

Rapid Refresh / Rapid Update Cycle (RR/RUC) Technical Review

[NOAA/ESRL/GSD/AMB](#)

Stan Benjamin	Bill Moninger
Steve Weygandt	John M. Brown
Curtis Alexander	Kevin Brundage
Dezso Devenyi	Mike Fiorino
Georg Grell	Ming Hu
Brian Jamison	Bernie Johnson
Joe Olson	Steven Peckham
Susan Sahn	Tom Schlatter
Tanya Smirnova	Shan Sun
Tracy Lorraine Smith	Doug Koch
Barry Schwartz	

[NCEP/EMC](#) – Geoff Manikin

Major transitions:

- RUC13 changes – Nov 08, Mar 09
– radar reflectivity assimilation, TAMDAR, mesonet, cloud analysis
- **Rapid Refresh – final testing, planned for NCEP implementation – 3Q-4Q-FY10**
- HRRR – now CONUS-wide

Central role for aviation, AQ, energy, other applications

Tues 3 Nov 2009



Earth System Research Laboratory
SCIENCE, SERVICE & STEWARDSHIP

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[NCEP/EMC](#) – **Geoff Manikin**

Other key partners in RR/HRRR include:

GSD: **Bob Lipschutz** **Chris Harrop**
Craig Tierney **Leslie Hart**

NCEP: **Geoff DiMego** **Dennis Keyser**

NCAR: **WRF, microphysics, Digital Filter**

DTC: **For GSI repository**

Tues 3 Nov 2009



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Rapid Refresh / RUC Technical Review - OUTLINE

- 1:30 – 1:45 **RUC → Rapid Refresh transition overview,
NCEP RUC changes – 2008-09** Stan Benjamin
- 1:45 – 2:00 **Observation impact experiments
- TAMDAR aircraft obs w/ moisture, larger OSE**
Bill Moninger
- 2:00 – 2:20 **Rapid Refresh overview, assimilation –**
Steve Weygandt, Ming Hu
- 2:20 – 2:30 **-- Break --**
- 2:30 – 3:05 **RR-WRF model development / testing
– physics, cloud, chemistry, PBL**
John Brown, Tanya Smirnova, Joe Olson
- 3:05 – 3:20 **The HRRR and HCPF (HRRR prob forecast)**
Curtis Alexander
- 3:20 – 3:30 **Future of RR/HRRR/ens** Stan Benjamin

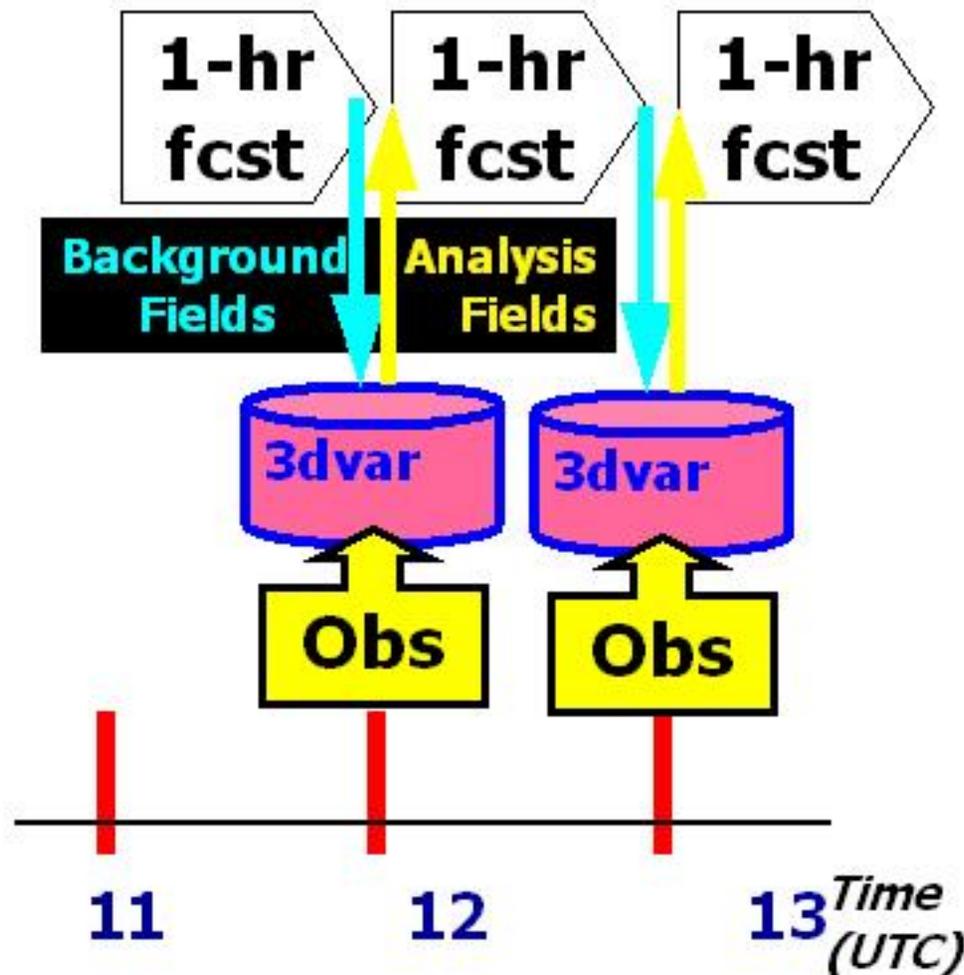
Why have a Rapid UC or Rapid Refresh?

- **Provide high-frequency (hourly) mesoscale analyses, short-range model forecasts**
- **Assimilate (“merge”) all available observations into single, physically consistent 3-d grid such that forecasts are improved**
- **Initial focus on aviation enroute & surface weather:**
 - Thunderstorms, severe weather, winter storms
 - Icing, ceiling and visibility, turbulence
 - Detailed surface temperature, dewpoint, winds
 - Upper-level winds
- **Users:**
 - aviation/transportation
 - severe weather forecasting
 - hydrology, energy (load, renewable)

*“Situational
Awareness
Model”*

RUC/Rapid Refresh Hourly Assimilation Cycle

Cycle hydrometeor, soil temp/moisture/snow plus atmosphere state variables



Hourly obs

Data Type ~Number

Rawinsonde (12h)	150
NOAA profilers	35
VAD winds	120-140
PBL – prof/RASS	~25
Aircraft (V,temp)	3500-10000
TAMDAR (V,T,RH)	200-3000
Surface/METAR	2000-2500
Buoy/ship	200-400
GOES cloud winds	4000-8000
GOES cloud-top pres	10 km res
GPS precip water	~300
Mesonet (temp, dpt)	~8000
Mesonet (wind)	~4000
METAR-cloud-vis-wx	~1800
AMSU-A/B/GOES radiances	
– RR only	
Radar reflectivity/ lightning	1km

Hourly Updated NOAA NWP Models

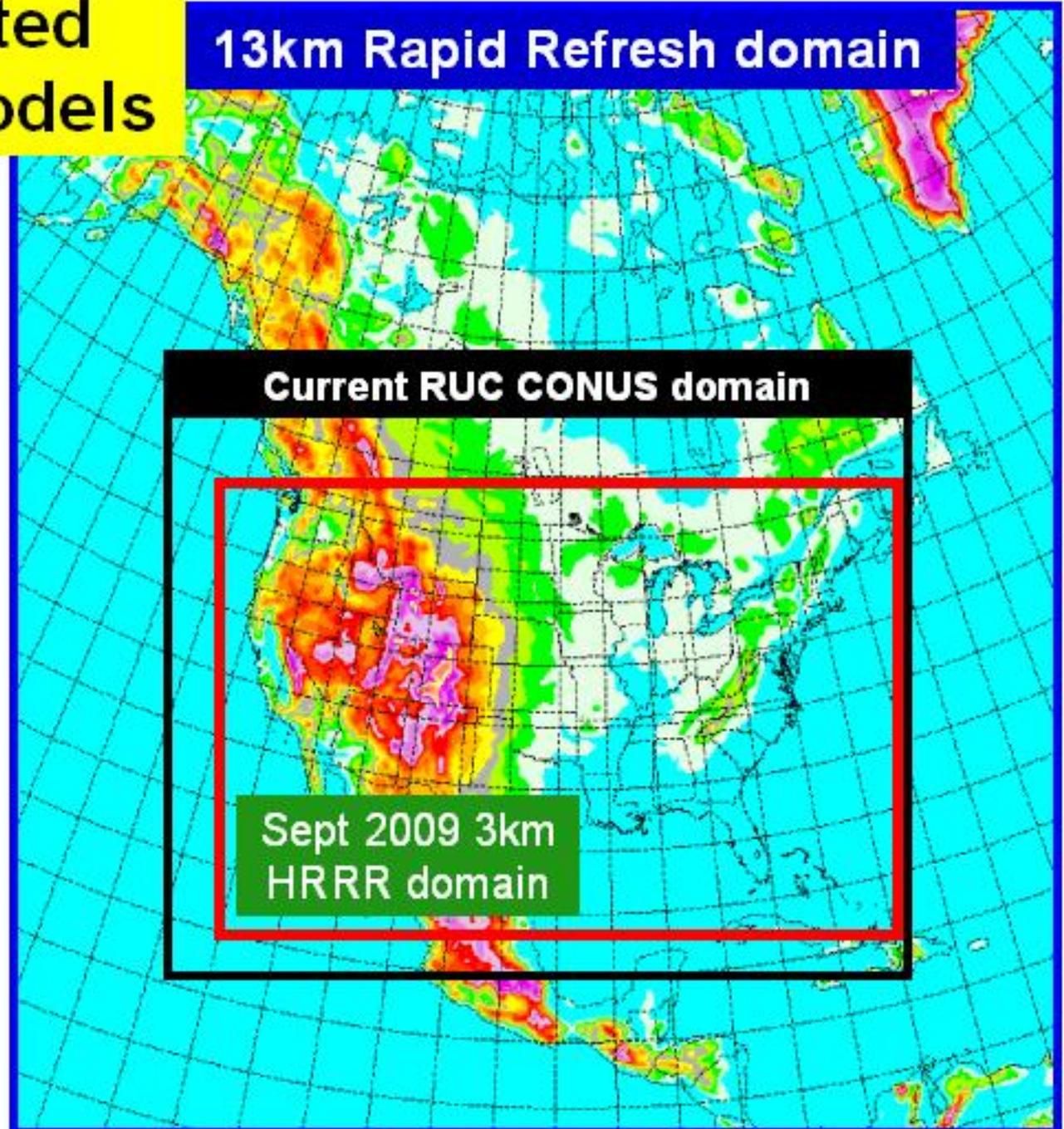
13km Rapid Refresh domain

RUC – current
oper model - 13km

Rapid Refresh
(RR) – replace
RUC at NCEP in
2010 - WRF, GSI w/
RUC-based
enhancements

HRRR - Hi-Res
Rapid Refresh
-Experimental 3km

12-h fcst updated
every hour



Transition to Rapid Refresh (RR)

Purpose:

Evolutionary upgrade to NCEP operational RUC

- More advanced model and analysis components, community code for WRF, GSI)
- Retains aviation specific features from RUC (hourly cycle, cloud analysis, use of surface observations)
- Consistent grids over all of N.America for aviation hazards (convection, icing, turbulence, ceiling, visibility, etc.)

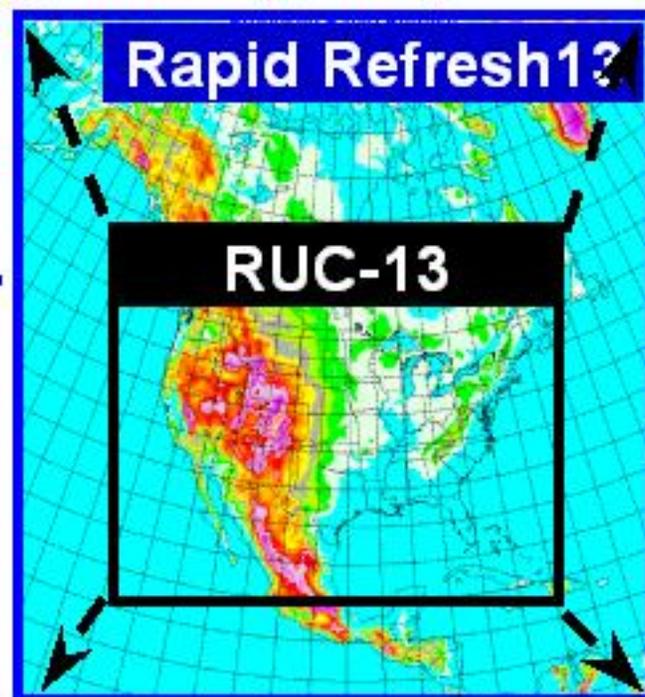
Status:

RR system approaching maturity.

NCEP implementation

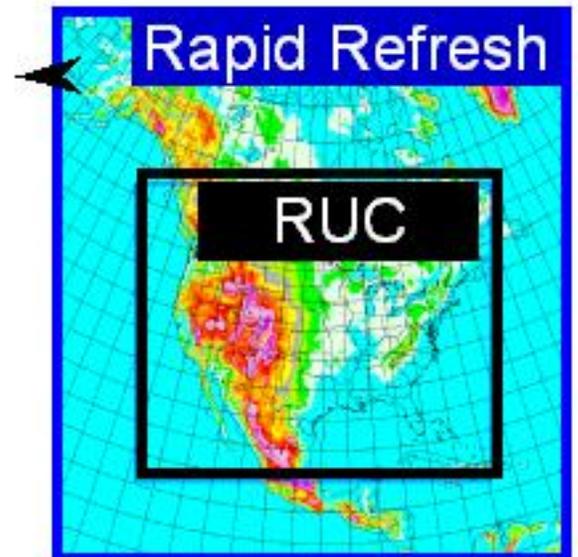
expected Q4 2010

- Refinements ongoing
- <http://rapidrefresh.noaa.gov>



RUC to Rapid Refresh

- CONUS domain (13km) → North American domain (13km)
- RUC 3DVAR → GSI (Gridpoint Statistical Interpolation) (incl. RR enhancements)
- RUC model → WRF-ARW Model (RR version)

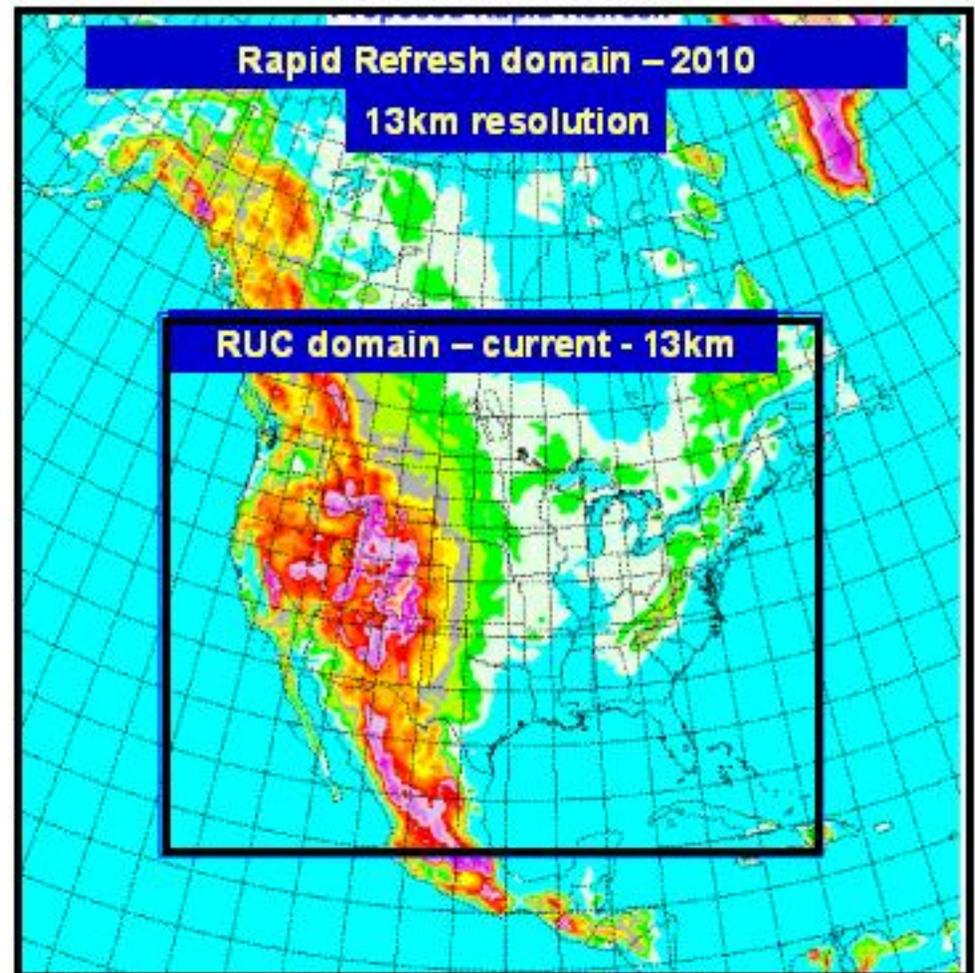


RUC upgrades since fall 2007

<http://ruc.noaa.gov>

<http://rapidrefresh.noaa.gov>

- **11/17/08** - radar reflectivity assimilation, RRTM longwave radiation, 12/16/08 - TAMDAR assimilation
- **3/31/09** - improved cloud analysis, snow cover trimming using satellite data
- **12/09 - 01/10** - RUC extension to 18h forecasts every hour



Nov 2008 Changes for oper RUC upgrade

- Assimilation
 - Use of **radar reflectivity** in RUC
 - **Mesonet winds** using mesonet station uselist
 - **TAMDAR aircraft** observations (16 Dec 2008)
- Model physics
 - RRTM longwave radiation - eliminates sfc warm bias
 - Mods to convective scheme, land-surface scheme
- Post-processing – add reflectivity fields, improved RTMA downscaling

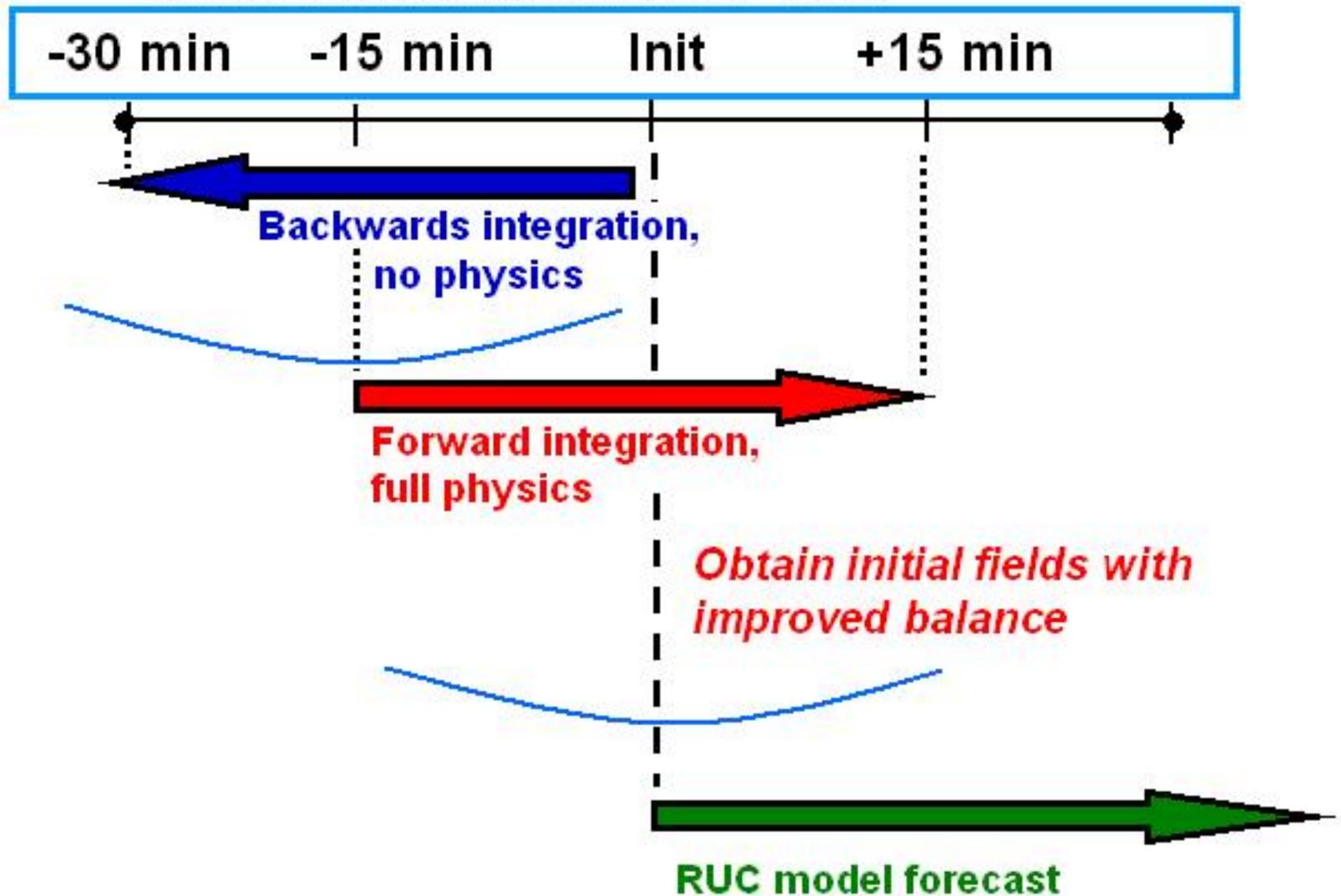
March 2009

- Added snow cover trimming using daily NESDIS snow analysis
- Important improvement to cloud analysis for retention of METAR and GOES cloud obs

RUC Diabatic Digital Filter Initialization (DDFI)

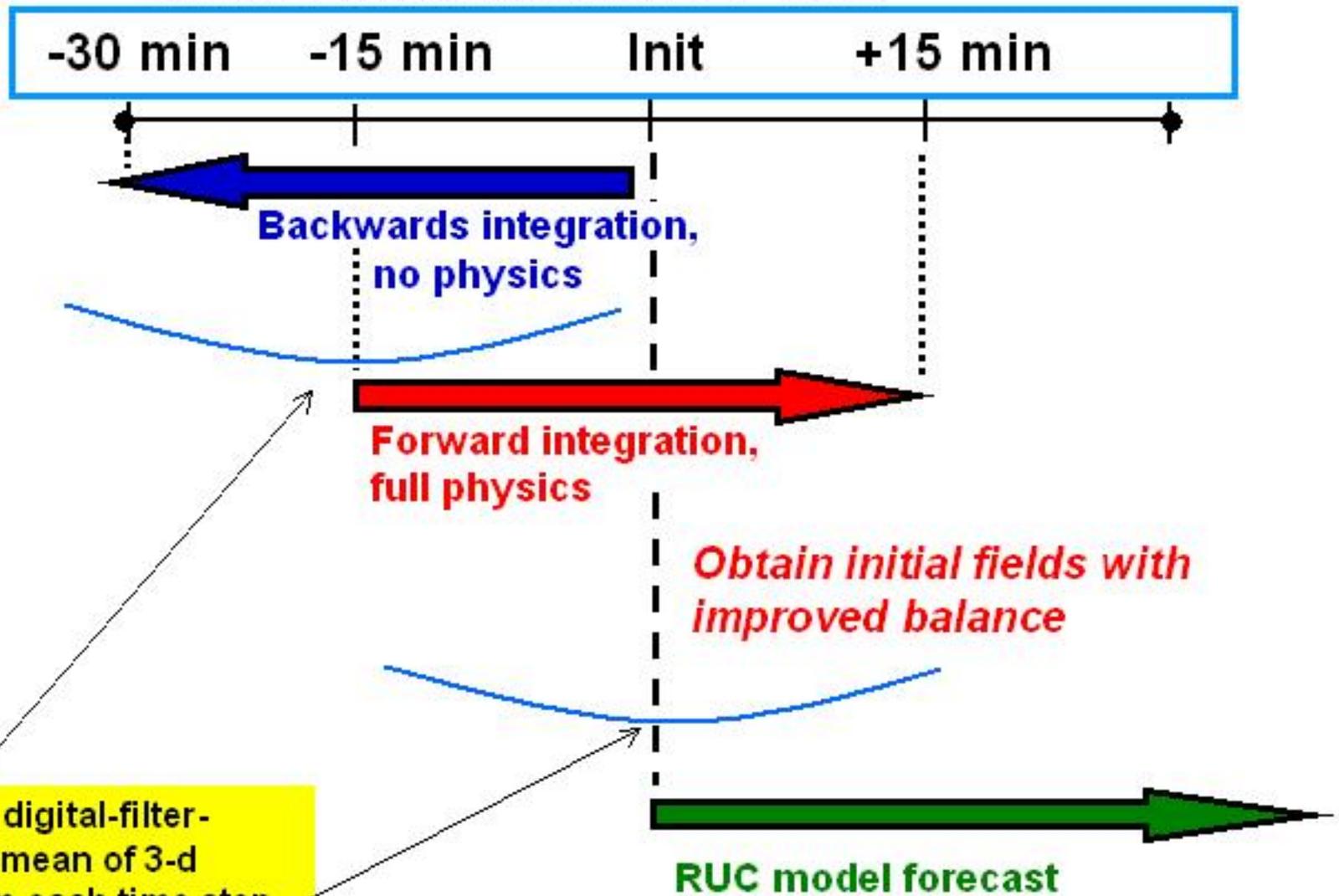
Initial DFI in RUC model at NCEP - 1998 - adiabatic DFI

Diabatic DFI introduced at NCEP - 2006



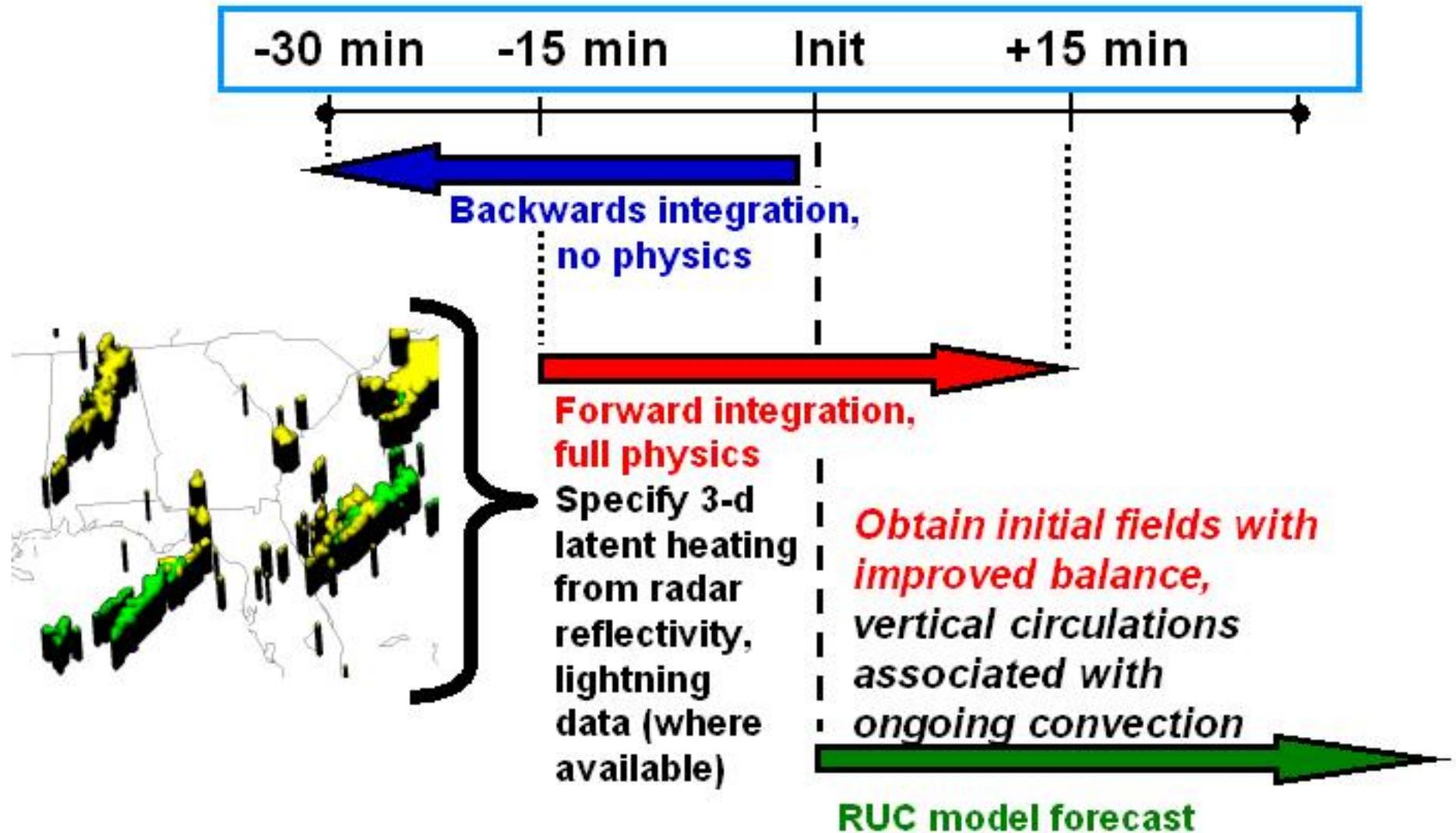
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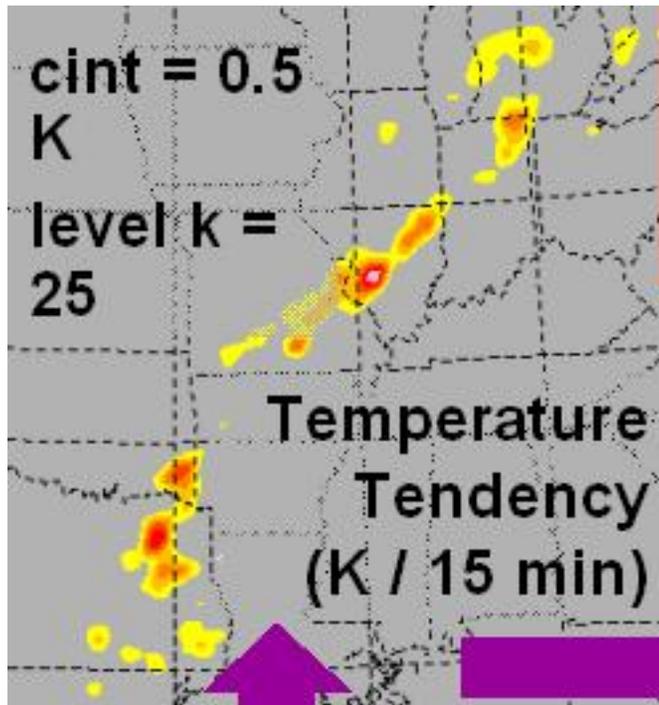


Diabatic Digital Filter Initialization (DDFI)

New - add assimilation of radar data



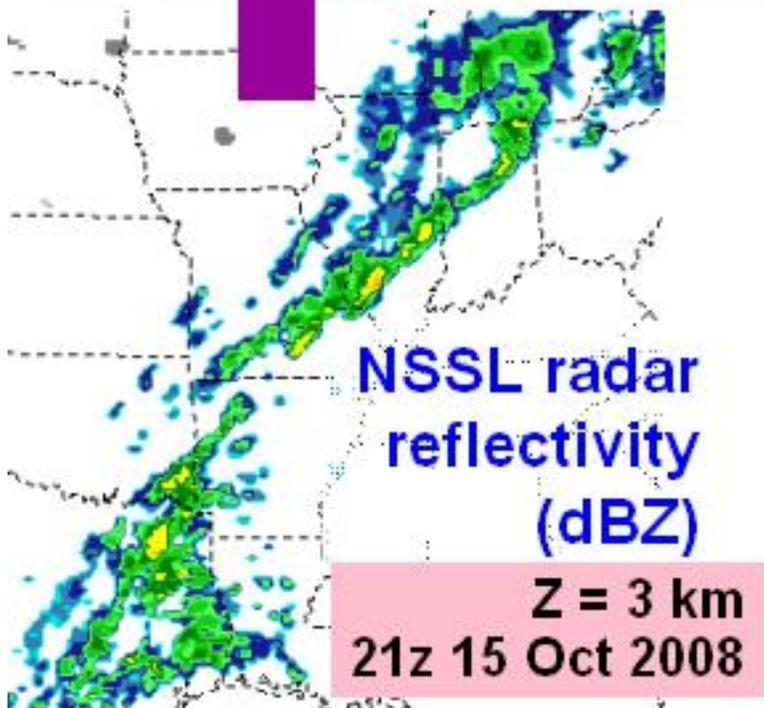
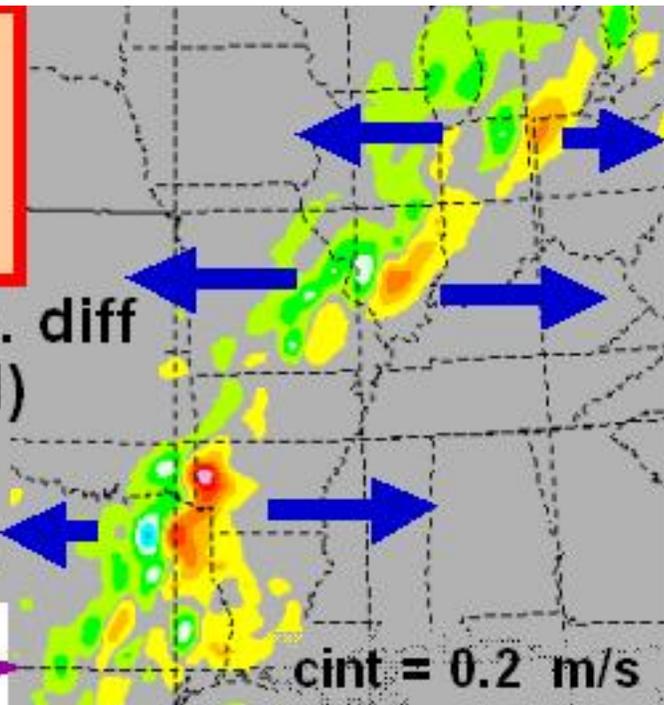
Radar reflectivity assimilation in RUC



**Sample radar
assimilation
(one cycle)**

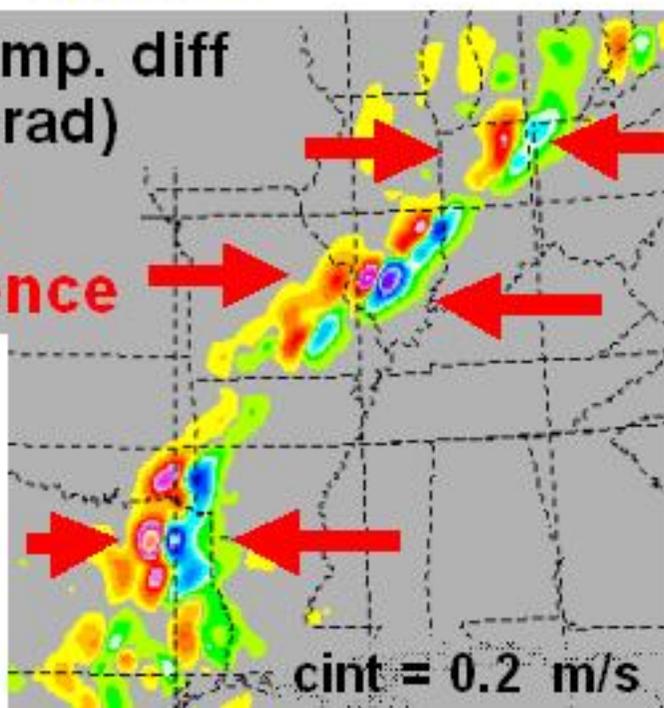
K=35 U-comp. diff
(radar - norad)

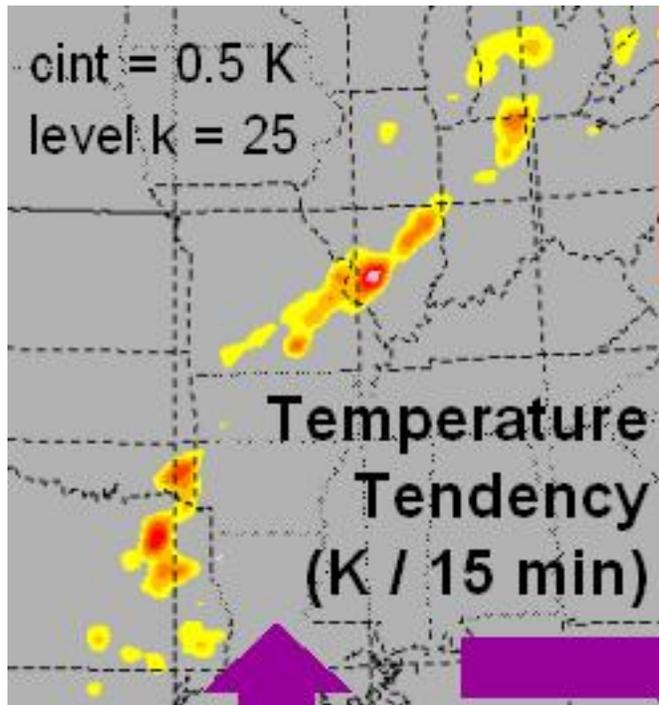
**Upper-level
Divergence**



K=15 U-comp. diff
(radar - norad)

**Low-level
Convergence**

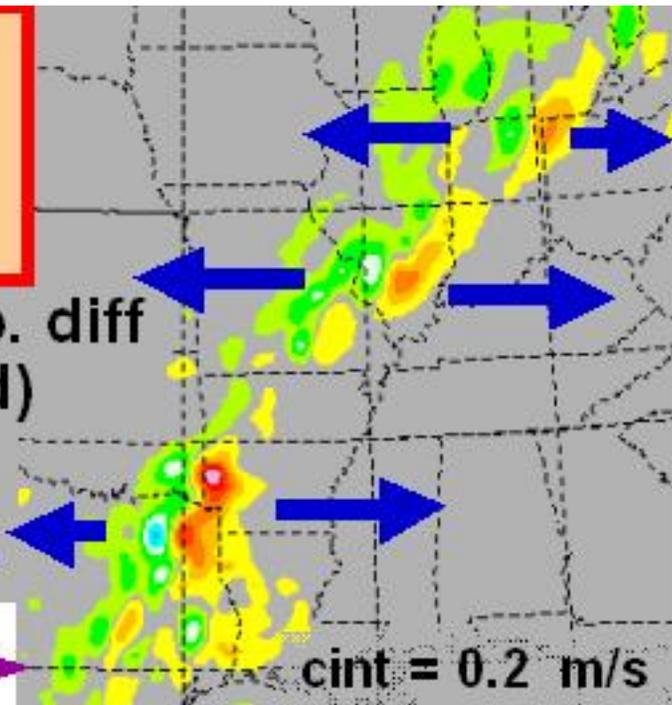




**Sample radar
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**K=35 U-comp. diff
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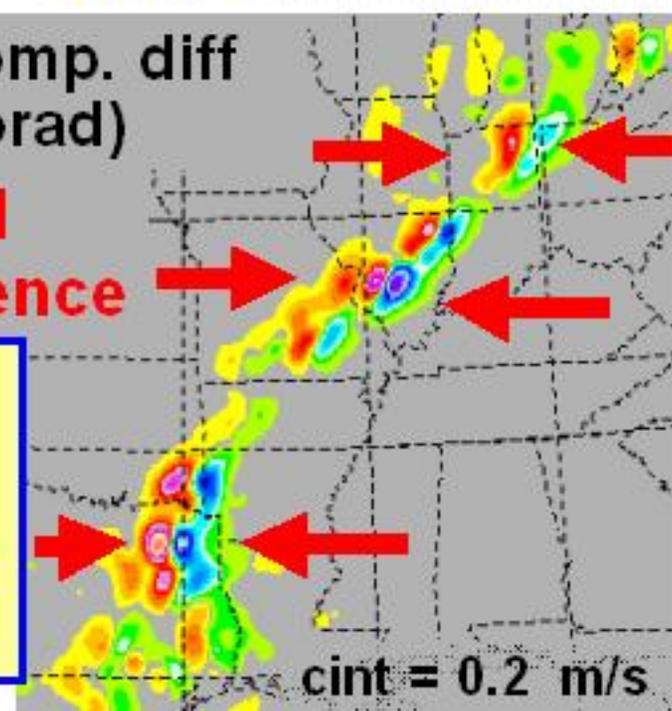
**Upper-level
Divergence**

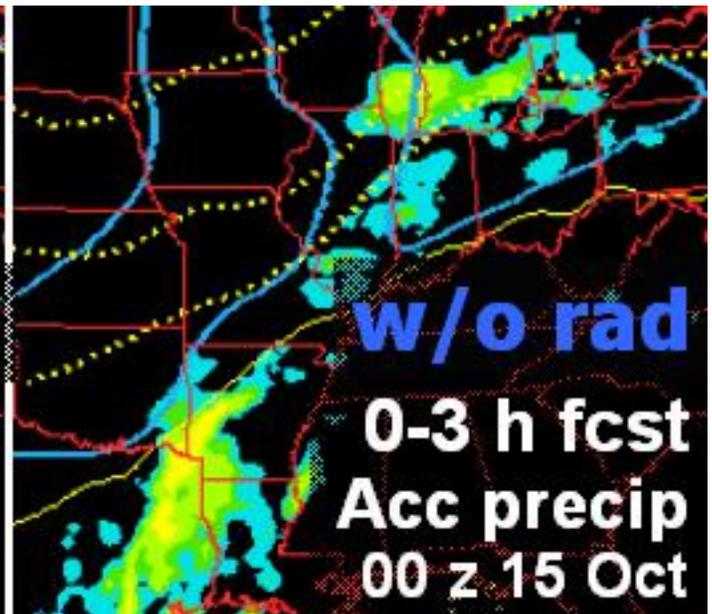
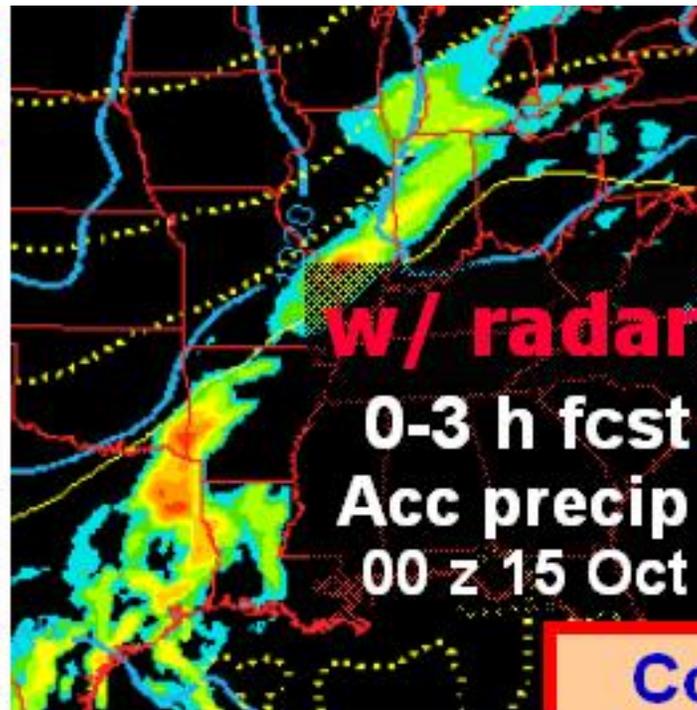


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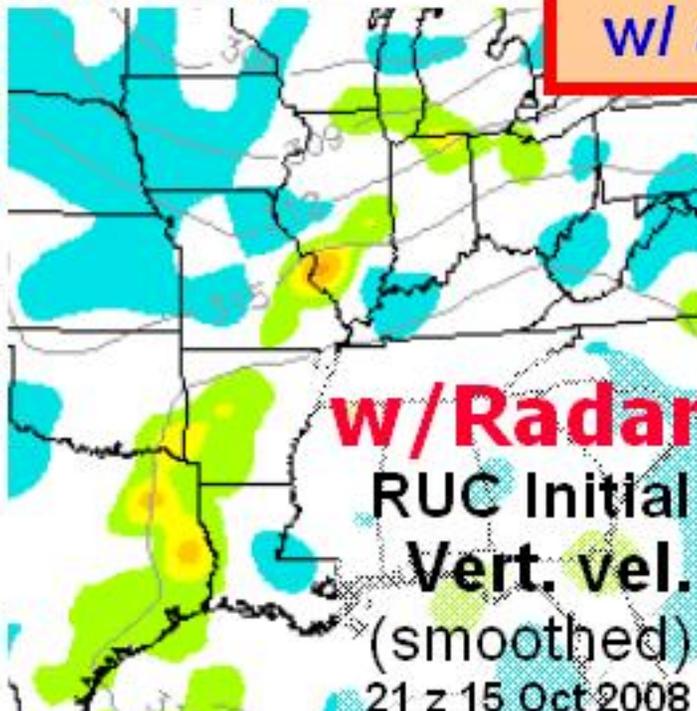
**Low-level
Convergence**

**Radar assimilation
applied each hour**
**Diff from single
update -- cycle
with radar assim**





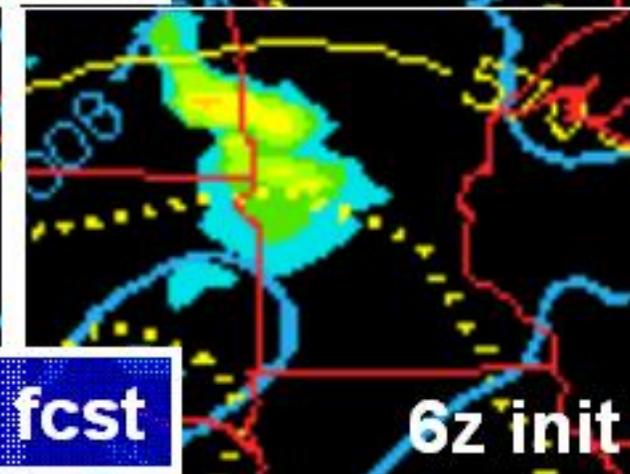
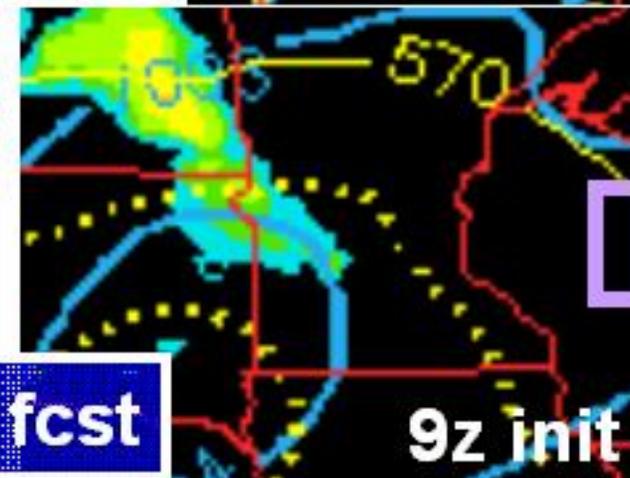
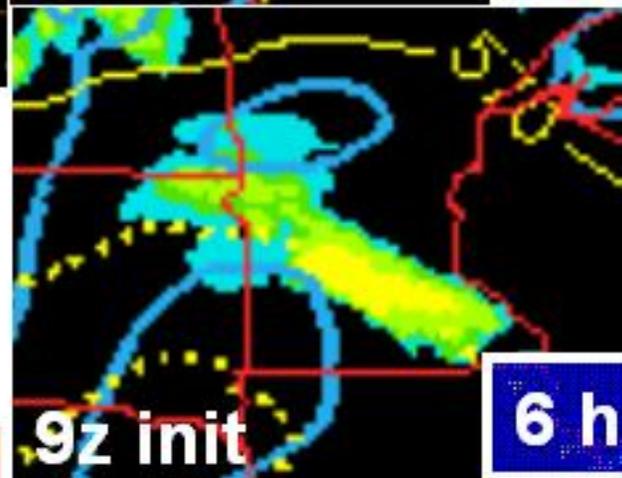
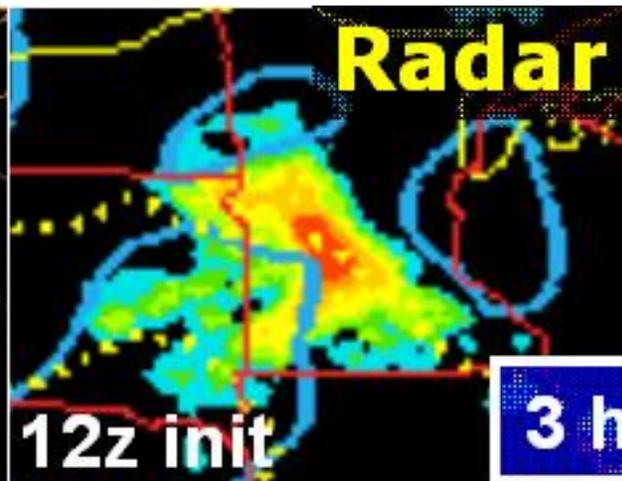
**Compare RUC cycles
w/ and w/o radar assim**





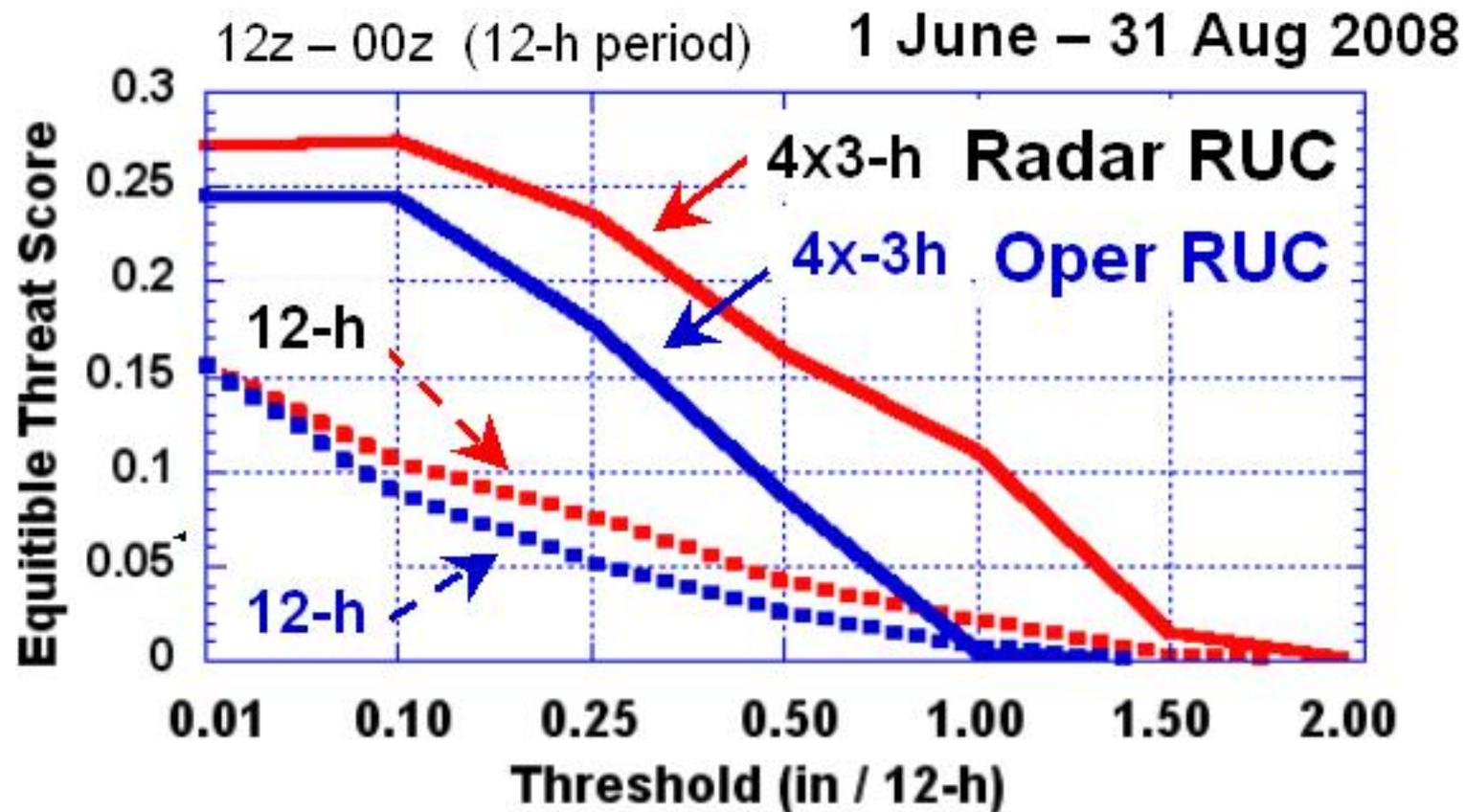
**3-h acc.
precip.**
Valid 15z
31 July 2008

**RUC radar
Assimilation
→ Better RUC
forecasts**



Radar assimilation impact on RUC precipitation skill scores

- Four 0-3h forecasts vs. one 0-12h forecast
- Summer - Daytime



Nov 2008 Changes for oper RUC upgrade

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NCEP

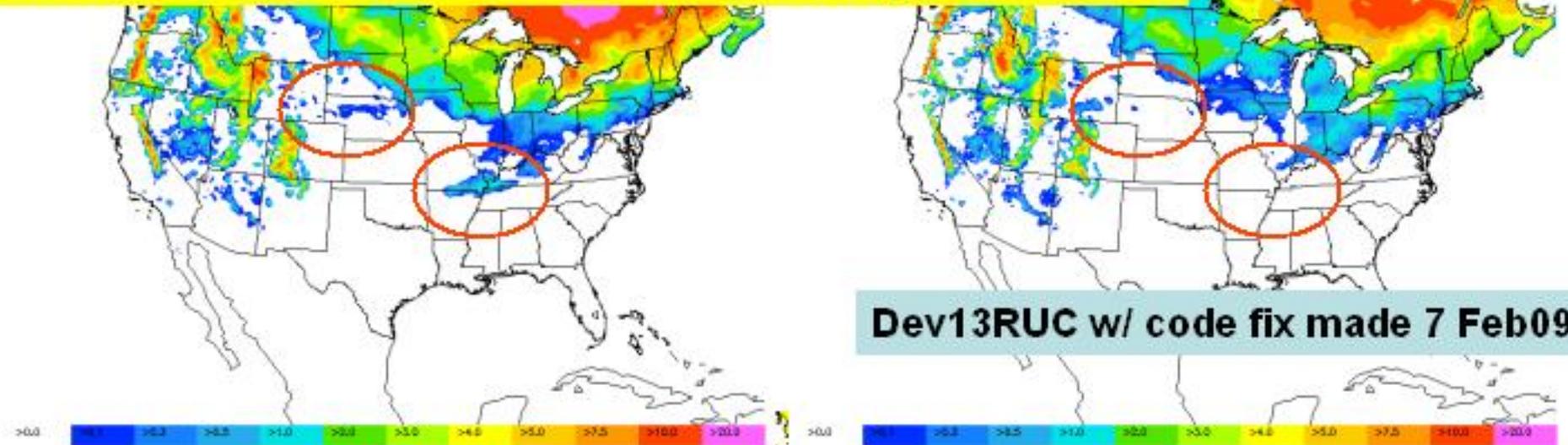
Operational
RUC13

NOAA GSD

Development
RUC13

NOAA

RUC/RR advantage - snow cycling in land-sfc model (LSM)
Problem - occasional excessive snow coverage



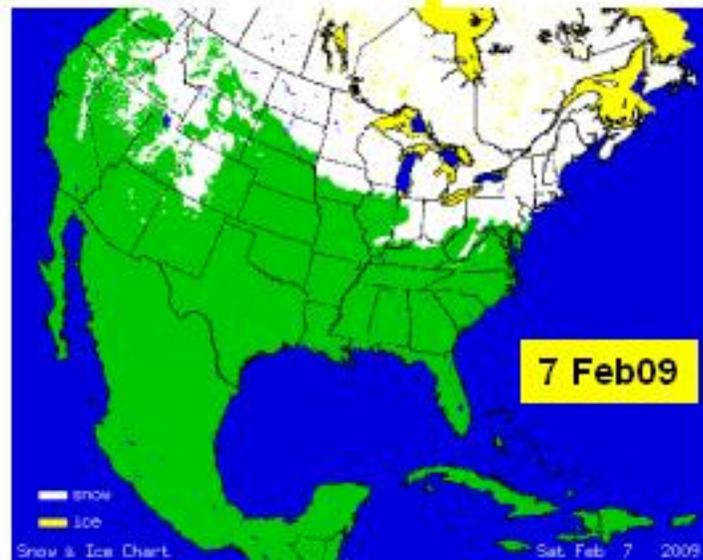
Dev13RUC w/ code fix made 7 Feb09

Snow Water Depth (inches)
3-hr fcst valid 08-Feb-09 22:00Z

Snow Water Depth (inches)
3-hr fcst valid 08-Feb-09 22:00Z

NESDIS snow cover

http://www.natice.noaa.gov/pub/ims_gif/DATA/cursnow_usa.gif



NCEP

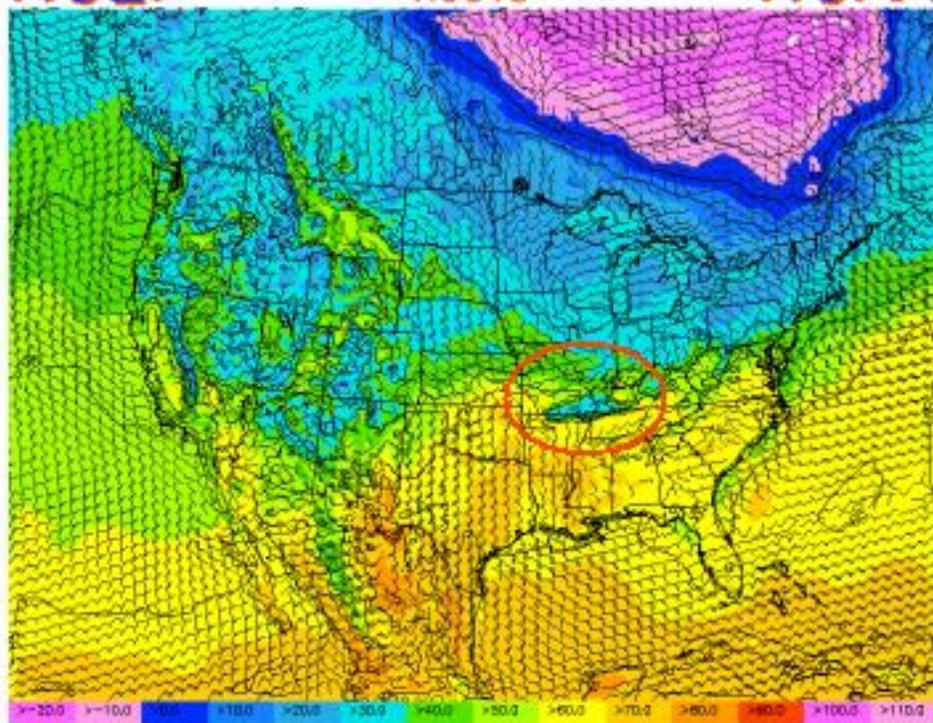
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GSD

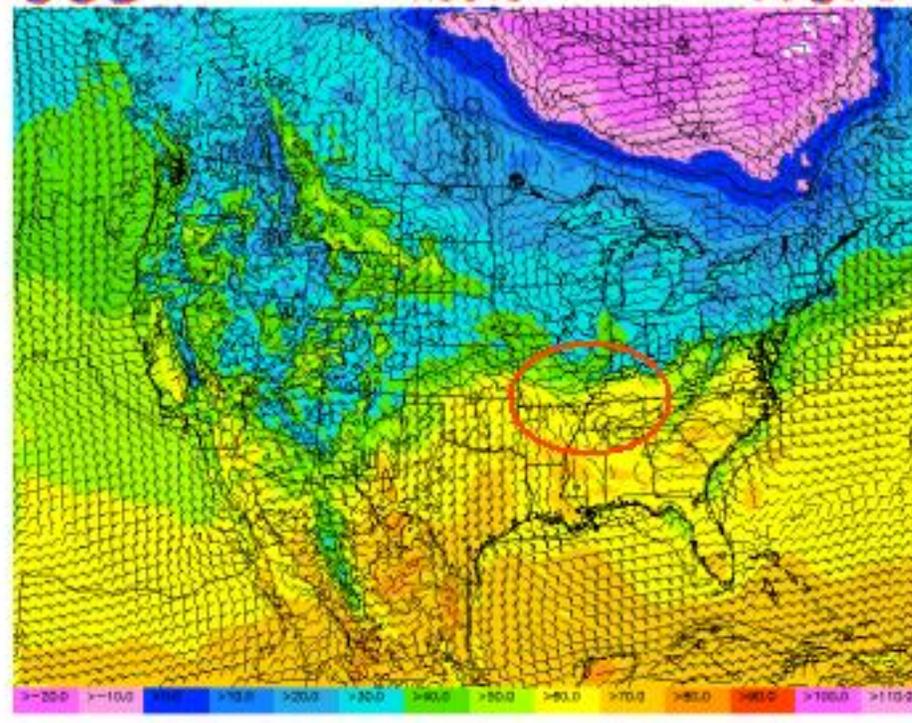
Development
RUC13

NOAA



Surface Temperature / Winds ($^{\circ}\text{F}$ / Knots)

3-hr fcst valid 08-Feb-09 22:00Z

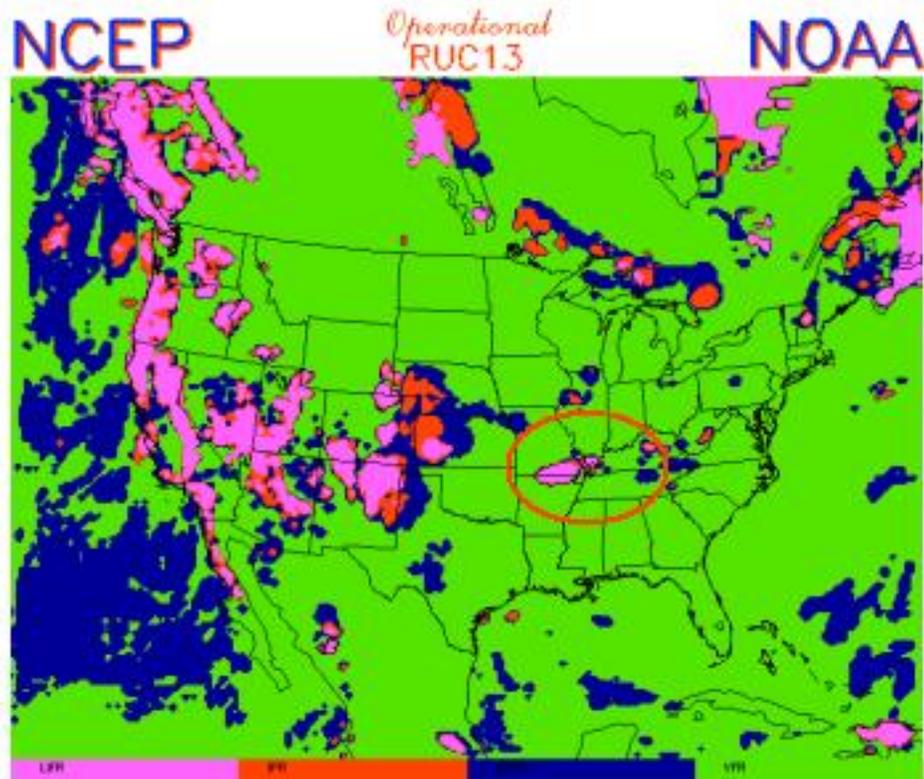


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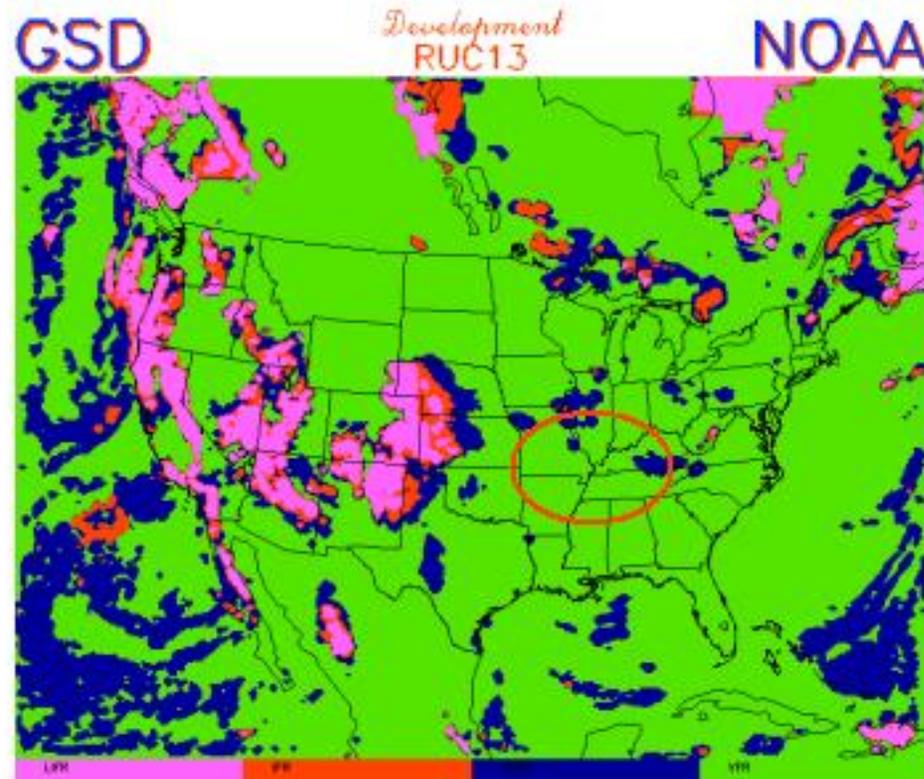
3-hr fcst valid 08-Feb-09 22:00Z

Errors in 2m temp due to erroneous snow cover in operational RUC

Improved 2m temp in dev13RUC with correction for NESDIS snow cover areal trimming.



Aviation Flight Rules (Experimental – Not for operational use!)
3-hr fcst valid 08-Feb-09 22:00Z



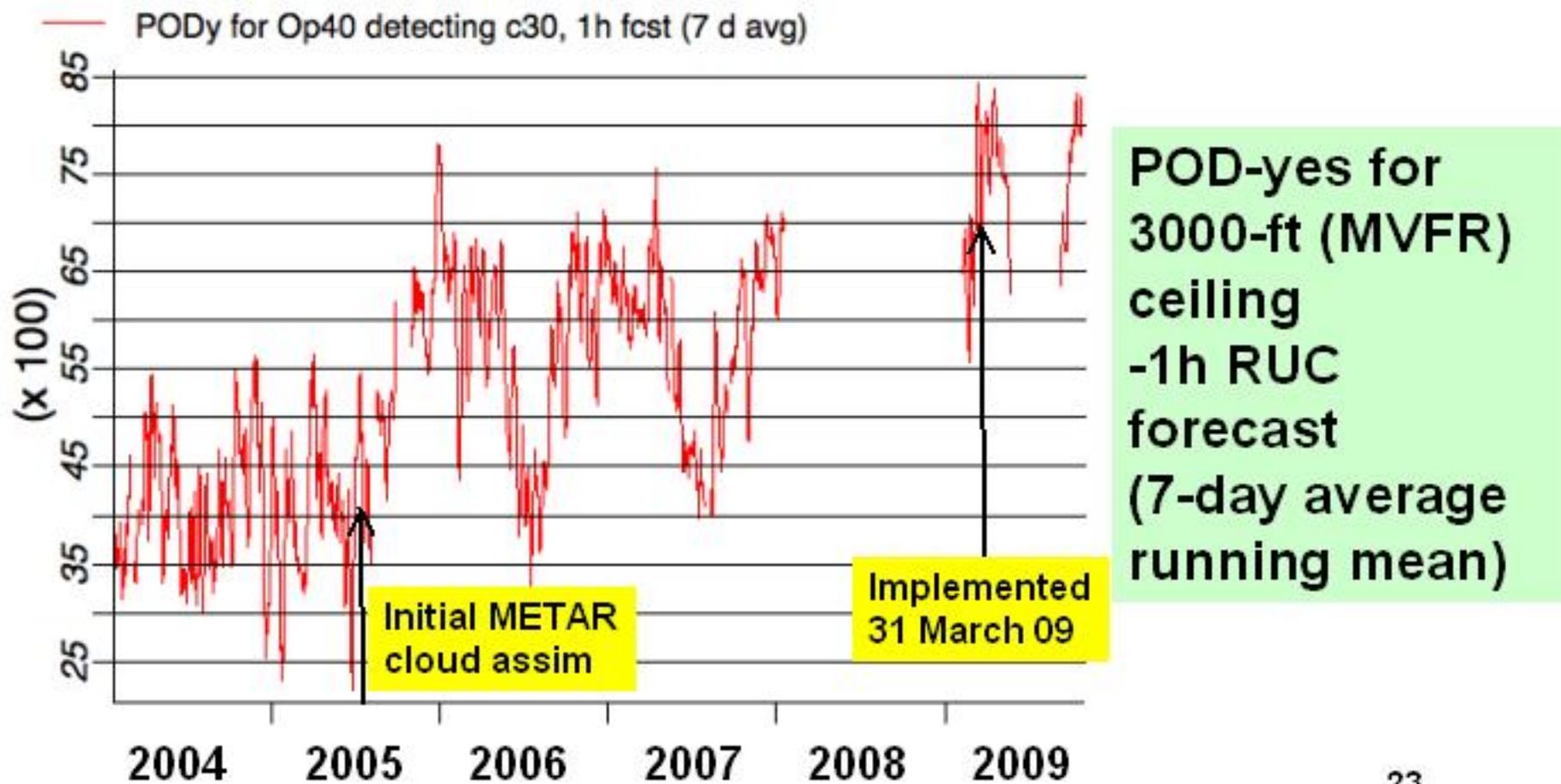
Aviation Flight Rules (Experimental – Not for operational use!)
3-hr fcst valid 08-Feb-09 22:00Z

Another consequence from snow cover error:
Low fog due to erroneous snow cover in operational RUC

Improved cloud cover in dev13RUC with correction for NESDIS snow areal trimming.

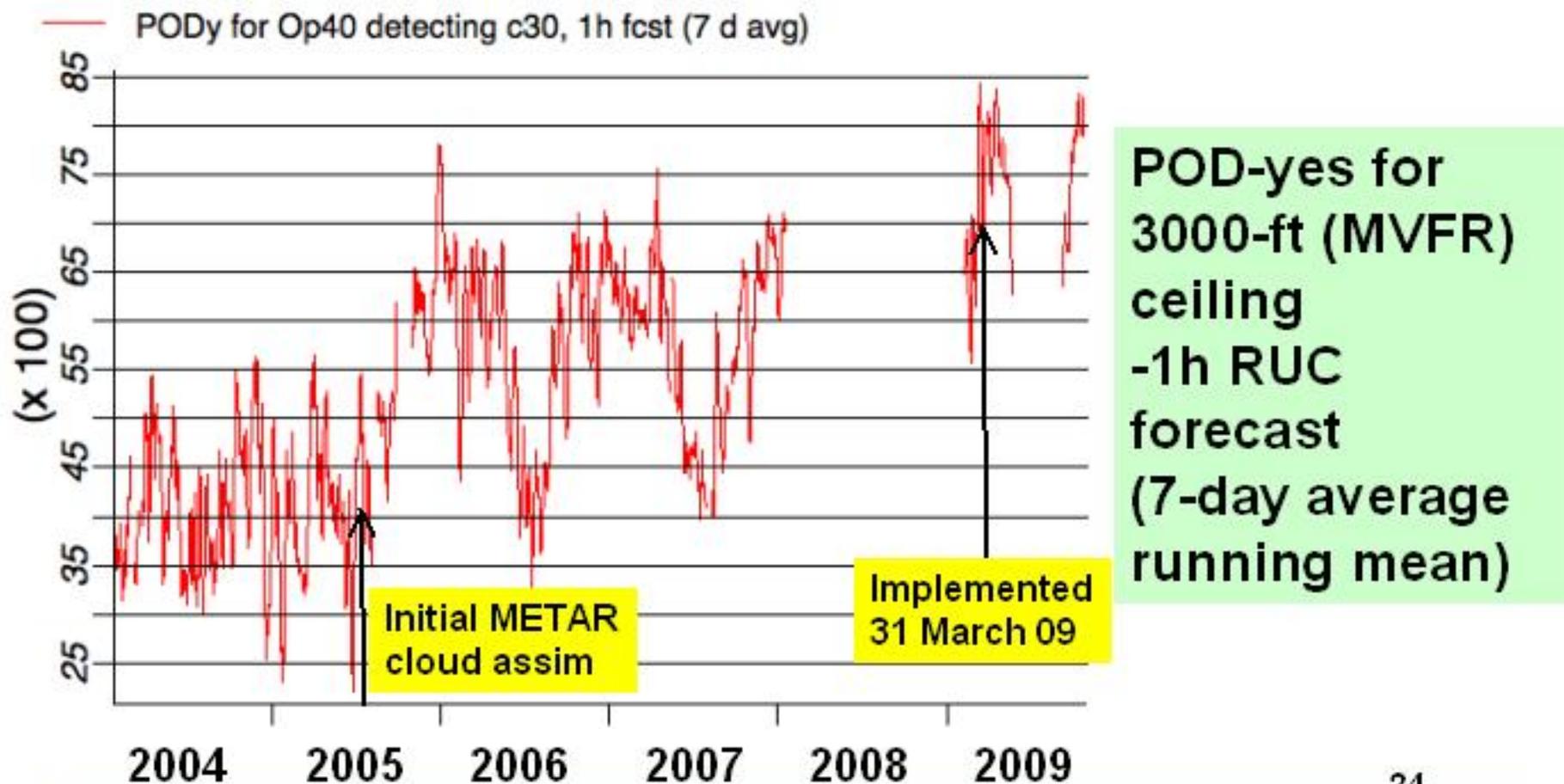
Mar 09 mods to RUC hydrometeor analysis

- ensures saturation for cloudy volumes
- cloud analysis call moved to last step.



Mar 09 mods to RUC hydrometeor analysis

- ensures saturation for cloudy volumes
- cloud analysis call moved to last step.



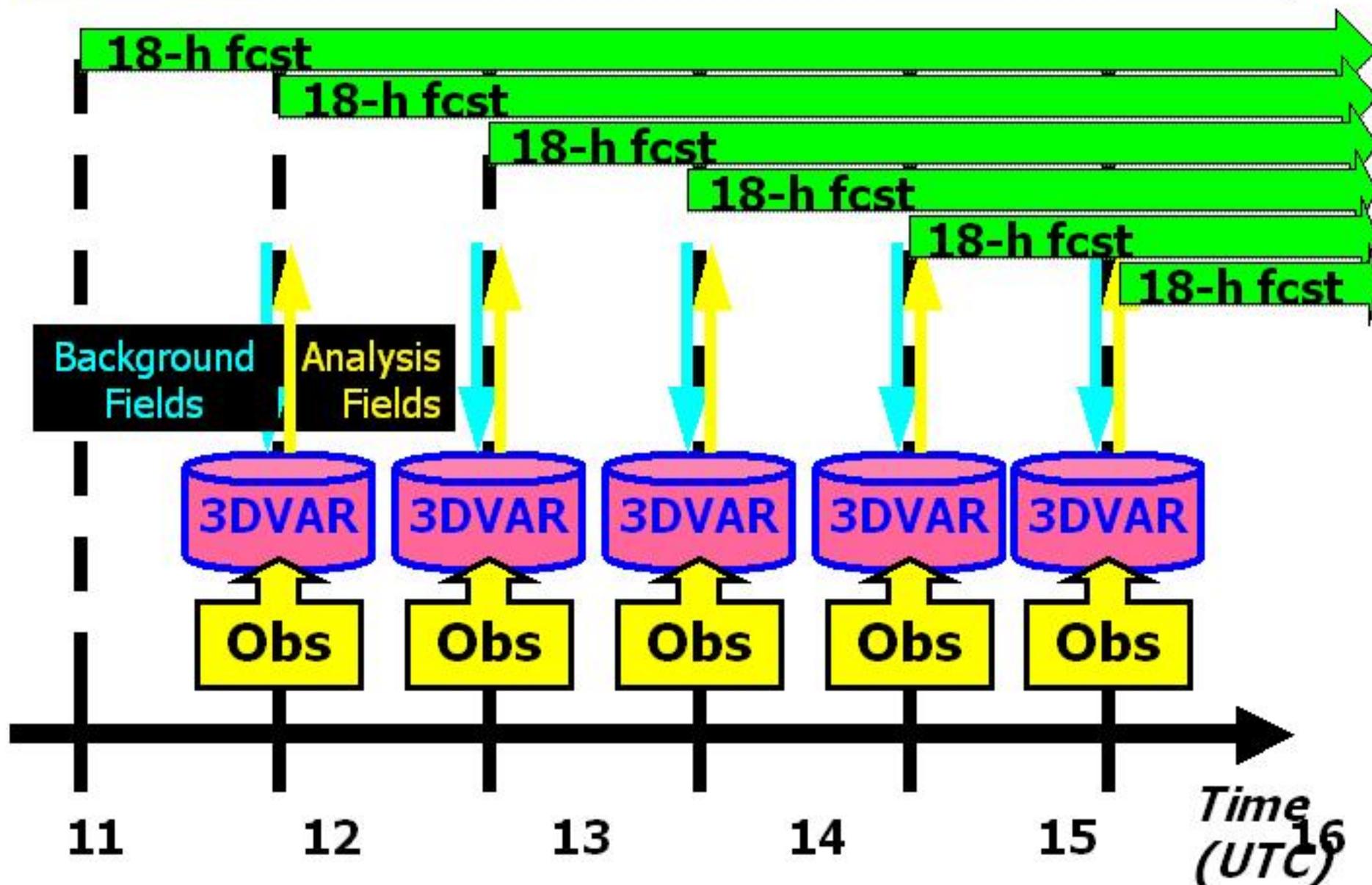
(Common web-based verification (Moninger, Sahn) used for RUC, RR, FIM)

Nov 2009 – further changes for oper RUC – now in testing @ NCEP

- **Extension of RUC to 18h every hour (requested by SPC and AWC)**
- **Further fix to cloud analysis**
 - **problem with saturation for warm clouds**
- **Addition of Canadian aircraft observations**
 - **1000-1200 reports / hour during flight ops hours**
 - **New study by GSD found that this data is now of good quality**
 - **Regional jets only, turboprops (bad headings) removed**

NOTE: All RUC changes have improved 2009 HRRR (via same changes in backup RUC @GSD) and transition to RR is complete or in process

18h RUC Hourly Assimilation Cycle - fall 2009



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- 3:20 – 3:30 Future of RR/HRRR/ens Stan Benjamin

Observation Sensitivity Experiments using the RUC and RR

- These allow us to assess the **impact** and **relative impact** of existing and proposed new operational data sources
- The RUC is an ideal basis for these tasks because
 - It is a state-of-the-art operational model
 - It ingests most currently available data, so new data are tested in a **realistic context**

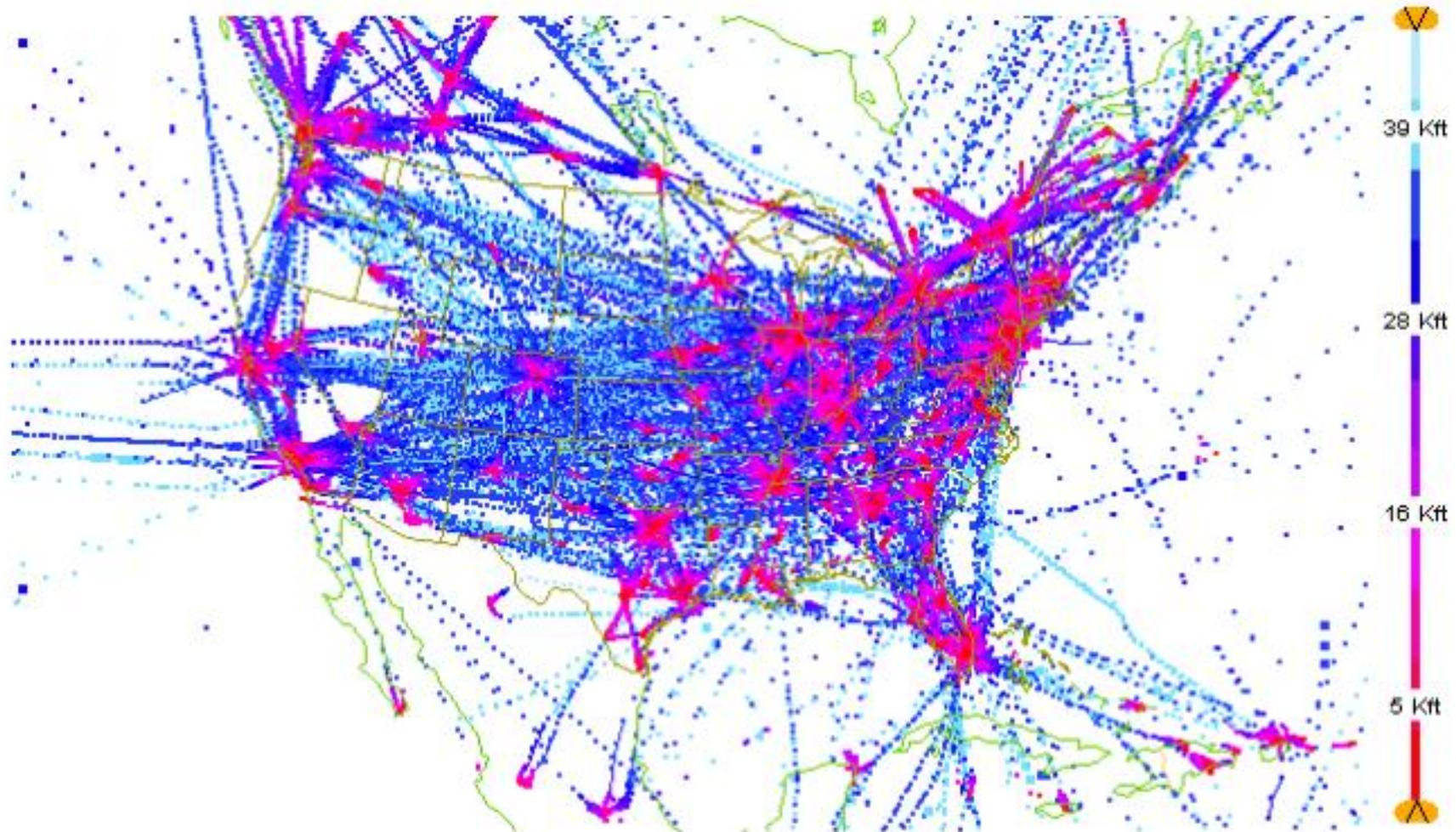
Why perform OSEs?

- The government is being asked to purchase or deploy new data systems.
 - Are they worth the money?
 - Will these systems improve relevant forecasts?
- Examples today:
 - TAMDAR
 - A wide variety of existing systems

TAMDAR

- A system that measures:
 - Wind, Temperature, Relative Humidity
- Installed on scheduled regional commercial aircraft
- Designed to fill a data-void region between major airports
- Developed by AirDat, LLC, initially under NASA sponsorship

Over CONUS, all altitudes, traditional AMDAR jets
More than 125,000 observations in 24 h

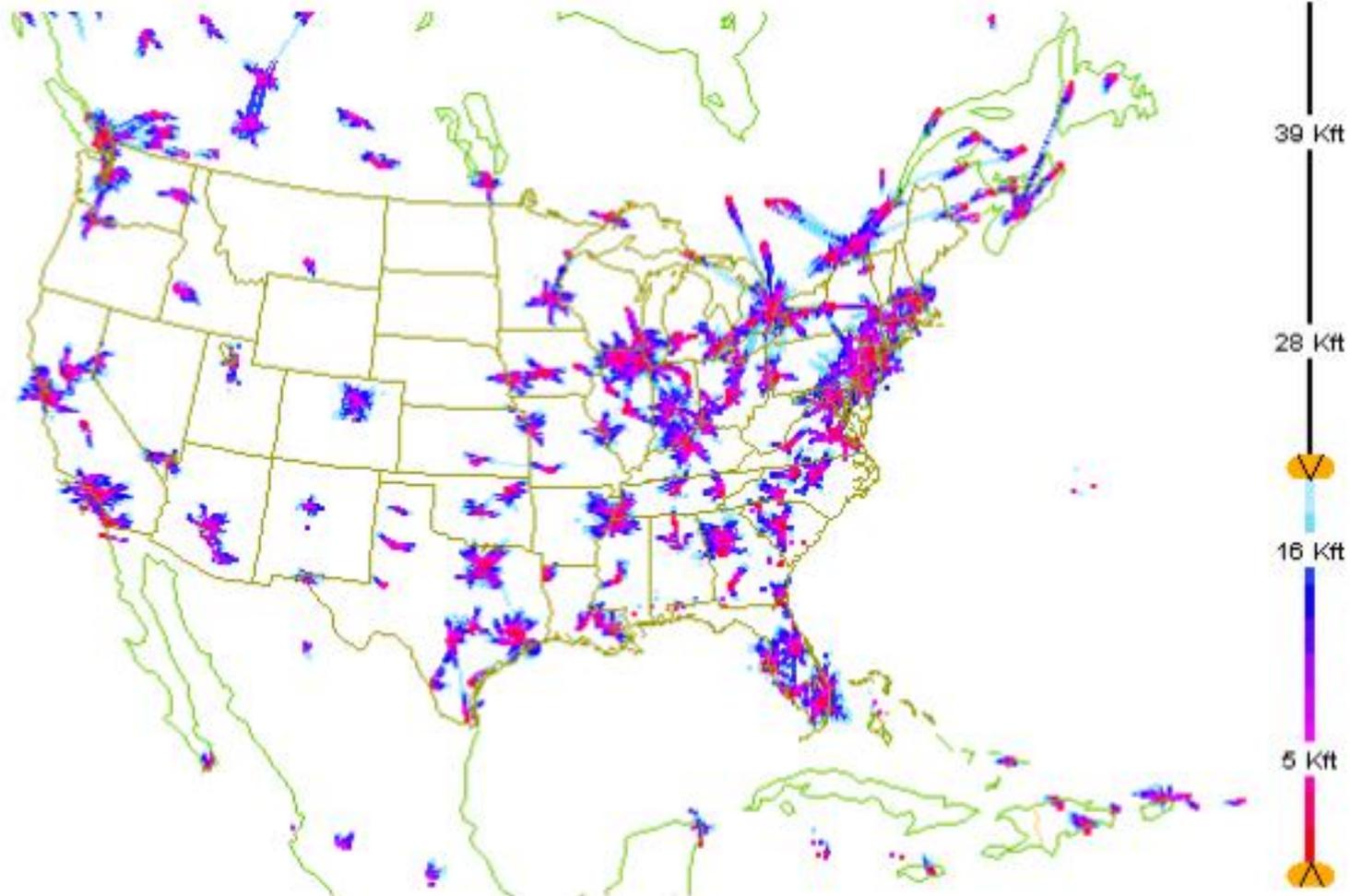


28-May-2008 00:00:00 -- 28-May-2008 23:59:59 (292156 obs loaded, 155719 in range, 33738 shown)

NOAA / ESRL / GSD Altitude: -1000 ft. to 45000 ft.

Good w and T not-TAMDAR

Coverage is limited to major hubs below 20 Kft,
(without TAMDAR)



28-May-2008 00:00:00 -- 28-May-2008 23:59:59 (292156 obs loaded, 98308 in range, 8898 shown)

NOAA / ESRL / GSD Altitude: -1000 ft. to 20000 ft.

Good w and T not-TAMDAR

TAMDAR, Circa 2006-2007

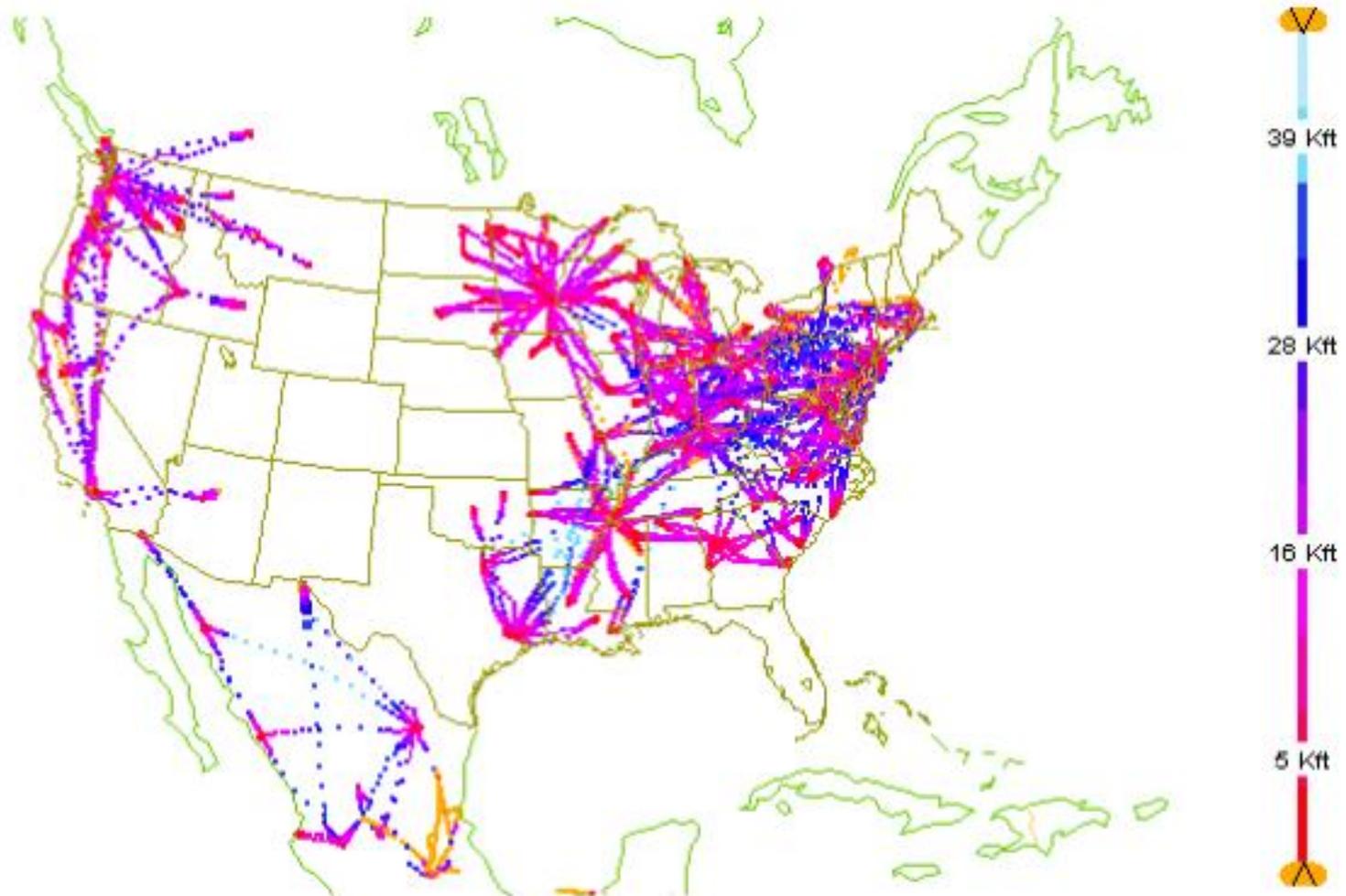


03-Jan-2007 00:00:00 -- 03-Jan-2007 23:59:59 (265043 obs loaded, 19680 in range, 2833 shown)

NOAA / ESRL / GSD Altitude: -1000 ft. to 45000 ft.

all TAMDAR

TAMDAR, current time (also in Alaska)



28-Oct-2009 00:00:00 -- 28-Oct-2009 23:59:59 (283689 obs loaded, 32235 in range, 7021 shown)

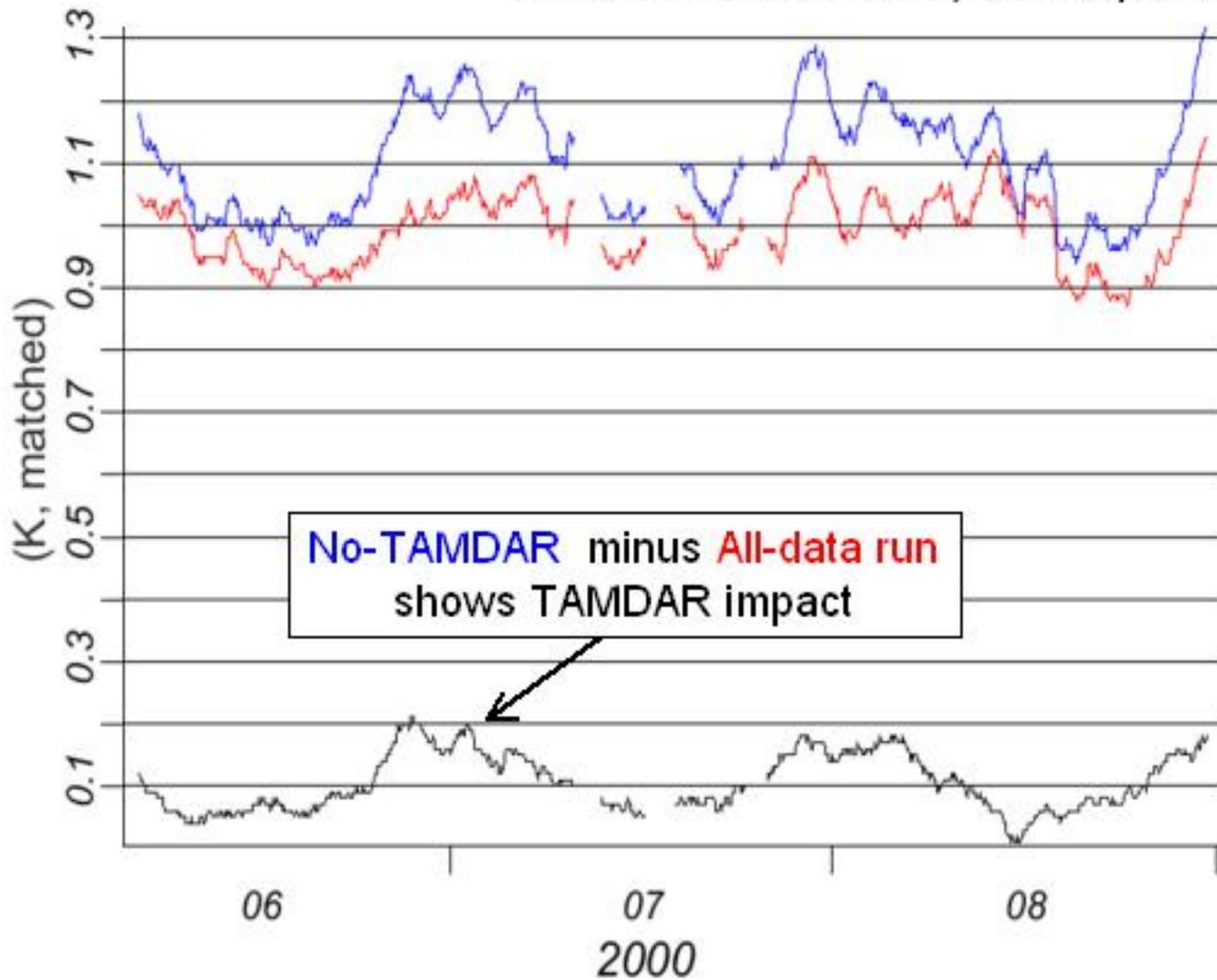
NOAA / ESRL / GSD Altitude: -1000 ft. to 45000 ft.

all TAMDAR

Parallel *real-time* RUC cycles

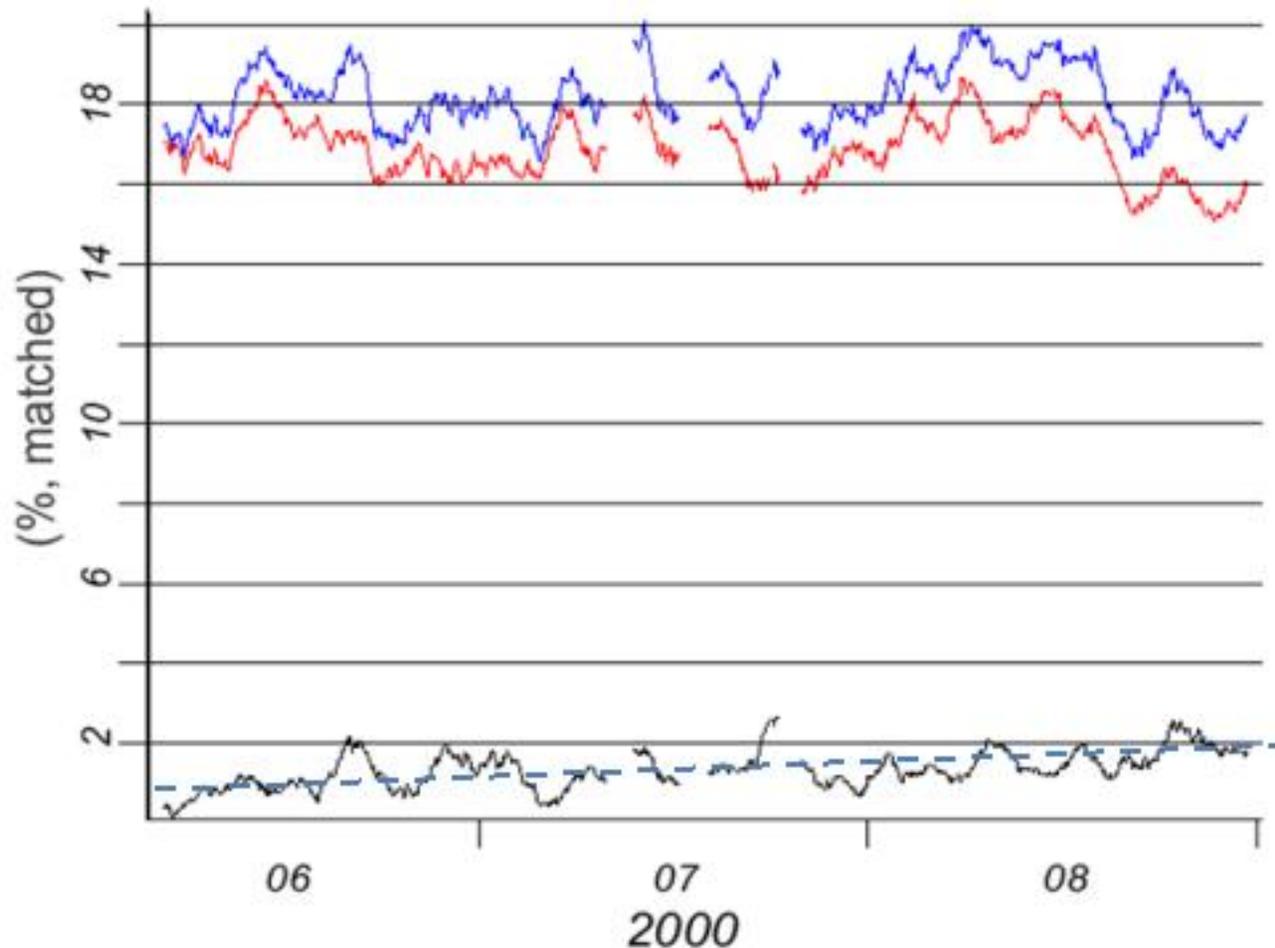
- One **with** TAMDAR data, one **without**
- Both run at 20-km, but are otherwise use same code as the (then) operational 13-km runs
- A **3-year long** parallel experiment at 20km
- (Continued to the present with 13-km TAMDAR and no-TAMDAR runs)

3-h Temperature forecast errors at 00 UTC, Great Lakes Region surface to 500 hPa, 30 day averages



TAMDAR impact on **short-term T forecasts** is **strong and consistent over time** (greatest when model errors are largest)

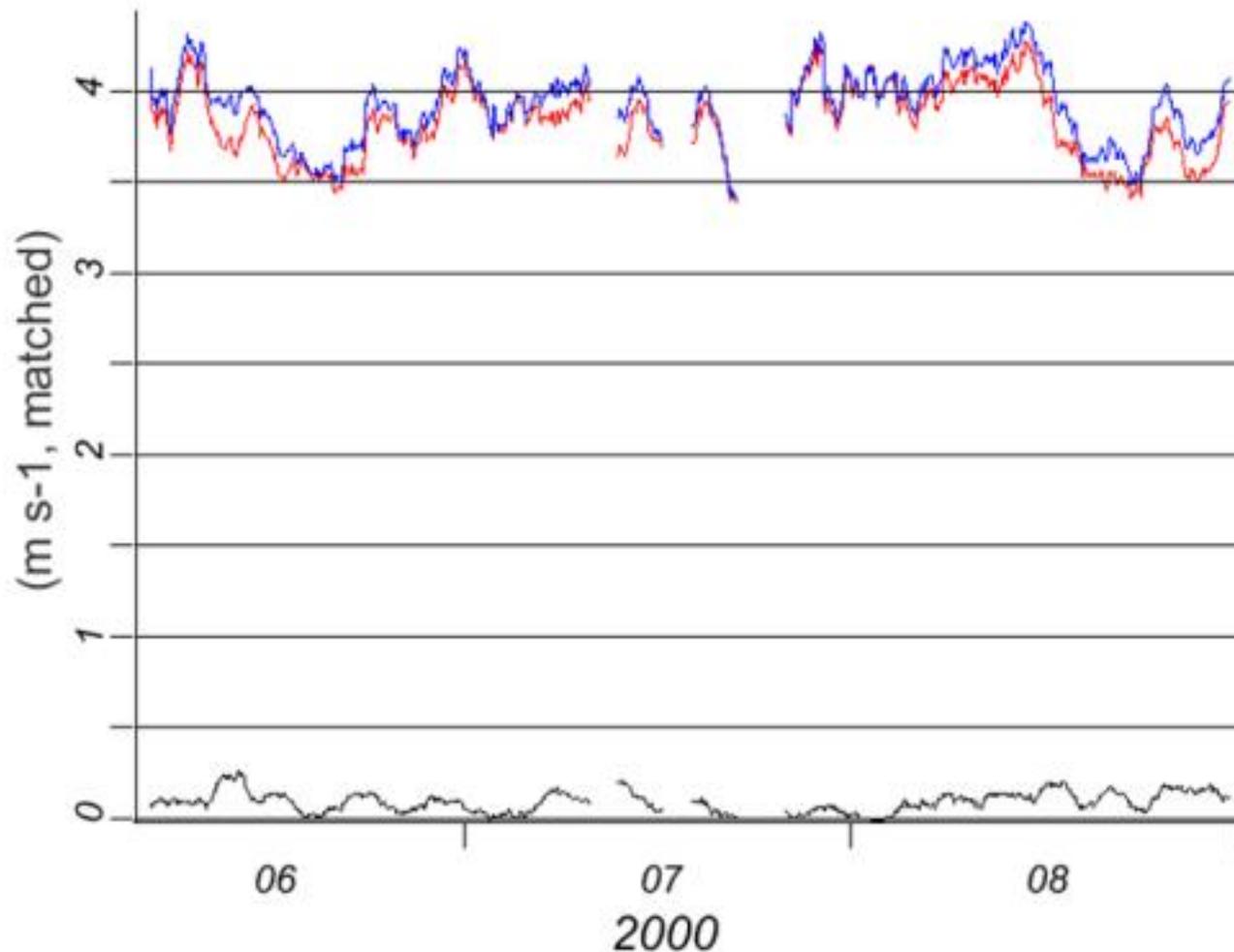
3-h Relative Humidity forecast errors at 00 UTC,
Great Lakes Region
surface to 500 hPa, 30 day averages



TAMDAR impact on
short-term RH fcsts
is **strong and**
consistent over time

The effect of
additional fleets
is evident in the
gradual
increase in RH
impact

3-h Wind forecast errors at 00 UTC, Great Lakes Region surface to 500 hPa, 30 day averages



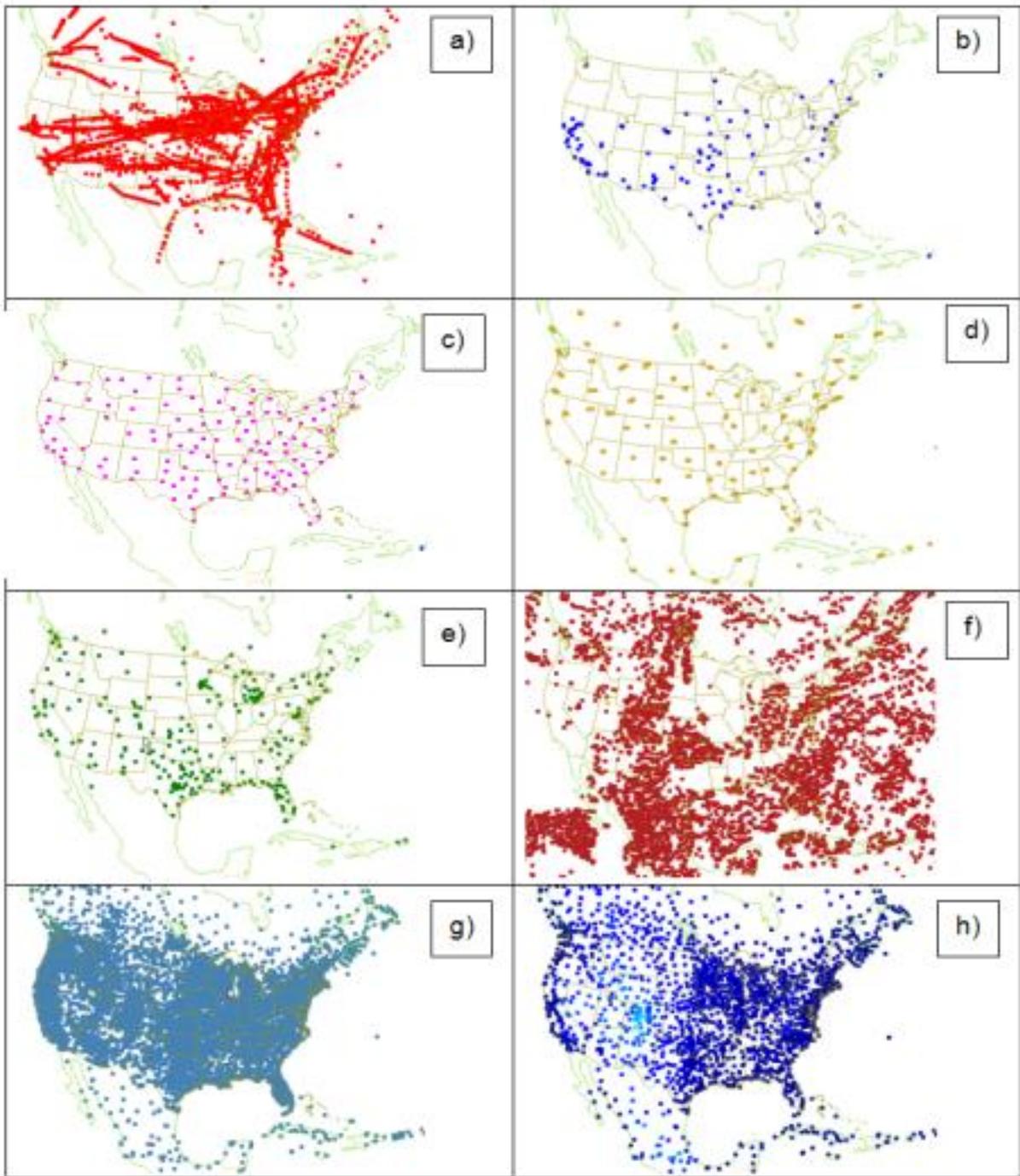
TAMDAR impact on
**short-term wind
fcsts** is **limited, but
positive**

We discovered that
turboprop fleets
provide **poor
heading
information.**

But the newer
TAMDAR-equipped
regional jet fleets
starting in 2008
improve wind
impact.

Retrospective OSEs

- For a wider range of data-suite comparisons, we use *retrospective periods* over which we can run multiple OSEs
- We focus on two 10-day periods
 - Fall 2006
 - August 2007
- We have run **51 cases** over these two periods
- Each takes about 5 days of supercomputer time

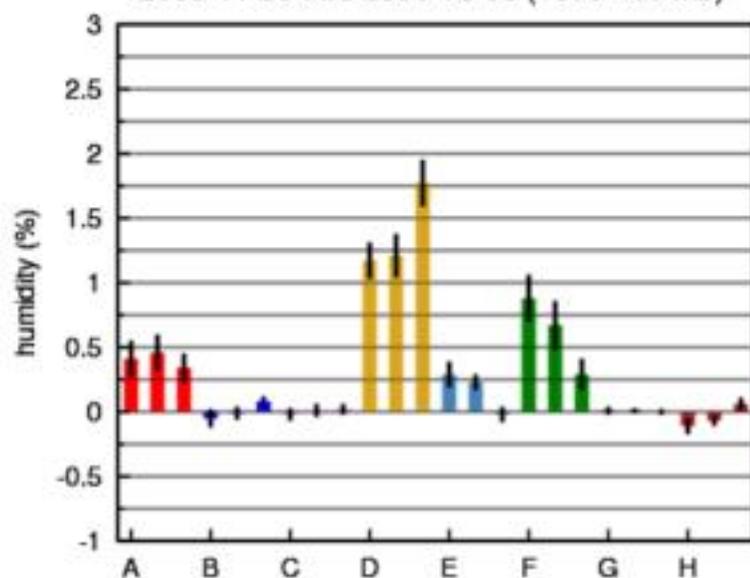


Data we denied:

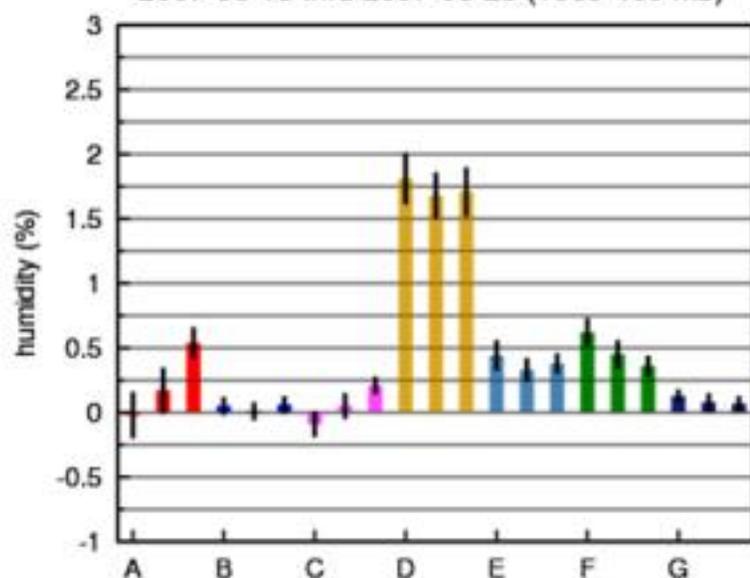
- a) aircraft / AMDAR
- b) Profilers (NPN plus CAP)
- c) VAD, from NEXRAD radars
- d) RAOBs
- e) GPS precipitable water
- f) AMV (atmos motion vectors = sat. cloud-drift winds)
- g) All surface (METARs plus mesonet)
- h) METAR, color coded by altitude.

Each denial run was compared with a control run.
Forecast errors between runs were compared.

Natl region, humidity averaged rms - matched
2006-11-26 thru 2006-12-06 (1000-400 mb)



Natl region, humidity averaged rms - matched
2007-08-15 thru 2007-08-25 (1000-400 mb)



RH forecasts

Bar height indicates impact

- Sfc - 400 hPa
- National region

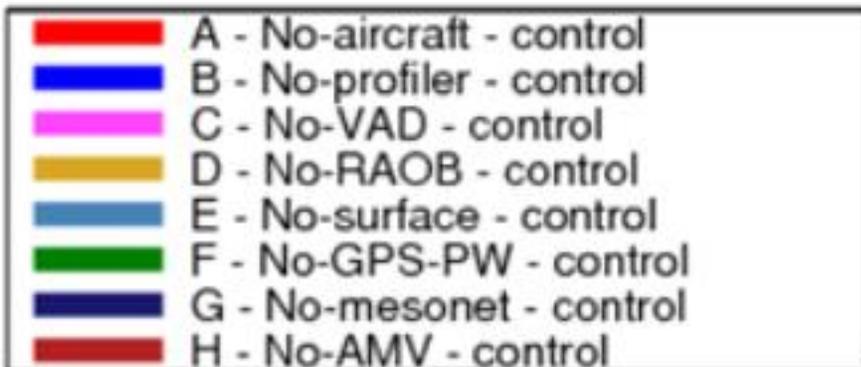
Groups: 3-h, 6-h, 12-h forecast for each data type

Top: Winter

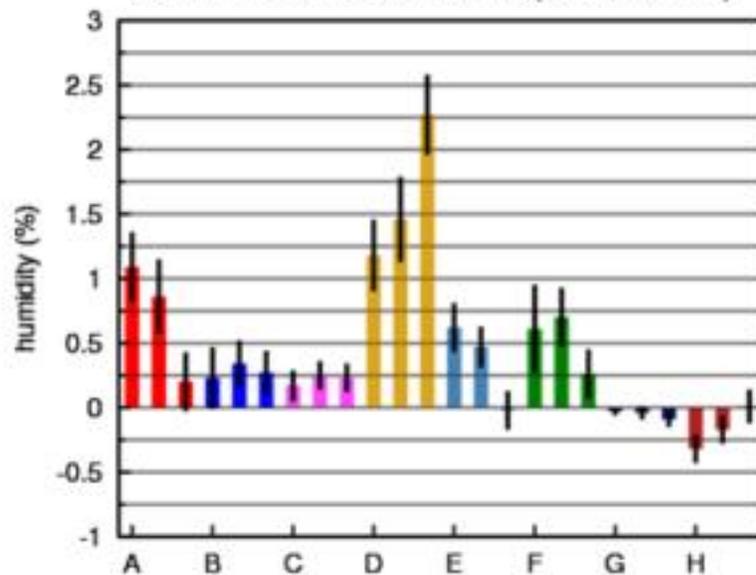
Bottom: Summer

Black bar: 1 std. error

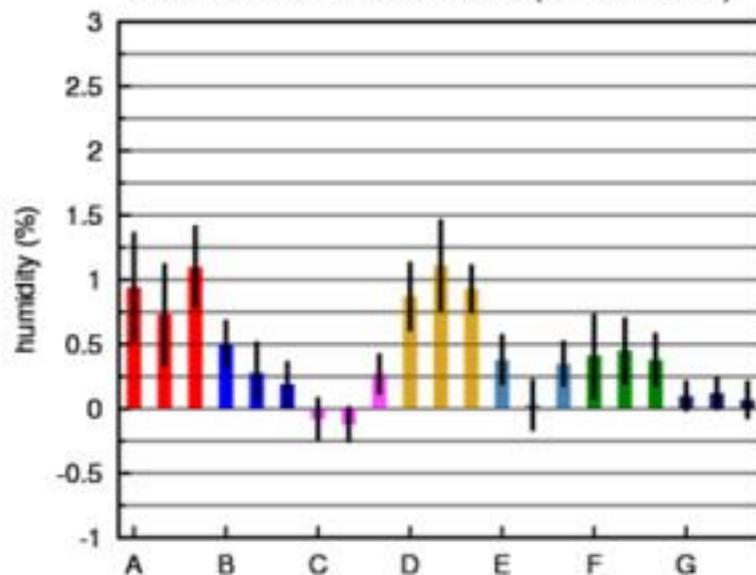
- **RAOBs have most impact**
- **Then GPS-PW**
- **Then Aircraft/Surface**



GtLk region, humidity averaged rms - matched
2006-11-26 thru 2006-12-06 (1000-400 mb)



GtLk region, humidity averaged rms - matched
2007-08-15 thru 2007-08-25 (1000-400 mb)



RH forecasts

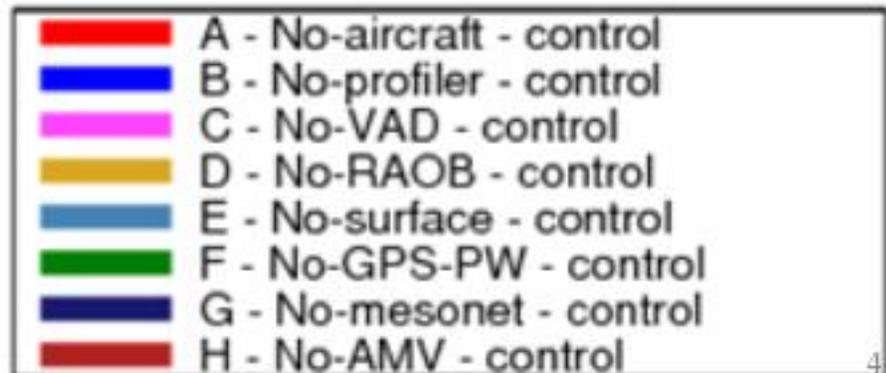
Now, for the data-rich Great Lakes region.

(Otherwise, as in previous slide)

- **RAOBS have most impact**
- **Then aircraft**

Increased aircraft impact reflects TAMDAR in the Midwest

- High data density
- RH measurements



Conclusions (1)

- **Each** of the heterogeneous data sources add value to RUC forecasts (under varying conditions)
- **TAMDAR** makes a positive and increasing contribution
- RUC/RR provide excellent platforms for performing Observation Sensitivity Experiments
 - (we have used the RR to evaluate the TAMDAR fleet flying in Alaska)

Conclusions (2)

- These RUC-based obs impact studies have led to **operational changes**
 - Three TAMDAR fleets are now **operational at NCEP, assimilated into RUC and NAM.**
 - New assimilation schemes are being implemented in the **operational RUC**
 - (The NWS has issued a procurement for a **National Profiler Network**, based in part on GSD's earlier studies of profiler impact.)
- This work has also resulted in a ***development verification infrastructure*** that has been critical for refining the RUC, RR, and FIM.

Rapid Refresh / RUC Technical Review - OUTLINE

- 1:30 – 1:45 RUC → RR transition overview,
NCEP RUC changes – 2008-09- Stan Benjamin
- 1:45 – 2:00 Observation impact experiments
- TAMDAR aircraft obs w/ moisture, larger OSE
Bill Moninger
- 2:00 – 2:20 Rapid Refresh overview, assimilation –
Steve Weygandt, Ming Hu
- 2:20 – 2:30 -- Break --
- 2:30 – 3:05 RR-WRF model development / testing
– physics, cloud, chemistry, PBL
John Brown, Tanya Smirnova, Joe Olson
- 3:05 – 3:20 The HRRR and HCPF (HRRR prob forecast)
Curtis Alexander
- 3:20 – 3:30 Future of RR/HRRR/ens Stan Benjamin

Background on Rapid Refresh, why replace the RUC?

- **More advanced model and analysis systems**
 - WRF-ARW: advanced numerics, non-hydrostatic
 - GSI: advanced satellite assim, 4DVAR development
 - Both community-based, ongoing code contributions
- **Domain expansion for consistent guidance**
 - Hourly-updating for Alaska, Caribbean users
 - Consistent input for aviation hazard guidance products over all of North America
 - Uniform, hourly-updated guidance for RTMA

RUC to Rapid Refresh

- **CONUS domain (13km)** → • **North American domain (13km)**
- **RUC 3DVAR** → • **GSI (Gridpoint Statistical Interpolation)**
(incl. RR enhancements)
- **RUC model + postprocessing** → • **WRF-ARW model (RR version) + WRFpost (with enhancements)**

RUC to Rapid Refresh

• CONUS domain
(13km)



• North American
domain (13km)

• RUC 3DVAR



• GSI (Gridpoint
Statistical
Interpolation)
(incl. RR enhancements)

• RUC model +
postprocessing



• WRF-ARW model
(RR version) +
WRFpost (with
enhancements)

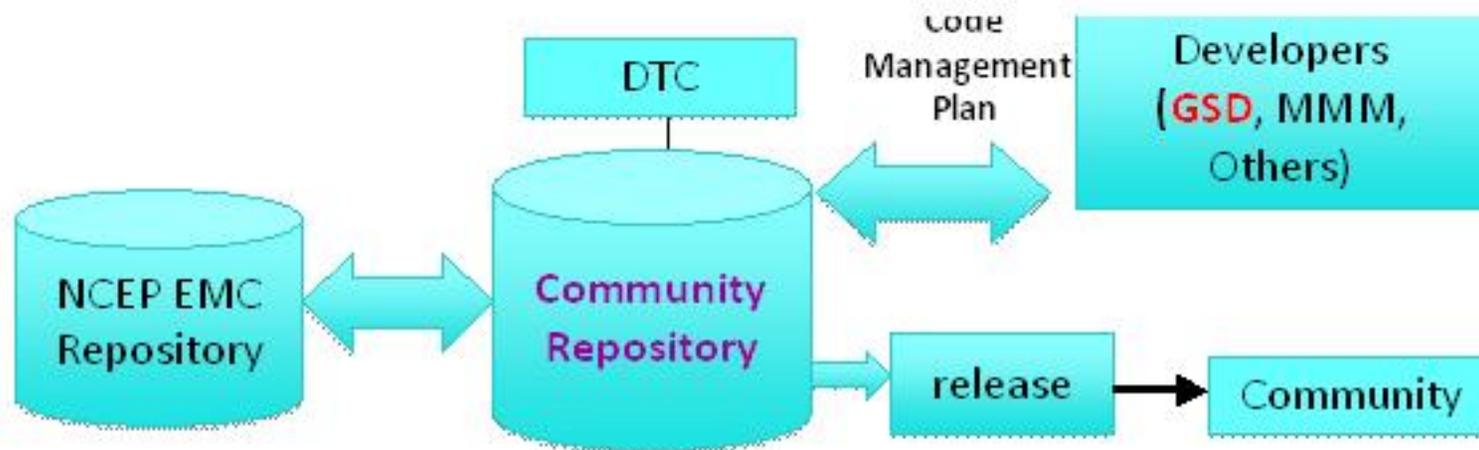
Background on GSI, why use it for Rapid Refresh?

- **NCEP, NASA GMAO supported “full” system**
 - Developed from global Spectral Statistical Interpolation
 - **Advanced satellite radiance assimilation with JCSDA**
 - NASA GMAO work to create GSI-based 4DVAR
- **Evolution toward community analysis system**
 - GSI used by NCEP for GFS and NAM
 - **Selection of GSI as analysis for RR (2005)**
 - Use of GSI obs processing for ESRL EnKF work
 - Transition to GSI by Air Force Weather Agency
 - **DTC work to make GSI available to research community**
 - **Evolution to community-wide SVN code management**

Community GSI Code Repository

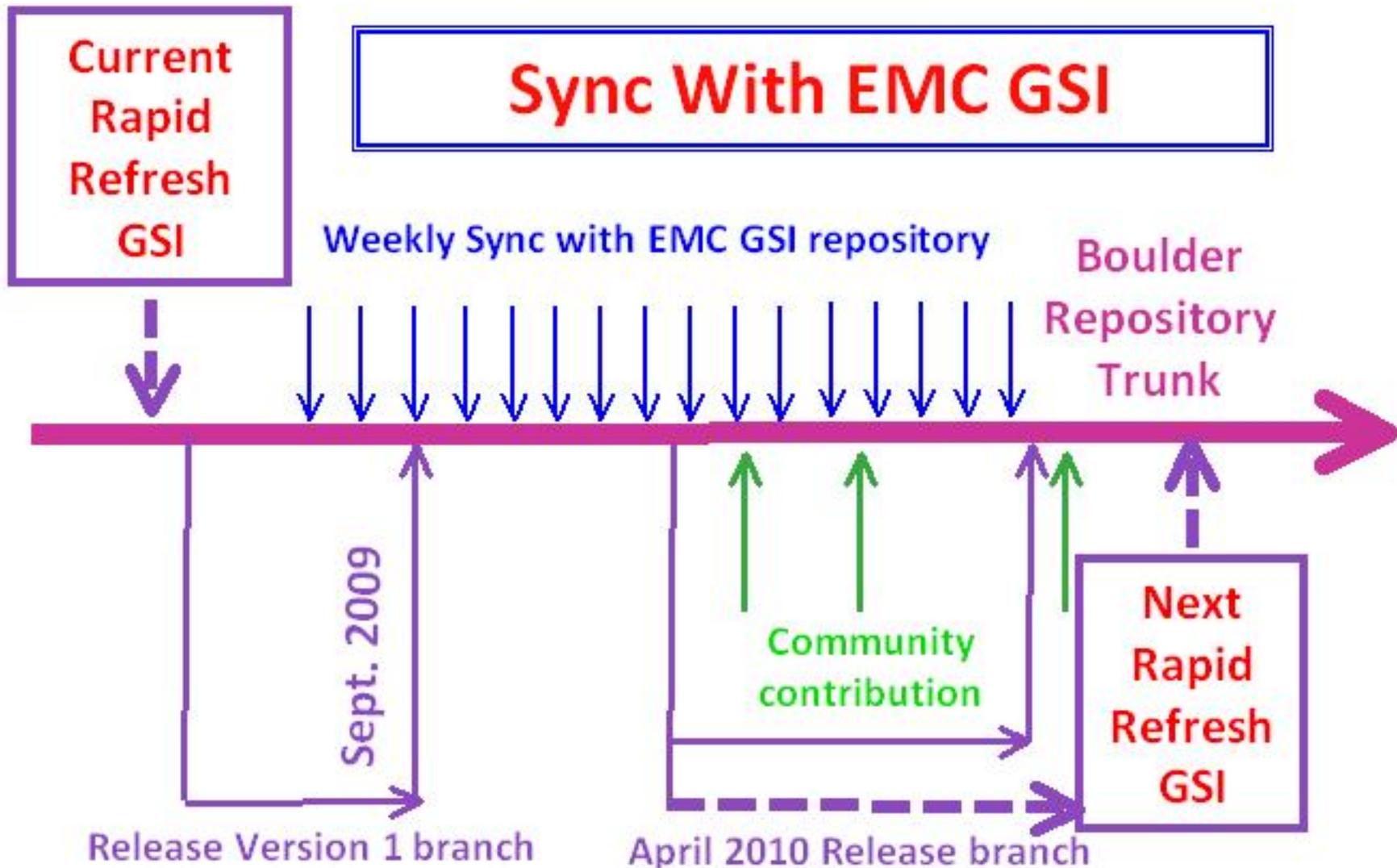
Boulder Community GSI Code Management Plan

Draft 09/02/2009



GSD - build and maintain server

<https://gsi.fsl.noaa.gov/svn/comgsi/trunk>



Significant AMB contribution:
 porting to Linux,
 coupling with ARW

DTC lead: porting & testing
 AMB focus: special RR features
 (cloud analysis, etc.)

ESRL and DTC work with GSI

- **Porting of GSI to from NCEP IBM to ESRL Linux**
 - Many IBM-specific coding features, especially I/O
 - Much work by ESRL IT team to get robust Linux GSI
 - Excellent DTC leadership in code testing, management
- **Coupling of GSI to WRF ARW**
 - Testing and evaluation of many GSI features for ARW
 - Completion of several GSI ARW code stubs
 - Adaptation of GSI and ARW modules to accommodate hourly cycling

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 - Adaptation of GSI and ARW modules to accommodate hourly cycling

Adding Rapid Refresh specific features to GSI

Introducing RR features into GSI

Hourly update cycle

- switch to partial cycling

- Use of observations (NCEP prepBUFR + satellite data)
- Satellite bias corrections (from NCEP)

Cloud analysis

- Uses METAR, satellite, radar data

- Updates cloud, hydrometeor, water vapor fields

- Diagnose latent heating (LH) from 3D radar reflectivity

Radar reflectivity assimilation

- Apply LH in diabatic digital filter initialization

Surface observation assimilation -- ongoing

- Account for model vs. terrain height difference
- Apply surface observation innovations through PBL
- Select best background for coastal observations

Introducing RR features into GSI

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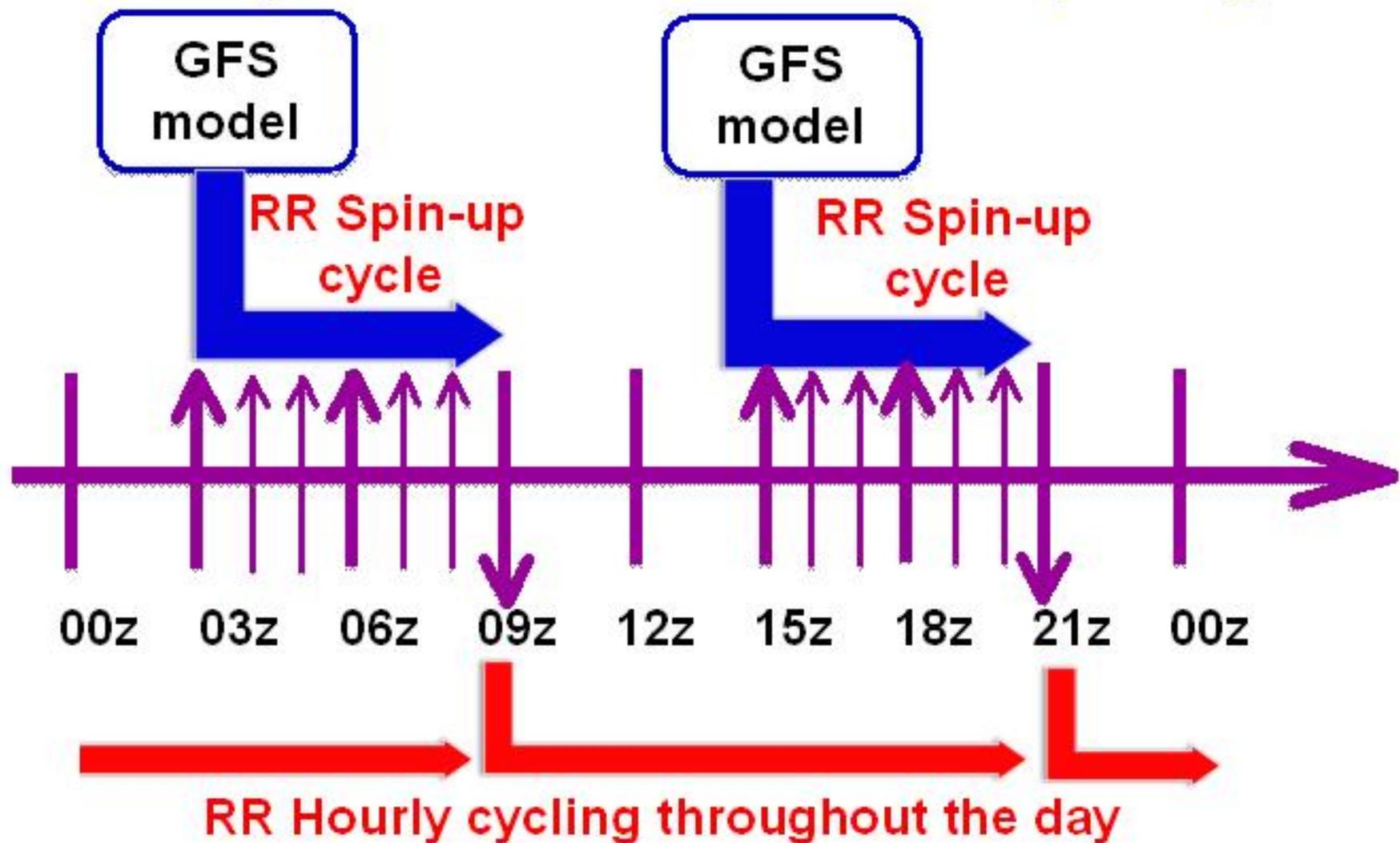
Radar reflectivity assimilation

- Apply LH in diabatic digital filter initialization

Surface observation assimilation -- ongoing

- Account for model vs. terrain height difference
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- Select best background for coastal observations

Rapid Refresh Partial Cycling



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

Introducing RR features into GSI

Hourly update cycle

- **switch to partial cycling**
- Use of observations (NCEP prepBUFR + satellite data)
- Satellite bias corrections (from NCEP)

Cloud analysis

- **Uses METAR, satellite, radar data**
- **Updates cloud, hydrometeor, water vapor fields**
- **Diagnose latent heating (LH) from 3D radar reflectivity**

Radar reflectivity assimilation

- **Apply LH in diabatic digital filter initialization**

Surface observation assimilation -- ongoing

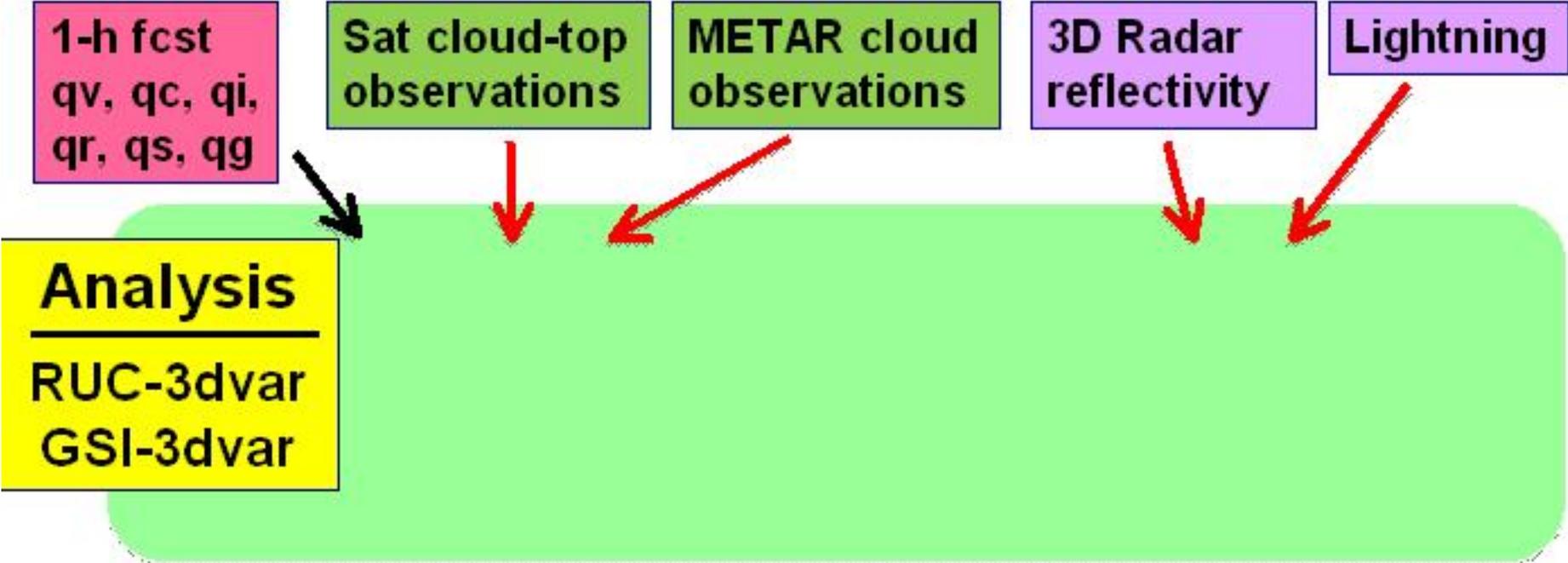
- **Account for model vs. terrain height difference**
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RUC/RR cloud / radar assimilation flowchart

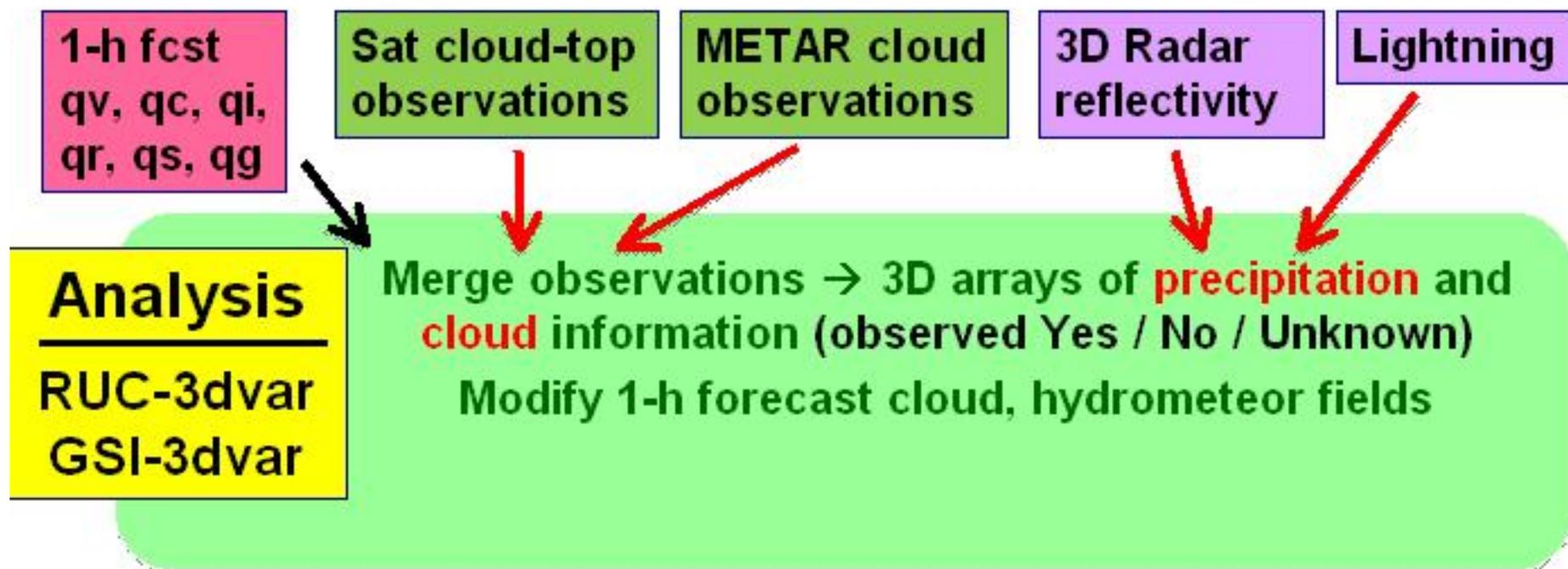
RUC/RR cloud / radar assimilation flowchart



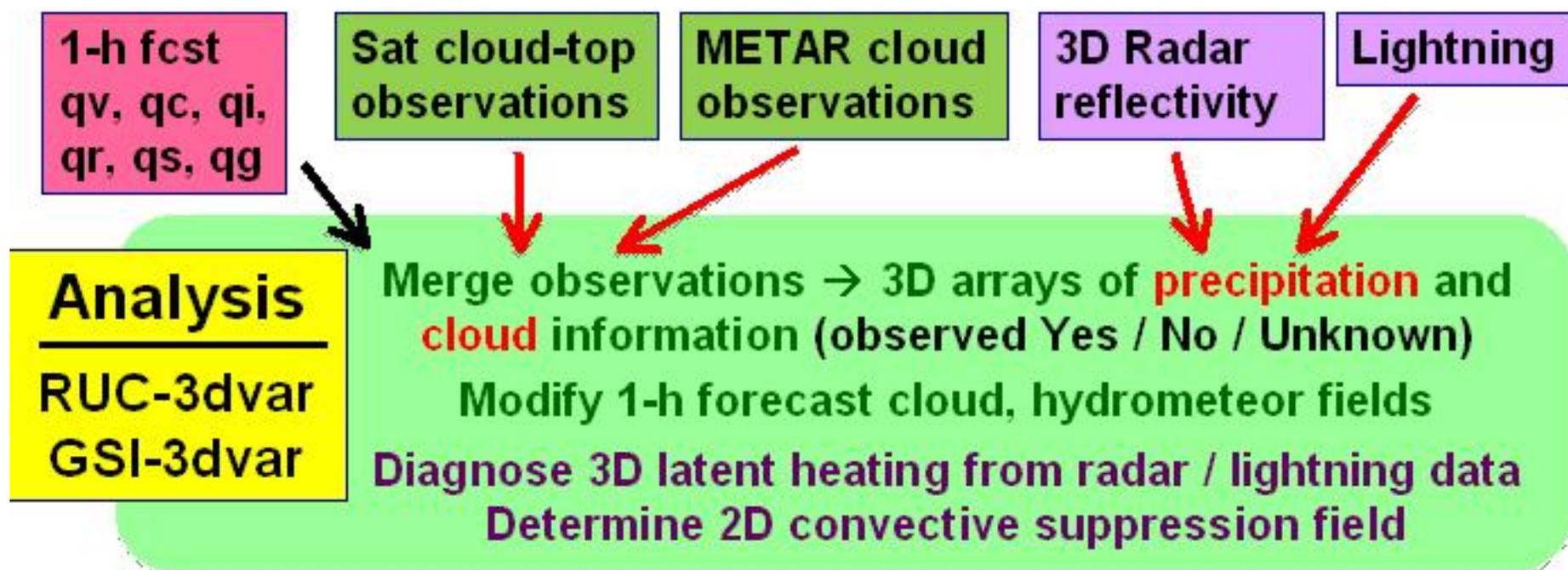
RUC/RR cloud / radar assimilation flowchart



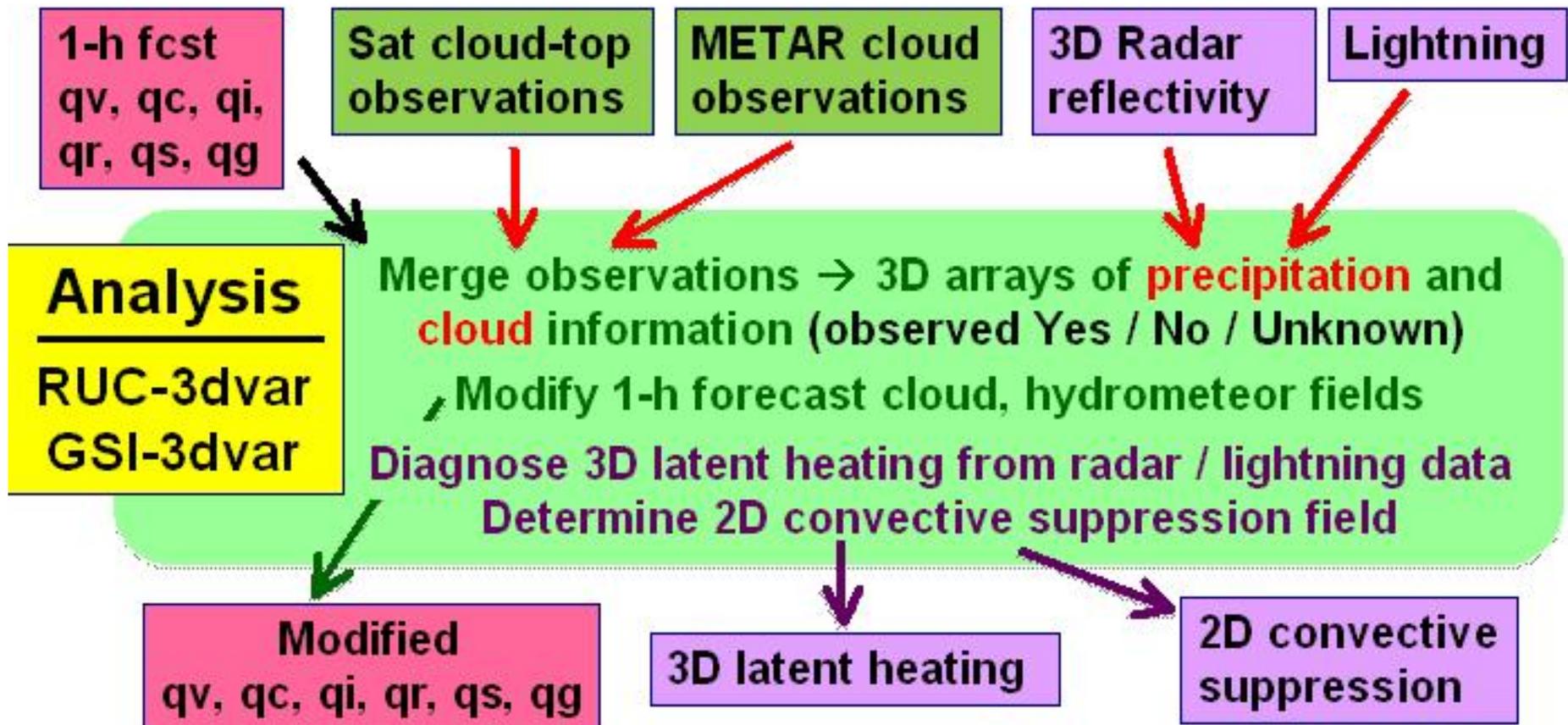
RUC/RR cloud / radar assimilation flowchart



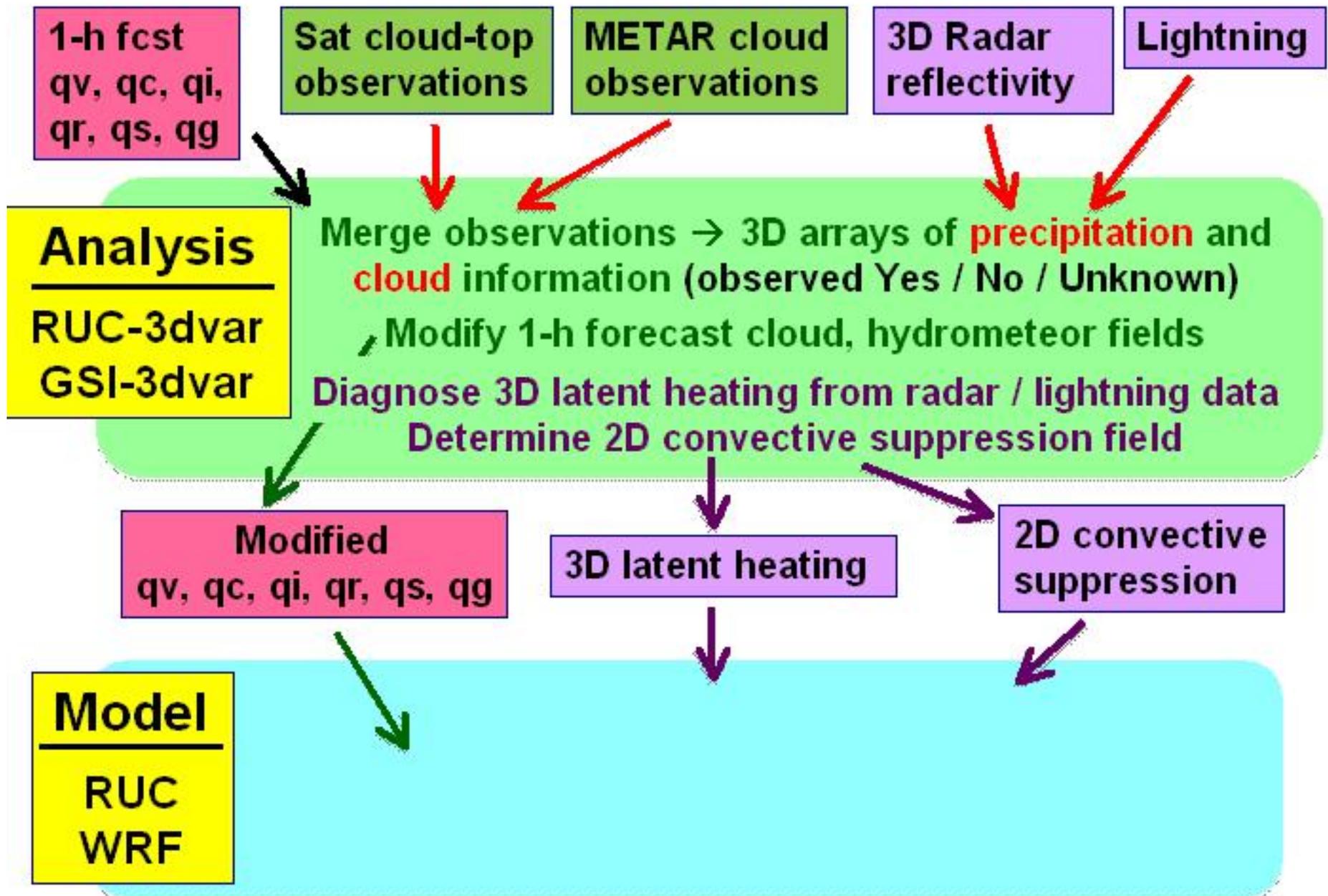
RUC/RR cloud / radar assimilation flowchart



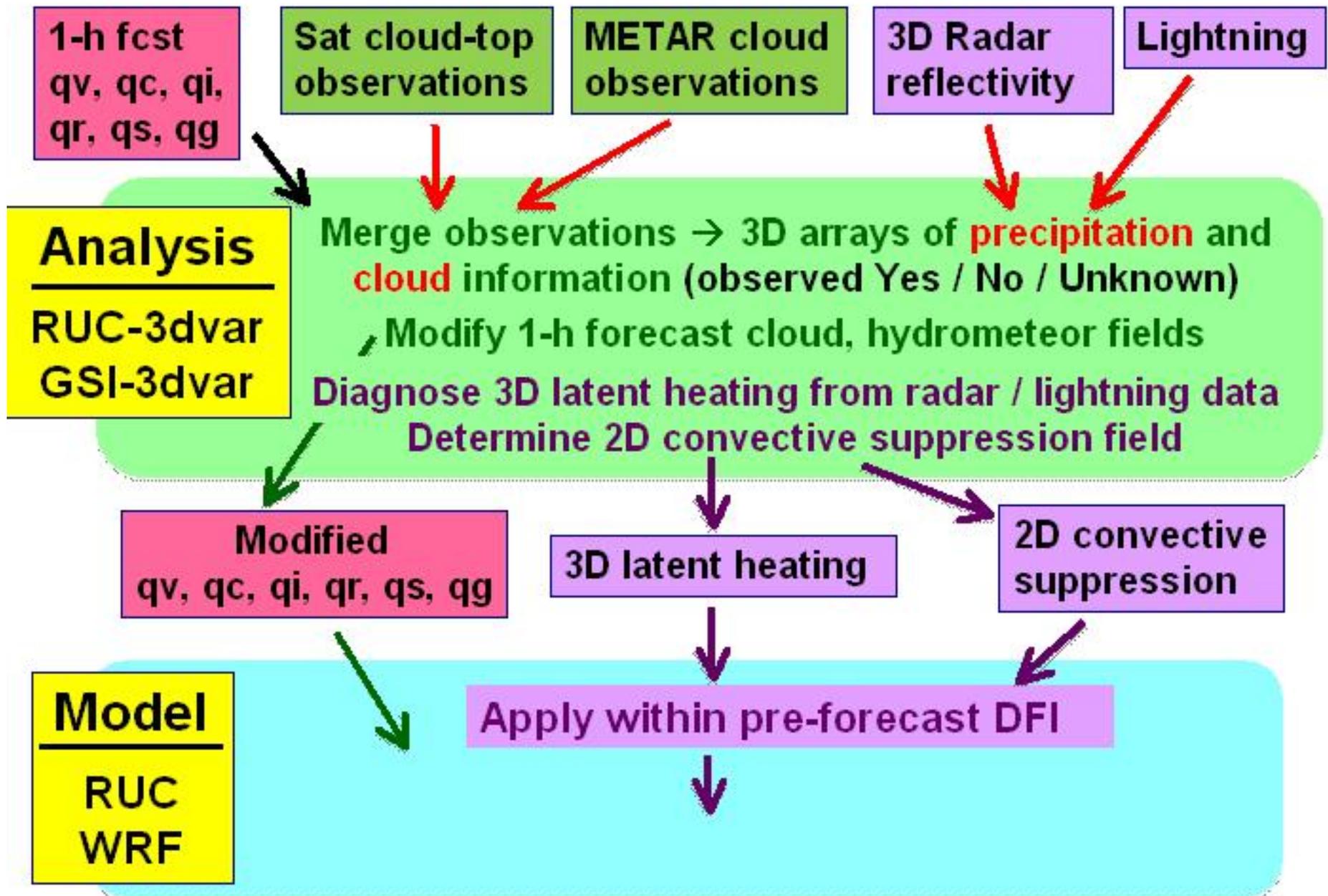
RUC/RR cloud / radar assimilation flowchart



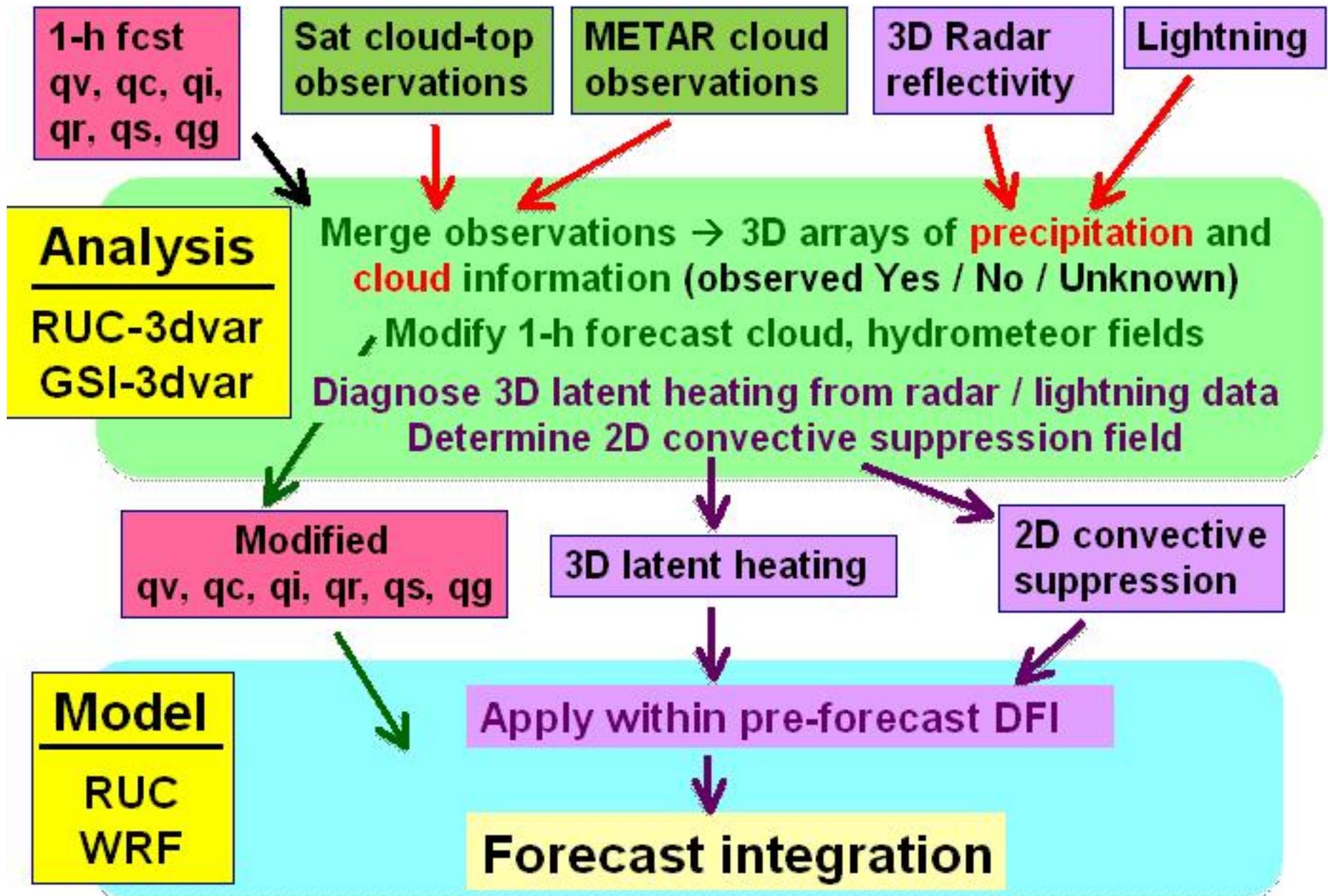
RUC/RR cloud / radar assimilation flowchart



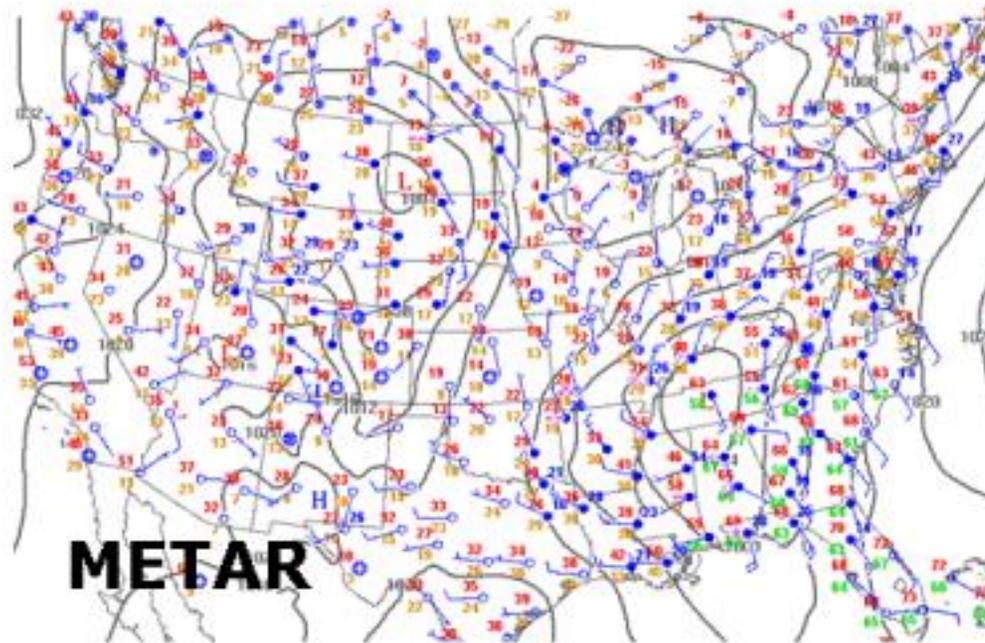
RUC/RR cloud / radar assimilation flowchart



RUC/RR cloud / radar assimilation flowchart

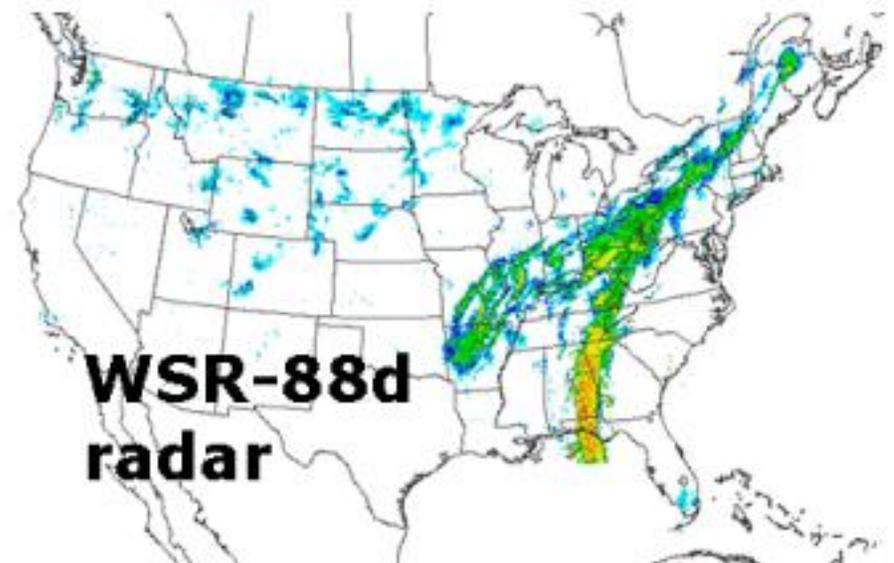
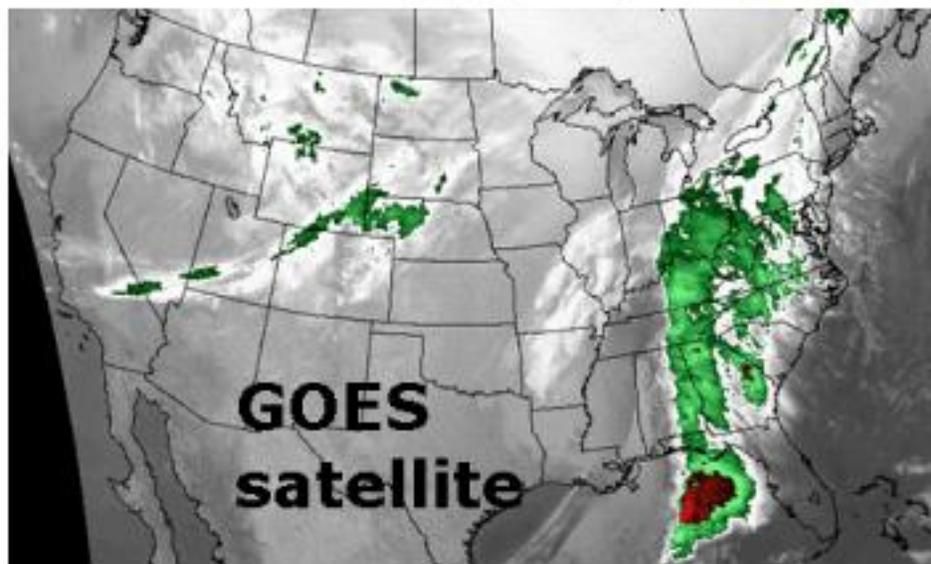


Cloud Observations from three sources



Combine with
1h fcst - 3-d
fields of qc,
qi, qr, qs, qg

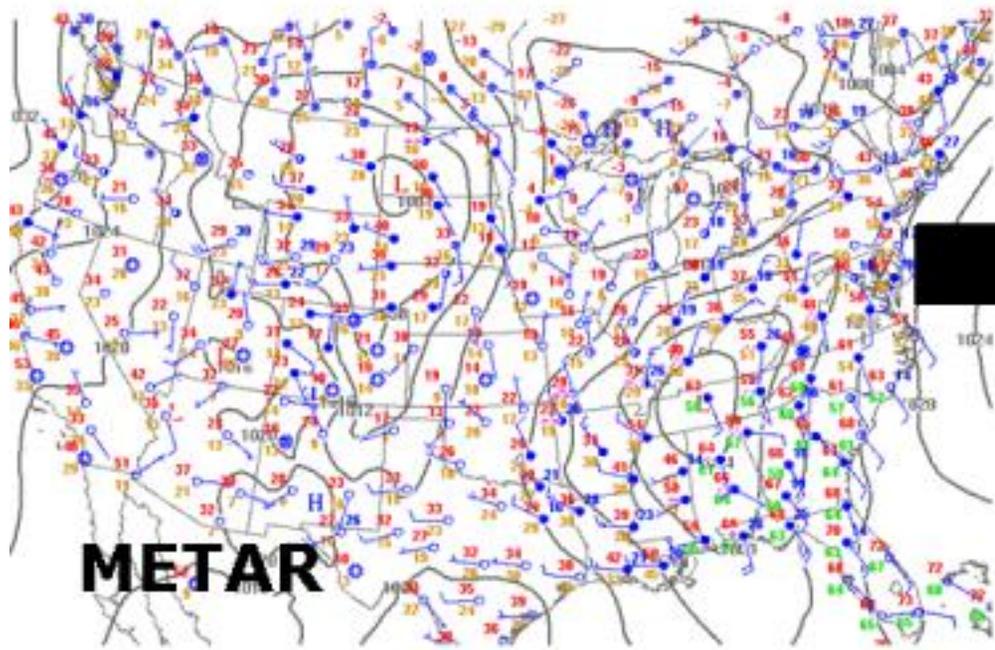
12 UTC 4 March 2008



Processing METAR observations

Column "maximum" cloud

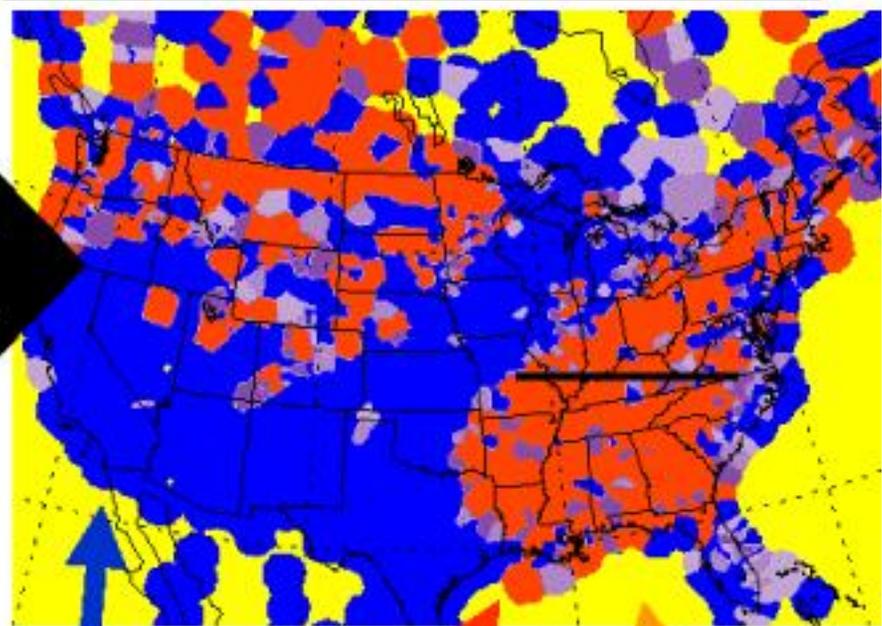
Yes > No > Unknown



METAR

12 UTC 4 March 2008

Cloud designation from observations



NO clouds

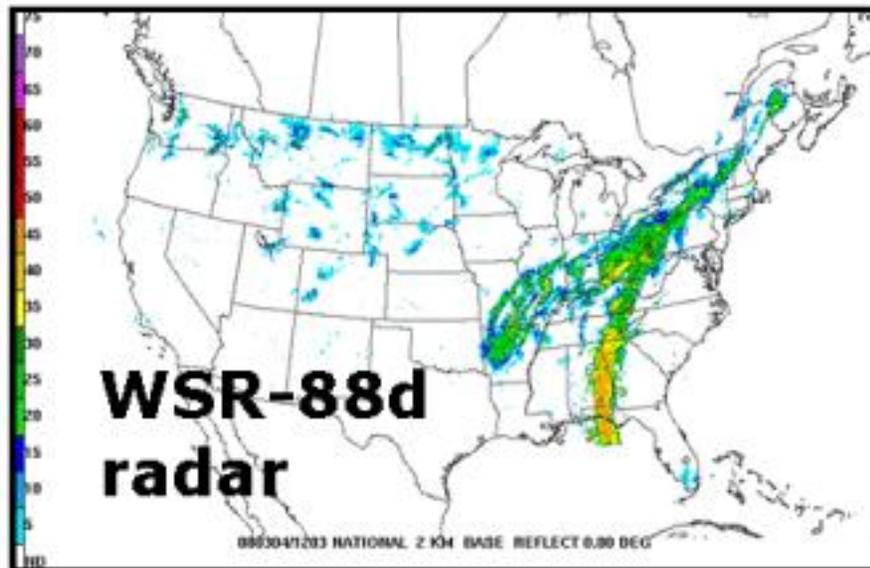
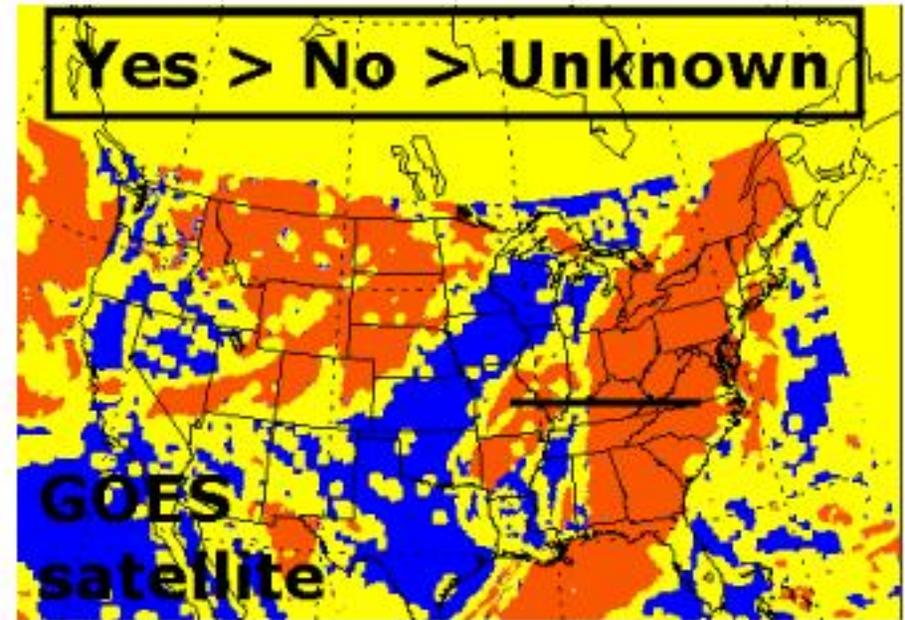
YES clouds

UNKNOWN clouds

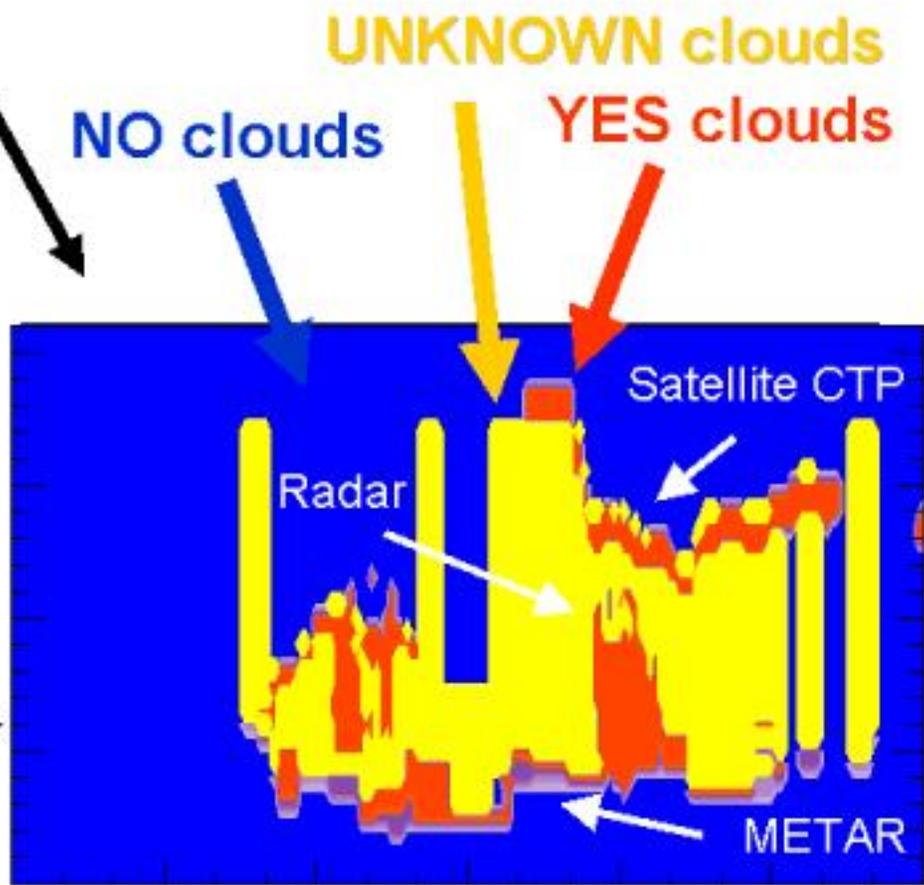
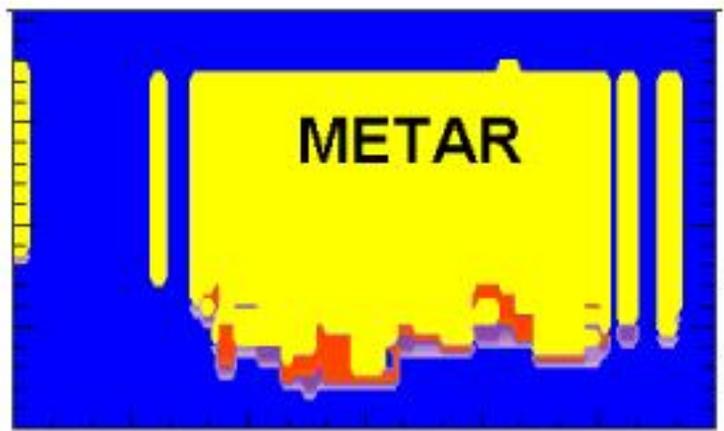
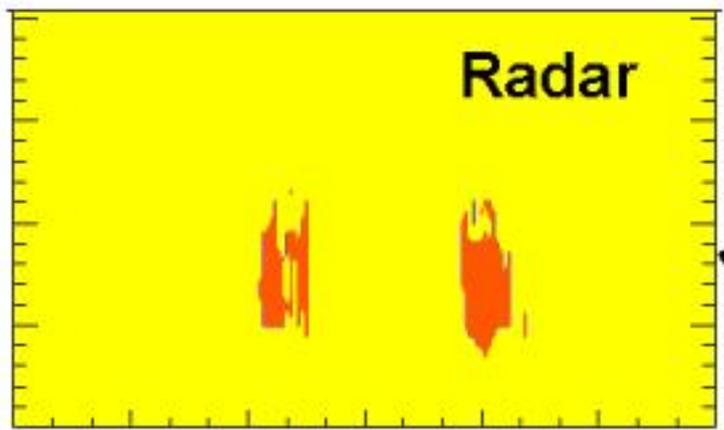
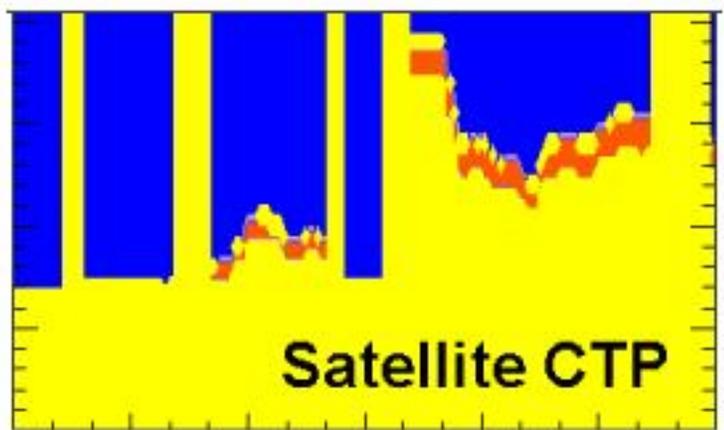
OVC
BKN
SCT

Specify 3-dimensional Yes/No/Unknown field

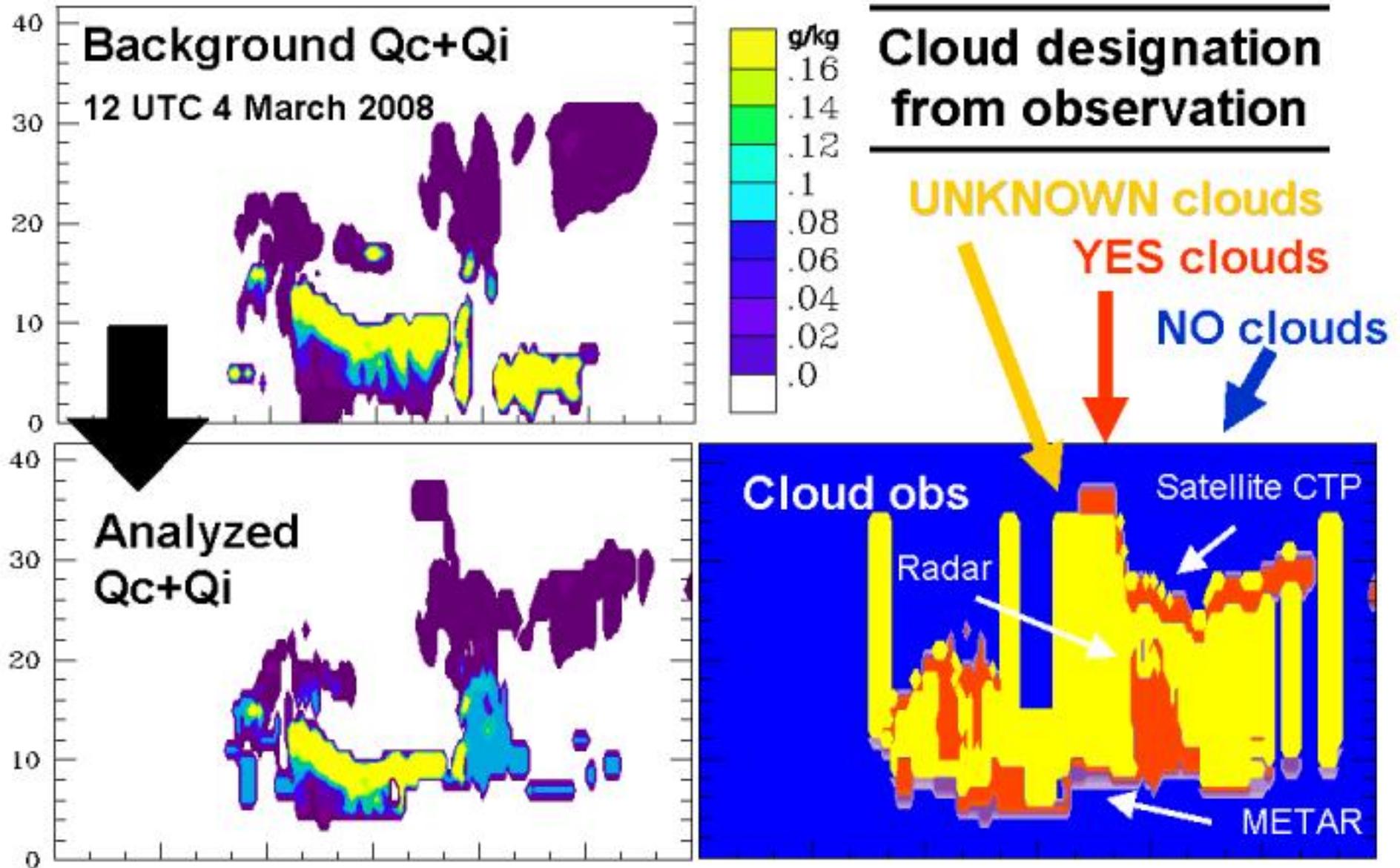
Observations → Column "maximum" cloud



Cloud designation from observations

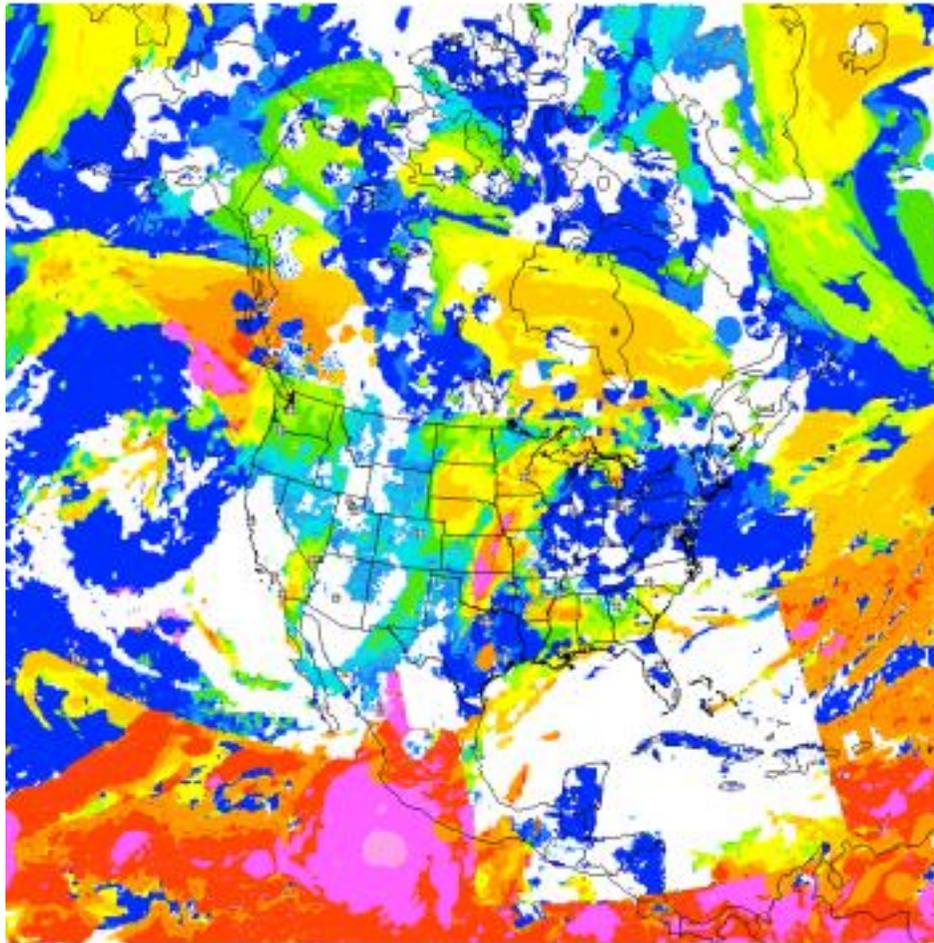


Modify background with cloud observations

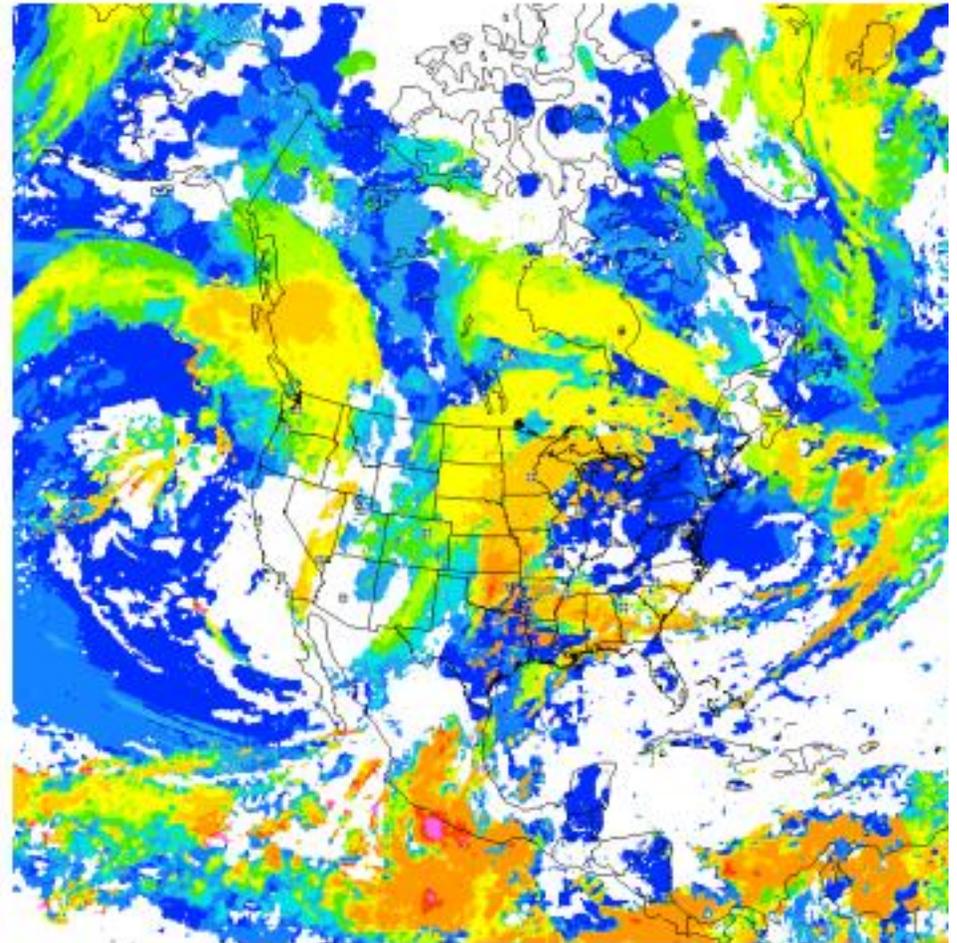


Use of NASA Langley satellite cloud data

RR with NESDIS data-
only over RUC domain



RR with NASA data -
over full RR domain



Analysis

Introducing RR features into GSI

Hourly update cycle

- switch to partial cycling

- Use of observations (NCEP prepBUFR + satellite data)
- Satellite bias corrections (from NCEP)

Cloud analysis

- Uses METAR, satellite, radar data

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- Diagnose latent heating (LH) from 3D radar reflectivity

Radar reflectivity assimilation

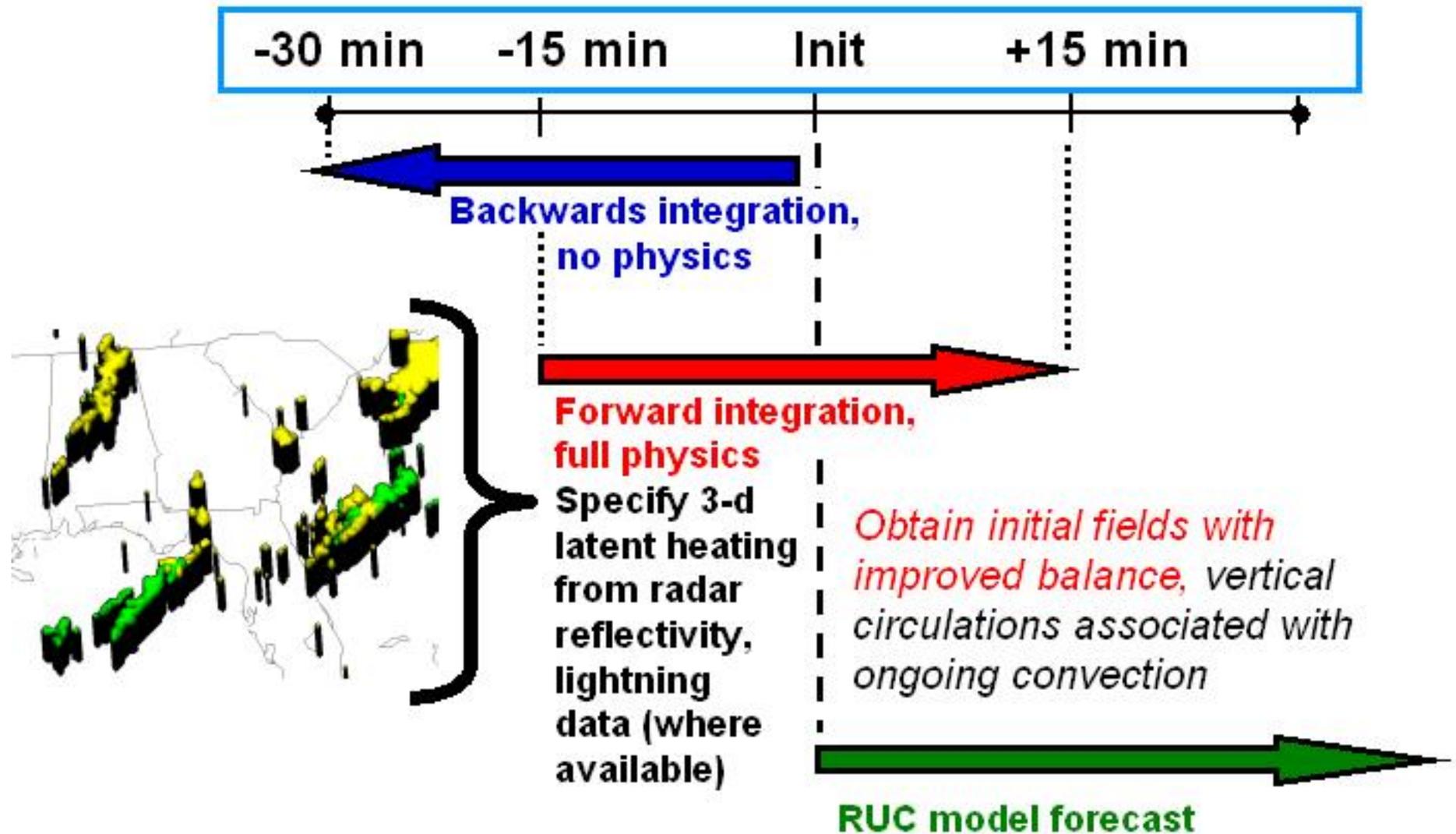
- Apply LH in diabatic digital filter initialization

Surface observation assimilation -- ongoing

- Account for model vs. terrain height difference
- Apply surface observation innovations through PBL
- Select best background for coastal observations

RUC / RR Diabatic Digital Filter Initialization (DDFI)

New - add assimilation of radar data



Radar reflectivity assimilation in RUC and Rapid Refresh

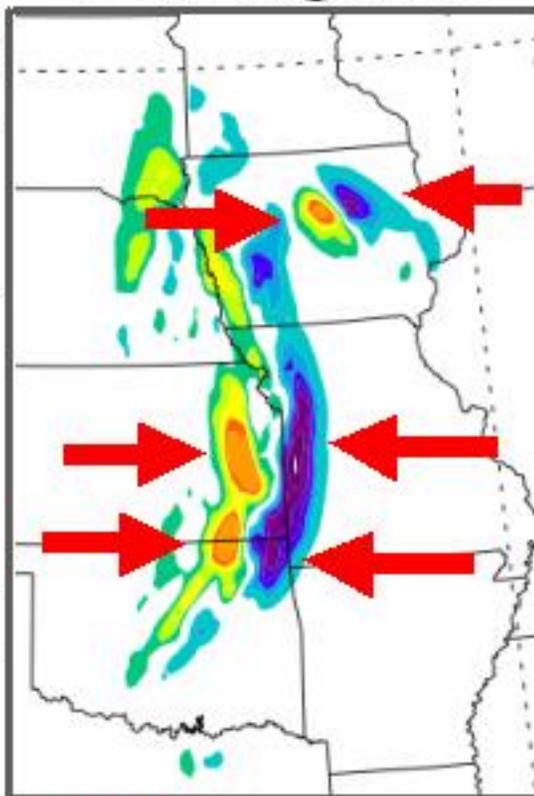
Rapid Refresh (GSI + ARW) reflectivity assimilation example

**NSSL radar
reflectivity (dBZ)**



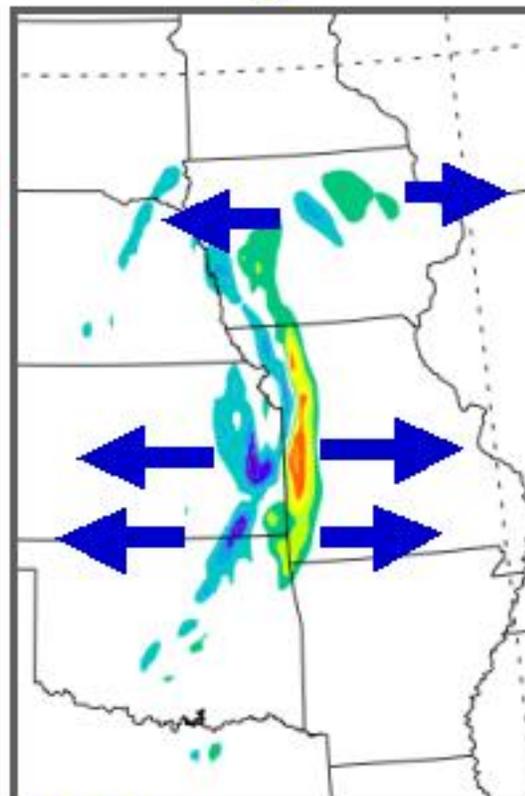
14z 22 Oct 2008
Z = 3 km

**Low-level
Convergence**

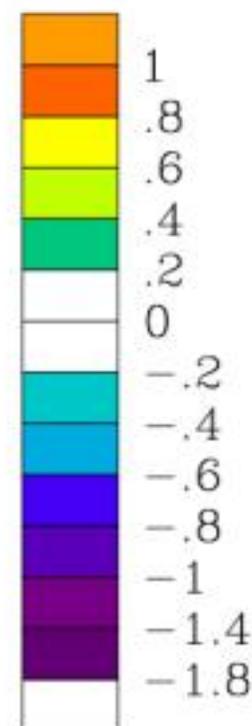


**K=4 U-comp. diff
(radar - norad)**

**Upper-level
Divergence**



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



Introducing RR features into GSI

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Surface observation assimilation -- ongoing

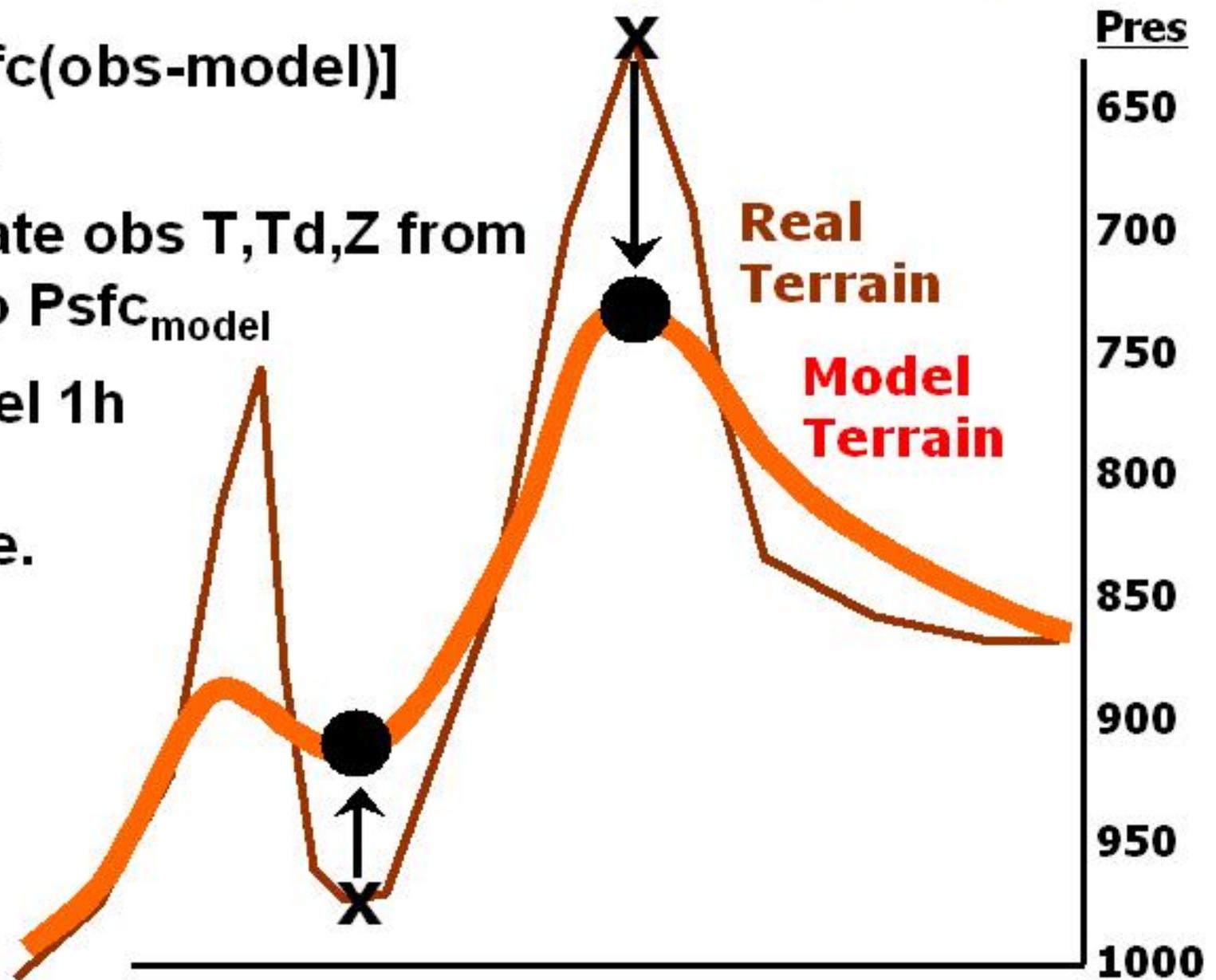
- Account for model vs. terrain height difference
- Apply surface observation innovations through PBL
- Select best background for coastal observations

Elevation correction (RUC/RR)

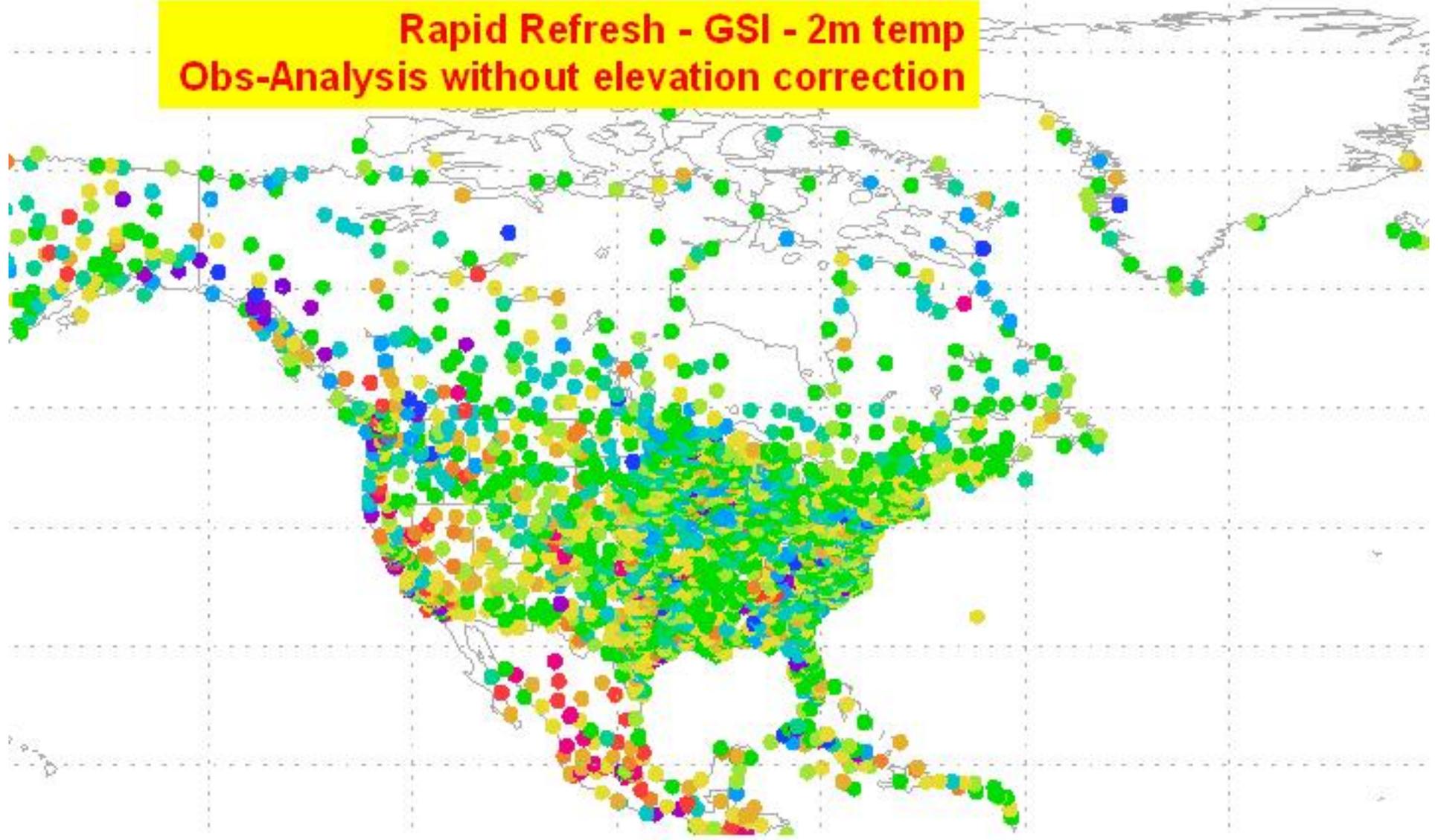
If $\text{abs}[\text{Psfc}(\text{obs}-\text{model})] < 70 \text{ hPa}$.

Extrapolate obs T, T_d, Z from Psfc_{obs} to $\text{Psfc}_{\text{model}}$

Use model 1h low-level lapse rate.



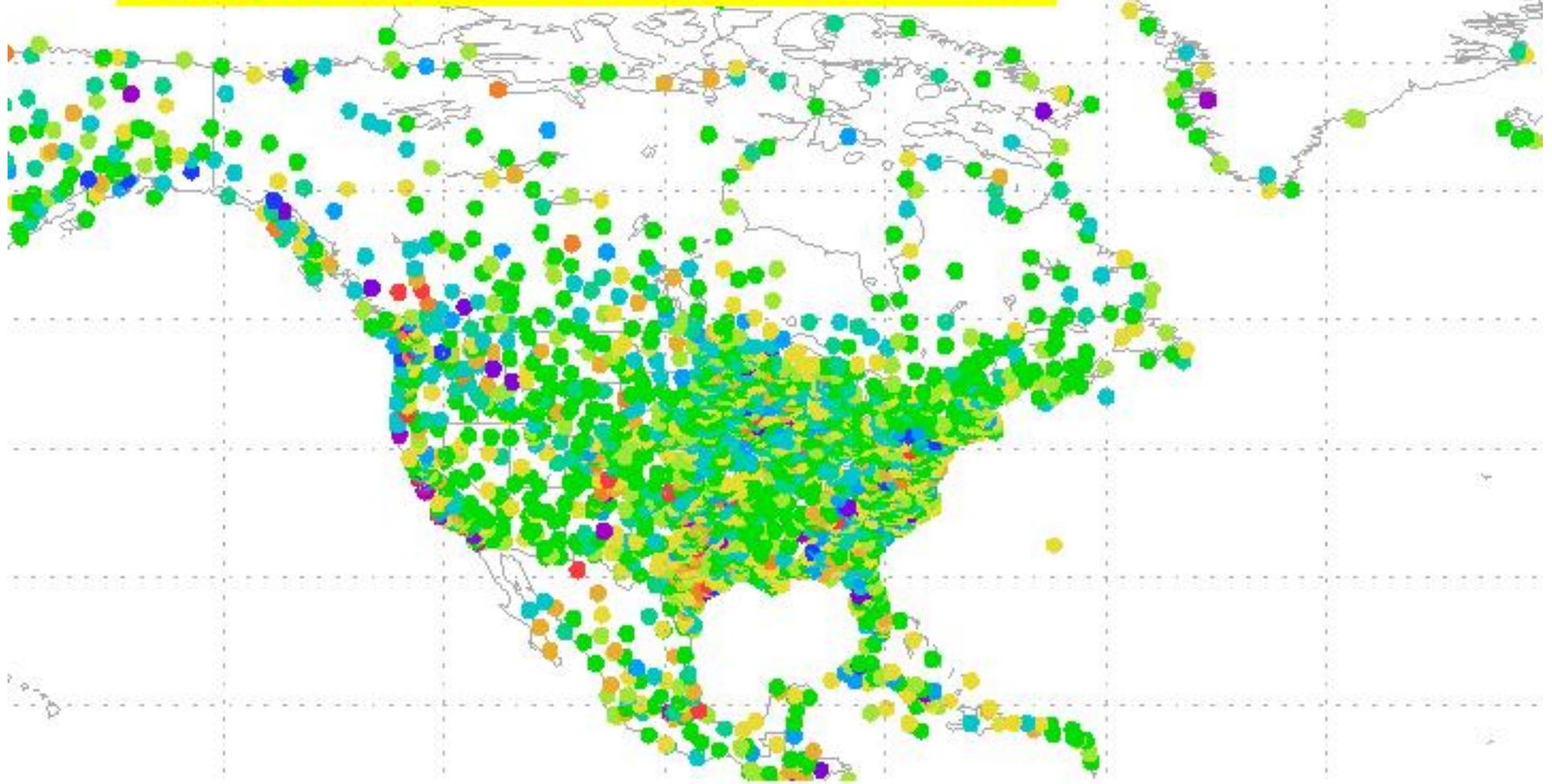
**Rapid Refresh - GSI - 2m temp
Obs-Analysis without elevation correction**



GrADS: COLA/IGES

2009-08-29-14:29

Rapid Refresh - GSI - 2m temp
Obs-Analysis with elevation correction



Verification (RR vs. RUC)

Upper-air

- Verify against rawinsonde
- Use native level data at 10 mb intervals

Major improvement from partial cycling

Surface

- Verify against METAR obs for T, Td, wind, ceiling, visibility

- **Surface skill dependent on:**
 - data assimilation**
 - model physics (BL, radiation)**
 - model post-processing**
- RR skill similar RUC**

Precipitation verification

- Verify against Stage 4
- RR similar skill, somewhat higher bias**

Verification (RR vs. RUC)

Upper-air

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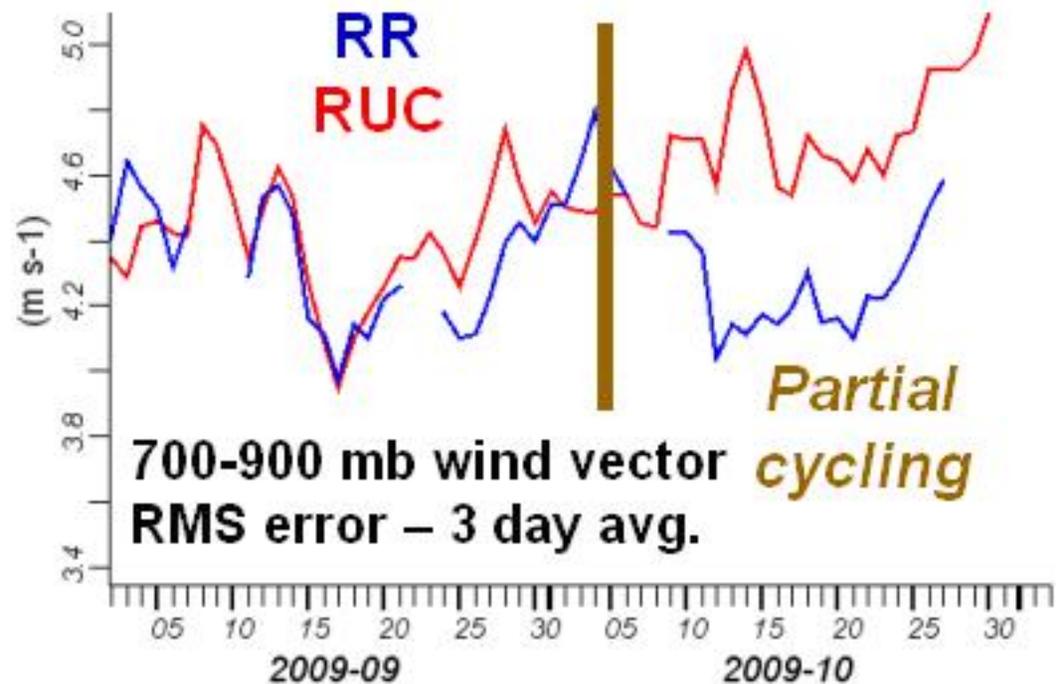
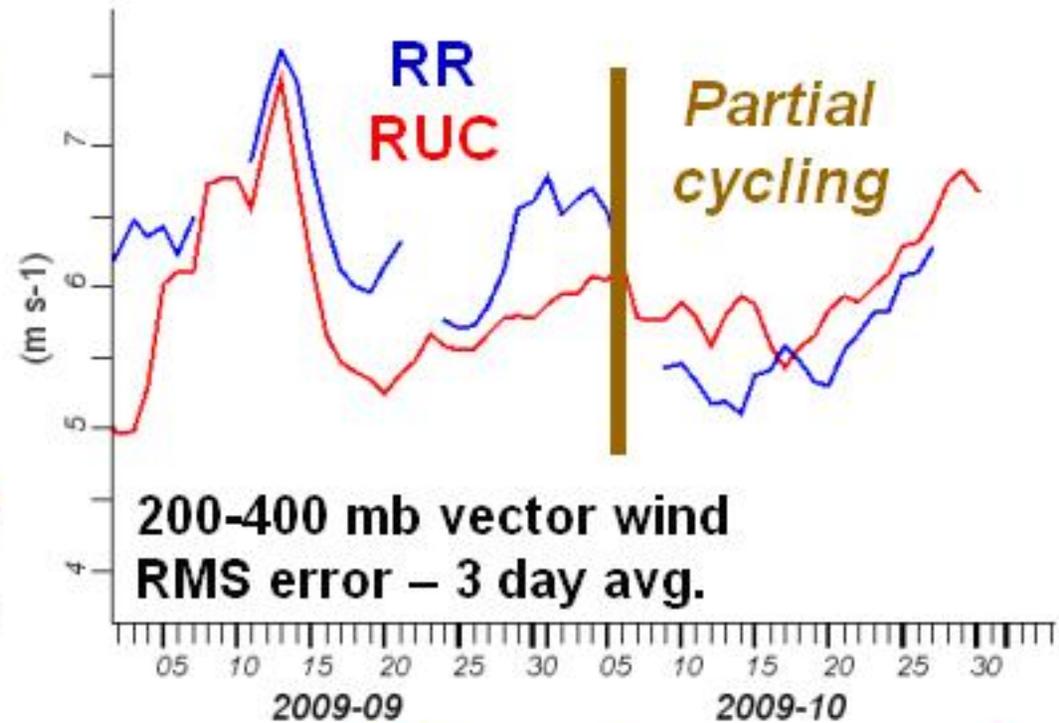
Rapid Refresh Upper-Air verification

Before partial cycling

Gradual error growth,
especially at upper-
levels from large-
scale inaccuracies

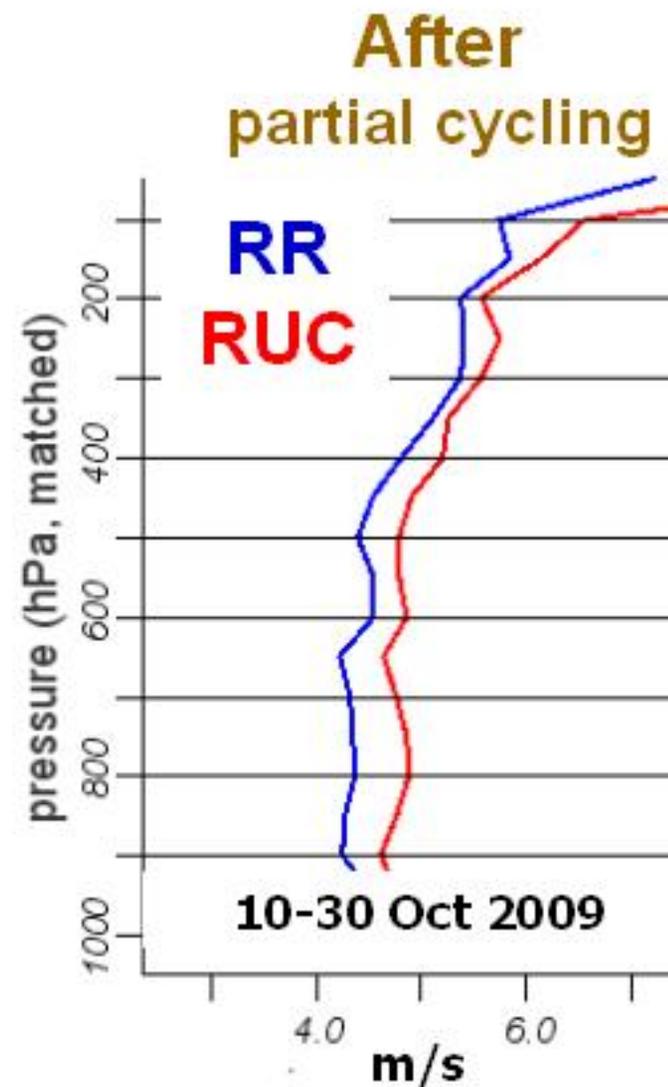
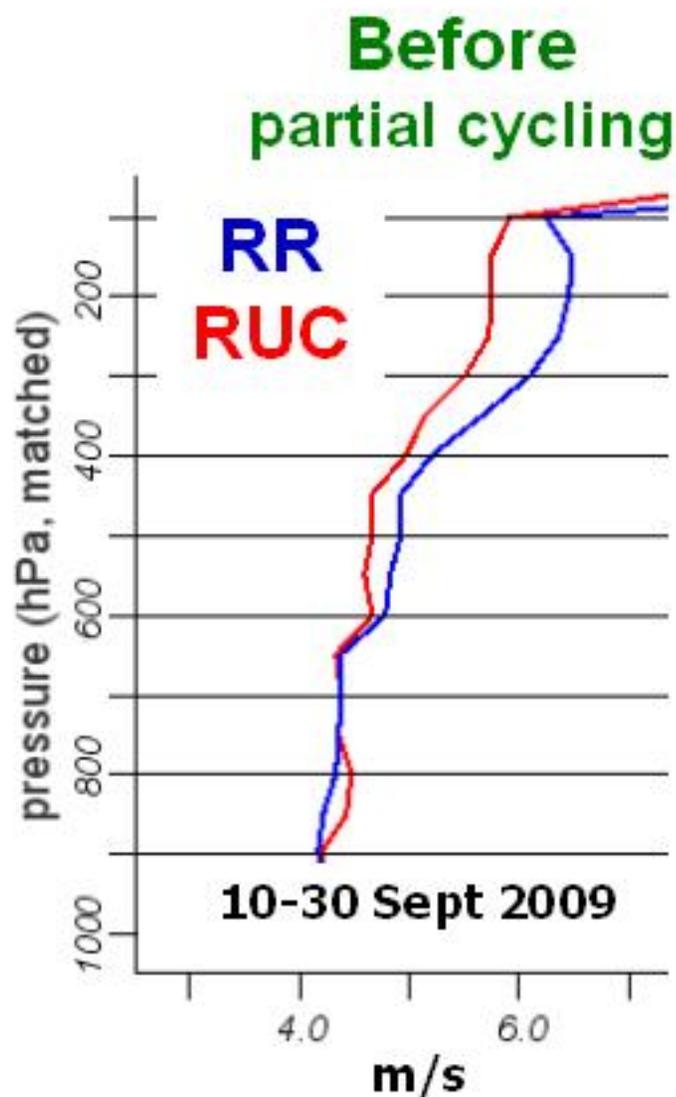
After partial cycling

Much improved
results, better
skill than RUC



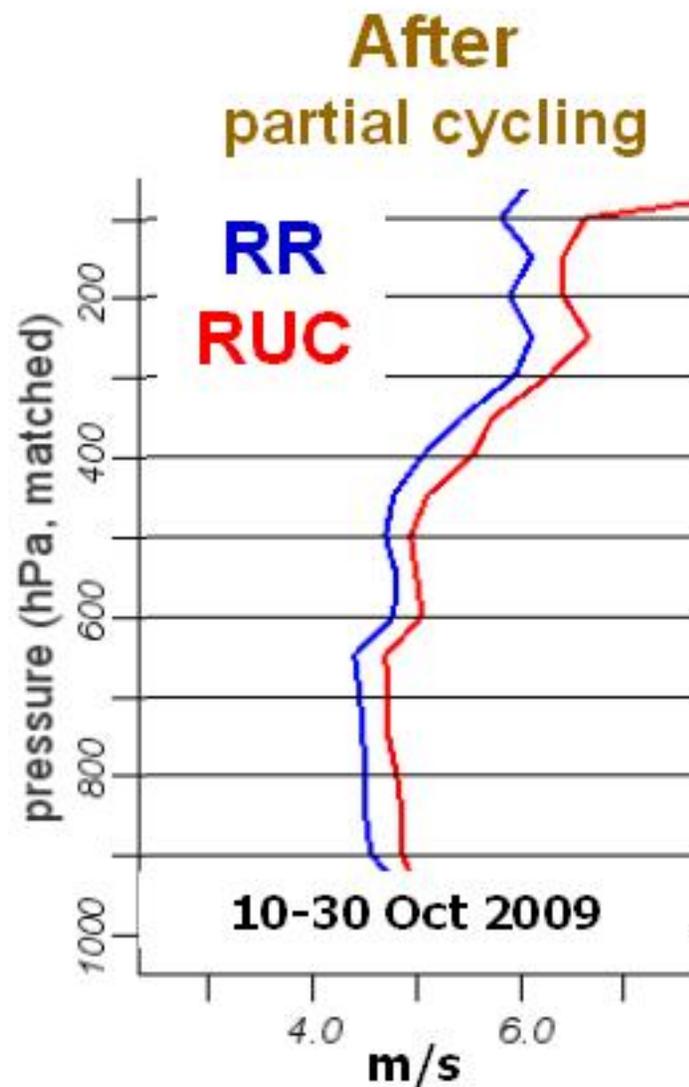
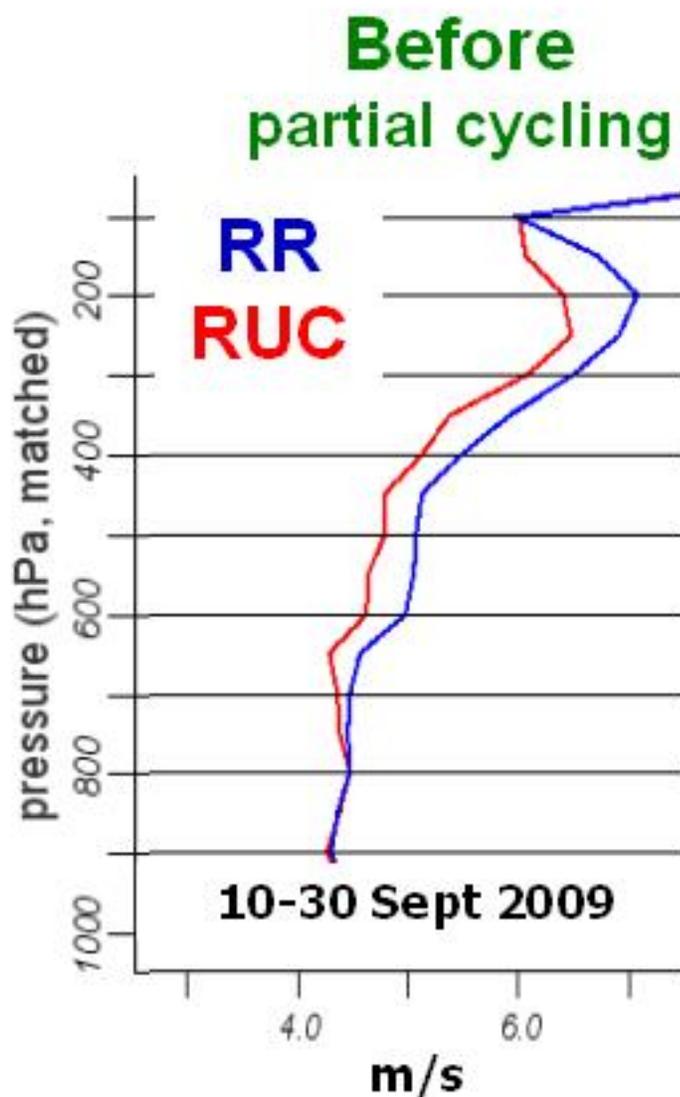
Rapid Refresh upper-air verification

3-h fcst vector wind RMS error



Rapid Refresh upper-air verification

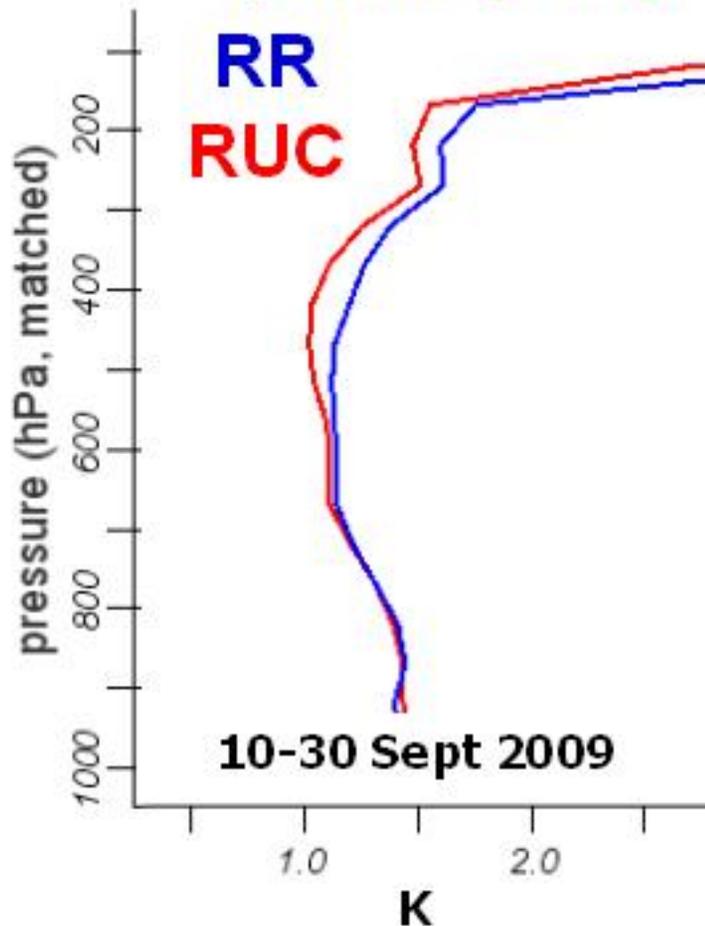
12-h fcst vector wind RMS error



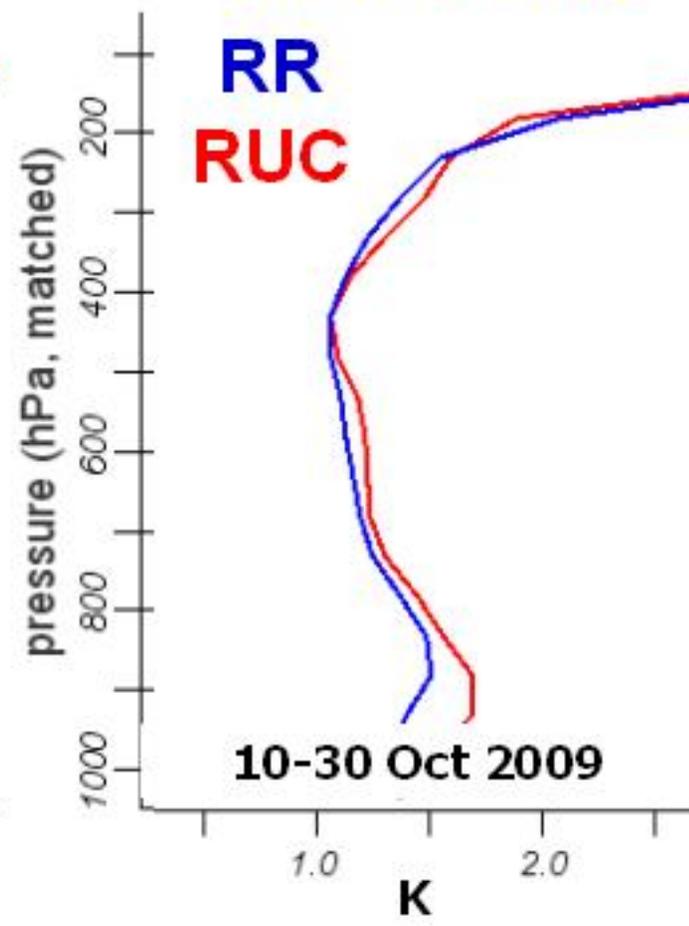
Rapid Refresh upper-air verification

3-h fcst Temperature RMS error

Before
partial cycling



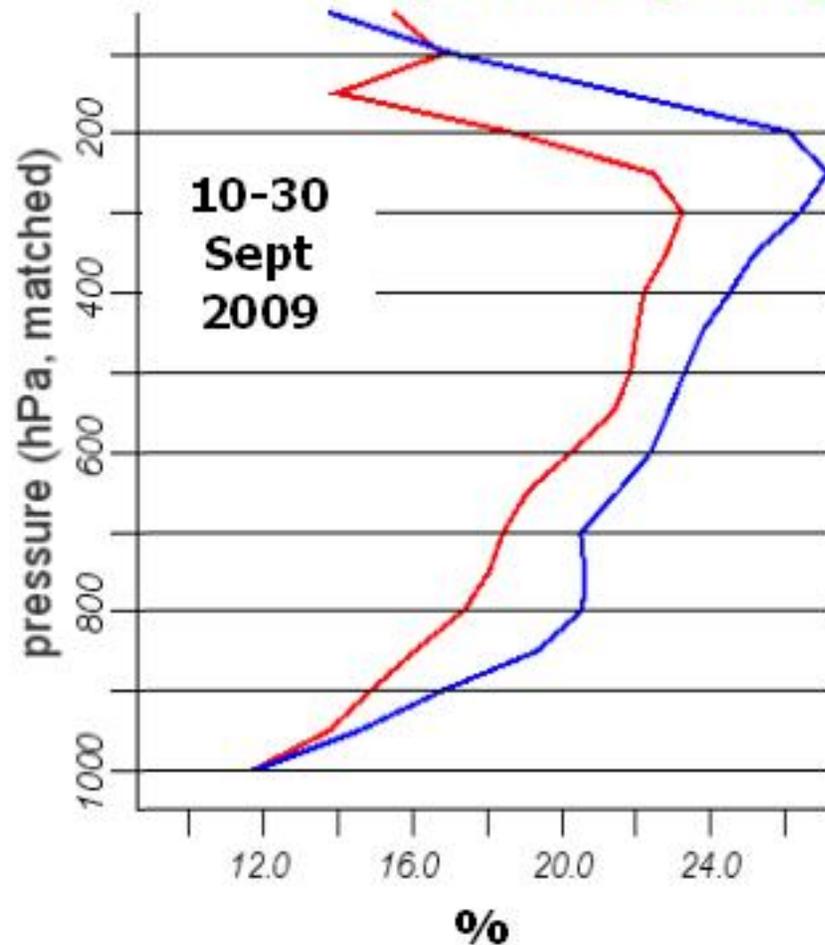
After
partial cycling



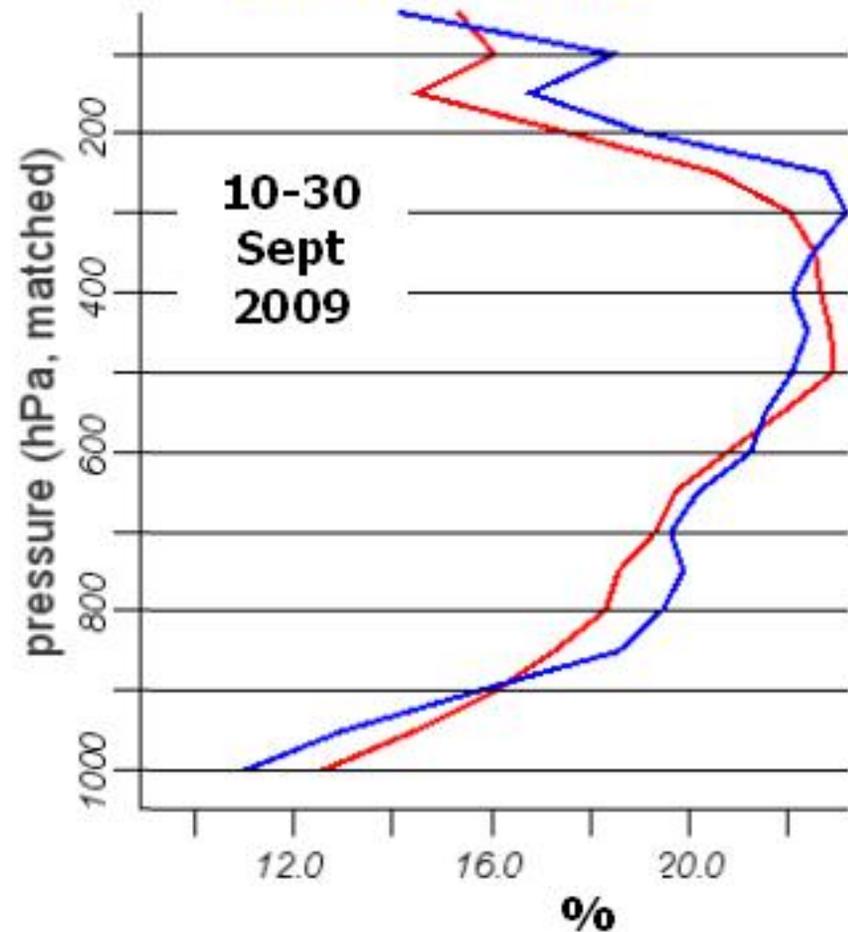
Rapid Refresh upper-air verification

3-h fcst Relative humidity RMS error

Before
partial cycling



After
partial cycling



Verification (RR vs. RUC)

Upper-air

- Verify against rawinsonde
- Use native level data at 10 mb intervals

Major improvement from partial cycling

Surface

- Verify against METAR obs for T, Td, wind, ceiling, visibility
- **Surface skill dependent on:**
 - data assimilation**
 - model physics (BL, radiation)**
 - model post-processing**

RR skill similar RUC

Precipitation verification

- Verify against Stage 4

RR similar skill, somewhat higher bias

RR vs. RUC surface verification

RR RMS errors nearly equal to RUC

RR bias errors equal to or better than RUC

3h fcst errors vs. METARs	rms		bias	
	RUC	RR	RUC	RR
2m Temp. (C)	1.7	2.0	-0.2	+0.2
2m Dew Pt. (C)	1.8	1.8	+0.9	+0.9
10m wind Speed (m/s)	1.9	2.1	+0.6	-0.1
10m vector Wind (m/s)	3.9	4.1		

RR vs. RUC surface verification

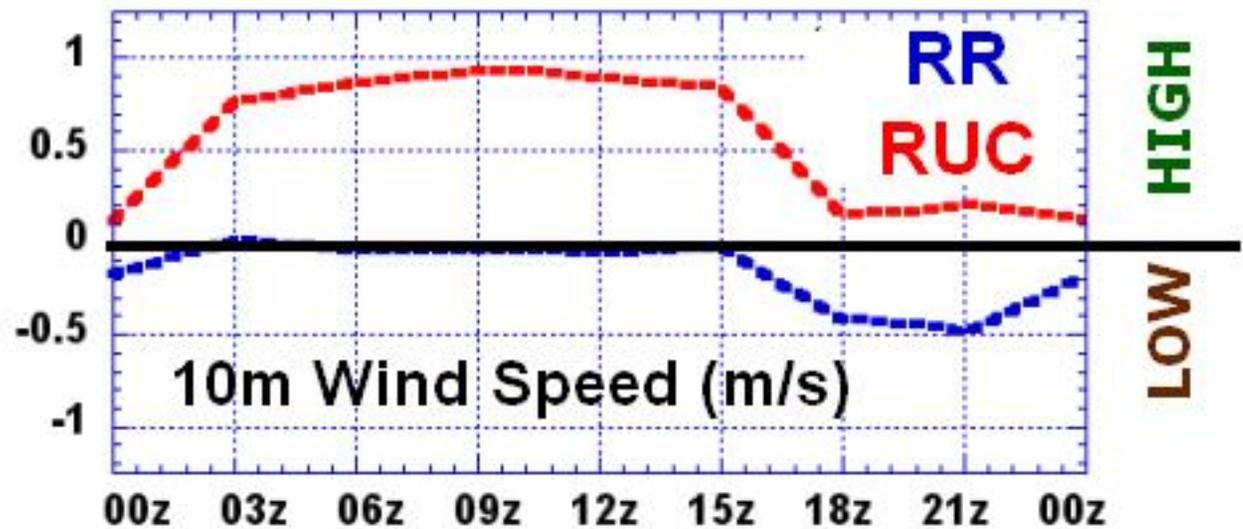
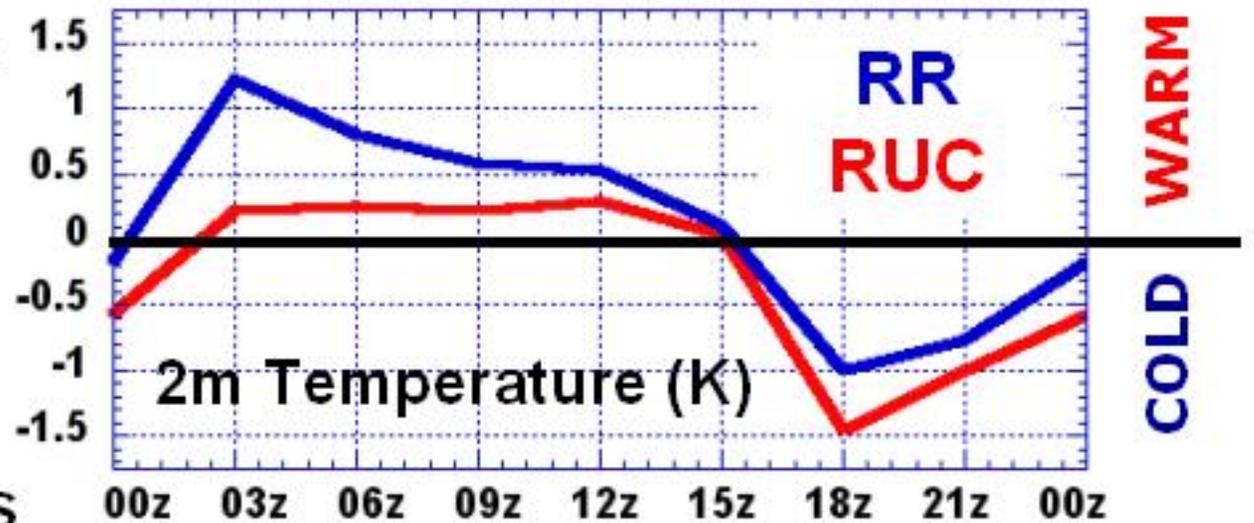
Diurnal bias variation for 3-h fcst

Diurnal temperature cycle too small in RR & RUC

Daytime too cool, not as bad in RR, consistent wind bias

Nighttime too warm, especially in RR, no bias in RR winds

2-week comparison
14-30 Oct 2009
Eastern US only



Verification (RR vs. RUC)

Upper-air

- Verify against rawinsonde
- Use native level data at 10 mb intervals

Big pickup from partial cycling

Surface

- Verify against METAR obs for T, Td, wind, ceiling, visibility

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RR skill similar RUC

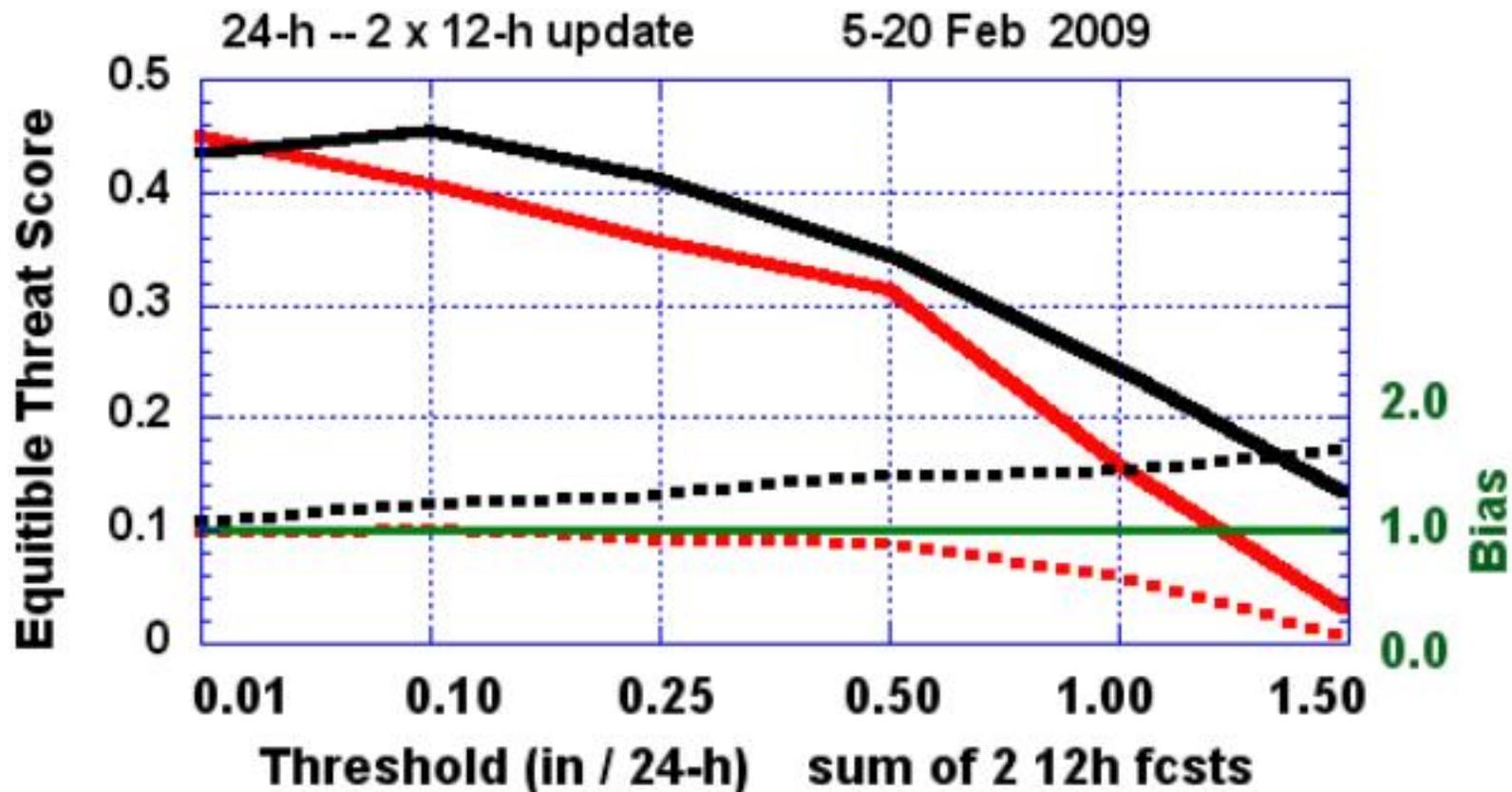
Precipitation verification

- Verify against Stage 4

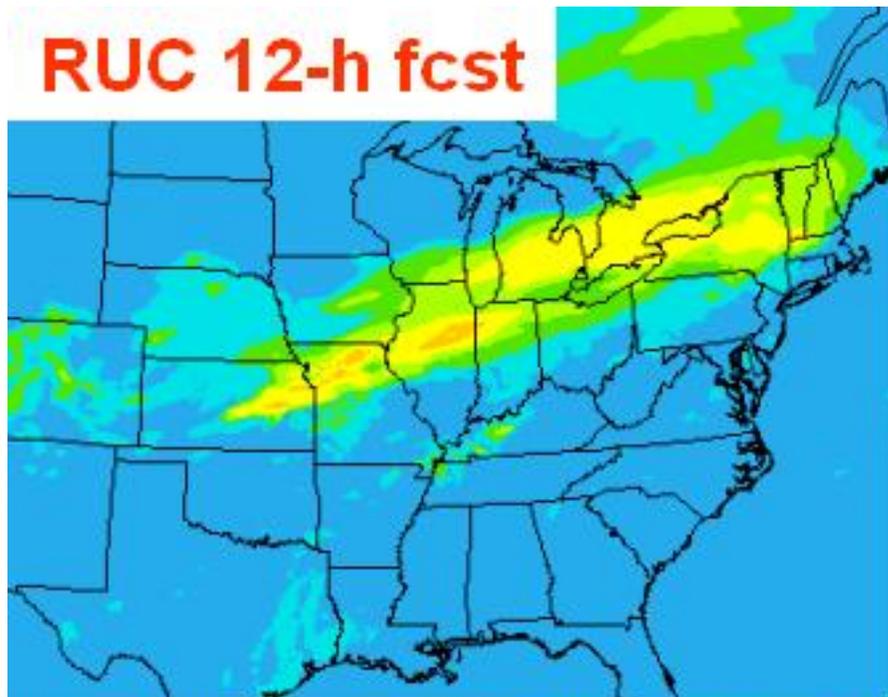
RR similar skill, somewhat higher bias

Comparison of Rapid Refresh and RUC precipitation skill scores

- RR has improved ETS for nearly all threshold
- RR bias higher, especially for higher thresholds



RUC 12-h fcst



RR 12-h fcst



**12-h accum.
precipitation
06z Mar 8, 2009**



**NSSL 12-h
precip verif**



Rapid Refresh Status and Plans

- **Current Status → early 2010**
 - Nearly all modifications in place, good verification
 - Final changes based on cycled RR testing (R/T, retro) (boundary layer assimilation, WRFpost changes)
 - Transfer code to NCEP, Parallel cycle (Geoff Manikin)
- **2010 - Q4** NCEP implementation of Rapid Refresh
- **2012** NCEP implementation of Rapid Refresh ensemble
 - 3 ARW members and 3 NMM members
 - using ESMF (Earth System Modeling Framework)

<http://rapidrefresh.noaa.gov>

Rapid Refresh / RUC Technical Review - OUTLINE

- 1:30 – 1:45 RUC → RR transition overview,
NCEP RUC changes – 2008-09- **Stan Benjamin**
- 1:45 – 2:00 Observation impact experiments
- TAMDAR aircraft obs w/ moisture, larger OSE
Bill Moninger
- 2:00 – 2:20 Rapid Refresh overview, assimilation –
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– physics, cloud, chemistry, PBL
John Brown, Tanya Smirnova, Joe Olson
- 3:05 – 3:20 The HRRR and HCPF (HRRR prob forecast)
Curtis Alexander
- 3:20 – 3:30 Future of RR/HRRR/ens **Stan Benjamin**

Some History of the Rapid Refresh

- **2003-2005 - WRF-RUC testing (WRF initialized with RUC initial conditions)**
- **2006 - Controlled ARW, NMM core comparison**
 - GSD-AMB recommended use of ARW core by slight margin in Aug. 2006
- **Late 2007 - First RR cycling with GSI, ARW**
 - Digital Filter Initialization
- **2008-2009 - Extensive testing; Grids → NCAR, AK**
 - Two RR 1-hour cycles + retrospective capability
 - RUC cloud analysis and radar initialization

Strong, long-term collaboration with NCAR WRF-ARW developers

GSD Contributions to WRF Code Repository

- RUC-LSM plus periodic updates
 - Grell-Devenyi convective scheme (two flavors)
 - MYNN (Mellor-Yamada Nakanishi Niino) PBL scheme
 - Digital Filter Initialization, including forward diabatic option (with Hans Huang, *et al*, NCAR)

 - Changes to metgrid (WPS) to accept RUC native-grid data, including hydrometeors, as input
 - Modifications to properly initialize soil when source model and WRF use different Land-Surface Model (LSM)
 - Mods to render it possible to run either NMM or ARW with Ferrier or Thompson microphysics, BMJ or GD convection
- Key additional contribution:*** Primary coordination and
- construction of WRF-Chem code elements

RR version of WRF model

ARW core (currently WRF v3.1 release, April 2009)

Grell-Devenyi convection

*Components in
red match RUC*

MYJ (NCEP/NAM) surface layer,

turbulent vertical mixing above surface layer

NCAR-Thompson microphysics (latest repos version)

RRTM longwave radiation

Goddard shortwave radiation (includes cloud effects)

RUC Land-Surface Model (with recent enhancement to
treat snow cover on sea ice)

Diabatic Digital Filter Initialization (DDFI) radar assim

*Result: RR physics behavior similar to RUC –
good for aviation applications and convective environment*

Planned Rapid
Refresh *domain*

-

649x648x50
grid pts

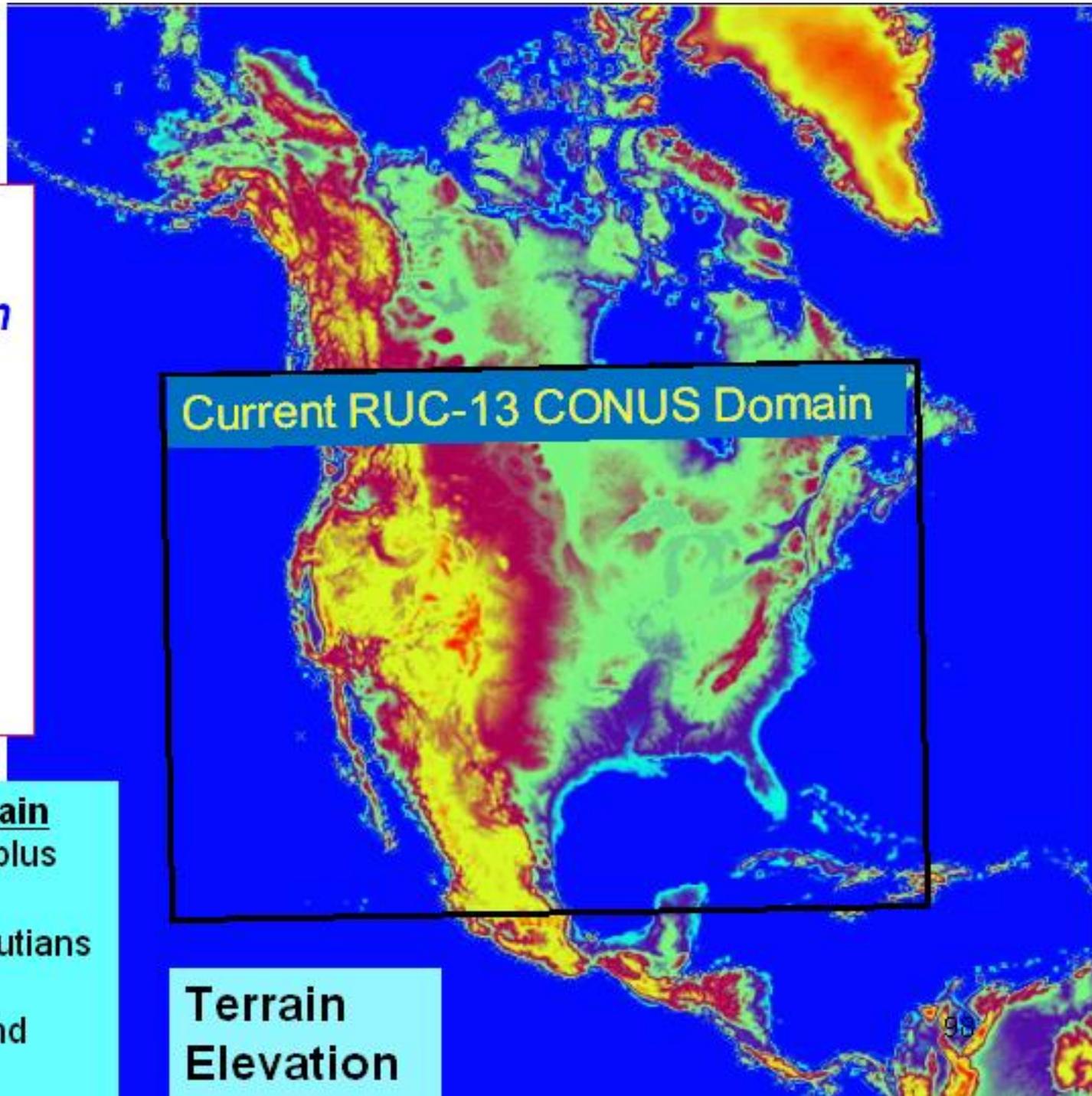
Nominal 13km
grid spacing

Constraints on domain

- Continental Alaska plus coastal margins
- Dutch Harbor in Aleutians
- Isthmus of Panama
- US Virgin Islands and most of Caribbean

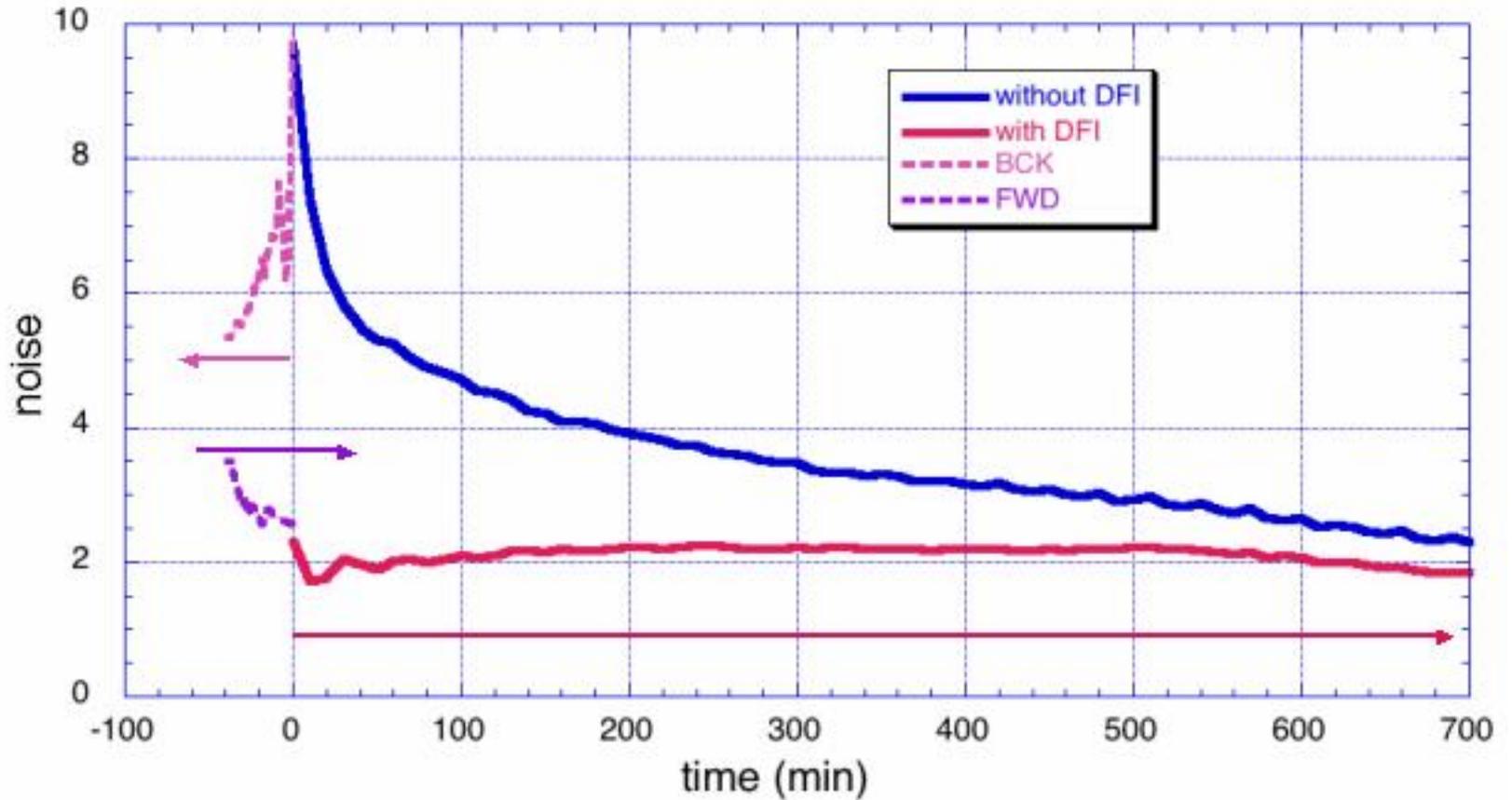
Current RUC-13 CONUS Domain

Terrain
Elevation



Noise = mean absolute sfc pressure tendency (hPa/h)

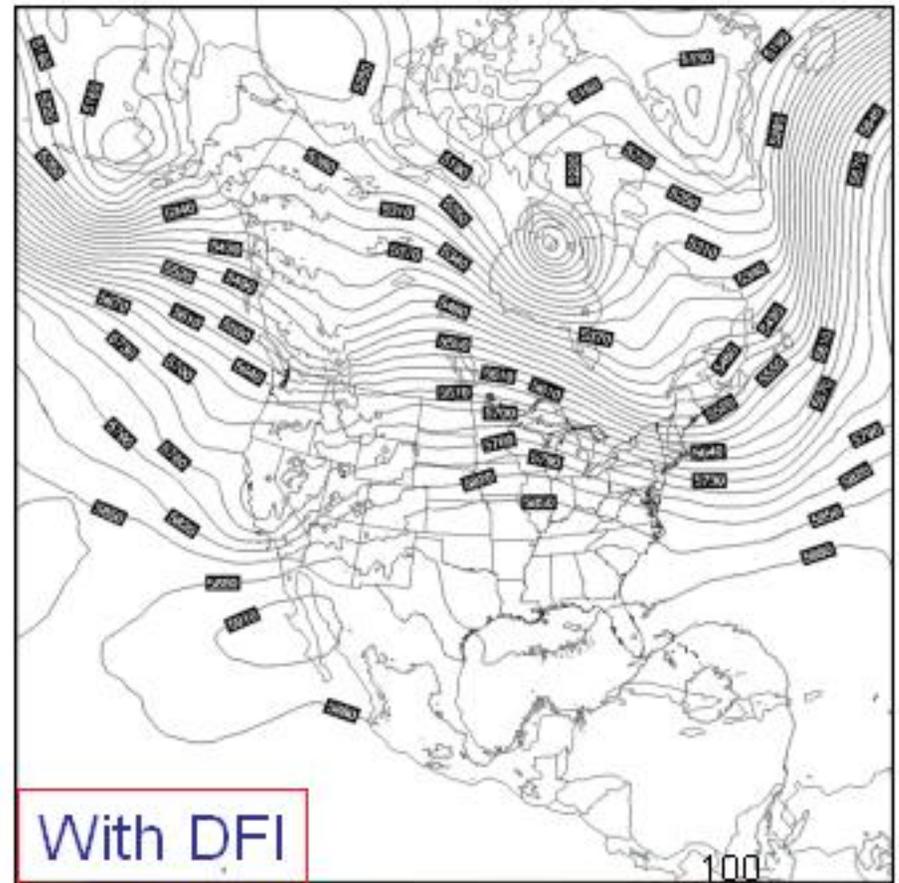
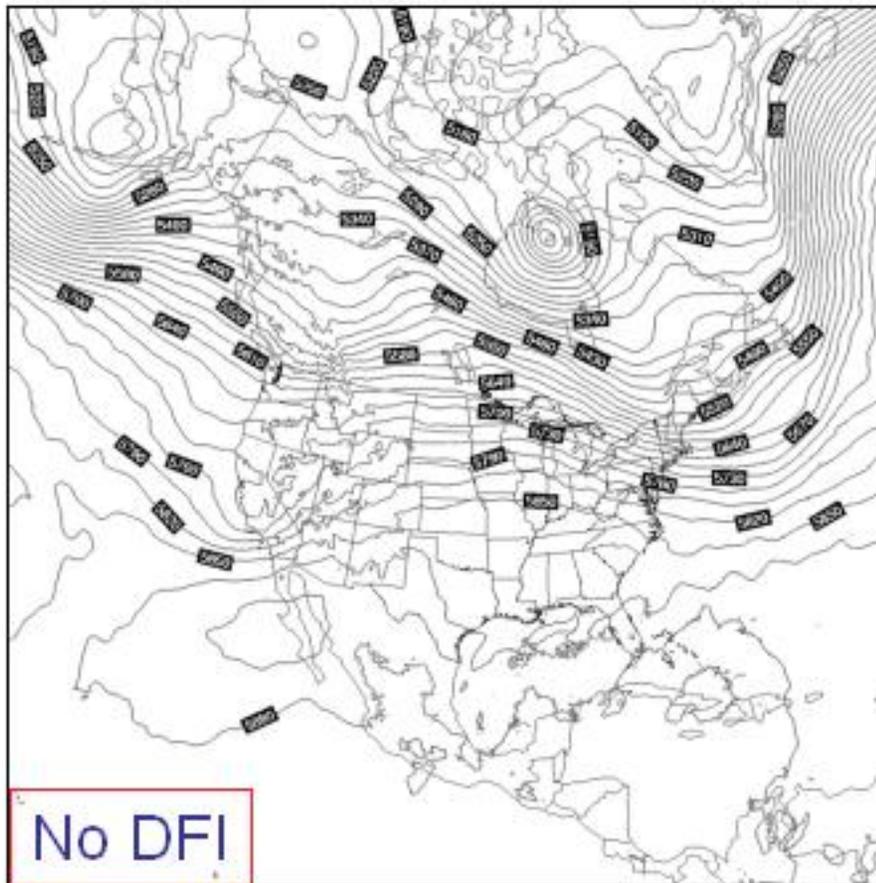
$$\left| \frac{\partial p_{sfc}}{\partial t} \right|$$



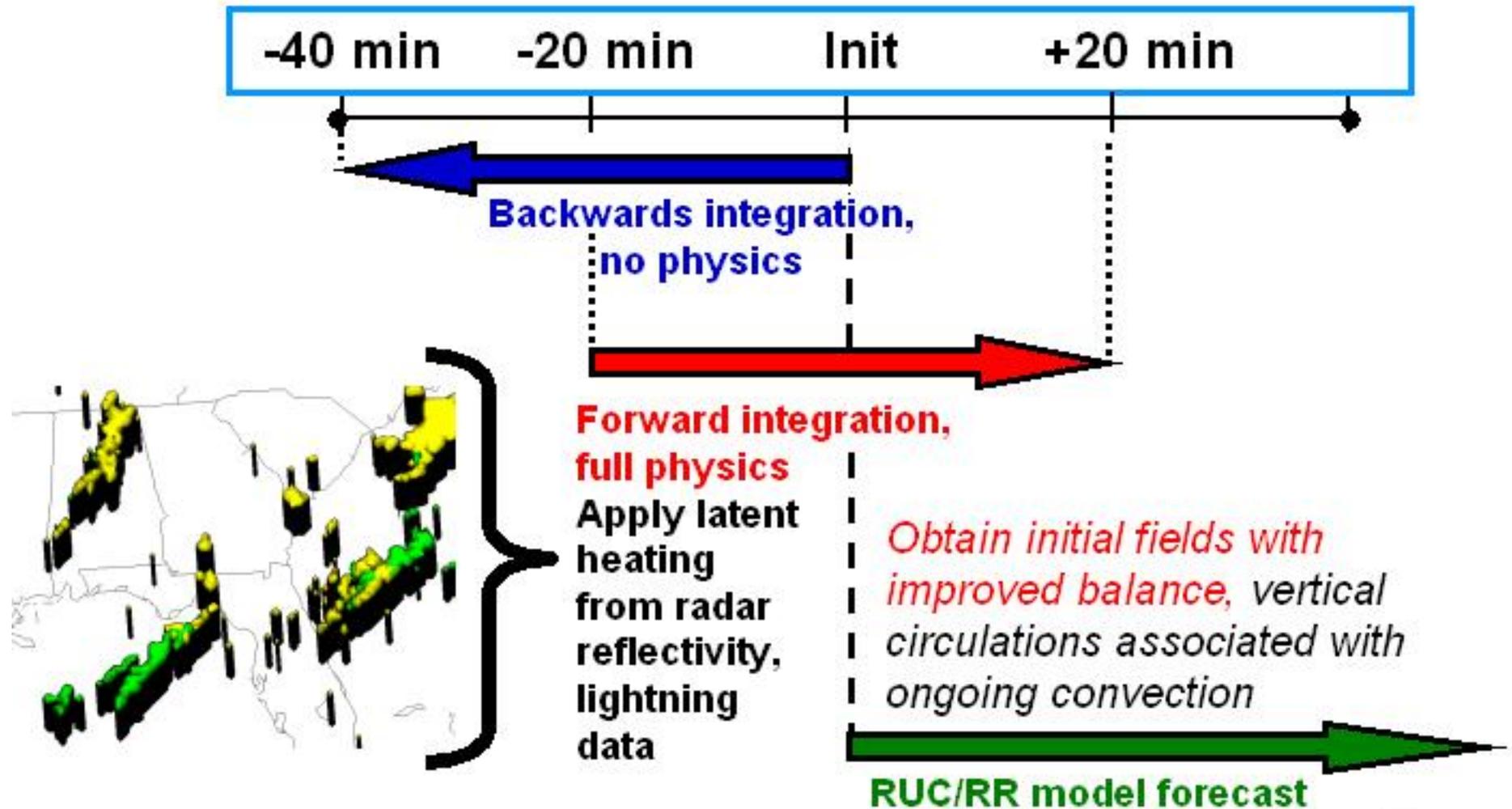
Using WRF-13km Rapid Refresh over N. American domain

500hPa Height 3-h Fcst for 03Z 30 Oct 07

Away from terrain and convection, height contours are smoother with DFI



Diabatic Digital Filter Initialization (DDFI)



NCAR-Thompson Microphysics

RUC uses Dec 2003 version of scheme

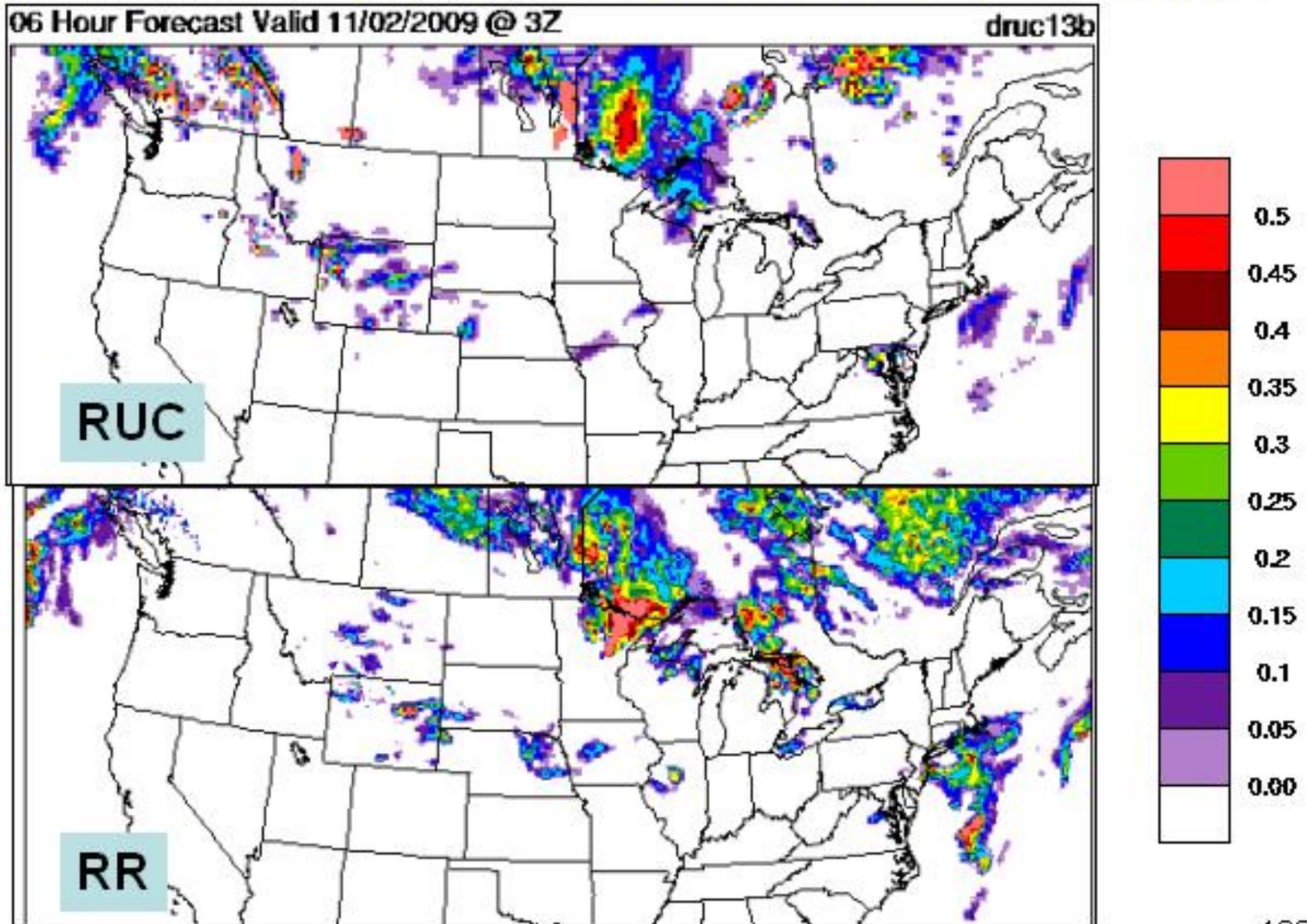
Version in WRF v3.1 (mp_physics = 8) has many changes

- **2-moment (mixing ratio and number concentration) rain** helps better simulate difference in drop-size distribution between rain resulting from melting snow and that from collision-coalescence of cloud drops
- Greater ice supersaturation allowed (up to water saturation)
- Snow particles assumed to be more 2-d than spherical (affects deposition, collision and fall speed)
- Revised collection of snow and graupel by rain
- Extensive use of lookup tables
- Option for Gamma distribution for all precip hydrometeors

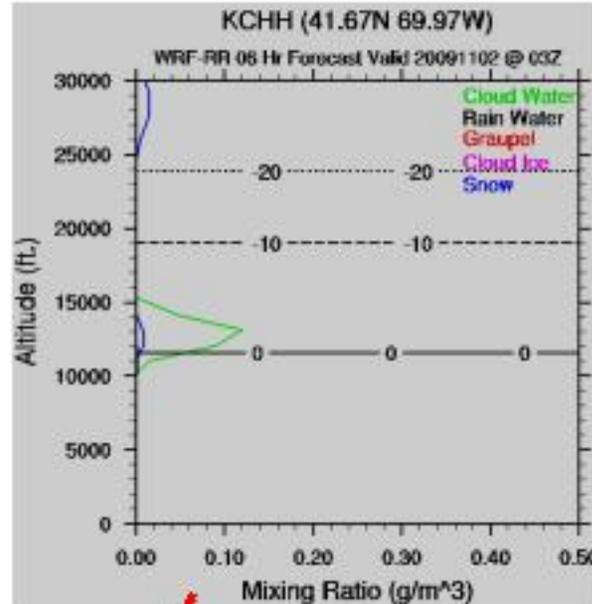
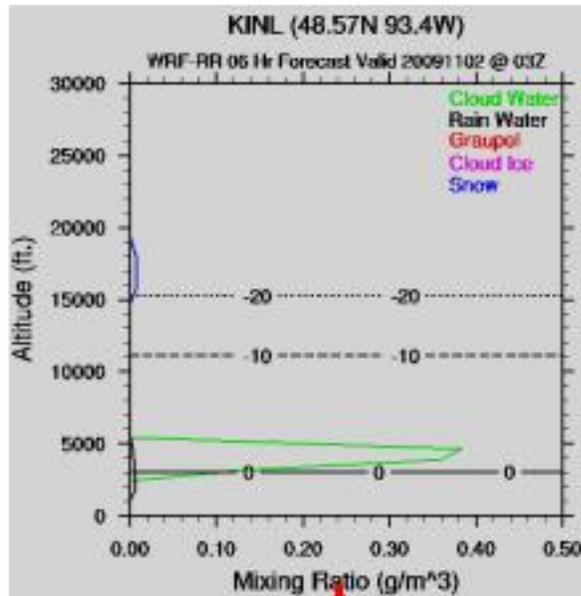
Subjective impressions for RR: Less graupel, more cloud ice and snow than in RUC version

Max supercooled cloud water (g/m^3)

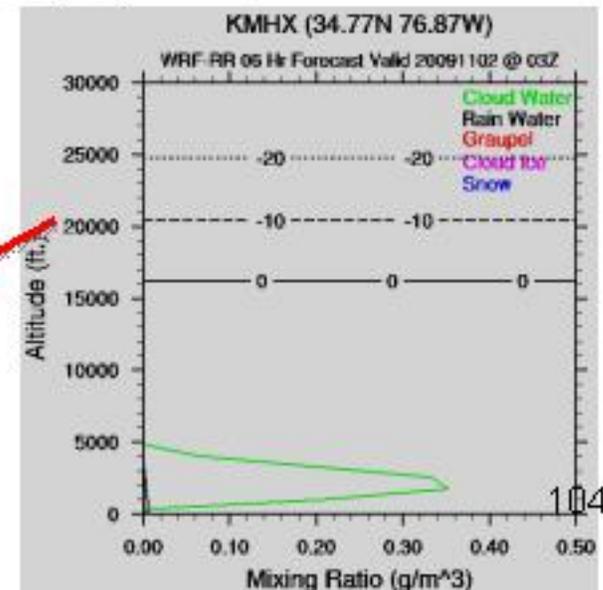
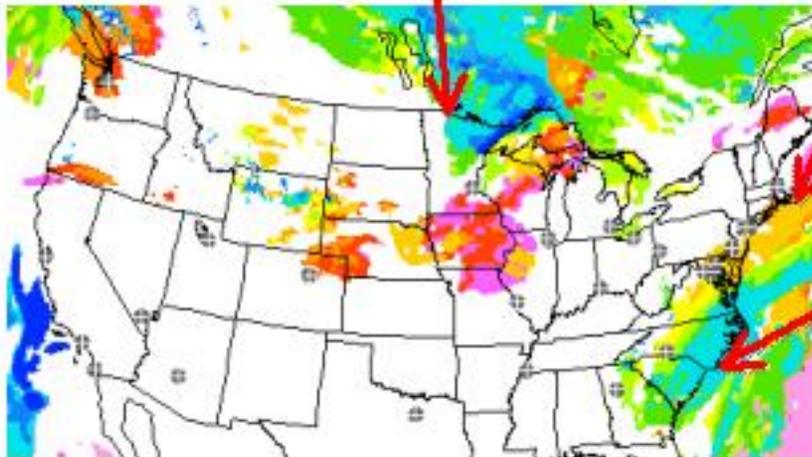
RR and RUC 6-h forecasts valid 03UTC 2 Nov 09



RR hydrometeor soundings from Cory Wolff, NCAR/RAL



6-h
forecasts
for 03UTC
2 Nov 09



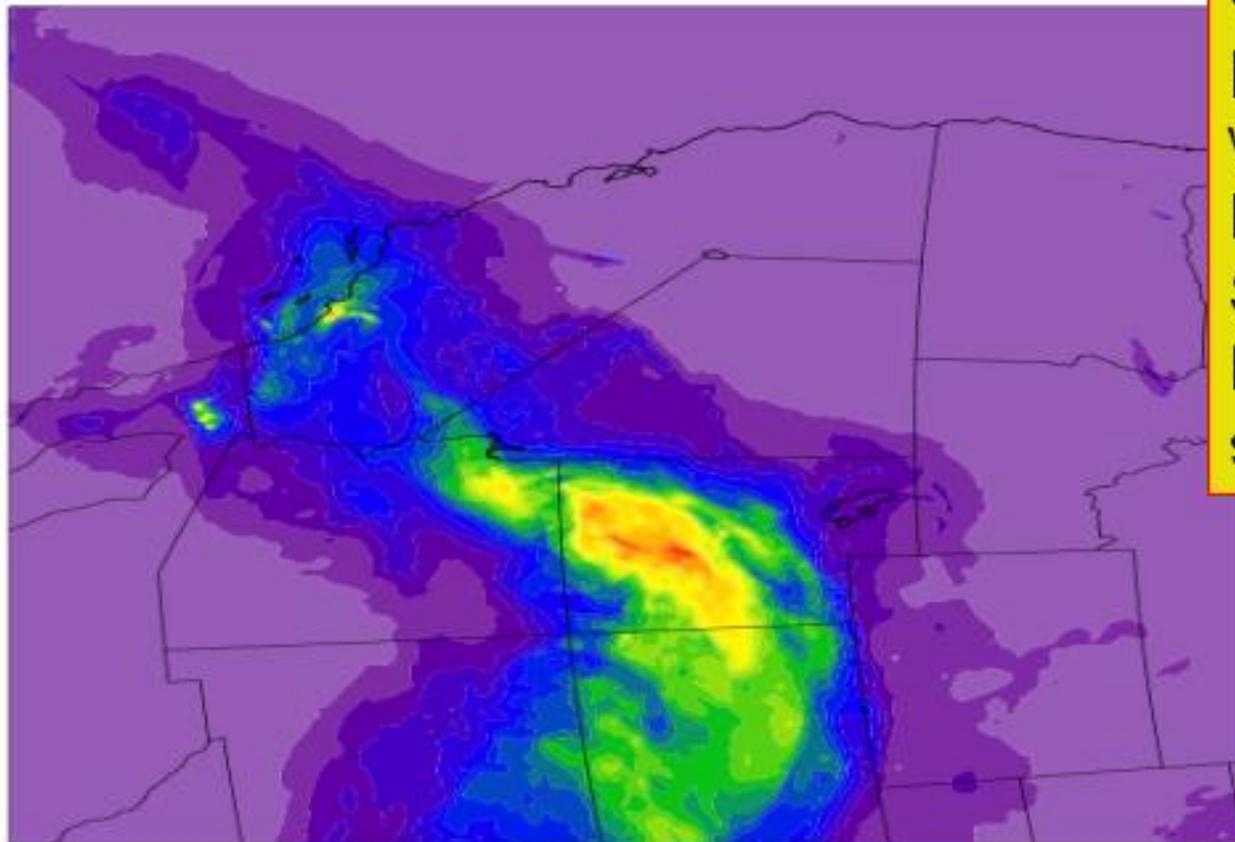
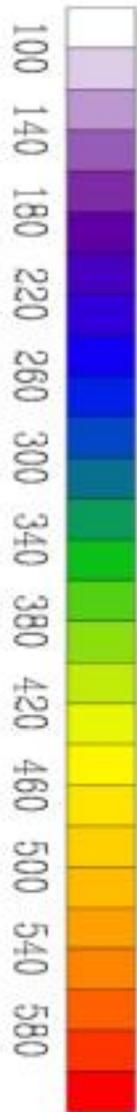
WRF-Chem and RR

Primary WRF-Chem development and coordination occurring in GSD (Georg, Steven, Mariusz)

Next few years: introduce simple version of WRF-Chem into the RR (or even HRRR) as a first step toward **integrated operational weather--air quality forecasting**

- **Aerosol direct effect on radiation** (e.g. solar direct-beam irradiance, surface temp forecasts)
- **Improved warm-rain and ice nucleation in microphysics** (aerosol indirect effects) for better cloud/precip forecasts (impact on ceiling, visibility, icing, surface temp)
- **First step:** RR-Chem put together by Steven and Tanya
 - * Once per day to 48h
 - * Aerosol cycling only

(HRRR-Chem Vertically Integrated Small Aerosol Concentration (relative units) 1200 UTC 2 Sep 2009



Sources are primarily wildfires, biggest in San Gabriel Mtns, southern CA

Rapid Refresh / RUC Technical Review - OUTLINE

- 1:30 – 1:45 RUC → RR transition overview,
NCEP RUC changes – 2008-09- Stan Benjamin
- 1:45 – 2:00 Observation impact experiments
- TAMDAR aircraft obs w/ moisture, larger OSE
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– physics, cloud, chemistry, PBL
John Brown, Tanya Smirnova, Joe Olson
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Curtis Alexander
- 3:20 – 3:30 Future of RR/HRRR/ens Stan Benjamin

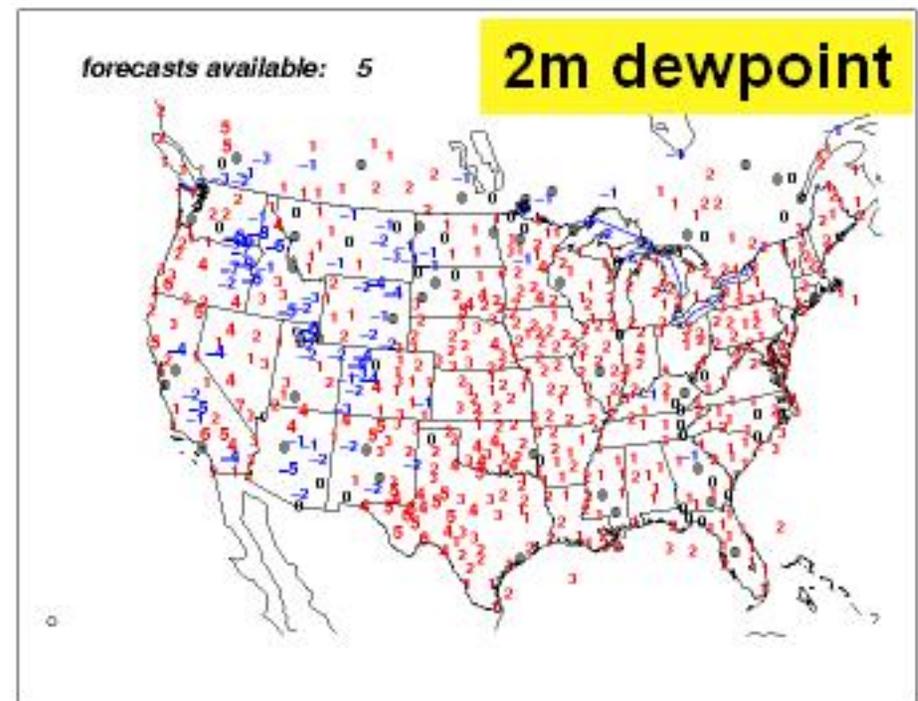
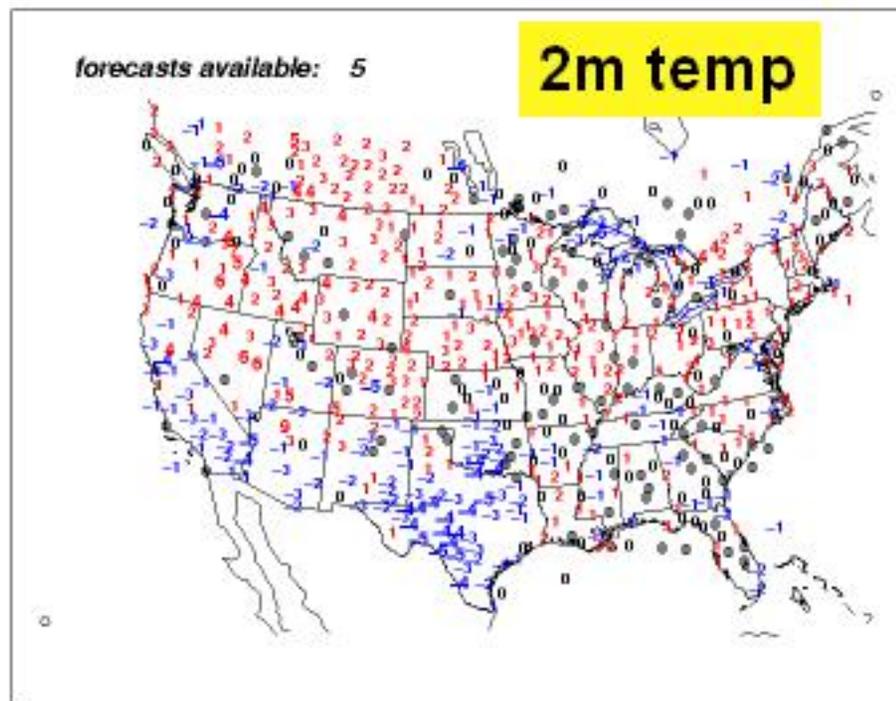
Typical Nighttime Surface Errors within the Rapid Refresh

Weekly composites of fcst hr 06 for all 00Z cycles during 20090813-20.

Error = F-O

RR Mean 2-m Temp Bias (C) 20090813-20090820 00Z FHR:06

RR Mean 2-m DewPt Temp Bias (C) 20090813-20090820 00Z FHR:06



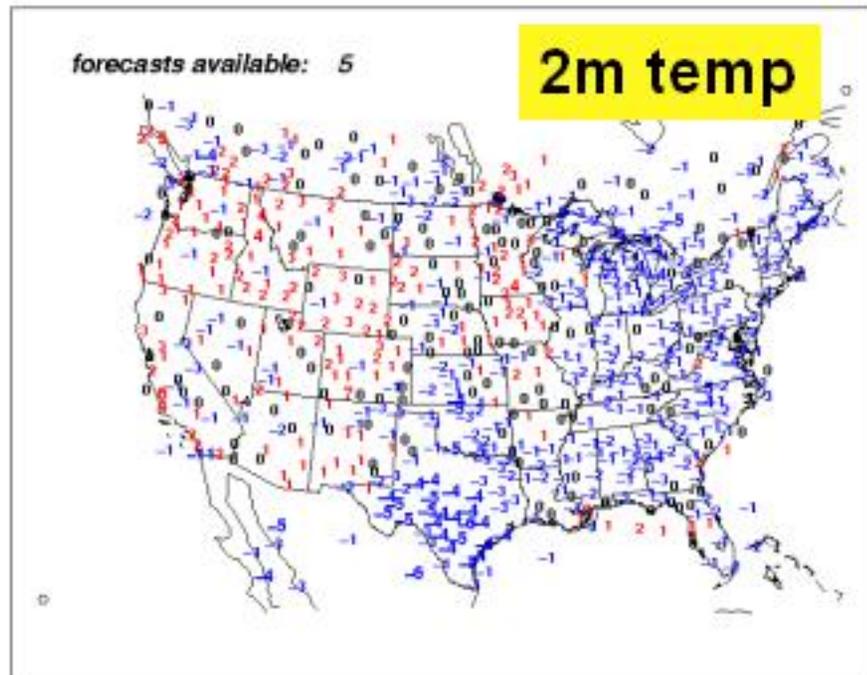
- RR (MYJ) is generally too warm at night over central plains.
- Dewpoint temperatures are typically too high at night.

Typical Daytime Surface Errors within the Rapid Refresh

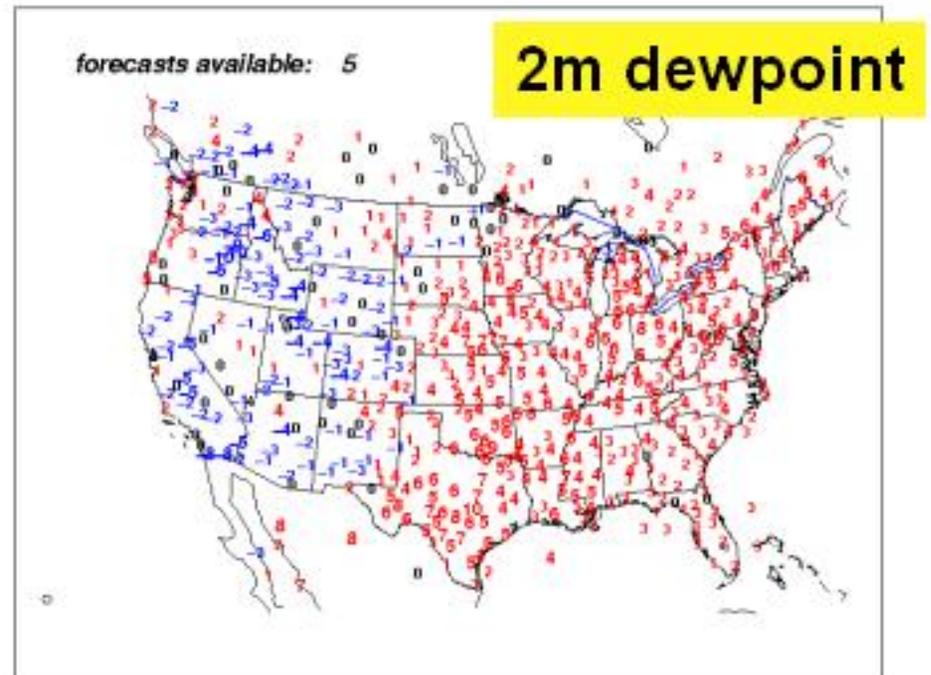
Weekly composites of fcst hr 06 for all 12Z cycles during 20090813-20.

Error = F-O

RR Mean 2-m Temp Bias (C) 20090813-20090820 12Z FHR:06



RR Mean 2-m DewPt Temp Bias (C) 20090813-20090820 12Z FHR:06



- RR (MYJ) is generally too cool during the day.
- Dewpoint temperatures remain too high during the day.

Investigating the source of surface errors with focus on PBL physics

When transitioning from RUC to RR, a similar TKE-based PBL scheme was chosen, the MYJ:

Model biases commonly reported in the literature (Zhang and Zheng 2004, Li and Pu 2008, among others):

- . Shallow PBL height.
- . Low surface temperature bias (too cool).
- . Positive surface moisture bias (too moist).

Alternative PBL schemes available in WRF-ARW:

YSU

- First-order bulk scheme.
- Includes a countergradient term to parameterize nonlocal mixing.
- Explicit entrainment which is proportional to surface buoyancy fluxes.
- Stronger vertical mixing may alleviate the bias found in the MYJ.

MYNN

- 2.5 and 3.0 level closure.
- The master length scale is a function of 3 independent length scale (turbulent, surface layer, and stable layer).
- Updated stability functions
- Condensation Module.
- Similar physics as MYJ, but tuned to LES simulations for more aggressive vertical mixing.

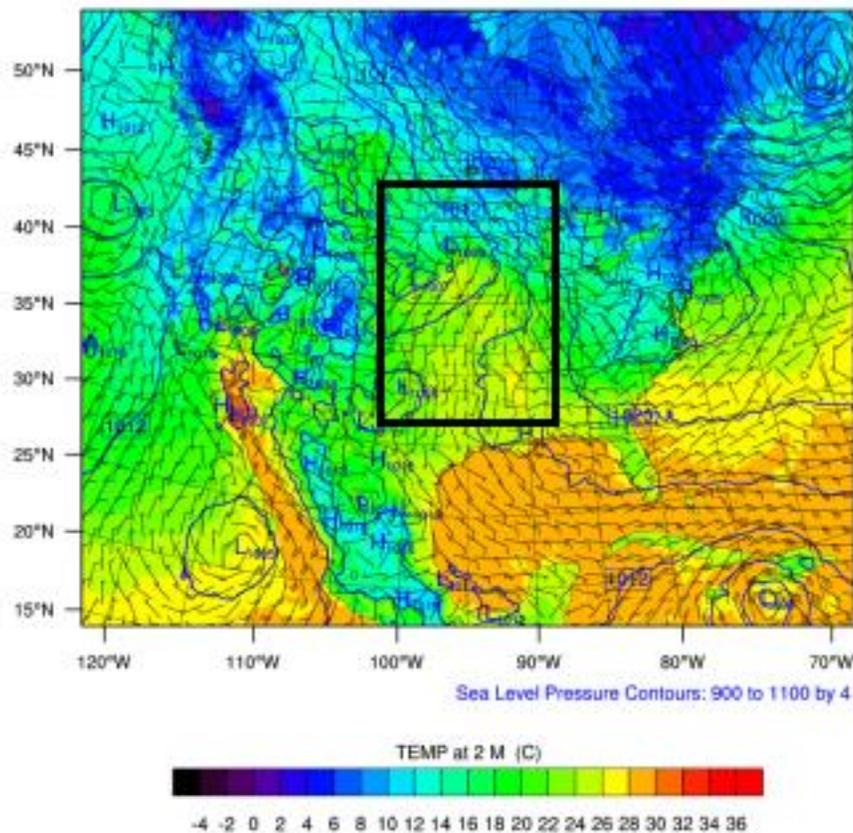
QNSE

- 2.5 level closure; similar to MYJ in neutral-unstable conditions, but in stable conditions, QNSE scheme is activated.
- Turbulent eddies and waves are treated as one entity in the stable regime.
- Similar physics as MYJ, but enhanced treatment of stable nocturnal boundary layer.

PBL Scheme Testing

New candidate PBL schemes need to show skill across RR domain and reduce biases compared with MYJ. Given recent interest in the RR (and HRRR) for wind energy applications, low-level jets and coastal jet cases are good tests for the new PBL schemes.

LLJ case(s) of 20070818-19



WRF-ARW Configuration (v3.1.1):

13.2 and 3.3 km grid spacing

51 vertical levels

RUC LSM

Grell-3 Cumulus Scheme

Thompson Microphysics Scheme

RRTM LW Radiation, Dudhia SW radiation

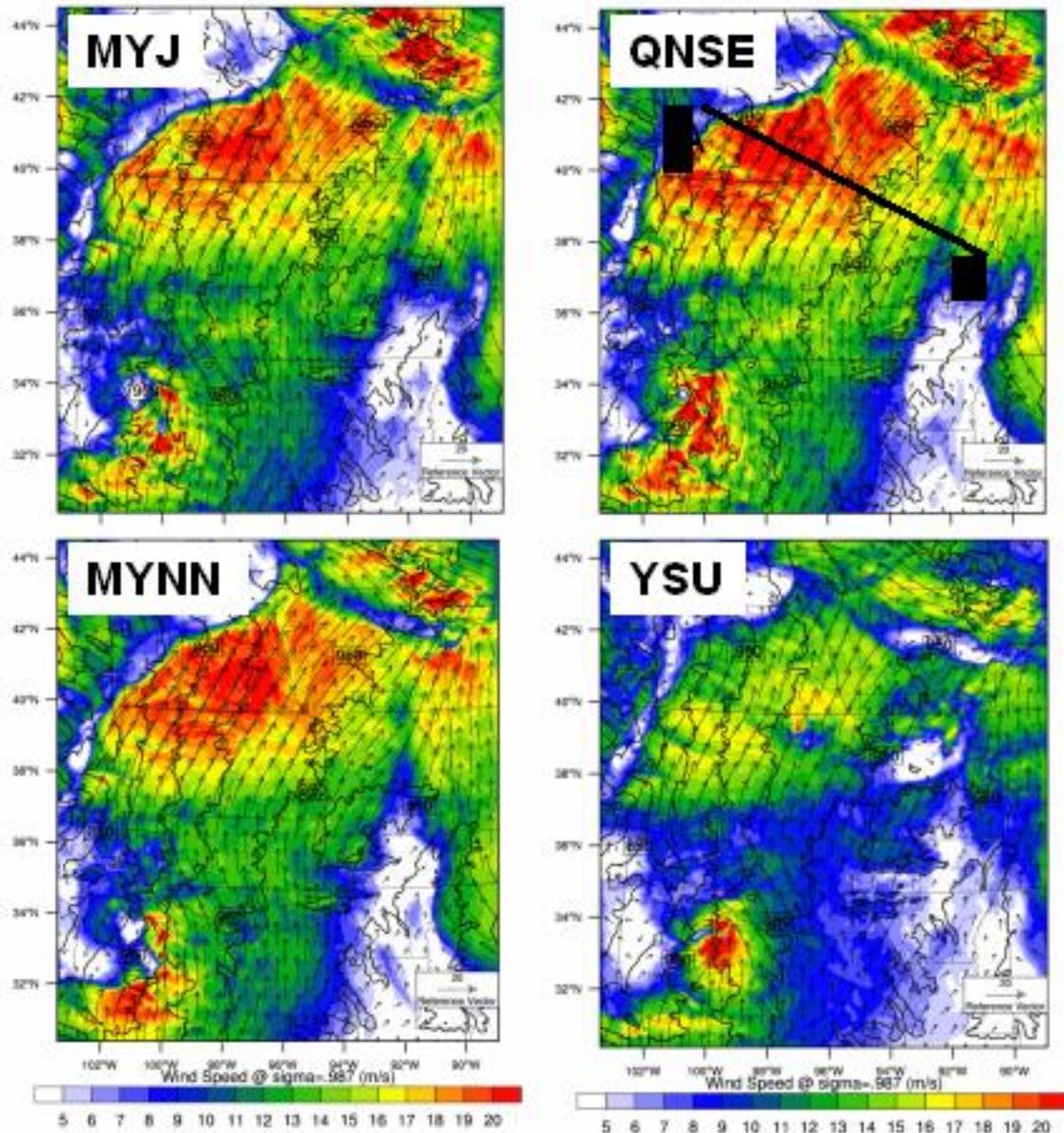
MYJ/MYNN/QNSE/YSU PBL

Initial Conditions:

GFS 6-hourly analyses

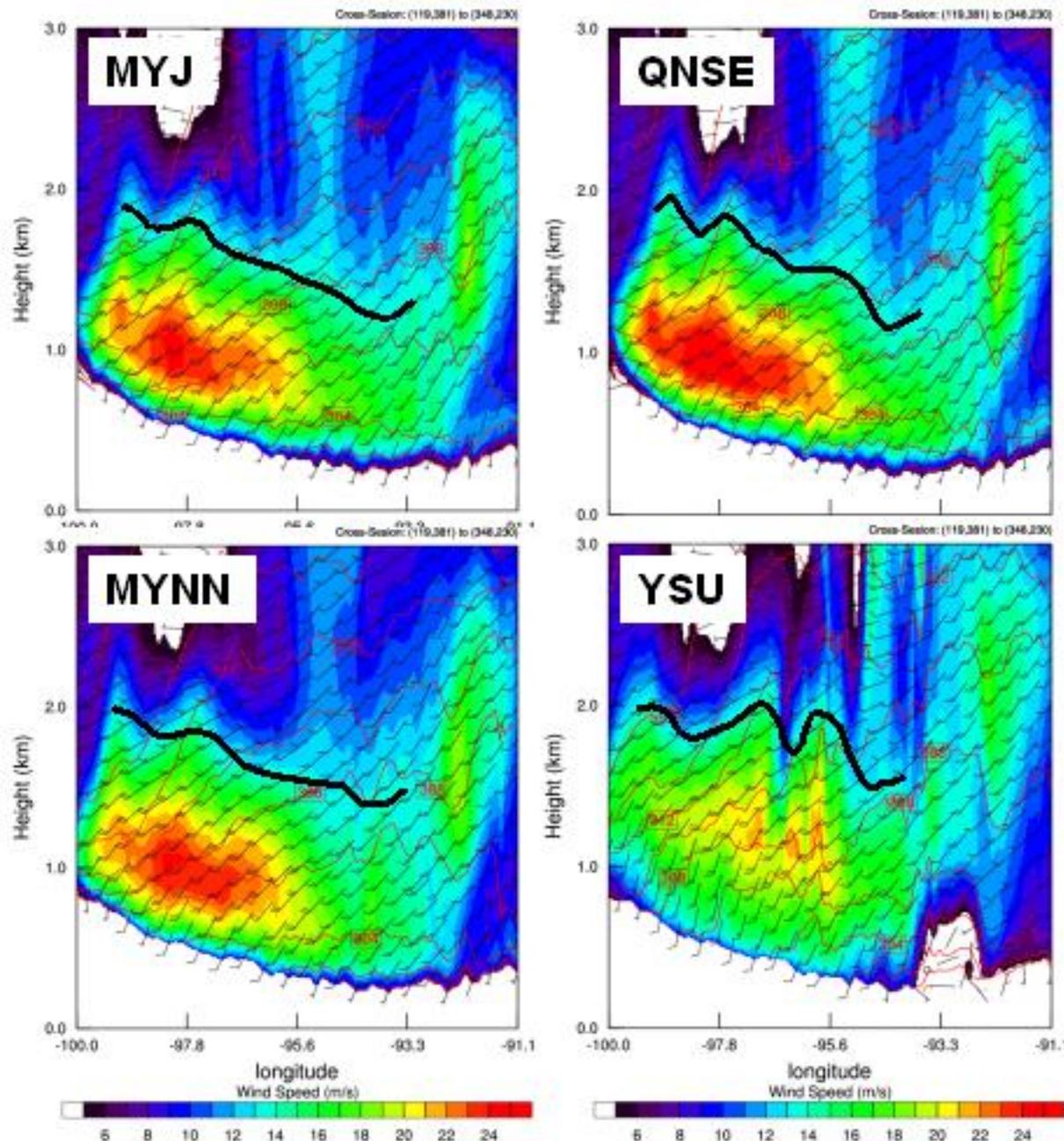
(Actual RR configuration covers all of North America)

100-m wind speed @ 09Z 20070819



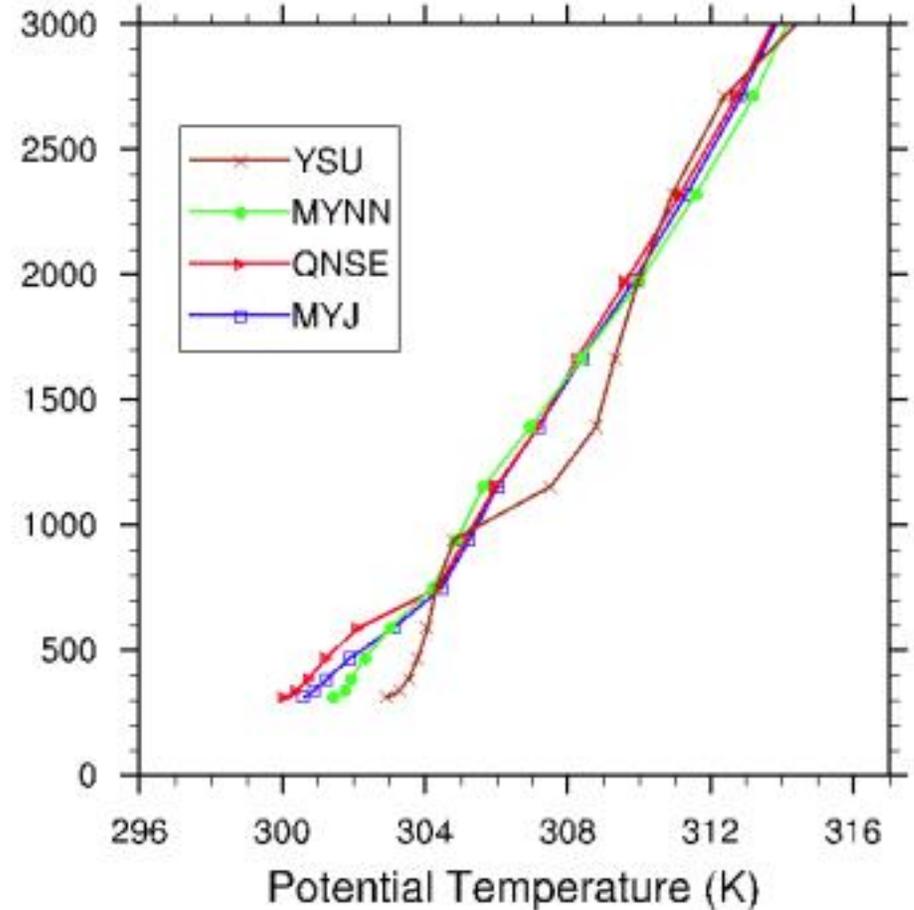
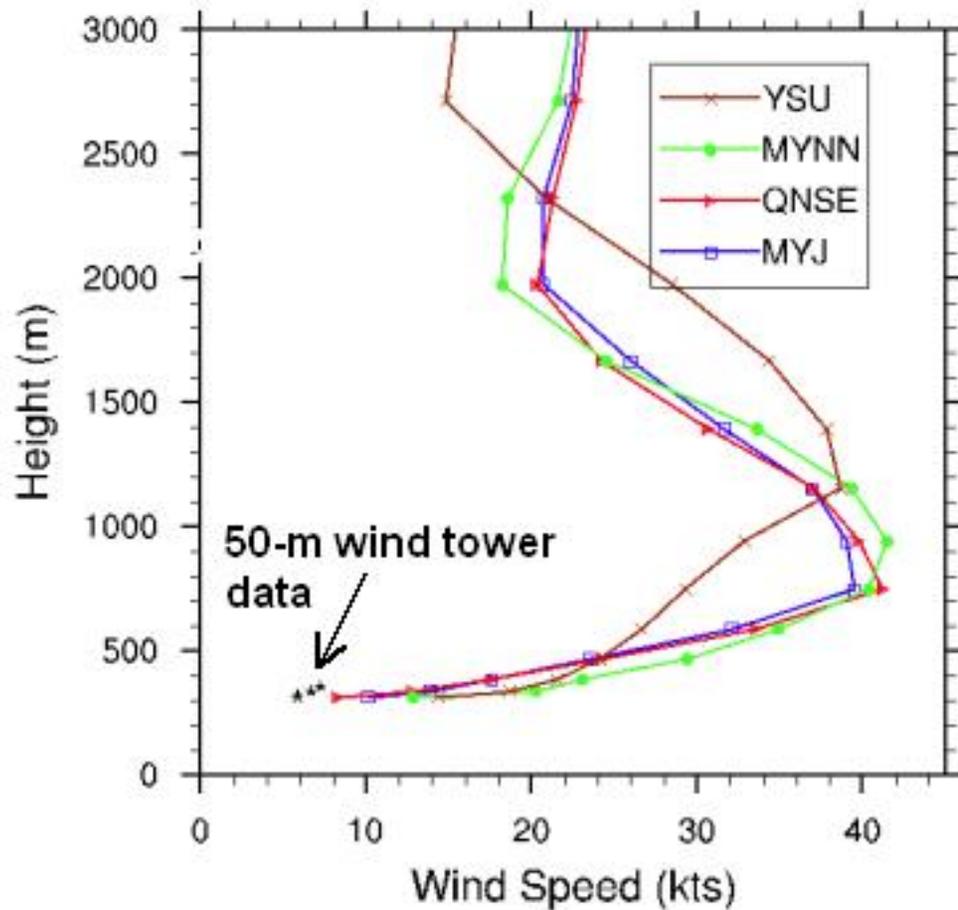
- Spatial extent of high wind speeds is similar in all TKE-based schemes.
- QNSE produces the strongest LLJ, generally 1 m/s stronger than MYJ.
- YSU has the weakest LLJ at the turbine height.

Vertical cross-section @ 09Z



- QNSE produces the strongest and widest LLJ.
- YSU has the weakest and most vertically diffuse LLJ.
- Of the 3 TKE-based schemes, the MYNN has stronger vertical mixing, with the jet top ~100 m higher than MYJ or QNSE.
- Strength of daytime vertical mixing is similar in rank, but has more variation (not shown).

Profile comparison @ 09Z 20070819



Performance across the CONUS region @ 21Z (afternoon) 20070818

Eastern U.S. (east of 100° W)

		TMP	TD	WSP
MYJ	Bias	-0.29	0.79	0.46
	MAE	2.73	2.34	1.52
MYNN	Bias	-0.22	0.07	0.66
	MAE	2.75	2.15	1.75

Western U.S. (west of 100° W)

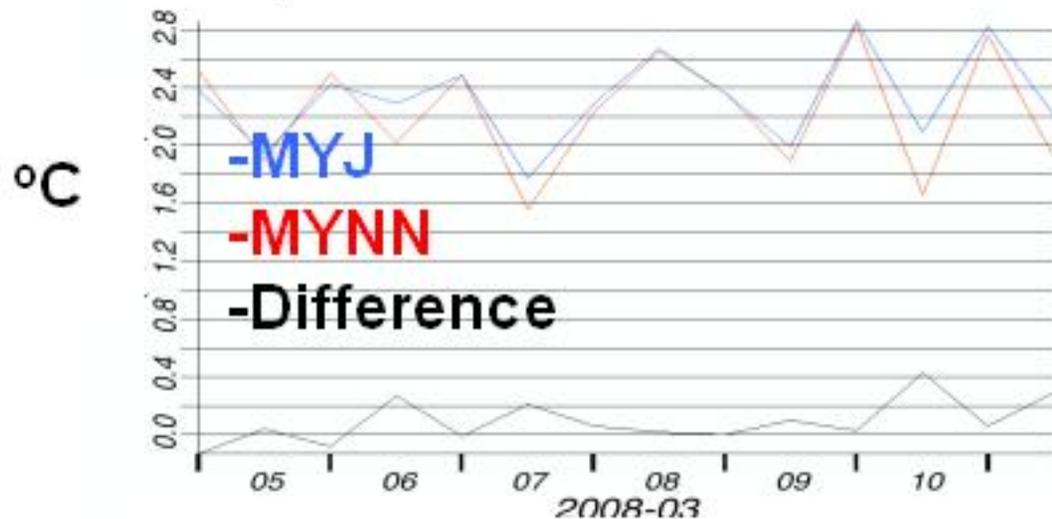
		TMP	TD	WSP
MYJ	Bias	-1.99	0.87	-0.99
	MAE	3.19	2.74	1.96
MYNN	Bias	-1.25	0.04	0.37
	MAE	3.21	2.46	1.96

Note: **Bold** denotes notably better performance

Statistics calculated from ~1500 surface stations.

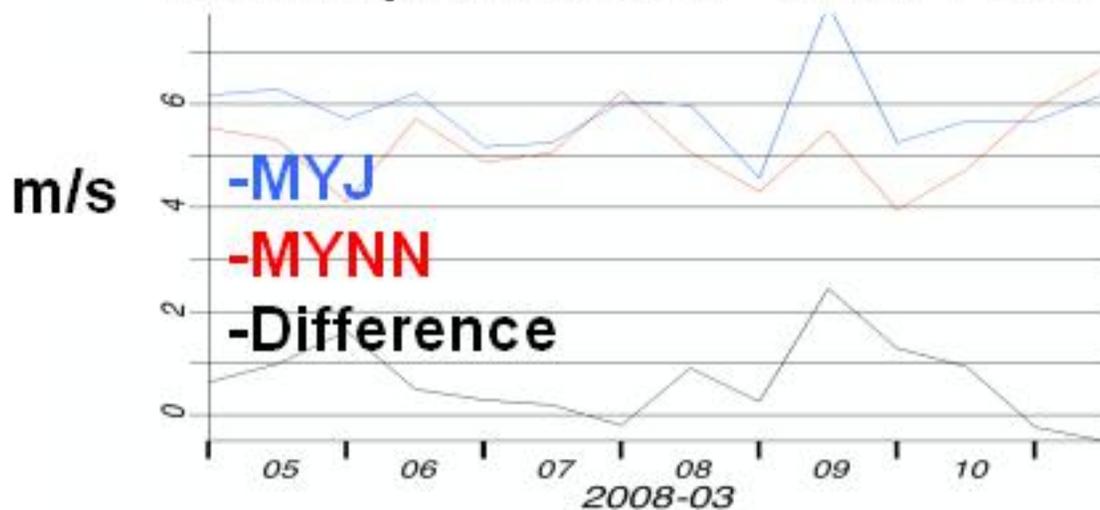
CONUS 900-1000 mb verification for retro-test period 05-10 March

Temperature RMSE 12HR FCST



- MYNN outperformed MYJ over the entire CONUS boundary layer.
- However, upper level winds were slightly better predicted by MYJ (not shown).
- Modifications to MYNN mixing length may remove this problem. New retro test is in queue.

Wind Speed RMSE 12HR FCST



Summary

- All TKE-based schemes simulate a strong LLJ, while the bulk scheme (YSU) vertically mixes the momentum more strongly.
- The MYNN had slightly stronger vertical mixing compared to MYJ and QNSE, but less than YSU.
- The MYNN generally alleviated the common biases associated with the MYJ, resulting in a slightly warmer and drier surface.
- Other coastal barrier jet case studies (SARJET) show similar relative behavior between the PBL schemes tested (not shown).
- Subject to more testing, the modified MYNN PBL scheme is a candidate for use in a future version of the Rapid Refresh.

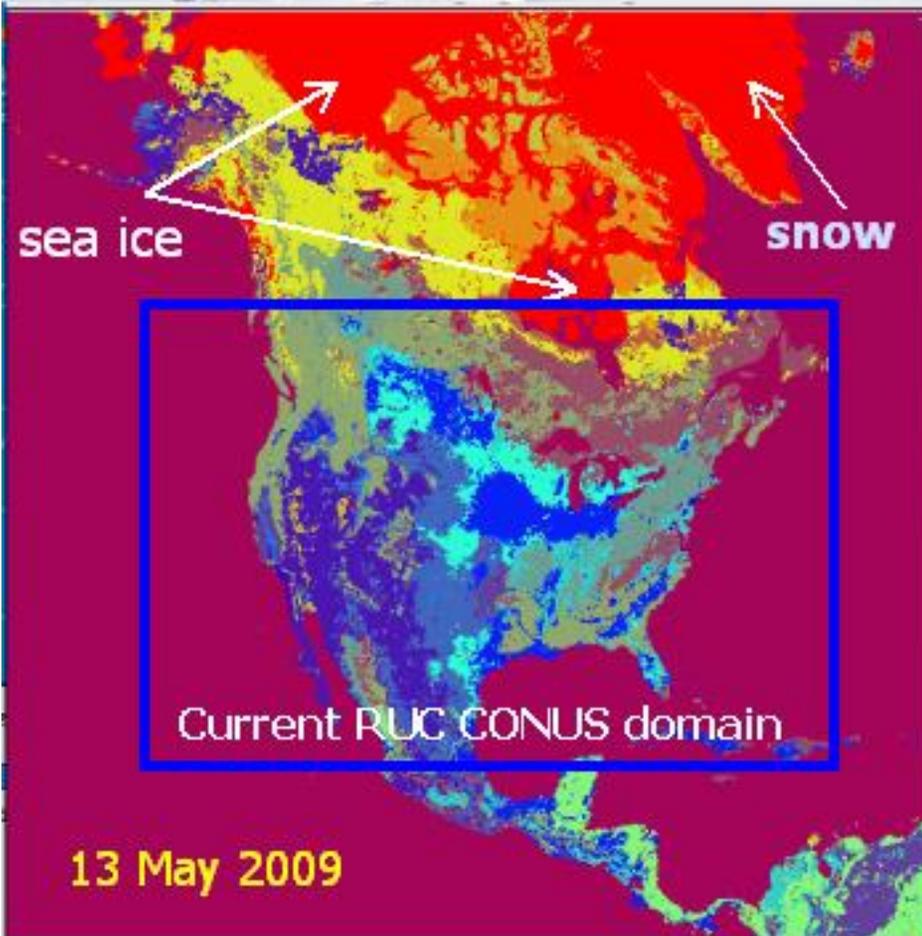
Future work

- Examine surface fluxes and near surface mixing of all PBL schemes. Simulations will be compared with Iberdrola wind tower data.
- Assess the potential benefits of assimilating wind tower data into RR system.
- Verify the modified MYNN over retro-period.
- Help debug the TEMF PBL scheme (*Mauritsen et al. 2007 and Angevine 2005*) and add it to the test matrix of simulations.

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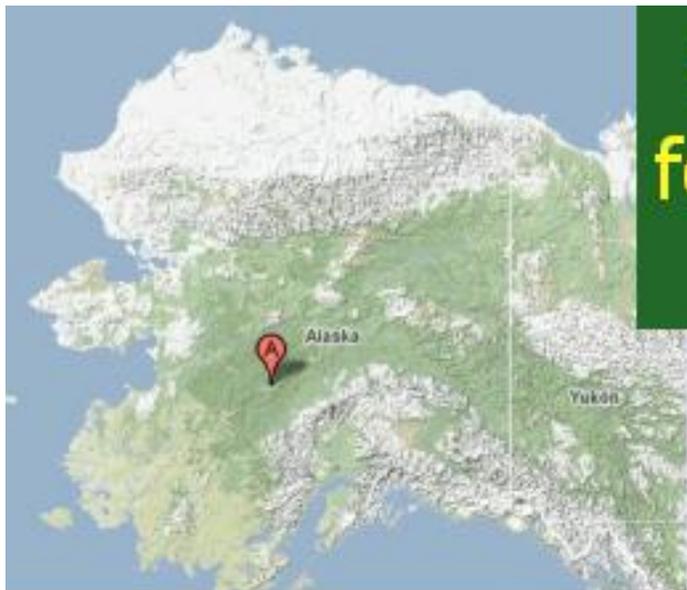
Challenges in parameterization of land surface processes in Rapid Refresh (RR)



RR land use types

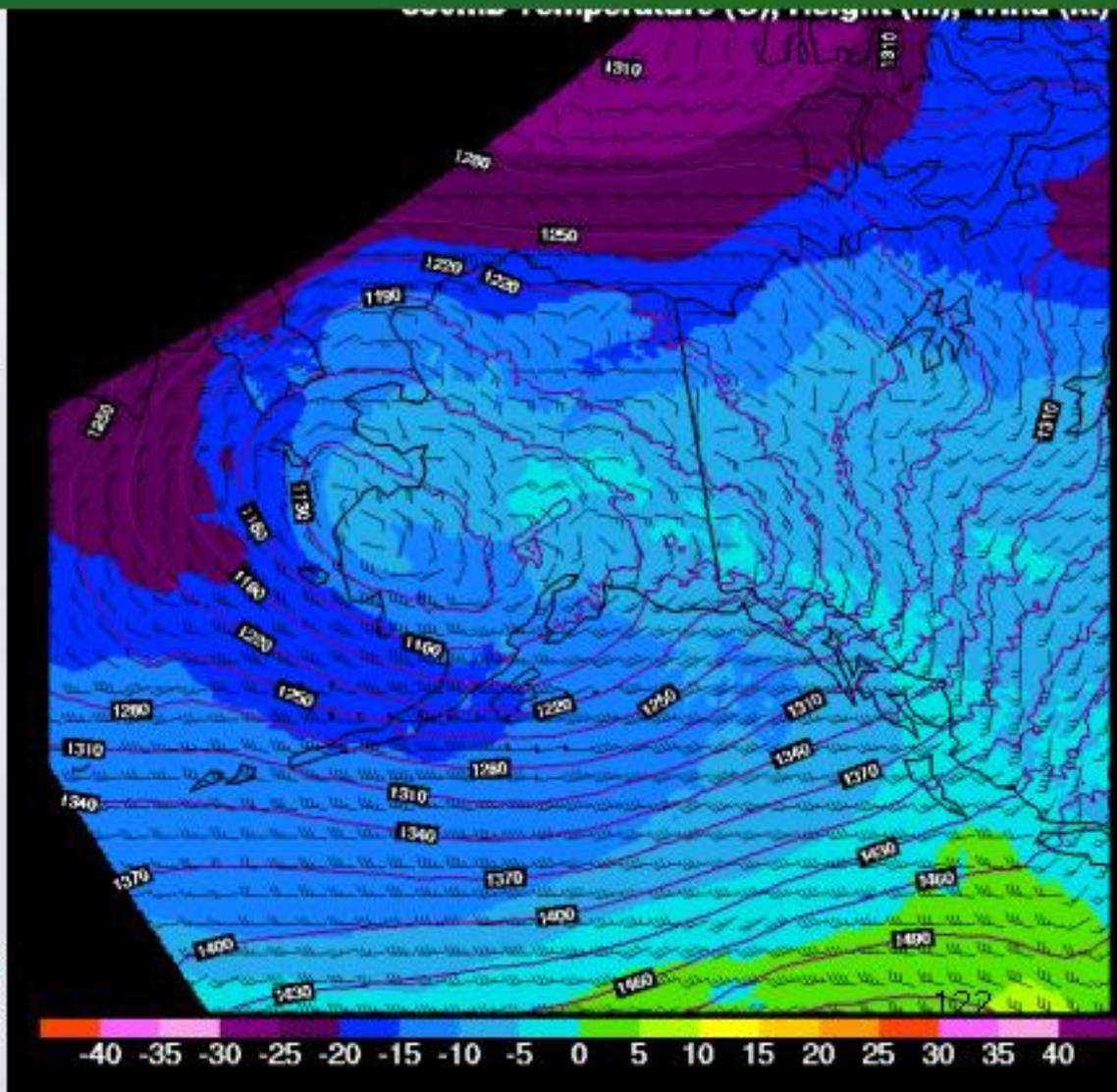
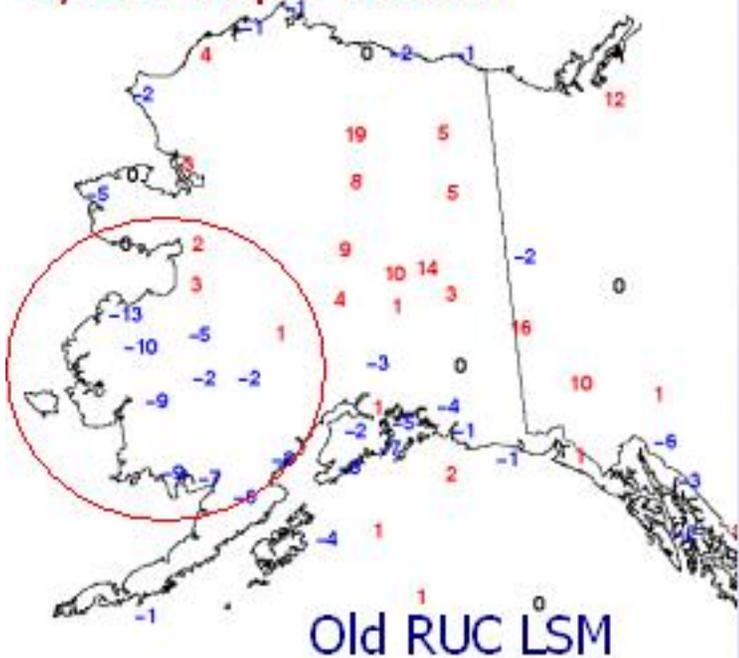
- RUC LSM validation and development for polar application in Canada and Alaska including extended permafrost tundra zones
 - new treatment for sea ice in RUC LSM
 - temperature dependence of snow and ice albedo
- Assimilation of satellite/in-situ data for snow depth, soil moisture, skin temperature
 - use of NESDIS snow/ice data to trim RR snow

2-m temperature verification for Alaska, 12h forecast valid at 12 UTC 30 March 2009



2-m Temperature Bias (C) INIT:2009033000 FHR:12

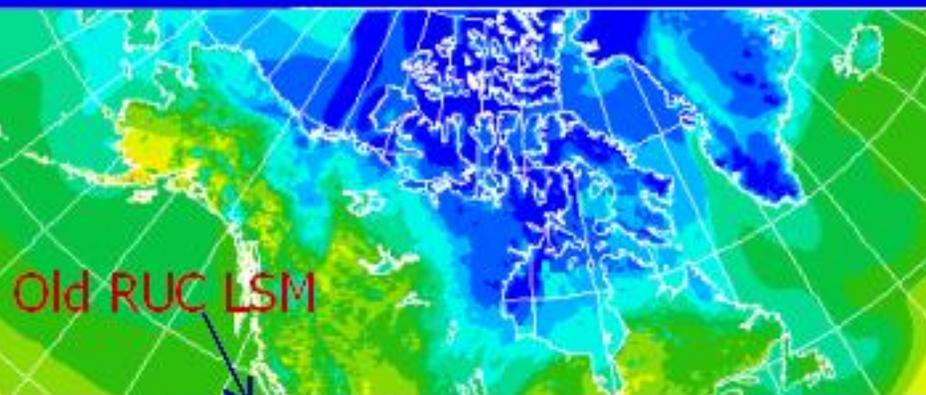
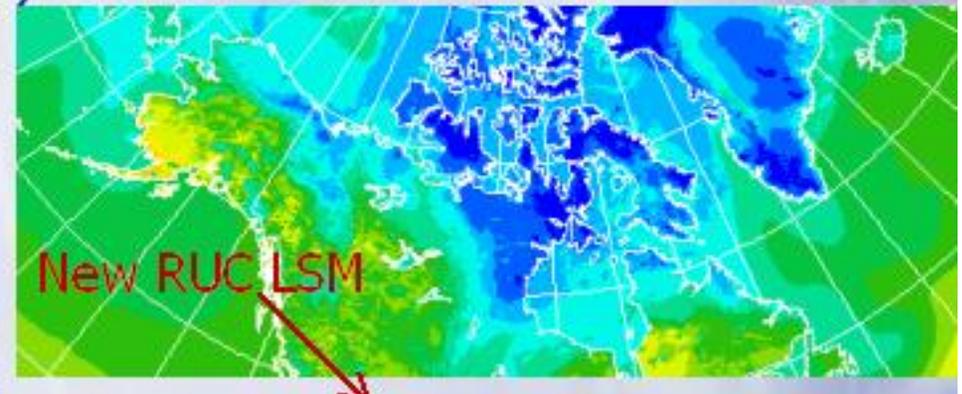
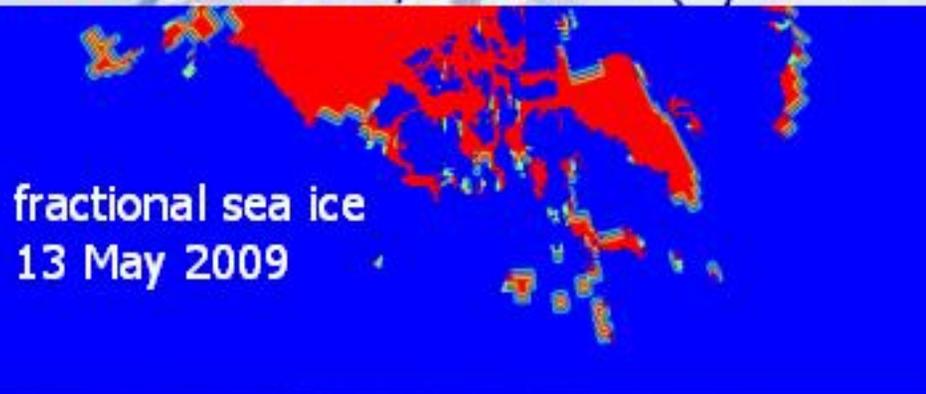
Cycled Rapid Refresh



New Treatment for Sea Ice in RUC LSM

Sea Ice is initialized in **RR** from **GFS** (cold-start RR) or from **NESDIS** snow/ice data (cycled RR)

RR 12-h forecasts of Skin Temperature
valid at 00 UTC 14 May 2009

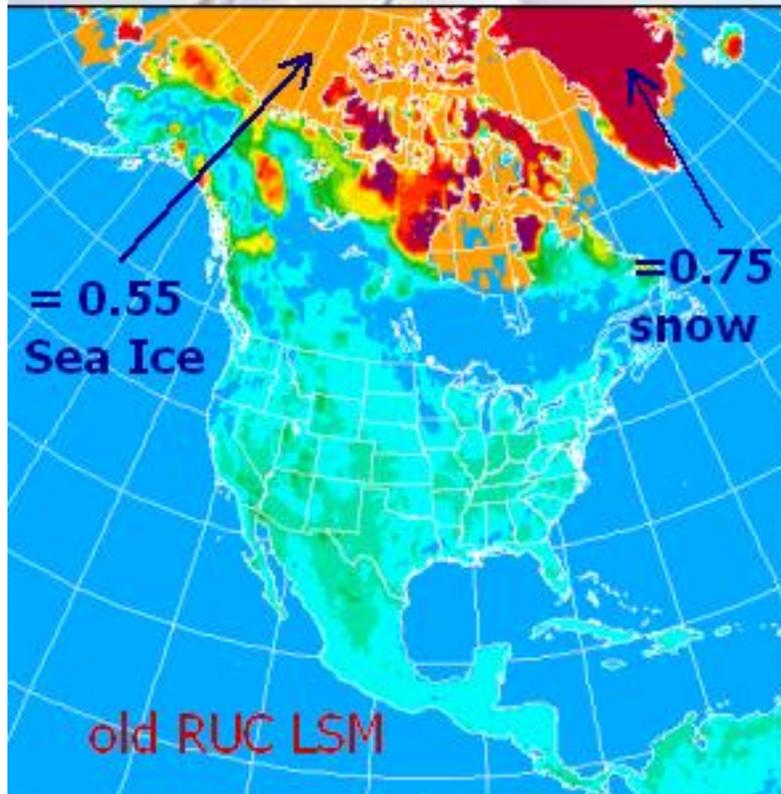


- Skin temperature is prescribed to be equal to temperature at the 1st atmospheric level
- No snow on sea ice

- Solution of surface energy budget and heat diffusion equation in ice
- Snow/Ice Albedo is a function of snow/ice surface temperature
- Snow accumulation on the sea ice surface
- No melting, drifting or building new sea ice
- Option of fractional sea ice

Albedo in Rapid Refresh

- Starts from NESDIS monthly climatological albedo interpolated to a current day
- Updates it for snow and ice using WRF maximum snow albedo data



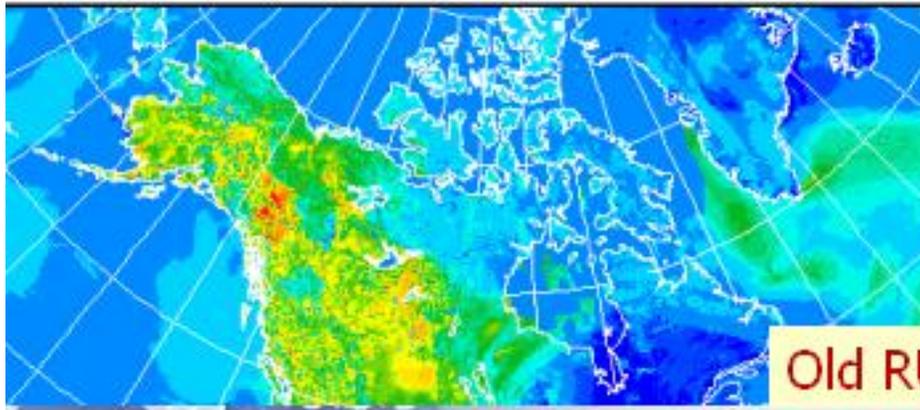
In both Old and New RUC LSM:
Snow albedo – “patchy” snow,
albedo reduced when
 $h_{\text{snow}} < h_{\text{crit}}$ (5-10 cm)



In New RUC LSM:
Snow/sea ice albedo is reduced when
 $T_{\text{snow/ice}} > -10 \text{ C}$
Minimum values for snow/ice when $T = 0 \text{ C}$

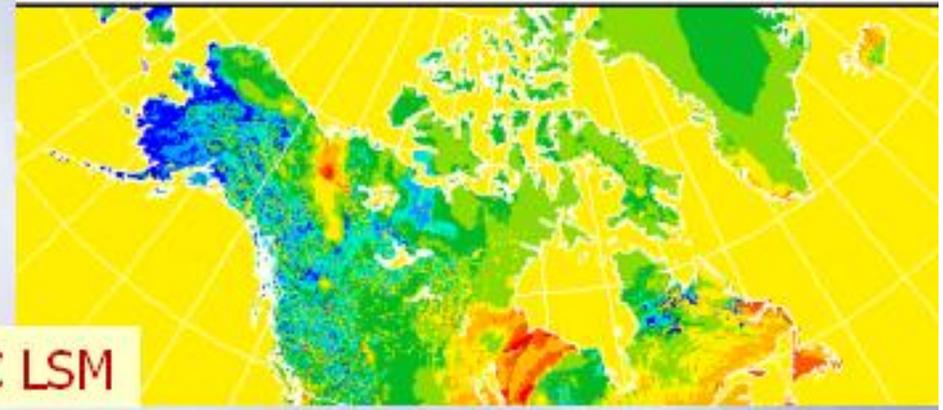
Surface Sensible and Ground Heat Fluxes

UPWARD HEAT FLUX AT THE SURFACE ($W m^{-2}$)

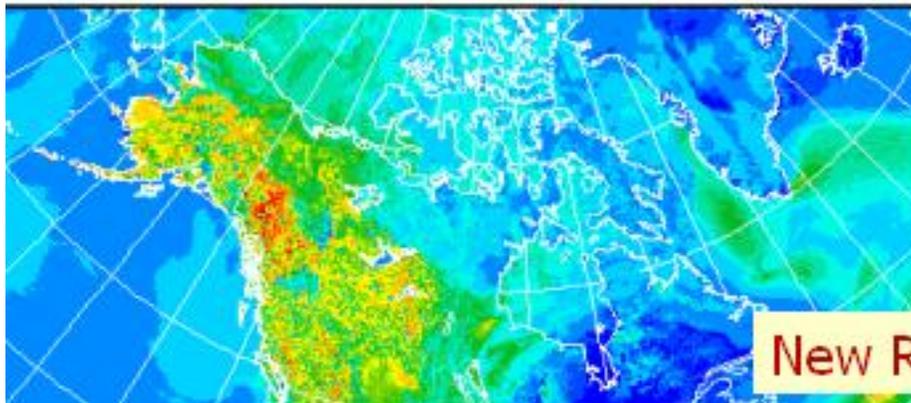


Old RUC LSM

GROUND HEAT FLUX ($W m^{-2}$)

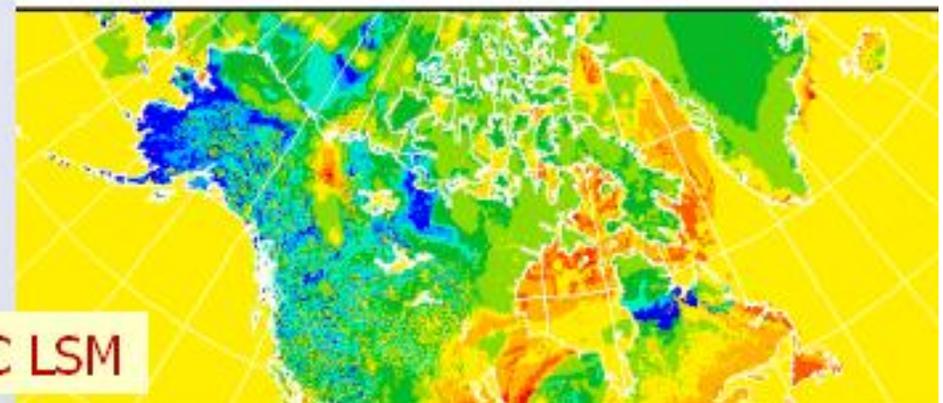


UPWARD HEAT FLUX AT THE SURFACE ($W m^{-2}$)

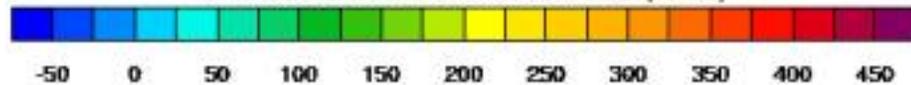


New RUC LSM

GROUND HEAT FLUX ($W m^{-2}$)



UPWARD HEAT FLUX AT THE SURFACE ($W m^{-2}$)



GROUND HEAT FLUX ($W m^{-2}$)



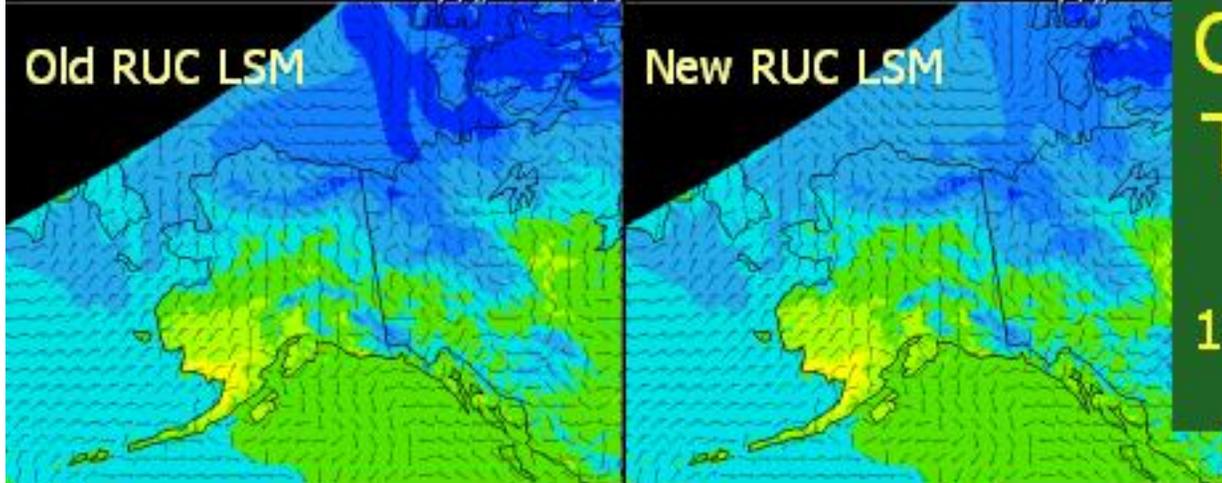
Cold-start RR 12-h forecast valid at 00 UTC, 14 May 2009

Old RUC LSM

New RUC LSM

Cold-start RR 2-m Temperature bias for Alaska

12-h forecast valid at 00 UTC
14 May 2009

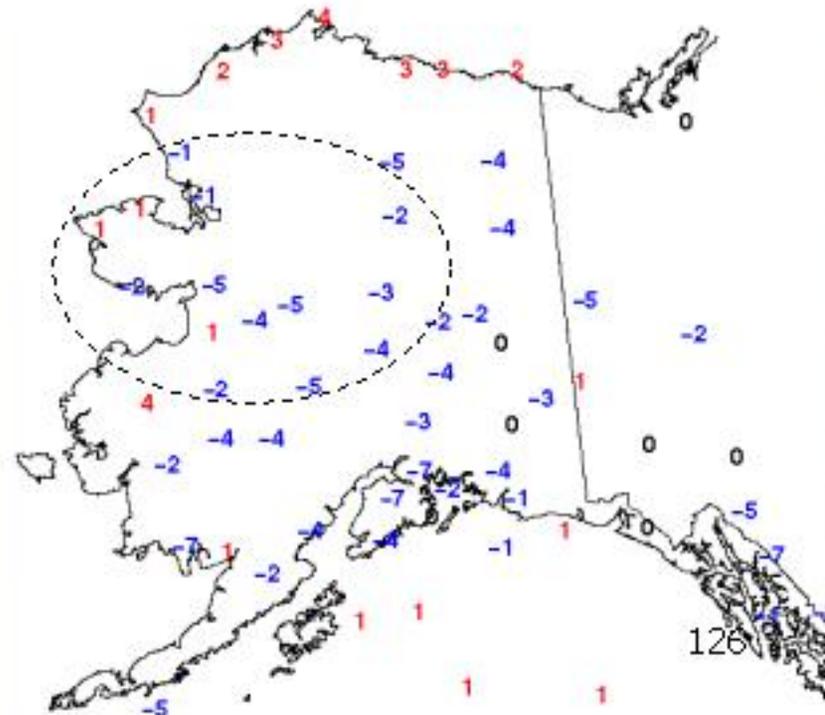
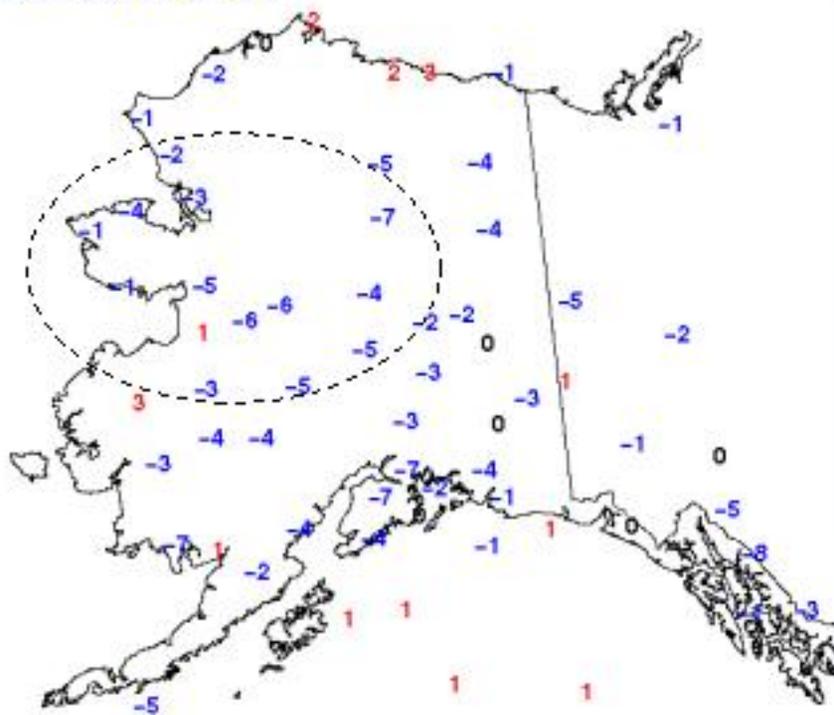


2-m Temperature Bias (C) INIT:2009051312 FHR:12

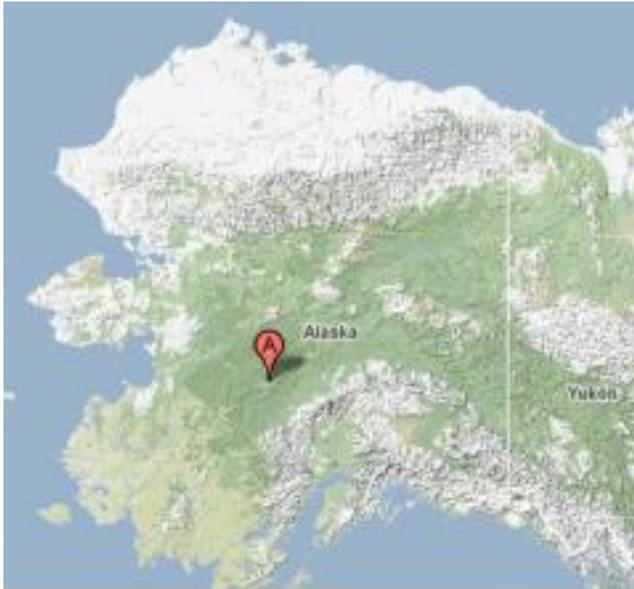
2-m Temperature Bias (C) INIT:2009051312 FHR:12

Old RUC LSM

New RUC LSM

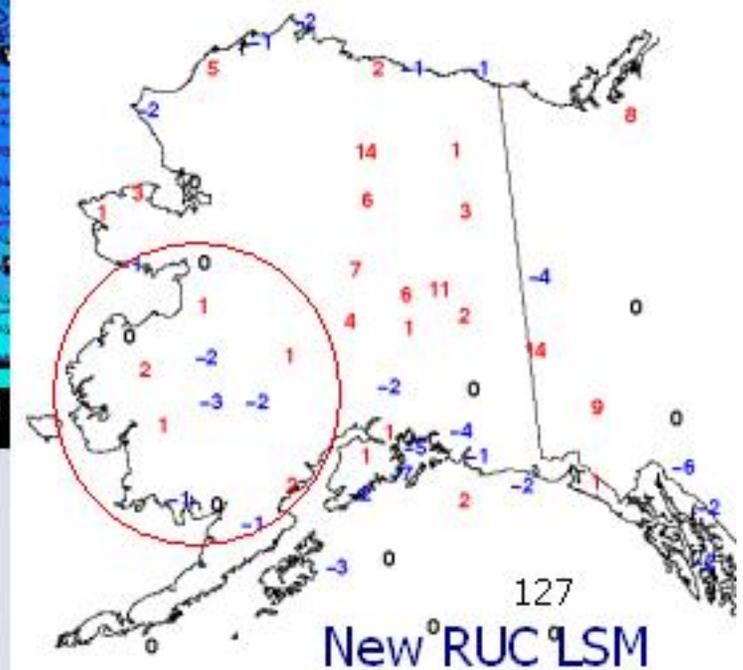
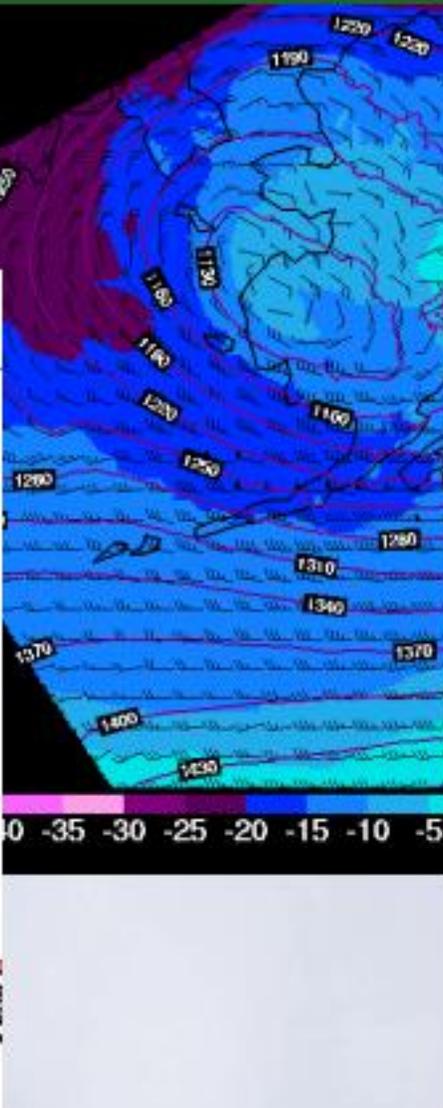
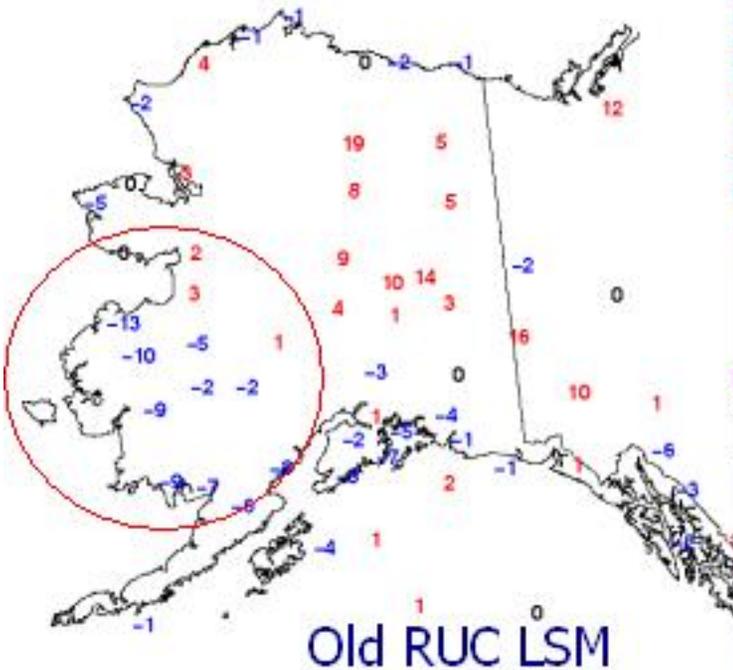


2-m temperature verification for Alaska, 12h forecast valid at 12 UTC 30 March 2009

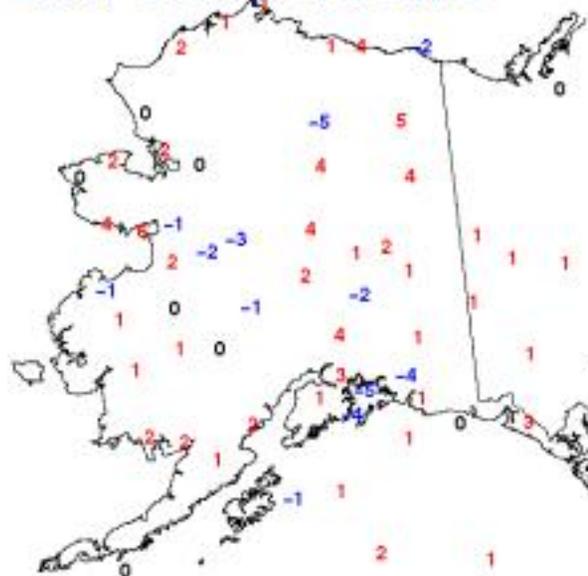


2-m Temperature Bias (C) INIT:2009033000 FHR:12

2-m Temperature Bias (C) INIT:2009033000 FHR:12



2-m temperature

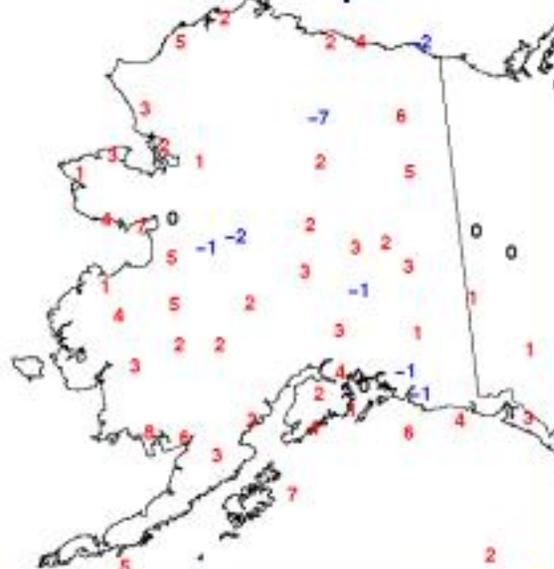


Cycled RR Surface Verification for Alaska

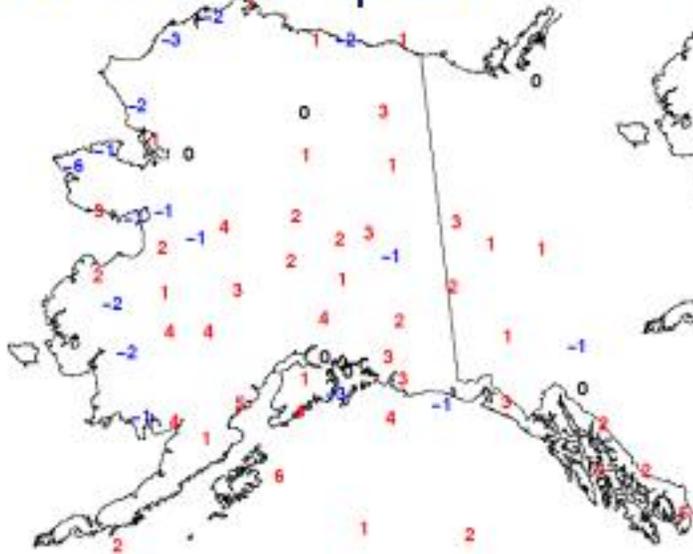
Cycling with New RUC LSM since 24 April 2009, modifications to surface diagnostics



2-m dew point



10-m wind speed



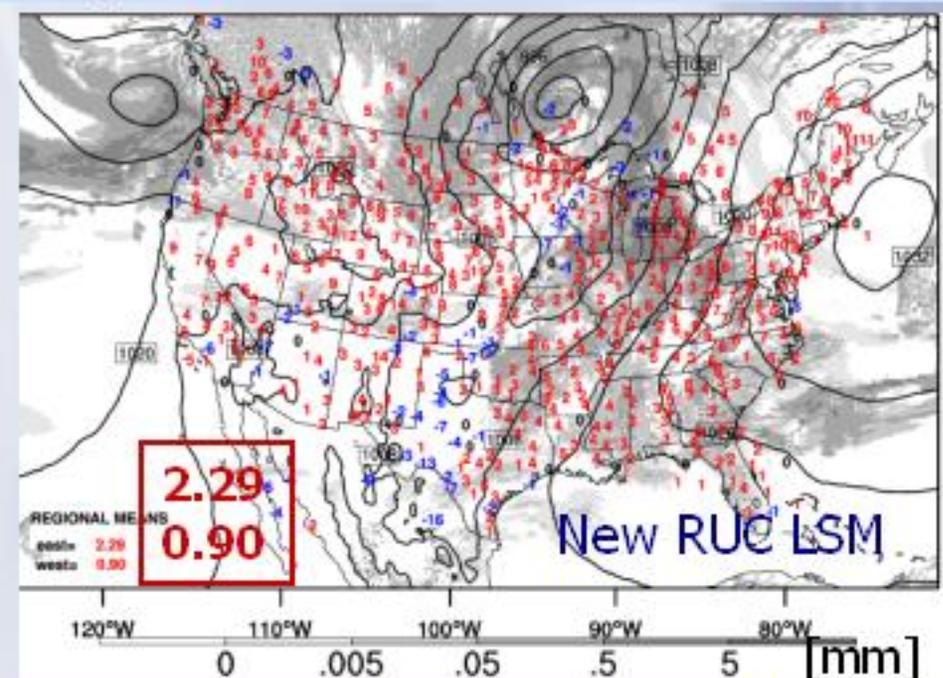
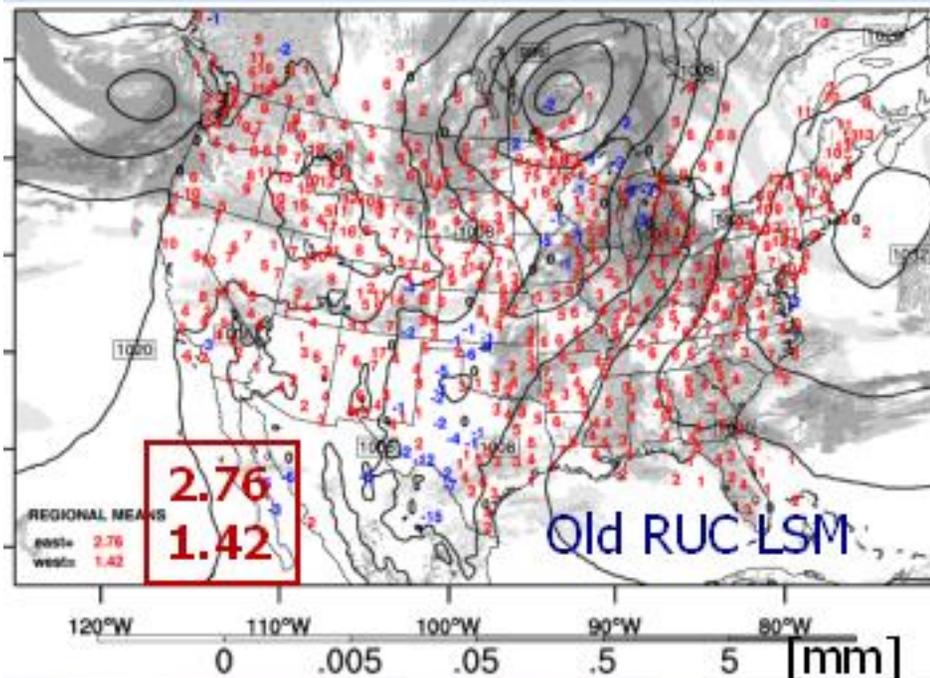
27 October 2009

Snow & Ice Chart (Alaska)
— snow
— ice
Tue Oct 27 2009

Valid at 00 UTC 27 October 2009

Cold-start RR 2-m dew point temperature verification

- Corrections to **RUC LSM** coupling with the PBL schemes in the **WRF** framework
- Mostly affected **moisture exchange** between ground surface and the atmosphere during the **daytime**



Shading - vertically integrated cloud water and ice mixing ratio

9-h forecast valid at 21 UTC 13 May 2009

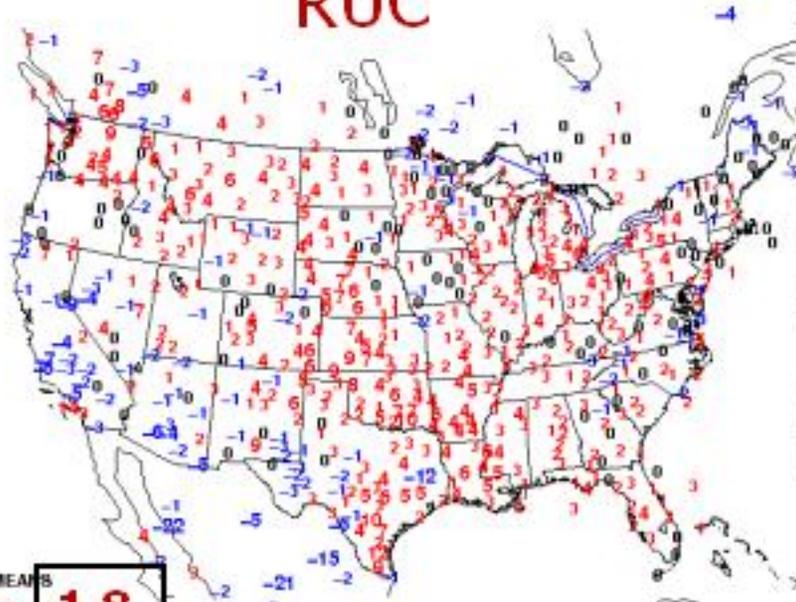
Cycled RR 2-m dew point verification compared to RUC

RR-1HRCYC 2-m Dewpoint Error (C) Fcst Hr 09

Int: 2009-10-31_12:00:00

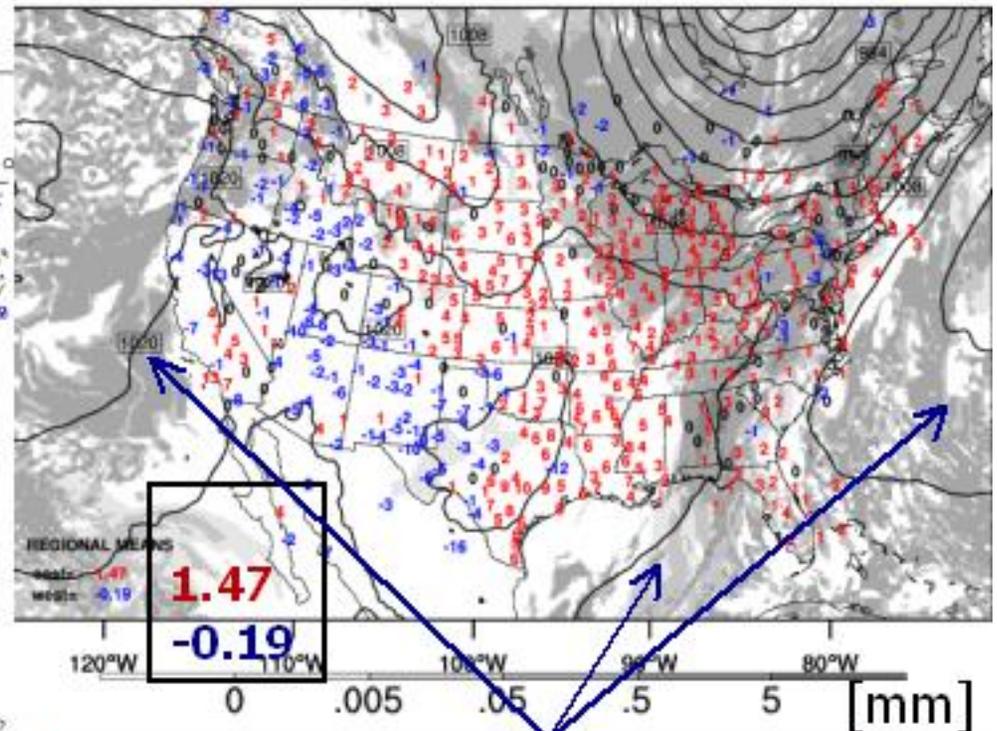
RUC 2-m Dewpoint Temperature Bias (C) INIT:2009103112 FHR:09

RUC



RR

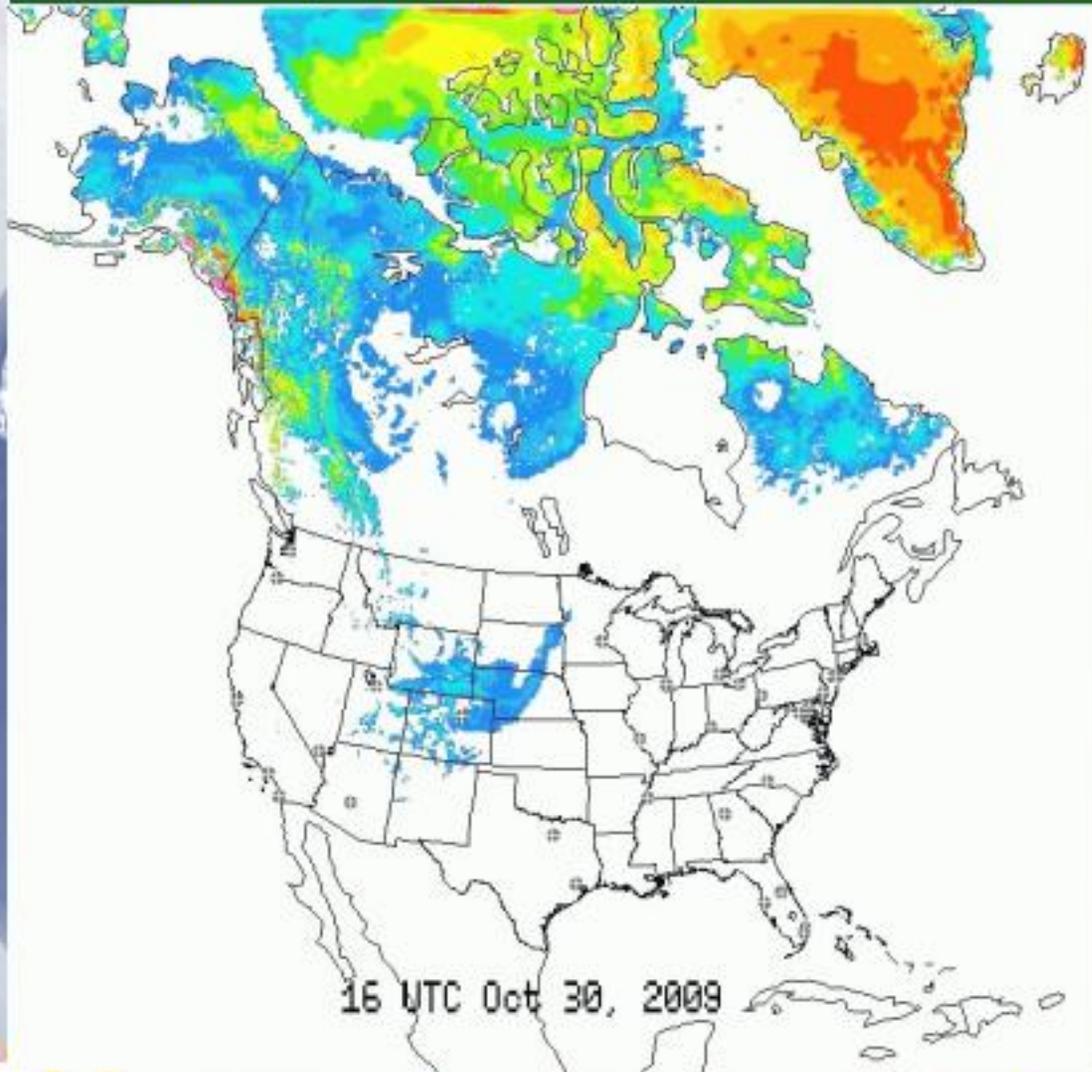
Vertically Integrated Cloud Mixing Ratio (kg m⁻³)
Sea Level Pressure (hPa)



Shading - vertically integrated cloud water and ice mixing ratio

Valid 21 UTC 31 October 2009

Snow cycling in 1-hour cycled Rapid Refresh



Start: 16 UTC October, 30 2009 End: 15 UTC November 1, 2009 (46 snapshots)

WRFPOST modifications

Added new diagnosed variables:

- MAPS Sea Level Pressure
- GSD Cloud bottom height
- GSD Cloud Top Height
- GSD visibility
- GSD Relative humidity
- Thompson Reflectivity

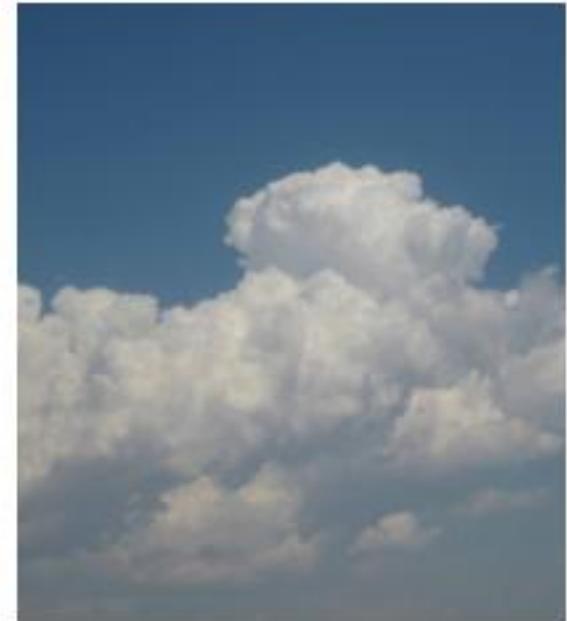
Collaboration with NCEP (Hui-ya Chang)
to get these modifications into **Unified
WRFPOST**

Rapid Refresh / RUC Technical Review - OUTLINE

- 1:30 – 1:45 RUC → RR transition overview,
NCEP RUC changes – 2008-09- Stan Benjamin
- 1:45 – 2:00 Observation impact experiments
- TAMDAR aircraft obs w/ moisture, larger OSE
Bill Moninger
- 2:00 – 2:20 Rapid Refresh overview, assimilation –
Steve Weygandt, Ming Hu
- 2:20 – 2:30 -- Break --
- 2:30 – 3:05 RR-WRF model development / testing
– physics, cloud, chemistry, PBL
John Brown, Tanya Smirnova, Joe Olson
- 3:05 – 3:20 The HRRR and HCPF (HRRR prob forecast)
Curtis Alexander
- 3:20 – 3:30 Future of RR/HRRR/ens Stan Benjamin

Very High Resolution Forecasts

- Deep moist **convection** has **low predictability**, partly because it occurs on **small spatial** and **temporal** scales
- Convective **parameterization** in RUC and RR **not sufficient** to reproduce convective-scale structures and evolution
- Need **hourly-updating convection-resolving model** that can assimilate convective-scale observations -- especially radar -- given **sufficient computing resources**



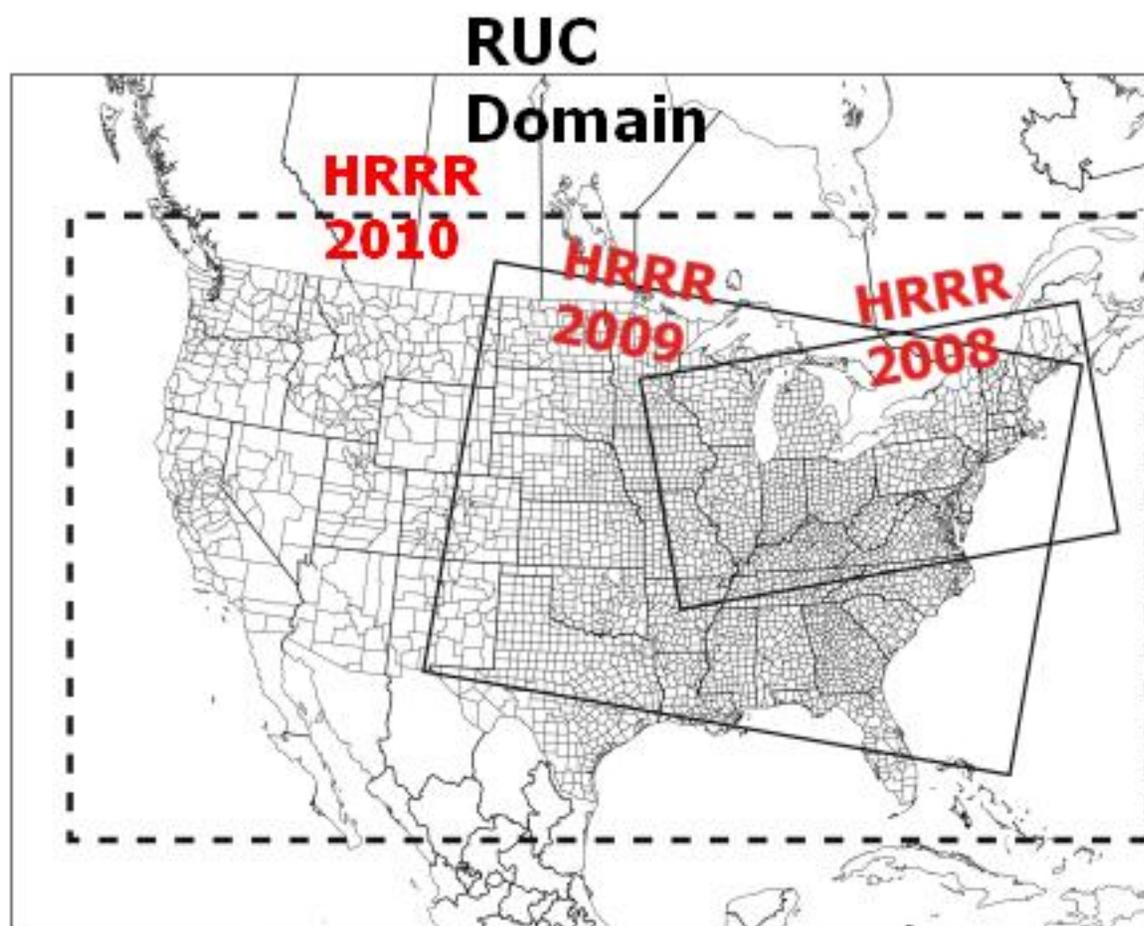
The HRRR

High-Resolution Rapid Refresh (HRRR)

- WRF-ARW dynamic core (same configuration as RR but without convective parameterization)
- **Convection resolving** using 3.0 km horizontal grid spacing
- **Hourly initialization**, 0-12 hr forecasts produced (2 hr latency)
- Initial conditions from same-cycle hourly 13 km RUC (RUC13)
- Boundary conditions provided via previous-cycle RUC13

- RUC13 hourly assimilation cycle uses a diabatic digital filter initialization (DDFI) for **assimilation of observed radar reflectivity** to **adjust mass** (temperature tendency) and **associated momentum fields** (divergence) without adjusting hydrometeor distribution

HRRR Domain(s)



September 2007

Initial HRRR domain over the northeastern United States "aviation corridor"
745 x 383 grid points, 200 processors

March 2009

Domain expanded to cover approximately eastern 2/3 of the US
1000 x 700 grid points, 568 processors

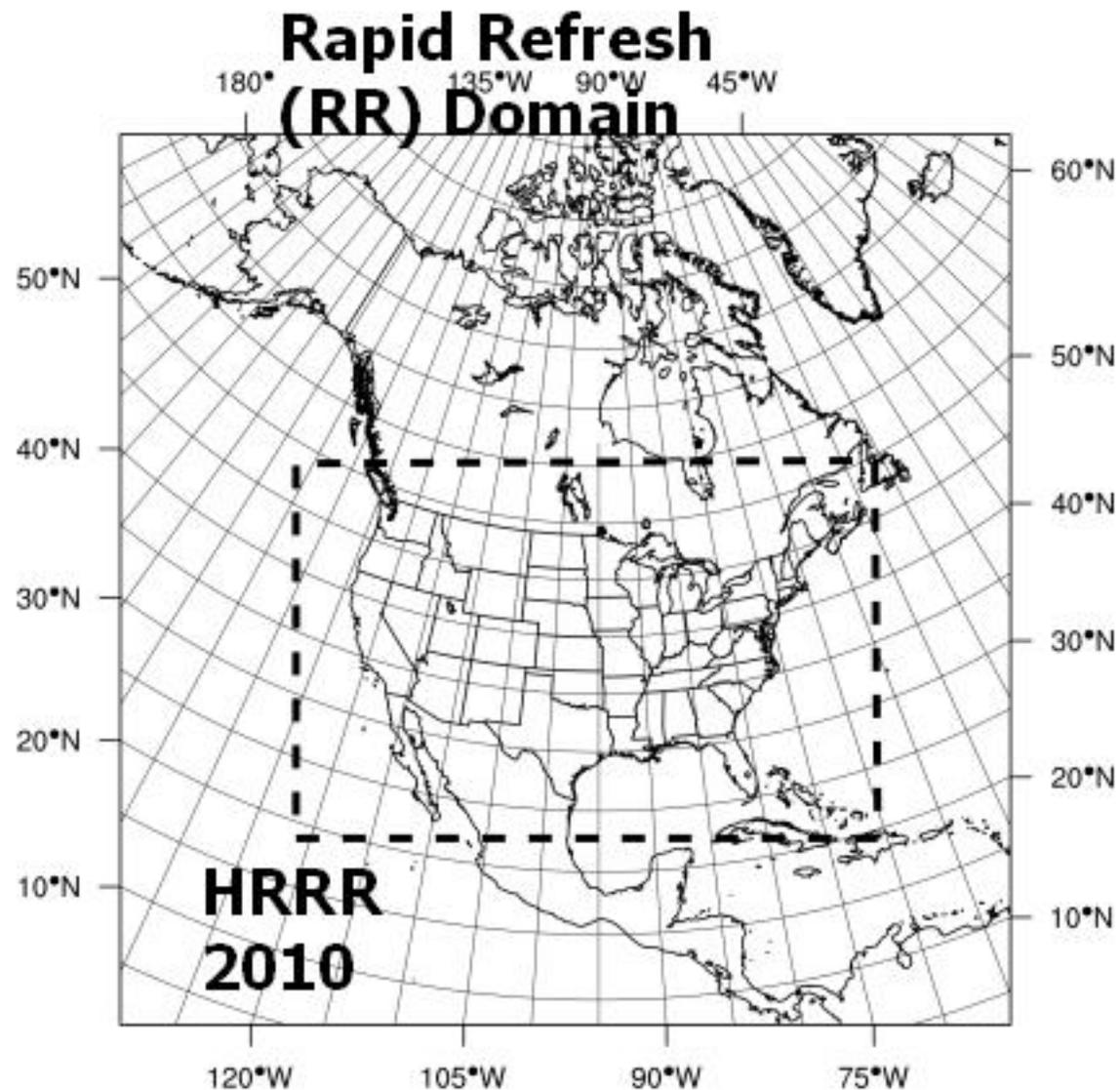
October 2009

Domain expanded to cover CONUS
1800 x 1060 grid points, 840 processors

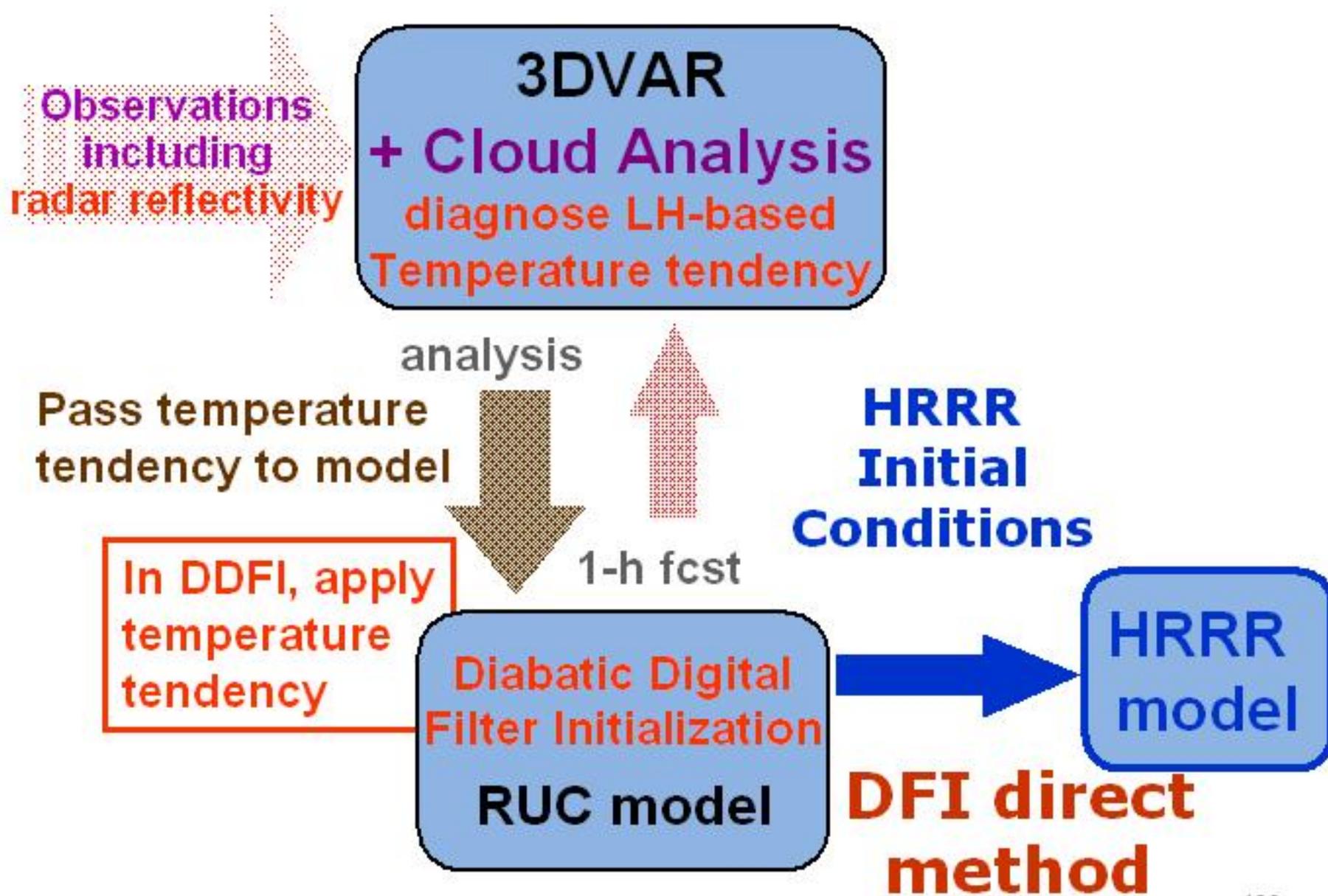
Hourly frequency maintained

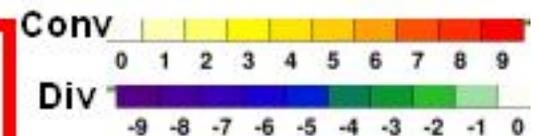
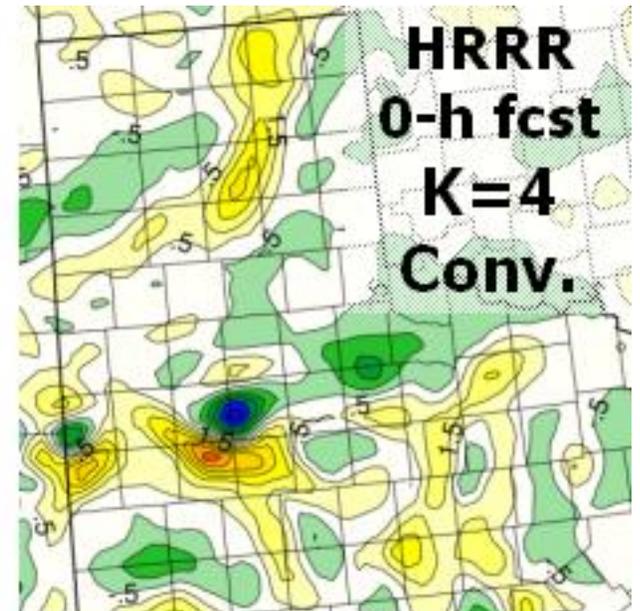
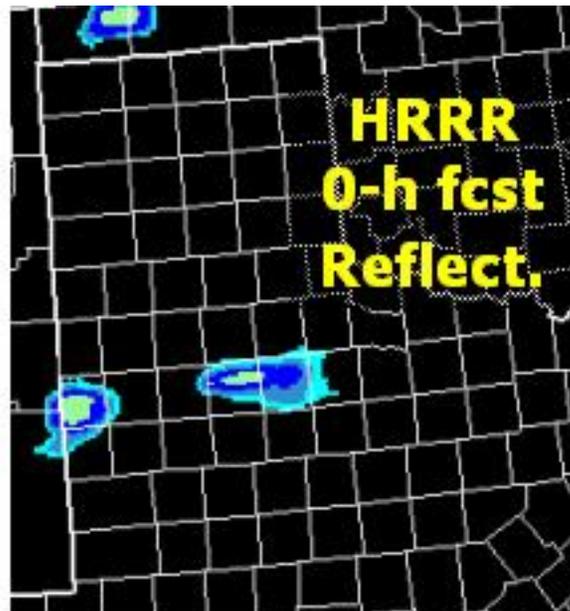
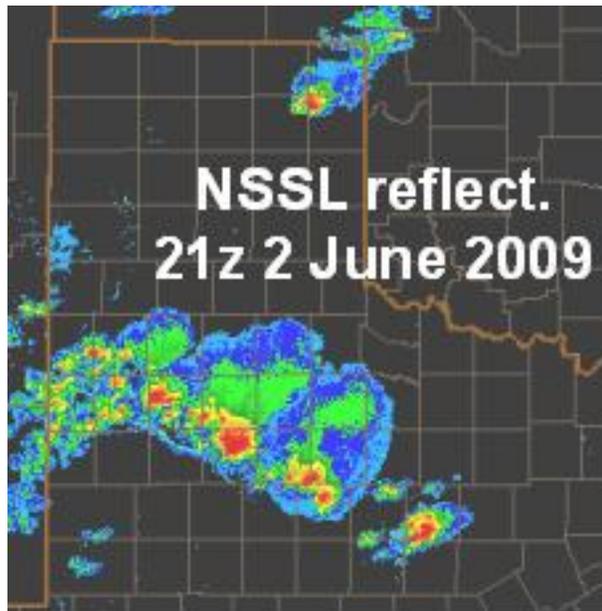
HRRR Domain(s)

Will nest
HRRR
in RR domain

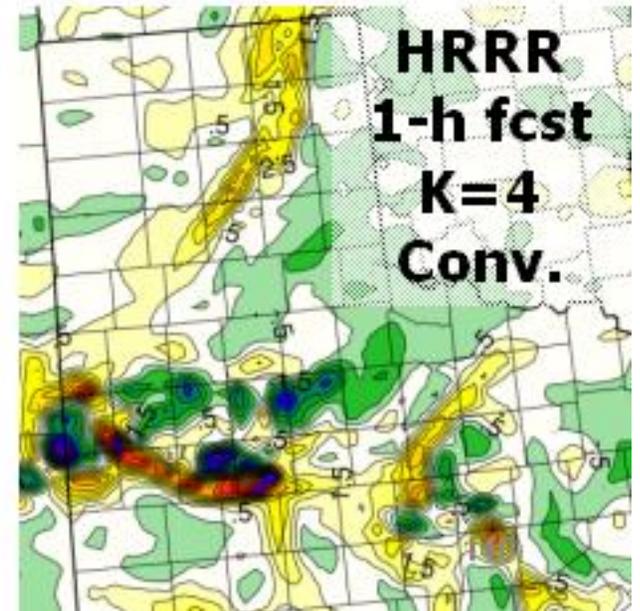
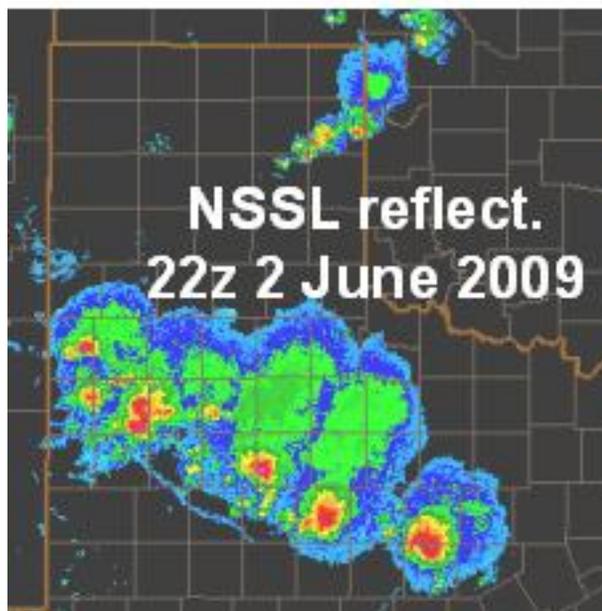


RUC / RR reflectivity assimilation





DFI impact on HRRR fields



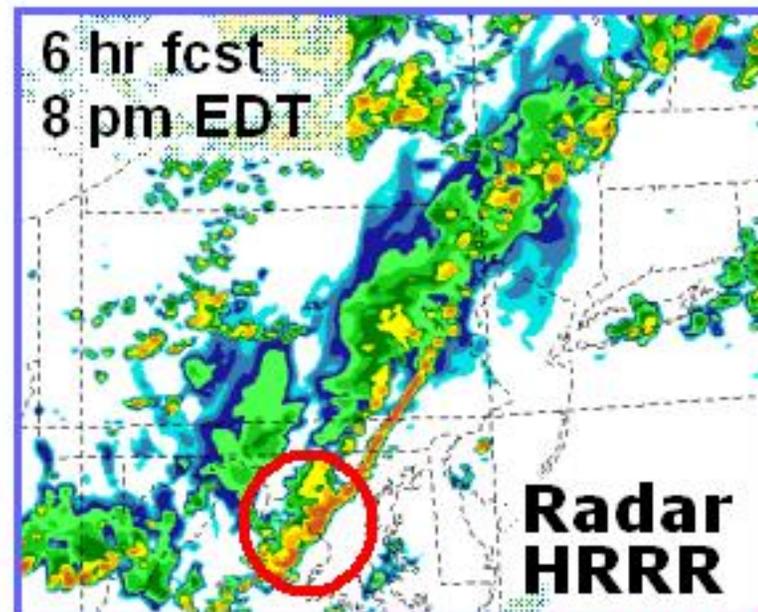
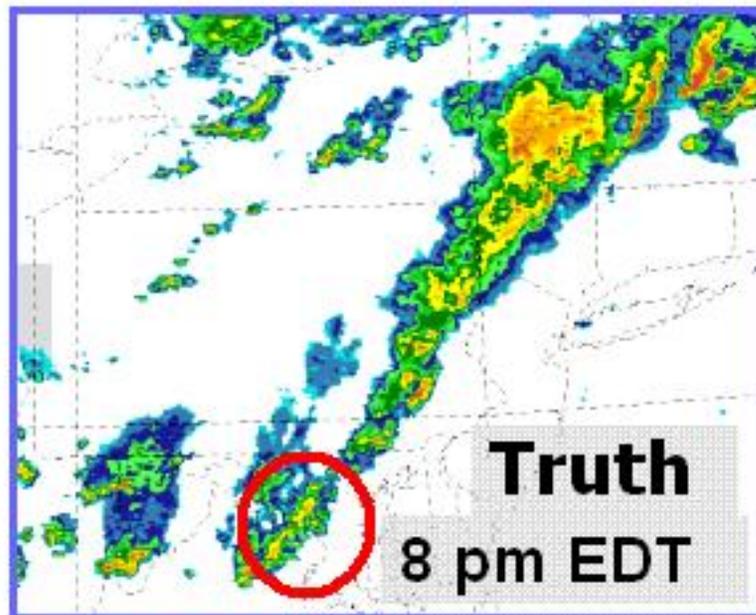
RUC radar assimilation improves HRRR

High resolution needed for realistic storm structure (storm-types, line gaps, etc.)

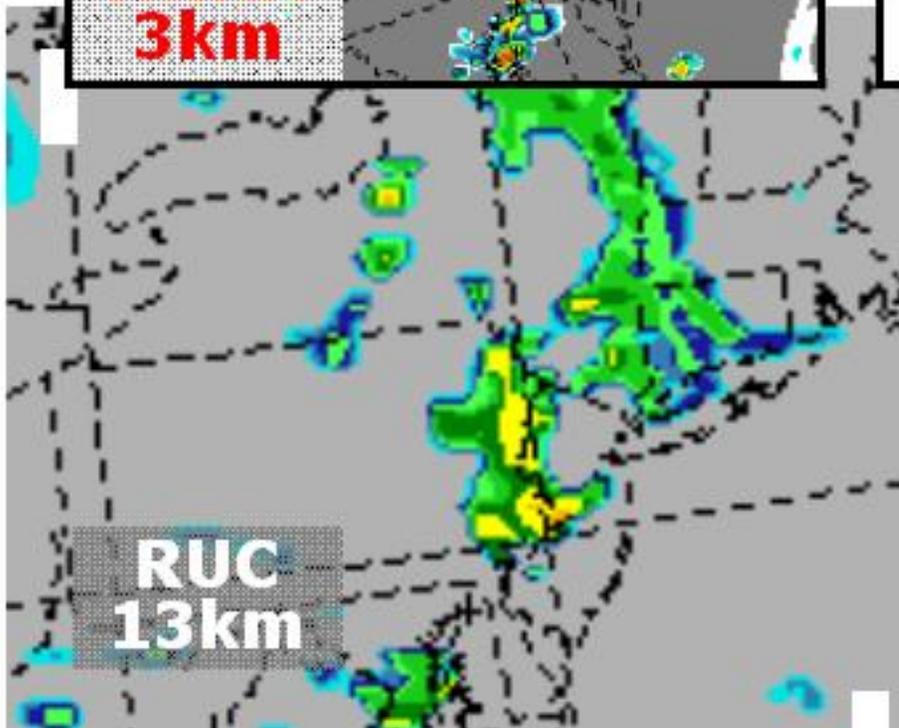
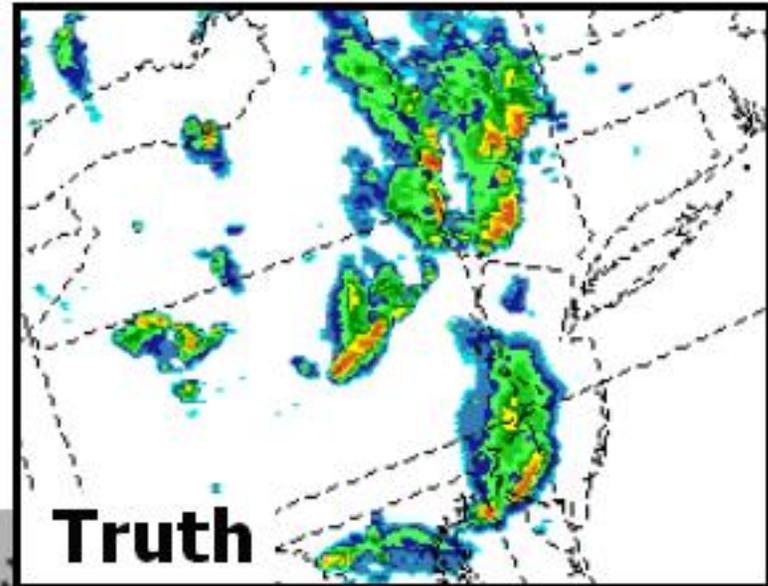
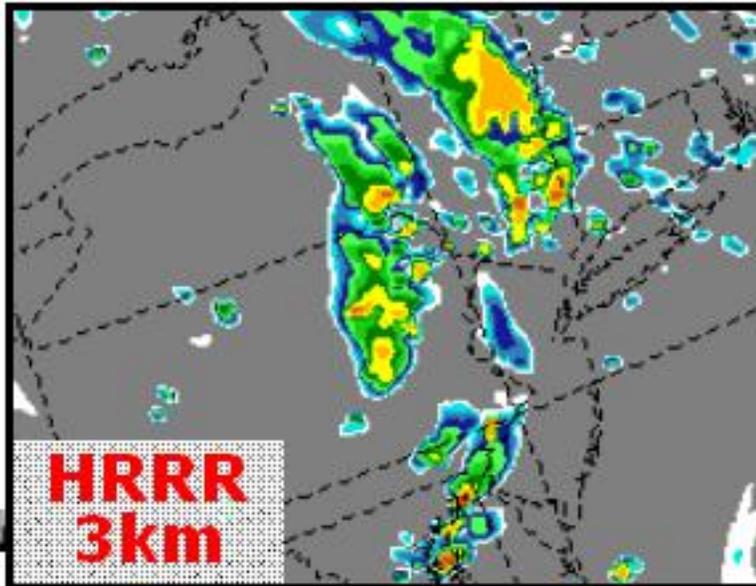
Hourly 12-h forecast,
15-min VIL output

20 July
2008

2 pm
initial
time



6-h forecasts valid at 8pm EDT 24 July 2008



**3km HRRR,
improved guidance
for ATM, terminal
over 13km RUC**

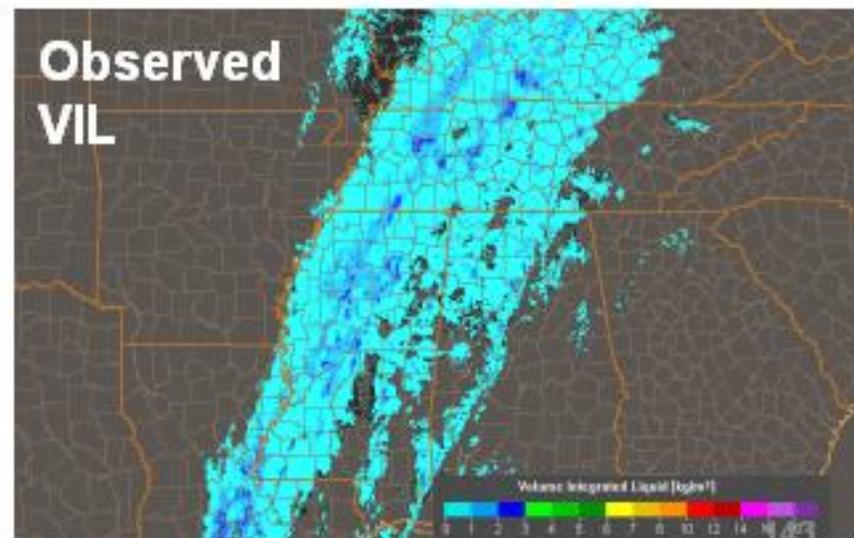
HRRR Users

**NCAR/MIT-LL/FAA:
Consolidated Storm Prediction
for Aviation (CoSPA)**

**NCEP Storm Prediction Center
(SPC)**

**Many NWS forecast offices
including Sterling, VA which
referenced use 60 times in 15
month period**

GSD/FAB Hydromet Testbed



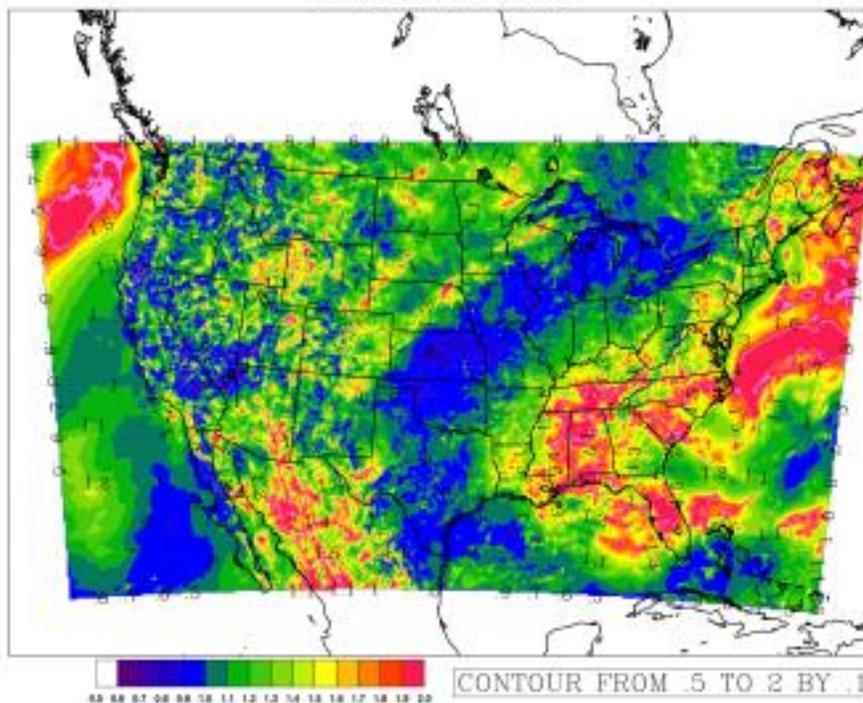
HRRR Users

Renewable Energy - Scaling factors of wind speeds at turbine height (80 m AGL) from 42 RUC to HRRR fcsts in each season

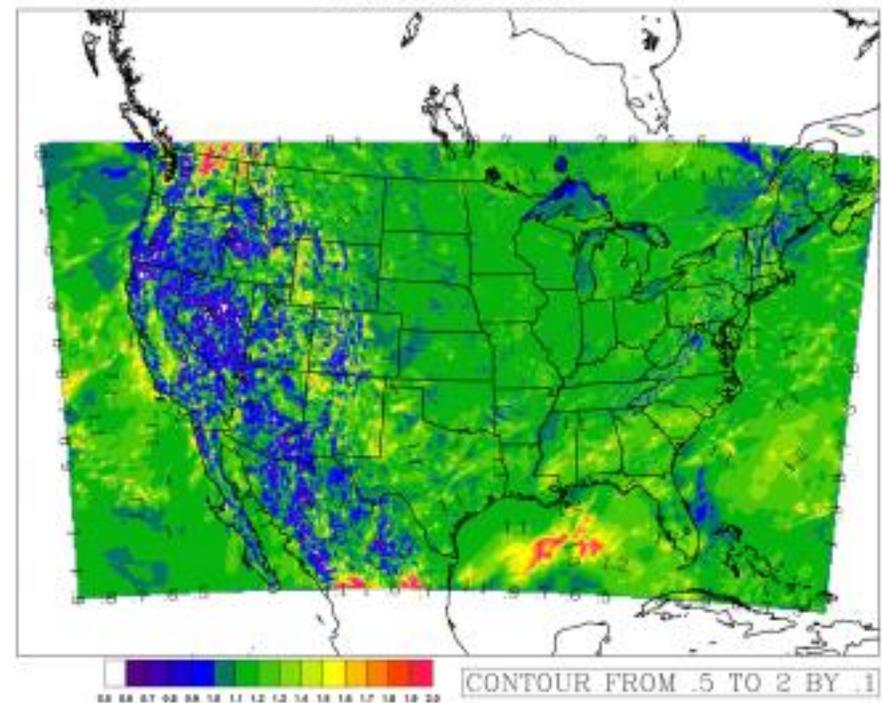
HRRR faster winds (yellow-red) in low-terrain in summer

HRRR slower winds (purple-blue) in high-terrain in winter

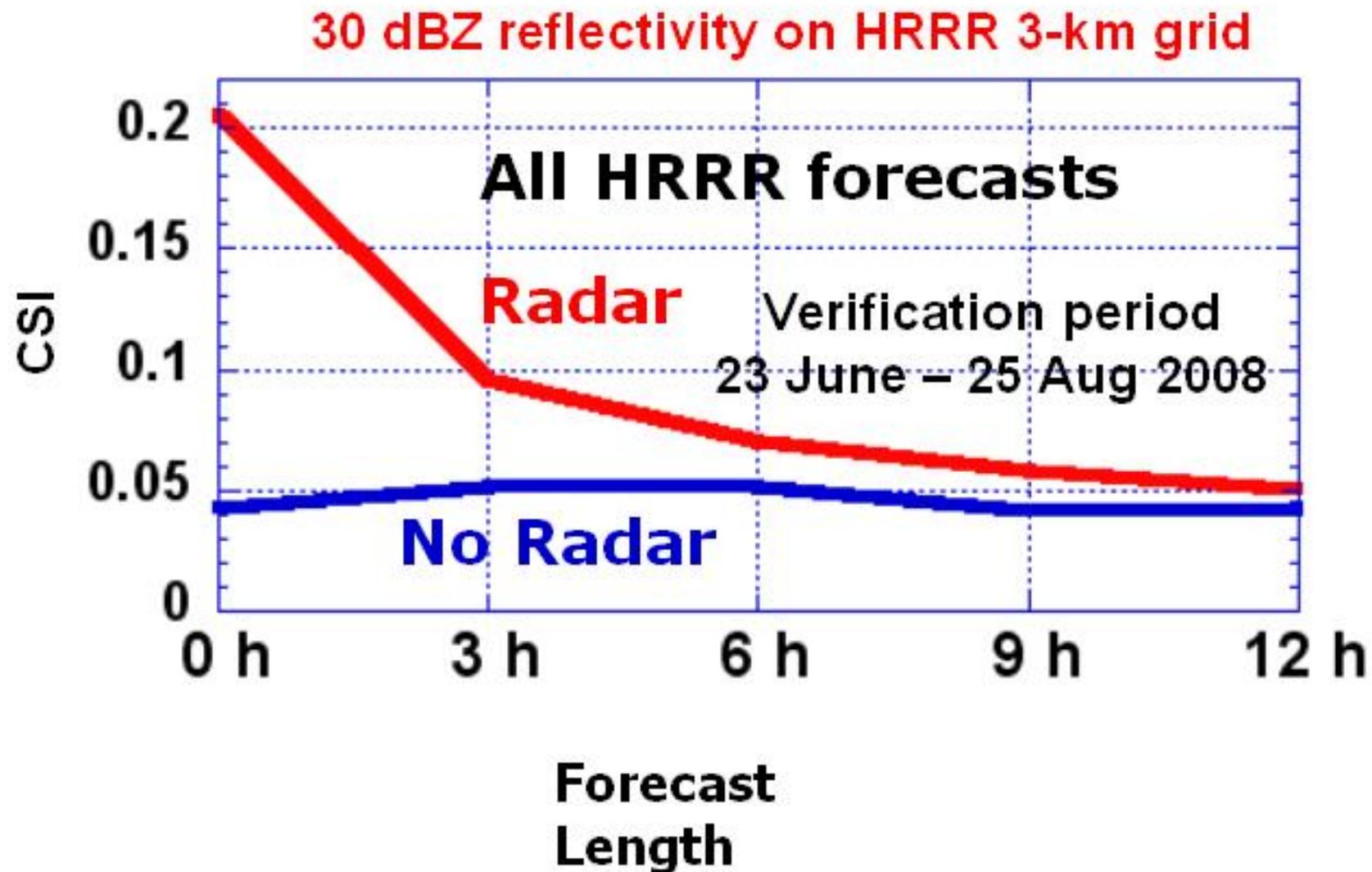
Summer Downscale Factors



Winter Downscale Factors



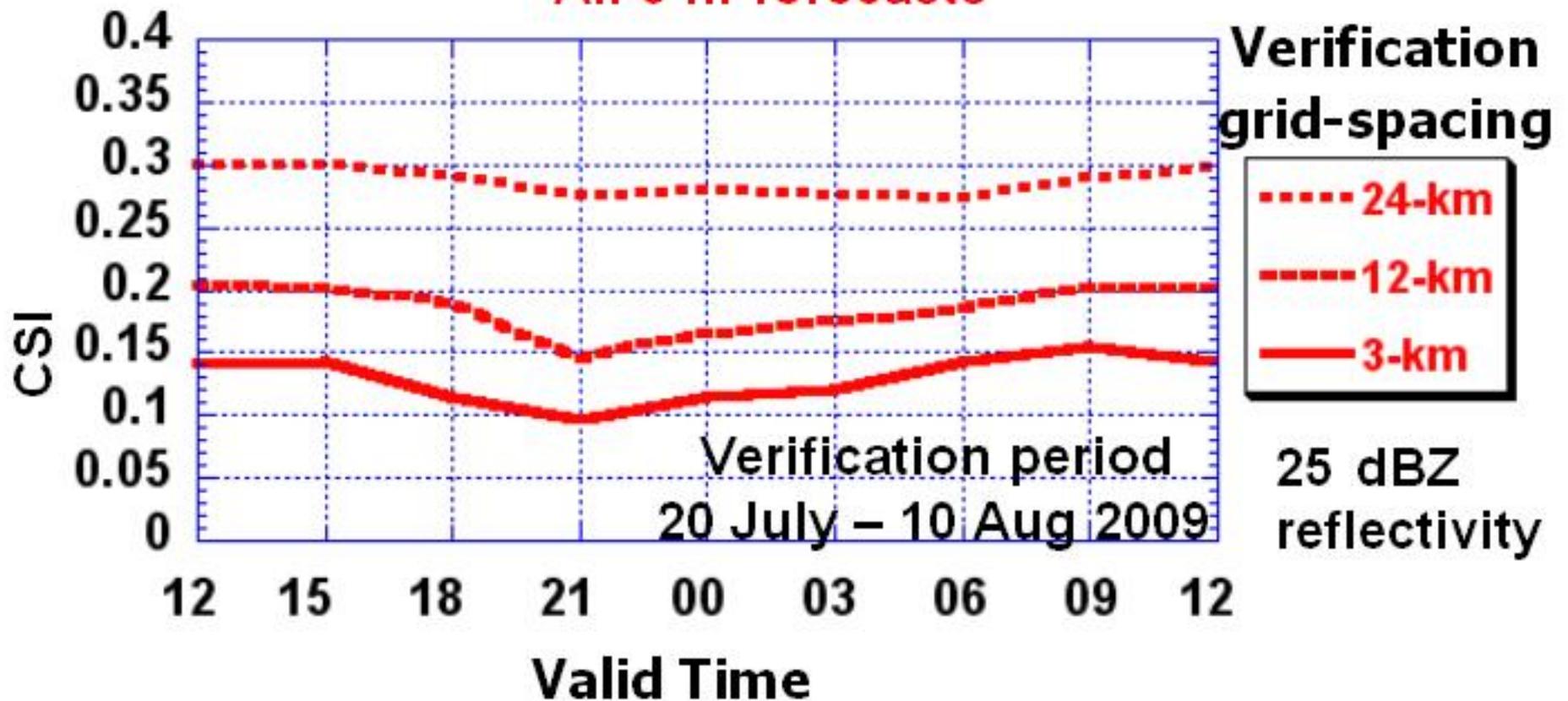
HRRR reflectivity verification skill vs. forecast length



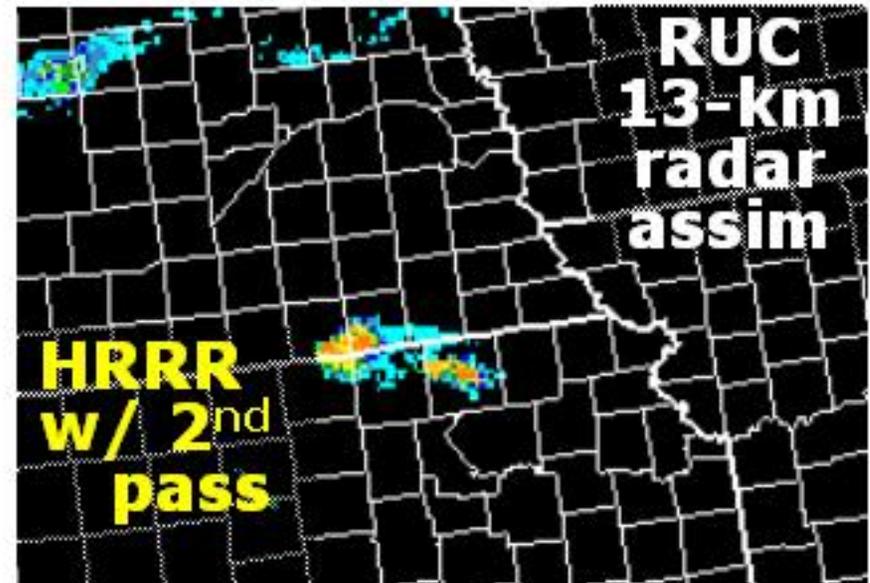
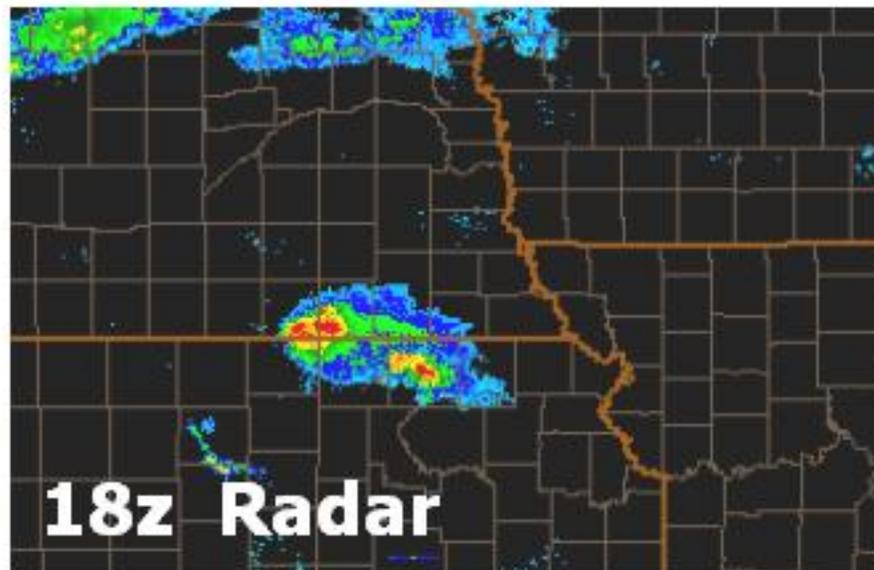
HRRR reflectivity verification with coarser grid

- Higher CSI
- Decreased diurnal effect

All 3 hr forecasts



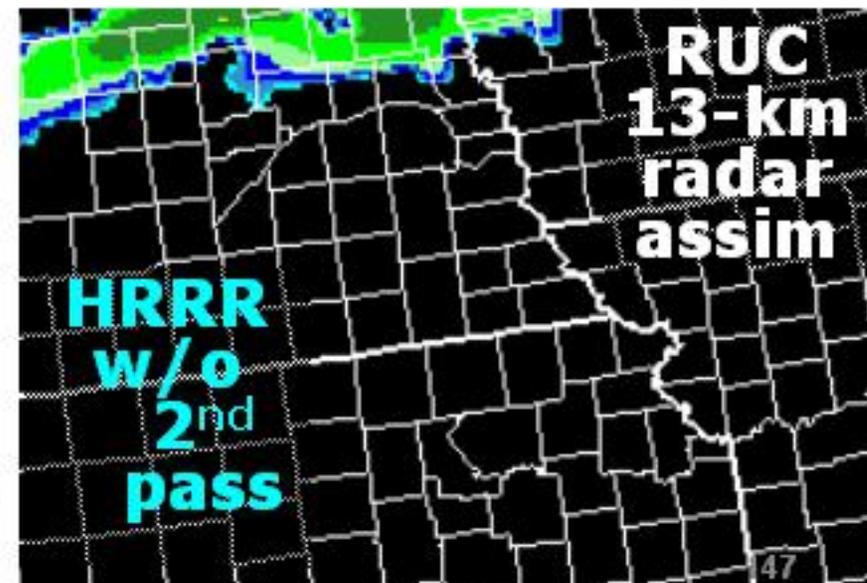
HRRR with 2nd pass radar DA on 3-km domain



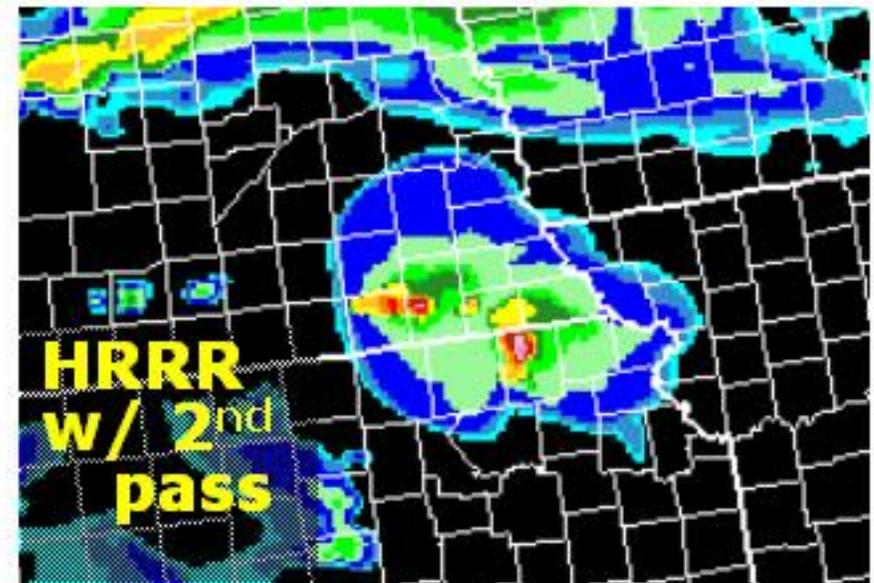
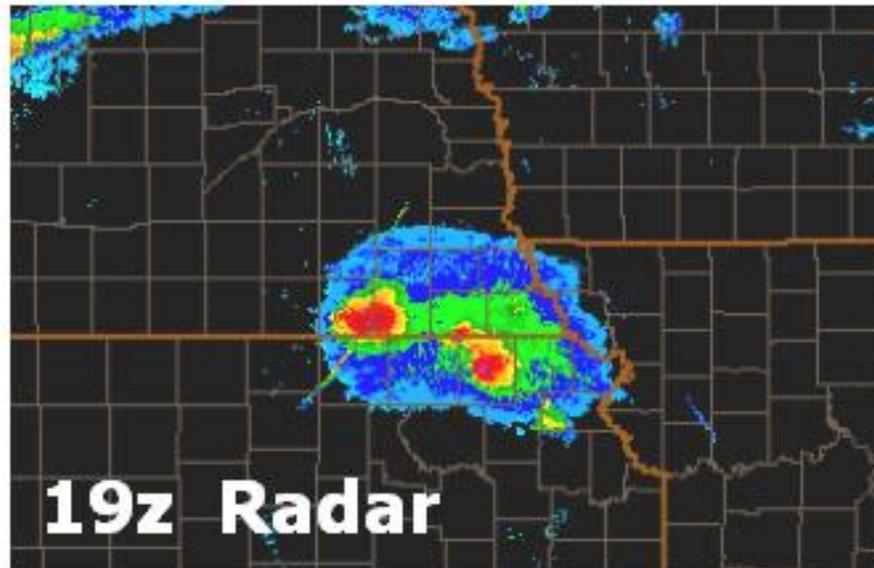
27 June 2009

+ 0h
fcsts

- Both forecasts have RUC 13-km DFI reflectivity assim.
- 2nd pass (3-km DFI radar DA) greatly reduces initial spin-up



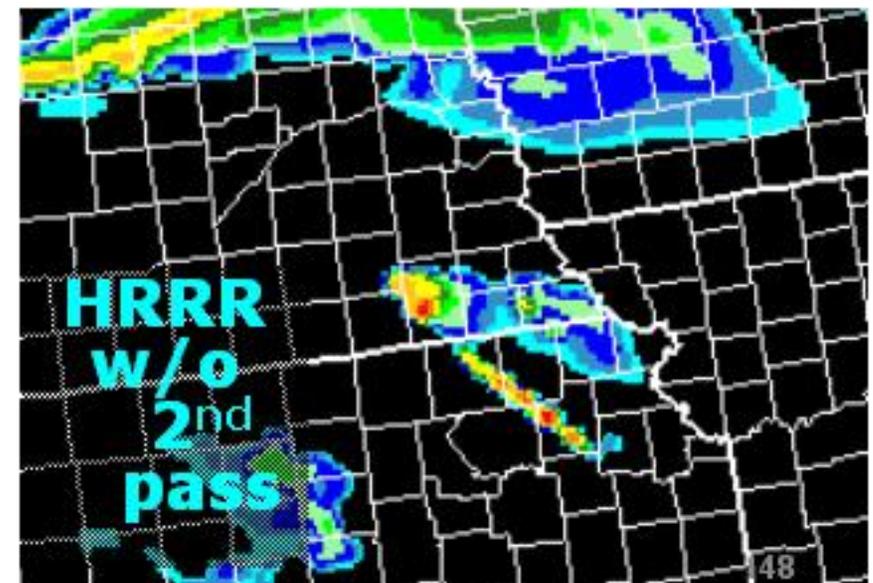
HRRR with 2nd pass radar DA on 3-km domain



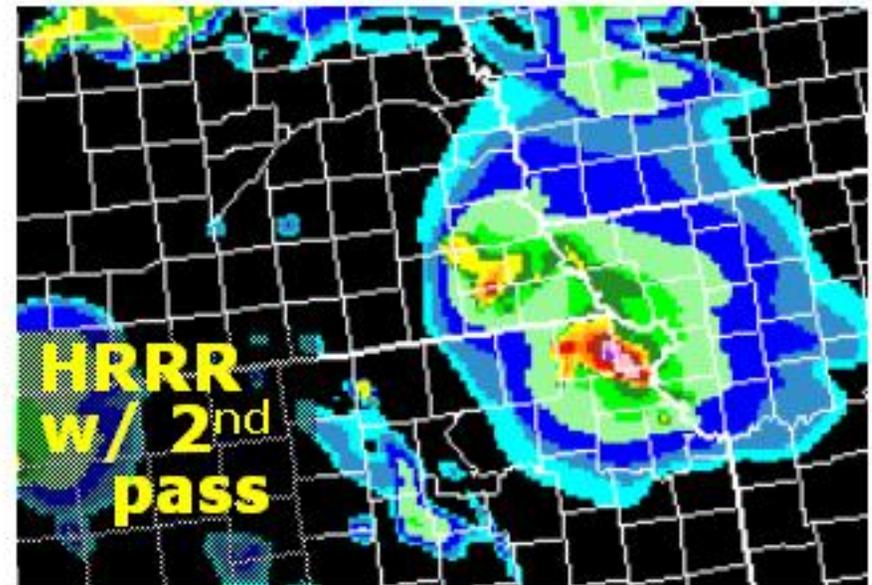
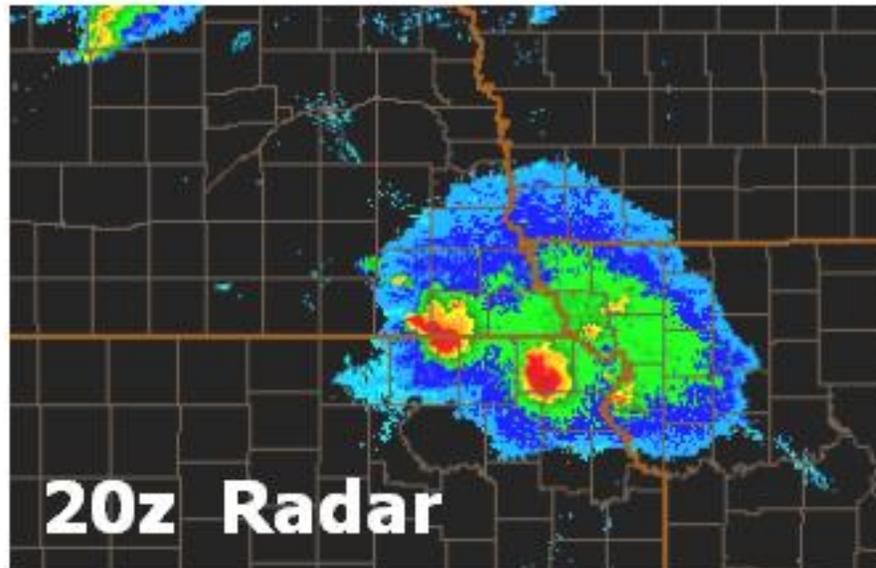
27 June 2009

+ 1h
fcsts

- Both forecasts have RUC 13-km DFI reflectivity assim.
- 2nd pass (3-km DFI radar DA) greatly reduces initial spin-up



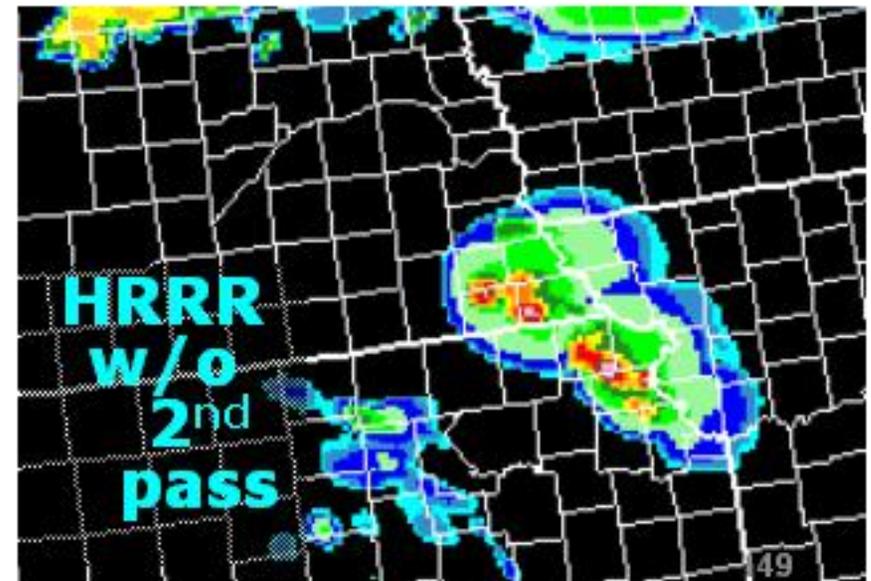
HRRR with 2nd pass radar DA on 3-km domain



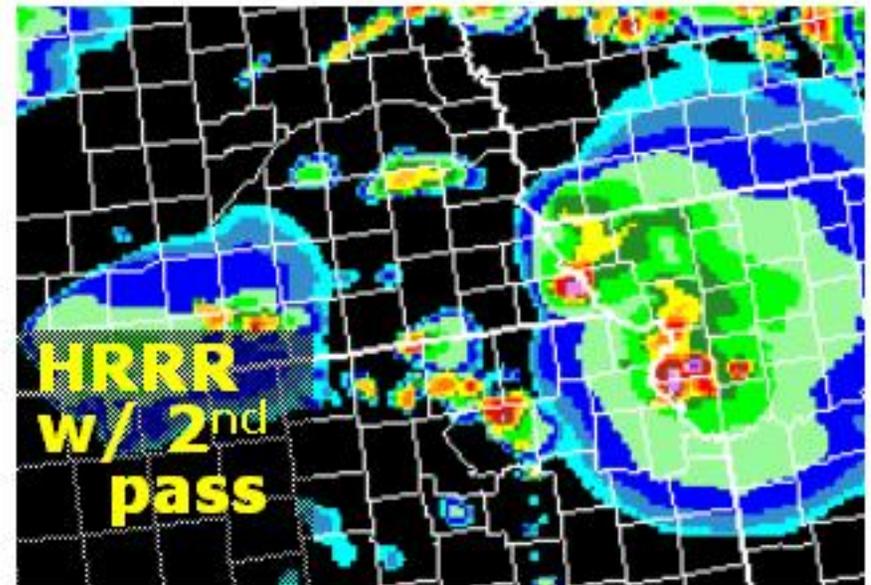
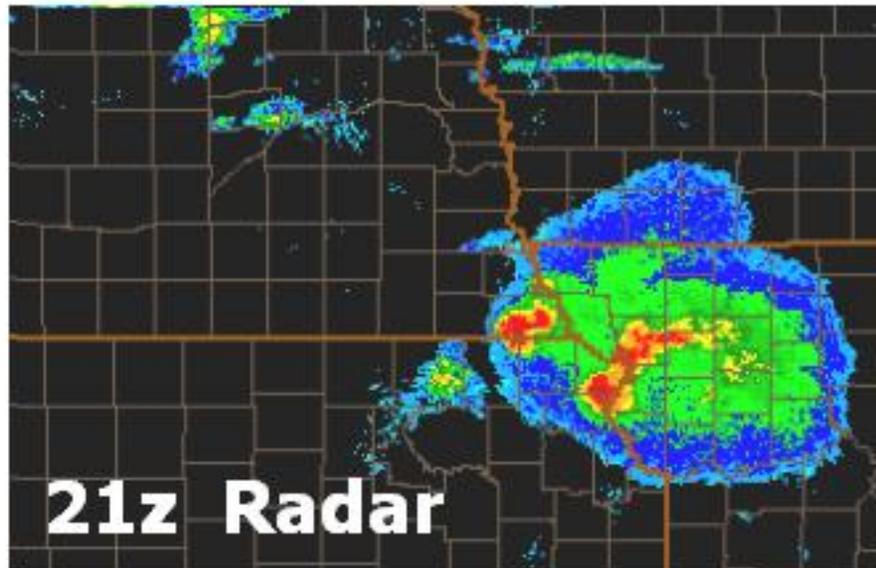
27 June 2009

+ 2h
fcsts

- Both forecasts have RUC 13-km DFI reflectivity assim.
- 2nd pass (3-km DFI radar DA) greatly reduces initial spin-up



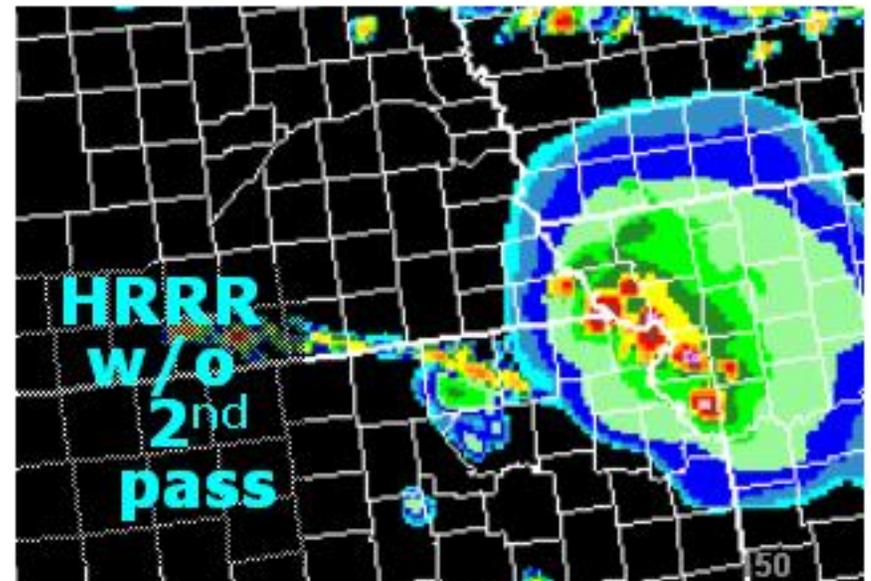
HRRR with 2nd pass radar DA on 3-km domain

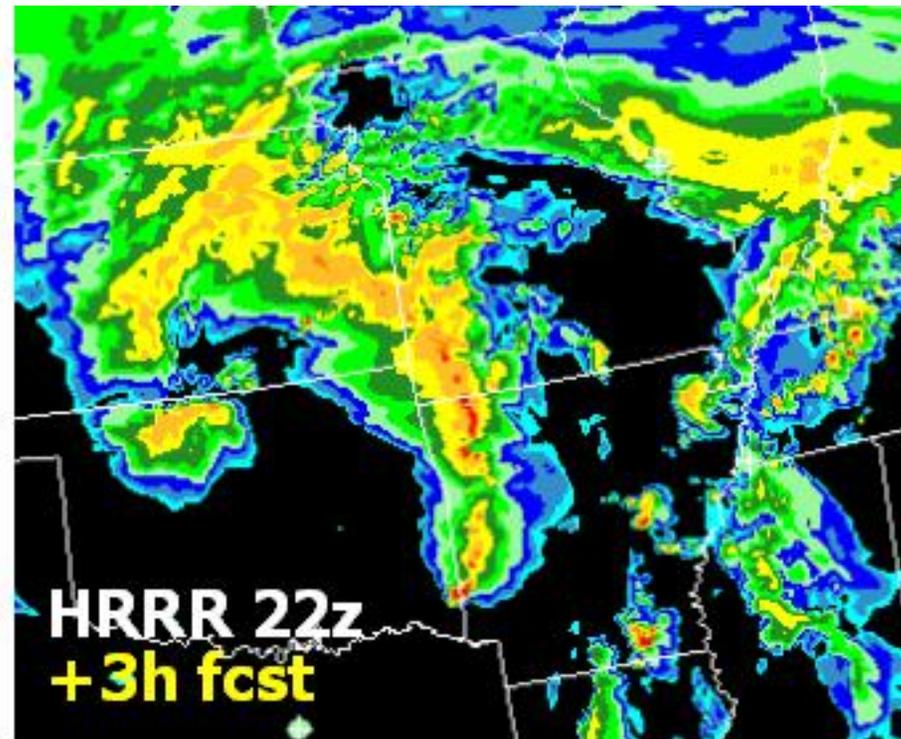
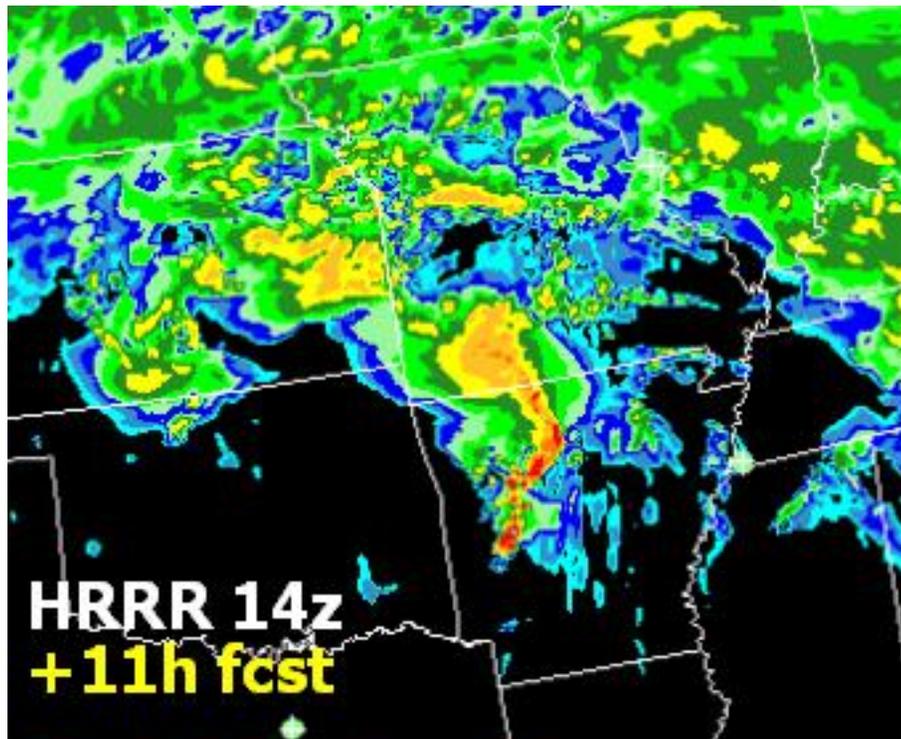


27 June 2009

+ 3h
fcsts

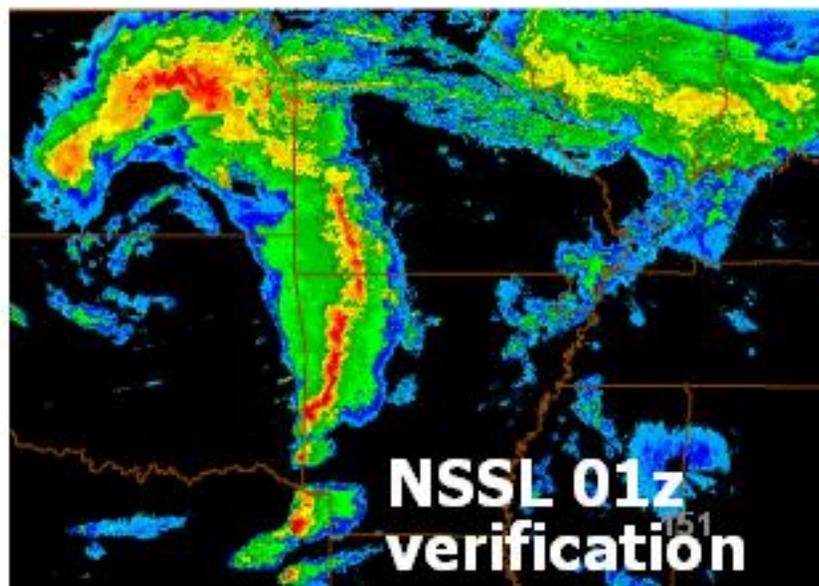
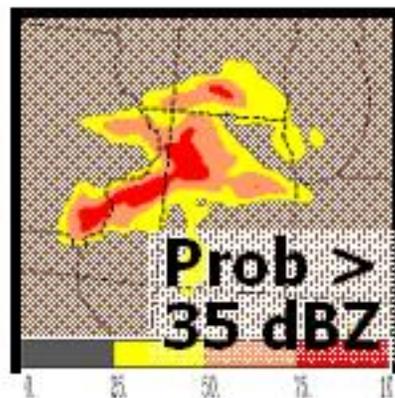
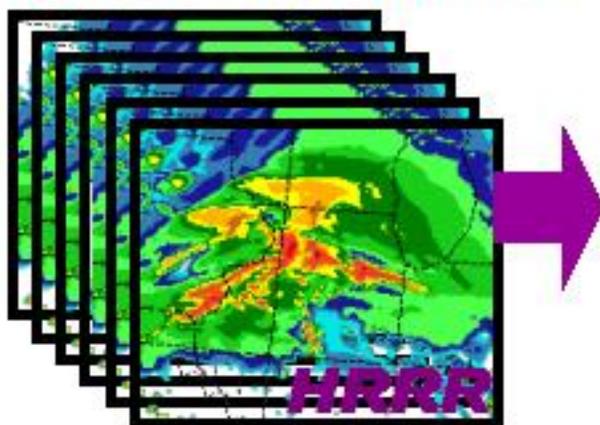
- Both forecasts have RUC 13-km DFI reflectivity assim.
- 2nd pass (3-km DFI radar DA) greatly reduces initial spin-up





Probabilistic guidance
from HRRR time-
lagged ensembles

Valid 01z 10 Apr



The HCPF

HRRR Convective Probabilistic Forecast (HCPF)

Identification of moist convection using model forecast fields:

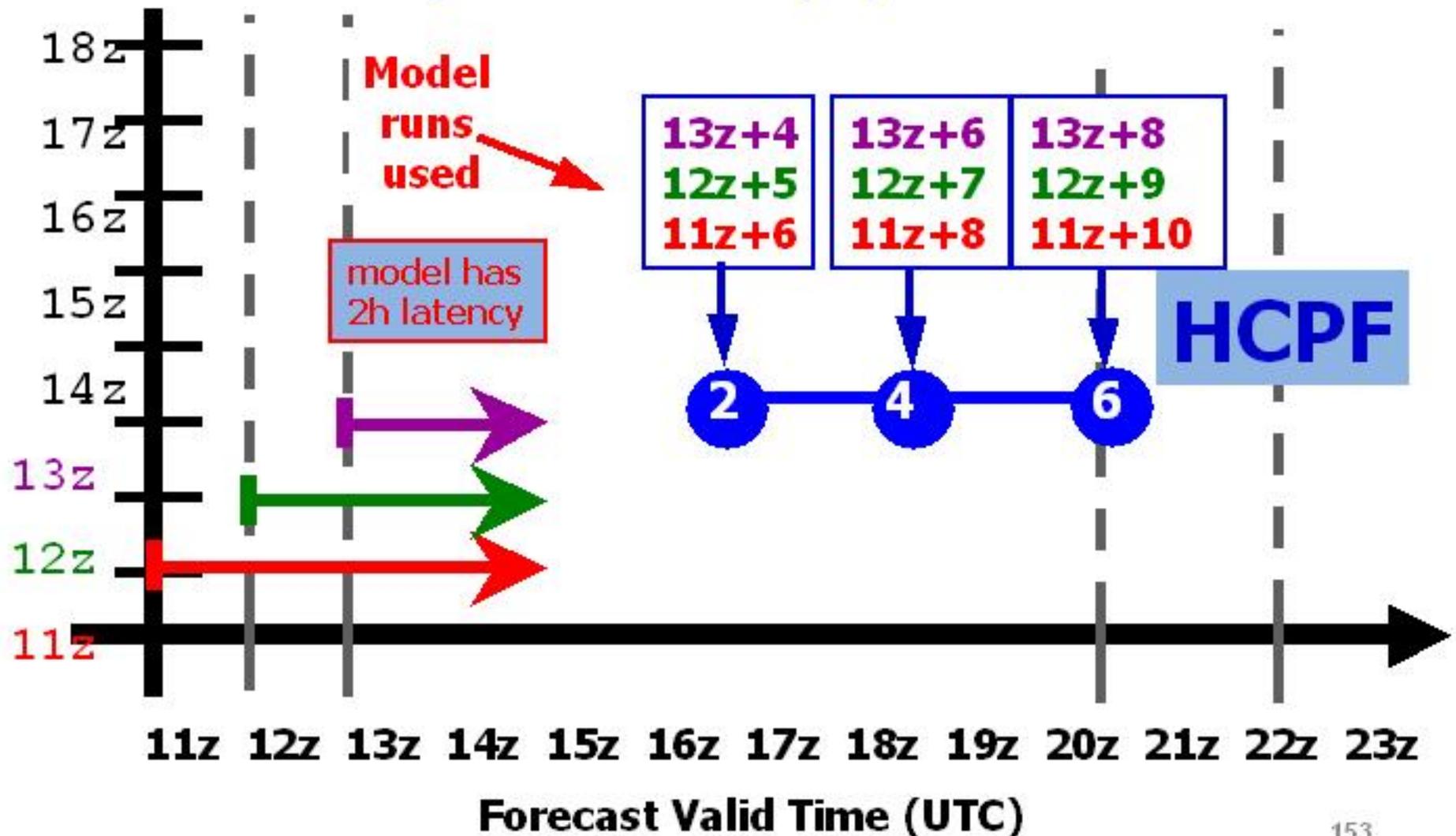
- Stability – Surface lifted index $< +2^{\circ}\text{C}$ (neutral to unstable)
- Intensity – Model reflectivity > 30 dBZ or updraft > 1 m s⁻¹
- Time – 2 hr search window centered on valid times
- Location – Stability and intensity criteria searched within 25 points (radius of ~ 78 km) of each point for each member

$$\text{HCPF} = \frac{\text{\# grid points matching criteria over all members}}{\text{total \# grid points searched over all members}}$$

Time-lagged ensemble

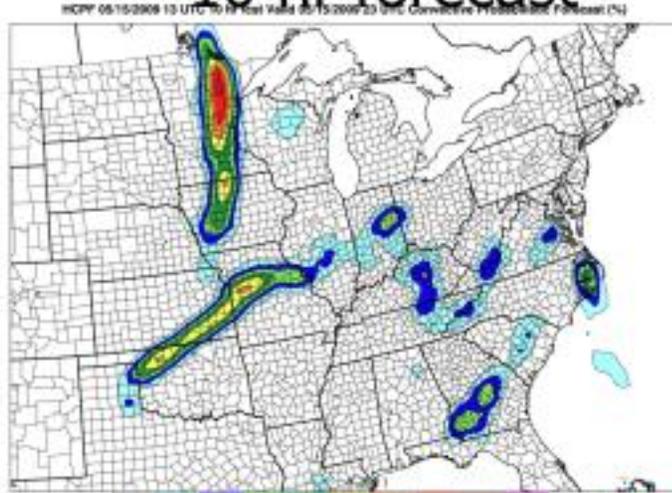
Example: 15z + 2, 4, 6 hour HCPF

Model
Init
Time



HCPF Example: 23 UTC 15 May 2009

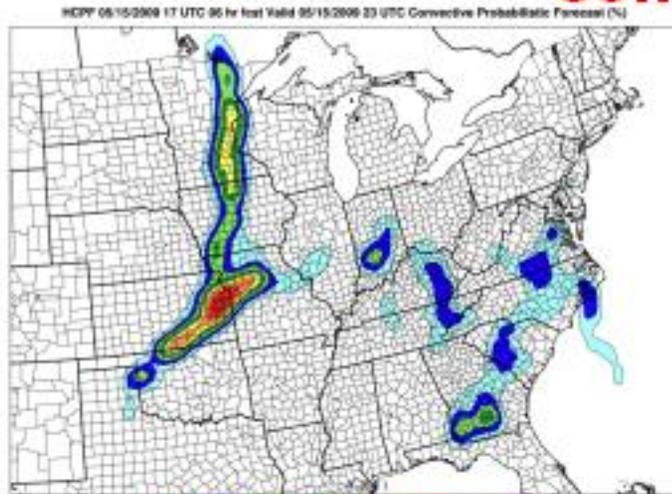
10 hr forecast



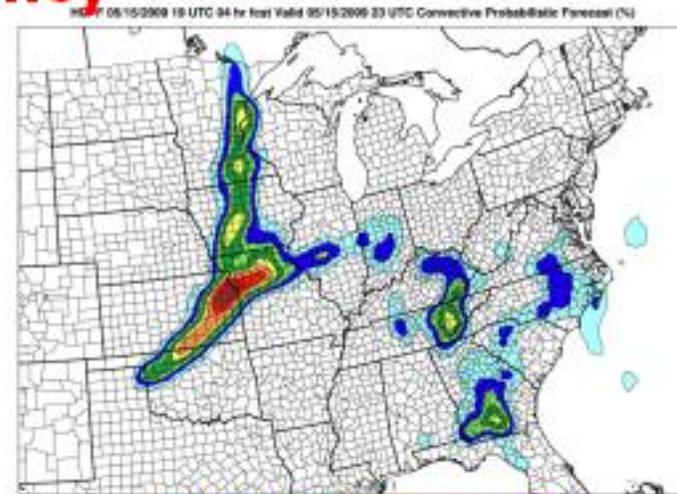
08 hr forecast



06 hr forecast



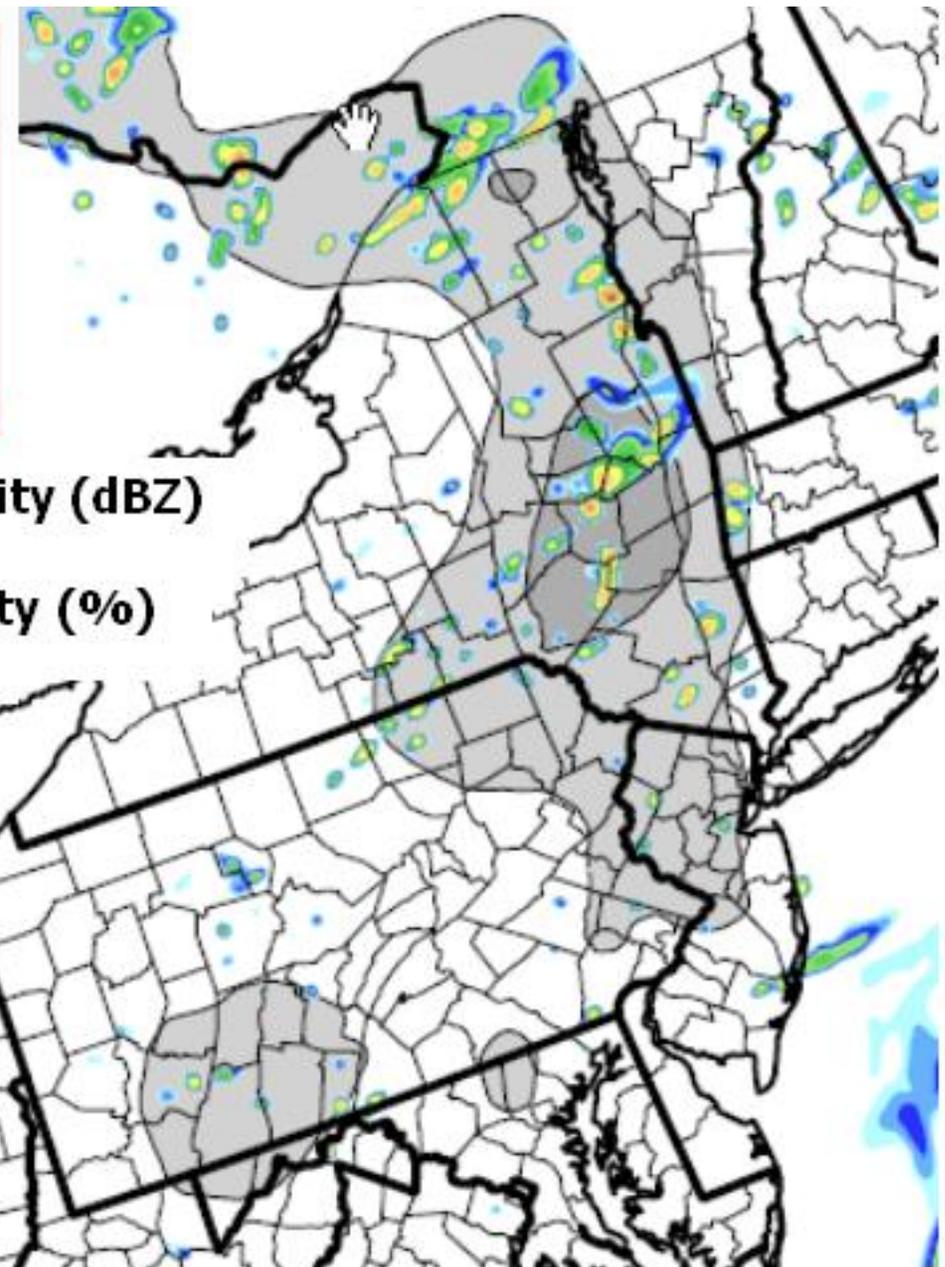
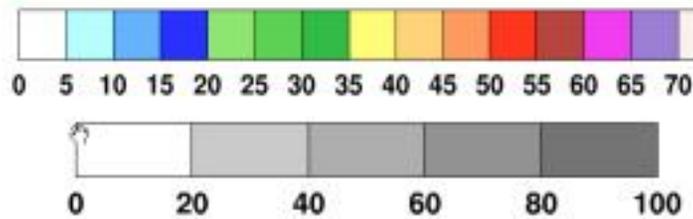
04 hr forecast



Forecast Consistency

Convective probability forecasts from HRRR time-lagged ensemble

(shown with deterministic fcst)

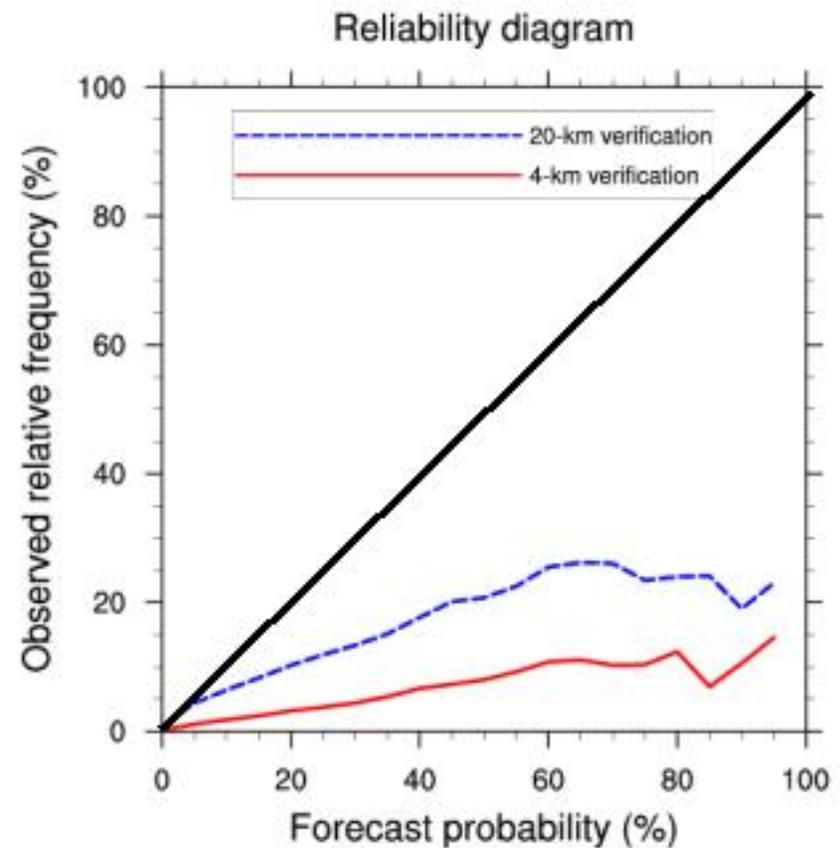
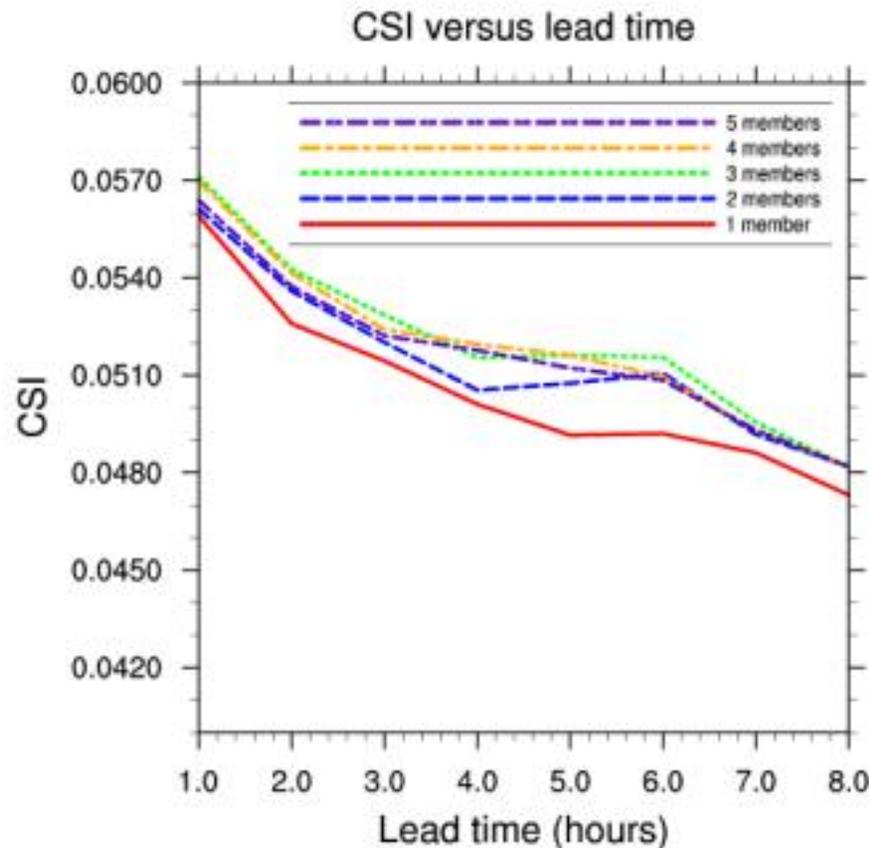


21z 16 July '09
Verification

15z + 6h HRRR and HCFP

HCPF probability verification

**40% probability
verified on a 4-km grid**

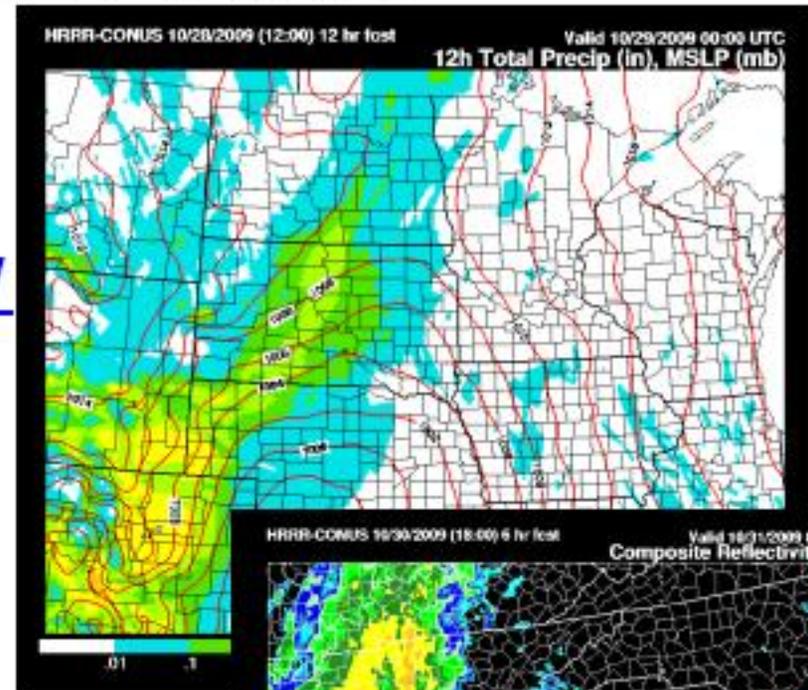


**Verification period
August 2009 - 540 forecasts**

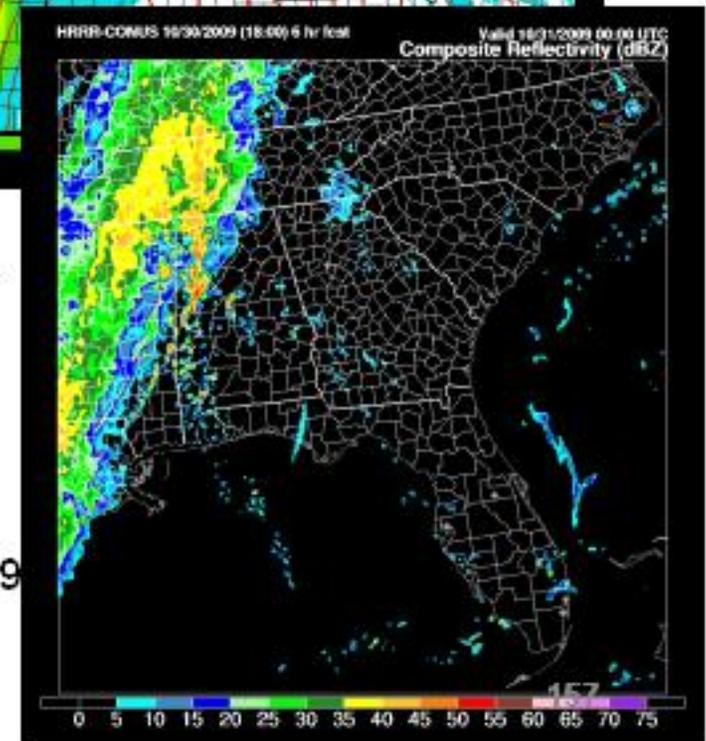
Real-Time HRRR

Front Range Winter Storm 12 hr fcst valid 00z 29 Oct 2009

<http://rapidrefresh.noaa.gov/hrrrconus/>



	All Series	Loop	Valid Time													
			Fr	Fr	Fr	Fr	Fr	Sat	Sat	Sat	Sat	Sat	Sat			
			18	19	20	21	22	23	24	25	26	27	28	29		
			Forecast Duration													
			00	01	02	03	04	05	06	07	08	09	10	11	12	
all fields			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	all fields
1 km agl reflectivity	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	1 km agl reflectivity
reflectivity	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	reflectivity
max reflectivity	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	max reflectivity
surface CAPE	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	surface CAPE
surface CIN	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	surface CIN
mixed CAPE	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	mixed CAPE
most unstable CAPE	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	most unstable CAPE
best LJ	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	best LJ
LCL	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	LCL
0-1 km shear	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	0-1 km shear
0-6 km shear	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	0-6 km shear
0-1 km helicity, storm rotation	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	0-1 km helicity, storm rotation
0-3 km helicity, storm rotation	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	0-3 km helicity, storm rotation
max updraft helicity	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	max updraft helicity
max vert int graupel	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	max vert int graupel
max 10m wind	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	max 10m wind
10m wind	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	10m wind
skin temp	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	skin temp
2m temp	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	2m temp
2m temp - skin temp	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	2m temp - skin temp
2m dew point	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	2m dew point
precipitable water	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	precipitable water
1h acc precip	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	1h acc precip
total acc precip	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	total acc precip
snow water equiv	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	snow water equiv
precip type	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	precip type
850mb temp	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	850mb temp
850mb wind	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	850mb wind
850mb rh	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	850mb rh
850-500mb mean rh	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	850-500mb mean rh
700mb temp	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	700mb temp



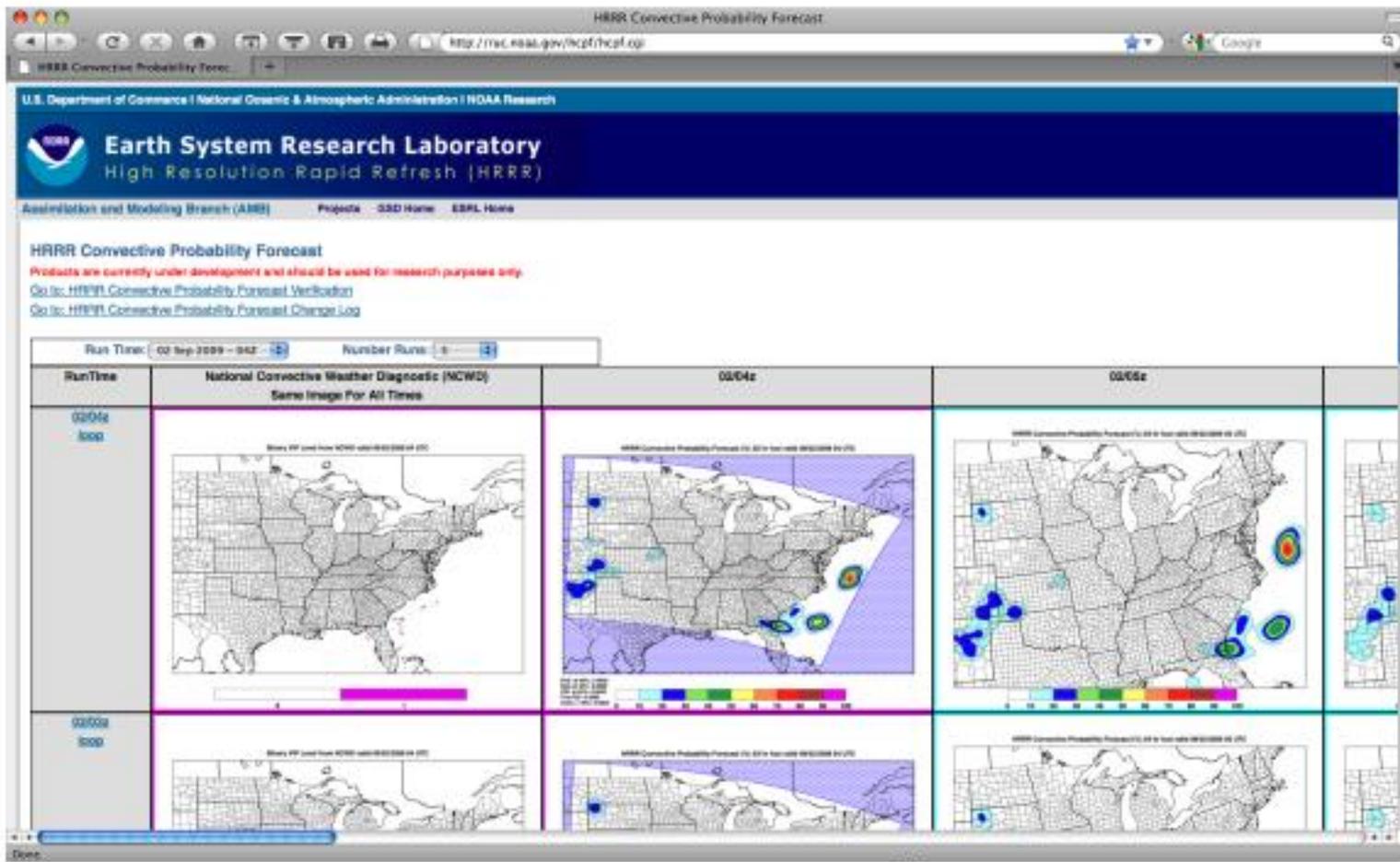
Squall-line
with
leading
supercells
6 hr fcst
valid 00z
31 Oct 2009

Diversity of convective-scale forecast fields

Real-Time HCPF

<http://ruc.noaa.gov/hcpf/hcpf.cgi>

HCPF generation time



Current verification - HCPF lead times

Summary on HRRR

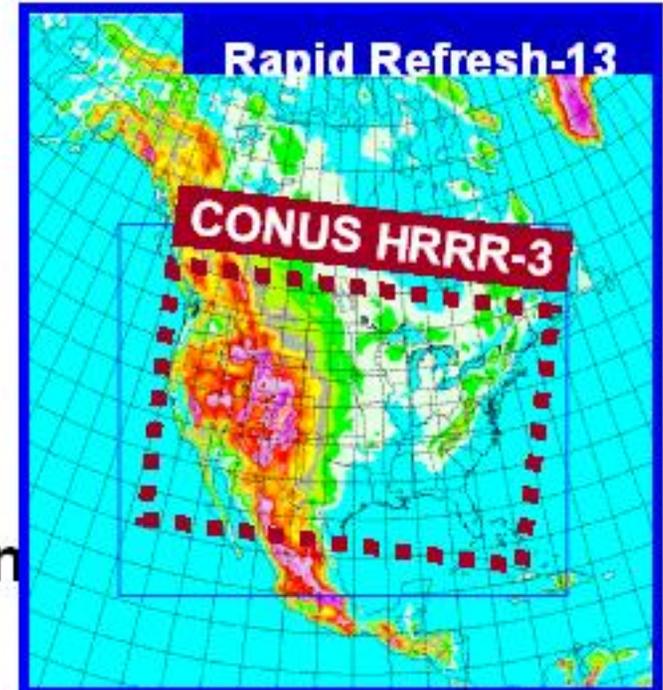
- Now CONUS-wide forecasts at 3 km scale
- Captures information of convective-scale structure and evolution not represented by lower-resolution models using parameterization
- Radar assimilation essential for accurate storm-scale prediction
- HRRR Convective Probabilistic Forecast (HCPF) via time-lagged ensemble shown to have comparable skill to other convective forecasts including the RUC convective probabilistic forecast (RCPF)

Rapid Refresh / RUC Technical Review - OUTLINE

- 1:30 – 1:45 RUC → RR transition overview,
NCEP RUC changes – 2008-09- Stan Benjamin
- 1:45 – 2:00 Observation impact experiments
- TAMDAR aircraft obs w/ moisture, larger OSE
Bill Moninger
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– physics, cloud, chemistry, PBL
John Brown, Tanya Smirnova, Joe Olson
- 3:05 – 3:20 The HRRR and HCPF (HRRR prob forecast)
Curtis Alexander
- 3:20 – 3:30 Future of RR/HRRR/ens Stan Benjamin

Relationship of HRRR to RR

- **HRRR runs as a *nest* within RUC, will be transitioned to a nest within Rapid Refresh**
- **Data assimilation for HRRR is within RUC, will be within the RR**
 - RR has same radar assimilation capability as RUC, improved assimilation for satellite data
 - Supplemental radar assimilation planned for HRRR 3-km grid
 - Assimilation of conventional observations and satellite data will likely remain on 13-km grid (computer cost, effectiveness)
 - HRRR with radar assimilation essential for convection, evaluation needed for other aviation hazards

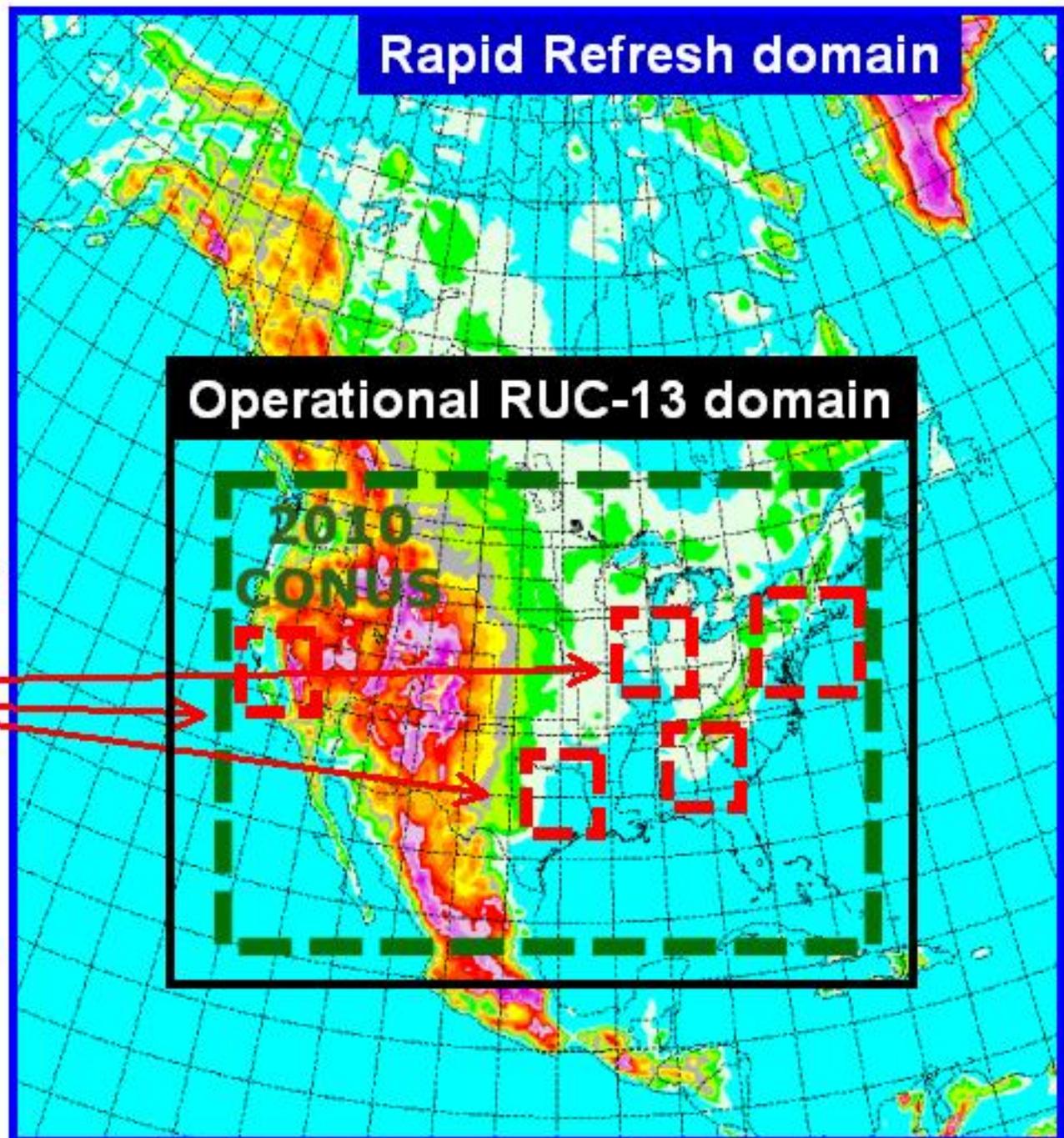


**Rapid Refresh,
HRRR, +0.5-
1.0km HRRR
subnests**

HRRR – CONUS

Planned HRRR 1-
km subnests (2-way
boundary!) –
testing

RR/HRRR
Applications –
aviation, severe wx,
renewable energy,
AQ, fire, hydro



Coordinated Meso- and Storm-scale ensembles The NARRE and the HRRRE

2012-2013

NAM/Rapid Refresh ENSEMBLE (NARRE)

- NEMS-based NMMB and ARW cores & GSI analysis
- Common NAM parent domain at 10-12 km (even larger than initial Rapid Refresh domain)
- Initially ~6 member ensemble made up of equal numbers of NMMB- & ARW-based configurations
- Hourly updated with forecasts to 24 hours
- NMMB & ARW control assimilation cycles with 3 hour pre-forecast period (catch-up) with hourly updating
- NAM 84 hr forecasts are extensions of the 00z, 06z, 12z, & 18z runs.

Coordinated Meso- and Storm-scale ensembles
The NARRE and the HRRRE

2012-2013

**High-Resolution Rapid Refresh Ensemble
(HRRRE)**

- **Each member of NARRE contains**
 - 3 km CONUS and Alaskan nests
 - Control runs initialized with radar data
- **Positions NWS/NCEP/ESRL to**
 - Provide NextGen enroute and terminal guidance
 - Provide probability guidance
 - Improve assimilation capabilities with radar and satellite
 - Tackle Warn-on-Forecast as resolutions evolve towards ~1 km

Very Short-Range Ensemble Forecasts - VSREF

- Updated hourly w/ available members valid at same time

VSREF members

RR – hourly

time-lagged (TL) ensemble members

- 2012 - ensemble RR

ESRL 3km HRRR (incl. TL ensemble)

- 2012 - proposed HRRR at NCEP

- **future HRRRE from NARRE**

NAM / NAM ensemble

GFS / GFS ensemble

SREF (updated every 6h)

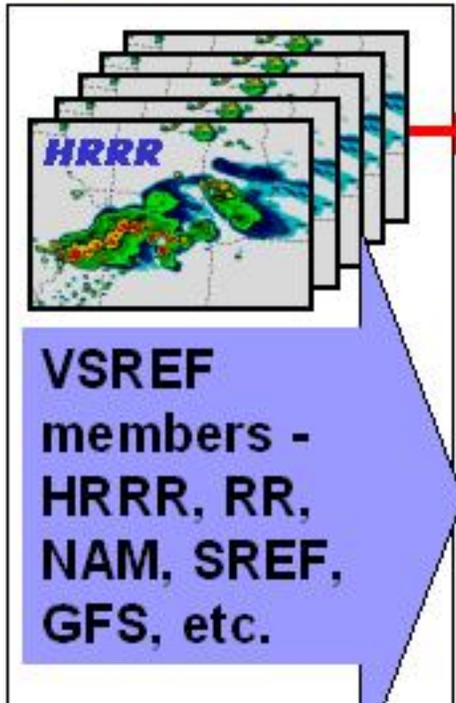
VSREF –
Hourly
Updated
Probabilistic
Forecasts
= **TL+**
ensemble

Time-lagged ensemble provides skill baseline for evaluating HRRRE and NARRE development

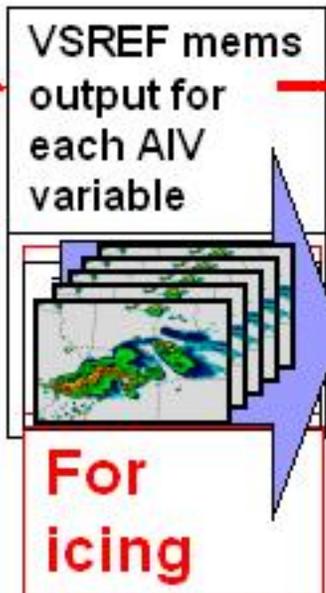
VSREF- Model Ensemble Members
- hourly ($\leq 1h$) updated

Unified Post-processing Algorithms (modularized!!)
for following: (multiple where appropriate), built on current WRFpost from NCEP

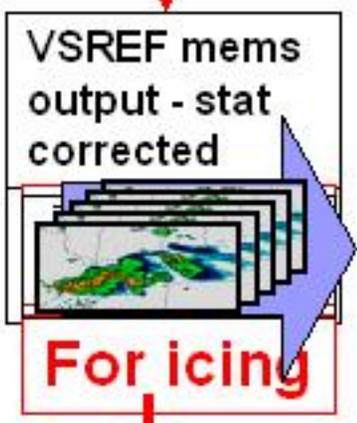
VISION: Toward estimating and reducing forecast uncertainty for aviation applications using high-frequency data assimilation



- Turb (e.g., GTG)
- Icing (e.g., FIP)
- Ceiling
- Visibility
- Convection
- ATM route options
- Wake vortex
- Terminal forecast
- Object diagnosis (line convection, clusters, embedded)
- Others...



Stat correction post-processing using recent obs



Optimal weighting

Most-likely-estimate single value
Probability/PDF output

Explicit met variables from each VSREF member - V,T,qv,q* (hydrometeors),p/z, land-surface, chem, etc.

Potentially multiple variables under each Avx-Impact-Var (AIV) area

Trends from our perspective - 2007

- Use of high-frequency NWP data continues to grow with increasing automation of decision-making, access to gridded data
- More interaction with intermediary developers of post-processing products, esp. probabilistic products
- Common development/implementation with NOAA – ESMF beyond WRF
- Ensemble Rapid Refresh
- Common computing system in NOAA
- Increasingly coupled environmental systems

Future plans (in collaboration with NCEP)

2010 – Rapid Refresh operational at NCEP

2012 – Operational (NCEP)
CONUS-wide High Resolution
Rapid Refresh nested inside RR

2013 – Ensemble RR
(~6 members, ARW, NMM cores)

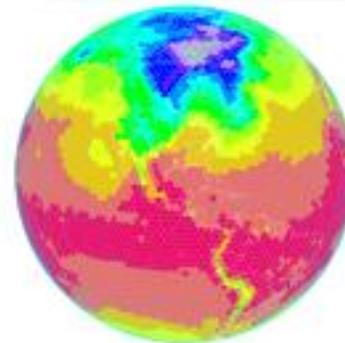
2014 – Add operational
Alaska HRRR

2015 – Ensemble CONUS HRRR
(6 members)

2017 – Global Rapid Refresh (GRR)

Incorporation of inline chemistry –
2012-15

- Assimilation of radial wind, new satellite, phased-array radar, CASA, new regional aircraft, chemistry obs...
- Frequency from 60min→30→15min
- 1h EnKF
- Improved nowcast/blend/NWP
- Ensemble-based post-processing



Applications:
Aviation, severe wx,
Hydrology, energy,
air quality, fire
weather,
volcanoes/hazards,
etc.