RUC/Rapid Refresh Review

NCEP Production Suite Review - 2009

NOAA/ESRL/GSD/AMB

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Tracy Lorraine Smith

NCEP/EMC –
Geoff Manikin, Geoff DiMego
NCEP/NCO

Tues 8 Dec 2009

Major transitions:

- RUC13 changes – Nov 08, Mar 09
  – radar reflectivity assimilation, TAMDAR, mesonet, cloud analysis, snow trimming

- Rapid Refresh – final testing at ESRL, planned for NCEP implementation – 4Q-FY10

- 3km HRRR @ESRL – now CONUS-wide

http://ruc.noaa.gov
http://rapidrefresh.noaa.gov

NCEP

Earth System Research Laboratory
SCIENCE, SERVICE & STEWARDSHIP

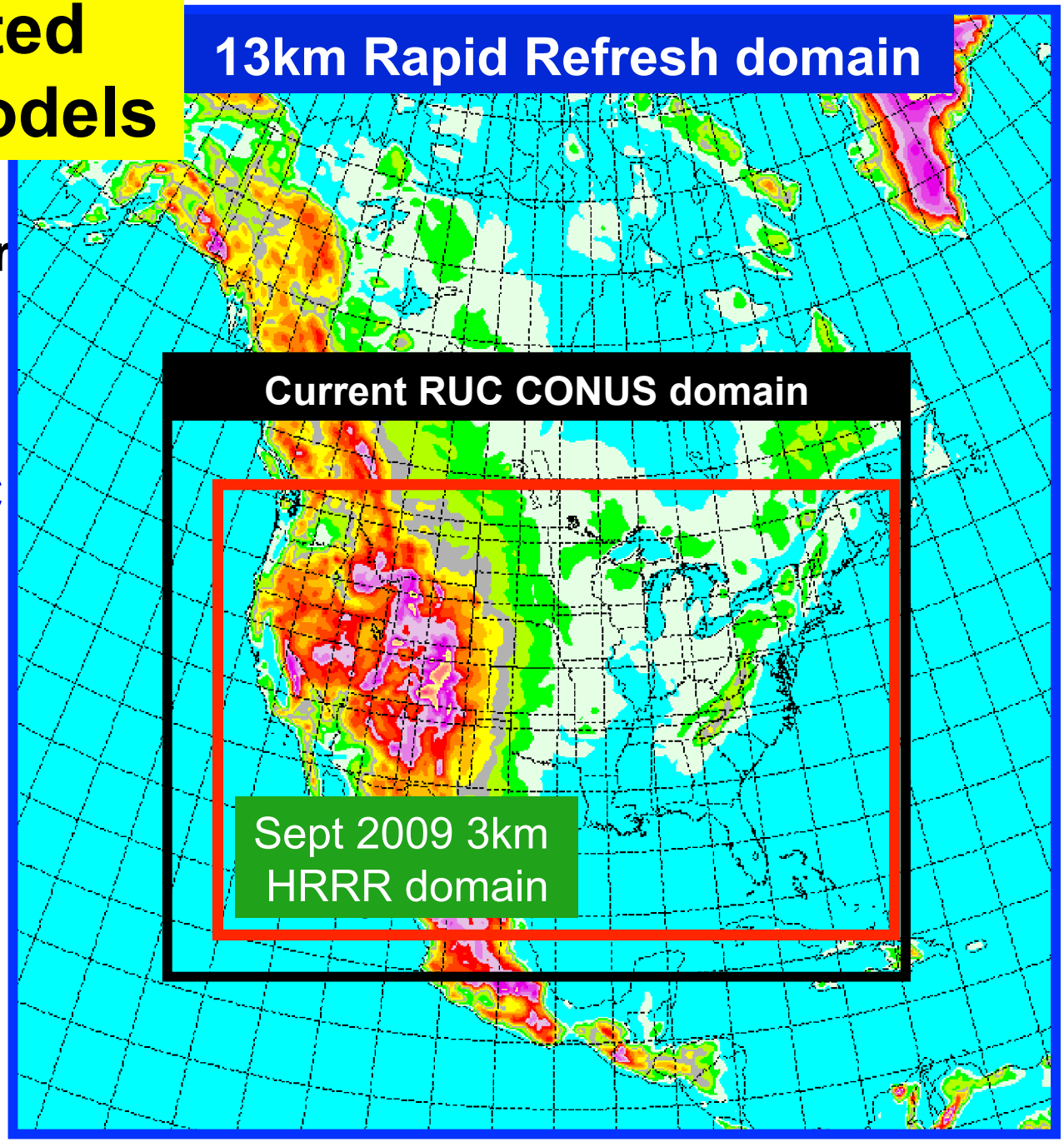
Hourly Updated NOAA NWP Models

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

12h (or 18h) fcst updated every hour



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*)**

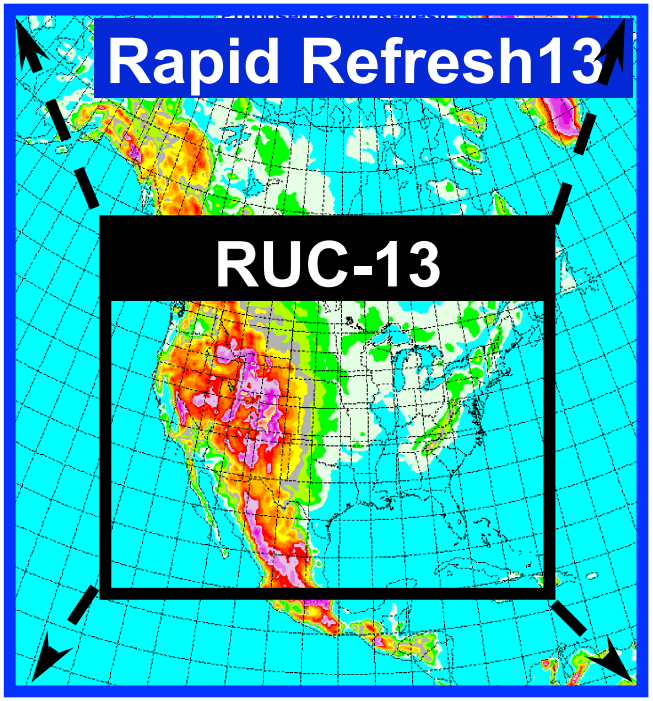
"Situational Awareness Model"

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:

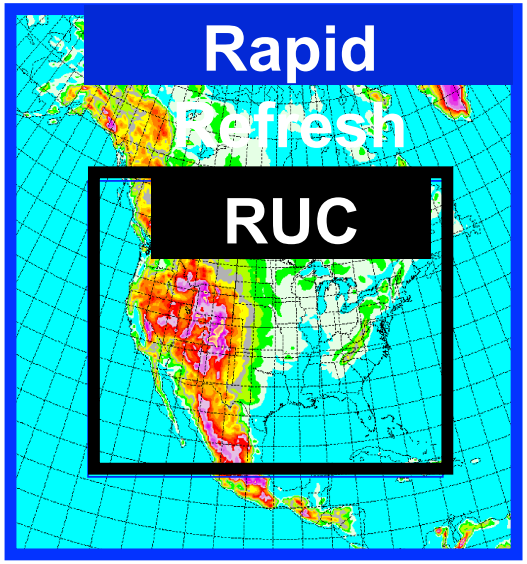
RR system approaching maturity.

NCEP implementation expected Q4 2010

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

RUC to Rapid Refresh

- CONUS domain (13km) → North American domain (13km)



- RUC model → WRF-ARW Model with RR features
- RUC 3DVAR → GSI (Gridpoint Statistical Interpolation) with RR enhancements)

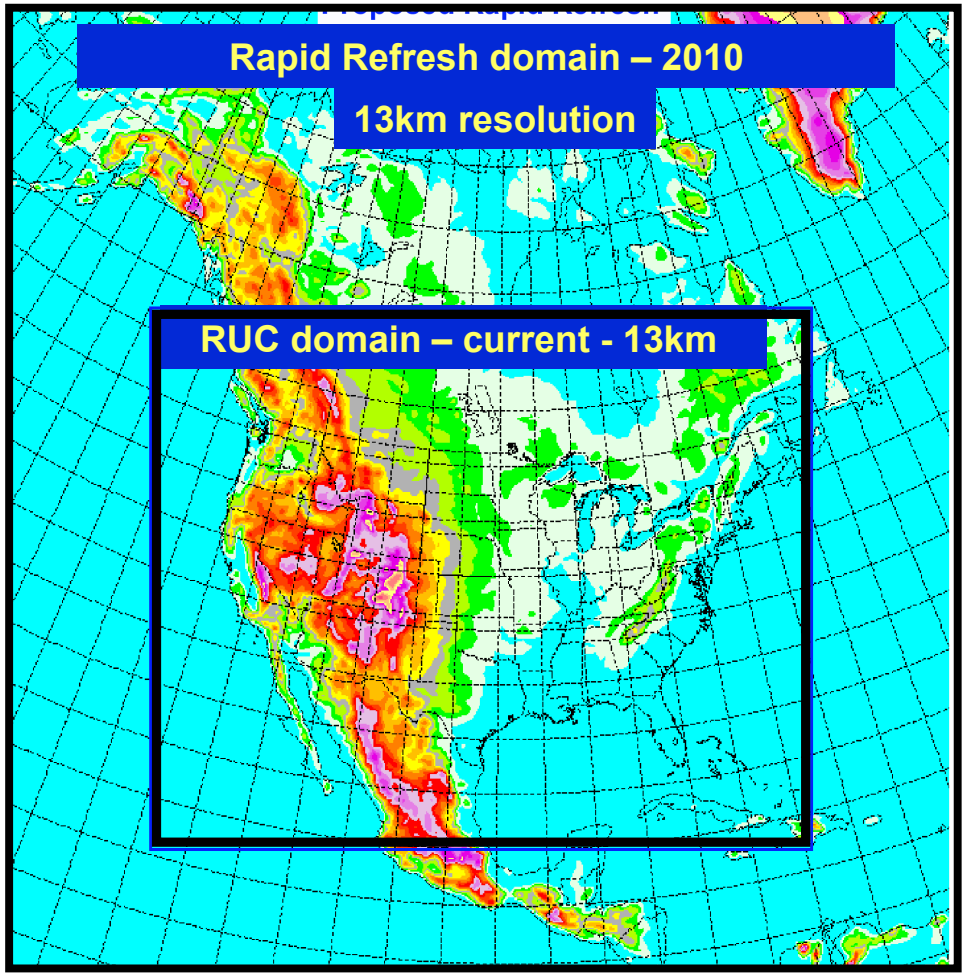
RUC upgrades since Nov 2008

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

- **~Feb 2010** - 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)**
    - **(but 90% thinning since 31 October 09!)**
- **Model physics**
  - **RRTM longwave radiation - eliminates sfc warm bias**
  - **Mods to convective scheme, land-surface scheme**
- **Post-processing – add reflectivity fields, improved RTMA downscaling**

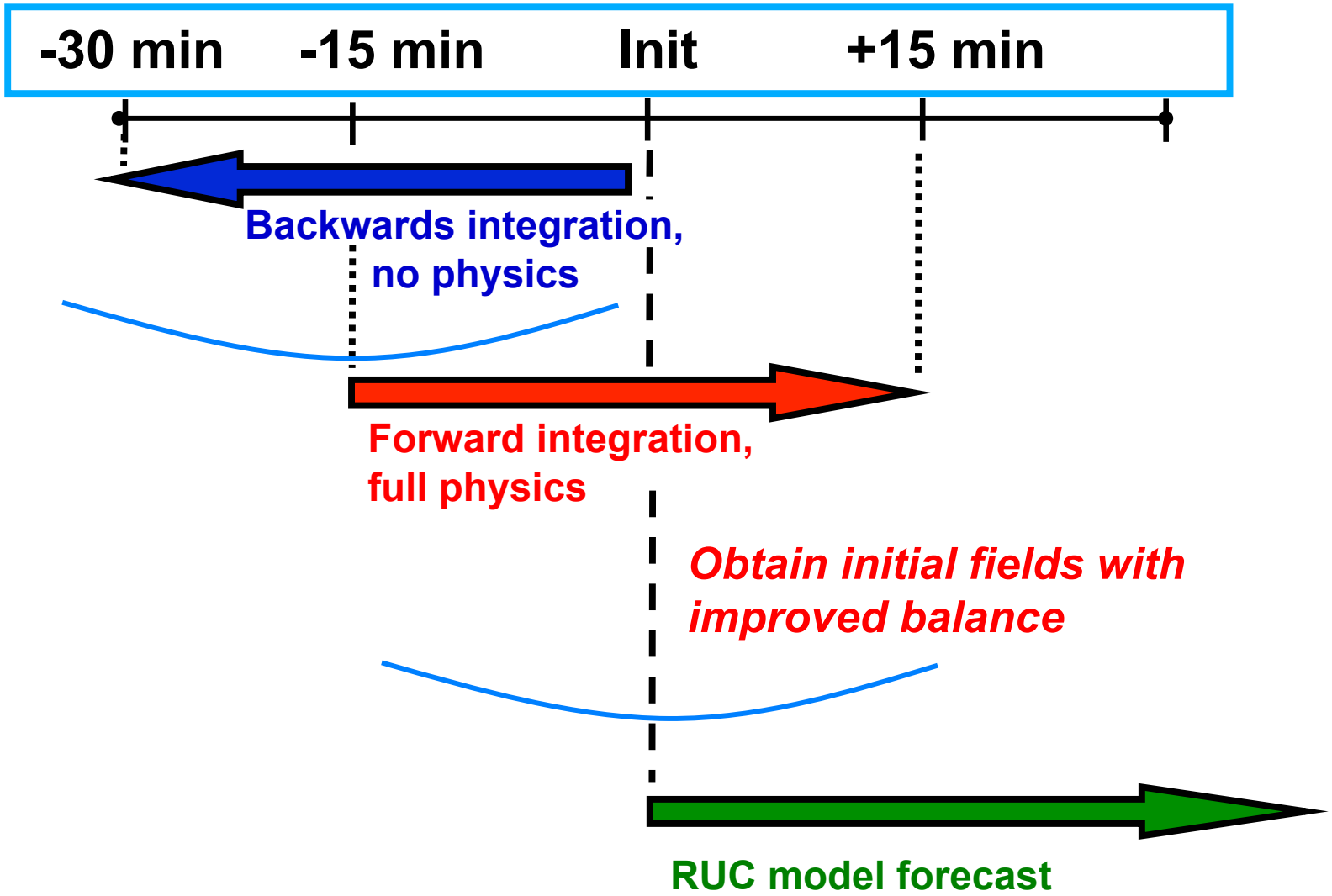
March 2009

- **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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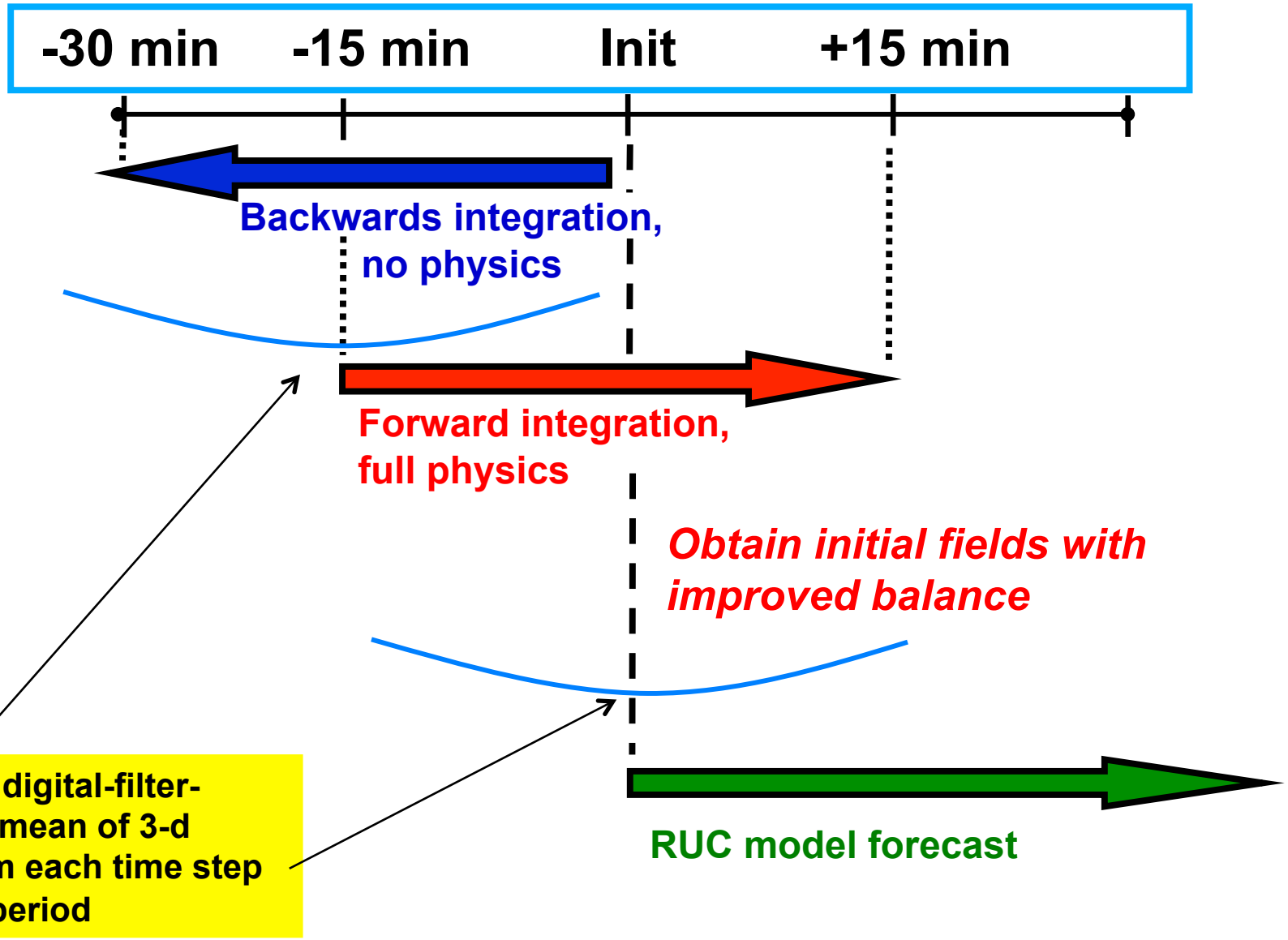


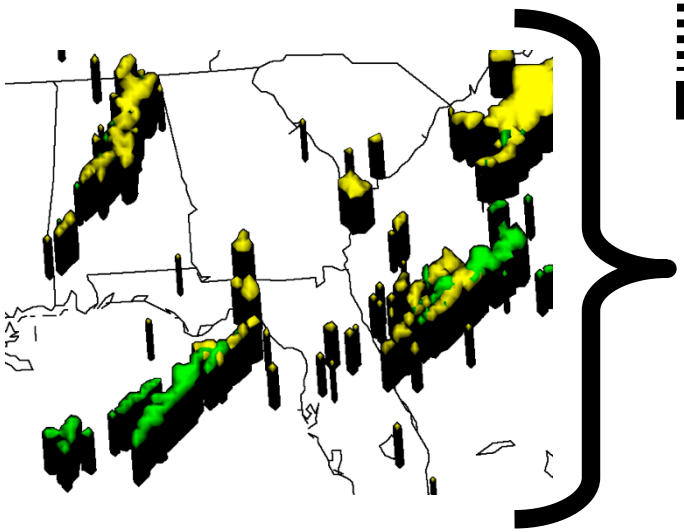
Calculate digital-filter-weighted mean of 3-d fields from each time step over DFI period

Diabatic Digital Filter Initialization (DDFI)

New - add assimilation of radar data

-30 min -15 min Init +15 min

Backwards integration, no physics



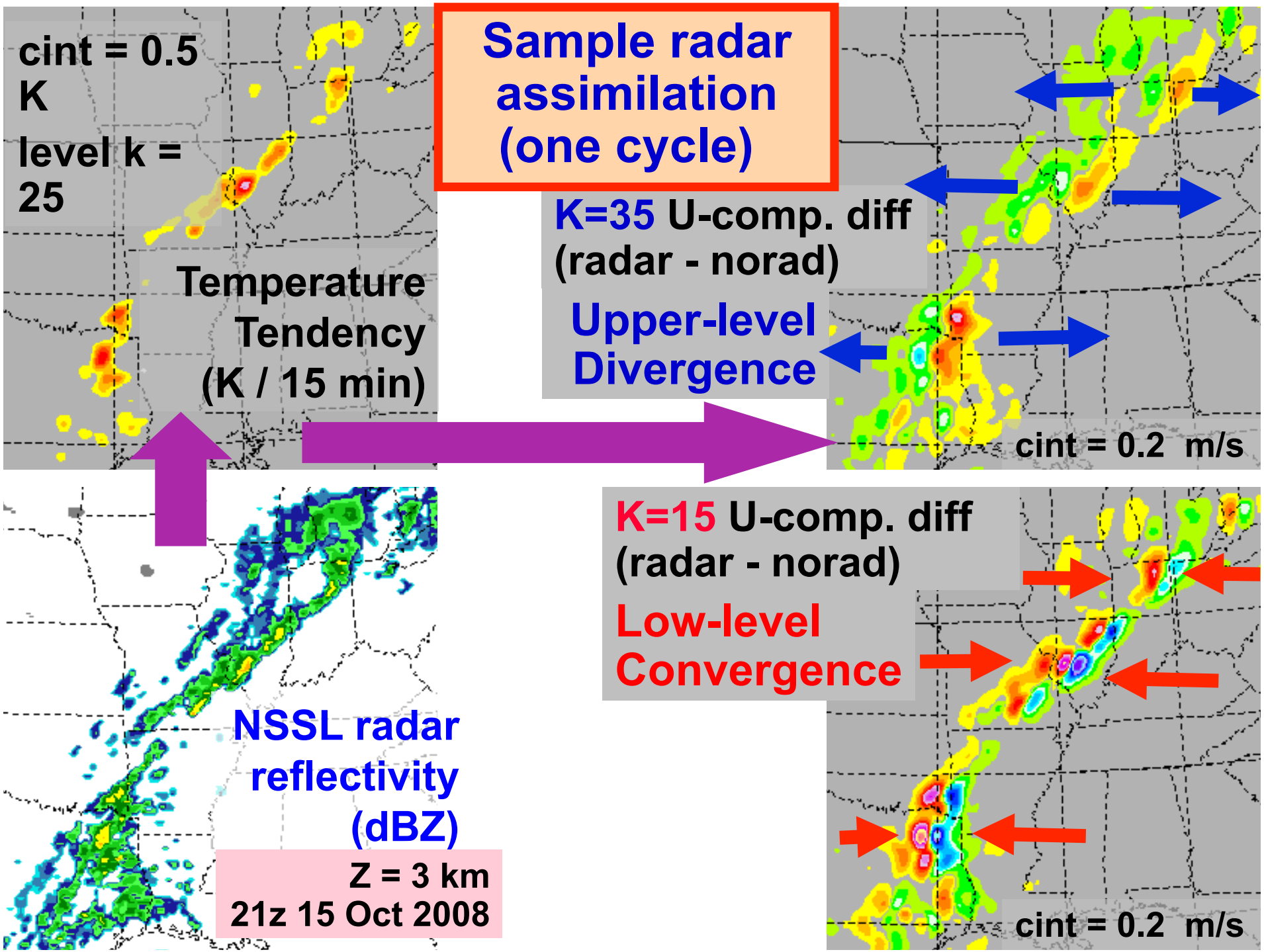
Forward integration, full physics

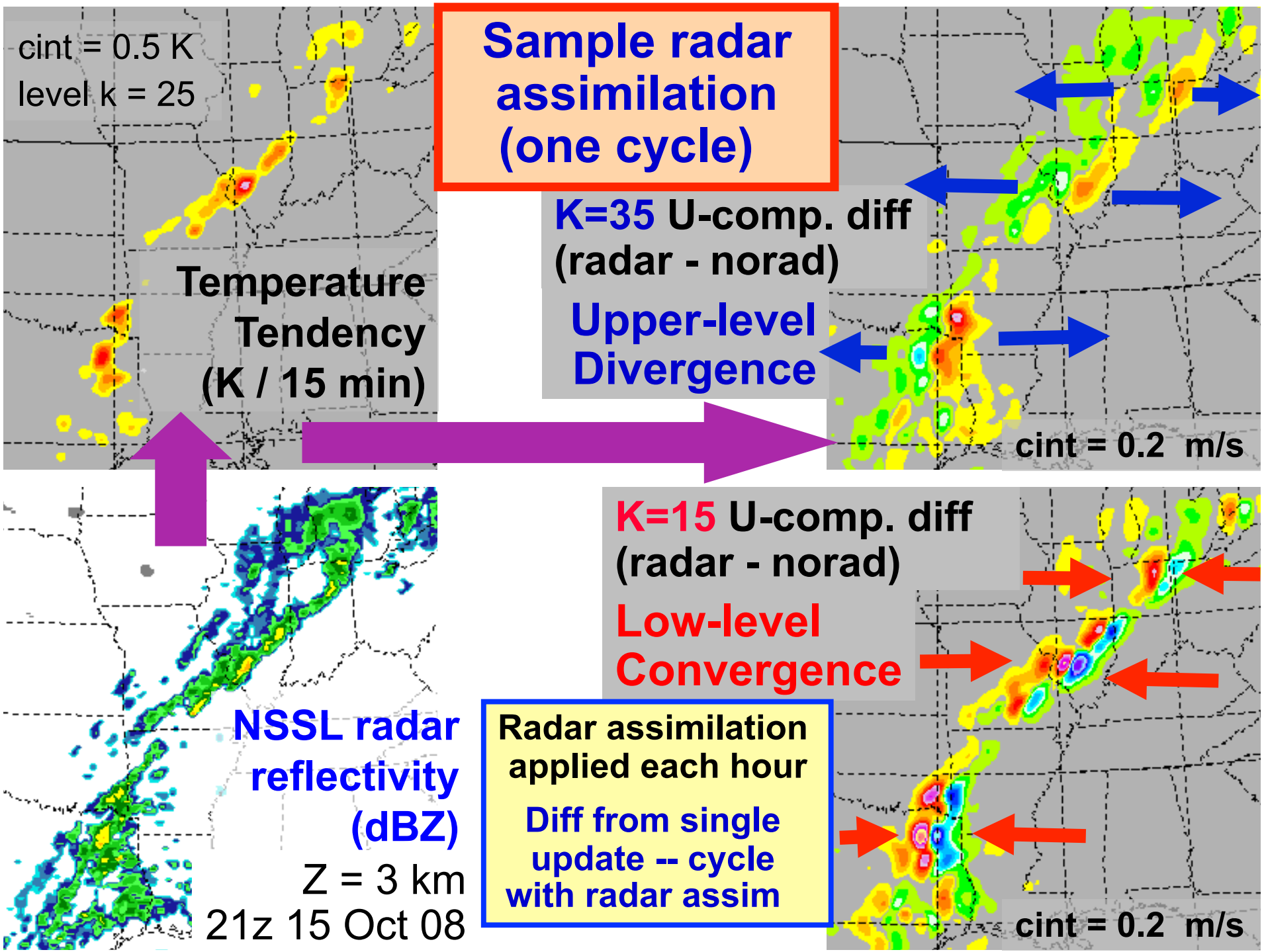
Specify 3-d latent heating from radar reflectivity, lightning data (where available)

Obtain initial fields with improved balance, vertical circulations associated with ongoing convection

RUC model forecast

Radar reflectivity assimilation in RUC


Sample radar assimilation (one cycle)
cint = 0.5 K
level k = 25
Temperature Tendency (K / 15 min)
K=35 U-comp. diff (radar - norad)
Upper-level Divergence
cint = 0.2 m/s
NSSL radar reflectivity (dBZ)
Z = 3 km
21z 15 Oct 2008
K=15 U-comp. diff (radar - norad)
Low-level Convergence
cint = 0.2 m/s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21z 15 Oct 08
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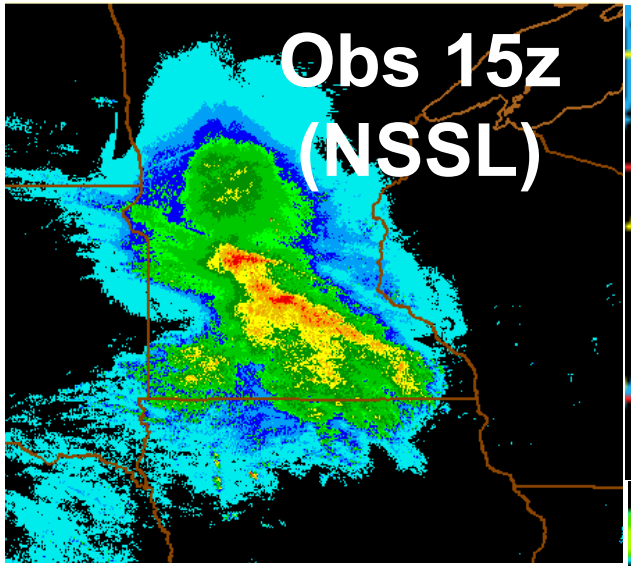
Low-level Convergence
Radar assimilation applied each hour
Diff from single update -- cycle with radar assim
cint = 0.2 m/s

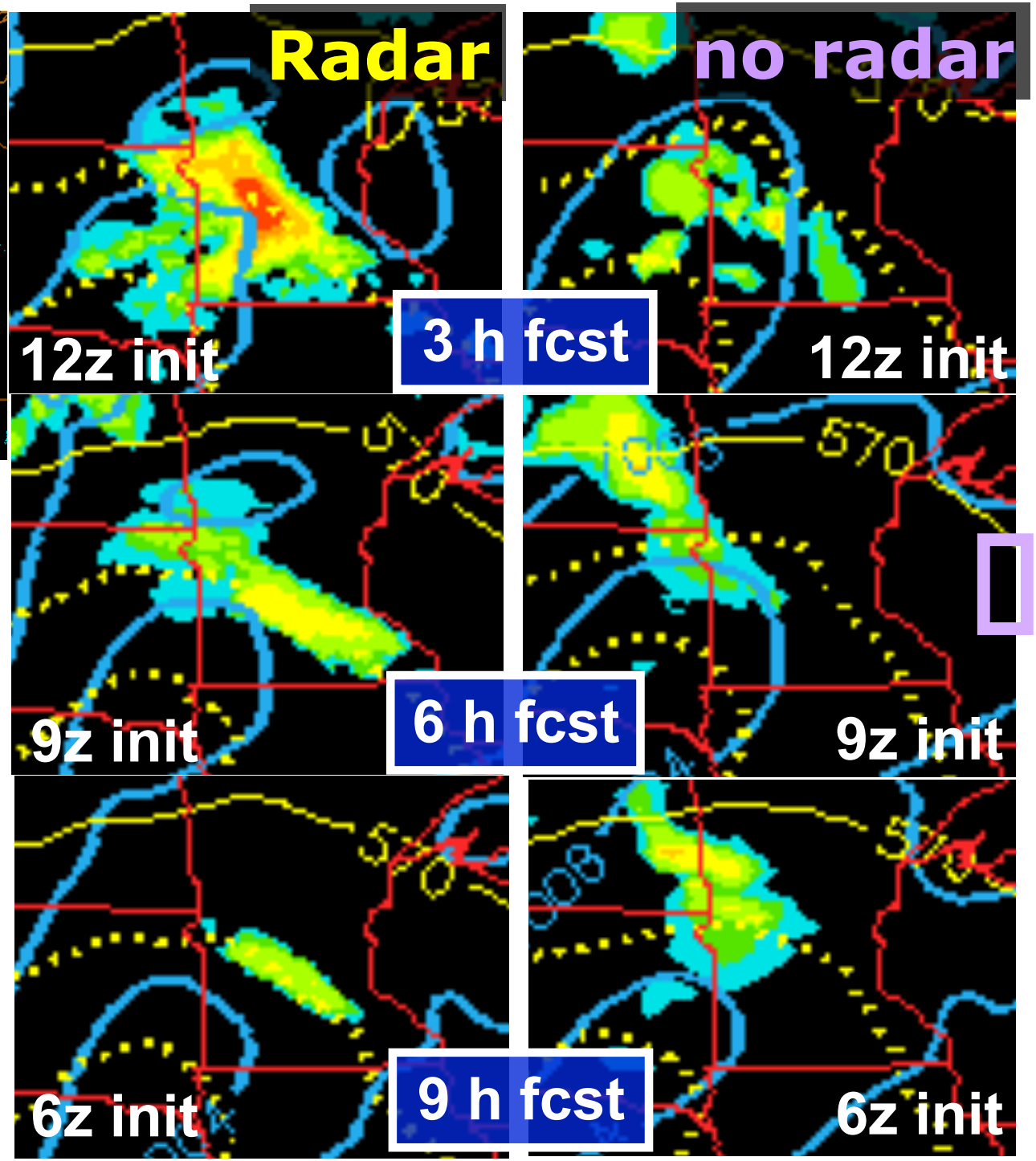


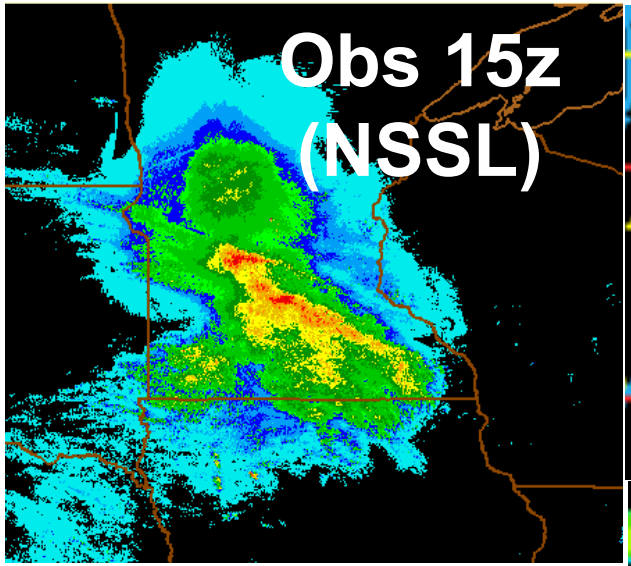
3-h acc. precip.

Valid 15z
31 July 2008

RUC radar Assimilation

→Better RUC forecasts





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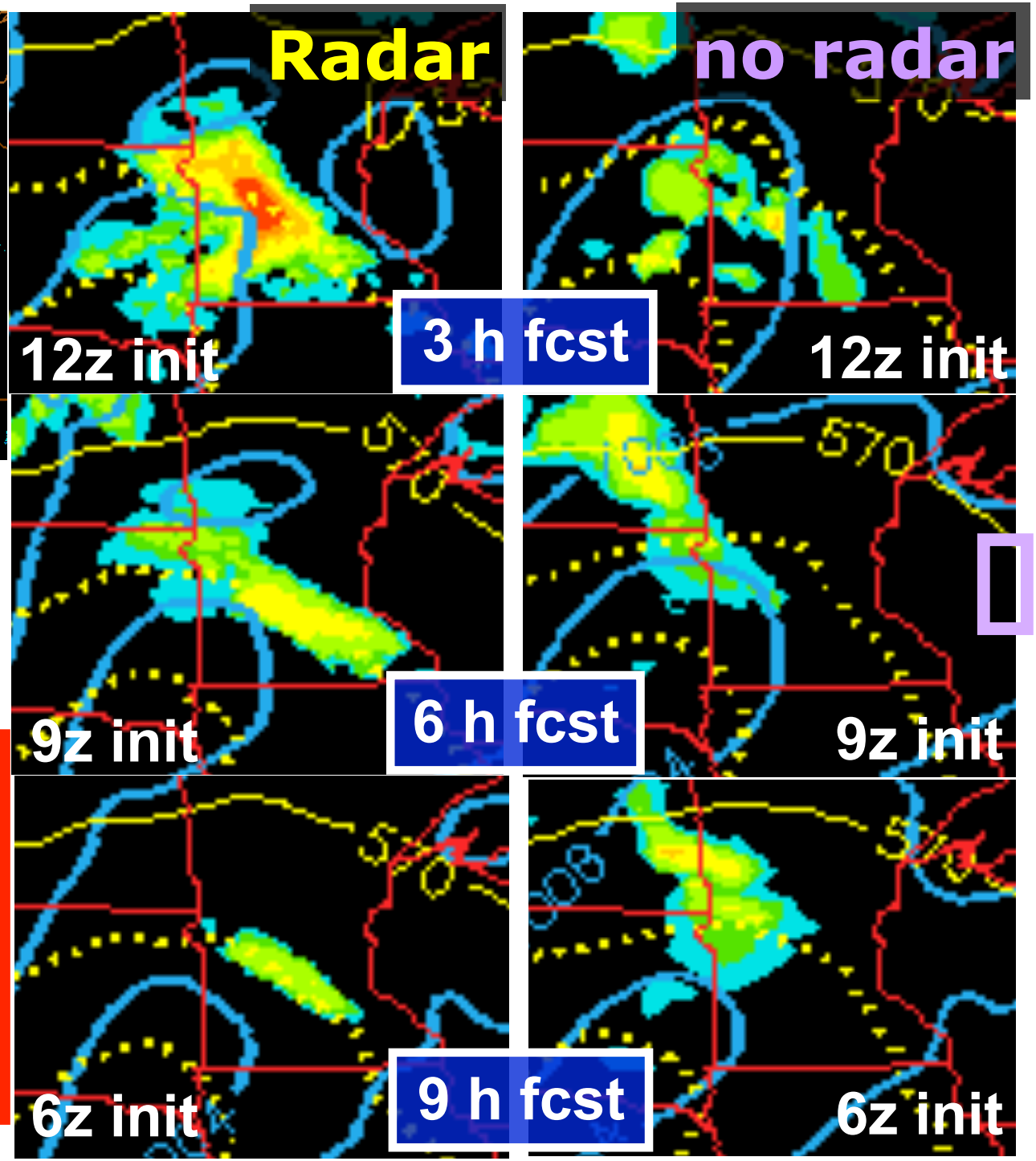
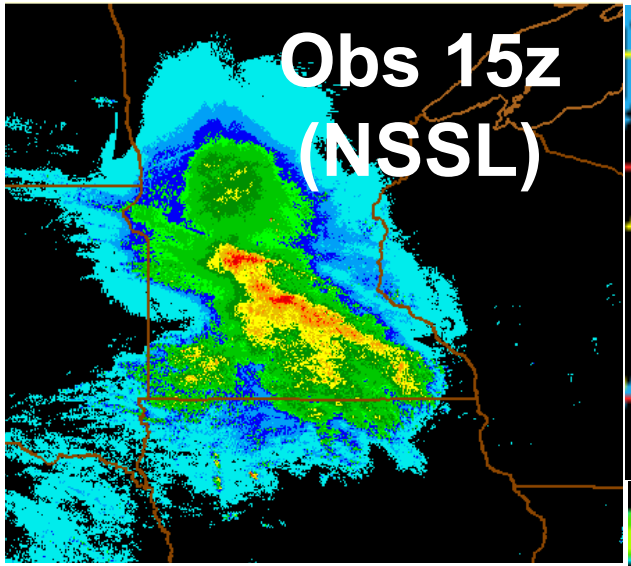
RUC radar Assimilation

→Also in Rapid Refresh





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Valid 15z
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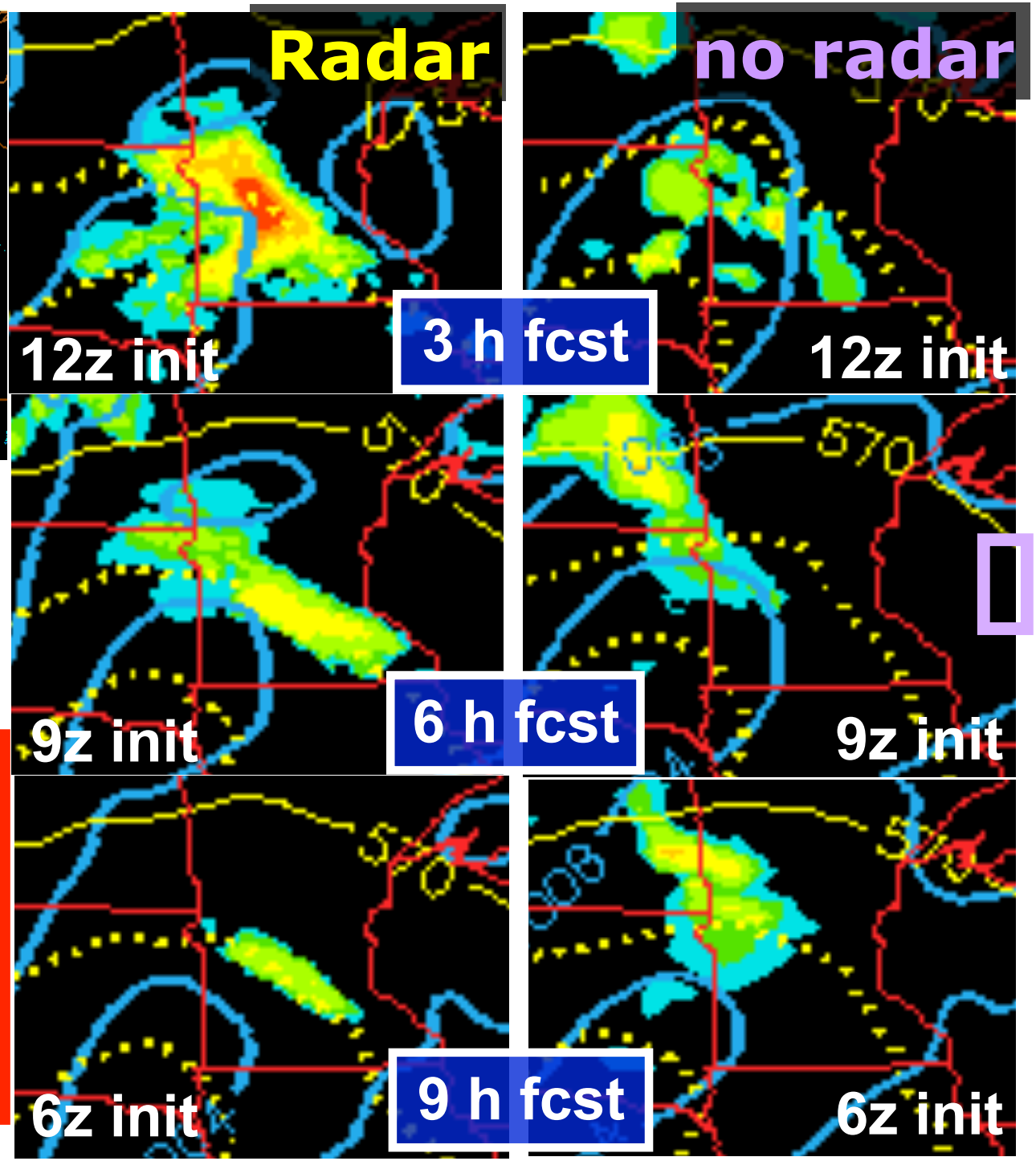
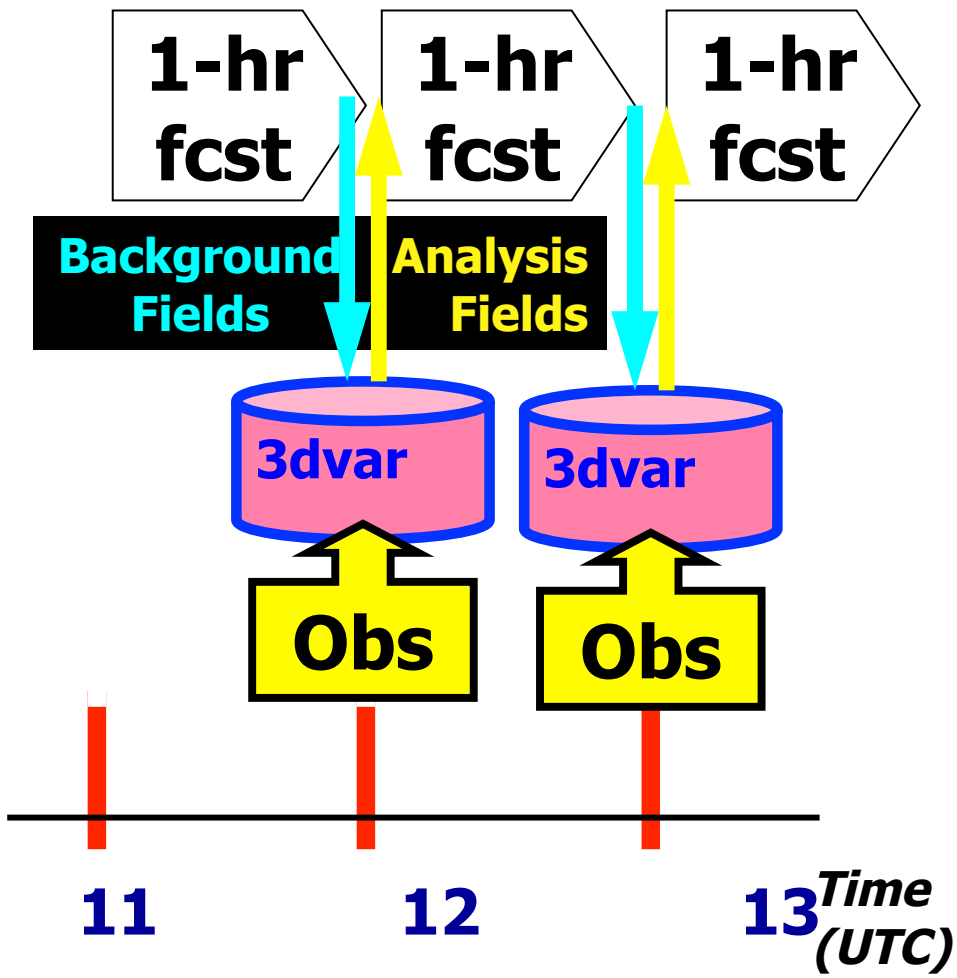
RUC/RR radar Assimilation

→Essential for 3km HRRR



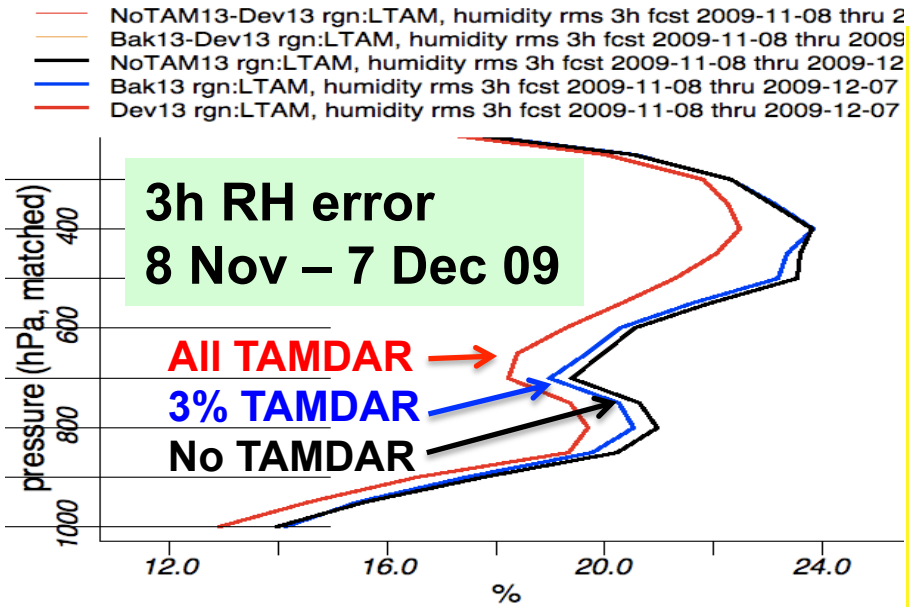
RUC/Rapid Refresh Hourly Assimilation Cycle

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

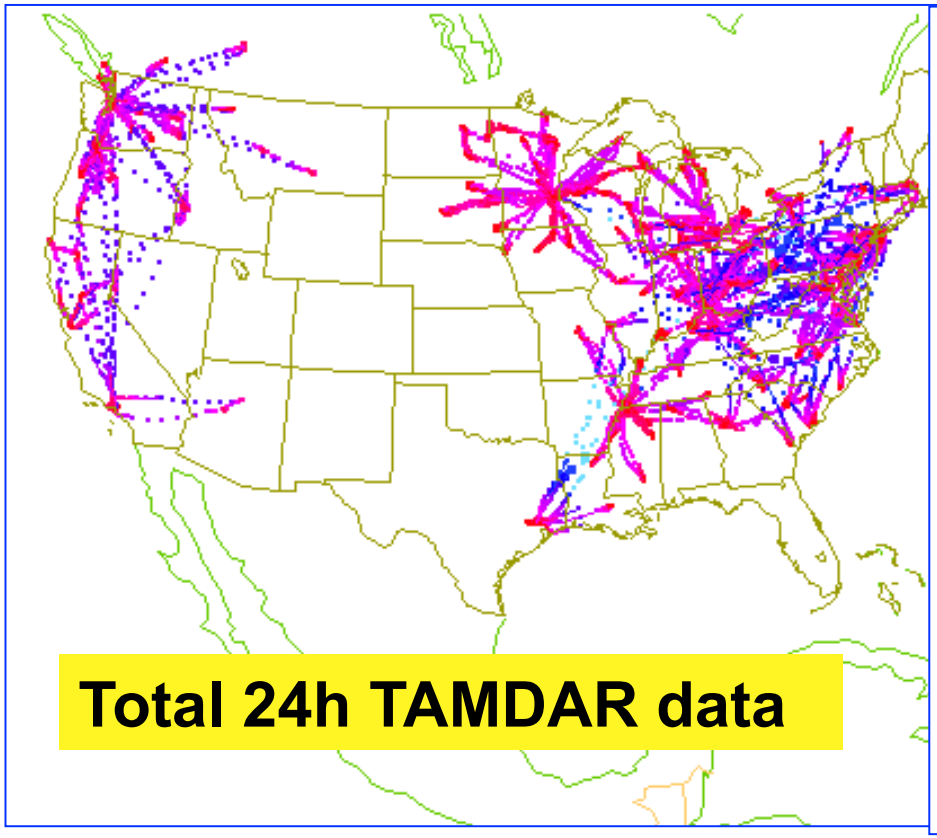


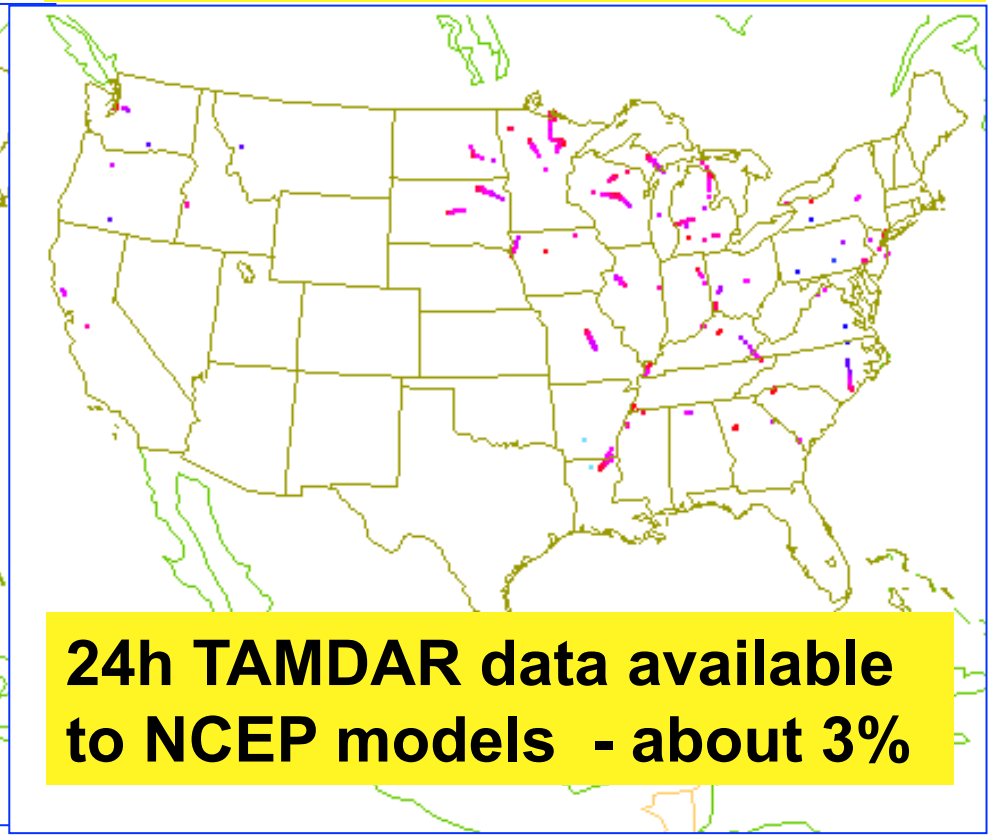
Hourly obs

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



TAMDAR data reduced by 97% effective 10/30/2009 per NOAA-AirDat agreement – buy fraction only of total data - $50/sounding





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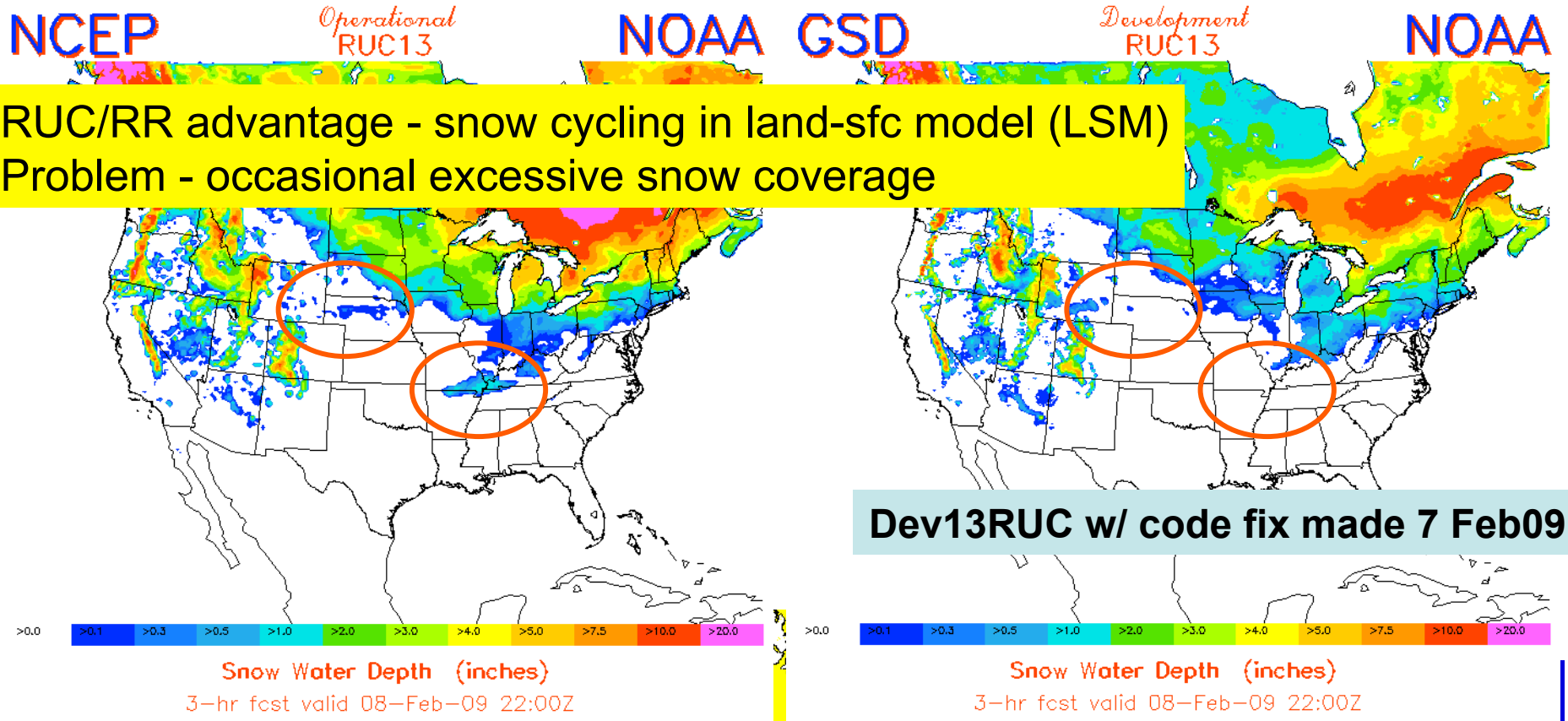
March 2009

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

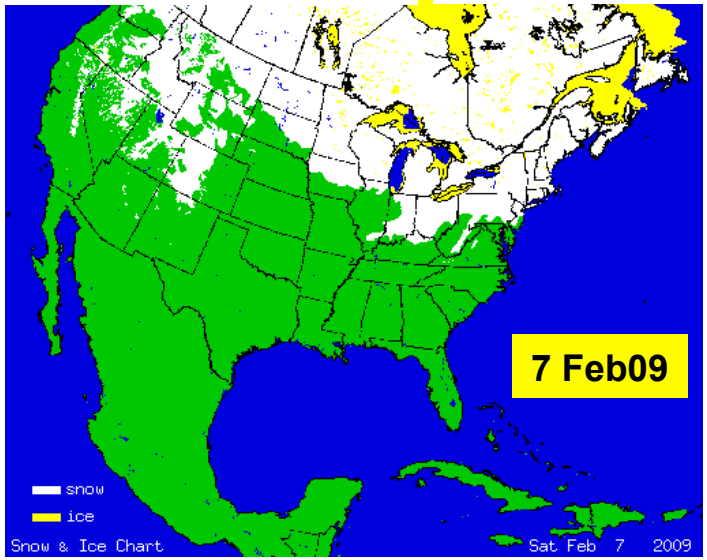
RUC/RR advantage - snow cycling in land-sfc model (LSM)
Problem - occasional excessive snow coverage

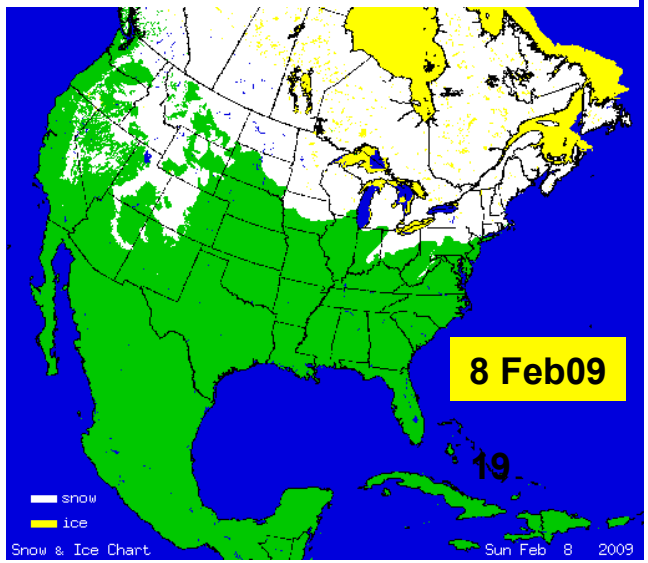


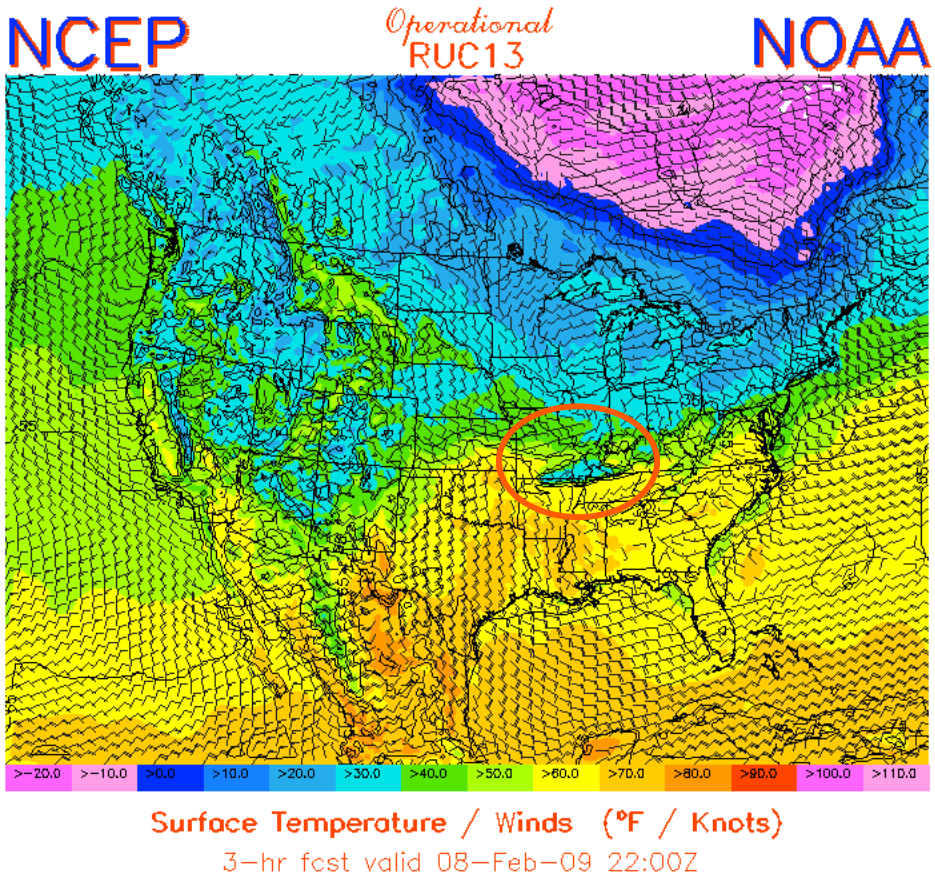
Dev13RUC w/ code fix made 7 Feb09

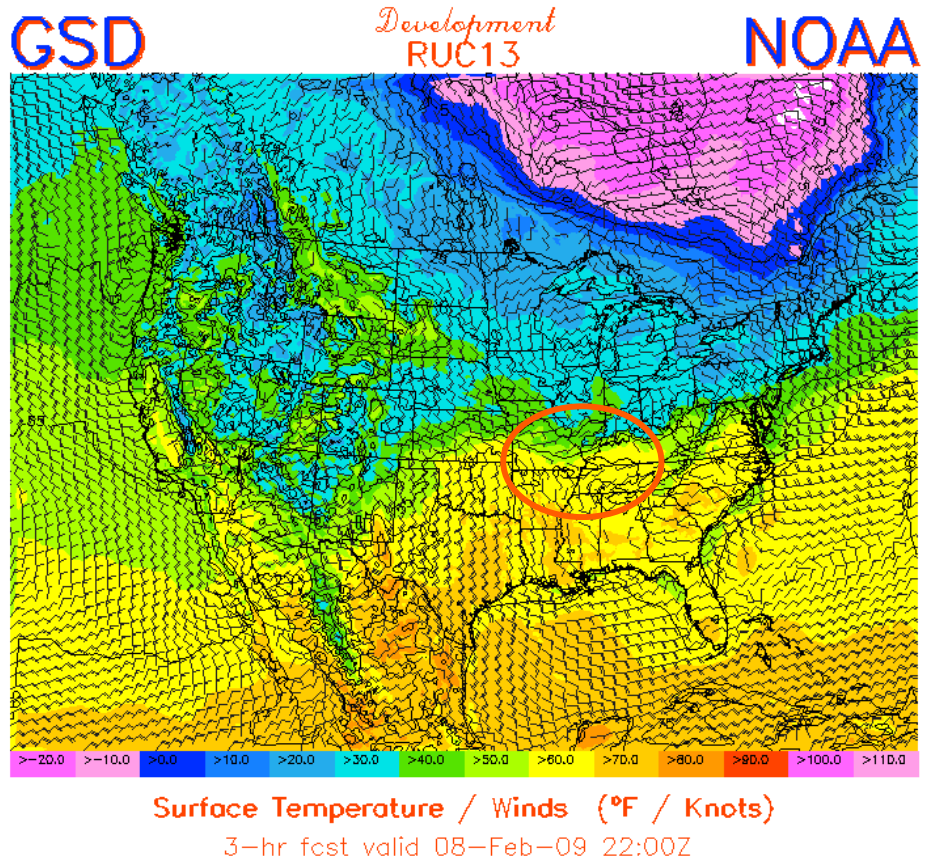
NESDIS snow cover

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



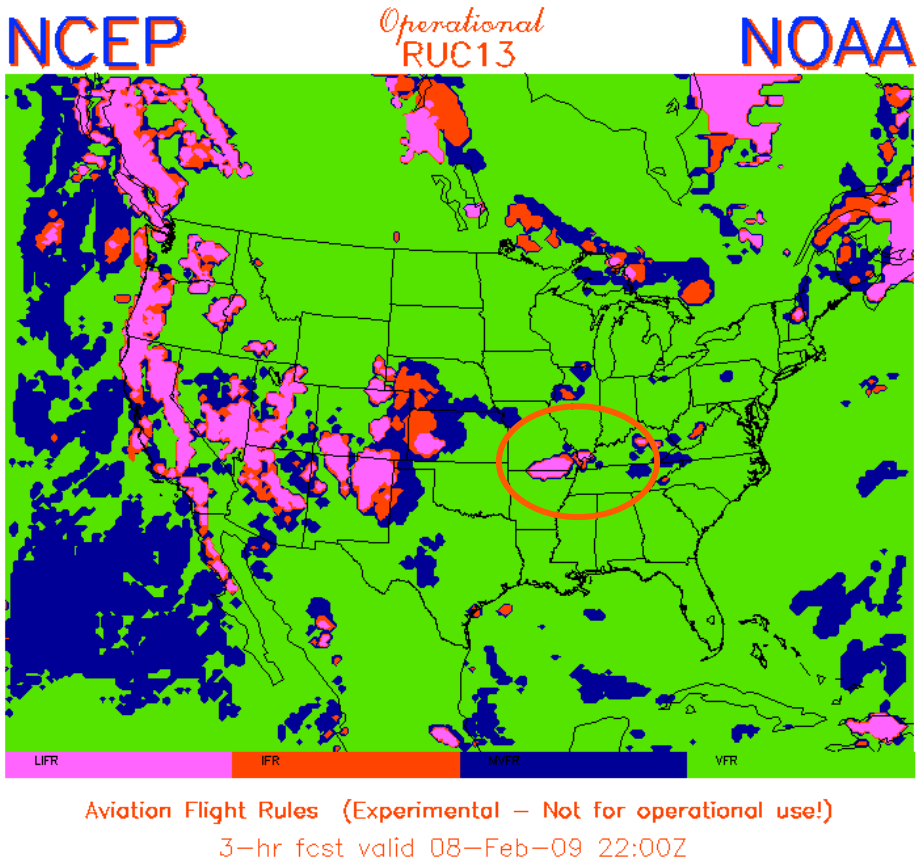


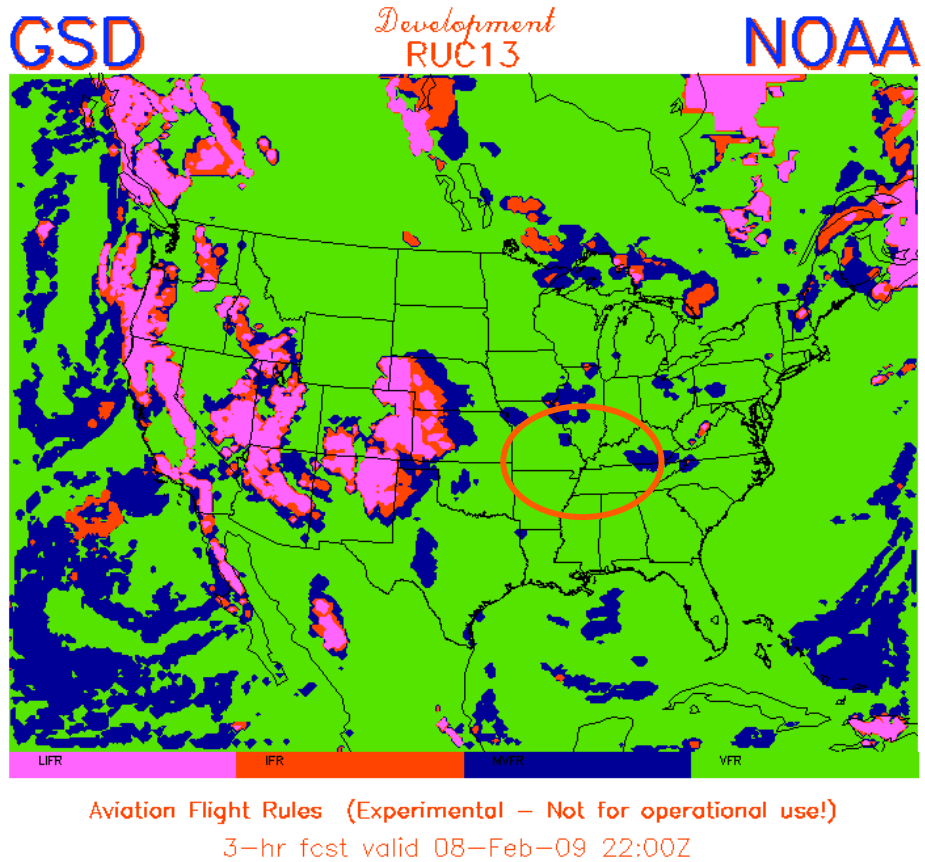




Errors in 2m temp due to erroneous snow cover in operational RUC

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





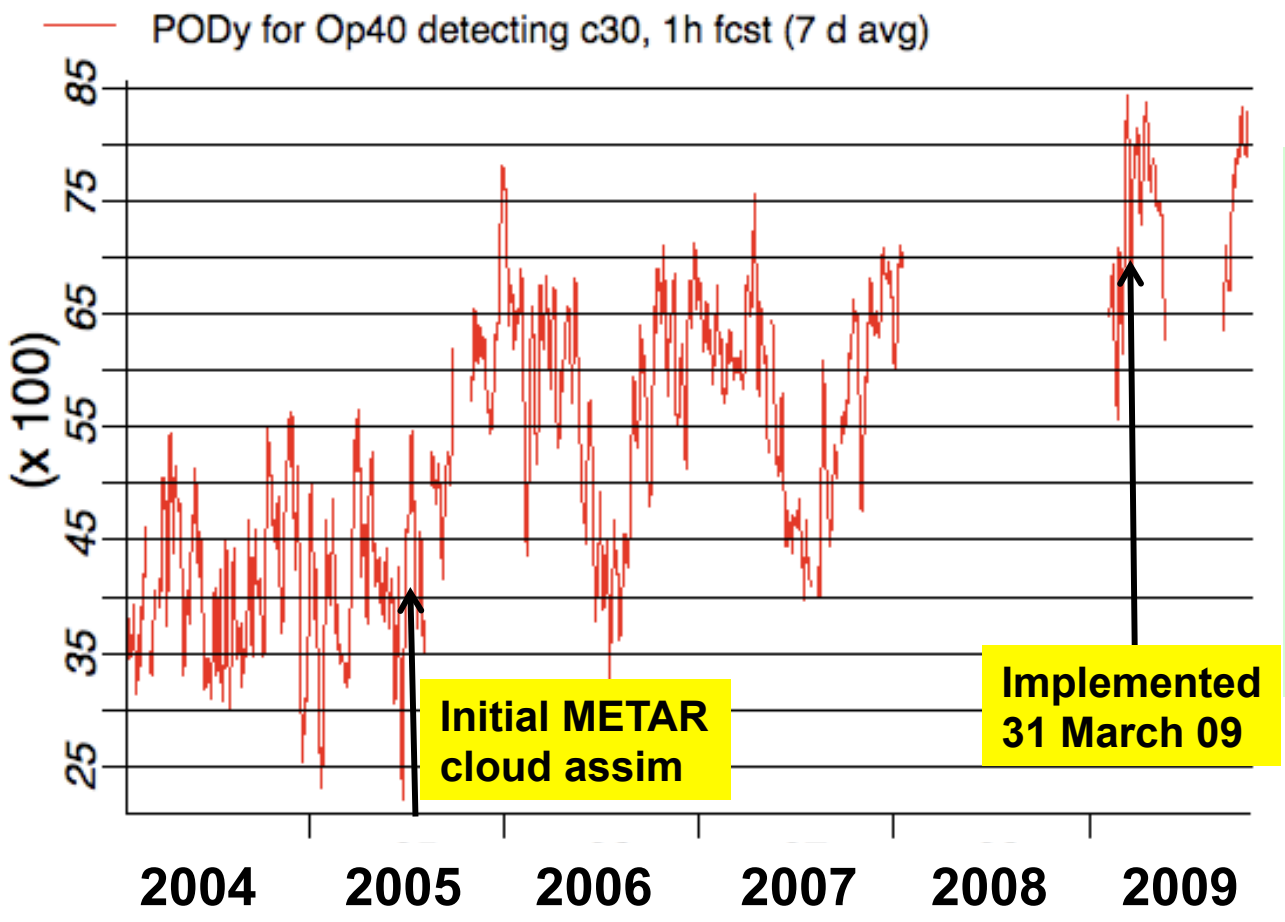
Another consequence from snow cover error:
Low fog due to erroneous snow cover in operational RUC

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.



POD-yes for 3000-ft (MVFR) ceiling -1h RUC forecast (7-day average running mean)

RUC/RR cloud / radar assimilation flowchart

1-h fcst
qv, qc, qi,
qr, qs, qg

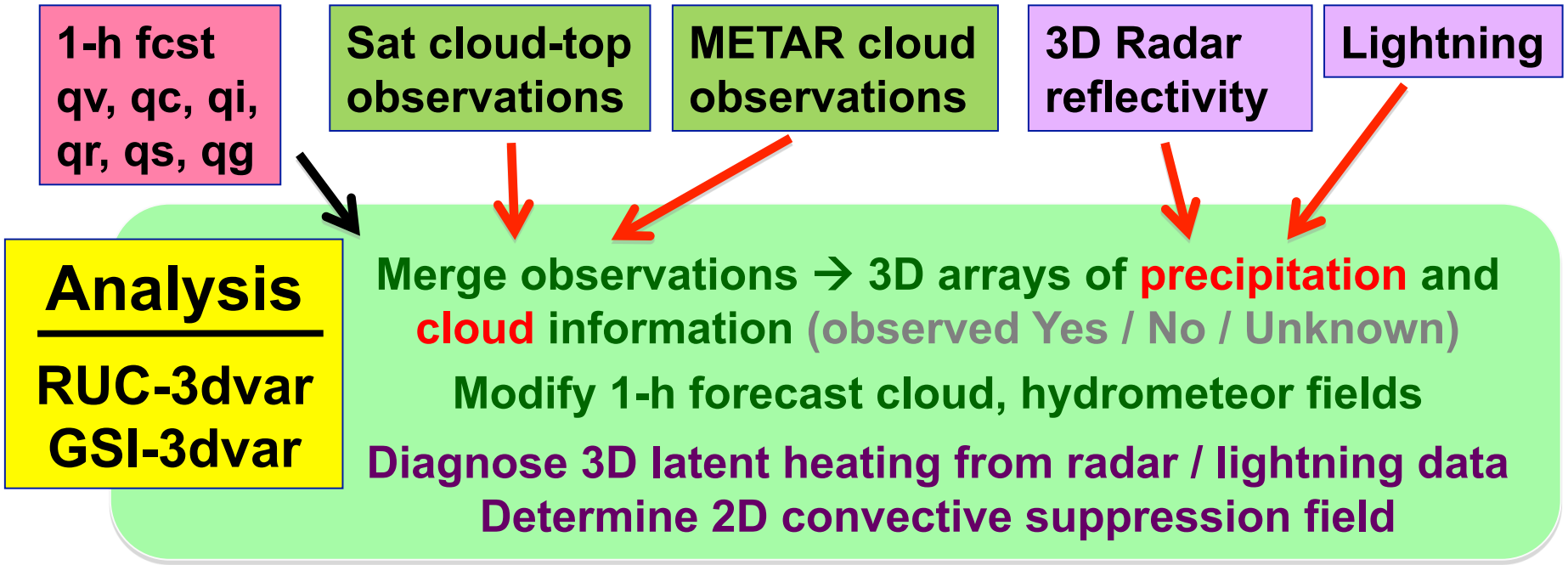
Sat cloud-top
observations

METAR cloud
observations

3D Radar
reflectivity

Lightning

RUC/RR cloud / radar assimilation flowchart



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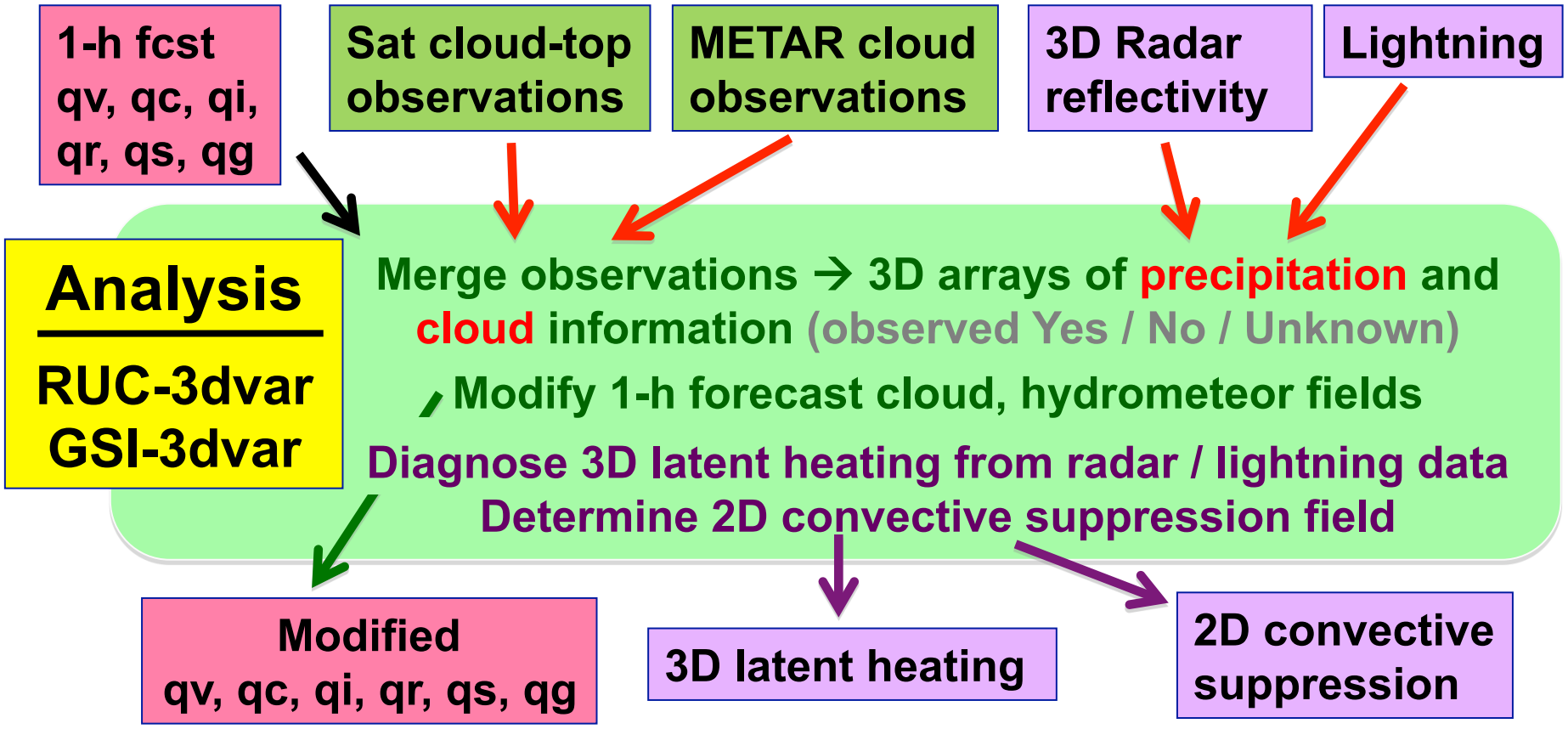

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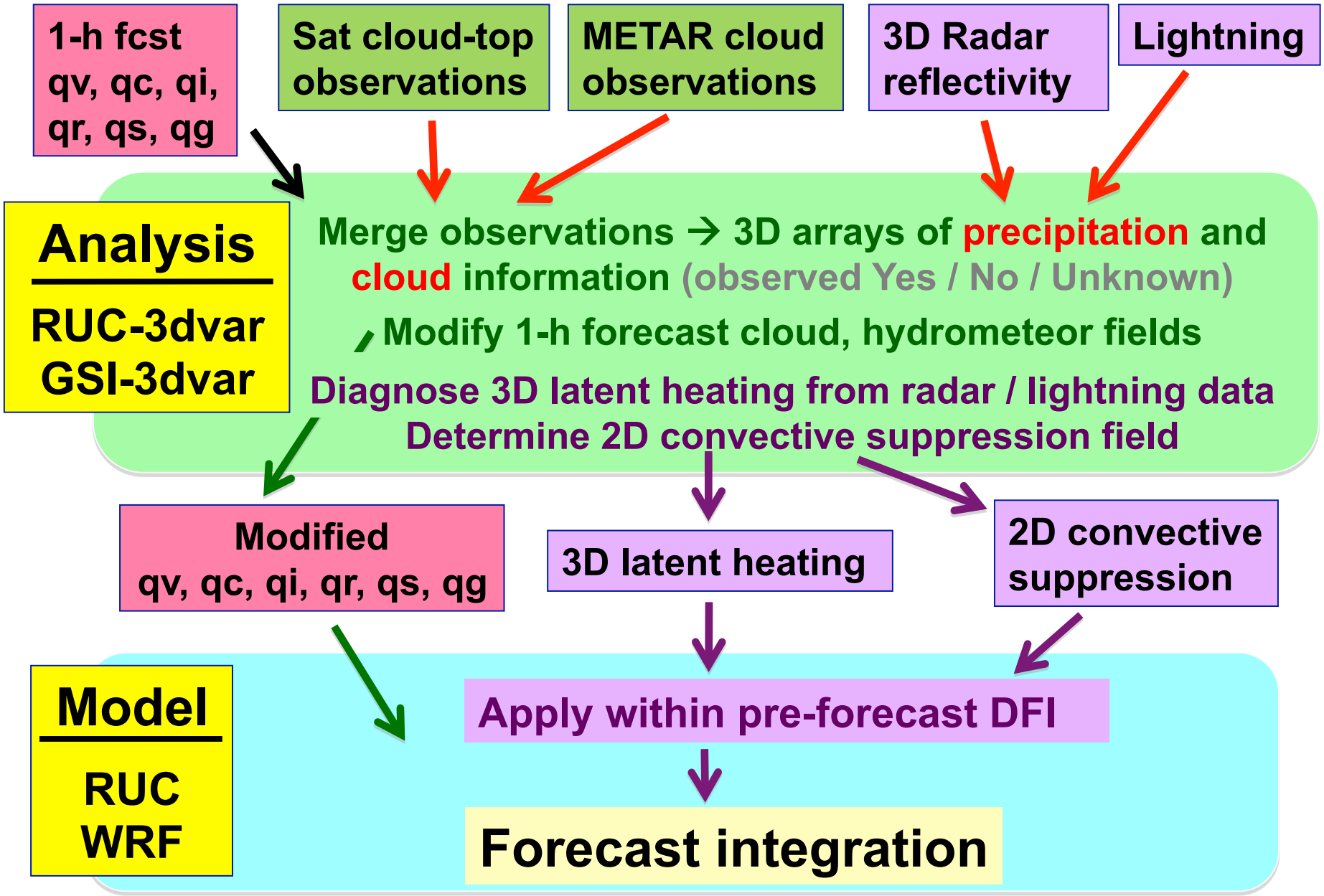
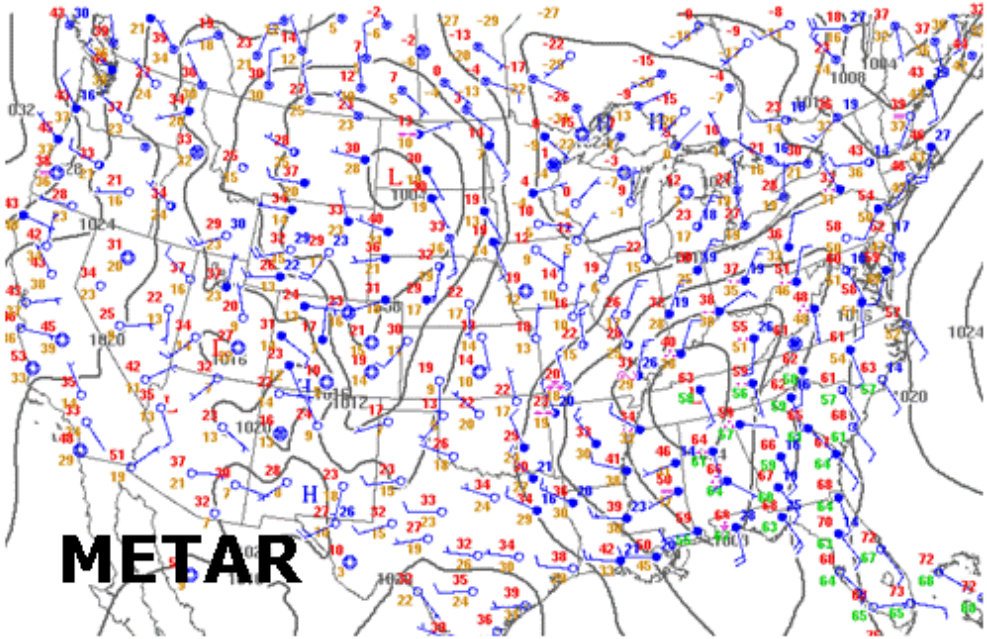
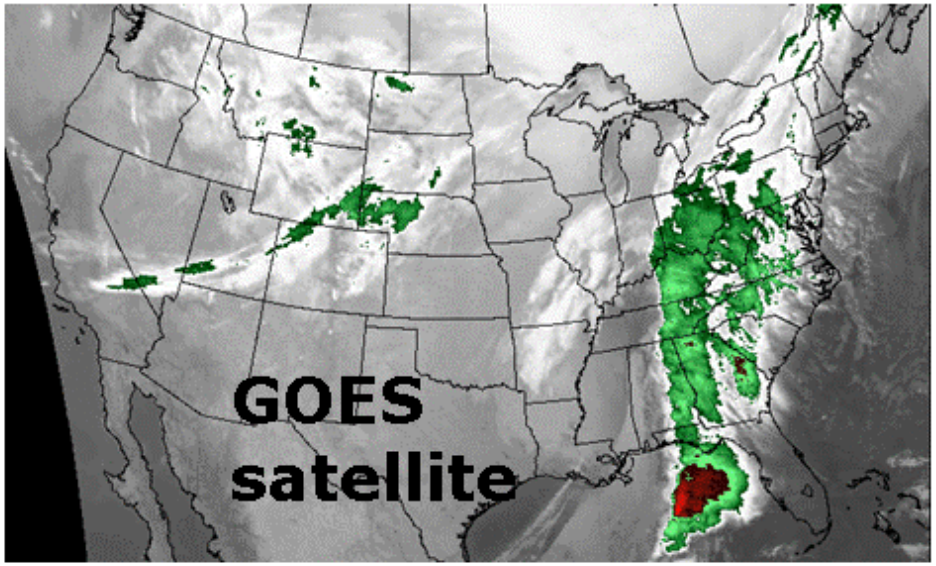


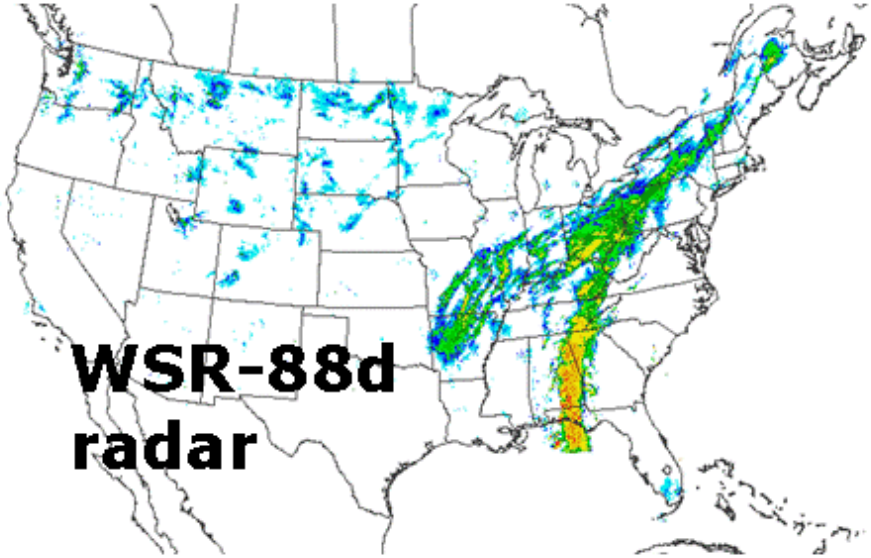
Cloud Observations from three sources



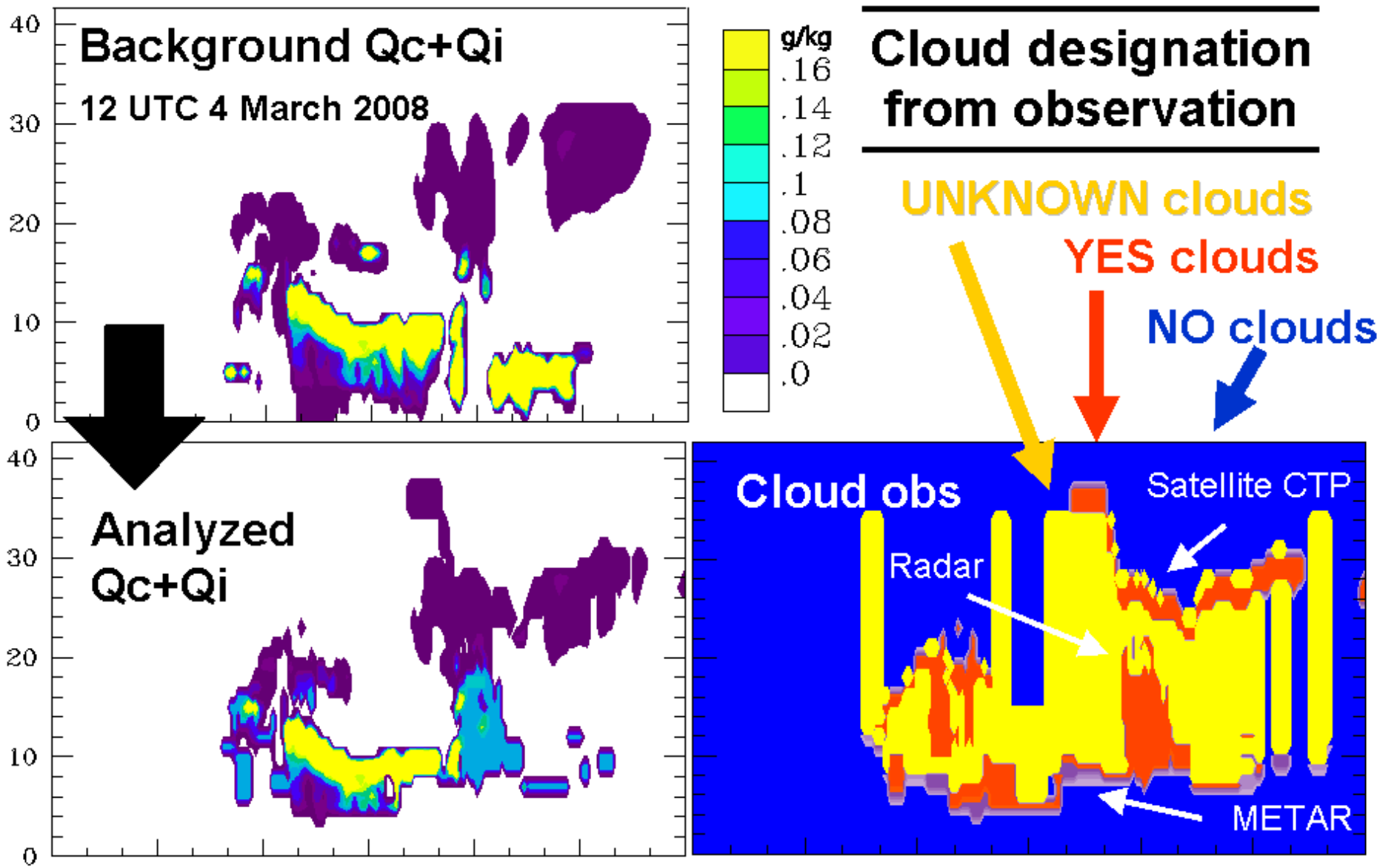
Combine with 1h fcst - 3-d fields of qc, qi, qr, qs, qg

12 UTC 4 March 2008





Modify background with cloud observations



Feb 2010 – further changes for oper RUC – now in testing @ NCEP

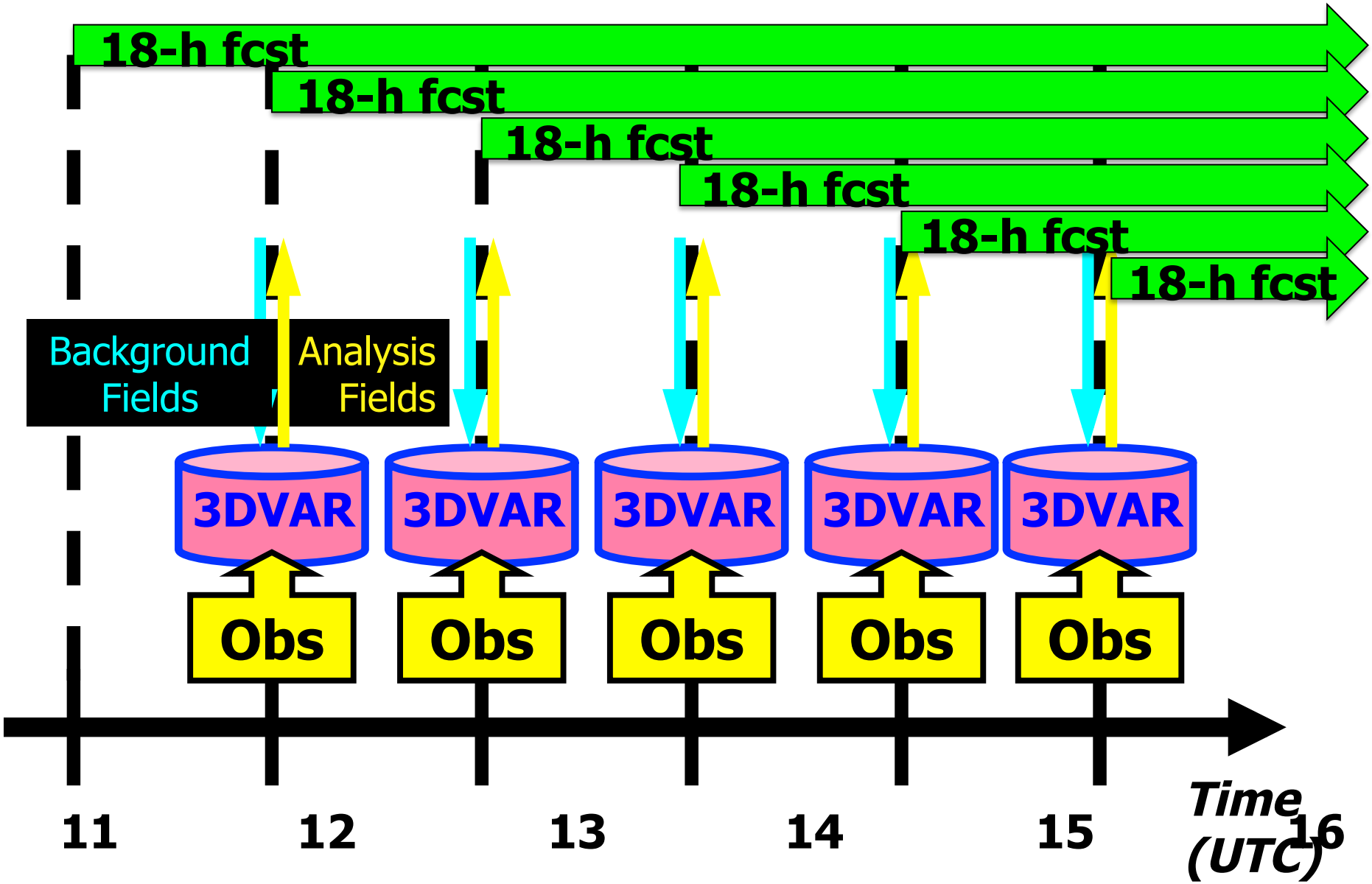
- **Extension of RUC to 18h every hour (requested by SPC and AWC)**

- **Further fix to cloud/hydrometeor assimilation**
  - **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 for cloud and radar assimilation have also been incorporated into the Rapid Refresh

18h RUC Hourly Assimilation Cycle - ~Feb 2010



RUC upgrades since Nov 2008

http://ruc.noaa.gov
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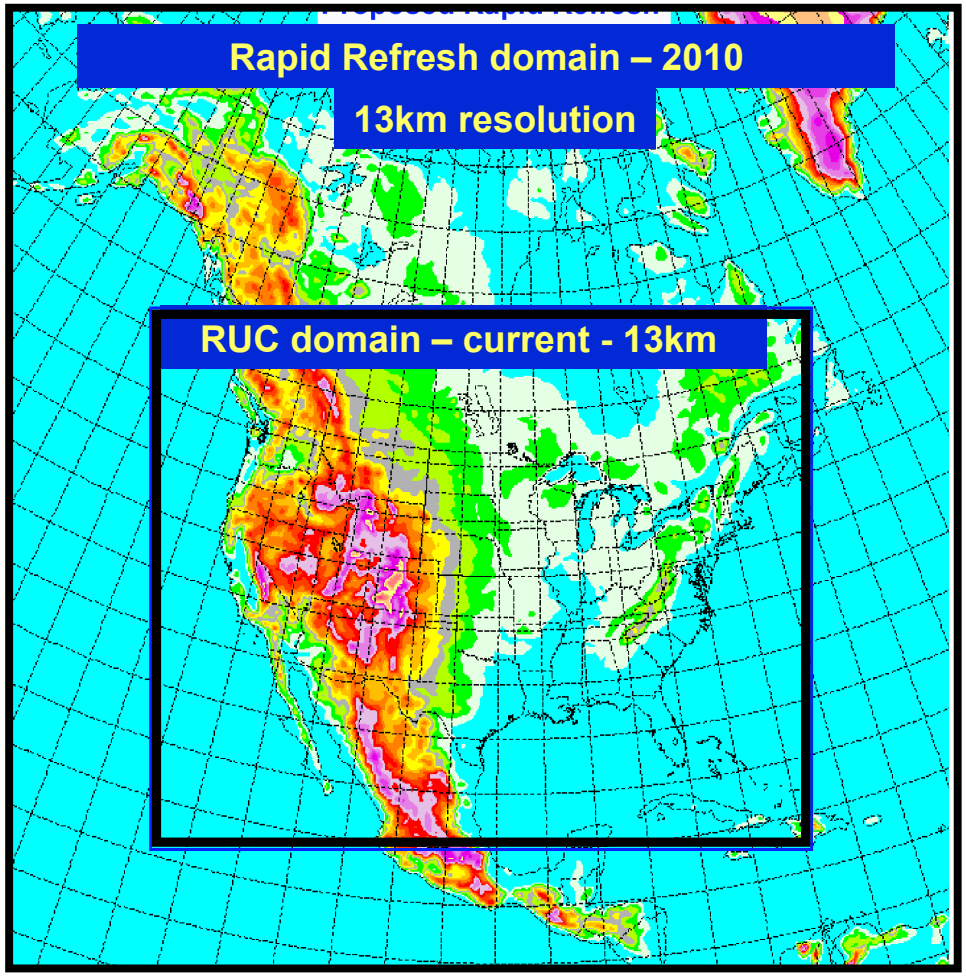


Rapid Refresh History and Status

- **2003-2005 - WRF-RUC testing**
  - WRF initialized with RUC initial conditions
- **2006 - Controlled ARW, NMM core comparison**
  - GSD-AMB recommends ARW by slight margin (Aug. 2006)
- **2007-2009 - Extensive RR testing and refinement**
  - First RR cycling with GSI, ARW (late 2007)
  - RUC cloud analysis, grids to experimental users
  - Digital Filter Initialization and radar assimilation

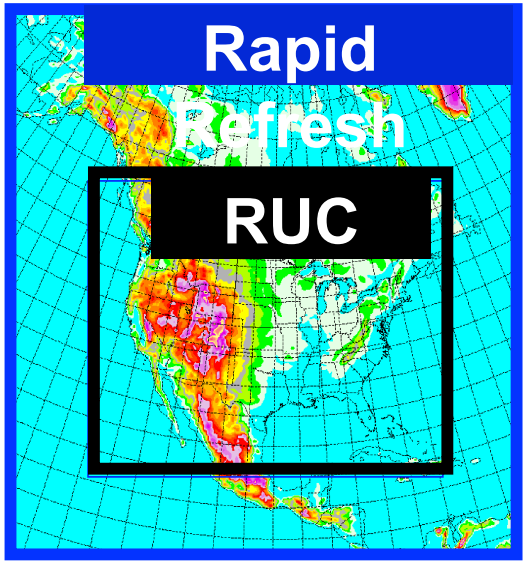
Current Status → Early 2010

- Nearly all modifications in place, good verification
- Final changes based on cycled RR testing
- Transfer code to NCEP, Begin Parallel cycle

Q4 2010 - Planned NCEP implementation of Rapid Refresh

RUC to Rapid Refresh

- CONUS domain (13km) → North American domain (13km)



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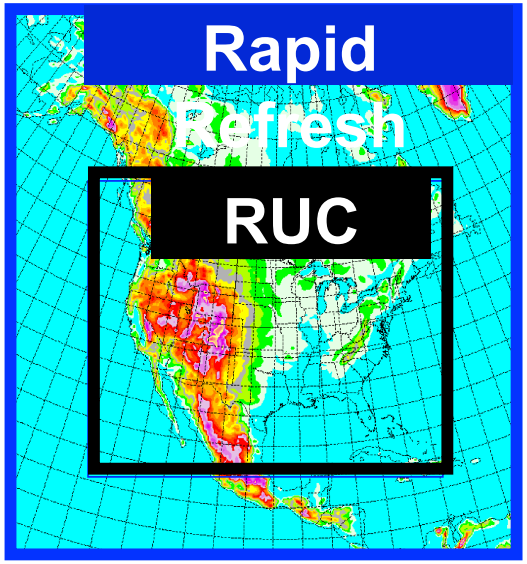

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RR version of WRF model

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

Grell-Devenyi convection

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

Components in red match RUC

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

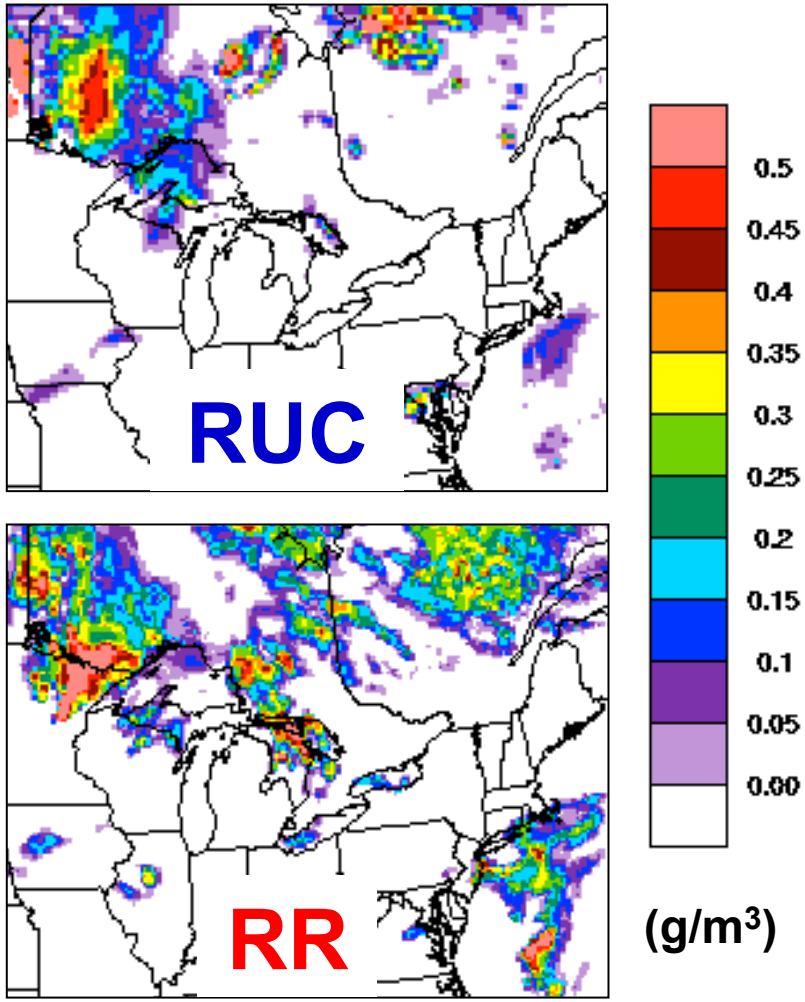
NCAR-Thompson Microphysics

RUC - Dec 2003 version

RR - new version in WRFv1 (mp_physics = 8) has many changes

- **2-moment rain (mixing ratio, number concentration)**
  Better simulation of difference in drop-size distribution between rain from melting snow and rain from collision-coalescence
- **More ice supersaturation (up to water saturation)**

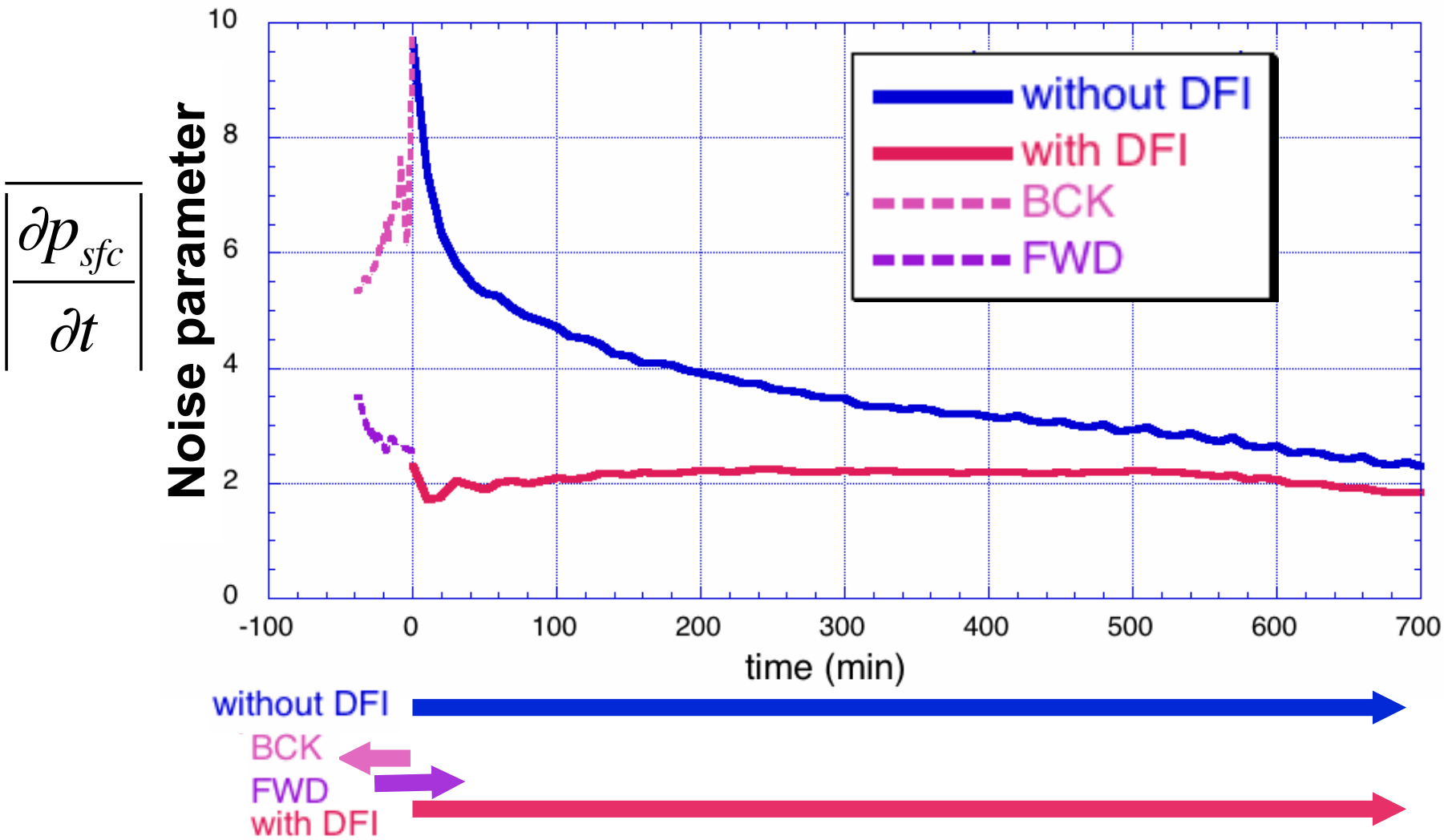
Subjective impression that RR has less graupel, more cloud ice & snow than RUC



Max supercooled cloud water
6-h fcst valid 03UTC 2 Nov 09

Diabatic Digital Filter Initialization

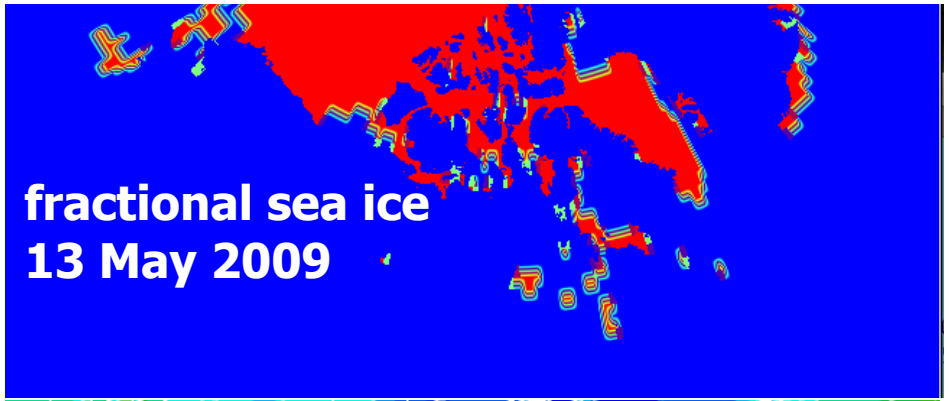
Reduce noise in RUC and Rapid Refresh

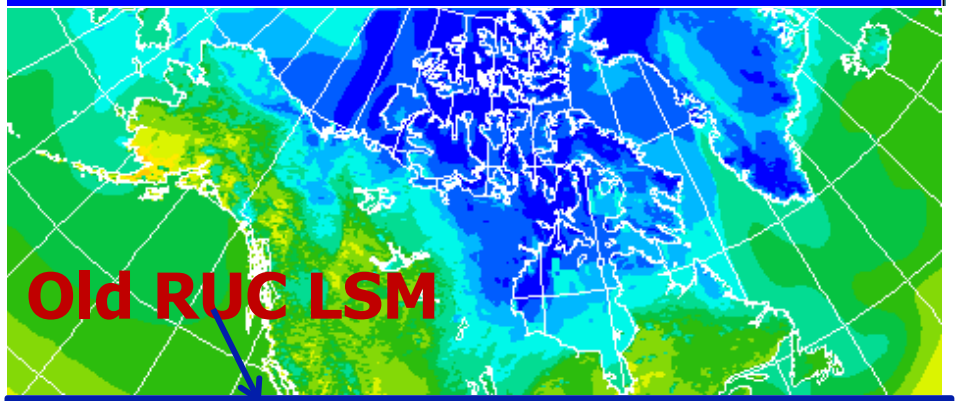


New Treatment for Sea Ice in RUC LSM

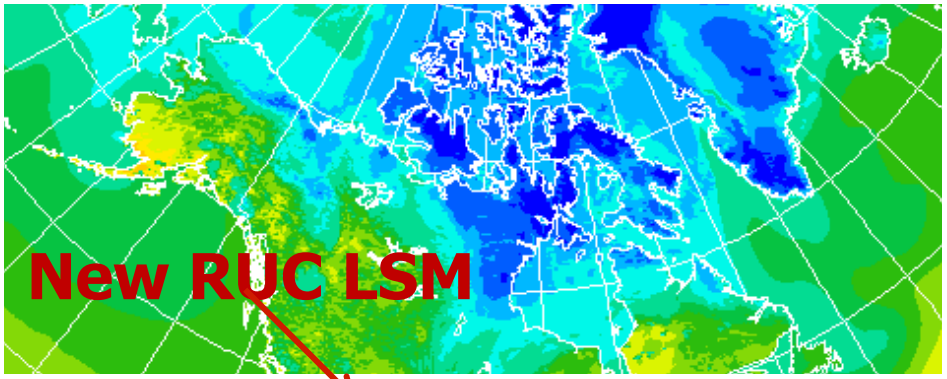
Sea Ice is initialized in RR from GFS (cold-start RR) or from NESDIS snow/ice data (cycled RR)

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



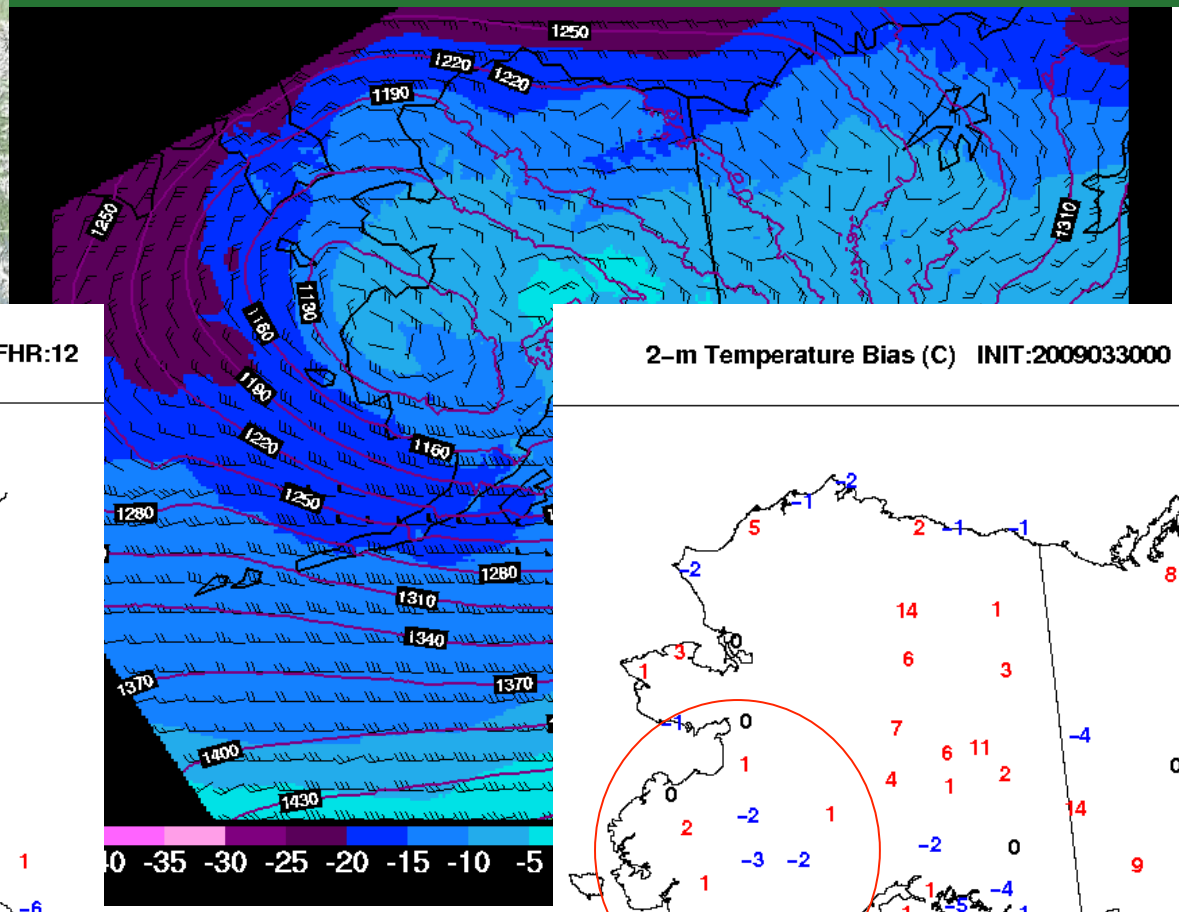


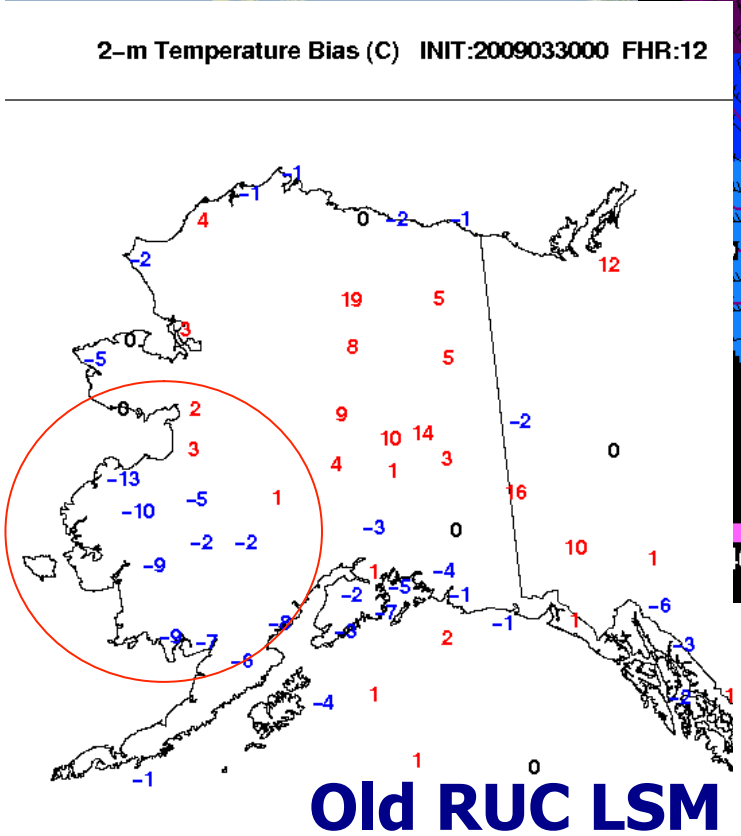
- Skin temperature is prescribed to be equal to temperature at the 1st atmospheric level
- No snow on sea ice



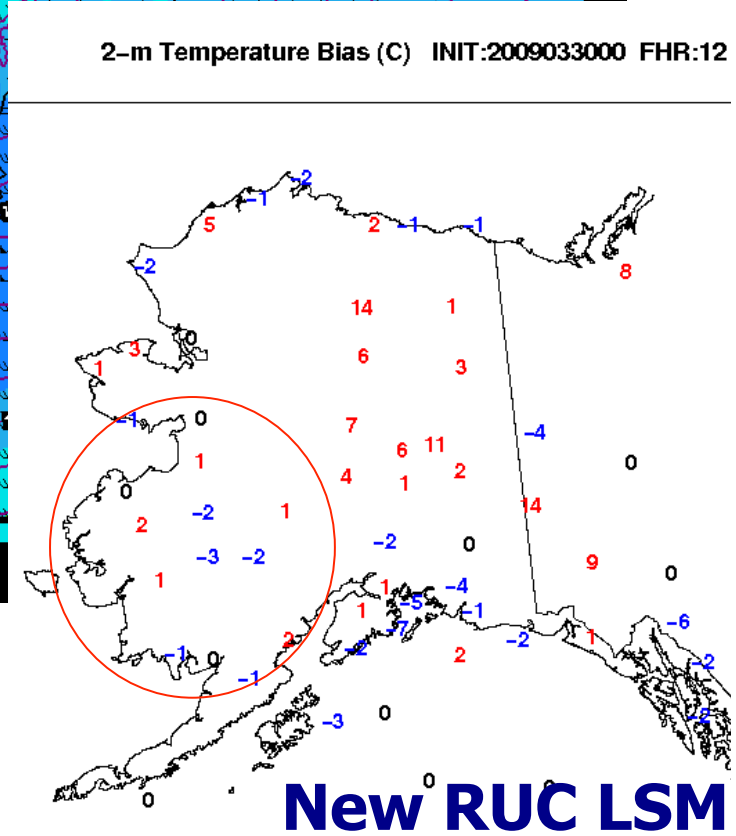
- Solution of surface energy budget and heat diffusion equation in ice
- Snow/Ice Albedo is a function of snow/ice surface temperature
- Snow accumulation on the sea ice surface
- No melting, drifting or building new sea ice
- Option of fractional sea ice

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





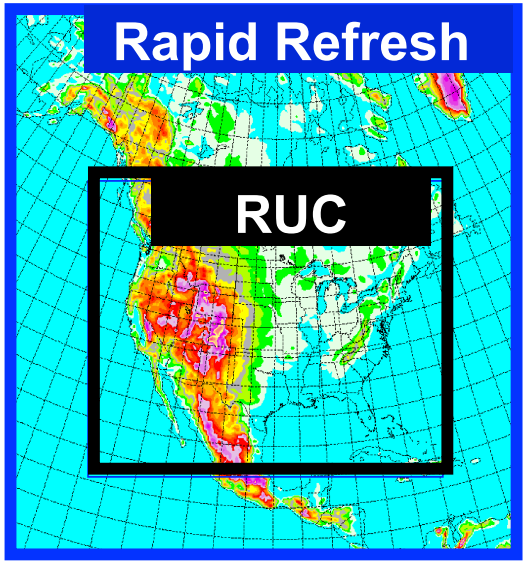
Old RUC LSM



New RUC LSM

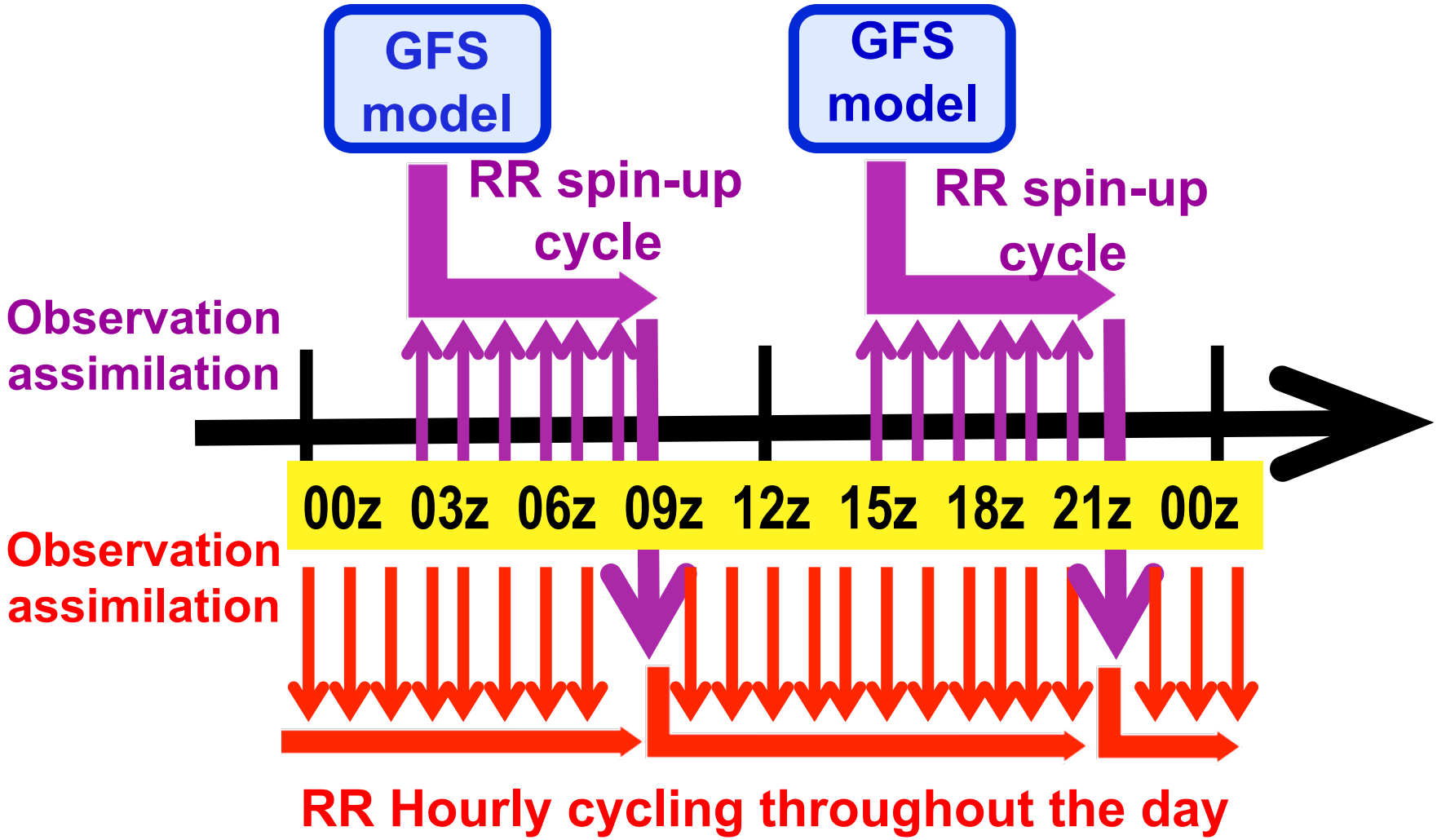
RUC to Rapid Refresh

- CONUS domain (13km) → North American domain (13km)
- RUC model → WRF-ARW Model with RR features



- RUC 3DVAR → GSI (Gridpoint Statistical Interpolation) with RR enhancements)

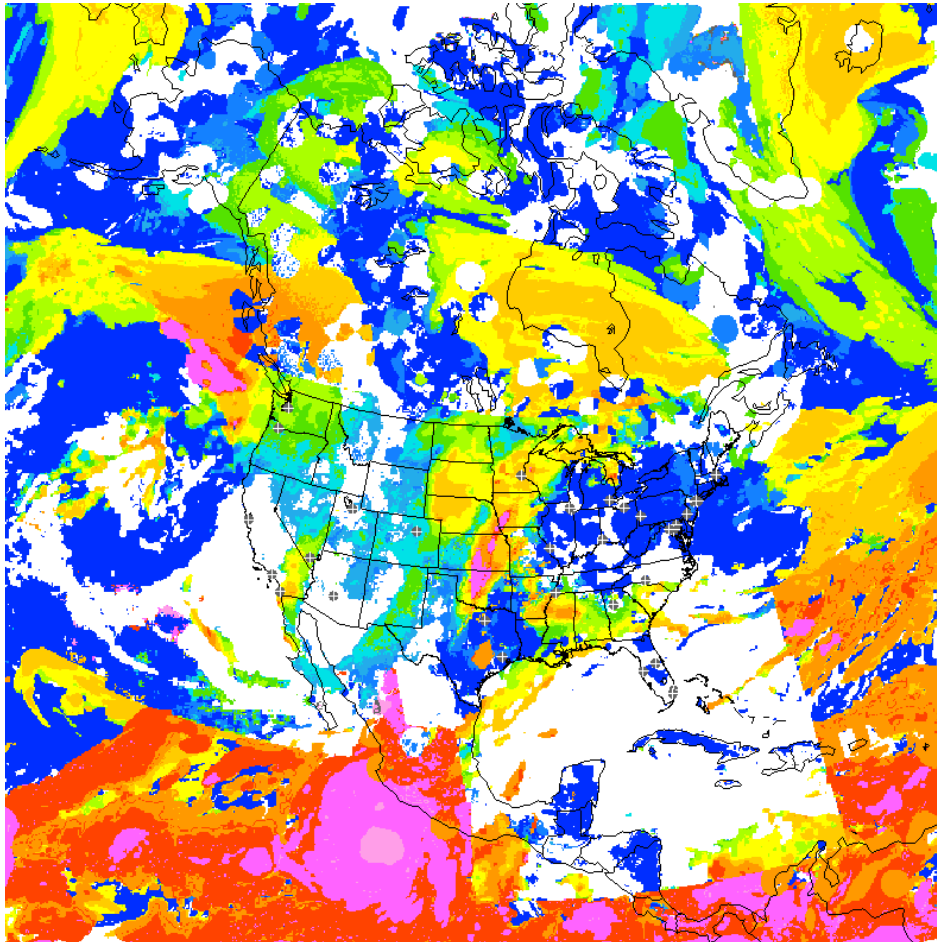
Rapid Refresh Partial Cycling



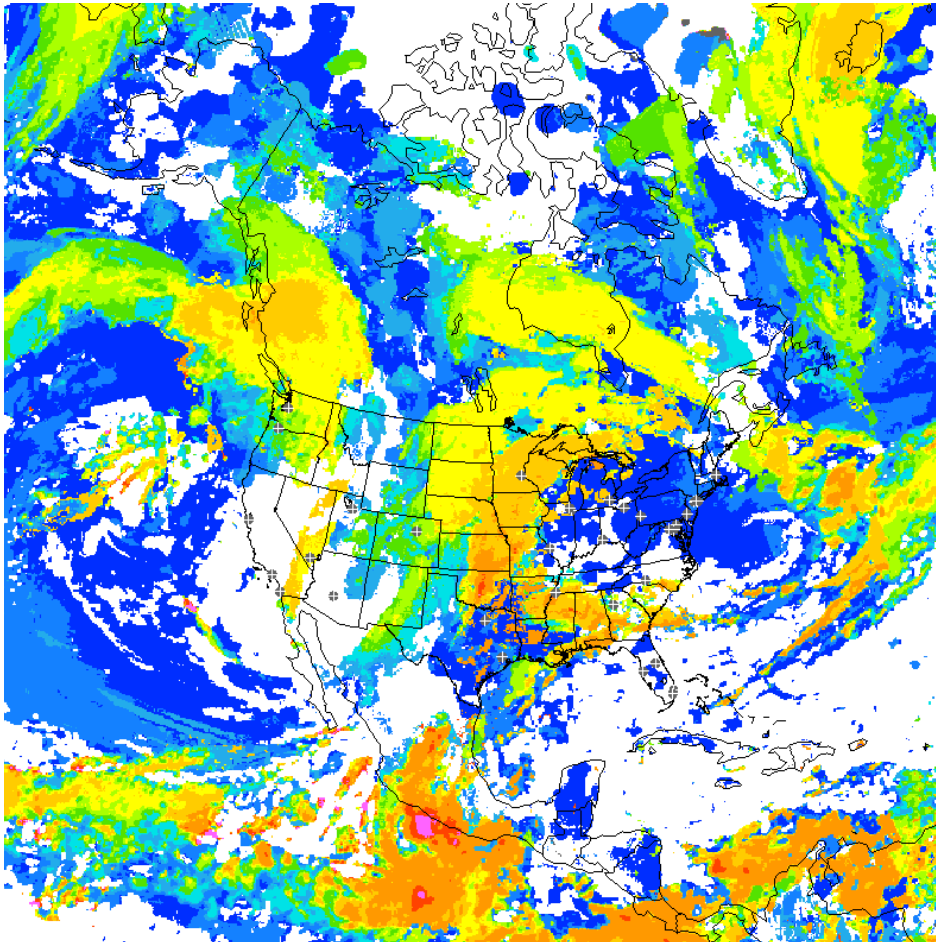
- Hourly cycling of land surface model fields
- 6 hour spin-up cycle for hydrometeors, surface fields

Use of NASA Langley satellite cloud data

RR with NESDIS data-
currently only over RUC domain



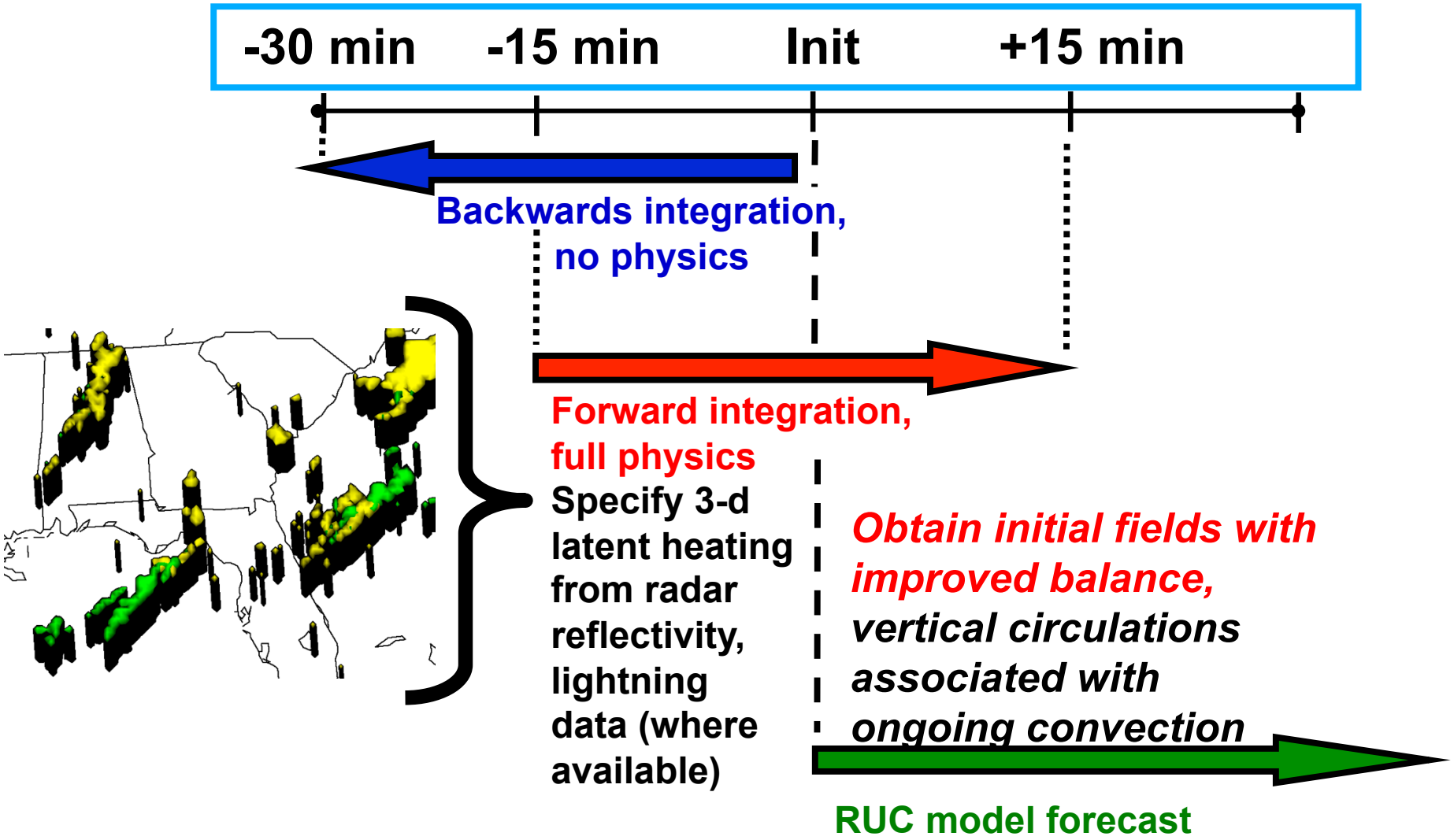
RR with NASA data - over full RR domain



Analysis

RUC / RR Diabatic Digital Filter Initialization (DDFI)

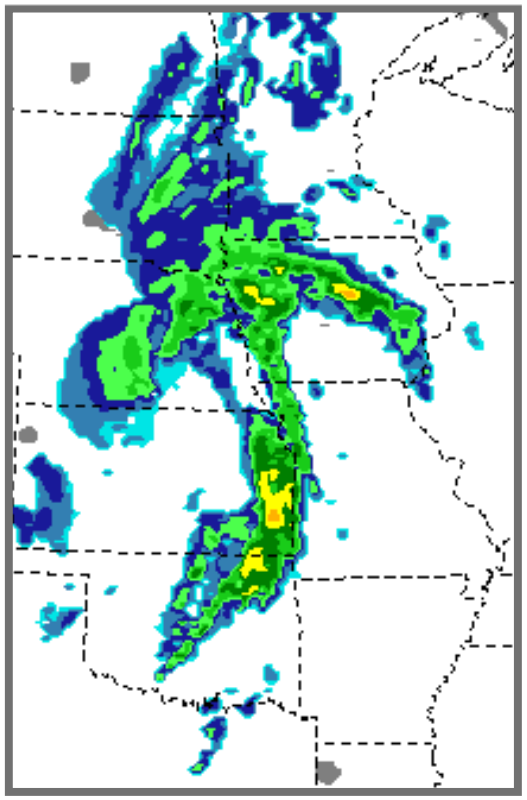
New - add assimilation of radar data



Radar reflectivity assimilation in RUC and Rapid Refresh

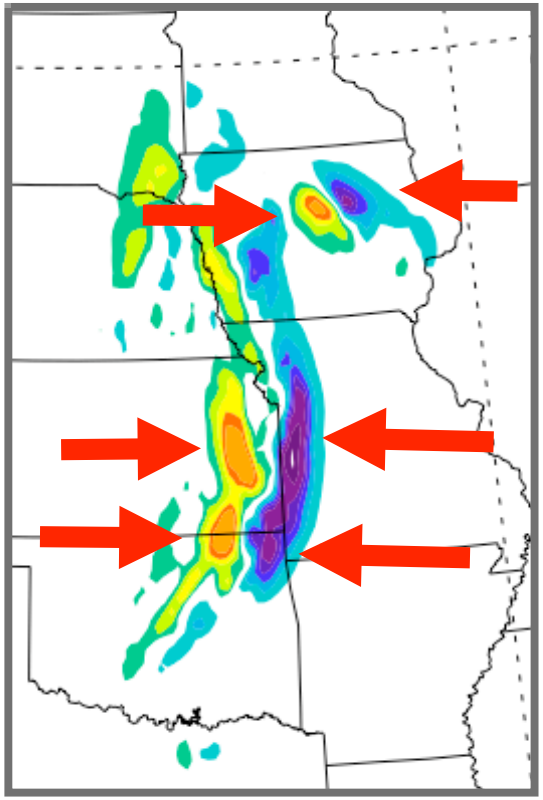
Rapid Refresh (GSI + ARW) reflectivity assimilation example

NSSL radar reflectivity (dBZ)



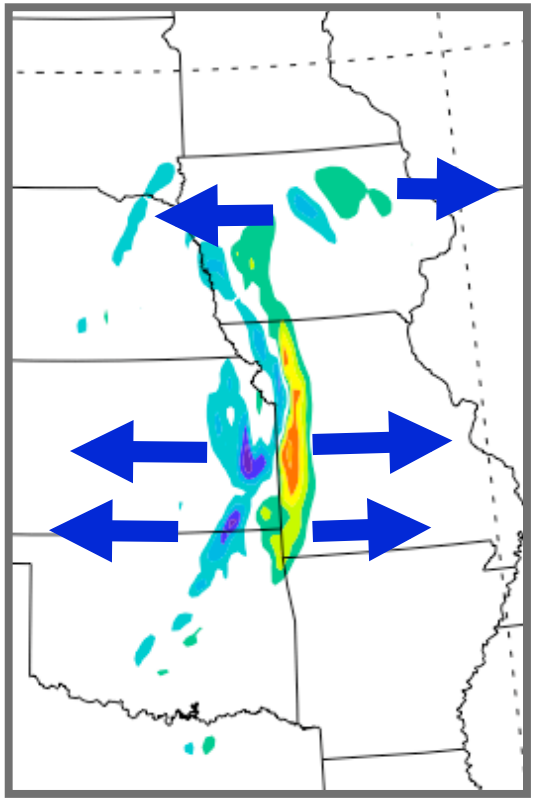
14z 22 Oct 2008
Z = 3 km

Low-level Convergence

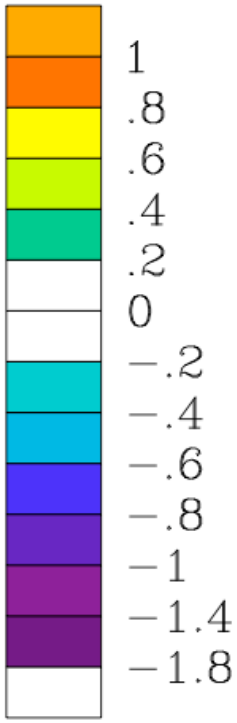


K=4 U-comp. diff
(radar - norad)

Upper-level Divergence

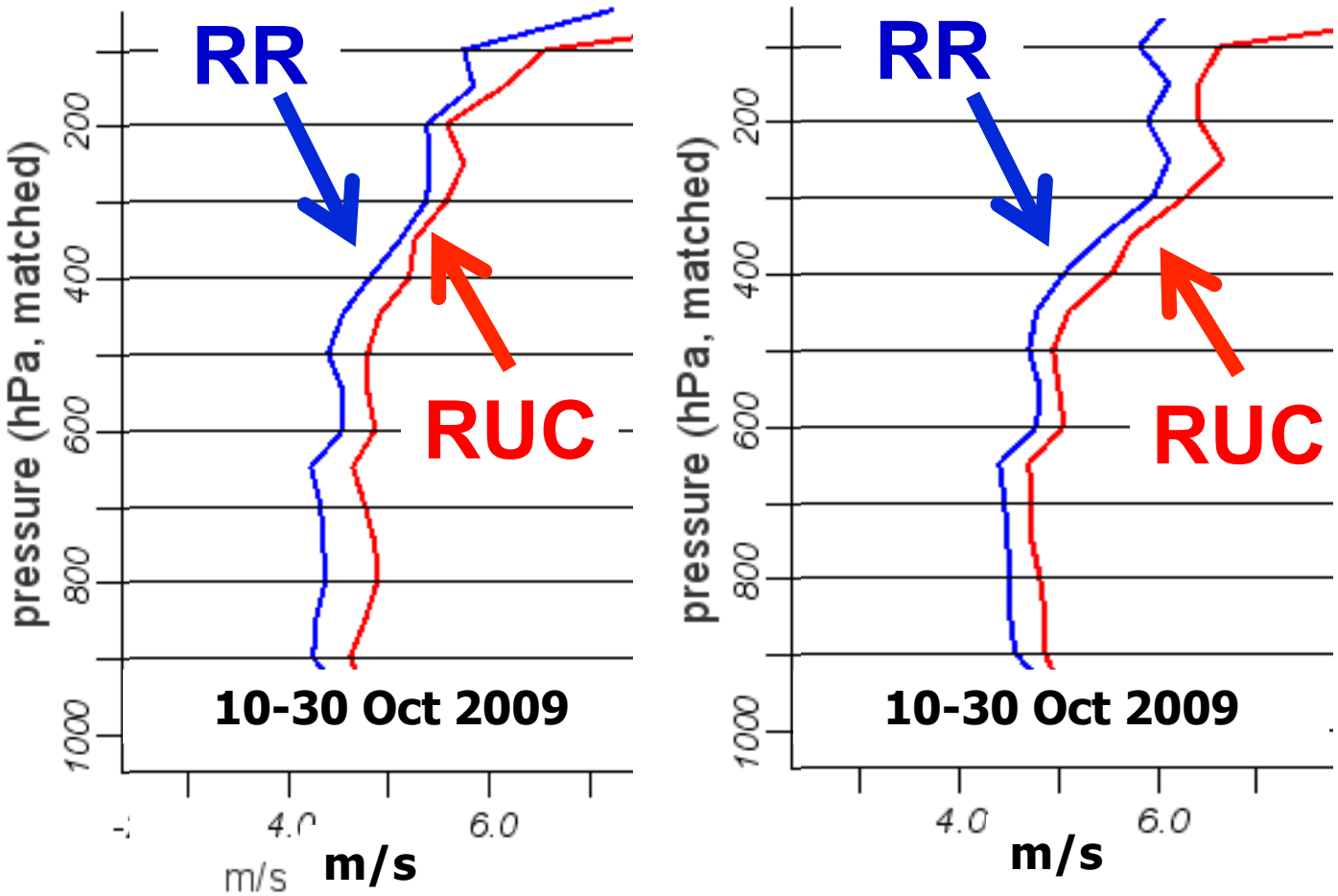


K=17 U-comp. diff
(radar - norad)



Rapid Refresh upper-air verification
vector wind RMS error

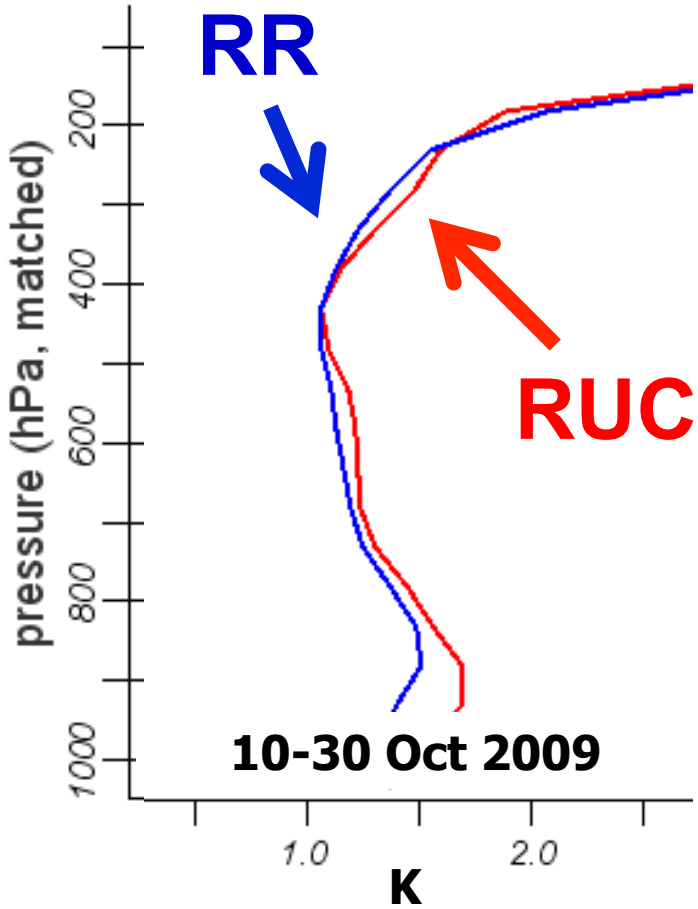
3-h fcst **12-h fcst**

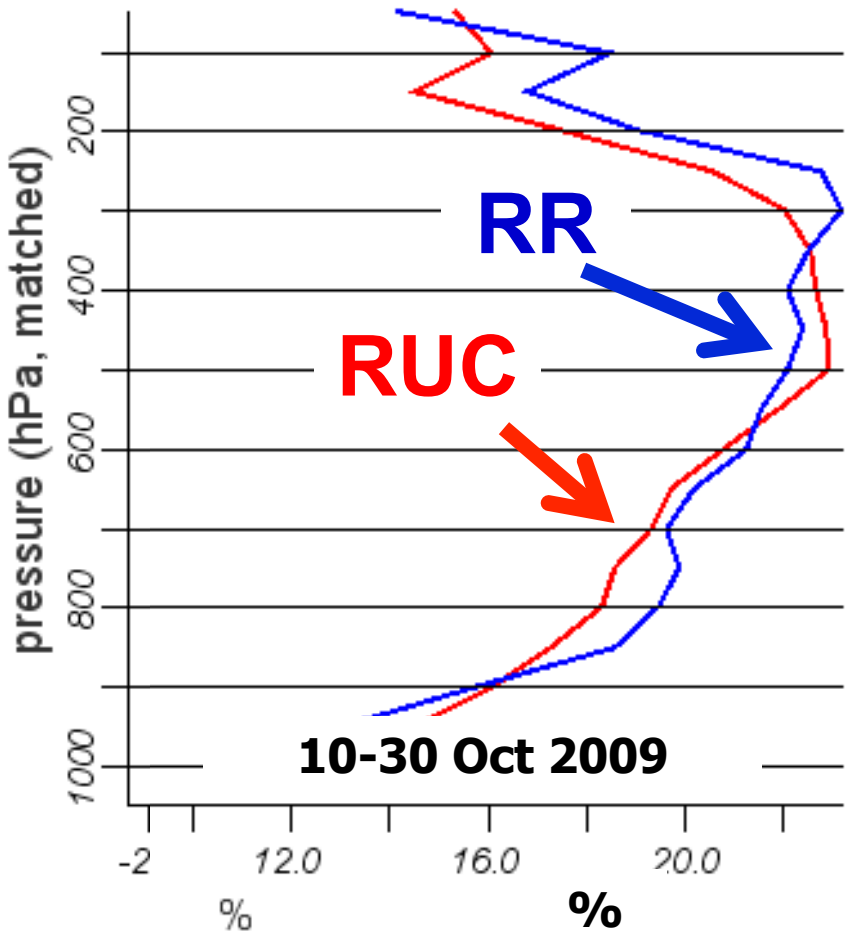


Rapid Refresh upper-air verification

3-h fcst RMS error

Temperature **Relative Humidity**



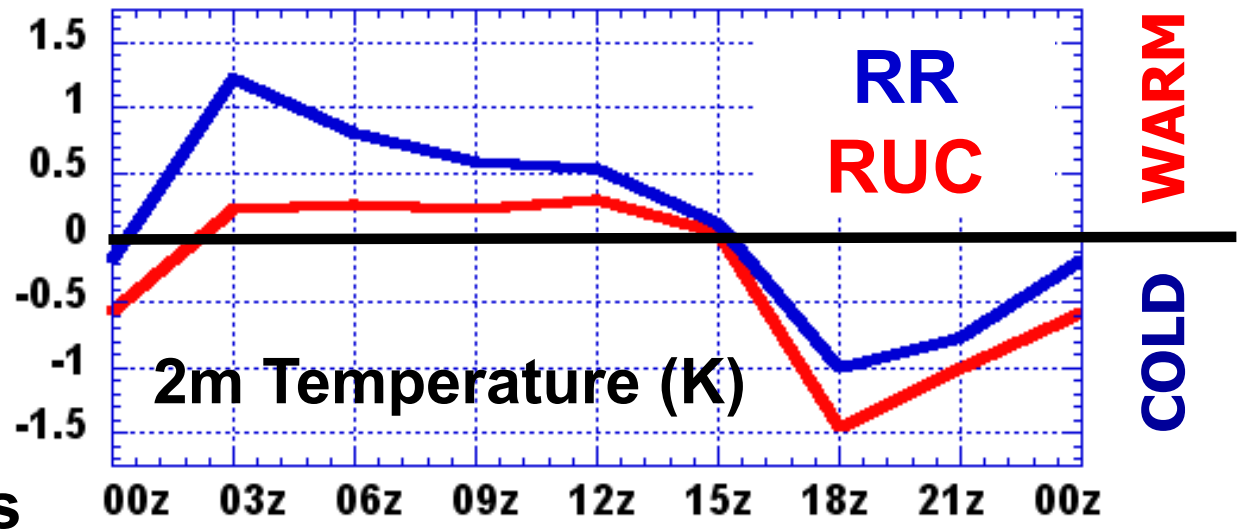


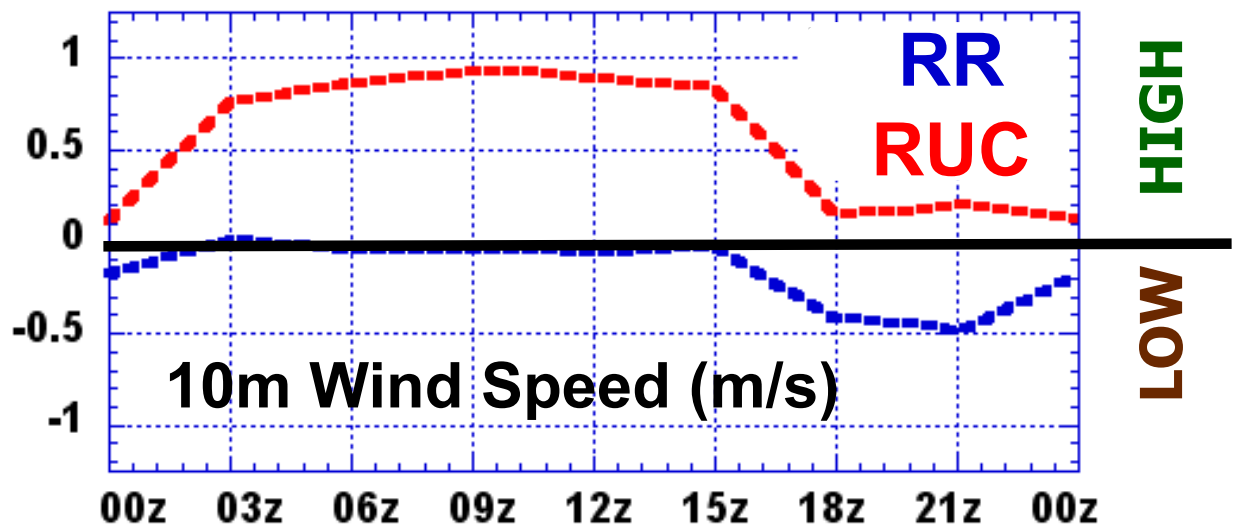
RR vs. RUC surface verification
Diurnal bias variation for 3-h fcst

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



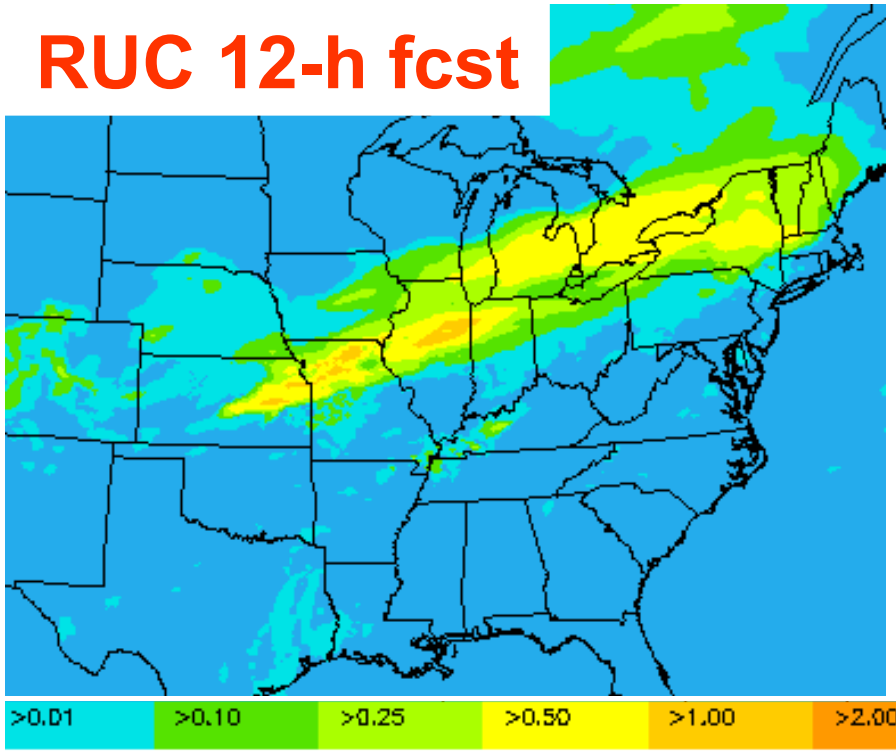


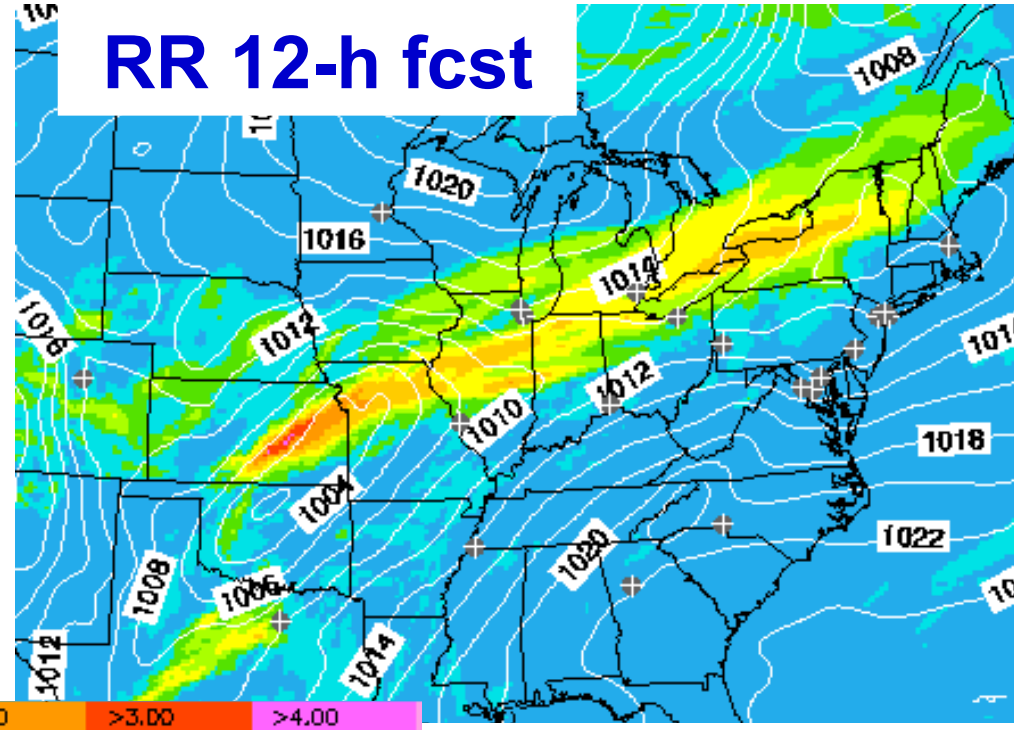
2-week comparison
14-30 Oct 2009
Eastern US only

RR vs. RUC surface verification

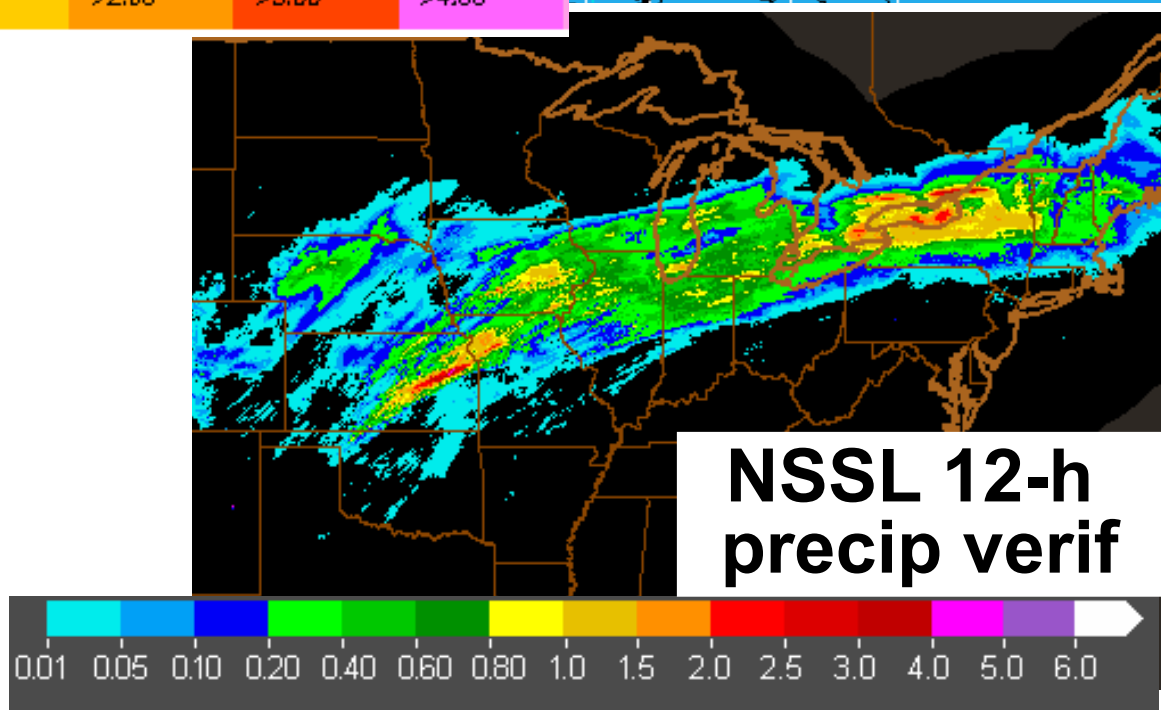
RR RMS errors nearly equal to RUC
RR bias errors equal to or better than RUC

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		



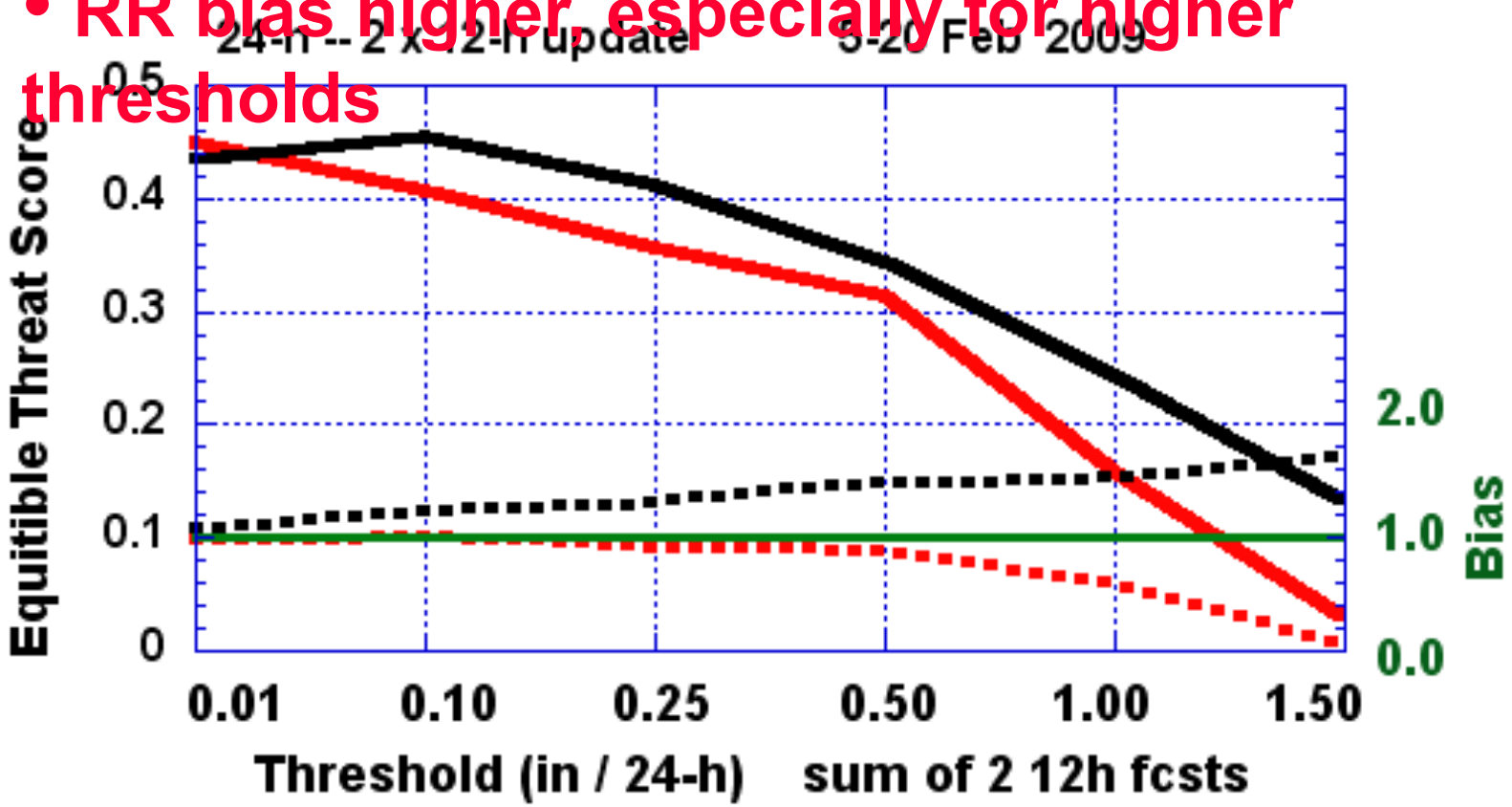


12-h accum. precipitation 06z Mar 8, 2009



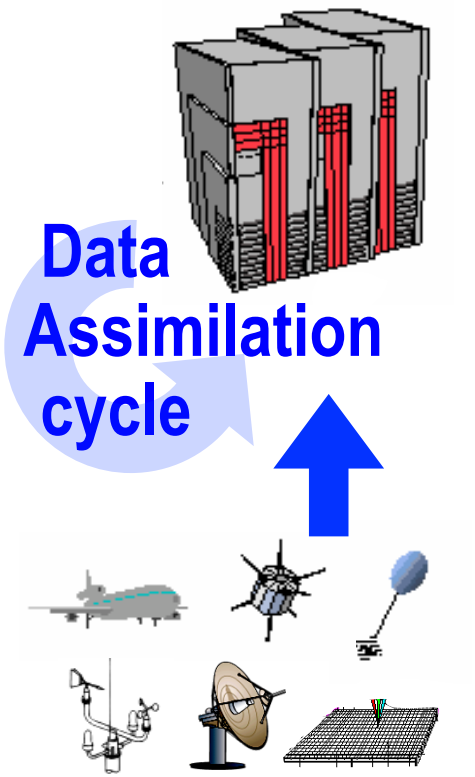
Comparison of Rapid Refresh and RUC precipitation skill scores

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

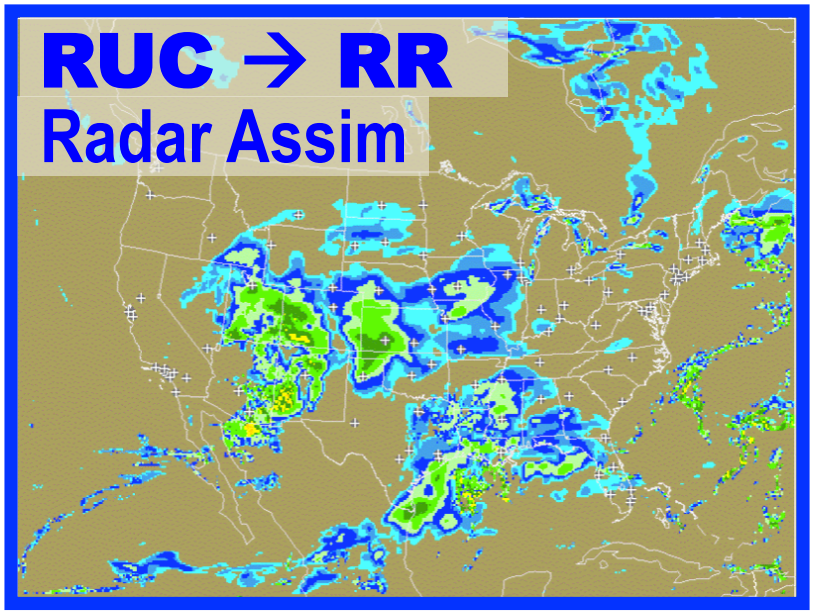


RUC / RR and HRRR models

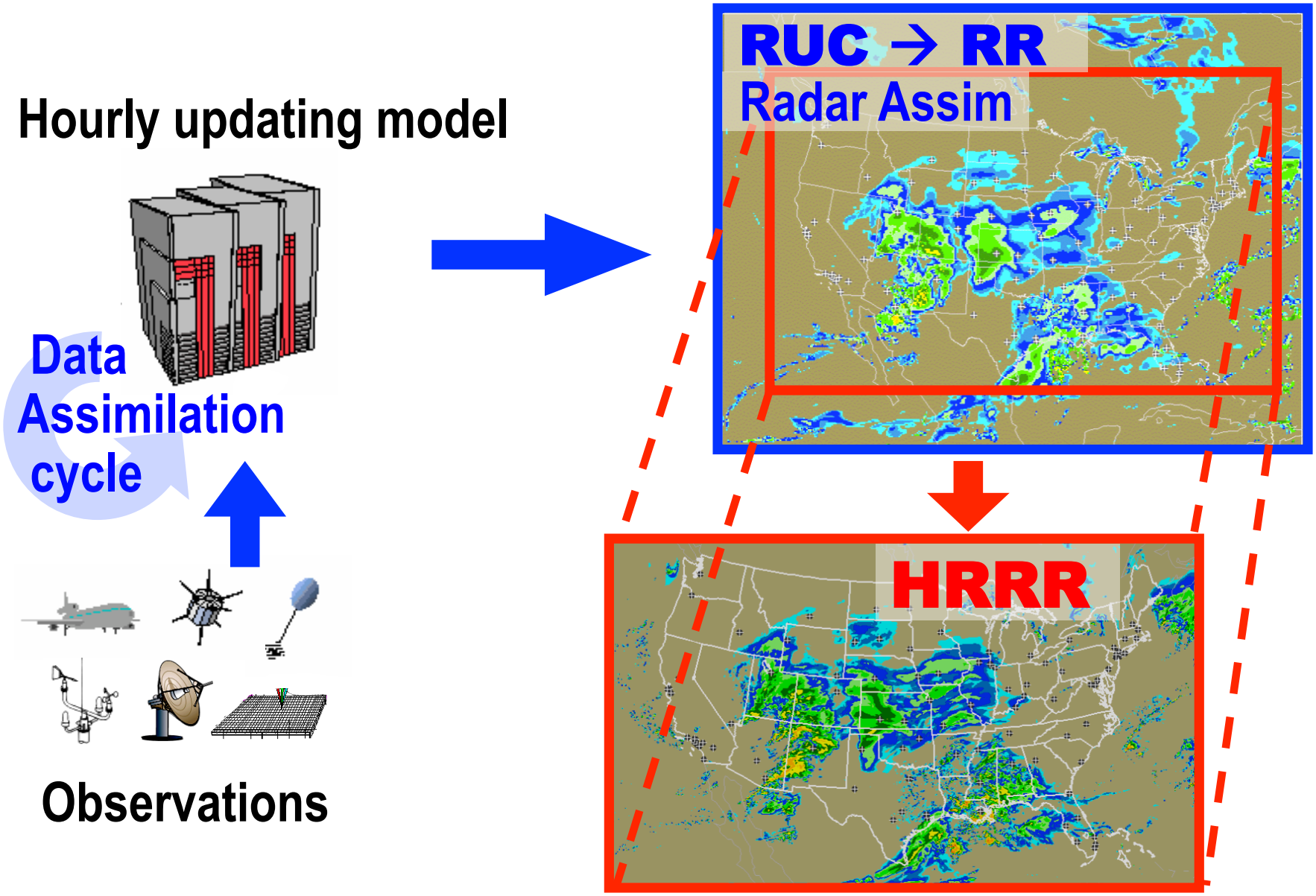
Hourly updating model

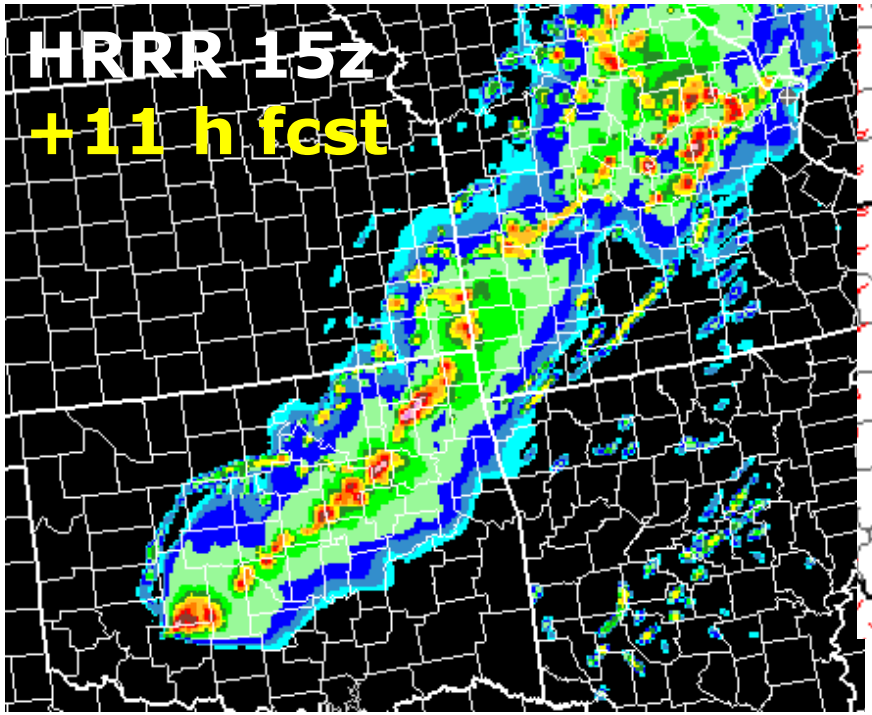


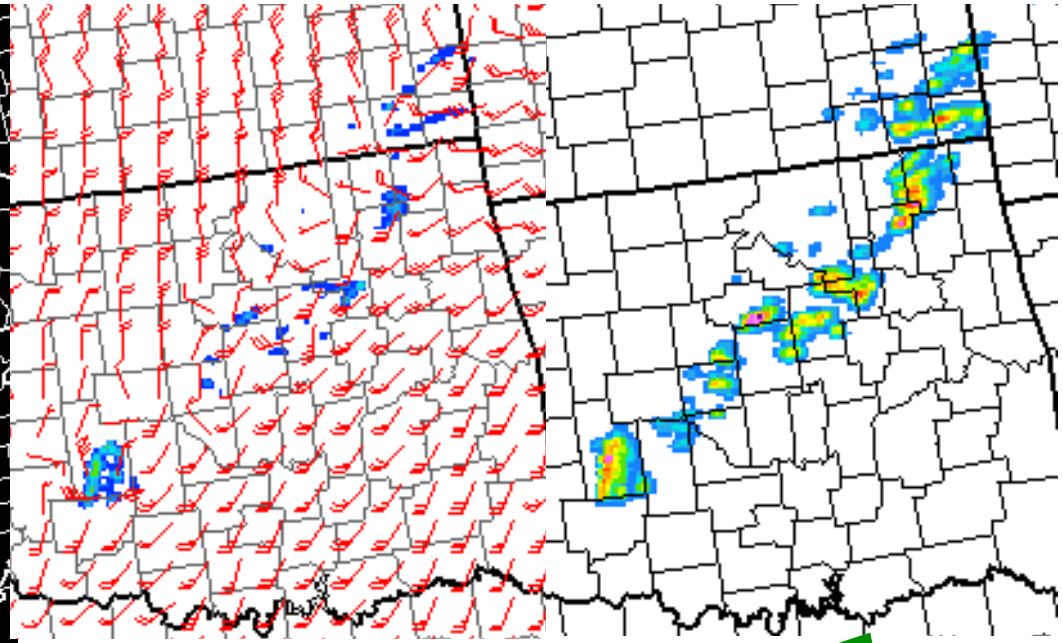
Observations

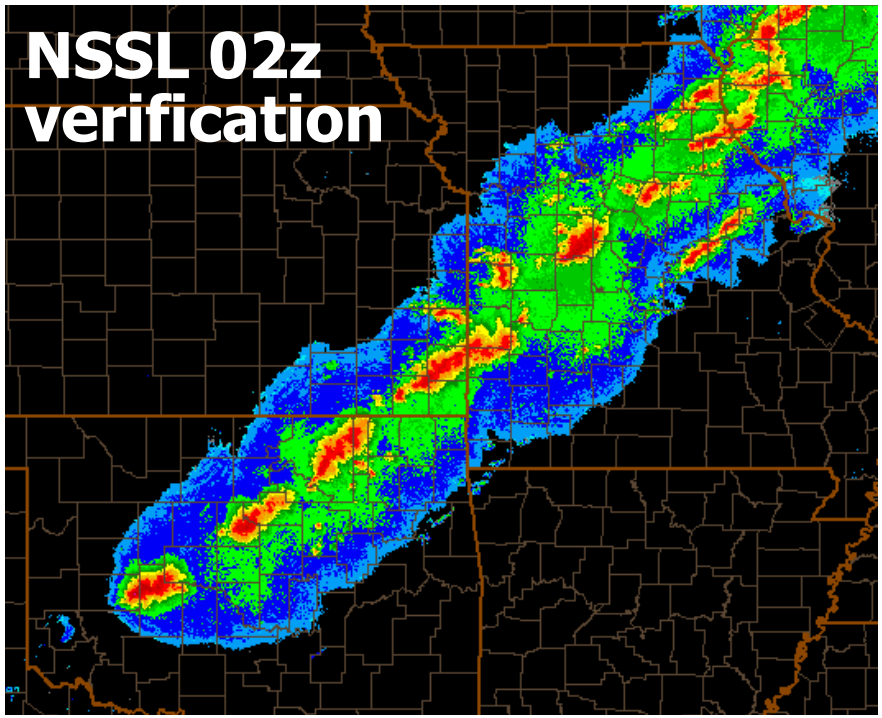


RUC / RR and HRRR models



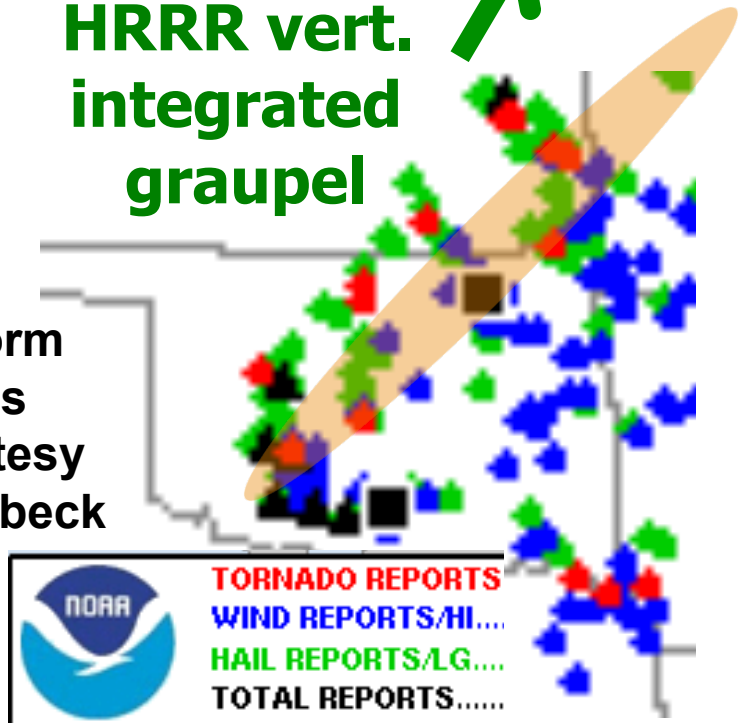






HRRR updraft helicity

HRRR vert. integrated graupel

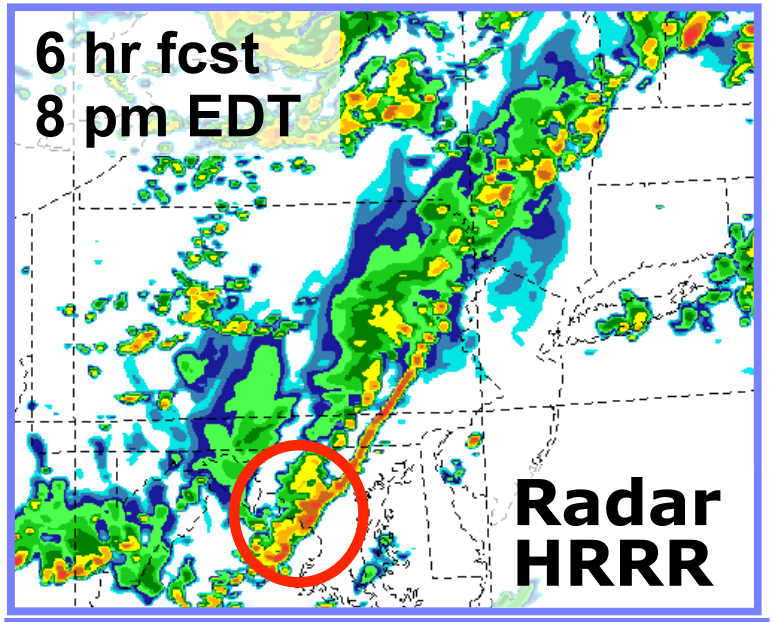


Severe storm diagnostics code courtesy Scott Dembeck and NSSL

RUC radar assimilation improves HRRR

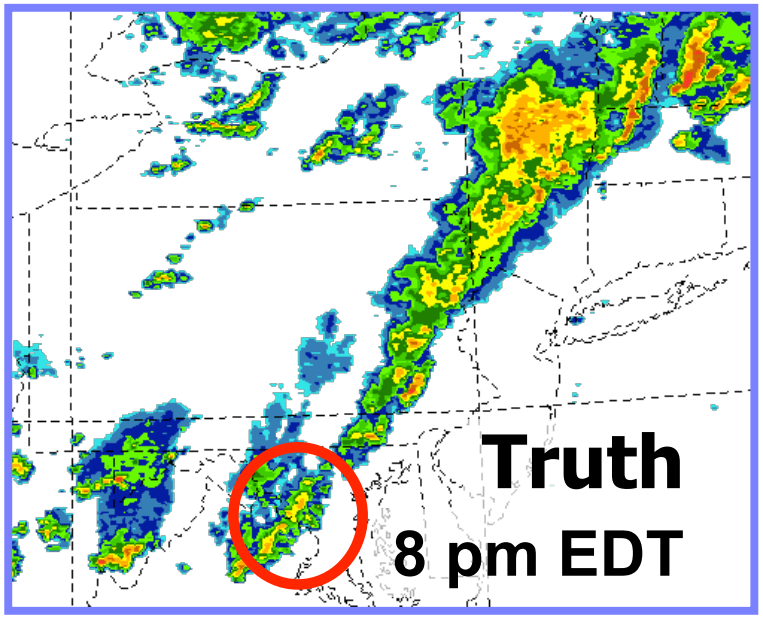
High resolution needed for realistic storm structure (storm-types, line gaps, etc.)

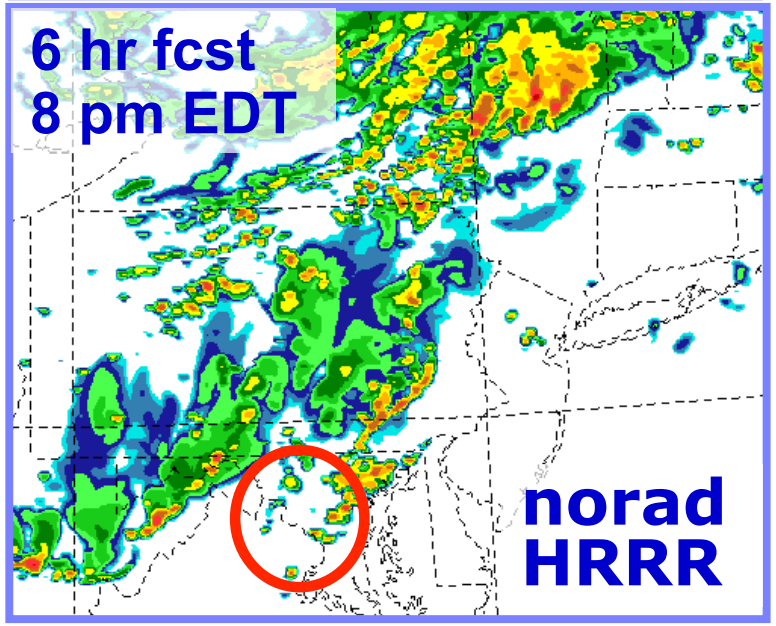
Radar assimilation needed for improved accuracy in storm location

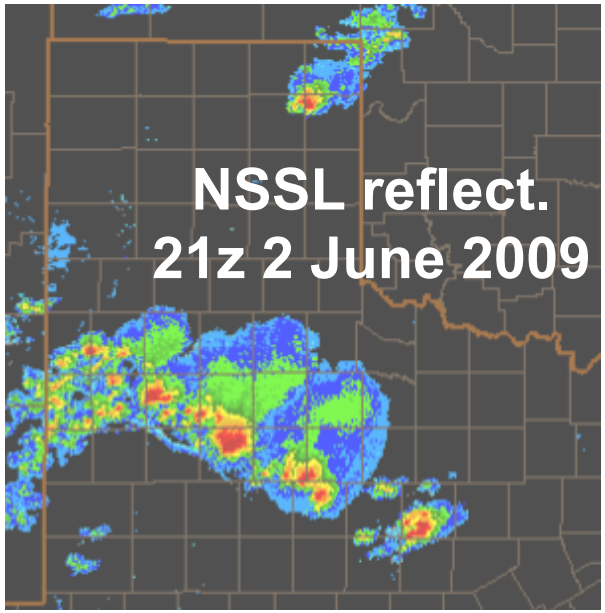


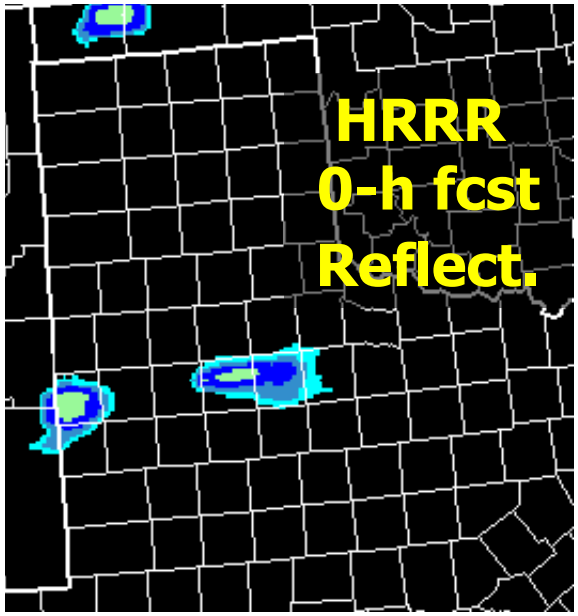
20 July 2008

2 pm initial time

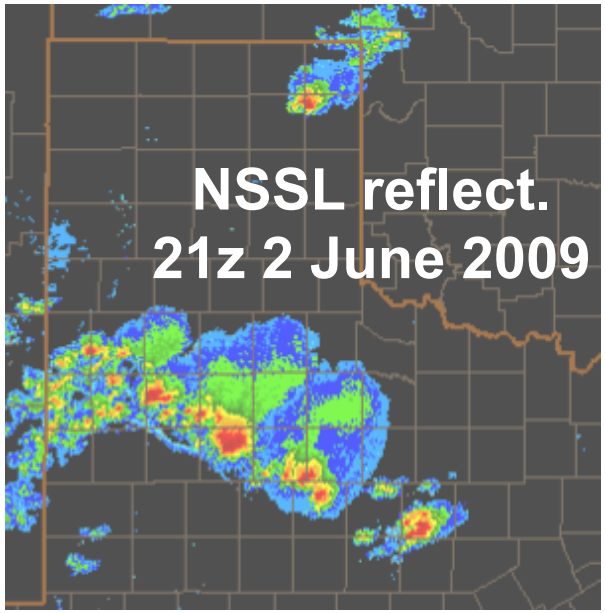


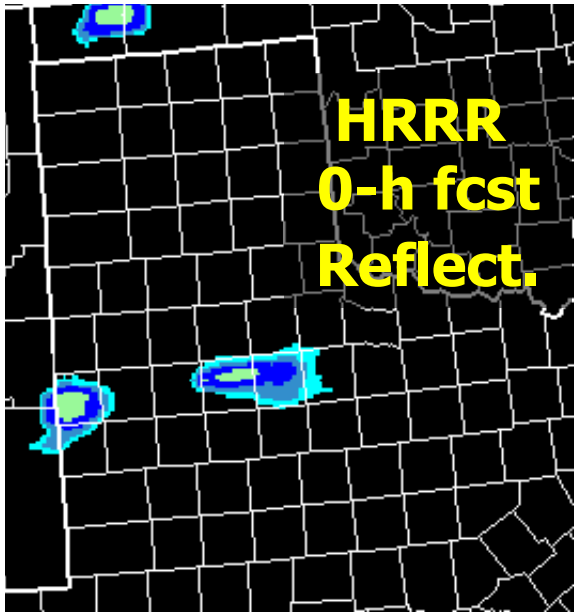


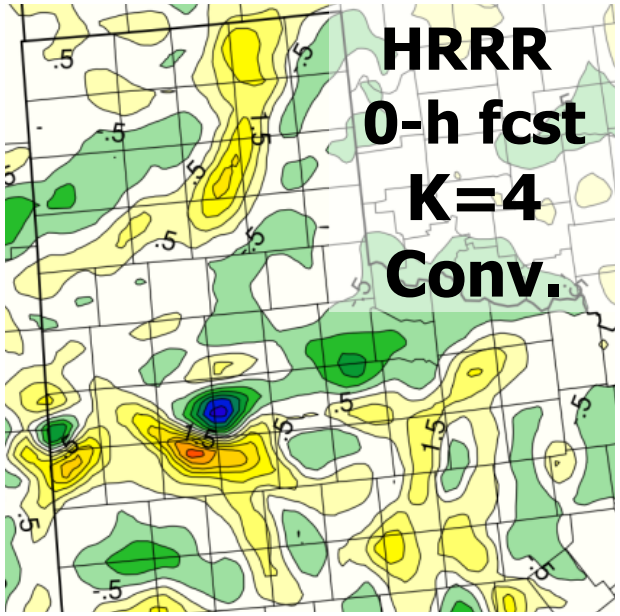




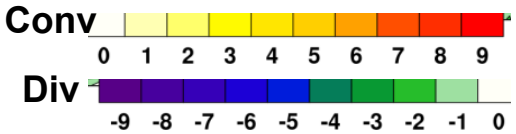
RUC DFI impact on HRRR fields

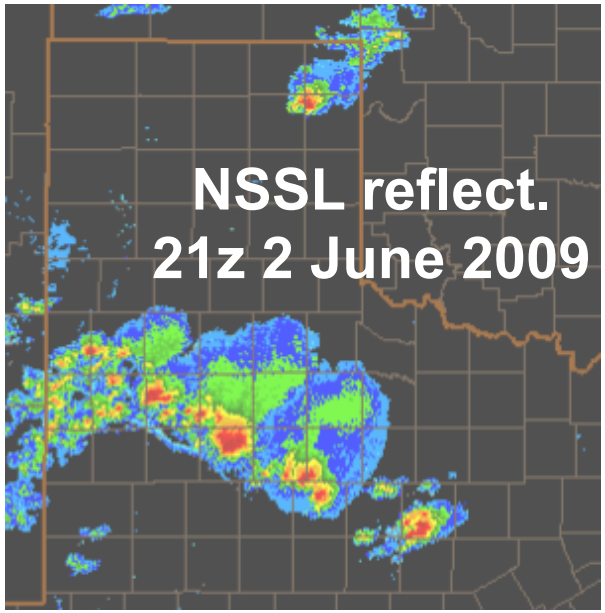


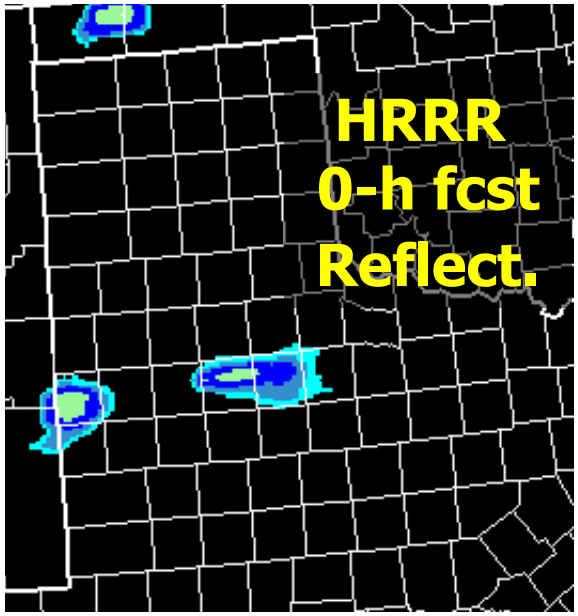


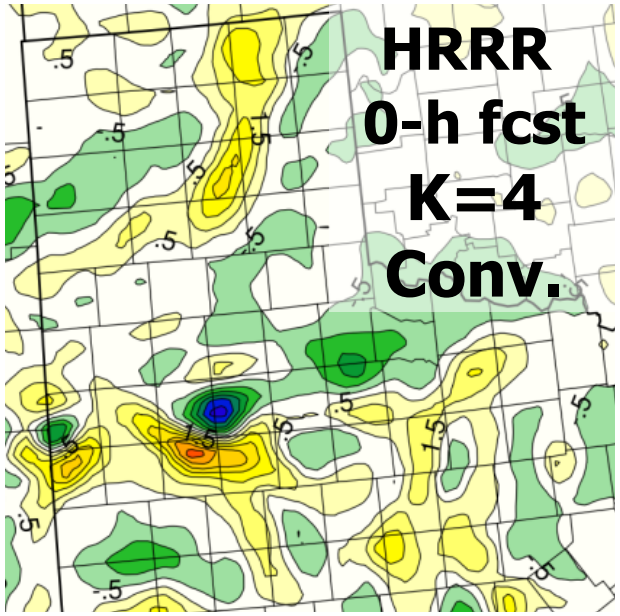


RUC DFI impact on HRRR fields

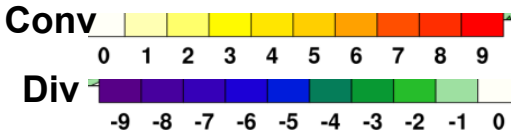


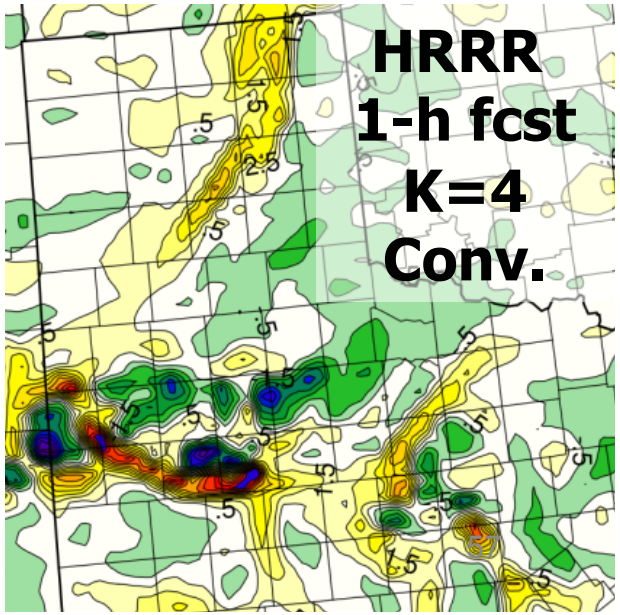


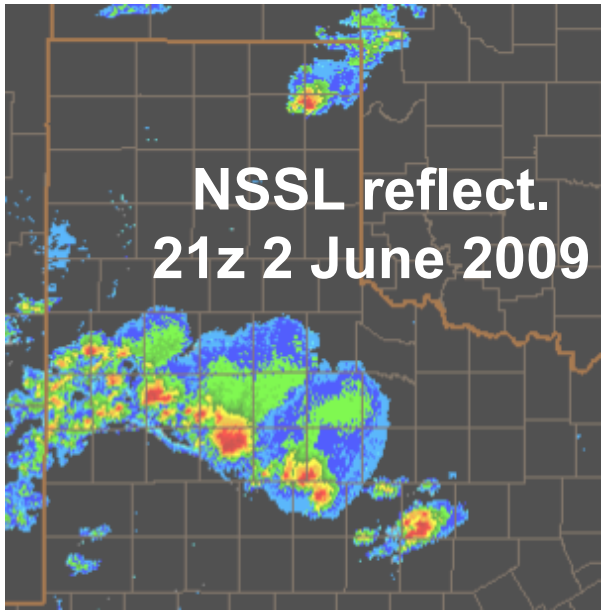


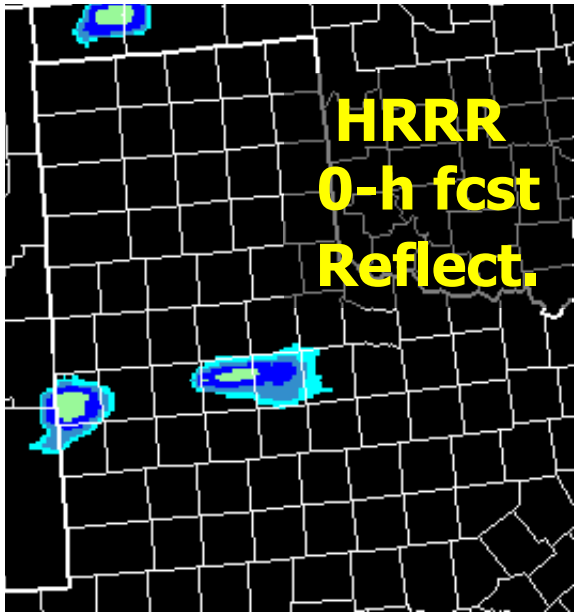


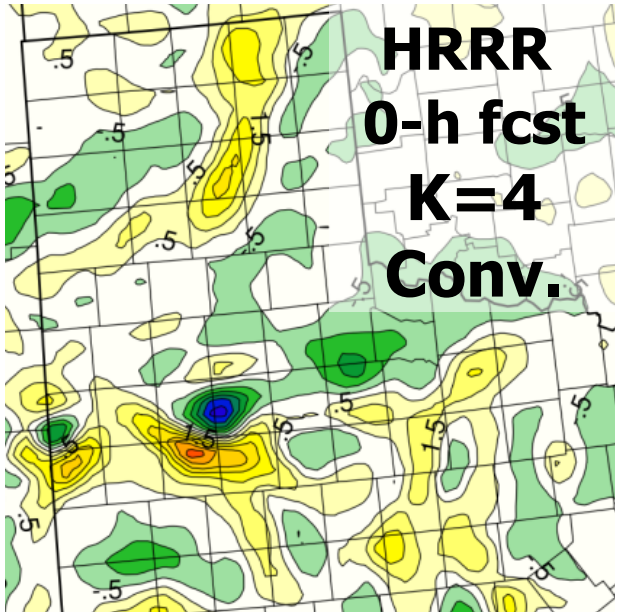
RUC DFI impact on HRRR fields



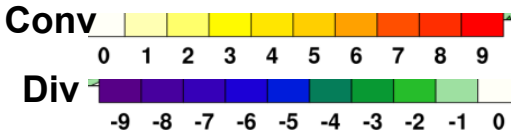


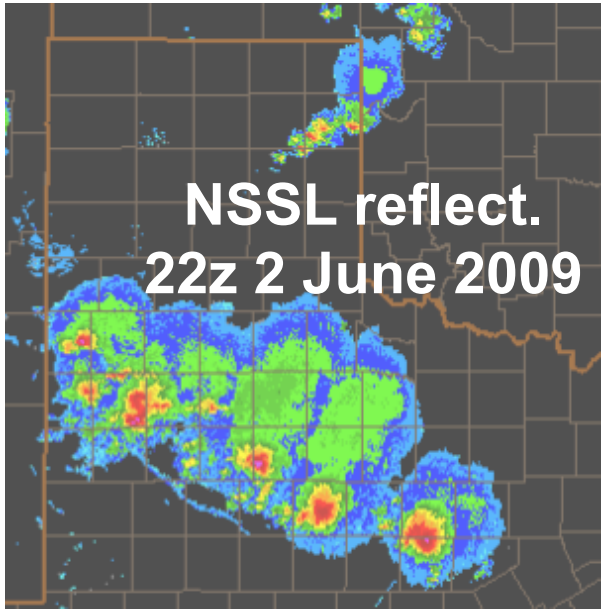


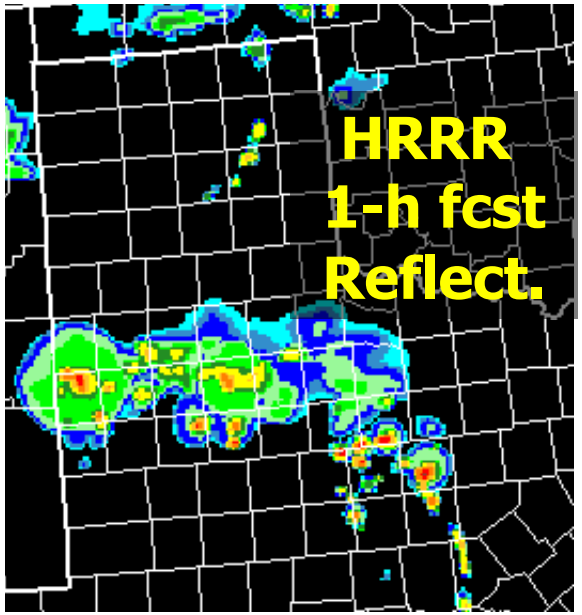


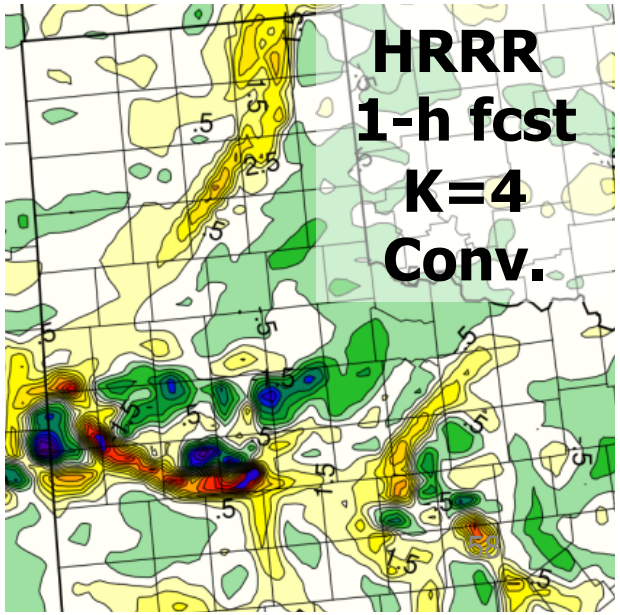


RUC DFI impact on HRRR fields



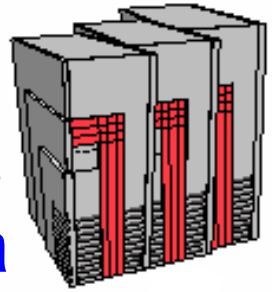




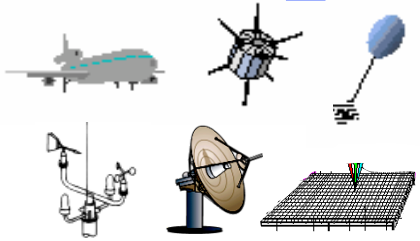


RUC / RR and HRRR models

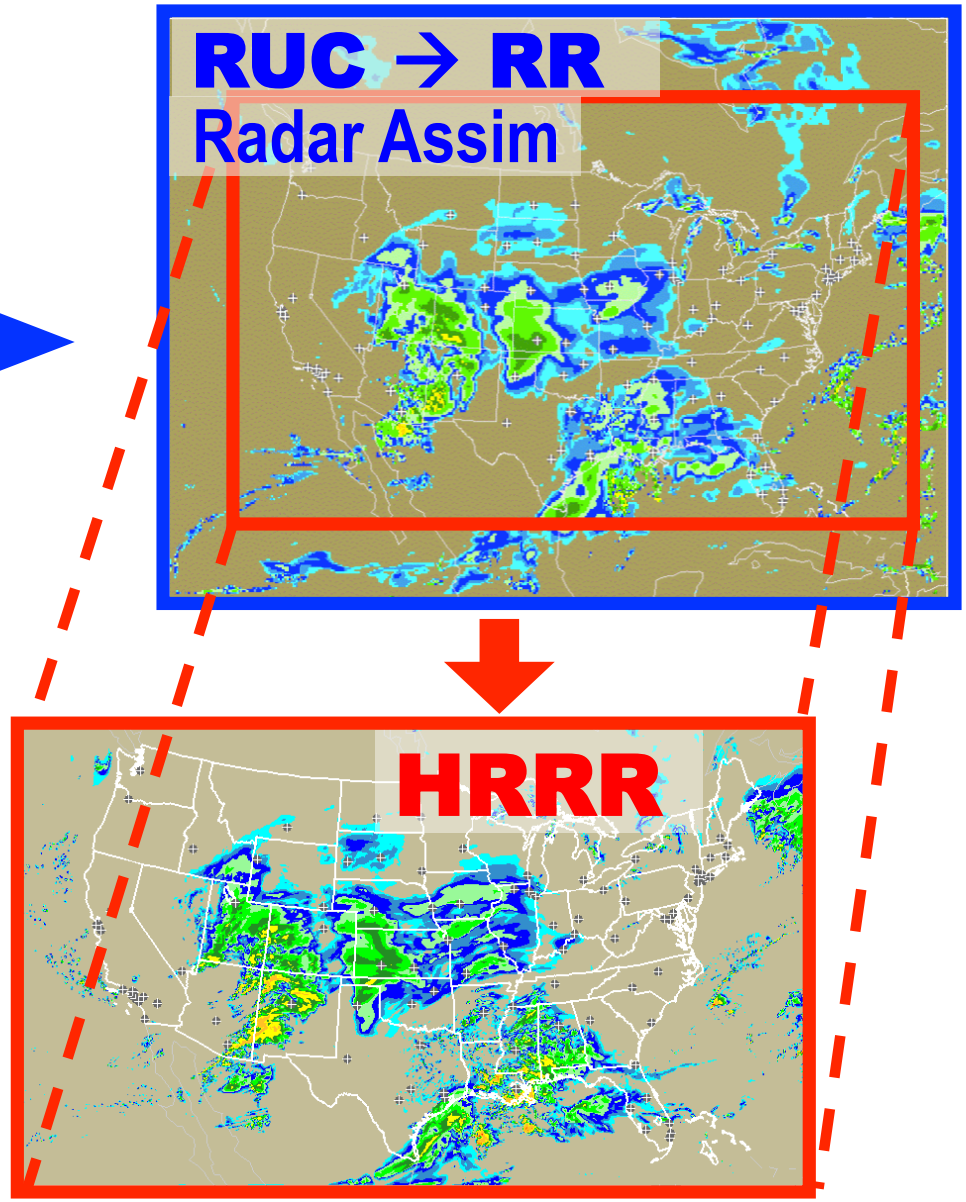
Hourly updating model



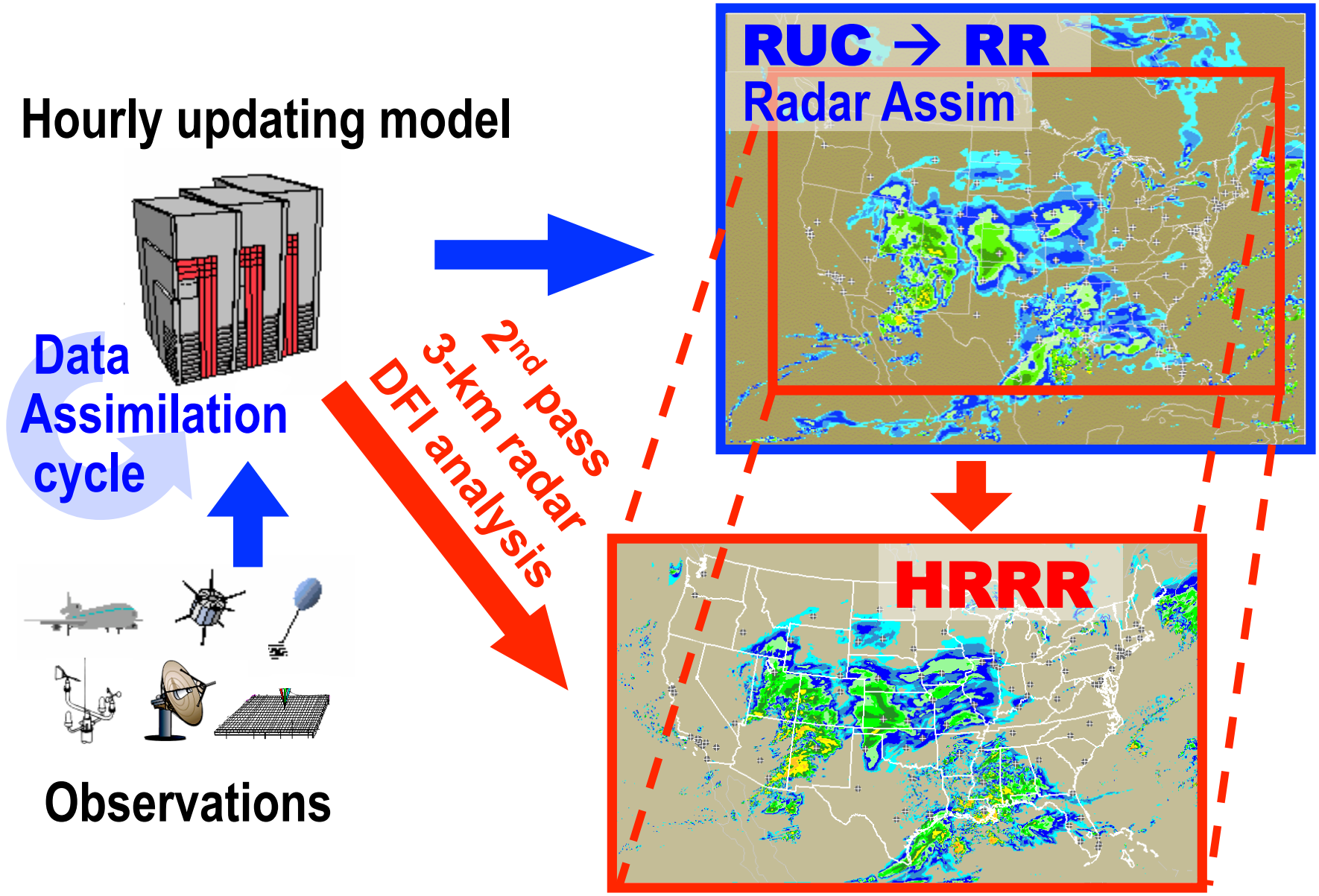
Data Assimilation cycle



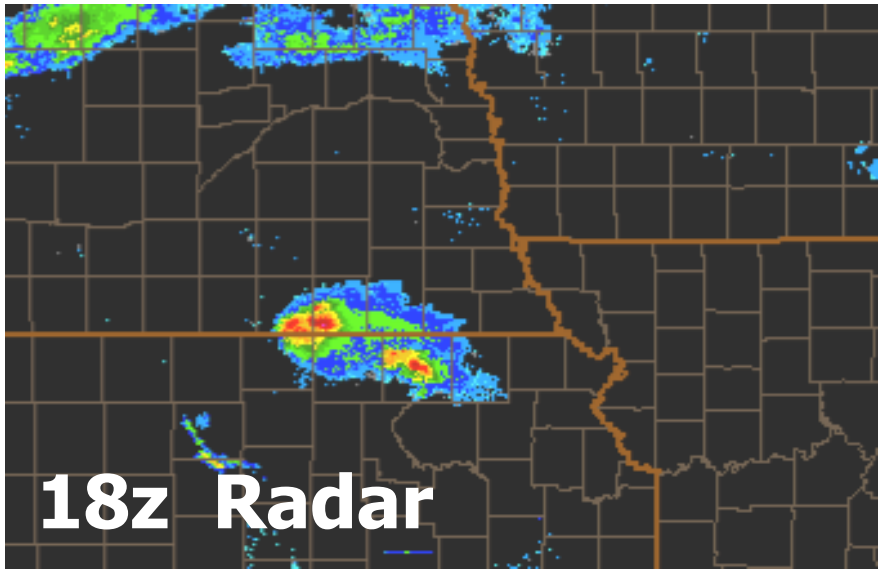
Observations

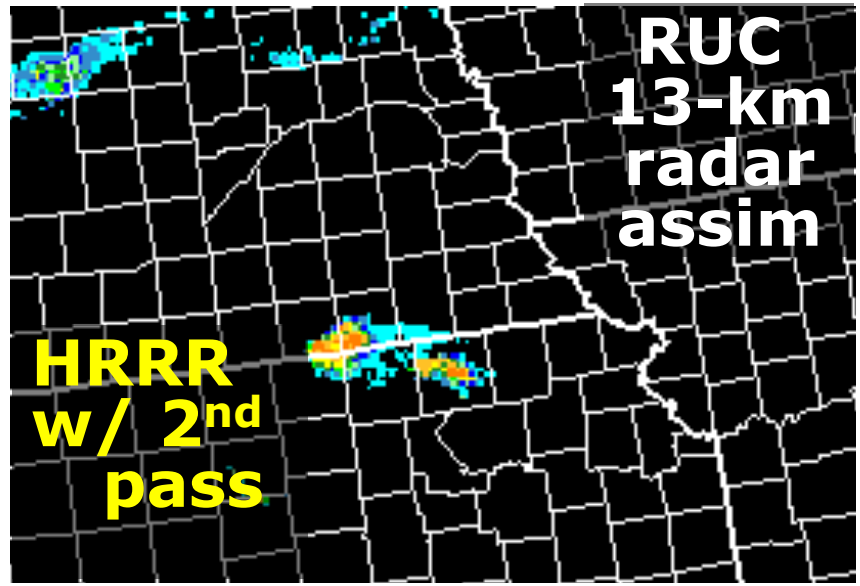


RUC / RR and HRRR models



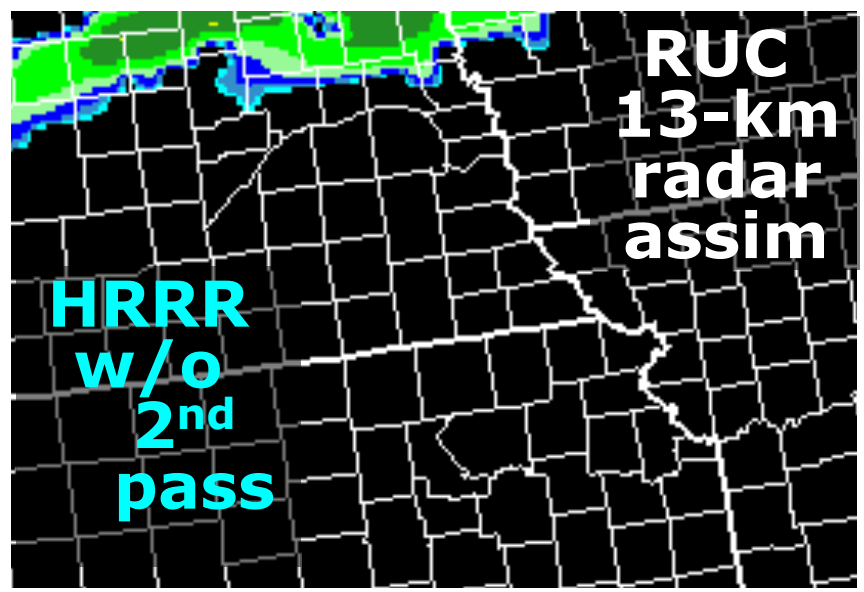
HRRR with 2nd pass radar DA on 3-km domain





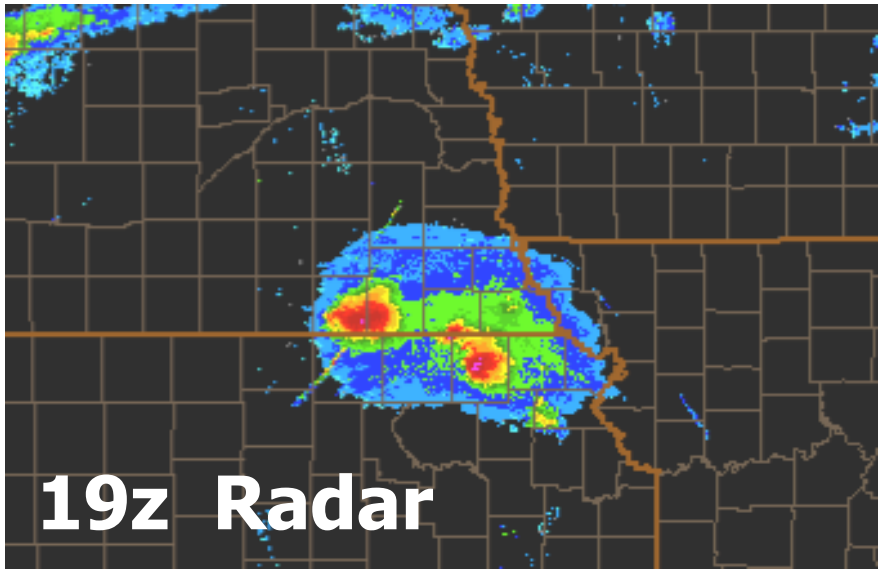
27 June 2009

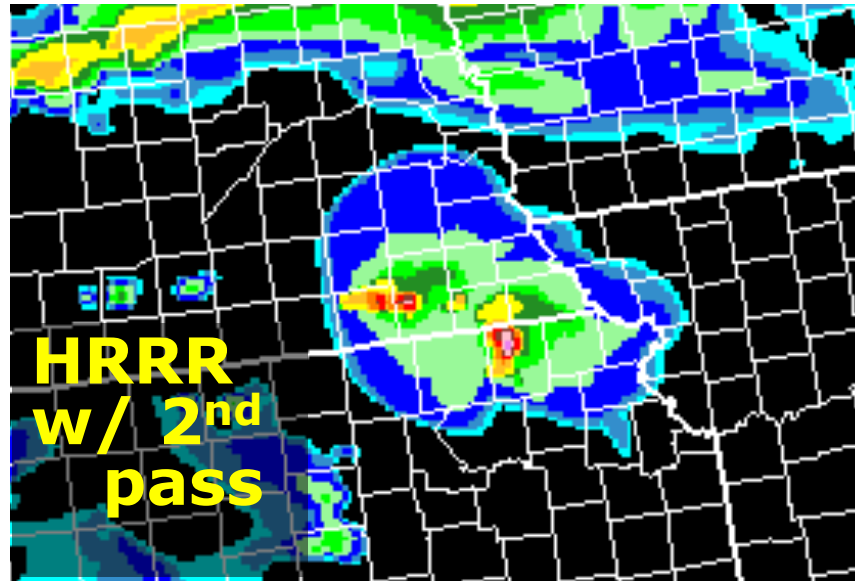
+ 0h fcsts



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

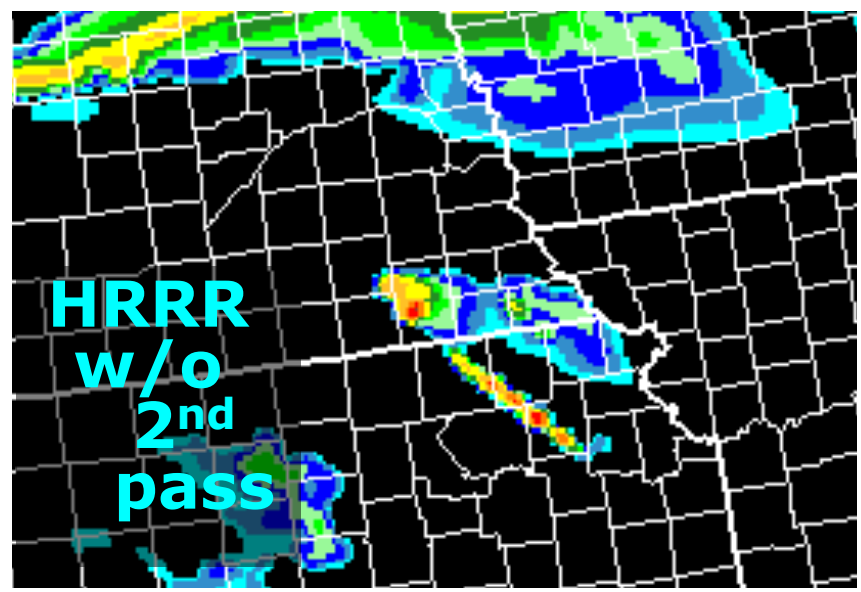
HRRR with 2nd pass radar DA on 3-km domain





27 June 2009

+ 1h fcsts



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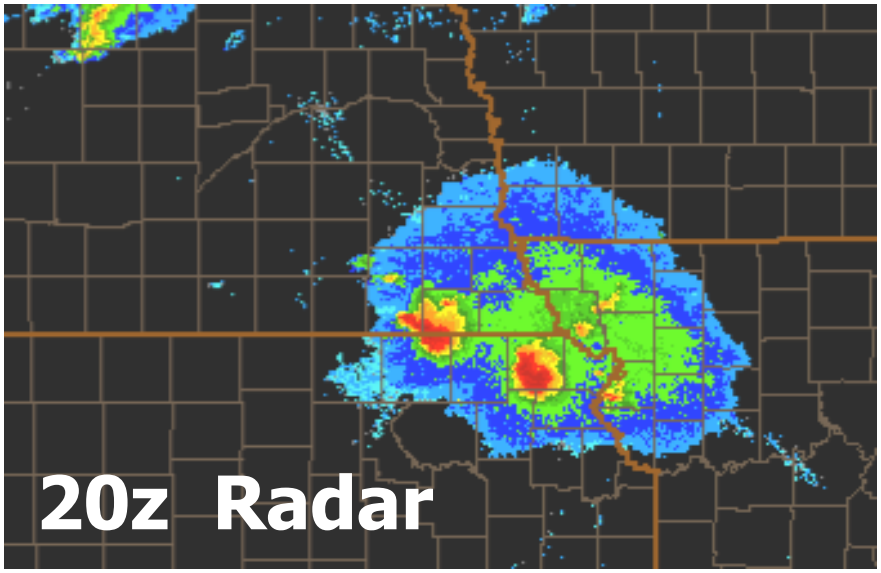
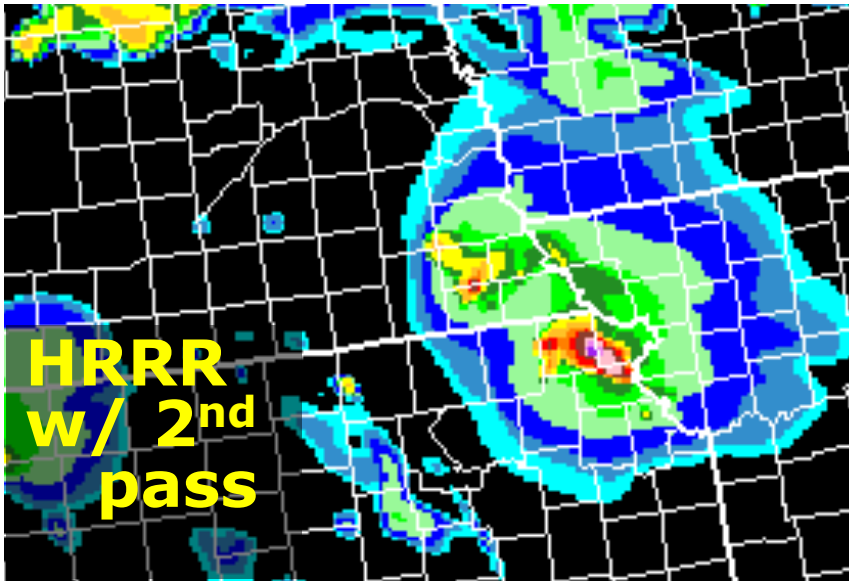
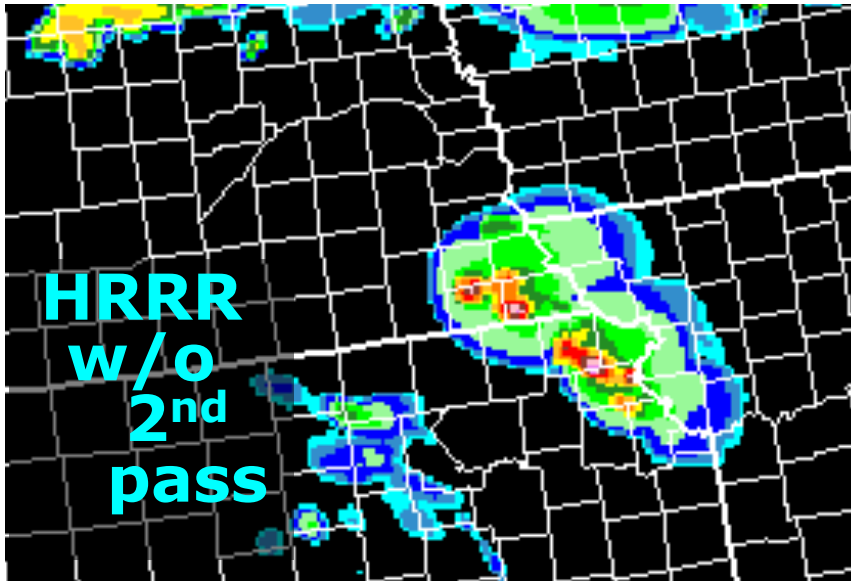
HRRR with 2nd pass radar DA on 3-km domain





27 June 2009

+ 2h fcsts



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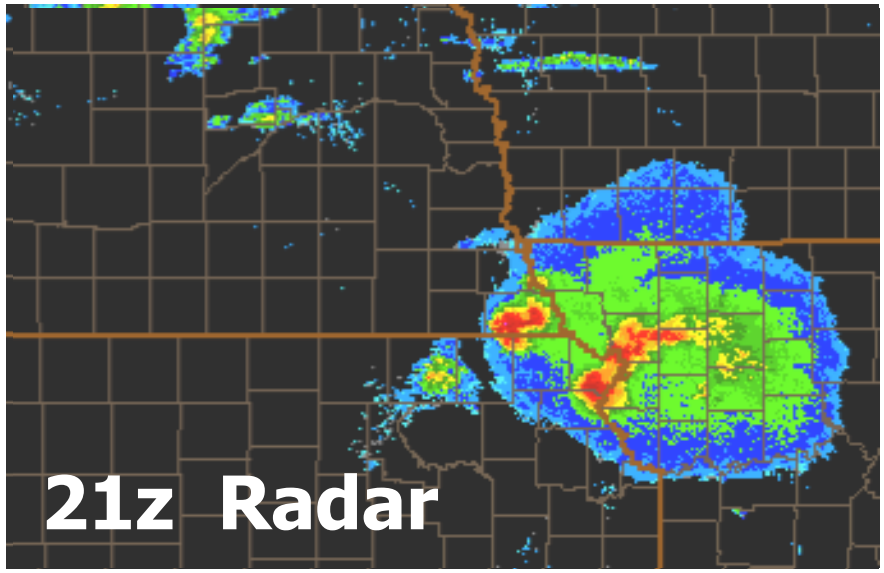
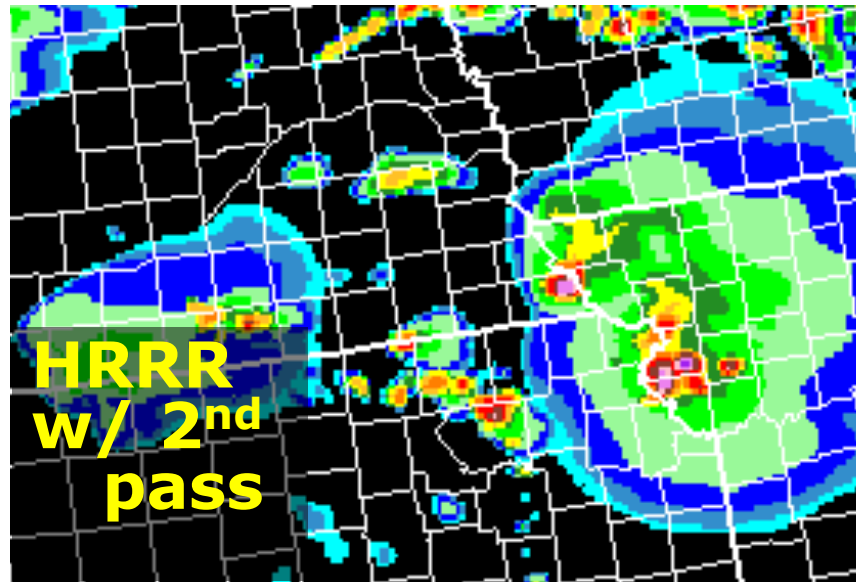
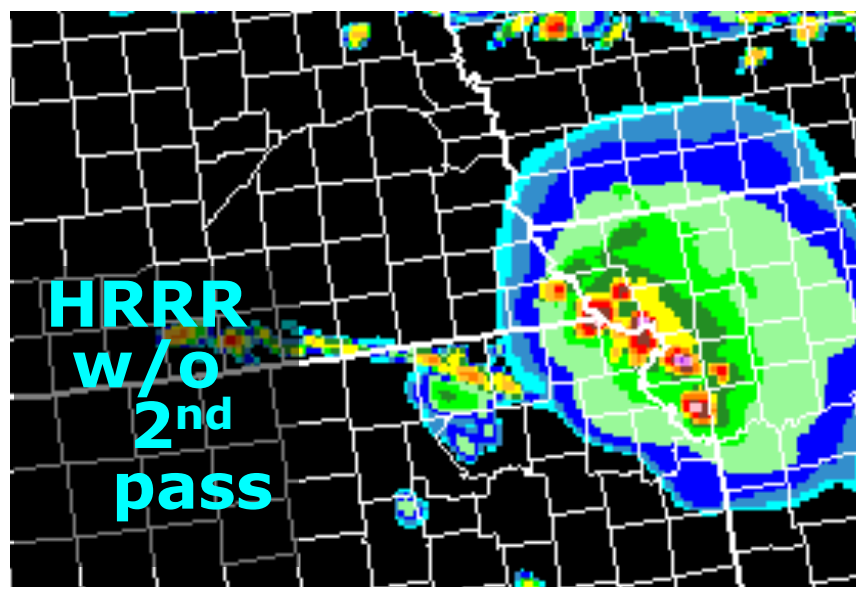
HRRR with 2nd pass radar DA on 3-km domain





27 June 2009

+ 3h fcsts



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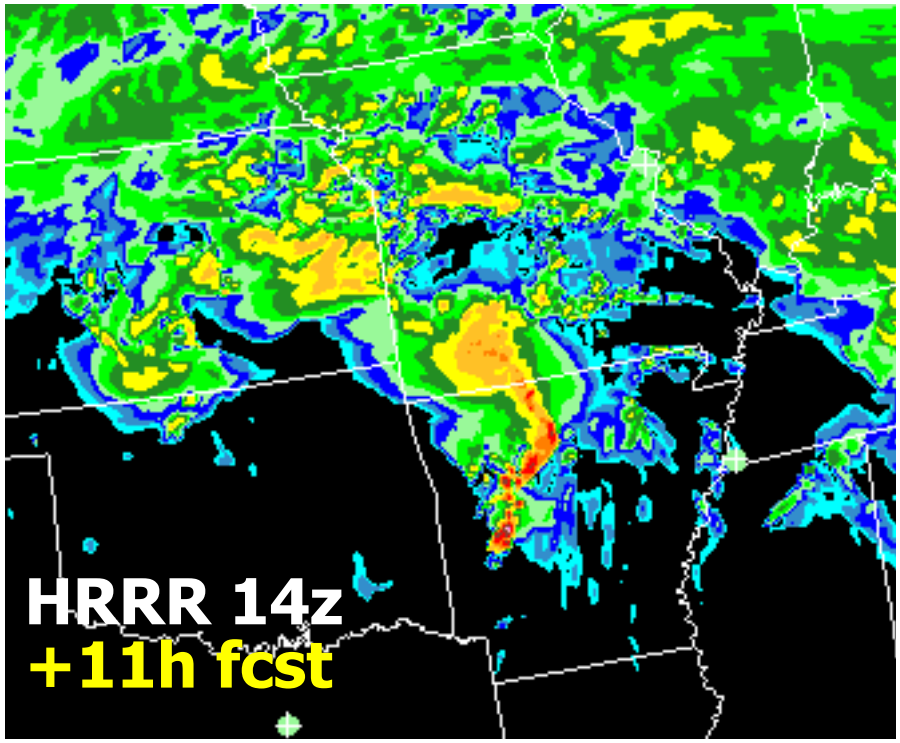
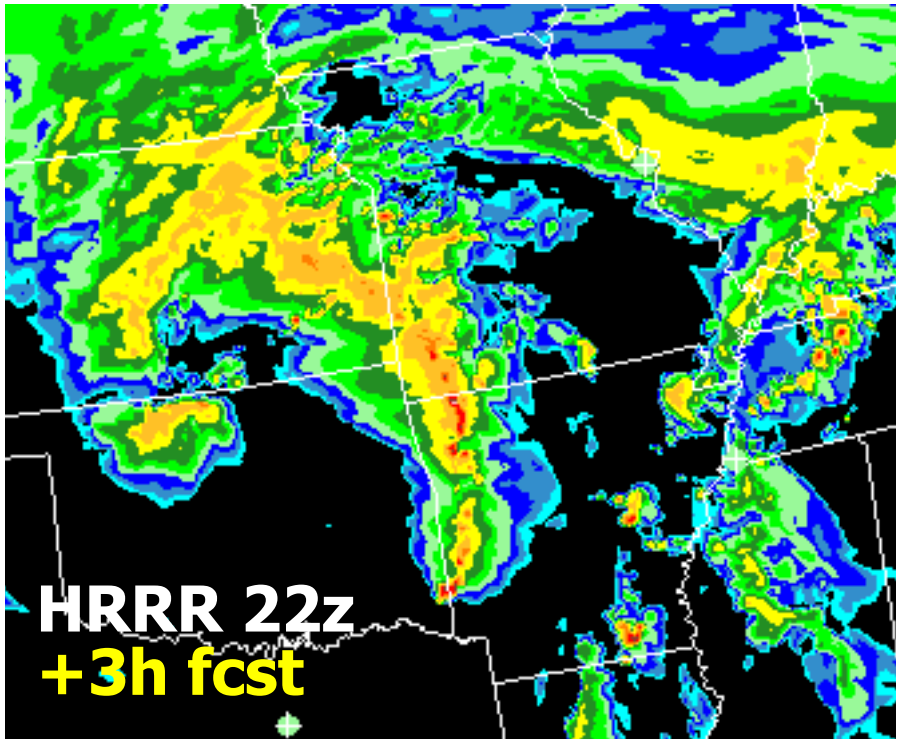
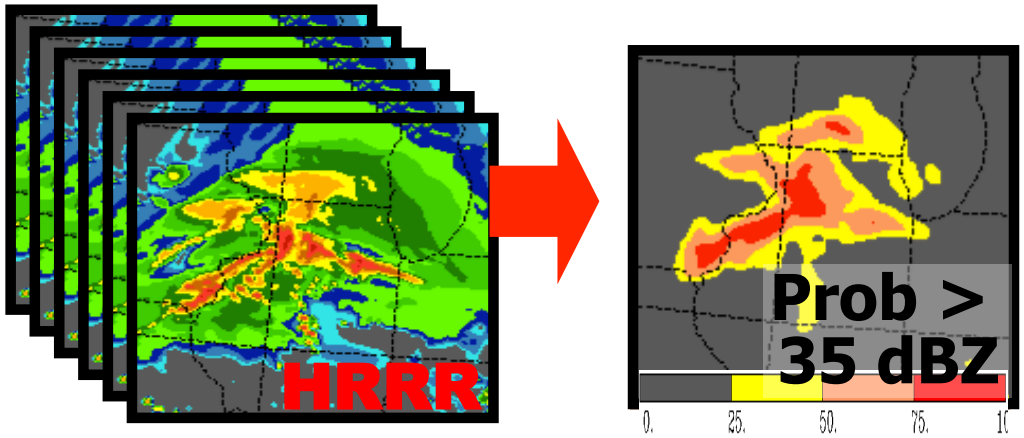
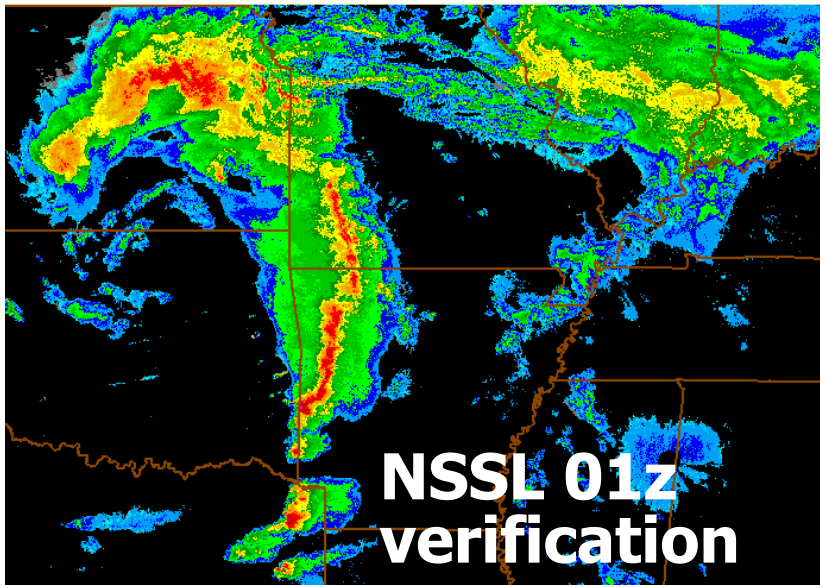




Probabilistic guidance from HRRR time-lagged ensembles

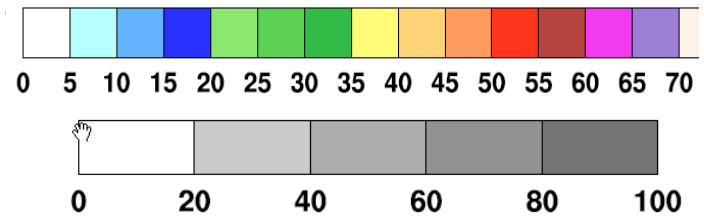
Valid 01z 10 Apr





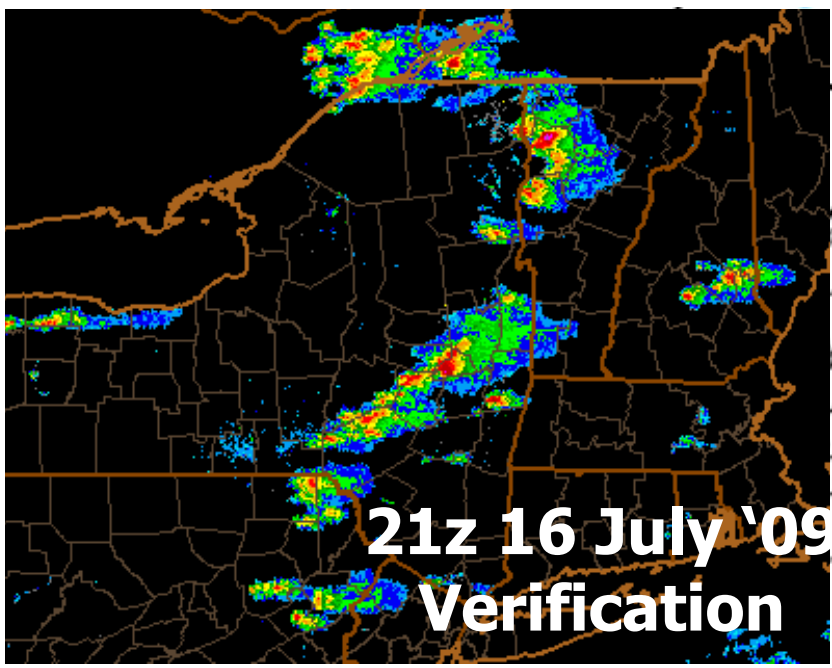
Convective probability forecasts from HRRR time-lagged ensemble

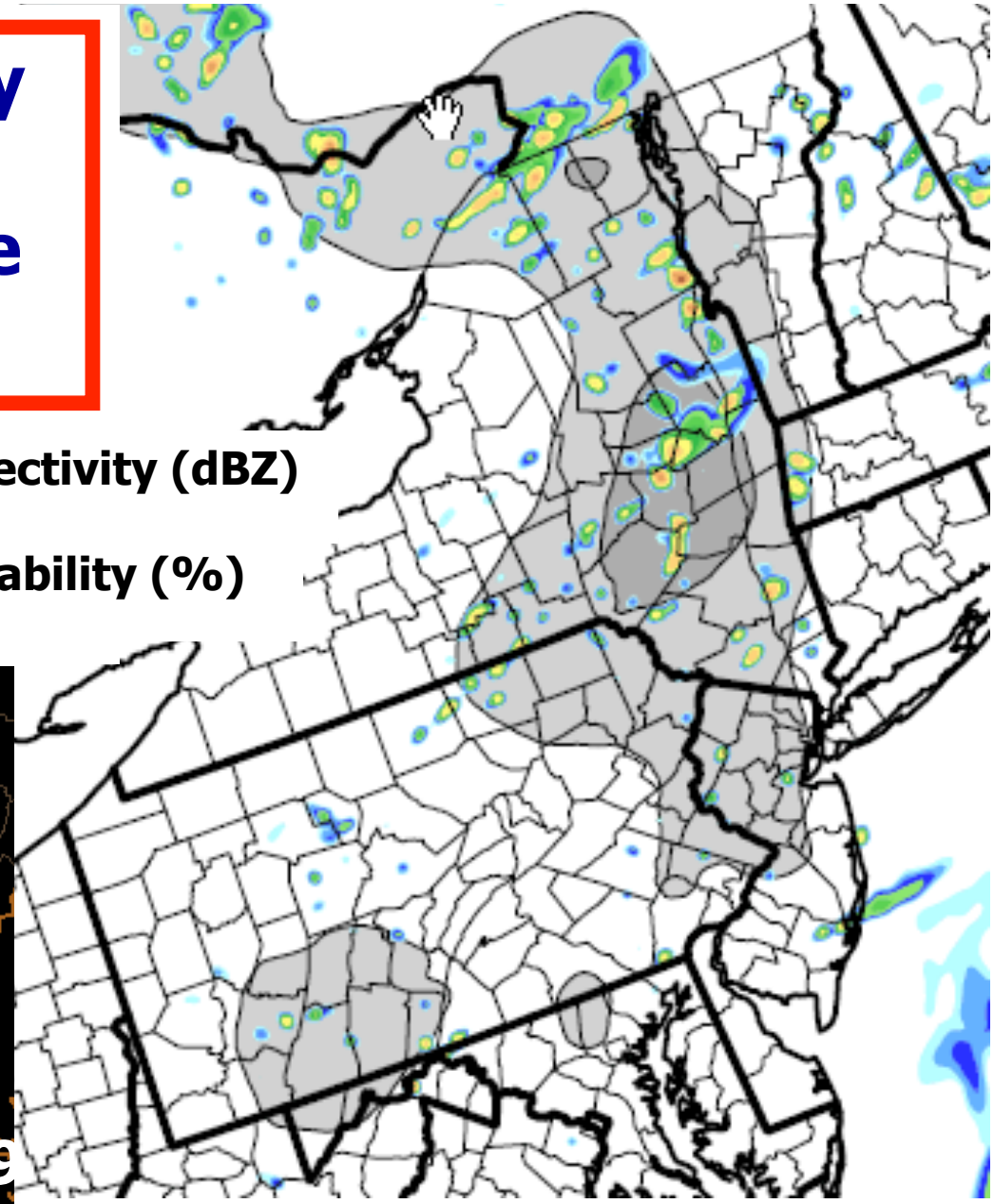
(shown with deterministic fcst)



Reflectivity (dBZ)

Probability (%)

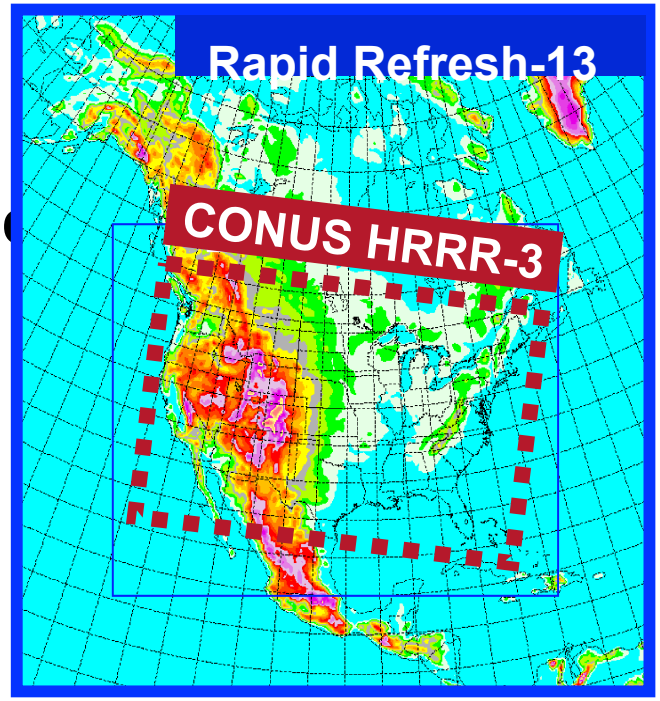




15z + 6h HRRR and HCPF

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 on HRRR 3-km grid allows initial conditions for individual (larger) cells. (Lightning, GOES/polar-based proxy reflectivity)
  - Assimilation of conventional observations and satellite data will likely remain on 13-km grid (computer cost, effectiveness)

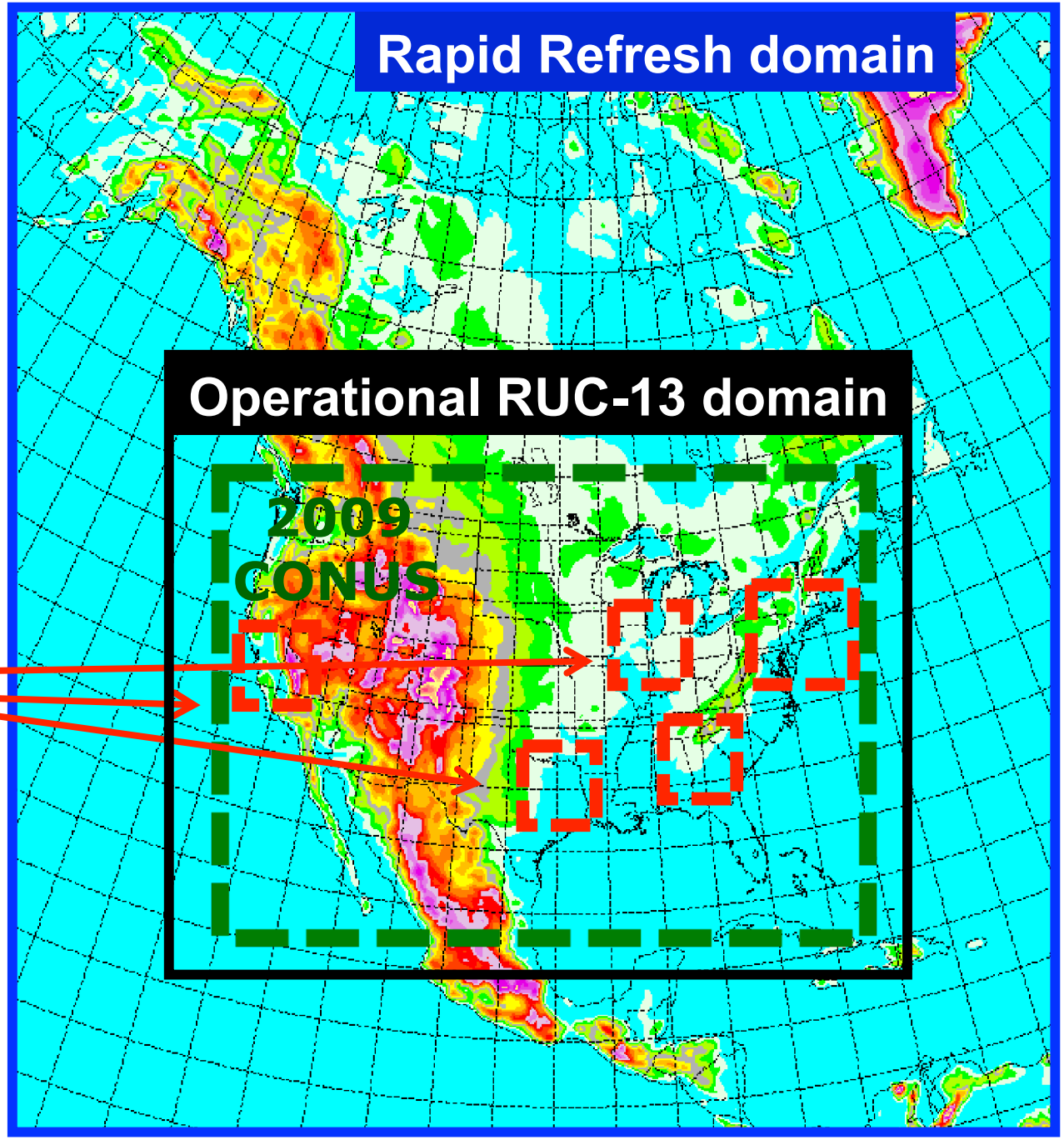


Rapid Refresh, HRRR, +0.5-1.0km HRRR subnests

HRRR – CONUS

Planned HRRR 1-km subnests (2-way boundary!) – testing in 2010

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



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

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 and 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

6 x HRRR – by 2013-2015

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

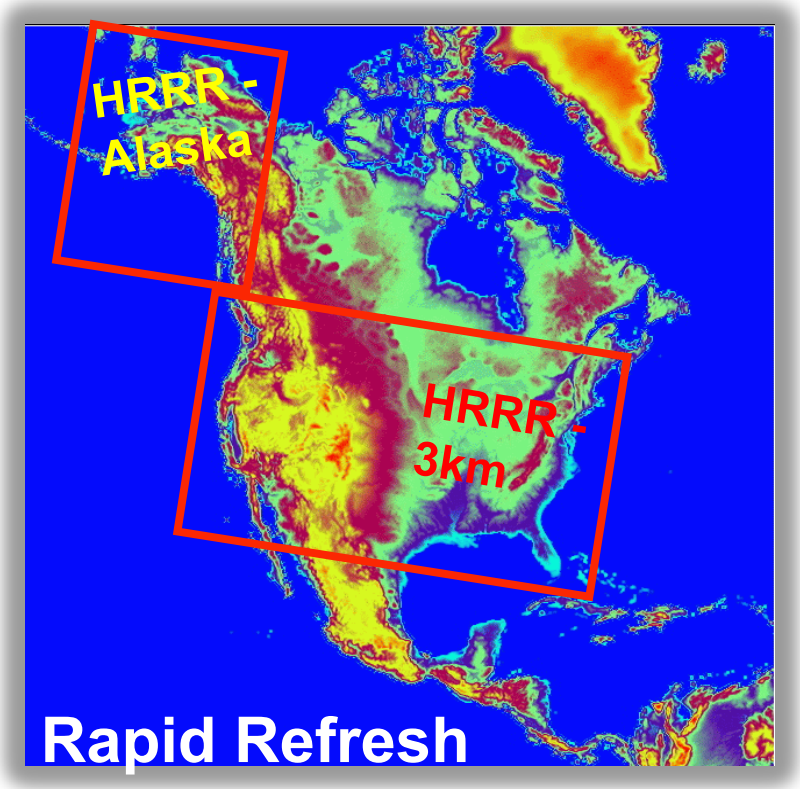
Time-lagged ensemble provides skill baseline for evaluating HRRRE and NARRE development

Future plans for ≤1h updated NWP

2010 – Rapid Refresh operational at NCEP
2012 – Operational (NCEP) CONUS-wide High Resolution Rapid Refresh nested inside RR
2013 – Ensemble RR - NARRe (~6 members, ARW, NMM cores)
2014 – Add operational Alaska HRRR
2015 – Ensemble CONUS HRRR - HRRRe (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 + 1h hybrid 4dvar/EnKF
- Improved nowcast/blend/NWP
- Ensemble-based post-processing



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

Firm NCEP plans

Plans in development