Development of data assimilation schemes suitable for convective-scale NWP for NOAA's Warn-on-Forecast project

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NOAA/National Severe Storm Laboratory

Acknowledgement: Yunheng, Dusty, Kent, Chenghao, Gerry, Thomas, Nusrat, Lou, and Jack

Warn-on-Forecast (WoF) Project

- Goal: To increase the lead time and accuracy for tornado, severe thunderstorm, and flash flood warning in order to reduce loss of life, injury, and damage to the economy.
- How? By incorporating 0-2 forecasts from a convection-allowing ensemble modeling system into the warning decision process.

Stensrud et al. (2009, BAMS)

Two issues: Microphysics & Data assimilation

OUTLINE

I. One radar data assimilation scheme for severe storms.

II. Weather-adaptive realtime analysis system.

III. A preliminary realtime short-term (0-3h) forecast system.

IV. On-going & future work.

OSSEs for Stormscale Radar Data Assimilation with an Ensemble of 3DVAR System

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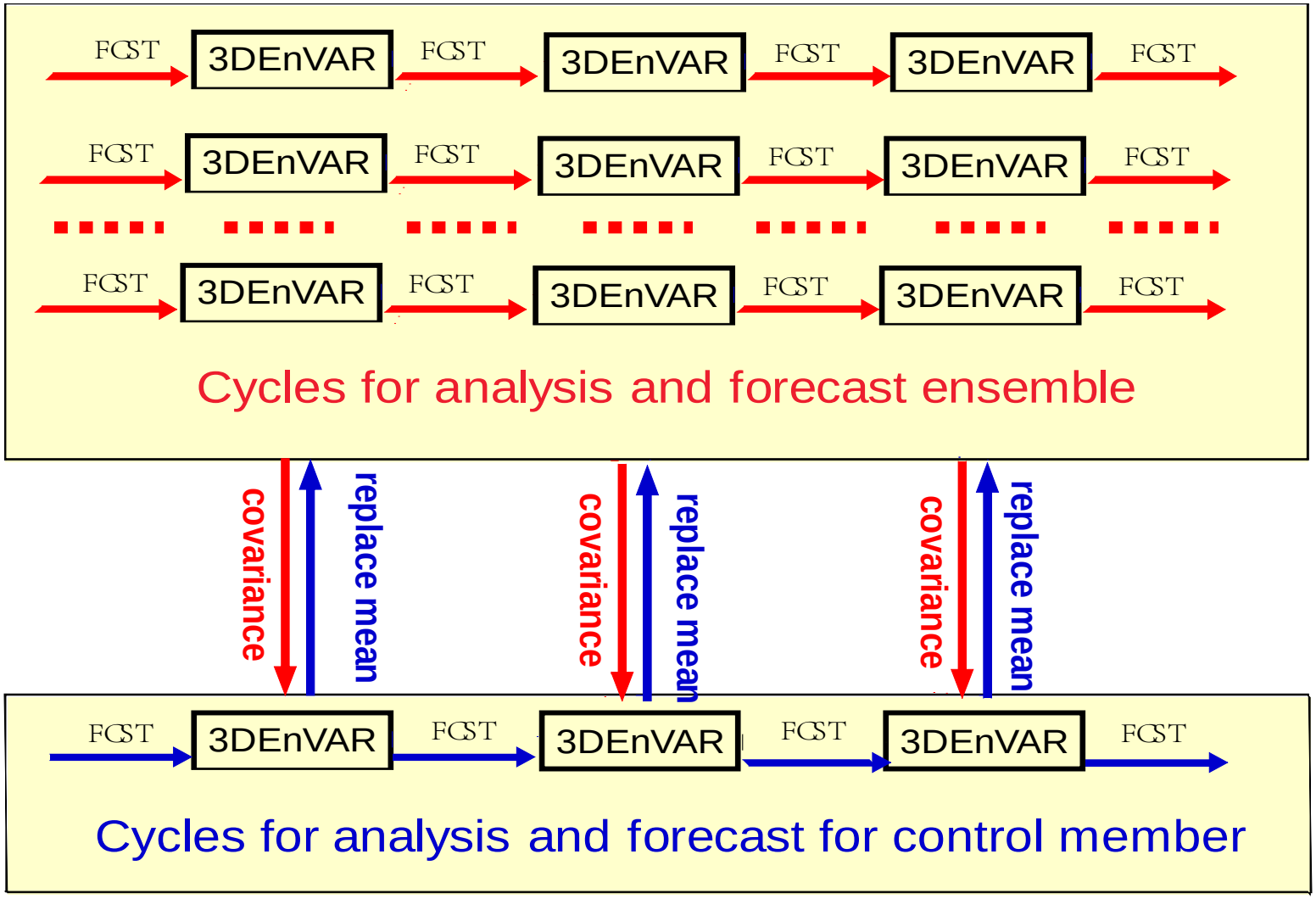
Why ensemble of 3DVAR?

- Ensemble information can be included in a 3DVAR by using ensemble derived flow-dependent error covariances.
- Variational method has an advantage of incorporating weak constraint, such as mass continuity equation to help balance different analysis variables.
- Well-designed ensemble of 3DVAR system could be efficient and effective enough for WoF purpose.

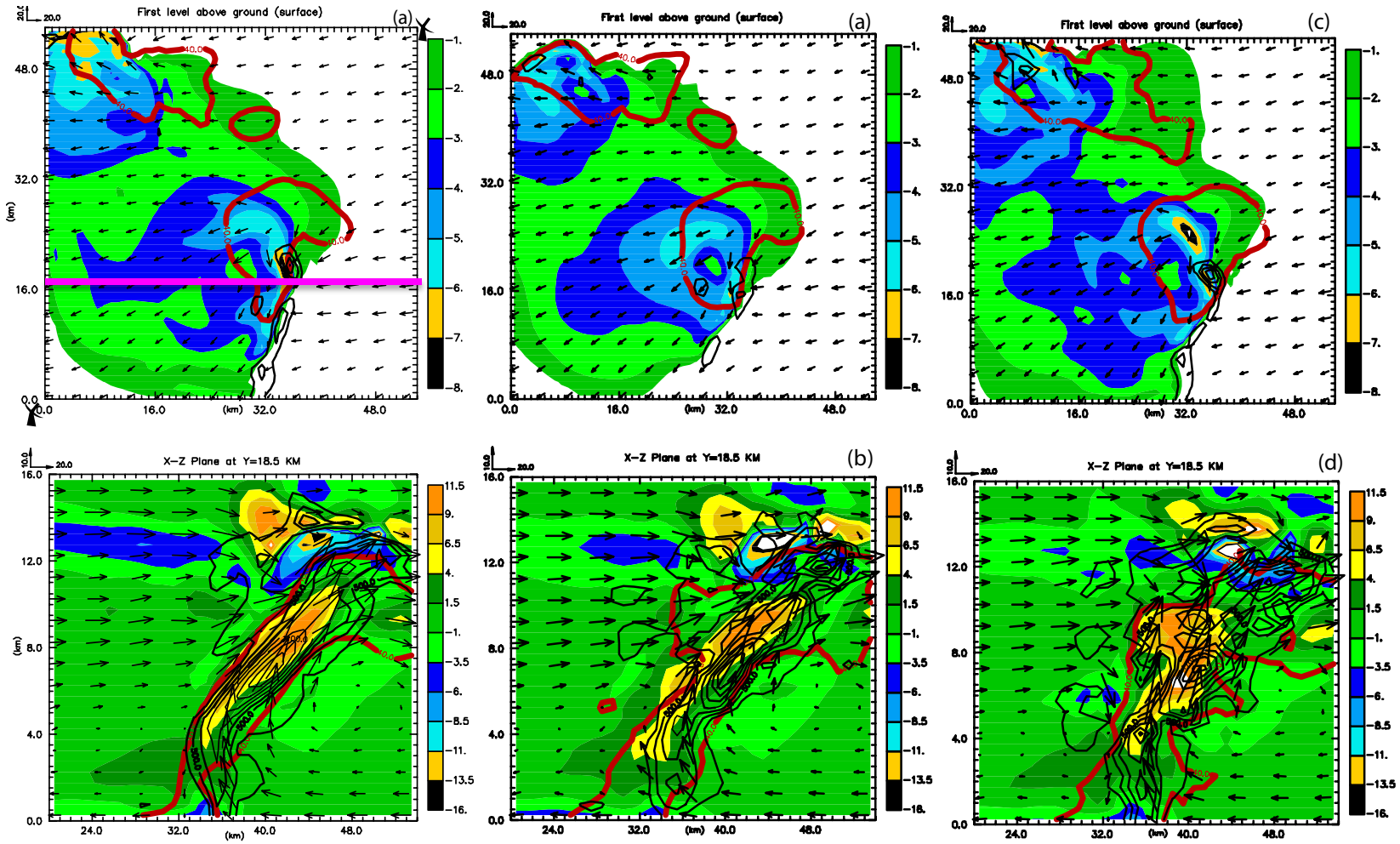
An Ensemble of 3DEnVAR Scheme



A seamless ensemble of data assimilation and forecast system.

Analysis for wind vectors, θ' (color-shaded), ξ (thin contours) and reflectivity (of 40 dBz red)

V_r error
5 m/s



truth with MC without MC

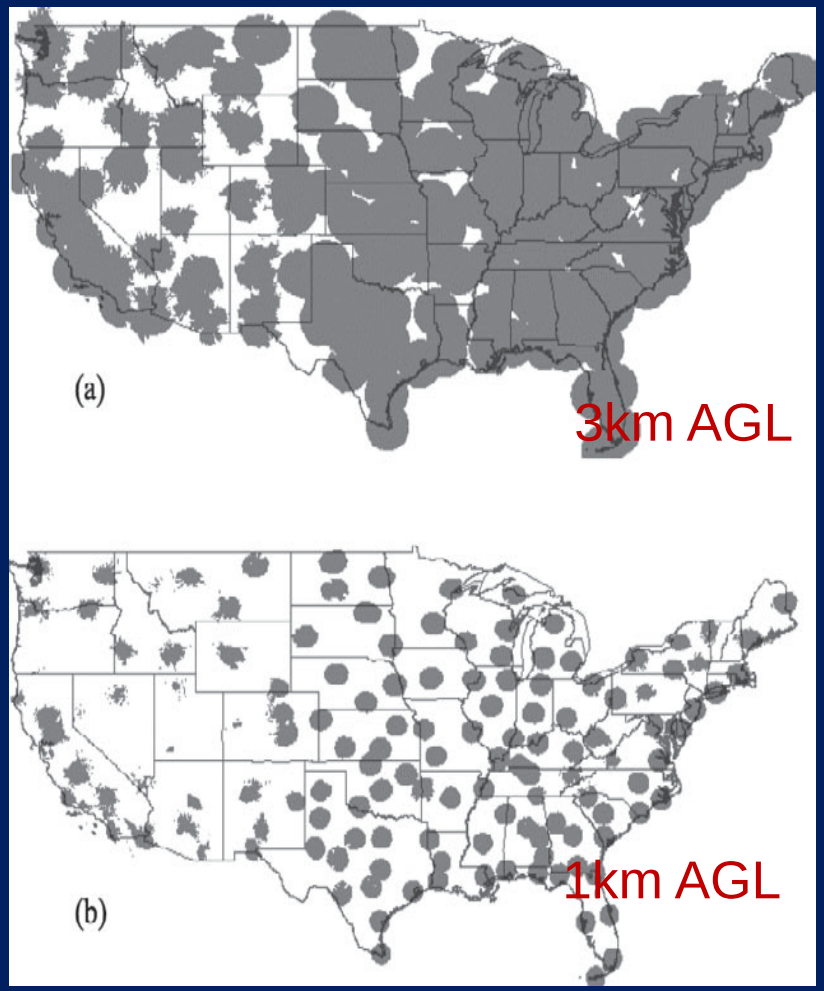
II. Weather-adaptive realtime analysis system

- To perform weather-adaptive 3DVAR analysis at high spatial resolution (1km) & high time frequency (5 min) in real time using all operationally 88D available data with 4 floating domains (automatic, or user-defined).

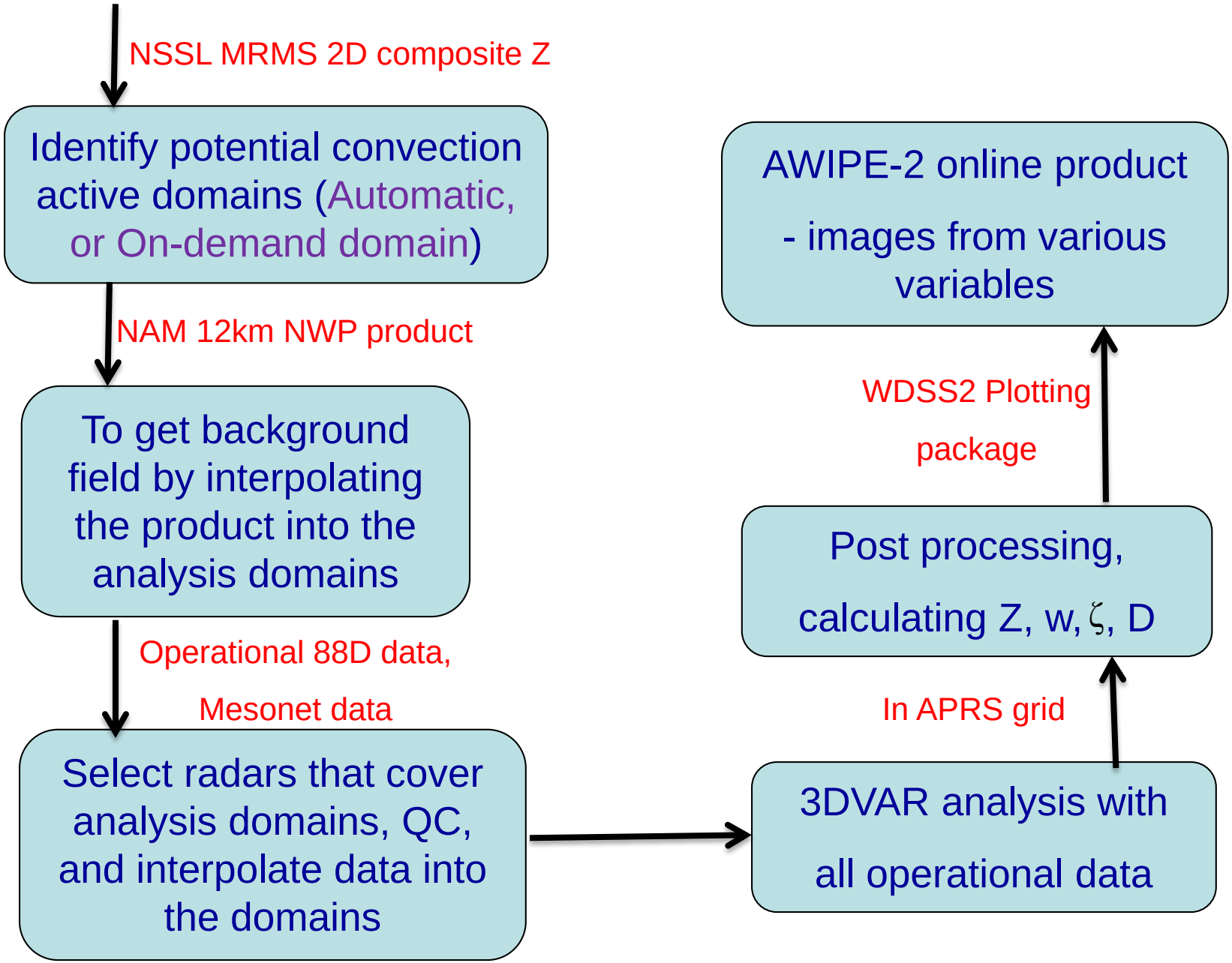
- To use the analysis product to detect supercells and assist a forecaster's awareness of the current state of the hazardous weather.

Why we can do this ?

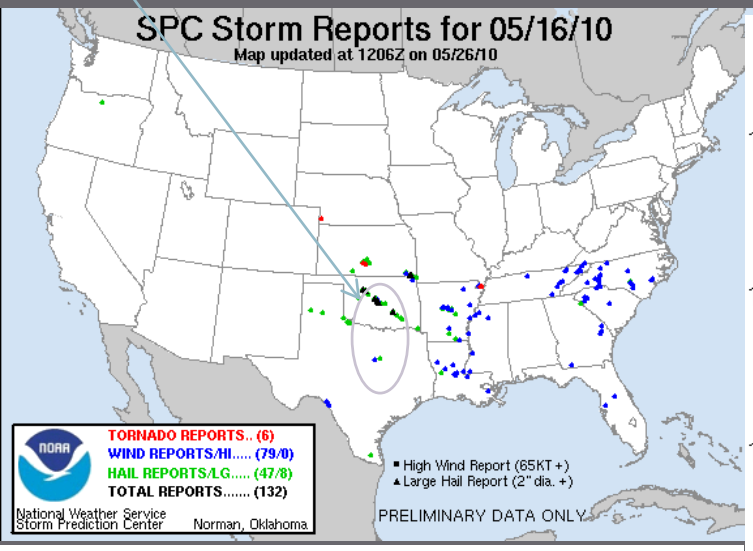
- In US, WSR-88Ds coverage is pretty good for vertical levels in between 3km to 5km from Mid. West to East areas, and severe wea. often happens in these area.
- We may use some good data assimilation strategy - take advantage of high-frequency of radar data and use multiple time level data.



Flow Chart of the System

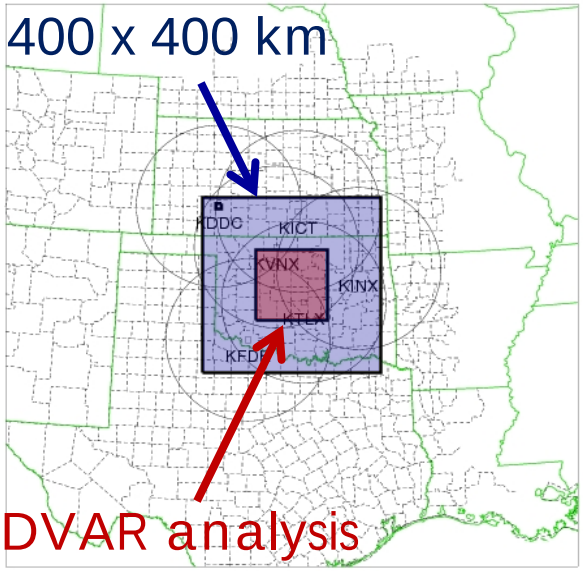


May 16th OKC, 2010 metro Hailstorm



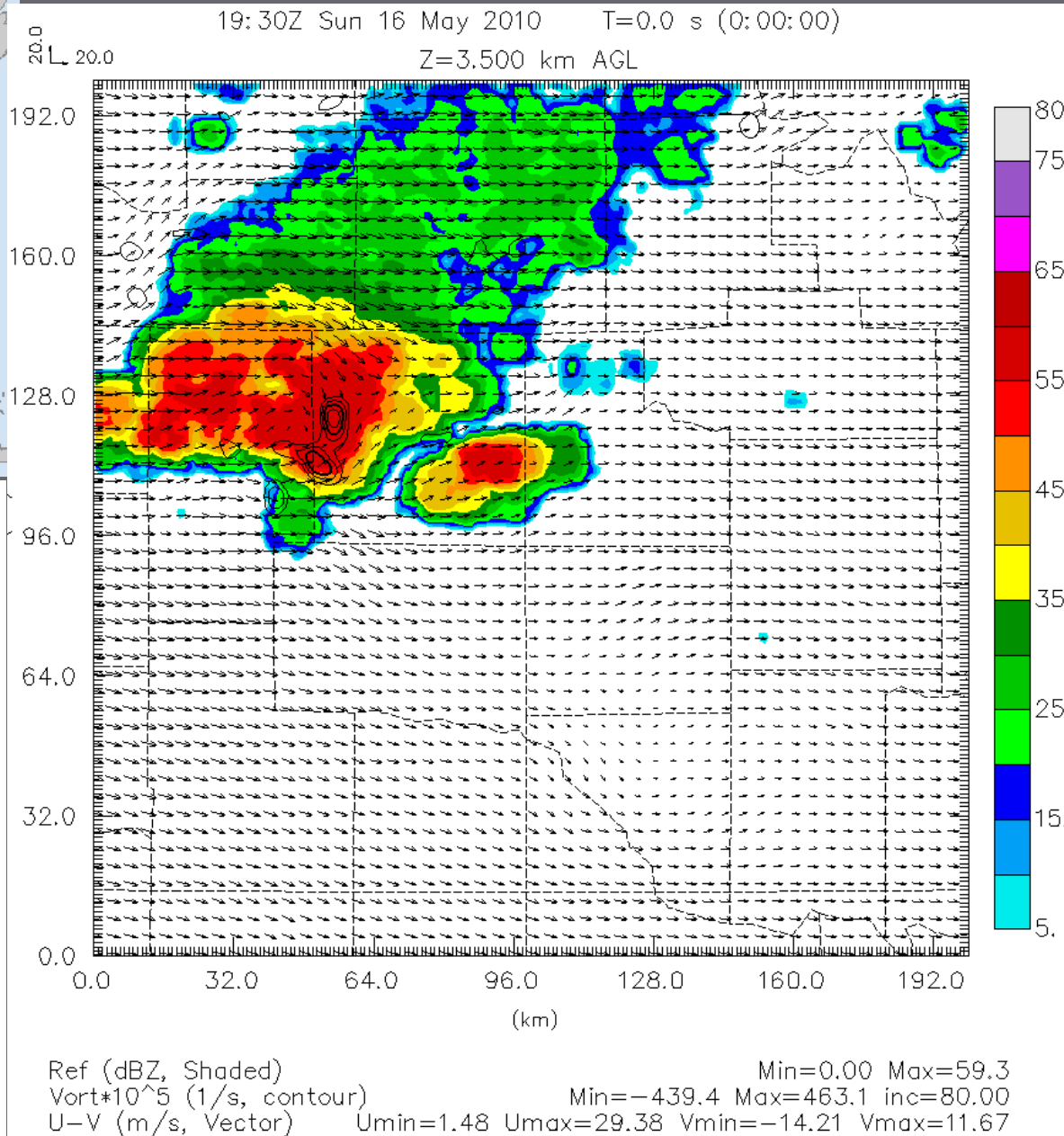
Radar selection

400 x 400 km

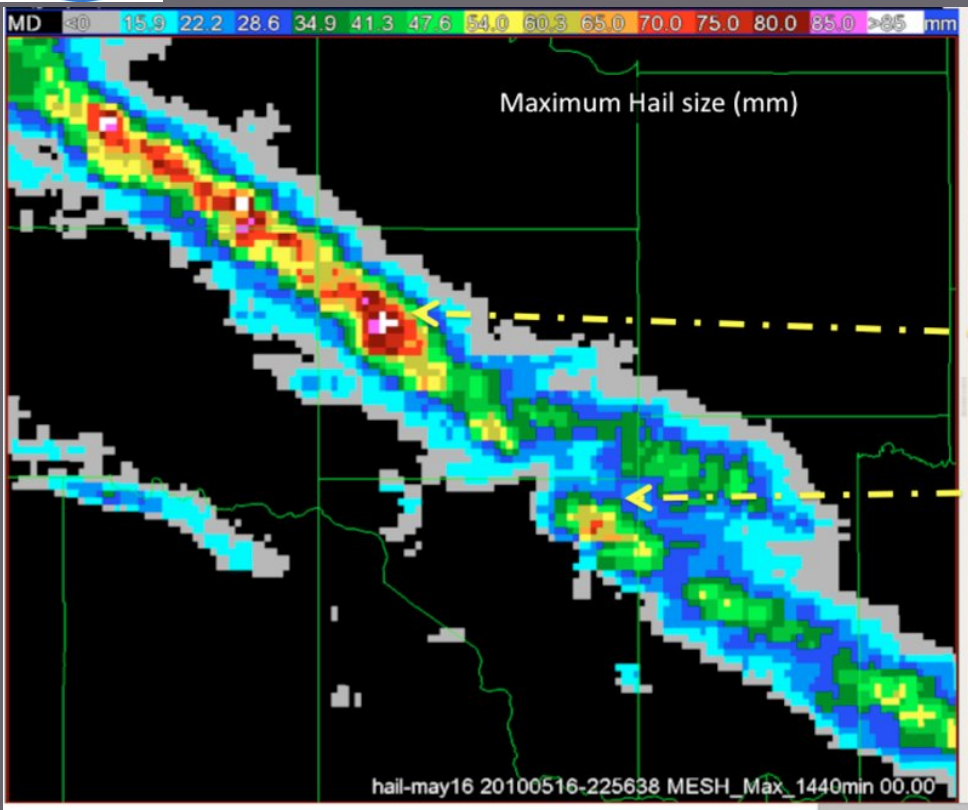


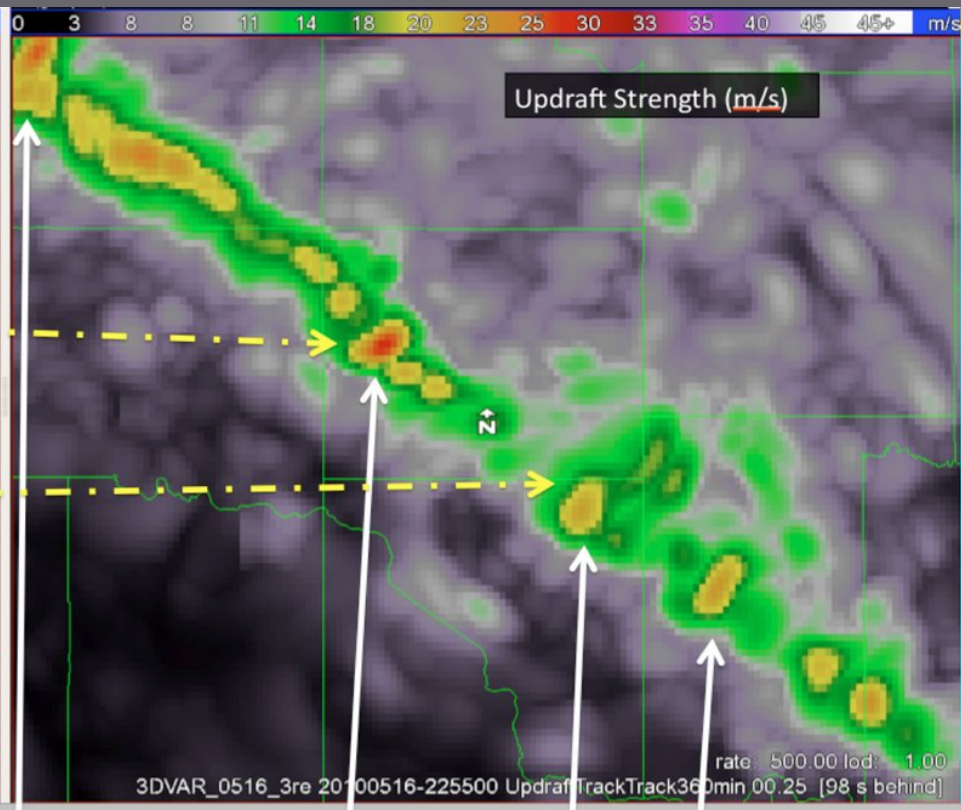
3DVAR analysis

200 x 200 km



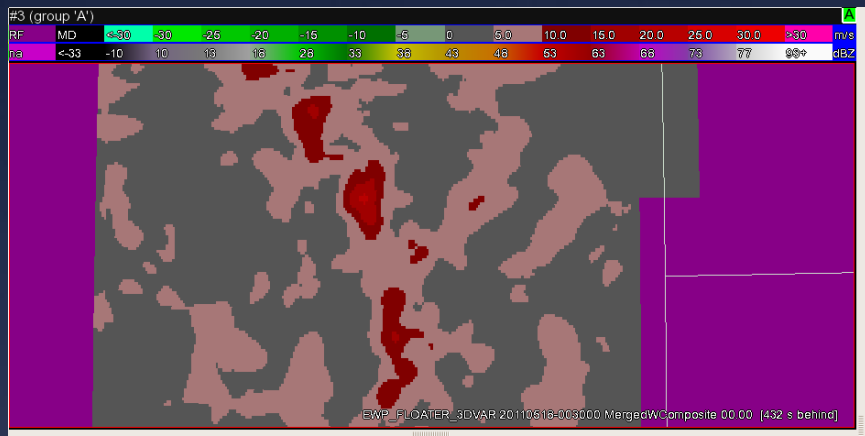
Hail Size (MR/MS) versus updraft intensity

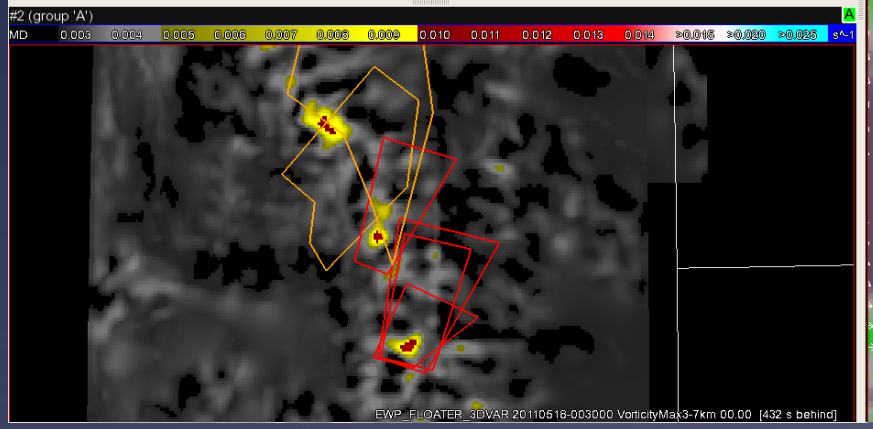


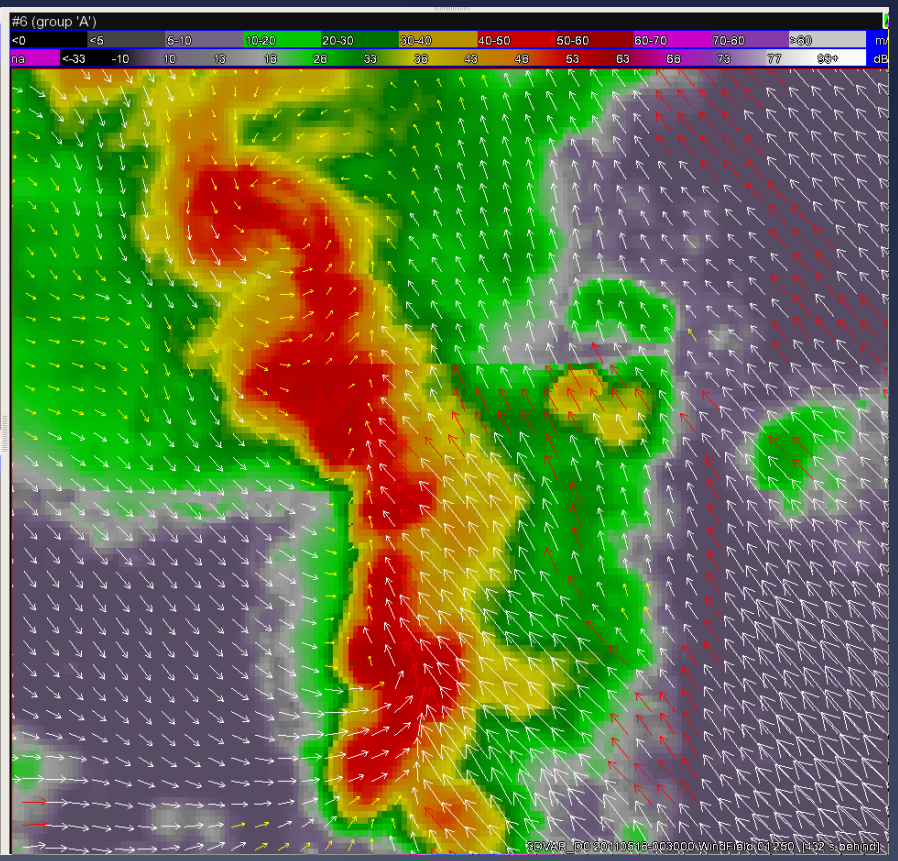


16 May 2010

Examples of Warning Operations with NWS Awips system





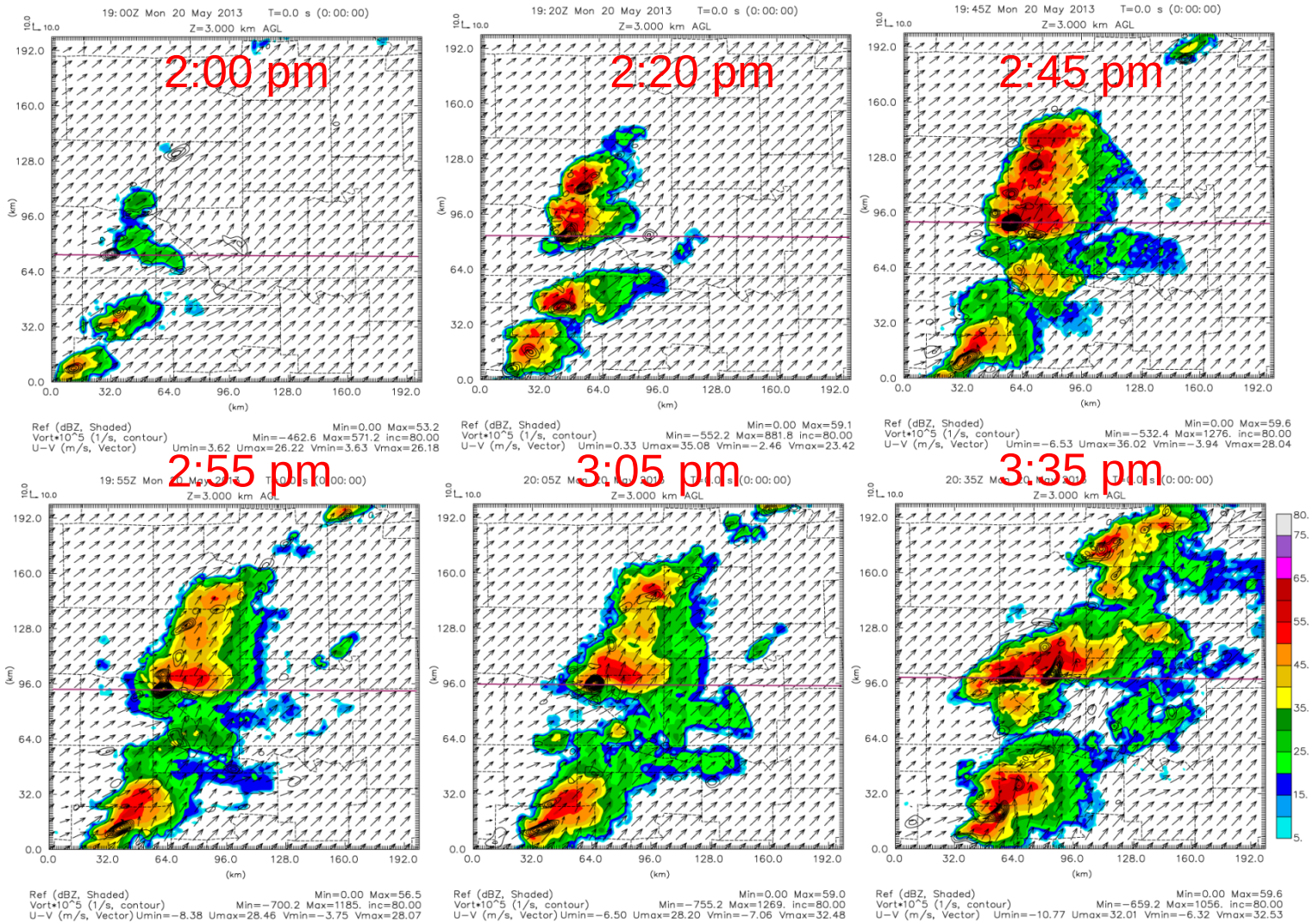


Updraft Composite (top)
Vertical Vorticity, max 3-7 km

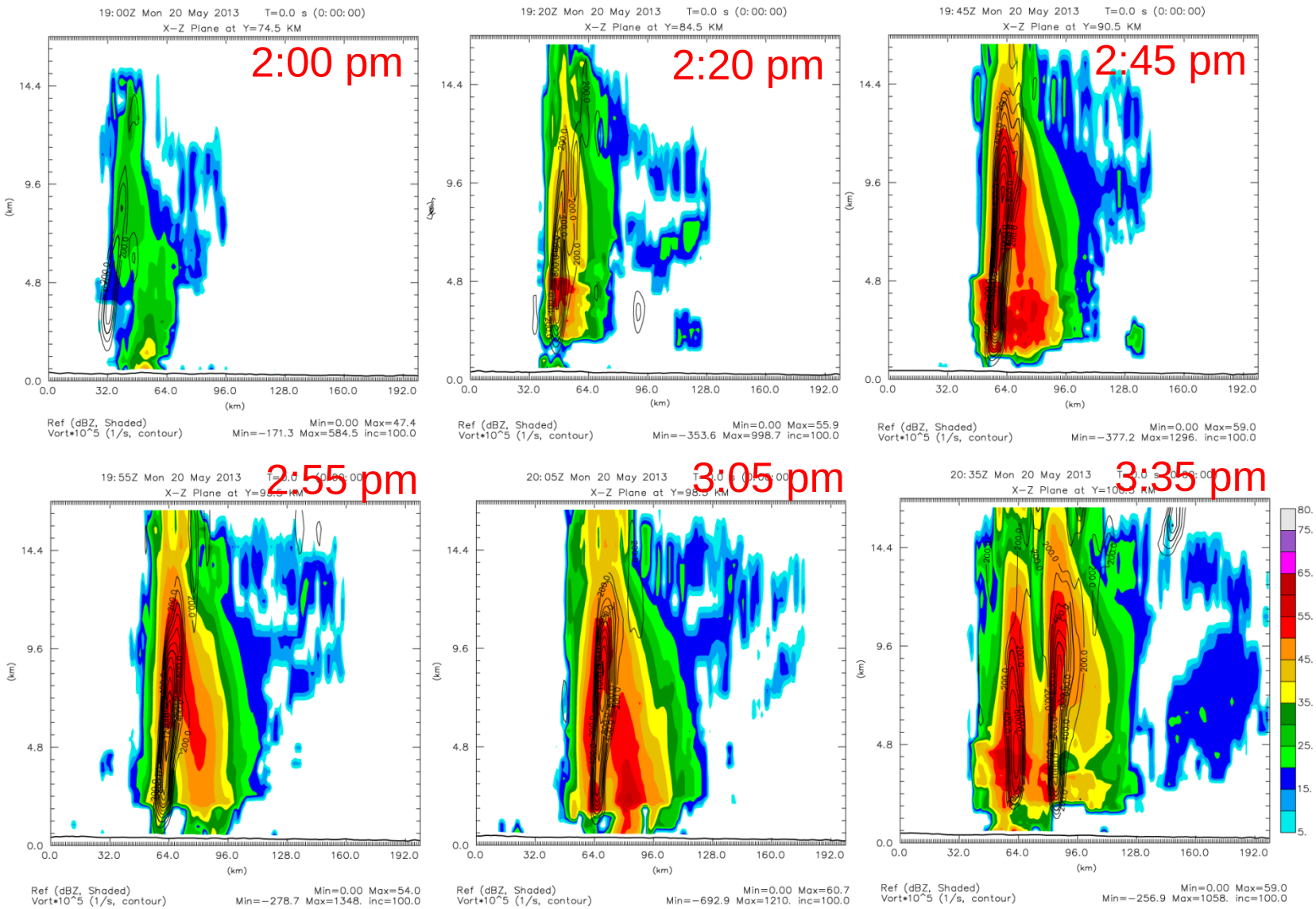
3DVAR merged
reflectivity & winds

17 May 2011 3DVAR 0030 UTC, NE Colorado

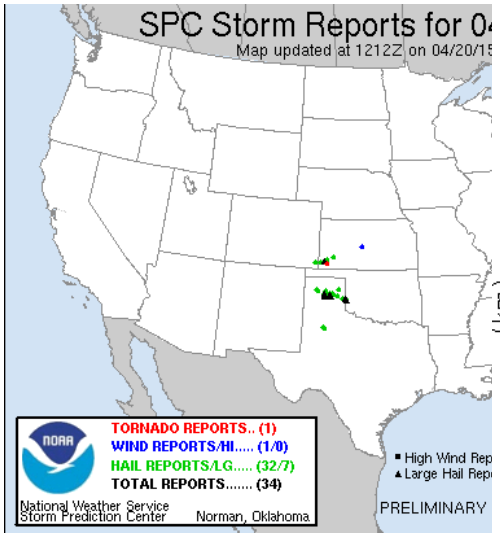
May 20th, 2013 Moore Tornadoes

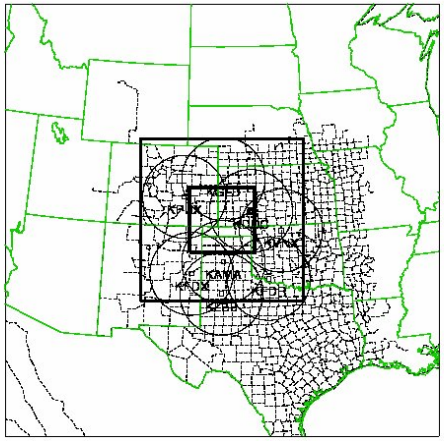


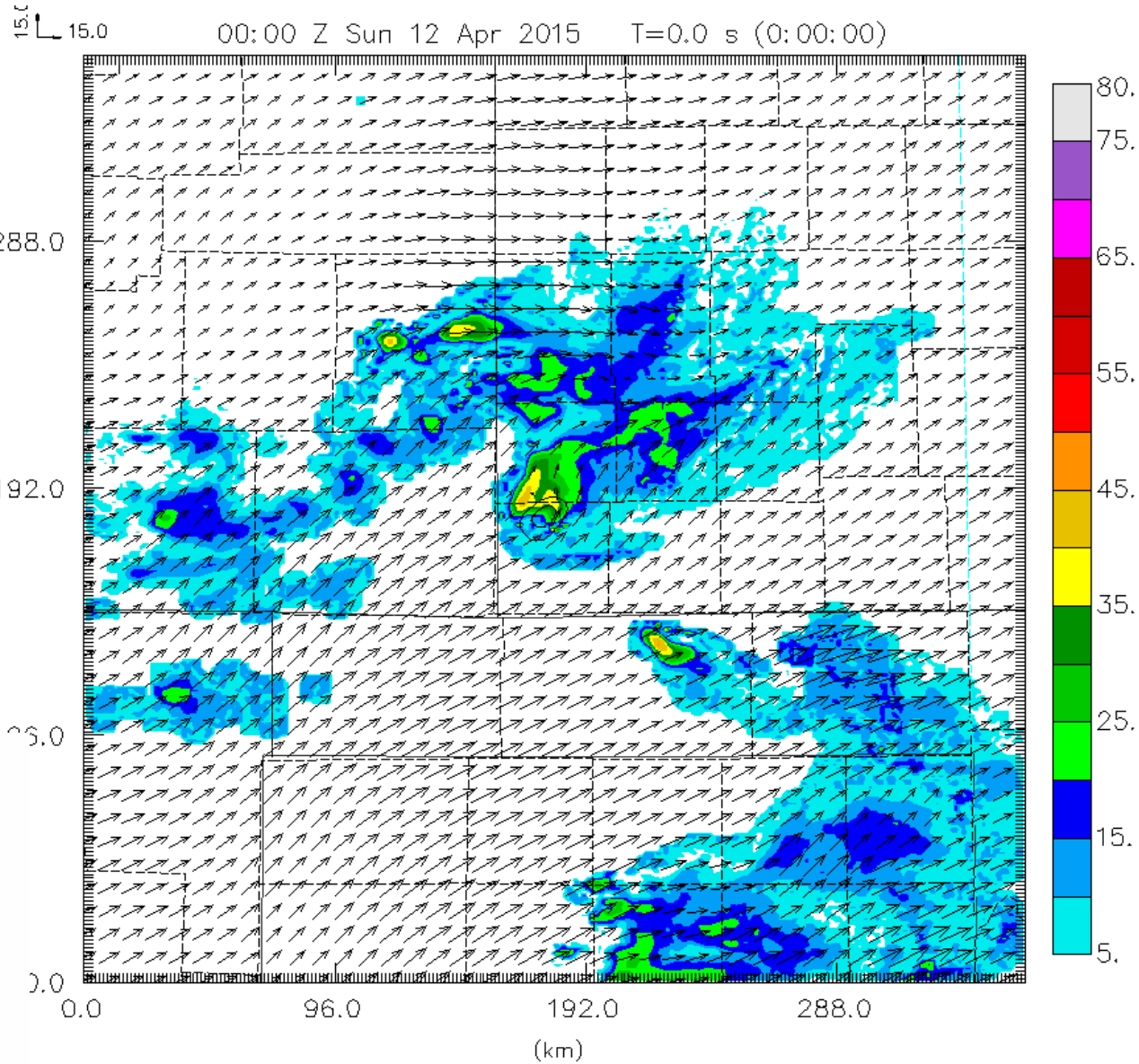
May 20th, 2013 Moore Tornadoes



April 11, 2015,7-8 pm,
SW Corner KS
(pre-HWT)





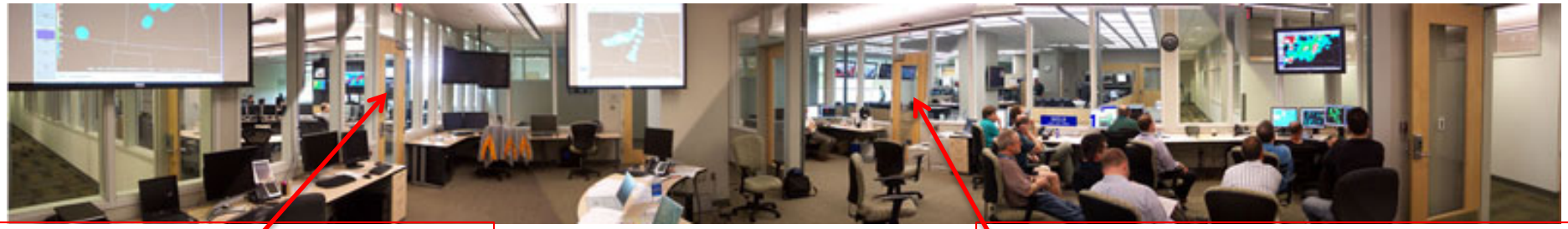


tke ((m/s)**2, Shaded) Min=0.00 Max=45.2
Vort*10^5 (1/s, contour) Min=−137.4 Max=220.1 inc=80.00
U−V (m/s, Vector) Umin=−3.24 Umax=28.19 Vmin=−3.49 Vmax=14.23

More cases can be found in my poster presentation B-04 this afternoon

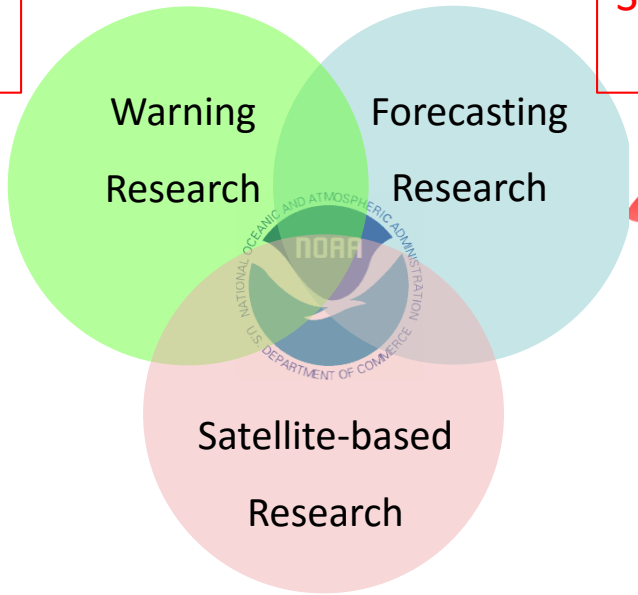
NOAA Hazardous Weather Testbed

Where practitioners and researchers work together…



Local NWS forecast office:
Regional responsibility

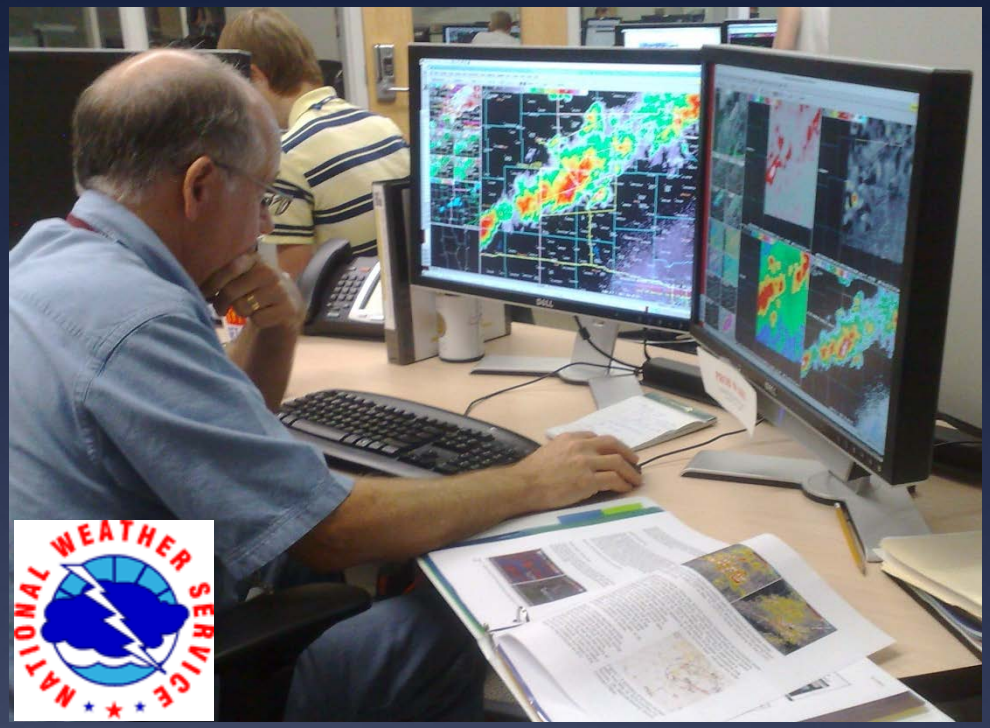
Storm Prediction Center:
Nationwide responsibility



Forecaster Feedback

Favorite products:

Updraft & Vertical Vorticity

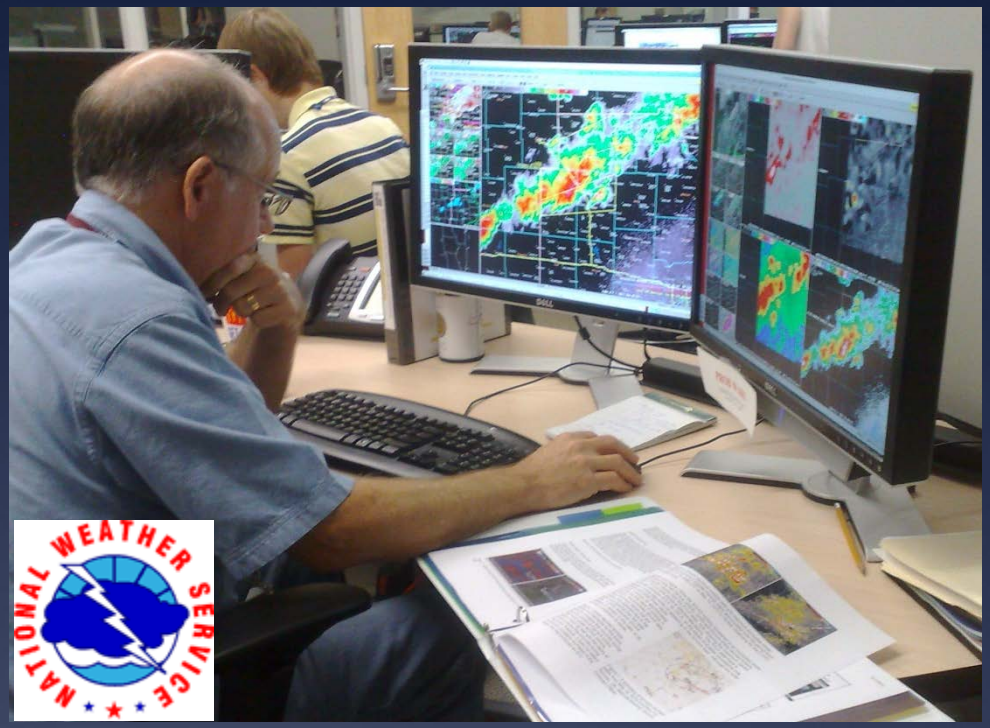


Useful when "trying to diagnose a large number of storms" and "sitting on the fence" (about issuing a warning)

Forecaster Feedback

Favorite products:

Updraft & Vertical Vorticity



More "efficient to view than existing algorithms" to diagnosis storm intensity and rotation

Forecaster Feedback

Real-time data Issues:

Data Latency
(approx 5 min)

Distance from Radar
(lack of low-level input)

Occasional unrealistic updraft/downdraft near interacting storms
(mass continuity constraints & radar QC)

The Ref. for system description & verification:

Gao J., Smith T. M., D. J. Stensrud, C. Fu, K. Calhoun, K. L. Manross, J. Brogden, V. Lakshmanan, Y. Wang, K. W. Thomas, K. Brewster, and M. Xue, 2013: A realtime weather-adaptive 3DVAR analysis system for severe weather detections and warnings with automatic storm positioning capability. *Wea. Forecasting*, **28**, 727-745.

Smith, T. M., J. Gao, K. M. Calhoun, D. J. Stensrud, K. L. Manross, K. L. Ortega, C. Fu, D. M. Kingfield, K. L. Elmore, V. Lakshmanan, and C. Riedel, 2014: Performance of a real-time 3DVAR analysis system in the Hazardous Weather Testbed. *Wea. Forecasting*, **29**, 63-77.

Calhoun, K., M., T. M. Smith, D. M. Kingfield, J. Gao, and D. J. Stenrud, 2014: Forecaster Use and Evaluation of realtime 3DVAR analyses during Severe Thunderstorm and Tornado Warning Operations in the Hazardous Weather Testbed **.** *Wea. Forecasting*, 29, 601-613.

Clark, A. J., J., Gao**,** P. T. Marsh, T. M. Smith**,** J. S. Kain, J. Correia Jr., M. Xue, and F. Kong*,* 2013: Tornado path length forecasts from 2011 using a 3-dimensional object identification algorithm applied to ensemble updraft helicity, *Wea. Foreacasting,* **28**, 387-407*.*

III. A preliminary realtime short-term (0-3h) forecast Exp.

--First step, only focus on deterministic forecasts, will involve ensemble of DA and forecast in the near future…

Configurations

- DA scheme and model: NSSL 3DEnVar (going to be 4DEnVar soon) and WRF model.
- Data: radar data & satellite Cloud Water Path
- Grid Size:

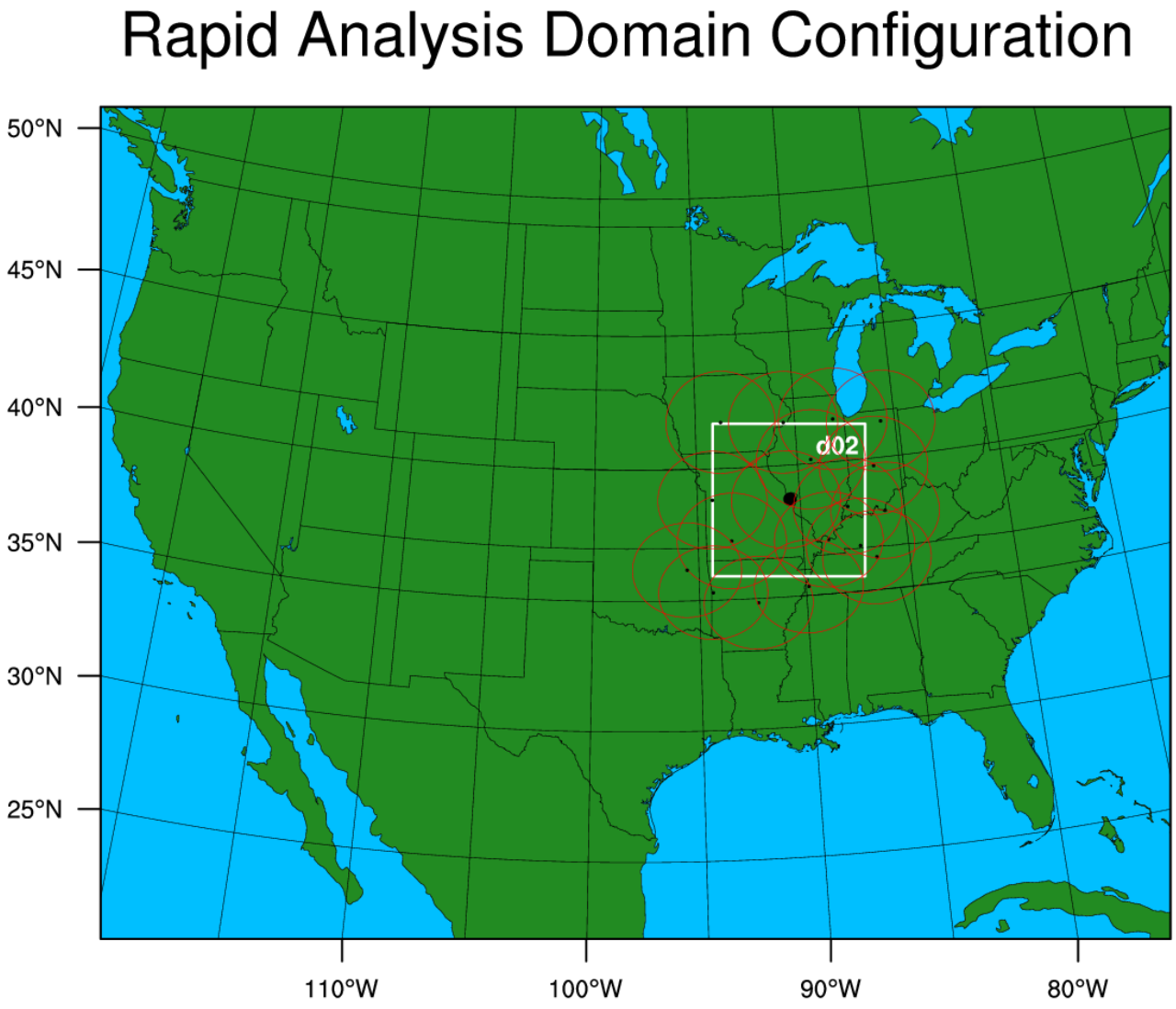
  horizontal: 480x480; vertical: 41.

  Resolution: dx = 1.33km; vertical stretching.
- Products include:

  Rapid analysis cycles: every 5 min.

  Forecast cycles: every 30 min

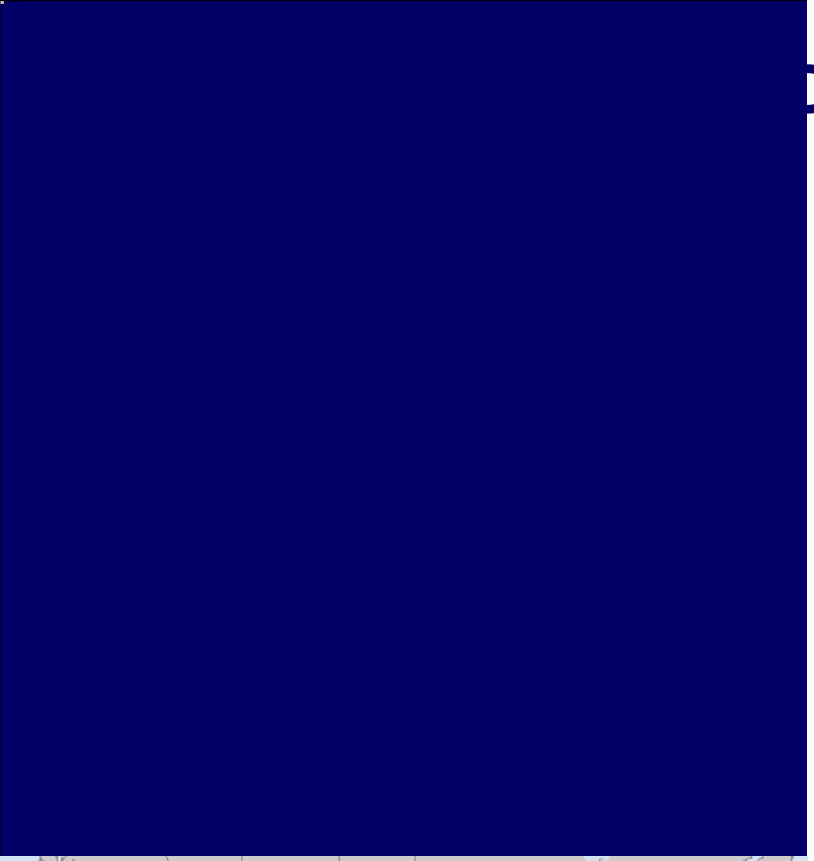
Example of Analysis and forecast domain

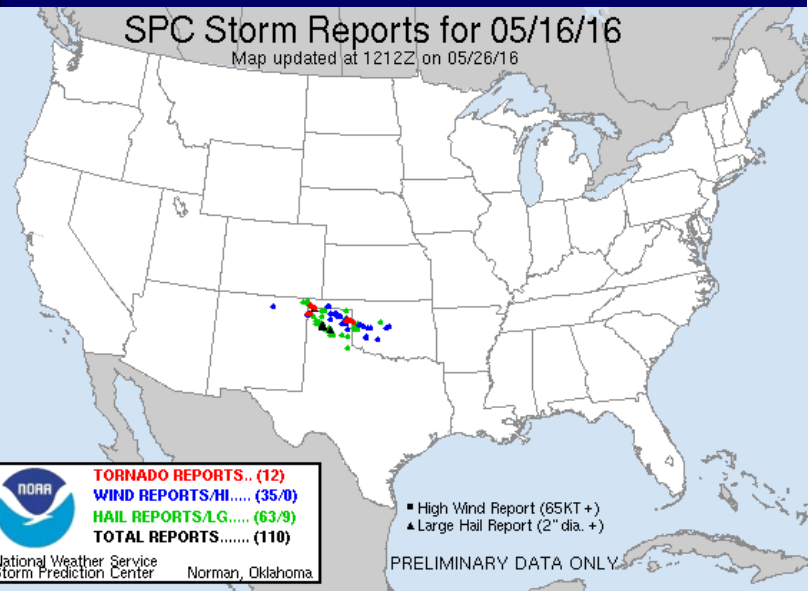


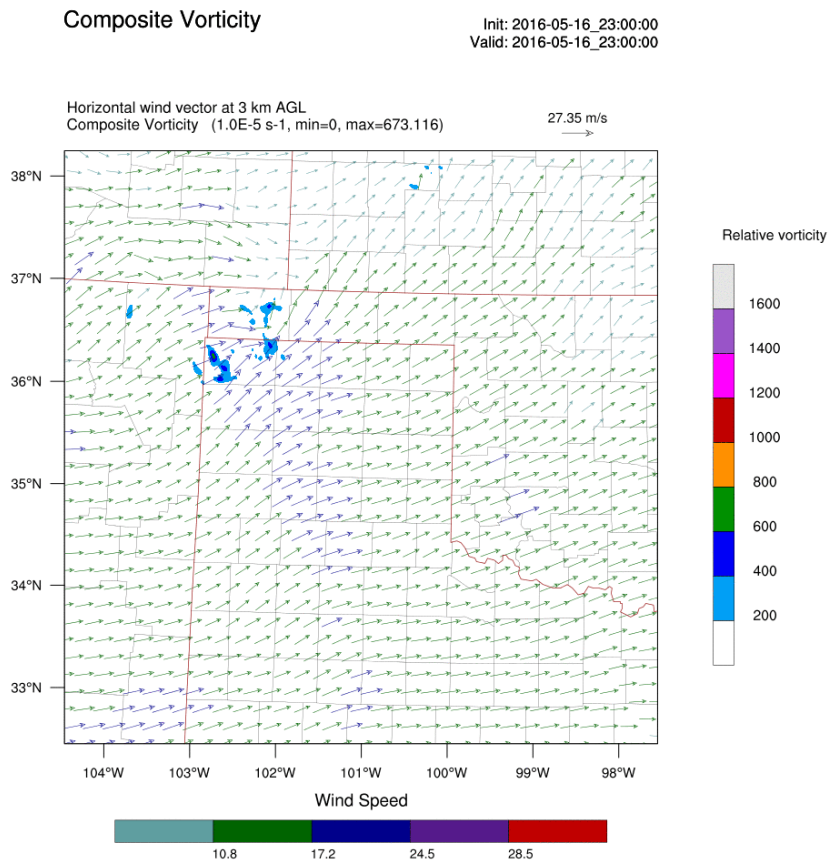
2016 Case Studies

1) May 16: Tornadic storms over Texas panhandle; they grow upscale as they move into Oklahoma (would probably be good to look at a case with mixed modes of convection).
2) May 24: Tens of tornado reports over western Kansas (in proximity to Dodge City); rather widespread event.
3) May 25: Very strong, long-lived tornadic supercell over northeastern Kansas.

Panhandle, W. OK







6:00 pm - 9:00 pm

OUTPUT FROM WRF V3.7.1 MODEL
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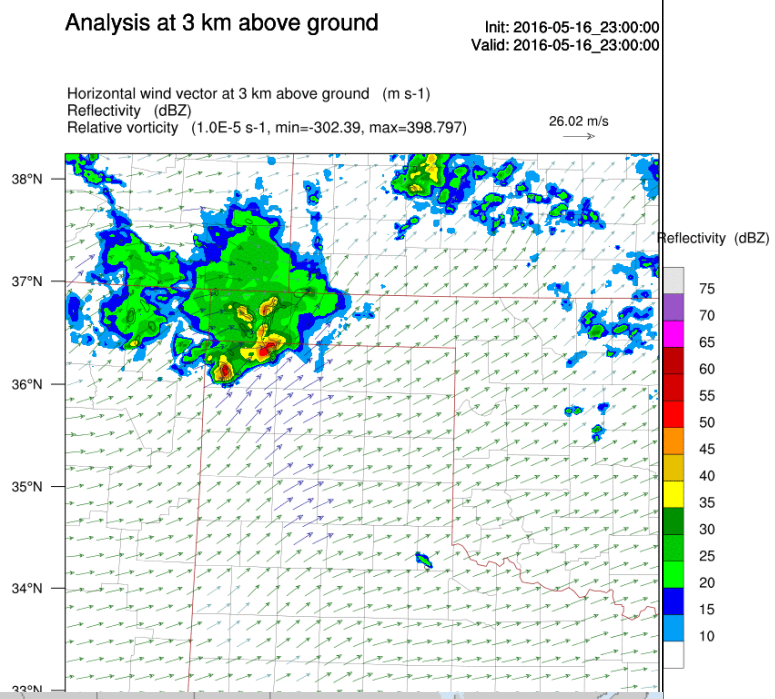
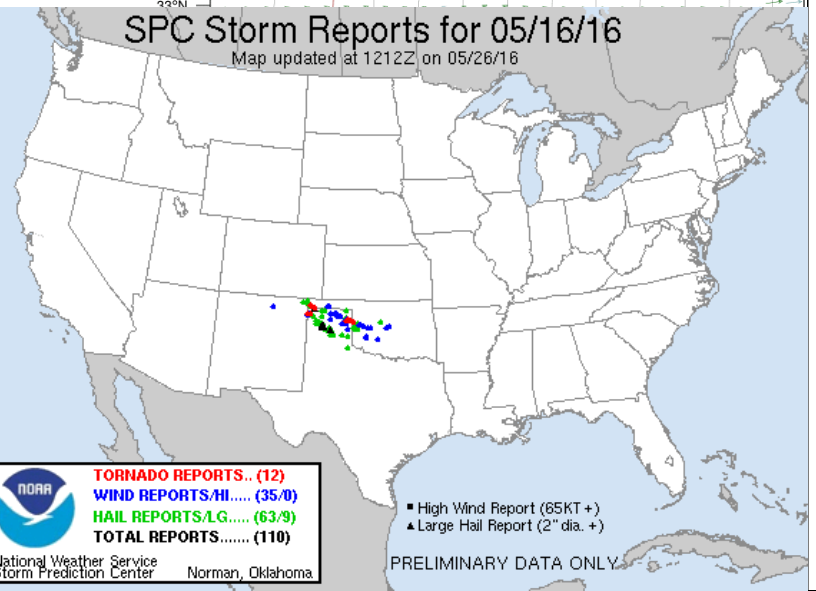
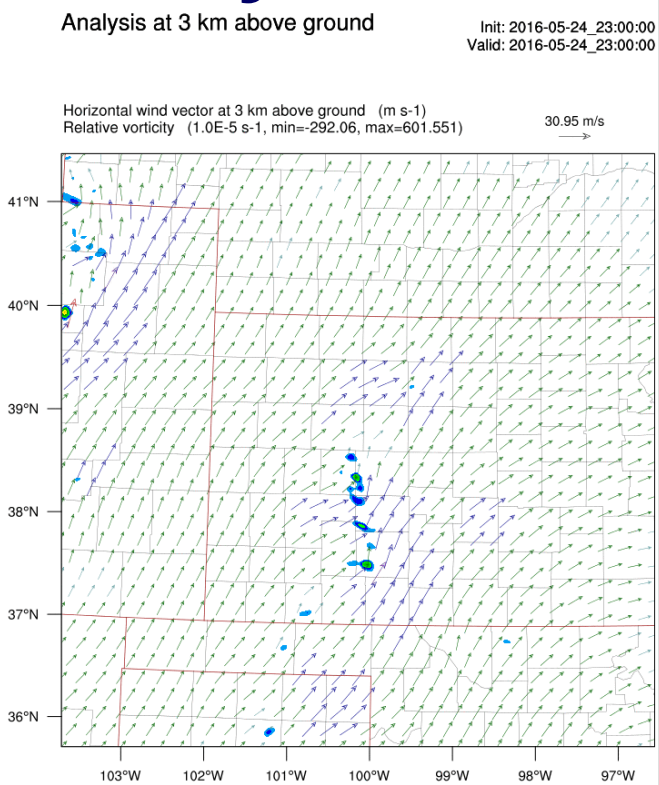
May 16, TX Panha

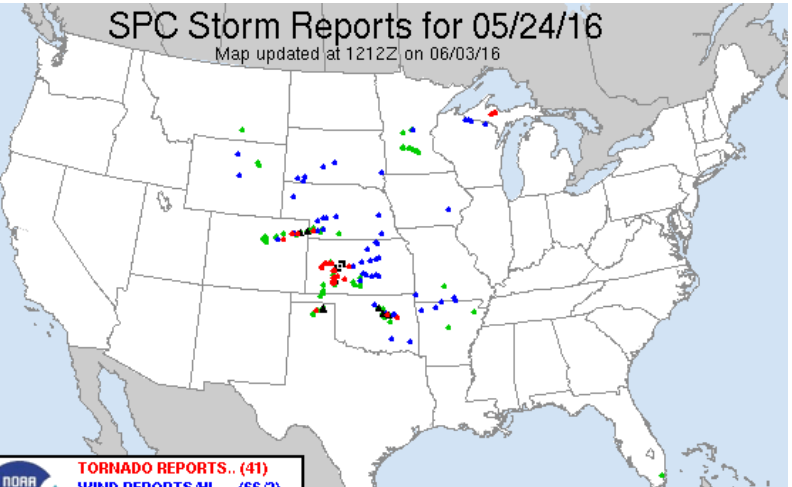




6:0

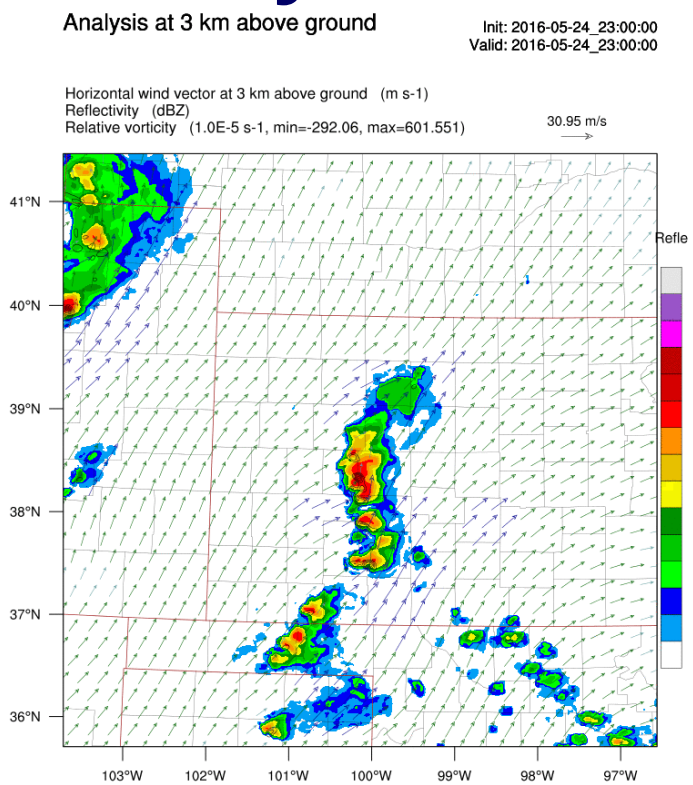
May 24 C. Kan ar

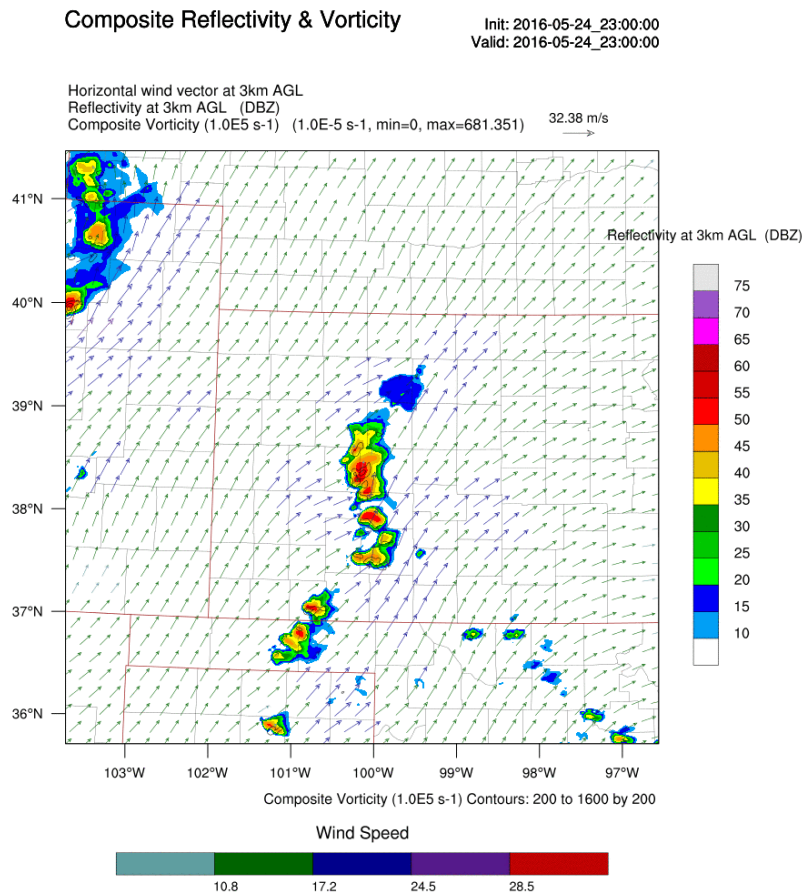


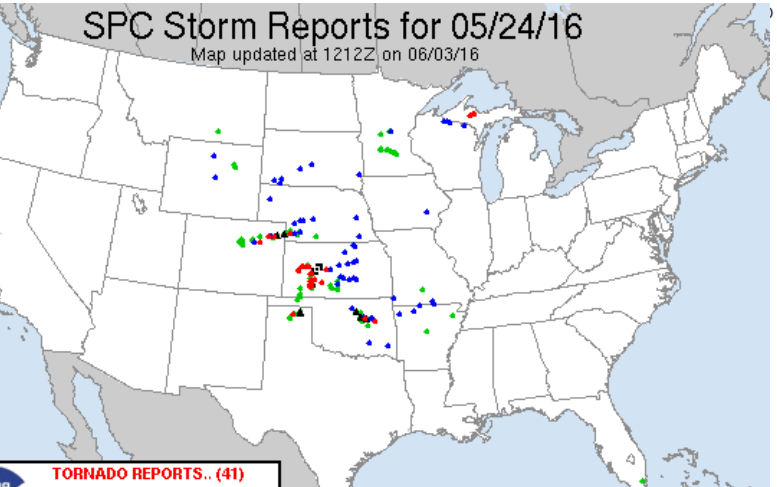


6:00

May 24 C. Kan and NE. CO







6:00 pm - 9:00 pm

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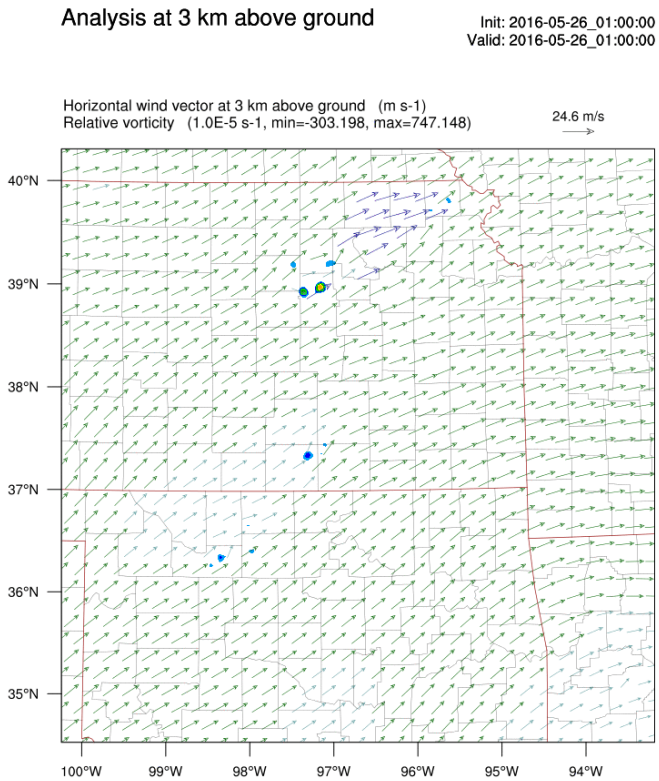
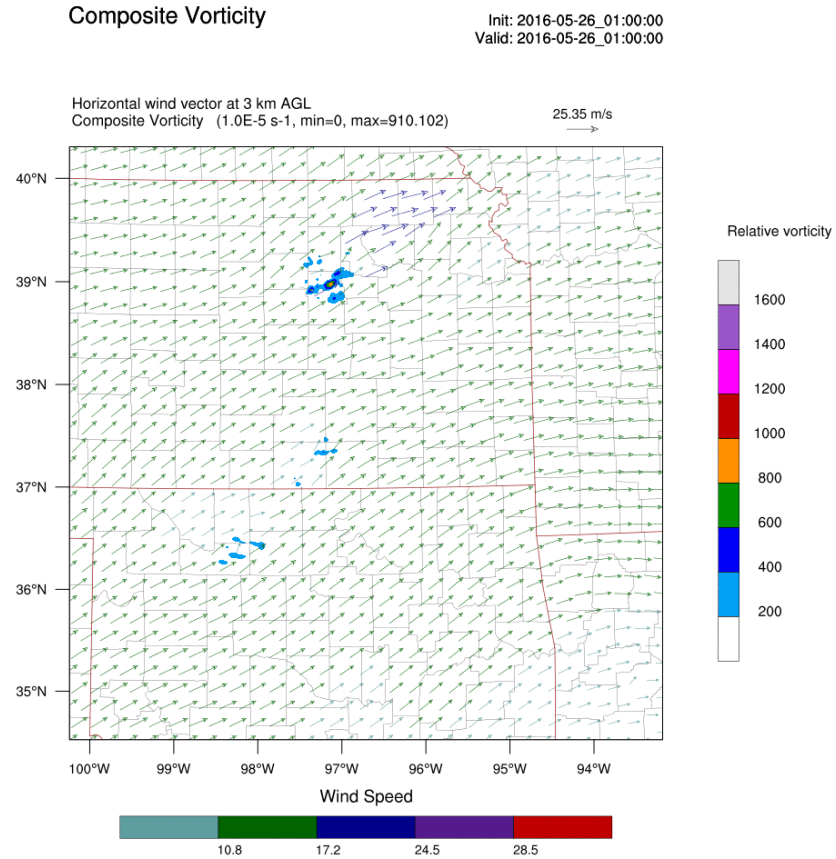
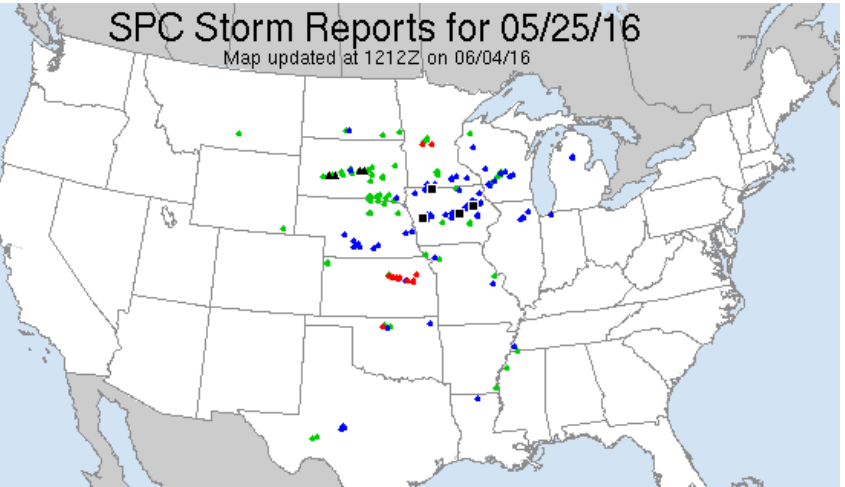
May 25 NE. Kan.







8:00 pm -11:00 pm

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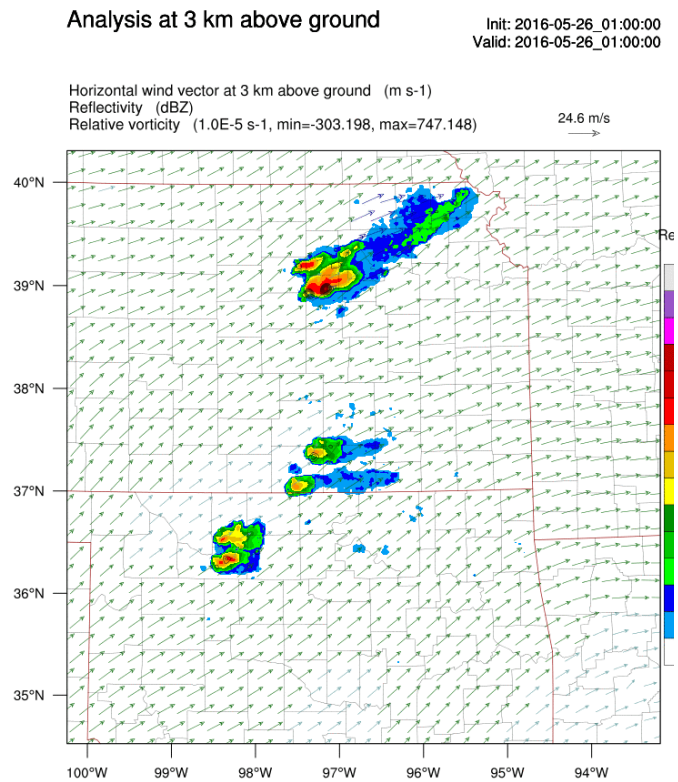
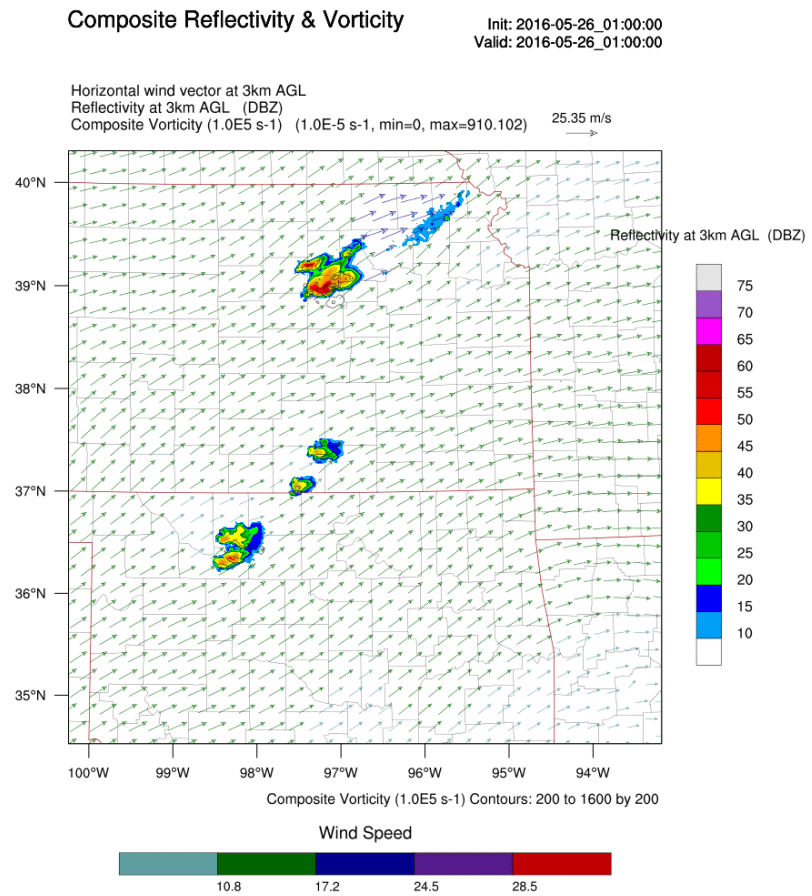
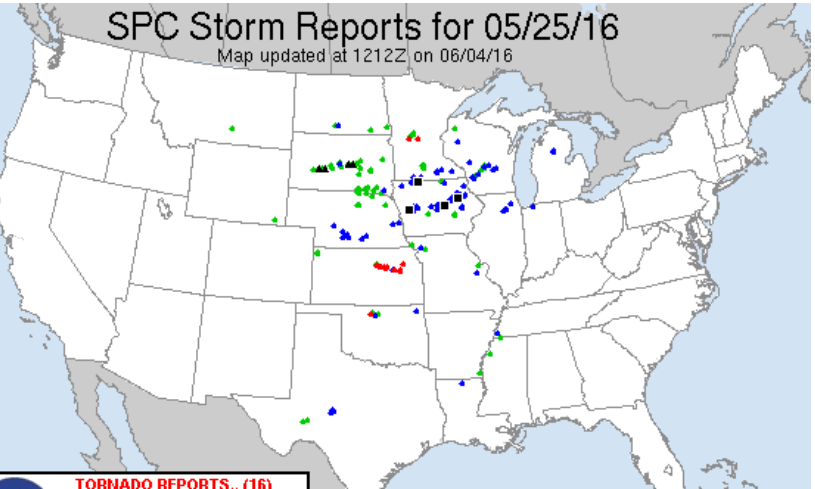
May 25 NE. Kan.







8:00 pm - 11:00 pm

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WE = 481 ; SN = 481 ; Levels = 41 ; Dis = 1.33333km ; Phys Opt = 8 ; PBL Opt = 2 ; Cu Opt = 0

Summary

1) Two separate analysis and forecast systems allow us to do comparisons and verifications easily (need improvement).
2) Very preliminary tests were performed in this year's HWT with some mixed results. The 3-h predictions of some supercell cases look good. Need improve for MCS, Squall line cases.
3) We will do more sensitivity experiments on these 3 events and hopefully further improve both the analysis and forecast systems.
4) Priority: To develop a hybrid gain (combined DART-3DVAR system) and EnVar system and be tested with these cases.

IV. Ongoing and future Work

- Improve storm environment: need to assimilate VAD wind from each 88D used (GVAD, Gao et al. 2004, *MWR*, *high vertical resolution*) and assimilate GOES-R TPW (total precipitable water, qv, clear air).
- Improve in-storm structure: Key issue is how to properly assimilate reflectivity (Gao and Stensrud, 2012, *J. of Atmos. Sci.*).
- Improve in-storm structure: need to test GOES-retrieved cloud water path together with radar data, and do comparison with cloud analysis.
- More research on dual-pol and lightning DA with my colleagues at NSSL.
- With the help of WoF project, hopefully we can improve Convective-scale NWP in the next few years.