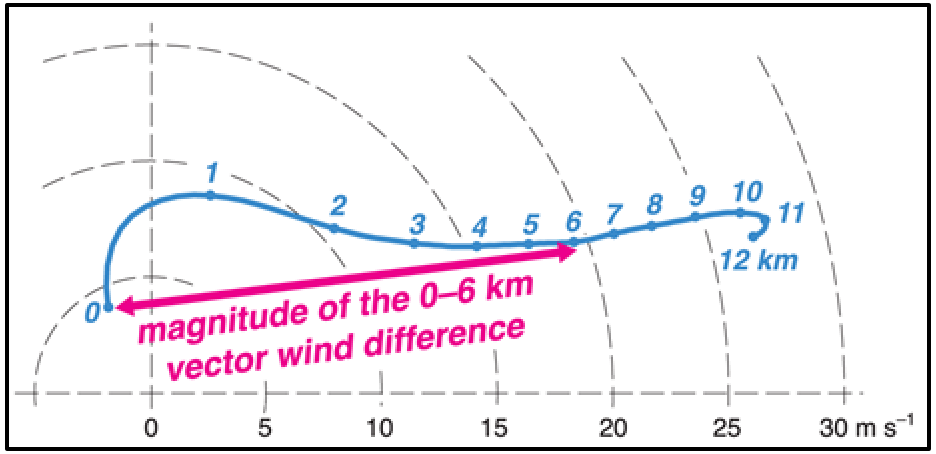
Mode of Convection

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
  - 10–20 m s^{-1} moderate
  - > 20 m s^{-1} strong



MR (2010), Fig. 8.1

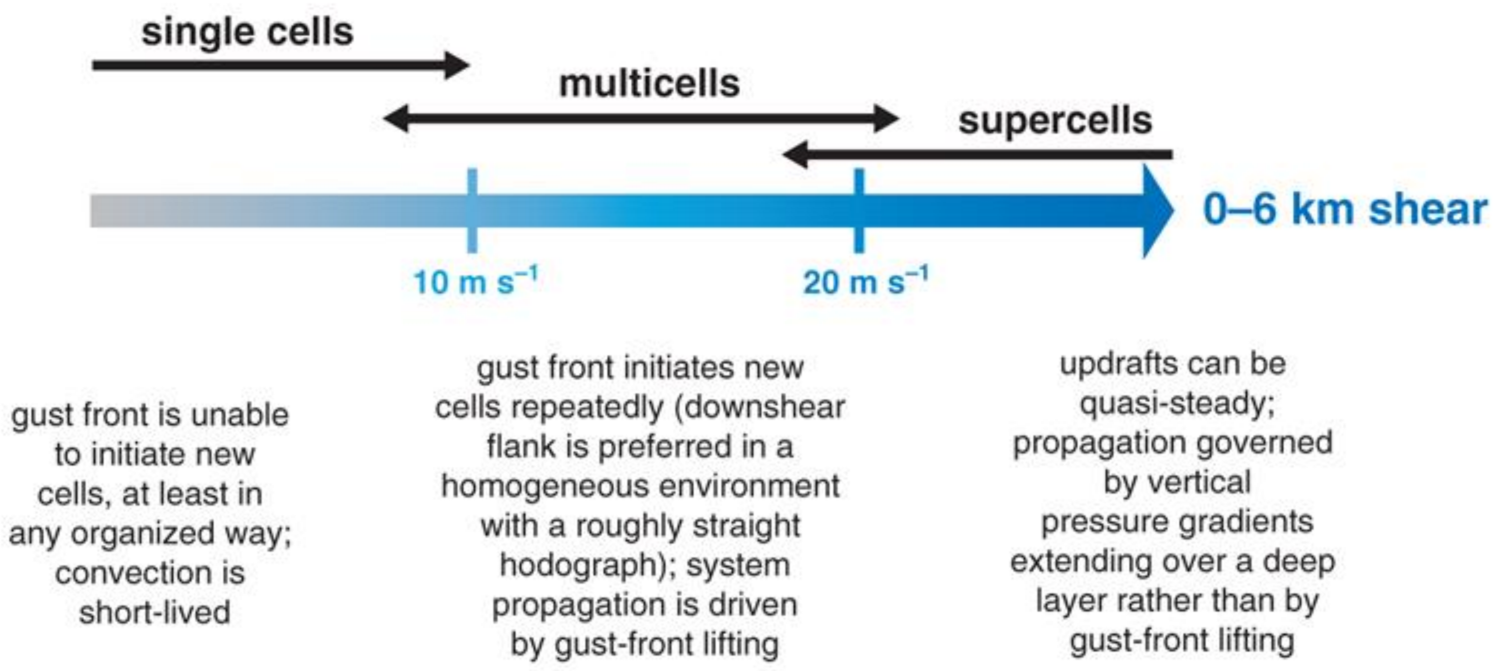


Figure 8.5

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)

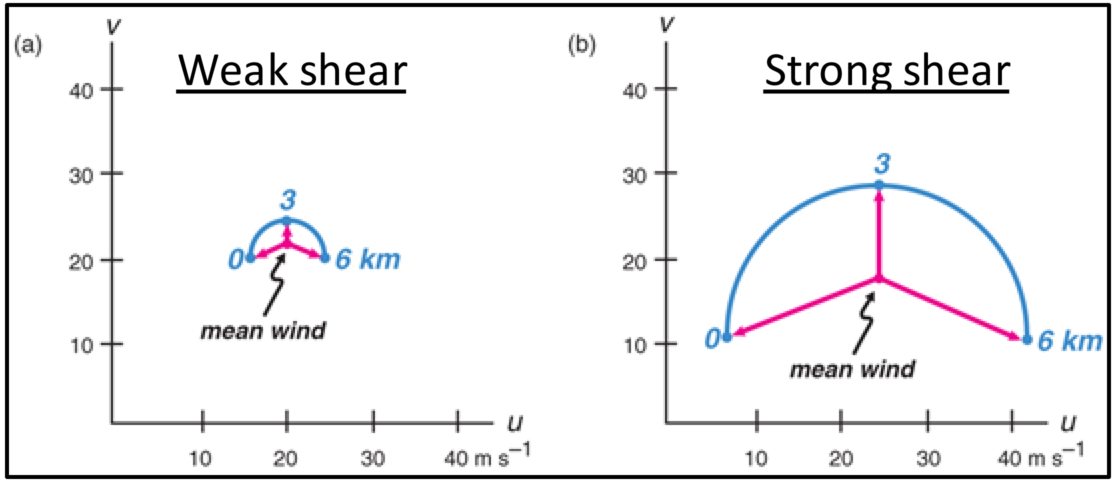
Importance of Vertical Shear

- **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** $\boldsymbol{\tau = \frac{H}{w_0} + \frac{H}{v_t}}$

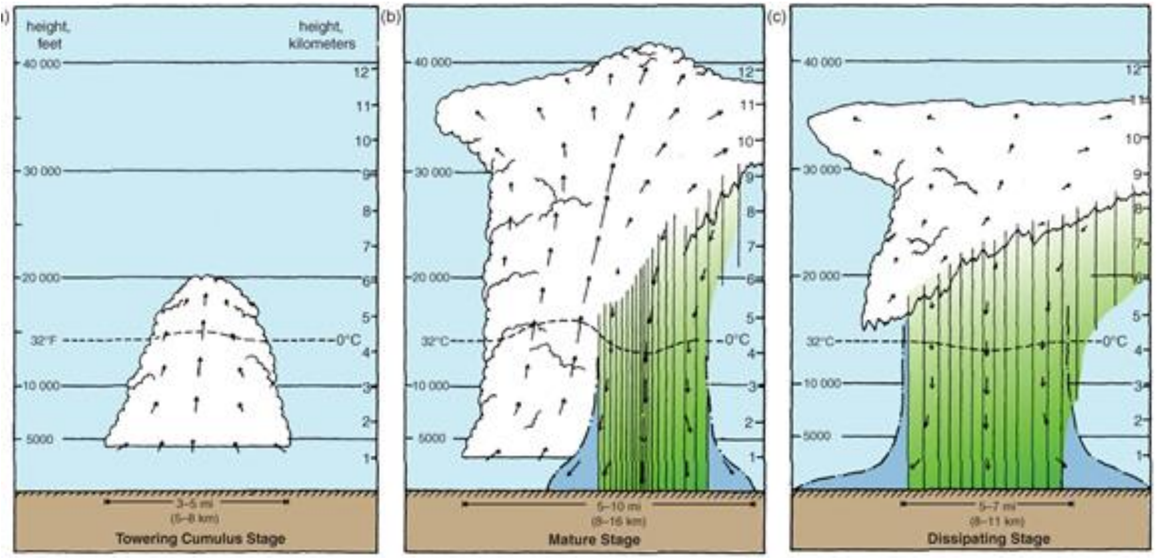
H=scale height
w_0=average updraft speed
v_t=terminal velocity of precipitation

Time for precipitation produced by ascent to fall to ground

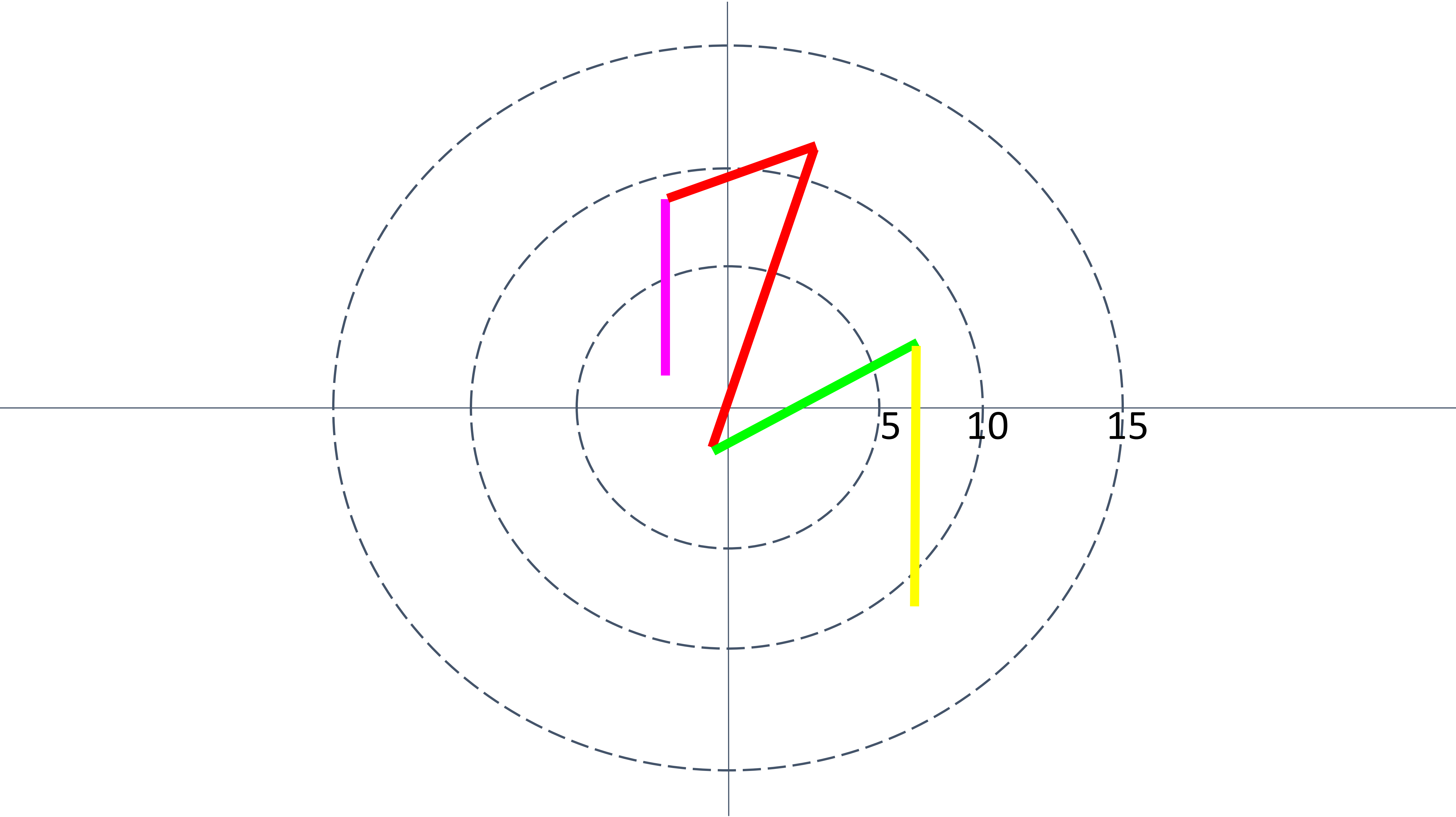
Time for air to ascend from surface to EL

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

- **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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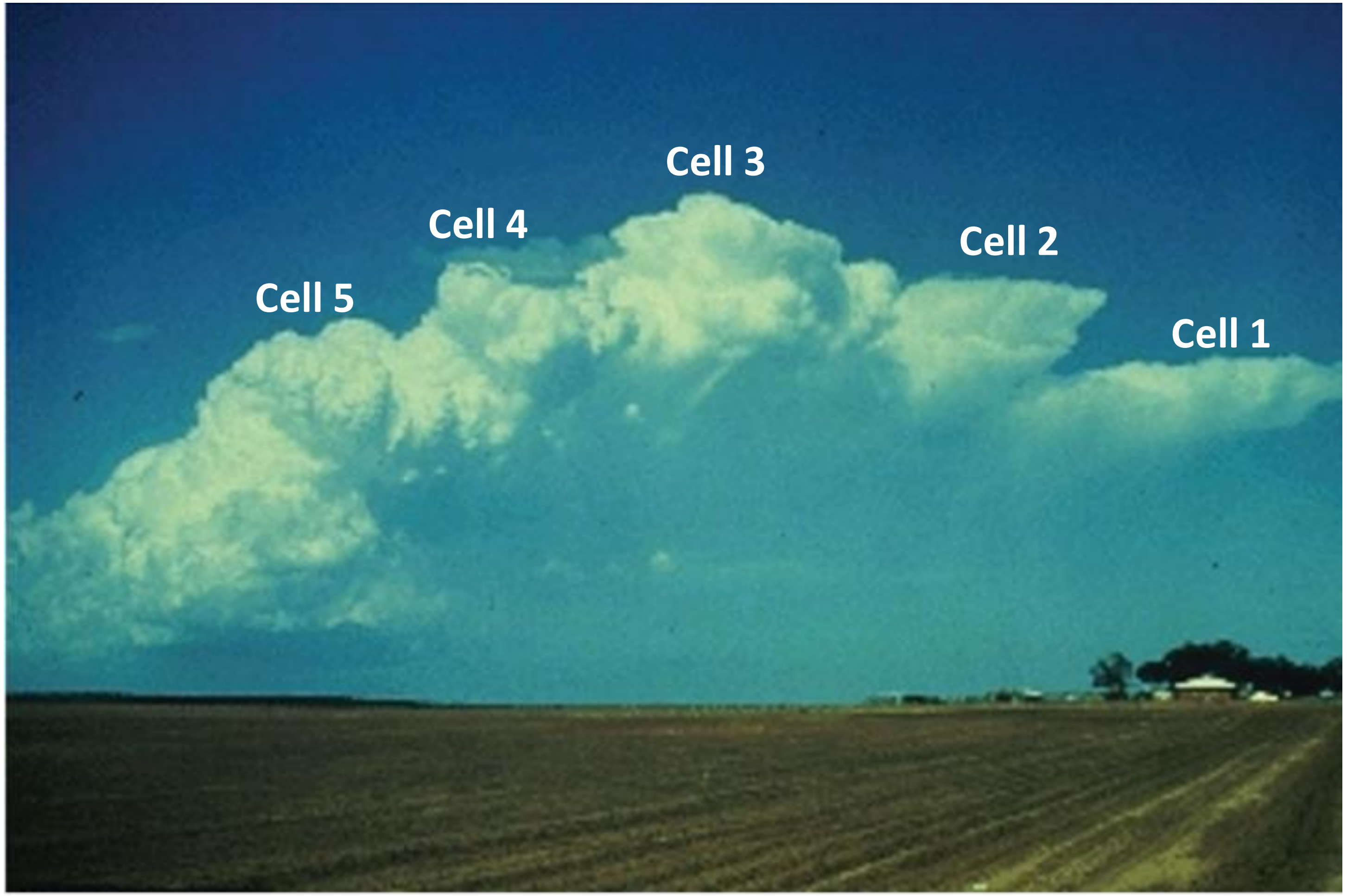
Multicell Convection

- 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

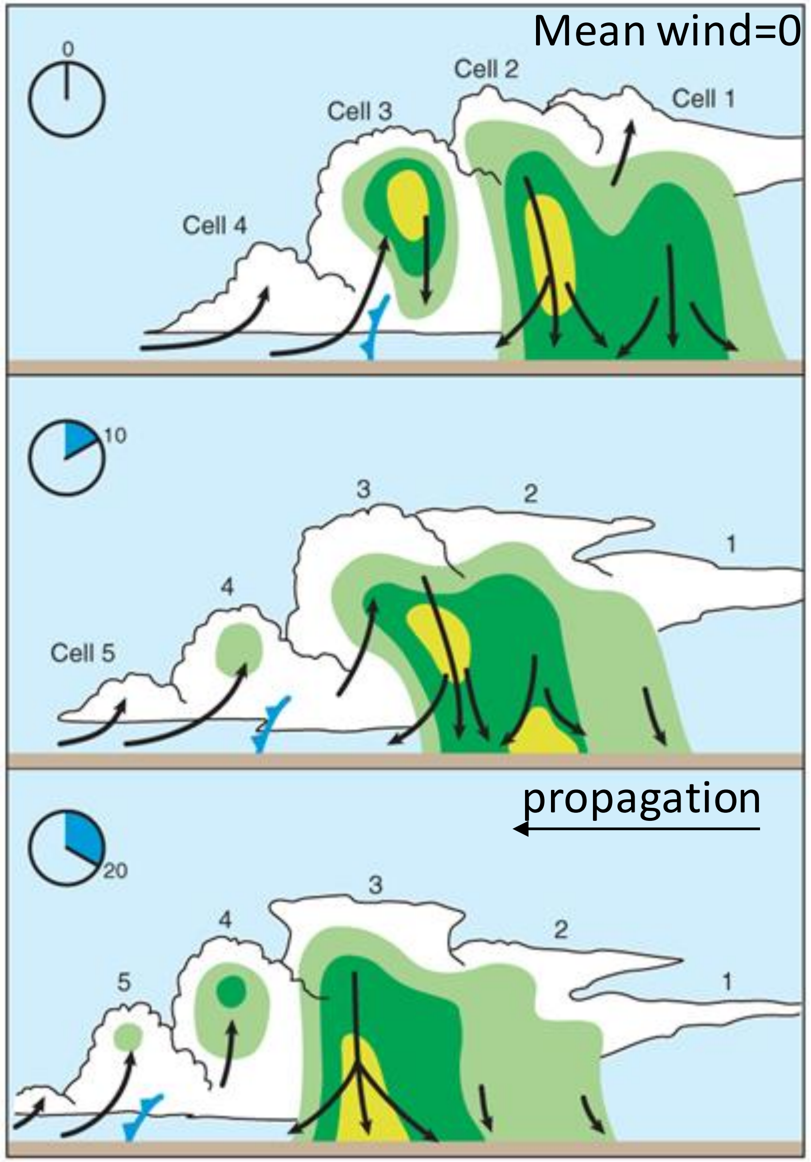
- In high CAPE moderate shear, multicell convection can produce swaths of damaging winds and hail



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

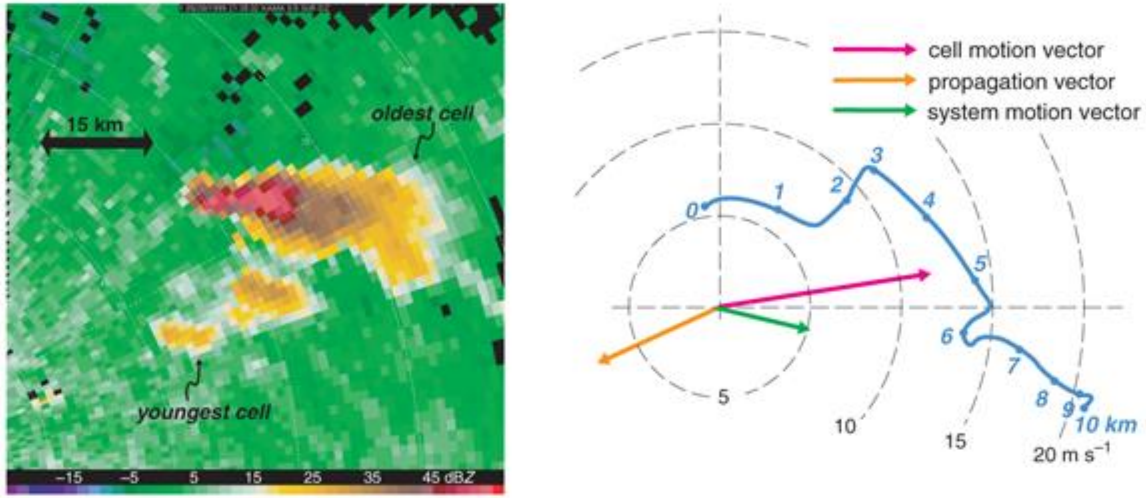
Movement versus propagation

- **Individual cells move with the mean wind**

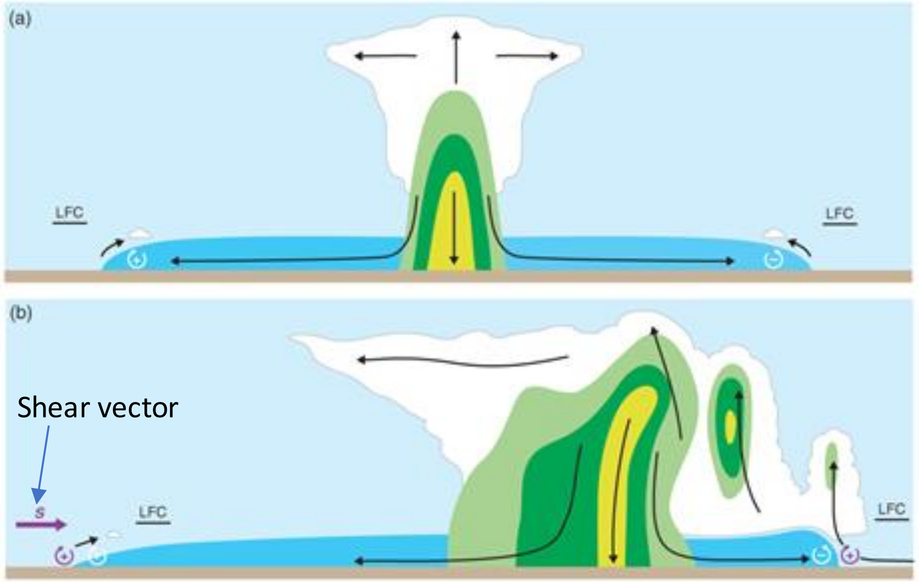
- **Repeated development of new cells on flank of system leads to propagation of system**

- **Total motion is cell motion+propagation**

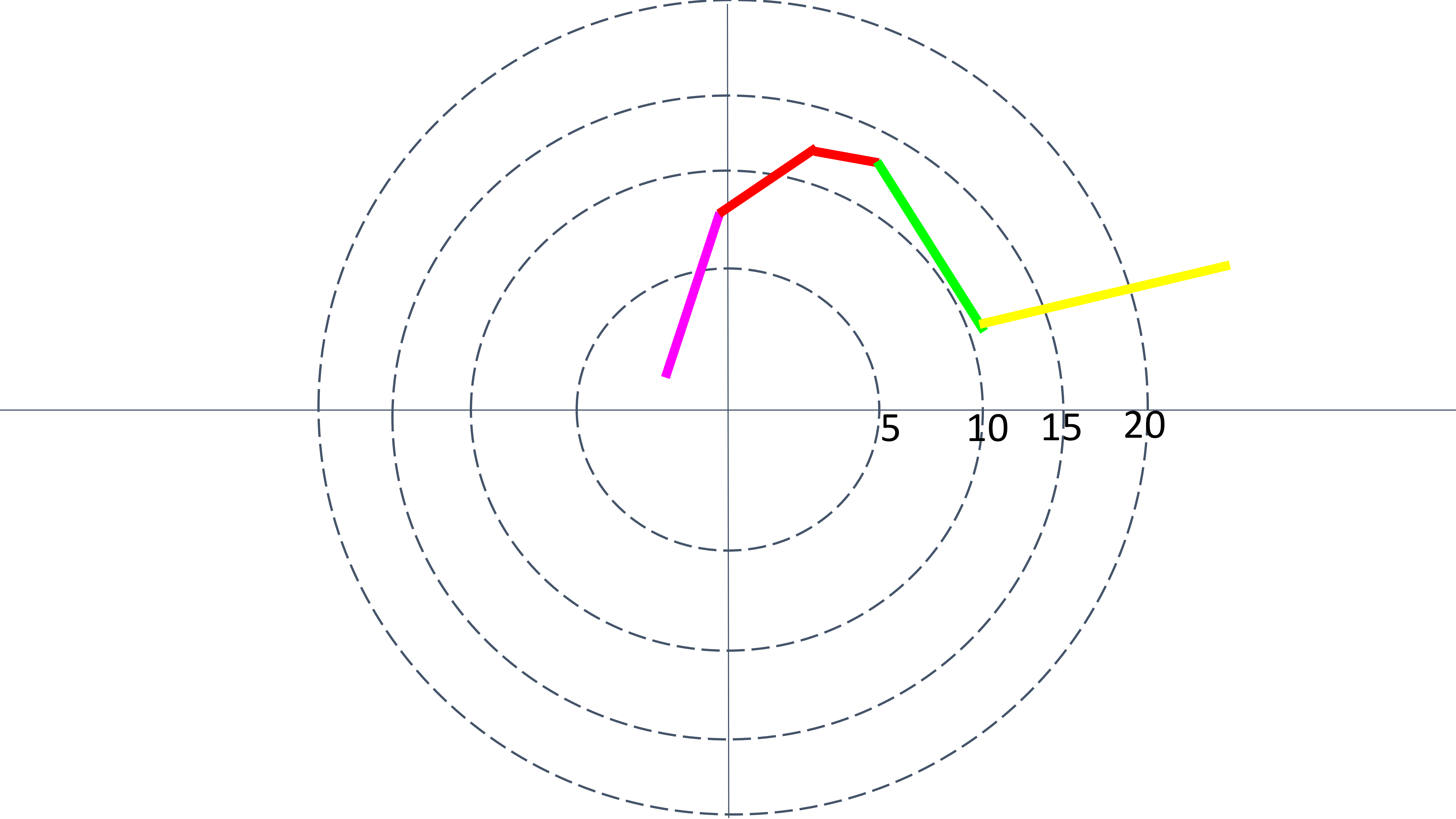
- **New cells develop on gust front on downshear side of cold pool**



MR (2010), Fig. 8.10



MR (2010), Fig. 8.12



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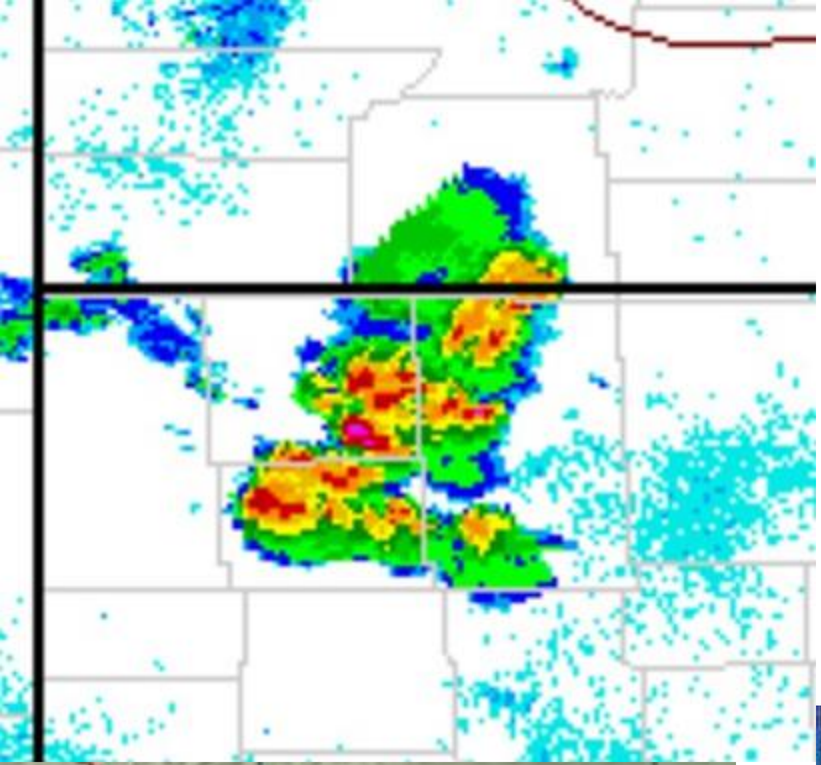
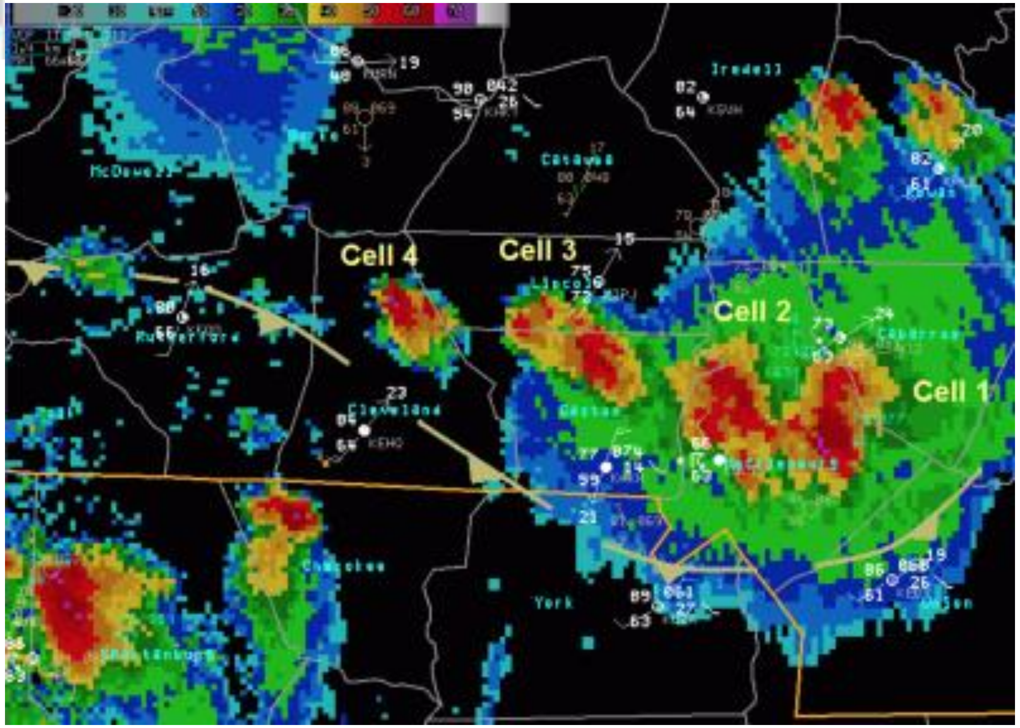
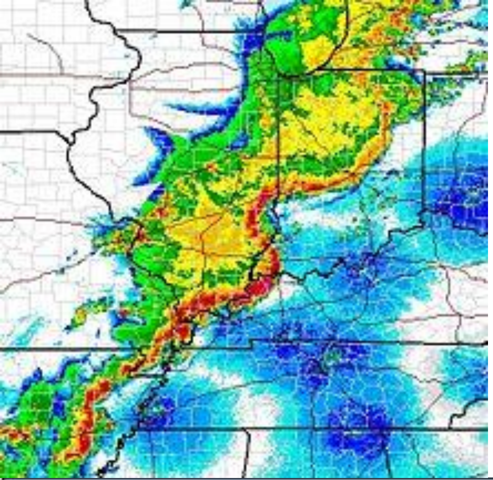
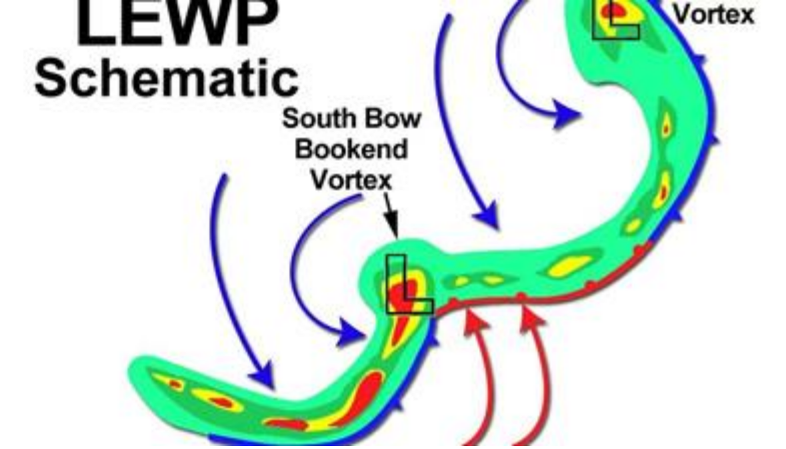


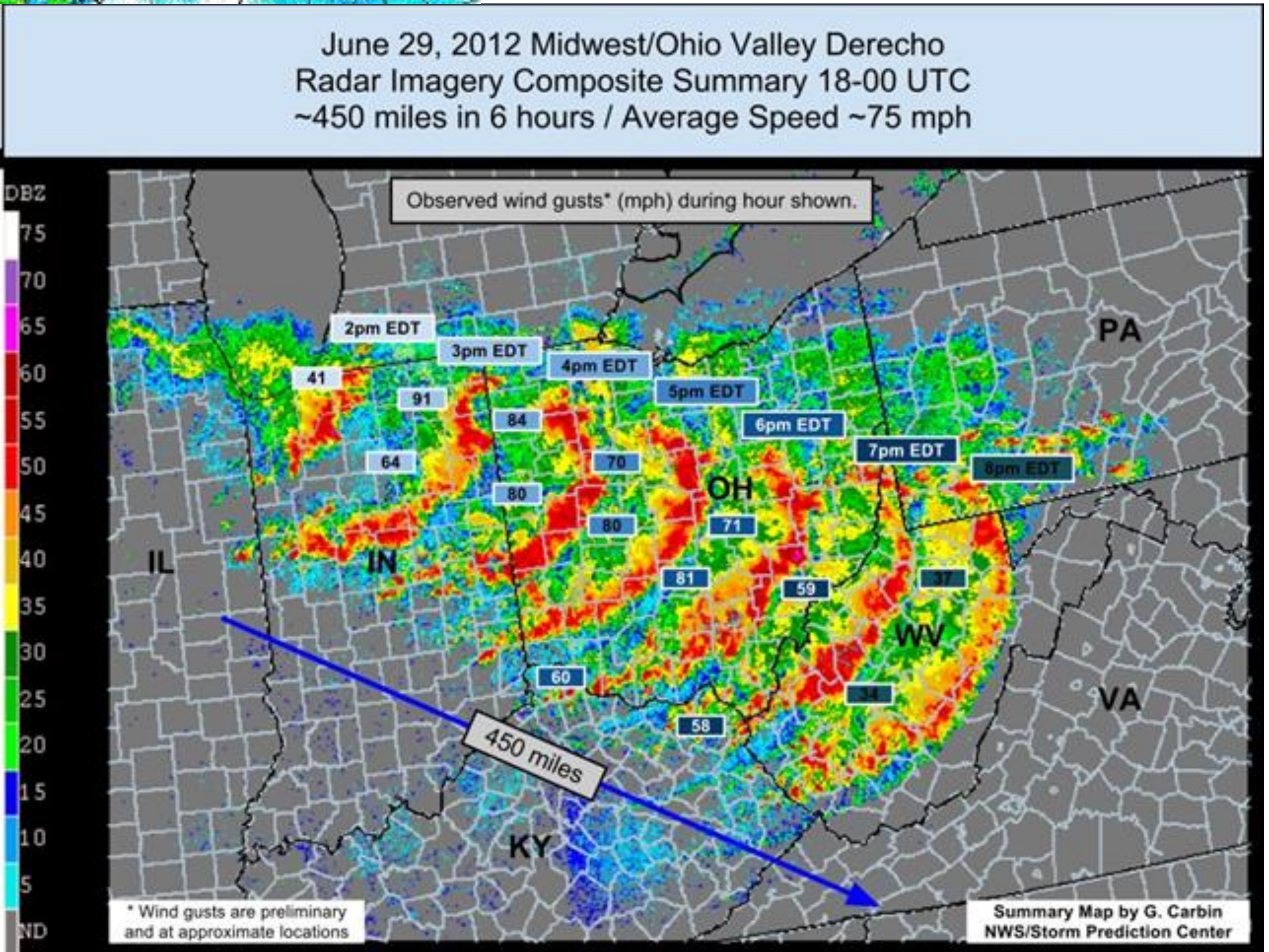
Multi Cell Clusters

- 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.









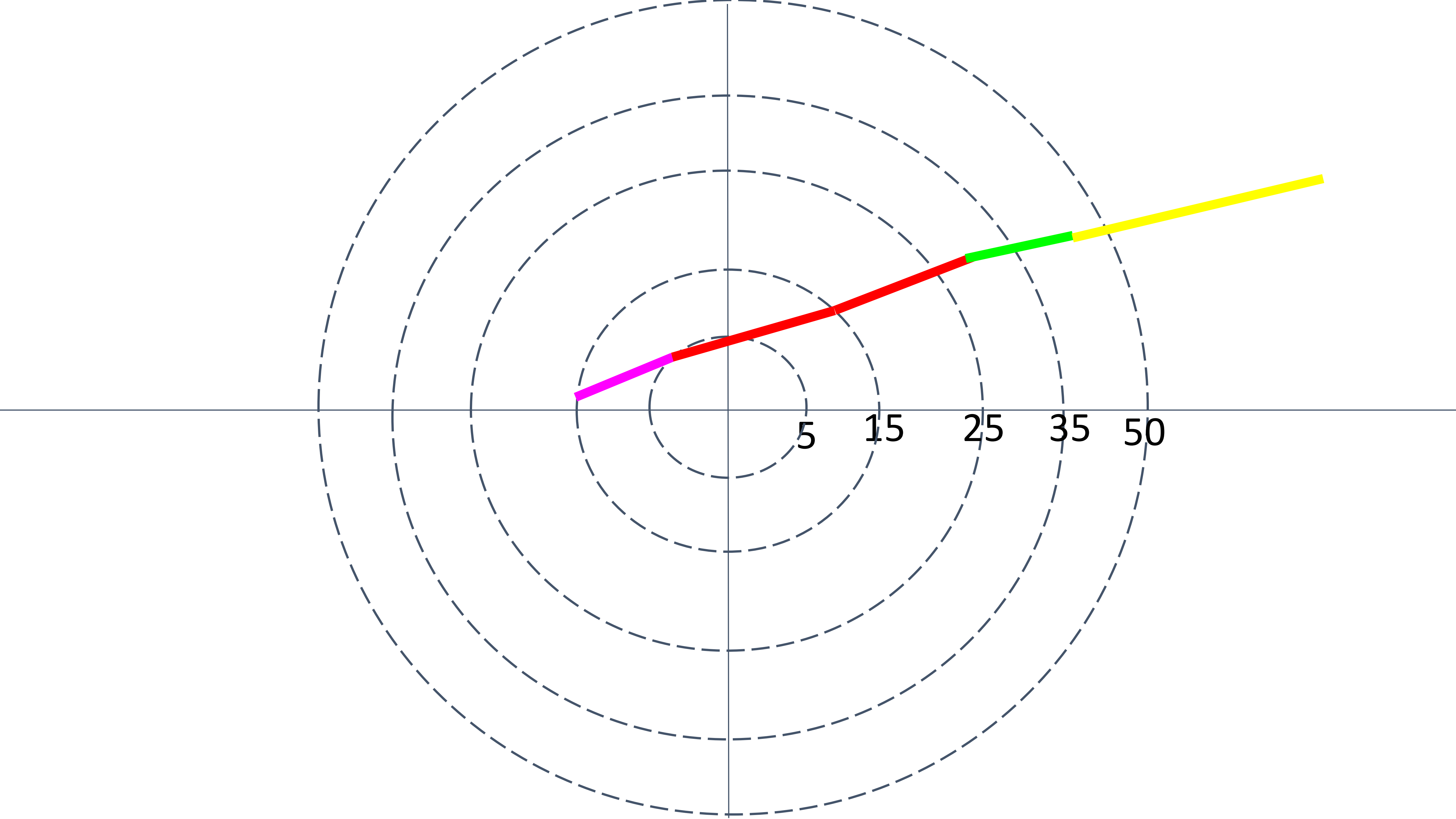
Multi Cell Lines

- 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**

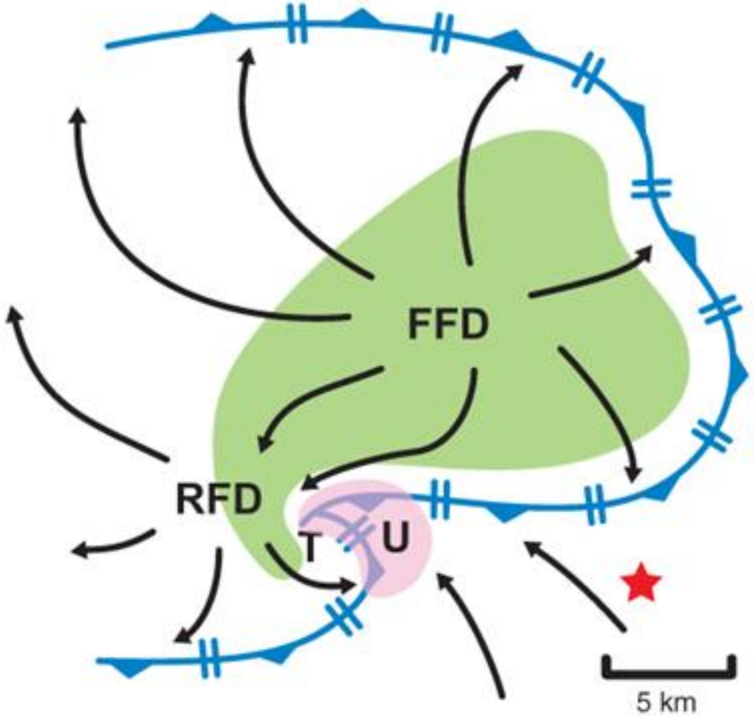
- **Motion deviates significantly from mean wind**

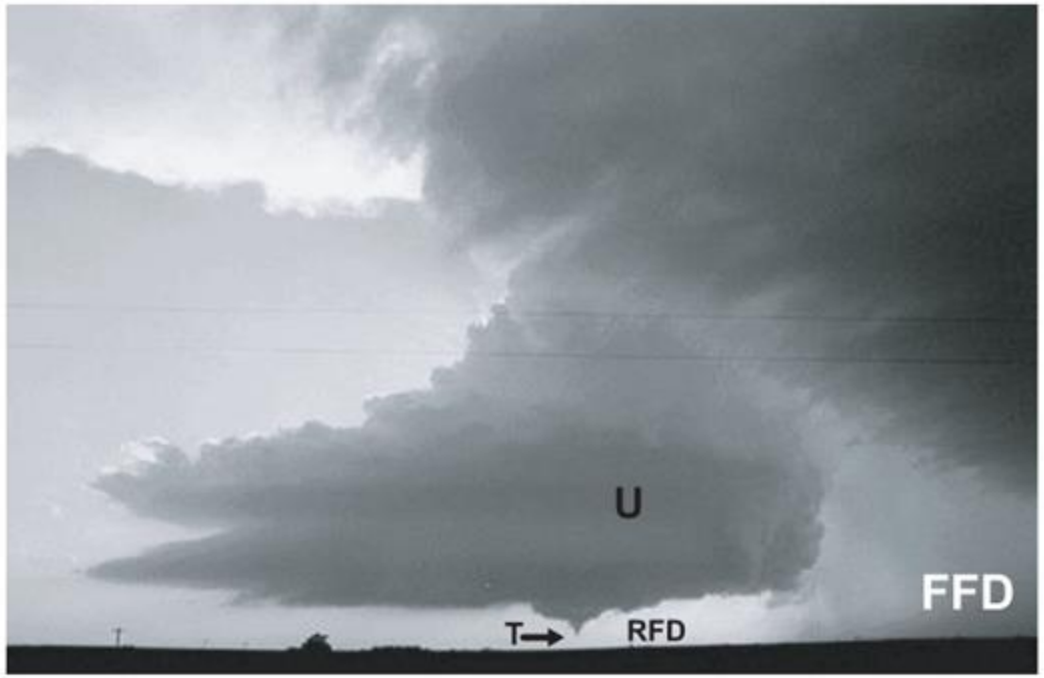
- **Vertical PGF enhances updraft, a special property of supercells**

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)

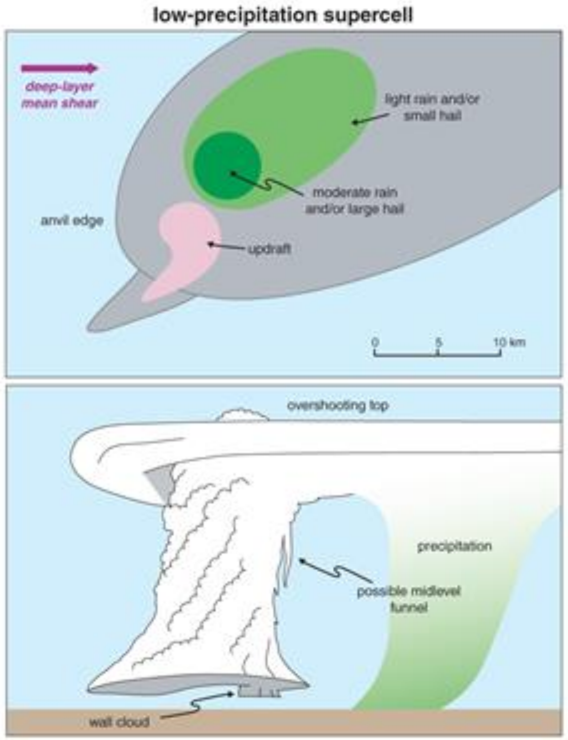




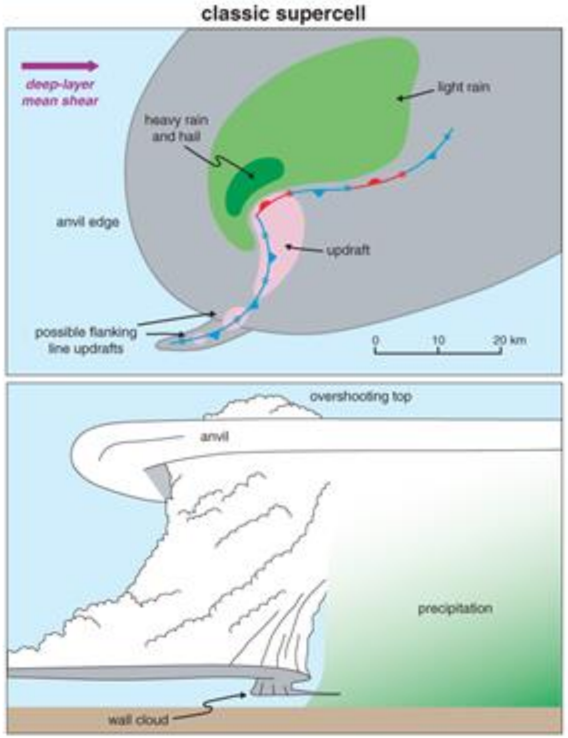
MR (2010), Fig. 8.22

Supercell Types

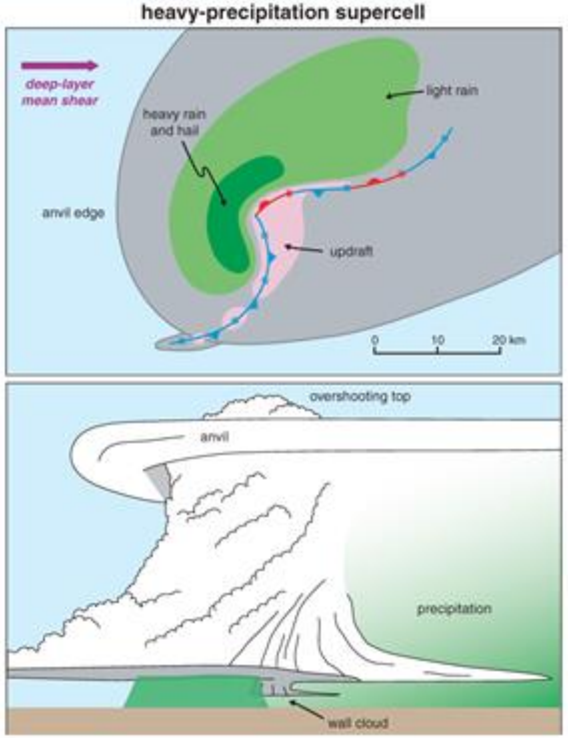
- For isolated storms, supercell type is (maybe) a function of storm-relative winds (SRW) at level of anvil (9–12 km AGL)
- Weak upper-level storm-relative winds (<18 m/s): HP; moderate (18-28 m/s): classic; strong (>28 m/s): LP
- For multiple storms in close proximity, precipitation from one storm may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



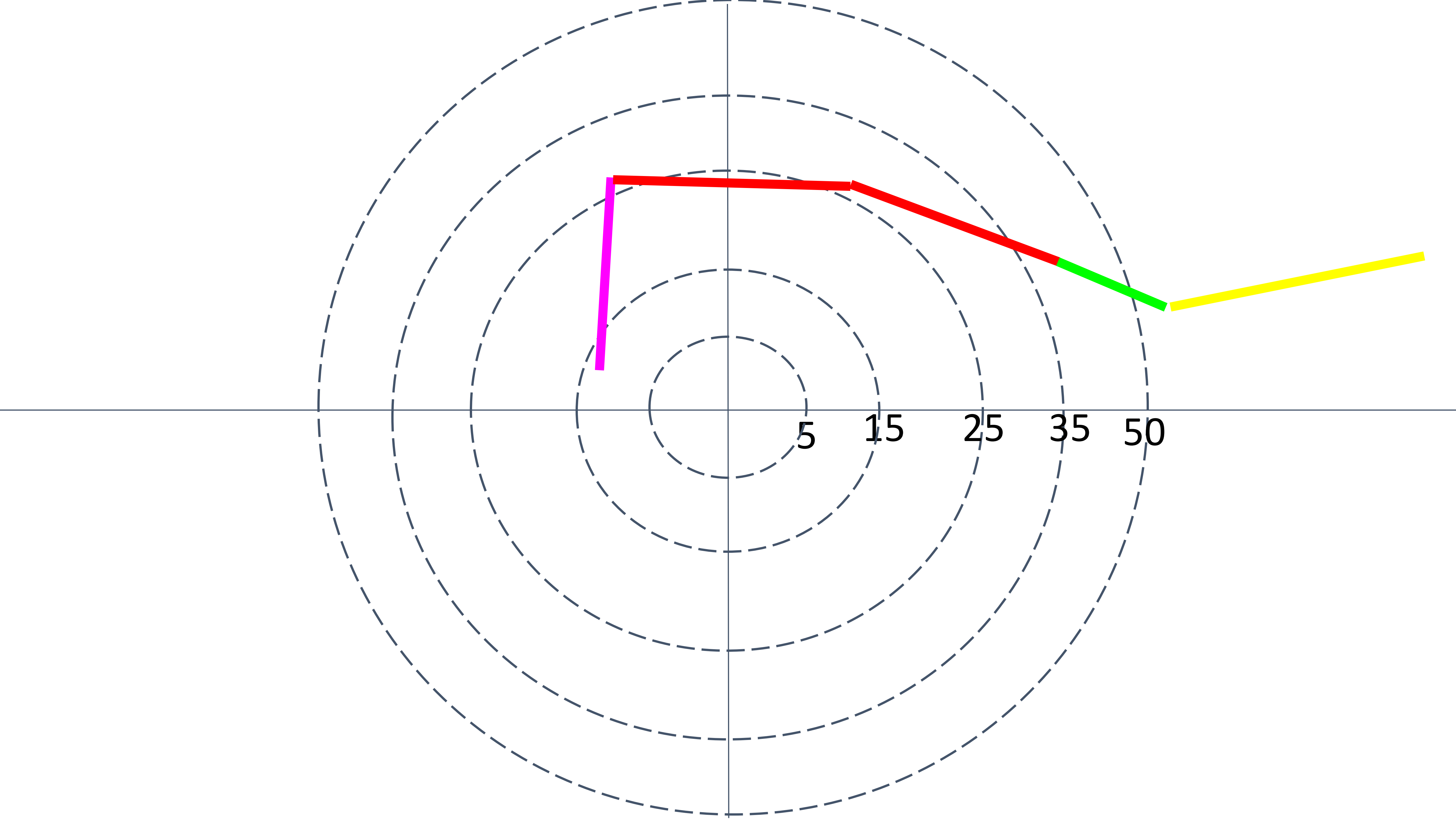
MR (2010), Fig. 8.24



MR (2010), Fig. 8.16



MR (2010), Fig. 8.26



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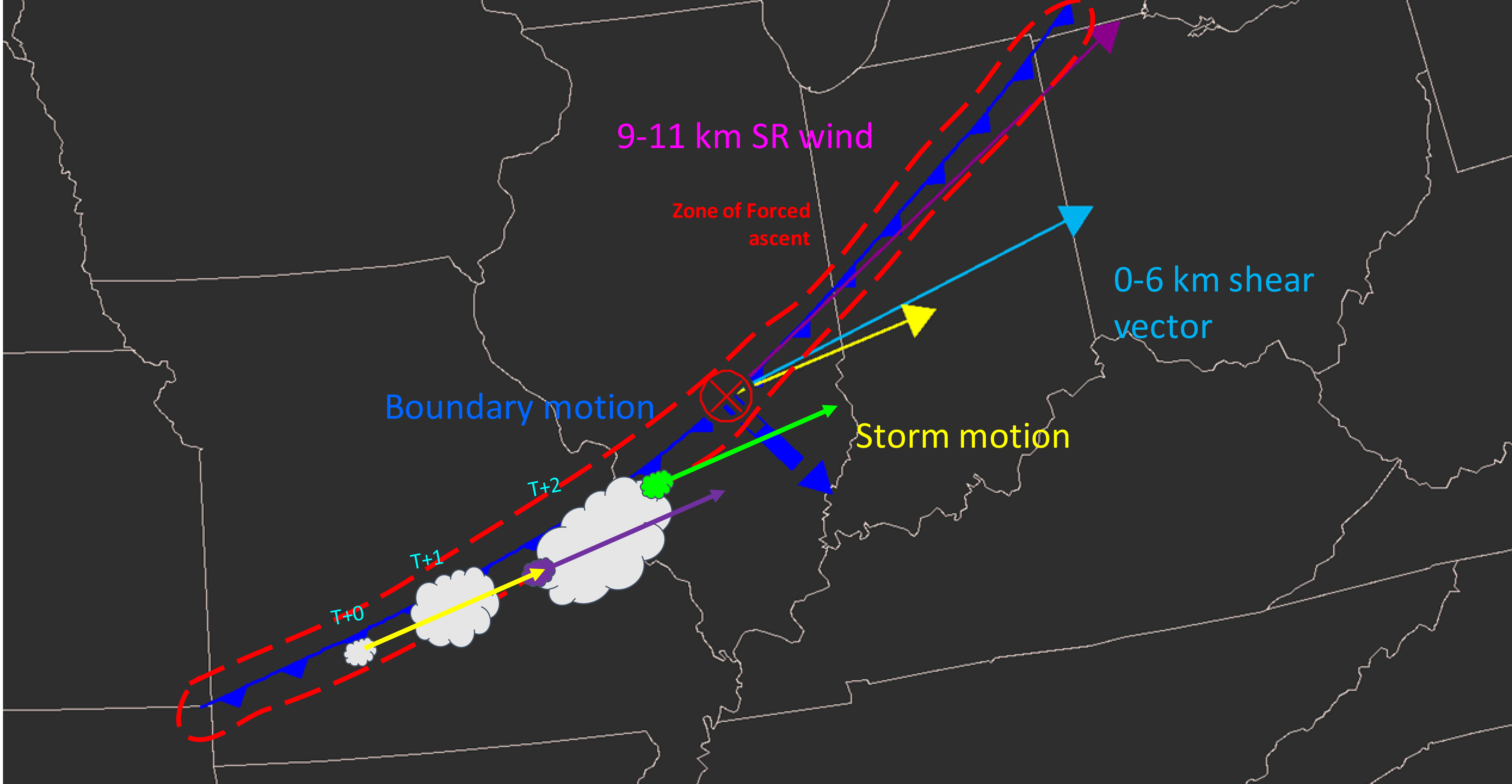
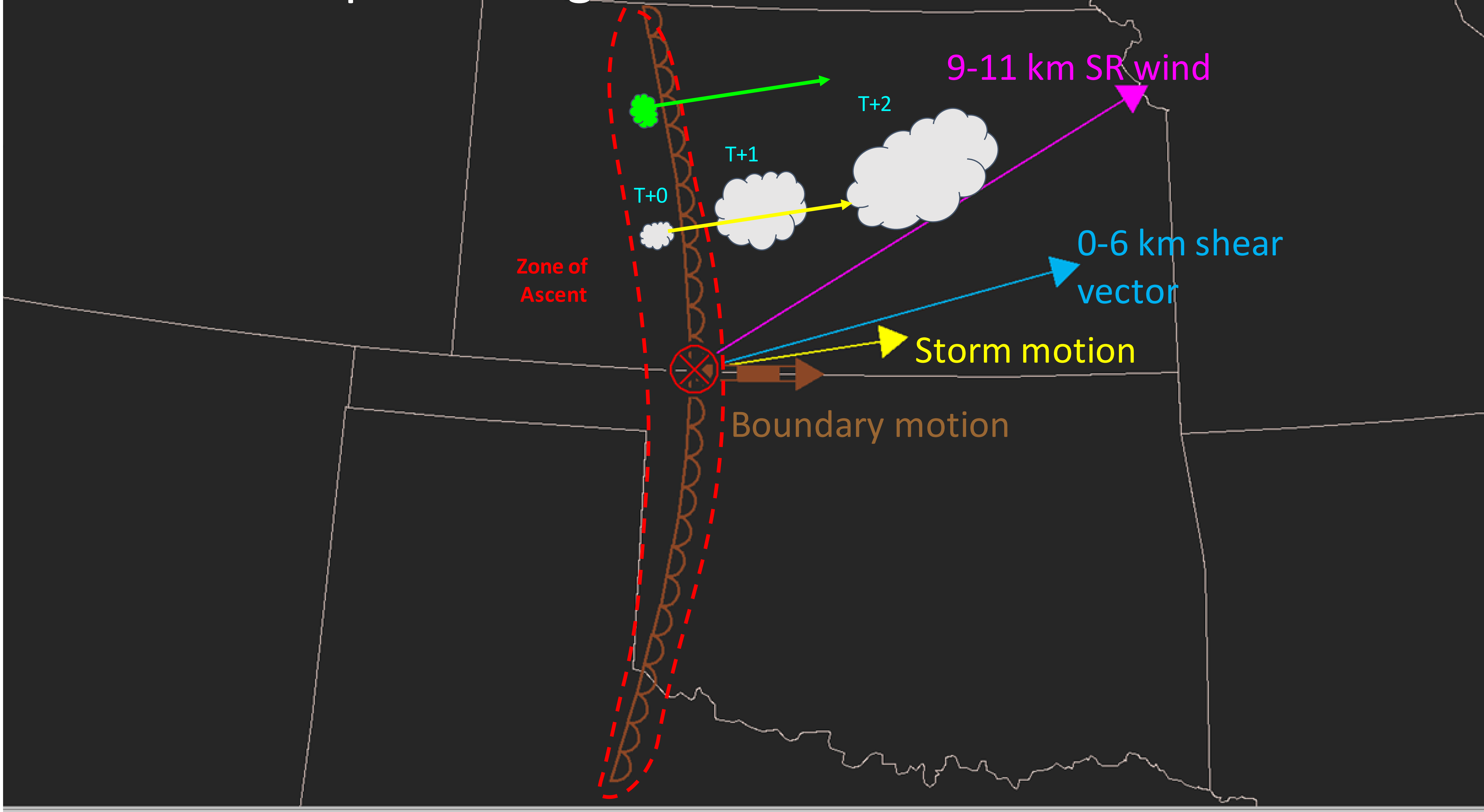
Setup Favoring Linear Convection



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.**

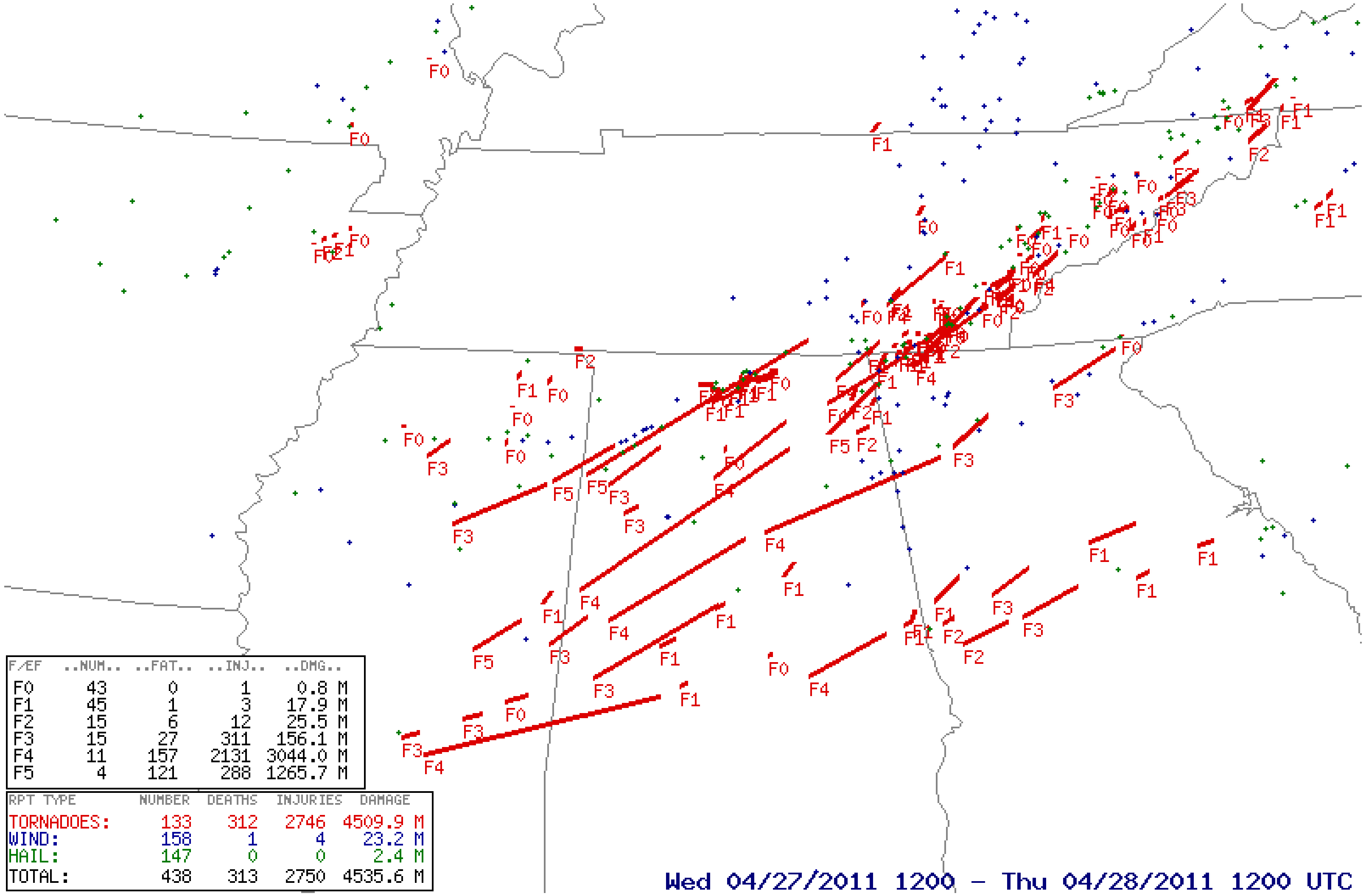
Setup Favoring Discrete Convection



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



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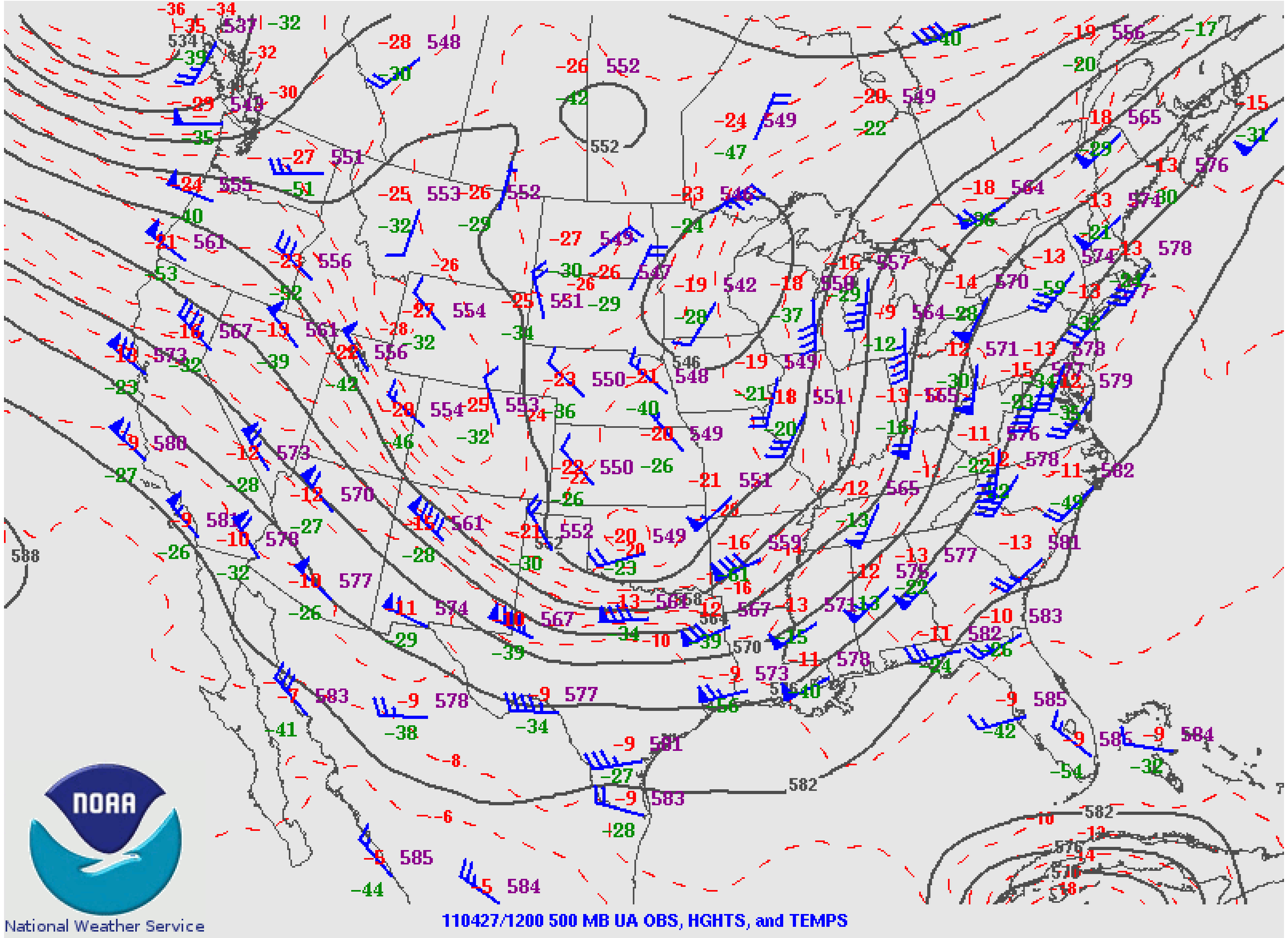
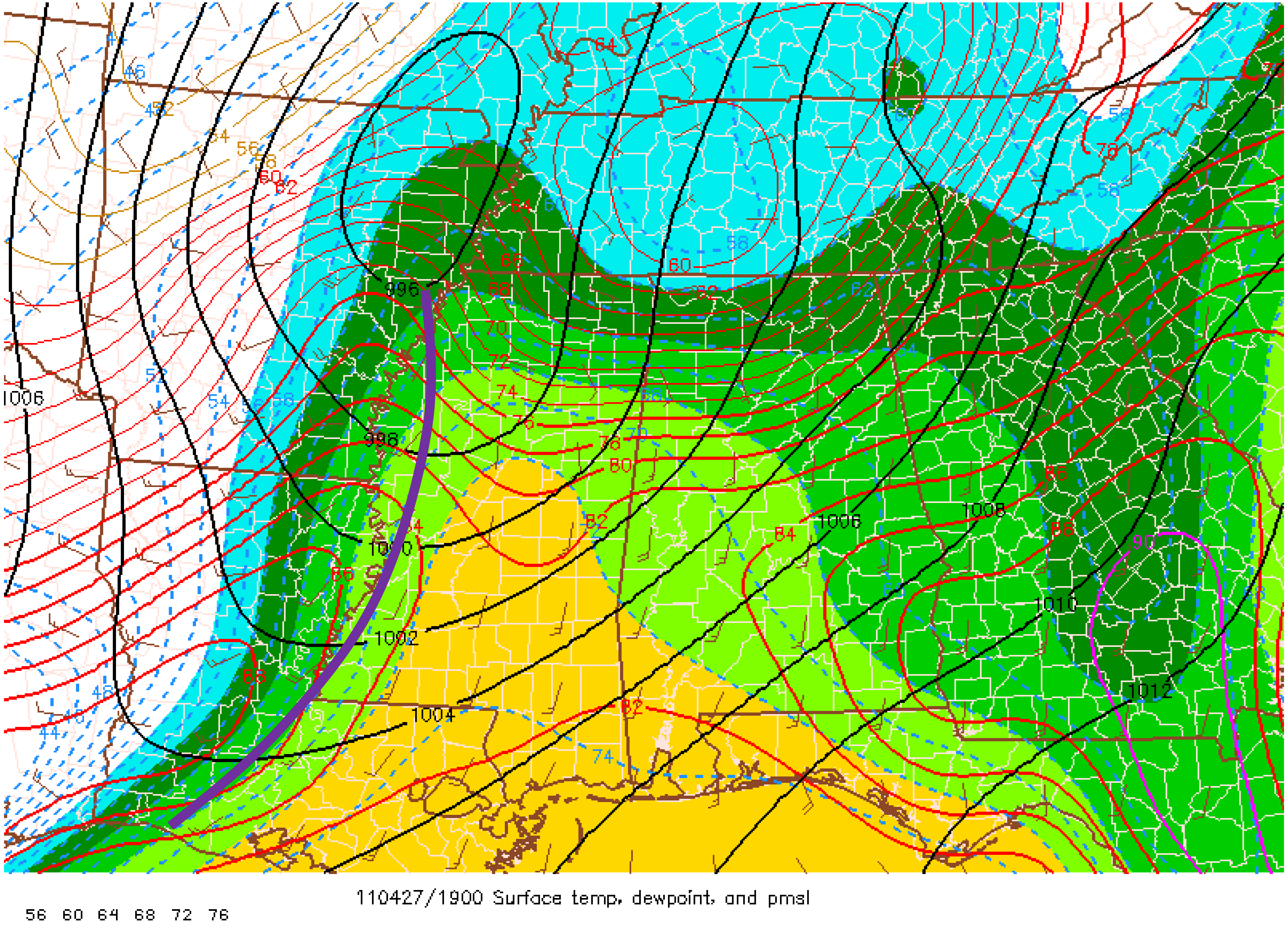
F0	43	0	1	0.8 M
F1	45	1	3	17.9 M
F2	15	6	12	25.5 M
F3	15	27	311	156.1 M
F4	11	157	2131	3044.0 M
F5	4	121	288	1265.7 M

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



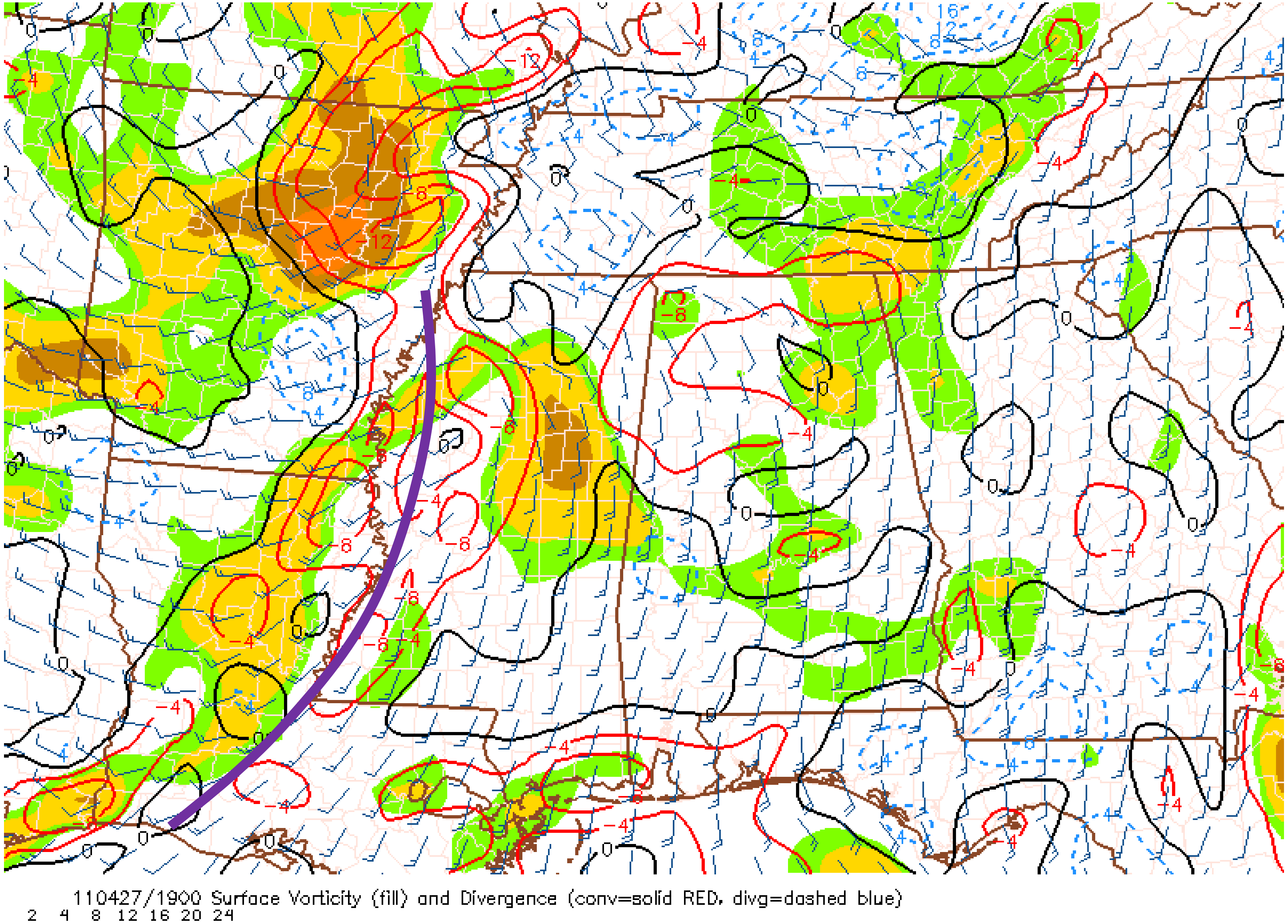
27 APR 2011 12z

Surface T, Td, and PMSL



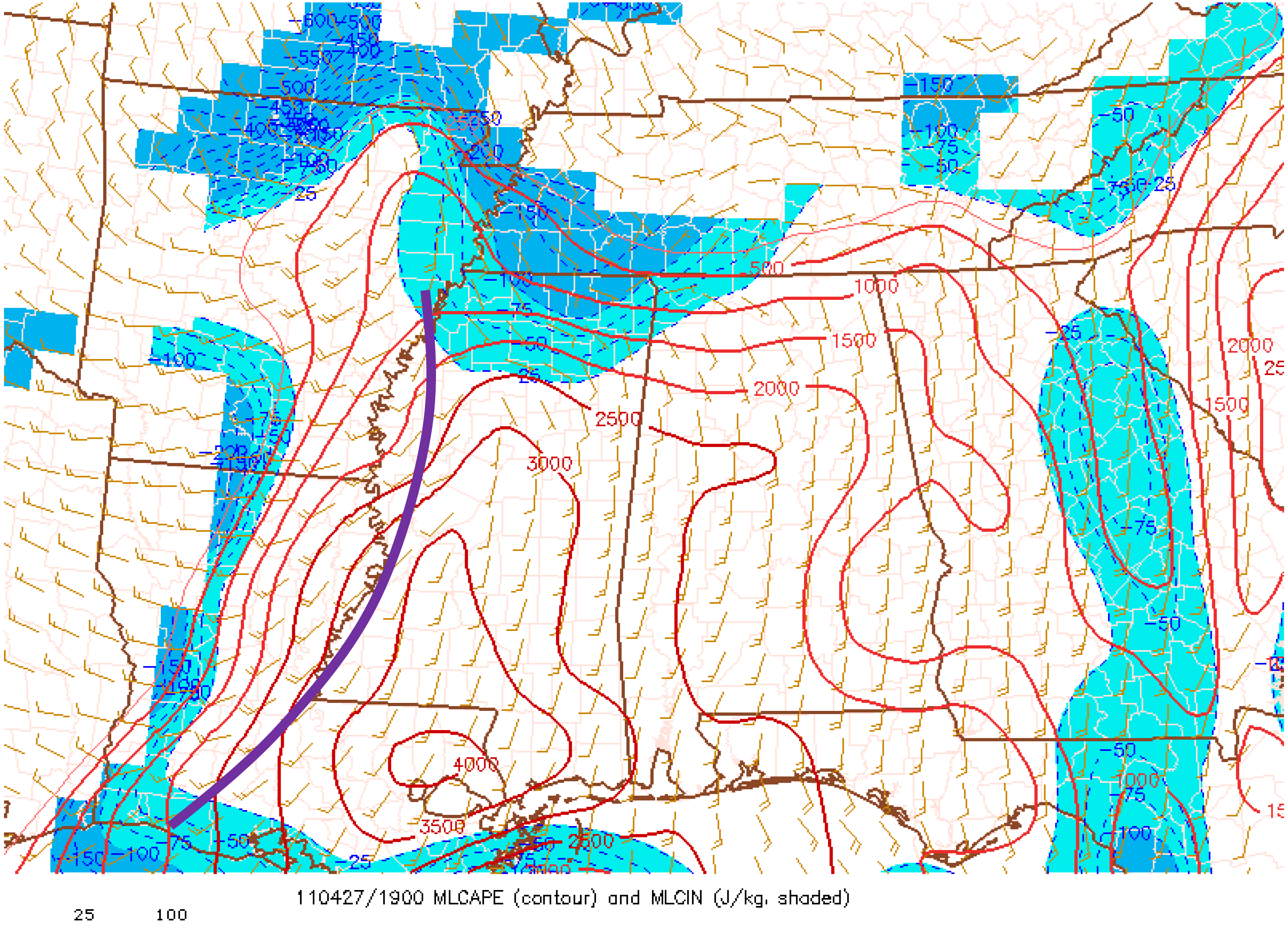
27 APR 19z

Surface convergence and vorticity



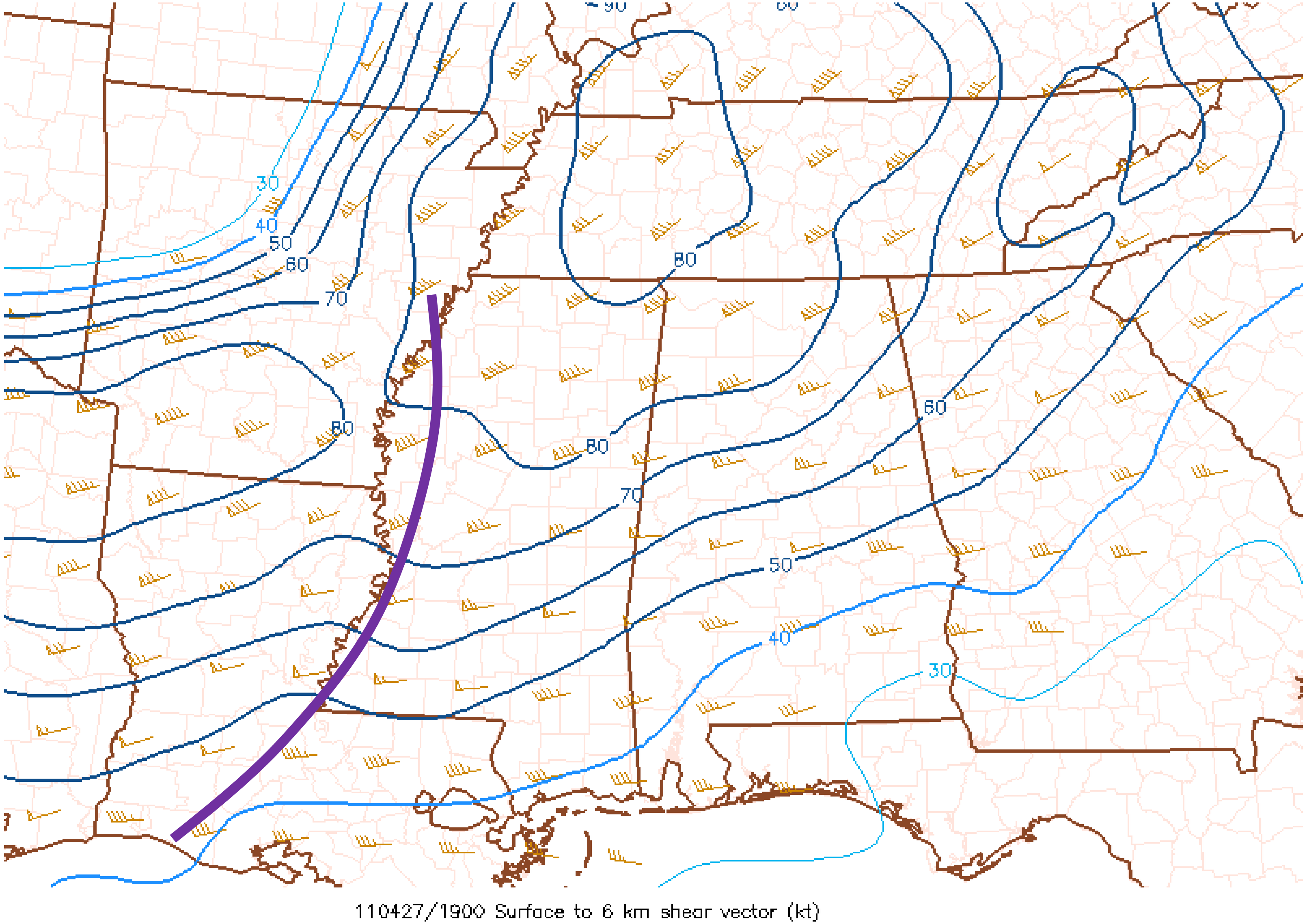
27 APR 19z

MLCAPE and MLCIN



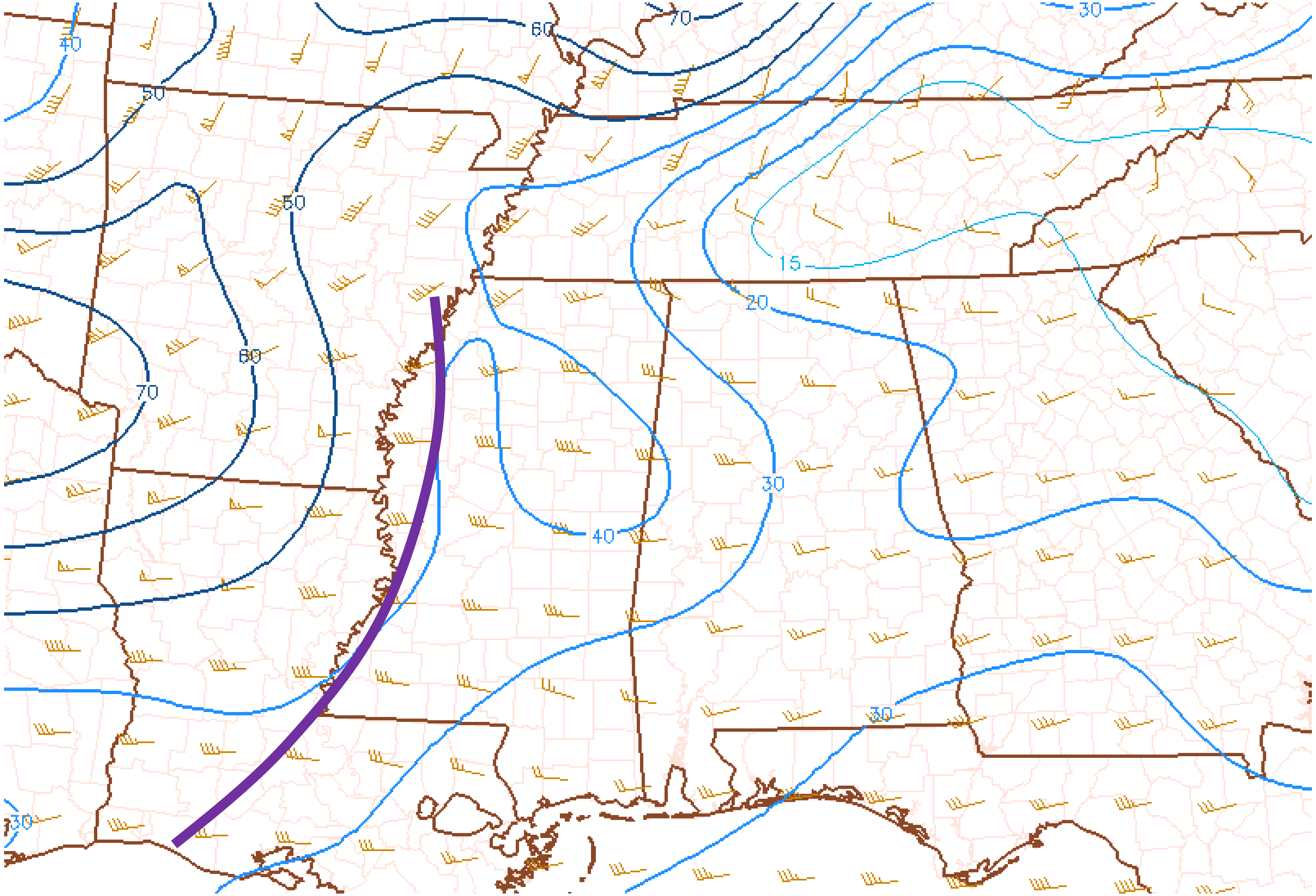
27 APR 19z

0-6 km shear vectors



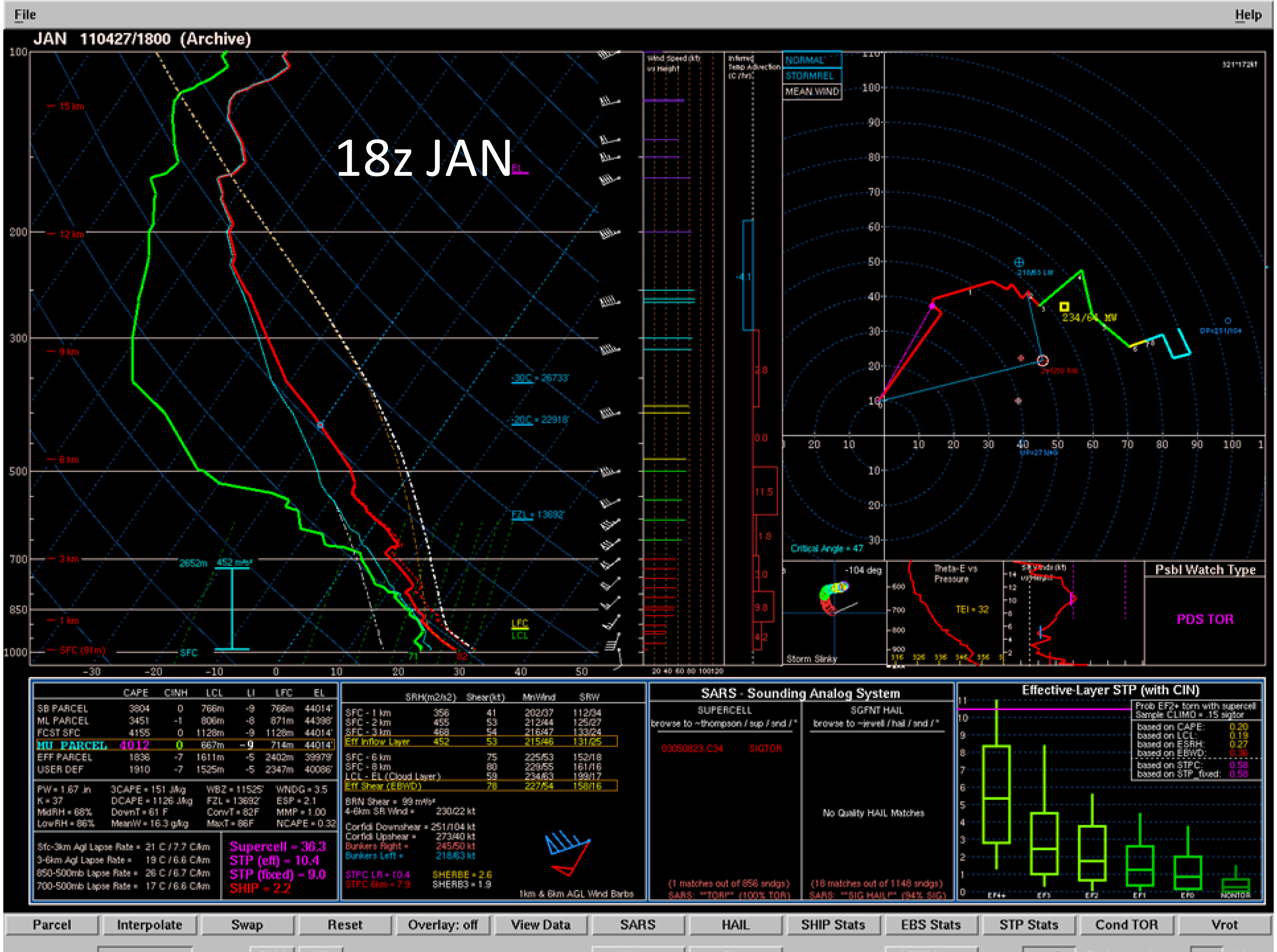
27 APR 19z

9-11 km storm-relative winds



110427/1900 9–11km SR Winds

27 APR 19z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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'
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K = 37
MidRH = 68%
LowRH = 86%
3CAPE = 151 J/kg
DCAPE = 1126 J/kg
DownT = 61 F
MeanW = 16.3 g/kg
WBZ = 11525'
FZL = 13692'
ConvT = 82F
MaxT = 86F
WNDG = 3.5
ESP = 2.1
MMP = 1.00
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
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 = 218/63 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
SGFNT HAIL
No Quality HAIL Matches
Effective-Layer STP (with CIN)
Psbl Watch Type
PDS TOR
Critical Angle = 47
Storm Slinky
TEI = 32
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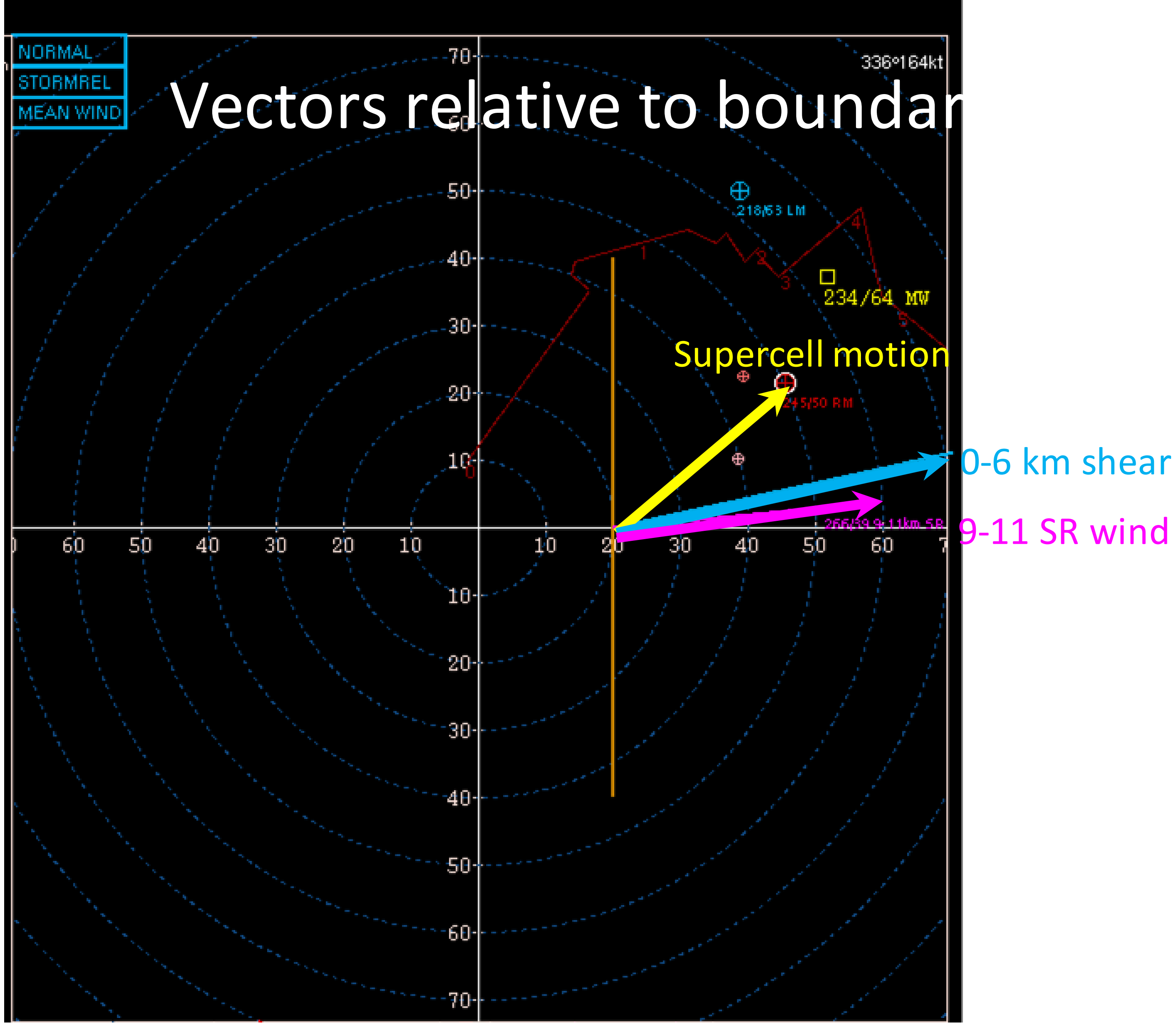
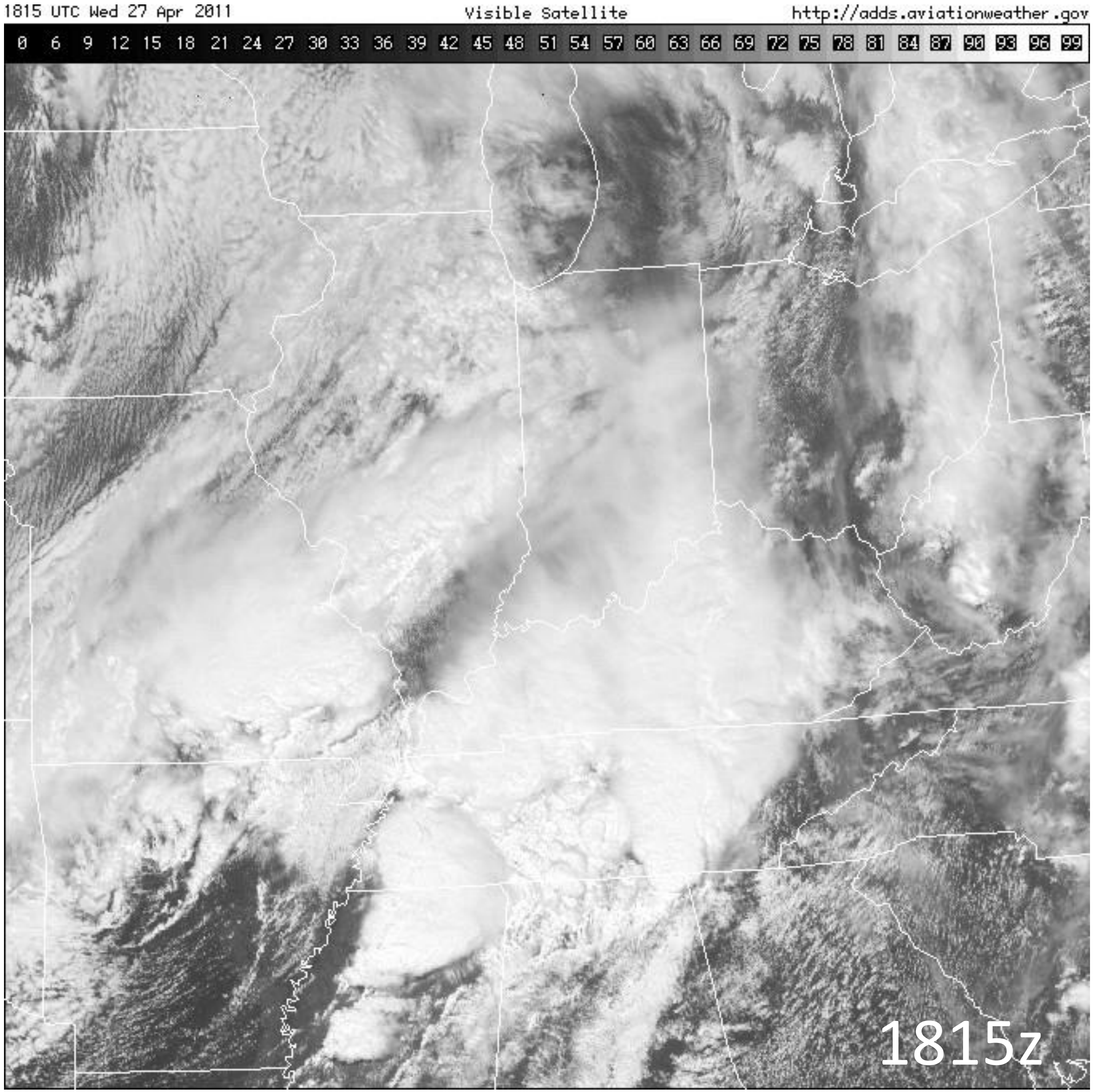
Vectors relative to boundar

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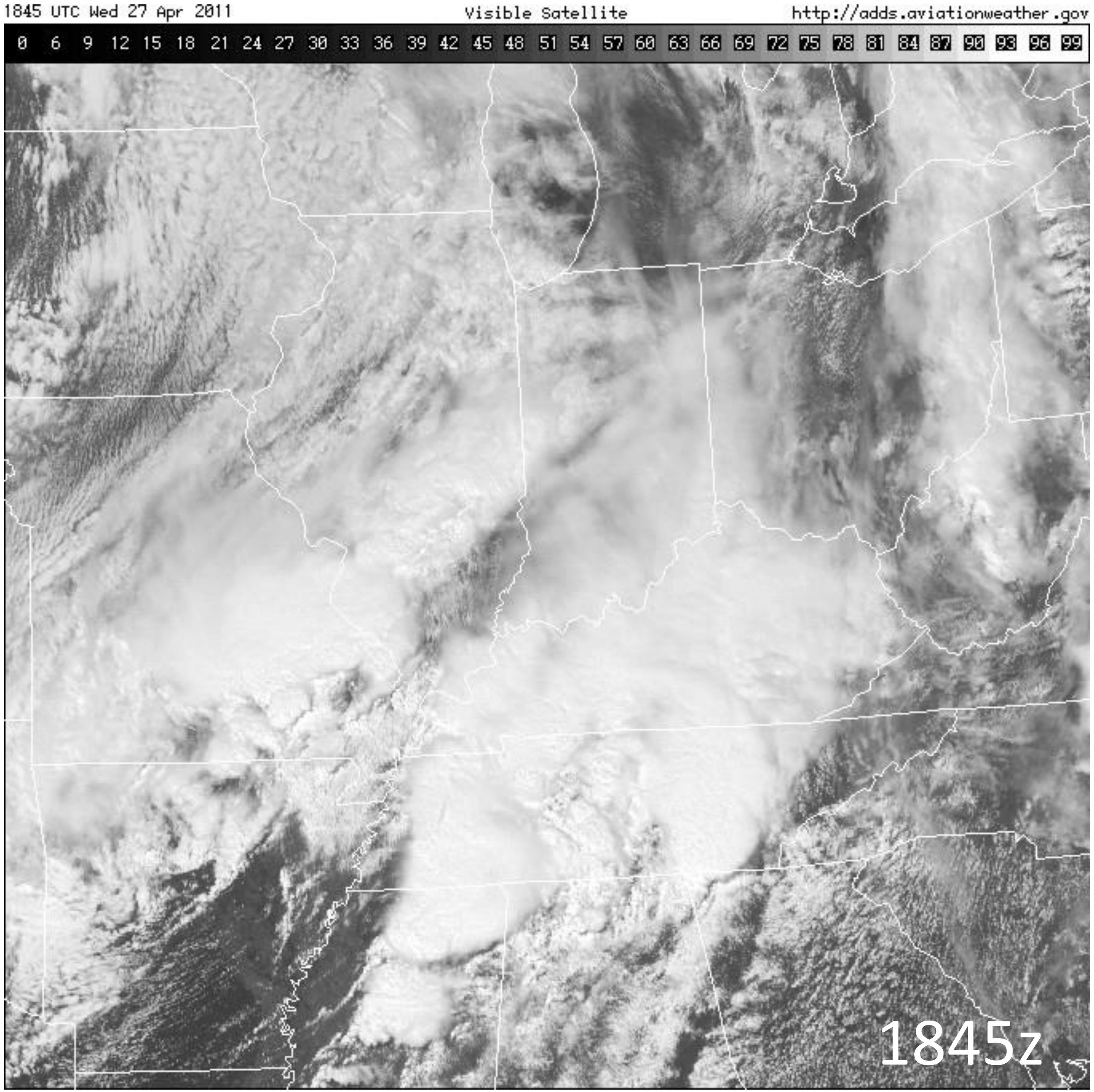
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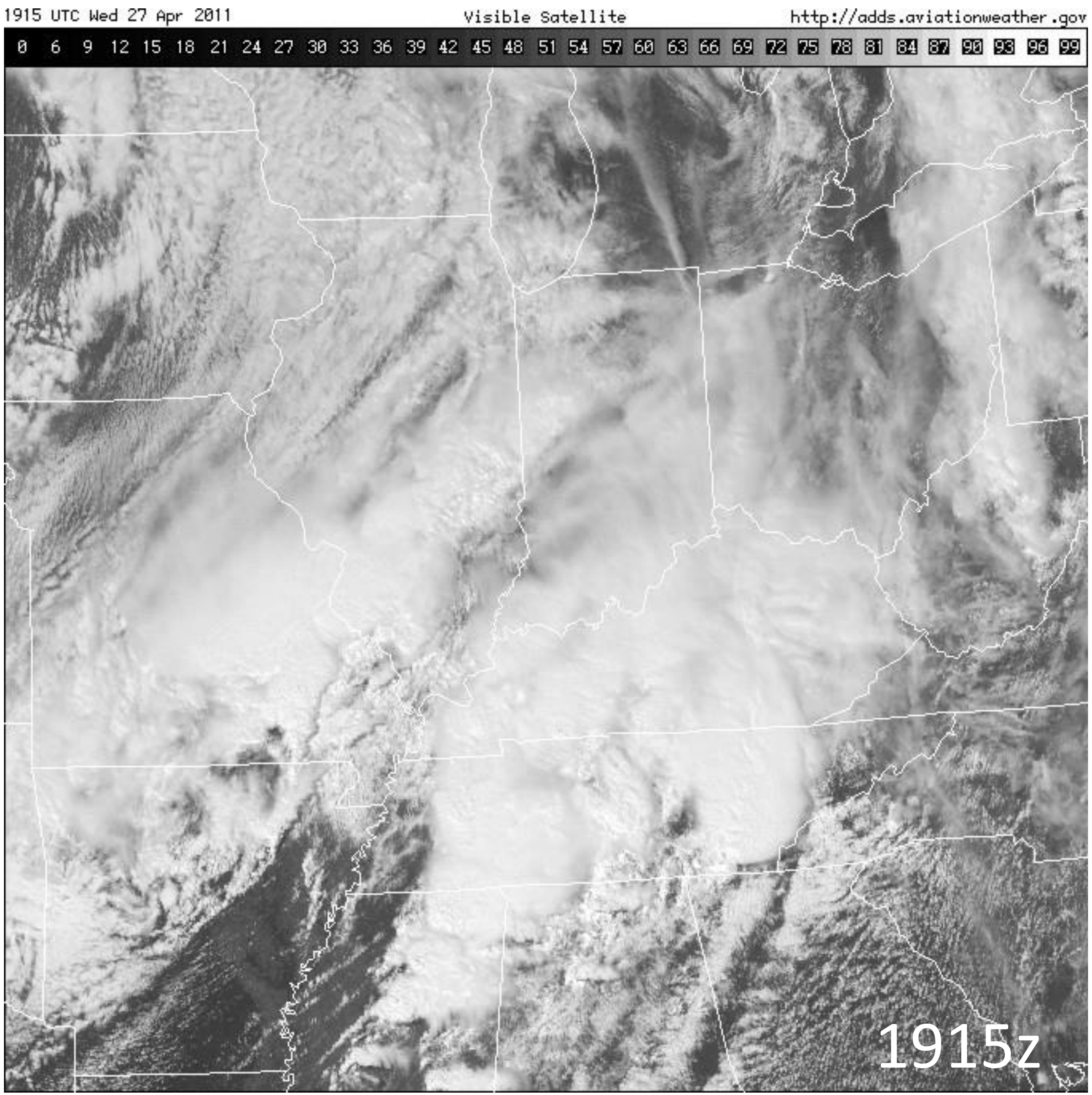

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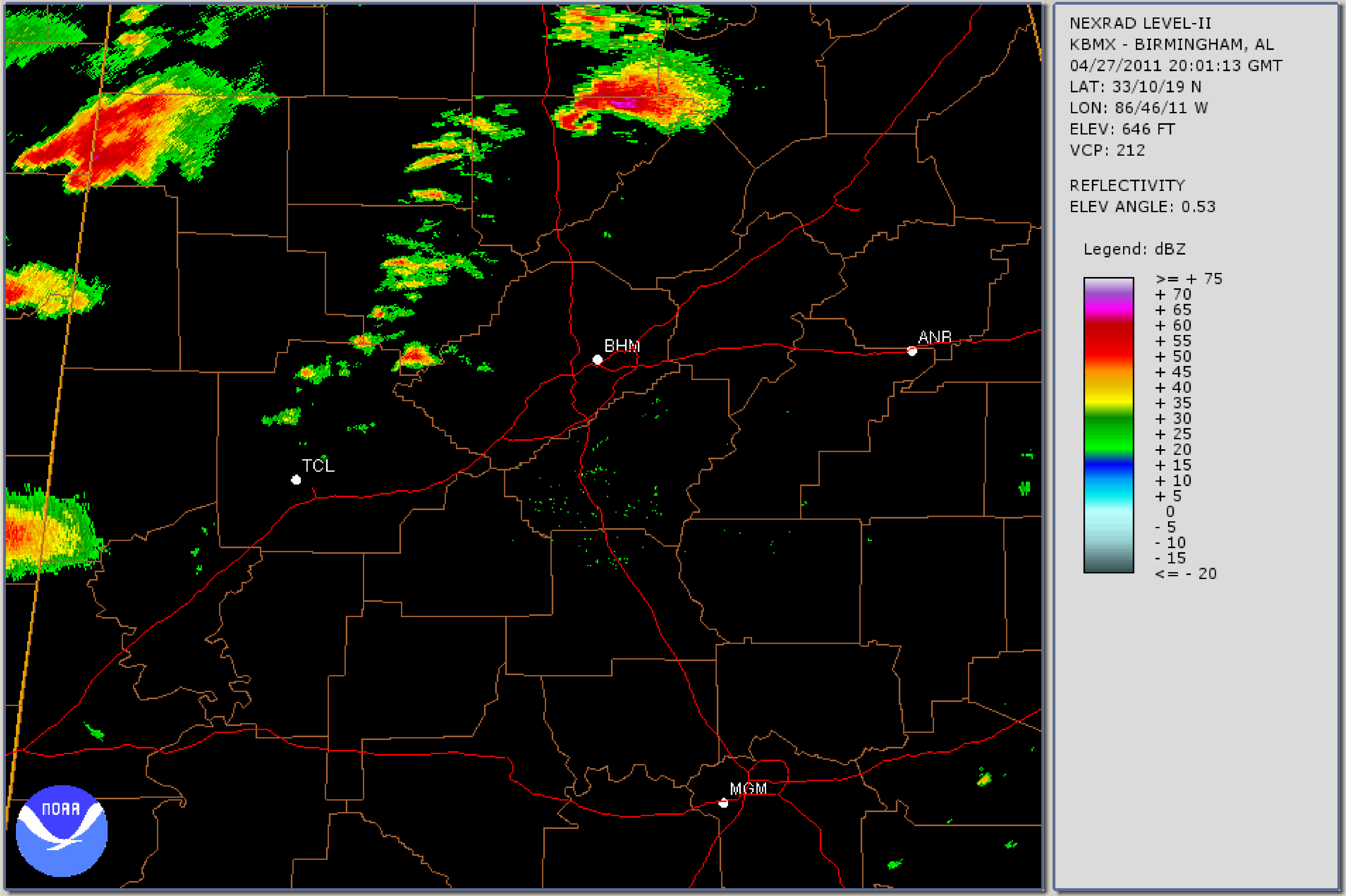
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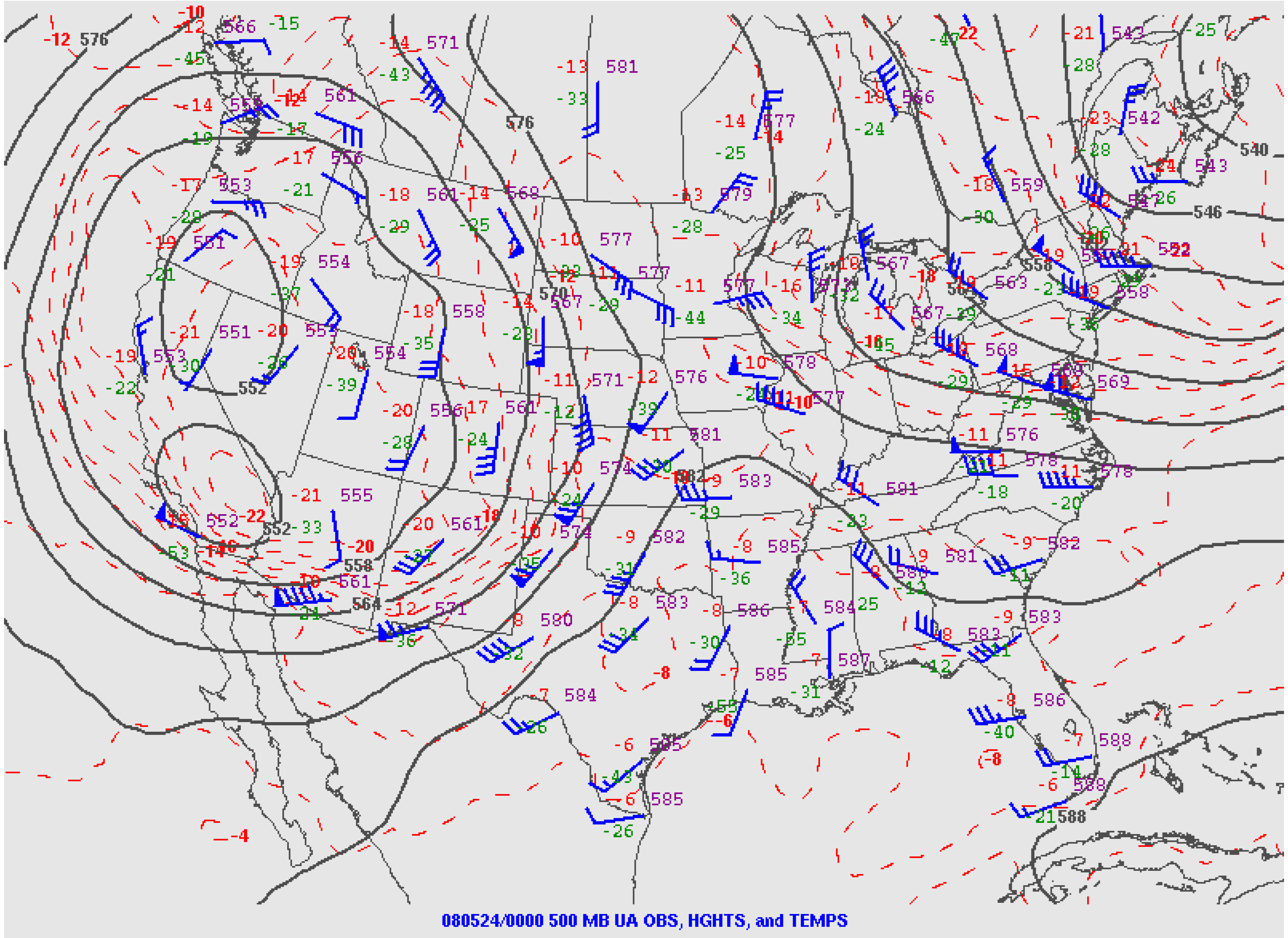
Forced Squall Line Case

- 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.



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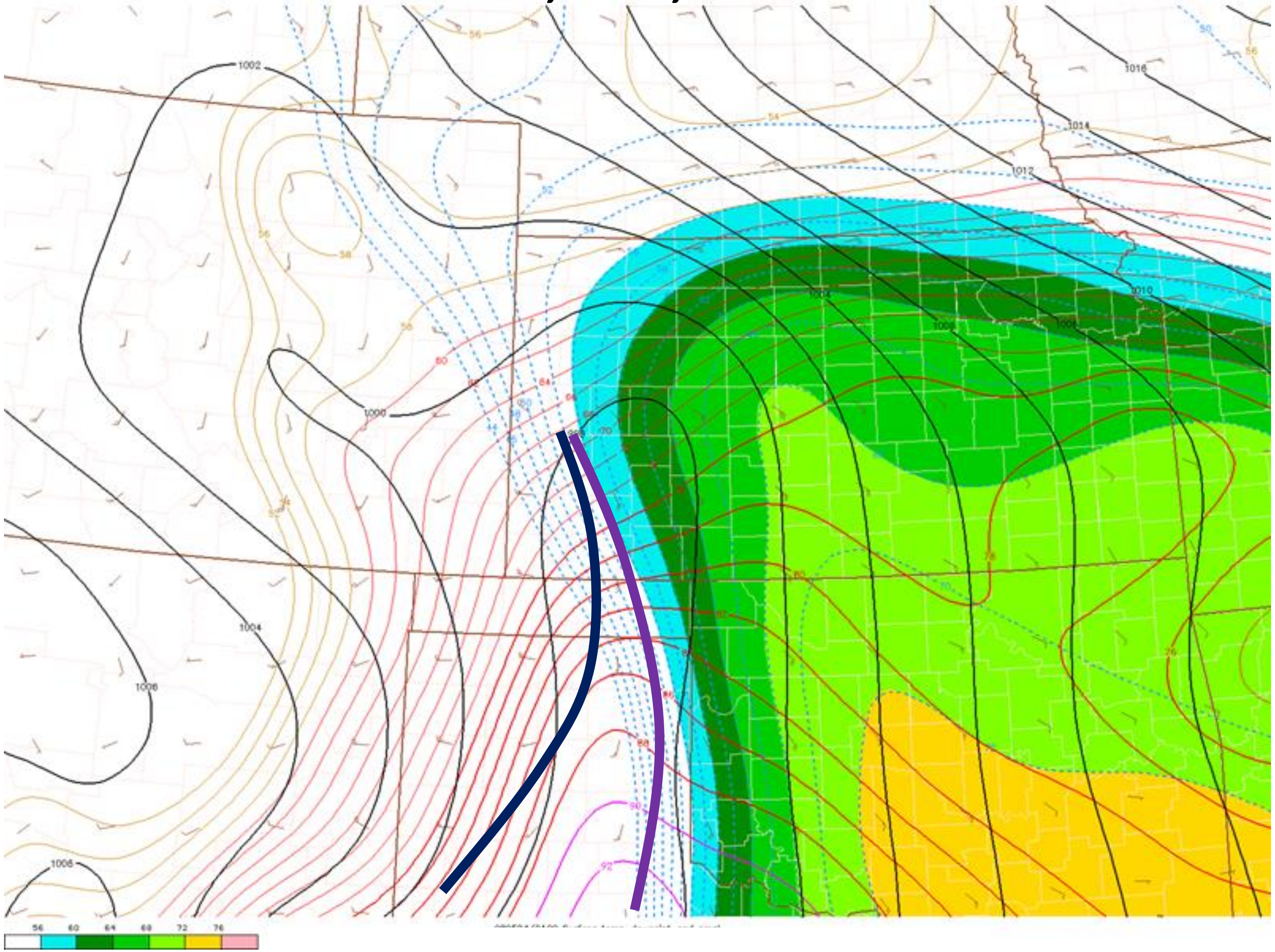
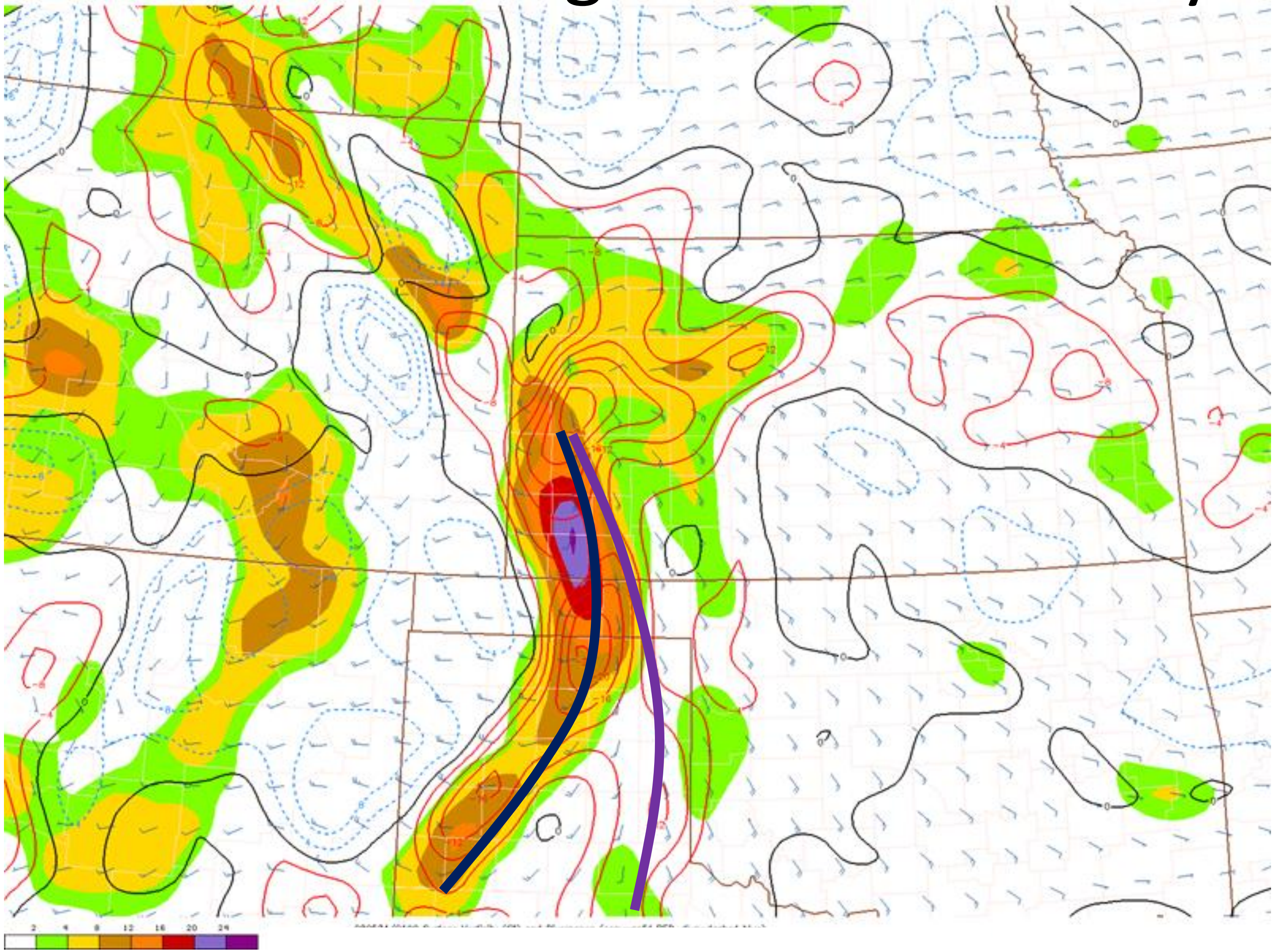
Surface T, Td, and PMSL



24 MAY 01z

Surface convergence and vorticity



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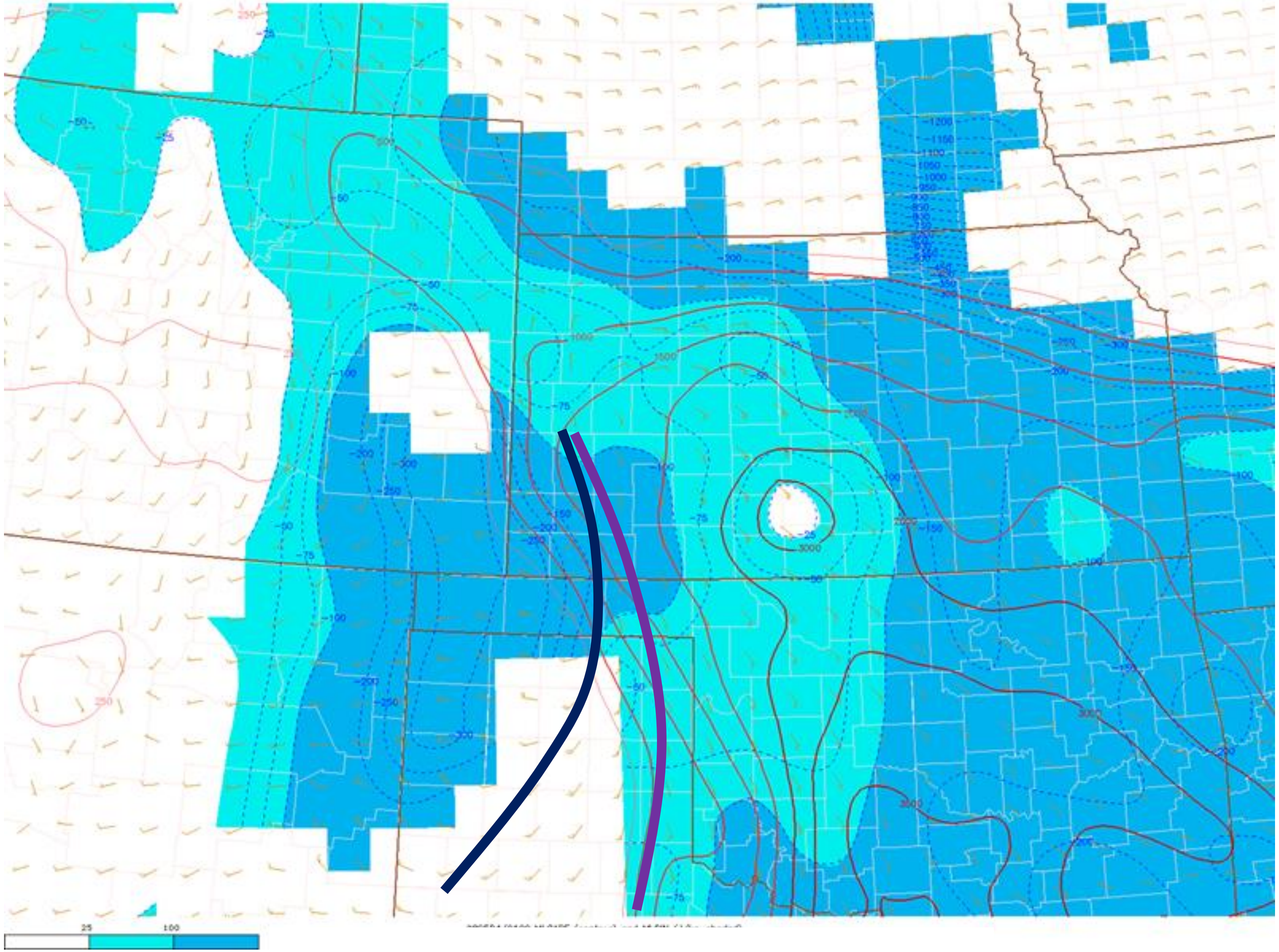
MLCAPE and MLCIN



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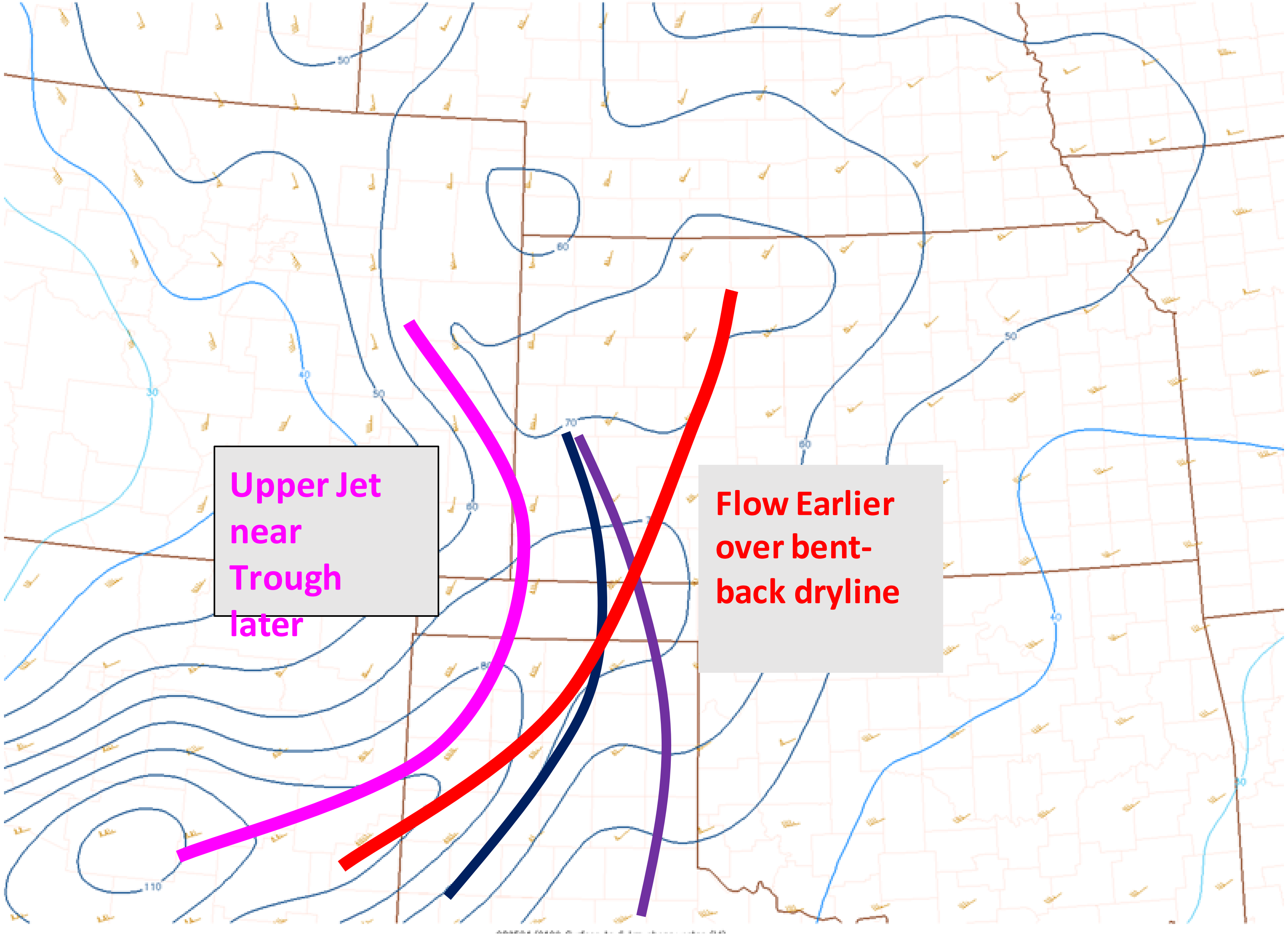
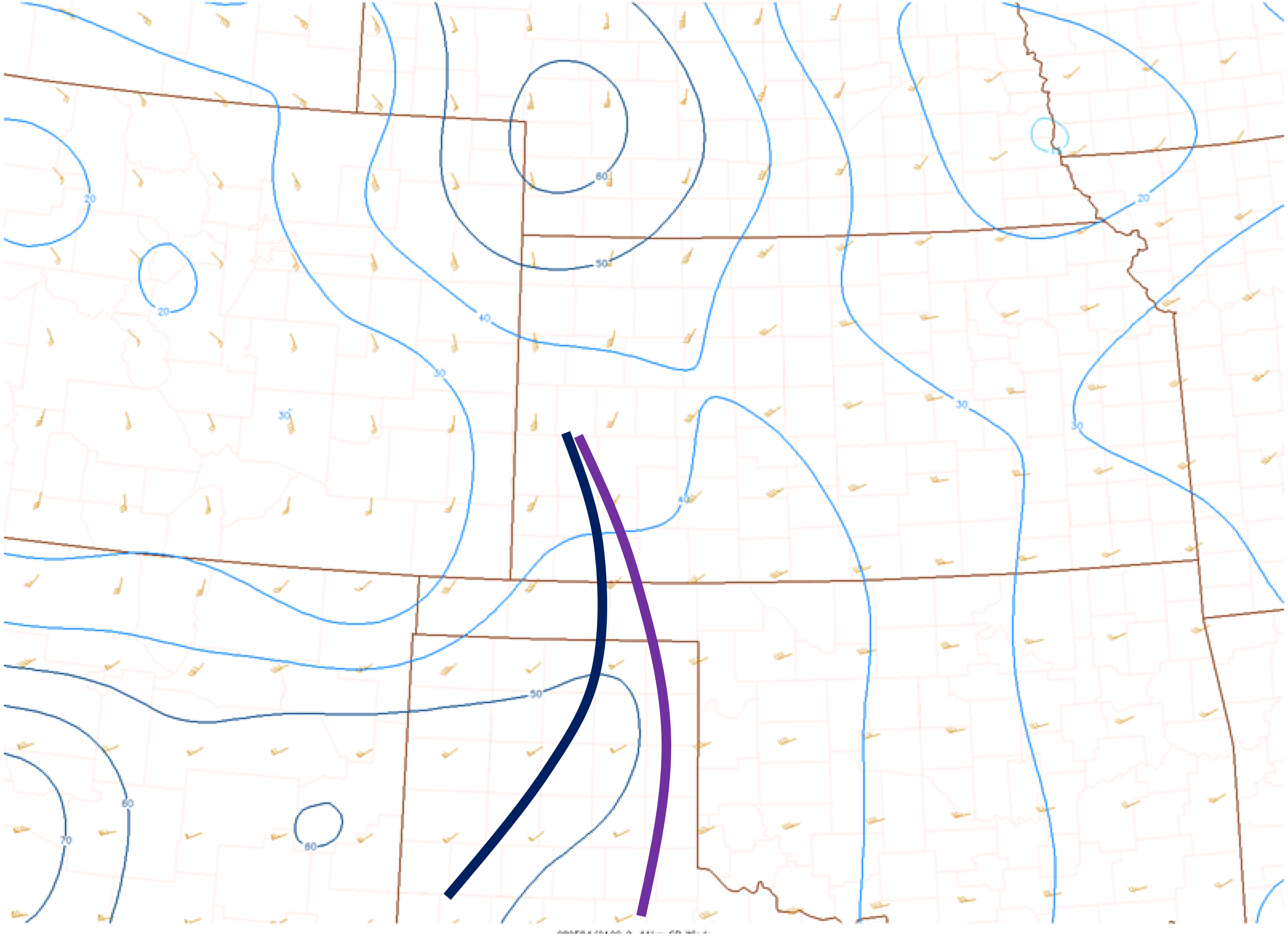
0-6 km shear vectors



24 MAY 01z

9-11 km storm-relative winds



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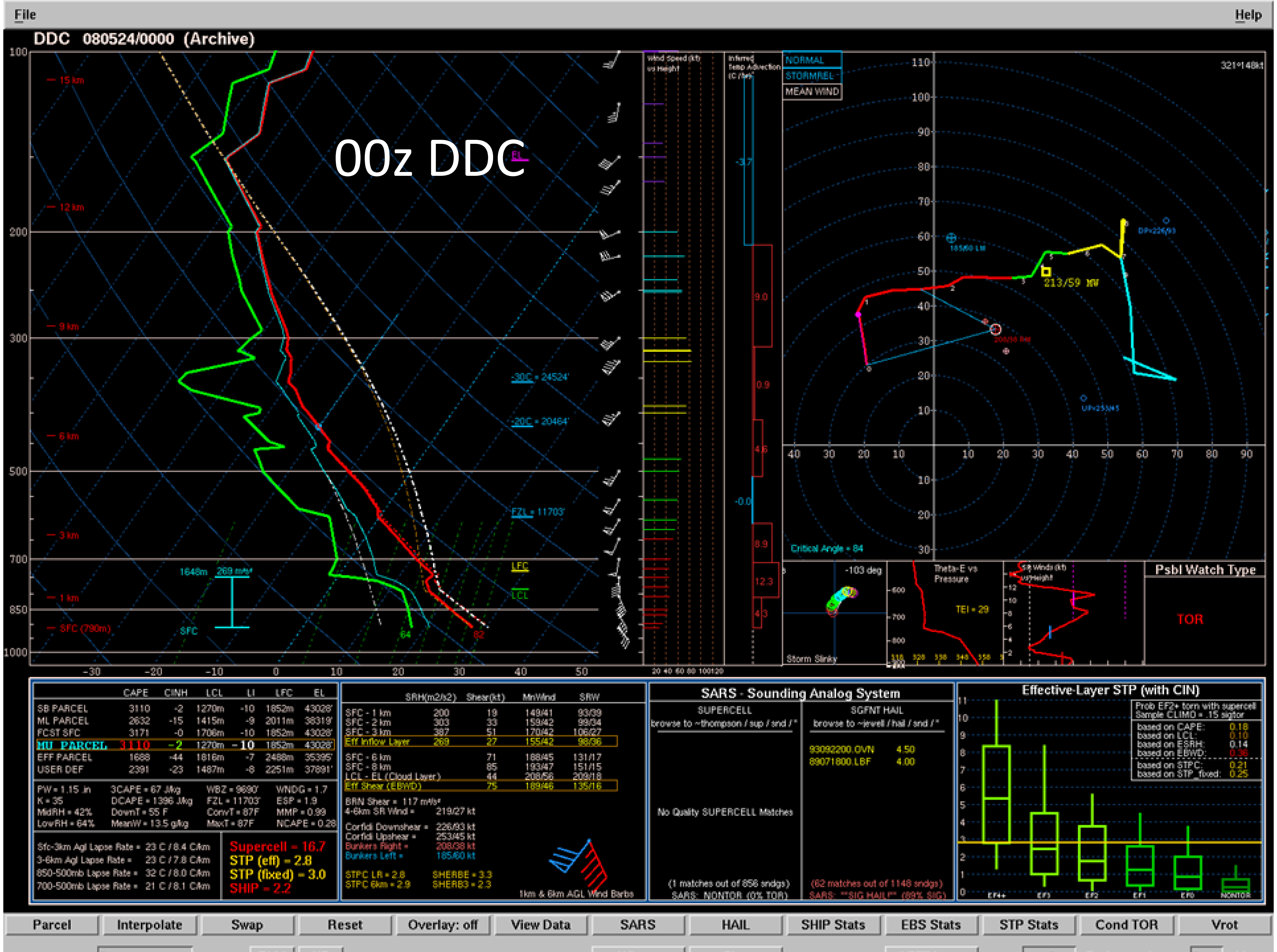
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STORMREL
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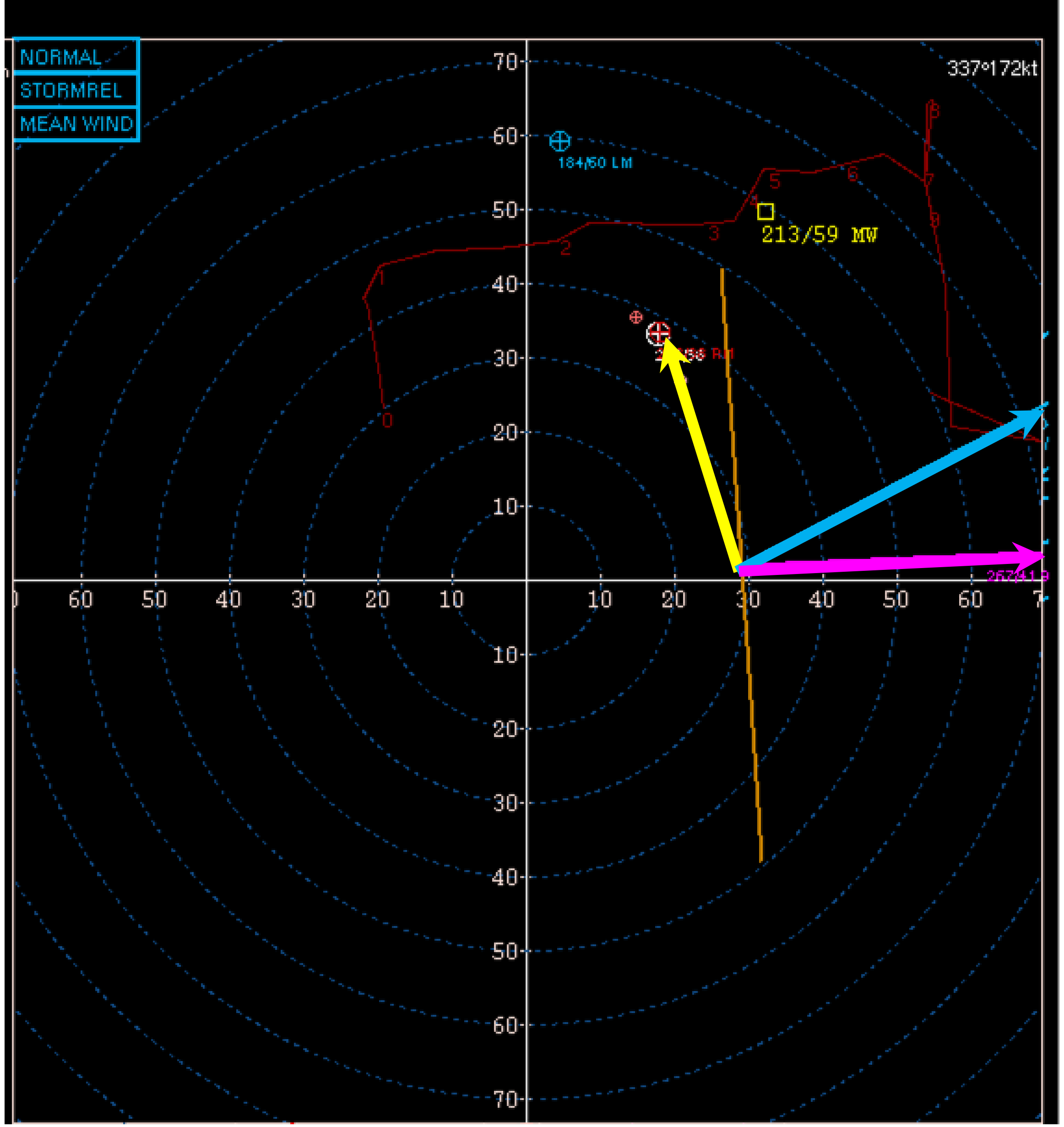
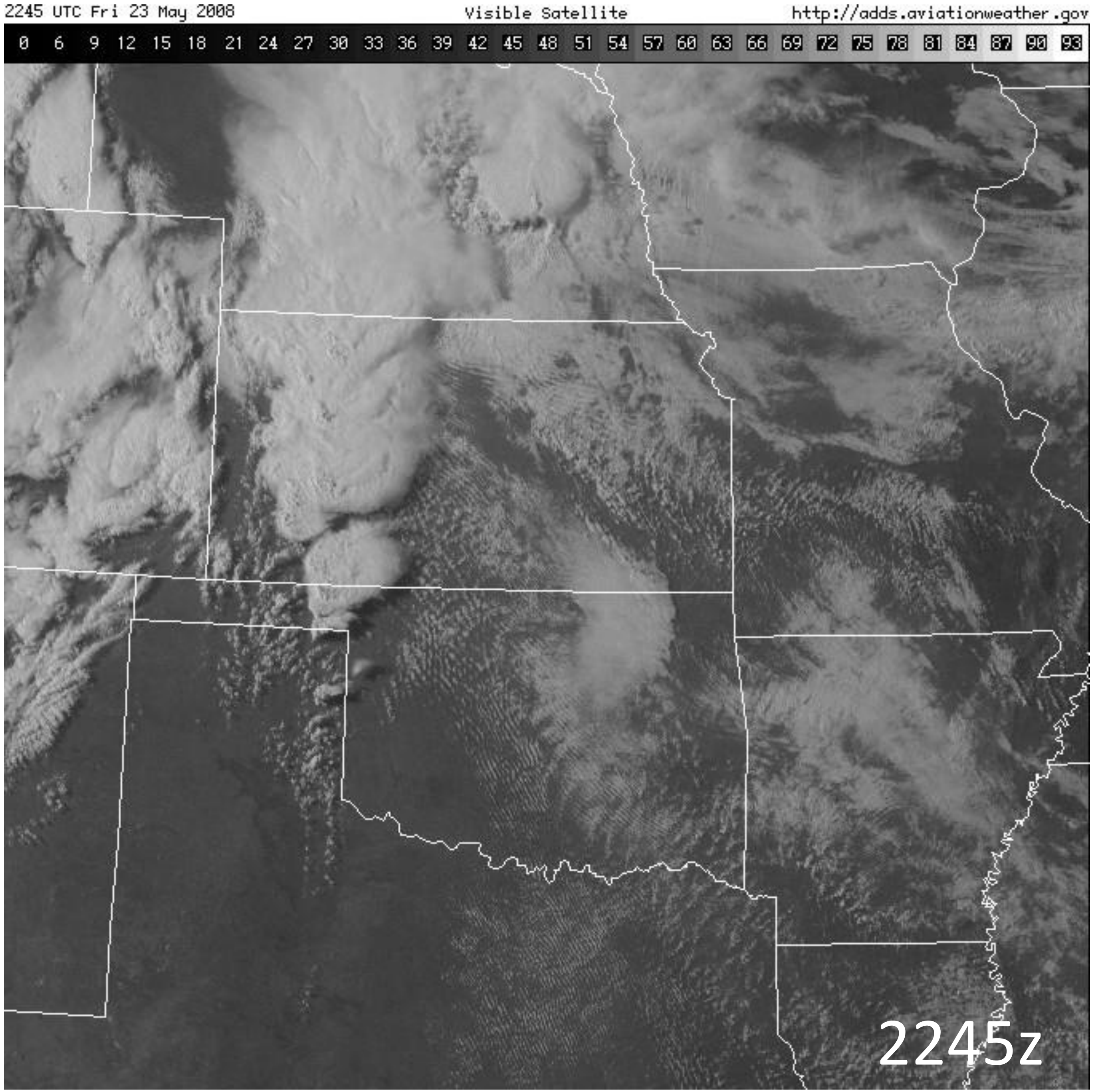
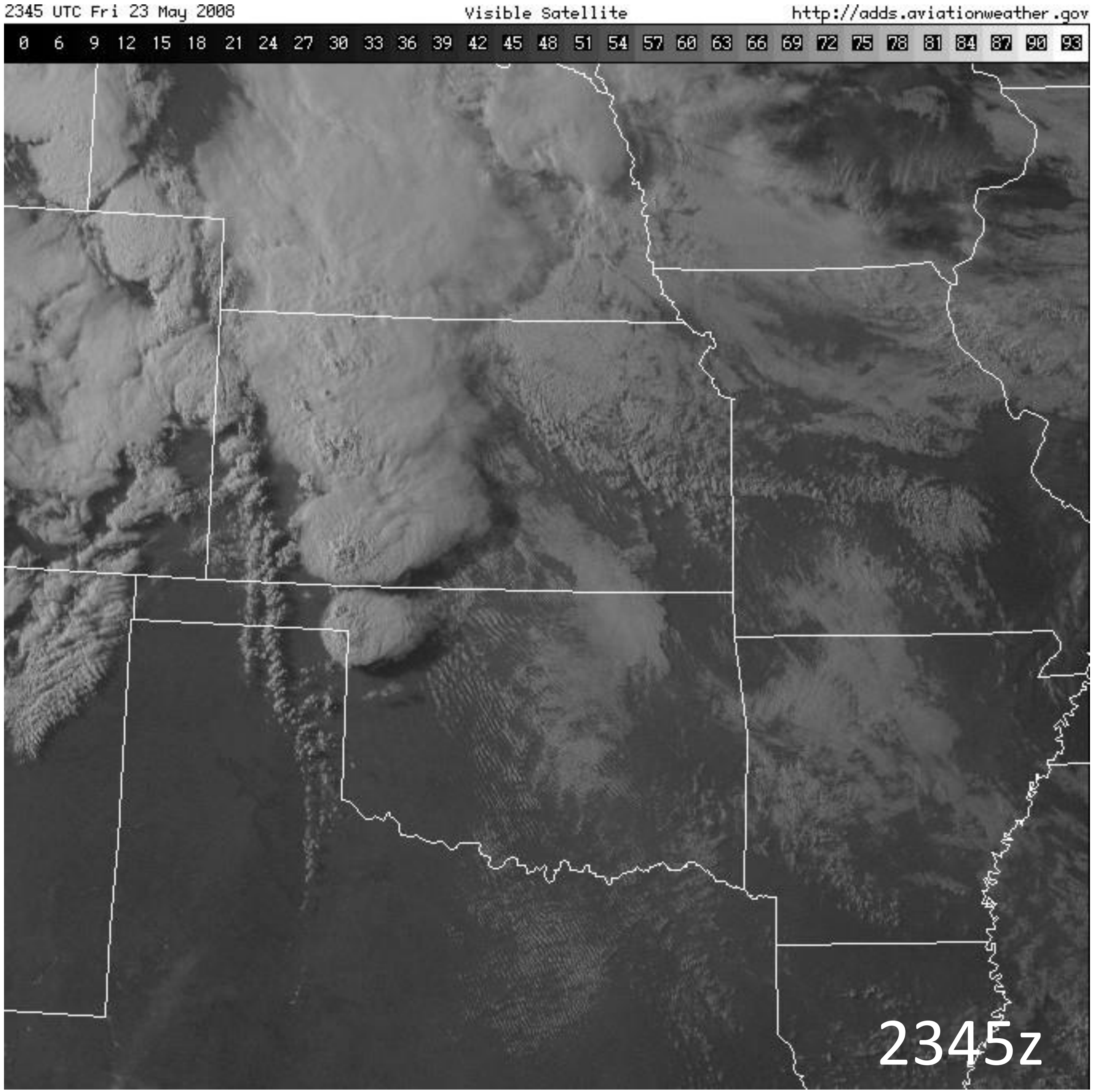
-30C = 24524'
-20C = 20464'
FZL = 11703'
LFC
LCL
SFC (790m)
1648m 269 m2/s2
Storm Slinky
Theta-E vs Pressure
TEI = 29
	CAPE	CINH	LCL	LI	LFC	EL
SB PARCEL	3110	-2	1270m	-10	1852m	43028'
ML PARCEL	2632	-15	1415m	-9	2011m	38319'
FCST SFC	3171	-0	1706m	-10	1852m	43028'
MU PARCEL	3110	-2	1270m	-10	1852m	43028'
EFF PARCEL	1688	-44	1816m	-7	2488m	35395'
USER DEF	2391	-23	1487m	-8	2251m	37891'
PW = 1.15 in
K = 35
MidRH = 42%
LowRH = 64%
3CAPE = 67 J/kg
DCAPE = 1396 J/kg
DownT = 55 F
MeanW = 13.5 g/kg
WBZ = 9690'
FZL = 11703'
ConvT = 87F
MaxT = 87F
WNDG = 1.7
ESP = 1.9
MMP = 0.99
NCAPE = 0.28
Sfc-3km Agl Lapse Rate = 23 C / 8.4 C/km
3-6km Agl Lapse Rate = 23 C / 7.8 C/km
850-500mb Lapse Rate = 32 C / 8.0 C/km
700-500mb Lapse Rate = 21 C / 8.1 C/km
Supercell = 16.7
STP (eff) = 2.8
STP (fixed) = 3.0
SHIP = 2.2
	SRH(m2/s2)	Shear(kt)	MnWind	SRW
SFC - 1 km	200	19	149/41	93/39
SFC - 2 km	303	33	159/42	99/34
SFC - 3 km	387	51	170/42	106/27
Eff Inflow Layer	269	27	155/42	98/36
SFC - 6 km		71	188/45	131/17
SFC - 8 km		85	193/47	151/15
LCL - EL (Cloud Layer)		44	208/56	209/18
Eff Shear (EBWD)		75	189/46	135/16
BRN Shear = 117 m2/s2
4-6km SR Wind = 219/27 kt
Corfidi Downshear = 226/93 kt
Corfidi Upshear = 253/45 kt
Bunkers Right = 208/38 kt
Bunkers Left = 185/60 kt
STPC LR = 2.8
STPC 6km = 2.9
SHERBE = 3.3
SHERB3 = 2.3
1km & 6km AGL Wind Barbs
SARS - Sounding Analog System
SUPERCELL
SGFNT HAIL
No Quality SUPERCELL Matches
93092200.OVN 4.50
89071800.LBF 4.00
(1 matches out of 856 sndgs)
SARS: NONTOR (0% TOR)
(62 matches out of 1148 sndgs)
SARS: **SIG HAIL** (89% SIG)
Effective-Layer STP (with CIN)
Prob EF2+ torn with supercell
Sample CLIMO = .15 sigtor
based on CAPE: 0.18
based on LCL: 0.10
based on ESRH: 0.14
based on EBWD: 0.36
based on STPC: 0.21
based on STP_fixed: 0.25
EF4+
EF3
EF2
EF1
EF0
NONTOR
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


2345 UTC Fri 23 May 2008
Visible Satellite
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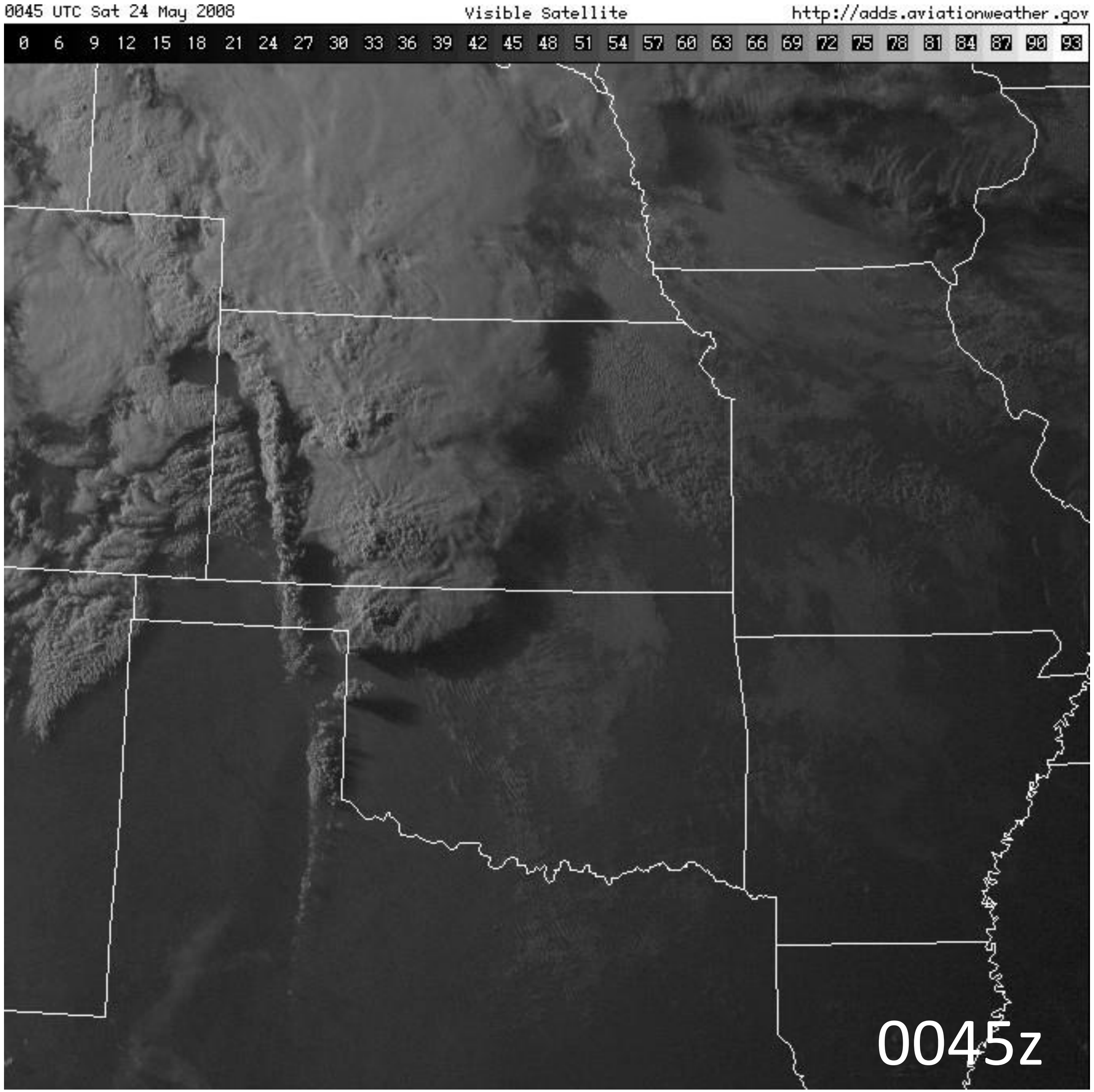
2345z


0045 UTC Sat 24 May 2008
Visible Satellite
http://adds.aviationweather.gov
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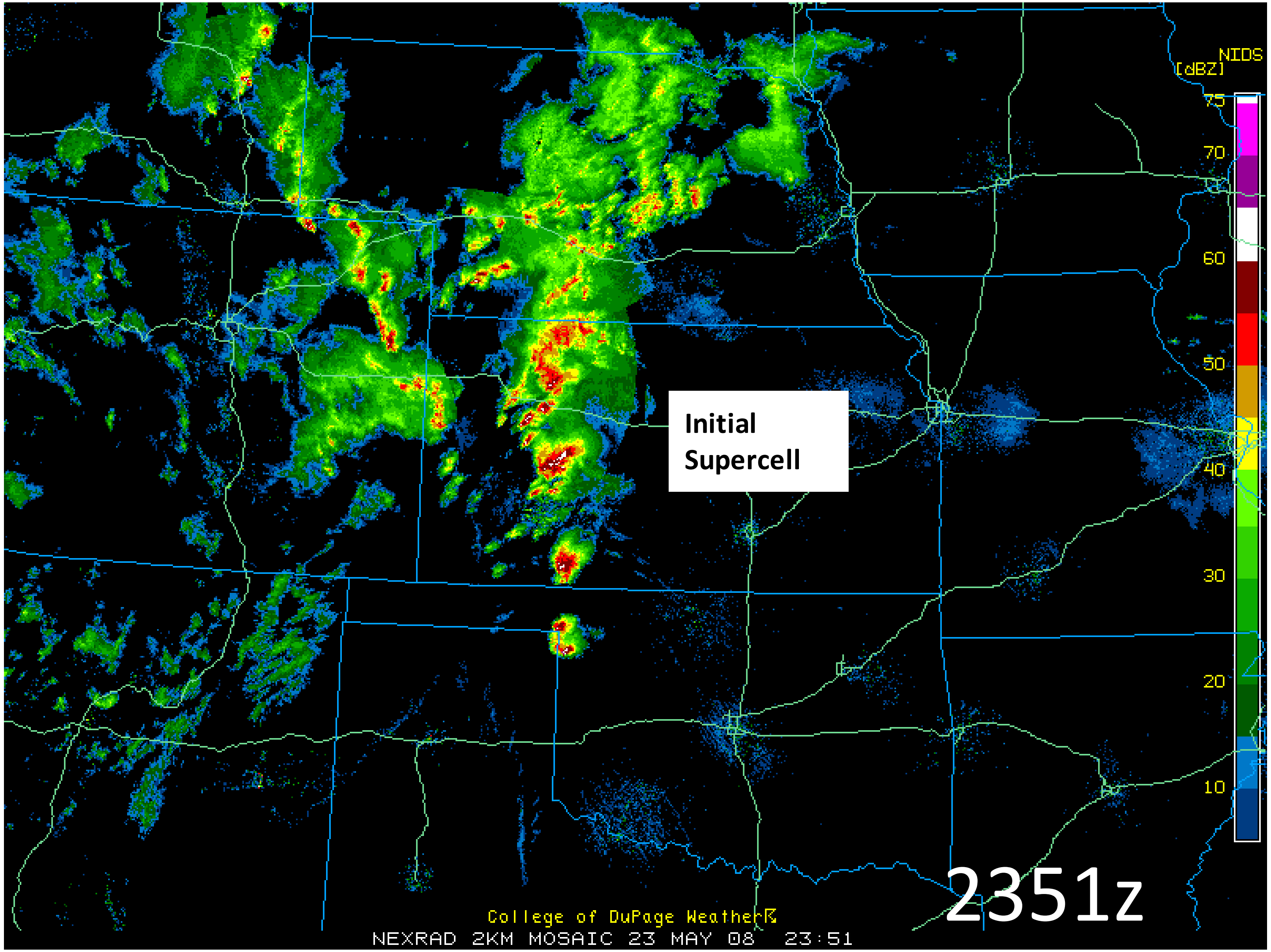
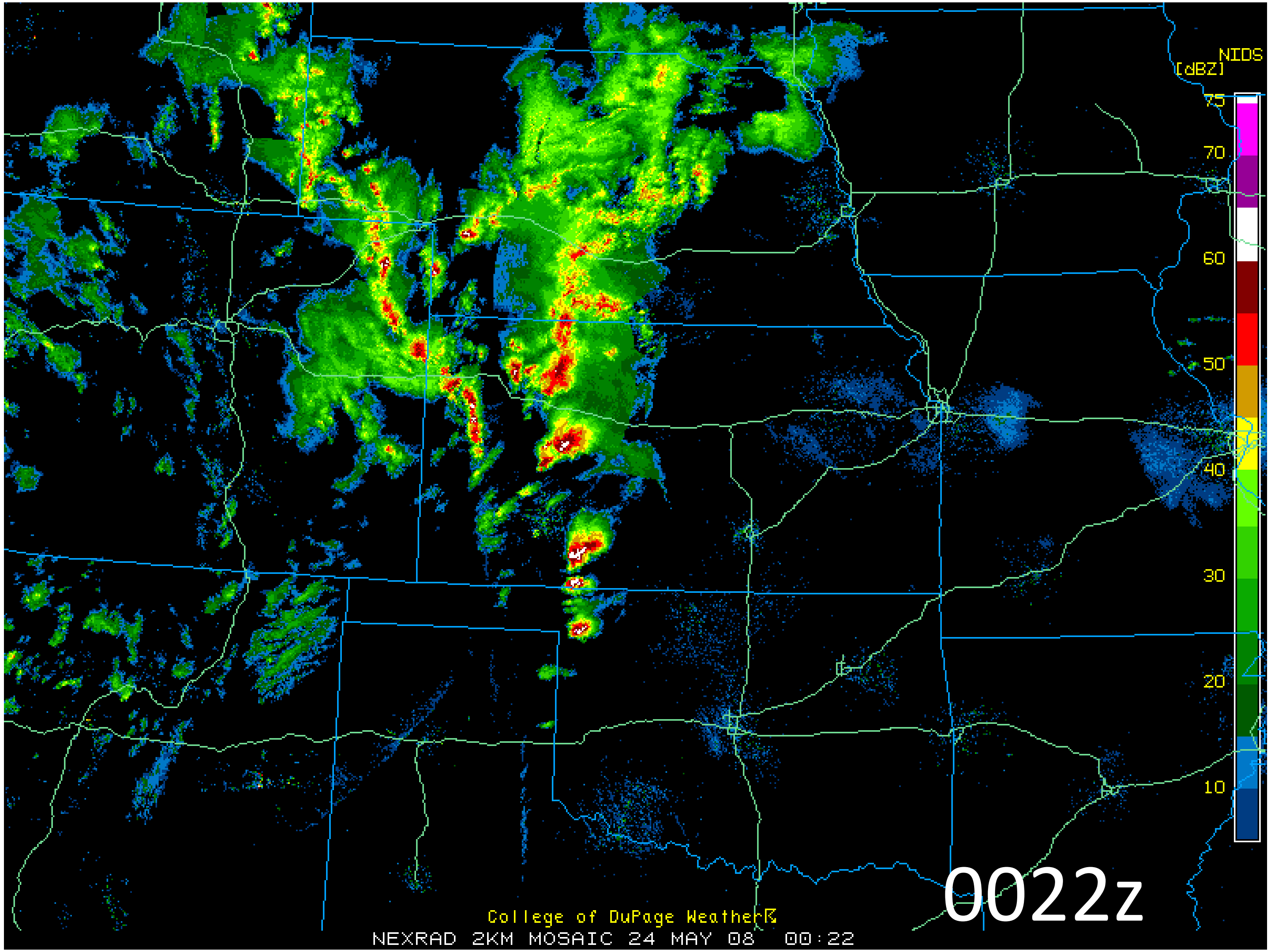
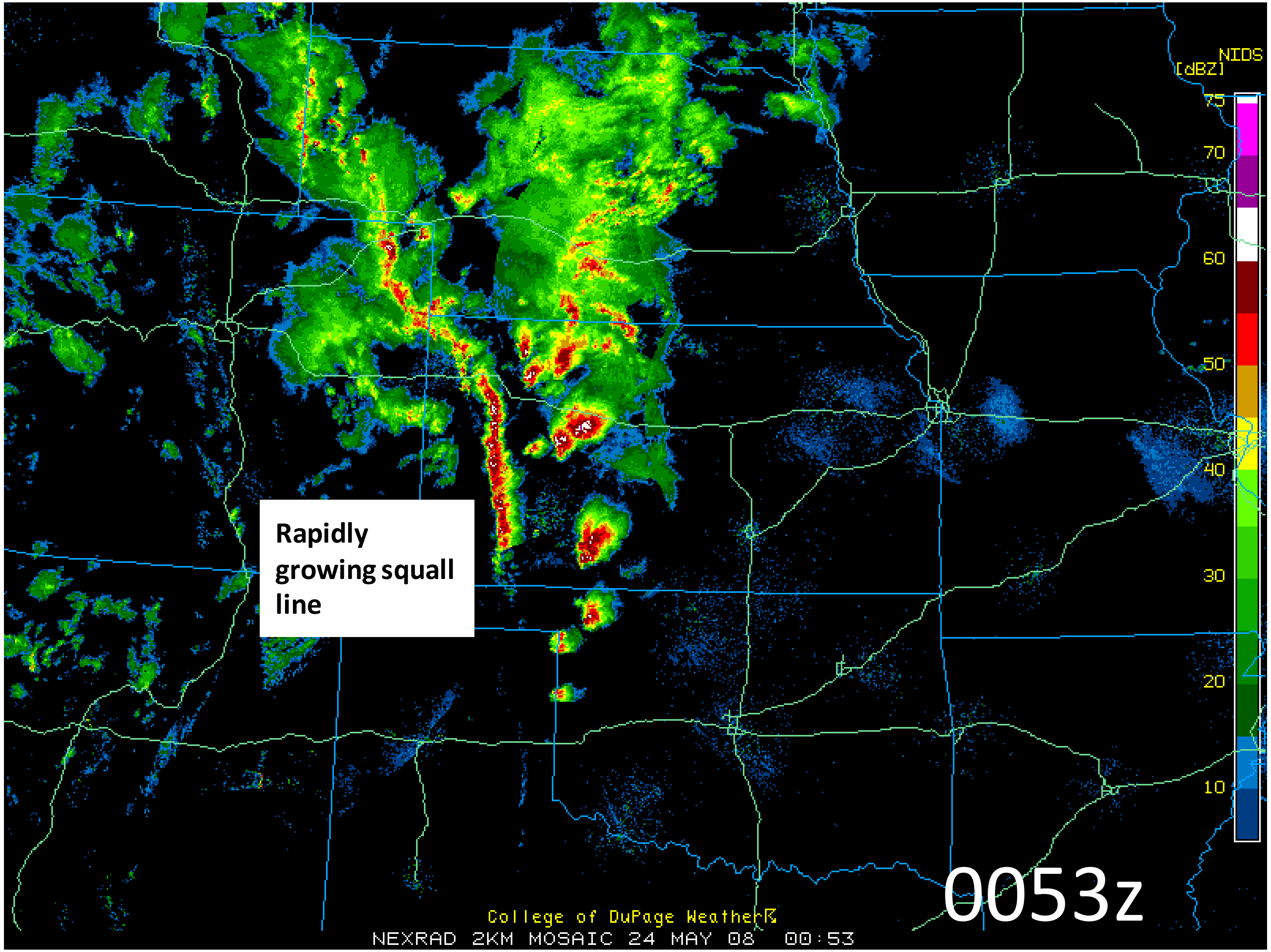
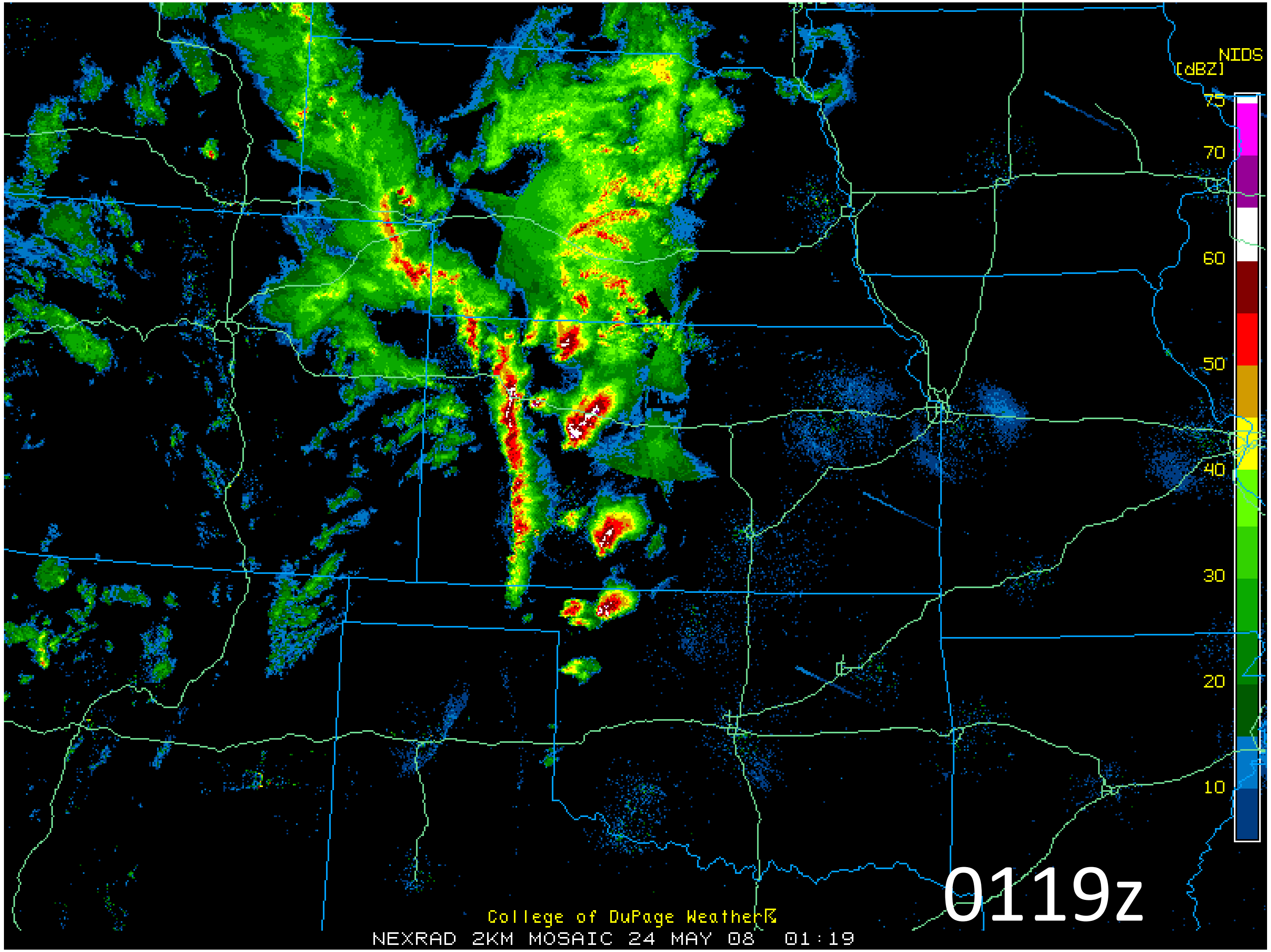
0045z

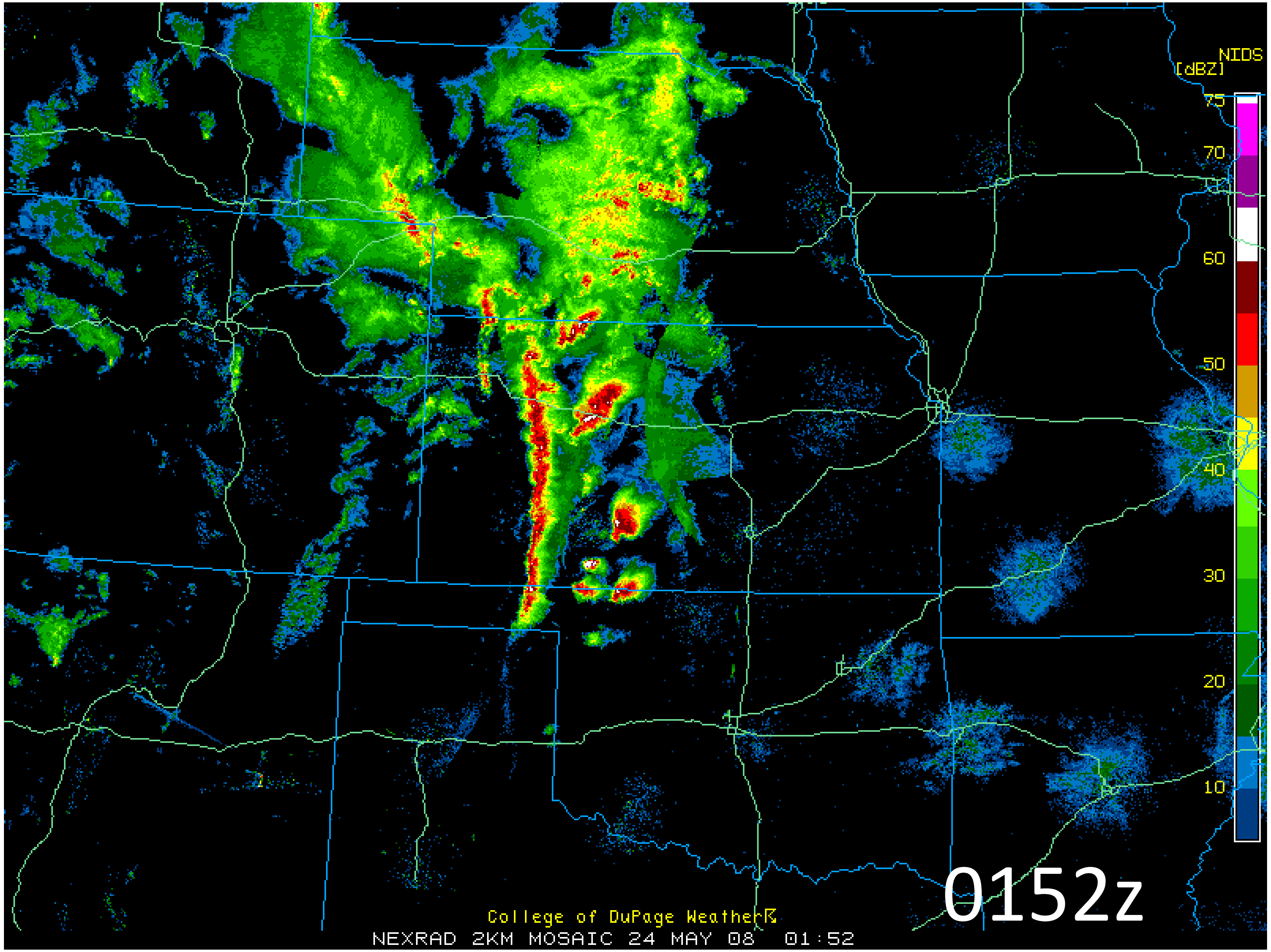

NIDS
[dBZ]
75
70
60
50
40
30
20
10
Initial
Supercell
2351z
College of DuPage WeatherLab
NEXRAD 2KM MOSAIC 23 MAY 08 23:51

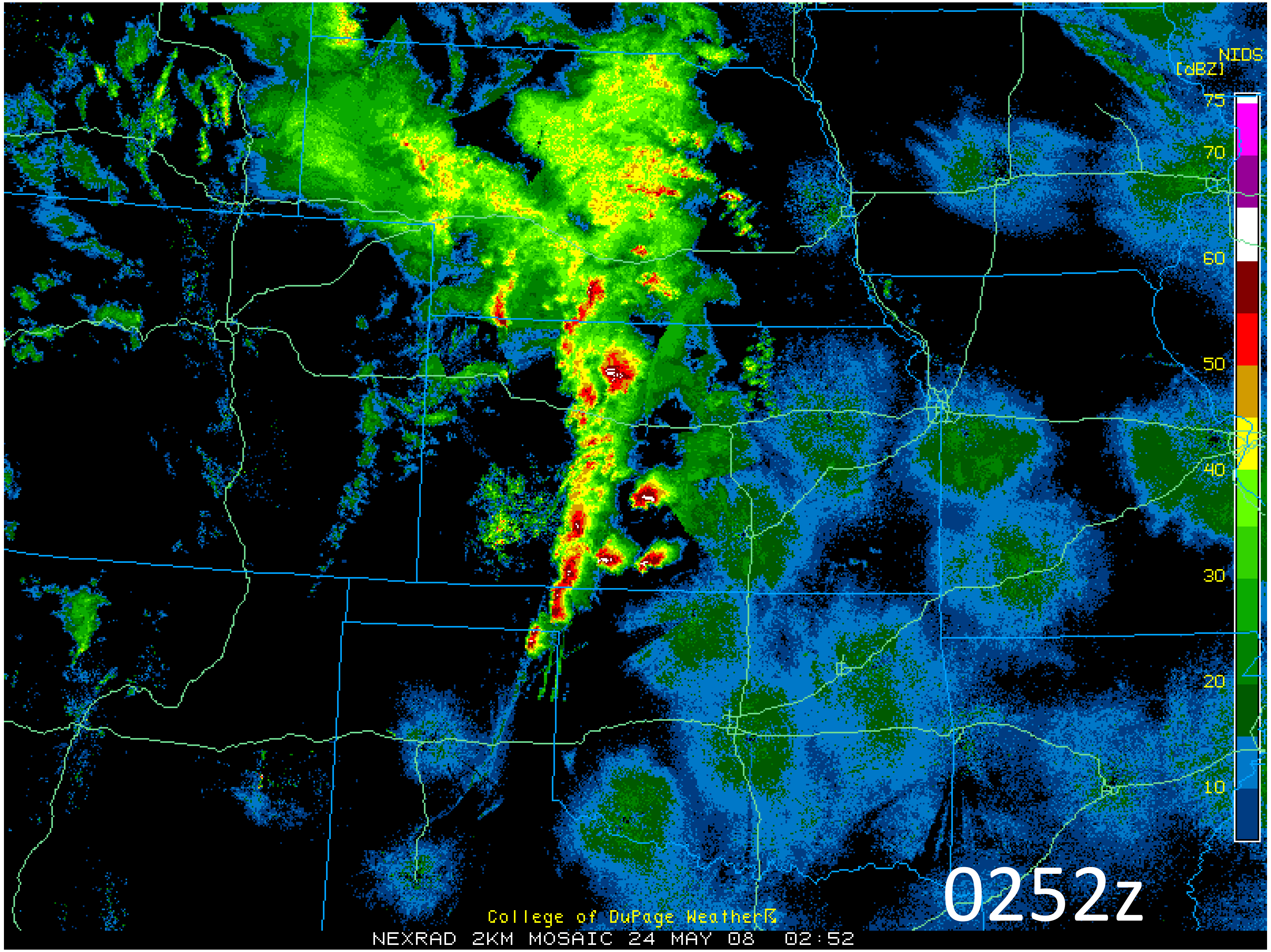

NIDS
[dBZ]
75
70
60
50
40
30
20
10
0022z
College of DuPage Weather
NEXRAD 2KM MOSAIC 24 MAY 08 00:22



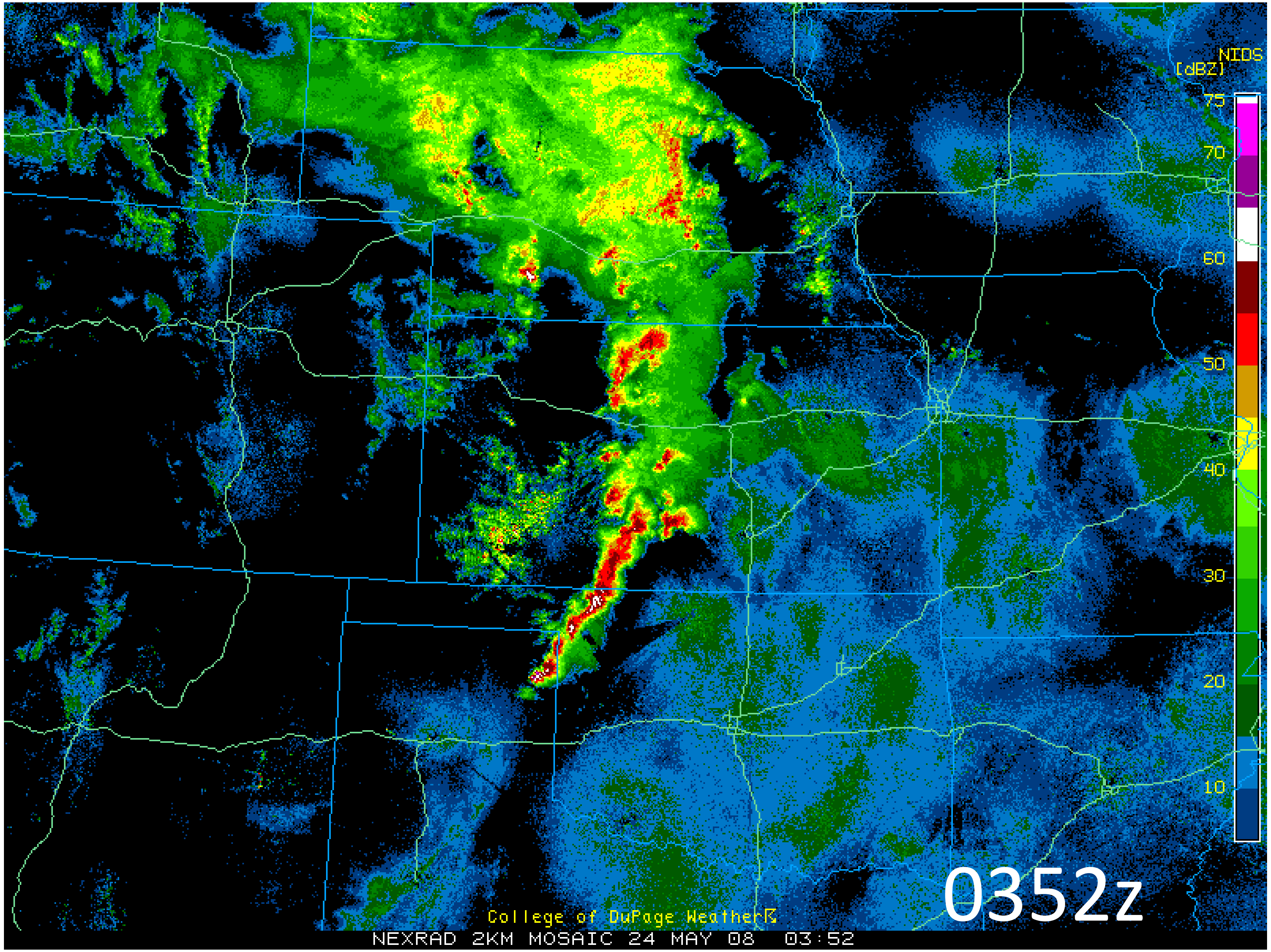
NIDS
[dBZ]
75
70
60
50
40
30
20
10
Rapidly growing squall line
0053z
College of DuPage Weather
NEXRAD 2KM MOSAIC 24 MAY 08 00:53

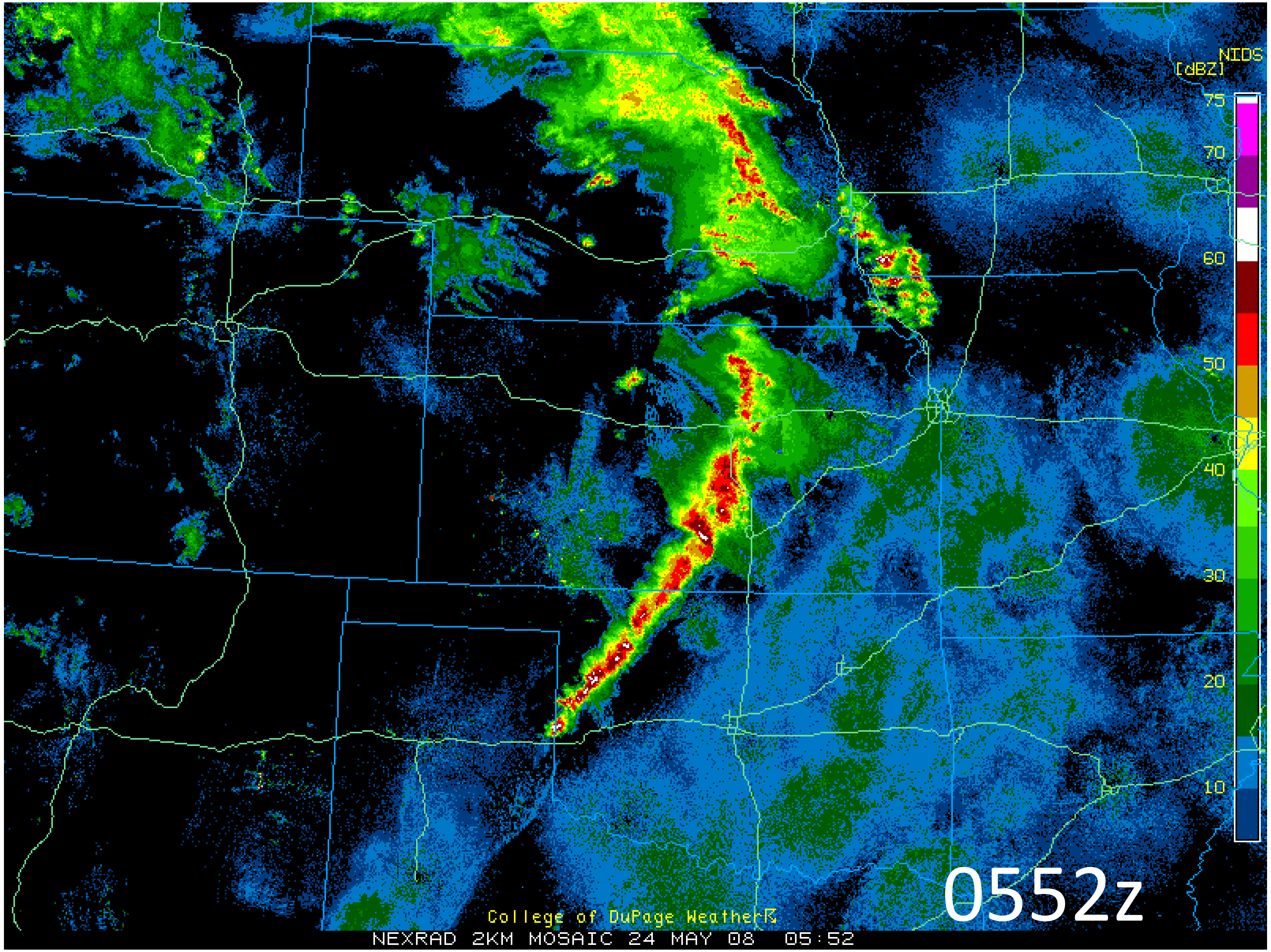

NIDS
[dBZ]
75
70
60
50
40
30
20
10
College of DuPage Weather
NEXRAD 2KM MOSAIC 24 MAY 08 01:19
0119z


NIDS
[dBZ]
75
70
60
50
40
30
20
10
0152z
College of DuPage Weather
NEXRAD 2KM MOSAIC 24 MAY 08   01:52



NIDS
[dBZ]
75
70
60
50
40
30
20
10
College of DuPage Weather
NEXRAD 2KM MOSAIC 24 MAY 08 02:52
0252z


NIDS
[dBZ]
75
70
60
50
40
30
20
10
0352z
College of DuPage Weather
NEXRAD 2KM MOSAIC 24 MAY 08 03:52


NIDS
[dBZ]
75
70
60
50
40
30
20
10
0552z
College of DuPage Weather
NEXRAD 2KM MOSAIC 24 MAY 08 05:52

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

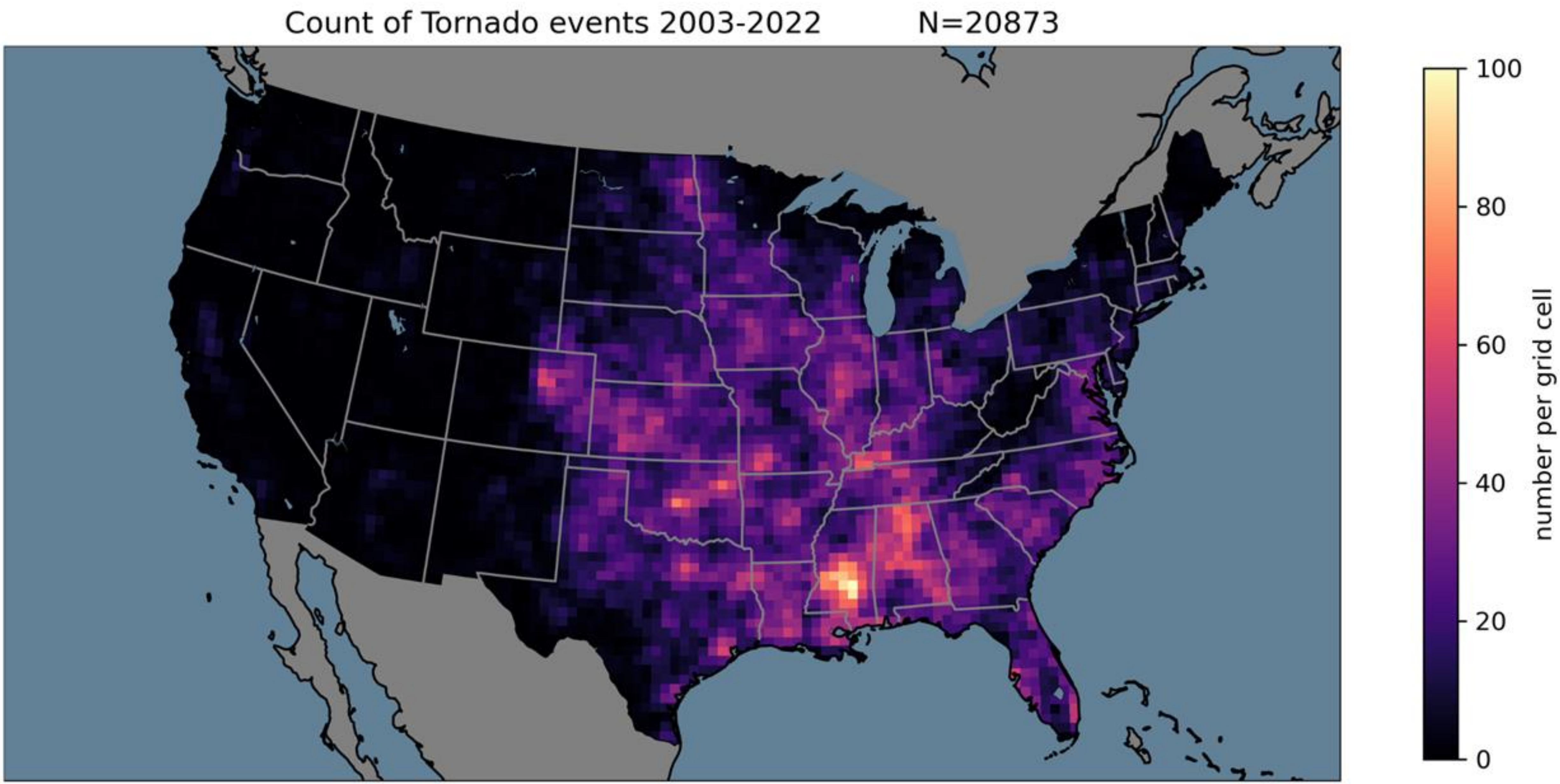
What is the best combination of flow aloft and lift to get linear storms?

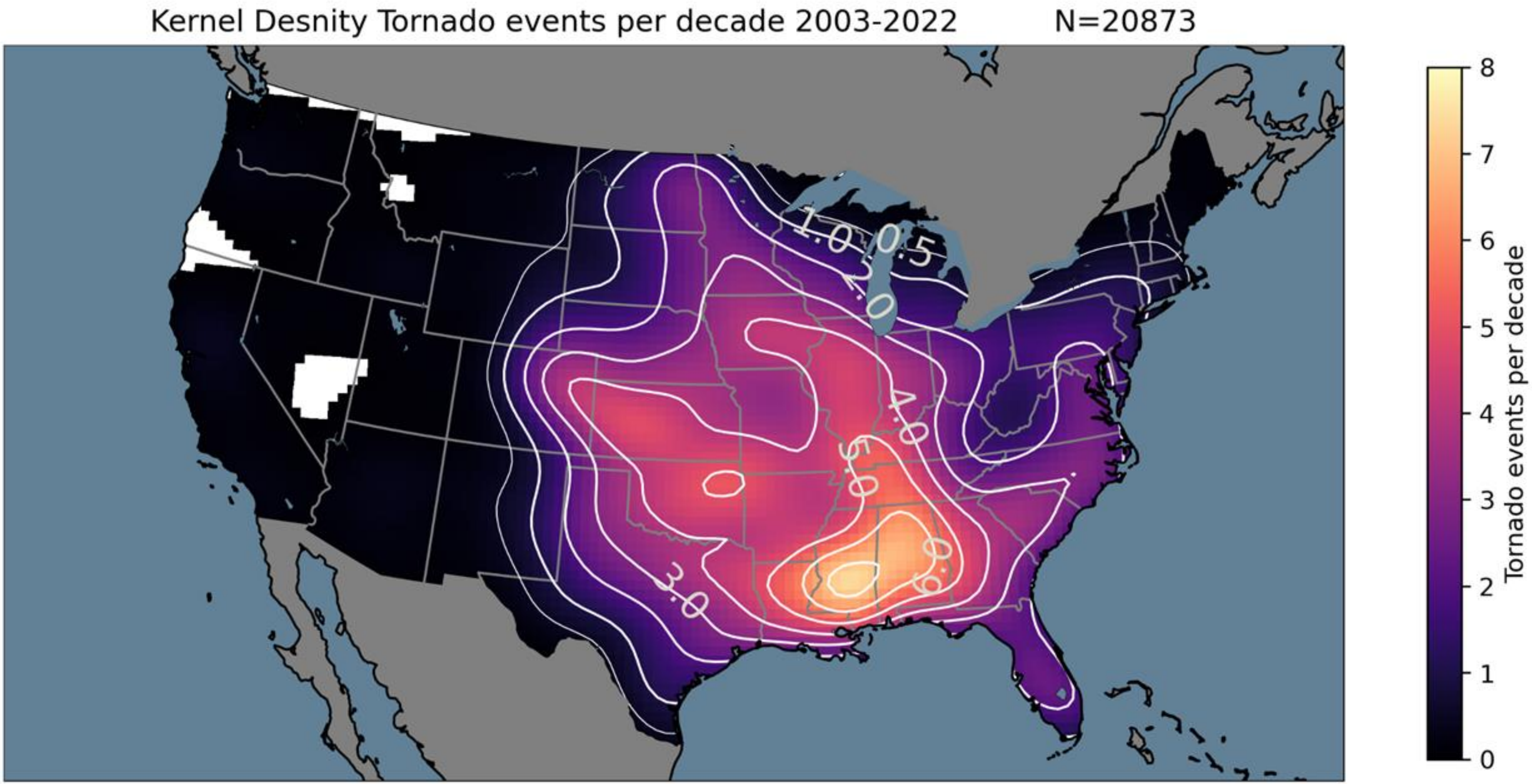
Strong forcing for ascent and flow across the initiating boundary.

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

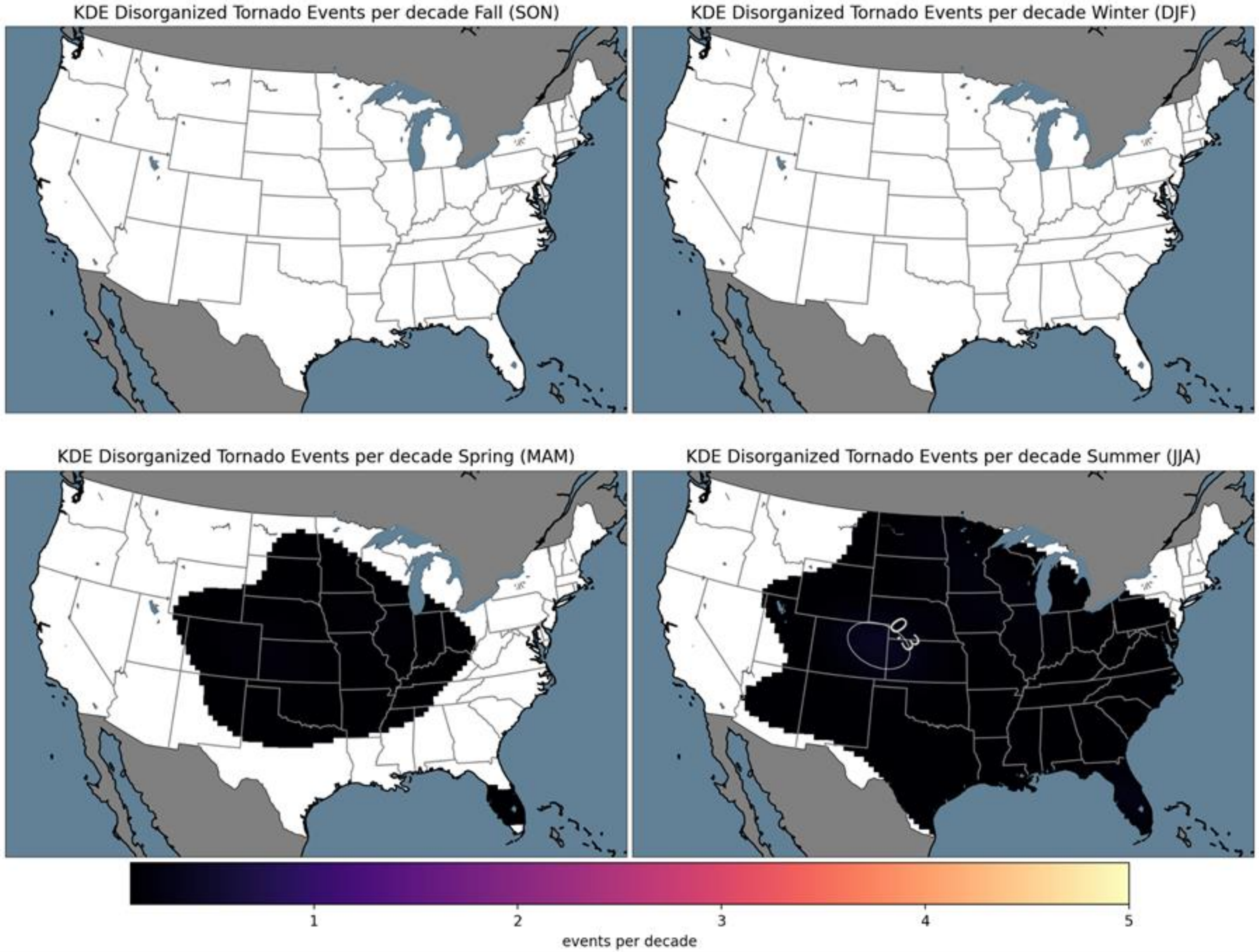
Strong forcing for ascent and flow parallel to the initiating boundary.

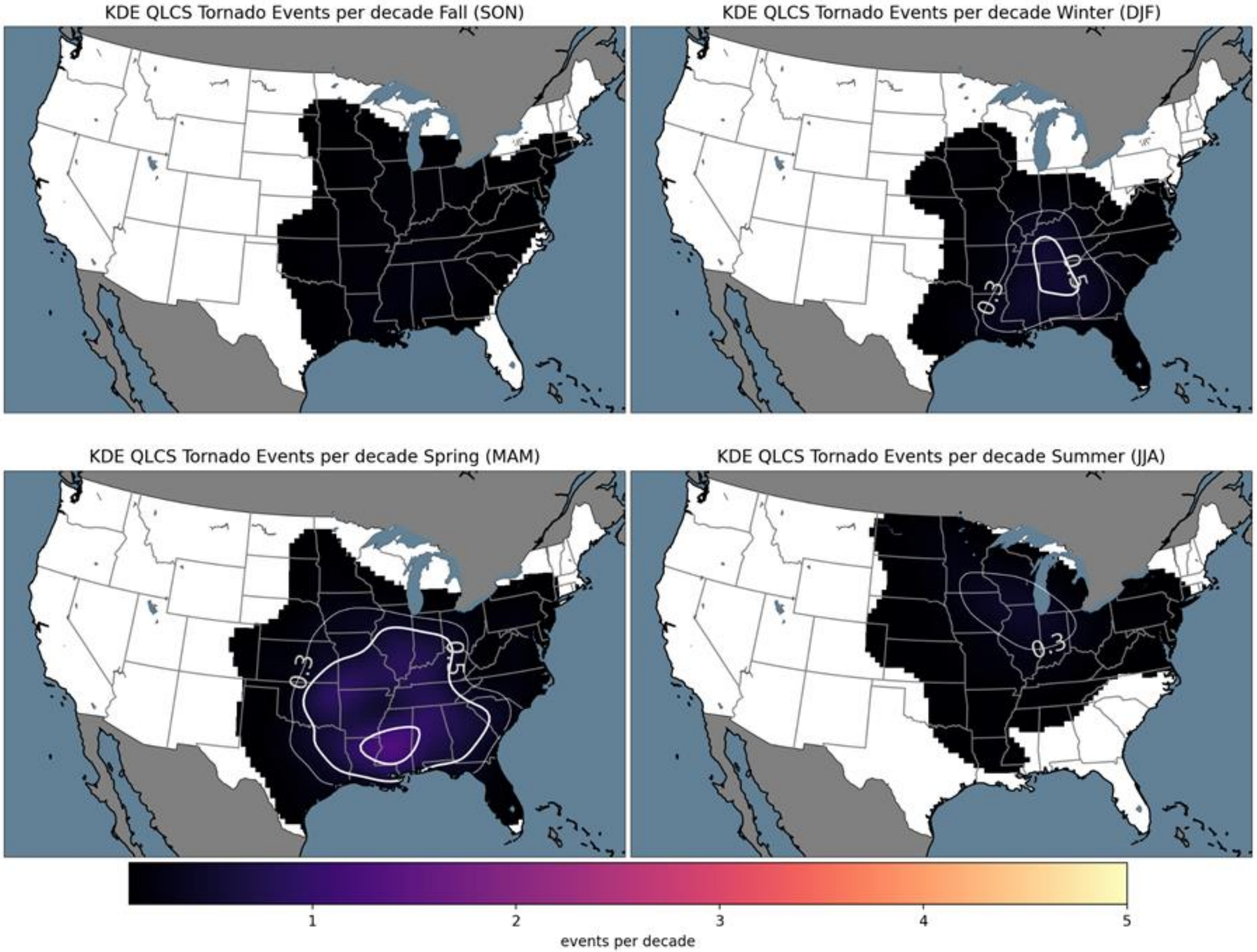
Weak forcing for ascent and flow across the initiating boundary.

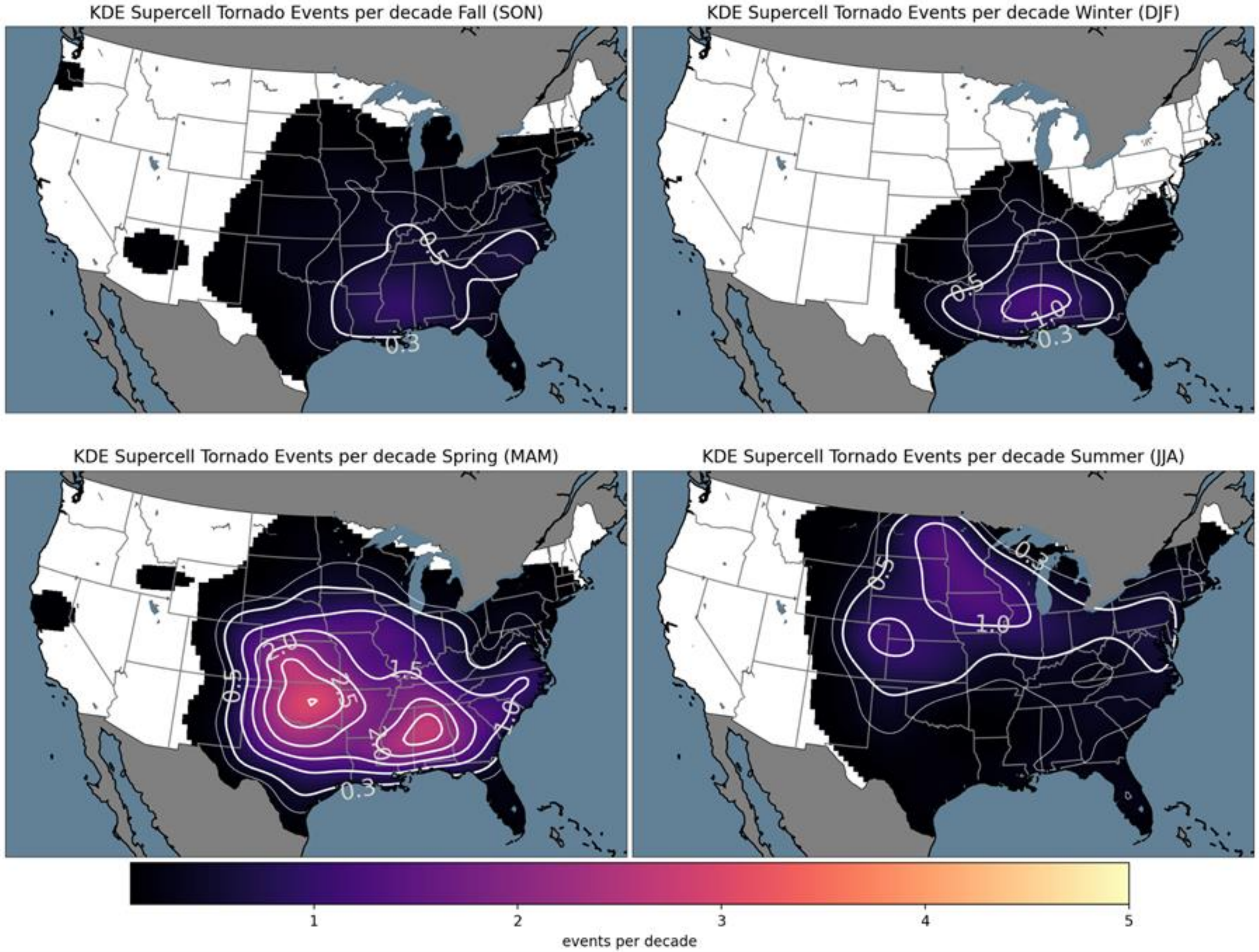

Count of Tornado events 2003-2022
N=20873
100
80
60
40
20
0
number per grid cell



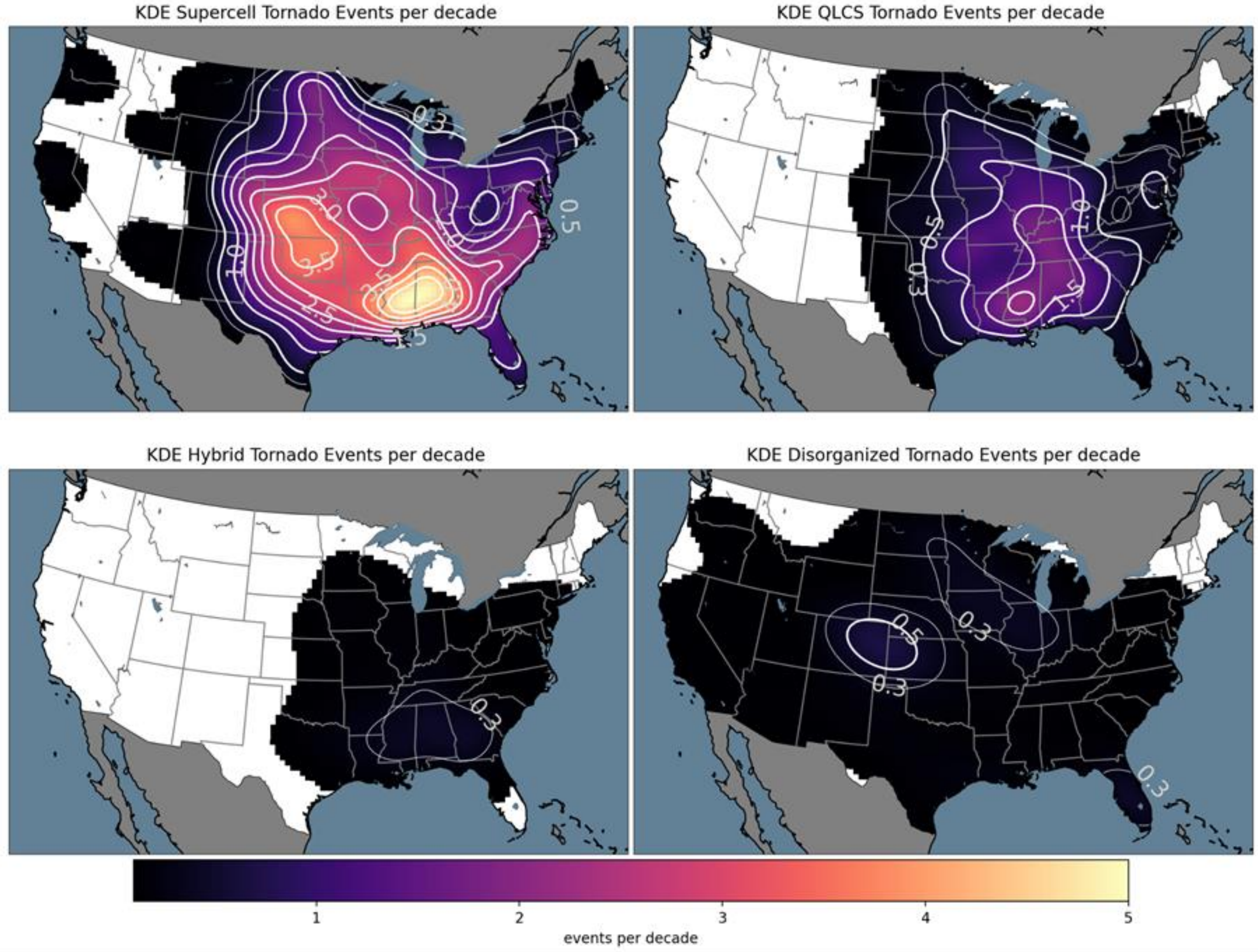
Kernel Desnity Tornado events per decade 2003-2022
N=20873
1.0
0.5
2.0
4.0
5.0
6.0
3.0
Tornado events per decade
0
1
2
3
4
5
6
7
8


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)
0.5
0.3
KDE Supercell Tornado Events per decade Winter (DJF)
0.5
1.0
0.3
KDE Supercell Tornado Events per decade Spring (MAM)
2.0
1.5
0.5
1.0
0.3
KDE Supercell Tornado Events per decade Summer (JJA)
0.5
0.3
1.0
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