

# CAPS Real-time Storm-scale EnKF Data Assimilation and Forecast System for the Hazardous Weather Testbed Spring Experiment

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# Background

- CAPS/OU has been producing 4-km CONUS-domain ensemble forecasts for evaluation at NOAA HWT (Hazardous Weather Testbed) since spring 2007
- Goals: To determine the **optimal design, configurations, and post-processing** of storm-scale ensemble prediction, and to provide the products for **evaluation** by forecasters and researchers, and test storm-scale **data assimilation** methods.
- Develop a hybrid MPI-OpenMP parallel algorithm for EnSRF (Wang et al. 2013)
- Case studies: 10 May 2010 tornado outbreak
- Spring 2013: Real-time experimental single EnKF DA in the central US domain. 24-hour daily forecast.

# 2013 Experimental single 4-km EnKF SSEF initialized at 00 UTC

- Forecast model: WRF-ARW
- Microphysics scheme: WSM6 with perturbed Nor, Nog,  $\rho_g$
- Multi-PBL schemes: MYJ, YSU, ACM2, MYNN, QNSE
- 40 member ensemble
- DA scheme: ARPS parallel EnSRF
- DA: single data assimilation at 0000 UTC
- 24-hour deterministic forecast from an ensemble mean analysis

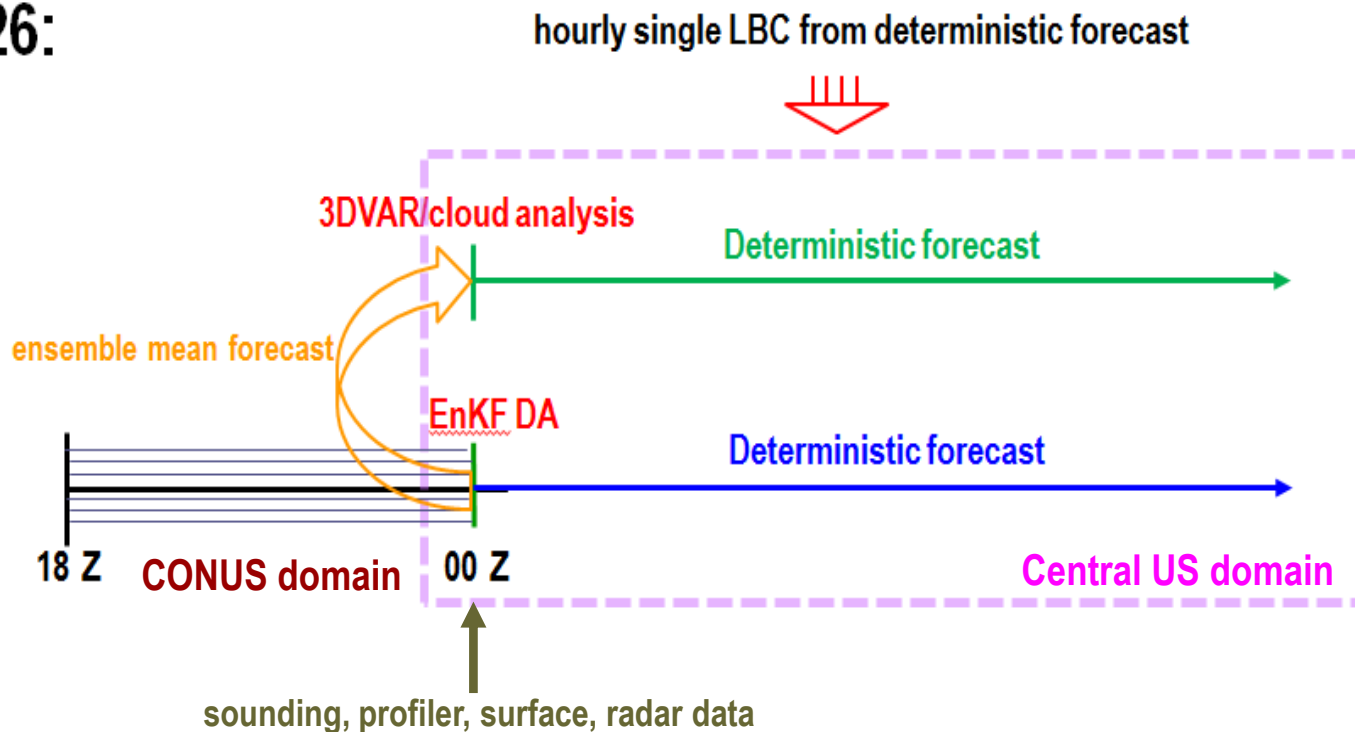
# 2013 Experimental single 4-km EnKF SSEF initialized at 00 UTC

- Initial conditions and lateral boundary conditions: NAM analysis + SREF perturbations
- Observations: sounding, profiler, surface, radar ( $Z$ ,  $V_r$ )
- Influence radii: sounding (800 km), profiler (800 km), surface (300 km), radar (16 km)
- Covariance inflation: Relaxation-to-prior-spread (RTPS) following Whitaker and Hamill (2012) + multiplicative (Anderson 2001; Xue et al. 2005)

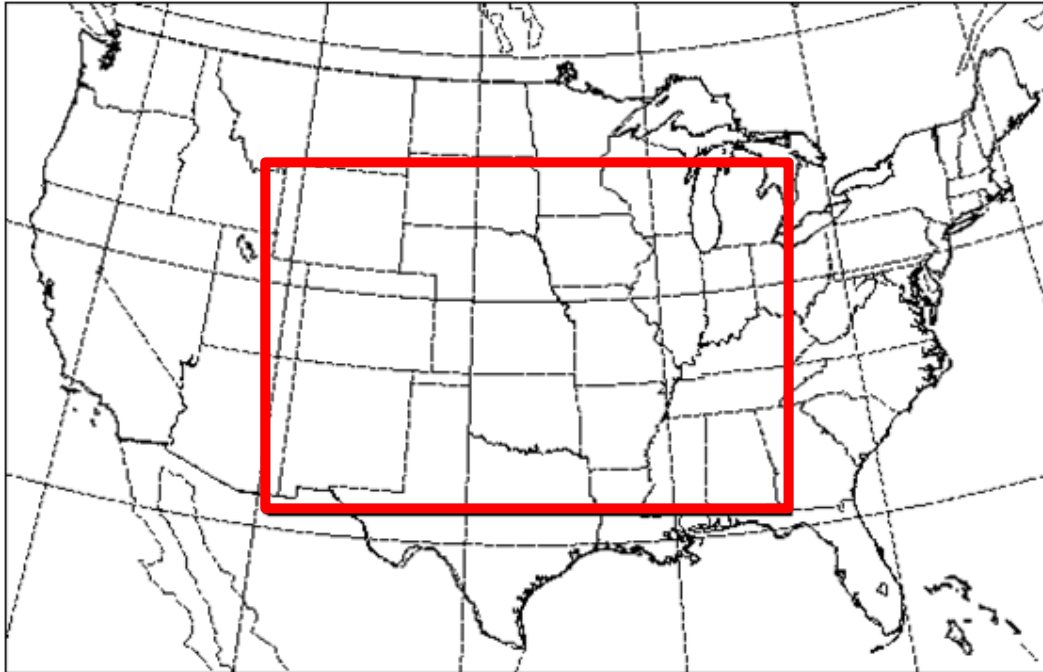
# 2013 Experimental 4km EnKF SSEF initialized at 00 UTC

HWT member 26:

4 km ensemble:



# 2013 Domain



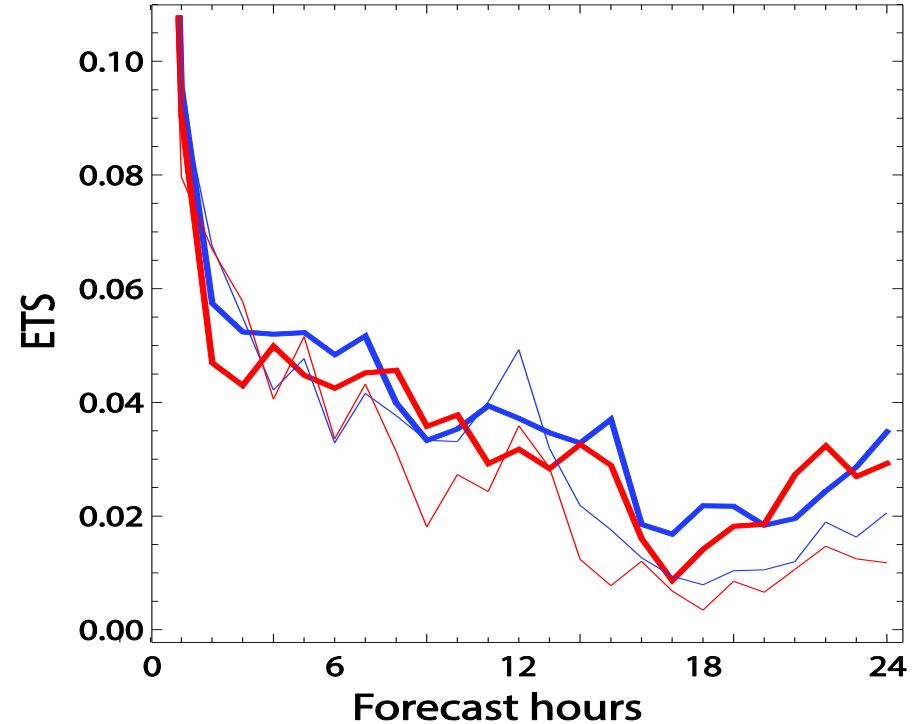
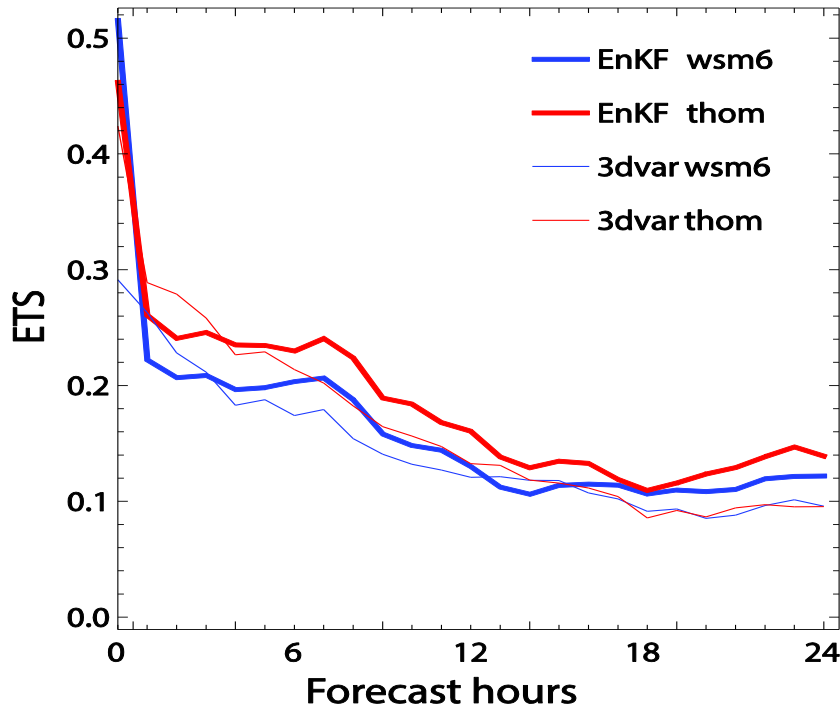
*CONUS domain: 1200x768*

***Central US domain: 600x400***

# ETS for composite reflectivity

$Z \geq 20$  dBZ

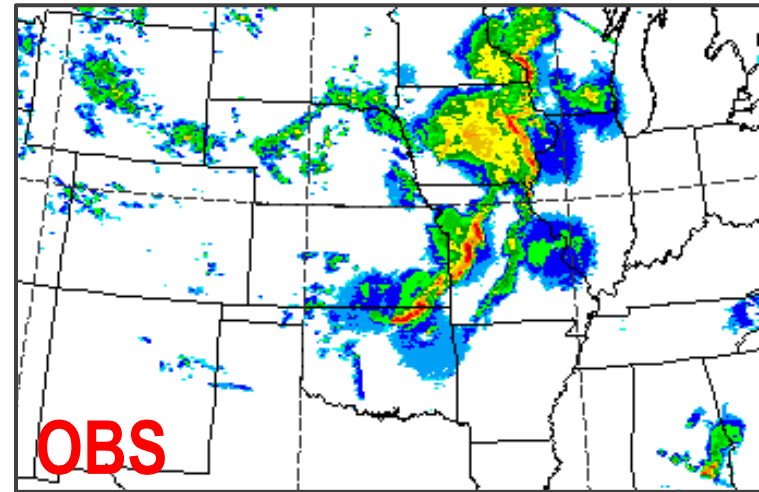
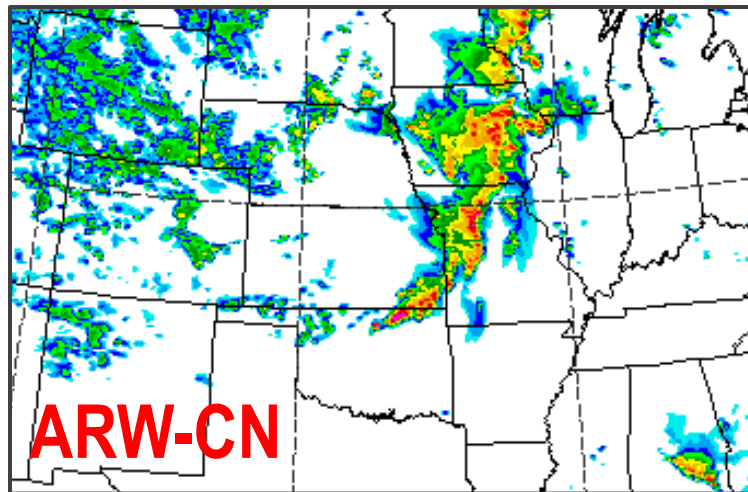
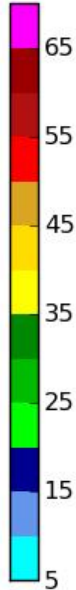
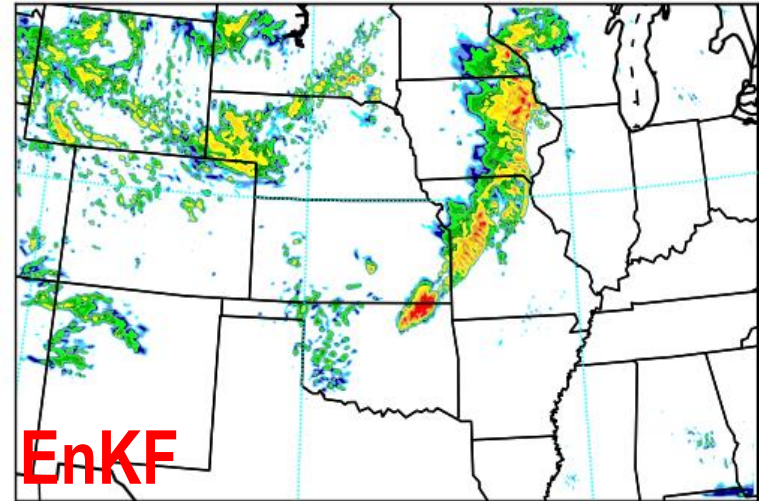
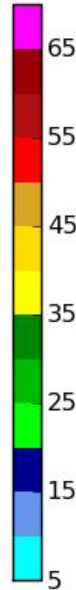
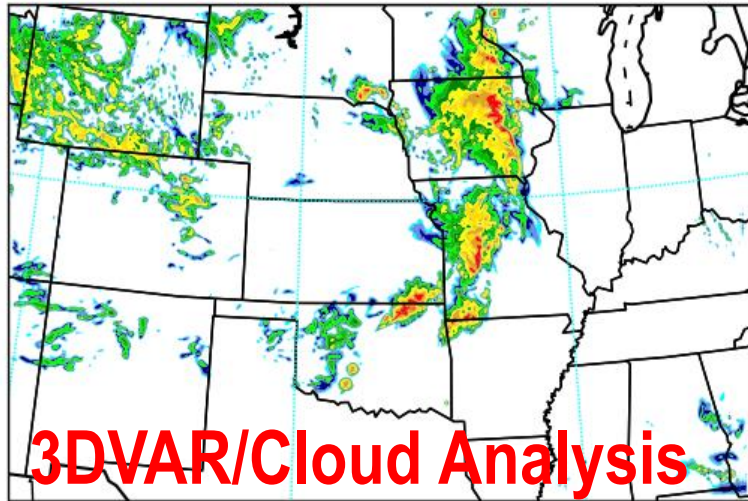
$Z \geq 40$  dBZ



*ETSs averaged over 14 forecast days for deterministic forecasts starting from the EnKF mean analysis*

# 20 May 2013 4hr forecast

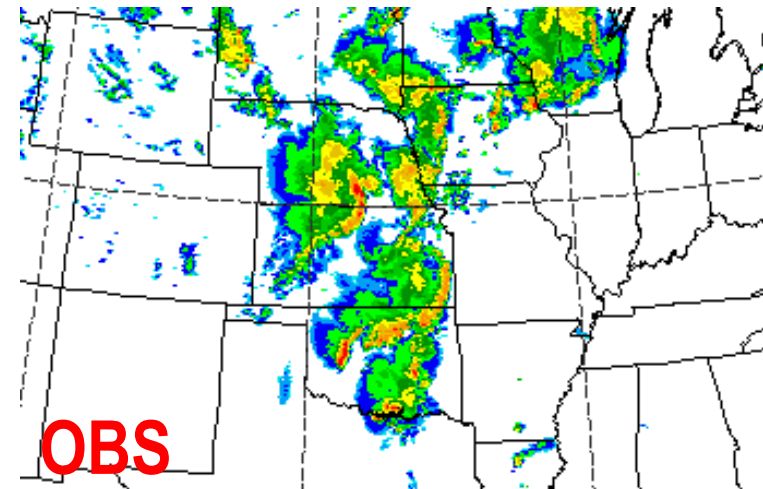
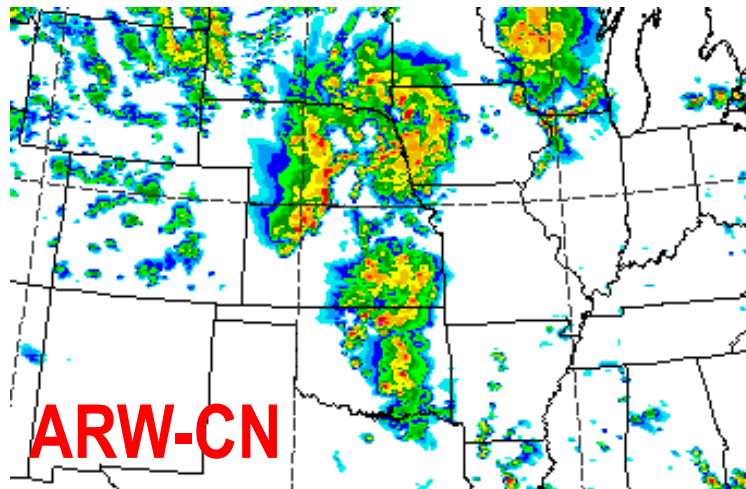
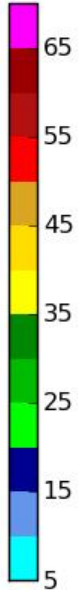
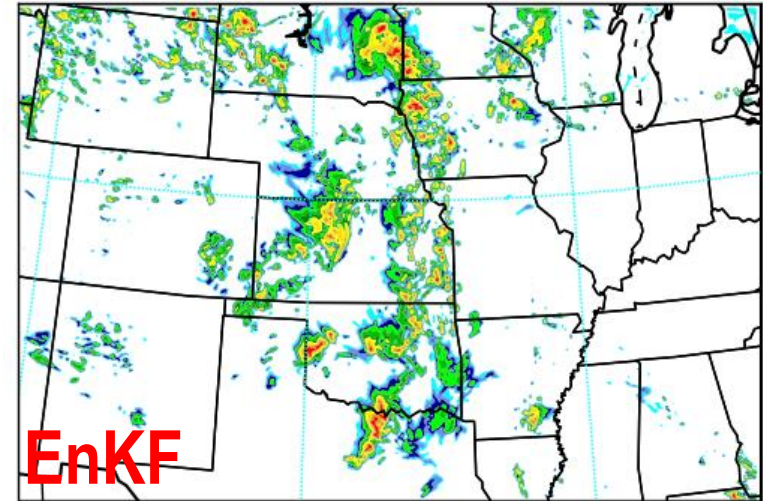
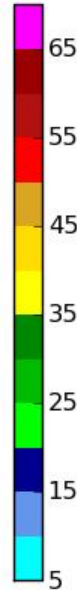
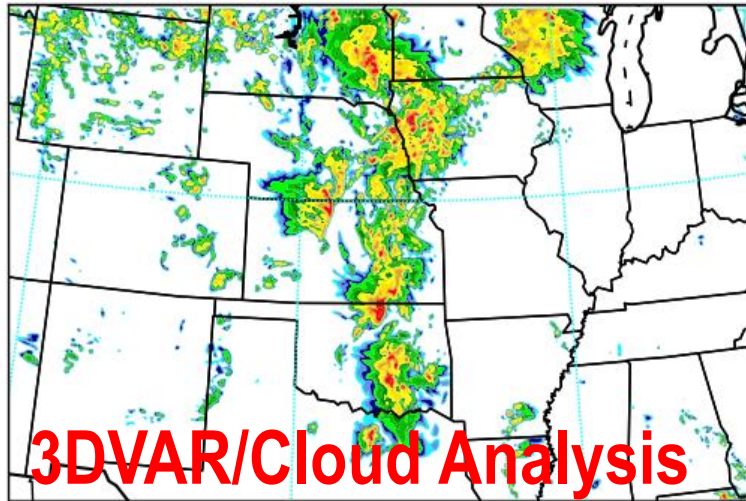
## Composite reflectivity





# 30 May 2013 3hr forecast

## Composite reflectivity



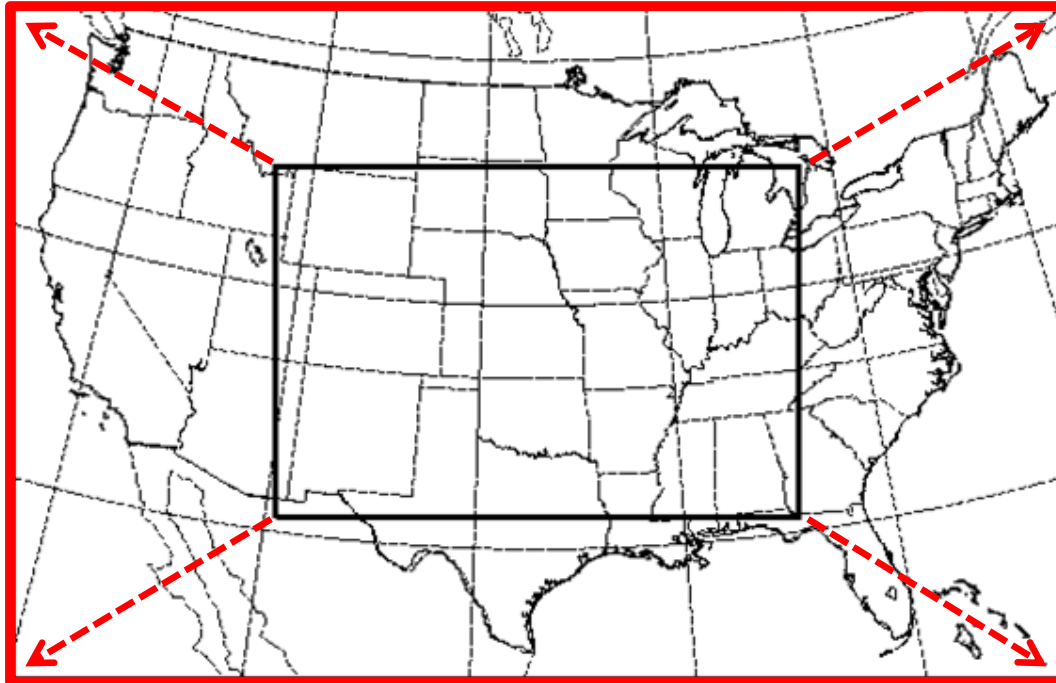
# 2014 partially cycled 4-km EnKF SSEF (Experimental)

- Forecast model: WRF-ARW
- Physical domain: CONUS (1200x768x50)
- 40 member ensemble
- DA: 2300, 2315, 2330, 2345, 0000 UTC
- Observations: sounding, profiler, surface, radar ( $Z$ ,  $V_r$ )
- Microphysics scheme: WSM6 with perturbed  $N0r$ ,  $N0g$ ,  $\rho_g$
- Multi-PBL schemes: MYJ, YSU, ACM2, MYNN, QNSE
- DA scheme: ARPS parallel EnSRF

# 2014 partially cycled 4-km EnKF SSEF (Experimental)

- Initial conditions and lateral boundary conditions: NAM analysis + SREF perturbations
- Influence radii: sounding (800 km), profiler (800 km), surface (300 km), radar (16 km)
- Relaxation-to-prior-spread (RTPS) Inflation following Whitaker and Hamill (2012)
- 24-hour 12 member ensemble forecasts

# 2014 Domain



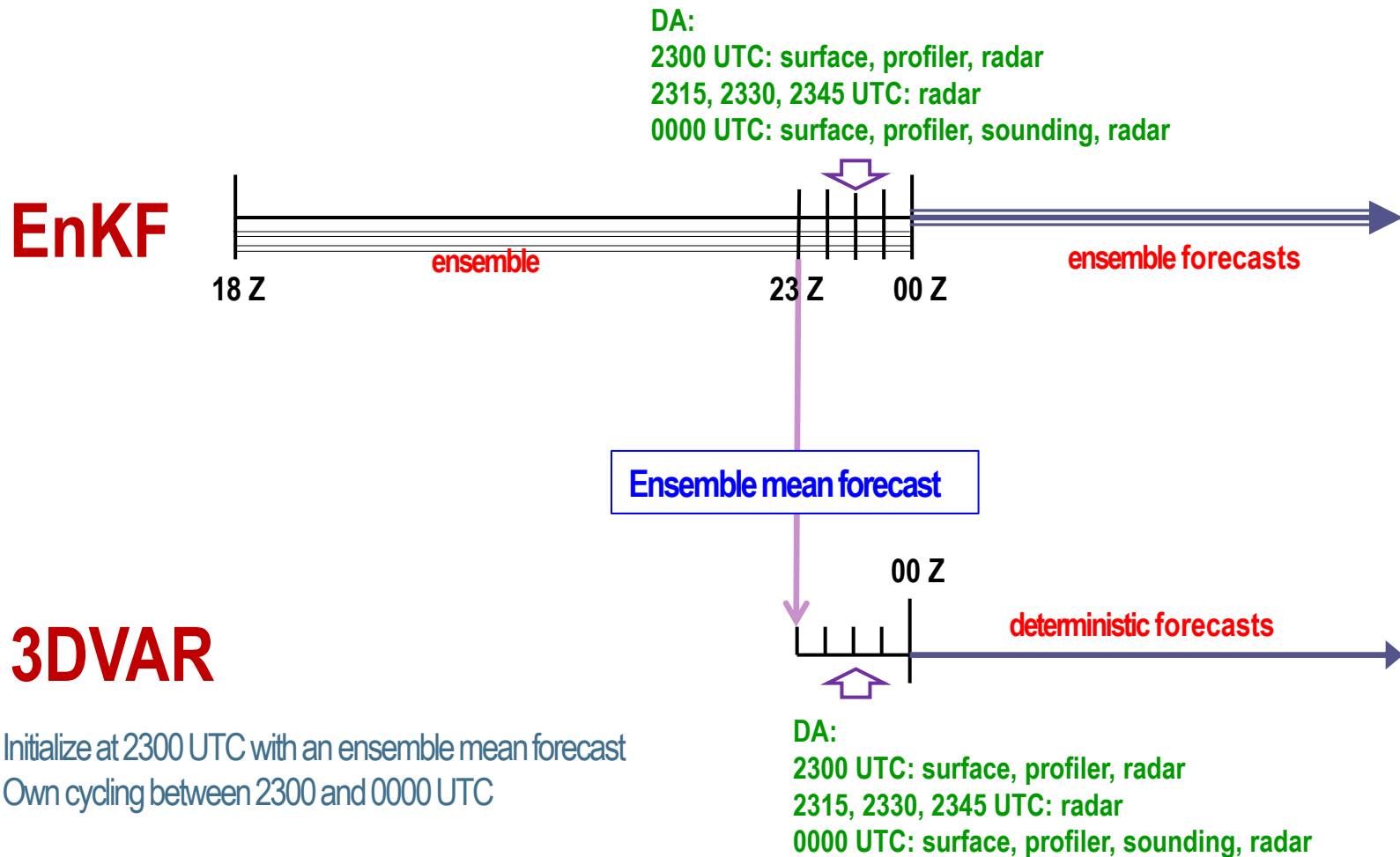
**CONUS domain: 1200x768**

*Central US domain: 600x400*

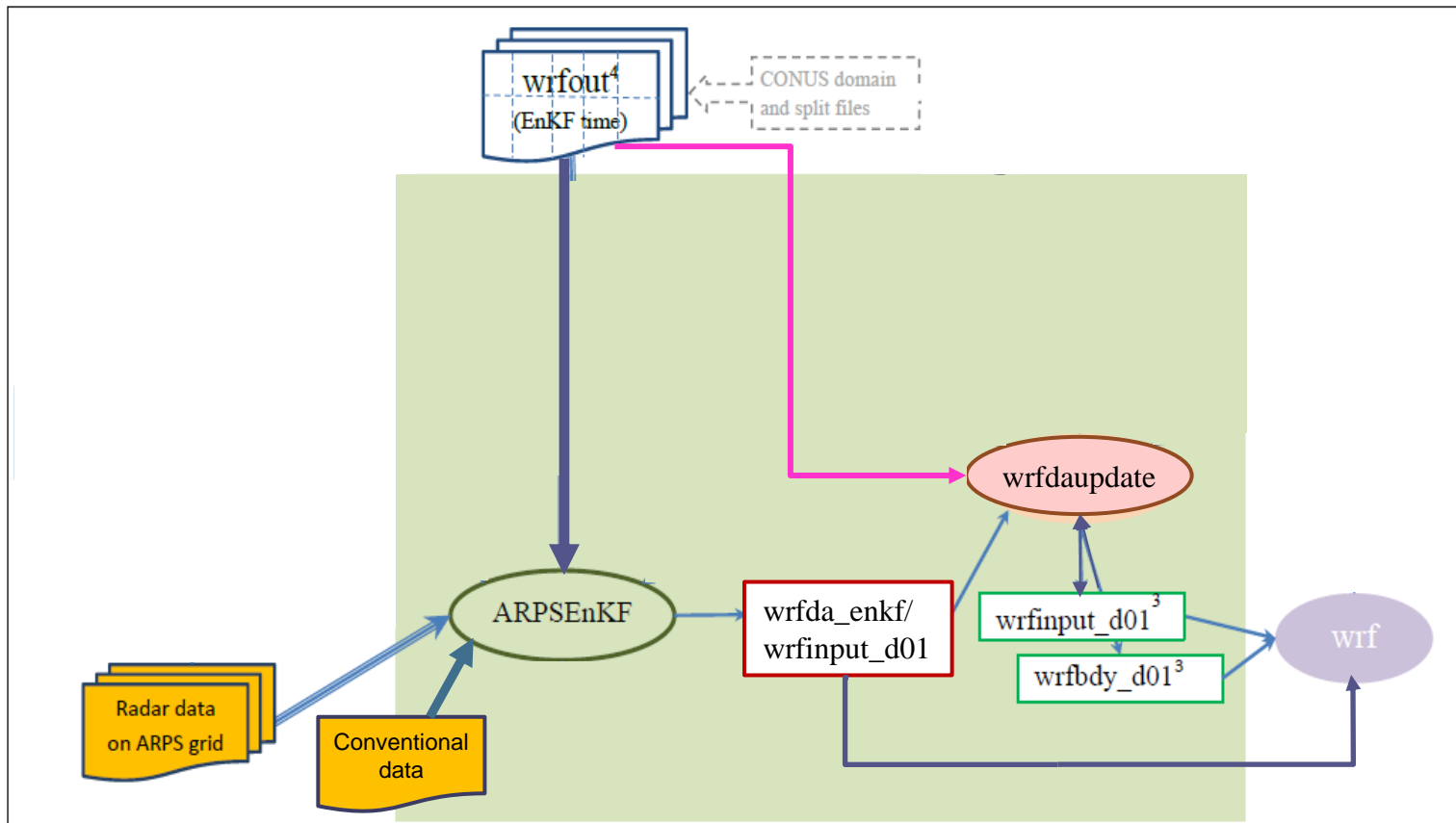
# Configurations for 12-member ensemble forecasts

Member	IC	BC	Microphysics	LSM	PBL
enkf_m1	enk_m1a	arw_cn	Thompson(8)	Noah	MYJ(2)
enkf_m2	enk_m2a	arw_m3	MY2(9)	Noah	MYJ(2)
enkf_m3	enk_m3a	arw_m4	Morrison(10)	Noah	MYJ(2)
enkf_m6	enk_m6a	arw_m5	Thompson(8)	Noah	MYNN(5)
enkf_m7	enk_m7a	arw_m6	MY2(9)	Noah	YSU(1)
enkf_m8	enk_m8a	arw_m7	Morrison(10)	Noah	YSU(1)
enkf_m9	enk_m9a	arw_m8	Thompson(8)	Noah	QNSE(4)
enkf_m10	enk_m10a	arw_m9	MY2(9)	Noah	MYNN(5)
enkf_m11	enk_m11a	arw_m10	Thompson(8)	Noah	YSU(1)
enkf_m12	enk_m12a	arw_m11	WDM6(16)	Noah	YSU(1)
enkf_m15	enk_m15a	arw_m12	Morrison(10)	Noah	MYNN(5)
enkf_m16	enk_m16a	arw_m13	WDM6(16)	Noah	MYJ(2)

# 2014 1-hour cycled 4-km EnKF SSEF initialized at 00 UTC



Initialize at 2300 UTC with an ensemble mean forecast  
Own cycling between 2300 and 0000 UTC



**Flow chart for the 2014 SE**

# Several new features of ARPS EnKF

- Can store only analyzed fields in enkf format or directly in wrfinput format (netCDF)
- Support more flexible MPI configurations for EnKF
  - WRF domain decomposition: 4x48 (192 split files)
  - EnKF domain decomposition: 24x48 MPI processes
- Can work with fewer ensemble members available at the analysis time
- Can handle missing radar files due to corruption of input data



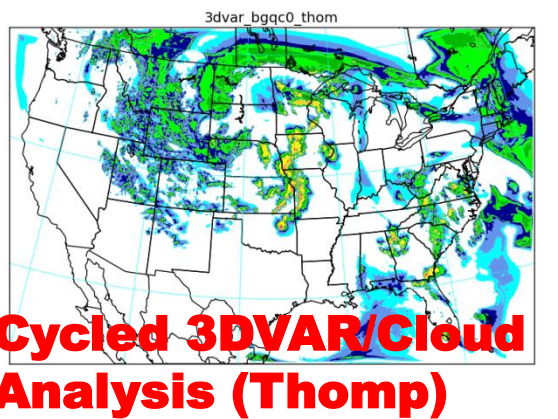
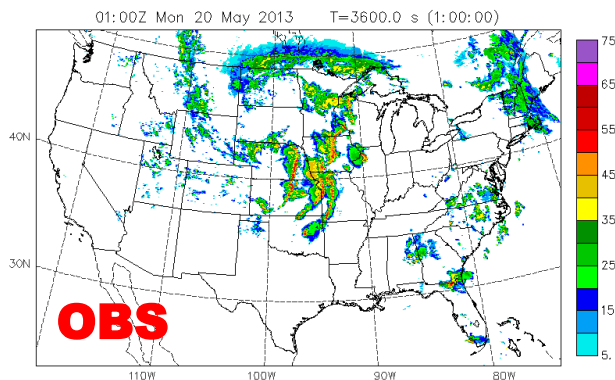
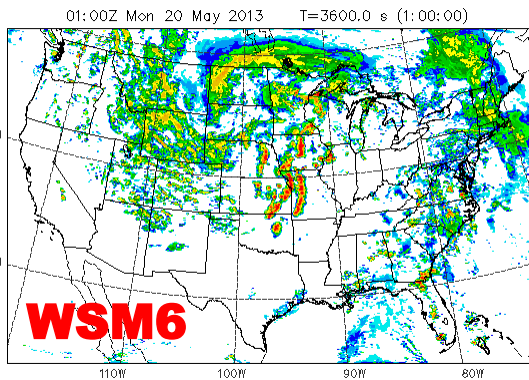
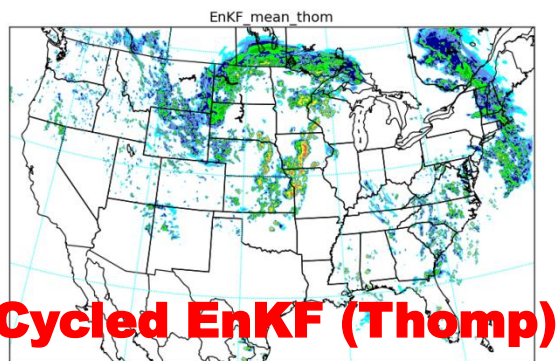
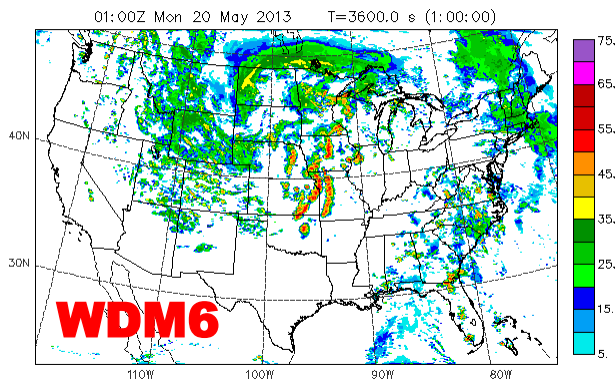
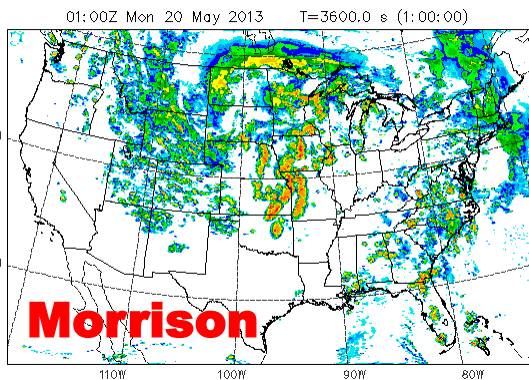
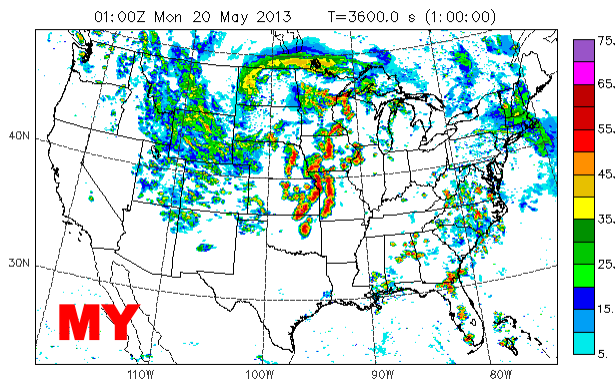
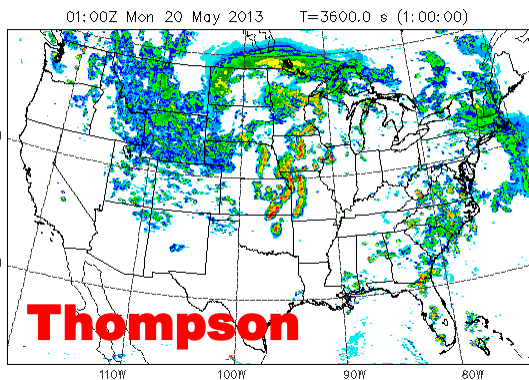
# Comparison with 2013 HWT forecasts for the tornado outbreak of 20 May 2013

Member	IC	BC	Radar	Micro	LSM	PBL
arw_cn	ooZAPRSa	ooZ NAMf	yes	Thompson	Noah	MYJ
arw_m20	ooZAPRSa	ooZ NAMf	yes	M-Y	Noah	MYJ
arw_m21	ooZAPRSa	ooZ NAMf	yes	Morrison	Noah	MYJ
arw_m22	ooZAPRSa	ooZ NAMf	yes	WDM6	Noah	MYJ
arw_m26	ooZAPRSa	ooZ NAMf	yes	WSM6	Noah	MYJ
EnKF mean	ooZ EnKFa	ooZ NAMf	yes	Thompson	Noah	MYJ
3DVAR +cloud	ooZ ARPSa	ooZ NAMf	yes	Thompson	Noah	MYJ



**3DVAR+Cloud Analysis**

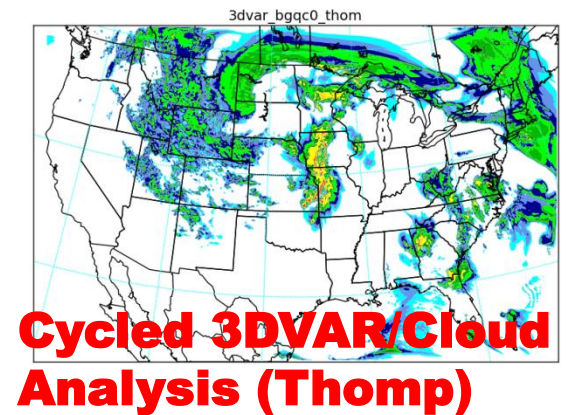
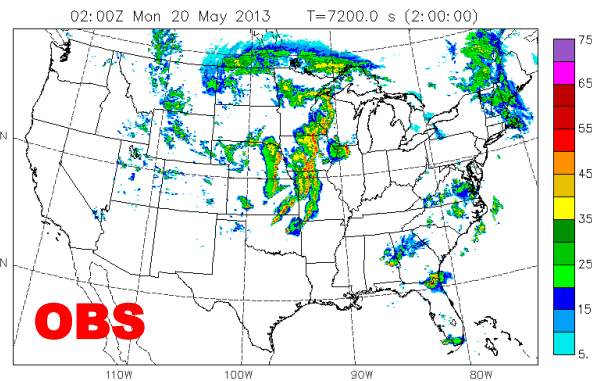
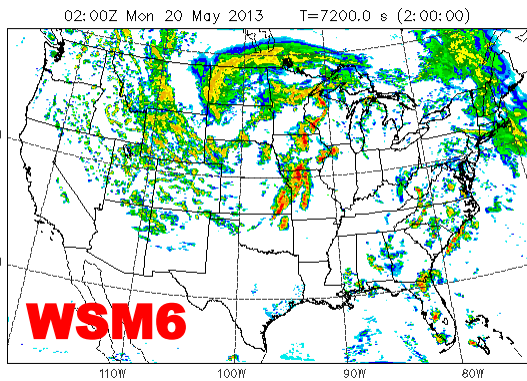
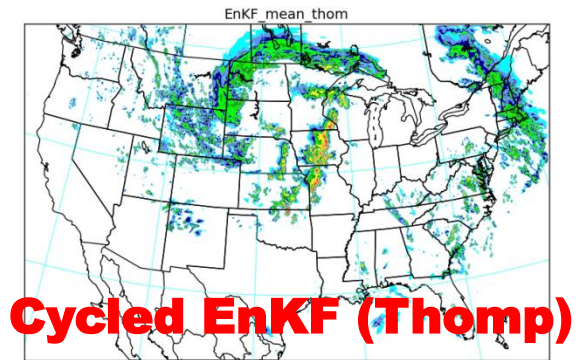
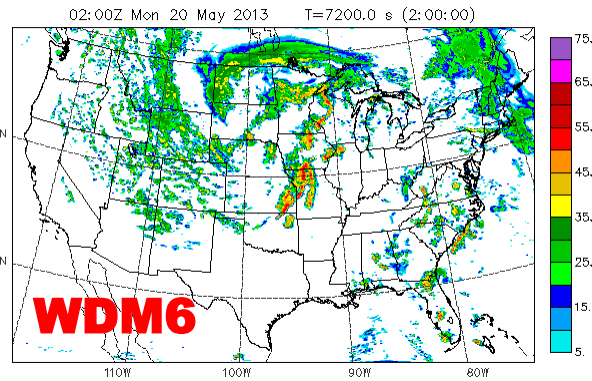
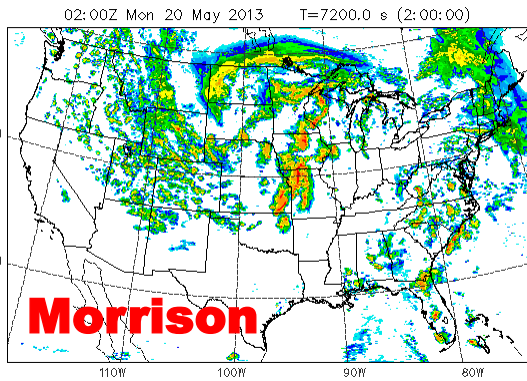
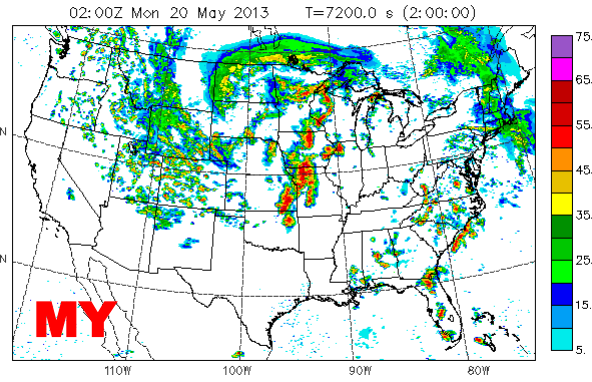
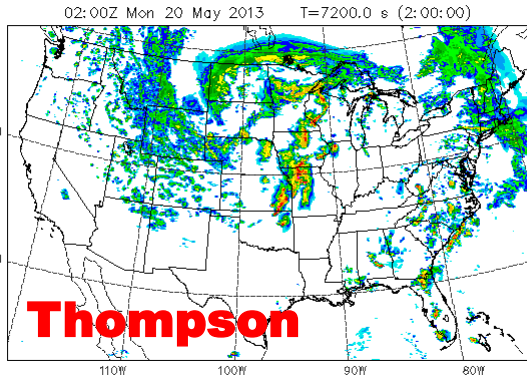
# 1 hr forecast Valid at 0100 UTC 20 May 2013



**3DVAR/Cloud Analysis**

Min=0.00 Max=66.3

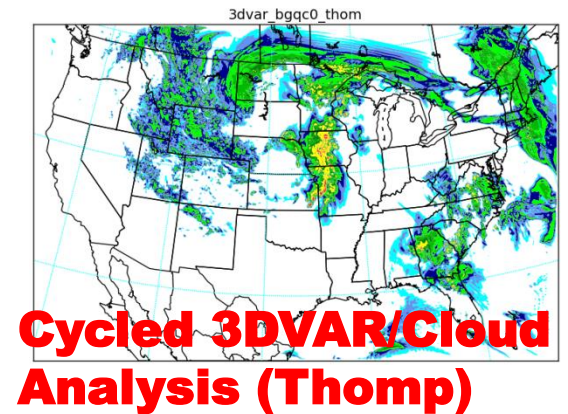
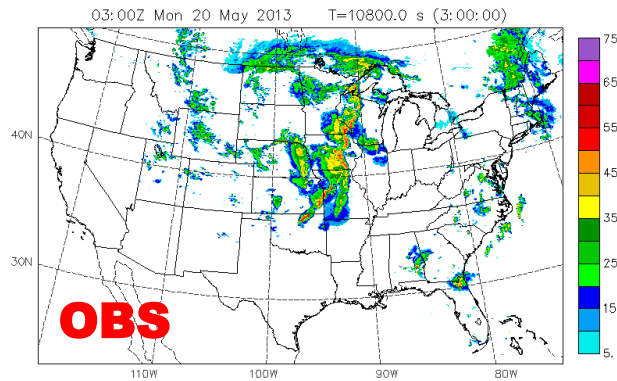
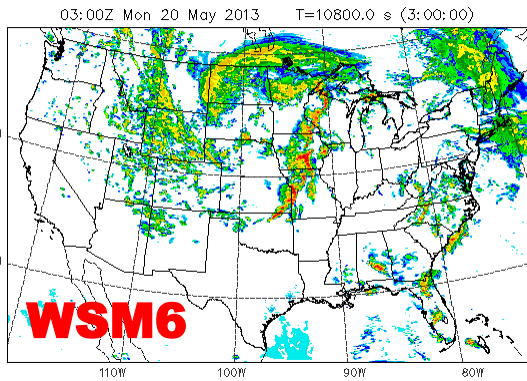
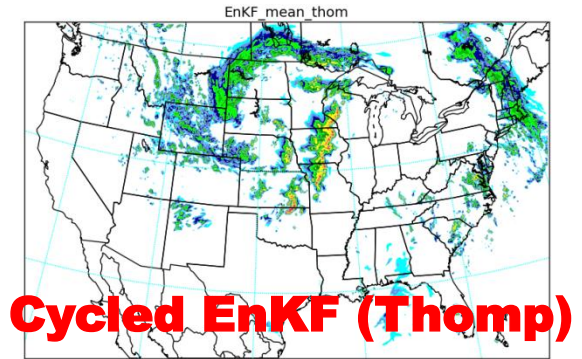
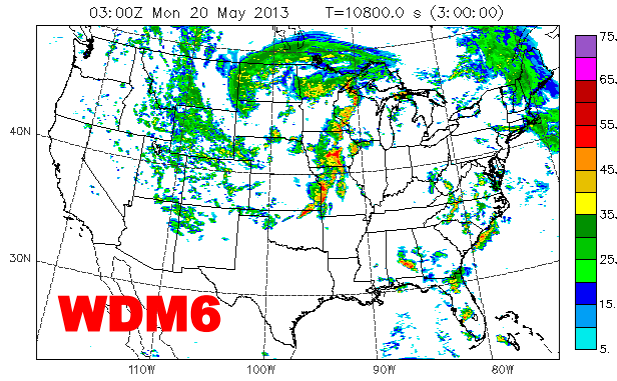
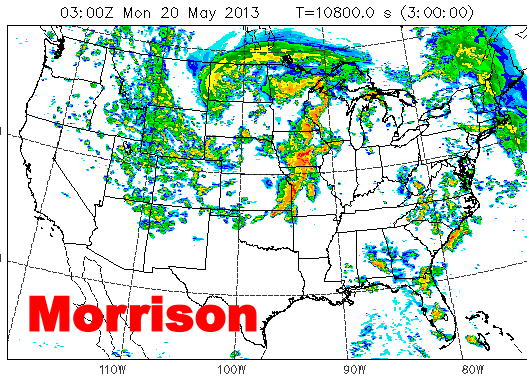
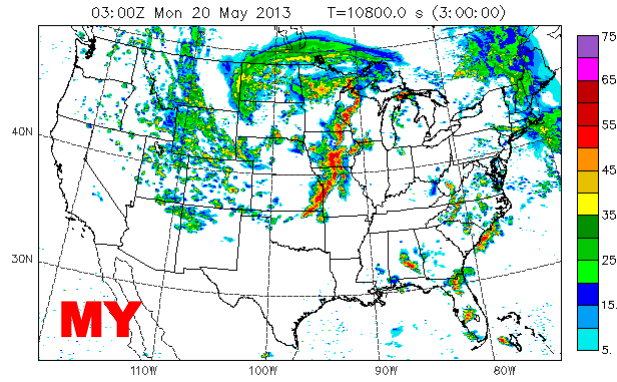
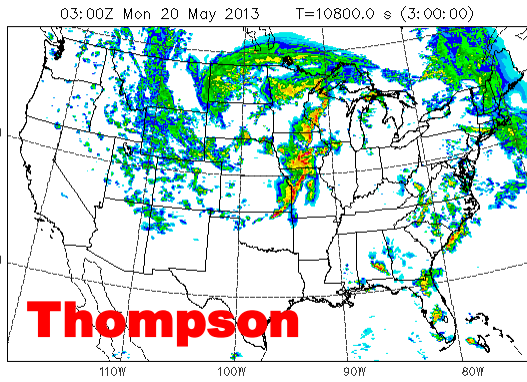
# 2 hr forecast Valid at 0200 UTC 20 May 2013



**3DVAR/Cloud Analysis**

Min=0.00 Max=63.9

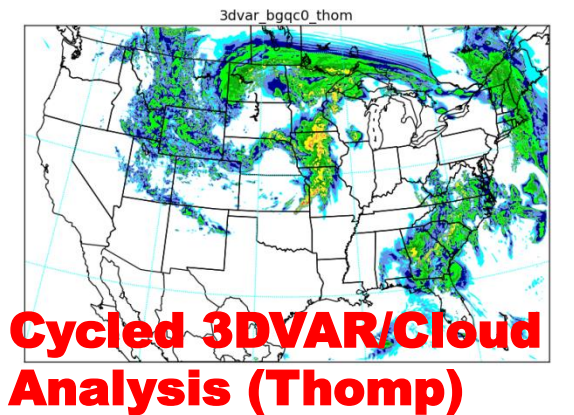
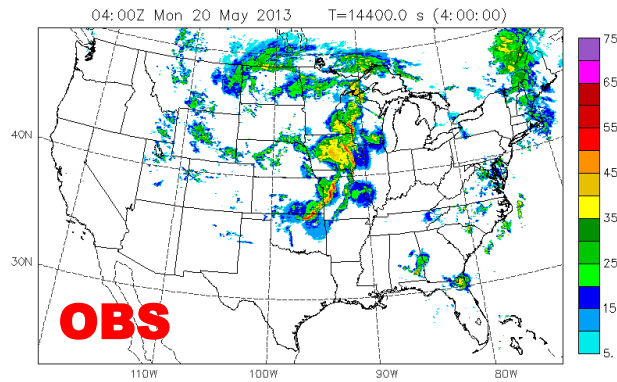
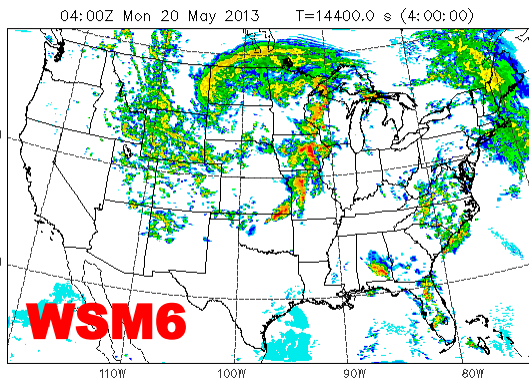
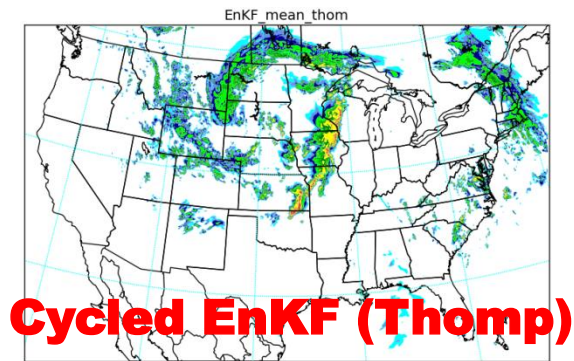
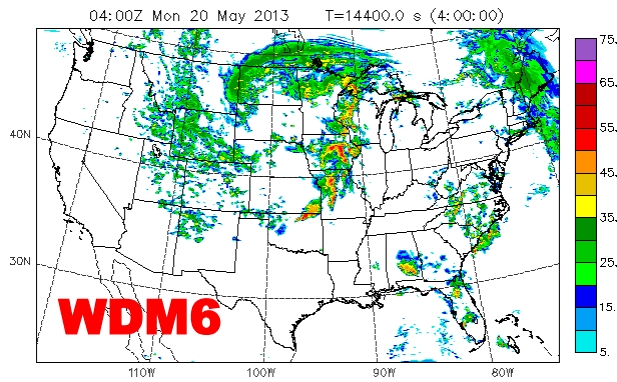
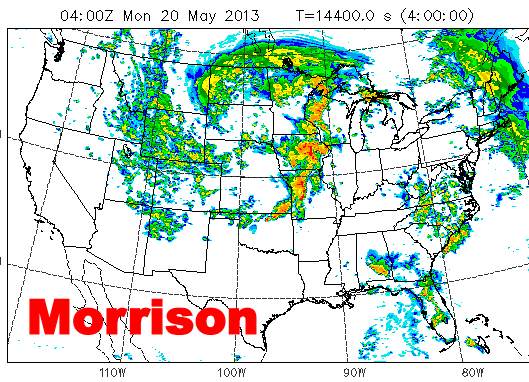
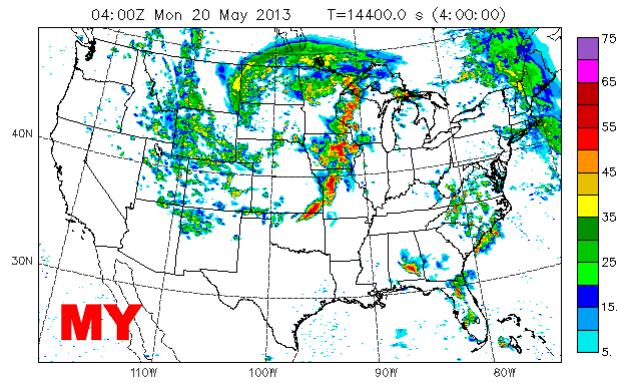
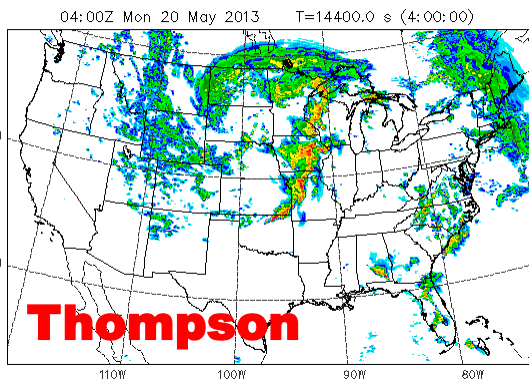
# 3 hr forecast Valid at 0300 UTC 20 May 2013



**3DVAR/Cloud Analysis**

Min=0.00 Max=63.2

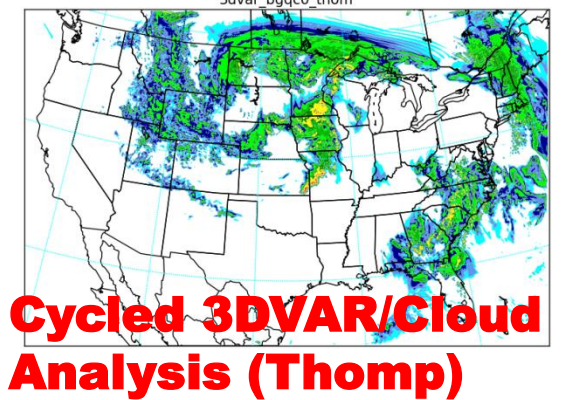
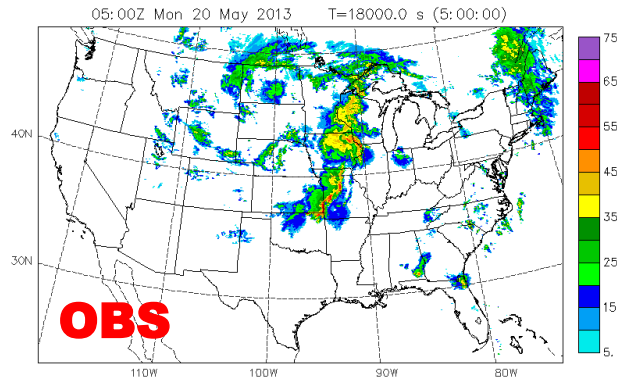
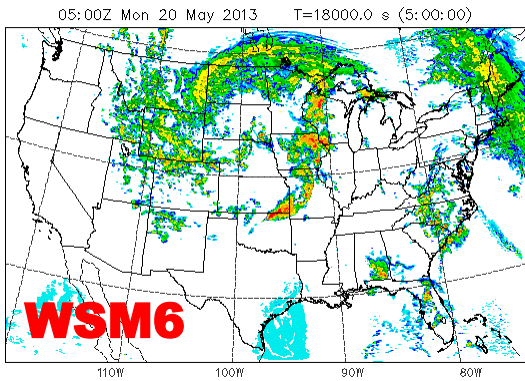
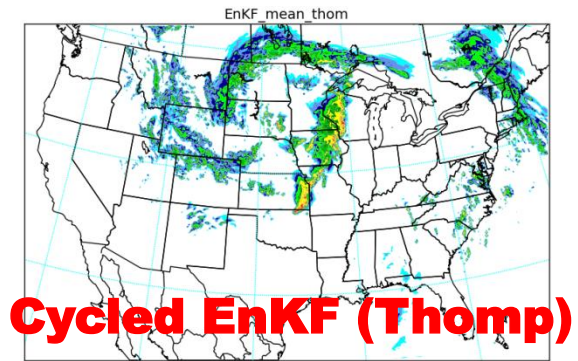
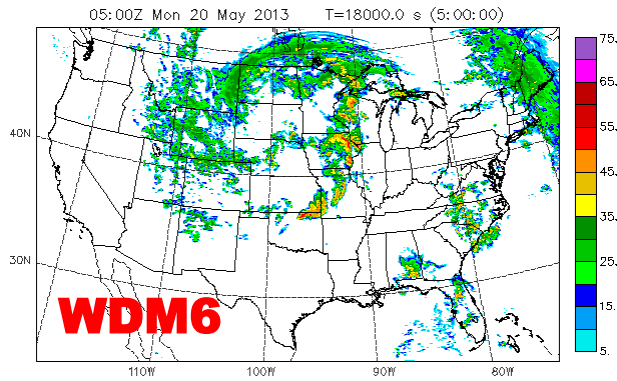
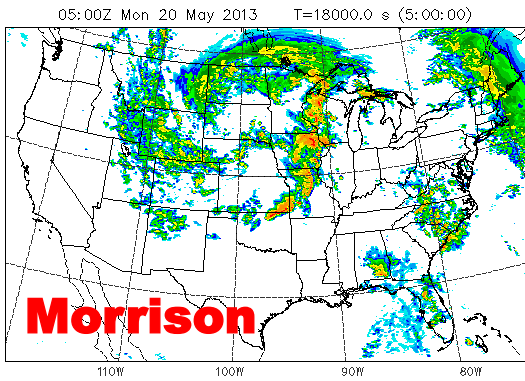
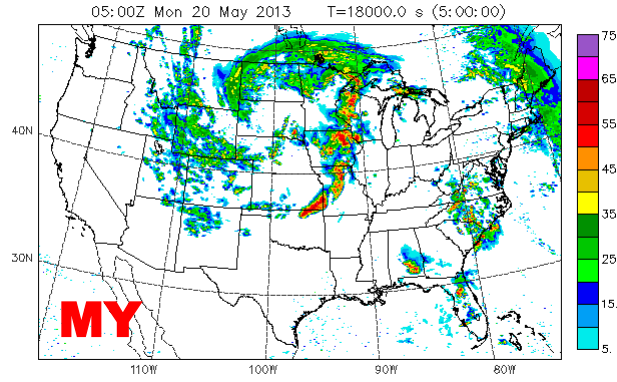
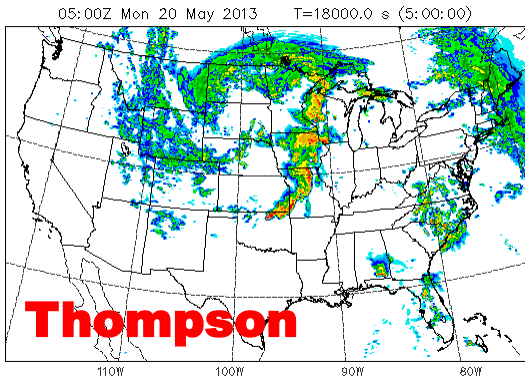
# 4 hr forecast Valid at 0400 UTC 20 May 2013



**3DVAR/Cloud Analysis**

Min=0.00 Max=64.4

# 5 hr forecast Valid at 0500 UTC 20 May 2013

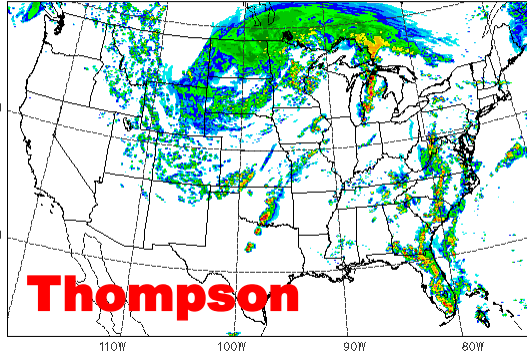


**3DVAR/Cloud Analysis**

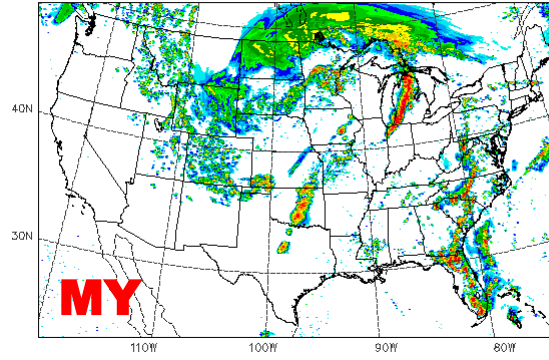
Min=0.00 Max=63.0

# 21 hr forecast Valid at 2100 UTC 20 May 2013

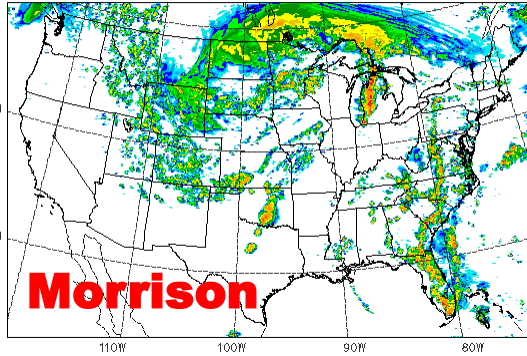
21:00Z Mon 20 May 2013 T=75600.0 s (21:00:00)



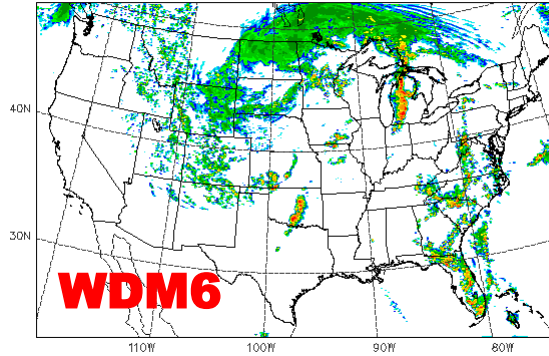
21:00Z Mon 20 May 2013 T=75600.0 s (21:00:00)



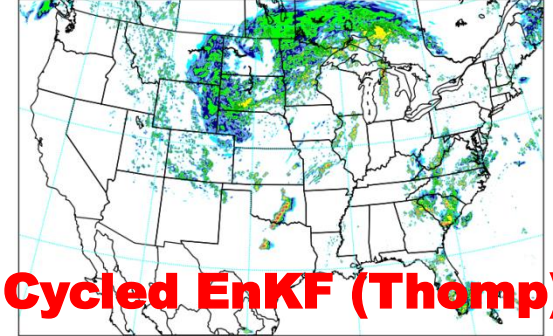
21:00Z Mon 20 May 2013 T=75600.0 s (21:00:00)



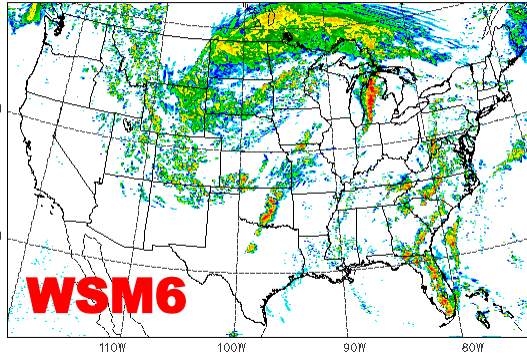
21:00Z Mon 20 May 2013 T=75600.0 s (21:00:00)



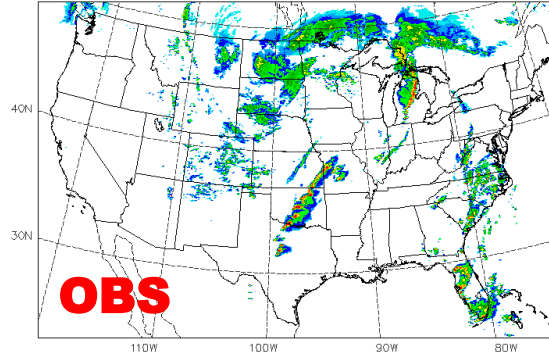
EnKF mean thomp



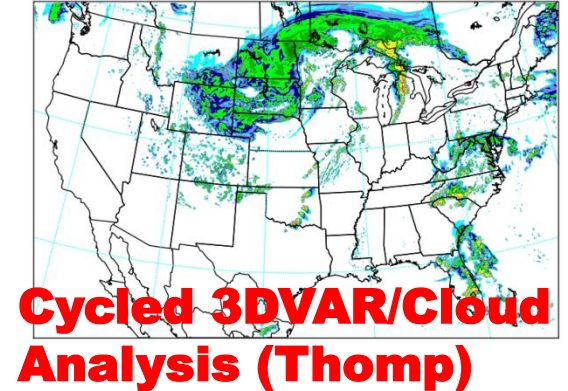
21:00Z Mon 20 May 2013 T=75600.0 s (21:00:00)



21:00Z Mon 20 May 2013 T=75600.0 s (21:00:00)

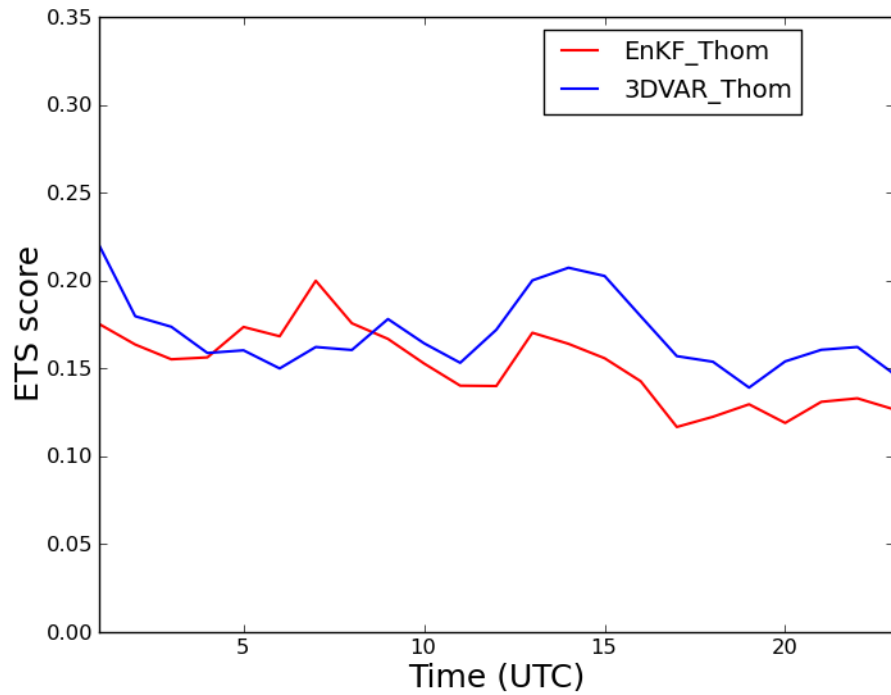


3dvar\_bgac0 thomp

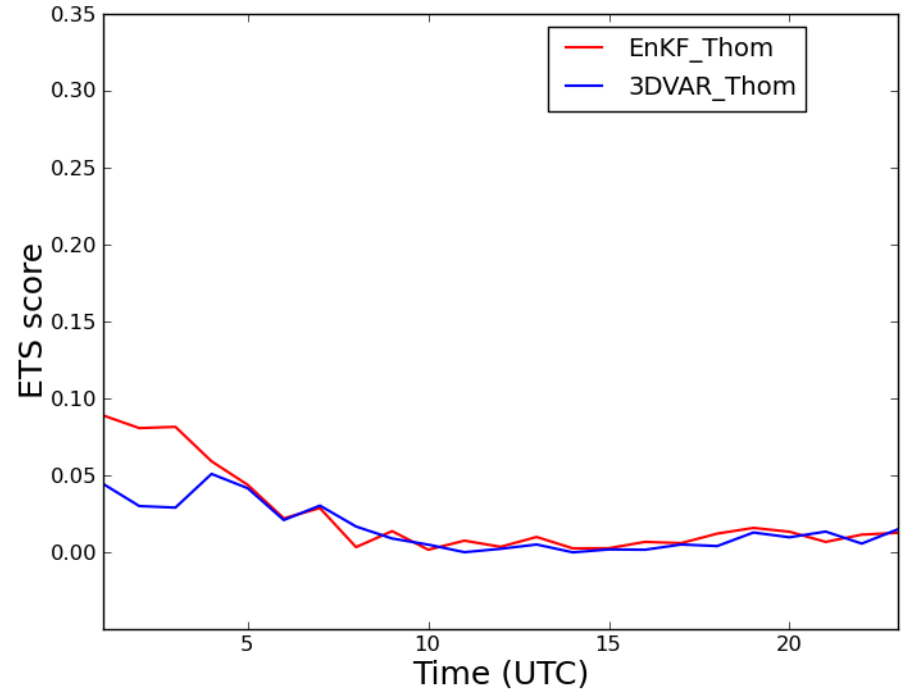


# ETS for composite reflectivity

$Z \geq 20$  dBZ



$Z \geq 40$  dBZ





# Performance statistics

- NICS Darter
  - Cray XC30 (Cascade) supercomputer
  - Two 2.6 GHz 64bit Intel 8-core XEON E5-2600 Series processors
  - Peak performance of 250 Tflops

# Performance statistics

- Test case: 12 May 2014 case
  - Radar assimilation: ~ 3 min (16x48 PEs, 768 cores)
  - Radar + surface + sounding + profiler: ~ 80 min (4x48 PEs, 2 OMP threads, 384 cores)
  - Radar + surface + sounding + profiler: ~ 15 min (24x48 PEs, 1152 cores)
  - Radar + surface + sounding + profiler: ~ 11 min (40x48 PEs, 1920 cores)
  - 15 min forecast: ~ 4 min (4x48 PEs, 192 cores)
  - 24 hour forecast: ~ 86 min (192 cores)

- Number of observations

Surface: 4, 205

Sounding: 8,966

Profiler: 54

Vr: 236,723

Z: 1,605,226

# Future plan

- 2015: Partially cycled real-time EnKF DA and ensemble forecasts in the CONUS domain
  - Longer DA window
  - Longer forecasts
- 2016 and beyond:
  - Continuously cycled real-time EnKF DA and forecasts
  - Assimilation of satellite radiance