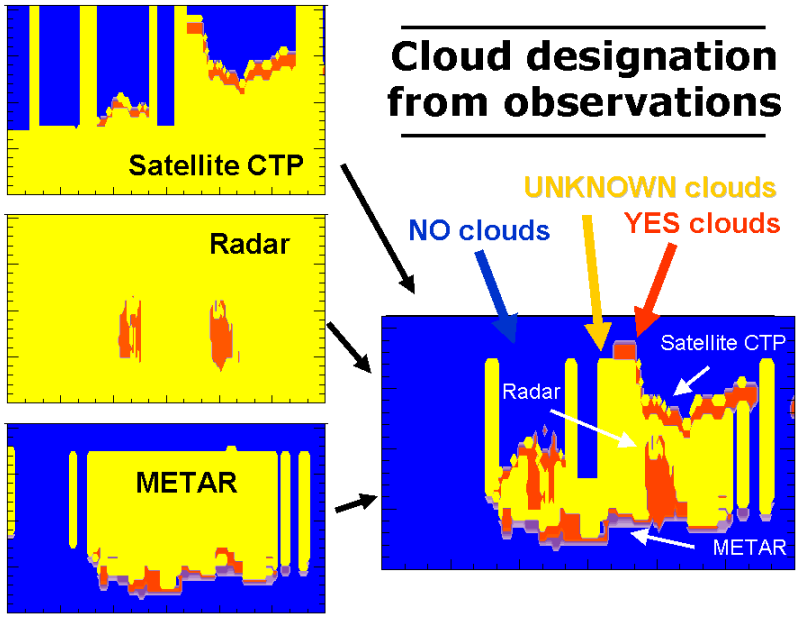
Rapid Refresh – specific analysis features

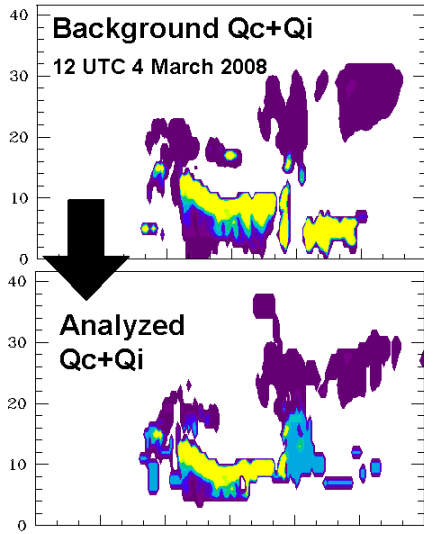
Cloud and hydrometeor analysis











UPDATE: No cloud building from NESDIS/ Langley cloud products in initial RAP. *(GOES cloud building re-enabled in ESRL RAP/HRRR on 2/15/12 – ready for NCEP RAPv2)*

Outline

- Model description for Rapid Refresh
- Data assimilation description for RR (RAP)
- Output from RAP (grids, Unipost mods, RTMA, BUFR)
- Partial cycling for Rapid Refresh, SST, land-surface grids
- Verification statistics for RAP vs. RUC

Rapid Refresh
NCEP planned grid distribution

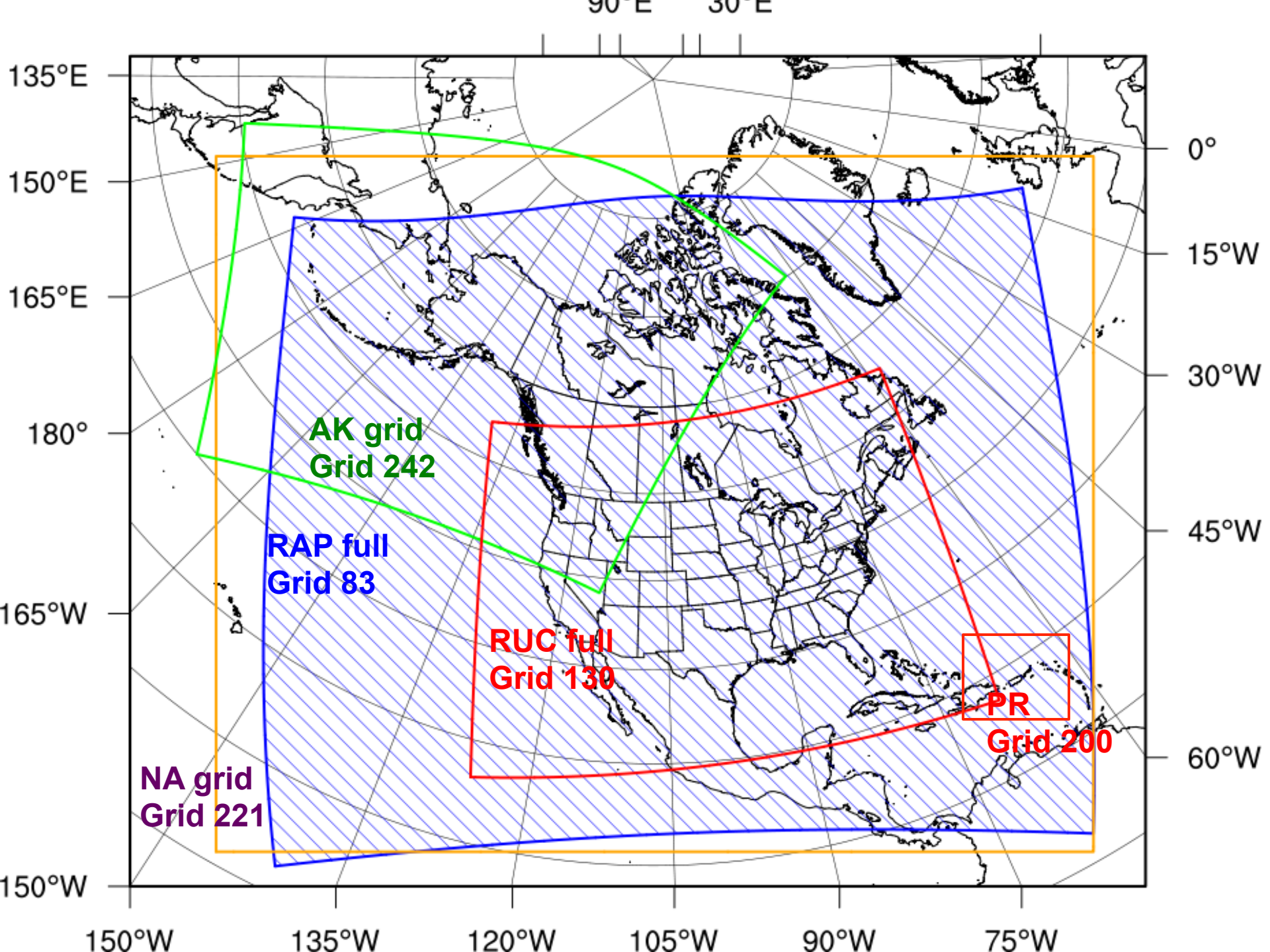
RAP grid distribution from NCEP will include:

- 130 (13 km CONUS): pressure level output, native level output
- 252 (20 km CONUS): pressure, native
- 236 (40 km CONUS): pressure levels only
- 242 (11 km Alaska): one file with all needed parameters
- 221 (32 km nearly full domain): one file with all needed parameters
- 200 (16 km Puerto Rico): one file with all needed parameters

(NOTE: Full NAM grid is also on 221 grid)

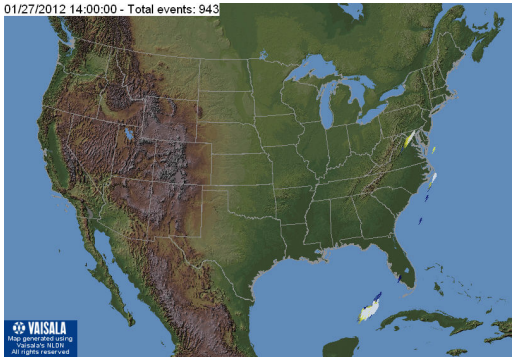
Additional grid not to be distributed initially due to bandwidth limitation:

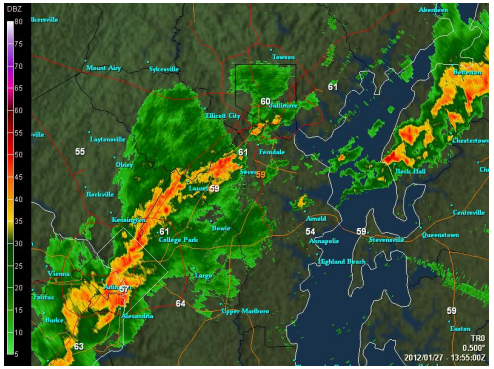
- 83 (13km full Rapid Refresh domain on rotated lat/lon grid)

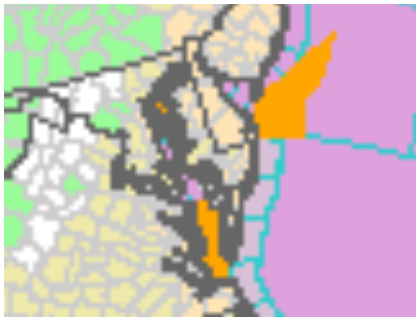

90°E
30°E
135°E
150°E
165°E
180°
165°W
150°W
0°
15°W
30°W
45°W
60°W
150°W
135°W
120°W
105°W
90°W
75°W
AK grid
Grid 242
RAP full
Grid 83
RUC full
Grid 130
PR
Grid 200
NA grid
Grid 221

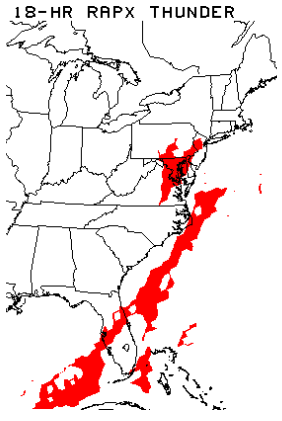
Unipost options added for Rapid Refresh application

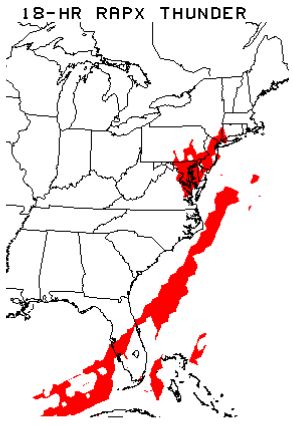
- **Ceiling** -includes NCAR code for effect of falling snow
- **Visibility** -includes RH component and updated coefficients from NCAR
  (Now used by Binbin Zhou also in SREF)
- **MAPS SLP reduction** – more coherent SLP pattern over elevated terrain, matches RUC output SLP
- **Precip-type** – based on explicit qi/qc/qr/qs/qg (bug in RUC for mixed snow/rain fixed with RAP)
- **Heights** for ARW input
- Switch to virtual temp for CAPE/CIN/LI
- All commits into NCEP Unipost repository

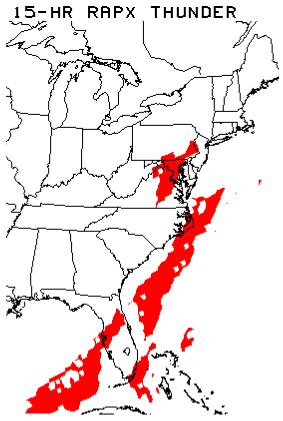


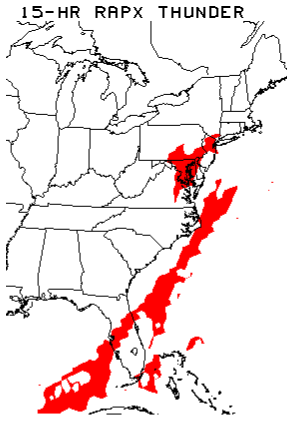


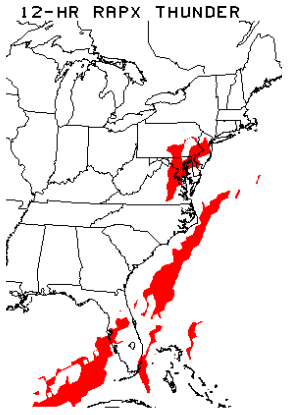




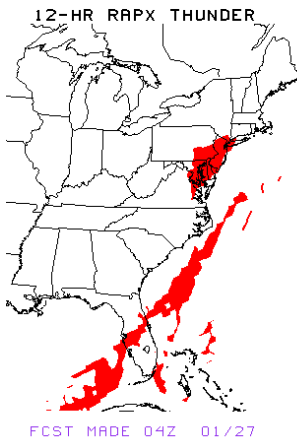


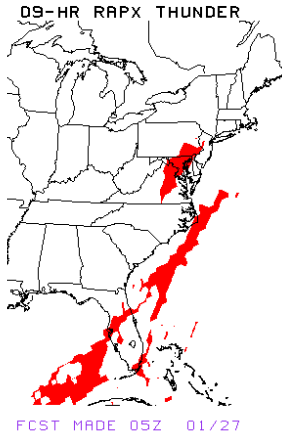


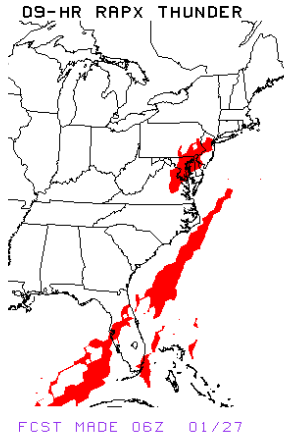




Post includes Thunderstorm yes/no prediction based on work of David Bright







Other post-processing, NARRE-TL

- **BUFR soundings**
- **replace RUC files for HYSPLIT background with RAP**
- **Downscaling for CONUS RTMA background**
  - RAP replacing RUC
- **GEMPAK grids**
  - for SPC, AWC, HPC
- **Hourly updated regional ensemble** with RAP and NAM time-lagged ensemble members
  - Formerly known as VSREF (very short range)
  - Official name – **NARRE-TL** – *N. American Rapid Refresh Ensemble – Time-lagged*

NARRE-TL ensemble - part of RAP implementation

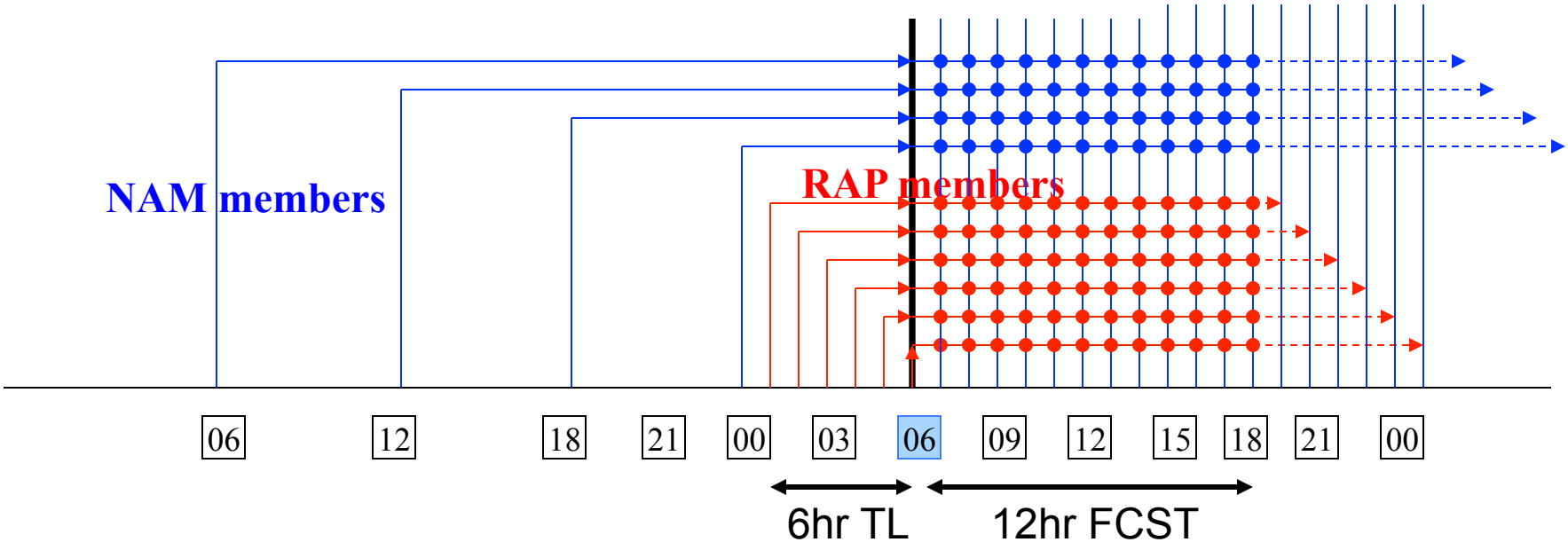
Member Weighting *= 1.0 minus forecast duration (hr)/30*:

e.g., 1 for current fcst and 0 for 30hr-old fcst

(NAM always older than RAP → gives more weight to RAP members)

Last 6 RAP hourly forecasts, last 4 NAM forecasts are used for time-lagged components

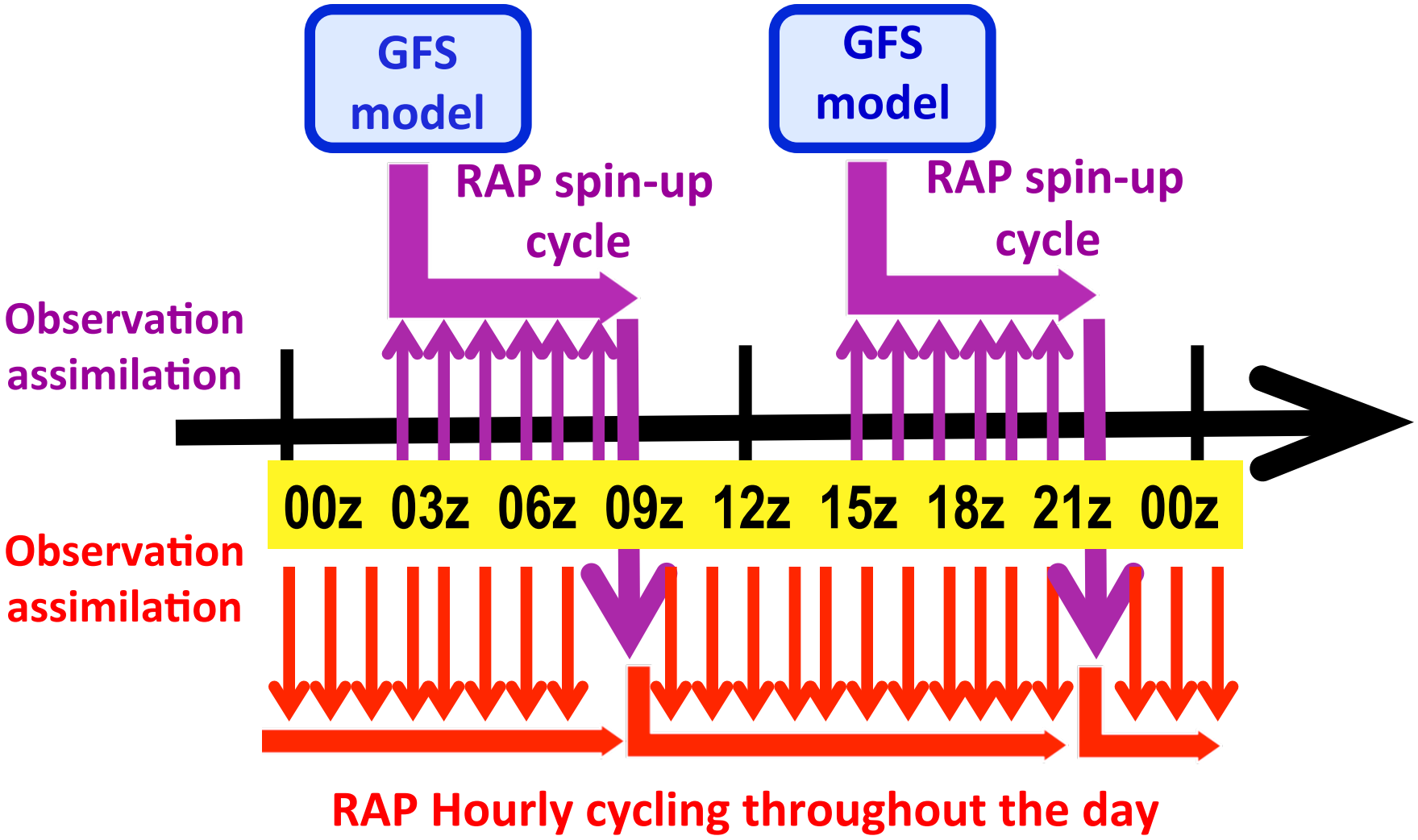
Example for 06Z cycle's NARRE-TL:



Outline

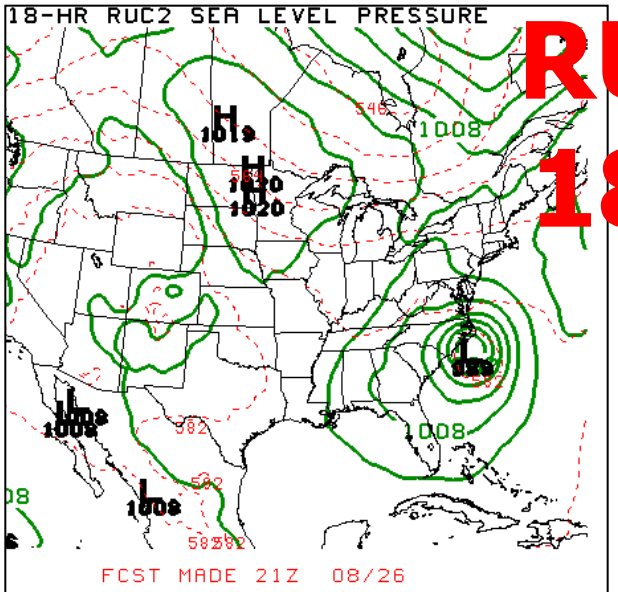
- Model description for Rapid Refresh
- Data assimilation description for RAP
- Output from RAP (grids, Unipost mods, RTMA, BUFR)
- Partial cycling for Rapid Refresh, SST now using RTG_SST_HR-12km
- Verification statistics for RAP vs. RUC

Rapid Refresh Partial Cycling

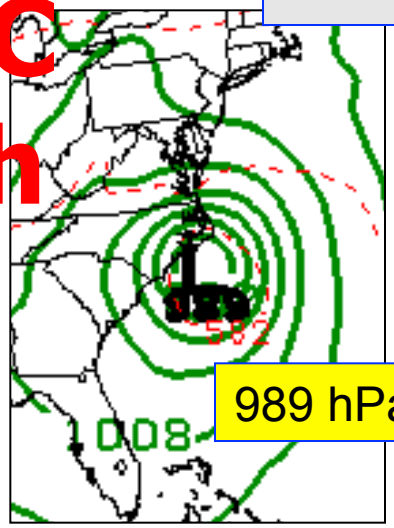


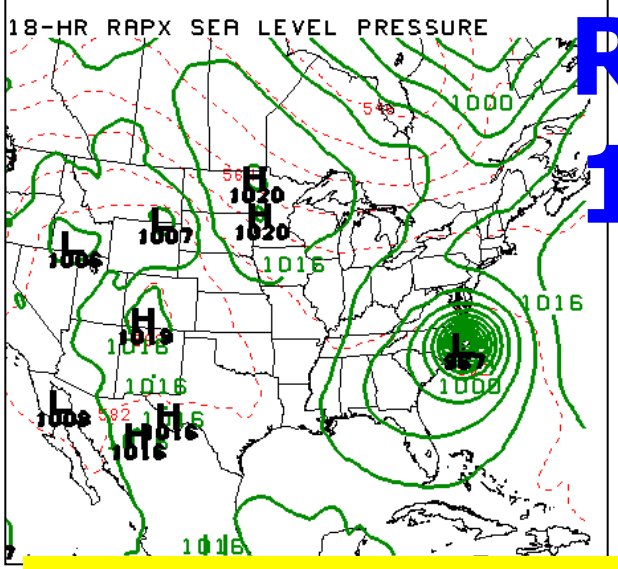
- Hourly cycling of land surface model fields
- 6 hour spin-up cycle for hydrometeors, surface fields

Hurricane Irene

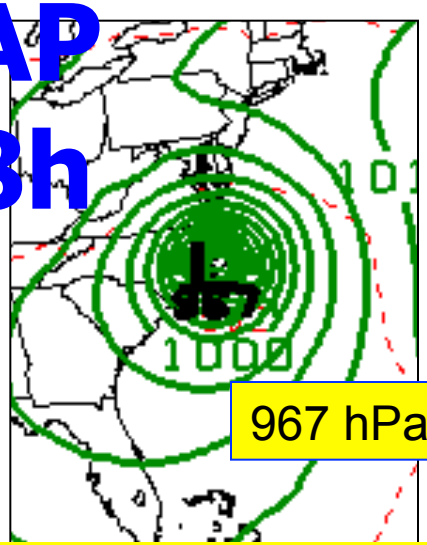


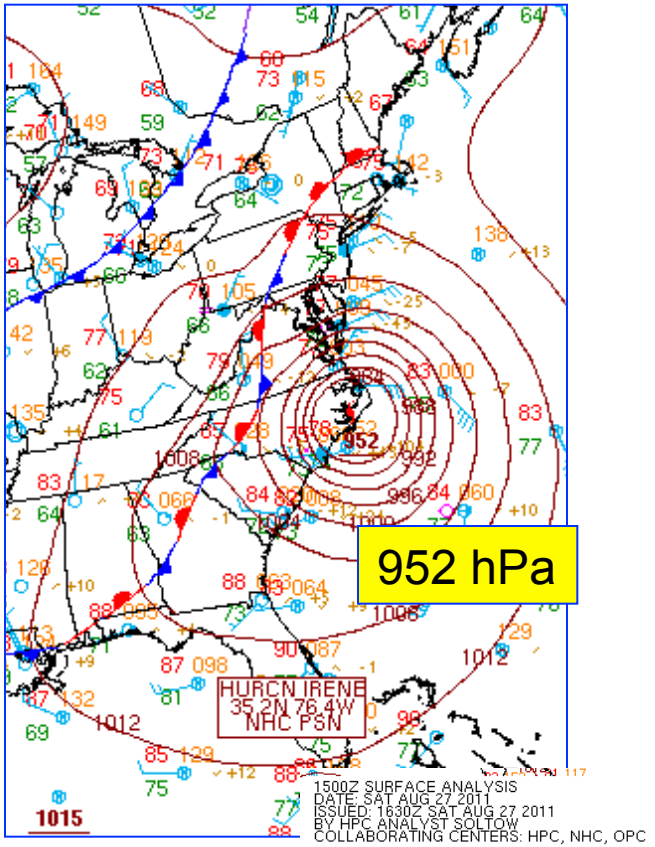
RUC 18h





RAP 18h





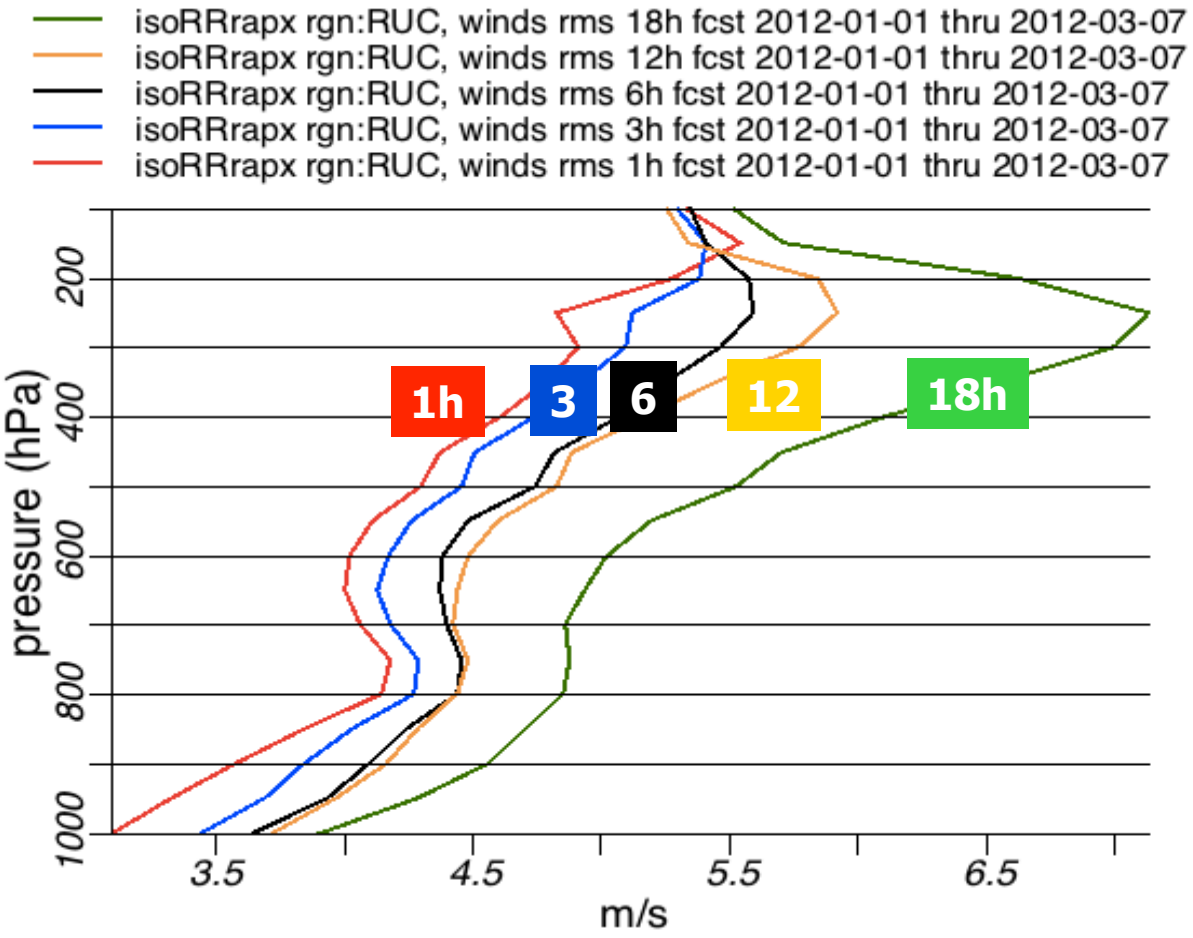
Obs

15z Sat 27 Aug 2011

- **RAP partial cycling with GFS inserted 2x/day very helpful for tropical cyclones in RAP, which then spins down TCs to 13km horizontal resolution.**
- **RAP will be much better background for RTMA for TCs**

Outline

- Model description for Rapid Refresh
- Data assimilation description for RAP
- Output from RAP (grids, Unipost mods, RTMA, BUFR)
- Partial cycling for Rapid Refresh, SST now using RTG_SST_HR-12km
- Case studies and verification statistics for RAP vs. RUC



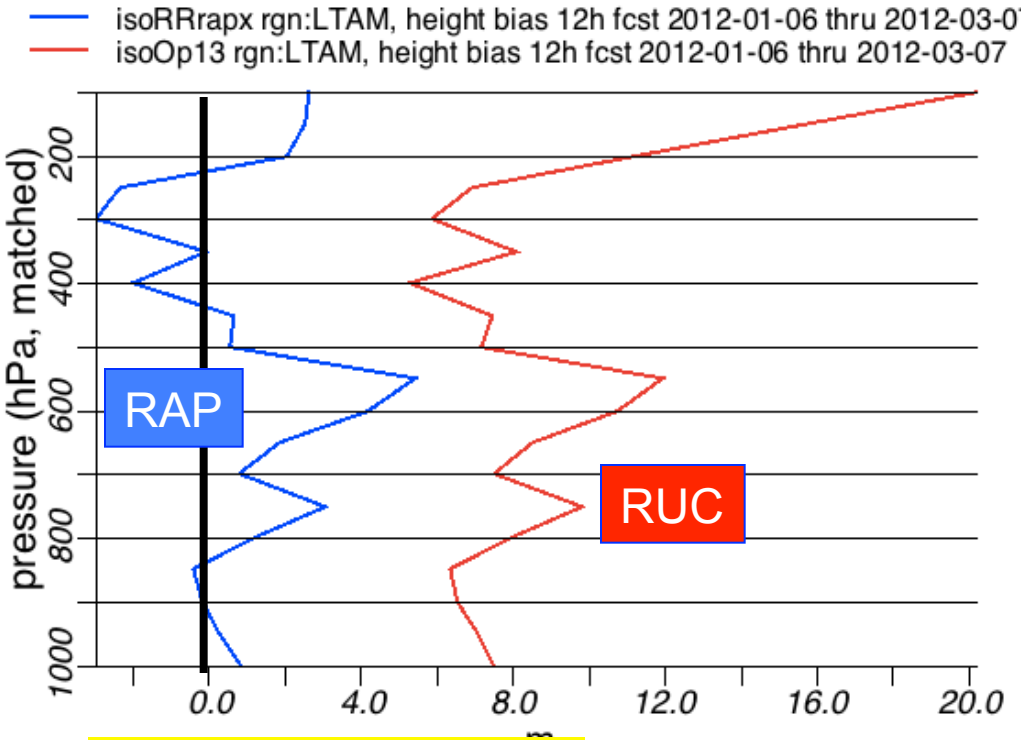
Rapid Refresh Wind forecast accuracy vs. forecast length

1 Jan - 7 Mar 2012

- Verification against raobs

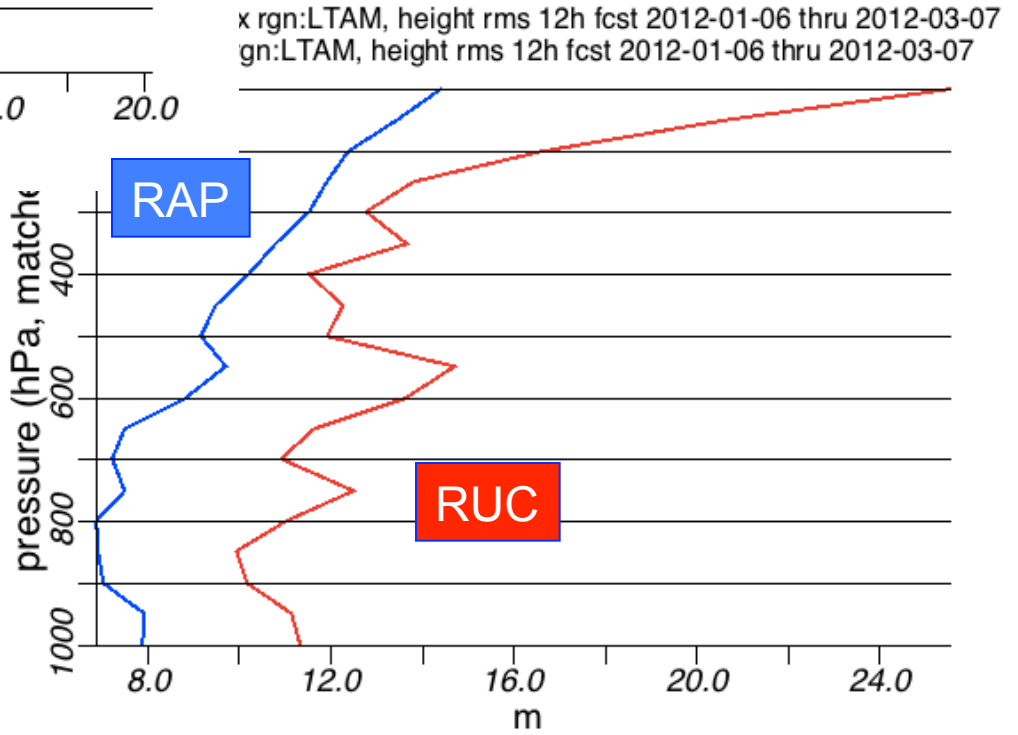
The Rapid Refresh is able to use recent obs to improve forecast skill down to 1-h projection

12h height forecasts RUC vs. RAP (eastern US)



Height –bias
6 Jan – 7 Mar 2012

Height – rms
6 Jan – 7 Mar 2012

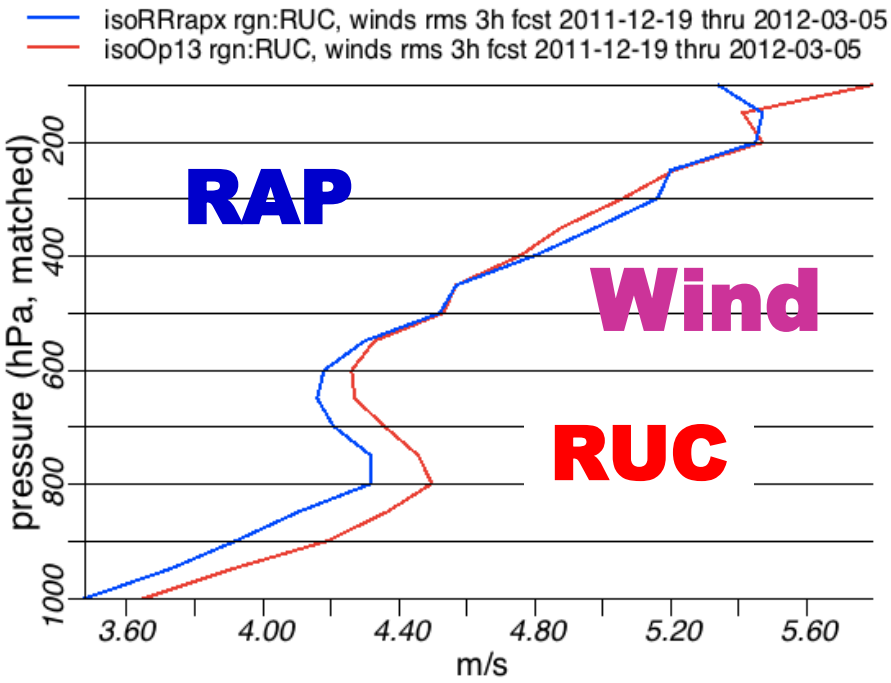


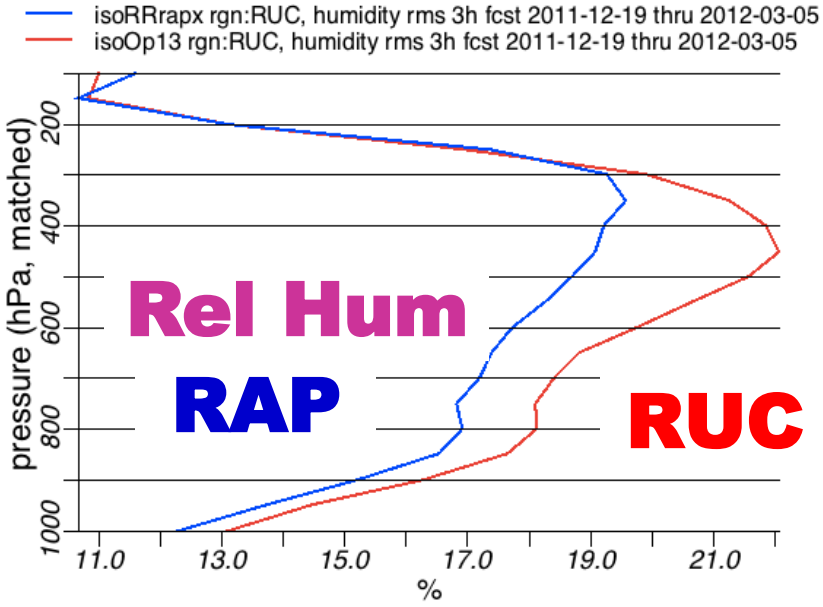
Rapid Refresh vs. RUC upper-air verification

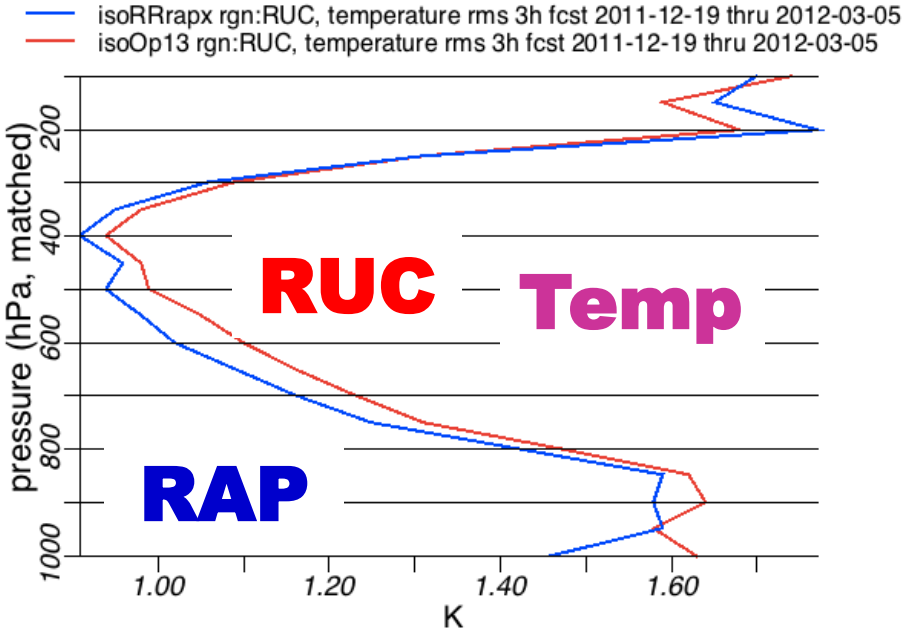
+ 3h forecast

RMS Error

12 Dec 2011 – 5 March 2012





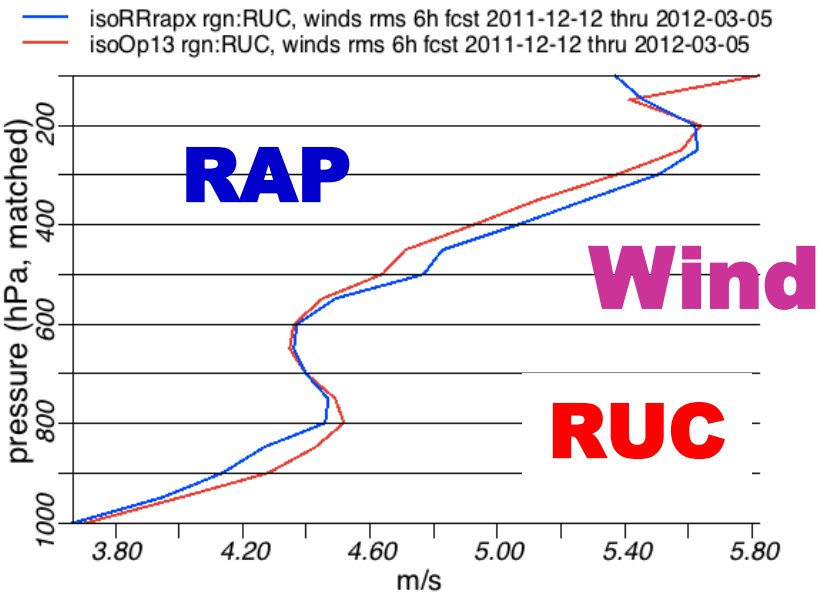


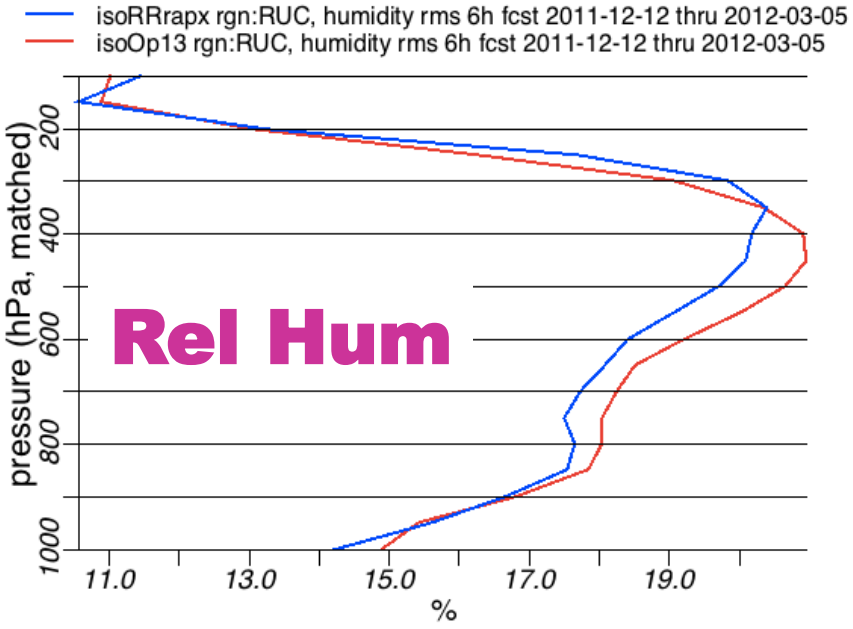
Rapid Refresh vs. RUC upper-air verification

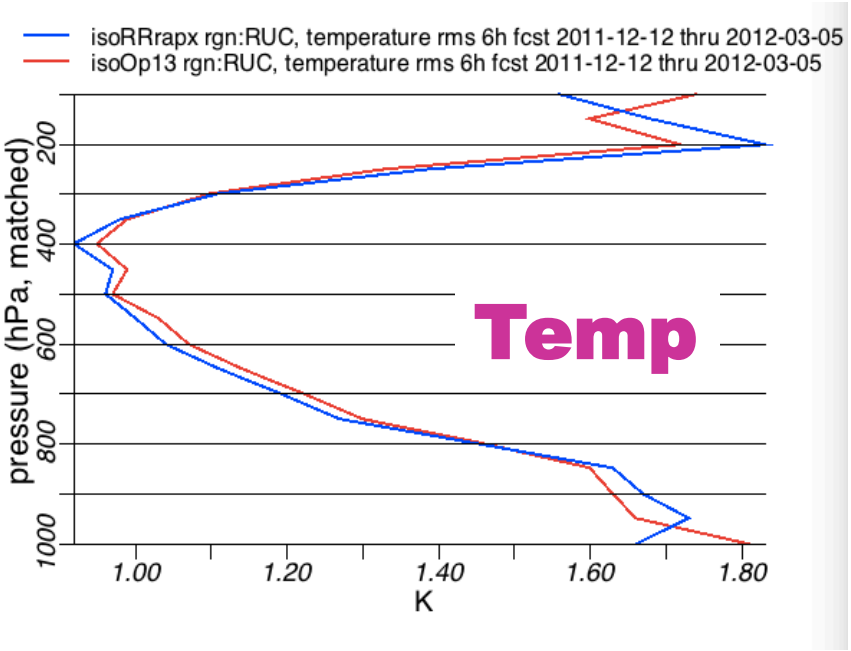
+ 6h forecast

RMS Error

12 Dec 2011 – 5 March 2012







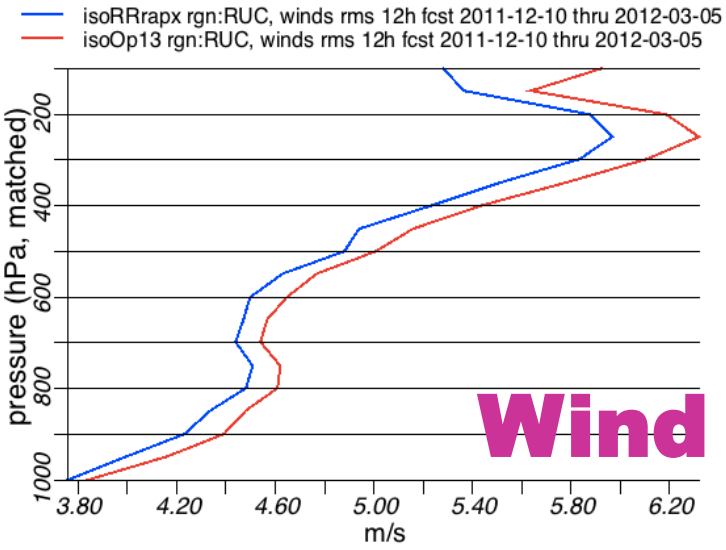
Rapid Refresh vs. RUC
upper-air verification

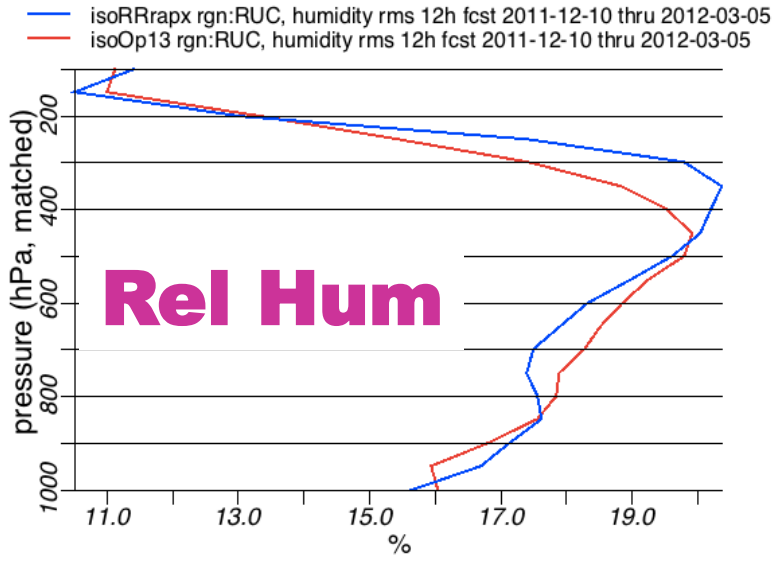
+12h forecast
RMS Error

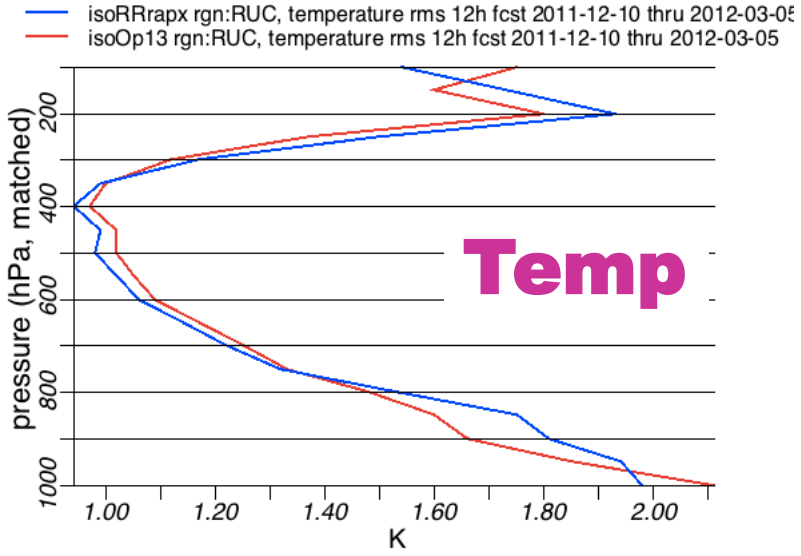
12 Dec 2011 – 5 March 2012

RAP

RUC







Rapid Refresh vs. RUC upper-air verification

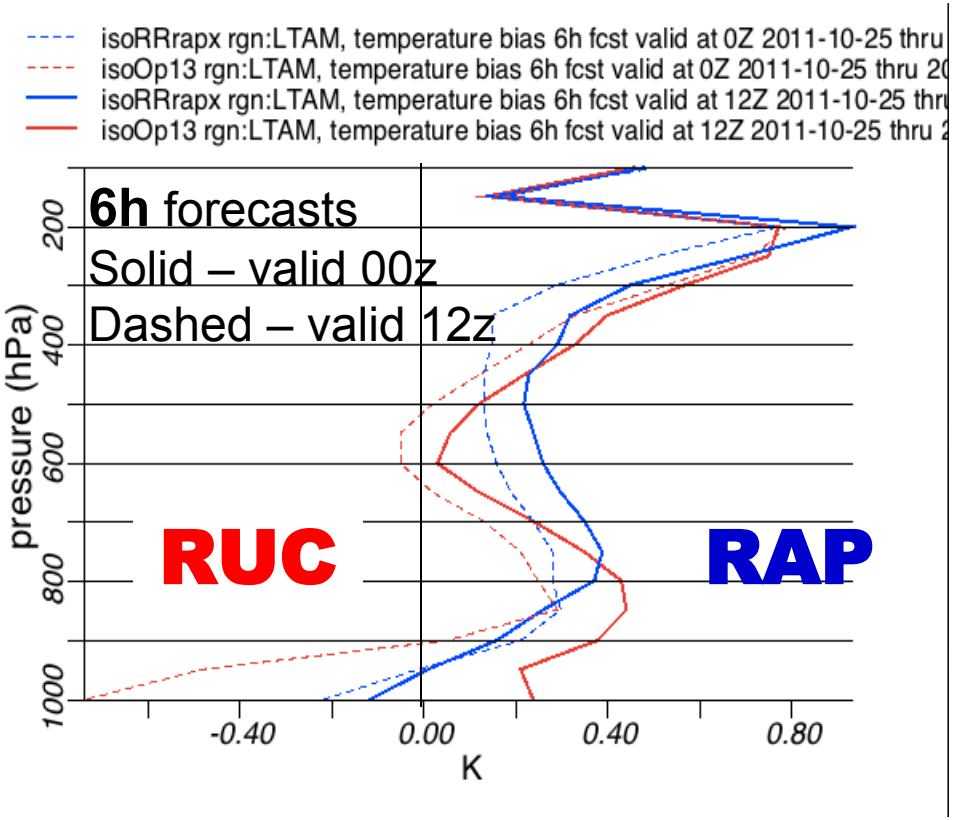
+6/12h forecast

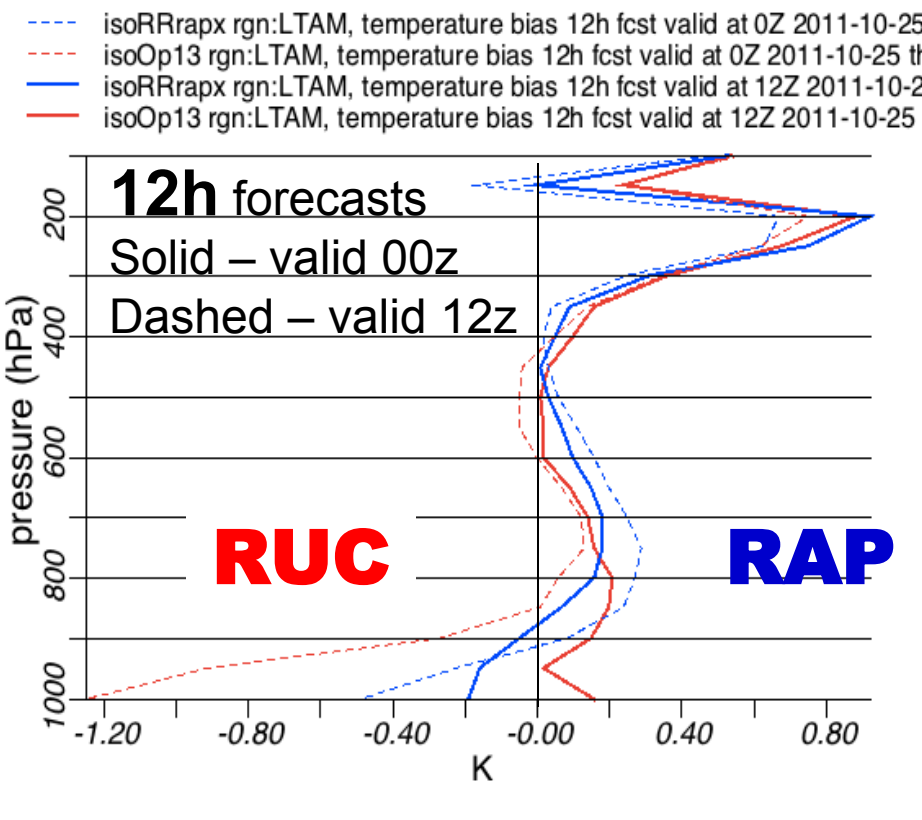
25 Oct 2011 – 5 March 2012

Temperature bias

00z (solid), 12z (dashed)

Bias = forecast-ob





RAP vs. RUC Precipitation Verification

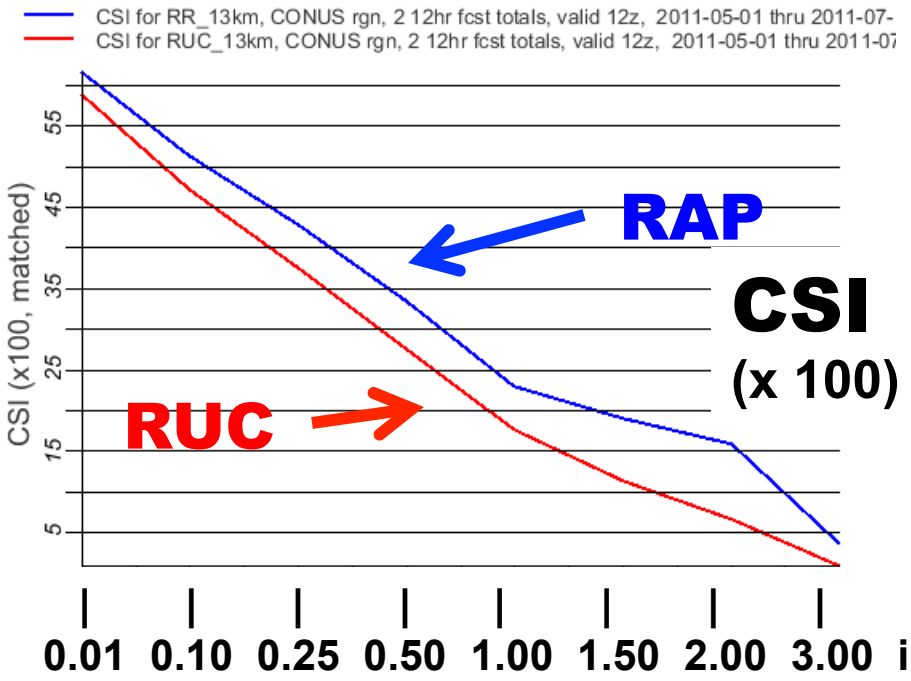
13-km CONUS

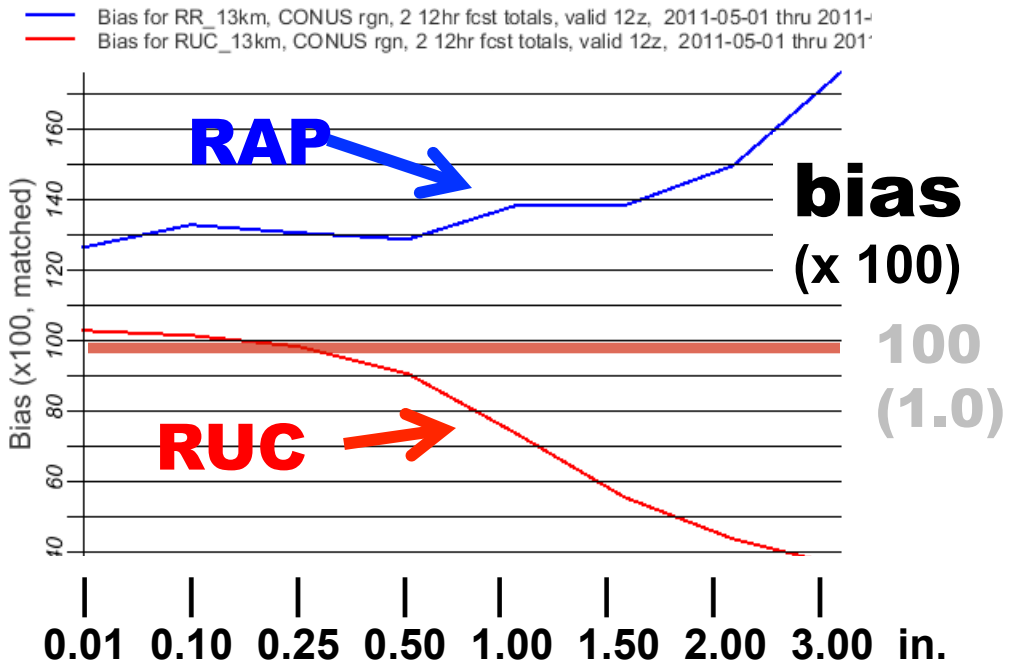
Comparison

2 X 12 hr fcst
vs. CPC 24-h analysis

1 May – 15 July 2011
Matched

SPRING/
SUMMER

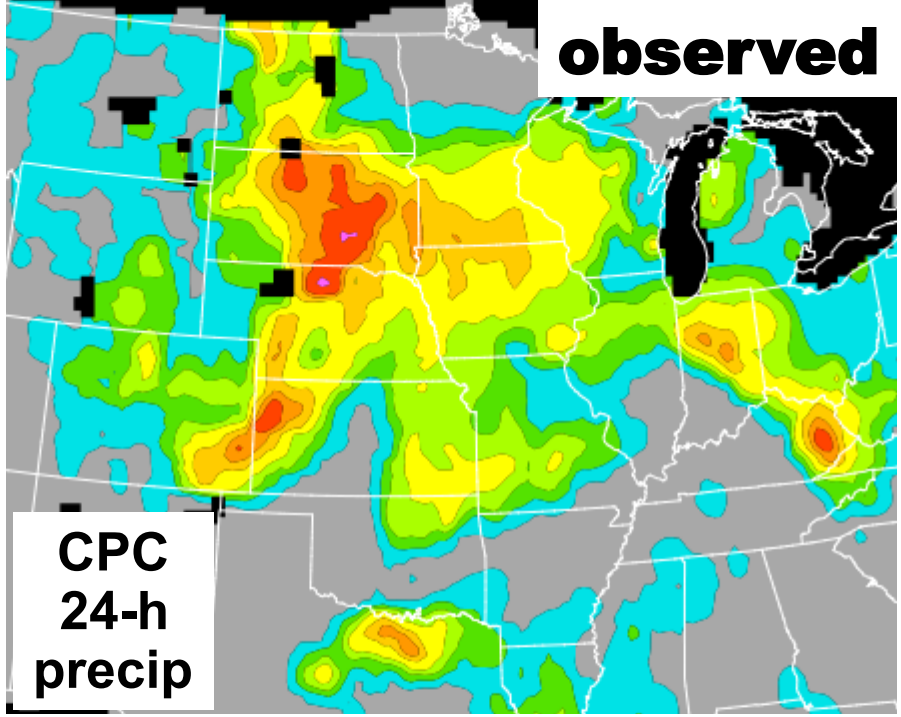


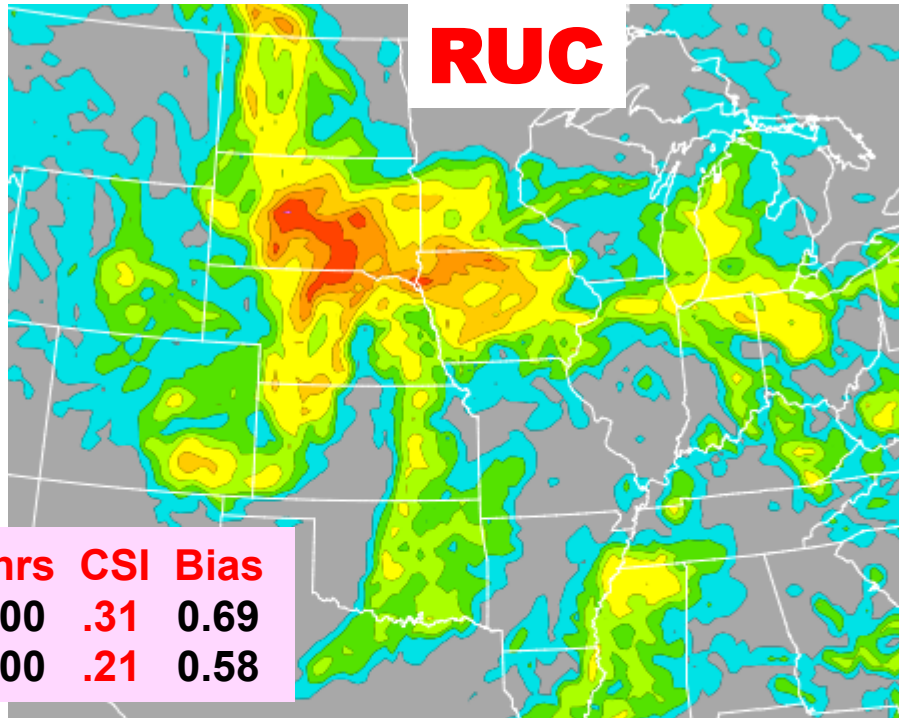


RAP vs. RUC 24-h precip. verif

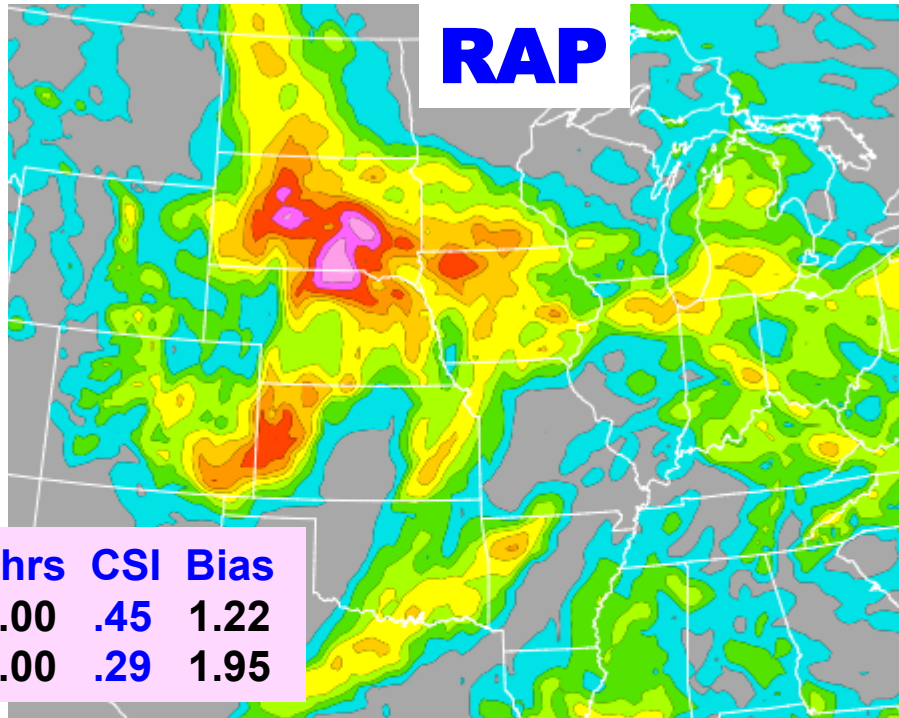
2 x 12h fcst
ending 12z
21 June 2011

Interpolated
to 20-km grid





Thrs	CSI	Bias
1.00	.31	0.69
2.00	.21	0.58

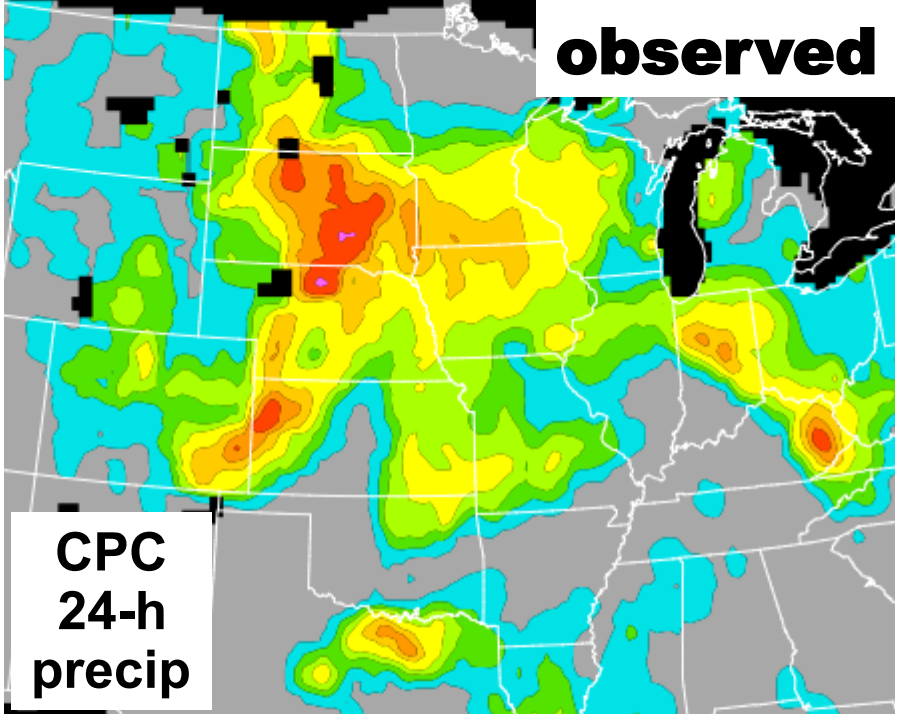


Thrs	CSI	Bias
1.00	.45	1.22
2.00	.29	1.95

RAP vs. RUC 24-h precip. verif

2 x 12h fcst
ending 12z
21 June 2011

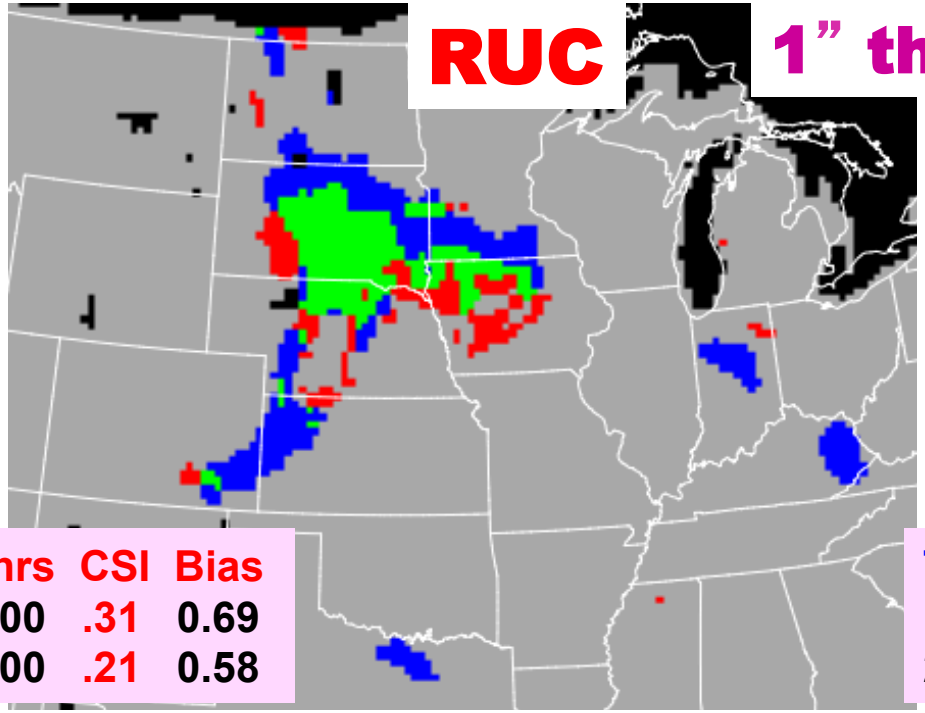
Interpolated
to 20-km grid



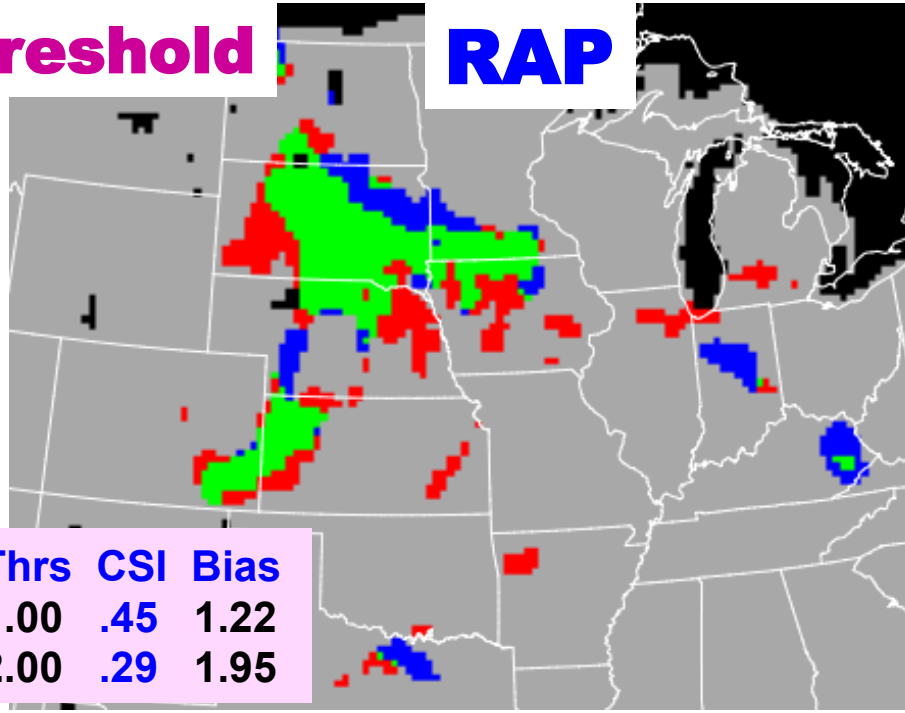
RUC

1” threshold

RAP



Thrs	CSI	Bias
1.00	.31	0.69
2.00	.21	0.58



Thrs	CSI	Bias
1.00	.45	1.22
2.00	.29	1.95

RAP vs. RUC surface – warm season

Diurnal bias variation

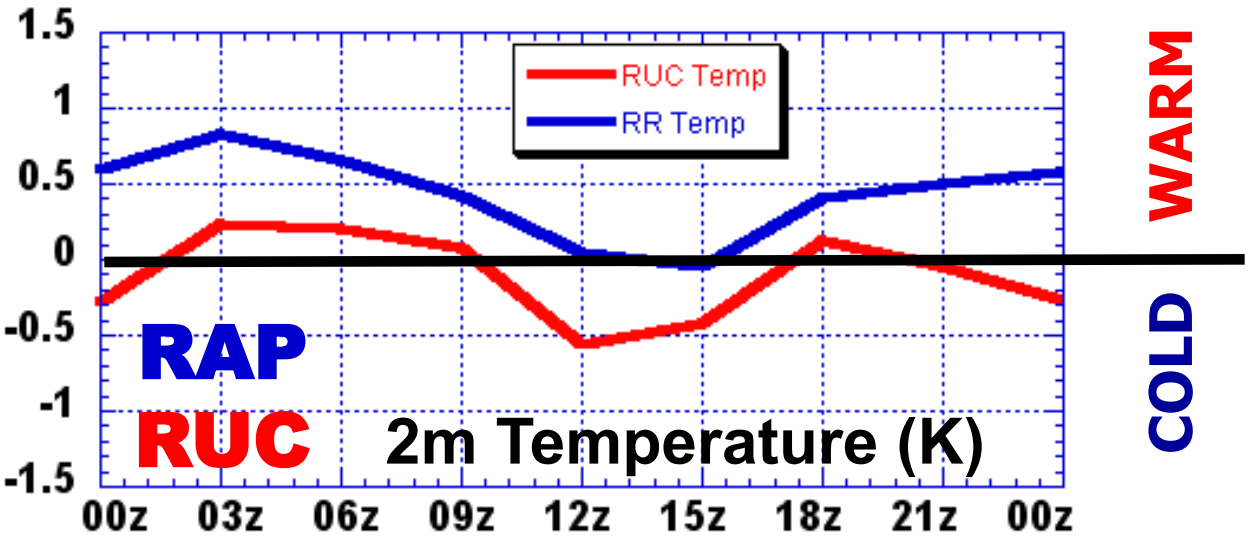
6-h fcst

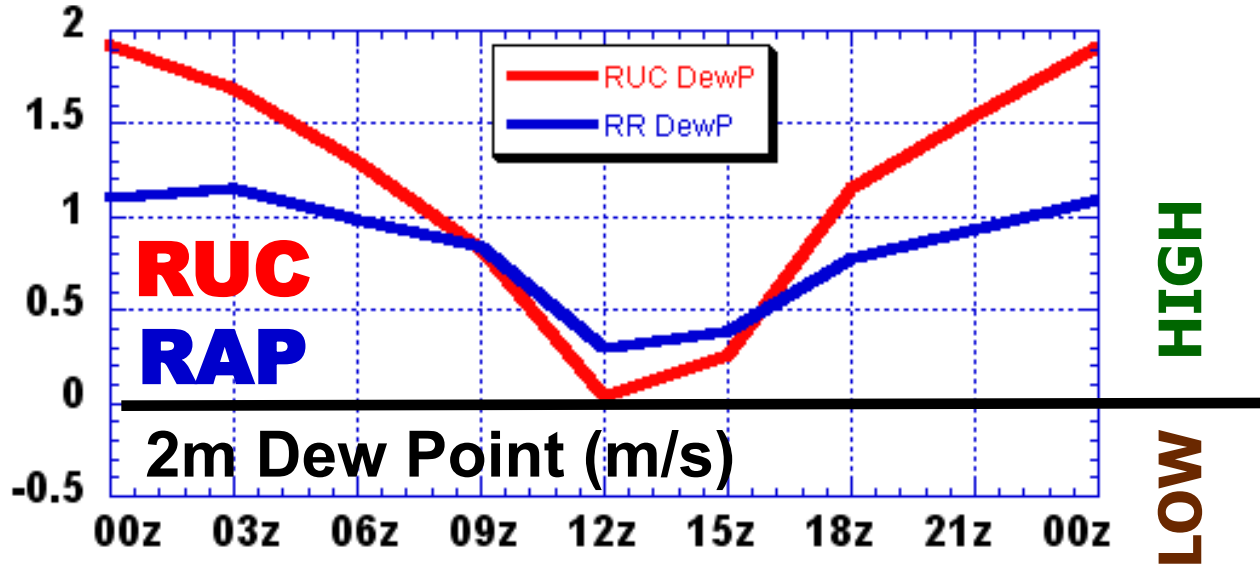
RUC daytime slightly cool, RAP warm, esp. overnight

Both too moist, especially at night

RUC worse than RAP

2-month comparison
20 April – 20 July 2011
Eastern US only





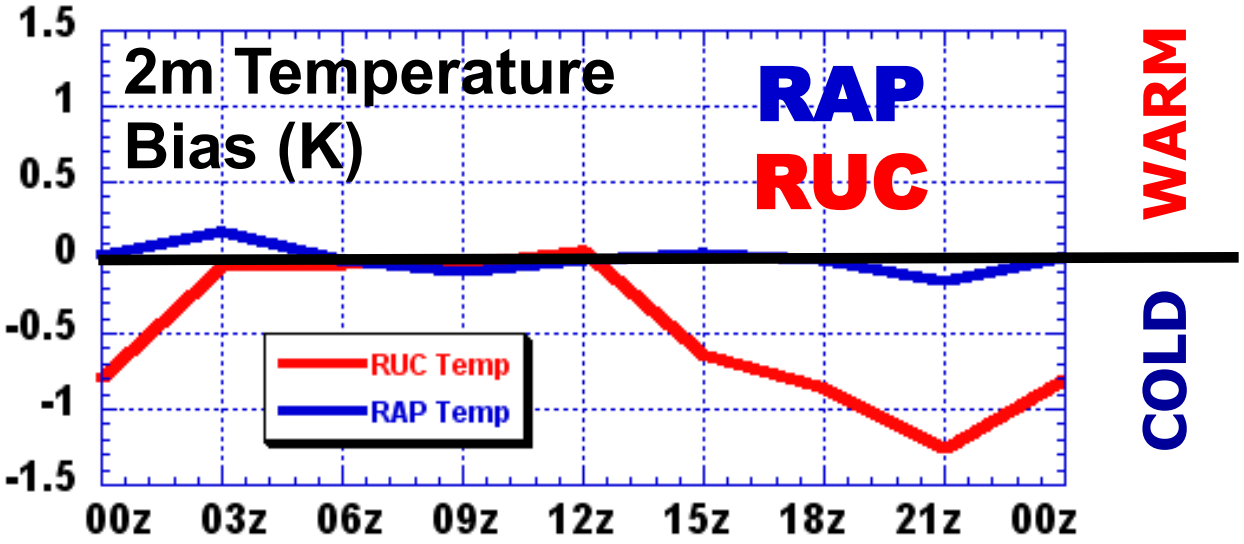
RAP vs. RUC surface – cold season

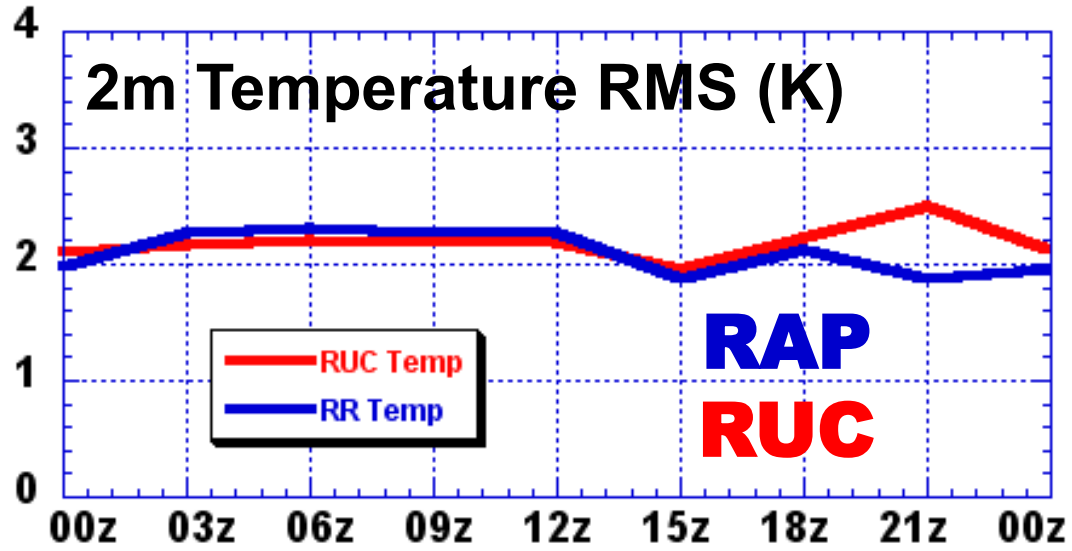
Temperature
bias and RMS diurnal variation
6-h fcst

Excellent RAP bias, RUC too cold in daytime, similar RMS errors

6-week comparison
15 Jan – 29 Feb 2012

Eastern US





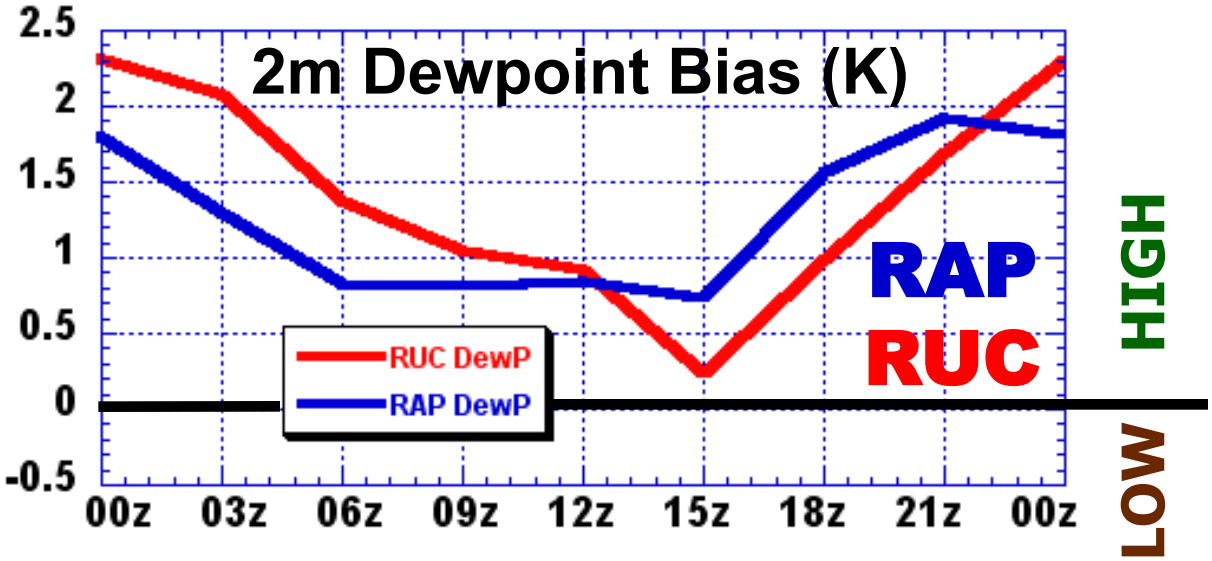
RAP vs. RUC surface – cold season

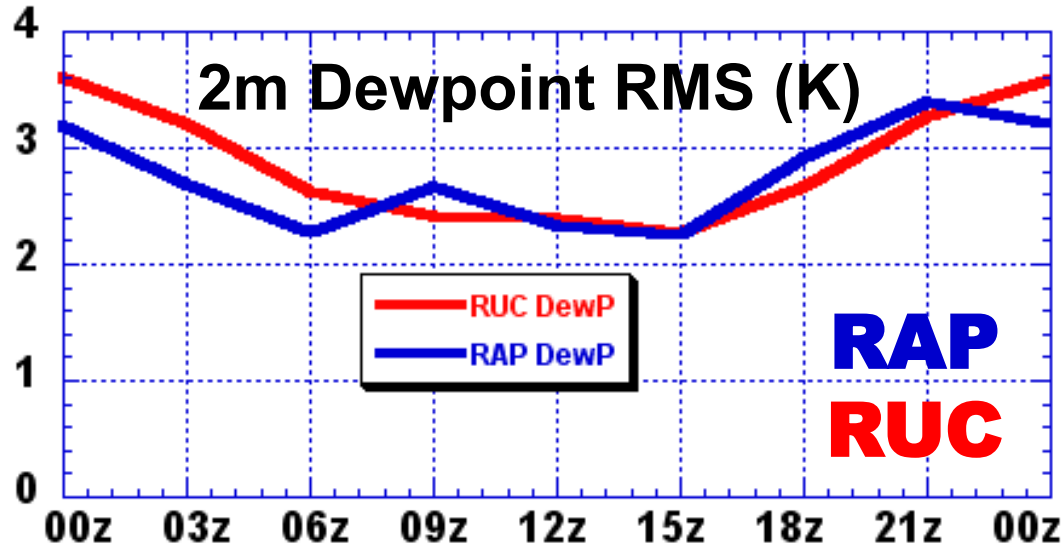
Dewpoint
bias and RMS
diurnal variation
6-h fcst

Both RAP and RUC too moist, similar RMS errors

6-week comparison
15 Jan – 29 Feb 2012

Eastern US





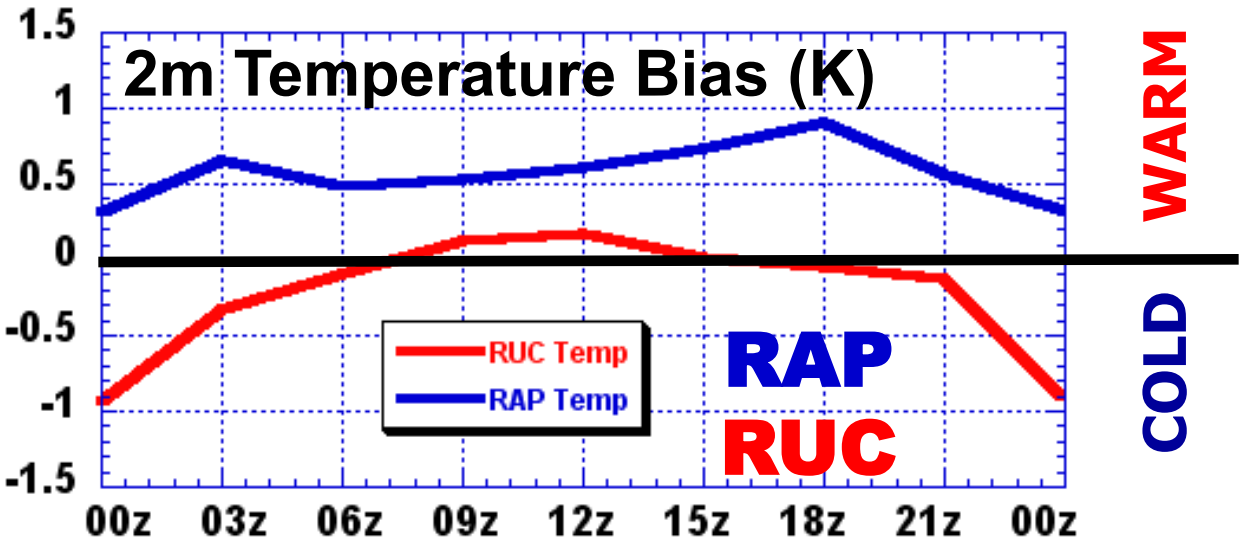
RAP vs. RUC surface – cold season

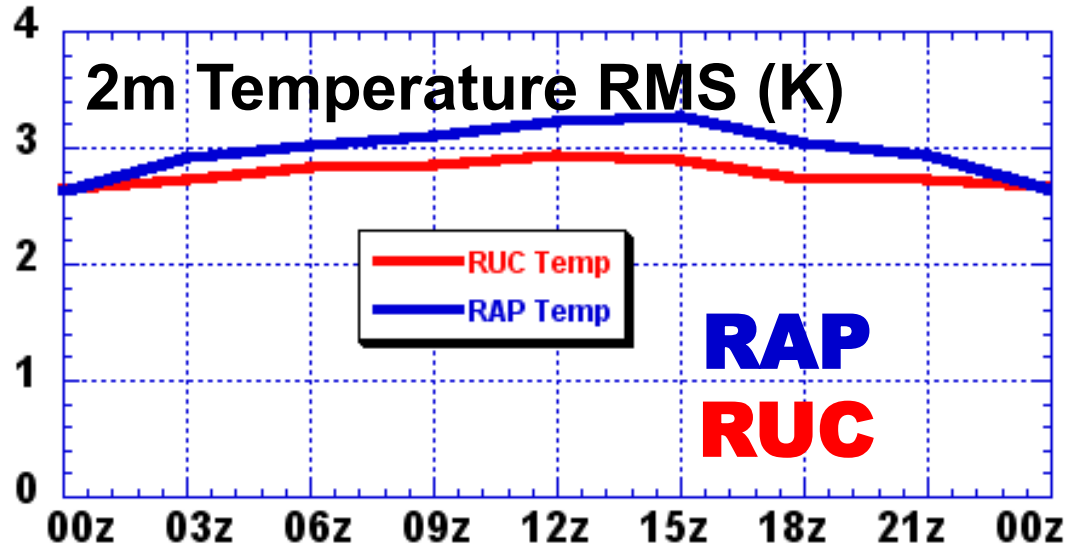
Temperature
bias and RMS diurnal variation
6-h fcst

RAP slightly too warm, slightly larger RMS errors than RUC (*Note: no "topomini" reduction in RAP as in RUC*)

6-week comparison
15 Jan – 29 Feb 2012

Western US





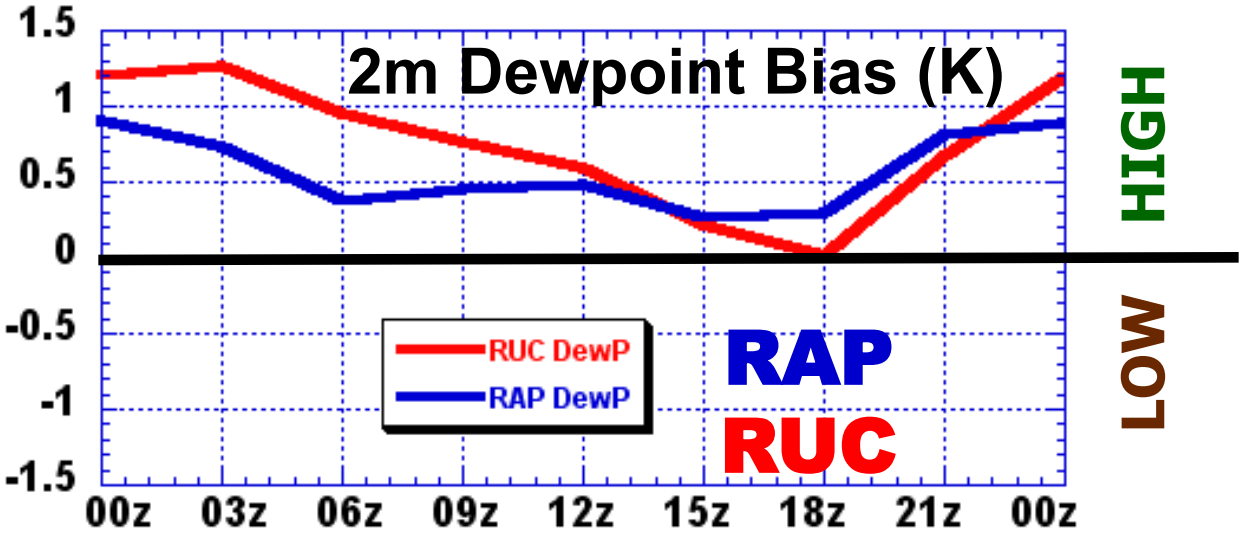
RAP vs. RUC surface – cold season

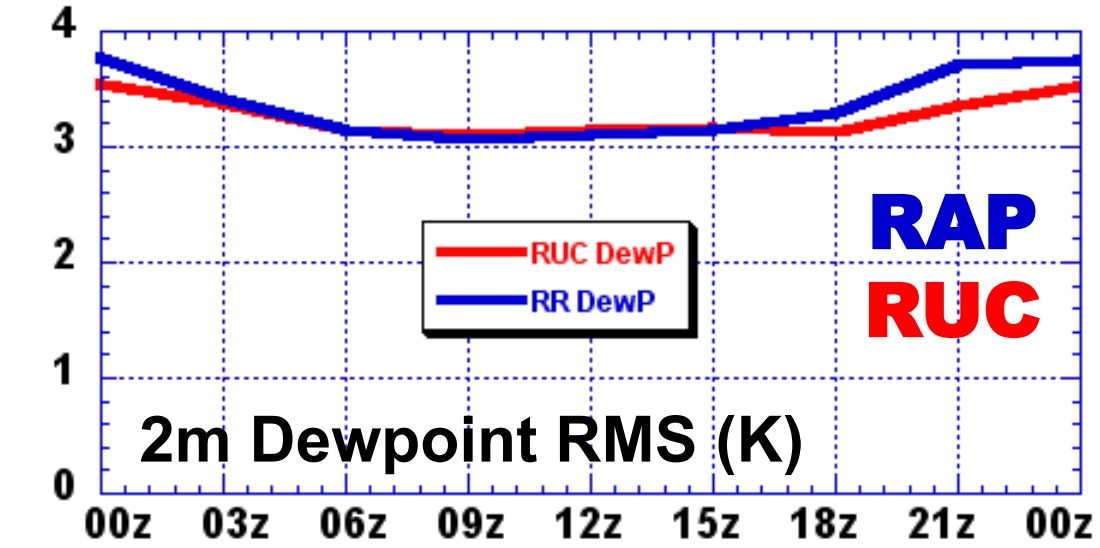
Dewpoint
bias and RMS diurnal variation
6-h fcst

Both RAP and RUC too moist, similar RMS errors

6-week comparison
15 Jan – 29 Feb 2012

Western US



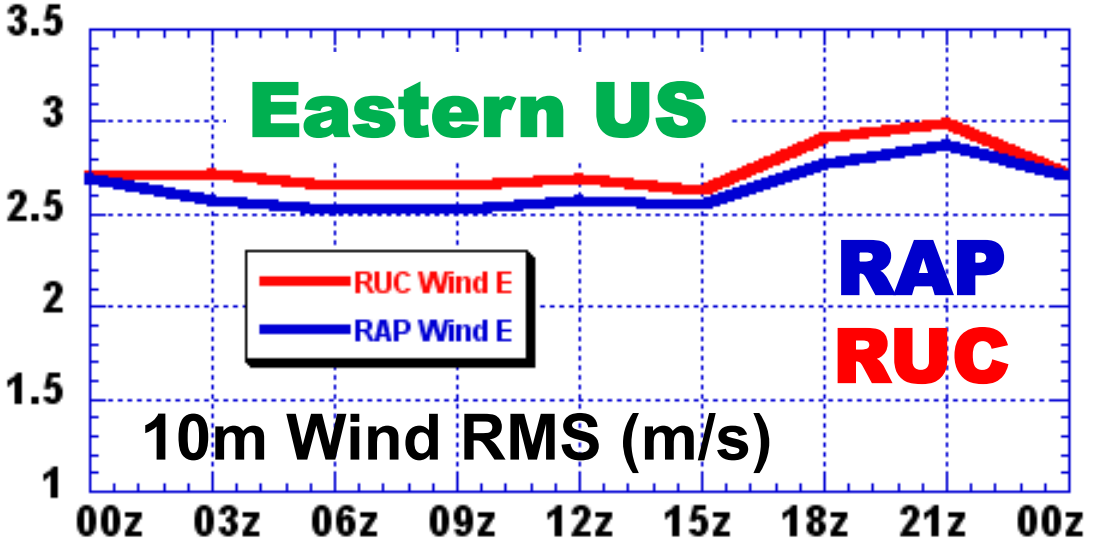


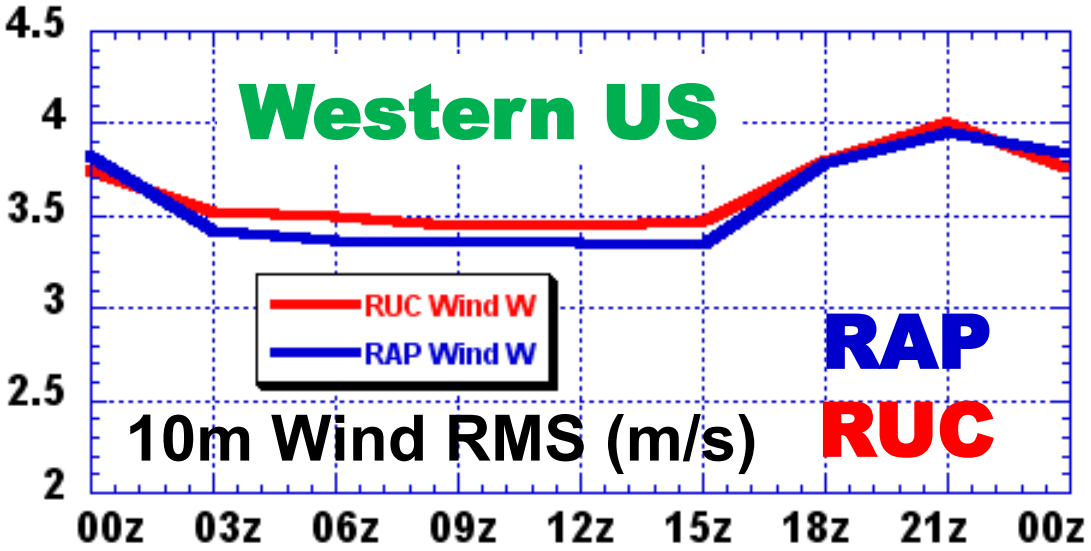
RAP vs. RUC surface wind verification

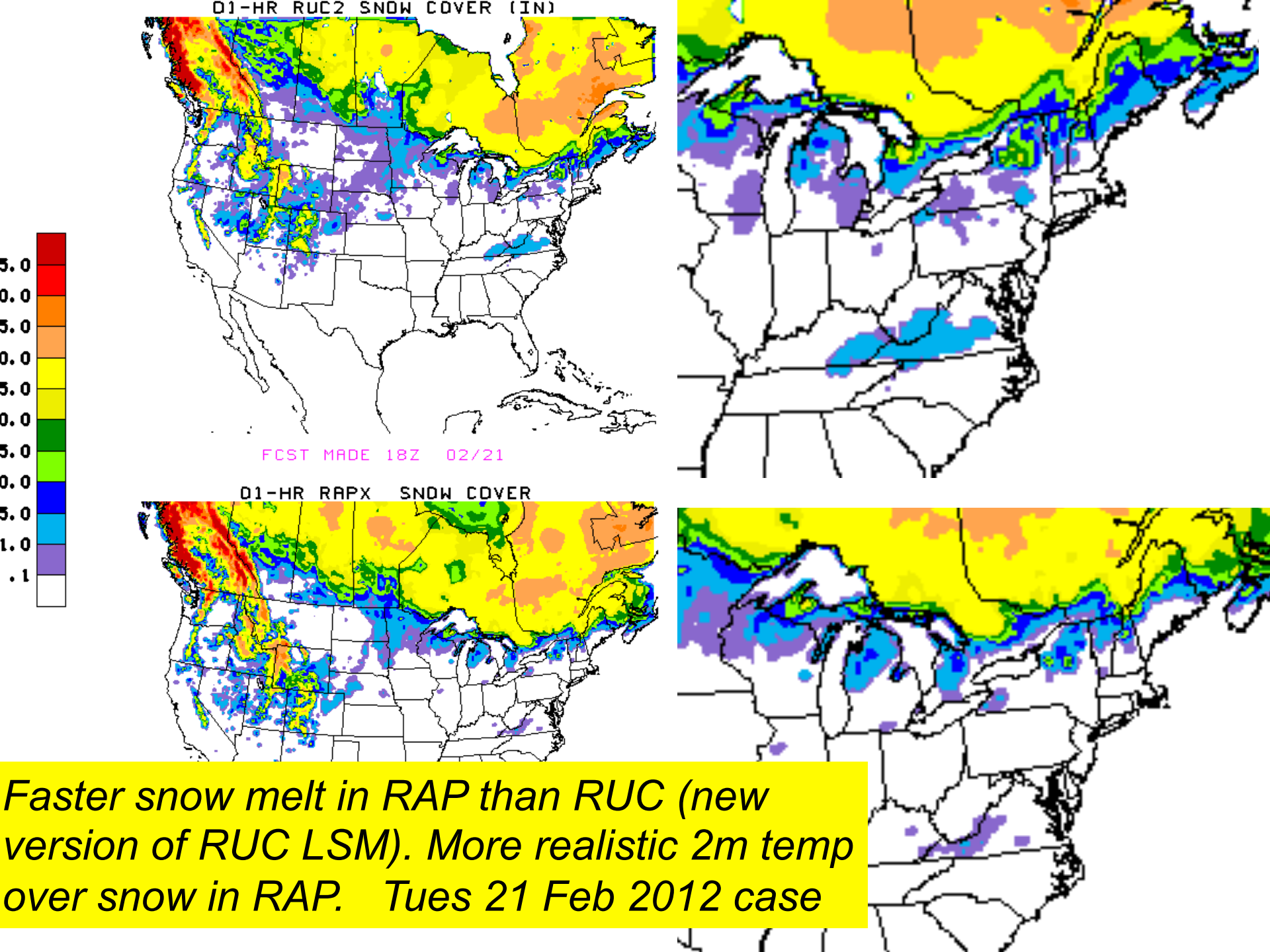
Wind RMS diurnal variation
6-h fcst

RAP RMS errors lower than RUC for both Eastern and Western U.S.

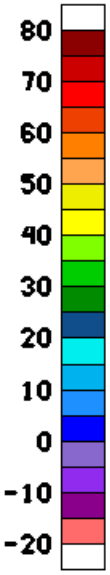
4-week comparison
9 Feb – 7 Mar 2012

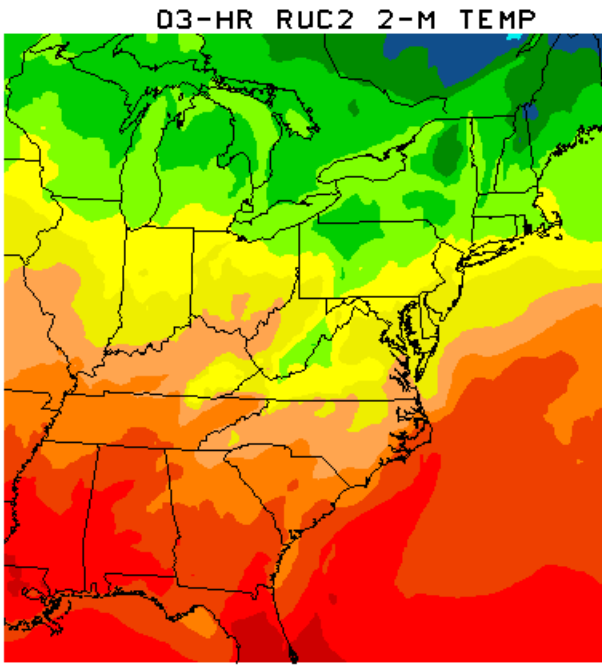


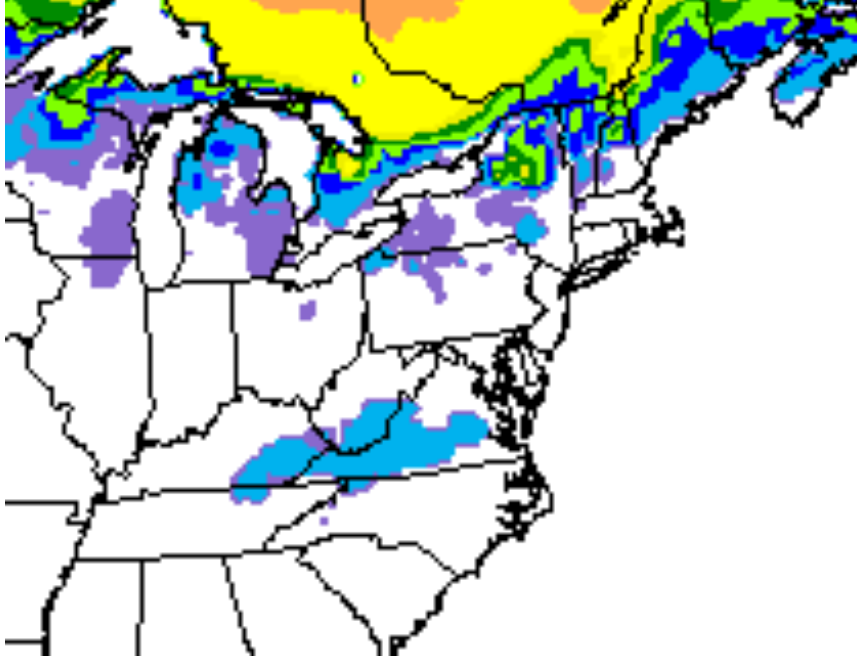


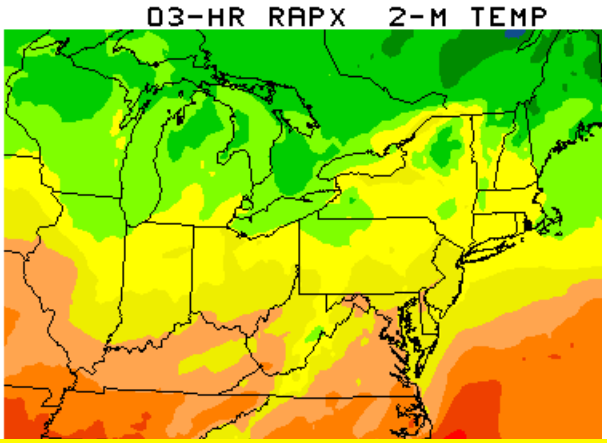


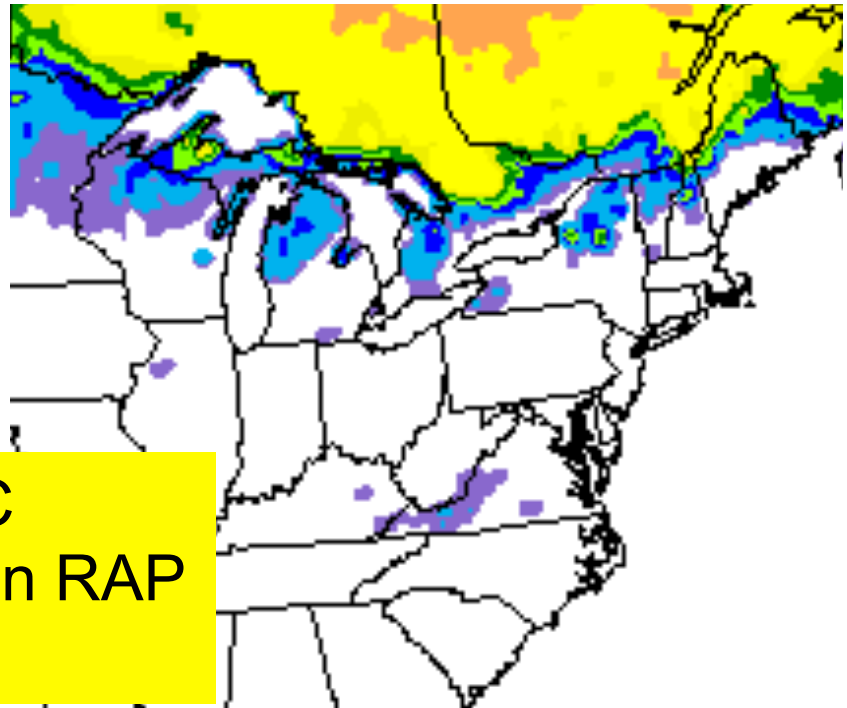
Faster snow melt in RAP than RUC (new version of RUC LSM). More realistic 2m temp over snow in RAP. Tues 21 Feb 2012 case



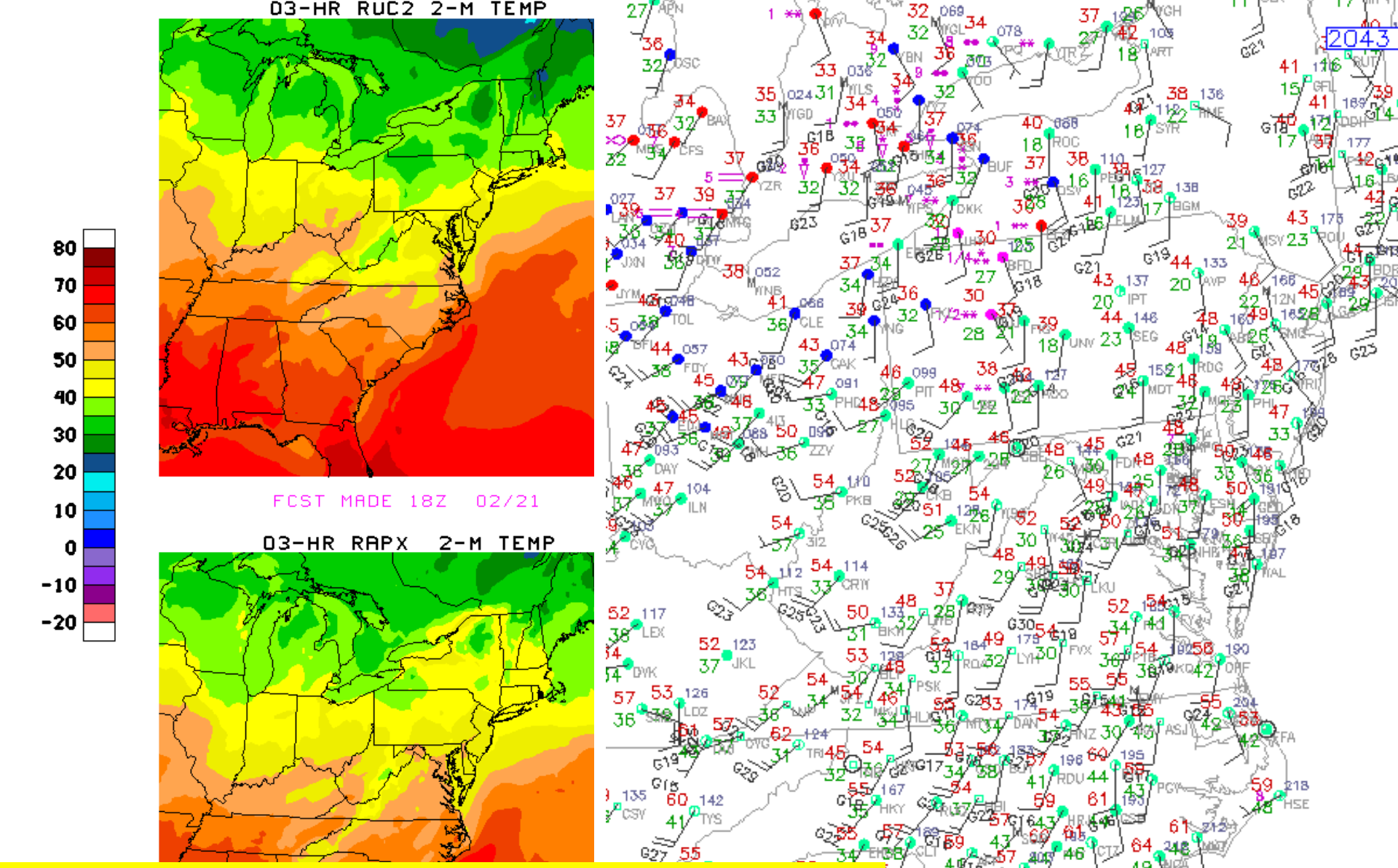








Faster snow melt in RAP than RUC
More realistic 2m temp over snow in RAP
Tues 21 Feb 2012 case



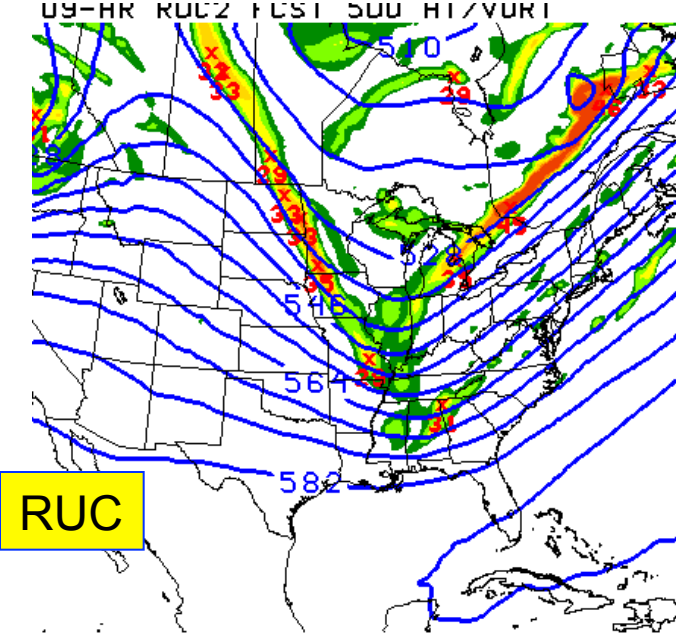
Faster snow melt in RAP than RUC

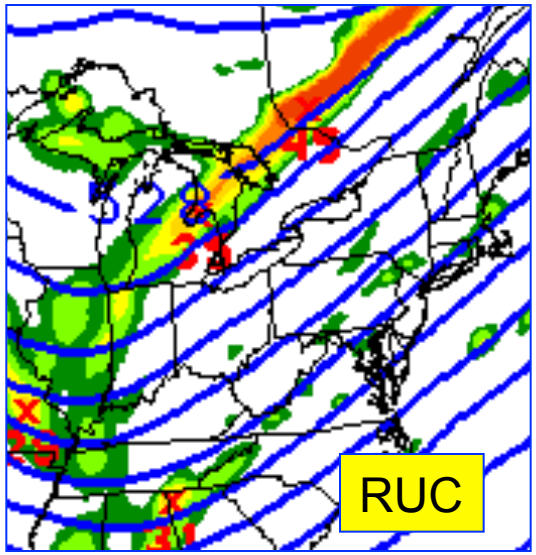
More realistic 2m temp over snow in RAP

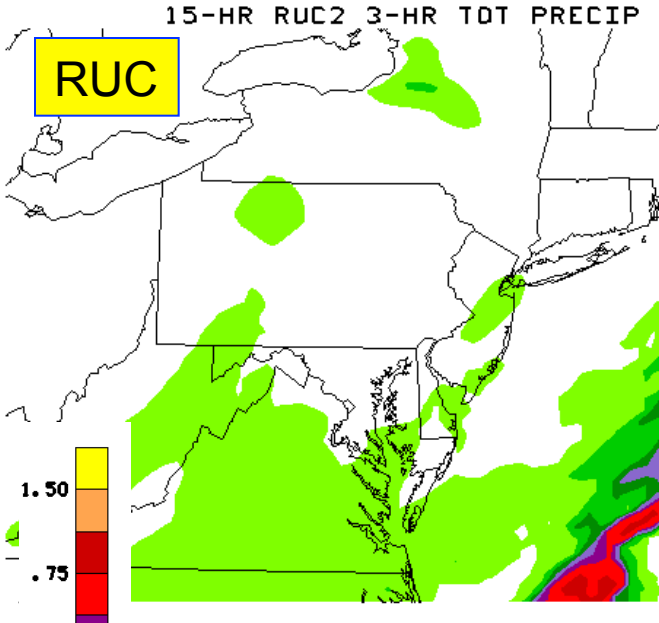
Tues 21 Feb 2012 case

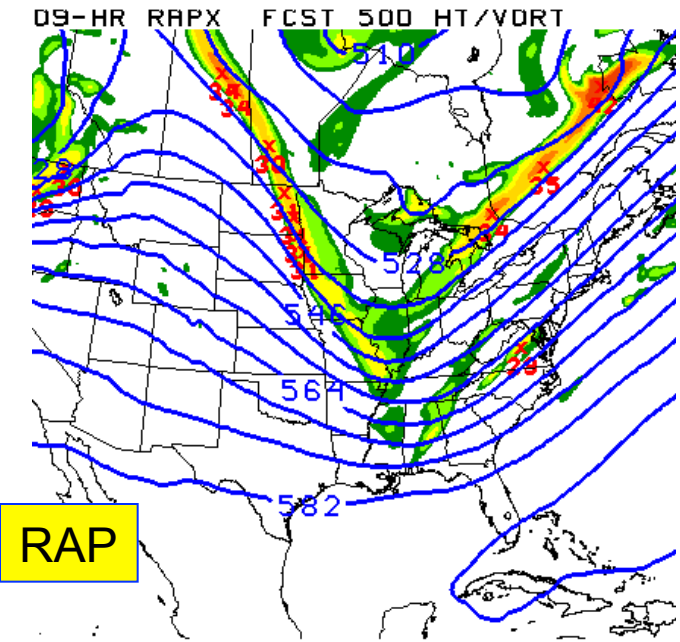
mid-Atlantic post-frontal rain band - 17 November 2011

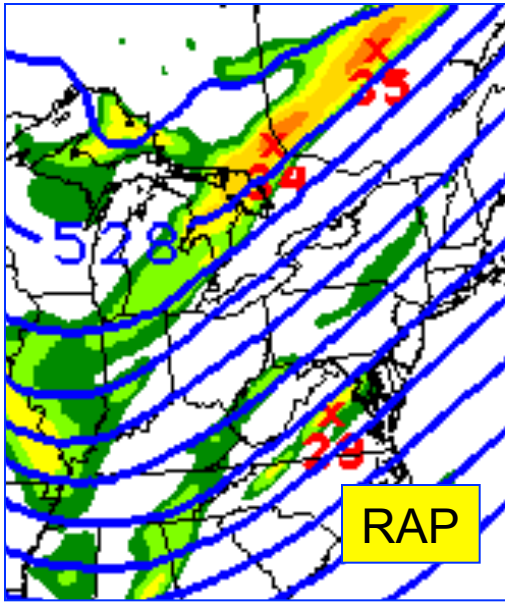
- RAP handled vort max much better, so it had stronger forcing than the RUC in the mid-Atlantic and showed better potential for a rain band behind the sfc cold front

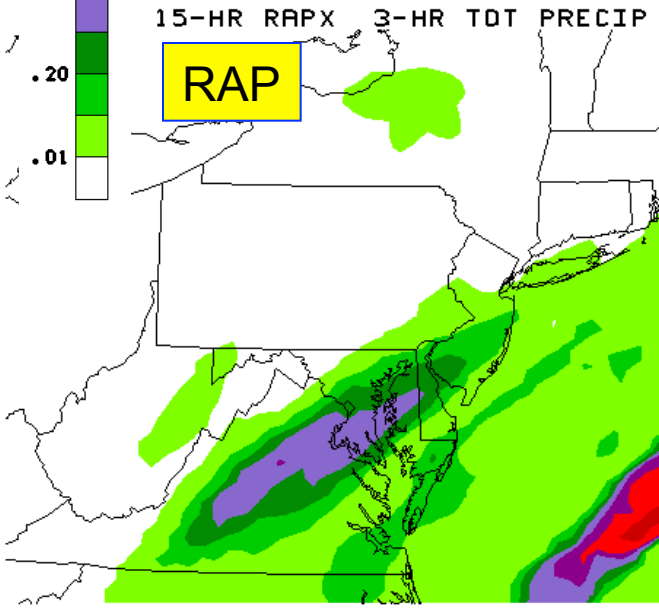

09-HR RUC2 FCST 500 HT/VORT
510
528
546
564
582
RUC
FCST MADE 02Z 11/17

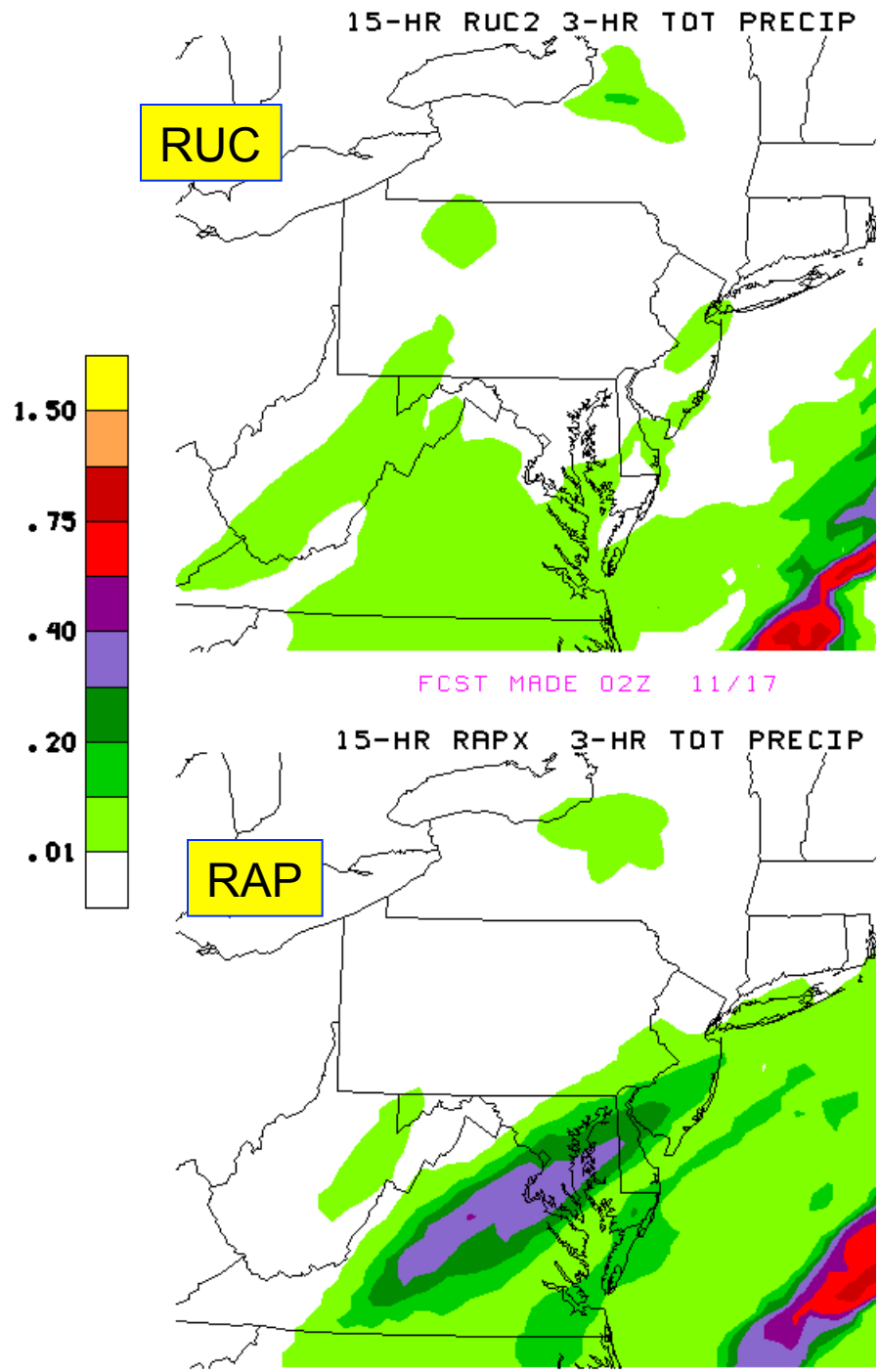

528
RUC

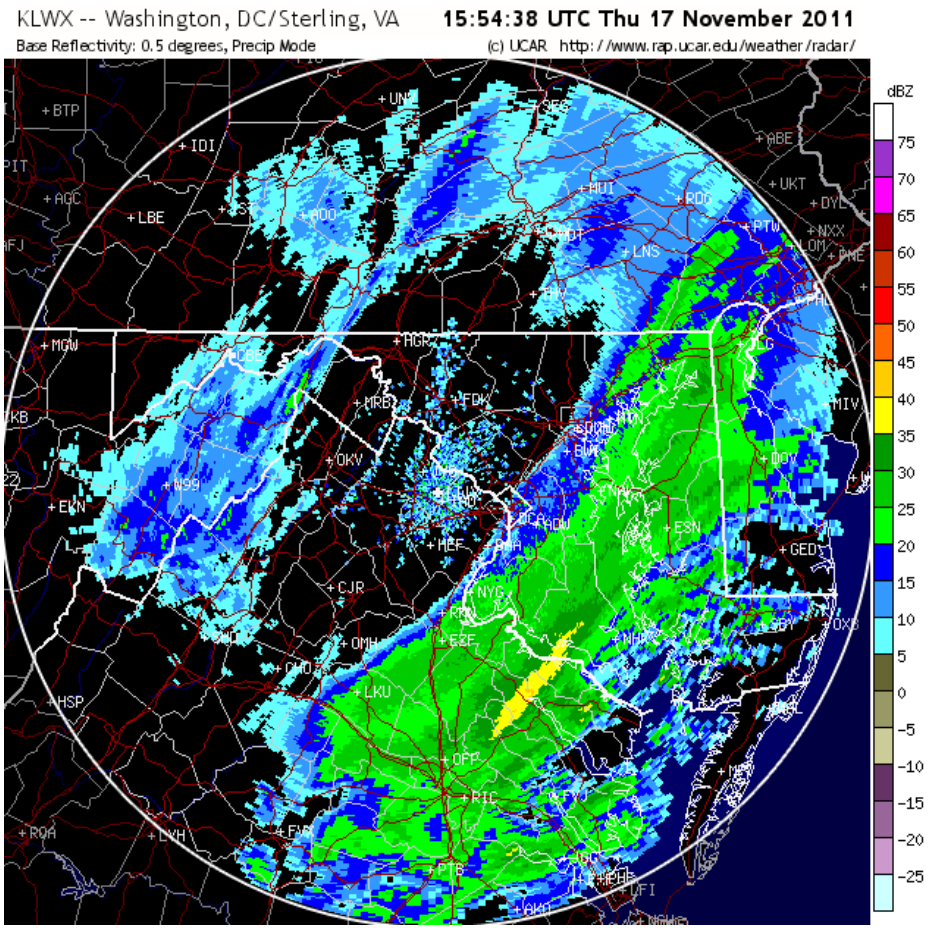

15-HR RUC2 3-HR TOT PRECIP
RUC
1.50
.75
.40
.20
.01
FCST MADE 02Z 11/17


09-HR RAPX FCST 500 HT/VORT
510
528
546
564
582
RAP


528
RAP

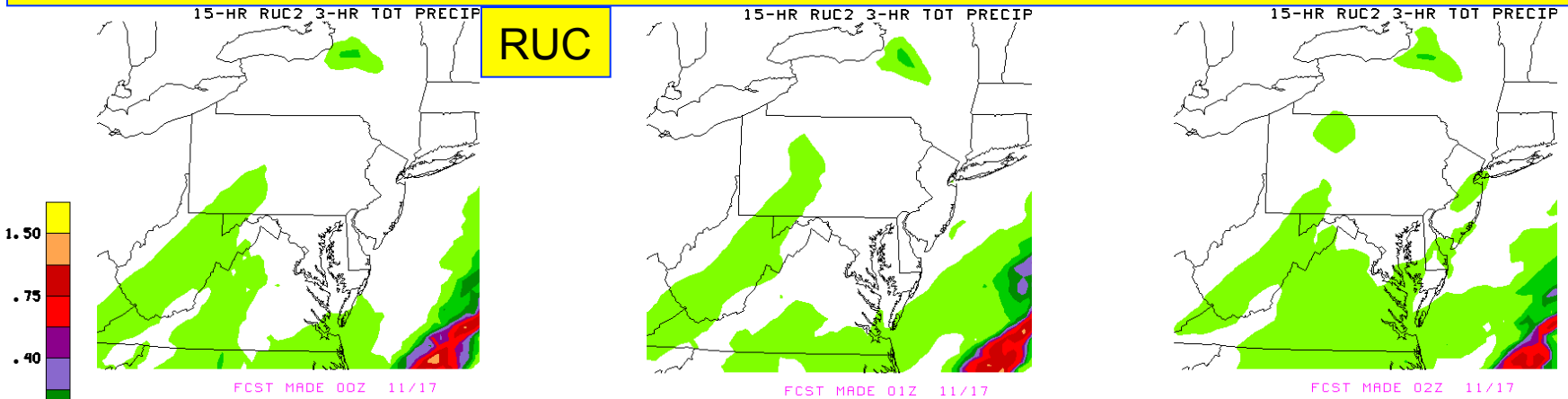

15-HR RAPX 3-HR TOT PRECIP
RAP


15-HR RUC2 3-HR TOT PRECIP
RUC
1.50
.75
.40
.20
.01
FCST MADE 02Z 11/17
15-HR RAPX 3-HR TOT PRECIP
RAP

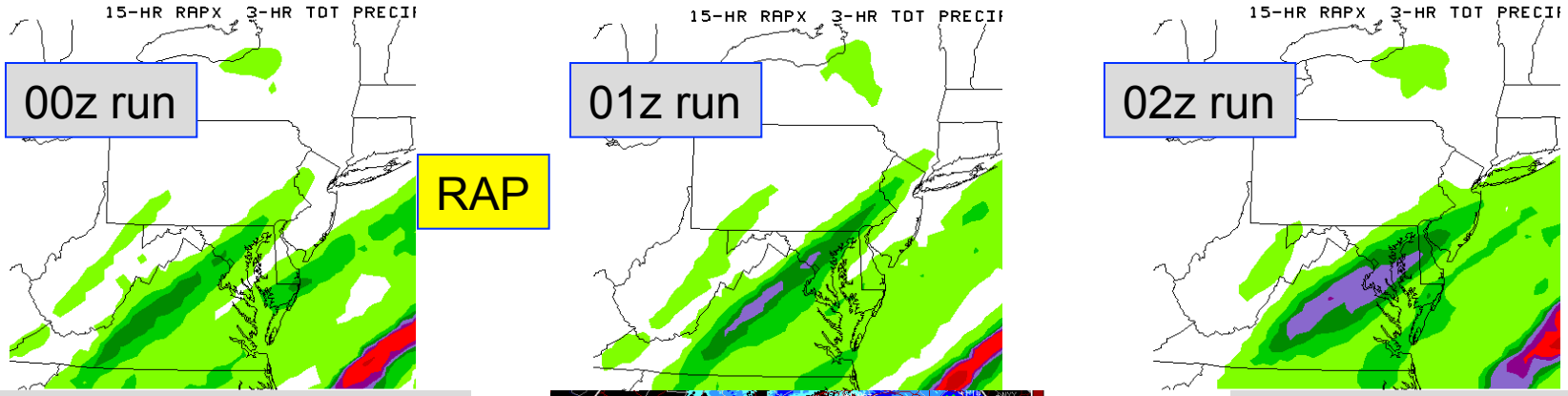

KLWX -- Washington, DC/Sterling, VA
15:54:38 UTC Thu 17 November 2011
Base Reflectivity: 0.5 degrees, Precip Mode
(c) UCAR http://www.rap.ucar.edu/weather/radar/
dBZ
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
-10
-15
-20
-25

How a sequence of hourly RAP runs can help piece together a forecast issue:

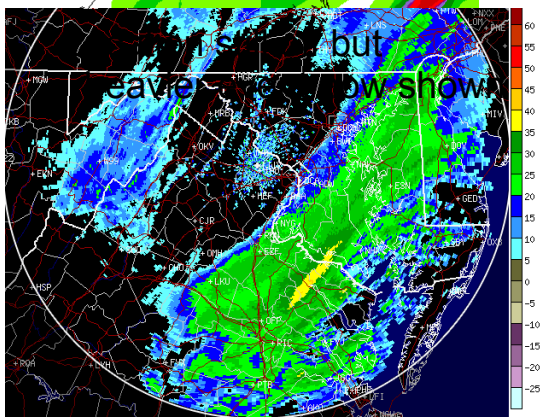
RUC



RAP



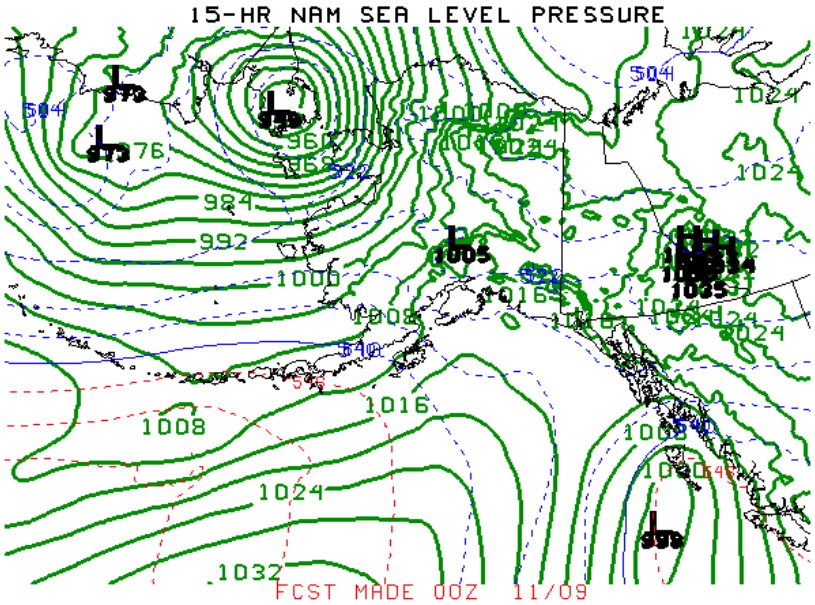
Location off but initial concept of event

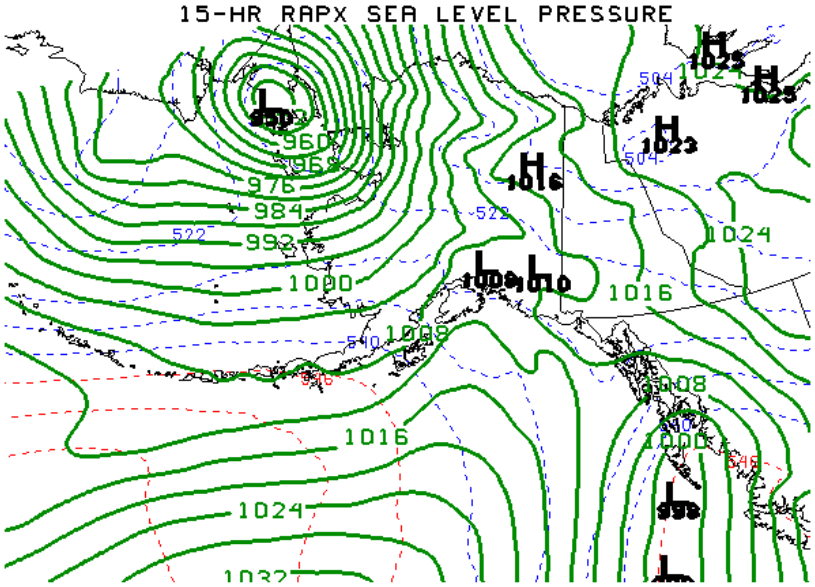


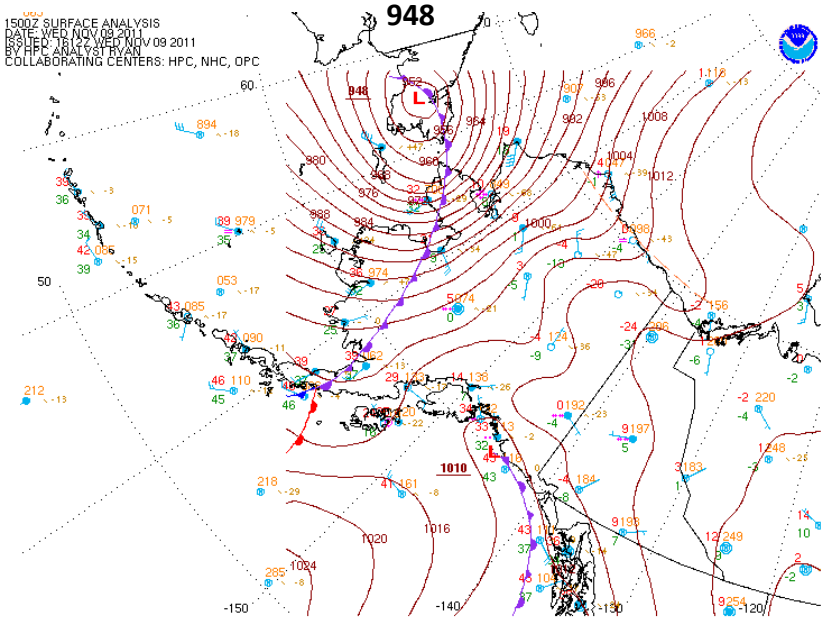
By 02z, starts to nail down location

Alaska Mega-Storm
8-9 November 2011

RAP handled strength of system as well as the NAM but with hourly updating

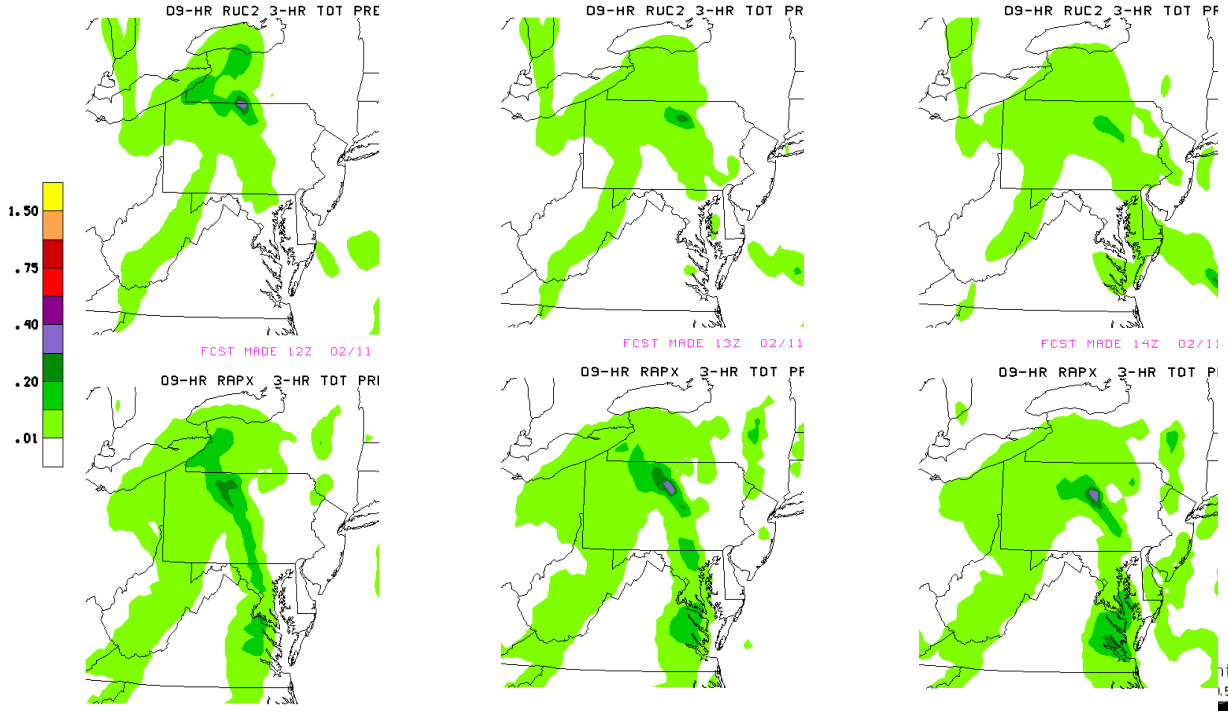

15-HR NAM SEA LEVEL PRESSURE
FCST MADE 00Z 11/09

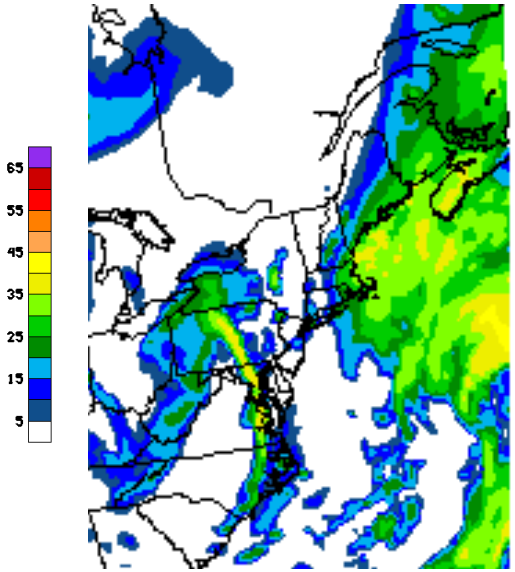

15-HR RAPX SEA LEVEL PRESSURE


1500Z SURFACE ANALYSIS
DATE: WED NOV 09 2011
ISSUED: 1512Z WED NOV 09 2011
BY HPC ANALYST RYAN
COLLABORATING CENTERS: HPC, NHC, OPC
948

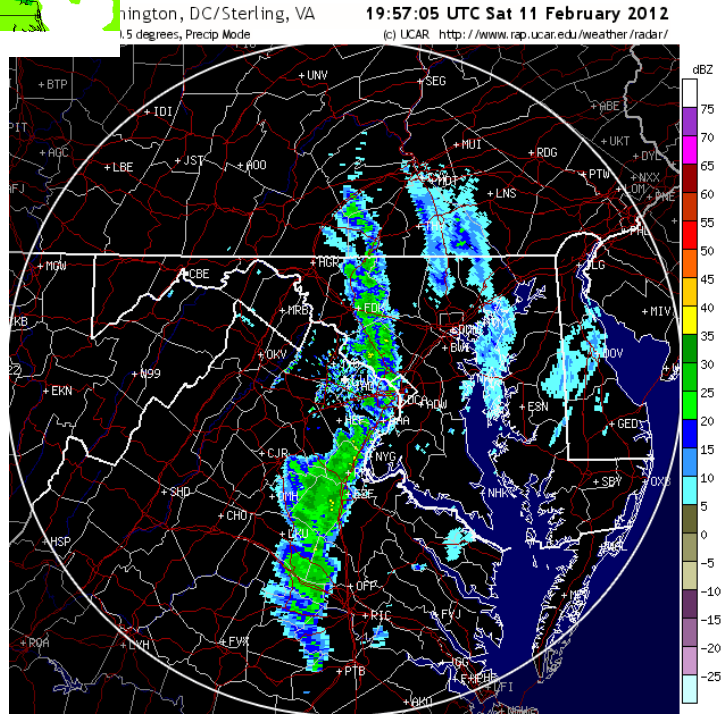
DC “Snow Squall Line” 11 February 2012

- Intense snow squalls created whiteout conditions
- RAP a significant improvement over RUC



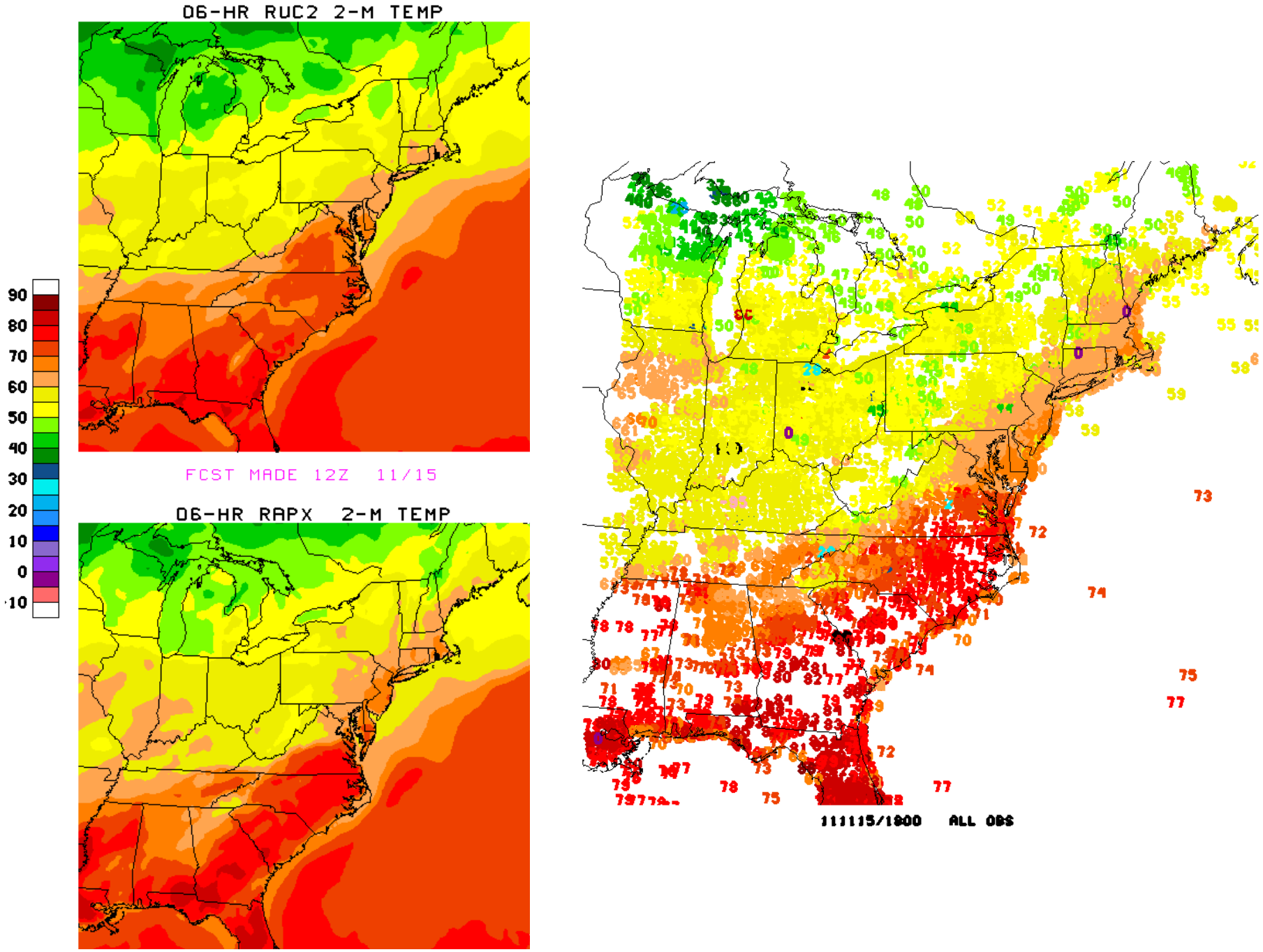


Sample RAP Simulated reflectivity



Mid-Atlantic Temperatures 15 November 2011

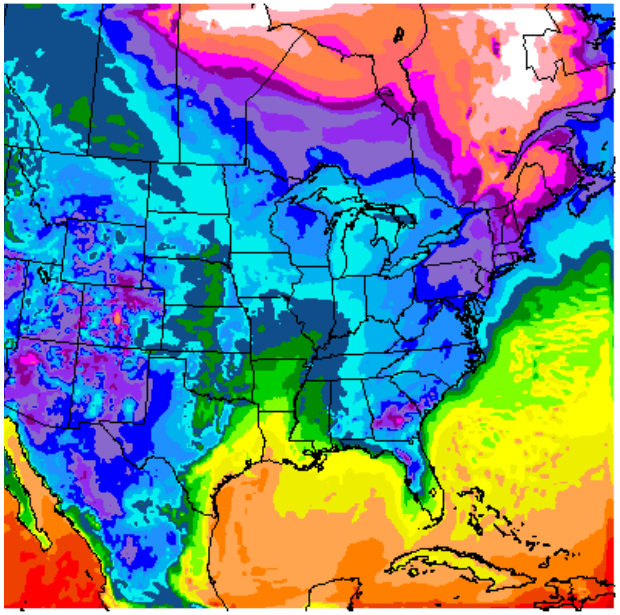
- RAP better handled gradient across south-central VA
- Overall better handling of warm air along eastern seaboard


06-HR RUC2 2-M TEMP
90
80
70
60
50
40
30
20
10
0
-10
FCST MADE 12Z 11/15
06-HR RAPX 2-M TEMP
111115/1800 ALL OBS

Very Dry Air Mass over Southeast 4 January 2012

- RAP slightly too dry but much closer to observations than the RUC
- handling of soil moisture appeared to play important role

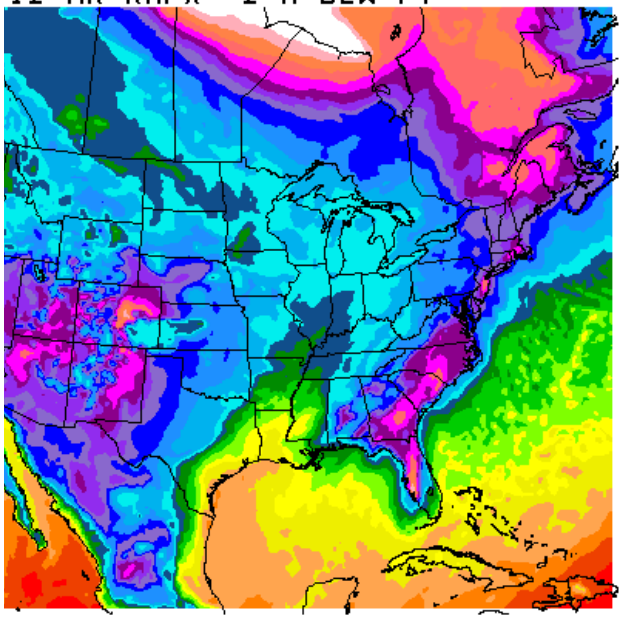
12-HR RUC2 2-M DEW PT

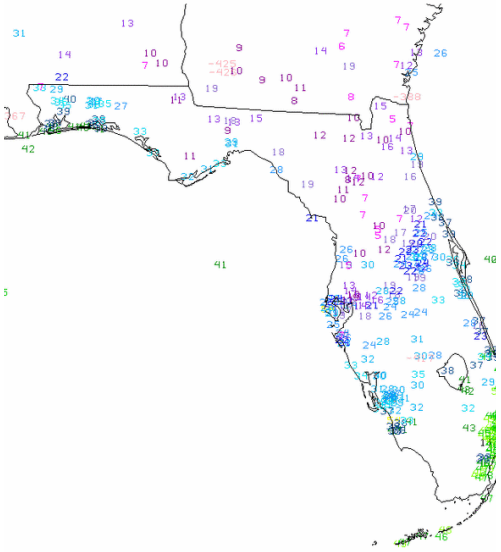


76
68
60
52
44
36
28
20
12
4
-4
-12

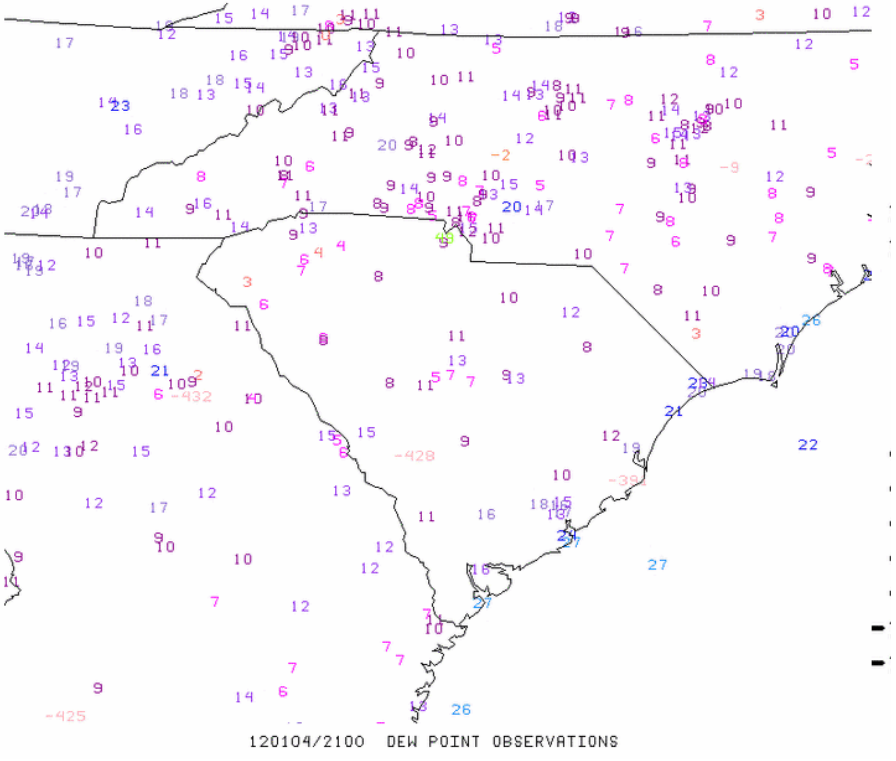
FCST MADE 09Z 01/04

12-HR RAPX 2-M DEW PT



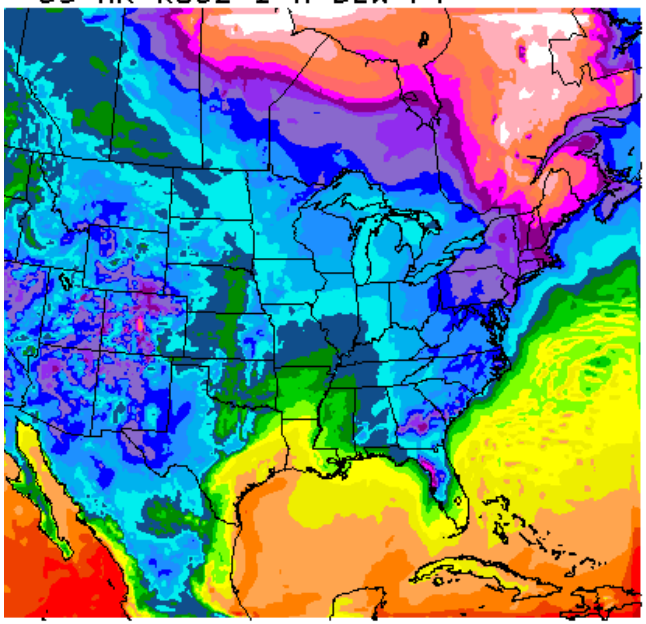


120104/2100 DEW POINT OBSERVATIONS



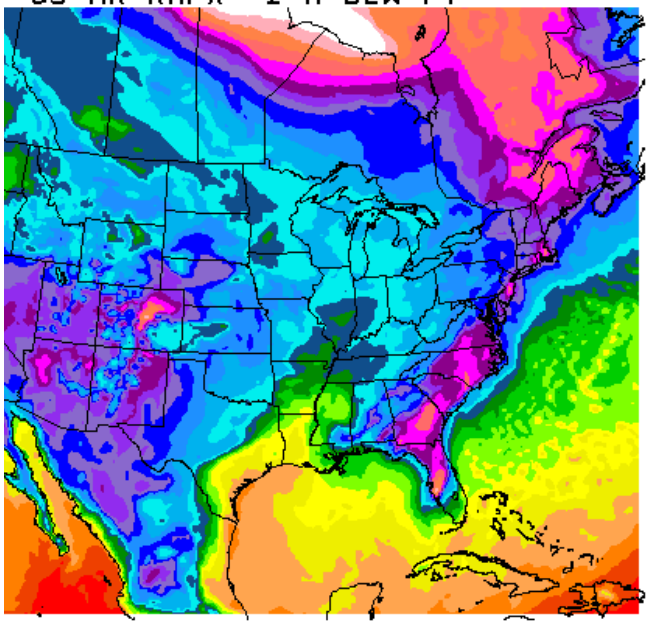
120104/2100 DEW POINT OBSERVATIONS

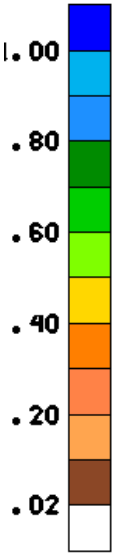
09-HR RUC2 2-M DEW PT



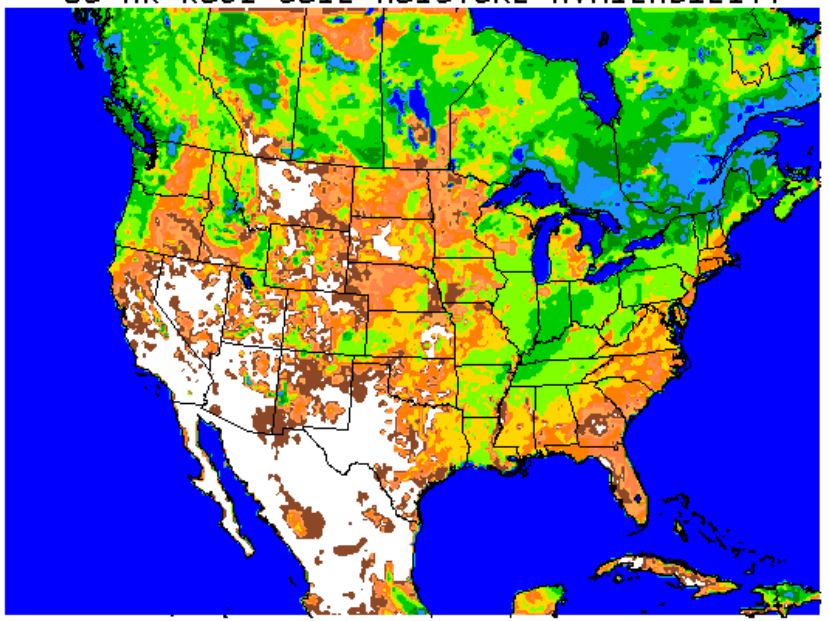
FCST MADE 12Z 01/04

09-HR RAPX 2-M DEW PT



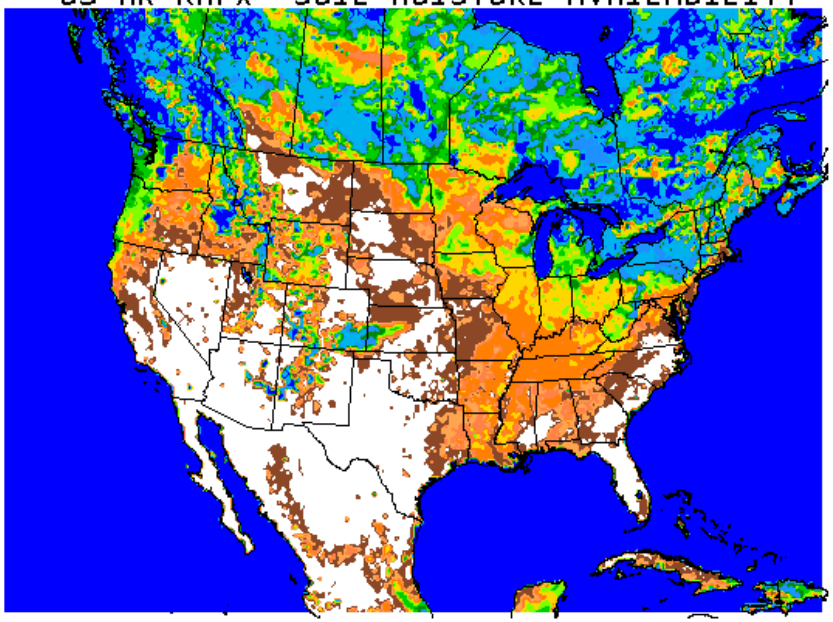


09-HR RUC2 SOIL MOISTURE AVAILABILITY



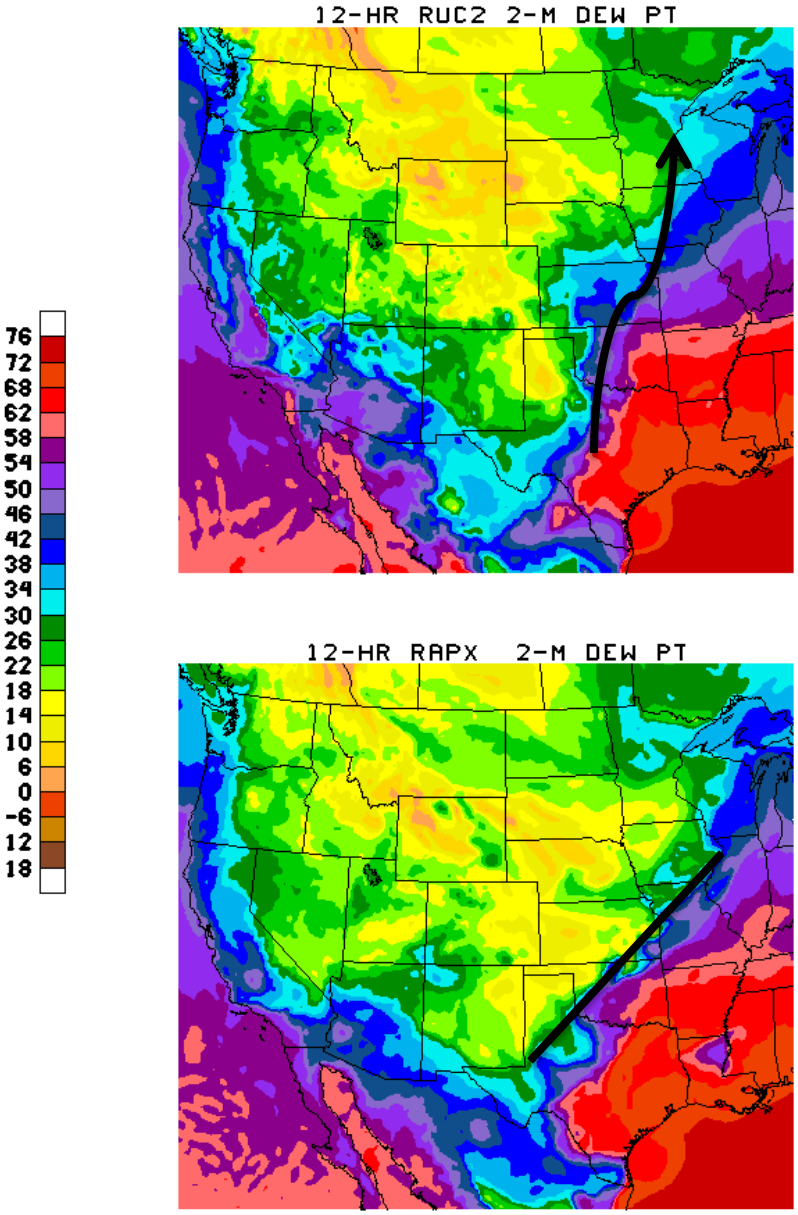
FCST MADE 12Z 01/04

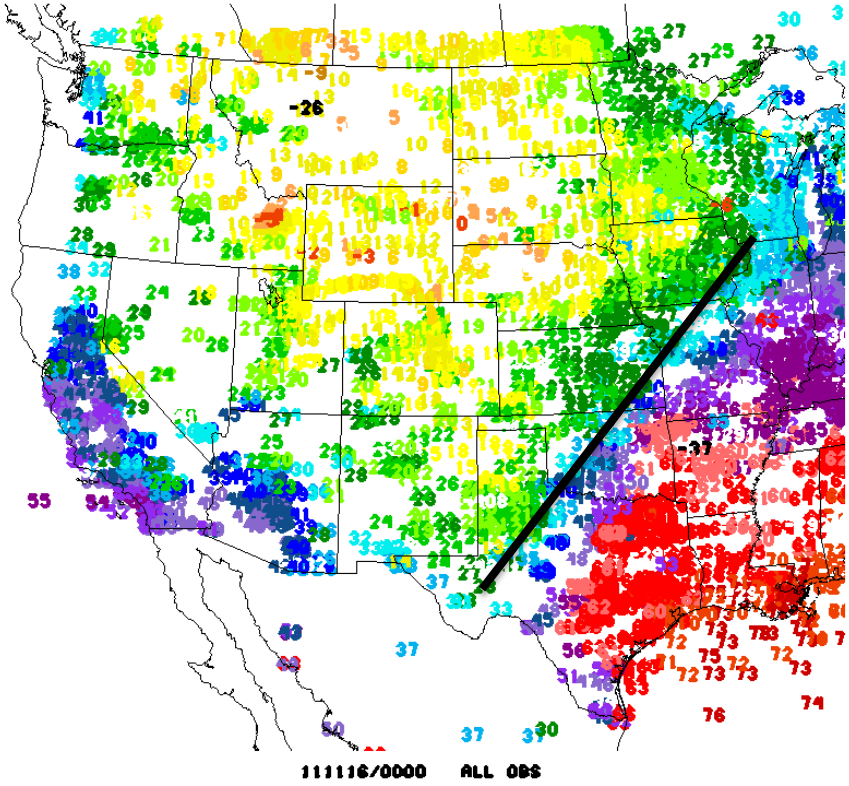
09-HR RAPX SOIL MOISTURE AVAILABILITY



Midwest Dew Points
15 November 2011

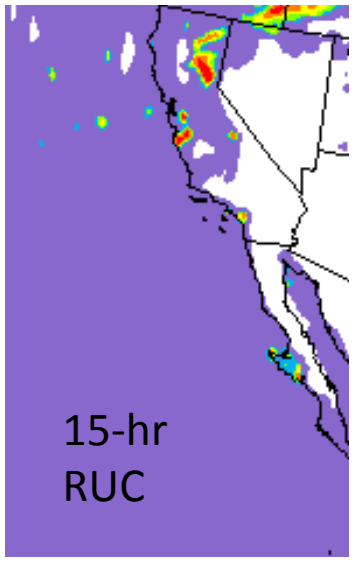
- RAP handled shape of gradient much better than RUC

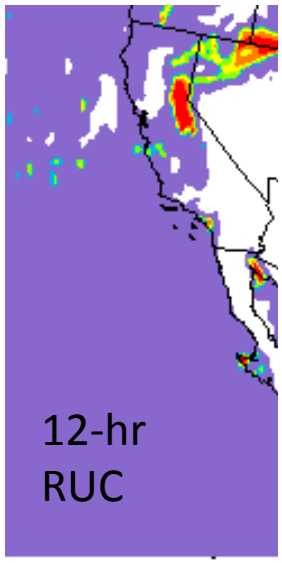

12-HR RUC2 2-M DEW PT
12-HR RAPX 2-M DEW PT
76
72
68
62
58
54
50
46
42
38
34
30
26
22
18
14
10
6
0
-6
12
18
FCST MADE 12Z 11/15

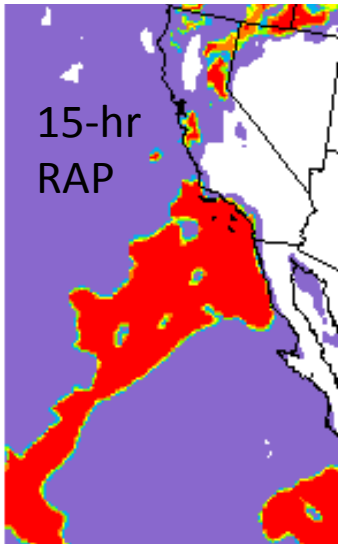

111116/0000 ALL OBS

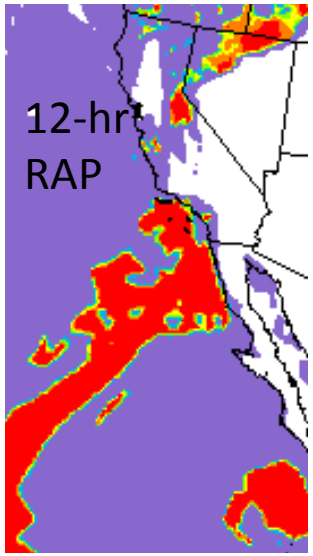
Southern California Coastal Fog
6 March 2012

VISIBILITY

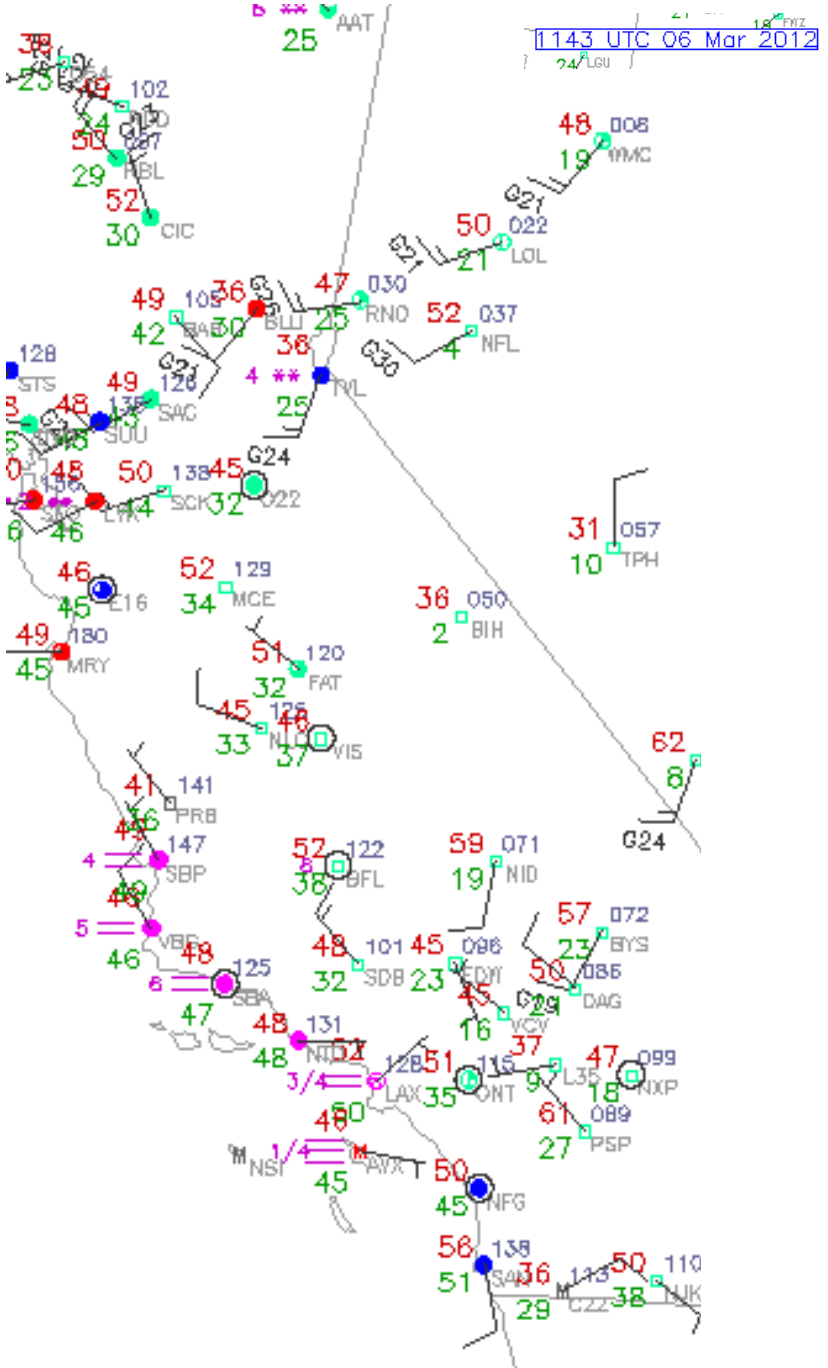

15-hr
RUC


12-hr
RUC

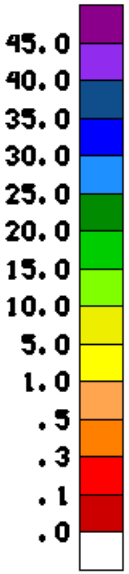

15-hr
RAP

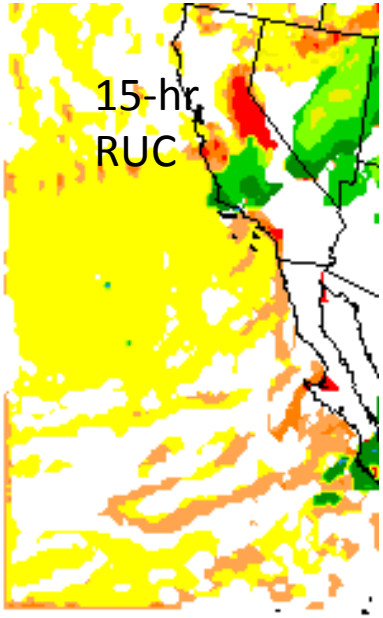

12-hr
RAP

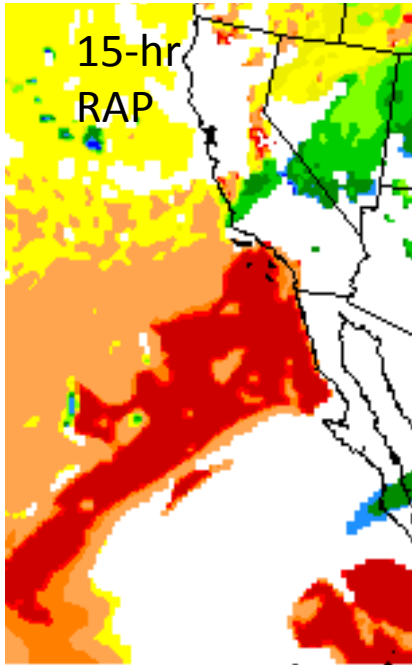

10
5
4
3
2
1

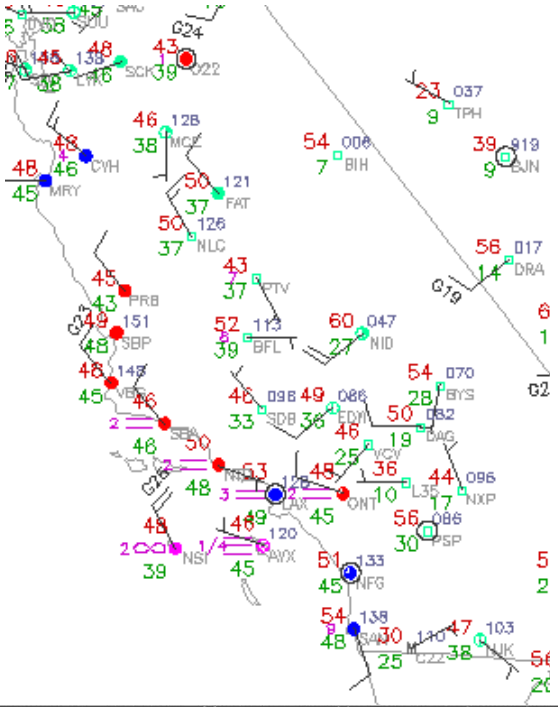

1143 UTC 06 Mar 2012
AAT
ABQ
RBL
CIC
LOL
RNO
NFL
BLU
RIL
SAC
SCK
MCE
BIH
MRY
FAT
VIS
PRB
SBP
BFL
NID
SDB
EDW
BYS
DAG
VCV
SBA
LAX
ONT
NXP
PSP
NSI
NFG
SAN

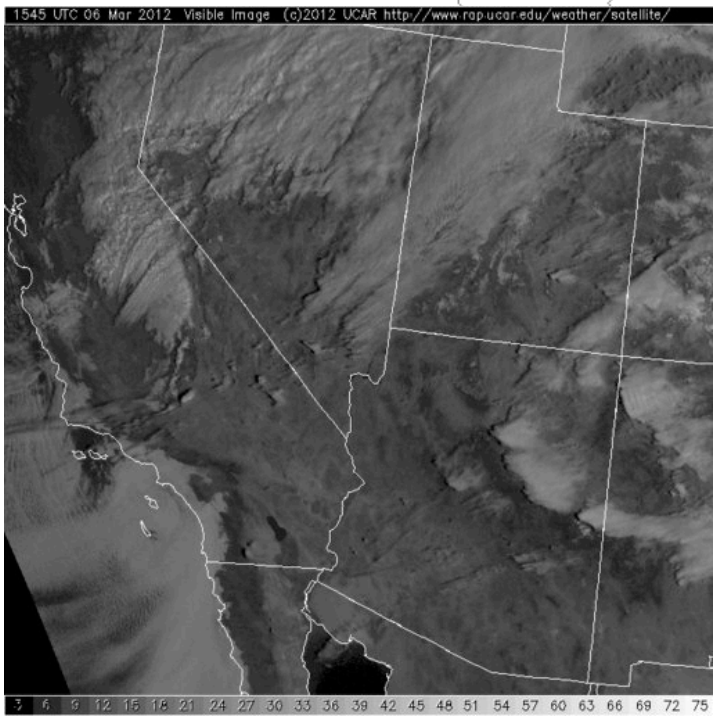
AGL CLOUD BASE HEIGHT (ft x 1000)









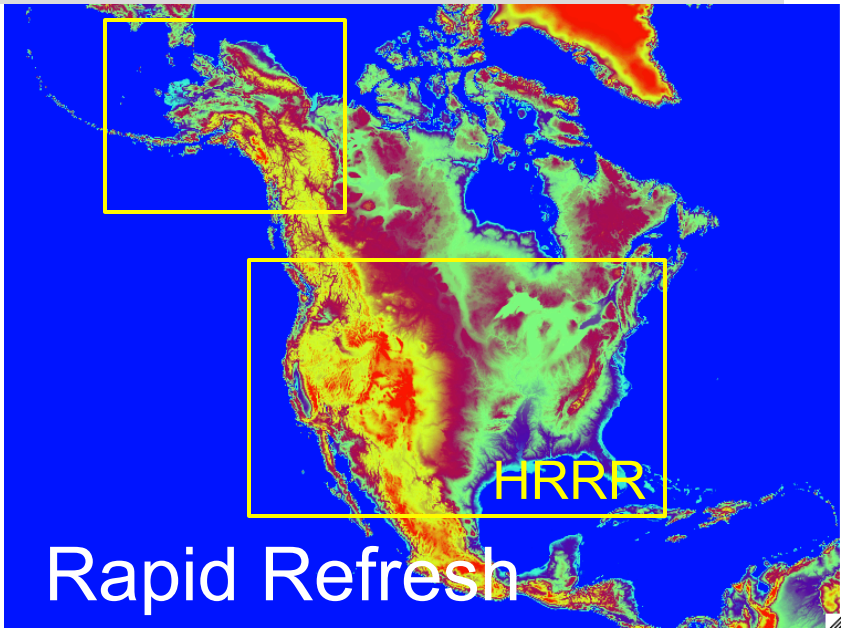


Overview on Rapid Refresh

- Improved or equal forecasts for all variables
- Improved winds overall
- Improved precip (but moist bias)
- Improved 2m temp, Td (less moist bias than RUC but still an issue)
- RAP version 2 will improve further when implemented by early 2013

Future plans for advanced hourly NWP/DA

- Mar 2012 – Rapid Refresh operational at NCEP
- Early 2013 – RapidRefresh v2 –
  - cloud/surface/soil assimilation➔much lower moist bias (better convective fcsts), GOES, sodar/tower/nacelle winds, updated GSI
  - model – MODIS, cloud/PBL/numerical improvements, updated WRF
- 2013 – application of hybrid/EnKF assimilation to RAP in real-time testing
- 2012-14 – HRRR @ESRL improves, add Fairmont/zeus HRRR to reach 99%
- 2015 – High-Resolution Rapid Refresh operational at NCEP for CONUS



- 2015 – Ensemble Rapid Refresh – **NARRE** w/ hybrid assim
- 2016 – Add operational Alaska HRRR
- 2017 – CONUS Ensemble HRRR – **HRRRE**

N.American Rapid Refresh Ensemble

- **NEMS-based NMM, ARW cores**
- **Hourly updating with GSI-hybrid EnKF**
- **Initially 6 members, 3 each core, physics diversity (RAP, NAM, NCAR suites)**
- **Forecasts to 24-h**
- **NMM to 84-h 4x per day**

Other improvements in init testing

- RAP with inline chem, chem DA
- 15-min radar assimilation
- Storm-scale radar assimilation