Forecast Sensitivities and Challenges

1. Model Parameterizations
2. Water-Vapor Initialization

David Dowell
NOAA/ESRL/GSD/AMB, Boulder, CO

Curtis Alexander, Stan Benjamin, Mike Coniglio, James Correia, Dan Dawson, Gabe Garfield, Patrick Hofmann, Ming Hu, Eric James, Thomas Jones, Youngsun Jung, Haidao Lin, Ted Mansell, Nate Snook, Steve Weygandt, Lou Wicker, Nusrat Yussouf

Warn-on-Forecast Workshop, Norman, OK, 8 February 2012

Preview of Precipitation-Microphysics Topics

(1) Realism of reflectivity and polarimetric fields

- 8 May 2003 Oklahoma City supercell
- analyses and forecasts initialized with EnKF radar DA
  - grid spacing ~1 km, radar data every few min
- results for MCS by *Putnam et al.* at poster session

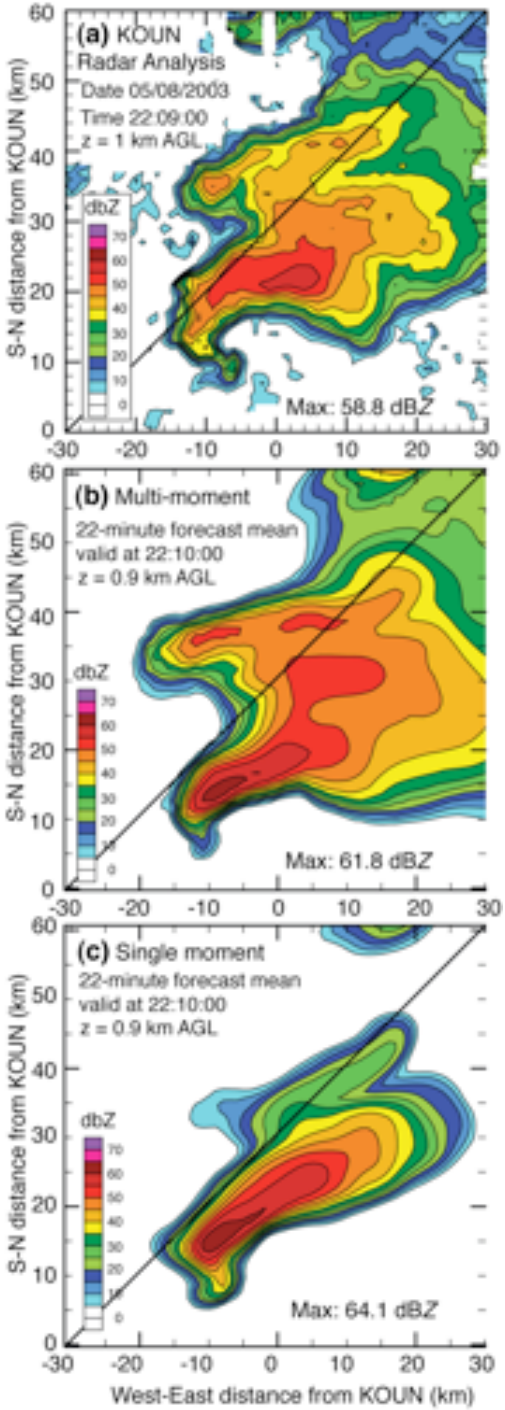
(2) Cold pools and mesocyclone / mesovortex tracks

- 8 May 2003 Oklahoma City supercell
- 4 May 2007 Greensburg, KS supercell
- 8 May 2007 southwest Oklahoma tornadic MCV
- ensemble forecasts initialized with WRF-DART mesoscale EnKF (5/8/2003 case) + EnKF radar DA (all cases)

(3) Real-time evaluation of microphysics schemes

- WRF-ARW forecasts produced by Norman WFO
- CAPS WRF-ARW ensemble spring 2011

Reflectivity in 8 May 2003 Oklahoma City Supercell 2210 UTC (tornadogenesis)



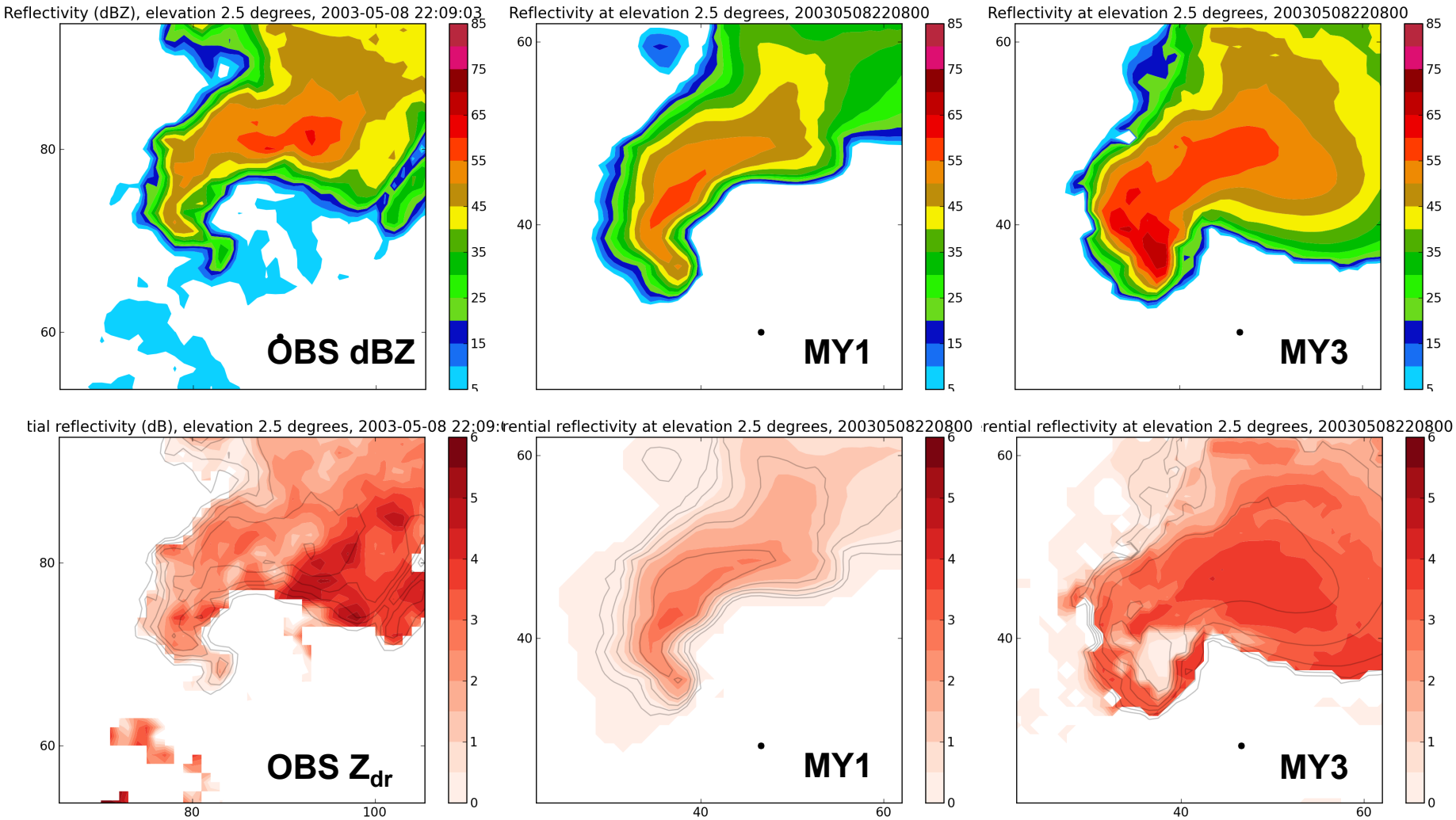
KOUN observations, 1 km AGL

ensemble mean, 22-min forecast
multi-moment microphysics

ensemble mean, 22-min forecast
single-moment microphysics

Ted Mansell and Lou Wicker

Reflectivity and Differential Reflectivity
8 May 2003 Oklahoma City Supercell



MY1: single-moment Milbrandt-Yau microphysics

MY3: triple-moment Milbrandt-Yau microphysics

Dan Dawson

Ensemble-Mean Temperature in Cold Pool of 8 May 2003 Oklahoma City Supercell

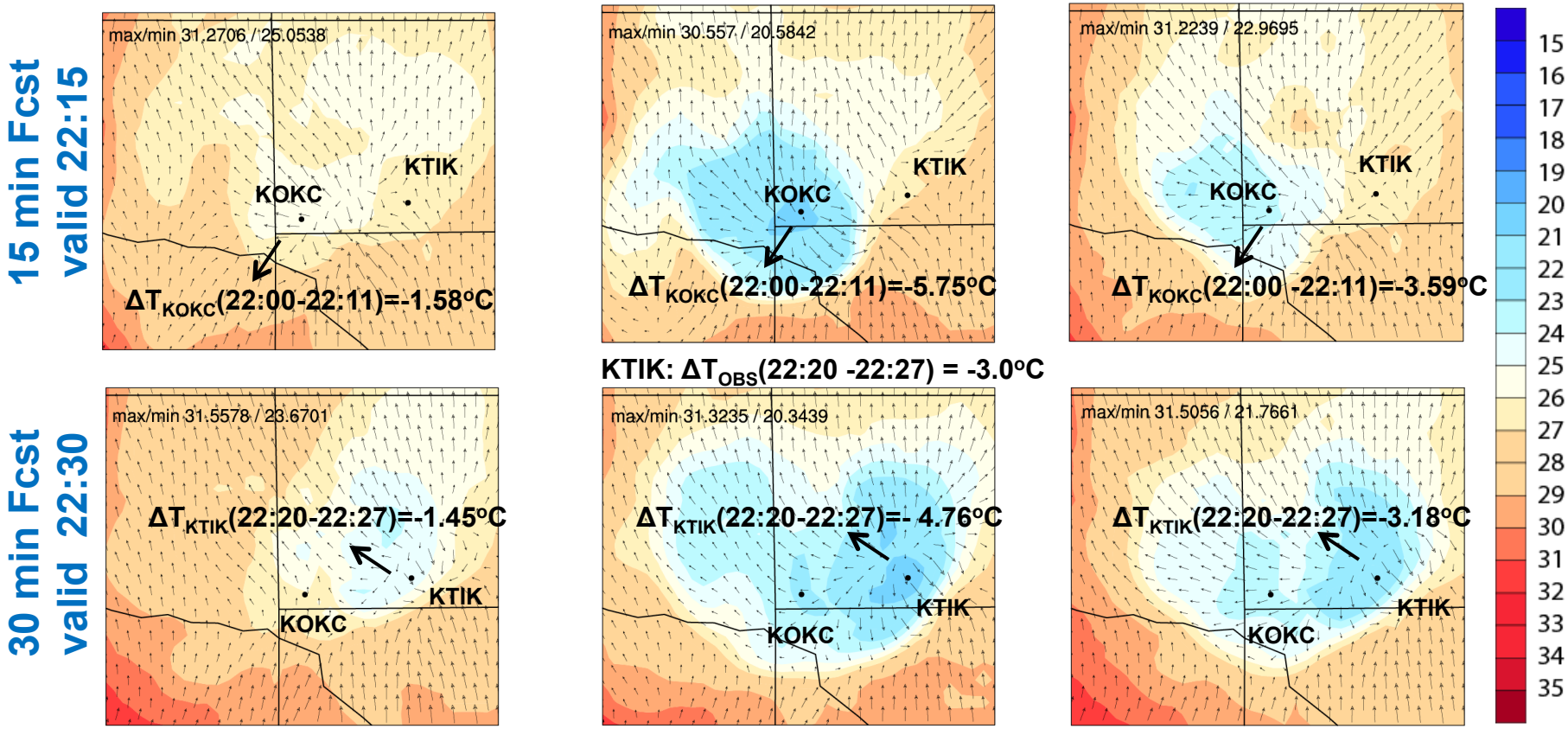
Nusrat Yussouf

Ziegler Variable Density (ZVD) microphysics scheme:
single moment (SM) or double moment (DM)
Thompson "1.5-moment" microphysics scheme

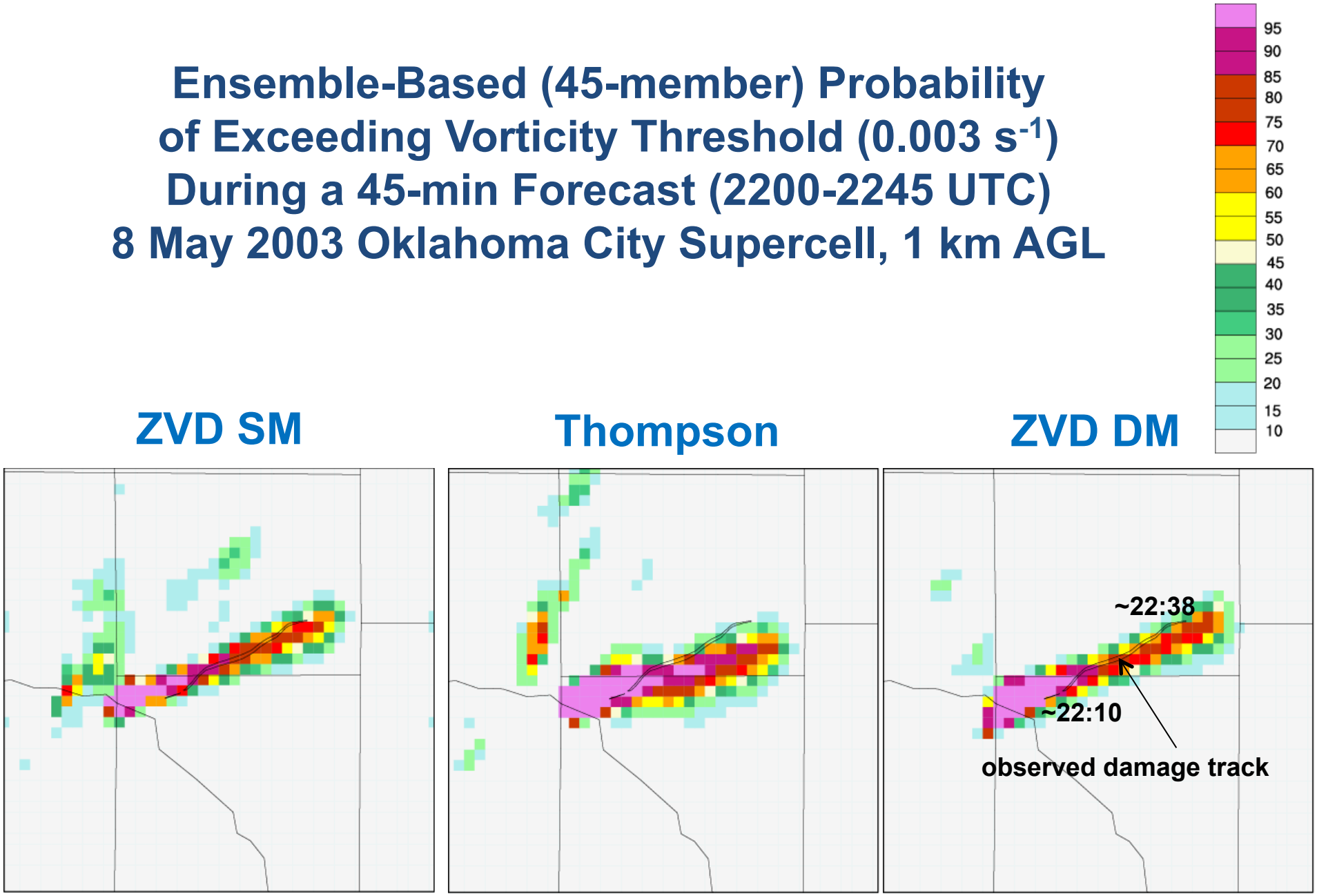
ZVD SM | Thompson | ZVD DM

KOKC: ΔT_{OBS}(21:59 -22:11) = -4.0°C

KTIK: ΔT_{OBS}(22:20 -22:27) = -3.0°C

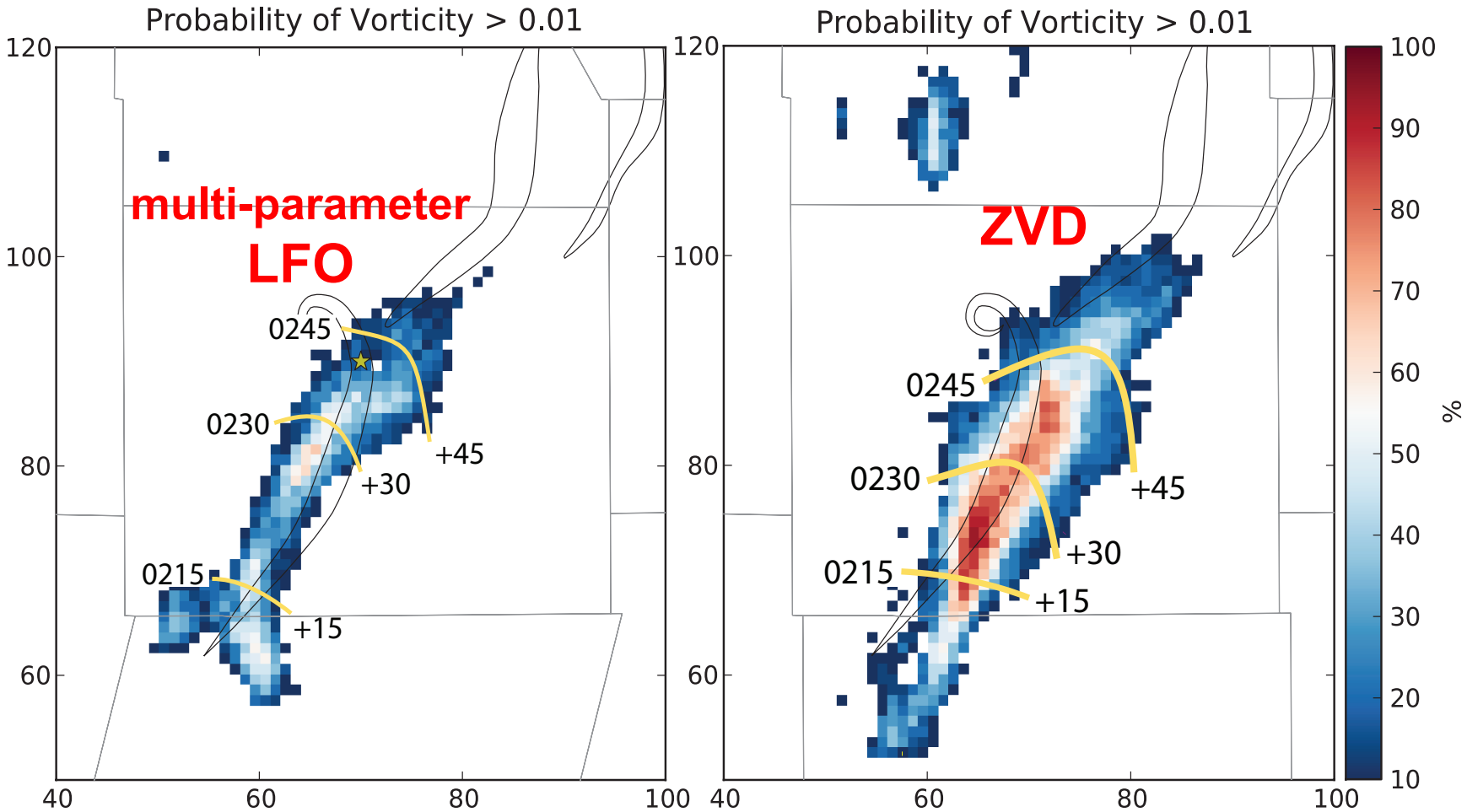


Ensemble-Based (45-member) Probability of Exceeding Vorticity Threshold (0.003 s^{-1}) During a 45-min Forecast (2200-2245 UTC) 8 May 2003 Oklahoma City Supercell, 1 km AGL



Nusrat Yussouf

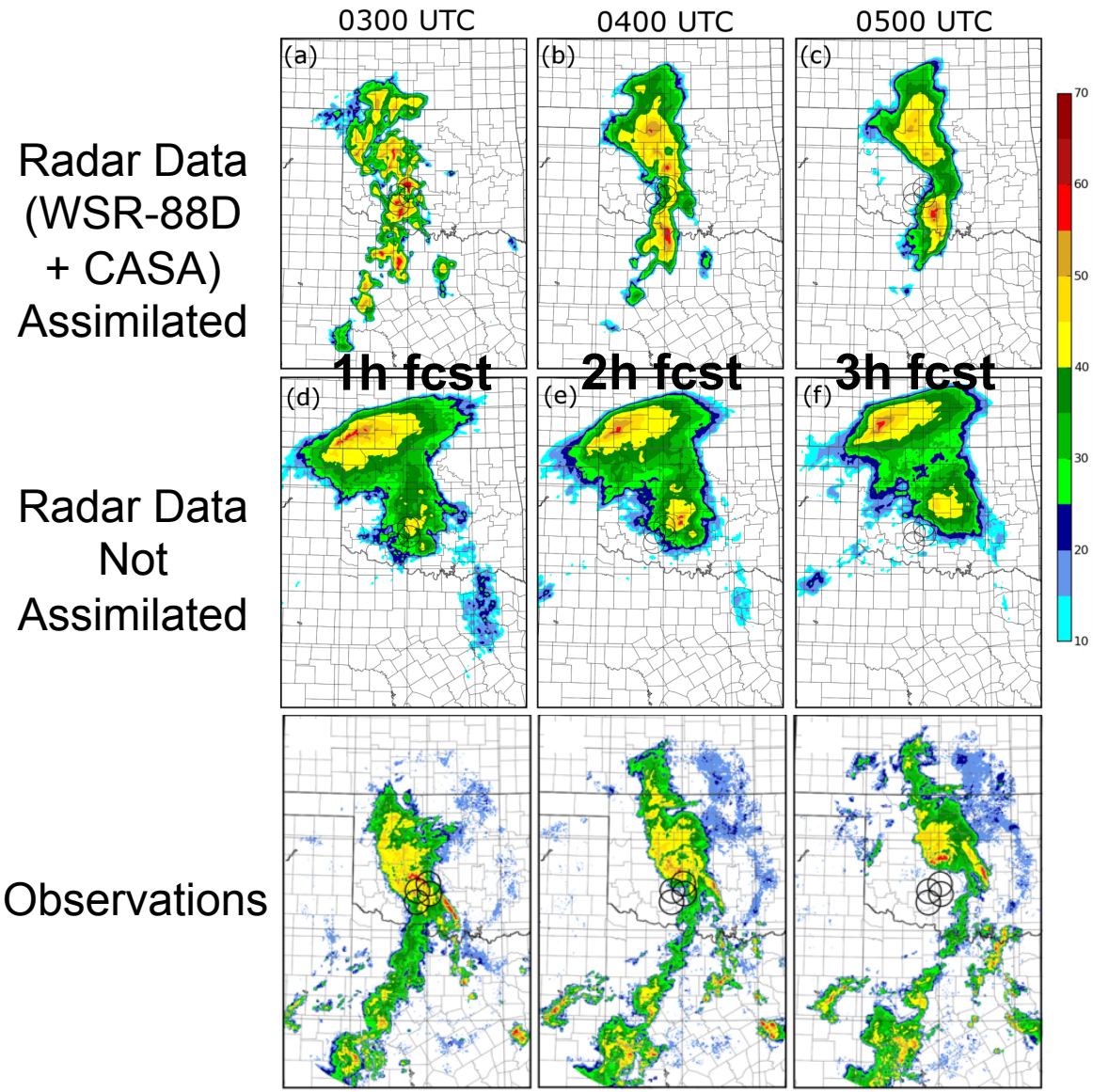
4 May 2007 Greensburg 0-75 Minute Ensemble Forecast
P (vorticity > 0.01 s^{-1} at 75 m AGL)



ZVD (double-moment) scheme results in higher probabilities and broader nonzero-probability swath than does LFO (single-moment) scheme

Dan Dawson

EnKF Radar DA and Ensemble Forecasts:
8 May 2007 Tornadic Mesoscale Convective Vortex

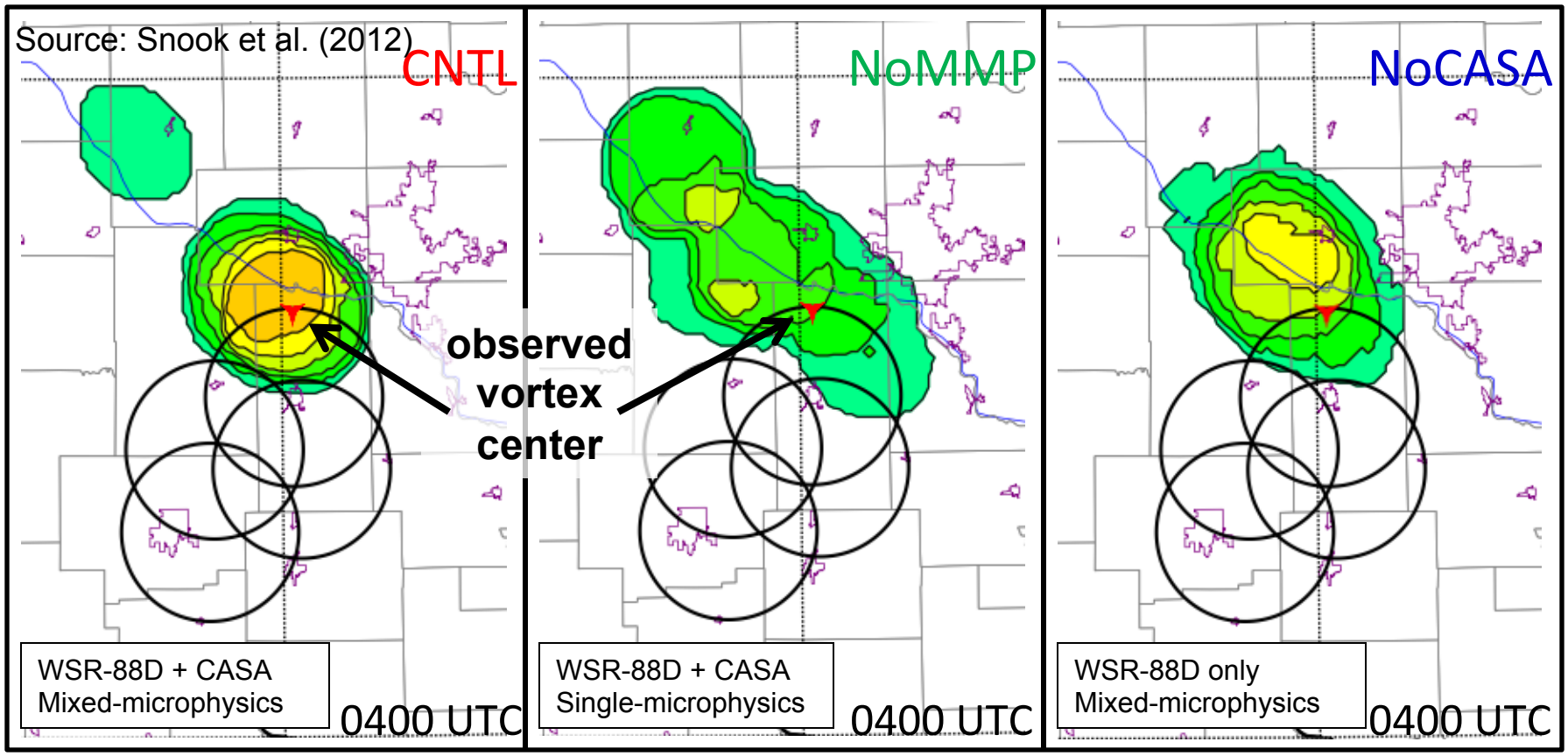


probability-matched ensemble-mean reflectivity 2 km AGL

Nate Snook

Mesovortex Forecast Sensitivity

probability of significant low-level vortex, 2-h forecast



CNTL: ensemble with multiple microphysics schemes and all radar data (WSR-88D + CASA) assimilated

NoMMP: same as CNTL except no microphysics variability

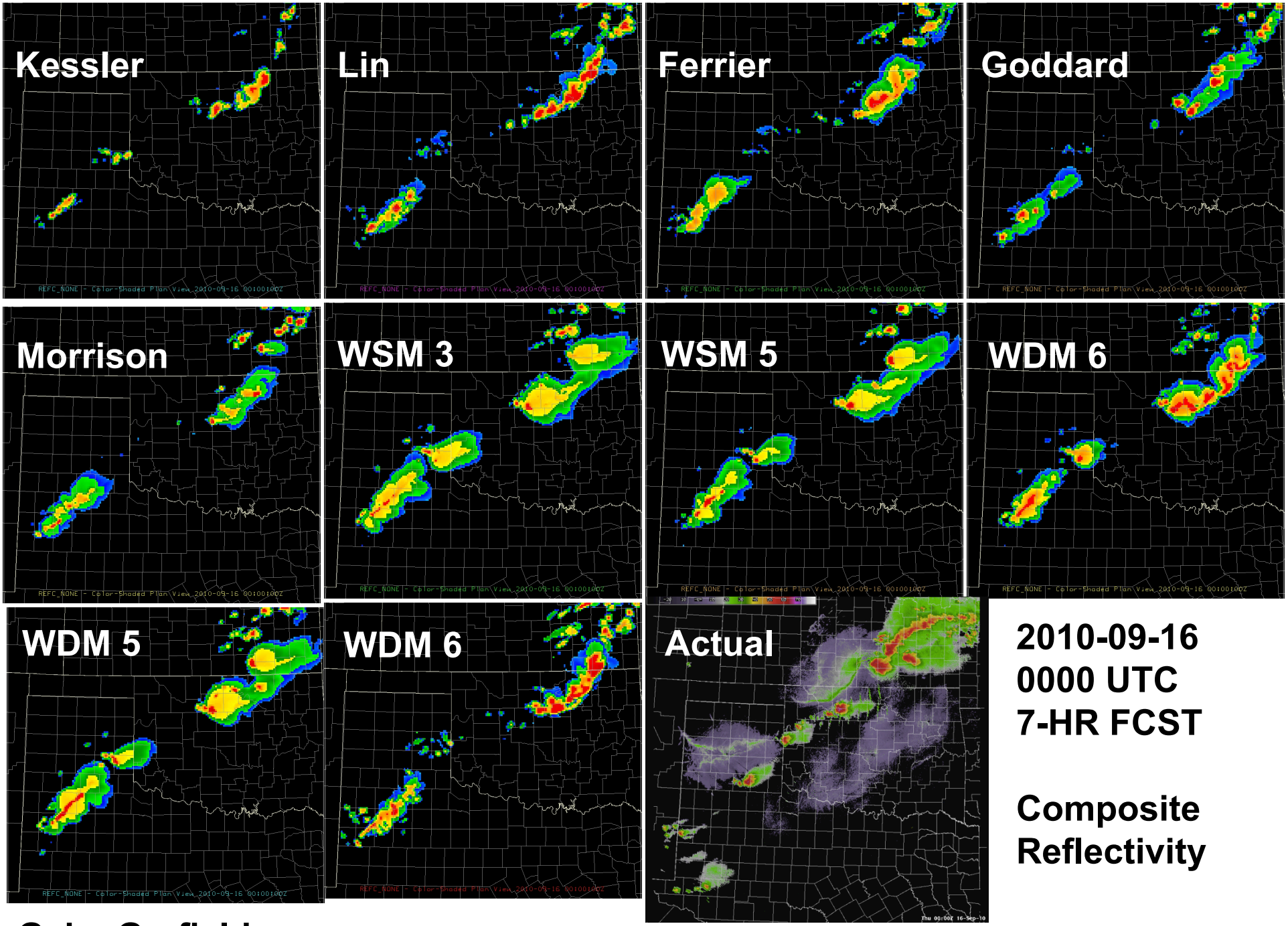
NoCASA: same as CNTL except CASA data not assimilated

Nate Snook

Norman Weather Forecast Office WRF Model

- **Hourly "OUN WRF" runs out to 8 hours**
  - "Hot start" LAPS initial conditions
  - NAM boundary conditions
  - 4-km grid spacing
- **Evaluation of forecasts with 10 different WRF microphysics schemes for several convective events**
  - Timing of convective initiation
  - Number, location, and intensity of storms
  - Storm mode
- **Findings**
  - *Forecast variability relatively large (small) when synoptic-scale / mesoscale forcing was relatively weak (strong)*
  - *Most realistic forecasts obtained with WRF single-moment, six-species (WSM6) and WRF double-moment, six-species (WDM6) schemes*

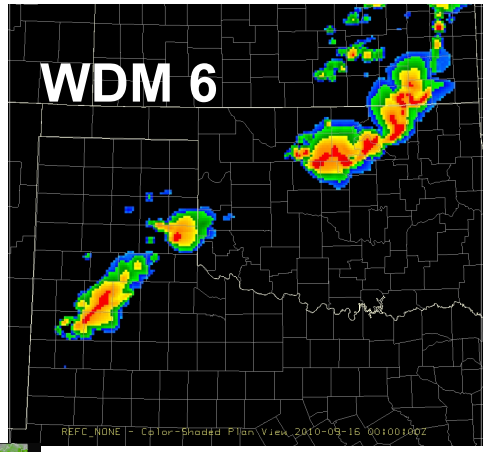
Gabe Garfield

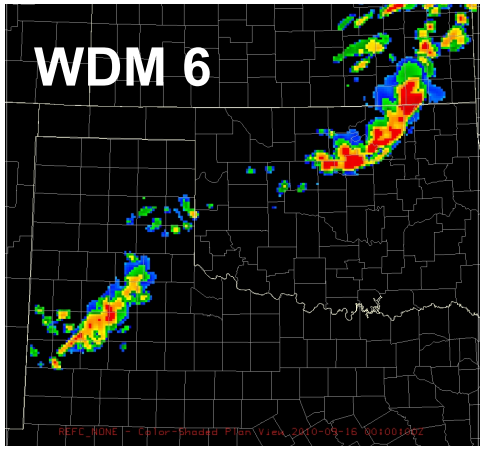


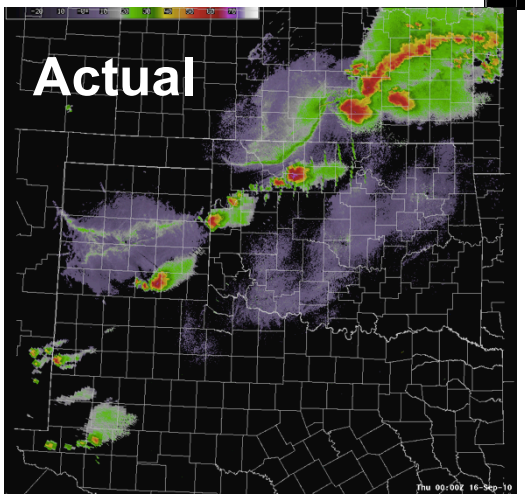
2010-09-16
0000 UTC
7-HR FCST

Composite Reflectivity

Gabe Garfield







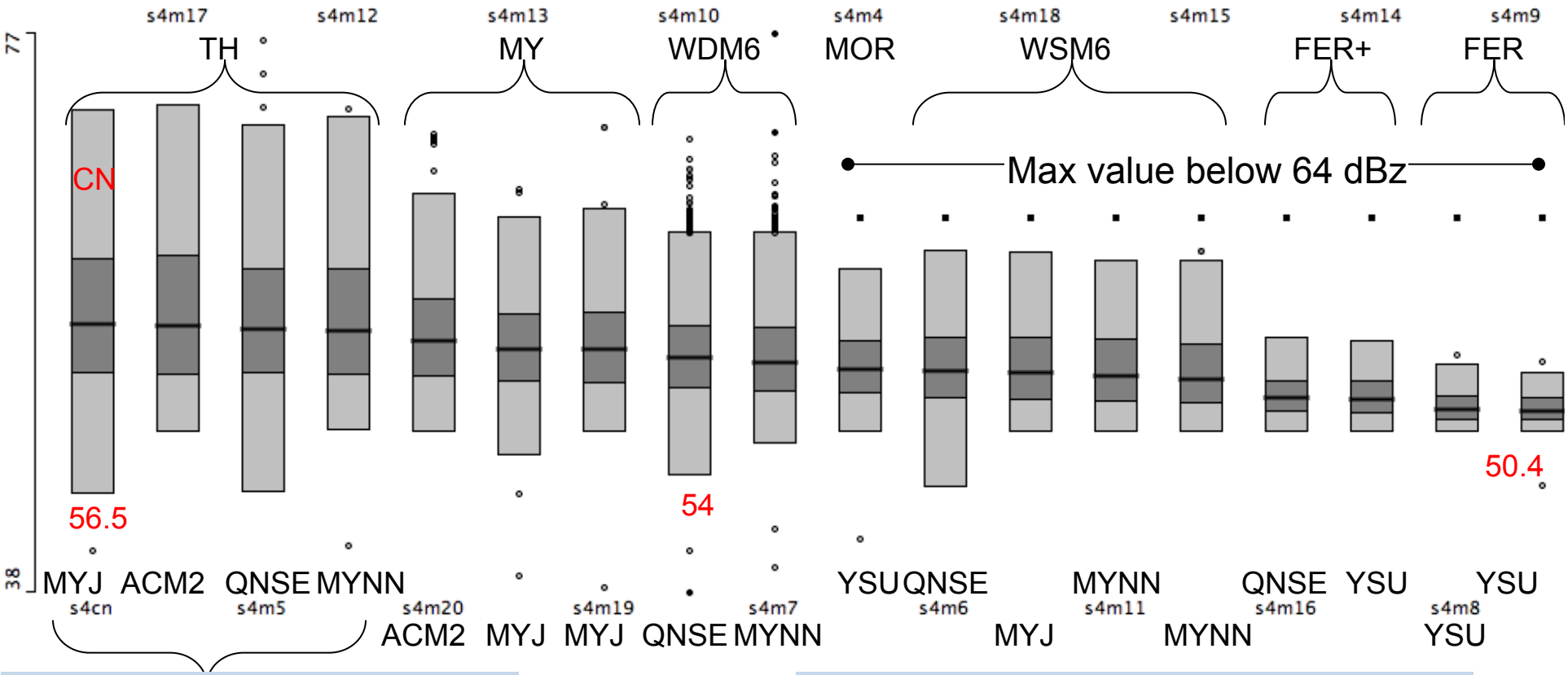
2010-09-16
0000 UTC
7-HR FCST

Composite Reflectivity

Gabe Garfield

Physics Sensitivity in CAPS Ensemble

Maximum composite reflectivity box plots by member for storm objects (52,671 storms defined by 34, 44 dBz with 8, 2 pixel minimum thresholds) for 28 SE2011 case days from the CAPS ARW ensemble sorted by the median value.



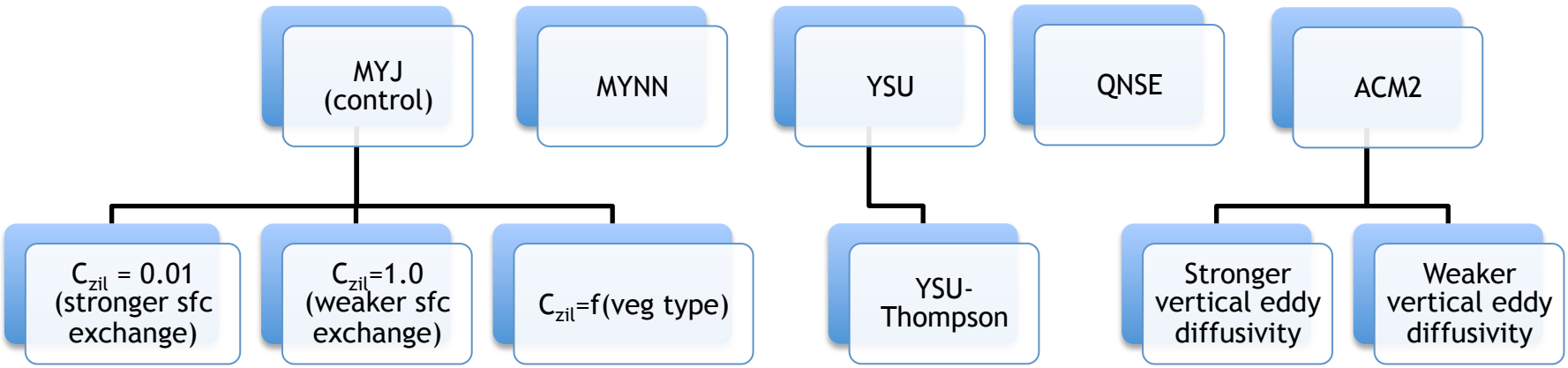
Same order from PBL-only members

Dependence on microphysics shows up quite distinctly.

James Correia

Sensitivity to PBL Scheme in CAPS Ensemble

- 2011 00Z CAPS ensemble included 11 members varying only by PBL scheme or parameter within PBL scheme

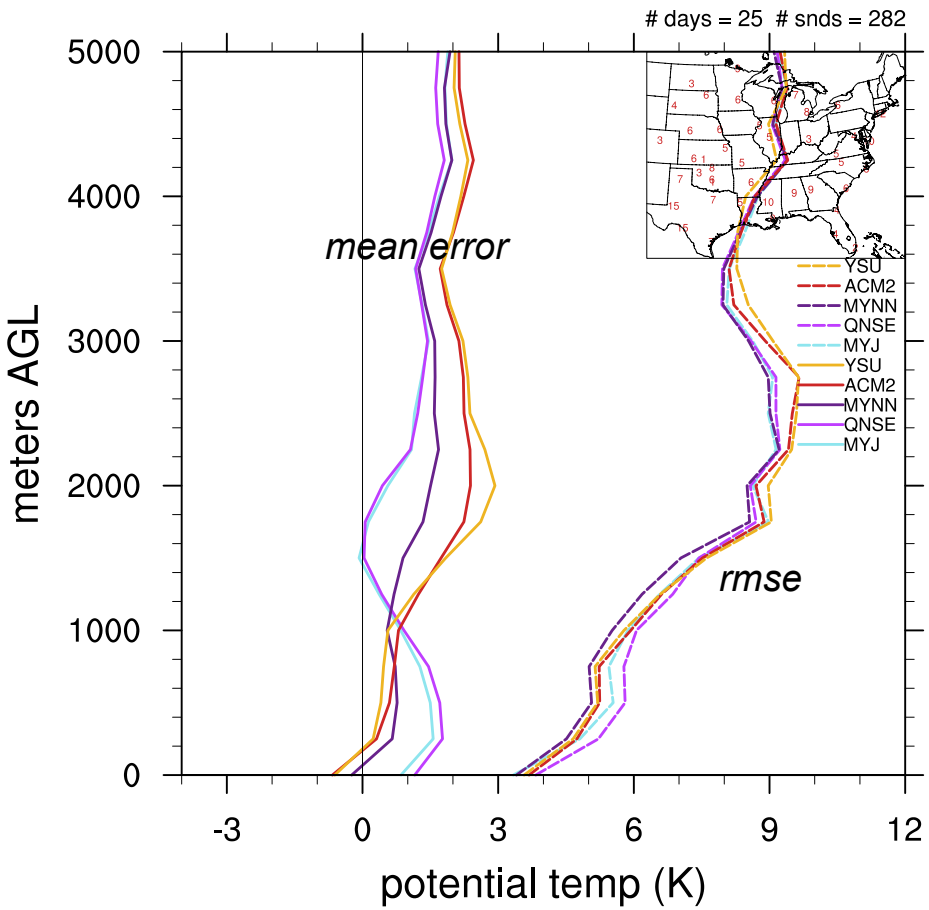


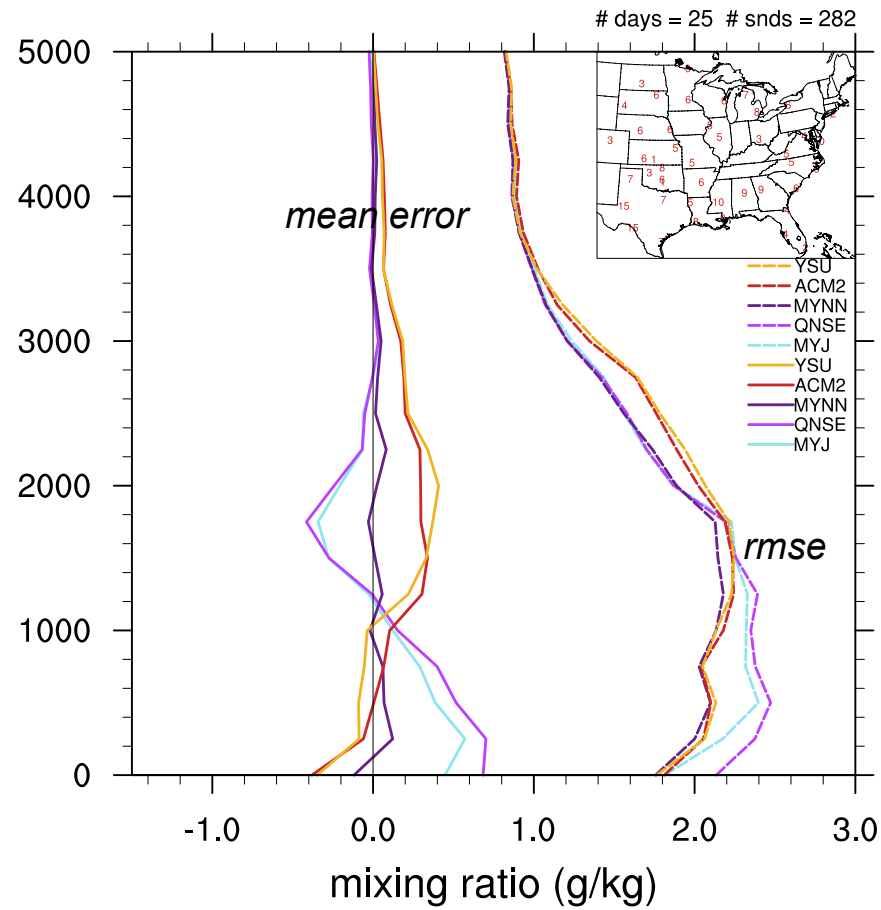
Trier et al. (2011) *Hu et al. (2010)*

- Model profiles are verified with observed radiosondes (both not disturbed by convection)
  - *12-h forecasts (valid 12 UTC) all very similar (except default YSU)*
  - *Only 25-35 mid-day observed soundings available*
  - *Selected results for evening soundings (23-24-h forecasts) upcoming…*

Mike Coniglio

Verification for Evening Soundings (23-/24-h forecasts valid 2300/0000 UTC): θ and q_v error profiles





Warm bias for all, average of MYJ/YSU still biased

MYNN bias falls between ACM2/YSU and MYJ/QNSE groupings, and lowest overall rmse

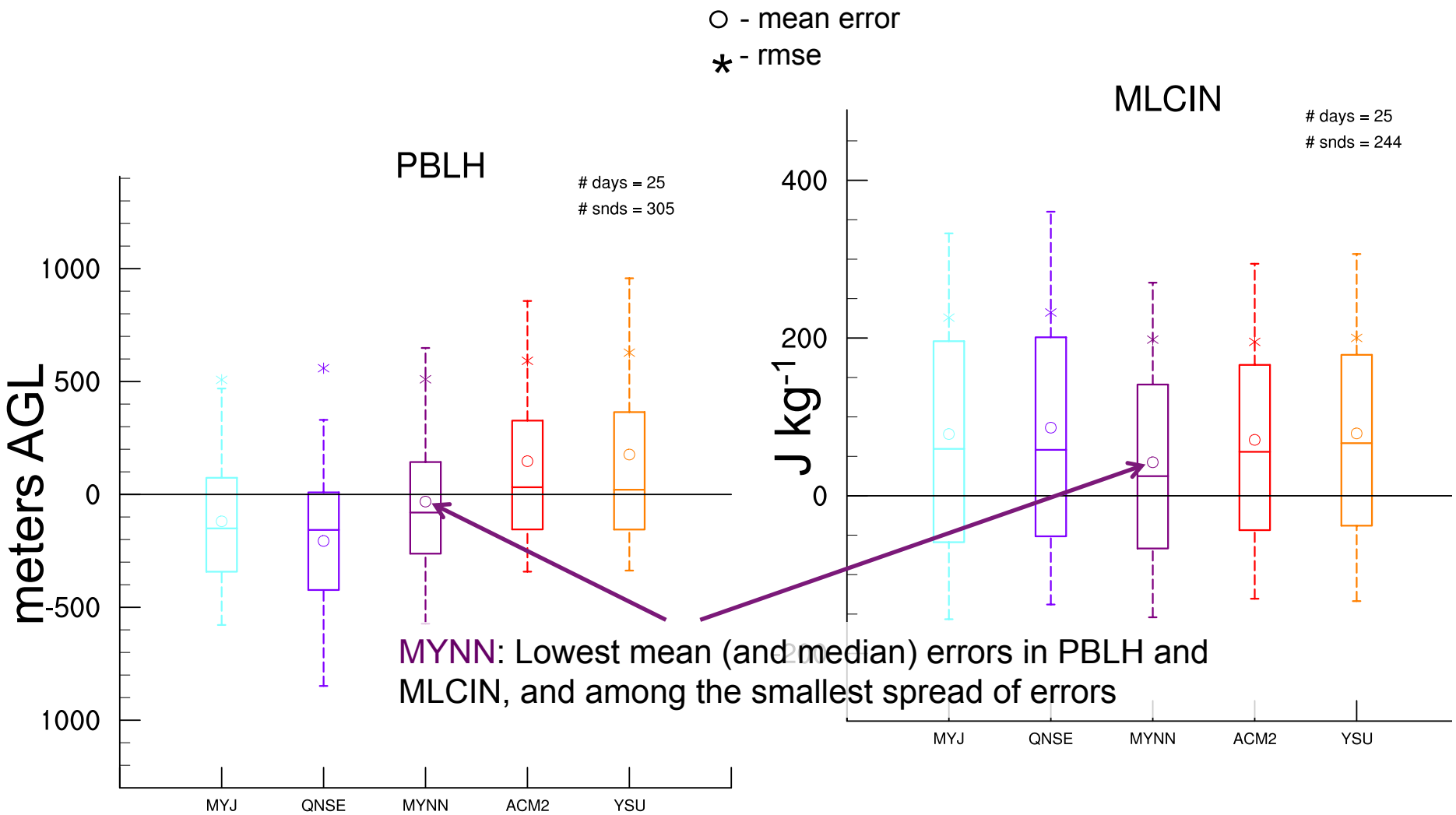
MYJ/QNSE clearly worst bias/rmse below 1 km

MYNN nearly unbiased, and has lowest overall rmse

MYNN rmse follows the better group (ACM2/YSU below ~1 km and MYJ/QNSE above ~2 km)

Mike Coniglio

Verification for Evening Soundings (23-/24-h forecasts valid 2300/0000 UTC): PBL height and CIN



MYNN: Lowest mean (and median) errors in PBLH and MLCIN, and among the smallest spread of errors

Mike Coniglio

Related Presentations

- **Sensitivity of WRF-DART analyses and near-term forecasts of a localized heavy precipitation event to planetary boundary layer physics (*Mike Coniglio et al.*) 6:30 PM Wednesday**
- **The impact of single and double moment microphysics schemes on ensemble Kalman filter analyses and forecasts of the 8 May 2003 tornadic supercell storm (*Nusrat Yussouf et al.*) 6:30 PM Wednesday**
- **Multi-moment and multi-phase ice microphysics in storm-scale EnKF (*Ted Mansell and Dan Dawson*) 6:30 PM Wednesday**
- **The analysis and prediction of microphysical states and polarimetric variables in a MCS using double-moment microphysics, multi-network radar data, and the ensemble Kalman filter (*Bryan Putnam et al.*) 6:30 PM Wednesday**
- **The 2011 OUN WRF Experiment: Results and Discussion (*Gabe Garfield et al.*) 6:30 PM Wednesday**
- **Ensemble prediction of the 4 May 2007 Greensburg, KS tornadic supercell: Impact of microphysics (*Dan Dawson et al.*) 6:30 PM Wednesday**
- **Results from the 2011 Hazardous Weather Testbed Spring Experiment (*James Correia et al.*) 6:30 PM Wednesday**
- **Ensemble and probabilistic forecasts of a tornadic mesoscale convective system using nested-grid ensemble Kalman filter data assimilation (*Nathan Snook et al.*) 11:00 AM Thursday**
- **Toward improving representation of model microphysics errors in a storm-scale ensemble: Evaluation and diagnosis of mixed-microphysics and perturbed microphysics parameter ensembles in the 2011 HWT Spring Experiment (*Jeff Duda et al.*) 11:20 AM Thursday**

Hourly Updated NOAA NWP Models

Rapid Refresh (RAP)

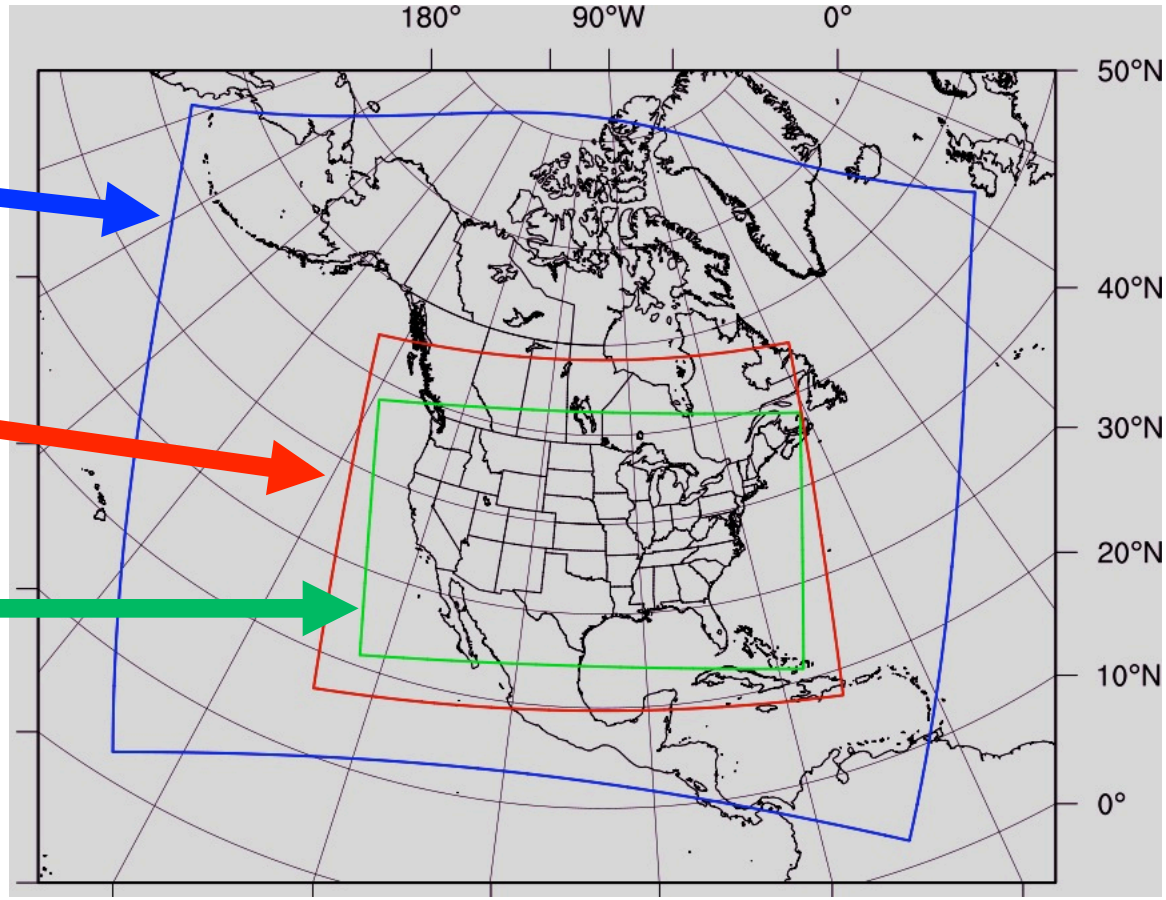
replaces RUC at NCEP in 2012

WRF-ARW & GSI w/ RUC features

13km Rapid Refresh (RAP) (mesoscale)

13km RUC (mesoscale)

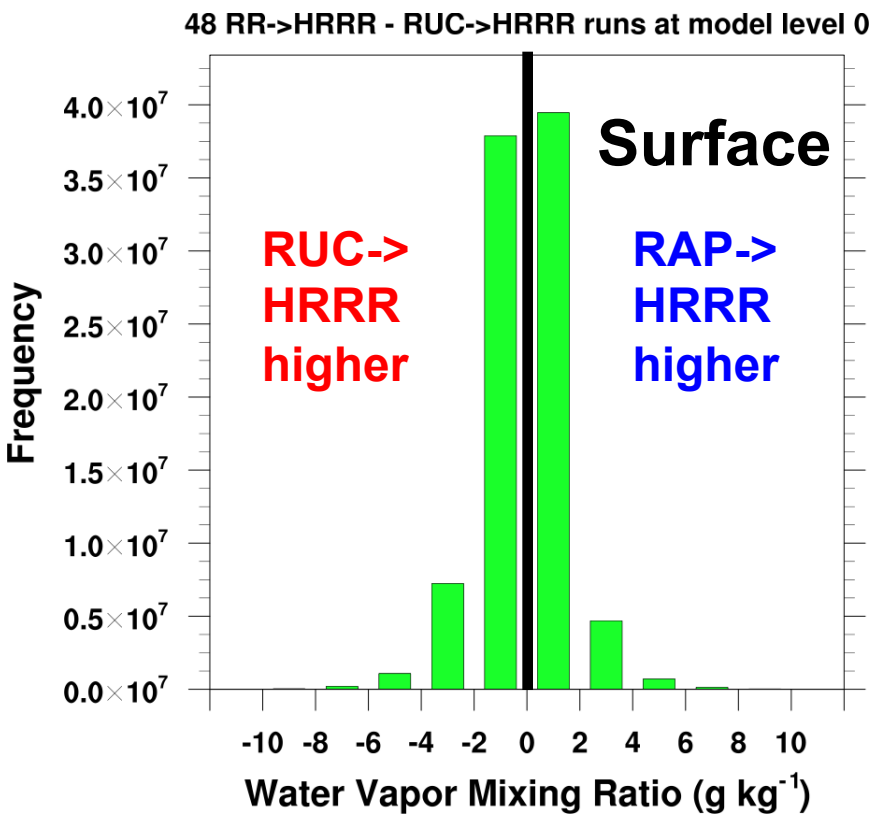
3km HRRR (storm-scale)

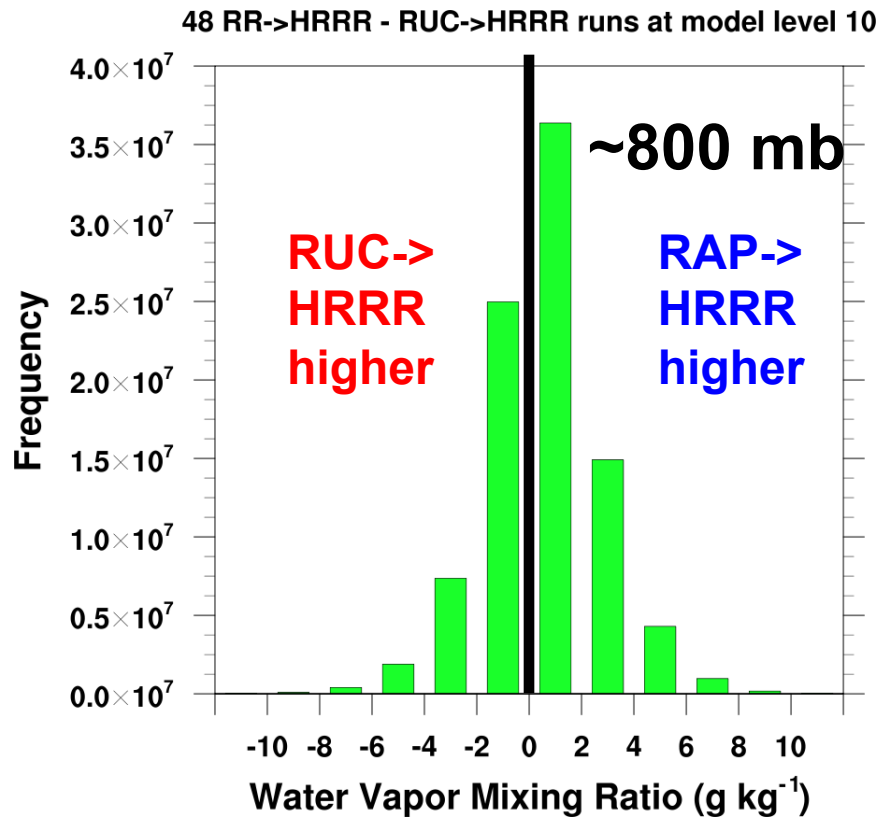


***RAP* and *HRRR* are candidate parent models for nested Warn-on-Forecast systems.**

Water-Vapor Histograms:
RAP->HRRR minus RUC->HRRR

CONUS, 11-22 August 2011, 0-h forecasts, no radar DA



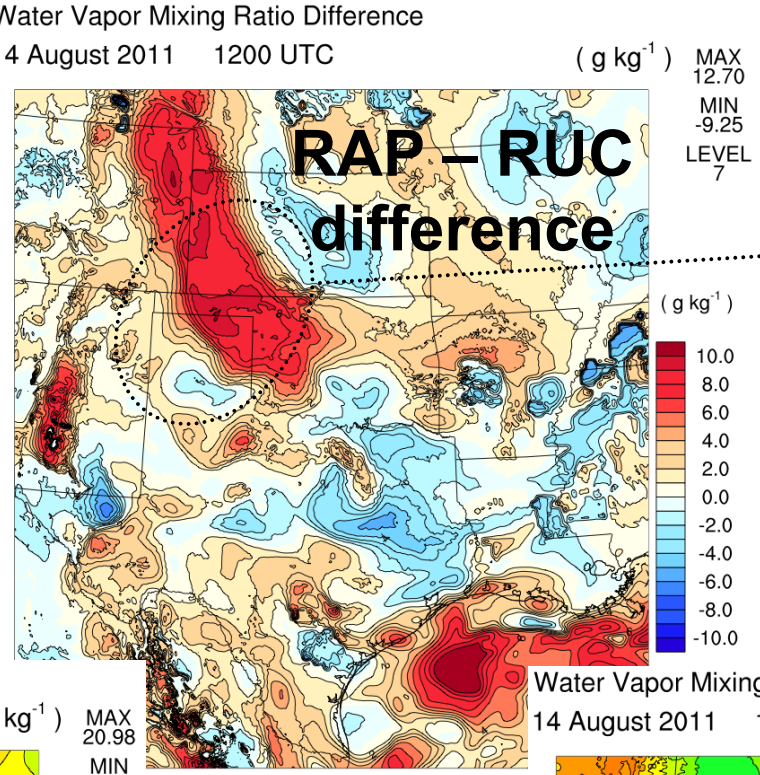


Differences large enough to affect convective forecasts!

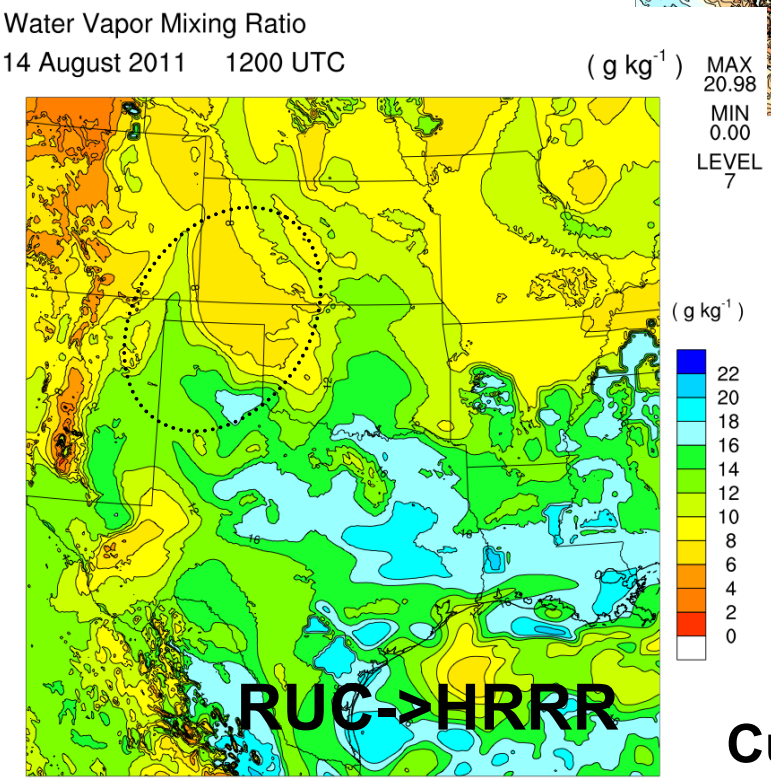
Differences representative of current analysis uncertainty?

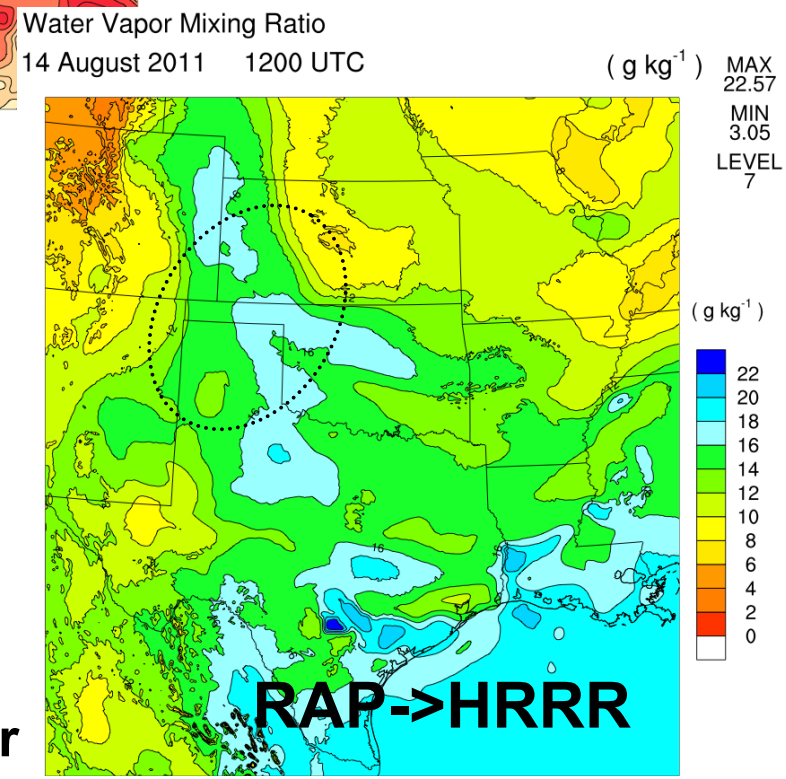
Curtis Alexander and David Dowell

Water Vapor Analyses
600 m AGL
1200 UTC
14 Aug 2011



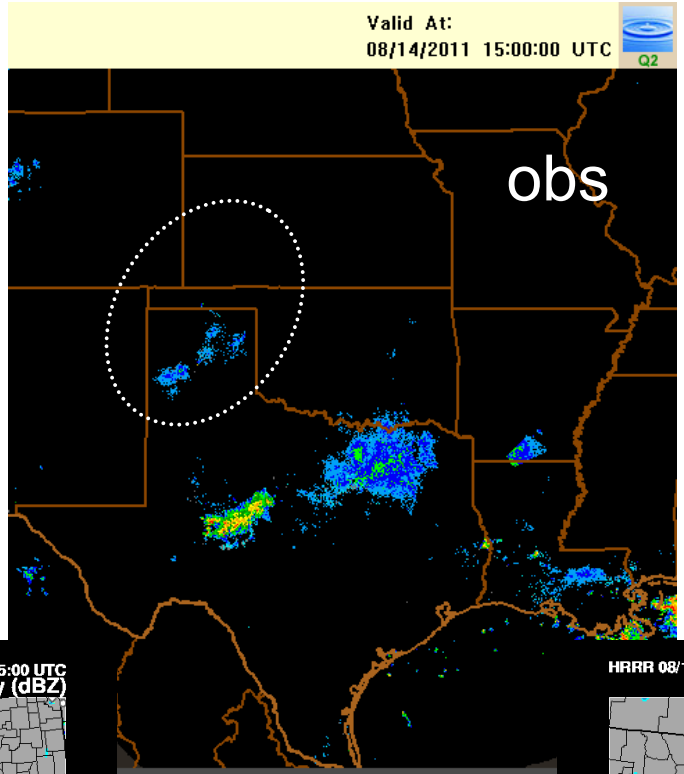
differences as much as 10 g/kg !



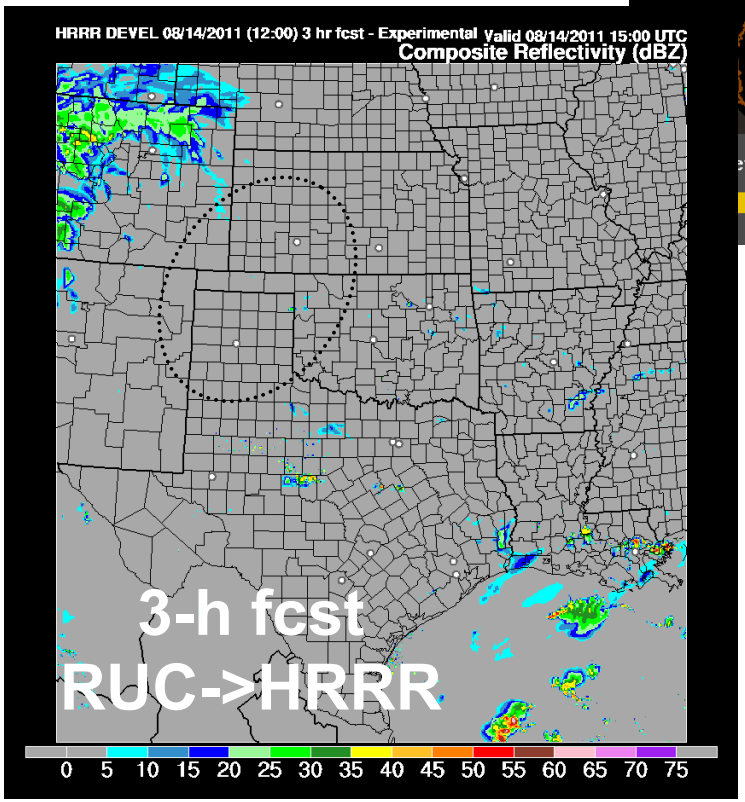


David Dowell and Curtis Alexander

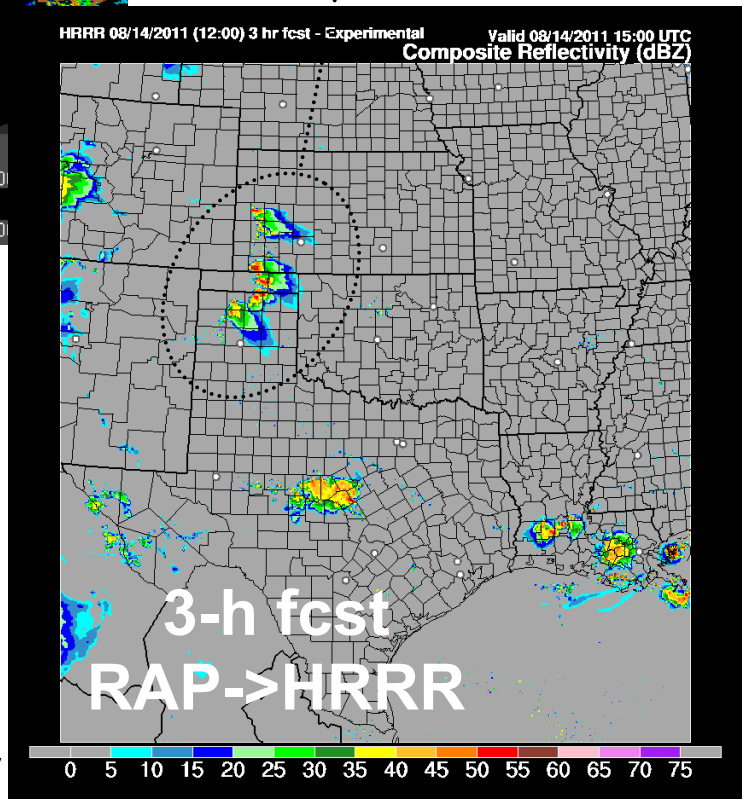
Composite Reflectivity 1500 UTC 14 Aug 2011



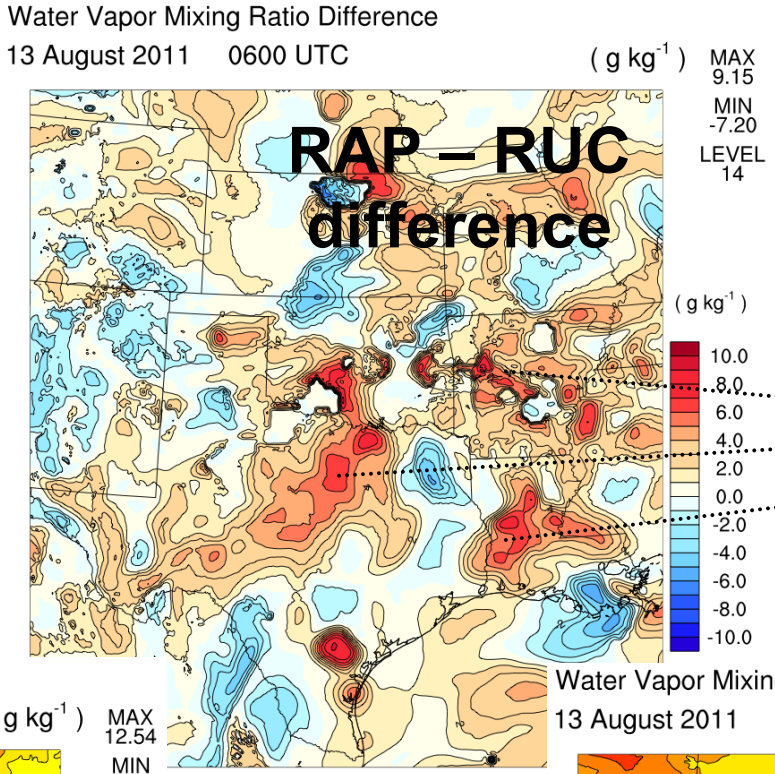
spurious convection in RAP->HRRR



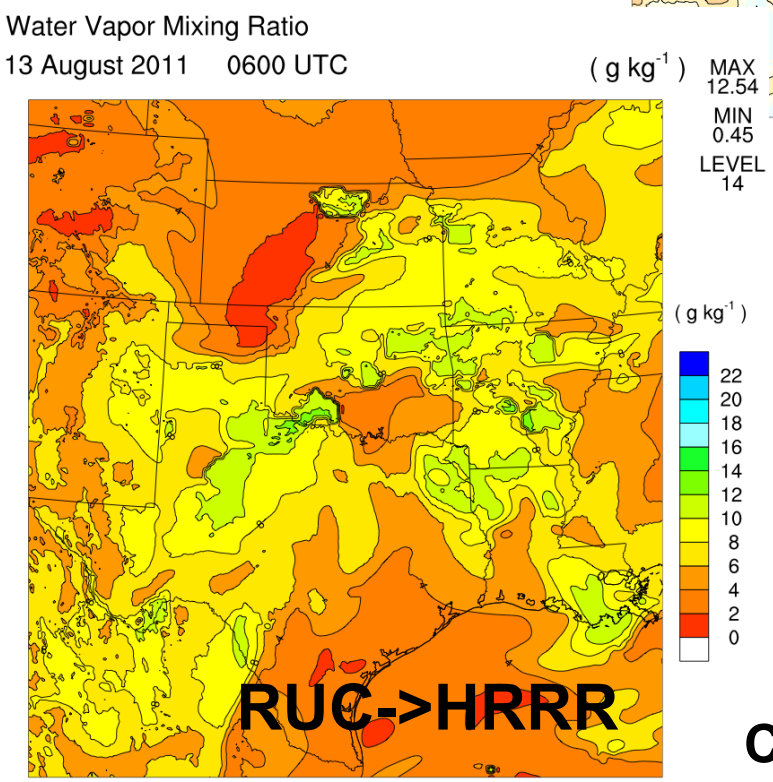
David Dowell and Curtis Alexander

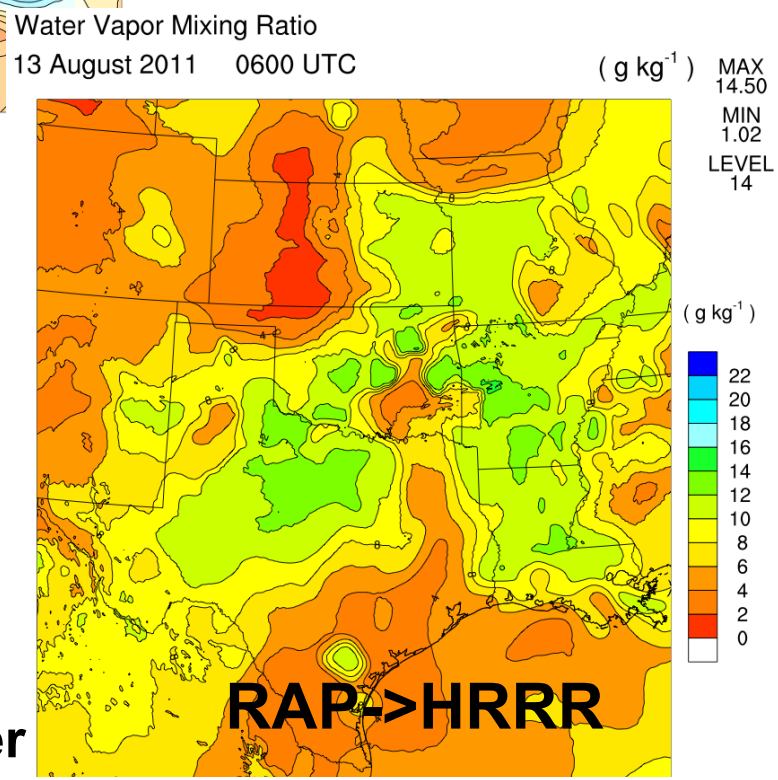


Water Vapor Analyses
2600 m AGL
0600 UTC
13 Aug 2011



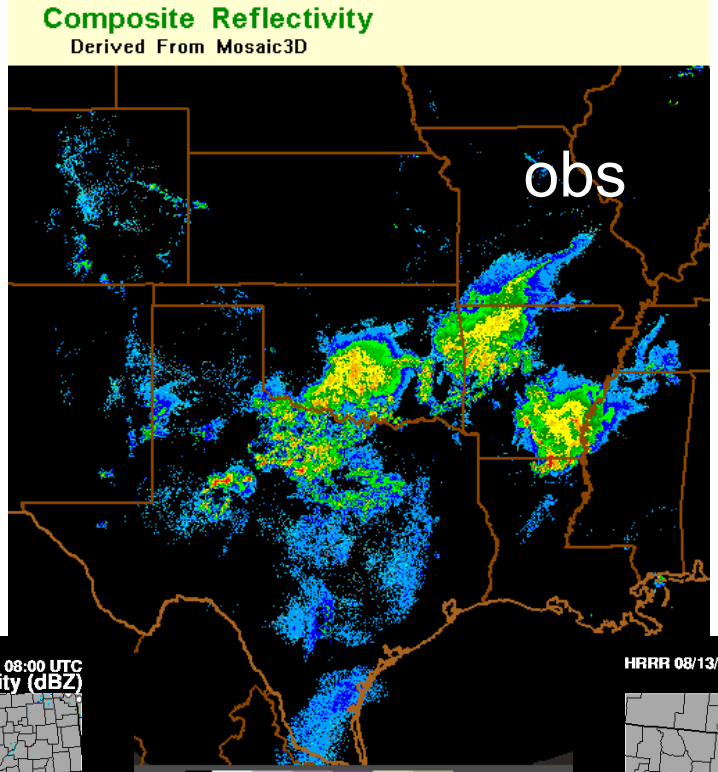
differences up to 5 g/kg typical



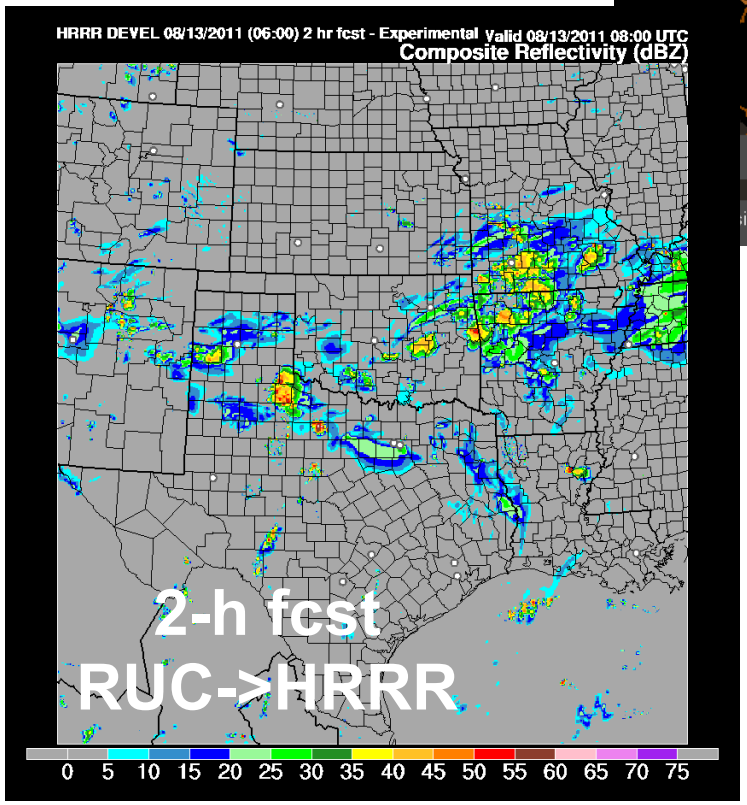


David Dowell and Curtis Alexander

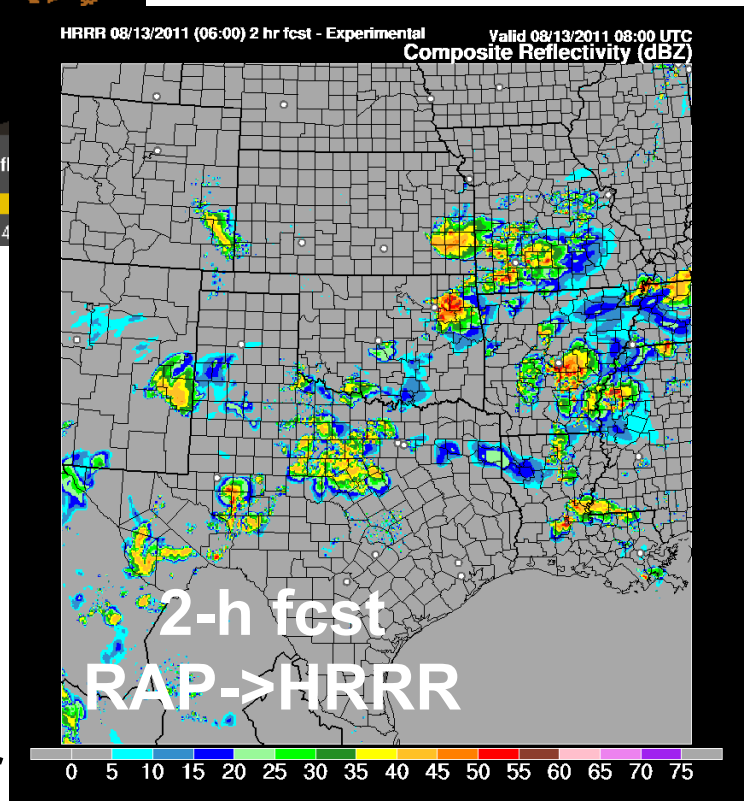
Composite Reflectivity 0800 UTC 13 Aug 2011



storm coverage underforecast in RUC->HRRR, overforecast in RAP->HRRR



David Dowell and Curtis Alexander



Recent Data-Assimilation Changes in Rapid Refresh Model

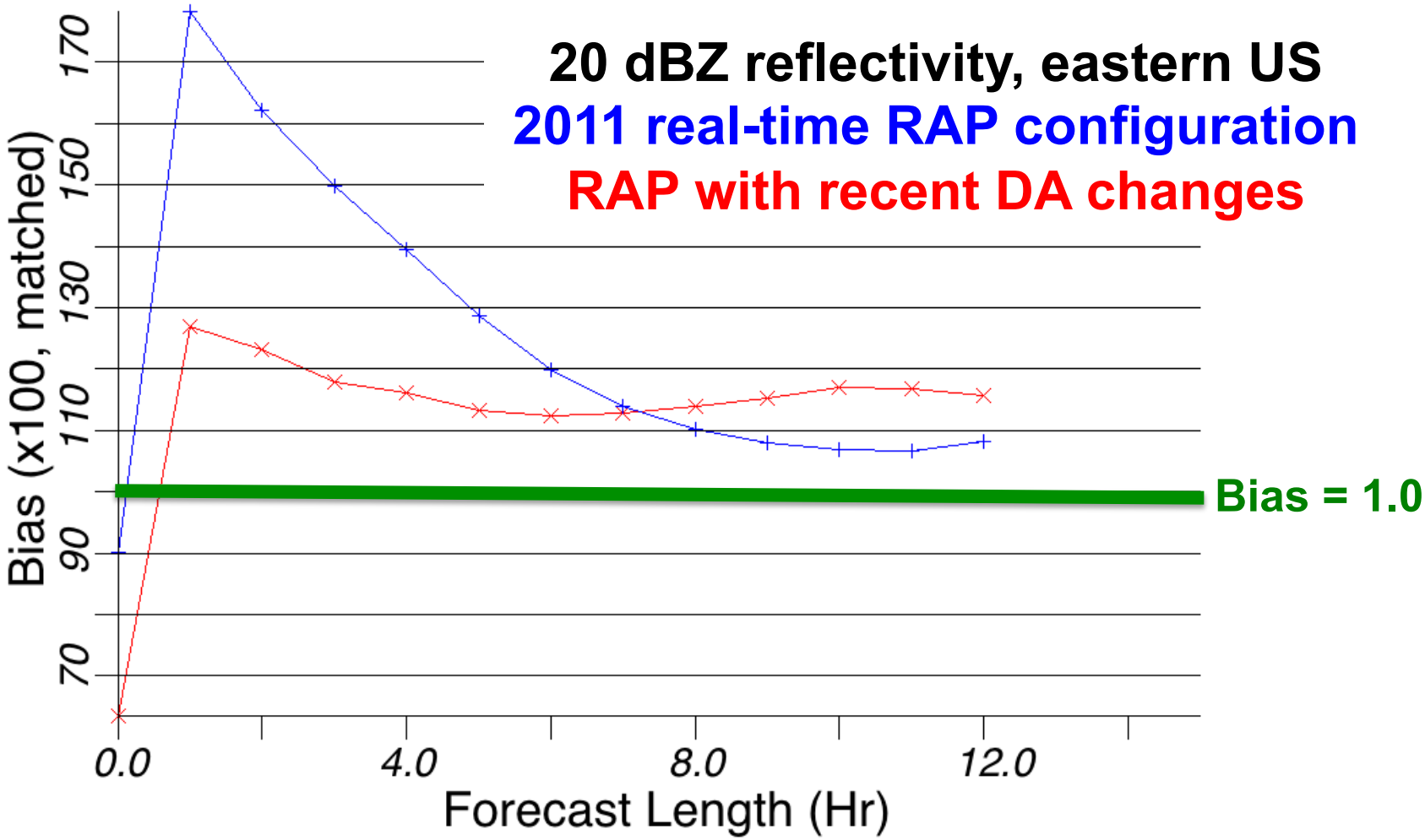
- **Limit precipitable-water innovations to 10% of prior values.**
- **Correct precipitable-water obs for height difference between ob and model terrain.**
- **Cool (warm) layers where clouds are added (removed).**
  - **conservation of virtual temperature**
- **Force subsaturation where clouds are removed.**
- **Limit snow specification from reflectivity data when T > 0°C.**
- **Assimilate water-vapor "pseudo obs" in boundary layer.**
  - **based on innovations for surface obs, when PBL is neutrally stratified**
- **Adjust soil temperature and moisture.**
  - **during daytime, when no clouds, and when 3DVar temperature and water-vapor increments have opposite sign at lowest model level**

Changes were motivated by detailed investigations of water-vapor fields and by successes with similar implementations in RUC model.

These changes might seem relatively minor, but….

Curtis Alexander and David Dowell

Verification for 10-Day Retrospective Period August 2011



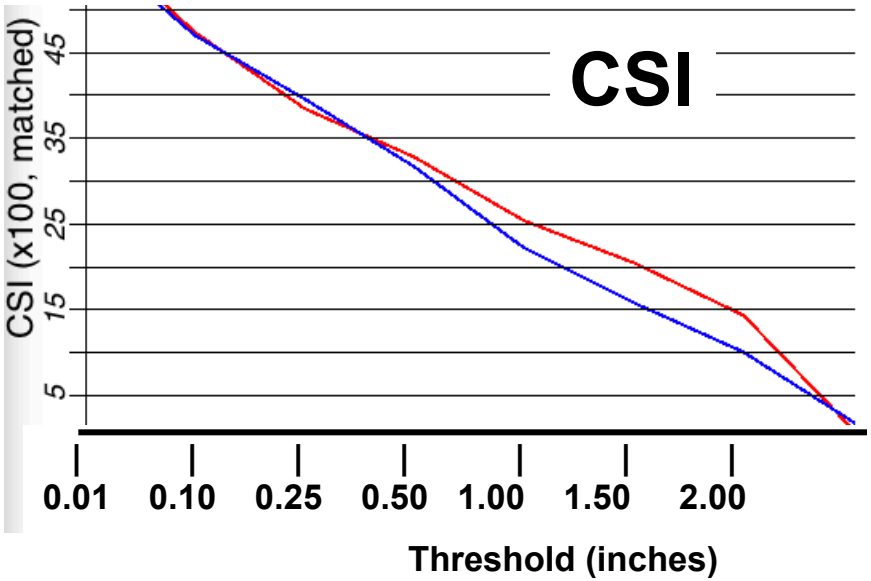
David Dowell and Patrick Hofmann

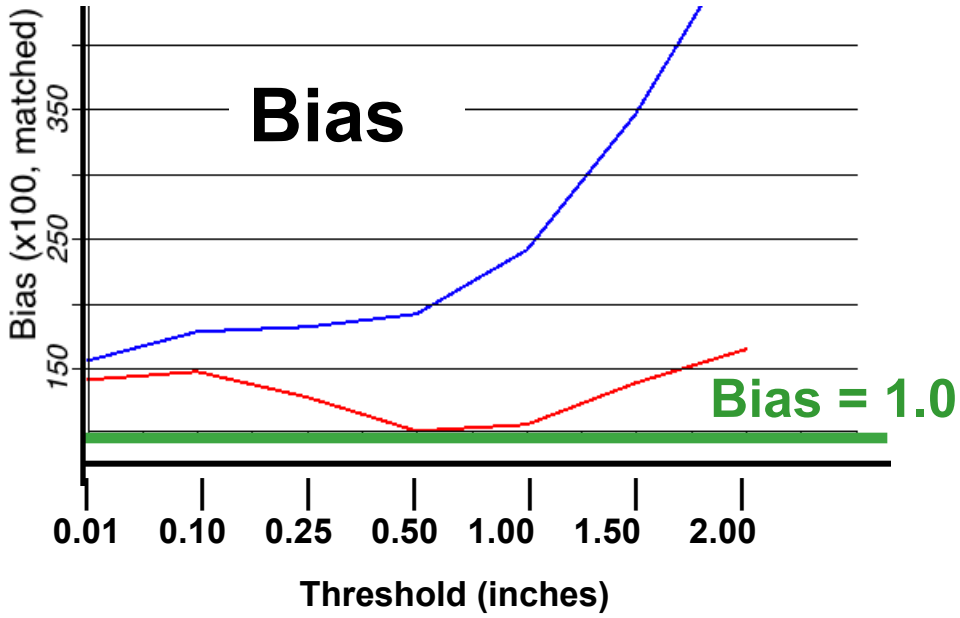
Verification for 10-Day Retrospective Period August 2011

precipitation, 8x3hr, eastern US

2011 real-time RAP configuration

RAP with recent DA changes



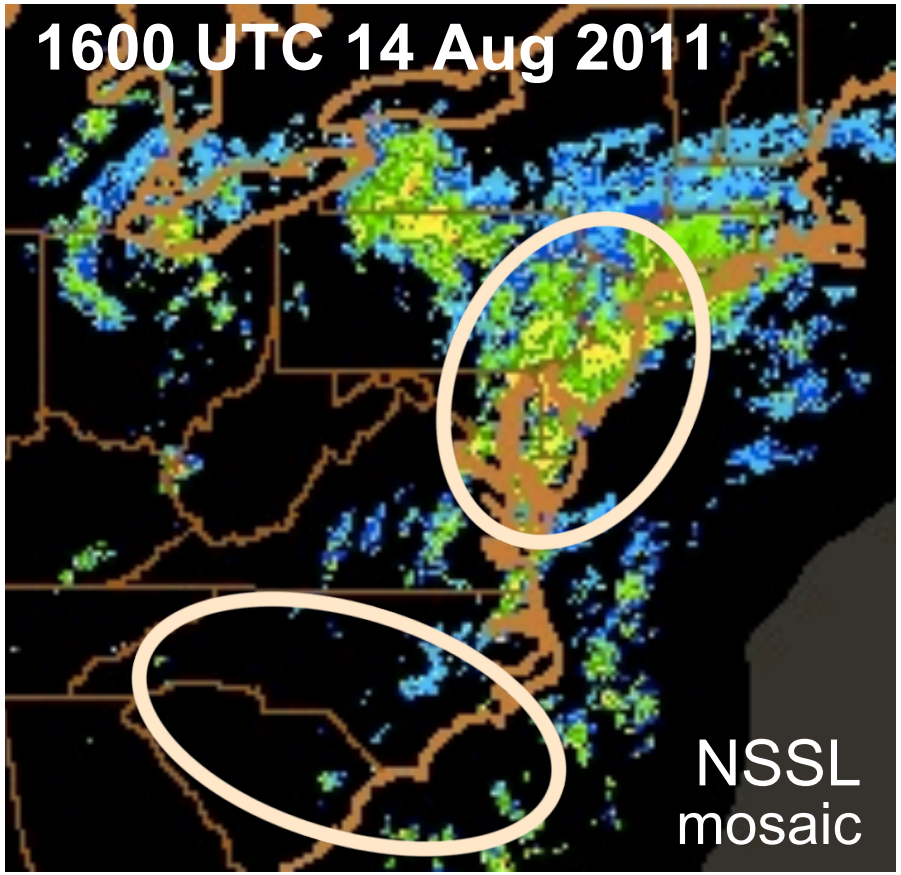


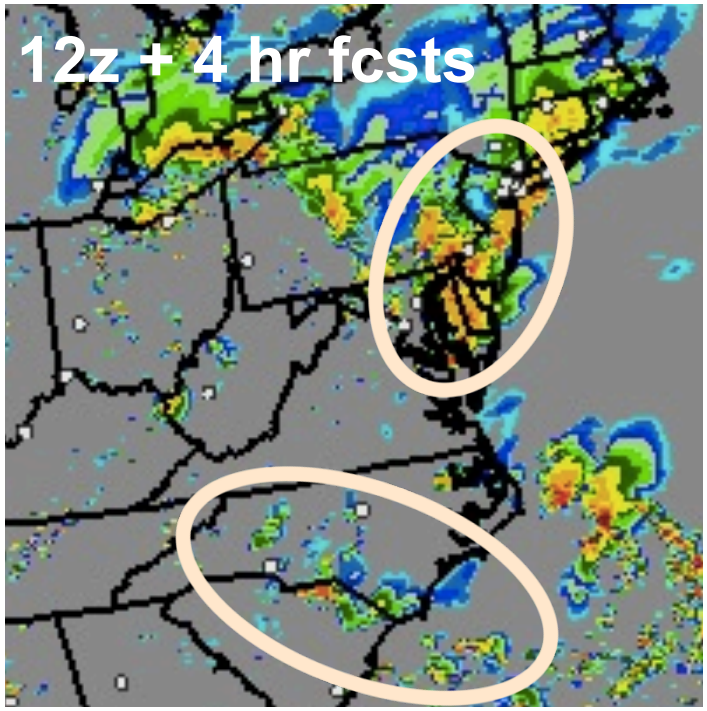
Updated RAP has similar CSI and much improved bias.

Steve Weygandt and Patrick Hofmann

HRRR improvements from RAP updates

(more accurate convection, reduced false alarm)

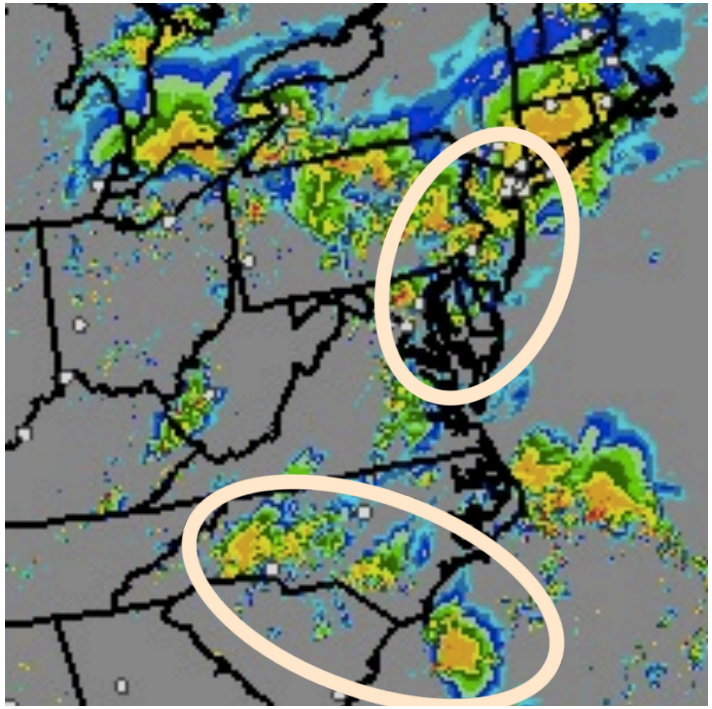




RAP
HRRR

2012
proto-
type

retro
test



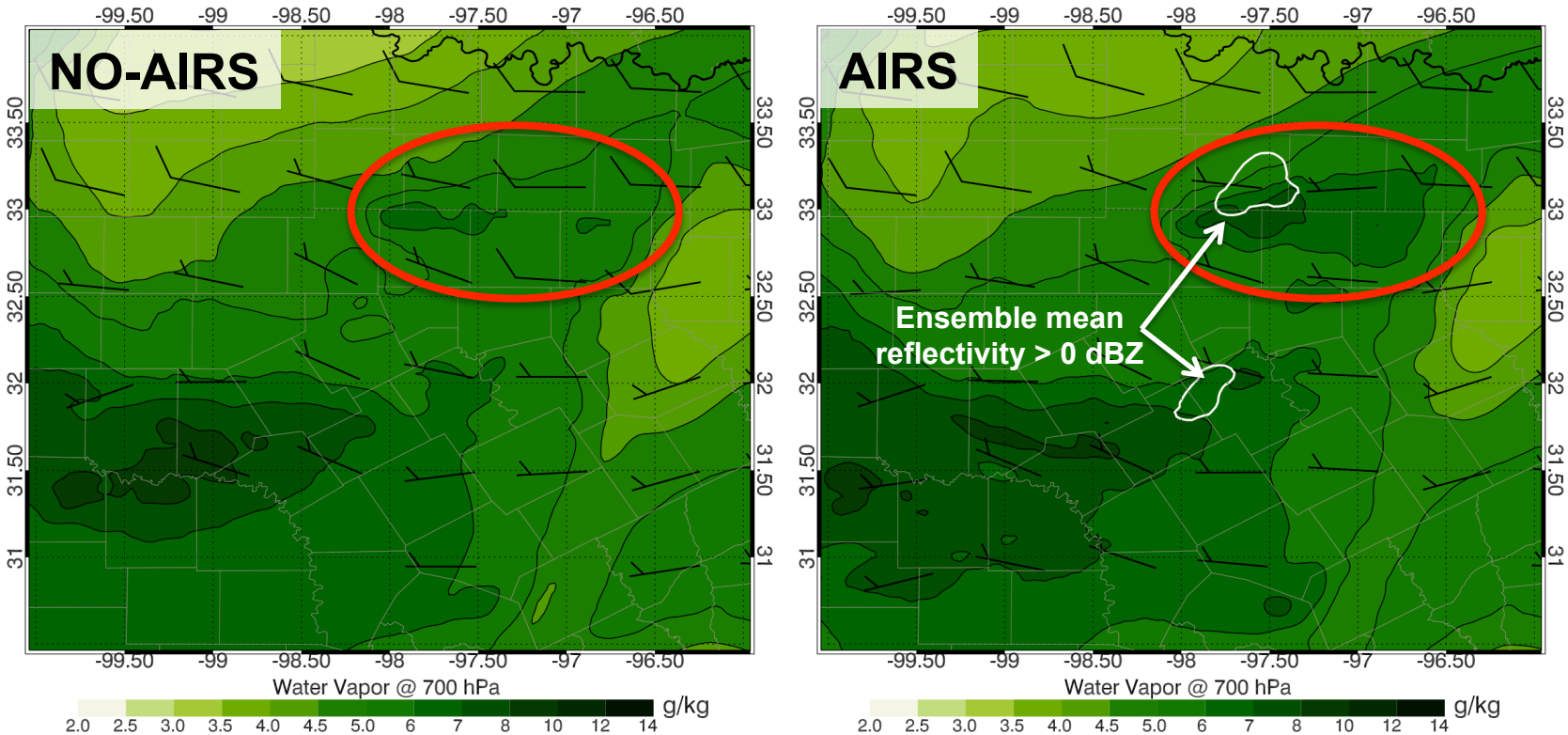
RAP
HRRR

2011
real-
time

Eric James and Steve Weygandt

Impact of AIRS T and T_d Profile Assimilation 15-km / 3-km WRF-DART Ensemble

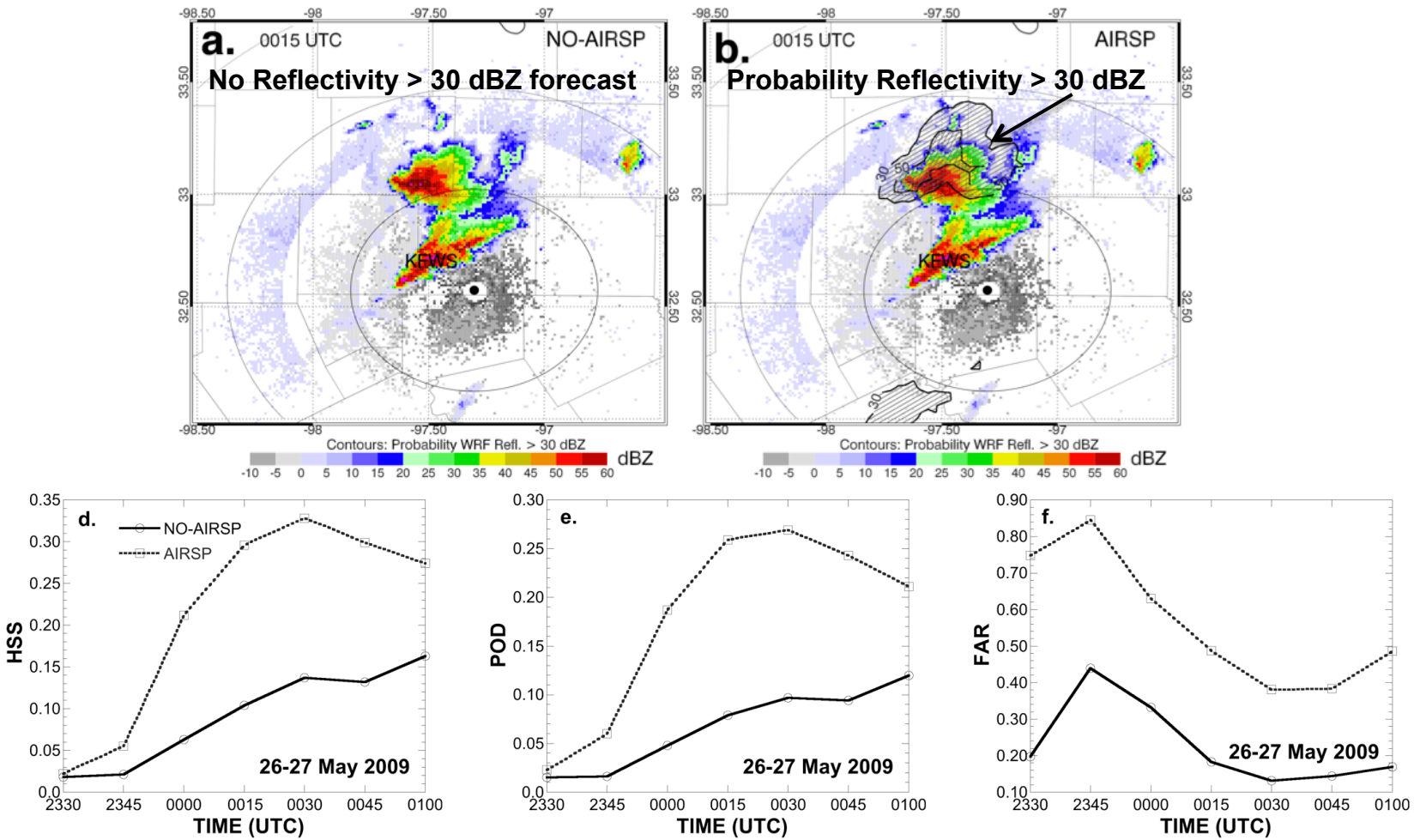
700 hPa QVAPOR: 3-h forecast at 0000 UTC 27 May 2009



- AIRS run generally more moist at 700 hPa
  - Greatest difference near location of forecast convection in AIRS run (white contours)
- AIRS run generates convection whereas NO-AIRS run does not

Thomas Jones

Impacts on ~3-h Reflectivity Forecasts



- NO-AIRS fails to generate storm in ~3 hour forecast
- AIRS is consistently more skillful between 2.5 - 4 hour forecasts
  - (except for FAR)

Thomas Jones

Related Presentations

EnKF assimilation of cloud properties retrieved from GOES (*Thomas Jones and David Stensrud*) 6:30 PM Wednesday

Assimilation of AIRS SFOV retrieval profiles in the Rapid Refresh model system: Assimilation modifications to maximize forecast improvement (*Haidao Lin et al.*) 6:30 PM Wednesday

Use of rapid updating meso- and storm-scale data assimilation to improve forecasts of thunderstorms and other high impact weather: The Rapid Refresh and HRRR forecast systems (*Curtis Alexander et al.*) 10:20 AM Thursday

Improving convection-allowing model forecasts from a cycled WRF-DART mesoscale analysis system (*Glen Romine et al.*) 10:40 AM Thursday

Conclusions

Multi-moment microphysics schemes are required for producing realistic **reflectivity** and **polarimetric** fields. Increases in computing power and storage make it feasible to use multi-moment schemes.

Precipitation microphysics affects

(1) **cold pools**, in systematic but difficult-to-verify ways

(2) **mesocyclone forecasts**, in apparently unsystematic ways.

Systematic differences among **PBL schemes** are large enough to affect convective forecasts. Biases common to all PBL schemes (e.g., too warm at 0Z) suggest new approaches are needed for PBL parameterizations and/or significant problems exist elsewhere.

Accurate **water-vapor analyses and forecasts** are difficult to obtain but are essential for Warn on Forecast. Can we reduce analysis uncertainty and model bias?

Satellite and/or radar data?

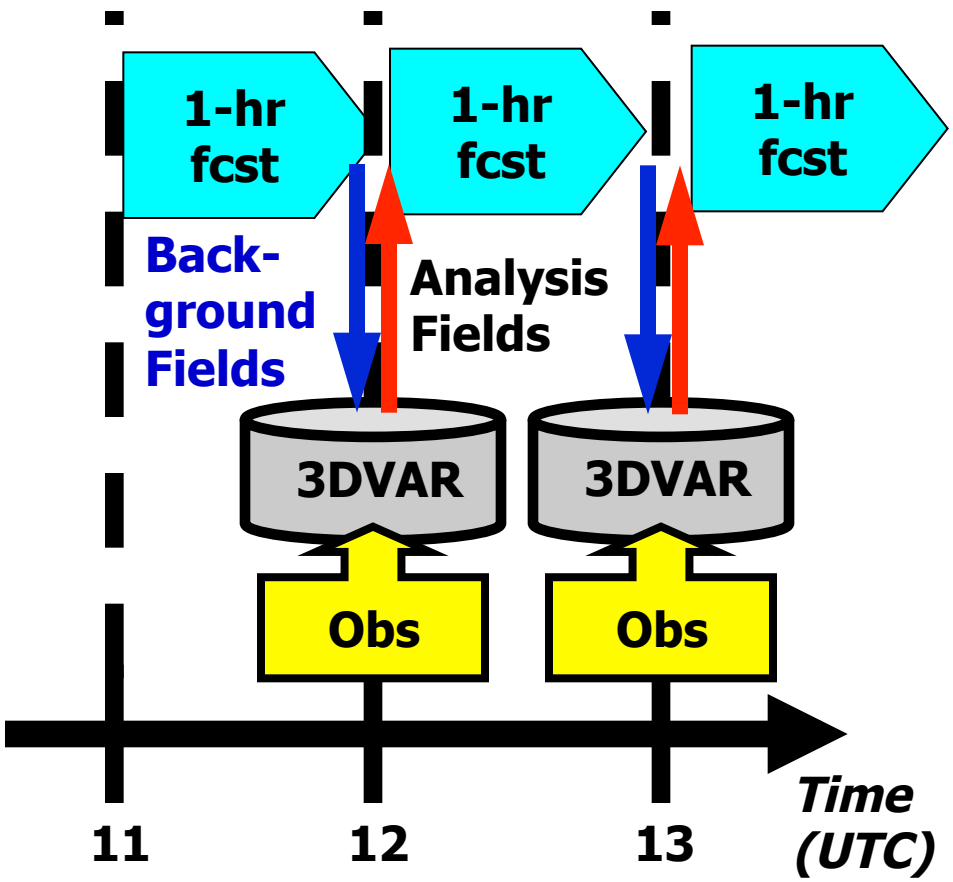
DA methods? e.g., flow-dependent background error covariances

Model improvements? e.g., PBL scheme

Rapid Refresh Hourly Update Cycle

Partial cycle atmospheric fields – introduce GFS information 2x per day

Fully cycle all land-sfc fields

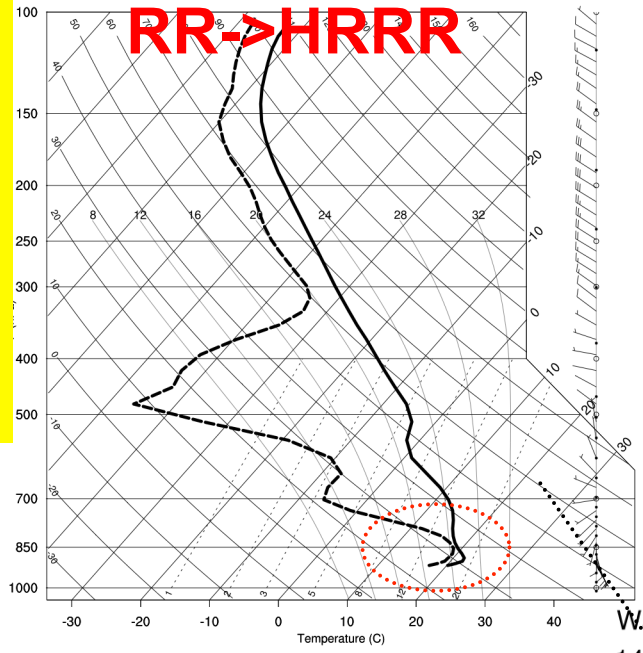


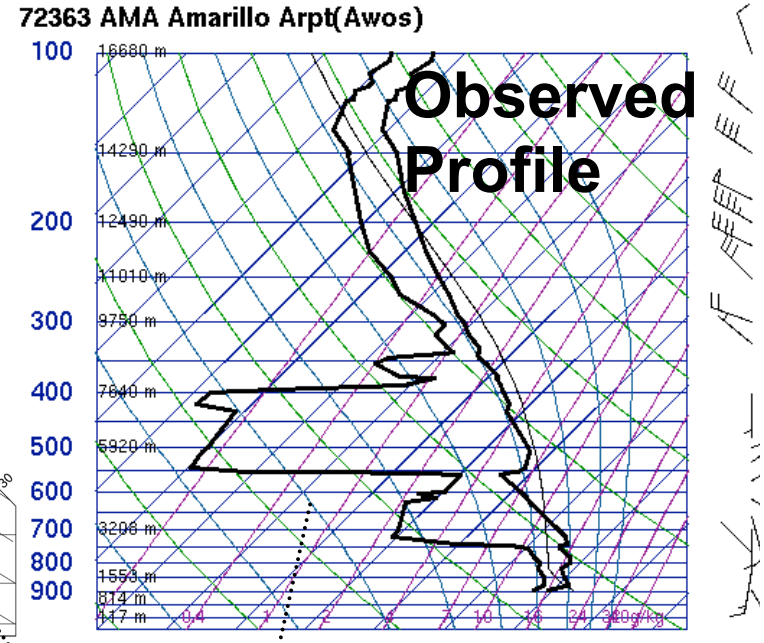
Data types – counts/hr

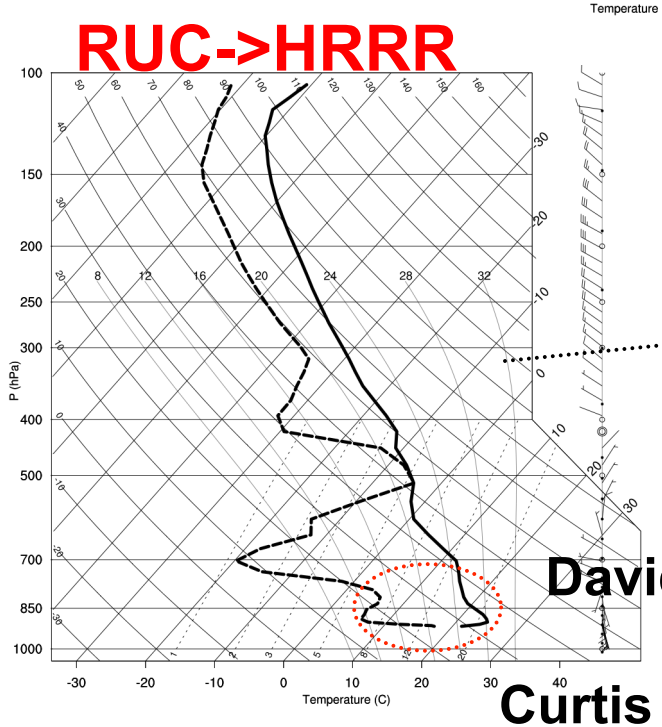
Rawinsonde (12h)	150
NOAA profilers	35
VAD winds	~130
PBL profilers / RASS	~25
Aircraft (V,T)	3500 – 10,000
TAMDAR	200 – 3000
METAR surface	2000 -2500
Mesonet (T,Td)	~8000
Mesonet (V)	~4000
Buoy / ship	200-400
GOES cloud winds	4000-8000
METAR cloud/vis/wx	~1800
GOES cloud-top P,T	10 km res.
Radar reflectivity	1 km res.
Satellite radiances	AMSU/A-B, HIRS, MHS

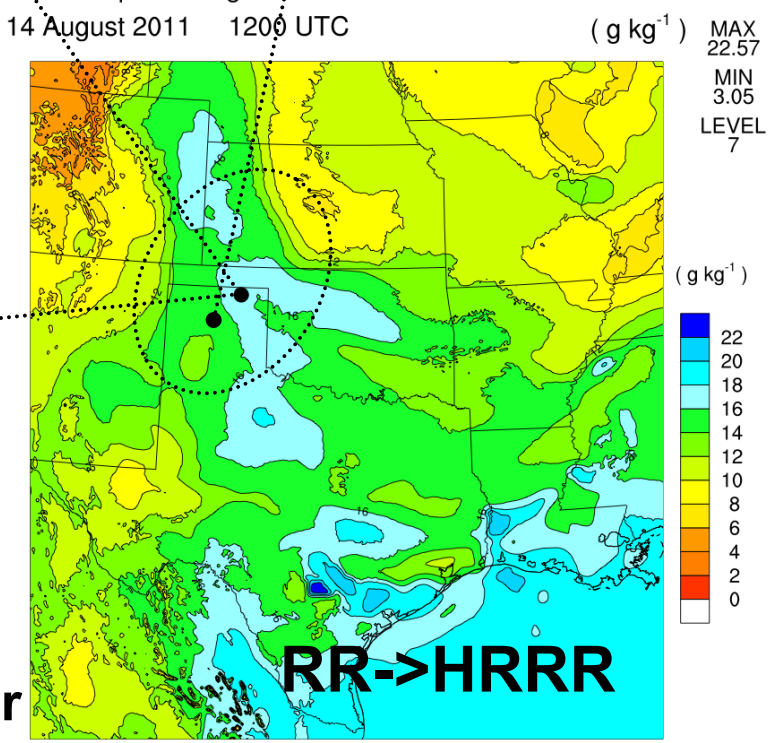
Steve Weygandt

Analysis Vertical Profiles 1200 UTC 14 Aug 2011









David Dowell and Curtis Alexander

Experimental Setup: 8 May 2003

Mesoscale Ensemble:

- A 45-member WRF mesoscale ensemble at 18-km horizontal grid spacing over CONUS initialized from GFS
- 3-day cycling with assimilation of routinely available observations from metar, marine, radiosondes and ACARS using DART system
- Physics options used: MYJ, Thompson, Kain-Fritsch, Noah, Dudhia and RRTM

Storm-scale Ensemble:

- A 45-member storm-scale ensemble nested down from the 45-member mesoscale ensemble data system
- 2-km horizontal grid spacing, 225 x 180 x 50 grid points
- Assimilates KTLX radar radial velocity and reflectivity observations every 3-min for a one-hour period

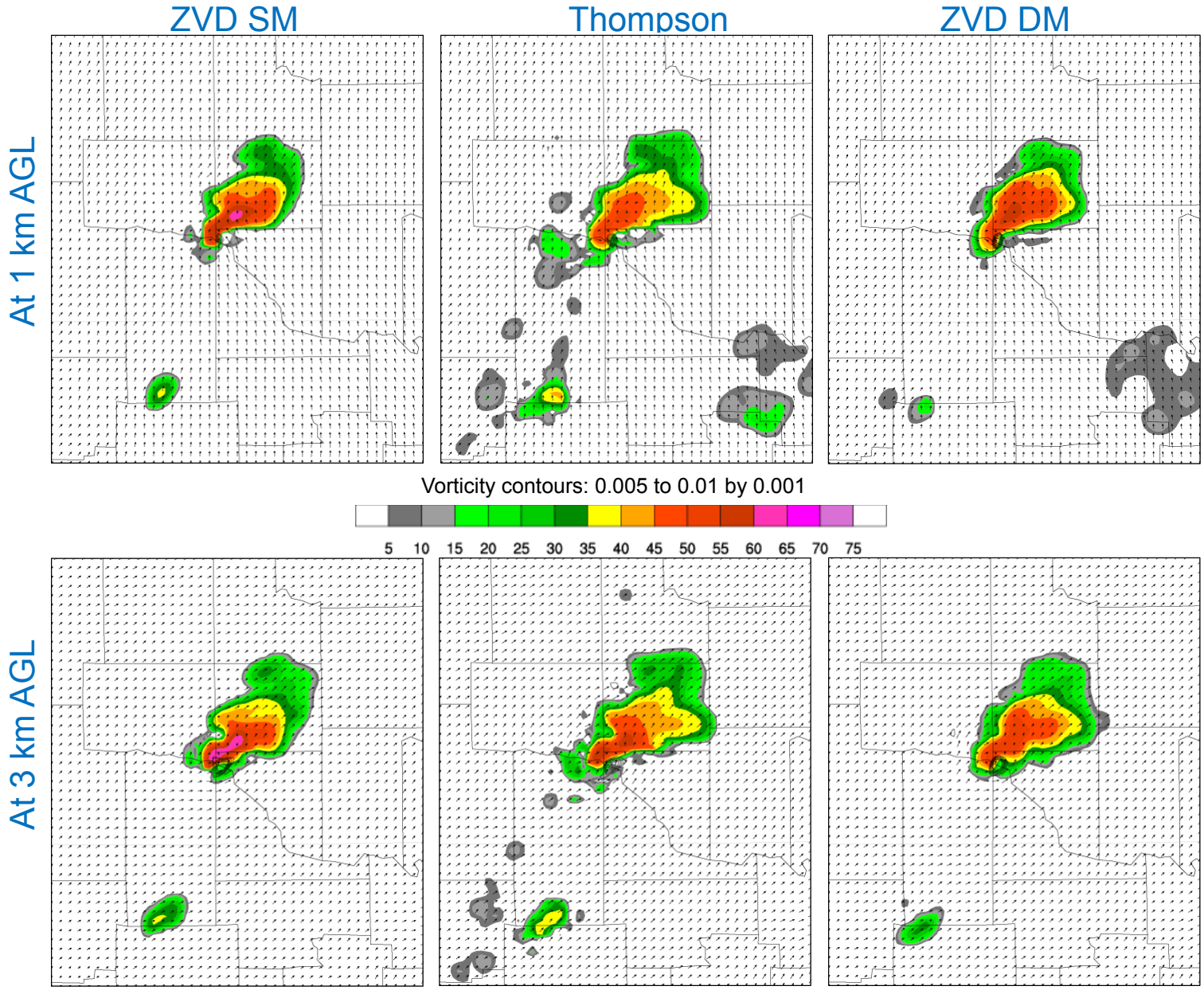
Nusrat Yussouf

Experimental Setup: 8 May 2003

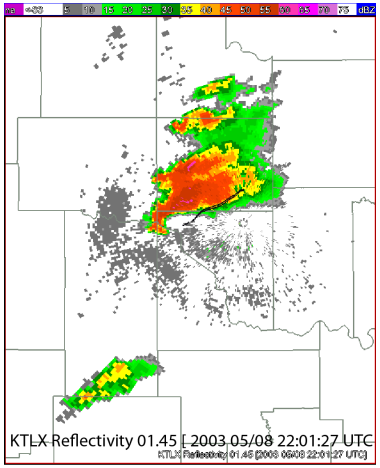
- Three Different Experiments at Storm-scale :
  1. Ziegler Variable Density (ZVD) double-moment microphysics scheme (ZVD DM)
     a. mixing ratios of cloud water, rain, ice, snow, graupel and hail
     b. number concentrations of cloud water, rain, ice, snow, graupel and hail
     c. Graupel particle volume
  2. Thompson "1.5-moment" microphysics scheme
     a. mixing ratios of cloud water, rain, ice, snow and graupel
     b. number concentrations of rain and ice
  3. ZVD single-moment microphysics scheme (ZVD SM)
     a. mixing ratios of cloud water, rain, ice, snow and graupel

Nusrat Yussouf

Final Analyses (Ens Mem # 9) at 22:00Z : Reflectivity and Vorticity

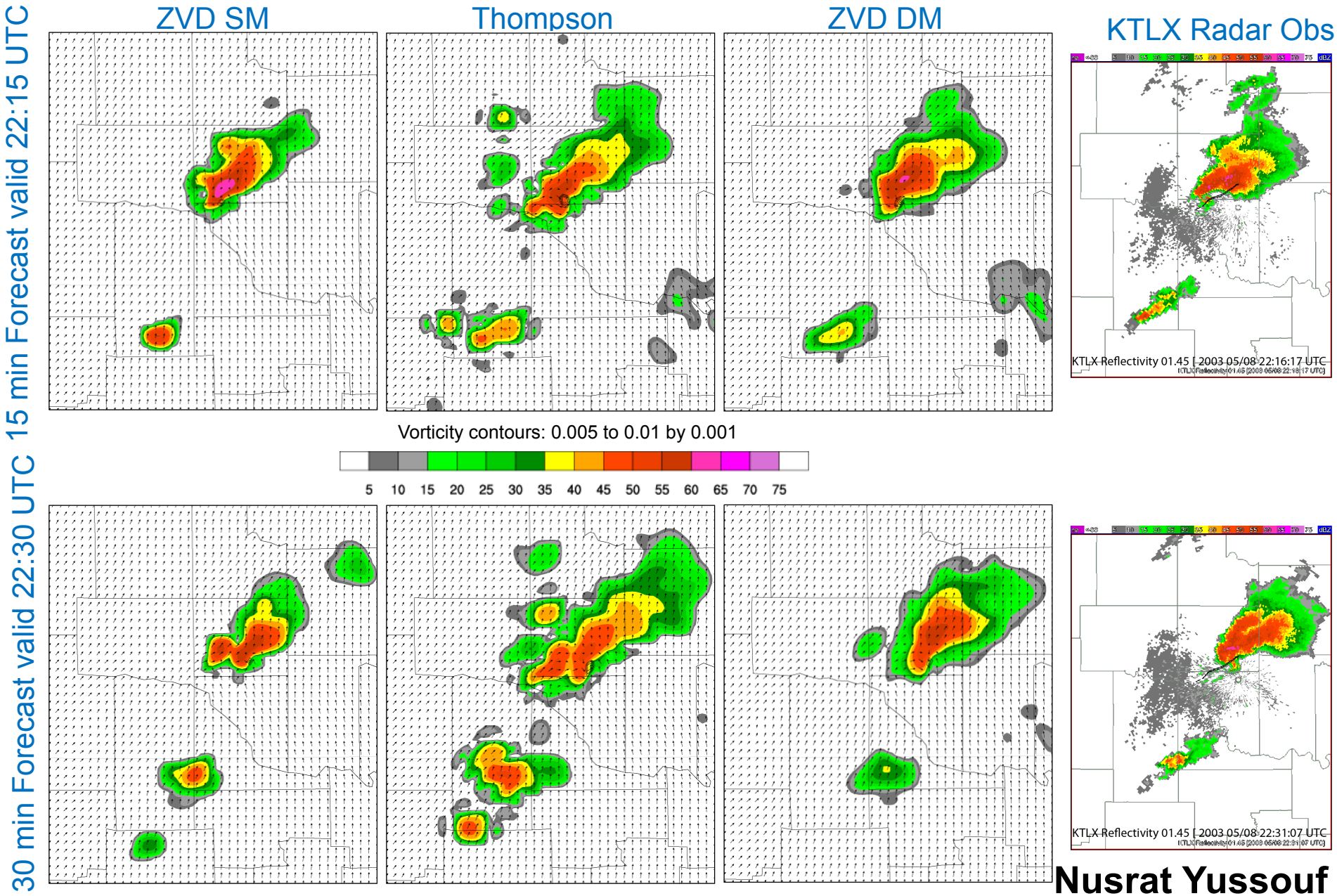


KTLX Radar Obs



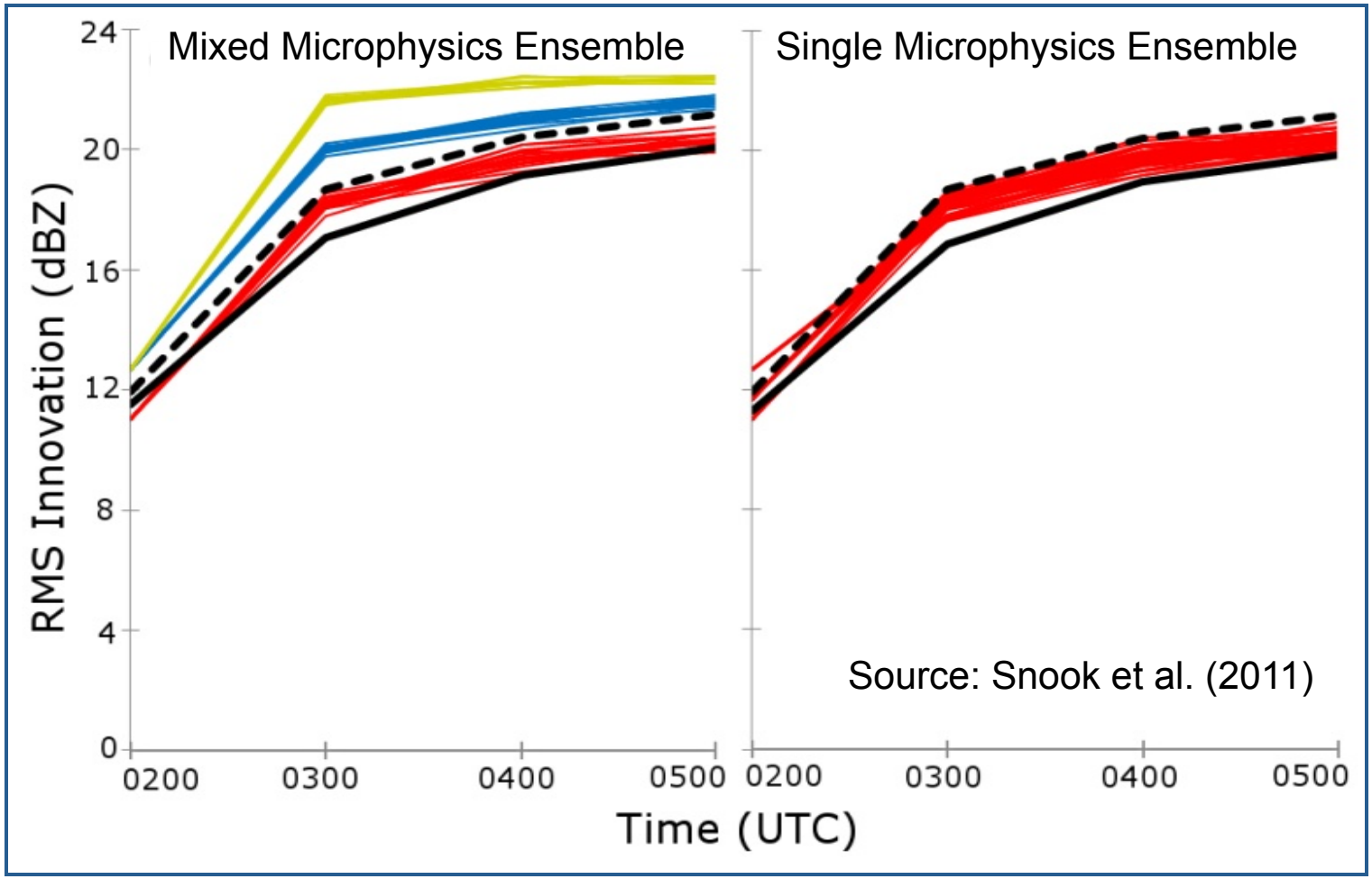
Nusrat Yussouf

15 and 30-min Forecasts (Ens Mem # 9) at 1 km AGL



Nusrat Yussouf

Ensemble Forecast: Microphysical Sensitivity

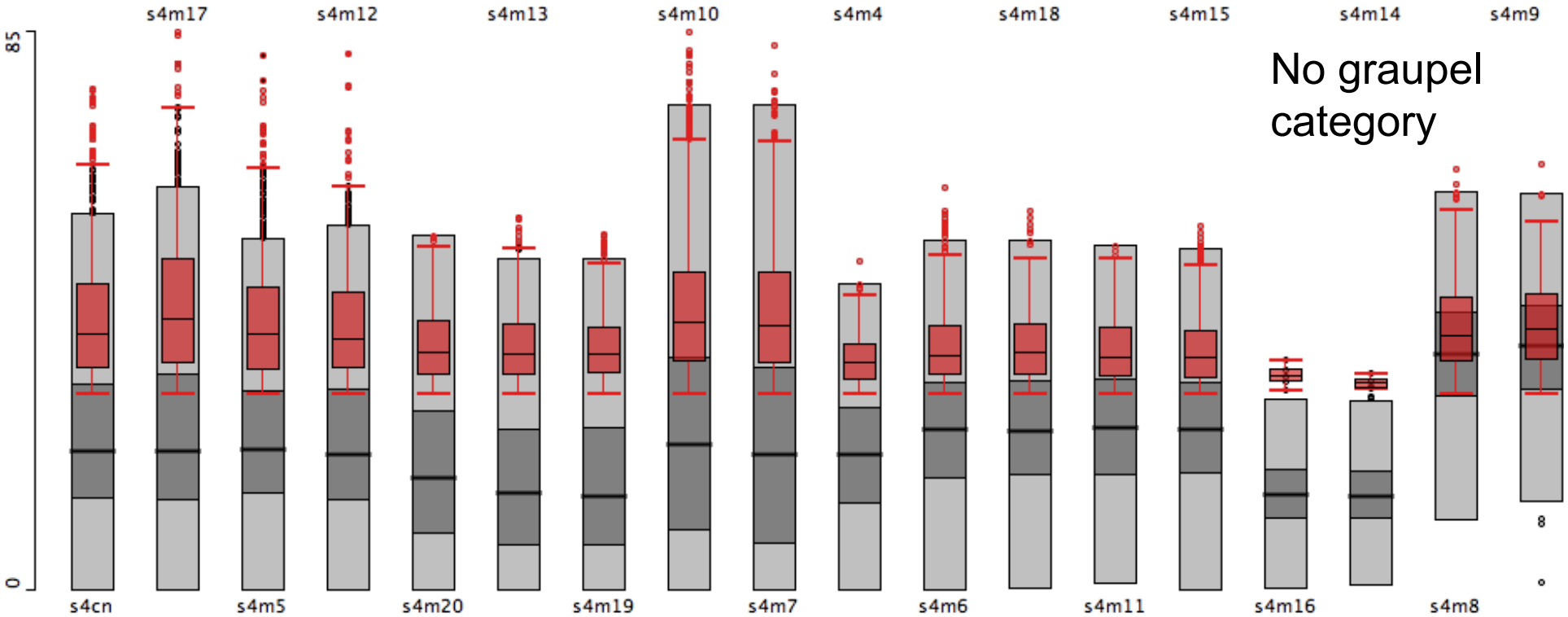


Using a mixed-microphysics forecast ensemble produces a trimodal distribution within the ensemble in the RMS innovation of radar reflectivity.

Nate Snook

Ensemble physics sensitivity

Maximum **Hourly Maximum graupel mixing ratio** box plots by member. Red box plots indicate arbitrarily defining 30 kg m^{-2} (~75th percentile of storm ensemble) as severe hail producing storms. The relative (red) and total ensemble (blue) contributions (%) for each member are shown.



	s4cn	s4m17	s4m5	s4m12	s4m20	s4m13	s4m19	s4m10	s4m7	s4m4	s4m6	s4m18	s4m11	s4m15	s4m16	s4m14	s4m8	s4m9
	27.4	29.6	25.5	25.7	19	15.1	15.1	34.1	31.9	18.1	29.8	29.7	30.5	29.6	0.2	0.2	73.6	76.3
	5.2	4.6	5.2	4.0	6.5	6.5	6.6	13.8	10.7	3.4	6.9	5.3	5.3	5.1	0.04	0.03	5.3	5.7

Spread implications: 24.5% from WDM6

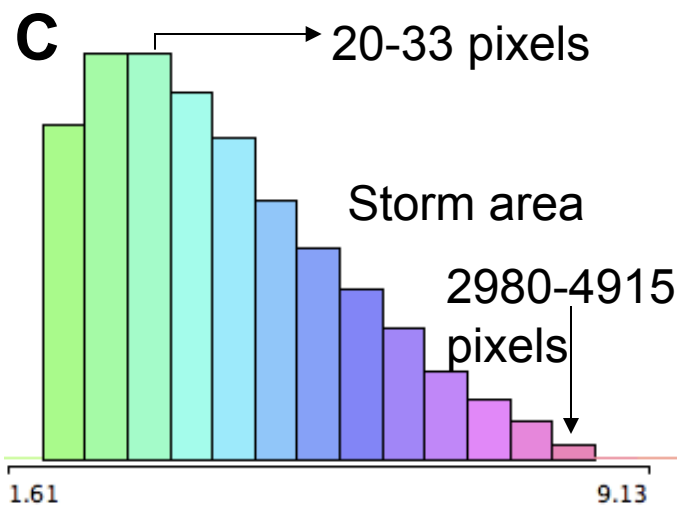
No contribution FER+

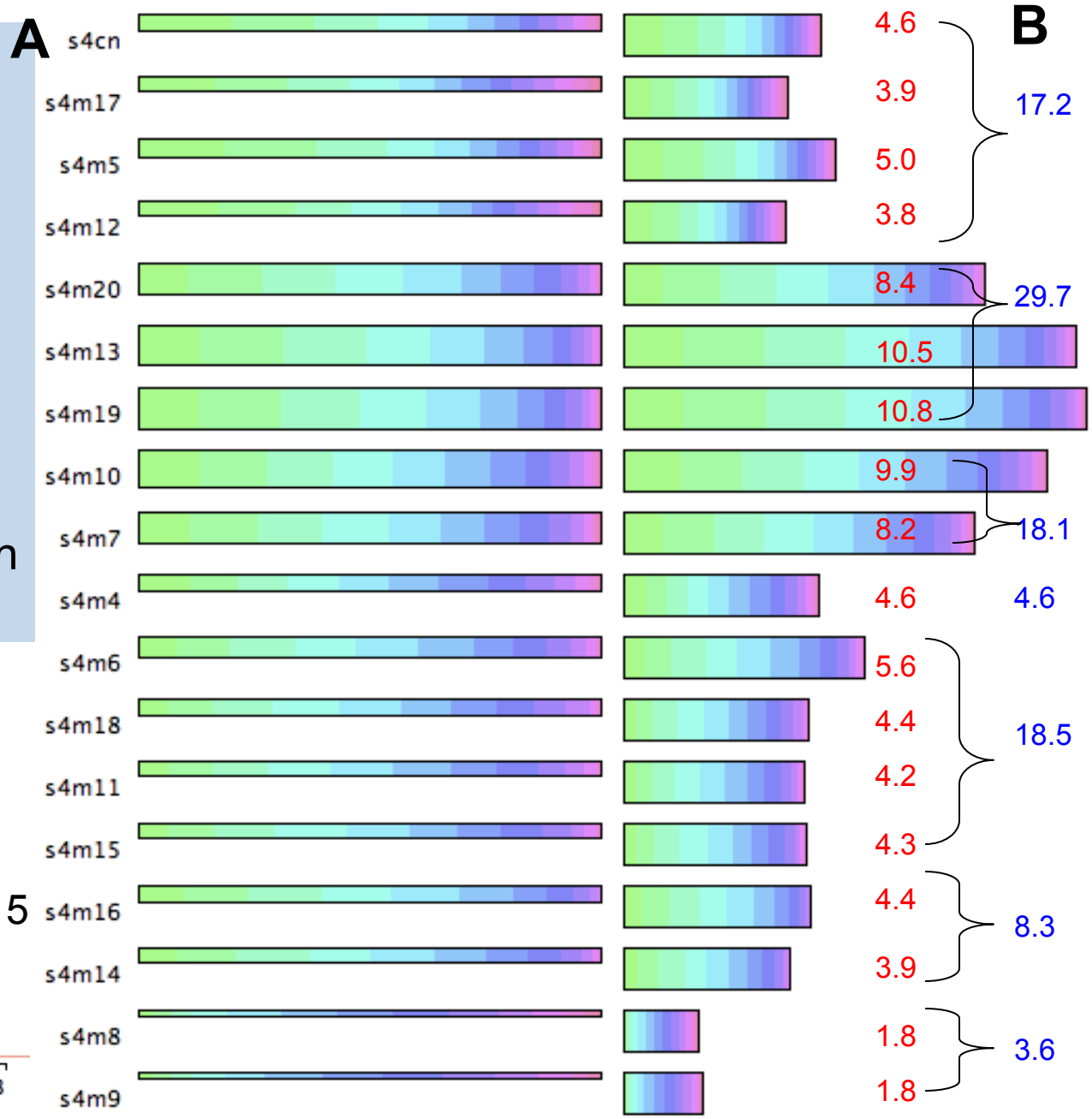
James Correia

Ensemble physics sensitivity

James Correia
Storm Prediction Center
Norman, Oklahoma

Number of storms by member shown (sorted by MP) via A. spine plot and B. bar chart with color brushing depicting C. natural log of storm pixel count. Percentages indicated in red represent the member contribution, while in blue that from each microphysics scheme.





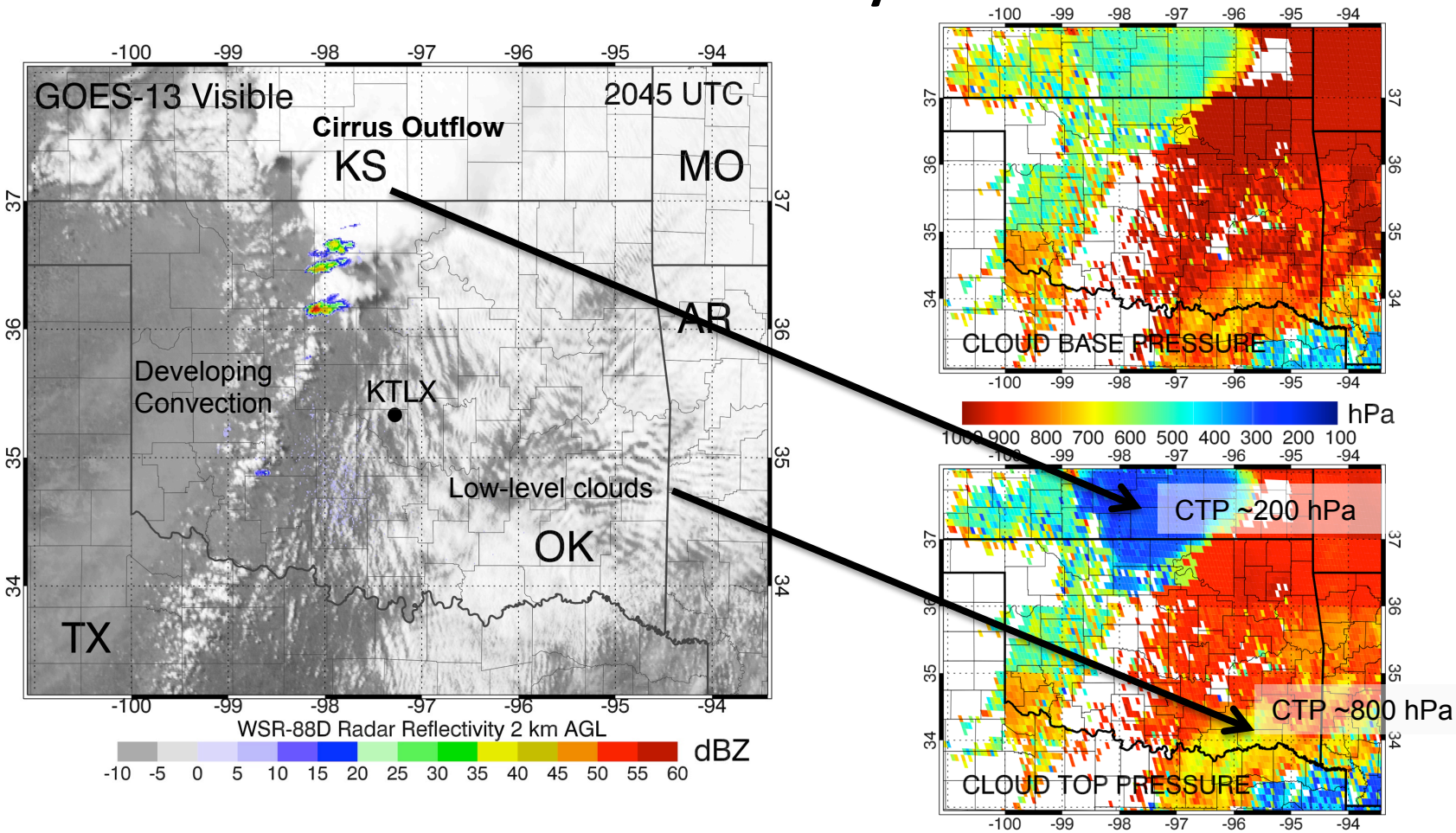
GOES Cloud Property Assimilation

- *GOAL:* Provide model analysis information on the location and vertical distribution of clouds
- Need high spatial and temporal resolution data
- 1 km, 30 minute cloud property retrievals available from GOES-13 data
  - Uses NASA Langley retrieval algorithm
  - Products include:
    - Cloud top pressure (CTP)
    - Cloud base pressure (CBP)
    - Cloud liquid water path (CLWP)
    - Cloud ice water path (CIWP)
    - Cloud phase
- These variables are not suitable for direct assimilation into WRF-DART
  - Must convert to QCLOUD, QICE, RH, etc.
  - Use CTP and CBP to determine location and thickness of clouds
  - Define Q* and RH variables to correspond to this information and then assimilate into WRF-DART

Thomas Jones

GOES Visible & CTP/CBP

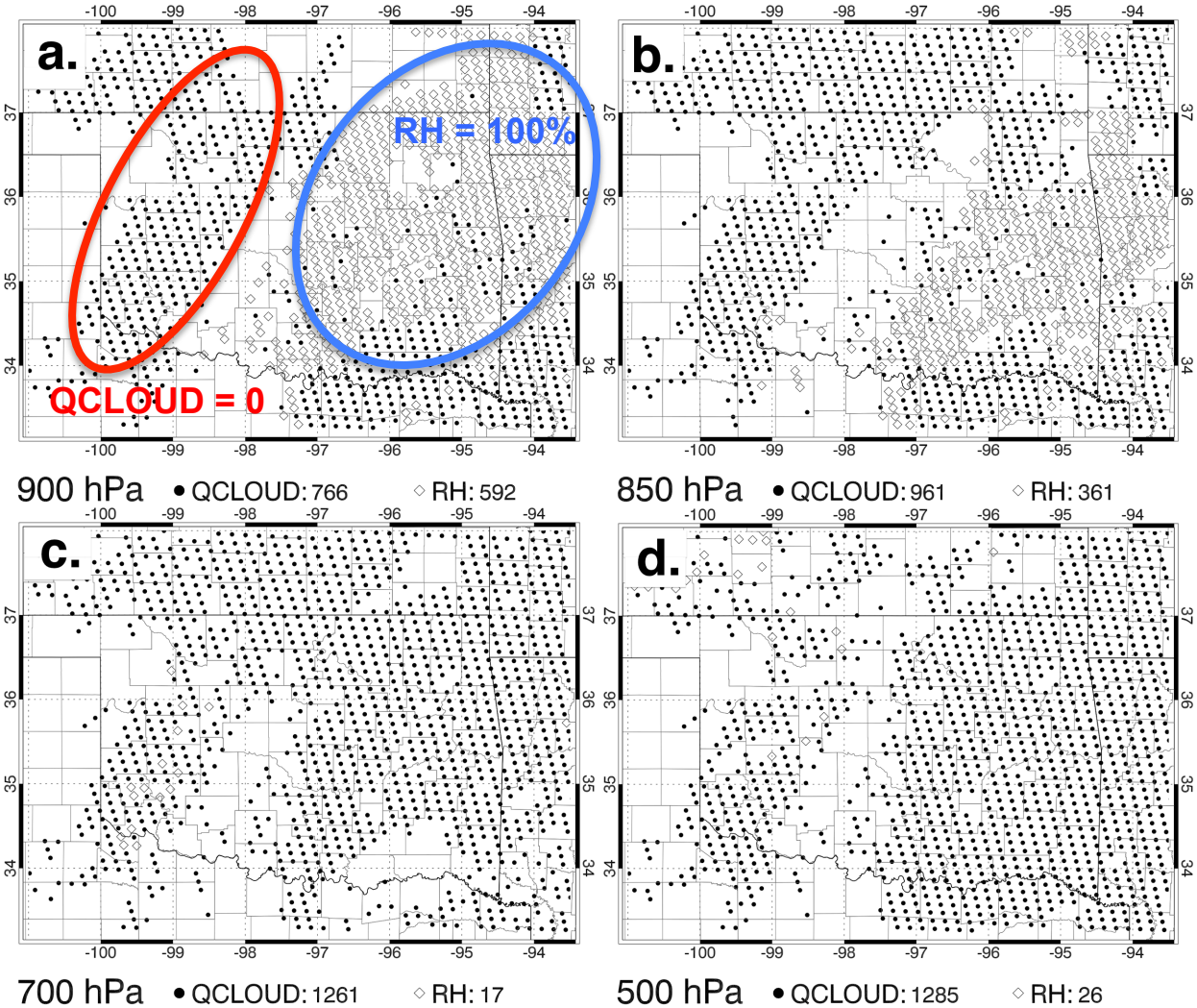
2045 UTC 10 May 2010



- Convection initiating ahead of dryline in OK
- Low-level clouds present in eastern OK

Thomas Jones

Assimilated Data at 2045 UTC



VARIABLE	N_{TOTAL}	N_{ASSIM}	$\%_{ASSIM}$
QCLOUD	205482	187042	91.0
QICE	205482	190796	92.8
QRAIN	205482	190380	92.6
QGRAUP	205482	196392	92.6
RH	37189	22357	60.1
TOTAL	*859117*	*780967*	*90.9*

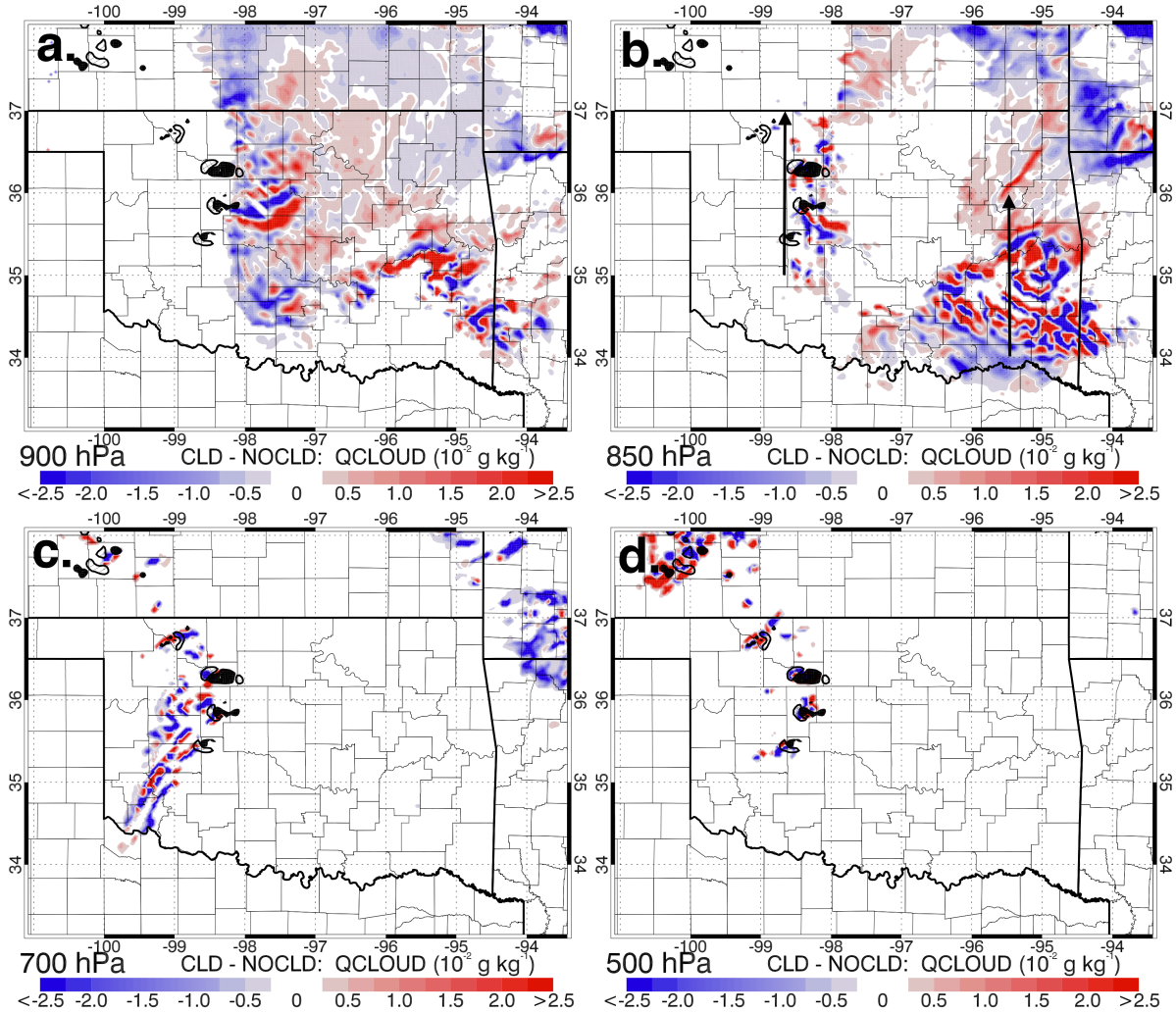
1800 – 2100 UTC
Sample size

- Where low clouds exist, *RH*=100% assimilated
- Above 850 hPa, few clouds resulting in *QCLOUD* = 0 being assimilated

Thomas Jones

QCLOUD Differences

2045 UTC



- Large areas of differences at 900 and 850 hPa
- Magnitude ~ 0.1 g kg^{-1}
- Greatest differences near developing cumulus and in low-level clouds fields further east
- Interesting wave-like pattern in QCLOUD differences at 850 hPa

- Differences at 700 hPa and above have limited coverage
- Only significant differences occur along dryline
- Also see differences in model IWP (black shading)
- Hard to ascertain physical significance of these differences

RED = CLD Greater **BLUE = NOCLD Greater**

Thomas Jones