NOAA
National
Weather
Service

An overview on derechos

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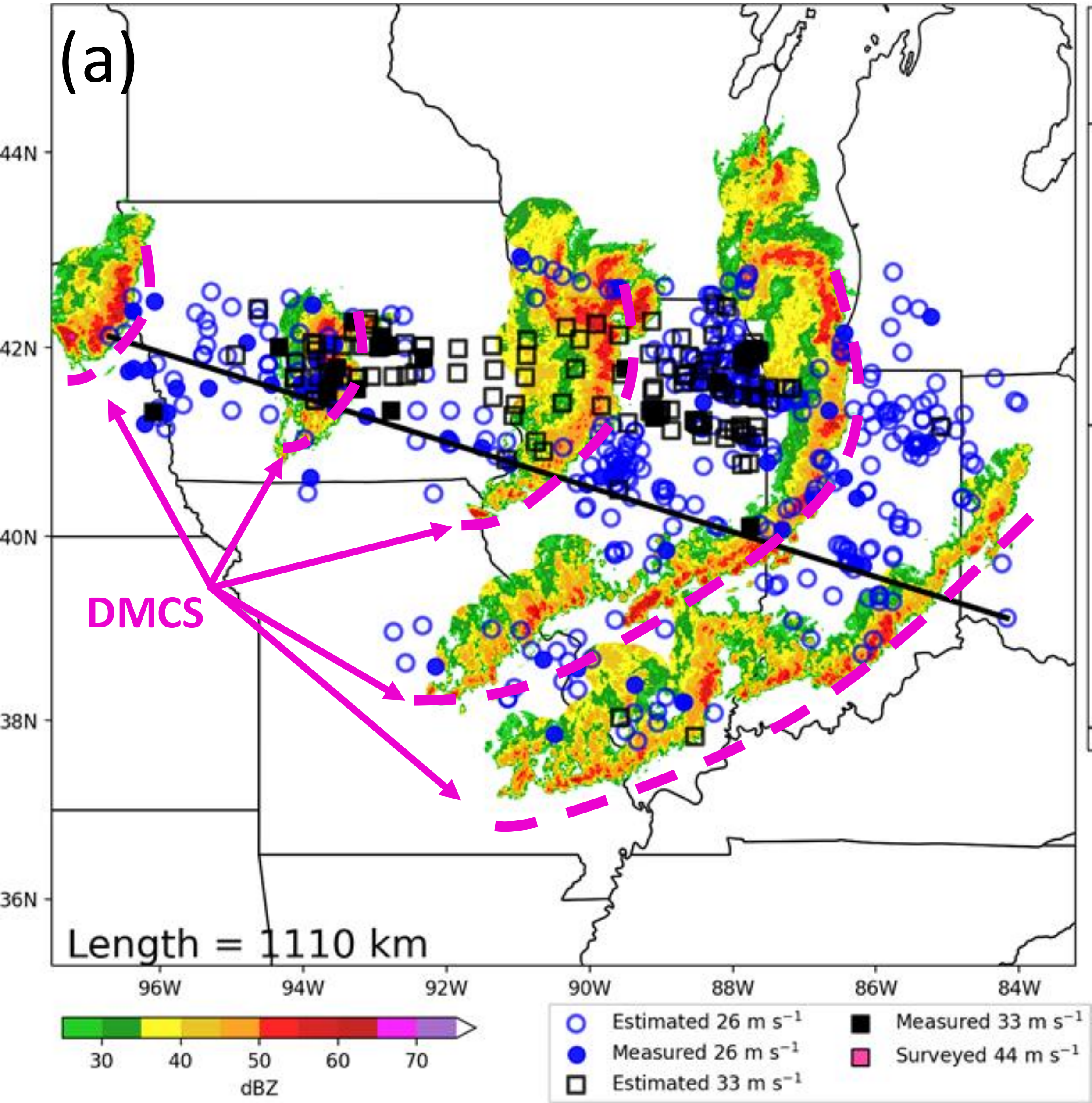
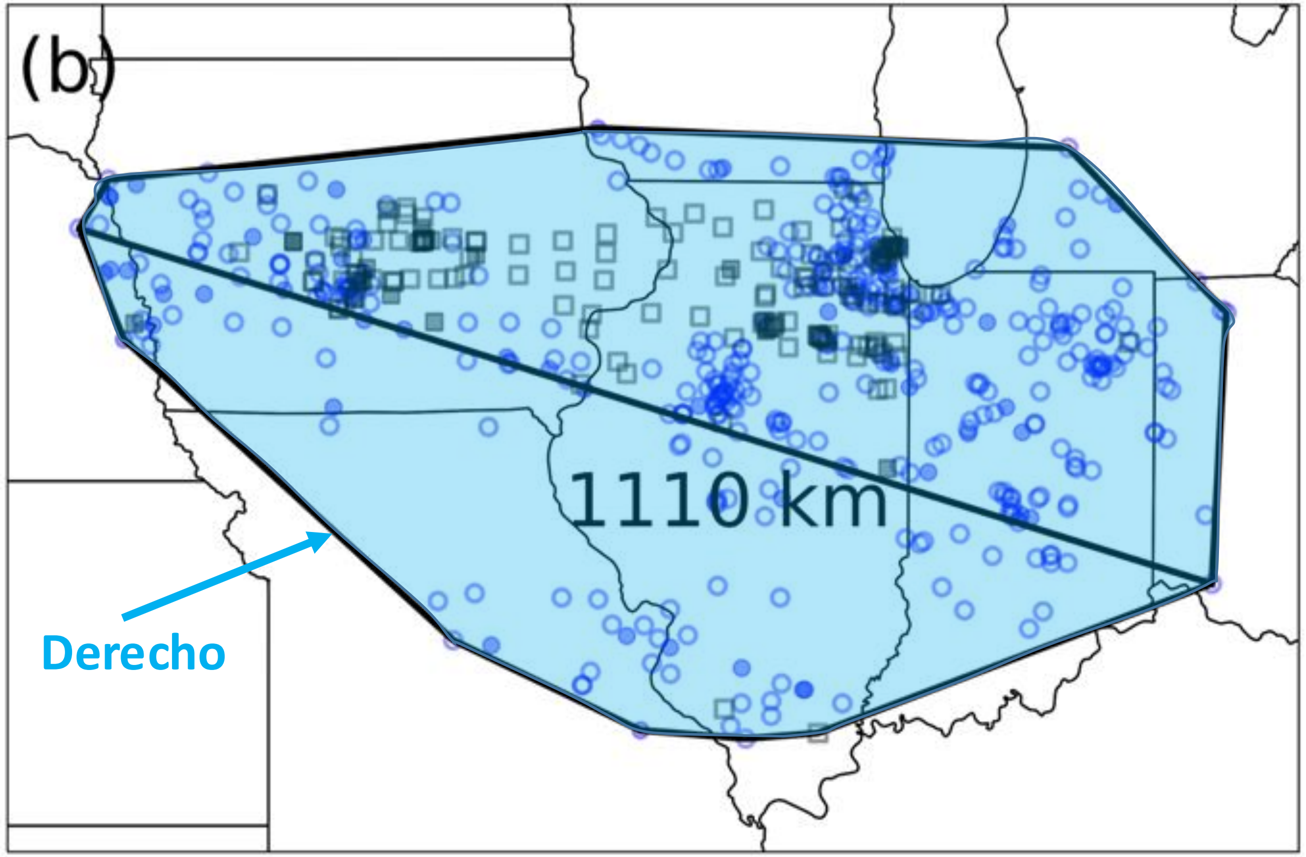
What is a derecho?

- Historically, the term derecho has been applied ambiguously
  - Lack of agreement as to the specific criteria needed to confirm a derecho
  - What storm modes and ambient environments support such events
  - Should internal storm-scale mechanisms matter in derecho production? Think of the differences between supercell-tornadoes vs. landspouts for example.

- **There is a general understanding (agreement) that derechos are widespread severe windstorms originating from MCSs (or organized, mostly linear convection)**
  - What makes a given event a derecho in the eyes of the meteorology community, broadcast media, stakeholders, or the public?
  - “You know it when you see it.”

What is a derecho?



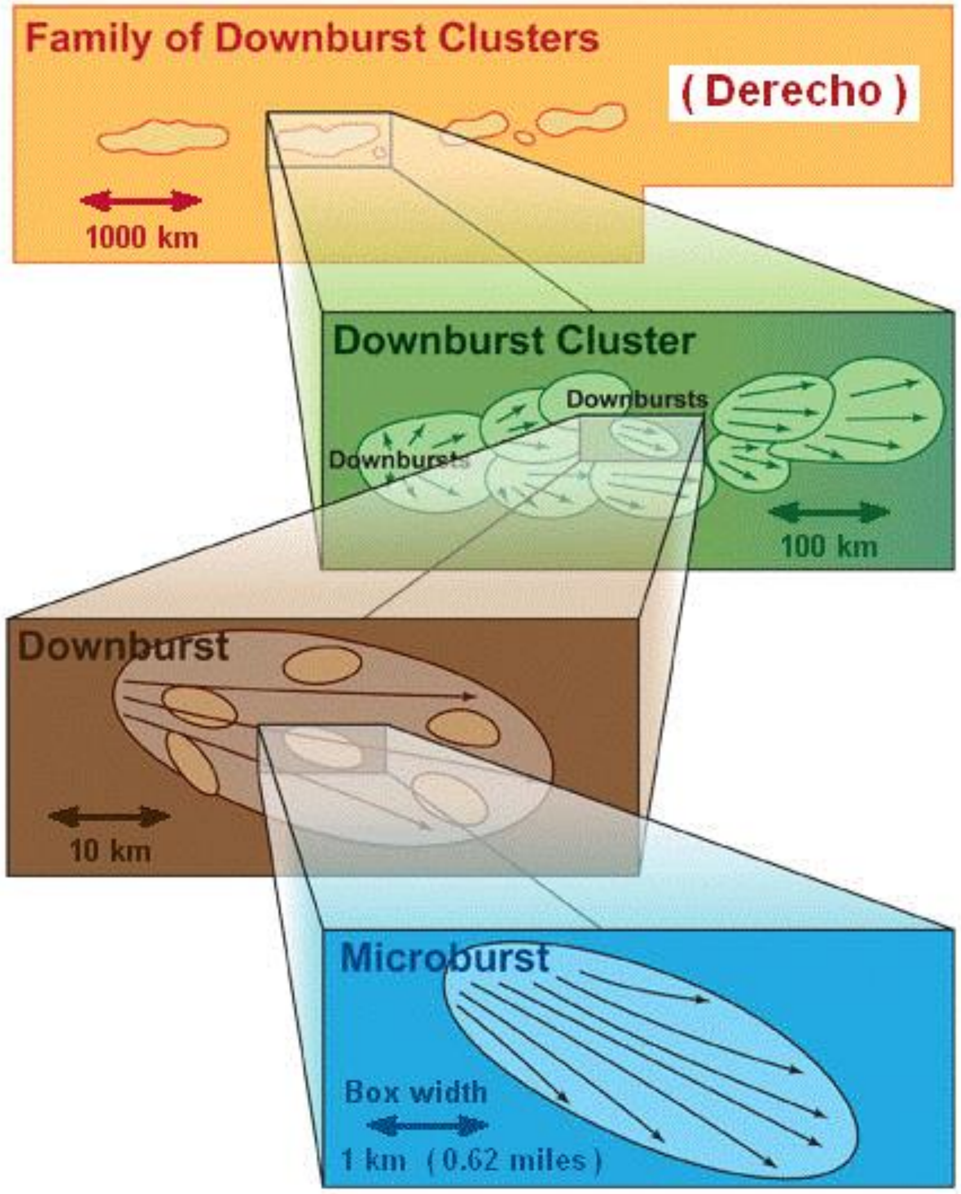


Parent MCS is known as the derecho-producing MCS (DMCS)

The derecho is the series of downbursts, evident via swaths of wind reports

Calling an MCS a derecho is like calling a supercell a tornado.

What is a derecho?



- Downburst winds occur on varying scales of motion.
- Typically, instances of stronger winds occur within increasingly shorter-lived, shorter-tracked, narrower swaths.
- Analogous to stronger winds contained within single-suction vortices of multiple-vortex tornadoes.

Fujita and Wakimoto (1981)

Defining Derechos

- Johns and Hirt (1987) was the first to robustly study derechos, identifying progressive/serial derecho types in the process.

- Quantitative criteria were introduced to stratify between potent wind swaths and more ordinary severe wind events.

- Defined derechos as “widespread windstorms originating from a singular MCS”

Defining Derechos

- Corfidi et al. (2016) proposed a new derecho definition:
  - “A family of damaging downburst clusters associated with a forward-propagating, mesoscale convective system (MCS) that, during part of its existence, displays evidence of one or more sustained bow echoes with mesoscale vortices and/or rear-inflow jets.”
- The proposed definition would exclude serial squall line events, which were hypothesized to be driven primarily be downward momentum transport of the synoptic flow aloft.
- The purpose of this definition modification was to associate the phrase ‘derecho’ to a phenomenological occurrence.
  - A phenomena is a unique observation, driven by a specific cause, that is recurrent in nature.

Derecho Classification

- What are the quantitative criteria that a wind swath must meet to be classified as a derecho?

	Johns and Hirt (1987) JH87	Bentley and Mote (1998) BM98	Bentley and Sparks (2003)	Coniglio and Stensrud (2004) CS04	Corfidi et al. (2016) C16
Years	1980-1983	1986-1995	1986-2000	1986-2001	2010-2014
N	70	112	230	244	365 (25)
Type	Progressive Serial	Progressive Serial	Progressive Serial	Progressive Serial	Progressive
1	There must be a concentrated area of convective wind gusts exceeding 26 m s^{-1} with a major axis path length of at least 400 km.	As in JH87	As in JH87	As in JH87	Like JH87, but for a path length of 650 km (N = 25 cases that met this length criteria).
2	There must be at least 3 reports (separated by 64 km) of F1 damage or 33+ m s^{-1} wind gusts during the MCS stage.	Not Used	As in BM98	Low end: BM98 Moderate: JH87 High end: Like JH87, but 3 reports must exceed 38 m s^{-1}, with 2 occurring at MCS stage.	As in BM98
3	No more than 3 h can elapse between successive reports.	No more than 2 h can elapse between successive reports.	As in BM98	Like JH87, but for 2.5 h.	No more than 1 h elapsed between successive reports.
4	Wind reports must have chronological progression.	As in JH87	As in JH87	As in JH87	As in JH87
5	The associated MCS must have spatial or temporal continuity in surface pressure or wind fields.	Continuity confirmed when no more than 2º lat/lon separation occurs between reports.	As in BM98	Like BM98, but no more than 200 km allowed between any reports in the swath.	Like CS04, but no more than 100 km allowed between any reports in the swath.
6	All damage swaths must accompany the same MCS based on radar data.	MCS confirmed by temporally mapping wind reports without radar	As in BM98	As in JH87	As in JH87

Focusing the Derecho Definition

- Varying quantitative criteria classifying derechos introduces sensitivity to spatial climatology and overall annual frequency

- Previous derecho studies evaluated events over smaller periods of time, which can also influence climatology results

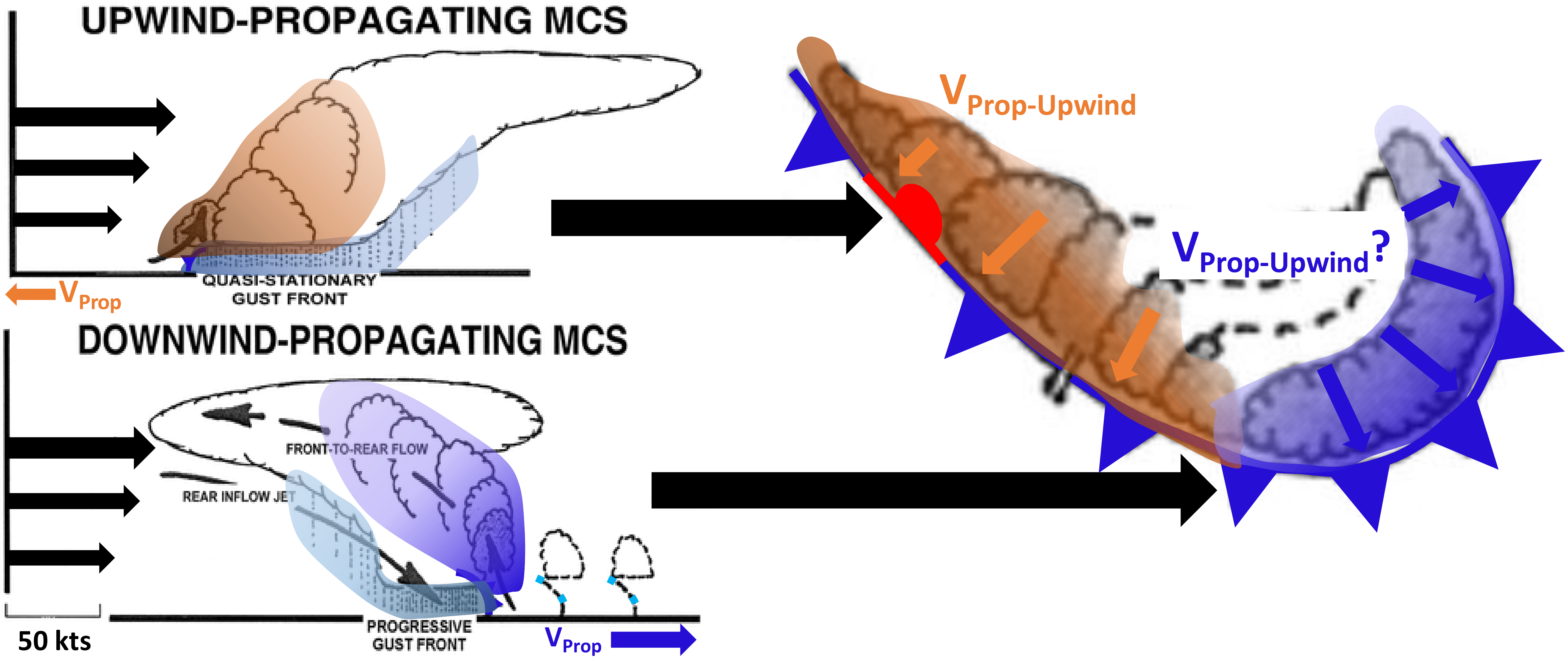
- A need arises for a more consistently applied definition and associated quantitative criteria to better understand the mechanisms and ambient environments supporting the most intense, destructive wind swaths. Can also derive a more accurate spatial climatology.

Focusing the Derecho Definition

- In agreement with Corfidi et al. (2016), the first step to better understanding derechos would be to define these events in a phenomenological sense.
- In tradition with many earlier studies, an intensity component to derechos is necessary to make such events phenomenally distinct.
- Defining derechos as widespread severe wind swaths originating from self-organized, cold-pool driven MCSs (as in Corfidi et al. 2016) accomplishes the ‘phenomenological’ component of the definition.
- Past research has shown that the most impactful feature to derecho wind swaths was the existence of multiple embedded 33+ m s^{-1} wind gusts (Squitieri et al. 2023a, b). Including multiple 33+ m s^{-1} wind gusts will make derechos phenomenally distinct.
- Many past studies (going back to Johns and Hirt 1987) noted the distinct phenomenal occurrence of derechos moving faster (sometimes much faster) than the mean wind speed.

MCS Forward Motion

- Recall that progressive cold pools can be heavily influential on MCS forward (downwind) propagation.

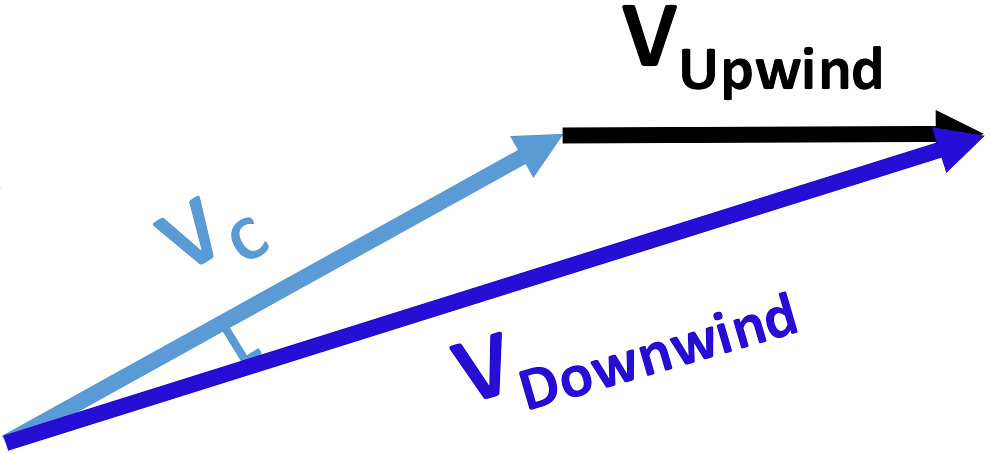


MCS Forward Motion Factors

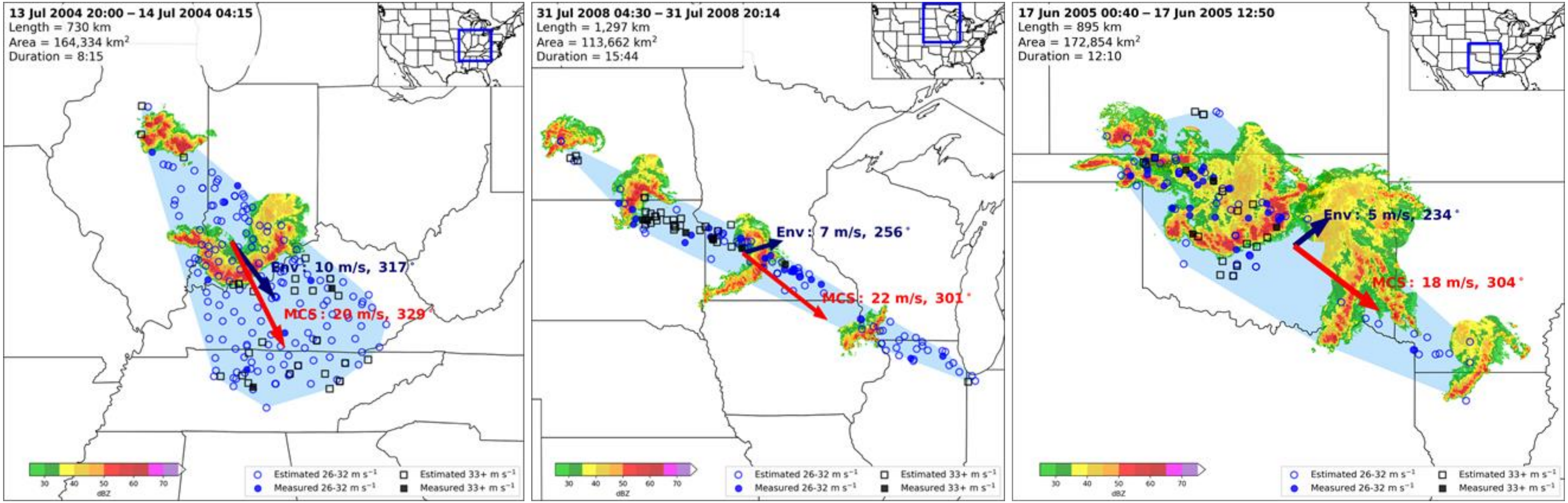
- Downwind-propagating MCSs are dominated by the cold pool, and derechos are also produced by cold-pool-driven MCSs, which are dominated by internal forcing mechanisms.

- As such, **$V_{downwind}$** would be a useful vector for monitoring derecho progression.

- Note that **$V_{downwind}$** is a longer vector than V_{CL}.



MCSs moving faster than the mean wind speed is an excellent discriminator between cold-pool-driven MCSs and their squall line counterparts.



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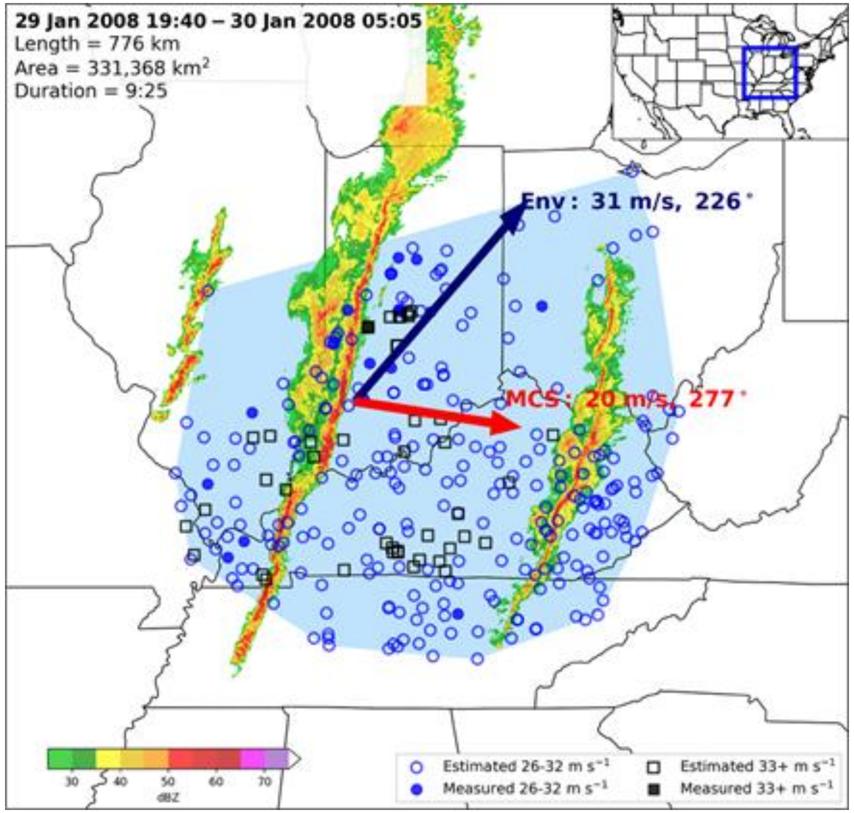
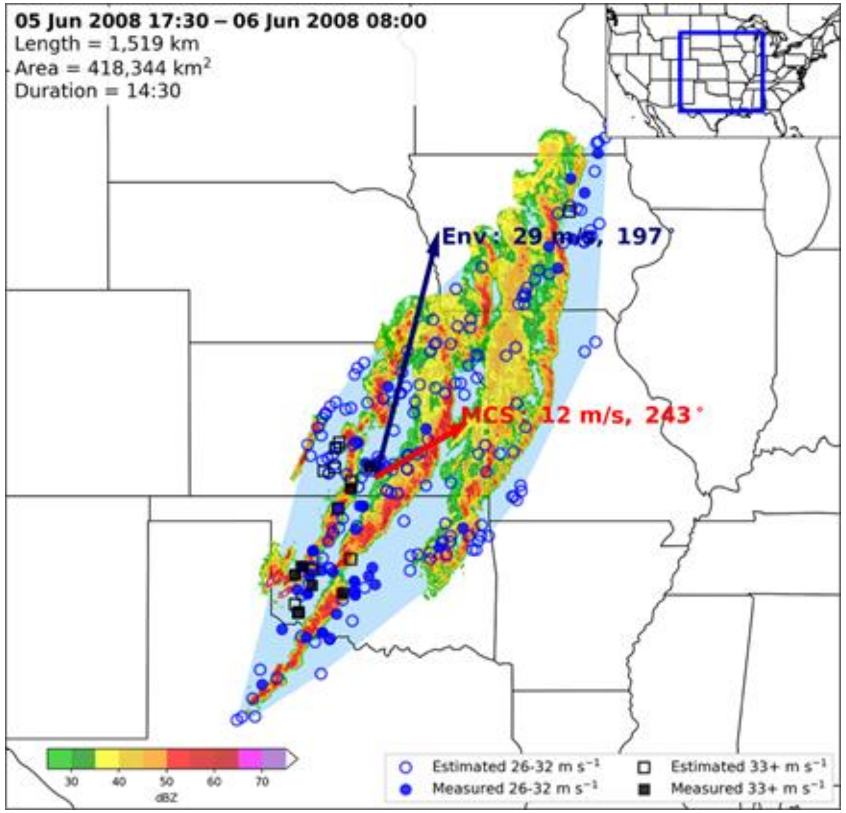
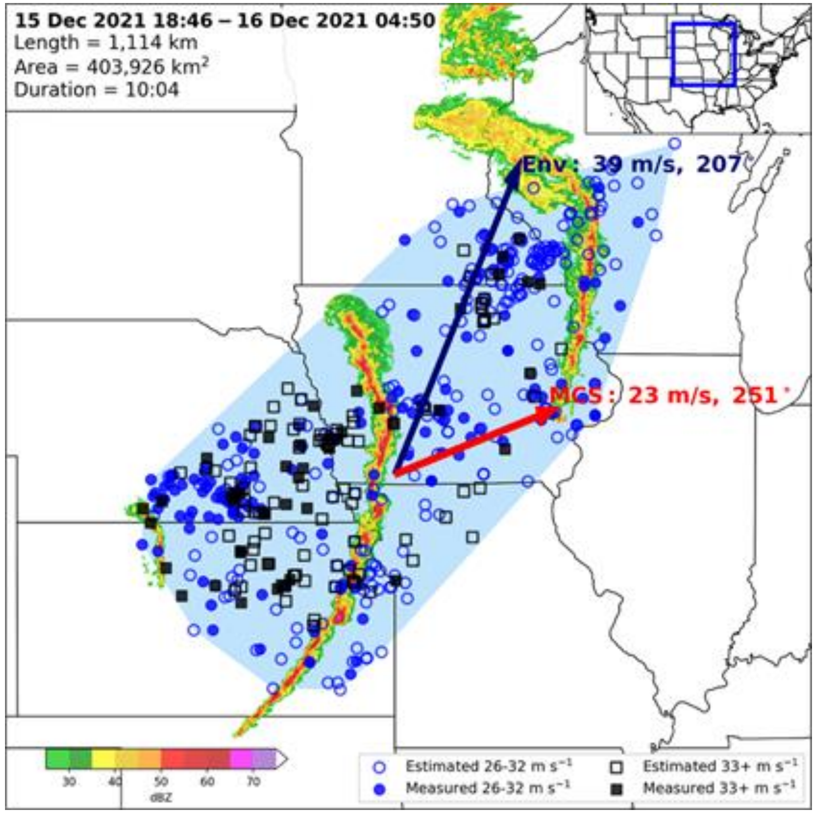
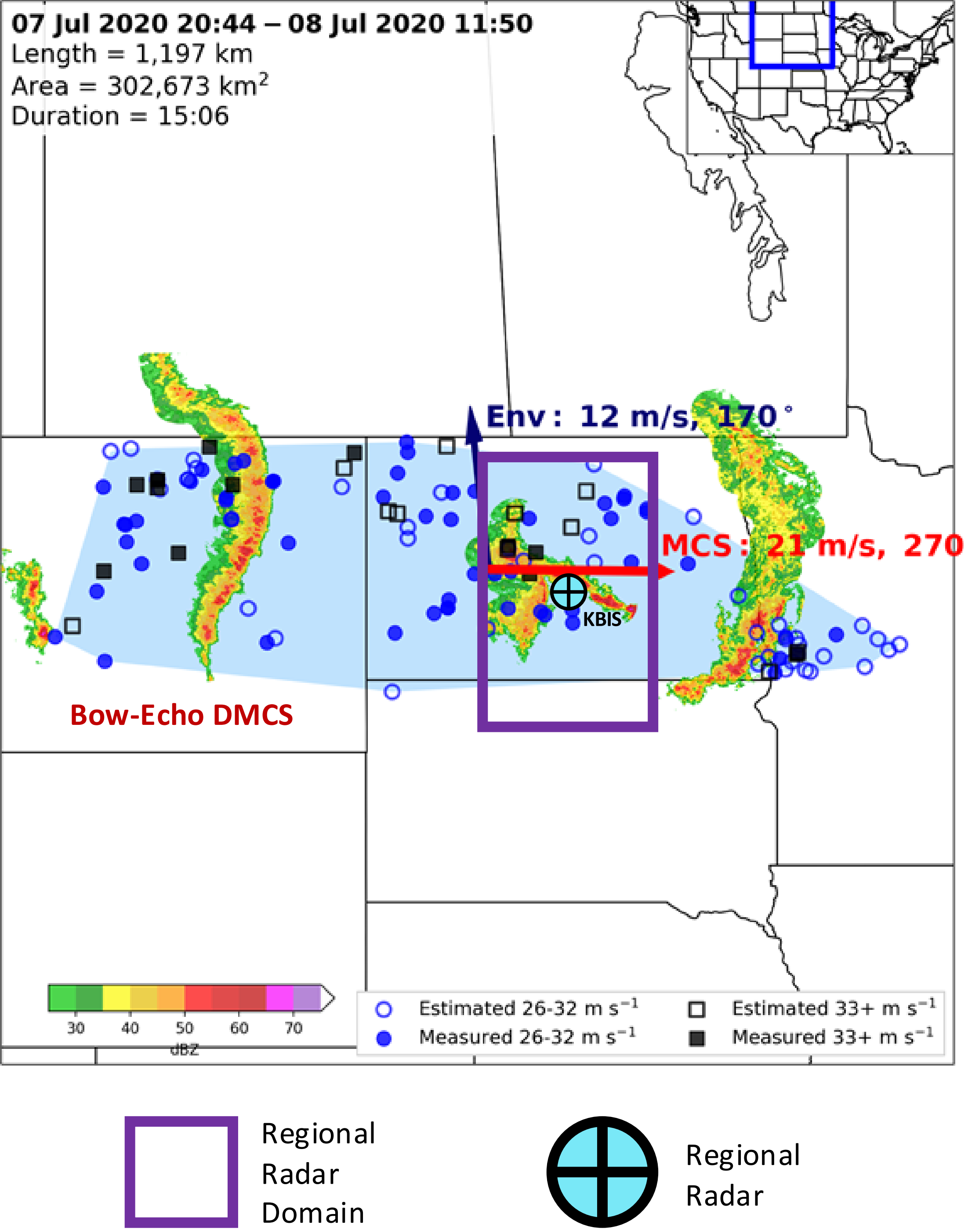


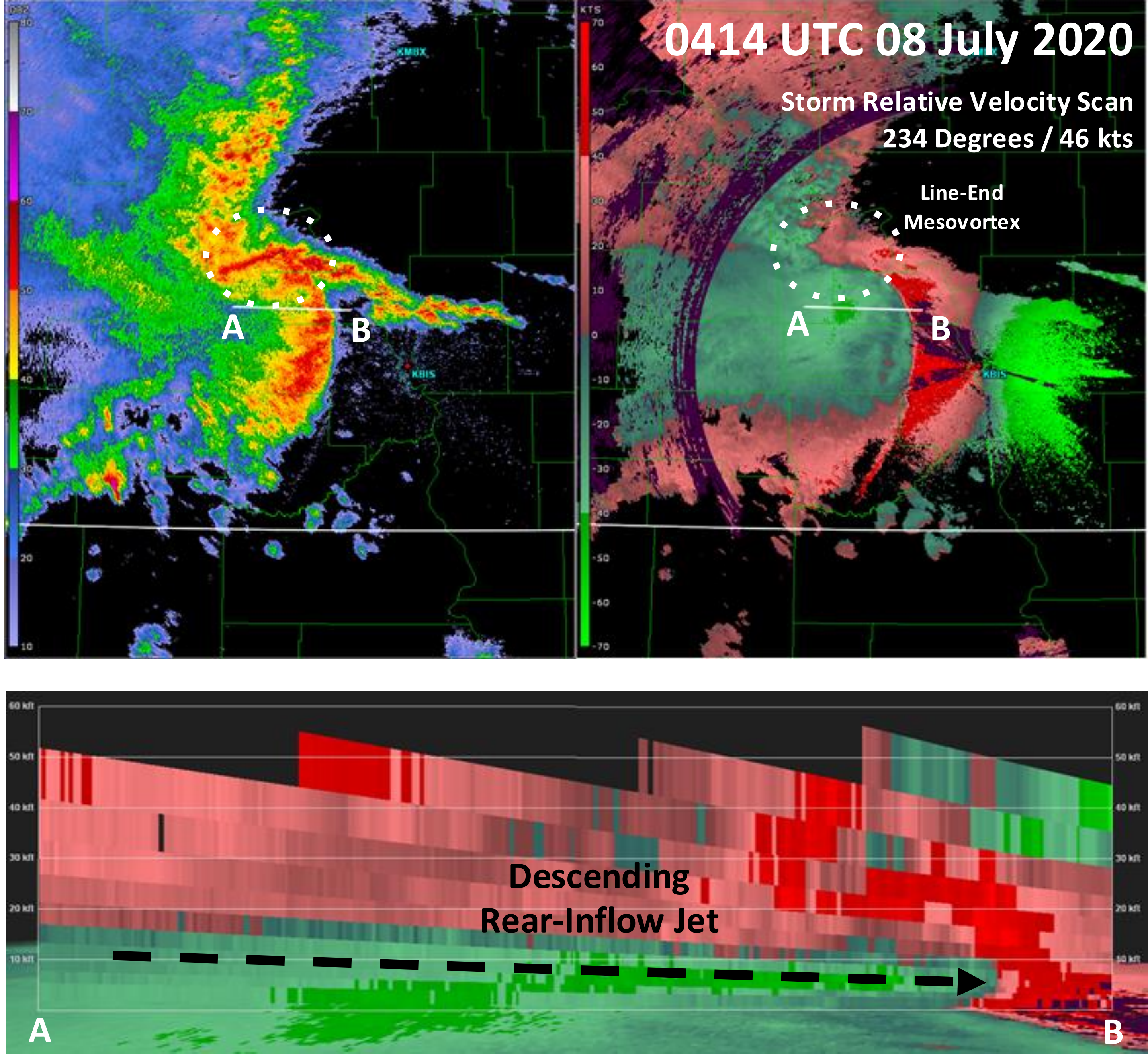




Note: Cold-pool-driven MCSs and strongly forced squall lines both have degrees of internal and external forcing (i.e. a level of contribution from the cold pool

The argument is that to define derechos as a distinct phenomena, internal forcing mechanisms must dominate, which is defined by the MCS moving faster than the full mean wind speed.


07 Jul 2020 20:44 – 08 Jul 2020 11:50
Length = 1,197 km
Area = 302,673 km²
Duration = 15:06
Env: 12 m/s, 170°
MCS: 21 m/s, 270°
KBIS
Bow-Echo DMCS
30
40
50
60
70
dBZ
Estimated 26-32 m s⁻¹
Measured 26-32 m s⁻¹
Estimated 33+ m s⁻¹
Measured 33+ m s⁻¹
Regional Radar Domain
Regional Radar


0414 UTC 08 July 2020
Storm Relative Velocity Scan
234 Degrees / 46 kts
Line-End Mesovortex
A
B
KBIS
KMBX
Descending Rear-Inflow Jet
A
B

Modified Derecho Definition

“A widespread severe windstorm characterized by a family of destructive downbursts containing hurricane-force gusts associated with an extra-tropical, cold-pool-driven Mesoscale Convective System.”

- For a wind swath to be classified as a derecho, the following criteria are needed:
    - Widespread severe reports (wind damage or 26+ m s^{-1} gusts) comprising the wind swath all occur from the same MCS.
    - All reports in the wind swath must occur in progressive sequence.
    - The MCS must move faster than the full mean wind speed.
    - No more than 1 h may elapse between reports in the wind swath.
    - Spatial gaps between reports in the wind swath may not exceed 200 km.
    - The wind swath must be at least 400 km long.
    - At least five 33+ m s^{-1} gust reports (separated by 80 km) must occur in the 400-km long wind swath.
    - At least three measured 33+ m s^{-1} (separated by 80 km) are required in the wind swath.

	Johns and Hirt (1987) JH87	Bentley and Mote (1998) BM98	Bentley and Sparks (2003)	Coniglio and Stensrud (2004) CS04	Corfidi et al. (2016) C16	Squitieri et al. (2025a)
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3	No more than 3 h can elapse between successive reports.	No more than 2 h can elapse between successive reports.	As in BM98	Like JH87, but for 2.5 h.	No more than 1 h elapsed between successive reports.	As in C16
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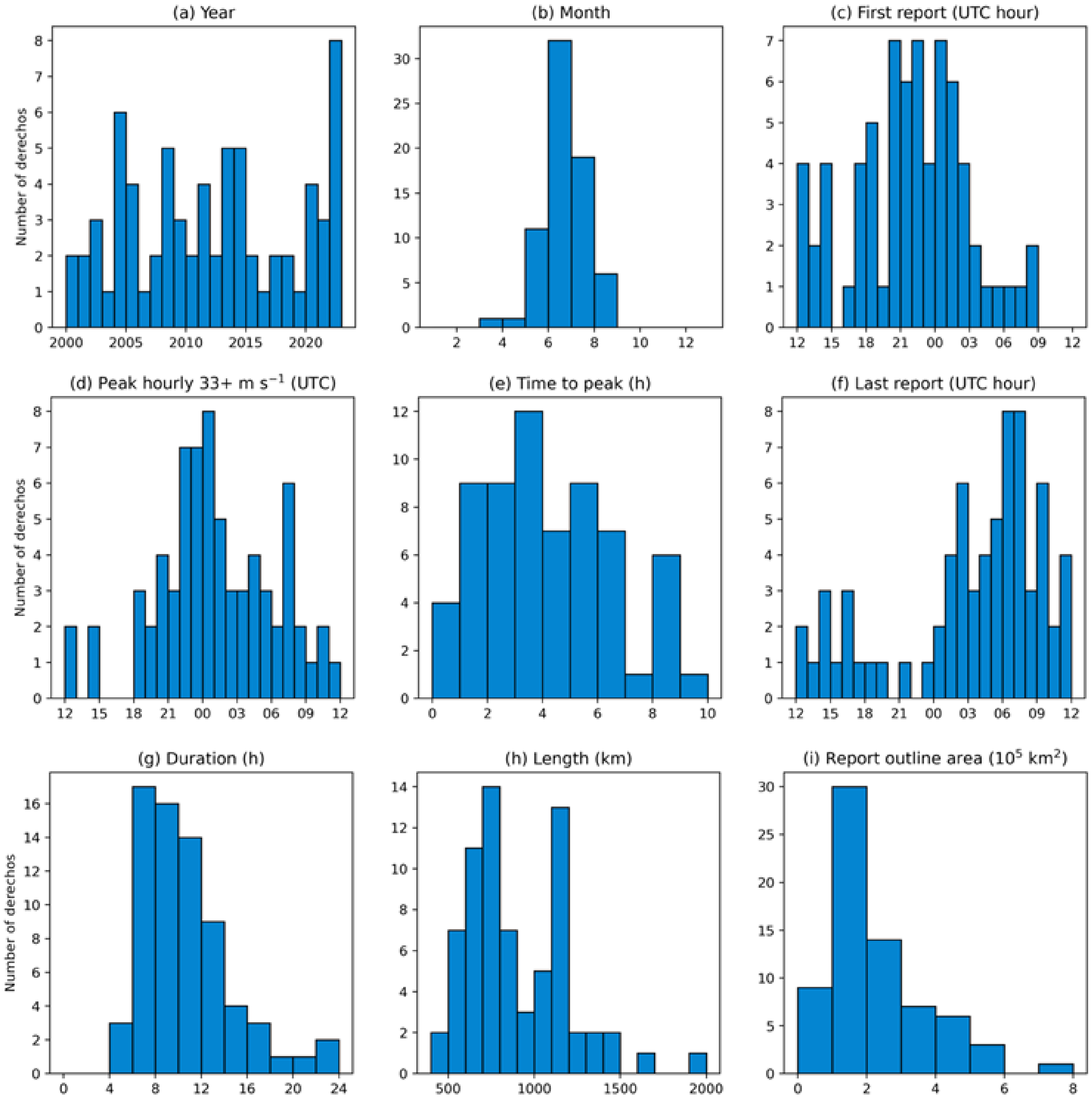
5	The associated MCS must have spatial or temporal continuity in surface pressure or wind fields.	Continuity confirmed when no more than 2º lat/lon separation occurs between reports.	As in BM98	Like BM98, but no more than 200 km allowed between any reports in the swath.	Like CS04, but no more than 100 km allowed between any reports in the swath.	As in CS04
6	All damage swaths must accompany the same MCS based on radar data.	MCS confirmed by temporally mapping wind reports without radar data.	As in BM98	As in JH87	As in JH87	As in JH87

Refined Derecho Definition

Key Takeaways

- Imposing strict 33+ m s^{-1} criteria reduces the derecho count, even with a longer study period (78 derechos in 23 years).

- Most previous studies average 10-15 derechos nationally. The current study only averages 3 derecho nationally.



Derecho Statistics (new definition) Key takeaways

Derechos can be frequent or infrequent on any given year

Derechos are a warm season phenomena

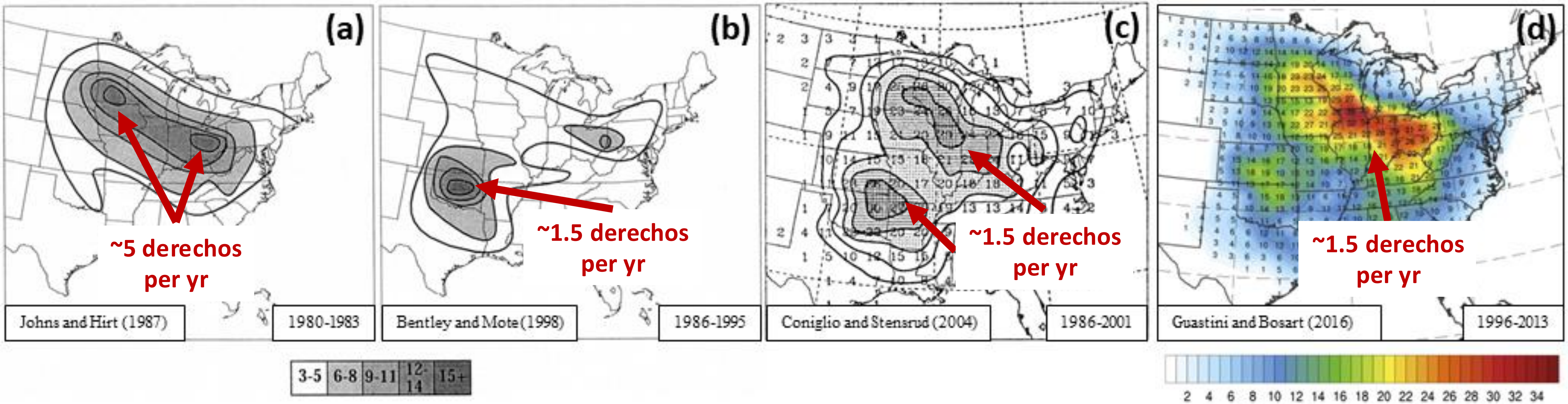
Derechos typically start during the afternoon, dissipate overnight, and peak in intensity only a few hours after initiation.

Derechos typically last ~6-18 hours.

Most derechos have 500-1200 km path lengths.

Most derechos have an areal coverage of 100,000-500,000 km^2.

Squitieri et al. (2025b)



~5 derechos per yr

~1.5 derechos per yr

~1.5 derechos per yr

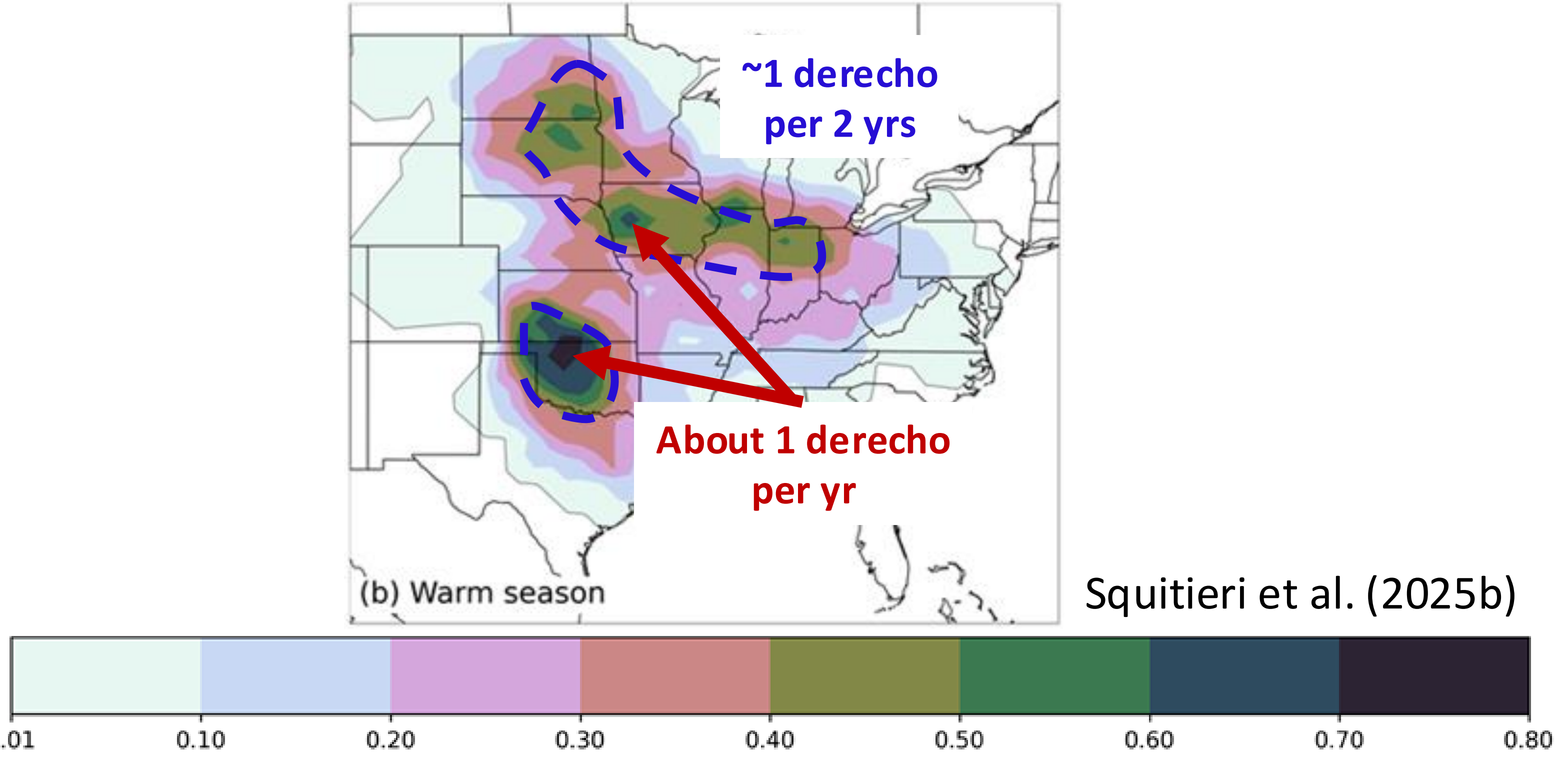
~1.5 derechos per yr

Johns and Hirt (1987) 1980-1983

Bentley and Mote (1998) 1986-1995

Coniglio and Stensrud (2004) 1986-2001

Guastini and Bosart (2016) 1996-2013

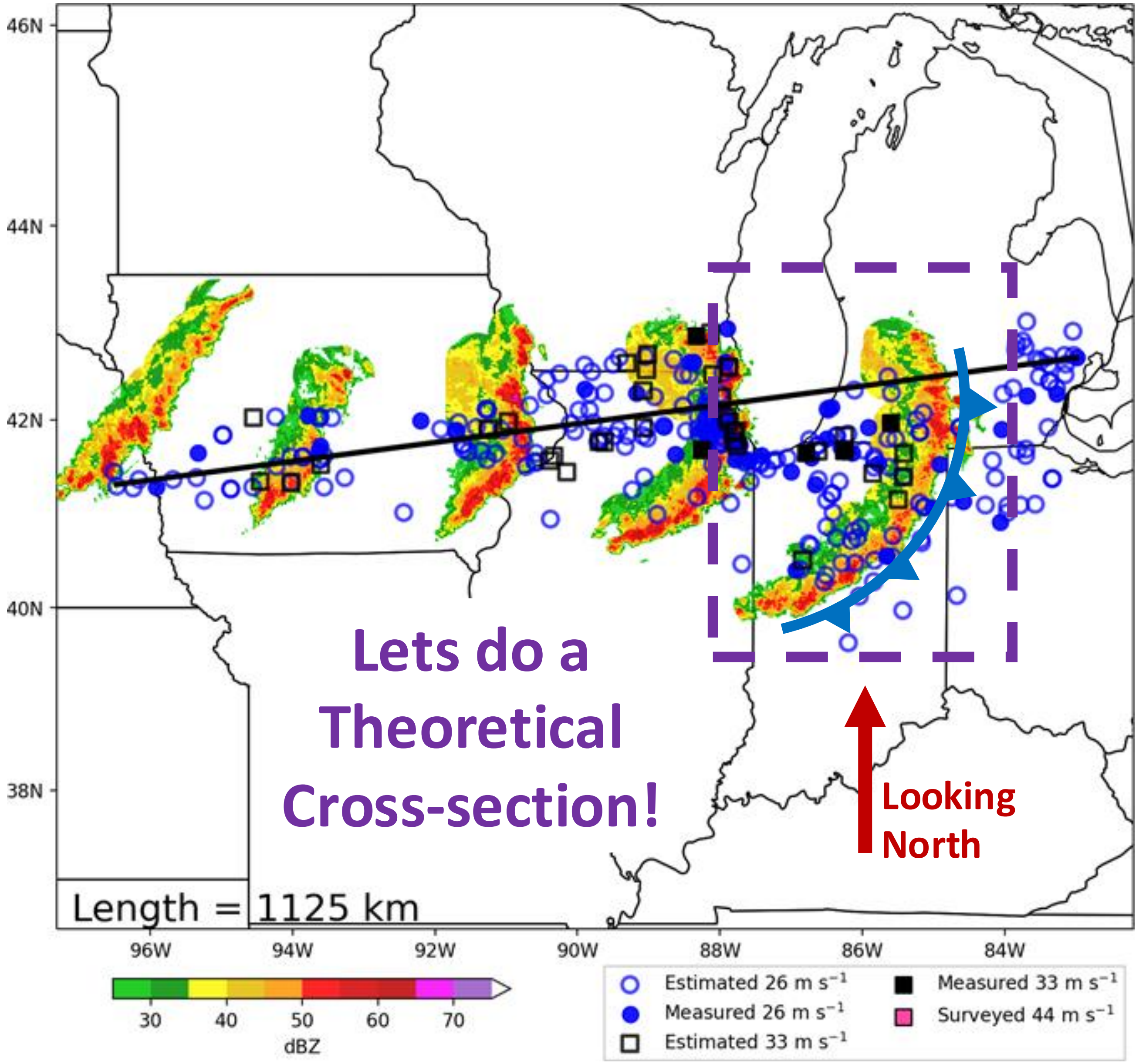


~1 derecho per 2 yrs

About 1 derecho per yr

Squitieri et al. (2025b)

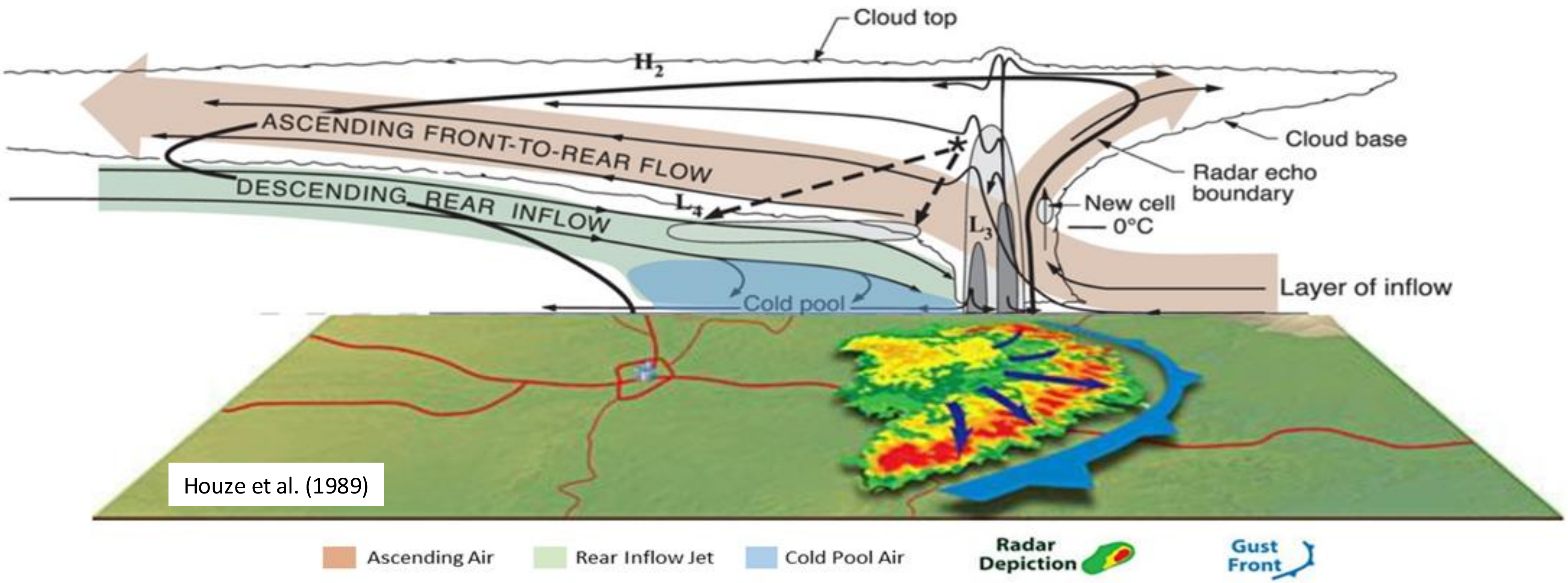
How do bow-echo DMCSs form?



Lets do a Theoretical Cross-section!

Looking North

How do bow-echo DMCSs form?



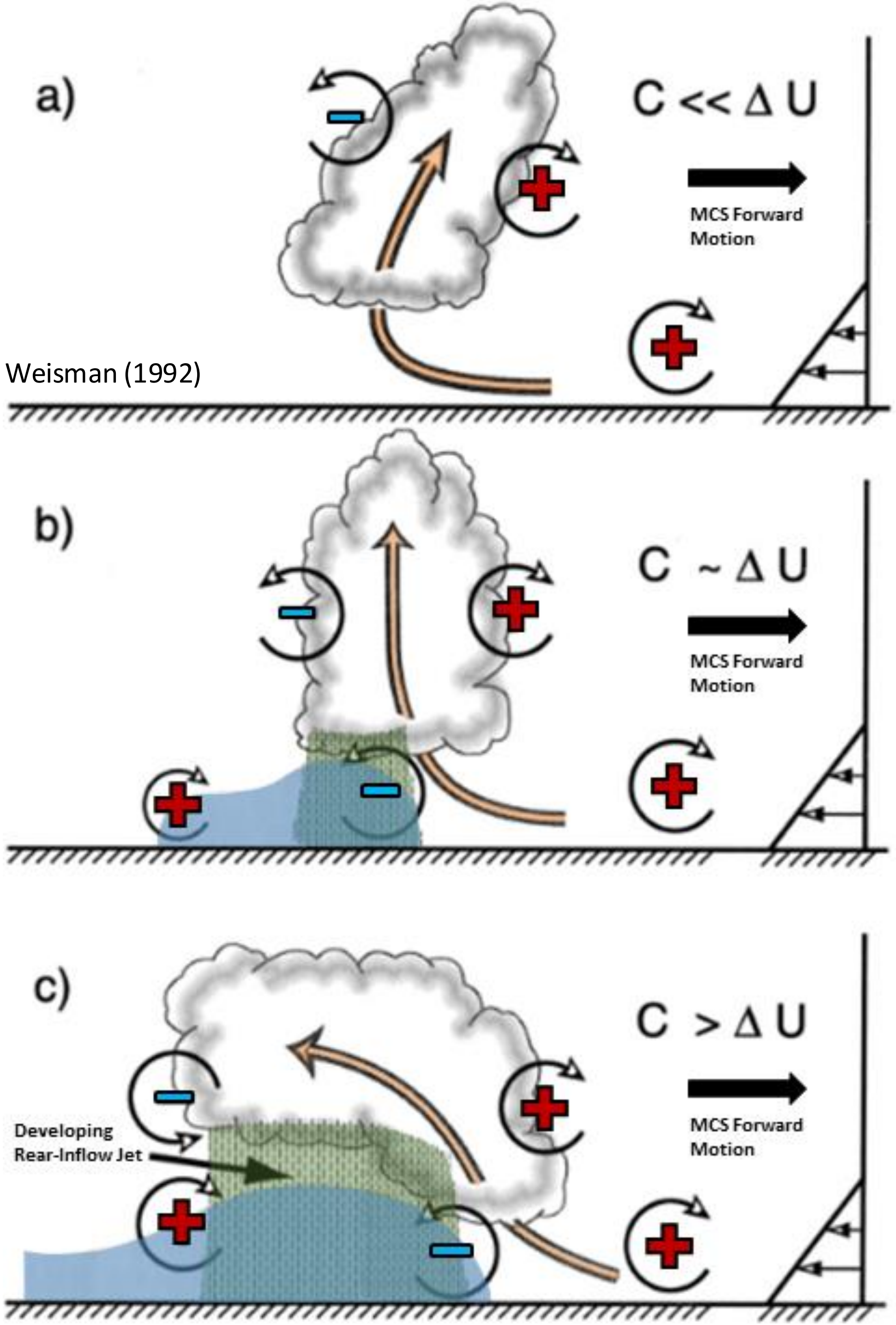
Houze et al. (1989)

Key Points

Derechos originate from highly organized MCSs and bow echoes.

Front-to-rear flow transports liquid/ice species that melt and evaporate behind the main leading line, generating a cold pool and horizontal buoyancy gradient

This buoyancy gradient fosters rear inflow jet development, which support bow-echo structure and derecho winds.



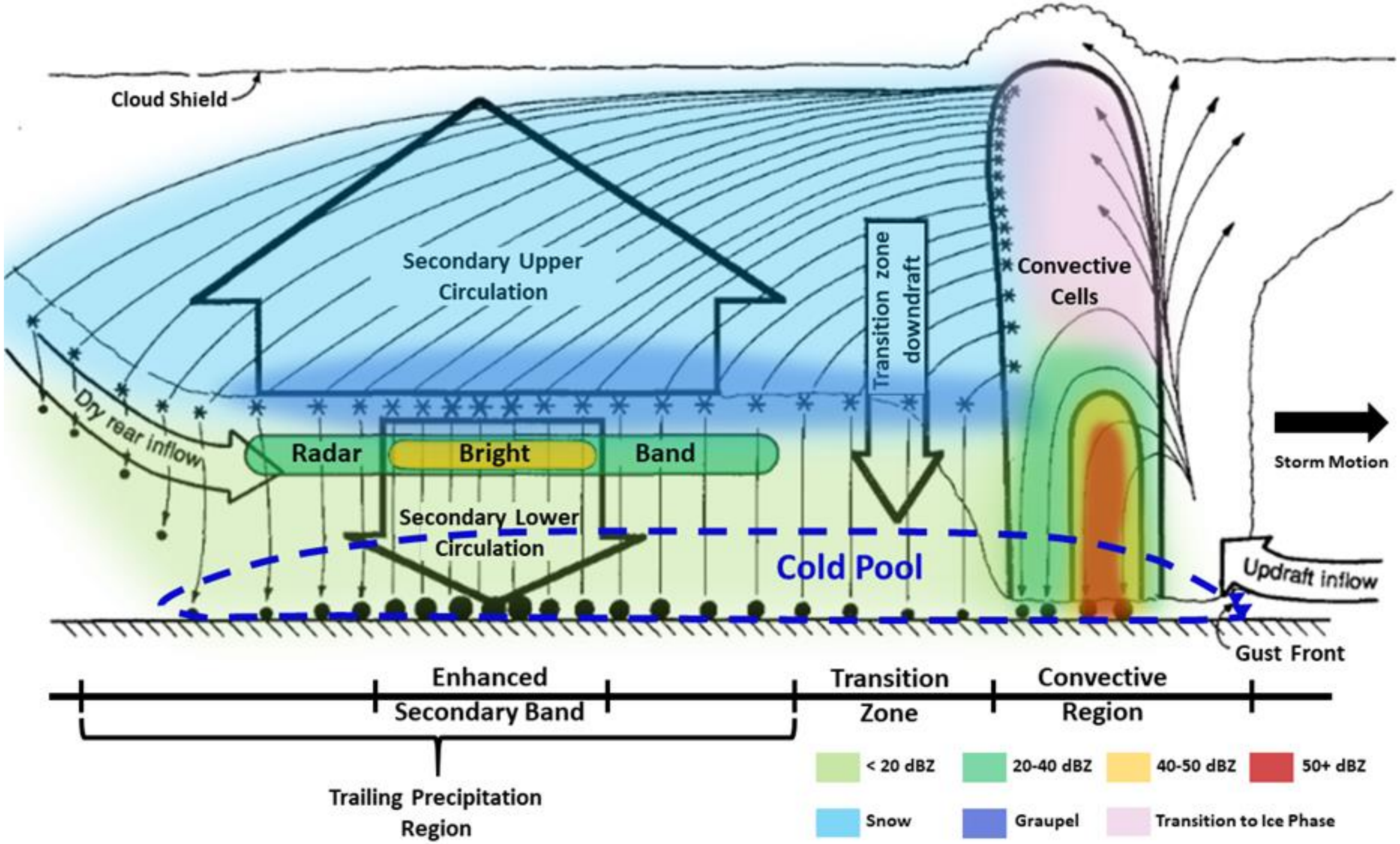
Weisman (1992)

Key Points

Combined cold pool depth and strength (C) must be at least a little stronger then the countering low-level shear (Δu) to allow for persistent rearward flow (C > Δu). C >> Δu is sub-optimal because the cold pool could undercut the convective leading line.

The persistent rearward flow allows for prolonged hydrometeor advection and rainfall evaporation, supporting a deepening, strengthening cold pool.

The horizontal buoyancy gradient also strengthens, promoting intensifying horizontal circulations, with countering circulations above/behind the cold pool fostering rear-inflow jet development.



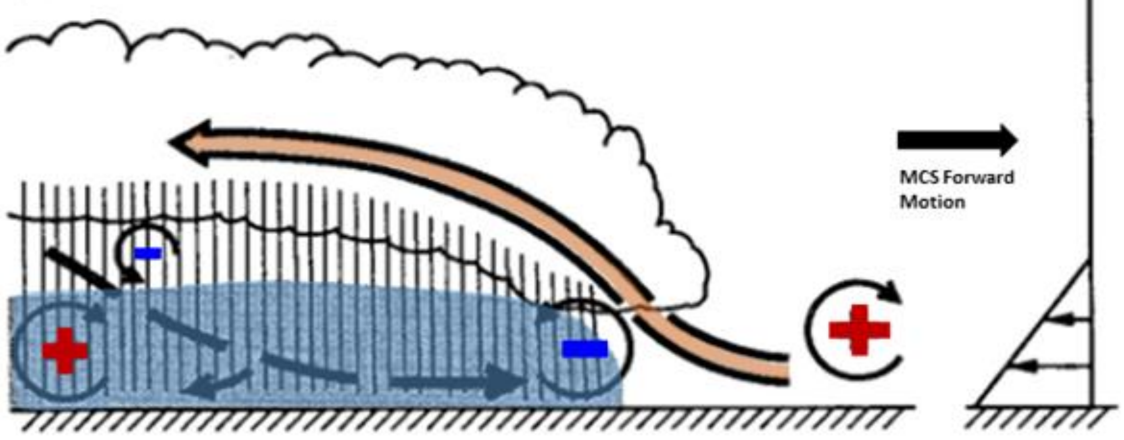
Biggerstaff and Houze (1991)

Most of the phase change along and beneath the RIJ axis is rainwater evaporation.

As such, rainwater evaporation is the biggest contributor to cold pool development and intensity.

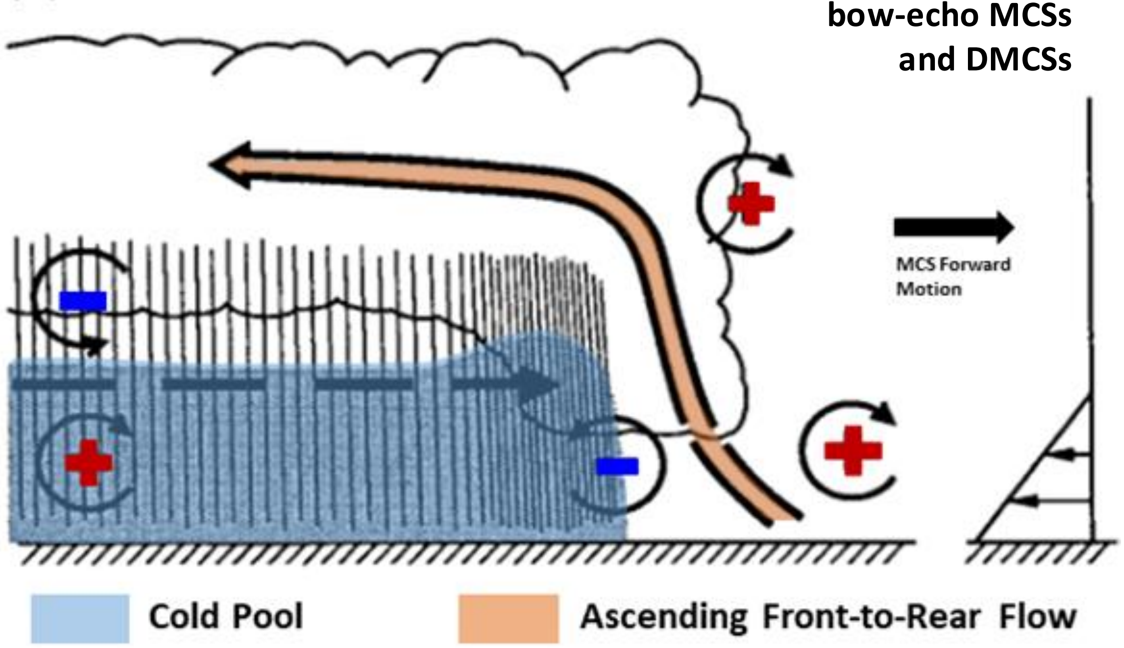
(a) Descending Rear-Inflow

Ordinary MCSs



(b) Elevated Rear-Inflow

Long-lived bow-echo MCSs and DMCSs



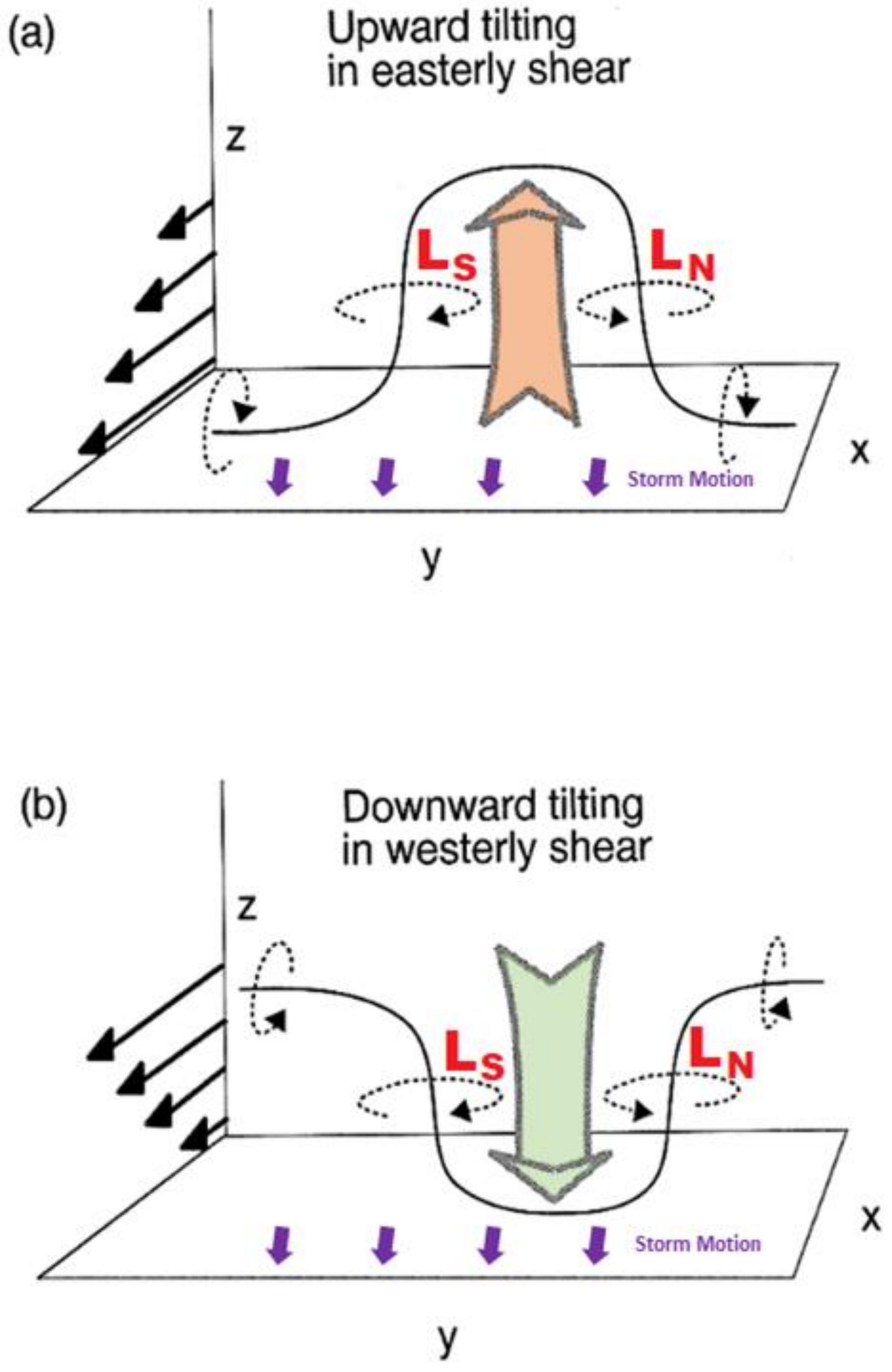
Weisman (1992)

Key Points

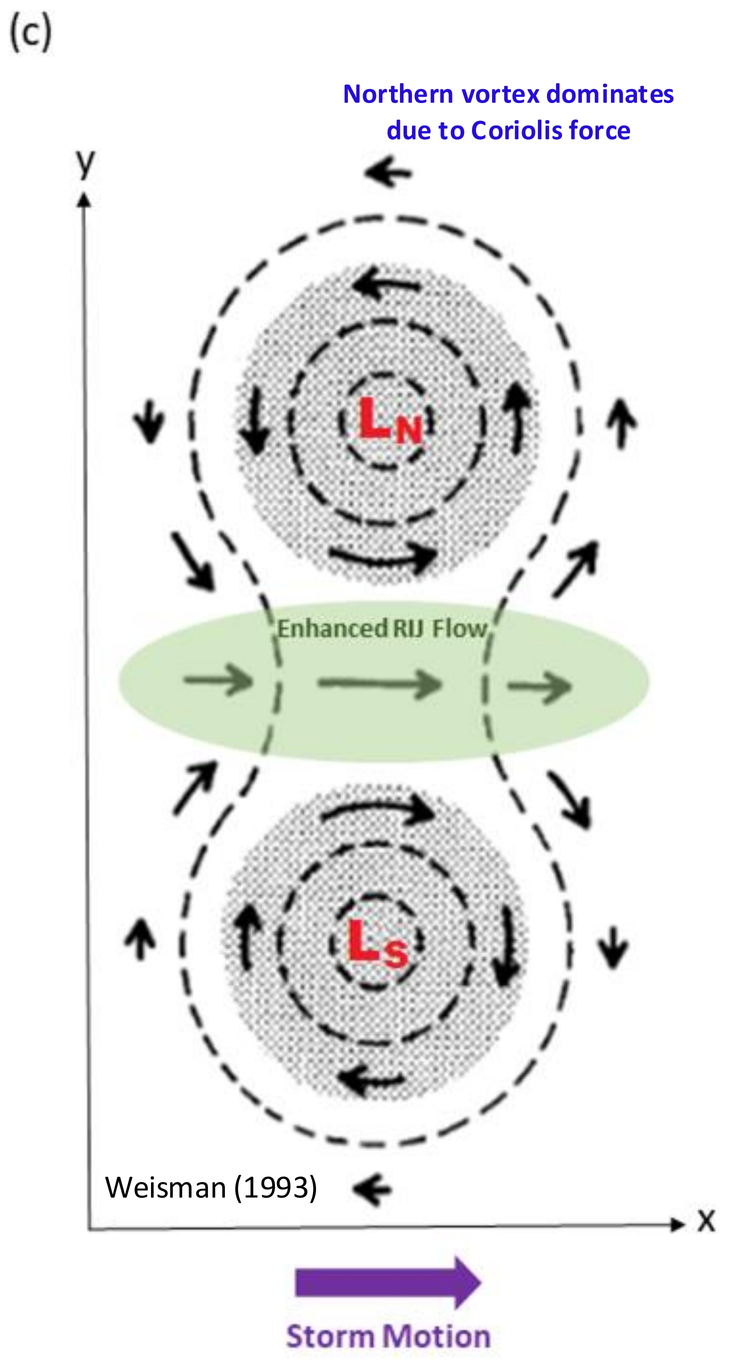
Most MCSs and bow echoes have rearward advection, evaporative cooling behind the main convective line, and cold pool development

The difference with the longest-lived bow-echoes and DMCSs is an unusually strong/deep cold pool, with pronounced countering circulations that support an intense but elevated rear inflow jet.

The stronger, elevated RIJ then supports stronger, deeper convergence along the MCS leading line, which augments leading-line updraft intensity, perhaps for long periods of time.



Weisman and Davis (1998)



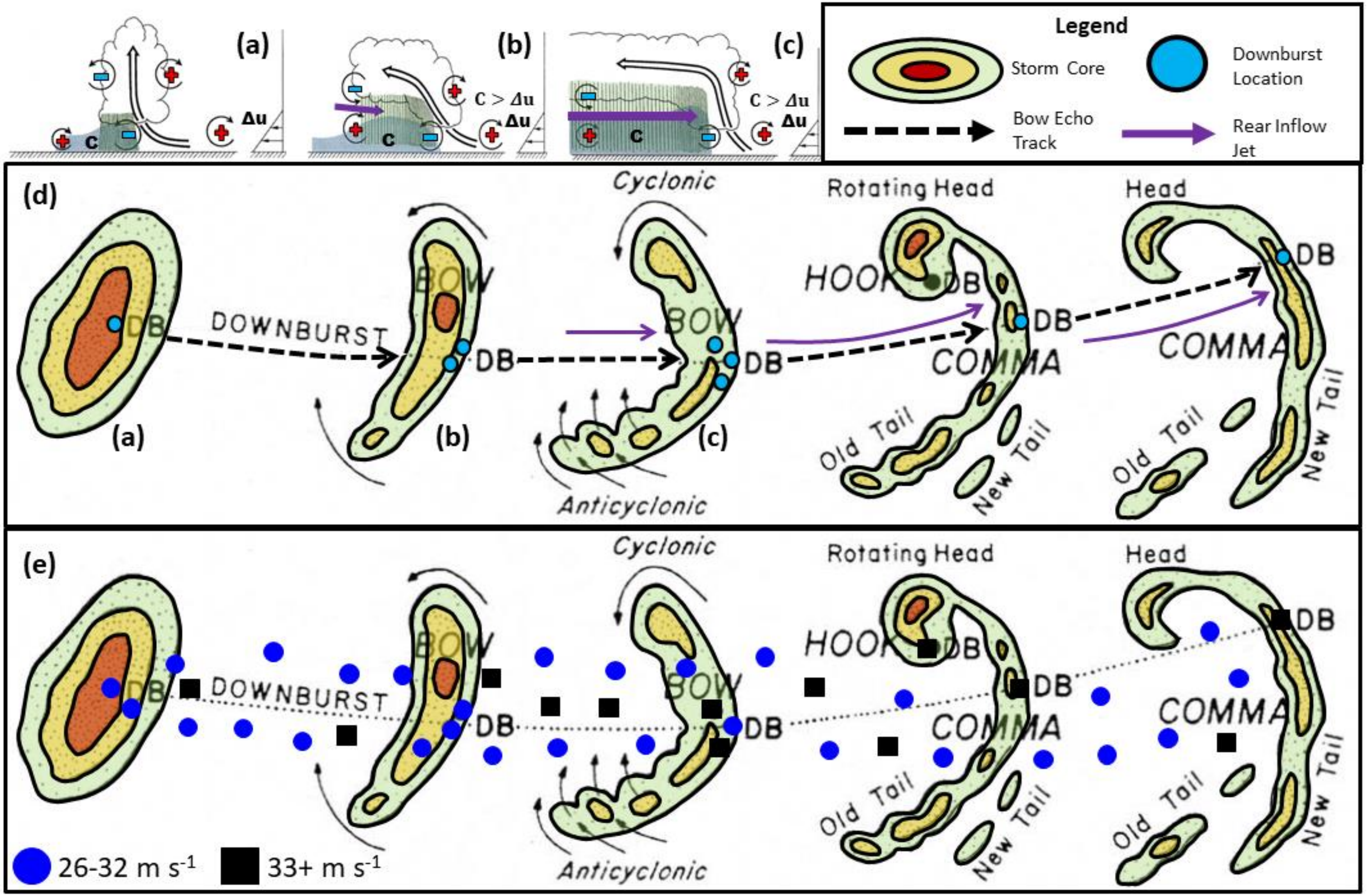
Weisman (1993)

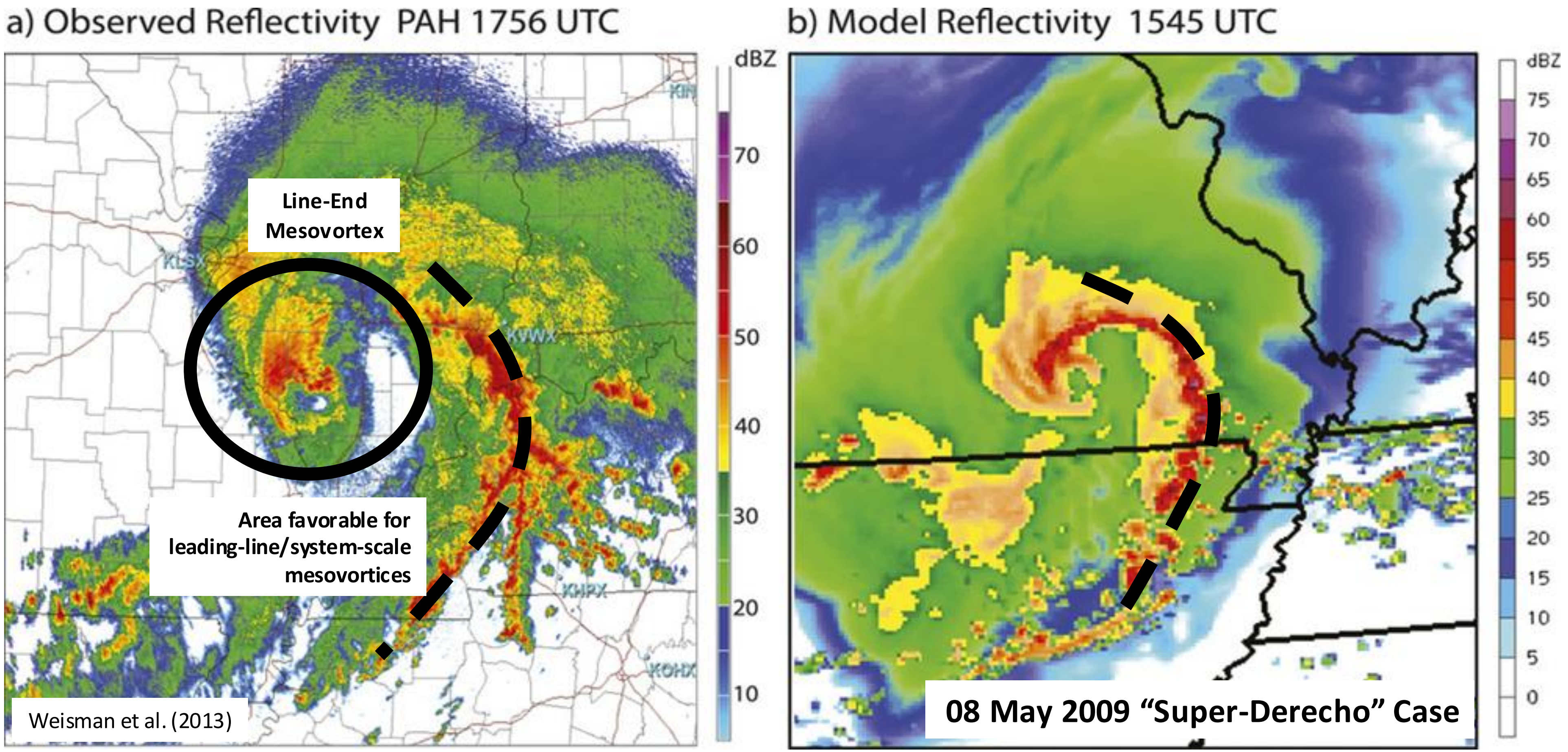
Key Points

The downward rear inflow jet, or upward motion from the convective leading-line, supports the tilting of horizontal vorticity, resulting in the development of “book-end” vortices.

Flow is augmented between the countering circulations, resulting in further strengthening of the RIJ, hence why the strongest surface winds are found near the bow-echo apex.

The northern book-end vortex often dominates due to effects related to the Coriolis force.


(a)
C
Δu
(b)
C > Δu
Δu
C
(c)
C > Δu
Δu
C
Legend
Storm Core
Downburst Location
Bow Echo Track
Rear Inflow Jet
(d)
DB
DOWNBURST
(a)
BOW
DB
(b)
Cyclonic
BOW
DB
(c)
Anticyclonic
Rotating Head
HOOK
DB
DB
COMMA
Old Tail
New Tail
Head
DB
COMMA
Old Tail
New Tail
(e)
DB
DOWNBURST
BOW
DB
Cyclonic
BOW
DB
Anticyclonic
Rotating Head
HOOK
DB
DB
COMMA
Old Tail
New Tail
Head
DB
COMMA
Old Tail
New Tail
26-32 m s-1
33+ m s-1


a) Observed Reflectivity PAH 1756 UTC

b) Model Reflectivity 1545 UTC

Line-End Mesovortex

Area favorable for leading-line/system-scale mesovortices

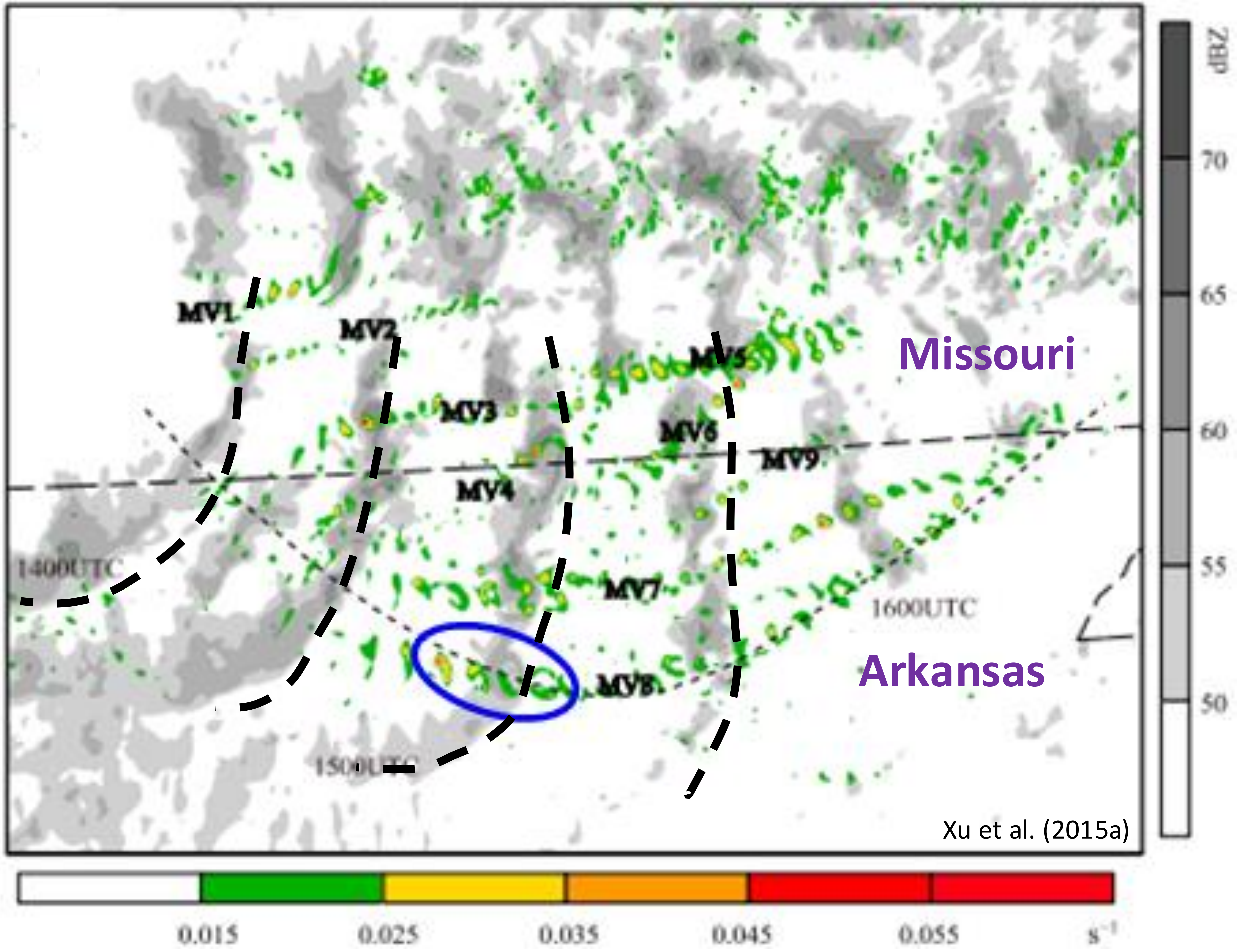
Weisman et al. (2013)

08 May 2009 “Super-Derecho” Case

In rare cases, deep, intense vortices may develop (such as the unusual warm-core vortex from the 08 May 2009 DMCS).

This DMCS was preceded by the strongest of LLJs and steepest of lapse rates observed by forecasters in this region of the county, and it is theorized that these anomalous conditions contributed to the development of this warm-core vortex.

Please read Weisman et al. (2013) and Evans et al. (2014) for details on the warm-core vortex origins and evolution.

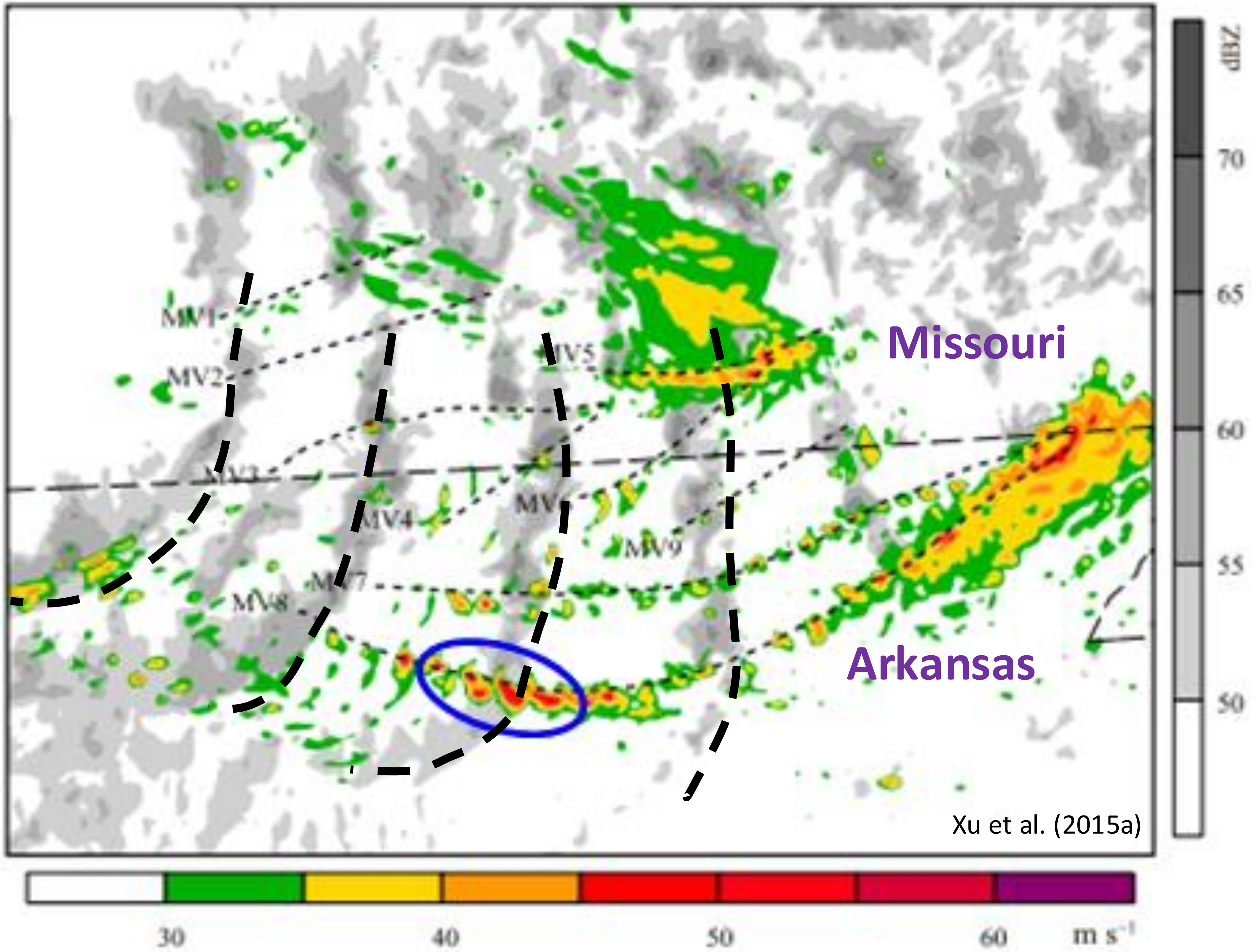


Xu et al. (2015a)

Key Points

Leading-line system-scale mesovortices are very small

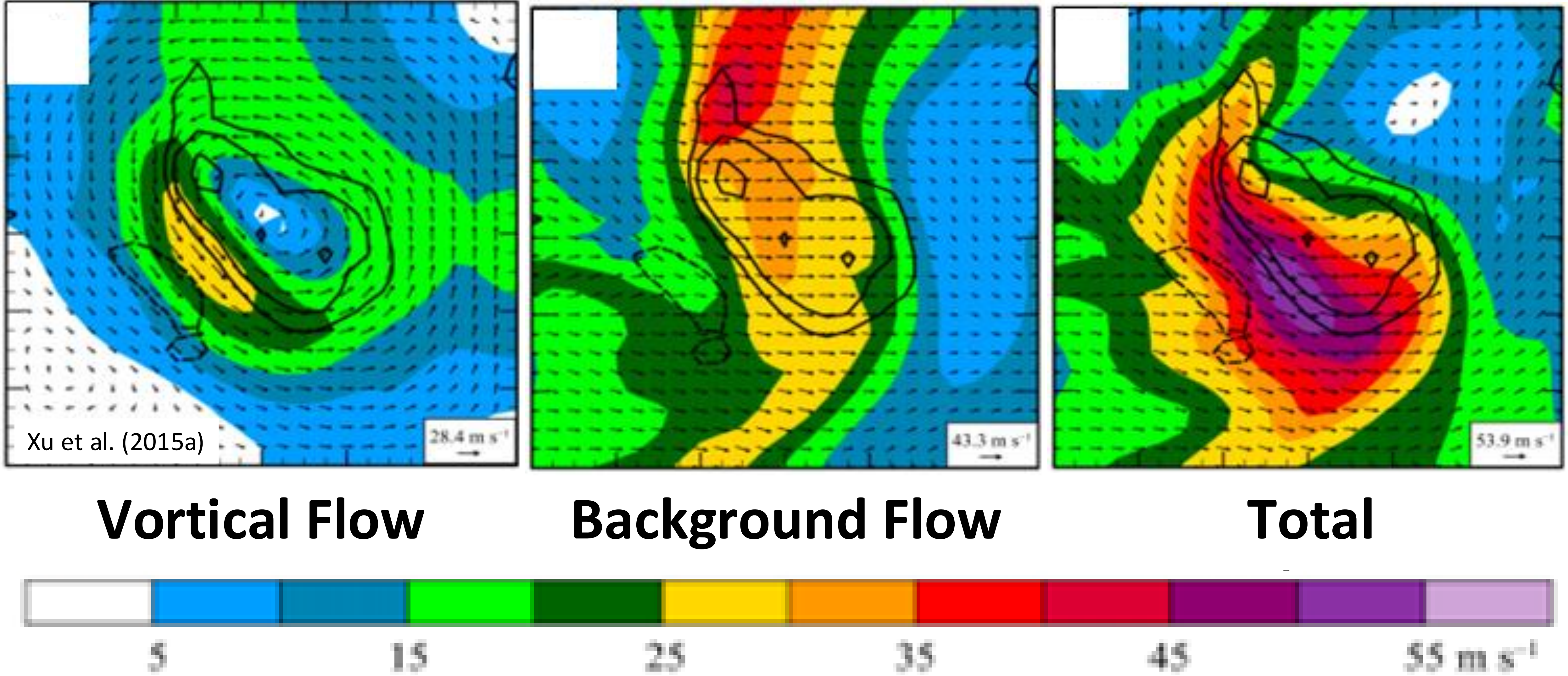
These mesovortices are responsible for many squall-line and bow-echo QLCS tornadoes that can accompany derecho events.



Xu et al. (2015a)

Key Points

The strongest surface winds with mesovortices are contained in narrow swaths (similar to supercell RFDs)



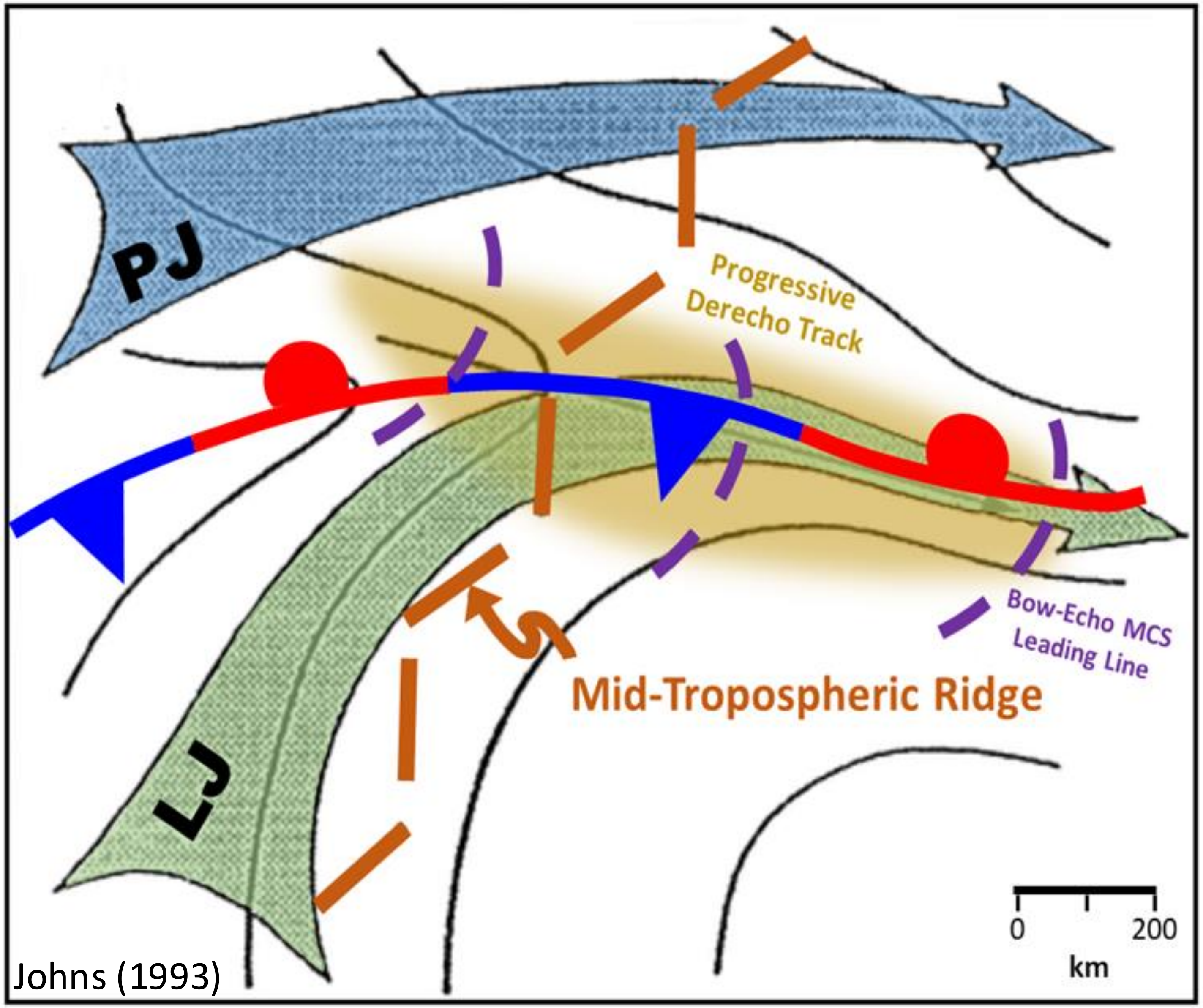
Xu et al. (2015a)

Vortical Flow **Background Flow** **Total**

The strongest winds in leading-line mesovortices tends to occur south of the circulation center, since the rotational component of flow and background flow align here. The background flow can originate from RIJs in bow-echoes or ambient winds in a squall line.

These narrow currents, especially aligned along and immediately north of a bow-echo apex, often produce the strongest gusts observed in a derecho, sometimes exceeding 100 mph. These may be the strongest winds seen in microbursts and burst-swaths (see slide 16 for illustrations)

Derecho Environments

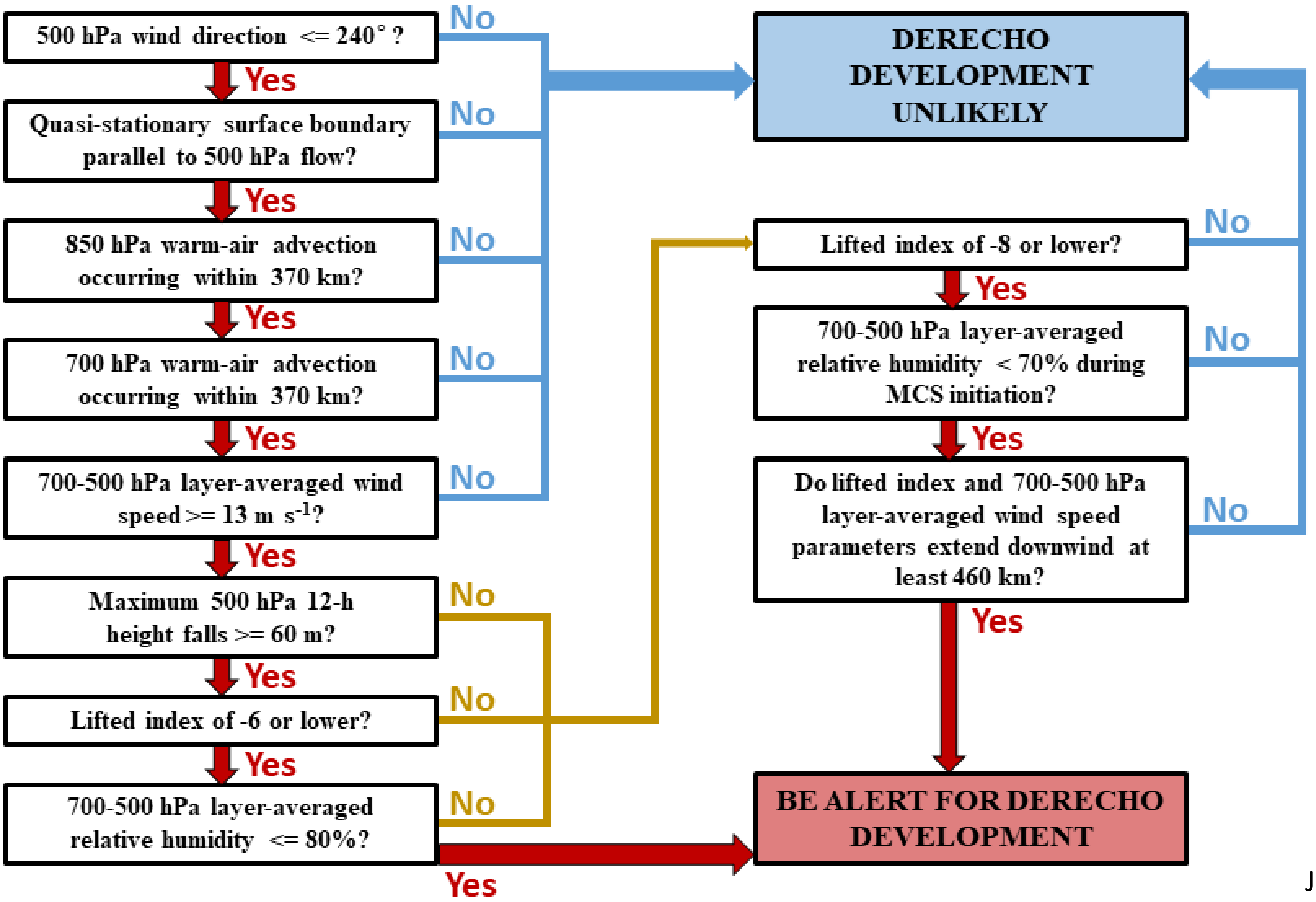


Johns (1993)

Derechos tend to be weakly forced, and usually occur in upper ridging environments. Harder to predict given weak forcing.

Near the mid-level ridge axis, DMCSs develop at the terminus (“nose”) of low-level warm-air advection, south of the right-entrance region of an upper-level jet streak.

The DMCS develops north of a surface boundary, and will either parallel the boundary to the north or traverse the boundary through evolution.



500 hPa wind direction <= 240° ?

No

Yes

Quasi-stationary surface boundary parallel to 500 hPa flow?

No

Yes

850 hPa warm-air advection occurring within 370 km?

No

Yes

700 hPa warm-air advection occurring within 370 km?

No

Yes

700-500 hPa layer-averaged wind speed >= 13 m s^{-1}?

No

Yes

Maximum 500 hPa 12-h height falls >= 60 m?

No

Yes

Lifted index of -6 or lower?

No

Yes

700-500 hPa layer-averaged relative humidity <= 80%?

No

Yes

DERECHO DEVELOPMENT UNLIKELY

Lifted index of -8 or lower?

No

Yes

700-500 hPa layer-averaged relative humidity < 70% during MCS initiation?

No

Yes

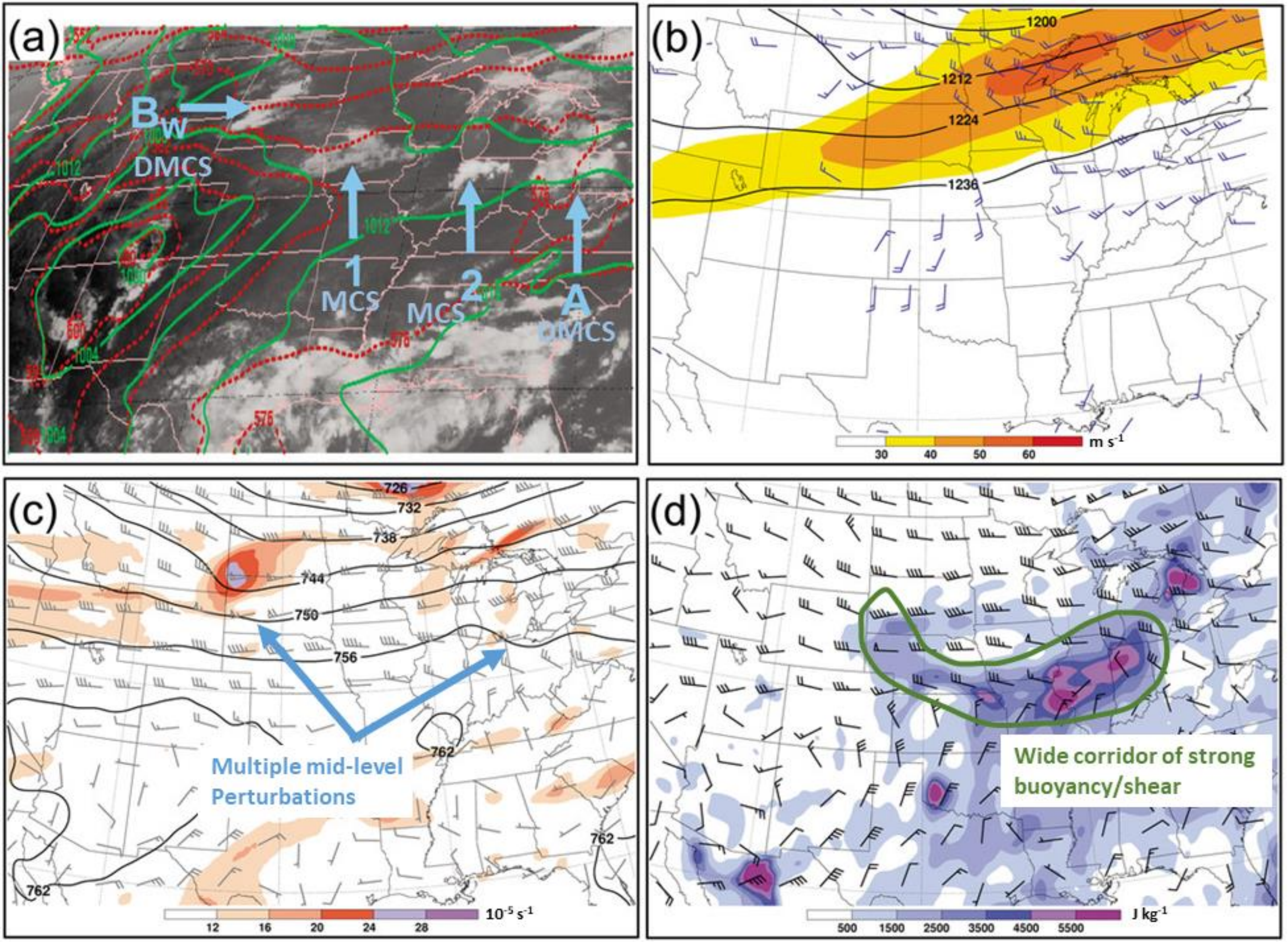
Do lifted index and 700-500 hPa layer-averaged wind speed parameters extend downwind at least 460 km?

No

Yes

BE ALERT FOR DERECHO DEVELOPMENT

Johns and Hirt (1987)



Metz and Bosart (2010)

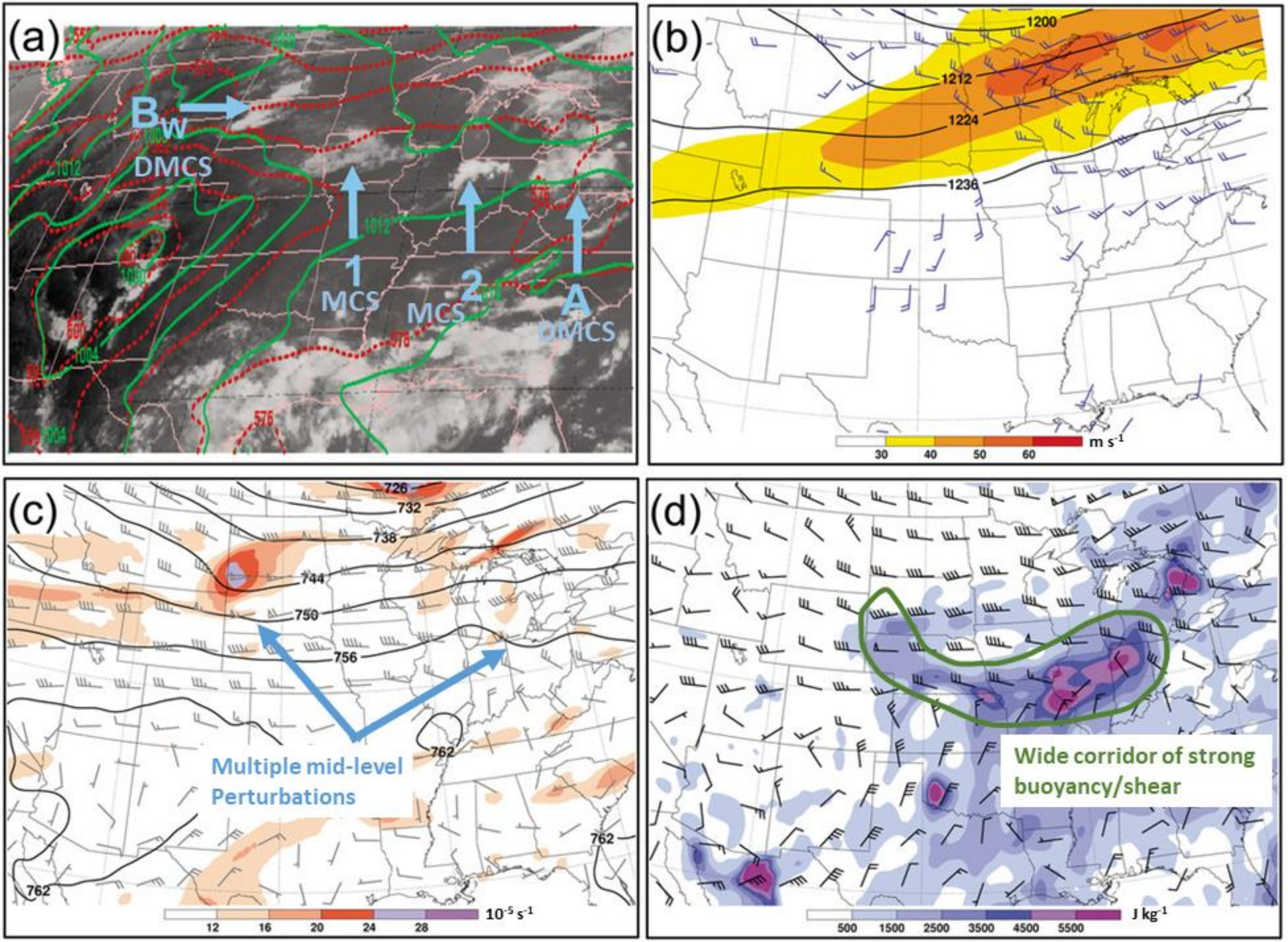
Key Points

DMCSs need an elongated corridor of overlapping extreme instability and favorable wind shear to support a long-track derecho wind event.

DMCSs rarely occur alone! When a given DMCS develops, there is a greater then 50% chance that 1-2 more efficient damaging-wind producing MCSs (perhaps producing derechos) will follow, each separated by no more than 72 hours.

The most favorable environment for intense MCSs occurring in series is a stationary mid/upper-level ridge. In this environment, MCSs can initiate from a series of embedded mid-level impulses traversing the ridge. Also, earlier MCSs can leave behind boundaries, serving as a focus for the initiation of additional MCSs.

Forecasters in the northern Plains, Midwest, and OH Valleys should pay close attention to these environments during the summer. When one damaging MCS occurs, it will probably be followed by another!



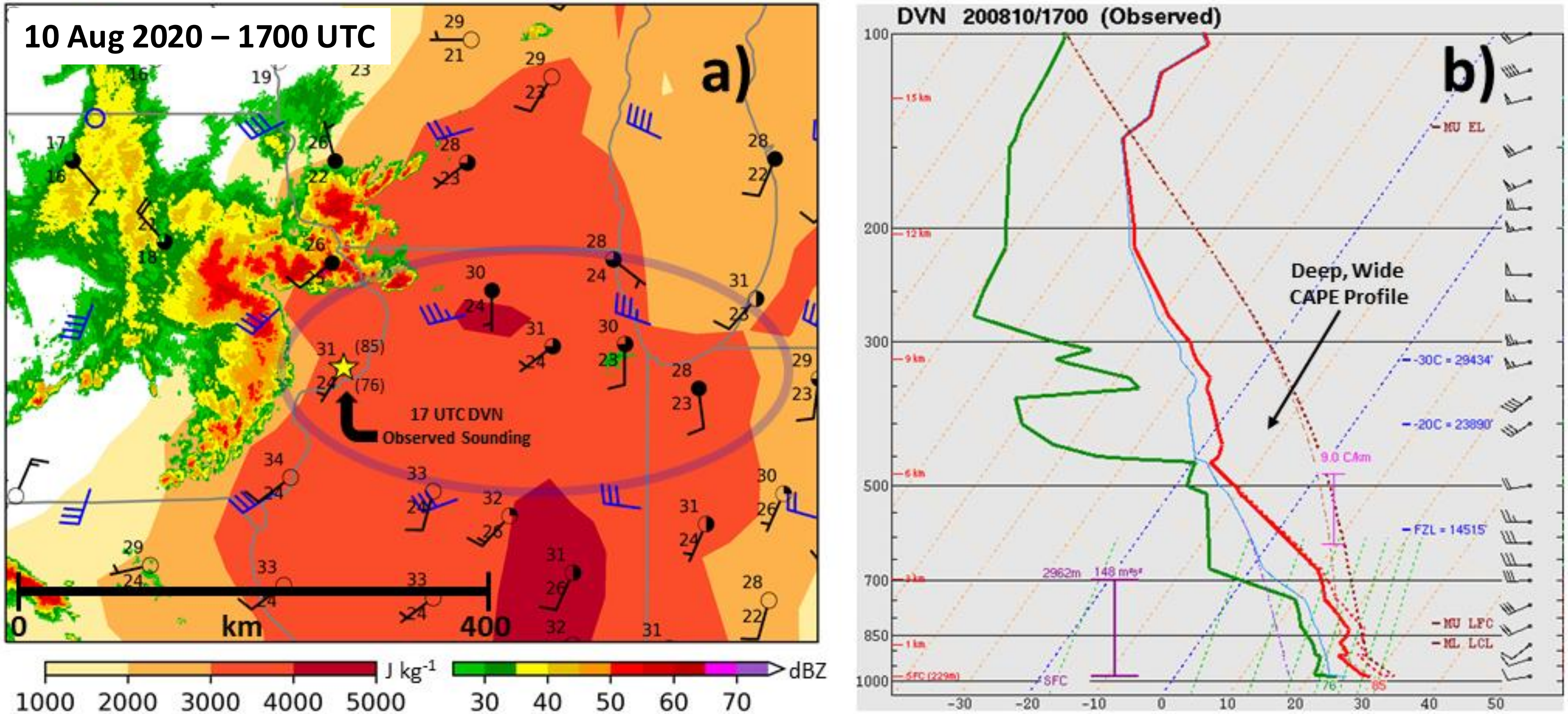
Metz and Bosart (2010)

Key Points

Derechos are notoriously difficult to forecast

Weak forcing lowers confidence in the parent MCS developing

There are several ways that a derecho forecast can fail including:
1.) Little to no convective initiation
2.) Lack of MCS organization
3.) Downstream convection contaminating the warm sector
4.) Wrong storm mode (i.e. could get more discrete supercells that do not merge their cold pools)
5.) Cold pool could undercut parent MCS too early, so a long duration wind event does not materialize.

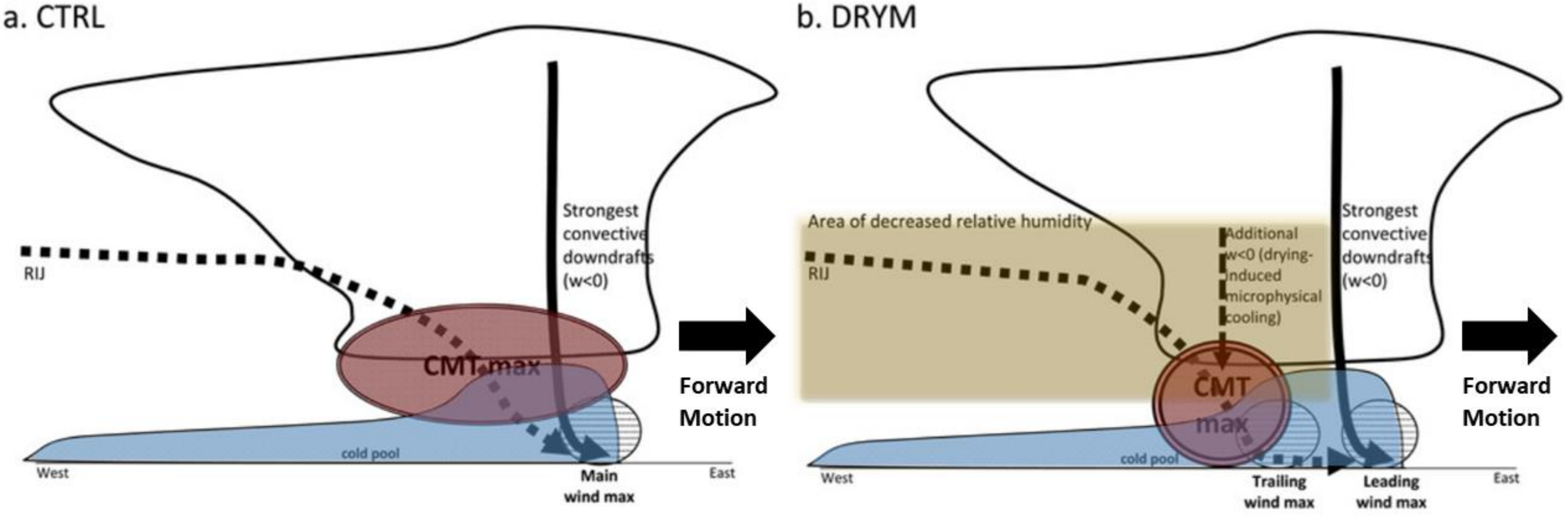


Squitieri et al. (2023b)

Derechos in weakly forced environments favor extreme buoyancy (i.e. several thousand J kg^{-1} MLCAPE).

Very strong to extreme CAPE in these environments is driven by rich low-level moisture, overspread by a deep elevated mixed layer, comprised of 700-500 mb dry air and very steep mid-level lapse rates. Previous studies suggest that anomalously steep lapse rates have often supported historic derecho events.

Deep-layer shear should be strong enough to support MCS organization.



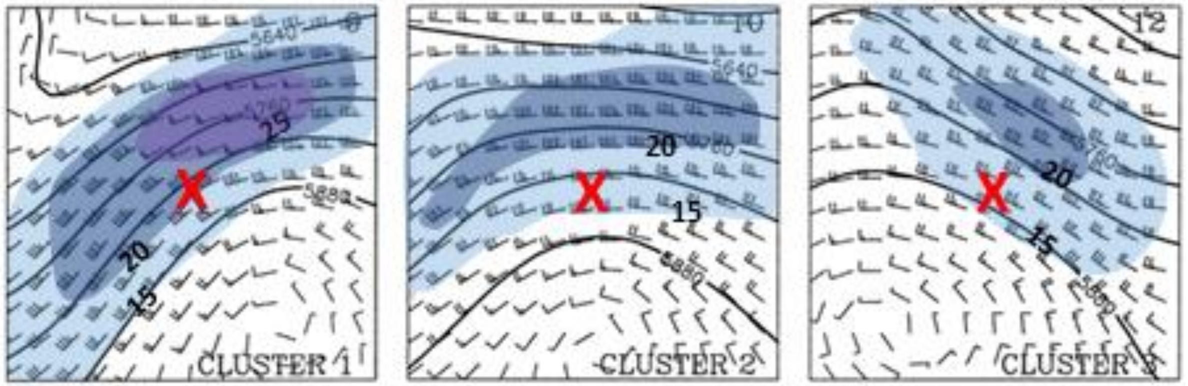
More dry air aloft supports stronger evaporative cooling

Greater evaporative cooling can support greater downward momentum transport of RIJ air over a broader area

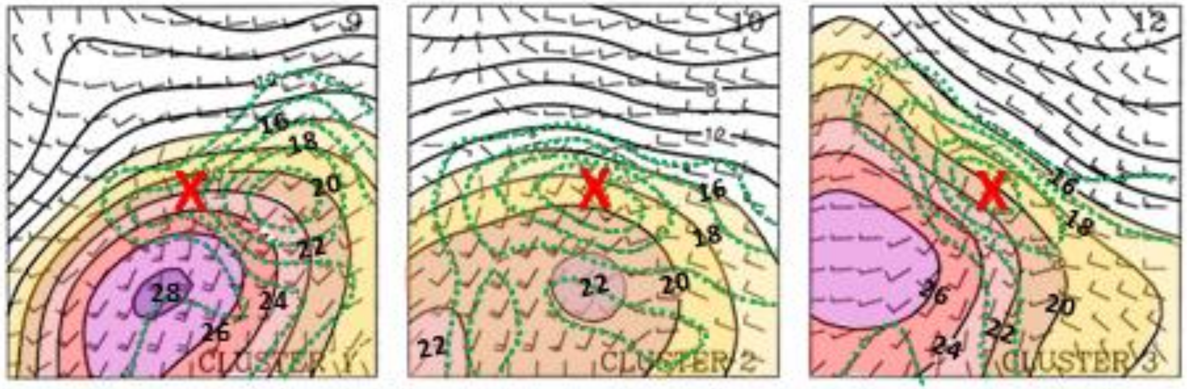
Severe winds can be more prolonged compared to ordinary squall-line/MCS cases

Mahoney and Lackmann (2011)

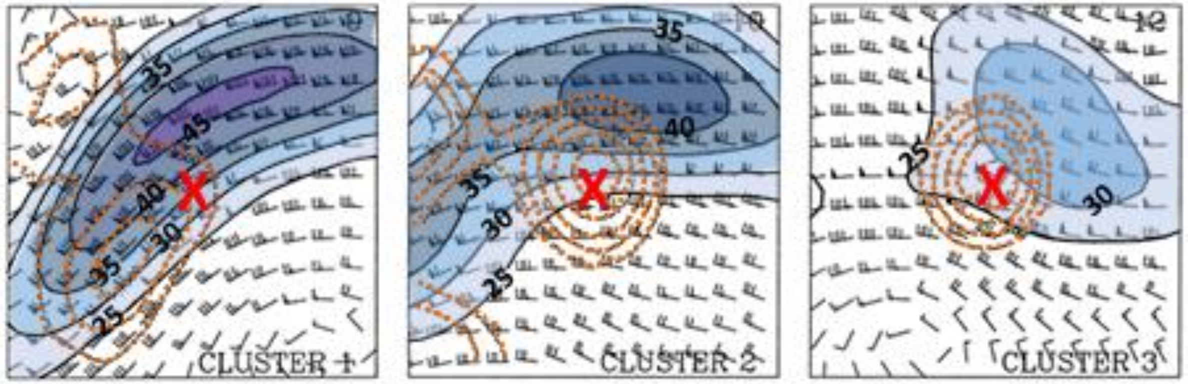
(a) 500-mb ϕ



(b) 850-mb T, q



(c) 250-mb |V|, Div (V)



Coniglio et al. (2004)

Derecho synoptic setups can vary appreciably.

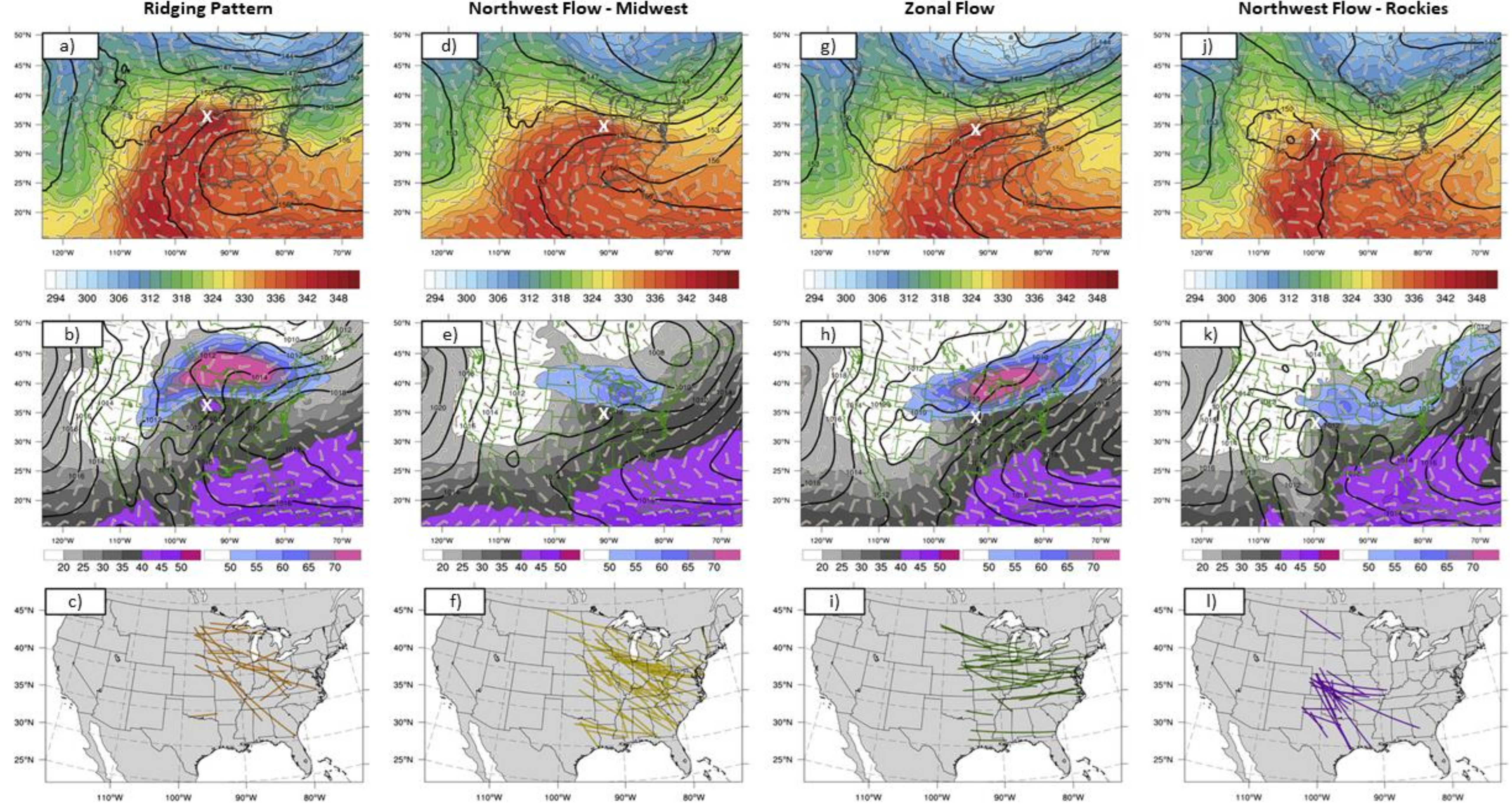
DMCSs can form along, upstream, or downstream of an upper-ridge axis and may occur along or upstream of low-level moisture advection.

Low-level warm-air advection usually originates from veered 850-700 mb flow.

Regardless of upper-level jet orientation, DMCSs almost always initiate to the south of the upper-jet maxima (closer to the right-front quadrant, where upper-level divergence is strongest).

As shown on next slide (first 3 columns) these environments support most derechos in the Upper MS Valley to the OH Valley.

The northwesterly mid-level flow setup over the Rockies is most conducive for supporting the Southern Plains derechos.



Guastini and Bosart (2016)

- Recommended Reading

  - Squitieri, B. J., A. R. Wade, and I. L. Jirak, 2023a: A historical overview on the science of derechos. Part I: Identification, climatology, and societal impacts. *Bull. Amer. Meteor. Soc.,* **104**, E1709–E1733, https://doi.org/10.1175/BAMS-D-22-0217.1
  - Squitieri, B. J., A. R. Wade, and I. L. Jirak, 2023b: A historical overview on the science of derechos. Part II: Parent storm structure, environmental conditions, and history of numerical forecasts. *Bull. Amer. Meteor. Soc.*, **104**, E1734-E1763, https://doi.org/10.1175/BAMS-D-22-0278.1
  - Squitieri, B. J., A. R. Wade, and I. L. Jirak, 2025a: On a modified definition of a derecho. Part I: Construction of the definition and quantitative criteria for identifying future derechos over the contiguous U.S. *Bull. Amer. Meteor. Soc.*, X, X-X, https://doi.org/10.1175/BAMS-D-24-0015.1.
  - Squitieri, B. J., A. R. Wade, and I. L. Jirak, 2025b:On a modified definition of a derecho. Part II: An updated spatial climatology of derechos across the contiguous United States. *Bull. Amer. Meteor. Soc.*, X, X-X, https://doi.org/10.1175/BAMS-D-24-0140.1.
  - Corfidi, S. F., 2003: Cold pools and MCS propagation: Forecasting the motion of downwind-developing MCSs. *Wea. Forecasting*, **18**, 997–1017, https://doi.org/10.1175/1520-0434(2003)018%3C0997:CPAMPF%3E2.0.CO;2.
  - Corfidi, S. F., J. H. Merritt, and J. M. Fritsch, 1996: Predicting the movement of mesoscale convective complexes. *Wea. Forecasting*, **11**, 41–46, https://doi.org/10.1175/1520-0434(1996)011%3C0041:PTMOMC%3E2.0.CO;2.