NSSL's EnKF Research: Recent Activities, Results, and Roadblocks

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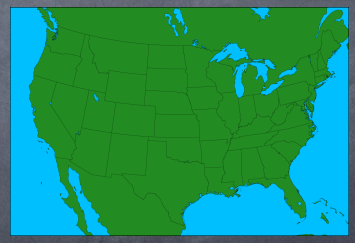
Current Activities

- Focused on testing all (or as many as possible) storm-scale DA methods
  - 3DVAR, EnSRF, LETKF
  - Ensemble/ENKF-nudging?
- Development of case studies for different types of convection
  - not just supercells
  - severe winds, hail, flash floods
- Get output in front of forecasters in the HWT
- Last 6 months developing 3-4 case studies

Case Studies

- Working toward quantitative comparison between various methods
- **Invite all groups to participate** – will share our cleaned up radar data
- Control experiments should be as **close as possible** between systems
- **Mesoscale** control run parameters
  - Start with 18 km WRF Conus, 45 members
  - 3 day cycling (6 hour updates)
  - 12Z day of event: 1 hour updates
  - All available observations
  - MYJ boundary layer
  - Thompson micro
  - KF convection
  - Noah land surface
  - Dudhia shortwave / RRTM longwave
- No physics diversity



Case Study Methodology

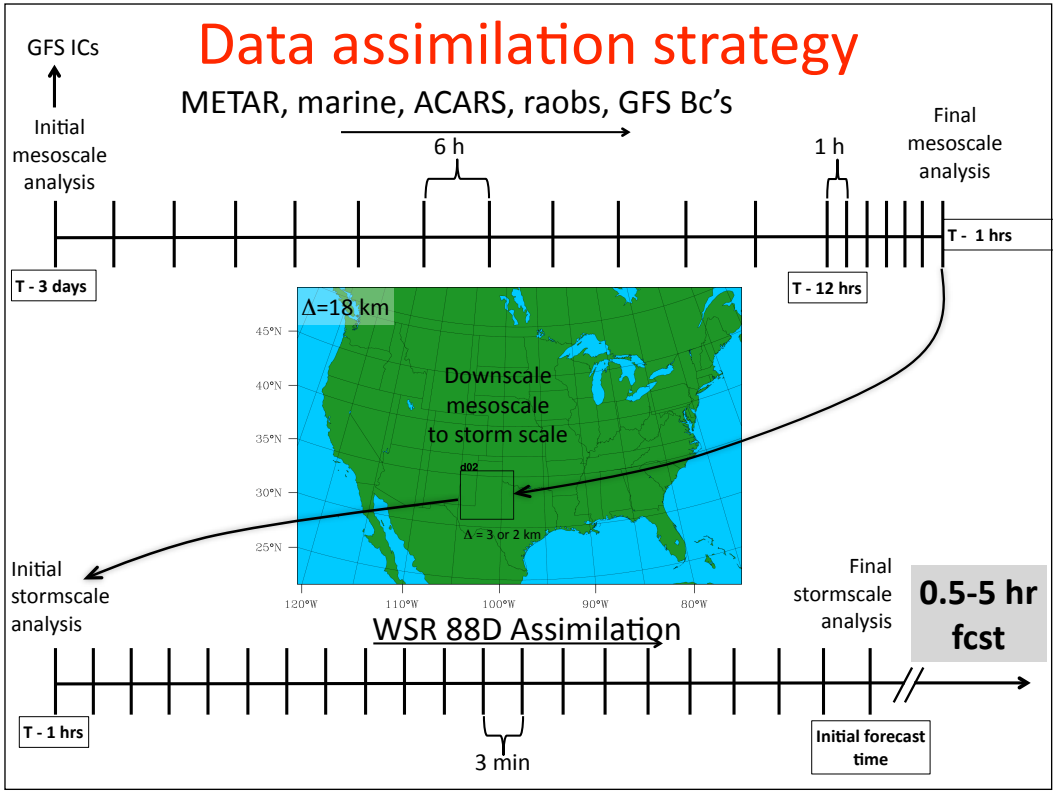
- Again: Working toward quantitative comparison
- **WRF Model**
  - Horizontal resolution: 3 km (or 2 km for supercells)
  - Microphysics: Thompson
- **Radar Observation characteristics**
  - Superob grid resolution: 6 km for Radial Velocity and Reflectivity
  - Superob grid resolution: 12 km for "Zero" Reflectivity obs
  - Observation errors: Vr = 2 m/s, dBZ = 5

- **DART Assimilation Parameters**
  - Assimilation frequency: 3 minutes
  - Localization: 12/6 km for horizontal/vertical
  - Adaptive inflation (default DART parameters)

Additive Noise parameters:

  - horizontal scale: 3 dx / vertical scale: 6 km
  - dBZ threshold for adding noise: 25 dBZ
  - Perturbations: 1 m/s for velocities, 1 K for temp/dewpt.
  - Noise frequency: for mesoscale convective systems: 30 min, for supercells: 3 min (same as assim freq)

Data assimilation strategy

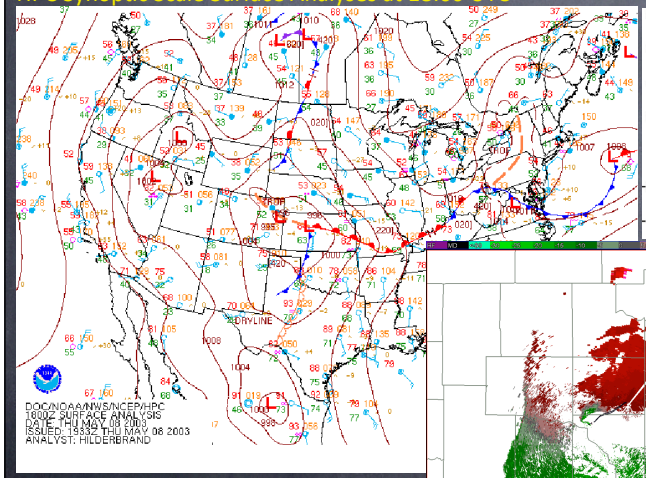


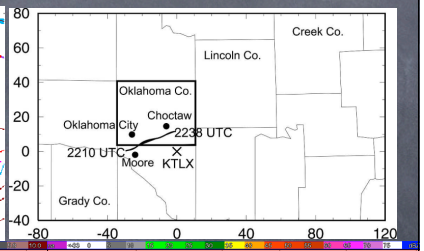
Current Storm-scale Cases

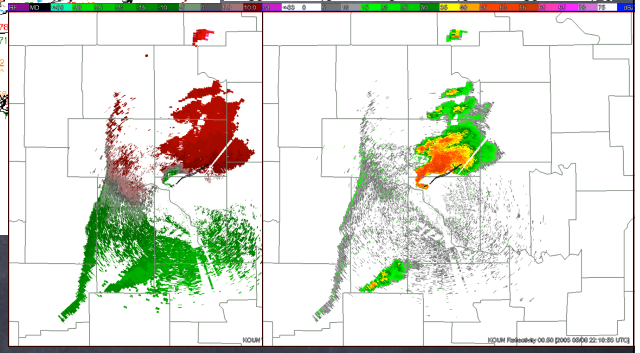
- Supercell
  - **8 May 2003 (F4 tornado, Moore OK)**
  - 10 May 2010 (cen. OK, T Jones, satellite study)
  - 27 April 2011 (Alabama super outbreak)
  - 24 May 2011 (F4/5 cen. OK tornado outbreak, MPAR)
- MCS
  - **4 July 2003 (Ohio Valley)**
- Flash Flood
  - **13 June 2011 (VORTEX-2 case, W. Tx)**
- Other
  - **14 June 2011 (downburst, MPAR)**

May 8, 2003 Oklahoma City Tornadic Supercell

HPC Synoptic Scale Surface Analyses at 18:00 UTC







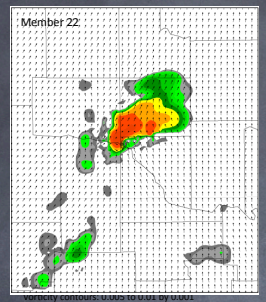
Reflectivity, Vorticity and Horizontal Winds at 1 km AGL

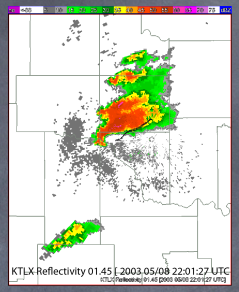
KTLX Experiment
Z and Vr Obs. Assimilation

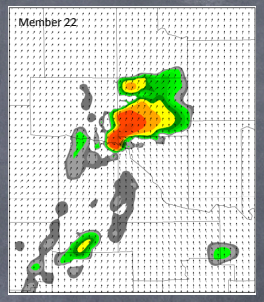
KTLX Observations

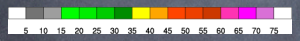
Four Radar Experiment
Z and Vr Obs. Assimilation

Final Analyses at 22:00 UTC

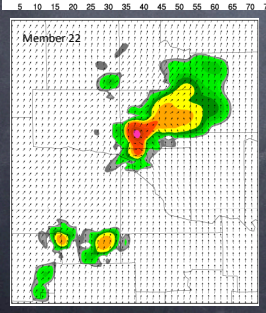


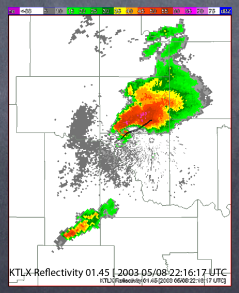


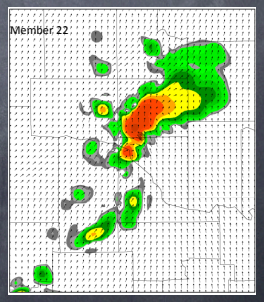




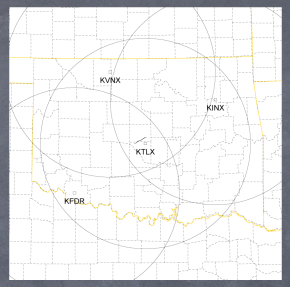
15 min Forecast at 22:15 UTC



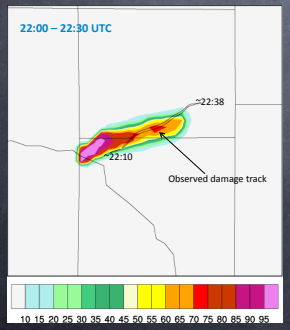




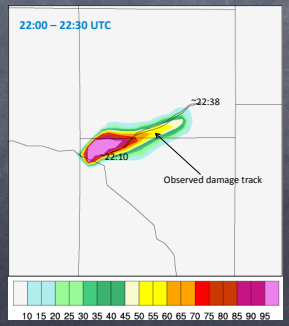
Probability of Vorticity ≥ 0.005 s^{-1} at 1 km AGL during the 30-min forecast



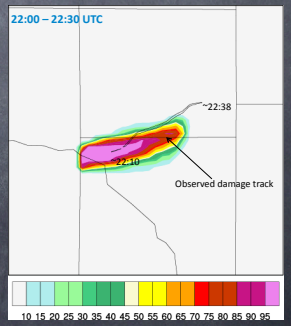
KTLX Experiment
Z and Vr Obs. Assimilation



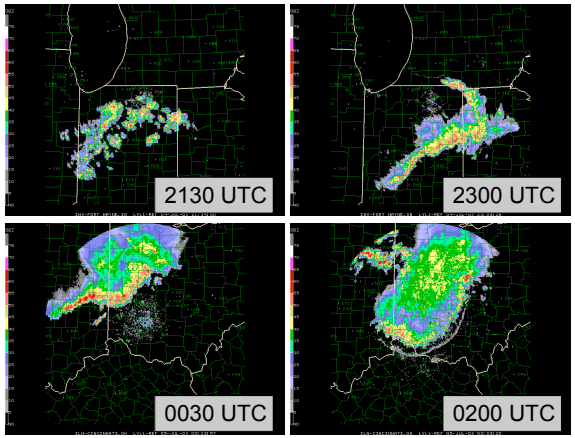
Four Radar Experiment
Z and Vr Obs. Assimilation



KTLX Experiment
Only Vr Obs. Assimilation



The 4-5 July 2003 MCS event



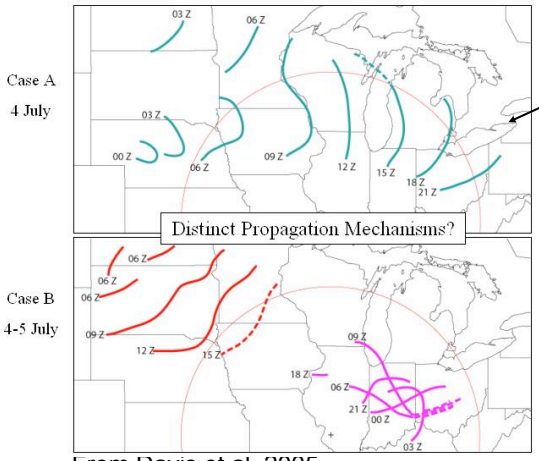
- Observed during BAMEX

- Produced 100+ wind reports across Indiana and Ohio

- Contributed to record flooding across north-central Indiana

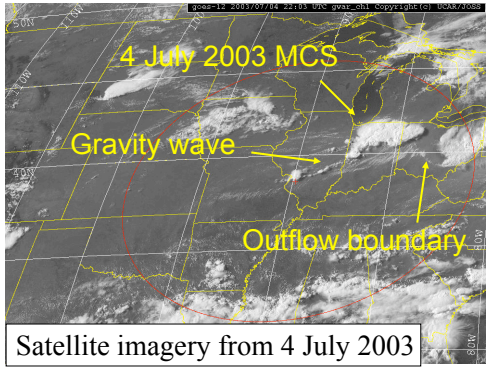
- Not captured in NWP models of the day (including the WRF model)

Sensitivity to previous convection



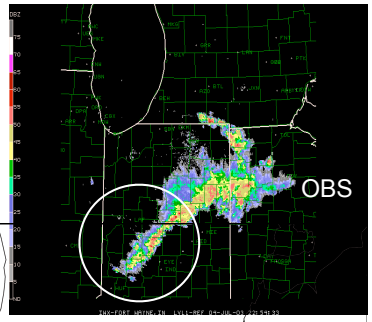
From Davis et al. 2005

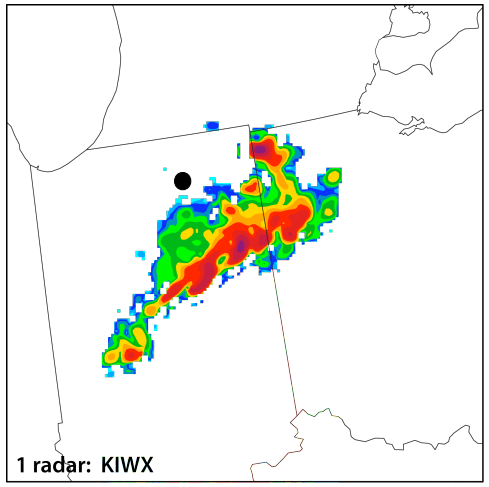
Depicts movement of two earlier systems

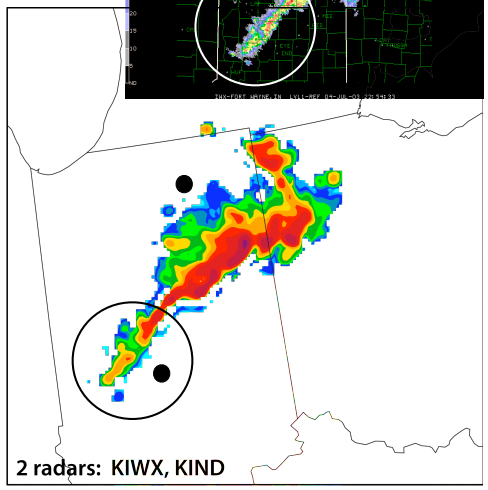


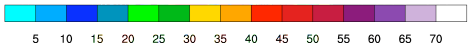
Satellite imagery from 4 July 2003

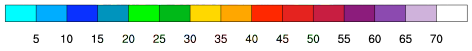
EnKF analyses at 2300 UTC 4 July:
1.5-km AGL simulated reflectivity



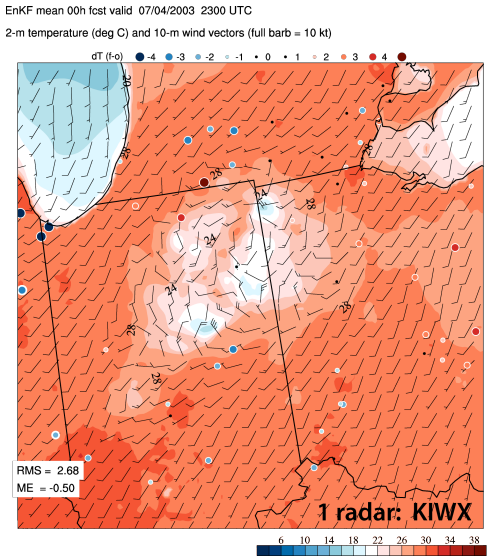


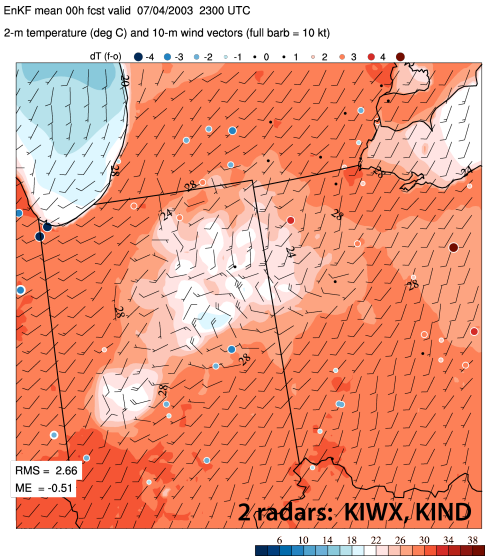




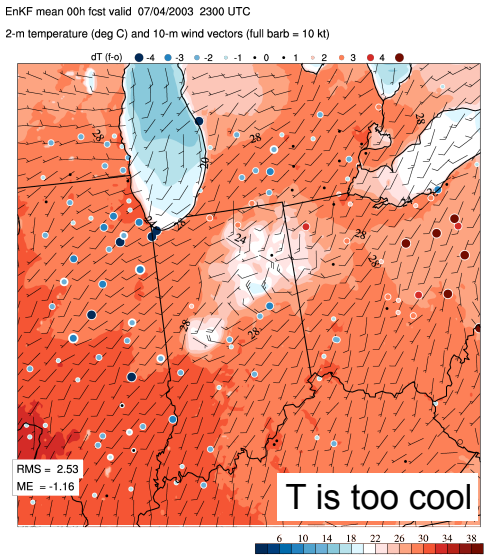


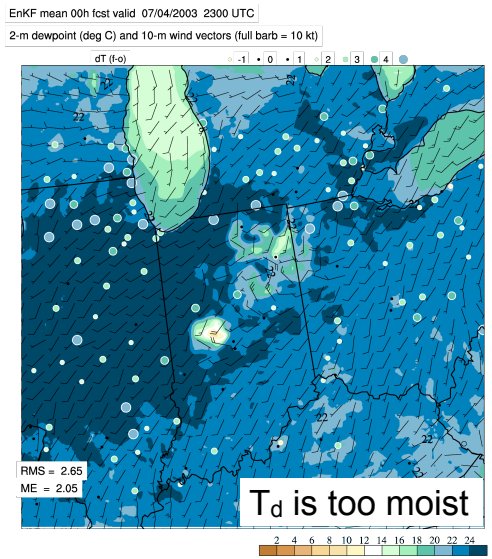
EnKF analyses at 2300 UTC 4 July:
2-m temperature (zoomed in)



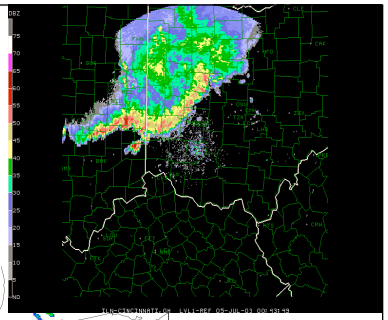


EnKF analyses at 2300 UTC 4 July:
2-m temperature (Wide view)

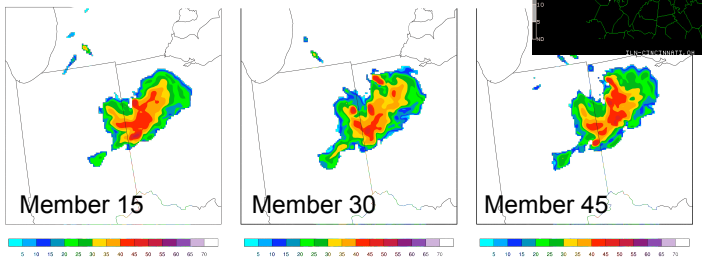




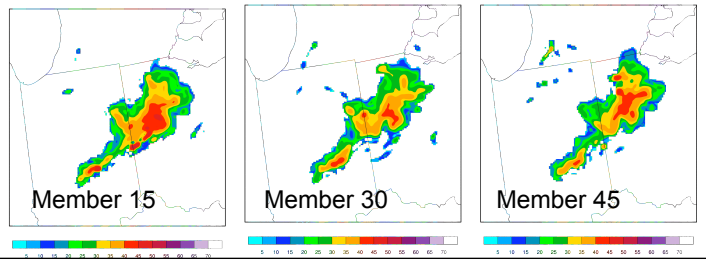
EnKF forecasts at
0030 UTC 5 July (90 min fcst)
1.5-km AGL simulated reflectivity



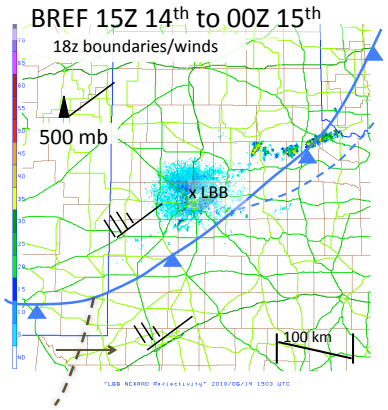
1 radar:



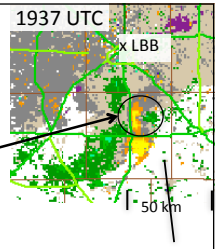
2 radars:



June 14, 2010 west-TX VORTEX2 event



1. Severe weather:

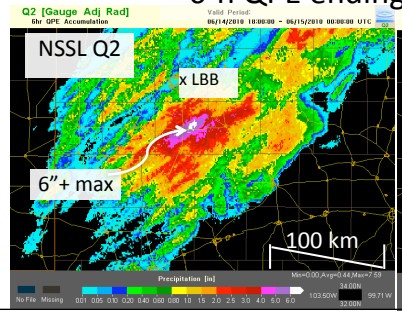


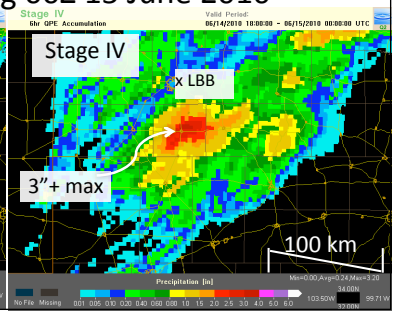
- HP supercell with weakly tornadic mesocyclone along gust front/pre-existing boundary intersection

- Severe wind gusts (34 – 37 m s^{-1} measured by VORTEX2) and strong cold pool (ΔT 15 - 18 K)

2. Flash flood:

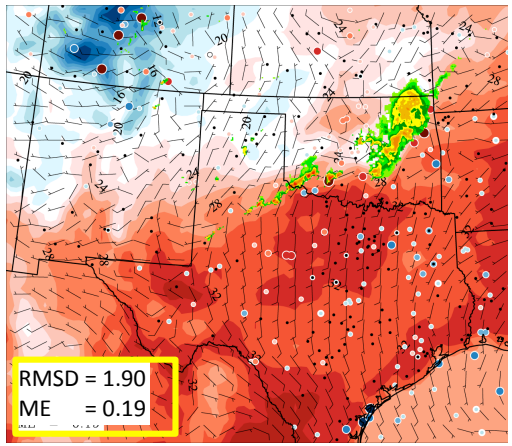
6-h QPE ending 00Z 15 June 2010



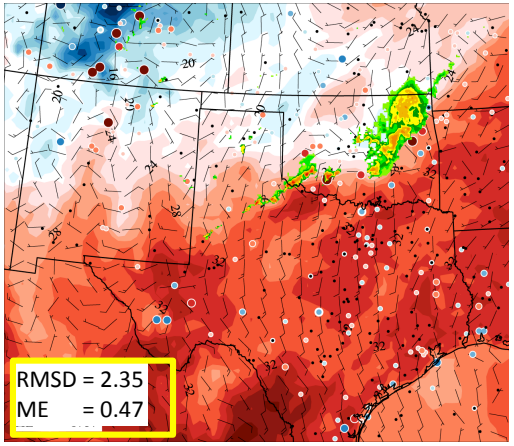


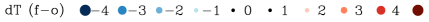
2m temperature fit to METAR obs at 1800 UTC

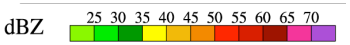
Final EnKF mesoscale analysis

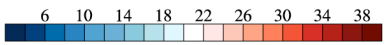


RUC analysis



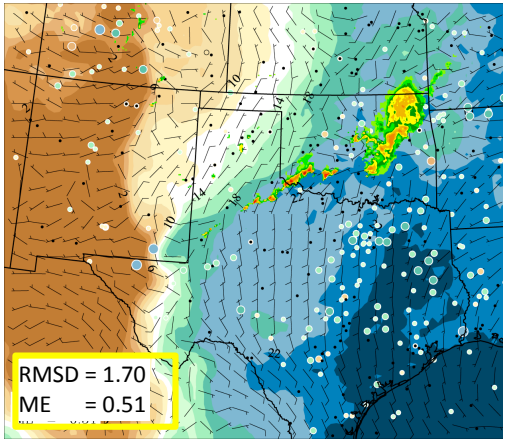




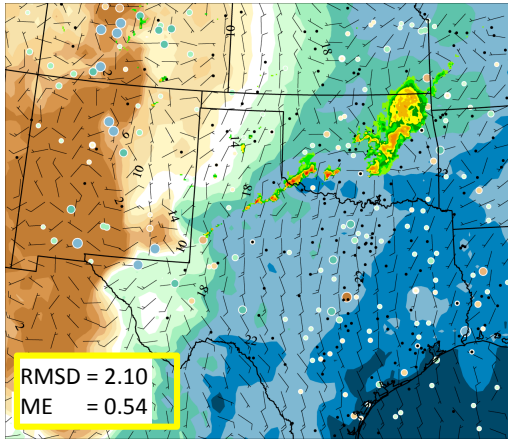


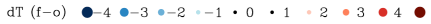
2m dewpoint temperature fit to METAR obs at 1800 UTC

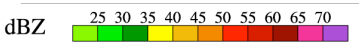
Final EnKF mesoscale analysis

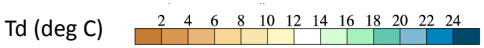


RUC analysis





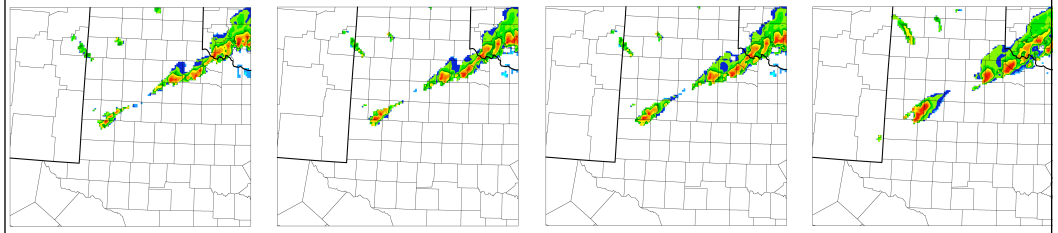


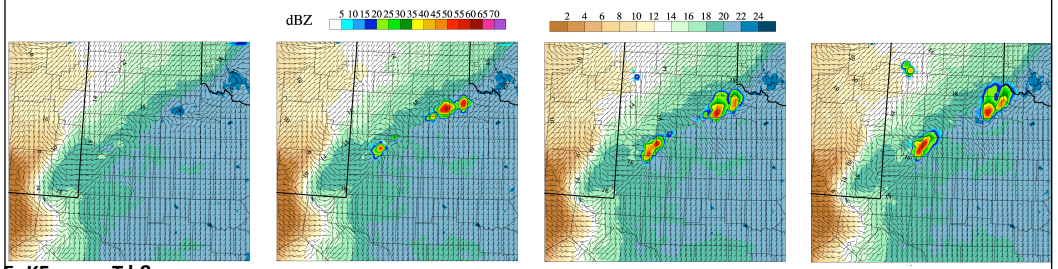


First crack at radar-assimilation run

4-km **obs comp refl**

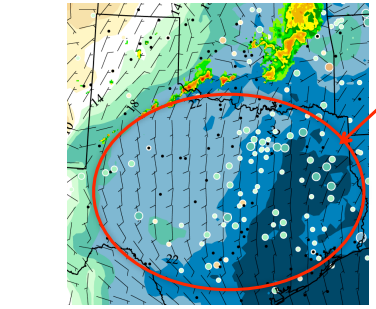
valid: 1815 1830 1845 1900



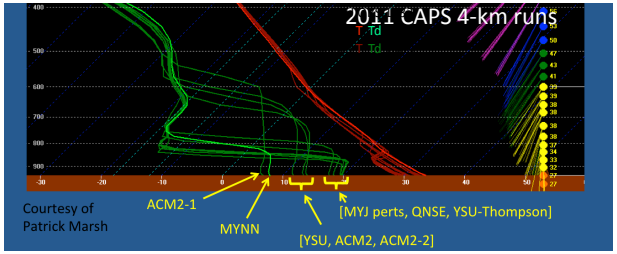


EnKF mean Td & comp refl after: 5 cycles 10 cycles 15 cycles 20 cycles

Issues/Challenges



- 2-m moist bias in the warm sector- will use of multiple PBL/land-surface schemes help? Only using MYJ currently.

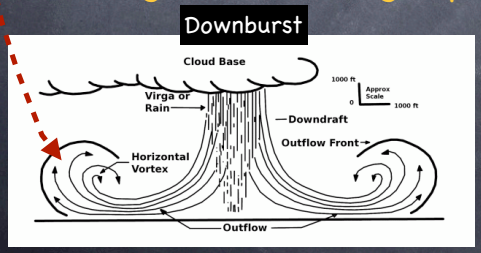


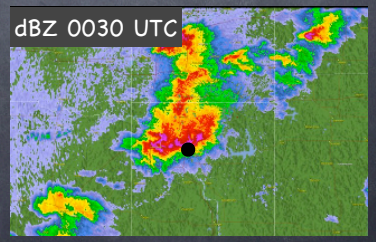
- **Case-specific challenges/questions**:
  - **Boundaries important for early storm-scale evolution**- is assimilation onto a mesoscale grid sufficient? Would assimilation directly onto 3-km grid improve things?
  - Event is **strongly cold-pool dependent**- stiff test for microphysics schemes.
  - Need a 5-h fcst to capture flash flood
  - stormscale details in forecasts likely to be inaccurate beyond 1 h, but **can a ~100 km scale heavy convective-precipitation event still be fcst well out to 5 h with current configurations**?
  - Good case to examine scale-dependent skill.

June 14 Downburst

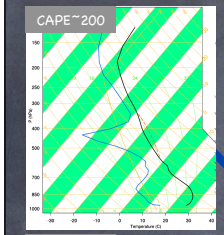
http://www.srh.noaa.gov/oun/?n=events-20110614

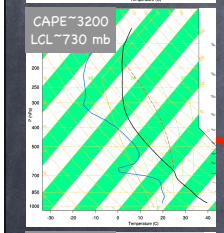
- Measured wind gusts > 36 m/s (130 km/hr)
- Wind-driven golf ball or larger hail
- 33,000 residents without power for over a day
- Damage is still being repaired today!

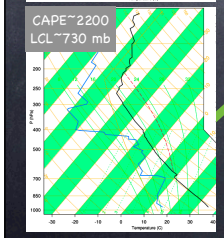


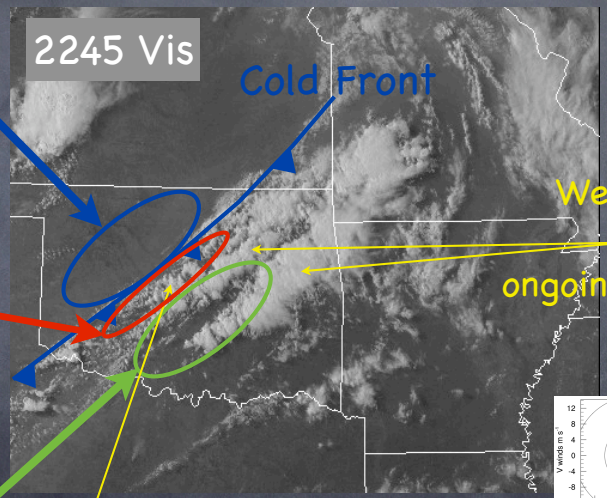


Mesoscale Environment

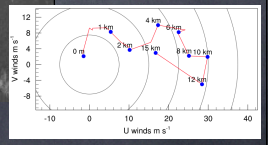








Weak elevated convection ongoing for hours



deep convection initiates ~2330 UTC

Two Research Questions

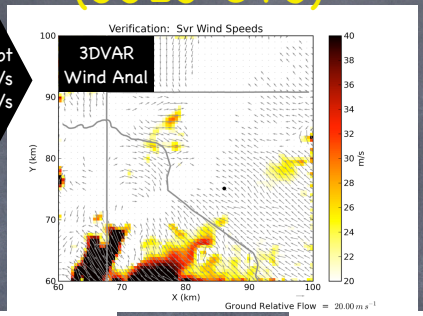
1. Storm-scale Prediction (and predictability)
   - some success with convection organized by rotation.....
     - (supercells, hurricanes)
   - what about other severe convective phenomena?
   - Predictability limits: what are they, and case dependent?
     - uncertainty in the mesoscale background....
     - uncertainty in storm-scale initial state....
2. Does inclusion of rapid-scan radar data improve storm-scale forecasts?

1 cookie is tasty!
(5 min radar volumes)

5 cookies are better?
(1 min radar volumes)

10 minute Ensemble Forecasts of Svr Wind (0020 UTC)

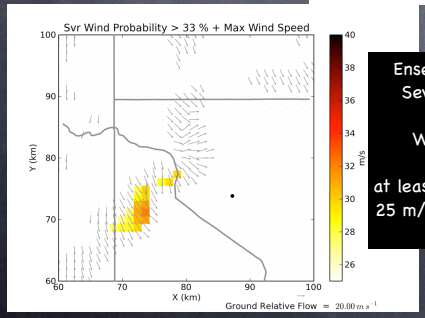
Verification Wind Plot
Vectors: Wind speed > 10 m/s
Color: 20 m/s < wind speed < 40 m/s



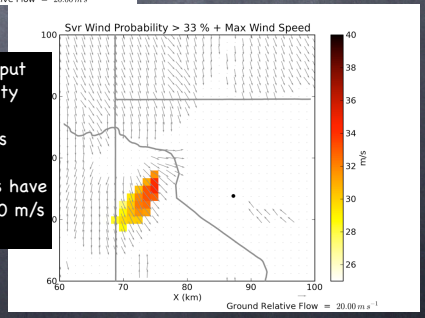
2 moment microphysics used

Control
5 min data

Rapid
1 min data



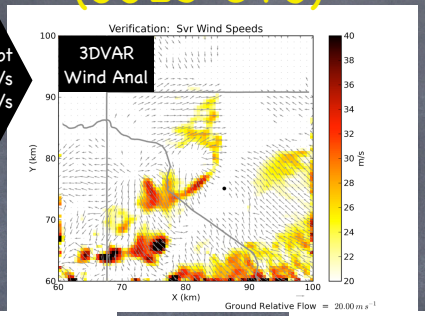
Ensemble Forecast Output
Severe Wind Probability
Vectors
Wind speed > 20 m/s
Color
at least 33% of members have
25 m/s < wind speed < 40 m/s



15 minute Ensemble Forecasts of Svr Wind (0025 UTC)

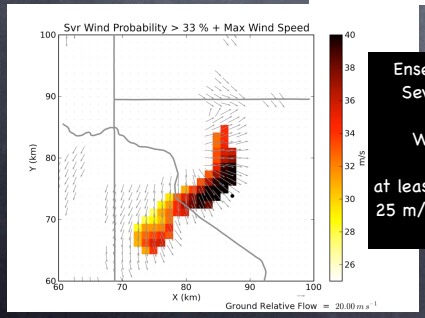
2 moment microphysics used

Verification Wind Plot
Vectors: Wind speed > 10 m/s
Color: 20 m/s < wind speed < 40 m/s

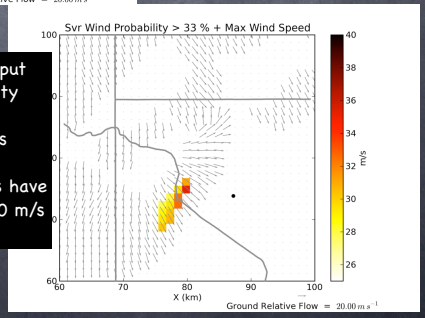


Control
5 min data

Rapid
1 min data



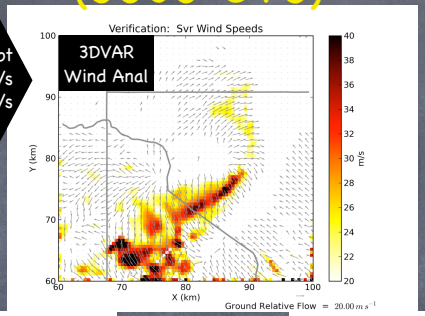
Ensemble Forecast Output
Severe Wind Probability
Vectors
Wind speed > 20 m/s
Color
at least 33% of members have
25 m/s < wind speed < 40 m/s



20 minute Ensemble Forecasts of Svr Wind (0030 UTC)

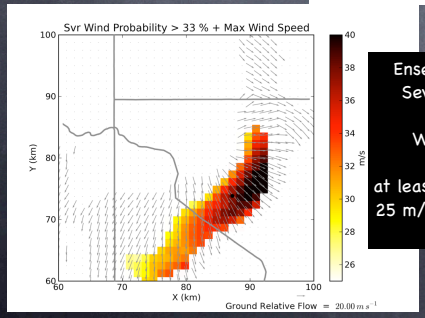
2 moment microphysics used

Verification Wind Plot
Vectors: Wind speed > 10 m/s
Color: 20 m/s < wind speed < 40 m/s

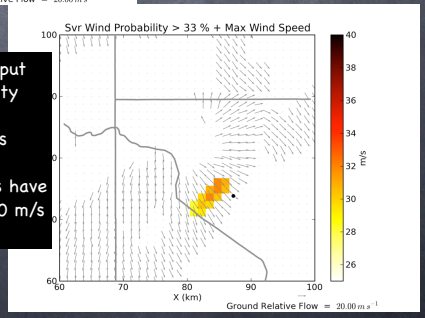


Control
5 min data

Rapid
1 min data



Ensemble Forecast Output
Severe Wind Probability
Vectors
Wind speed > 20 m/s
Color
at least 33% of members have
25 m/s < wind speed < 40 m/s



Summary

- Supercell case (80% completed)
  - unclear more data is better
  - use of reflectivity from multiple radars probably not optimal
  - storm weakens too quickly
- MCS case (50% completed)
  - cold pool is taking too long to spin up
  - inflow environment too cool and moist (MYJ bias)
- Downburst (50% completed)
  - some success in predicting strong winds
  - rapid scan data worsens solution
  - used a toy mesoscale environment, needs a better IC
- Flash flood (20% completed)
  - initial results look promising

Roadblocks

- Mesoscale: PBL, PBL, PBL
  - serious issue, will likely severely limit our predictions
  - multi-PBL can mitigate, but not solve the problem (multi-modal solutions wont yield good covariances)
  - may need to seriously consider surface nudging?
- Radar data assimilation
  - microphysics: WRF needs more 2 moment schemes
  - Ted Mansell has ported his 4 class ice 2 moment ZVD into WRF
  - reflectivity:
    - consolidation of multi-radar views of same volumes (roughly)
    - complexity of forward operator (e.g. F. Frabric ideas?)
  - How much radar data optimizes our analyses and forecasts? Is it a function of model resolution?

Roadblocks

- EnKF Multiscale DA (once the PBL is better?)
  - need dx < 5km to spin up mesoscale features properly?
  - need more complex localization: Fnc(observation type, time + space)
  - very expensive - need to revisit multi-resolution/time staggered ensembles
  - LETKF formulation might provide simpler framework for multiscale
- Software: Too much complexity
  - WRF software has bugs (often associated with platform/compiler)
  - need to be careful about changing versions. Things get broken
  - Complexity of WRF/DART system limits experimentation
- Diagnostics! Diagnostics! Diagnostics!

PBL errors

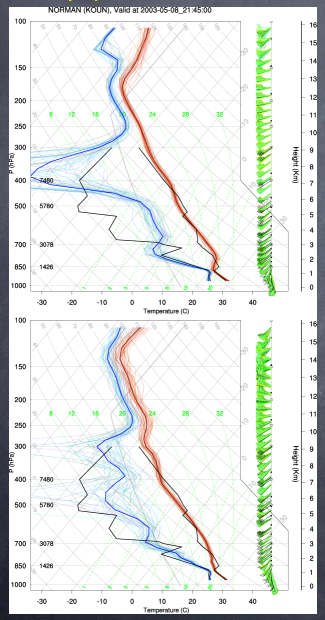
Soundings at Norman

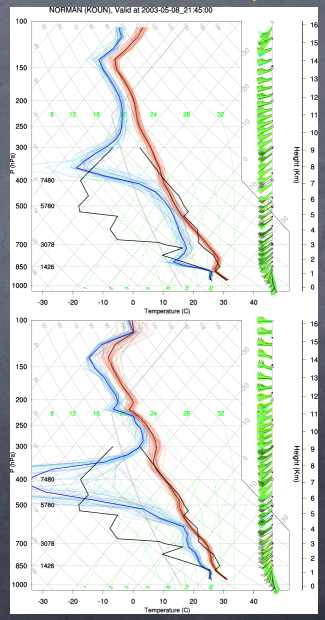
KTLX-only Experiment

Four Radar Experiment

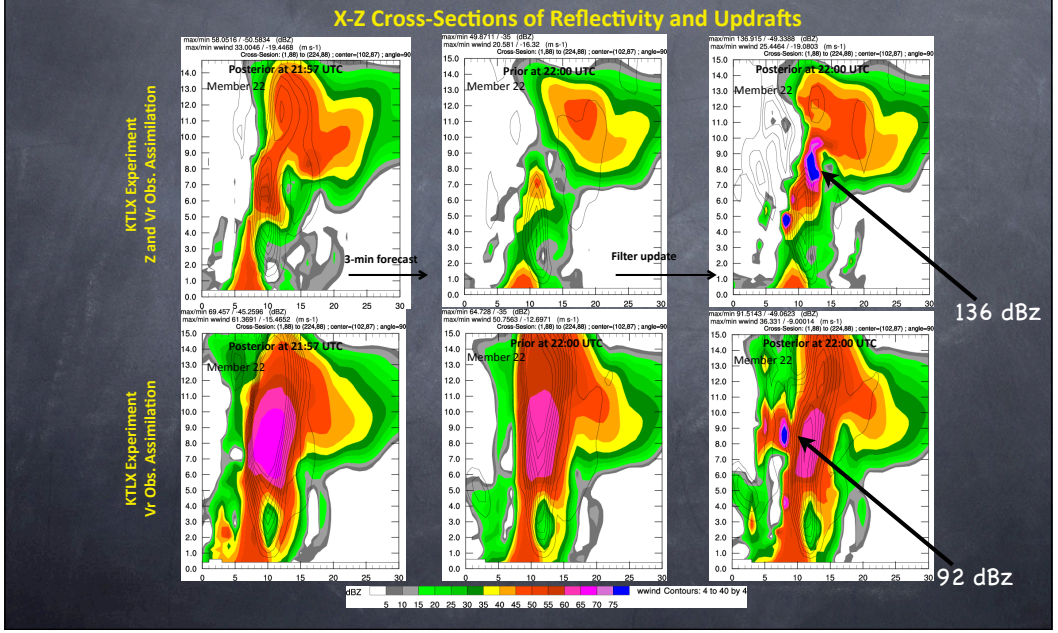
Analyses at 21:45 UTC

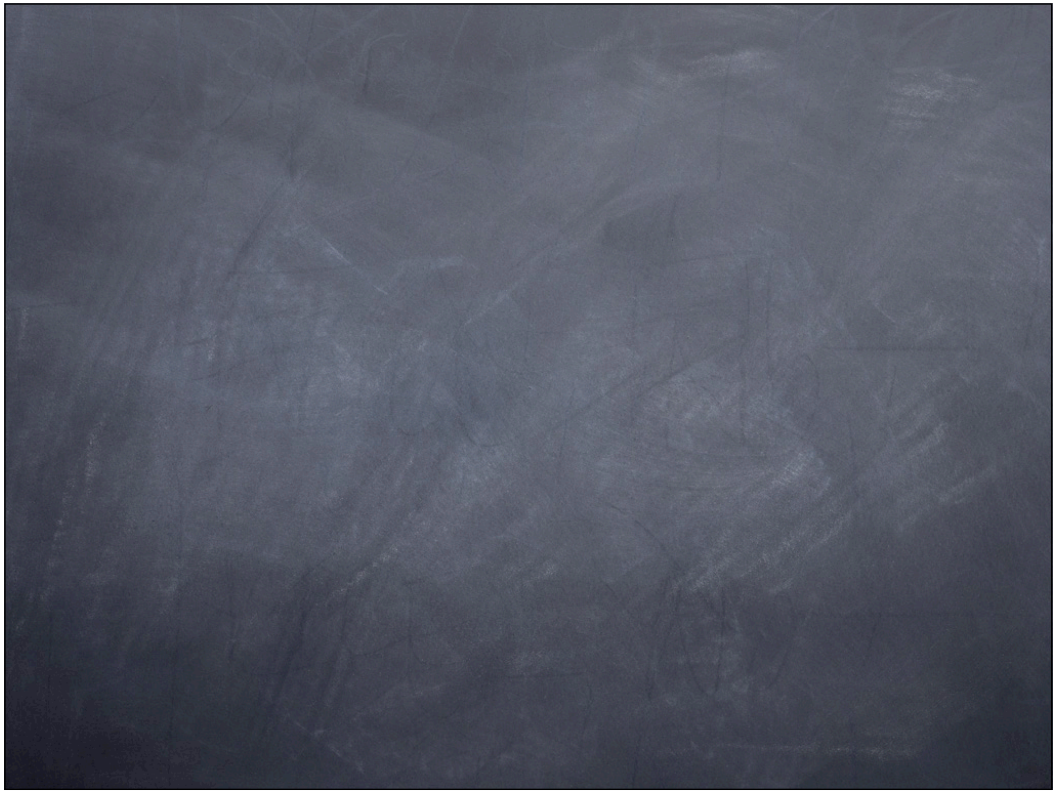
Analyses at 22:00 UTC





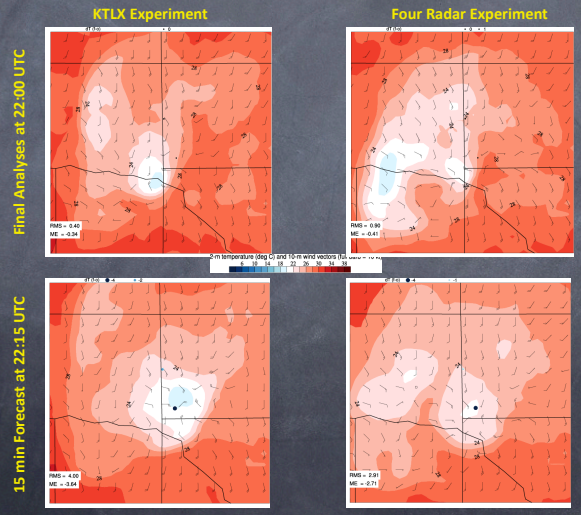
Spurious values of posterior reflectivity generated with Thompson microphysics (even with Vr-only assimilation)





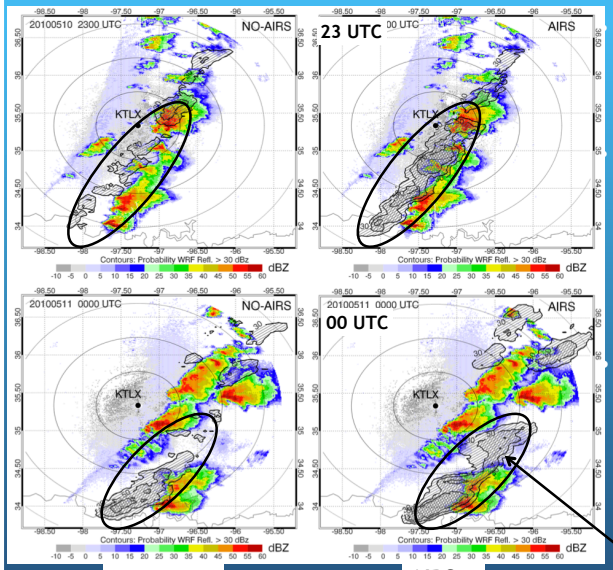
RoadBlock #1: mesoscale

Ensemble Mean Cold Pool and Horizontal Winds (Zoomed)



Simulated Radar Reflectivity Probability

AIRS vs. NO-AIRS: 2 and 3 hour forecasts



WSR-88D observations from KTLX indicate a line of supercells oriented N-S across central OK

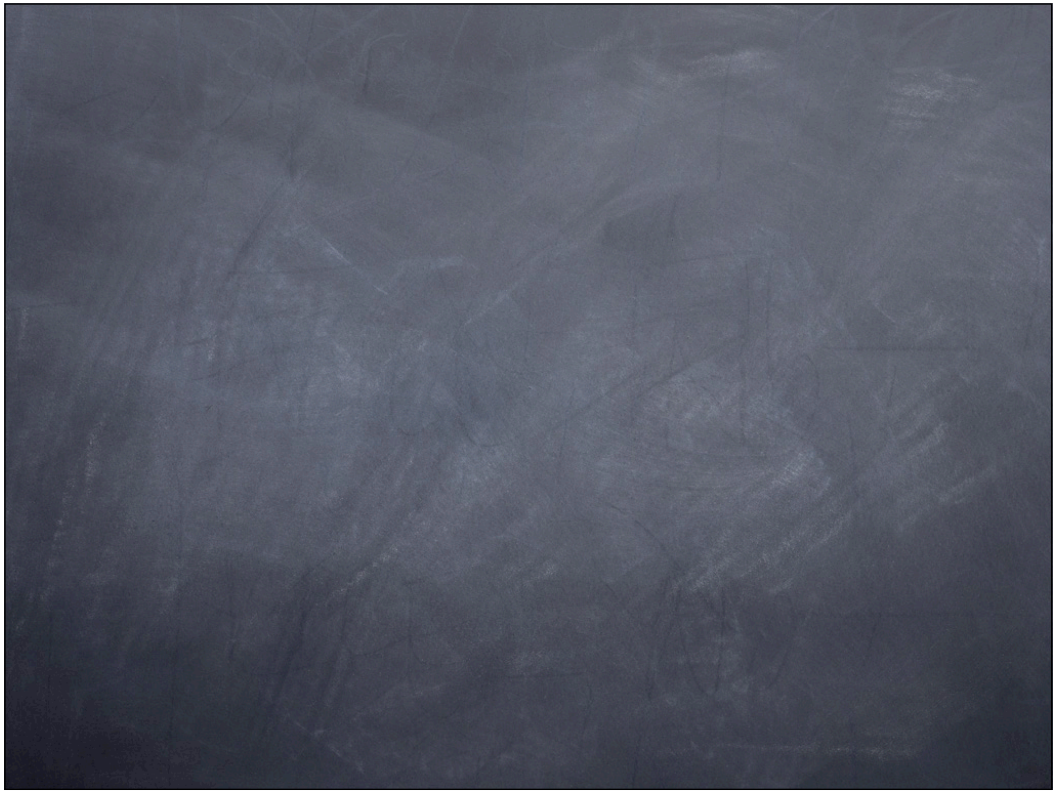
- Reflectivity > 60 dBz
- Storms move east from 23-00 UTC
- New line develops behind initial storm front

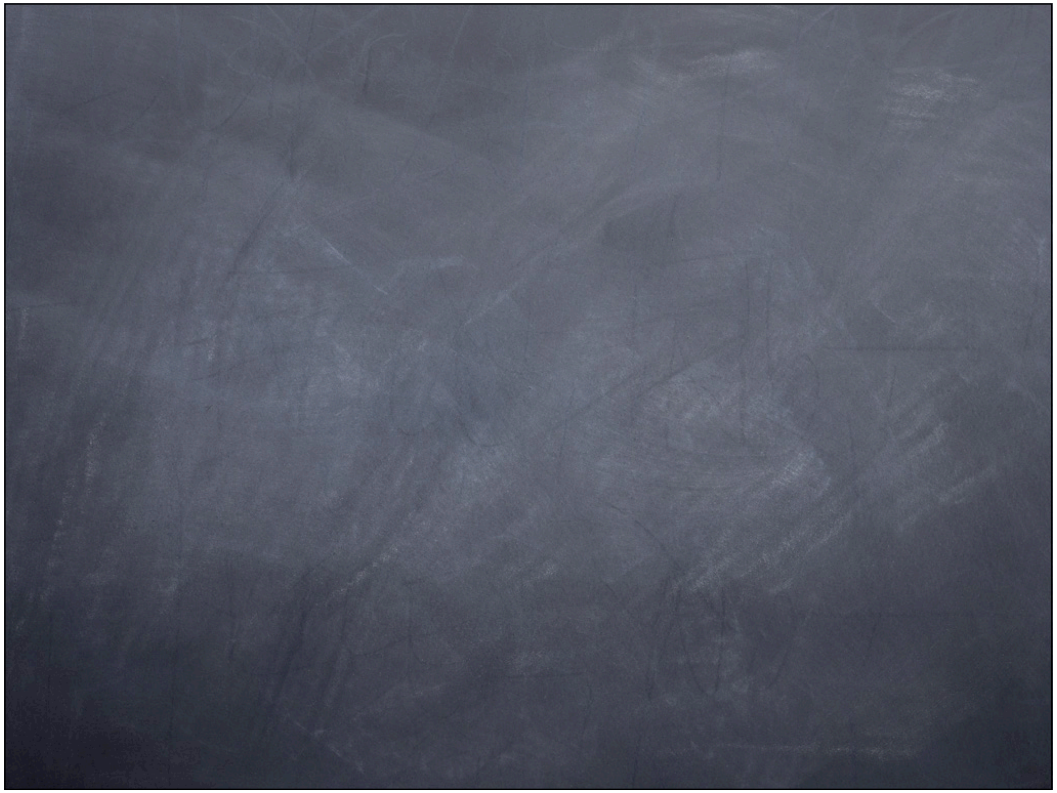
Simulated reflectivity from both NO-AIRS and AIRS models capture orientation and nature of convective features

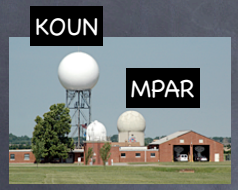
- AIRS run forecasts consistently greater coverage of simulated reflectivity > 30 dBz
- Much better agreement with observations at 2300 UTC
- Both fail to accurately develop second line at 0000 UTC, but at least the AIRS run forecasts greater probabilities in central OK where the NO-AIRS run has little convection

Both models have a temporal lag and are too slow with moving the convection eastward

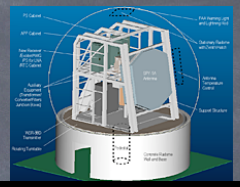
Probability of simulated reflectivity > 30 dBz
Hatched areas indicates probability > 30%





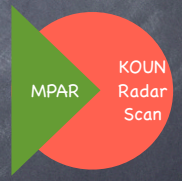


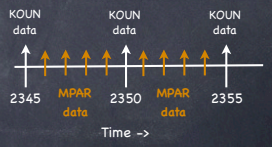
Radar Data



MPAR: Single flat plate that scans 90 degrees via electronic beam steering

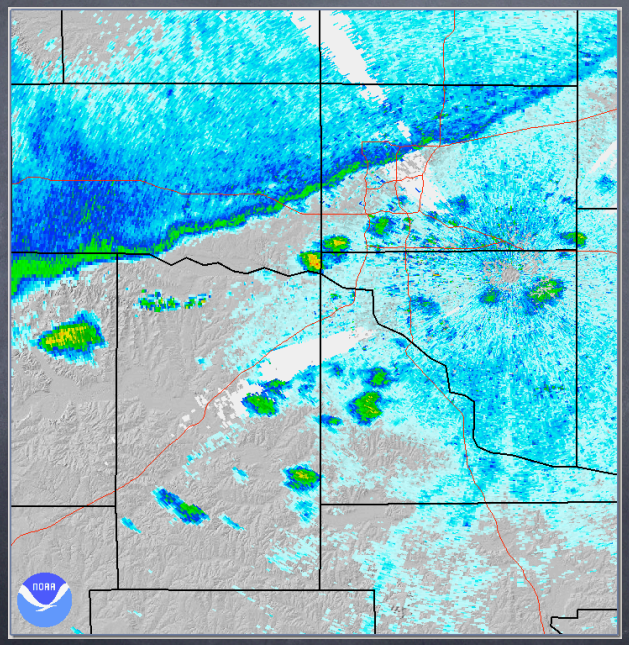
- NSSL has two co-located 10 cm radars
- KOUN: WSR-88D dual-polarization system
  - 1.0 to 1.39 deg effective beamwidth
  - 14 tilt volume scan completed every 5 minutes
- MPAR: Multifunction phased-array radar system
  - Single flat plate can only scan a 90 deg sector
  - 19 tilt volume scan completed every MINUTE
  - Horizontal resolution is slightly coarser than KOUN
- MPAR sector scan requires some extra preprocessing when combined with KOUN
- **Control Experiment**: Uses KOUN volumes at 5 min intervals
- **Rapid Experiment**: Adds MPAR volumes every minute in-between





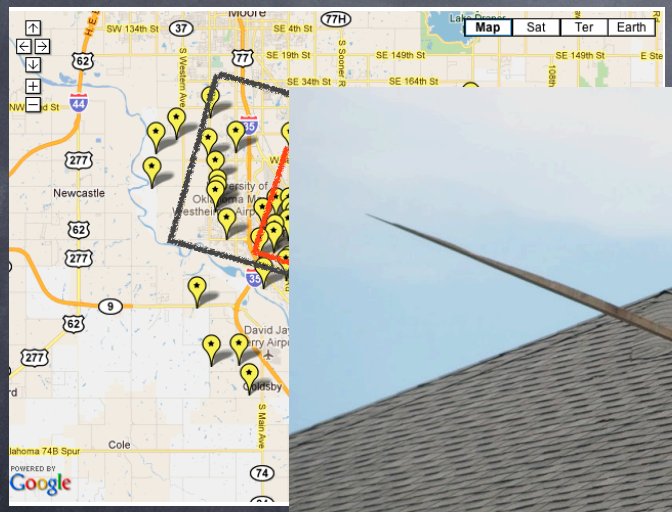
KTLX (central OK) Radar Loop

Loop
Start Time
2325 UTC



Loop
End Time
0035 UTC

Damage



Damage Survey and Photographs
from
Kiel Ortega

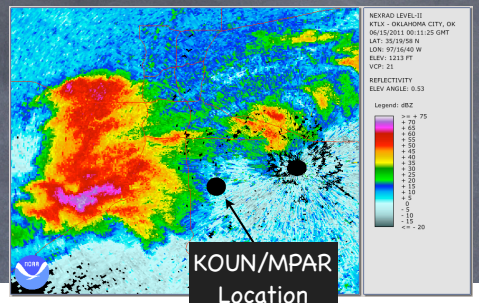
Video from Dr. Mike Coniglio (NSSL)
Taken in NE Norman OK around 0030 UTC
View is initially to south, then moves toward southwest

Model & EnKF Assimilation Details

- Prediction model: NCOMMAS (similar to NCAR ARW and DWD Lokal-Modell)
- Microphysics: Ziegler-Variable-Density (ZVD) microphysics (4 ice class, 2 moments predicted)
- Model Grid:
  - 125 km^2 horizontal domain, 20 km deep
  - 1.25 km horizontal grid spacing, 200 m vertical grid spacing sfc to 4 km.
- Initial Conditions: Heteorogeneous, three soundings shown in earlier slide are used to create a NW-SE gradient in temperature, moisture, and winds
- Ensemble Square Root Filter (EnSRF)
  - 40 members, both reflectivity and radial velocity are assimilated
  - Initial ensemble is populated with warm bubbles where radar echoes are located.
  - Ensemble spread is maintained by using additive noise method (Dowell & Wicker 2010)
  - Reflectivity is not used to update temperature and moisture (limits model error @ low levels)
  - Spread was tuned for each case to be close to observational radial velocity error (2 m/s)

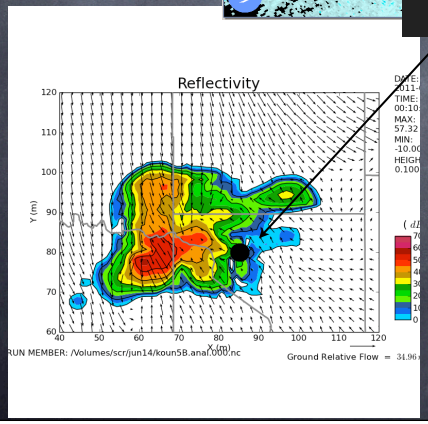
Control & Rapid Analyses vs Obs at 0010 UTC

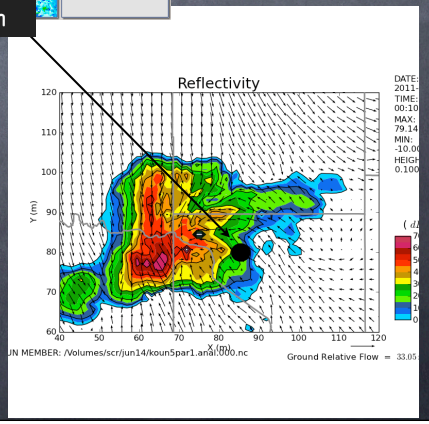
35 min
of DA
8 volumes
CNTRL



KOUN/MPAR
Location

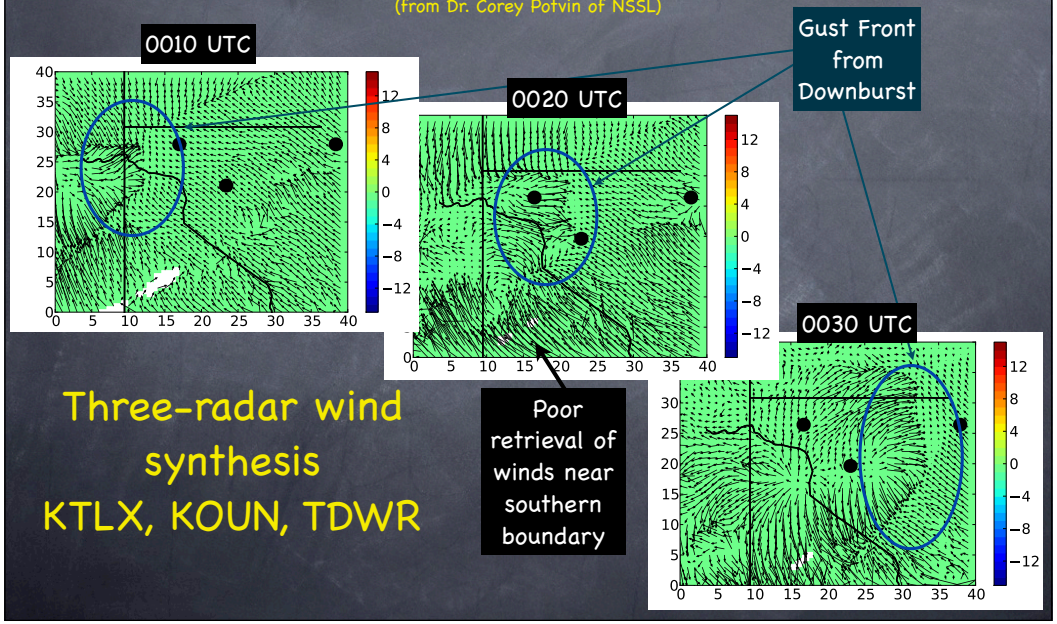
35 min
of DA
36 volumes
RAPID





Verification: Surface Winds Derived from 3DVAR Analysis

(from Dr. Corey Potvin of NSSL)

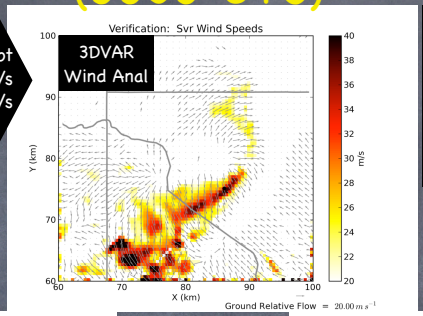


Summary (so far)

- More data does NOT improve forecast!
- In fact, it seems to makes it worse!
- Why?
  - Differences between radars?
  - Differences in # of observations assimilated each time?
  - Large # of observations every minute: disrupts model balance?
- This suggests two more experiments....

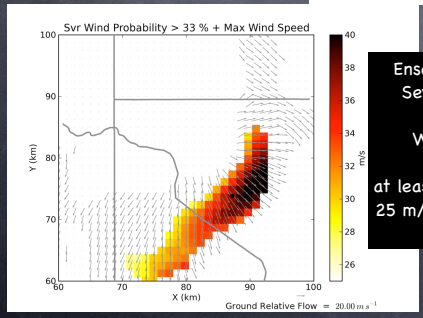
20 minute Ensemble Forecasts of Svr Wind (0030 UTC)

Verification Wind Plot
Vectors: Wind speed > 10 m/s
Color: 20 m/s < wind speed < 40 m/s



Data Freq Exp
Replace MPAR rapid-scan data with proxy KOUN data
Assimilate every 1 min

Control
5 min data



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Wind speed > 20 m/s
Color
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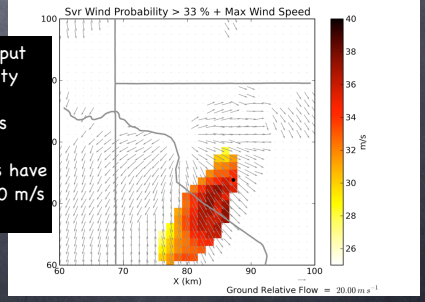

Rapid
1 min data

20 minute Ensemble Forecasts of Svr Wind (0030 UTC)

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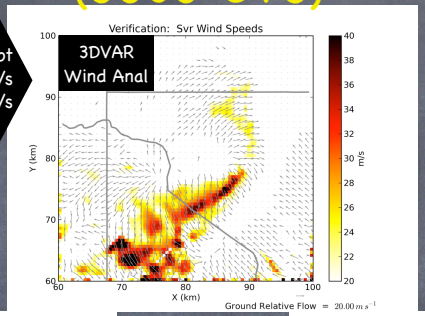
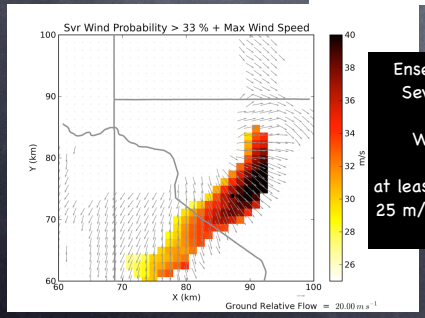
Color: 20 m/s < wind speed < 40 m/s



Original Exp

Control
5 min data

Rapid
1 min data



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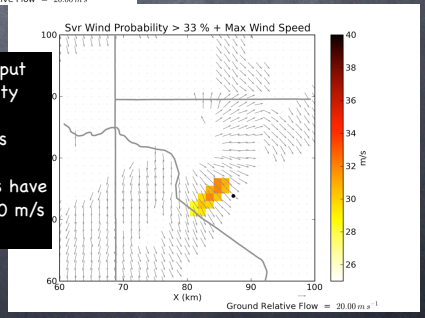

20 minute Ensemble Forecasts of Svr Wind (0030 UTC)

Verification Wind Plot
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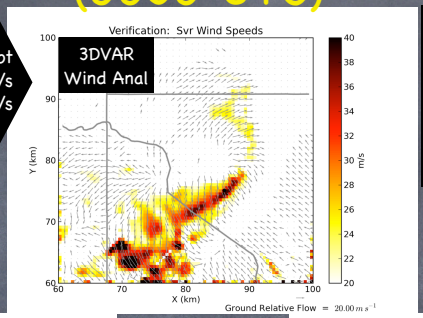
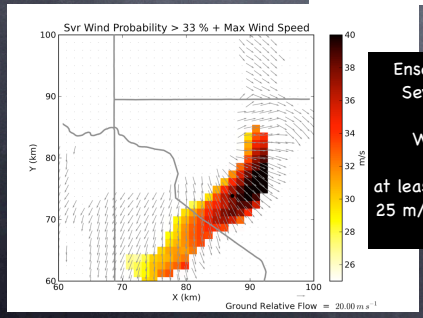


Data Quality Exp
Replace KOUN data inside 90 deg MPAR sector with MPAR data
Assimilate every 5 min

Control
5 min data



Ensemble Forecast Output
Severe Wind Probability
Vectors
Wind speed > 20 m/s
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at least 33% of members have
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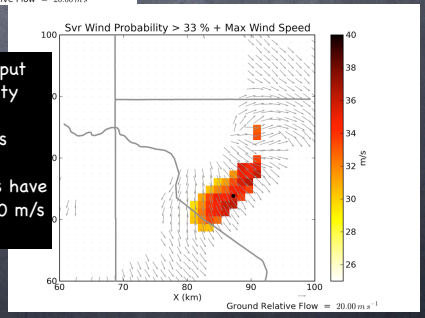

CNTRL2
5 min data

Conclusions & Future Work

- **Rapid-scan data from the MPAR system has shown great value when used by operational forecasters for Oklahoma severe weather warning operations.**
- Storm-scale NWP with rapid-scan radar data: things are much more complicated…
- Best forecasts were obtained when assimilation frequency ~5 min
- Both RAPID-scan forecast experiments were worse. Why?
  - does model error accumulate faster?
  - are model dynamics unable to adjust to the large number of observations being assimilated?
  - do observation errors become too correlated on these time scales?
- Optimal assimilation of rapid-scan radar data may require:
  - larger ensembles -> better covariances?
  - finer grid resolution -> more scales resolved -> faster adjustment to imbalances?
- More work on 14 June case, and many more case studies needed
- Asynchronous EnKF, LETKF, adaptive observations and localization


Questions?