Impact of dropsonde observations on predictability of severe convection

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Motivation:

1) reduce IC uncertainty through assimilation of research observations – test impact on ensemble forecast skill

2) Investigate value of ensemble sensitivity analysis to identify targeted observations: from 00 UTC (we used the 12 UTC in realtime decision making) Ryan will cover this in next talk

Status:

1) Review of baseline (realtime) forecast skill, Identified primary cases of interest: from 12 UTC
15 May, 23 May, 28 May, 30 May, 8 June, 11 June

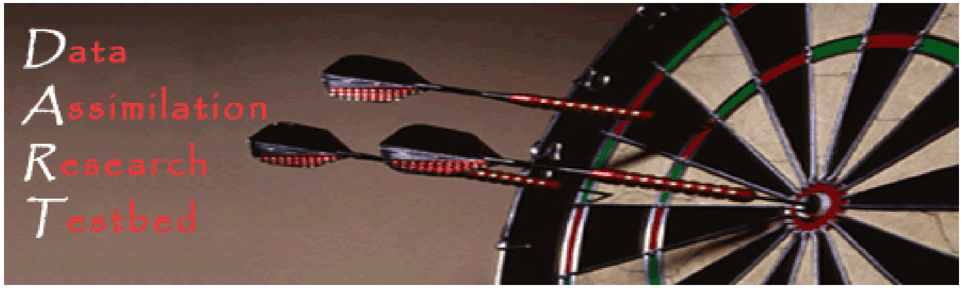
2) Prep work to prepare for assimilating dropsondes mostly complete, need upsonde obs (verification), computing resources, but mostly available time…

Data Assimilation Research Testbed (DART) – A community facility for ensemble data assimilation

DART provides a tool for generating ensemble initial conditions consistent with the forecast model. Ensemble forecast can be leveraged in targeted observation studies

Goal: Reliable mesoscale forecasts of intense convection
- e.g. 6-18 Fhr; severe weather 'watch' guidance

WRF/DART forecast system realtime demonstration:
Mesoscale Predictability Experiment (MPEX) – Spring 2013



DA driven field campaign

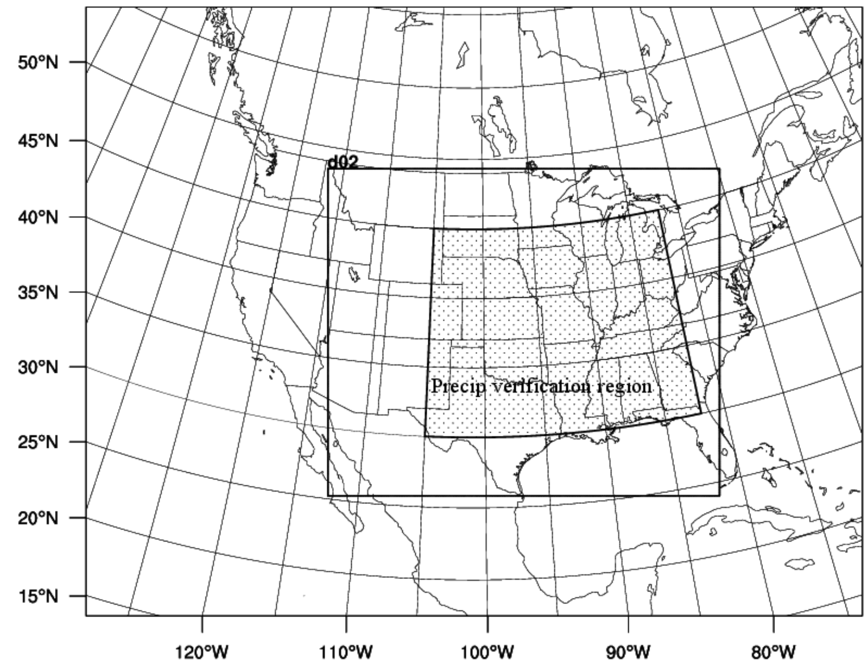
WRF and DART realtime configuration options

WRF V3.3.1

- 415x325x40 [1045x870] (E-W)x(N-S)x(B-T), model top 50 mb
- 15 [3] km grid spacing
- Key physics options: **Tiedtke, RRTMG**, Thompson, MYJ, NOAH
- **Ensemble forecasts – 30 members + GFS control 12/00 UTC daily**

DART development branch (approx. Kodiak release)

- 50 member ensemble
- 6 hourly continuous cycling assimilation
- adaptive prior inflation, sampling error correction, adaptive localization
- conventional obs (ACARS, METAR, Radiosondes, Marine, Profiler, CIMMS motion vectors), ~180k obs/day



Continuous cycling – for 46 days

See Romine et al. 2013 for more details

Ensemble Sensitivity Analysis (ESA)

$$\frac{\partial J_e}{\partial x_j} \equiv cov(\delta J, \delta \mathrm{x}_{o,j})\mathrm{D}_j^{-1} = \frac{cov(\mathrm{J}, \mathrm{X}_j)}{var(\mathrm{X}_j)}$$

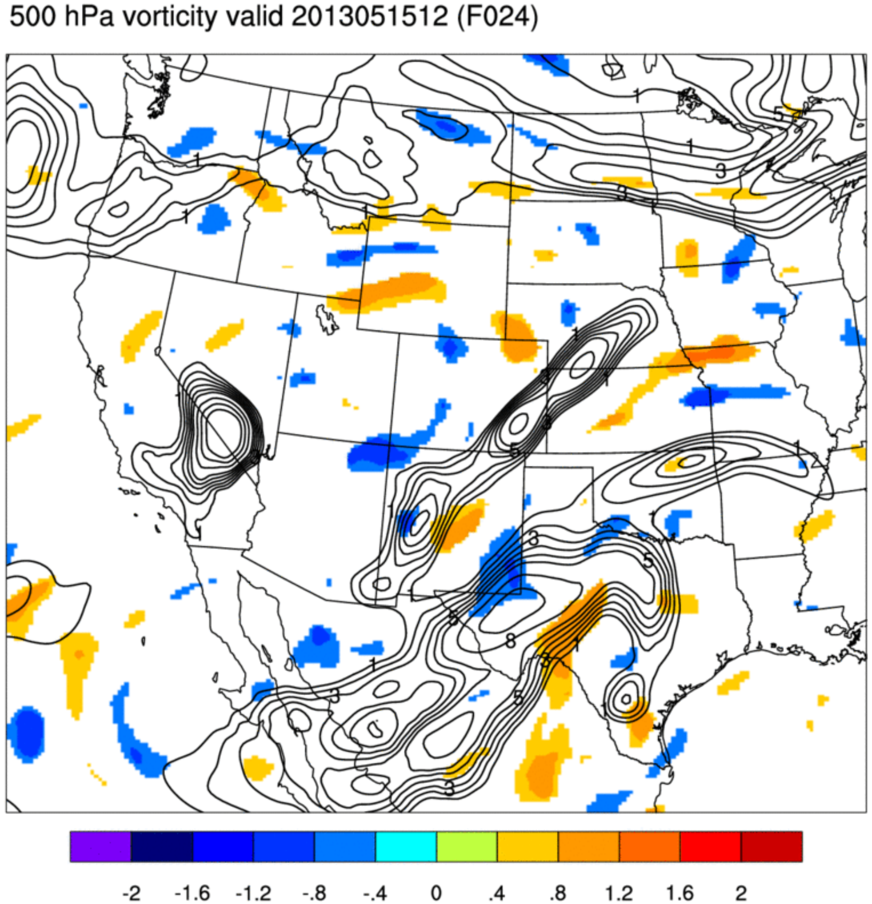
Covariance between forecast metric and state divided by state variance

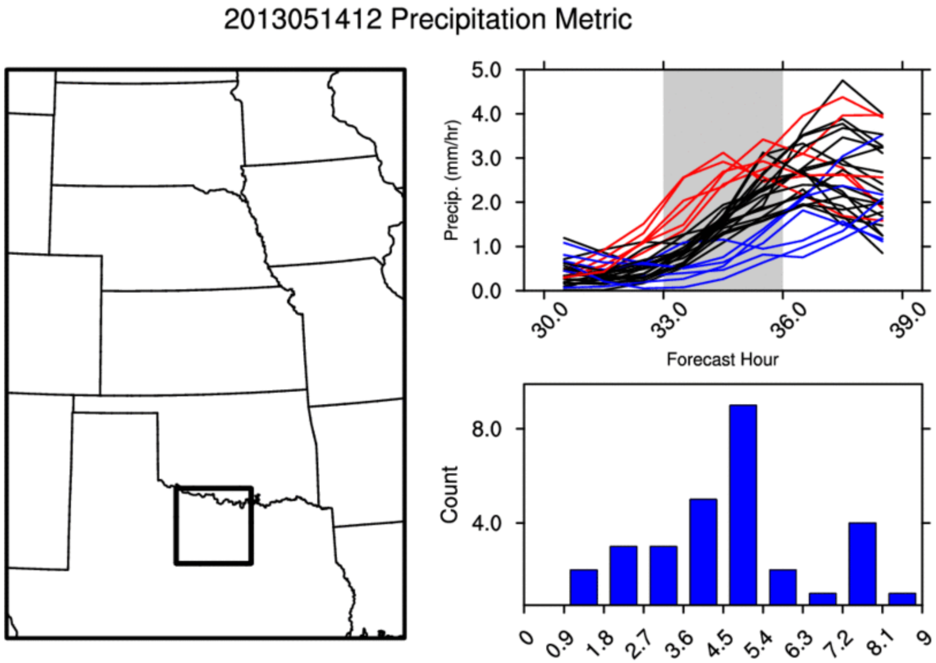
Ancell and Hakim 2007, Hakim and Torn 2008

- Ensemble-based method of computing forecast sensitivity to the initial conditions (or prior forecast states)
- From linear regression based on ensemble:
  - Dependent variable is ensemble estimate forecast metric (e.g. average accumulated precipitation over an area)
  - Independent variable is ensemble estimate of state variable (e.g. mid-tropospheric humidity)
- Works best when the forecast metric is more continuous
- Can also compare subset of members that have particular metric properties (e.g. max – min metric groups)

Sample ensemble sensitivity

Warm (cool) colors – increase (decrease) in field at 12 UTC associated with more precipitation in area at right from Fhr 33-36





Shifting shortwave in SW Texas further ESE is associated with more precipitation in box

Hypothetical observation impact

- Ensemble-based method allows for estimate of observation impact
  - Can get change in metric value if you know observation properties, ensemble metric values and observation value itself
  - Can still get reduction in variance knowing only first two above (no need for observation)

$$\delta J = \mathbf{J}(\mathbf{H}\mathbf{X}^b)^{\mathrm{T}}(\mathbf{H}\mathbf{P}^b\mathbf{H}^{\mathrm{T}} + \mathbf{R})^{-1}[\mathbf{y} - \mathcal{H}(\mathbf{x}^b)]$$

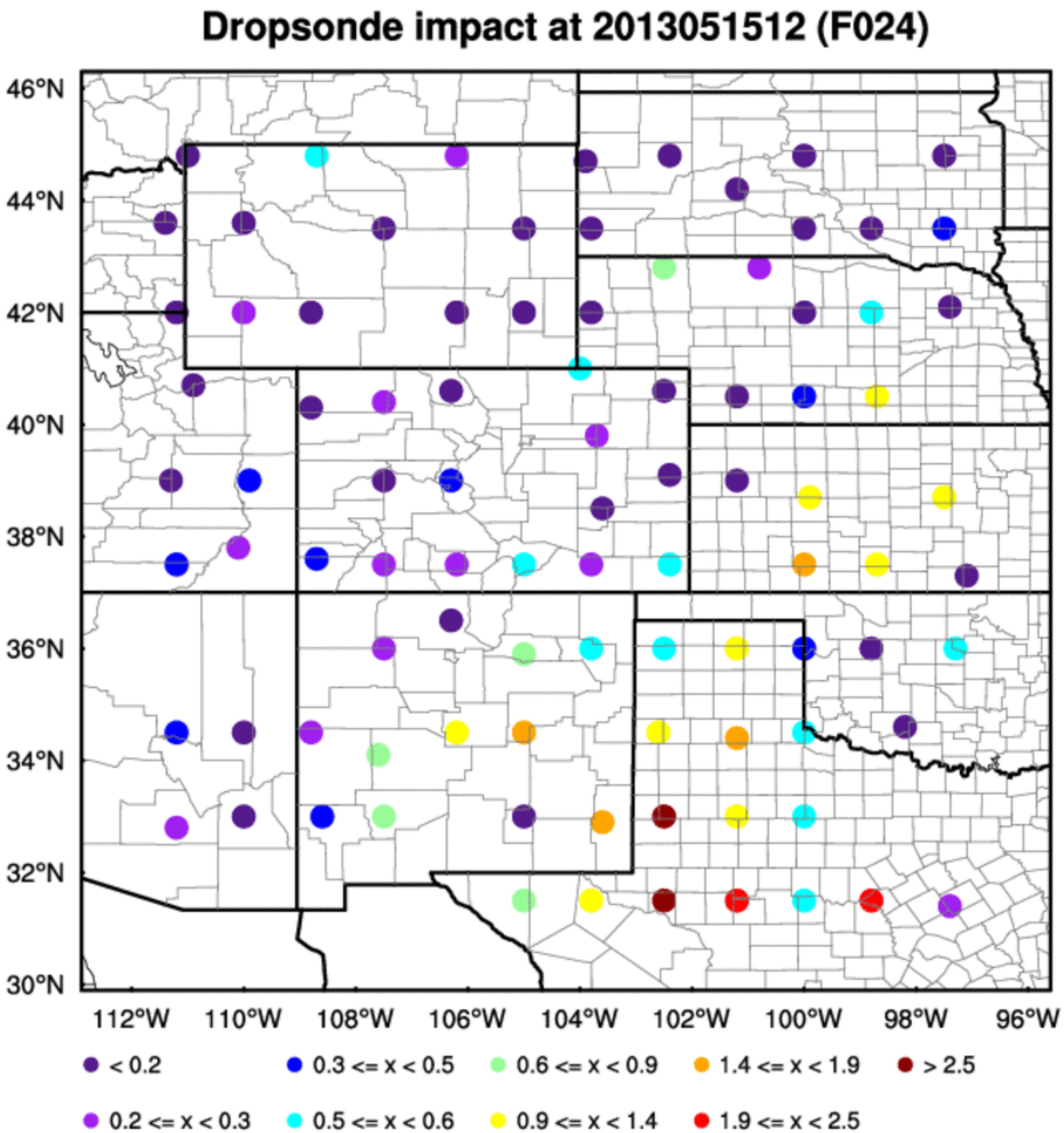
Change in Forecast metric | slope | innovation covariance | innovation

$$\delta\sigma = -\mathbf{J}(\mathbf{H}\mathbf{X}^b)^{\mathrm{T}}(\mathbf{H}\mathbf{P}^b\mathbf{H}^{\mathrm{T}} + \mathbf{R})^{-1}\mathbf{H}\mathbf{X}^b\mathbf{J}^{\mathrm{T}}$$

Change in forecast metric variance | Forecast metric observation covariance x inverse innovation covariance

See Torn and Hakim 2008, MWR

Hypothetical dropsonde impact



Change in forecast metric variance for hypothetical dropsonde locations. Bkgd analysis would be 'sensitive' to new information.

If the 24/36h ensemble forecasts were accurate, including new information at the points with the warmer colors would lead to the largest impact on the 12 UTC analysis.

Point values shown include vertical and horizontal averaging

Does ESA provide useful guidance?

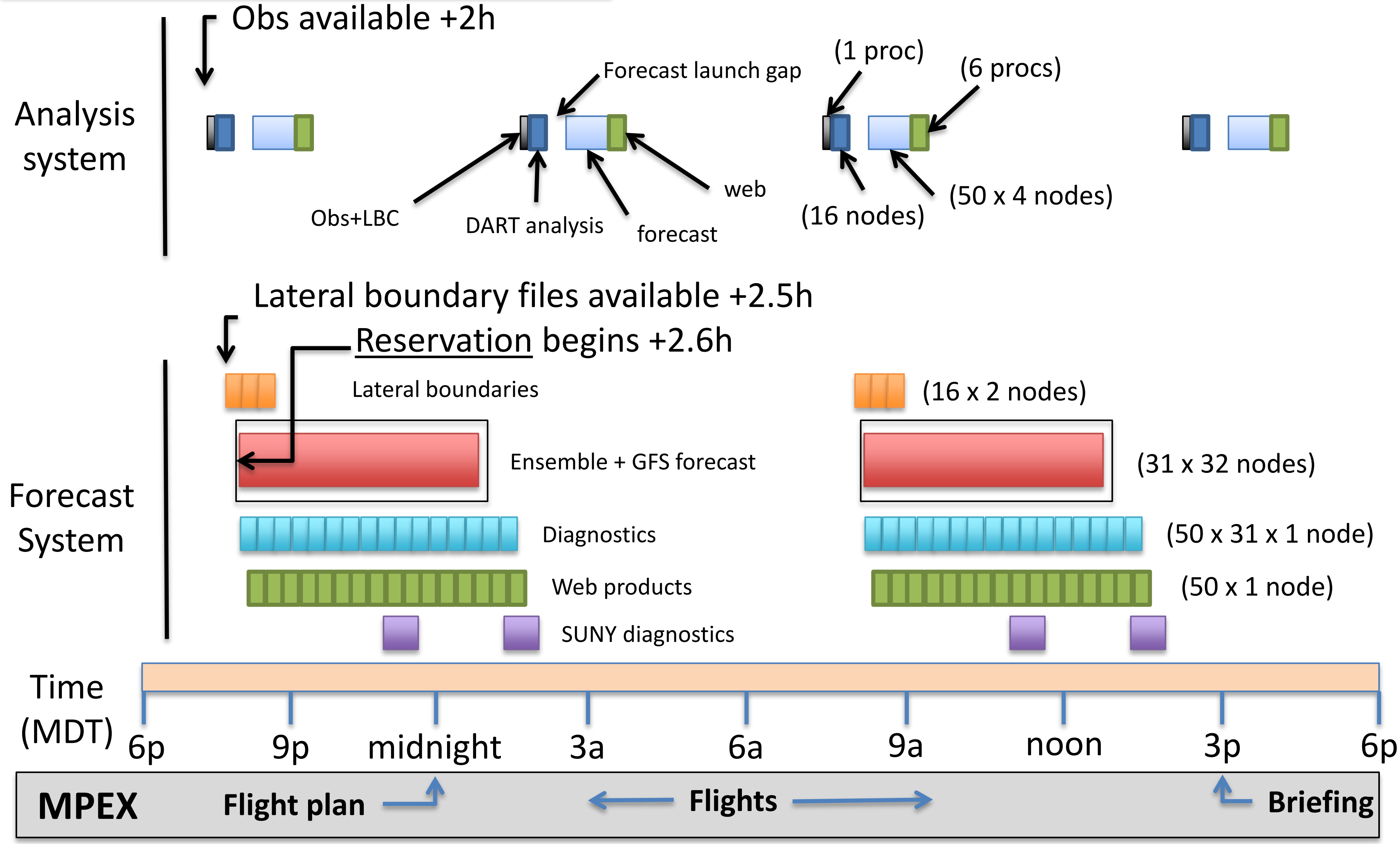
Plan to investigate ensemble sensitivity for targeted obs – did our strategy work reasonably well for targeting mesoscale observed features?

Preliminary assessment of all case events:

- All cases had convective development
- Reliance on accurate 24 h ensemble forecasts of small scale (often) weak disturbances
- Realtime metric regions were automatically generated, rarely overlapped exactly in long to shorter range forecasts
- Small variance in analysis state, rarely with statistically significant pattern sensitivity

Real-time forecast system timeline

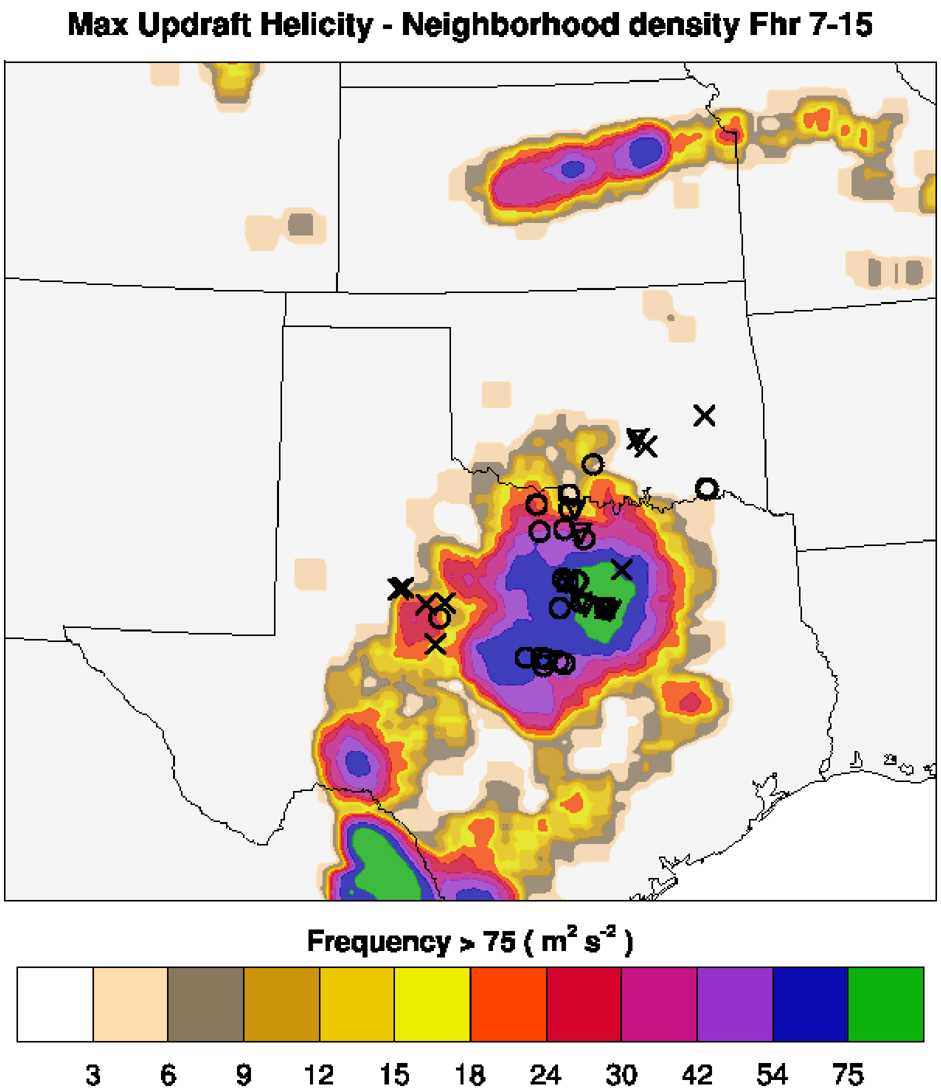
Resources from NCAR Director's Reserve, NESL Reserve, CISL support, and NCAR Strategic Capability NMMM0001



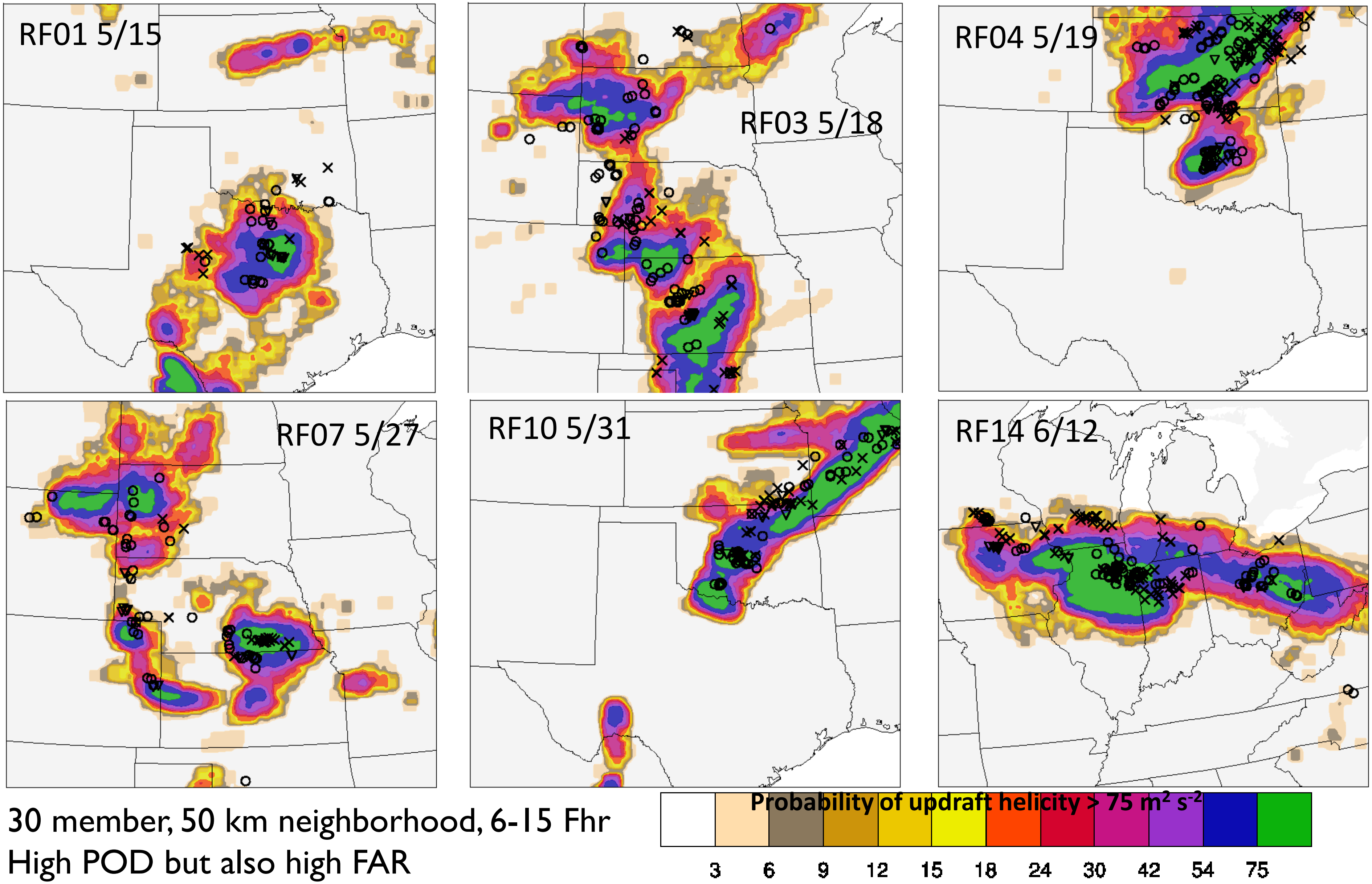
Control forecast performance: Case 1: 2013-05-15 – 12 UTC forecast

On 'watch guidance' time windows, NCAR ensemble consistently had high POD for severe storms (e.g. in North-Central TX here), but also high FAR (e.g. in KS)

Quality of timing in forecast threats at a specific point varied (examples follow)



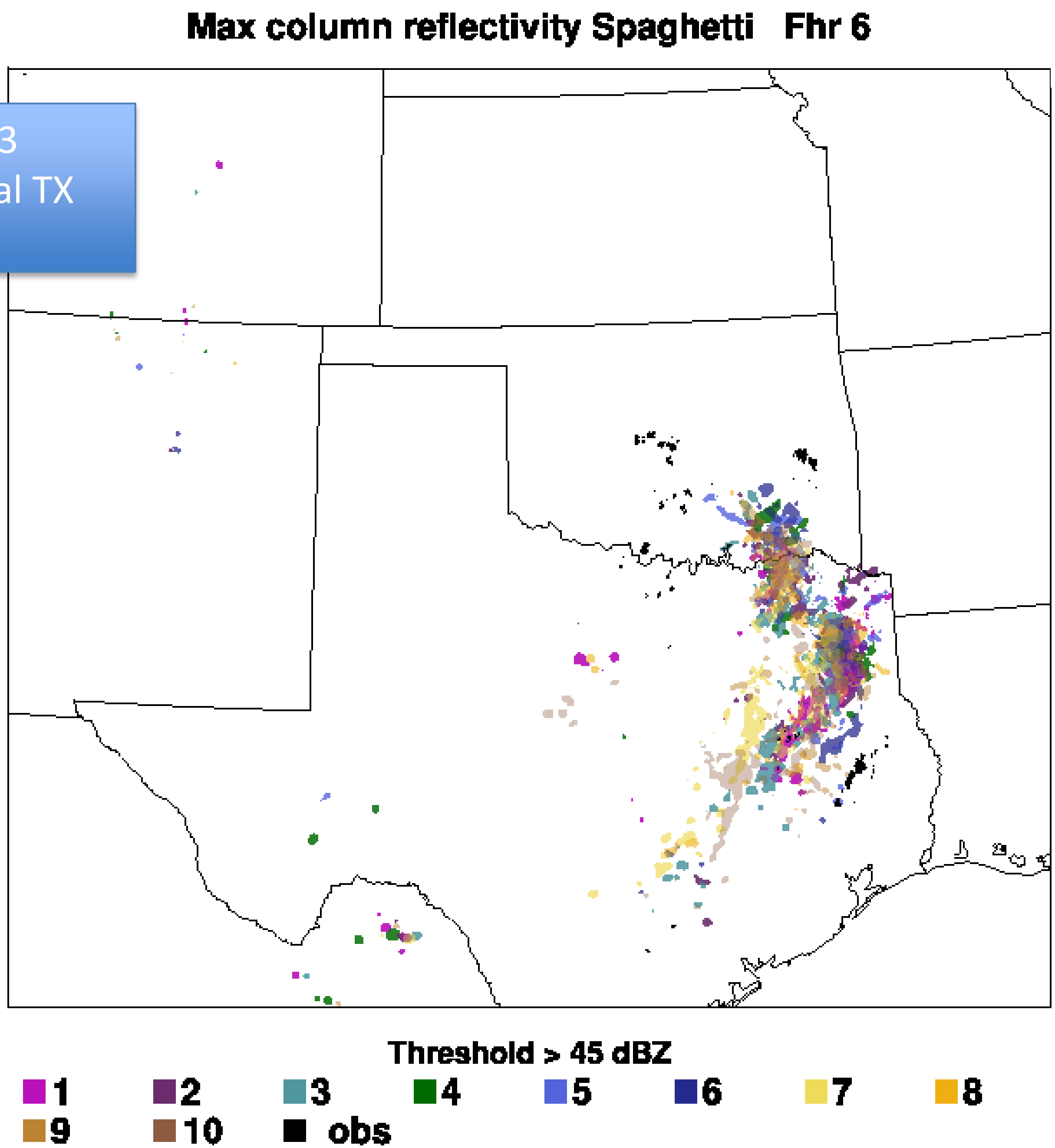
Probability of organized convection from 12 UTC fcsts



30 member, 50 km neighborhood, 6-15 Fhr
High POD but also high FAR

May 15, 2013
North-Central TX
tornadoes

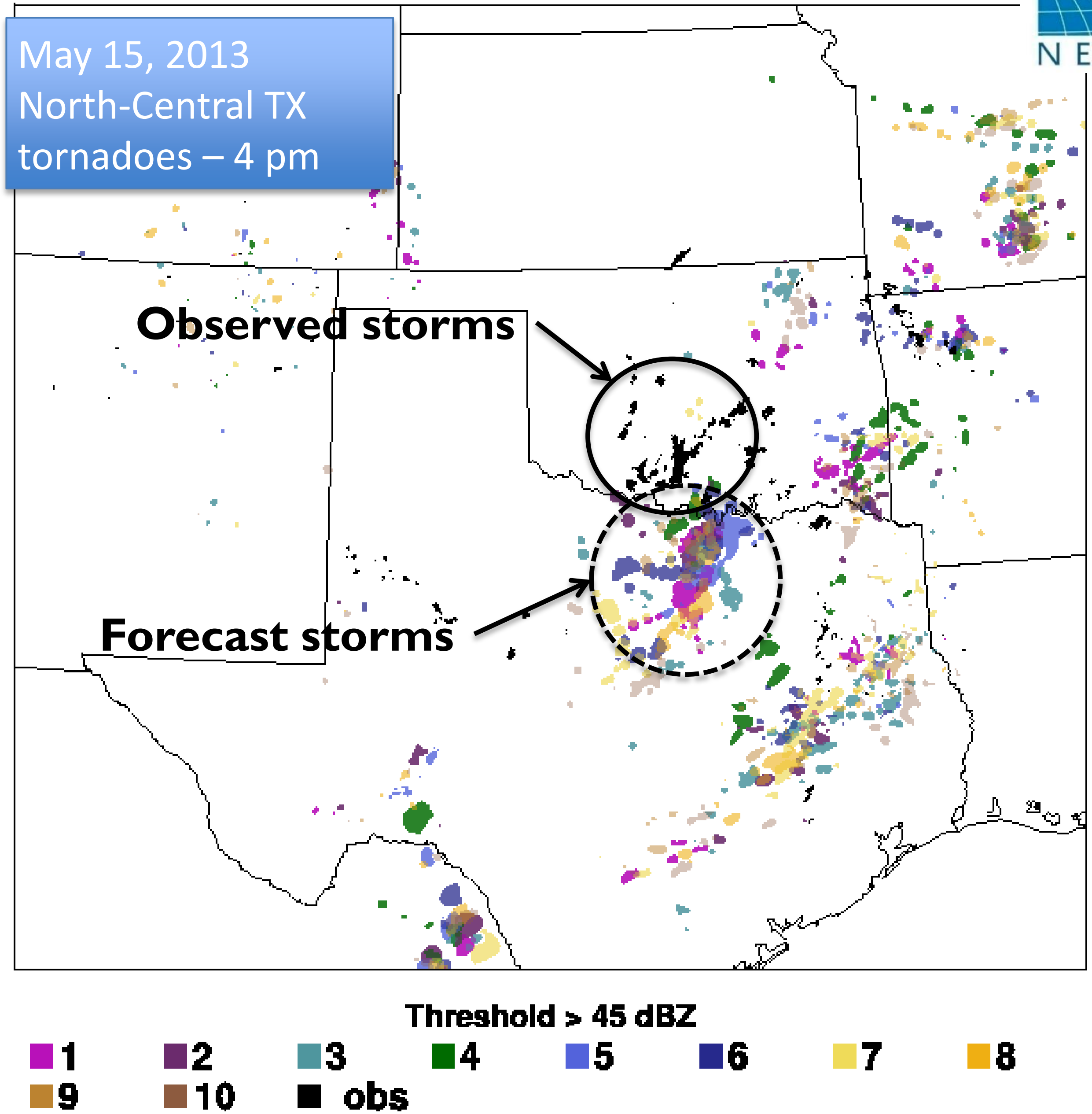
Shortcomings in timing, location, dominant mode, but mesoscale forecast is still useful guidance



WRF/DART ensemble analysis serves as initial conditions for forecasts, providing useful guidance for hazard prediction

At times, **ensemble forecasts are over-confident** and misfit from the observed event in timing and location

Motivates alternate techniques to improve reliability of ensemble forecasts (separate study underway)

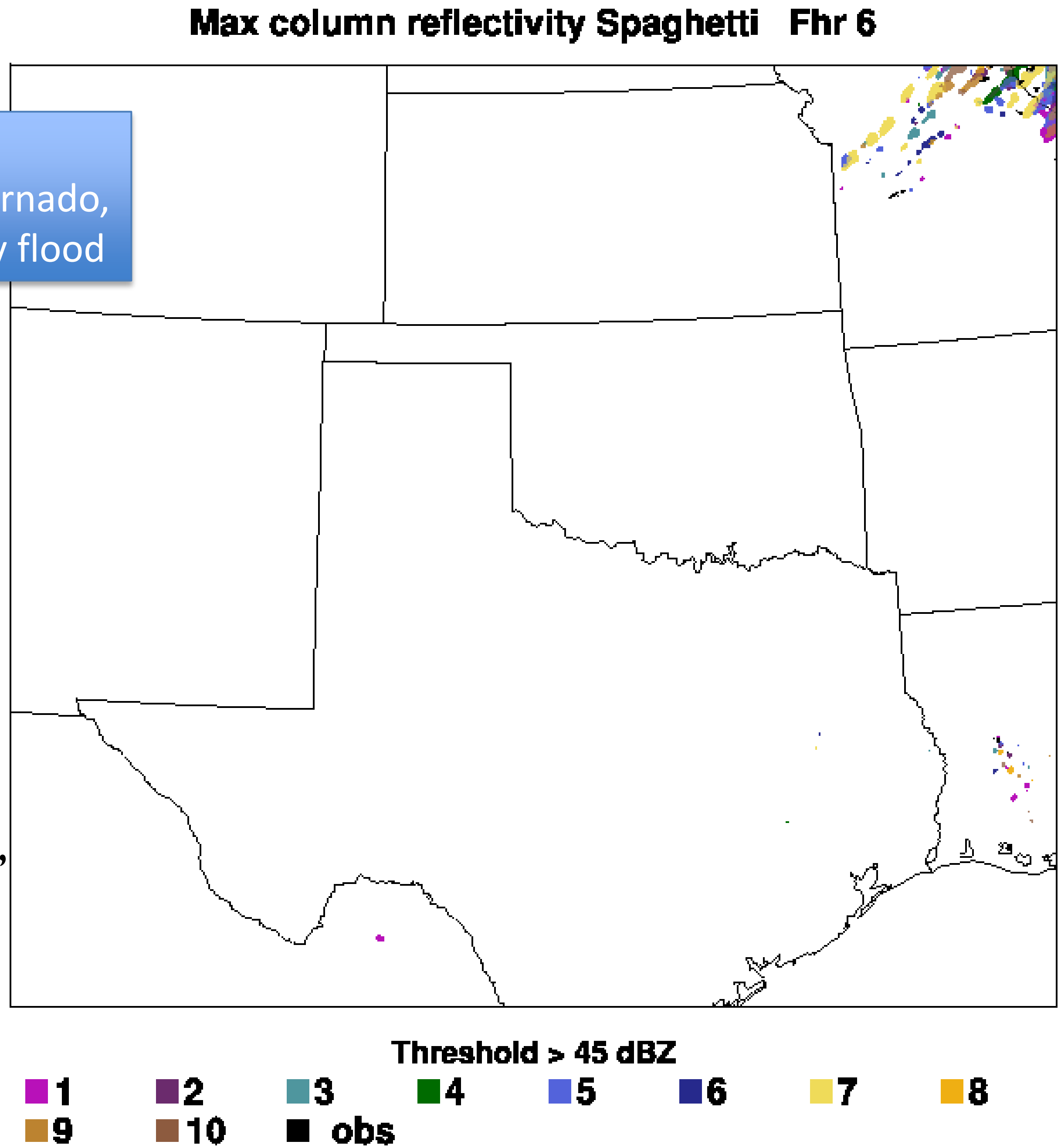


May 31, 2013
El Reno, OK tornado,
Oklahoma City flood

Here, smaller forecast variance and some details such as the threat of flash flooding in Central OK are well forecast

Does smaller forecast Variability consistently indicate reliable forecast, or is ensemble under dispersive?

Need several seasons of forecasts



Plan of attack: MPEX dropsonde impact on forecast skill

Control: Hourly cycling from 00 UTC based on the realtime continuously cycled 6 hourly analysis. Ensemble forecasts from 16 UTC (after all drops complete for all cases).

Includes additional conventional observations: hourly windows
+ GPS, mesonet, OK mesonet

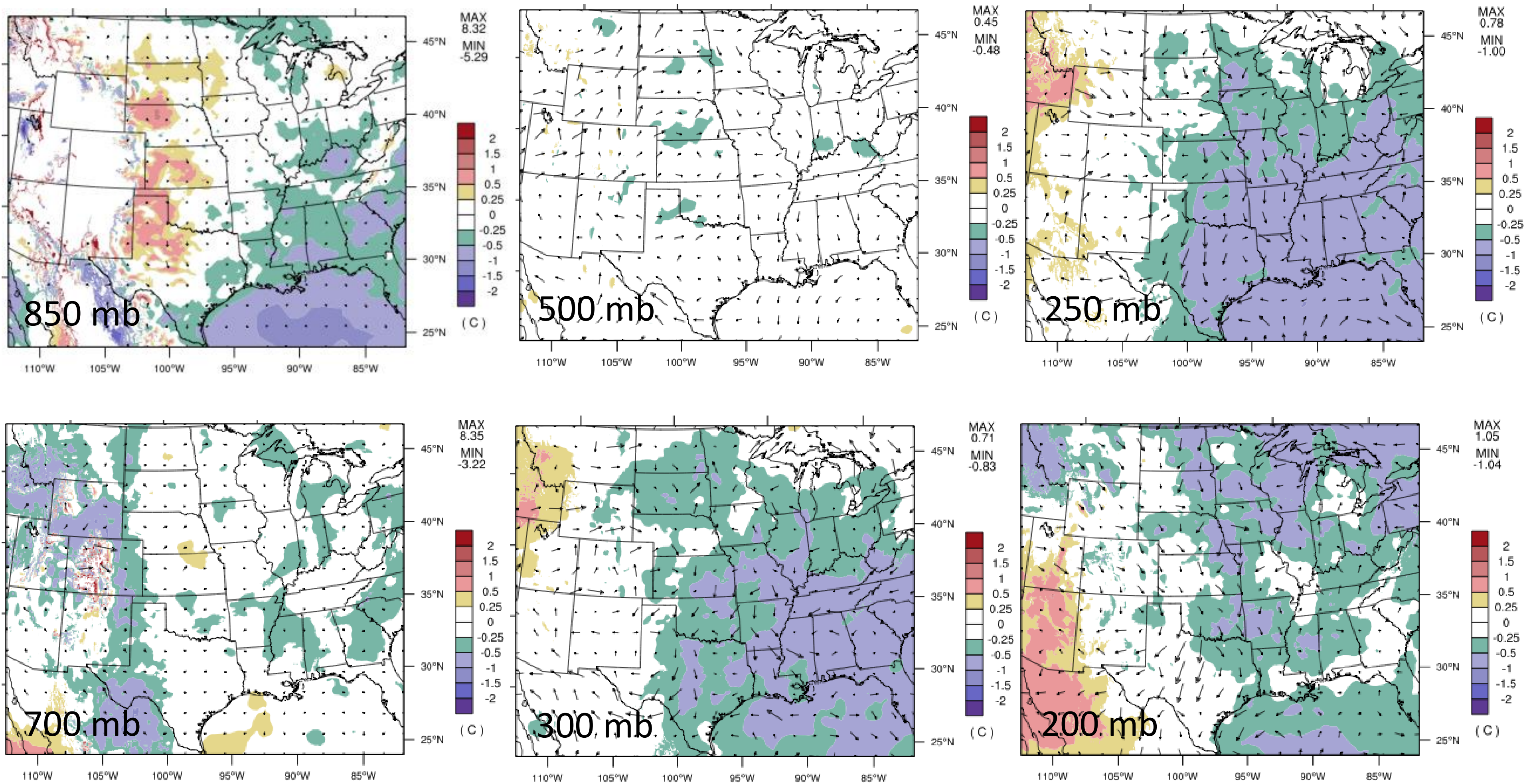
Dropsondes: Same as control – but assimilate available dropsonde observations nearest in time to each hour (based on mid-time from release to reaching surface) QC'd temp drop message obs only for now

Verification: Forecasts against Stage IV accumulated precip, POD for severe storms (obs are difficult here), possibly GOES radiance (exploring)

Reliable skill: Are there identifiable characteristics of more skillful forecasts? Under-dispersive, so forecast variance is insufficient by itself.

Mean difference (5/14-6/15) between WRFDART analysis and downscaled GFS analysis temperature on nest domain for 12 UTC initial conditions – WRF physics related drift?

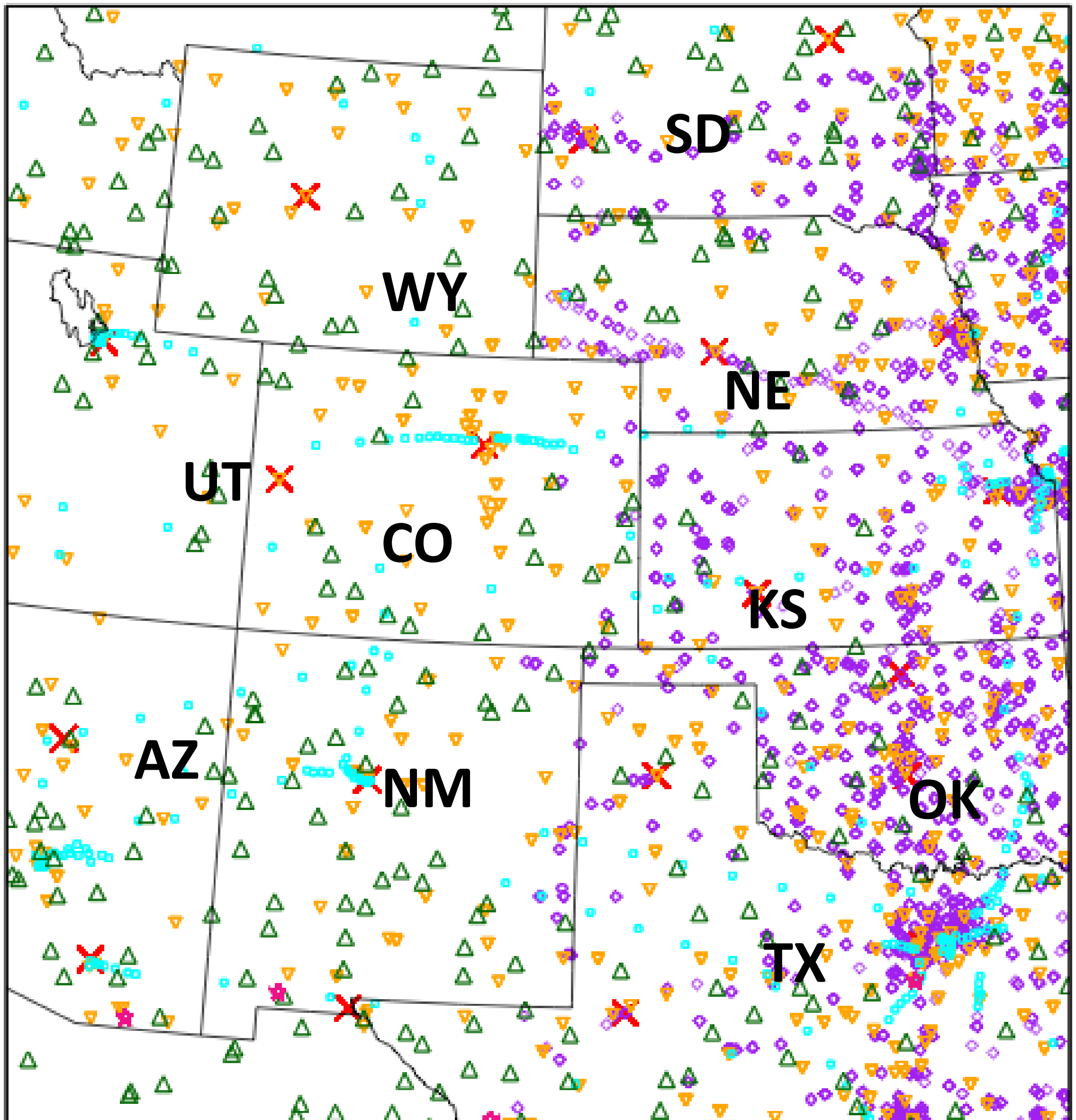
EKF-GFS



Will need to evaluate both against obs

Will explore options to control drift

Retrospective runs



Relative to the realtime system, for retrospectives will apply **hourly cycling** with additional surface observations (violet)

Eventually, plan to also test having nest analysis at same resolution as the convective forecasts (**3 km, bypass downscaling, initial analysis runs @ 15 km grid spacing**)

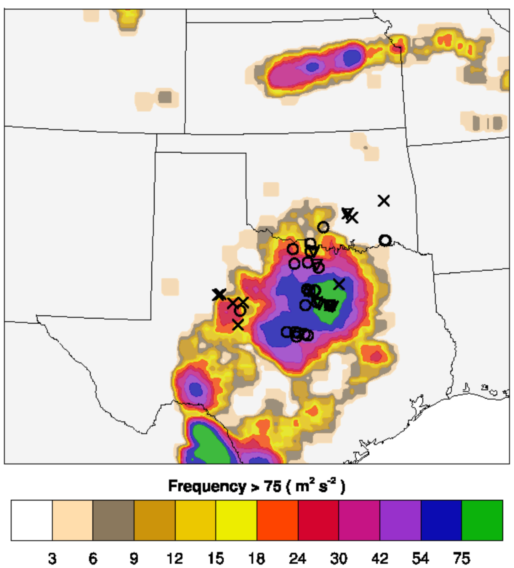
Case A: 2013-05-15

Ensemble mean analysis pos. absolute vorticity (yellow)

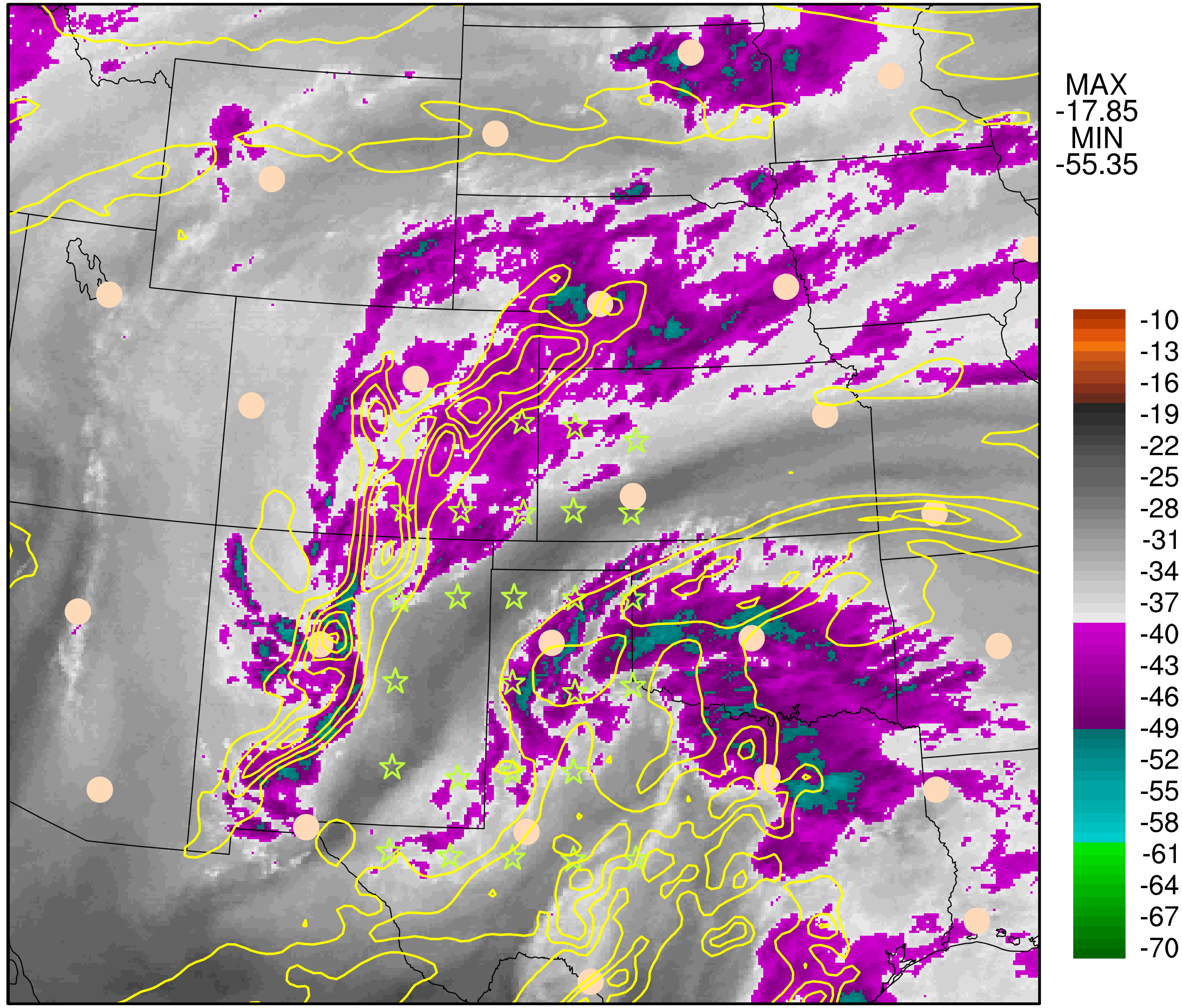
Drop locations & NWS sondes

Sampled western side of upper level disturbance in TX – agrees well with ESA

Max Updraft Helicity - Neighborhood density Fhr 7-15



GOES-15 gvar_ch3 brightness Date: 2013-05-15_1200

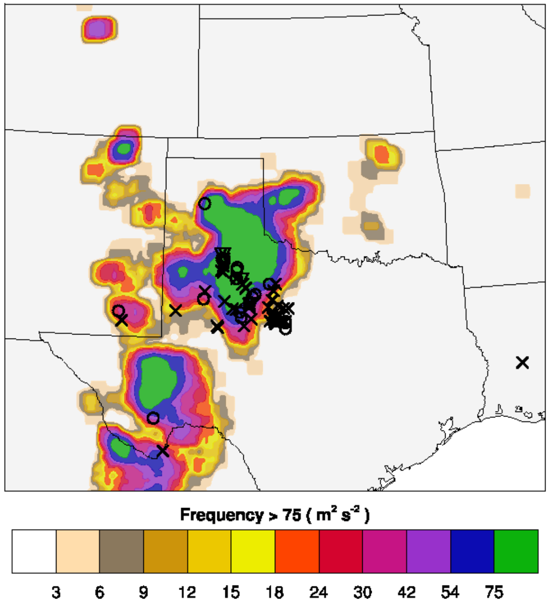


NWS - circles, MPEX drops - stars Brightness (K)

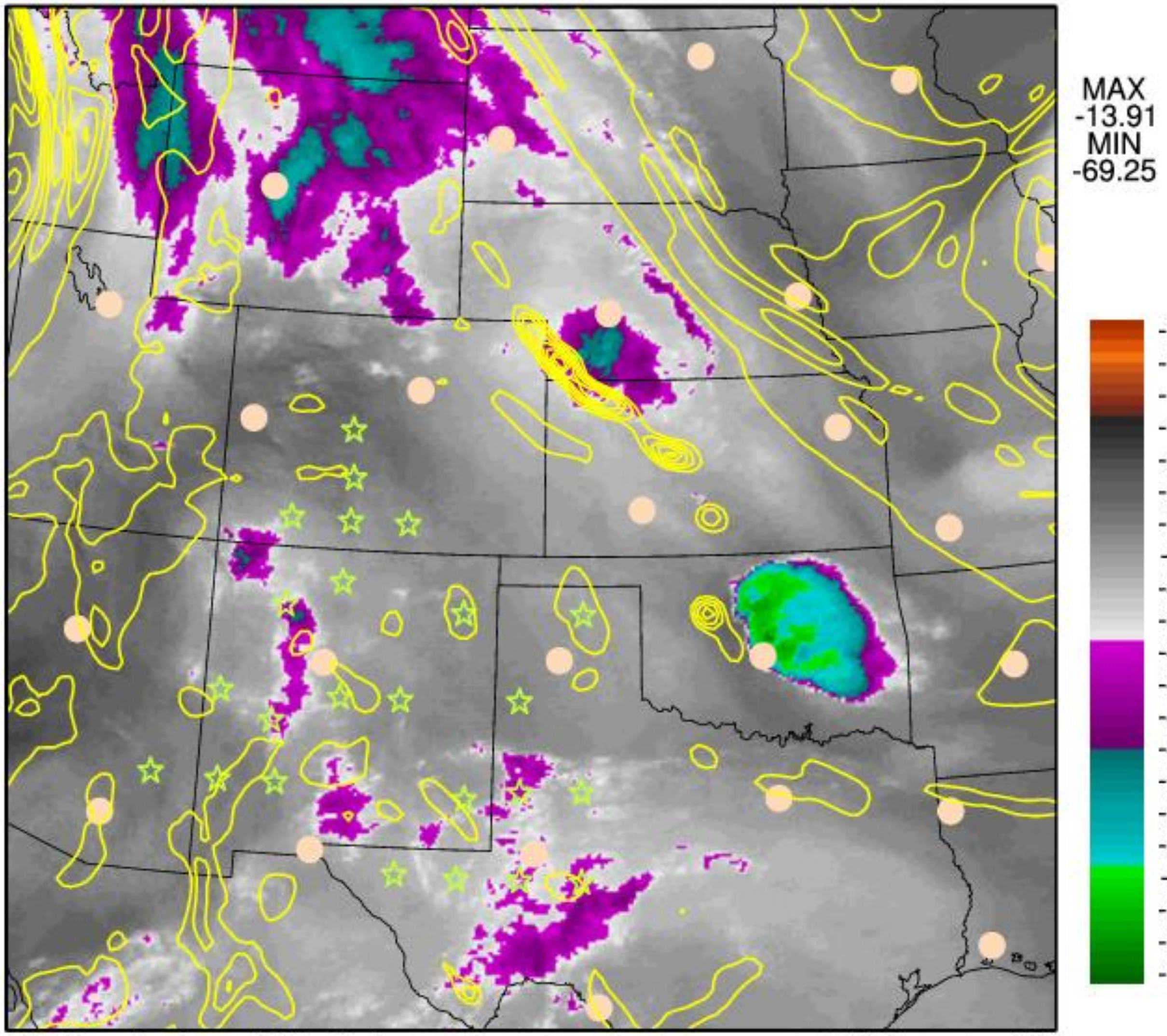
Abs. vorticity, 10-45 by 5 (10^{-5} s^{-1})

Case B: 2013-05-23

Max Updraft Helicity - Neighborhood density Fhr 7-15



GOES-15 gvar_ch3 brightness   Date: 2013-05-23_1200



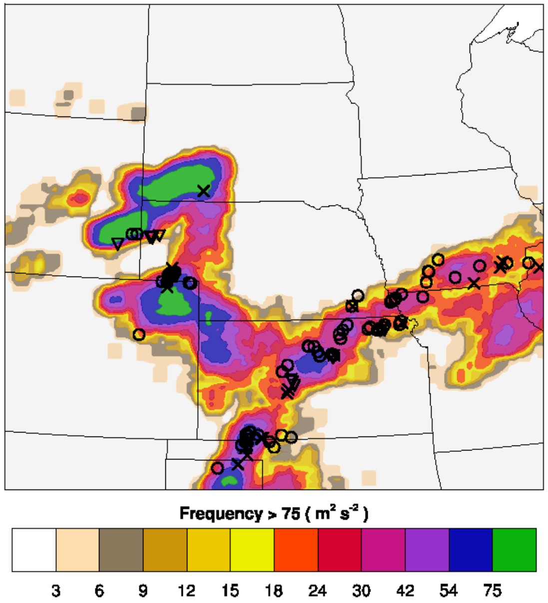
NWS - circles, MPEX drops - stars

Abs. vorticity, 10-45 by 5 (10^{-5} s^{-1})

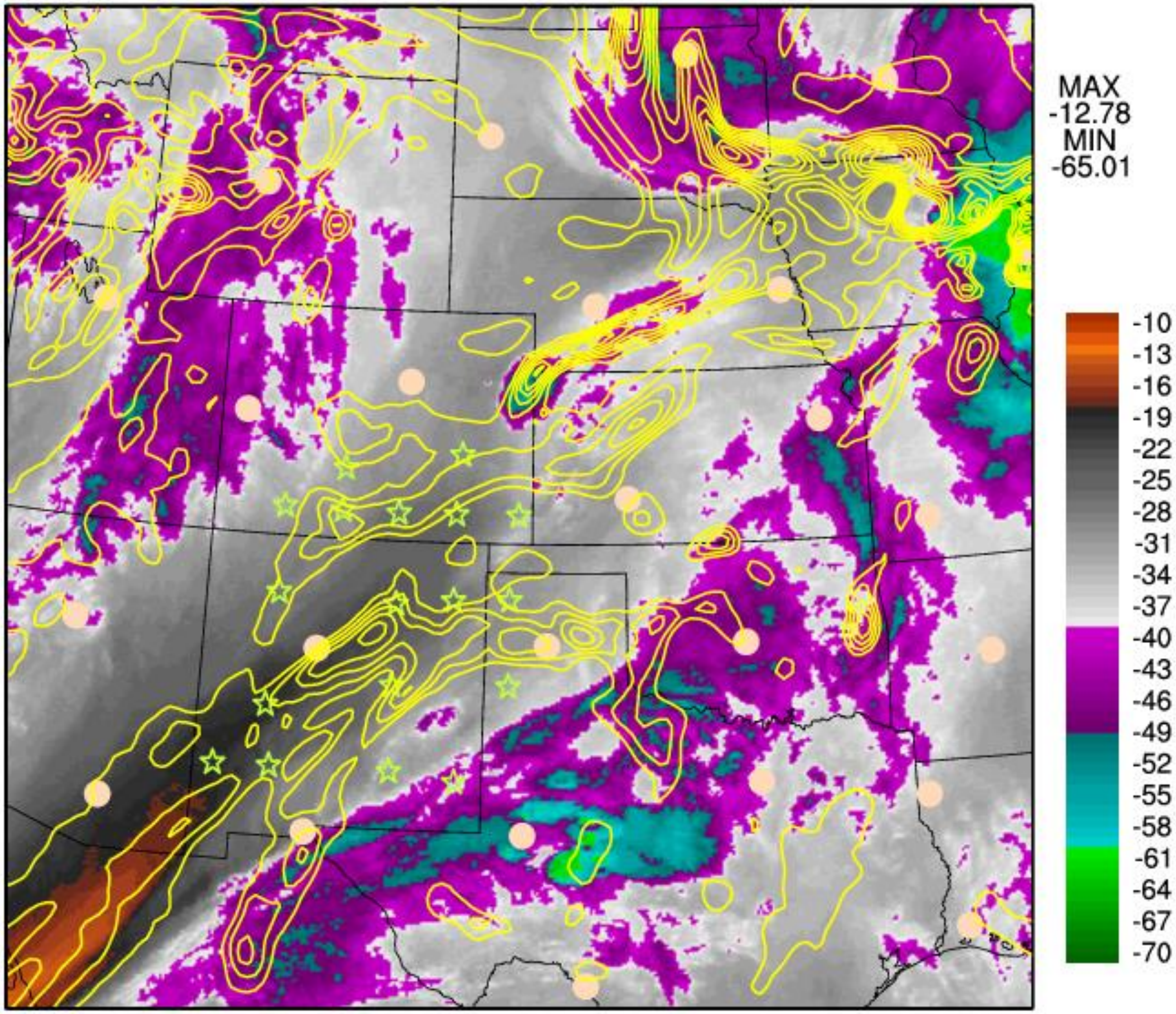
Brightness (K)

Case C: 2013-05-28

Max Updraft Helicity - Neighborhood density Fhr 7-15



GOES-15 gvar_ch3 brightness Date: 2013-05-28_1200



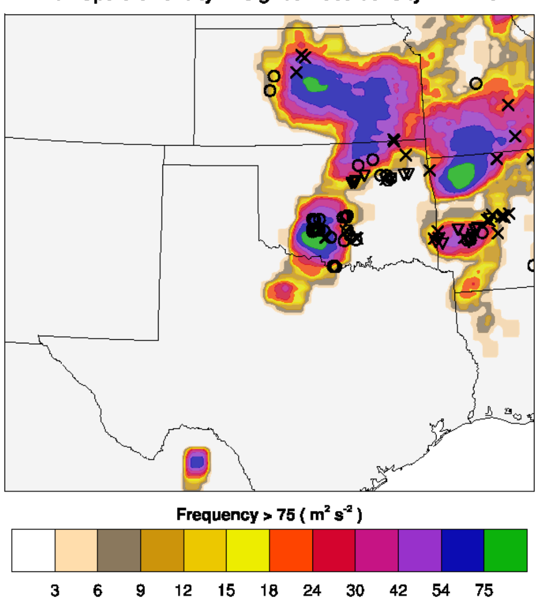
NWS - circles, MPEX drops - stars

Brightness (K)

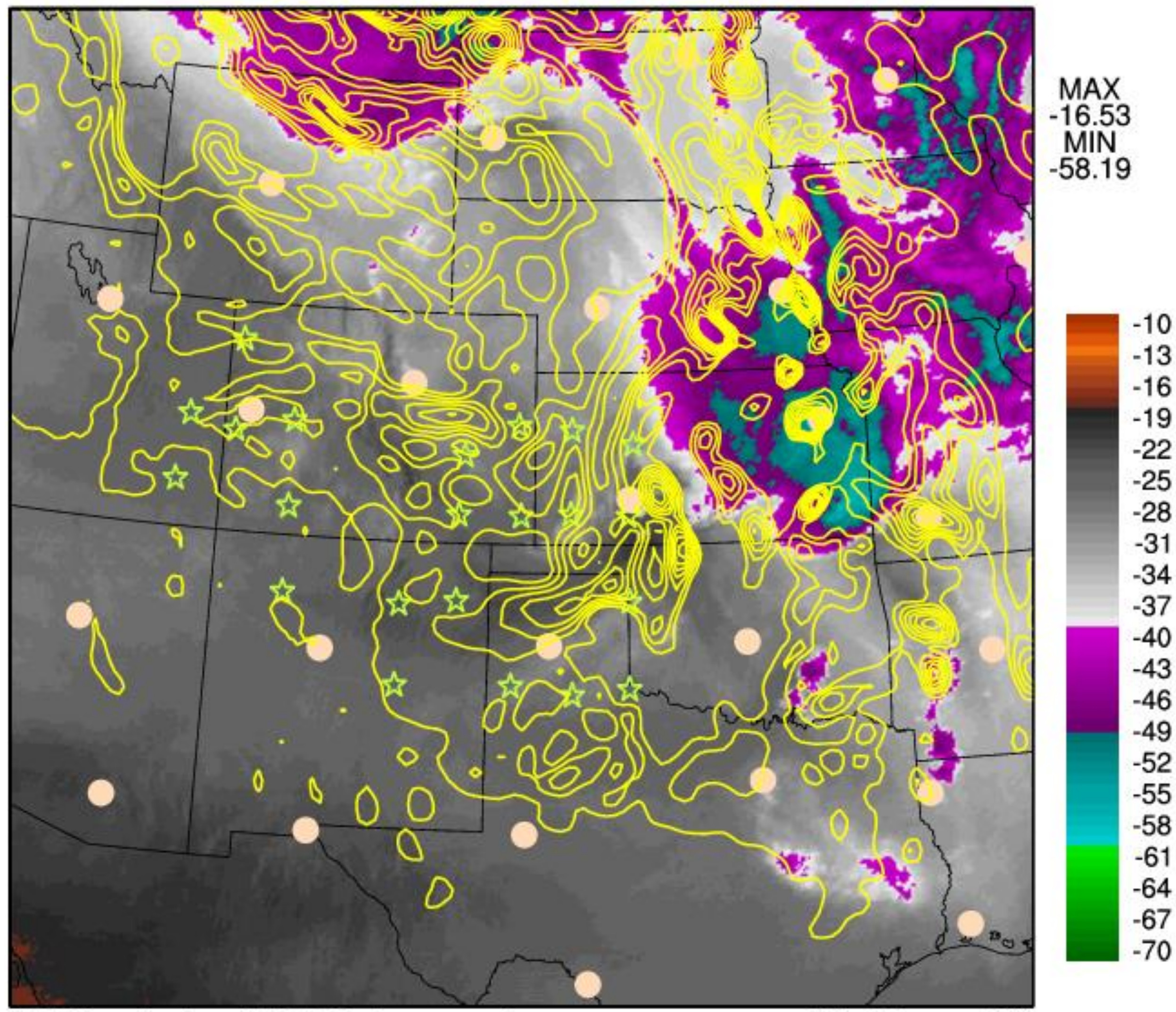
Abs. vorticity, 10-45 by 5 (10^{-5} s^{-1})

Case D: 2013-05-30

Max Updraft Helicity - Neighborhood density Fhr 7-15



GOES-15 gvar_ch3 brightness Date: 2013-05-30_1200



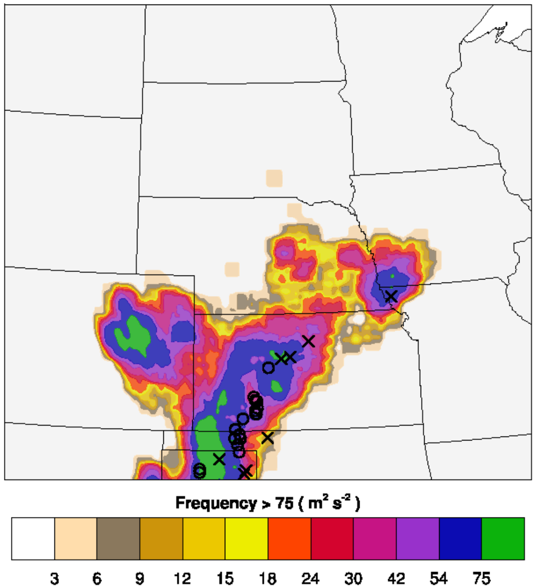
NWS - circles, MPEX drops - stars

Brightness (K)

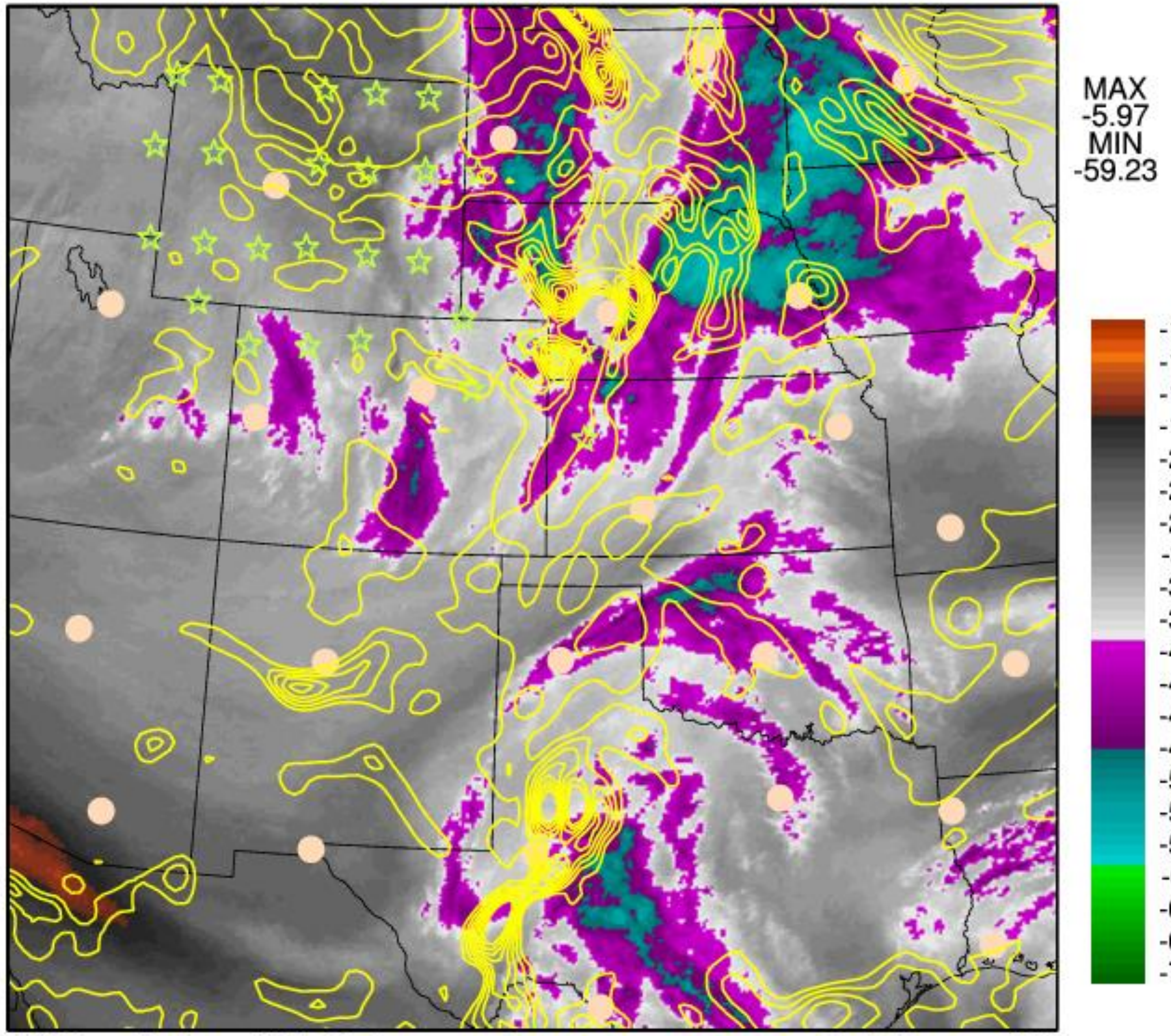
Abs. vorticity, 10-45 by 5 (10^{-5} s^{-1})

Case E: 2013-06-08

Max Updraft Helicity - Neighborhood density Fhr 7-15

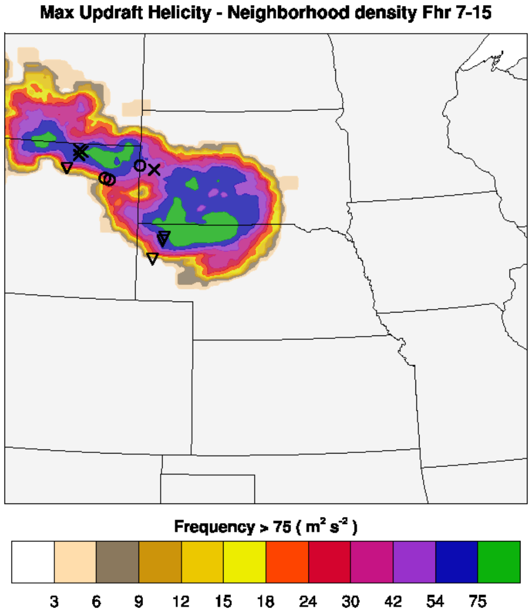


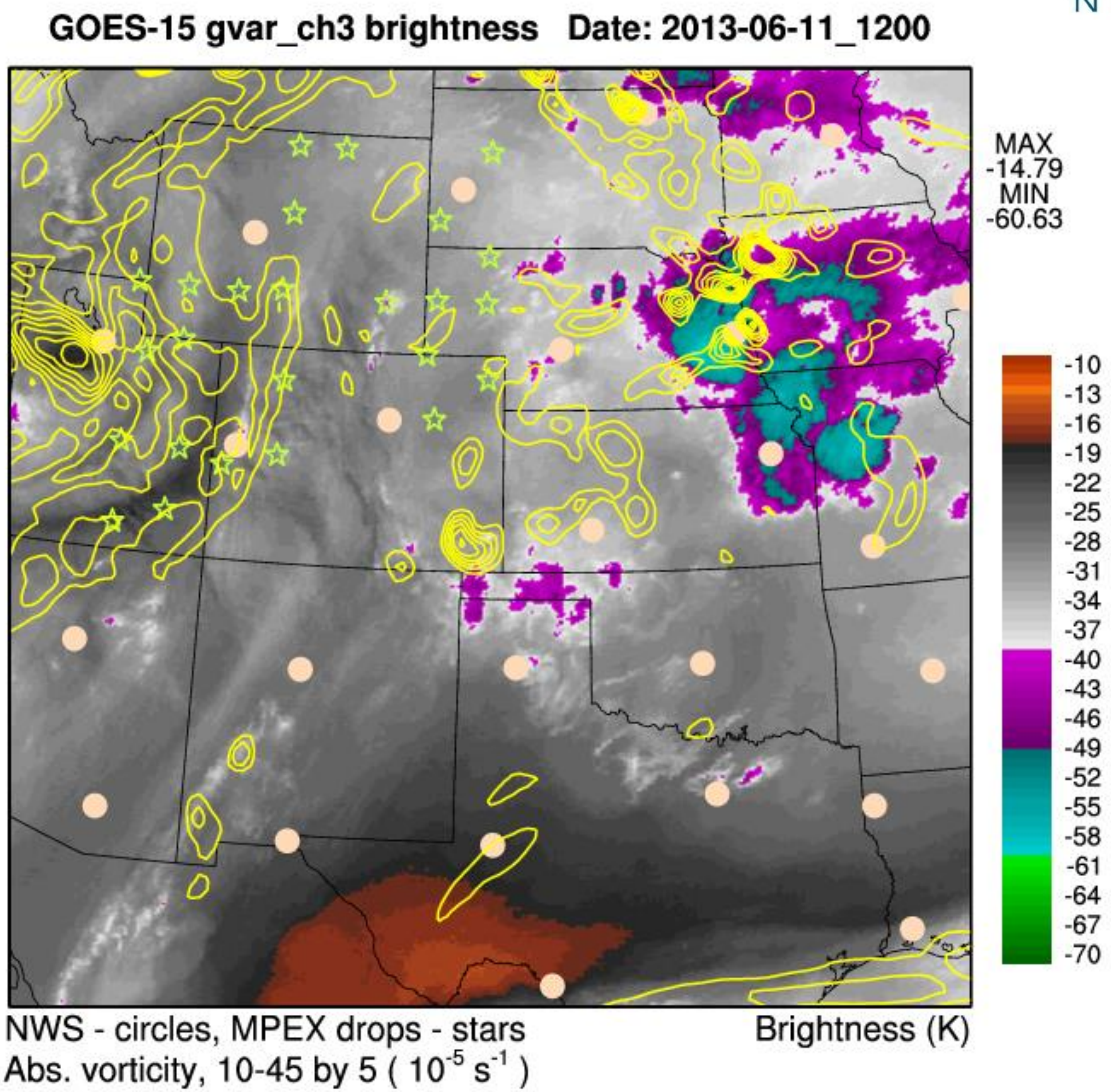
GOES-15 gvar_ch3 brightness   Date: 2013-06-08_1200



NWS - circles, MPEX drops - stars
Abs. vorticity, 10-45 by 5 (10^{-5} s^{-1})
Brightness (K)

Case F: 2013-06-11





Status and Future work

- WRF-DART initialized ensemble forecasts with convection-permitting grid spacing provided useful guidance during MPEX of significant severe weather hazards, particularly during day 1 of the forecast
    - many strongly forced events

- Ensemble sensitivity analysis applied to targeted observing strategies will be further explored, reliance on accurate 24 h ensemble forecasts of small disturbances is a weakness

- We will be assimilating MPEX sondes in retrospective studies with WRF-DART with subsequent CP ensemble forecasts (data denial obs impact experiments)

- Evidence of 'drift' in continuously cycled WRF model analysis/forecasts, will be exploring impact of model error representation schemes to improve forecasts, perhaps also analysis system