Analysis of environmental modifications by deep convection during MPEX

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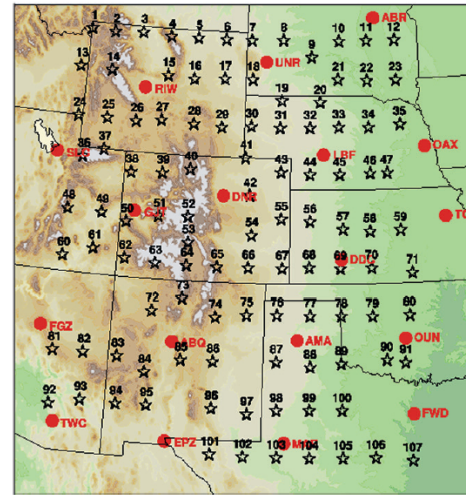
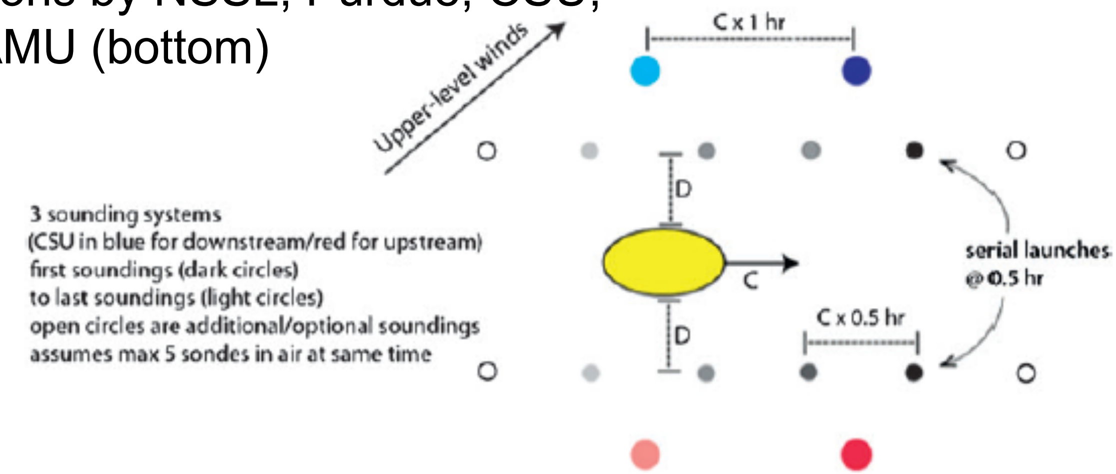
The Mesoscale Predictability Experiment (MPEX) had many objectives

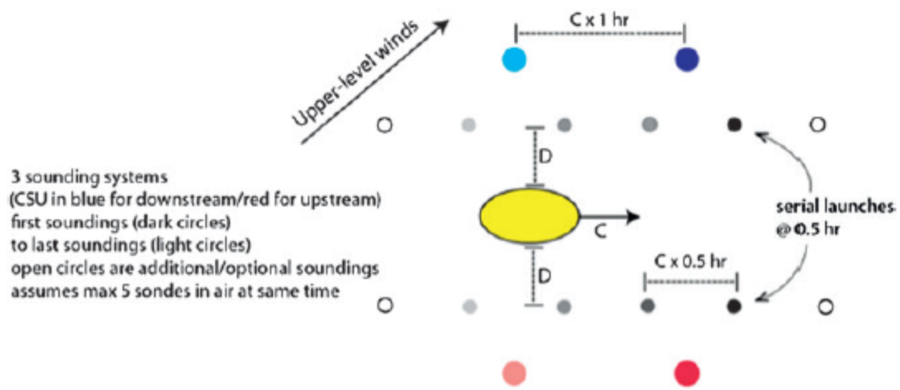
- 15 May – 15 June 2013
- Early morning dropsonde operations by NCAR Gulf-stream V (right)
- Pre- and post-CI mobile upsonde operations by NSSL, Purdue, CSU, and TAMU (bottom)

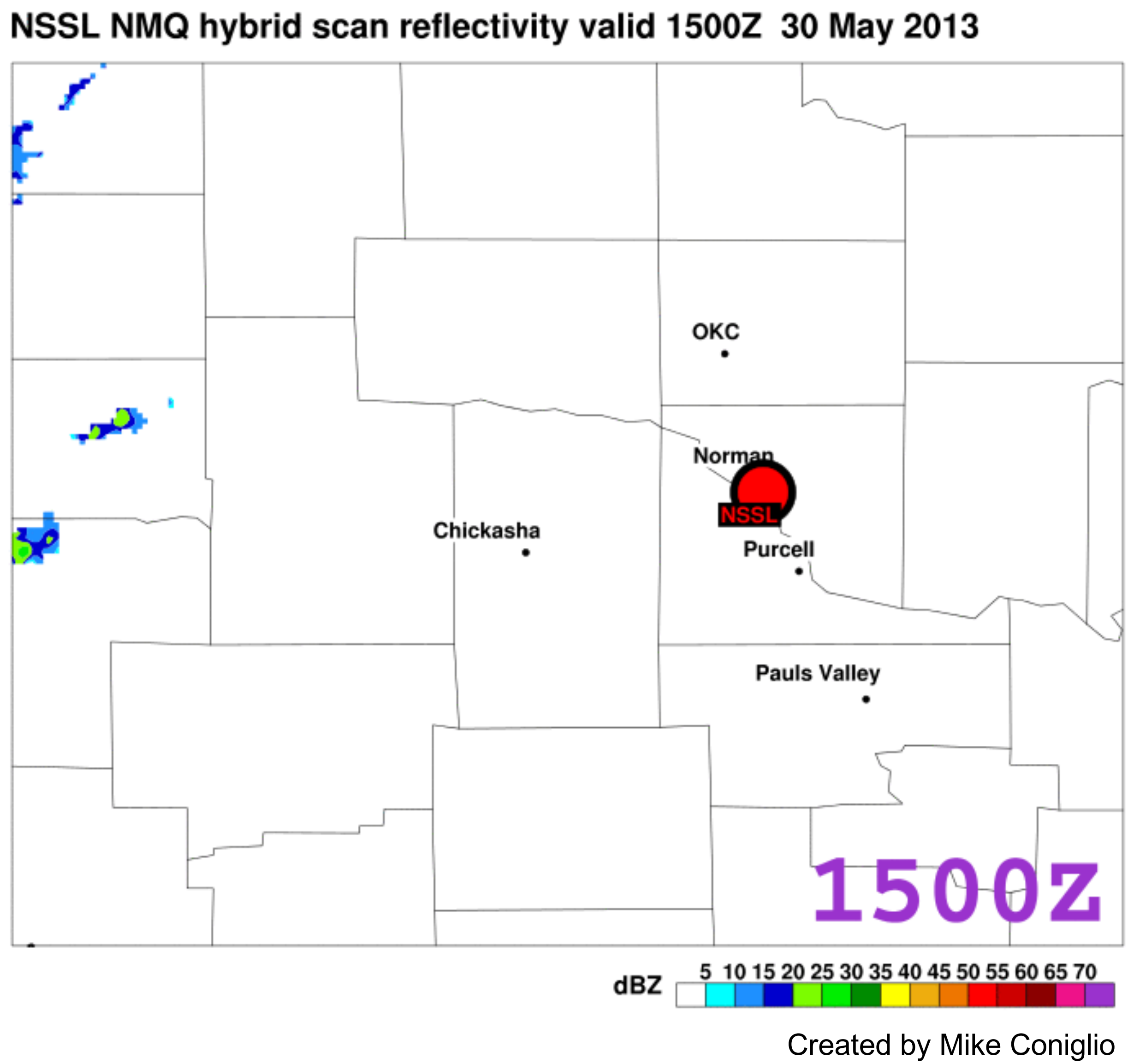




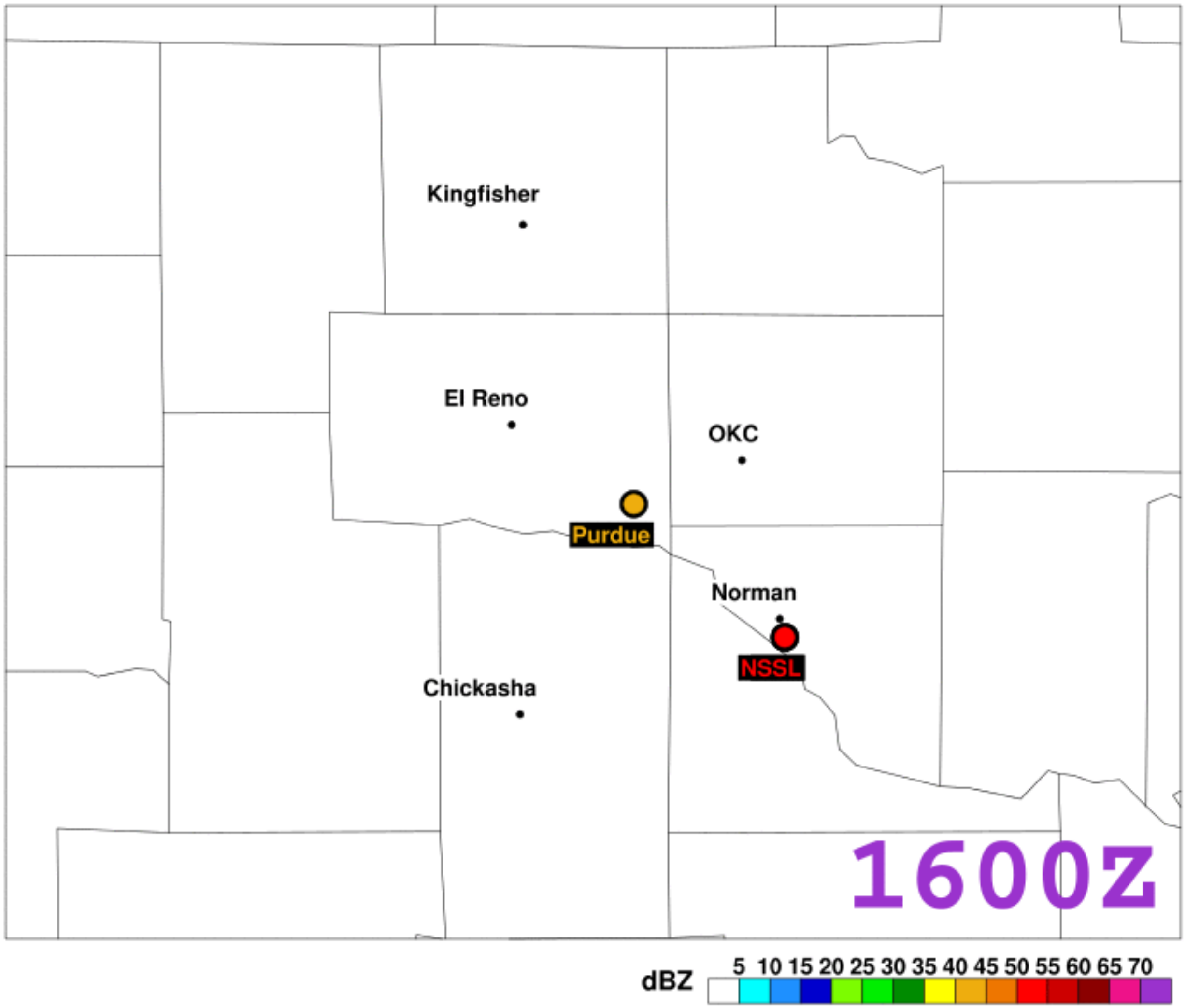
Figures adapted from Weisman et al. 2015


VERE STORMS LAB



Upper-level winds
C x 1 hr
D
D
C
C x 0.5 hr
serial launches @ 0.5 hr
3 sounding systems
(CSU in blue for downstream/red for upstream)
first soundings (dark circles)
to last soundings (light circles)
open circles are additional/optional soundings
assumes max 5 sondes in air at same time


NSSL NMQ hybrid scan reflectivity valid 1500Z 30 May 2013
OKC
Norman
NSSL
Chickasha
Purcell
Pauls Valley
1500z
dBZ
5 10 15 20 25 30 35 40 45 50 55 60 65 70
Created by Mike Coniglio

NSSL NMQ hybrid scan reflectivity valid 1600Z 31 May 2013



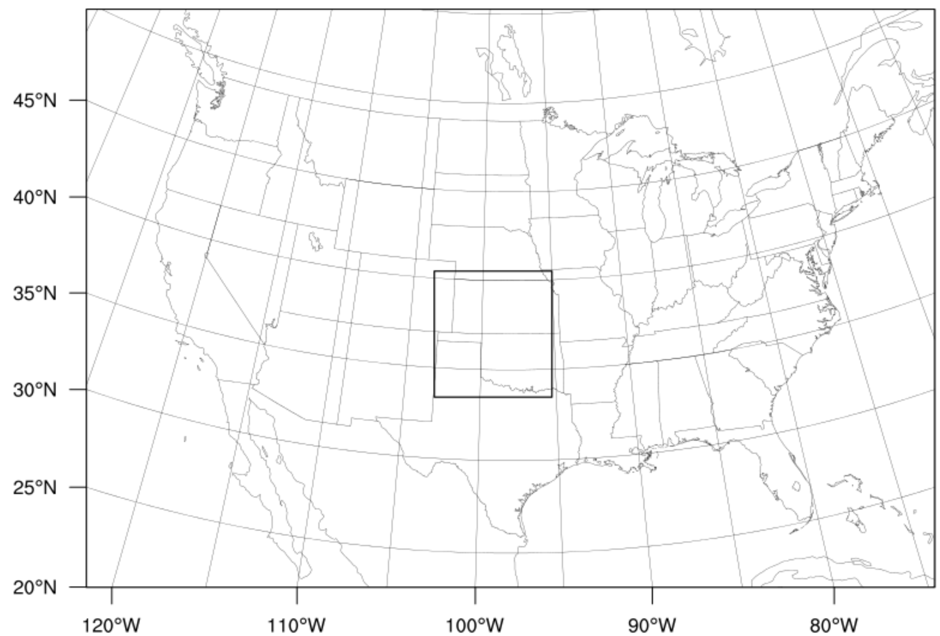
Created by Mike Coniglio

Field experiment provides means to validate convection-allowing model (CAM) accuracy

- MPEX has provided unique observations of near-storm environments via upsondes
- Few studies have looked into numerical weather prediction models' ability to reproduce environments near ongoing deep convection given lack of observations
- Many studies have used models to analyze convective impacts on the surrounding environment (e.g., Brooks et al. 1994 and Weisman et al. 1998)
- How well do CAMs replicate the surrounding mesoscale environment? This is important for short-term model forecasts

Experiments configured to properly simulate MPEX targeted convection

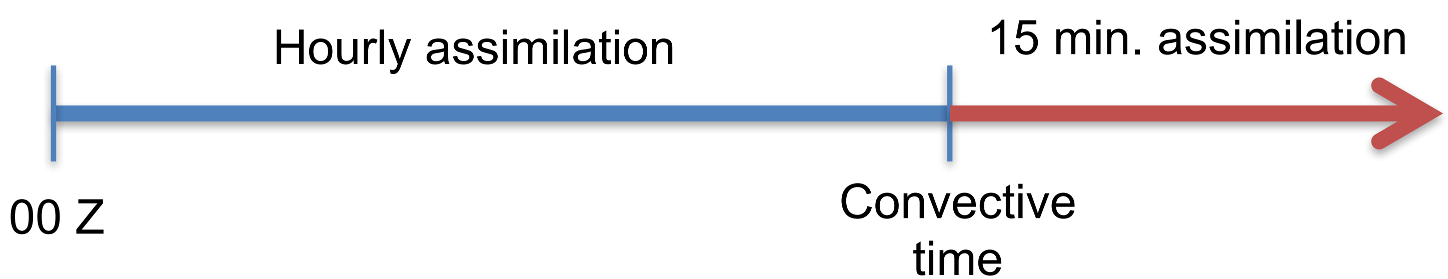
- 28-31 May 2013 KS, TX, OK convective events
- 36-member ensemble created with physics diversity using nested Advanced Research version 3.4.1 of Weather Research and Forecasting (WRF-ARW) Model (Wheatley et al. 2015)
- Outer domain (CONUS) has 15 km grid spacing while inner domain has 3 km grid spacing



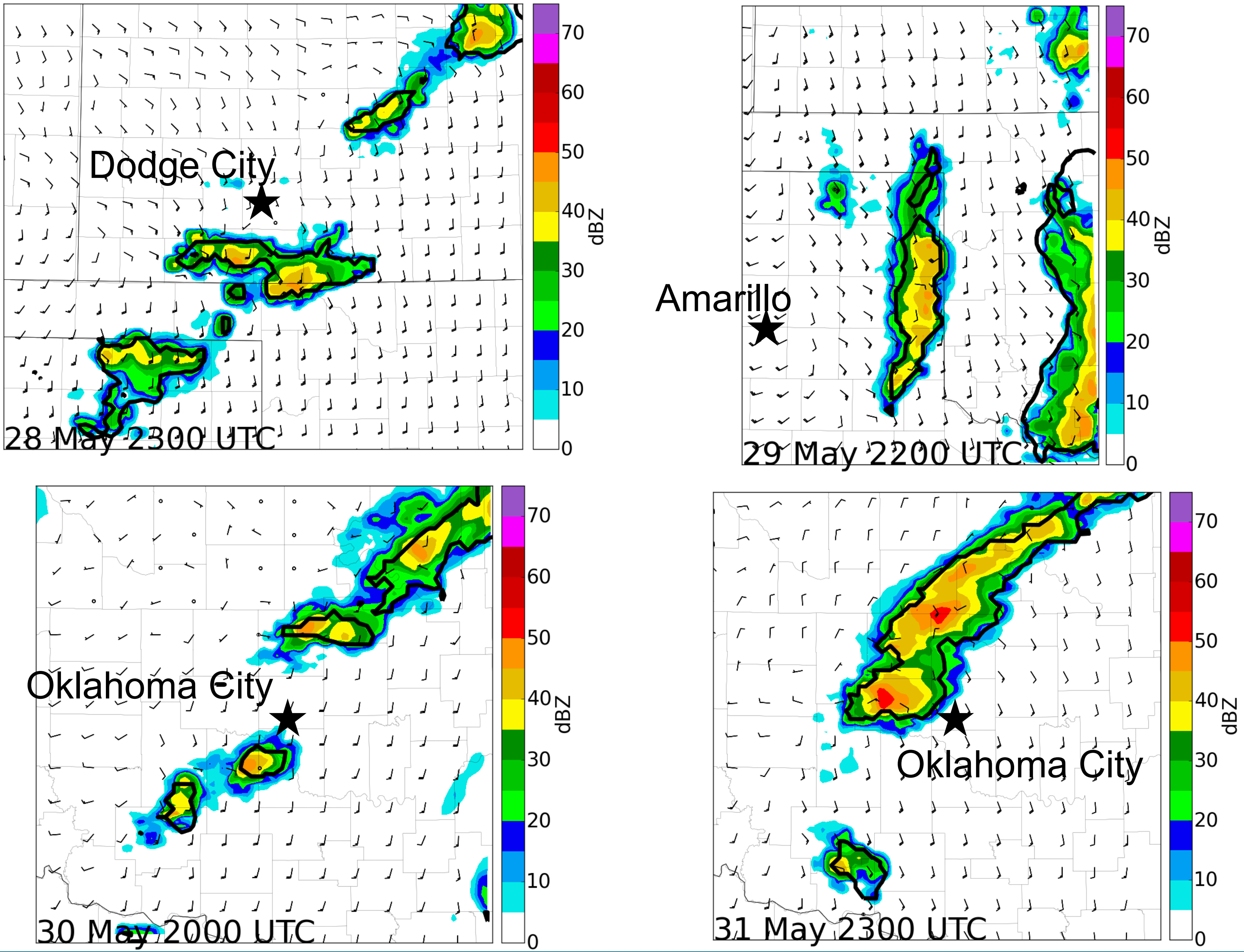
Mesoscale and storm-scale domains for all four days

Repeated assimilation cycles improve environmental initial conditions before convection initiation

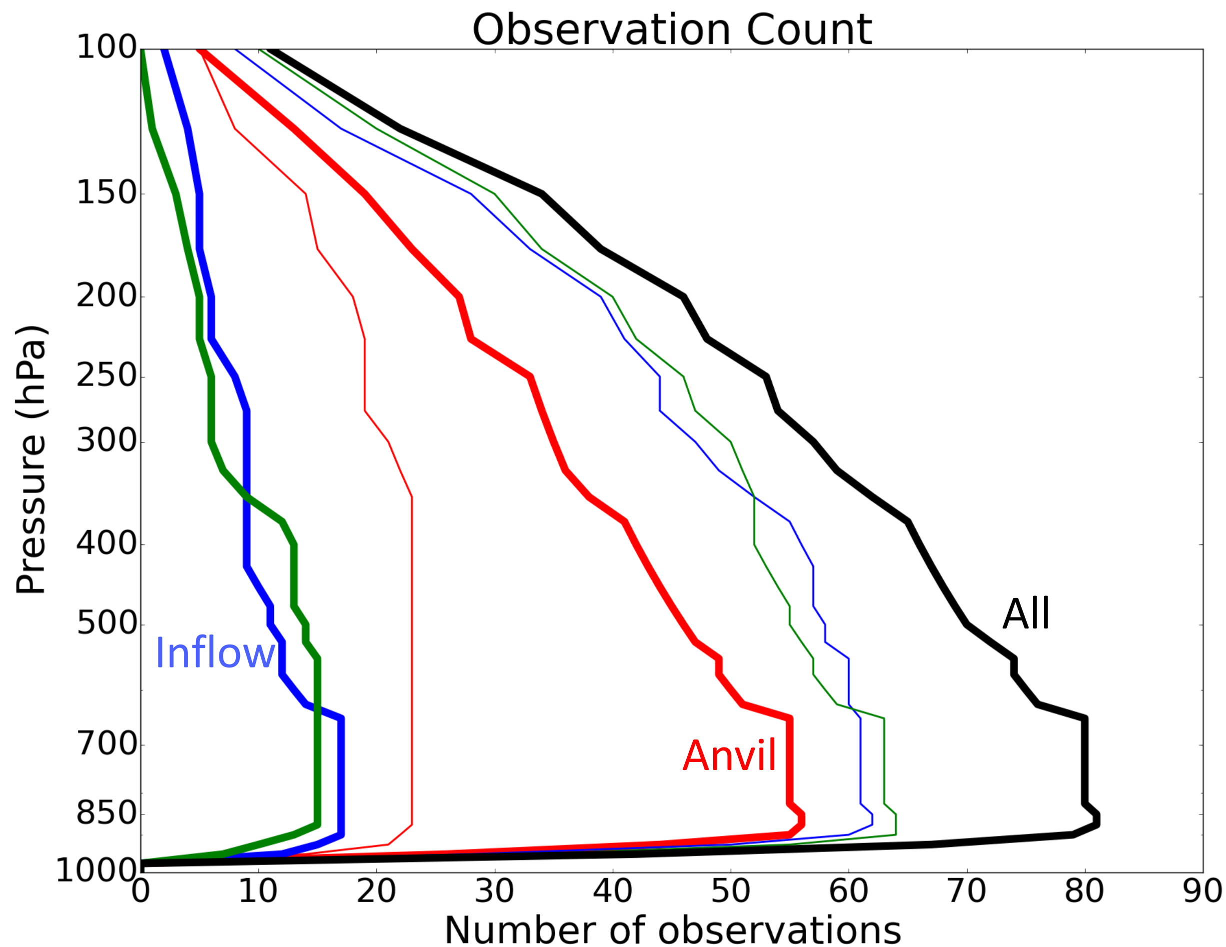
- Assimilate conventional obs. in hourly cycles beginning at 00 Z each day until a specified "convective time" via the ensemble adjustment Kalman filter (Anderson 2001)
- After the specified convective time, assimilate radar, surface, and NWS rawinsonde obs. on inner domain *only* every 15 mins.
- Adaptive inflation used to maintain ensemble spread and additive noise used to spin-up convection (Dowell and Wicker 2009; Sobash and Wicker 2015)



Reflectivity EnKF analyses examples show correct storm locations

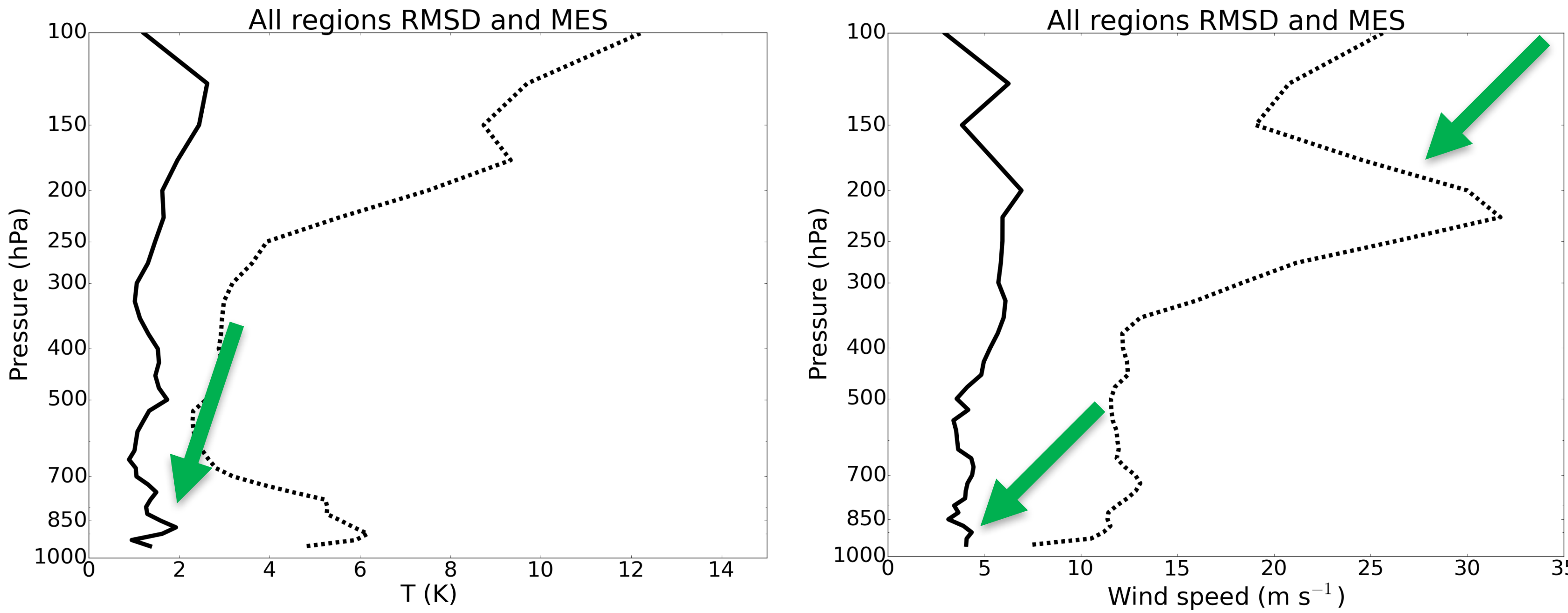


81 upsondes released over four-day period



All (black), anvil (thick red), non-anvil (thin red), inflow (thick blue), non-inflow (thin blue), outflow (thick green), non-outflow (thin green)
Sample size decreases with height due to a variety of upsonde failures

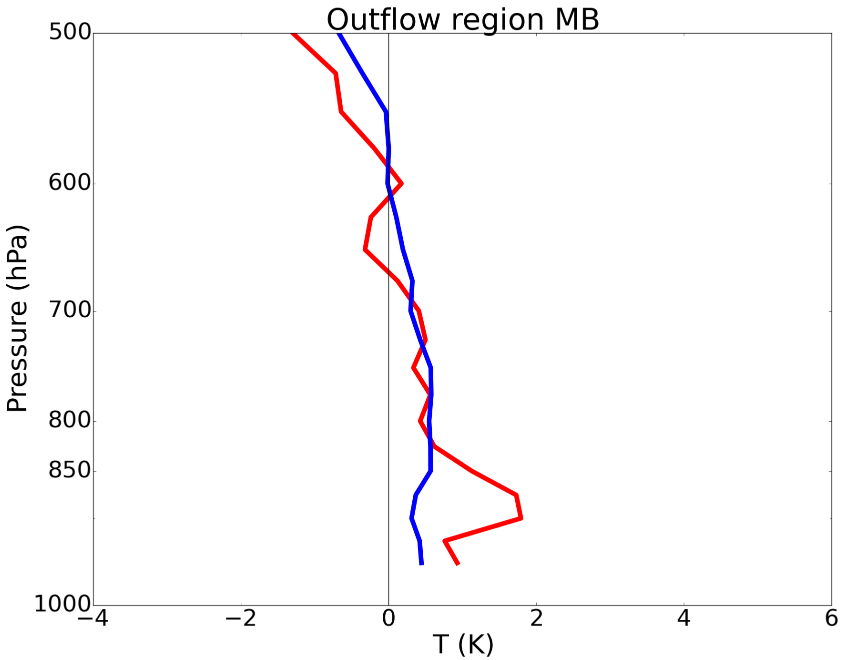
Vertical error profile examples reveal biases



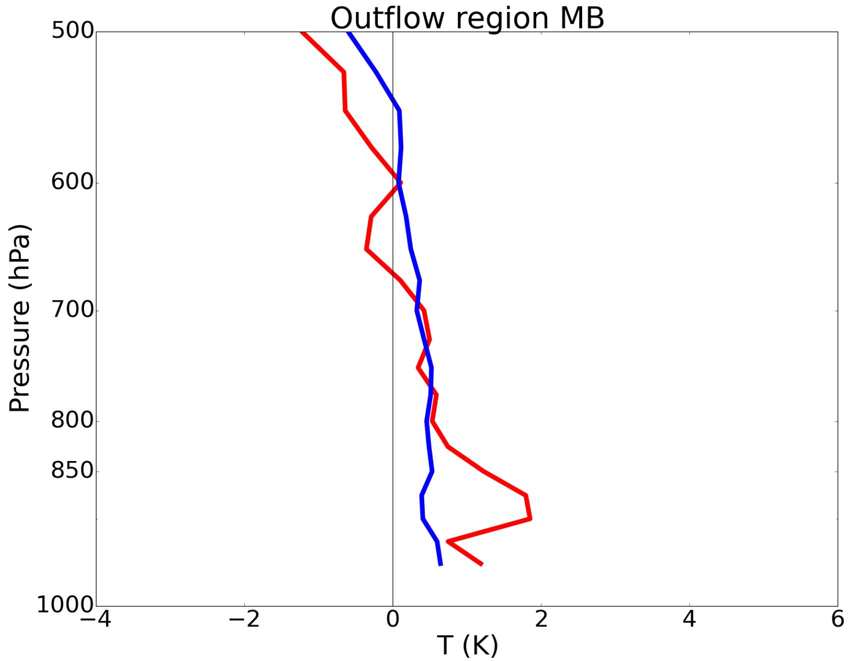
Root mean square difference (RMSD) of ensemble mean – solid
Mean ensemble spread (MES) – dashed

Are analysis biases larger in specific near-storm environment regions?

Low-level temperature error originates within outflow



Analysis



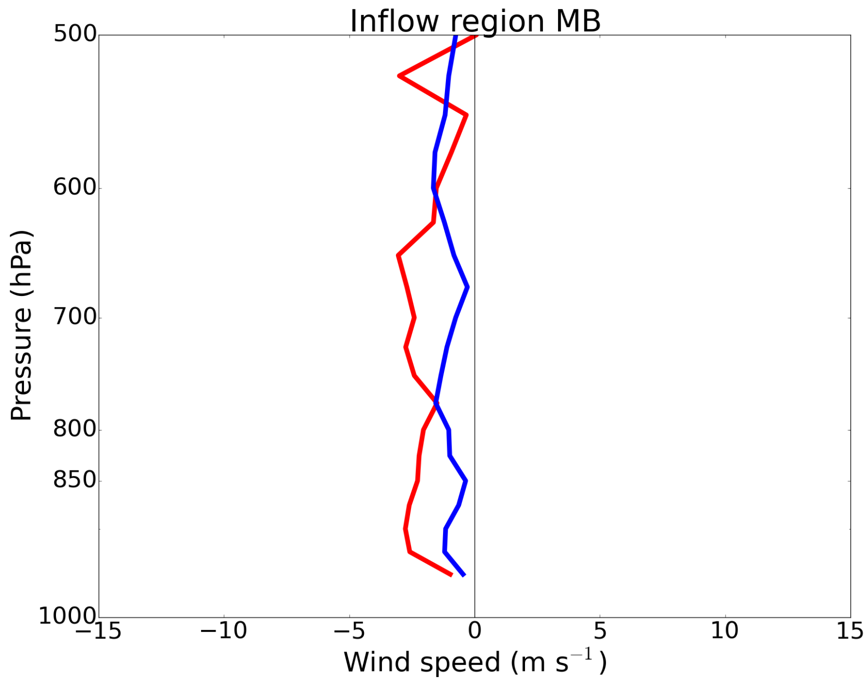
60 min. forecast

Mean bias (MB) of ensemble mean – outflow (red) and non-outflow (blue)

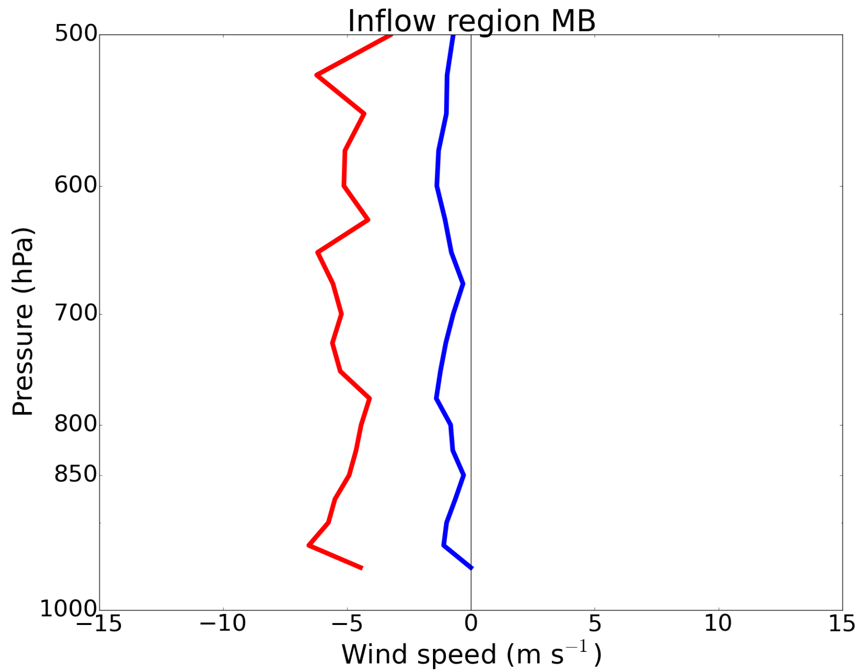
Large warm bias below 850 hPa appears in outflow analyses

This appears to be due to cold pools that are too shallow

Low-level wind speed bias originates within inflow



Analysis



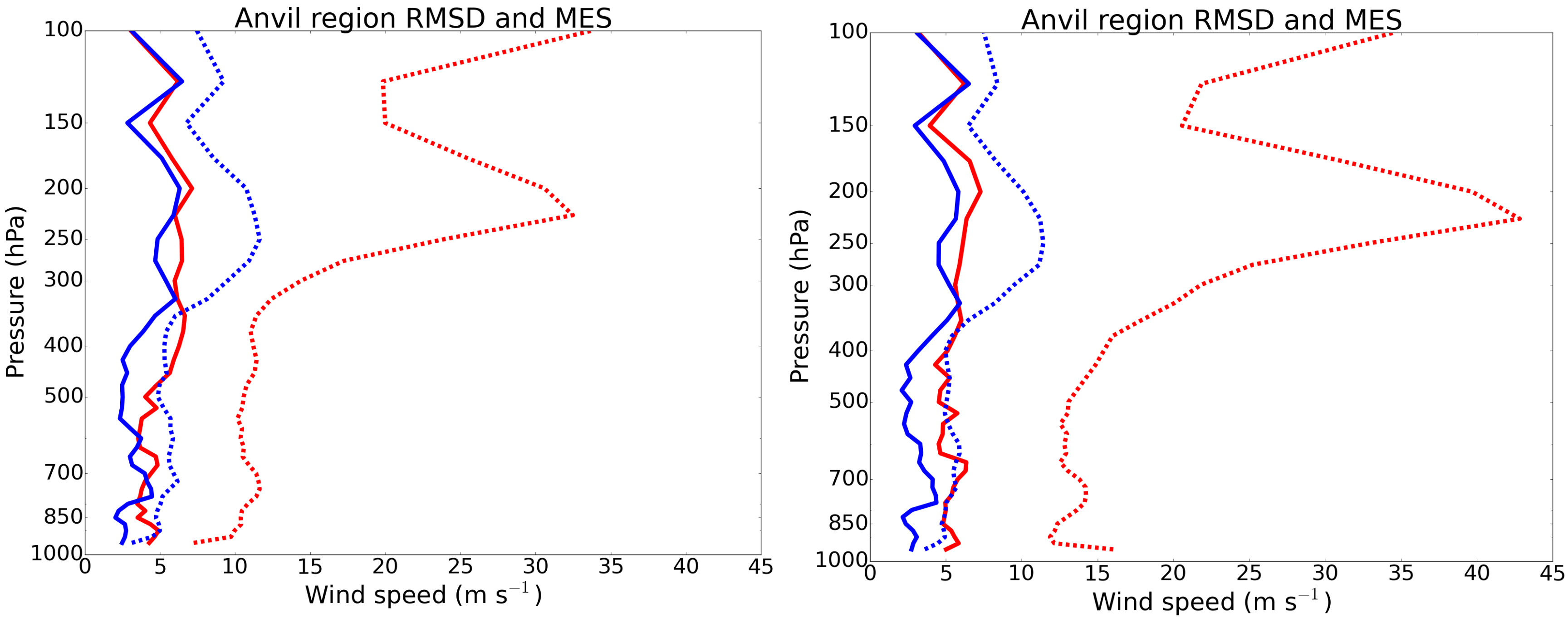
60 min. forecast

Mean bias (MB) of ensemble mean – inflow (red) and non-inflow (blue)

Larger negative bias within inflow regions

Model under-depicts wind speed within inflow, which is generally enhanced by convection

Large ensemble spread of wind speed within anvil regions



Analysis

60 min. forecast

RMSD (solid) and MES (mean ensemble spread,dashed)
– anvil (red) and non-anvil (blue)

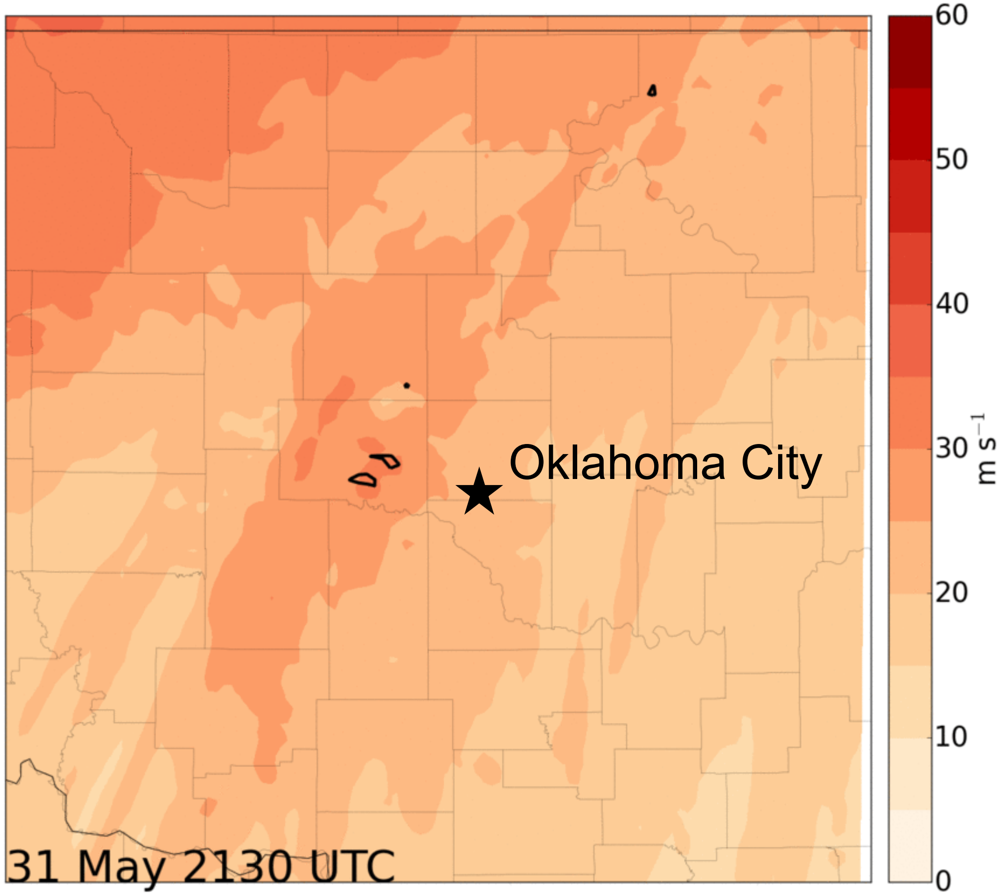
Wind speed MES within thunderstorm anvils is substantially large

Steep horizontal gradients of wind speed lead to large MES due to storm position errors

EnKF radar and surface DA allows analyses and forecasts to reasonably depict near-storm environments, including convective impacts

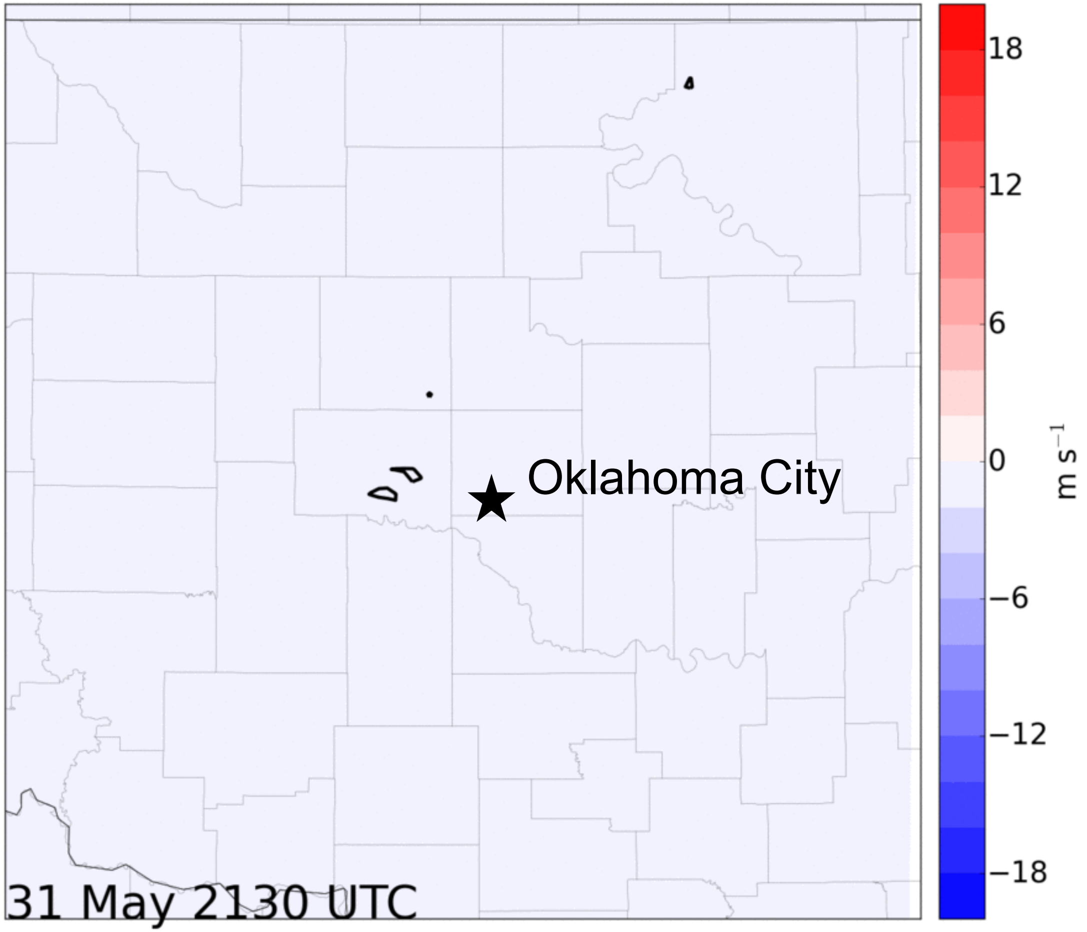
- Errors in some fields are specific to particular regions of near-storm environments
- These four cases reveal a negative inflow wind speed bias and shallow cold pool bias
- Comprehensive results can be found in our 2017 MWR article
- How rapidly does convection perturb the environment? How sensitive is forecasted convection evolution to nearby environmental features?

0-6 km vertical wind shear enhances within storm inflow region over a short time period



Ensemble mean analysis 0-6 km shear (filled contours) and low-level reflectivity (black contours)

0-6 km vertical wind shear enhances within storm inflow region over a short time period



Ensemble mean analysis 0-6 km shear difference from 2130 UTC (filled contours) and low-level reflectivity (black contours)

Ensemble Sensitivity Analysis (ESA) is used to determine how changes in initial conditions (ICs) will affect forecast metrics

- Numerous studies have applied this technique to synoptic-scale and mesoscale phenomena

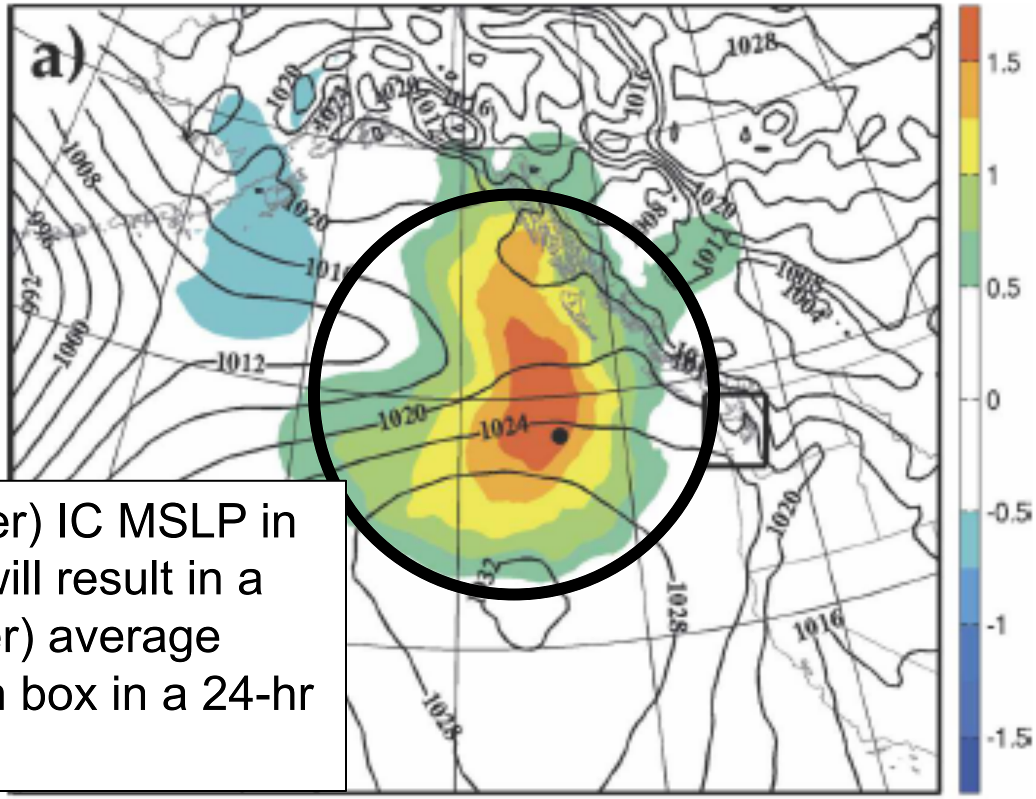
ESA is defined by:

$$\frac{\partial J}{\partial x} = \frac{cov(J,x)}{var(x)}$$

where *J* is a scalar forecast metric and *x* is an IC variable

- This linear regression method is a variation of a simple correlation
- There are instances where this procedure fails if the forecast-IC relationship is highly nonlinear or there is large ensemble sampling error

ESA was applied to MSLP off the Pacific Northwest coast (Torn and Hakim 2008)

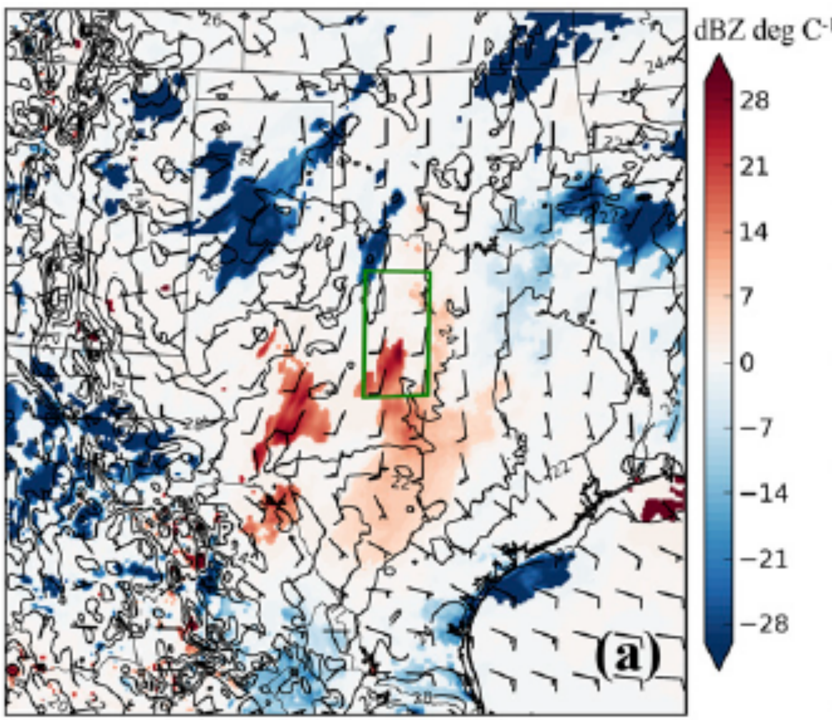


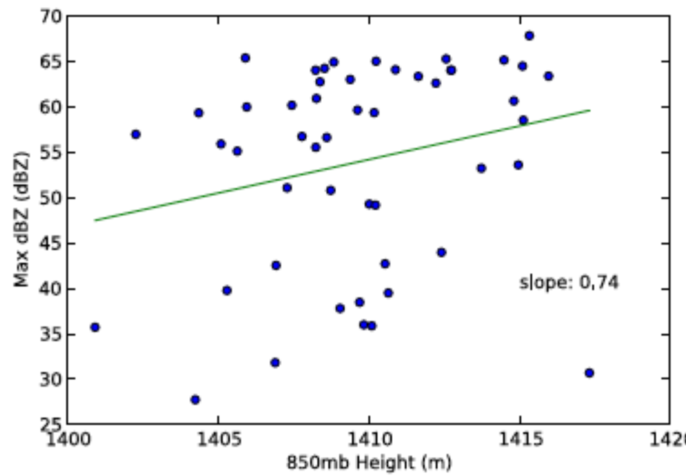
Higher (lower) IC MSLP in this region will result in a higher (lower) average MSLP within box in a 24-hr forecast

Sensitivity of 24-hr forecasted MSLP averaged within box (western Washington) to IC MSLP

Recently, ESA has been applied to smaller scales

This includes 12-24 convection forecasts (Bednarczyk and Ancell 2015; Hill et al. 2016)



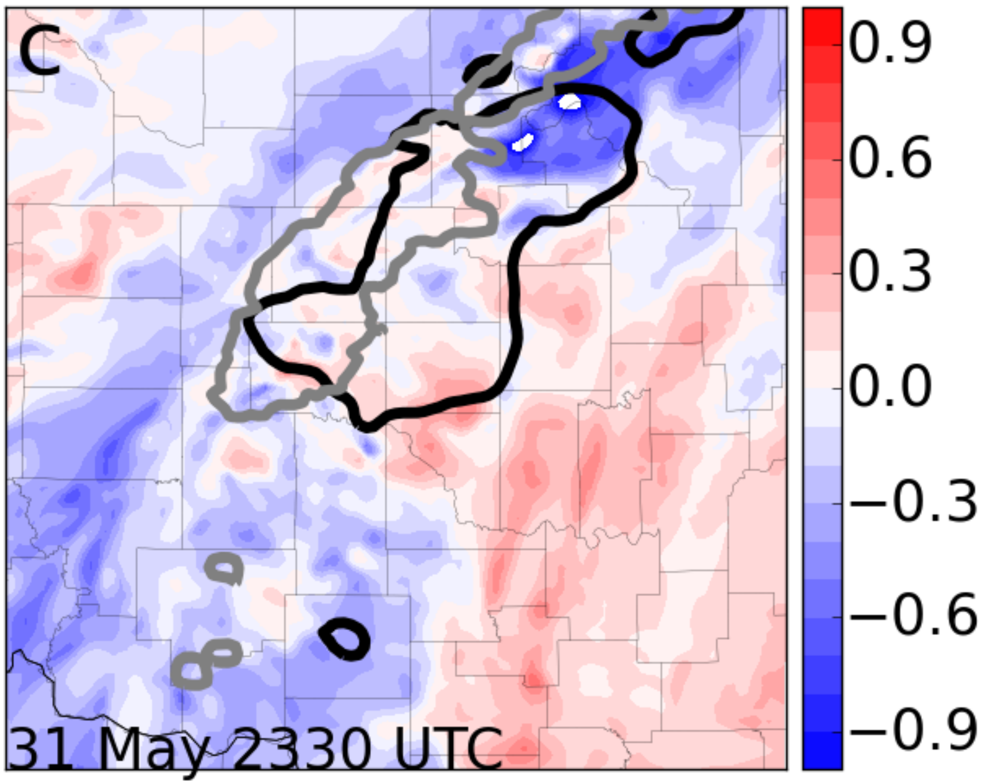


Left: Sensitivity of max reflectivity in green box to 2-m T six hours prior

Above: Scatter plot example of sensitivity

Figures adapted from Hill et al. 2016

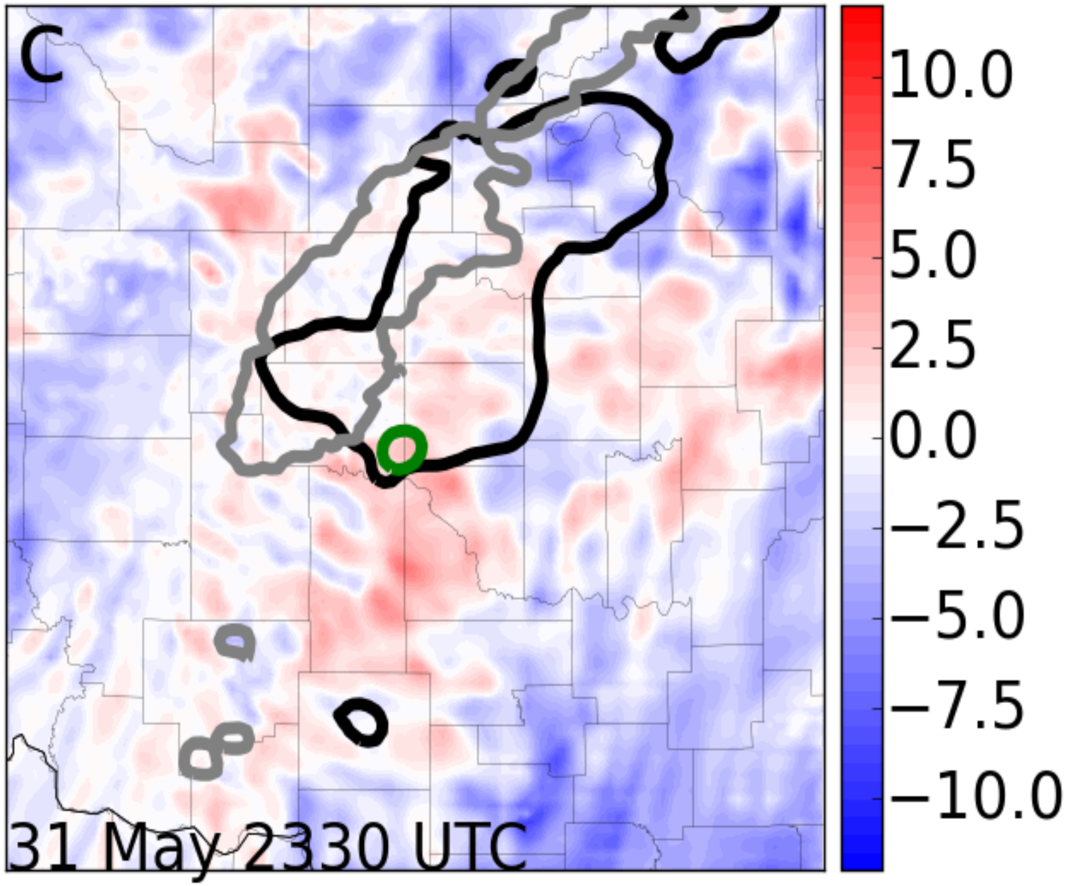
ESA is applied to short-term individual convective storm forecasts



1-hr forecast valid 2330 UTC 31 May

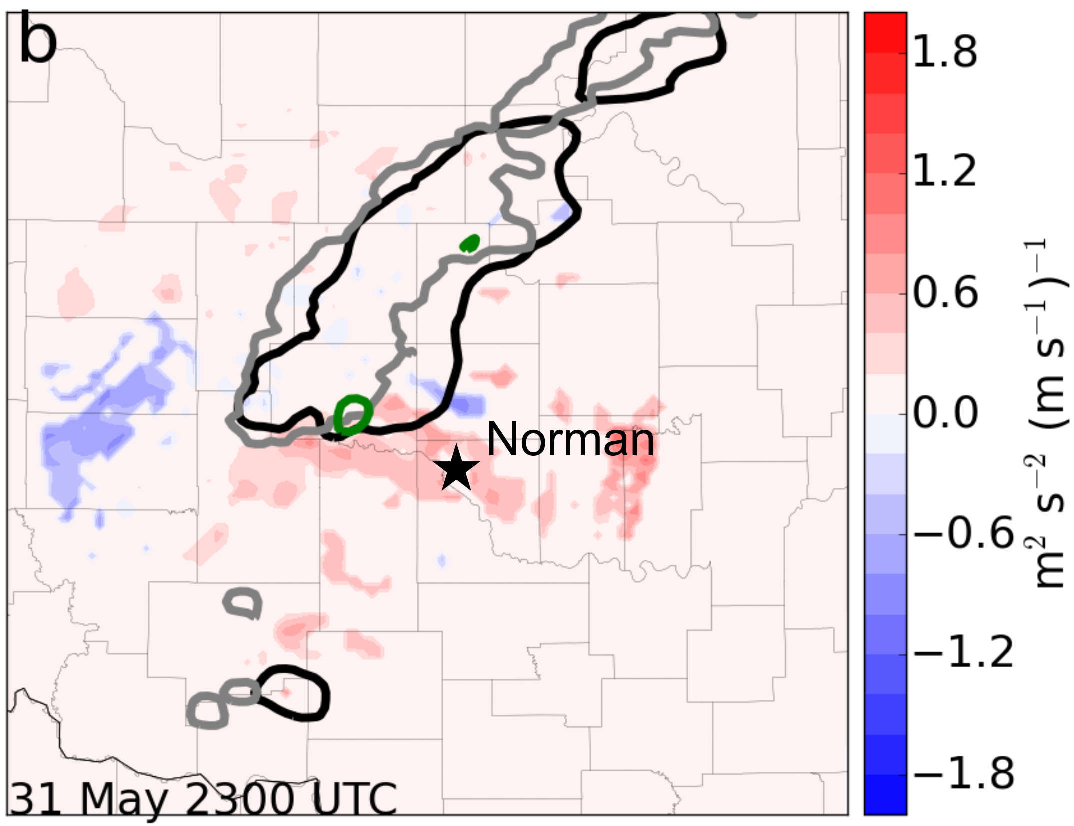
Sensitivity of forecasted storm-averaged composite reflectivity to IC 850 hPa water vapor mixing ratio

Updraft helicity (UH) is a measure of updraft rotation



Sensitivity of forecasted storm-averaged 2-5 km UH (2330 UTC) to IC 0-6 km vertical wind shear (2230 UTC)

0-1 km UH is sensitive to 0-1 km shear, but with short lead times



Sensitivity of forecasted storm-averaged 0-1 km UH (2300 UTC) to IC 0-1 km vertical wind shear (2230 UTC)

In summary, short-term forecasts of convective storms are sensitive to their near-storm environments

- Convection perturbs the environment over short time periods
- It is important the model replicates the near-storm environment well as potential hazard prediction is dependent on this
- Short-term changes in the environment can have a significant impact on further convection evolution
- This is notable in the 31 May case where UH is sensitive to environmental shear enhancements