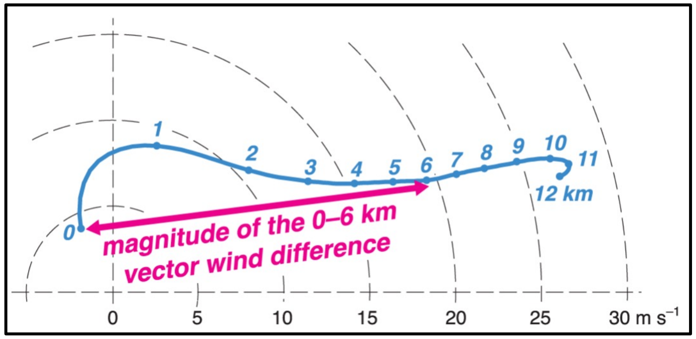
Mode of Convection

METR 4403/5403 – Spring 2024

Mode and Environment Conditions

- **Ordinary thunderstorm, multicell storms, and supercells**
- **Environment conditions (CAPE and shear) influence convective mode**
- **Vertical wind shear:**
  - **has greatest influence on thunderstorm structure and behavior (mode)**
  - **acts to promote longevity and organization of thunderstorms**
- **0–6 km bulk shear is most common measure (but it neglects details in hodograph that matter!)**
  - **< 10 m s^{-1} weak (<20 kt)**
  - **10–20 m s^{-1} moderate (20-40 kt)**
  - **> 20 m s^{-1} strong (40+ kt)**



MR (2010), Fig. 8.1

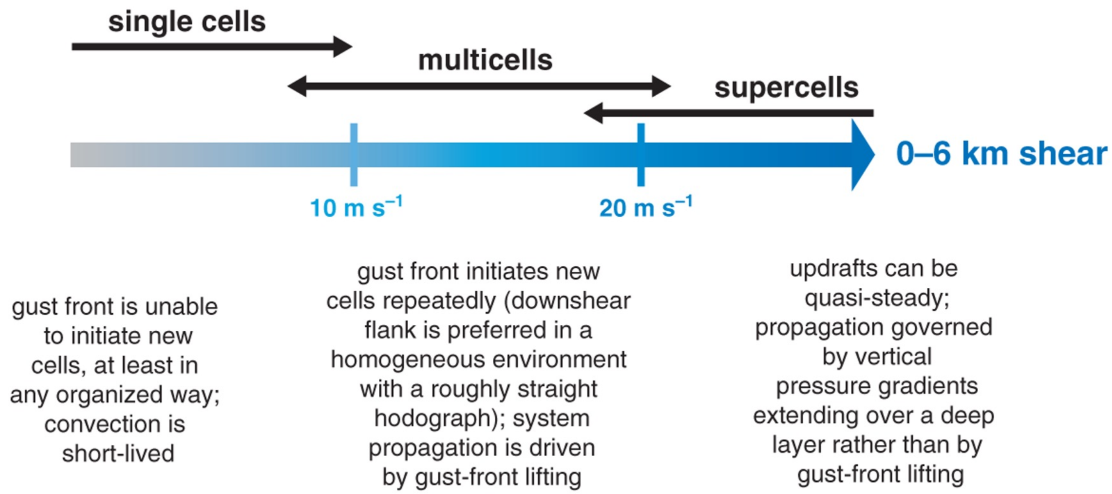


Figure 8.5

Spectrum of storm types as a function of vertical wind shear. Although the vertical shear exerts the greatest influence on storm type, other secondary factors can also affect the mode of convection (e.g., vertical distribution of buoyancy, moisture, and shear, as well as the means by which storms are initiated); thus, some overlap among storm types exists in this simple single-parameter depiction. The relationship between vertical wind shear magnitudes and the nature of cell regeneration/propagation is also shown. MR (2010)

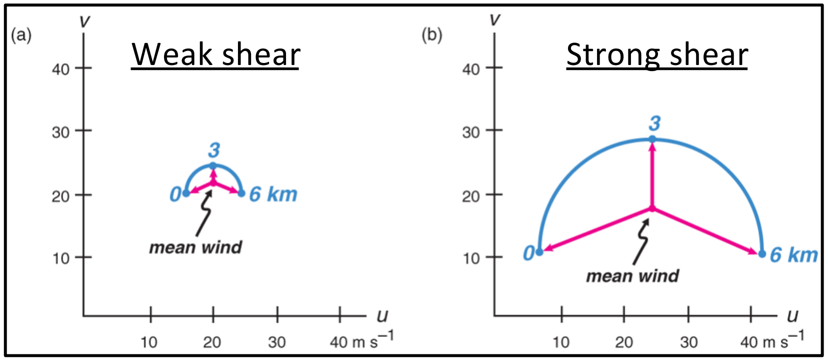
Importance of Vertical Shear

- **Interference between precipitation and updraft is reduced as vertical shear increases**

- **Precipitation falls downwind of updraft**
  - **Strong storm-relative winds aloft blows precipitation away from updraft core**

- **Storm-relative inflow at low-levels can slow speed of gust front, limiting its ability to undercut updraft**

- **Dynamic pressure effects via vertical PGF in shear can produce strong lifting**



MR (2010), Fig. 8.2

Ordinary Thunderstorm (single cell)

- **Consists of one updraft, outflow gust front spreads in all directions**
- **Forms in weak shear and modest CAPE, in weak synoptic forcing and typically occur just after max daytime heating**
- **Pulse severe possible (wind, hail)**
- **Lifetime approximated as** $\boldsymbol{\tau = \frac{H}{w_0} + \frac{H}{v_t}}$

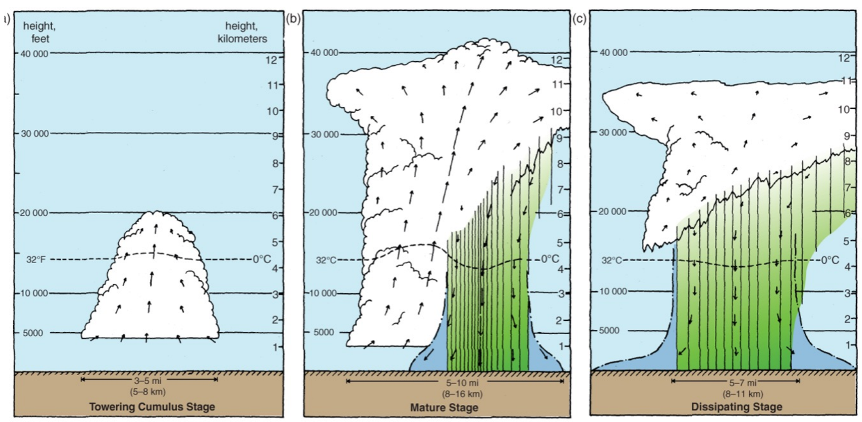
H=scale height
w_0=average updraft speed
v_t=terminal velocity of precipitation

Time for precipitation produced by ascent to fall to ground ($\frac{H}{v_t}$)

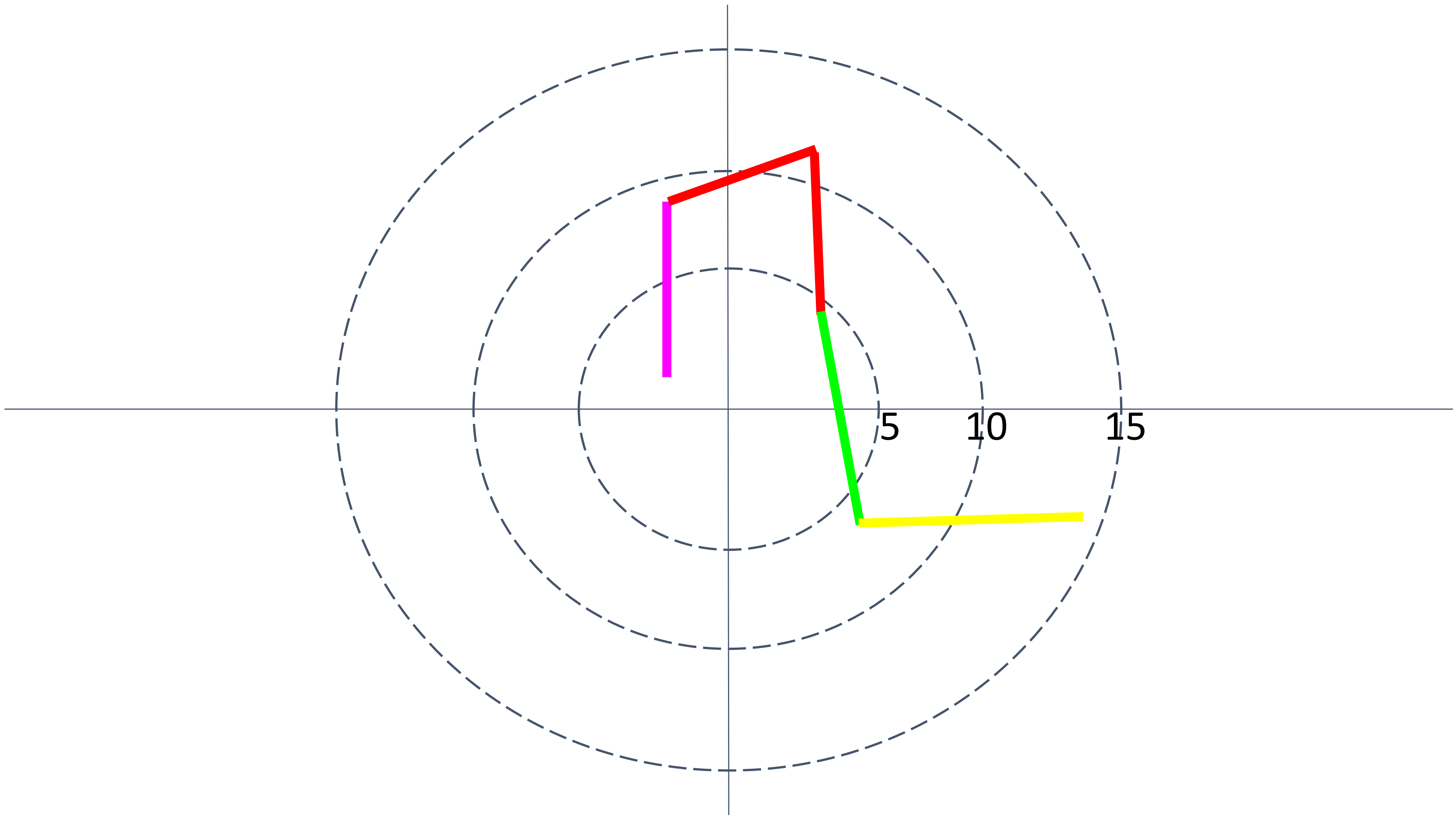
Time for air to ascend from surface to EL ($\frac{H}{w_0}$)

$$\tau = \frac{10^4\,m}{10\,m\,s^{-1}} + \frac{10^4\,m}{10\,m\,s^{-1}} = 10^3\,s + 10^3\,s = 2000\,s = 30\,min$$

- **Life cycle:**
  - **Towering cumulus (only updraft)**
  - **Mature (precipitation falls into updraft, downdraft and gust front forms, anvil forms)**
  - **Dissipating stage (downdraft cuts off updraft; orphan anvil)**



MR (2010), Fig. 8.8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Multicell Convection

- Characterized by repeated development of new cells along the gust front

- Longer-lived cluster of storms in moderate vertical shear and small to large CAPE

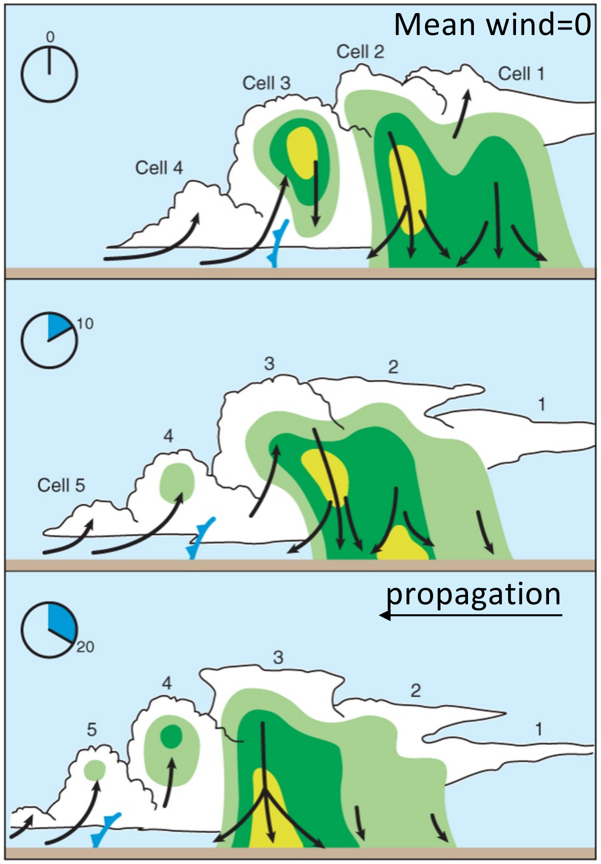
- Individual storms in cluster may be ordinary, lasting 30-60 mins

- In high CAPE moderate shear, multicell convection can produce swaths of damaging winds and hail

MR (2010), Fig. 8.9

Evolution of Multicell Convection

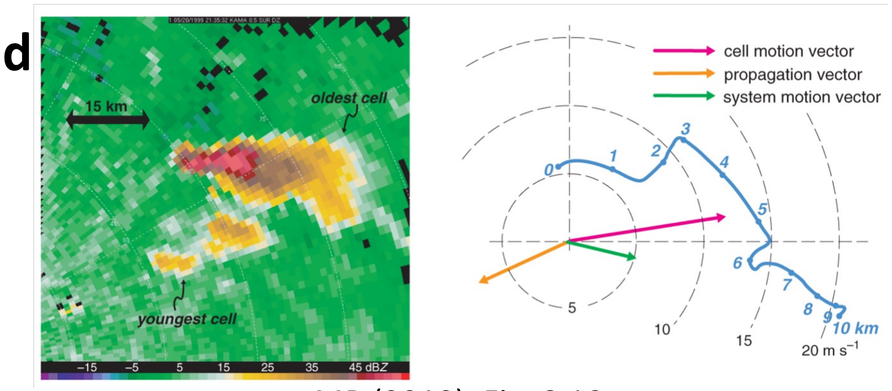
- Individual cells move with the mean wind averaged over their depth
- New cells initiate along gust front
- @ Time 0:
  - Cell 1 – dissipative stage
  - Cell 2 – mature stage
  - Cell 3 – precipitation beginning to form
  - Cell 4 – towering cumulus stage
- @ Time 10:
  - Cell 1 – orphan anvil
  - Cell 2 – dissipative stage
  - Cell 3 – mature stage
  - Cell 4 – precipitation beginning to form
  - Cell 5 – towering cumulus stage
- @ Time 20: …and so on.



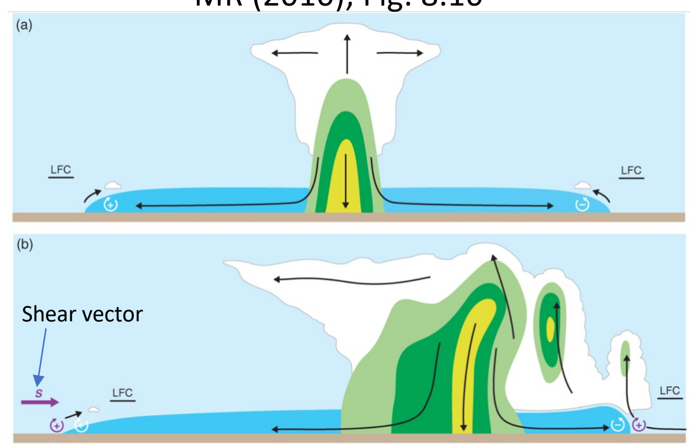
MR (2010), Fig. 8.11

Movement versus propagation

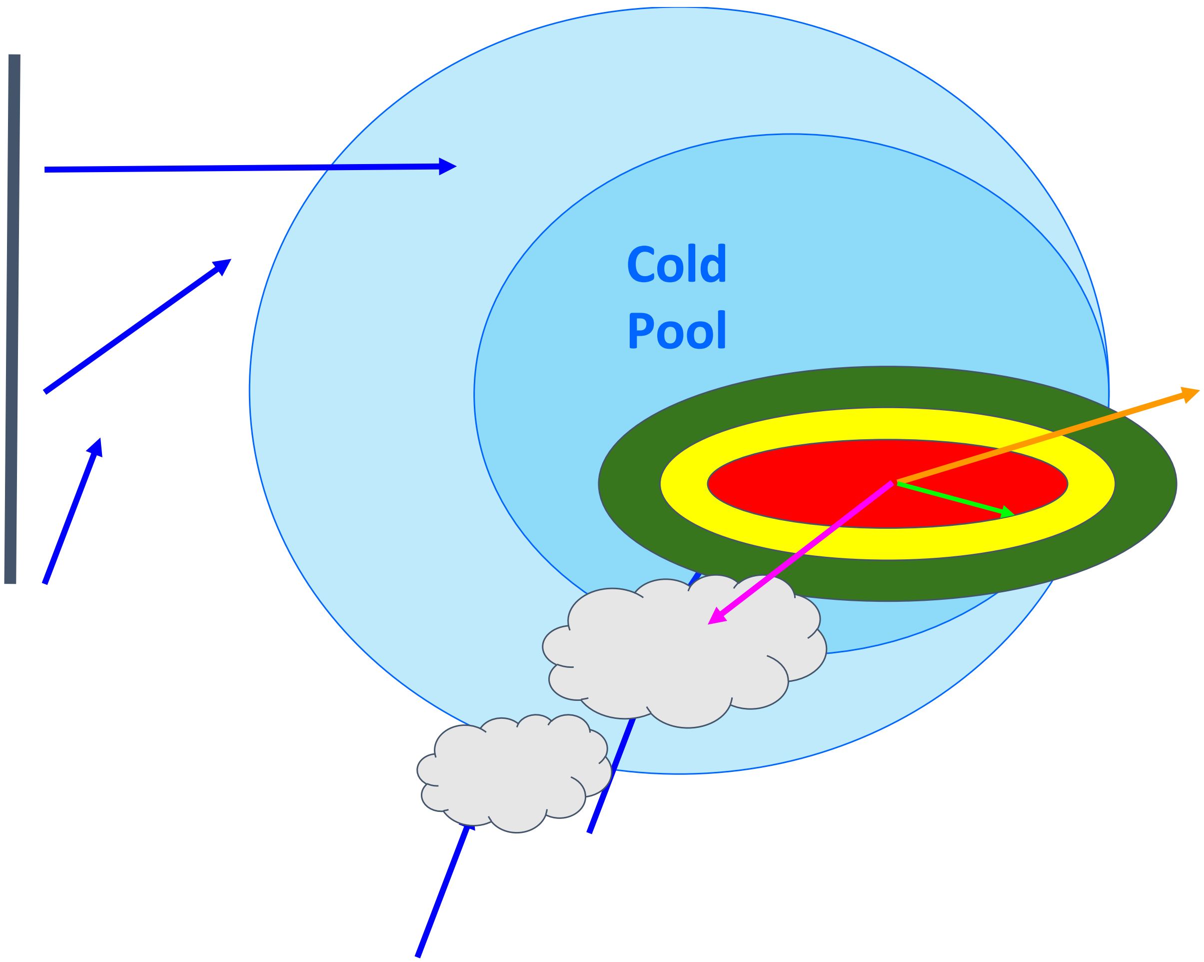
- **Individual cells move with the mean wind**
- **Repeated development of new cells on flank of system leads to propagation of system**
- **Total motion is cell motion+propagation**
- **New cells develop on gust front on downshear side of cold pool**
- **Will cover more of this with MCS motion later**



MR (2010), Fig. 8.10

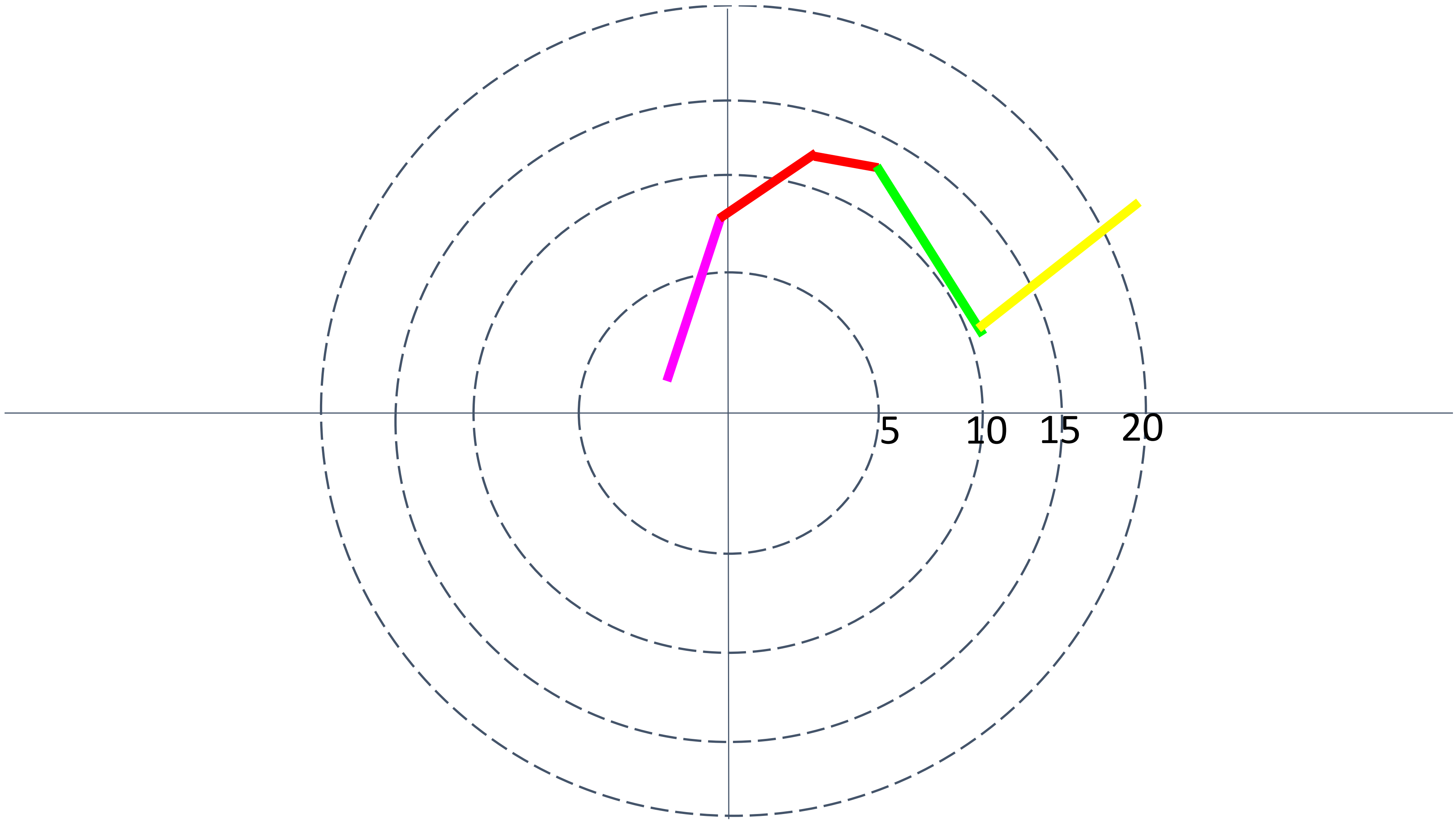


MR (2010), Fig. 8.12



Multicell system motion can be difficult to determine. It is a combination of new cell development (propagation) and the mean cell motion

- Cell motion vector (mean wind)
- New cell development (propagation vector)
- Net system motion vector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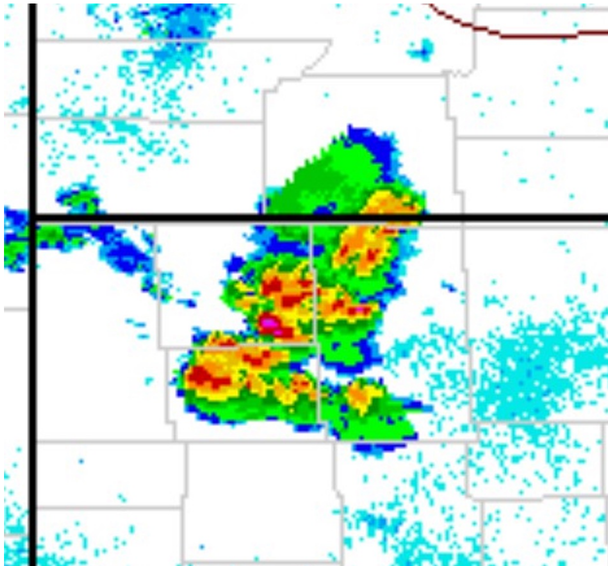
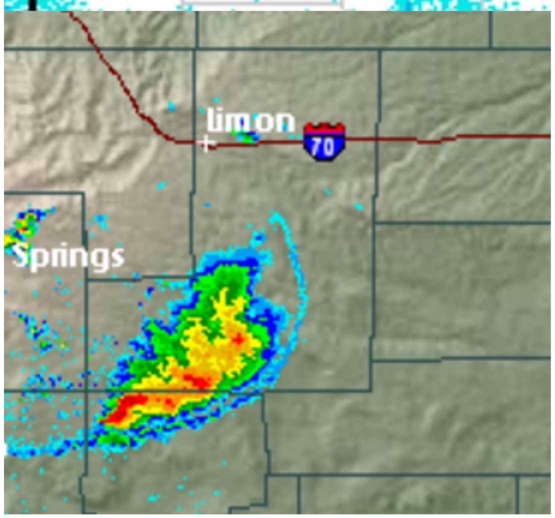
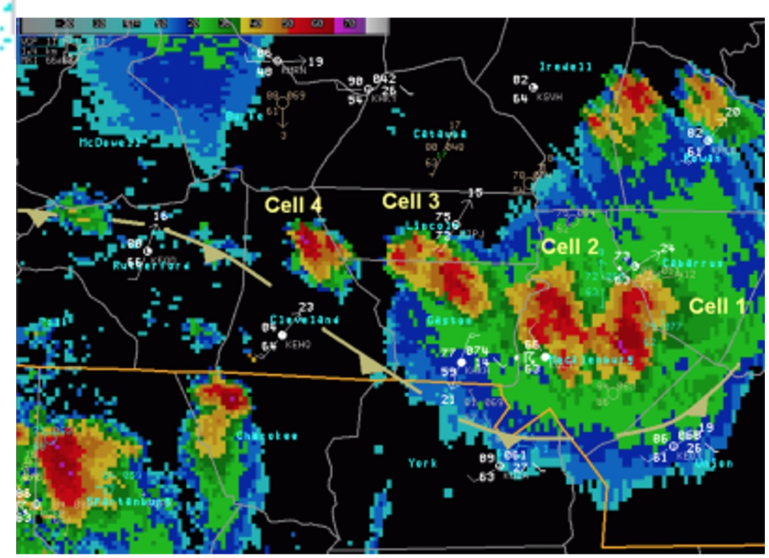
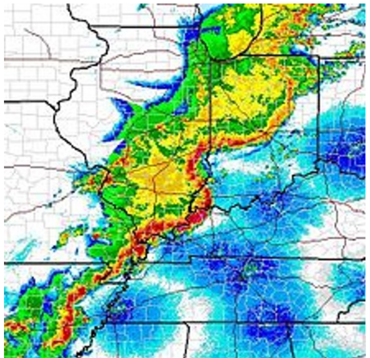


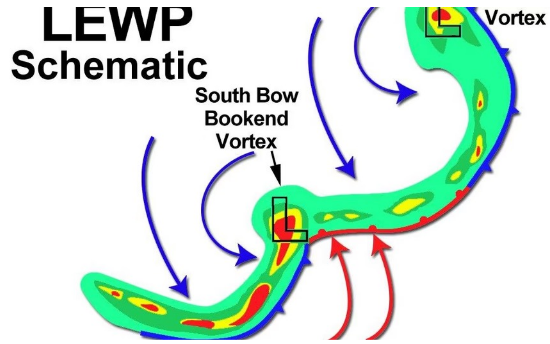
Multi Cell Clusters

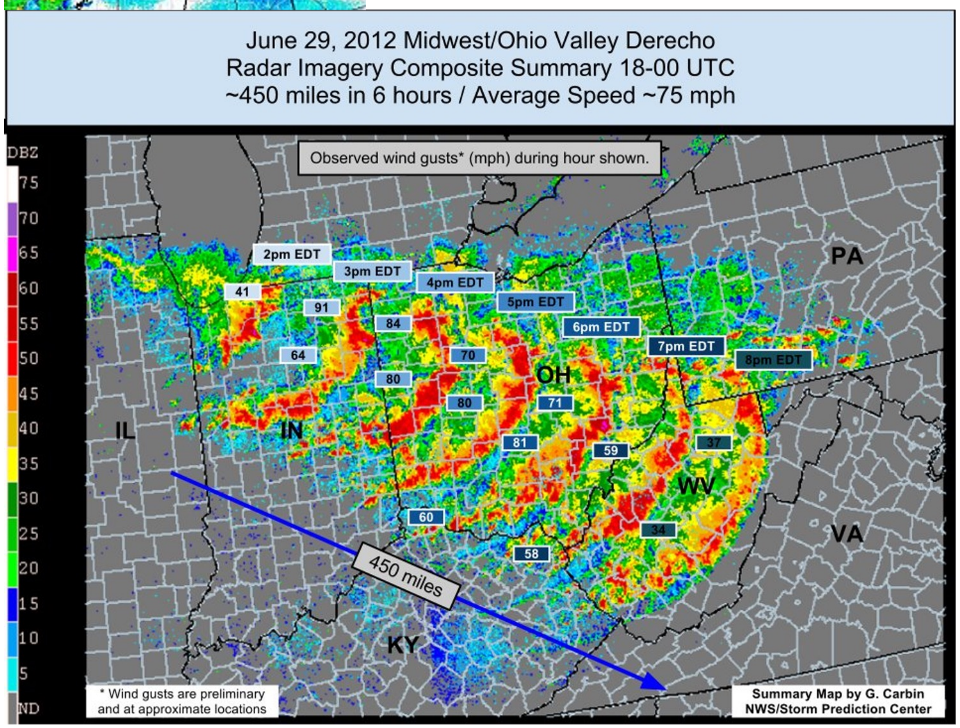
- Aggregates of multi-cell storms are common over parts of the Southeast in the summer. Each storm can be in a different phase of the life cycle.
- Can act as a loosely organized MCS or as vague as a large convective blob.
- Forcing is usually weak and the primary risk is damaging outflow winds from collapsing storms but can also produce hail.





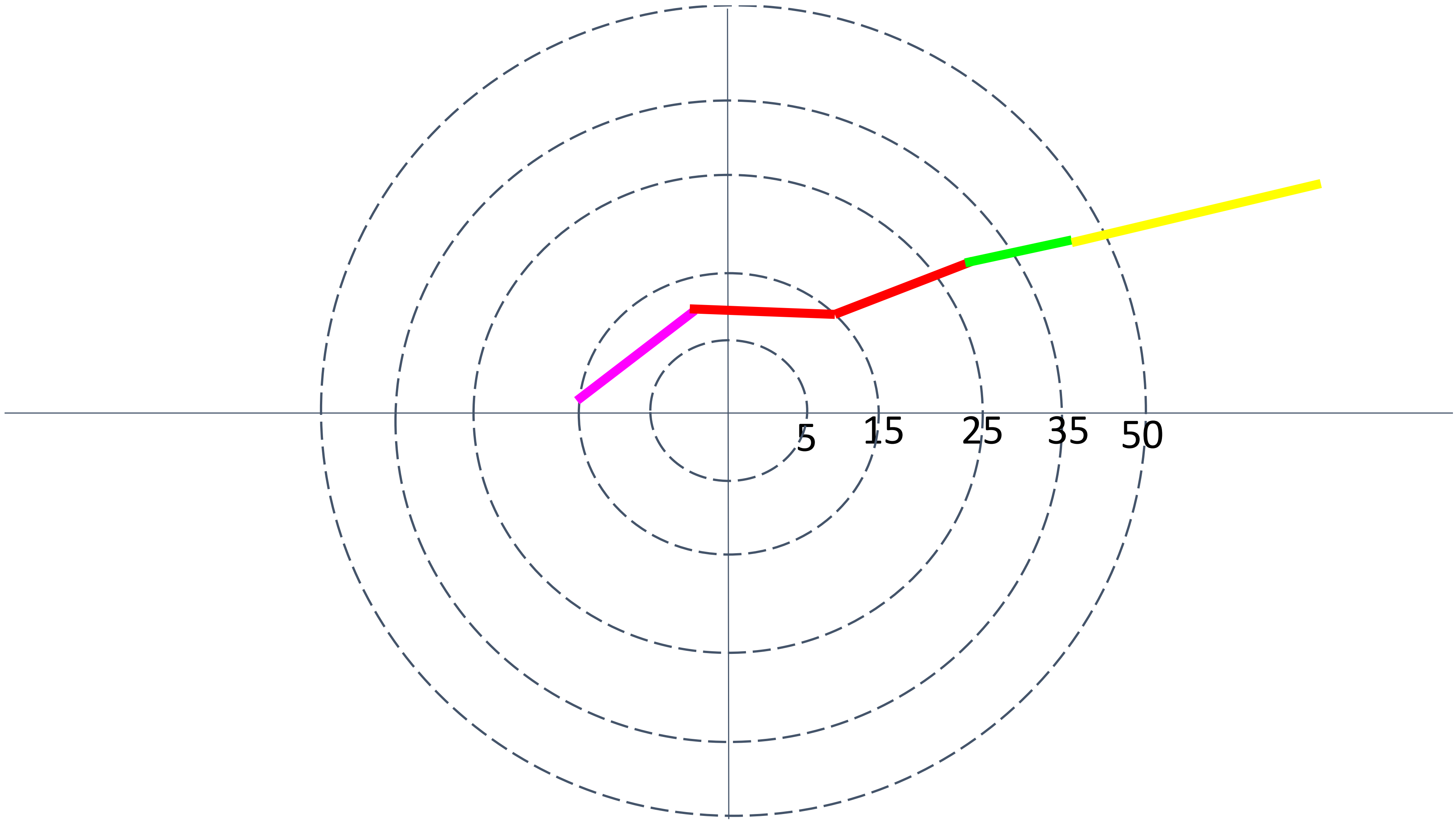






Multi Cell Lines

- Collections of multicell storms along a line with a large length to width ratio.
- Can take multiple forms
  - Serial MCS
  - Progressive MCS
  - LEWPs (line echo wave patterns)
  - Bow echos
  - Derechos
- Usually more organized than clusters with stronger vertical shear.
- Can produce Damaging wind gusts tornadoes and some hail.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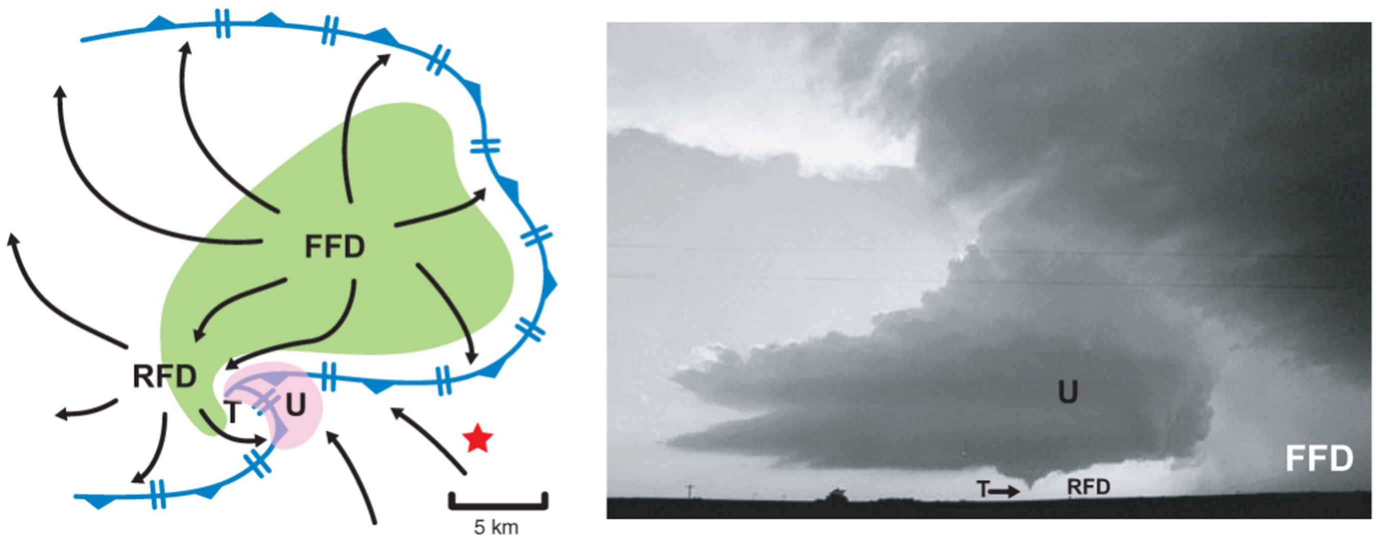
Supercells

- **Characterized by a thunderstorm with a sustained, deep, rotating updraft → mesocyclone**
- **Occur in strong vertical shear through a deep layer (big storm-relative winds), but high CAPE not necessary**
- **Motion deviates significantly from mean wind**
- **Vertical PGF enhances updraft, a special property of supercells**

MR (2010), Fig. 8.17

Supercell Features

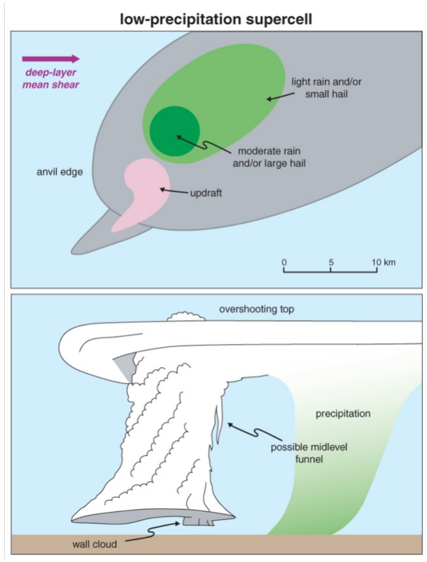
- Single, long-lived, quasi-steady, rotating, precipitation free, updraft
- Wall cloud at updraft base where humid, rain-cooled air drawn upward
- Two downdraft regions: rear flank downdraft (RFD) and forward flank downdraft (FFD)



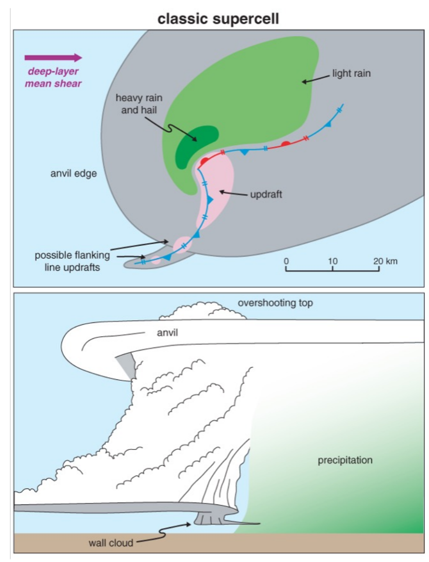
MR (2010), Fig. 8.22

Supercell Types

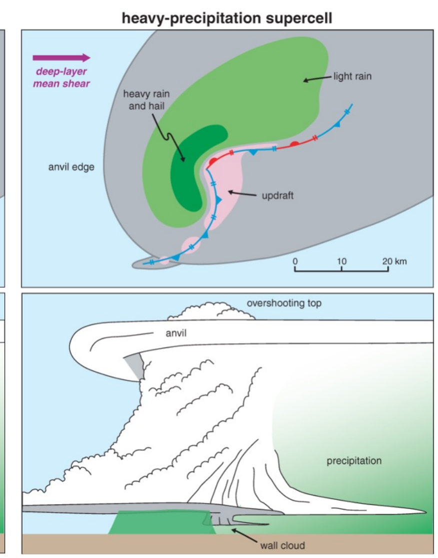
- **For isolated storms, supercell type is <u>(maybe)</u> a function of storm-relative winds (SRW) at level of anvil (9–12 km AGL)**
- **Weak upper-level storm-relative winds (<18 m/s): HP; moderate (18-28 m/s): classic; strong (>28 m/s): LP**
- **For multiple storms in close proximity, precipitation from one storm may seed another storm, favoring HP types**
- **Stronger SRW favors larger updrafts resistant to entrainment.**



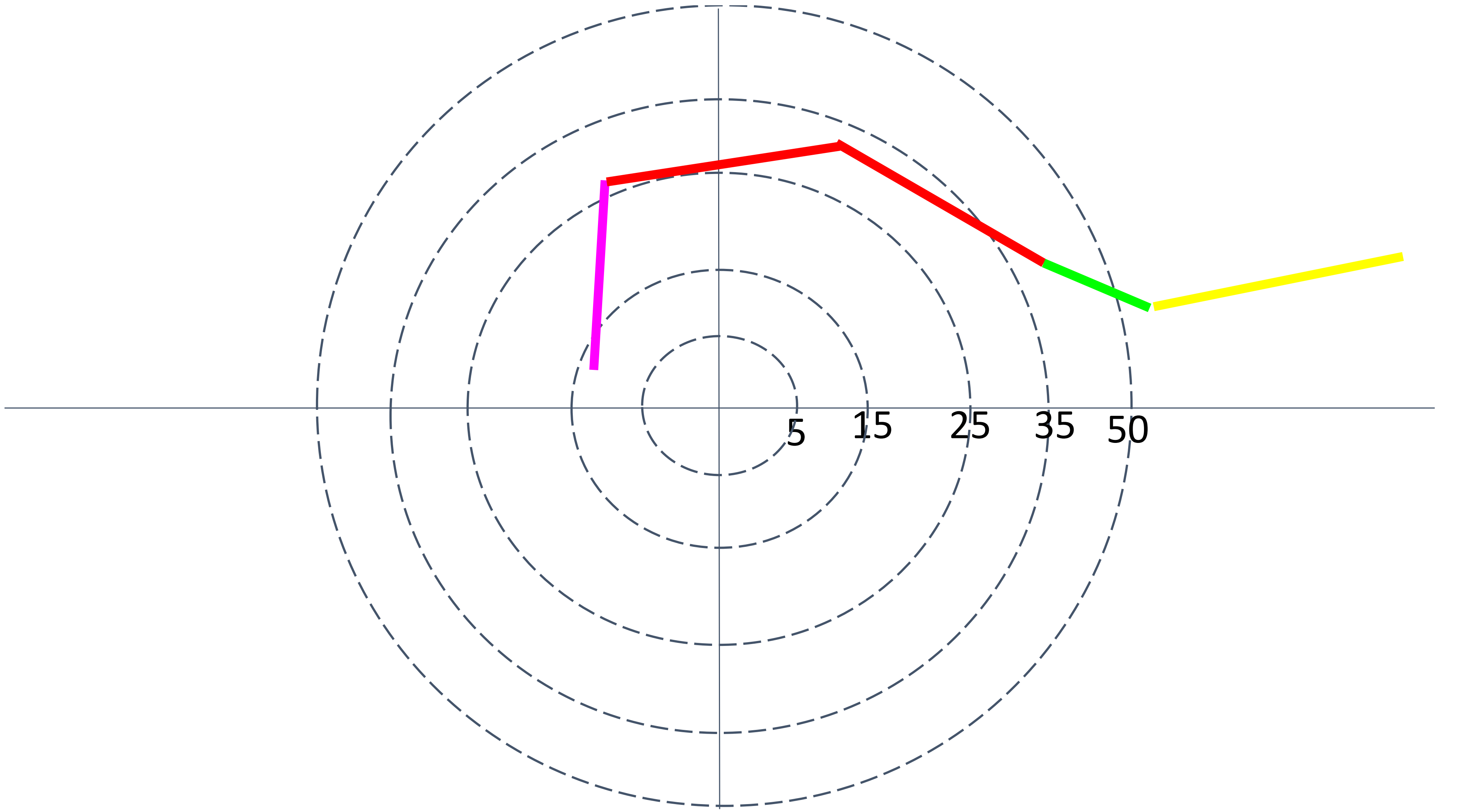
MR (2010), Fig. 8.24



MR (2010), Fig. 8.16



MR (2010), Fig. 8.26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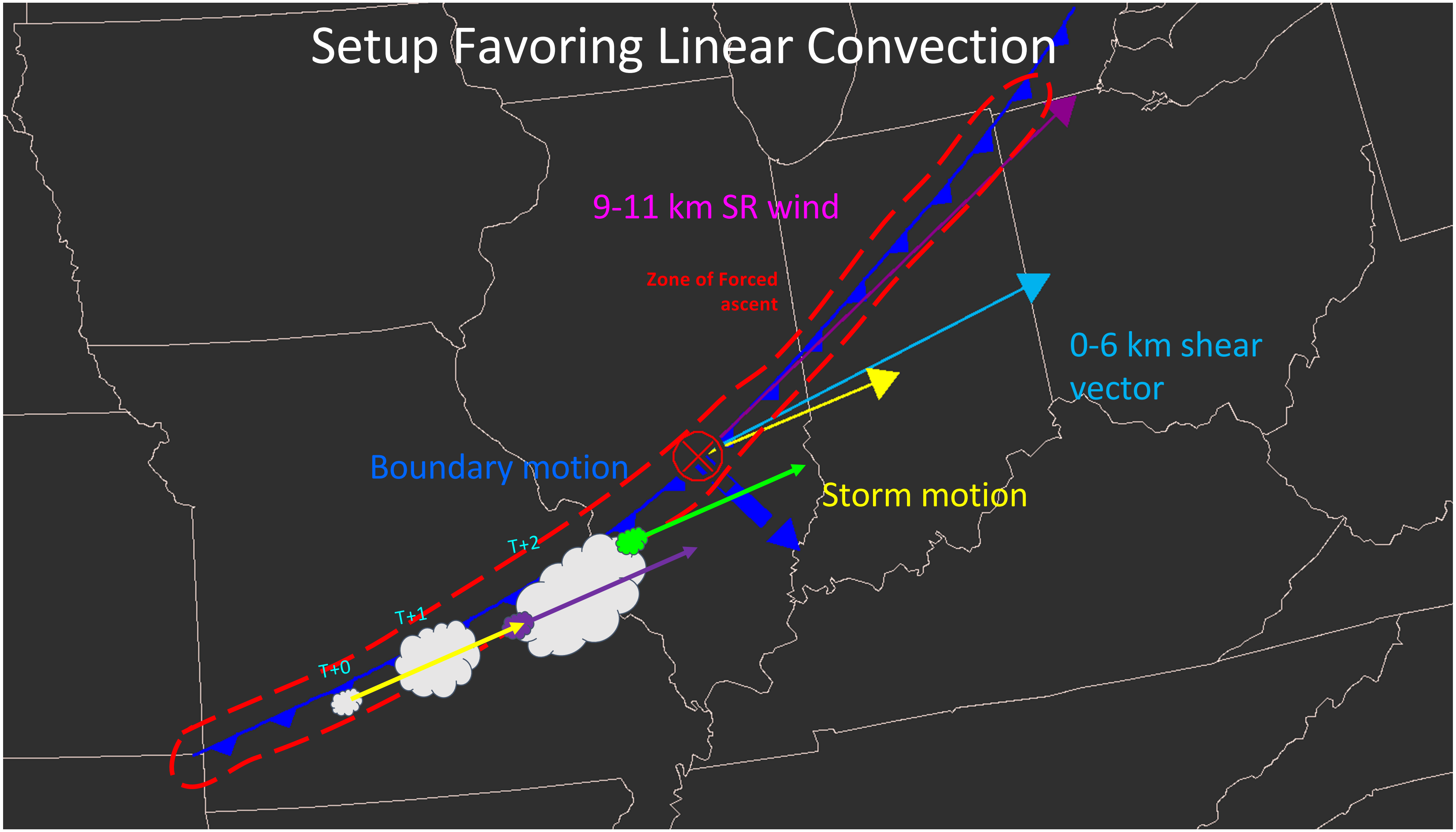
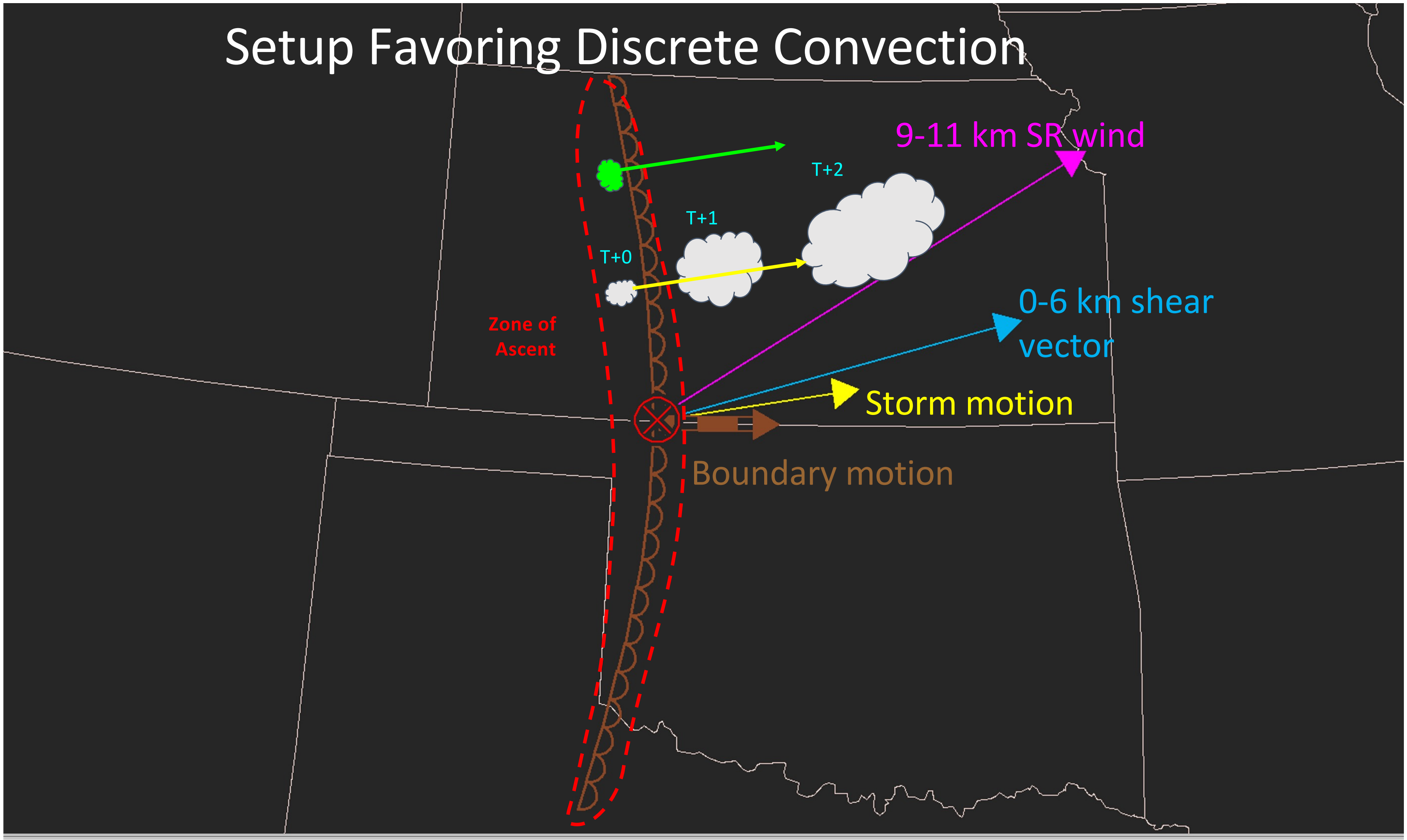


Setup Favoring Linear Convection
9-11 km SR wind
Zone of Forced ascent
0-6 km shear vector
Boundary motion
Storm motion
T+2
T+1
T+0

Recipe for a Squall Line

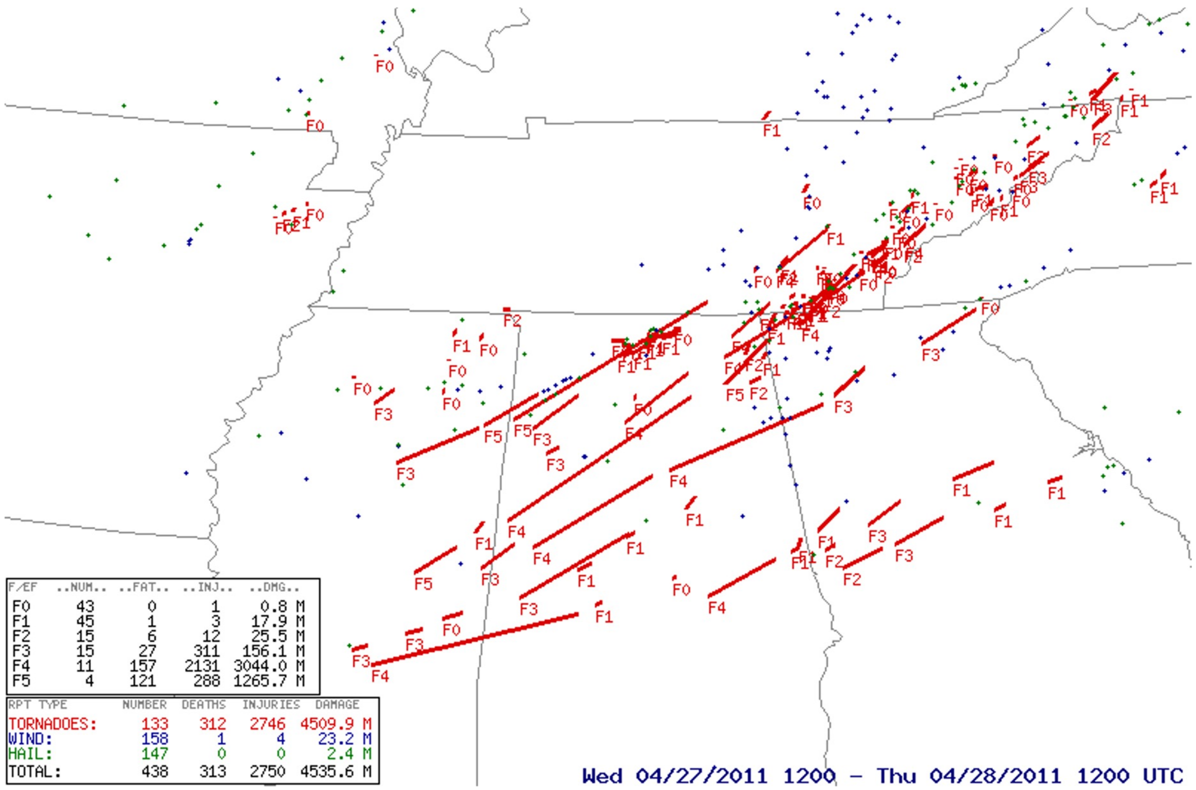
- **Deep-Layer flow, shear vectors, and SR winds largely parallel to boundary**
  - **Overlapping and interacting storms**
- **Strong linear convergence (ascent) along the boundary**
  - **Form lots of storms close to one another**
- **Storms do not move away from the zone of ascent**
  - **Longer residence time in the zone of ascent leads to more updrafts and more mature updrafts interacting with each other.**


Setup Favoring Discrete Convection
9-11 km SR wind
T+2
T+1
T+0
0-6 km shear vector
Zone of Ascent
Storm motion
Boundary motion

Recipe for Discrete Storms

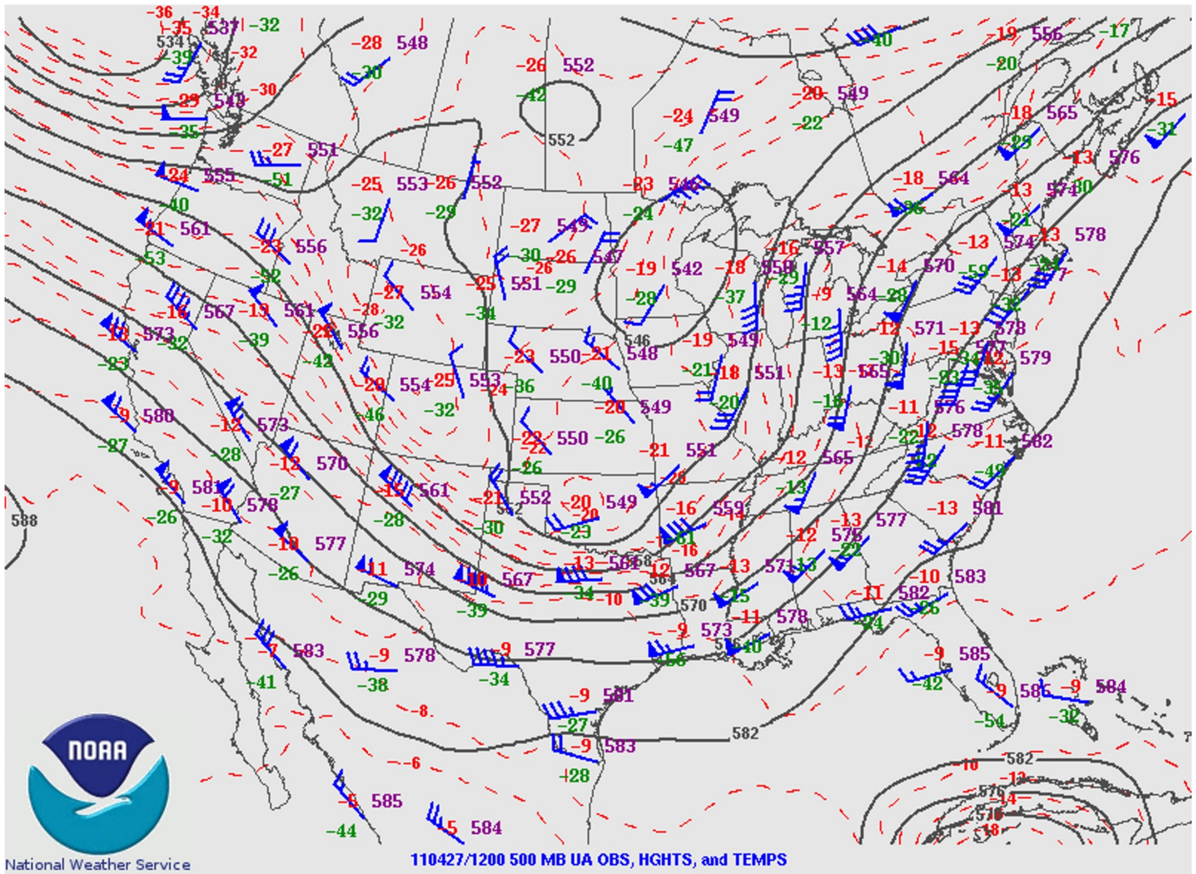
- **Deep-Layer flow, shear vectors, and SR winds oriented across a boundary**
  - **Storms tend to not interact (need to also consider storm splitting)**
- **Weaker convergence (ascent) along the boundary**
  - **Fewer storms form**
- **Storms move away from the zone of ascent faster**
  - **Less chance for upscale growth into a line**

27 April 2011 Supercell Mode Case



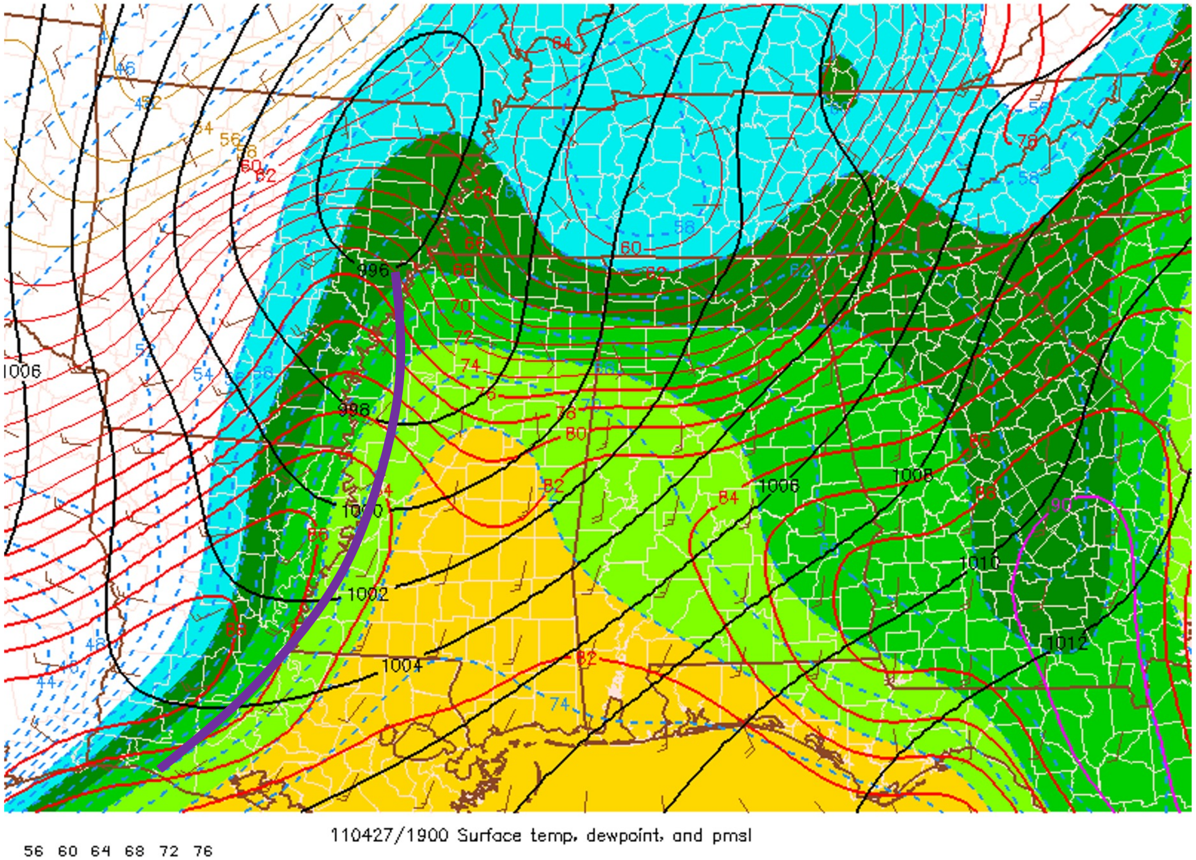
F/EF	..NUM..	..FAT..	..INJ..	..DMG..
F0	43	0	1	0.8 M
F1	45	1	3	17.9 M
F2	15	6	12	25.5 M
F3	15	27	311	156.1 M
F4	11	157	2131	3044.0 M
F5	4	121	288	1265.7 M

RPT TYPE	NUMBER	DEATHS	INJURIES	DAMAGE
TORNADOES:	133	312	2746	4509.9 M
WIND:	158	1	4	23.2 M
HAIL:	147	0	0	2.4 M
TOTAL:	438	313	2750	4535.6 M



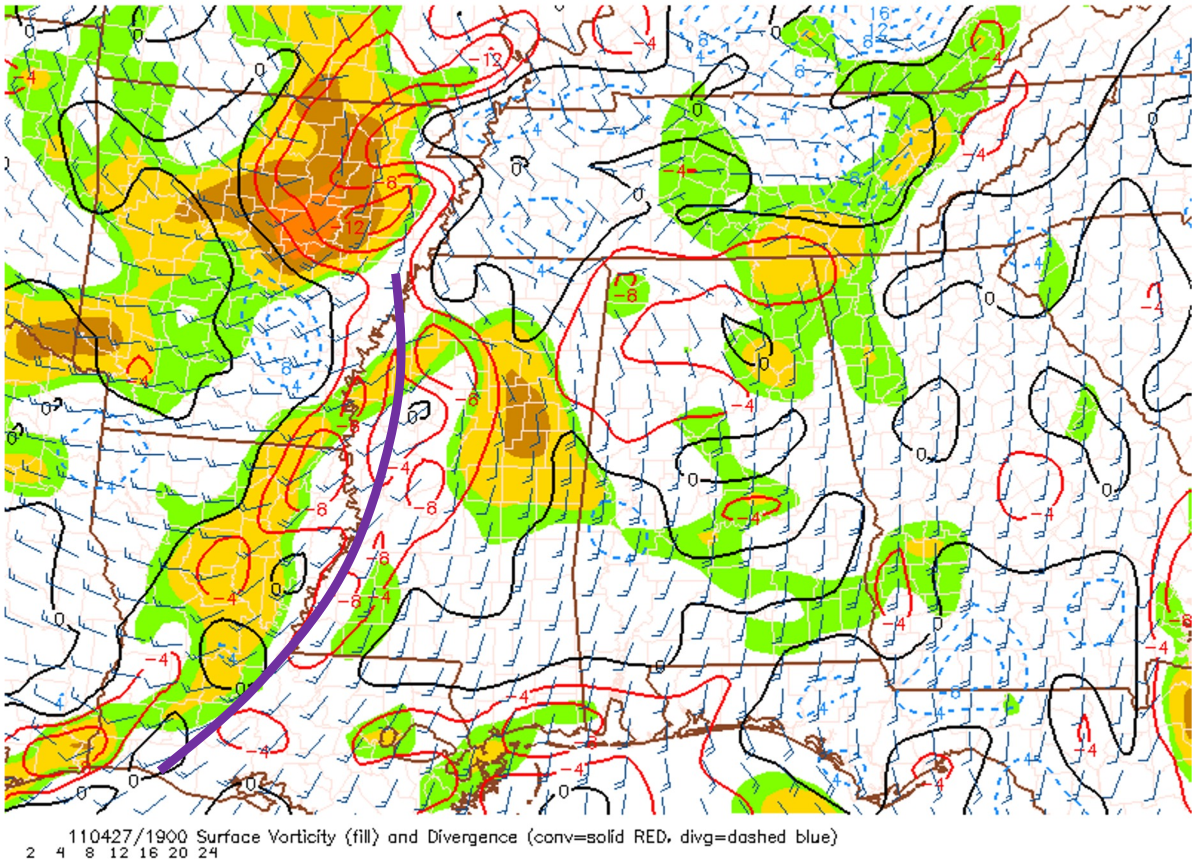
27 APR 2011 12z

Surface T, Td, and PMSL



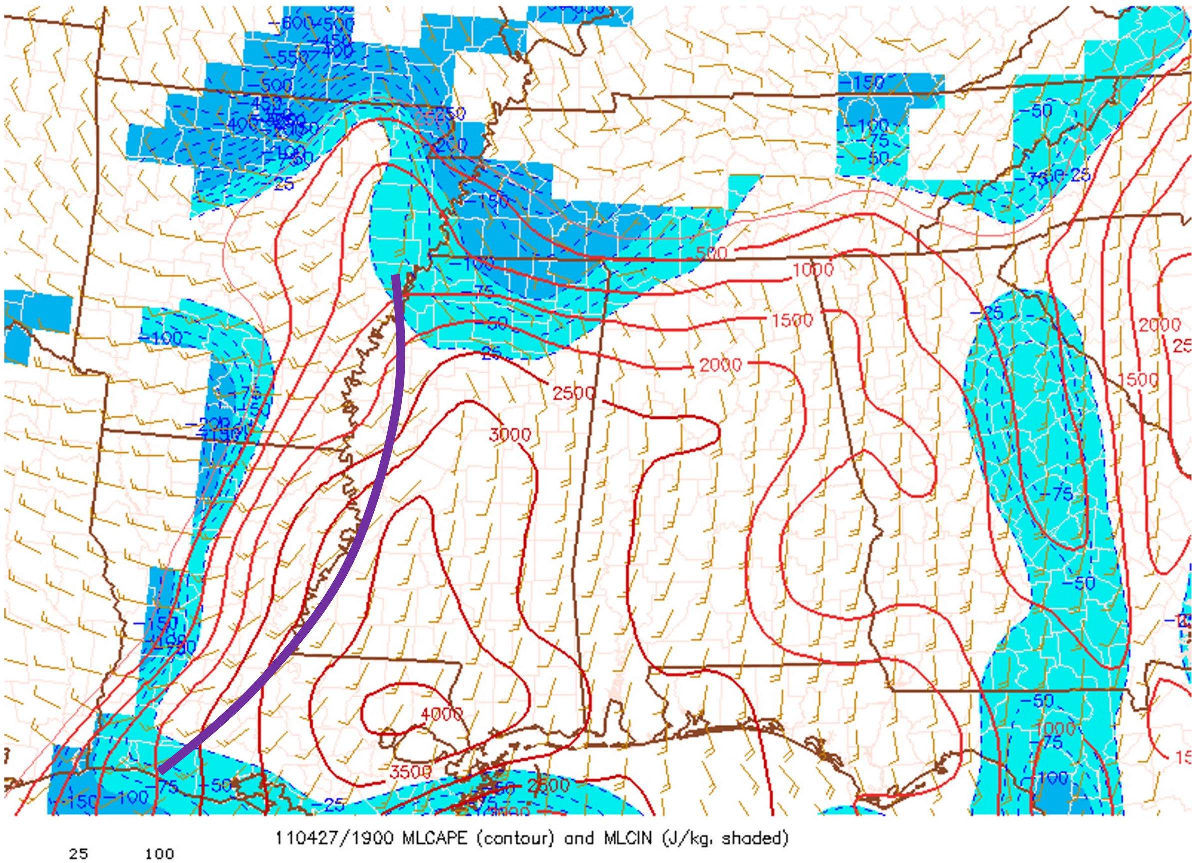
27 APR 19z

Surface convergence and vorticity



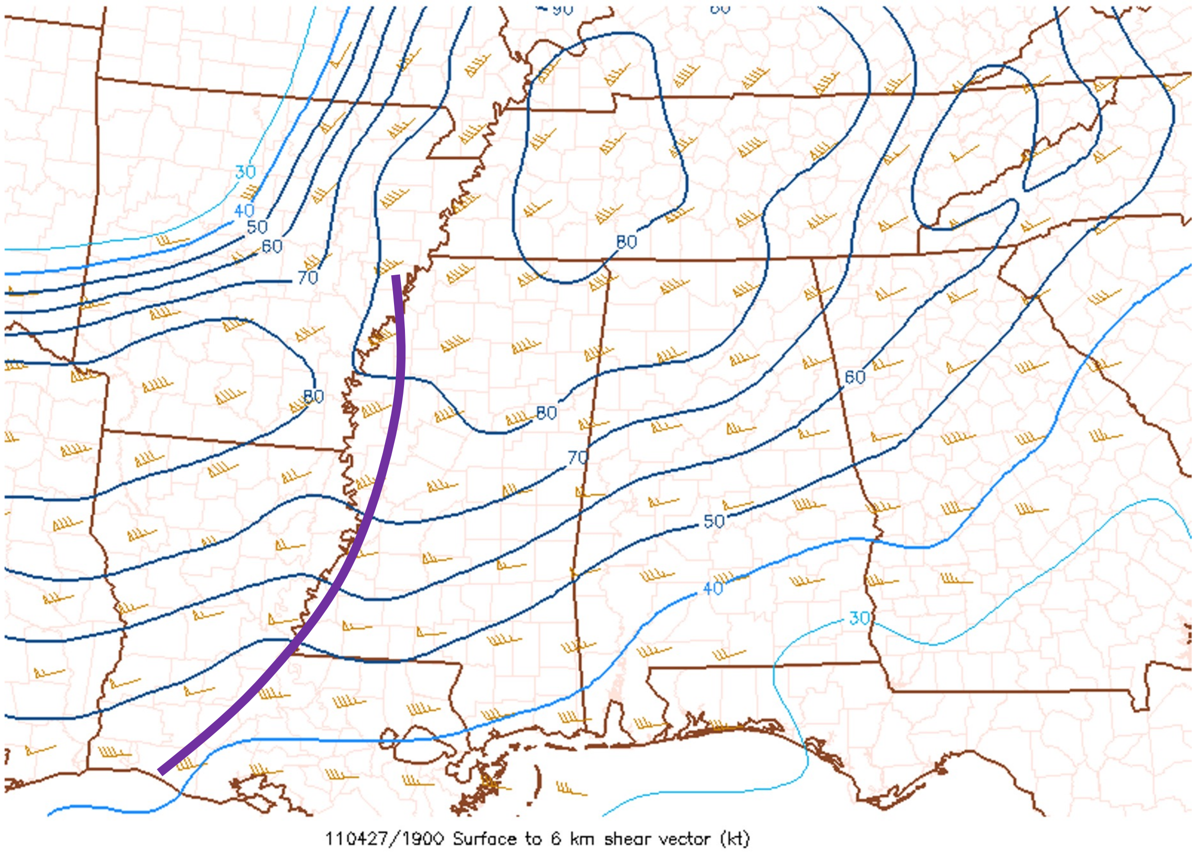
27 APR 19z

MLCAPE and MLCIN



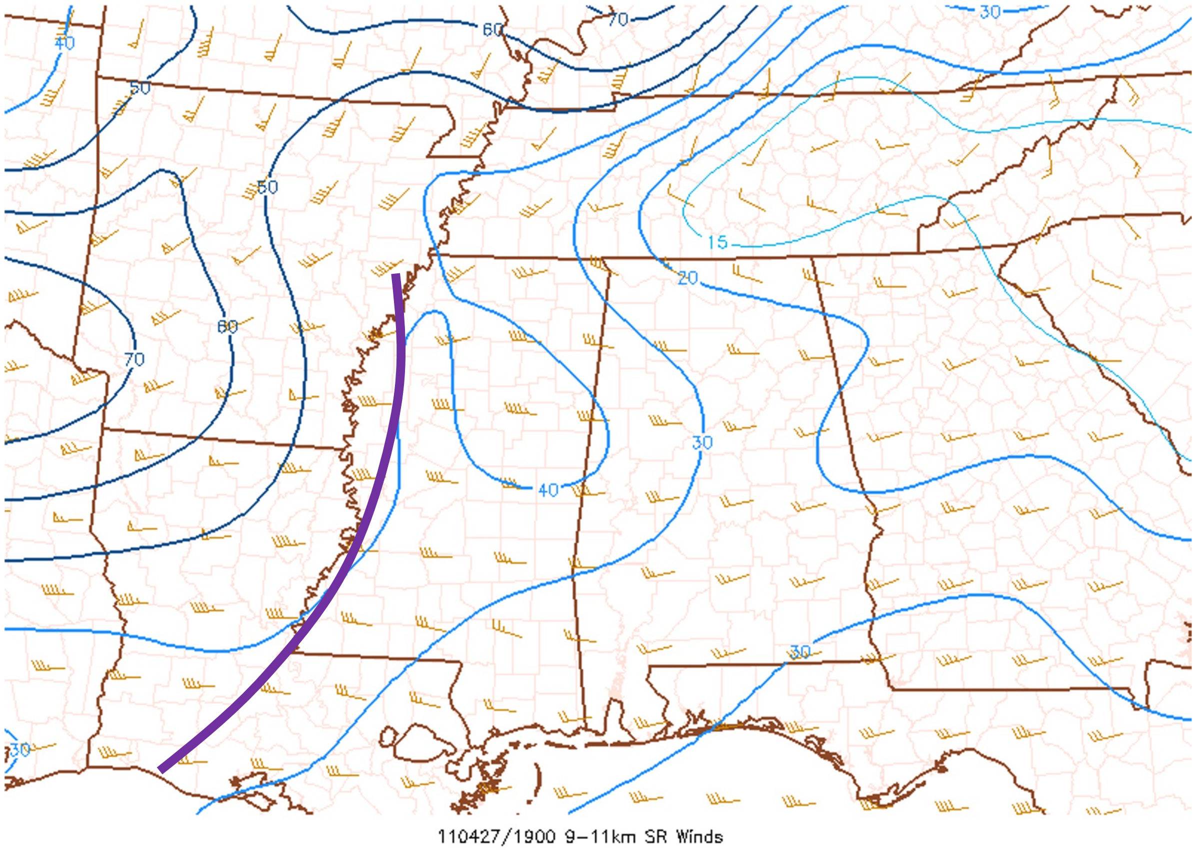
27 APR 19z

0-6 km shear vectors

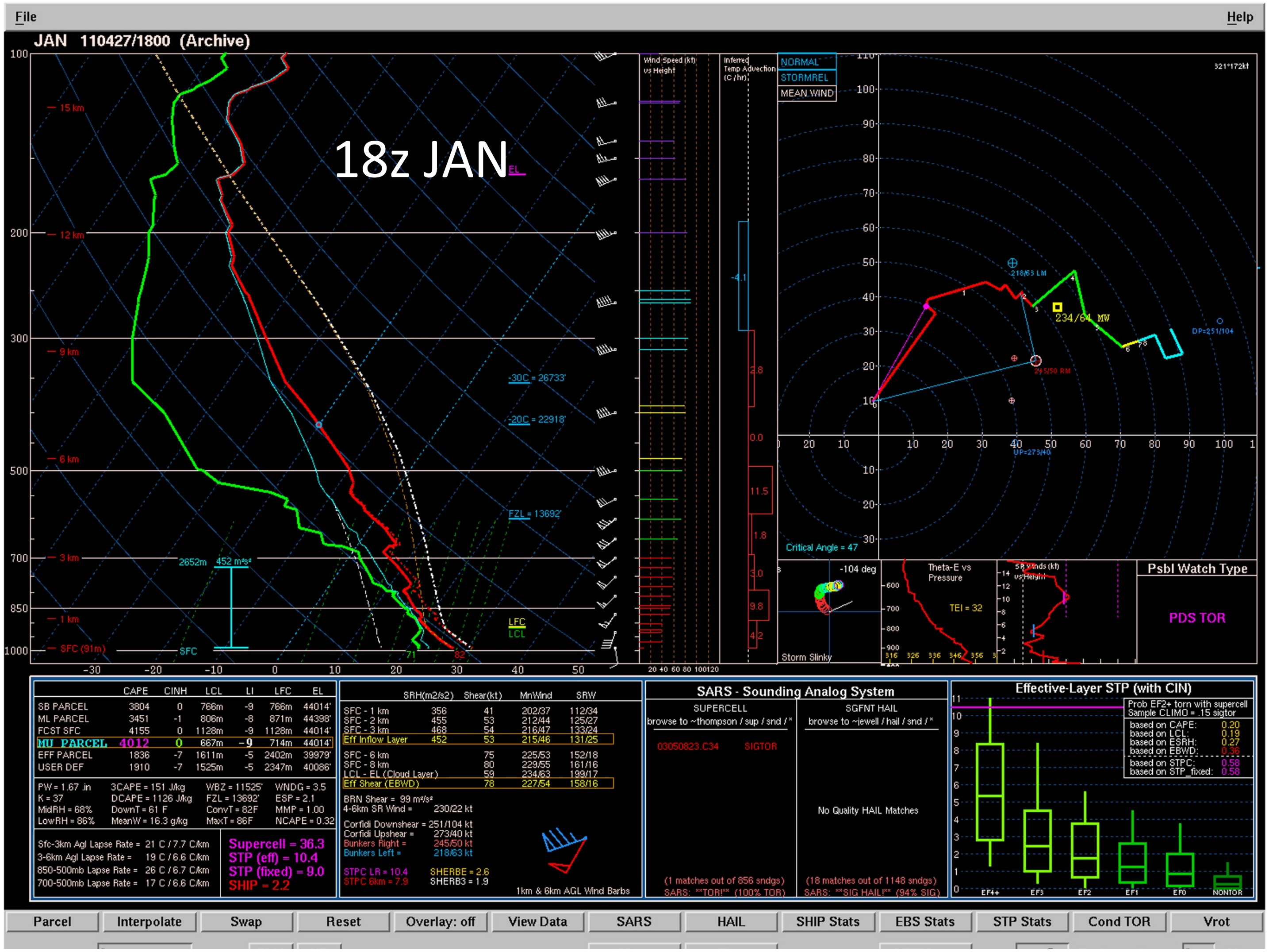


27 APR 19z

9-11 km storm-relative winds



27 APR 19z


File
Help
JAN 110427/1800 (Archive)
18z JAN
-30C = 26733'
-20C = 22918'
FZL = 13692'
LFC
LCL
2652m
452 m²/s²
SFC
SFC (91m)
15 km
12 km
9 km
6 km
3 km
1 km
NORMAL
STORMREL
MEAN WIND
234/64 MW
218/53 LM
245/50 RM
DP=251/104
Critical Angle = 47
Storm Slinky
-104 deg
Theta-E vs Pressure
TEI = 32
SR Winds (kt) vs Height
Psbl Watch Type
PDS TOR
CAPE CINH LCL LI LFC EL
SB PARCEL 3804 0 766m -9 766m 44014'
ML PARCEL 3451 -1 806m -8 871m 44398'
FCST SFC 4155 0 1128m -9 1128m 44014'
MU PARCEL 4012 0 667m -9 714m 44014'
EFF PARCEL 1836 -7 1611m -5 2402m 39979'
USER DEF 1910 -7 1525m -5 2347m 40086'
PW = 1.67 in 3CAPE = 151 J/kg WBZ = 11525' WNDG = 3.5
K = 37 DCAPE = 1126 J/kg FZL = 13692' ESP = 2.1
MidRH = 68% DownT = 61 F ConvT = 82F MMP = 1.00
LowRH = 86% MeanW = 16.3 g/kg MaxT = 86F NCAPE = 0.32
Sfc-3km Agl Lapse Rate = 21 C / 7.7 C/km
3-6km Agl Lapse Rate = 19 C / 6.6 C/km
850-500mb Lapse Rate = 26 C / 6.7 C/km
700-500mb Lapse Rate = 17 C / 6.6 C/km
Supercell = 36.3
STP (eff) = 10.4
STP (fixed) = 9.0
SHIP = 2.2
SRH(m2/s2) Shear(kt) MnWind SRW
SFC - 1 km 356 41 202/37 112/34
SFC - 2 km 455 53 212/44 125/27
SFC - 3 km 468 54 216/47 133/24
Eff Inflow Layer 452 53 215/46 131/25
SFC - 6 km 75 225/53 152/18
SFC - 8 km 80 229/55 161/16
LCL - EL (Cloud Layer) 59 234/63 199/17
Eff Shear (EBWD) 78 227/54 158/16
BRN Shear = 99 m²/s²
4-6km SR Wind = 230/22 kt
Corfidi Downshear = 251/104 kt
Corfidi Upshear = 273/40 kt
Bunkers Right = 245/50 kt
Bunkers Left = 218/53 kt
STPC LR = 10.4
STPC 6km = 7.9
SHERBE = 2.6
SHERB3 = 1.9
1km & 6km AGL Wind Barbs
SARS - Sounding Analog System
SUPERCELL
browse to ~thompson / sup / snd / *
03050823.C34 SIGTOR
(1 matches out of 856 sndgs)
SARS: **TOR** (100% TOR)
SGFNT HAIL
browse to ~jewell / hail / snd / *
No Quality HAIL Matches
(18 matches out of 1148 sndgs)
SARS: **SIG HAIL** (94% SIG)
Effective-Layer STP (with CIN)
Prob EF2+ torn with supercell
Sample CLIMO = .15 sigtor
based on CAPE: 0.20
based on LCL: 0.19
based on ESRH: 0.27
based on EBWD: 0.38
based on STPC: 0.58
based on STP_fixed: 0.58
EF4+ EF3 EF2 EF1 EF0 NONTOR
Parcel
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HAIL
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EBS Stats
STP Stats
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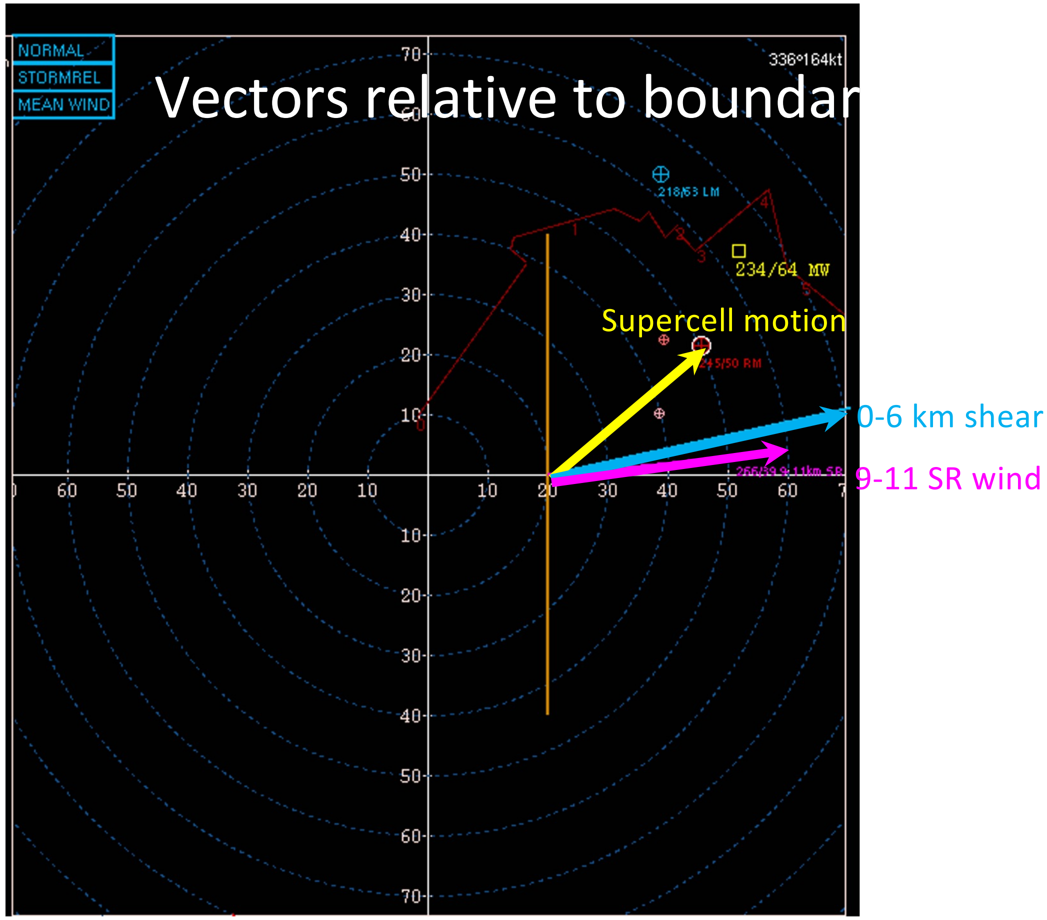
Vrot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STORMREL
MEAN WIND
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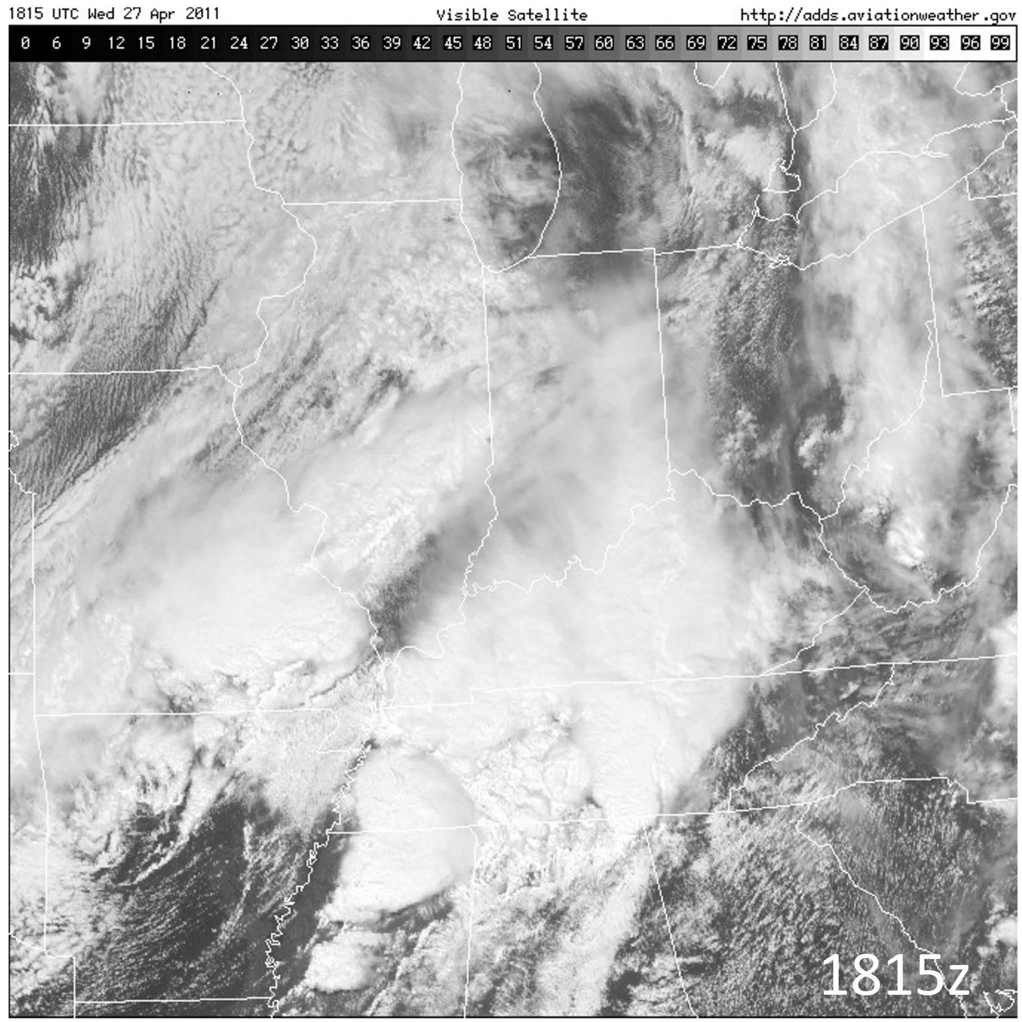
Vectors relative to boundar
218/63 LM
234/64 MW
Supercell motion
0-6 km shear
9-11 SR wind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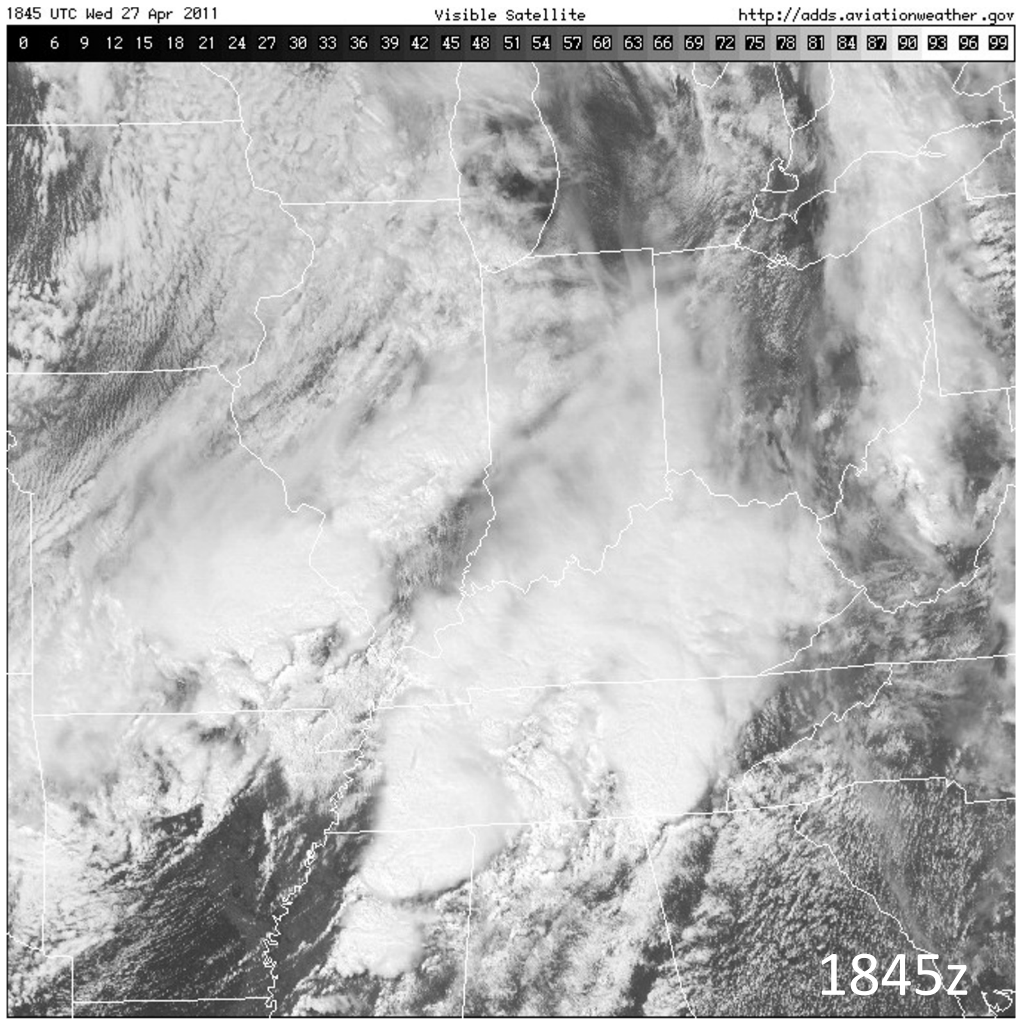
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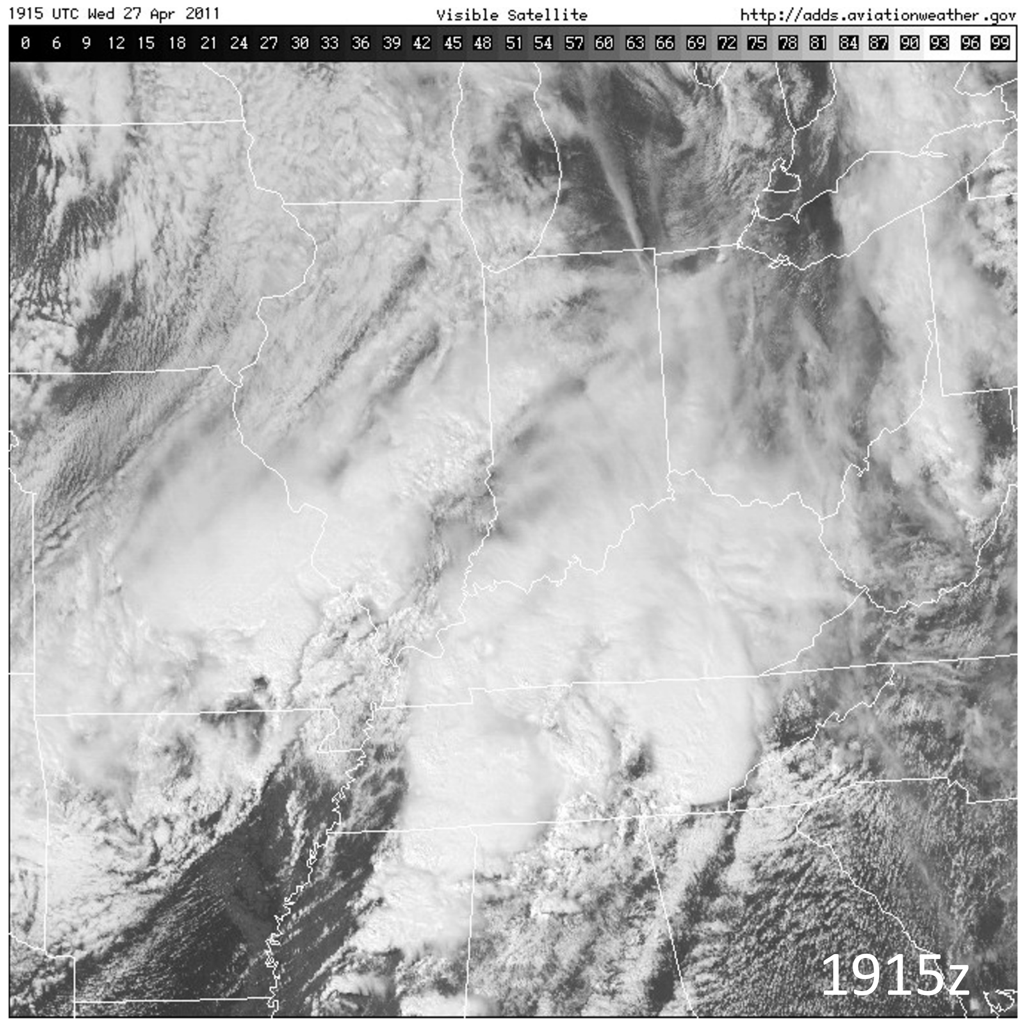
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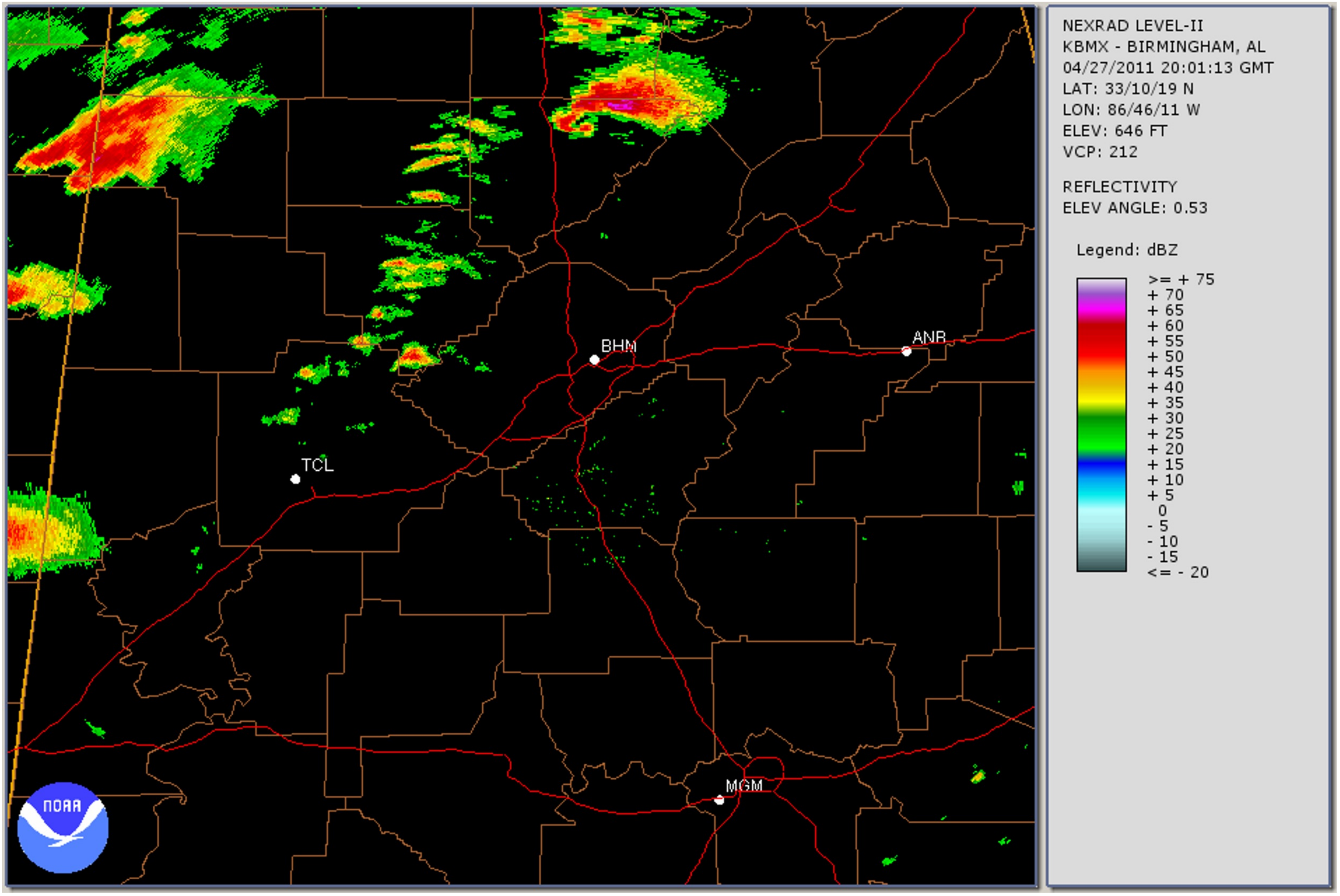
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LON: 86/46/11 W
ELEV: 646 FT
VCP: 212
REFLECTIVITY
ELEV ANGLE: 0.53
Legend: dBZ
>= + 75
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+ 65
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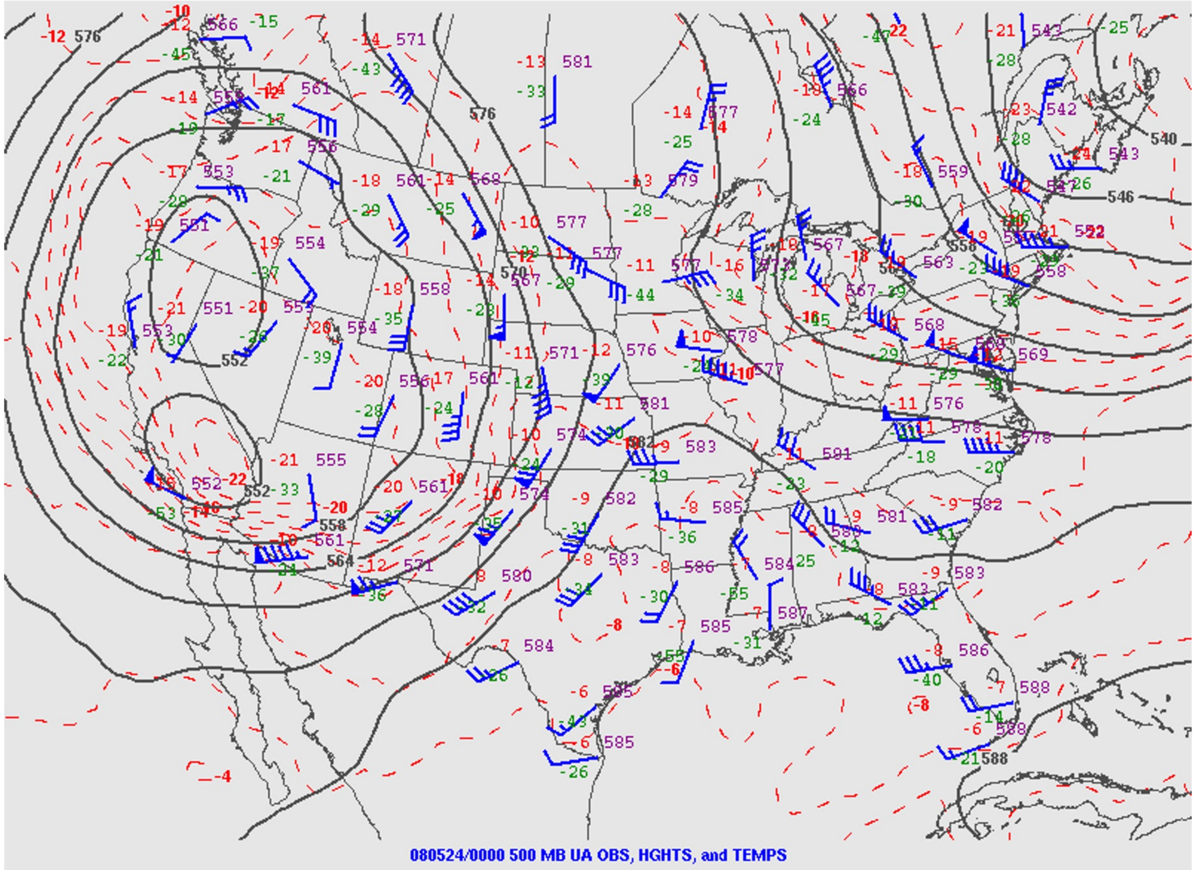
+ 40
+ 35
+ 30
+ 25
+ 20
+ 15
+ 10
+ 5
0
- 5
- 10
- 15
<= - 20

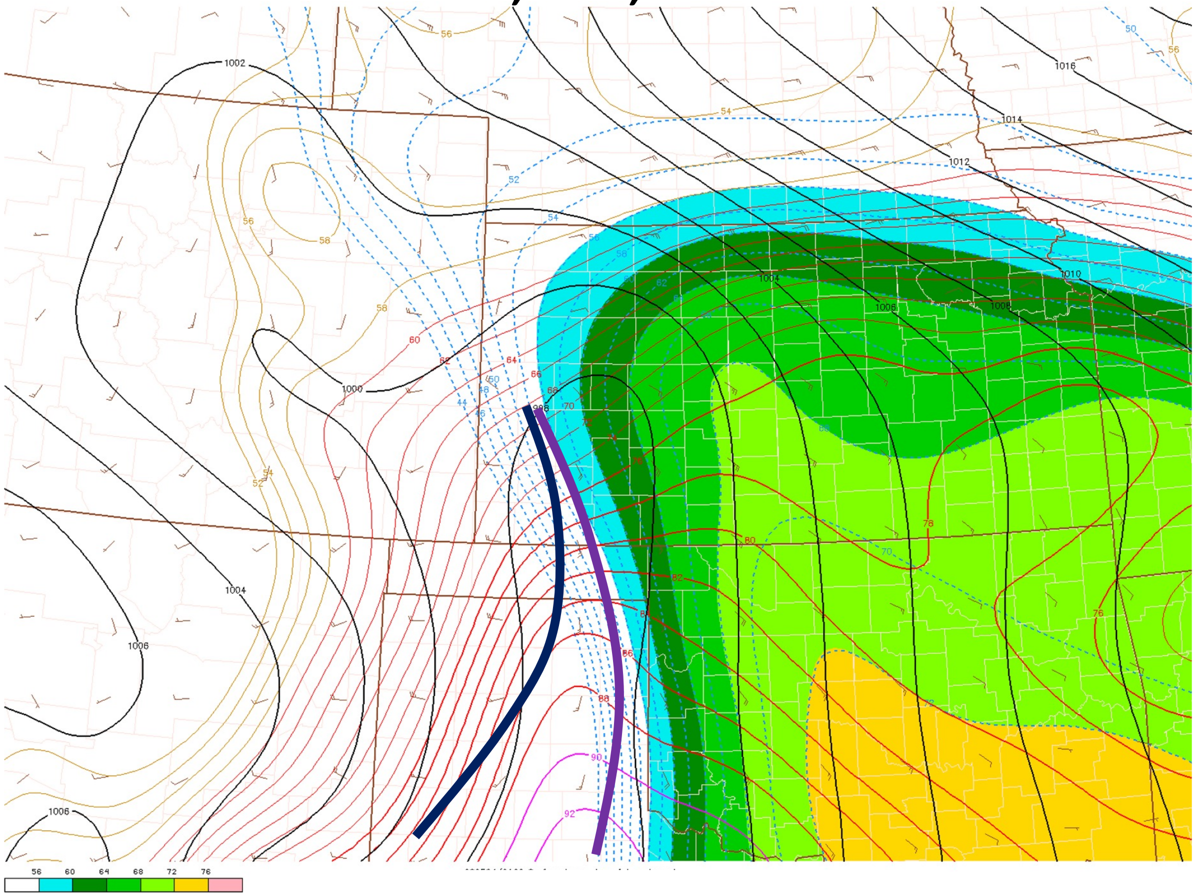
Forced Squall Line Case

- Still some cross-boundary flow and shear vectors
- Stronger cap and moderate buoyancy
- Much stronger low-level convergence
- Front moved as fast as the storms
  - Relative speed is often overlooked. A surging front may travel as fast if not faster than the storms that form on it.



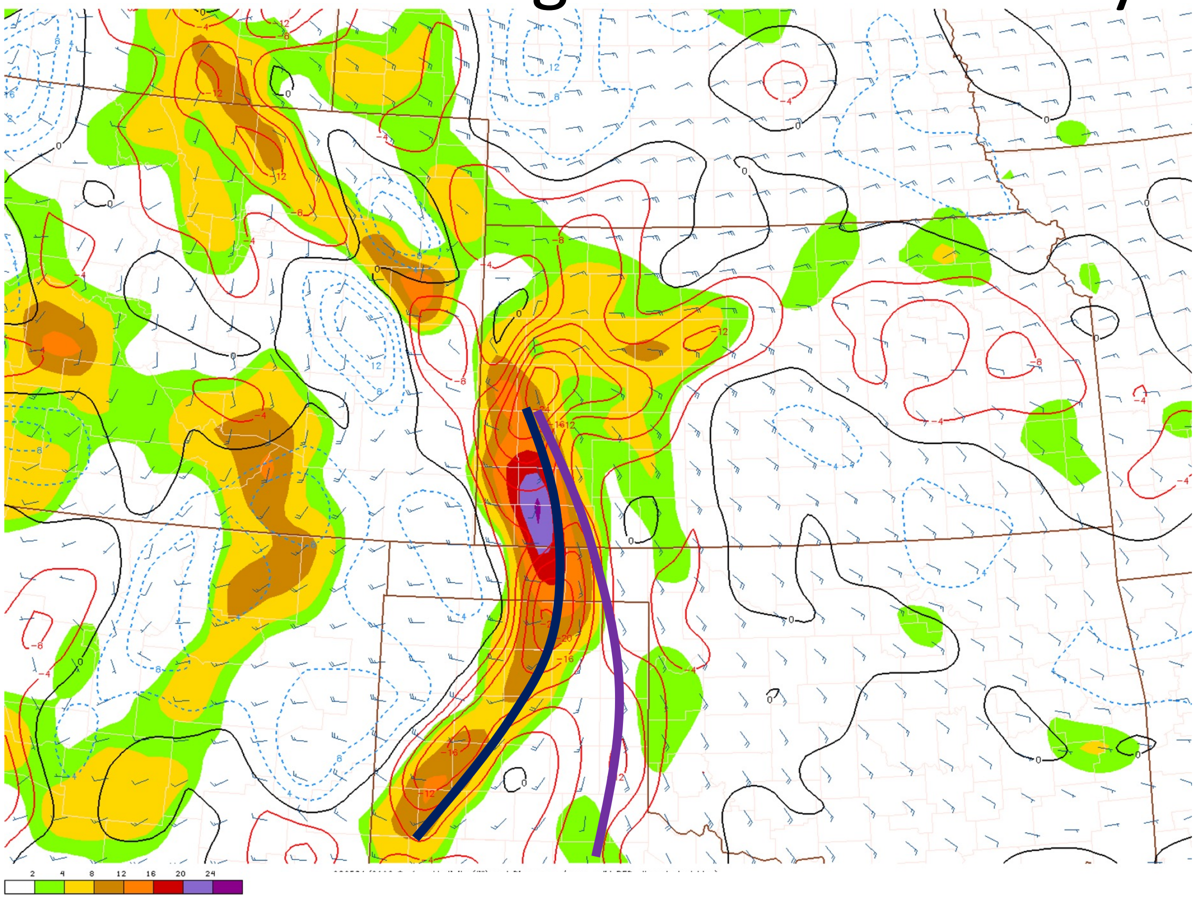
24 MAY 2008 00z

Surface T, Td, and PMSL



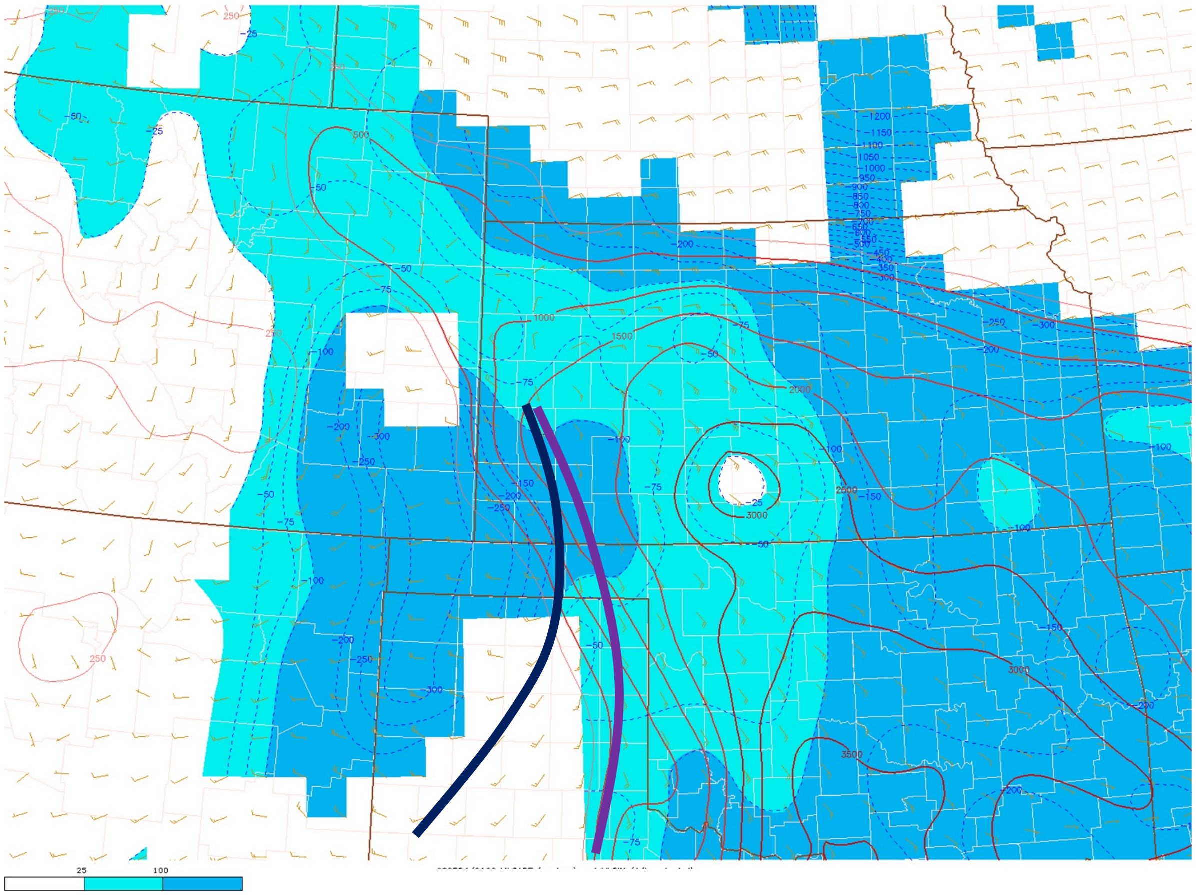
24 MAY 01z

Surface convergence and vorticity



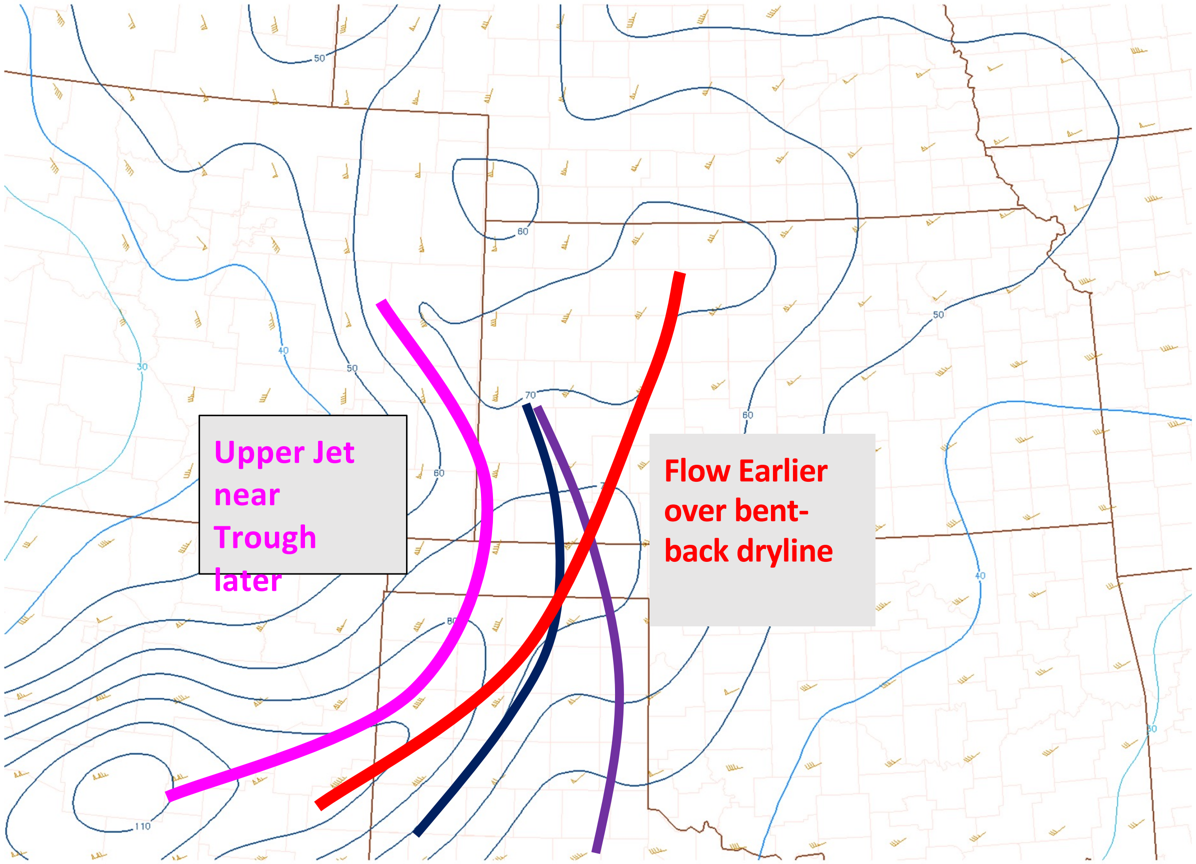
24 MAY 01z

MLCAPE and MLCIN



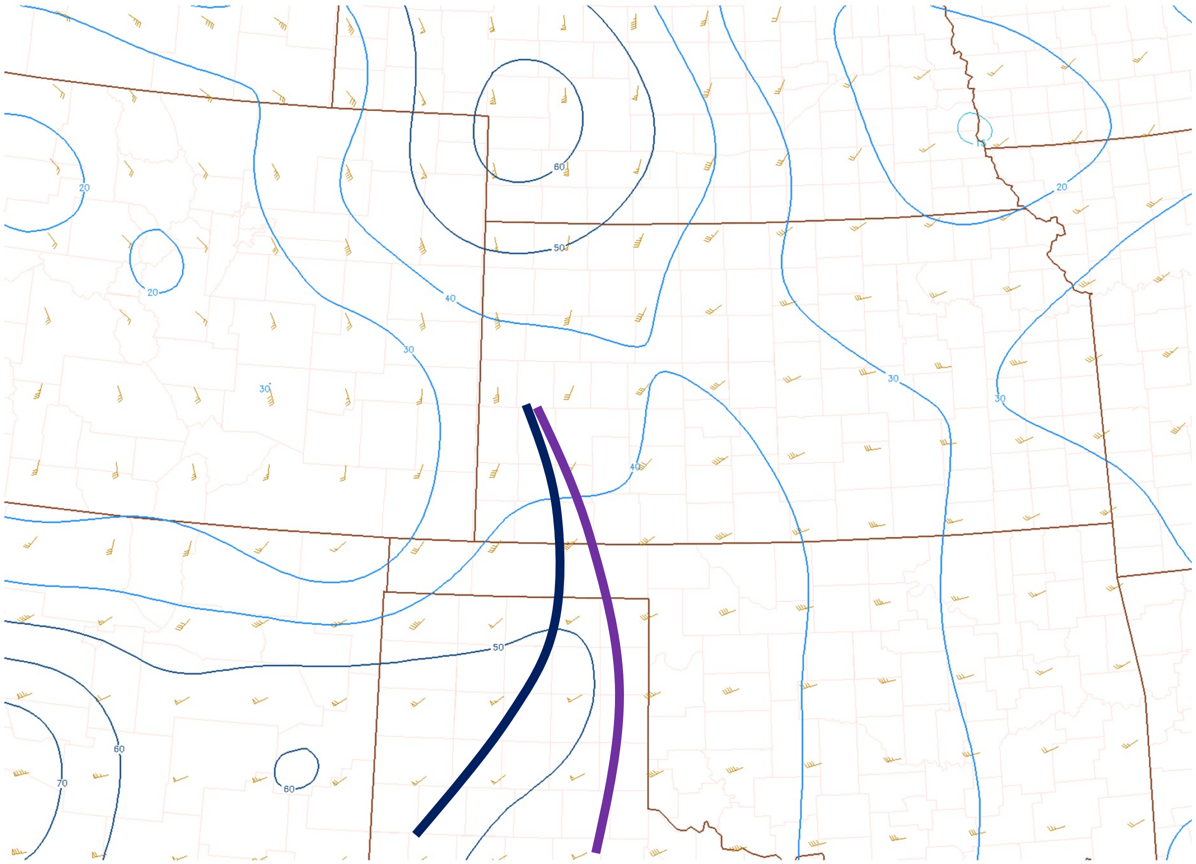
24 MAY 01z

0-6 km shear vectors

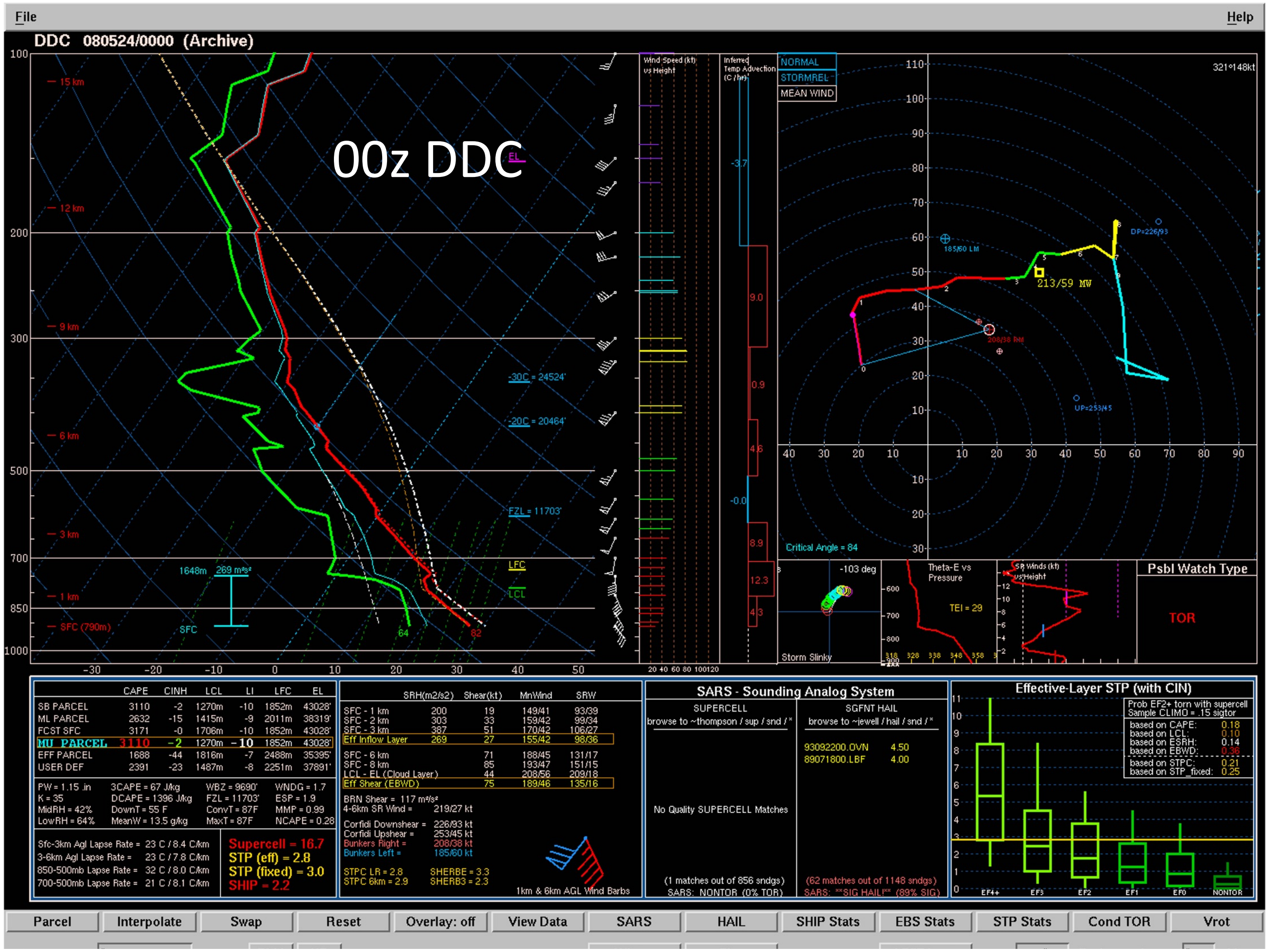


24 MAY 01z

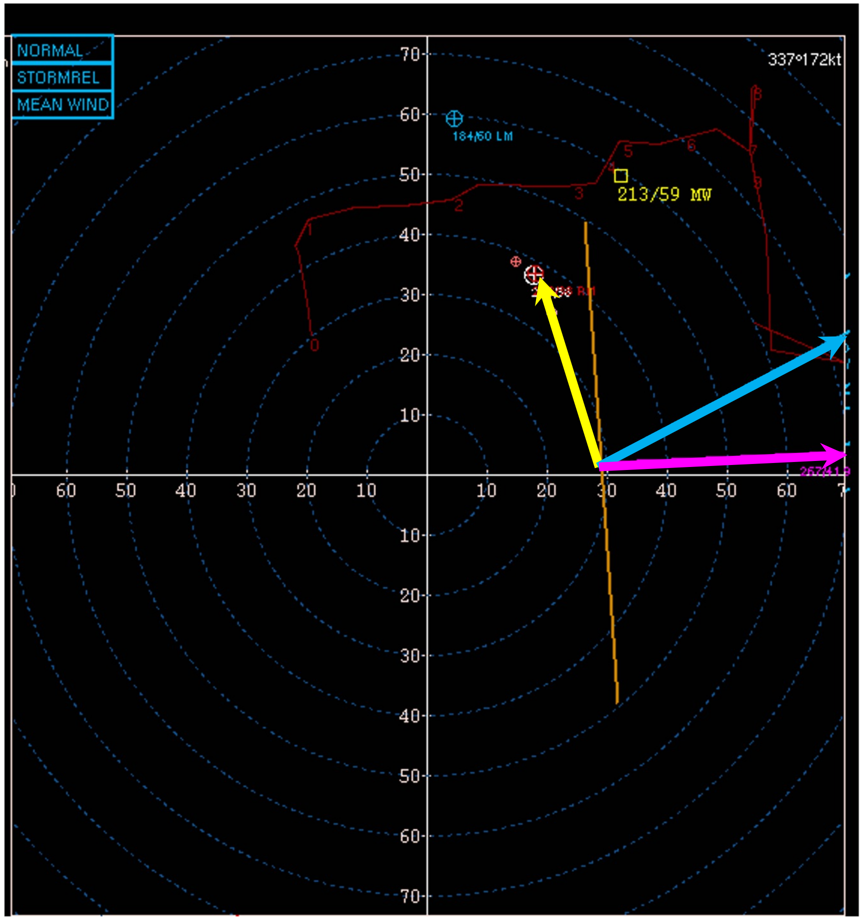
9-11 km storm-relative winds

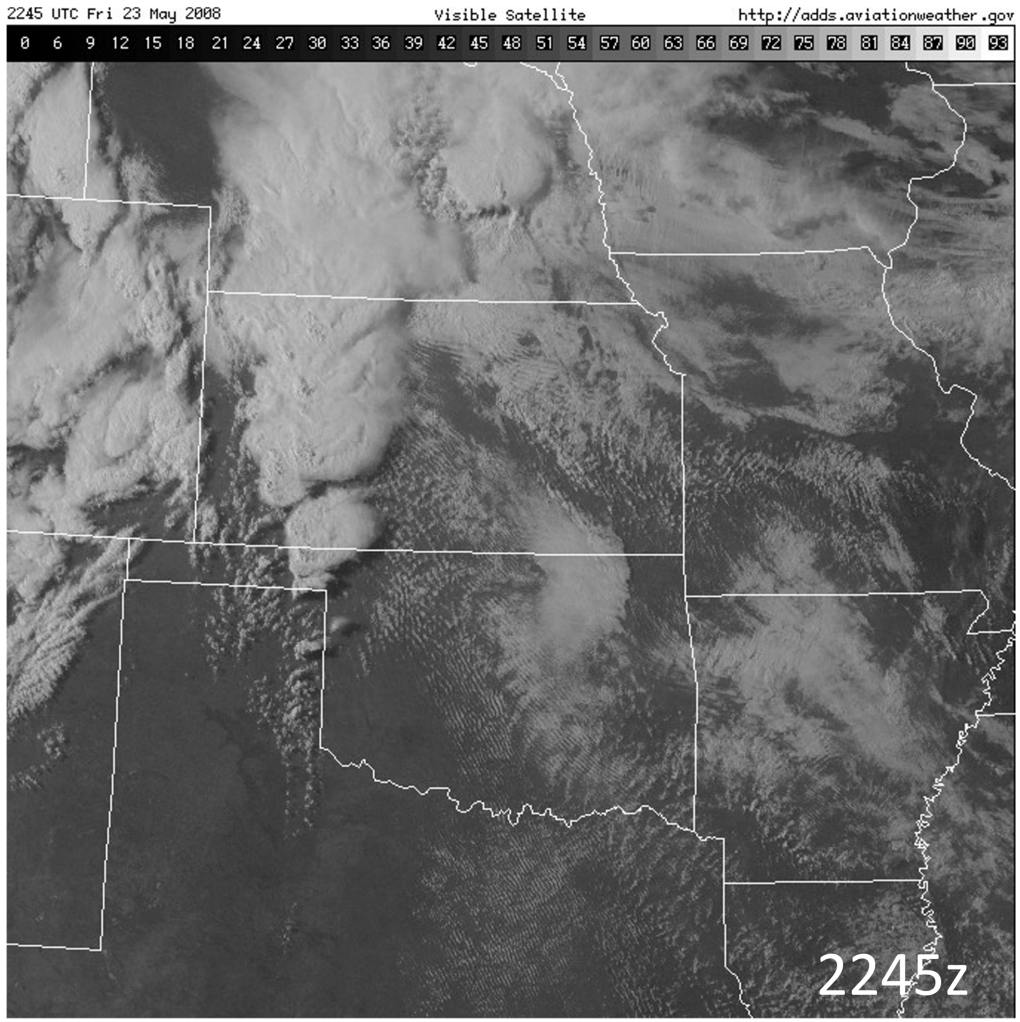


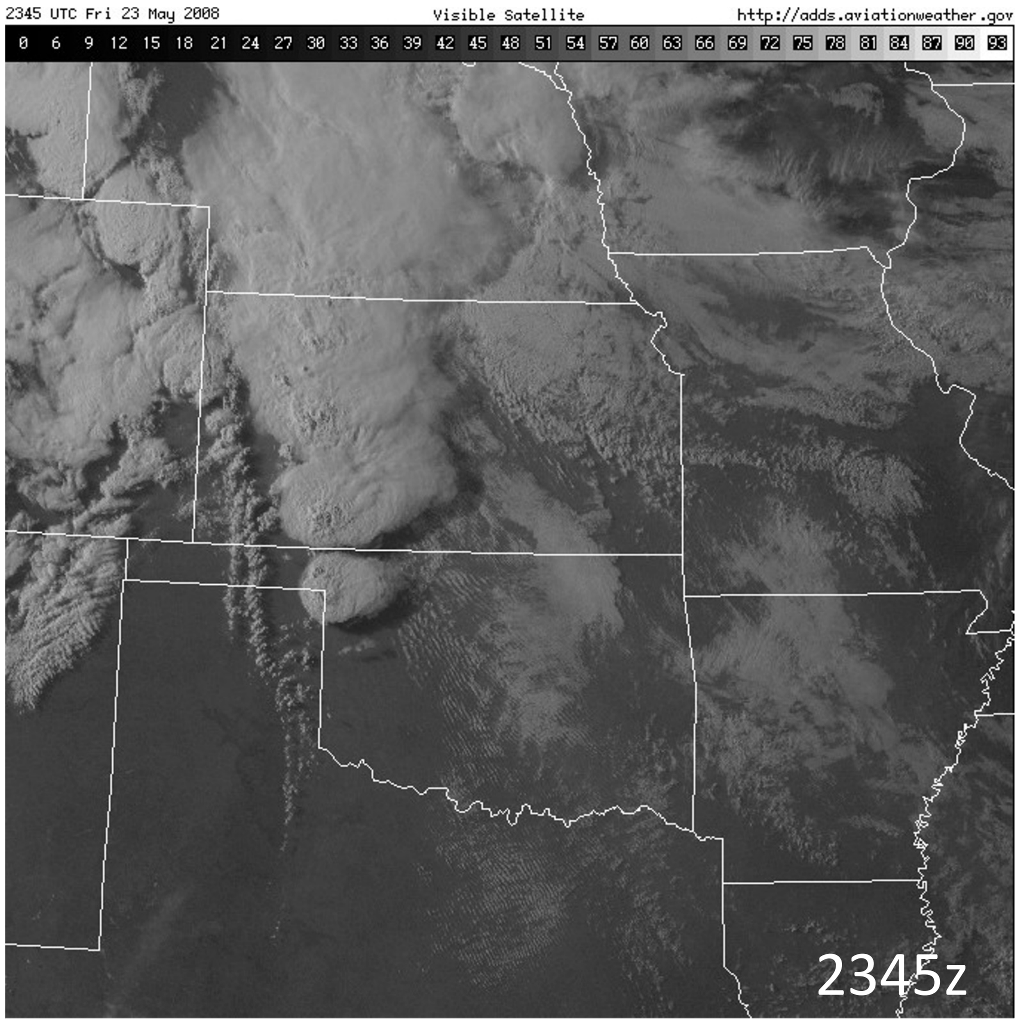
24 MAY 01z



00z DDC
File
Help
DDC 080524/0000 (Archive)
SARS - Sounding Analog System
Effective-Layer STP (with CIN)
Psbl Watch Type
TOR
Supercell = 16.7
STP (eff) = 2.8
STP (fixed) = 3.0
SHIP = 2.2
No Quality SUPERCELL Matches
Storm Slinky
Critical Angle = 84
NORMAL
STORMREL
MEAN WIND
Parcel
Interpolate
Swap
Reset
Overlay: off
View Data
SARS
HAIL
SHIP Stats
EBS Stats
STP Stats
Cond TOR
Vrot


NORMAL
STORMREL
MEAN WIND
337°172kt
184/60 LM
213/59 MW


2245 UTC Fri 23 May 2008
Visible Satellite
http://adds.aviationweather.gov
0 6 9 12 15 18 21 24 27 30 33 36 39 42 45 48 51 54 57 60 63 66 69 72 75 78 81 84 87 90 93
2245z



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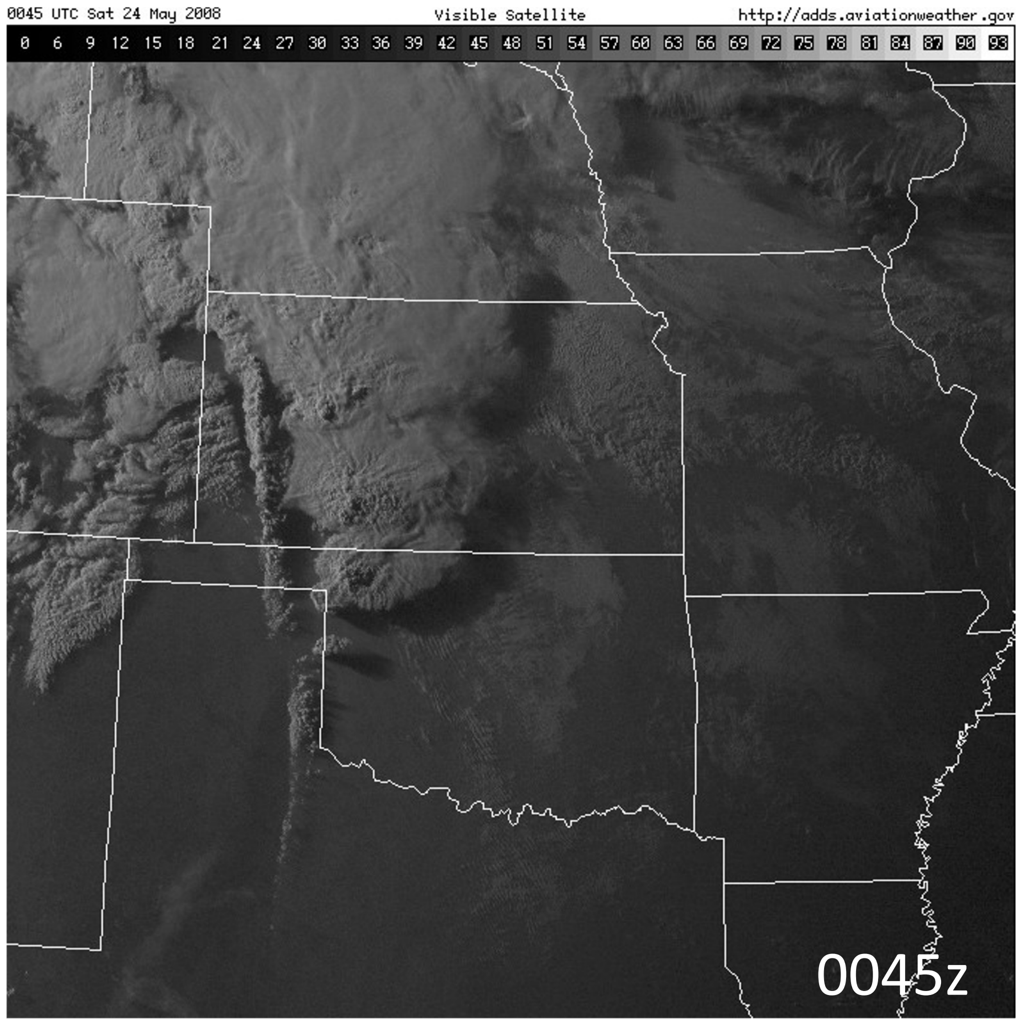
2345z


0045 UTC Sat 24 May 2008
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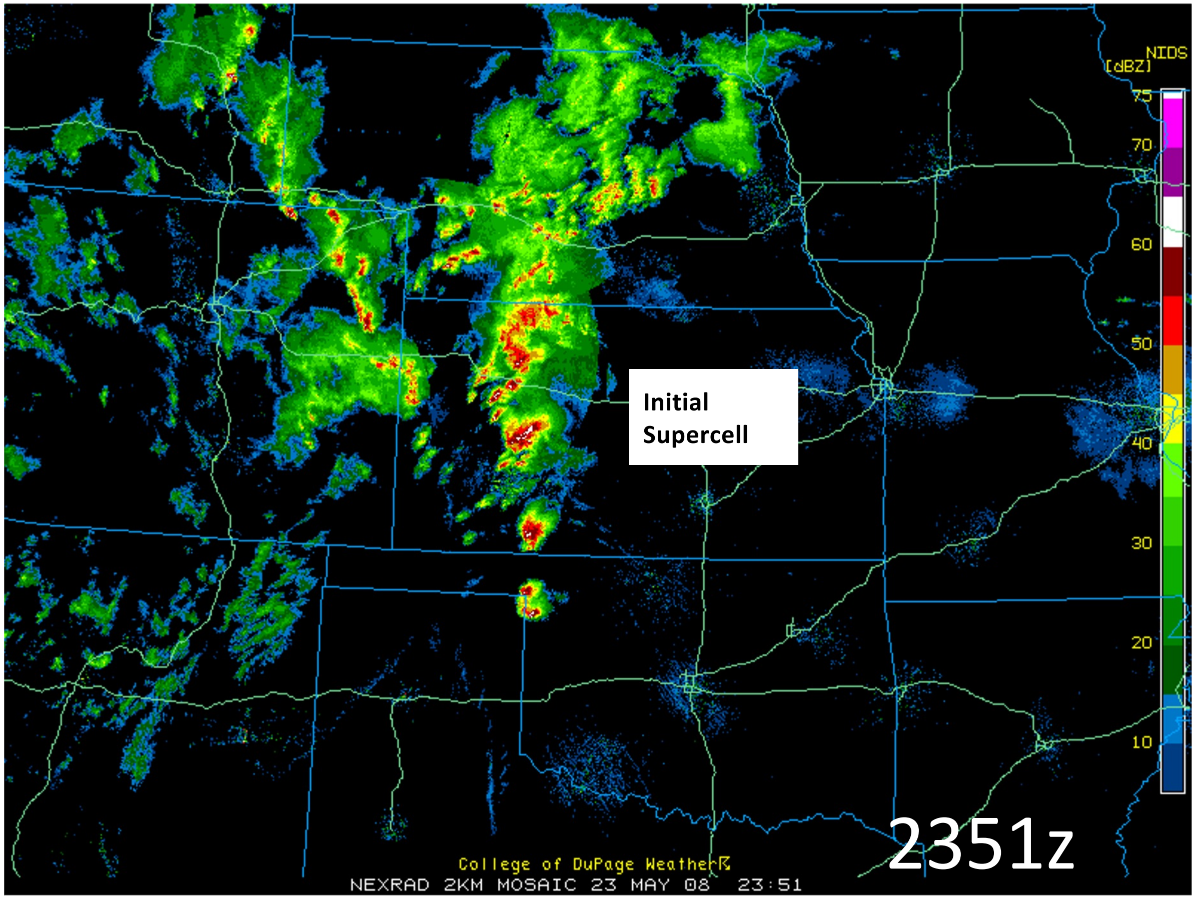
0045z



NIDS
[dBZ]
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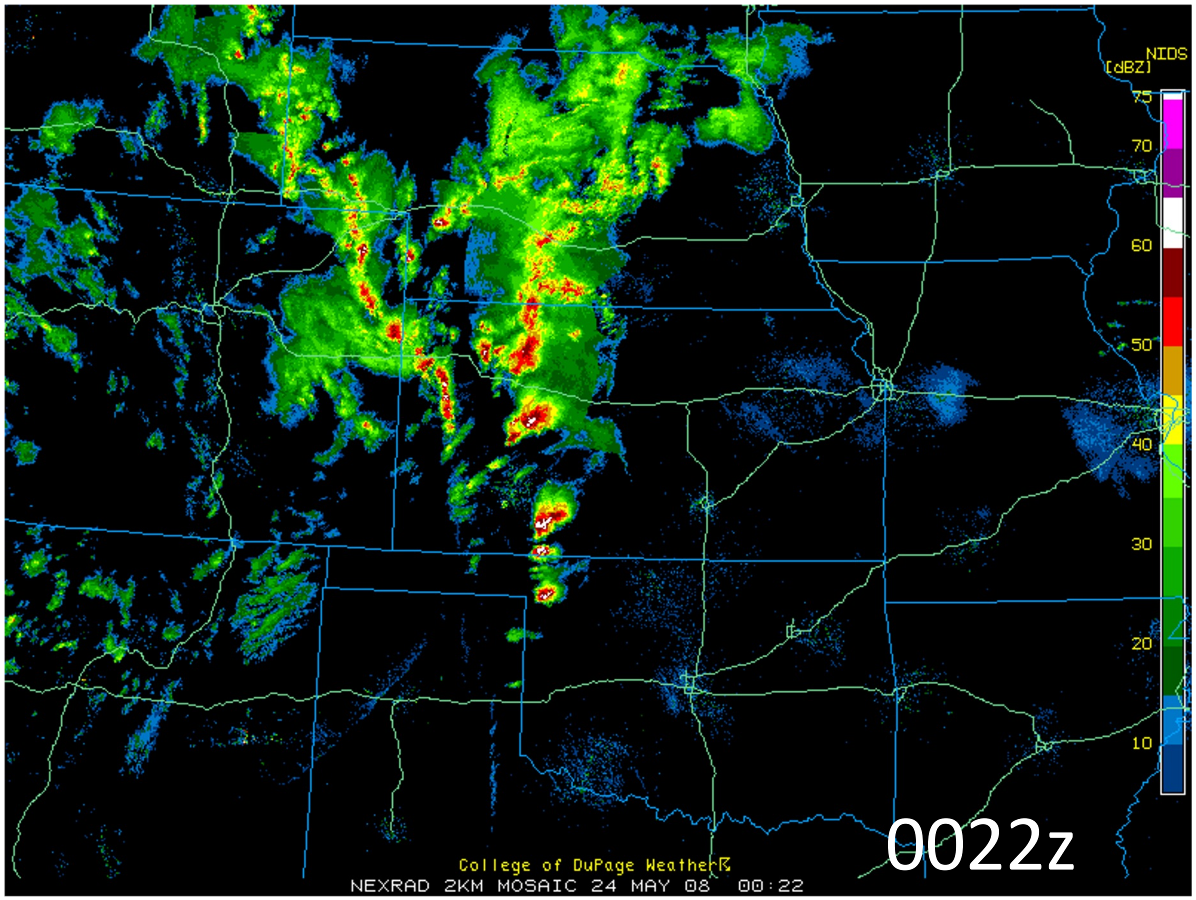
70
60
50
40
30
20
10
Initial
Supercell
2351z
College of DuPage Weather
NEXRAD 2KM MOSAIC 23 MAY 08 23:51


NIDS
[dBZ]
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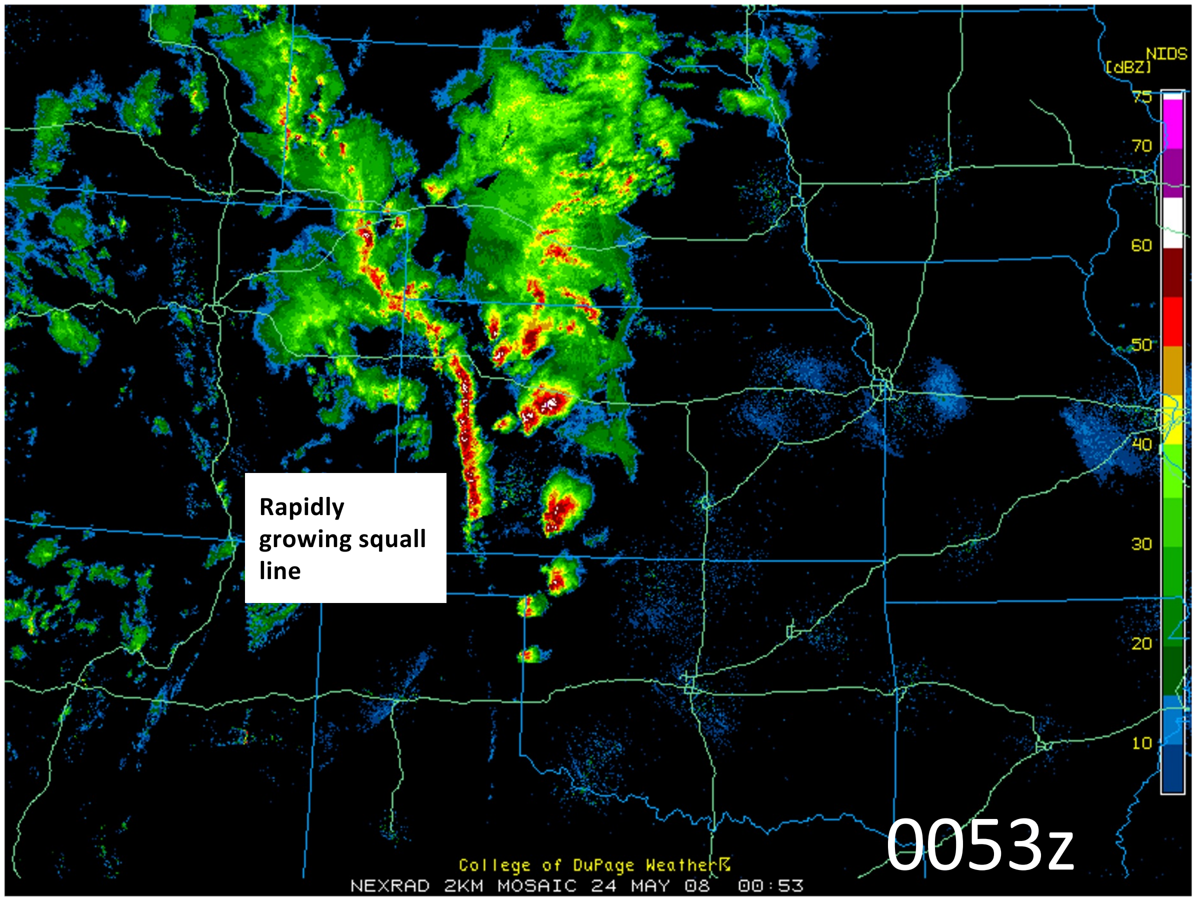
10
College of DuPage Weather
NEXRAD 2KM MOSAIC 24 MAY 08 00:22
0022z


NIDS
[dBZ]
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10
Rapidly
growing squall
line
0053z
College of DuPage Weather
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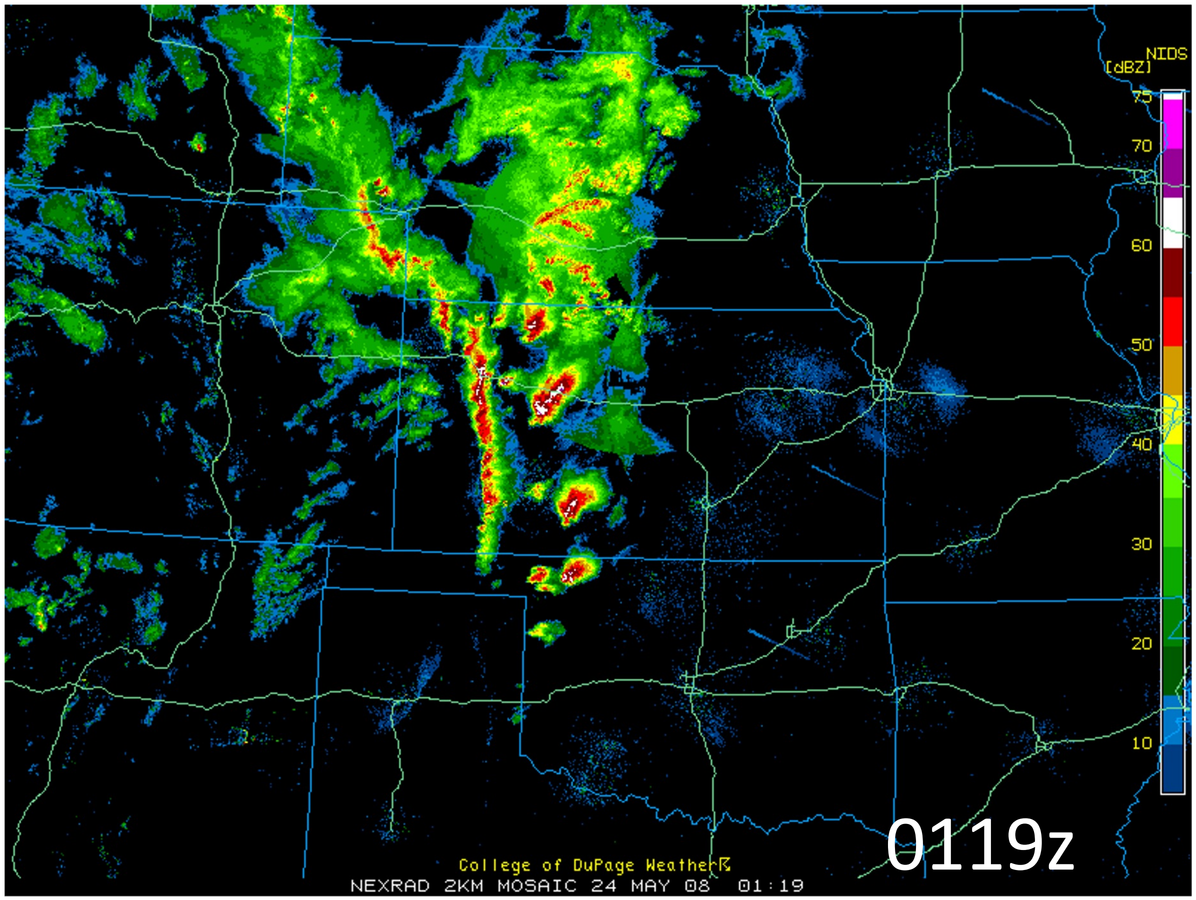
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[dBZ]
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10
0119z
College of DuPage Weather
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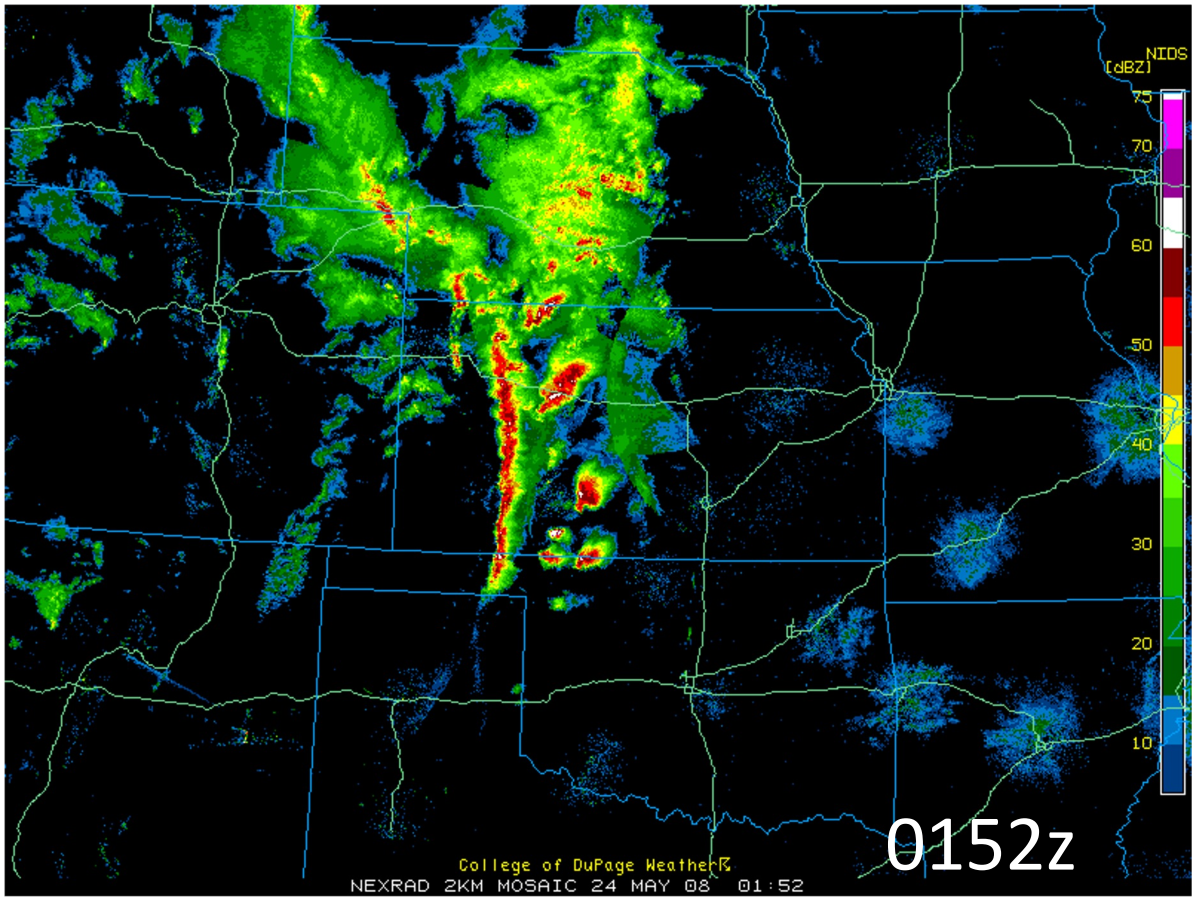
NIDS
[dBZ]
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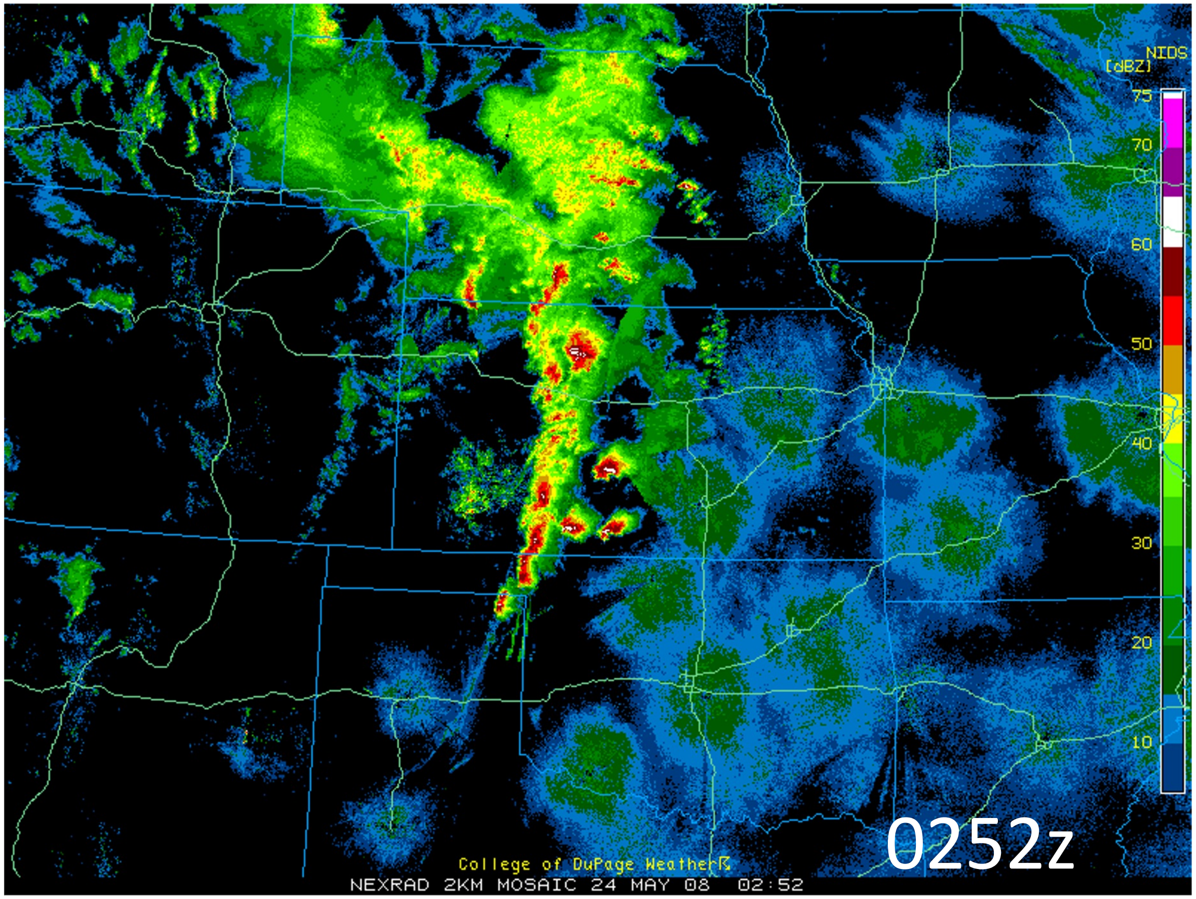
30
20
10
0152z
College of DuPage Weather
NEXRAD 2KM MOSAIC 24 MAY 08 01:52


NIDS
[dBZ]
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70
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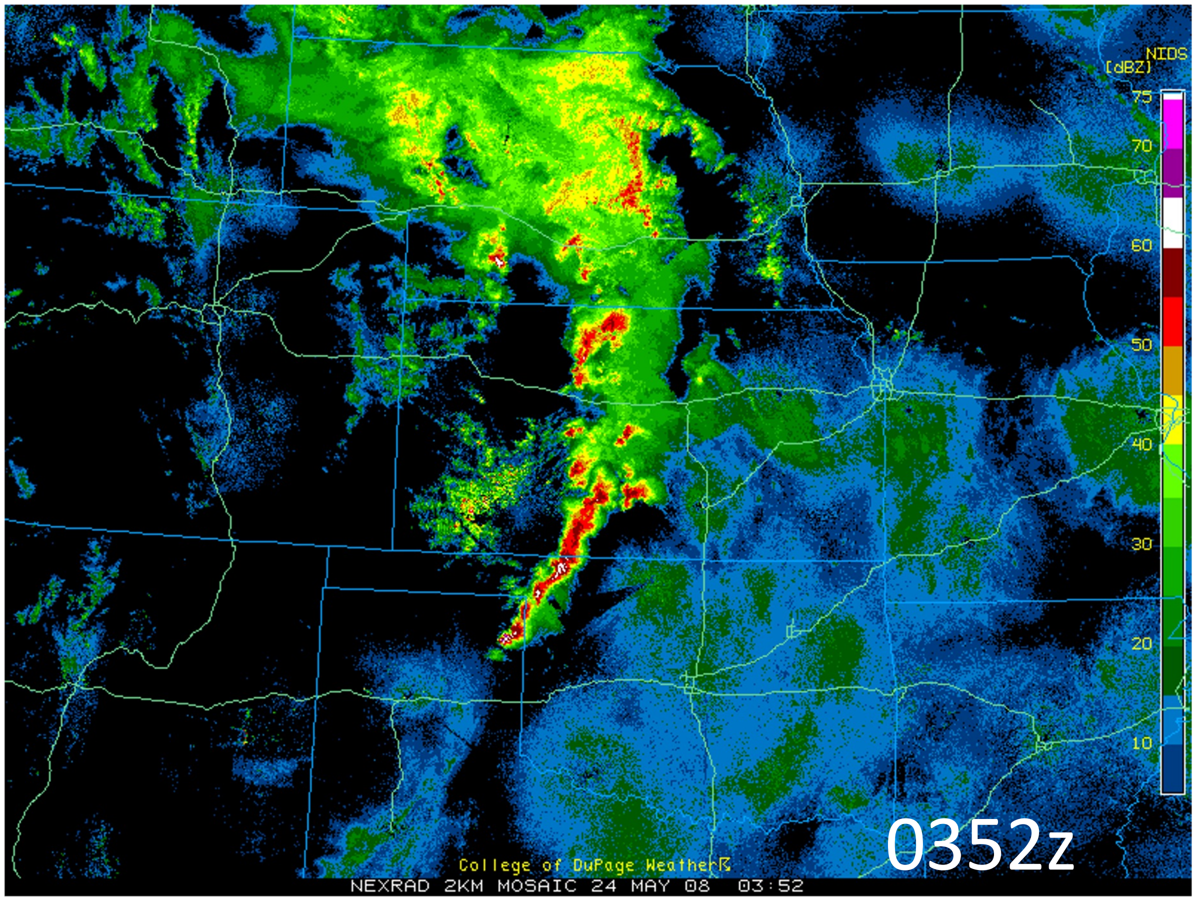
40
30
20
10
0252z
College of DuPage Weather
NEXRAD 2KM MOSAIC 24 MAY 08 02:52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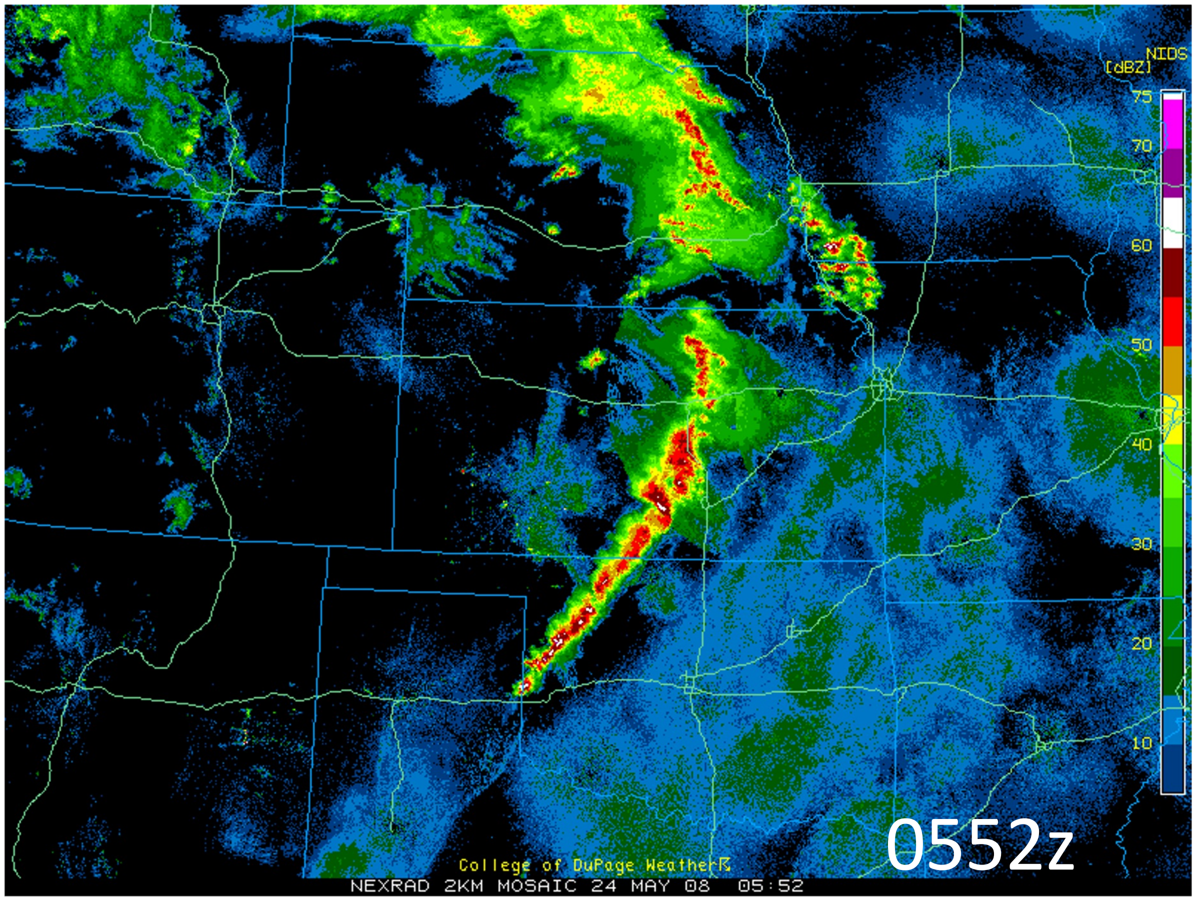
College of DuPage Weather
NEXRAD 2KM MOSAIC 24 MAY 08 03:52
0352z


NIDS
[dBZ]
75
70
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50
40
30
20
10
College of DuPage Weather
NEXRAD 2KM MOSAIC 24 MAY 08 05:52
0552z

Summary

- Convective mode and storm organization are primarily modulated by vertical shear.

- Strength of forcing for ascent is likely the most important factor, along with whether or not storms will move off a boundary.

- Shear Vector orientation and storm relative flow determine residence time within zones of ascent along boundaries.

- Shear vector orientation is more important in cases with weaker forcing for ascent, where storm interactions could lead to upscale growth

When poll is active, respond at **pollev.com/severeclass641**

What is the approximate life time of a single cell thunderstorm?

- 1 hour
- 30 min
- 3 hours
- 10 min

When poll is active, respond at **pollev.com/severeclass641**

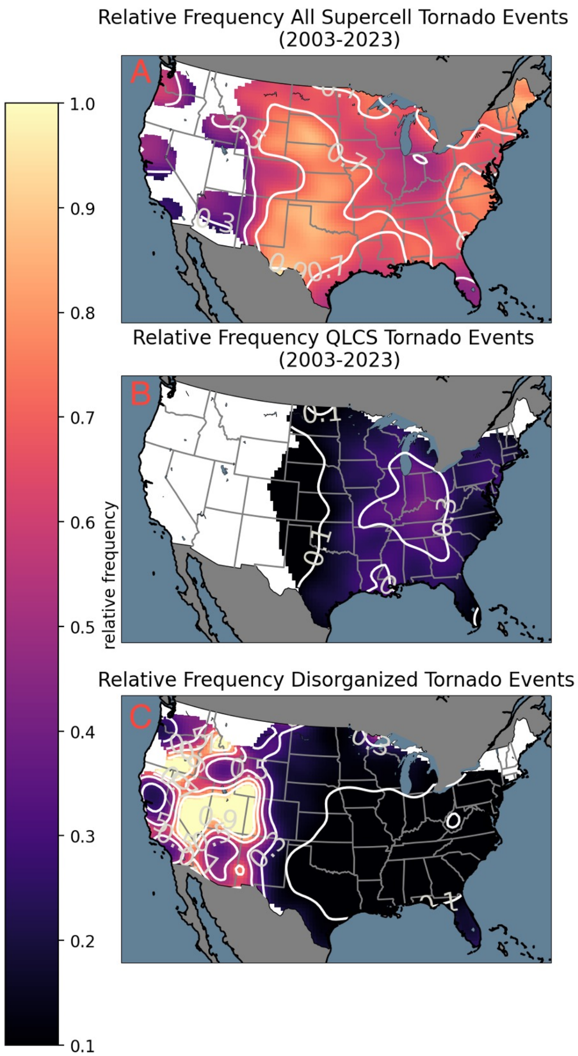
What is the best combination of flow aloft and lift to get linear storms?

Strong forcing for ascent and flow across the initiating boundary.

Weak forcing for ascent and flow parallel to the initiating boundary.

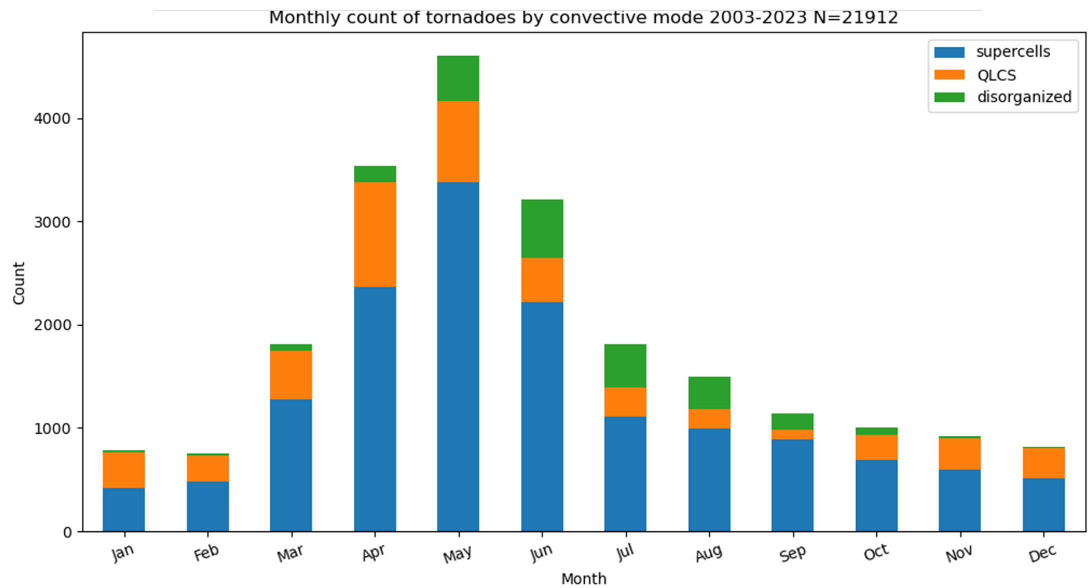
Strong forcing for ascent and flow parallel to the initiating boundary.

Weak forcing for ascent and flow across the initiating boundary.

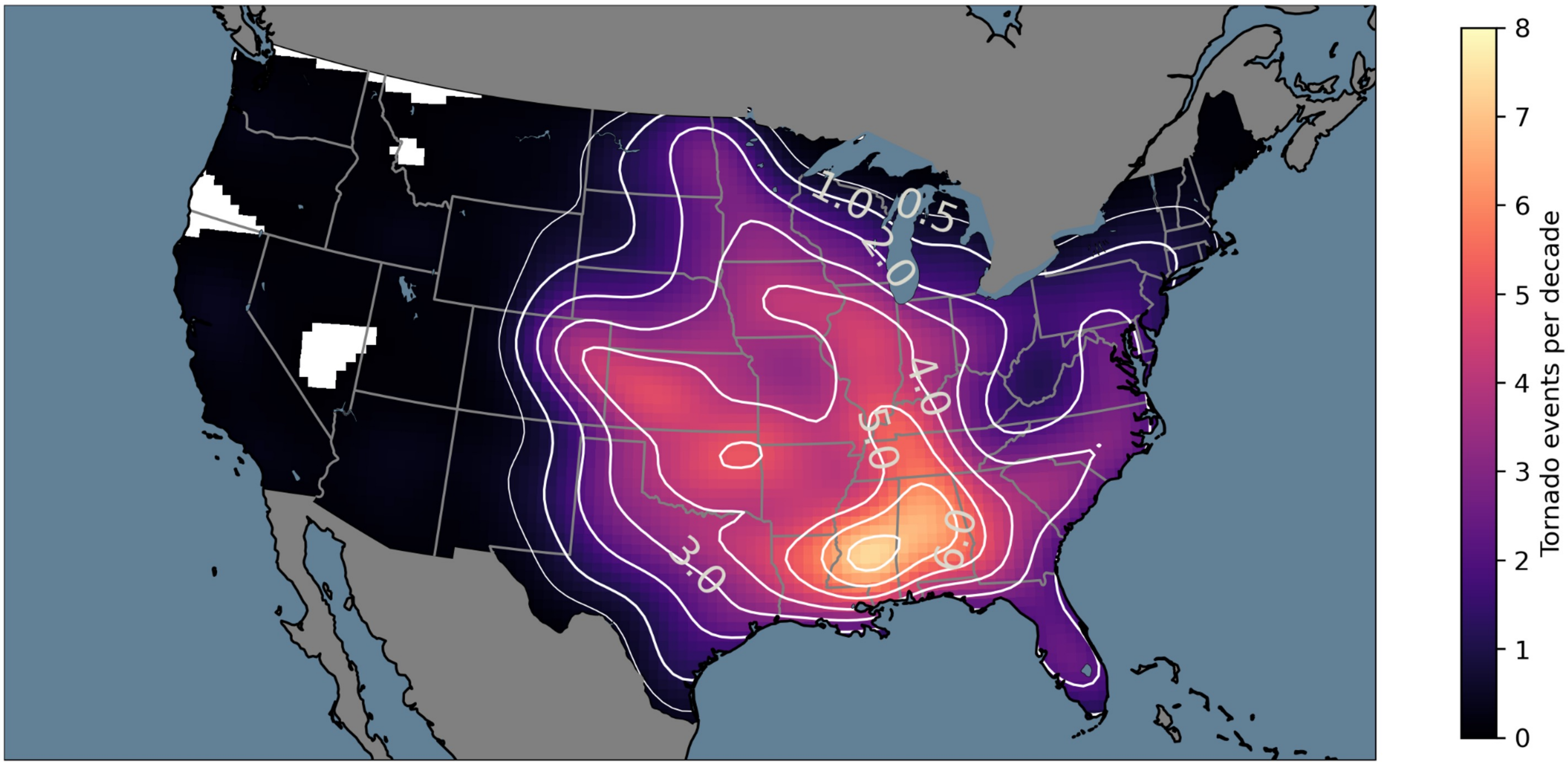


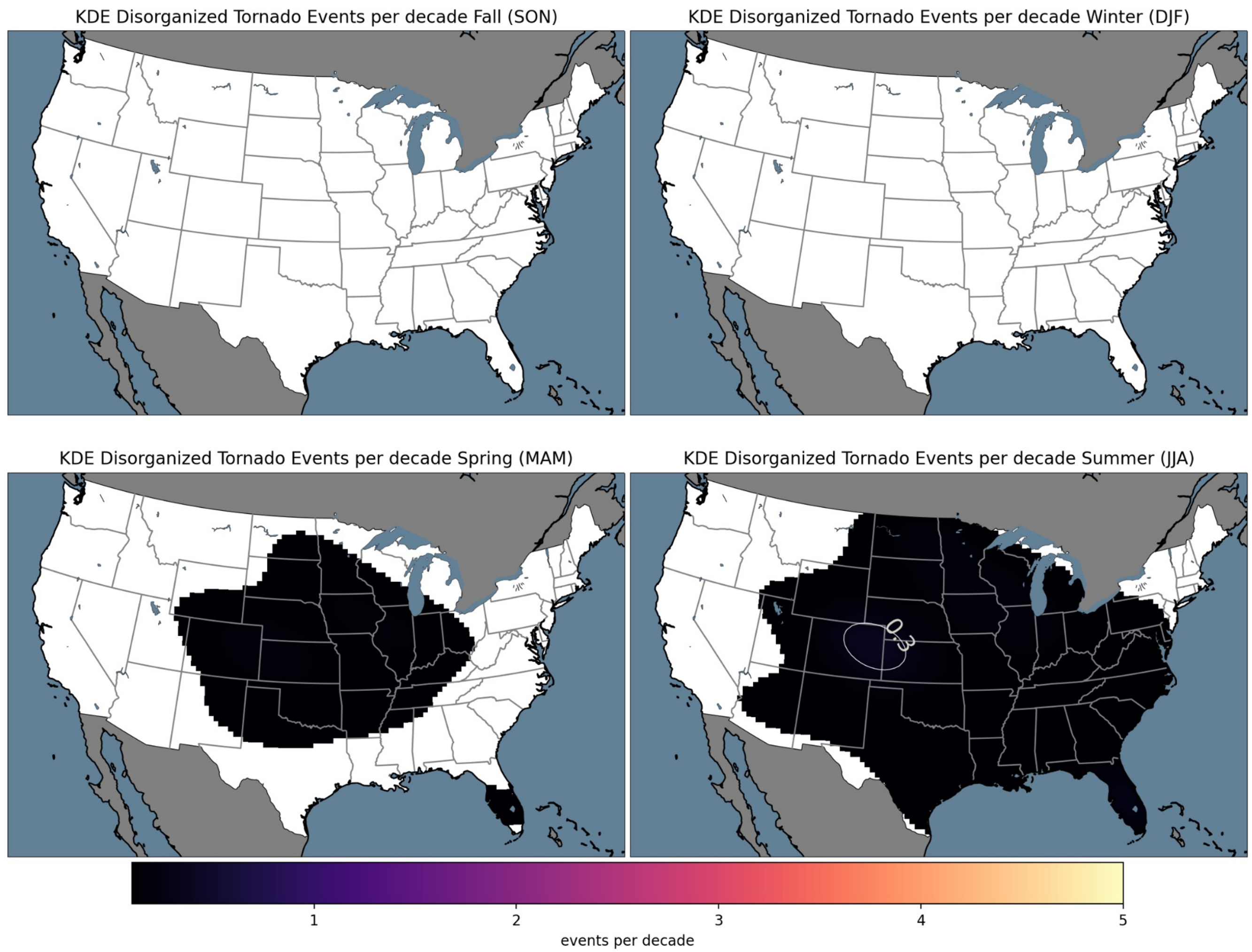
Mode	Number	Relative Frequency	F/EF-0 EF-U	F/EF-1	F/EF-2	F/EF-3	F/EF-4	F/EF-5
Supercell (All RM+LM)	14934	0.682	7765	4696	1733	595	134	11
QLCS	4710	0.215	2025	2240	412	33	0	0
Disorganized	2268	0.104	2015	238	13	2	0	0
Total	21912	1	11805	7174	2158	630	134	11

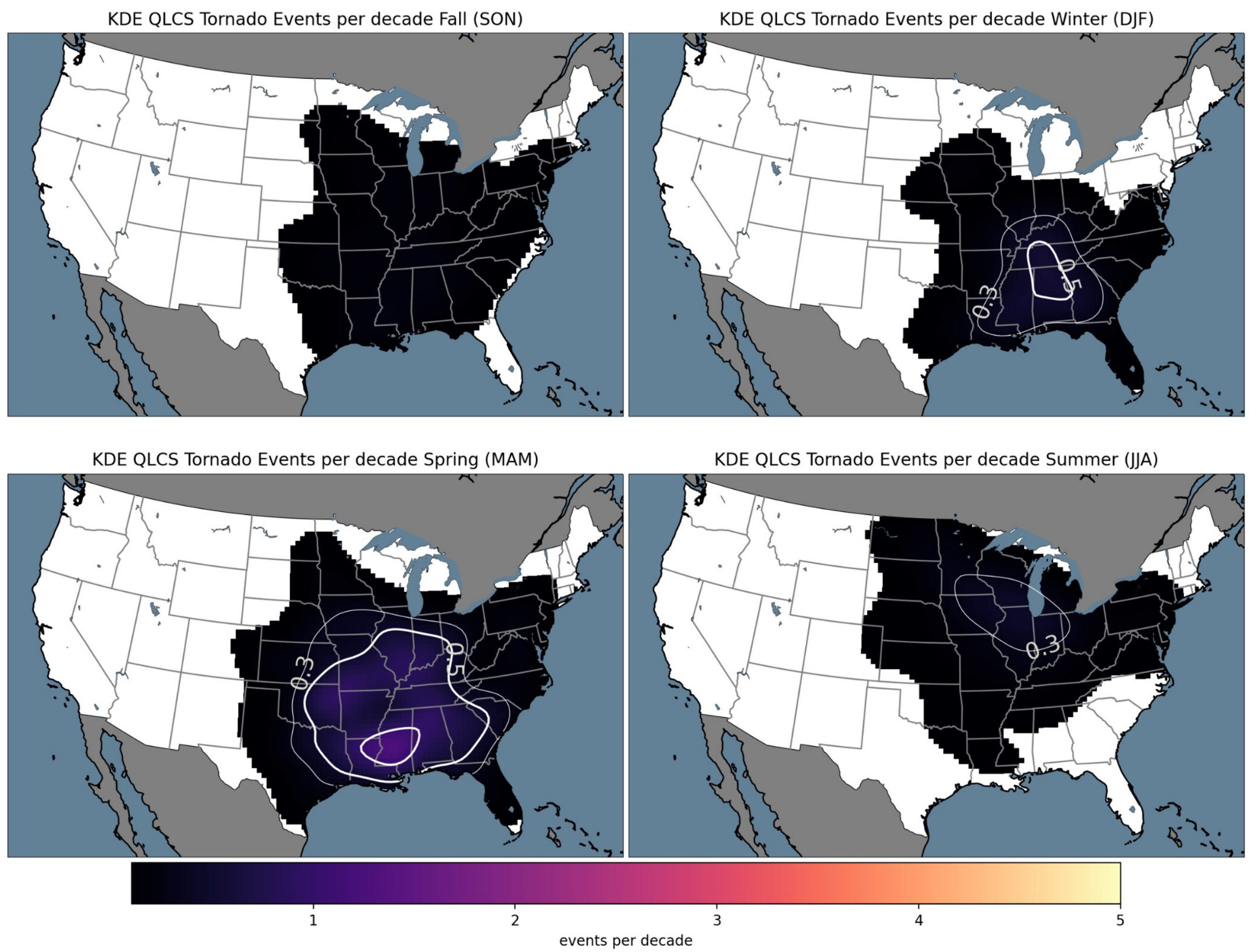
Table 1. Number and relative frequency of tornadoes by F/EF scale from all supercell, QLCS, disorganized and total modes across the CONUS from 2003–2023. RM/LM denotes right (cyclonic)/left-moving (anticyclonic) supercells respectively. Note the unusually large number of QLCS tornadoes with F/EF-1 ratings.



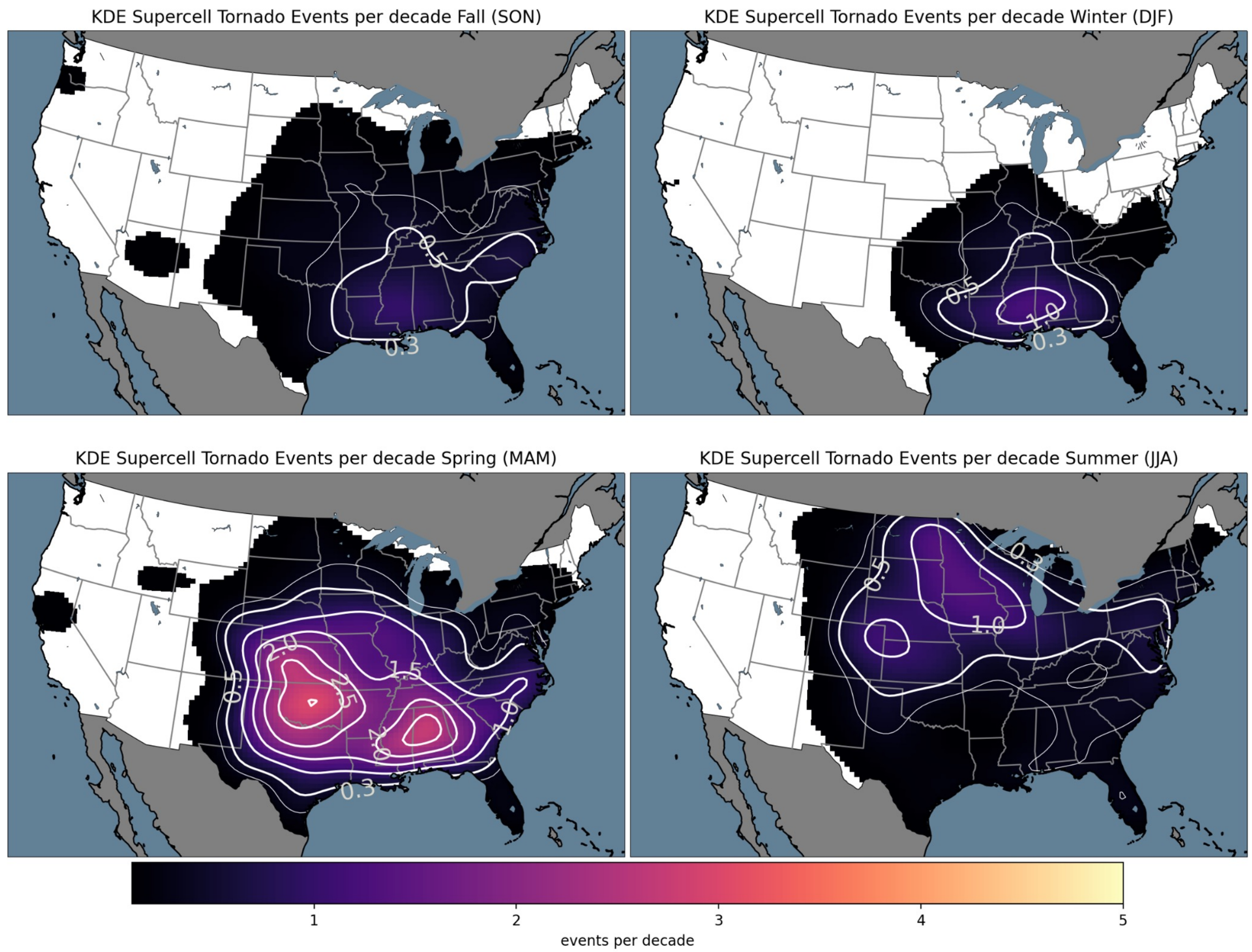
Kernel Desnity Tornado events per decade 2003-2022   N=20873

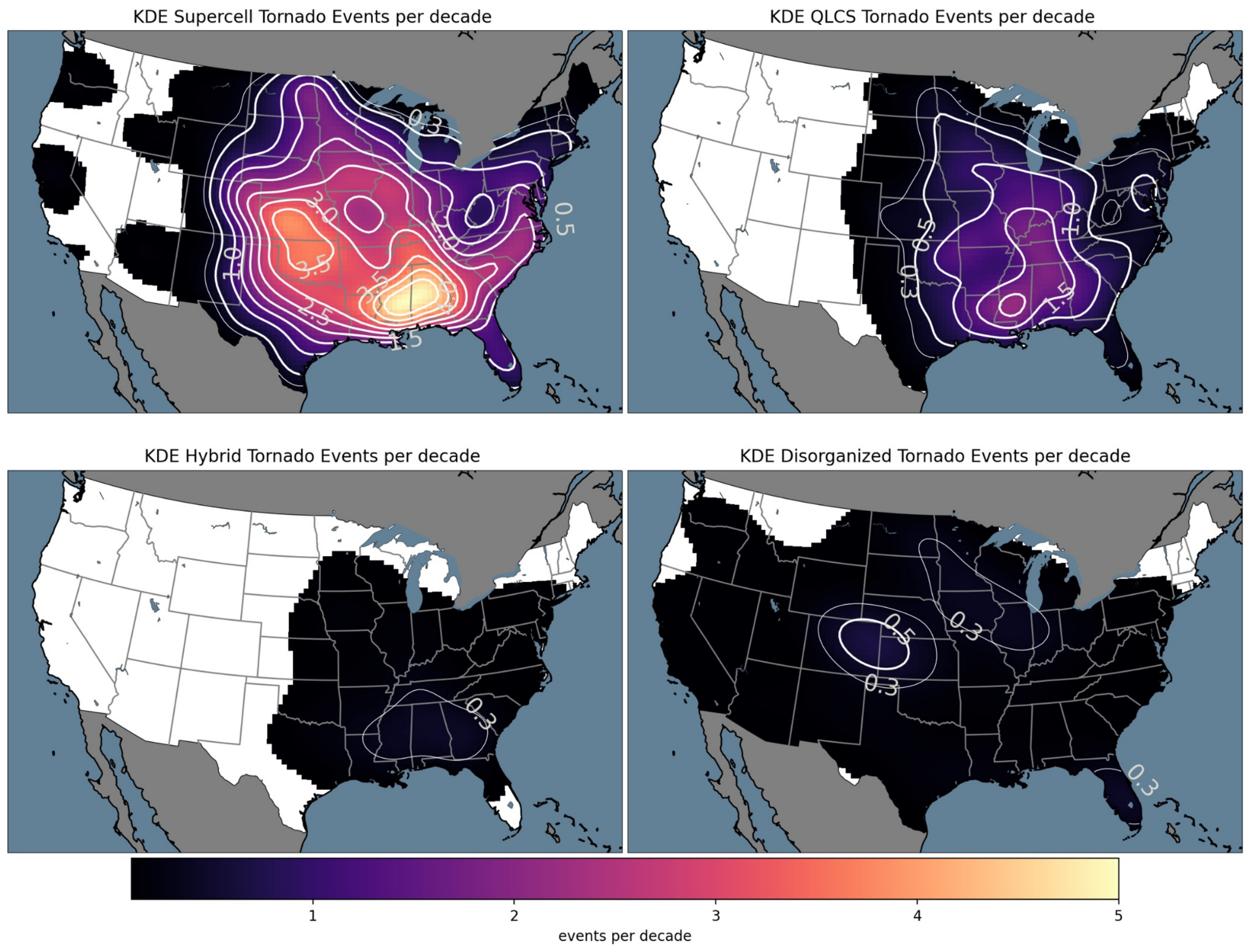



KDE Disorganized Tornado Events per decade Fall (SON)
KDE Disorganized Tornado Events per decade Winter (DJF)
KDE Disorganized Tornado Events per decade Spring (MAM)
KDE Disorganized Tornado Events per decade Summer (JJA)
0.3
1
2
3
4
5
events per decade



KDE QLCS Tornado Events per decade Fall (SON)
KDE QLCS Tornado Events per decade Winter (DJF)
0.3
0.5
KDE QLCS Tornado Events per decade Spring (MAM)
0.3
0.5
KDE QLCS Tornado Events per decade Summer (JJA)
0.3
1
2
3
4
5
events per decade


KDE Supercell Tornado Events per decade Fall (SON)
KDE Supercell Tornado Events per decade Winter (DJF)
KDE Supercell Tornado Events per decade Spring (MAM)
KDE Supercell Tornado Events per decade Summer (JJA)
1
2
3
4
5
events per decade


KDE Supercell Tornado Events per decade
KDE QLCS Tornado Events per decade
KDE Hybrid Tornado Events per decade
KDE Disorganized Tornado Events per decade
1
2
3
4
5
events per decade