What is RKW Theory?

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NCAR

26th Conference on Severe Local Storms
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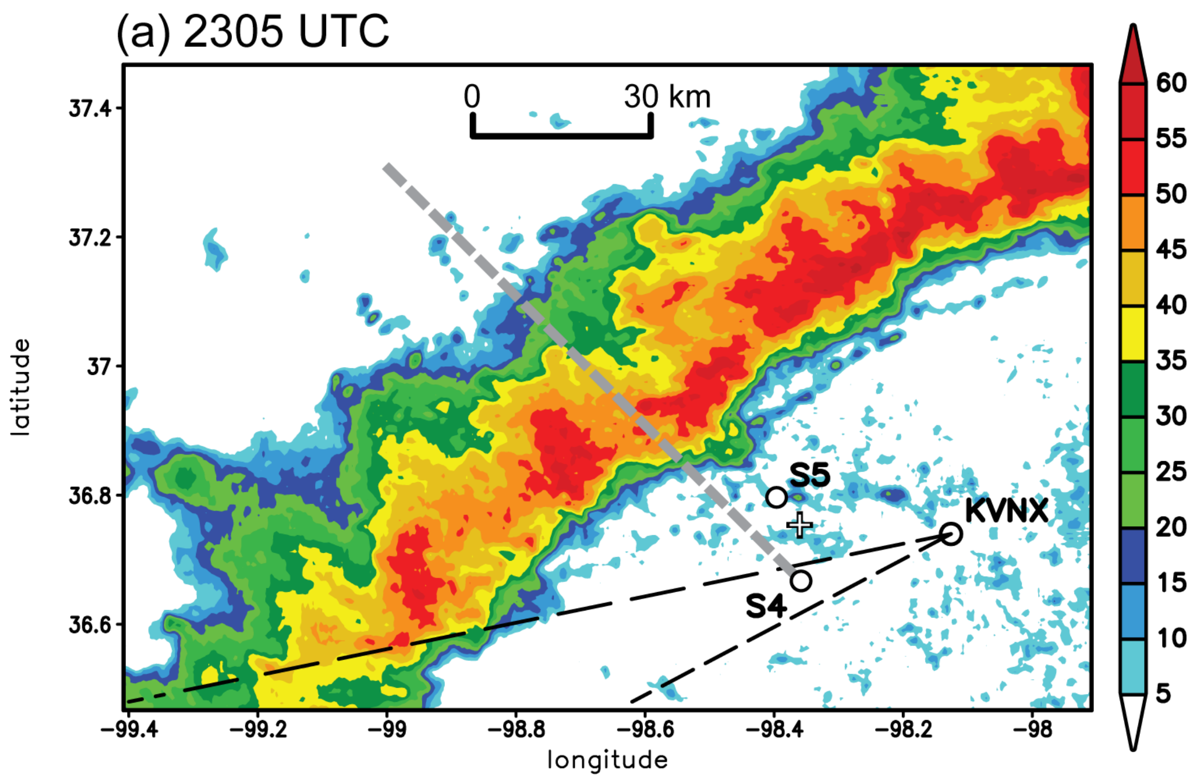
- "RKW Theory" is the nickname for the concepts presented by Rotunno, Klemp, and Weisman in the 1980s.

- It has something to do with squall lines …

WSR-88D reflectivity, lowest elevation scan:



Bryan and Parker (2010)

"Preprint" paper for this conference (available online):

4B.6 **WHAT IS RKW THEORY?**

George H. Bryan,* Richard Rotunno, and Morris L. Weisman
National Center for Atmospheric Research, Boulder, Colorado

Primary conclusion: If an extremely short description of RKW Theory is needed then it is probably best to use the phrase "A Theory for Squall Line Structure."

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"I'm Rich Rotunno and I approve this message."

"I'm Morris Weisman and I approve this message."

- Isn’t RKW Theory simply “A Theory for Strong, Long-Lived Squall Lines”?

1 FEBRUARY 1988 ROTUNNO, KLEMP AND WEISMAN 463

A Theory for Strong, Long-Lived Squall Lines

RICHARD ROTUNNO, JOSEPH B. KLEMP AND MORRIS L. WEISMAN
National Center for Atmospheric Research, Boulder, Colorado*

(Manuscript received 27 February 1987, in final form 7 September 1987)

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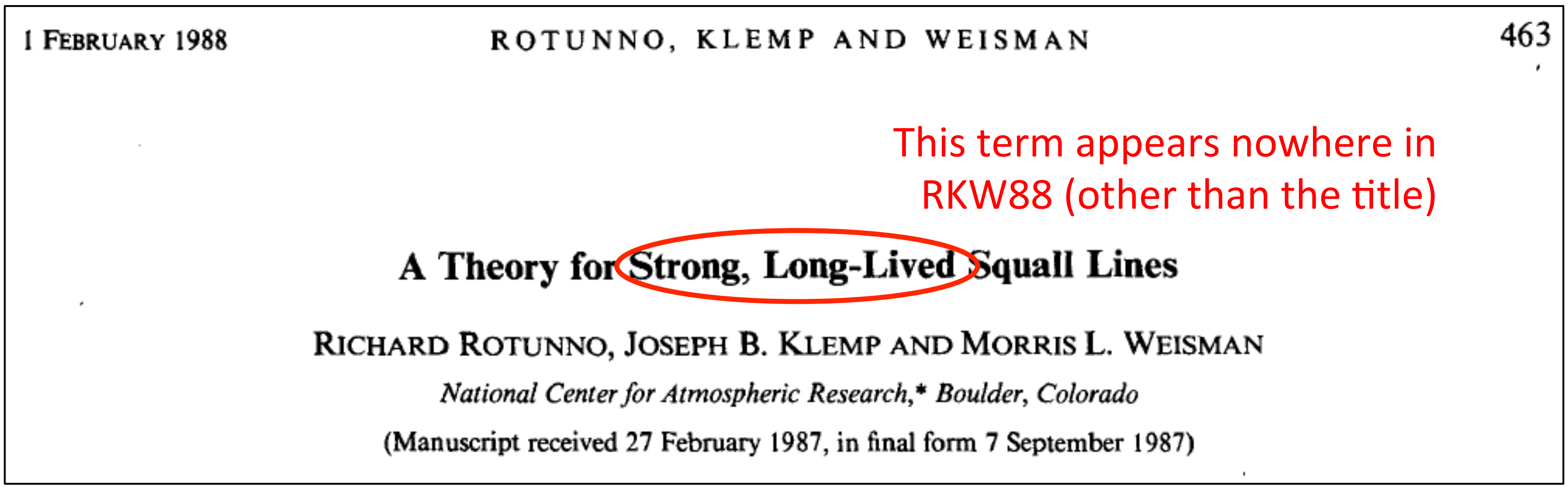
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A Theory for Strong, Long-Lived Squall Lines

RICHARD ROTUNNO, JOSEPH B. KLEMP AND MORRIS L. WEISMAN

National Center for Atmospheric Research, Boulder, Colorado*

(Manuscript received 27 February 1987, in final form 7 September 1987)

--> Seems to make people think about necessary conditions for severe squall lines

The preprint paper presented at the 3rd Conference on Mesoscale Processes (21–26 August 1987).

J1.2.1

A THEORY FOR SQUALL LINES

Richard Rotunno, Joseph B. Klemp, and Morris L. Weisman

National Center for Atmospheric Research
Boulder, Colorado

--> (in my opinion, a better title)

--> Seems to make people think about how squall lines work

More recently …

VOL. 61, NO. 4 JOURNAL OF THE ATMOSPHERIC SCIENCES 15 FEBRUARY 2004

“A Theory for Strong Long-Lived Squall Lines” Revisited

MORRIS L. WEISMAN AND RICHARD ROTUNNO

National Center for Atmospheric Research, Boulder, Colorado*

(Manuscript received 29 April 2002, in final form 7 August 2003)

--> Contains some notable revisions to RKW Theory …

--> … but concludes that “the basic interpretations of the RKW theory are reconfirmed”

--> My talk focuses on “the basic interpretations” of RKW Theory

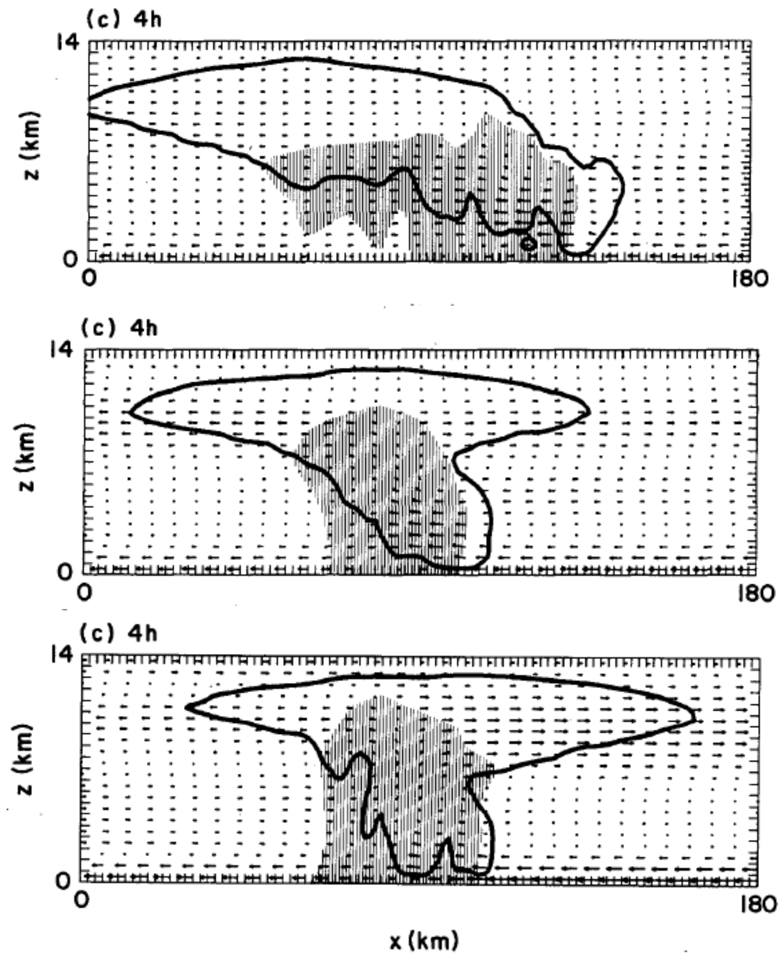
Background

- A large number of 3d simulations were conducted in the mid-1980s.
  - Weisman and Klemp (1986); Weisman, Klemp, and Rotunno (1988)
- Conclusion: a broad range of convective structures could be produced in numerical models by changing *only* the environmental shear profile

Weak shear:

Moderate shear:

Strong shear:



Thick contour: cloud boundary

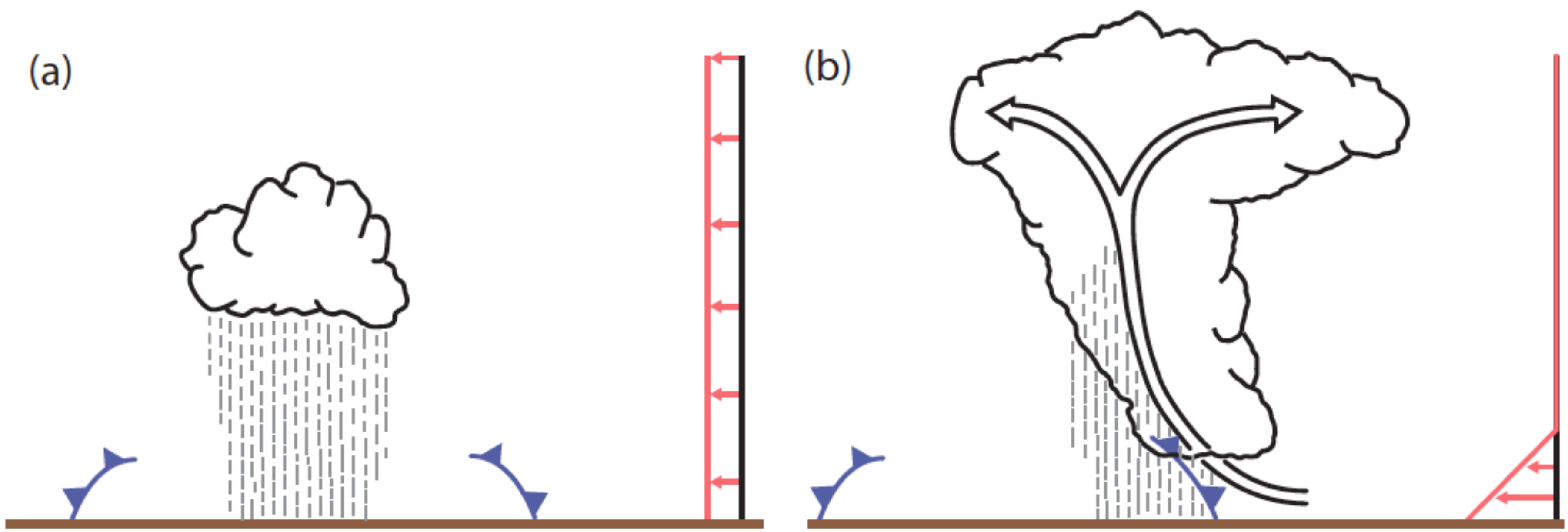
Gray shading: rain

Weisman et al. (1988)

Thorpe, Miller, and Moncrieff (1982) viewpoint

Without shear, cold pools propagate away from clouds above:

With a difference in horizontal windspeed, there is a difference in horizontal advection, so the cold pool can remain below the cloud:

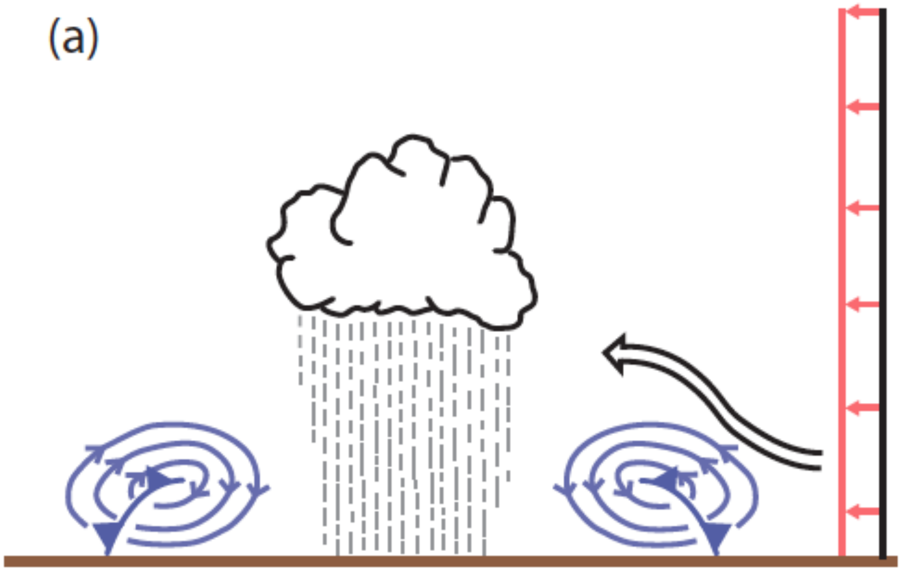


--> “low-level shear is a desirable and necessary feature” (Thorpe et al, 1982, pg 742)

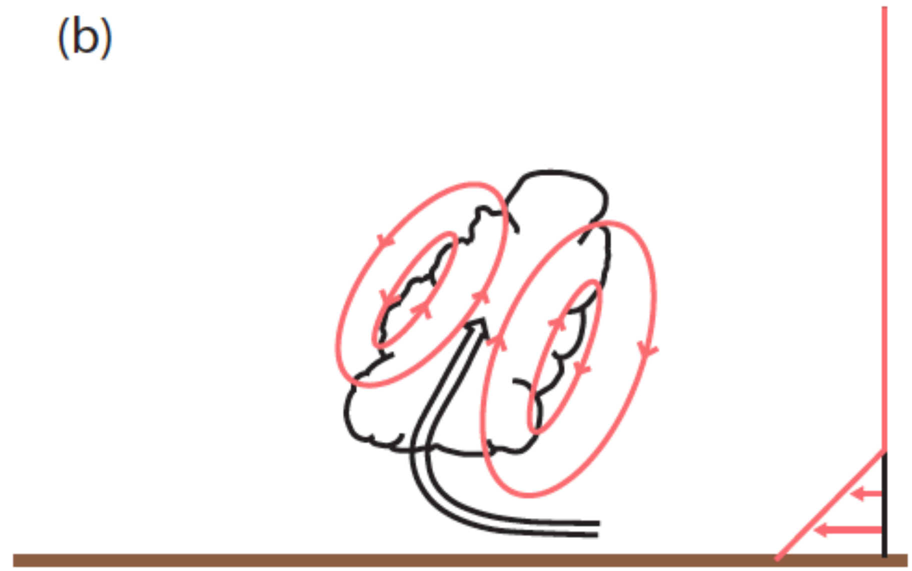
--> although these two processes do occur, this explanation is incomplete …

RKW88 viewpoint: Two Opposing Processes

Cold Pool (without shear)



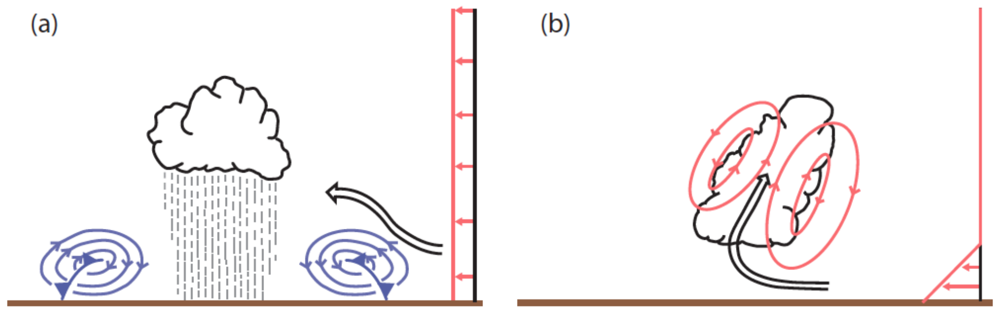
Convective Updraft (without cold pool)

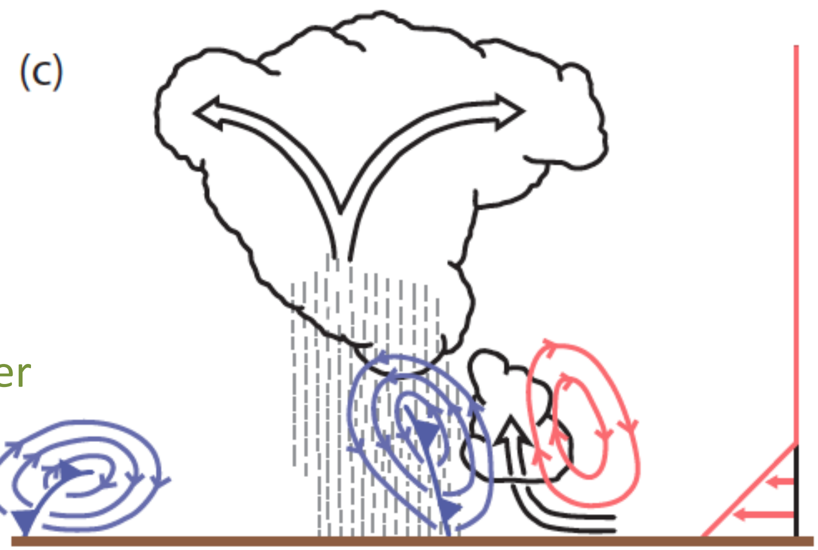


- Complete "circulation" induced by cold pool: (blue streamlines)
- Air "sweeps" over cold pool
- Upward displacements are inhibited

- Complete "circulation" induced by updraft in shear (red streamlines)
- Updrafts tilt downshear
- Not good for updrafts (e.g., Lilly 1979)

The “Fundamental Interpretation” of RKW Theory:
these two processes can <u>offset</u> on the downshear side of cold pool





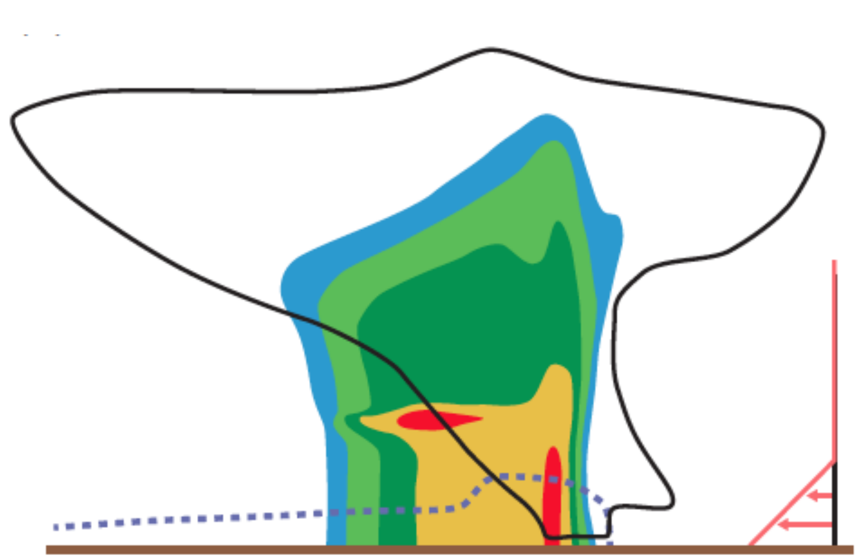
Upshear side:
two tendencies add together
--> not favorable

Downshear side:
two tendencies offset
--> favorable

Application to squall lines: Squall-line Structure

Case 1:

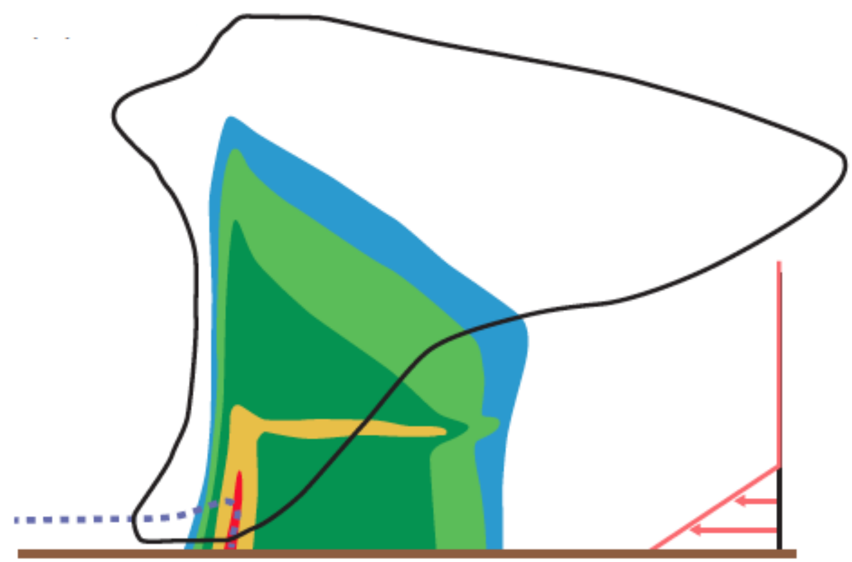
When effects of cold pool (upshear accel.)
are stronger
than effects of wind shear (downshear accel.)



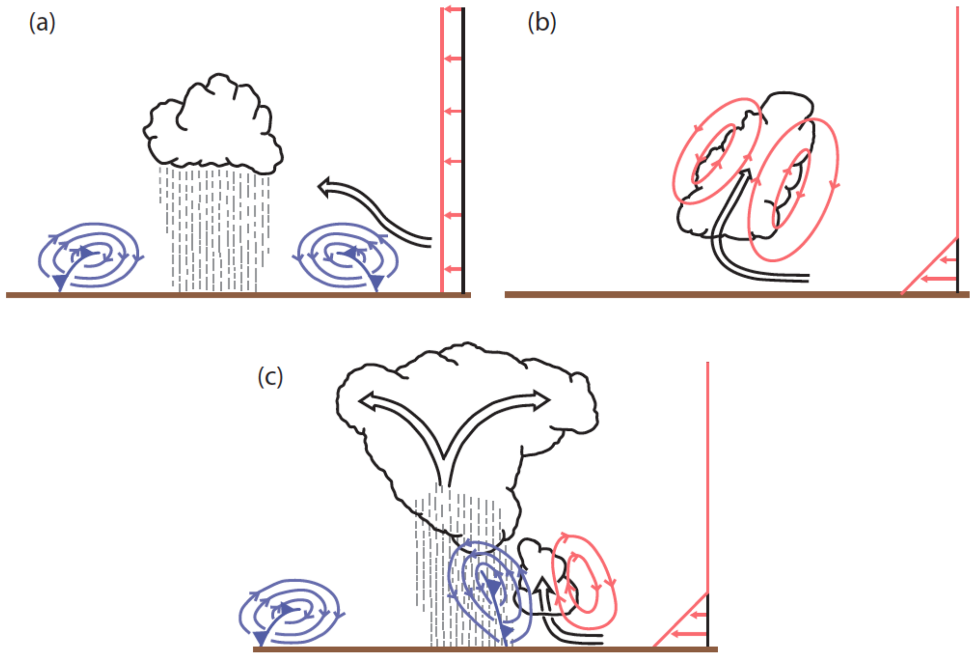
Overall effect: upshear-tilted system
--> Trailing-stratiform squall line

Case 2:

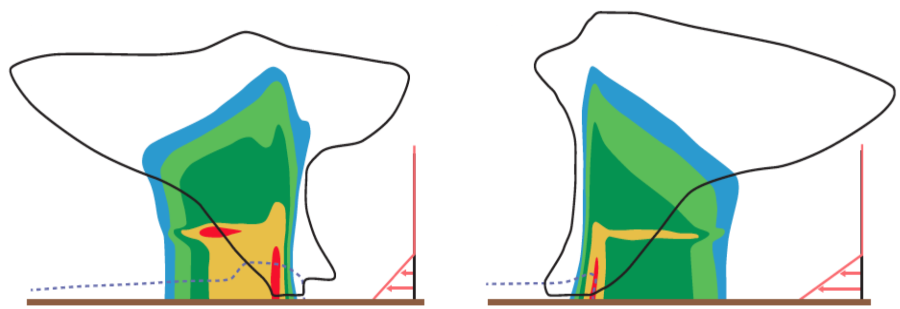
When effects of cold pool (upshear accel.)
are weaker
than effects of wind shear (downshear accel.)



Overall effect: downshear-tilted system
--> Leading-stratiform squall line



--> These concepts have stood the test of time

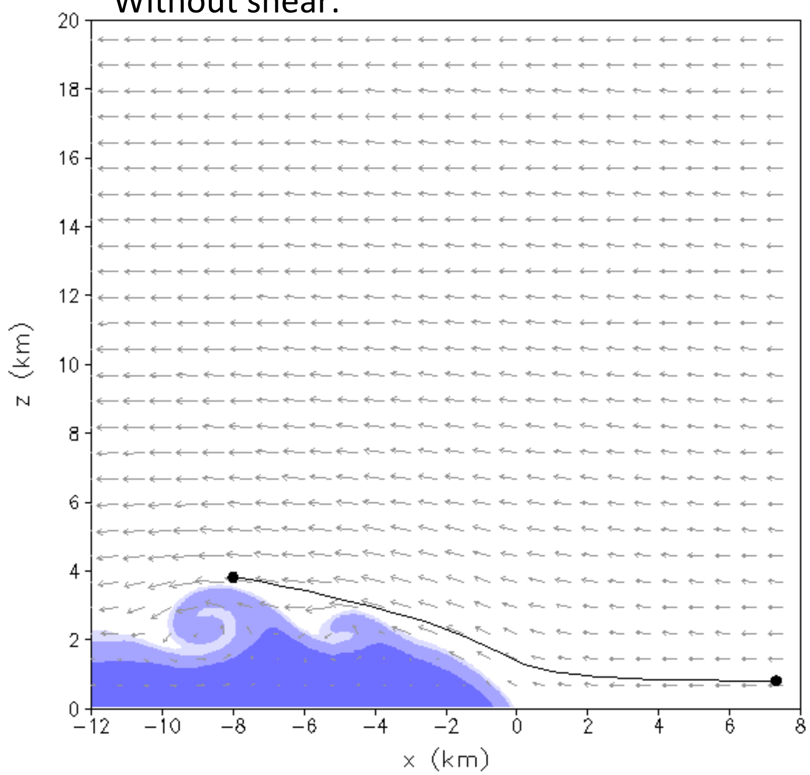


--> The application squall-line structure seems to be the <u>most robust</u> element of RKW Theory … and, hence, why I argue RKW Theory is best thought of as “A Theory for Squall Line Structure”

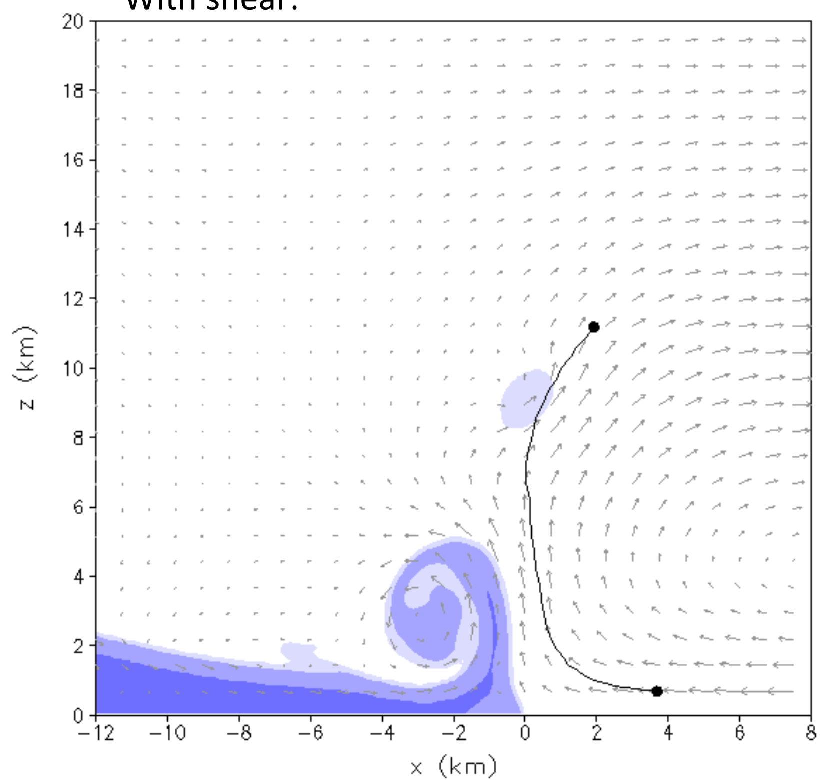
Towards the RKW "Quantitative Criterion"

- The preceding discussion summarizes the *qualitative* aspects of RKW Theory
- The concepts were supported *quantitatively* in RKW88's famous/infamous sections 4a/4b
- First … consider the problem as *only* involving cold pool in shear:

Without shear:



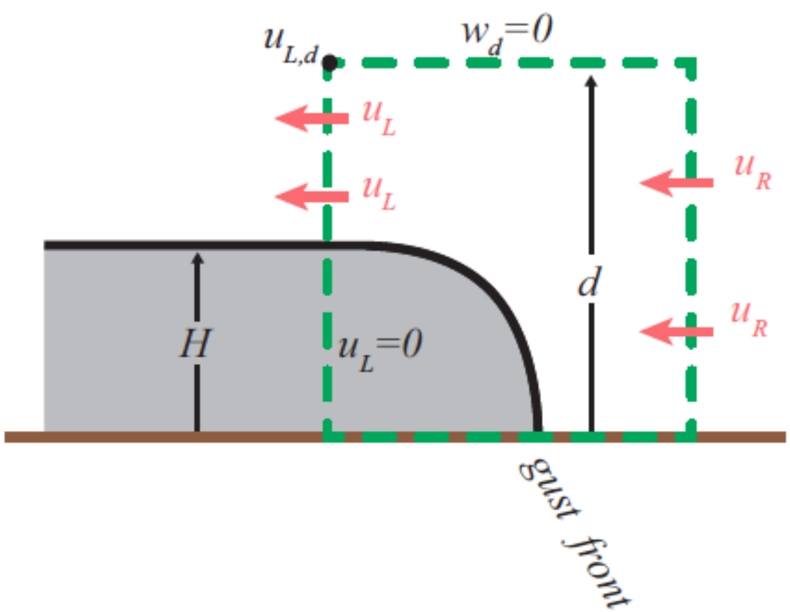
With shear:



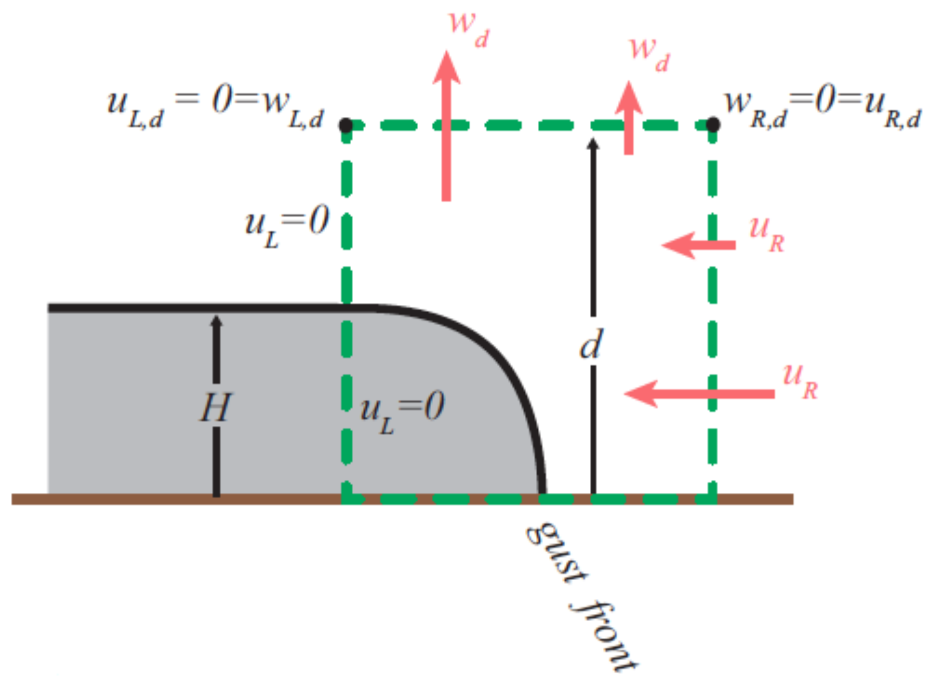
The RKW Control-Volume Analysis:

Quantifying "cold pool effects" and "shear effects"

Case 1: without shear



Case 2: with shear



A variable to quantify "cold pool intensity": $c^2 \equiv -2\int_0^H B_L \, dz$

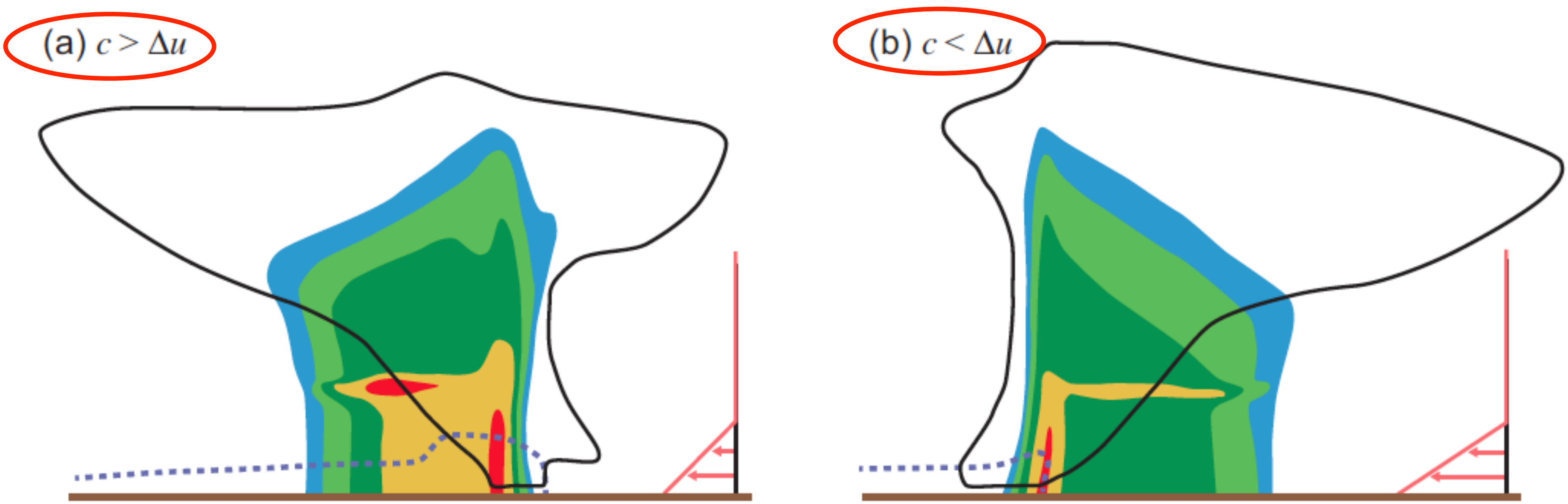
A variable to quantify "shear intensity": $\Delta u \equiv u_{R,d} - u_{R,0}$

The case on the right … a "vertically oriented jet" … can occur when $c = \Delta u$

Quantitative Criterion applied to Squall Lines

When effects of cold pool (upshear accel.) are stronger than effects of wind shear (downshear accel.)

When effects of cold pool (upshear accel.) are weaker than effects of wind shear (downshear accel.)

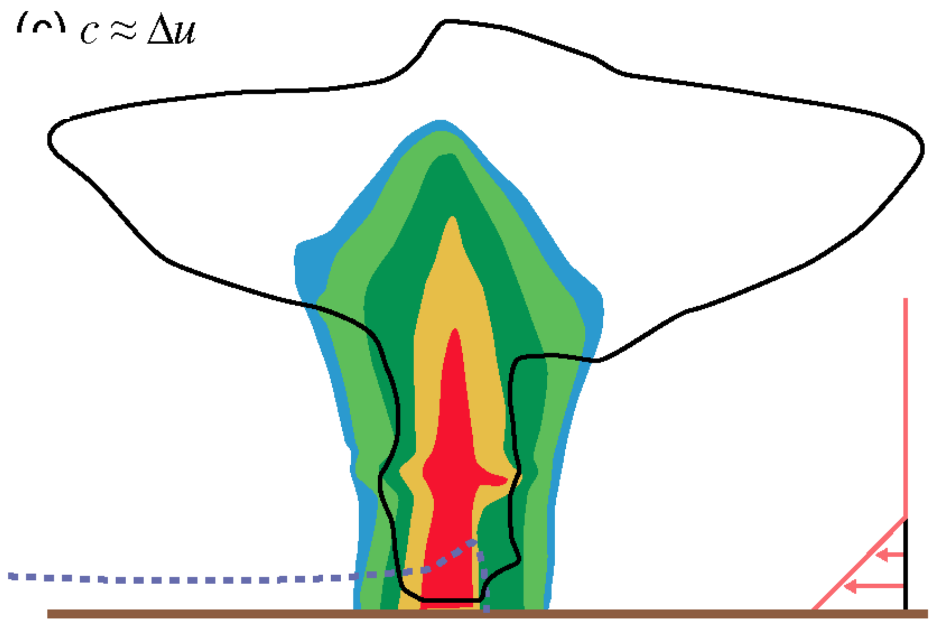


--> There are uncertainties in how, exactly, to calculate c and Δu …

--> … nevertheless, this "basic interpretation" has been supported by both model simulations *and* observations

The RKW "Optimal State"

- When cold pool intensity equals shear intensity ($c = \Delta u$)
- What RKW Theory expects: "upright" structure --> strongest updraft



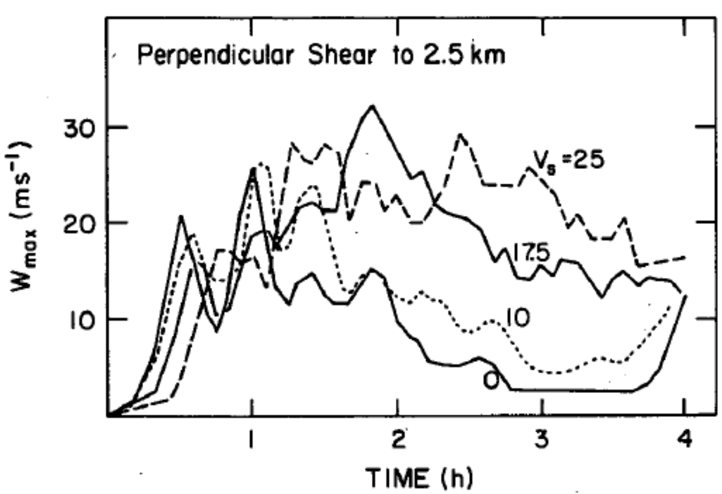
--> Should be interpreted as "most favorable" structure for strong updrafts

--> ... but *NOT* a requirement to have a squall line
--> ... and *NOT* a requirement to have a severe squall line
--> (There does seem to be some relevance to intensity; see preprint paper)

Revisions to RKW Theory
(see preprint paper for more detail)

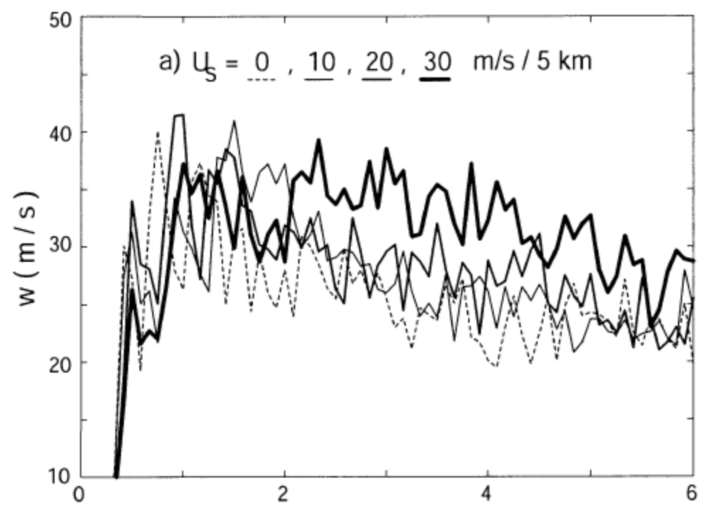
- Squall-line Longevity (Fovell et al., ‘89, ‘95, ‘98)
  - RKW88 clearly over-emphasized applicability to longevity (model domain was too small)
  - Rob Fovell’s studies deserve much credit for diagnosing how strongly tilted systems can be “long-lived”

Weisman, Klemp, Rotunno (1988)



Domain size: 180 km × 120 km × 17.5 km

Weisman, Rotunno (2004)



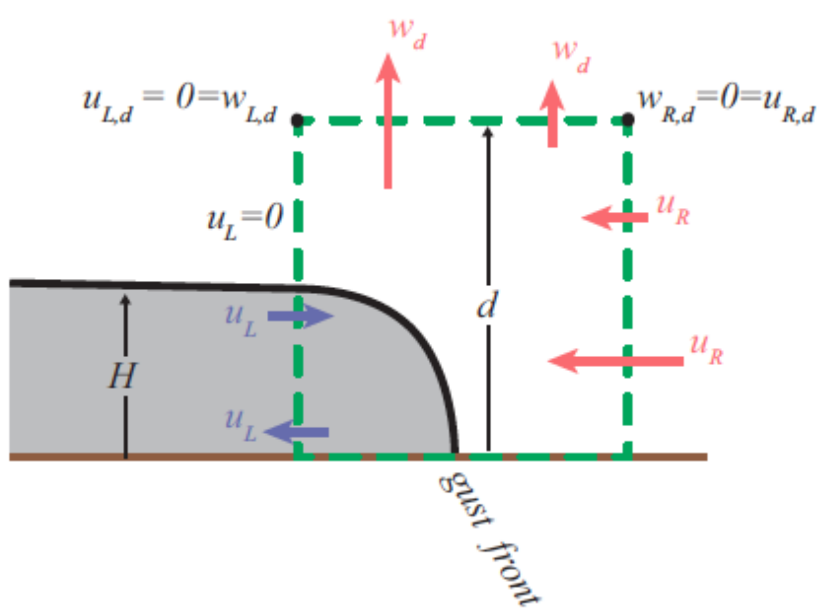
Domain size: 600 km × 160 km × 17.5 km

Revisions to RKW Theory
(see preprint paper for more detail)

- Rear-inflow Jets (Weisman 1992)
  - also known as "flow in the cold pool" (or, "circulation of the cold pool")
  - Influences squall-line structure

Note: blue arrows
(flow in the cold pool)

(a) Elevated rear-inflow jet

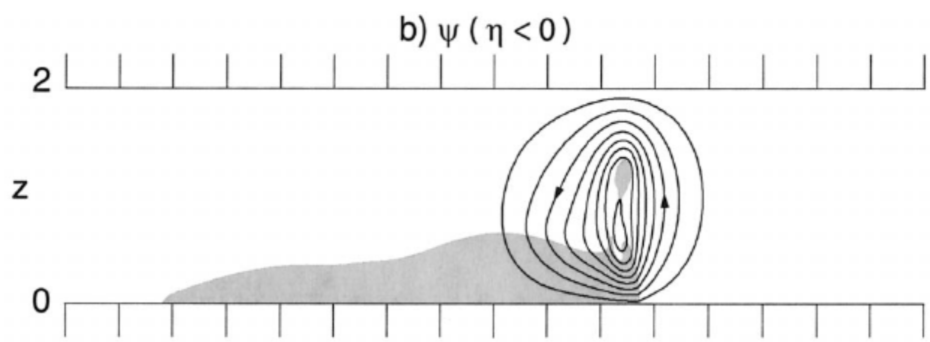


--> Can support "vertically oriented jet" with weaker environmental shear (but is often negligible)

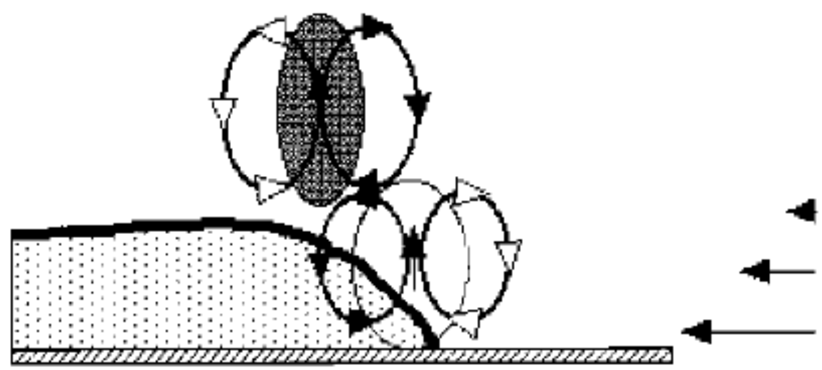
Revisions to RKW Theory
(see preprint paper for more detail)

- Mid- and Upper-Level Shear (many articles; eg, Coniglio et al 2012)
  - Cold pool affects flow beyond its confines (Weisman and Rotunno 2004)
  - Buoyancy aloft (condensation!) (Fovell and Tan 1998)

Weisman and Rotunno (2004)



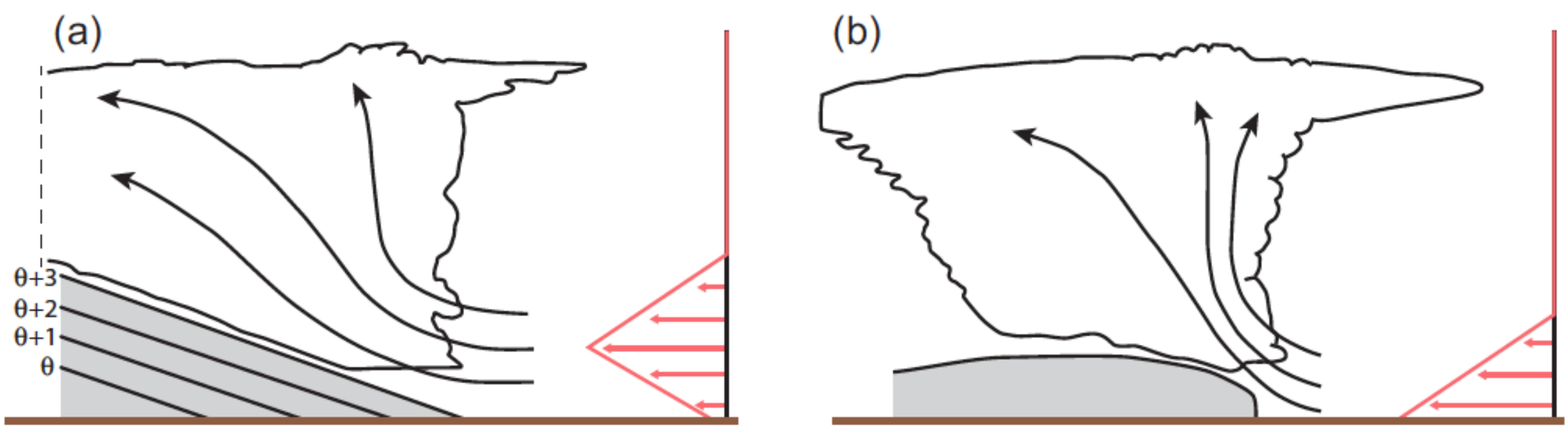
Fovell and Tan (1998)



Beyond RKW Theory

- RKW Theory doesn't explain every squall line!
  - It applies most directly to squall lines with surface-based cold pools
- Types of systems *not* explained by RKW Theory:
  - Low-level jets intersecting frontal zones (see Fritsch and Forbes 2001); see below
  - Linear bands within balanced vortices (e.g., hurricane rainbands; MCVs)
  - Strong cold fronts (narrow cold frontal rainbands), etc …

Fritsch and Forbes (2001)



- It is "A Theory…" not "The One-and-Only Theory…"

What is RKW Theory?

- A conceptual model based on two fundamental effects:
  - Cold pools (without shear) limit vertical motion
  - Shear (without cold pools) can limit vertical motion
- The "Basic Interpretation" of RKW Theory:
  - These two processes counteract each other on the downshear side of cold pools

- The most robust application of RKW Theory: Squall-Line Structure
  - Squall lines usually tilt upshear when $c / \Delta u > 1$
  - Squall lines usually tilt downshear when $c / \Delta u < 1$

- If an extremely short description of RKW Theory is needed:
  - "A Theory for Squall Line Structure"