Development of Rapid Update Cycle and Rapid Refresh at NOAA

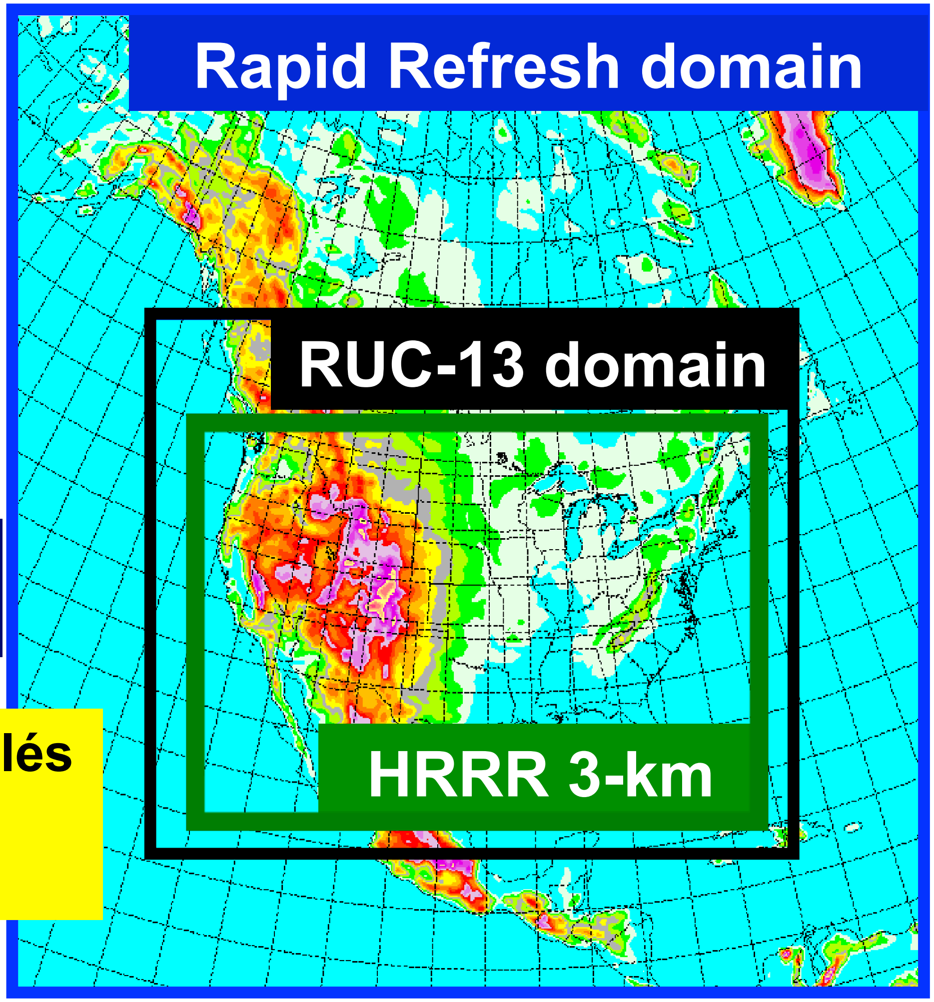
Stan Benjamin

+

Steve Weygandt, Ming Hu
Curtis Alexander, John Brown
Tanya Smirnova, Bill Moninger
Georg Grell, Steven Peckham,
Dezső Dévényi (in memoriam)

Assimilation and Modeling Branch
Global Systems Division

Earth System Research Laboratory
SCIENCE, SERVICE & STEWARDSHIP



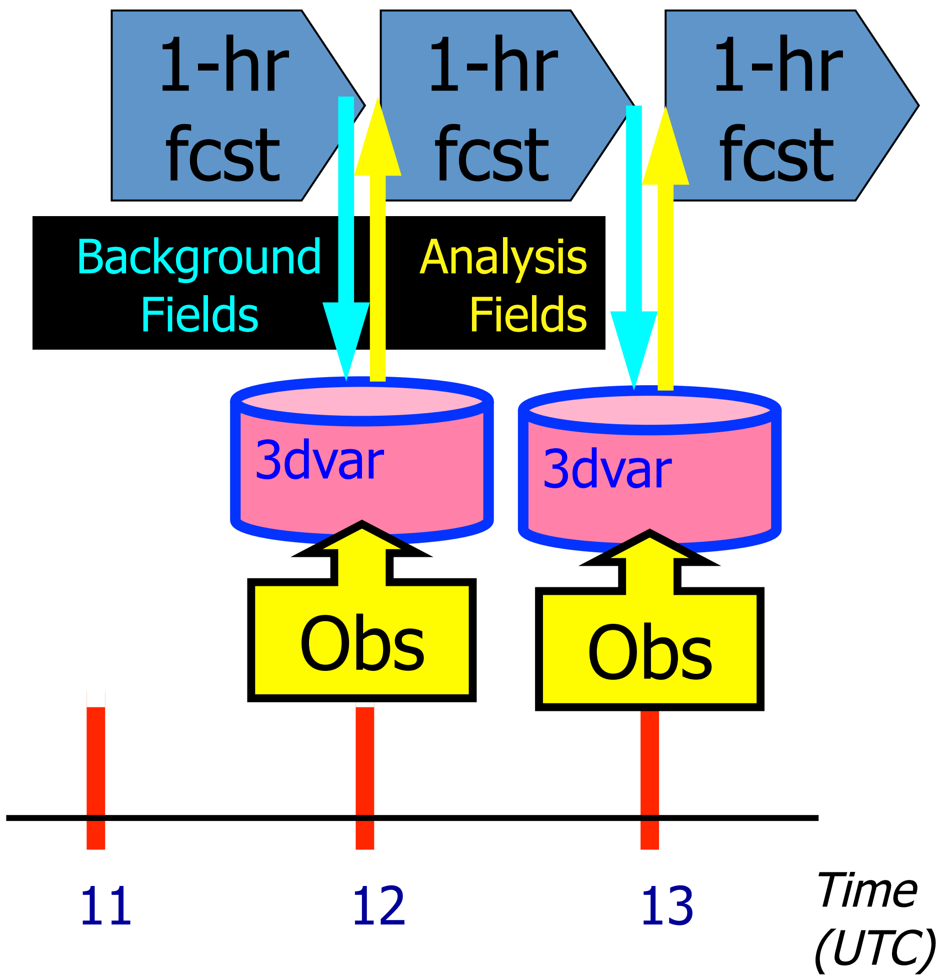
Dévényi Dezső tudományos emlékülés
Budapest
21 June 2010

Dezső Dévényi, 1948-2009

- Best assimilation scientist in RUC / Rapid Refresh group
- Ph.D. from Eötvös Loránd University in Budapest
- Formerly with Hungarian Met Service (even Vice President (Deputy Director))
- Taught NWP in Hungary, called the "father of NWP in Hungary" by former students
- Spent a year with Lev Gandin in 1975
- Developed the RUC 3dVAR
- Co-led development of Rapid Refresh version of GSI with Ming Hu and others

RUC/Rapid Refresh Hourly Assimilation Cycle

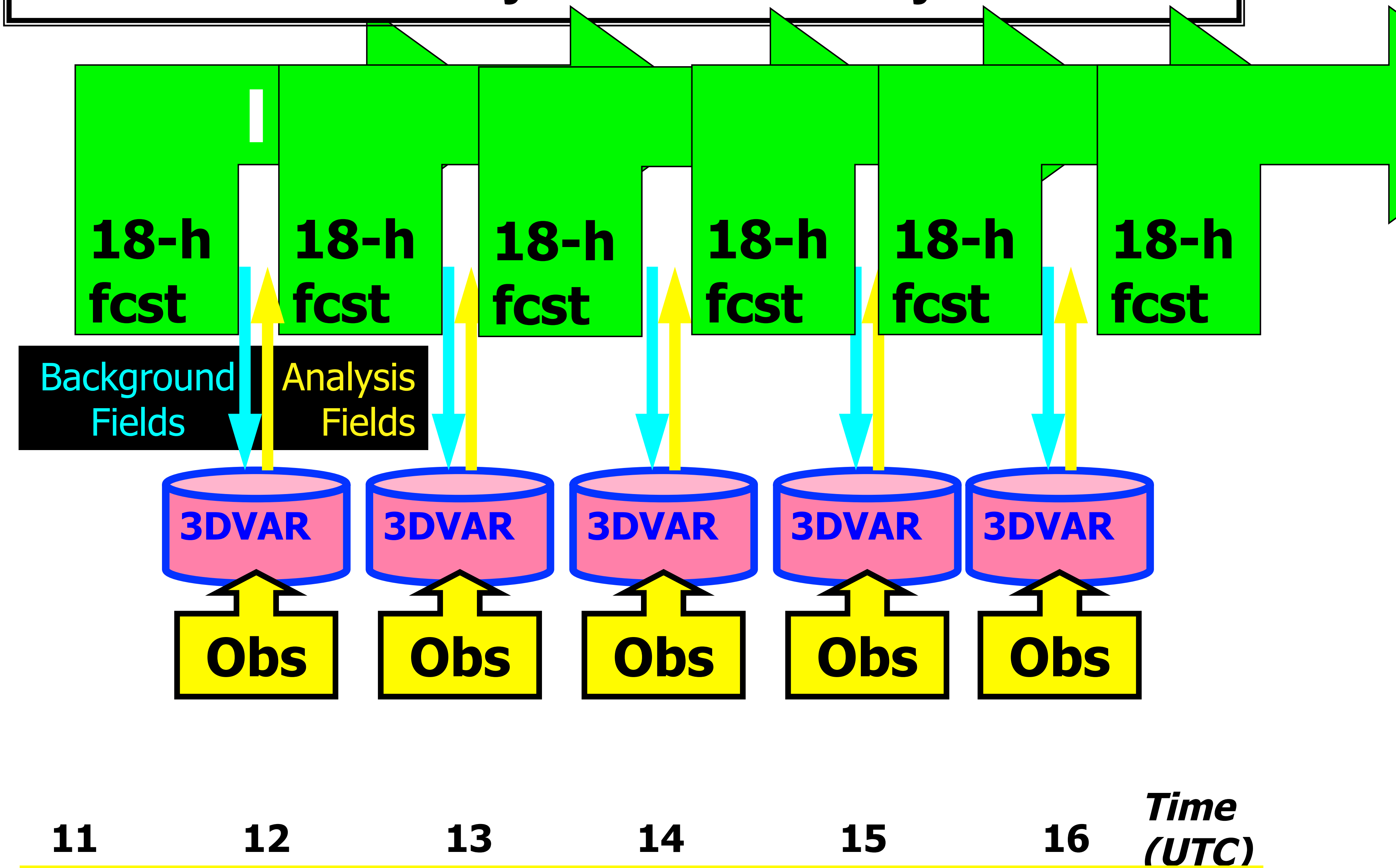
Cycle hydrometeor, soil temp/moisture/snow plus atmosphere state variables



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

RUC Hourly Assimilation Cycle



NCEP Extension to 18h at every hour – planned 2 Mar 2010

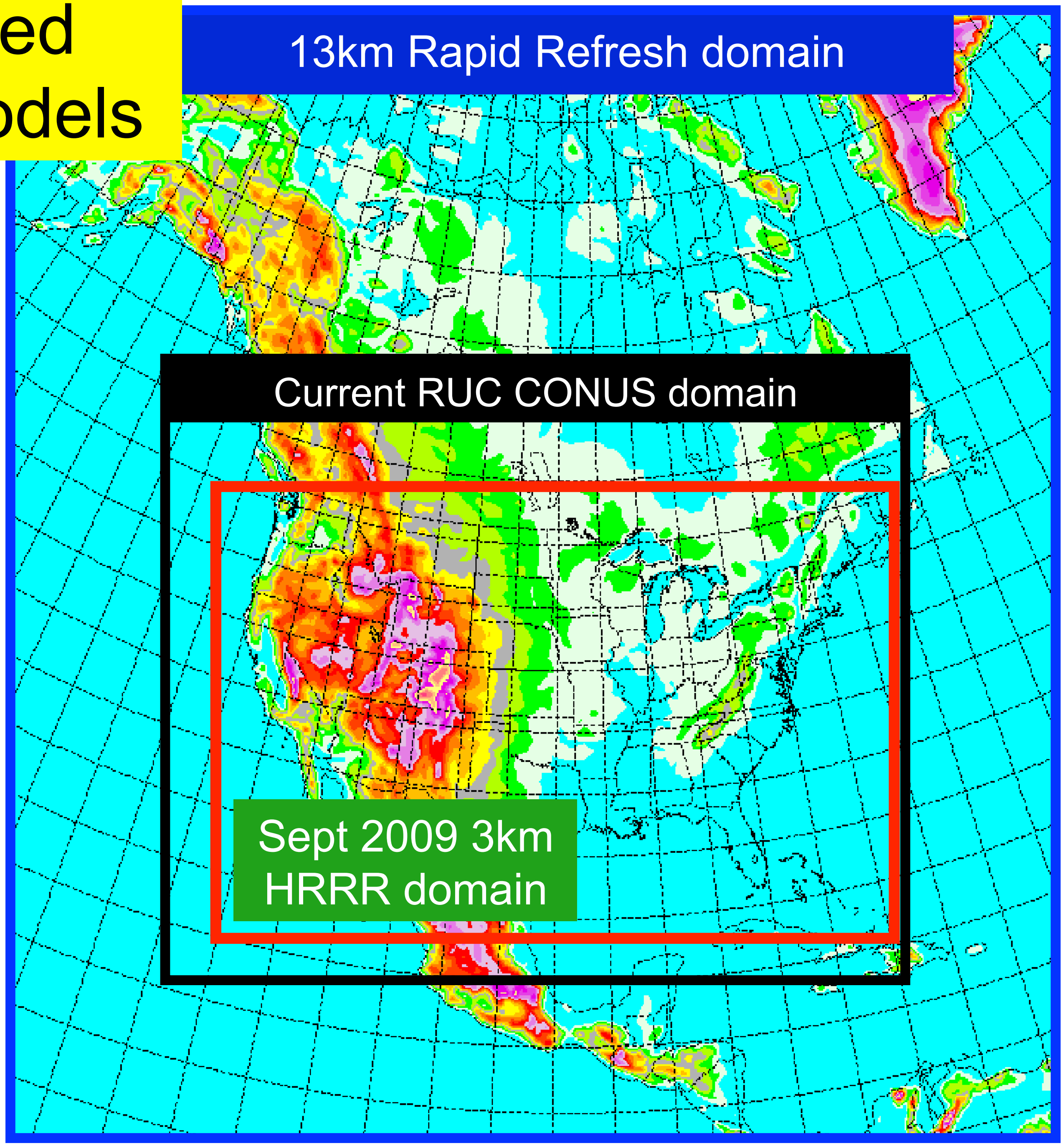
Hourly Updated NOAA NWP Models

RUC – current oper model - 13km
- 18h fcst updated every hour

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

HRRR - Hi-Res Rapid Refresh
- Experimental 3km
- Nest inside RUC or RR

15-h 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”

RUC History – NCEP (NMC) Implementations

1994 First operational implementation of RUC
60km resolution, 3-h cycle
1998 40km resolution, 1-h cycle,
Cloud physics, land-surface model

2002 20km resolution
GOES cloud data assimilation, 3-d hydrometeor fields
modified
2003 Change to 3dVAR analysis from previous "optimal
Interpolation"
2005 13km resolution
New observation types (METAR cloud, GPS-PW, new
cloud physics
2008 Assim of radar reflectivity, mesonet winds,
modified Grell/Devenyi, other physics
2010 WRF/GSI-based Rapid Refresh to replace RUC

The RUC history and Dezső

- Isentropic analysis

  - Reading, UK IUGG - 1989

- First RUC Optimal Interpolation analysis in isentropic coordinates

  - Dezső's first visit to Colorado - 1991

- RUC 3dvar – development – 2000-2003

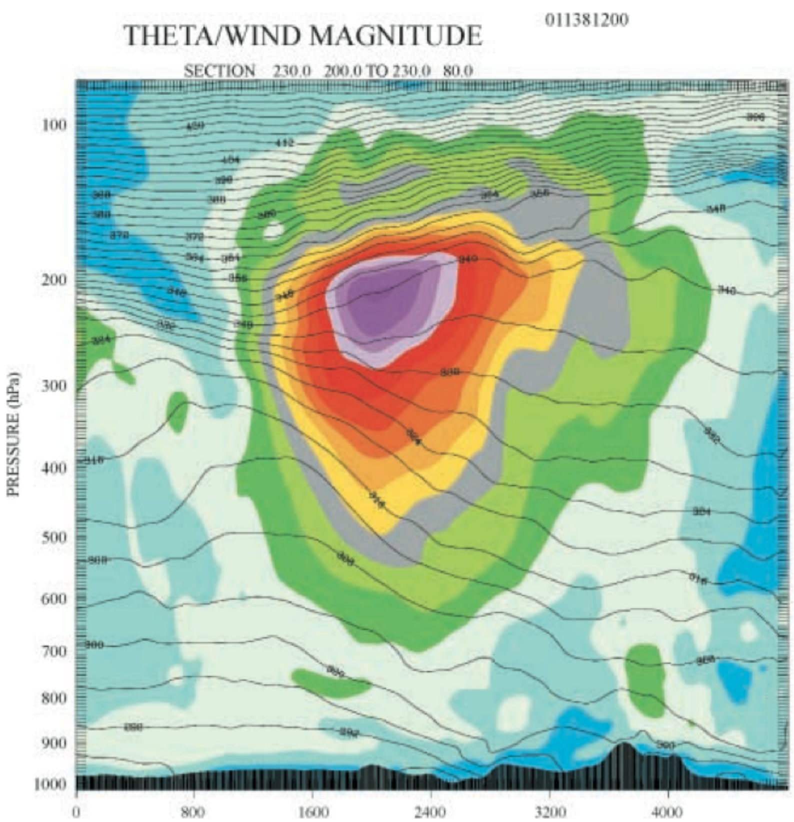
  - Dezső returns to Boulder – 2000

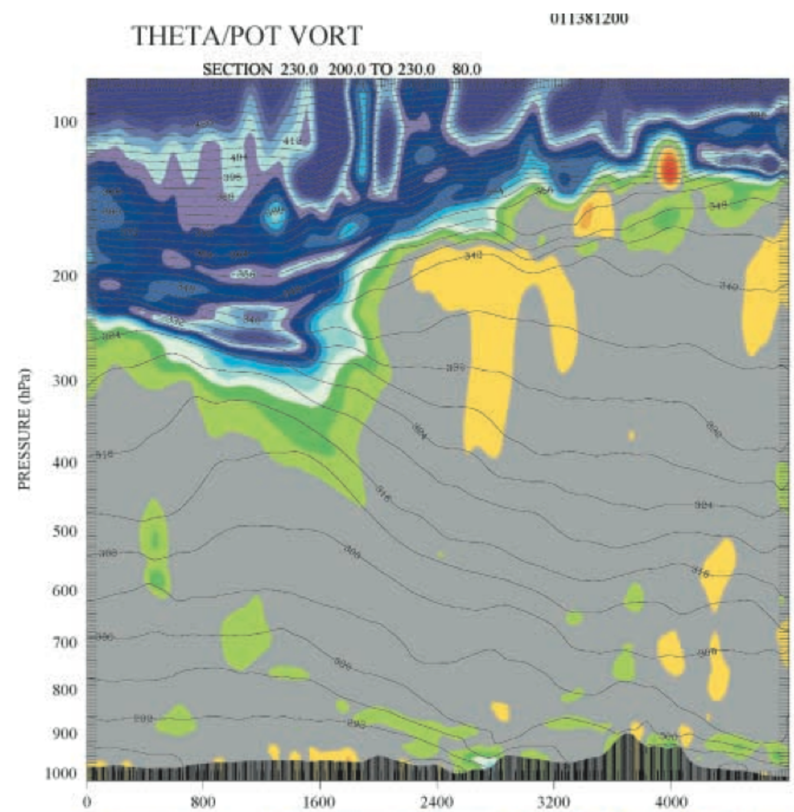
- GSI adaptation for hourly Rapid Refresh – 2006-current

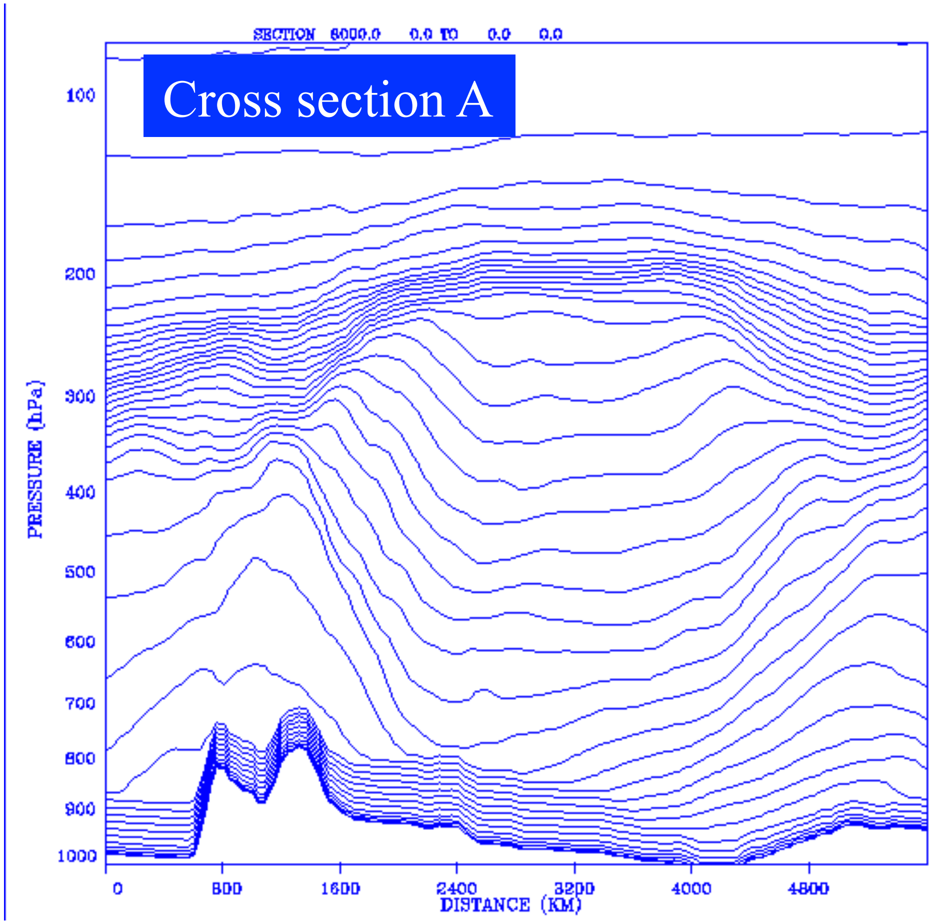
  - Dezső wrestled first with it

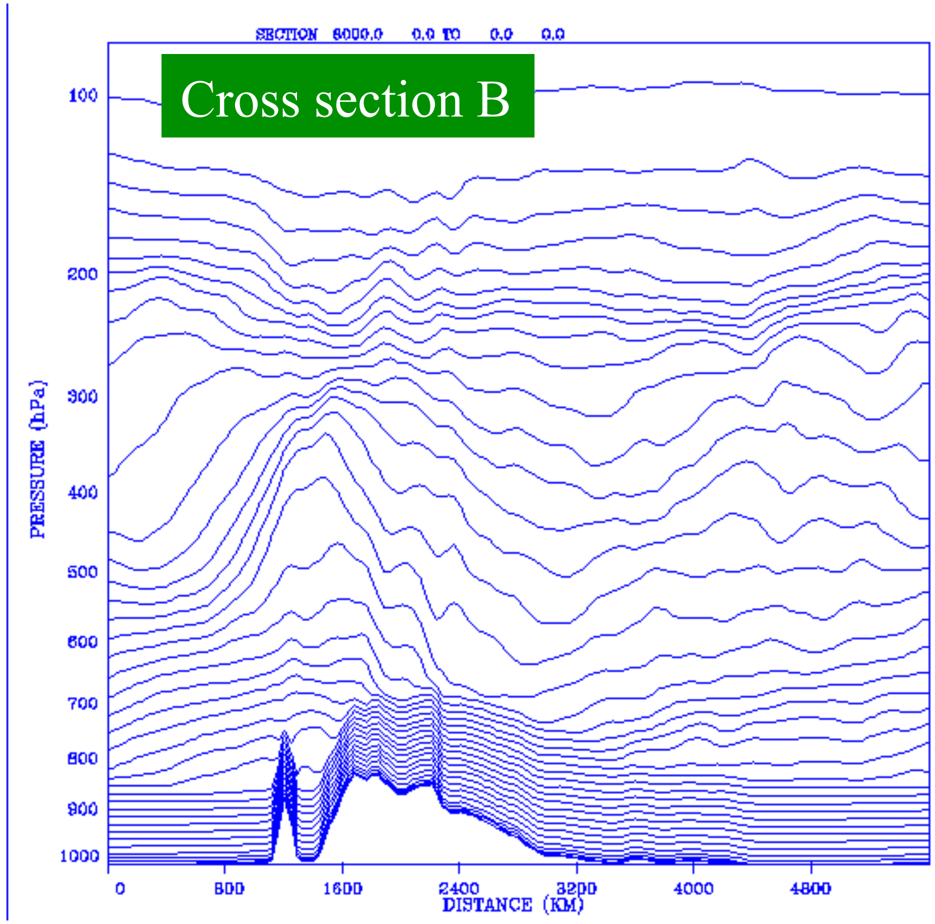
The RUC 3dVAR

- **3d variational analysis in isentropic-sigma hybrid vertical coordinate**
- **Described by Devenyi and Benjamin – 2003 – MAP**
  - Help from Steve Weygandt – NOAA- Boulder
  - Dave Parrish, Wan-Shu Wu, Jim Purser – NOAA-NCEP

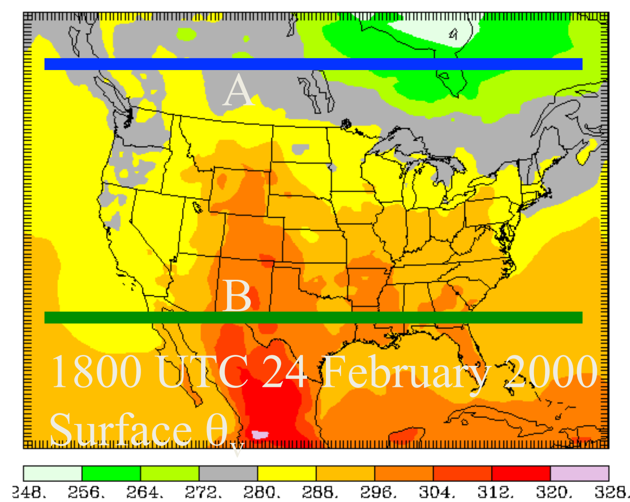








RUC generalized vertical coordinate
set as θ-σ hybrid coordinate



Reference θ_v values (224-500K) pre-assigned to each of the 50 RUC levels.
More levels become terrain-following levels in warmer parts of domain/times of year.

More of Dezso's key scientific contributions/papers to NOAA Research (FSL, GSD)

- Benjamin, …. Schlatter, Devenyi, - *Idojaras*, 1993

  Recent developments in the MAPS/RUC isentropic-sigma data assimilation system

- Devenyi and Schlatter, *Monthly Weather Review*, 1994

  Statistical properties of 3h prediction errors from MAPS/RUC

- Grell and Devenyi – *Geophys. Res. Letters*, 2002

  Generalized approach to parameterizing convection combining ensemble and data assimilation techniques

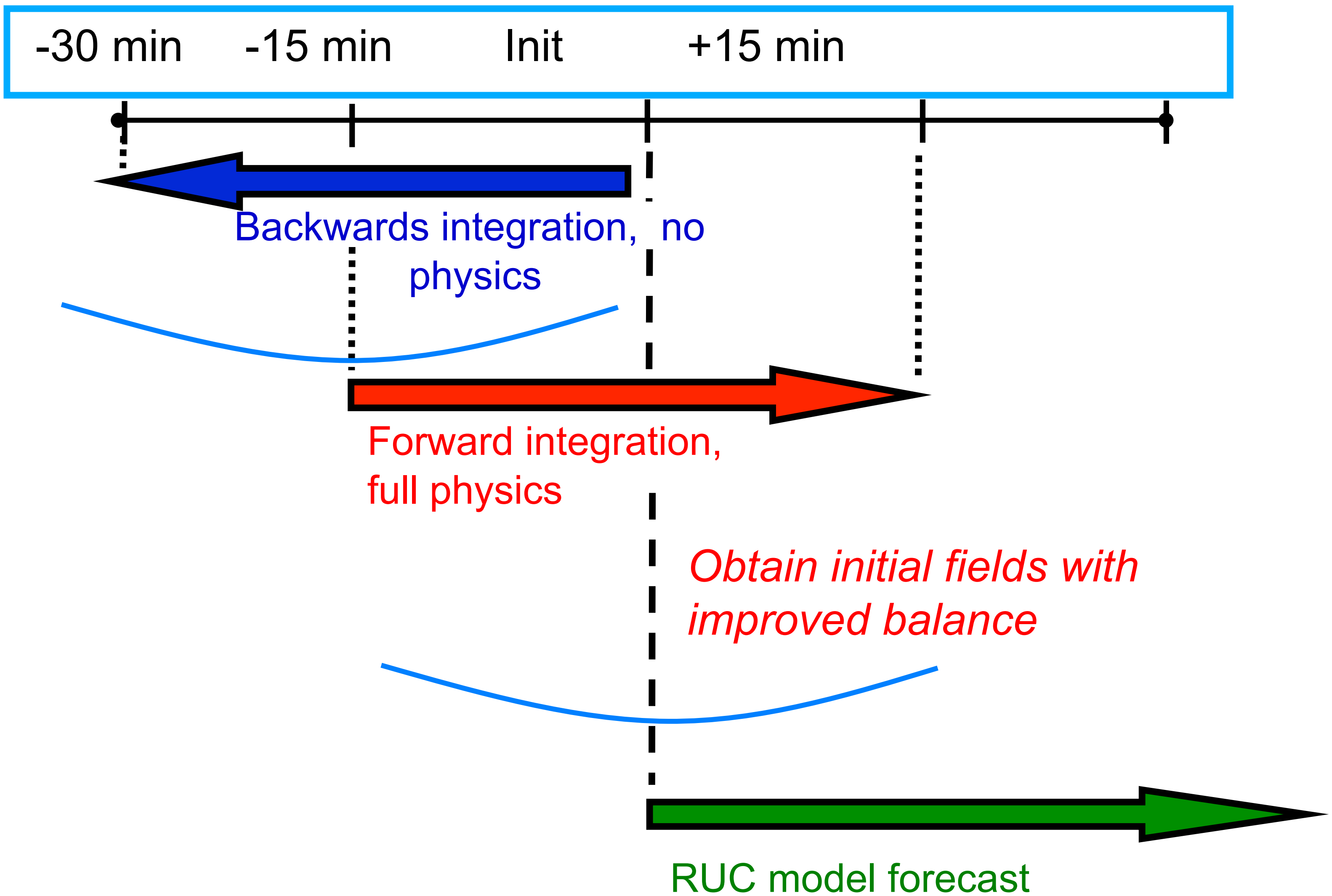
- Benjamin, Devenyi, …. *Mon. Wea. Rev*., 2004

  An hourly assimilation cycle – the RUC – NOAA Research Paper of the Year award - 2004

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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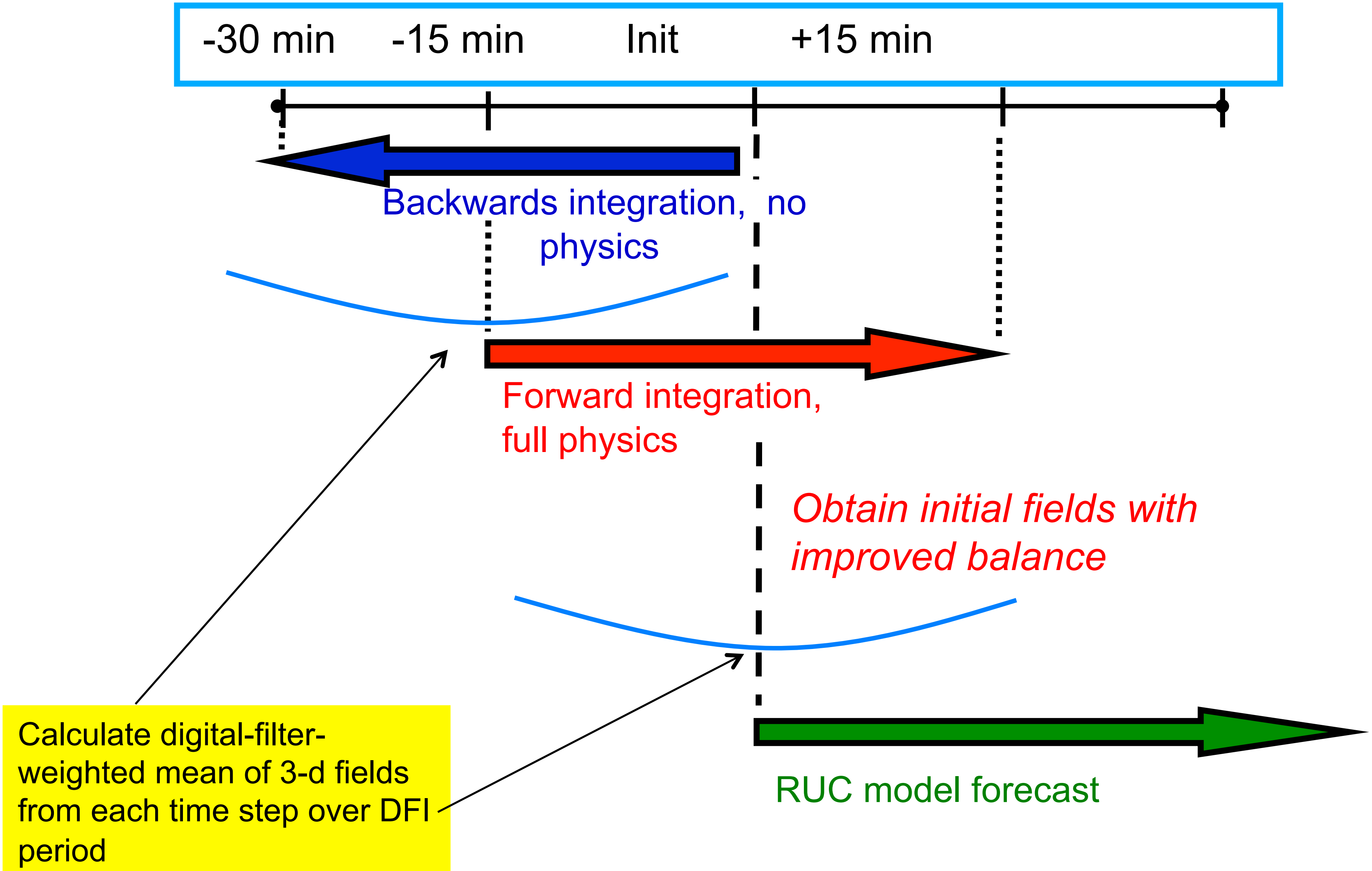
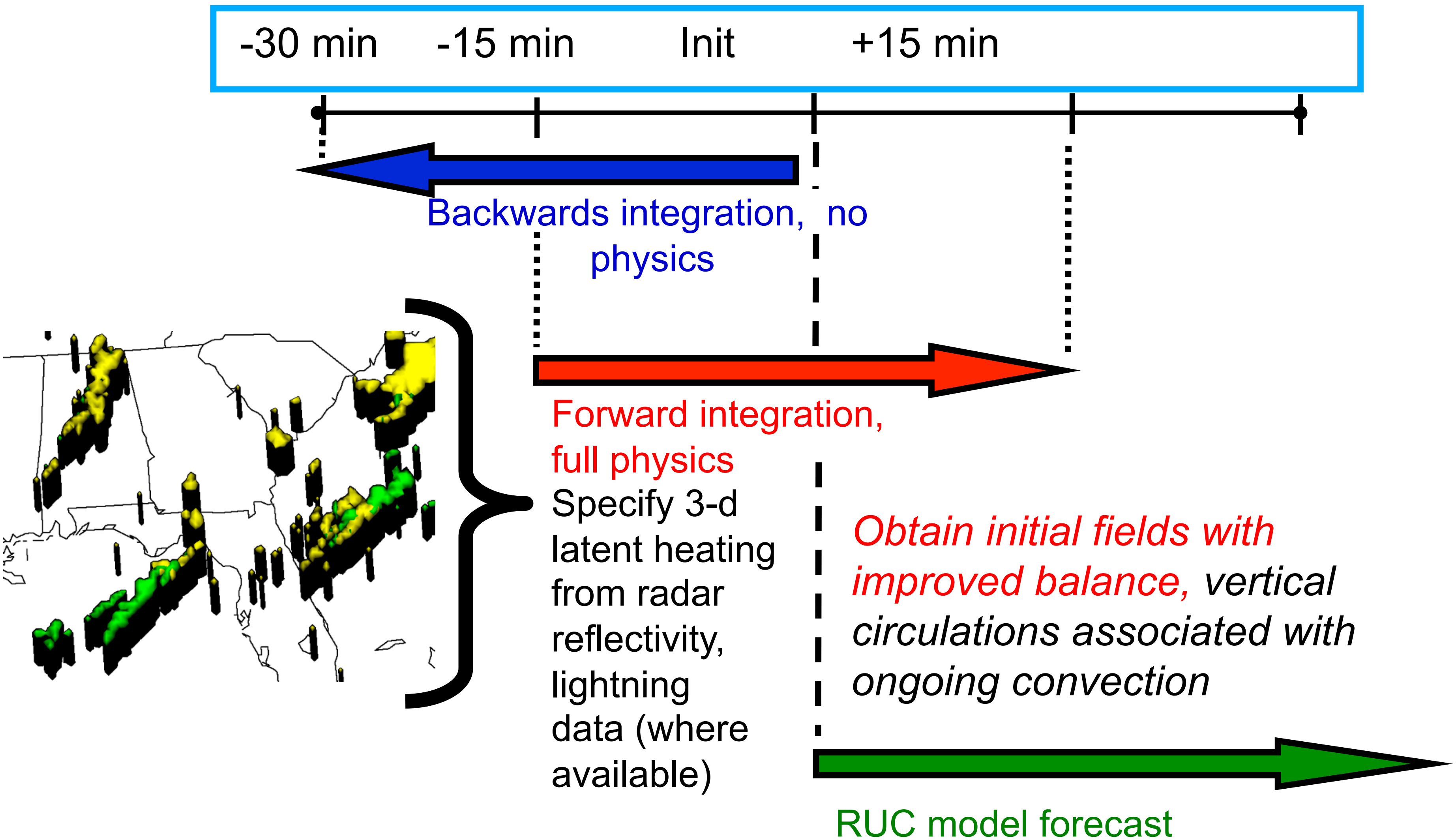
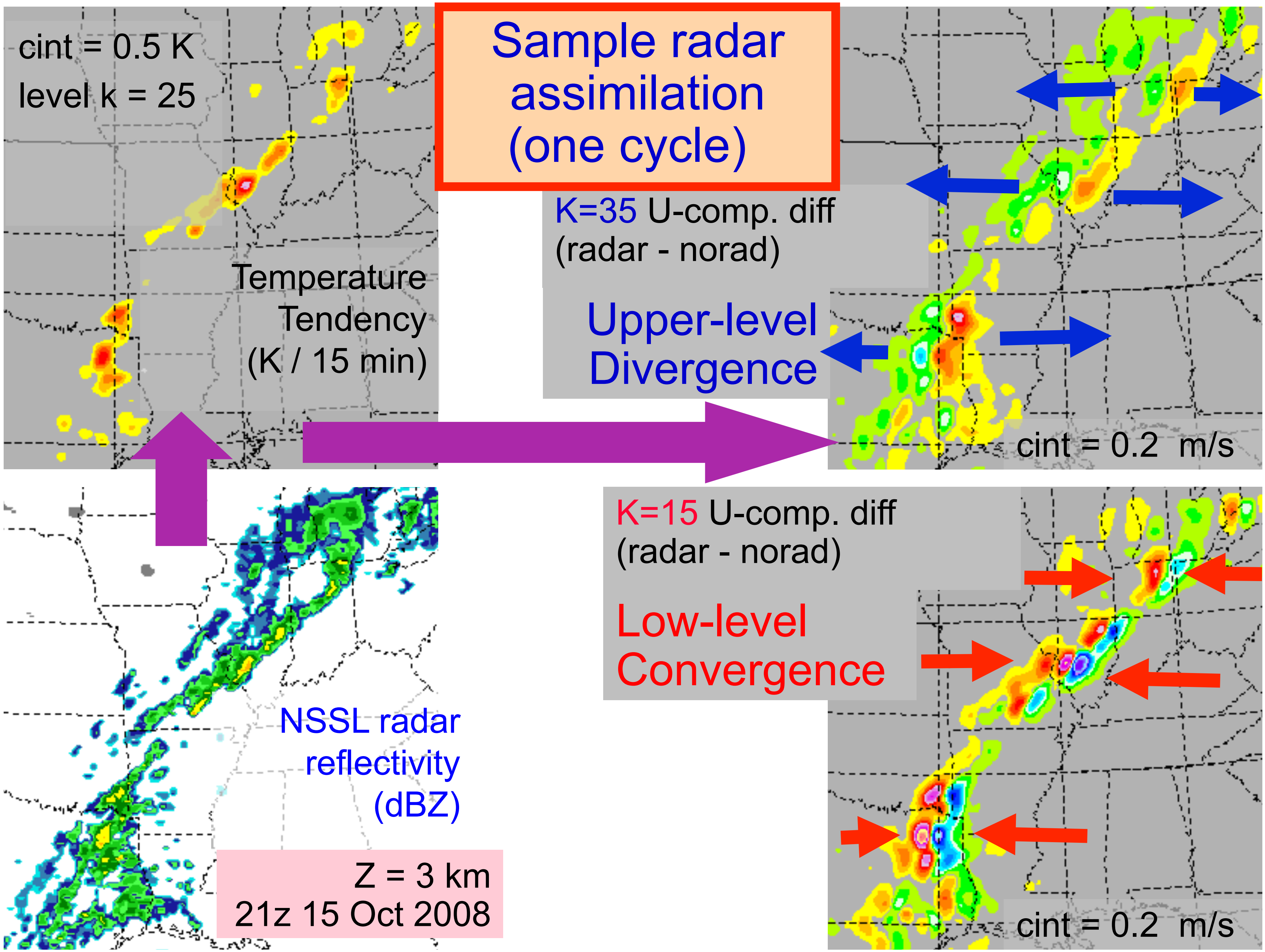


Diabatic Digital Filter Initialization (DDFI)

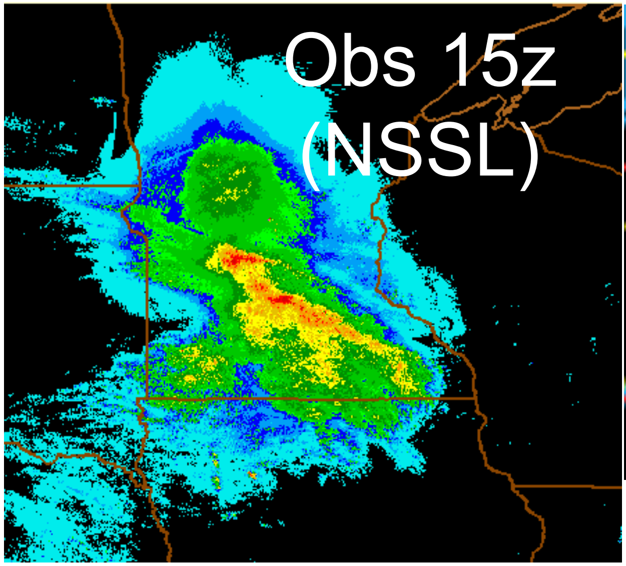
New - add assimilation of radar data

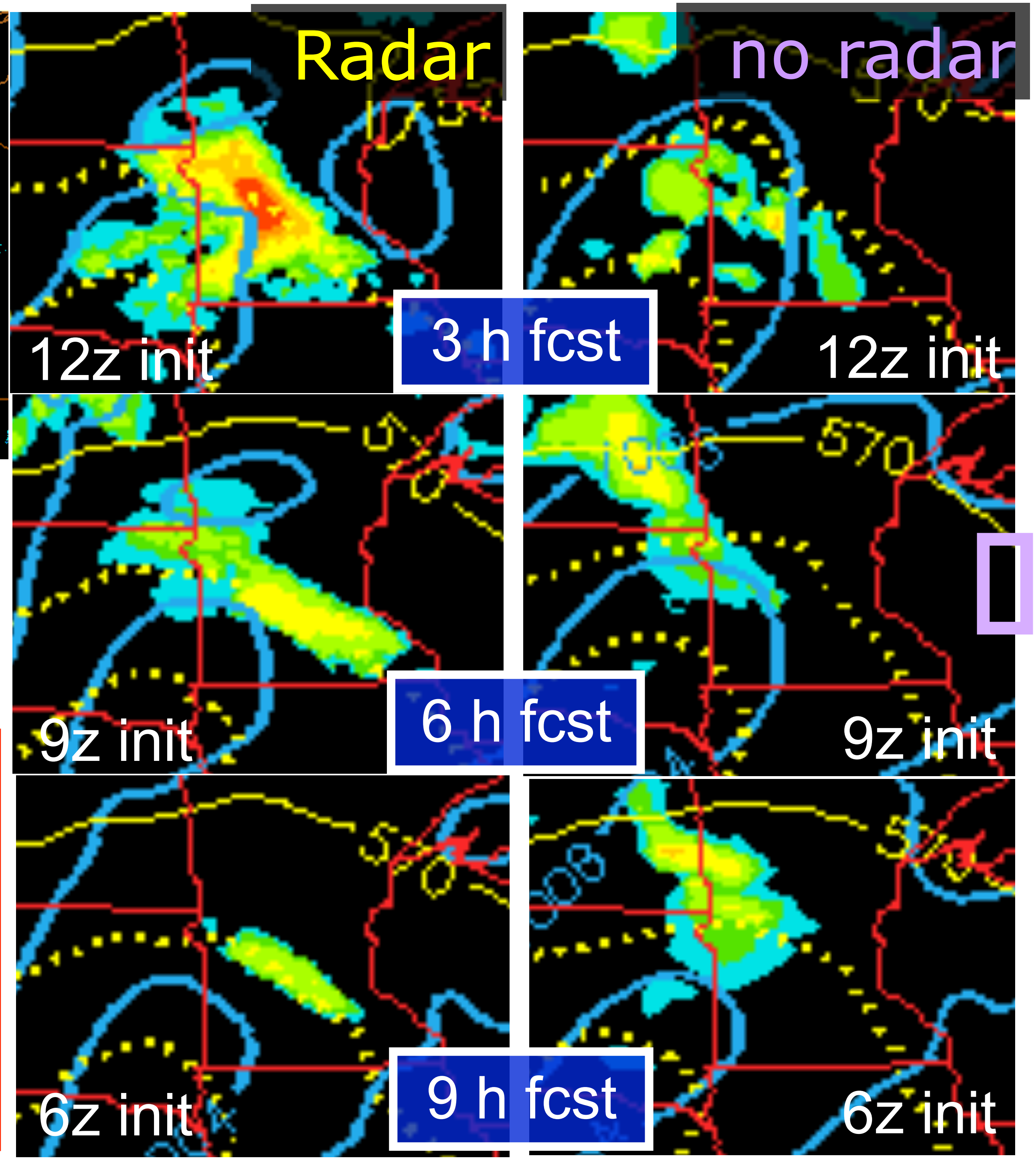


Radar reflectivity assimilation in RUC



Sample radar assimilation (one cycle)
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
K=15 U-comp. diff (radar - norad)
Low-level Convergence
cint = 0.2 m/s
NSSL radar reflectivity (dBZ)
Z = 3 km
21z 15 Oct 2008





3-h acc. precip.

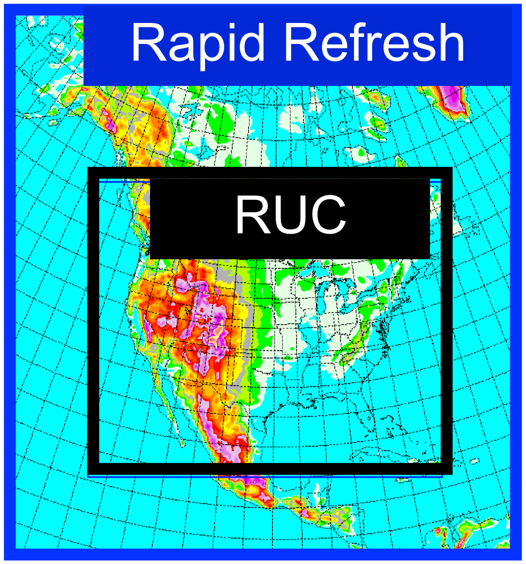
Valid 15z
31 July 2008

RUC radar Assimilation

→Better RUC forecasts

RUC to Rapid Refresh (est. Jan 2011@NCEP)

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



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

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

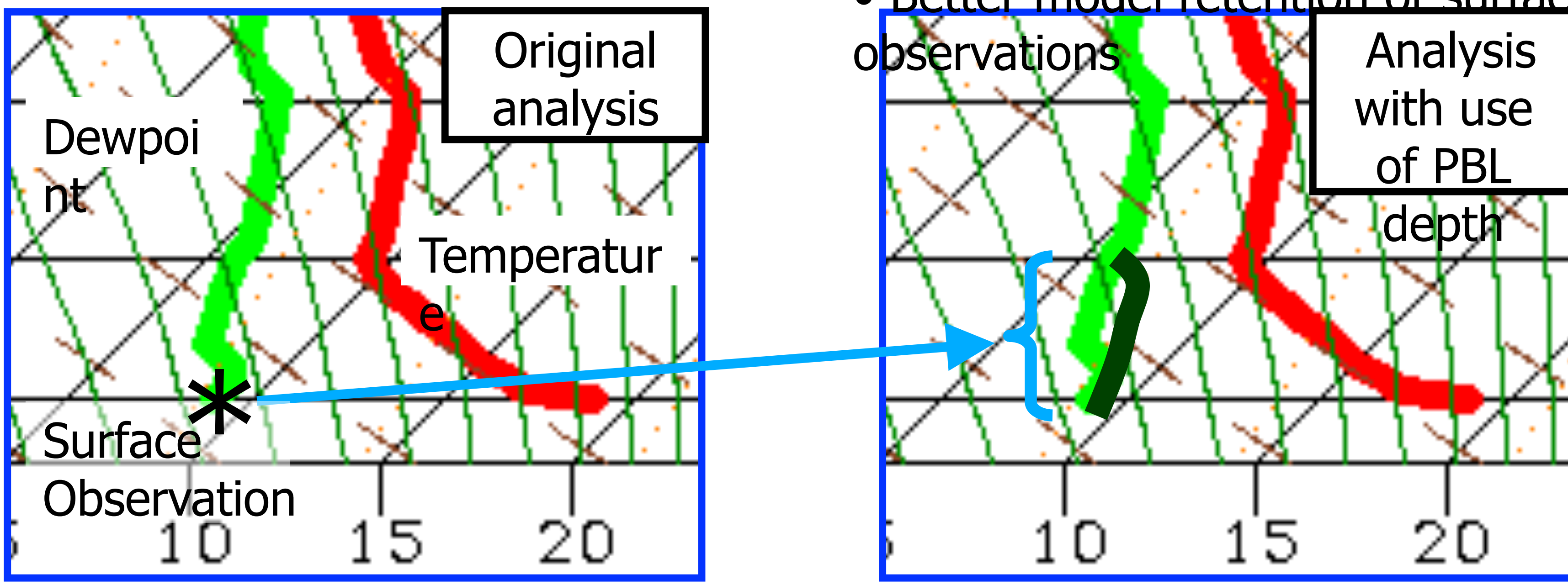
Use of surface obs information throughout boundary layer

Problem

- Information from surface observation not used through depth of PBL by RUC analysis
- Surface observation not retained in model forecast

Solution

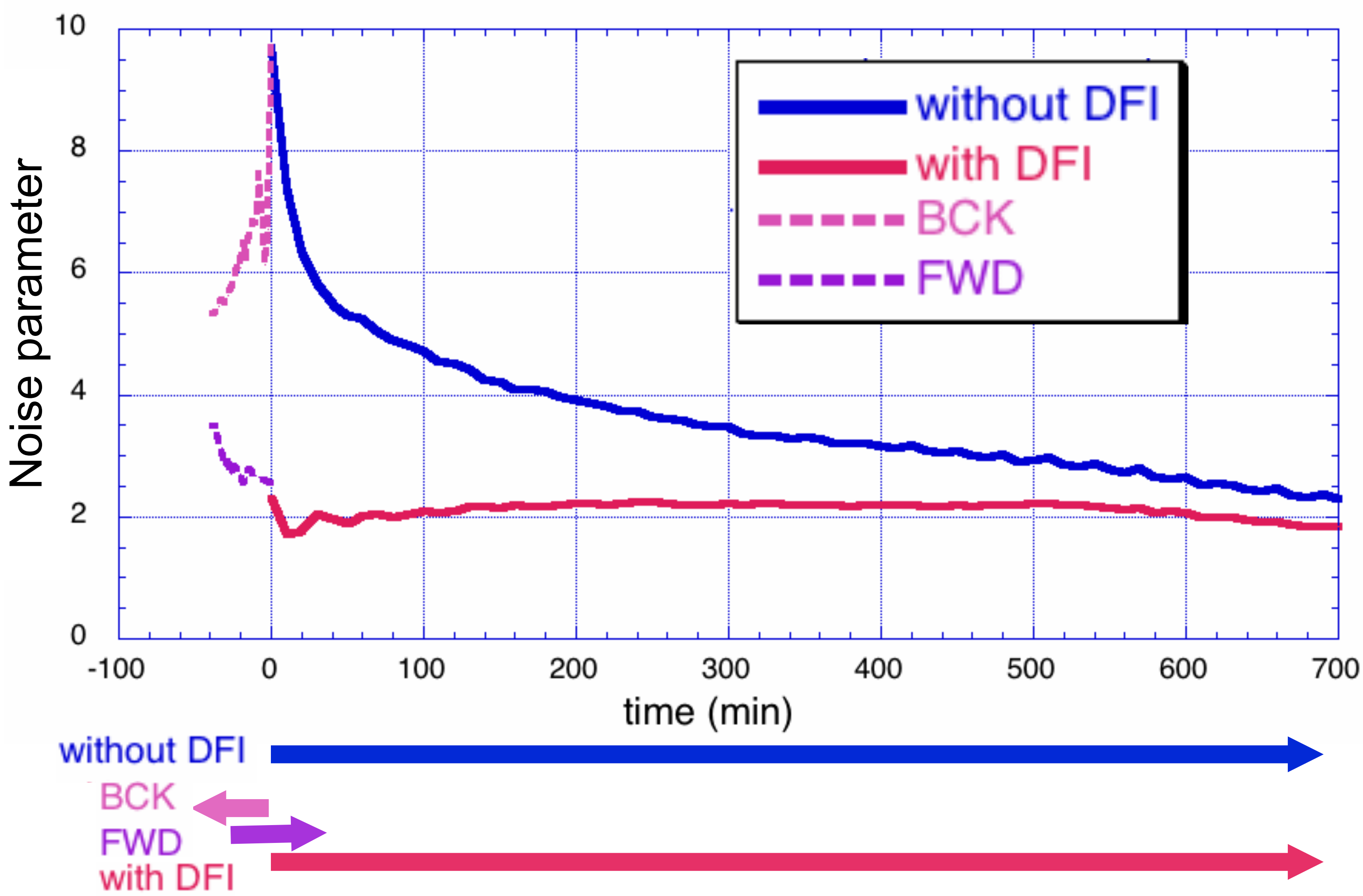
- Use METAR observation throughout PBL depth (from background field) by creating pseudo-innovations in PBL
- Better model retention of surface observations



Diabatic Digital Filter Initialization

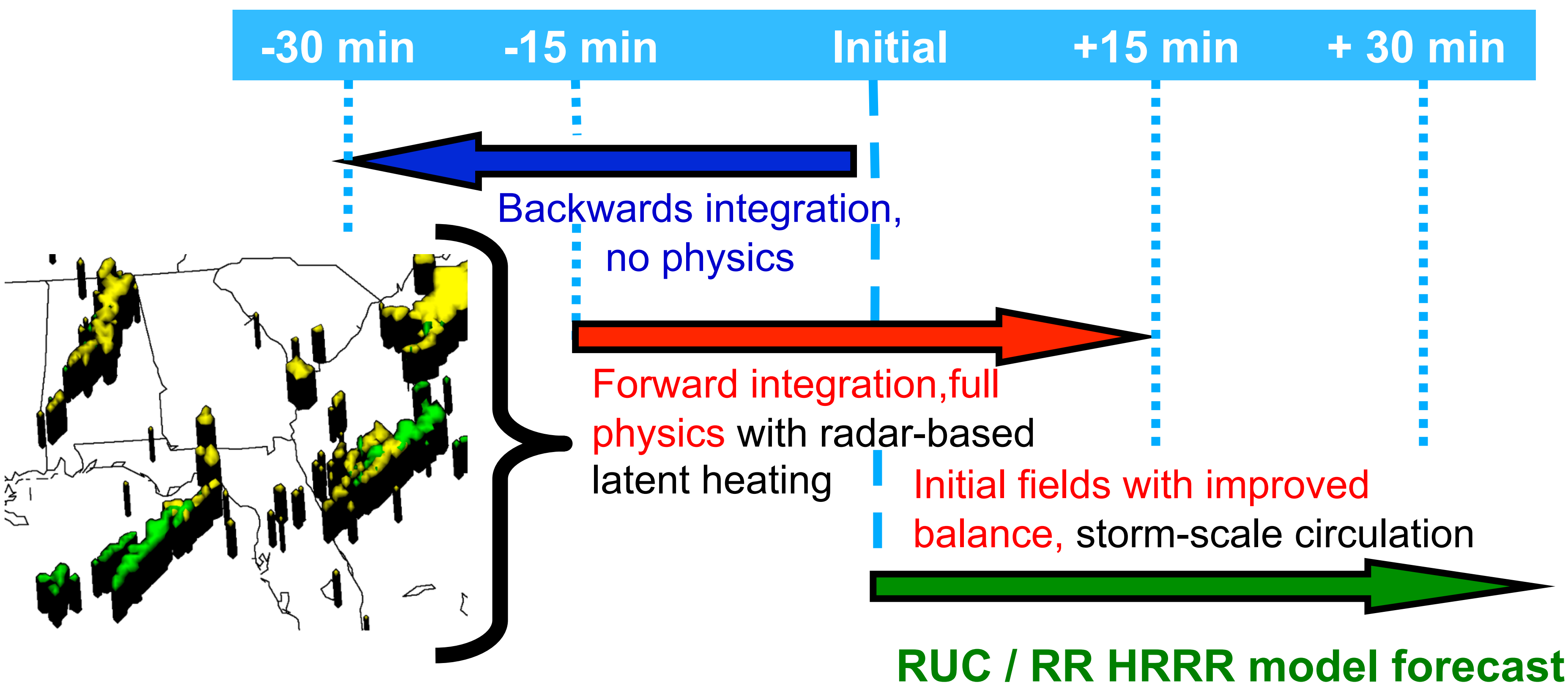
Reduce noise in RUC and Rapid Refresh

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



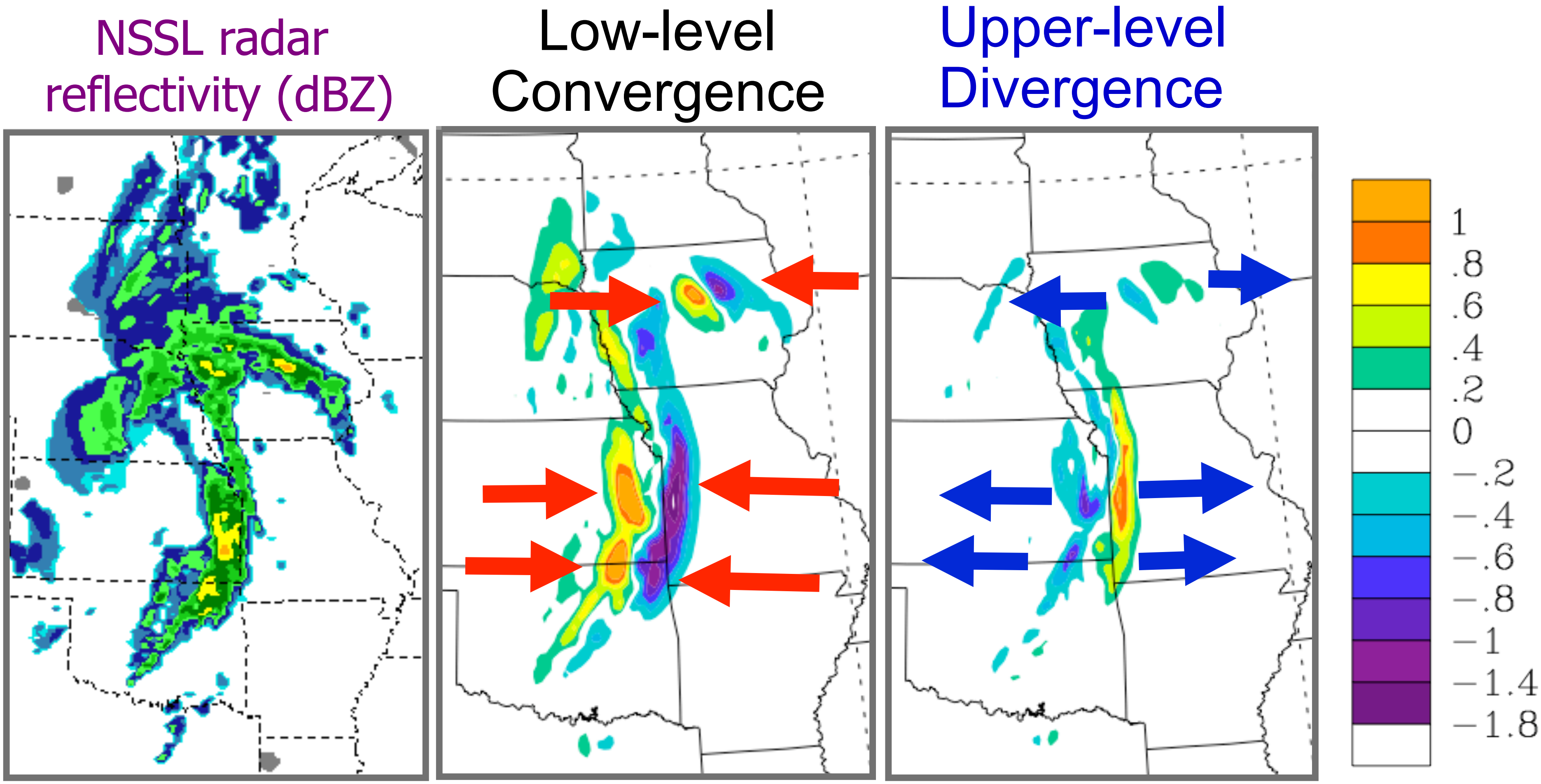
Radar reflectivity assimilation

Digital Filter-based reflectivity assimilation initializes ongoing precipitation regions



+ RUC/RR Convection suppression – ask us about it…

Rapid Refresh (GSI + ARW)
reflectivity assimilation example



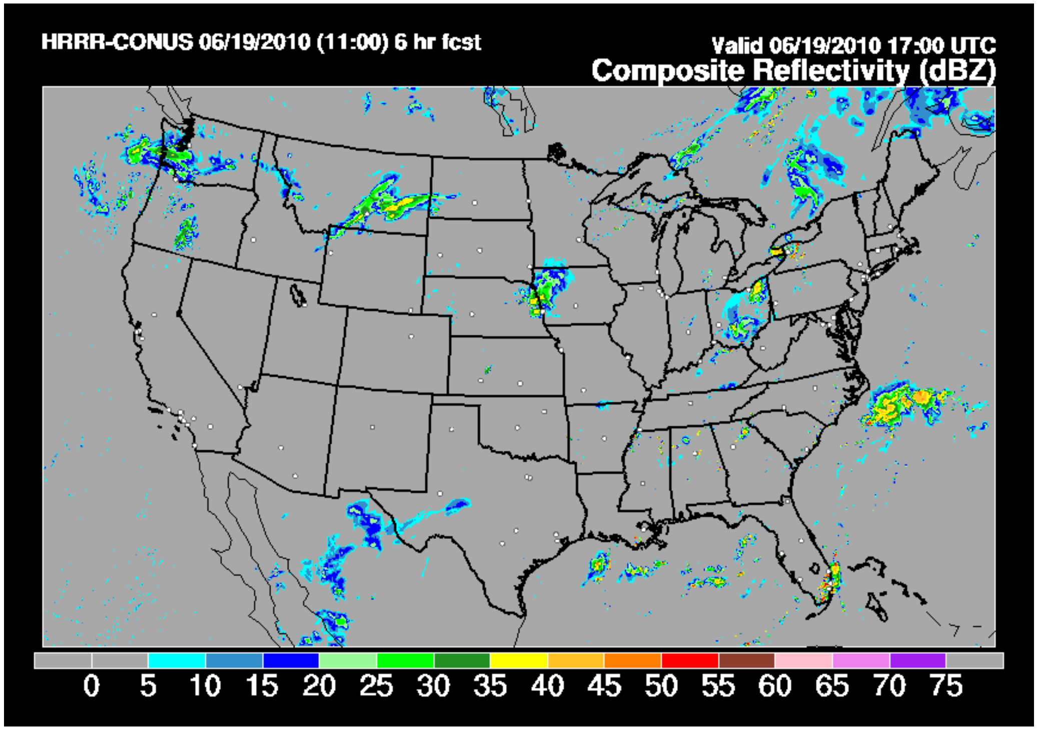
14z 22 Oct 2008
Z = 3 km

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

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

The HRRR

High-Resolution
Rapid Refresh (HRRR)

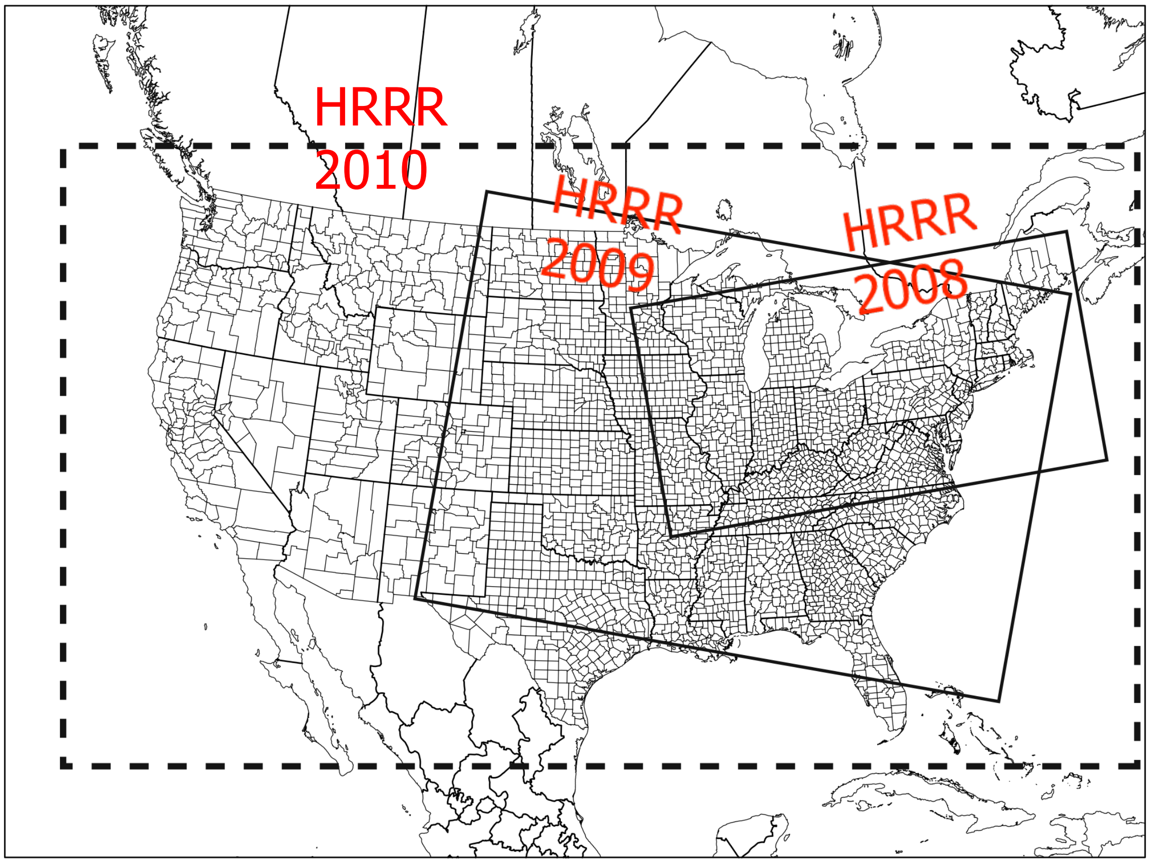


- WRF-ARW dynamic core (same configuration as RR but without convective parameterization)
- Convection resolving using 3.0 km horizontal grid spacing
- Hourly initialization, 0-15 hr forecasts produced (2 hr latency)

- 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)

RUC Domain

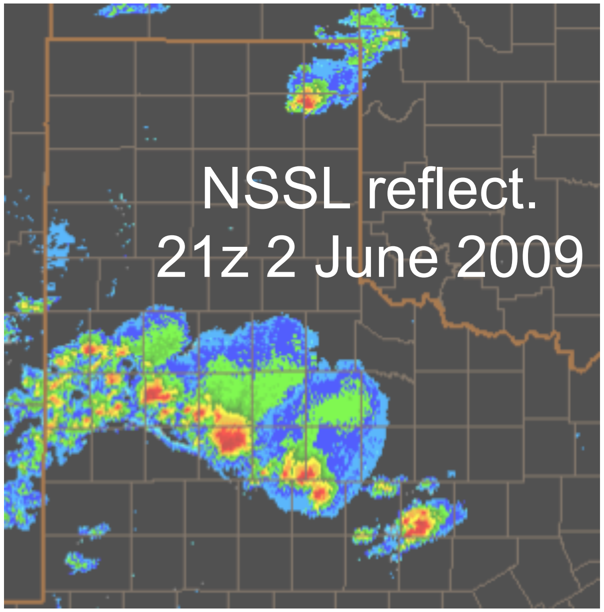


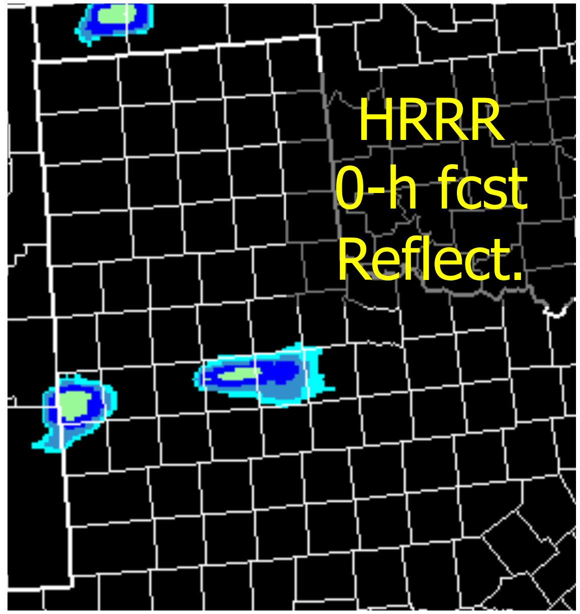
September 2007
Initial HRRR domain over the northeastern United States "aviation corridor"
745 x 383 grid points, 200 processors

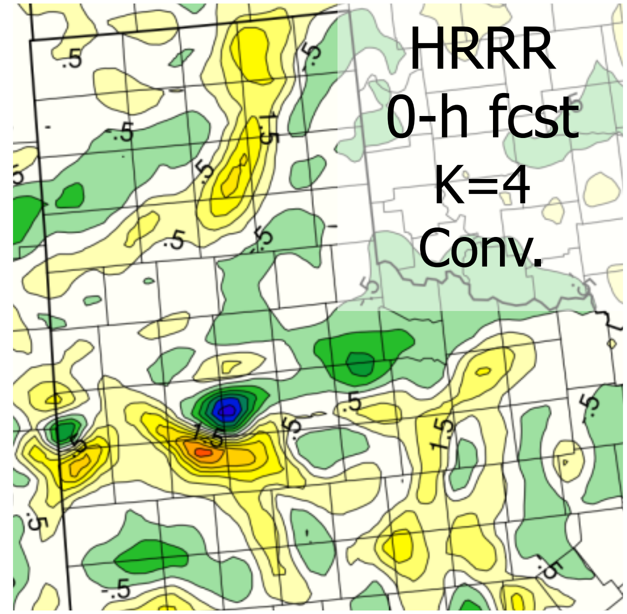
March 2009
Domain expanded to cover approximately eastern 2/3 of the US
1000 x 700 grid points, 568 processors

October 2009
Domain expanded to cover CONUS
1800 x 1060 grid points, 840 processors

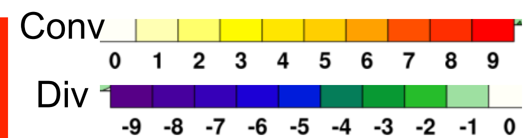
Hourly frequency maintained

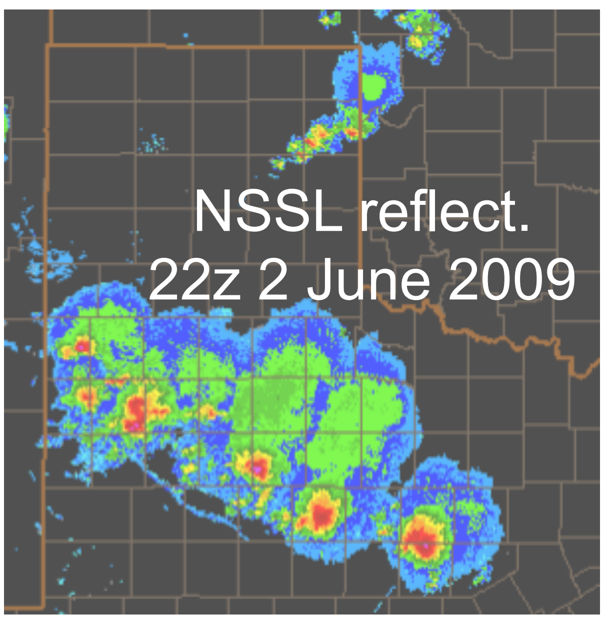


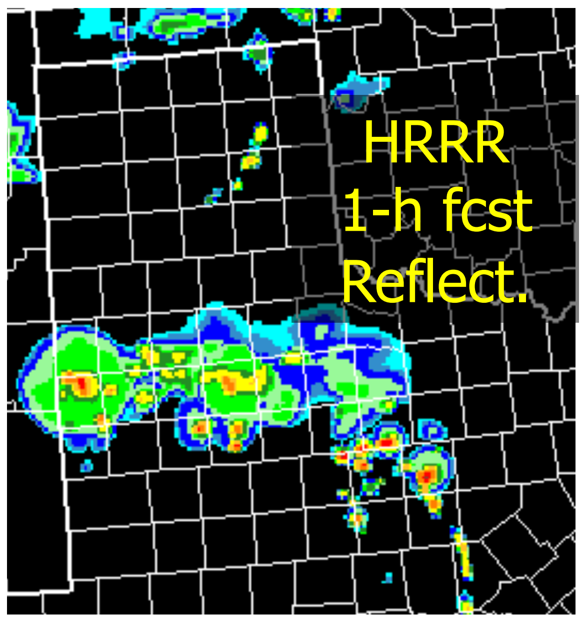


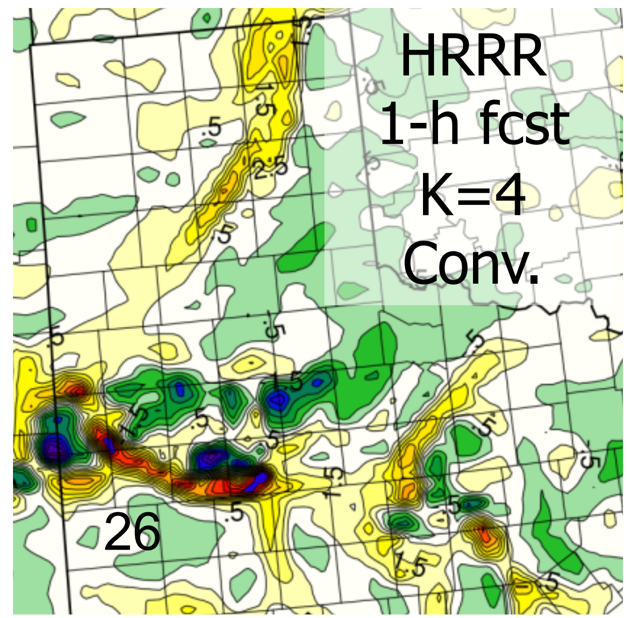


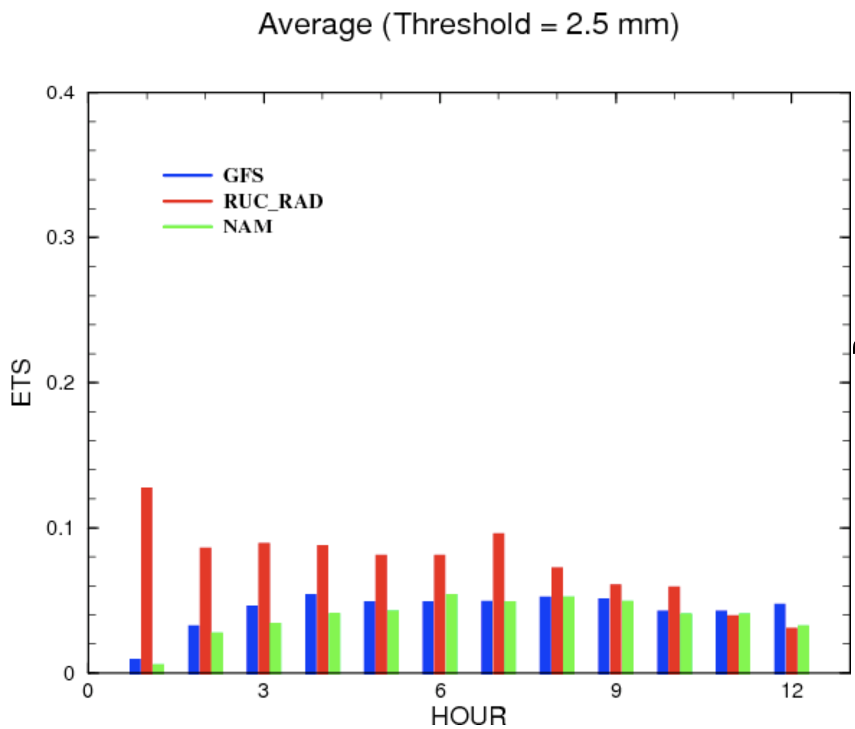
DFI impact on HRRR fields

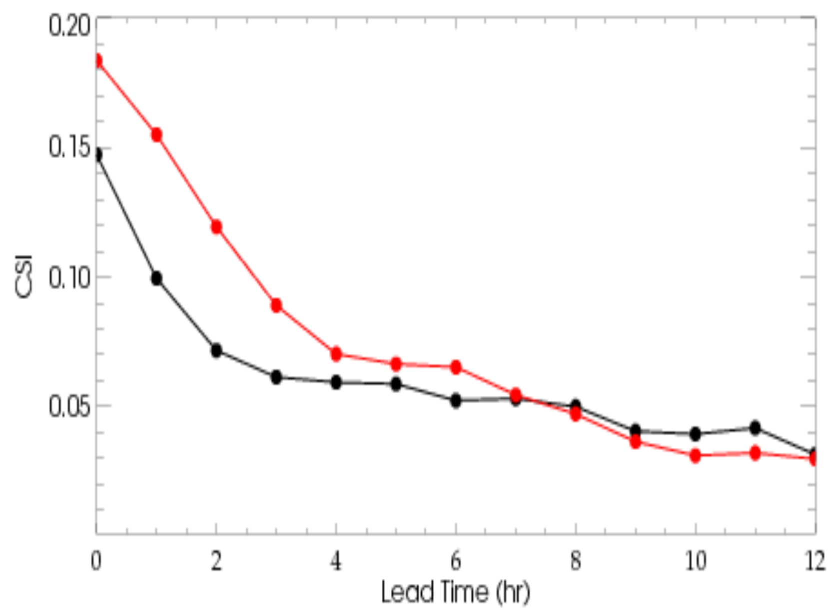












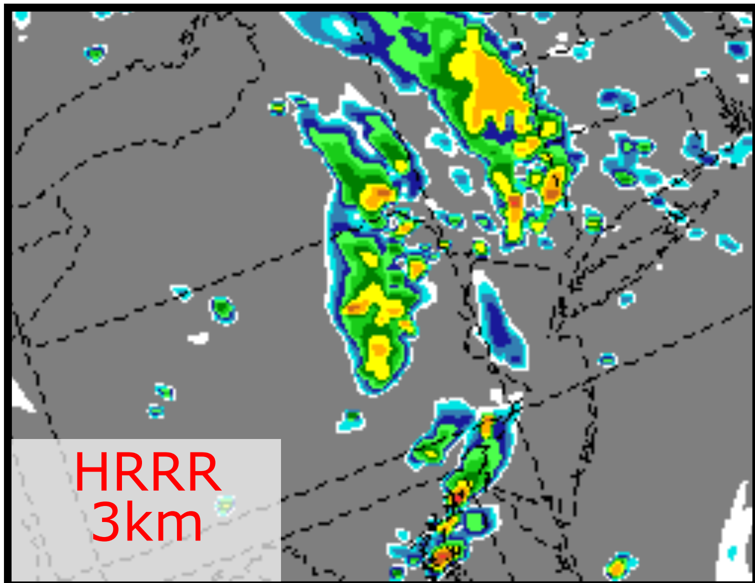
3km HRRR verification
- From NCAR report
- 16 Dec 2009

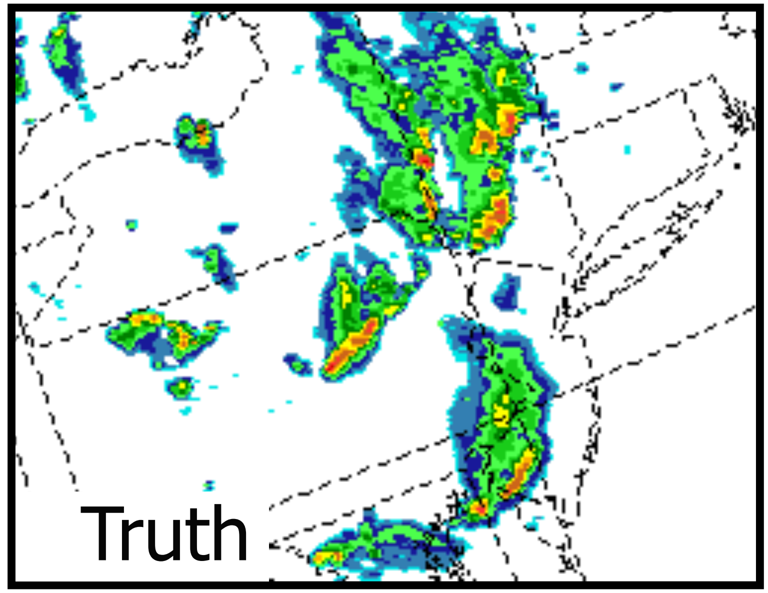
'Model Performance and Sensitivity"
(Mei Xu, David Dowell, Jenny Sun)

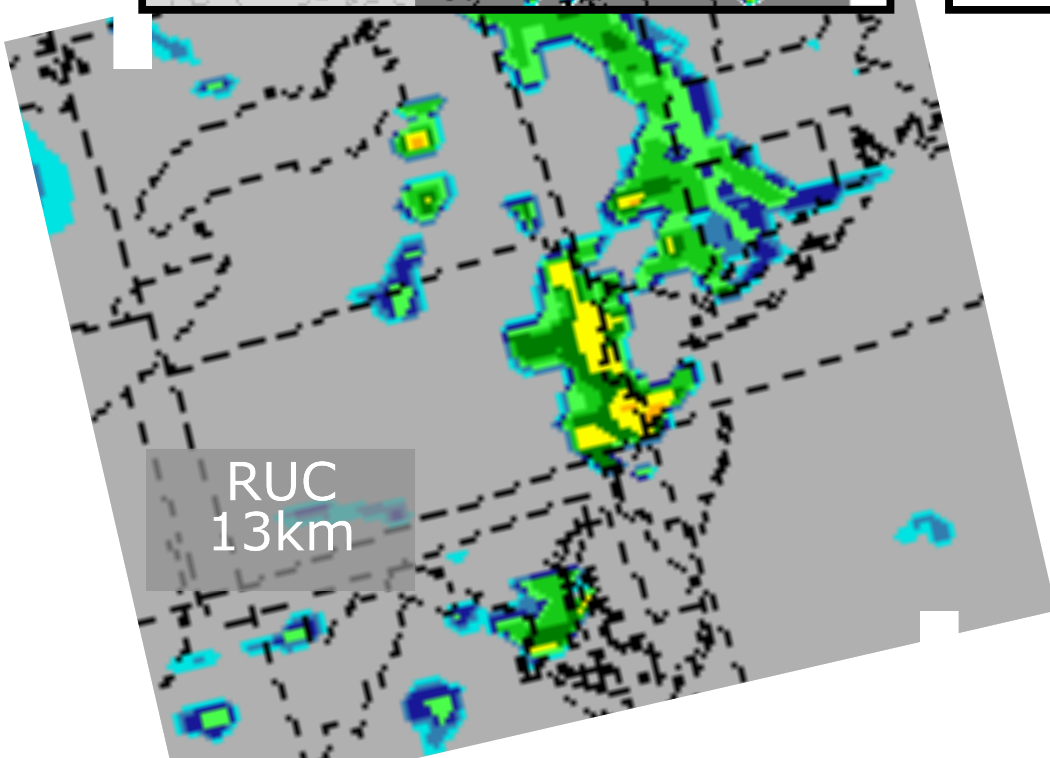
RUC grids provided much improved initial condition for HRRR than NAM or GFS grids, especially in 1-6h

Addition of radar assimilation to RUC convective environment adds further improvement for first ~6h
(representative example from individual case from late July 2009)

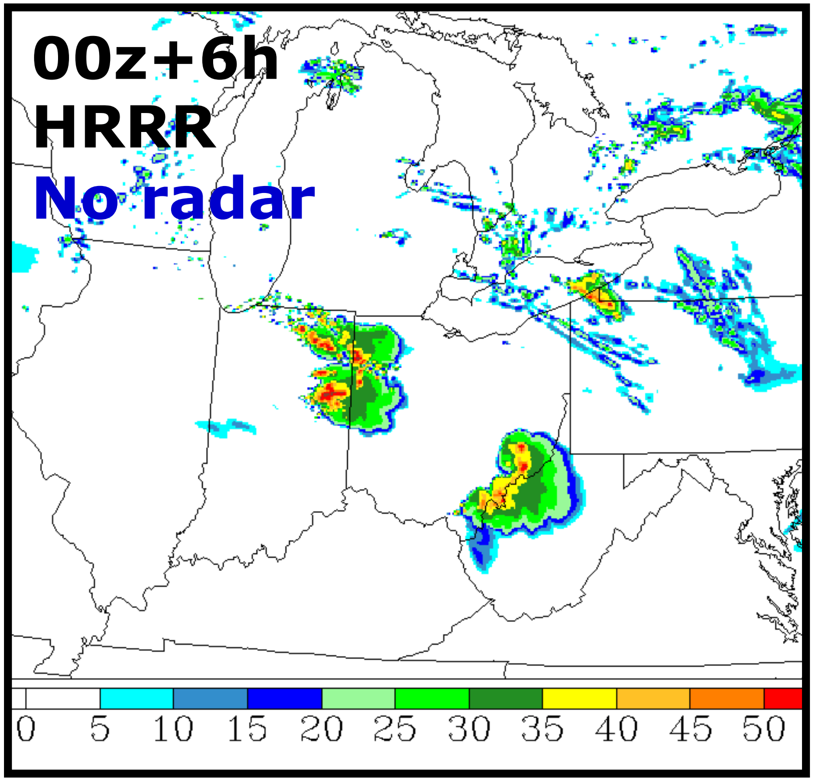
6-h forecasts valid at 8pm EDT 24 July 2008

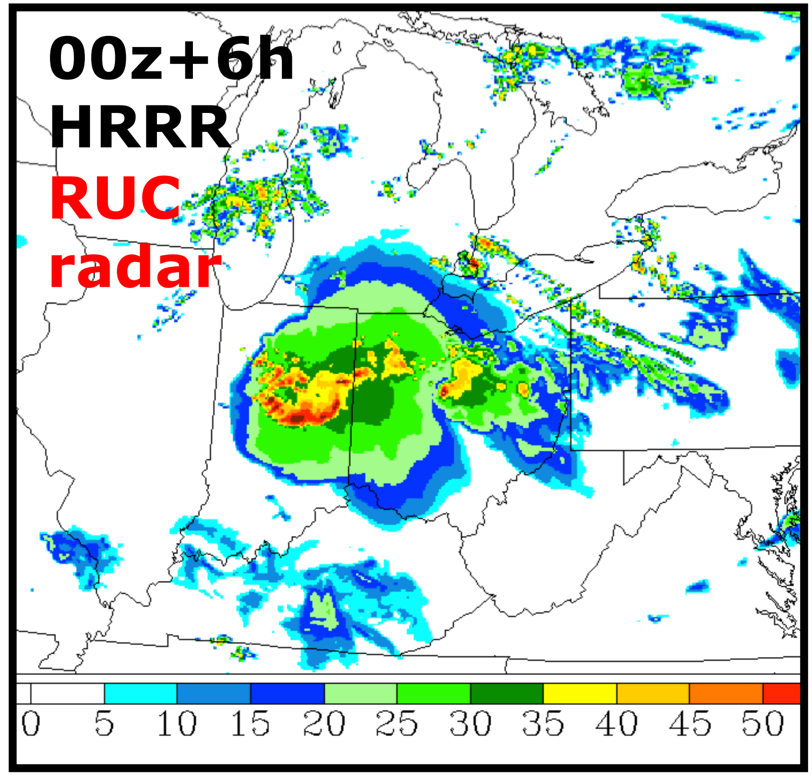




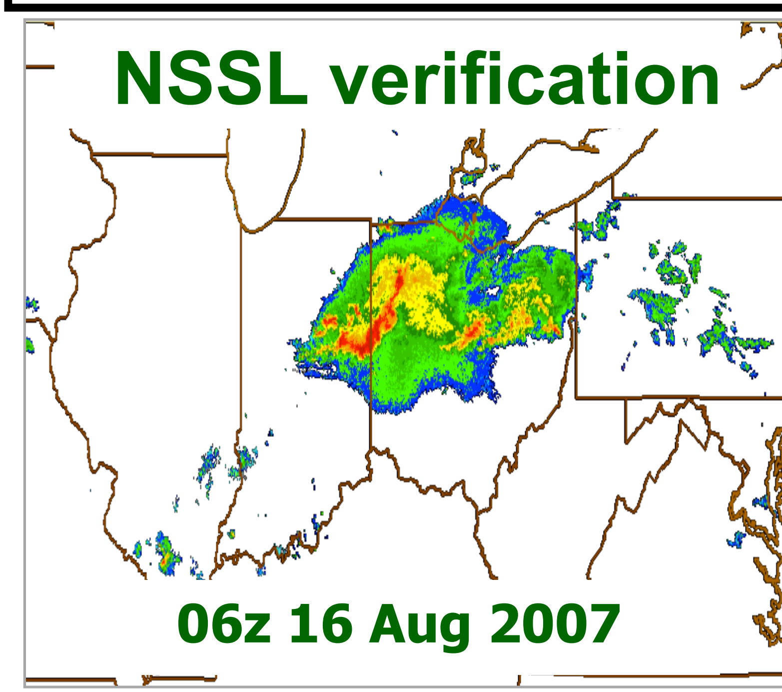


3km HRRR, improved guidance for ATM, terminal over 13km RUC





RUC radar assimilation on 13-km grid improves HRRR 3-km forecast

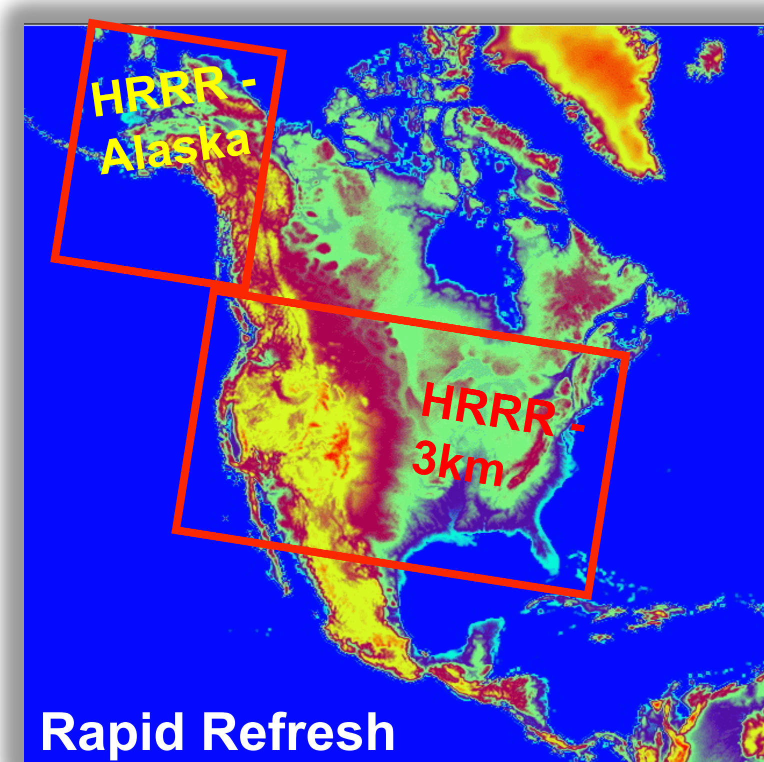


Future plans for ≤1h updated NWP

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
2013-15 – 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

Dezső Dévényi, 1948-2009

- Best assimilation scientist in RUC / Rapid Refresh group
- Ph.D. from Eötvös Loránd University in Budapest
- Formerly with Hungarian Met Service (even Vice President (Deputy Director))
- Taught NWP in Hungary, called the “father of NWP in Hungary” by former students
- Spent a year with Lev Gandin in 1975
- Developed the RUC 3dVAR
- Co-led development of Rapid Refresh version of GSI with Ming Hu and others