CAPS Realtime 4-km Multi-Model Convection-Allowing Ensemble and 1-km Convection-Resolving Forecasts for the NOAA Hazardous Weather Testbed (HWT) 2009 Spring Experiment

Ming Xue, Fanyou Kong, Kevin W. Thomas, Jidong Gao, Yunheng Wang, Keith Brewster, Kelvin K. Droegemeier, Xuguang Wang

Center for Analysis and Prediction of Storms (CAPS), University of Oklahoma

John Kain[2], Steve Weiss[3], David Bright[3], Mike Coniglio[2] and Jun Du[4]

[2]National Severe Storms Laboratory
[3]Storm Prediction Center
[4]Environmental Modeling Center/NCEP

Contact: mxue@ou.edu

Forecast Configurations of Three Years

- Spring 2007: 10-member WRF-ARW, 4 km, 33 h, 21Z start time, NAM+SREF ICs. 5 members physics perturbations only, 5 with Phy+IC+LBC perturbations. Single 2 km grid. 2/3 CONUS (2007 NWP conf.)
- Spring 2008: larger domain, 00Z start, Phy+IC+LBC pert for all. Radar Vr and Z data assimilation for 4 and 2 km grids! (2008 SLS Conf.)
- Spring 2009: 20 members, CONUS-scale, 4 km, 3 models (ARW, NMM, ARPS), mixed physics/IC/LBCs, radar DA, once a day, 30-hour forecasts from 0Z. + Single 1 km deterministic.
- About 1.5 months each spring season from mid-April through early June

Table 1. Configurations of the ARW members of 4-km ensemble. NAMa and NAMf refer to 12 km NAM analysis and forecast, respectively. ARPSa refers to ARPS 3DVAR analysis.

ARW

member	IC	LBC	Radar	MPhys	SWRad	LSM	PBL
arw_cn	00Z ARPSa	00Z NAMf	yes	Thompson	Goddard	Noah	MYJ
arw_c0	00Z NAMa	00Z NAMf	no	Thompson	Goddard	Noah	MYJ
arw_n1	arw_cn – em_pert	SREF em-n1	yes	Ferrier	Goddard	Noah	YSU
arw_p1	arw_cn + em_pert	SREF em-p1	yes	WSM6	Dudhia	Noah	MYJ
arw_n2	arw_cn – nmm_pert	SREF nmm-n1	yes	Thompson	Dudhia	RUC	MYJ
arw_p2	arw_cn + nmm_pert	SREF nmm-p1	yes	WSM6	Dudhia	Noah	YSU
arw_n3	arw_cn – etaKF_pert	SREF etaKF-n1	yes	Thompson	Dudhia	Noah	YSU
arw_p3	arw_cn + etaKF_pert	SREF etaKF-p1	yes	Ferrier	Dudhia	Noah	MYJ
arw_n4	arw_cn – etaBMJ_pert	SREF etaBMJ-n1	yes	WSM6	Goddard	Noah	MYJ
arw_p4	arw_cn + etaBMJ_pert	SREF etaBMJ-p1	yes	Thompson	Goddard	RUC	YSU

* For all members: long wave radiation = RRTM; cumulus parameterization = None

Table 2. Configurations for NMM members of the 4-km ensemble

NMM

member	IC	LBC	Radar	MPhys	LWRad	SWRad	LSM	PBL
nmm_cn	00Z ARPSa	00Z NAMf	yes	Ferrier	GFDL	GFDL	Noah	MYJ
nmm_c0	00Z NAMa	00Z NAMf	no	Ferrier	GFDL	GFDL	Noah	MYJ
nmm_n1	*nmm_cn – em_pert*	*SREF em-n1*	*yes*	*Thompson*	*RRTM*	*Dudhia*	*Noah*	*MYJ*
nmm_p1	nmm_cn + em_pert	SREF em-p1	yes	WSM6	GFDL	GFDL	RUC	MYJ
nmm_n2	nmm_cn – nmm_pert	SREF nmm-n1	yes	Ferrier	RRTM	Dudhia	Noah	YSU
nmm_p2	nmm_cn + nmm_pert	SREF nmm-p1	yes	Thompson	GFDL	GFDL	RUC	YSU
nmm_n3	nmm_cn – etaKF_pert	SREF etaKF-n1	yes	WSM6	RRTM	Dudhia	Noah	YSU
nmm_p3	*nmm_cn + etaKF_pert*	*SREF etaKF-p1*	*yes*	*Thompson*	*RRTM*	*Dudhia*	*RUC*	*MYJ*
nmm_n4	nmm_cn – etaBMJ_pert	SREF etaBMJ-n1	yes	WSM6	RRTM	Dudhia	RUC	MYJ
nmm_p4	nmm_cn + etaBMJ_pert	SREF etaBMJ-p1	yes	Ferrier	RRTM	Dudhia	RUC	YSU

* For all members: cumulus parameterization = None. nmm_n1 and nmm_p3 (shaded) were removed from the list after the first week of experiment because they took too long to complete, reducing the NMM ensemble size from 10 to 8.

Table 3. Configurations of the ARPS members of the 4-km ensemble

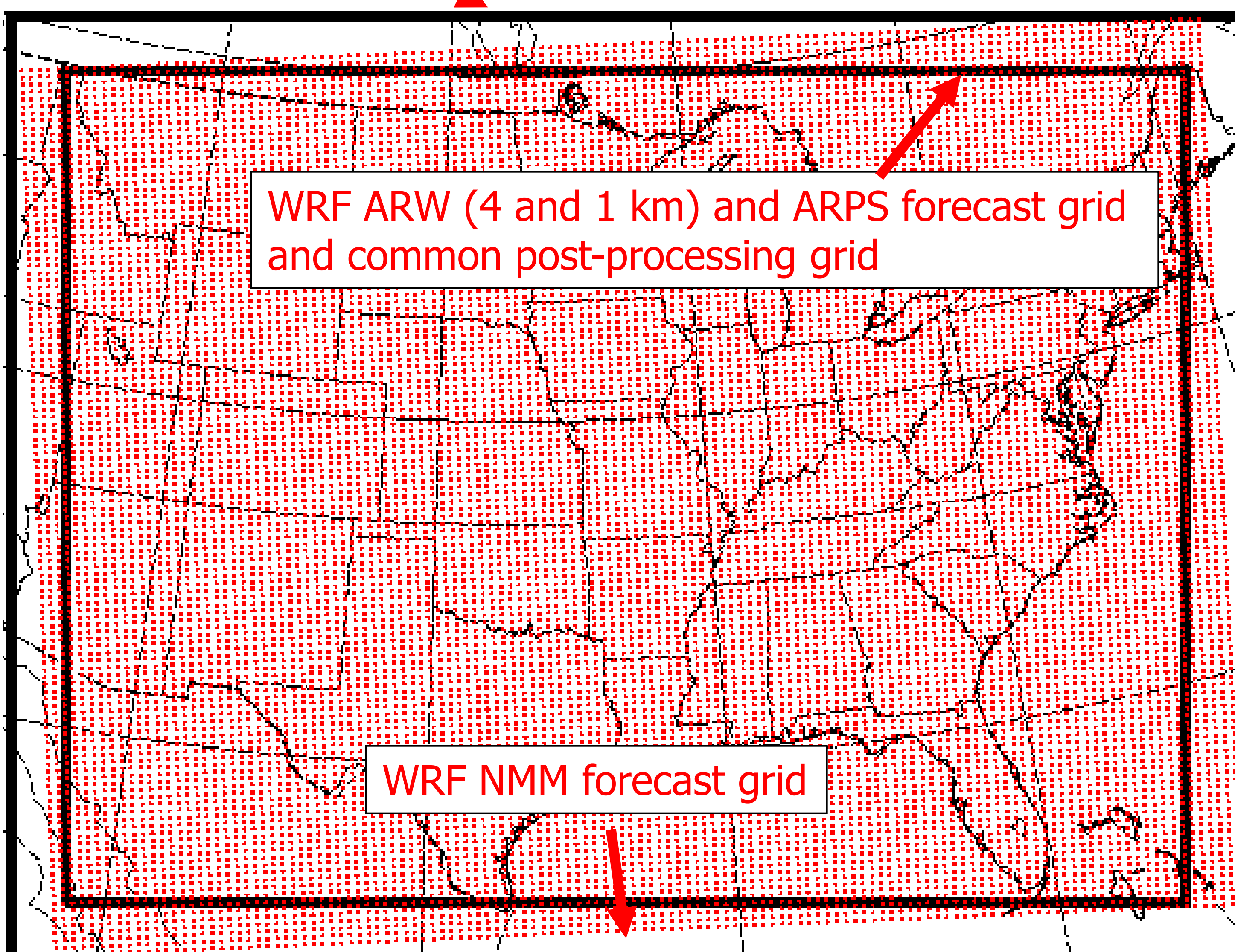
ARPS

member	IC	LBC	Radar	MPhys	LWRad	SWRad	LSM	PBL	SGS turb
arps_cn	00Z ARPSa	00Z NAMf	yes	Lin	Goddard	Goddard	2-layer	TKE	3D TKE
arps_c0	00Z NAMa	00Z NAMf	no	Lin	Goddard	Goddard	2-layer	TKE	3D TKE

* For all members: cumulus parameterization = None

ARPS 3DVAR Analysis Grid

1 km grid: 3603 x 2691 x 51



Forecast Configurations – more details

- ARPS 3DVAR+Cloud Analysis provide control IC
- IC perturbations and LBCs from SREF for perturbed members
- NAM forecasts for control LBCs
- Level-2 radial velocity and reflectivity data from over 120 WSR-88D radars analyzed.
- Physics options: mixed for the ensemble.
- 3D output every hour, selected 2D output every 5 minutes.
- Hourly graphics posted on the web, and extracted 2D fields sent to HWT N-AWIPS
- 1 km forecasts using ~10,000 cores on a Cray XT5 at National Institute for Computational Science (NICS) at University of Tennessee
- 4 km ensembles using ~2000 cores on a Cray XT3 at Pittsburgh Supercomputing Center (PSC).
- 4 million CPU-hours used. Over 100 TB of data archived.
- Forecasts completed in 5-9 hours over night.

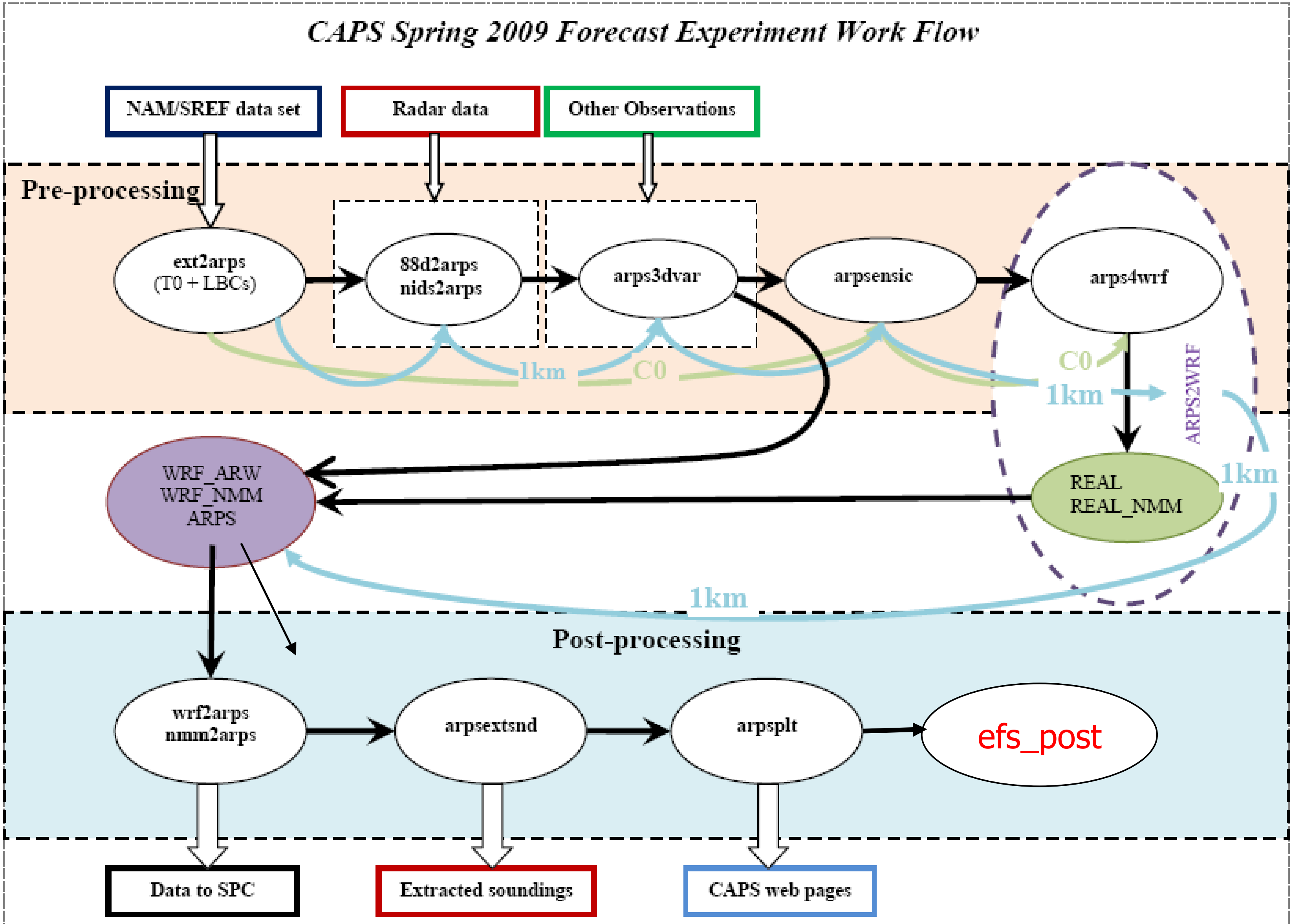


Fig. 4. The 2009 CAPS Spring Forecast Experiment workflow, in which gridded NAM and SREF data are first interpolated to a lager ARPS grid, and radar and other observational data are preprocessed for analysis by the ARPS 3DVAR. The 3DVAR analysis is combined with SREF perturbations to create perturbed initial conditions and these initial conditions as well as the boundary conditions are converted into WRF ARW and WRF NMM IC and LBC fields for running the ensemble forecasts. The model outputs are interpolated to a common ARPS grid for post-processing.

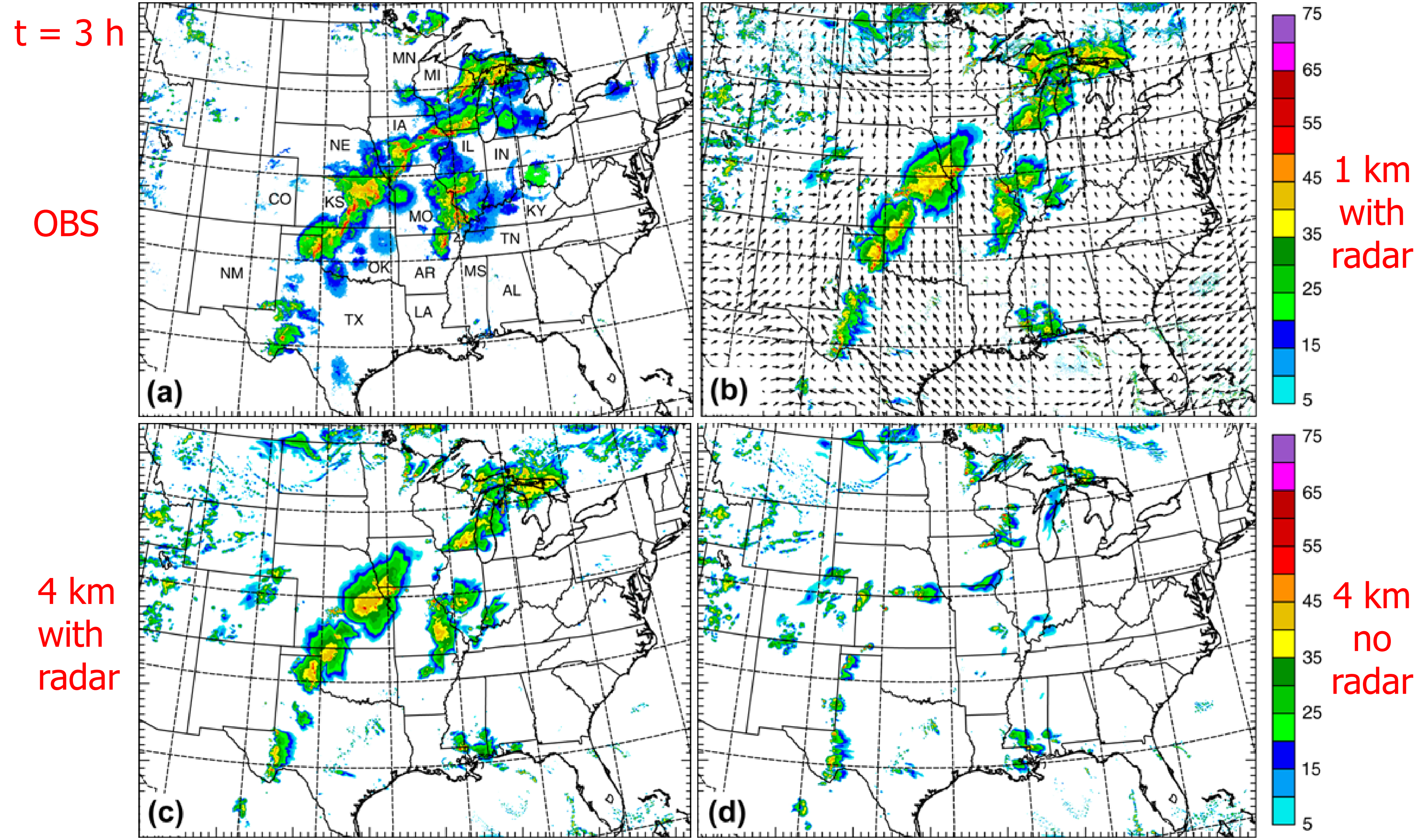


Fig. 1. Observed composite radar reflectivity (a), and 3-hour forecasts of the same field valid at 0300 UTC, May 26, 200, from (b) the 1-km forecast with radar data assimilation, (c) 4-km control forecast with radar data assimilation, and (d) 4-km forecast without radar data. For forecast domain is shown.

May 26, 2008 case

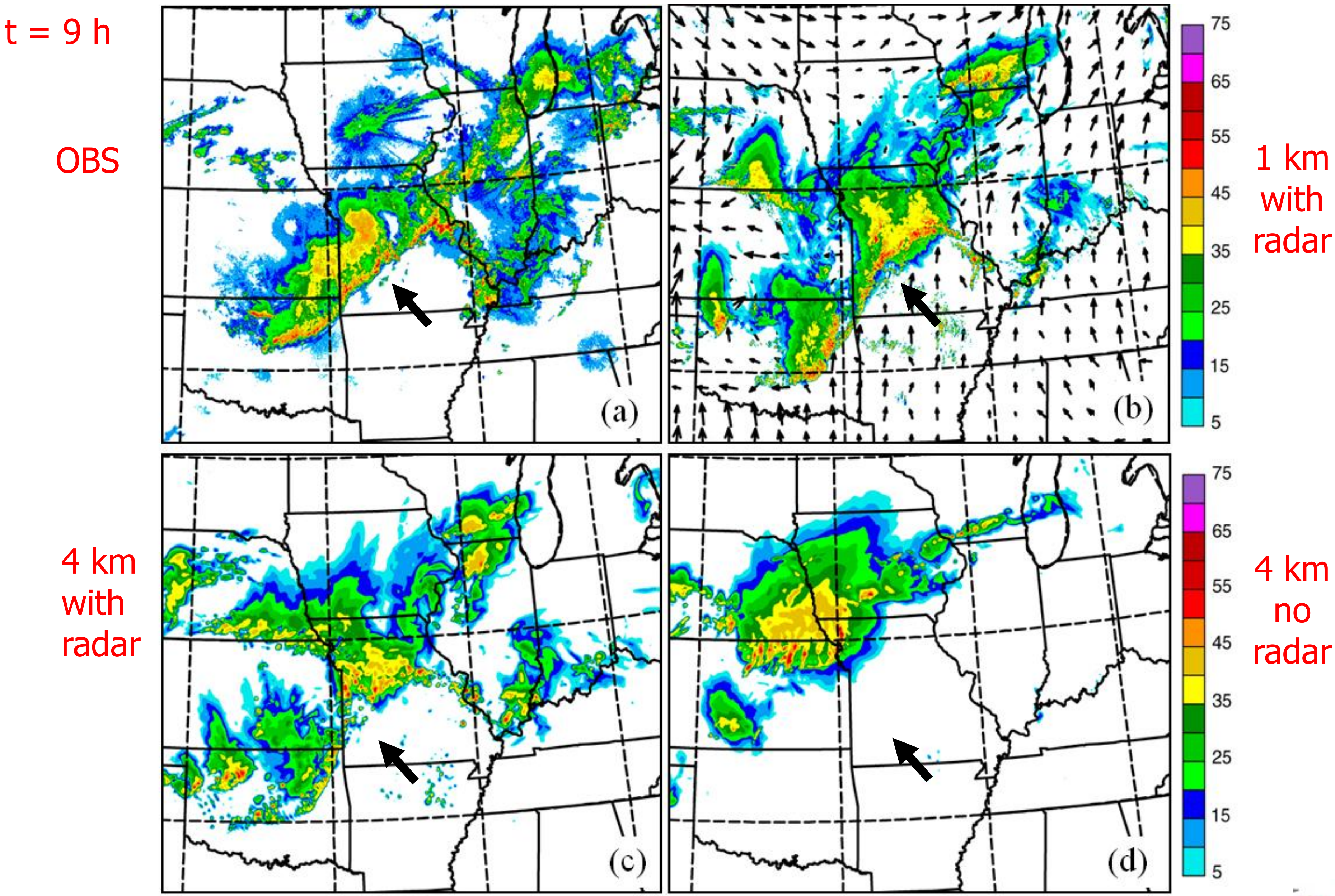


Fig. 2. As Fig. 1 but valid at 0900 UTC, 26 May 2008, corresponding to 9 hour forecast time, and for a zoomed-in domain.

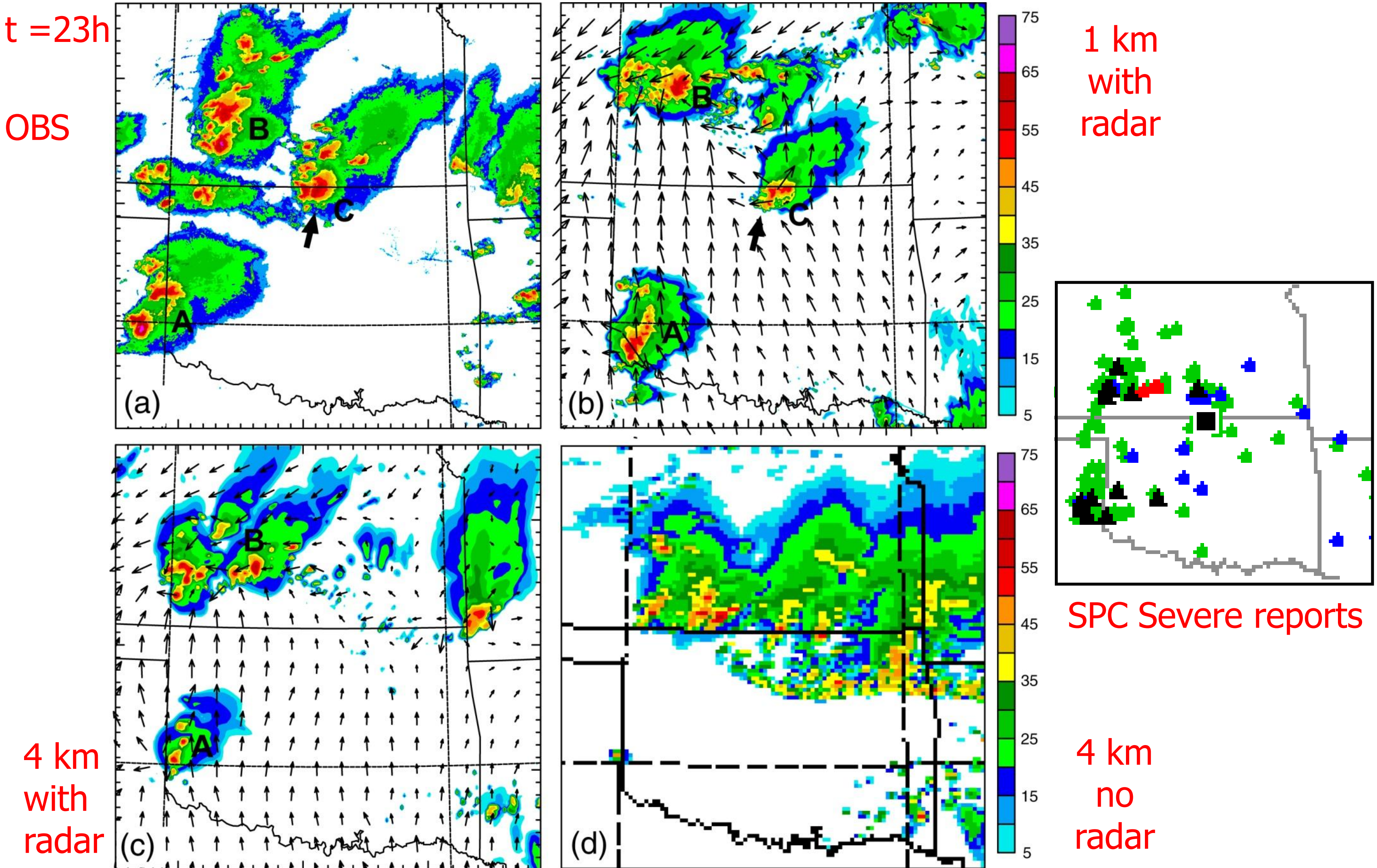
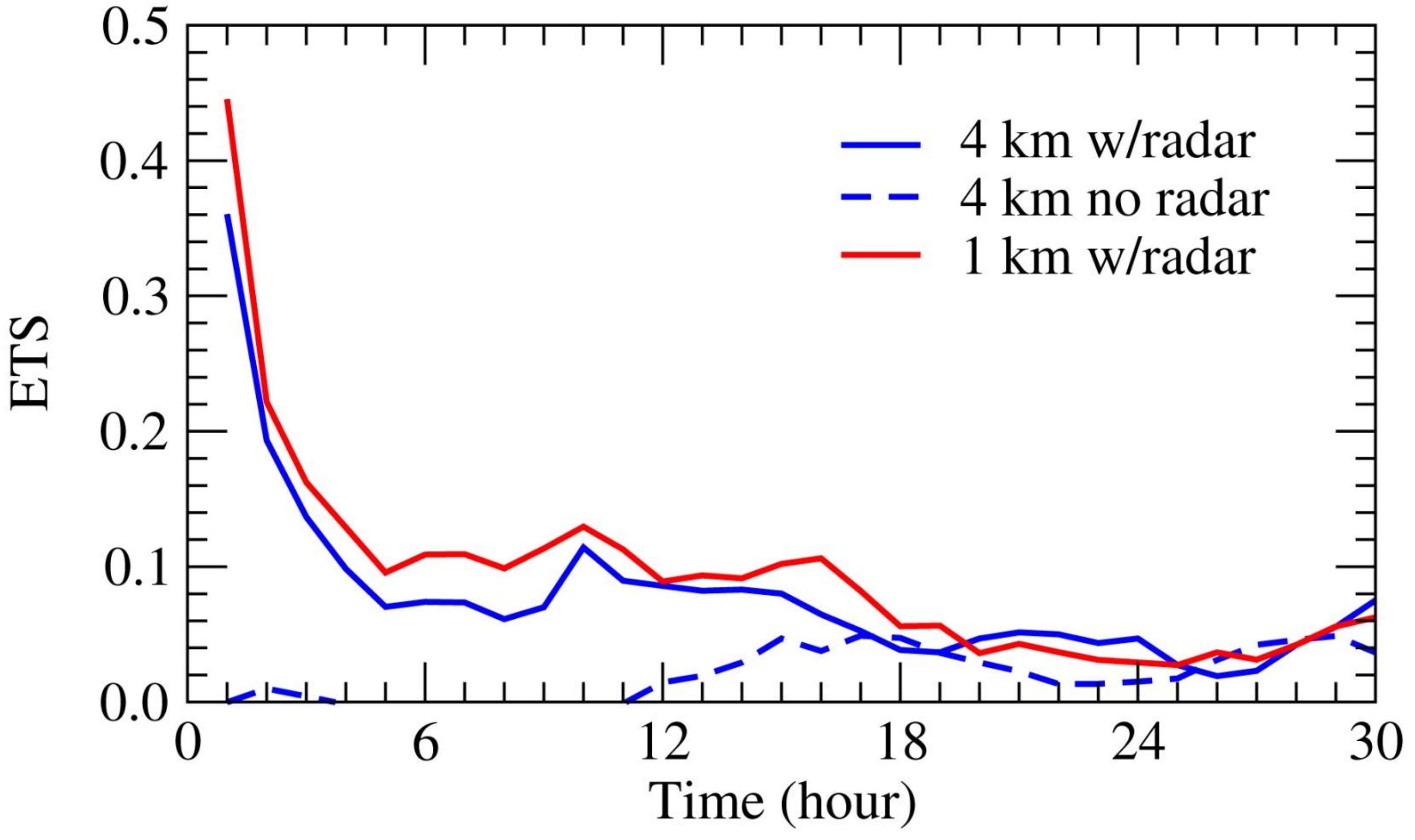
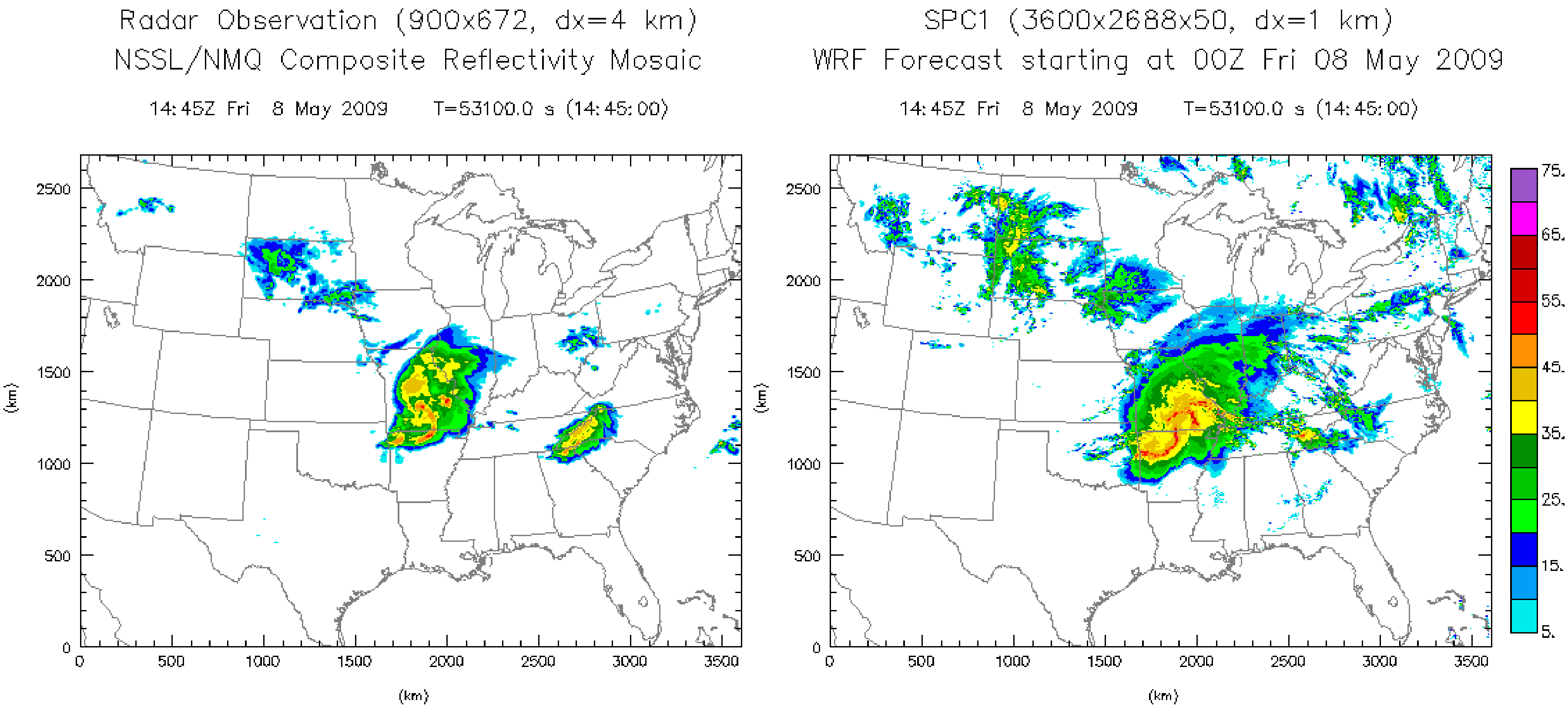


Fig. 3. As Fig. 1 but valid at 2300 UTC, 26 May 2008, corresponding to 23 hour forecast time, and for a further zoomed-in domain.

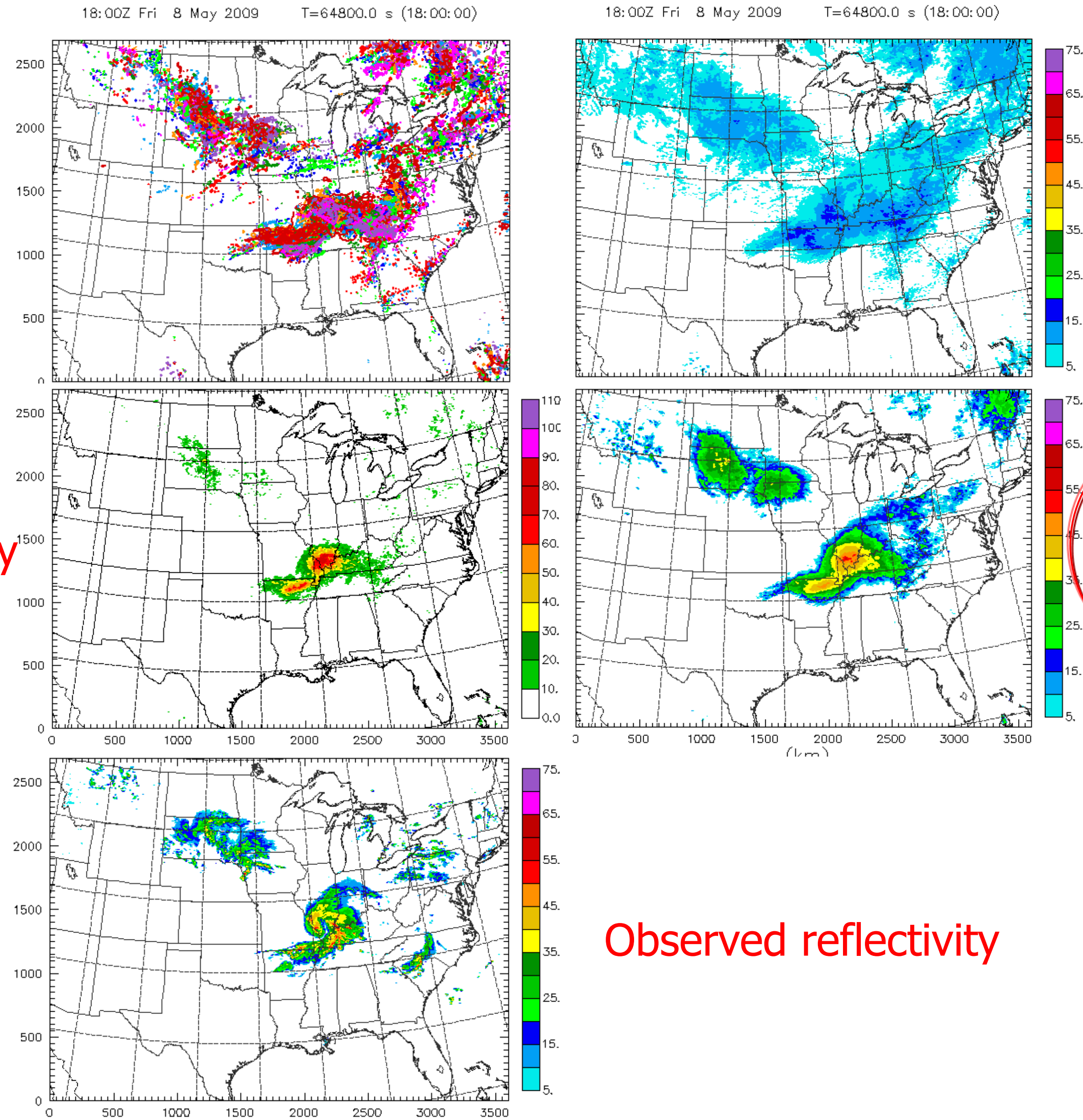
ETSs of hourly precipitation at 0.10 inch threshold for 26 May 2008 case



1 km Prediction of Entire Domain- Movie



18-hour ensemble forecast products



Spaghetti of 35 dBZ reflectivity

Spread

Probability of reflectivity >35 dBZ

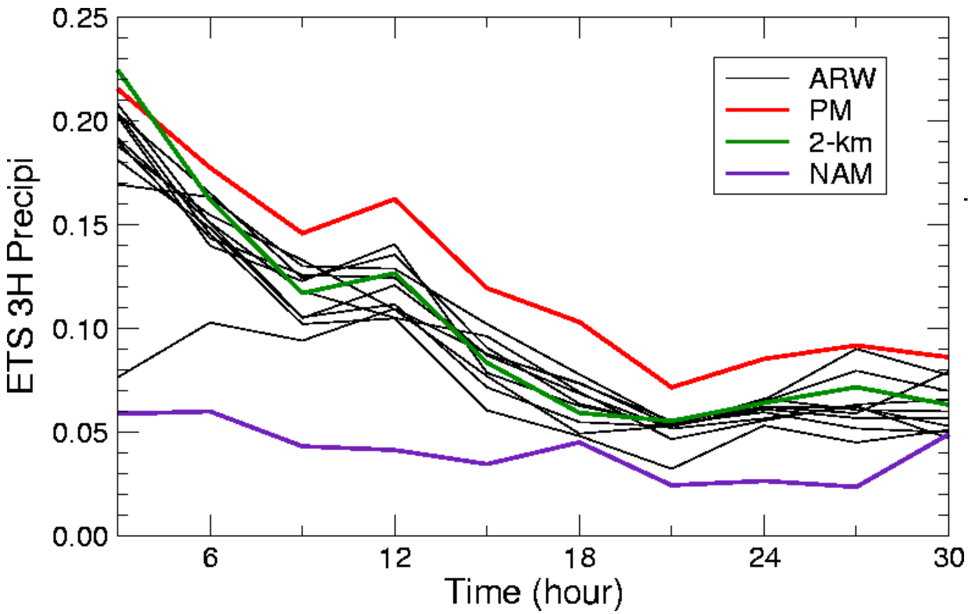
Probability matched reflectivity

Observed reflectivity

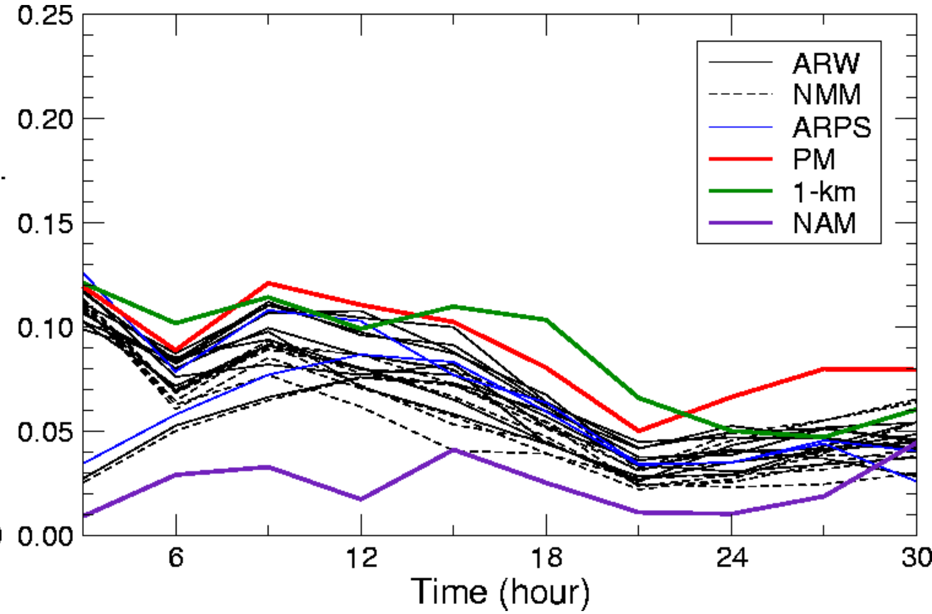
1800 UTC, May 8, 2009

ETS for 3-hourly precip ≥ 0.5 in

2008 (32-day)



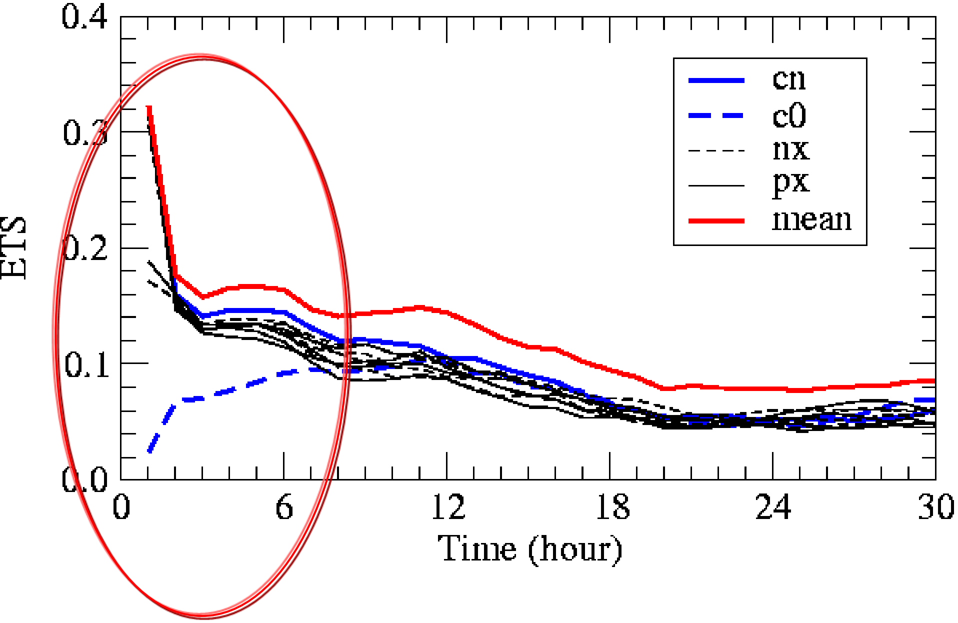
2009 (26-day)



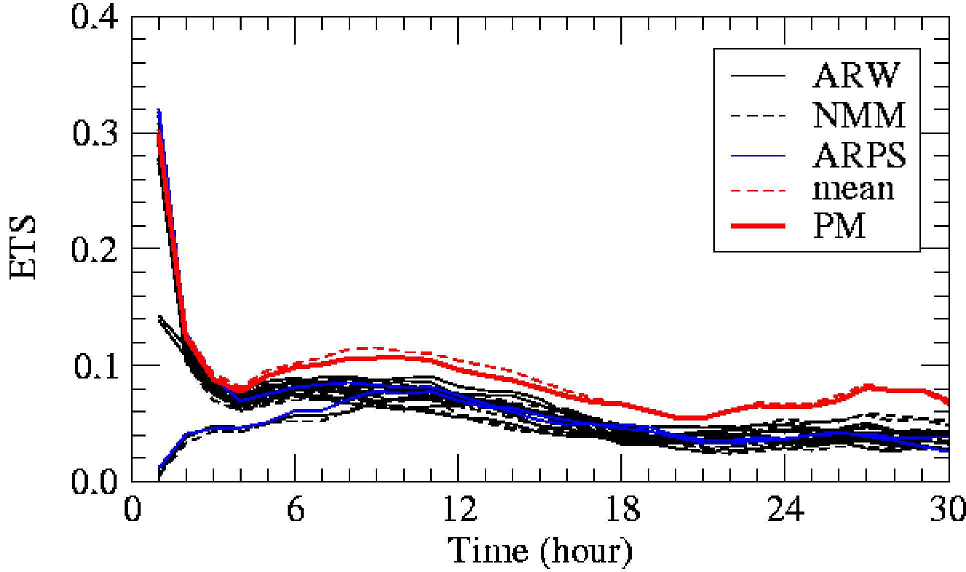
Probability-matched score generally better than any ensemble member
2 km score no-better than the best 4-km ensemble member – may be due to physics
1-km score better than any 4-km member and than the 4 km PM score.

ETS for hourly precip ≥ 0.1 in

2008 (36-day)

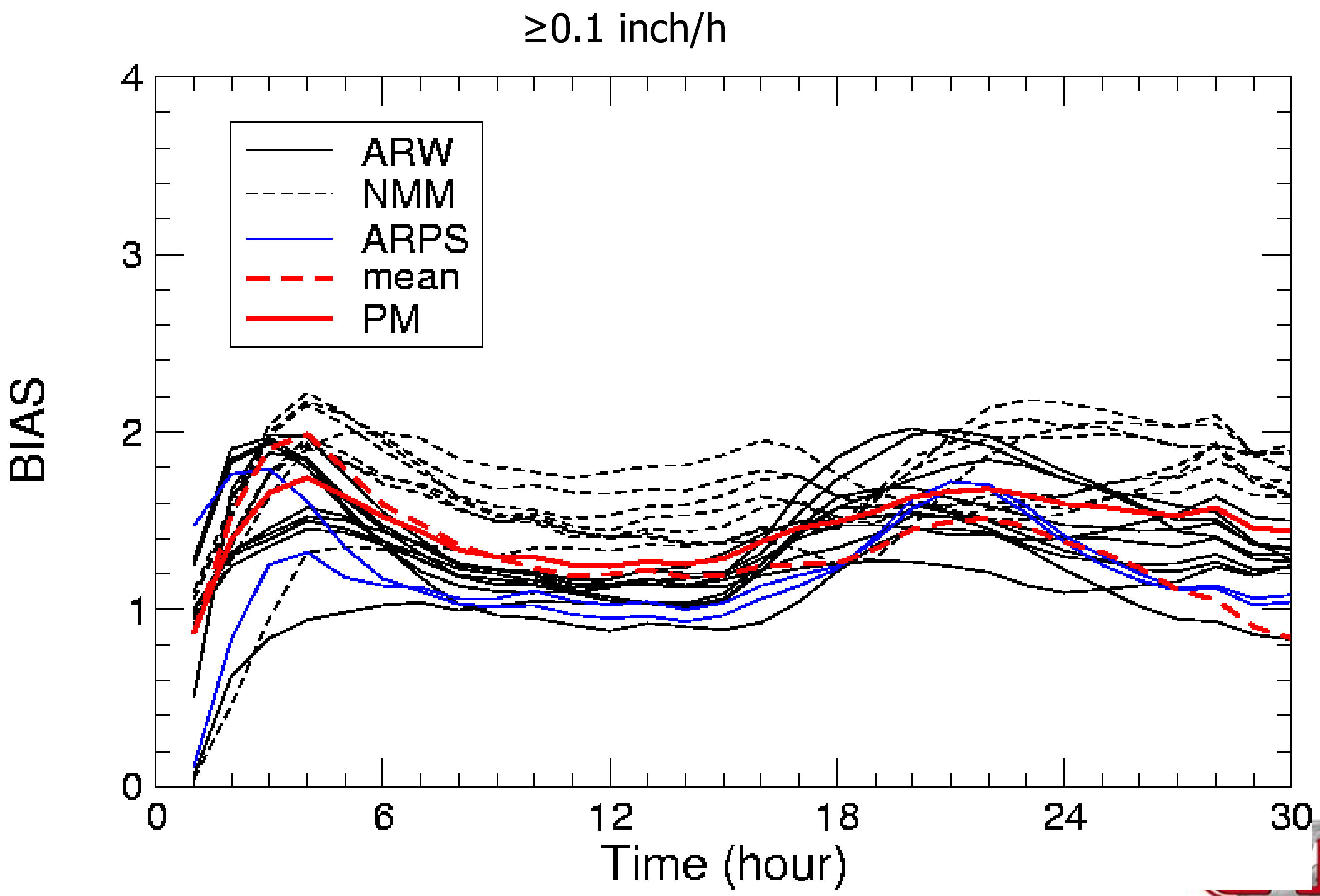


2009 (24-day)

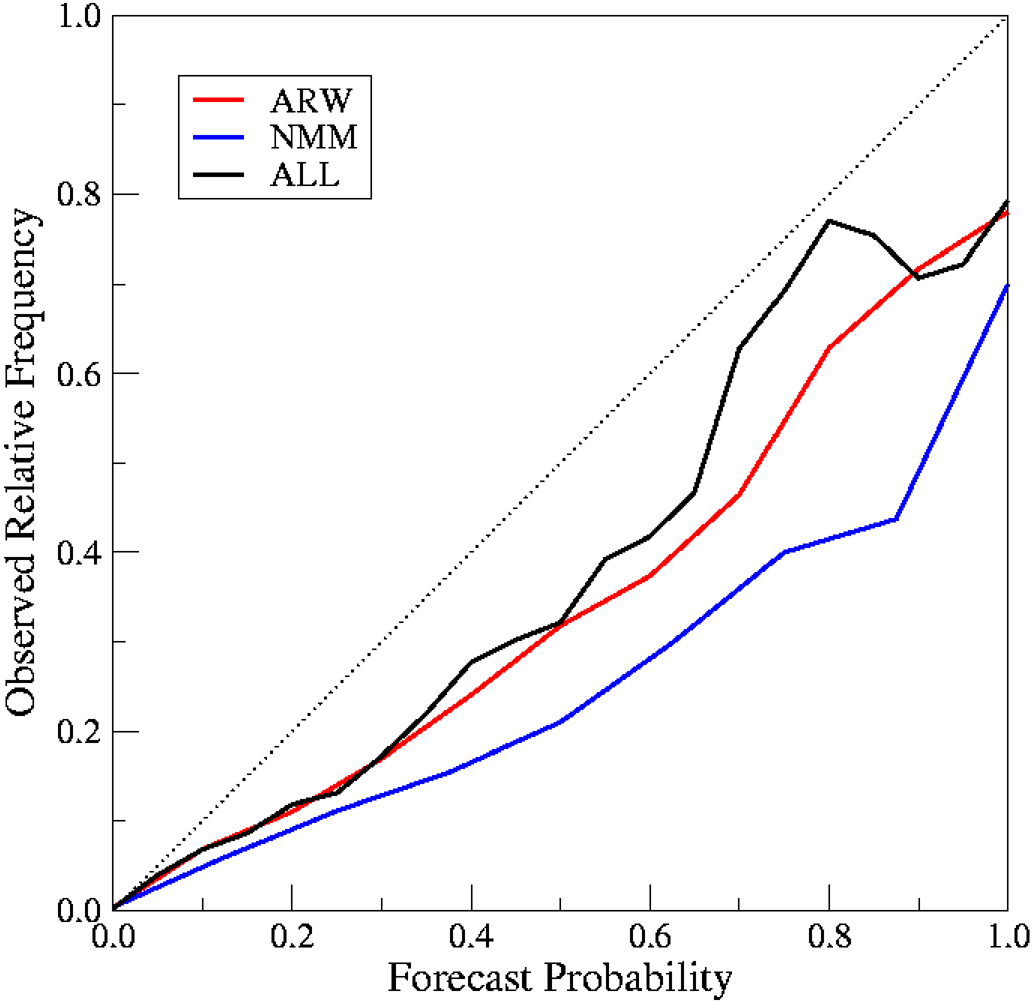


0 – 6h forecasts!

BIAS for 1 h precip of 2009 (24-day average)

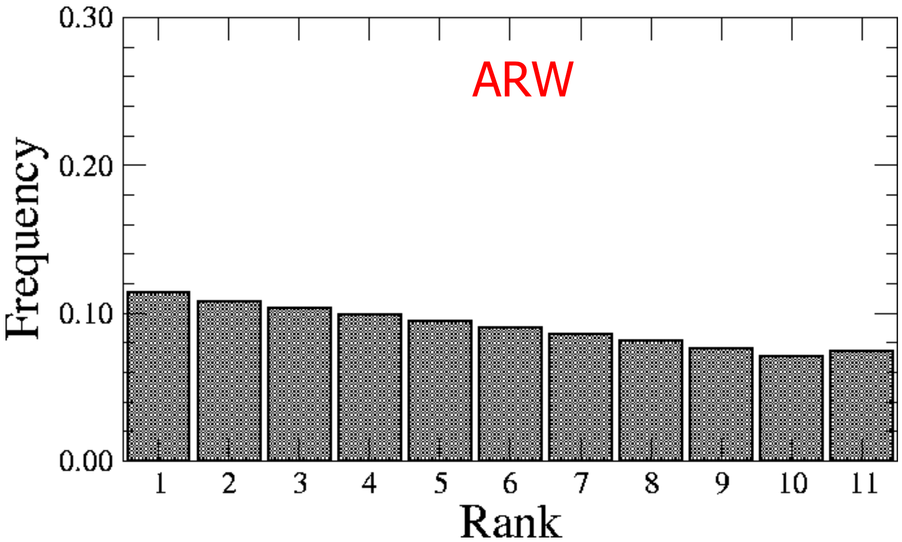


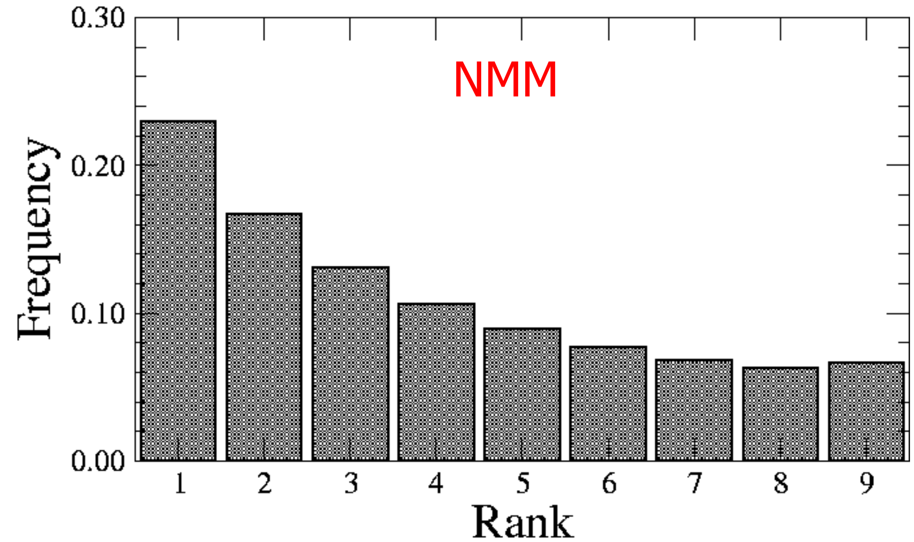
Reliability diagram for precipitation probability forecast

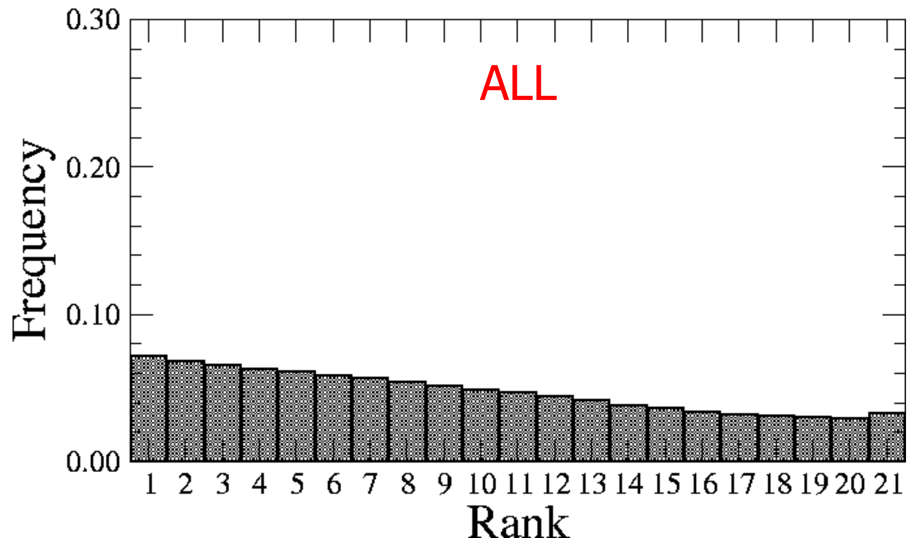


12 h forecast of 1 h accumulated precip. ≥ 0.1in

24 h forecast 1 h accumulated precip.
(24-day average)







Preliminary Conclusions/Discussion

- All aspects of uncertainty should be taken into account for convective scale ensemble (a multi-scale problem) – optimal design remains a research question;
- Multi-model seems to be beneficial but for 0-12 hour precipitation forecast, radar data impact much larger than impact of model/physics uncertainties.
- Special challenges with post-processing for precipitation-type forecasting fields;
- Systematic precipitation bias can significantly affect ensemble reliability;
- Convection-allowing ensemble clearly outperforms convection-parameterized ensembles (Clark et al. 2009, not shown);
- Radar data assimilation removes spin up problem, improves QPF, and the impacts last longer for organized convection with weak large-scale forcing; impacts are expected to be larger with more advanced DA methods;
- Probability-matched ensemble precipitation forecast better than any 4 km-member
- 1-km forecasts generally better than 4-km forecasts, better than 4-km PM ensemble forecast for heavy precipitation;
- 4-km QPF significantly better than 12-km ETA QPF.

List of referred publications using the data

- Schwartz, C., J. Kain, S. Weiss, M. Xue, D. Bright, F. Kong, K. Thomas, J. Levit, and M. Coniglio, 2009: Next-day convection-allowing WRF model guidance: A second look at 2 vs. 4 km grid spacing. Mon. Wea. Rev., Accepted.

- Schwartz, C. S., J. S. Kain, S. J. Weiss, M. Xue, D. R. Bright, F. Kong, K. W.Thomas, J. J. Levit, M. C. Coniglio, and M. S. Wandishin, 2009: Toward improved convection-allowing ensembles: model physics sensitivities and optimizing probabilistic guidance with small ensemble membership. Wea. Forcasting, Conditionally accepted.

- Clark, A. J., W. A. Gallus, Jr., M. Xue, and F. Kong, 2009: A comparison of precipitation forecast skill between small near-convection-permitting and large convection-parameterizing ensembles. Wea. and Forecasting, Accepted.

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- Coniglio, M. C., K. L. Elmore, J. S. Kain, S. Weiss, and M. Xue, 2009: Evaluation of WRF model output for severe-weather forecasting from the 2008 NOAA Hazardous Weather Testbed Spring Experiment. Wea. Forcasting, Conditionally accepted.

- More coming.

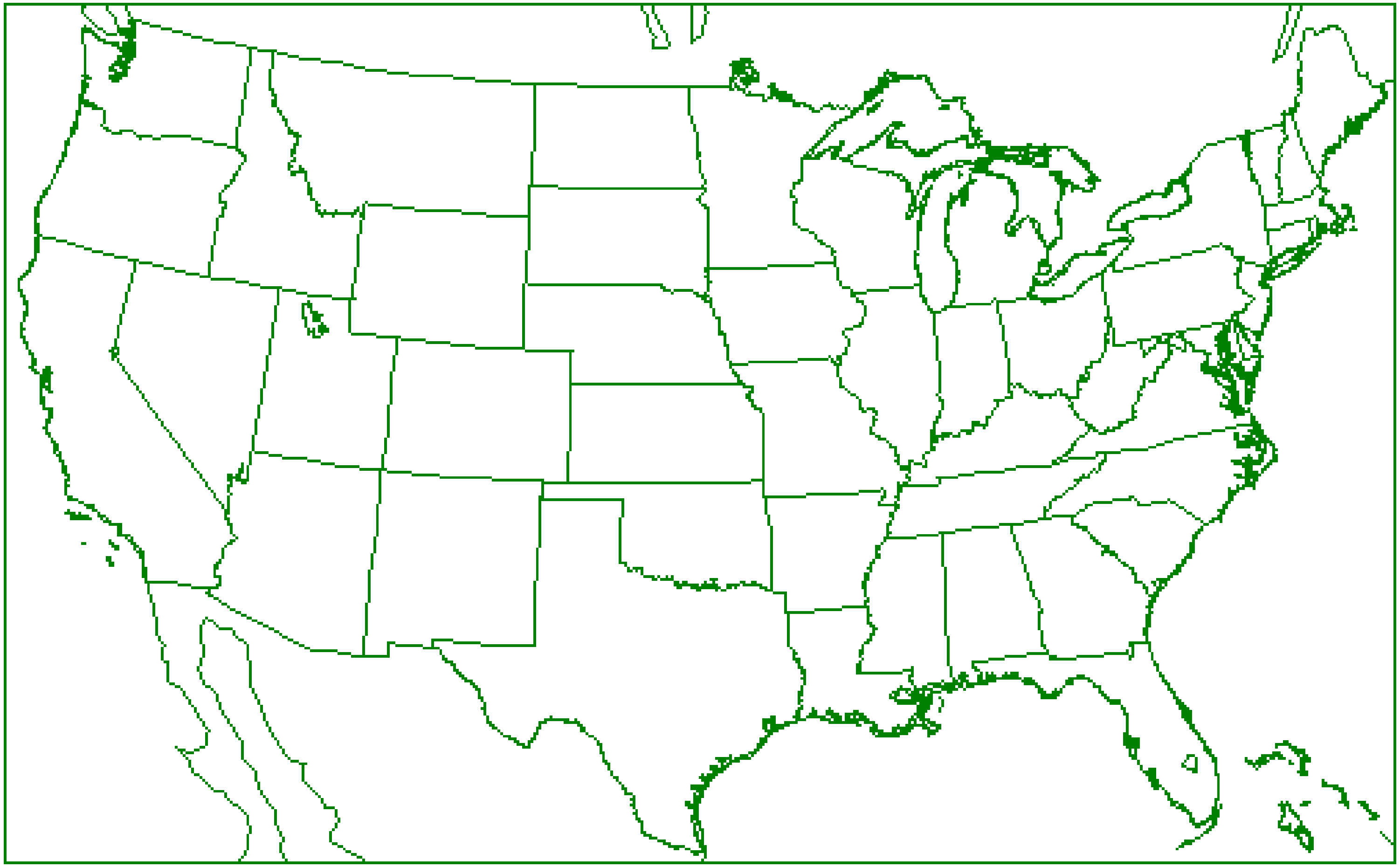
Current Status

- One-of-a-kind data set awaiting for more complete/detailed post-analysis/evaluation, to help answer many of the questions raised at the workshop and in our original CSTAR proposal;
- CSTAR ($125K/year) support hardly enough to developing the ensential software (grid converters and ensemble products) and making the runs;
- Have benefited from leverages and collaborations on data analysis;
- Data sets partially analyzed, resulting in 5-6 referred publications.

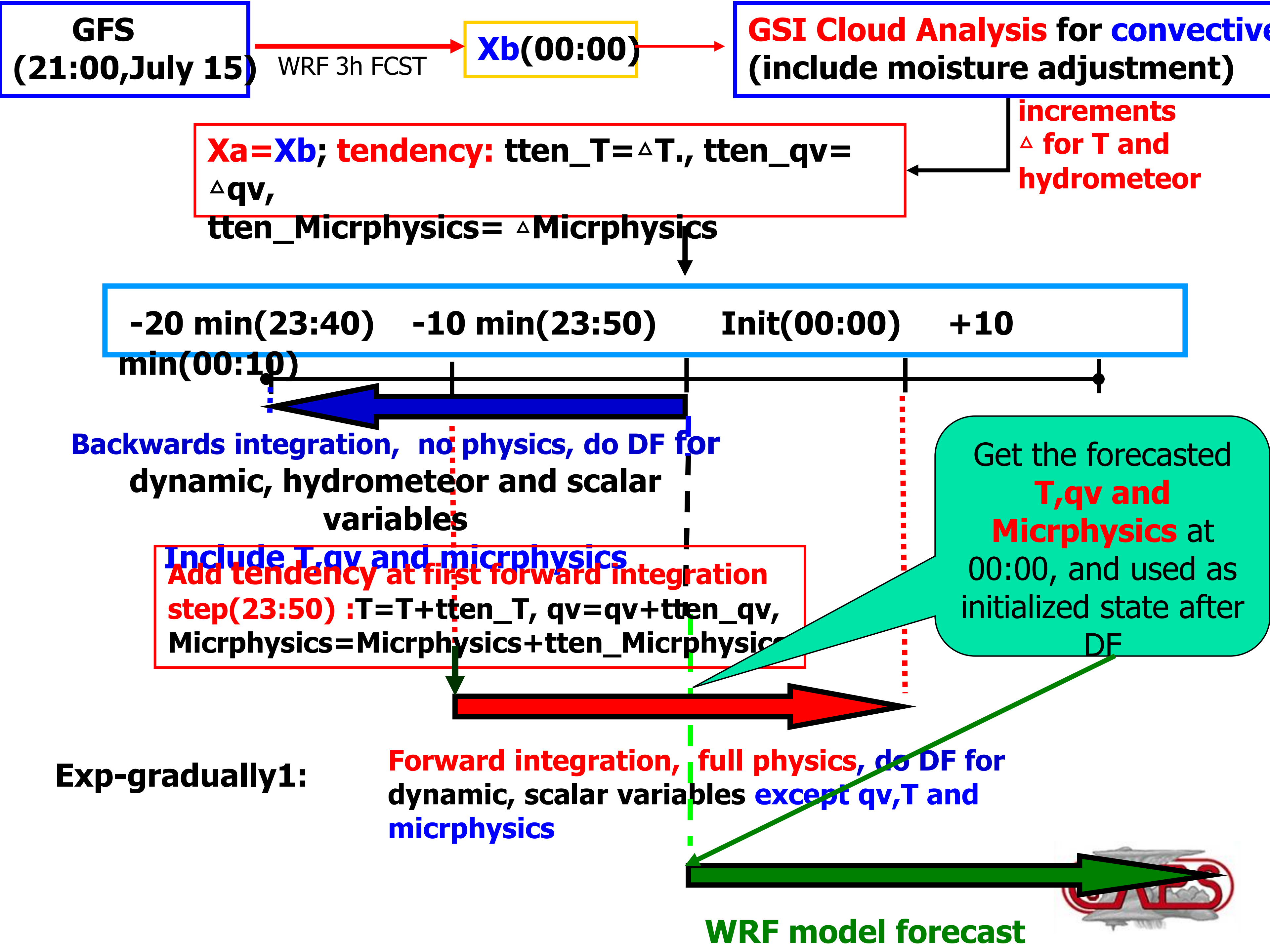
CAPS Realtime Forecast Plan for next 3 Years

- General direction: more emphasis on aviation weather (e.g., 3 weeks in June and May), more runs/day, shorter forecast ranges, fine-tuning of ensemble design,
  - Multi-scale IC perturbations, ETKF perturbations, EnKF-based perturbations
  - Land surface perturbations,
  - Possible LBC perturbations,
  - More intelligent choices of physics suites
  - Possible addition of COAMPS
- Improved initial conditions via data assimilation
  - Possible GSI analyses with target HRRR set up and other more experimental configurations/schemes
  - Possible hybrid ensemble-GSI analysis
  - Possible EnKF analysis
- Post-analysis and probabilistic products: e.g., calibration, bias removal, detailed performance evaluation, cost-benefit/trade off assessment, effective products for end users (e.g., those for aviation weather, severe storms);
- Integration/coordination with national efforts.

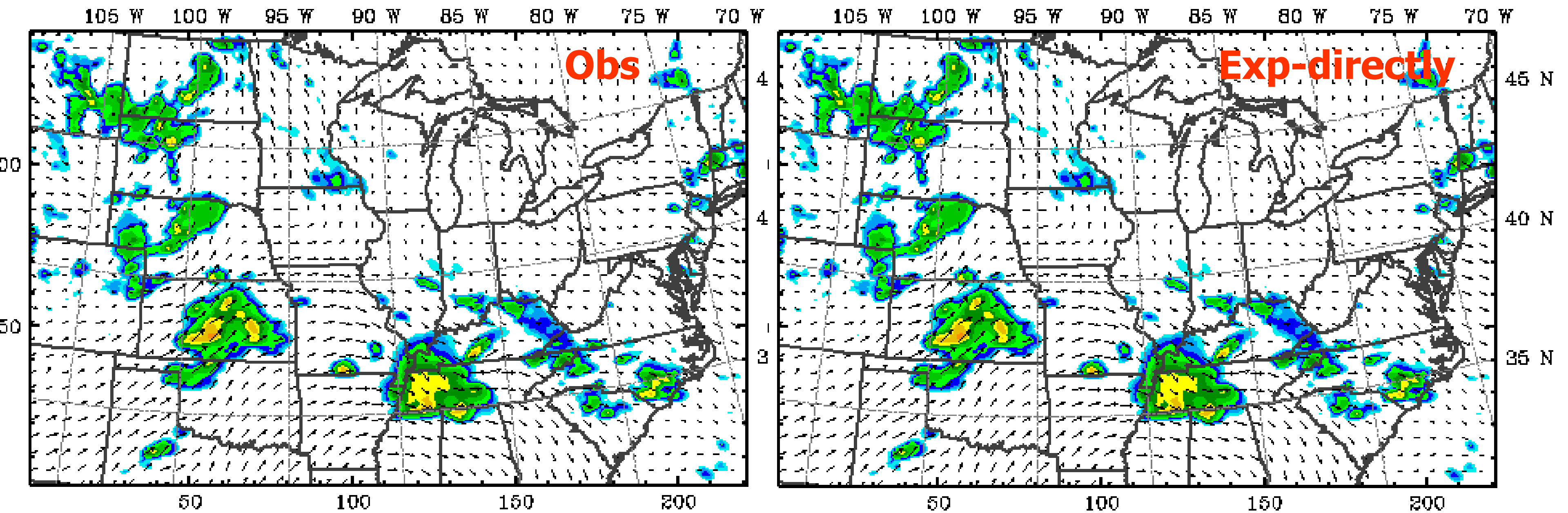
Proposed domain for spring 2010



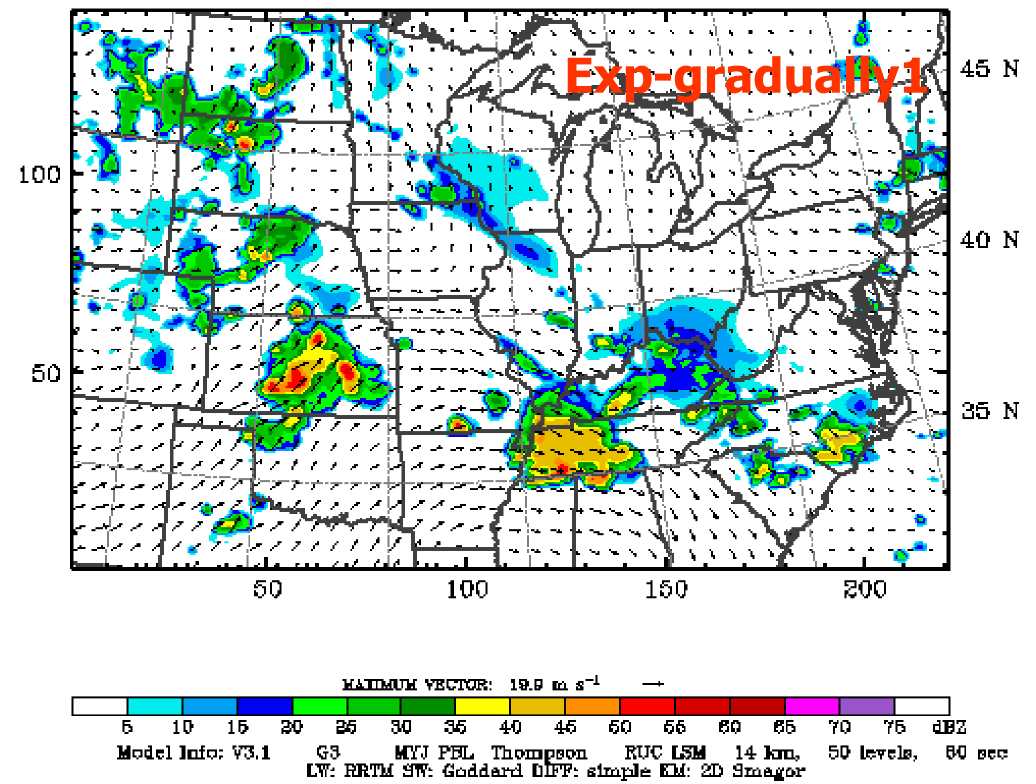
- 6.3 million CPU-hours requested for the realtime forecasts in CAPS annual proposal
- Larger domain but generally similar setup at 2010 (20-member 4 km and single 1 km)



GFS (21:00,July 15)
WRF 3h FCST
Xb(00:00)
GSI Cloud Analysis for convective (include moisture adjustment)
increments △ for T and hydrometeor
Xa=Xb; tendency: tten_T=△T., tten_qv= △qv, tten_Micrphysics= △Micrphysics
-20 min(23:40) -10 min(23:50) Init(00:00) +10 min(00:10)
Backwards integration, no physics, do DF for dynamic, hydrometeor and scalar variables
Include T,qv and micrphysics
Add tendency at first forward integration step(23:50) :T=T+tten_T, qv=qv+tten_qv, Micrphysics=Micrphysics+tten_Micrphysic
Get the forecasted T,qv and Micrphysics at 00:00, and used as initialized state after DF
Exp-gradually1:
Forward integration, full physics, do DF for dynamic, scalar variables except qv,T and micrphysics
WRF model forecast



Composite reflectivity
At 00:00 July 16,2009



Resources and Support

- A NSF Track-1 system with 1 petaflops sustained performance (10-20 times of the current track-2 system) with > 200K cores is expected to be in place in 2011 (ready for use in 2012);
- To submit a new CSTAR proposal for the next 3 years (125K/year limit per proposal) – can we convince CSTAR program to fund CAPS at ~250K/year? Need help! Have Don Berchoff talk to CSTAR program manager Sam Contorno?
- New NSF PetaApps grant to develop a scalable EnKF system for NSF Petascale computers ($1.2 m/4 years, 900K at OU, led by Xue) is expected to develop an EnKF system that could be ready for CONUS-scale 1-4 km grids in 3 years (3rd year of next CSTAR project if funded);
- Wang, Xue and Kong submitting an NSF proposal for basic research on the optimal design of multi-scale ensemble system for convection-resolving forecasting;
- Partnership with DTC in system design and evaluation? Funding from/via DTC?
- Other sources of support (FAA NexGen, NOAA Warn-on-Forecast funding)?

- To answer many questions related to the next-generation national mesoscale ensemble system at an accelerated pace requires much more resources than currently available for system design/testing/post-analysis/evaluation

List of referred publications using the data

- Schwartz, C., J. Kain, S. Weiss, M. Xue, D. Bright, F. Kong, K. Thomas, J. Levit, and M. Coniglio, 2009: Next-day convection-allowing WRF model guidance: A second look at 2 vs. 4 km grid spacing. Mon. Wea. Rev., Accepted.

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