

Multi-scale EnKF data assimilation and forecasts of the 10 May 2010 tornado case in the central US domain

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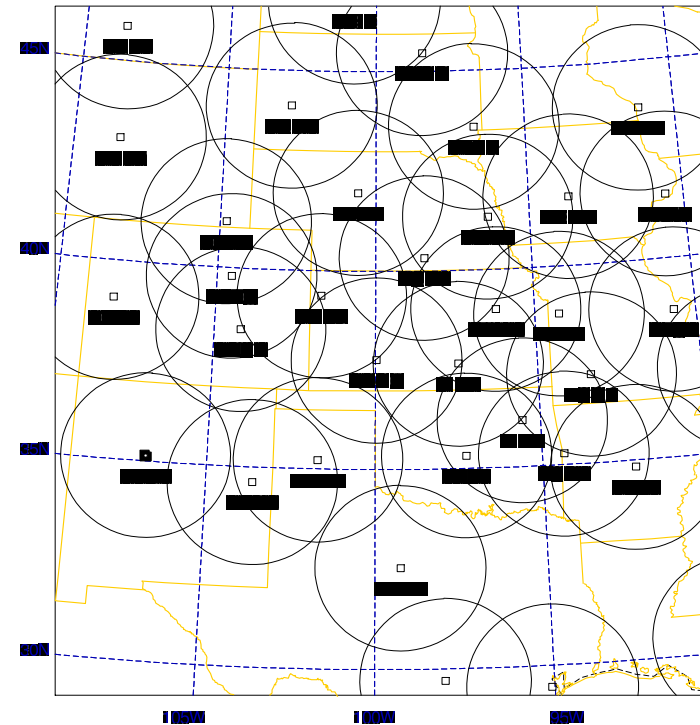
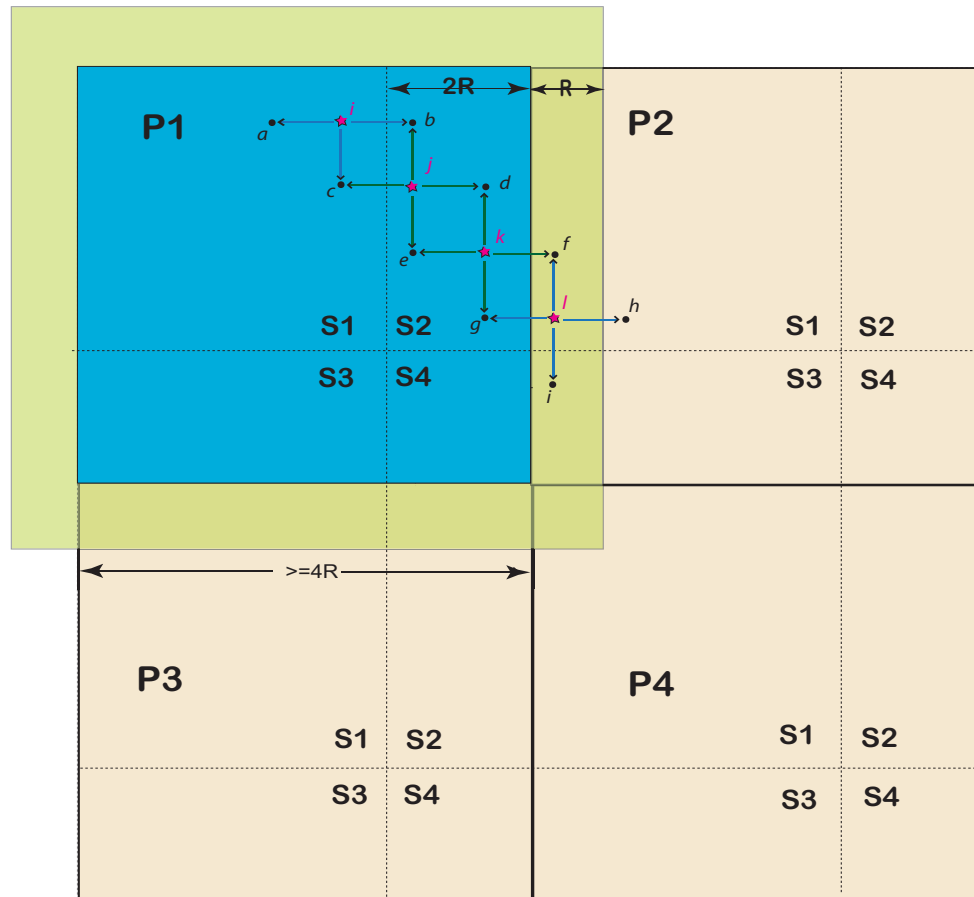


Goal

- Establish an efficient parallel EnKF system capable of assimilating multi-scale observations including surface, upper-air, profiler, and radar observations
- Work toward to the goal of the CONUS-domain storm-scale EnKF DA and ensemble forecasts and possible real-time implementation



Parallel EnSRF algorithm suitable for dense radar data using domain decomposition



Wang et al. (2012)

Treatment of conventional data

PU0	PU1	PU2	PU3	PU4	PU5
PU6	PU7	PU8	PU9	PU10	PU11
PU12	PU13	PU14 $\dot{H}(x_i)$	PU15	PU16	PU17
PU18	PU19	PU20	PU21	PU22	PU23
PU24	PU25	PU26	PU27	PU28	PU29
PU30	PU31	PU32	PU33	PU34	PU35

1) Compute $H(x_i)$

2) Broadcast $H(x_i)$

3) Parallel update of x_i

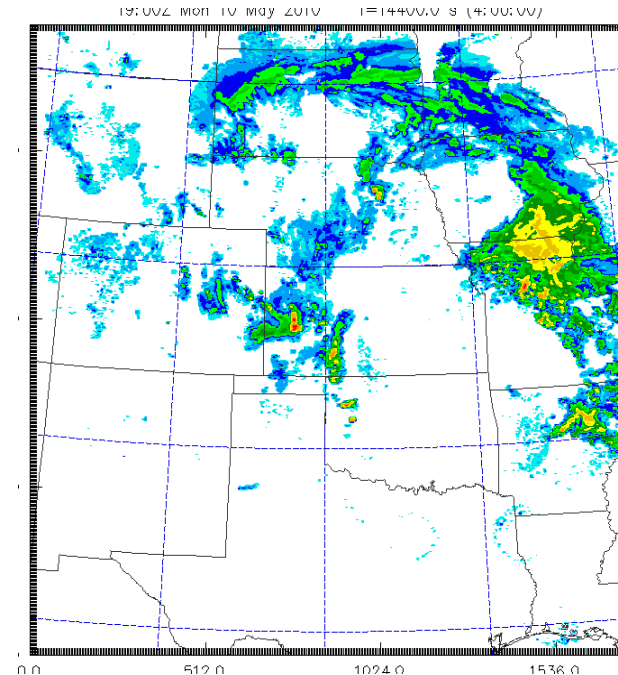
Wang et al. (2012)



Timing benchmark

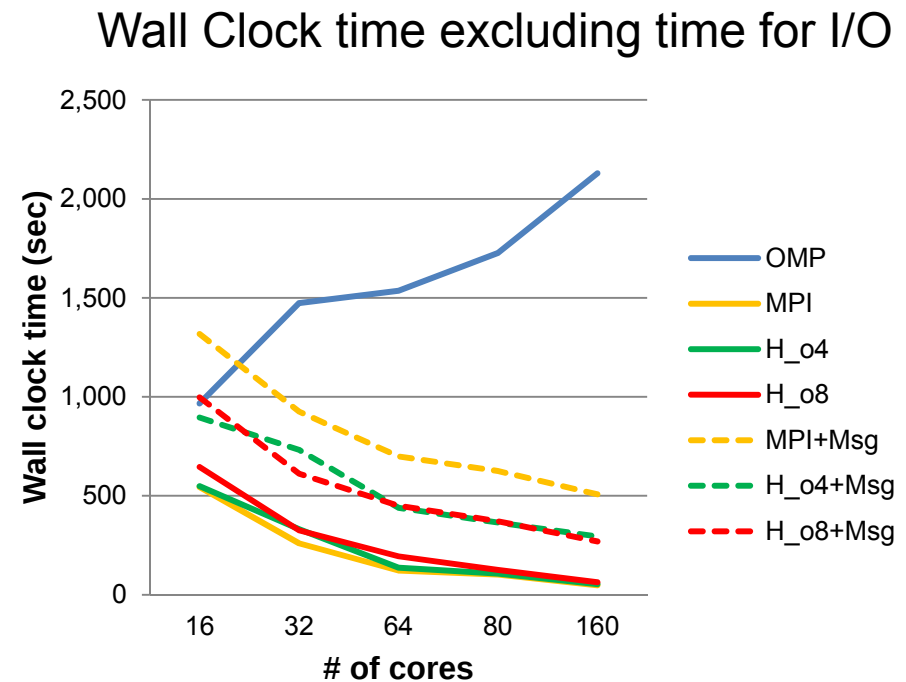
Number of observations assimilated

- Data from 35 radars
 - Vr: 119,407
 - Z: 661,814
- Conventional data
 - Surface: 2,244
 - Sounding: 596
 - Profiler: 641



Performance statistics on blacklight

- PSC Blacklight
 - SGI UV 1000 cc-NUMA shared-memory system
 - 256 blades, 2 Intel Xeon X7569 eight-core processors/blades
 - Each core: 2.27 GHz, 9 Gflops
 - Peak performance: 27 Tflops
 - Radar assimilation: 48 sec excluding I/O and message passing (10 PEs x 16 PEs)



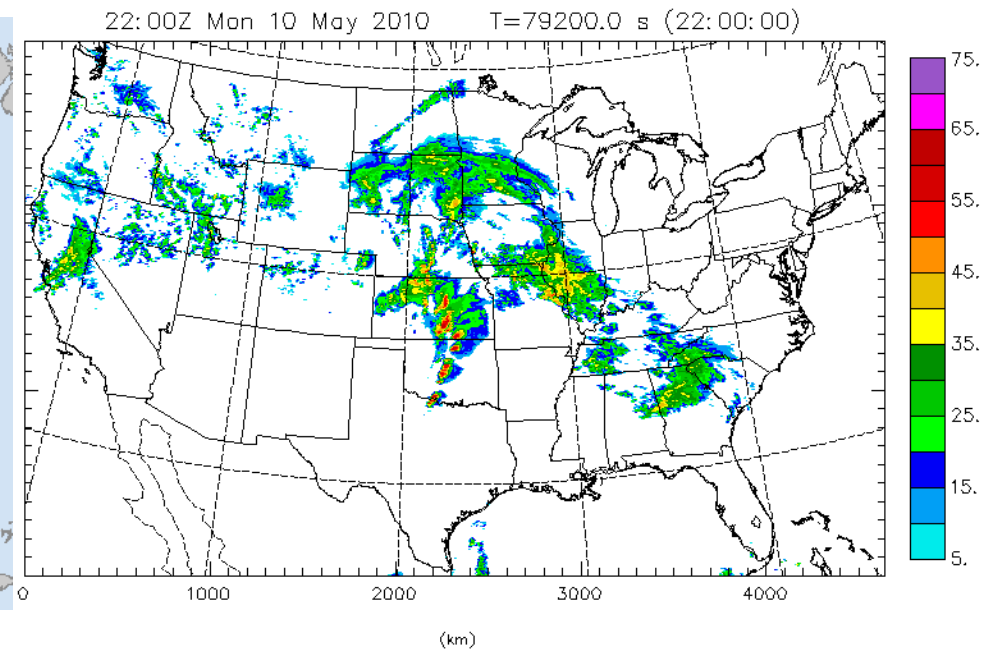
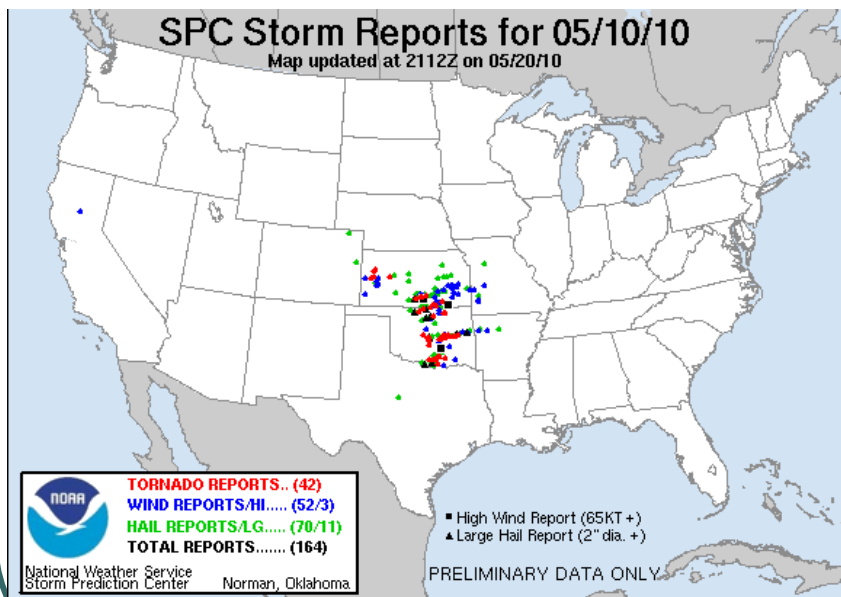
Performance statistics

- NICS Kraken (4 PEs x 6 PEs x 3 threads)
 - Two 2.6 GHZ six-core-AMD Opteron processors
 - Peak performance: 1.17 Pflops
 - Radar assimilation: 1.99 min excluding IO (4x6 subdomains)
- OU Sooner (4 PEs x 8 PEs x 8 threads)
 - Pentium5 Xeon EM64T quad core “Harpertown” E5405 2.0 GHz
 - Peak performance: 34 Tflops
 - Radar assimilation: 4.18 min
 - Conventional (surface, sounding, profiler) data assimilation: 2.11 min
 - Radar + conventional data: 6.96 min



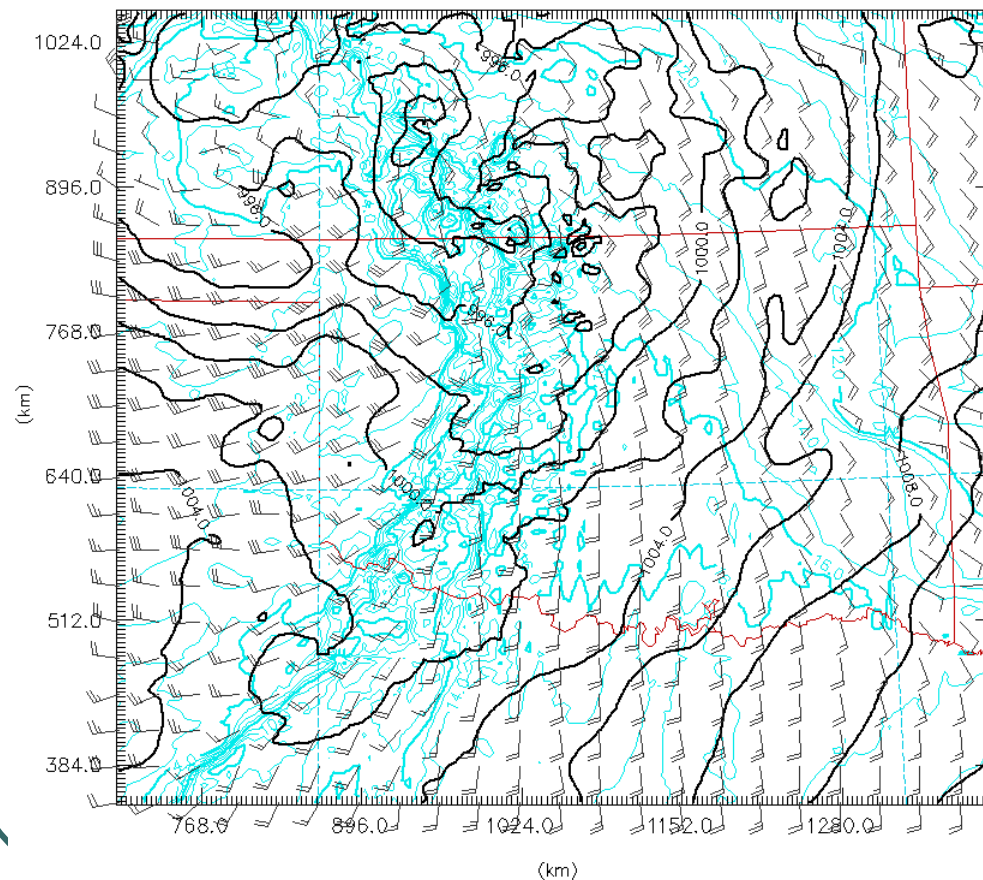
10 May 2010 Oklahoma-Kansas tornado outbreak

- Overview
 - Spawned over 40 tornadoes, with up to EF4 intensity

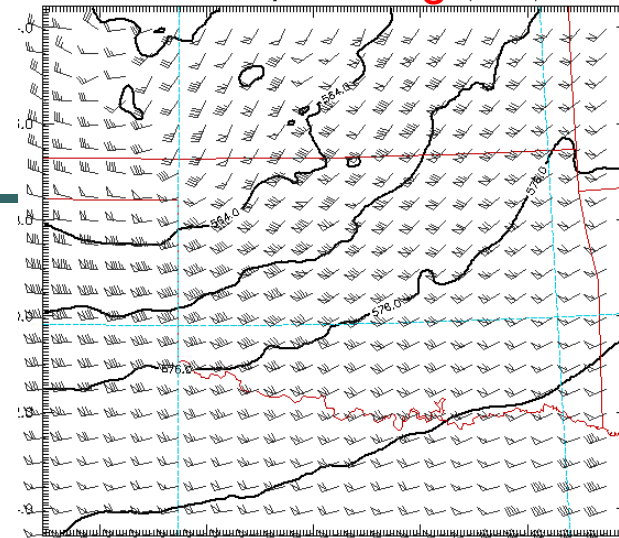


2100 UTC analysis

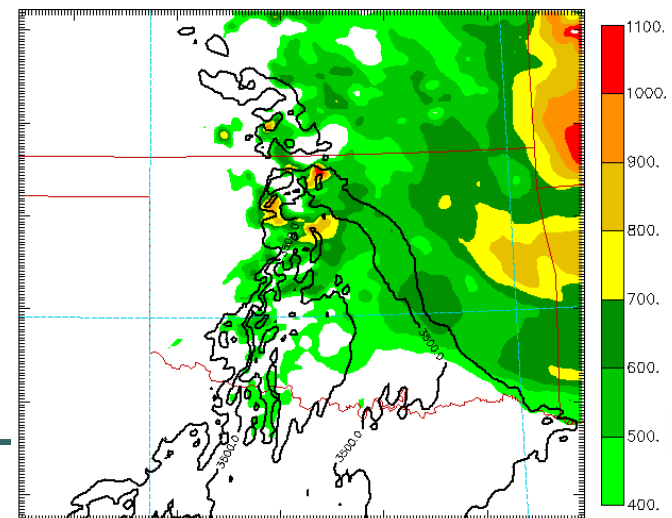
MSLP (hPa) and q_v (g/kg)



500 hPa height



Contour: CAPE > 2500 J/kg
Shade: 0-3km Helicity (m^2/s^2)



DA procedure

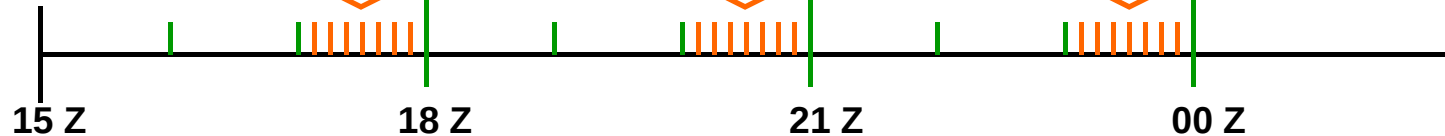
40 km Regional
ensemble :

3 hourly single LBC from deterministic forecast
and
ensemble of LBC from ensemble forecast



Deterministic and
ensemble forecast

Storm-scale:
4 km

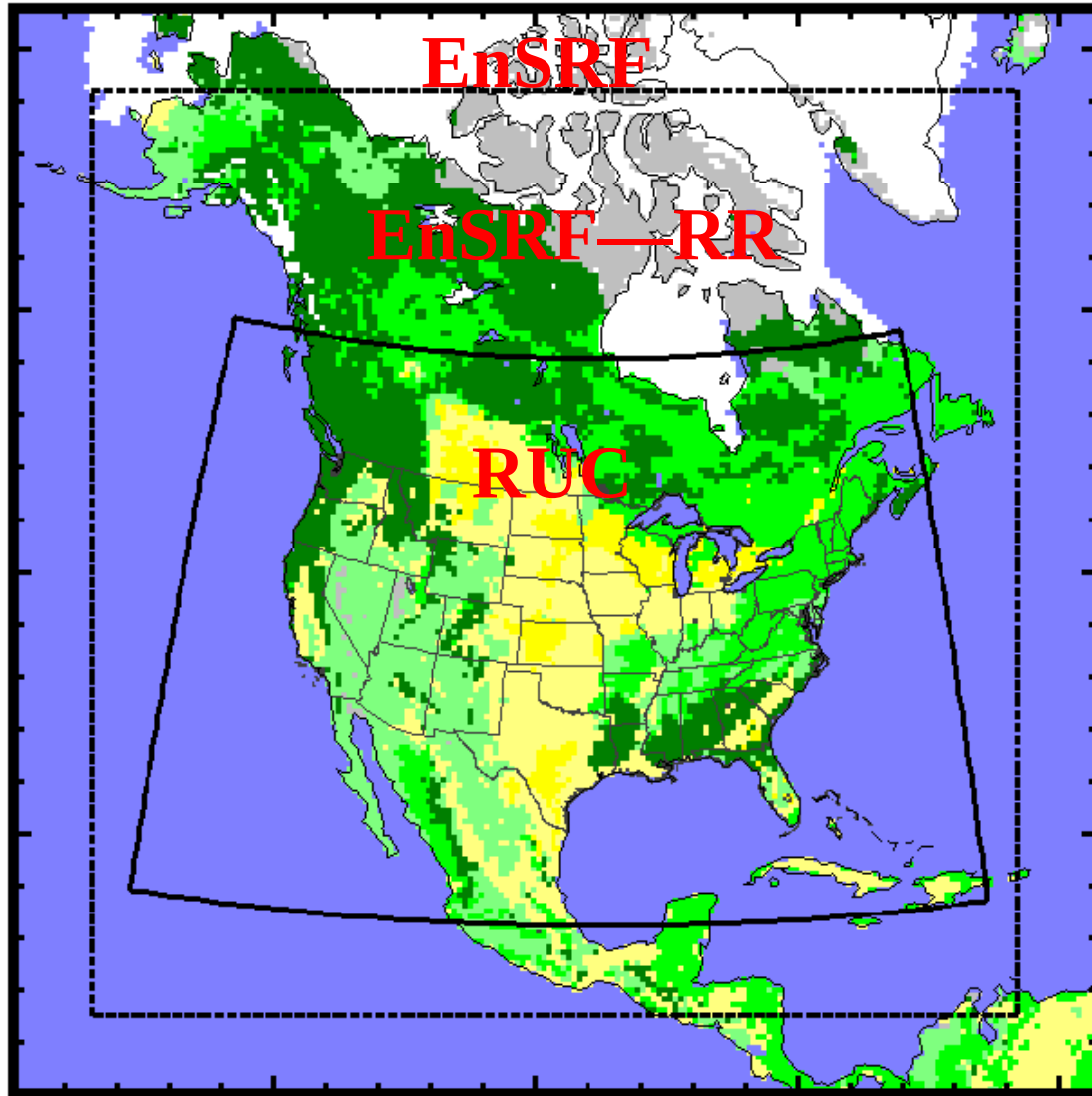


10 min. interval radar/surface DA

Hourly surface/profiler/sounding/radar DA



40 km regional ensemble



Ensemble size: 40

EnKF Test Domain
207x207 grid points
~40 km, 51 levels

Model: WRF-ARW

“Development and testing of a regional GSI-based EnKF-hybrid system for the Rapid Refresh configuration (Pan et al.)”



Configurations

- Model: ARPS
- Microphysics scheme: LFO83
- Grid configurations: nested grid (40 km -> 4 km)
- Physical domain: 443x483x53 (1768km x 1928 km)
- 40 ensemble members
- DA scheme: parallel EnSRF
- Observations
 - conventional data: surface, sounding, profiler, mesonet
 - radar: 32-38 WSR-88D radars



Experiments

CNTL_2100

NCYL_2100

DA_2100

15 Z

18 Z

21 Z

CNTL_1800

DA_1800

15 Z

18 Z

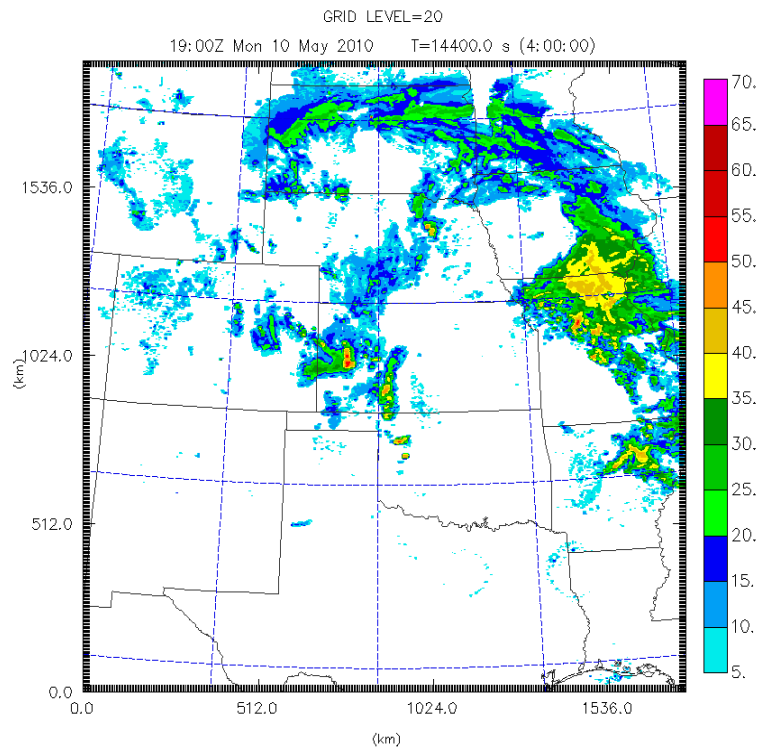
CNTL_1500

Deterministic and ensemble forecast



CAPS real-time forecast (1h)

Observed radar reflectivity mosaic

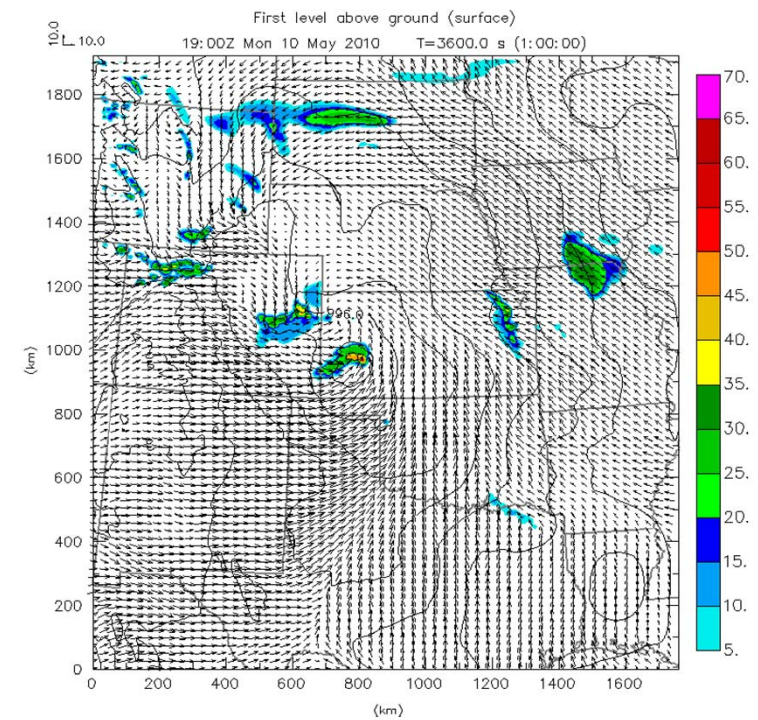


refmos(dBZ, Shaded)

Min=-.100E-19 Max=61.0

WRF ARW forecast reflectivity

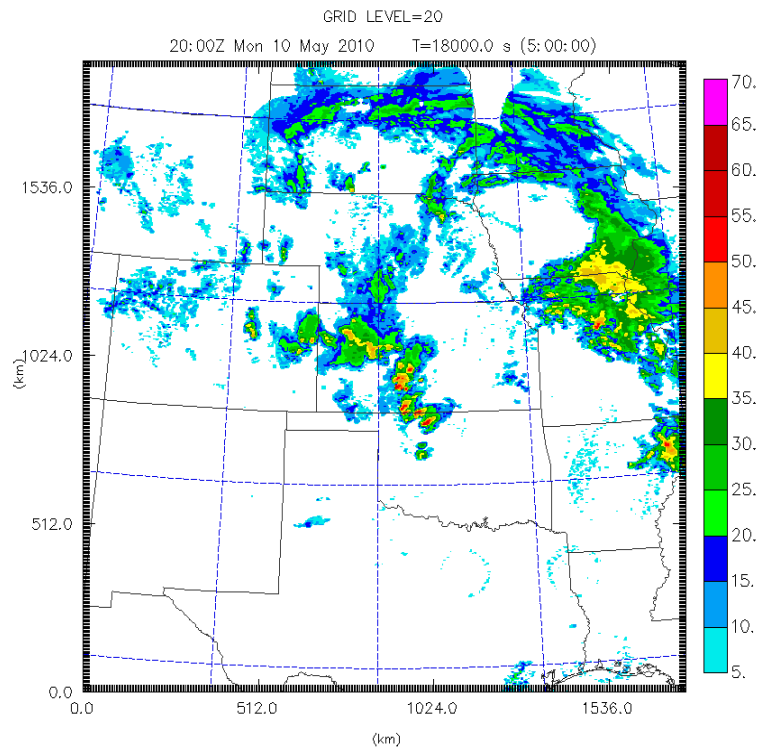
SPV4C0 (440x480x50, dx=4 km)
1:00 h WRF/ARW Forecast valid 1900Z Mon 10 May 2010



Composite Ref (dBZ, Shaded) Min=0.00 Max=52.0
U-V (m/s, Vector) Umin=-12.44 Umax=19.56 Vmin=-13.82 Vmax=13.84
Sea Level Pressure (mb, contour) Min=988.1 Max=1026. inc=4.000

CAPS real-time forecast (2h)

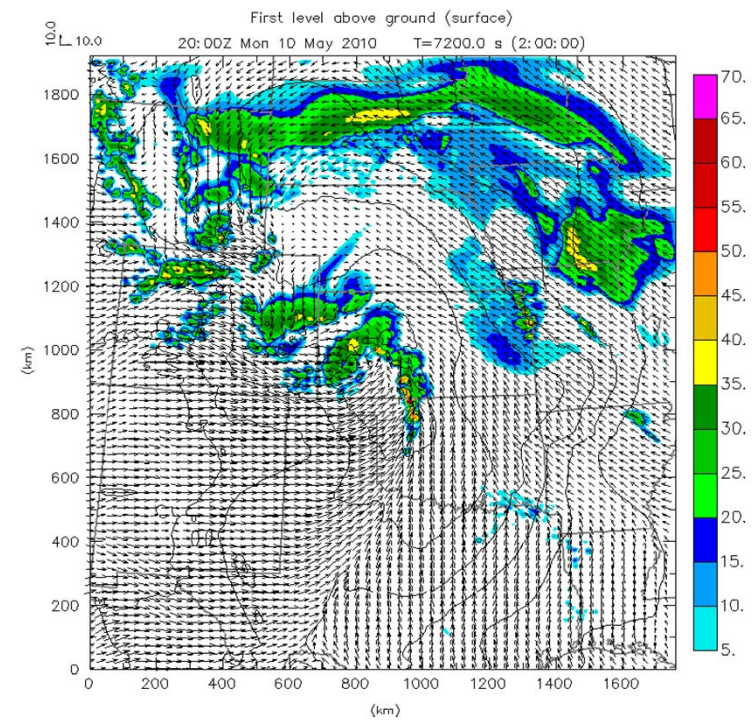
Observed radar reflectivity mosaic



Min=-.100E-19 Max=61.0

WRF ARW forecast reflectivity

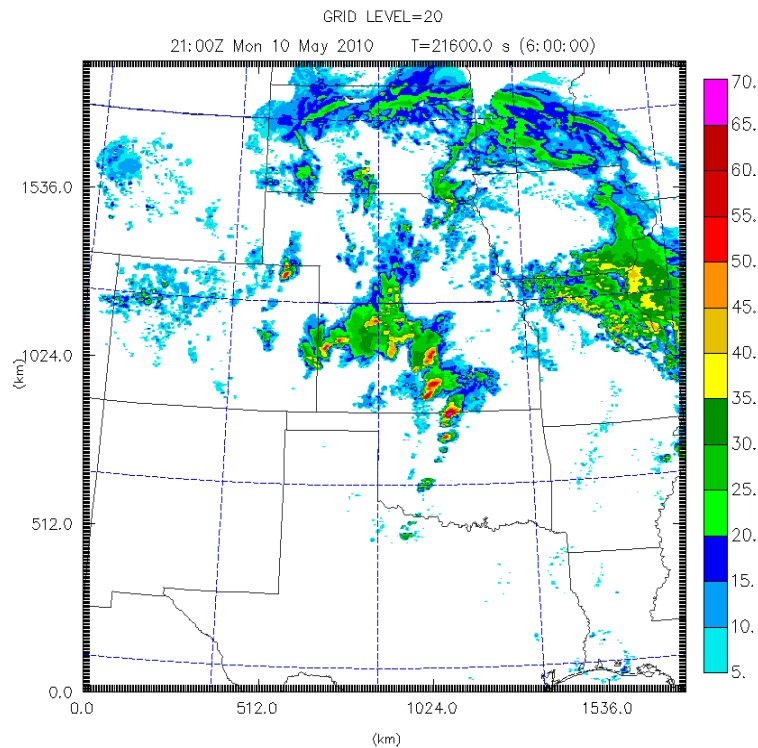
SPV4C0 (440x480x50, dx=4 km)
2:00 h WRF/ARW Forecast valid 2000Z Mon 10 May 2010



Composite Ref (dBZ, Shaded) Min=0.00 Max=58.1
U-V (m/s, Vector) Umin=-12.80 Umax=20.58 Vmin=-15.17 Vmax=16.79
Sea Level Pressure (mb, contour) Min=990.9 Max=1025. inc=4.000

CAPS real-time forecast (3h)

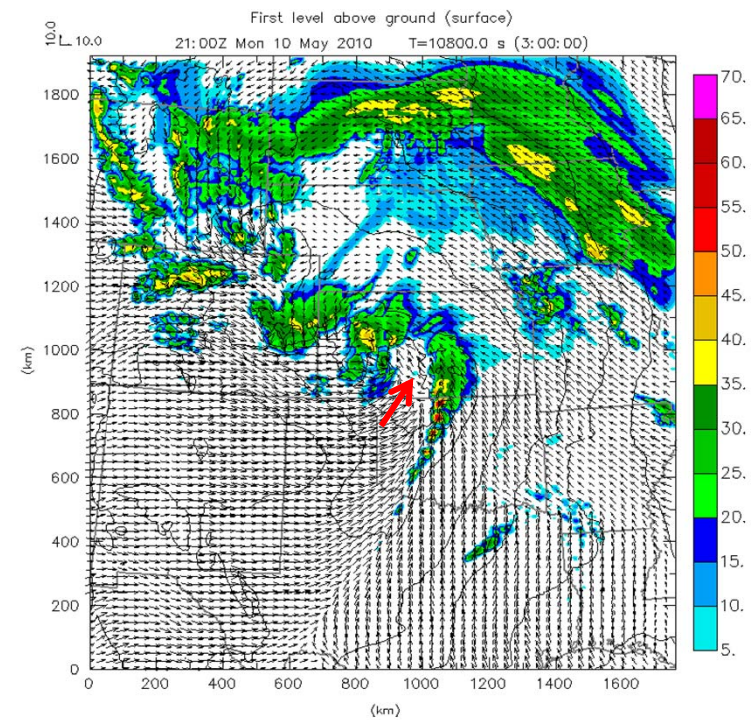
Observed radar reflectivity mosaic



Min=-100E-19 Max=69.5

WRF ARW forecast reflectivity

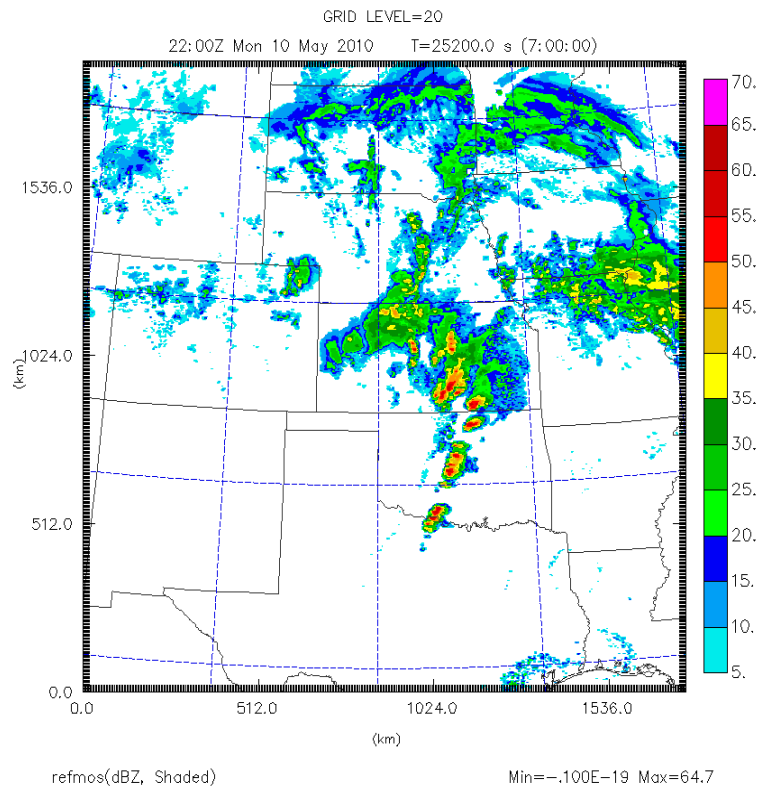
SPV4C0 (440x480x50, dx=4 km)
3:00 h WRF/ARW Forecast valid 2100Z Mon 10 May 2010



Composite Ref (dBZ, Shaded) Min=0.00 Max=62.8
U-V (m/s, Vector) Umin=-12.08 Umax=21.74 Vmin=-20.80 Vmax=18.51
Sea Level Pressure (mb, contour) Min=991.2 Max=1025. Inc=4.000

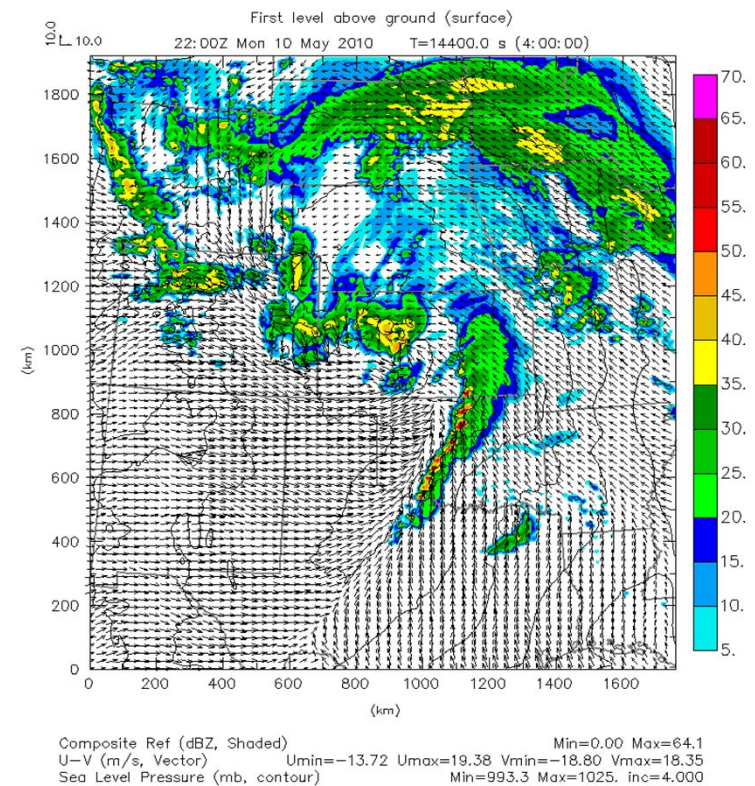
CAPS real-time forecast (4h)

Observed radar reflectivity mosaic



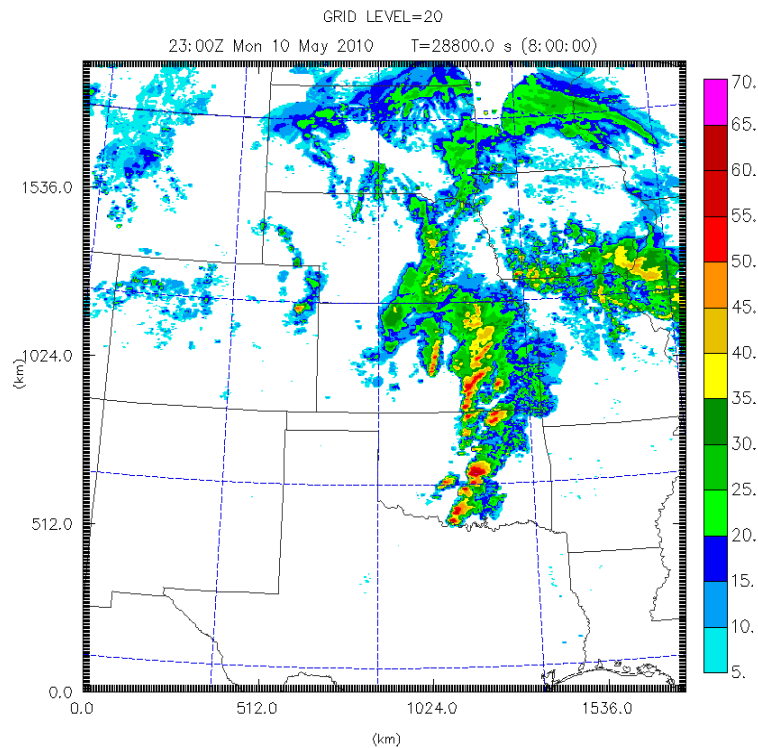
WRF ARW forecast reflectivity

SPV4C0 (440x480x50, dx=4 km)
4:00 h WRF/ARW Forecast valid 2200Z Mon 10 May 2010



CAPS real-time forecast (5h)

Observed radar reflectivity mosaic

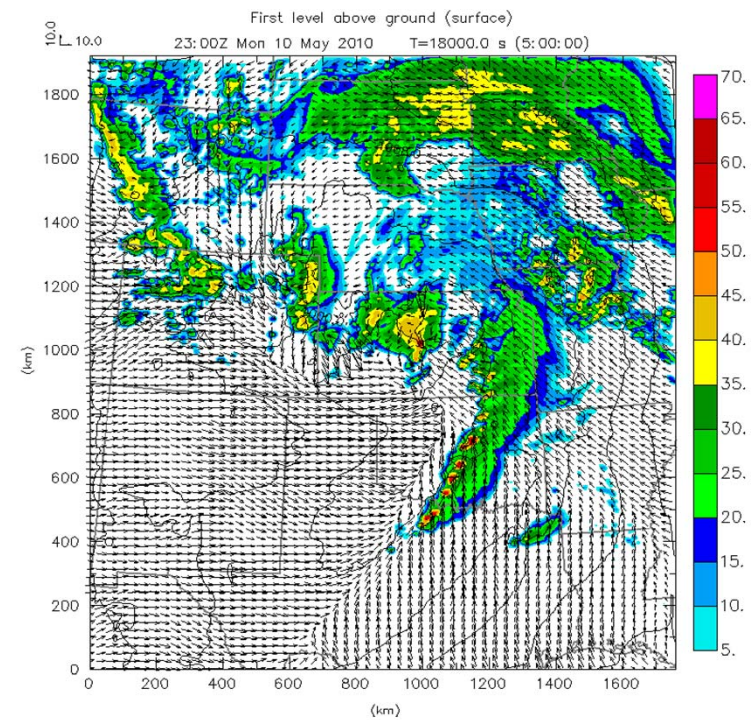


refmos(dBZ, Shaded)

Min=-100E-19 Max=65.7

WRF ARW forecast reflectivity

SPV4C0 (440x480x50, dx=4 km)
5:00 h WRF/ARW Forecast valid 2300Z Mon 10 May 2010



Composite Ref (dBZ, Shaded)

U-V (m/s, Vector)

Sea Level Pressure (mb, contour)

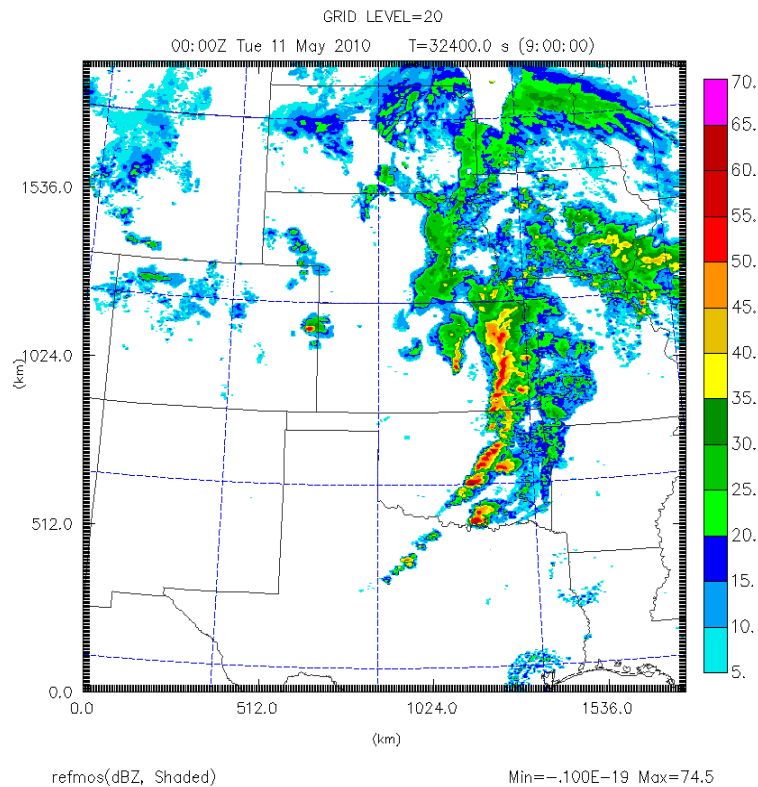
Min=0.00 Max=62.5

Umin=-14.02 Umax=18.24 Vmin=-16.97 Vmax=22.81

Min=995.1 Max=1025.1 inc=4.000

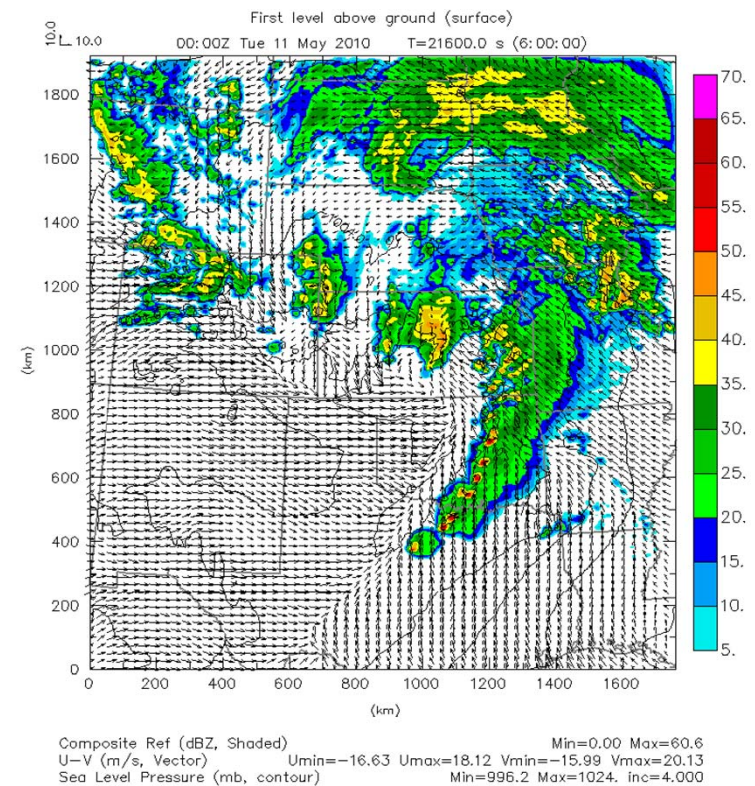
CAPS real-time forecast (6h)

Observed radar reflectivity mosaic



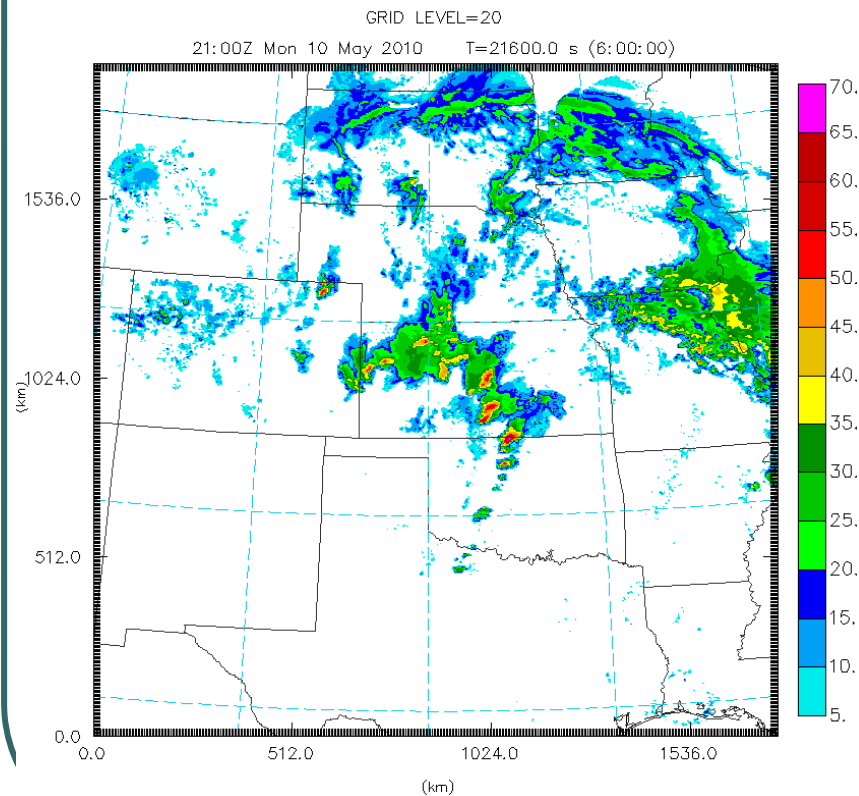
WRF ARW forecast reflectivity

SPV4C0 (440x480x50, dx=4 km)
6:00 h WRF/ARW Forecast valid 0000Z Tue 11 May 2010

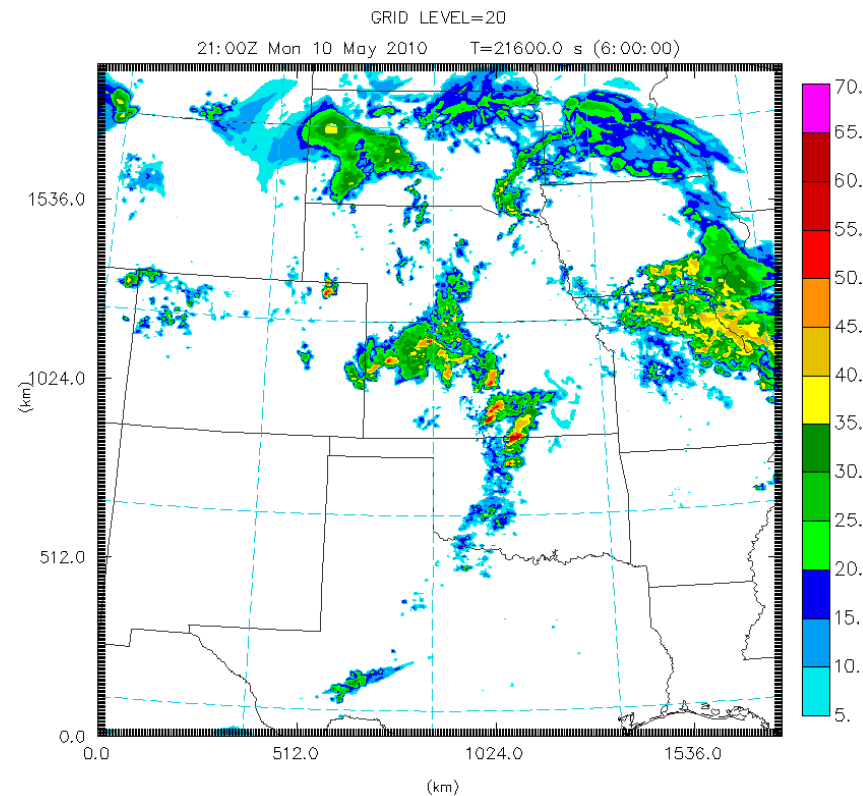


Analysis at 2100 UTC

Observed radar reflectivity mosaic



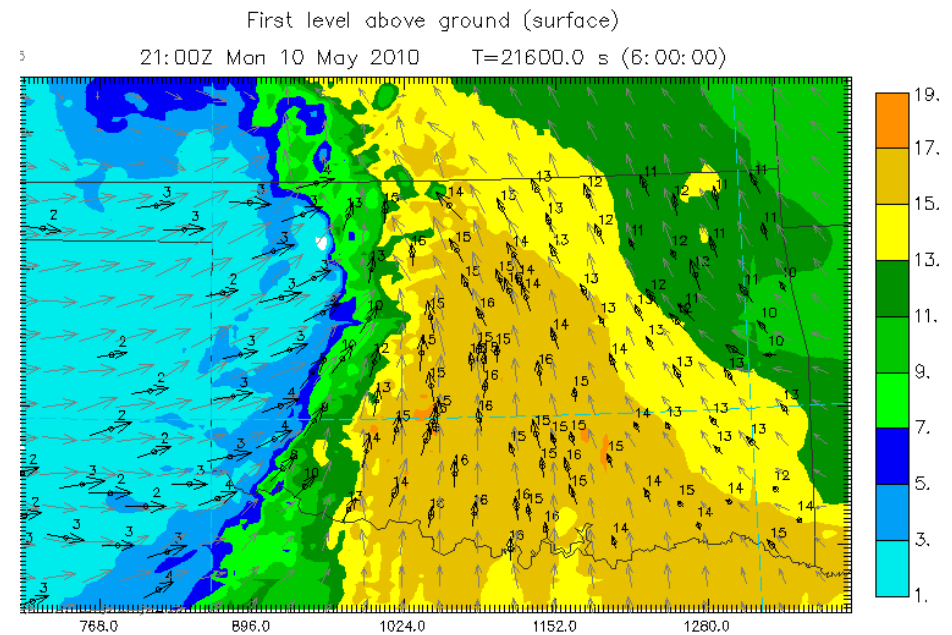
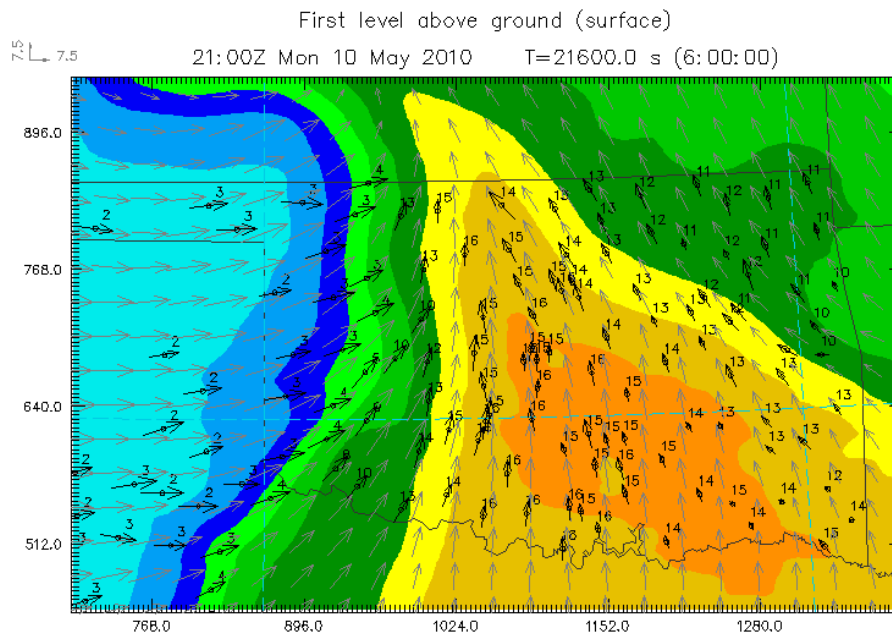
Model reflectivity at 2100 UTC



Analysis at 2100 UTC

40 km regional EnKF analysis

4 km storm-scale EnKF analysis



Surface q_v (shade, g/kg) and wind (m/s)



Experiments

CNTL_2100

DA_2100

15 Z

18 Z

21 Z

CNTL_1800

DA_1800

15 Z

18 Z

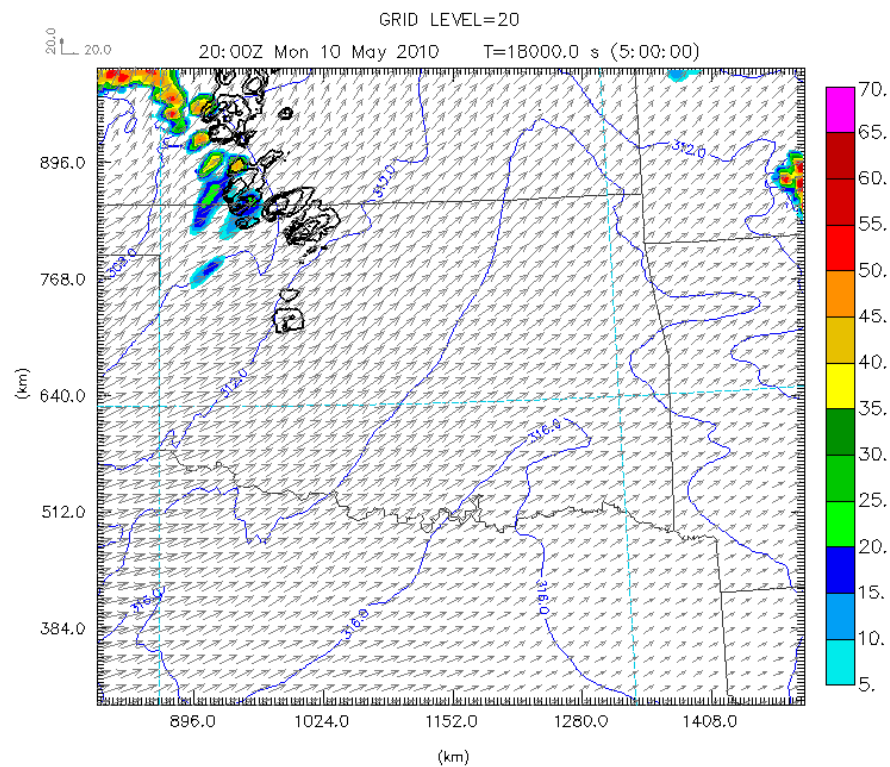
CNTL_1500

Deterministic and ensemble forecast



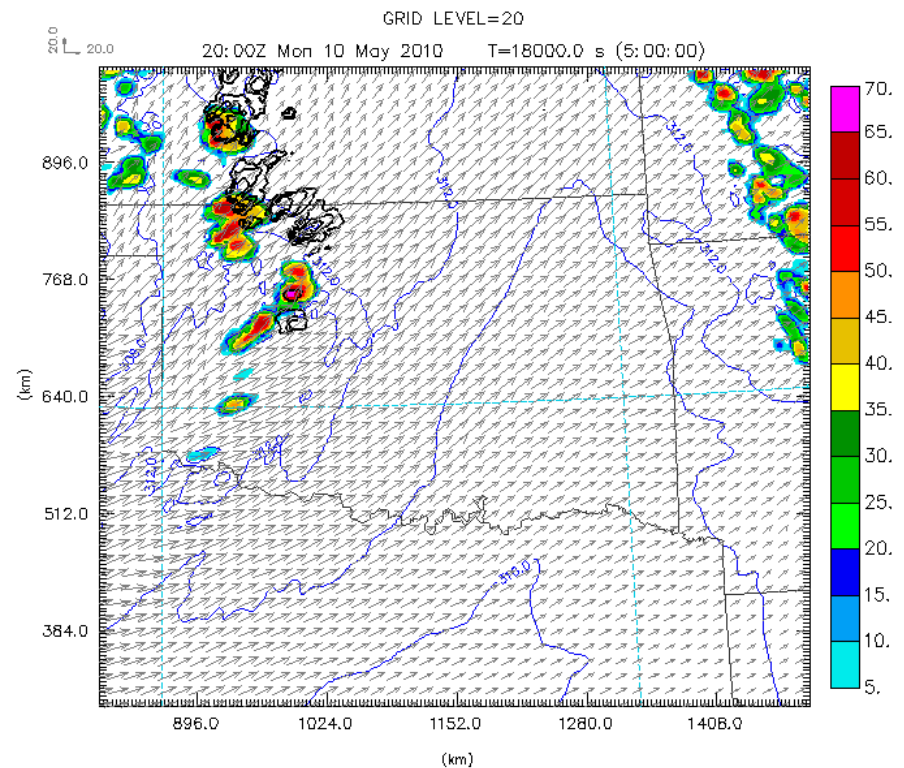
Deterministic forecasts (1h)

CNTL_1800



pt (K, contour) Min=306.0 Max=316.9 inc=2.000
Ref (dBZ, Shaded) Min=0.00 Max=62.3
refmos(dBZ, contour) Min=-.1000E-19 Max=61.00 inc=10.00
U-V (m/s, Vector) Umin=1.43 Umax=34.93 Vmin=4.56 Vmax=31.05

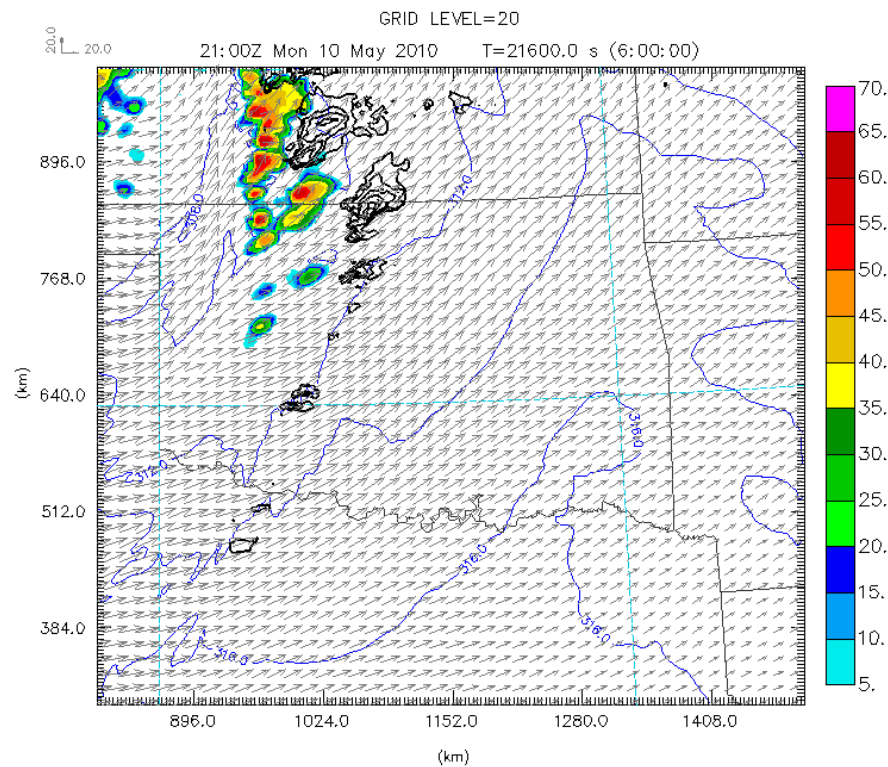
DA_1800



pt (K, contour) Min=304.9 Max=318.5 inc=2.000
Ref (dBZ, Shaded) Min=0.00 Max=68.0
refmos(dBZ, contour) Min=-.1000E-19 Max=61.00 inc=10.00
U-V (m/s, Vector) Umin=-1.13 Umax=43.66 Vmin=3.57 Vmax=38.91

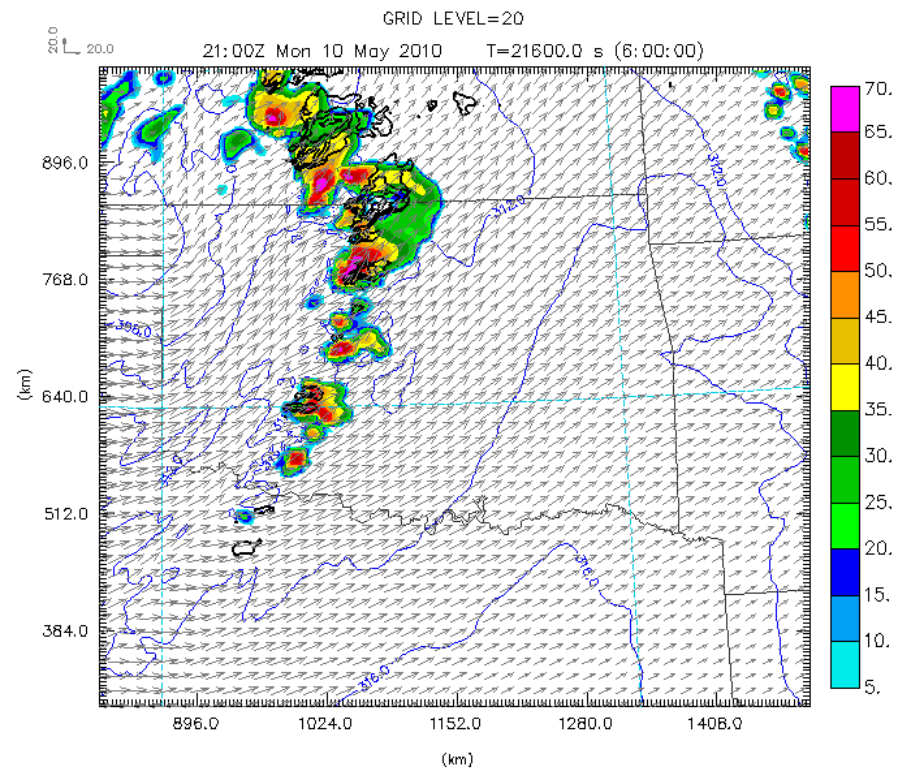
Deterministic forecasts (2h)

CNTL_1800



pt (K, contour) Min=306.4 Max=316.9 inc=2.000
 Ref (dBZ, Shaded) Min=0.00 Max=61.8
 refmos(dBZ, contour) Min=-.1000E-19 Max=69.49 inc=10.00
 U-V (m/s, Vector) Umin=-1.58 Umax=36.92 Vmin=-8.76 Vmax=33.57

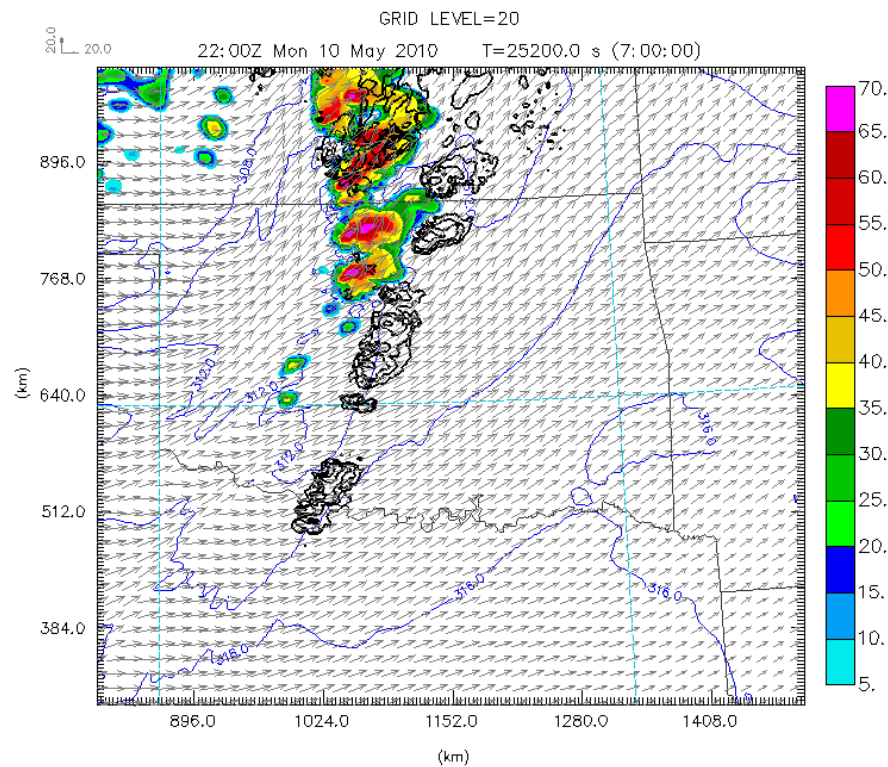
DA_1800



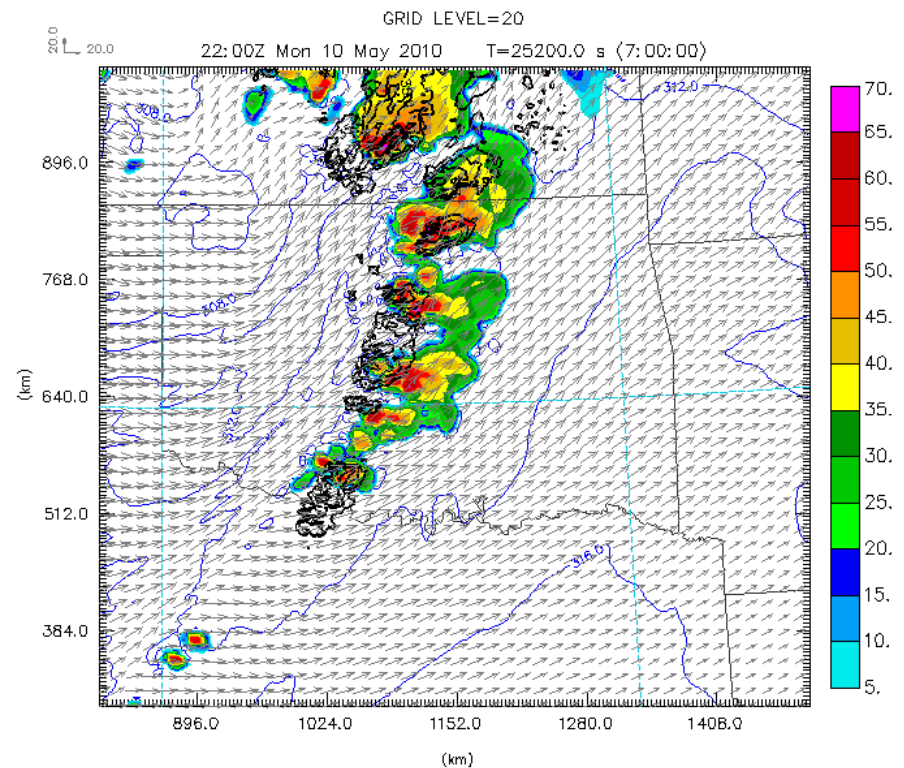
pt (K, contour) Min=304.8 Max=319.3 inc=2.000
 Ref (dBZ, Shaded) Min=0.00 Max=70.0
 refmos(dBZ, contour) Min=-.1000E-19 Max=69.49 inc=10.00
 U-V (m/s, Vector) Umin=-6.08 Umax=51.76 Vmin=-8.18 Vmax=44.57

Deterministic forecasts (3h)

CNTL_1800

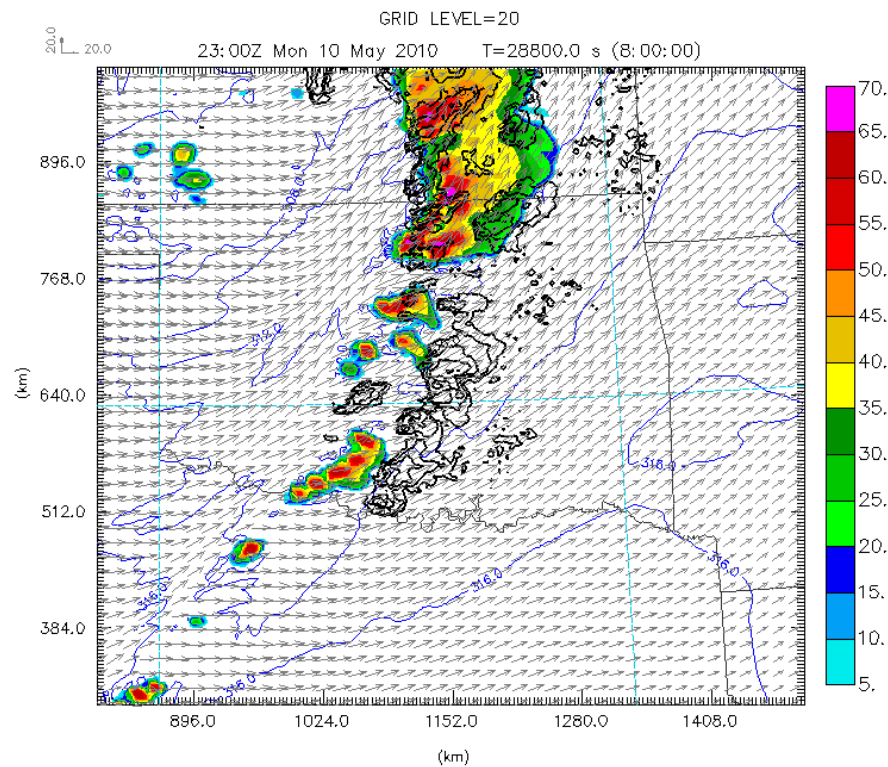


DA_1800

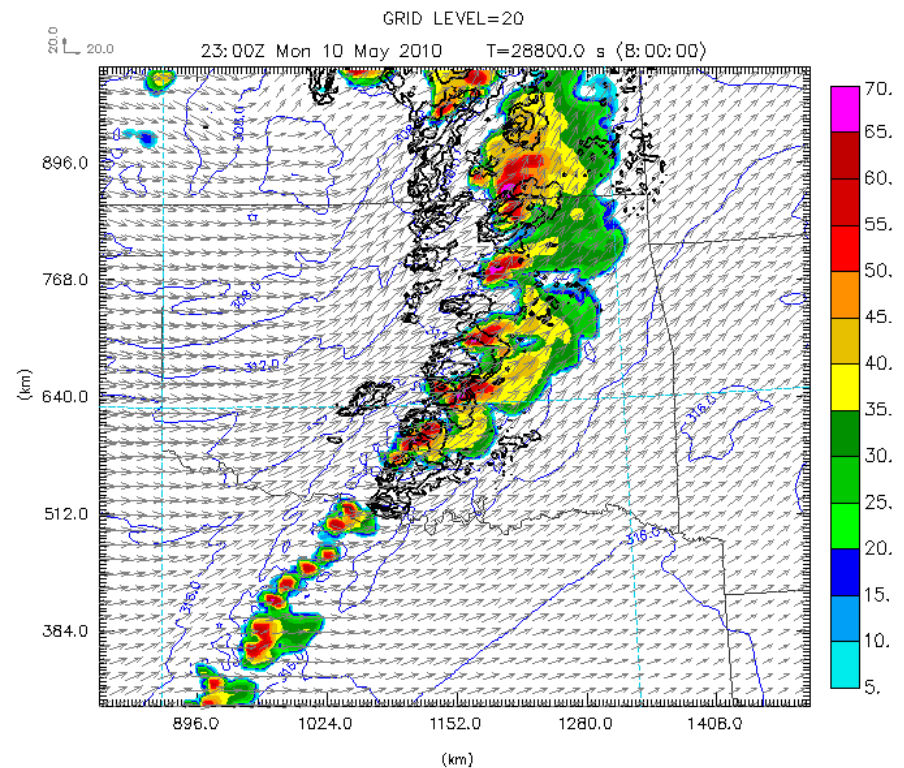


Deterministic forecasts (4h)

CNTL_1800

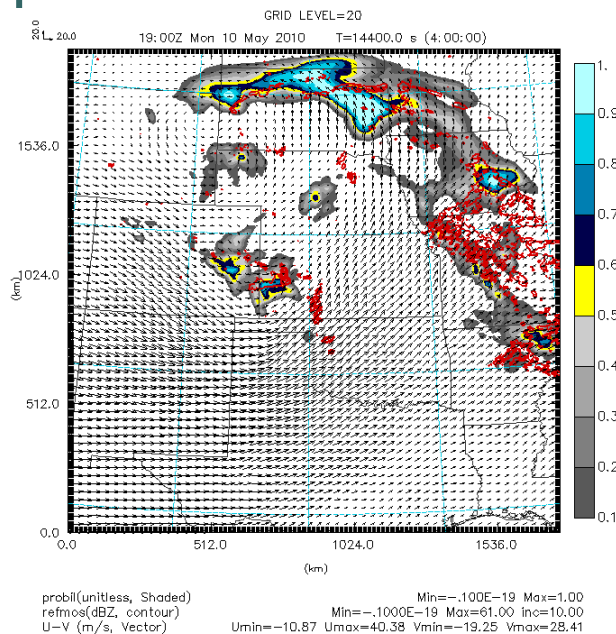


DA_1800

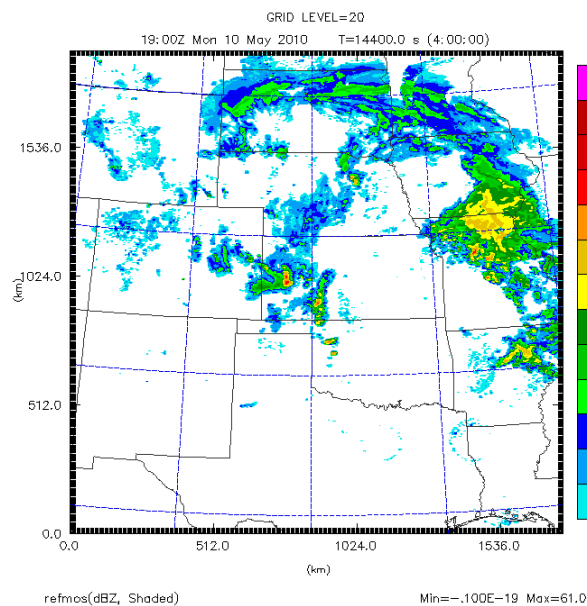


Ensemble probability (1h)

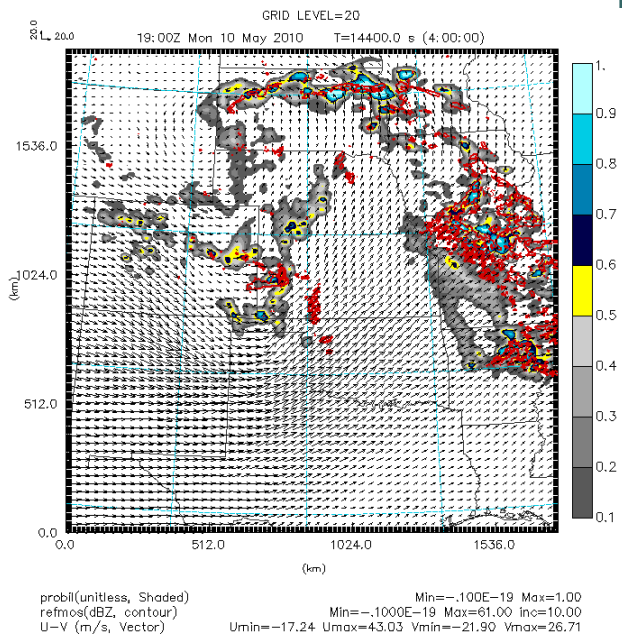
CNTL_1800



mosaic



DA_1800



Probability (shade, $Z_H > 25$ dBZ, $r = 10$ km)
Observed Z (contour, ≥ 25 dBZ)

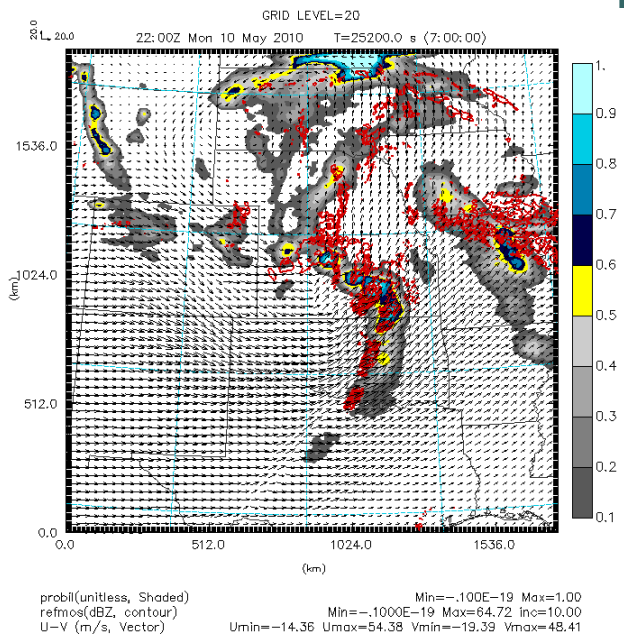
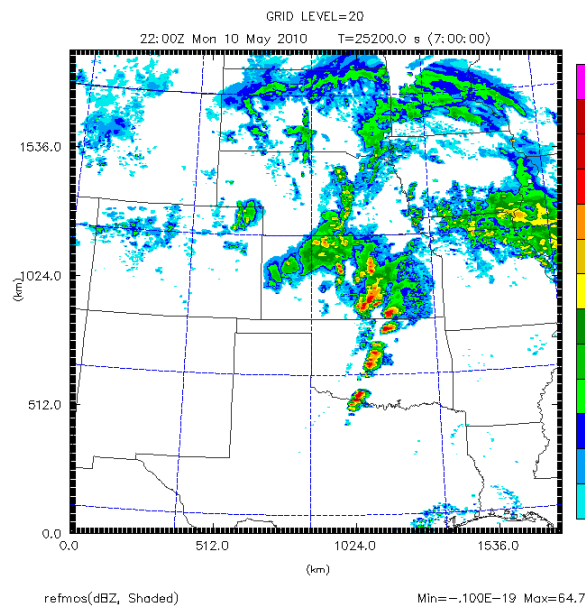
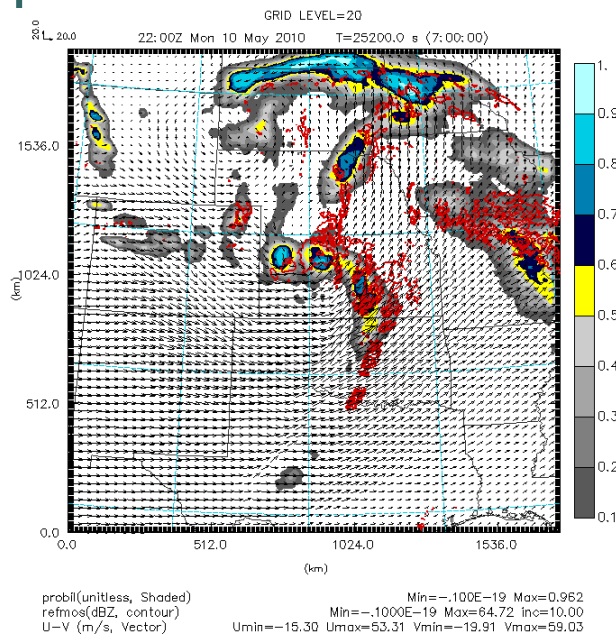


Ensemble probability (4h)

CNTL_1800

mosaic

DA_1800

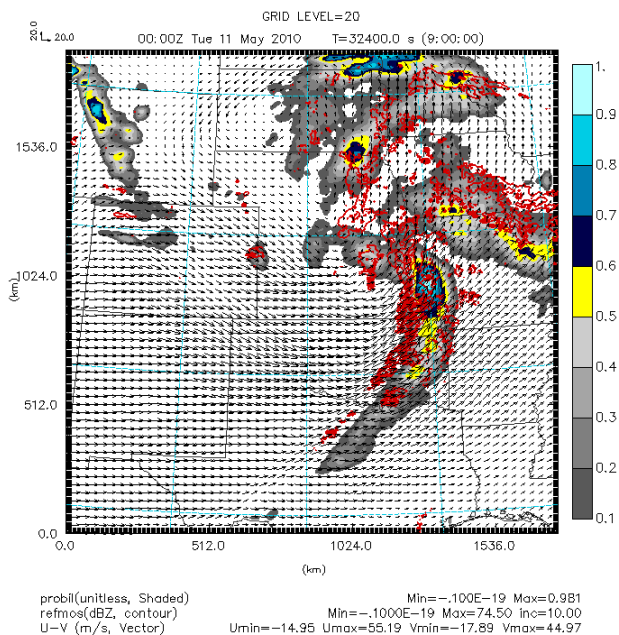
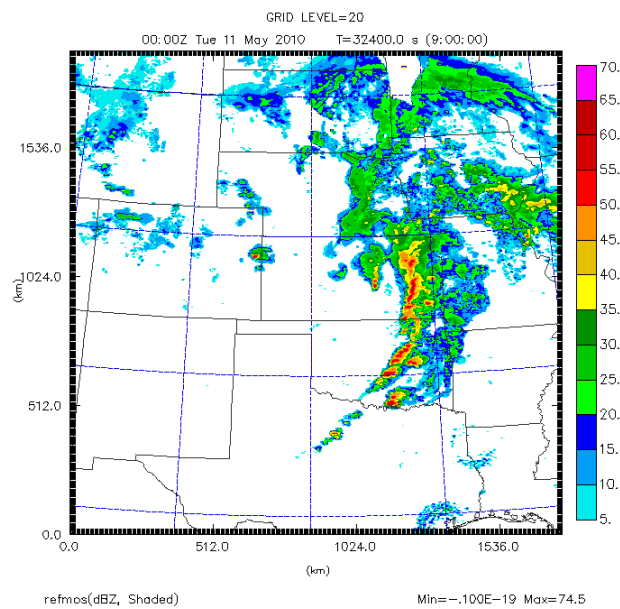
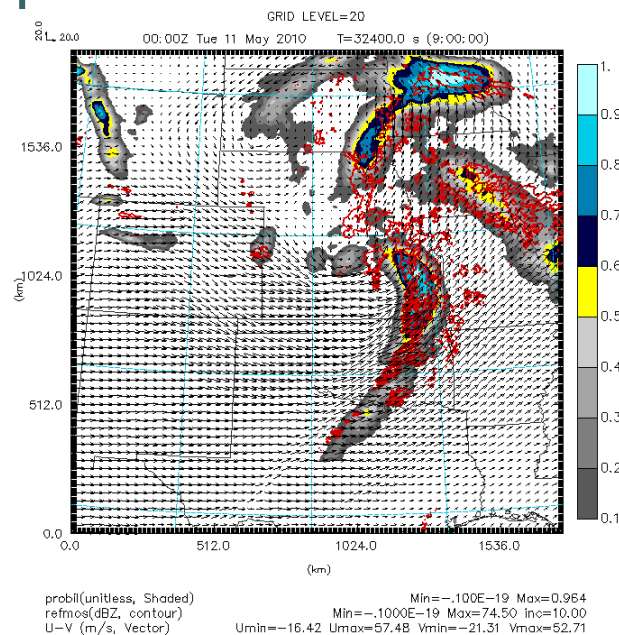


Ensemble probability (6h)

CNTL_1800

mosaic

DA_1800



Experiments

CNTL_2100

DA_2100

15 Z

18 Z

21 Z

CNTL_1800

DA_1800

15 Z

18 Z

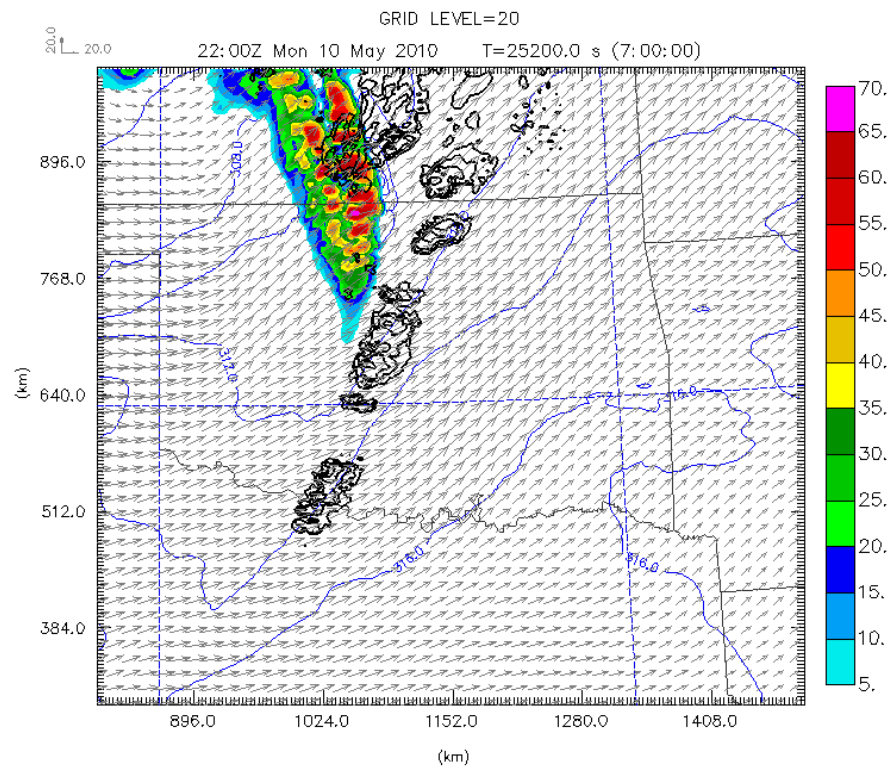
CNTL_1500

Deterministic and ensemble forecast

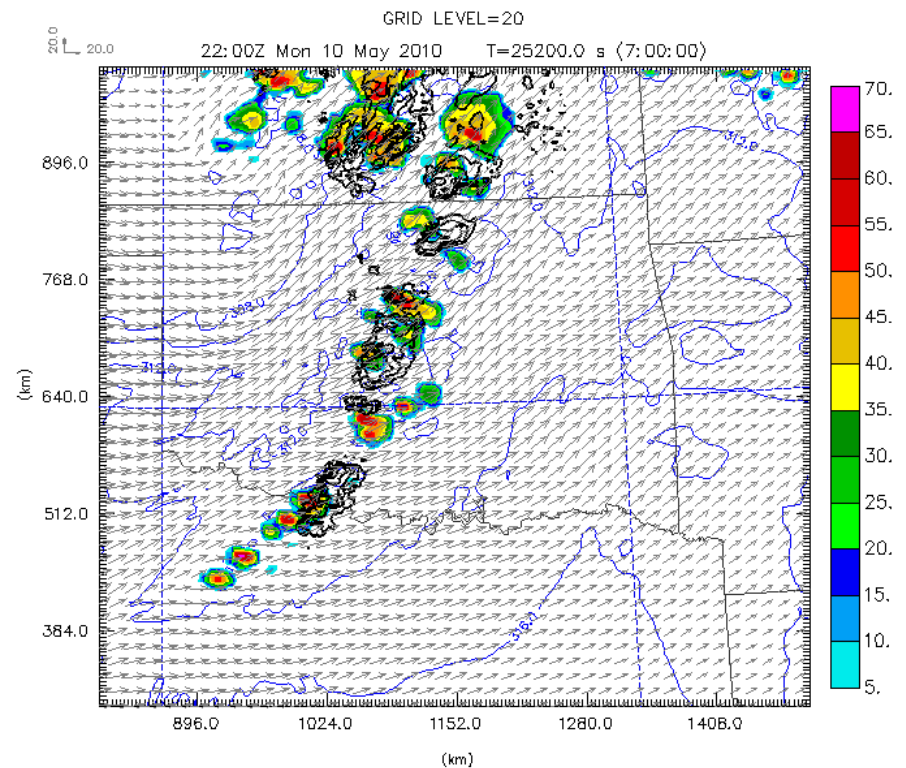


Deterministic forecasts (1h)

CNTL_2100

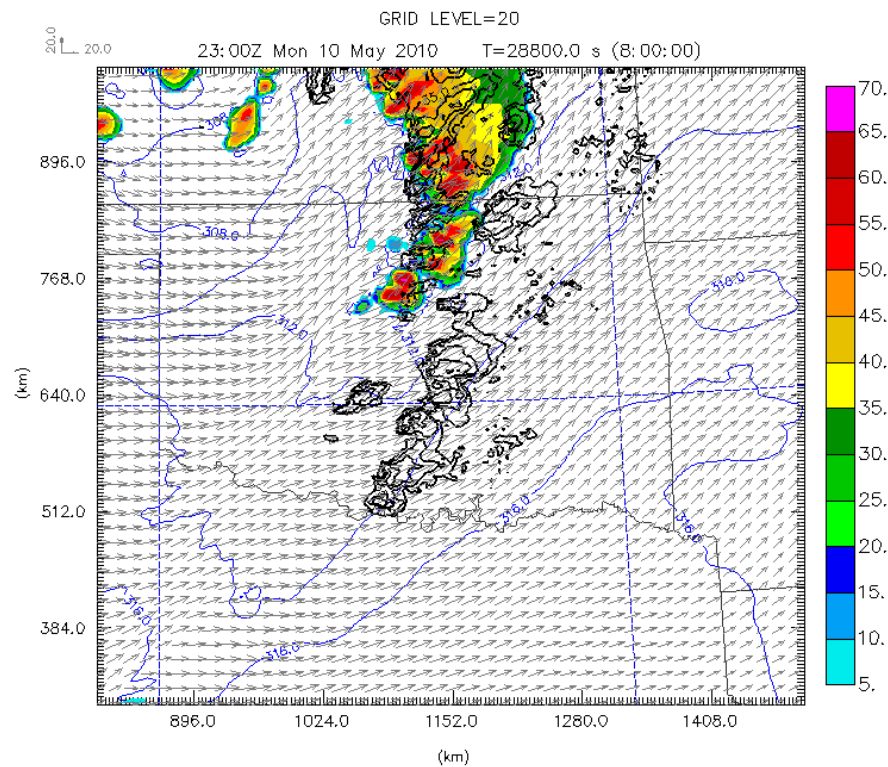


DA_2100

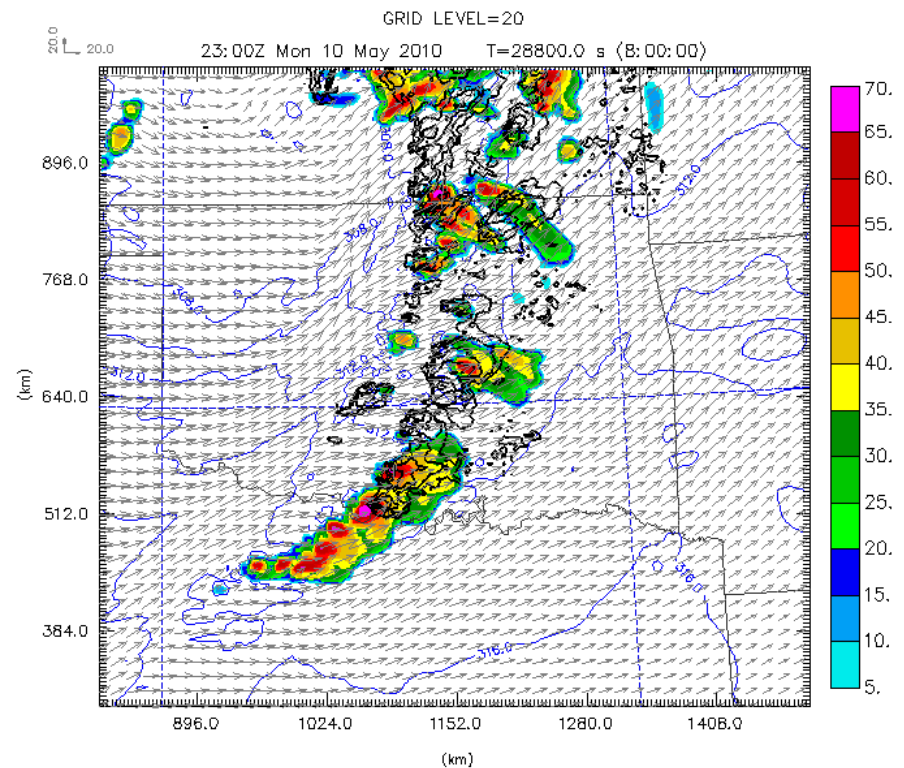


Deterministic forecasts (2h)

CNTL_2100

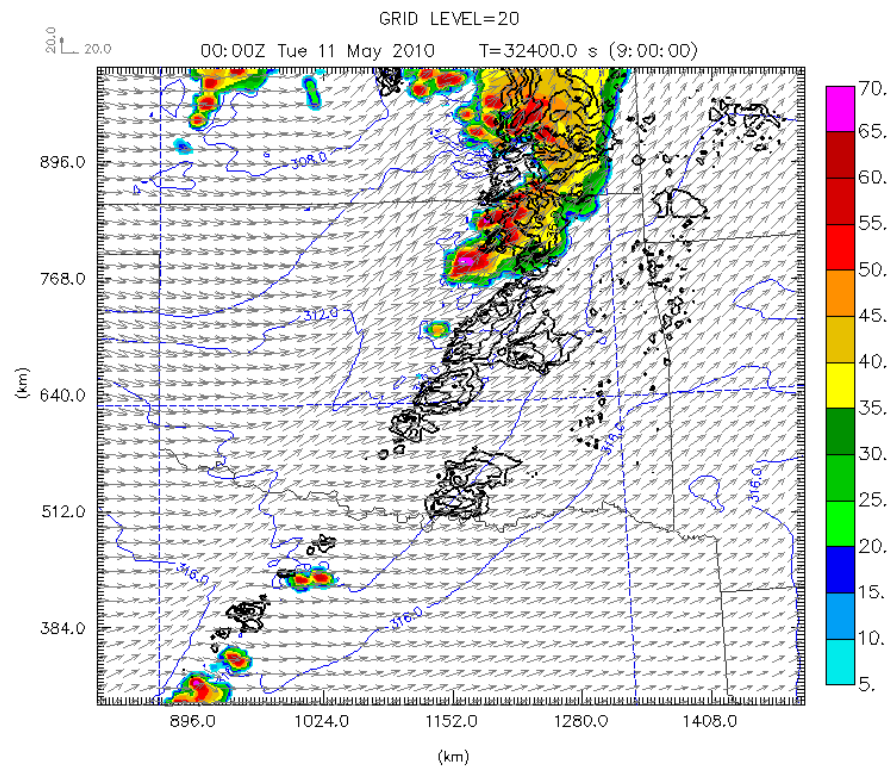


DA_2100



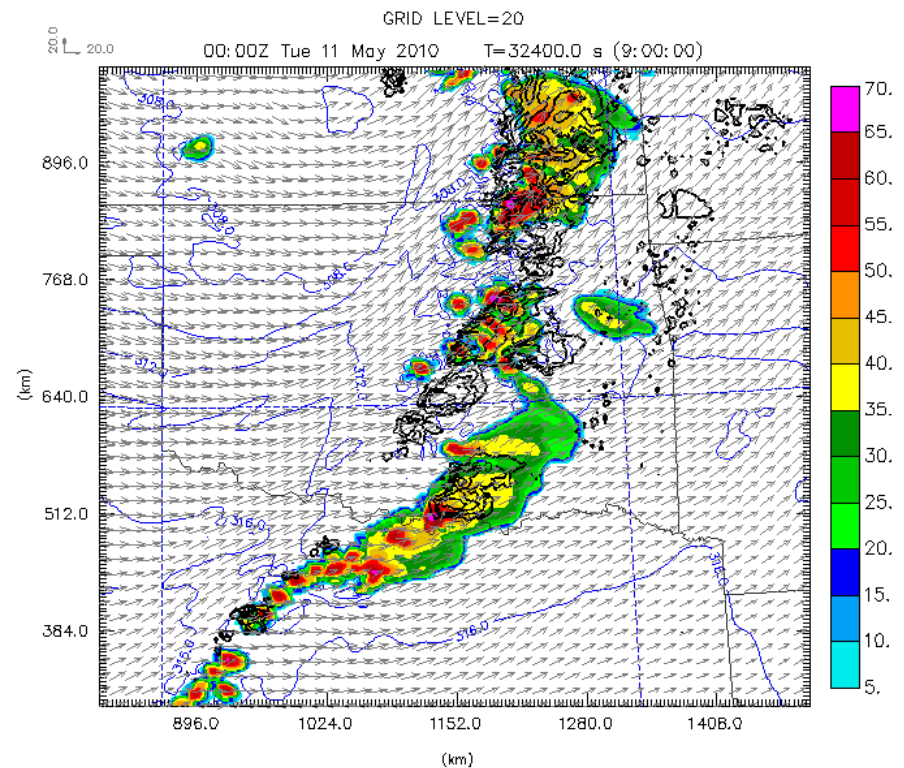
Deterministic forecasts (3h)

CNTL_2100



pt (K, contour) Min=306.5 Max=321.4 inc=2.000
 Ref (dBZ, Shaded) Min=0.00 Max=71.2
 refmos(dBZ, contour) Min=-.1000E-19 Max=63.97 inc=10.00
 U-V (m/s, Vector) Umin=-0.15 Umax=51.17 Vmin=-14.97 Vmax=45.57

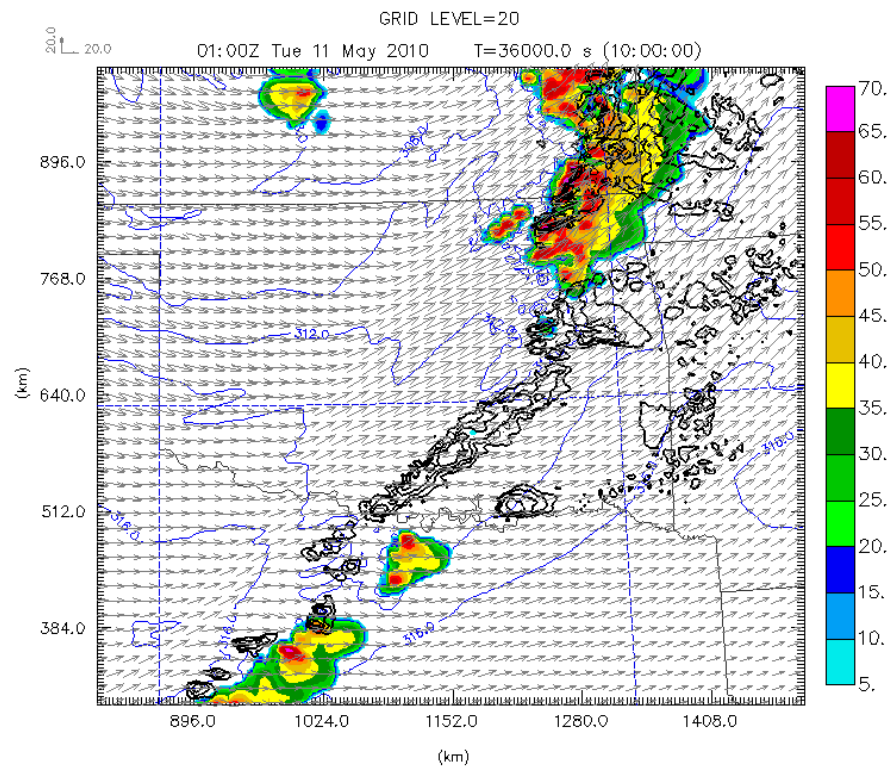
DA_2100



pt (K, contour) Min=305.5 Max=319.3 inc=2.000
 Ref (dBZ, Shaded) Min=0.00 Max=69.8
 refmos(dBZ, contour) Min=-.1000E-19 Max=63.97 inc=10.00
 U-V (m/s, Vector) Umin=-3.64 Umax=55.10 Vmin=-12.18 Vmax=44.75

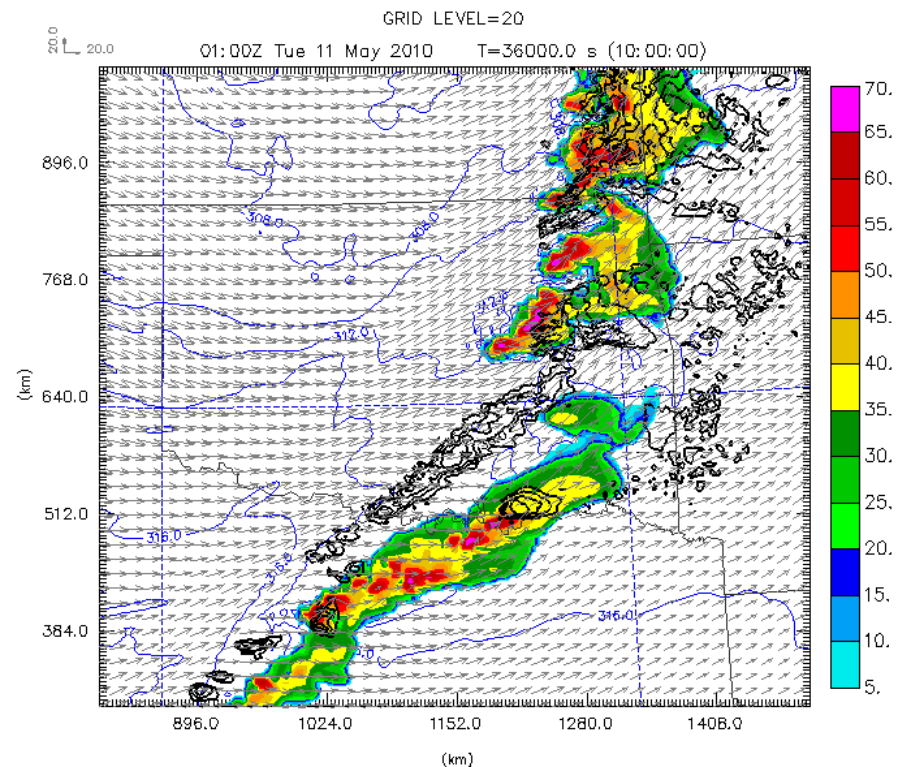
Deterministic forecasts (4h)

CNTL_2100



pt (K, contour) Min=306.4 Max=319.8 inc=2.000
Ref (dBZ, Shaded) Min=0.00 Max=68.7
refmos(dBZ, contour) Min=-.1000E-19 Max=65.00 inc=10.00
U-V (m/s, Vector) Umin=-3.18 Umax=55.45 Vmin=-14.46 Vmax=47.92

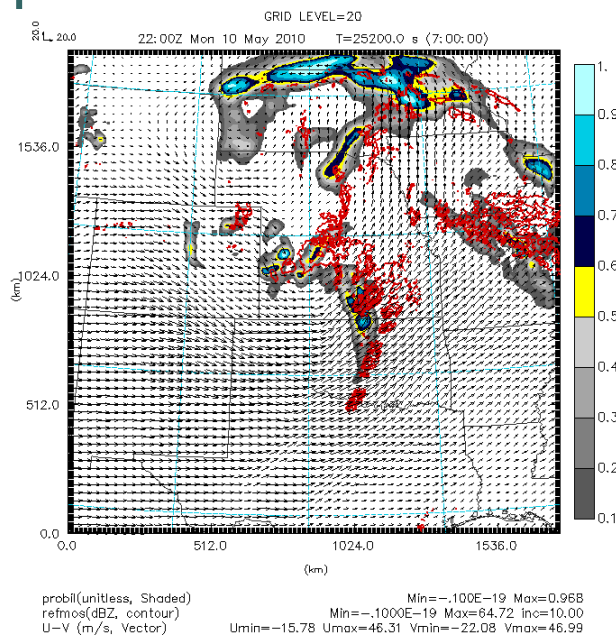
DA_2100



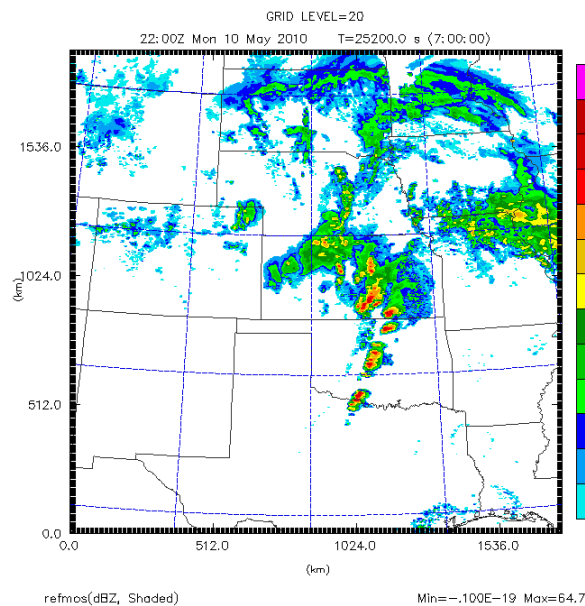
pt (K, contour) Min=305.3 Max=321.3 inc=2.000
Ref (dBZ, Shaded) Min=0.00 Max=69.8
refmos(dBZ, contour) Min=-.1000E-19 Max=65.00 inc=10.00
U-V (m/s, Vector) Umin=1.89 Umax=55.35 Vmin=-16.05 Vmax=45.25

Ensemble probability (1h)

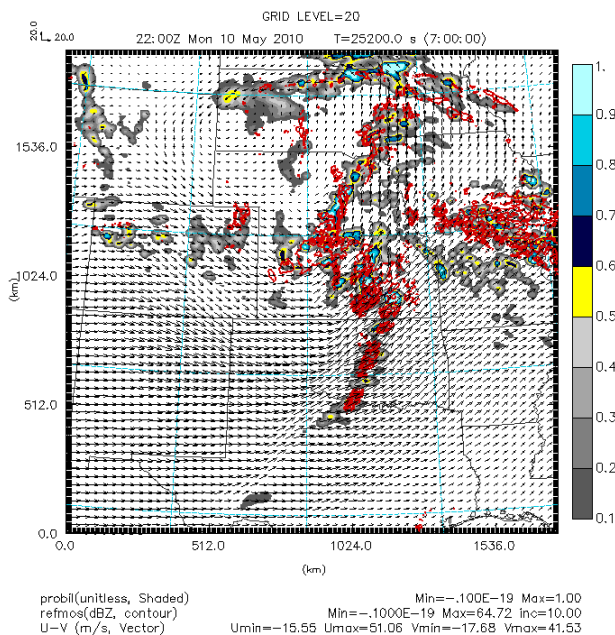
CNTL_2100



mosaic

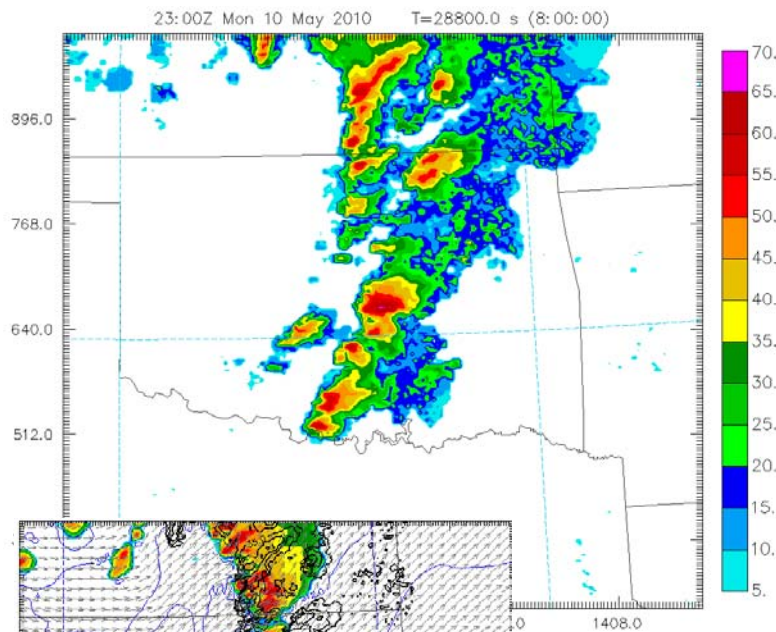


DA_2100

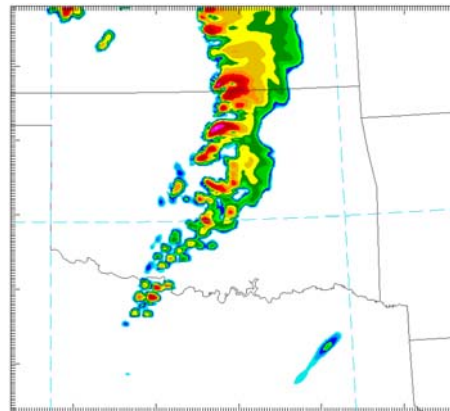


Some members of CNTL_2100 (2h)

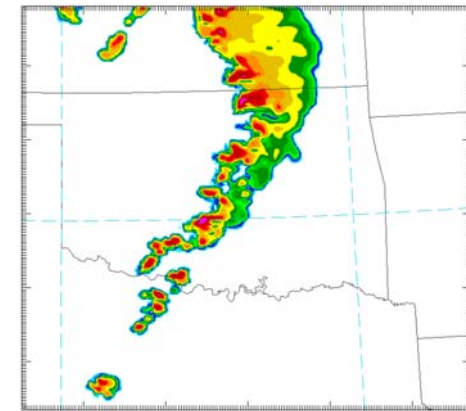
observation



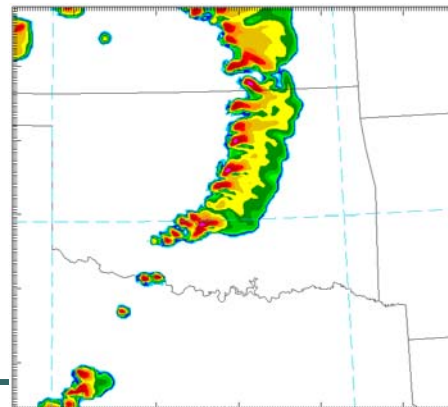
Member 6



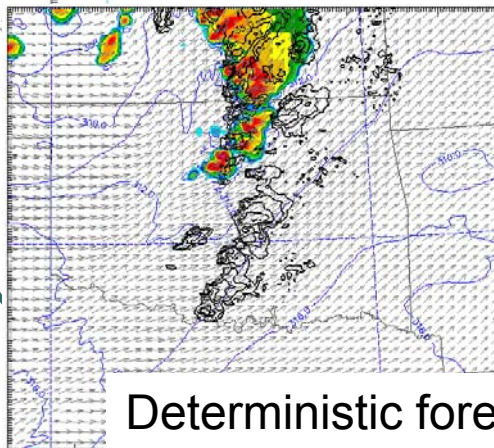
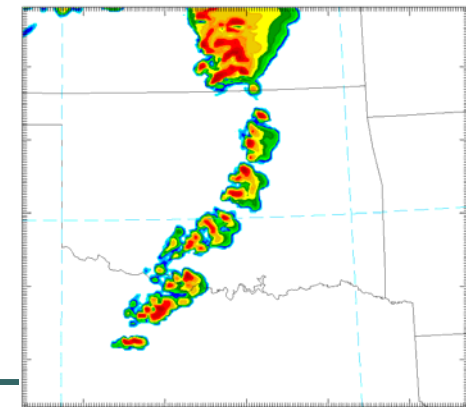
Member 30



Member 4



Member 33



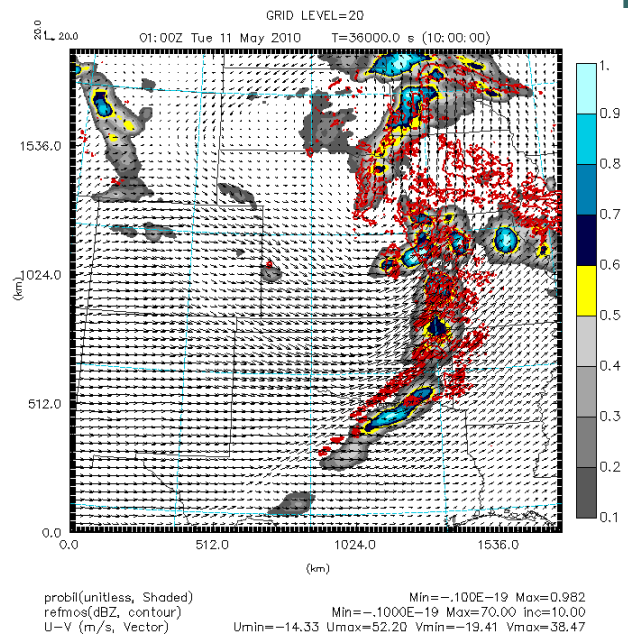
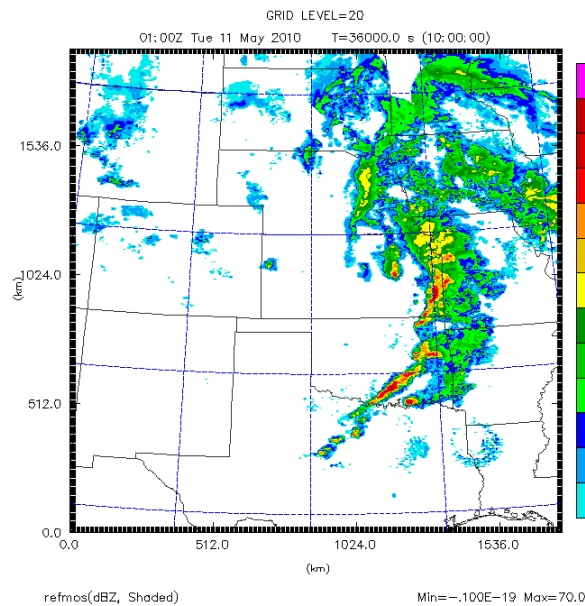
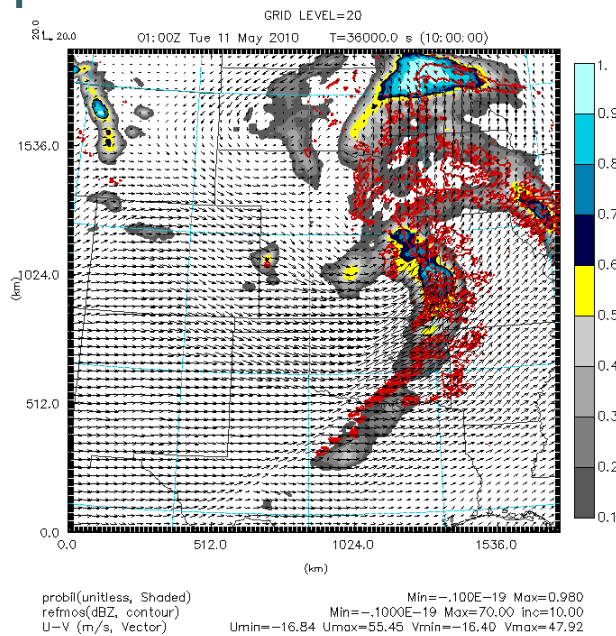
Deterministic forecast

Ensemble probability (4h)

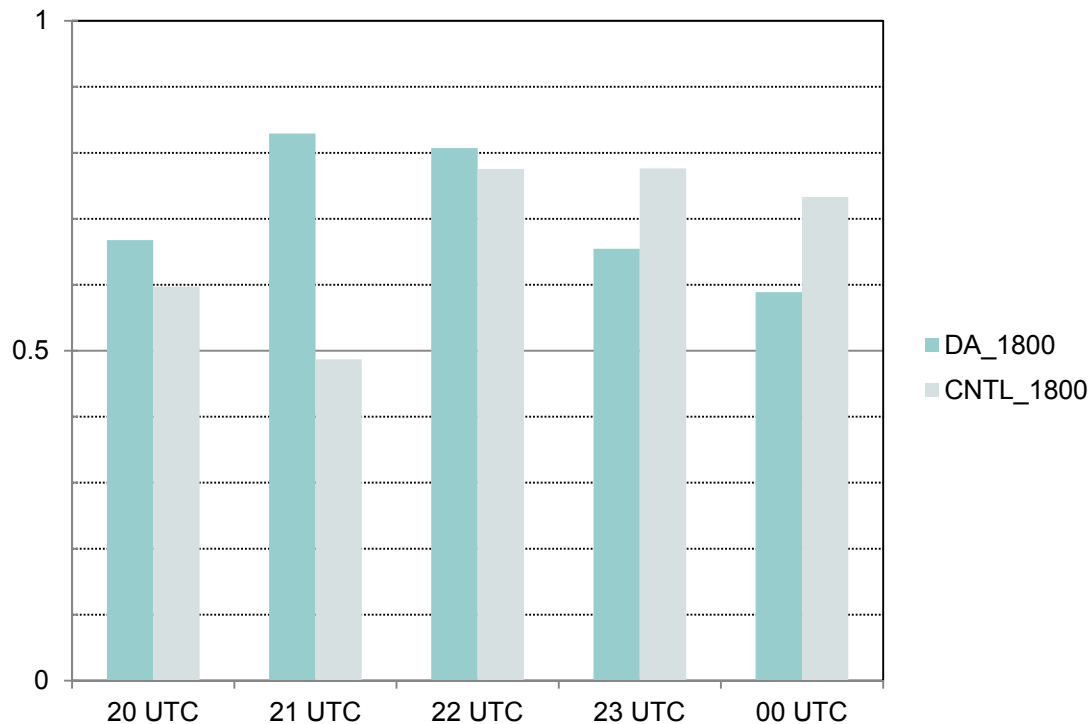
CNTL_2100

mosaic

DA_2100



ROC skill score (OK domain)



- ROC skill score is generally higher than 0.5 throughout the forecast period.
- DA_1800 shows lower score after 2300 UTC because of the higher false alarm rate.



Summary

- A hybrid parallel scheme based on domain decomposition shows good scalability for dense radar observations.
- The analyzed reflectivity, wind, and moisture field at the end of the assimilation window exhibited a good fit with the observations in shape, structure, and magnitude.
- A line of cells with supercell characteristics in central Kansas and Oklahoma was well-captured by the storm-scale deterministic and ensemble forecasts.
- The benefit of storm-scale DA is clear in early forecast periods.
- Several members of CNTL_2100 were able to predict convective storms in central and southern Oklahoma even when a deterministic forecast failed to predict them, suggesting the benefit of ensemble forecasts.

Future work

- Tune the EnKF system to further improve the analyses and forecasts.
- Compare the performance of the no-cycled and partially-cycled experiments.
- Apply the EnKF system to the CONUS domain and assess its computational requirement.

