Improving Understanding and Prediction of High Impact Weather Associated with Low-Topped Severe Convection in the Southeastern U.S.

Keith Sherburn

PIs: Matthew Parker, Gary Lackmann, Lian Xie
Students: Lindsay Blank, Dianna Francisco, Jessica King, Xia Sun
Collaborators: ESRL; EMC; SPC; WFOs Birmingham, Blacksburg, Charleston (SC), Columbia, Greer, Huntsville, Morehead City/Newport, Peachtree City, Raleigh, Sterling, Tallahassee, Wakefield, Wilmington (NC), Wilmington (OH)

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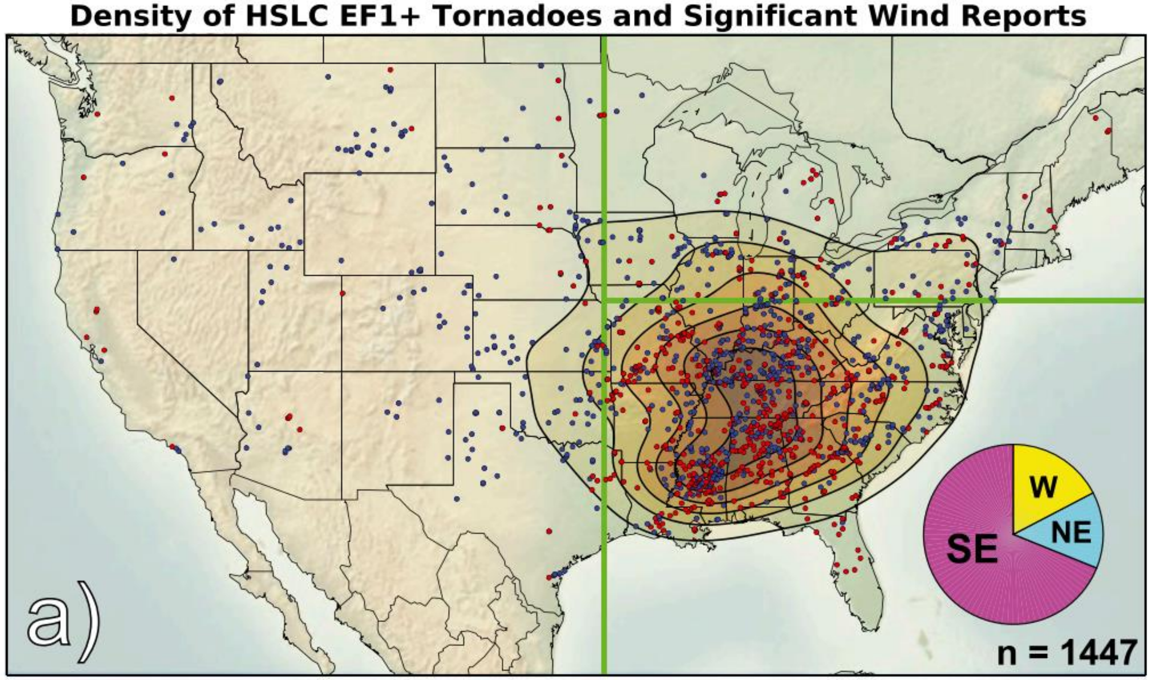
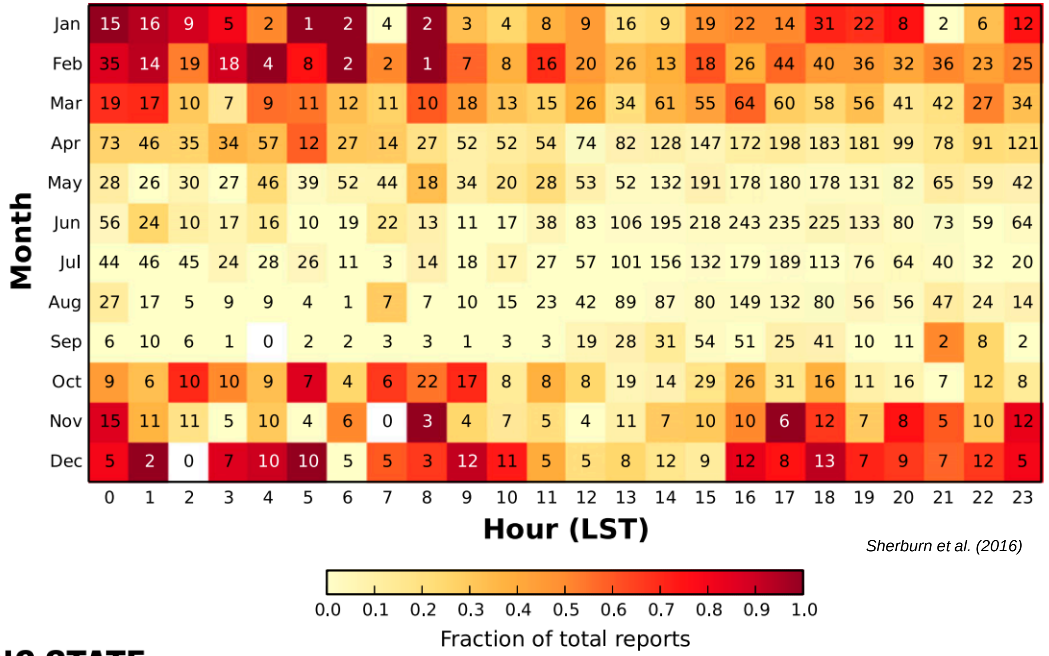
Problem overview

High-shear, low-CAPE (HSLC*) severe convection is a considerable forecasting challenge across the eastern U.S., particularly during the cool season and overnight

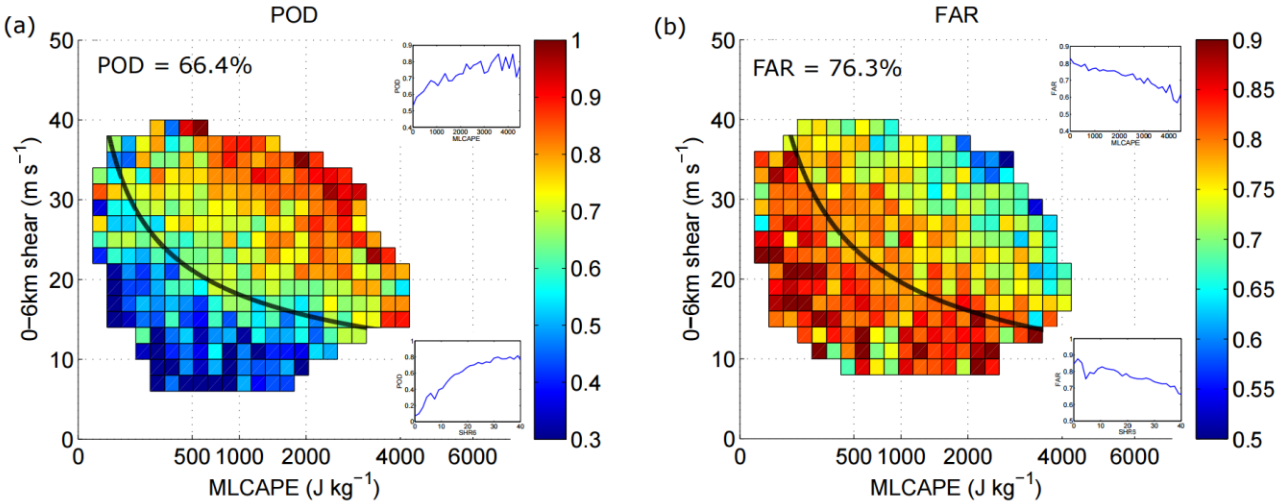


Sherburn et al. (2016)



Month	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Jan	15	16	9	5	2	1	2	4	2	3	4	8	9	16	9	19	22	14	31	22	8	2	6	12
Feb	35	14	19	18	4	8	2	2	1	7	8	16	20	26	13	18	26	44	40	36	32	36	23	25
Mar	19	17	10	7	9	11	12	11	10	18	13	15	26	34	61	55	64	60	58	56	41	42	27	34
Apr	73	46	35	34	57	12	27	14	27	52	52	54	74	82	128	147	172	198	183	181	99	78	91	121
May	28	26	30	27	46	39	52	44	18	34	20	28	53	52	132	191	178	180	178	131	82	65	59	42
Jun	56	24	10	17	16	10	19	22	13	11	17	38	83	106	195	218	243	235	225	133	80	73	59	64
Jul	44	46	45	24	28	26	11	3	14	18	17	27	57	101	156	132	179	189	113	76	64	40	32	20
Aug	27	17	5	9	9	4	1	7	7	10	15	23	42	89	87	80	149	132	80	56	56	47	24	14
Sep	6	10	6	1	0	2	2	3	3	1	3	3	19	28	31	54	51	25	41	10	11	2	8	2
Oct	9	6	10	10	9	7	4	6	22	17	8	8	8	19	14	29	26	31	16	11	16	7	12	8
Nov	15	11	11	5	10	4	6	0	3	4	7	5	4	11	7	10	10	6	12	7	8	5	10	12
Dec	5	2	0	7	10	10	5	5	3	12	11	5	5	8	12	9	12	8	13	7	9	7	12	5

Sherburn et al. (2016)



Anderson-Frey et al. (2016)

*Here, defined as SBCAPE ≤ 500 J kg^{-1}, MUCAPE ≤ 1000 J kg^{-1}, and 0-6 km bulk wind difference ≥ 18 m s^{-1}

Project overview

Five components:

- Composite maps and parameters:
  - Determine typical features associated with severe/nonsevere HSLC events (Sherburn et al. 2017)
  - Assess operational utility of existing and new forecasting parameters (Sherburn et al. 2017)
- Process studies 1: Case simulations to study mesoscale/synoptic scale evolution (King et al. 2017)
- NWP studies: Case simulations to investigate resolution requirements
- Process studies 2: Idealized simulations to study convective-scale dynamics
- Statistical studies: Dynamical-statistical downscaling to investigate predictability

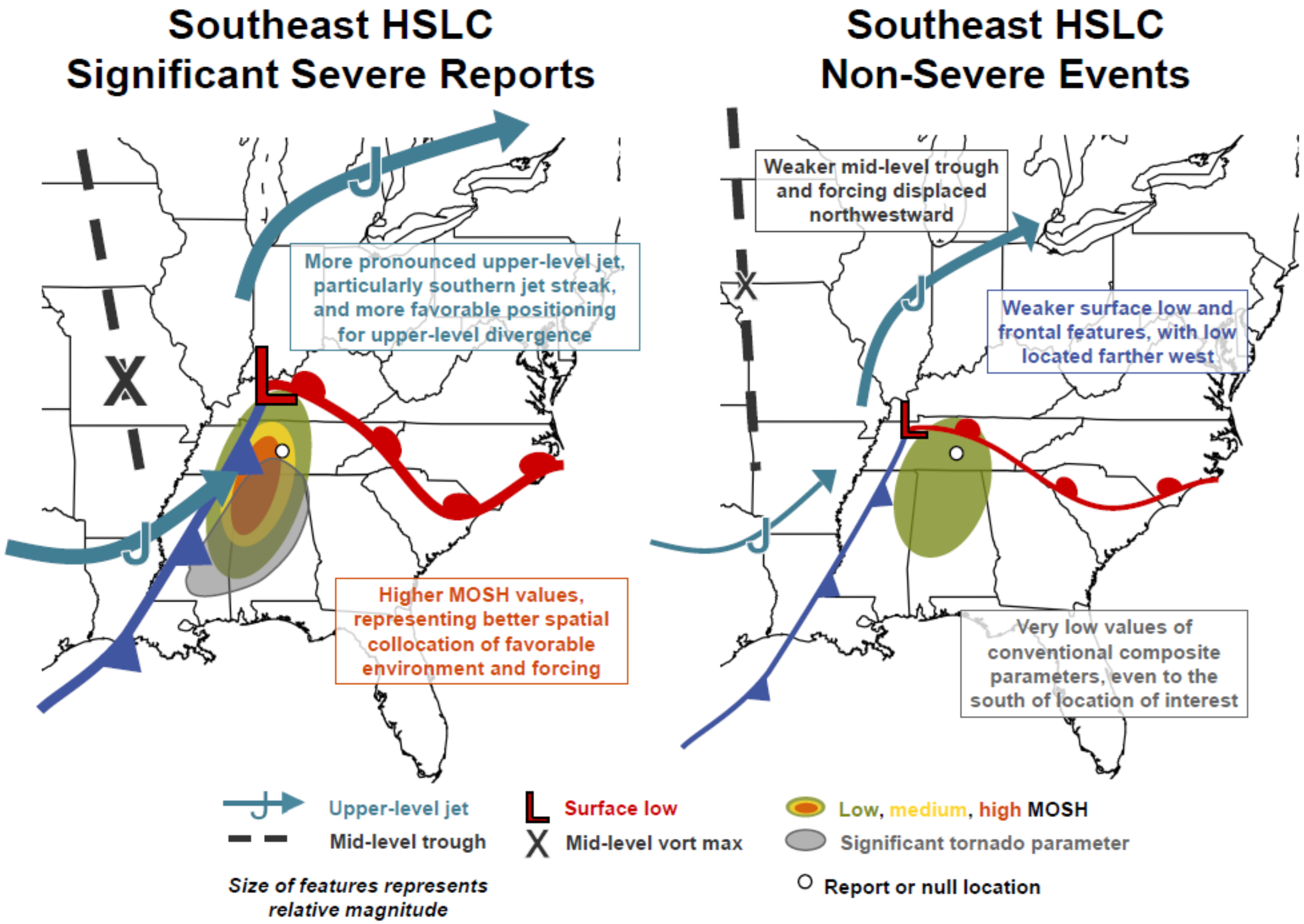
HSLC composites: Key points

Created using NARR data and severe reports versus false alarm warnings

Stronger, more closely collocated features are conducive to severe HSLC events

Release of potential instability and/or strong low-level θ_e advection are responsible for rapid destabilization immediately ahead of HSLC convection

Low-level lapse rates and shear vector magnitudes remain skillful



Southeast HSLC
Significant Severe Reports

More pronounced upper-level jet, particularly southern jet streak, and more favorable positioning for upper-level divergence

Higher MOSH values, representing better spatial collocation of favorable environment and forcing

Southeast HSLC
Non-Severe Events

Weaker mid-level trough and forcing displaced northwestward

Weaker surface low and frontal features, with low located farther west

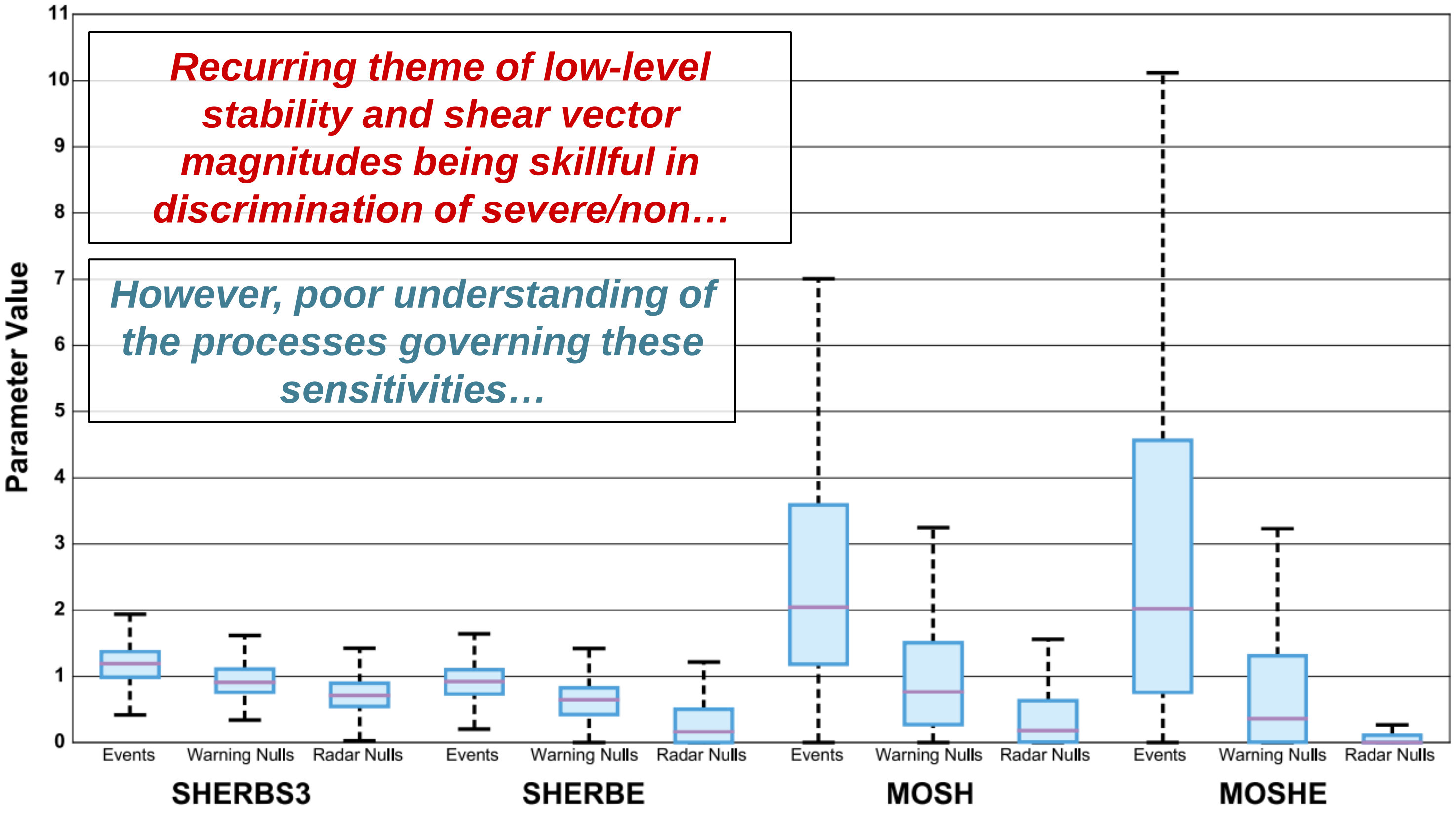
Very low values of conventional composite parameters, even to the south of location of interest

Size of features represents relative magnitude

HSLC composites: Updated forecasting parameter

$$\mathrm{MOSH} = \frac{(\mathrm{LLLR} - 4\,\mathrm{K\,km^{-1}})^2}{4\,\mathrm{K^2\,km^{-2}}} \times \frac{(\mathrm{S15MG} - 8\,\mathrm{m\,s^{-1}})}{10\,\mathrm{m\,s^{-1}}} \times \frac{(\mathrm{MAXTEVV} + 10\,\mathrm{K\,Pa\,km^{-1}\,s^{-1}})}{9\,\mathrm{K\,Pa\,km^{-1}\,s^{-1}}}.$$

$$\mathrm{MOSHE} = \frac{(\mathrm{LLLR} - 4\,\mathrm{K\,km^{-1}})^2}{4\,\mathrm{K^2\,km^{-2}}} \times \frac{(\mathrm{S15MG} - 8\,\mathrm{m\,s^{-1}})}{10\,\mathrm{m\,s^{-1}}} \times \frac{(\mathrm{ESHR} - 8\,\mathrm{m\,s^{-1}})}{10\,\mathrm{m\,s^{-1}}} \times \frac{(\mathrm{MAXTEVV} + 10\,\mathrm{K\,Pa\,km^{-1}\,s^{-1}})}{9\,\mathrm{K\,Pa\,km^{-1}\,s^{-1}}},$$



Recurring theme of low-level stability and shear vector magnitudes being skillful in discrimination of severe/non…

However, poor understanding of the processes governing these sensitivities…

LLLR: 0-3 km lapse rate
S15MG: 0-1.5 km shear vector magnitude
ESHR: Effective shear magnitude
MAXTEVV: Maximum dθ_e/dz * ω product from 0-2 km through 0-6 km, calculated at 0.5 km intervals (positive: unstable/upward motion)

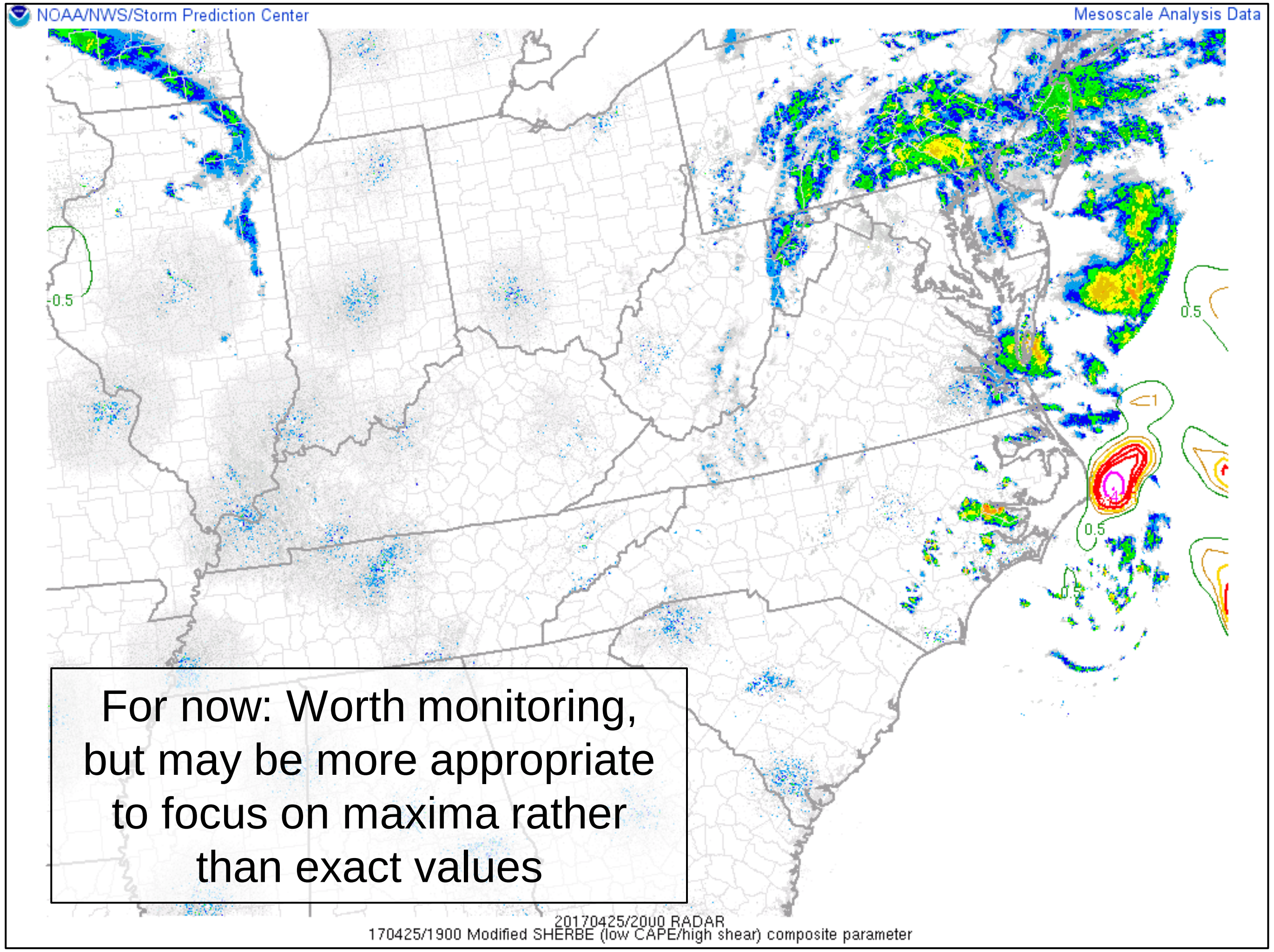
HSLC composites: MOSHE on SPC Mesoanalysis

$$\mathrm{MOSH} = \frac{(\mathrm{LLLR} - 4\,\mathrm{K\,km^{-1}})^2}{4\,\mathrm{K^2\,km^{-2}}} \times \frac{(\mathrm{S15MG} - 8\,\mathrm{m\,s^{-1}})}{10\,\mathrm{m\,s^{-1}}} \times \frac{(\mathrm{MAXTEVV} + 10\,\mathrm{K\,Pa\,km^{-1}\,s^{-1}})}{9\,\mathrm{K\,Pa\,km^{-1}\,s^{-1}}}.$$

$$\mathrm{MOSHE} = \boxed{\frac{(\mathrm{LLLR} - 4\,\mathrm{K\,km^{-1}})^2}{4\,\mathrm{K^2\,km^{-2}}}} \times \frac{(\mathrm{S15MG} - 8\,\mathrm{m\,s^{-1}})}{10\,\mathrm{m\,s^{-1}}} \times \frac{(\mathrm{ESHR} - 8\,\mathrm{m\,s^{-1}})}{10\,\mathrm{m\,s^{-1}}} \times \boxed{\frac{(\mathrm{MAXTEVV} + 10\,\mathrm{K\,Pa\,km^{-1}\,s^{-1}})}{9\,\mathrm{K\,Pa\,km^{-1}\,s^{-1}}}},$$

Adjustments potentially necessary; NARR values biased low

Could “cap” terms to limit contributions or reevaluate normalization values



170425/1900 Modified SHERBE (low CAPE/high shear) composite parameter

For now: Worth monitoring, but may be more appropriate to focus on maxima rather than exact values

LLLR: 0-3 km lapse rate
S15MG: 0-1.5 km shear vector magnitude
ESHR: Effective shear magnitude
MAXTEVV: Maximum dθ_e/dz * ω product from 0-2 km through 0-6 km, calculated at 0.5 km intervals (positive: unstable/upward motion)

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Process studies: Case study selection

Requirements:

- At least “slight” risk for severe convection
  - SPC mesoanalysis CAPE ≤ 1000 J kg^{-1}
  - 0-3 km shear ≥ 18 m s^{-1}

6 non-severe events (no storm reports)

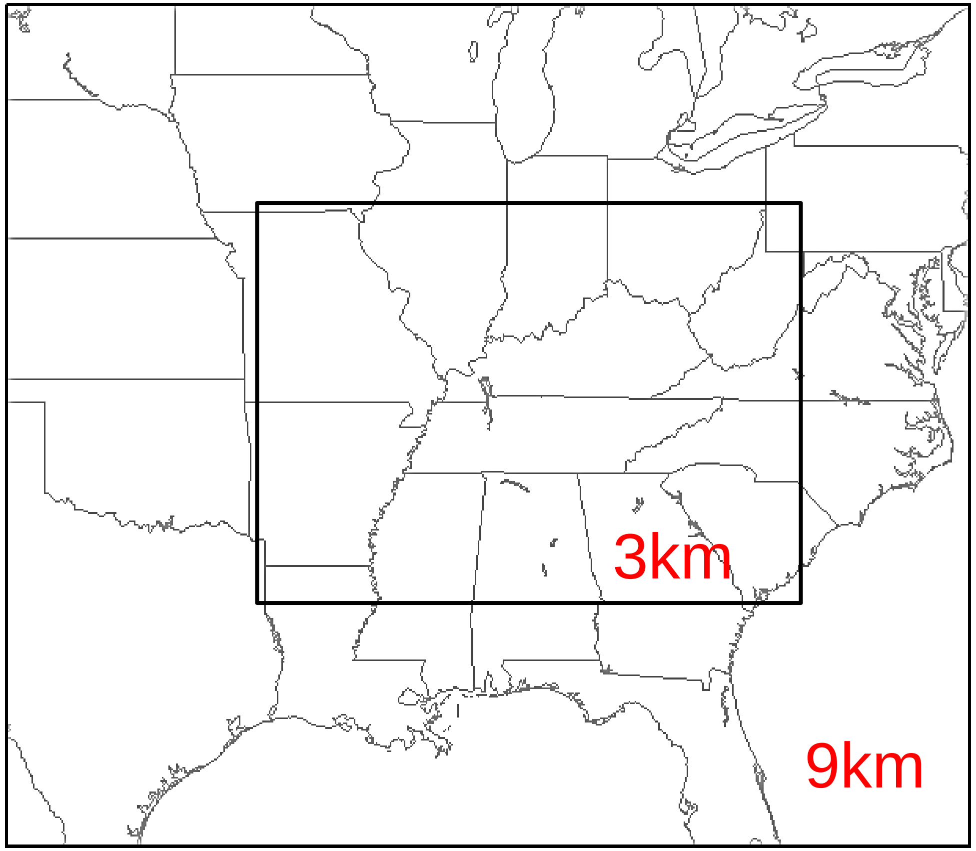
11 severe events (multiple reports)

Simulations run with ARW-WRF, v3.5.1

50 vertical levels

6-h NAM 12-km analyses as IC/LBC

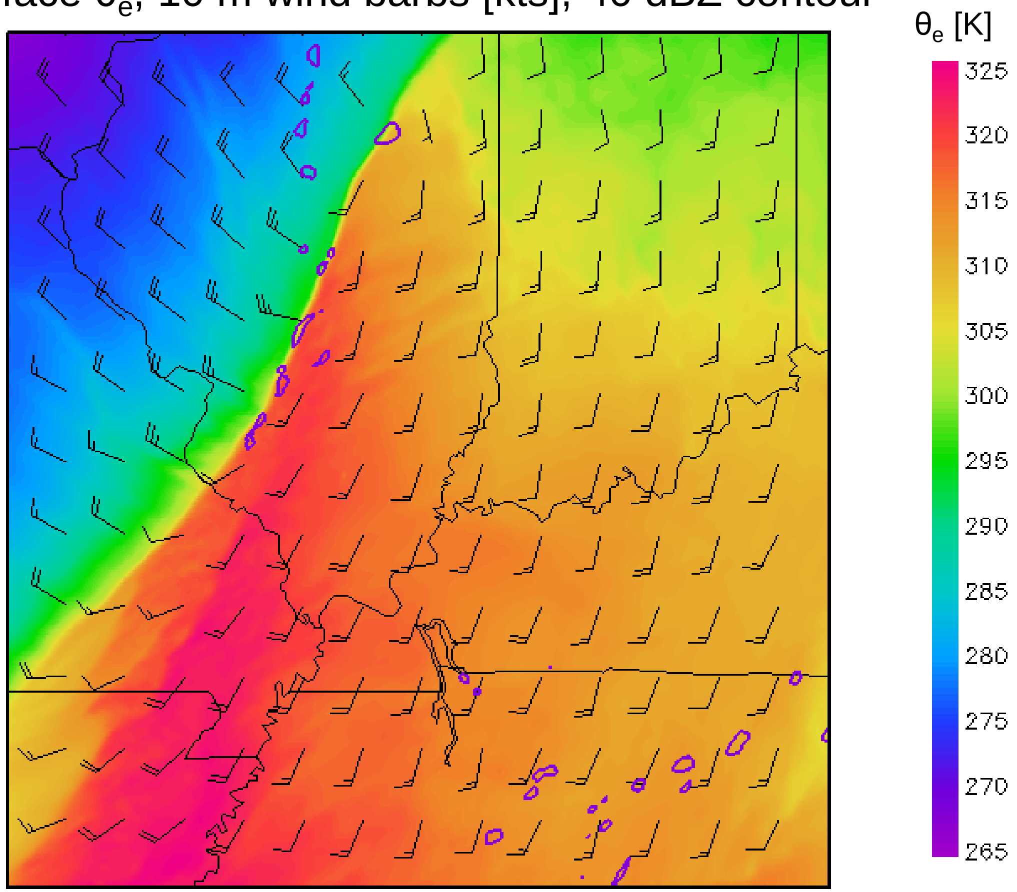
At least 30 hrs simulation time



Process studies: Simulated environments

Jan. 29, 2008: 2pm – 6pm

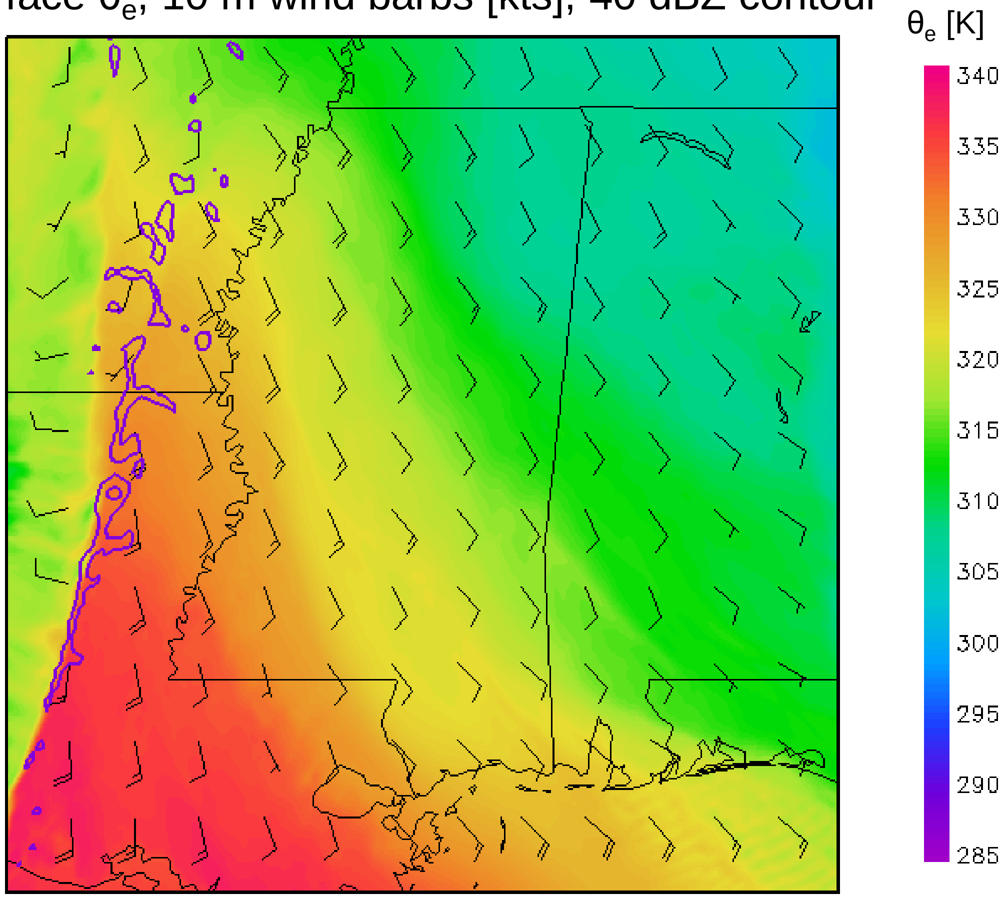
Surface θ_e, 10 m wind barbs [kts], 40 dBZ contour



Severe

Dec. 22, 2007: 4pm – 8pm

Surface θ_e, 10 m wind barbs [kts], 40 dBZ contour



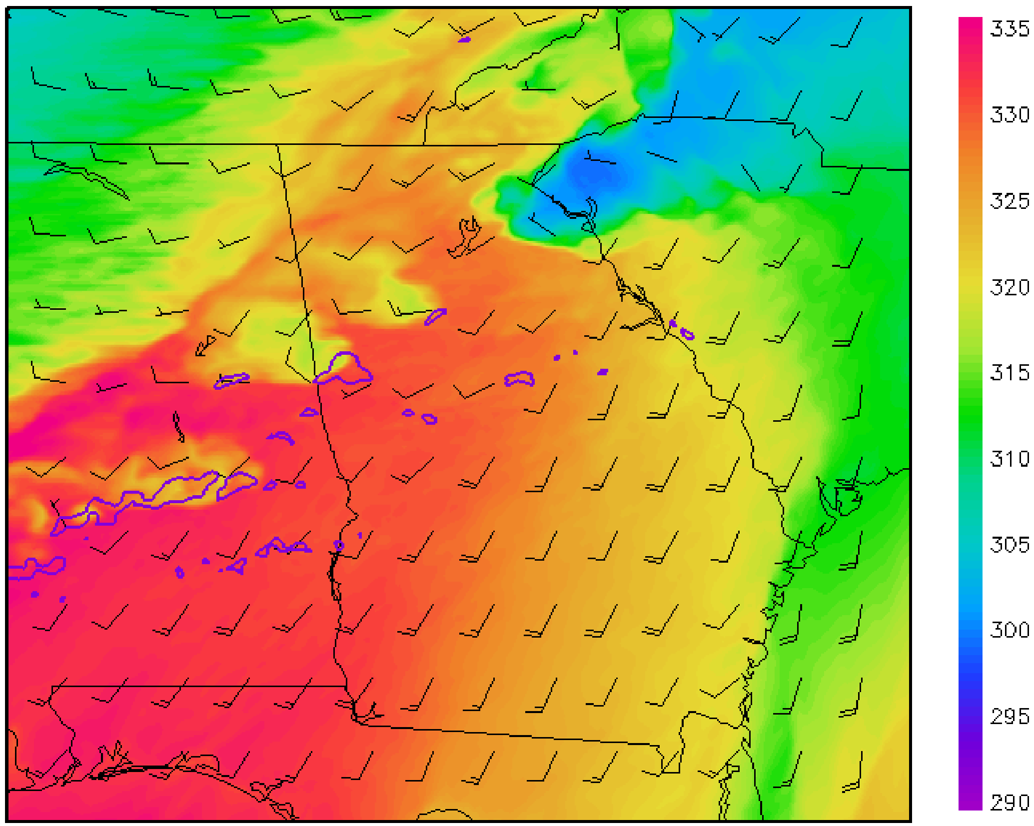
Nonsevere

Linear cold frontal boundary

Process studies: Simulated environments

Feb. 18, 2009: 5pm – 9pm

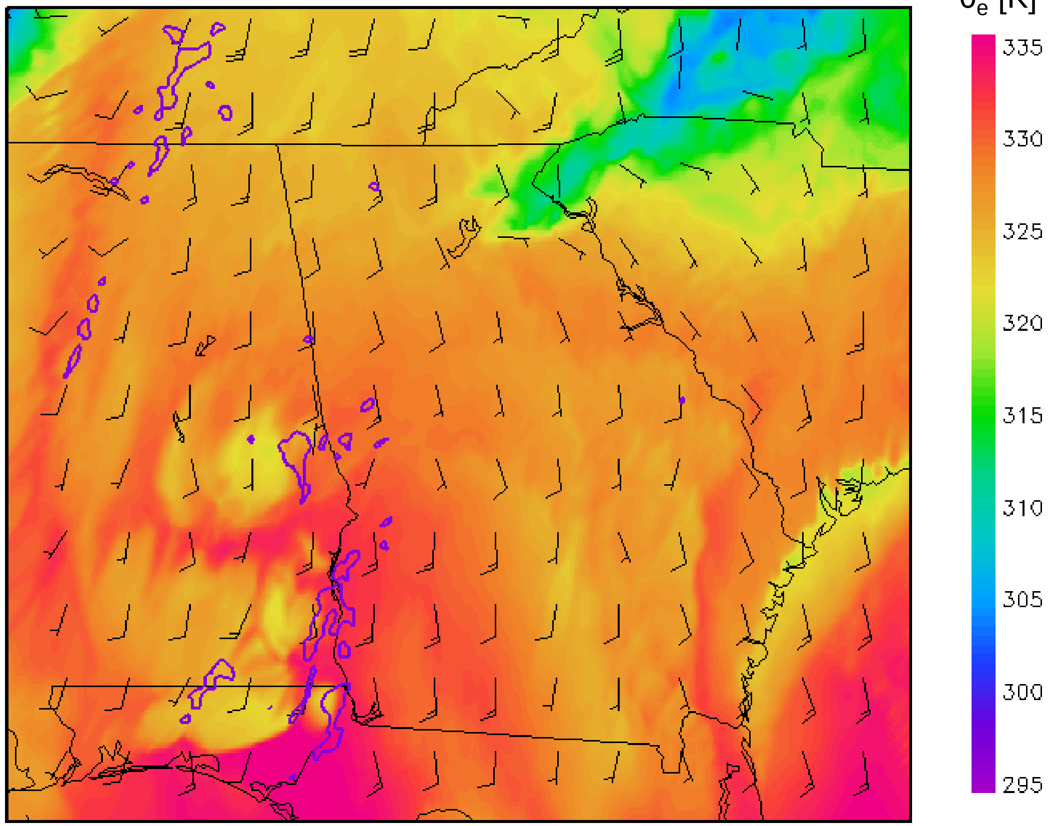
Surface θ_e, 10 m wind barbs [kts], 40 dBZ contour



Severe

Jan 26, 2012: 5pm – 9pm

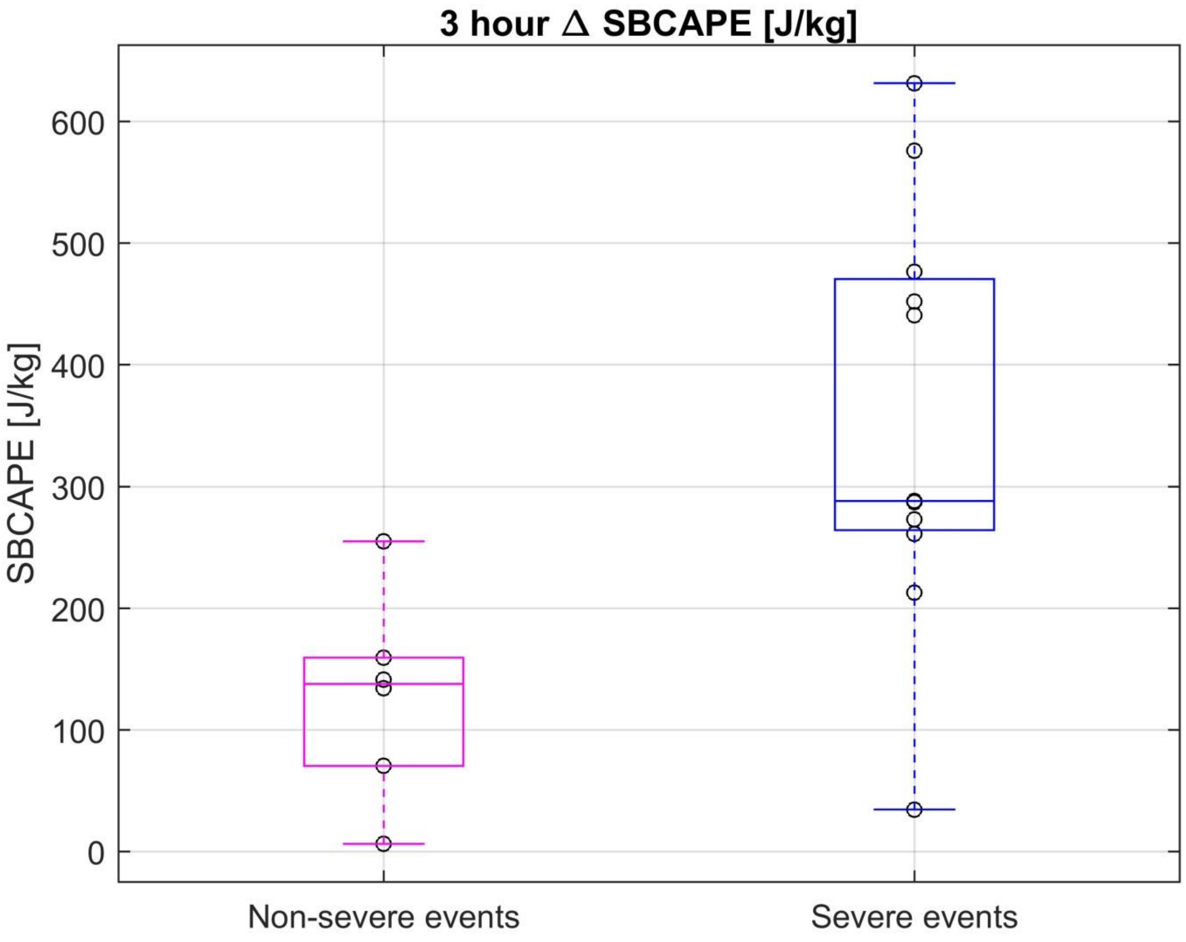
Surface θ_e, 10 m wind barbs [kts], 40 dBZ contour



Nonsevere

Isolated convection

Process studies: CAPE increases

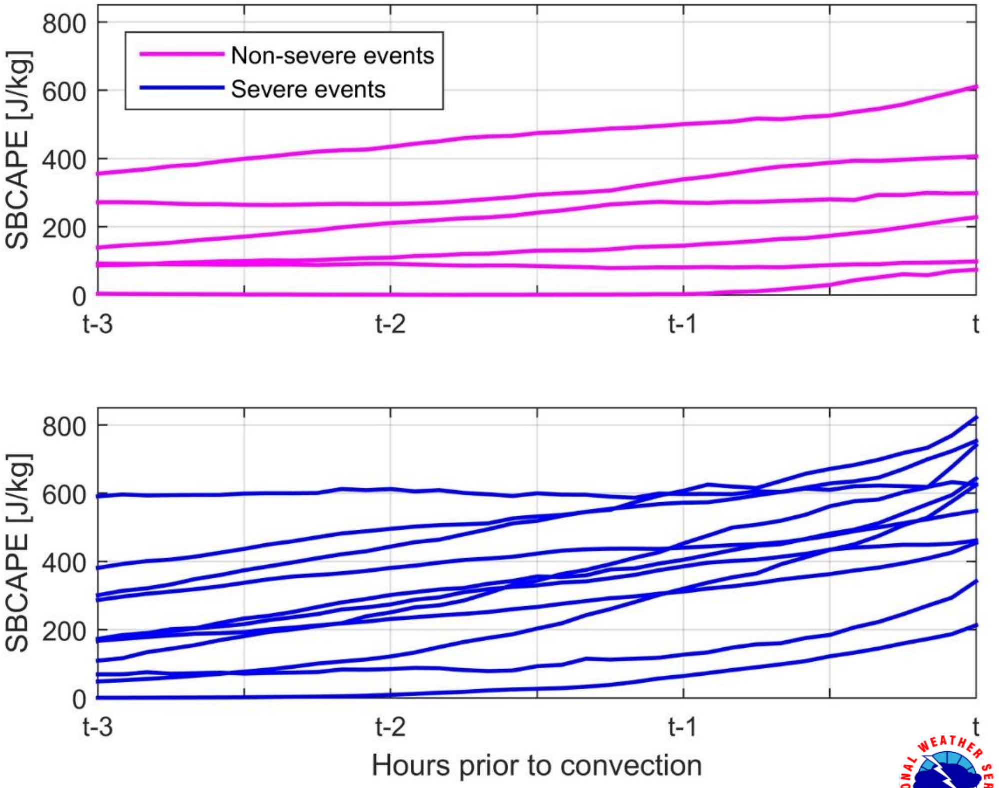

3 hour Δ SBCAPE [J/kg]

CAPE increases could arise from:

Increased surface temperature

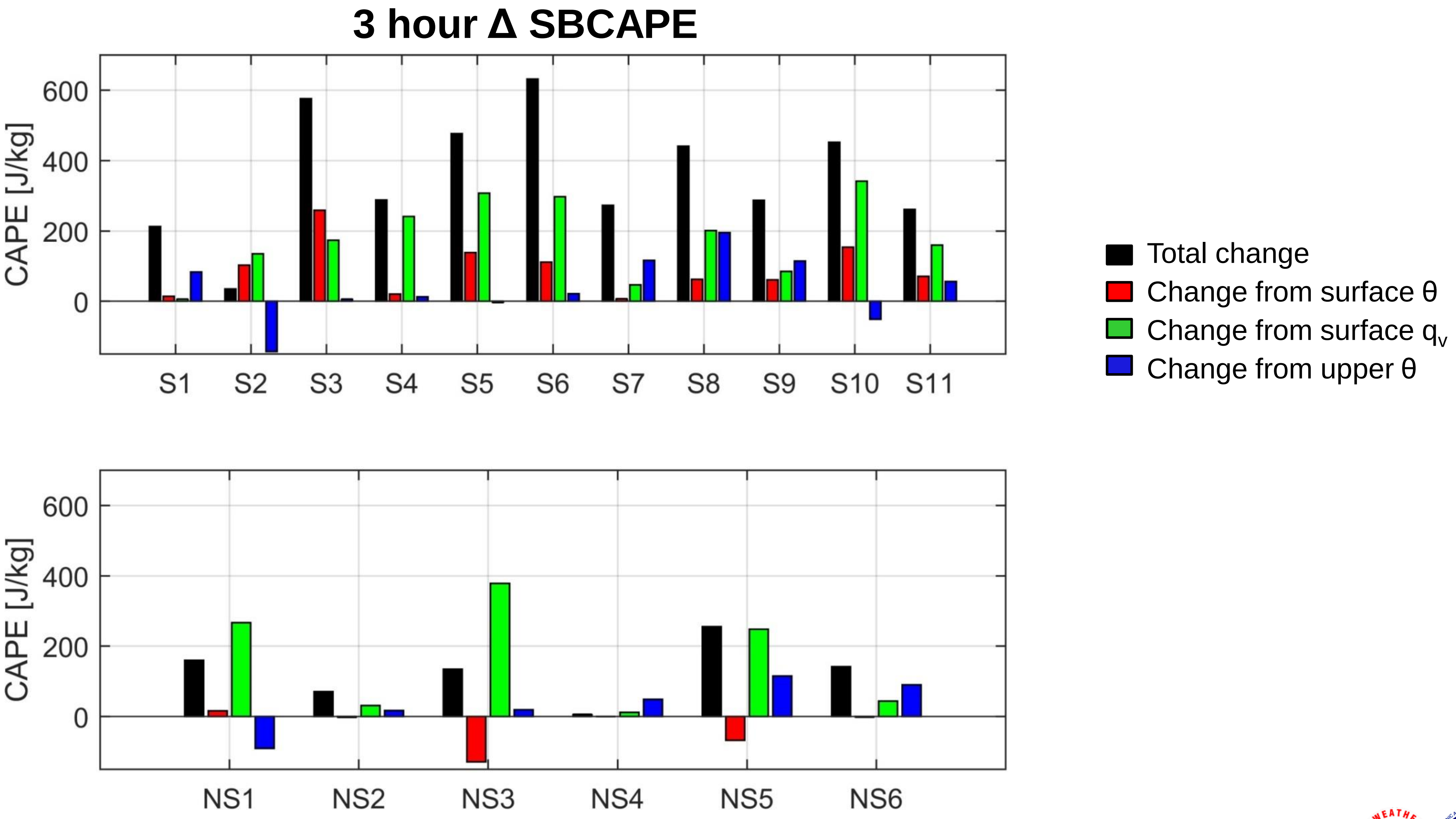
Increased surface moisture

Decreased temperature aloft

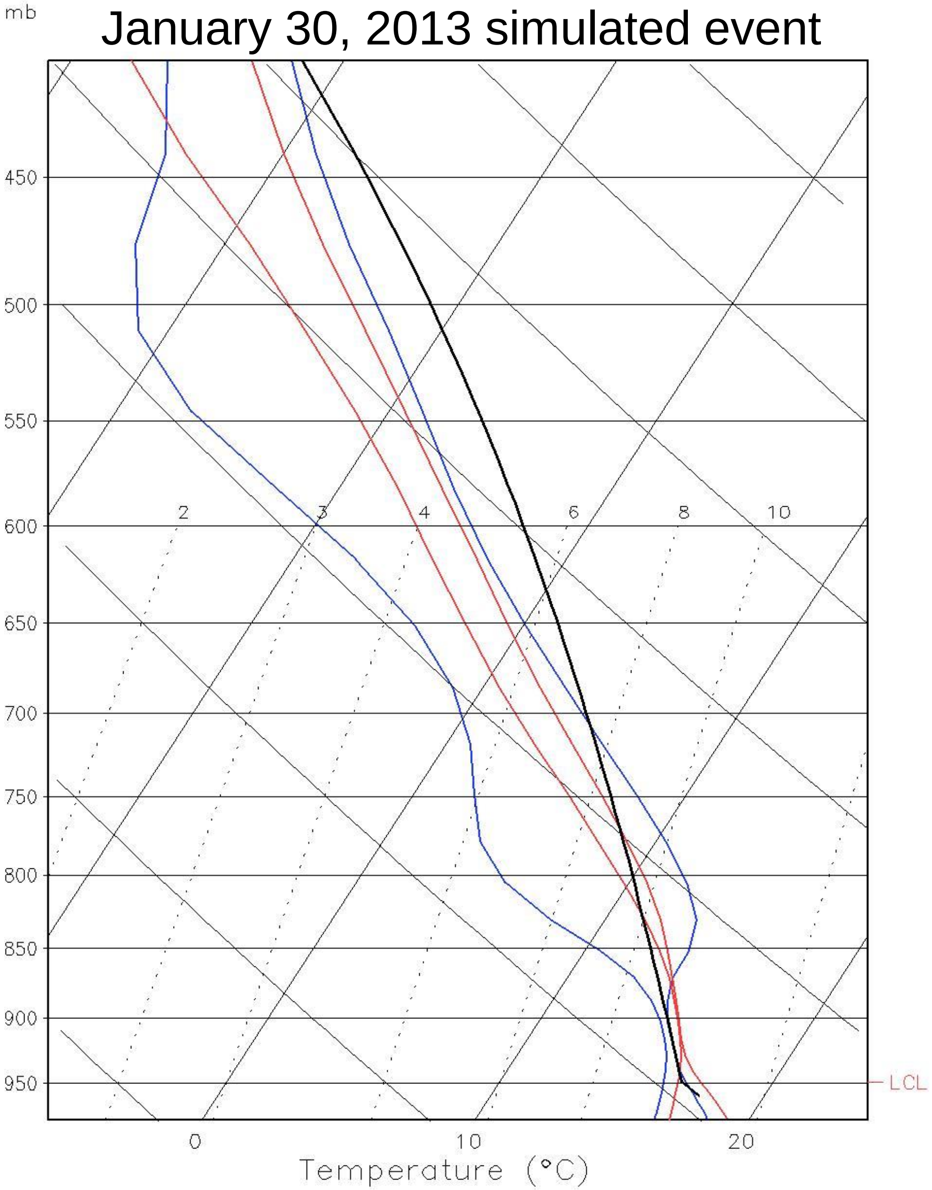


Goal: Determine which processes are most important by calculating contributions to CAPE from each process

Process studies: CAPE increases



Process studies: Potential instability


January 30, 2013 simulated event

Potentially unstable sounding (θ_e decreasing with height)

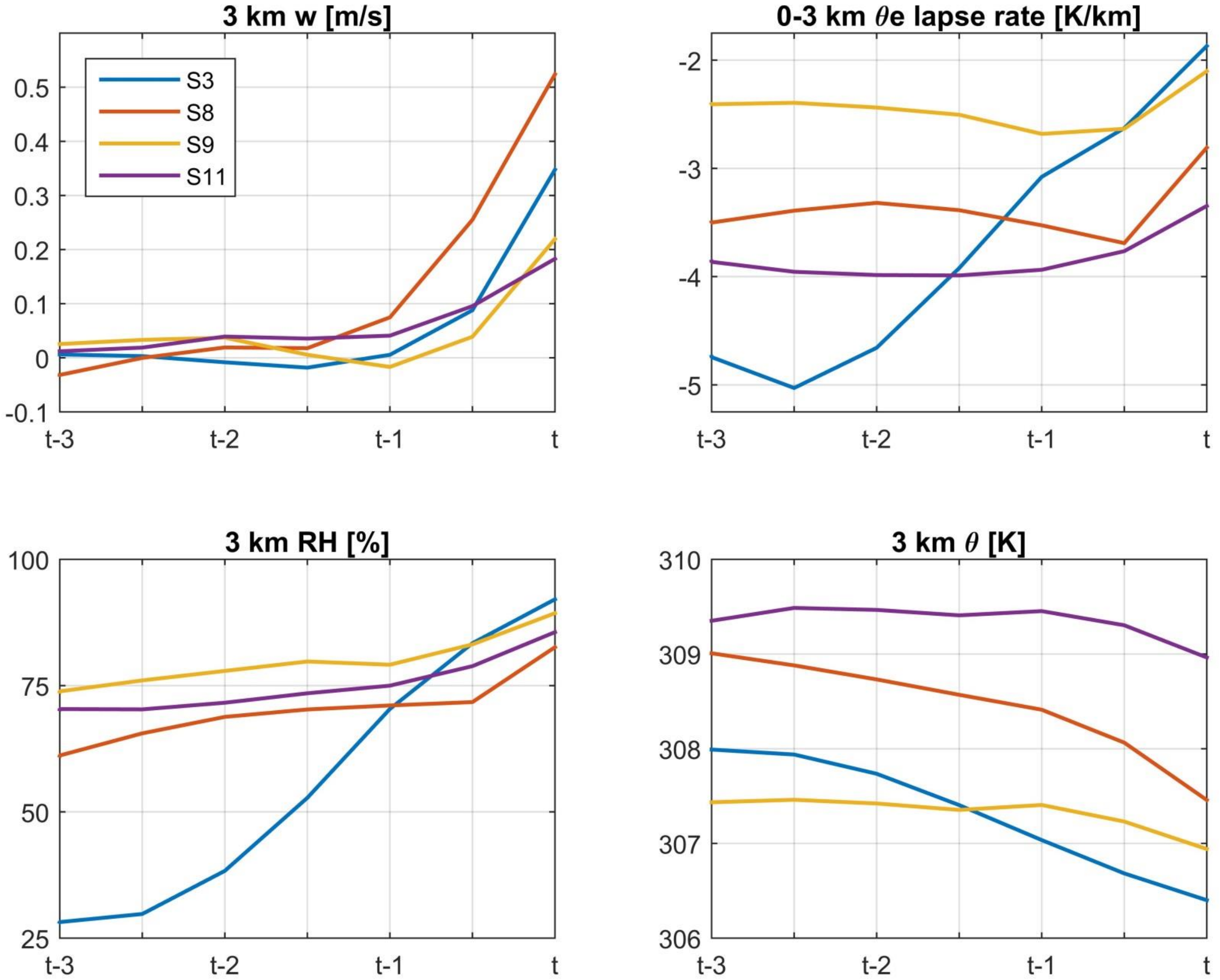
Lifting = cooling and moistening

Potential instability released, increase in CAPE

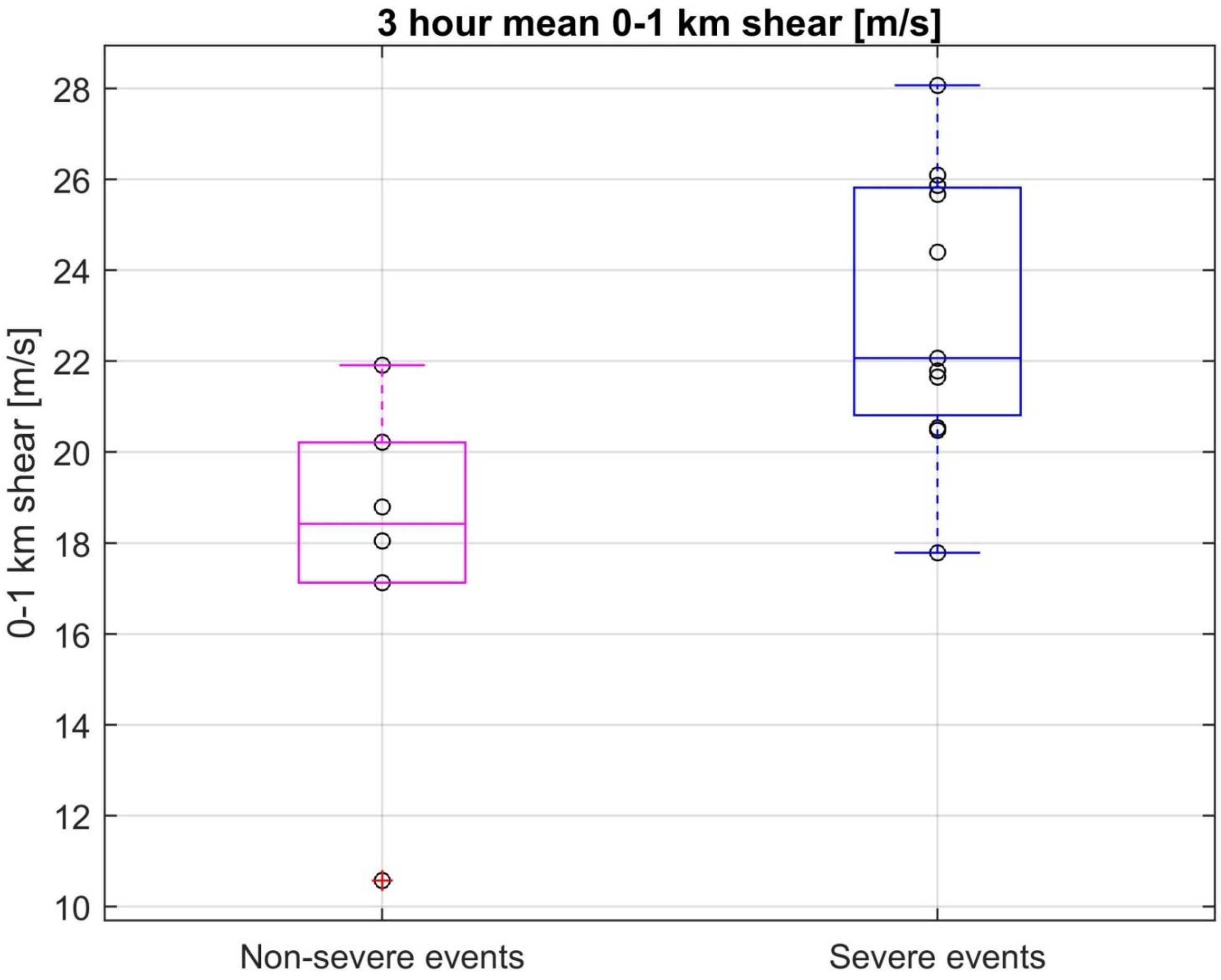
3 hours prior to convection

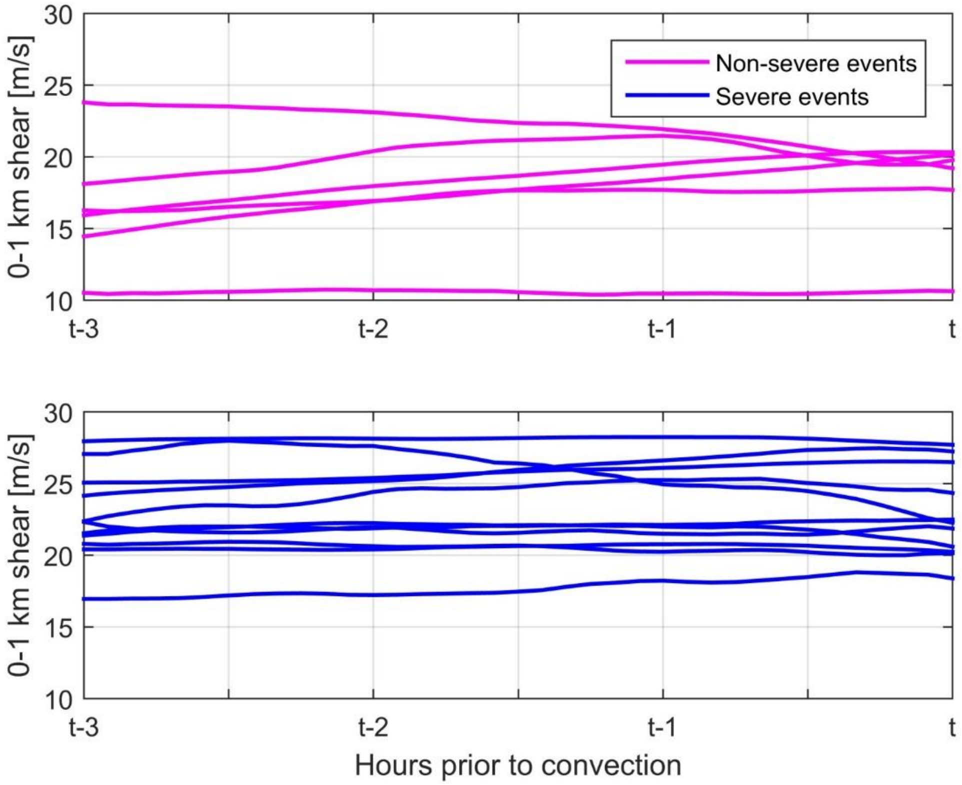
Just prior to convection (parcel path)

Process studies: Synoptic ascent



Process studies: Low-level shear

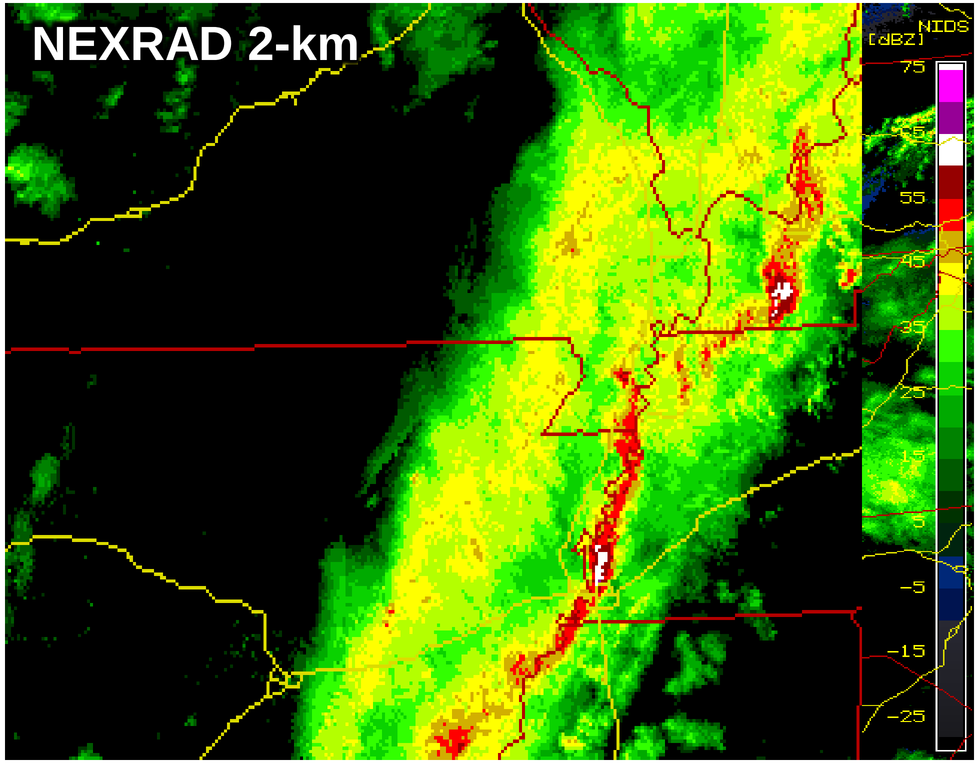




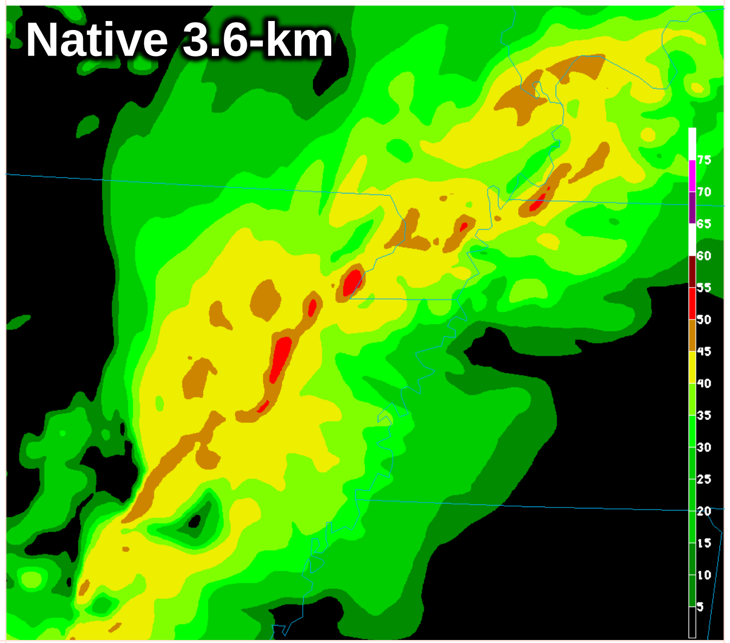
Discrimination between severe/nonsevere…

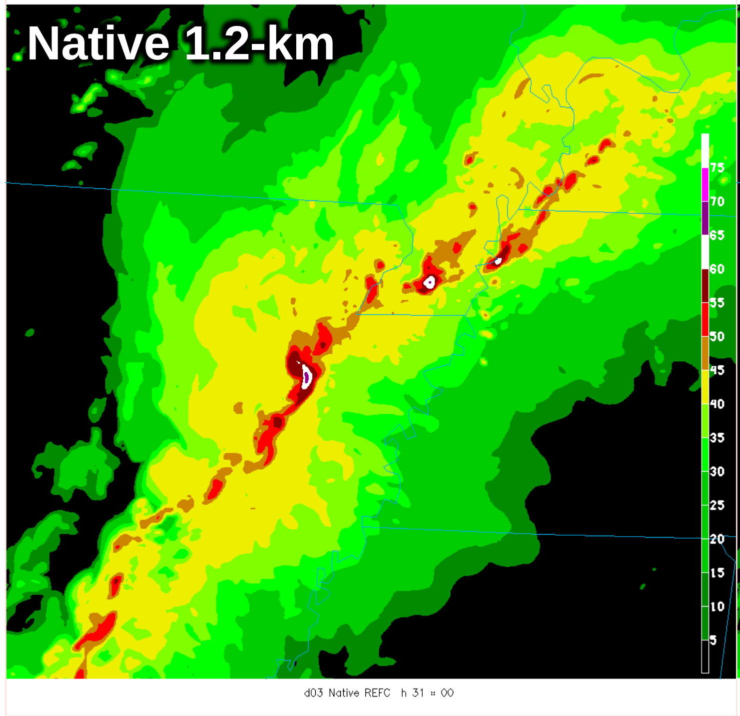
…but relatively constant over time

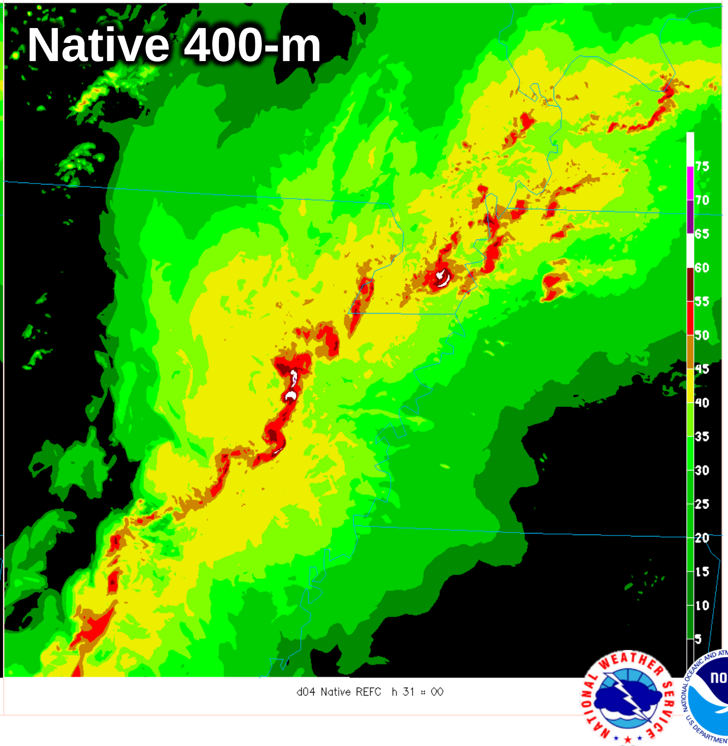
NWP studies: Resolution differences



Convective characteristics well-handled at all resolutions, though finer resolution obviously captures more detail







Differences clearer when evaluating fields such as 10-m wind speeds…

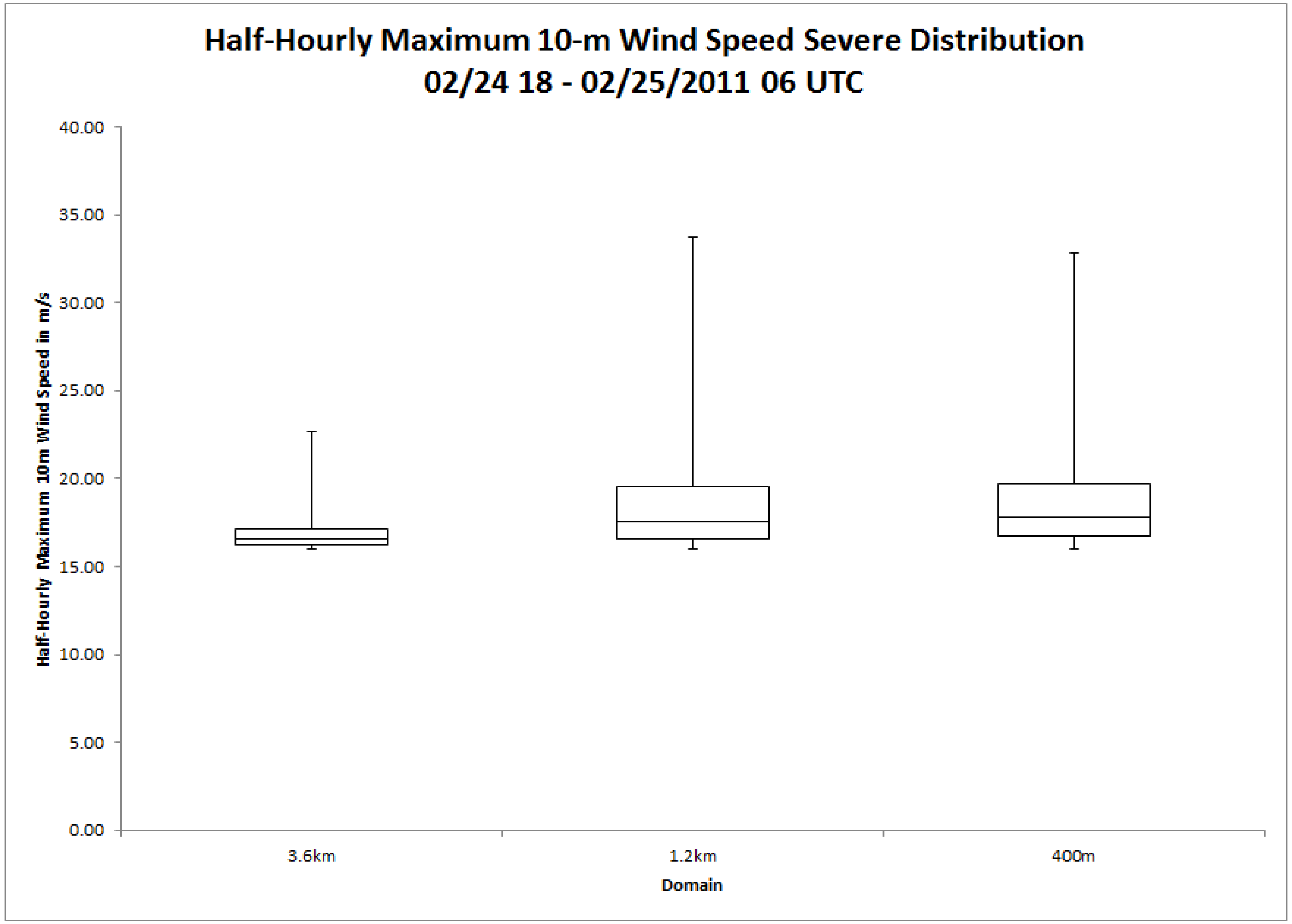
NWP studies: Resolution differences

Fairly large difference between 3.6-km and 1.2-km grid spacing, particularly when compared to jump from 1.2-km to 400-m

Similar findings for second case investigated

Suggests convergence of solution between 3.6-km and 1.2-km grid spacing, at least for sensible hazards

Work continues; more cases needed to corroborate initial findings

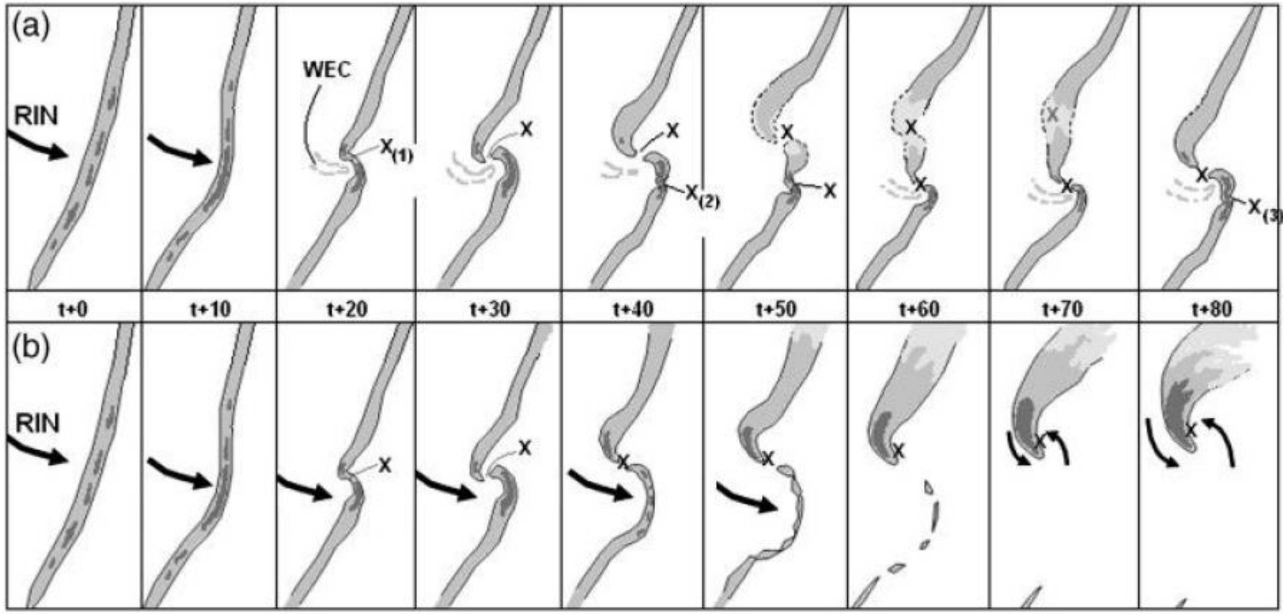


Idealized simulations: Motivation

Poor radar resolution and discrimination

Some potential radar precursors (such as broken-S, right), but high associated FAR

Rapid destabilization

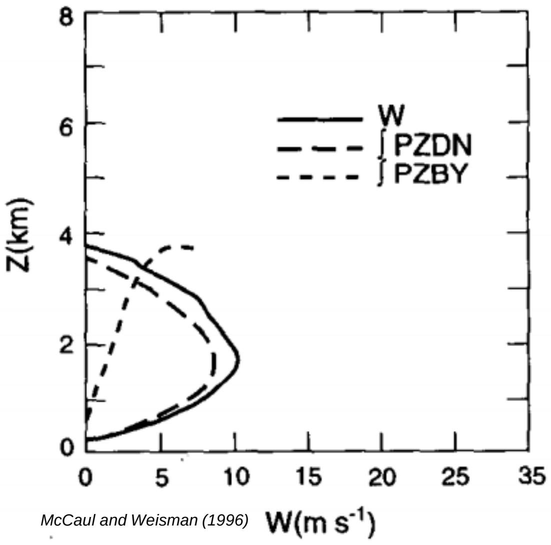


Clark (2011)

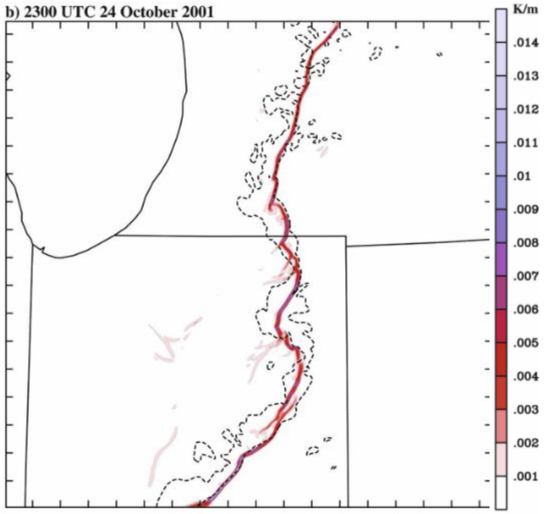
Prior HSLC simulations mainly tropical mini-supercells with insufficient resolution

Very few HSLC QLCS studies, limited in scope

QLCS mesovortex genesis mechanisms uncertain



McCaul and Weisman (1996)



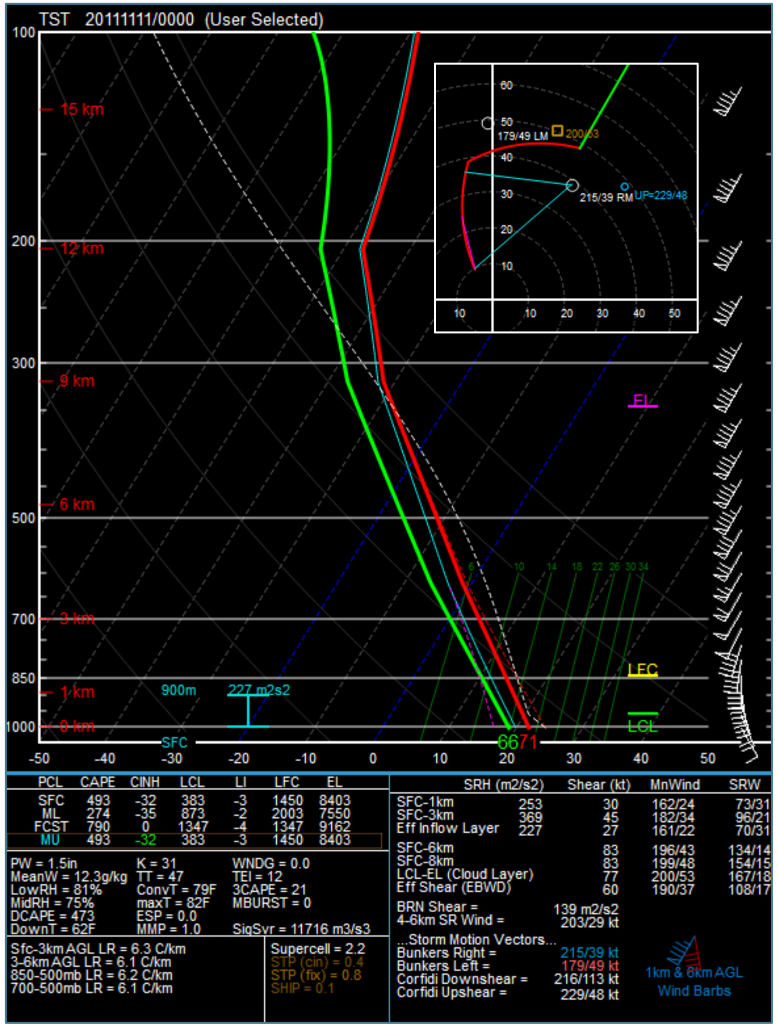
Wheatley and Trapp (2008)

Idealized simulations: Overview

Two primary goals:

1. Determine environmental parameter space within HSLC environments where long-lived, strong, low-level vortices capable of producing severe hazards are likely
2. Determine precursors for the development of strong, low-level vortices to determine the dynamics governing documented sensitivities

We must first understand the links in the chain that extend from the development of HSLC convection to the development of strong, near-surface vortices therein before we can assess which links are broken or missing.



PCL	CAPE	CINH	LCL	LI	LFC	EL
SFC	493	-32	383	-3	1450	8403
ML	274	-35	873	-2	2003	7550
FCST	790	0	1347	-4	1347	9162
MU	493	-32	383	-3	1450	8403

PW = 1.5in
MeanW = 12.3g/kg
LowRH = 81%
MidRH = 75%
DCAPE = 473
DownT = 62F

K = 31
TT = 47
ConvT = 79F
maxT = 82F
ESP = 0.0
MMP = 1.0

WNDG = 0.0
TEI = 12
3CAPE = 21
MBURST = 0
SigSvr = 11716 m3/s3

Sfc-3km AGL LR = 6.3 C/km
3-6km AGL LR = 6.1 C/km
850-500mb LR = 6.2 C/km
700-500mb LR = 6.1 C/km

Supercell = 2.2
STP (cin) = 0.4
STP (fix) = 0.8
SHIP = 0.1

	SRH (m2/s2)	Shear (kt)	MnWind	SRW
SFC-1km	253	30	162/24	73/31
SFC-3km	369	45	182/34	96/21
Eff Inflow Layer	227	27	161/22	70/31
SFC-6km		83	196/43	134/14
SFC-8km		83	199/48	154/15
LCL-EL (Cloud Layer)		77	200/53	167/18
Eff Shear (EBWD)		60	190/37	108/17

BRN Shear = 139 m2/s2
4-6km SR Wind = 203/29 kt

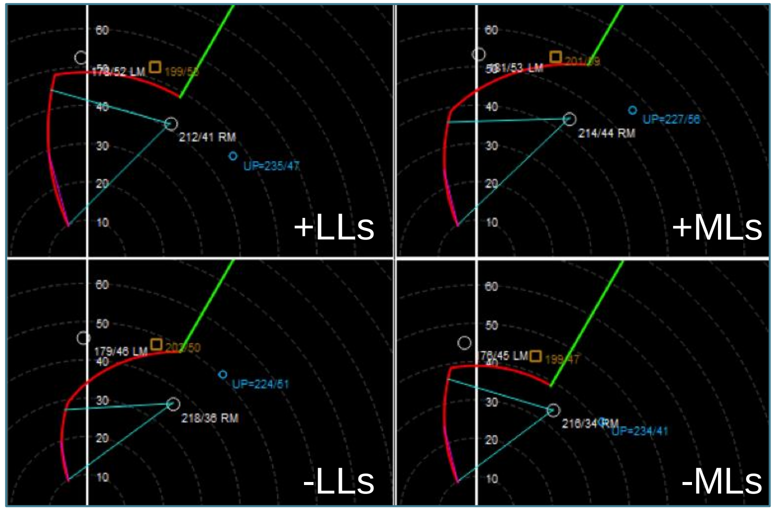
...Storm Motion Vectors...
Bunkers Right = 215/39 kt
Bunkers Left = 179/49 kt
Corfidi Downshear = 216/113 kt
Corfidi Upshear = 229/48 kt

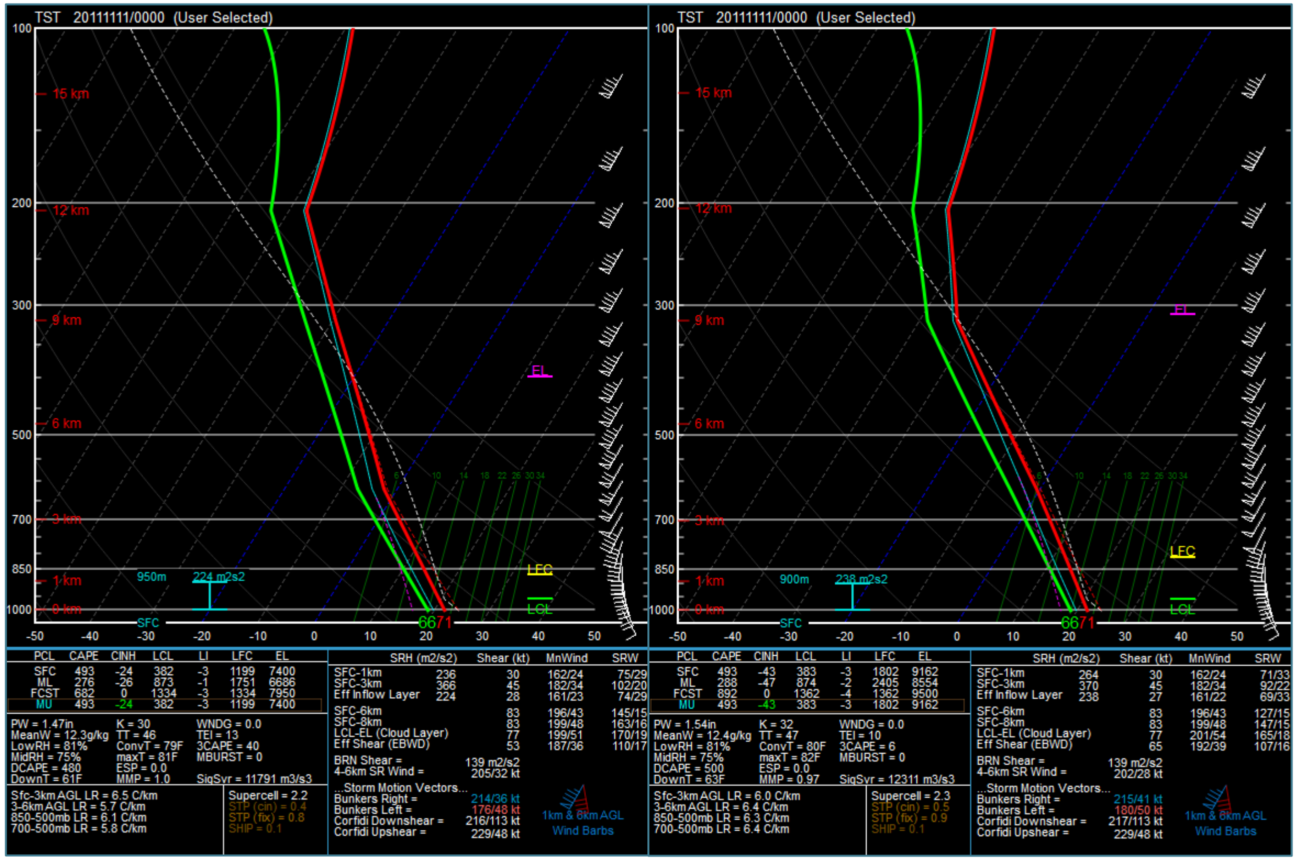
Control base-state environment

Idealized simulations: Sensitivity tests

Based on prior environmental studies and skill tests leading to the development of the SHERB/MOSH

Focus on varying low-level CAPE (here, equivalent to low-level lapse rates) and low/mid-level shear vector magnitudes





PCL	CAPE	CINH	LCL	LI	LFC	EL
SFC	493	-24	382	-3	1199	7400
ML	276	-26	873	-1	1751	6686
FCST	682	0	1334	-3	1334	7950
MU	493	-24	382	-3	1199	7400

PW = 1.47in
MeanW = 12.3g/kg
LowRH = 81%
MidRH = 75%
DCAPE = 480
DownT = 61F
K = 30
TT = 46
ConvT = 79F
maxT = 81F
ESP = 0.0
MMP = 1.0
WNDG = 0.0
TEI = 13
3CAPE = 40
MBURST = 0
SigSvr = 11791 m3/s3

Sfc-3km AGL LR = 6.5 C/km
3-6km AGL LR = 5.7 C/km
850-500mb LR = 6.1 C/km
700-500mb LR = 5.8 C/km

Supercell = 2.2
STP (cin) = 0.4
STP (fix) = 0.8
SHIP = 0.1

	SRH (m2/s2)	Shear (kt)	MnWind	SRW
SFC-1km	236	30	162/24	75/29
SFC-3km	366	45	182/34	102/20
Eff Inflow Layer	224	28	161/23	74/29
SFC-6km		83	196/43	145/15
SFC-8km		83	199/48	163/16
LCL-EL (Cloud Layer)		77	199/51	170/19
Eff Shear (EBWD)		53	187/36	110/17

BRN Shear = 139 m2/s2
4-6km SR Wind = 205/32 kt

...Storm Motion Vectors...
Bunkers Right = 214/36 kt
Bunkers Left = 176/48 kt
Corfidi Downshear = 216/113 kt
Corfidi Upshear = 229/48 kt

PCL	CAPE	CINH	LCL	LI	LFC	EL
SFC	493	-43	383	-3	1802	9162
ML	288	-47	874	-2	2405	8554
FCST	892	0	1362	-4	1362	9500
MU	493	-43	383	-3	1802	9162

PW = 1.54in
MeanW = 12.4g/kg
LowRH = 81%
MidRH = 75%
DCAPE = 500
DownT = 63F
K = 32
TT = 47
ConvT = 80F
maxT = 82F
ESP = 0.0
MMP = 0.97
WNDG = 0.0
TEI = 10
3CAPE = 6
MBURST = 0
SigSvr = 12311 m3/s3

Sfc-3km AGL LR = 6.0 C/km
3-6km AGL LR = 6.4 C/km
850-500mb LR = 6.3 C/km
700-500mb LR = 6.4 C/km

Supercell = 2.3
STP (cin) = 0.5
STP (fix) = 0.9
SHIP = 0.1

	SRH (m2/s2)	Shear (kt)	MnWind	SRW
SFC-1km	264	30	162/24	71/33
SFC-3km	370	45	182/34	92/22
Eff Inflow Layer	238	27	161/22	69/33
SFC-6km		83	196/43	127/15
SFC-8km		83	199/48	147/15
LCL-EL (Cloud Layer)		77	201/54	165/18
Eff Shear (EBWD)		65	192/39	107/16

BRN Shear = 139 m2/s2
4-6km SR Wind = 202/28 kt

...Storm Motion Vectors...
Bunkers Right = 215/41 kt
Bunkers Left = 180/50 kt
Corfidi Downshear = 217/113 kt
Corfidi Upshear = 229/48 kt

Increased low-level CAPE (+LLc)

Decreased low-level CAPE (-LLc)

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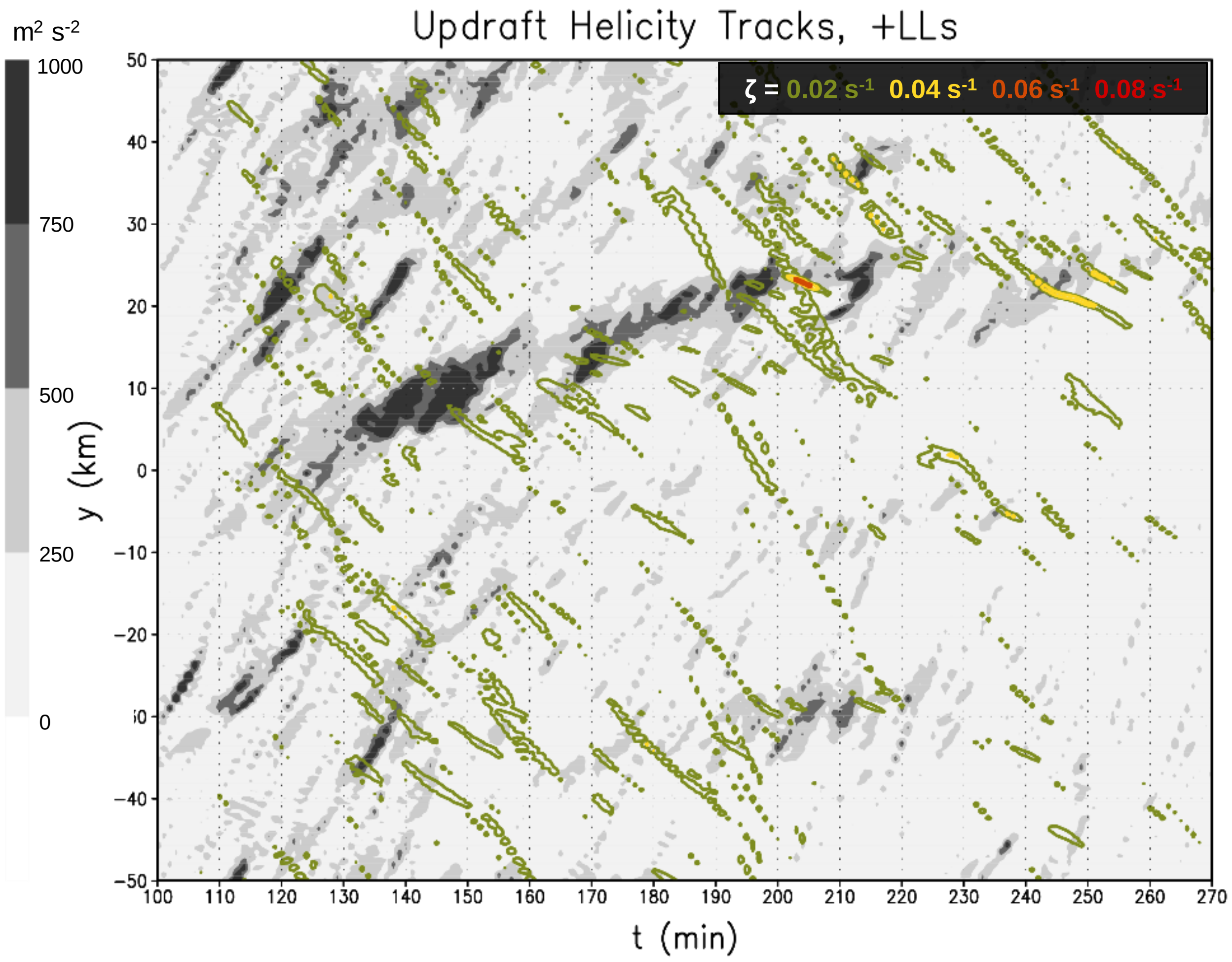
Idealized simulations: Informed hypotheses

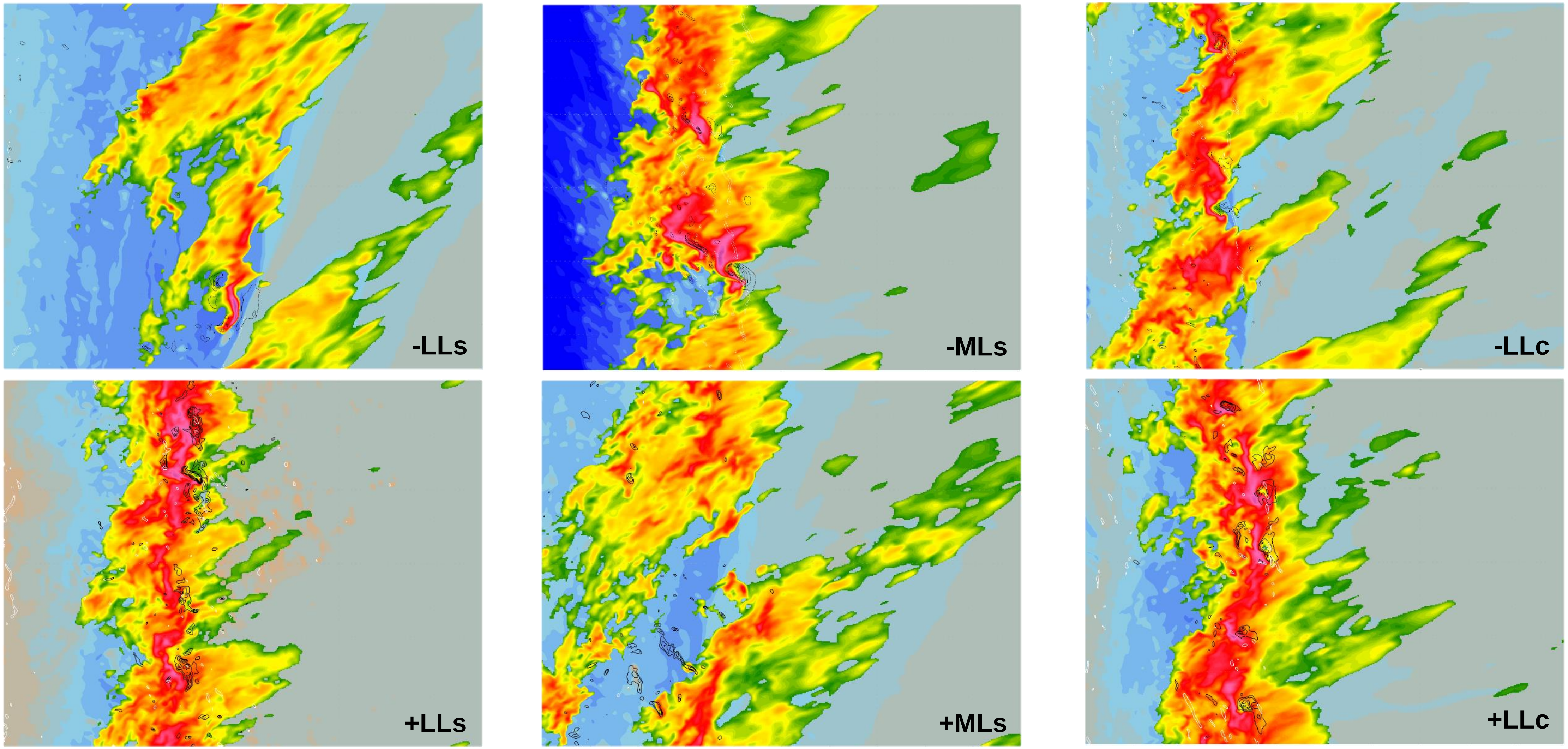
A strong, low-level updraft (~20 m s^{-1} in the lowest 2 km) is a necessary but insufficient precursor to low-level vortexgenesis

Increasing this variable…	**…will lead to these results**
Low-level shear	• Increased *number* of strong low-level updrafts and near-surface ζ centers • Increased probability of producing a strong, near-surface vortex
Low-level CAPE	• Increased *number and magnitude* of strong low-level updrafts • Increased probability of producing a strong, near-surface vortex



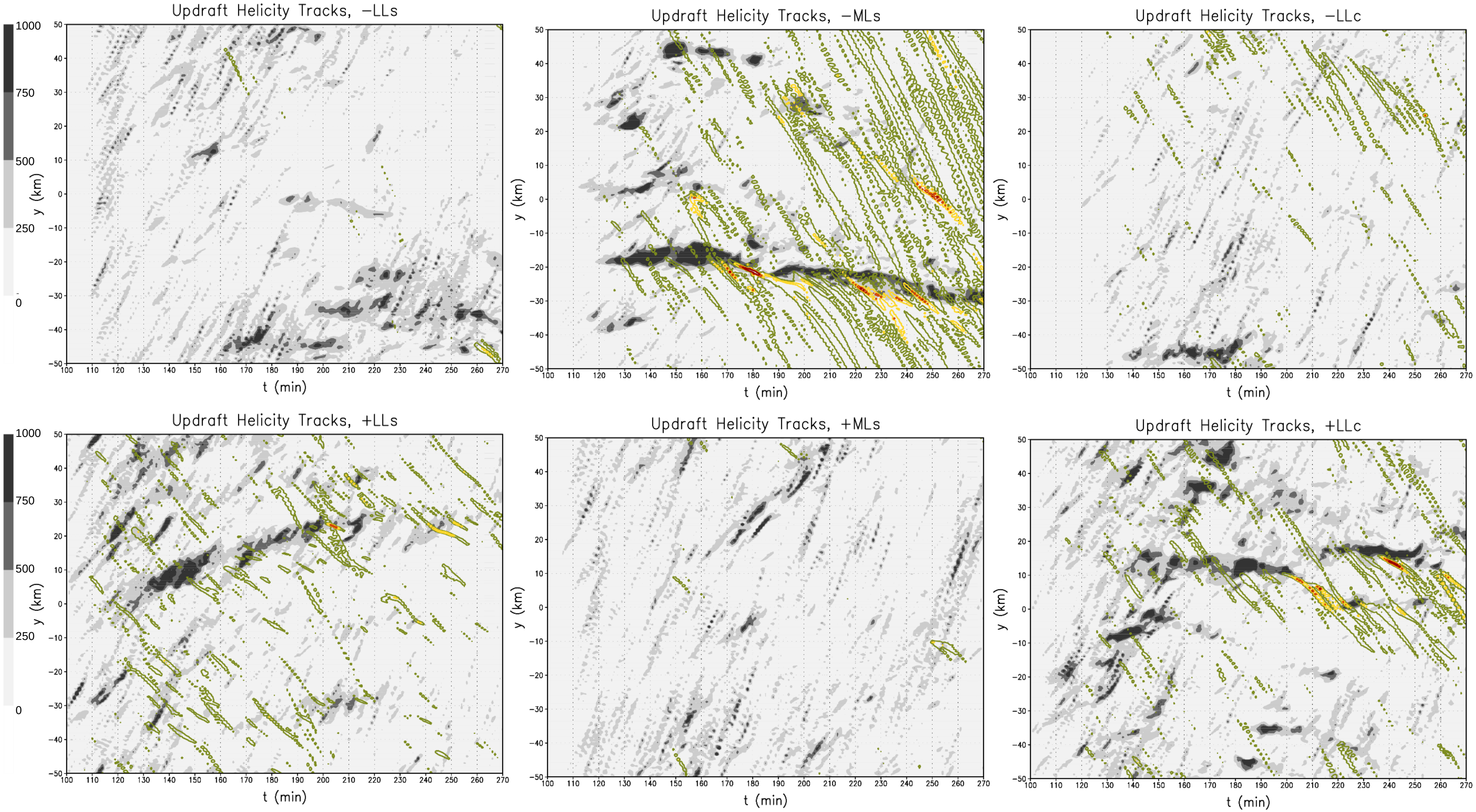
Idealized simulations: Results

Black contours: 1-km vertical velocity
White contours: 10-m vertical vorticity
Reflectivity (dBZ) Surface θ' (K)



Idealized simulations: Results

ζ = 0.02 s^{-1} 0.04 s^{-1} 0.06 s^{-1} 0.08 s^{-1}



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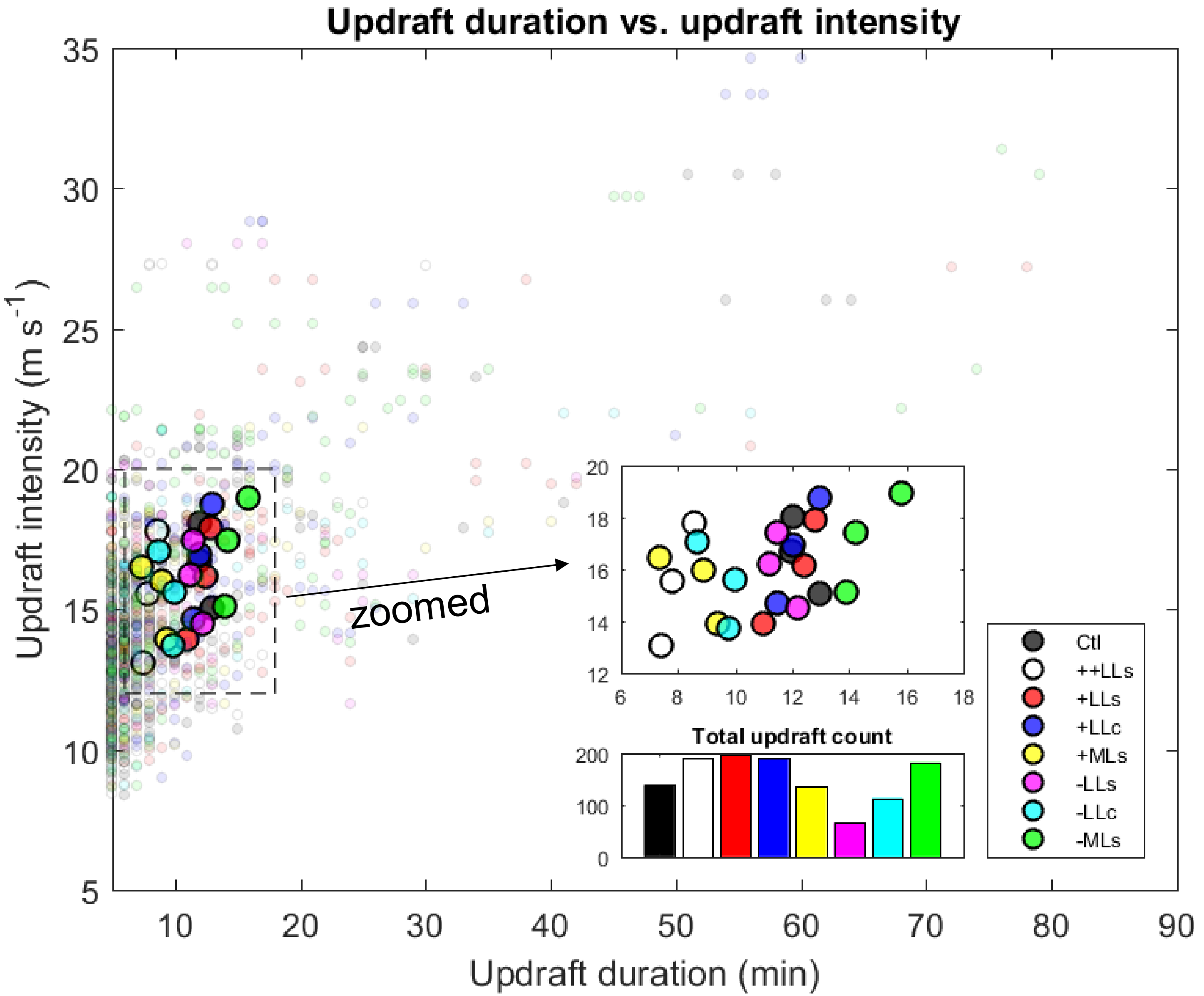
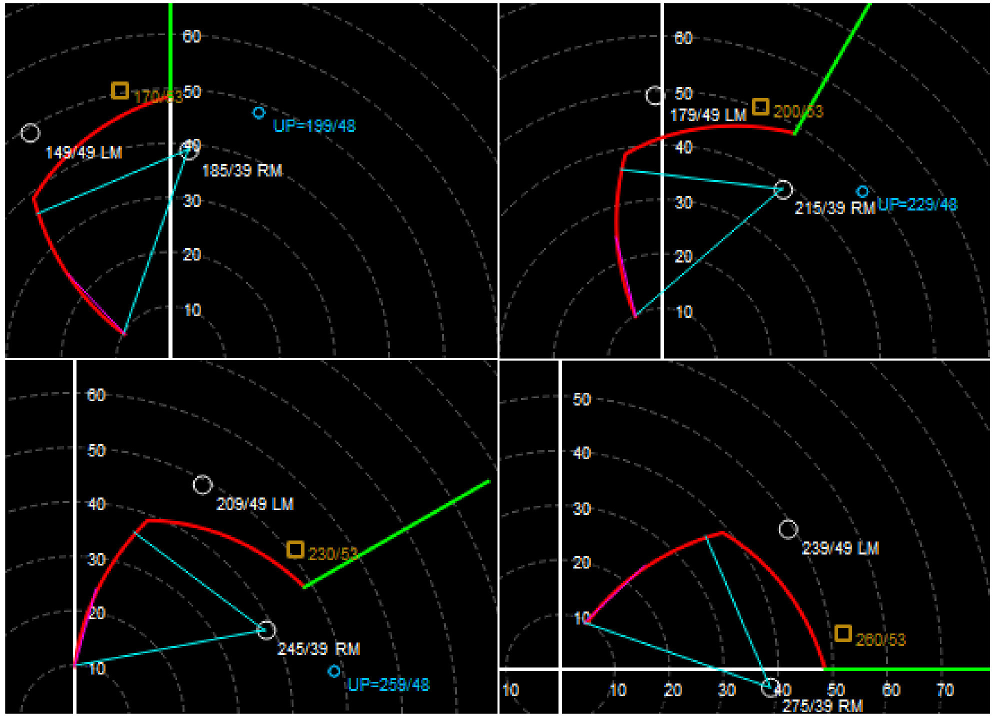
Idealized simulations: Results

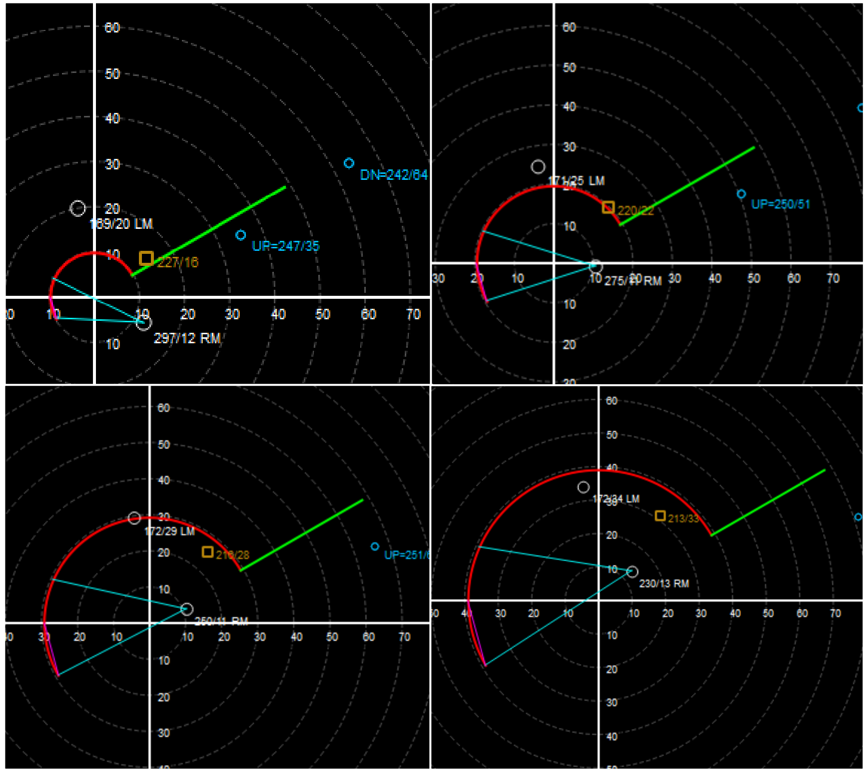


Idealized simulations: Ongoing tests



Maintain hodograph shape, vary orientation relative to initiating boundary

Similar to prior hodograph sensitivity tests, but based upon control hodograph in this matrix



Maintain hodograph shape, vary diameter of “ball cap”

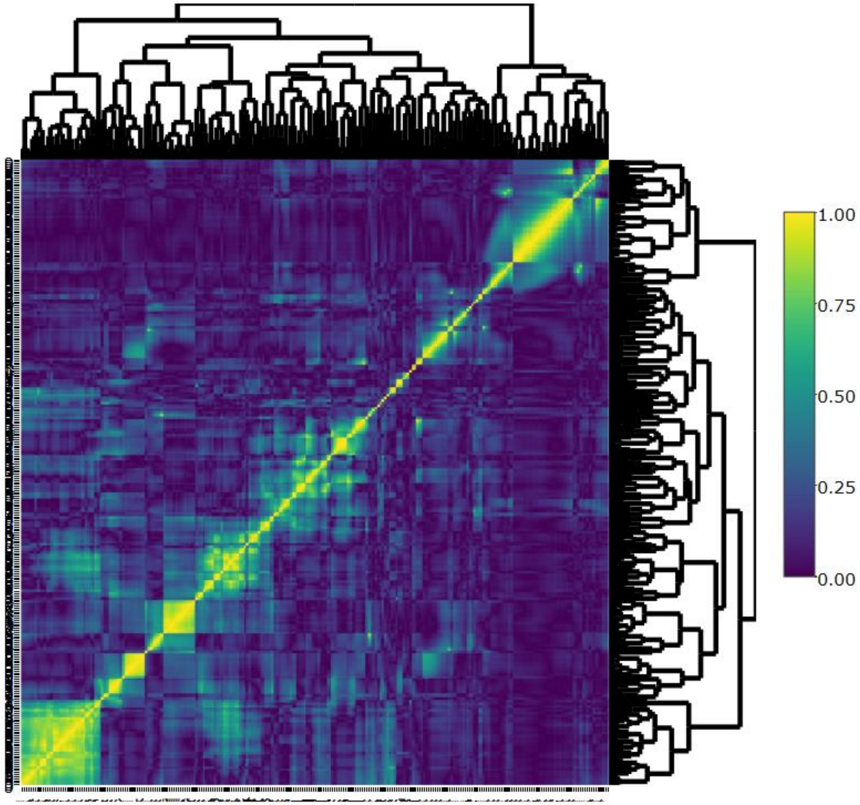
Statistical modeling: Research questions

Two primary questions:

1. Are there statistically significant differences between a tornado-producing environment and an null environment at operational grid lengths, as described by a set of pre-selected variables in HSLC severe environments?

2. What statistical techniques (and in what order/combination) can identify predictive variables, as well as determine the variables' corresponding weights of influence, to differentiate severe/nonsevere environments?

Techniques include: Clustering, linear regression, development of statistical models

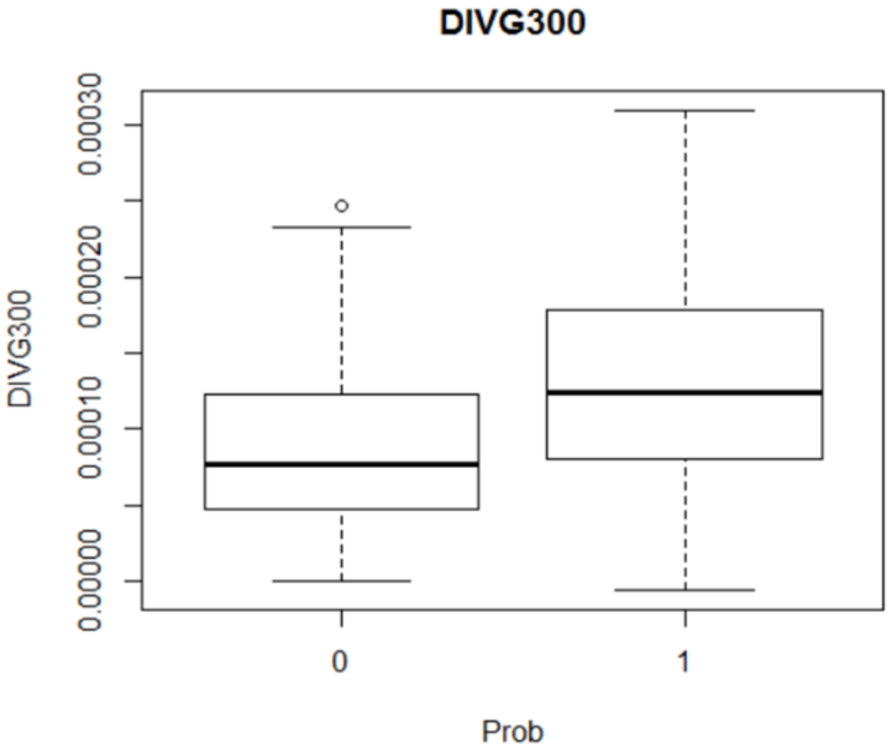


Clustering technique

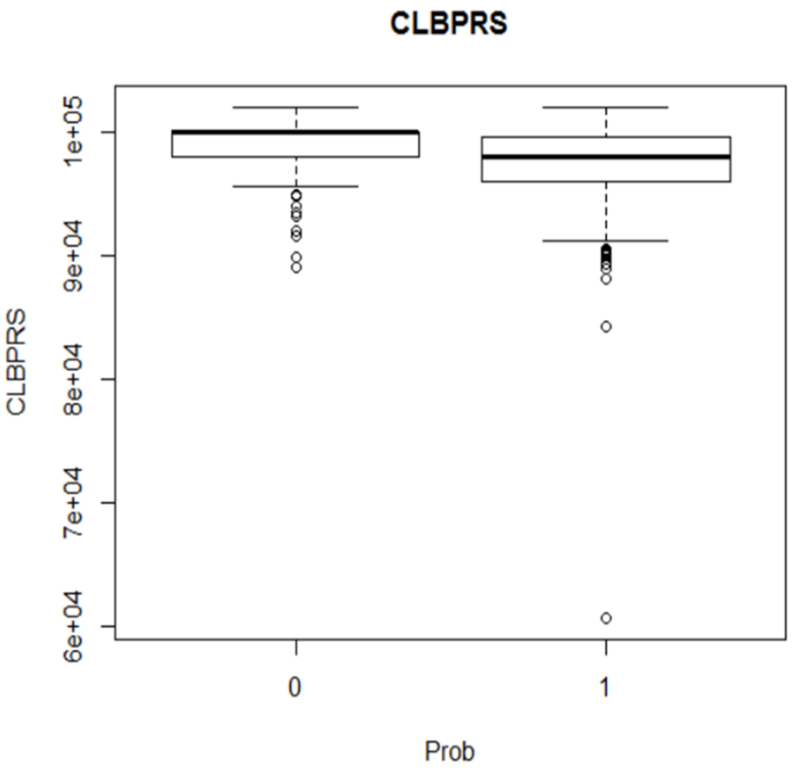
Statistical modeling: Preliminary results

Discriminators that were identified across several techniques/datasets

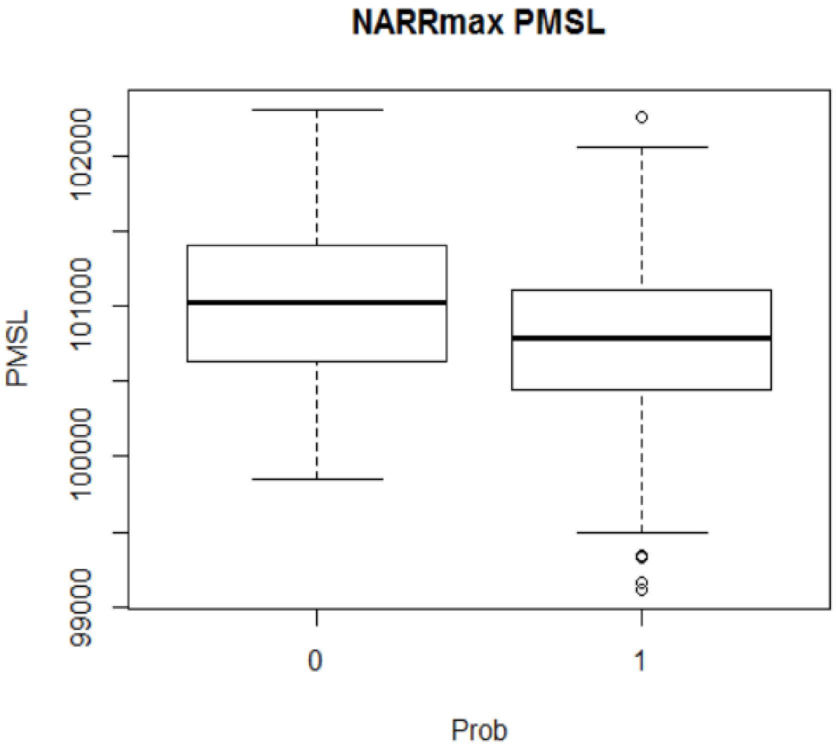
0 = null
1 = tornado report



Proxy for upper-level forcing?



Proxy for low-level stability?



Proxy for synoptic-scale forcing/shear/advection?

Summary

Five components:

- Composite maps and parameters (Sherburn et al. 2017):
  - Favorable environment coupled with strong synoptic-scale forcing for ascent critical in discriminating between severe/nonsevere
  - Combined factors distilled into MOSHE parameter available in beta form on SPC Mesoanalysis; adjustments maybe coming
- Process studies 1: Case simulations to study mesoscale/synoptic scale evolution (King et al. 2017)
  - Rapid destabilization evident in narrow temporal/spatial zone ahead of severe convection
  - Low-level θ_e advection and/or release of potential instability responsible for this destabilization
- NWP studies: Case simulations to investigate resolution requirements
  - 3.6-km, 1.2-km, and 400-m domains all represent convective mode and structure fairly well
  - From 3.6-km to 1.2-km grid spacing, potential convergence of solution
- Process studies 2: Idealized simulations to study convective-scale dynamics
  - Sensitivity studies aimed at understanding prior environmental discriminators
  - Increasing low-level shear or lapse rates appears to increase potential for strong low-level updrafts and vortices to interact
- Statistical studies: Dynamical-statistical downscaling to investigate predictability
  - In progress; several factors indicate large-scale forcing and low-level stability again among most important considerations