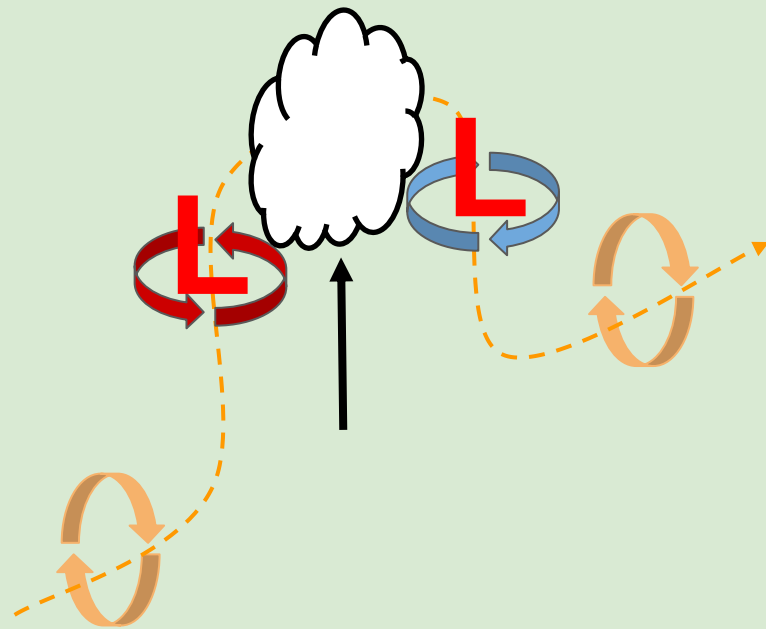


# Supercell Dynamics and Pressure Perturbations

**Harry Weinman** – Meteorologist, Storm Prediction Center  
(harry.weinman@noaa.gov)

Cameron Nixon – Research Scientist, SPC / CIWRO  
(cameron.nixon@noaa.gov)



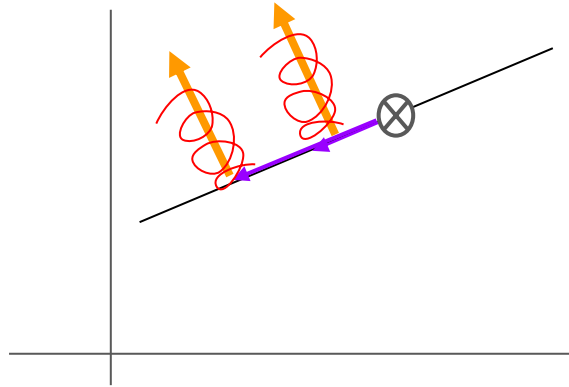
## During the next lectures, let's explain:

- 1) Origins of midlevel updraft rotation (mesocyclone)
- 1) Dynamic pressure perturbations (**non-linear and linear terms**)
  - 2a) Supercell propagation (and storm splitting)
  - 2b) Why right-movers are sometimes favored over left-movers and vice versa

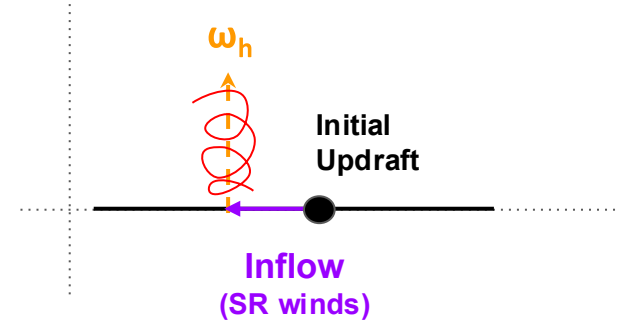
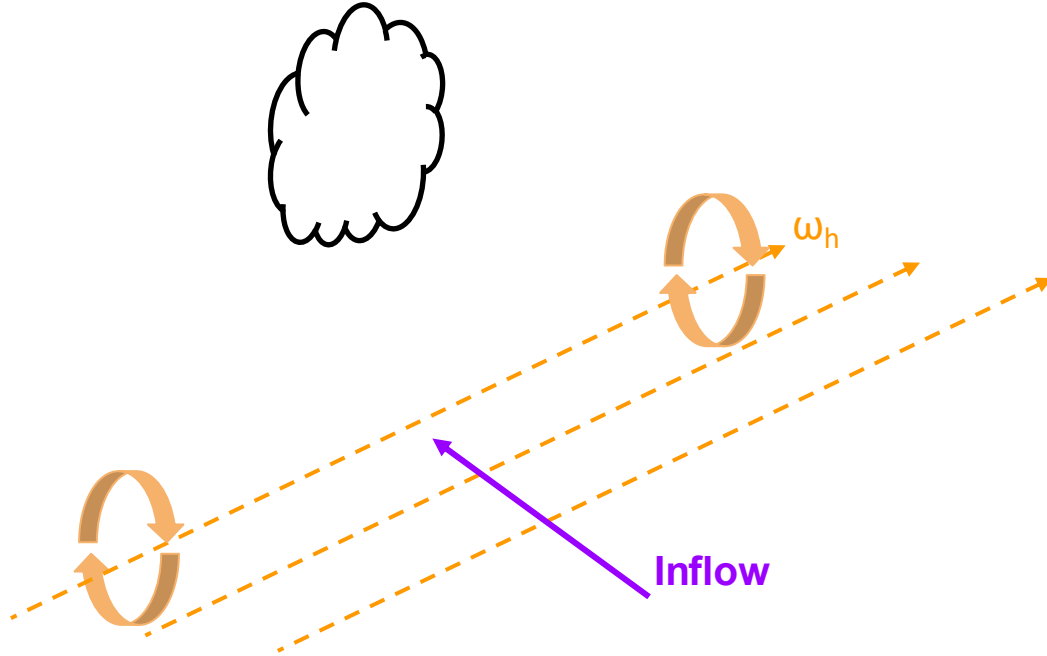
**Origins of midlevel updraft rotation**  
**(mesocyclone)**

**See text**

Start with  
**Crosswise Vorticity**

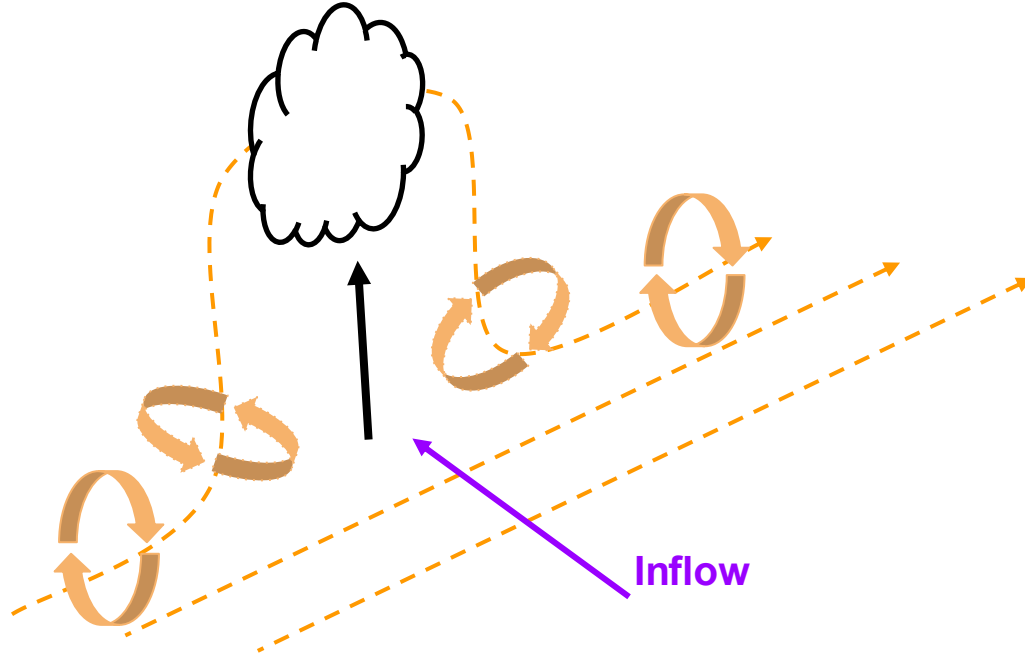


# An Updraft Emerges!



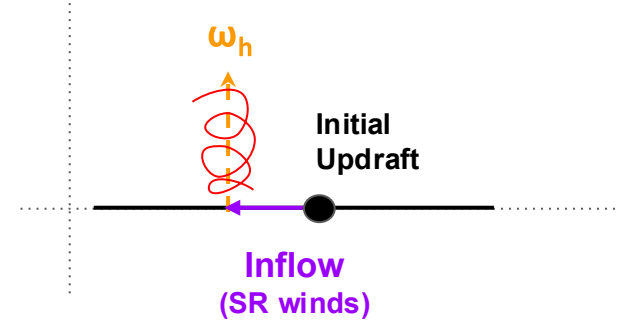
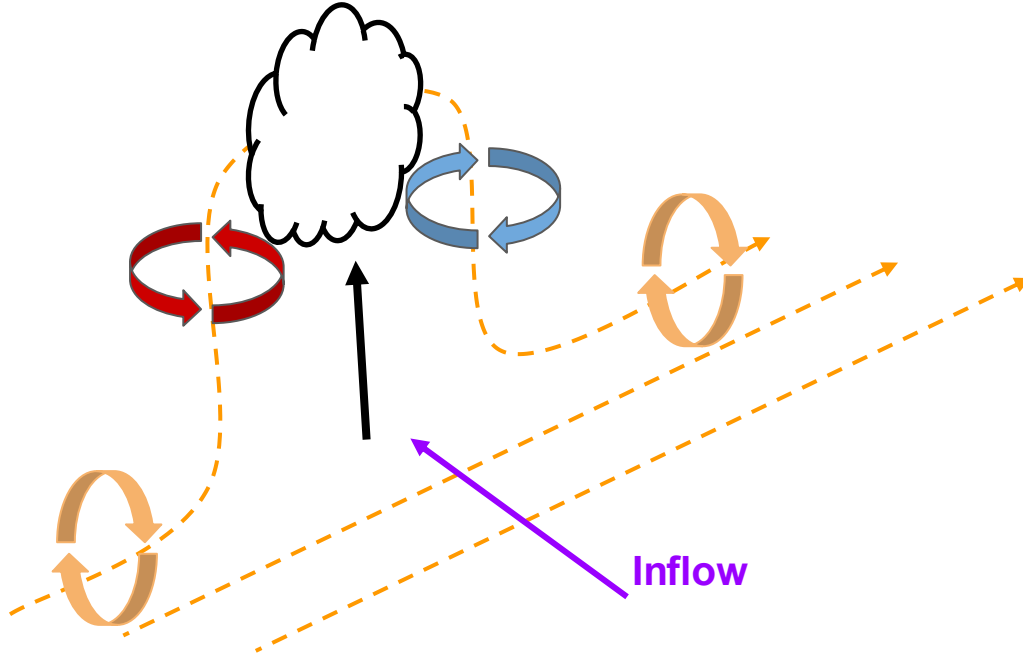
**Inflow** not aligned with **vortex tubes** (crosswise vorticity)

## Tilting of The Vortex Tubes



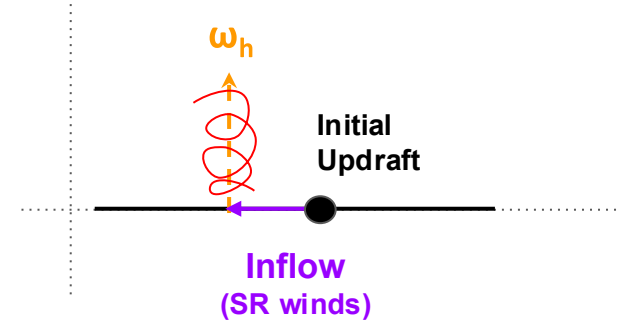
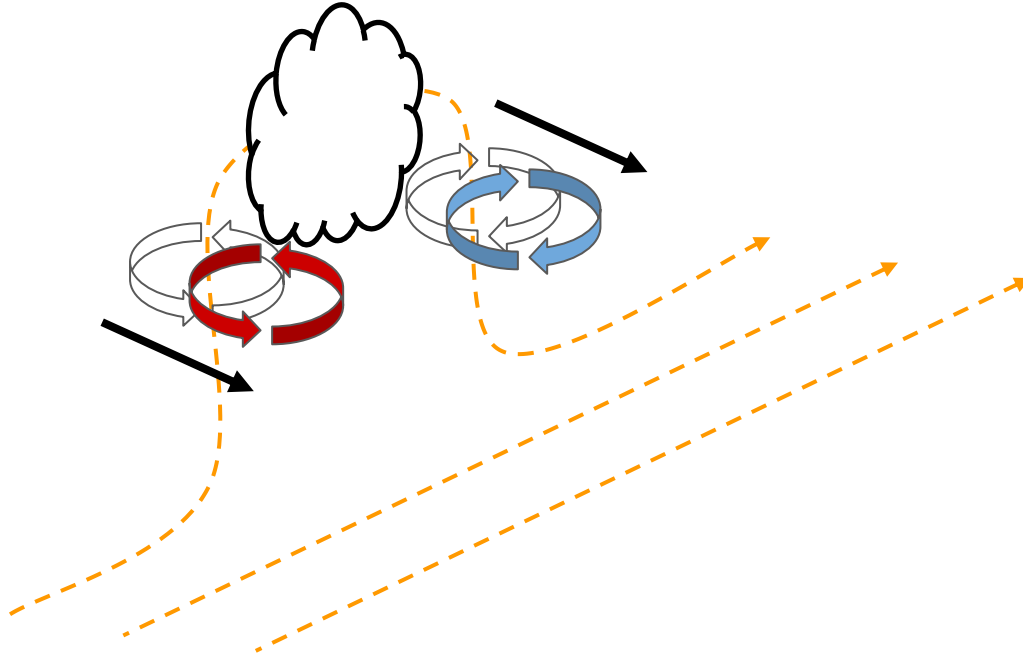
Updraft draws **crosswise** horizontal vorticity into the vertical (tilting)

# Tilting of The Vortex Tubes



Counter-rotating vorticity centers flank the updraft;  
**cyclonic** to the right, **anticyclonic** to the left!

# Tilting + Advection – Crosswise Vorticity

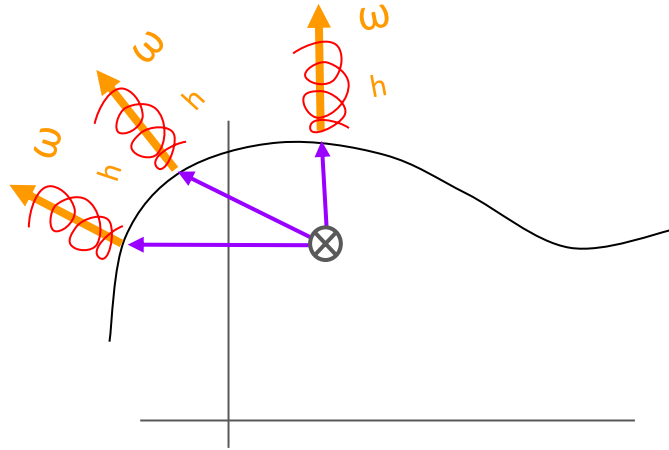


Advection slightly shifts the vertical vorticity centers **downshear**

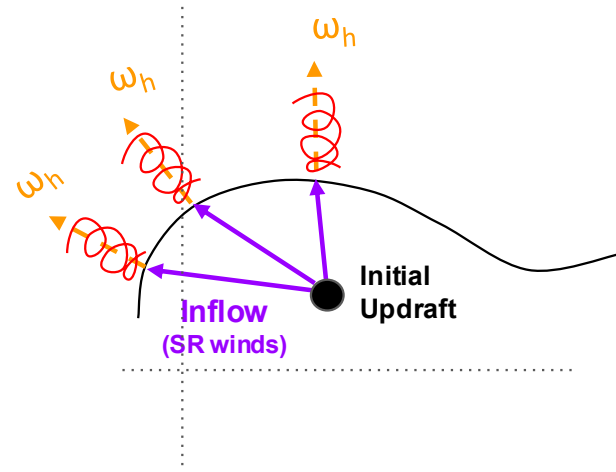
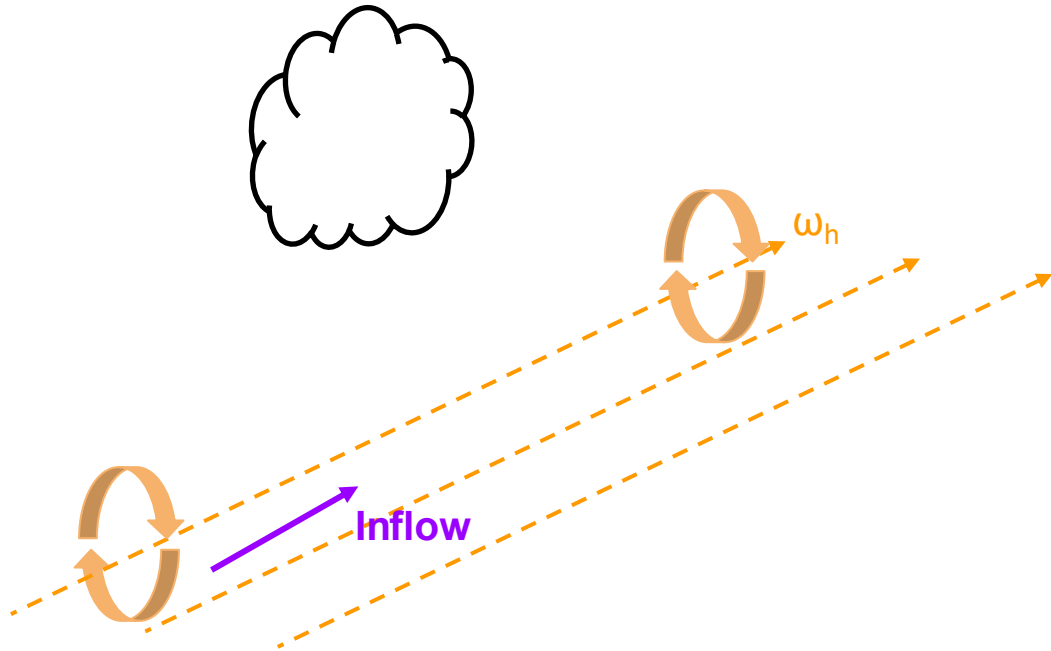
**Does not fully explain midlevel updraft rotation – initial updraft not aligned with vertical vorticity!**

Now

# Streamwise Vorticity

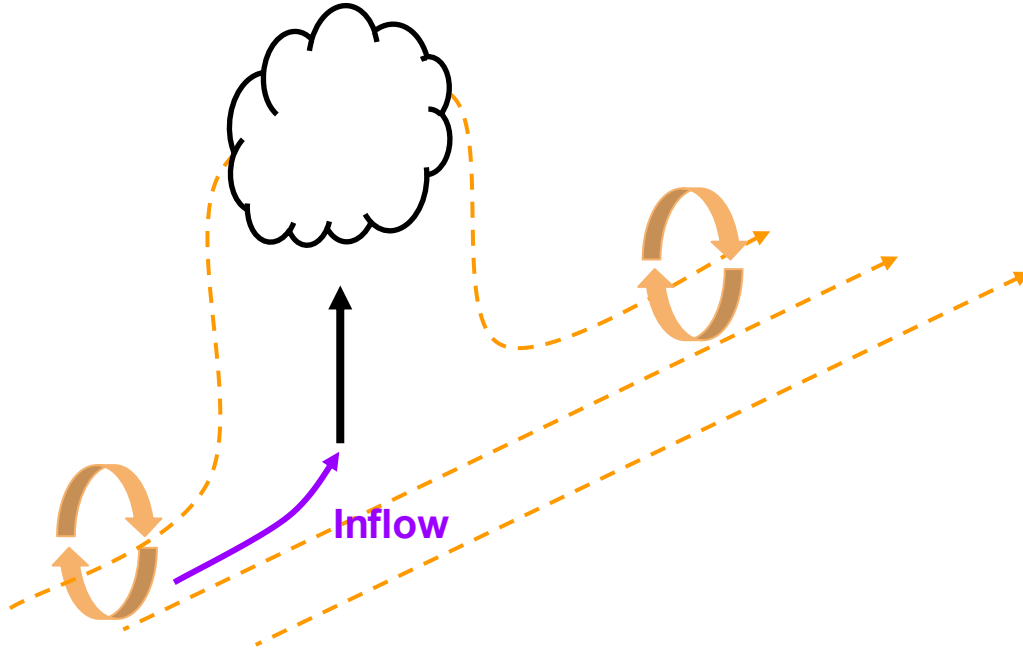


# An Updraft Emerges!



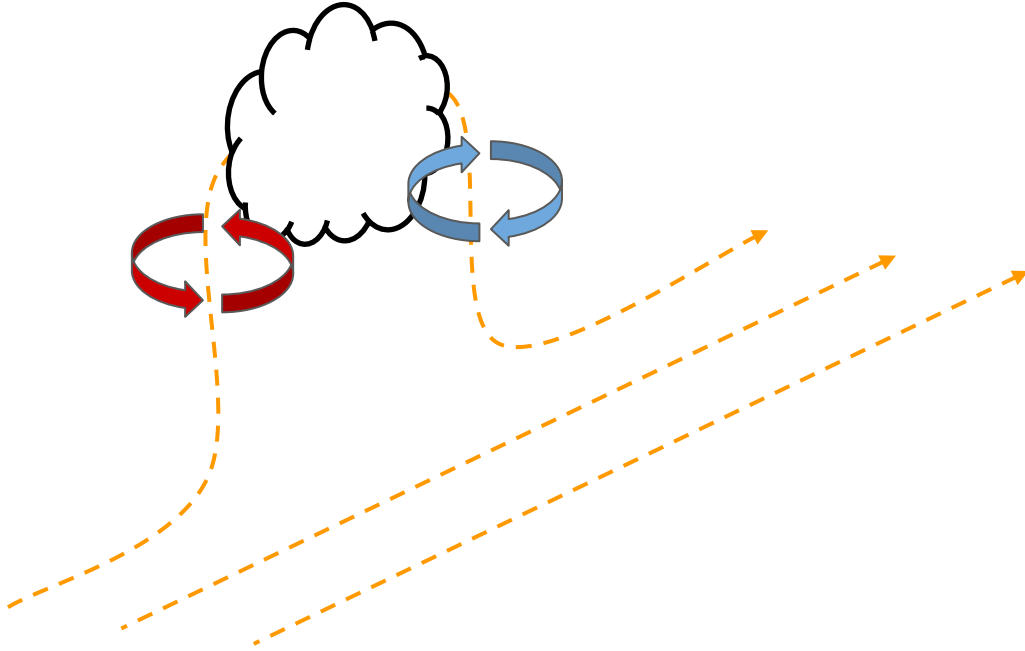
**Inflow** aligned with **vortex tubes** (streamwise vorticity!)

## Tilting of The Vortex Tubes



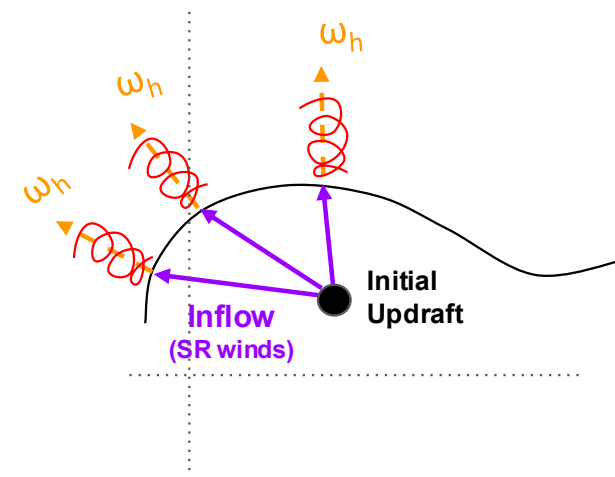
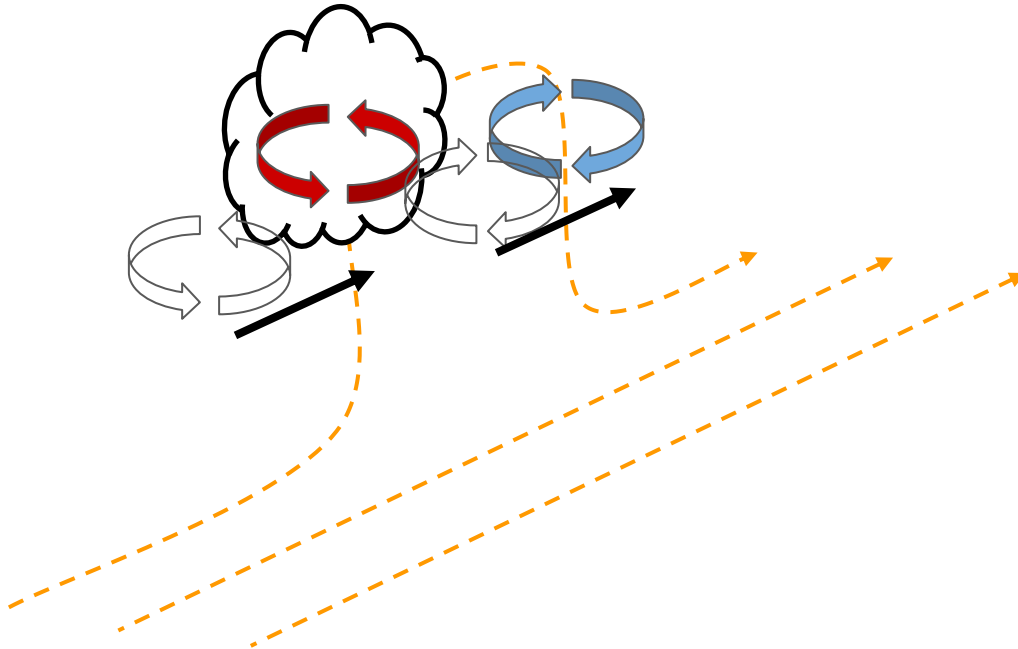
Updraft draws **streamwise** horizontal vorticity into the vertical (tilting)

## Tilting of The Vortex Tubes

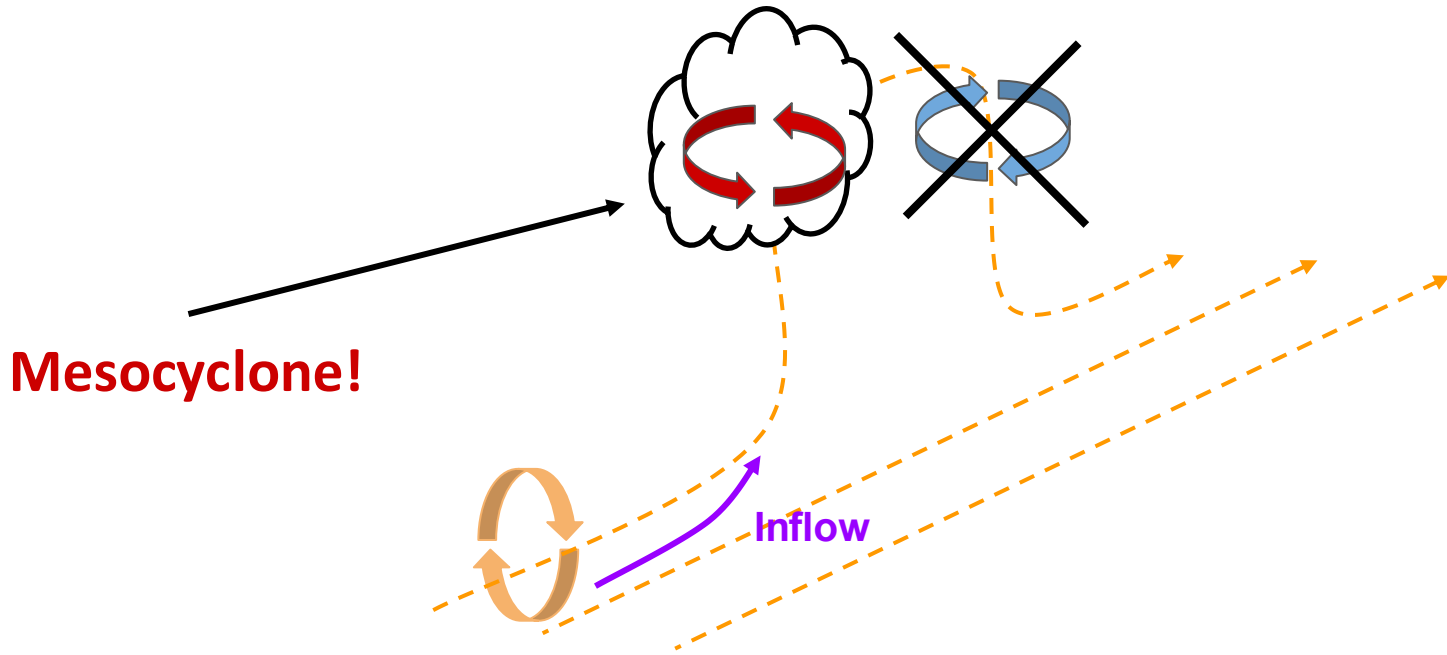


Updraft draws **streamwise** horizontal vorticity into the vertical (tilting)

# Tilting + Advection – Streamwise Vorticity



**Cyclonic** vorticity center induced in updraft!  
(**Anticyclonic** vorticity is displaced from updraft)



Tilting + Advection of streamwise vorticity → **Origin of midlevel rotation!**

# Dynamic Pressure Perturbations

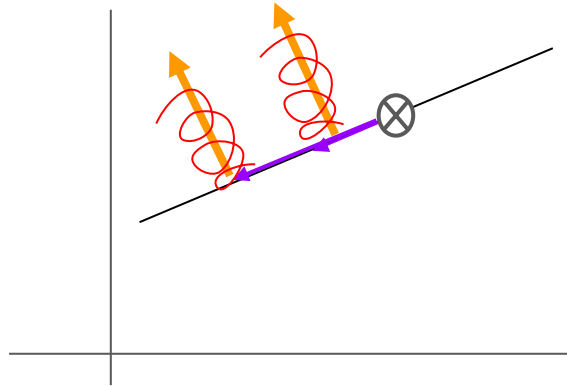
**See text**

# **1. Non-Linear Dynamics Terms**

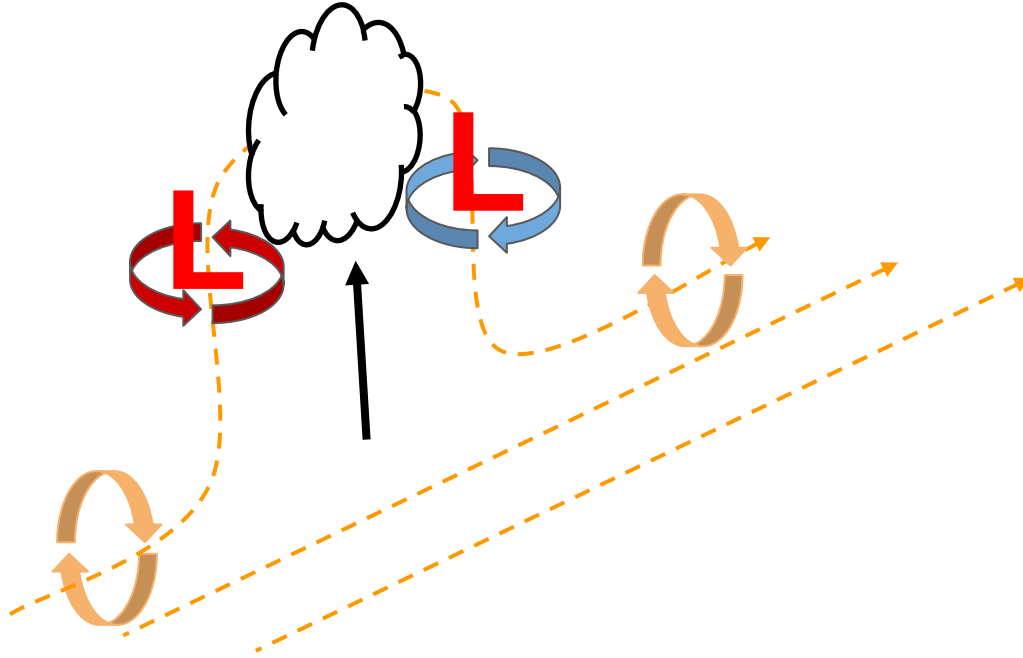
2. Linear Dynamics Term

# Non-Linear Terms

**Straight Hodograph - Crosswise Vorticity**

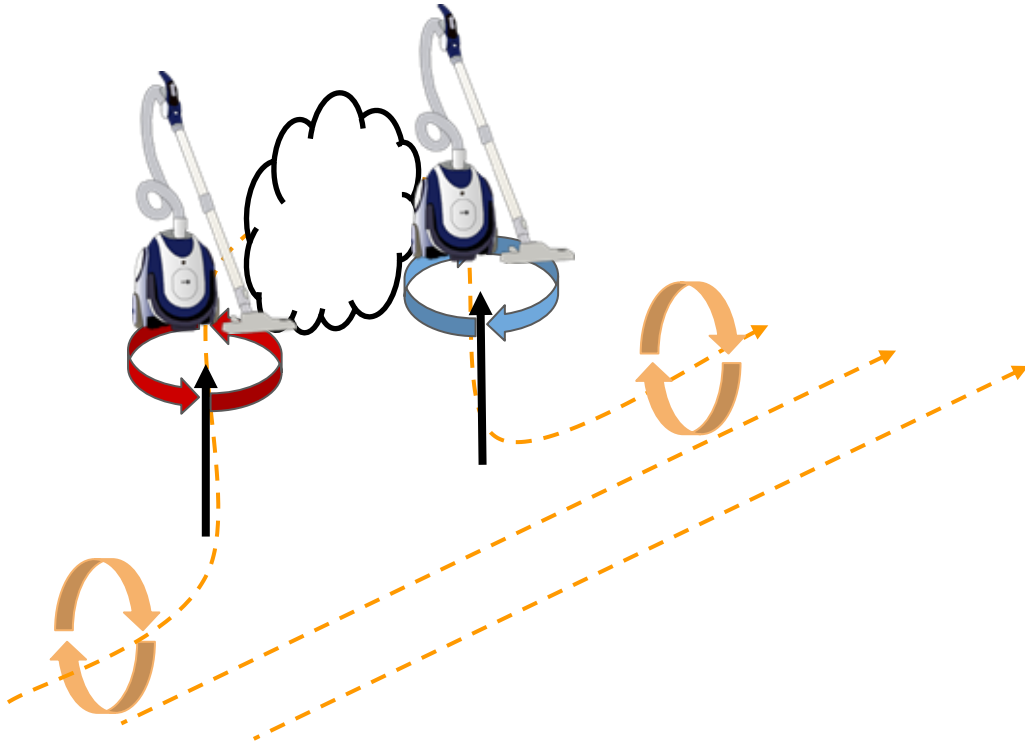


# Tilting of The Vortex Tubes



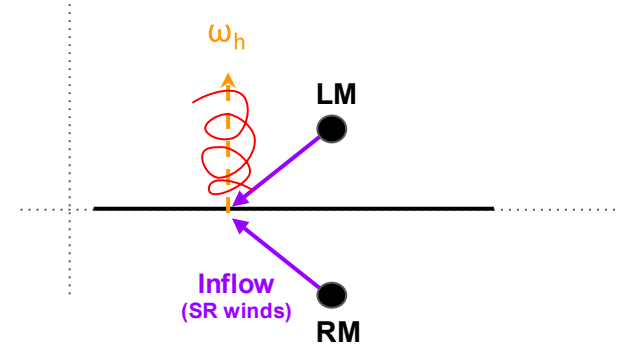
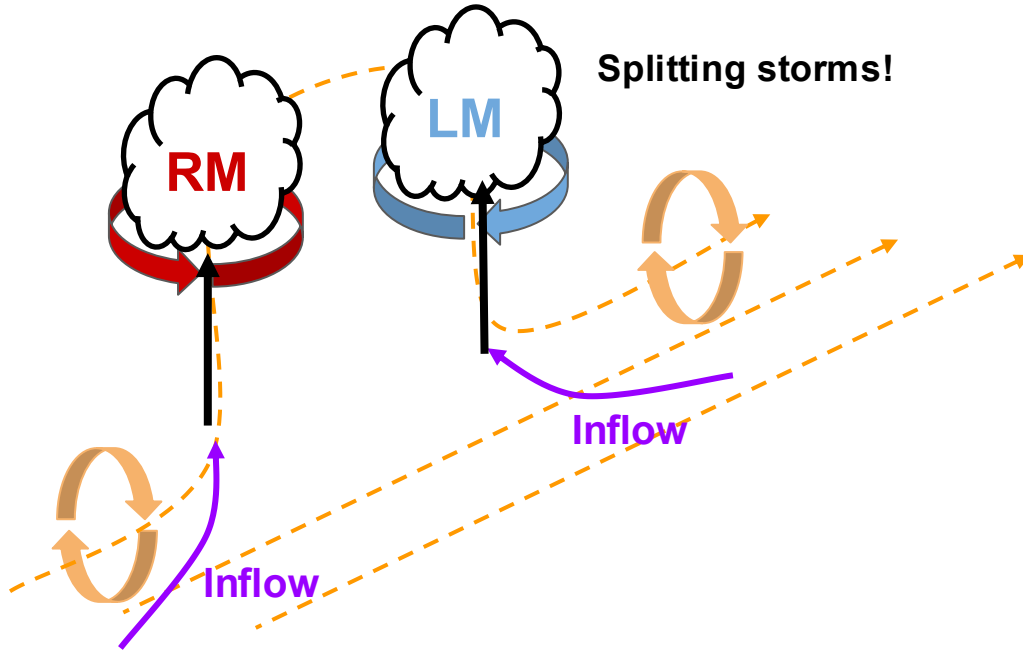
**Low** pressure perturbations are induced in vertical vorticity centers

# The Vacuum Cleaner Effect



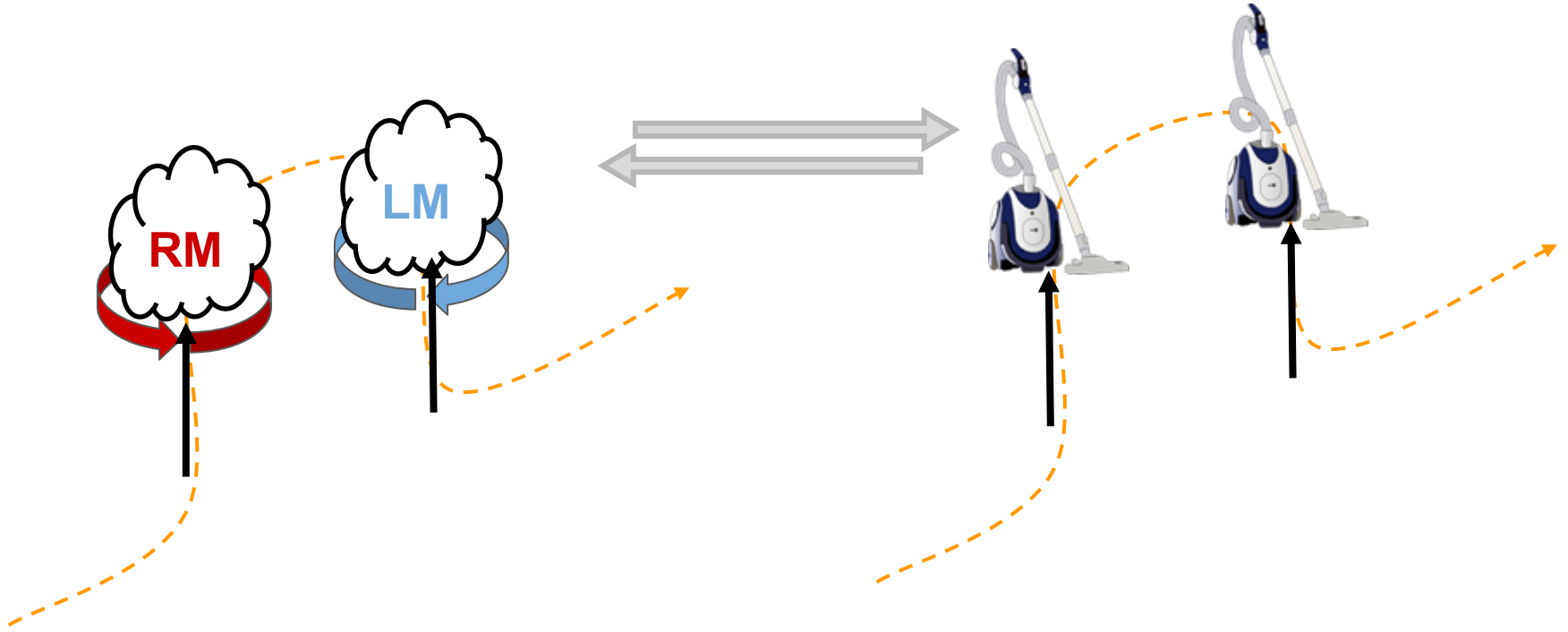
These perturbation pressure deficits aloft act like **vacuum cleaners**, drawing air upward!

# Two New ROTATING Updrafts Emerge!



Results in two new updrafts that are now correlated with vertical vorticity and **acquire rotation**

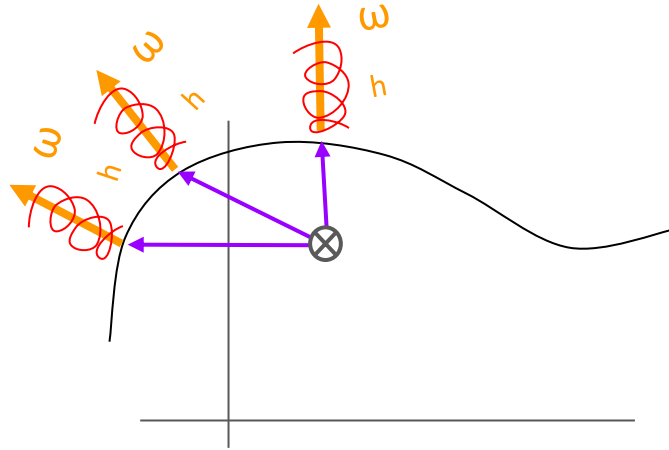
# Non-Linear Feedback Process Begins!



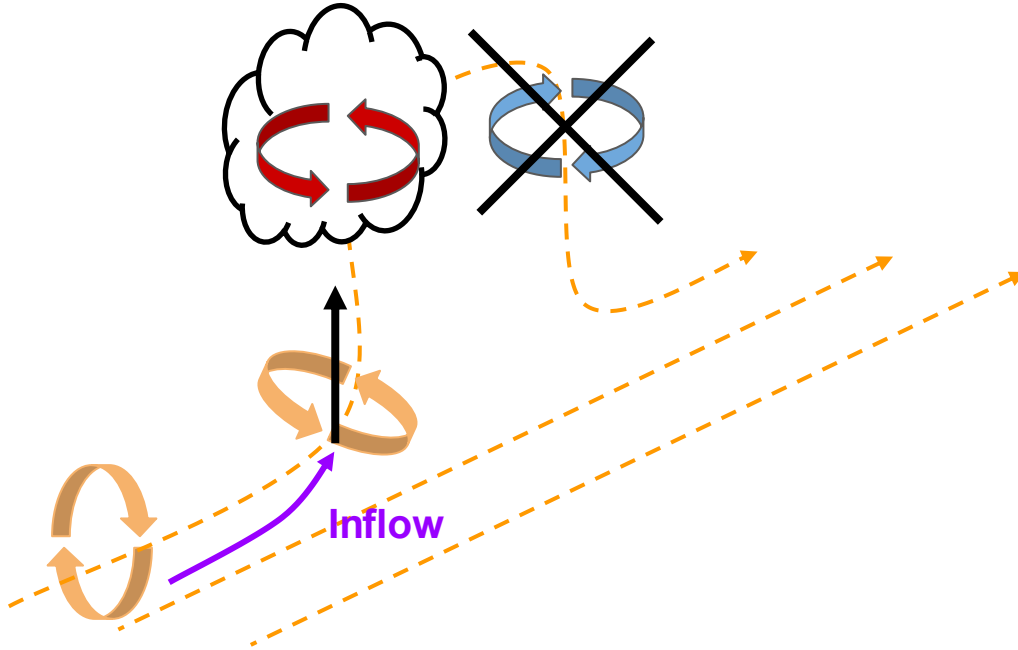
New updrafts stretch vorticity → strengthen vorticity → strengthen the updrafts → stronger stretching → stronger vacuums → stronger updrafts ... **non-linear feedback process!**

# Non-Linear Terms

## Curved Hodograph



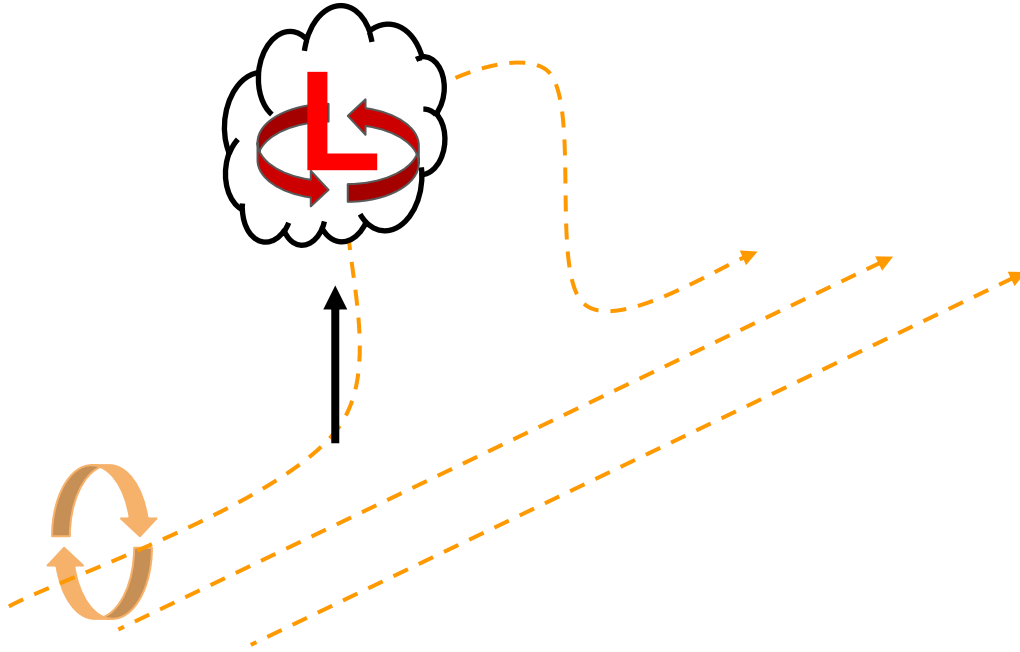
# Tilting + Advection of Streamwise Vorticity



Updraft draws **streamwise** vorticity into the vertical (tilting)

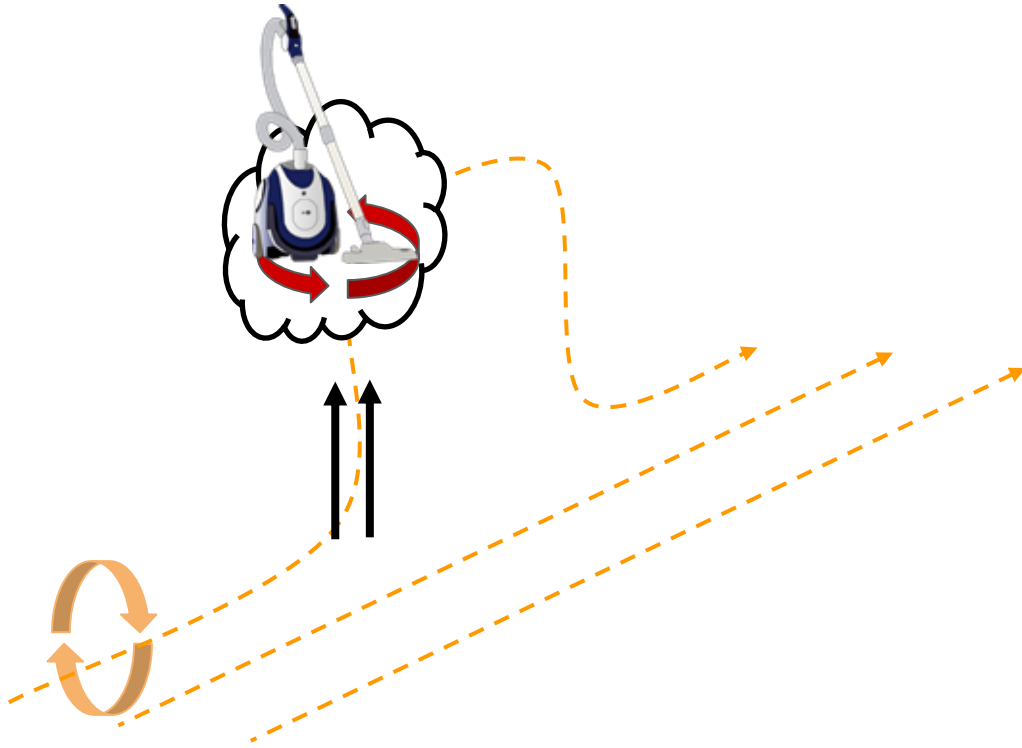
**Cyclonic** vorticity center induced in updraft!  
(**Anticyclonic** vorticity is displaced from updraft)

## Tilting of The Vortex Tubes



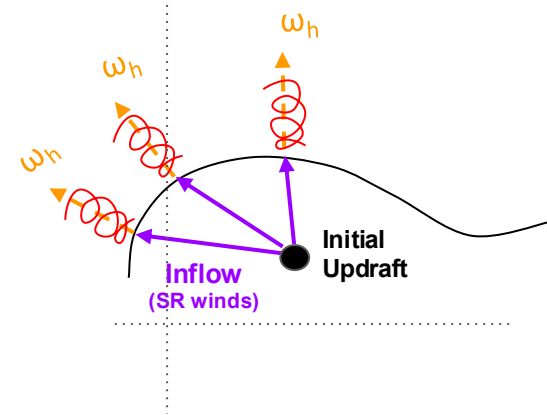
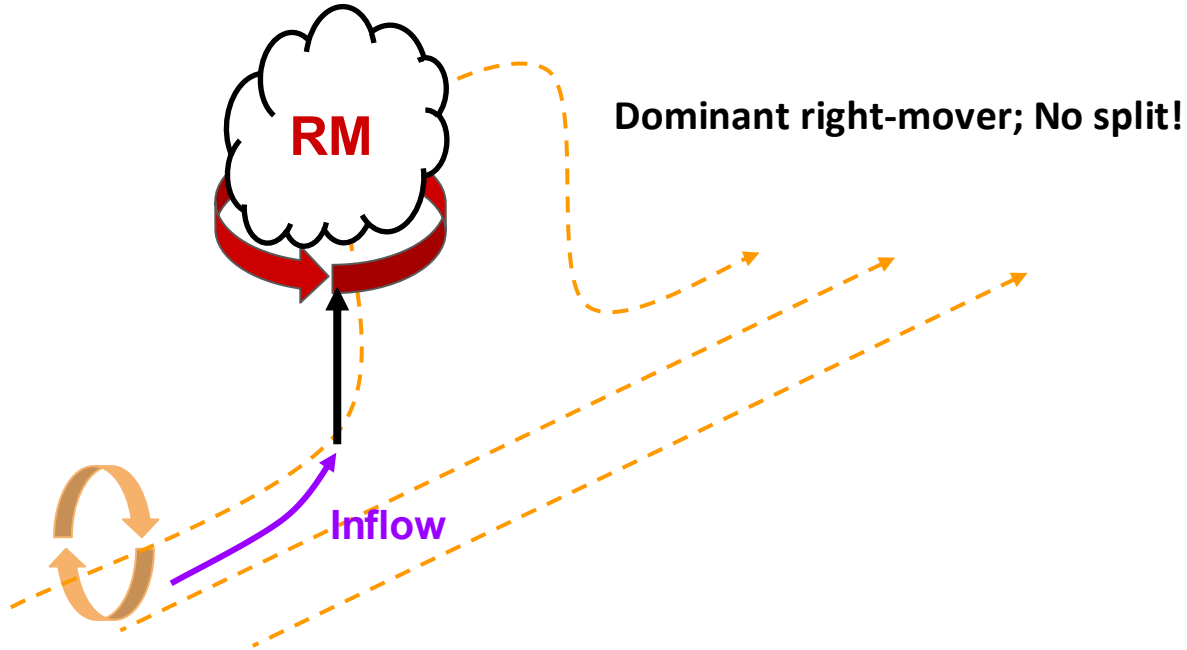
**Low** pressure perturbation is induced in the vorticity center, which is centered on initial updraft!

# The Vacuum Cleaner Effect



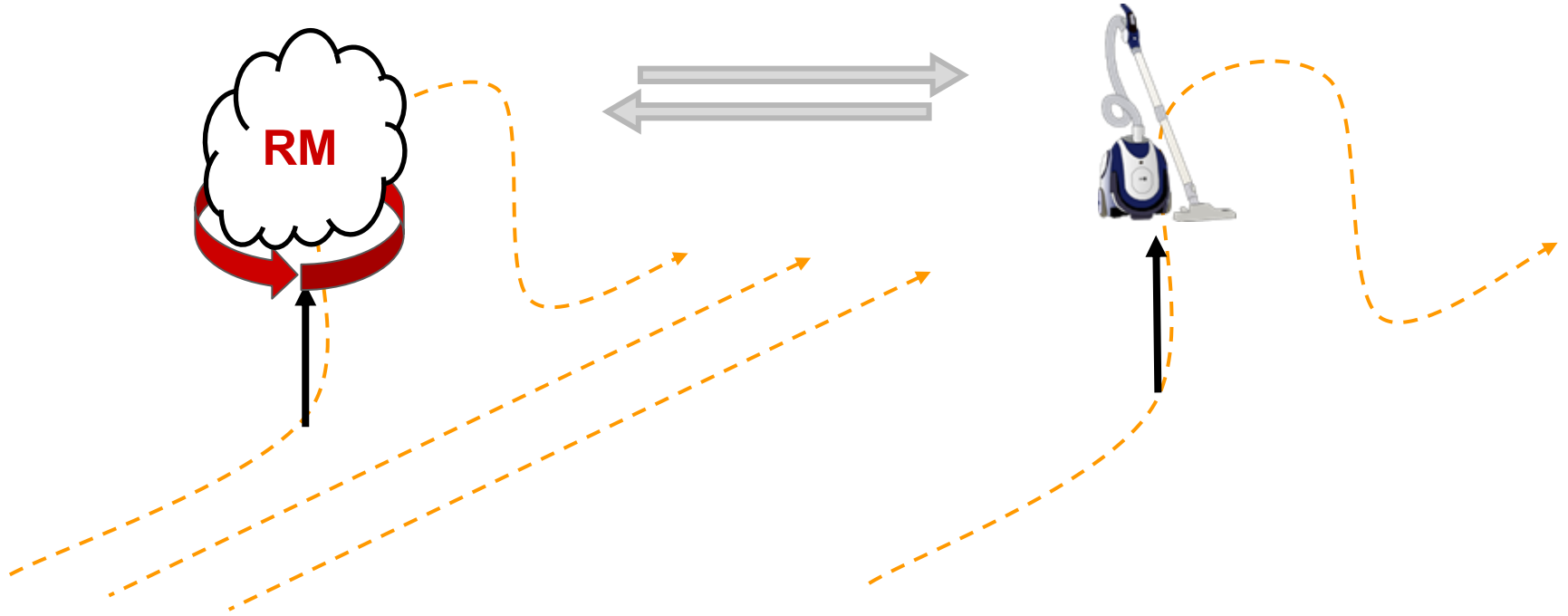
Vacuum sucks air upward from below!

# Rotating Updraft



Initial updraft was correlated with the cyclonic vorticity from the start – streamwise vorticity ingestion!

# Non-Linear Feedback Process Begins!

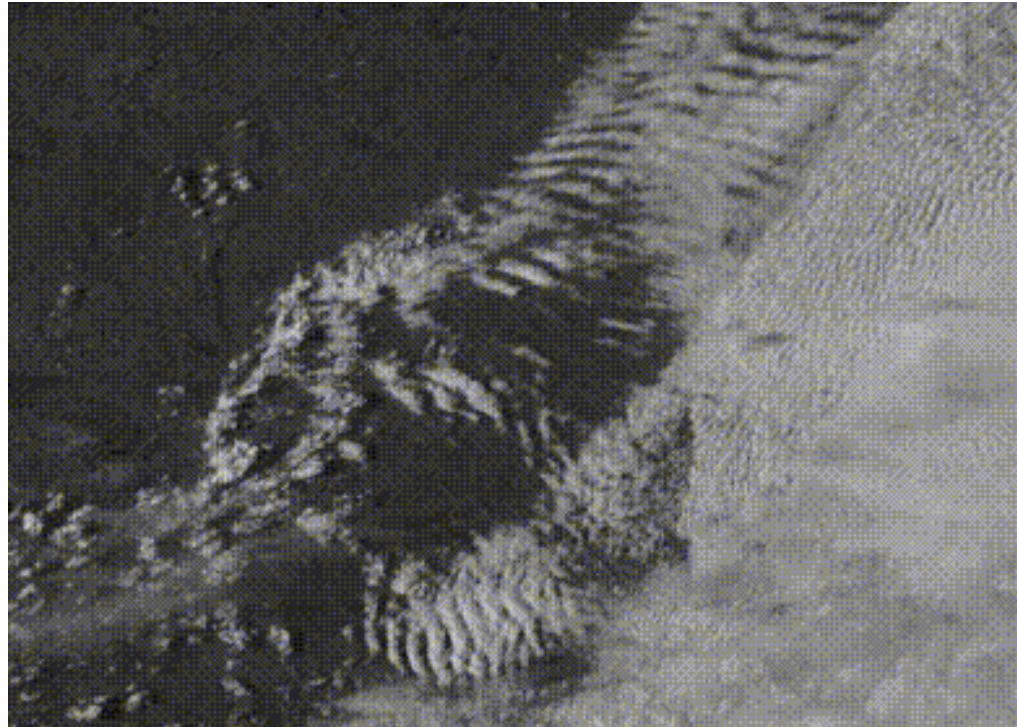


Same stretching, vacuum cleaner effect (**non-linear feedback process**) – but faster/more efficient owing to streamwise vorticity!

# Non-Linear Takeaways

## Summary:

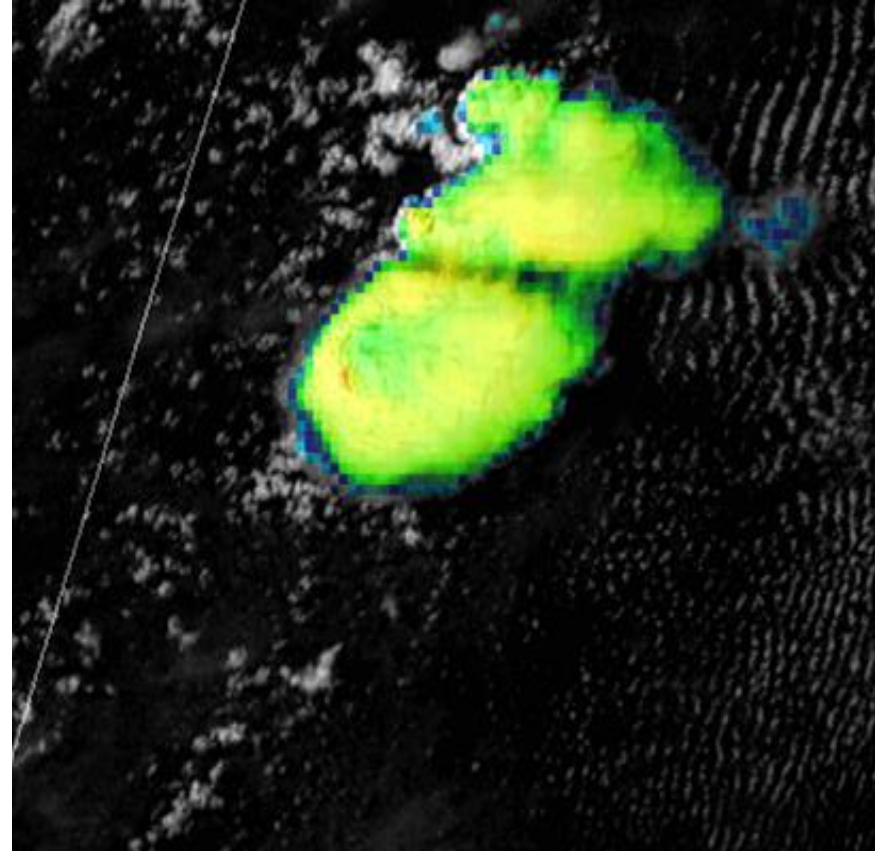
In crosswise vorticity, storms split



# Non-Linear Takeaways

## Summary:

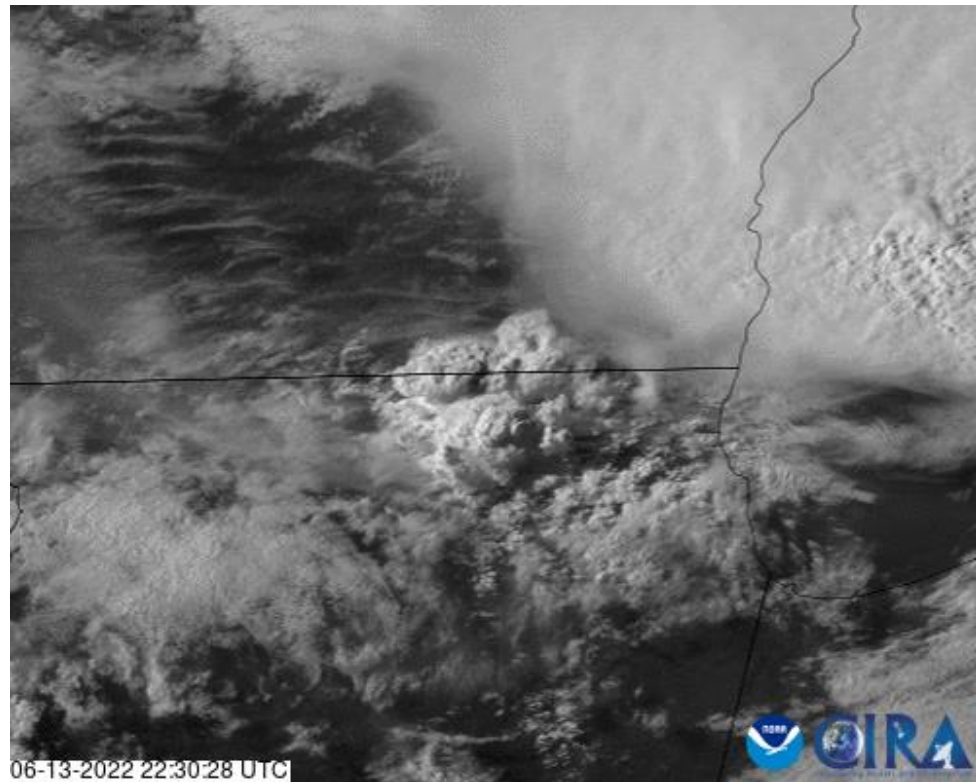
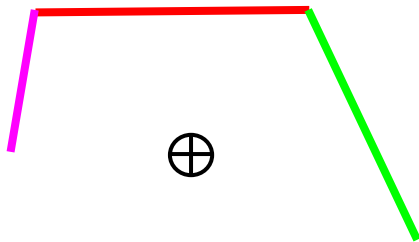
Then, storms acquire some streamwise vorticity and strengthen



# Non-Linear Takeaways

## Summary:

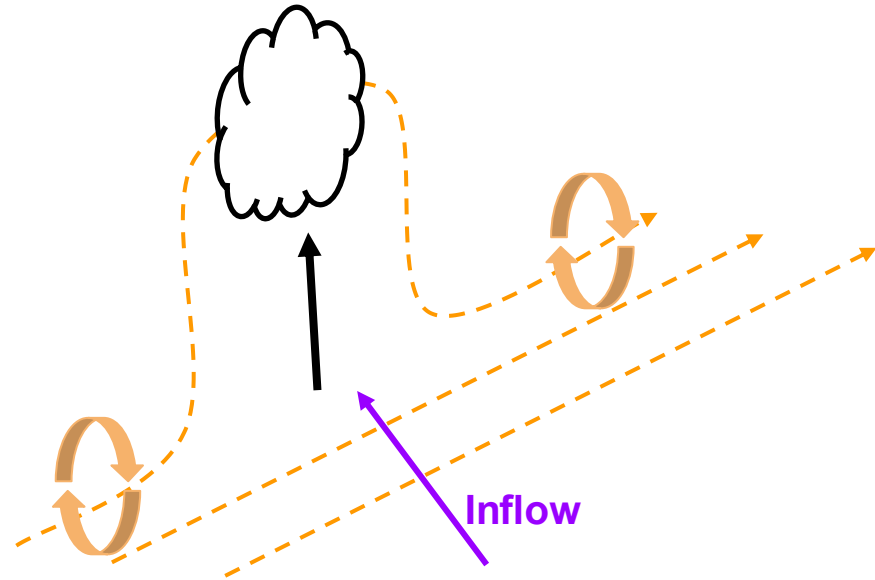
In streamwise vorticity, no splitting!



# Non-Linear Terms

The tilting of *crosswise vorticity* results in:

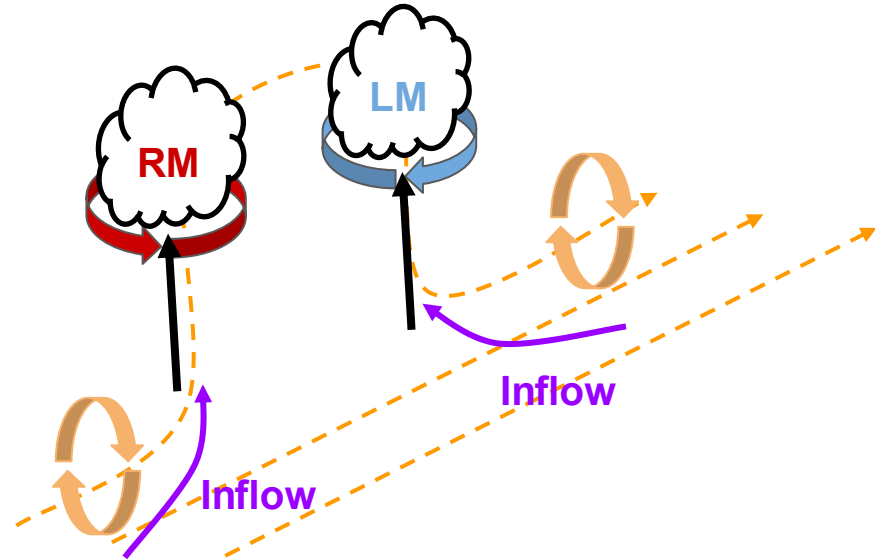
- a. Immediate rotation for initial updraft
- a. Vertical vorticity on flanks of initial updraft and storm splitting
- a. A high pressure perturbation and downward motion



# Non-Linear Terms

The tilting of *crosswise vorticity* results in:

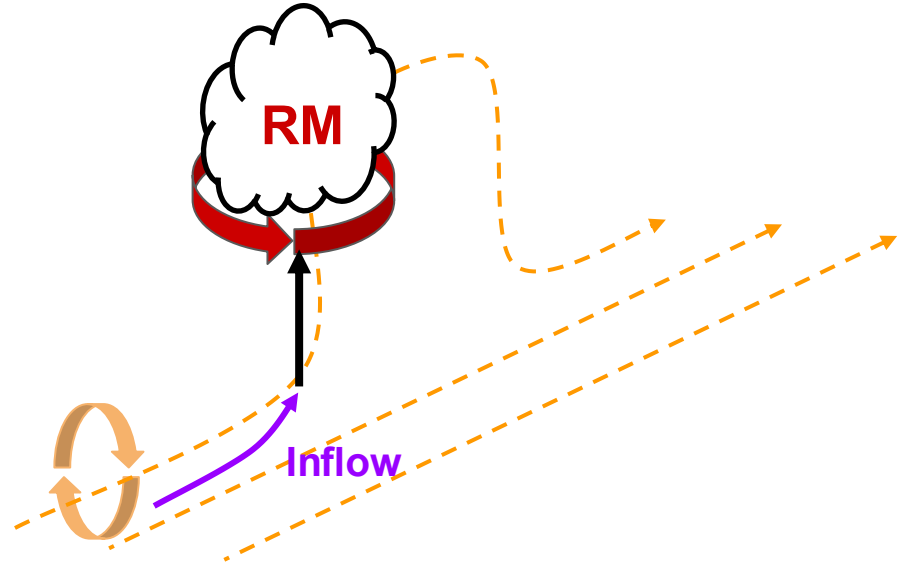
- a. Immediate rotation for initial updraft
- a. Vertical vorticity on flanks of initial updraft and storm splitting
- a. A high pressure perturbation and downward motion



# Non-Linear Terms

Why does streamwise vorticity support immediate updraft rotation?

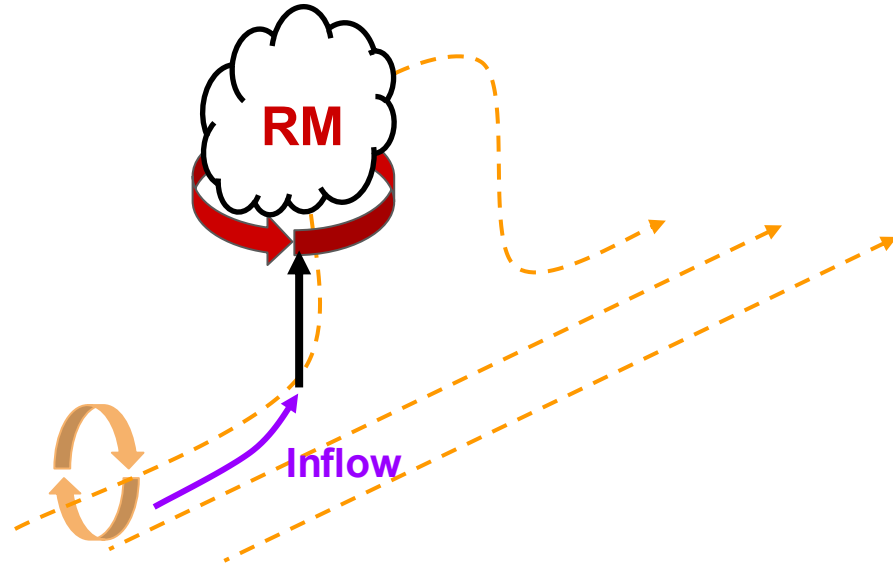
- a. Because cyclonic vorticity is more efficient than anticyclonic vorticity
- a. Stretching is stronger
- a. The vertical vorticity is aligned with the initial updraft



# Non-Linear Terms

Why does streamwise vorticity support immediate updraft rotation?

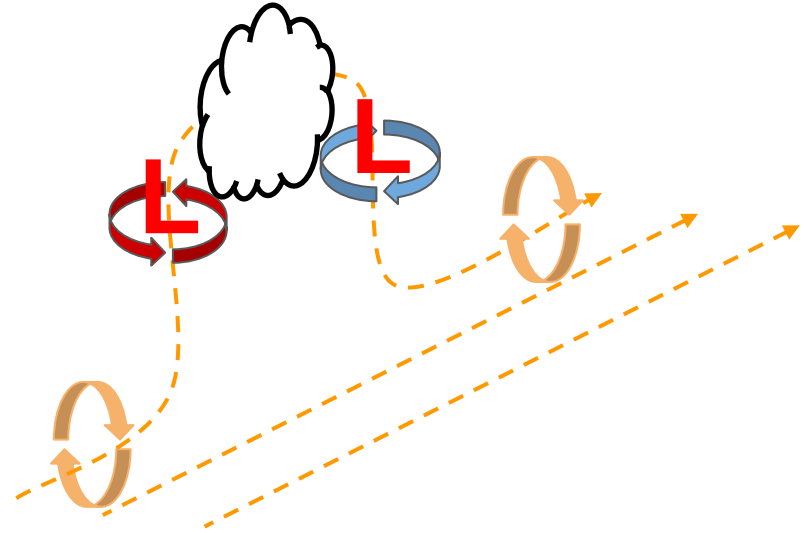
- a. Because cyclonic vorticity is more efficient than anticyclonic vorticity
- a. Stretching is stronger
- a. The vertical vorticity is aligned with the initial updraft



# Non-Linear Terms

What is the significance of low pressure perturbations aloft?

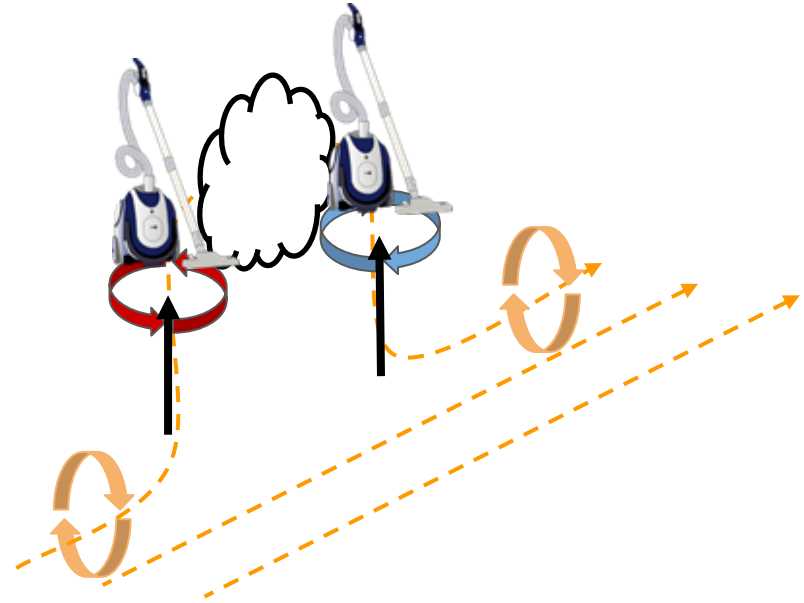
- a. Can limit cell splitting
- a. Can suppress downdrafts
- a. Can dynamically lift inflow air to to the LFC, even with CIN



# Non-Linear Terms

What is the significance of low pressure perturbations aloft?

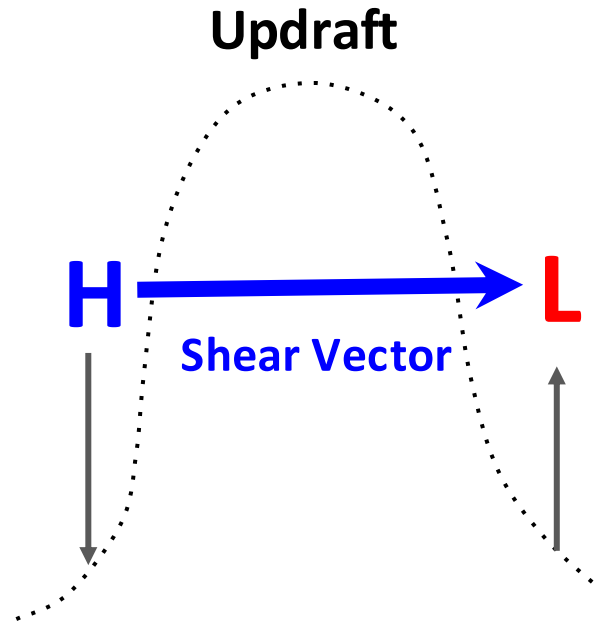
- a. Can limit cell splitting
- a. Can suppress downdrafts
- a. Can dynamically lift inflow air to the LFC, even with CIN



1. Non-Linear Dynamics Terms

**2. Linear Dynamics Term**

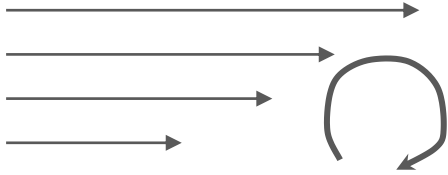
# Linear Dynamics Term



# Dynamic Lifting and Suppression

(an additional contribution to vertical motion)

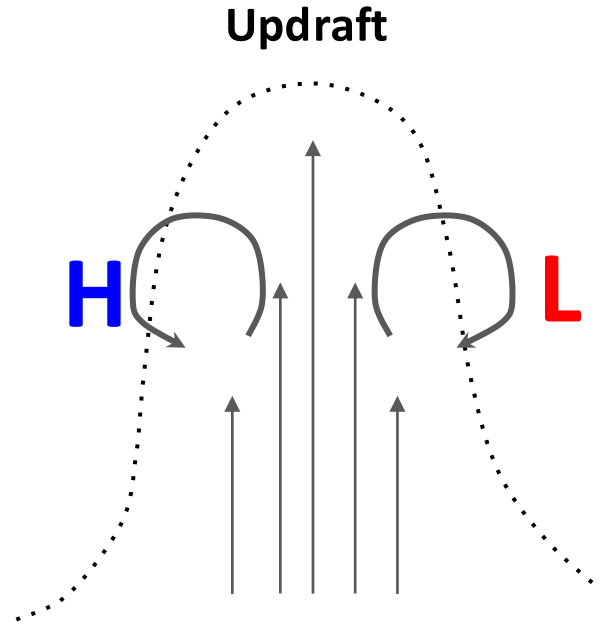
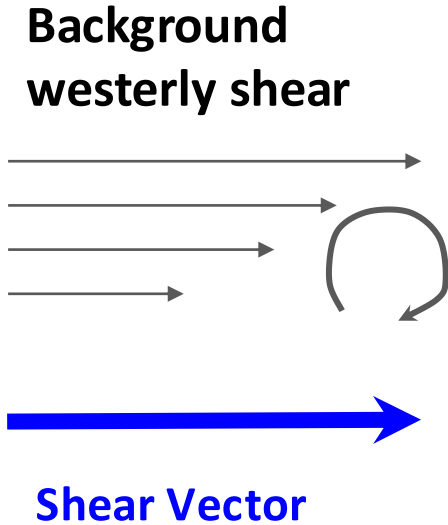
Background  
westerly shear



Shear Vector

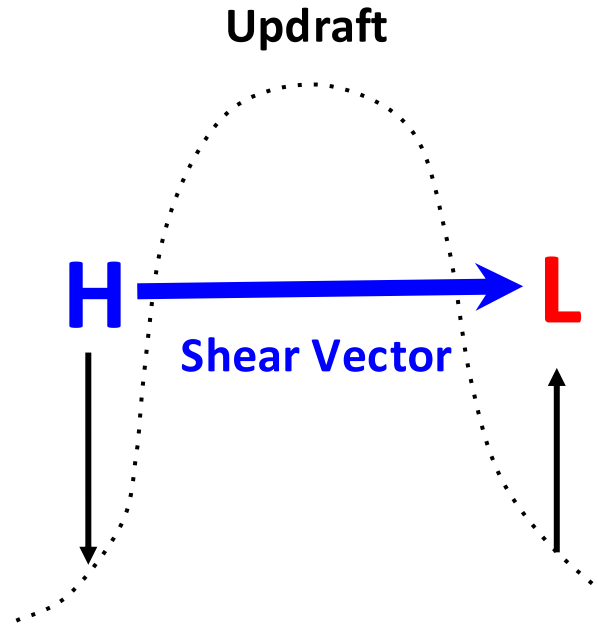
# Dynamic Lifting and Suppression

(an additional contribution to vertical motion)



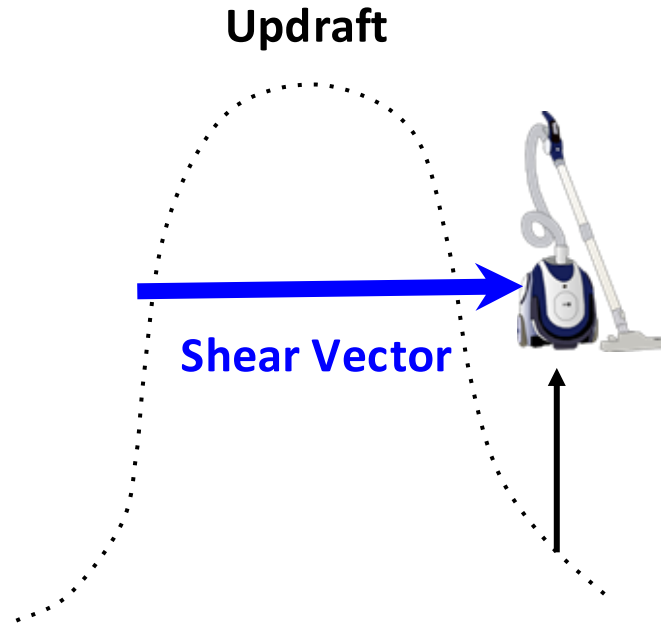
**Think of a log in a stream**  
(mass build-up upshear, mass deficit downshear)

# Dynamic Lifting and Suppression



Dynamic subsidence occurs upshear and dynamic lifting  
downshear – “**Updraft-in-shear effect**”

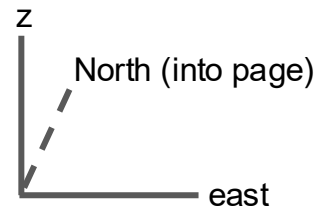
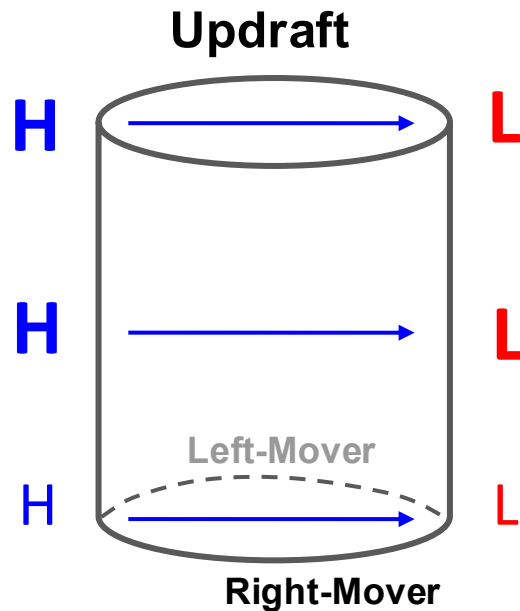
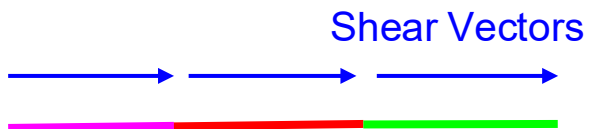
# Dynamic Lifting and Suppression



Generates a **vacuum** causing deep lifting downshear of updraft

# Straight Hodograph

Let's look at the straight hodograph case...

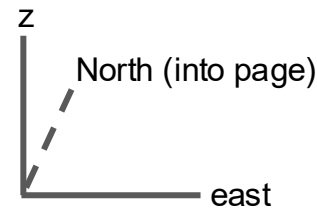
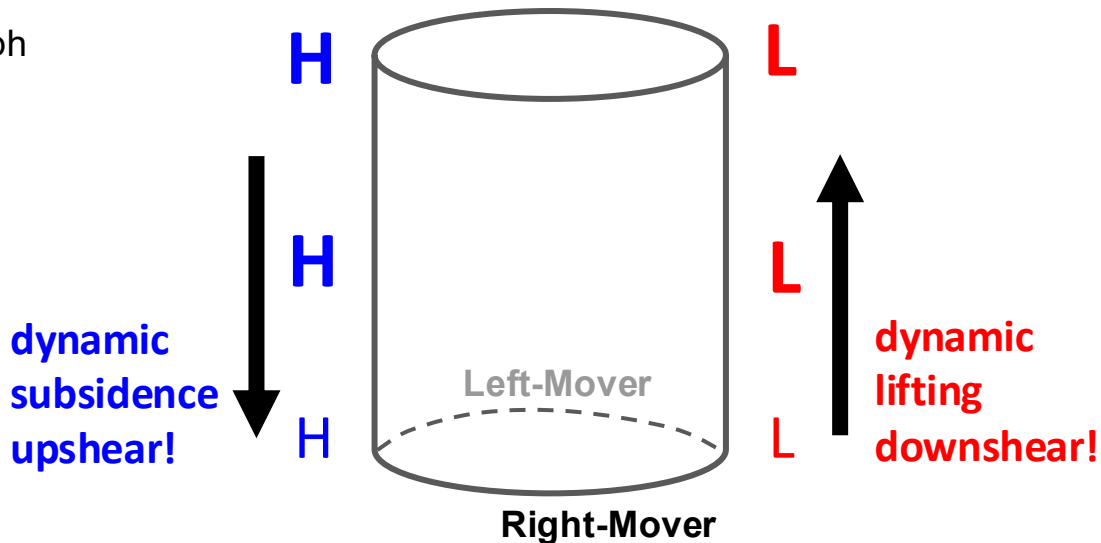


# Straight Hodograph

Let's look at the straight hodograph case...



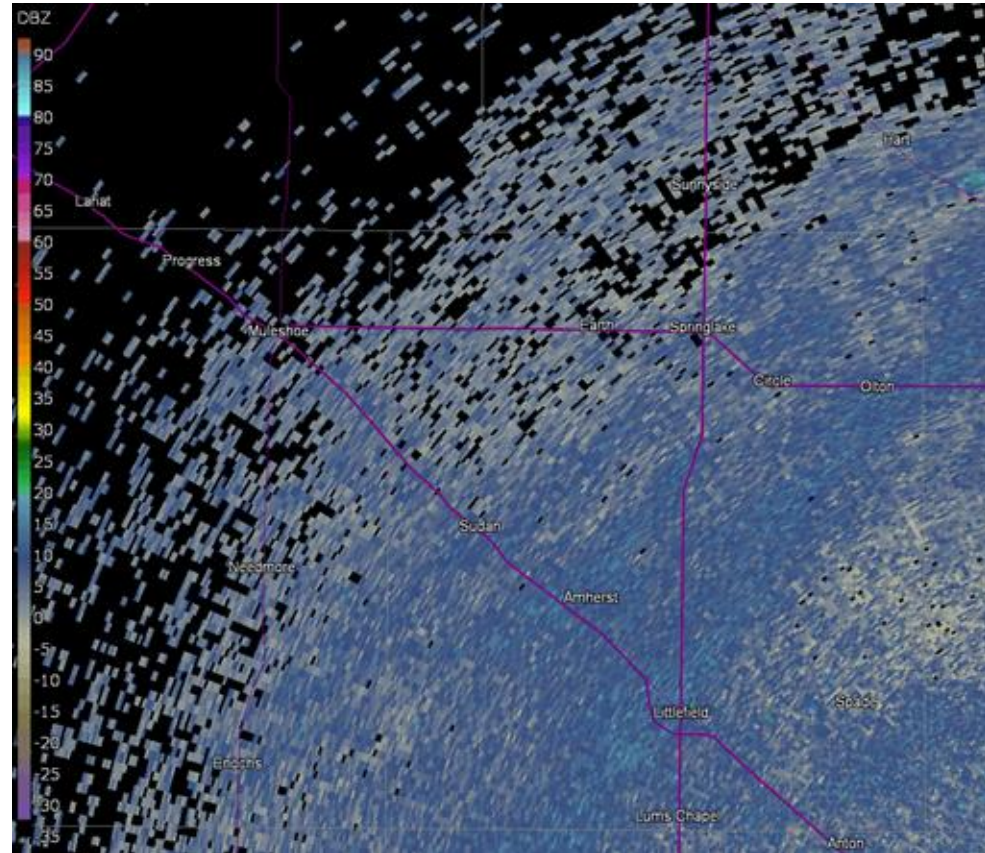
Neither RM nor LM  
enhanced/suppressed



# Straight Hodograph

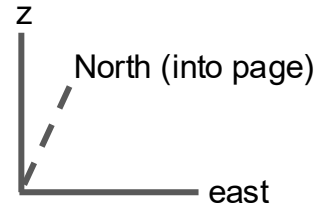
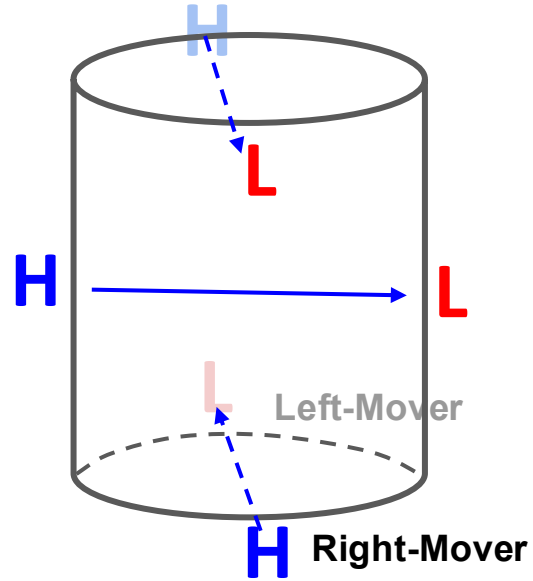
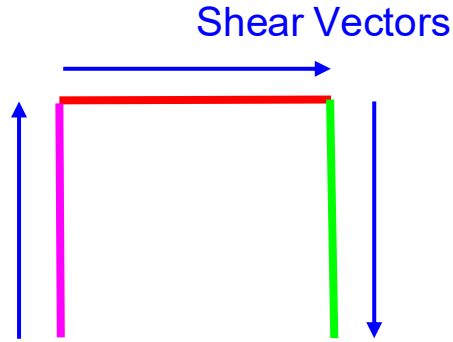


Neither RM nor LM enhanced/suppressed  
Mirror-image splitting cells!



# Half-Circle Hodograph

Now, let's do a half-circle hodograph!



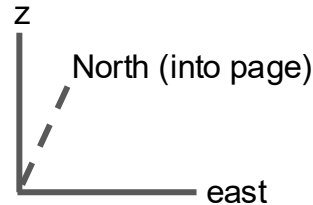
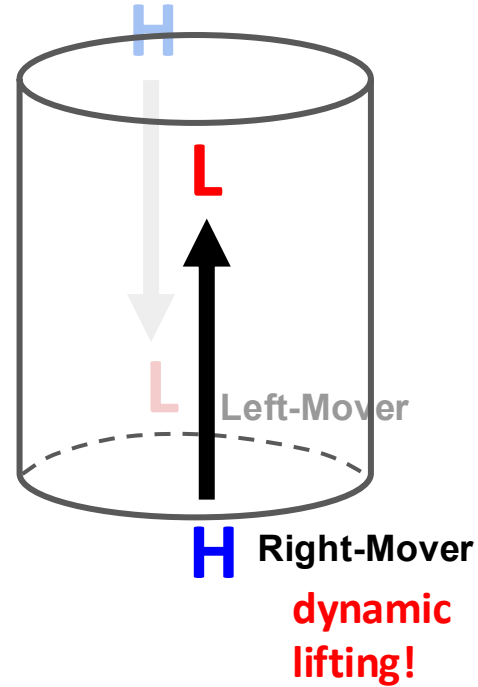
# Half-Circle Hodograph

Now, let's do a half-circle hodograph!



**RM enhanced**, LM suppressed!

Upward motion **right** of initial updraft



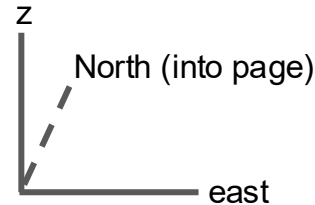
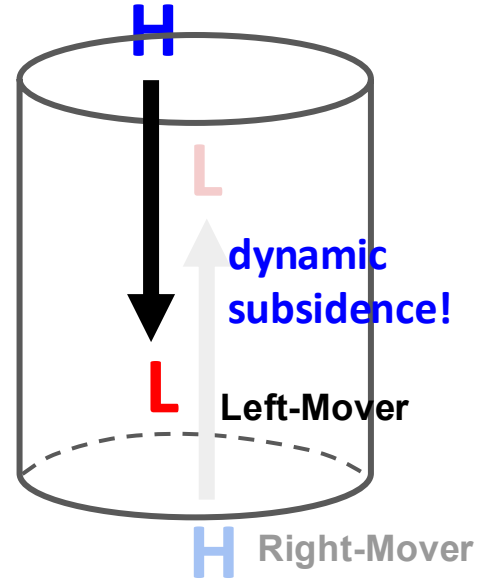
# Half-Circle Hodograph

Now, let's do a half-circle hodograph!



RM enhanced, **LM suppressed!**

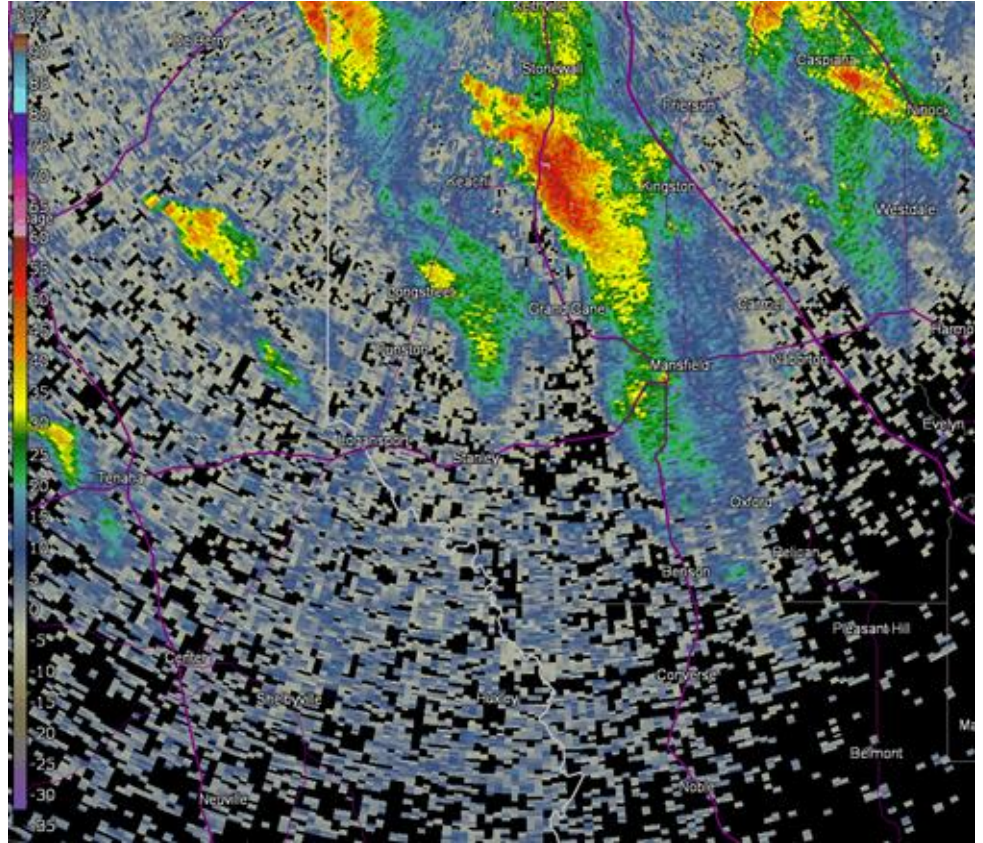
Downward motion **left** of initial updraft



# Half-Circle Hodograph



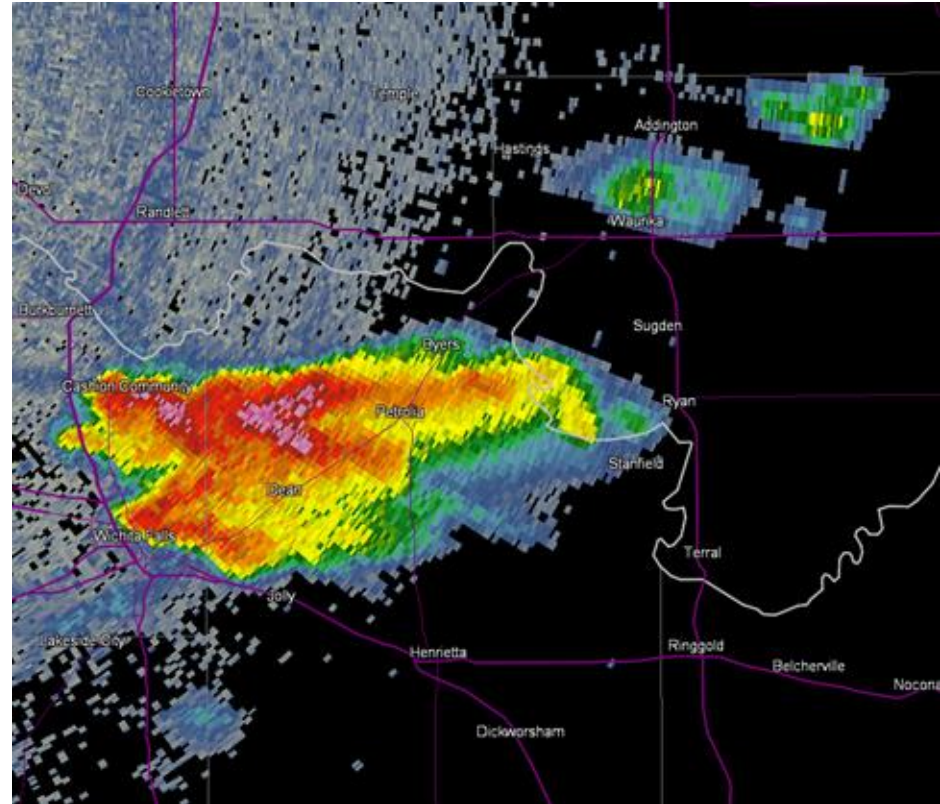
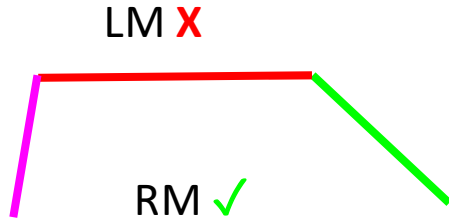
RM enhanced, LM suppressed  
No splitting!



# Linear Dynamics Takeaways

## Takeaways:

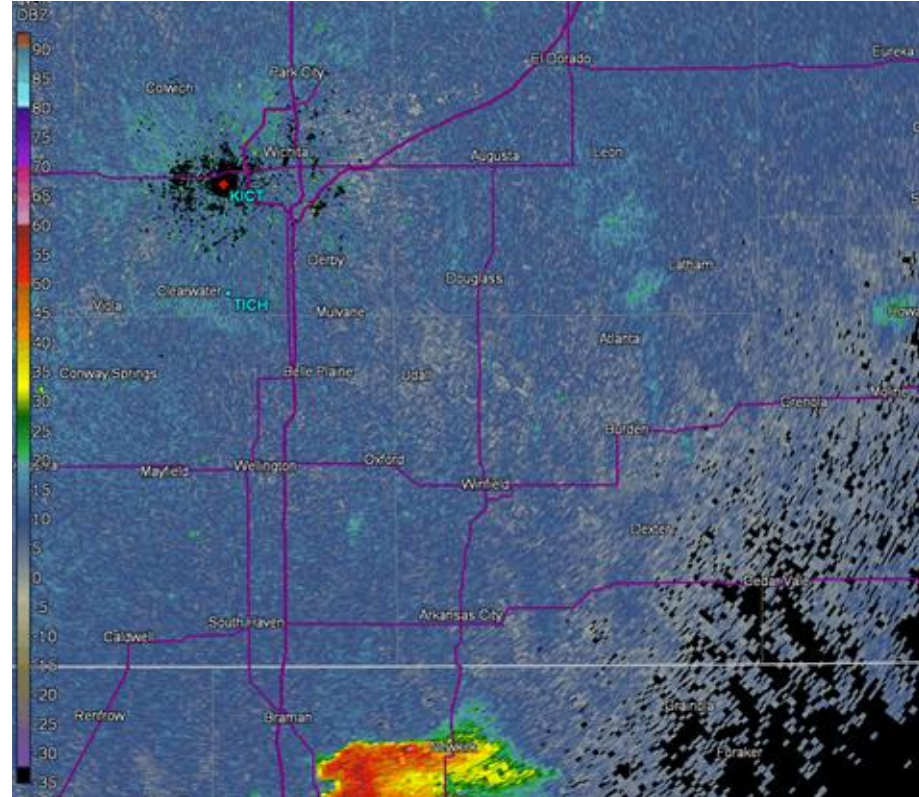
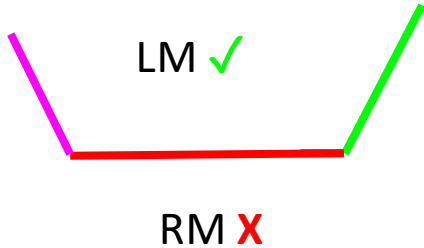
Updraft is enhanced on the concave side, and suppressed on the convex side.



# Linear Dynamics Takeaways

## Takeaways:

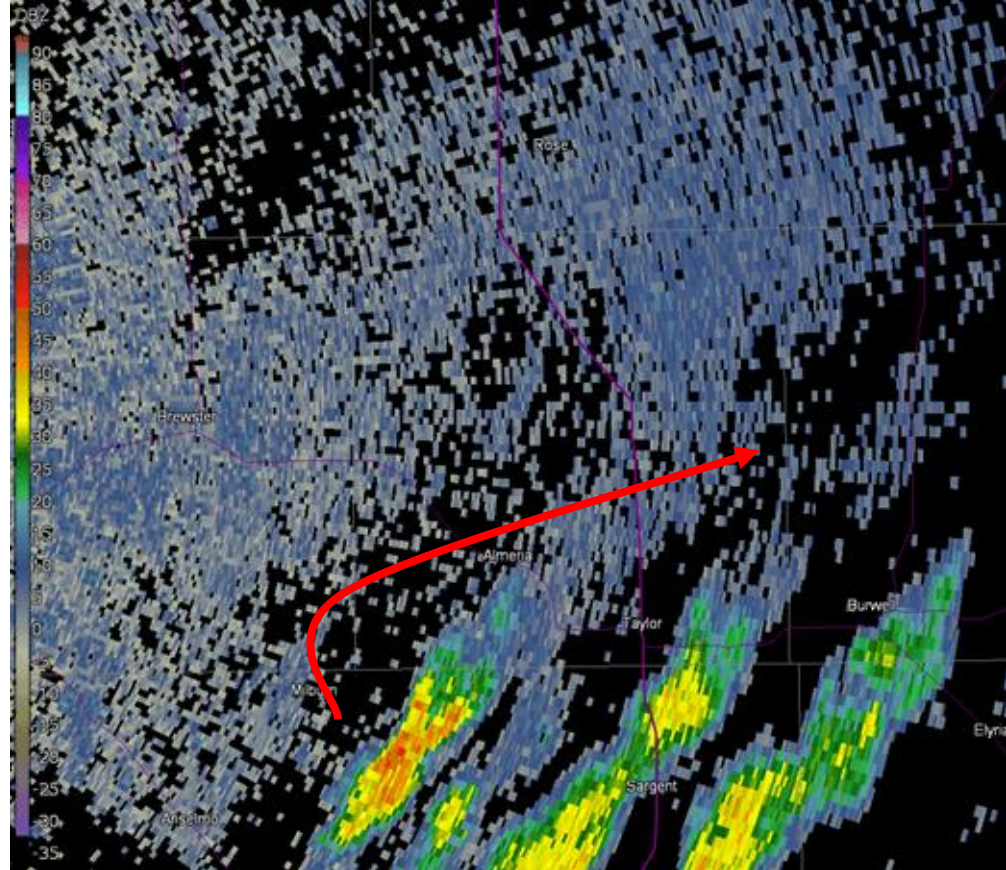
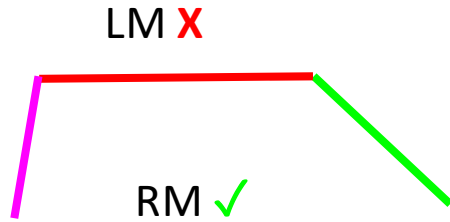
Updraft is enhanced on the concave side, and suppressed on the convex side.



# Linear Dynamics Takeaways

## Takeaways:

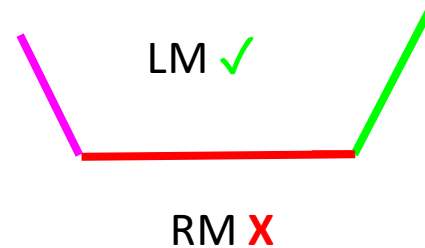
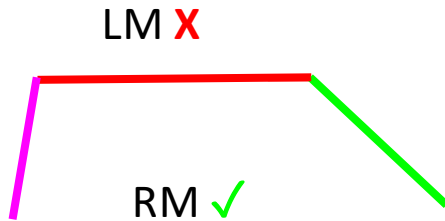
Enhanced upward motion can induce deviant motion



# Propagation (Deviant Updraft Motion)

## For a CURVED hodograph:

Deviant updraft motion (propagation)  
away from the mean wind is  
explained by the **LINEAR DYNAMICS**  
terms.

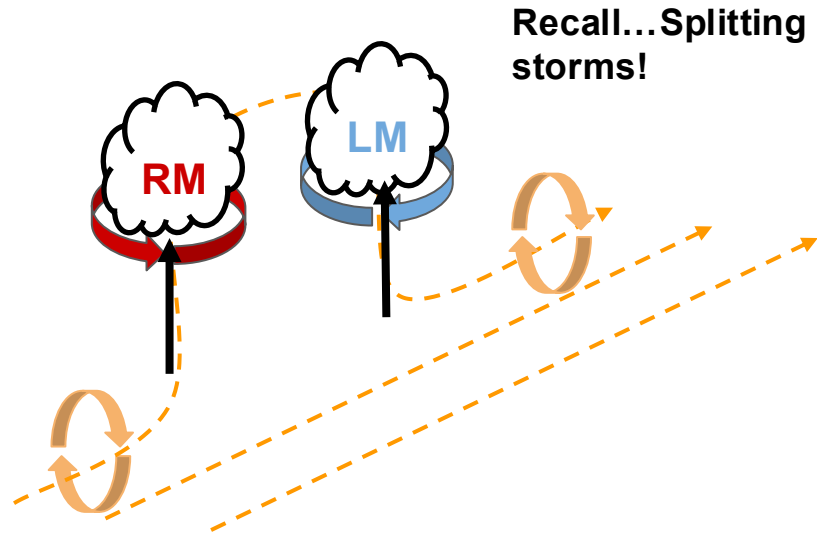


Updrafts propagate into the region of  
enhanced storm-scale dynamic ascent

# Propagation (Deviant Updraft Motion)

## For a STRAIGHT hodograph:

Deviant updraft motion (propagation) away from the mean wind is explained by the **NON-LINEAR DYNAMICS** terms.

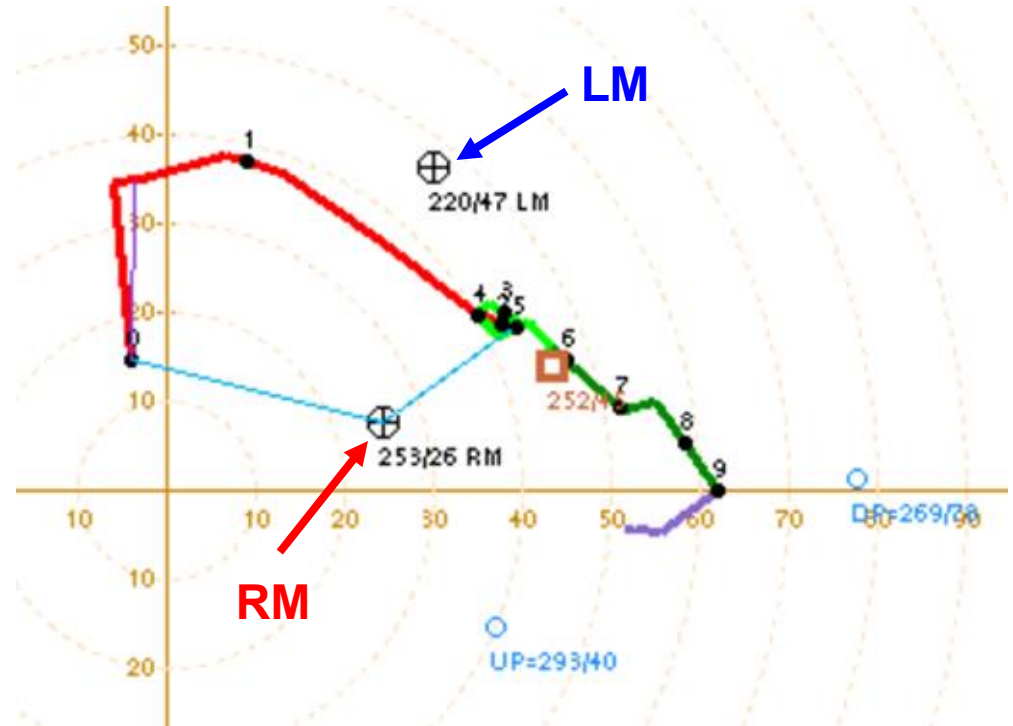


Updrafts propagate away from mean wind due to tilting of crosswise vorticity

# Propagation (Deviant Updraft Motion)

Use Bunkers Storm motion estimates to account for deviant motions!

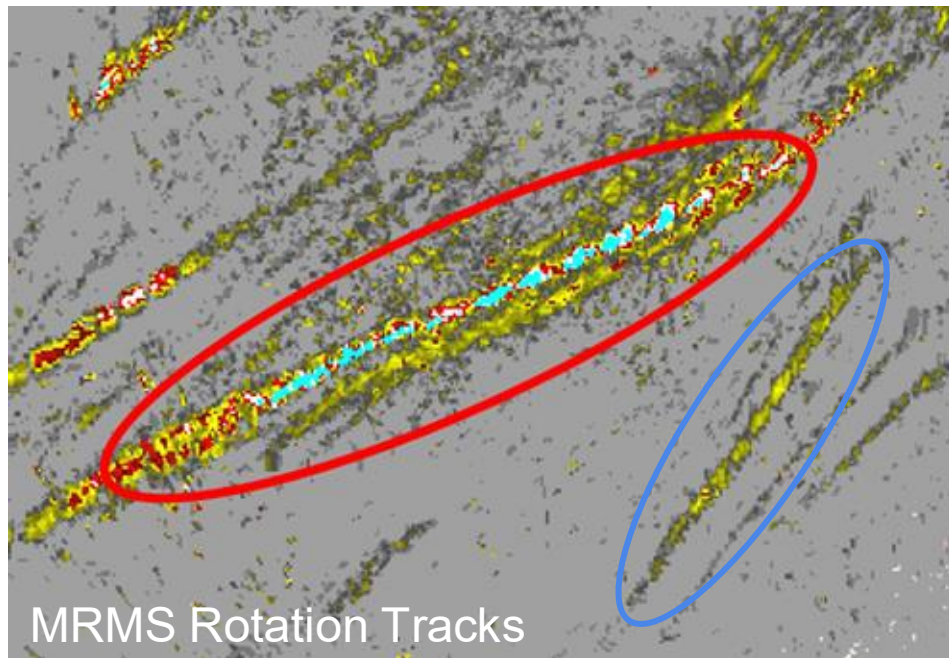
\*Bunkers Storm motion accounts for propagation due to linear AND non-linear dynamics



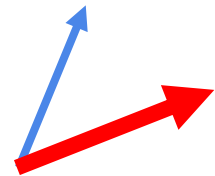
# Propagation (Deviant Updraft Motion)

**Keep in mind:**

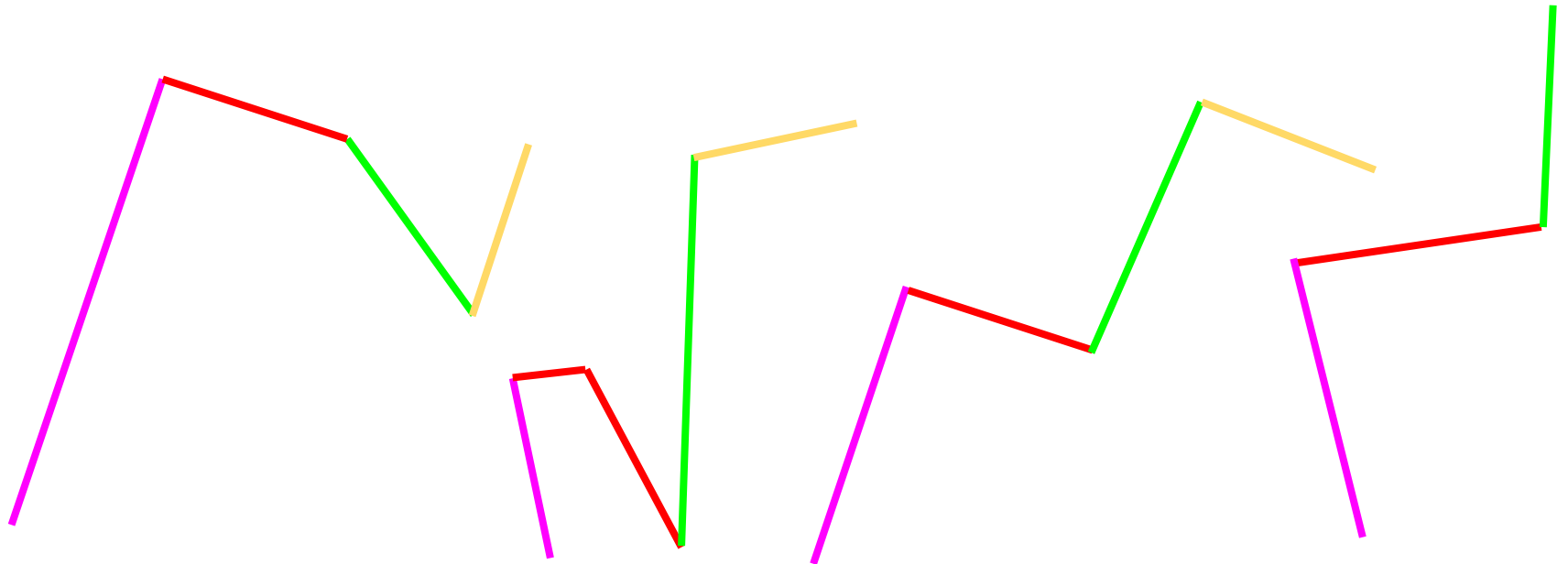
Larger, stronger storms can deviate more.



A larger, stronger supercell may turn more “right” than a weaker one

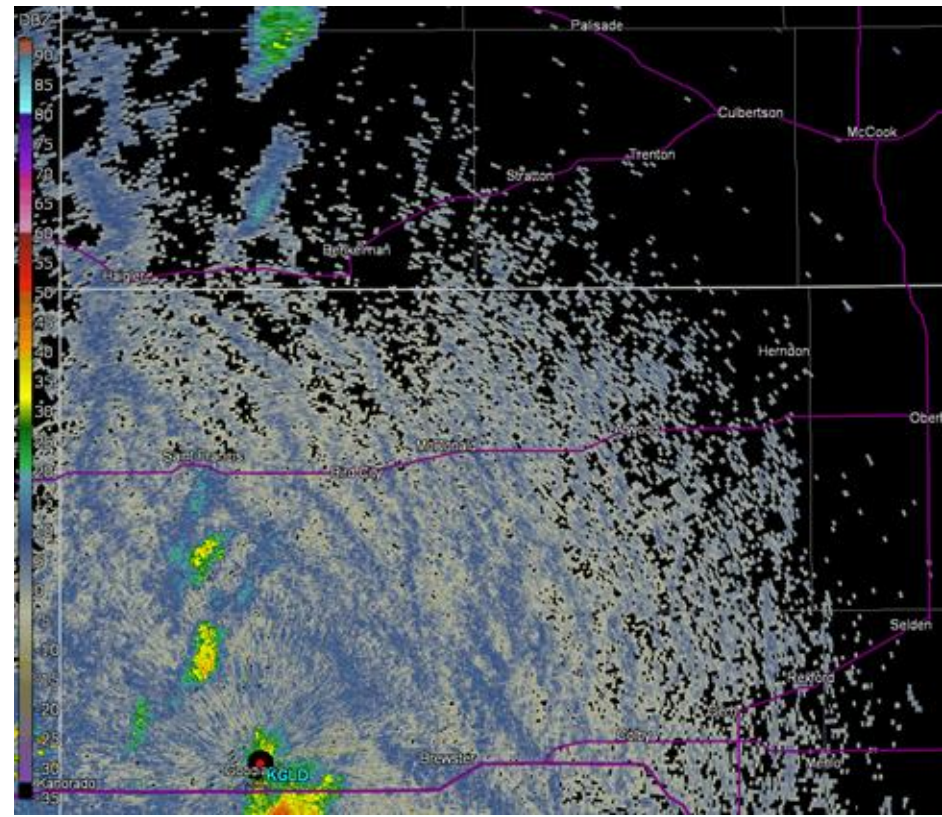
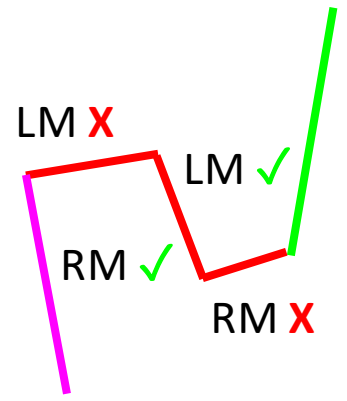


# Bonus Material – Complex Hodograph Shapes



# Linear Dynamics and Complex Hodo Shapes– Bonus Material

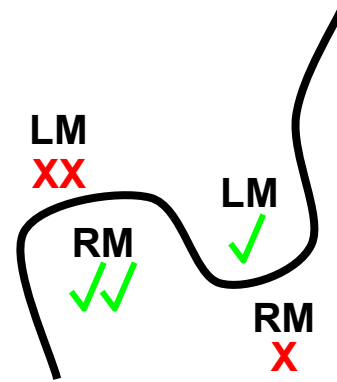
Updrafts can be enhanced/suppressed at different levels



# Linear Dynamics and Complex Hodo Shapes– Bonus Material

Multi-inflection hodographs may suppress right- and left-movers, depending on the situation.

## Multi-Inflection Hodograph



✓✓ means more lift than ✓

XX means more suppression than X

# Complex Hodographs

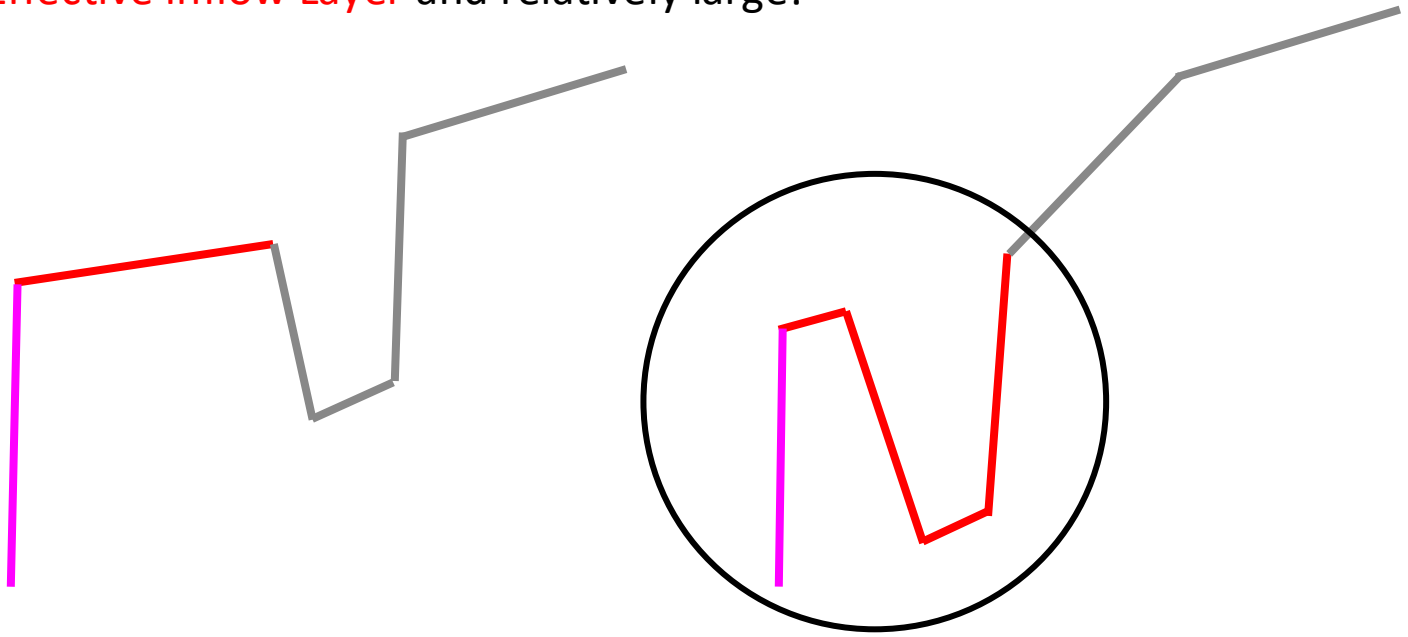
When should we “worry” about dynamic suppression?



# Complex Hodographs

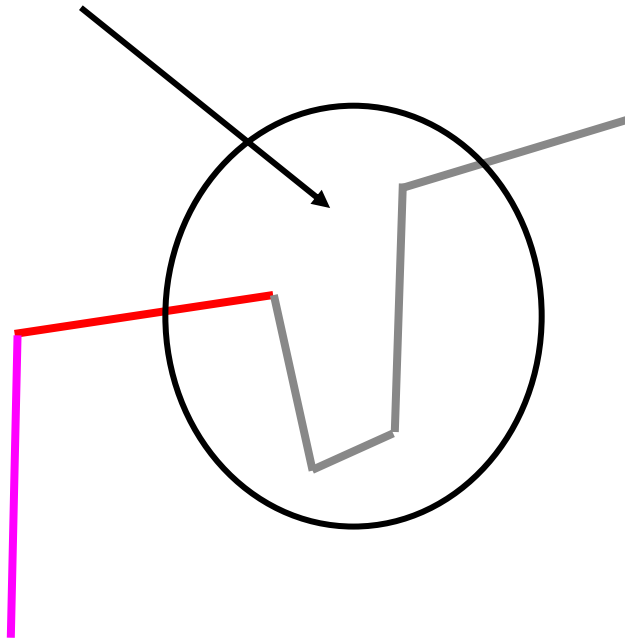
When should we “worry” about dynamic suppression?

Worry about dynamic suppression if alternating concavity is within the **Effective Inflow Layer** and relatively large!

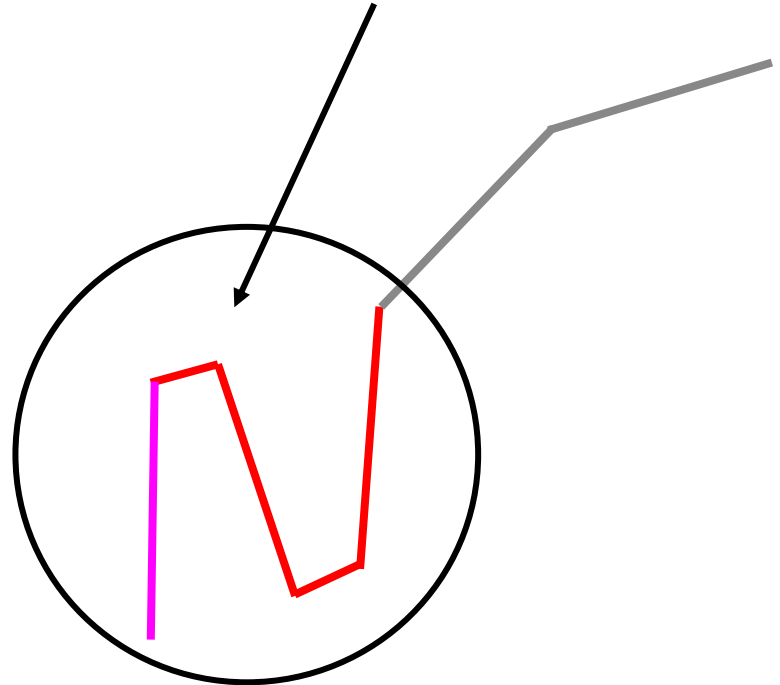


# Complex Hodographs

**This MAY not negatively influence RM, it is higher in the profile.**



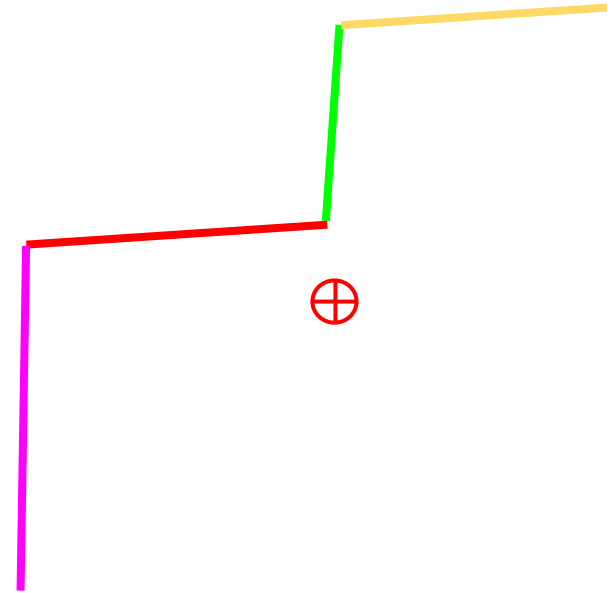
**Strong dynamic suppression on RM (lower in the profile)**



# Complex Hodographs

Should we “worry”?

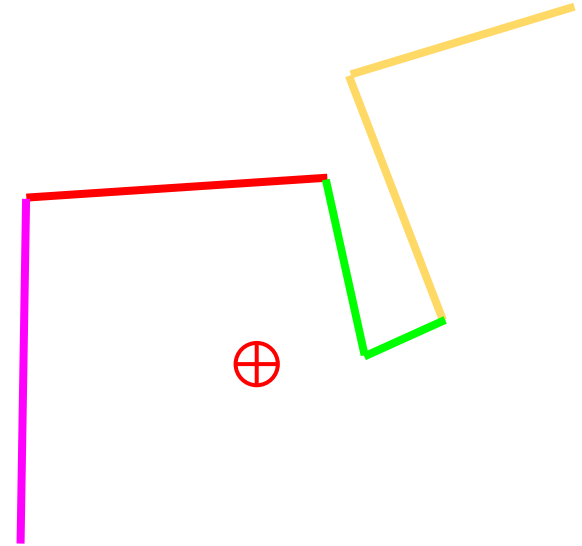
No reason to worry - shear does not reverse direction with height.



# Complex Hodographs

Should we “worry”?

No worries still - inflection is well above the effective inflow layer

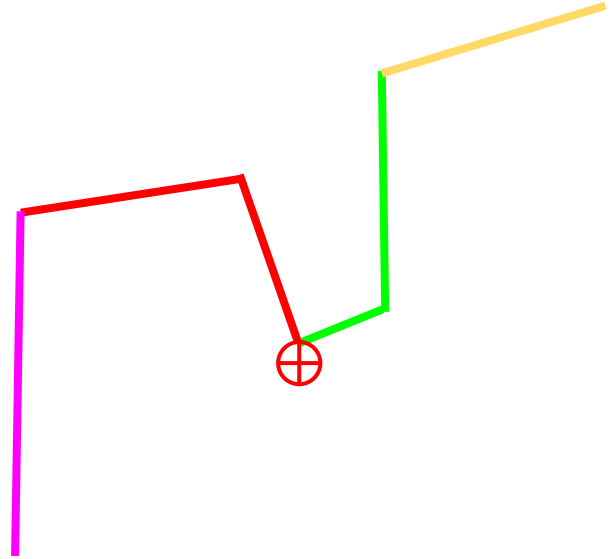


# Complex Hodographs

Should we “worry”?

Might not be ideal, **but**:

Inflection is near the effective inflow layer,  
but streamwise vorticity is abundant!

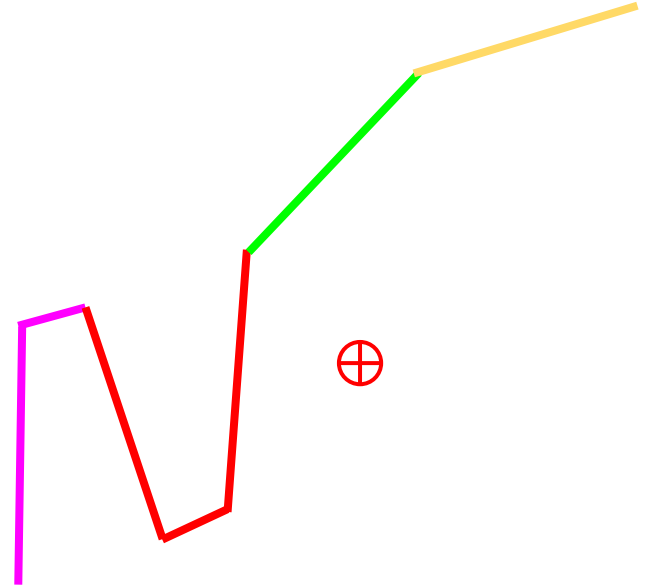


# Complex Hodographs

Should we “worry”?

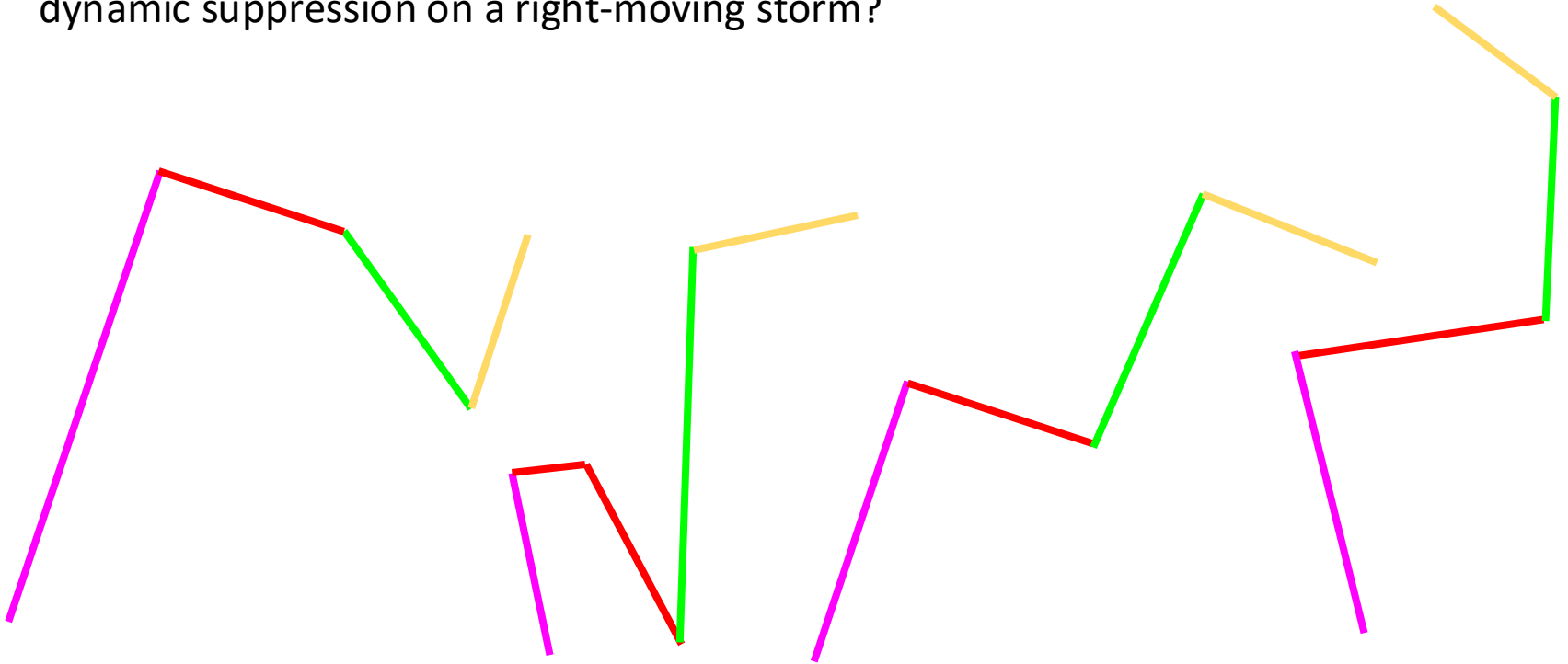
Worry!

Inflection is within the effective inflow layer,  
and streamwise vorticity is reduced!



# Dynamic Suppression

With which hodograph would you be *most* concerned about dynamic suppression on a right-moving storm?



# Dynamic Suppression

With which hodograph would you be *most* concerned about dynamic suppression on a right-moving storm?

