WRF-ARW in NCEP operations: Rapid Refresh

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Major topics:

- Overview
- WRF-ARW model configuration at NCEP
- RAPv2 changes
- Case examples

http://rapidrefresh.noaa.gov

Transition from RUC to Rapid Refresh

Provides hourly cycled guidance to all North America

Community-based model and analysis

- **WRF-ARW: better numerics than RUC, 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

Hourly Updated NOAA NWP Models

Rapid Refresh (RAP)

replaces RUC at NCEP

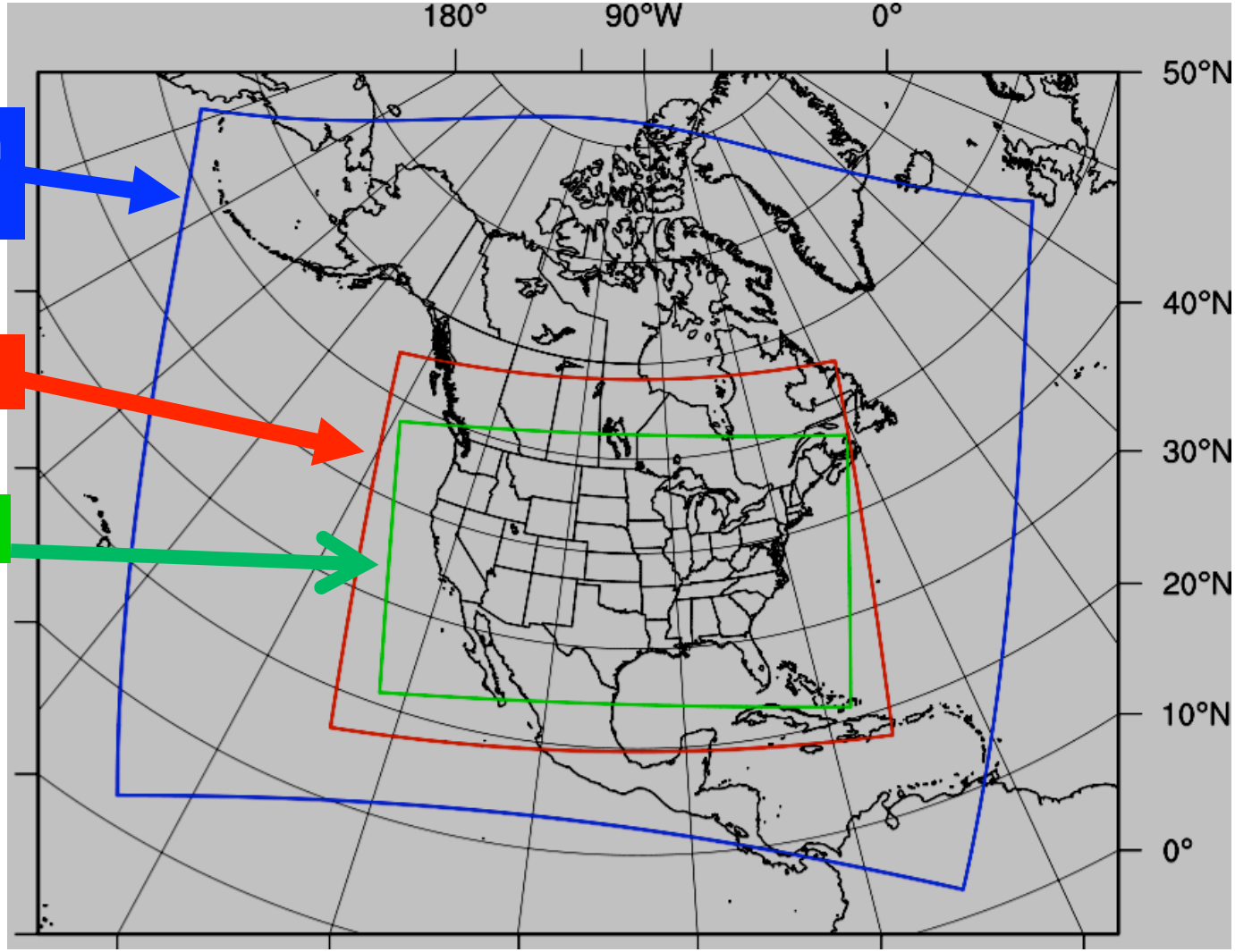
WRF, GSI with RUC features

13km Rapid Refresh

13km RUC

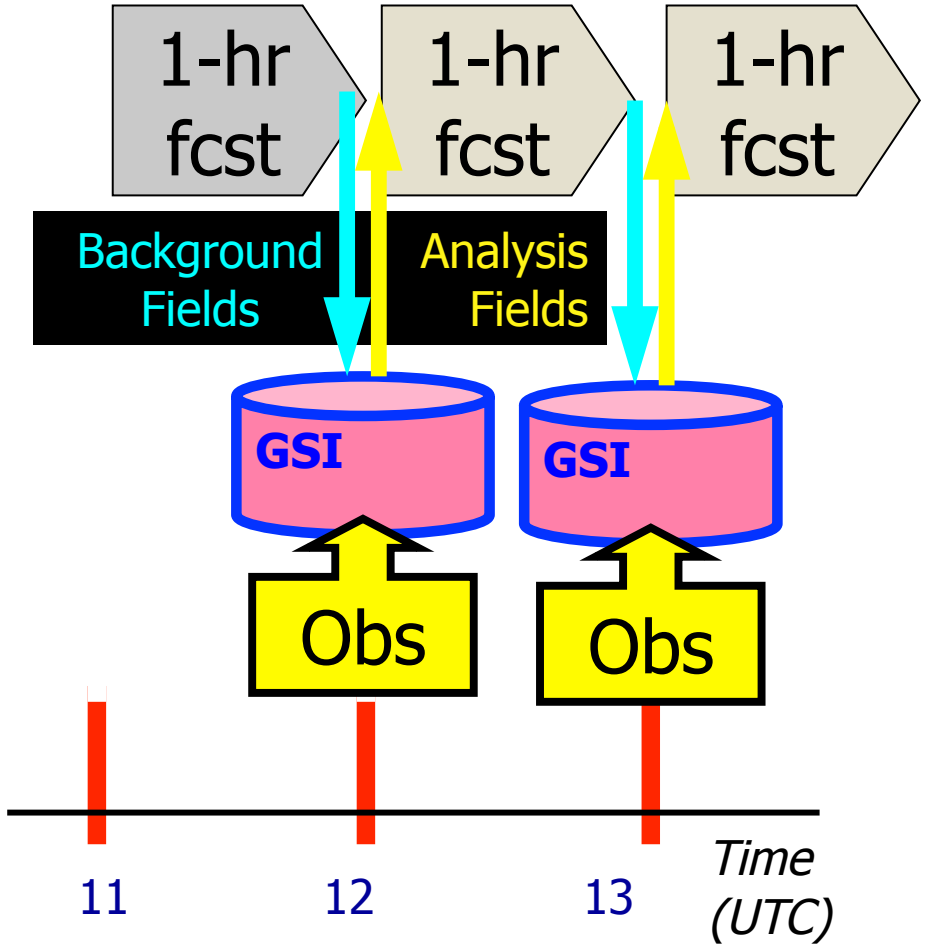
3km HRRR

HRRR talk by Curtis Alexander 0830 tomorrow



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*	

WRF model enhancements for Rapid Refresh

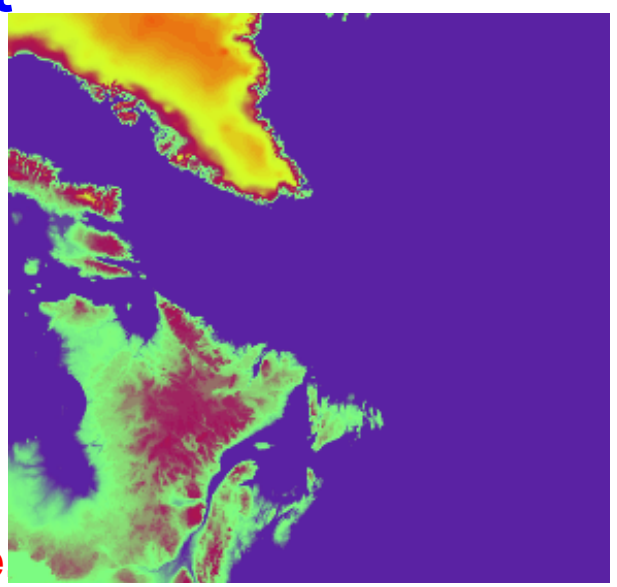
- WRF - ARW - v3.2.1+ for initial RAP
  - WRF v3.3 issued too late in April 2011 – NCEP code freeze
- Benefited from ongoing community improvements to WRF
- GSD contributions –
  - Digital filter initialization (DFI - allows quiet 1h forecasts) (with NCAR)
  - DFI-radar
  - Grell 3-d cumulus
  - RUC LSM (snow LSM cycling on sea ice and modifications to snow melt--v3.3.1+ version)
- Use of rotated lat-lon grid - GSD was first to make extensive use of ARW with RLL

Hydrostatic v non-hydrostatic option

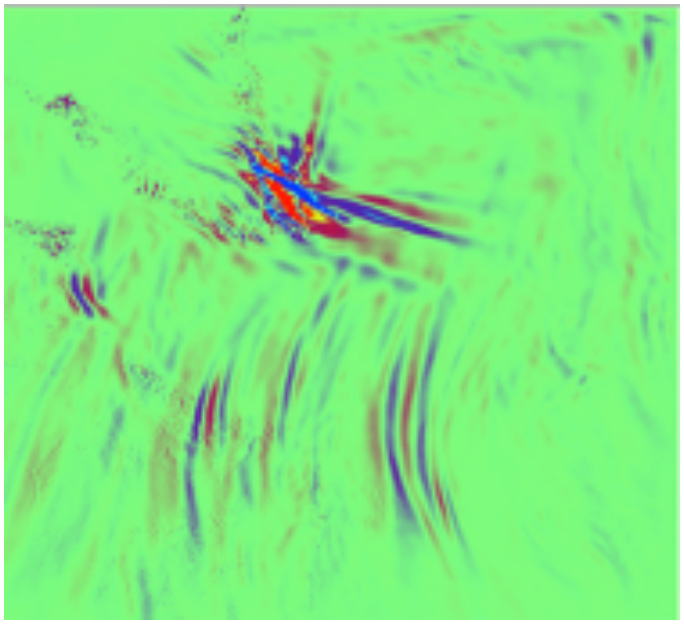
- Changed to non_hydrostatic = .false. spring 2011 in attempt to cure some balance issues with RAP use of DFI
- (later cured by changes to dfi.F, discussed June 2011)
- June 2011 workshop: hydrostatic option reported
- During NCEP field test late December last year: crashes
- Traced to CFL violations with Greenland Tip Jet
- Tried non-hydrostatic option with damp_opt =3 (Rayleigh damping, only available with non_hydrostatic = .true.)
- No such crashes on rerun and since …
- Not surprising: very little difference in any of our non_hydrostatic .false. / .true. comparisons at dx = 13km

ncview plots for Greenland tip jet
NE corner RAP domain

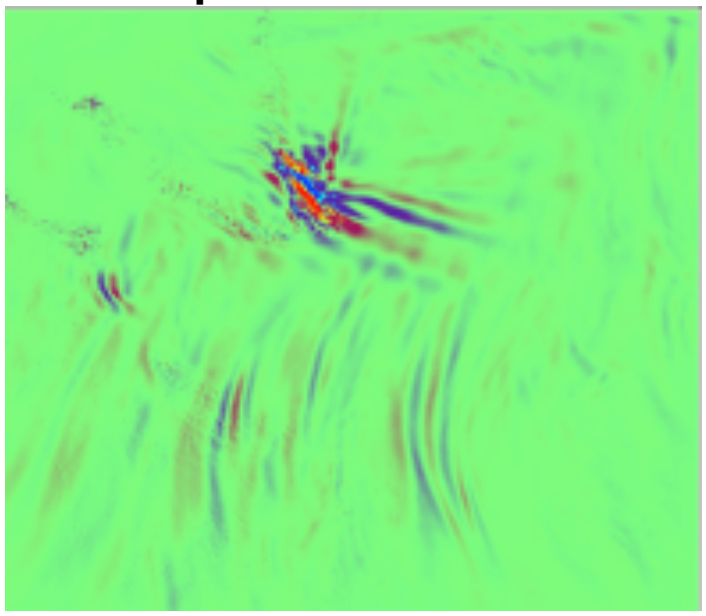
Terrrain

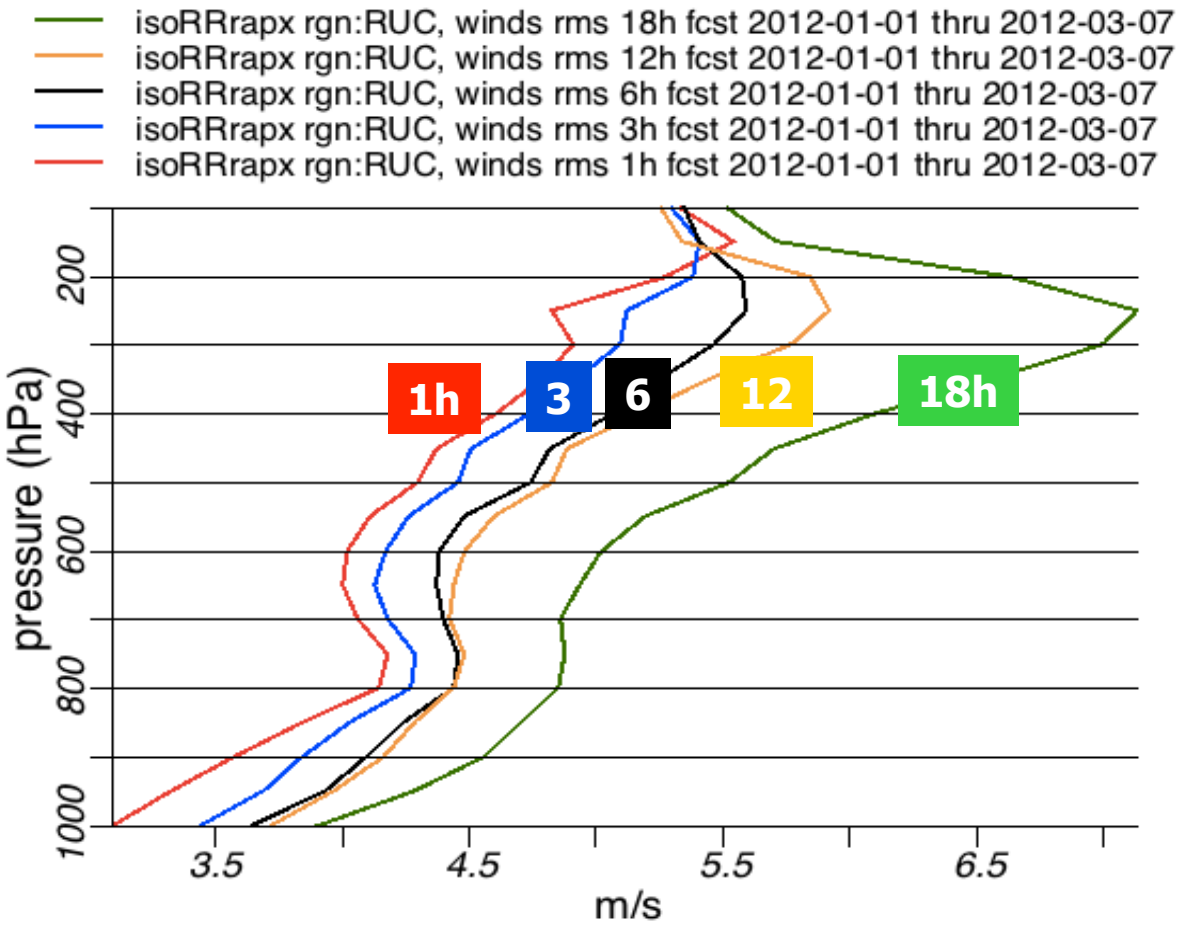


non-hydrostatic = .false.
damp_opt = 1
damp_coeff = 0.02
zdamp = 5000



non-hydrostatic = .true
damp_opt =3
damp_coeff = 0.2
zdamp - 5000





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

RAP vs. RUC Precipitation Verification

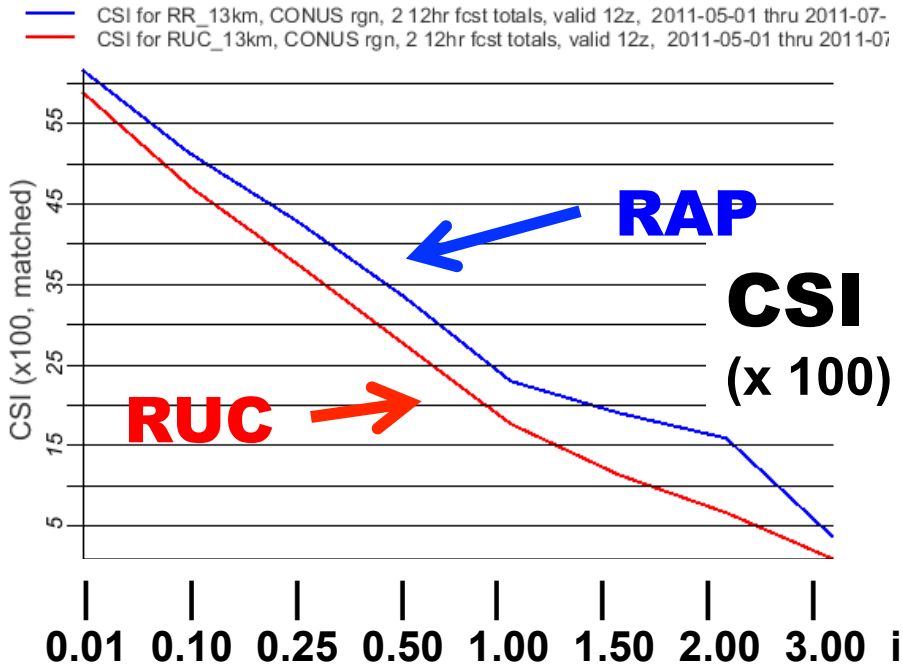
13-km CONUS

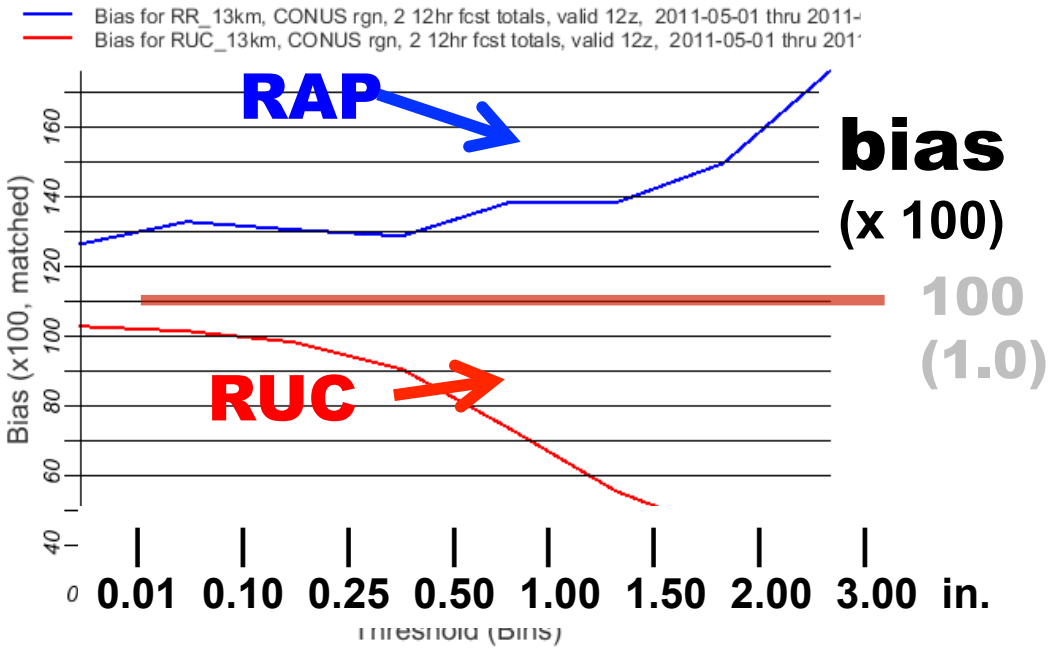
Comparison

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

1 May – 15 July 2011
Matched

SPRING/
SUMMER

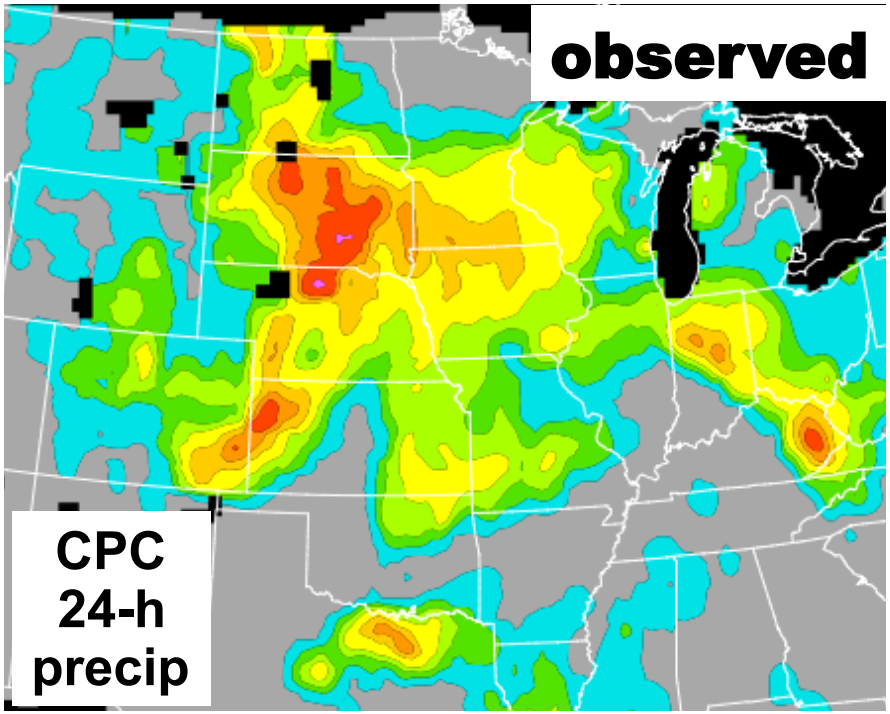


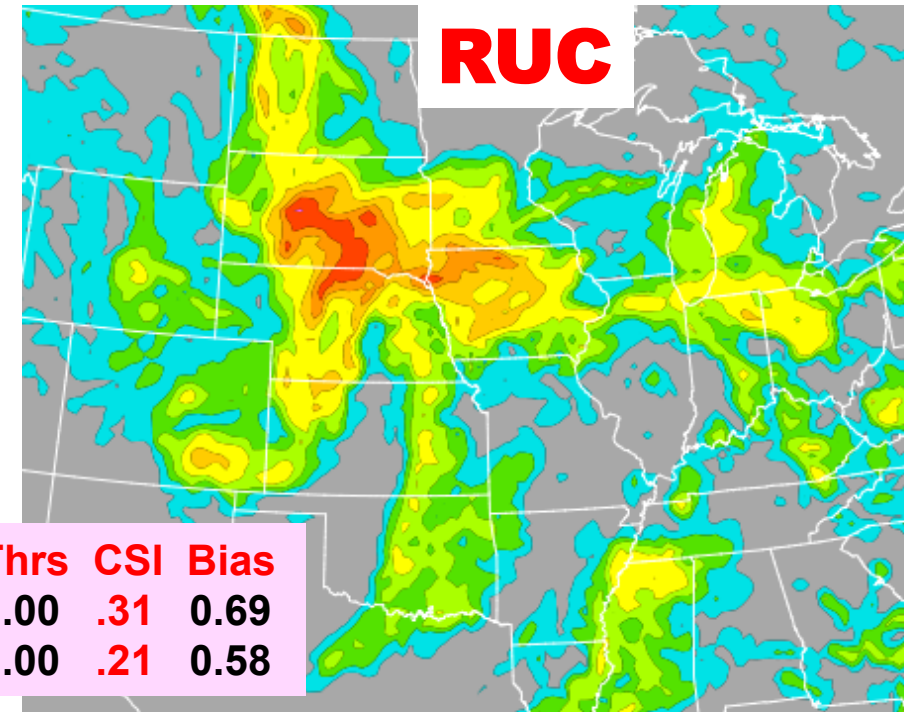


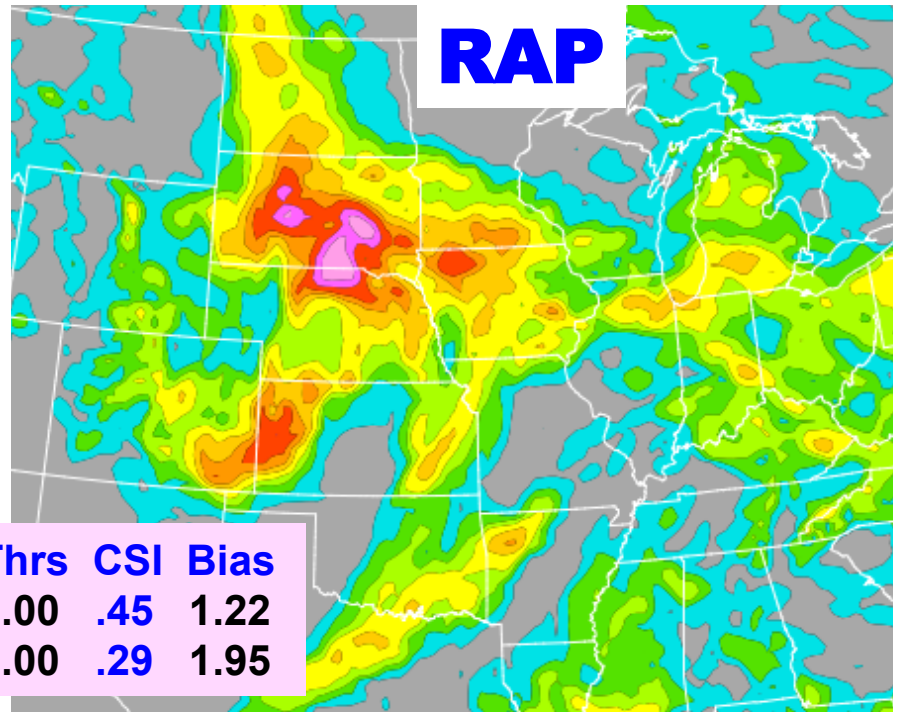
RAP vs. RUC 24-h precip. verif

2 x 12h fcst
ending 12z
21 June 2011

Interpolated
to 20-km grid

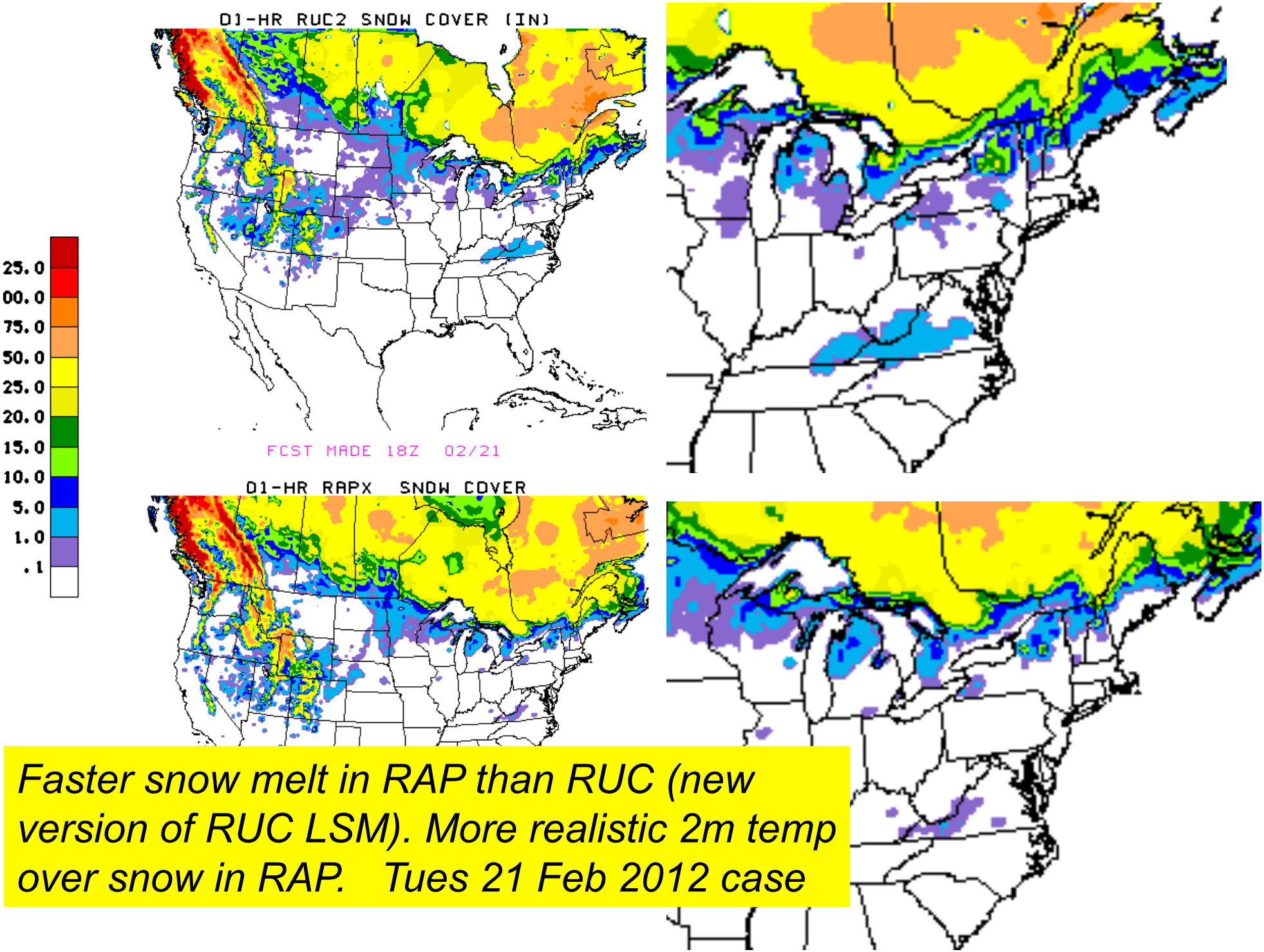




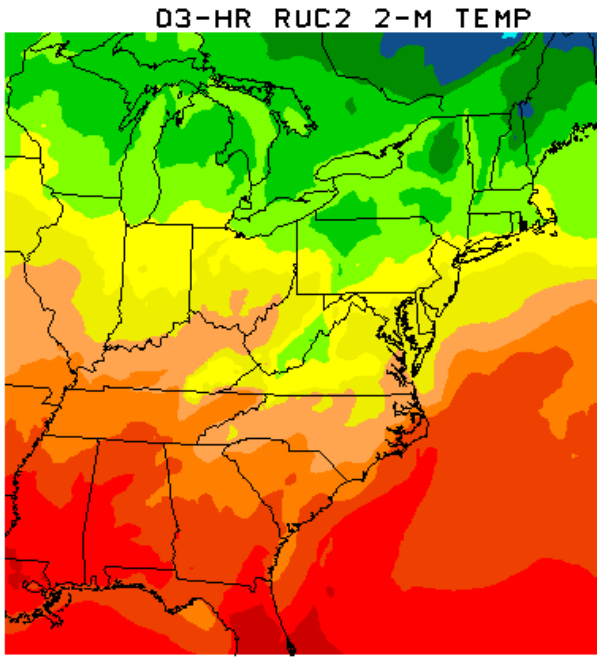


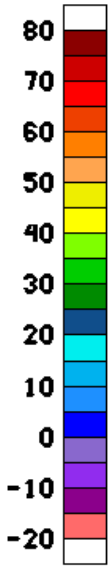
Snow cover and daytime temperature 21 Feb 2012

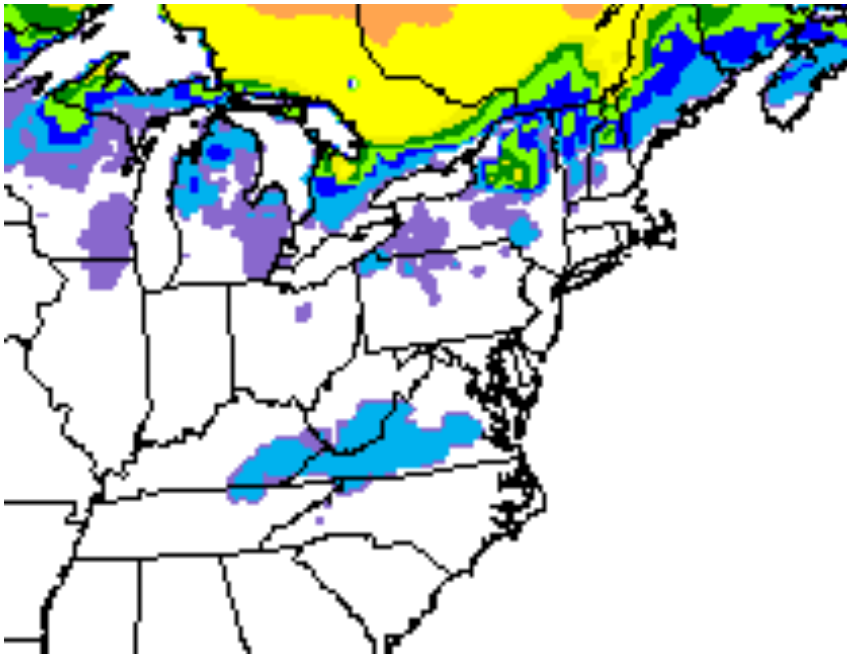
Better daytime temperature forecast in RAP with faster snowmelt (Virginia USA) (enhancements to RUC LSM) .

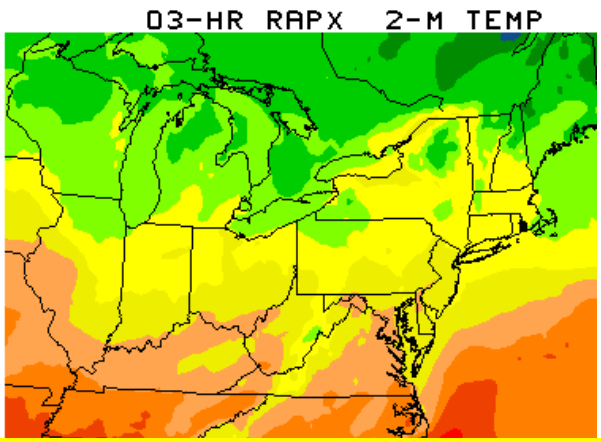


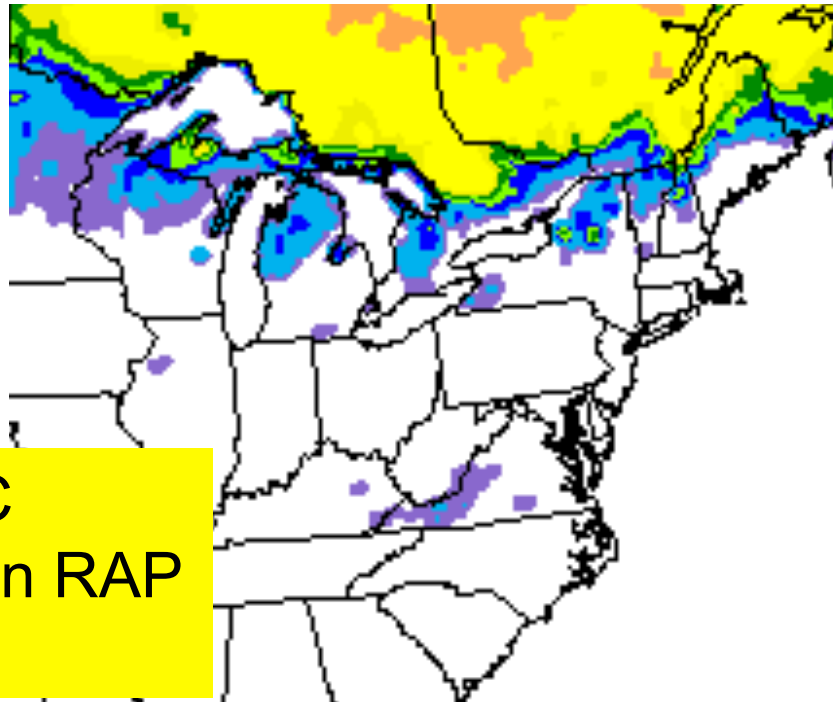
Faster snow melt in RAP than RUC (new version of RUC LSM). More realistic 2m temp over snow in RAP. Tues 21 Feb 2012 case



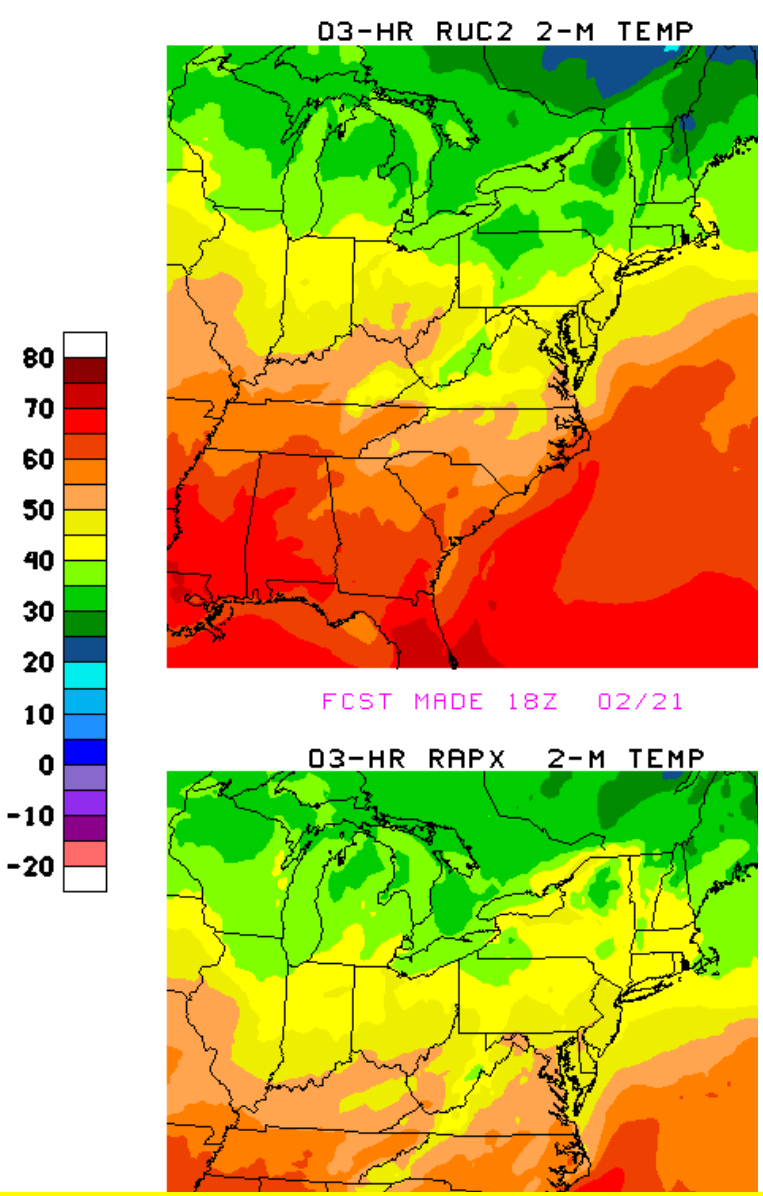


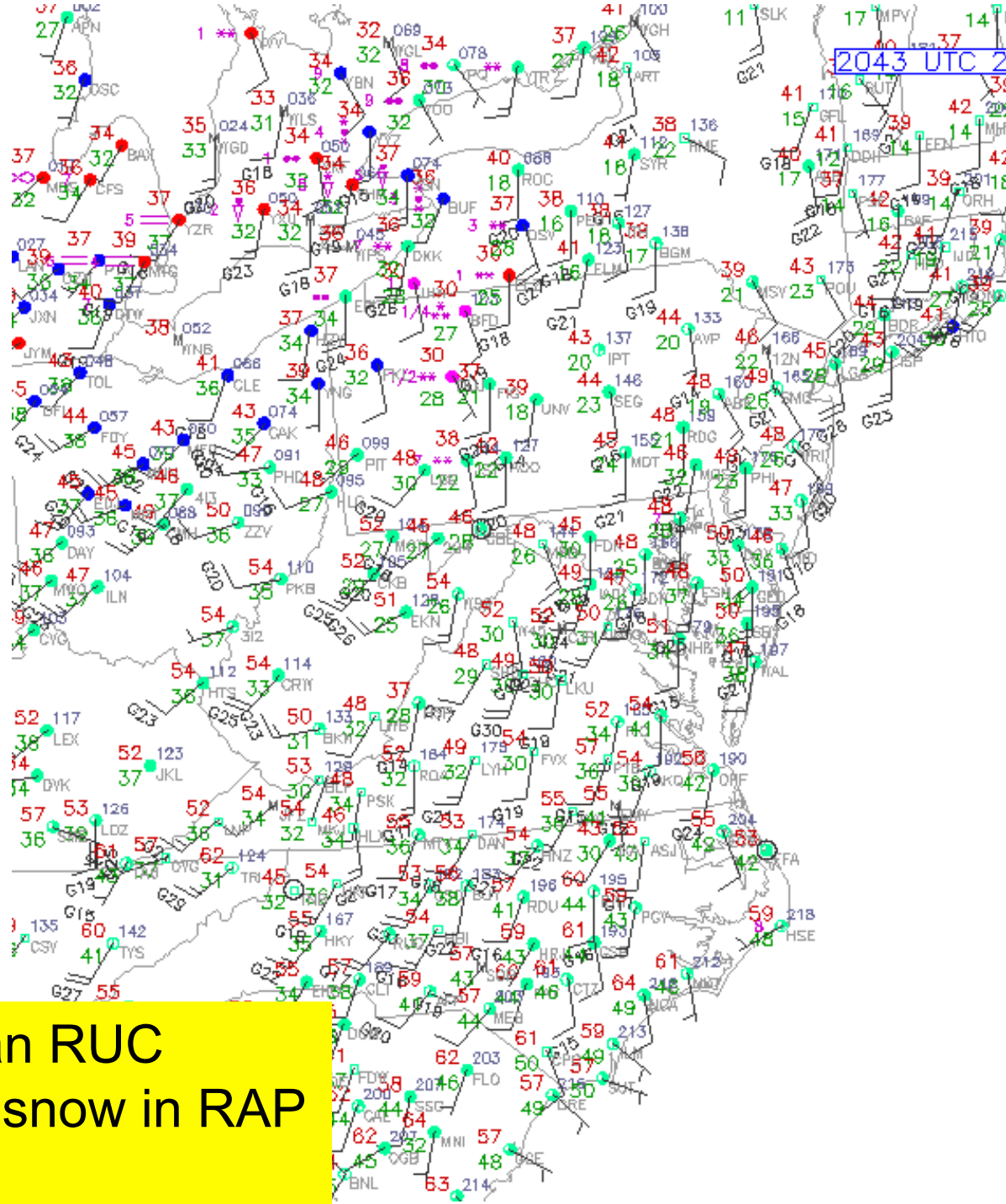






Faster snow melt in RAP than RUC
More realistic 2m temp over snow in RAP
Tues 21 Feb 2012 case





Faster snow melt in RAP than RUC

More realistic 2m temp over snow in RAP

Tues 21 Feb 2012 case

Rapid Refresh version 2

- **RAPv2 modifications driven in part by overzealous HRRR convection forecasts in summer 2011**
- **New observations: level II radial wind, lightning, wind energy obs**
- **Significant improvement over RAPv1 esp. for improved precipitation and convective environment (less false alarms for thunderstorms), improved data assimilation (surface, radar, cloud)**
- **Replace GSI and WRF versions with updates to trunk**

NOAA Earth System Research Laboratory, Boulder, CO

Main differences RAPv1 vs. RAPv2 - assimilation

- Updated already to much more recent community repositories
  - GSI - r9374 (2010-09-23) to r16882 (2012-01-05)
- **Better use of surface observations**
  - Pseudo-PBL obs for moisture (in RUC, not in RAPv1)
  - Soil adjustment (in RUC, not in RAPv1)
- **Cloud assimilation**
  - Building from GOES restored (in RUC (large moist bias), not in RAPv1)
  - Forcing subsaturation in clearing, conserve q_v,
  - Allow partial cloudiness in METAR assimilation
- New observations
  - Radial wind (level 2, following NAM)
  - Lightning (proxy for radar reflectivity)
  - Wind energy obs available
    - Tower, nacelle, special sodar, profiler obs
- Change to radar reflectivity assimilation
  - Hydrometeor addition largely removed in RAPv2 (avoids moist bias)
- PW obs (GPS primarily) – elevation correction, innovation limitation

Main differences RAPv1 vs. RAPv2 - model

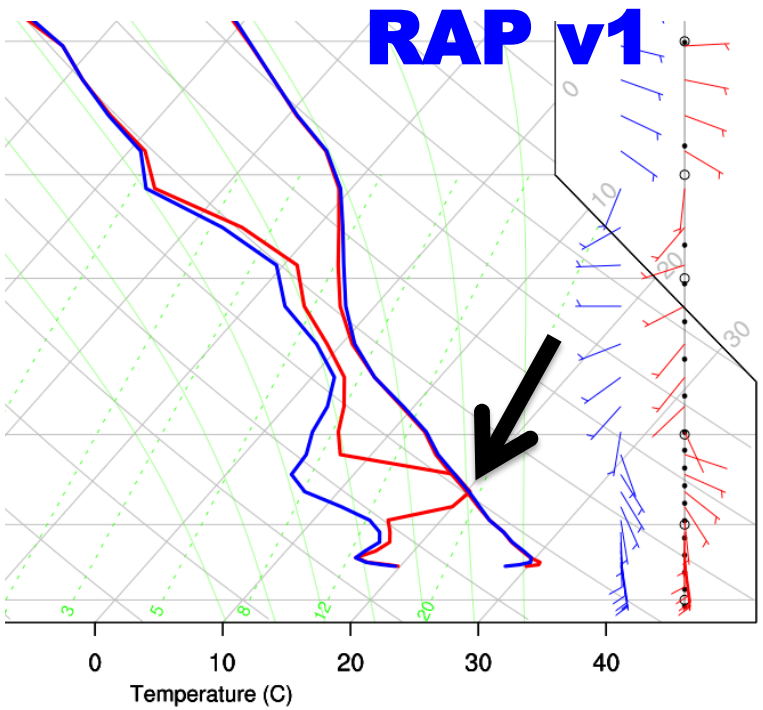
- **WRF – v3.2 (from summer 2010) to v3.3.1+ (summer 2011)**

- MODIS land use instead of USGS land-use
  - Updated land-use information
  - Following NAM change in October 2011

- **Updated Thompson microphysics**
  - Reflectivity now calculated consistently inside WRF
  - RAPv1 – inconsistent reflectivity calculation in Unipost, exaggerates snow reflectivity

- **Higher-order (5^{th} vs. 3^{rd}) vertical advection**
  - Improved cloud forecasts, better retention of stable layers and inversions

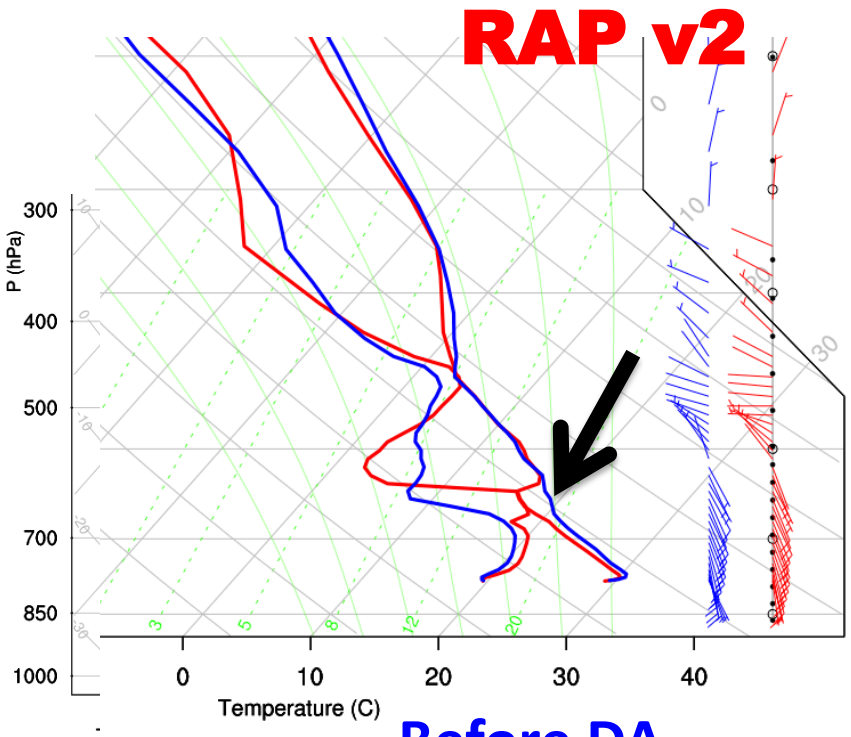
Improved cloud analysis: assume virtual potential temperature is conserved



Before DA

After DA

NOT conserving θ_v



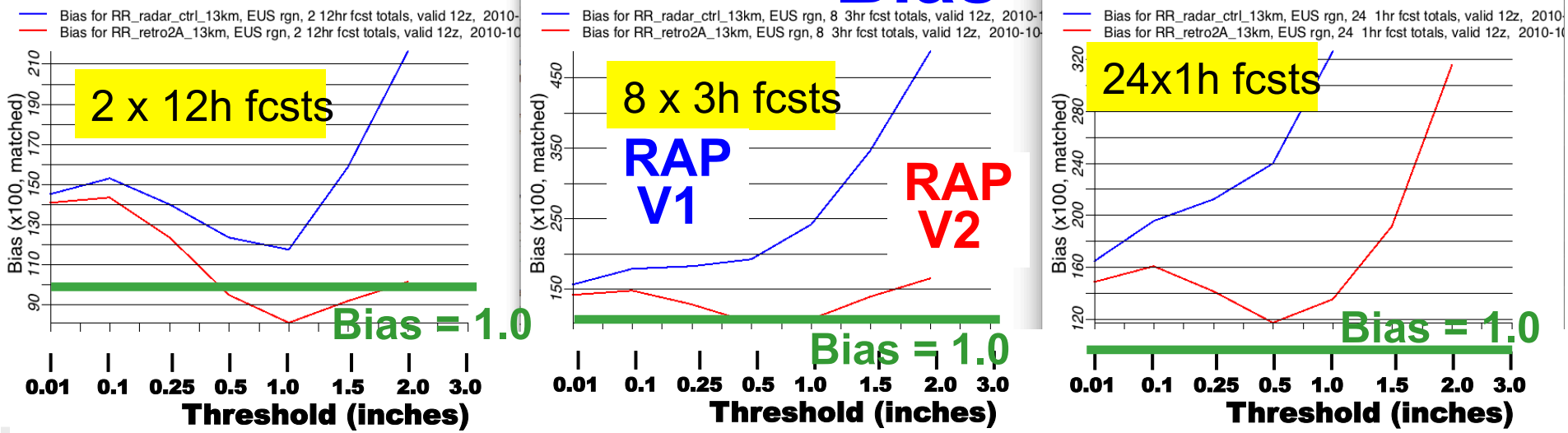
Before DA

After DA

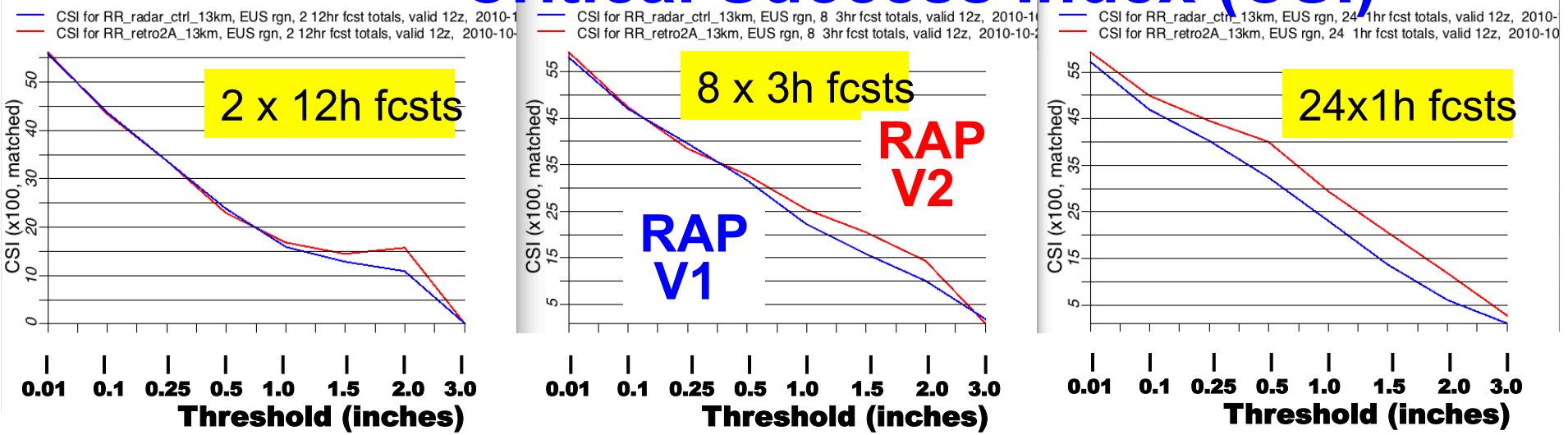
conserving θ_v

Precipitation verification in RAP

Bias



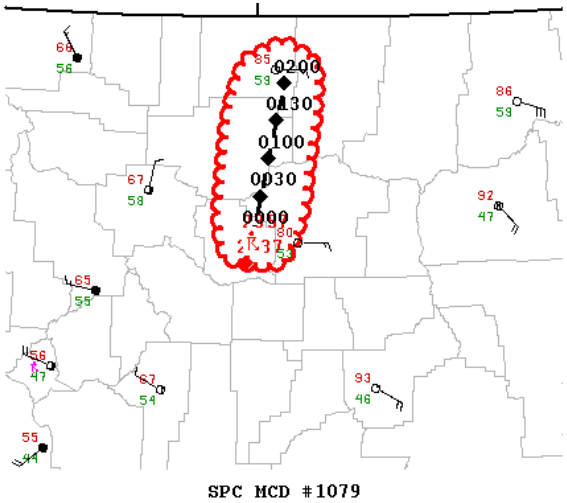
Critical Success Index (CSI)

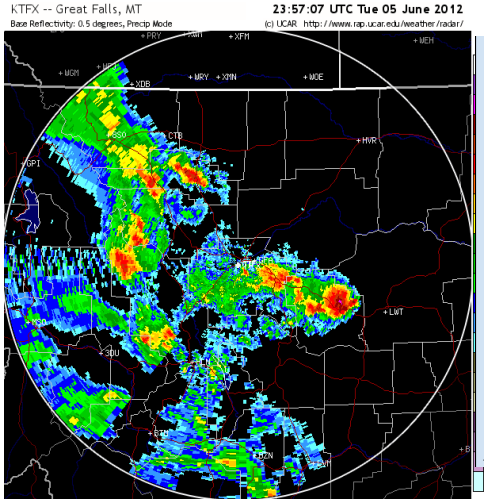


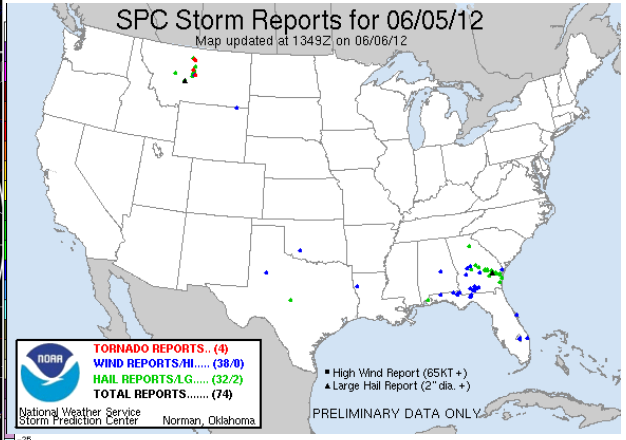
Eastern US, 2x12hr Forecasts vs. 24h CPC

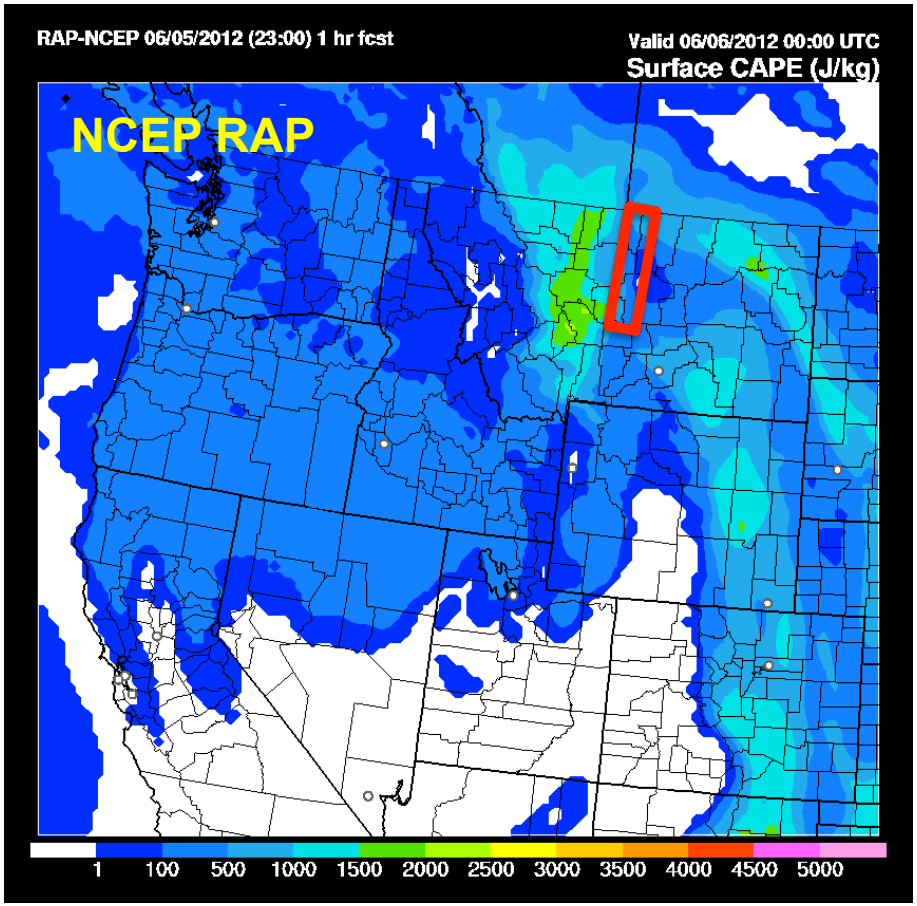
11-21 August 2011

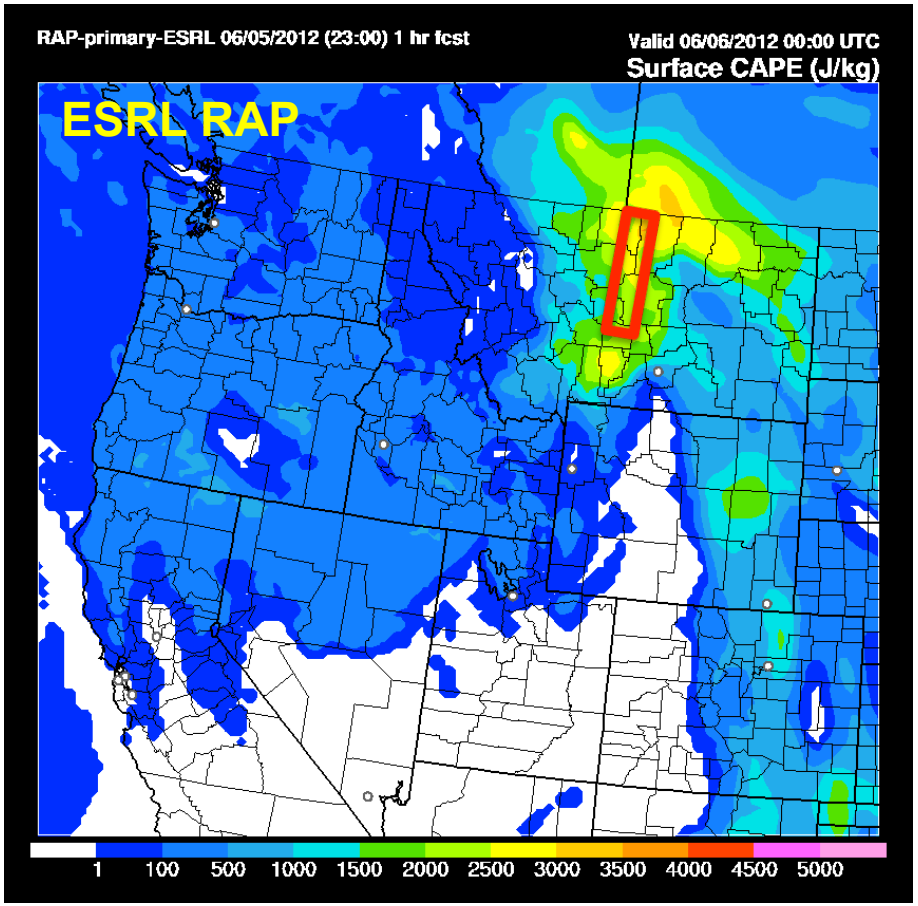
RAP V2 = 2012 ESRL RAP


0200
0130
0100
0030
0000
SPC MCD #1079


KTFX -- Great Falls, MT
23:57:07 UTC Tue 05 June 2012
Base Reflectivity: 0.5 degrees, Precip Mode
(c) UCAR http://www.rap.ucar.edu/weather/radar/


SPC Storm Reports for 06/05/12
Map updated at 1349Z on 06/06/12
TORNADO REPORTS.. (4)
WIND REPORTS/HI..... (38/0)
HAIL REPORTS/LG..... (32/2)
TOTAL REPORTS..... (74)
National Weather Service
Storm Prediction Center
Norman, Oklahoma
High Wind Report (65KT+)
Large Hail Report (2" dia.+)
PRELIMINARY DATA ONLY


RAP-NCEP 06/05/2012 (23:00) 1 hr fcst
Valid 06/06/2012 00:00 UTC
Surface CAPE (J/kg)
NCEP RAP
1 100 500 1000 1500 2000 2500 3000 3500 4000 4500 5000


RAP-primary-ESRL 06/05/2012 (23:00) 1 hr fcst
Valid 06/06/2012 00:00 UTC
Surface CAPE (J/kg)
ESRL RAP
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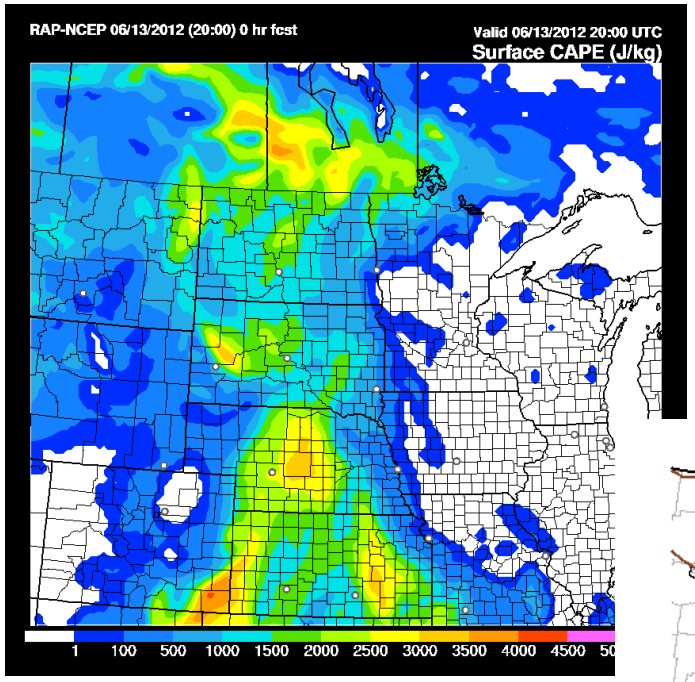
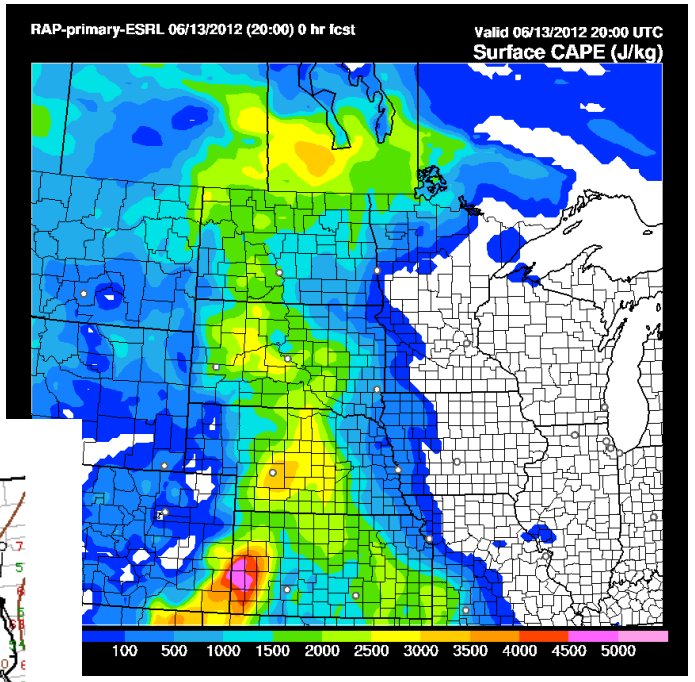
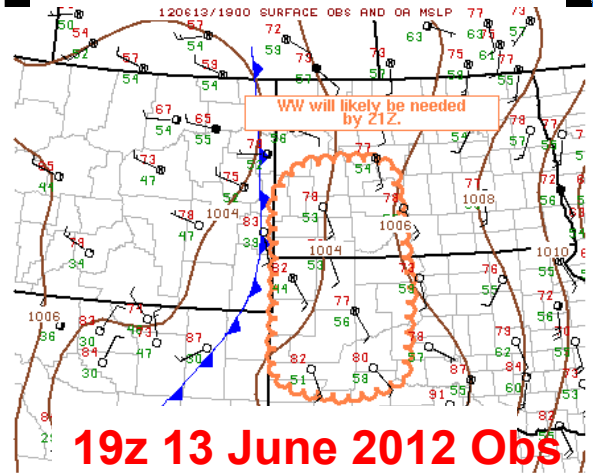


20z 13 June 2012 analysis

←NCEP-RAP

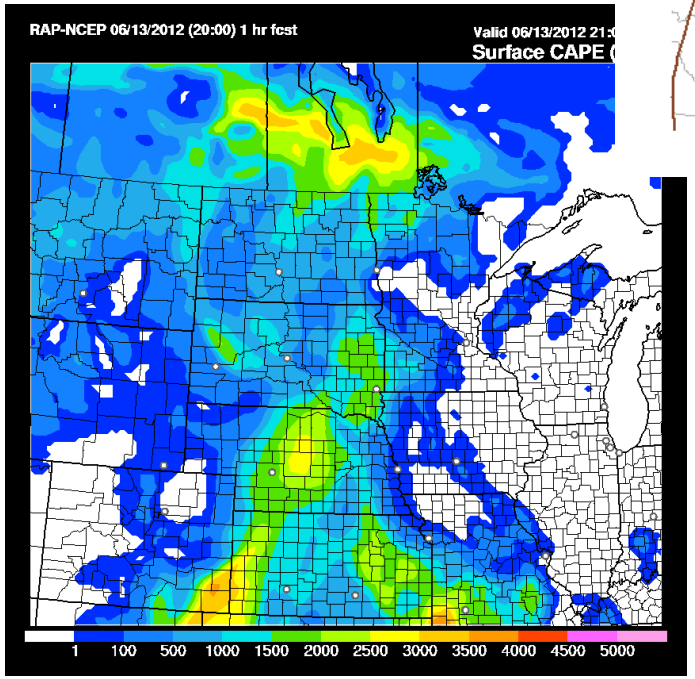
ESRL-RAP →





19z 13 June 2012 Obs

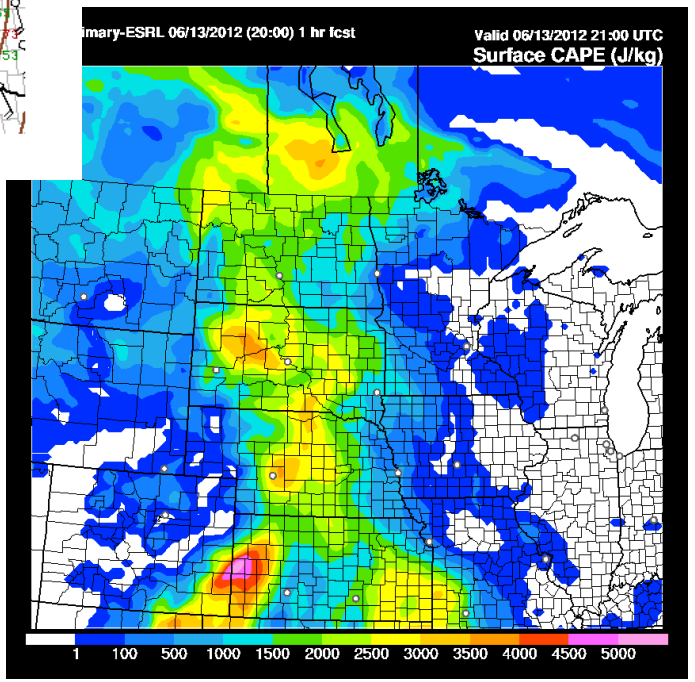
SPC MCD #1152

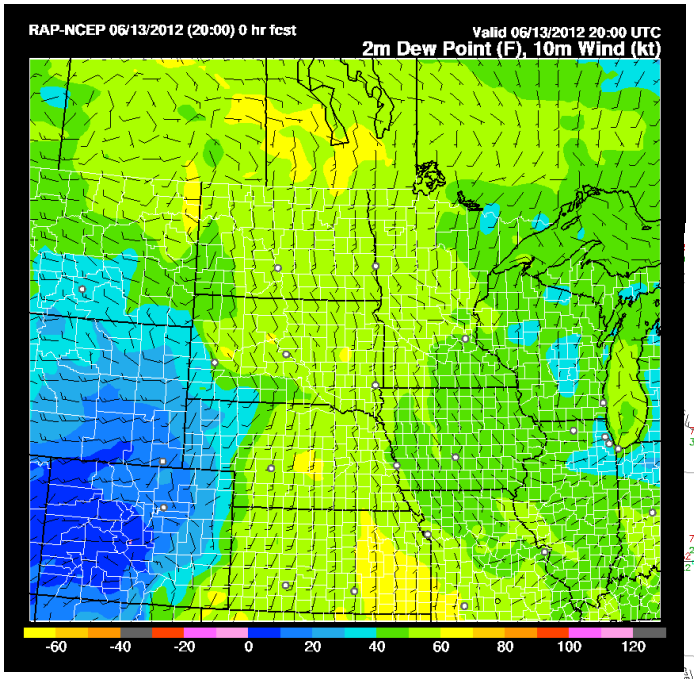


20z 13 June 2012 1hr fcst

←NCEP-RAP

ESRL-RAP →

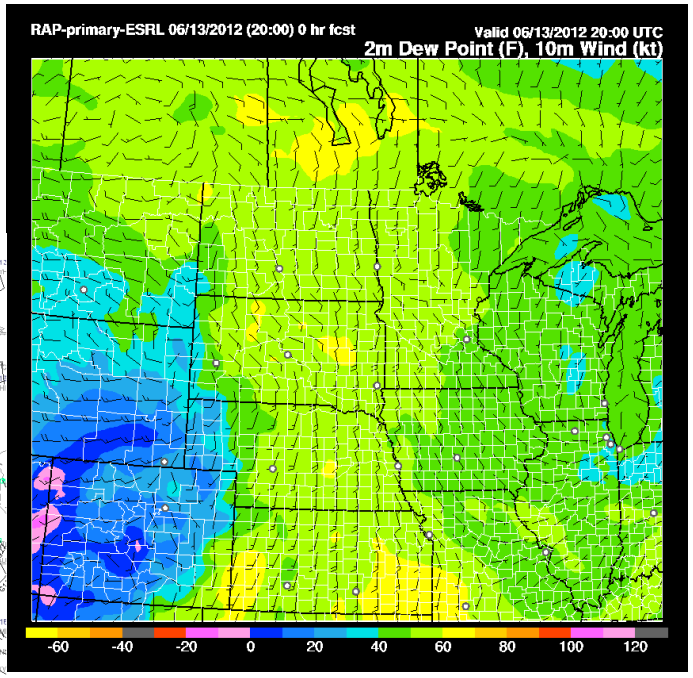




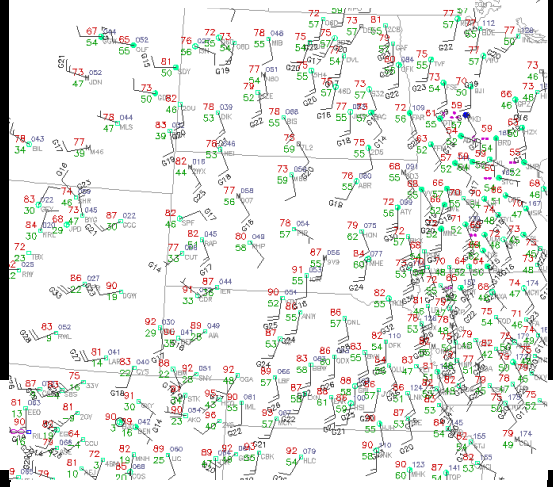
20z 13 June 2012 analysis

←NCEP-RAP

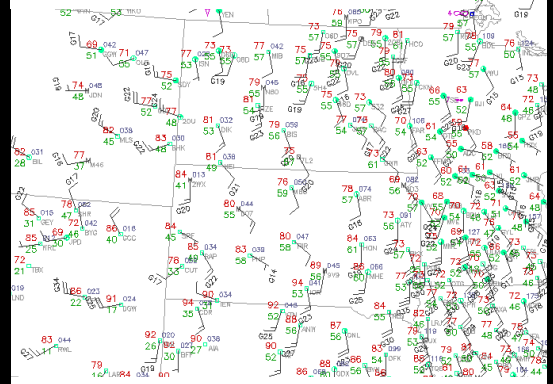
ESRL-RAP →

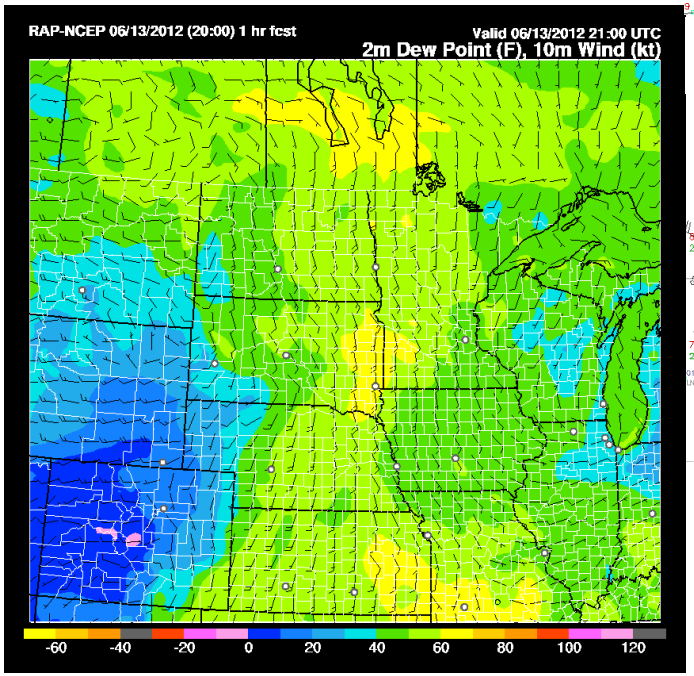


20z 13 June 2012 Obs



21z 13 June 2012 Obs

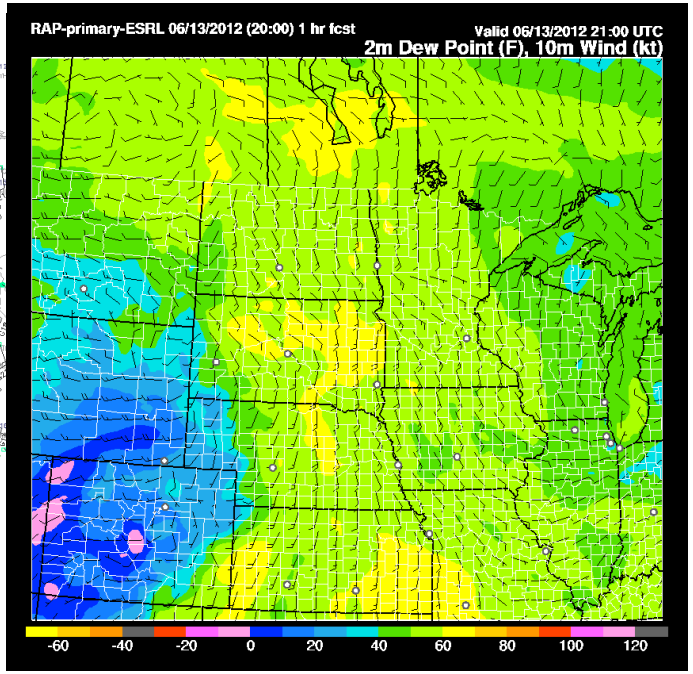




20z 13 June 2012 1hr fcst

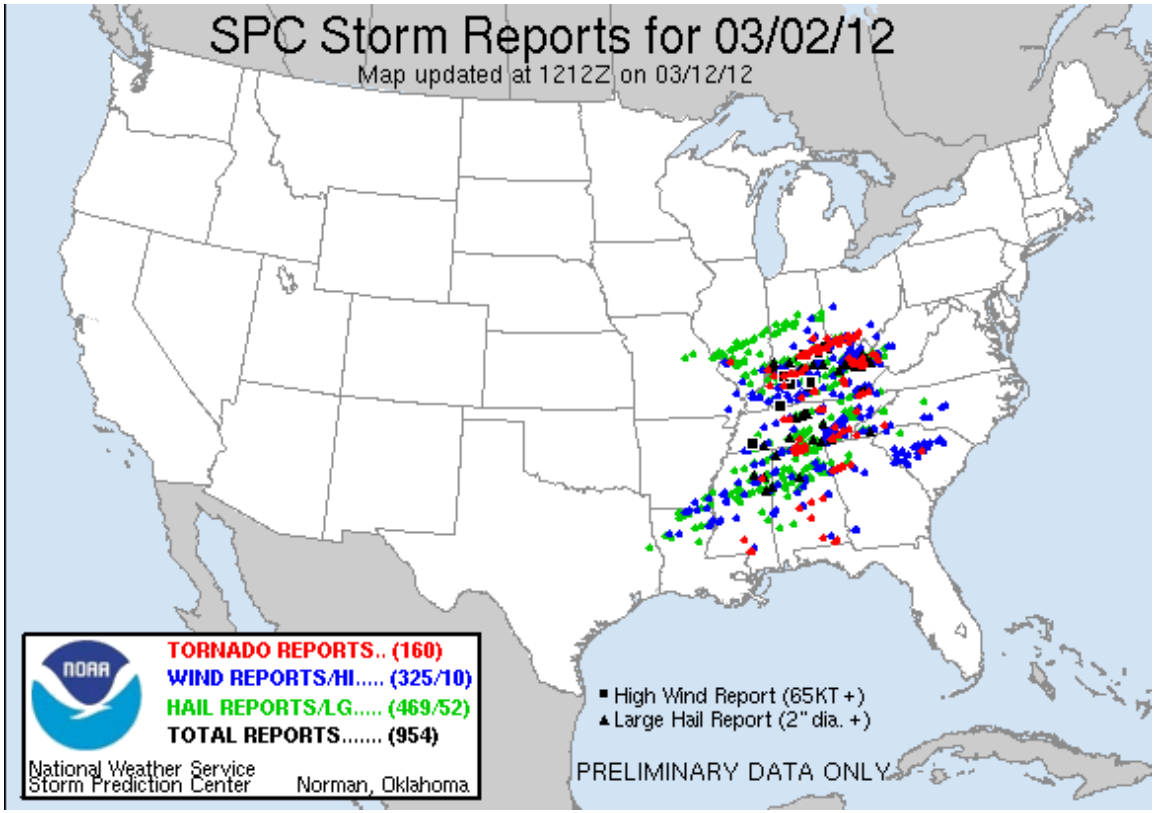
←NCEP-RAP

ESRL-RAP →



Case study – NCEP (RAPv1) vs. ESRL (RAPv2) versions 1h forecasts init 20z 2 Mar 2012

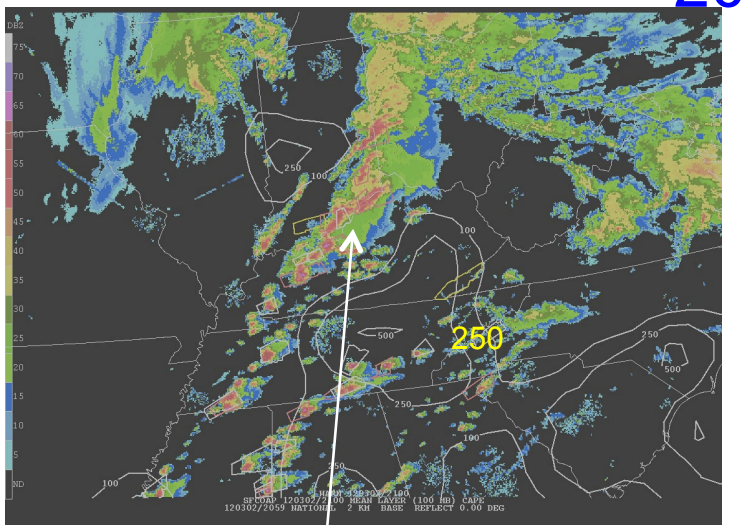
2 March 2012 severe weather outbreak- 160 tornadoes, 29 fatalities

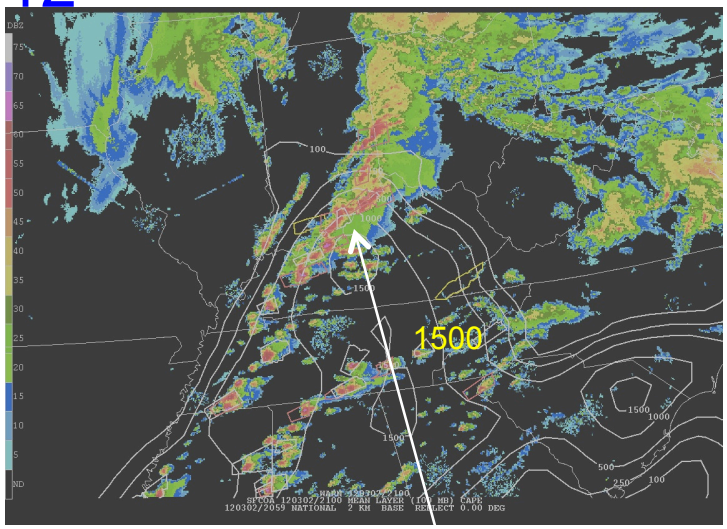


SPC RAP evaluation slide

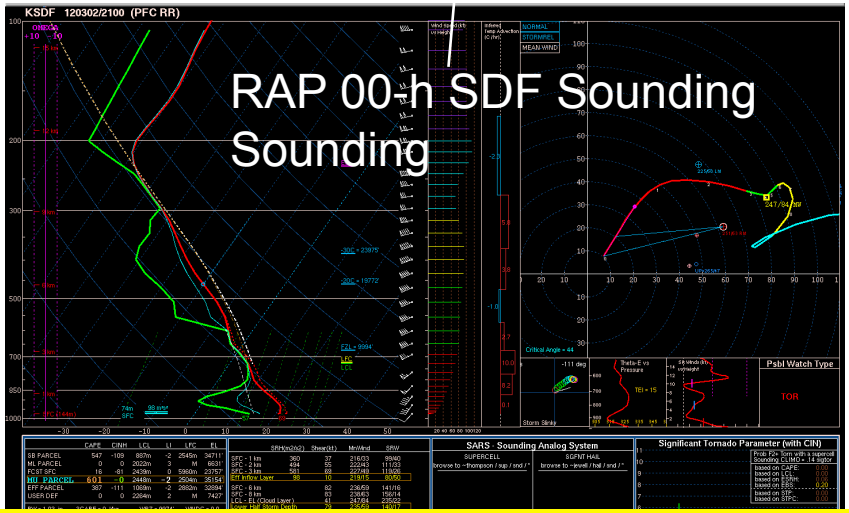
Comparison of RAP(v1) (left) and RUC (right) 21z 2 March 2012

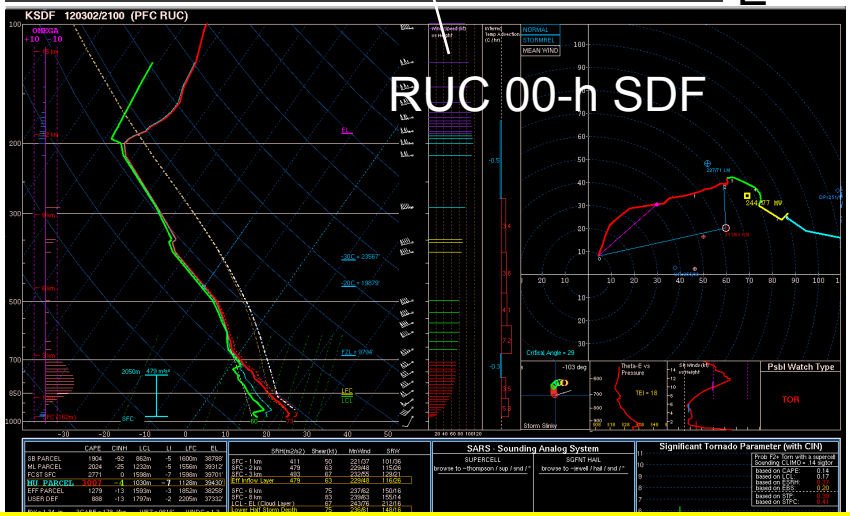
RAP-based sfcoa MLCAPE



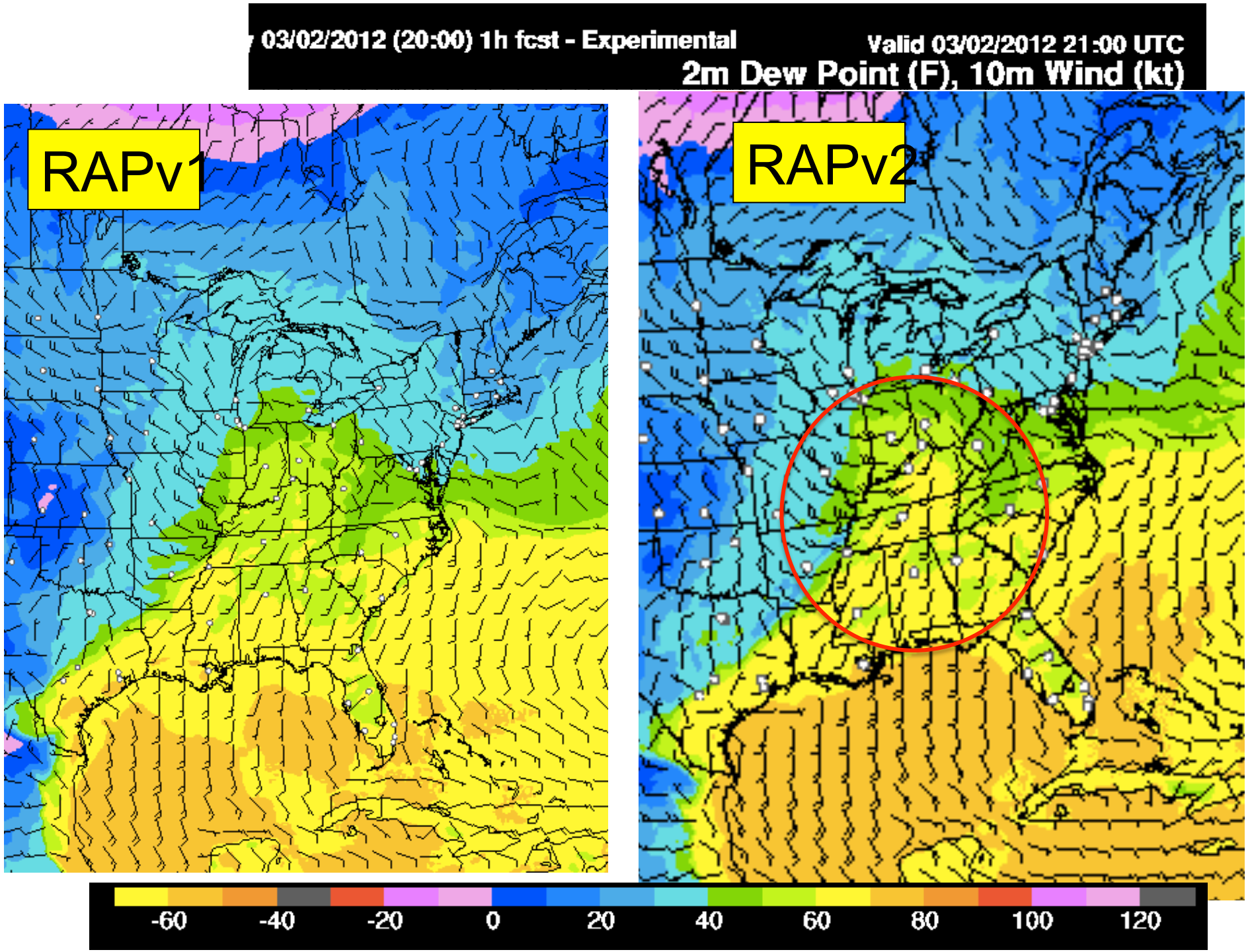


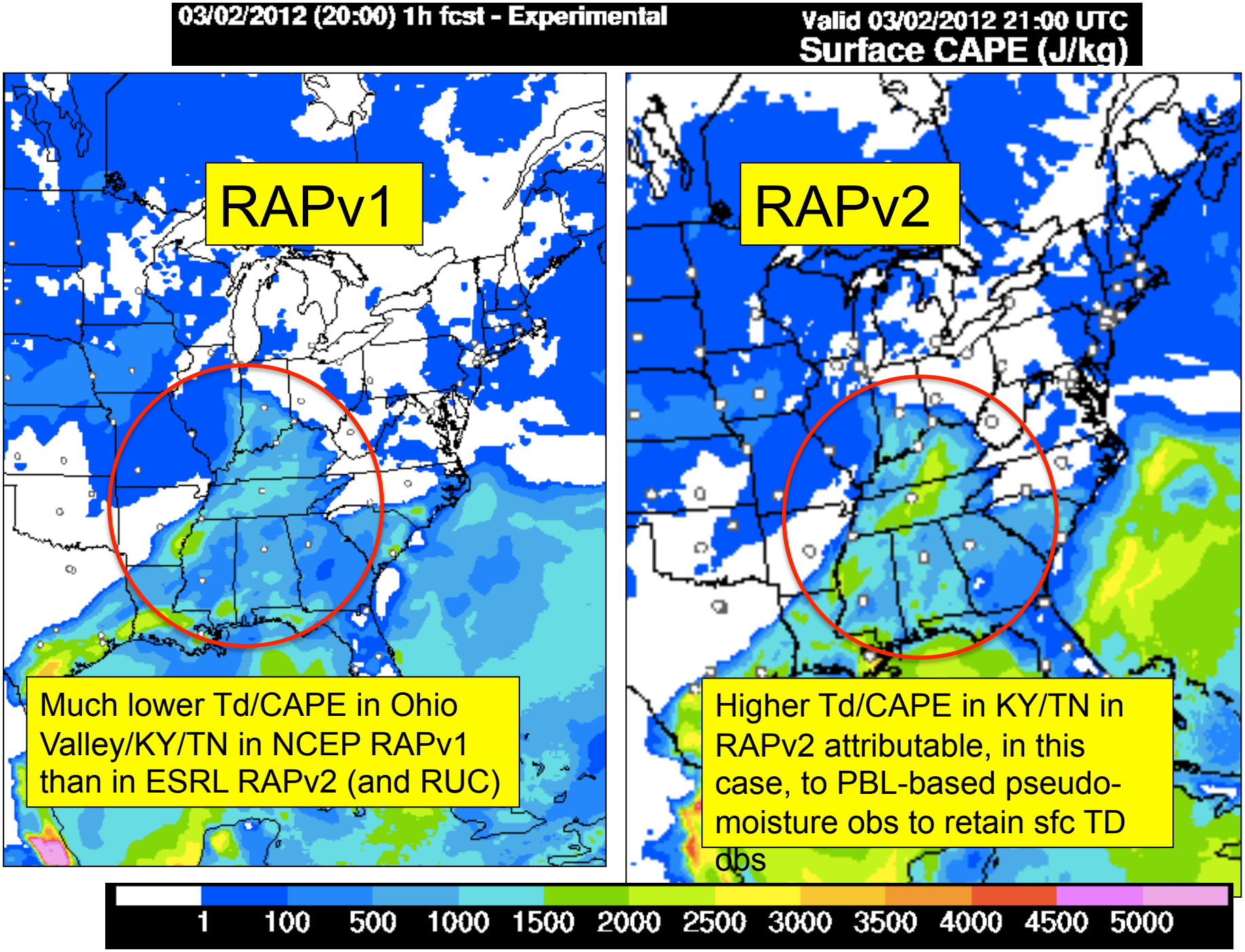
RUC-based sfcoa MLCAPE





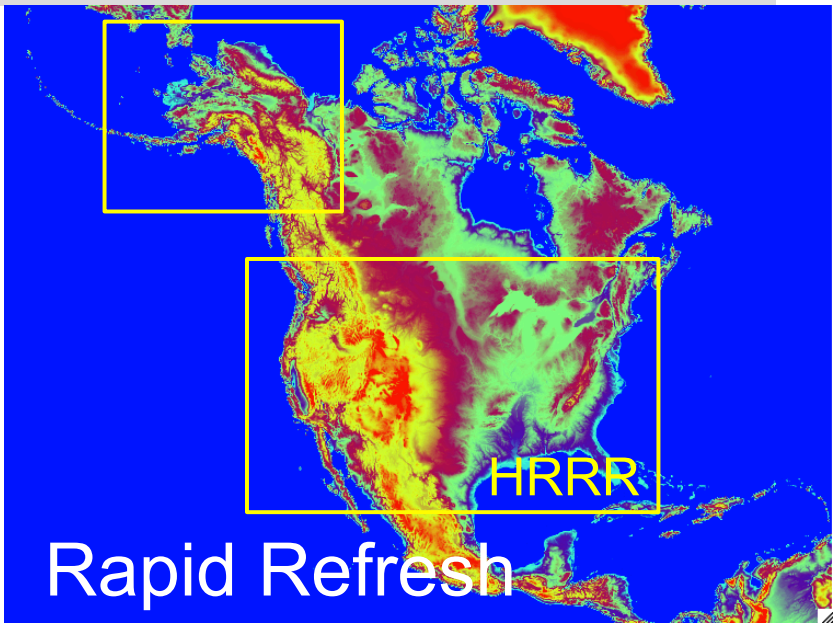
Problem: RAP(v1) had too low dewpoint in 1-6h forecast in Ohio Valley.


03/02/2012 (20:00) 1h fcst - Experimental
Valid 03/02/2012 21:00 UTC
2m Dew Point (F), 10m Wind (kt)
RAPv1
RAPv2
-60
-40
-20
0
20
40
60
80
100
120


03/02/2012 (20:00) 1h fcst - Experimental
Valid 03/02/2012 21:00 UTC
Surface CAPE (J/kg)
RAPv1
RAPv2
Much lower Td/CAPE in Ohio Valley/KY/TN in NCEP RAPv1 than in ESRL RAPv2 (and RUC)
Higher Td/CAPE in KY/TN in RAPv2 attributable, in this case, to PBL-based pseudo-moisture obs to retain sfc TD dbs
1
100
500
1000
1500
2000
2500
3000
3500
4000
4500
5000

Future plans for advanced hourly NWP/DA

- 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
- 2013-14 – 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 NMMB, ARW cores**
- **Hourly updating with GSI-hybrid EnKF**
- **Initially 2 members, 1 each core, later 6, physics diversity (RAP, NAM, other 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

NCEP Unipost options for output added for Rapid Refresh application

- **Ceiling** -includes NCAR code for effect of falling snow
- **Visibility** -includes RH component and updated coefficients from NCAR
- **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

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*

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	J Han & H-L Pan (2011)	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

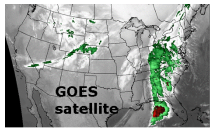
Rapid Refresh layer-interface sigma values (50 layers)

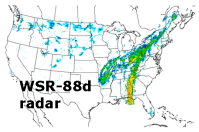
1.0000, 0.9980, 0.9940, 0.9870, 0.9750, 0.9590,
0.9390, 0.9160, 0.8920, 0.8650, 0.8350, 0.8020, 0.7660,
0.7270, 0.6850, 0.6400, 0.5920, 0.5420, 0.4970, 0.4565,
0.4205, 0.3877, 0.3582, 0.3317, 0.3078, **0.2863, 0.2670,**
0.2496, 0.2329, 0.2188, 0.2047, 0.1906, 0.1765, 0.1624,
0.1483, 0.1342, 0.1201, 0.1060, 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,

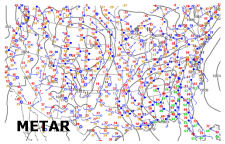
Consistent with RUC in having high resolution close to ground and in vicinity of the tropopause

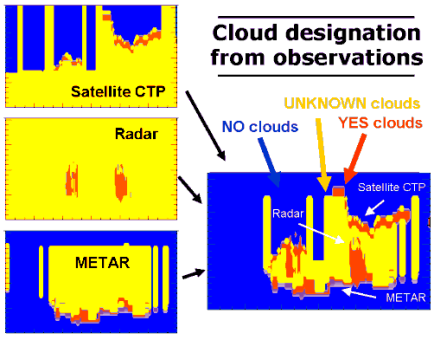
Rapid Refresh – specific analysis features

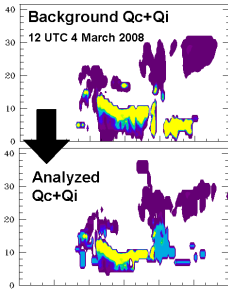
Cloud and hydrometeor analysis











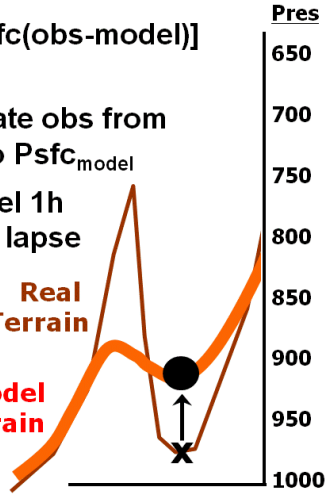
Special treatments for surface observations

Elevation correction

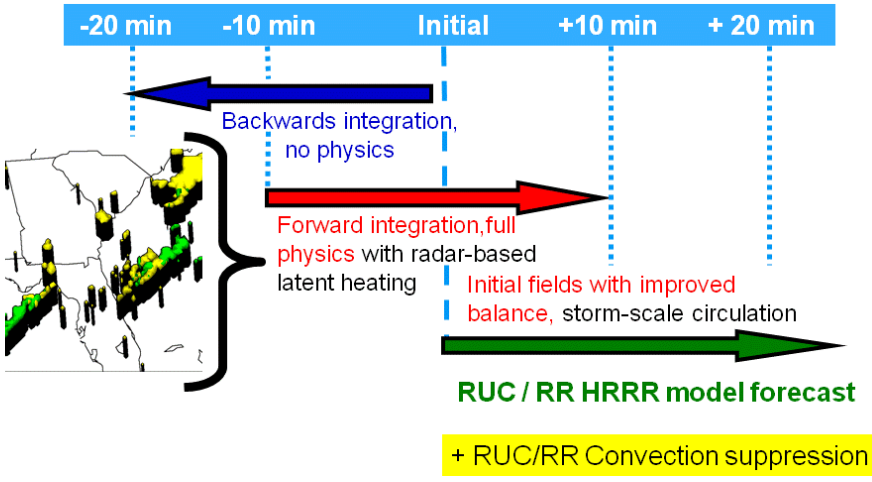
If abs[Psfc(obs-model)] < 70 hPa.

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

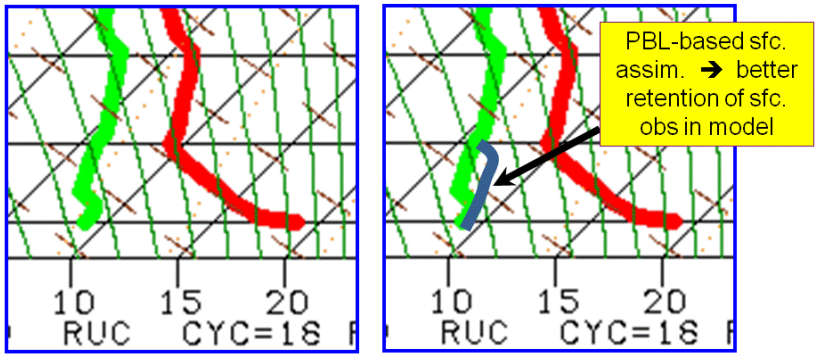
Use model 1h low-level lapse rate.



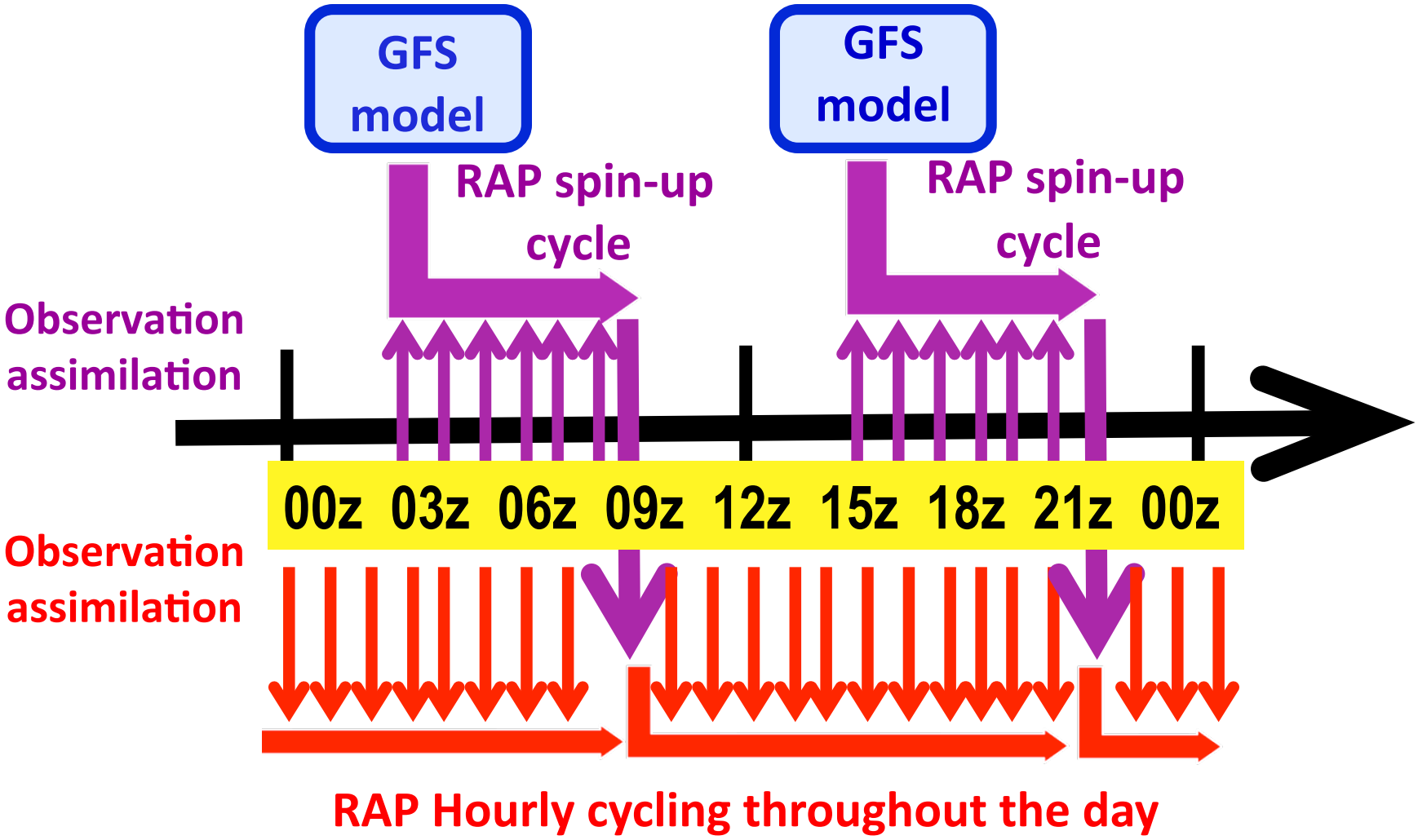
Digital filter-based reflectivity assimilation



PBL-based pseudo-observations



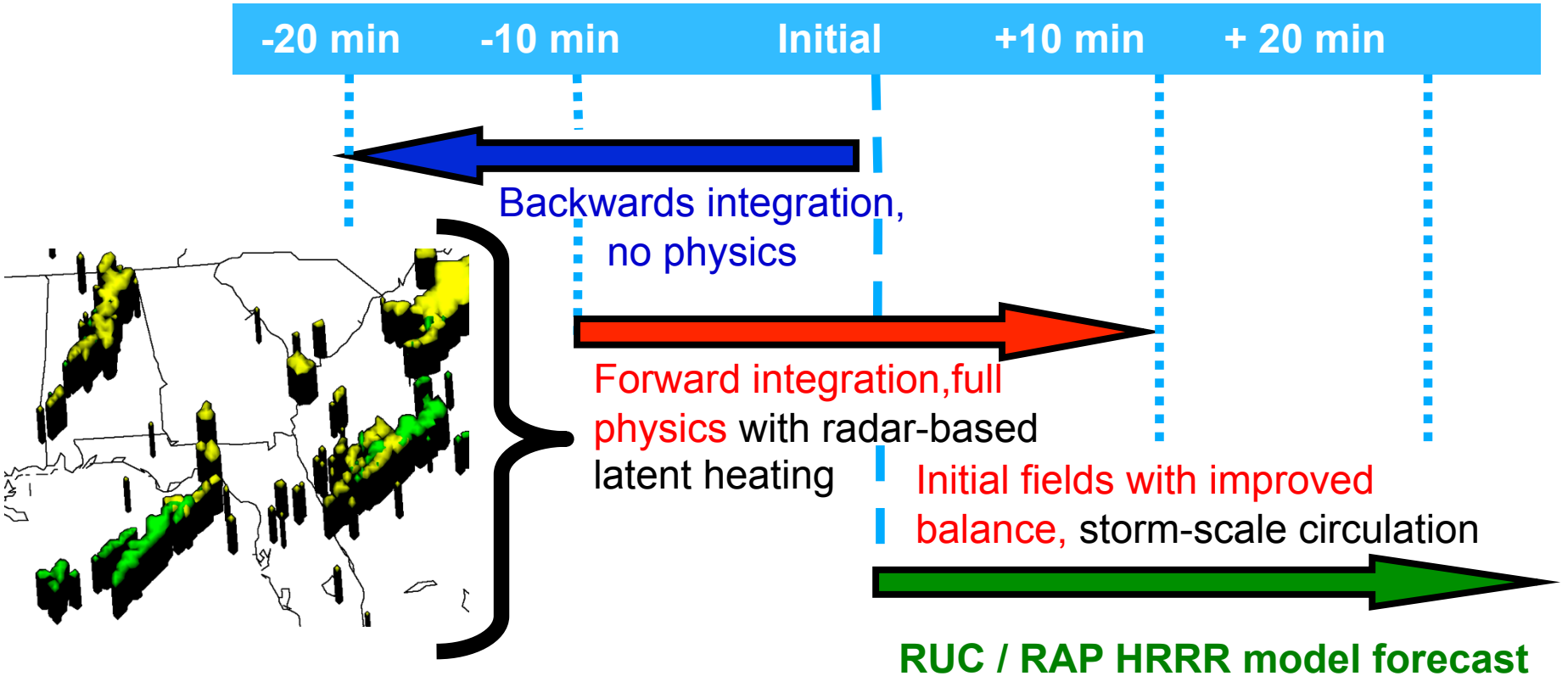
Rapid Refresh Partial Cycling



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

Radar reflectivity assimilation

Digital filter-based reflectivity assimilation initializes ongoing precipitation regions



NARRE-TL ensemble - part of RAP implementation

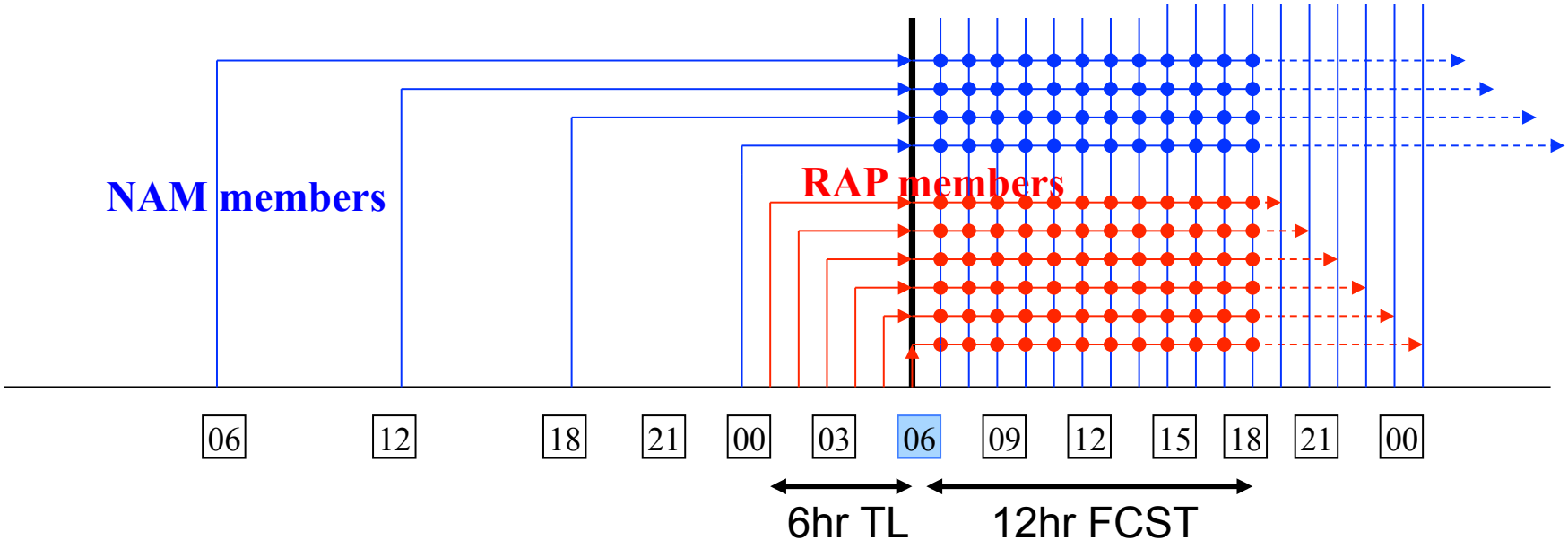
Member Weighting *= 1.0 minus forecast duration (hr)/30*:

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:



Rapid Refresh
NCEP 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

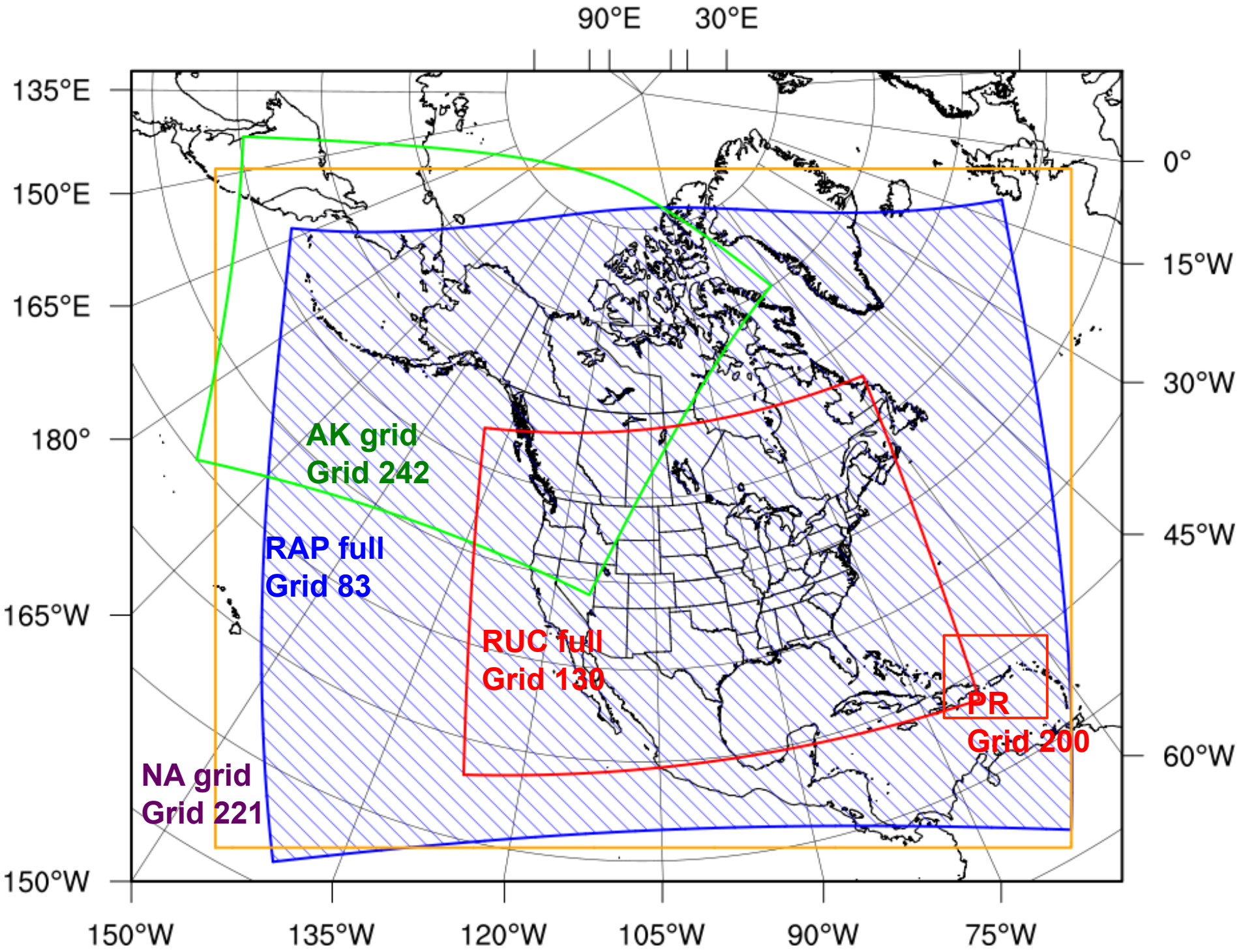
RUC "look-alike" grids

- 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