RUC/Rapid Refresh Technical Review

NOAA/ESRL/GSD/AMB

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Tracy Lorraine Smith

NCEP/EMC – Geoff Manikin

Major transitions:

- RUC13 change package – ~Feb 2008
  – radar reflectivity assimilation, TAMDAR, mesonet, RUC/WRF physics
- Rapid Refresh - planned for ~4Q 2009

Fresh, tasty results on RUC, observation impact studies, Rapid Refresh, GSI, HRRR + plans

http://ruc.noaa.gov

Tues 30 Oct 2007

Earth System Research Laboratory
SCIENCE, SERVICE & STEWARDSHIP

RUC/Rapid Refresh Technical Review - OUTLINE

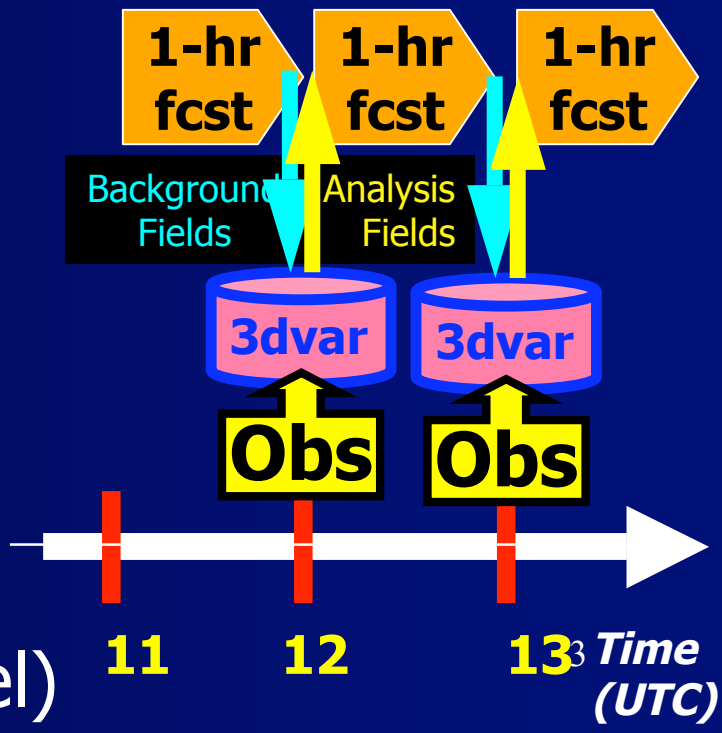
1:30 - 1:50	RUC upgrade - assimilation - radar reflectivity, mesonet/RTMA, physics - Stan Benjamin
1:50 - 2:15	Observation assessment activities - TAMDAR aircraft obs w/ moisture, larger obs sensitivity experiment (OSE) - Bill Moninger, Brian Jamison
2:15 - 2:25	Rapid Refresh background - core, NCEP - Stan
2:25 - 2:35	-- Break --
2:35 - 2:50	Rapid Refresh model description testing - ARW core, physics, DFI - John Brown
2:50 - 3:15	RR assimilation w/ GSI, Details on RUC/RR/HRRR convection Steve Weygandt
3:15 - 3:25	Future of Rapid Refresh Stan Benjamin

RUC Purpose

"Situational Awareness Model"

- Provide high-frequency mesoscale analyses and short-range (1-12h) numerical forecasts for users including:
  - aviation
  - severe weather forecasting
  - general public forecasting

RUC - one of 2 NCEP operational forecast models developed outside of NCEP
(other – GFDL hurricane model)



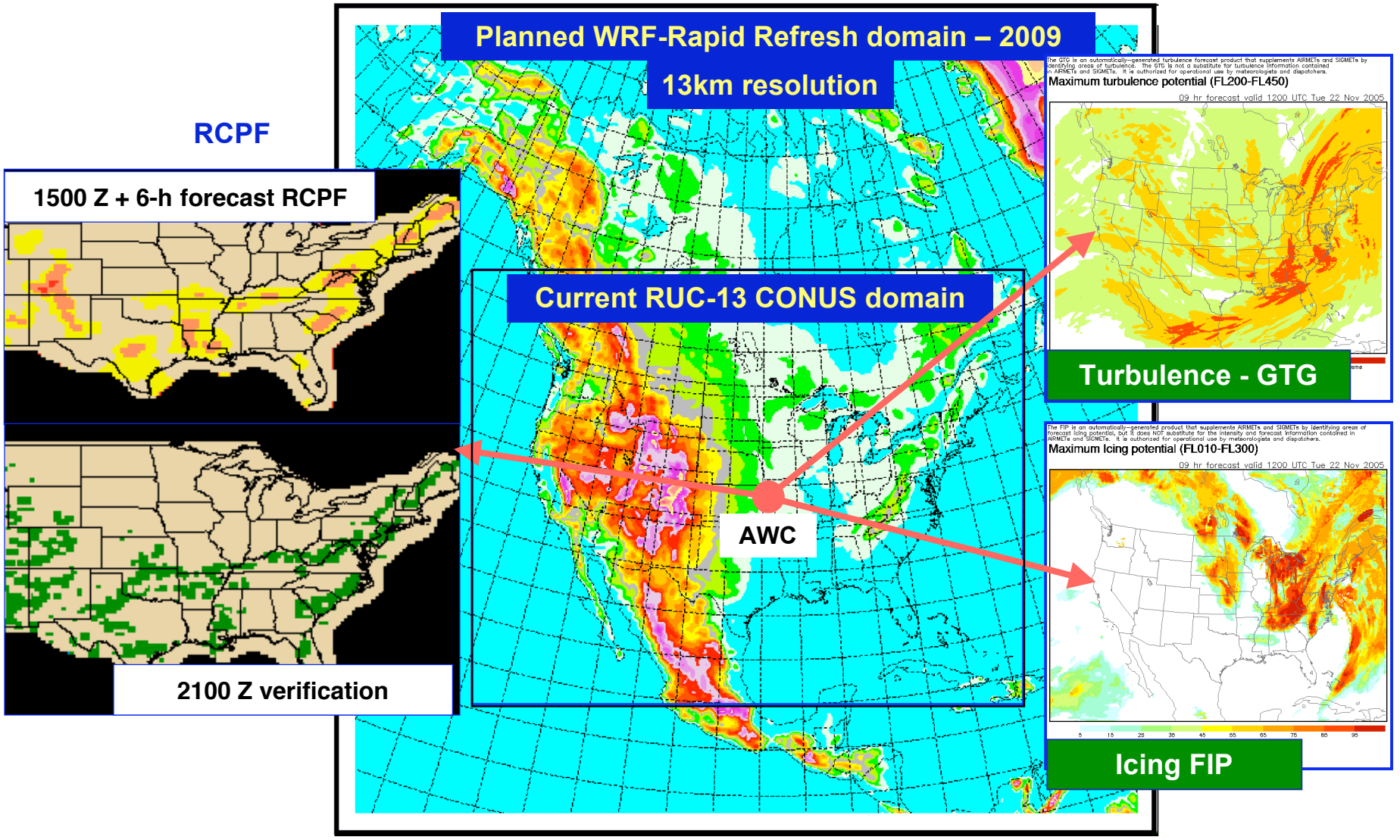
Some places where the RUC is used

- NCEP Aviation Weather Center - airmets, sigmets
- NCEP Storm Prediction Center - severe weather watches
- Federal Aviation Administration (FAA) – CWSUs, WARP, air traffic management, free-flight (URET), ITWS..
- Airline flight dispatchers
- NWS Forecast Offices, NWS RTMA
- NASA Space Flight Centers
- NWS Operational Hydro Remote Sensing Center – US snow cover
- NSSL QPE project - snow level
- Initialization for WRF (e.g., WSI 5km RPM for television customers)
- Private vendors – forecasting (WSI, Weather Channel, …)
- Initialization for WRF-chem, dispersion models …

- Other Aviation Weather Research teams – icing, turbulence, ADDS/RTVS, convective weather, winter weather
- Private users through web sites, especially pilots (general aviation, soaring, balloons), sailors, windsurfers, etc.

RUC/RR - backbone for high-frequency aviation products

Icing Potential (FIP), Graphical Turbulence Guidance (GTG), National Convective Weather Forecast (NCWF), and other aviation weather products



NOAA/ESRL/GSD, NCEP, NCAR, U. Okla, others

RUC History – NCEP operational implementations

1994 - First operational implementation of RUC
- 60km resolution, 3-h cycle

1998 – 40km resolution, 1-h cycle,
- cloud physics, land-sfc model

2002 – 20km resolution
- addition of GOES cloud data in assimilation

2005 – 13km resolution, new obs (METAR clouds, GPS moisture), new model physics

2008 – Assimilation of radar reflectivity/TAMDAR, improved thunderstorm forecasting

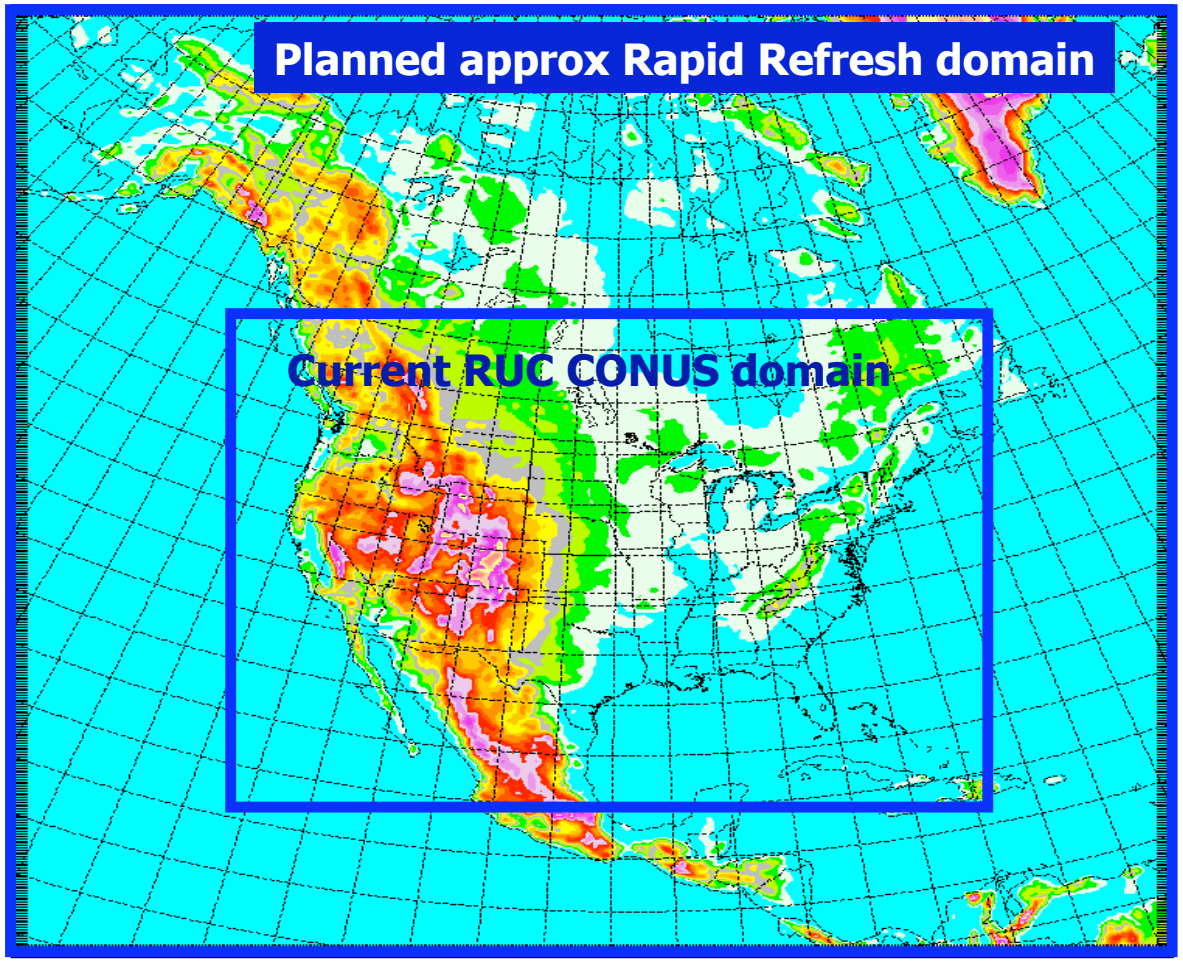
2009 – WRF-based Rapid Refresh to replace RUC

NOAA/GSD testing – precedes NCEP ops by 0.5-3 years

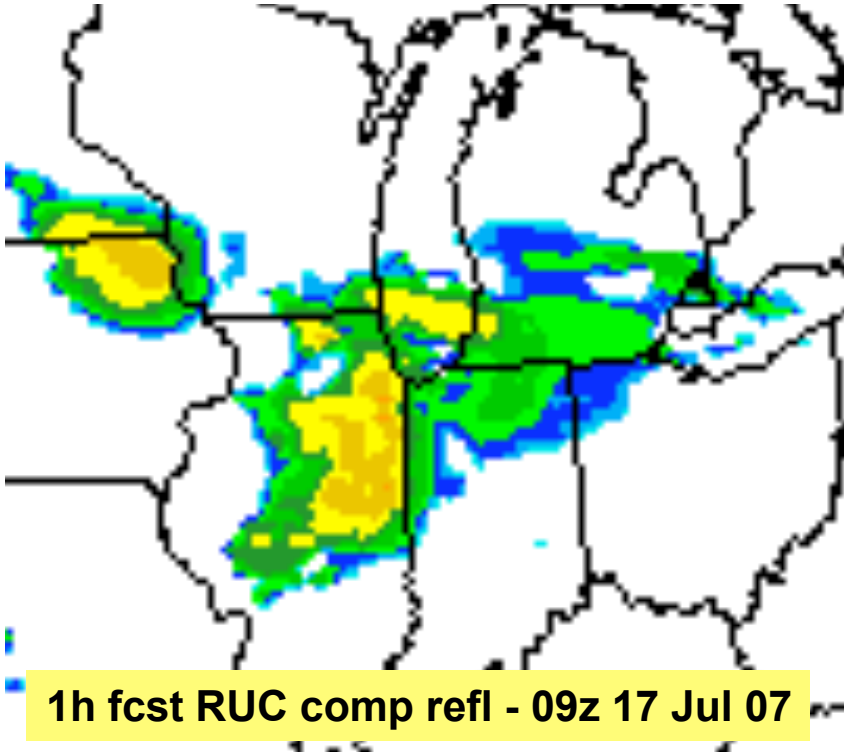
RUC ⇩ Rapid Refresh (2009)

NWP updated hourly w/ latest obs
- Aviation / transportation
- Severe weather
- Decision support tools

Hourly NWP Update for:
- CONUS
- AK/Can
- Pac/Atl
- Caribbean



RUC Upgrade at NCEP - Jan-Apr 08



1h fcst RUC comp refl - 09z 17 Jul 07

RUC 13 change package

- Components
  - Assimilation of new obs - radar reflectivity, TAMDAR wind/temp/RH, mesonet winds
  - Improved surface, precip, reflectivity forecasts
- Status
  - in real-time parallel testing at NCEP (since Aug 2007)
  - Real-time and retrospective tests by 2Q FY08.
  - Implementation by 3Q FY08.

NCEP RUC parallel web site:
http://www.emc.ncep.noaa.gov/mmb/ruc2/para
Comparisons between para and oper RUC

Early 2008 Changes for oper RUC upgrade

- Assimilation additions
  - Use of **radar reflectivity** in RUC diabatic digital filter initialization in RUC model, big plus in short-range precip
  - **Mesonet winds** via mesonet station uselist
  - **TAMDAR aircraft** observations

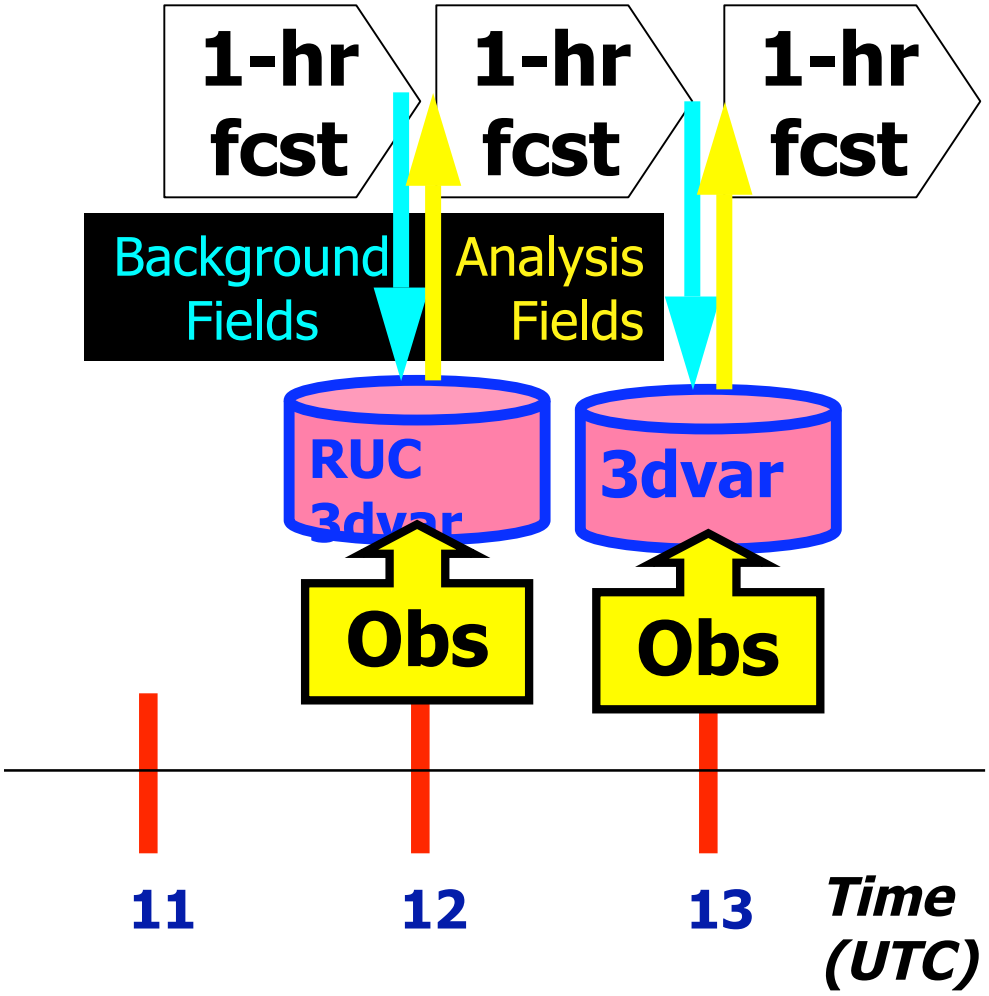
- Model physics
  - RRTM longwave radiation - eliminates sfc warm bias
  - Mod to Grell-Devenyi – decrease areal coverage, non-local subsidence warming - further improvement

  - Improved ceiling/visibility, sfc winds, precip
- Post-processing – add reflectivity fields, improved RTMA downscaling

RUC parallel web site:
http://www.emc.ncep.noaa.gov/mmb/ruc2/para

RUC Hourly Assimilation Cycle

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



Hourly obs in 2008 RUC

Data Type	~Number
Rawinsonde (12h)	80
NOAA profilers	30
VAD winds	110-130
PBL – prof/RASS	~25
Aircraft (V,temp)	1400-7000
→ **TAMDAR (V,T,RH)**	0 - 800
Surface/METAR	1800-2000
Buoy/ship	100- 200
GOES cloud winds	1000-2500
GOES cloud-top pres	10 km res
GPS precip water	~300
Mesonet (temp, dpt)	~7000
→ **Mesonet (wind)**	2000-4000
METAR-cloud-vis-wx	~1600
→ **Radar reflectivity**	2km

New for NCEP upgrade

RRTM Longwave Radiation in RUC Upgrade
Effect on 2-m temperature forecasts

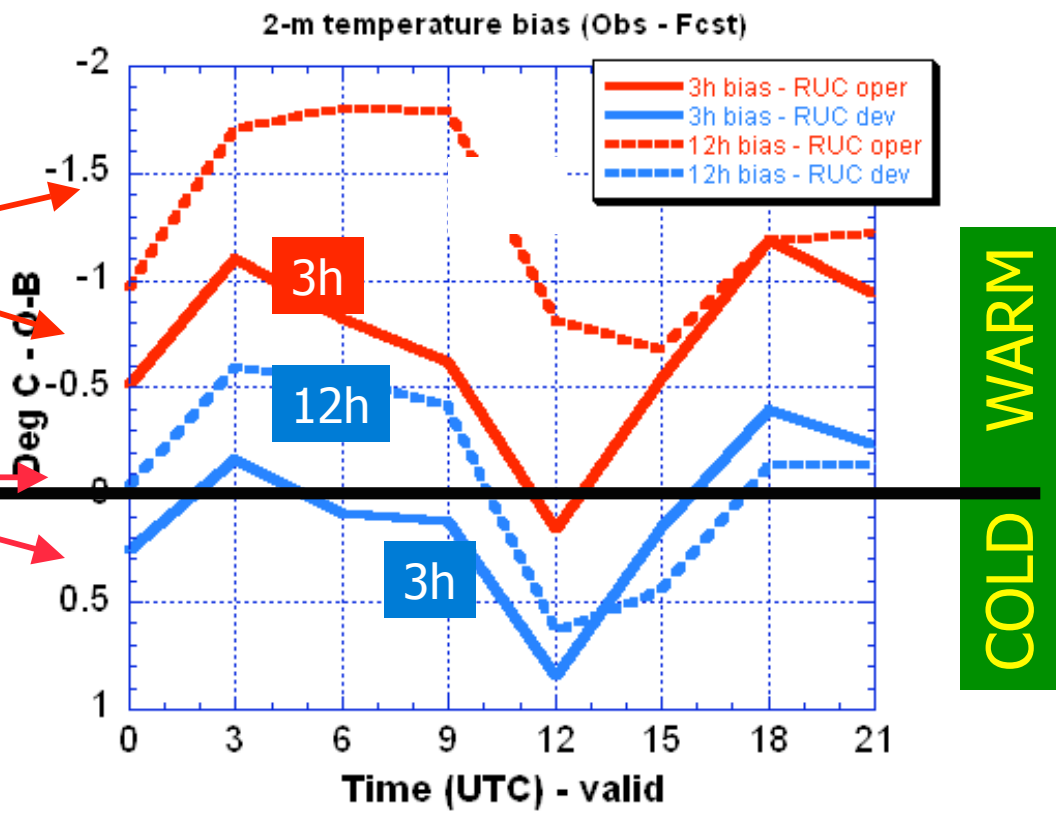
- Much decreased warm bias near surface

1-month comparison
14 May –13 June 07
Eastern US only

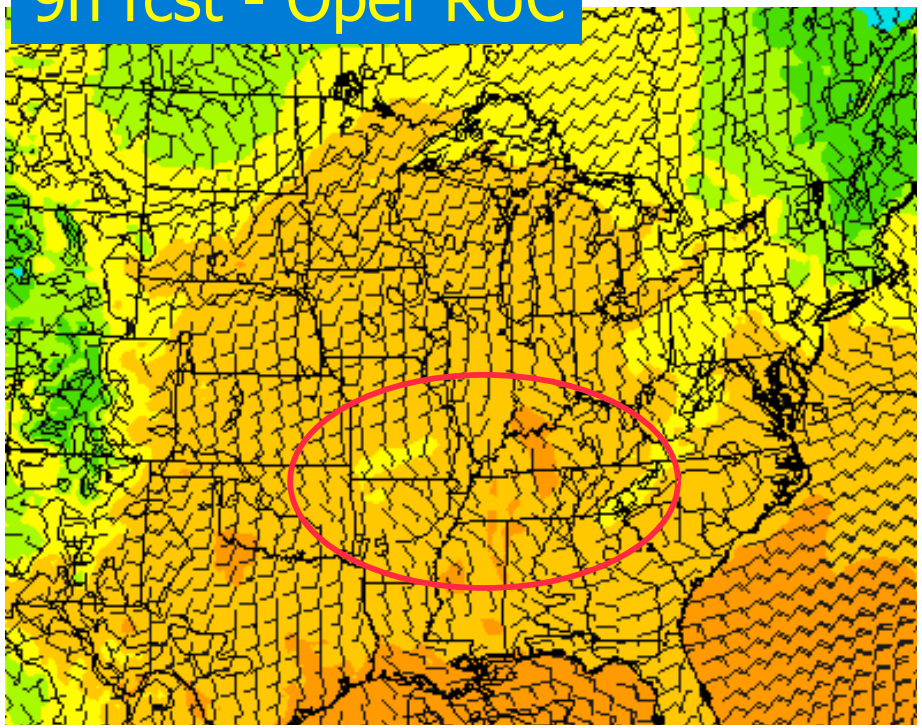
RUC oper – Dudhia LW

RUC para – RRTM LW

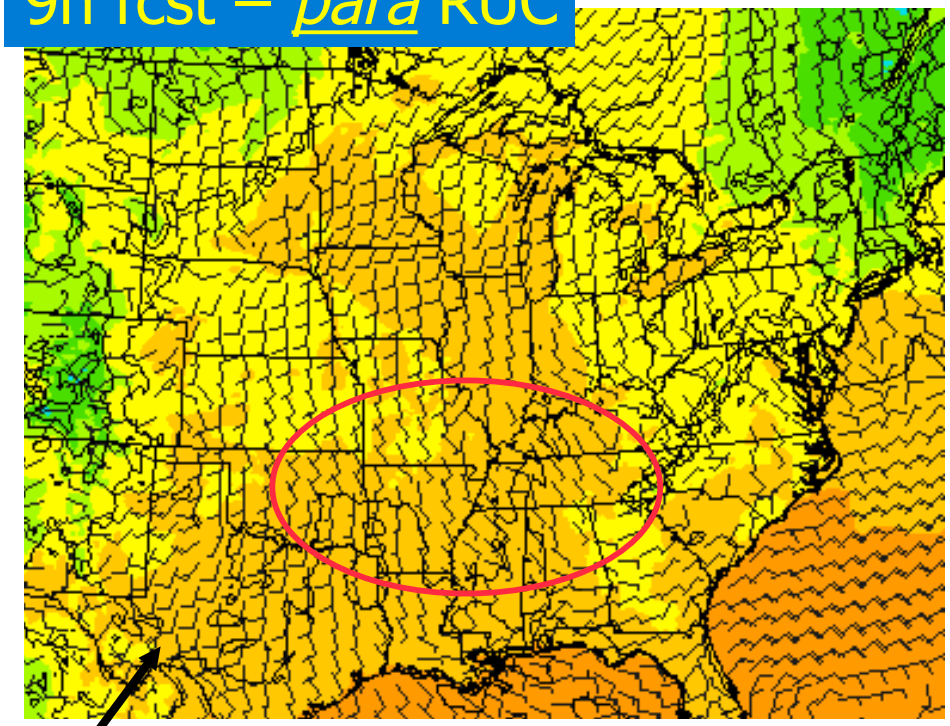
2-m temp bias (obs – forecast)



9h fcst - Oper RUC



9h fcst – *para* RUC

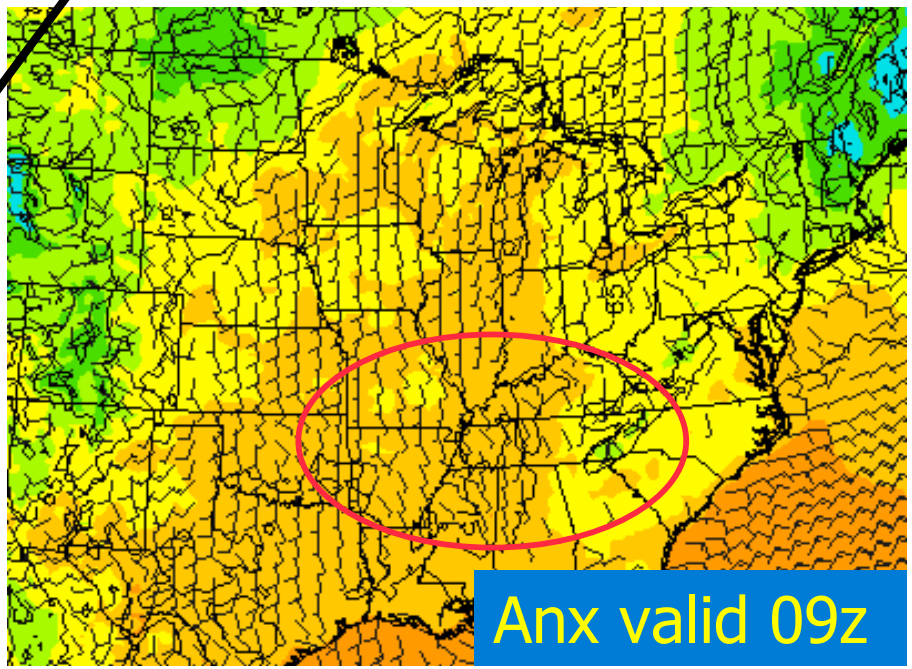


Surface Temperature / Winds (°F / Kn

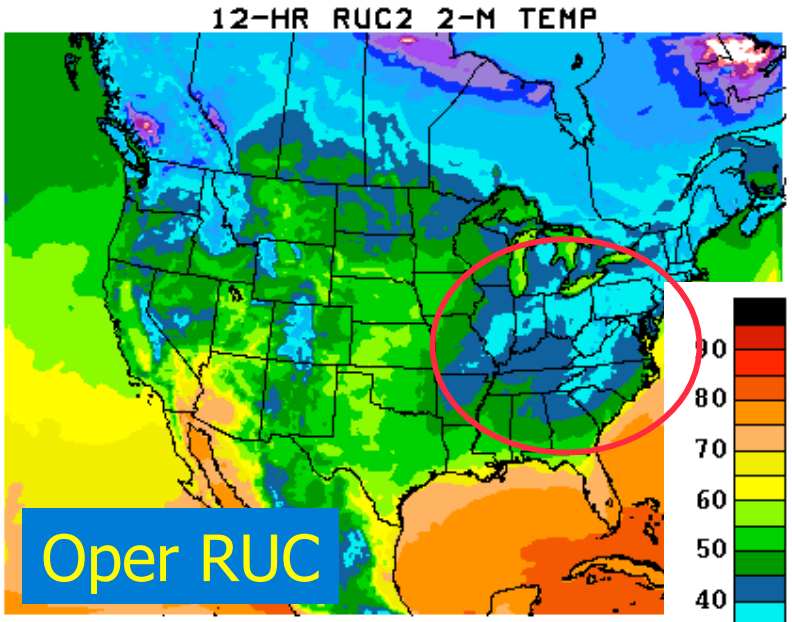
9–hr fcst valid 06–Sep–07 09:00Z

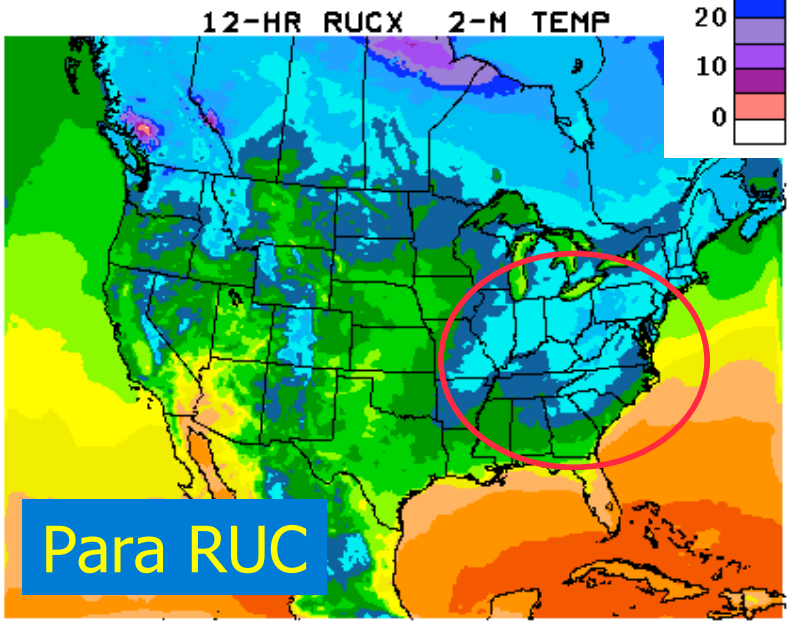
6 Sept 2007

Better 2m temp forecast
From para RUC w/ RRTM LW

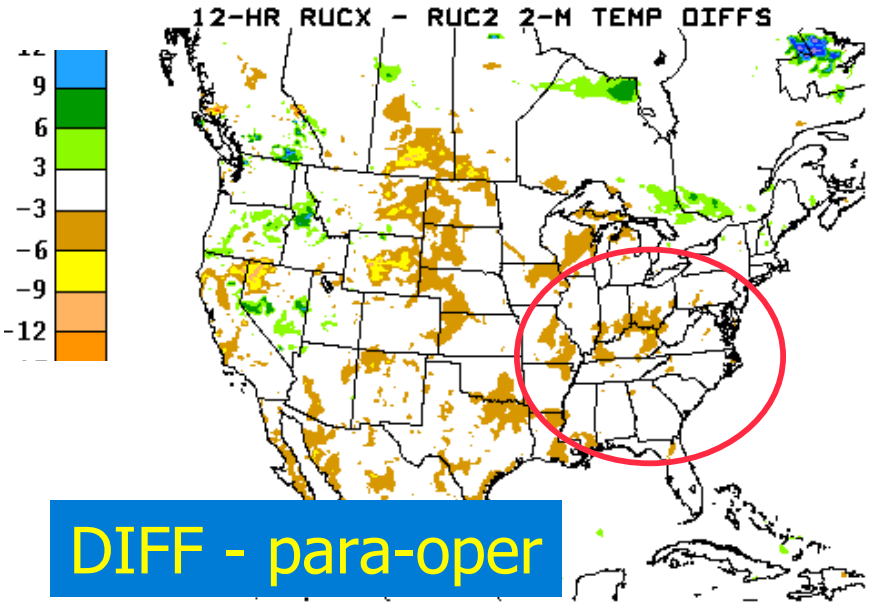


Anx valid 09z

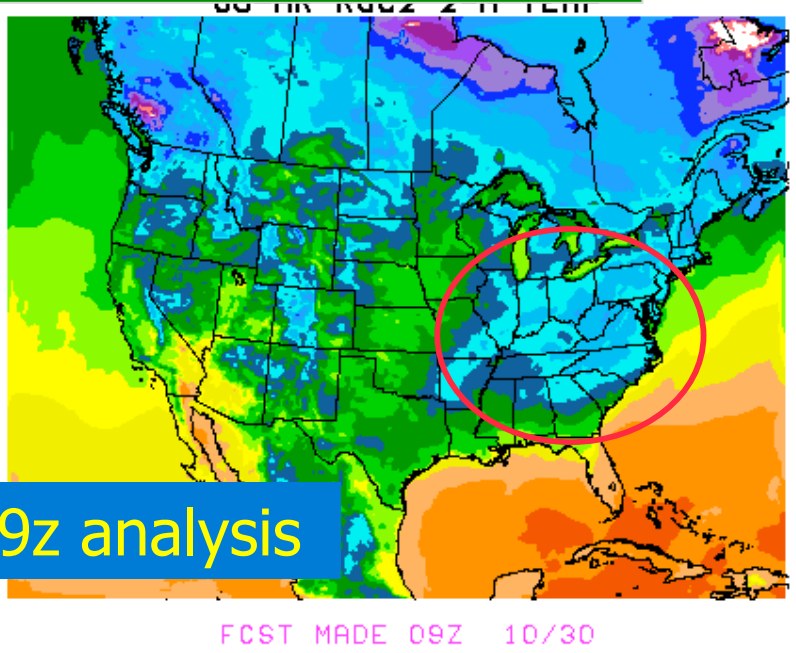




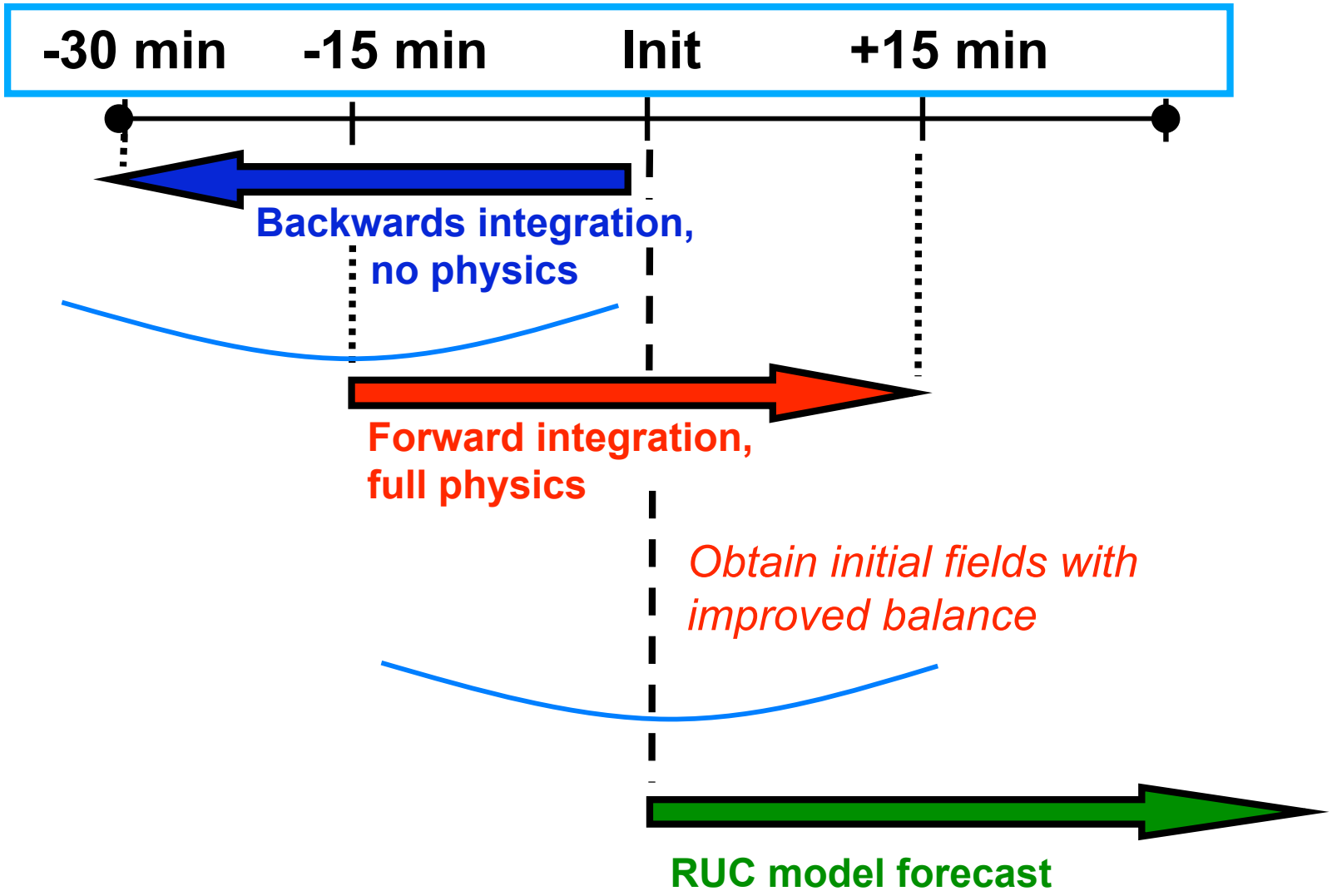
12h fcst – valid 09z 30 Oct



Better 2m temp forecast
From para RUC w/ RRTM LW



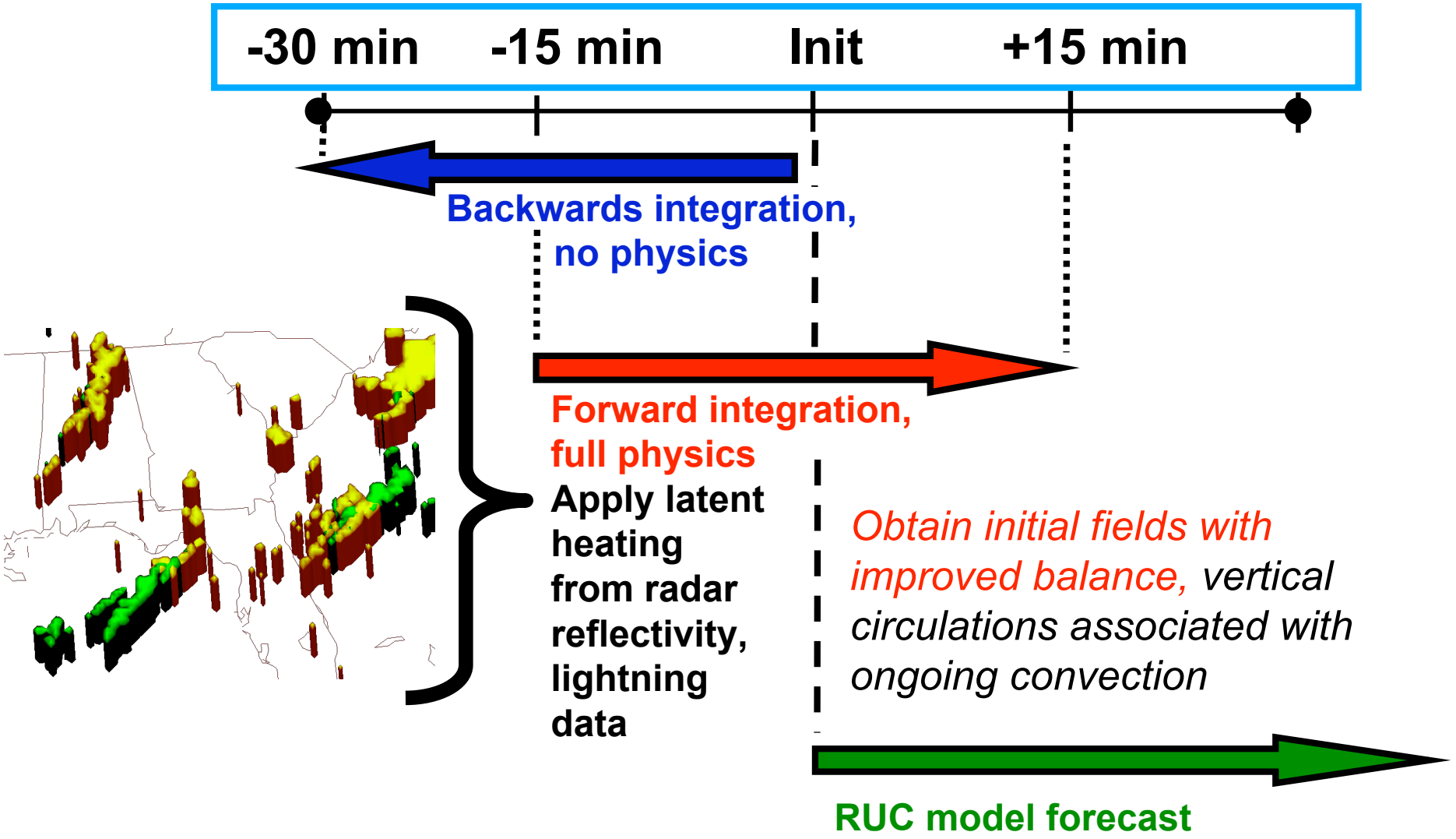
RUC Diabatic Digital Filter Initialization (DDFI)



Radar reflectivity assimilation in RUC/RR

Diabatic Digital Filter Initialization (DDFI)

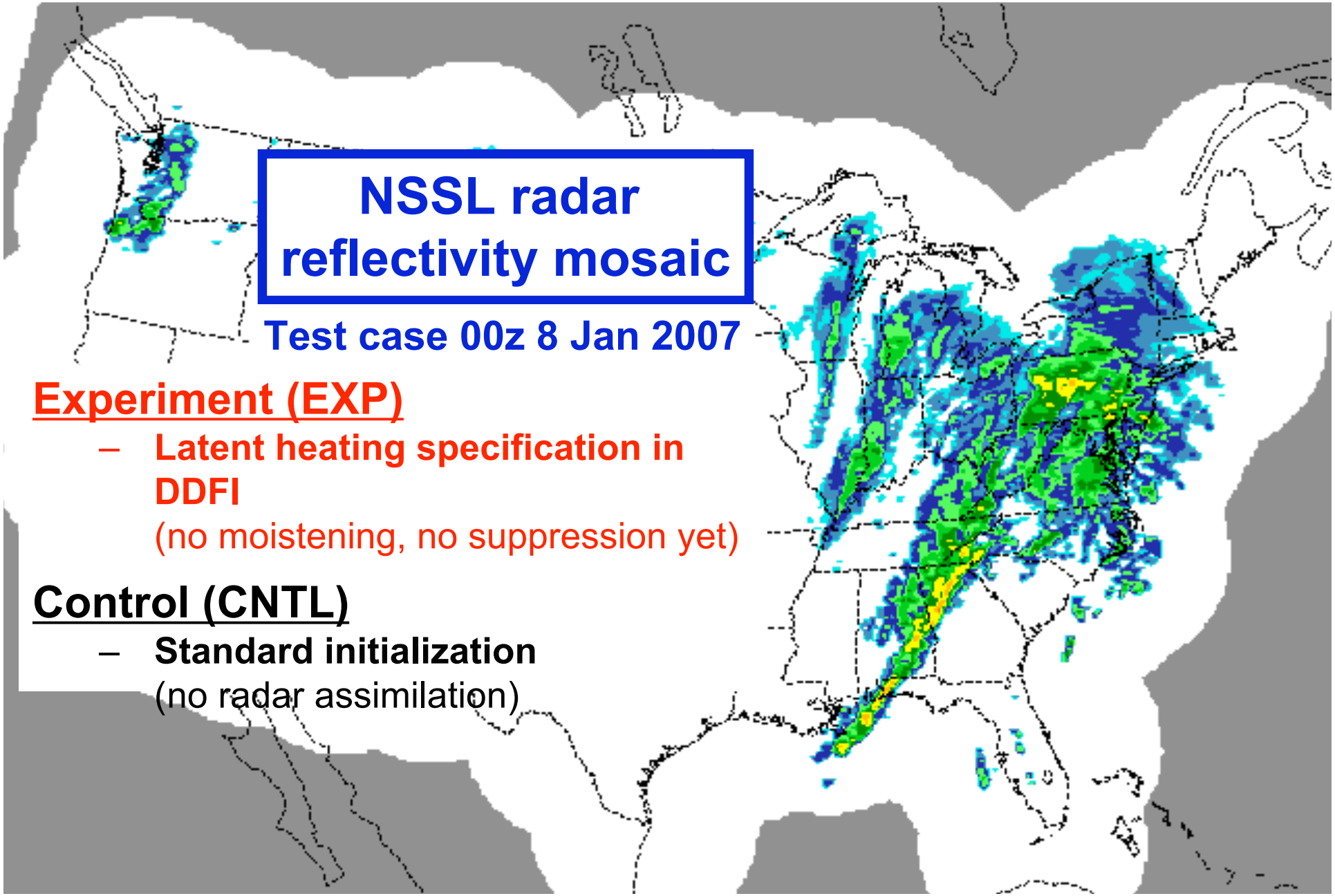
New - add assimilation of radar data



Advantages of radar assimilation procedure

1. **Minimal shock to model**
   - Coherent wind, temperature and moisture fields evolve in response to heating within DDFI
2. **Very little additional computer cost**
   - DDFI already used to control noise
3. **Independent of model or physics packages**
   - Is being added to WRF (for Rapid Refresh)

RUC radar assimilation test case



Experiment (EXP)

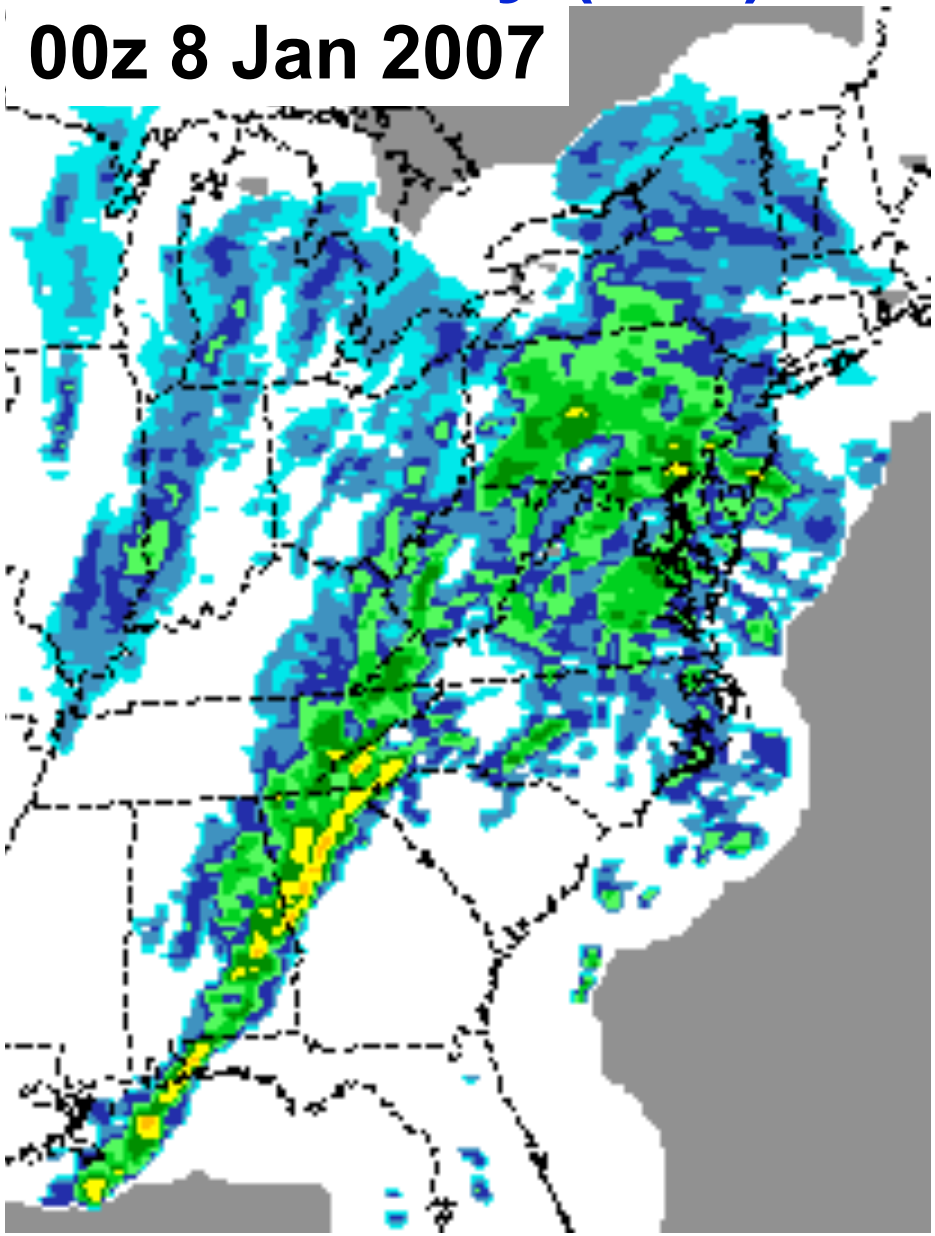
- **Latent heating specification in DDFI**
  (no moistening, no suppression yet)

Control (CNTL)

- **Standard initialization**
  (no radar assimilation)

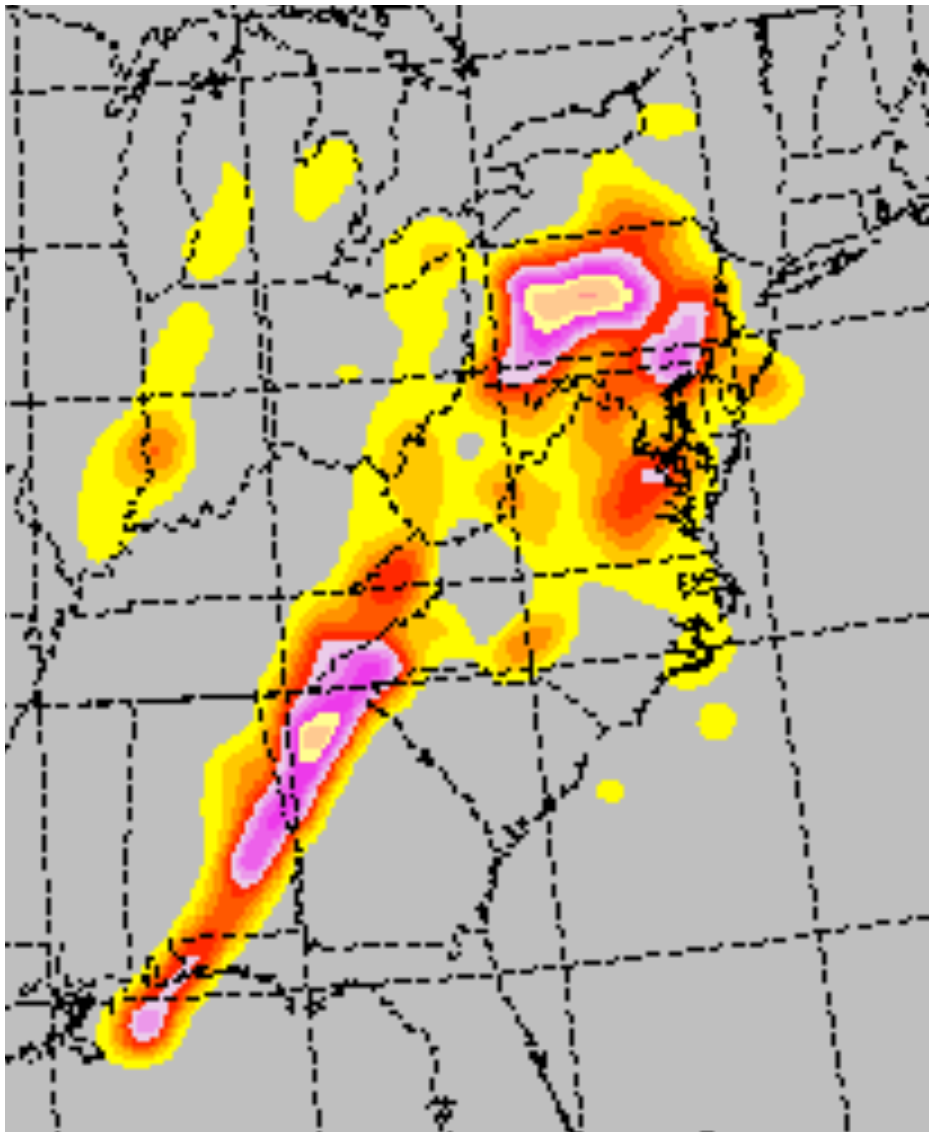
NSSL 3-km radar reflectivity (dbz)

00z 8 Jan 2007



K=15 LH temp. tend. (K / 15 min)

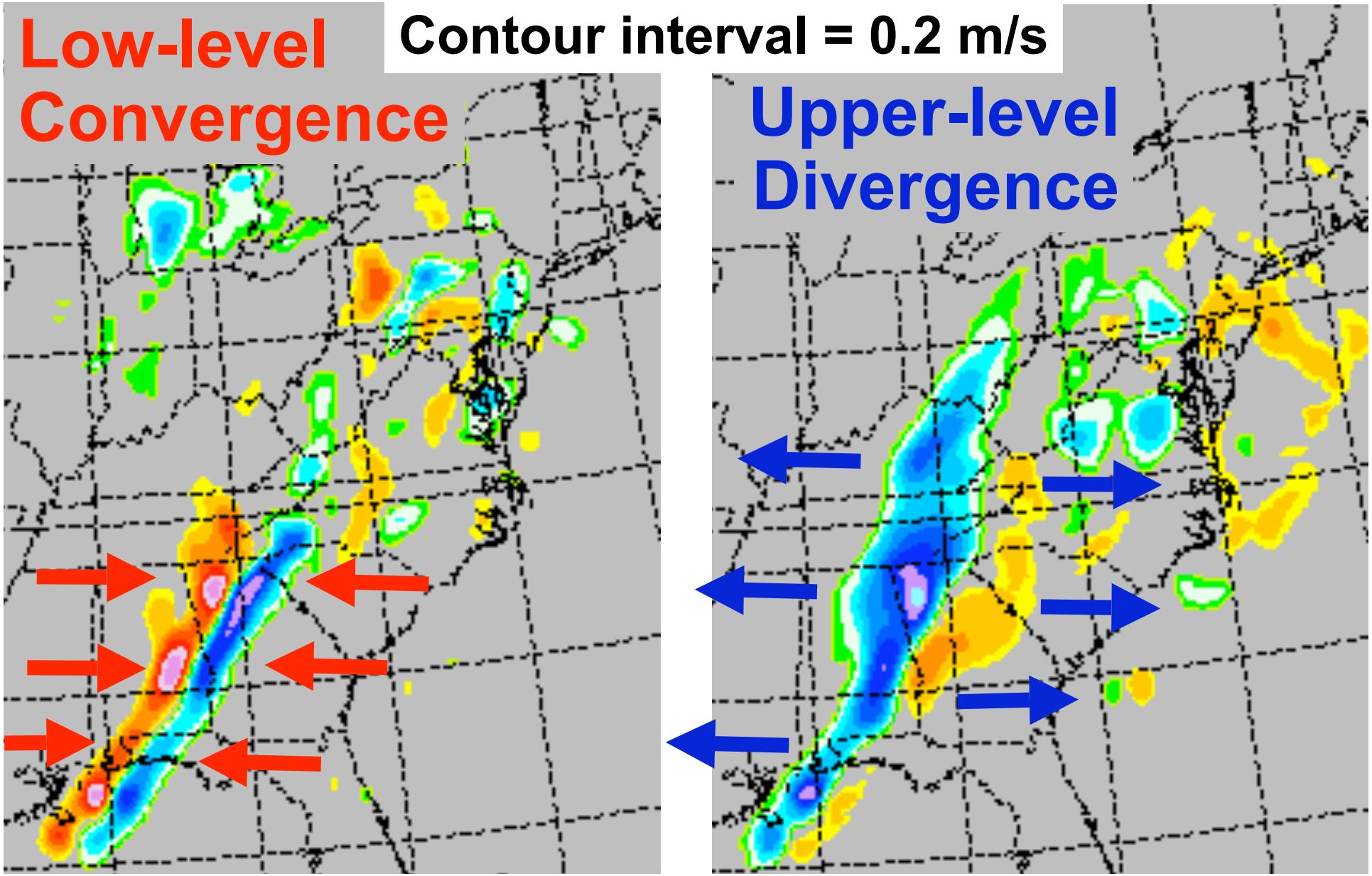
Contour interval = 0.5 K

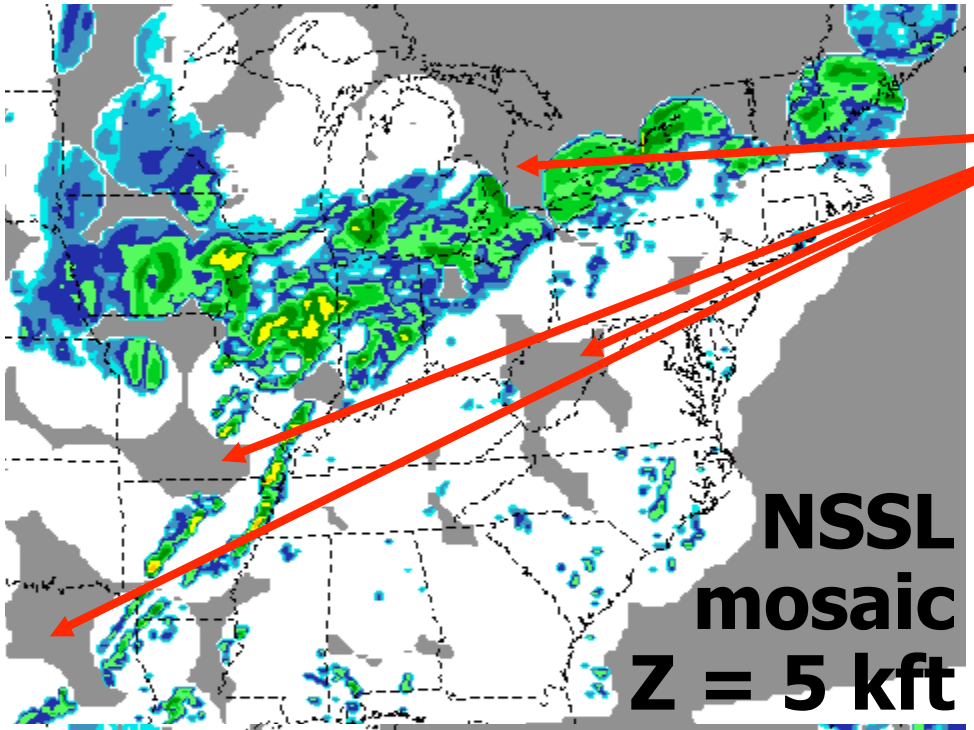


K=15 U-comp. diff (EXP - CNTL)

K=35 U-comp. diff (EXP - CNTL)

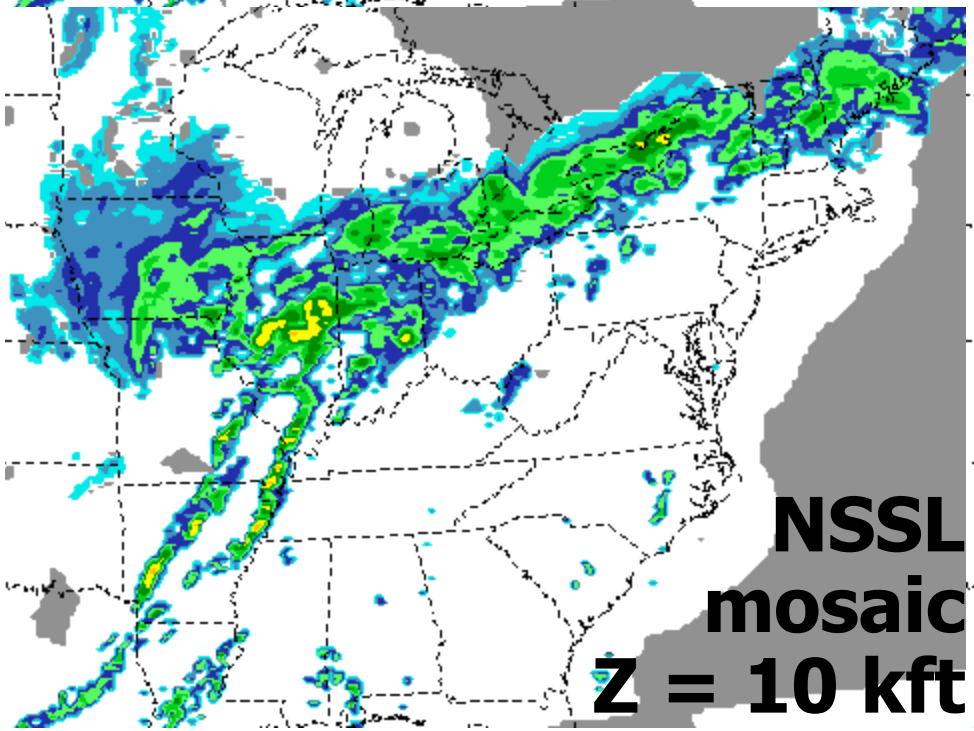
Contour interval = 0.2 m/s



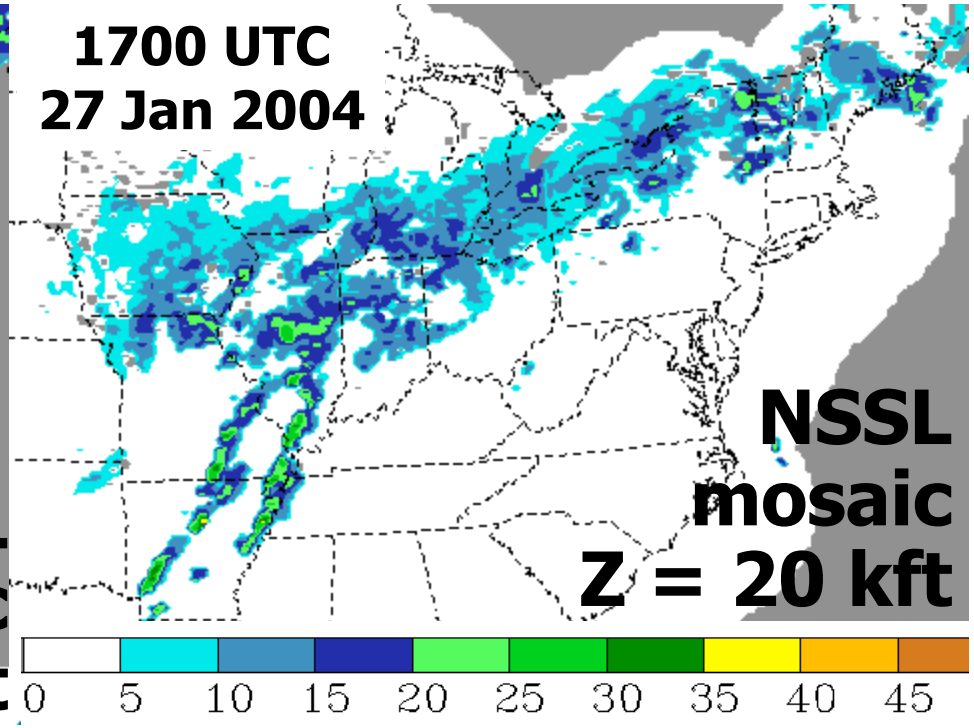


Data gap regions
complement volumes of radar coverage

Latent heating in diabatic forward DFI step specified *only* where 3-d radar data available

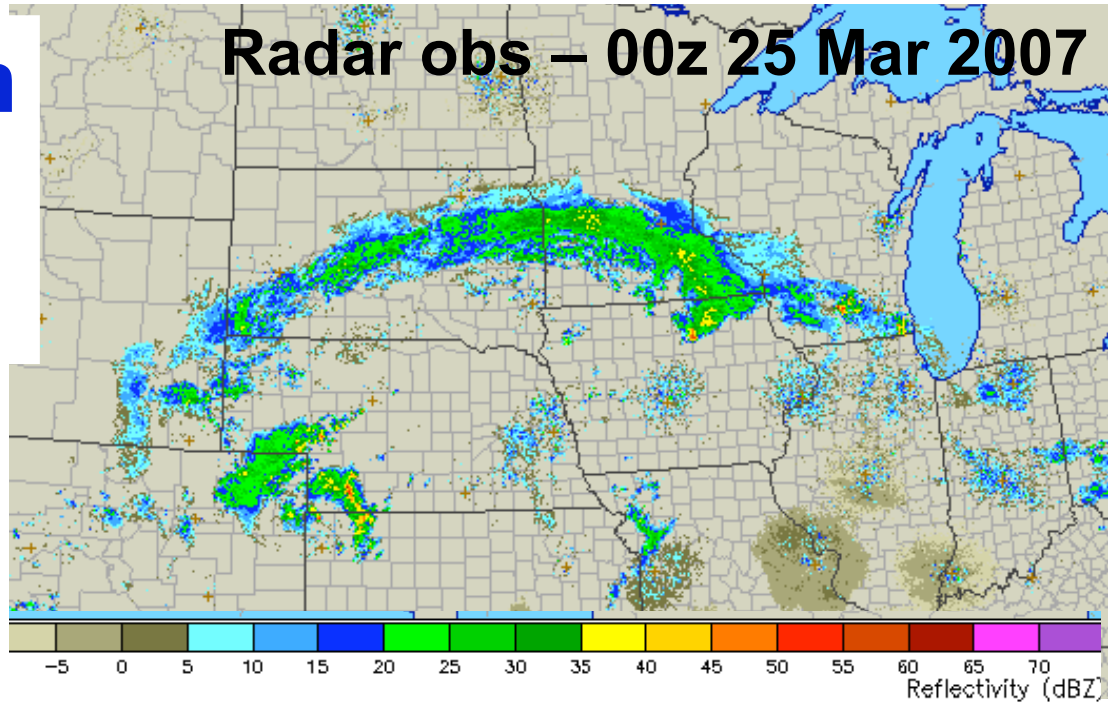


1700 UTC
27 Jan 2004

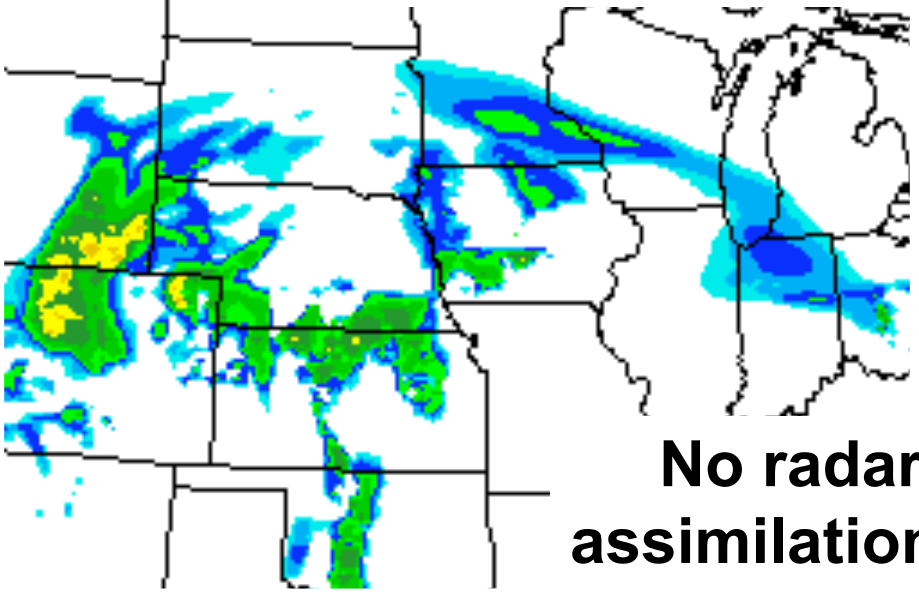


Radar assimilation in RUC - winter storm example

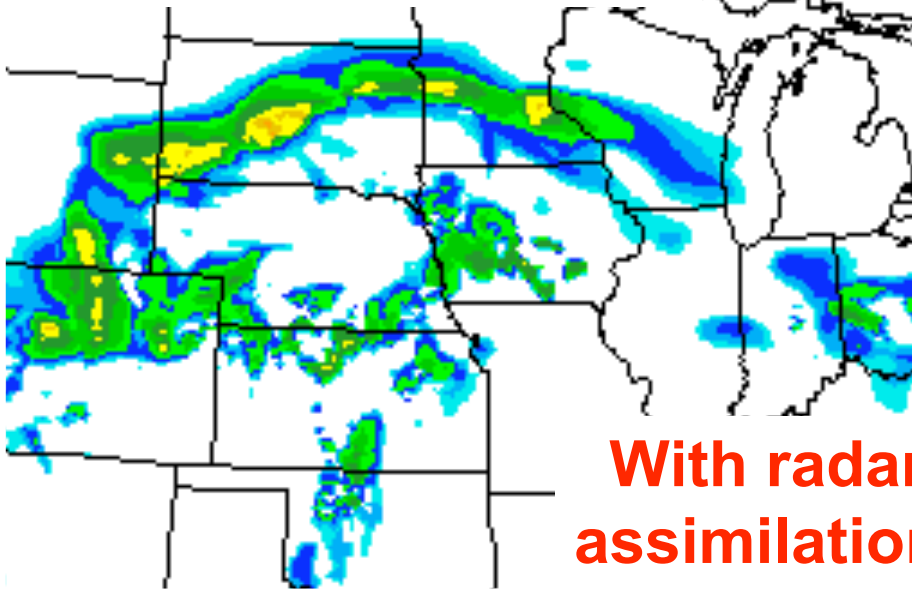
Also, added simulated radar reflectivity field to RUC output



RUC 3-h forecasts valid 00z 25 Mar 2007



No radar assimilation



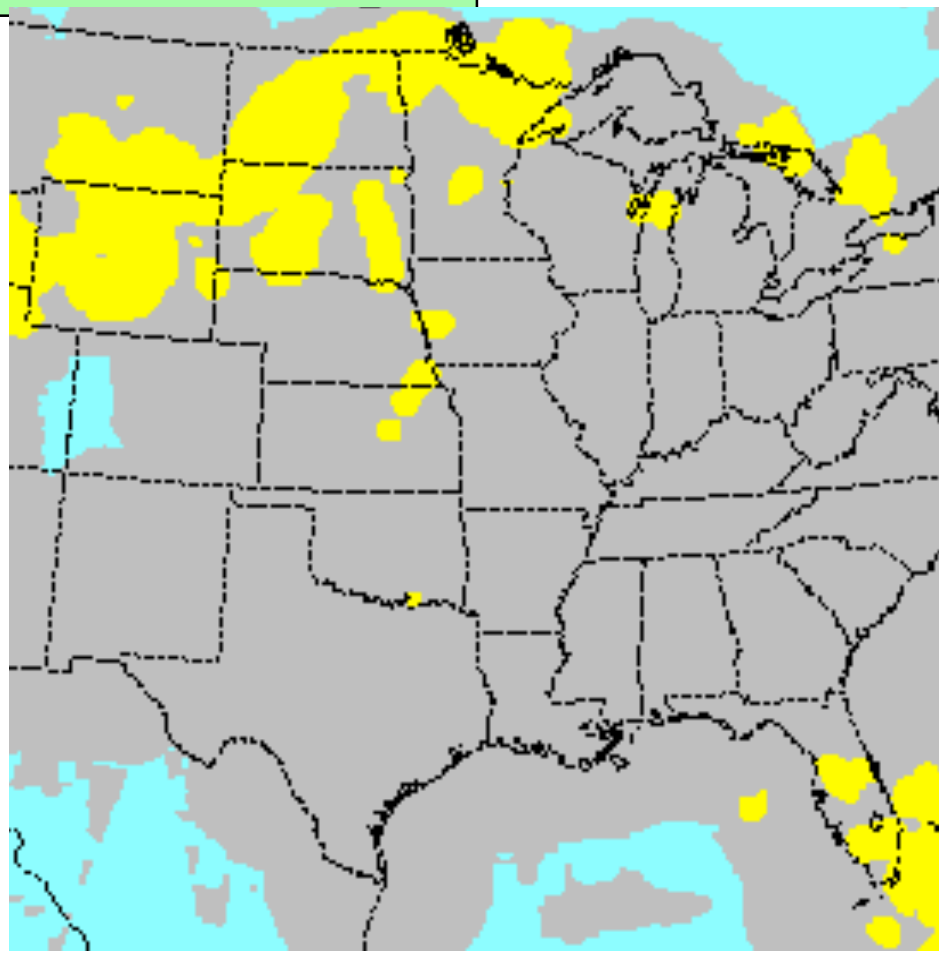
With radar assimilation

Radar reflectivity assimilation

Part 2 – convection suppression

- Define suppression areas as follows:

- No reflectivity > 20 dbZ within 100 km
- Depth of radar data > 300 hPa
- Complemented by GOES fully clear areas



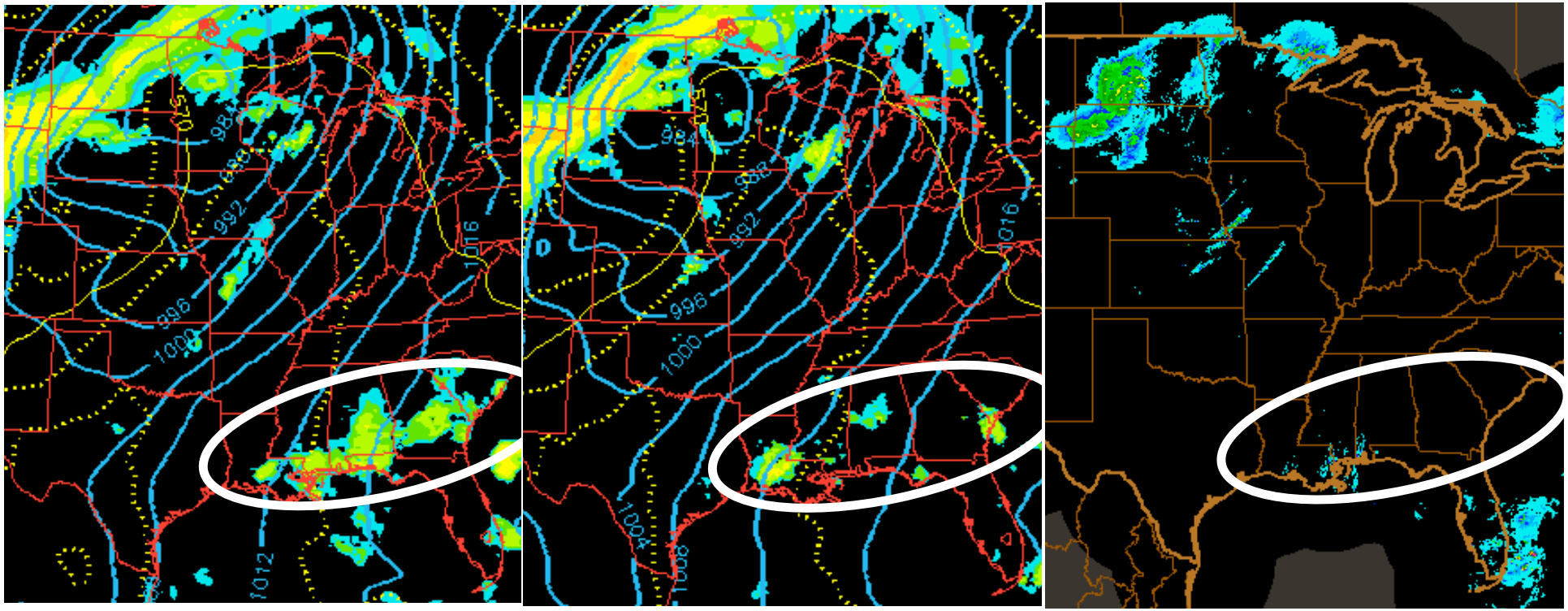
No coverage	Suppress convection	Allow convection

Convective suppression example

Control - radar assim without suppression

Add conv suppression to radar assimilation

NSSL 3-h precipitation



Real-time 3-h forecasts valid 15z 7 June 2007

Valid 15z 7 June 2007

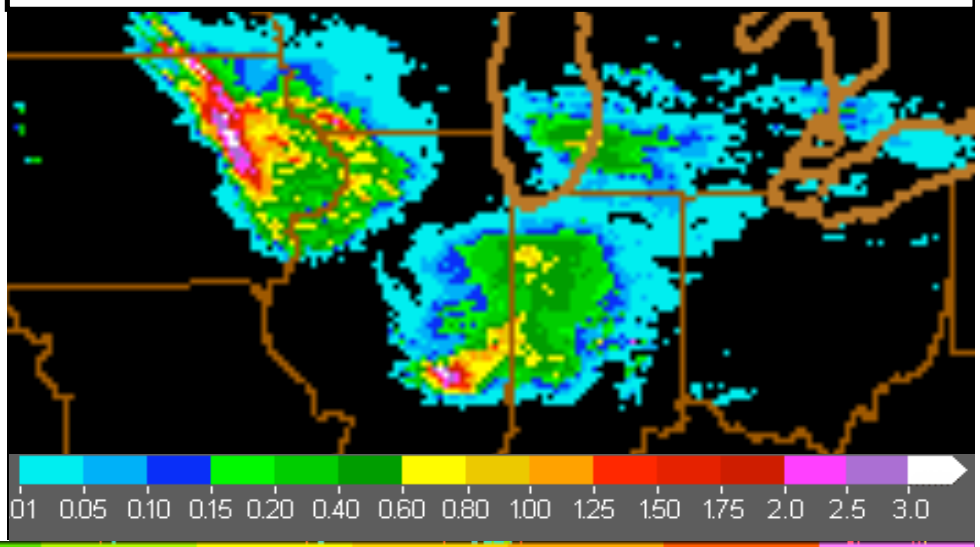
convective suppression - *How does it work? – Reduces latent heating, vert. motion in erroneous conv areas*

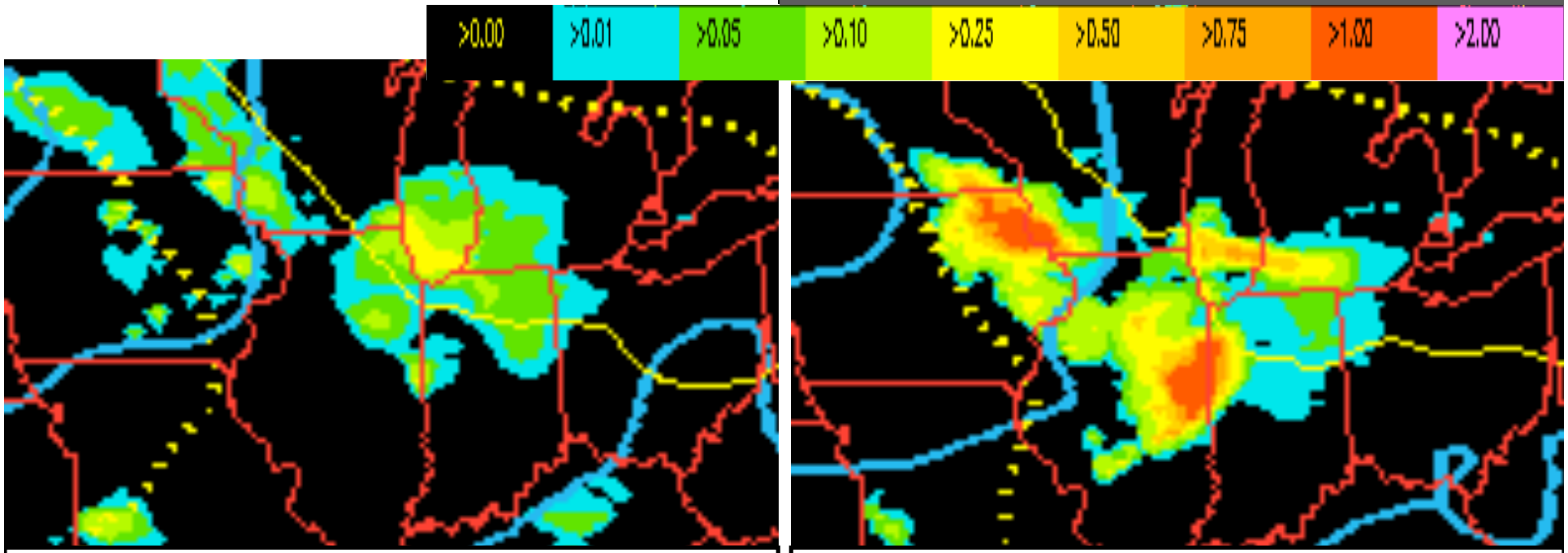
Overall effect of RUC radar assimilation

- Overnight convection

valid 12z 17 July 2007

NSSL 12z 3-h accum. Precip.

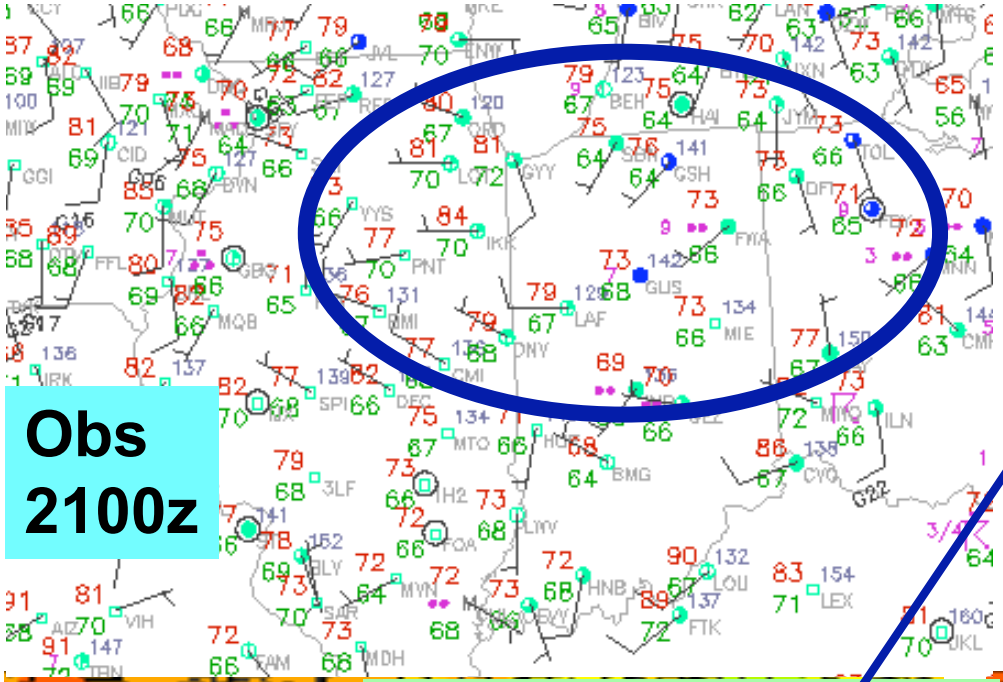




No radar assimilation

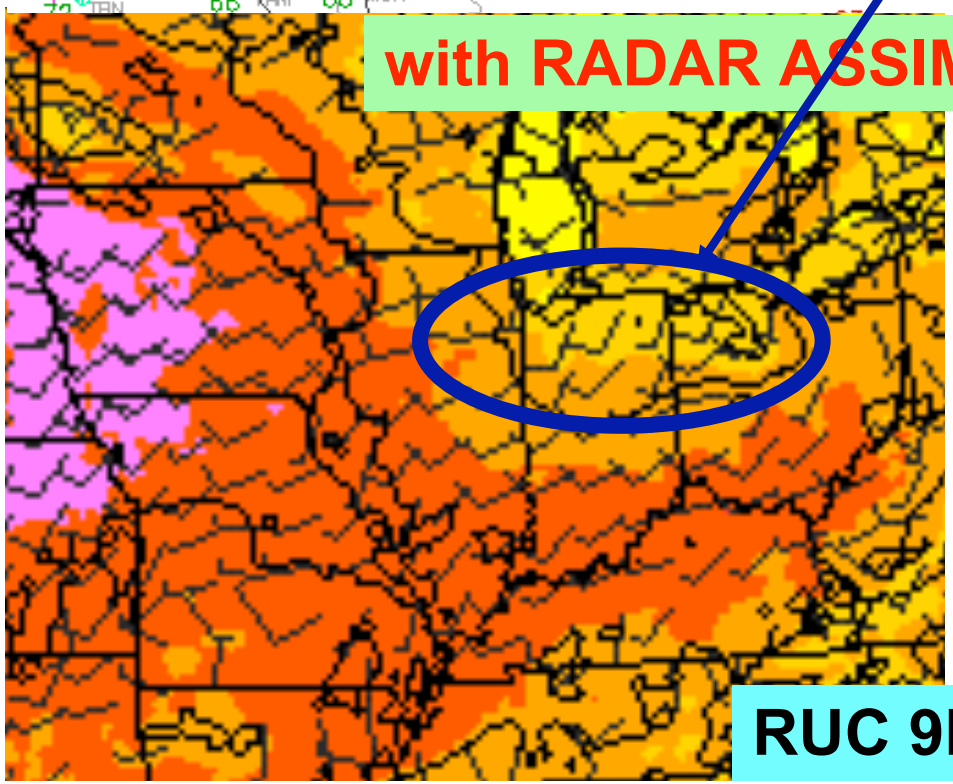
Radar assimilation

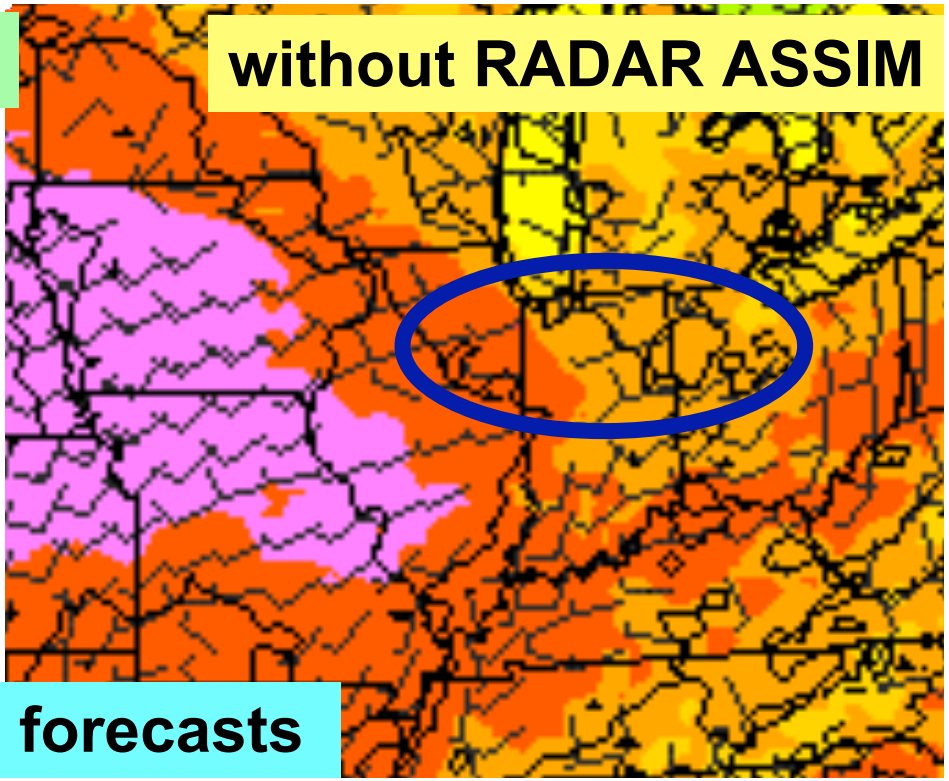
Evaporative cooling - improved cold pool with radar assim



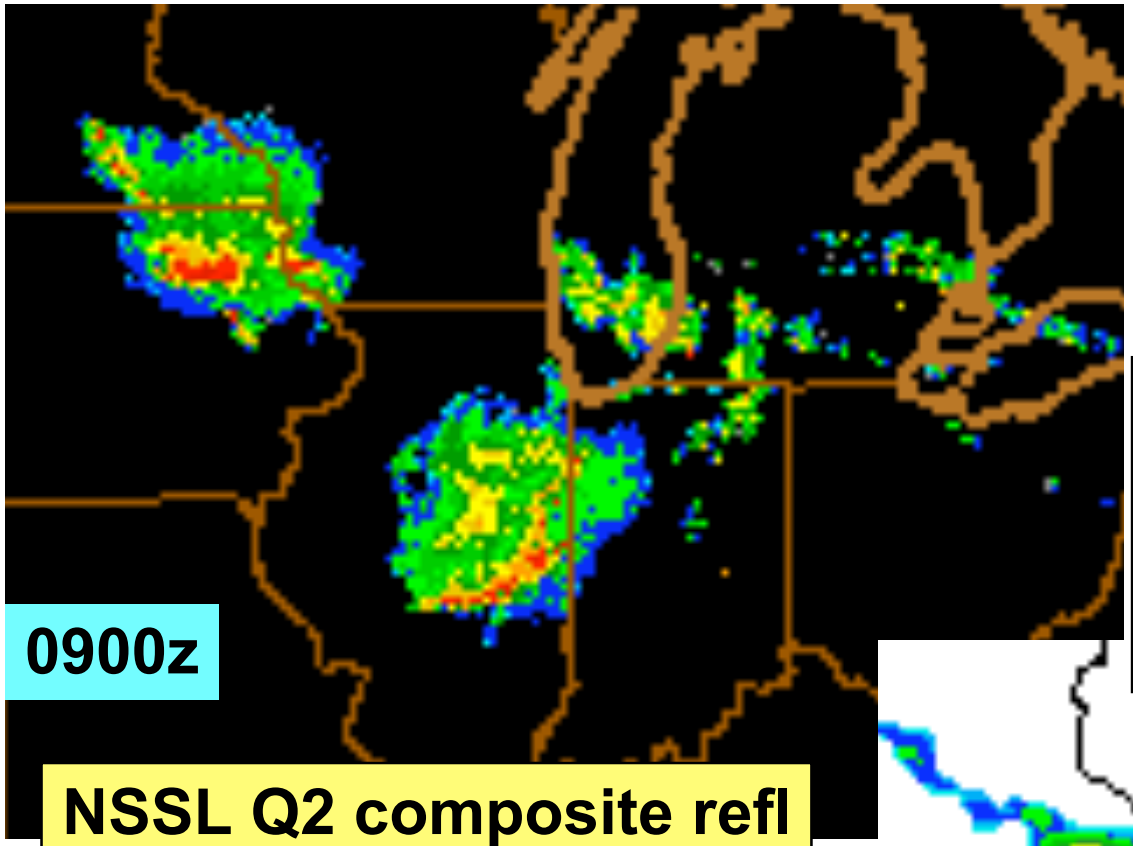
Sfc Temp – 21z
Tues 17 July 2007

>60.0 >70.0 >80.0 >90.0 >100.0

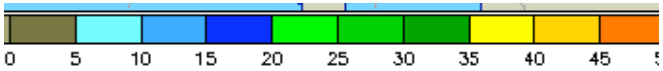




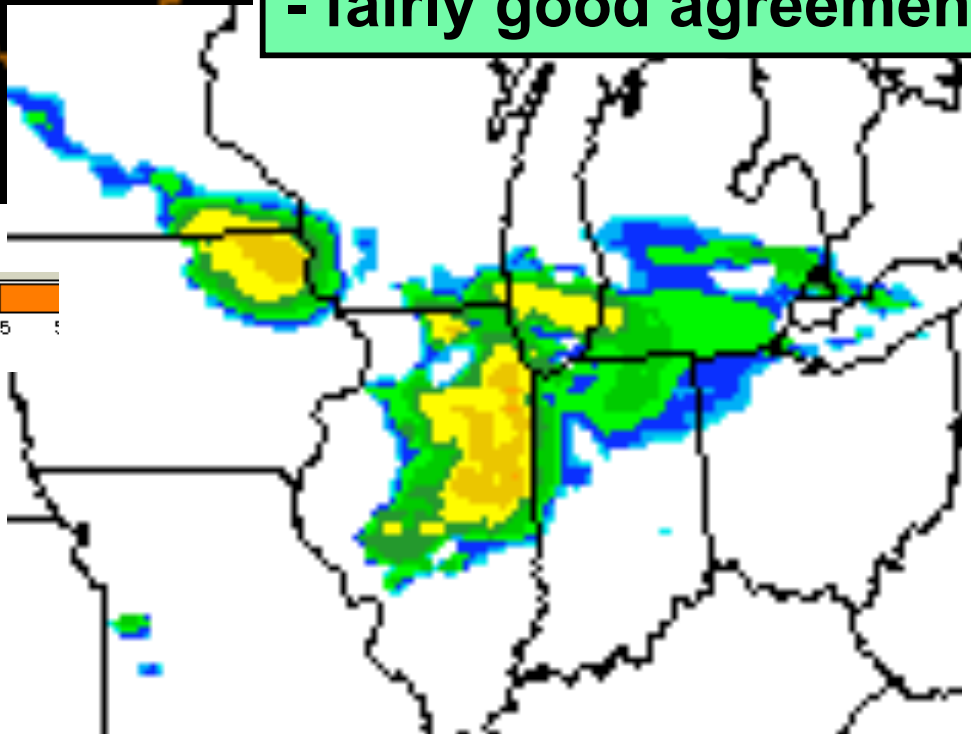
RUC 9h forecasts



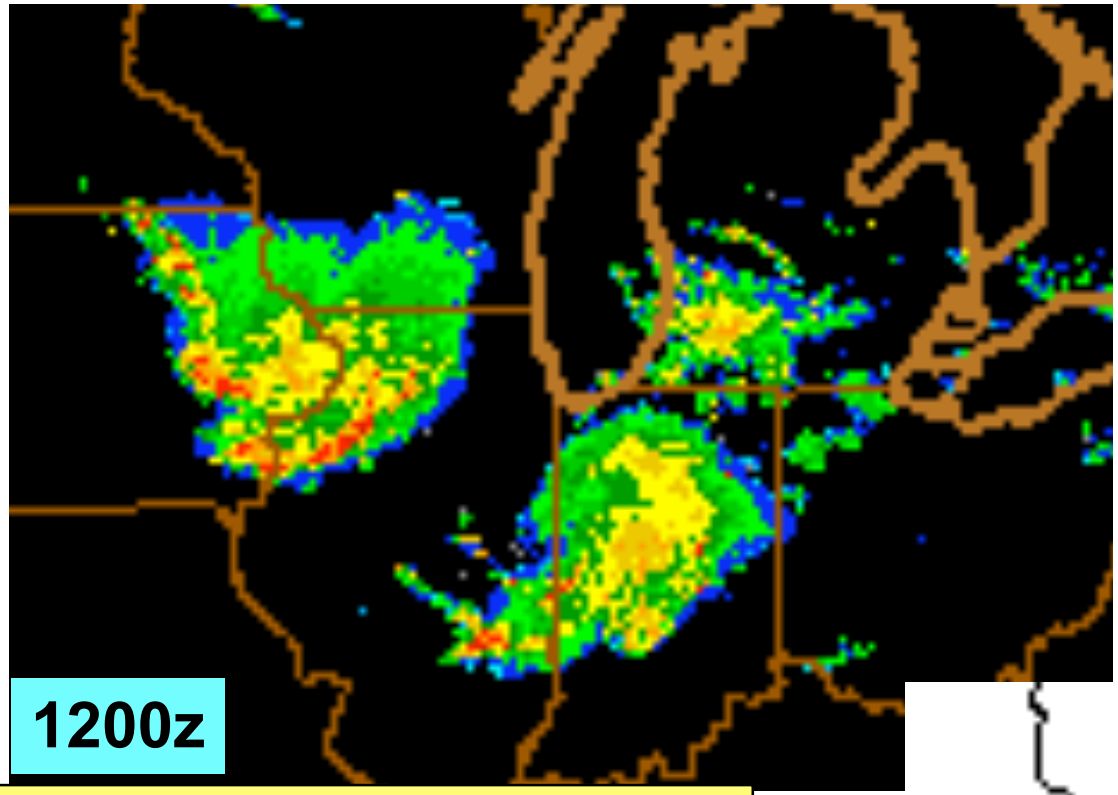
NSSL Q2 composite refl



RUC "analysis"
composite reflectivity
(actually 1h fcst)
- fairly good agreement

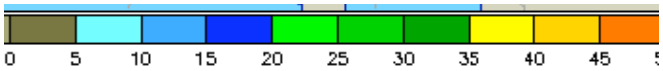


0900z reflectivity
Tues 17 July 2007

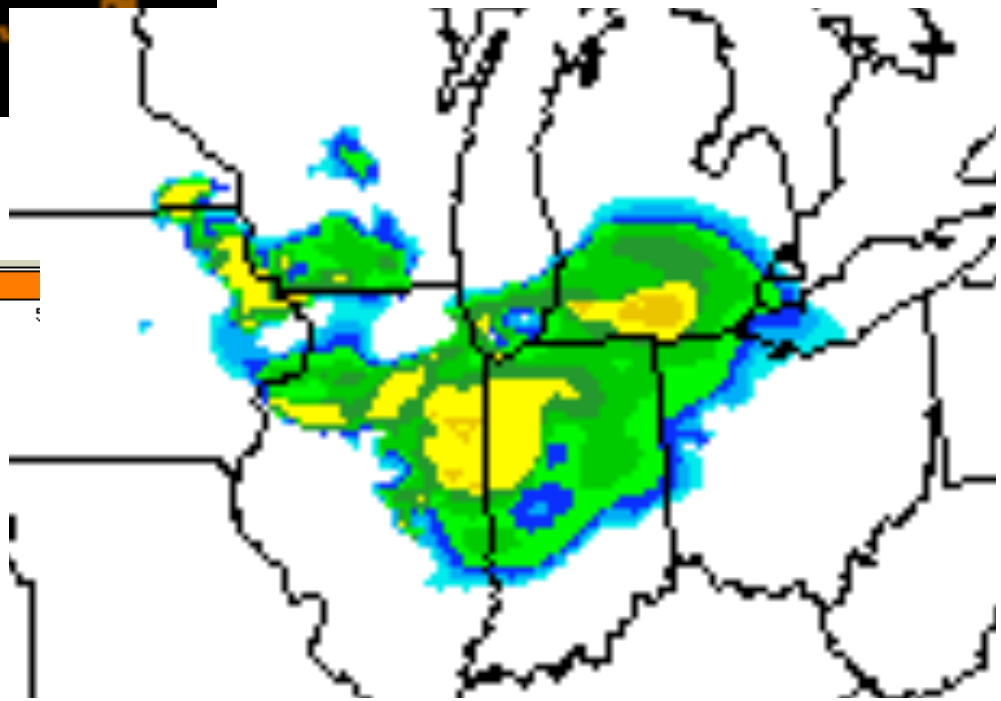


1200z

NSSL Q2 composite refl



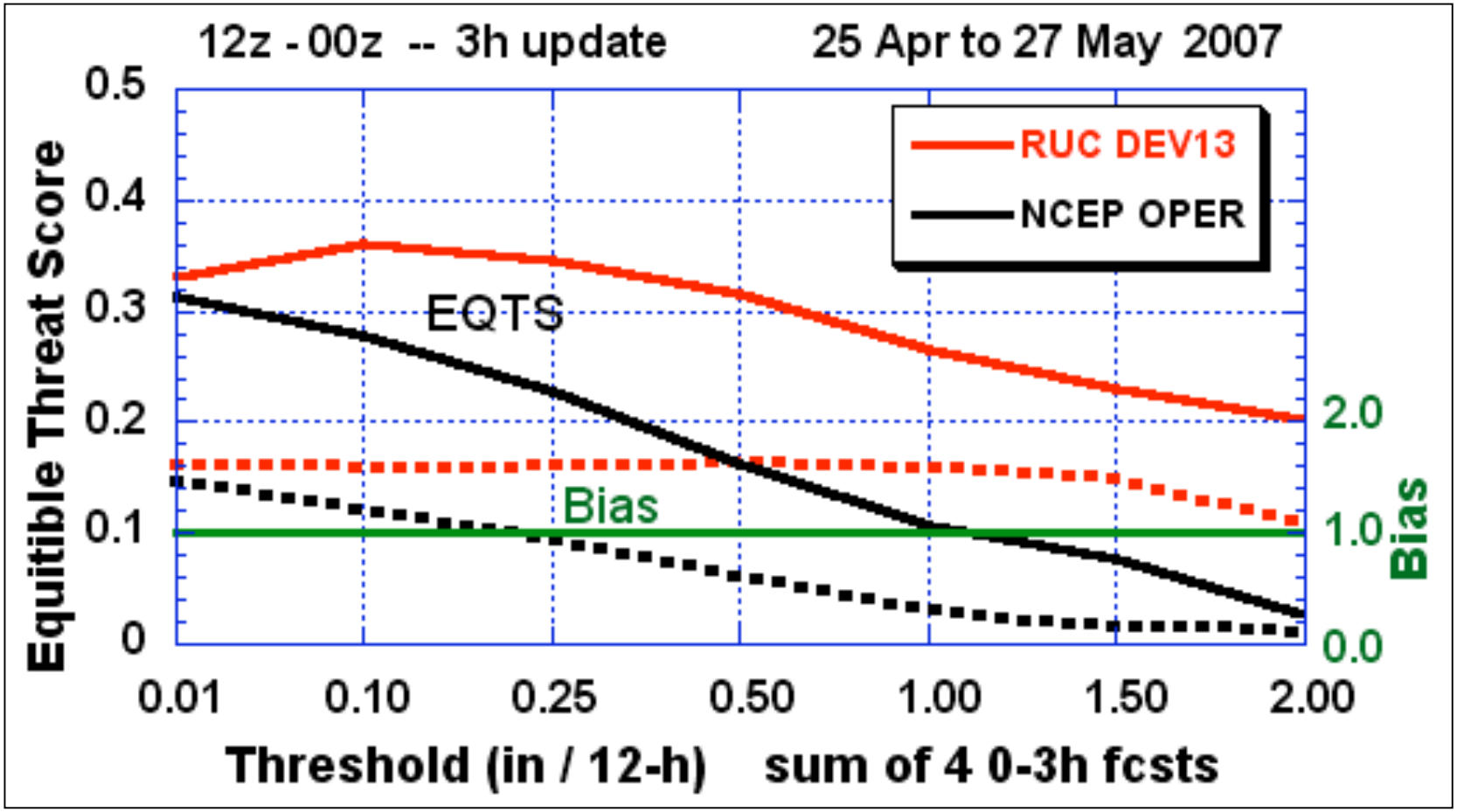
RUC 3h forecast composite refl



Valid 1200z
Tues 17 July 2007

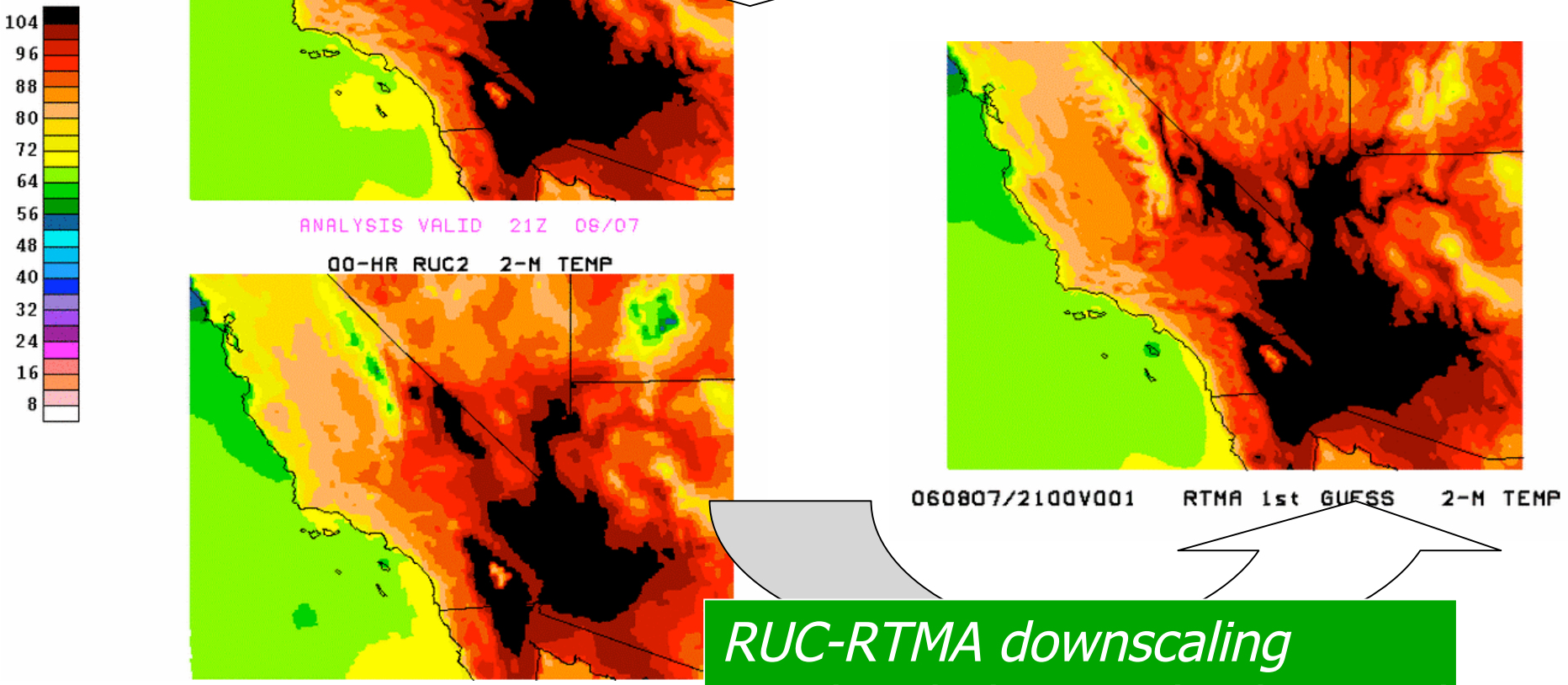
Radar assimilation impact on 3-h precipitation skill scores

- Significant improvement in ETS and bias
- Spring - daytime

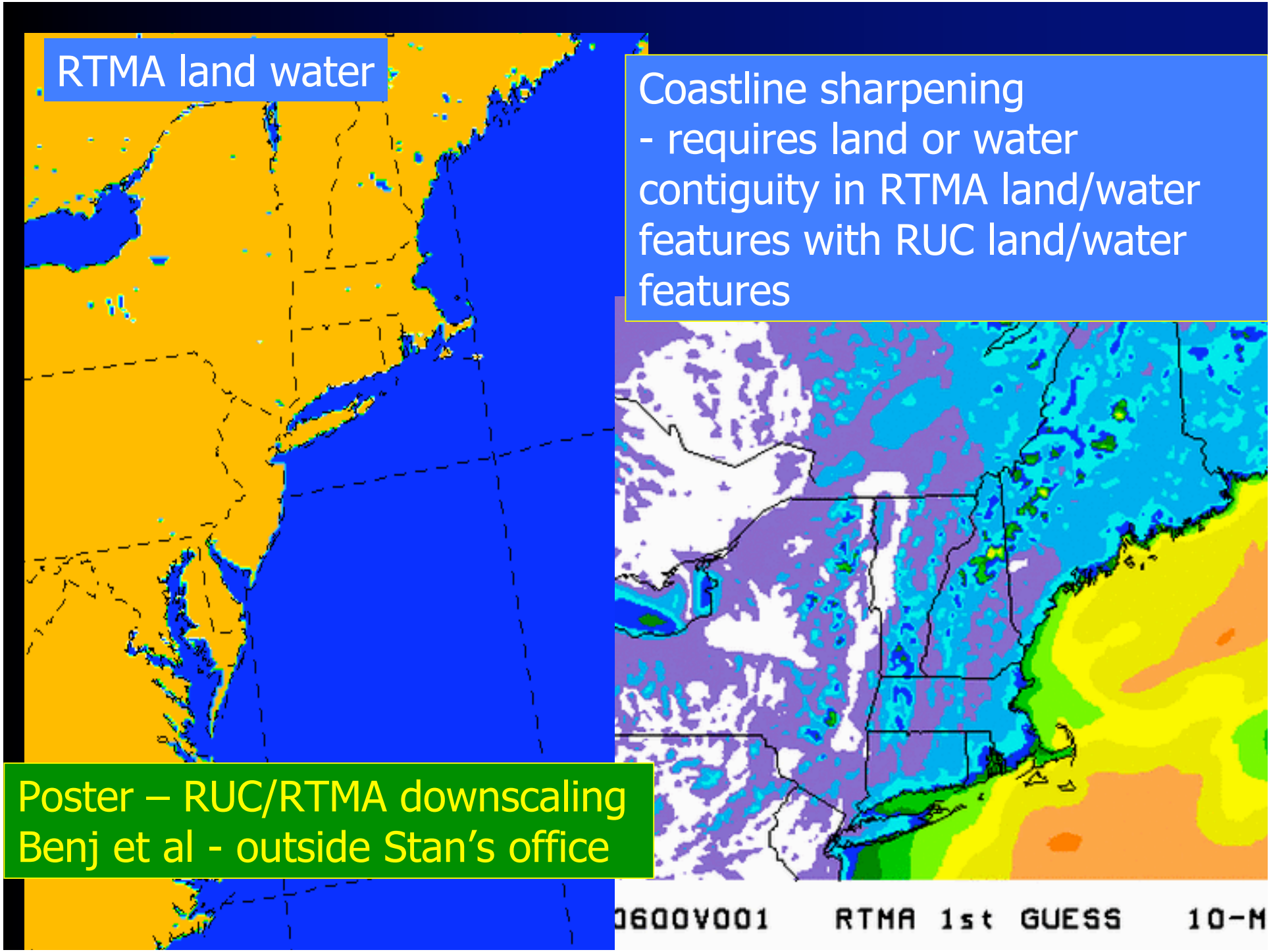


RUC-RTMA downscaling
2008 change - improved cold valleys
RUC post code used (w/ mods)
for RTMA downscaling

RTMA 2dVAR update



RUC-RTMA downscaling
to detailed RTMA background


RTMA land water
Coastline sharpening
- requires land or water contiguity in RTMA land/water features with RUC land/water features
Poster – RUC/RTMA downscaling
Benj et al - outside Stan's office
0600V001 RTMA 1st GUESS 10-M

Mesonet station wind uselist: ~4400 out of 12,100 stations

Basis:

* mean wind speed diff from RUC 1h forecast < 1.0 m/s
  (over 10-day period in October 2007 - 18-21z-daytime)
* All winds used from METAR, RAWS, OK-Meso,
  other selected providers

Network	uselist	total	% low 10m spd bias
UrbaNet	357	810	44
Citizens	659	3422	19
AWS	2207	5226	43
OK-Meso	80	116	69
GoMOOS	10	11	91
MesoWest	454	972	47
RAWS	826	1696	49
METAR	1284	2069	62
WXforYou	20	97	21

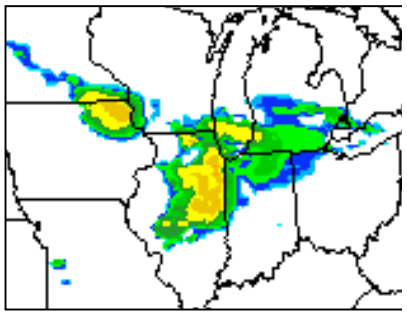
Early 2008 Changes for oper RUC upgrade

- Assimilation additions
  - Use of **radar reflectivity** in RUC diabatic digital filter initialization in RUC model, big plus in short-range precip
  - **Mesonet winds** via mesonet station uselist
  - **TAMDAR aircraft** observations

- Model physics
  - RRTM longwave radiation - eliminates sfc warm bias
  - Mod to Grell-Devenyi – decrease areal coverage, non-local subsidence warming - further improvement

  - Improved ceiling/visibility, sfc winds, precip
- Post-processing – add reflectivity fields, improved RTMA downscaling

RUC parallel web site:
http://www.emc.ncep.noaa.gov/mmb/ruc2/para



Early 2008 Changes for oper RUC upgrade - forecast performance improvements

- Surface temperature and winds
  - Much lower bias, all times of day and seasons

- Precipitation, reflectivity
  - Much improved QPF, new reflectivity product consistent with reflectivity observations
- Ceiling and visibility

- Lower tropospheric temperature, RH in eastern US

- Improved RTMA downscaling and accuracy

RUC parallel web site:
http://www.emc.ncep.noaa.gov/mmb/ruc2/para

RUC/Rapid Refresh Technical Review - OUTLINE

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2:15 - 2:25	Rapid Refresh background - core, NCEP - Stan
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2:35 - 2:50	Rapid Refresh model description testing - ARW core, physics, DFI - John Brown
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3:15 - 3:25	Future of Rapid Refresh Stan Benjamin

Why perform OSEs?

- The government is being asked to purchase or deploy new data systems.
- Will these systems improve relevant forecasts? Are they worth the money?
- Examples today:
  - TAMDAR, a new commercial aircraft data system
  - GPS-IPW, a new remote sensing system

TAMDAR

- A system to measure:
  - Wind, Temperature, RH, icing, turbulence
- Installed on scheduled regional commercial aircraft
- Designed to fill a data-void region
  - below 20,000 ft
  - between major airports
- Developed by AirDat, LLC under NASA sponsorship

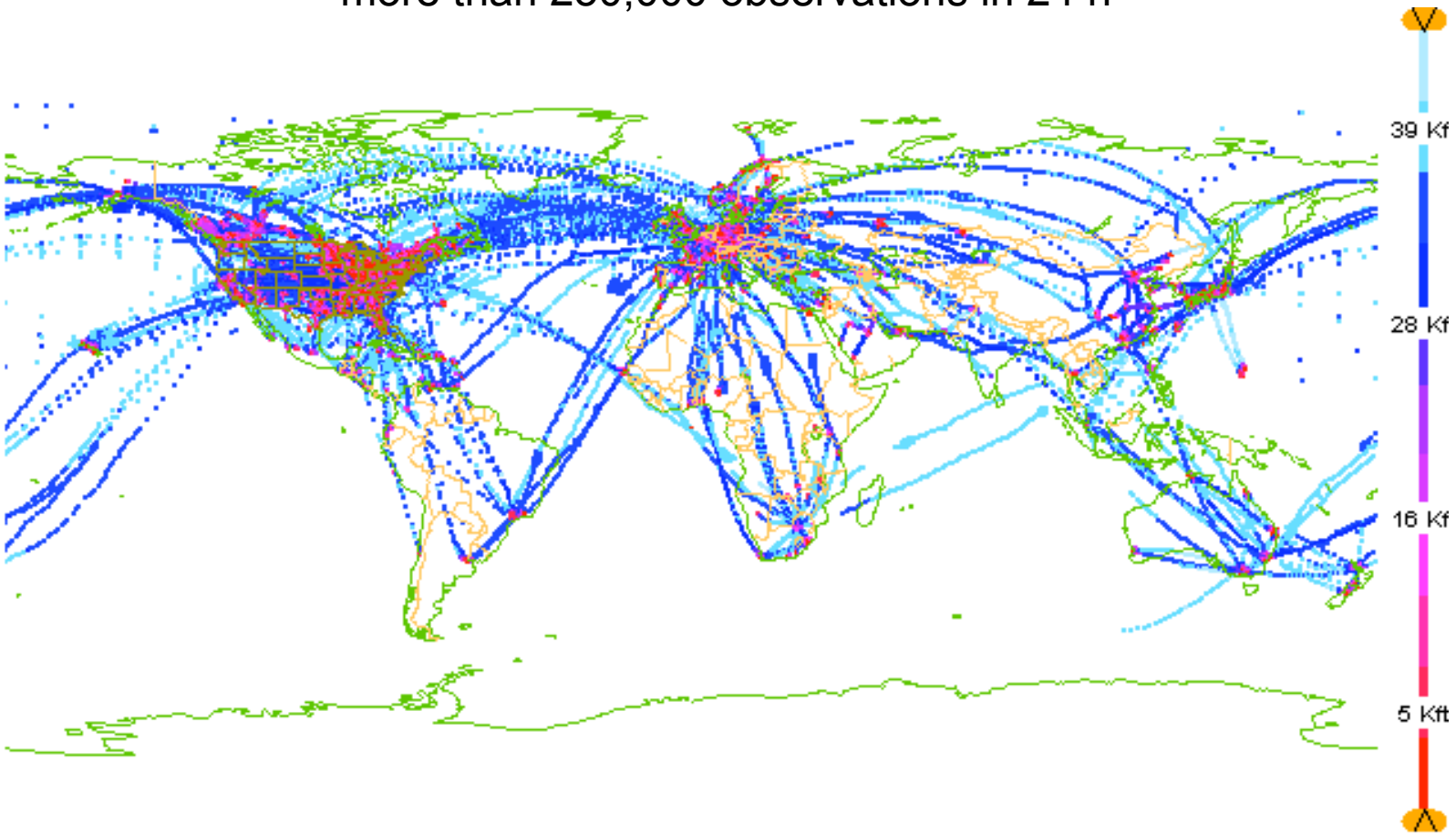
AMDAR and TAMDAR

- “AMDAR” (Automated Meteorological Data and Recording) – are automatically sent from commercial aircraft, mostly large jets

- “TAMDAR” (Tropospheric AMDAR) – automatic reports from (currently) ~50 turboprops flying regionally in the US Midwest

World-wide AMDAR coverage, Tuesday 5 June 2007

more than 250,000 observations in 24 h



05-Jun-2007 00:00:00 -- 05-Jun-2007 23:59:59 (287984 obs loaded, 250711 in range, 15910 shown)

NOAA / ESRL / GSD Altitude: -1000 ft. to 45000 ft. Good w and T

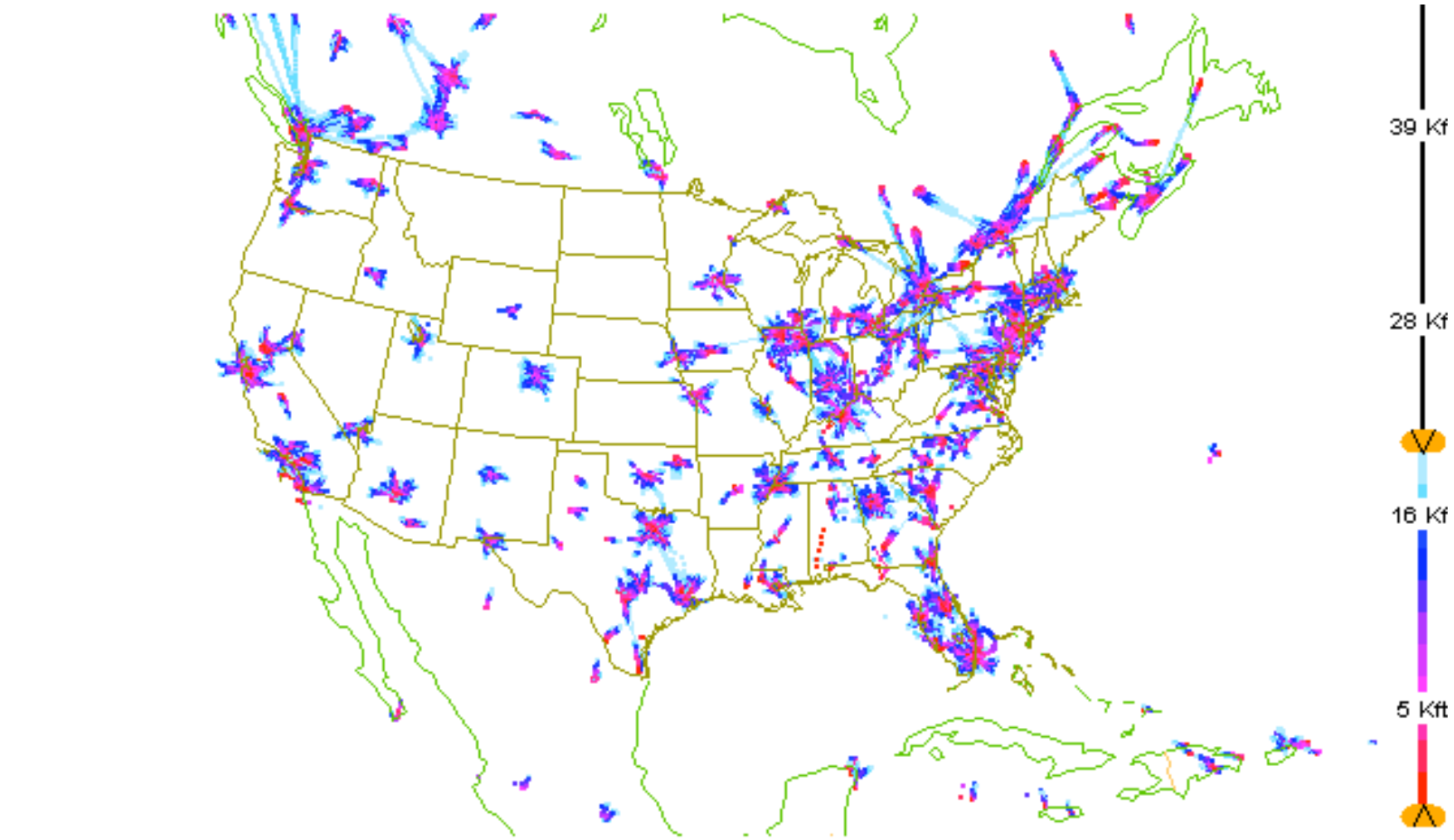
Over CONUS, all altitudes

more than 172,000 observations in 24 h

05-Jun-2007 00:00:00 -- 05-Jun-2007 23:59:59 (287984 obs loaded, 172575 in range, 35977 shown)

NOAA / ESRL / GSD Altitude: -1000 ft. to 45000 ft. Good w and T

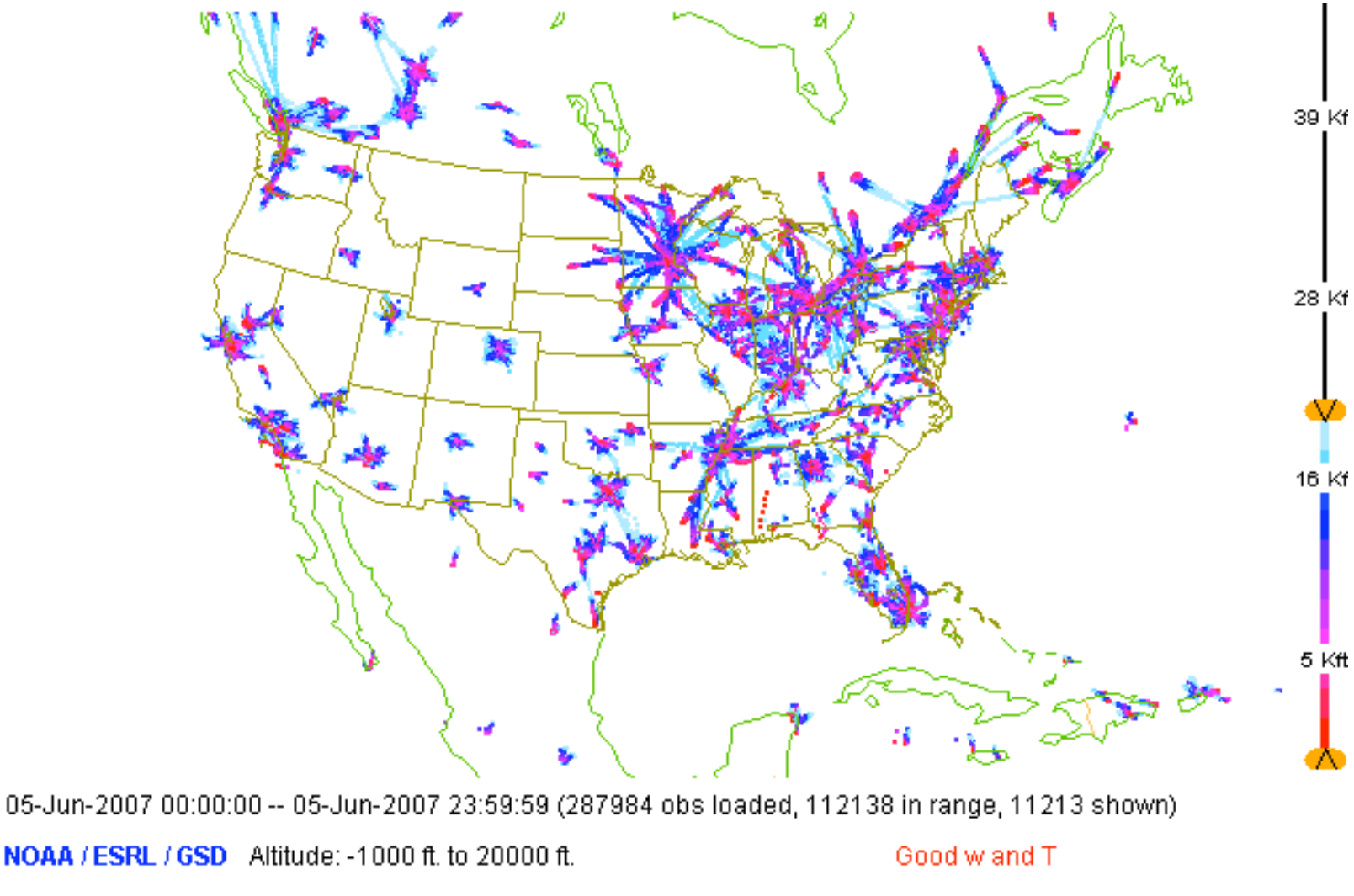
Coverage is limited to major hubs below 20 Kft, (without TAMDAR)



05-Jun-2007 00:00:00 -- 05-Jun-2007 23:59:59 (287984 obs loaded, 102442 in range, 9337 shown)

NOAA / ESRL / GSD Altitude: -1000 ft. to 20000 ft. Good w and T not-TAMDAR

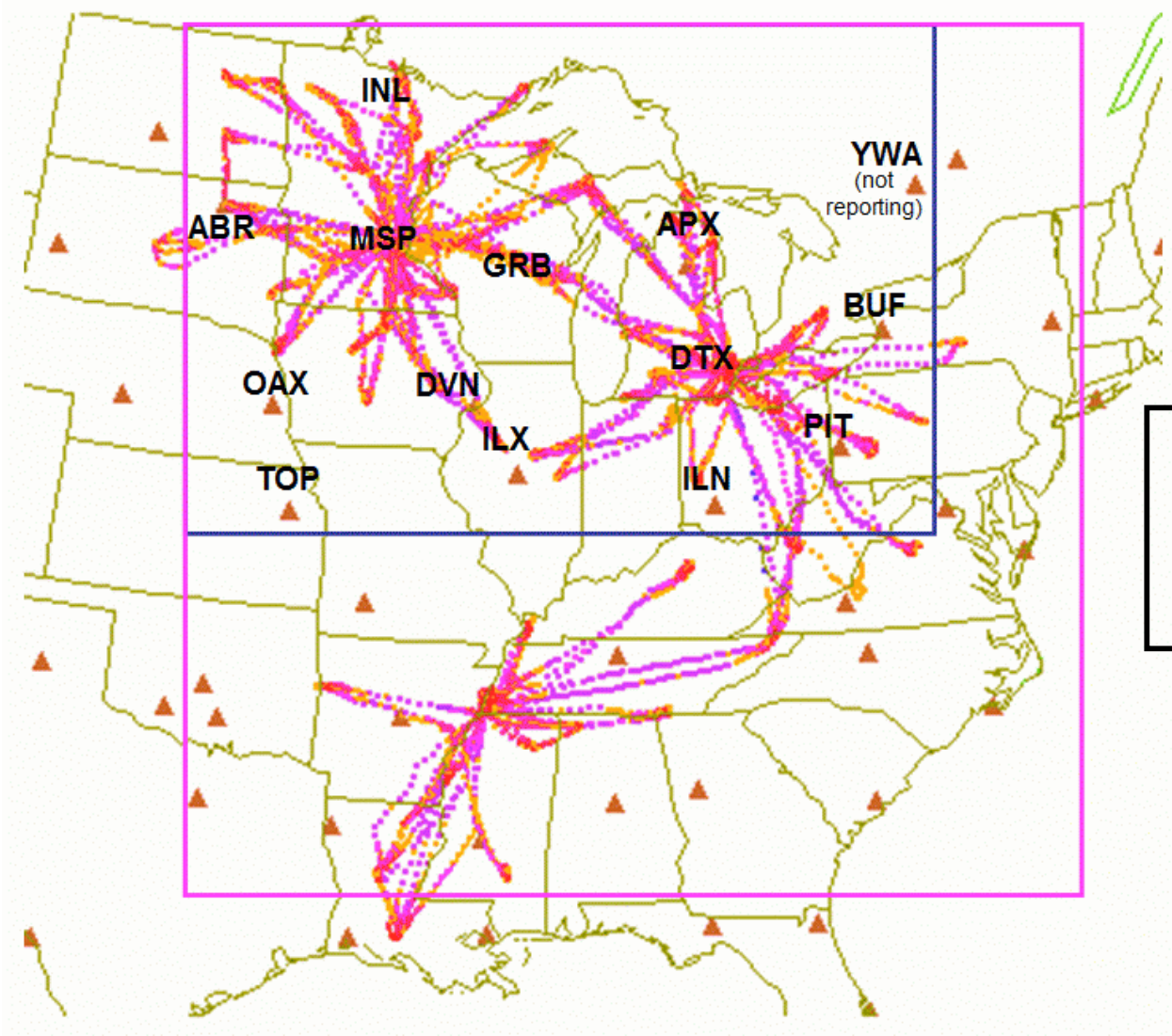
Below 20 Kft, with TAMDAR *added* – better regional coverage in the Midwest



Parallel *real-time* RUC cycles

- "dev2" – includes TAMDAR and *all* other data typically assimilated by the RUC
- "dev" – lacks only TAMDAR data
- Both cycles use NAM boundary conditions
- Both run at 20-km, but are otherwise use same code as the operational 13-km runs
- Background fields are set equal every 48 h
- Running since February 2005

Verification Regions:
Great Lakes Region includes 13 RAOBs
Eastern US Region includes 38 RAOBs
National Region is the RUC domain (CONUS and adjacent)

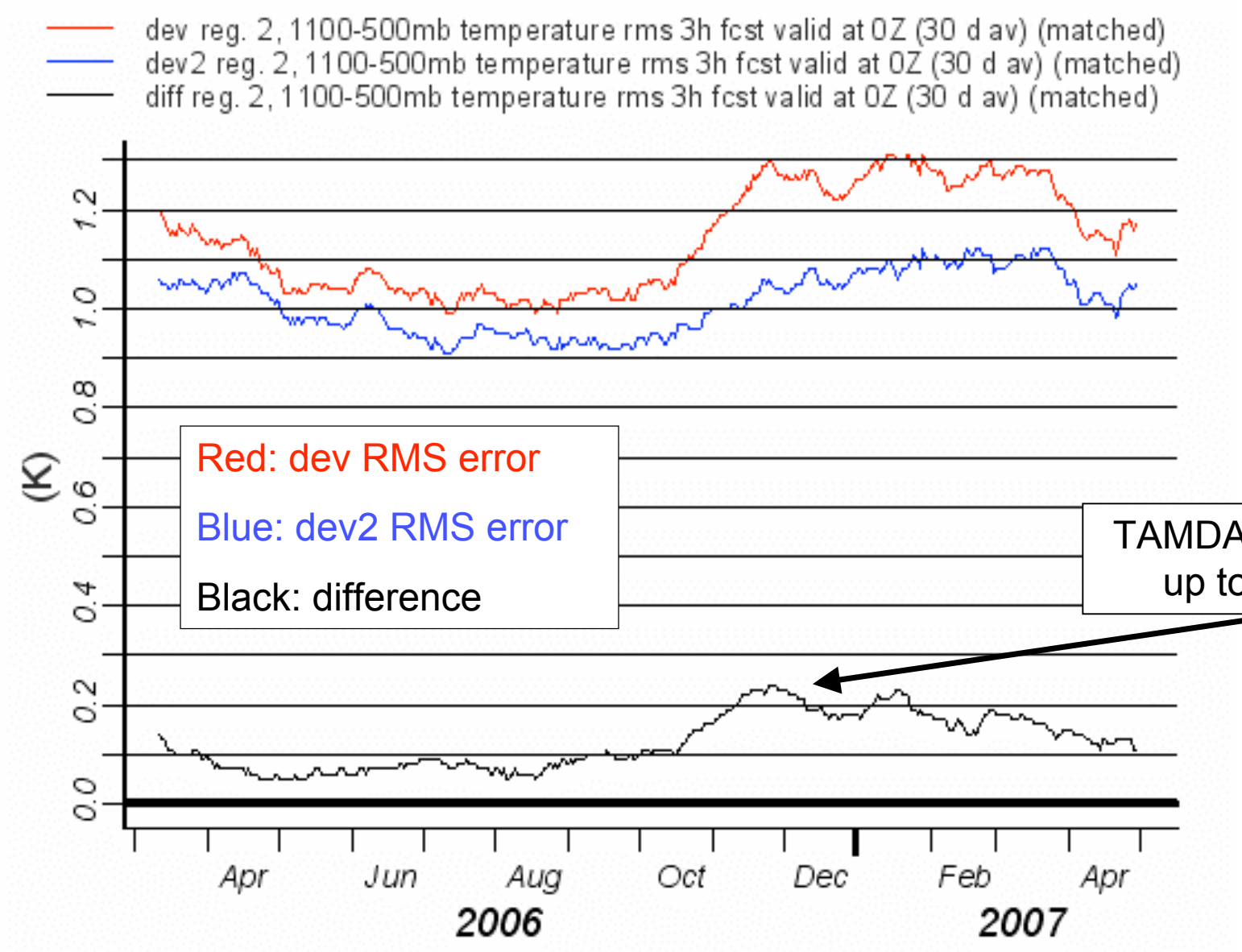


Results today are from the Great Lakes region, where most TAMDAR aircraft fly

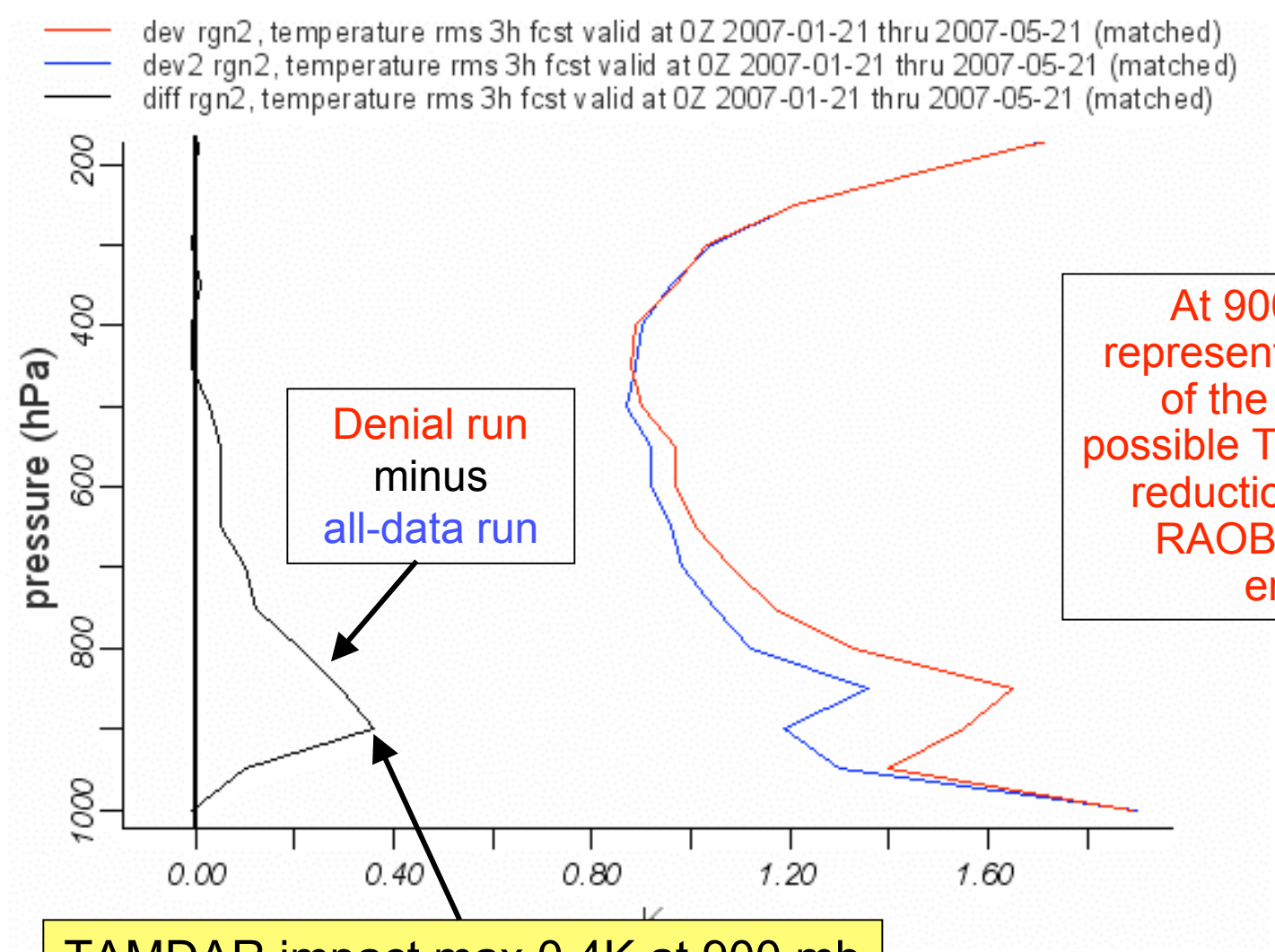
Verification against RAOBs

- RUC and RAOB soundings are interpolated to 10 mb levels
- Comparisons of T, RH, Wind are made at every level from the surface upward
- A few RAOBs eliminated by hand
  - (about a dozen in 18 months)

Temperature RMS error time series, 3-h forecasts, Great Lakes Region, surface to 500 mb



Temperature RMS error **profile**, 3-h forecasts, Great Lakes Region, Jan-May 2007

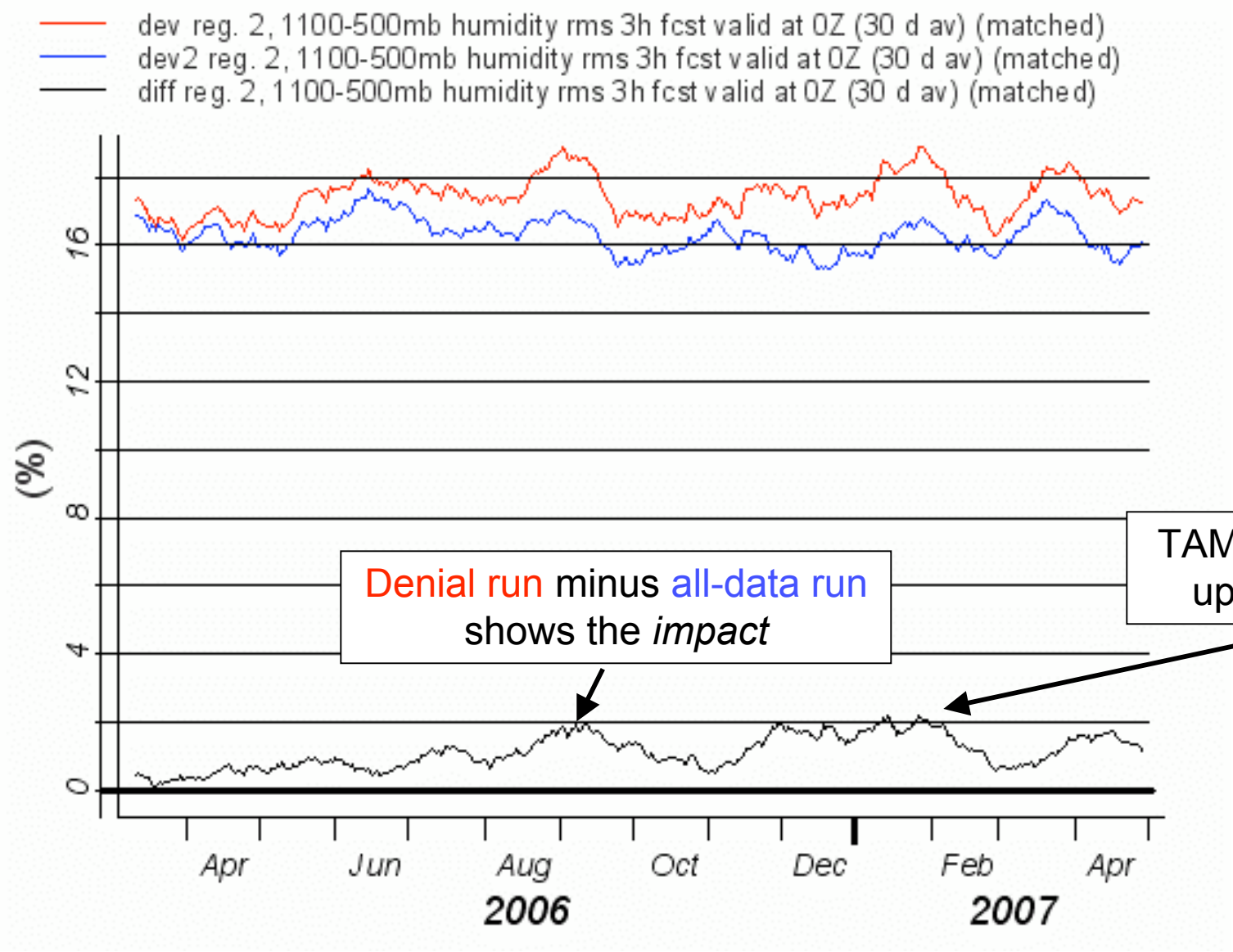


Denial run
minus
all-data run

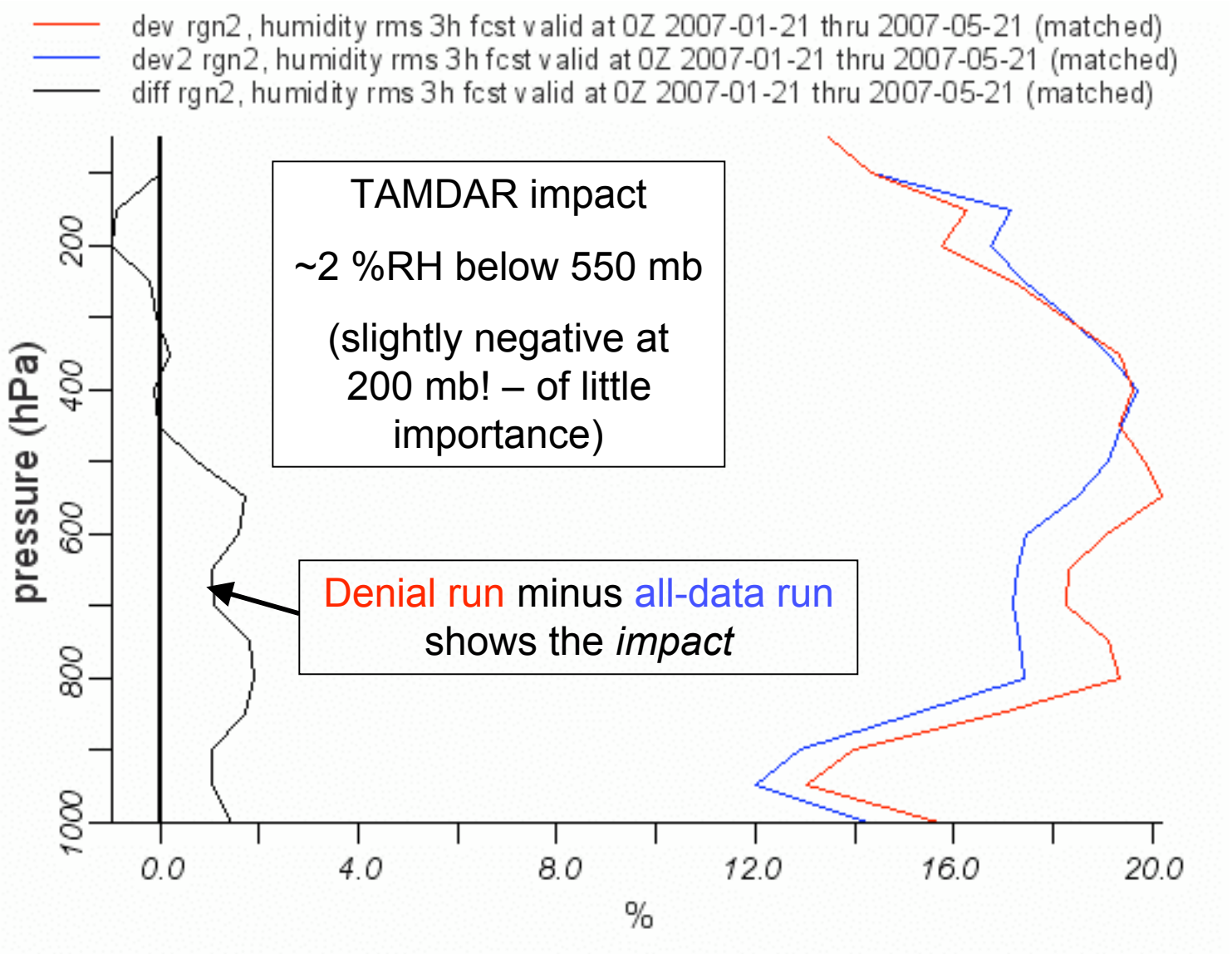
At 900 mb, this represents about 35% of the maximum possible T forecast error reduction (because RAOB also have errors).

TAMDAR impact max 0.4K at 900 mb
-- Inversion level, cloud ceiling

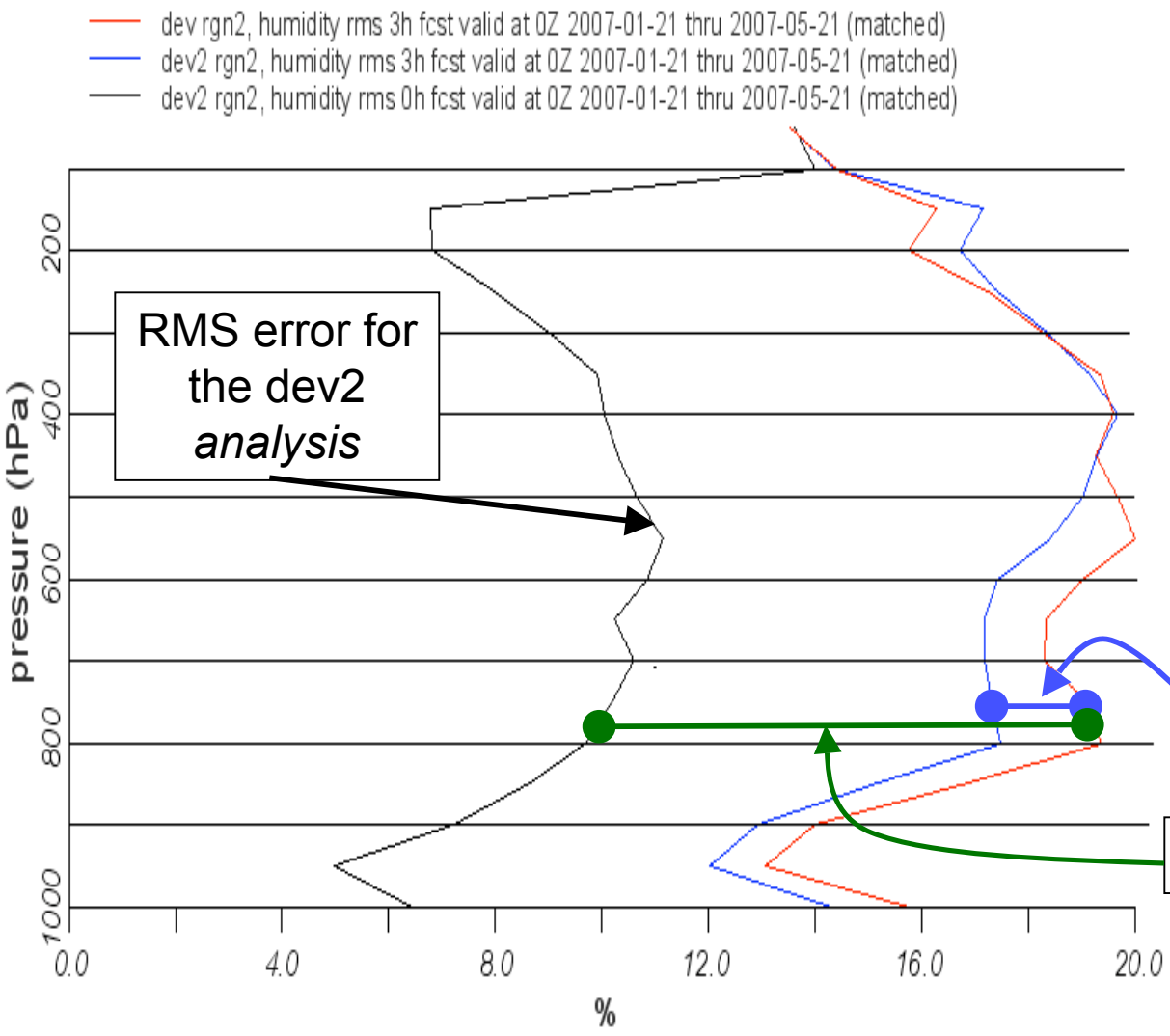
RH error time series, 3-h forecasts, Great Lakes Region, surface to 500 mb



RH RMS error profile, 3-h forecasts, Great Lakes Region



RH RMS 3-hr error profile, no TAMDAR (red), TAMDAR (blue), and *Analysis* (black), Great Lakes Region



Normalized Impact:

For 3-h RH forecasts, TAMDAR reduces the RMS error by 10% to 20% of the way to the analysis fit below 550 mb, thus represents a 10-20% reduction in 3-h RH forecast error in this region

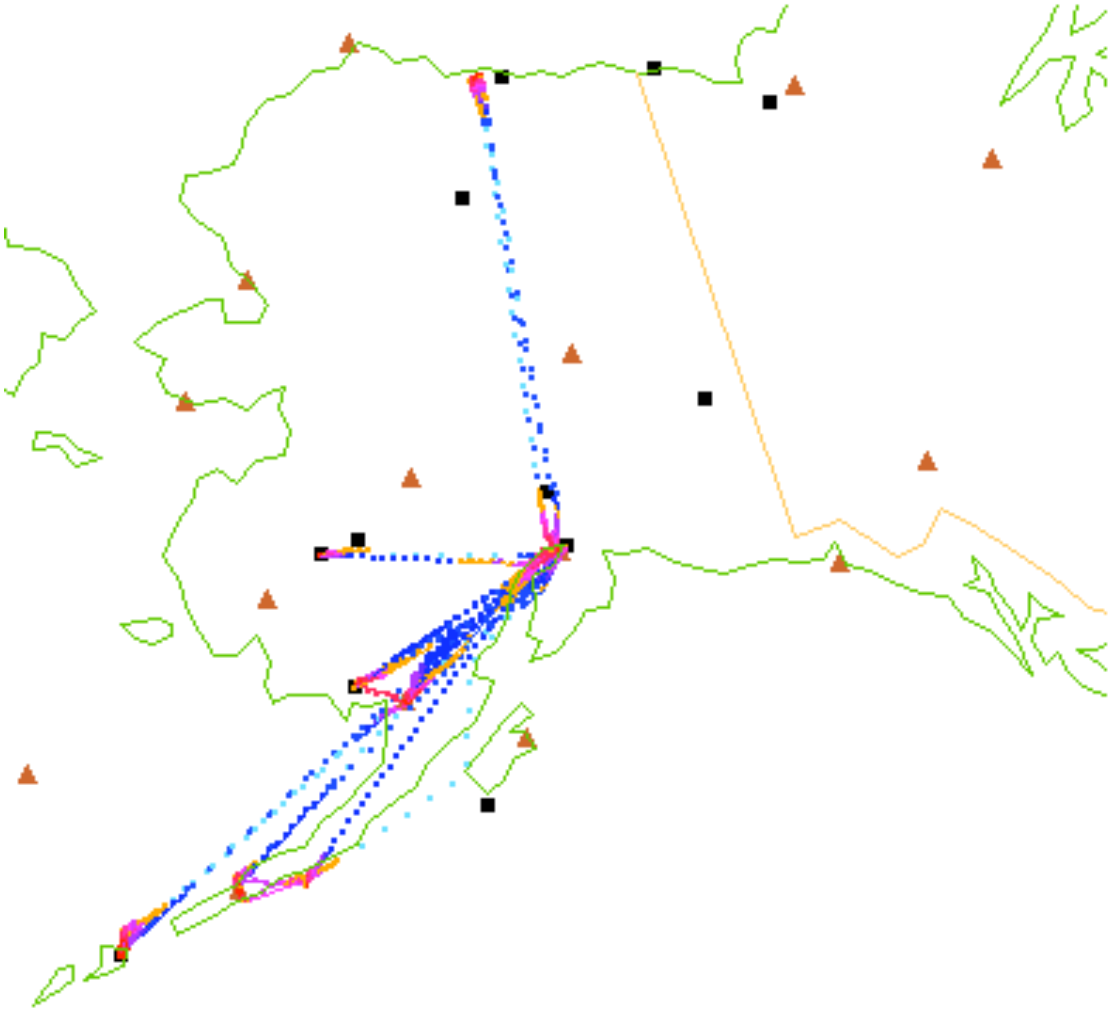
Resulting NOAA Actions:

- As a result of these and some NWS studies
  - TAMDAR data from the Mesaba fleet are now purchased by NWS
  - TAMDAR/Mesaba data are now operational data
- New TAMDAR fleets remain to be evaluated by GSD
  - FAA is funding these studies
  - (FAA Flight Information System Data Link office, not AWRP)

New TAMDAR Fleets

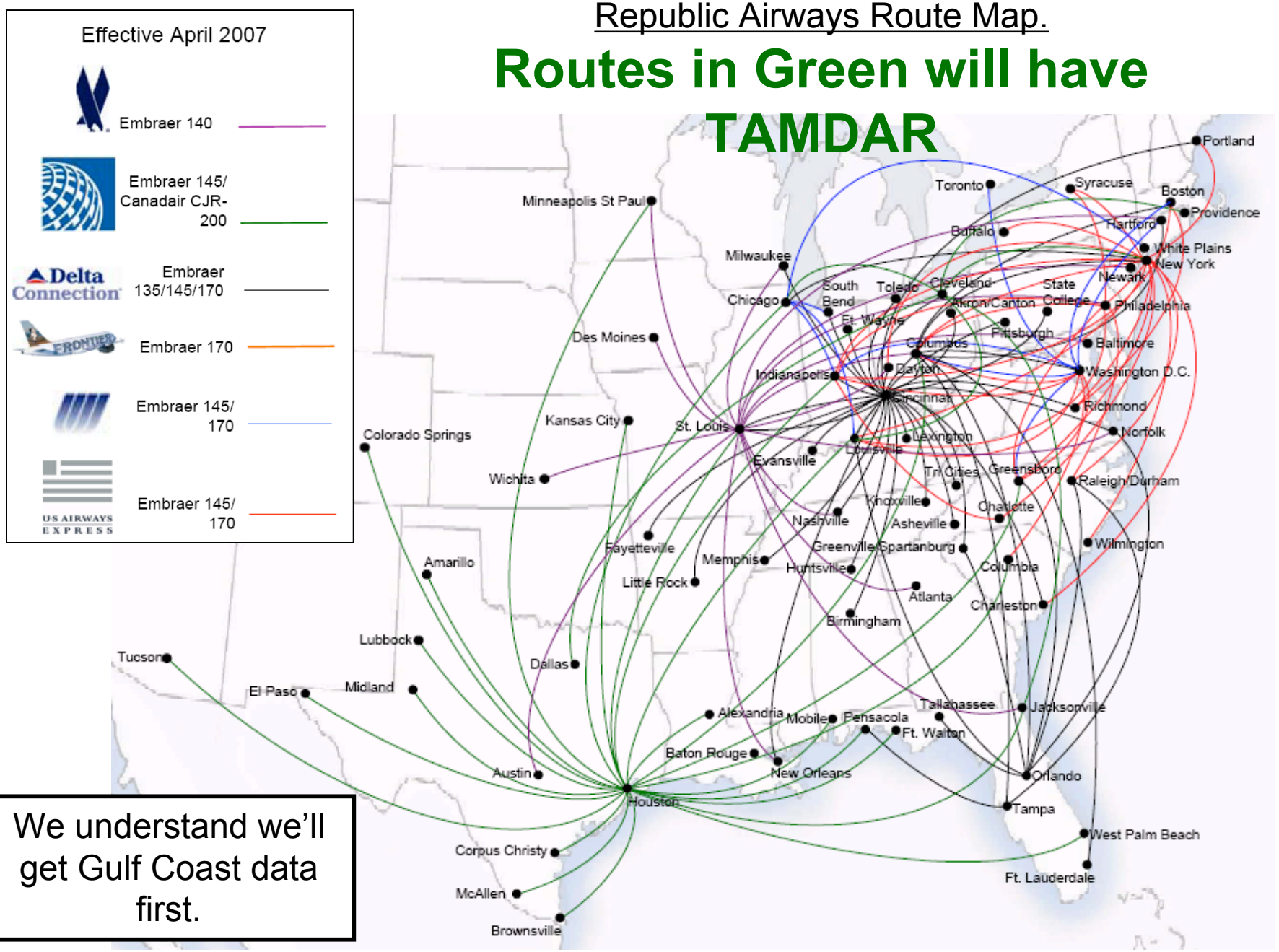
- More than 300 aircraft
- These fleets include some jet aircraft
  - higher altitudes, speeds (implications??)
  - better heading => reduced wind errors
- (Unfortunately, these new data will not be available beyond GSD, per AirDat)

Pen Air TAMDAR Data, 22 Oct 2007
(1520 Observations)



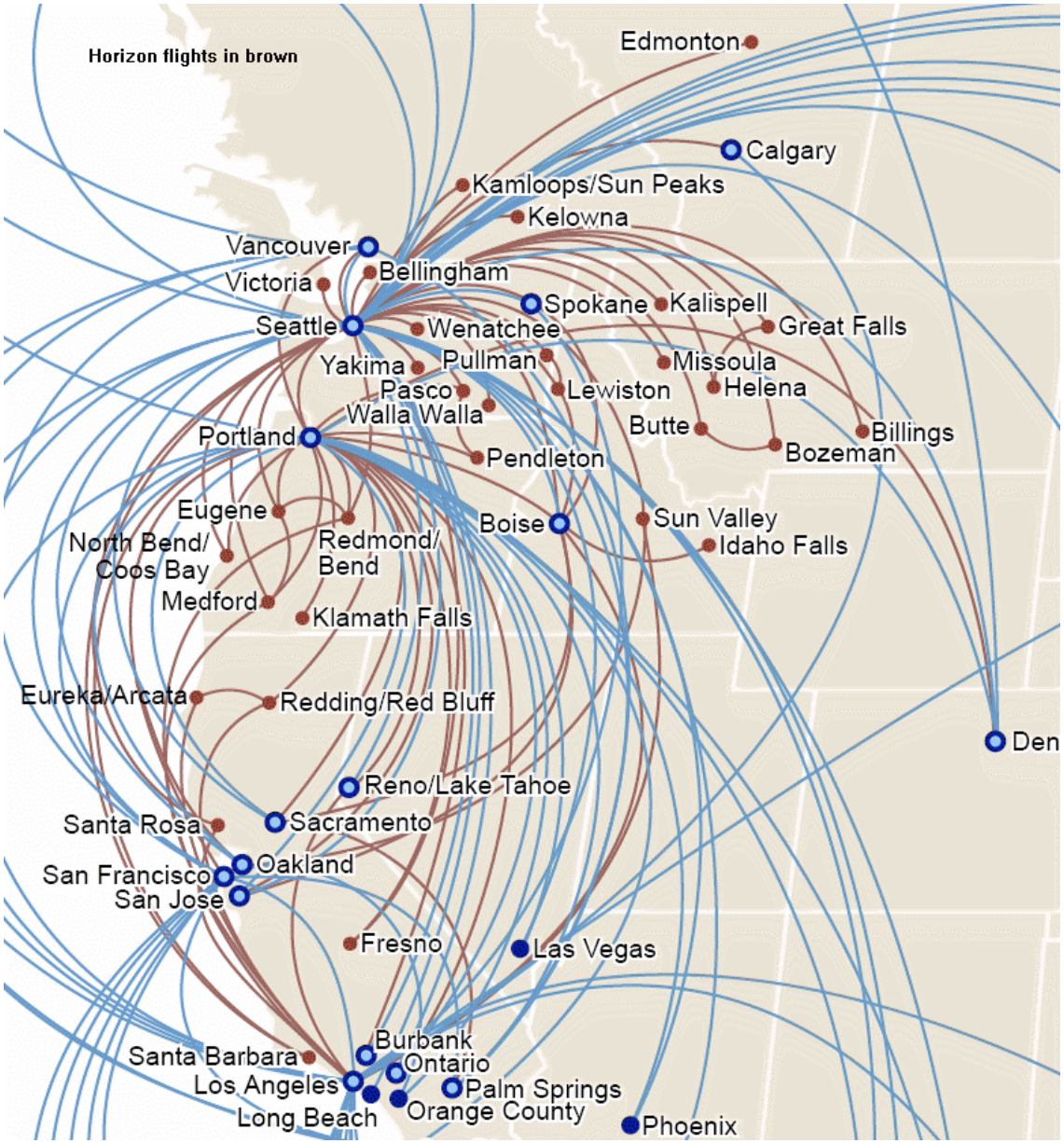
Republic Airways Route Map.

Routes in Green will have TAMDAR



We understand we'll get Gulf Coast data first.

Alaska Airlines / Horizon Air Route Map

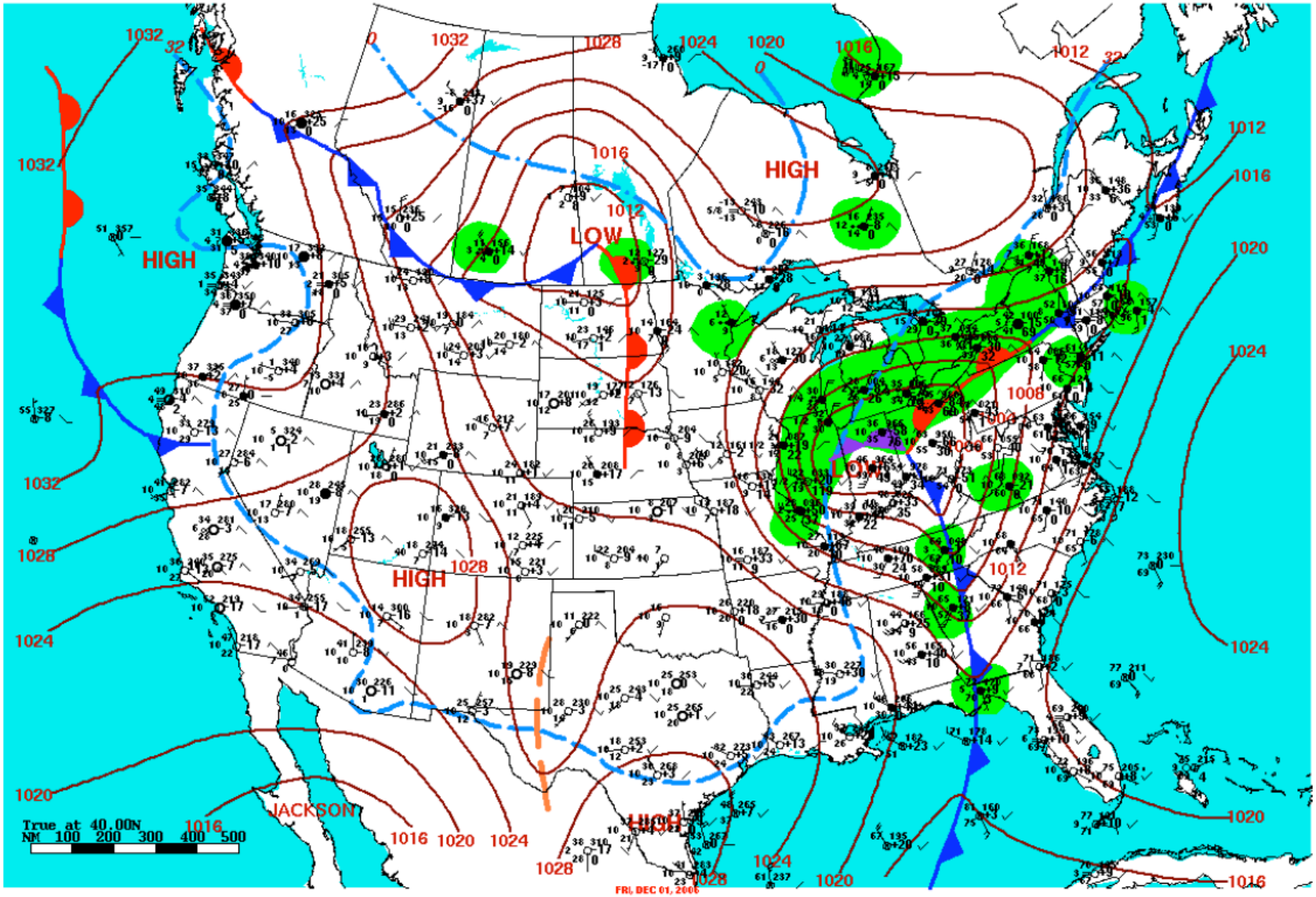


Routes in brown will have TAMDAR

(Ignore the Alaska Airlines routes in blue)

Retrospective Runs – an excellent test bed for measuring the impact of observing systems

- All RUC data were saved for a 10-day period
  - 12 UTC 26 November to 12 UTC 5 December 2006
  - Includes a potent winter storm early, and more moderate weather later



Surface Weather Map and Station Weather at 7:00 A.M. E.S.T.

Surface analysis and data for 1200 UTC on 1 December 2006.

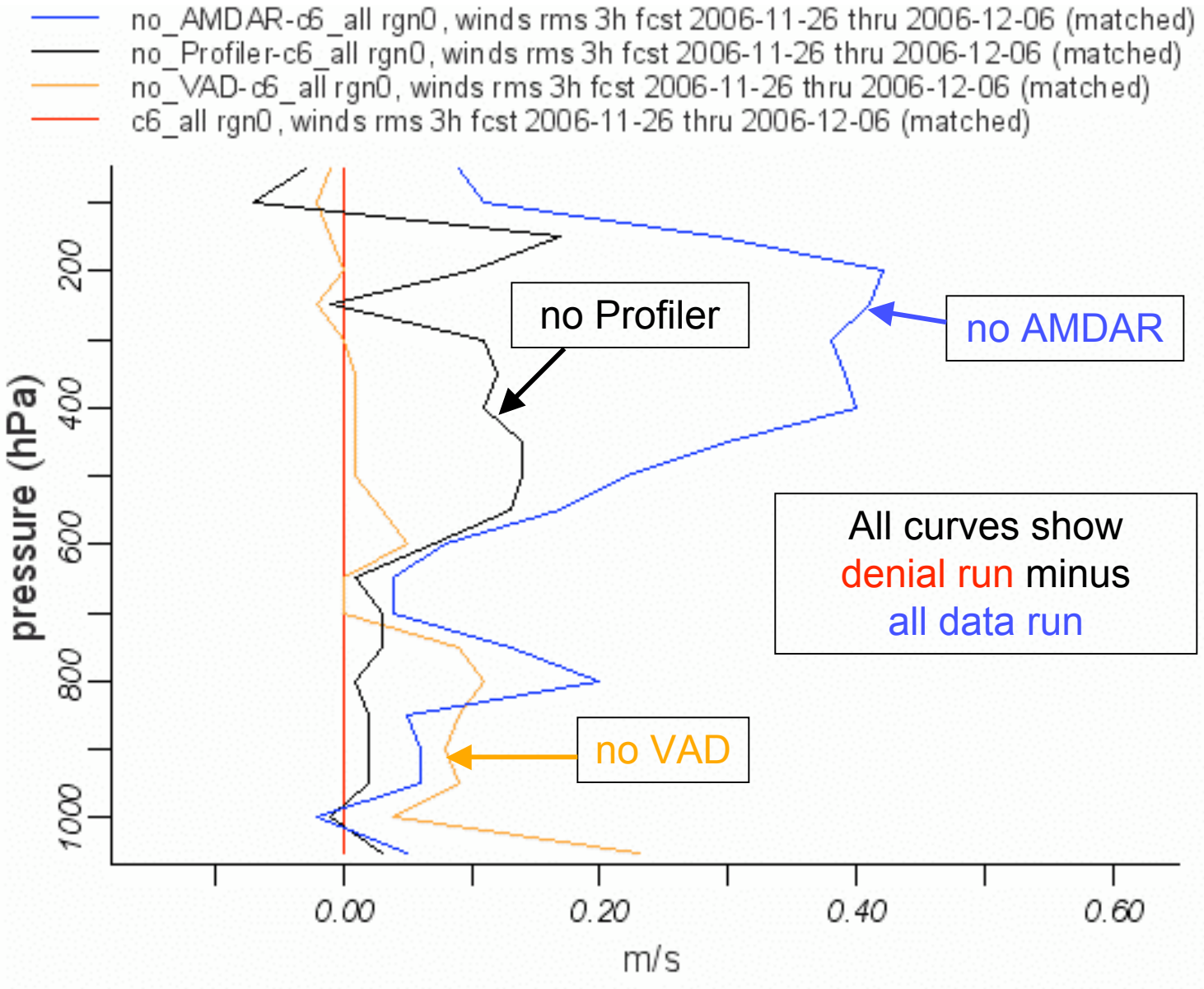
Retro runs:

- This case was originally assembled for our TAMDAR studies
  - allowed us to tune TAMDAR RH assimilation procedures
  - this increased the TAMDAR RH impact notably
- The case is also being used to study other RUC data assimilation modifications
  - examples follow

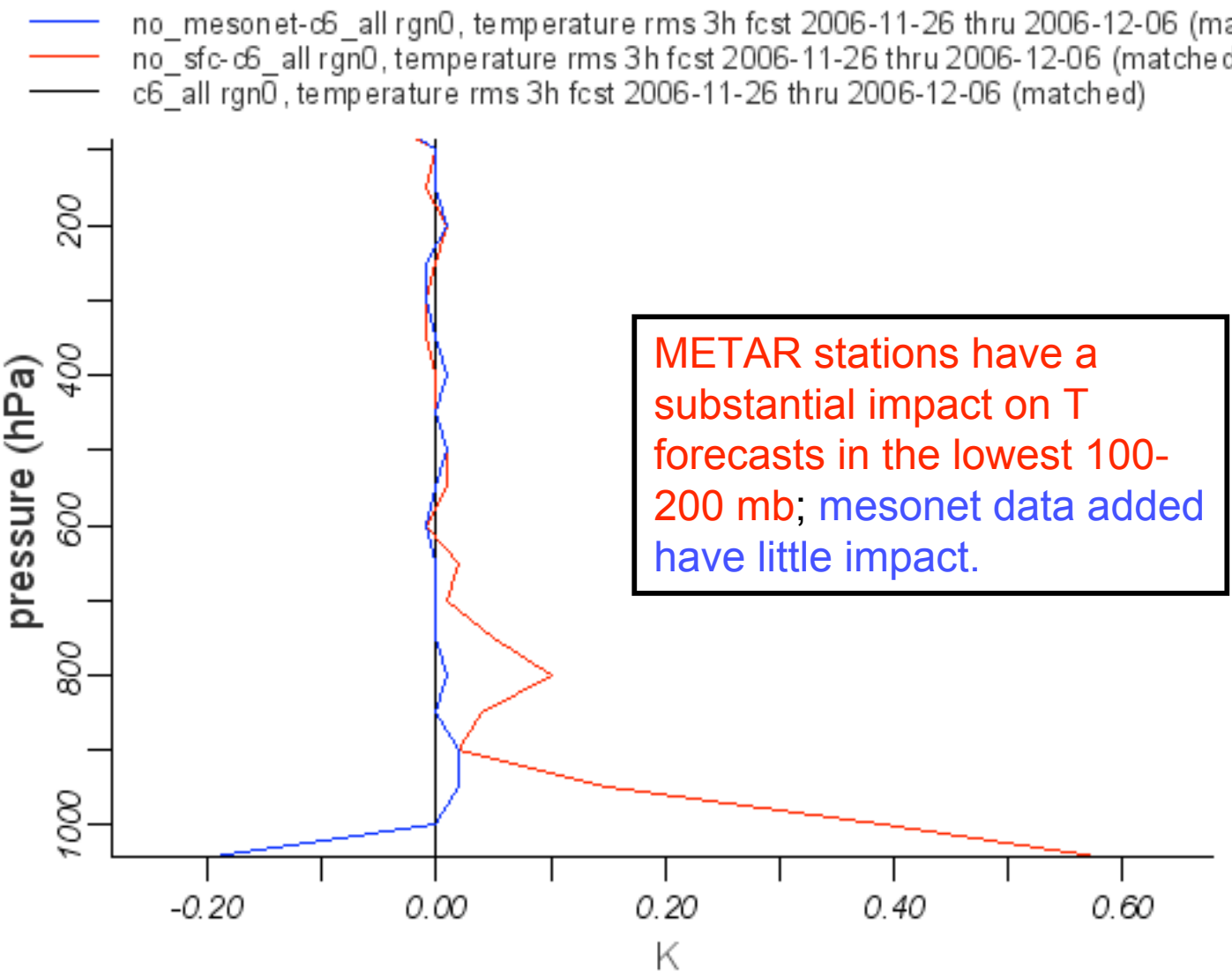
Other Retrospective Observing System Experiments

- no Profilers
- no Aircraft
- no VAD
- no surface observations
- No mesonet
- no RAOBs
- no GPS Precipitable Water (GPS-IPW)
- Several other tests of assimilation schemes

Wind Impact: AMDAR, Profiler, VAD. National Region

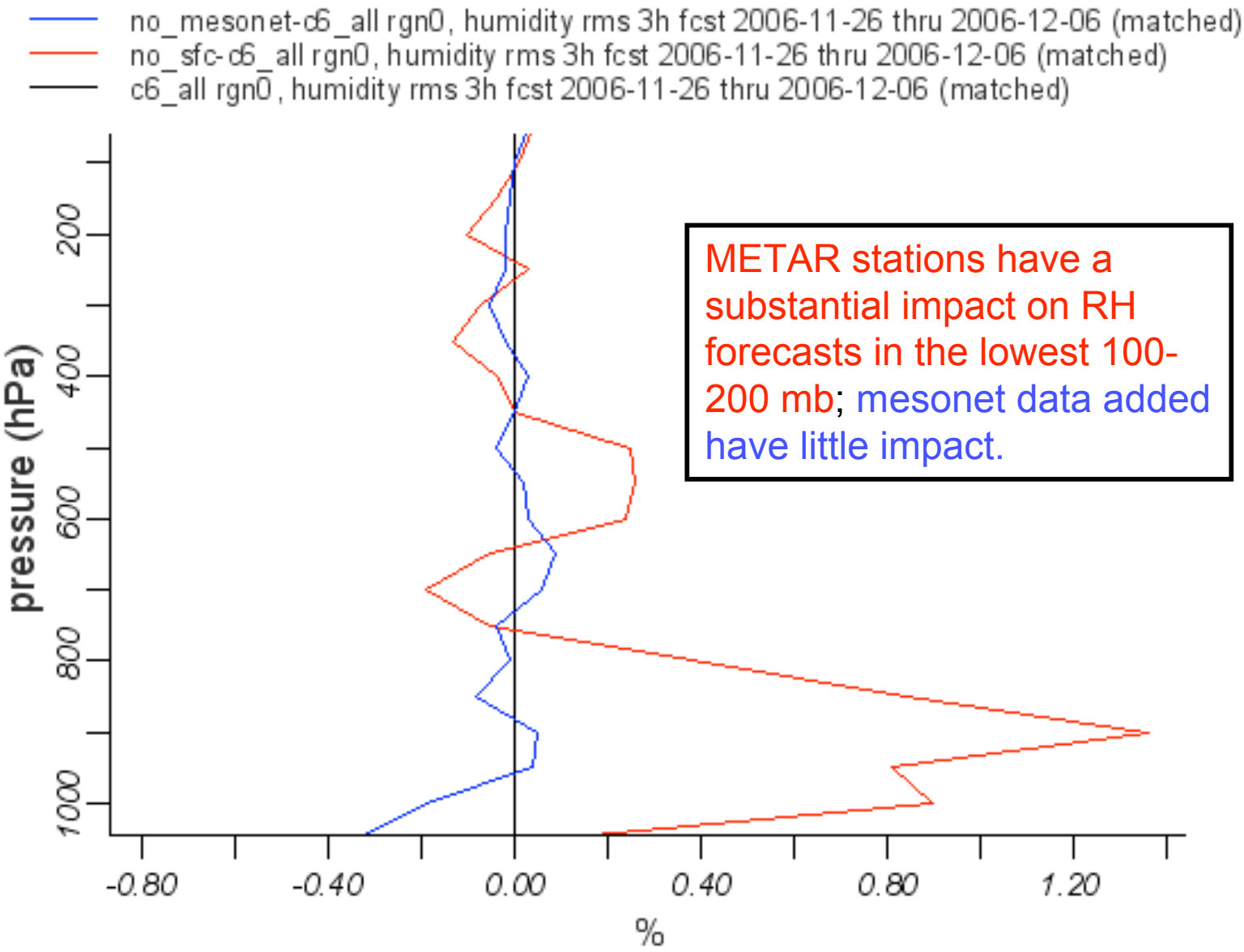


Low-altitude impact on Temperature: surface observations



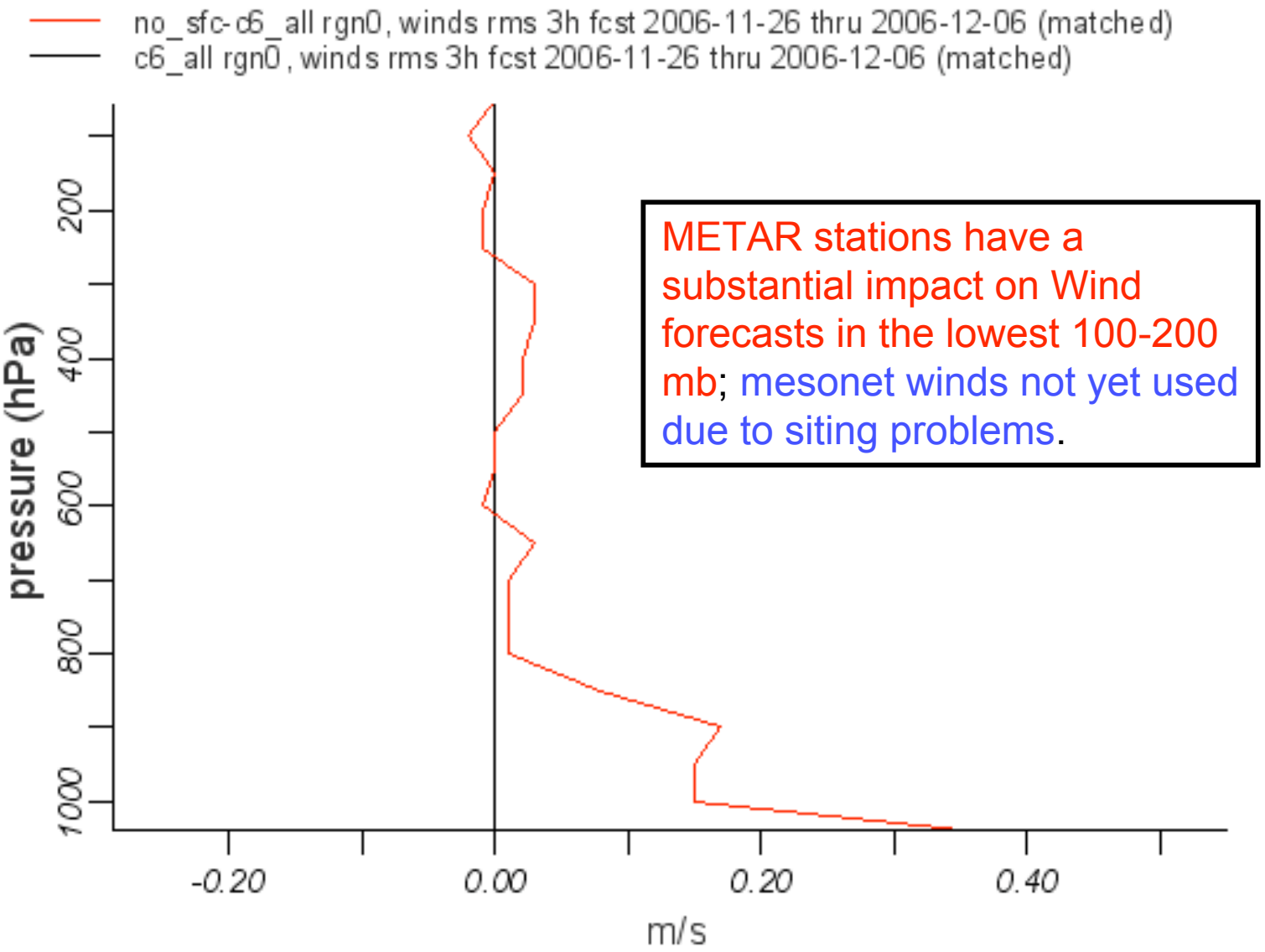
METAR stations have a substantial impact on T forecasts in the lowest 100-200 mb; mesonet data added have little impact.

Low-altitude impact on Relative Humidity: surface observations



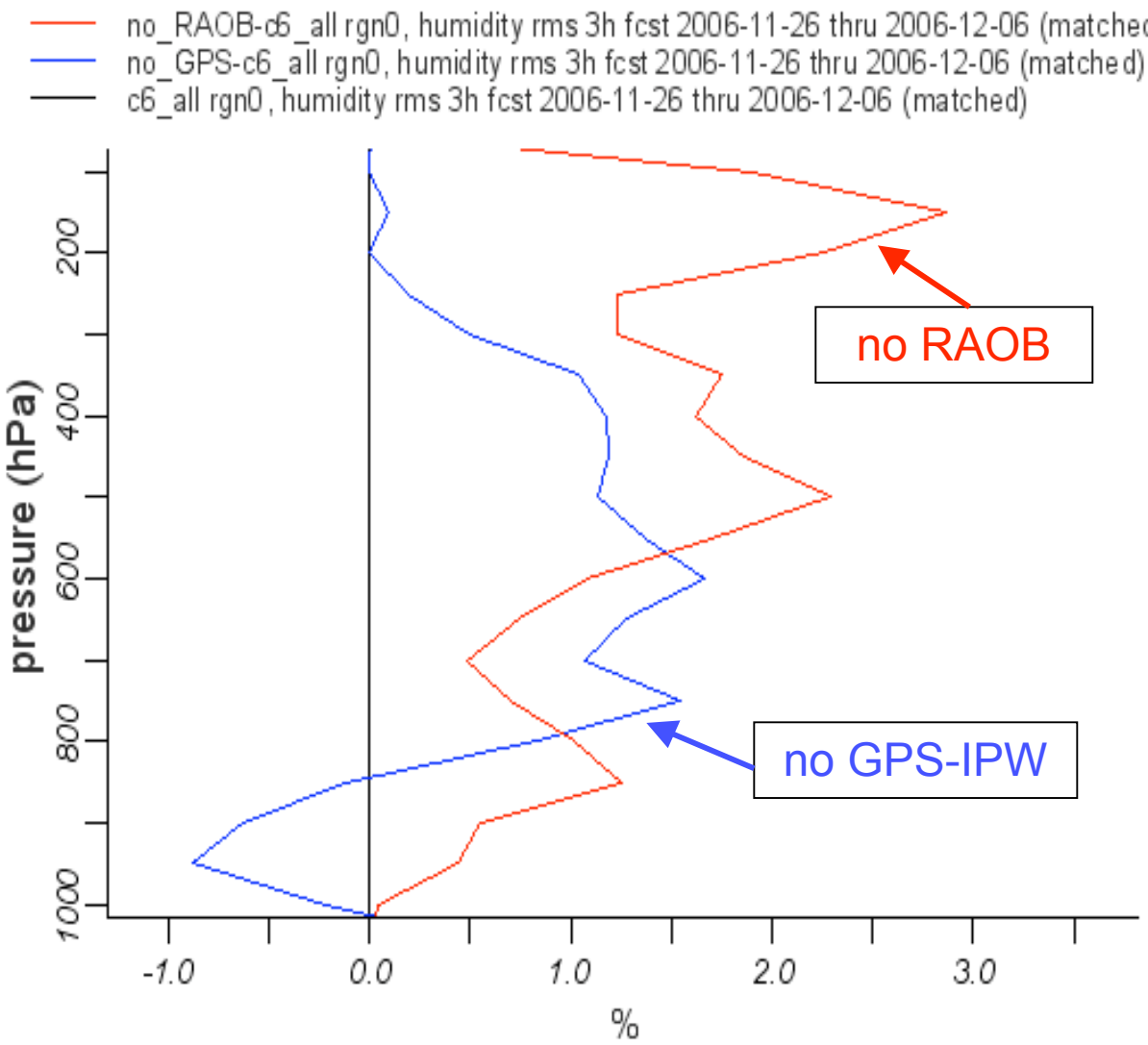
METAR stations have a substantial impact on RH forecasts in the lowest 100-200 mb; mesonet data added have little impact.

Low-altitude impact on Winds: surface observations



METAR stations have a substantial impact on Wind forecasts in the lowest 100-200 mb; mesonet winds not yet used due to siting problems.

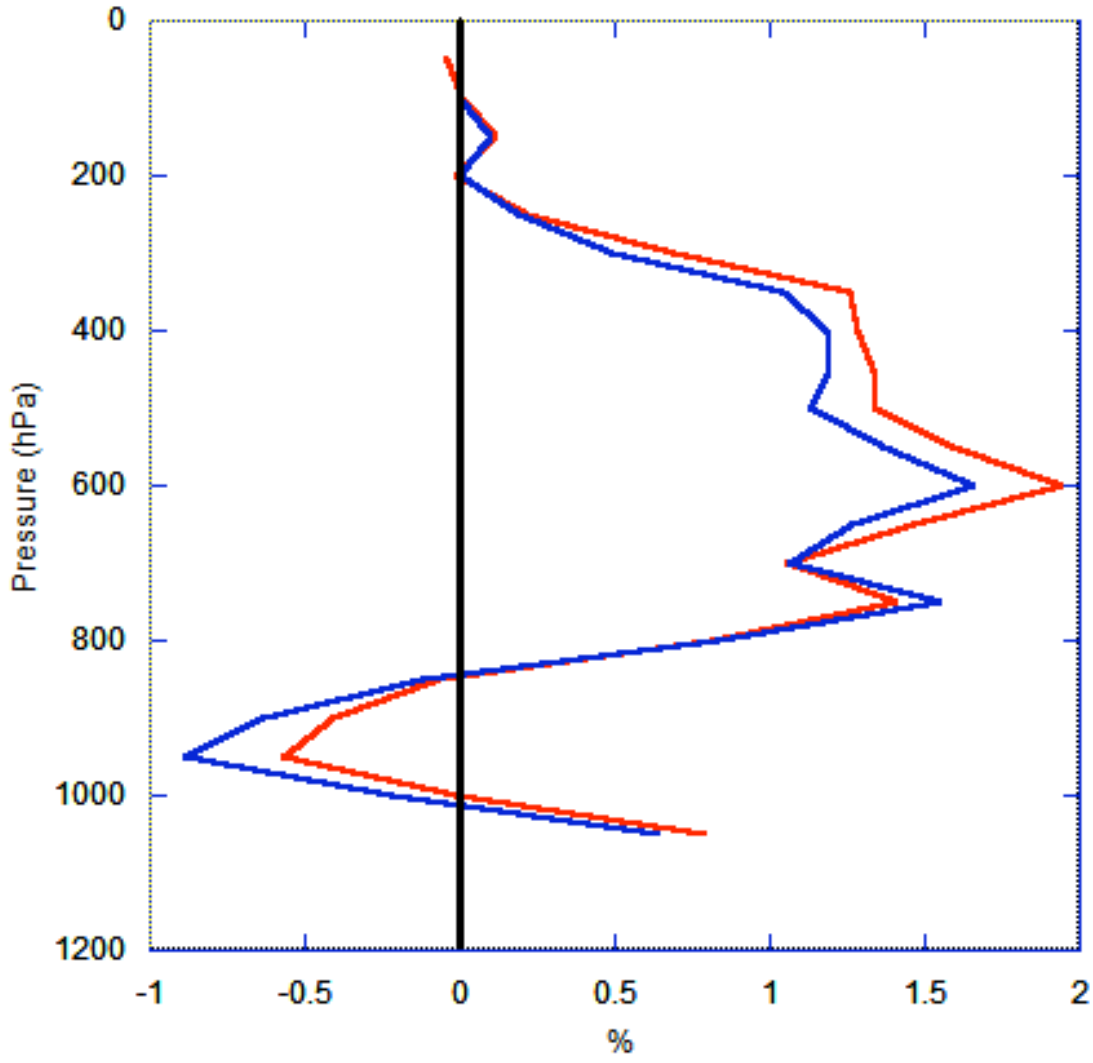
Relative humidity impact: no RAOB, no GPS-IPW



GPS-IPW impact on RH forecasts is **substantial and similar to RAOB impact in the mid-troposphere.**

However, at low levels, GPS-IPW impact was negative, so we developed and tested some changes in moisture assimilation (next slide)

GPS-IPW Humidity impact: old assimilation (blue, as in previous slide), new assimilation (red).



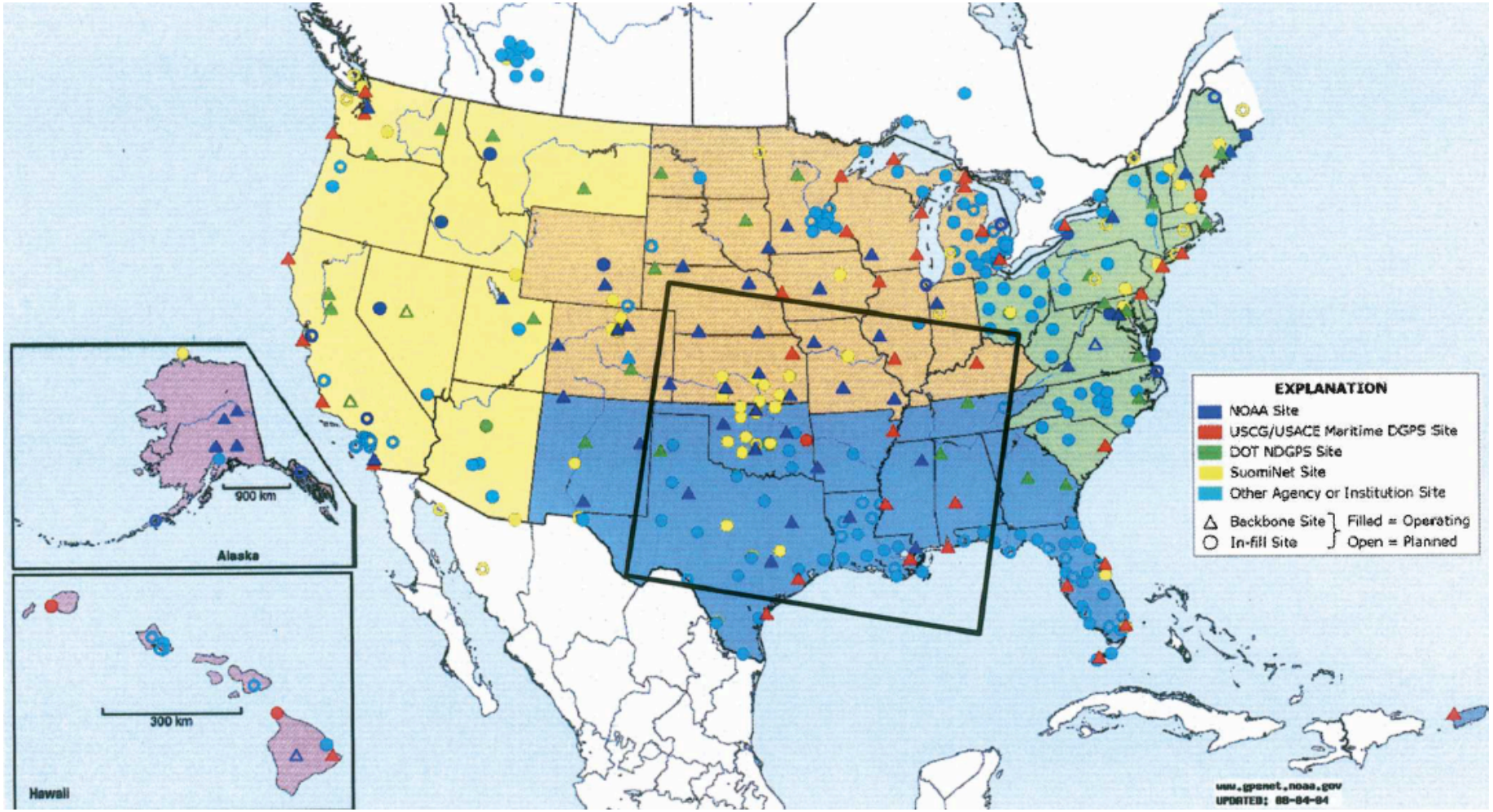
Modified PW assimilation background error increases the impact (red curve). This modification is part of the upcoming change package for the **operational RUC**.

A broader example: GPS-IPW impact

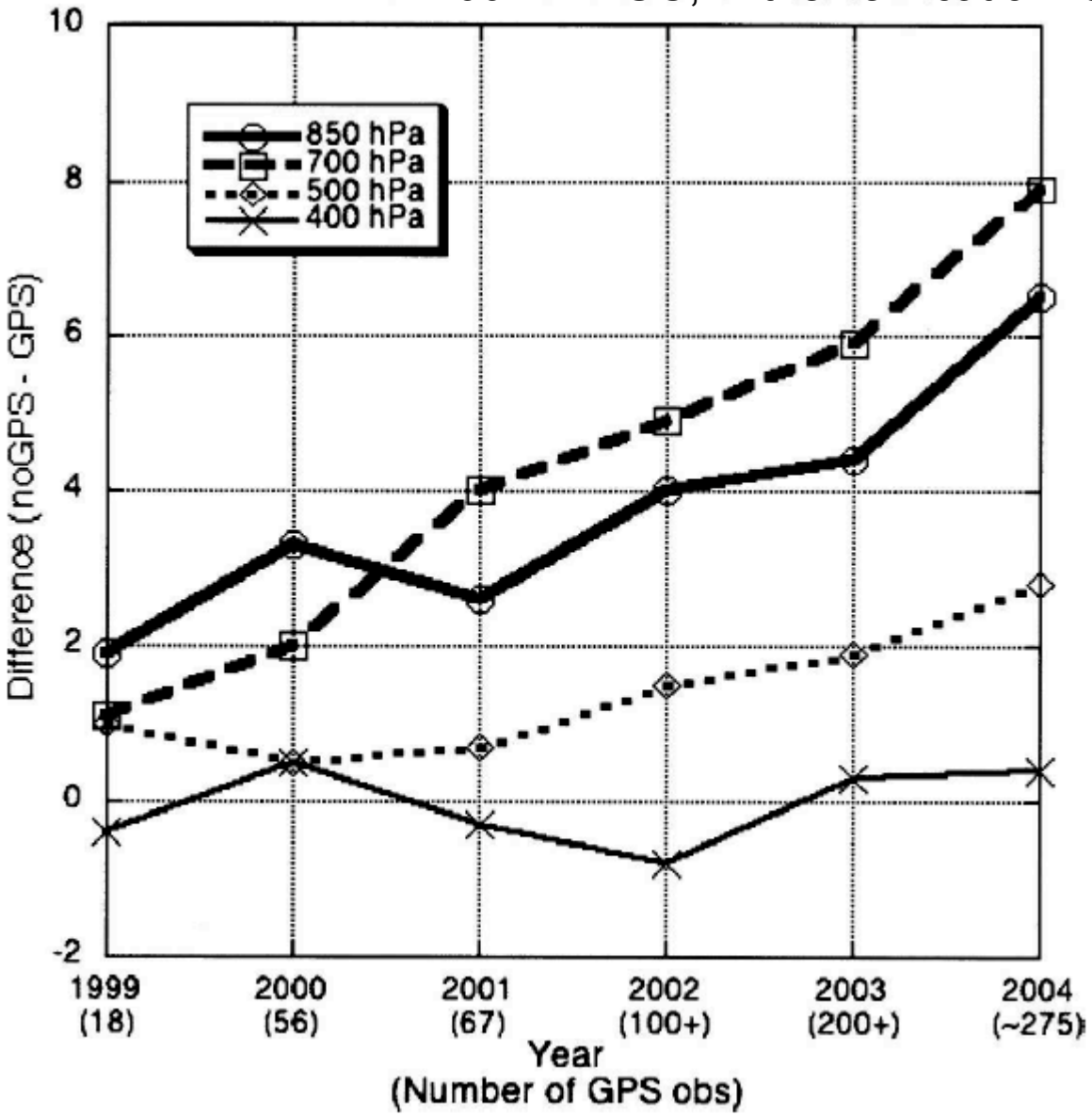
- We consider a multi-year time period, during which the GPS network expanded
- We consider multiple forecasts
- “Normalized impact”
- Published by Tracy Smith et al. (2007) in Monthly Weather Review:

Short-Range Forecast Impact from Assimilation of GPS-IPW Observations into the Rapid Update Cycle

GPS-IPW verification region (black box)
(this region was also used for Profiler Network OSEs)



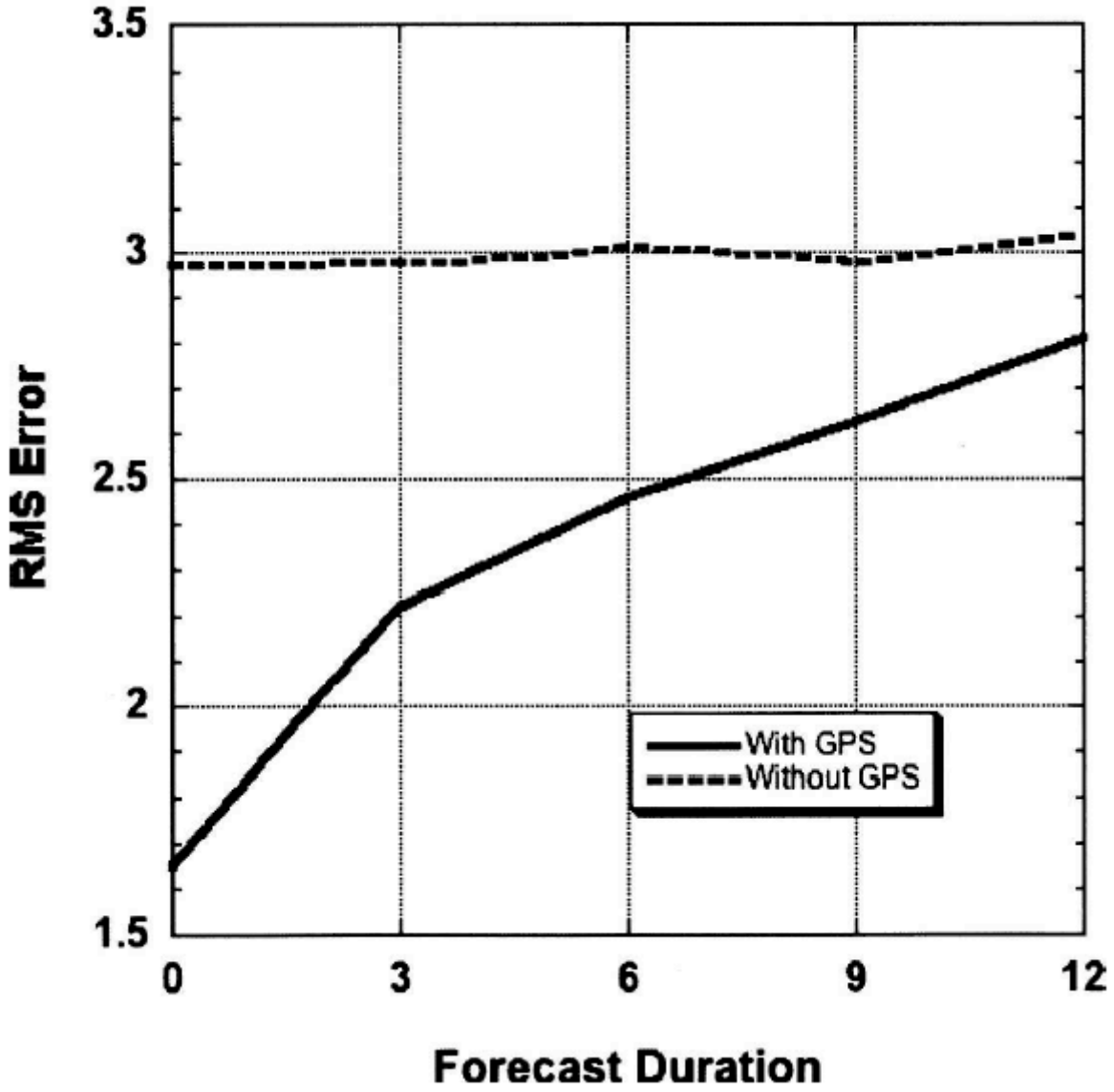
Normalized impact of GPS-IPW on 3-hr RH forecasts,
60 km RUC, in the verification region



This longer time period shows positive impact at all levels since 2003, in the GPS-IPW verification region.

20 km RUC, National Domain

IPW error, Mar-May 2004



Improvement due to GPS is greatest for shortest forecasts, and persists out to 12 hr forecasts.

We expect even greater impact with the new PW assimilation scheme resulting from our recent retrospective studies.

Conclusions (1)

- The RUC is an excellent platform for performing Observing System Experiments
  - Runs hourly, so is ideal for continuously-reporting data systems
  - Ingests a complete set of observations, so provides **realistic** impact estimates
- Parallel real-time runs can provide critical information on the impact of evolving operational systems, such as TAMDAR and GPS-IPW
- Retrospective runs can provide detailed information on the impact of
  - various data systems
  - different assimilation strategies
- **The impact of any data system depends critically on the data assimilation strategies used.**
- Considerable computing power is required for these studies. We're very fortunate to have access to this power here at GSD.

Conclusions (2)

- These studies have led to changes in **operational systems**
  - The TAMDAR Mesaba fleet is now **operational**
  - GPS-IPW is expecting a new infusion of resources
  - 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.

RUC/Rapid Refresh Technical Review - OUTLINE

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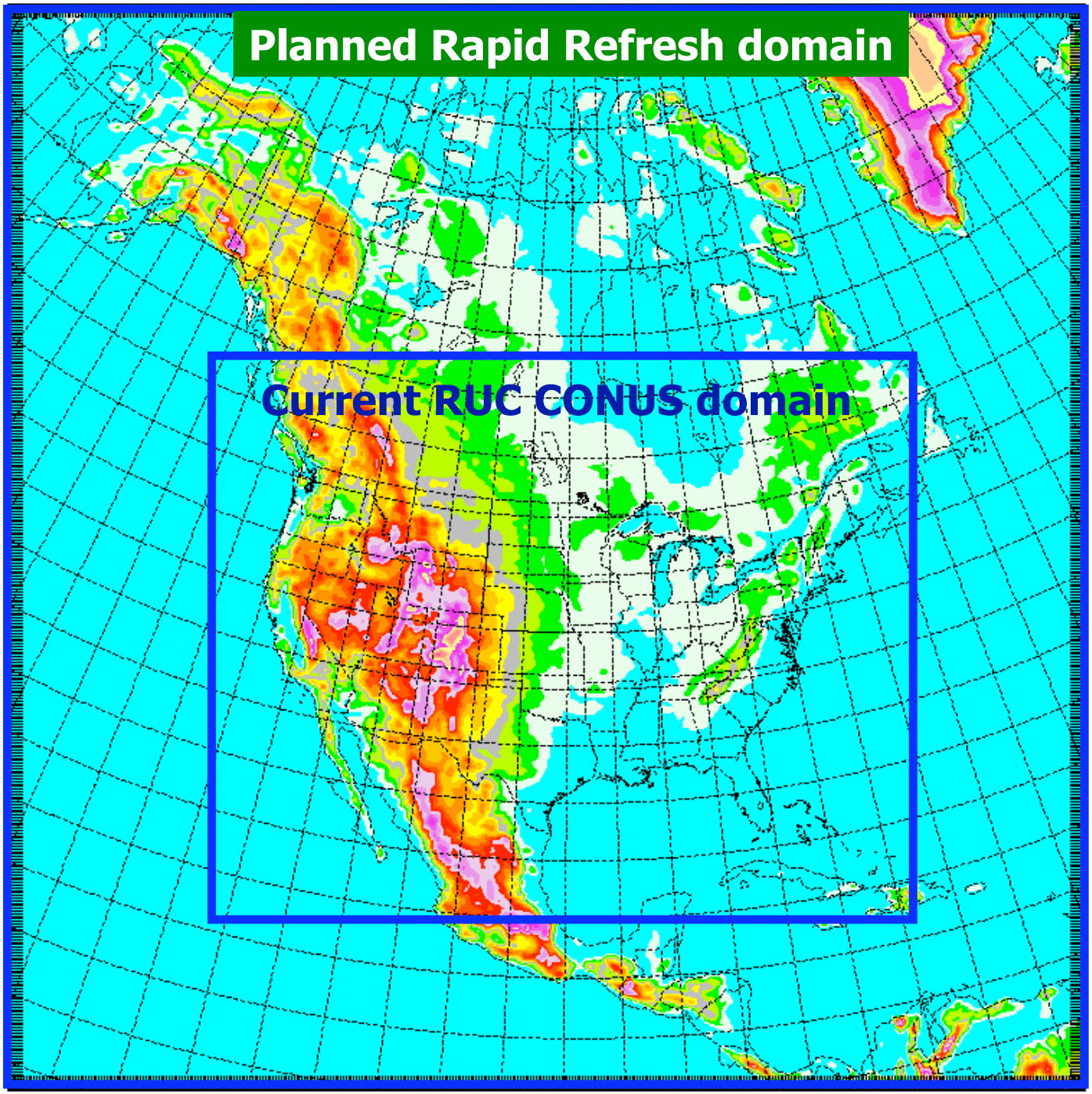
RUC ⇩ Rapid-Refresh (2009)

Continental situational awareness model

Hourly NWP Update for:
- CONUS
- AK/Can
- Pac/Atl
- Caribbean



RUC to Rapid Refresh

- **CONUS domain (13km)** → **North American domain (13km)**
- **RUC model** → **WRF model (dynamic core in question until Sept 07)**
- **RUC 3DVAR** → **GSI (Gridpoint Statistical Interpolation)**

Some History of the Rapid Refresh

- **2003-2005 - WRF-RUC testing (WRF initialized with RUC initial conditions)**

- **2006 - Controlled ARW, NMM core comparison**
  - **Result: Physics interoperability between cores**
  - **RUC init conditions (incl. clouds) - 13km CONUS domain**
  - **Controlled retrospective for all 4 seasons (help from DTC)**
  - **GSD-AMB recommended use of ARW core by slight margin in Aug. 2006**

RR-core-test comparison experiments
ESRL/GSD and DTC (Dev. Testbed Center)

- GOAL: Recommendation from GSD to NCEP/EMC on preferred version of WRF core …

  Choices
  - ARW
  - NMM

•Focus on ~13km/50-60 levels, short-range (1-12h), aviation/severe-weather application

VIA

- *Fully controlled* core-test comparisons
  - Requires use of same physics suite in each core
- Use of RUC initial conditions (clouds, assim of sfc obs, etc.)

Contributors to WRF-RR core-test evaluation project

Louisa Nance (DTC)

Chris Harrop (GSD-DTC)

Ligia Bernardet (DTC-GSD)

Meral Demirtas (DTC)

James Pinto (NCAR-RAL)

Marcia Politovich (NCAR-RAL)

Ben Bernstein (NCAR-RAL)

Paul Herzegh (NCAR/RAL)
Richard Bateman, Jenny Simard (NCAR/RAL)

Roy Rasmussen (NCAR/RAL)

Greg Thompson (NCAR/RAL)

Bob Sharman (NCAR/RAL)

Rod Frehlich (NCAR/RAL)
Bruce Carmichael (NCAR/RAL)
Jimy Dudhia (NCAR/MMM)
Wei Wang (NCAR/MMM)
Dave Gill (NCAR/MMM)

Tanya Smirnova (ESRL/GSD)

John Brown (ESRL/GSD)

Stan Benjamin (ESRL/GSD)

Kevin Brundage (ESRL/GSD)
Randy Collander (GSD-DTC)

Georg Grell (ESRL/GSD)

Ed Szoke (ESRL-GSD)

Jennifer Mahoney (ESRL/GSD)

Andy Loughe (GSD-DTC)

Steve Koch (DTC)

Robert Gall (DTC)

Nelson Seaman (NWS)

Matt Pyle (NCEP/EMC)
Brad Ferrier (NCEP/EMC)
Tom Black (NCEP/EMC)
Hui-ya Chuang (NCEP/EMC)

Goal for RR core test

-- two sets of physical parameterizations

(GFDL radiation used for both)

- Phase 1 - Default NMM physics (thought to be "easiest")
- Phase 2 - RUC-like physics

	Phase 1	Phase 2
Explicit clouds	Ferrier	Thompson-NCAR
Sub-grid convection	Betts-Miller-Janjic	Grell-Devenyi
Land-surface	F77 version of Noah ("99" LSM)	RUC-Smirnova
Turbulent mixing	Mellor-Yamada-Janjic	Mellor-Yamada-Janjic

ARW advantages

Major advantages

- Upper-level wind. This is apparent in aircraft verification. Rawinsonde verification (where ARW advantage was even stronger) is considered flawed.
- Lower-troposphere temperature
- Lower-troposphere relative humidity, primarily at 850 hPa, considered to be potentially important for icing and ceiling forecasts.
- Turbulence (see objective verification results)

Secondary advantages

- Community involvement – Currently more significant with ARW testing and applications than with NMM. This may be different after additional NMM community exposure via DTC, workshops, etc.

NOAA/ESRL/GSD recommendation to NCEP– 1 Sept 2006

Excerpts:

By a slight margin, the ARW core over the NMM core for the initial operational Rapid Refresh implementation .

- Some significant advantages evident for one core or the other, dependent on variable or vertical level, with a slight edge for ARW overall, but …
- No strong overall advantage for either.
- GSD will fully support NCEP decision, regardless of which core chosen. We urge your careful consideration of the comparison results in the report.

(**http://ruc.noaa.gov/coretest2/GSD-report.pdf**)

- RUC physics (Grell-Devenyi convection, NCAR-Thompson microphysics) ready to go for either NMM or ARW cores

June 06 - Physics availability **due to** WRF-RR Core-Test Project -- all now in WRF v2.2

	NMM	ARW
Ferrier microphysics	✓	✓
NCAR-Thompson microphysics	✓	✓
MYJ PBL	✓	✓
BMJ conv	✓	✓
Grell/Dev conv	✓	✓
Option 99 LSM	✓	✓
Noah LSM	--	✓
RUC LSM	✓	✓
RUC init conds	✓	✓

NCEP/GSD Agreement on Rapid Refresh - signed 12 September 2007

- **2009 – Initial Rapid Refresh – Phase 1**
  - **Model - WRF-ARW, Rapid Refresh physics**
  - **Data assimilation – GSI with RR-unique enhancements**
  - **13km resolution**
  - **Submitted for operations by Sept 2009**

- **2012 – Ensemble Rapid Refresh – Phase 2**
  - **6 members, 3 each using ARW and NMM**
  - **Model (ARW, NMM) and GSI will use ESMF framework, not WRF framework**
  - **Model/assimilation systems from GSD and NCEP**
  - **Will still be at 13km resolution**

RUC to Rapid Refresh

- CONUS domain (13km) → North American domain (13km)
- RUC model → WRF model (ARW dynamic core)
- RUC 3DVAR → GSI (Gridpoint Statistical Interpolation)

Transitioning to operations (RUC, RR)

- Code must run at NCEP
- Must run within available computer resources and time constraints

  (RUC - 5 min – assim, 17 min- 12h fcst)
- Must be built into existing code infrastructure

  (e.g.: Build assimilation capability within GSI, develop hourly probabilistic forecast products within NCEP SREF framework)

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Rapid-Refresh Model Configuration and Testing

Tanya Smirnova
Georg Grell
Steven Peckham
John Brown

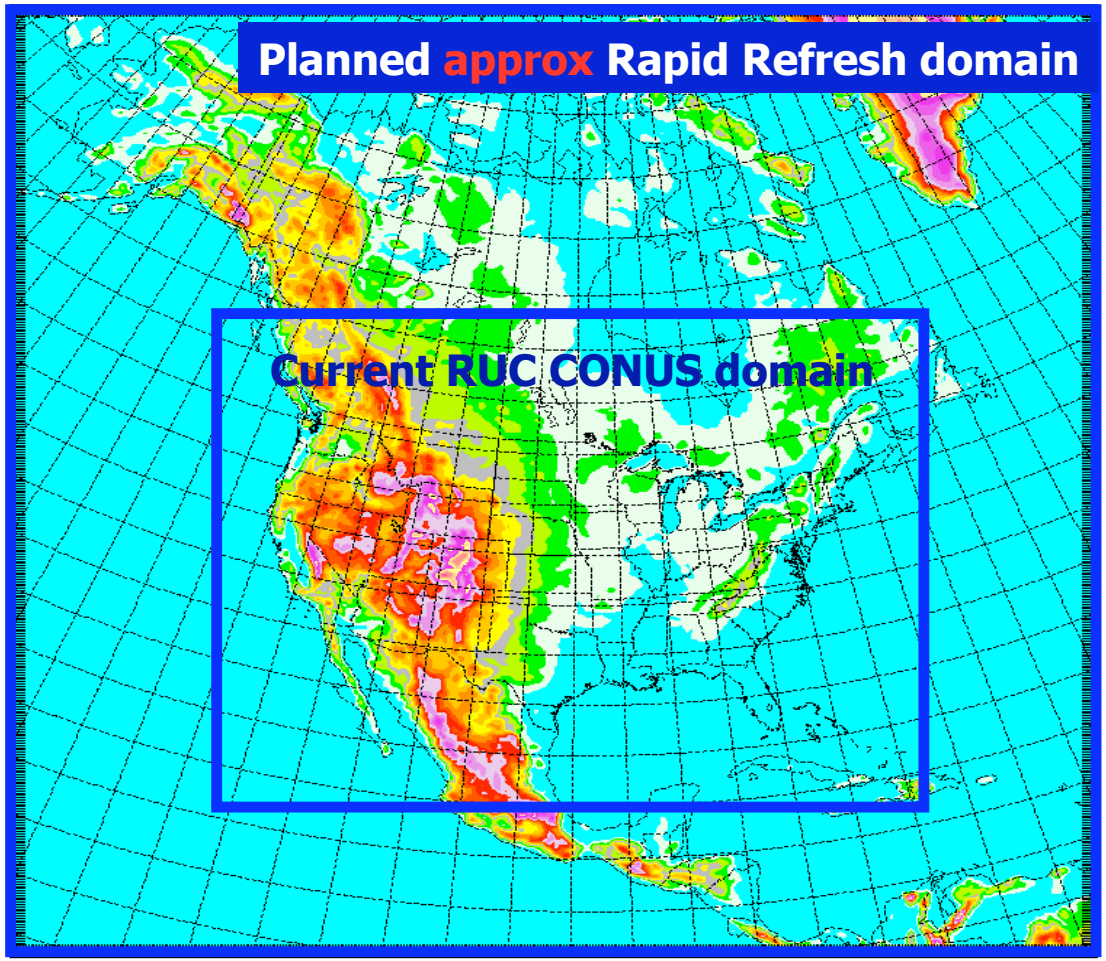
WRF-ARW Configuration
Physics
New GSD Digital Filter Initialization

Rapid-Refresh Domain and Grid

Constraints on domain

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

Lambert-Conformal
649 X 648 X 50 layers
Δx = 13.5km
Δt = 60s



WRF Model Configuration

WRF-ARW v2.2 (Dec 06, plus later repository enhancements)

Some namelist options:

- w_damping on - precaution against CFL violation in vertical
- No 6th order diffusion
- Smagorinsky first-order closure for horizontal diffusion
- Upper level wave-damping layer
  Effective in top 5km
  dampcoef = 0.02 (same as core test)
- 3-d divergence damping
- External-mode damping
- 5th order horizontal advection, 3rd order vertical advection
  positive definite for q_v and hydrometeors

default values

RR "RUC-Like" Physics Options

GFDL radiation (l/w and s/w, with cloud effects)

RUC Land-Surface Model => surface fluxes

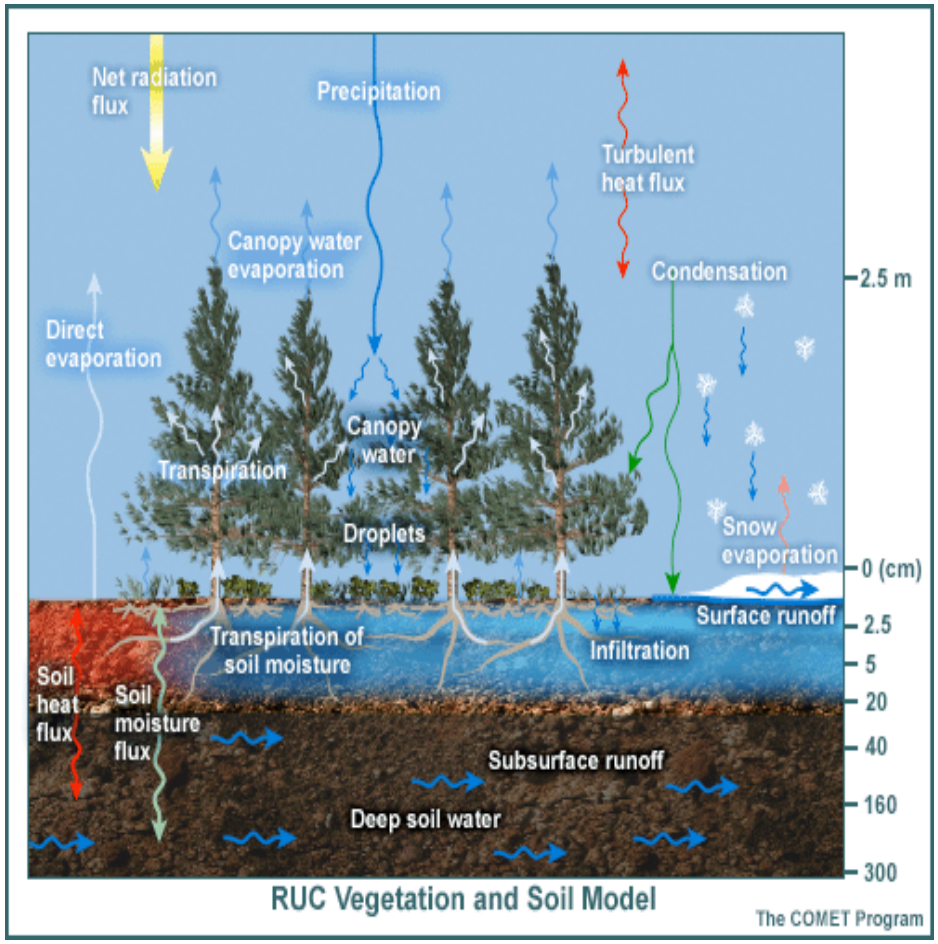
NAM (NCEP) surface layer and turbulent vertical mixing above surface layer

Grell-Devenyi convection

NCAR-Thompson microphysics

This is very similar to the physics configuration used in Phase 2 of the 2006 RR Core Test

Recent RUCLSM Changes



Increased density of snow on ground to ≥100 kg/m3 (from ≥50 kg/m^3) to reduce cold bias over fresh snow cover when temps are ≤ -15C.

Performance of RUCLSM as compared with Noah (NAM) LSM for 2-m temperature in snowmelt conditions is under investigation by DTC in collaboration with RR developers.

Grell-Devenyi Convection

Problems in operational RUC

- Excessive coverage of small precipitation amounts
- Heating-induced convective initiation too early in the day
- Despite detrainment of cloud hydrometeors, seldom initiates much grid-scale precipitation (drying at mid levels)
- Cold pools too weak; too slow (or nil) propagation of convective systems
- Fundamental issue: scale-separation between convection and larger scales (fundamental assumption) becomes less distinct at $\Delta x \leq 20$km

Grell-Devenyi Convection

Changes to address these issues

Reduce weight given to Arakawa-Schubert closure => helps a little the high bias of small amounts

Require smaller CIN for convective initiation => convection starts later

No longer treat individual grid columns independently: spread "compensating subsidence" into adjacent grid columns => contributes to more realistic initiation of grid-scale precip (and associated subcloud evaporation and cooling).

These will be introduced into RR version of Grell-Devenyi scheme

Grell-Devenyi Convection

Problems in Oct-2007 NCEP operational RUC

- Excessive coverage of small precipitation amounts

- Heating-induced convective initiation too early in the day

- Despite detrainment of cloud hydrometeors, seldom initiates much grid-scale precipitation (drying at mid levels)

- Cold pools too weak; too slow (or nil) propagation of convective systems

- Fundamental issue: scale-separation between convection and larger scales (fundamental assumption) becomes less distinct at $\Delta x \leq 20$km.

Grell-Devenyi Convection

Changes to address these issues

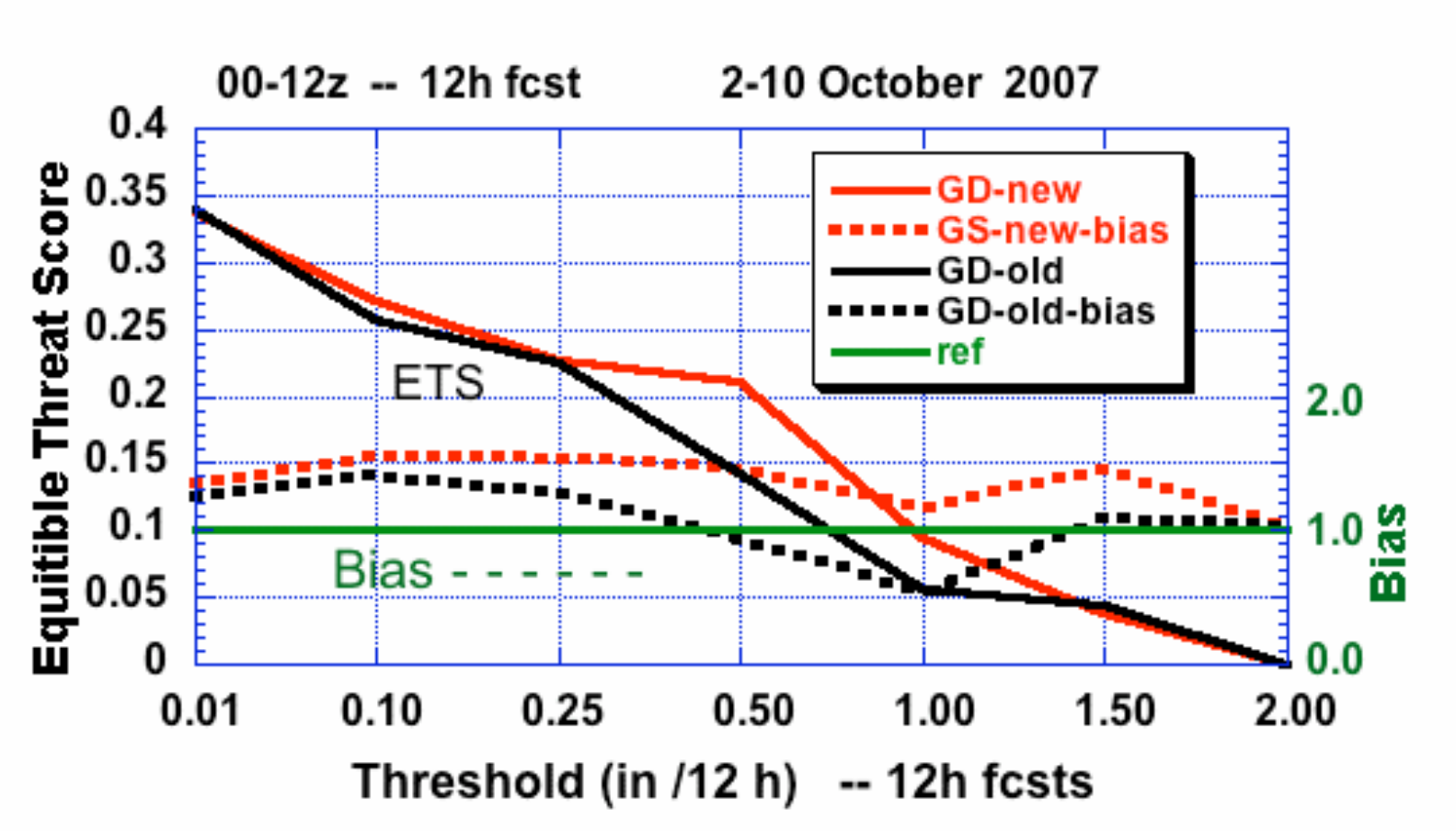
Reduce weight given to Arakawa-Schubert closure
Result: Reduces the high spatial coverage bias of small amounts

Use smaller depth for cap adequate to deny convective initiation

Result: convection starts later in diurnal cycle

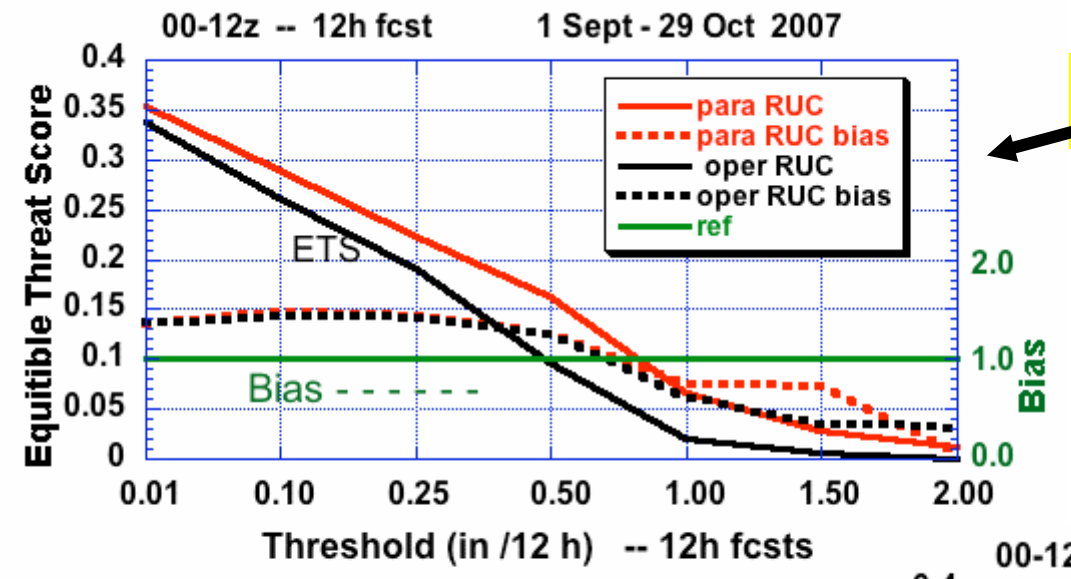
No longer treat individual grid columns independently: spread "compensating subsidence" into adjacent grid columns => contributes to more realistic initiation of grid-scale precip (and associated subcloud evaporation and cooling).

Grell-Devenyi Convection-- effect of non-local subsidence warming



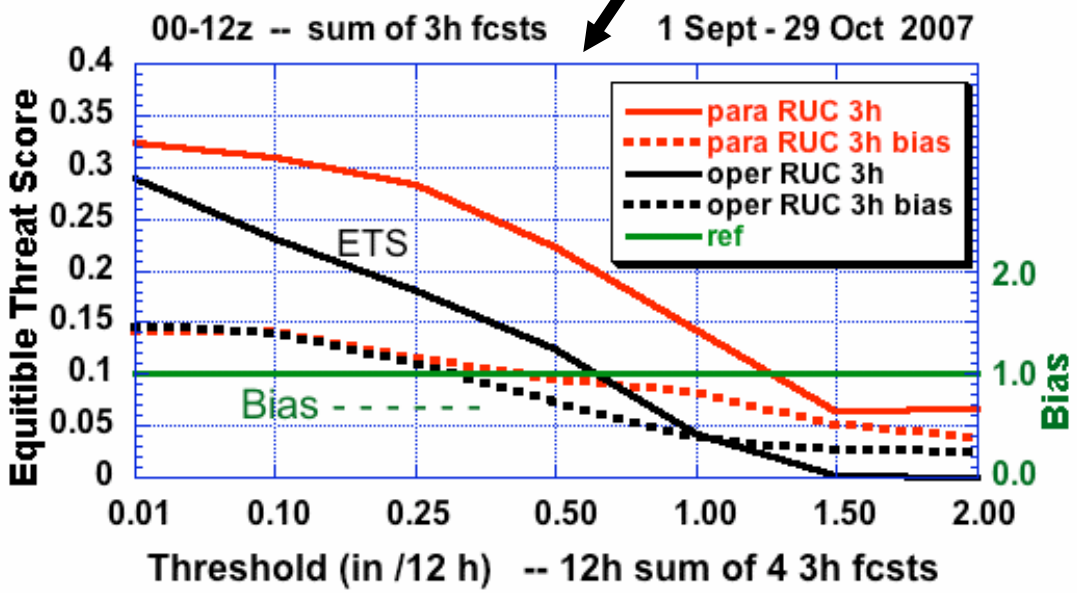
Adds further to the improvement shown on the next slide ….→

Overall improvement in precip forecasts - parallel RUC vs. NCEP oper RUC



12h forecast,

3h forecast



Large improvements due to

- **Radar reflectivity assimilation**
- **Improvements in Grell-Devenyi scheme**
- **Other para changes**

NCAR-Thompson Microphysics

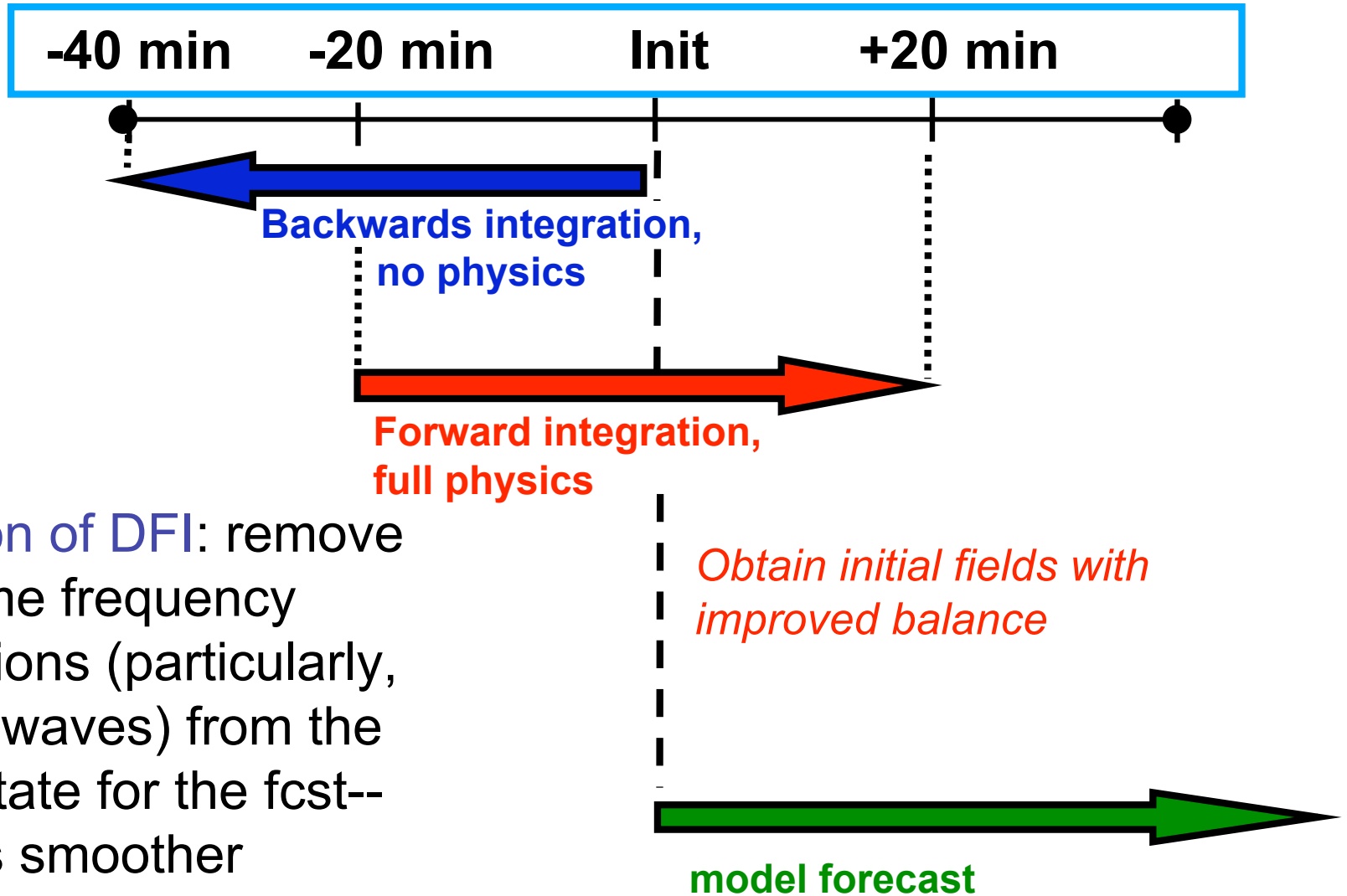
RUC uses Dec 2003 version of scheme

Version in WRF v2.2 (plus more recent bug fixes) has many changes

- Snow particles assumed to be more 2-d than spherical (affects deposition, collision and fall speed)
- Revised collection of snow and graupel by rain
- Rain drop-size distribution depends on estimate of origin of rain (melting snow or collision-coalescence)
- Extensive use of lookup tables
- Gamma distribution for all pcpn hydrometeors

What we have seen: Less graupel than Dec 2003 version, more cloud ice and snow

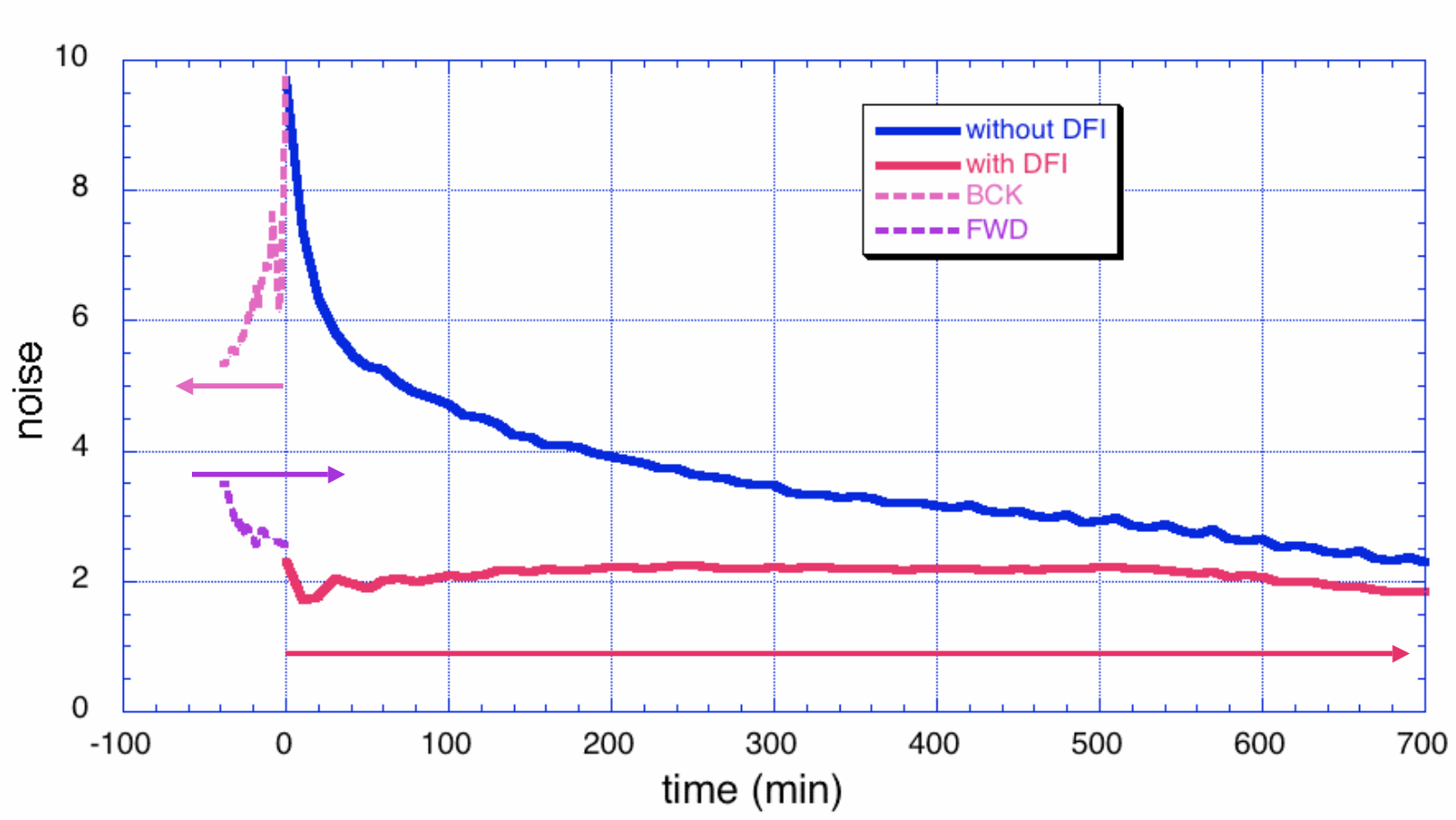
Diabatic Digital Filter Initialization (DDFI)
- Application into WRF - recently completed for ARW
(Tanya Smirnova, Steve Peckham)



Function of DFI: remove high time frequency oscillations (particularly, gravity waves) from the initial state for the fcst--creates smoother background for next analysis

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

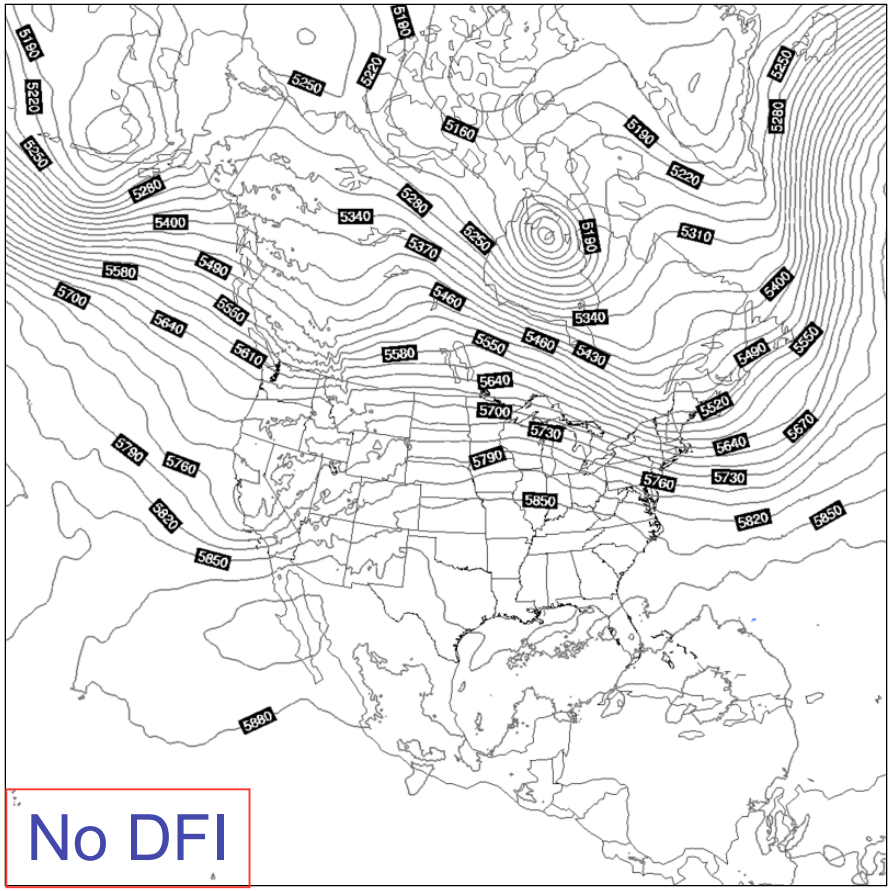
$$\left| \frac{\partial p_{sfc}}{\partial t} \right|$$

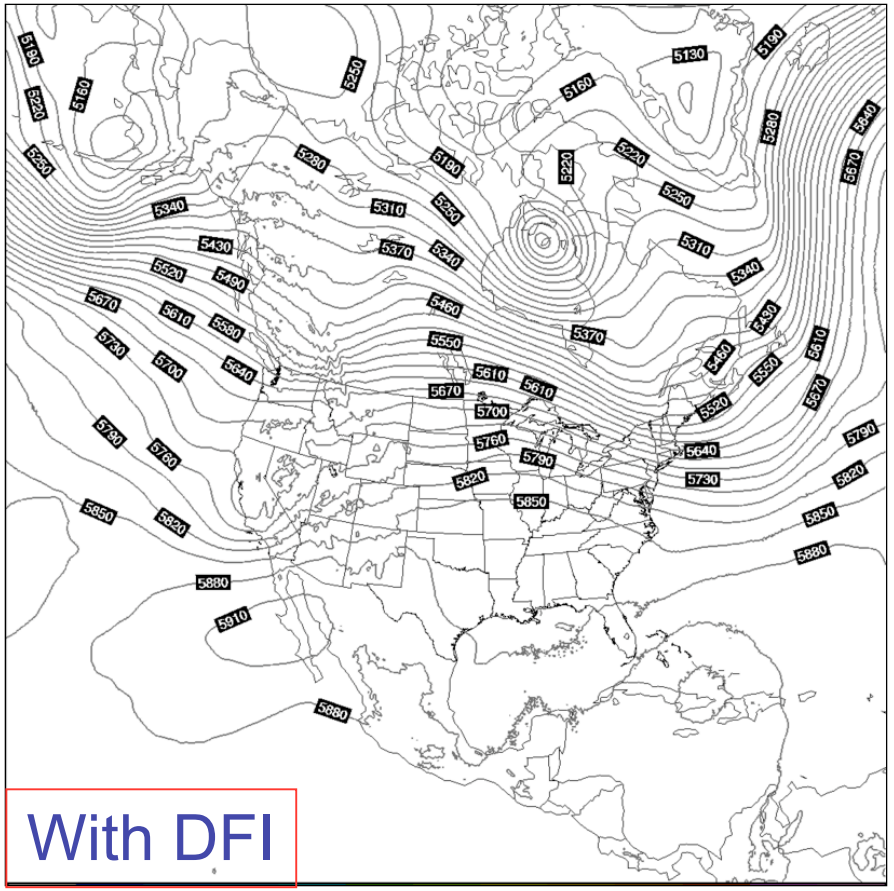


Using WRF-13km Rapid Refresh over N. American domain

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

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





Example of DFI Addition to namelist.input

&dfi_control

- dfi_opt = 1,
- dfi_fwdstop_year = 2007,
- dfi_fwdstop_month = 09,
- dfi_fwdstop_day = 05,
- dfi_fwdstop_hour = 00,
- dfi_fwdstop_minute = 20,
- dfi_fwdstop_second = 00,
- dfi_bckstop_year = 2007,
- dfi_bckstop_month = 09,
- dfi_bckstop_day = 04,
- dfi_bckstop_hour = 23,
- dfi_bckstop_minute = 40,
- dfi_bckstop_second = 00,
- runlength_dfi_fwd = 40,
- runlength_dfi_bck = 40

```
!#ifdef DFI
  if(config_flags%dfi_opt .NE. 0) then

! Initialization for backward integration
      wrf_err_message = ' WRF: Backward Digital Filter turned on '
      CALL wrf_message(TRIM(wrf_err_message))

CALL wrf_DFI_bck_init

      CALL wrf_run

      CALL wrf_DFI_array_reset

! Initialization for forward integration
      wrf_err_message = ' WRF: Forward Digital Filter turned on '
      CALL wrf_message(TRIM(wrf_err_message))
      CALL wrf_DFI_fwd_init

      CALL wrf_run

      CALL wrf_DFI_array_reset

!   if(config_flags%dfi_opt .NE. 0) then

! need to reset config_flags%dfi_opt to 0 for the WRF model run
      CALL wrf_DFI_reset_init
  endif
!#endif

  ! WRF model time-stepping.  Calls integrate().
   CALL wrf_run

   ! WRF model clean-up.  This calls MPI_FINALIZE() for DM parallel runs.
   CALL wrf_finalize
```

Code added to wrf.F to accommodate diabatic DFI within a single WRF executable

RUC/Rapid Refresh Technical Review - OUTLINE

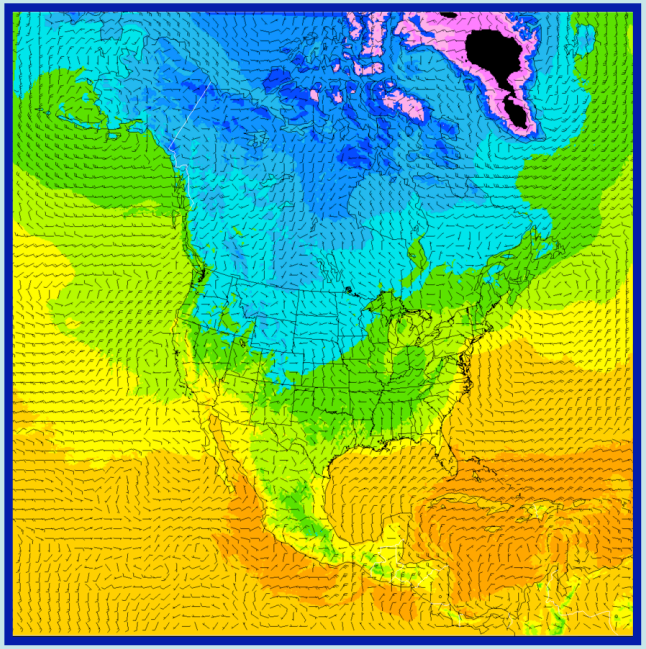
1:30 - 1:50	RUC upgrade - assim - radar reflectivity, mesonet/RTMA, physics - Stan Benjamin
1:50 - 2:15	Observation assessment activities - TAMDAR aircraft obs w/ moisture, larger obs sensitivity experiment (OSE) - Bill Moninger, Brian Jamison
2:15 - 2:25	Rapid Refresh background - core, NCEP - Stan
2:25 - 2:35	-- Break --
2:35 - 2:50	Rapid Refresh model description testing - ARW core, physics, DFI - John Brown
2:50 - 3:15	RR assimilation w/ GSI, Details on RUC/RR/HRRR convection Steve Weygandt
3:15 - 3:25	Future of Rapid Refresh Stan Benjamin

Rapid Refresh assimilation with GSI

Steve Weygandt
Dezso Devenyi
Ming Hu

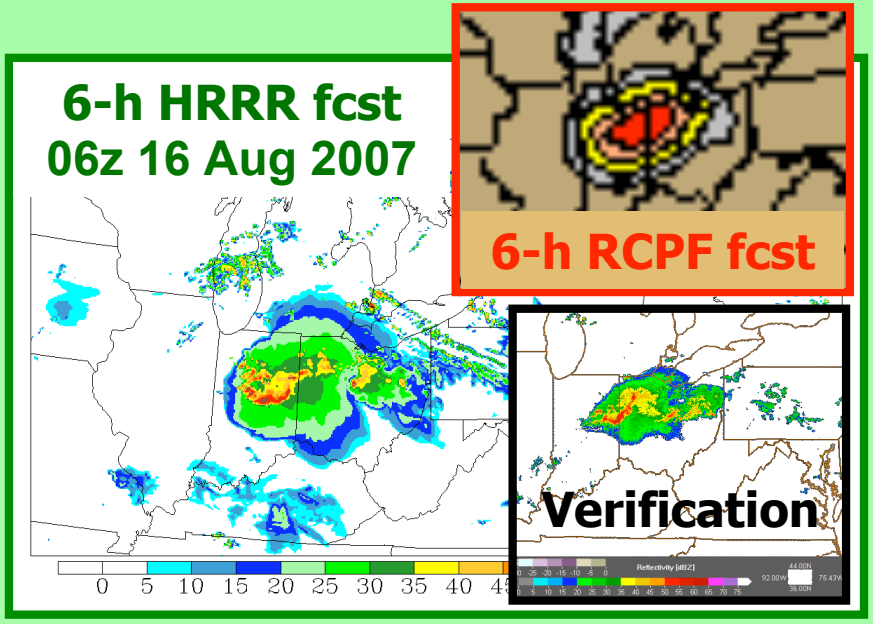
6-h fcst surface temp. 12z 27 Oct 2007

WRF ARW Cycled with GSI



Convection forecasting with HRRR and RCPF

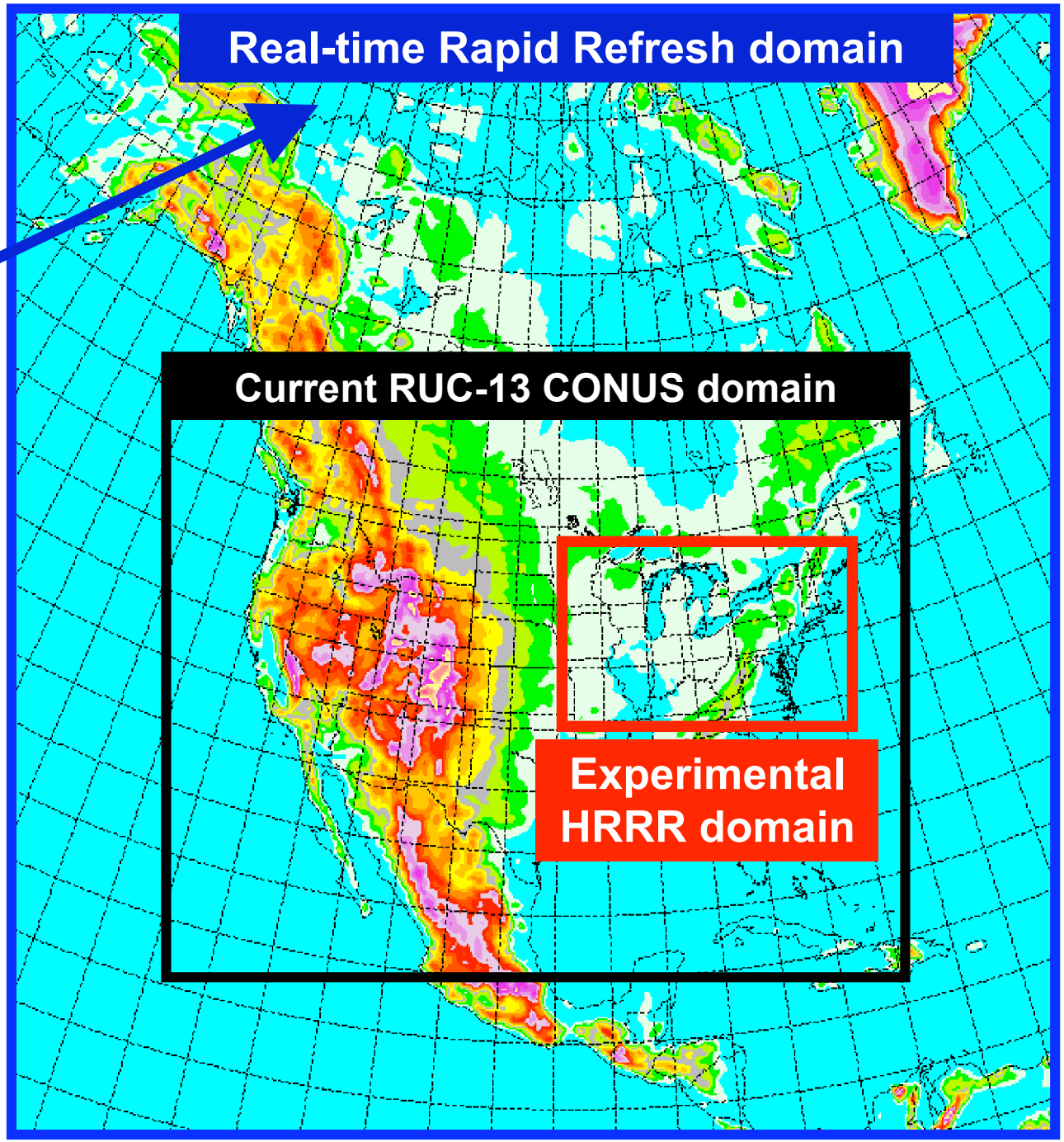
Steve Weygandt
Tanya Smirnova



RUC, Rapid Refresh and HRRR domains

Rapid Refresh domain

- Cycling on full North American domain
- Eventually update every hour, include satellite data
- Consistent hi-res, frequently updated grids for all of North America



Background on GSI for RR
(Gridpoint Statistical Interpolation)

- **Adapted from successful Spectral Statistical Interpolation (SSI) used for global model at NCEP**
  - **Used for operational NAM, becoming NOAA unified analysis**
  - **Collaborative work with NASA, JCSDA (20+ researchers)**
- **Includes full satellite radiance assimilation**
- **For expanded RR domain (much ocean area), start with existing, mature analysis system (GSI)**
- **Build in "RR-specific" components:**
  1) **1-h cycling including cloud/precip and LSM fields**
  2) **Cloud analysis (satellite, METAR, radar, LTG obs)**
  3) **surface obs assimilation (BL depth, coast-lines)**
  4) **Force convection from radar, lightning data in model DDFI**
  5) **Mesoscale error covariances and balance constraints**

Use of Satellite Data within GSI

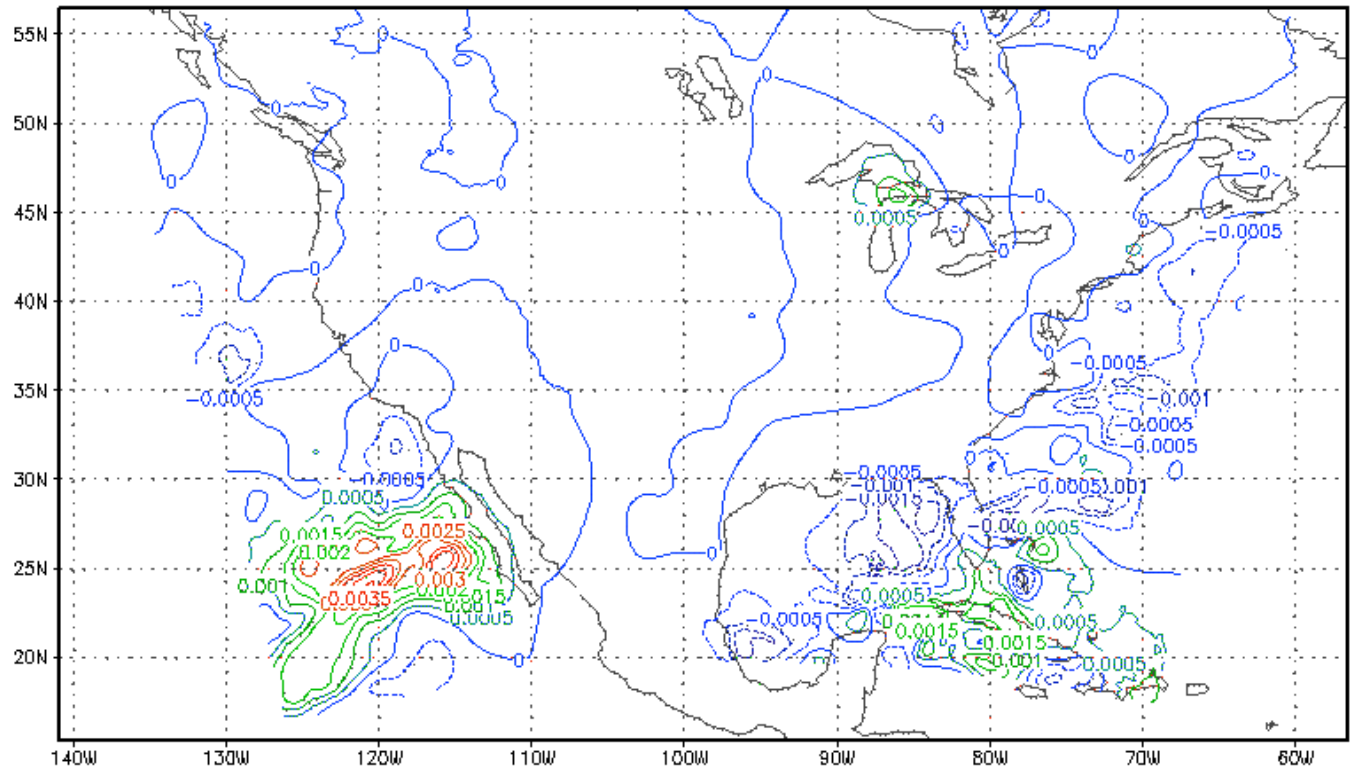
Both HIRS and MSU -- Use of Community Radiative Transfer Model (CRTM)

Preliminary experiments with NAM satellite radiance and bias files over CONUS domain using RUC background fields. Case of 11 April 2006, 1200 UTC.

Difference

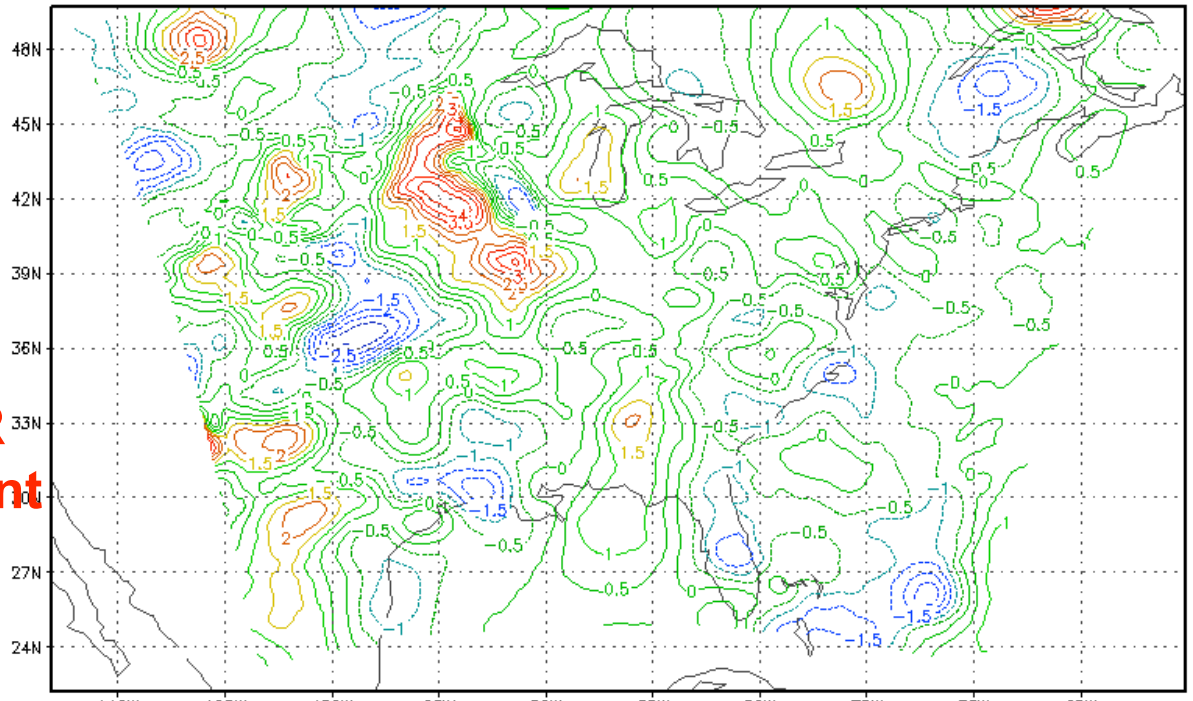
satellite minus no-satellite data; specific humidity.

Model level=10.



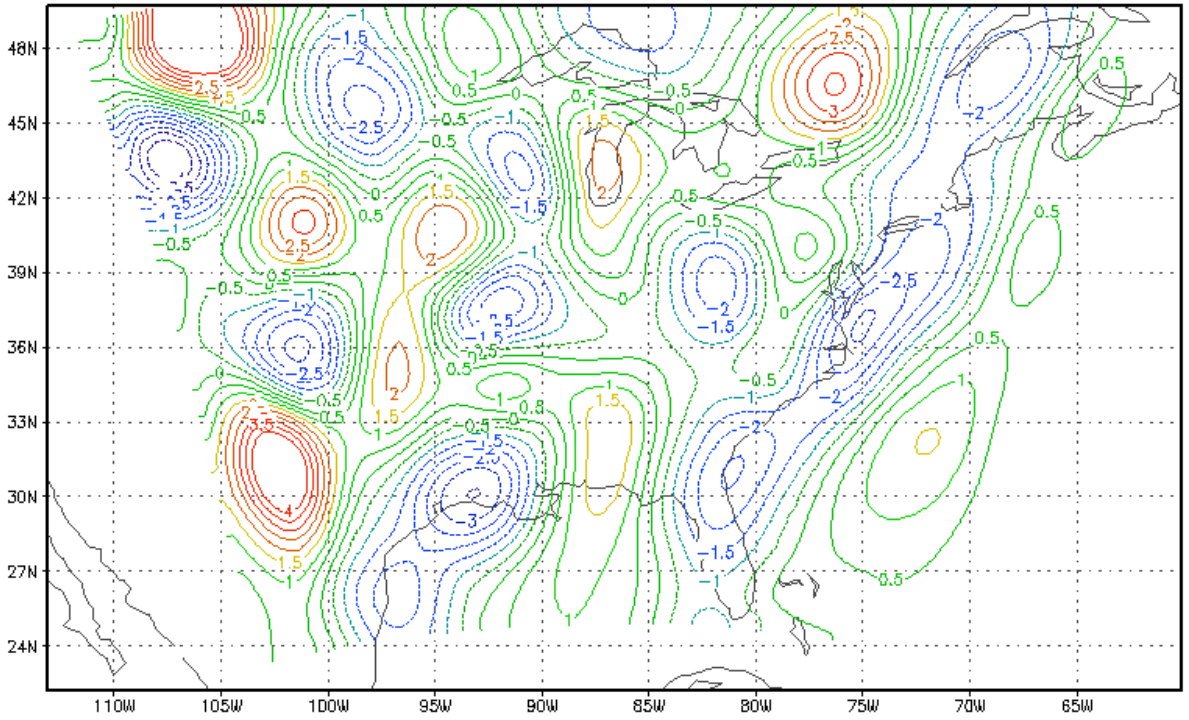
GSI analysis increments (with NAM background error covariances) smoother than RUC

RUC 3DVAR increment

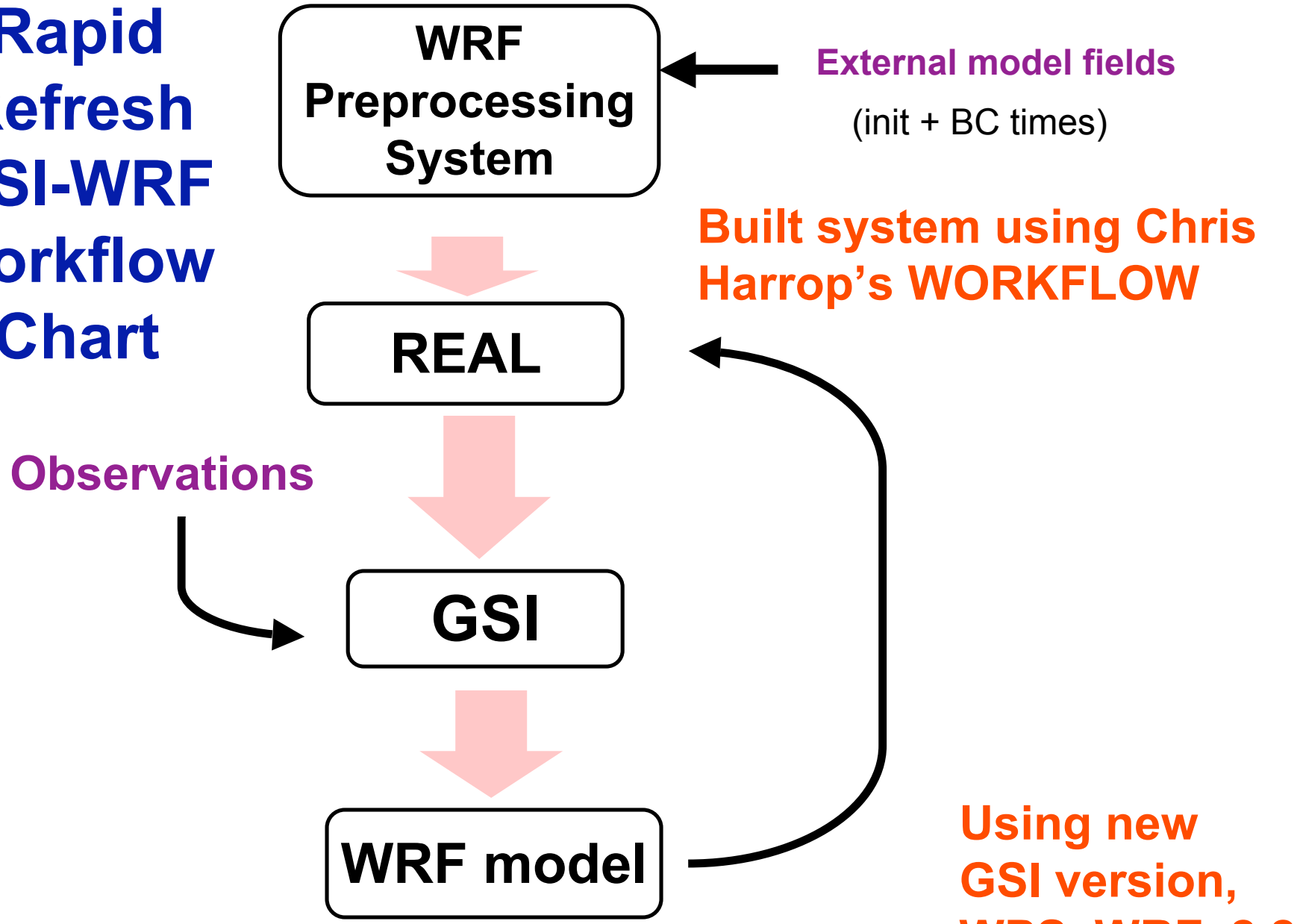


Model level=20 v-component of wind

GSI 3DVAR increment



Rapid Refresh GSI-WRF workflow Chart

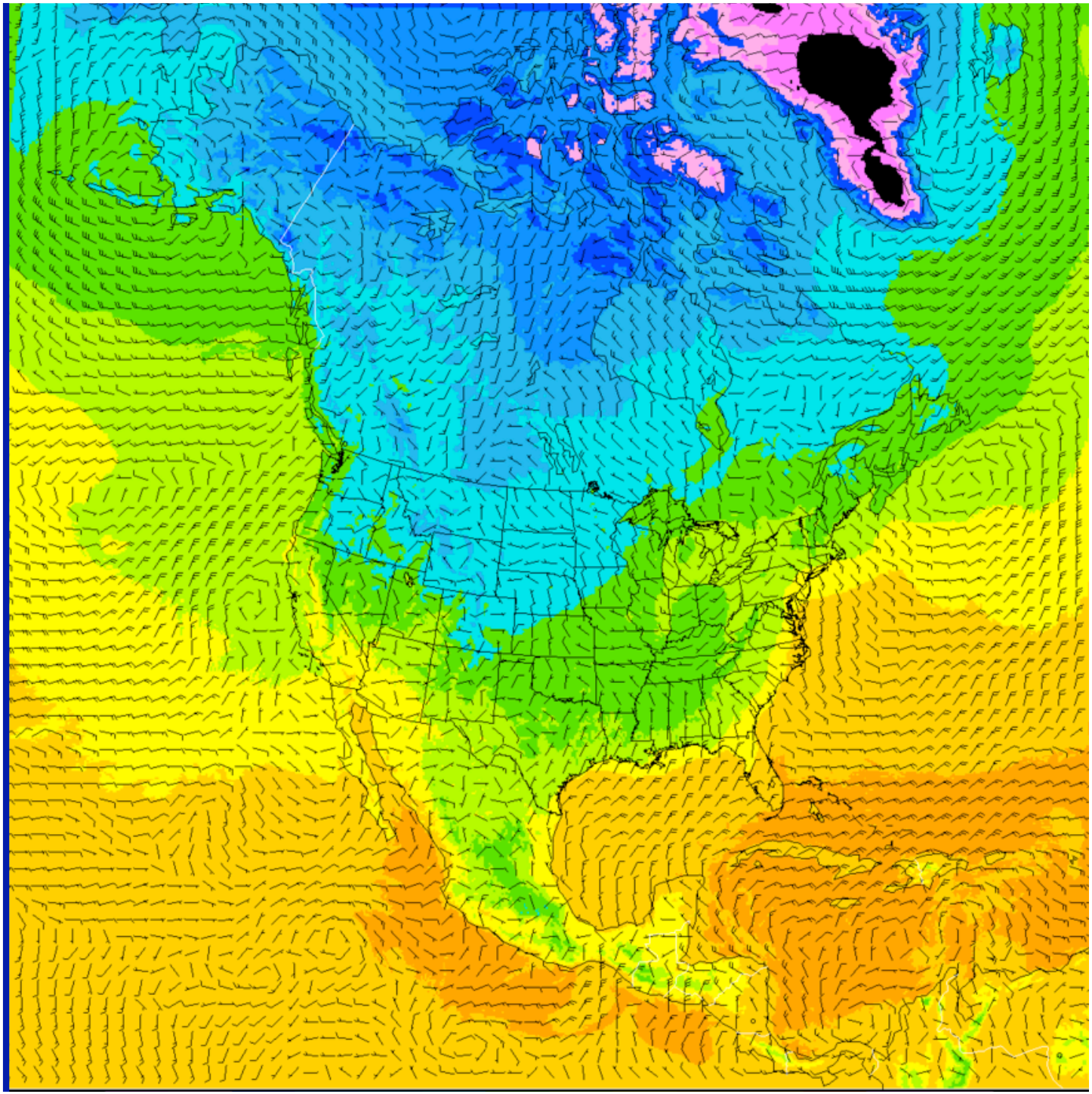


Combined Effort to get RR cycle (GSI + WRF) running on wJET

- **Numerous computer issues with GSI**
  - **Optimized to work on NCEP IBM supercomputer**
  - **Significant parallel I/O issues for other computers**
  - **Major issues from security patch (Aug. 2007)**
- **Major effort by numerous people**
  - **Jacques Middlecoff, Chris Harrop**
  - **Leslie Hart and entire jet management team**
- **Major progress late Oct. 2007**
  - **Updated wjet kernels for MPI (24 Oct.)**

Two RR 13-km cycles (6-h full domain, 3-h CONUS domain) running as of 27 Oct.

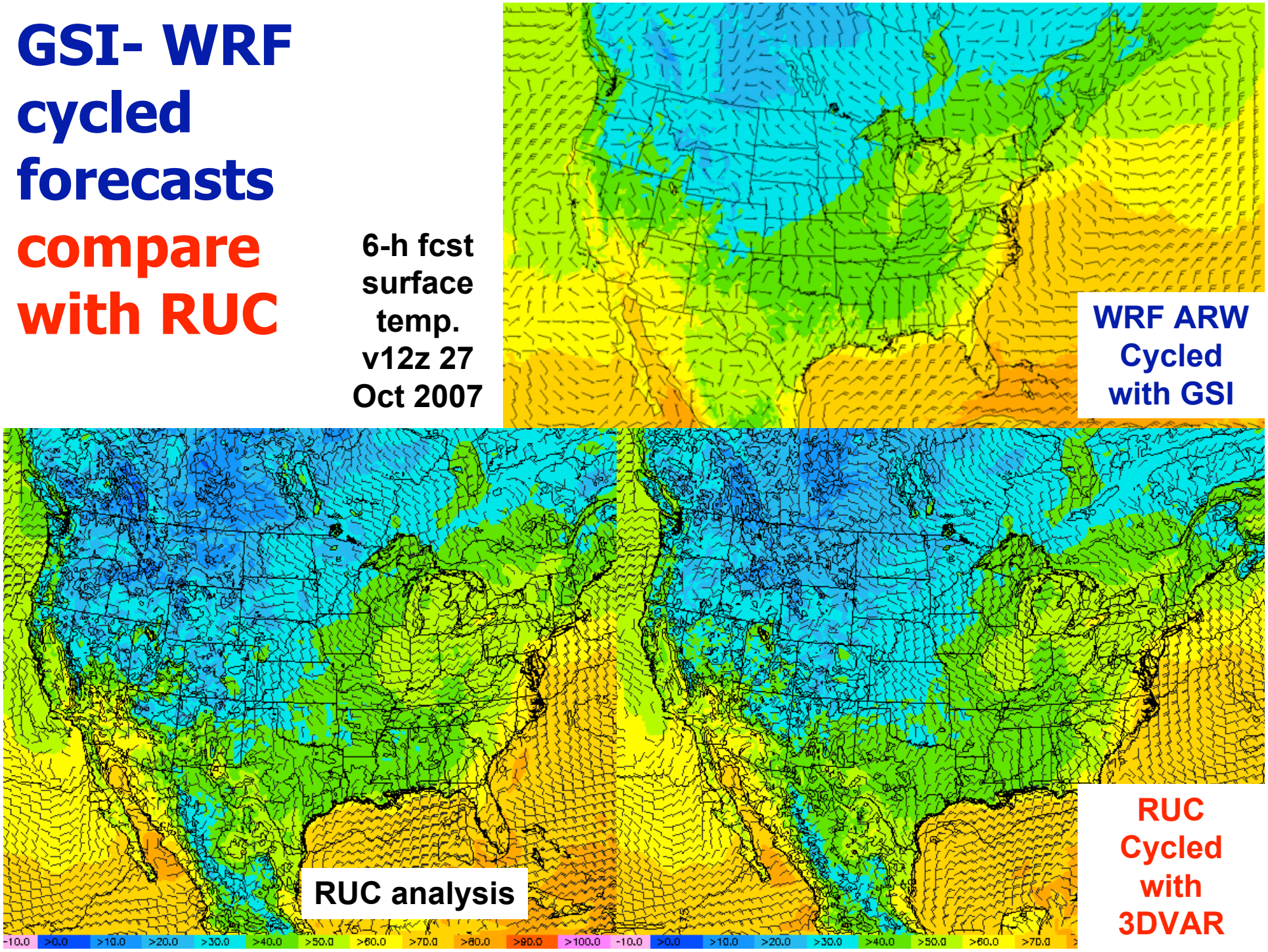
Cycled GSI- WRF forecasts on full Rapid Refresh



6-h fcst surface Temp. Valid 12z 27 Oct 2007

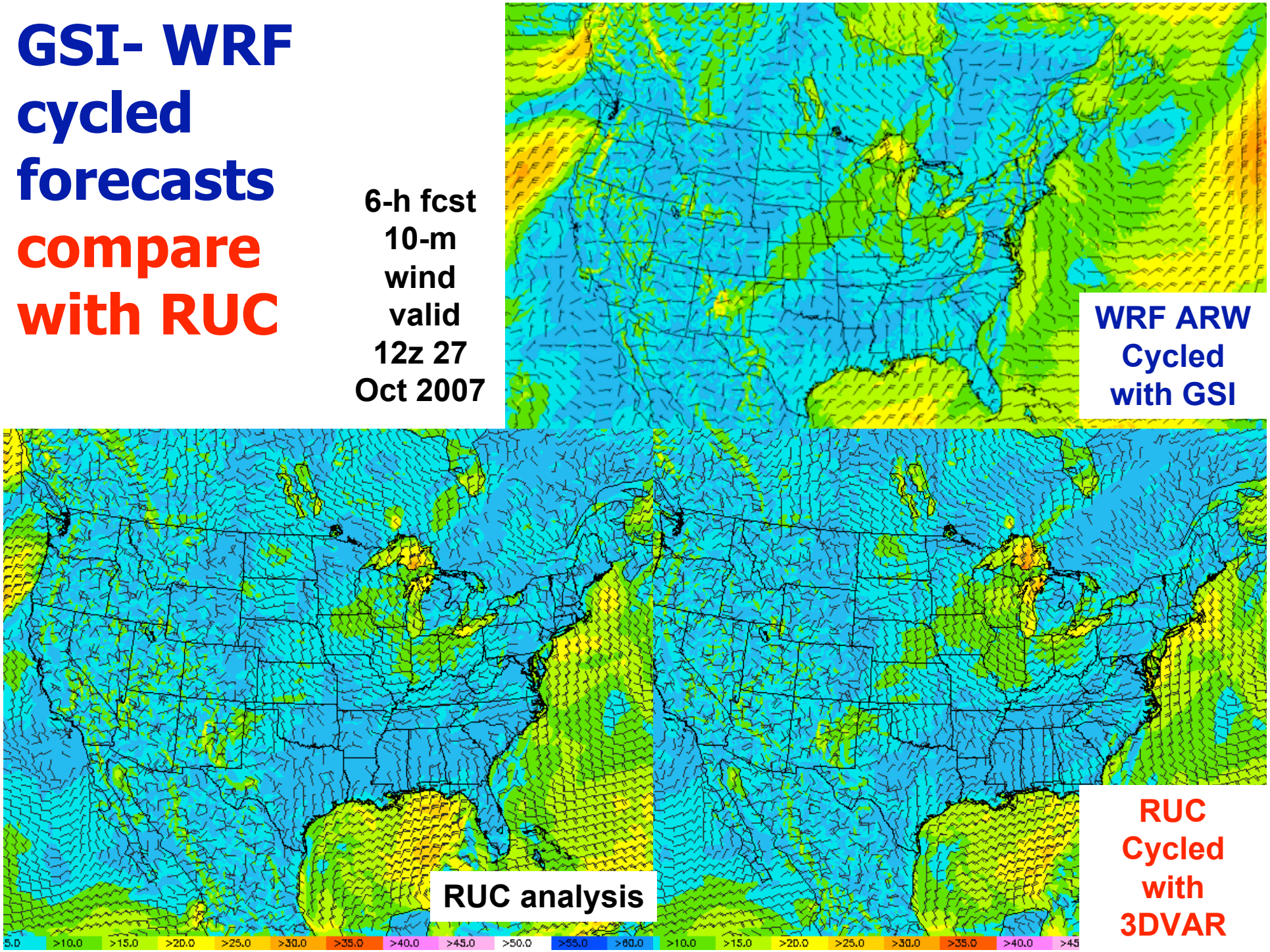
GSI- WRF cycled forecasts compare with RUC

6-h fcst surface temp. v12z 27 Oct 2007

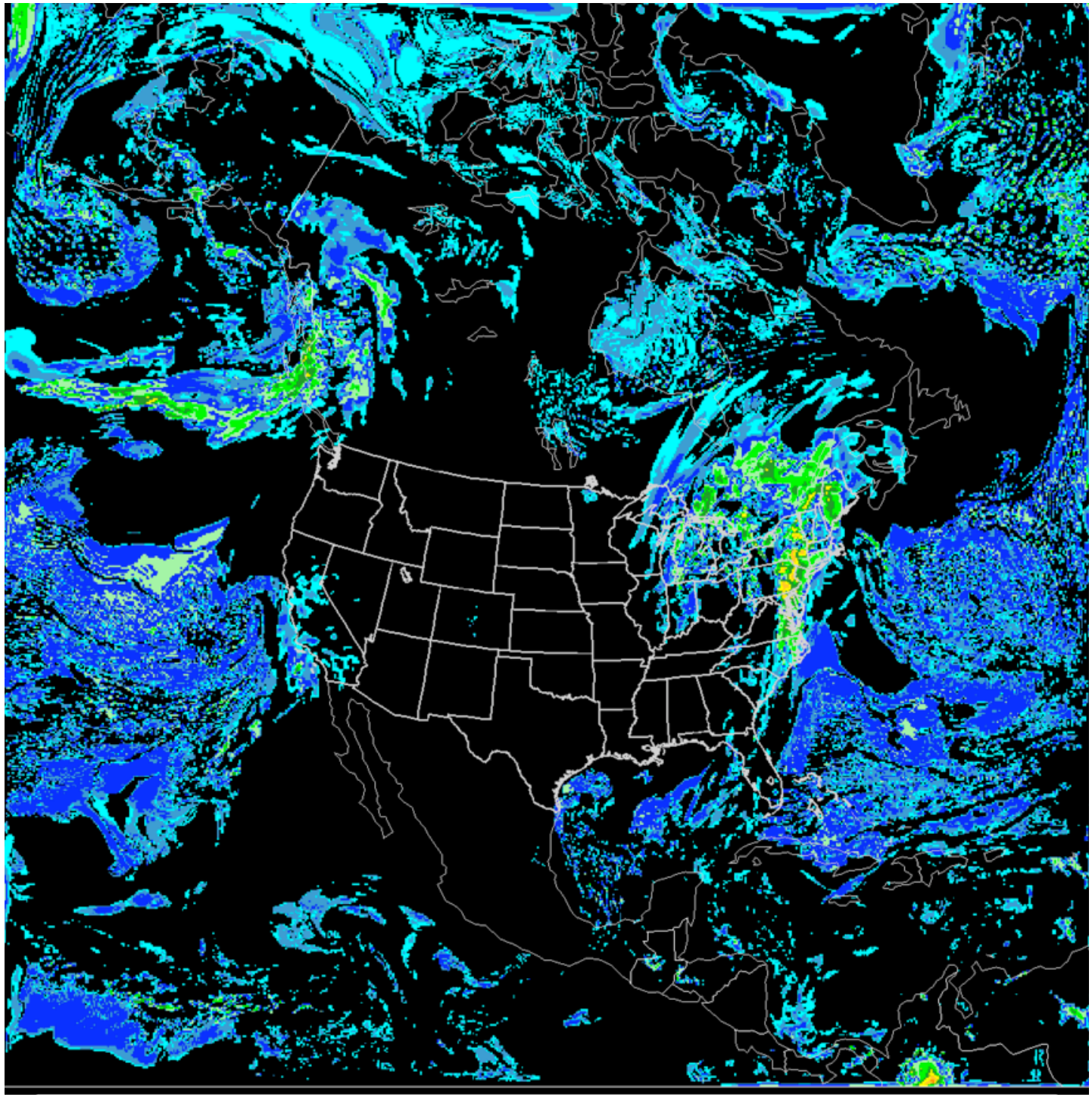


GSI- WRF cycled forecasts compare with RUC

6-h fcst
10-m
wind
valid
12z 27
Oct 2007



Cycled GSI- WRF forecasts on full Rapid Refresh



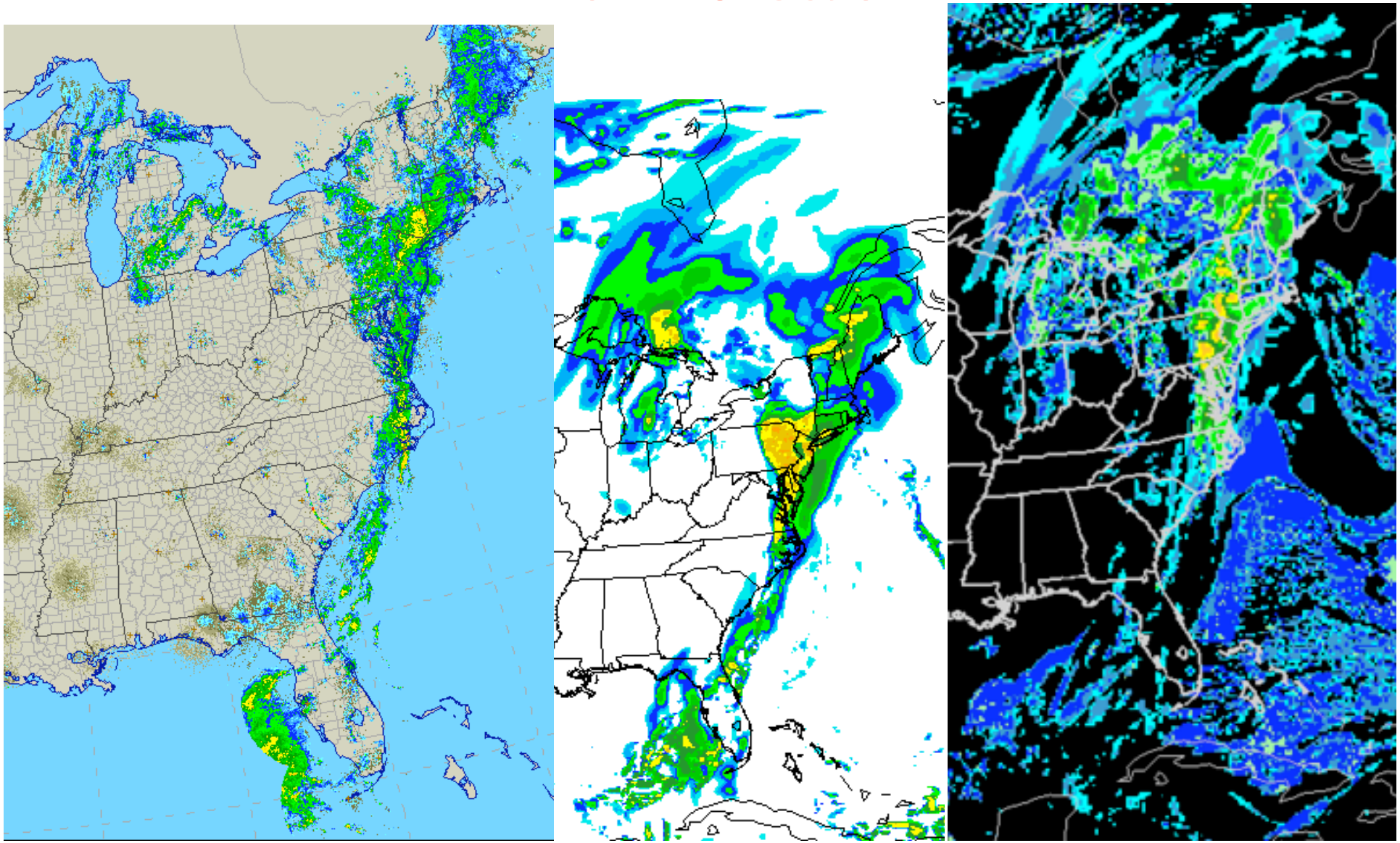
6-h fcst
Composite
Reflectivity
12z 27
Oct 2007

Full Rapid Refresh domain (6-h cycle)

Radar mosaic
12z 27 Oct 2007

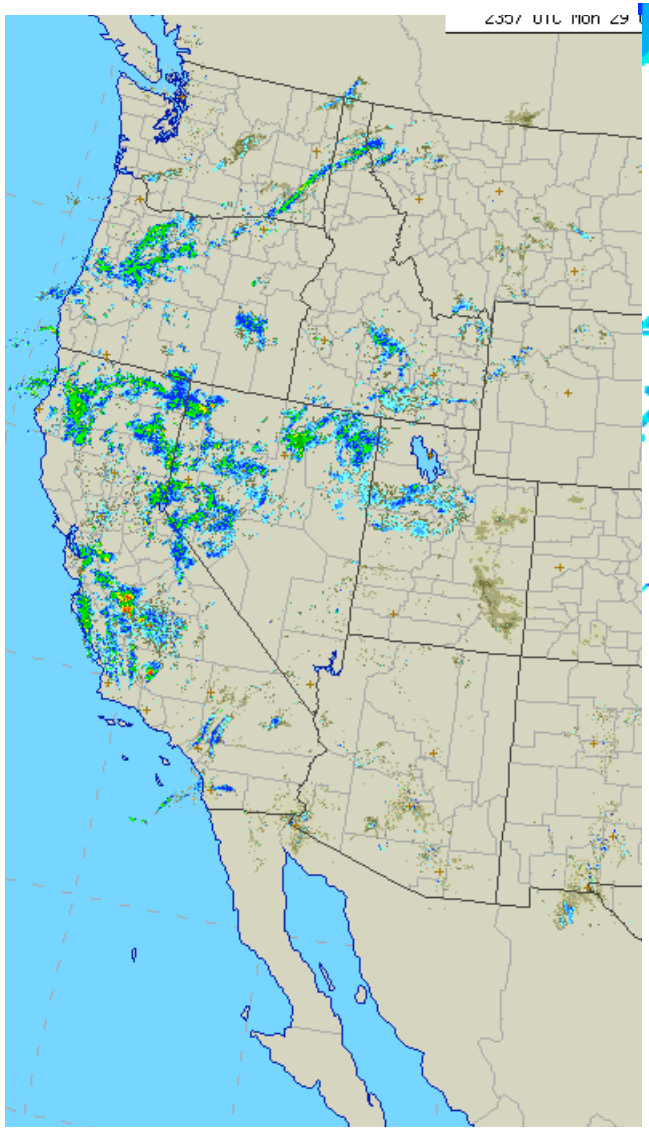
RUC cycled
6-h forecast

GSI- WRF cycled
6-h forecast

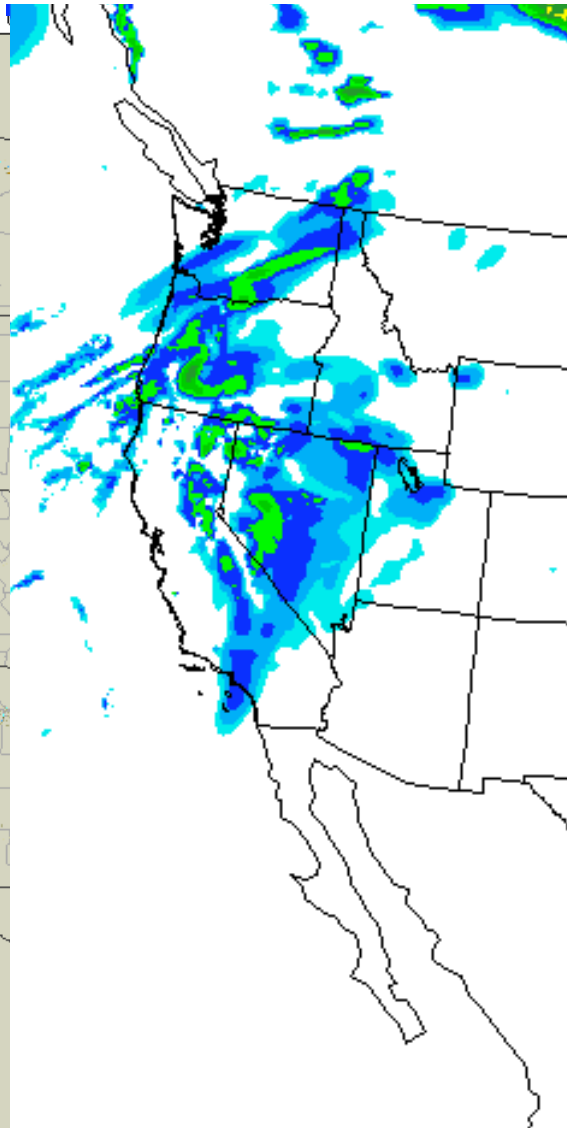


CONUS Rapid Refresh domain (3-h cycle)

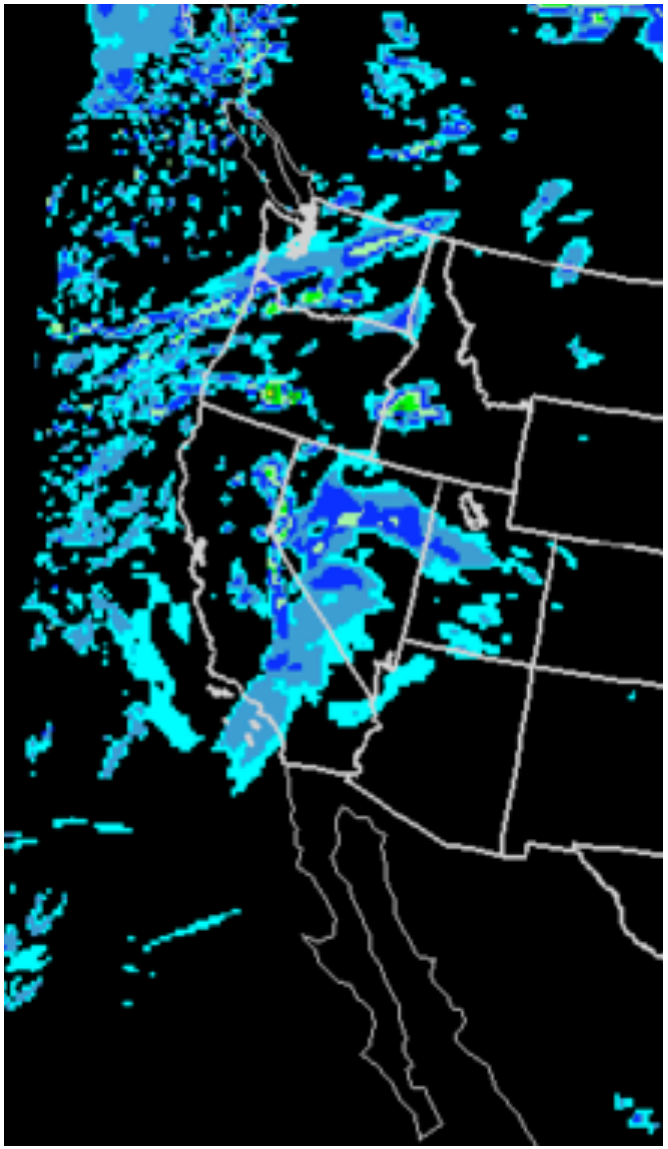
Radar mosaic
00z 30 Oct 2007



RUC cycled
12-h forecast

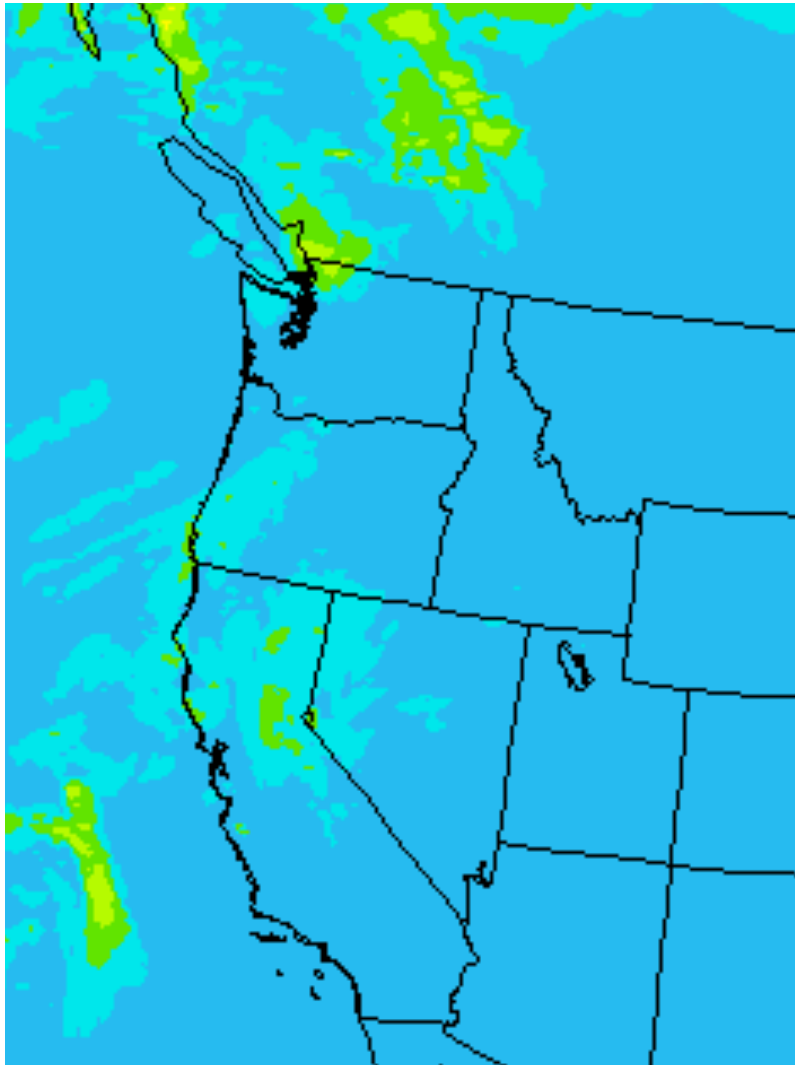


GSI- WRF cycled
12-h forecast

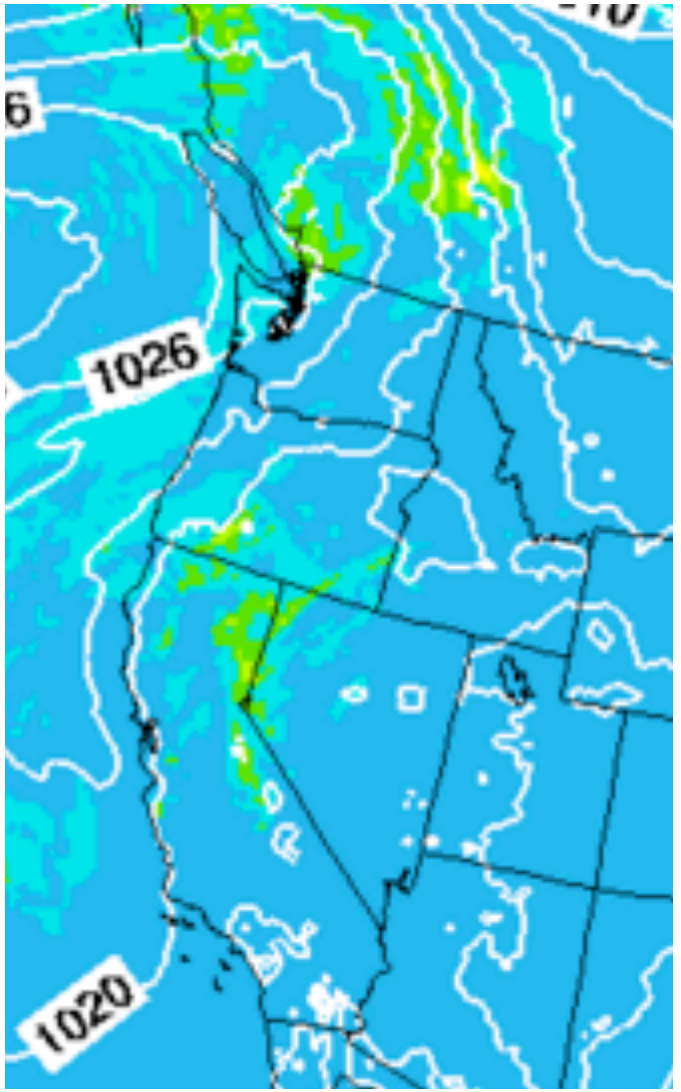


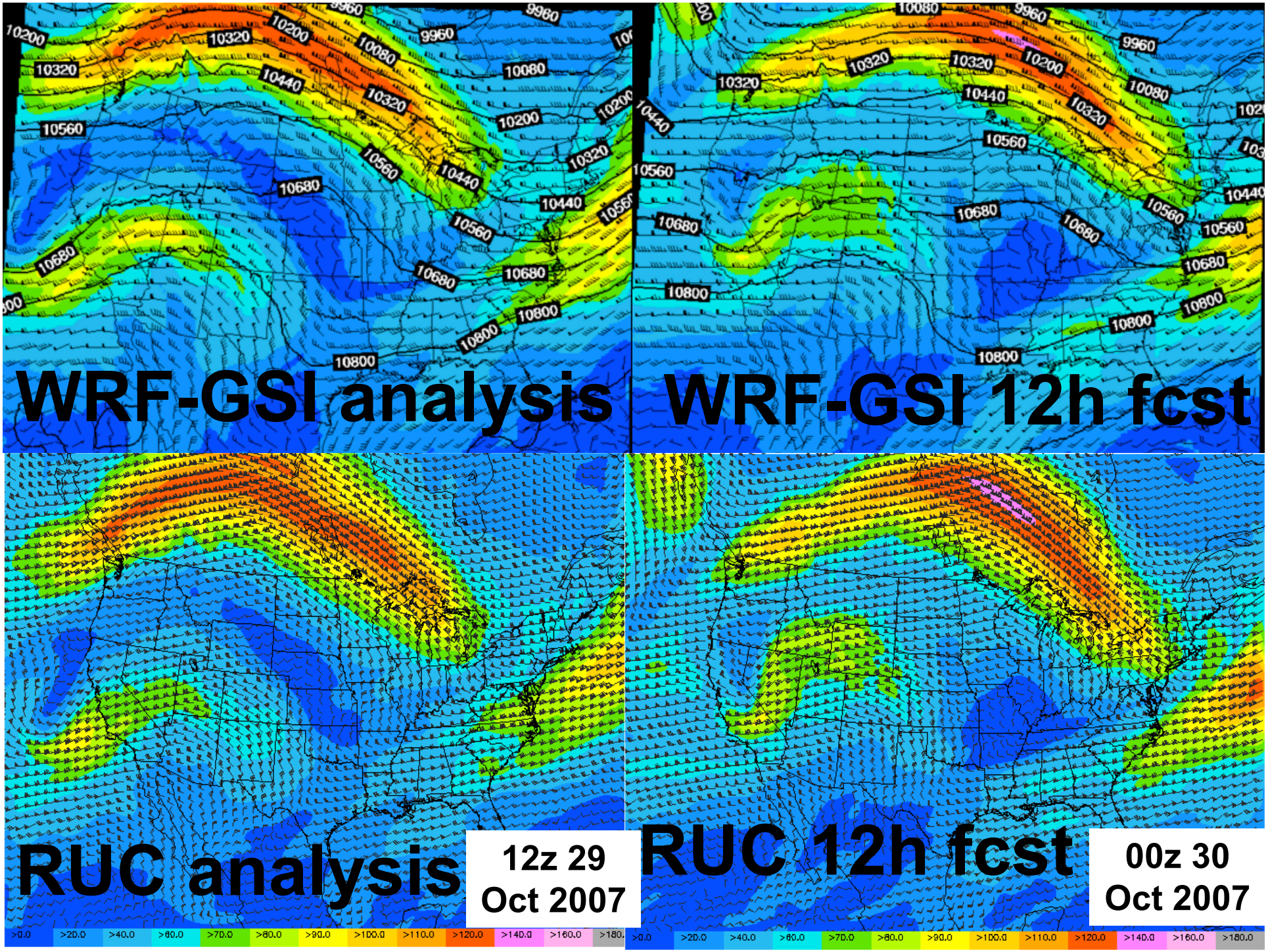
CONUS Rapid Refresh domain (3-h cycle)

RUC cycled
12-h forecast



GSI- WRF cycled
12-h forecast




WRF-GSI analysis
WRF-GSI 12h fcst
RUC analysis
12z 29
Oct 2007
RUC 12h fcst
00z 30
Oct 2007

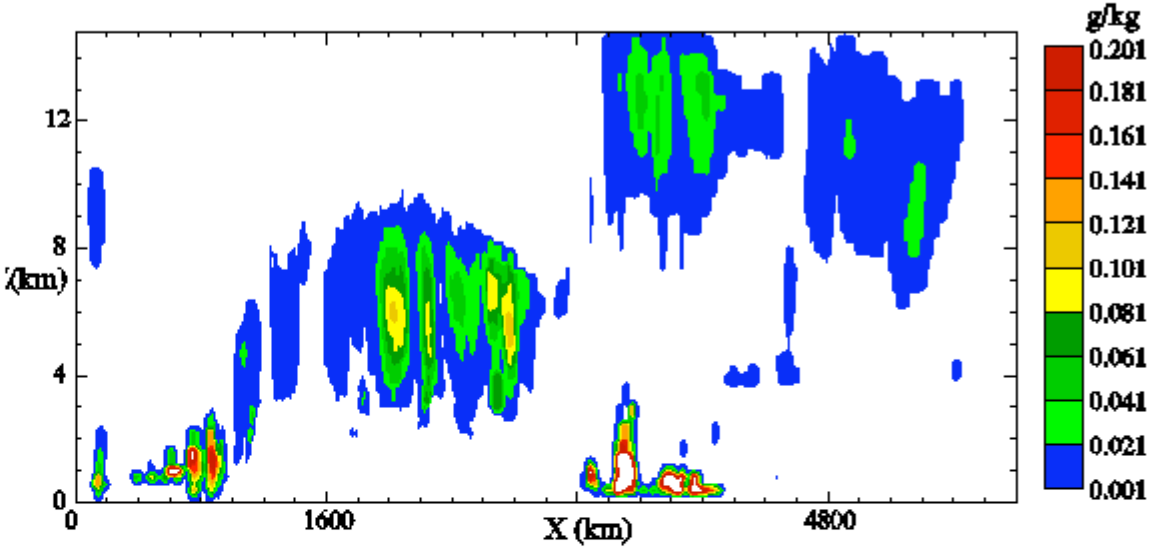
"RUC specific" components in GSI:

Cloud analysis (Ming Hu)

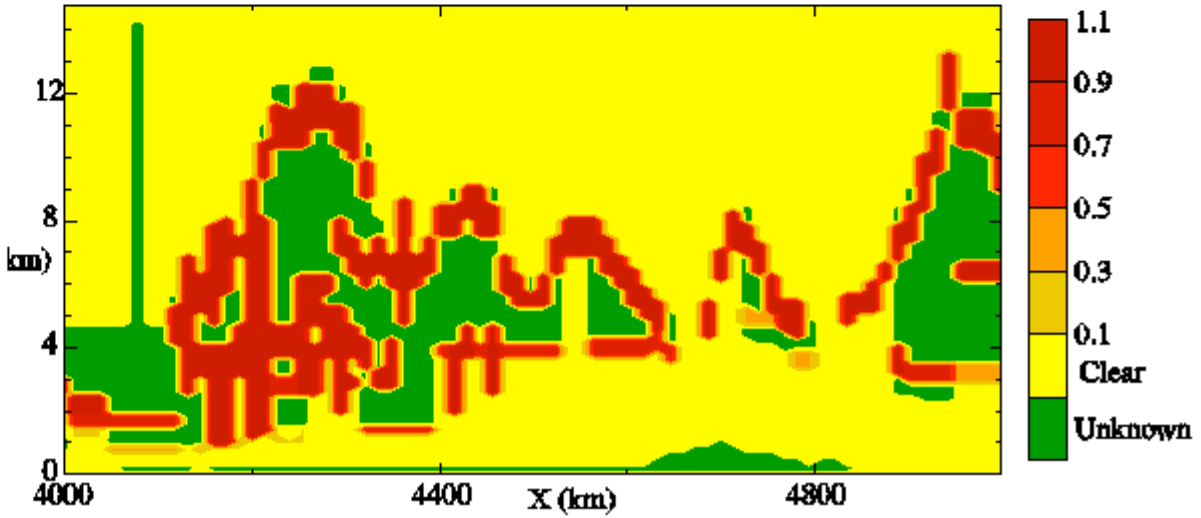
- Uses techniques from RUC, ARPS cloud analysis
- Utilizes METAR, satellite, radar data
- Modifies background cloud, hydrometeor fields
- Cycled testing within GSI framework
- Parallelized version for inclusion in full GSI

Updating cycled cloud / hydrometeor fields with METAR, satellite, radar observations

Background Cloud water + cloud ice



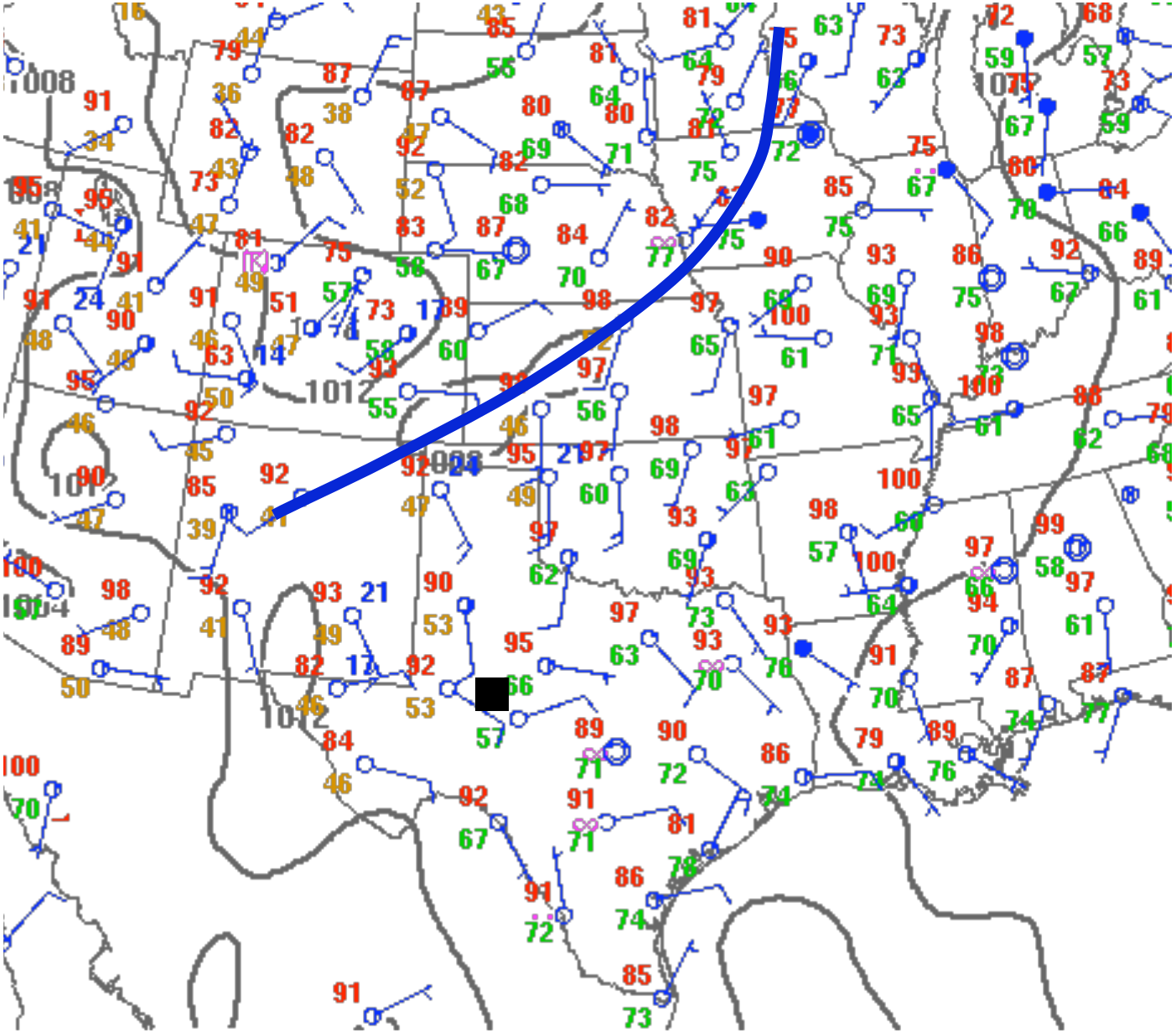
Cloud assessment (YES/NO/UNKNOWN) from observations (METAR/sat/radar)

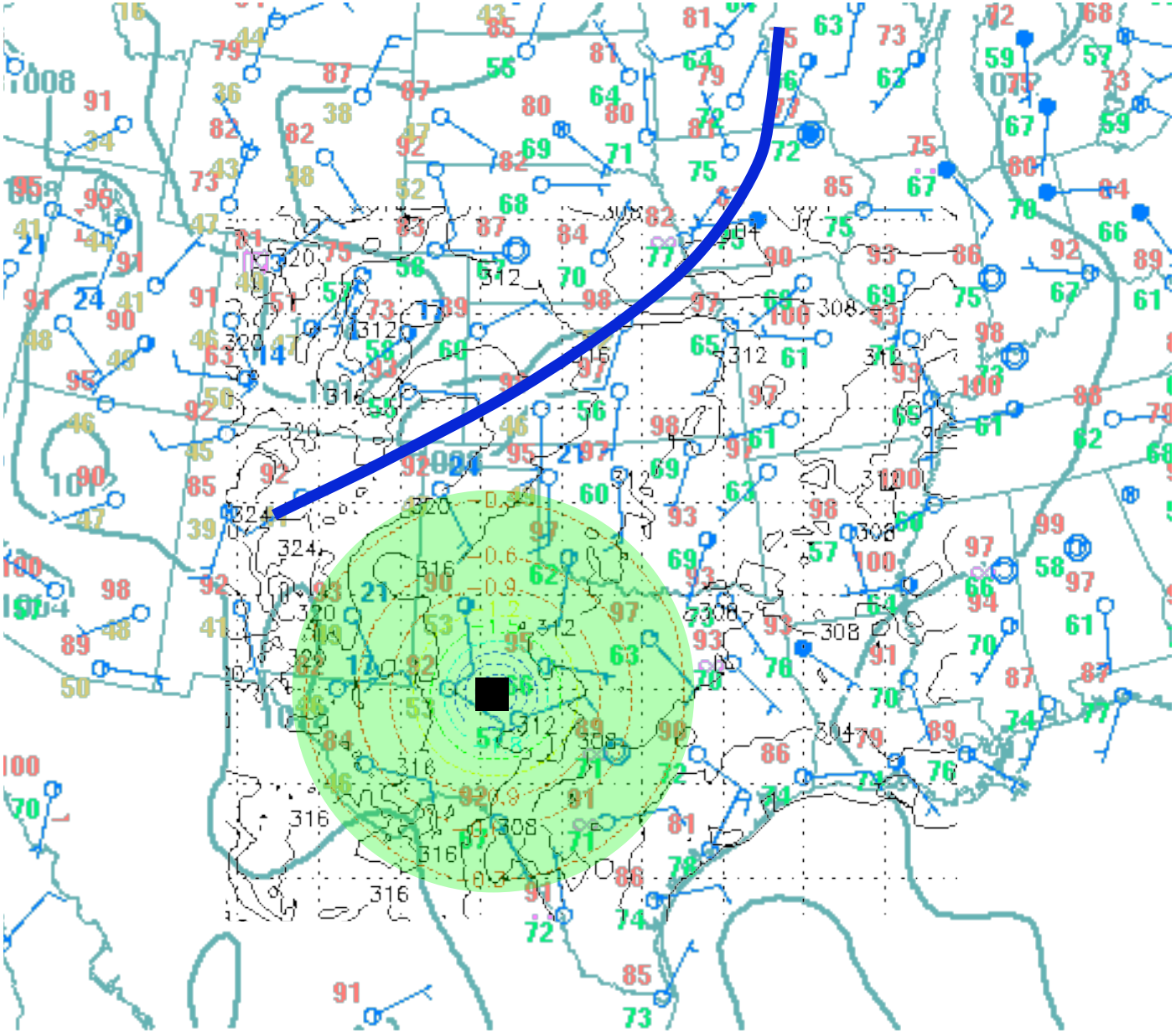


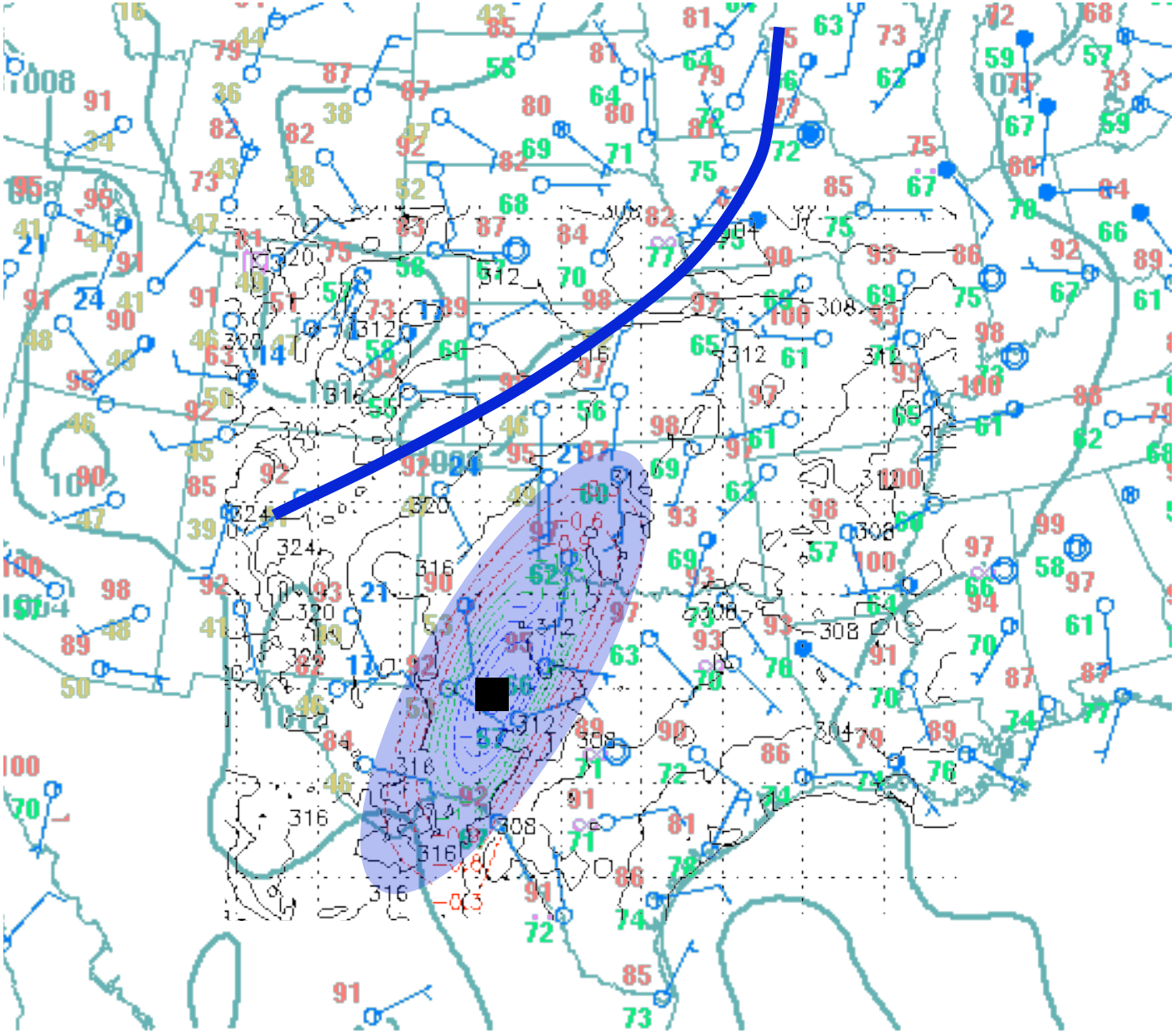
"RUC specific" components in GSI:

Anisotropic error covariance (Dezso Devenyi)

- Uses Jim Purser anisotropic recursive filters
- Collaboration with NCEP (Manuel Pondeca)
- Computationally feasible with coarser grid
- May improve horizontal observation influence
- Can use to vary vertical observation influence
- Use to do "PBL depth-based" surface observation assimilation







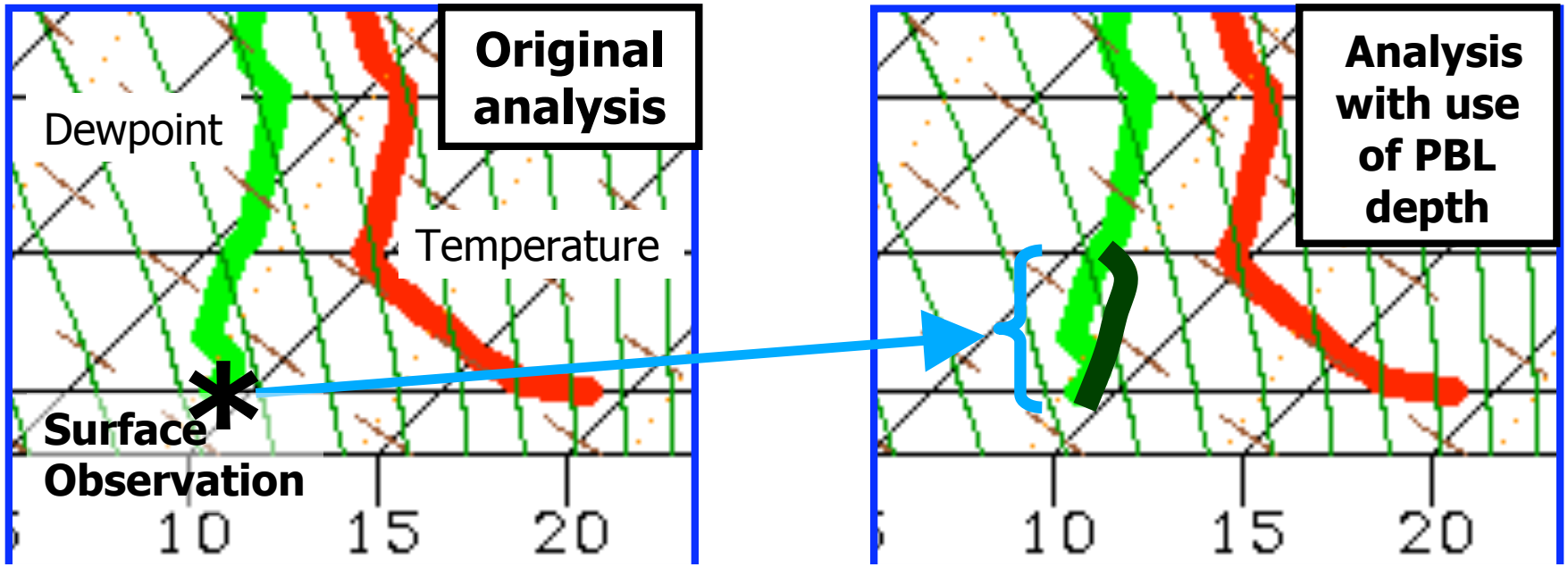
Use of surface information throughout boundary layer in the RUC & RR analysis

Problem

- Vertical influence of surface observations too small
- Surface information not retained in model forecast

Solution

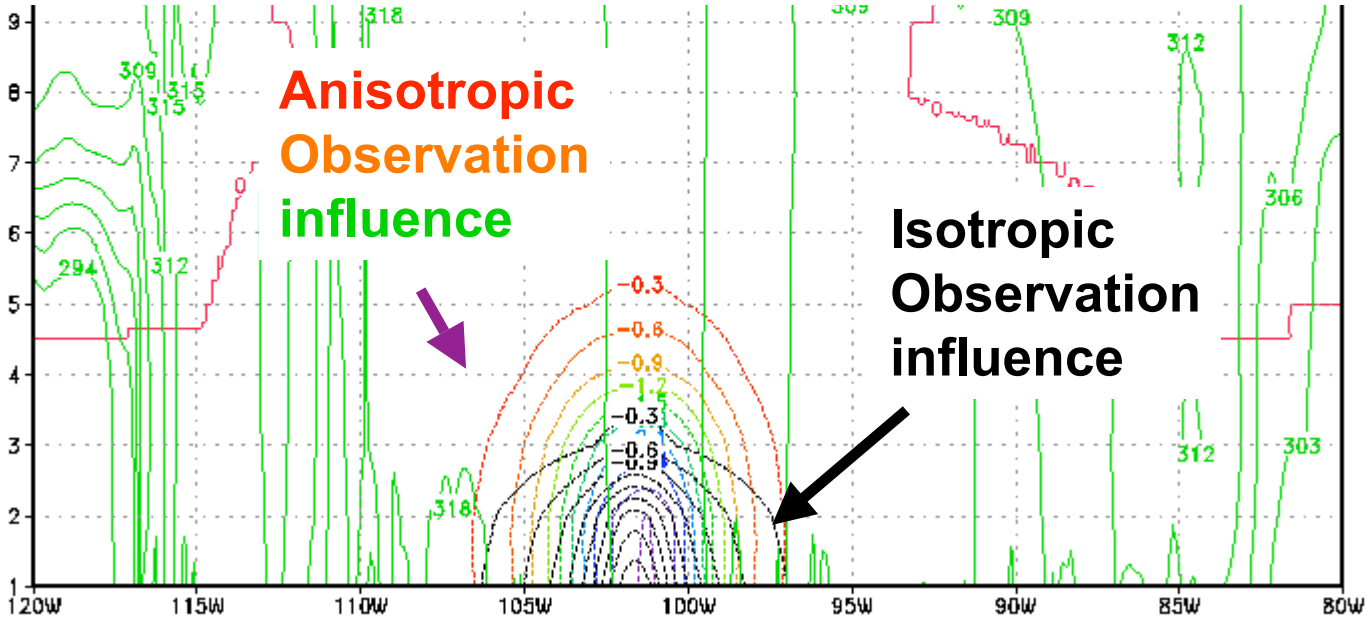
- Use METAR observation throughout PBL depth (from background field)
- Better model retention of surface observations



Varying vertical correlation length scale

- Can relate vertical length scale to potential temperature gradients

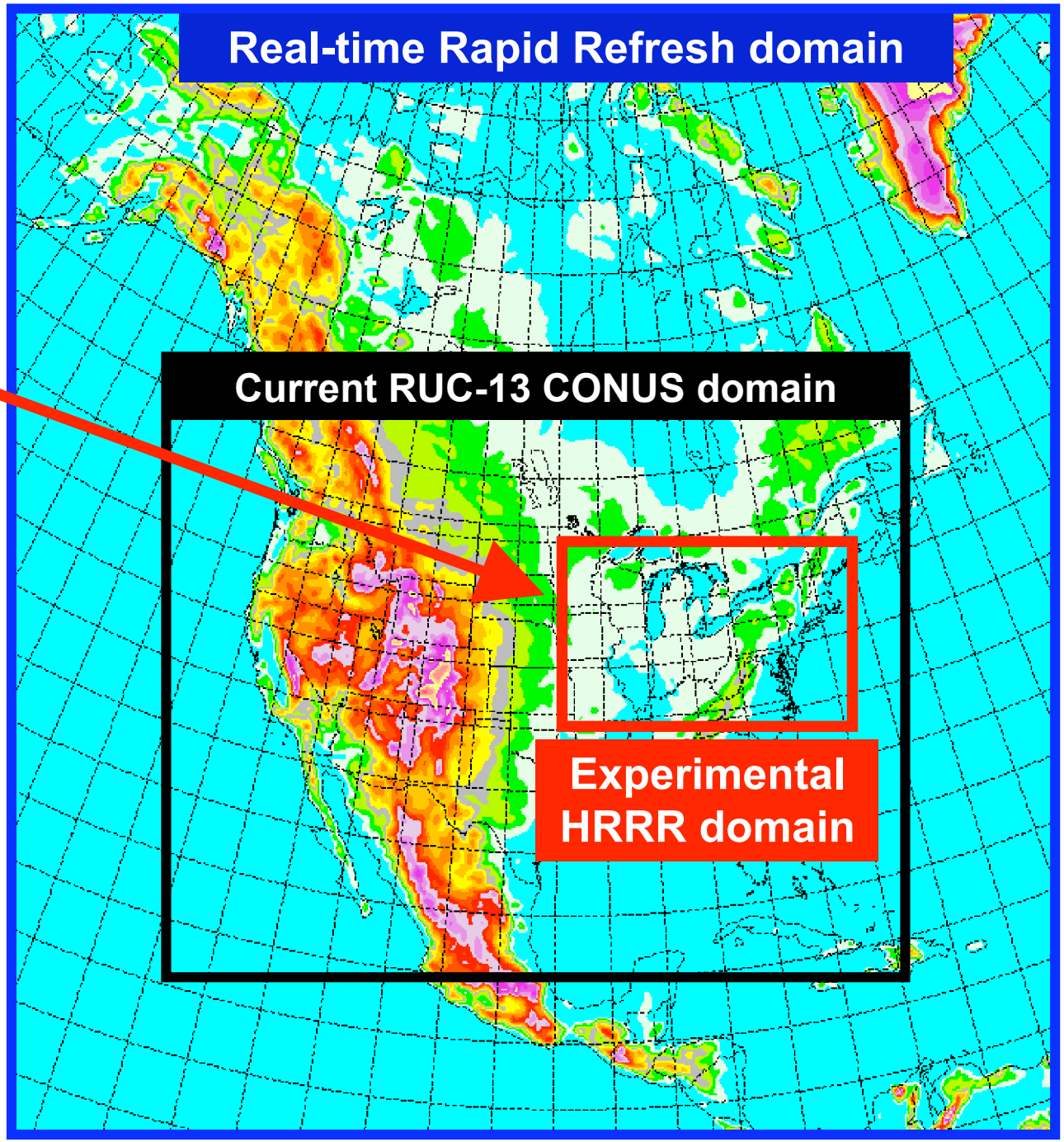
- Use to do "PBL depth-based" surface observation assimilation



RUC, Rapid Refresh and HRRR domains

Experimental High-Resolution Rapid refresh

- Storm-resolving (3-km) model
- Initialize from RUC 13-km which uses diabatic DFI to assimilate radar reflectivity data
- Eventually update every 30-60 min using latest radar data, surface obs



Factors for Hourly Updating CoSPA NWP

- **10-13 km resolution (NAM, RUC, Rapid Refresh)**
  - **Good convective environment and parameterized storms**
  - **Good MCS prediction with radar enhanced RUC**
  - **Supported by NOAA/NCEP for operational reliability**
- **5-9 km resolution**
  - **Not recommended for convective applications**
    (convection parameterizations not appropriate
    and explicit convection does not behave properly)
- **1-4 km resolution**
  - **3-km recommended for initial CoSPA HRRR**
  - **3-km requires ~80x more computer resources than 13-km**
  - **3-km better than 4-5km in GSD and NCAR experiments**
  - **1-2km resolution may be better still but far more expensive**

GSD High Resolution Rapid Refresh (HRRR) 3-km domain

NE Corridor test domain - realtime forecasts started August 2007

Run Status:

Real-time at GSD, 12-h run every 3-h initialized from radar enhanced RUC - NE Corridor domain

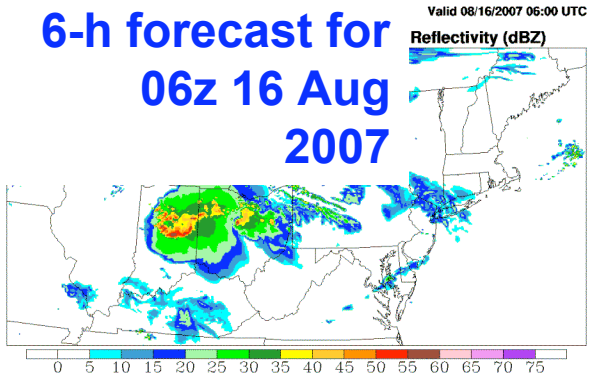
Storm-scale fields for evaluation, time-lagged ensemble.

Collaboration:

AWRP partners, FAA, MIT/LL, NCAR, CAPS.

Proposed full CONUS DOMAIN

6-h forecast for 06z 16 Aug 2007



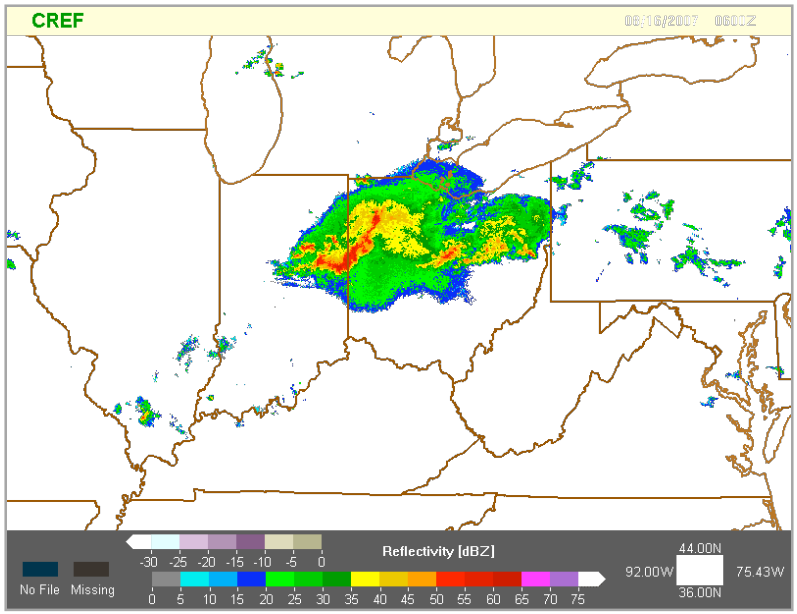
Hourly-updated CONUS 3-km forecast, 15-min output frequency

DEPENDENT on RAPID REFRESH

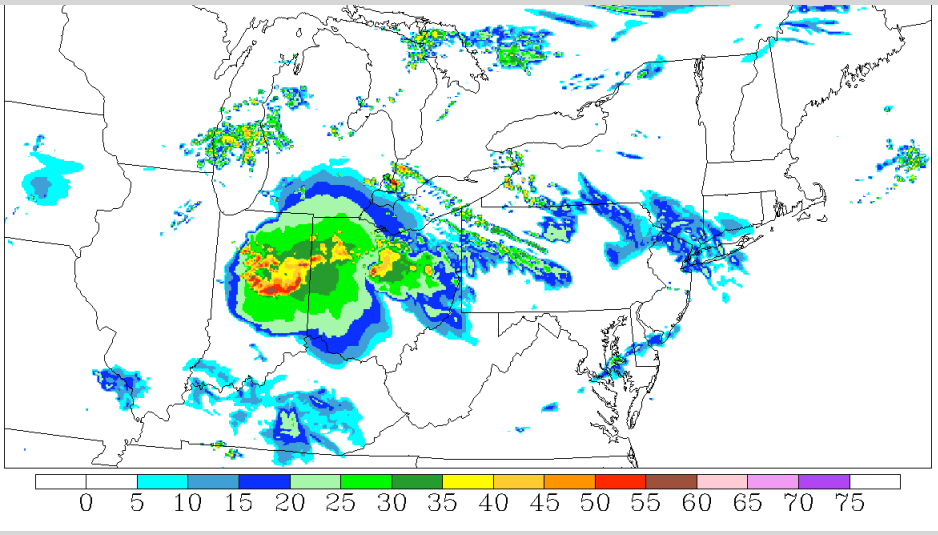
Proposed inclusion as *nest* within NCEP Rapid Refresh by 2012; domain dependent on NCEP resources

Sample HRRR from Radar-Enhanced RUC

NSSL verification



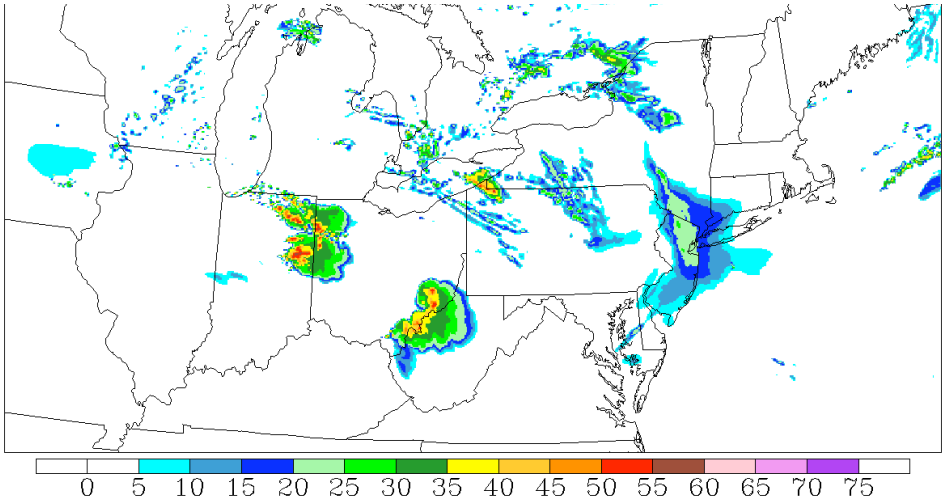
HRRR 3-km run initialized From radar-enhanced RUC

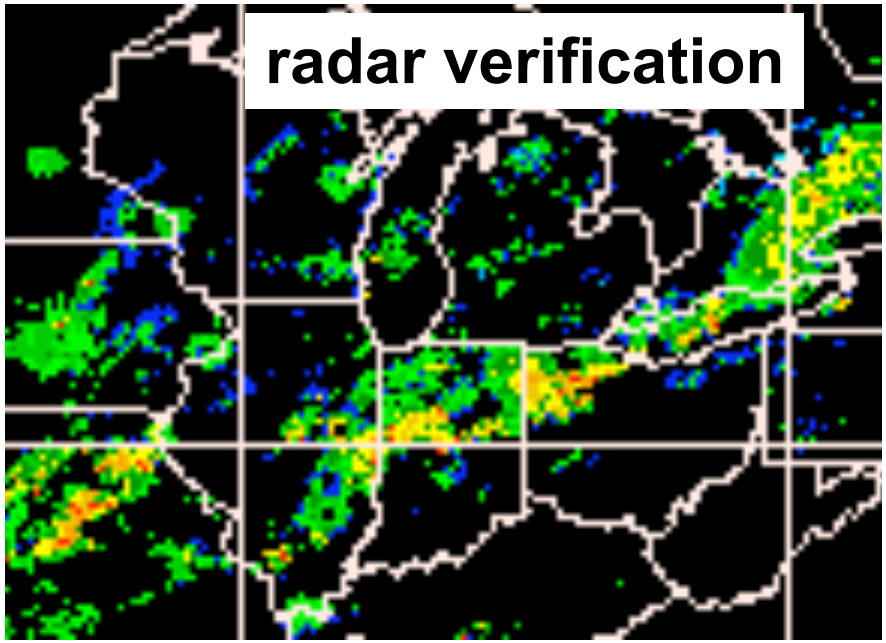


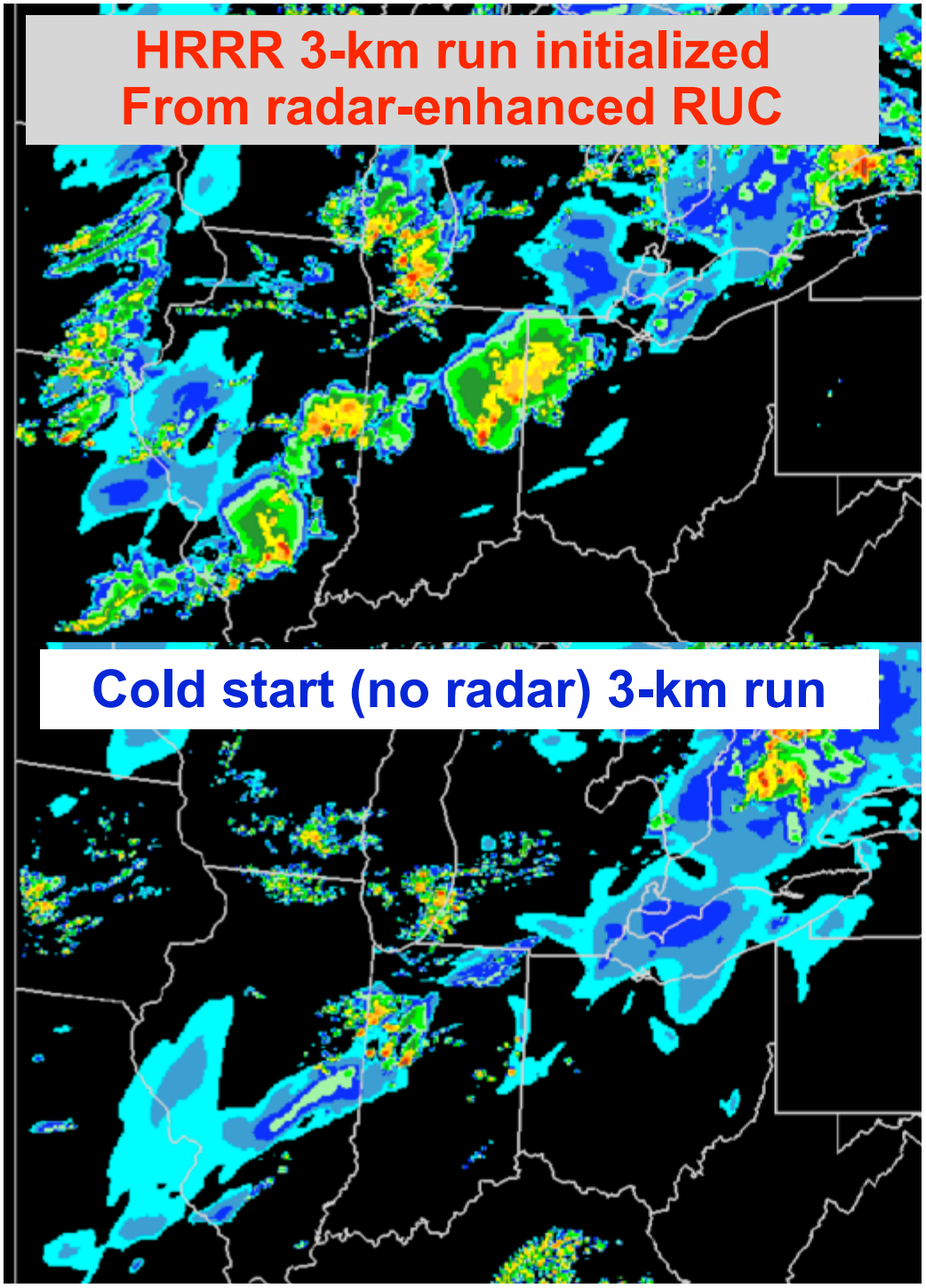
- **Much improved convection forecast from HRRR (*but* only if HRRR nested within radar-enhanced RR/RUC)**

6-h forecasts valid 06z 16 Aug 2007

Cold start 3-km run







HRRR from
rad RUC
and norad RUC

00z 25 AUG + 3h
fcst

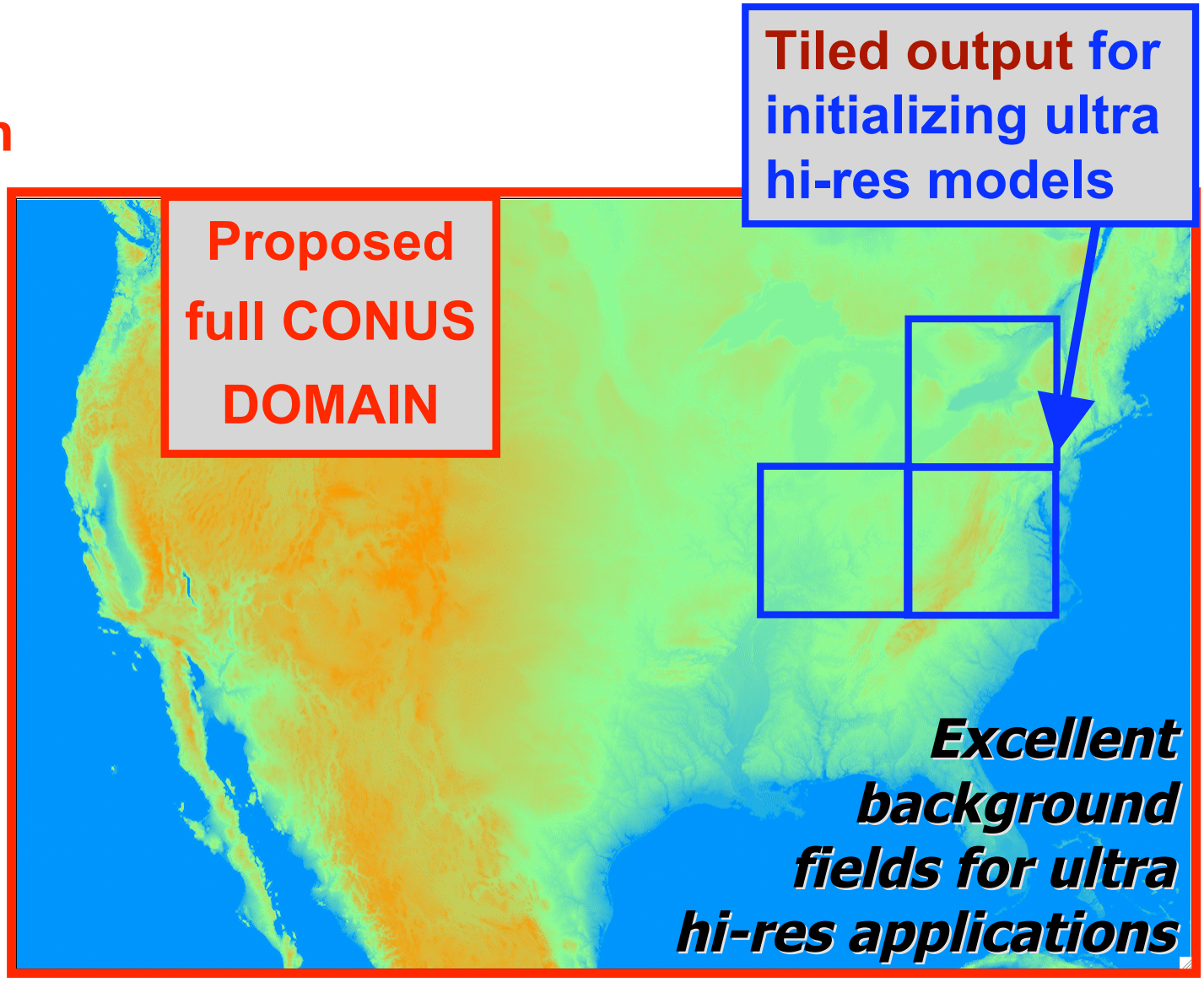
GSD High Resolution Rapid Refresh (HRRR) 3-km domain

Possible Ultra High Resolution applications:

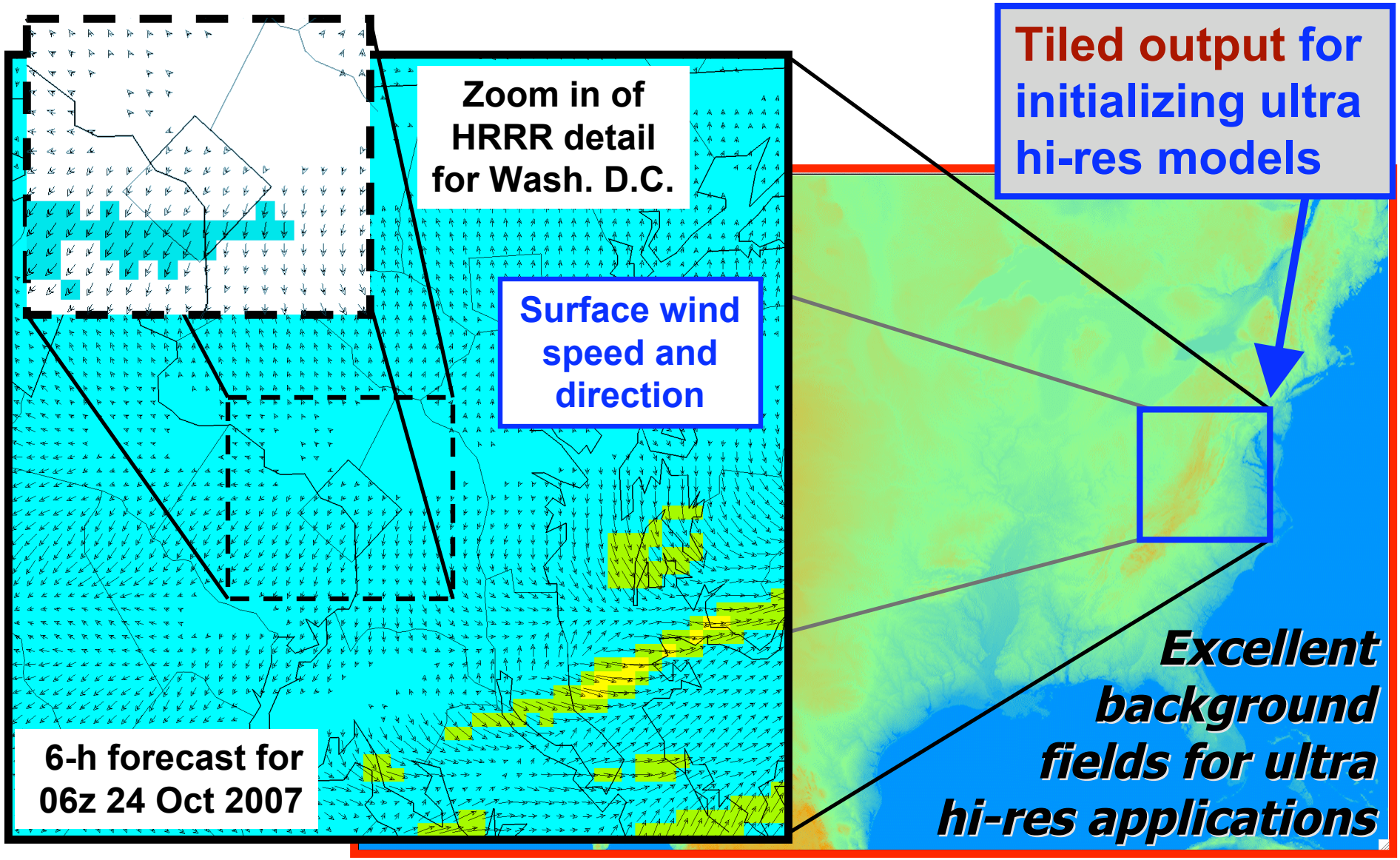
Sub-storm-scale severe t-storm / Tornado prediction (Warn on Forecast)

Wildland fire modeling

Urban pollution / hazardous release (using WRF-chem)



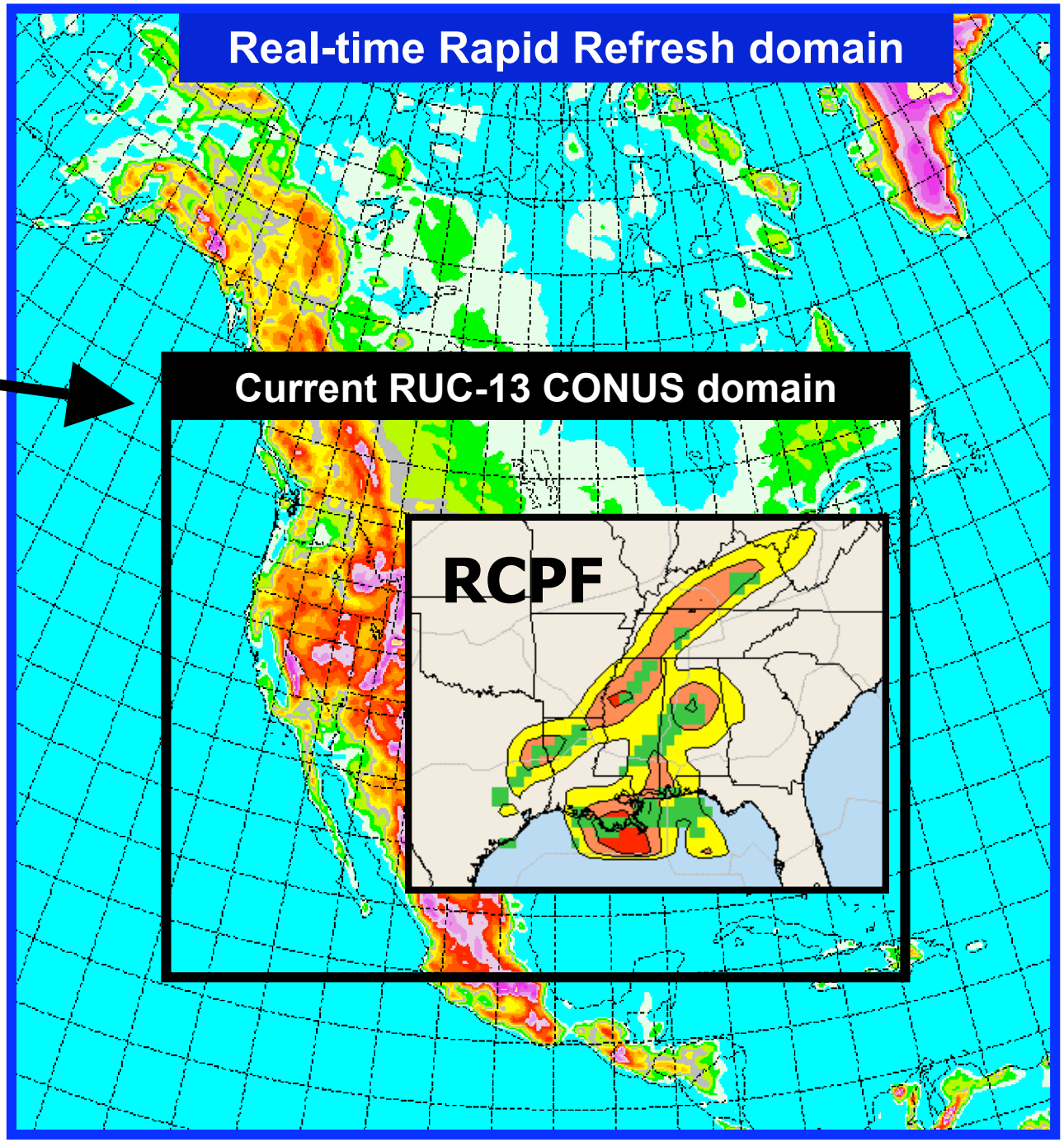
GSD High Resolution Rapid Refresh (HRRR) 3-km domain



RUC, Rapid Refresh and HRRR domains

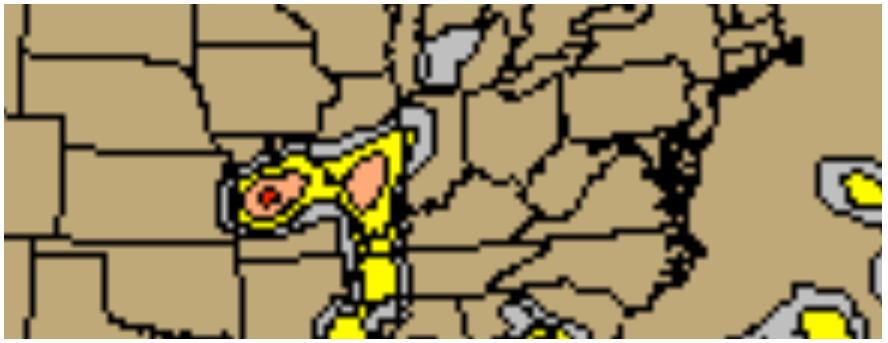
RUC Convective Probability Forecast (from 13-km RUC)

- Automated, hourly 2 - 10 h forecast of Thunderstorm likelihood
- Apply ensemble post-processing techniques to RUC model output

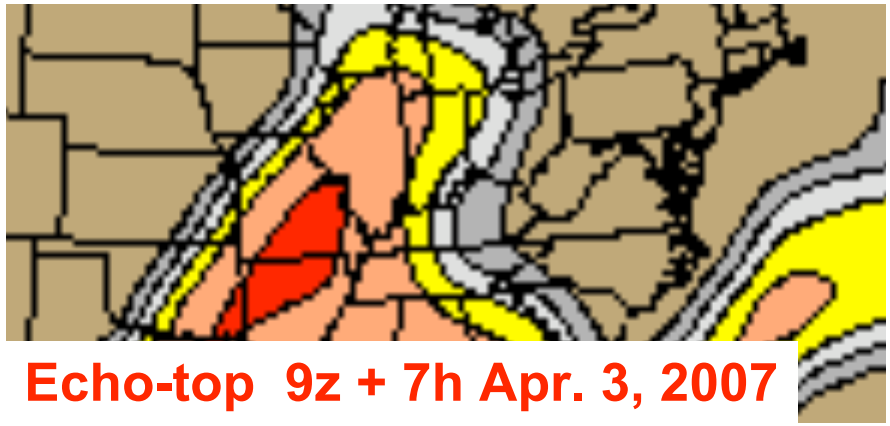


RUC Convective Probability Forecast (RCPF)

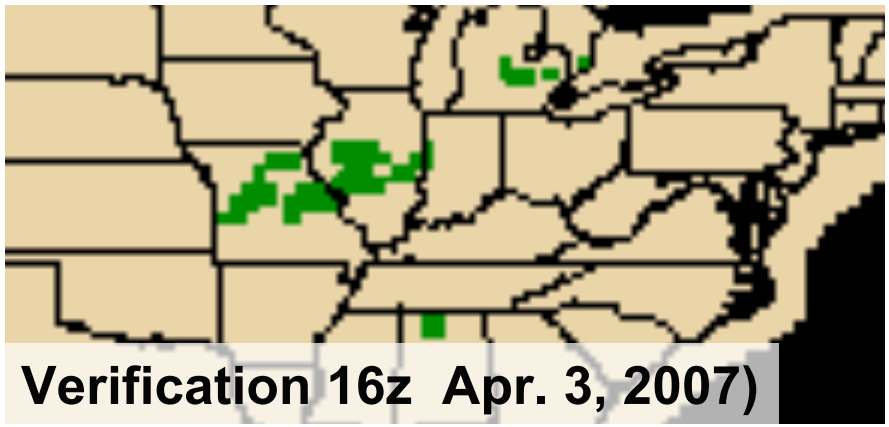
- Hourly 2 → 10 h thunderstorm probability forecast
- Made from time-lagged ensemble of hourly RUC model forecasts with radar assimilation
- Experimental real-time feed of RCPF to AWC for convection guidance
- Modified RCPF to reflect improvements from radar assimilation (summer 2007)



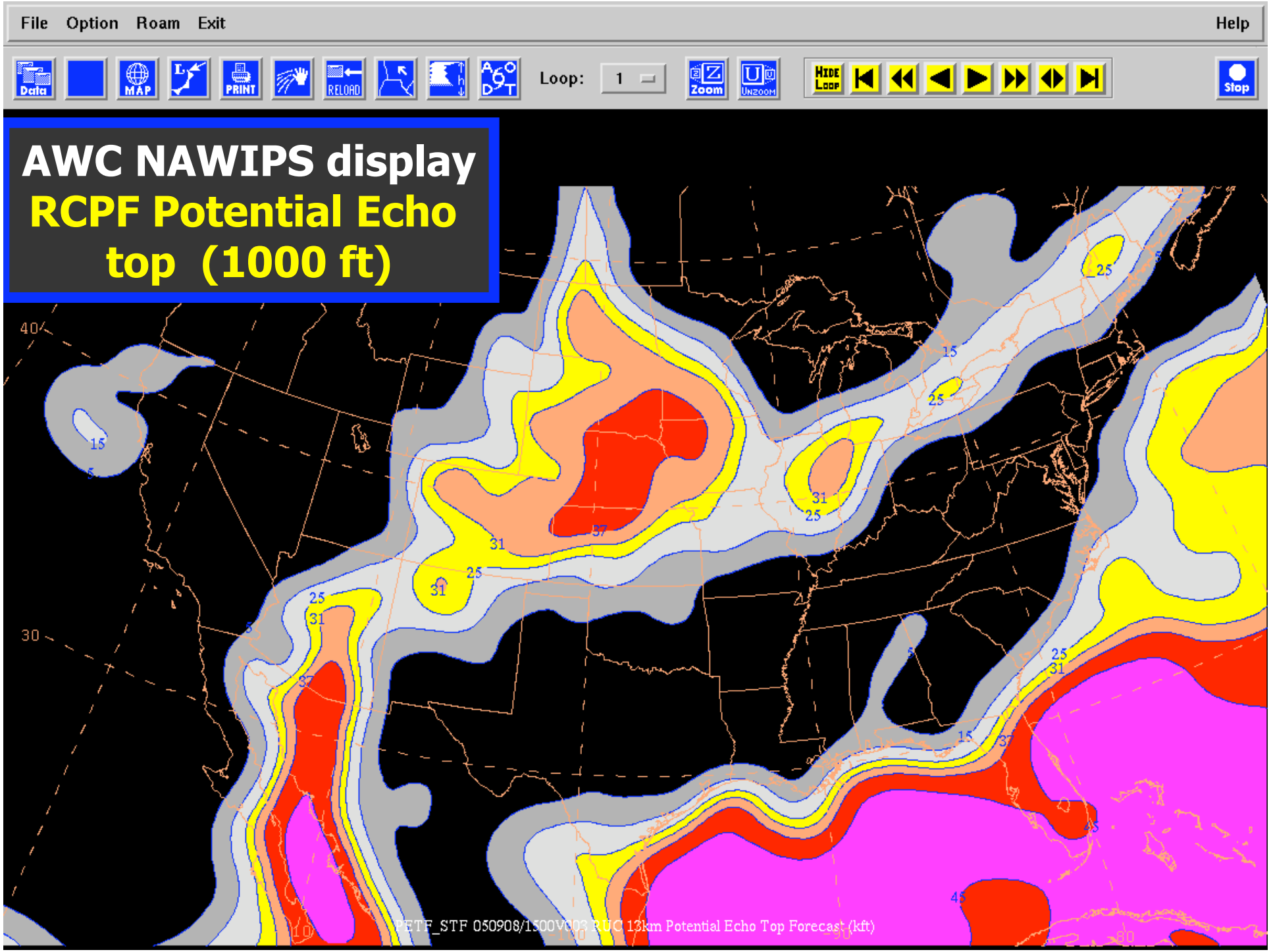
Convect. Prob. 9z + 7h Apr. 3, 2007



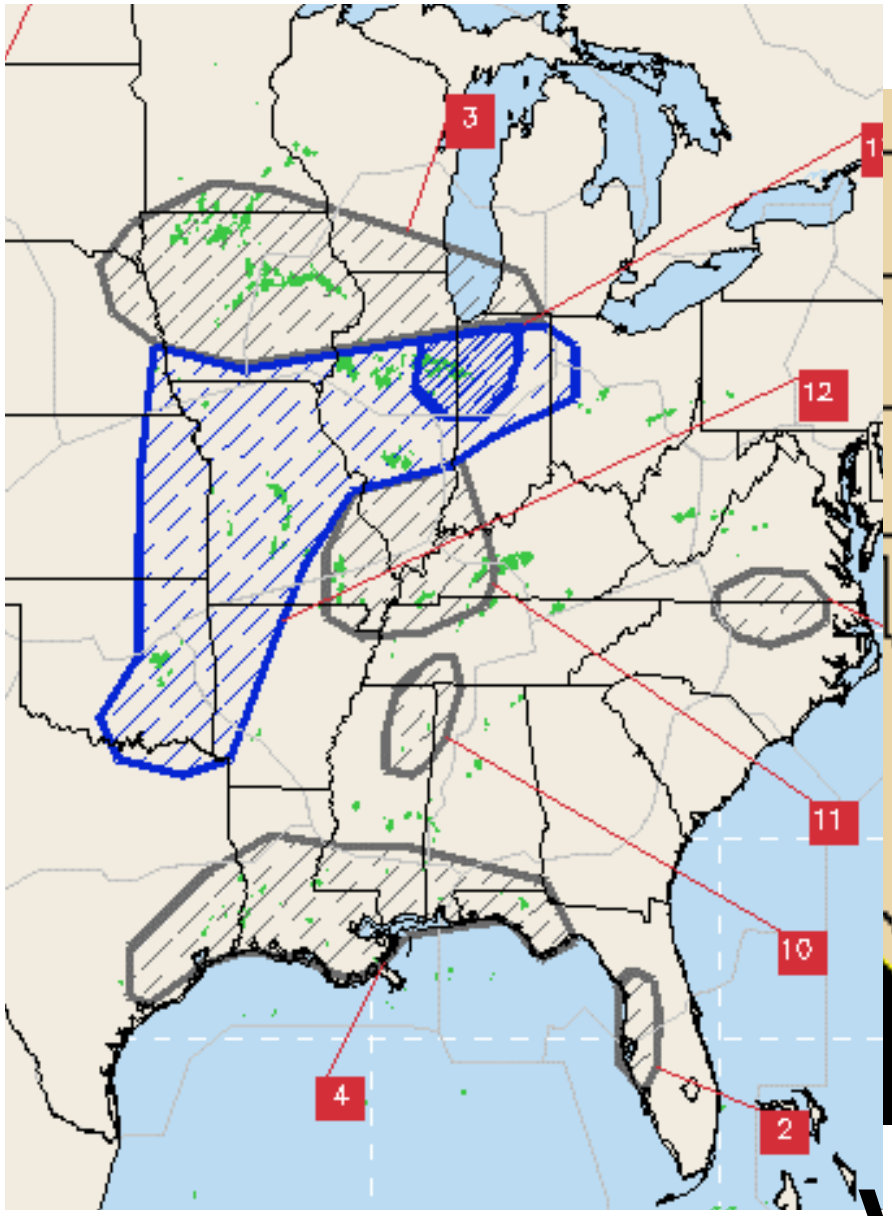
Echo-top 9z + 7h Apr. 3, 2007



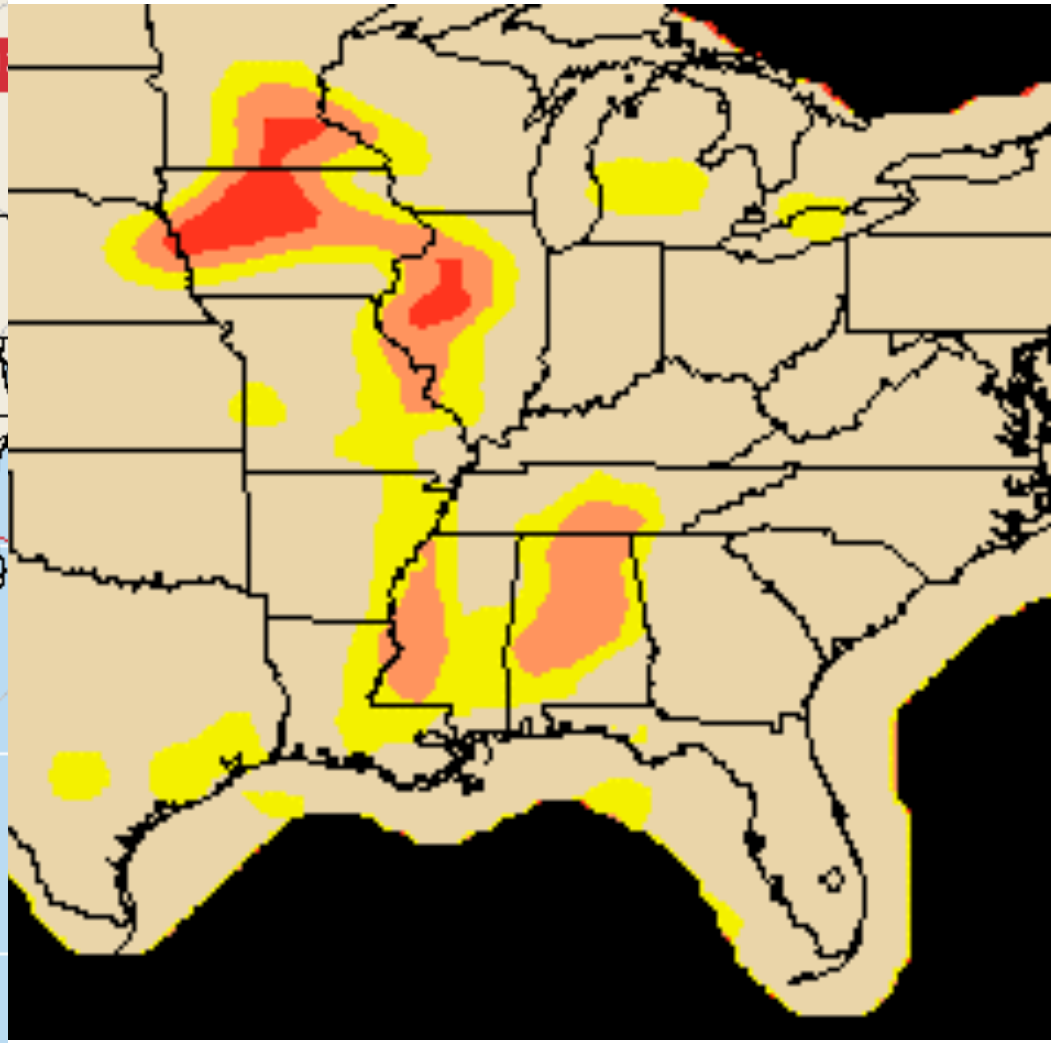
Verification 16z Apr. 3, 2007)


File Option Roam Exit
Help
Data
MAP
PRINT
RELOAD
Loop: 1
Zoom
UnZoom
Hide Loop
Stop
AWC NAWIPS display
RCPF Potential Echo top (1000 ft)
40
30
15
25
31
37
45
VETF_STF 050908/1500V003 RUC 13km Potential Echo Top Forecast (kft)

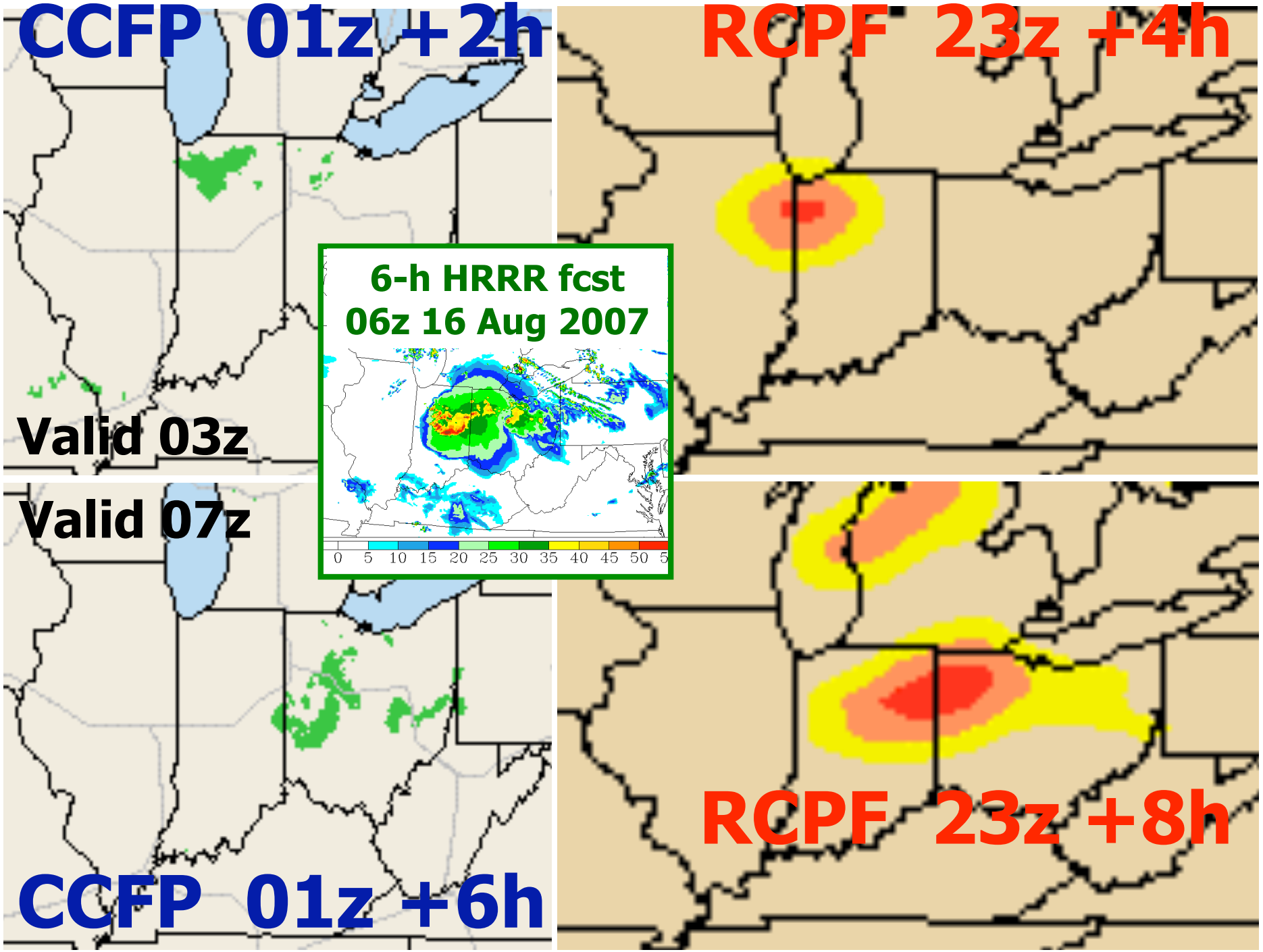
CCFP 15z +6h

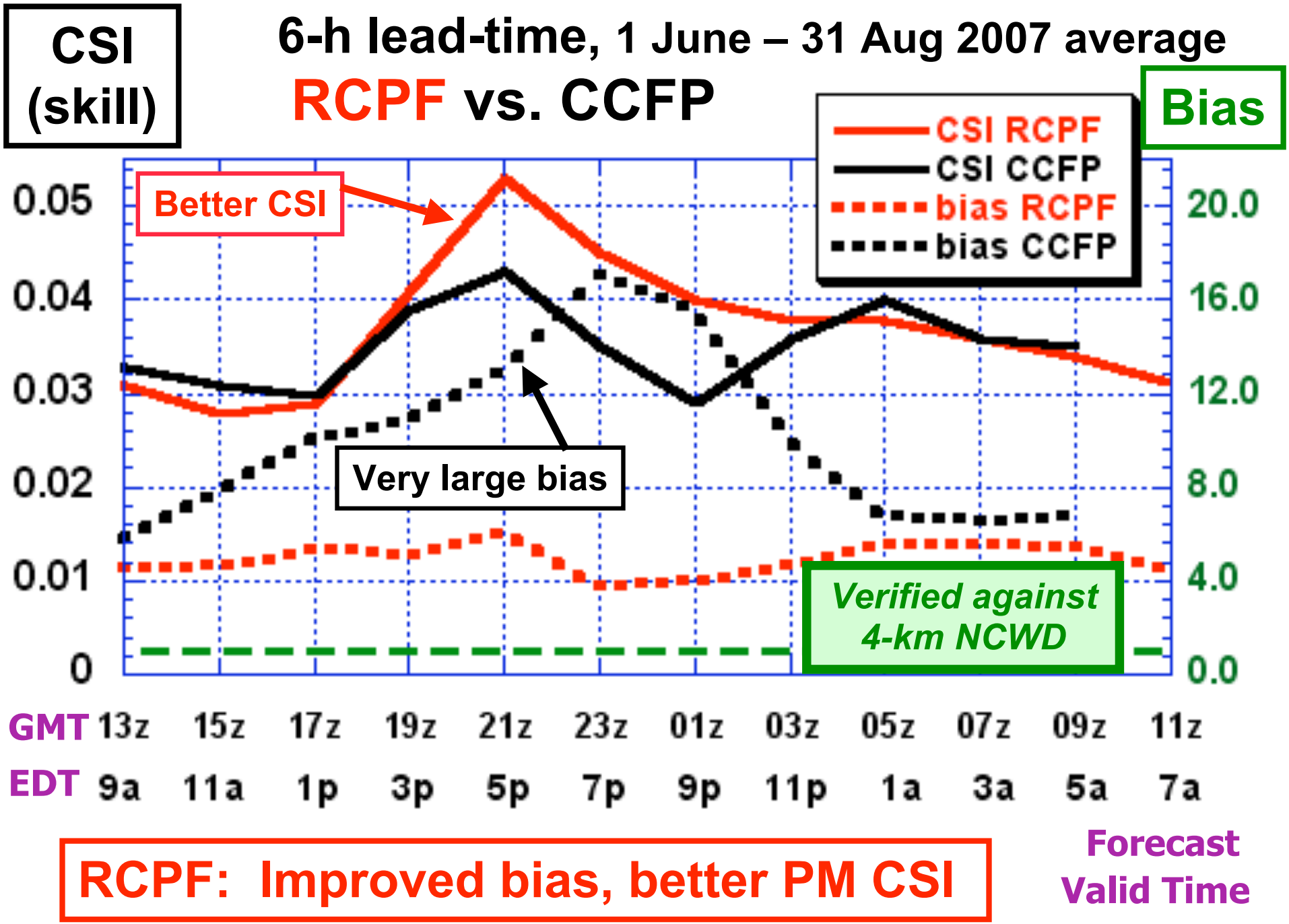


RCPF 13z +8h



Valid 21z 19 Aug. 2007


CCFP 01z +2h
Valid 03z
6-h HRRR fcst
06z 16 Aug 2007
0 5 10 15 20 25 30 35 40 45 50 5
RCPF 23z +4h
Valid 07z
CCFP 01z +6h
RCPF 23z +8h


CSI (skill)
6-h lead-time, 1 June – 31 Aug 2007 average
RCPF vs. CCFP
Bias
CSI RCPF
CSI CCFP
bias RCPF
bias CCFP
Better CSI
Very large bias
Verified against 4-km NCWD
0.05
0.04
0.03
0.02
0.01
0
20.0
16.0
12.0
8.0
4.0
0.0
GMT 13z 15z 17z 19z 21z 23z 01z 03z 05z 07z 09z 11z
EDT 9a 11a 1p 3p 5p 7p 9p 11p 1a 3a 5a 7a
Forecast Valid Time
RCPF: Improved bias, better PM CSI

GSD Plans for future CW RT work

RELATED MD&E RT WORK:

Modifications to RUC radar assimilation and Grell-Devenyi cumulus scheme to improve model initialization and evolution of convection

CW RT WORK:

- **Calibration of RCPF to improvements in model and assimilation formulation**
- **Calibration of potential echo-top product**
- **Add simulated reflectivity to RUC 15-min. output fields, use 15 min. fields in RCPF**
- **Procedures to improve RCPF skill, reliability**

RUC/Rapid Refresh Technical Review - OUTLINE

1:30 - 1:50	RUC upgrade - assim - radar reflectivity, mesonet/RTMA, physics - Stan Benjamin
1:50 - 2:15	Observation assessment activities - TAMDAR aircraft obs w/ moisture, larger obs sensitivity experiment (OSE) - Bill Moninger, Brian Jamison
2:15 - 2:25	Rapid Refresh background - core, NCEP - Stan
2:25 - 2:35	-- Break --
2:35 - 2:50	Rapid Refresh model description testing - ARW core, physics, DFI - John Brown
2:50 - 3:15	RR assimilation w/ GSI, Details on RUC/RR/HRRR convection Steve Weygandt
3:15 - 3:25	Future of Rapid Refresh Stan Benjamin

Future of Rapid Refresh

- **Fall 2007 – Spring 2008**
  - **Real-time and retrospective cycled RR testing**
  - Testing of diabatic DFI with radar data assimilation
- **Summer-fall 2008**
  - **Transfer Rapid Refresh code to NCEP, testing begins there**
  - **Testing continues at GSD**
- **Fall 2009**
  - **NCEP implementation of Rapid Refresh to replace RUC**
- **2012**
  - **NCEP implementation of Rapid Refresh ensemble with**
    - **3 ARW members and 3 NMM members**
    - **using ESMF framework (Earth System Modeling Framework - NOAA, NASA, DOD, NCAR consortium)**

RUC/RR project sponsors

- FAA Aviation Weather Research Program
  - Model Development and Enhancement Research Team
  - Convective Weather Research Team
- NOAA/ESRL/GSD
- FAA TAMDAR project

RUC colleagues (outside ESRL)

- NCEP – Geoff Manikin, Geoff DiMego, EMC, NCO…
- FAA Aviation Weather Research Program
  - Ken Leonard, Gloria Kulesa, Warren Fellner…
- NCAR
  -Roy Rasmussen, Greg Thompson, Jenny Sun, Jordan Powers, …
- WRF community
- DTC (NCAR and GSD colleagues)
- Aviation Weather Center
  - Fred Johnson, Clinton Wallace, Steve Silberberg
- Storm Prediction Center
  - Steve Weiss, Jack Kain, Phillip Bothwell…

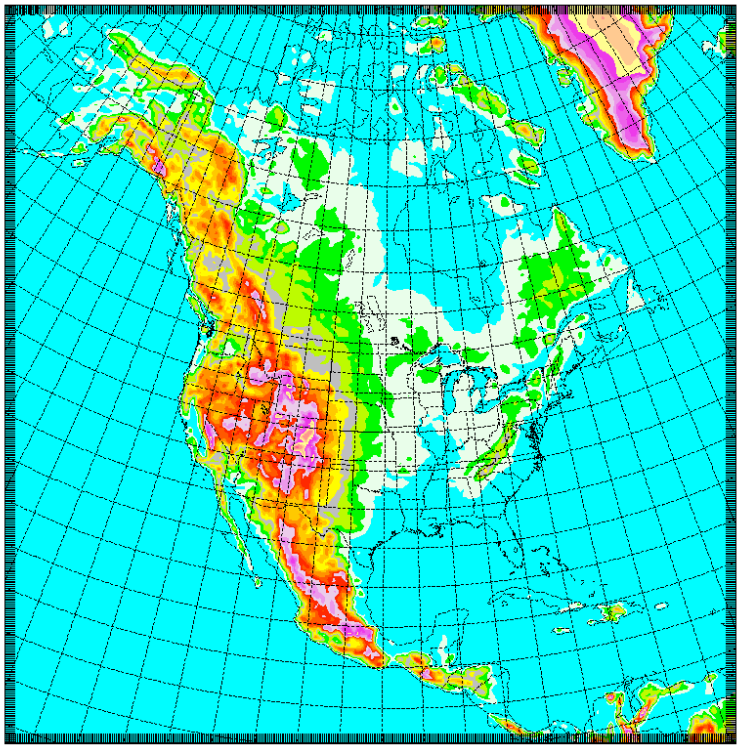
- NWS Regions, individual WFOs
- NESDIS/CIMSS – Madison, WI – Bob Aune, Paul Menzel
- NWS – Kevin Johnston, Dave Helms….

Rapid Refresh – 2009+

- International use throughout North America
→ ultimately, global

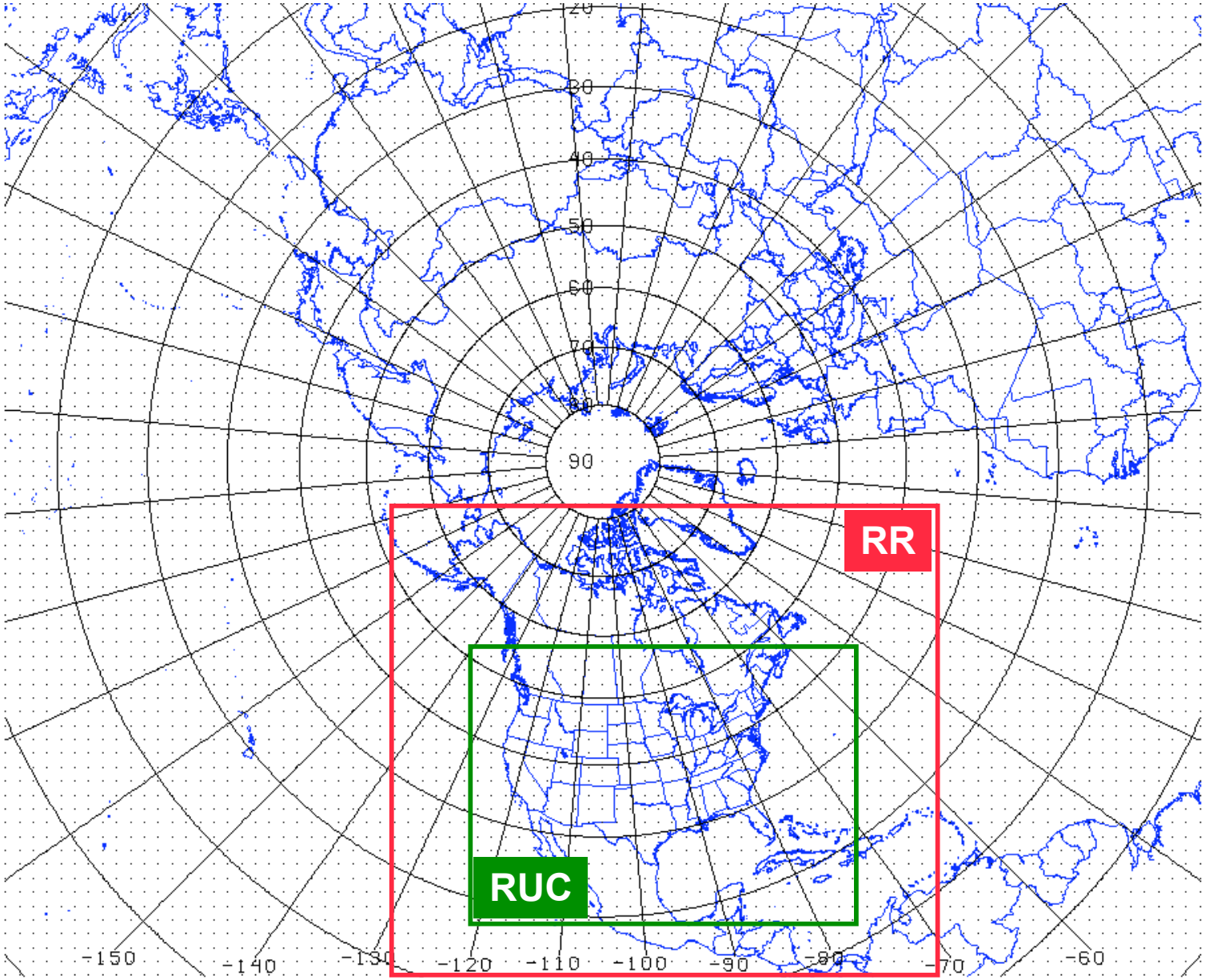
- Assimilation of
  - radar reflectivity, radial winds
  - GOES /POES satellite radiances
  - satellite cloud drift winds
  - scatterometer winds
  - All RUC-assimilated observations

- 'Situational awareness fcst model'
- 3-km High-Resolution Rapid Refresh (HRRR)
- Chem-Rapid Refresh
  - improved clouds, visibility



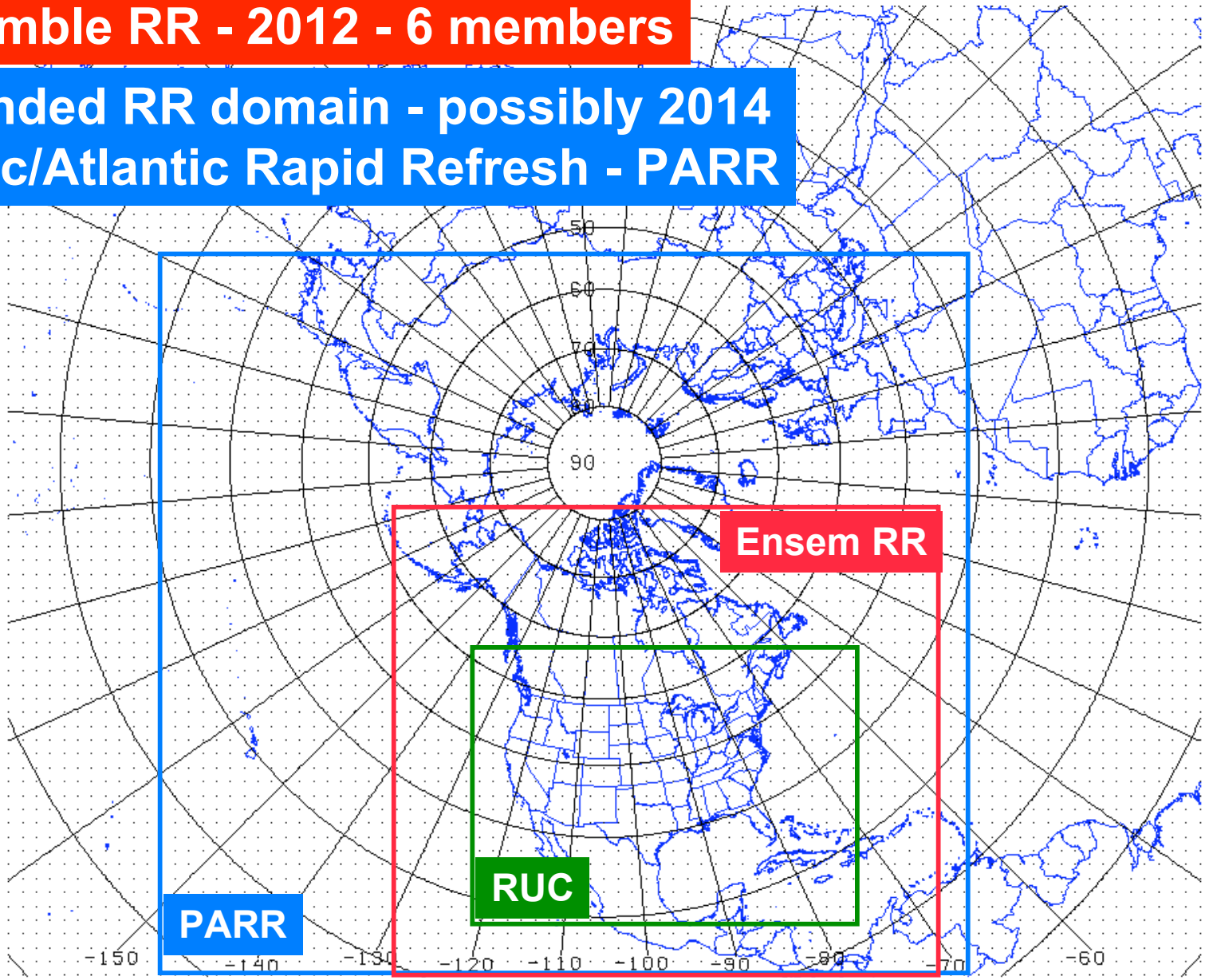
Trends for our perspective

- 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

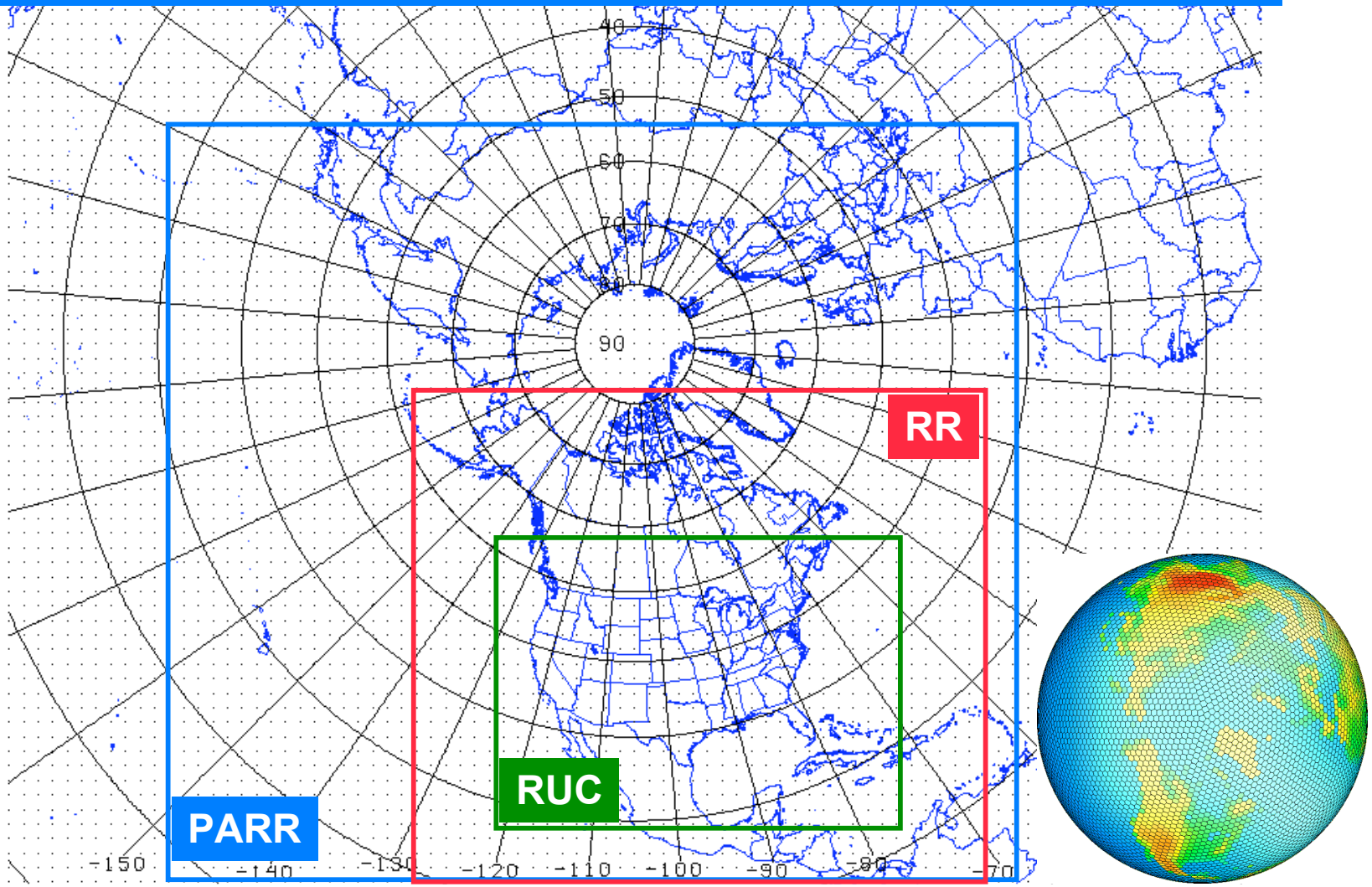

RR
RUC
-150
-140
-120
-110
-100
-90
-70
-60
90
NCEP Grid 55

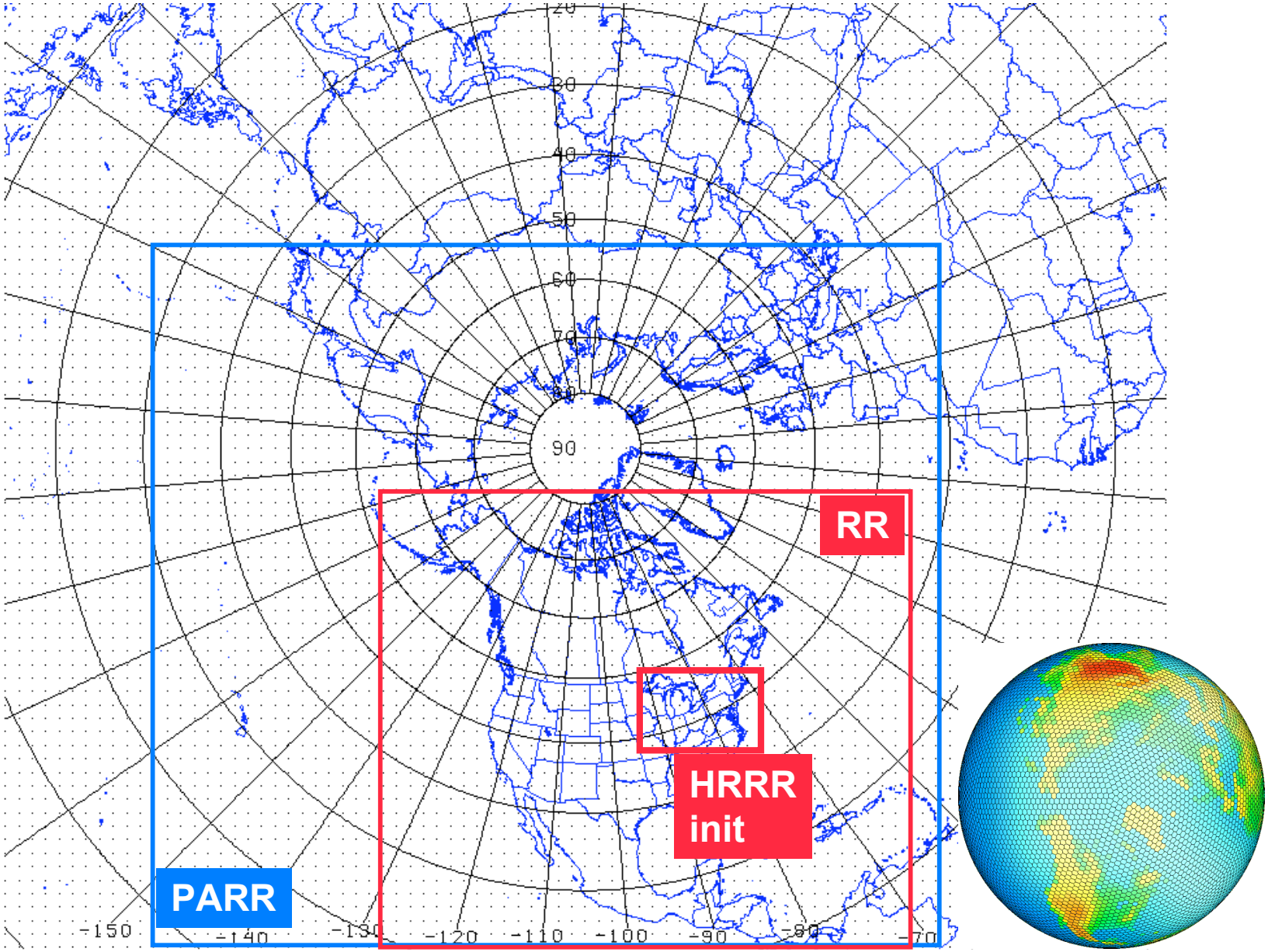
Ensemble RR - 2012 - 6 members

Expanded RR domain - possibly 2014
Pacific/Atlantic Rapid Refresh - PARR

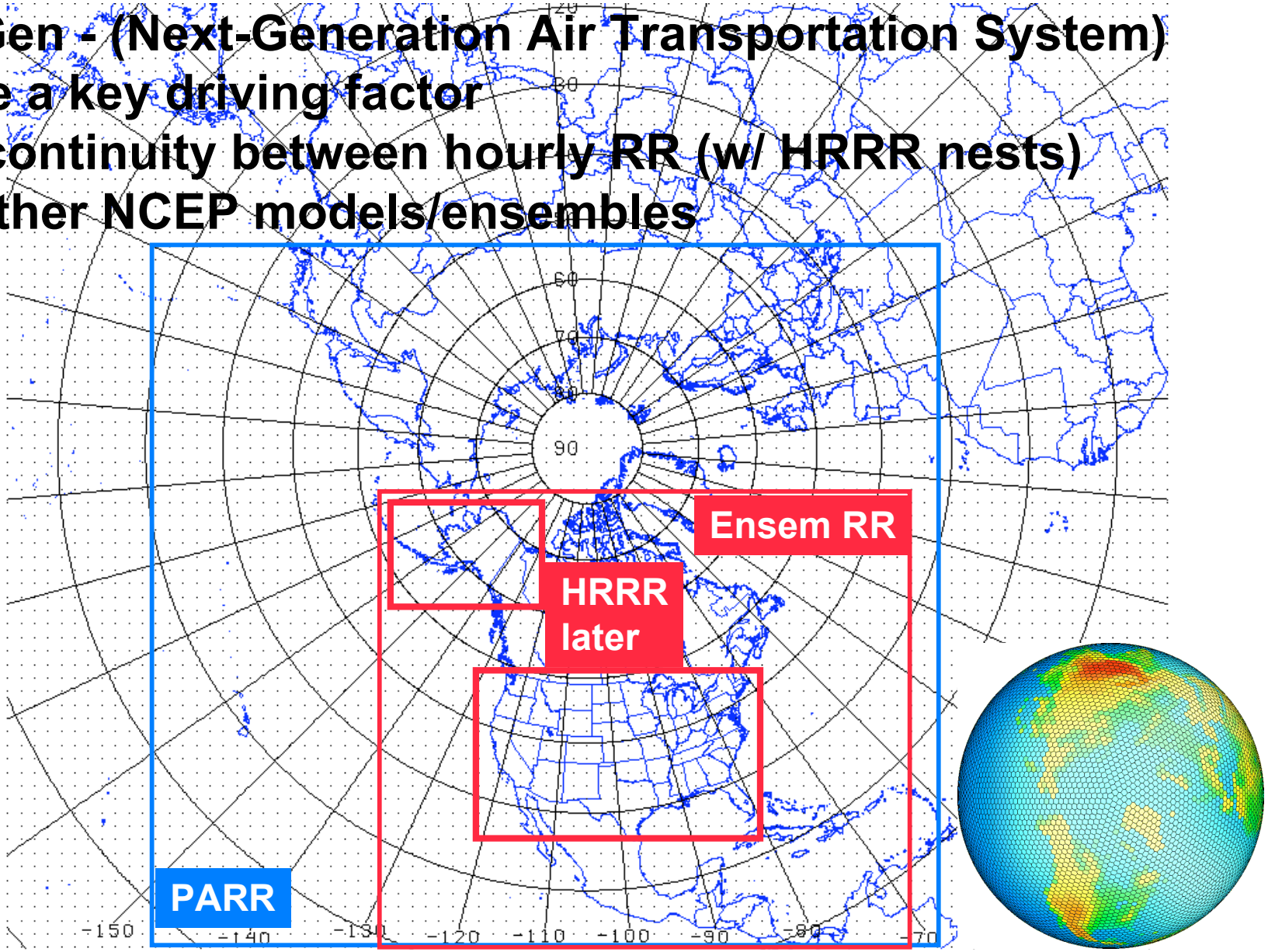


Global Rapid Refresh - hourly updated - 2016
New global satellite ground stations - 40min availability




RR
HRRR
init
PARR
Global RR
NCEP Grid 55

NextGen - (Next-Generation Air Transportation System) will be a key driving factor
-Full continuity between hourly RR (w/ HRRR nests) and other NCEP models/ensembles



Very Short-Range Ensemble Forecasts - VSREF
- Updated hourly

RR – time-lagged ensemble members
- 2012 - ensemble RR

NAM / NAM ensemble

GFS / GFS ensemble

SREF (updated every 6-12h)

MOS/LAMP, statistical correction

VSREF to include
- merged RCPF/extrap
- similar for icing, turb, etc.

VSREF – *Hourly* Updated Probabilistic Forecasts

RUC/Rapid Refresh Development and Testing

Major transitions:

- RUC13 change package – Early 2008
  - – radar reflectivity assimilation
  - - TAMDAR
  - - Improved radiation, convection physics in RUC
- Rapid Refresh planned for FY09
  - • WRF ARW, GSI, North America
- Ensemble Rapid Refresh
  - • proposed by 2012, to use ESMF framework
- High-Res Rapid Refresh (HRRR) – proposed to NCEP by 2012
  - • 3km hourly updated 12h forecast
  - • In testing at GSD
  - • Covering NE Corridor

http://Ruc.noaa.gov