Meso- and Storm-scale Probabilistic Forecasts from the RUC, Rapid Refresh, and High-Res Rapid Refresh (HRRR)

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Earth System Research Laboratory
SCIENCE, SERVICE & STEWARDSHIP

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

Meso- and Storm-scale Probabilistic Forecasts from the RUC, Rapid Refresh, and HRRR

Outline:

- Need for hourly updated probabilistic forecasts from the RUC (and upcoming Rapid Refresh and HRRR)

- Experiences with Time-lagged ensembles
  - **RUC Convective Probabilistic Forecast (RCPF)**
  - **HRRR Convective Probabilistic Forecast (HPCF)**
- Plans on hourly-updated ensembles in ESRL and NCEP plans
  - **NAM / Rapid Refresh Ensemble (NARRE)**
  - **High Resolution Rapid Refresh Ensemble (HRRRE)**

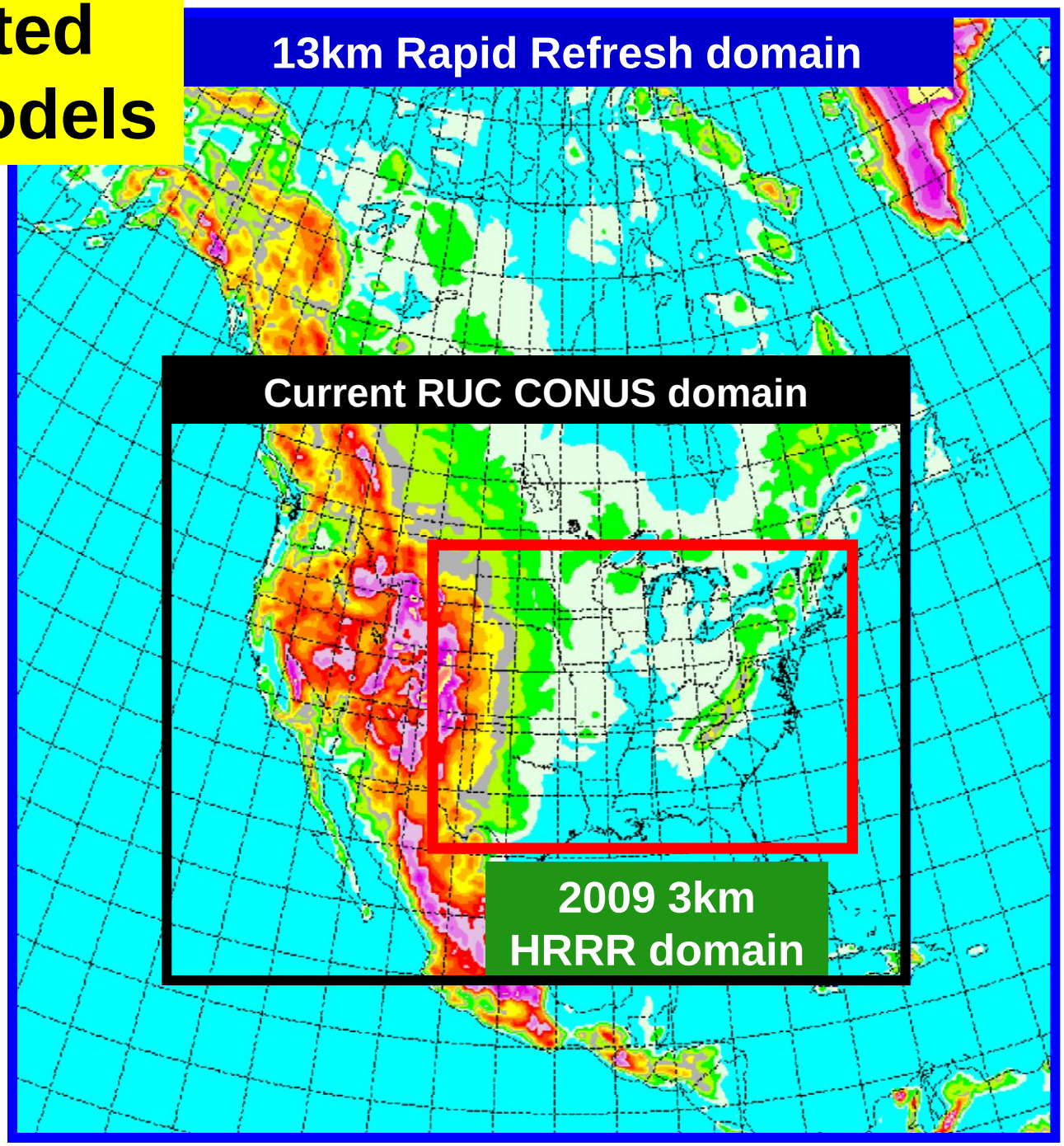
- Post-processing for probabilistic hazard guidance

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
- Goes to 6-member ensemble in 2012-13

HRRR - Hi-Res Rapid Refresh
-Experimental 3km

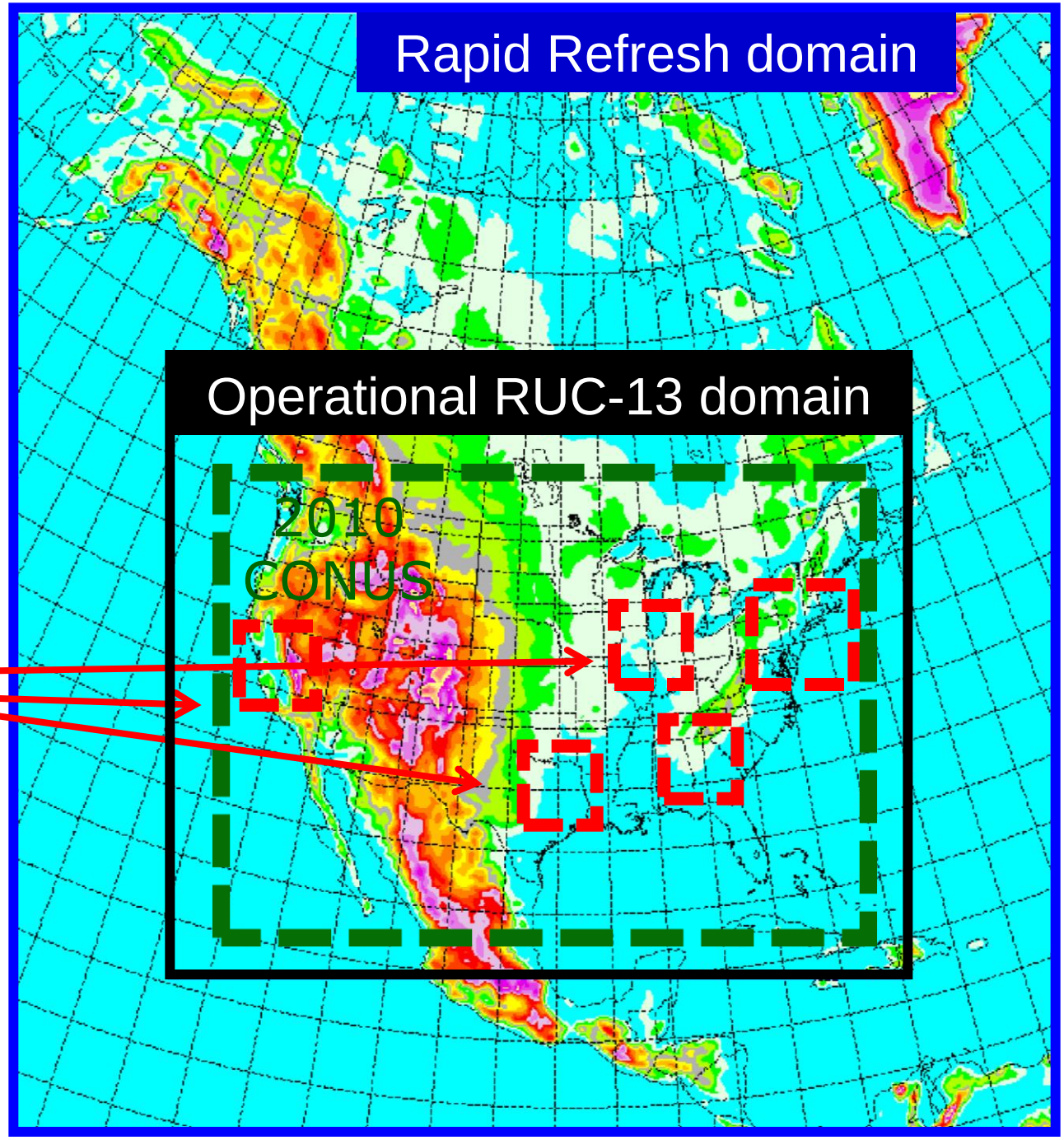


Rapid Refresh, HRRR, +0.5-1.0km HRRR subnests

HRRR – 2010 demo for aviation impact

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

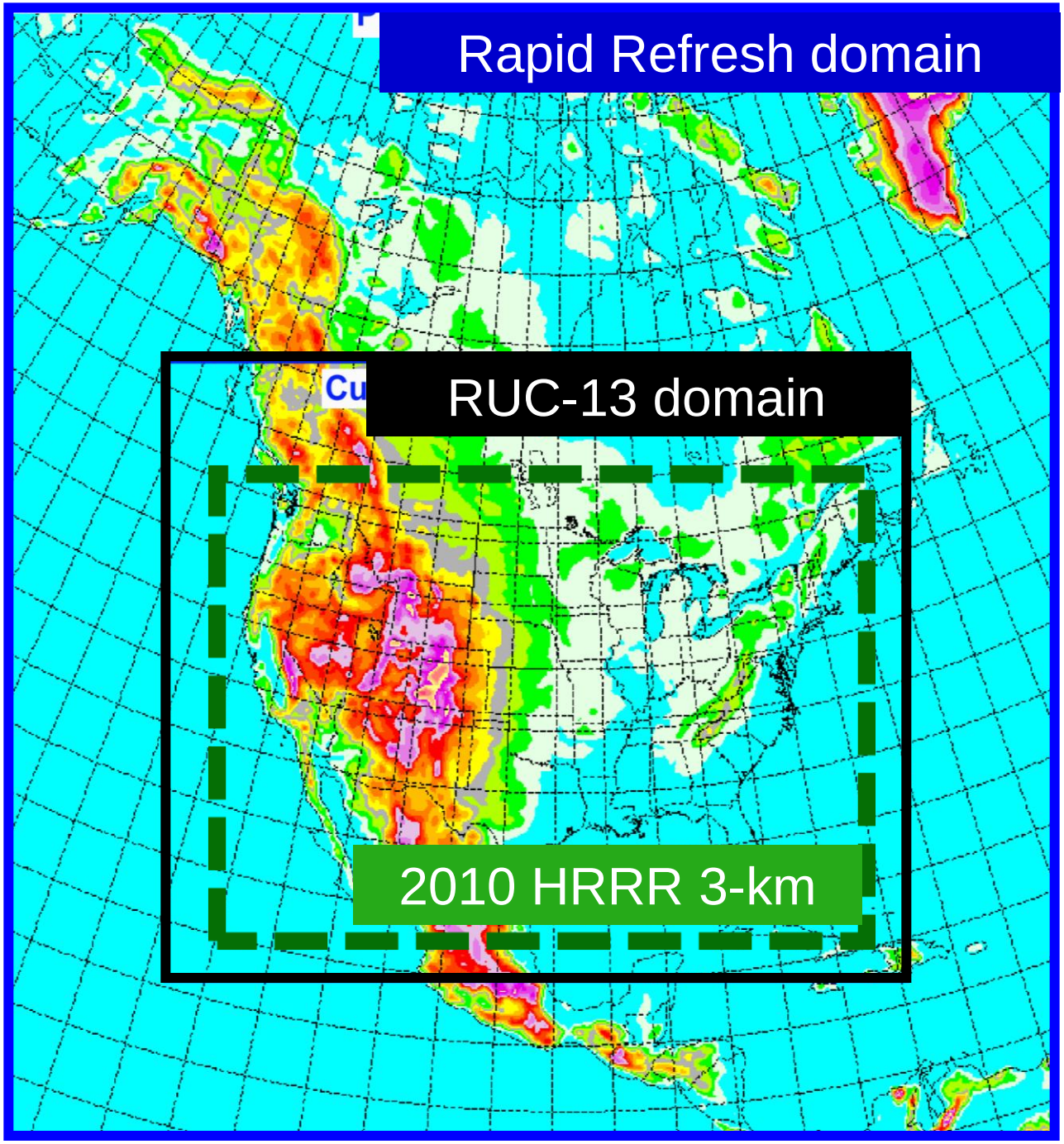
RR/HRRR Applications – aviation, severe wx, renewable energy, AQ, fire, hydro



RUC, Rapid Refresh and HRRR **Time-lagged ensembles**

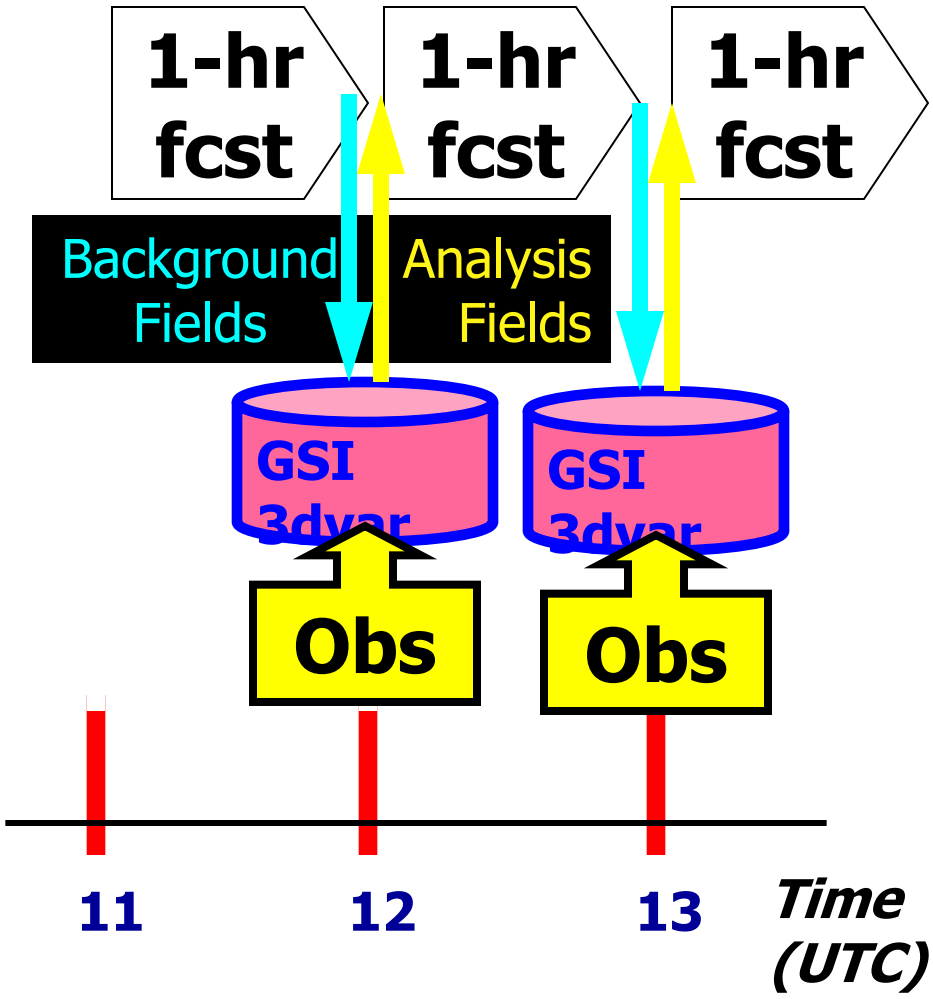
RUC –
- **RCPF** = RUC Conv Prob Fcst

HRRR –
- **HCPF** = HRRR Conv Prob Fcst



RUC/Rapid Refresh Hourly Assimilation Cycle

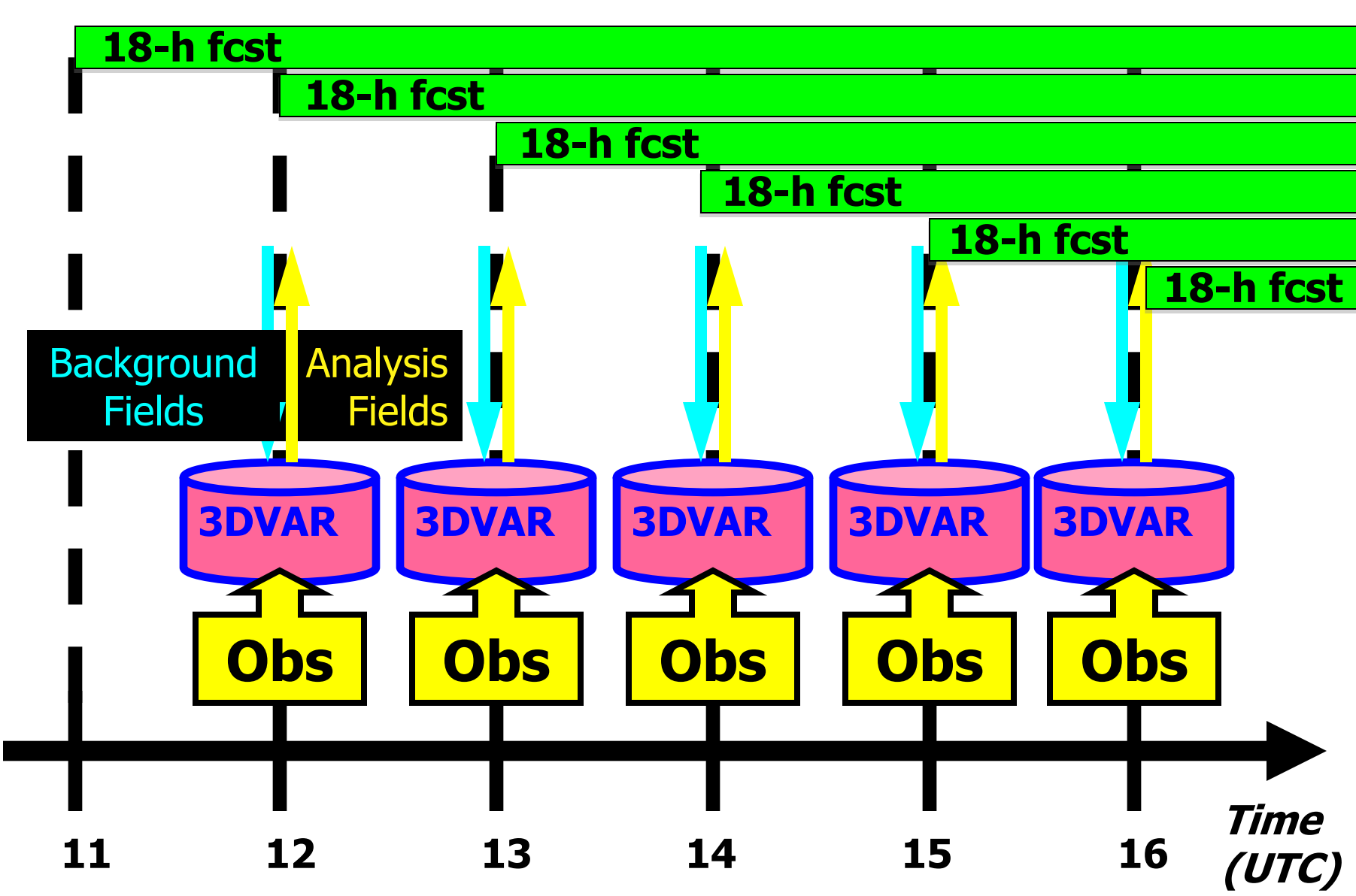
Cycle hydrometeor, soil temp/moisture/snow plus atmosphere state variables



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	
Radar reflectivity/ lightning	1km

RUC Hourly Assimilation Cycle - fall 2009



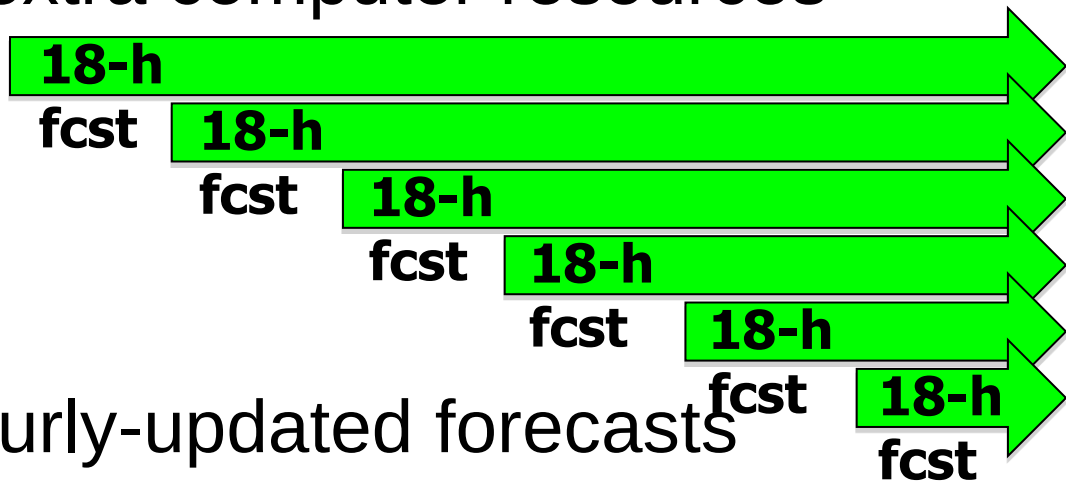
Meso- and Storm-scale Probabilistic Forecasts from the RUC, Rapid Refresh, and HRRR

Original motivation for the crudest of ensembling:

- Convection forecasts from RUC
  - Consideration for air-traffic management, QPF not accurate especially at fine resolution

Dilemma:

- Niche=hourly NWP, no extra computer resources



Opportunity:

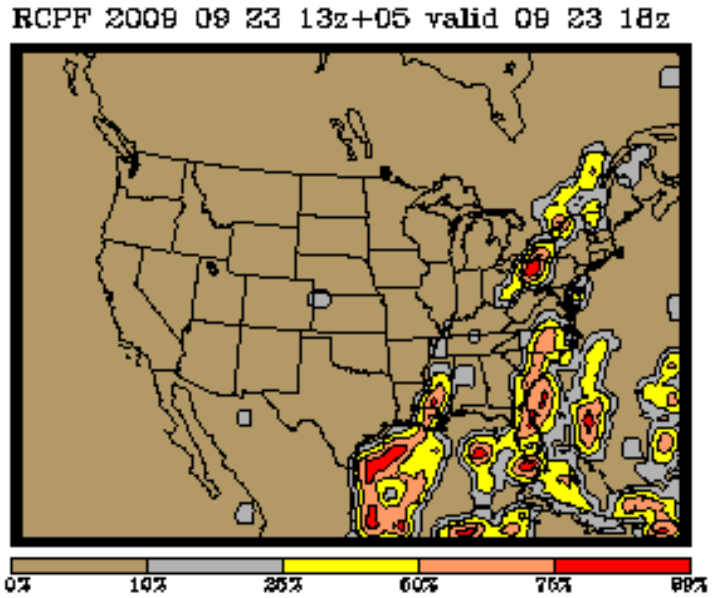
- Strongly overlapping hourly-updated forecasts

RUC, Rapid Refresh and HRRR
Time-lagged ensembles

RCPF = RUC Conv Prob Fcst

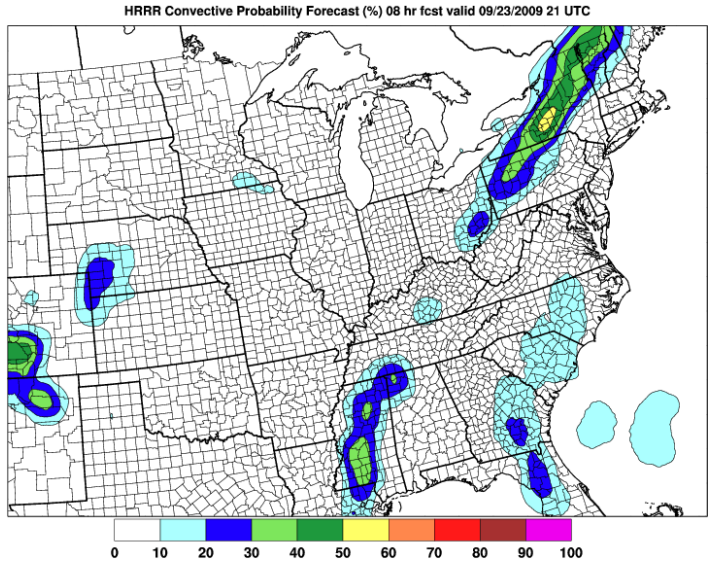
http://ruc.noaa.gov/rcpf.

- Running since 2004 through current (Oct 2008).
- Runs hourly based on13km RUC run at ESRL.
- Provides hourly updated 3,4,5,6,7,8,9h probabilistic forecasts of the likelihood of 40-dbZ radar echoes within a 40-km-side grid volume.
- Gridded RCPF data provides guidance to NOAA Aviation Weather Center for the Collaborative Convective Forecast Product (CCFP) .



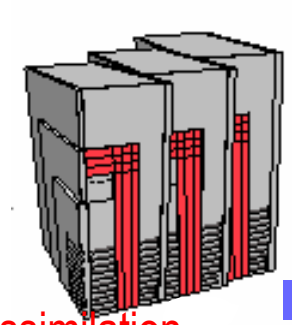
HCPF = HRRR Conv Prob Fcst

- Running since June 2009
- Hourly updated based on 3km HRRR
- http://ruc.fsl.noaa.gov/hcpf/hcpf.cgi

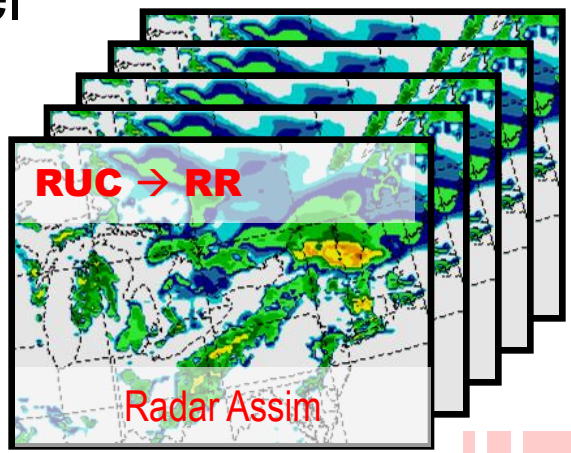


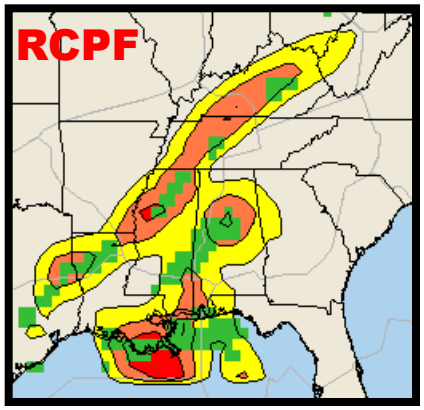
Model-based *probabilistic* storm guidance

Hourly updating model

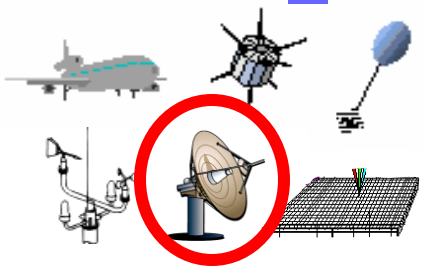


Data Assimilation cycle

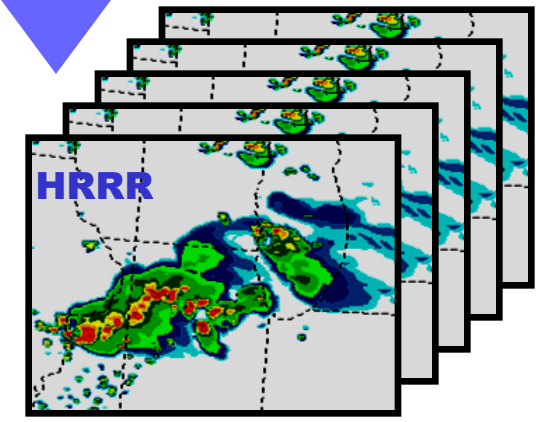




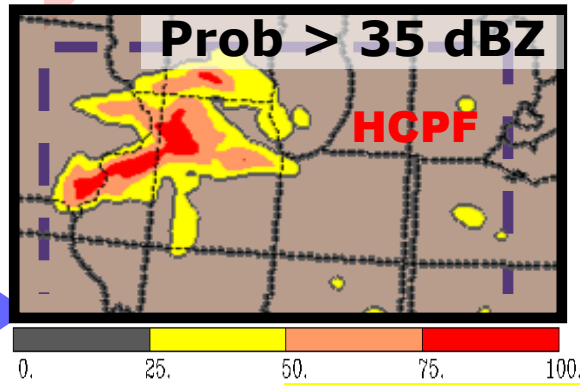
Model post-processing



Observations



time-lagged ensembles



Probability products

(HRRR-based) HCPF
Storm-scale probability information

Spatial filter

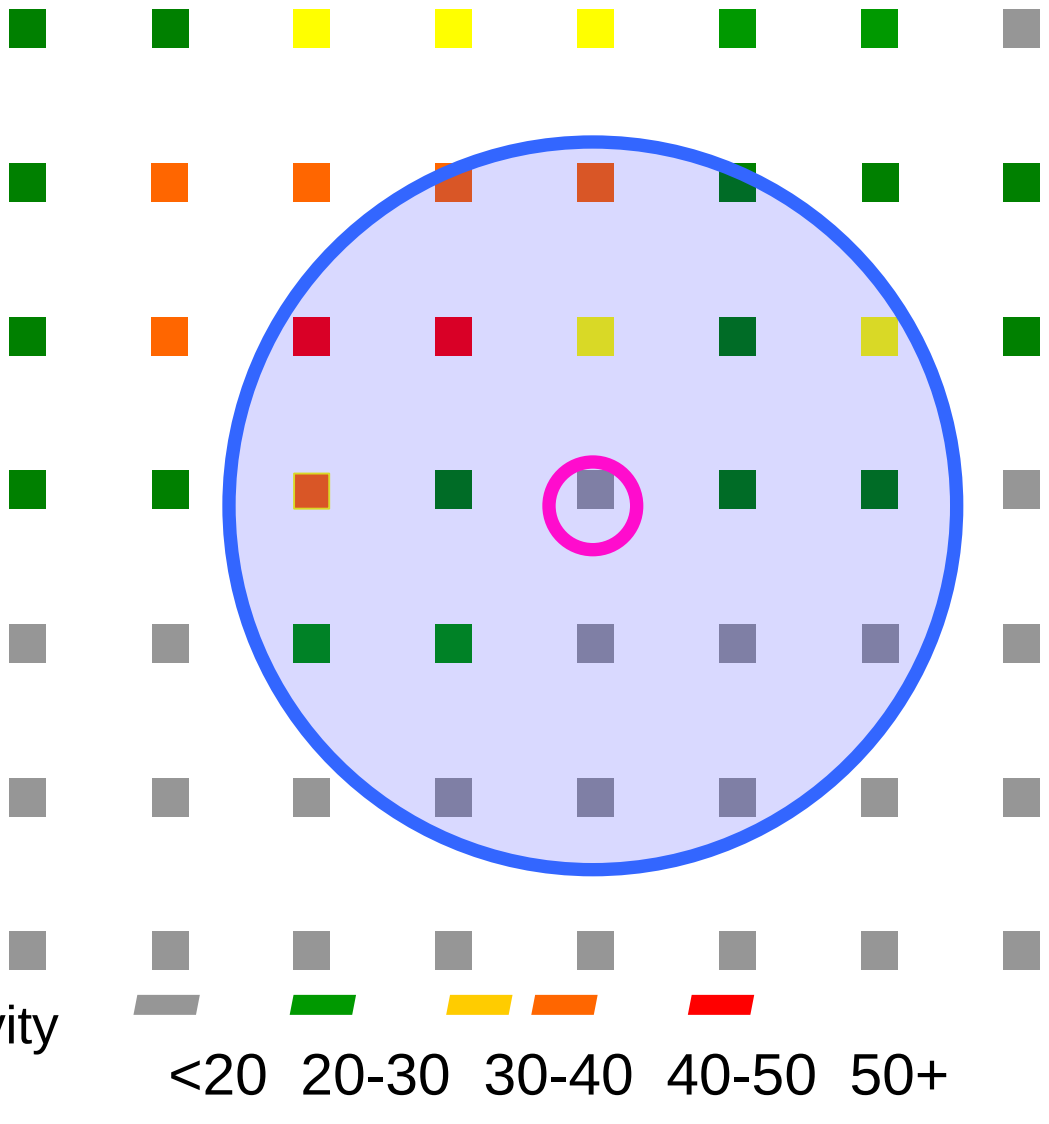
Calculate probability:

Find fraction of points within box that exceed the threshold

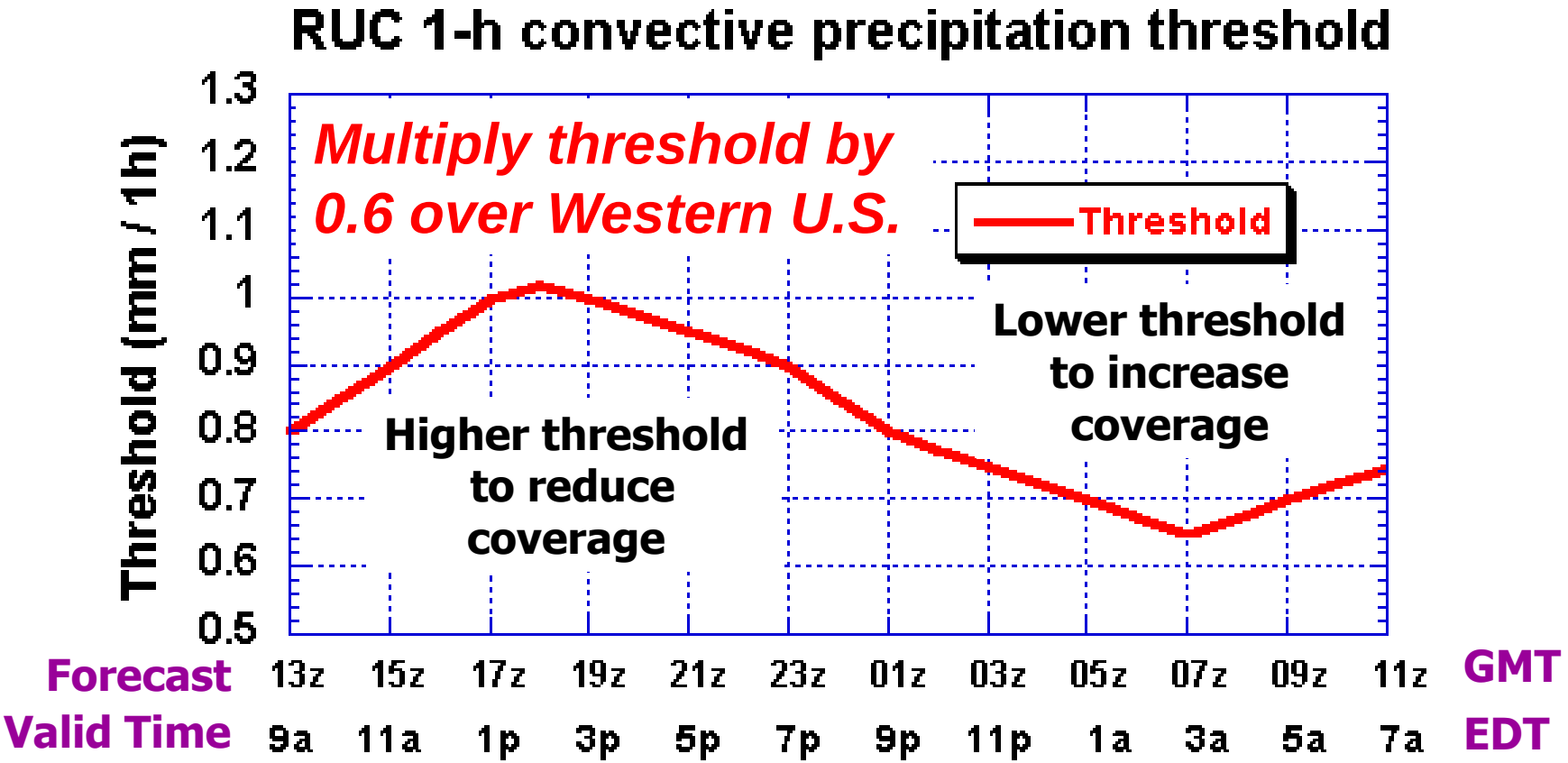
Example

Threshold > 30 dBZ

Probability = 7 / 21
= 33 %



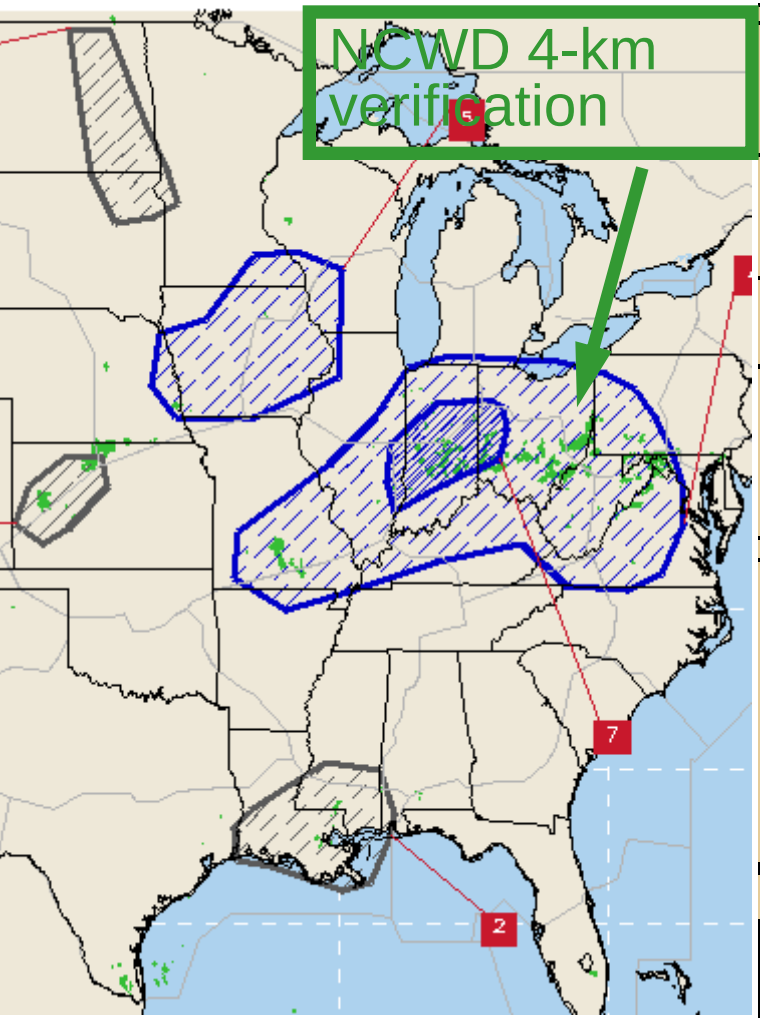
RCPF bias corrections

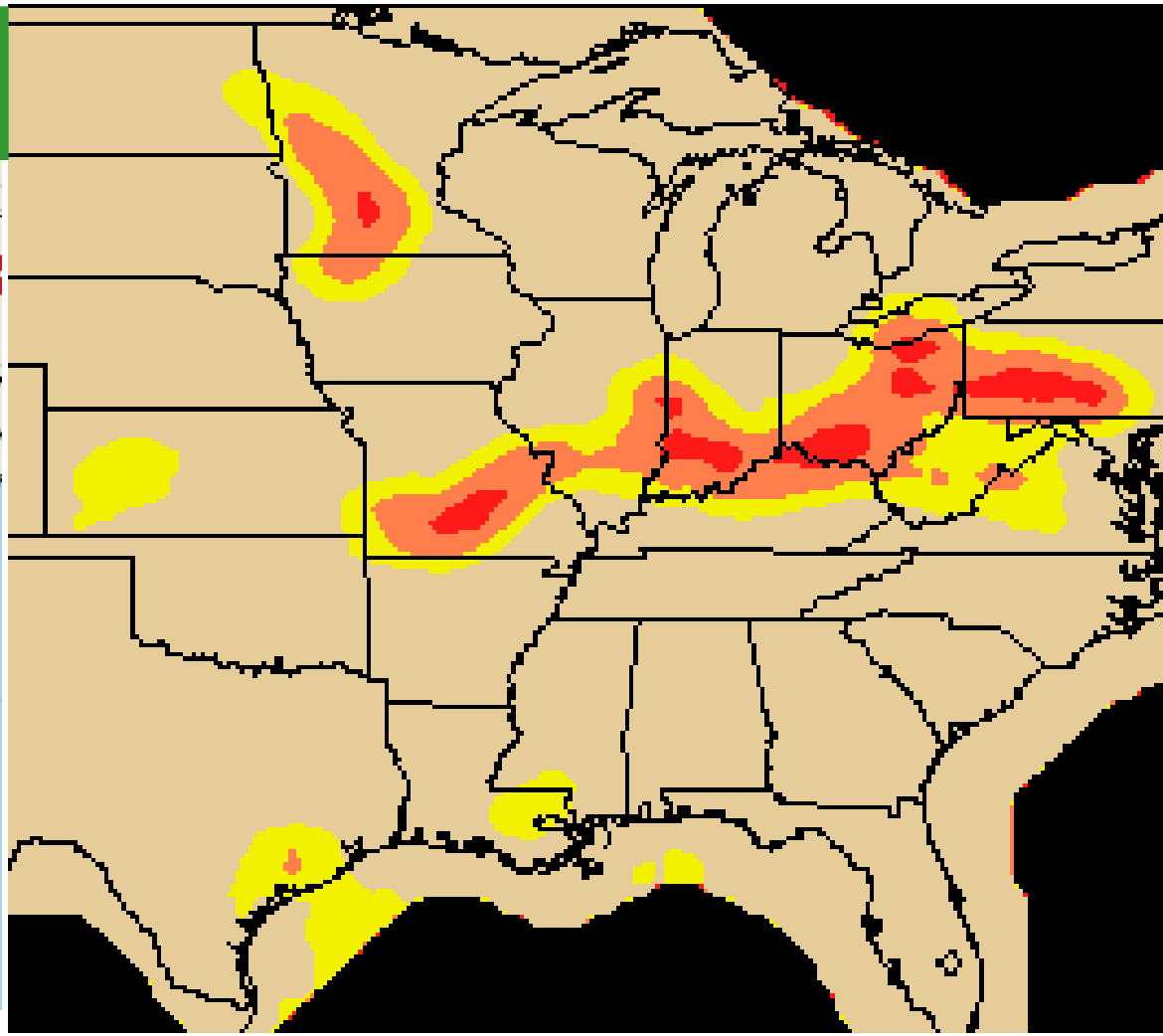


- Precipitation threshold adjusted diurnally and regionally to optimize the forecast bias
- Use smaller filter length-scale in Western U.S.

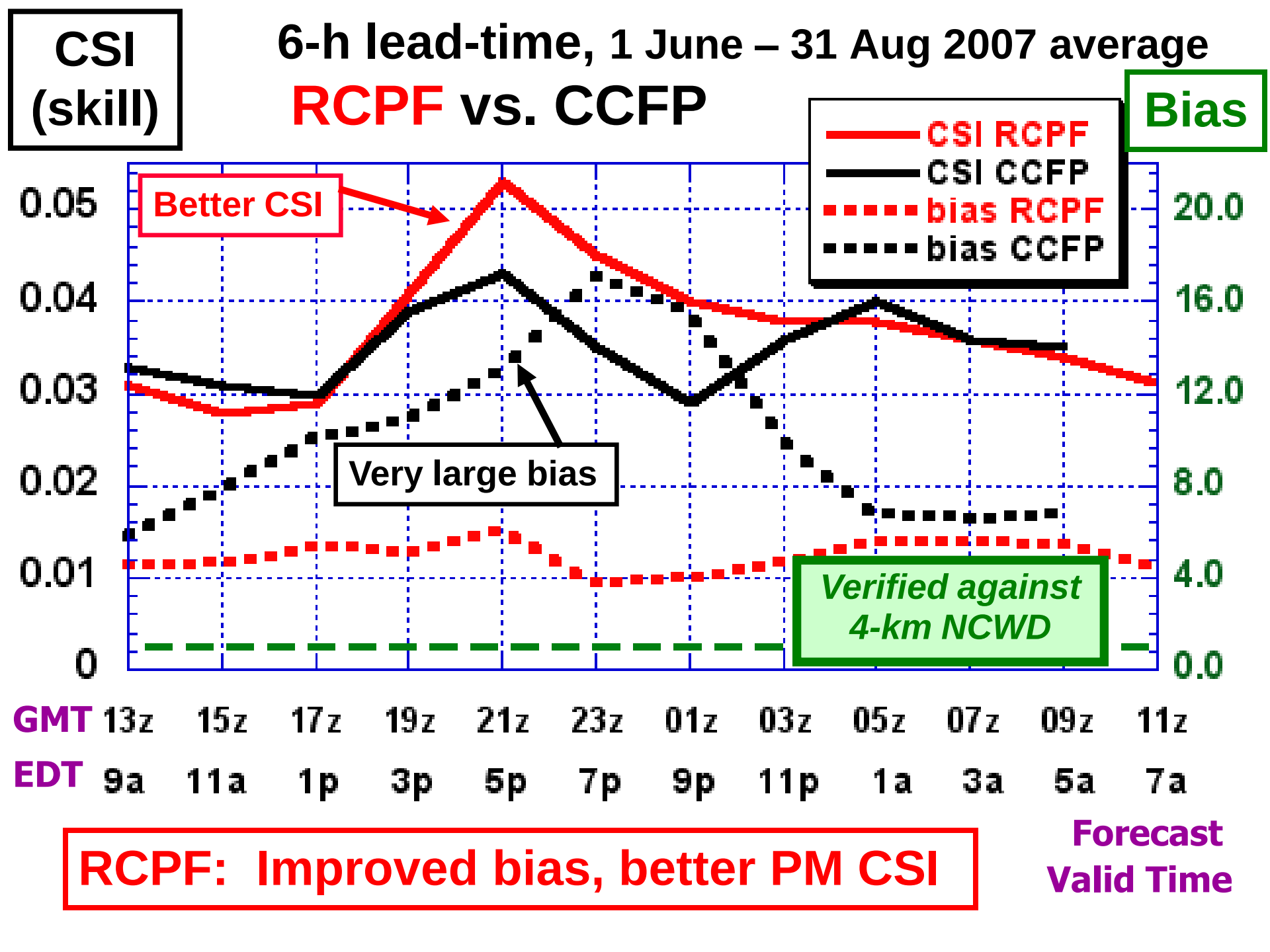
CCFP 15z +6h

RCPF 13z +8h



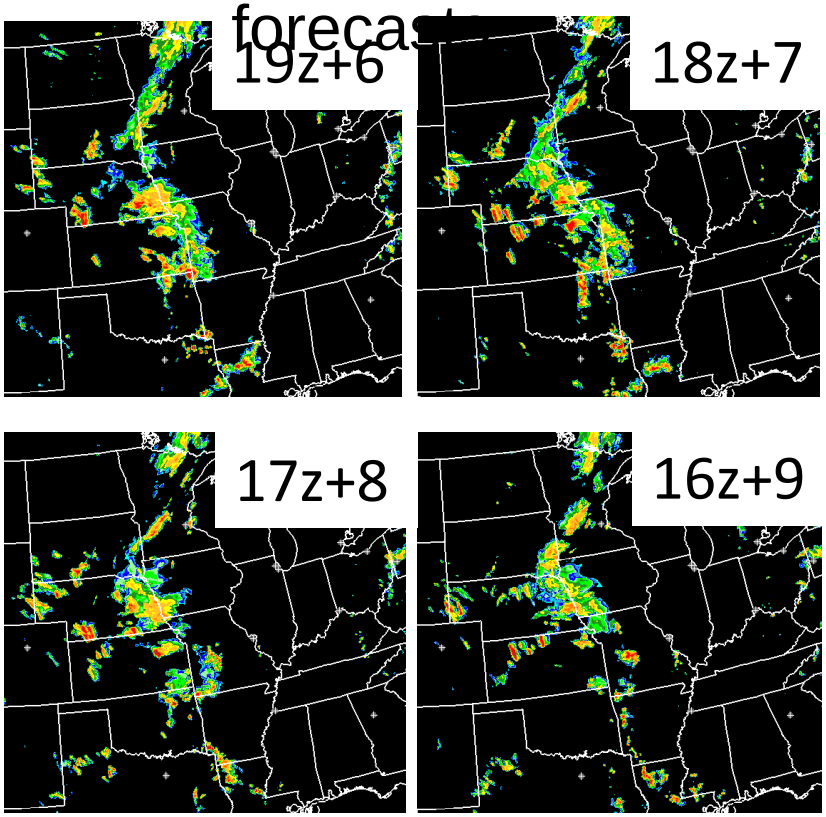


Valid 21z 20 Aug. 2007

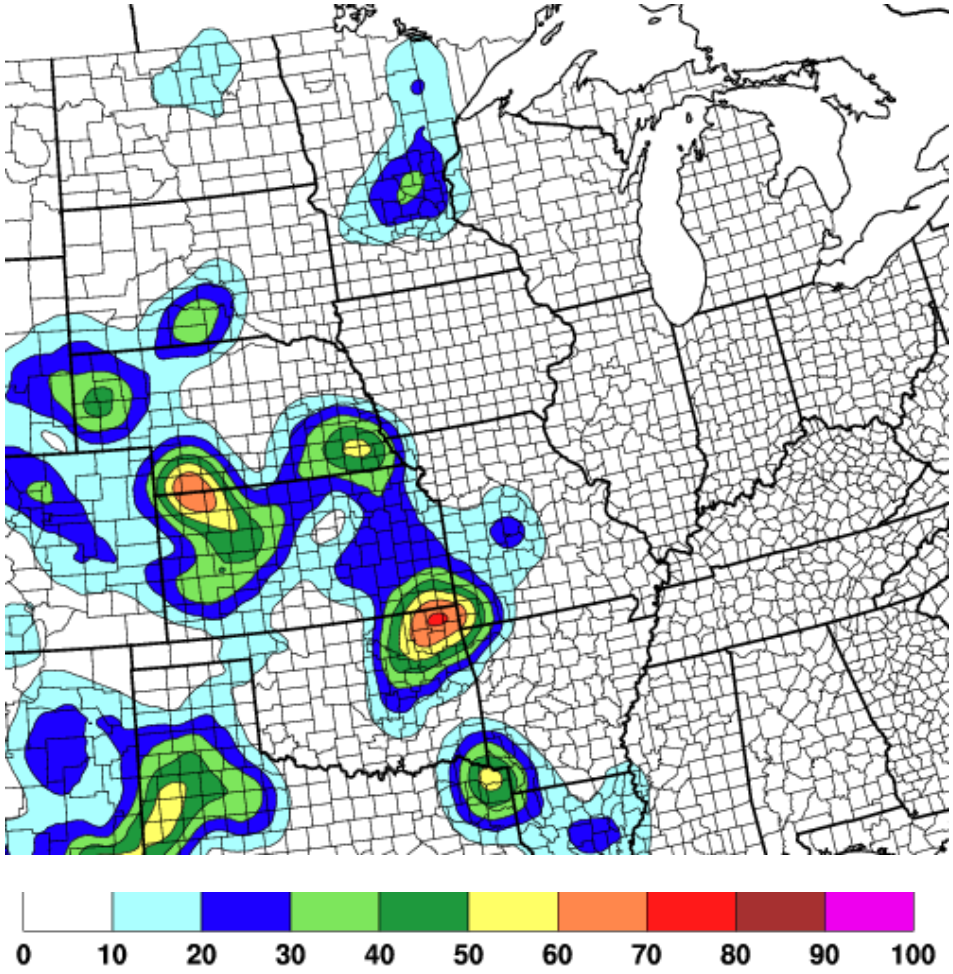

CSI (skill)
6-h lead-time, 1 June – 31 Aug 2007 average
RCPF vs. CCFP
Bias
CSI RCPF
CSI CCFP
bias RCPF
bias CCFP
Better CSI
Very large bias
Verified against 4-km NCWD
0.05
0.04
0.03
0.02
0.01
0
20.0
16.0
12.0
8.0
4.0
0.0
GMT 13z 15z 17z 19z 21z 23z 01z 03z 05z 07z 09z 11z
EDT 9a 11a 1p 3p 5p 7p 9p 11p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

HCPF example
valid 01z 21 July 2009

HRRR forecasts

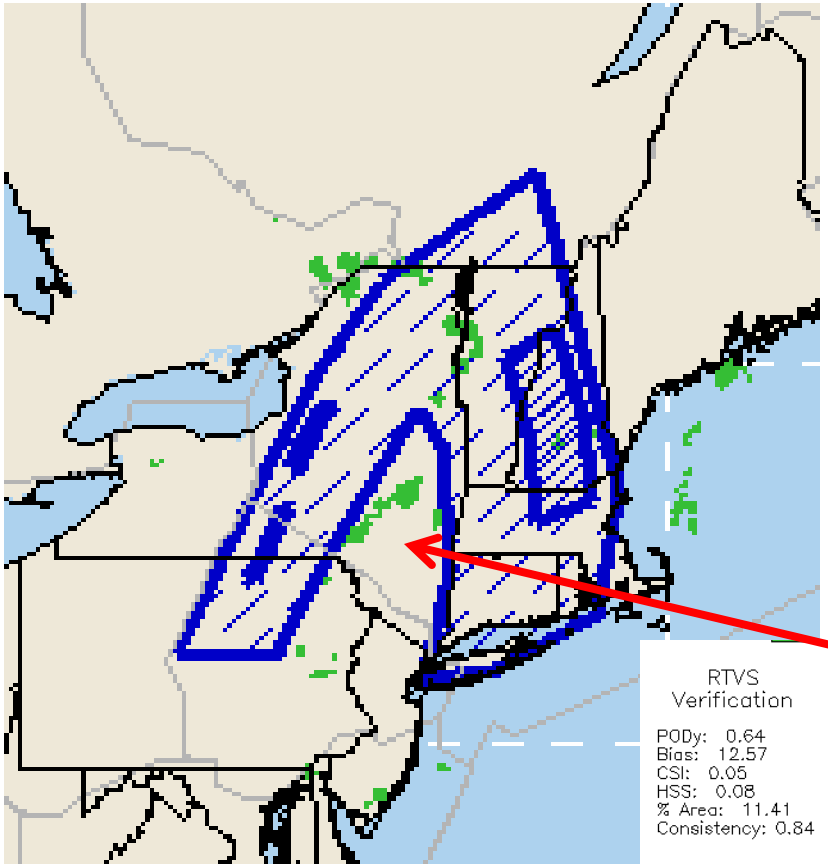


HCPF (4-hour lead)

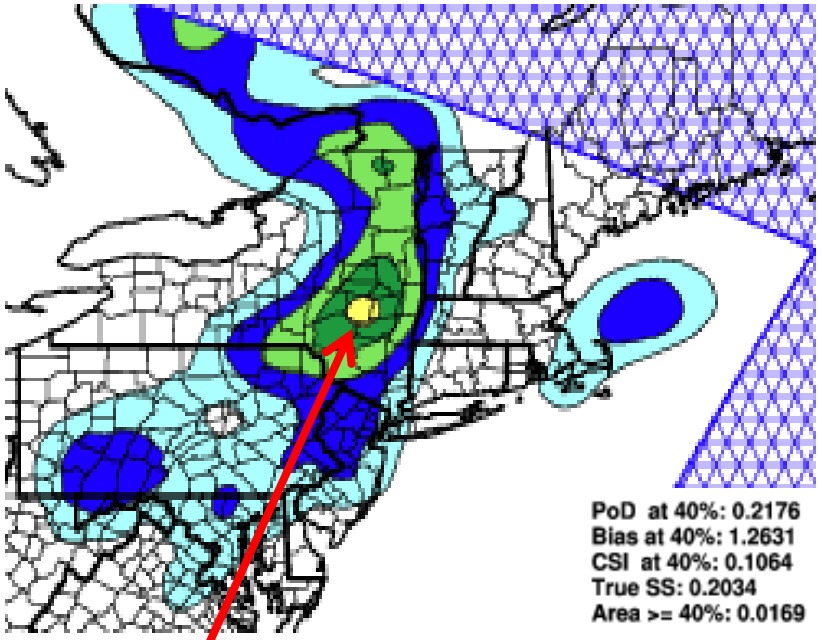


16 July 2009 case study

17z + 4 hour CCFP:



15z + 6 hour HCPF:

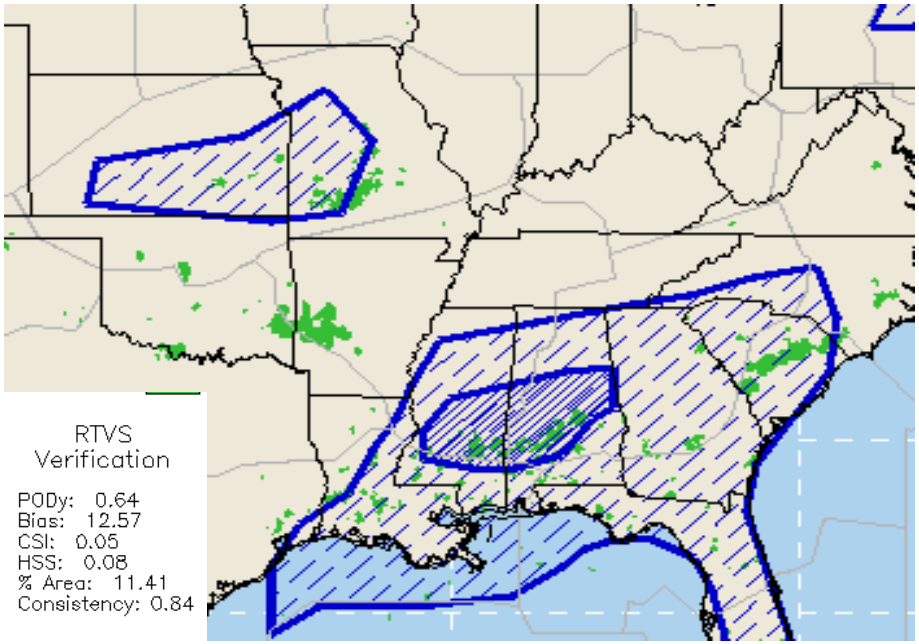


HCPF accurately placed a bulls eye over east-central NY

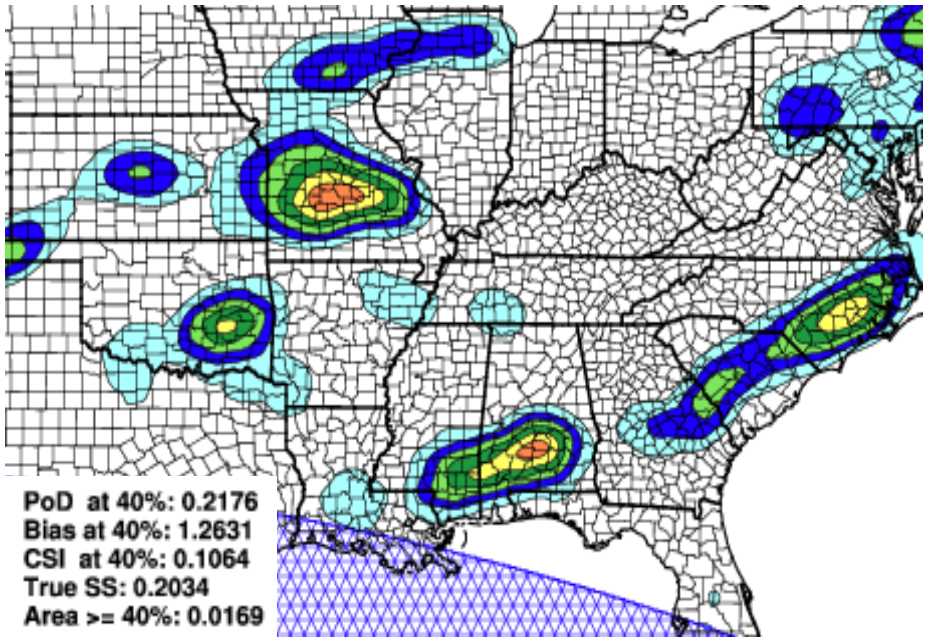
CCFP missed this cluster of storms

16 July 2009 case study

17z + 4 hour CCFP:



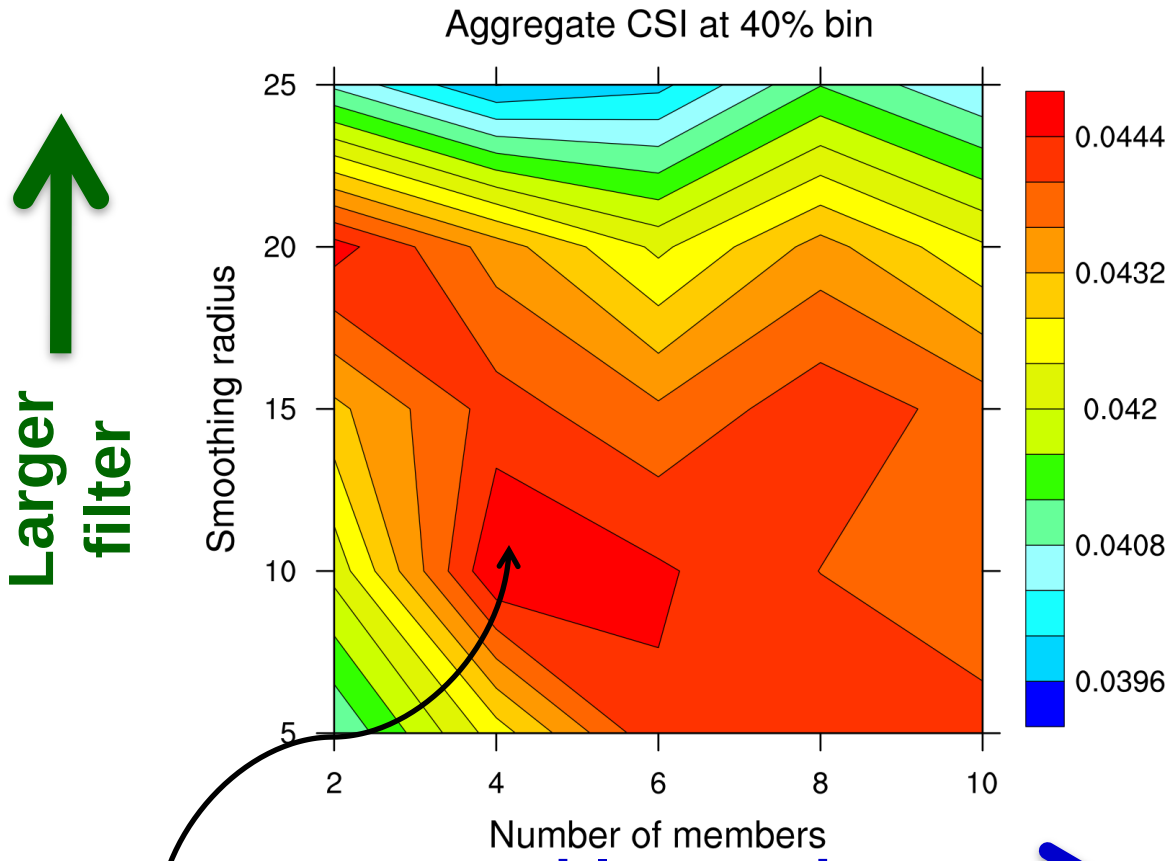
15z + 6 hour HCPF:



HCPF pinpoints the major areas of convection, avoiding excessive false alarms

CCFP captures much of the convection, at the cost of a very high bias

Optimizing the HCPF algorithm



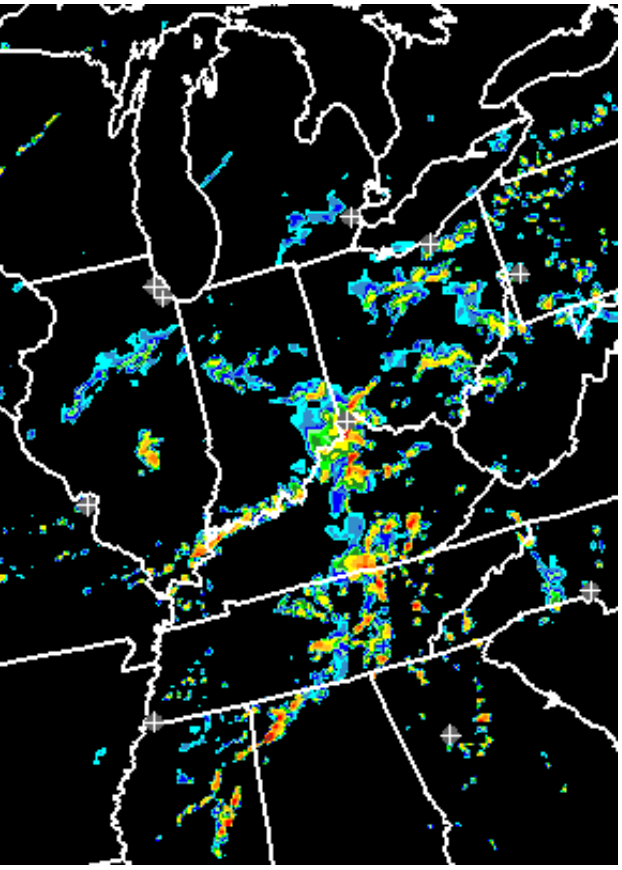
Optimal # of members is O(3-5):

too few = low PoD, too many = low bias

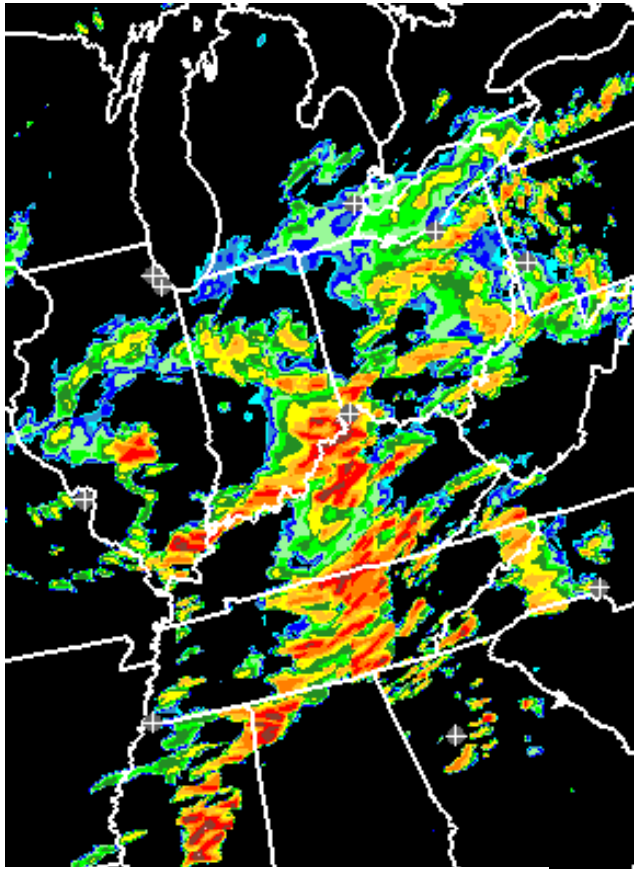
Optimizing the HCPF algorithm

Instantaneous reflectivity suffers from phase errors

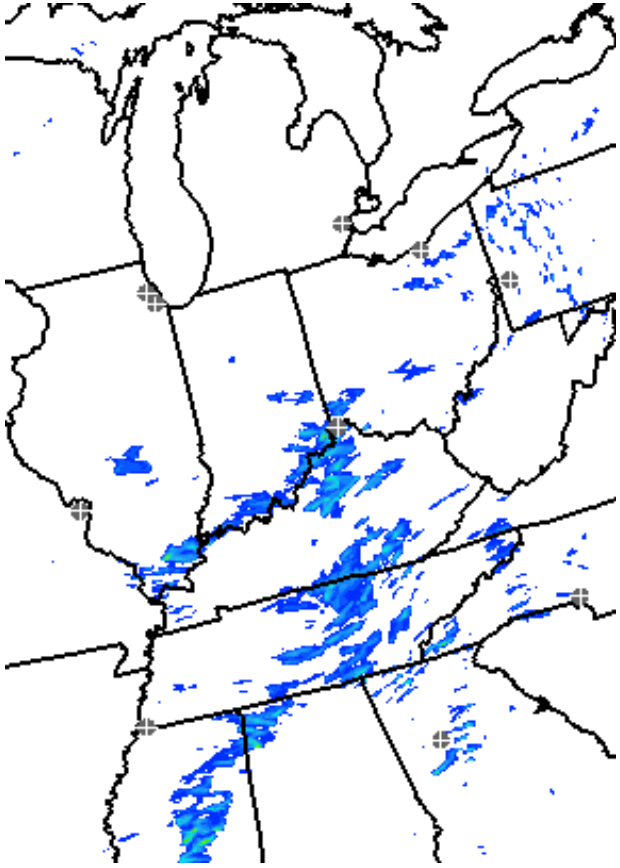
Using hourly maximum increases coverage → better predictor



HRRR reflectivity



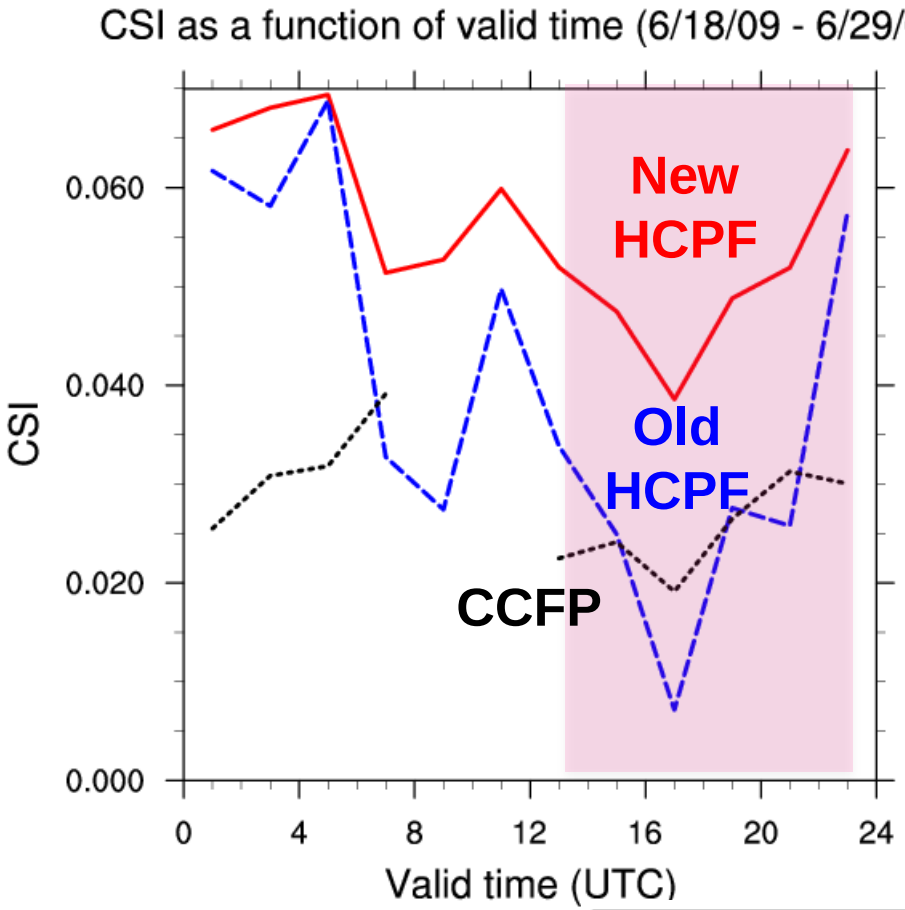
Hrly max HRRR refl

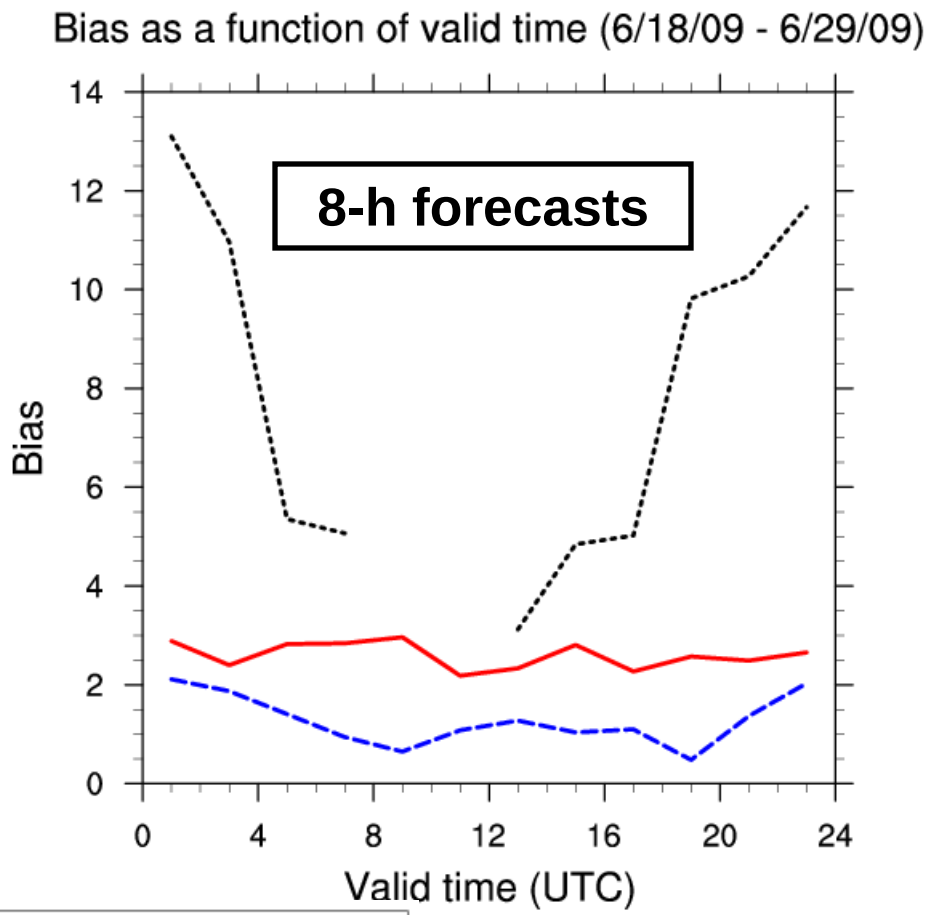


Hrly max updraft

HCPF improvement from optimizing parameters

- switch predictors
- use diurnal threshold selection
- reduce time-lag
- optimize spatial filter size



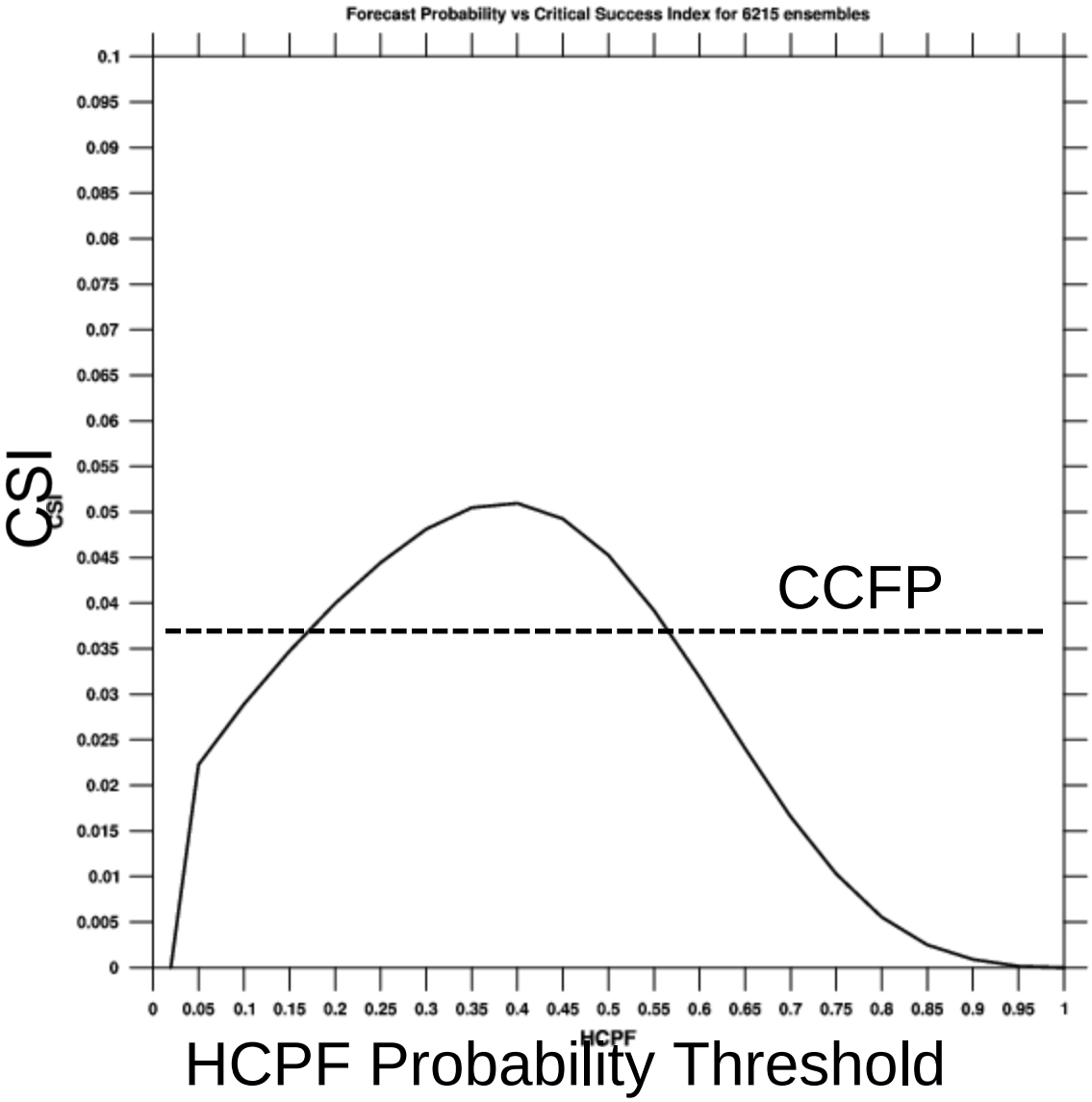


Verification results

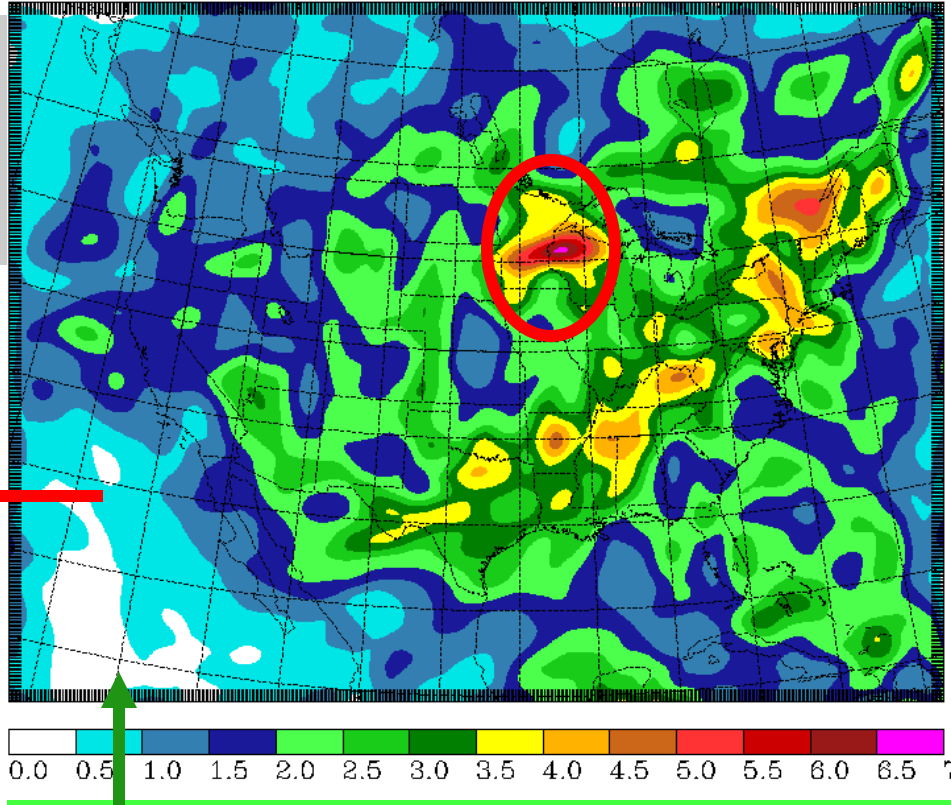
HCPFs for all of August 2009 comprising 6215 ensemble forecasts (all lead and valid times)

Shows comparable skill to the CCFP

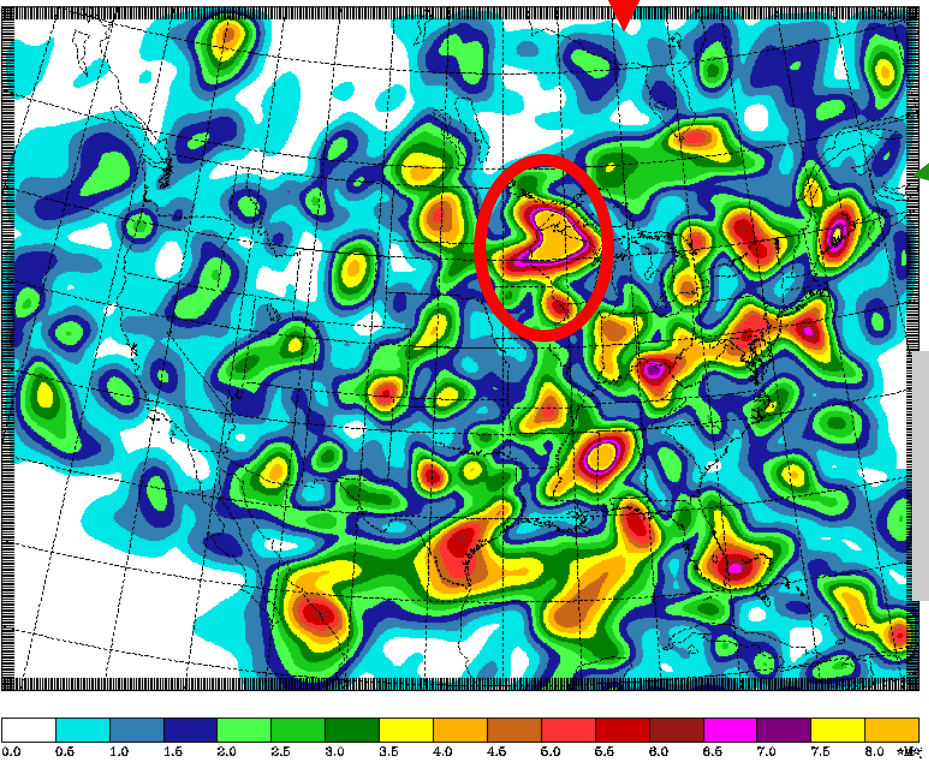
Caveat: HCPF currently on smaller domain than CCFP (but is issued every hour unlike CCFP)



Variance of 250 hPa wind forecast ensemble from 4 forecasts (4h, 3h, 2h, 1h)



Time-lagged-ensemble variance can be used to estimate wind forecast error



0.60 - correlation between variance/error

Mean absolute wind vector error of 4-h forecast

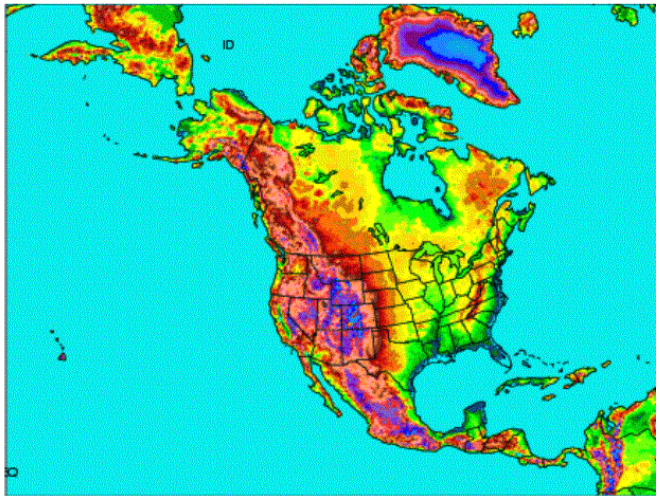
00 UTC 23 Oct 2008 - using RUC

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

CURRENT (2009)

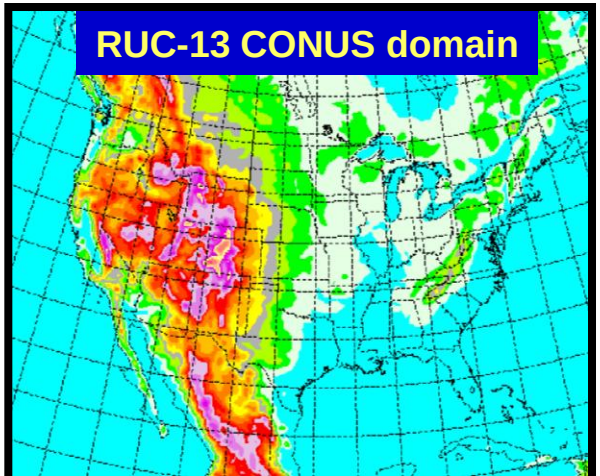
NAM

- WRF-NMM (Egrid)
- GSI analysis
- 4/Day = 6 hr update
- Forecasts to 84 hours
- 12 km horizontal
- 60 layers with 2 mb top
- 12 hr pre-forecast assimilation period **with 3hr updates (catch-up)**



RUC

- Non-WRF RUC model
- RUC 3DVAR analysis
- 24/Day = hourly update
- Forecasts to 18 hours
- 13 km horizontal
- 50 layers with 50 mb top
- Continuous forward cycle with no pre-forecast assimilation **period**

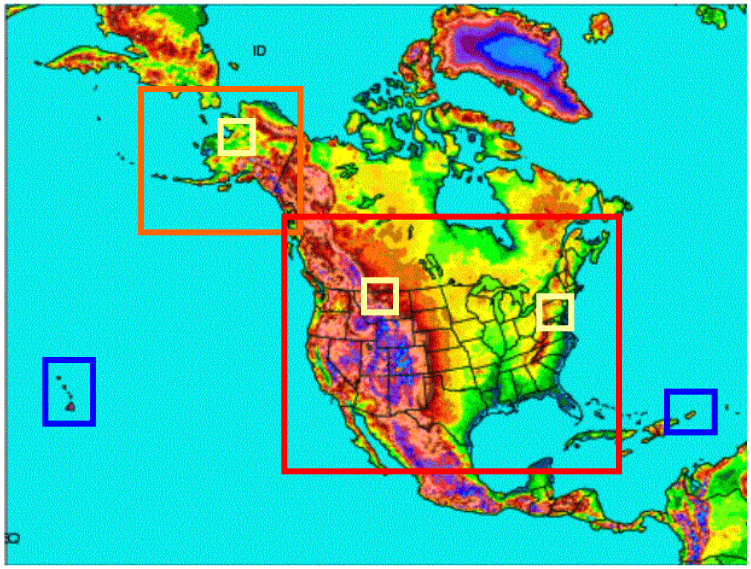


Coordinated Meso- and Storm-scale ensembles
The NARRE and the HRRRE

2010-2011

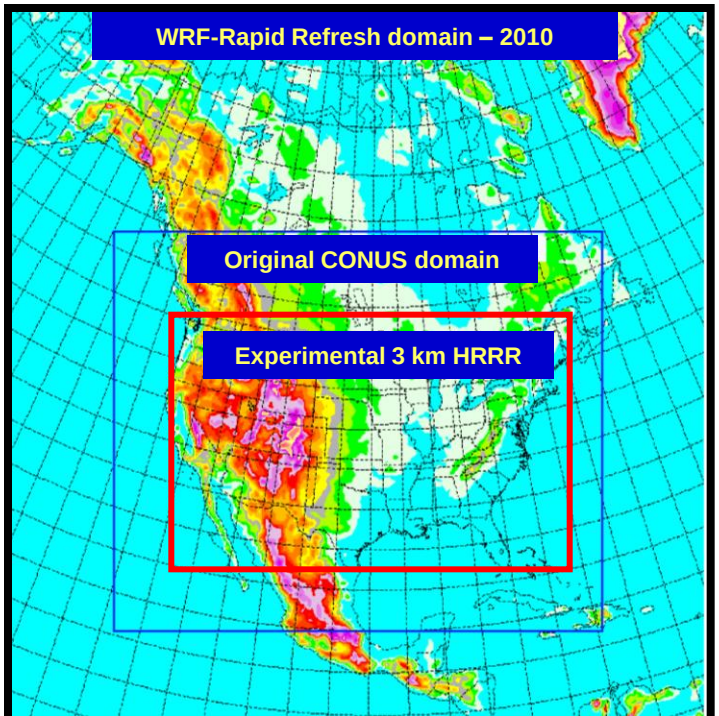
NAM

- NEMS based NMM
- Bgrid replaces Egrid
- Parent remains at 12 km
- Multiple Nests Run to 48hr
  - ~4 km CONUS nest
  - ~6 km Alaska nest
  - ~3 km HI & PR nests, and/or a ~1.5-2km DHS/FireWeather/IMET are possible



Rapid Refresh

- WRF-based ARW
- NCEP's GSI analysis (RR-version)
- Expanded 13 km Domain to include Alaska
- Experimental 3 km HRRR @ ESRL



2012-2013

NAM/Rapid Refresh ENSEMBLE (NARRE)

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

2012-2013

High-Resolution Rapid Refresh Ensemble (HRRRE)

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

Very Short-Range Ensemble Forecasts - VSREF

- Updated hourly w/ available members valid at same time

VSREF members

RR – hourly
time-lagged (TL) ensemble members
- 2012 - ensemble RR

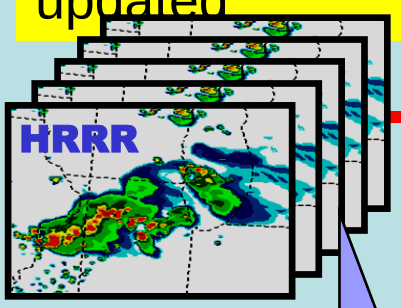
ESRL 3km HRRR (incl. TL ensemble)
- 2012 - proposed HRRR at NCEP
- future HRRRE from NARRE
NAM / NAM ensemble
GFS / GFS ensemble
SREF (updated every 6h)

VSREF –
Hourly
Updated Probabilistic Forecasts
= TL+ ensemble

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

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

VSREF-
Model Ensemble Members
- hourly (≤1h) updated



VSREF members - HRRR, RR, NAM, SREF, GFS, etc.

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

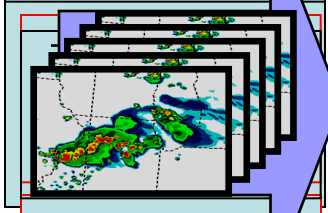
Unified Post-processing

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

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

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

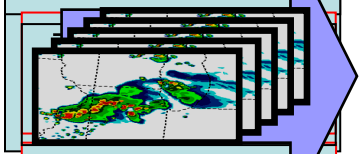
VSREF mems output for each AIV variable



For icing

Stat correction post- processing using recent obs

VSREF mems output - stat corrected



For icing

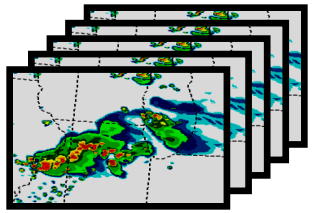
Optimal weighting

Most-likely-estimate single value

Probability/PDF output

Hourly updated ensemble forecasts:
Lessons learned and plans:

- Original context for RCPF: convection forecasts
- RCPF - provided automated convection product that matched CCFP, better for convective initiation
- Spatial and temporal (time-lagged) averaging – both needed
- Geographic and diurnal variations in accuracy – must be accounted for in averaging and bias correction
- Time-lagged ensemble does provide temporal continuity to prob forecasts from hour to hour – desirable by forecasters
- Formal hourly-updated ensembles are coming:
  - NAM/Rapid Refresh ensemble – 6 members
  - HRRR ensemble – 6 members



- Time-lagged ensembling provides 3-4x multiplier, may or may not add value as “multiplier” to NARRE or HRRRE (only 6 members)

Hourly Updated Ensemble Forecasts – experience, plans

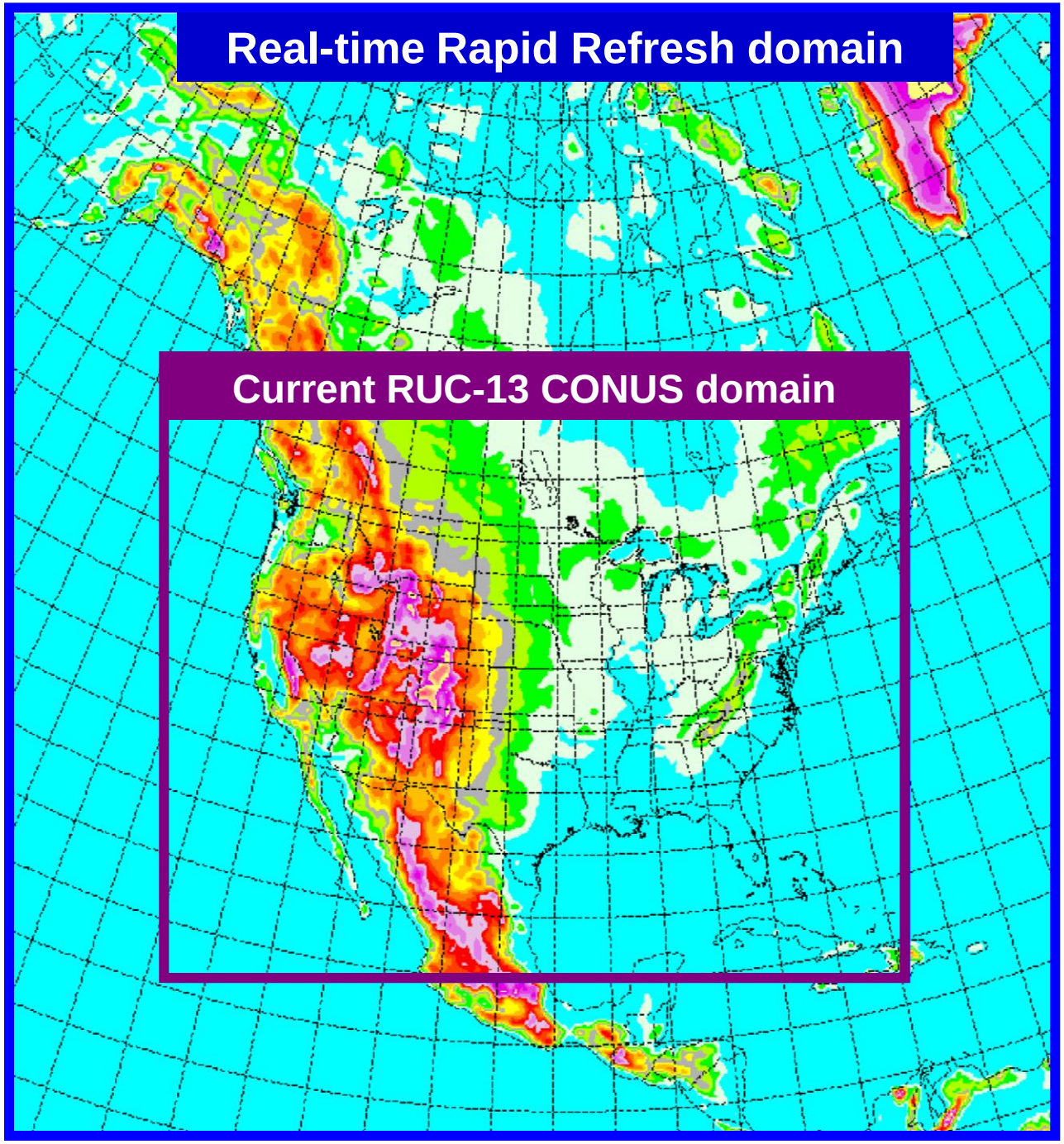
- RCPF/HCPF TL ensemble experience
- Plans for RR ensemble and HRRR ensemble
- Recommendation:
    - Use merged time-lagged + formal ensemble members toward "HFProb" (High-Frequency Probabilistic Forecasts)

RUC and Rapid Refresh

Rapid Refresh

NCEP implement:
Planned summer 2010

Features:
- **WRF-ARW w/ RUC physics**
- **GSI assim (like NAM but w/ RUC enhancements)**
- **Radar assim (like RUC)**



RUC, Rapid Refresh and HRRR

RUC – NCEP

upgrade 17 Nov 08

(Radar refl assim, TAMDAR aircraft).

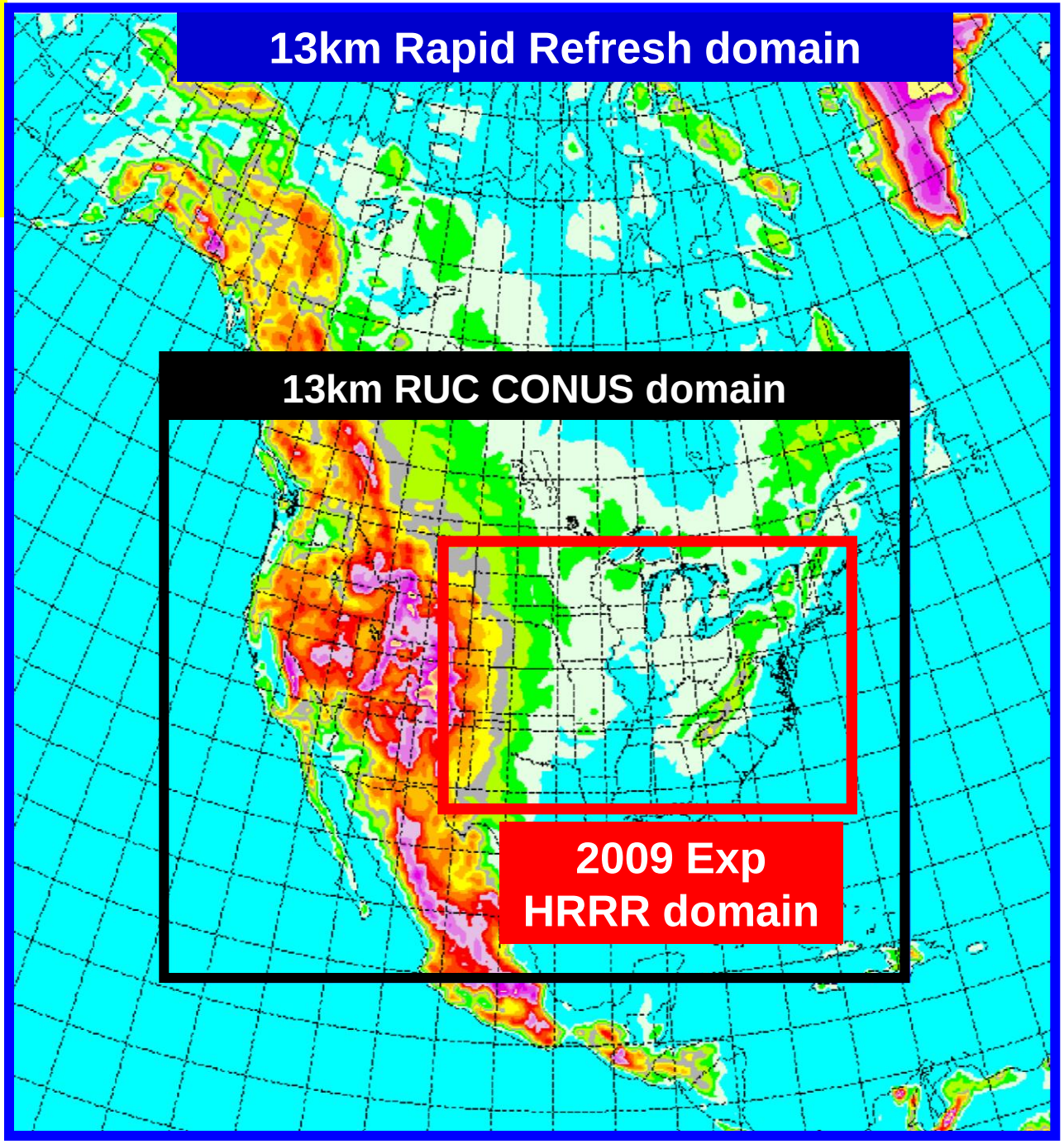
All runs to 18h- Fall09

RR – 2010 at NCEP

2 R/T cycles at GSD, full radiance assim, cloud anx + radar assimilation

HRRR – FAA demo

for aviation impact, radar assim from RUC, 12-h fcst each hour



Mesoscale Uncertainty

- Uncertainty varies for different different weather hazards

  -- very high uncertainty for convection

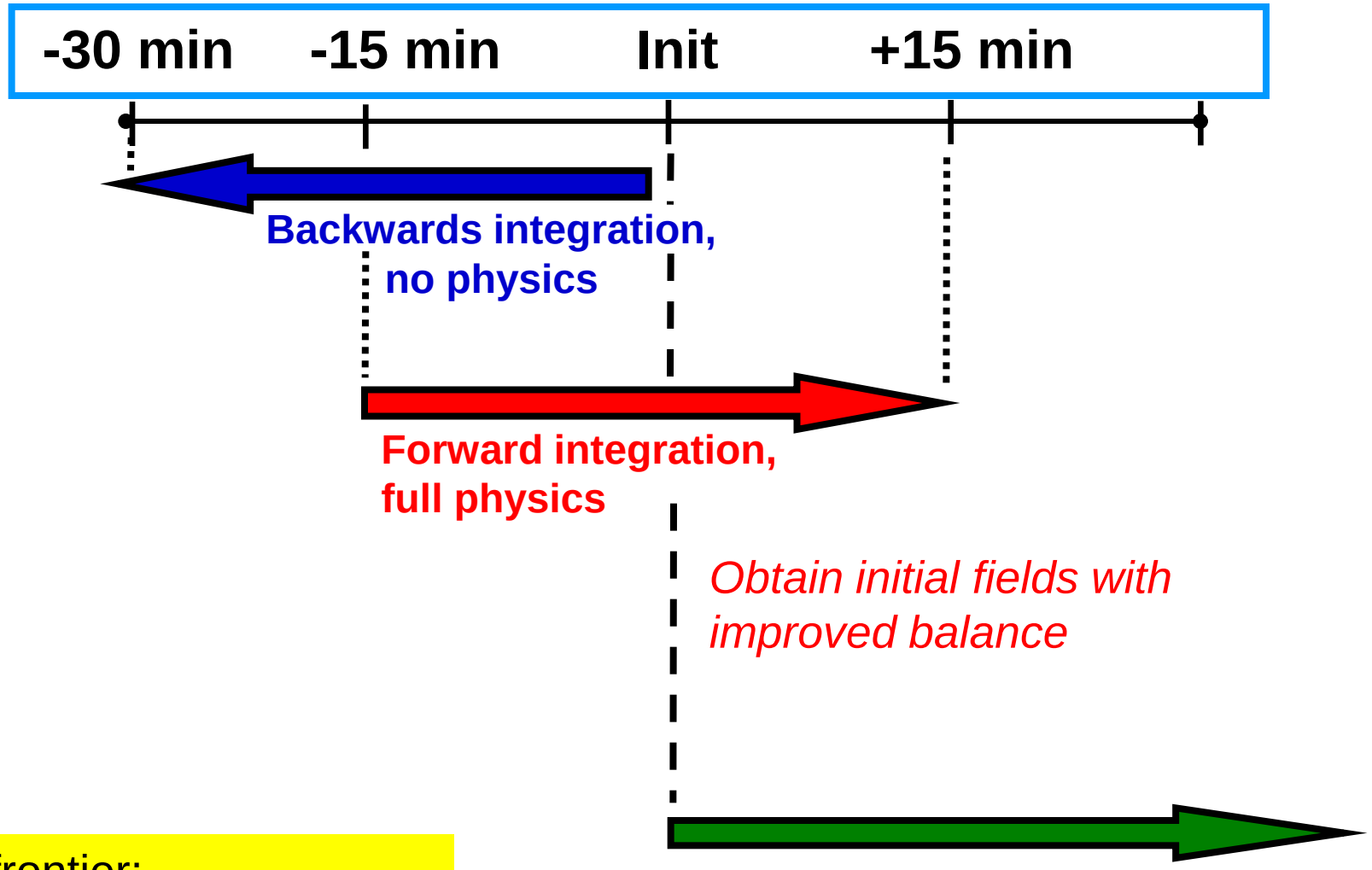
  --

- Uncertainty is scale and lead-time dependent
- Uncertainty reduced by high-frequency assimilation

Desirable attributes for mesoscale probabilistic forecasts

- **Multiple models**
- **Ensemble lateral boundary condition information**
- **Optimally perturbed Initial conditions**
- **Bias correction / Spatial filtering**
- **Use of high frequency assimilation with radar data**
- **Blending with nowcast systems for very short-range**
- **Ensembling of extracted information relevant to problem**

Diabatic Digital Filter Initialization (DDFI) in RUC model



A recent frontier:
Assimilation of radar reflectivity

RUC, Rapid Refresh and HRRR

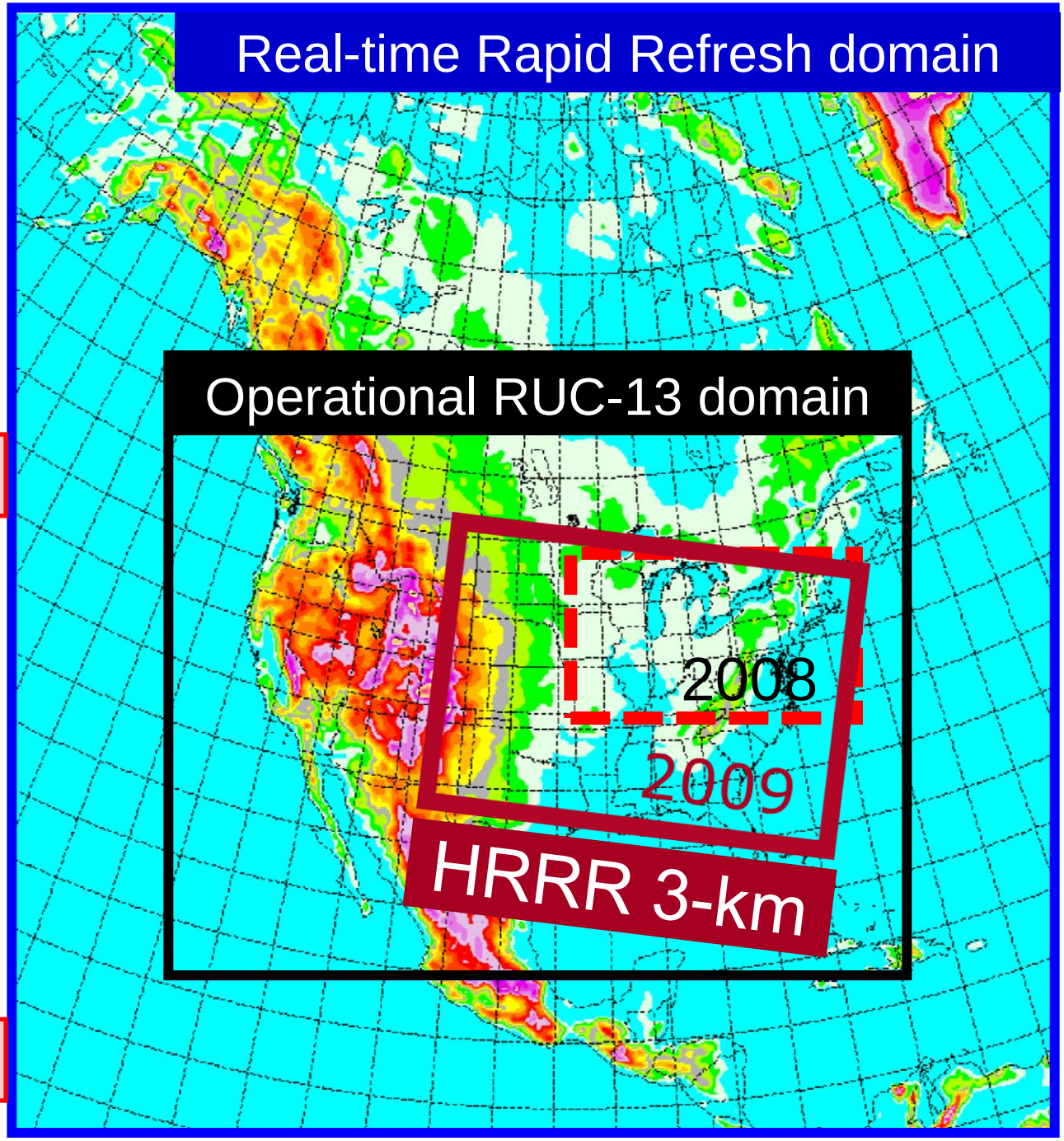
RUC – Major NCEP upgrade 17 Nov 2008

- Radar refl assim
- TAMDAR RH

RR – Planned to replace RUC at NCEP in 2010

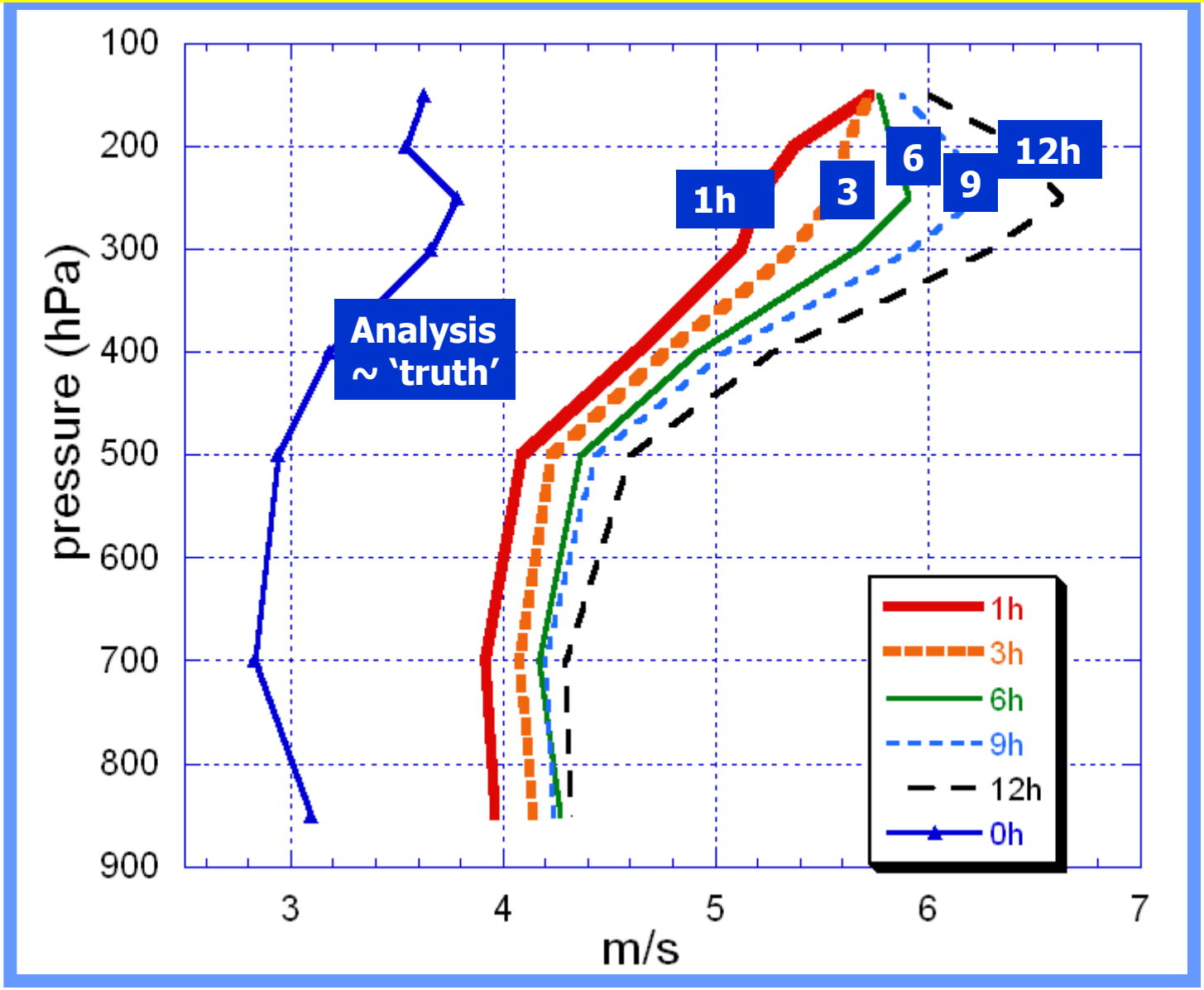
HRRR – R/T demo for aviation impact

12-h fcst each hour



RUC forecast accuracy higher with assimilation of recent observations

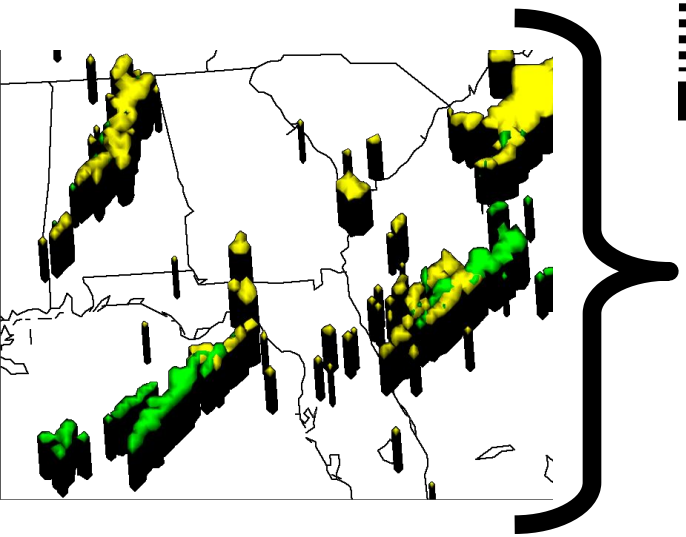
Verification against RAOBs - Sept-Dec 2001



Diabatic Digital Filter Initialization (DDFI)

add assimilation of radar data

Backwards integration, no physics



Forward integration, full physics

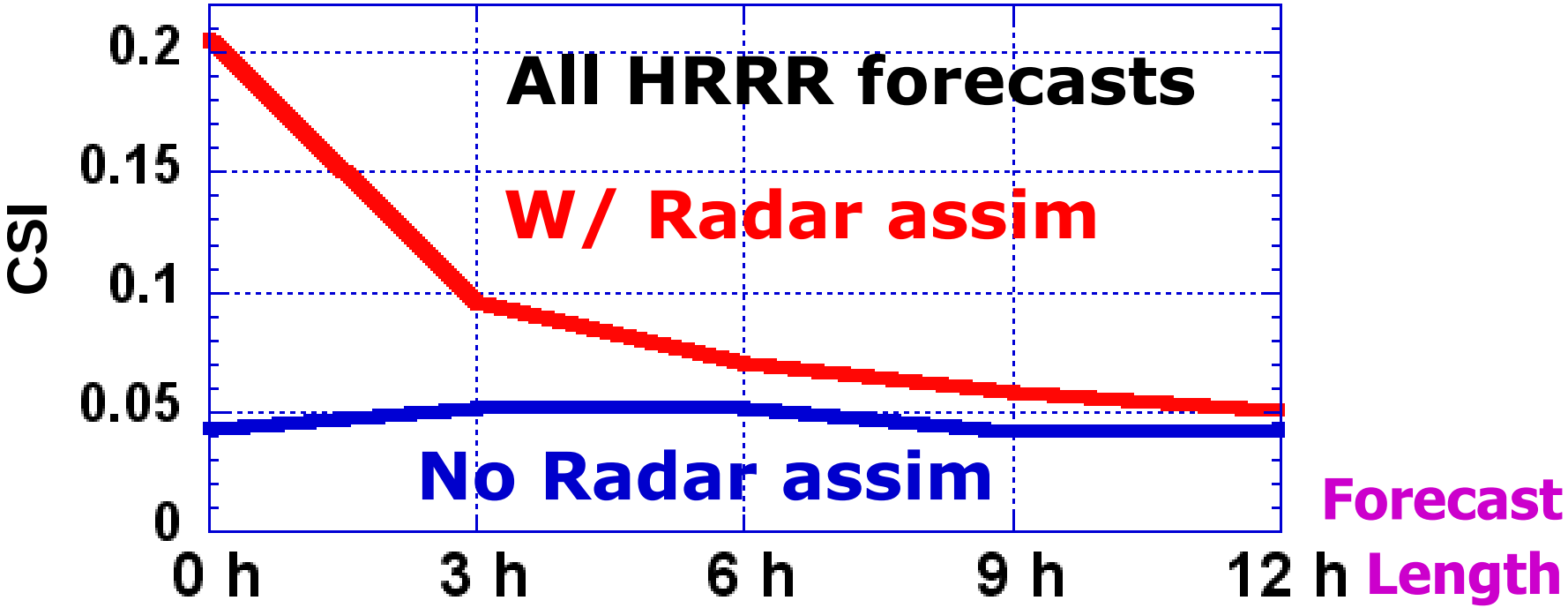
Apply latent heating from radar reflectivity, lightning data

Obtain initial fields with improved balance, ***divergent wind fields associated with ongoing convection***

RUC model forecast

A recent frontier:
Assimilation of radar reflectivity

HRRR reflectivity verification
Skill vs. forecast length



30 dBZ reflectivity on HRRR 3-km grid

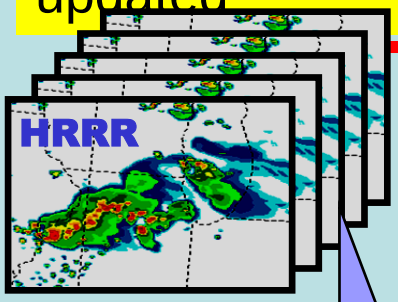
Verification period 23 June – 25 Aug 2008

- Storm-scale modeling is not enough, must have radar reflectivity assimilation
- Hourly updating is critical

Post-processing Techniques / Attributes	No. of NWP models	Use of hourly updated NWP	Use of radar-initialized explicit storm model	Multiple algorithms	Blended nowcast and NWP	Adaptive/ recent obs-based stat post	Actual prob output
GTG	1	Y	N	Y	N	In between	N
NCV	Multiple	Y		N	Y	Y	N
FIP	1	Y		N	N	N	N
RCPF	Multiple time-lag	Y	N	N	N	N	Y
CoSPA (incl. HRRR)	1	Y	Y	N	Y	Y	N
Future HPCF	Multiple TL +	Y	Y	N	N	N	N
LAMP	1	N		N	Y	Y	Y
NCEP/Toth w/ RTMA	Multiple	N	N	?	N	Y	Y
SREF	Multiple	N		N	N	N	Y
HMT/FAB ens precip fcst	Multiple	N		N	N	Y	Y - in progress
Desirable attributes	Multiple TL+	Y	Y	Where needed	Y	Y	Y

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

VSREF-
Model Ensemble Members
- hourly (≤1h) updated



VSREF members - HRRR, RR, NAM, SREF, GFS, etc.

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

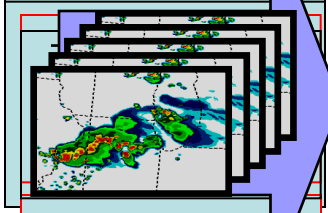
Unified Post-processing

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

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

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

VSREF mems output for each AIV variable



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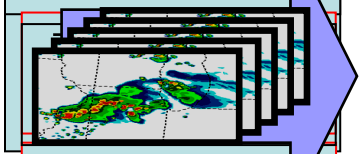

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Most-likely-estimate single value

Probability/PDF output

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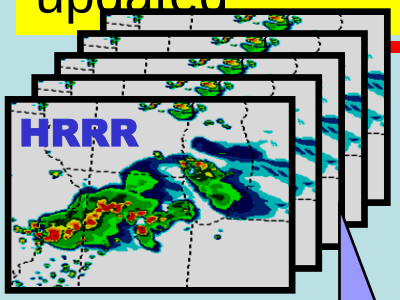

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4D-datacube

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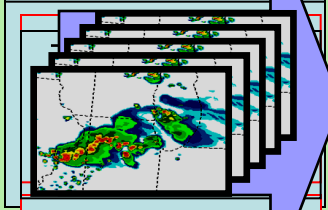

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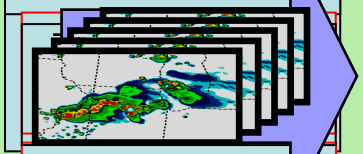

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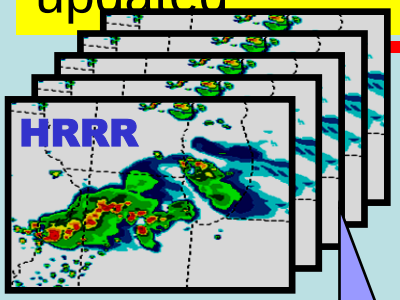

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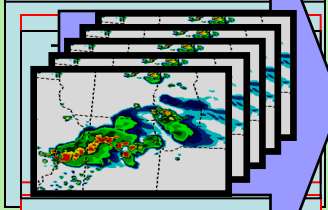

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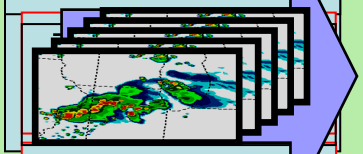


For turb

Optimal weighting

SAS

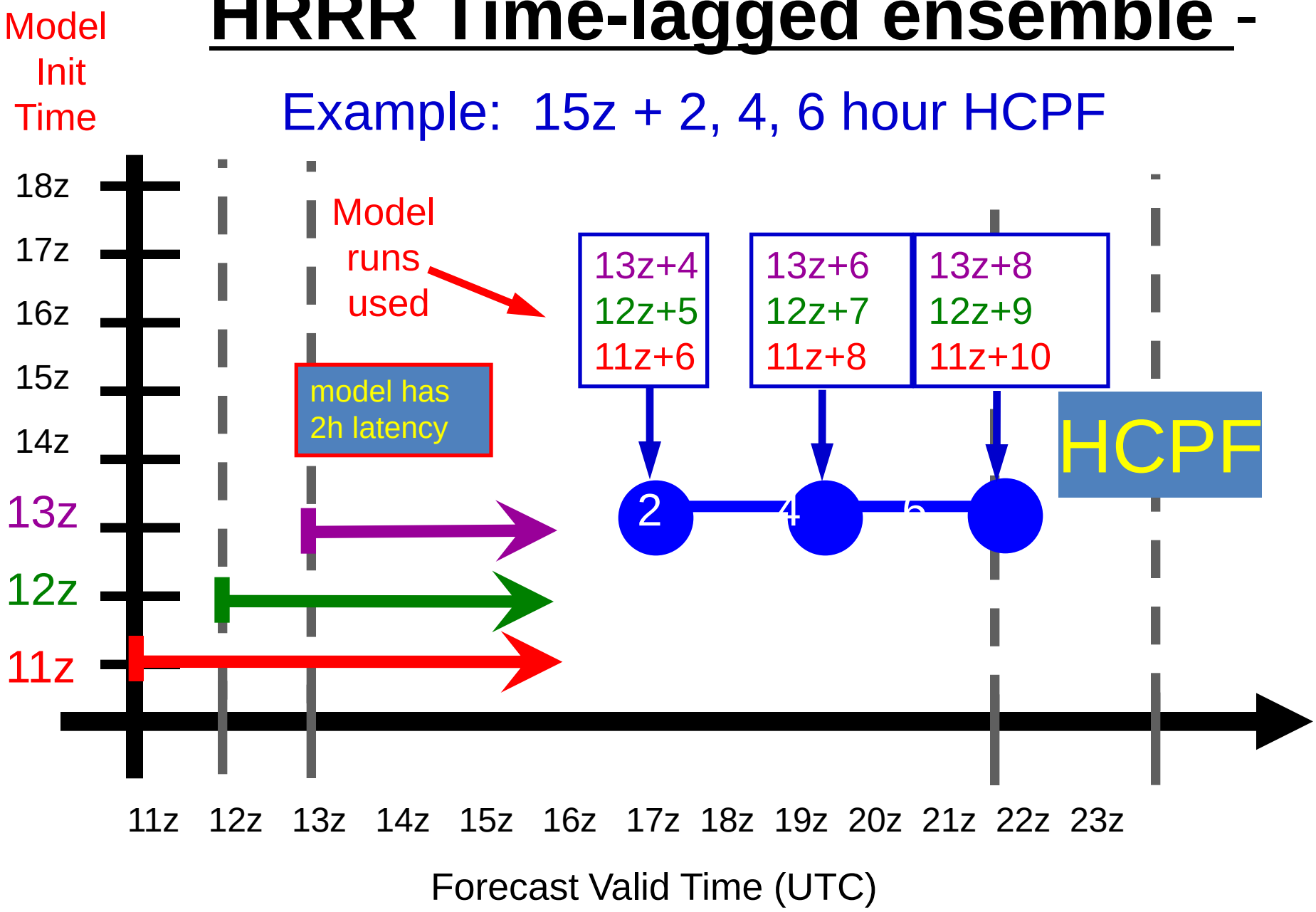
Most-likely-estimate single value

Probability/PDF output

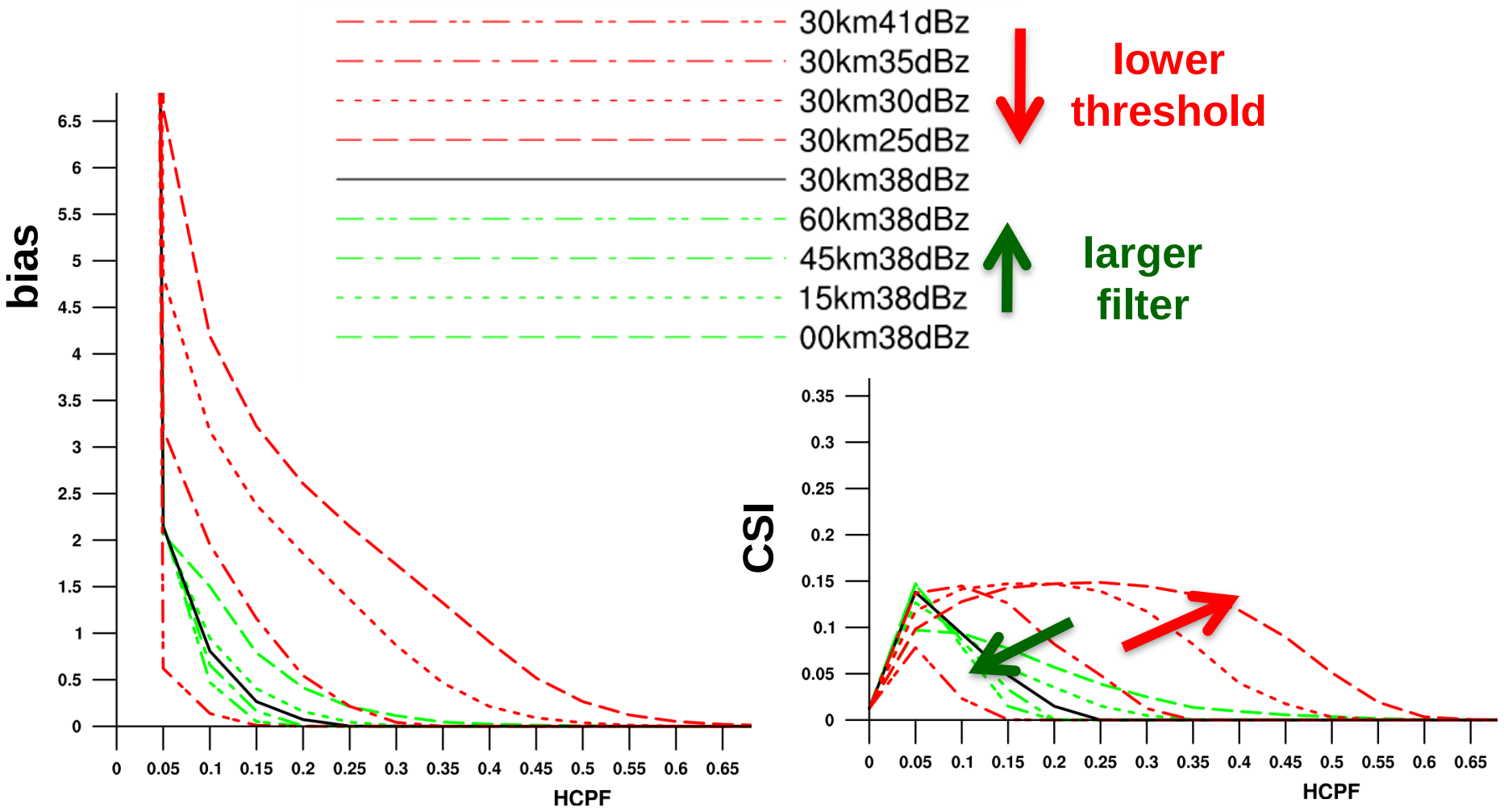
Key issues for improving the HCPF

- **Selecting best predictors**
- **Predictor threshold for diurnal bias correction**
- **Use of hourly “integrated” fields (phase errrors)**
- **Optimal spatial filtering**

HRRR Time-lagged ensemble -



Optimizing the HCPF algorithm

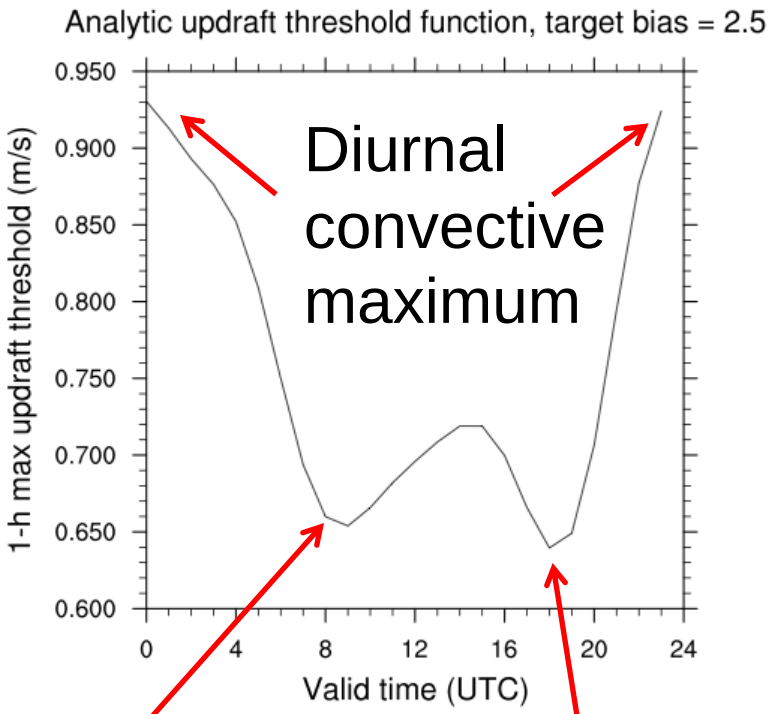


Perturbing detection threshold (red lines) has much larger impact on CSI and bias than spatial filter size

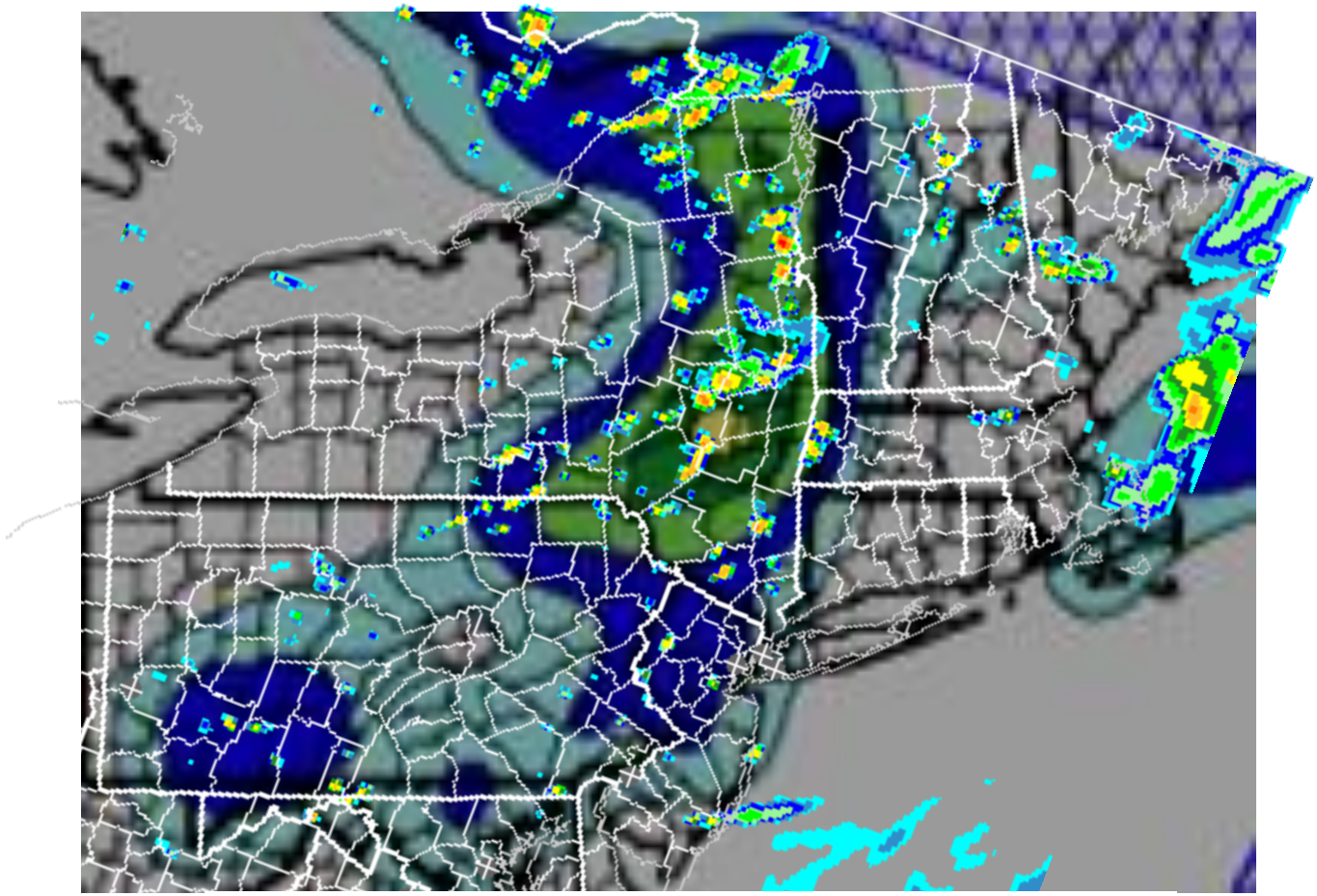
Optimizing the HCPF algorithm

Early versions of the HCPF had inconsistent skill, with large bias swings throughout the diurnal convective cycle

- Perform bias correction via a diurnally varying updraft (w) threshold
- Find threshold values at each hour that achieve a fixed bias
- Perform a Fourier synthesis to generate a smooth, analytic function for updraft velocity



16 July 2009 HCPF / HRRR overlay



15z + 6 hour HRRR and HCPF

HCPF summary

Use of time-lagged ensemble from rapidly updating, convection resolving model yields a skillful convective probability product.

Strengths:

1) Excellent performance (especially with traditional metrics)

2) Similar “look and feel” to existing products (CCFP, etc.)

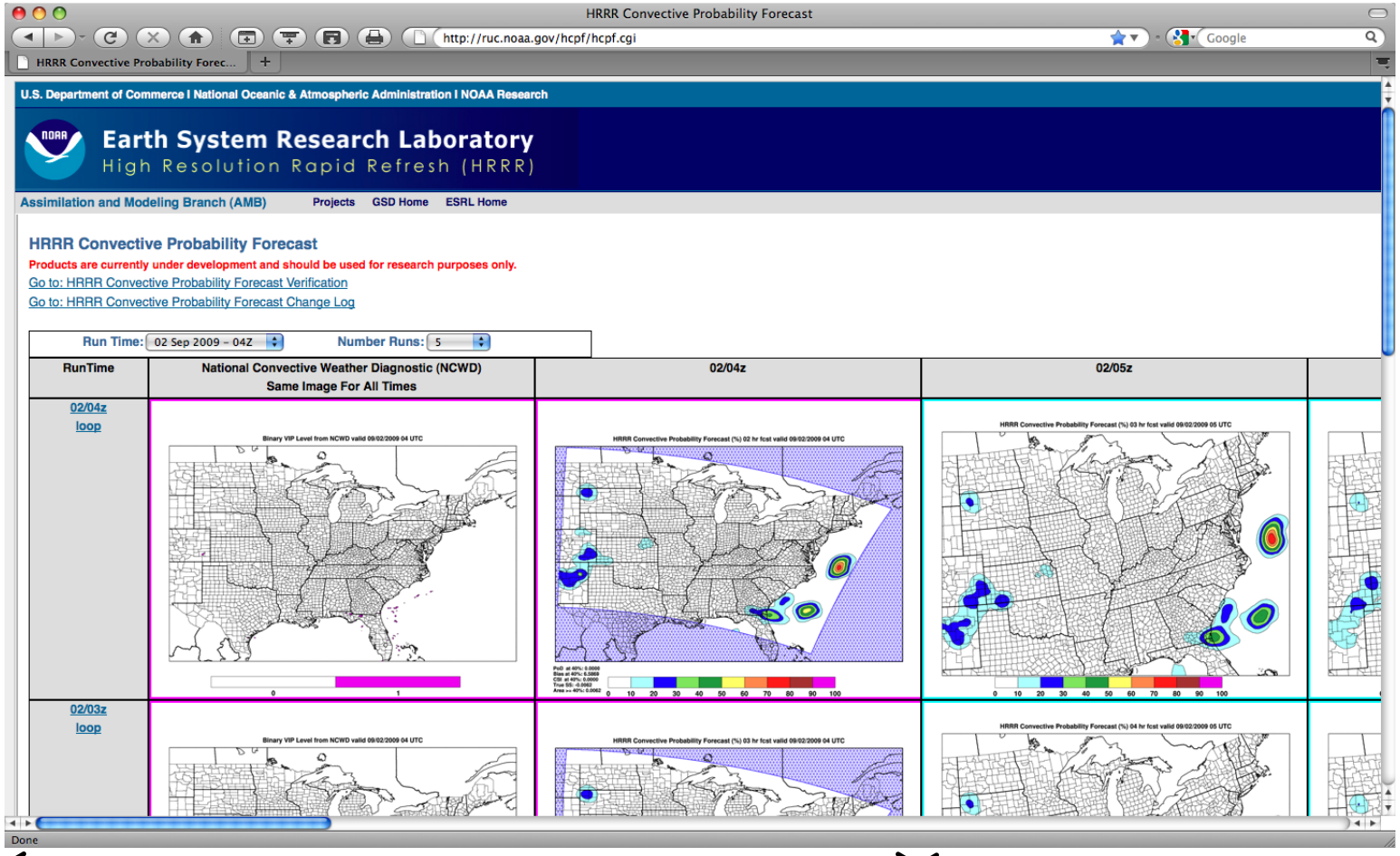
3) Excellent product consistency

4) Can combine with deterministic CoSPA forecast to convey storm structure / convective mode and areas probabilities

5) Technique can be used to provide probabilistic forecasts of other high impact events (high wind, hail, tornadoes, flash flooding, heavy ice/snow)

Real-Time HCPF

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



HCPF generation time

Current verification

HCPF lead times

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

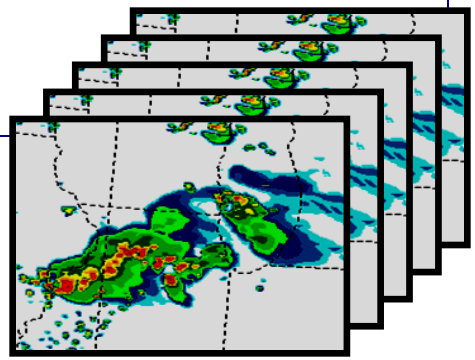
Outline:

- Uncertainty in short-range aviation forecasts
  - varies for different aviation weather hazards
    - e.g., very high uncertainty for convection for ATM
    - safety vs. efficiency concerns
  - is scale dependent and lead-time dependent
- High-frequency data assimilation narrows uncertainty
- Desirable attributes for aviation probabilistic forecasts

Conclusions

Recommend use of

- Hourly (or subhourly) data assimilation w/ radar
- Blended nowcast and NWP forecast
- Modularized algorithms into unified post
- Statistical post-processing for aviation gridded forecasts for multiple forecasts (time-lagged ensembles, etc.)
- Extended time-lagged ensembles from **18h** RUC/RR/HRRR



http://ruc.noaa.gov/hrrr