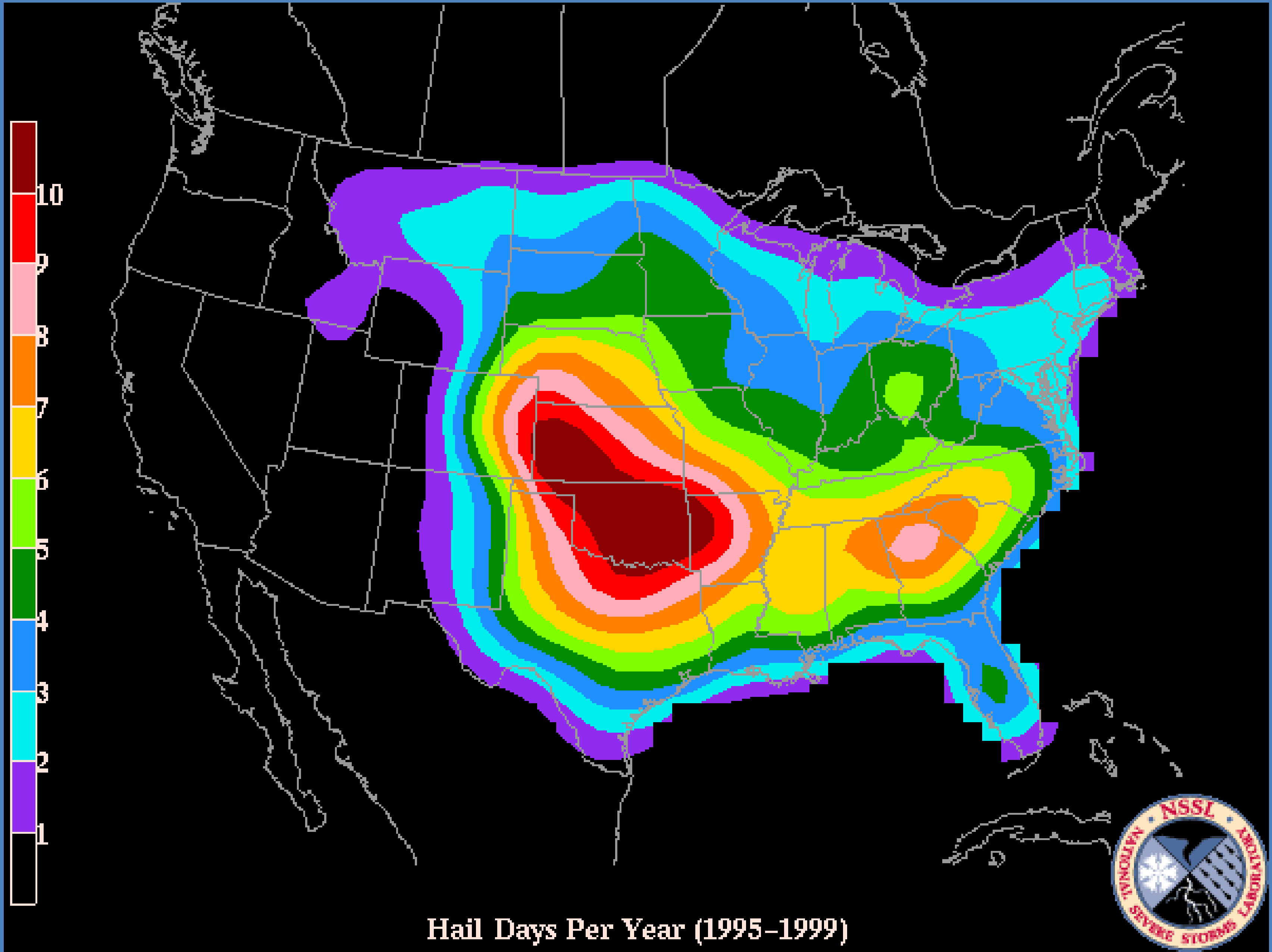
A Comparison of Sounding-Derived Hail Parameters from Observed and NARR Proximity Soundings

Aaron W. Johnson

SOO – NOAA/NWS Dodge City KS

DDC Hail Climatology



Wide spectrum of documented hail sizes over several decades BUT

In comparison to 20 years ago...how much more accurate are we at forecasting maximum expected hail size in 2011??? What are the issues?

REALITY CHECK!!!!!!!!!

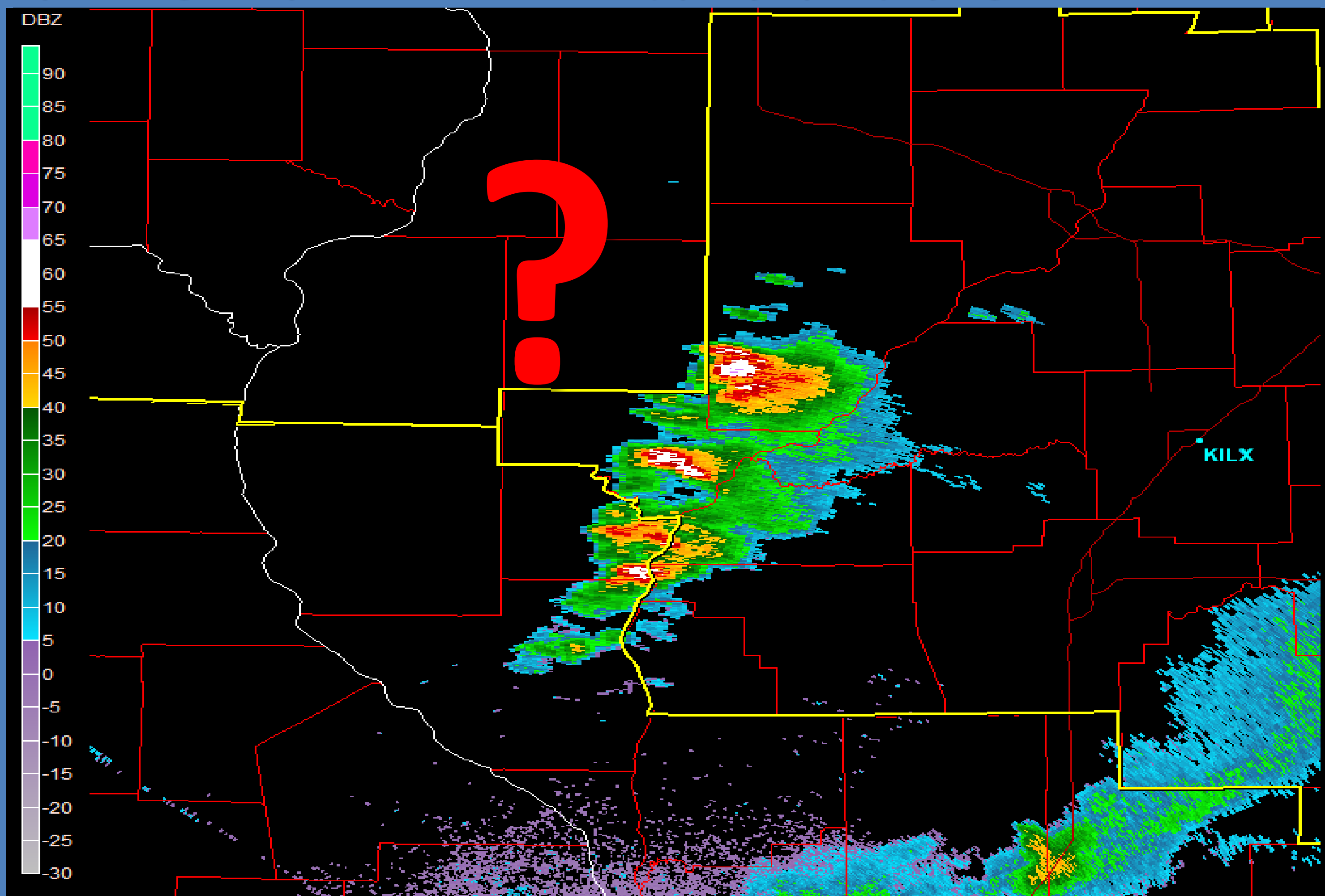
We still have a long way to go to accurately forecast something as complex as hail growth in the pre-storm environment

Hail Trajectory Complexities

Storm Scale Environmental Variations

* Hail density variations
* Hydrometeor redistribution due to varying winds with height
* Rapid change in Dynamic Pressure Force (updraft speed) lofting hail

Which storm will produce Quarters vs. Golf Balls vs. Tennis Balls vs. Grapefruits????



Unbalanced Supercell Research

=

≠

BRIEF LITERATURE REVIEW

Rasmussen and Blanchard (1998) published a baseline climatology of numerous sounding-derived supercell and tornado related parameters. This study became (and continues to be) the springboard for multiple other studies.

HOWEVER… A similar type of study reviewing the climatology of numerous thermodynamic/kinematic parameters across multiple binned hail sizes is missing.

HAIL FORECASTING IN 2011

1. *Goal at this point is limited to forecasting maximum expected hail size and/or frequency of maximum expected hail size falling over a larger meso-β scale domain*

   - ***NOTE: We all know "maximum" may be a little misleading as we simply don't know if a report is close to the actual max size or something closer to the 75th to 90th percentile of hail sizes falling***

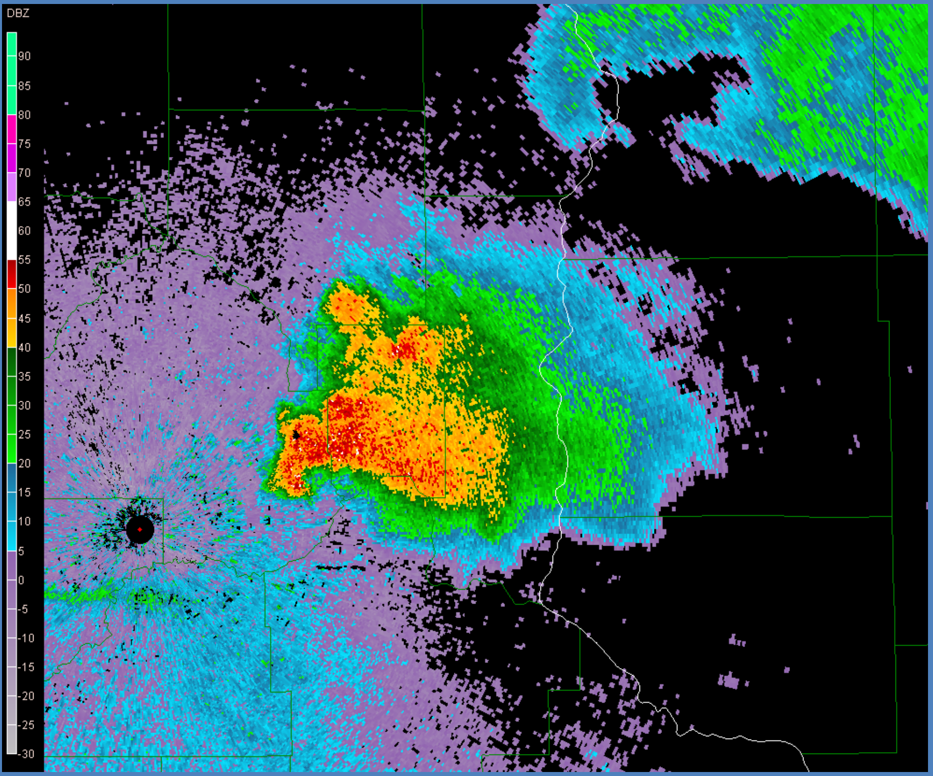
2. *Existing supercell based parameter climatology is biased toward tornado related studies. When this knowledge is applied operationally it often leads to instances where the pre-storm environment (and the storms themselves) looks identical. However, some of these "similar" environments easily produce significant to giant hail while others struggle to produce golf ball size hail*

3. *Something is different beyond just storm scale issues yet up to this point we have had limited skill at delineating these differences in the pre-storm environment*

   - *This frequently leads to forecaster apathy in attempting to forecast max hail size in forecast products such as the HWO with this apathy routinely leaking into SVR/TOR warning products*

HAIL FORECASTING IN 2011

.DAY ONE...TODAY AND TONIGHT
THERE IS A SLIGHT RISK OF SEVERE STORMS FOR CENTRAL AND EAST CENTRAL XXXXX AND WEST CENTRAL XXXX...MAINLY ALONG AND NORTH OF THE INTERSTATE XX CORRIDOR FROM THIS MORNING INTO THE EVENING. A WARM FRONT OVER SOUTHWEST XXX WILL LIFT NORTHEAST ACROSS THE OUTLOOK AREA THROUGH THE DAY...WITH THUNDERSTORMS EXPECTED TO DEVELOP OUT AHEAD OF IT. **THE STRONGER STORMS WILL BE CAPABLE OF PRODUCING LARGE HAIL** AND DAMAGING WIND GUSTS. IN ADDITION...A FEW TORNADOES WILL BE POSSIBLE BY THE AFTERNOON.



=

*** AT 1036 AM...RADAR INDICATED A SEVERE THUNDERSTORM...CAPABLE OF PRODUCING QUARTER SIZE HAIL**

Is this really the best we can provide????

Initial Motivation

1. *Provide more tools to forecast maximum expected hail size in the pre-storm environment…*

    - *A small database (~ 100 events) of observed DDC proximity soundings associated with multiple binned hail sizes…not just giant/significant hail events or all hail events ≥ 1" binned into one category*

    - *Climatology of various thermodynamic/kinematic parameters derived from these soundings to aid in forecaster identifying potential max hail size for a particular event*

2. *Indirectly…allow this to boost forecaster confidence in hail prediction and begin to push staff toward mentioning larger hail in Severe Thunderstorm or Tornado warnings **BEFORE** reports of larger hail influence warnings*

Questionable Reanalysis Data Set Substitution

1. *Became concerned at the increasing number of sounding based studies substituting observed soundings with Reanalysis data such as the NCEP/NCAR Reanalysis or the North American Regional Reanalysis (NARR)* ***WITHOUT*** *a comparative study*

NARR ≠ RUC

- *Thompson and Edwards (2000), Thompson et al. (2002) and Thompson et al. (2003) compared RUC-2 analysis soundings to observed proximity soundings and found errors small enough for RUC-2 soundings that it can be an adequate replacement*

ADDITIONAL GOAL

- *Reanalysis based studies have blindly followed this substitution with the assumption that the coarser reanalysis data would have similar values to the RUC*

Collect NARR soundings near reported events and check validity of substituting observed with NARR soundings by comparing thermodynamic/kinematic variables

2. *RUC now has a horizontal grid resolution of 13 km with 50 vertical levels with hourly data available for interrogation*

3. *NARR has a horizontal grid resolution of 32 km with 45 vertical levels with data limited to every 3 hours for interrogation*

Hail Report Criteria/Database Specifics

- *NCDC Storm Data and SeverePlot 2.0 (Hart 1993) utilized to parse reports from 1986-2006*

- *Hail events binned into 1 of 4 categories (101 total events):*

  1. *0.75 in. - 1.25 in. (24 events)* = ***Marginal Severe/Sub-Severe***
  2. *1.5 in. - 2.0 in. (25 events)* = ***Golf Ball Hail Range***
  3. *2.25 in. – 3.25 in. (29 events)* = ***Significant Large Hail***
  4. *≥ 3.5 in. (23 events)* = ***Giant Hail***

  Note: Following correction of reported "softball" hail from 4.5 in. to 3.65 in. as noted in Jewell and Brimelow, 2009

- *Hail event inclusion criteria:*

  1. *Only reports centered around 00 UTC sounding were included*
     (too many unknowns with elevated events at 12 UTC)
  2. *Must fall within 175 km (~ 95 n mi) of KDDC*
  3. *+/- 3 hrs of 23 UTC (~ release time for most soundings)*
  4. *Similar air mass as KDDC*
  5. *Only largest hail report included*
  6. *Event discarded if larger hail fell between 175-250 km of KDDC*

Hail Report Criteria/Database Specifics

- *Observed sounding obtained from the NCDC Integrated Global Radionsonde Archive*

- *In a few events, the lower 50 hPa of observed soundings were modified slightly to match more representative conditions from nearby surface observation sites. Data was then analyzed with Environmental Research Services Rawinsonde OBservation Program (RAOB)*

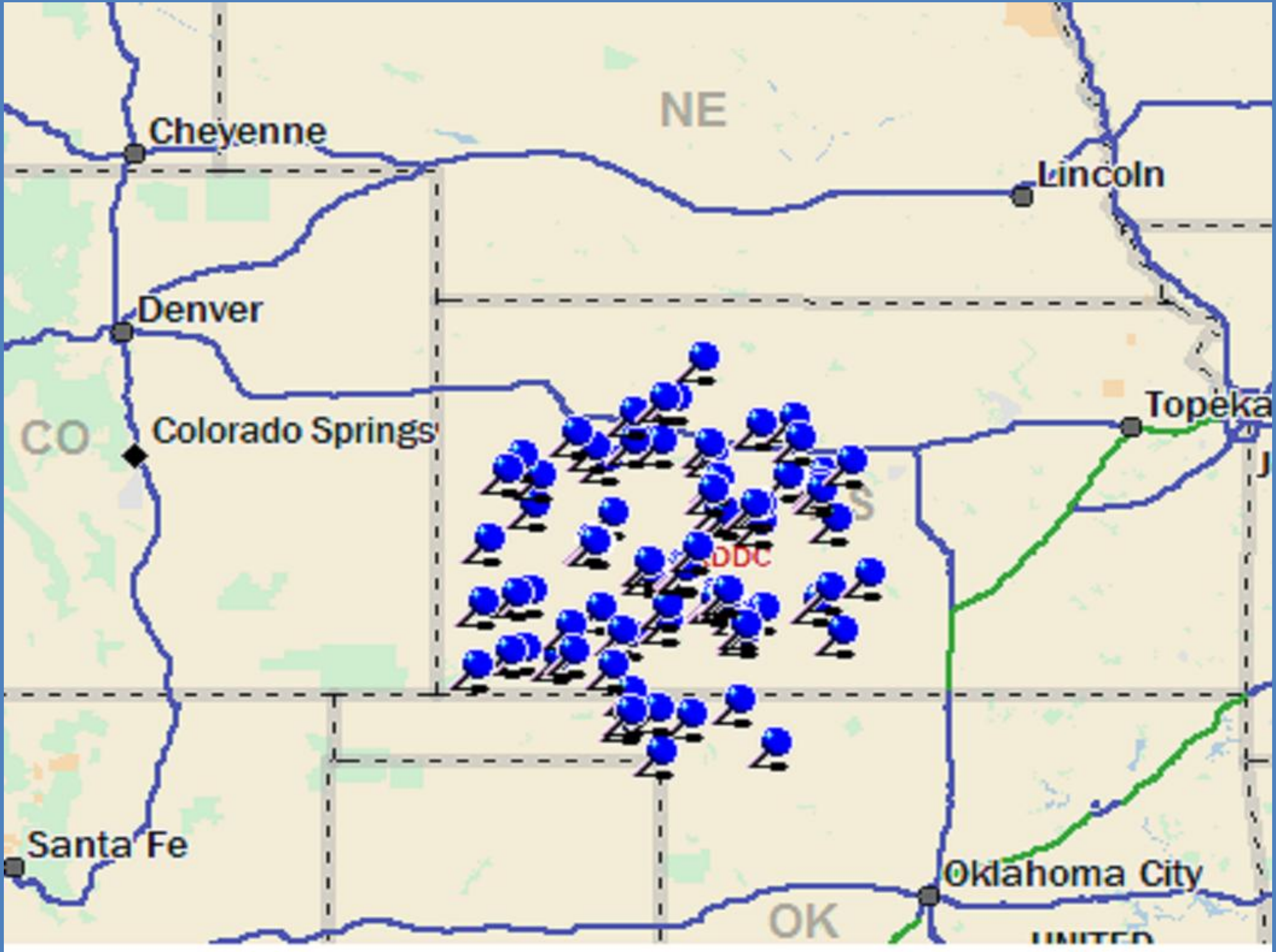
- *NARR sounding criteria:*

  1. *NARR soundings obtained from the NCDC National Operational Model Archive & Distribution System (NOMADS). Data was then analyzed with Unidata's Integrated Data Viewer (IDV) and RAOB*

  2. *21 UTC NARR data was utilized if a report fell between 20-22 UTC and 00 UTC NARR data for reports between 22 UTC and 02 UTC*

  3. *In contrast to Thompson et al. (2003), NARR soundings were obtained from grid points closest to the report rather than at the observation site*

Plot of Events



Parameters Studied

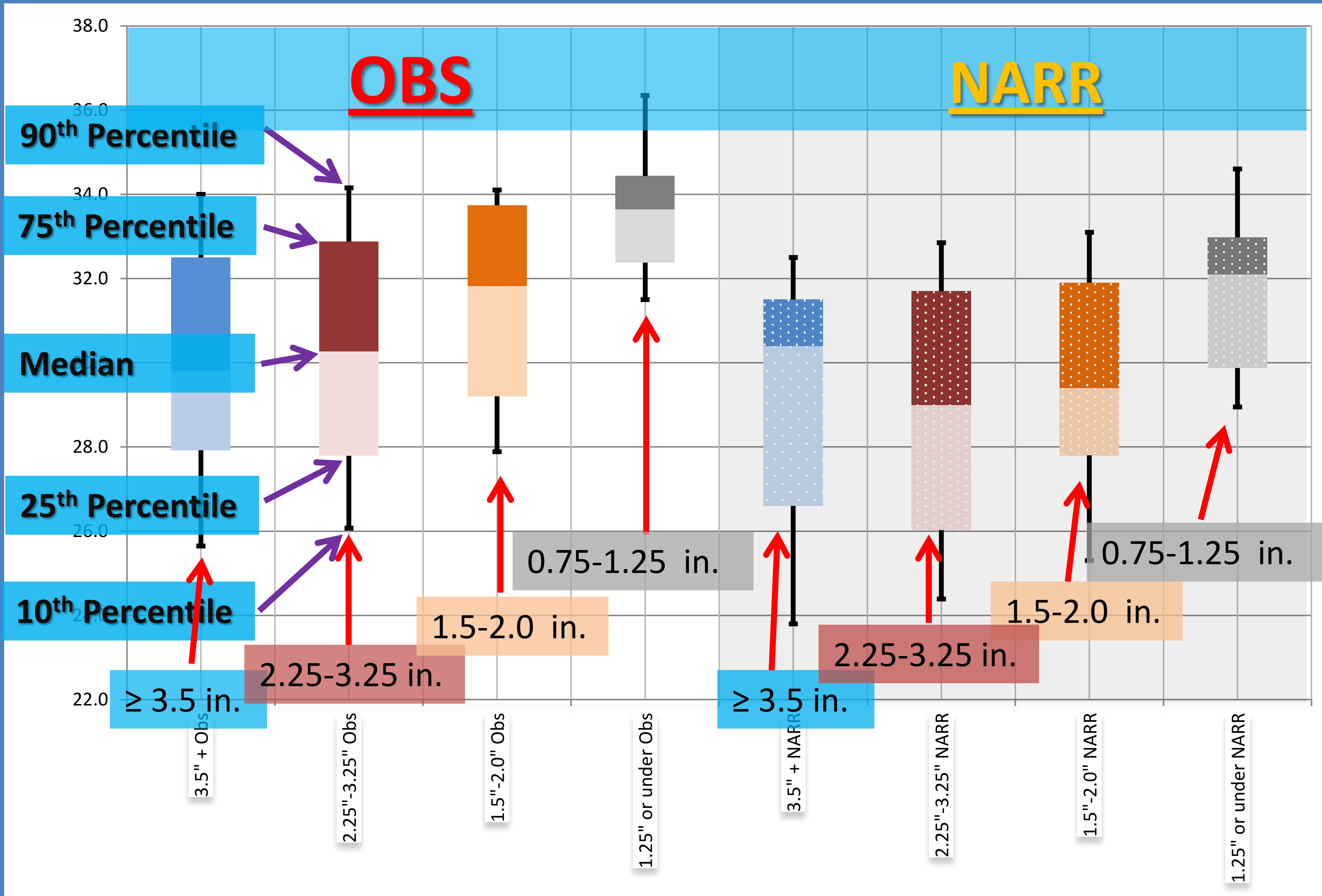
Thermodynamic (19 parameters)

- ✓ Sfc T
- ✓ Sfc Td
- ✓ Sfc Tdd
- ✓ SB/MU/ML parcel CAPE
- ✓ SB/MU/ML parcel -10 to -30 ˚C CAPE
- ✓ SB/MU/ML parcel Lifted Index
- ✓ SB/MU/ML parcel LCL height
- ✓ 700-500 hPa and 500-300 hPa lapse rates
- ✓ Freezing Level and Wet Bulb Zero height (agl)

Kinematic (11 parameters)

- ✓ 0-10 km bulk shear
- ✓ 0-6 km bulk shear
- ✓ 0-1 km bulk shear
- ✓ 0-EL bulk shear
- ✓ 6-10 km bulk shear
- ✓ 6-EL bulk shear
- ✓ 0-3 km SRH
- ✓ EL Storm Relative Flow
- ✓ 10 km Storm Relative Flow
- ✓ 6 km Storm Relative Flow
- ✓ 4-6 km Storm Relative Flow

Box and Whisker Plot Details



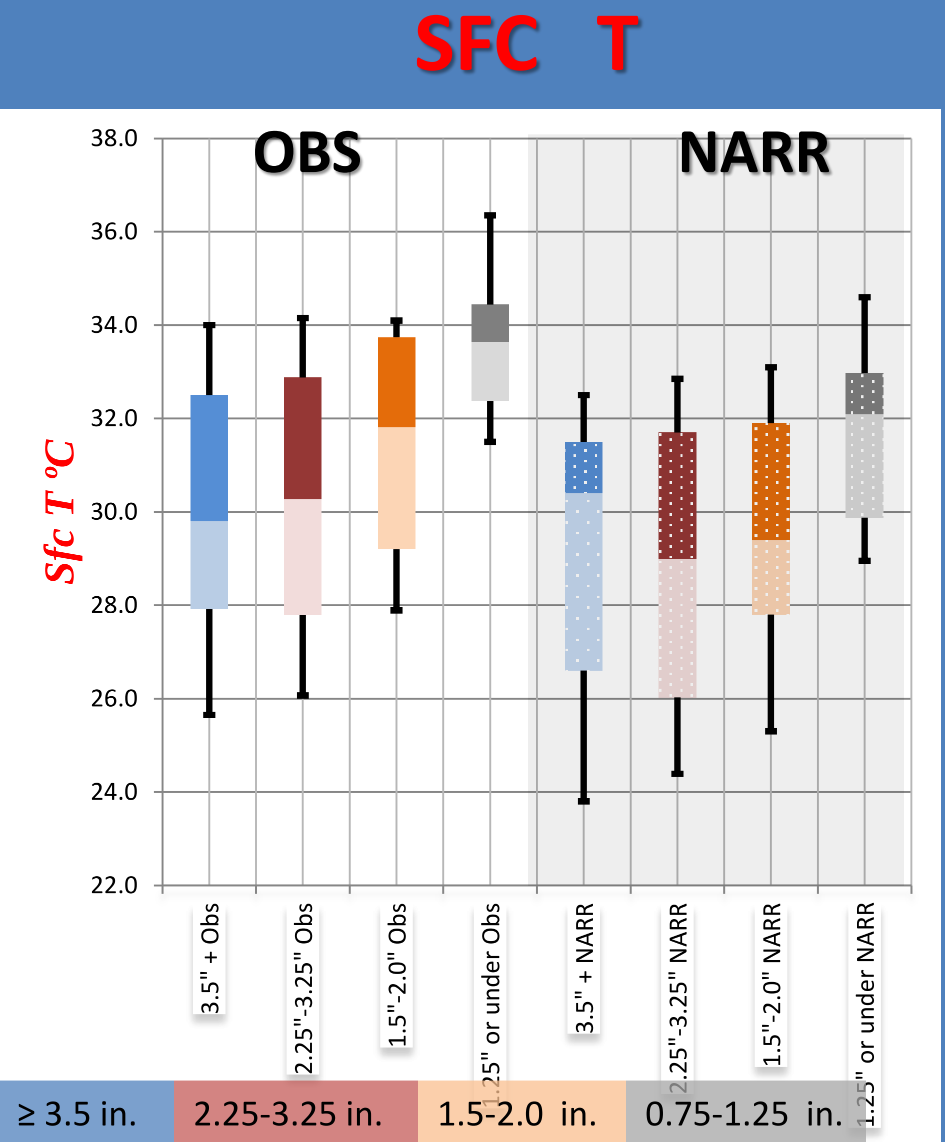
Thermodynamic Variables

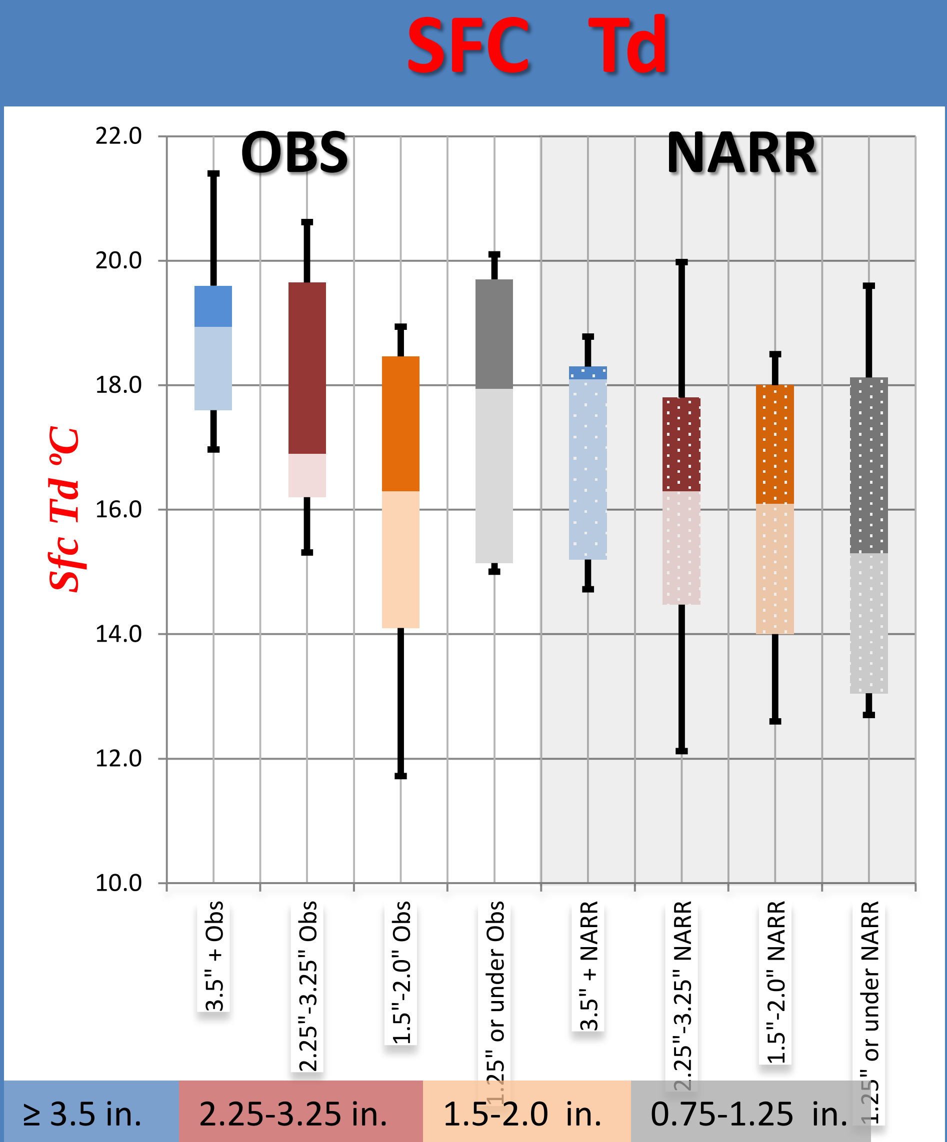
LCL (SFC parcel)	-39.2 m	237.7 m

Thermodynamics from NARR = strong cold bias

WBZ Height (m agl)	54.6 m	170.6 m
SB CAPE	-1251 J/kg	1336 J/kg
ML CAPE	-1029 J/kg	1089 J/kg
MU CAPE	- 1241 J/kg	1329 J/kg
MU -10˚C to -30˚C CAPE	- 504 J/kg	530 J/kg
MU LI	+4.2	4.4
700-500 hPa Lapse Rates	-0.3	0.6
500-300 hPa Lapse Rates	-0.1	0.3

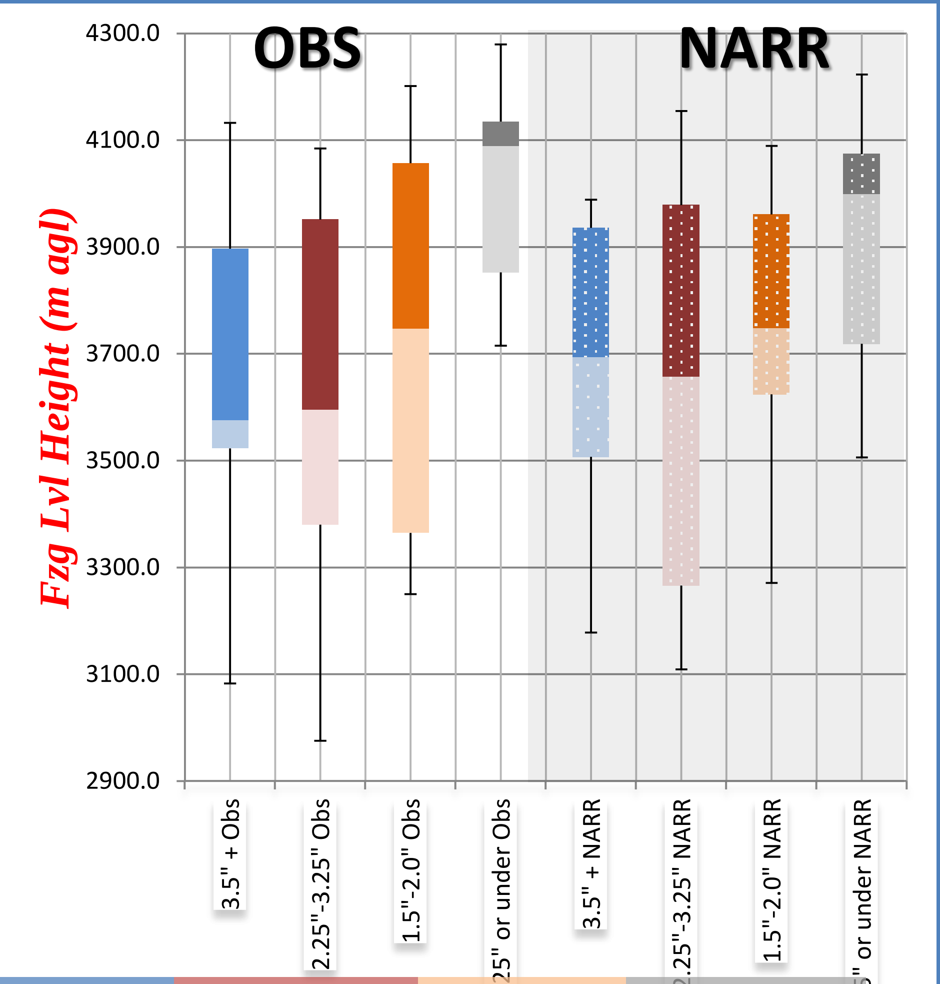
Thermodynamic Variables



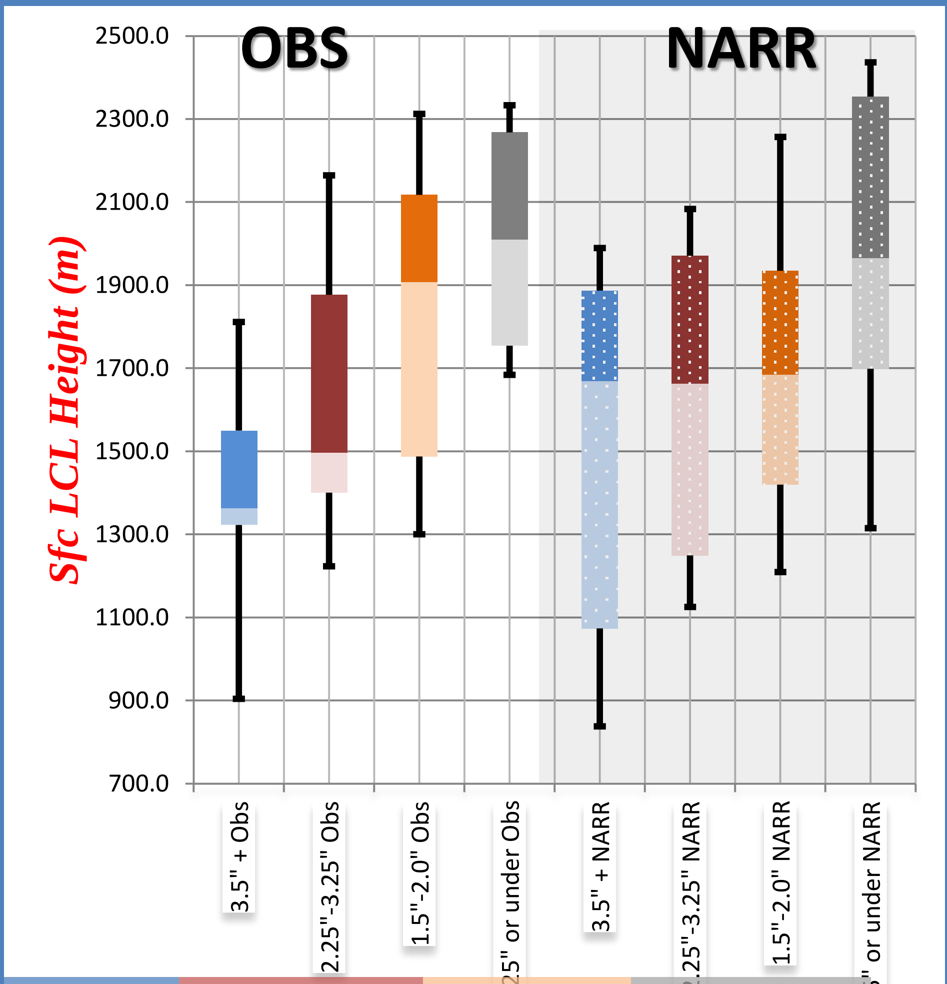


Thermodynamic Variables

Fzg Lvl Height (m agl)



SFC LCL (m)



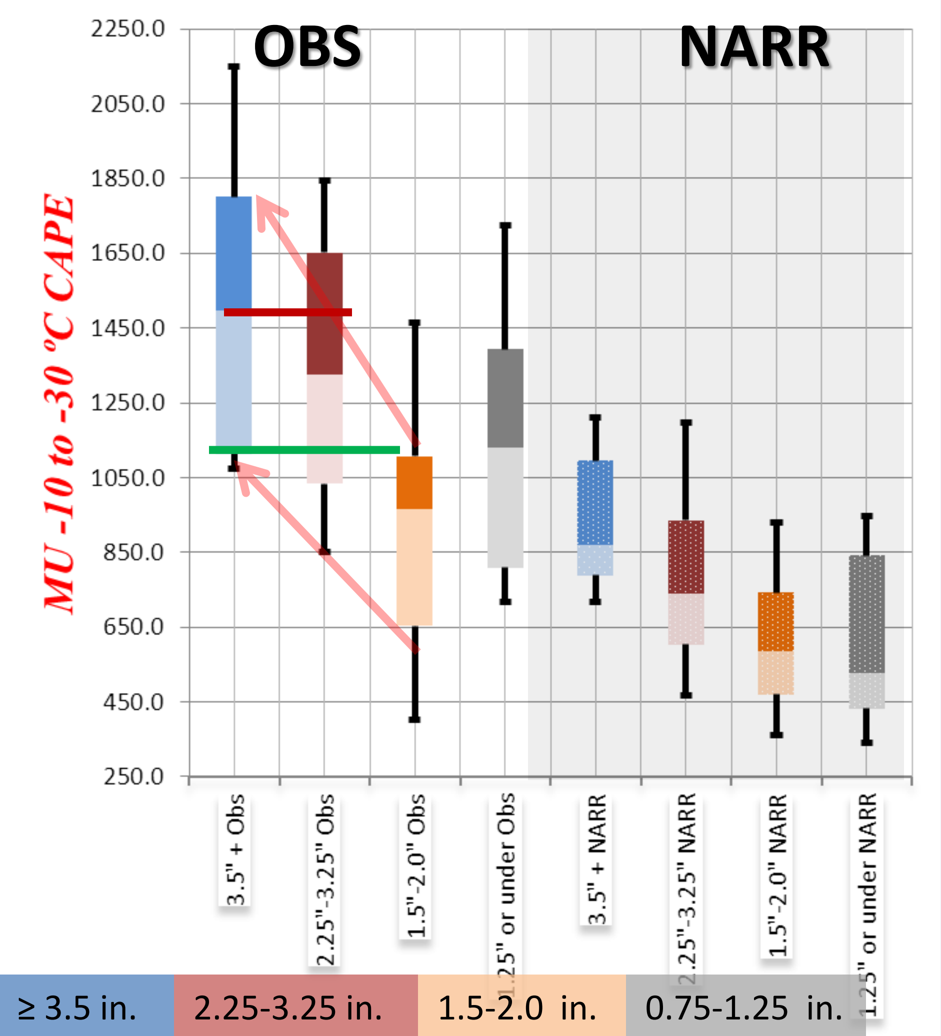
≥ 3.5 in. | 2.25-3.25 in. | 1.5-2.0 in. | 0.75-1.25 in.

≥ 3.5 in. | 2.25-3.25 in. | 1.5-2.0 in. | 0.75-1.25 in.

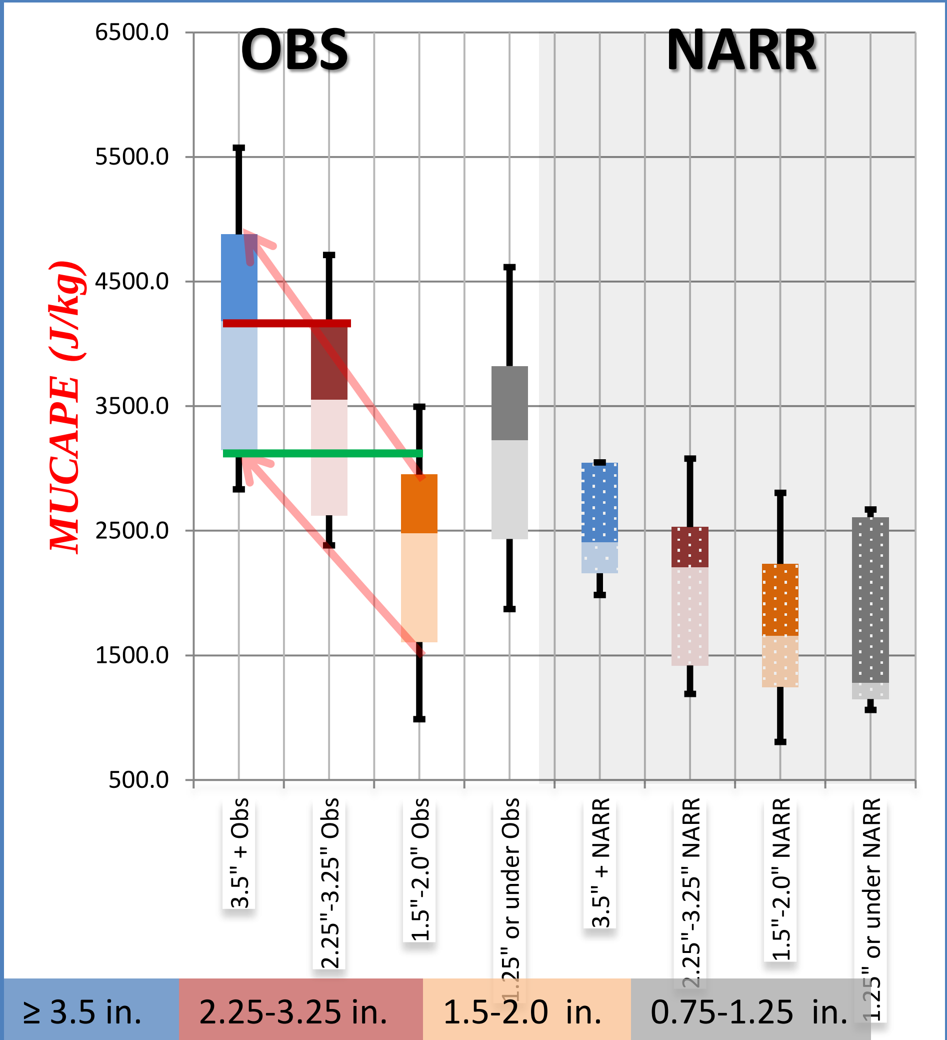
Hail Growth Zone Stability

Correlation between -10˚C to -30˚C CAPE and total MU CAPE = 0.82

MU -10˚C to -30˚C CAPE

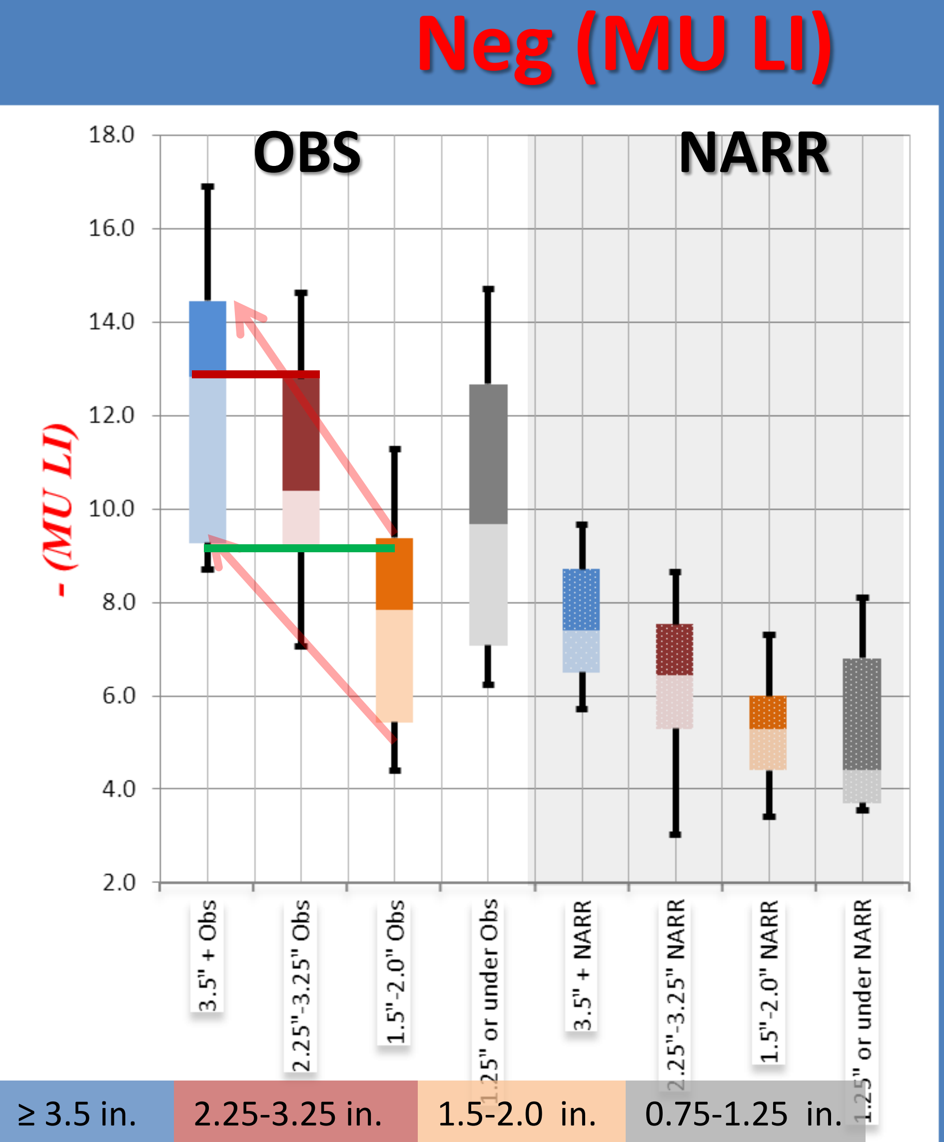


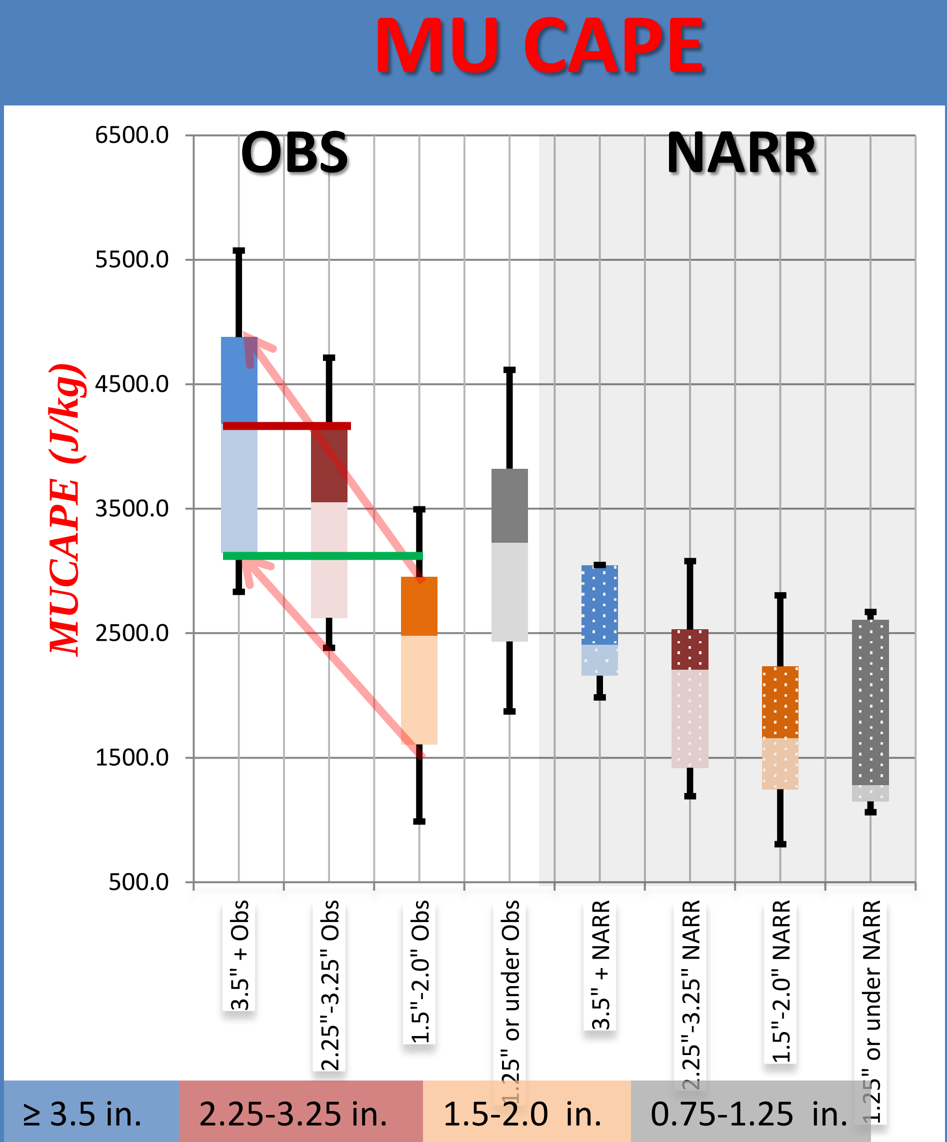
MU CAPE



Hail Growth Zone Stability

Correlation between MU LI and total MU CAPE = 0.69

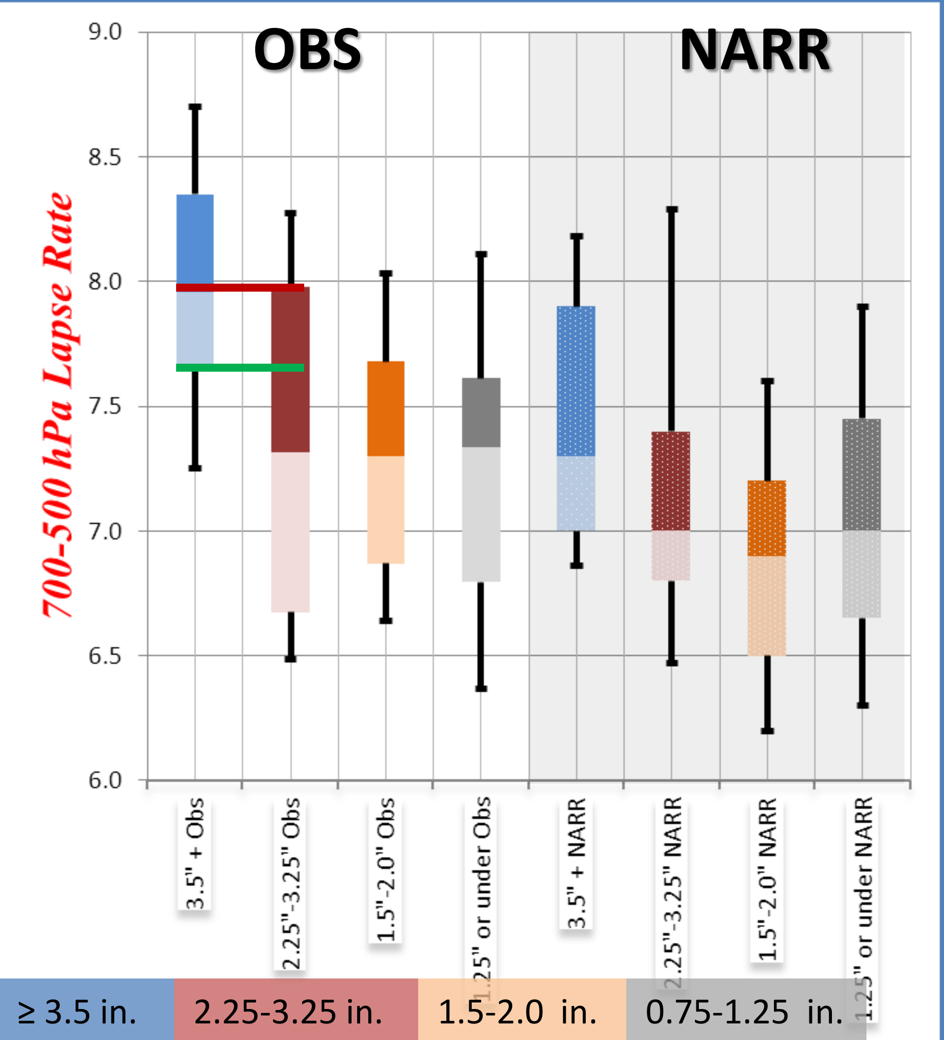




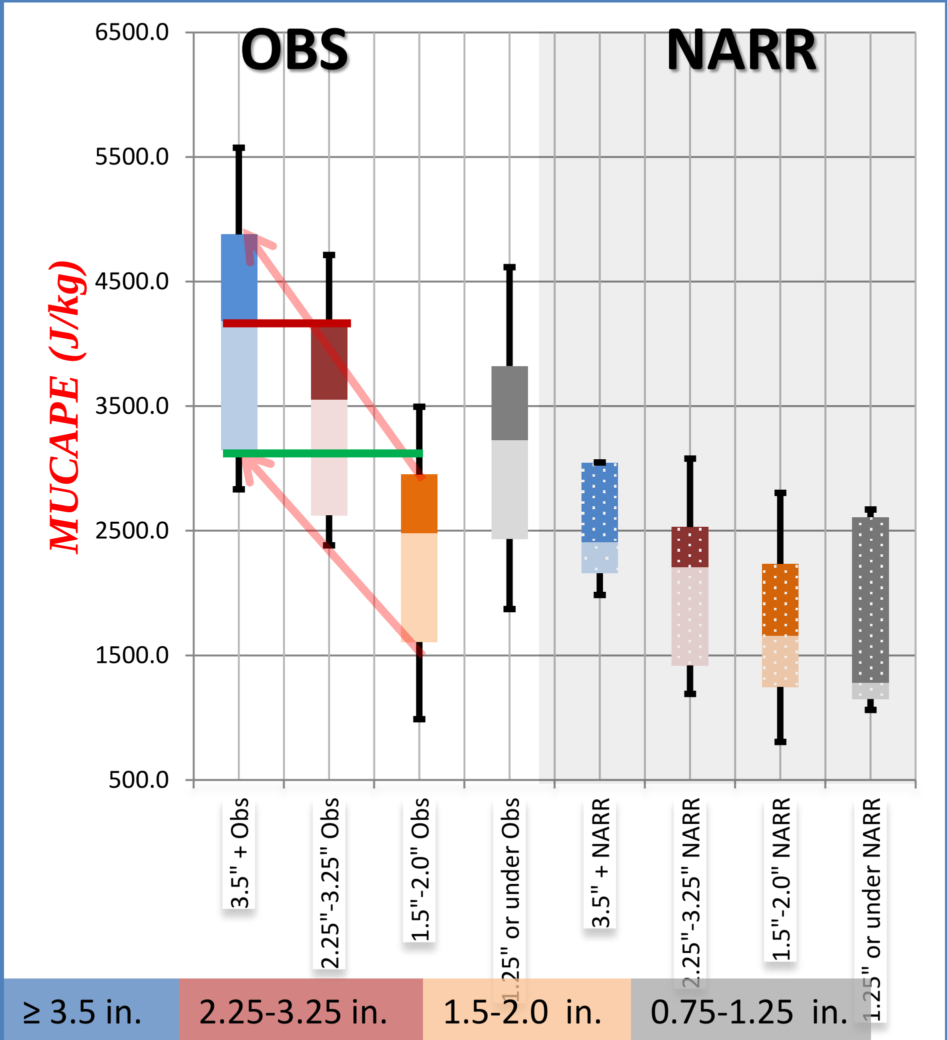
Hail Growth Zone Stability

Correlation between 700-500 hPa Lapse Rate and total MU CAPE = 0.09

700-500 hPa Lapse Rates



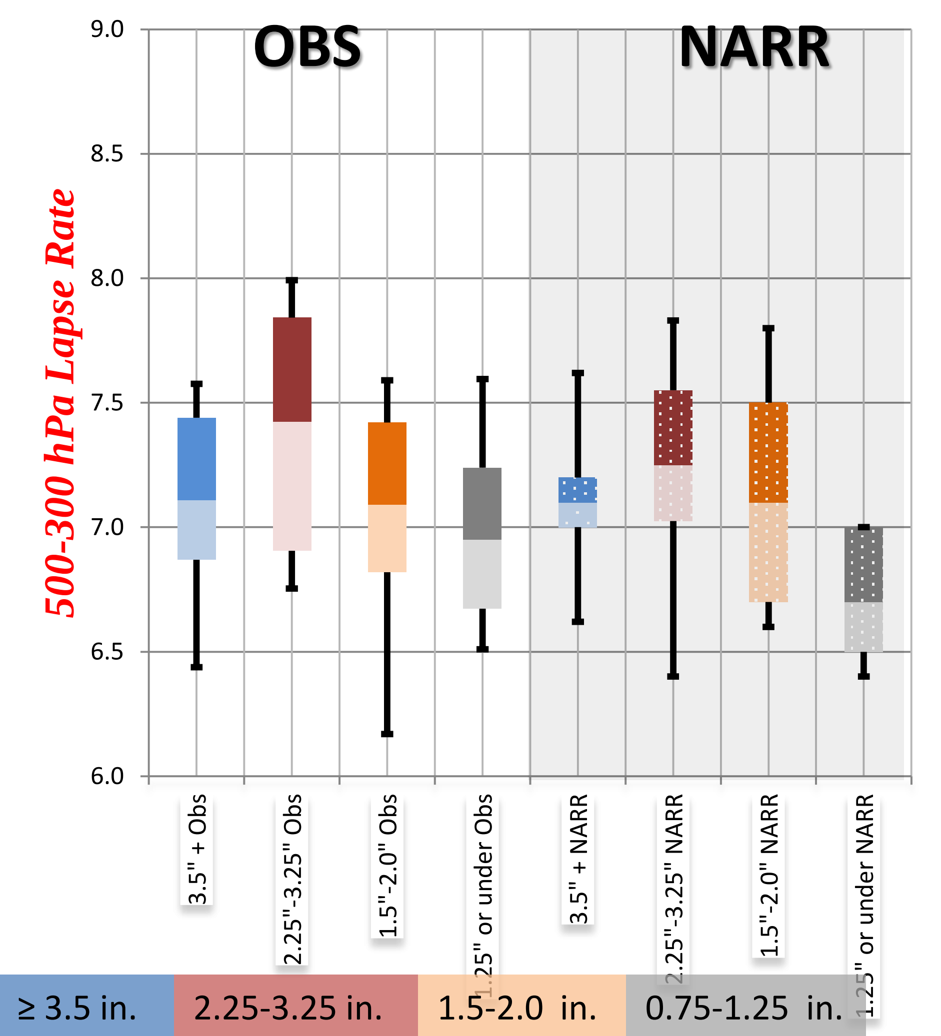
MU CAPE



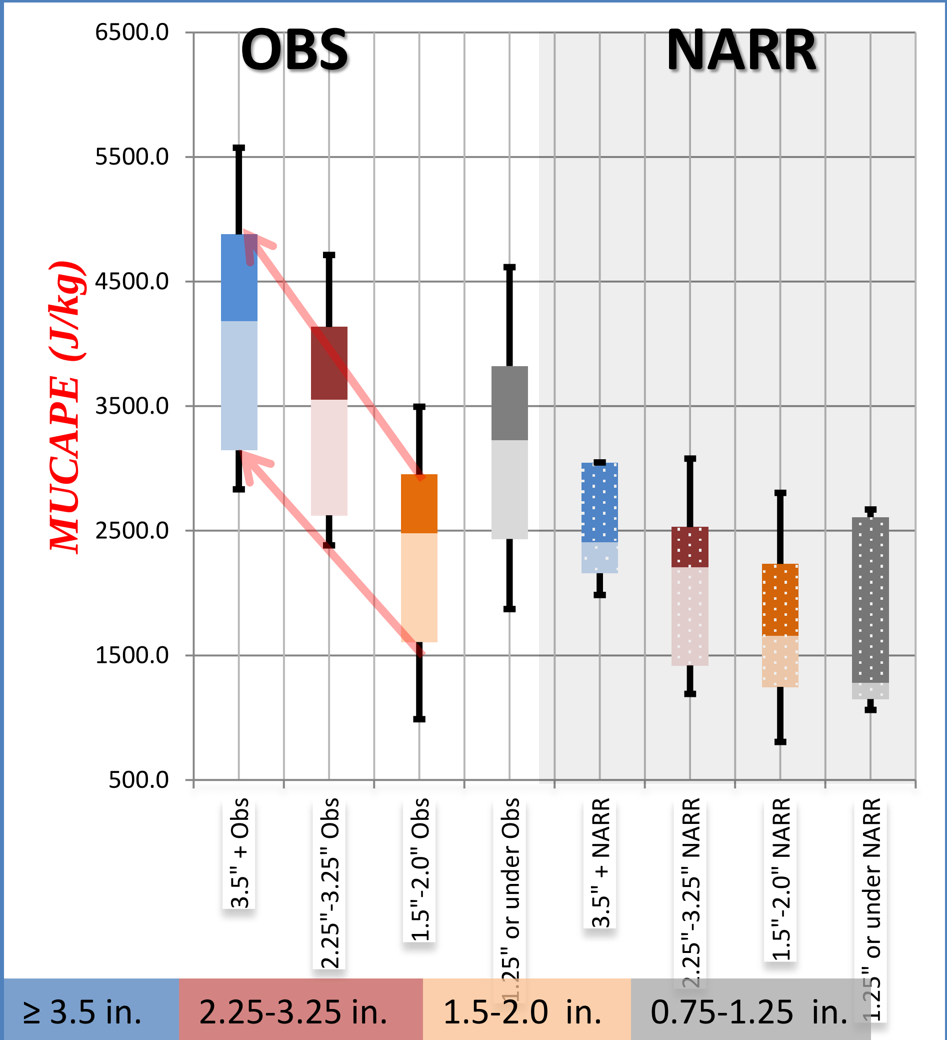
Hail Growth Zone Stability

Correlation between 500-300 hPa Lapse Rate and total MU CAPE = 0.11

500-300 hPa Lapse Rates



MU CAPE



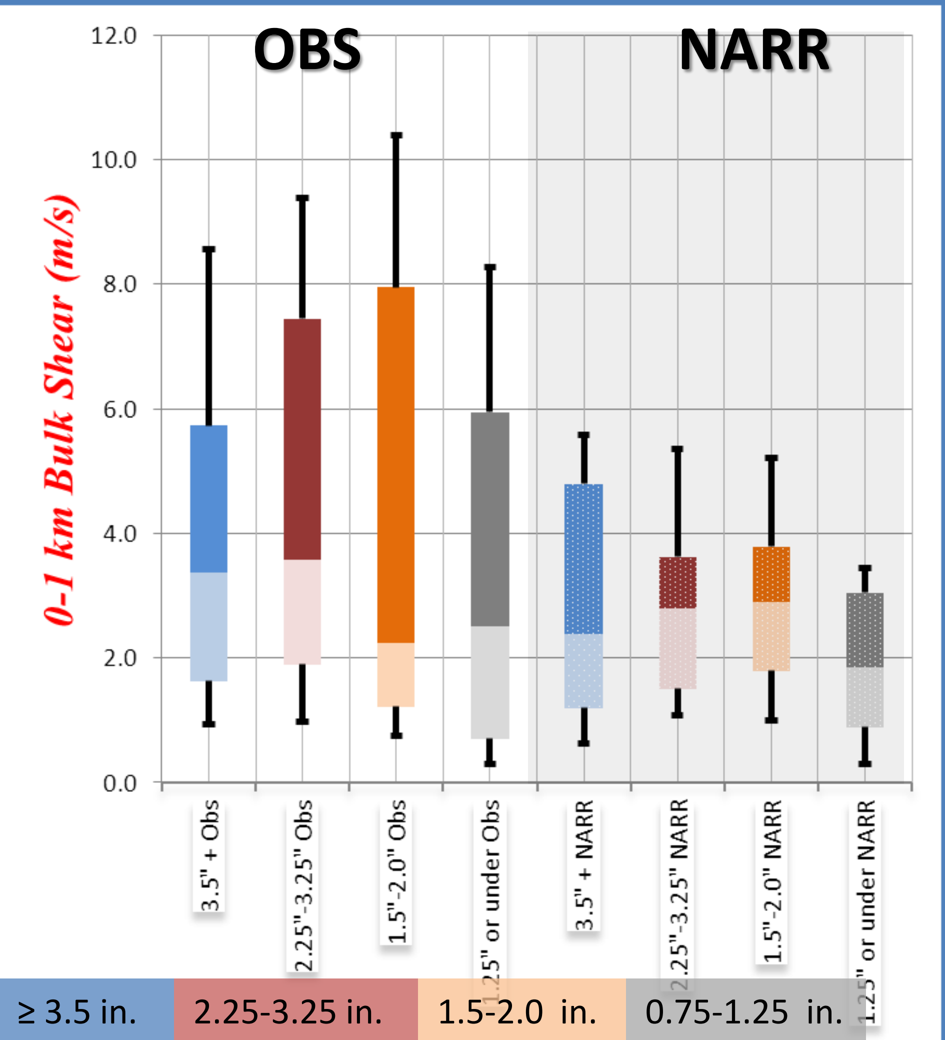
Kinematic Variables

NARR Kinematic Bias/MAE

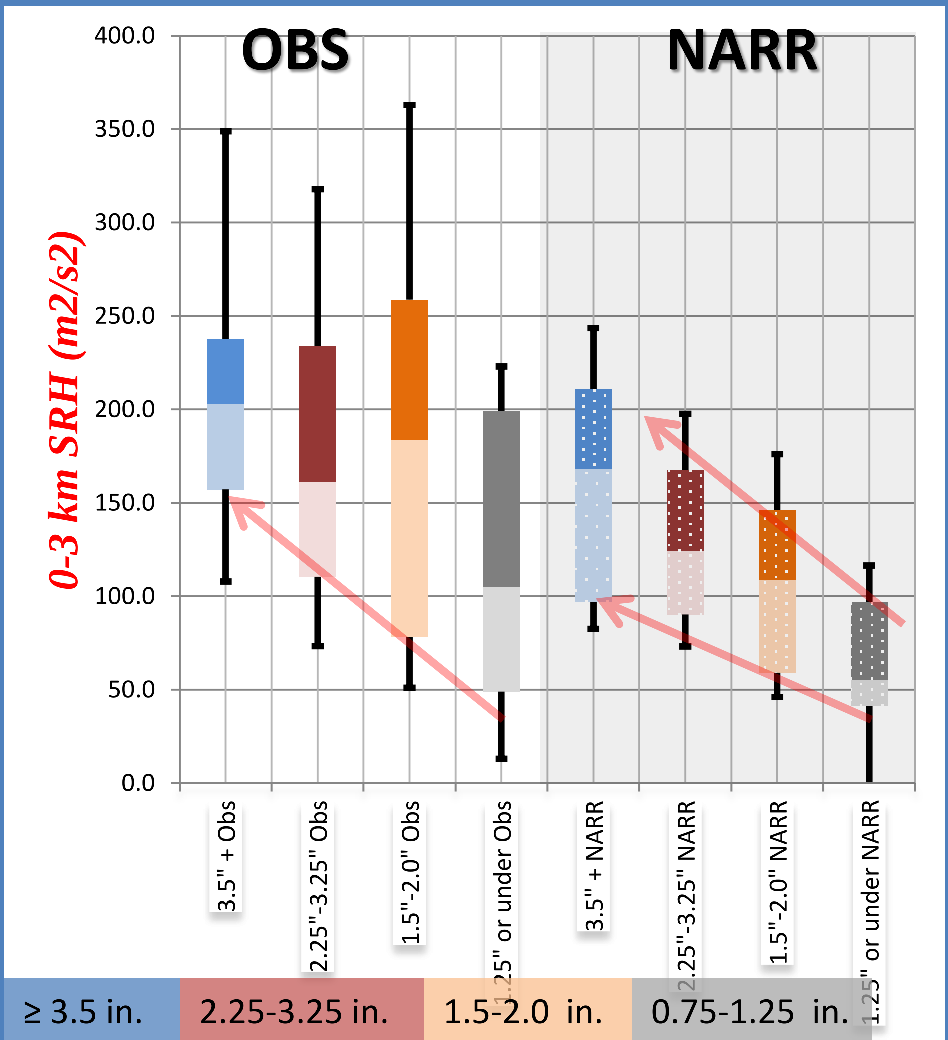
Parameter	BIAS	MAE
0-1 km bulk shear	-1.4 m/s	2.1 m/s
0-3 km SRH	-58 m2/s2	81 m2/s2
0-6 km bulk shear	-1.0 m/s	2.8 m/s
0-10 km bulk shear	-0.2 m/s	3.8 m/s
0-EL bulk shear	0.18 m/s	2.6 m/s
6-10 km bulk shear	0.02 m/s	3.6 m/s
6 km-EL bulk shear	0.01 m/s	3.2 m/s
4-6 km SR Flow	-0.3 m/s	1.6 m/s
6 km SR Flow	-0.6 m/s	2.3 m/s
10 km SR Flow	- 0.01 m/s	3.6 m/s
EL SR Flow	-0.02 m/s	3.4 m/s

Kinematic Variables

0-1 km bulk shear



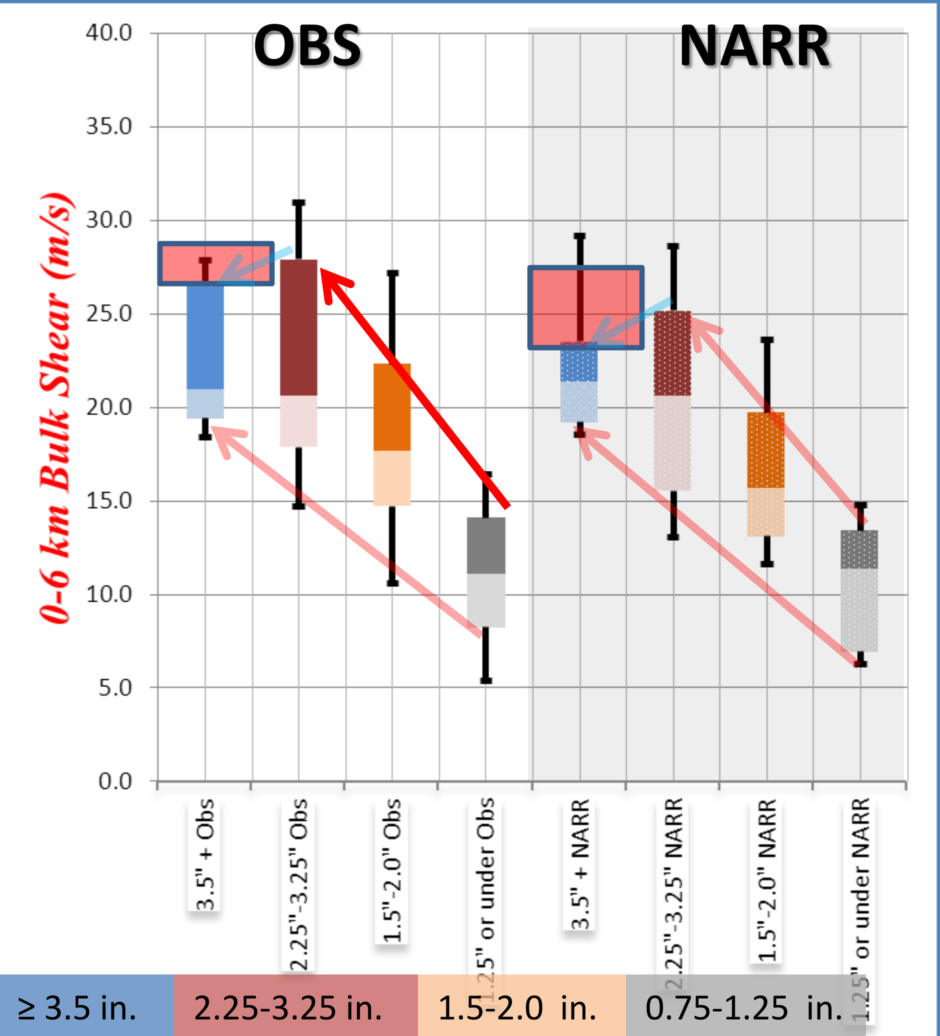
0-3 km SRH



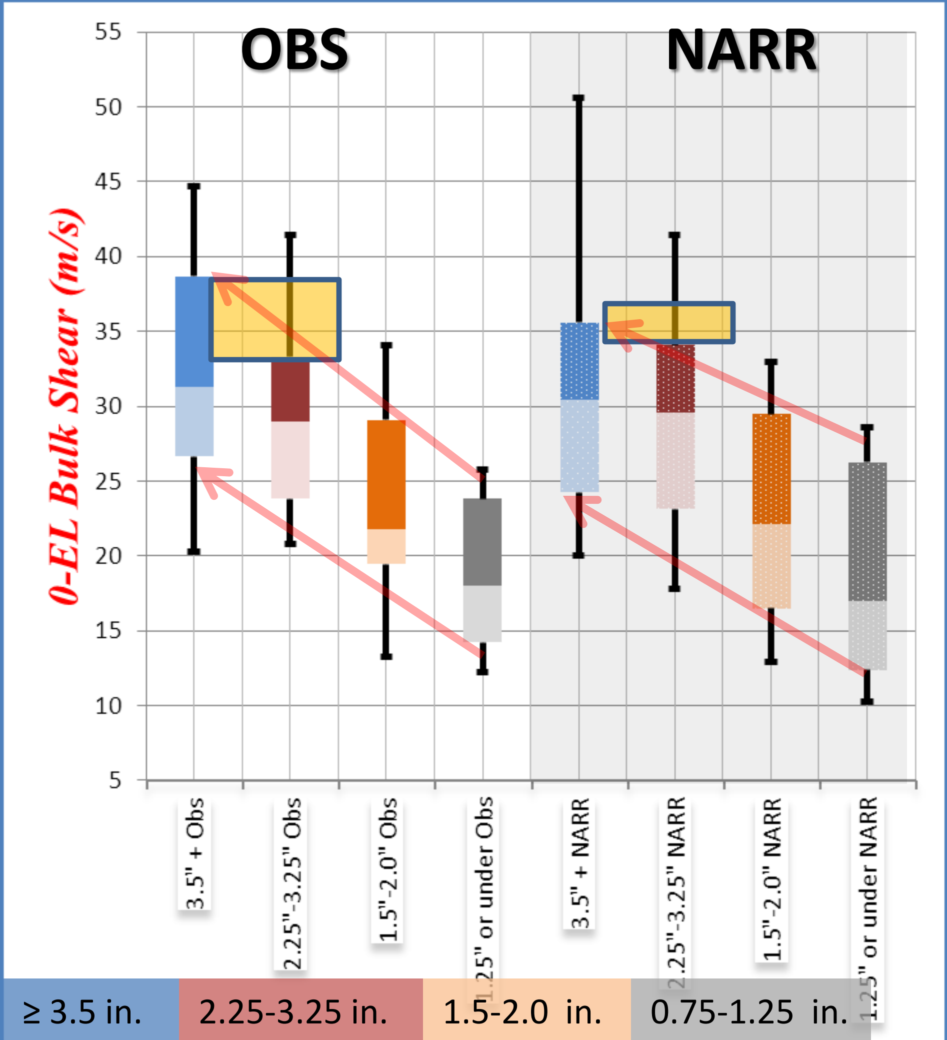
Kinematic Variables

Correlation between 0-6 km/0-EL Bulk Shear= 0.69

0-6 km bulk shear

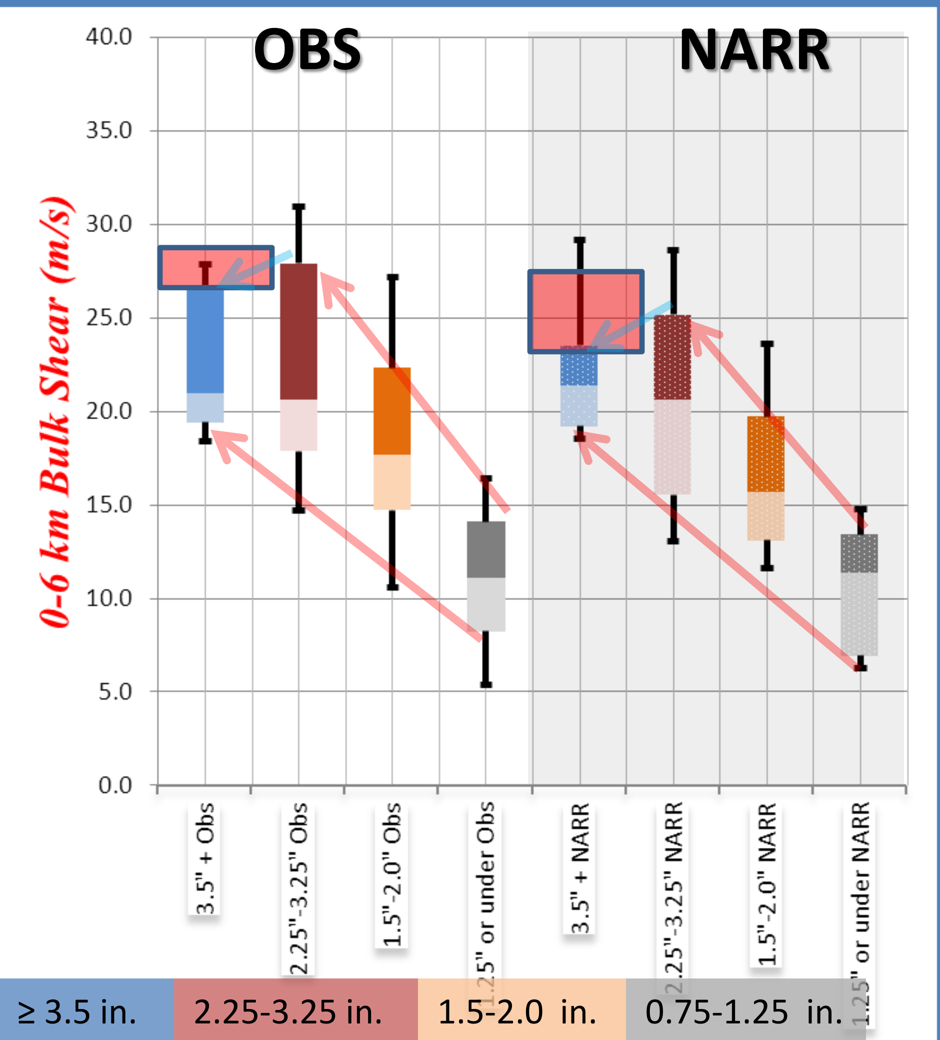


0-EL bulk shear

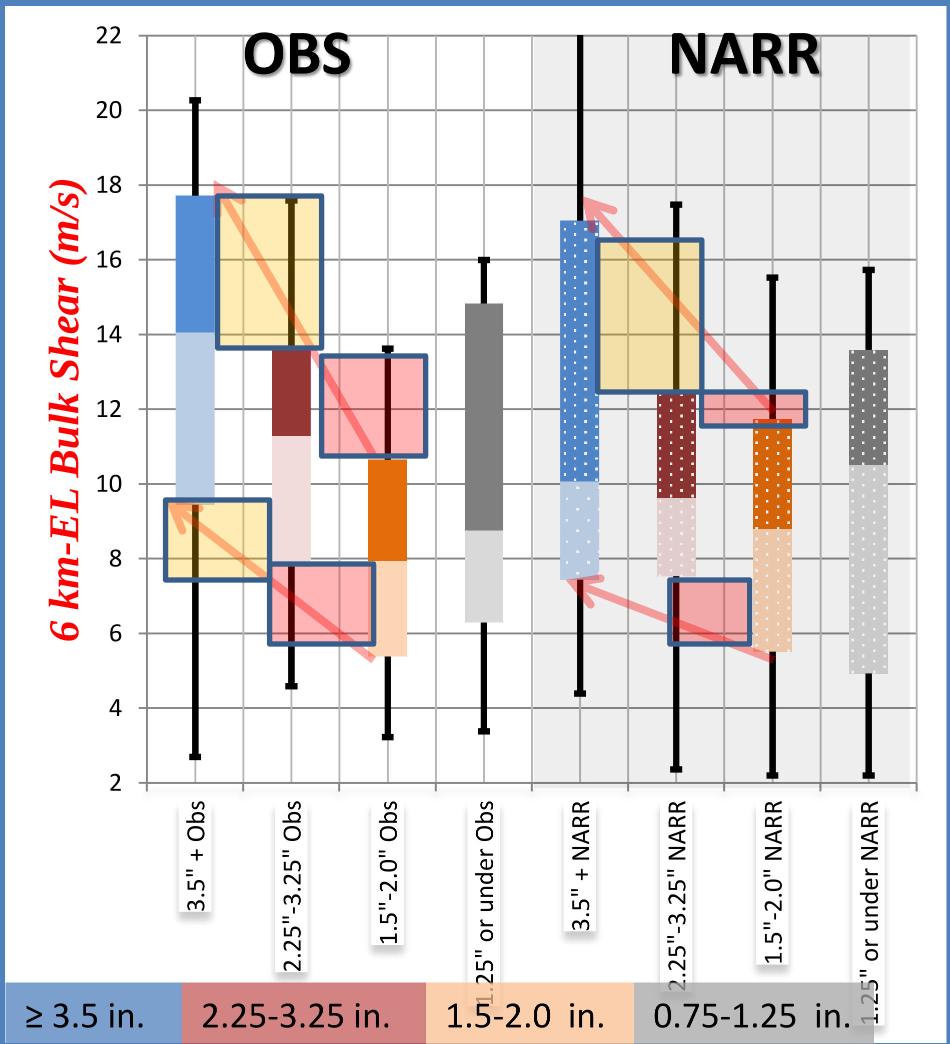


Kinematic Variables

0-6 km bulk shear

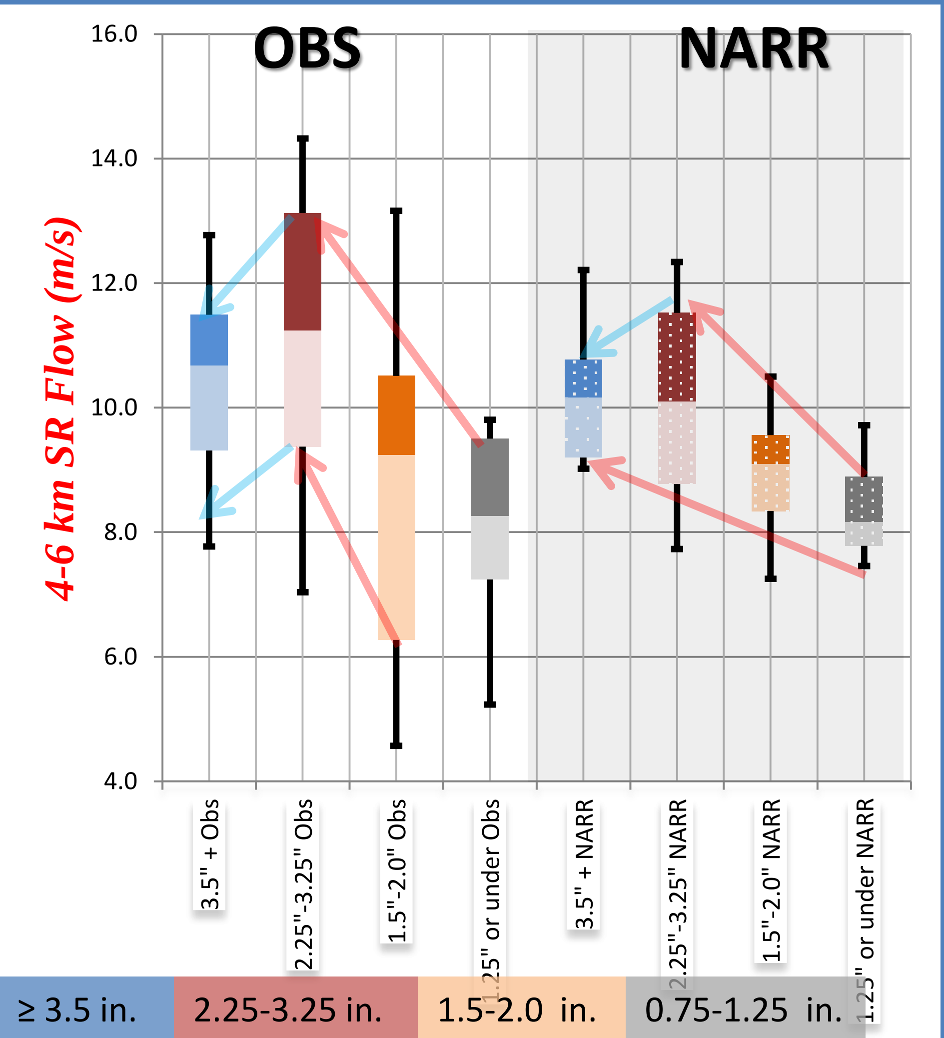


6 km-EL bulk shear

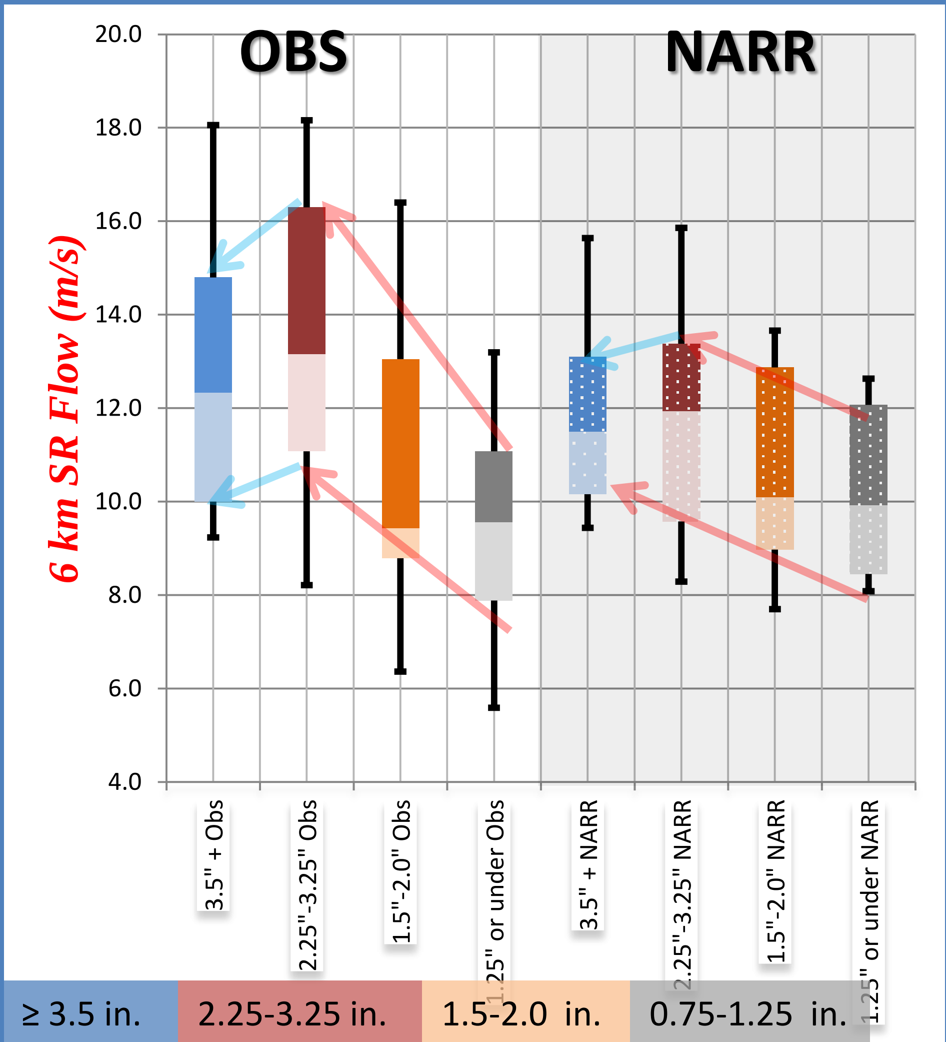


Kinematic Variables

4-6 km SR Flow



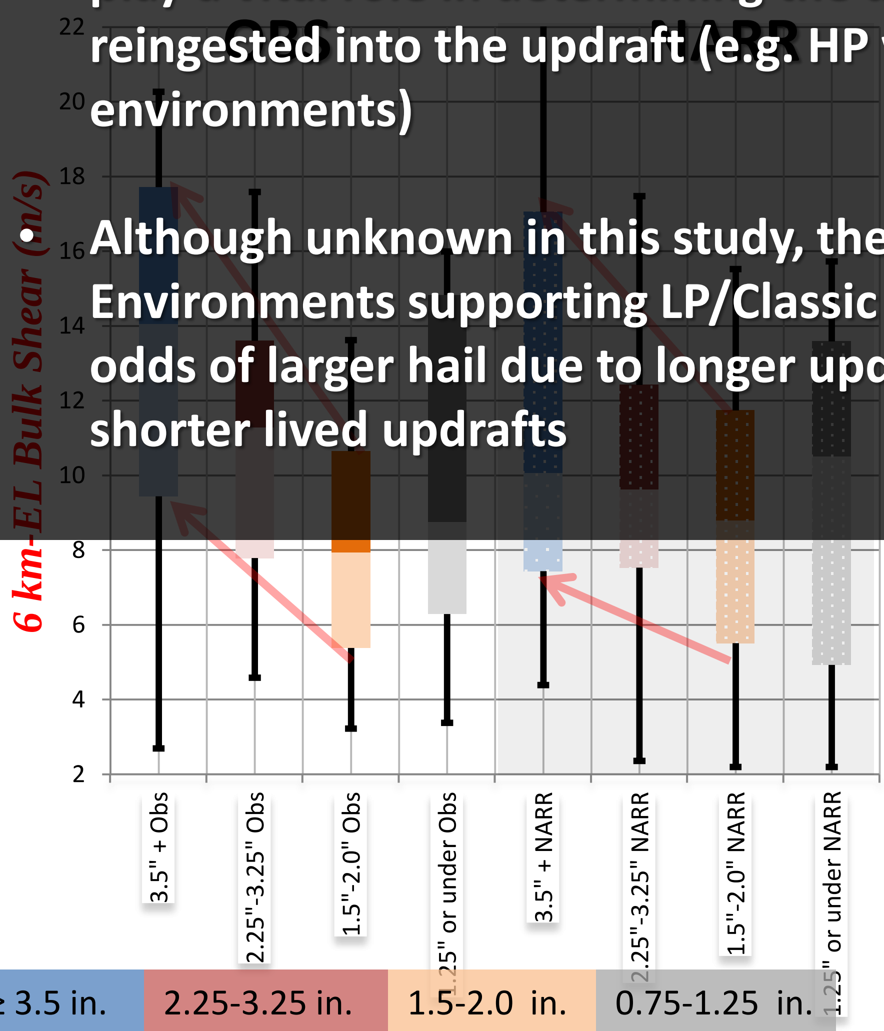
6 km SR Flow

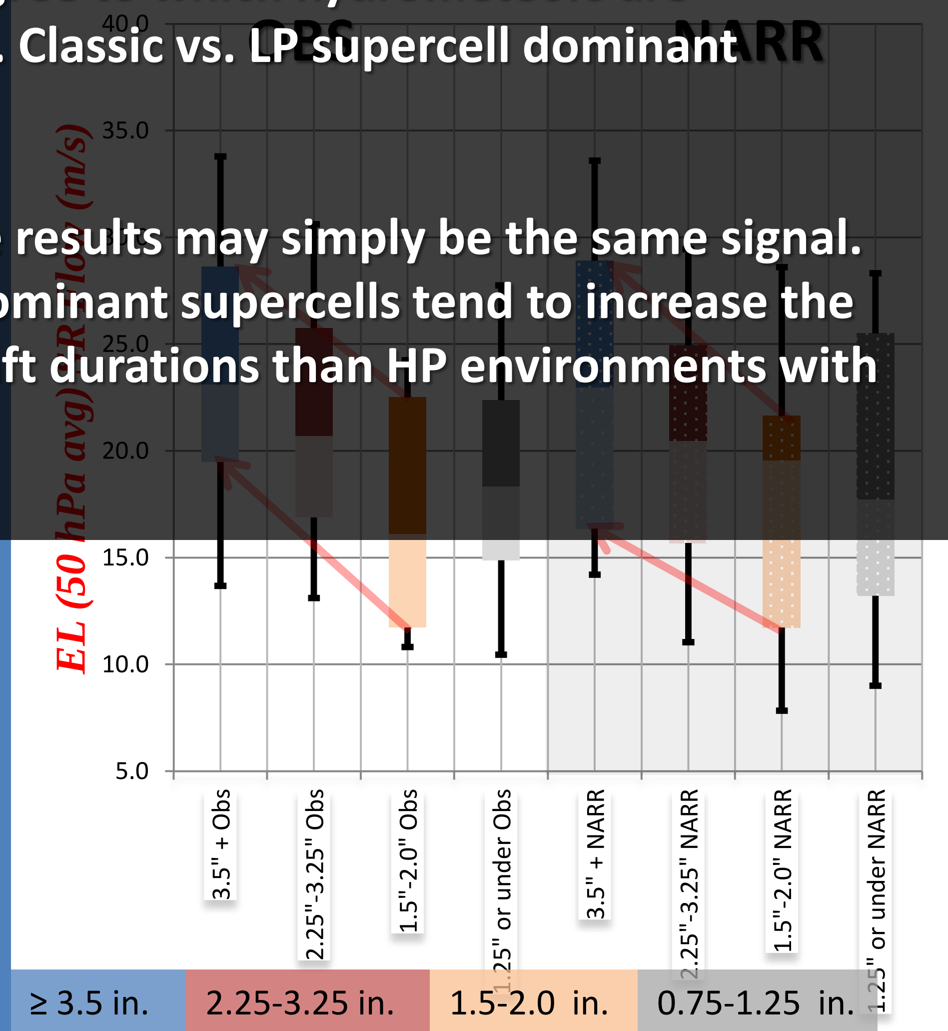


Upper Tropospheric Flow/Shear

Correlation between MU CAPE and 6 km-EL bulk shear= 0.09

- Rasmussen and Straka (1997) found both 9 km SR flow and 4-10 km Bulk shear play a vital role in determining the degree to which hydrometeors are reingested into the updraft (e.g. HP vs. Classic vs. LP supercell dominant environments)
- Although unknown in this study, these results may simply be the same signal. Environments supporting LP/Classic dominant supercells tend to increase the odds of larger hail due to longer updraft durations than HP environments with shorter lived updrafts





Parameter Combinations

- ML/MU CAPE and deep layer bulk shear are the usual combinations

  1. Energy Shear Index (ESI): Brimelow et al. (2002) uses the product of MU CAPE and 850 hPa – 6 km bulk shear

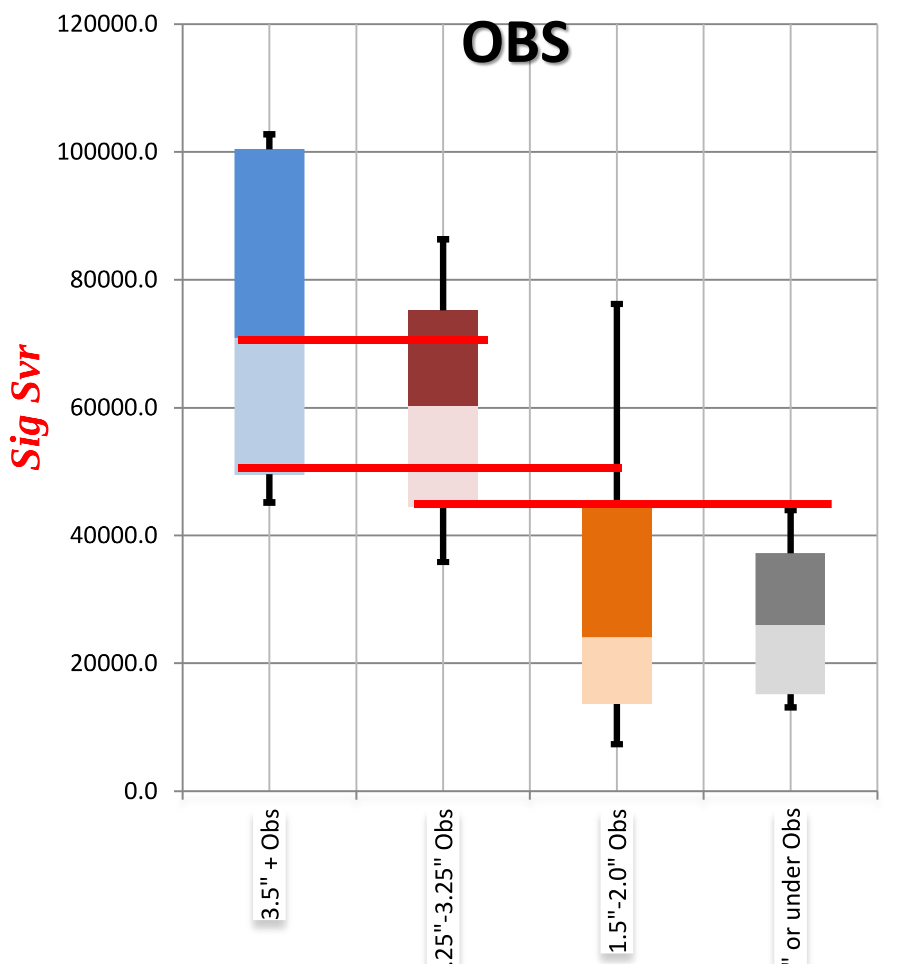
  2. Significant Severe parameter (SigSvr): Craven (2004) defines the SigSvr parameter as the product of a ML CAPE/0-6 km bulk shear combination

- What about a combination that includes 6 km-EL bulk shear and 700-500 hPa lapse rates?

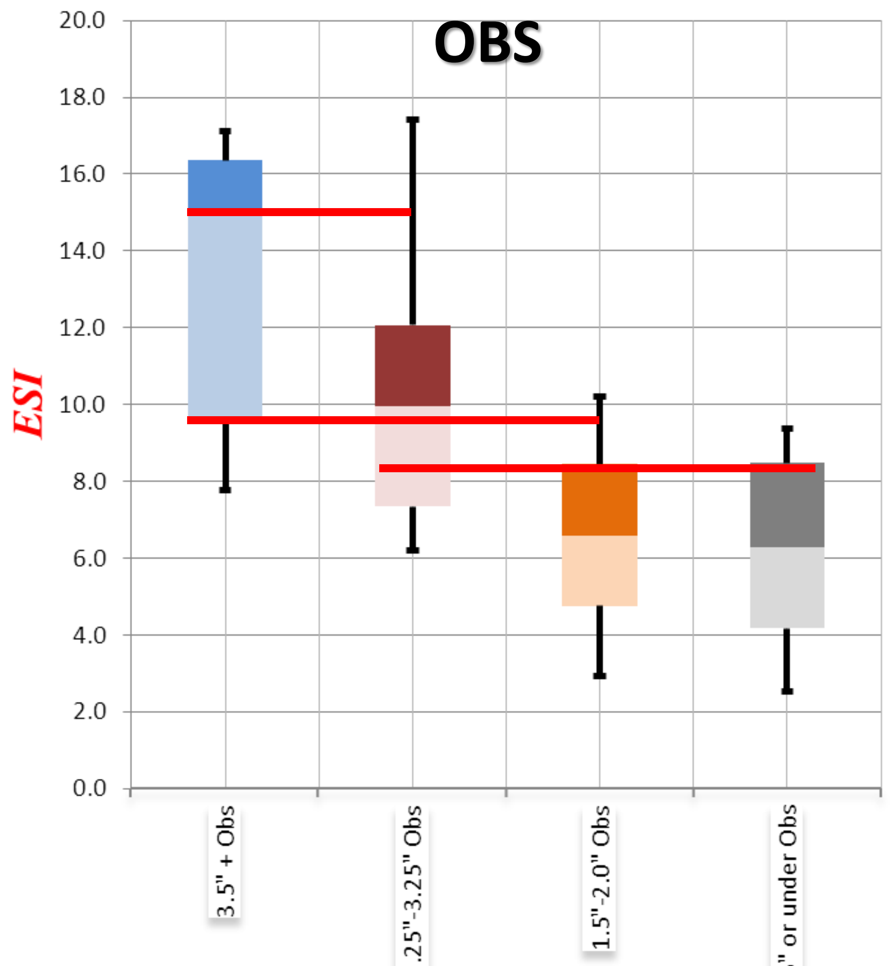
- NOTE: ONLY Observed studied do to questionable NARR thermodynamic variables

Parameter Combinations

Sig Svr



ESI

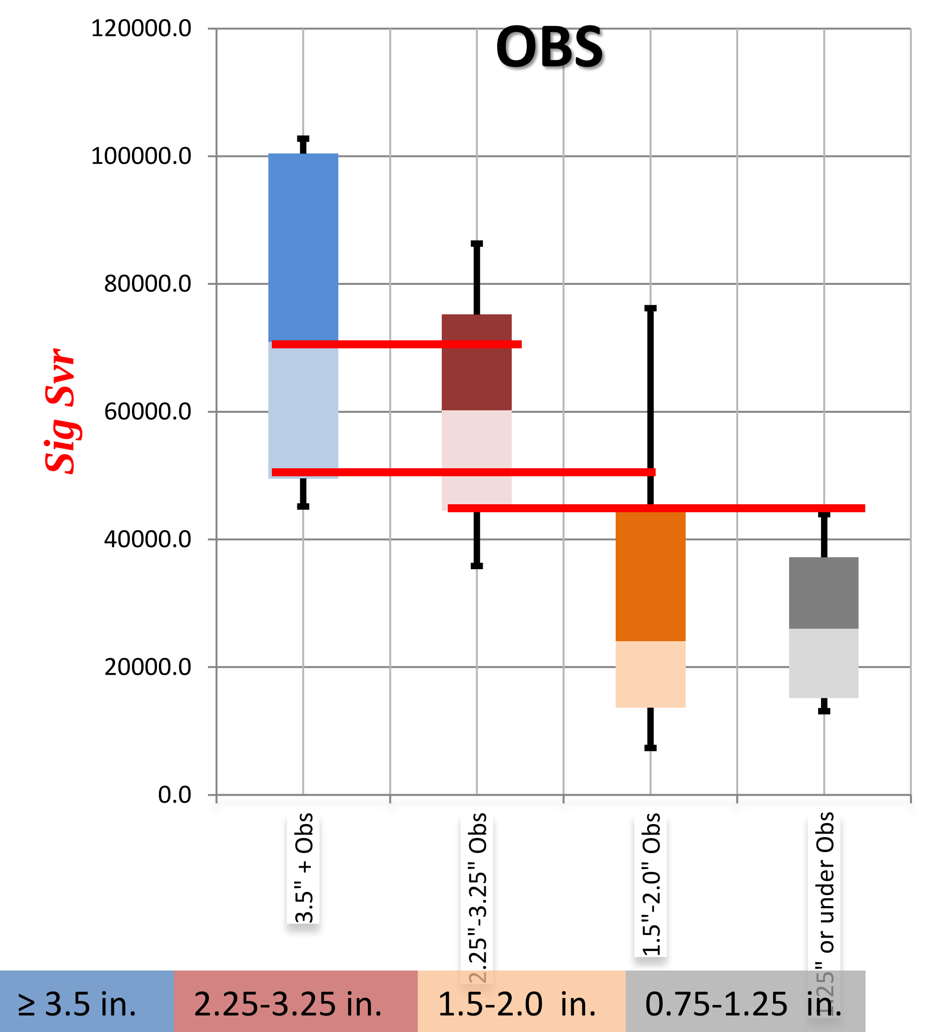


≥ 3.5 in.	2.25-3.25 in.	1.5-2.0 in.	0.75-1.25 in.

≥ 3.5 in.	2.25-3.25 in.	1.5-2.0 in.	0.75-1.25 in.

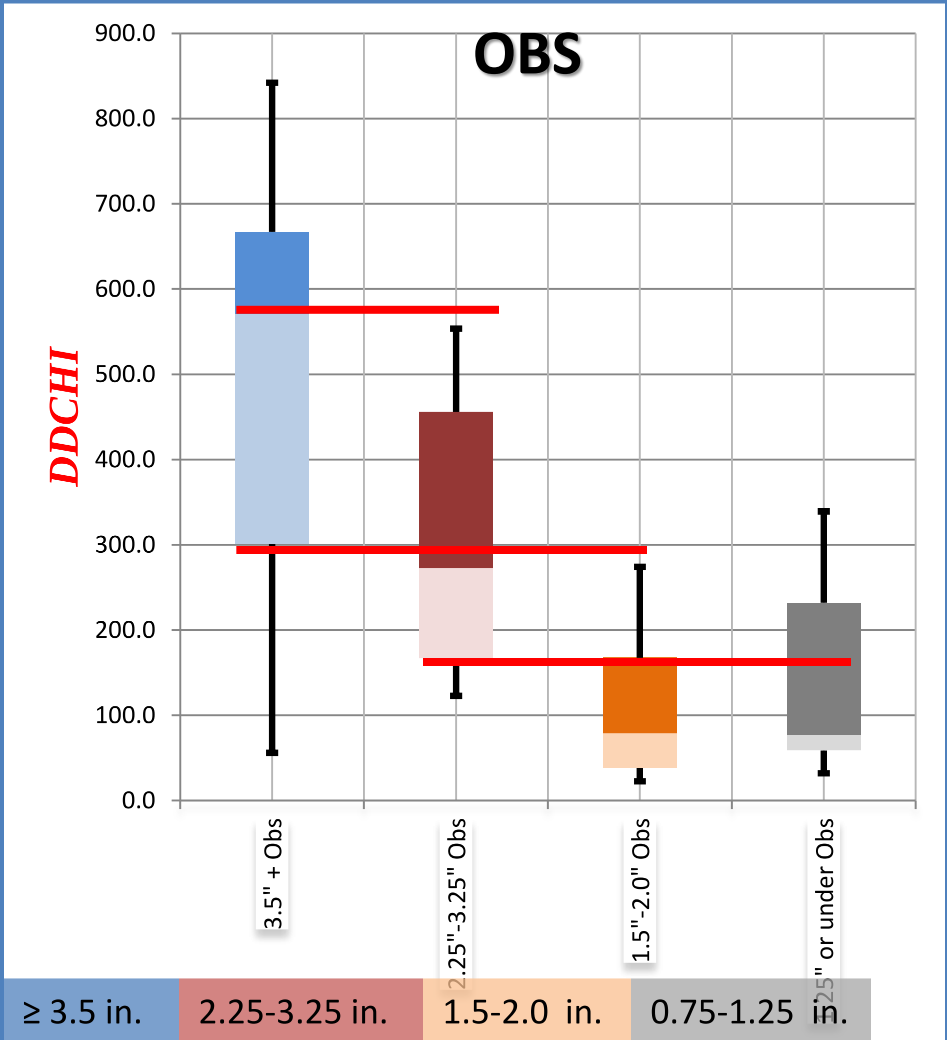
Parameter Combinations

Sig Svr



DDC Hail Index

Product of MU CAPE…0-6 km bulk shear…
6 km-EL bulk shear…700-500 hPa Lapse Rate



Revisiting Key Points

- ***Thermodynamic Parameters***

  - **Winners**

    1. **MU/SB/ML CAPE…sig/giant hail vs. non-sig severe hail (except marginal severe)**
    2. **-10˚C to -30˚C CAPE and LI…adequate substitute for total CAPE but no improvement in skill shown over total CAPE**
    3. **700-500 hPa lapse rates with giant hail**

  - **Losers**

    1. **NARR thermodynamic parameters (notable cold/dry bias in parameters in lower 3 km)**
    2. **500-300 hPa lapse rates**
    3. **Freezing Level/LCL Height**

Revisiting Key Points

➢ *Kinematic Parameters*

- Winners

  1. 0-EL bulk shear
  2. 6 km bulk shear/6km SR Flow…not including giant hail
  3. 6 km-EL bulk shear/EL SR Flow…not including marginal severe hail
  4. NARR kinematic variables adequate replacement for observed data

- Losers

  1. 0-1 km bulk shear…great tornado parameter but not a hail tool

➢ *Parameter Combinations*

- Standard CAPE and bulk shear combinations (e.g. SigSvr and ESI) do well at differentiating sig/giant hail (≥ 2.5 in.) vs non-sig/giant hail but significant overlap exists between giant and sig hail

- Adding upper tropospheric shear and mid level lapse rates to standard CAPE/Shear combinations increases the parameter spacing between giant and sig categories

Future Work

- *Ultimately expand into a larger regional or national database*
- *Include RUC/Rapid Refresh data along with NARR*
- *Evaluate other parameters such as 3-6 km CAPE, 0-12 km Bulk Shear, 6-12 km Bulk Shear*
- ***We still have a long way to go to accurately forecast something as complex as hail growth in the pre-storm environment. Ultimately, encourage additional hail related research.***


QUESTIONS???