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

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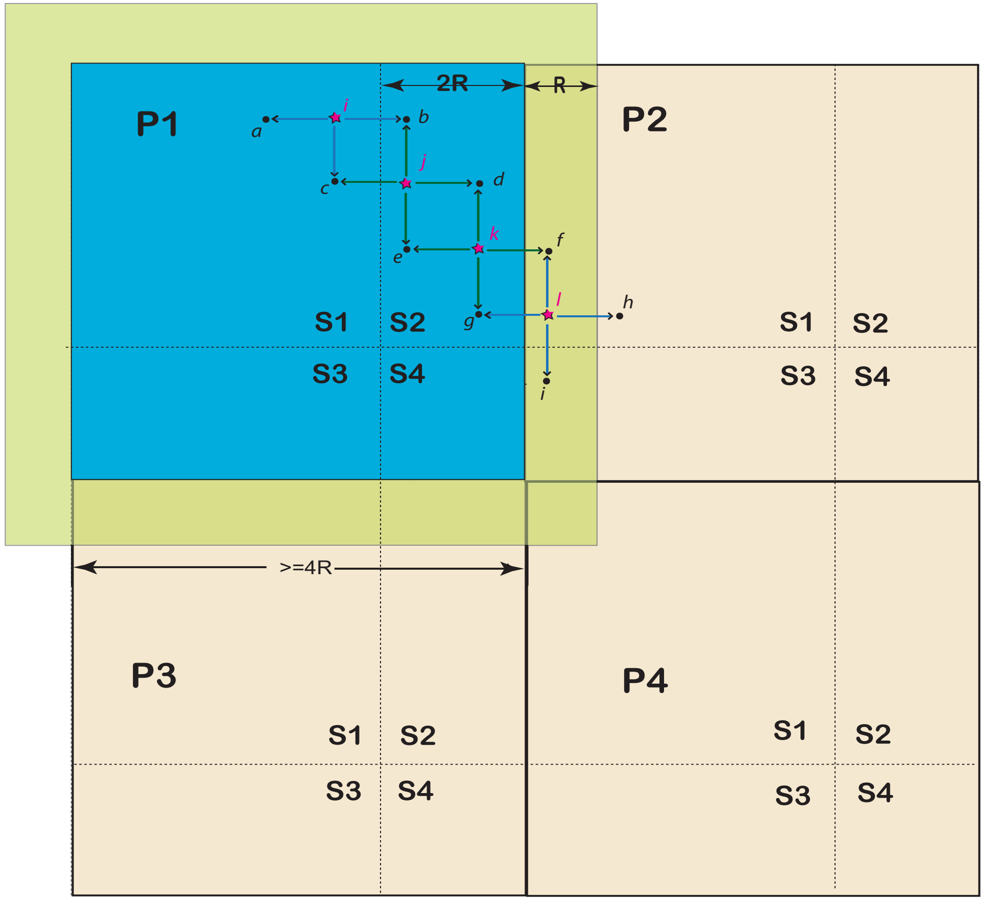
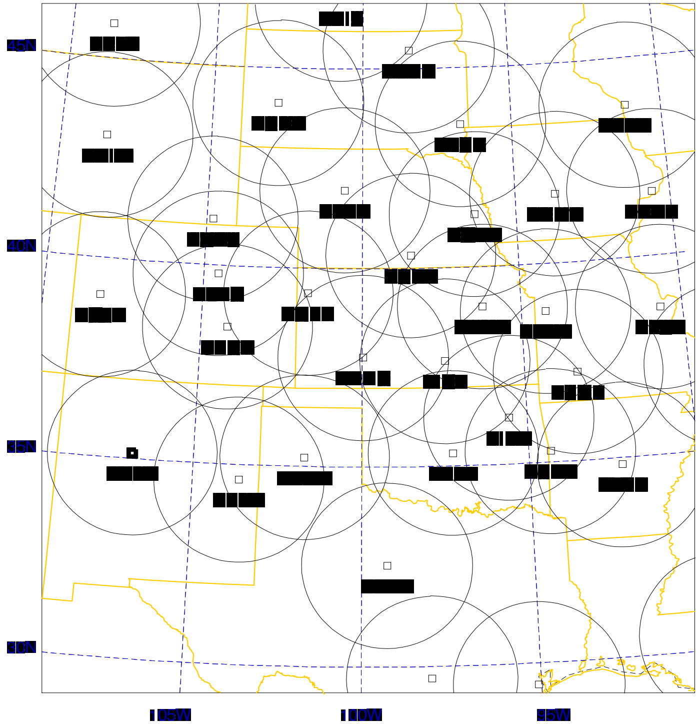
Goal

- 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

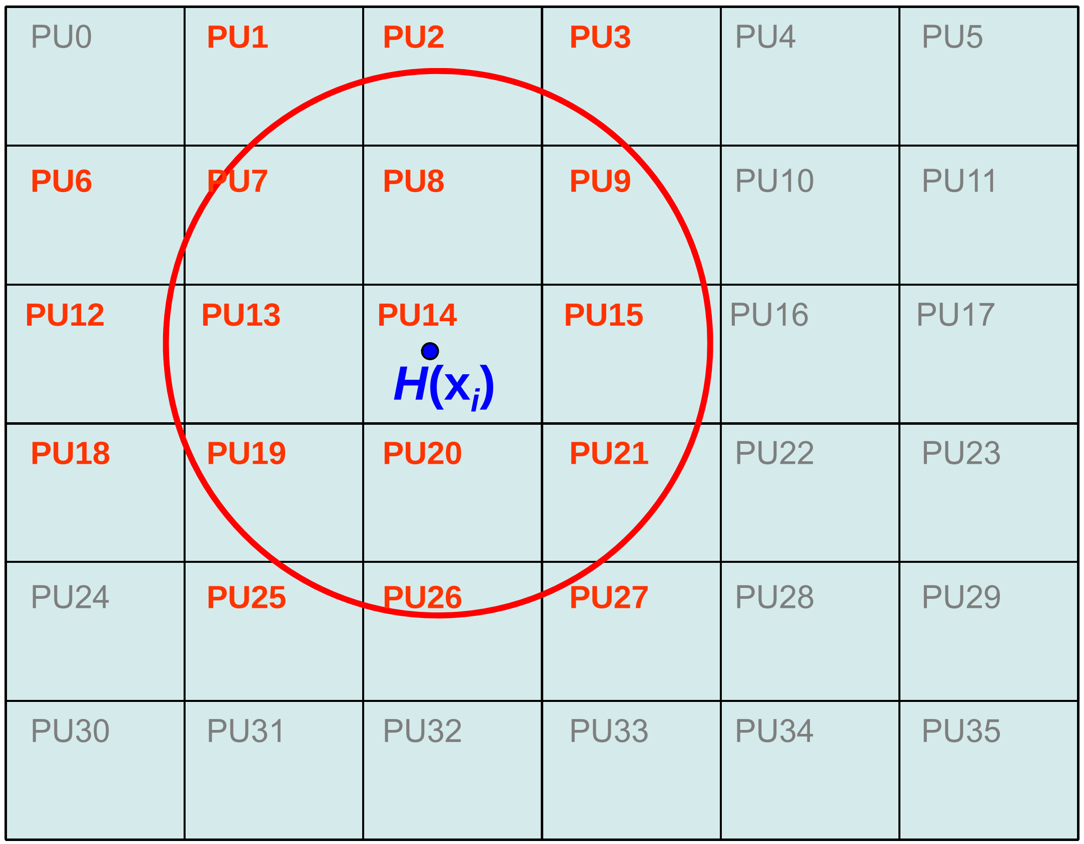
Parallel EnSRF algorithm suitable for dense radar data using domain decomposition





Wang et al. (2012)

Treatment of conventional data



1) Compute $H(x_i)$

2) Broadcast $H(x_i)$

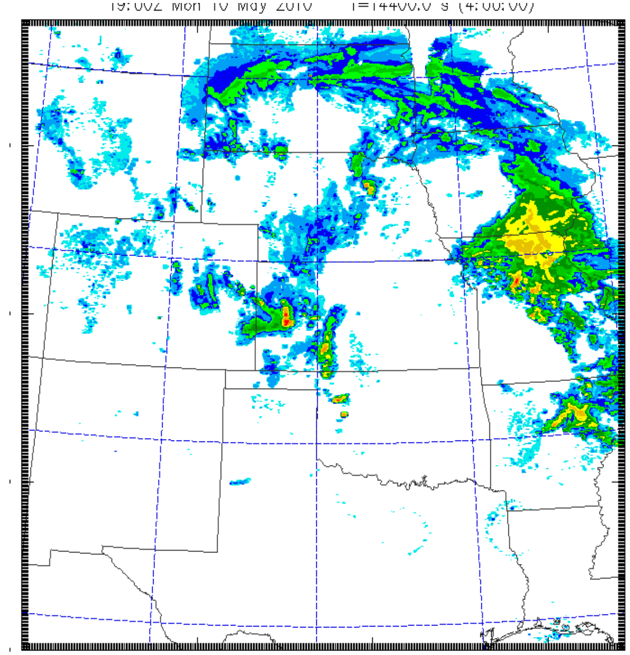
3) Parallel update of x_i

Wang et al. (2012)

Timing benchmark

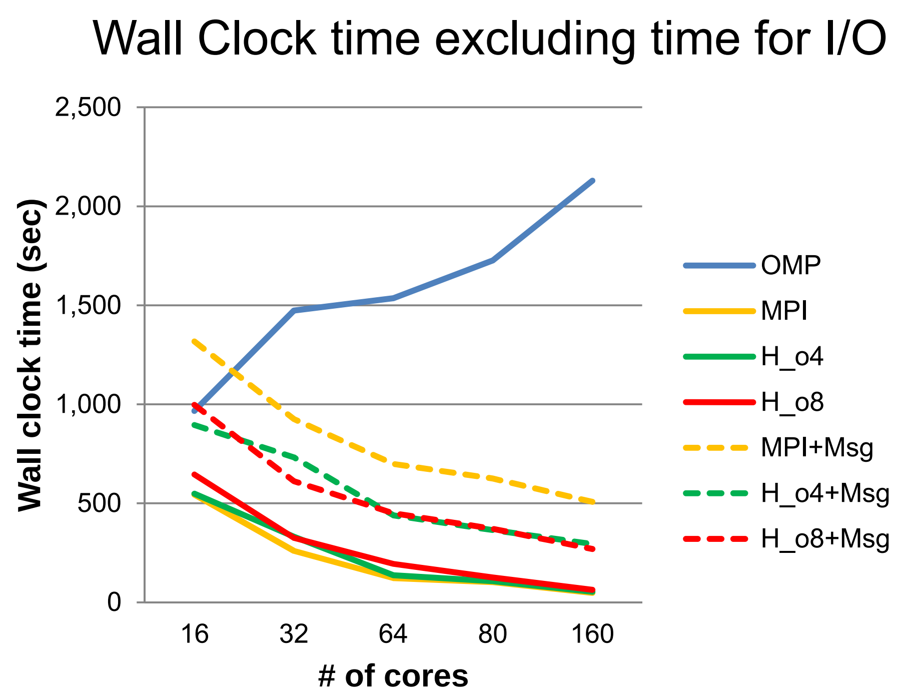
Number of observations assimilated

- 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)



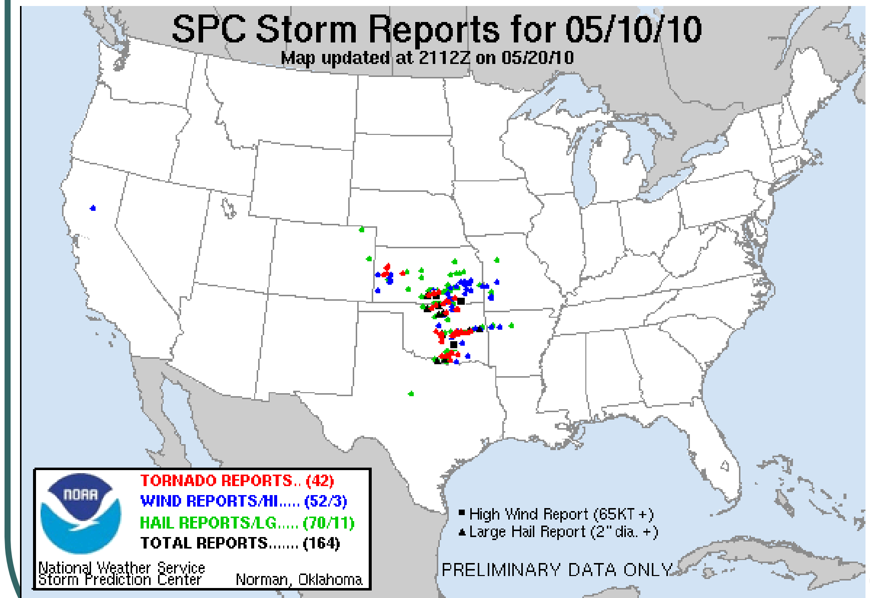
Performance statistics

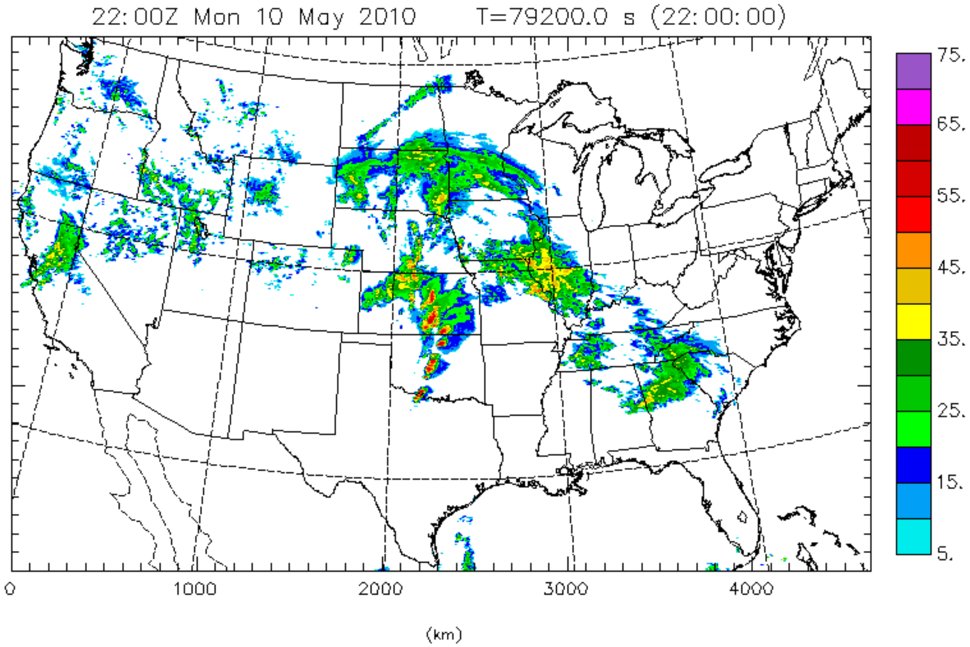
- NICS Kraken (4 PEs x 6 PEs x 3 threads)
  - Two 2.6 GHZ six-core-AMD Opteron processors
  - Peak performance: 1.17 Pflops
  - Radar assimilation: 1.99 min excluding IO (4x6 subdomains)

- 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

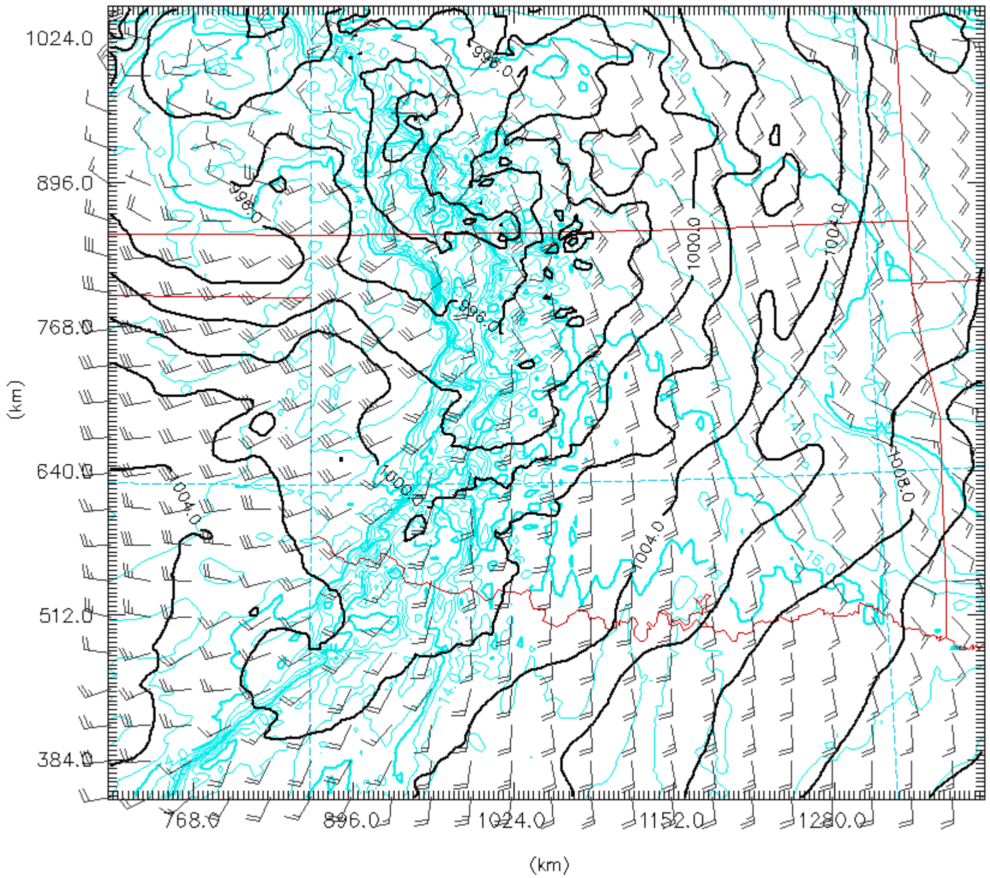
- Overview
  - Spawned over 40 tornadoes, with up to EF4 intensity



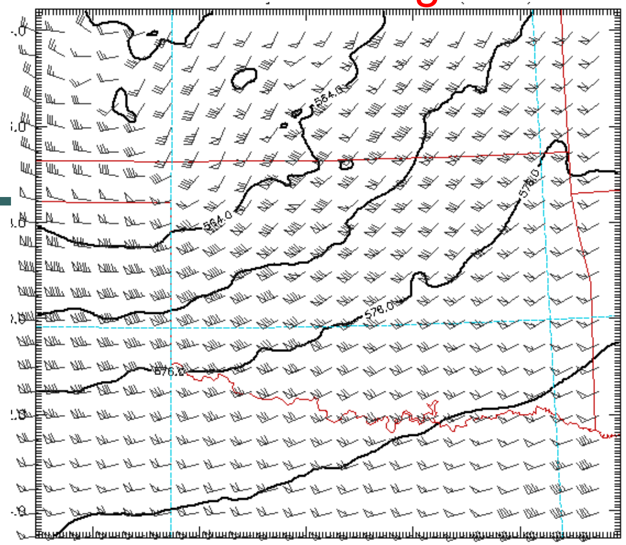


2100 UTC analysis

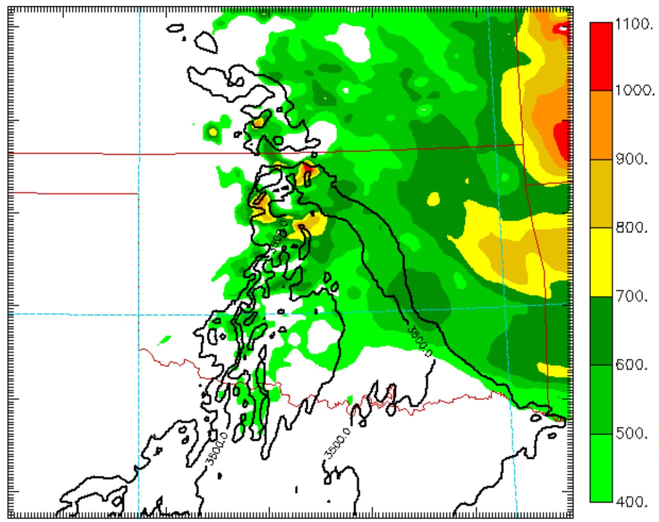
MSLP (hPa) and q_v (g/kg)



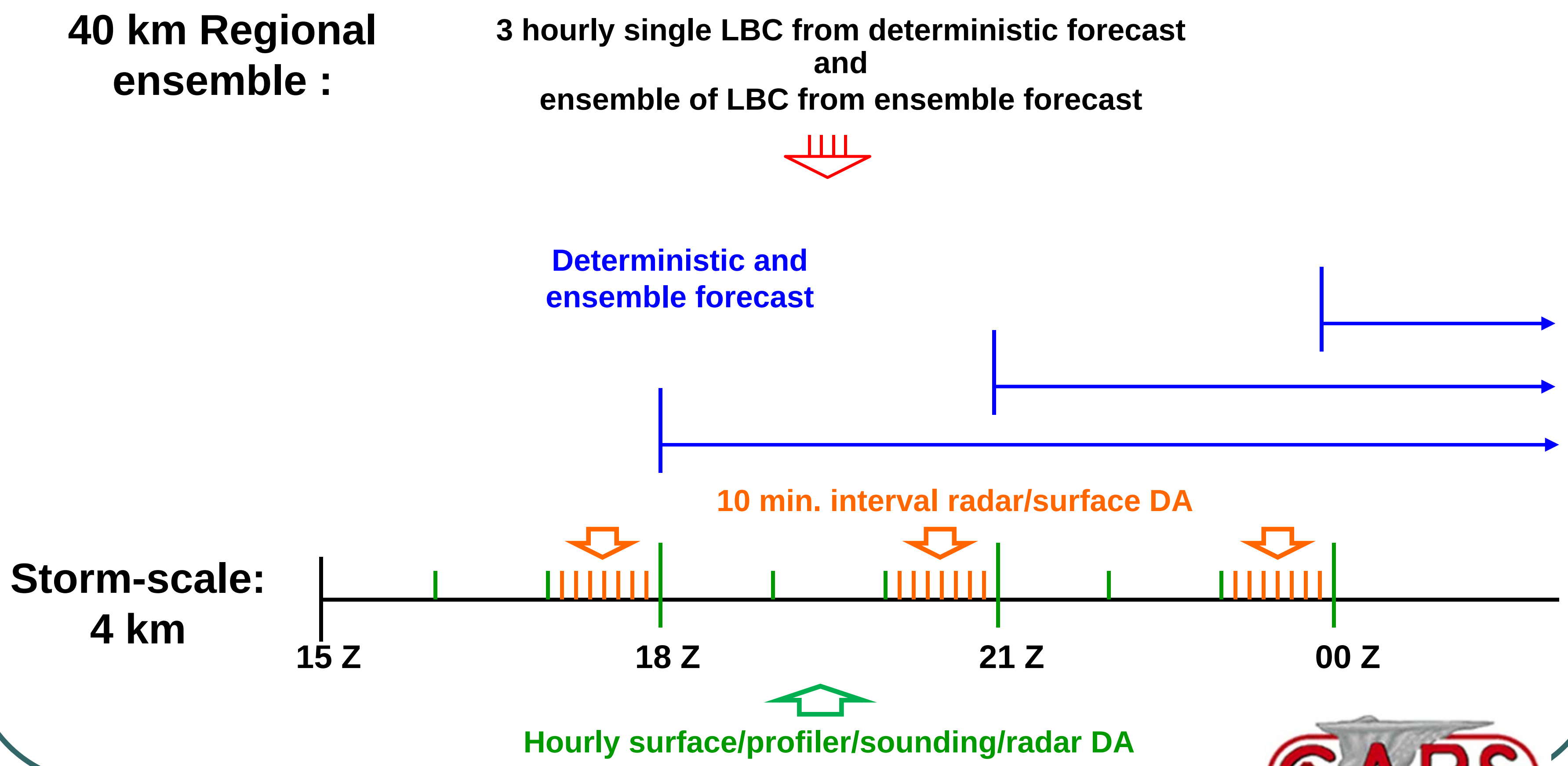
500 hPa height



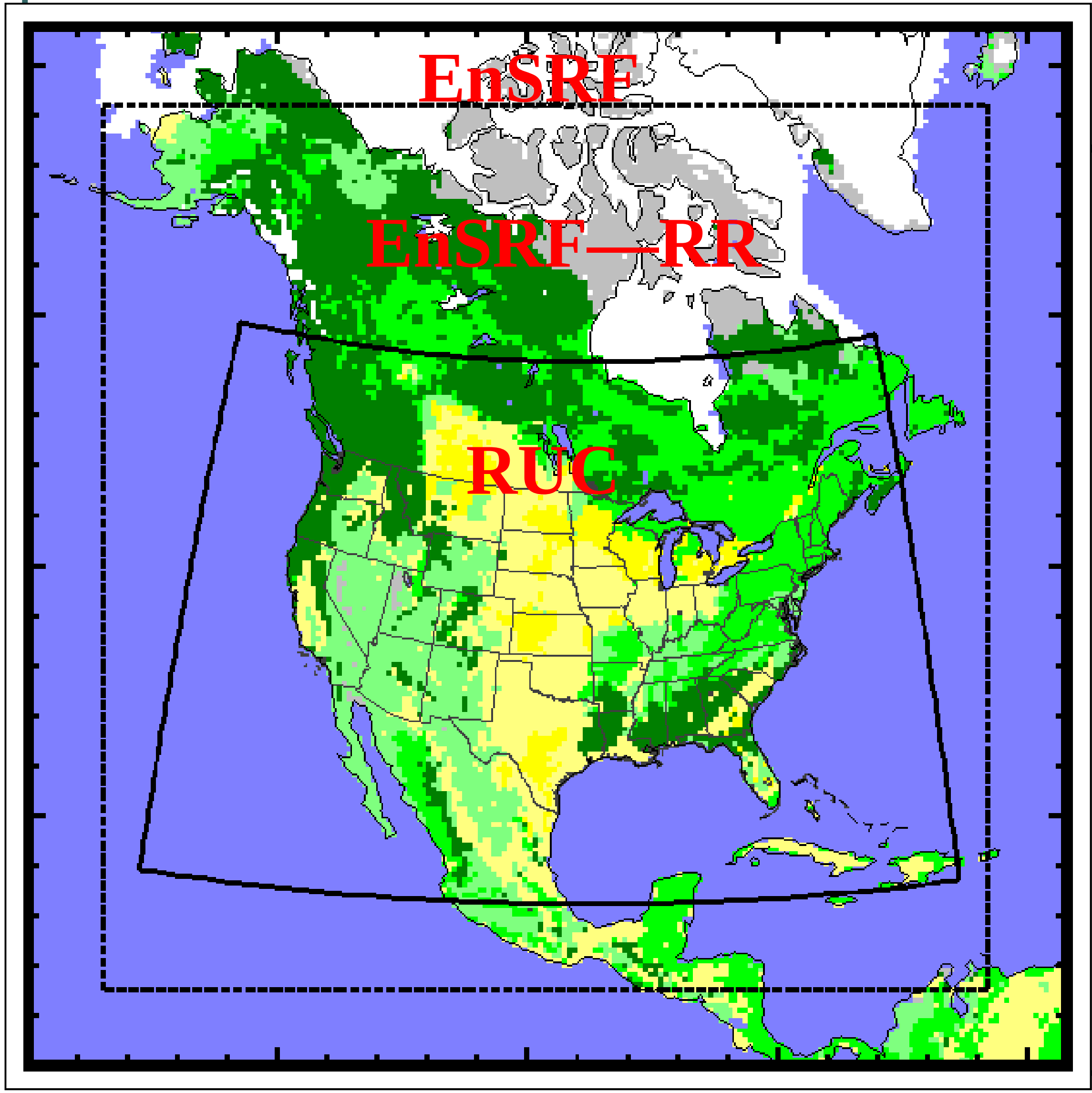
Contour: CAPE > 2500 J/kg
Shade: 0-3km Helicity (m^2/s^2)



DA procedure



40 km regional ensemble



Ensemble size: 40

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

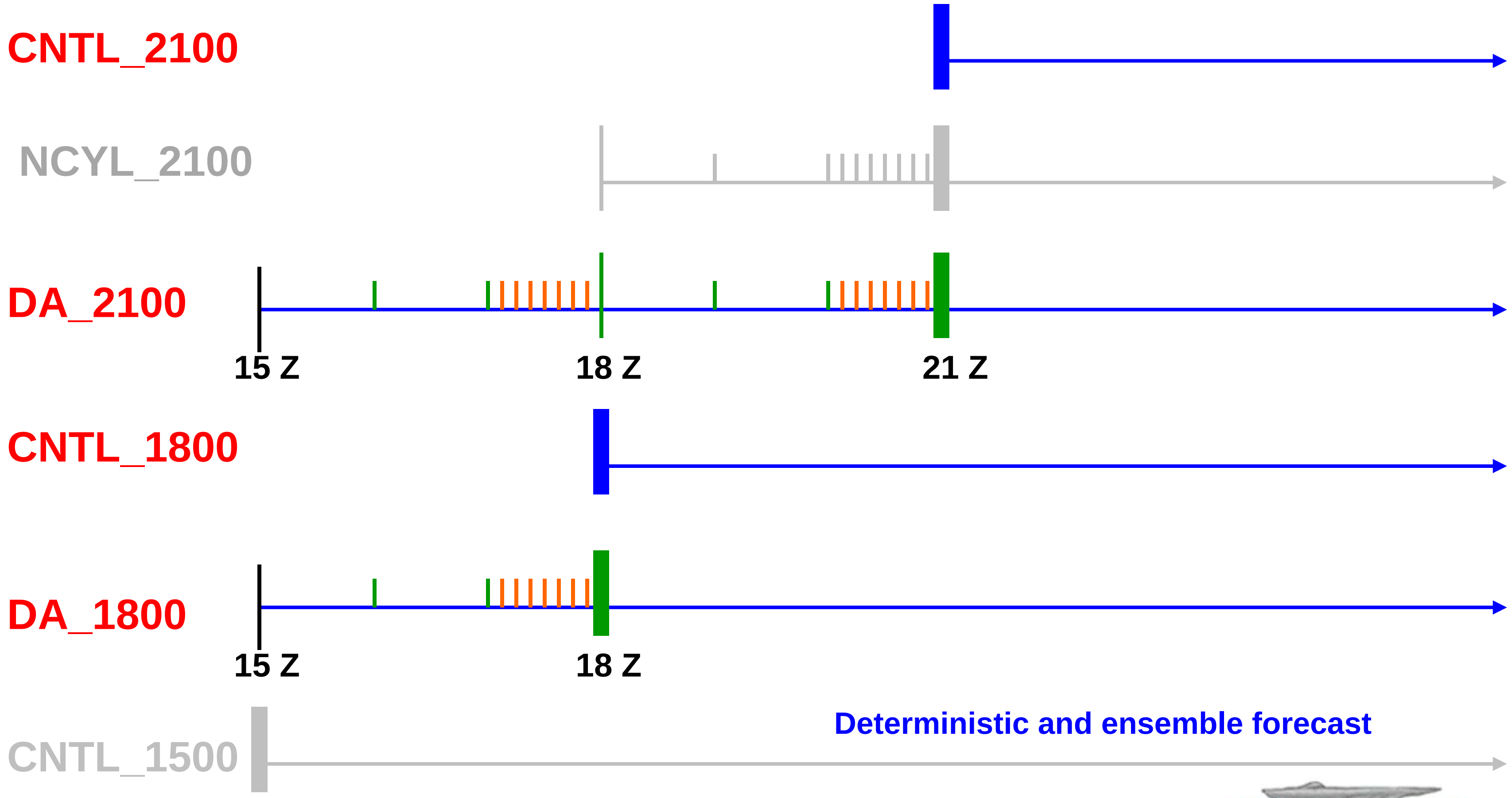
Model: WRF-ARW

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

Configurations

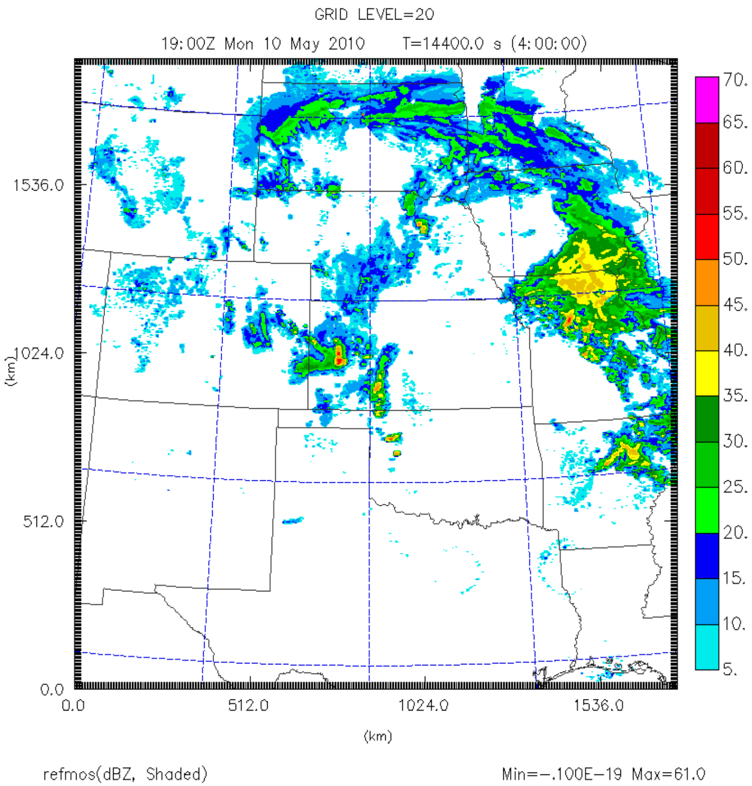
- Model: ARPS
- Microphysics scheme: LFO83
- Grid configurations: nested grid (40 km -> 4 km)
- Physical domain: 443x483x53 (1768km x 1928 km)
- 40 ensemble members
- DA scheme: parallel EnSRF
- Observations
  - conventional data: surface, sounding, profiler, mesonet
  - radar: 32-38 WSR-88D radars

Experiments

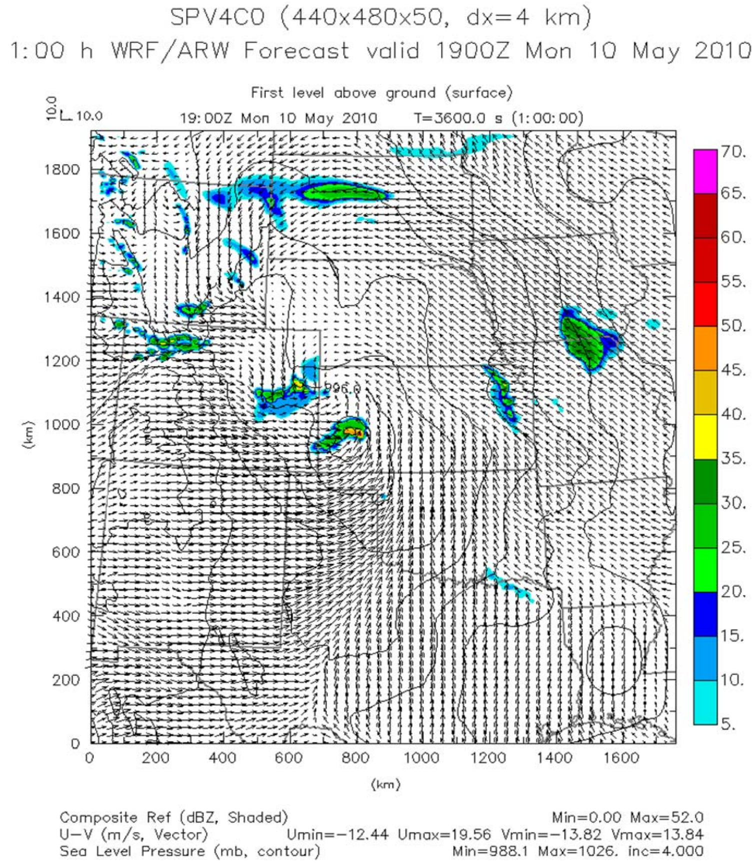


CAPS real-time forecast (1h)

Observed radar reflectivity mosaic

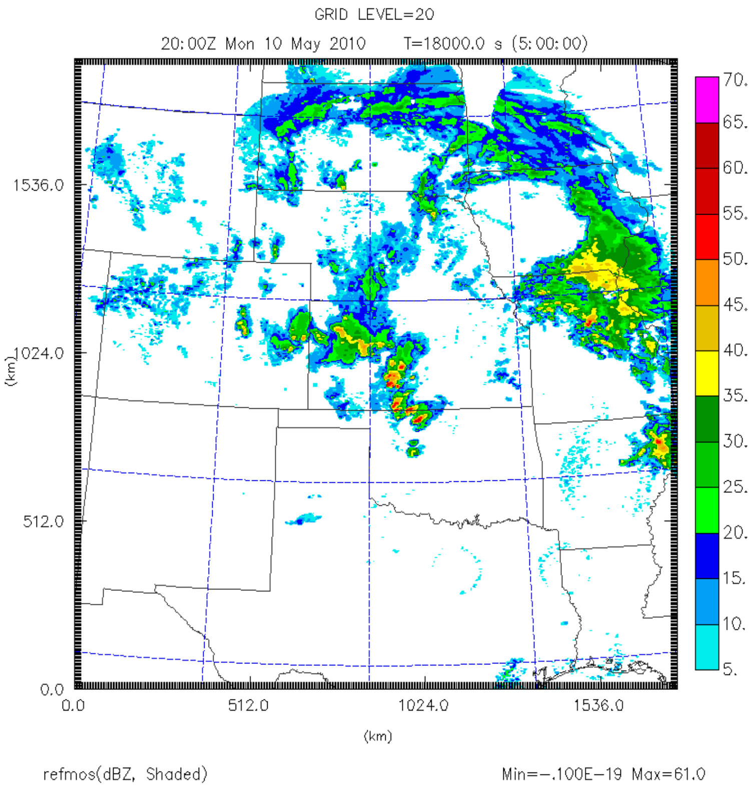


WRF ARW forecast reflectivity

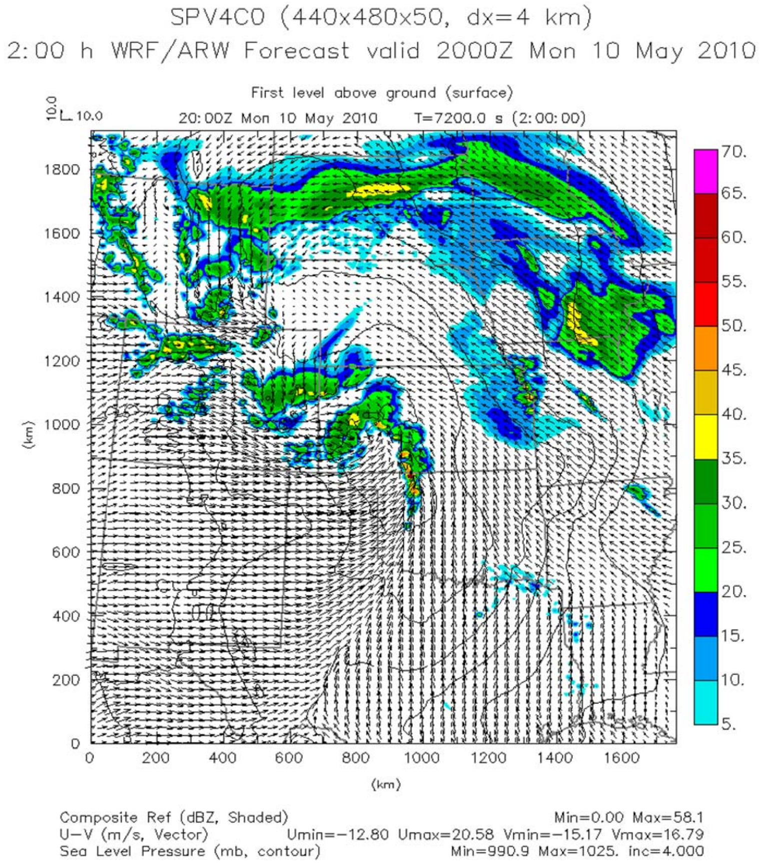


CAPS real-time forecast (2h)

Observed radar reflectivity mosaic

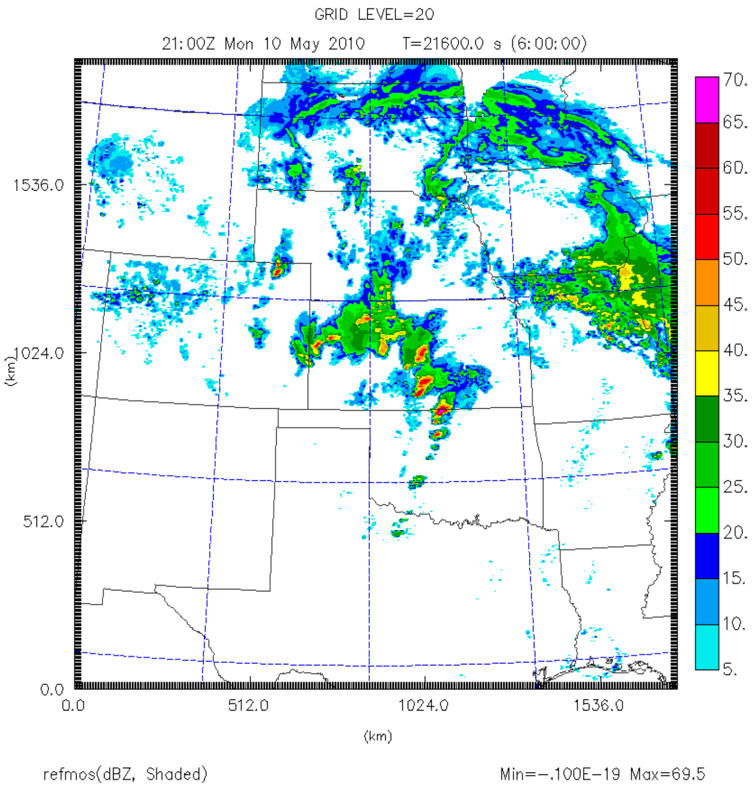


WRF ARW forecast reflectivity

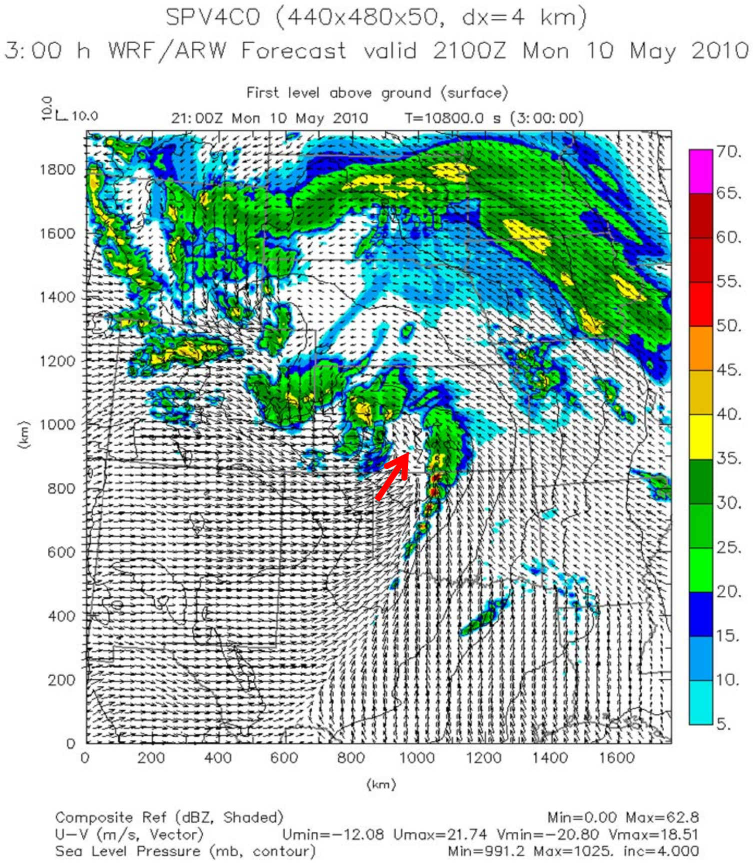


CAPS real-time forecast (3h)

Observed radar reflectivity mosaic

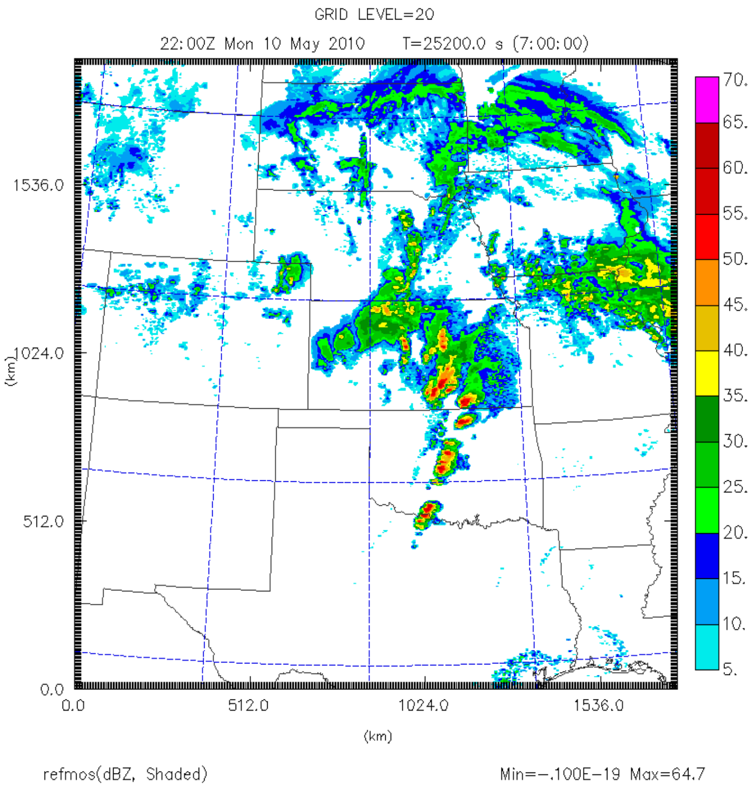


WRF ARW forecast reflectivity

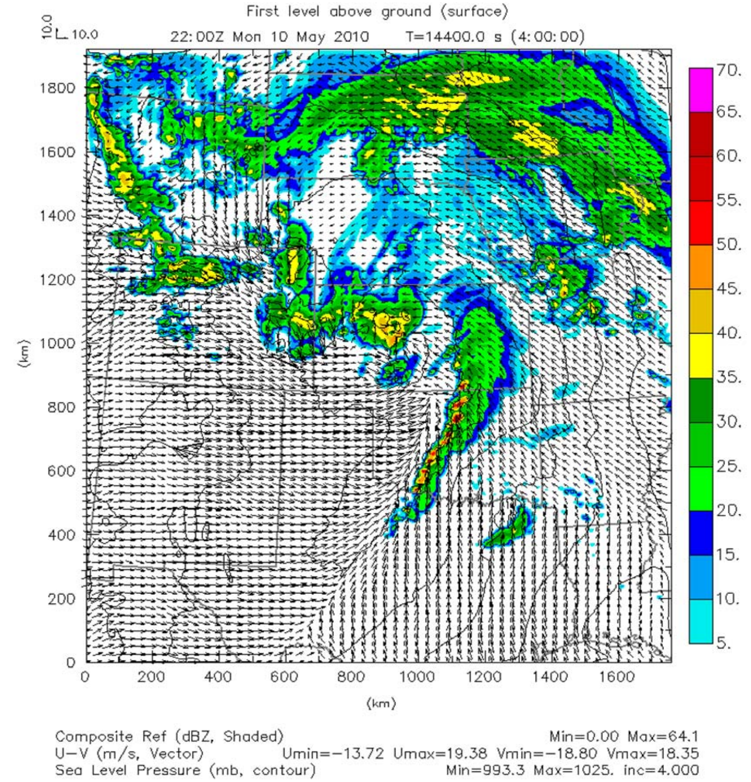


CAPS real-time forecast (4h)

Observed radar reflectivity mosaic

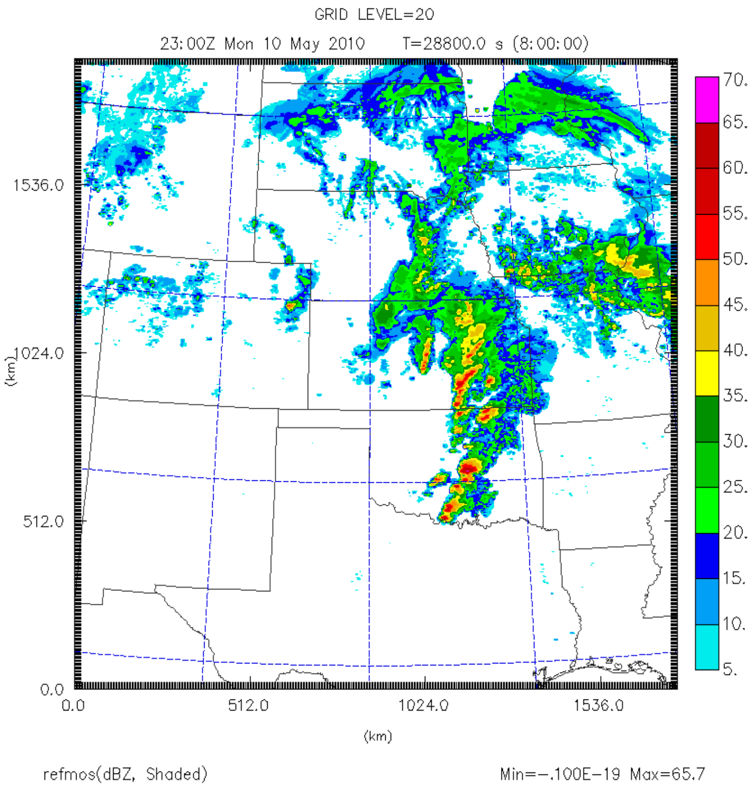


WRF ARW forecast reflectivity

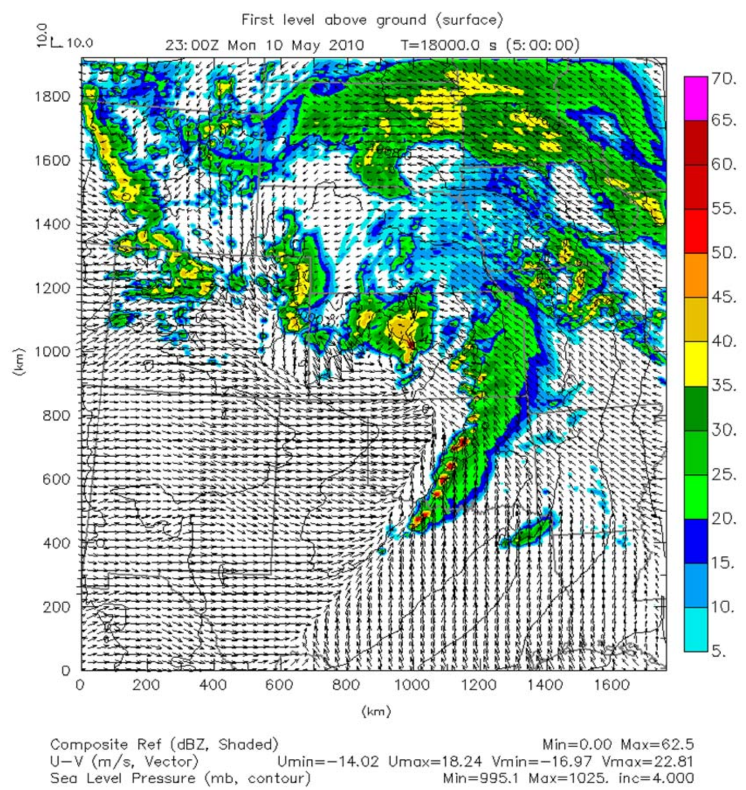


CAPS real-time forecast (5h)

Observed radar reflectivity mosaic

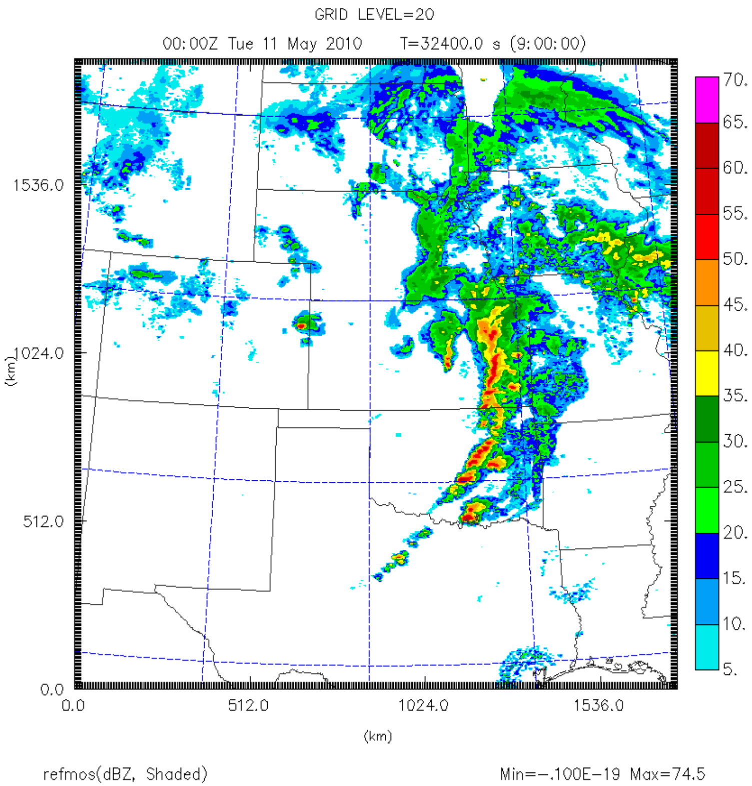


WRF ARW forecast reflectivity

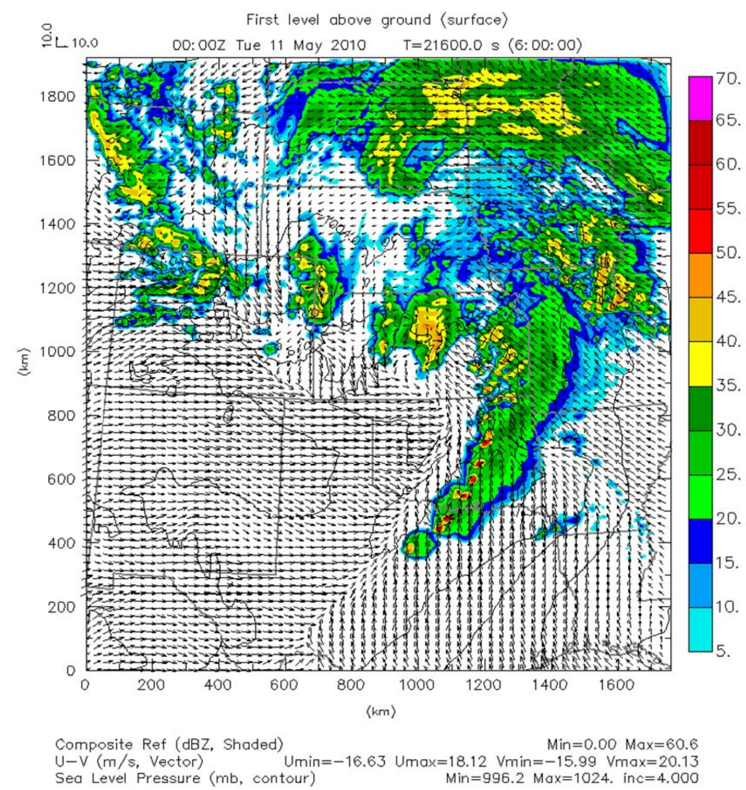


CAPS real-time forecast (6h)

Observed radar reflectivity mosaic

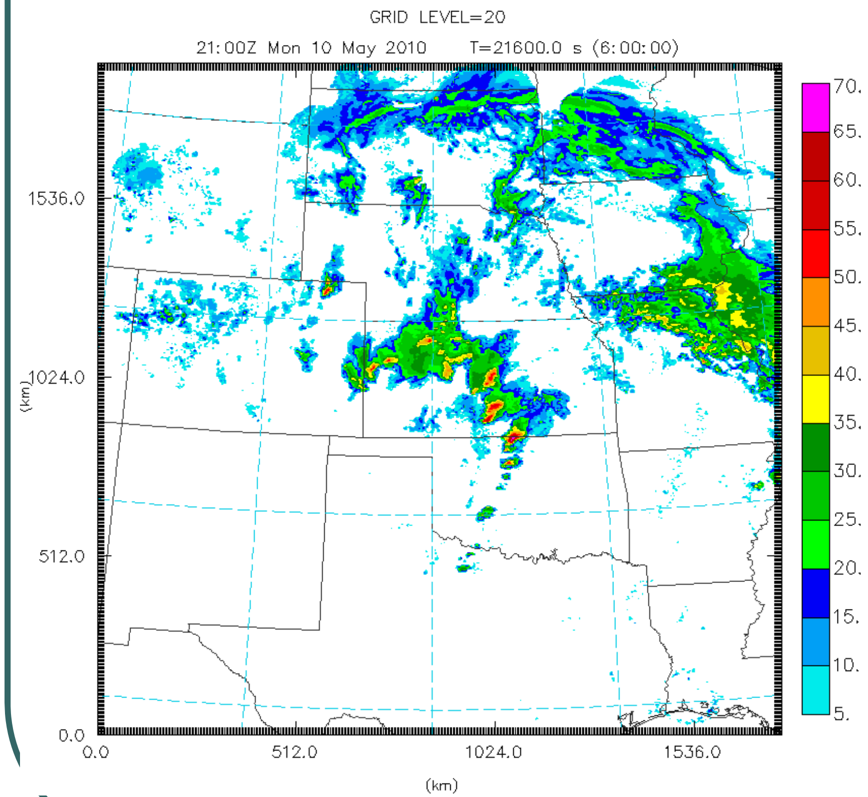


WRF ARW forecast reflectivity

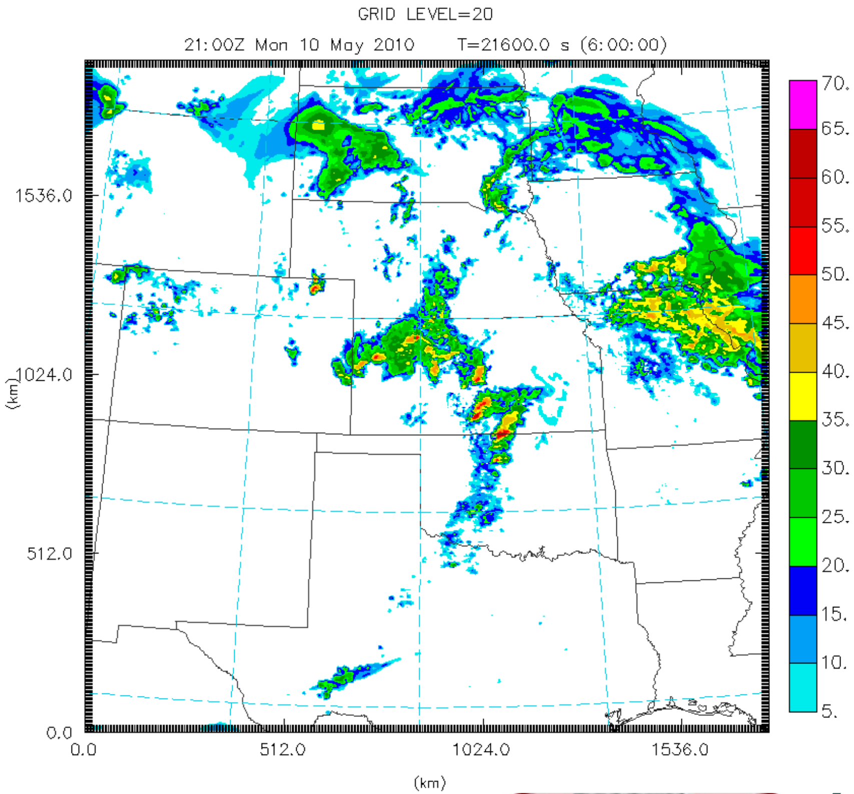


Analysis at 2100 UTC

Observed radar reflectivity mosaic



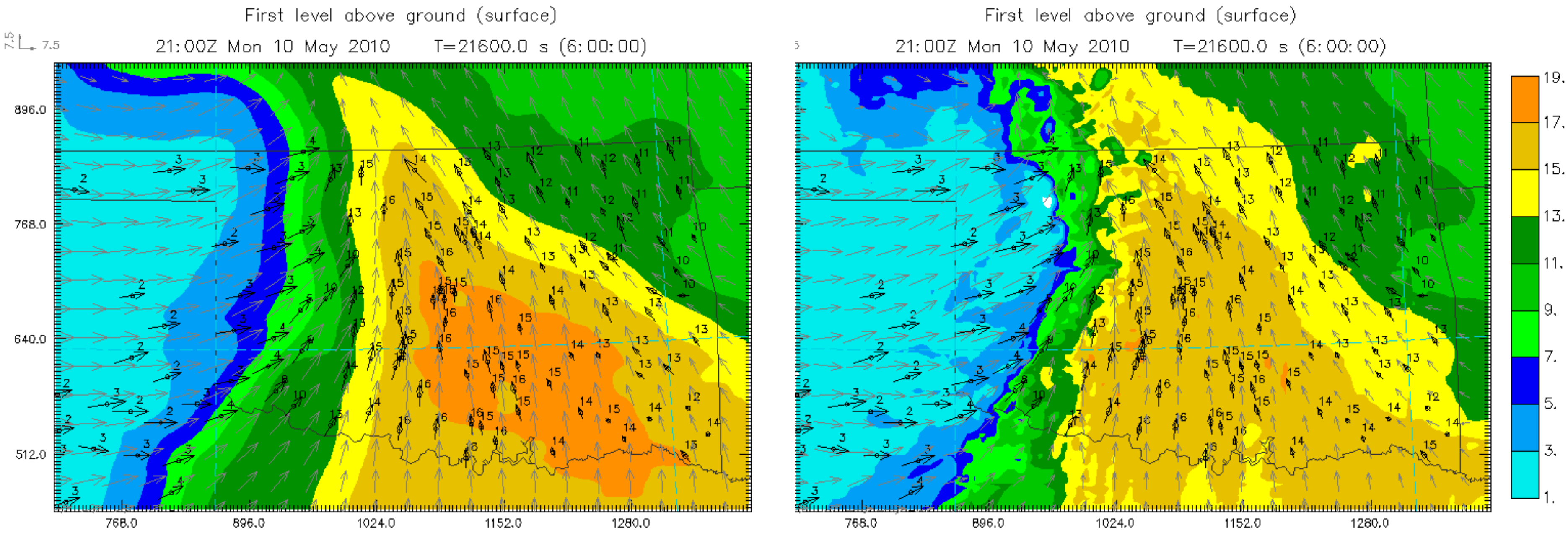
Model reflectivity at 2100 UTC



Analysis at 2100 UTC

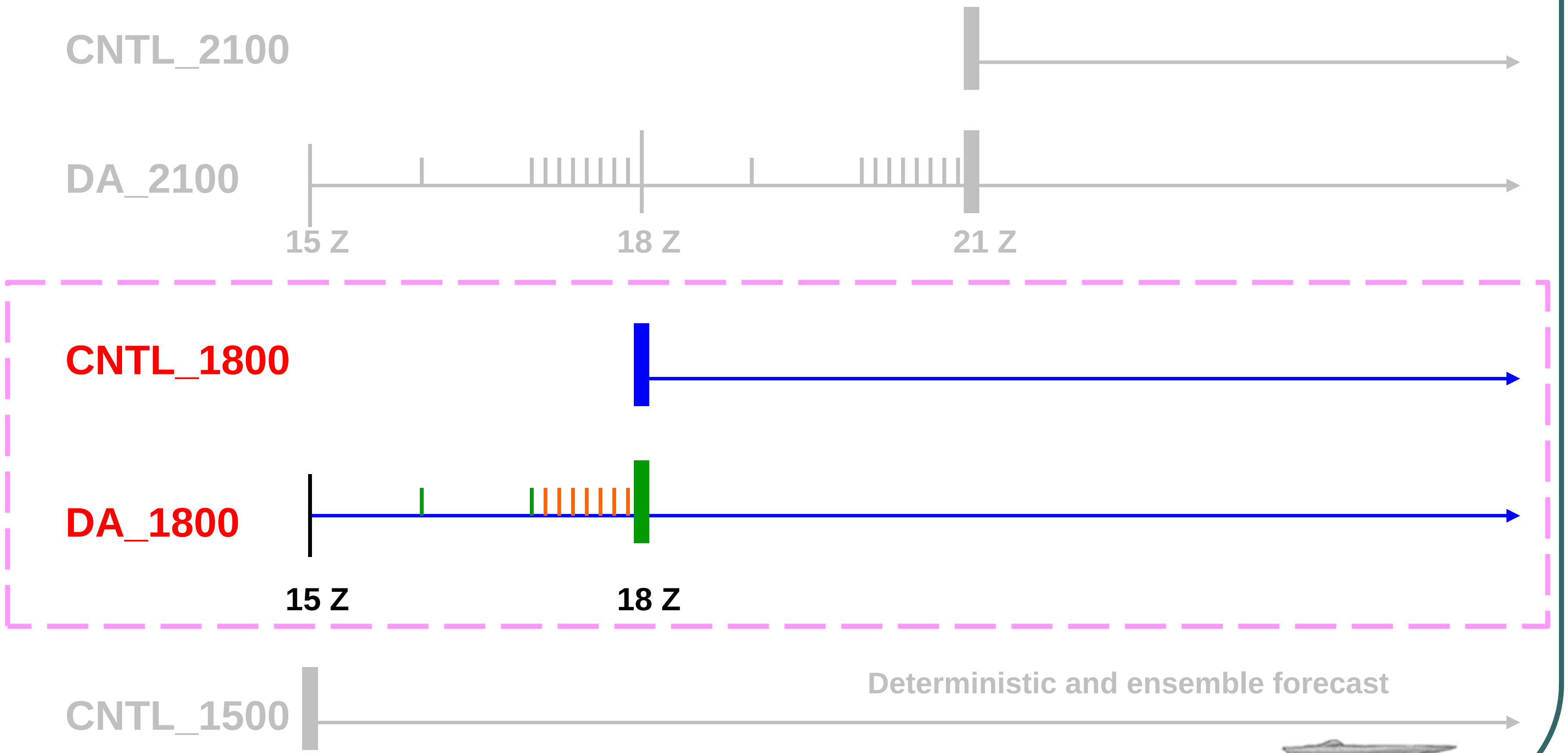
40 km regional EnKF analysis

4 km storm-scale EnKF analysis



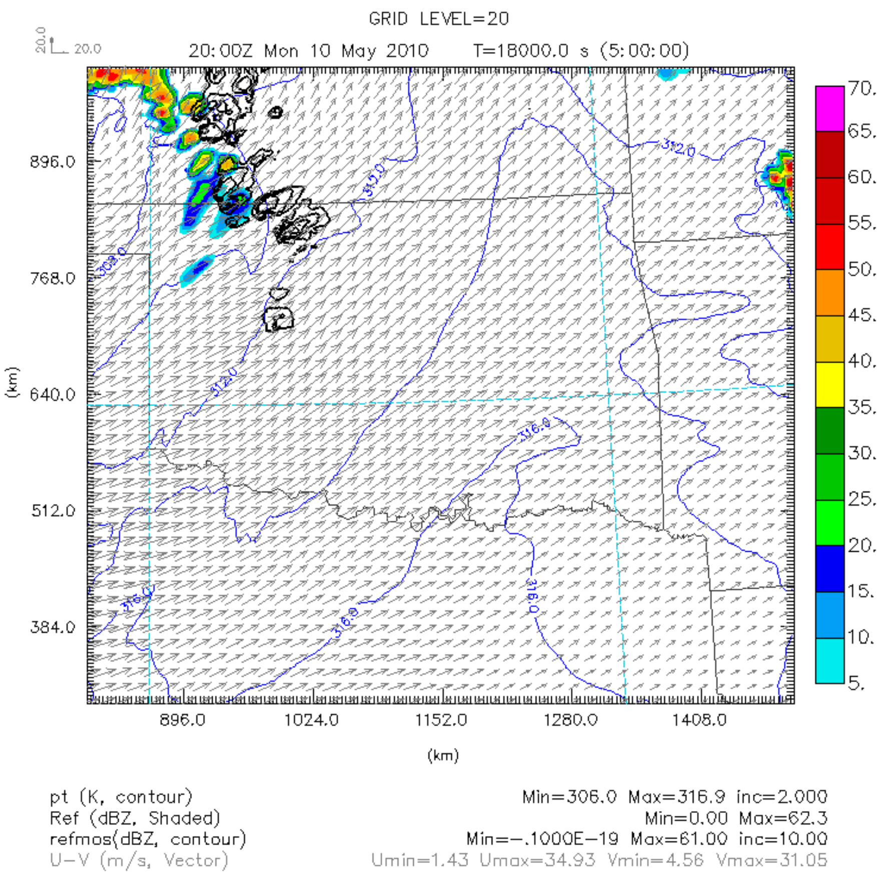
Surface q_v (shade, g/kg) and wind (m/s)

Experiments

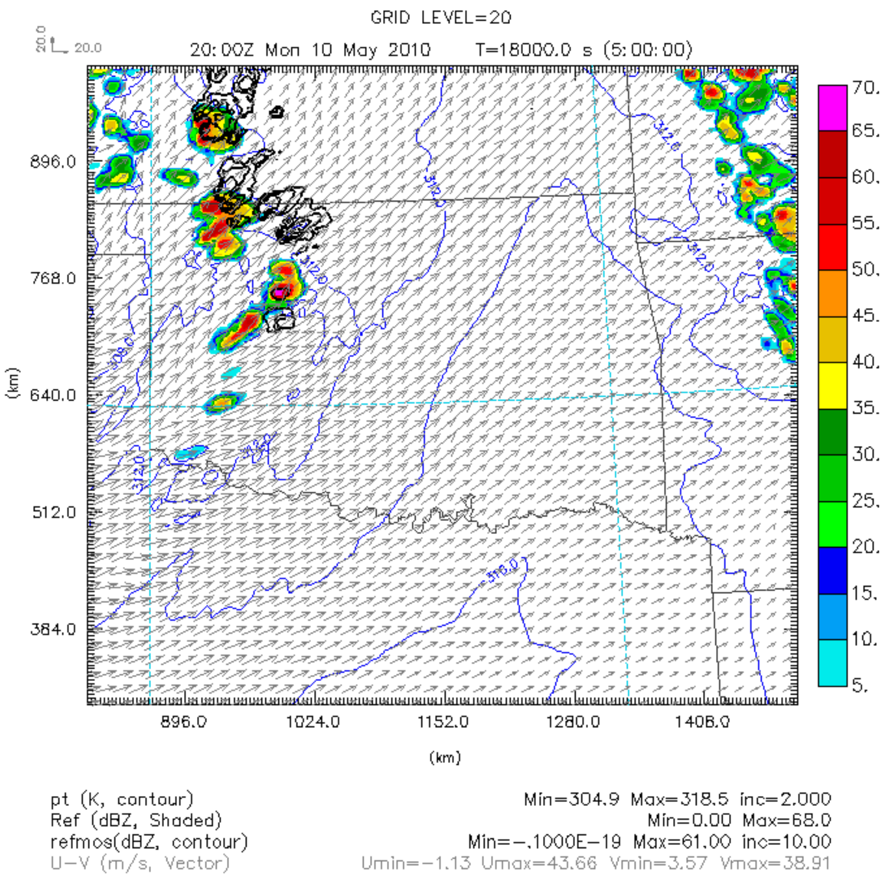


Deterministic forecasts (1h)

CNTL_1800



DA_1800



Deterministic forecasts (2h)

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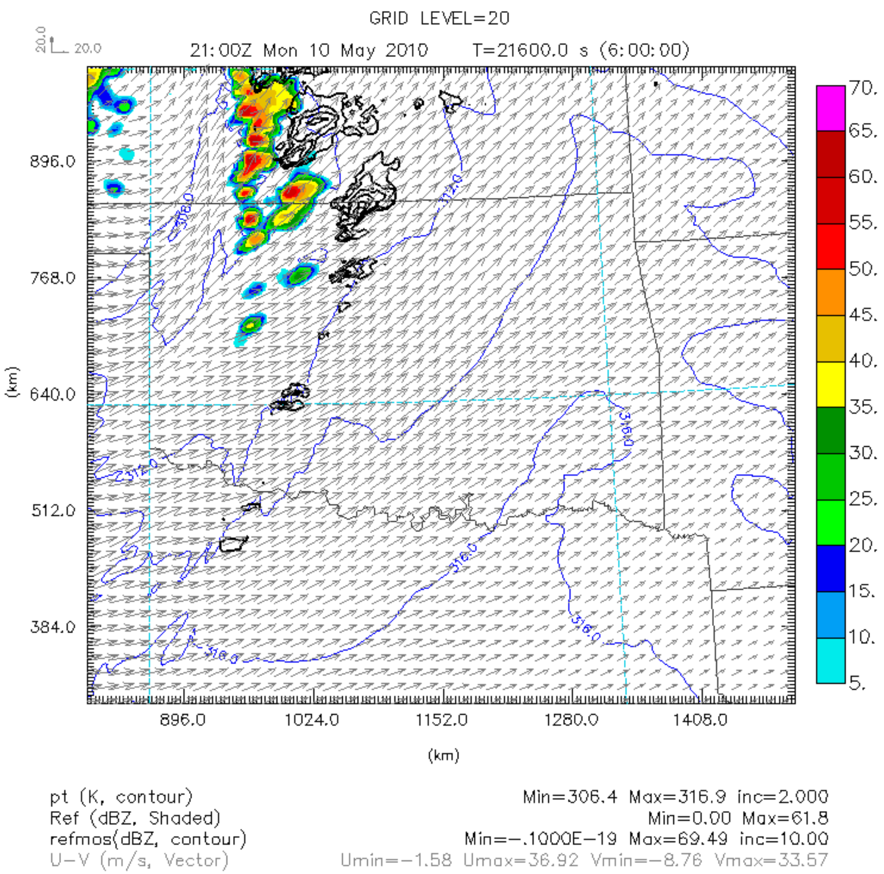
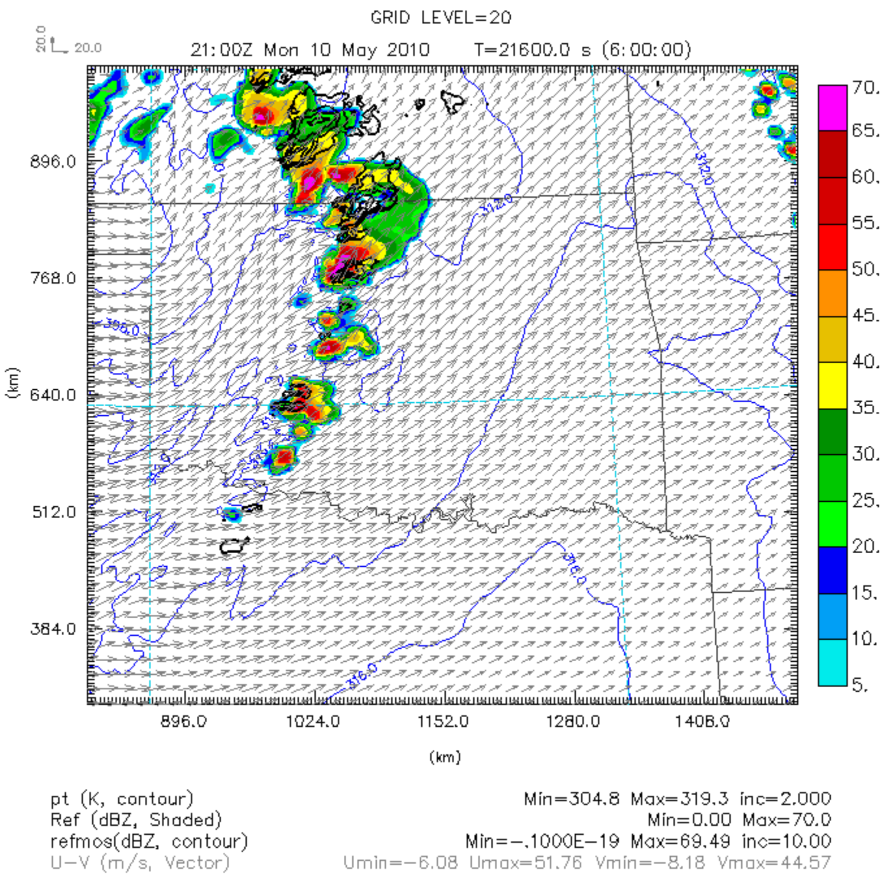


DA_1800



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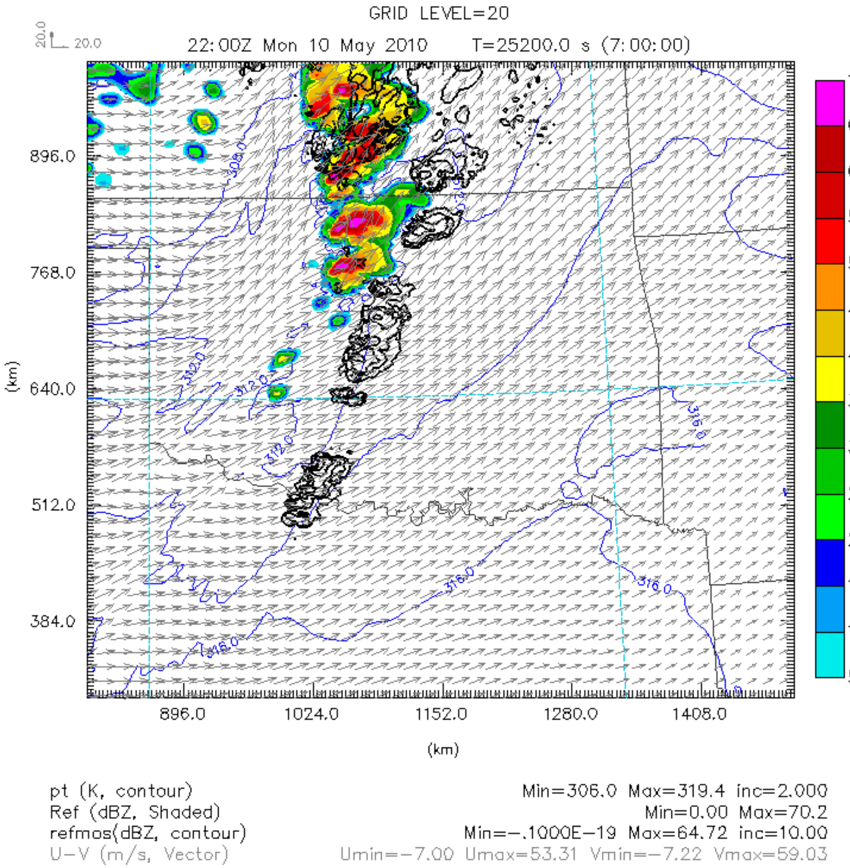

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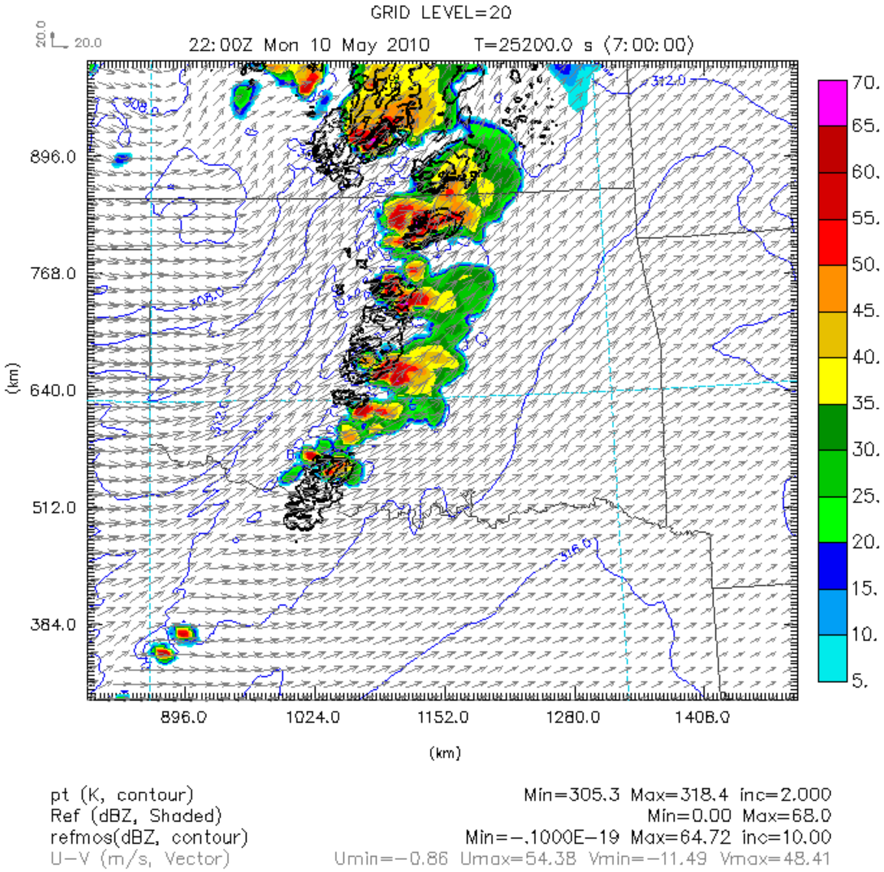

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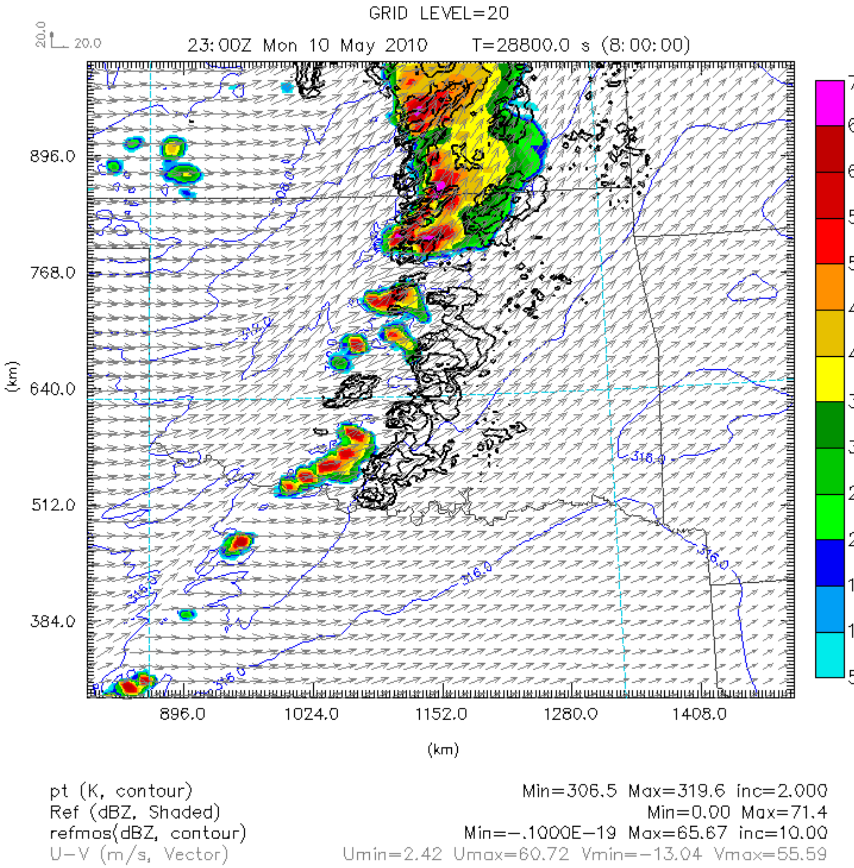

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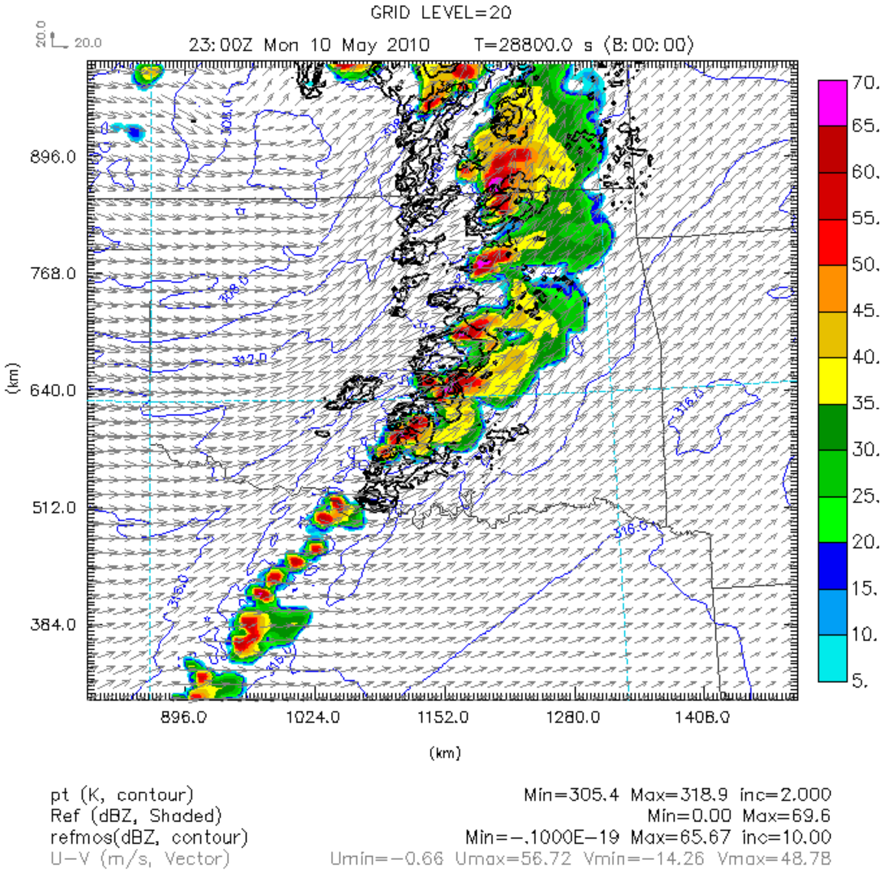
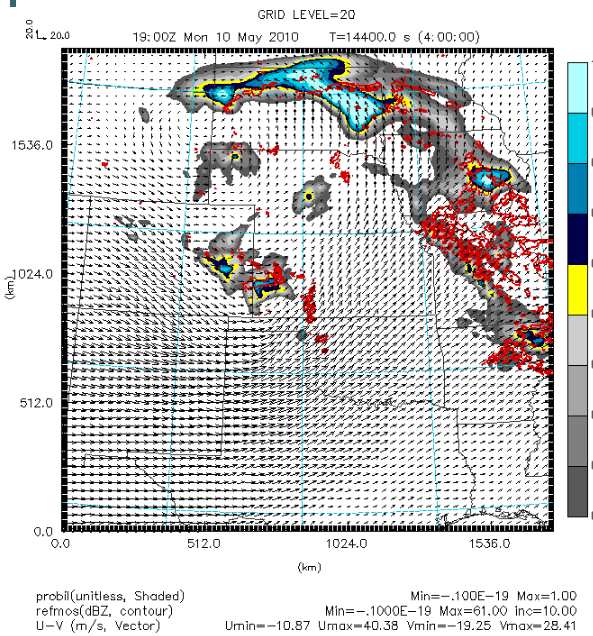
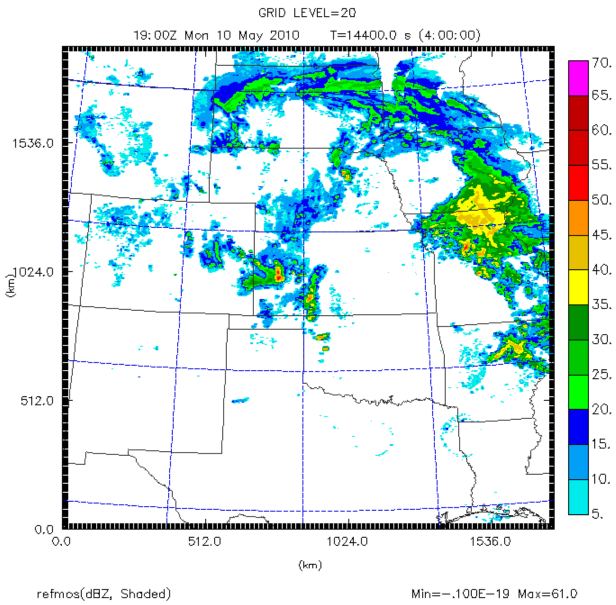


Ensemble probability (1h)

CNTL_1800



mosaic



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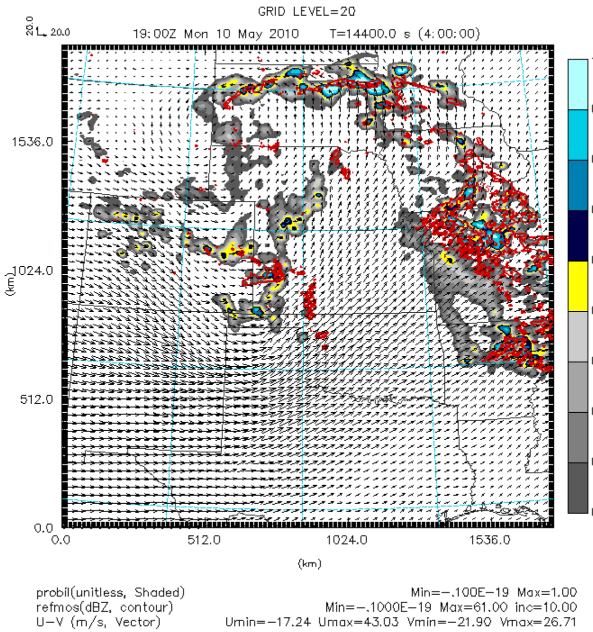
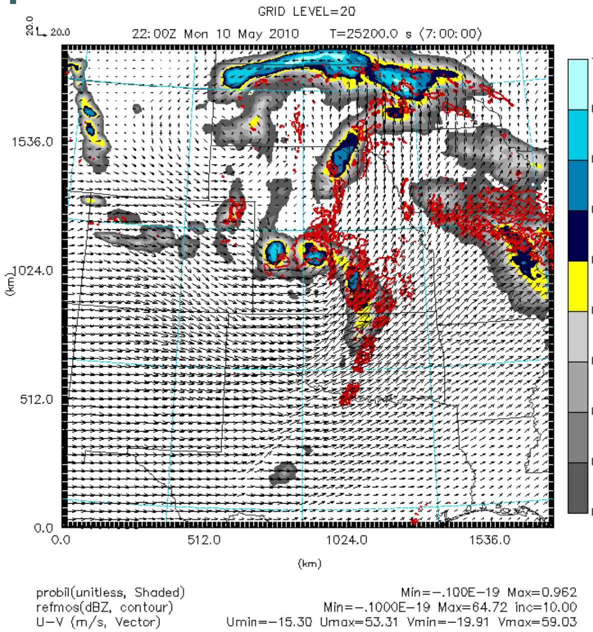


Probability (shade, Z_H > 25 dBZ, r = 10 km)

Observed *Z* (contour, ≥ 25 dBZ)

Ensemble probability (4h)

CNTL_1800



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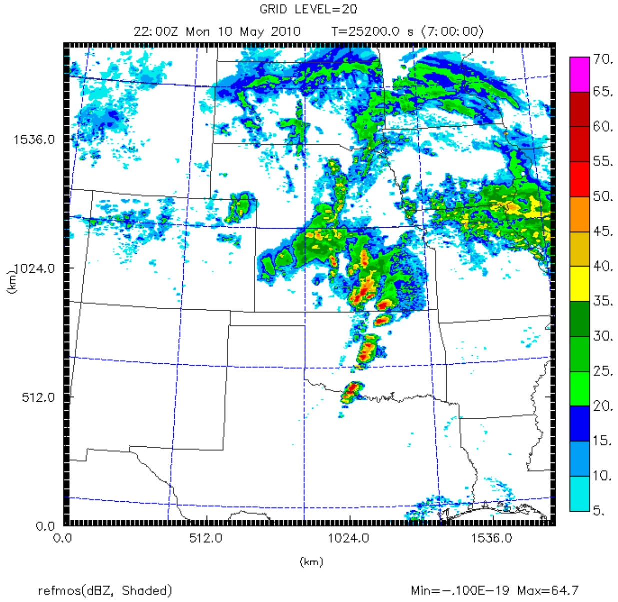

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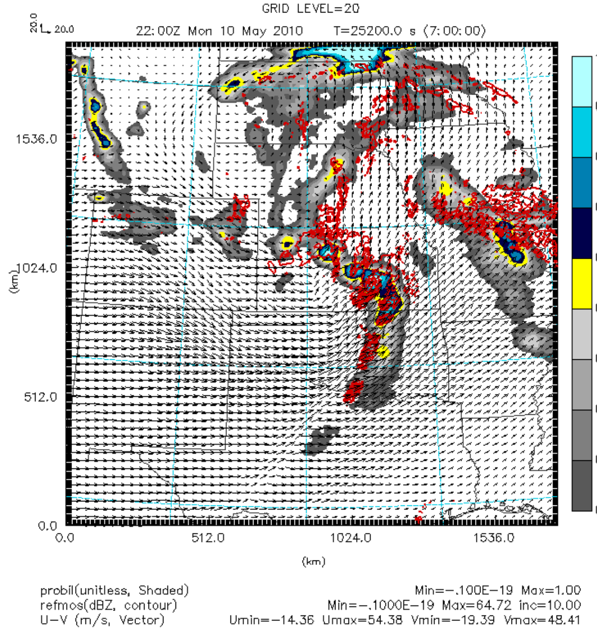

Ensemble probability (6h)

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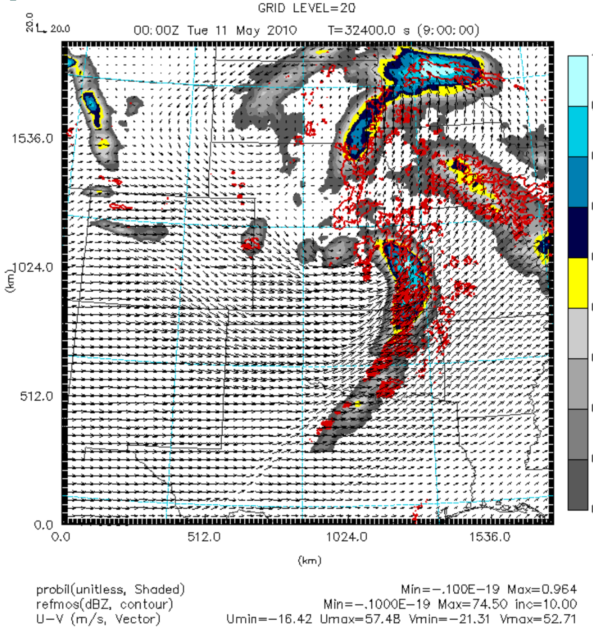
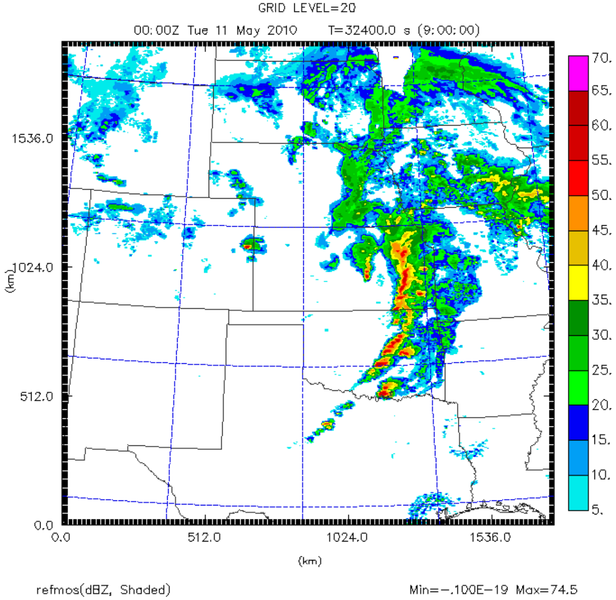


mosaic



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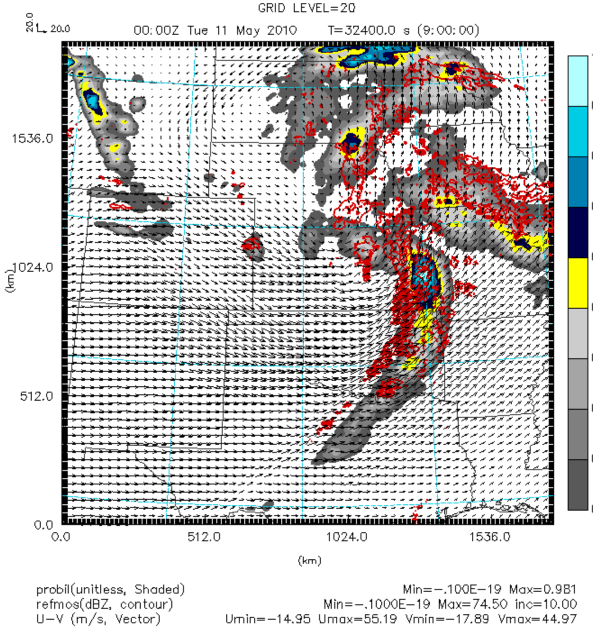
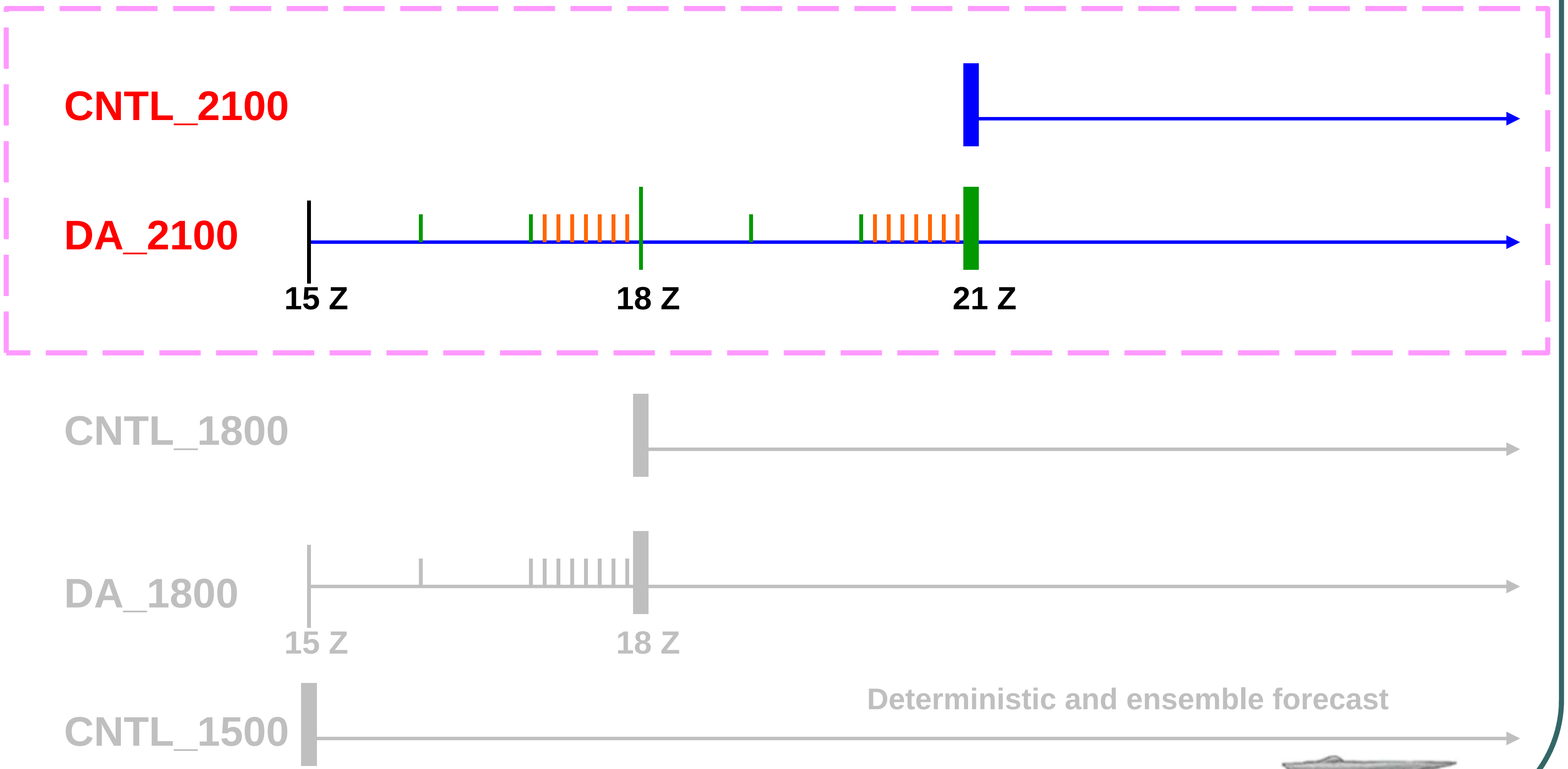
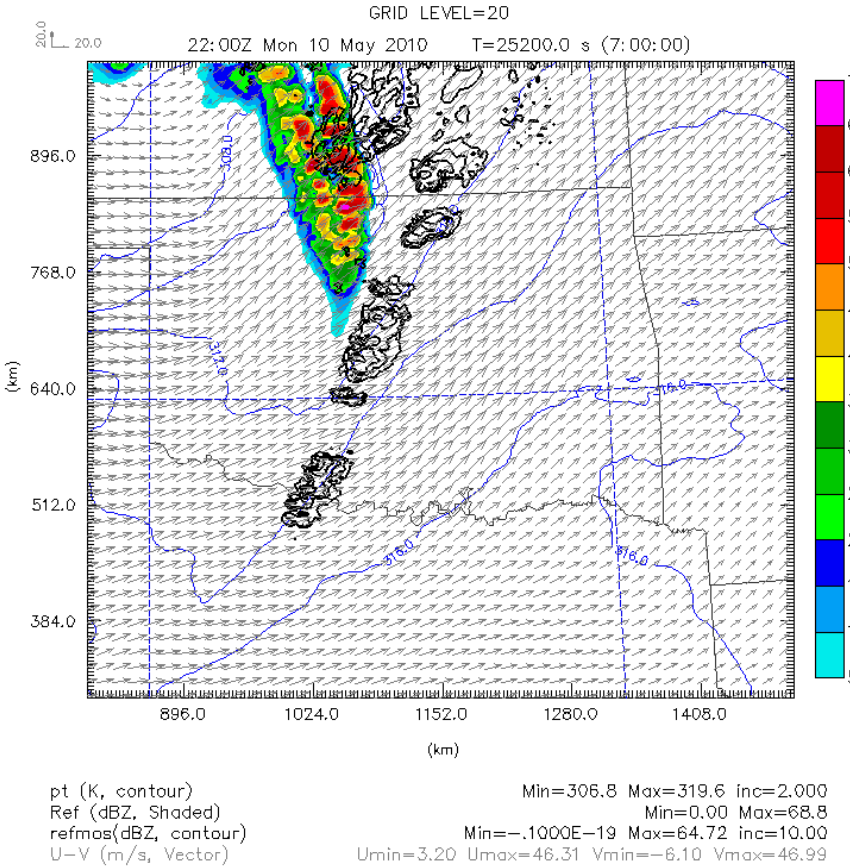


Experiments

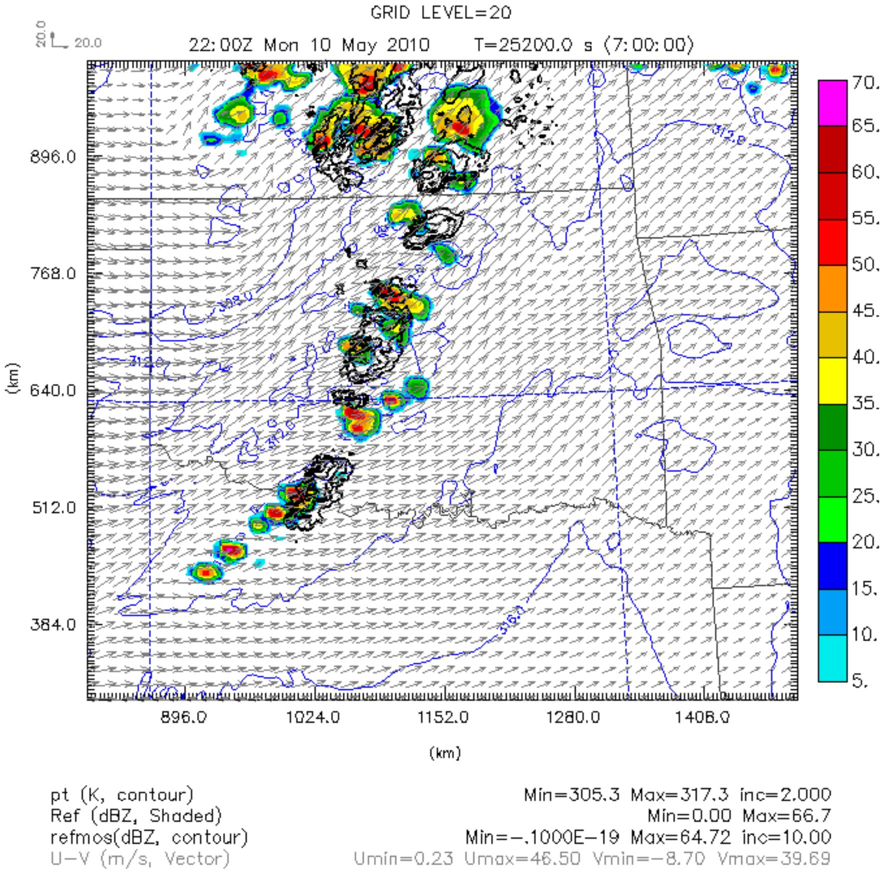


Deterministic forecasts (1h)

CNTL_2100

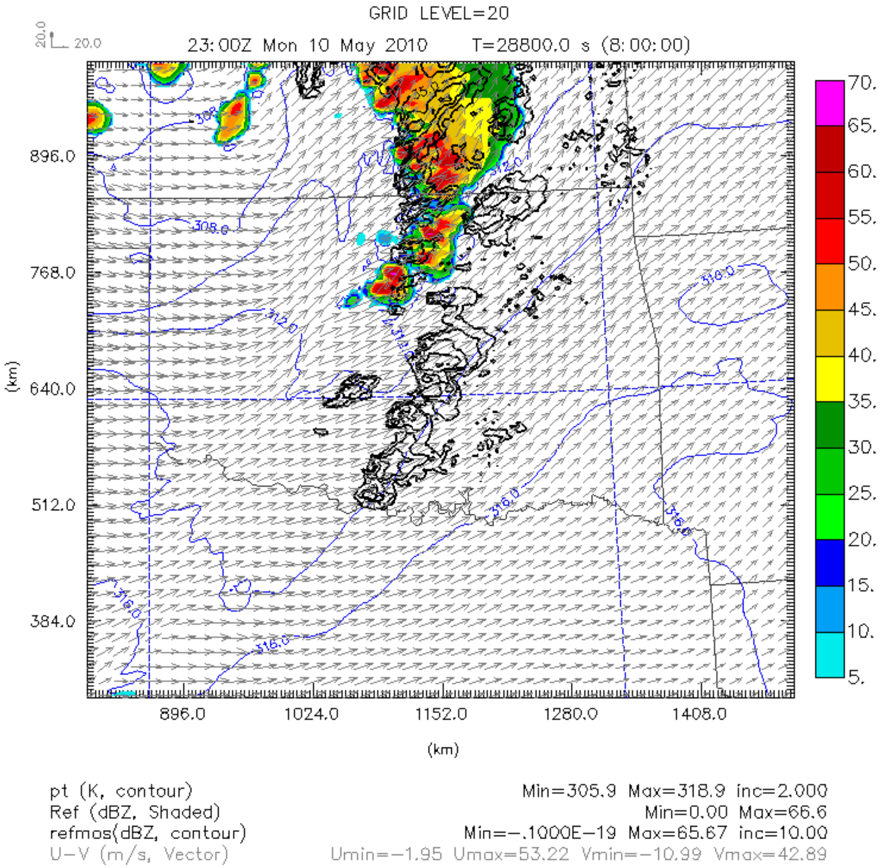


DA_2100



Deterministic forecasts (2h)

CNTL_2100



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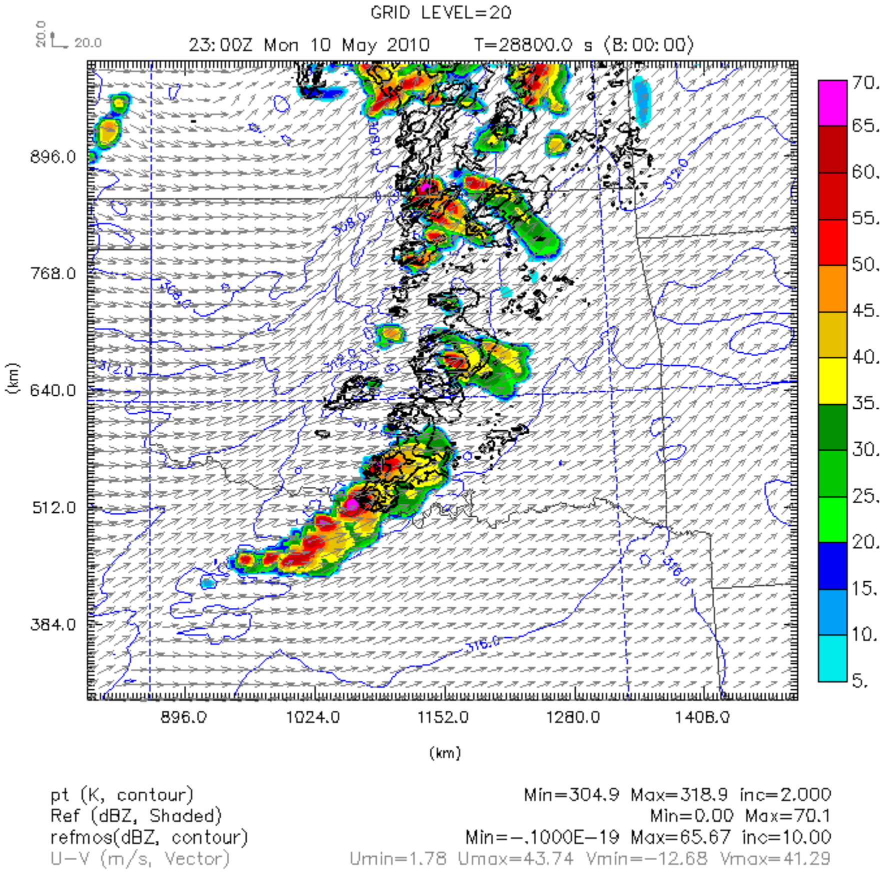
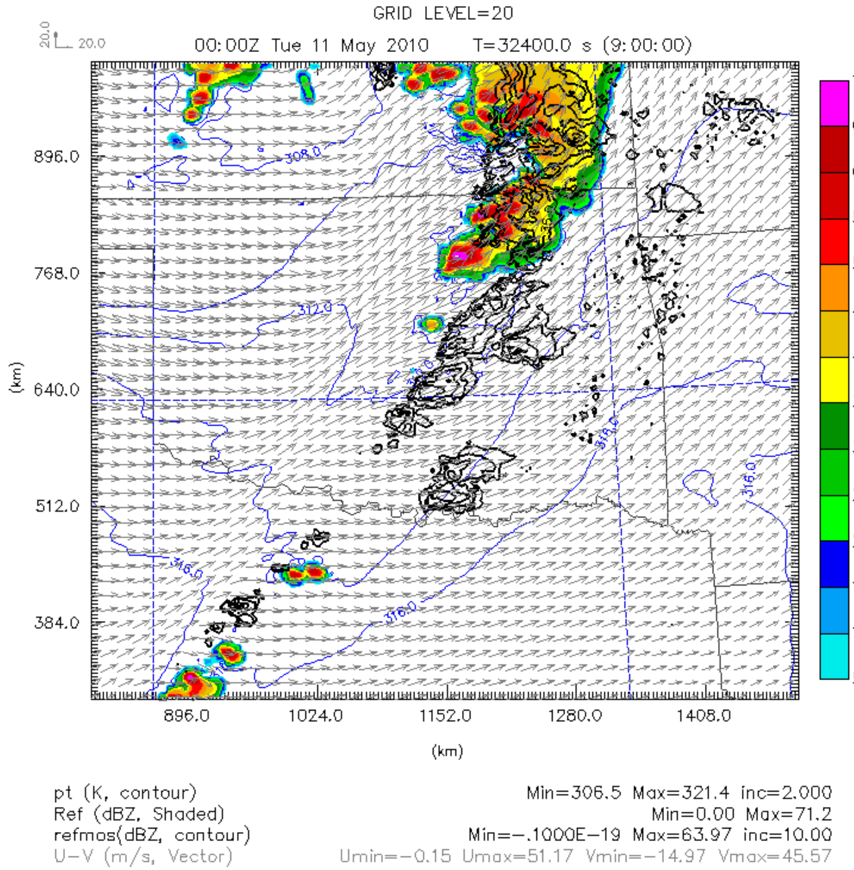


Deterministic forecasts (3h)

CNTL_2100



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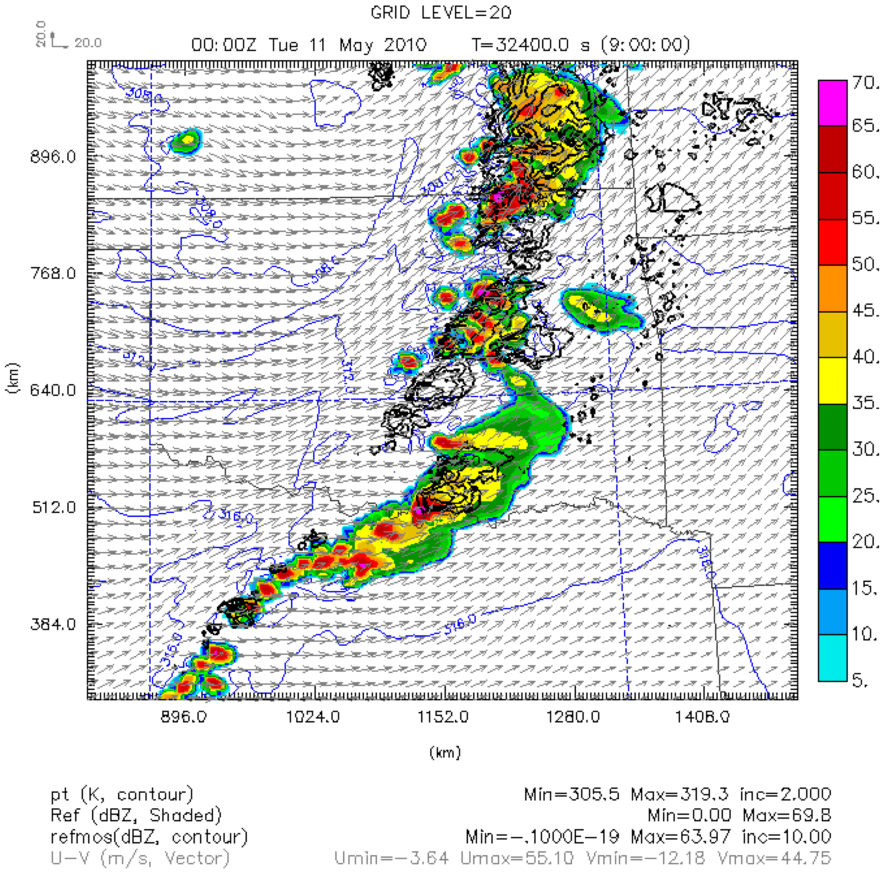
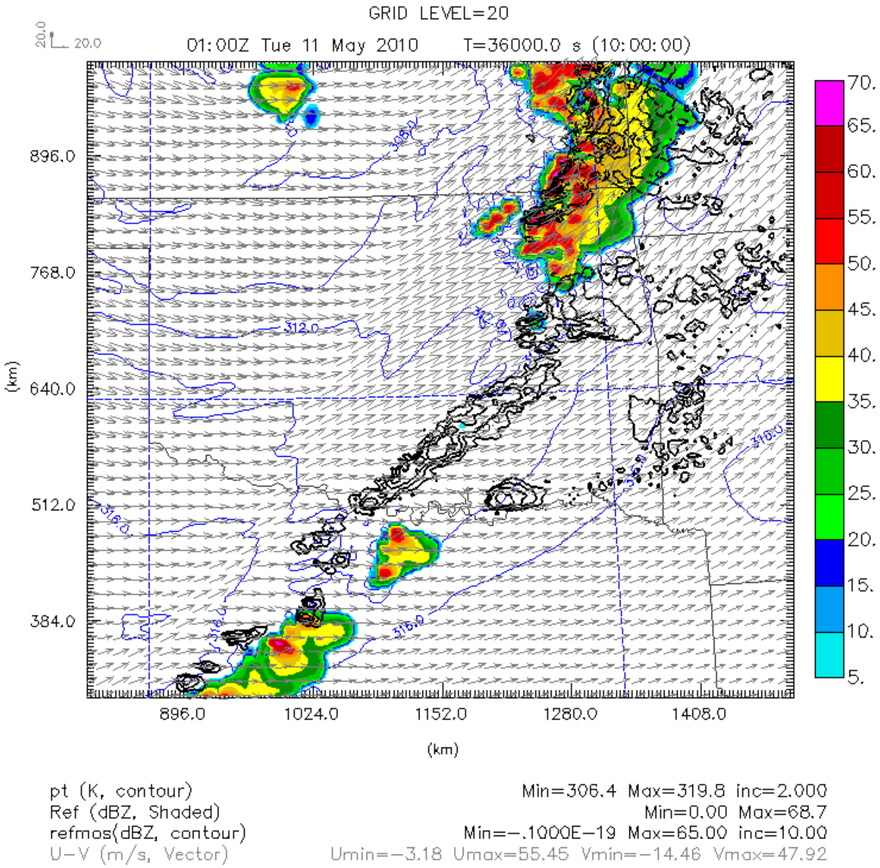


Deterministic forecasts (4h)

CNTL_2100



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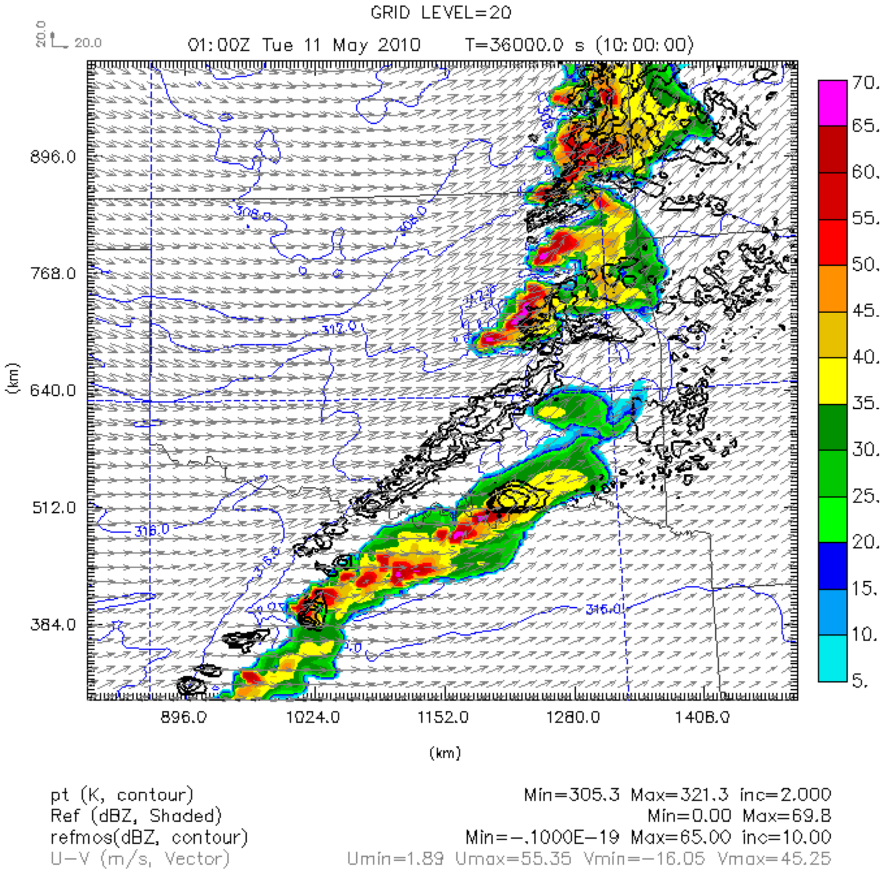
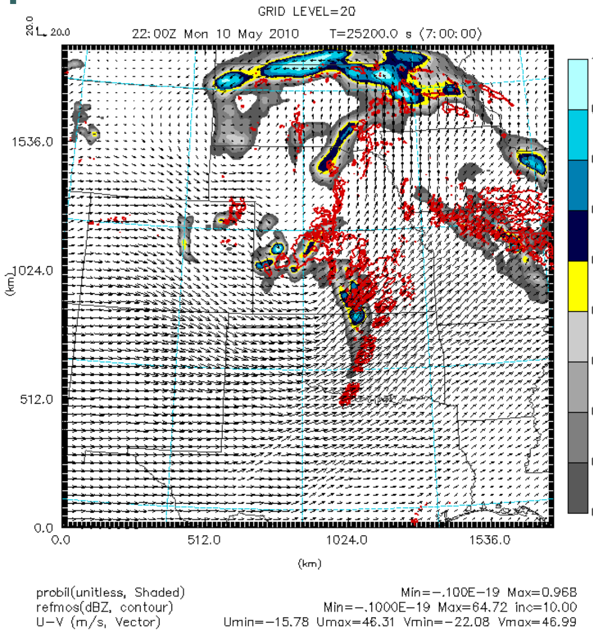
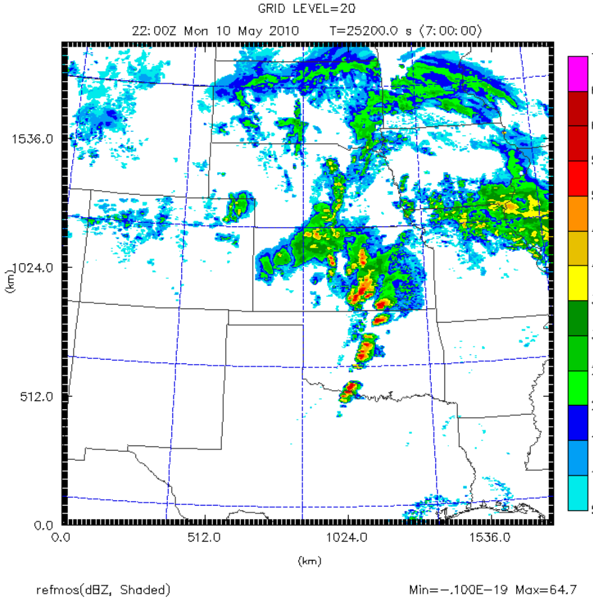


Ensemble probability (1h)

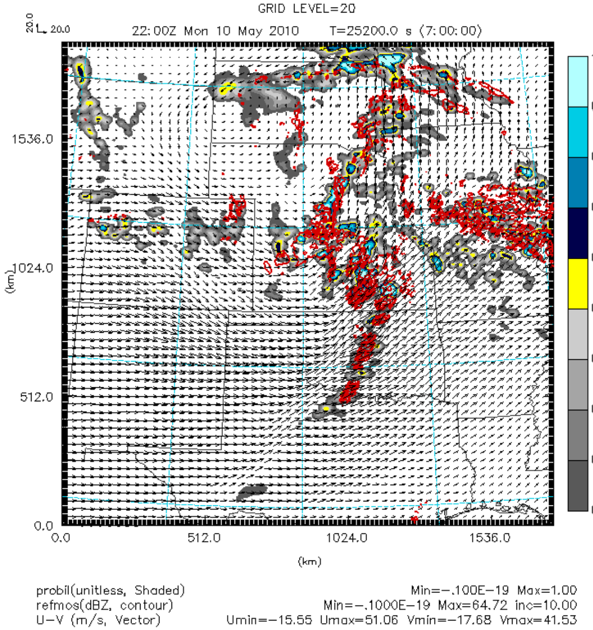
CNTL_2100



mosaic

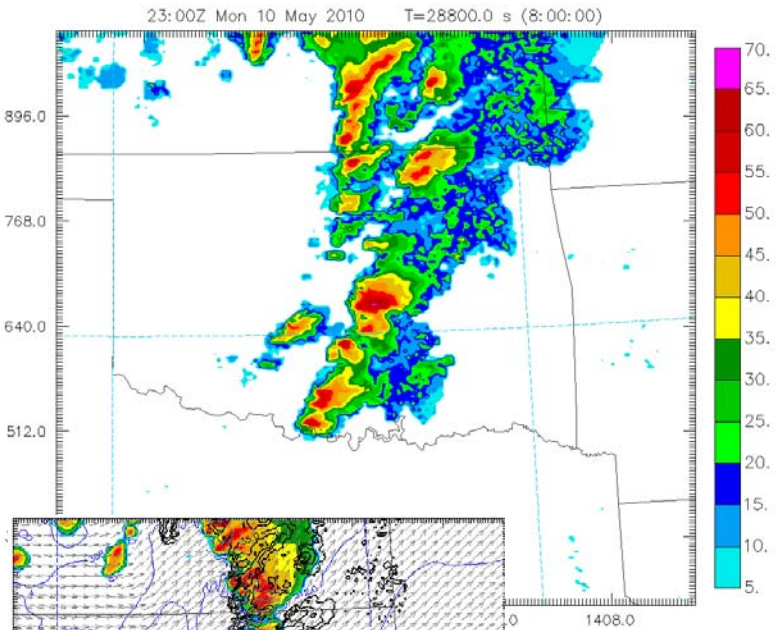


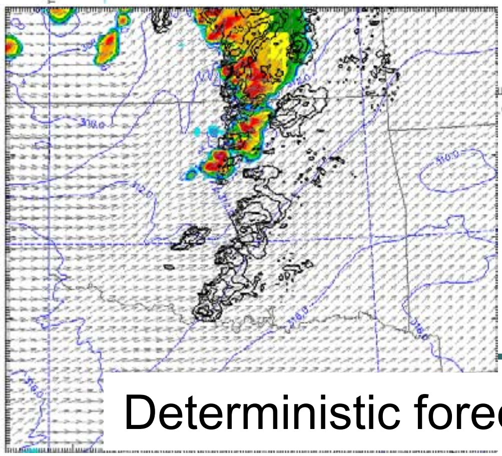
DA_2100



Some members of CNTL_2100 (2h)

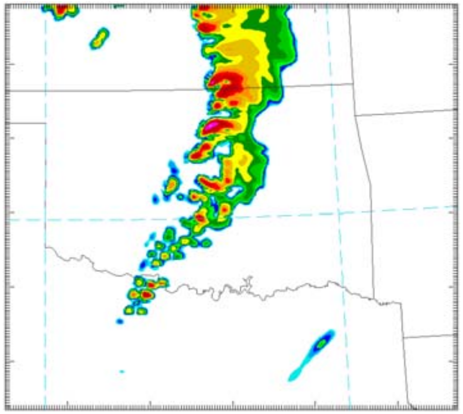
observation



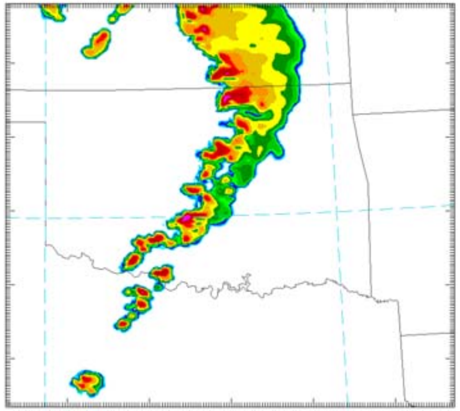


Deterministic forecast

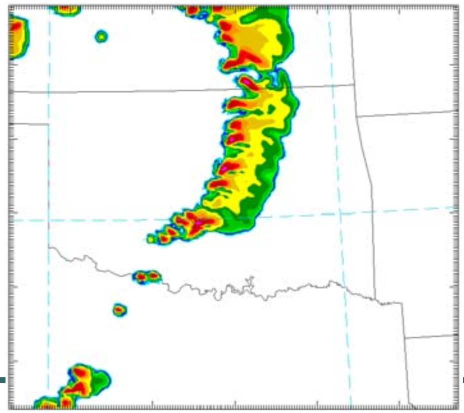
Member 6



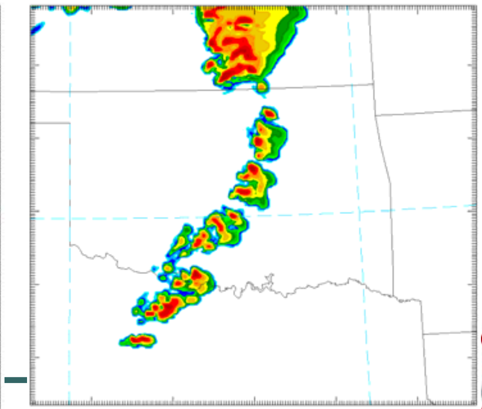
Member 30



Member 4

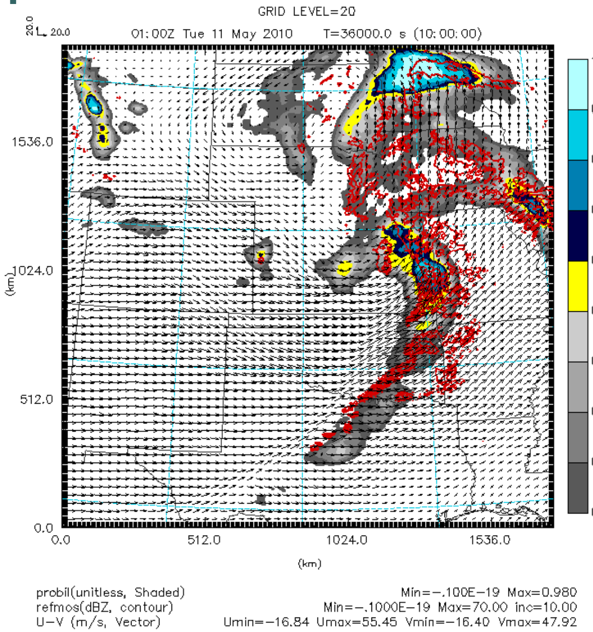


Member 33

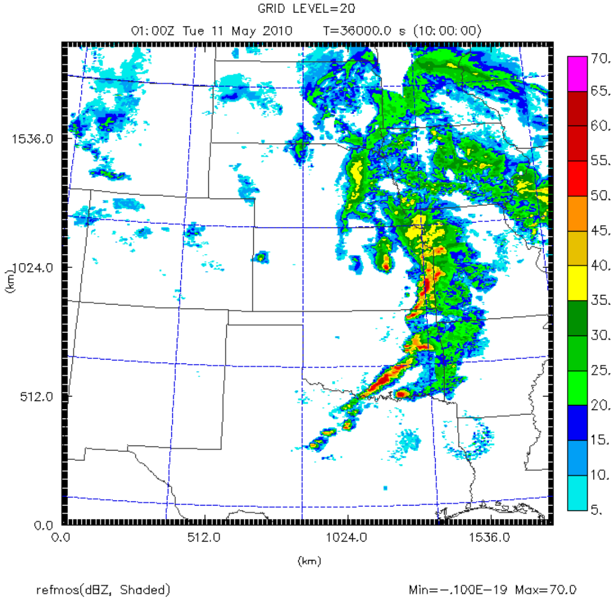


Ensemble probability (4h)

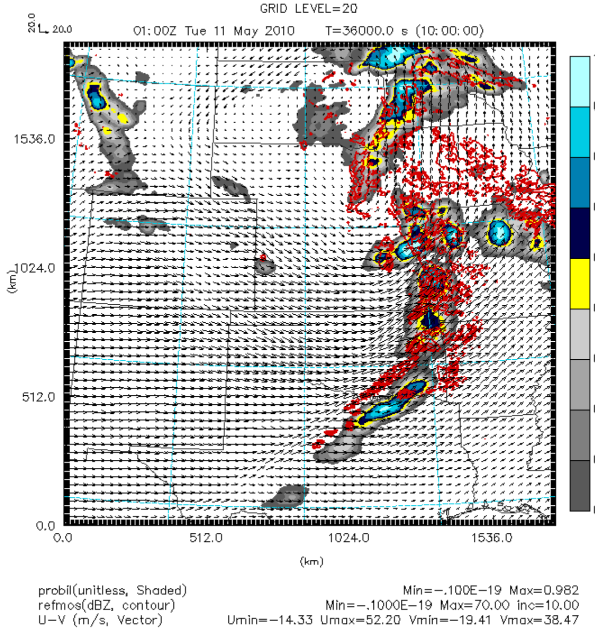
CNTL_2100



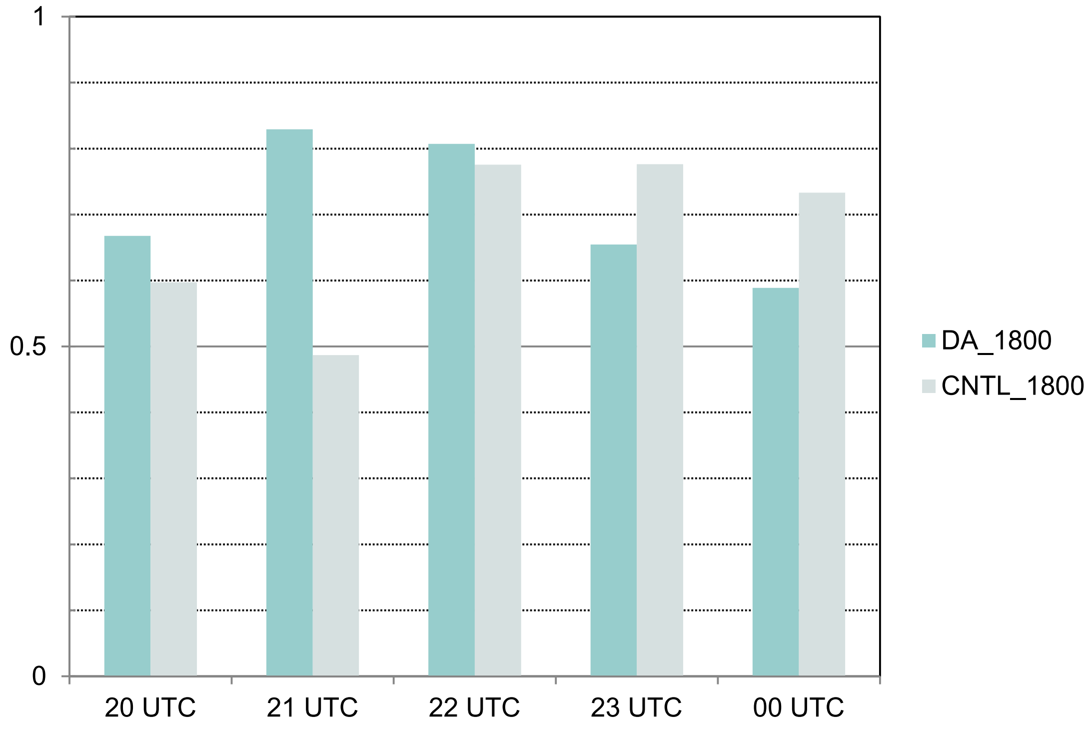
mosaic



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.