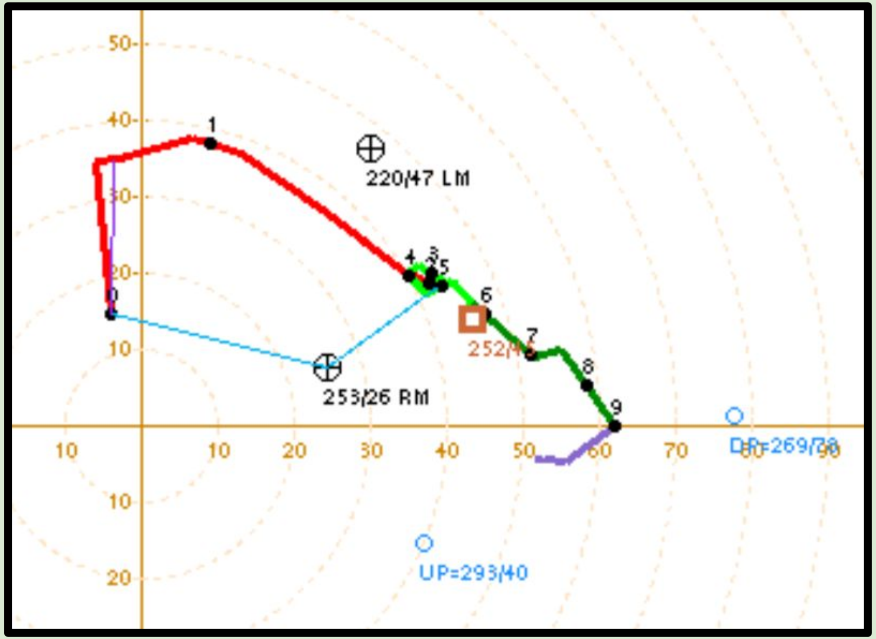
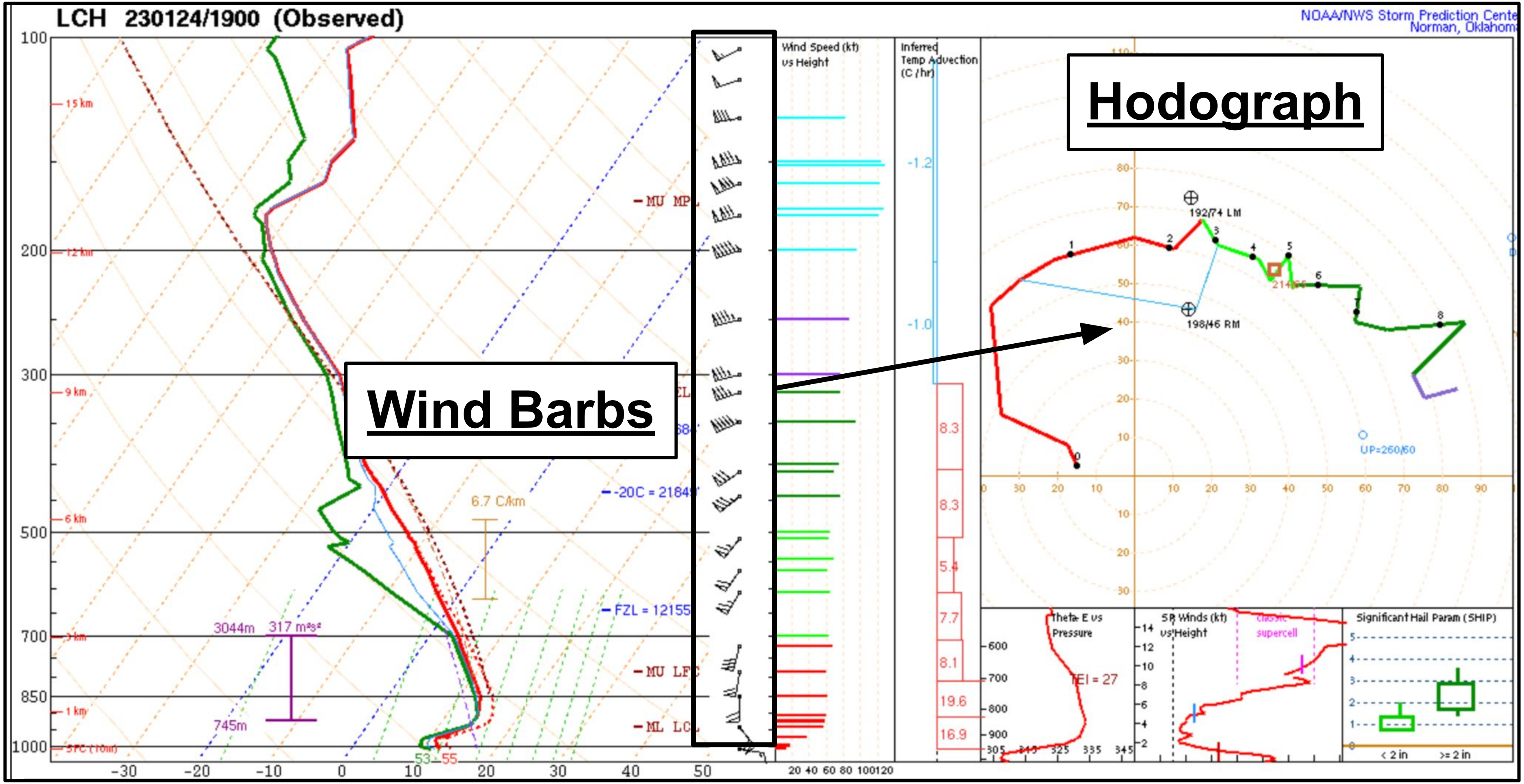
Lesson 1: Hodograph Fundamentals



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

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



LCH 230124/1900 (Observed)
NOAA/NWS Storm Prediction Center
Norman, Oklahoma
Wind Barbs
Hodograph
Wind Speed (kt) vs Height
Inferred Temp Advection (C / hr)
192/74 LM
198/46 RM
UP=260/60
MU MPL
-20C = 21849'
FZL = 12155'
MU LFC
ML LCL
6.7 C/km
3044m 317 m²s²
745m
Theta-E vs Pressure
TEI = 27
SR Winds (kt) vs Height
classic supercell
Significant Hail Param (SHIP)
< 2 in
>= 2 in

What is a Hodograph?

Hodograph: Plot of vertical wind shear (change in wind speed/direction) with height

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- Highly useful tool for assessing wind shear, storm-relative winds, and horizontal vorticity (more to come on this)

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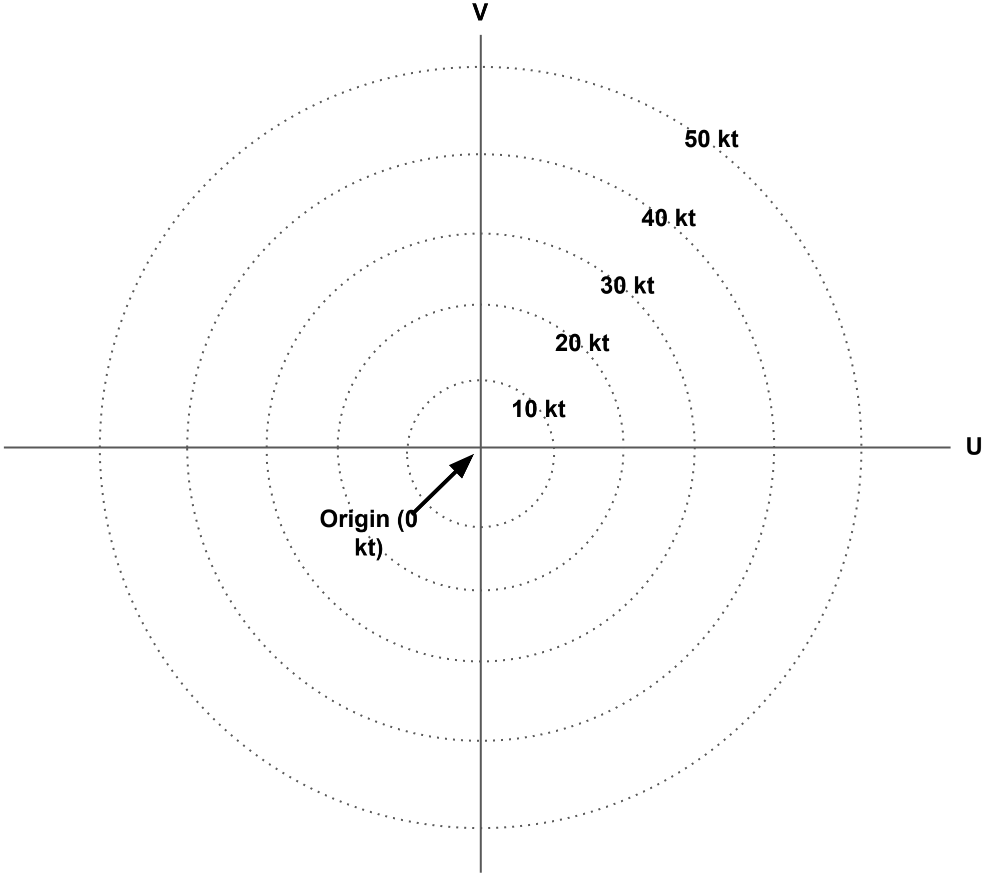
Hodograph: Plot of vertical wind shear (change in wind speed/direction) with height

- Highly useful tool for assessing wind shear, storm-relative winds, and horizontal vorticity (more to come on this)

- Hodograph length and shape have direct implications on storm mode, evolution, and overall behavior (more to come on this)

Plotting a Hodograph

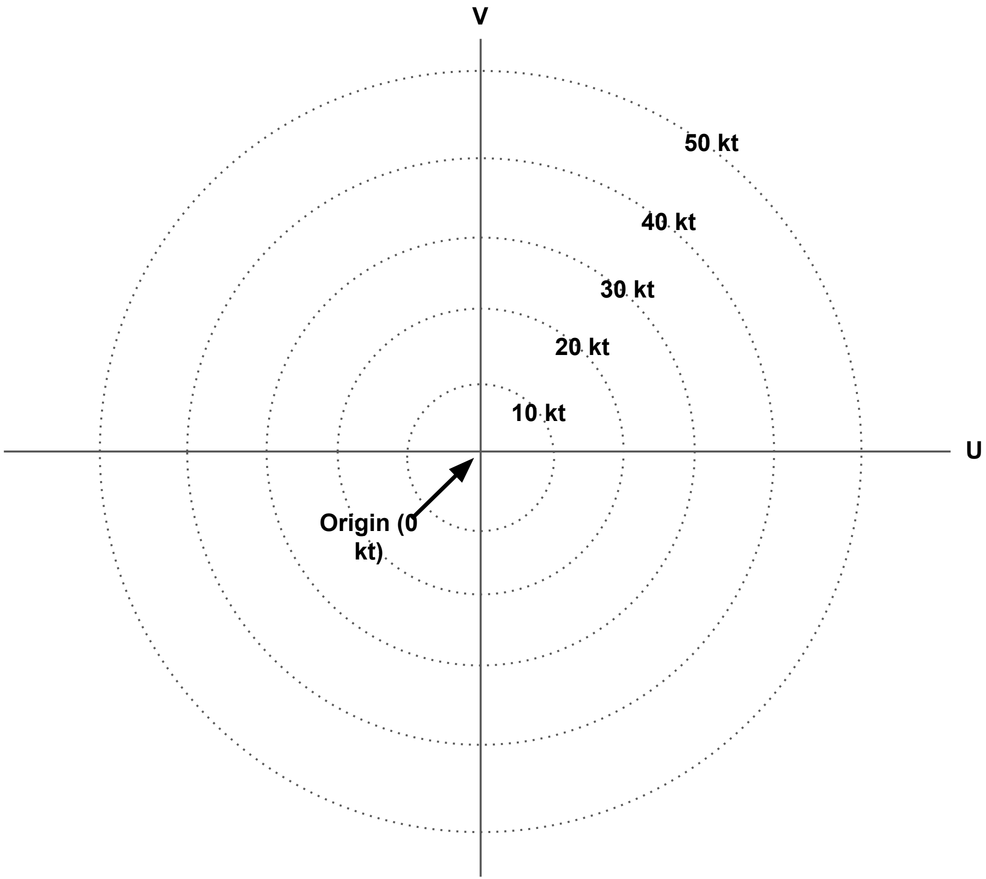
Plotting a Hodograph



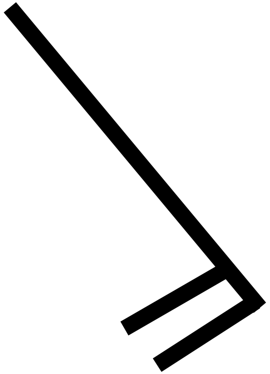
Wind speed increases radially outward from the origin

Axes represent zonal and meridional directions

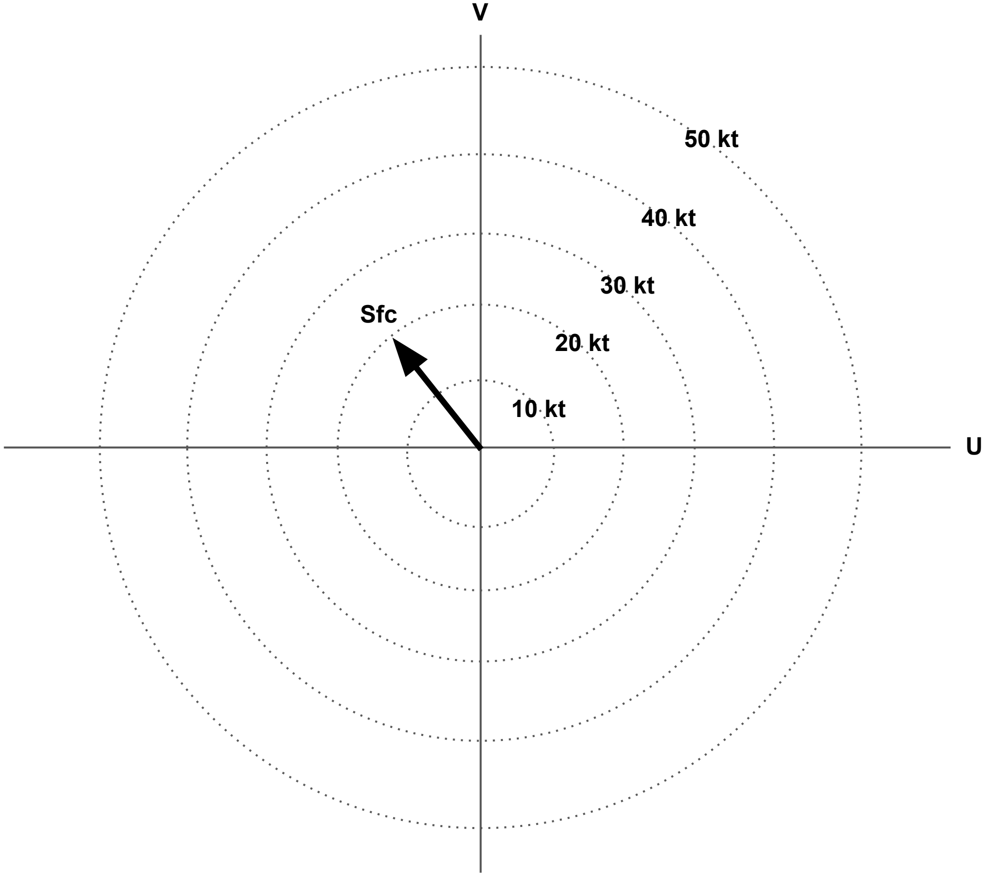
Plotting a Hodograph



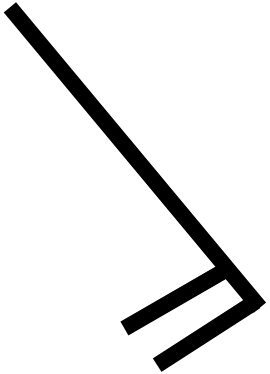
Given a southeasterly surface wind,



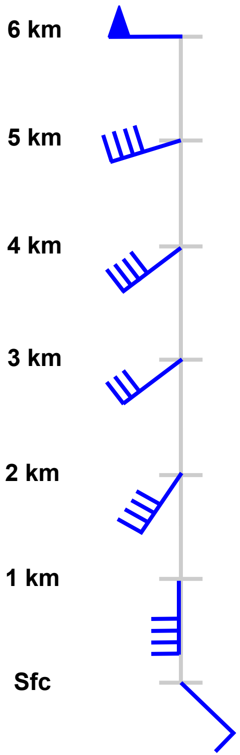
Plotting a Hodograph



Start at the origin, then draw a wind vector toward the direction the wind is blowing!

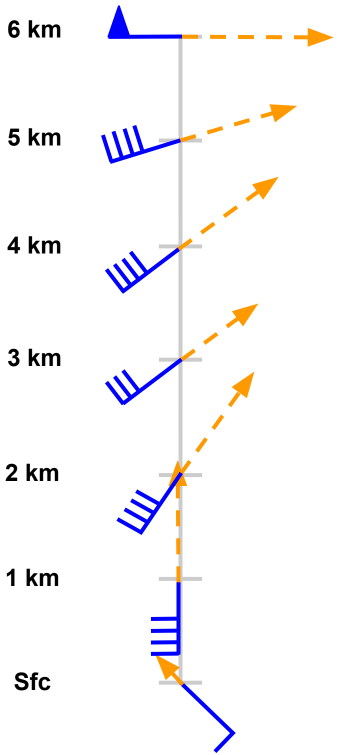


Plotting a Hodograph



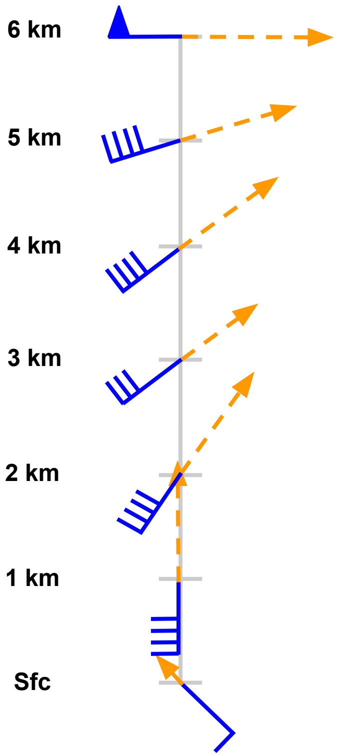
1. Take these wind barbs

Plotting a Hodograph

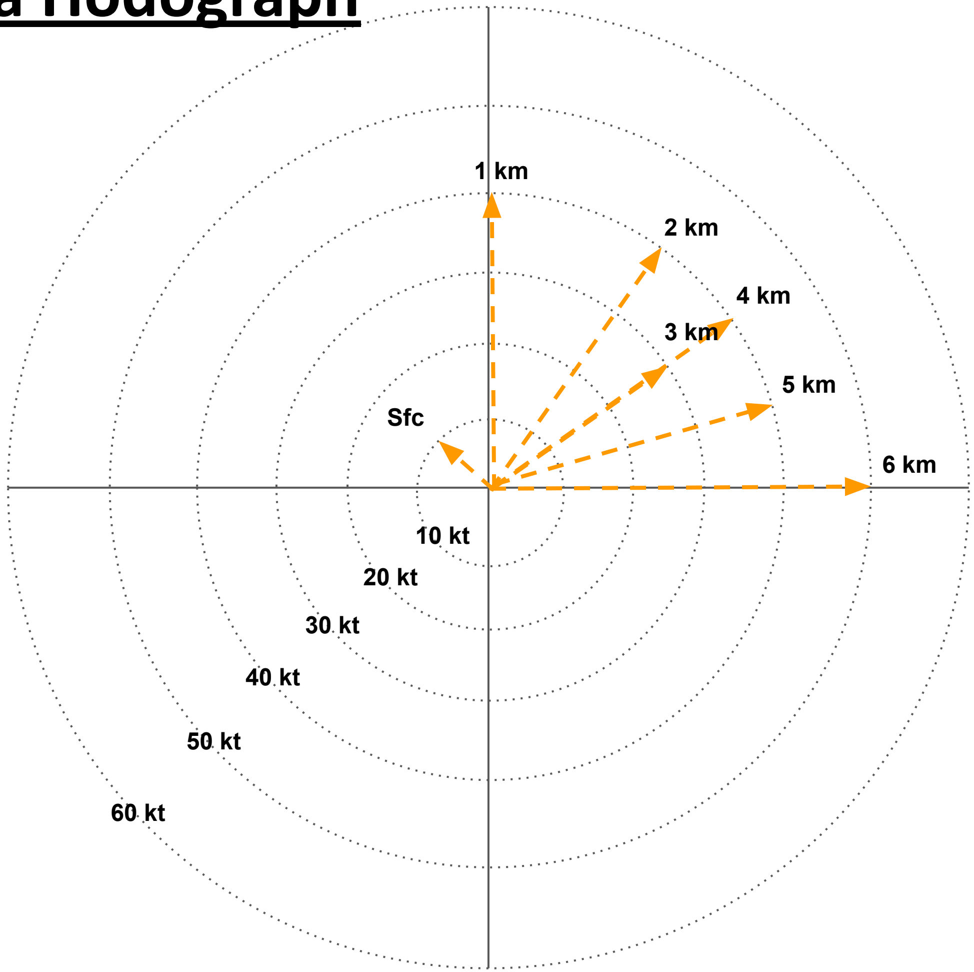


1. Take these wind barbs
and **convert them to vectors**

Plotting a Hodograph



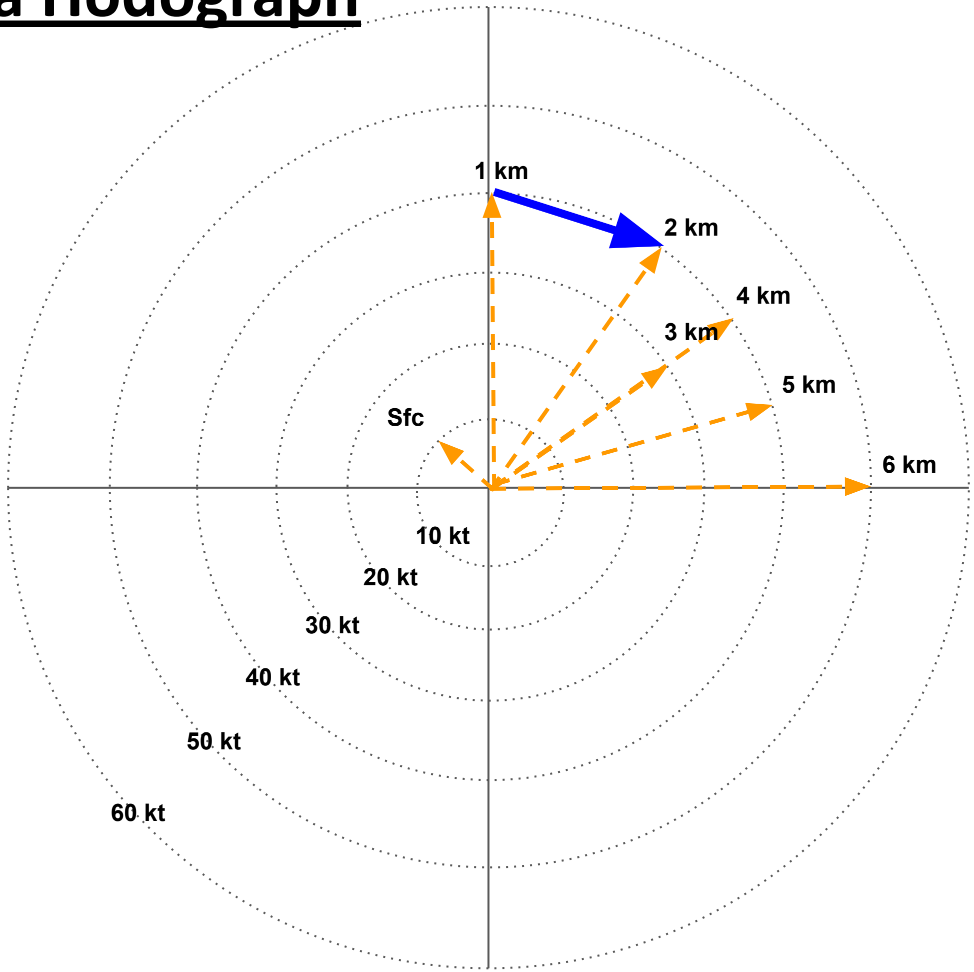
2. Plot wind vectors



Plotting a Hodograph

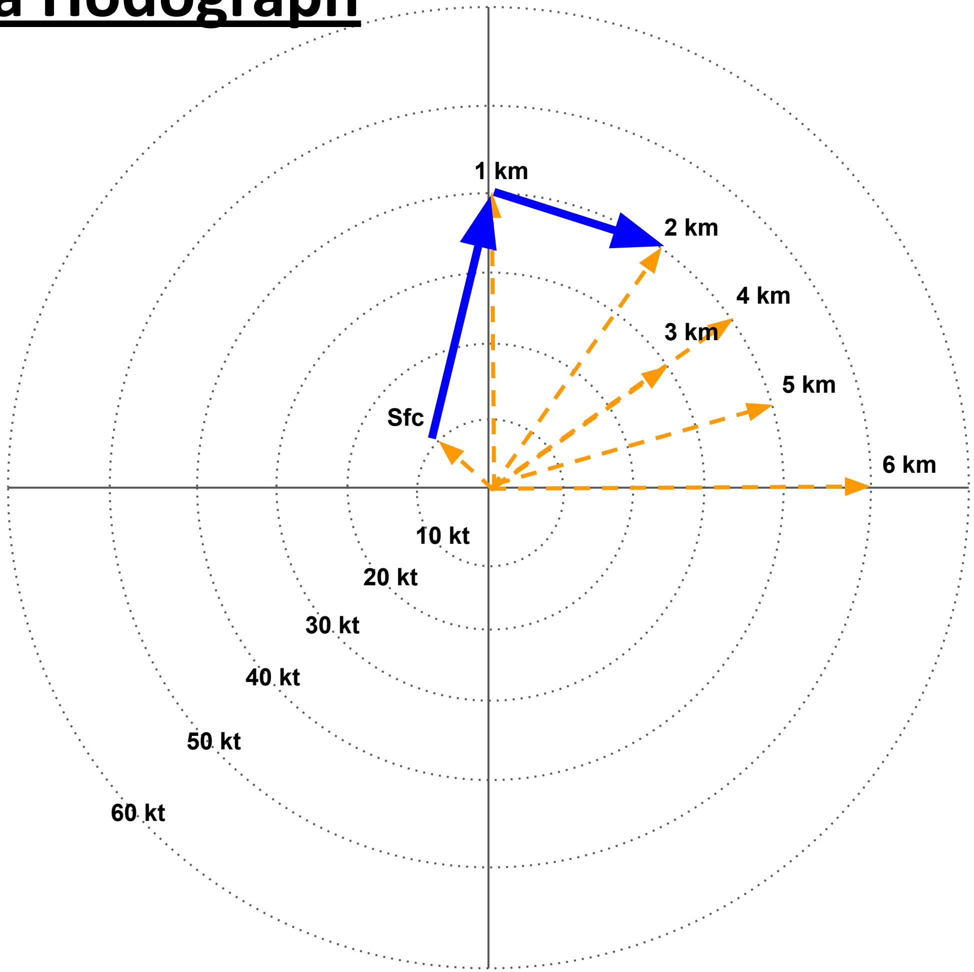
3. Connect the tips of the wind vectors

(This is the **vertical shear vector**!)



Plotting a Hodograph

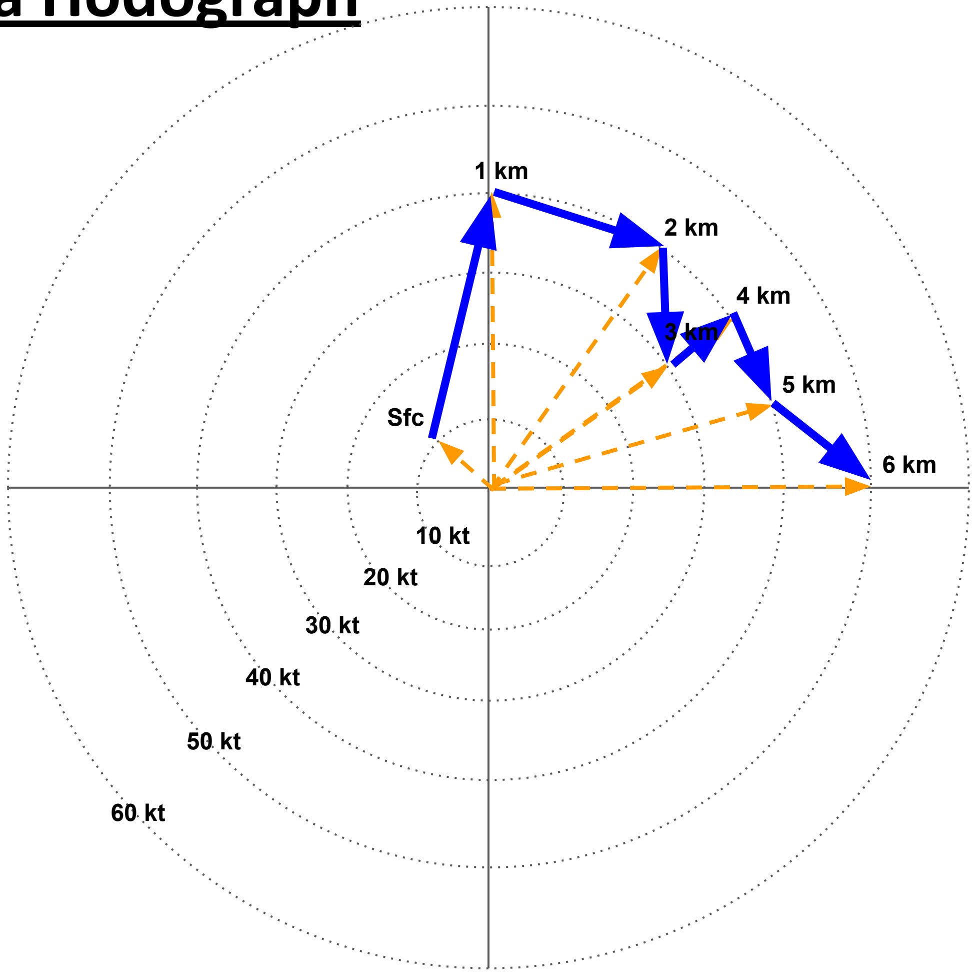
The longer the shear vector,
the stronger the shear!



Plotting a Hodograph

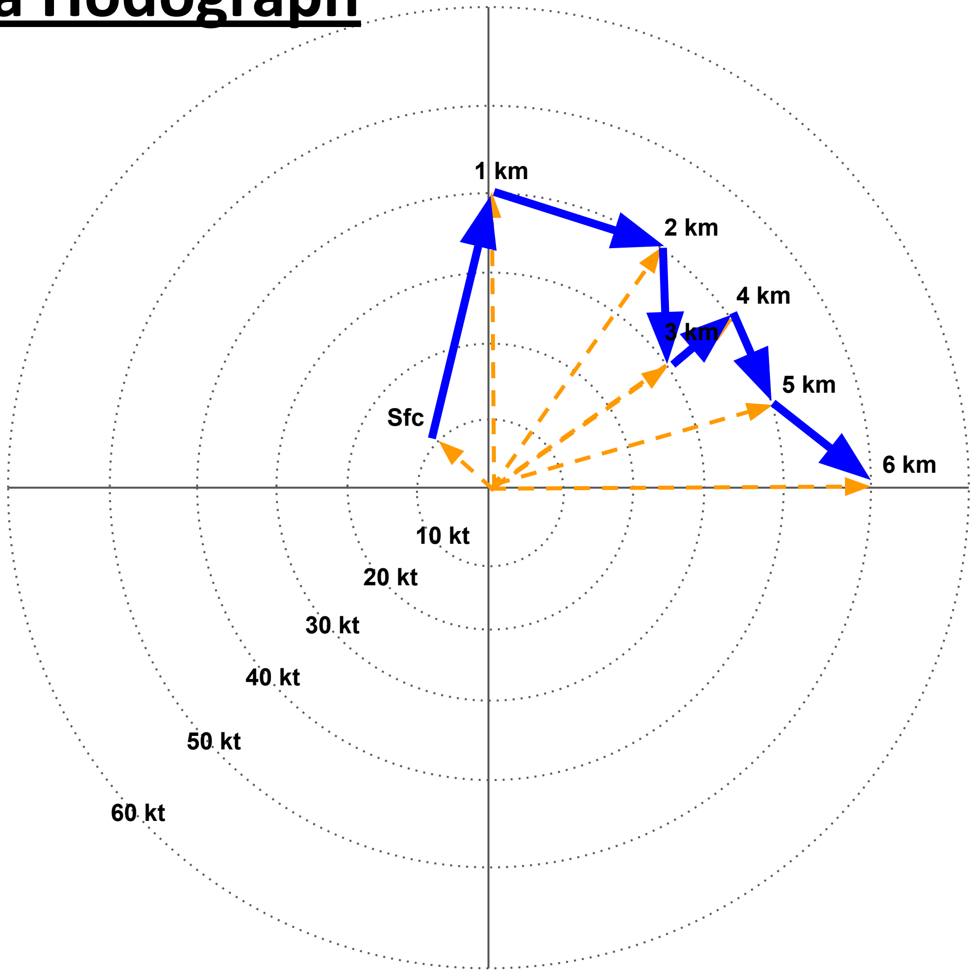
4. Draw all shear vectors

(This traces out the hodograph)



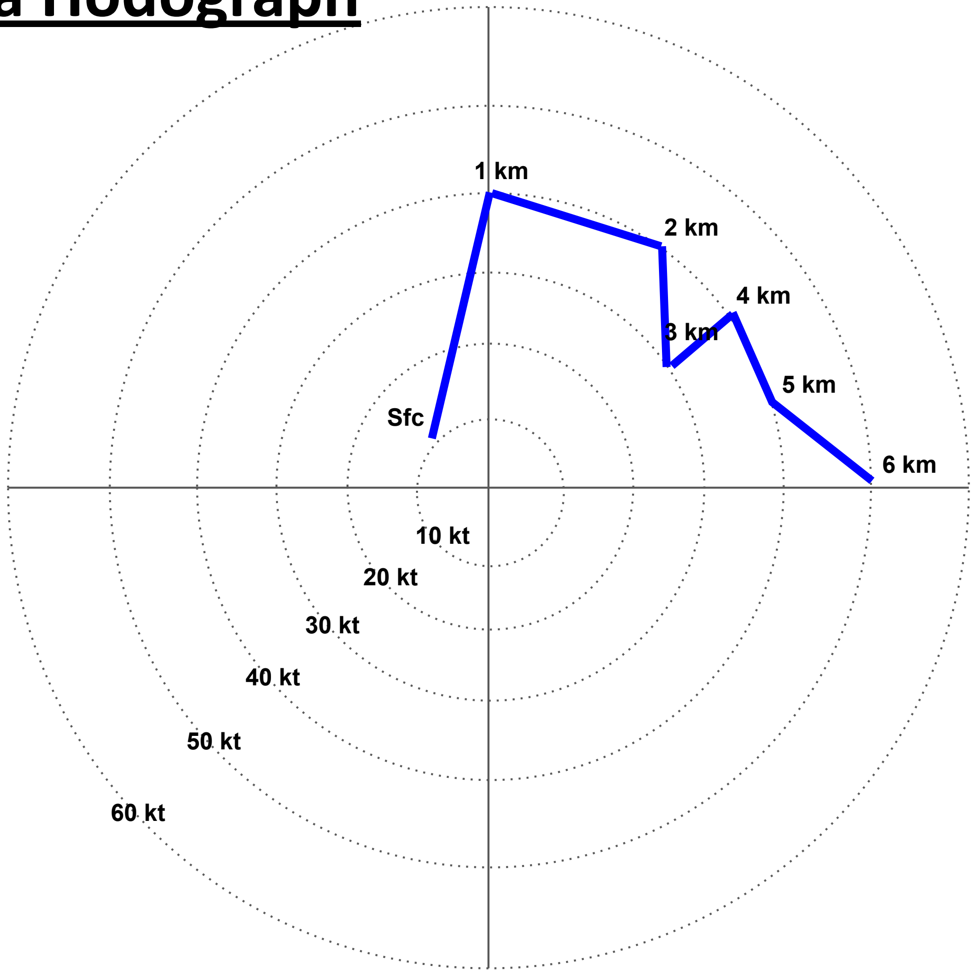
Plotting a Hodograph

The hodograph is a plot of vertical shear with height!



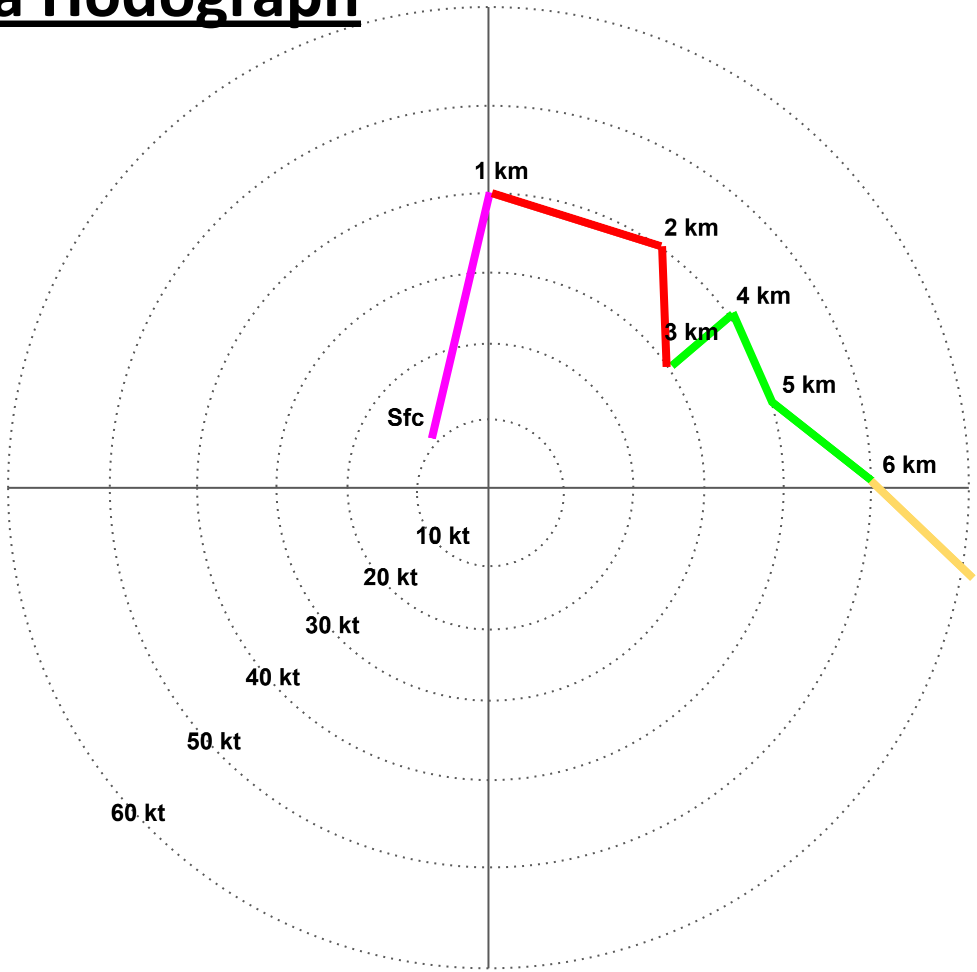
Plotting a Hodograph

In practice, the wind vectors are not plotted, just the hodograph!

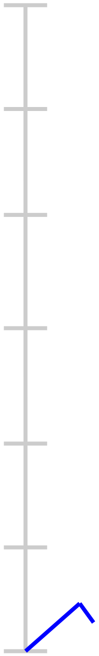


Plotting a Hodograph

Hodographs are often color-coded by level:

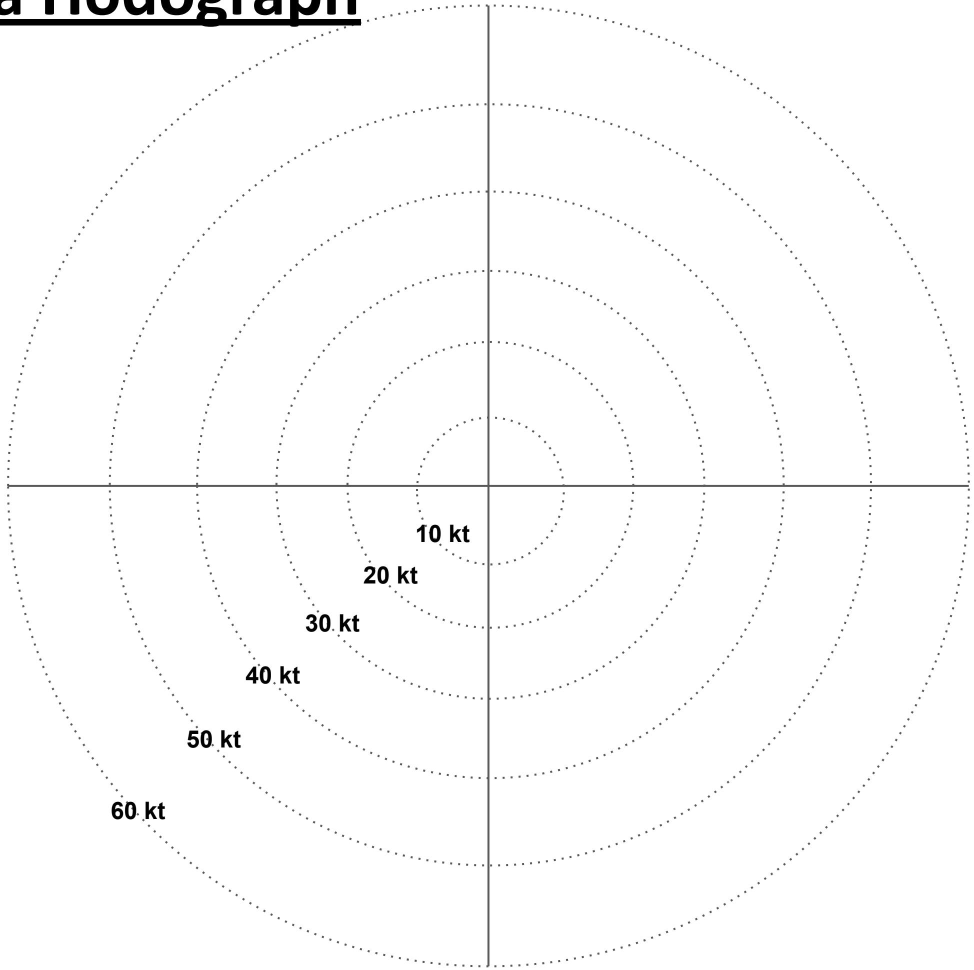


Plotting a Hodograph



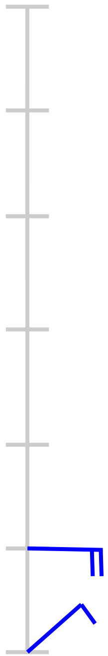
Now it’s your turn!

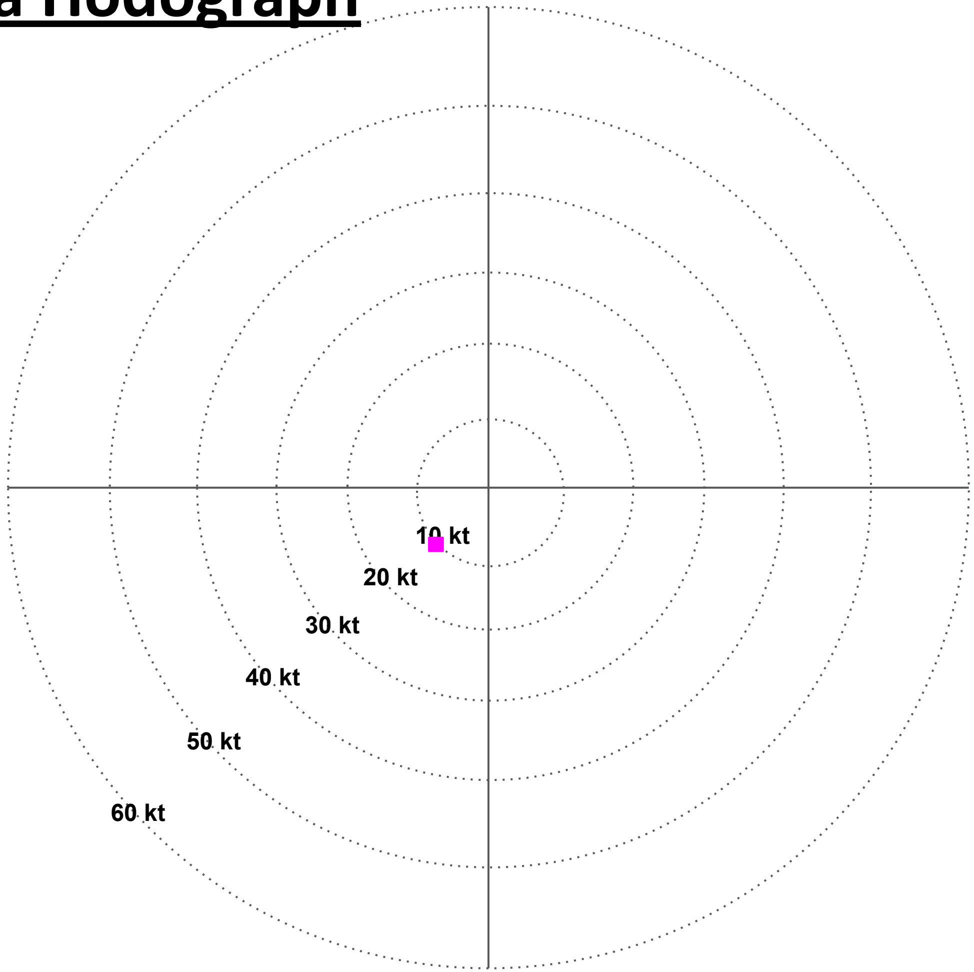
Click on the hodograph to draw the wind vector:



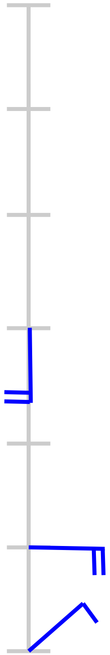
Plotting a Hodograph

You got it, Keep going!

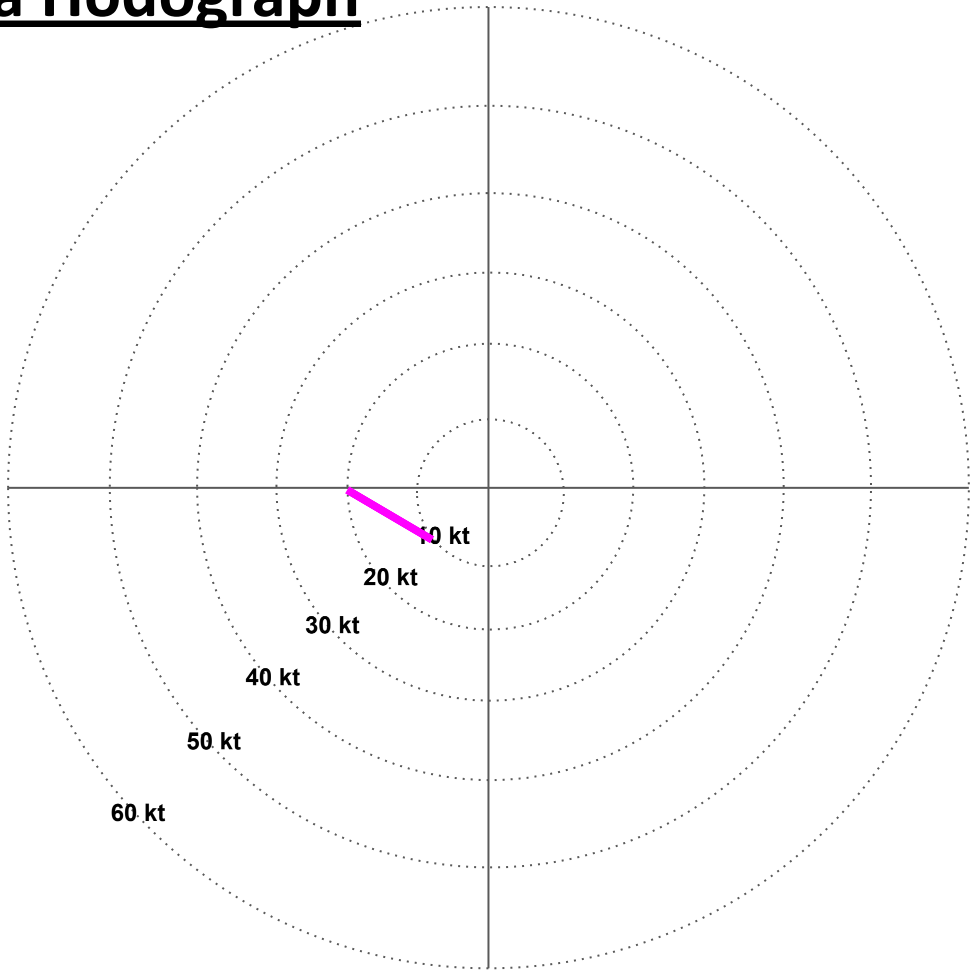




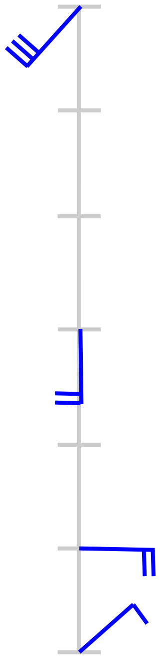
Plotting a Hodograph



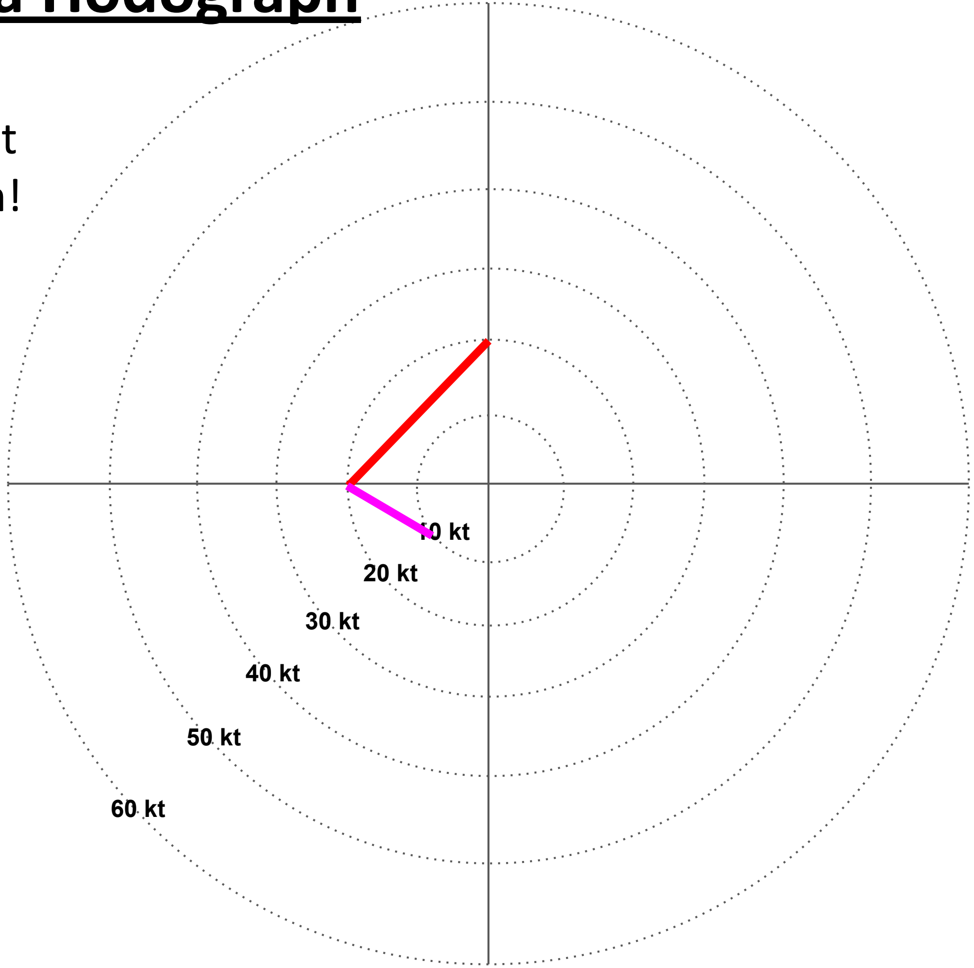
Yes! How about this one?



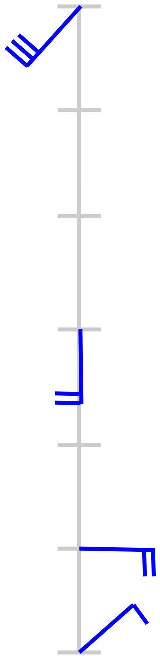
Plotting a Hodograph



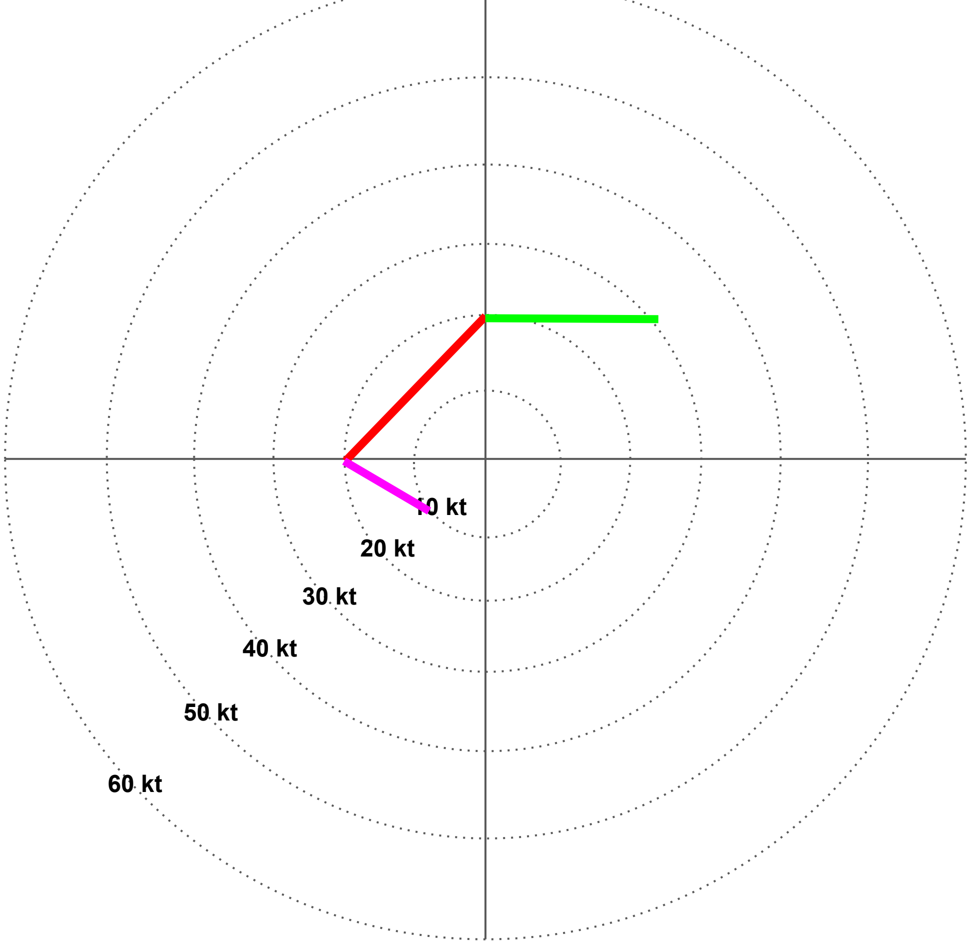
Correct! Click the final point to complete the hodograph!



Plotting a Hodograph



That was a ~breeze~ :)



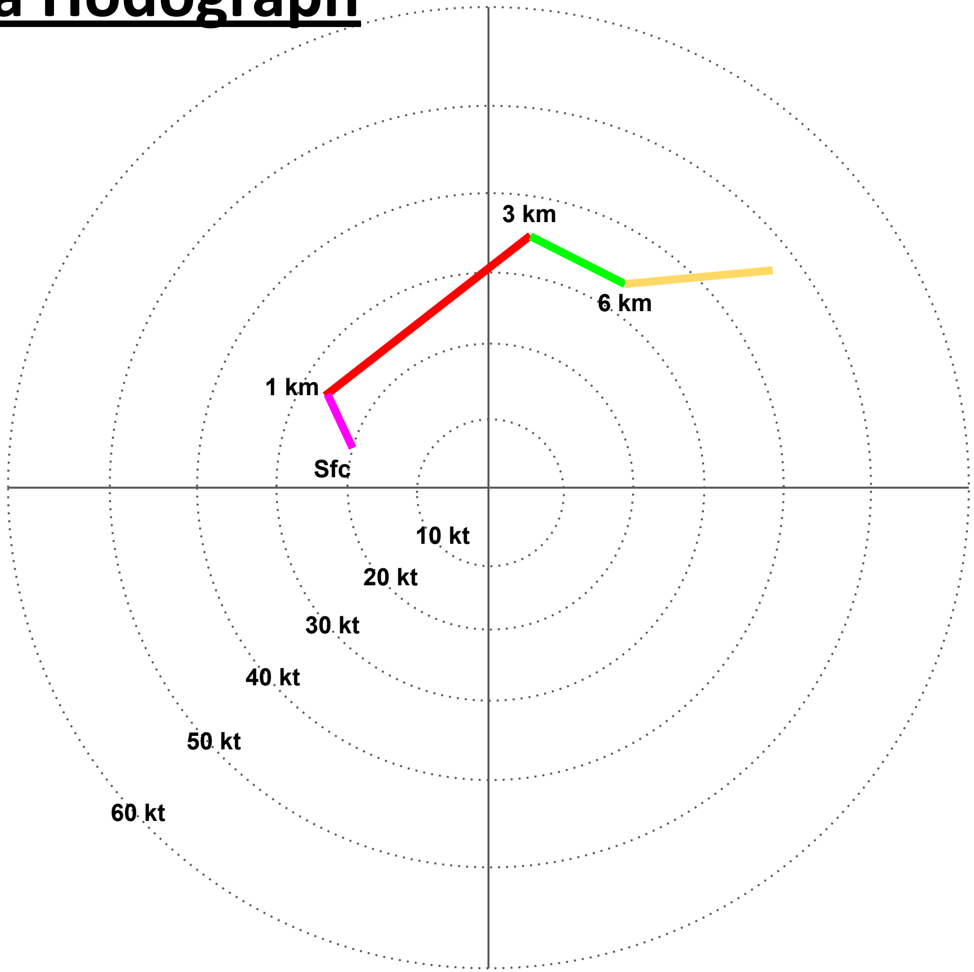
Plotting a Hodograph

Where is the strongest vertical shear located in this hodograph?

a. 3-6 km layer

b. 1-3 km layer

c. Sfc-1 km layer



Plotting a Hodograph

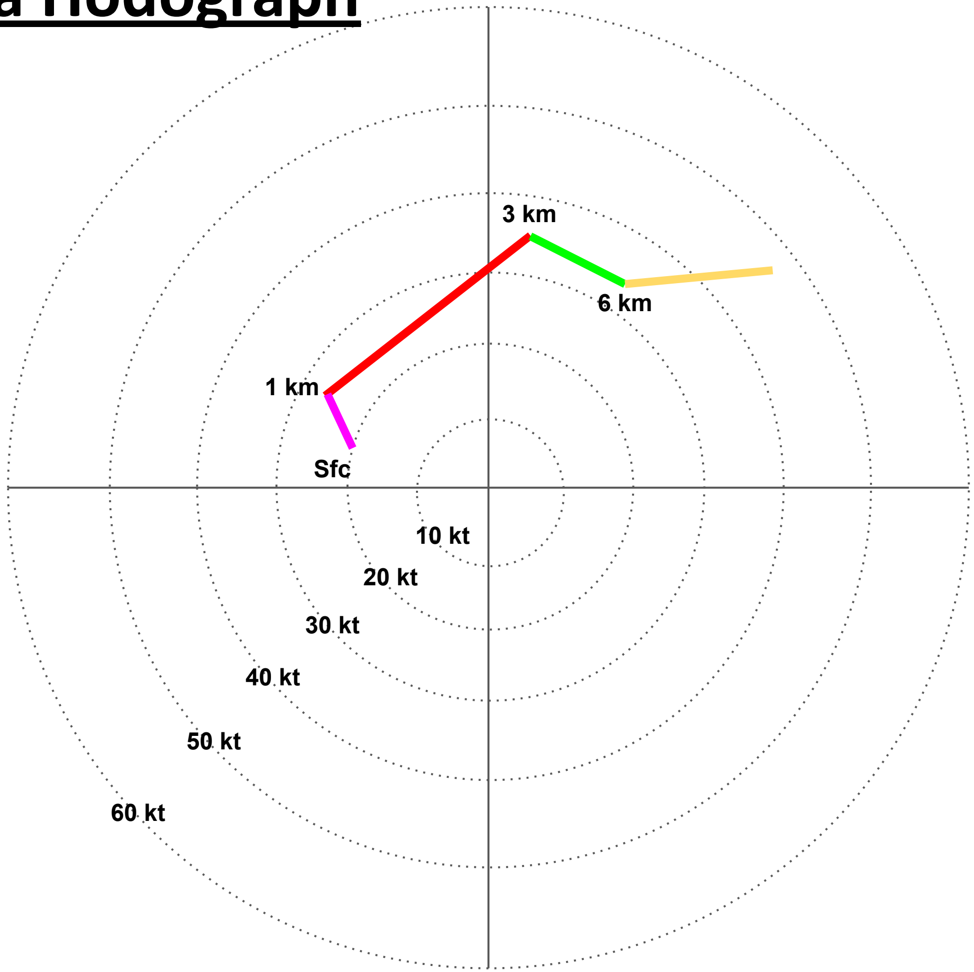
Where is the strongest vertical shear located in this hodograph?

a. 3-6 km layer

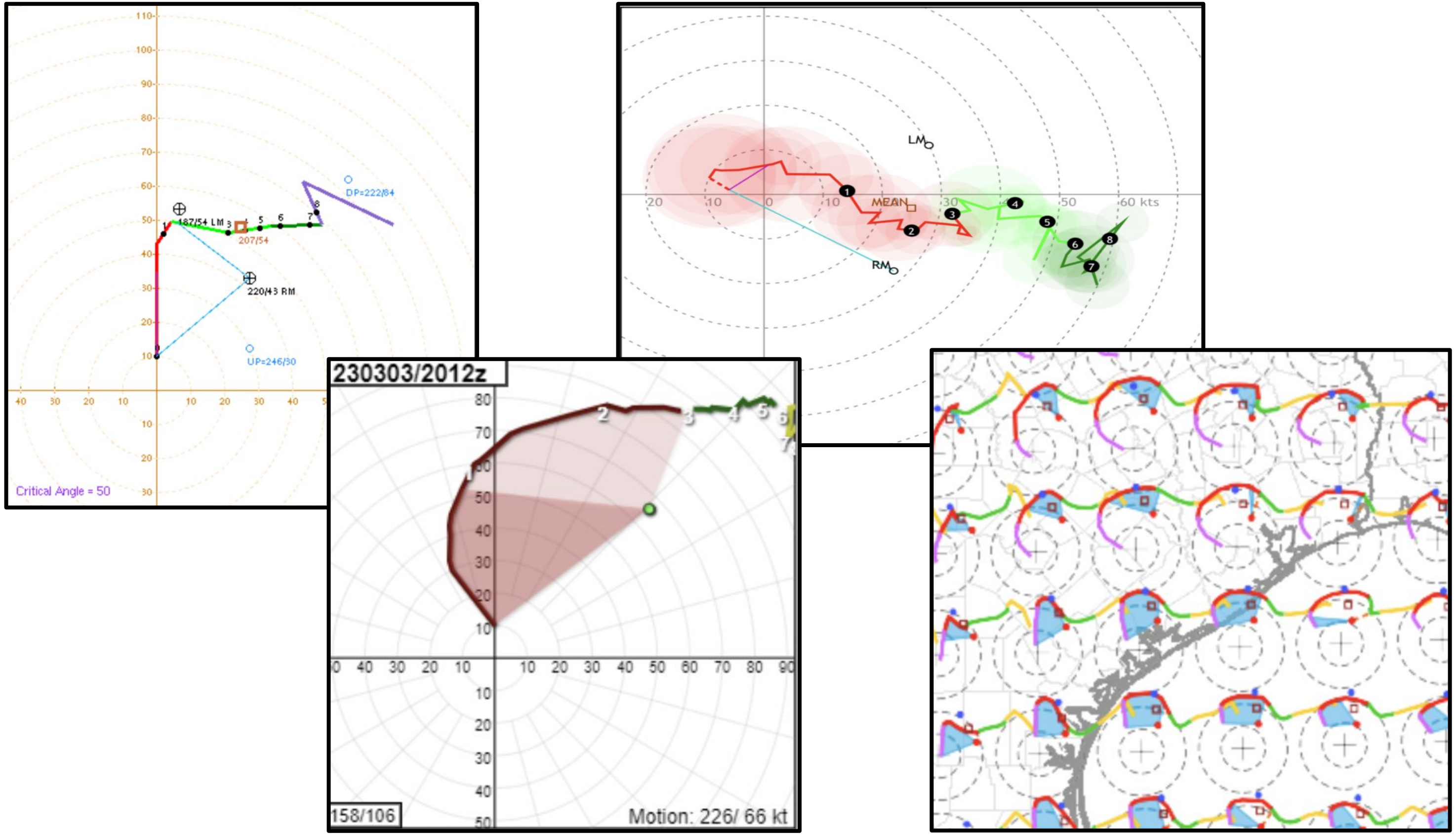
b. 1-3 km layer

c. Sfc-1 km layer

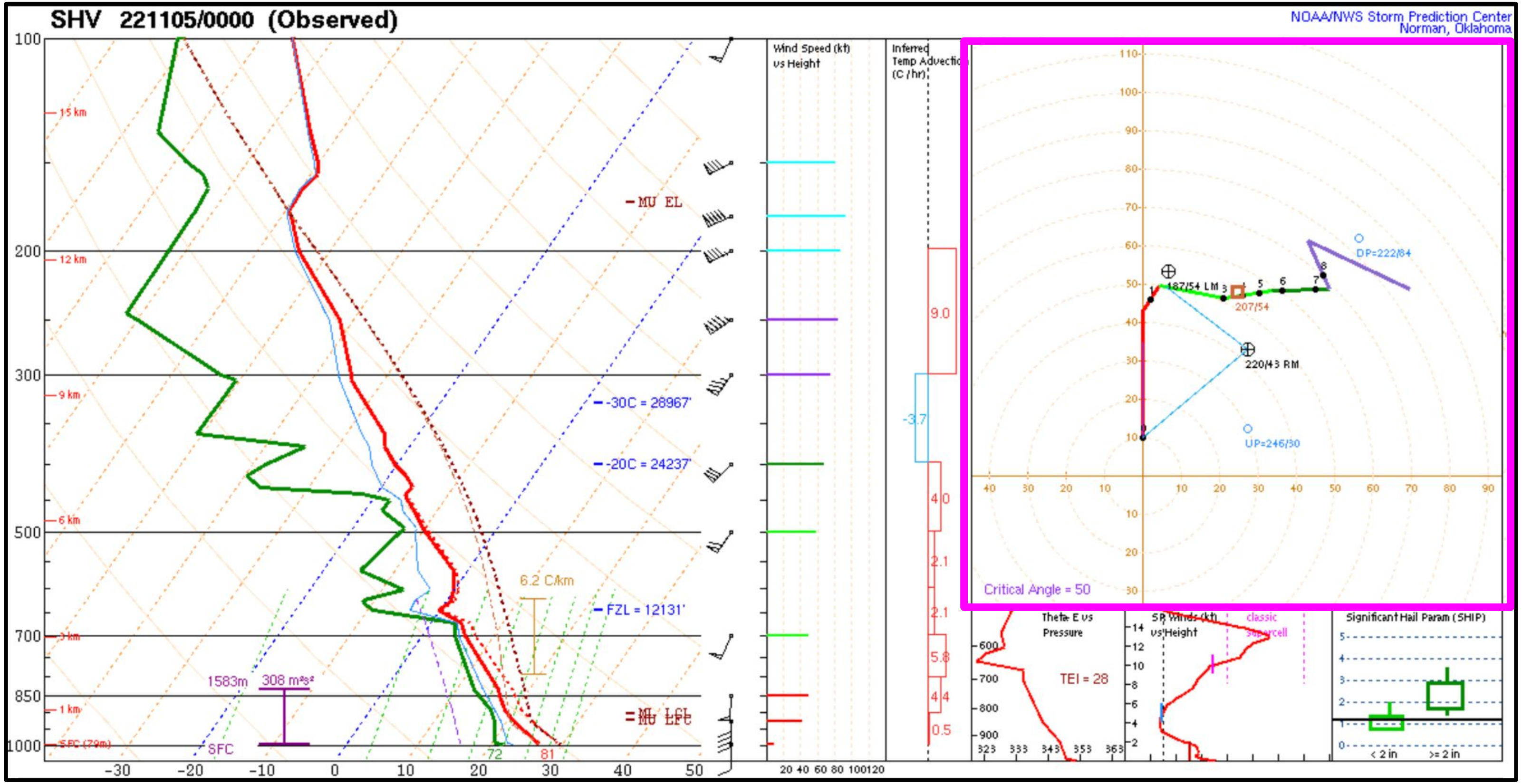
Correct!



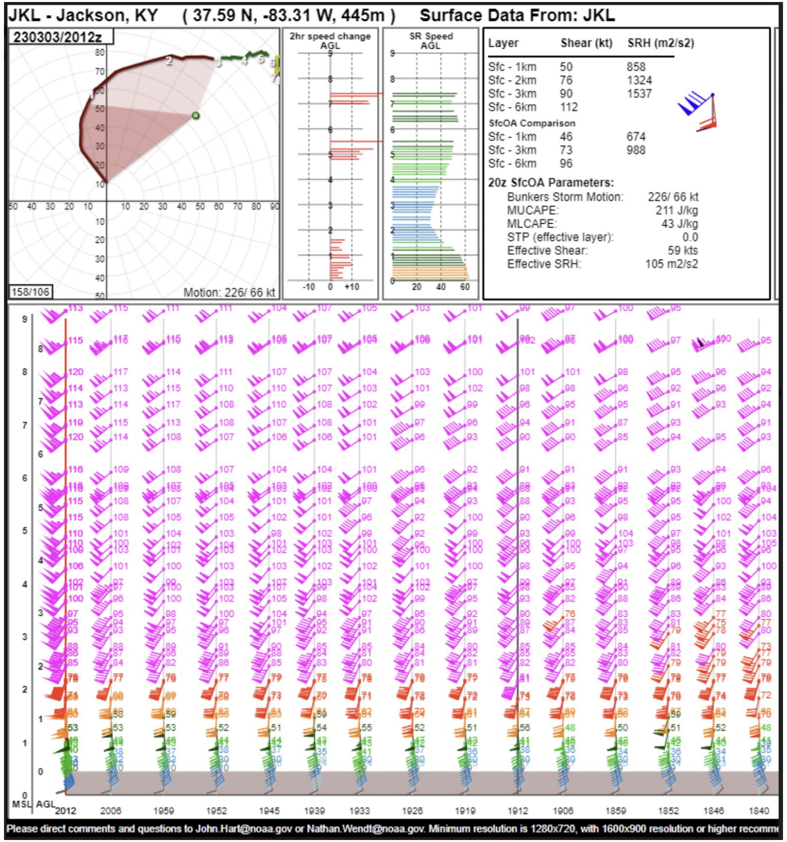
Where Can You Find Hodographs?

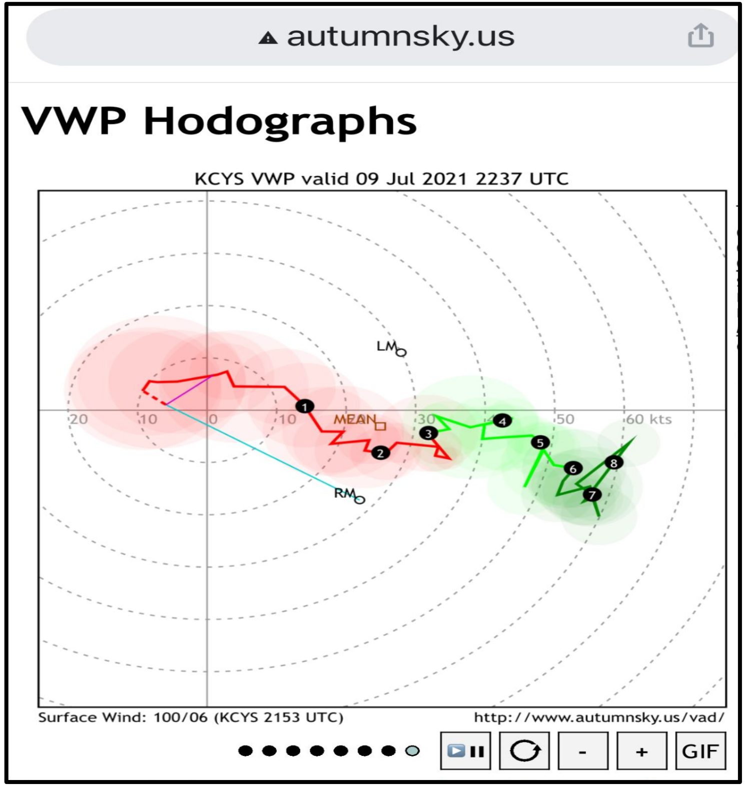


Observed Soundings

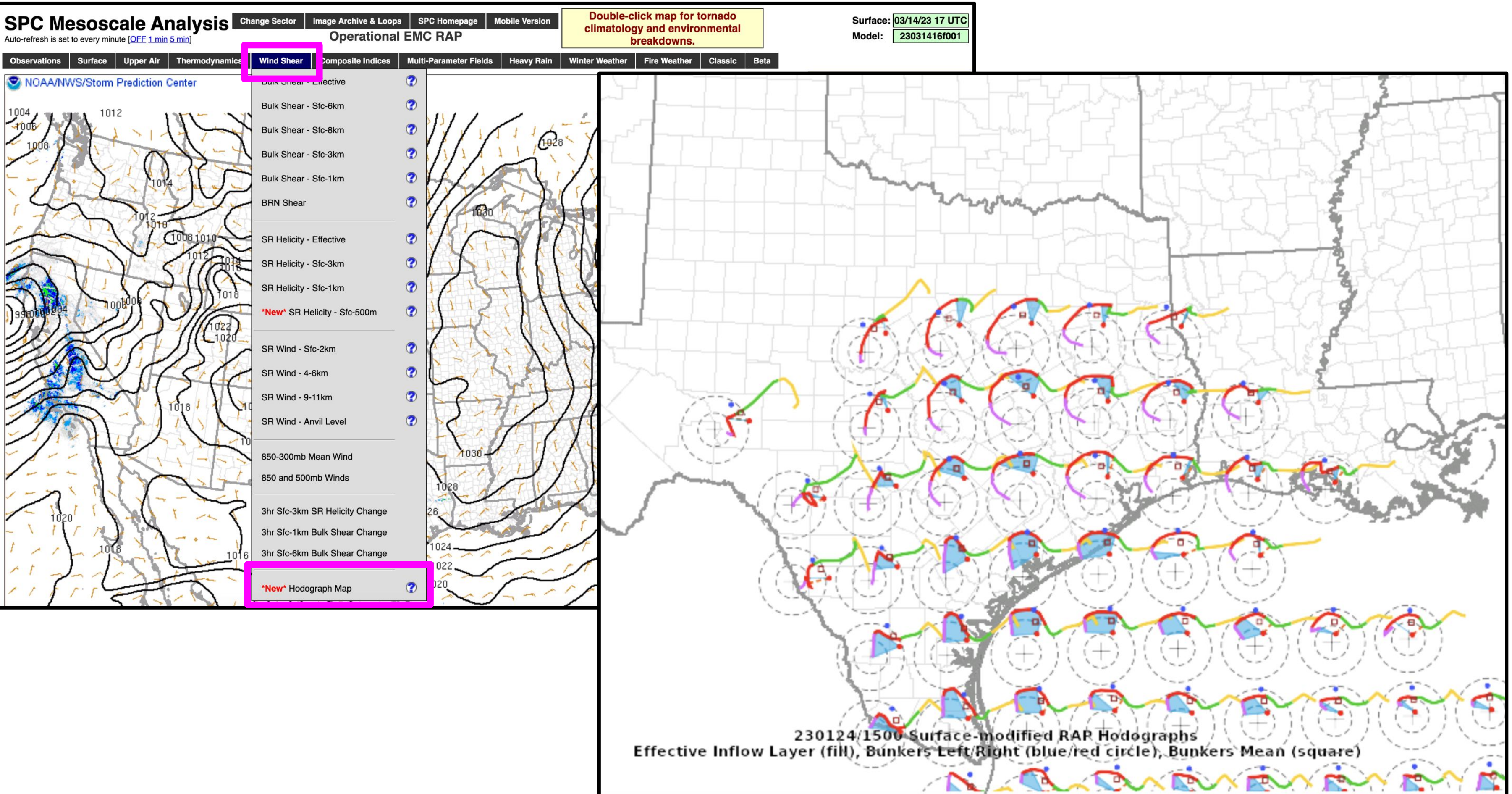


VWP Data

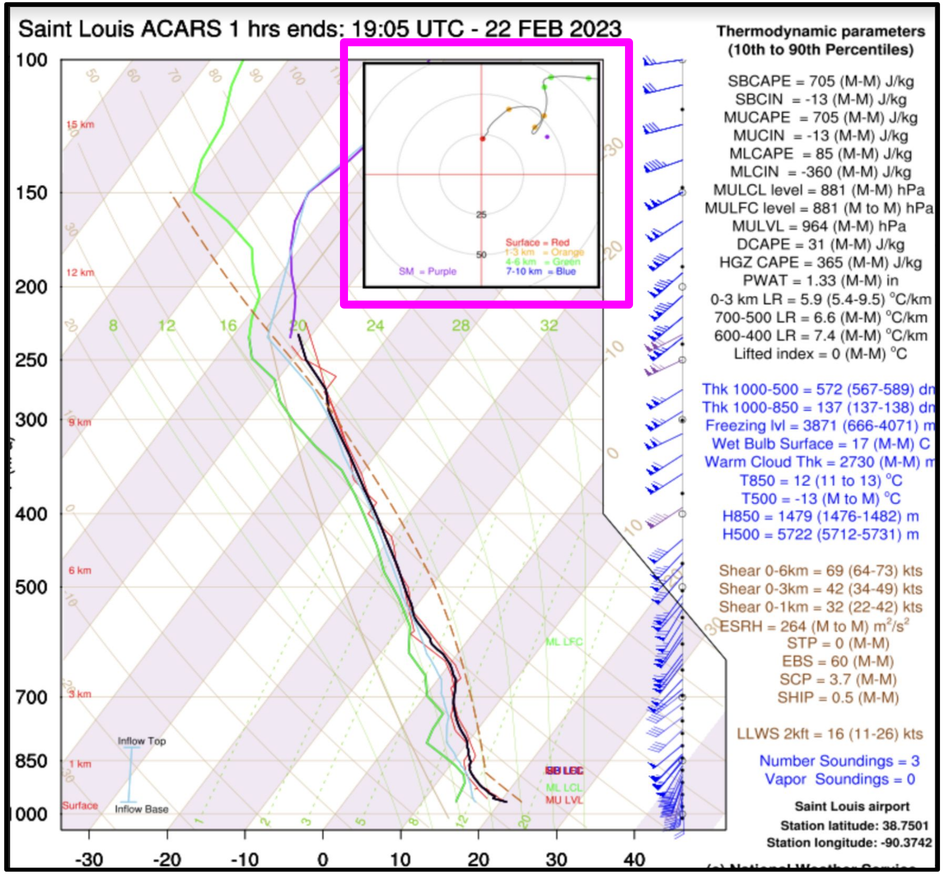

JKL - Jackson, KY (37.59 N, -83.31 W, 445m) Surface Data From: JKL
230303/2012z
158/106
Motion: 226/ 66 kt
2hr speed change AGL
SR Speed AGL
Layer Shear (kt) SRH (m2/s2)
Sfc - 1km 50 858
Sfc - 2km 76 1324
Sfc - 3km 90 1537
Sfc - 6km 112
SfcOA Comparison
Sfc - 1km 46 674
Sfc - 3km 73 988
Sfc - 6km 96
20z SfcOA Parameters:
Bunkers Storm Motion: 226/ 66 kt
MUCAPE: 211 J/kg
MLCAPE: 43 J/kg
STP (effective layer): 0.0
Effective Shear: 59 kts
Effective SRH: 105 m2/s2
MSL AGL
Please direct comments and questions to John.Hart@noaa.gov or Nathan.Wendt@noaa.gov. Minimum resolution is 1280x720, with 1600x900 resolution or higher recomme


autumnsky.us
VWP Hodographs
KCYS VWP valid 09 Jul 2021 2237 UTC
LM
MEAN
RM
60 kts
Surface Wind: 100/06 (KCYS 2153 UTC)
http://www.autumnsky.us/vad/
-
+
GIF

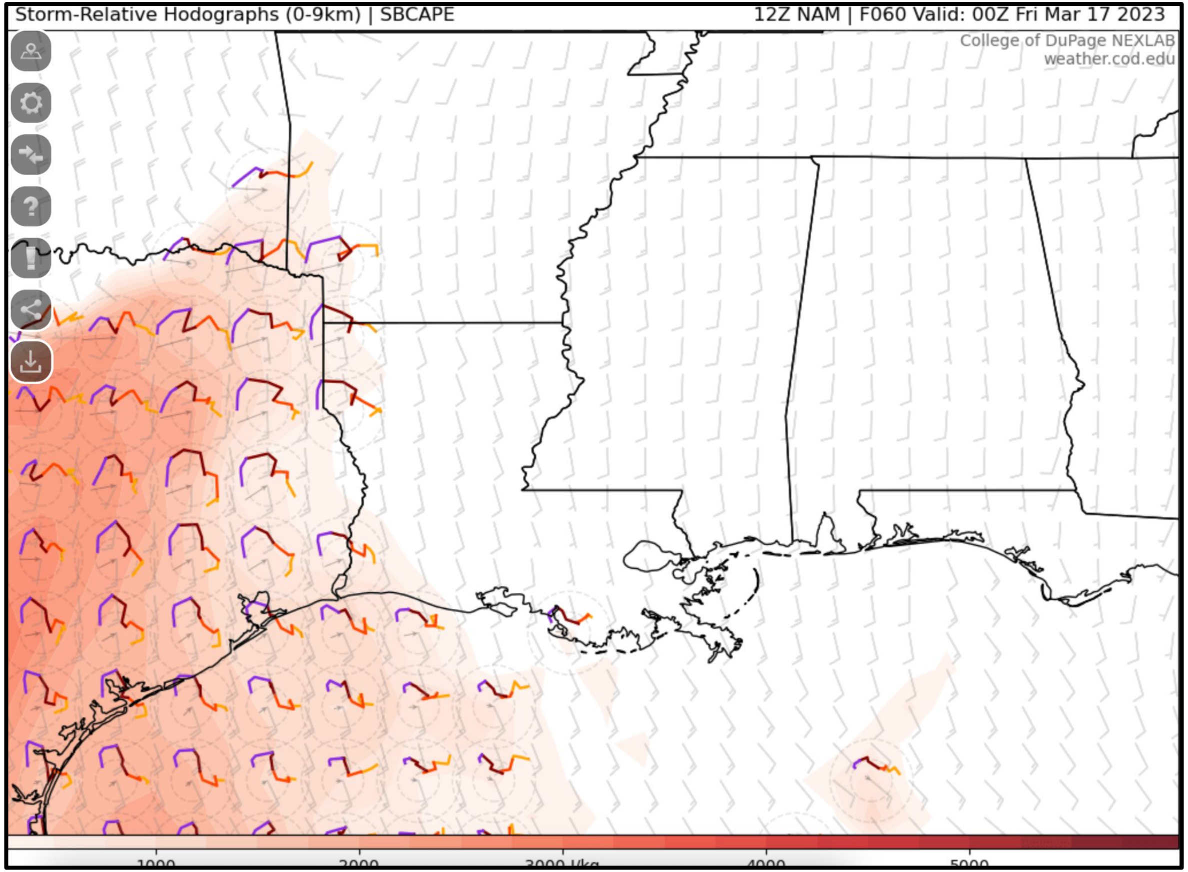
SPC Mesoanalysis



ACARS Data


Saint Louis ACARS 1 hrs ends: 19:05 UTC - 22 FEB 2023
Thermodynamic parameters
(10th to 90th Percentiles)
SBCAPE = 705 (M-M) J/kg
SBCIN = -13 (M-M) J/kg
MUCAPE = 705 (M-M) J/kg
MUCIN = -13 (M-M) J/kg
MLCAPE = 85 (M-M) J/kg
MLCIN = -360 (M-M) J/kg
MULCL level = 881 (M-M) hPa
MULFC level = 881 (M to M) hPa
MULVL = 964 (M-M) hPa
DCAPE = 31 (M-M) J/kg
HGZ CAPE = 365 (M-M) J/kg
PWAT = 1.33 (M-M) in
0-3 km LR = 5.9 (5.4-9.5) °C/km
700-500 LR = 6.6 (M-M) °C/km
600-400 LR = 7.4 (M-M) °C/km
Lifted index = 0 (M-M) °C
Thk 1000-500 = 572 (567-589) dm
Thk 1000-850 = 137 (137-138) dm
Freezing lvl = 3871 (666-4071) m
Wet Bulb Surface = 17 (M-M) C
Warm Cloud Thk = 2730 (M-M) m
T850 = 12 (11 to 13) °C
T500 = -13 (M to M) °C
H850 = 1479 (1476-1482) m
H500 = 5722 (5712-5731) m
Shear 0-6km = 69 (64-73) kts
Shear 0-3km = 42 (34-49) kts
Shear 0-1km = 32 (22-42) kts
ESRH = 264 (M to M) m²/s²
STP = 0 (M-M)
EBS = 60 (M-M)
SCP = 3.7 (M-M)
SHIP = 0.5 (M-M)
LLWS 2kft = 16 (11-26) kts
Number Soundings = 3
Vapor Soundings = 0
Saint Louis airport
Station latitude: 38.7501
Station longitude: -90.3742
Surface = Red
1-3 km = Orange
4-6 km = Green
7-10 km = Blue
SM = Purple
15 km
12 km
9 km
6 km
3 km
1 km
Surface
Inflow Top
Inflow Base
ML LFC
SB LCL
ML LCL
MU LVL
100
150
200
250
300
400
500
700
850
1000
-30
-20
-10
0
10
20
30
40

Model Data



Storm-Relative Hodographs (0-9km) | SBCAPE
12Z NAM | F060 Valid: 00Z Fri Mar 17 2023
College of DuPage NEXLAB
weather.cod.edu
1000
2000
3000 J/kg
4000
5000

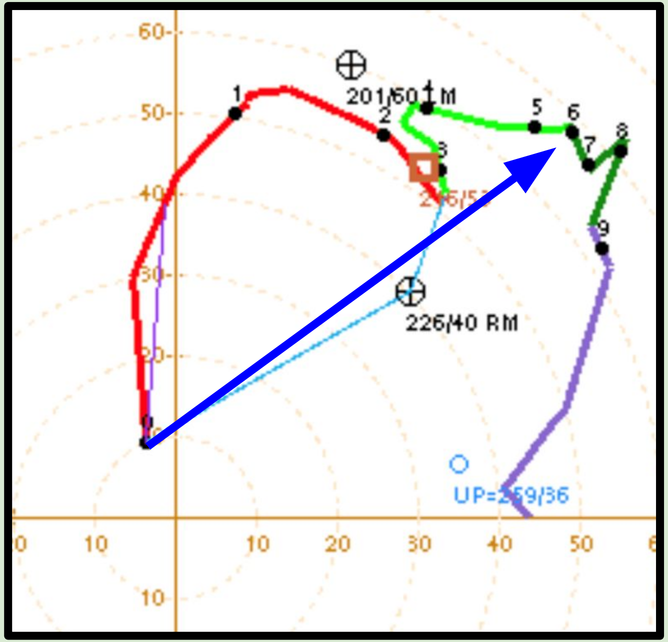
Hodograph Fundamentals Summary

1. Hodograph is a plot of vertical wind shear with height.

2. The length and shape of the hodograph have direct implications on storm mode, evolution, and overall behavior (more to come on this).

3. Understand how a hodograph is plotted.

Lesson 2: Bulk Shear

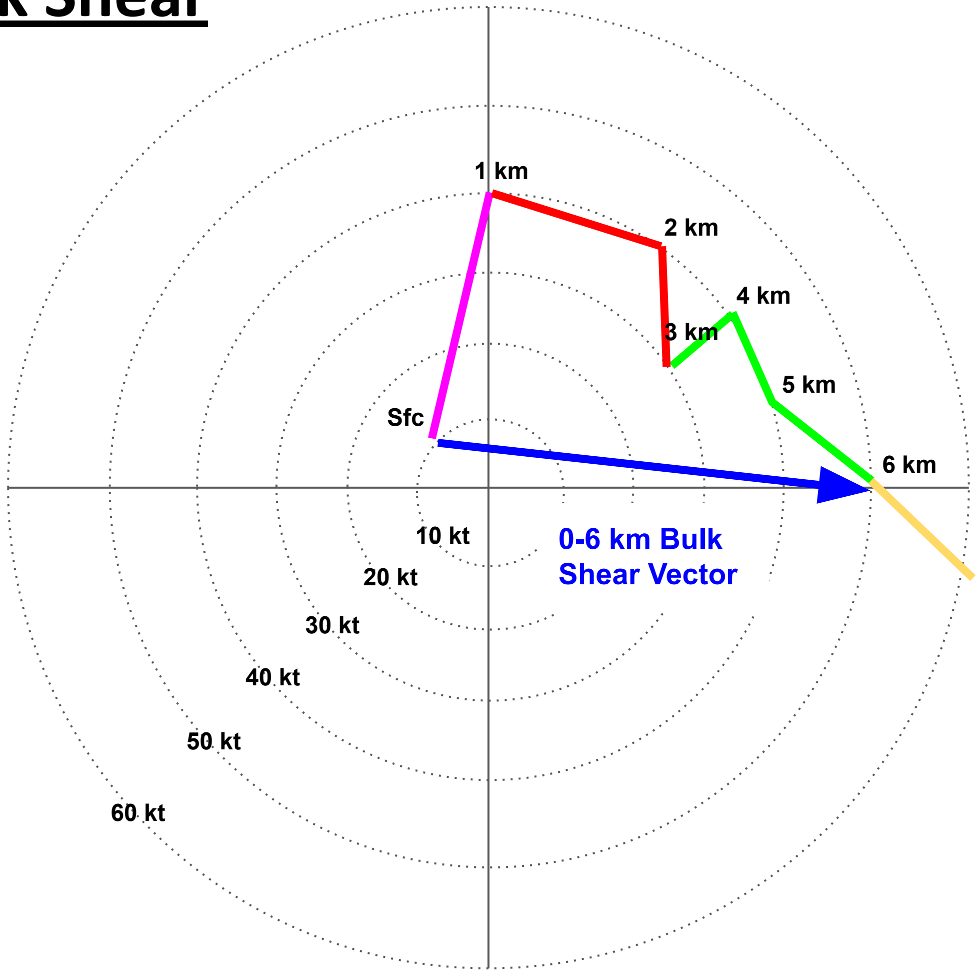


Cameron Nixon – Research Scientist, SPC / CIWRO
(cameron.nixon@noaa.gov)

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

Bulk Shear

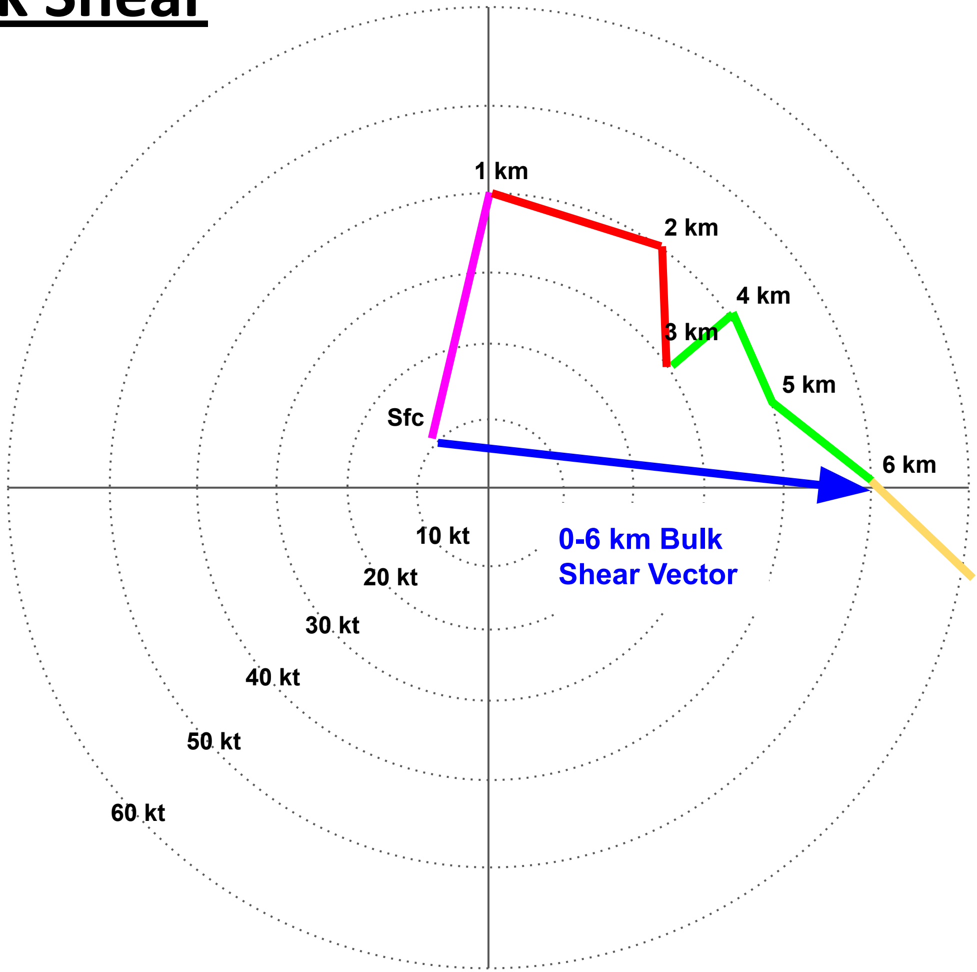
Bulk Shear is the difference in wind between *any* two levels on the hodograph



Bulk Shear

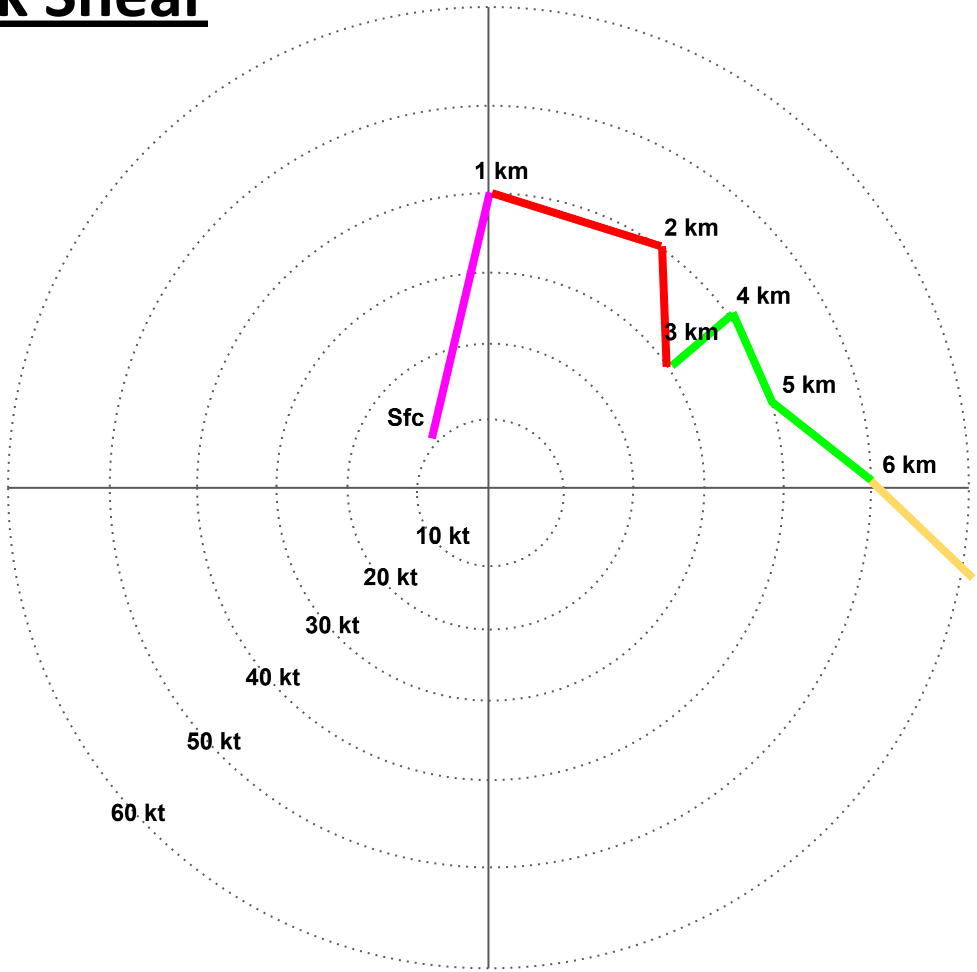
Bulk Shear is the difference in wind between *any* two levels on the hodograph

In this case, we have ~60 kts of 0-6 km bulk shear



Bulk Shear

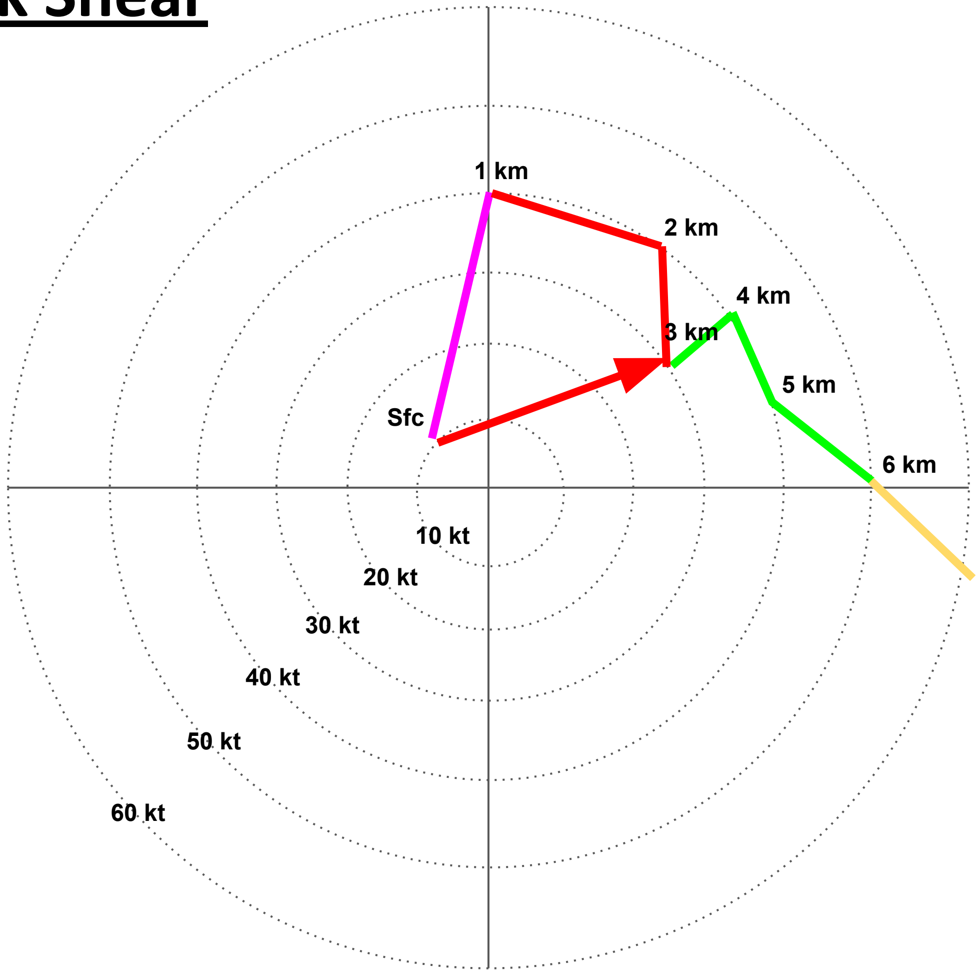
Draw a 0-3 km shear vector!



Bulk Shear

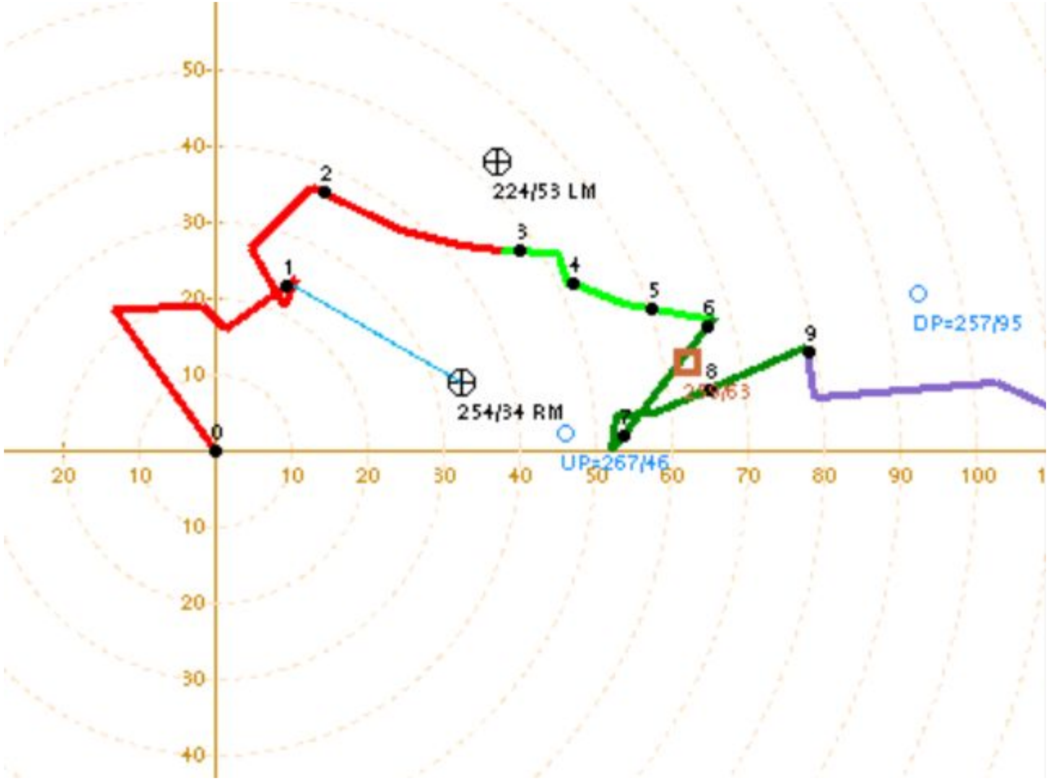
Draw a 0-3 km shear vector!

Excellent!!



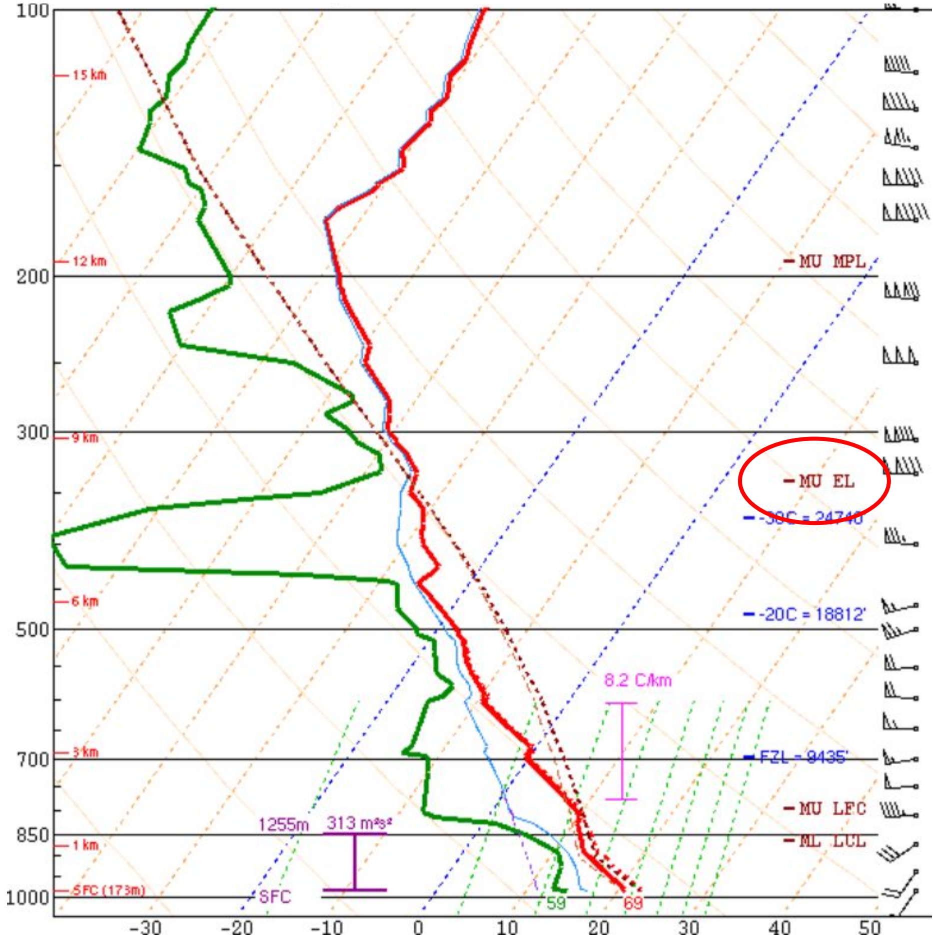
Bulk Shear

How much of the hodograph matters for convective storms?



Bulk Shear

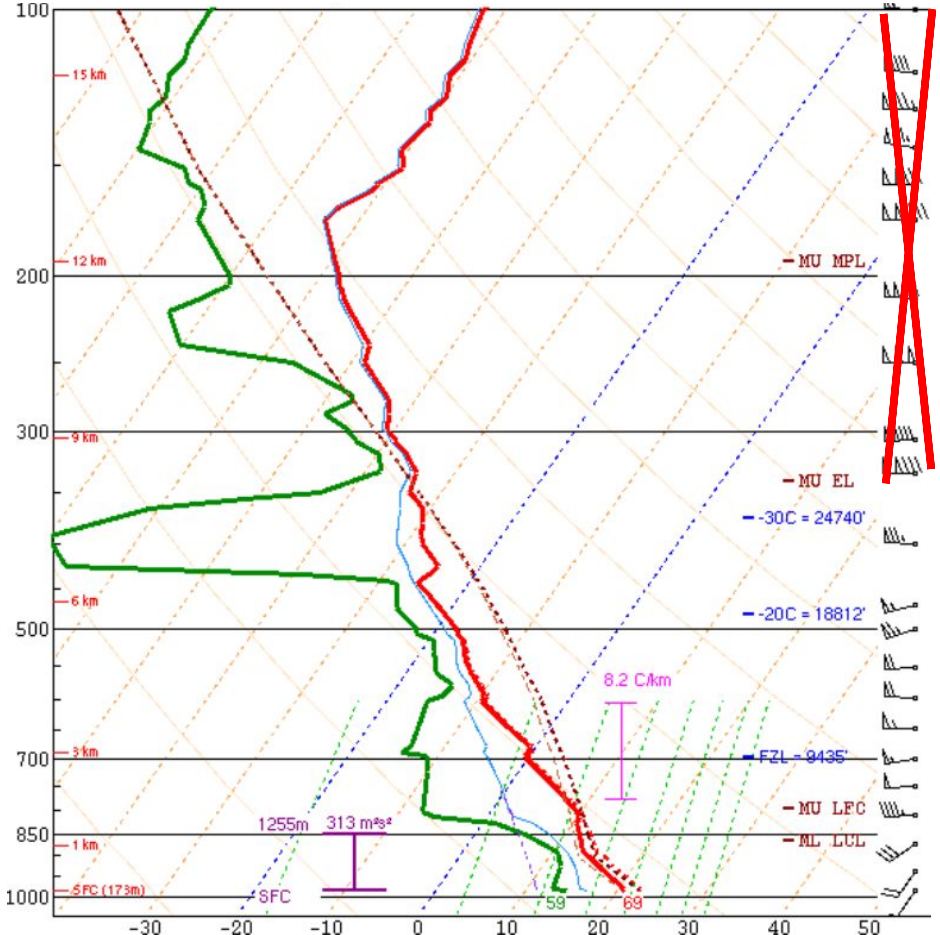
Generally, shear only matters up to the **equilibrium level**.



Bulk Shear

Generally, shear only matters up to the **equilibrium level**.

In this case, we can neglect shear above 8 km.



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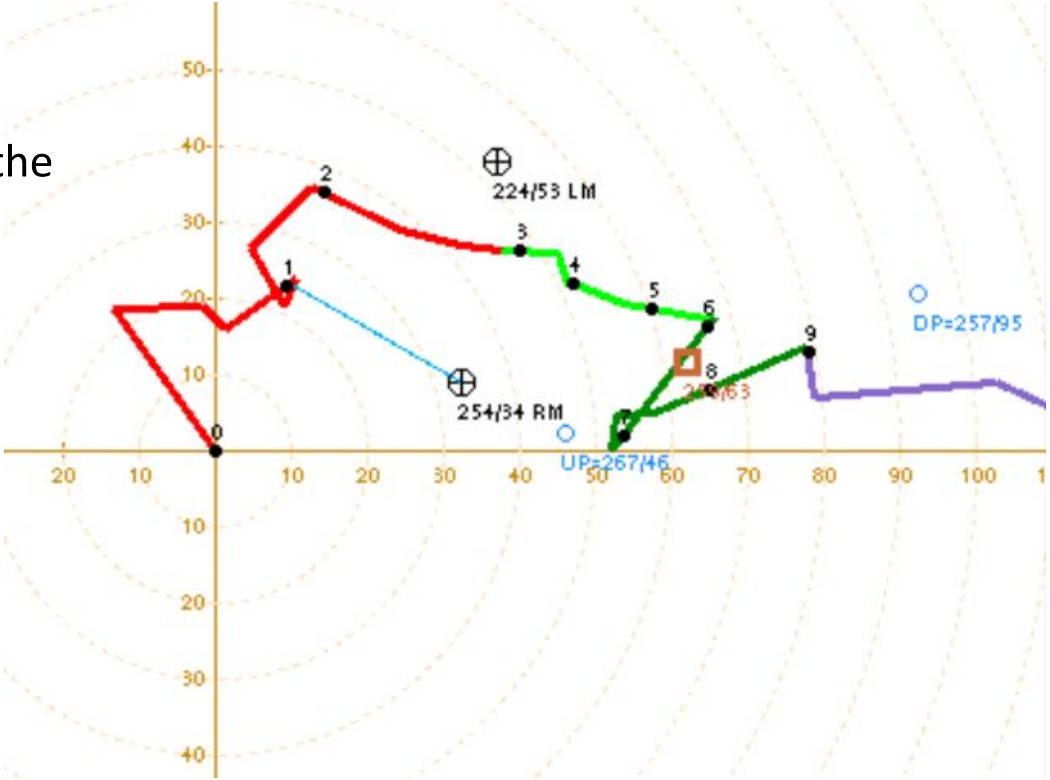

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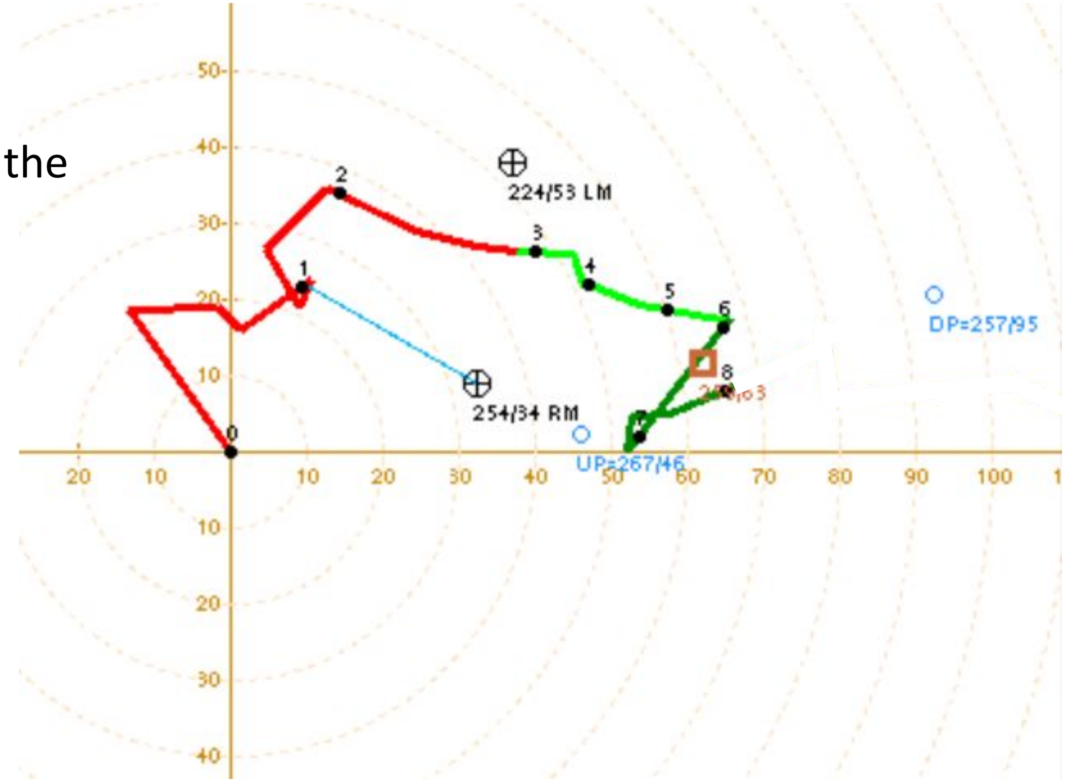
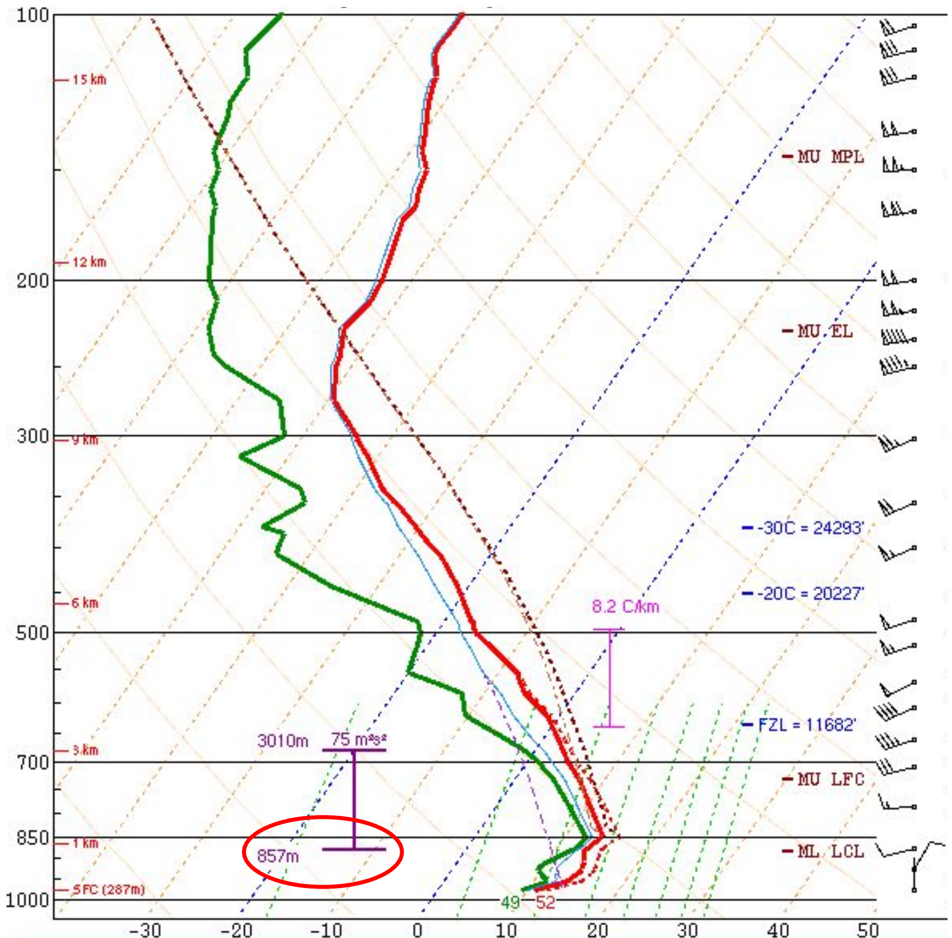
In this case, we can neglect shear above 8 km.



Bulk Shear

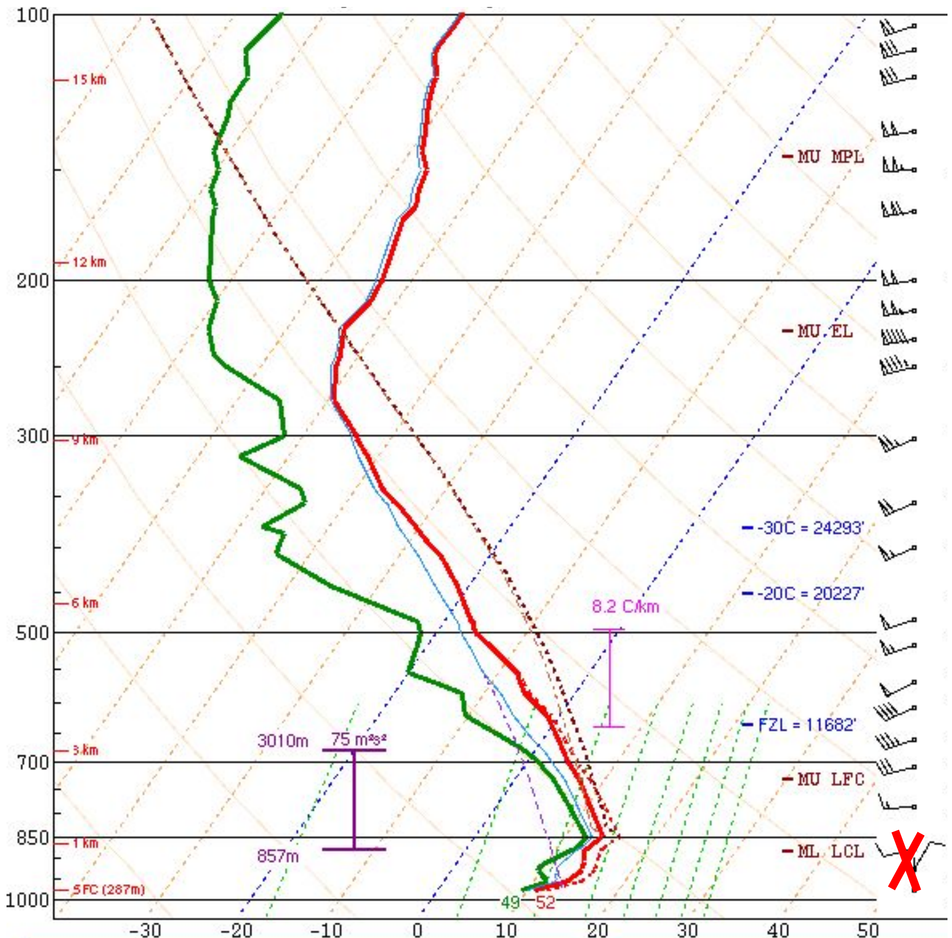
Generally, shear only matters above the **effective inflow base**.



Bulk Shear

Generally, shear only matters above the **effective inflow base**.

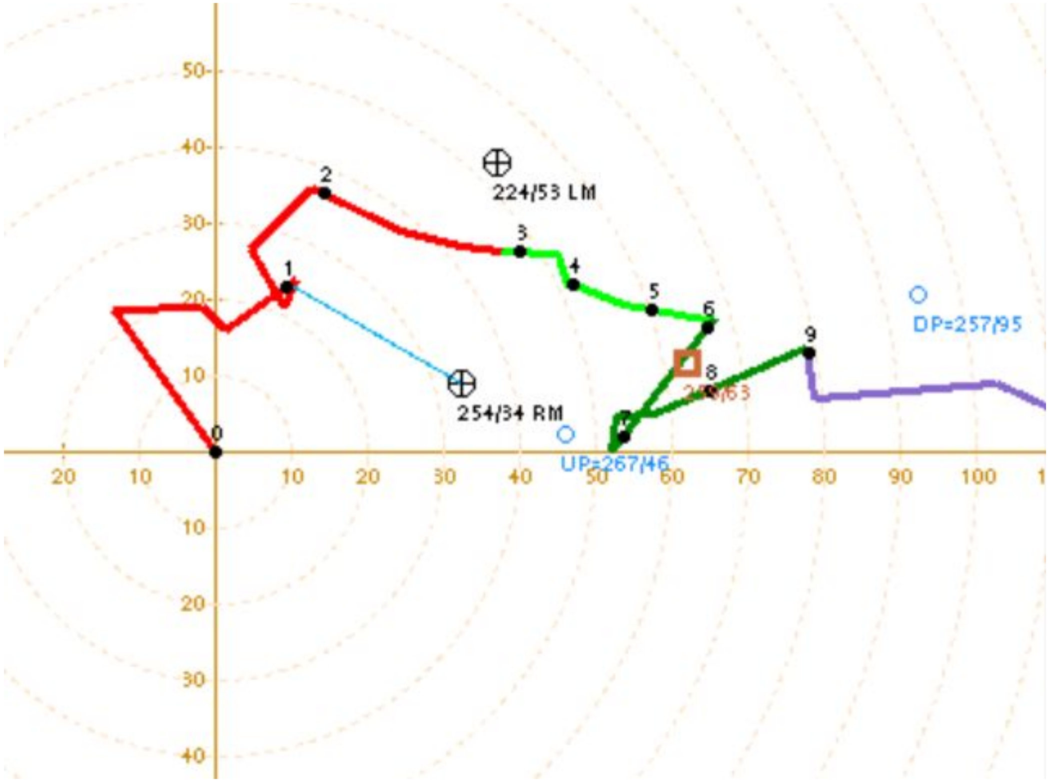
In this case, we can neglect shear below 800 m



Bulk Shear

Generally, shear only matters above the **effective inflow base**.

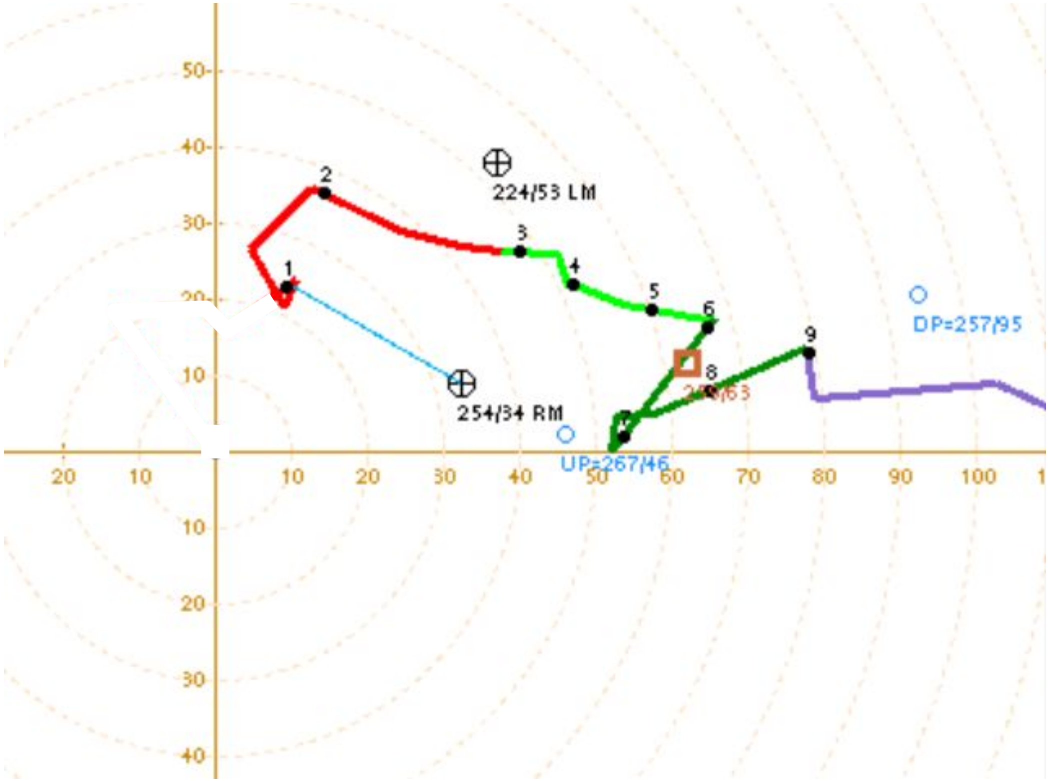
In this case, we can neglect shear below 1 km.



Bulk Shear

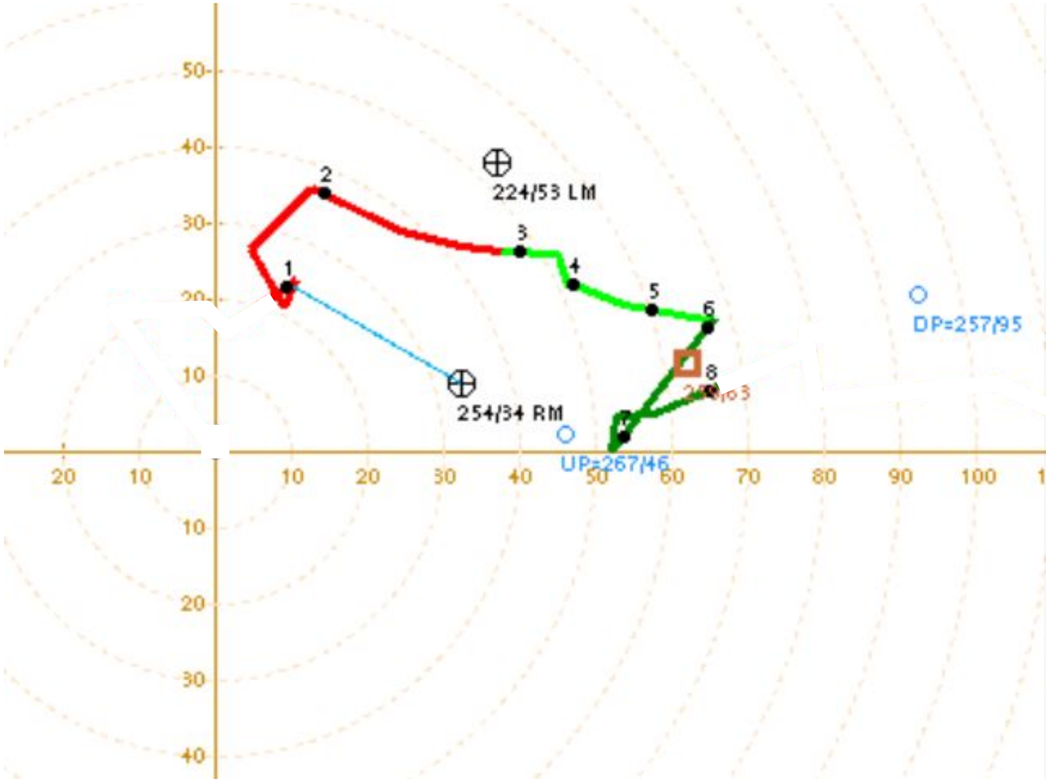
Generally, shear only matters above the **effective inflow base**.

In this case, we can neglect shear below 1 km.



Bulk Shear

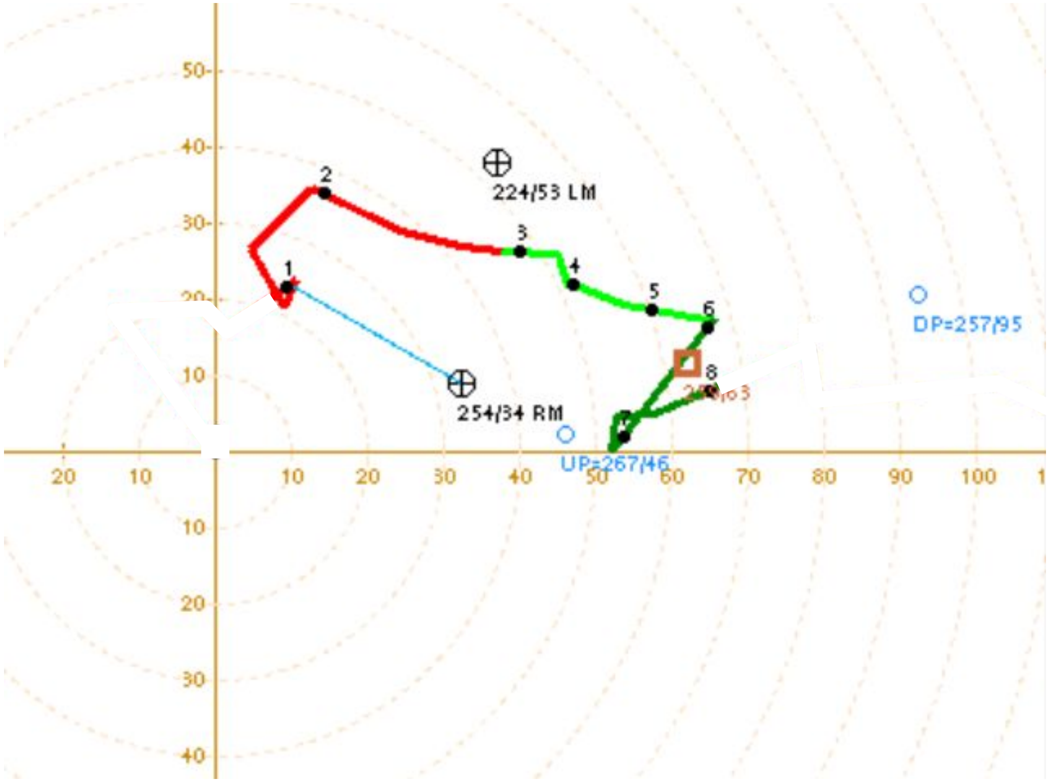
Effective Bulk Shear takes into account *both* the equilibrium level and effective inflow base.



Bulk Shear

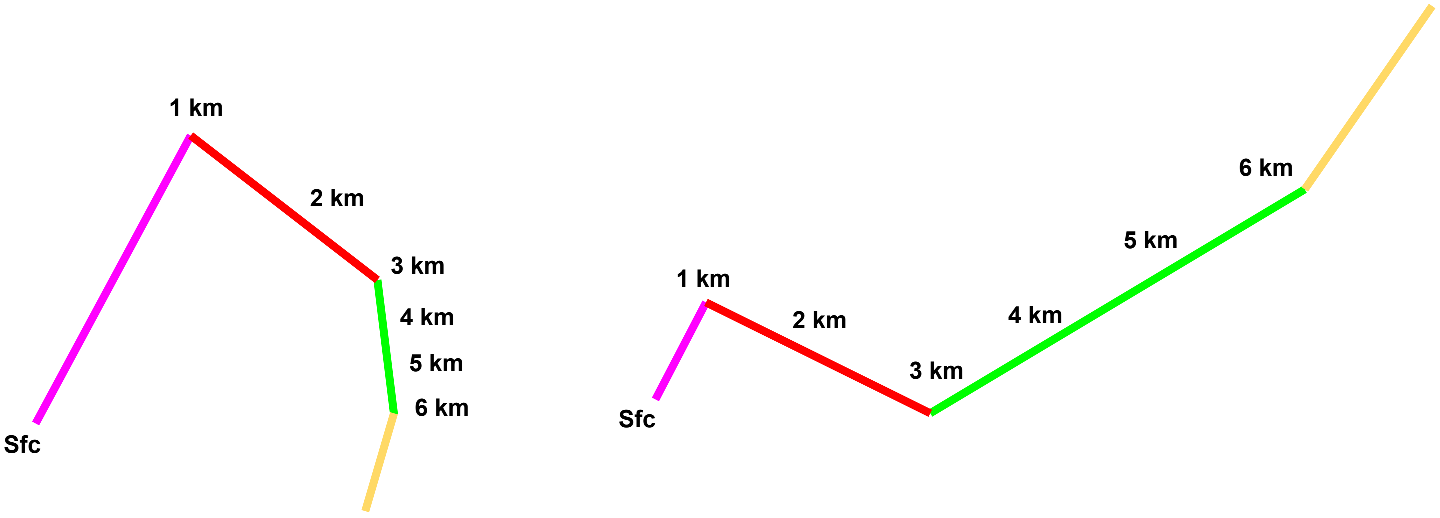
Effective Bulk Shear takes into account *both* the equilibrium level and effective inflow base.

It’s useful in a wide variety of scenarios, including shallow or elevated storms.



Bulk Shear

Which hodograph has stronger 0-6 km shear?



Bulk Shear

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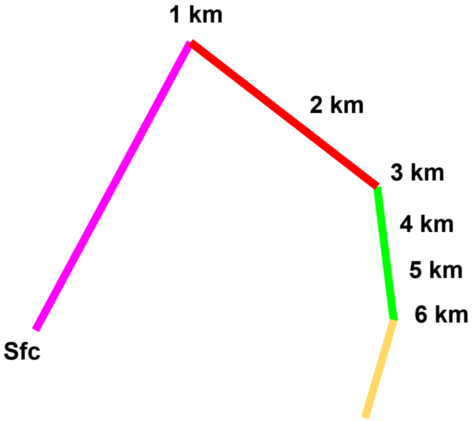
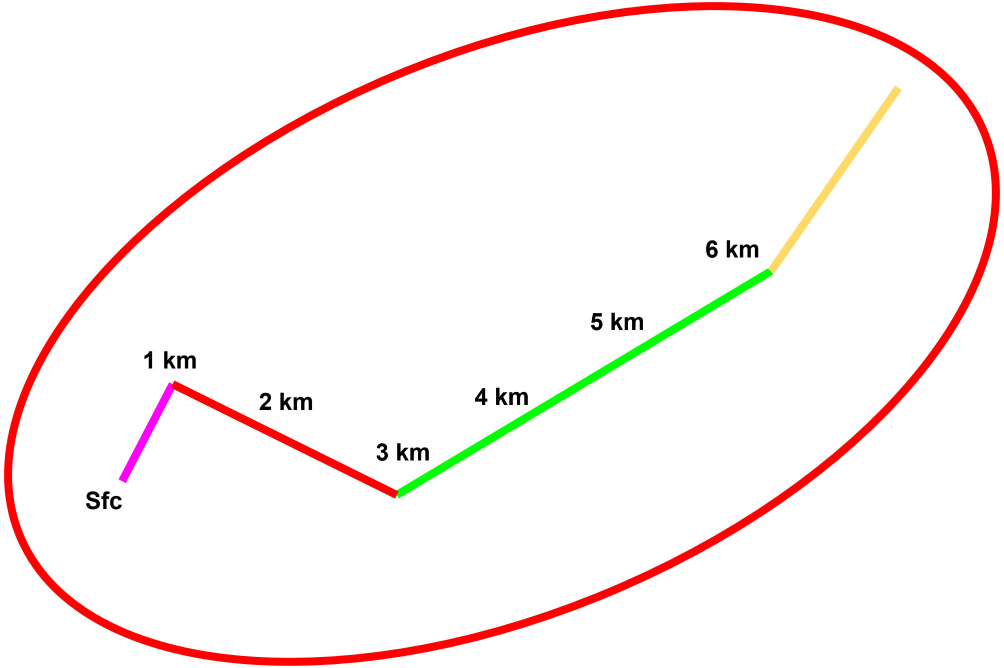
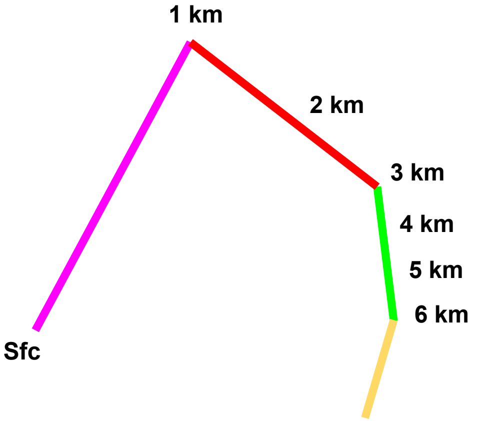
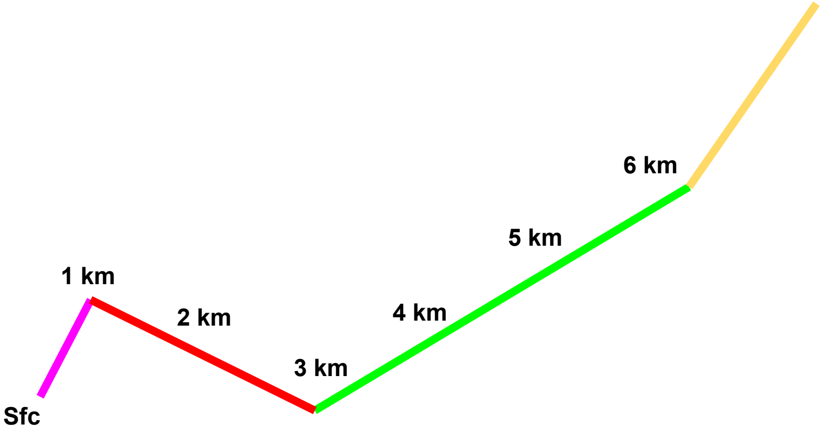




Bulk Shear

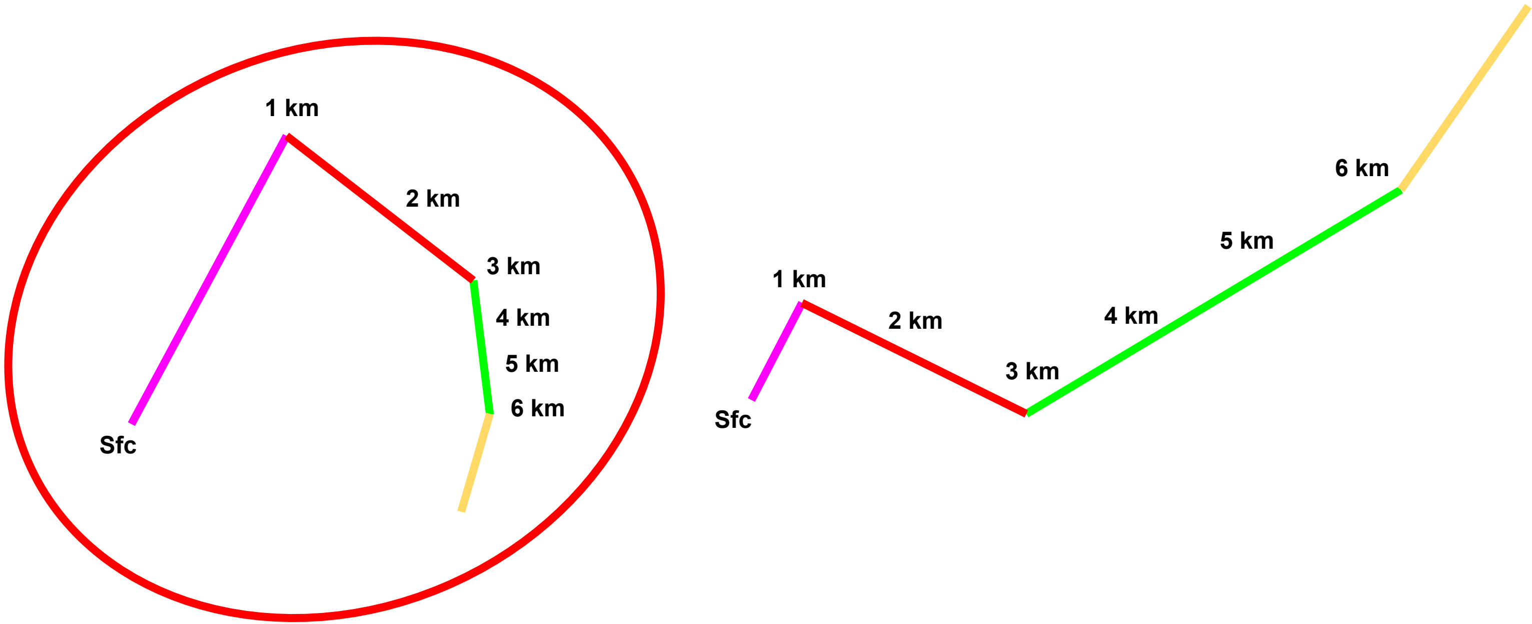
Which hodograph has stronger 0-1 km shear?





Bulk Shear

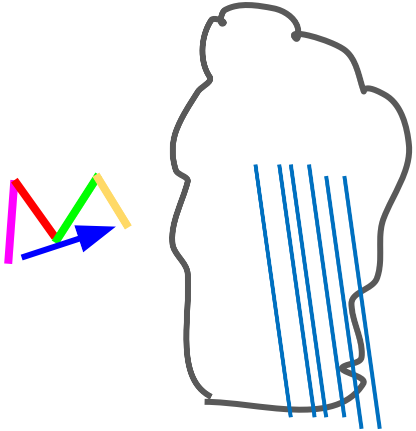
Nice job!

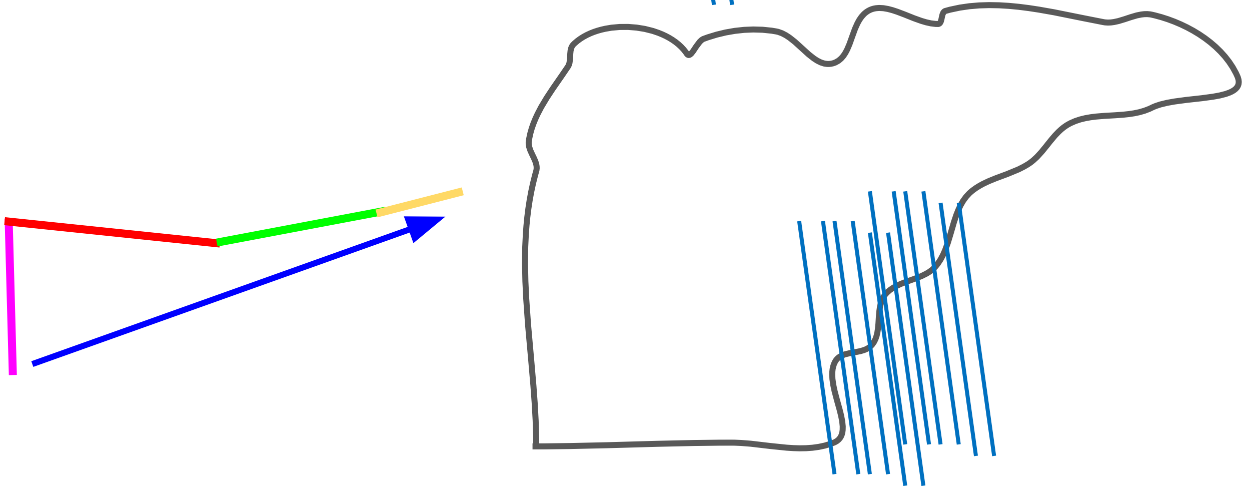


Storm Strength

Stronger bulk shear can create convective storms that are:

- Stronger
- Larger
- More organized
- Longer-lived



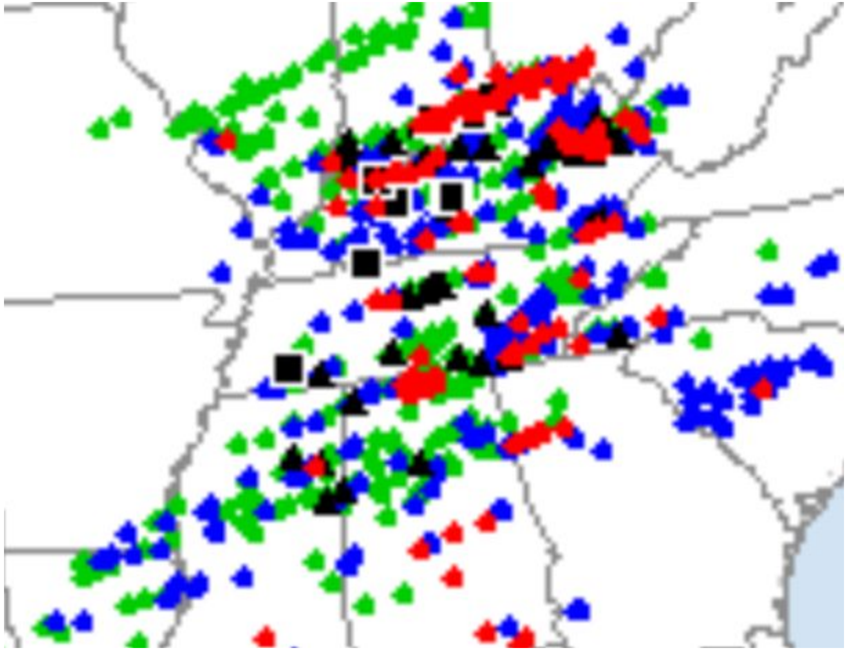


Storm Strength

Stronger bulk shear can create convective storms that are:

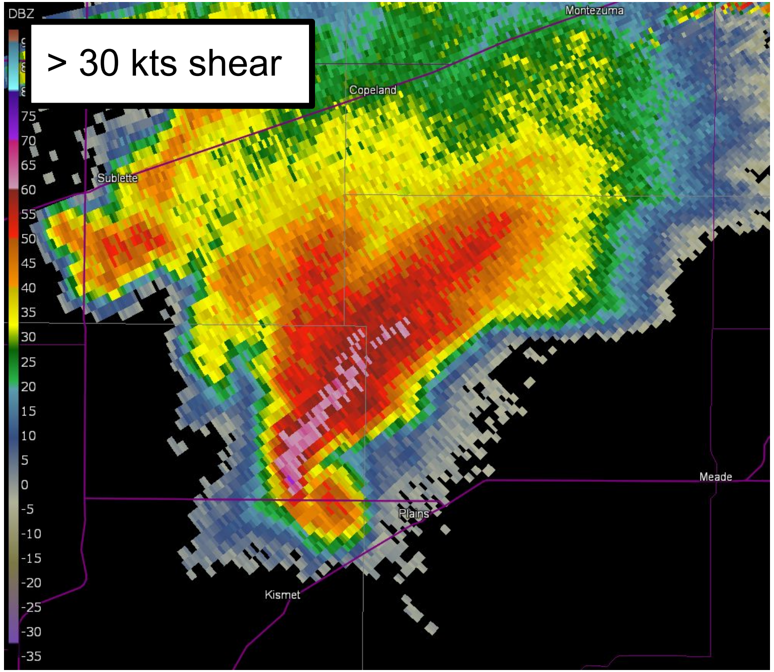
- Stronger
- Larger
- More organized
- Longer-lived

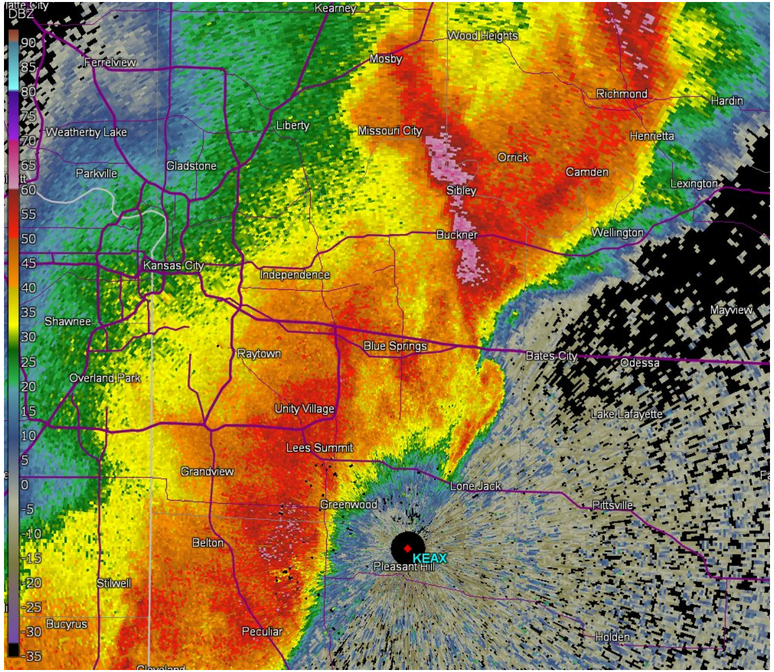
…and more hazardous!



Storm Strength

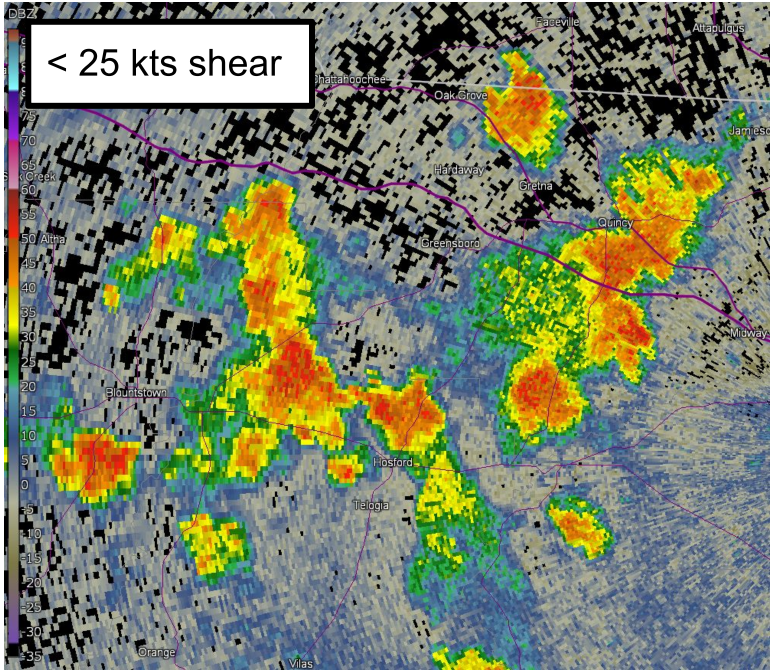
Stronger shear can support supercells and organized convective systems

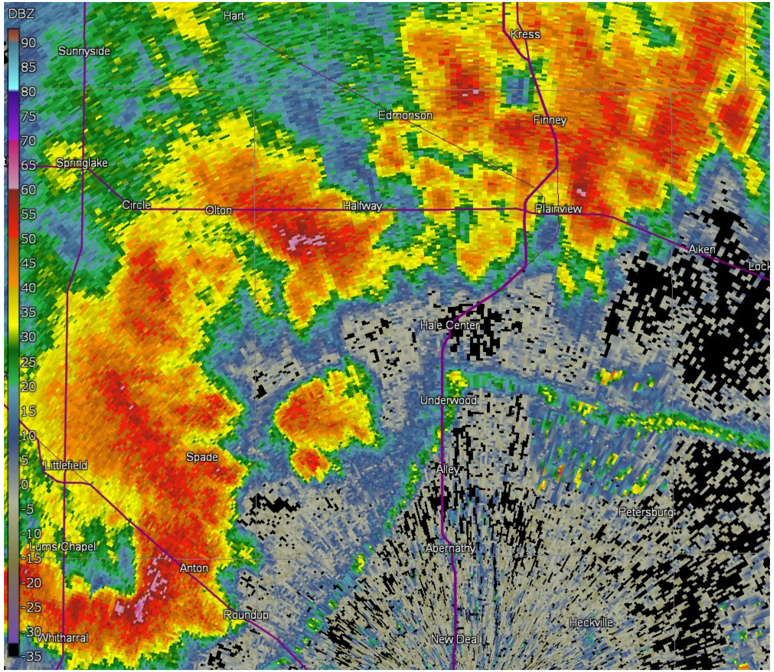




Storm Strength

Weak shear may only support brief, weakly-organized storms

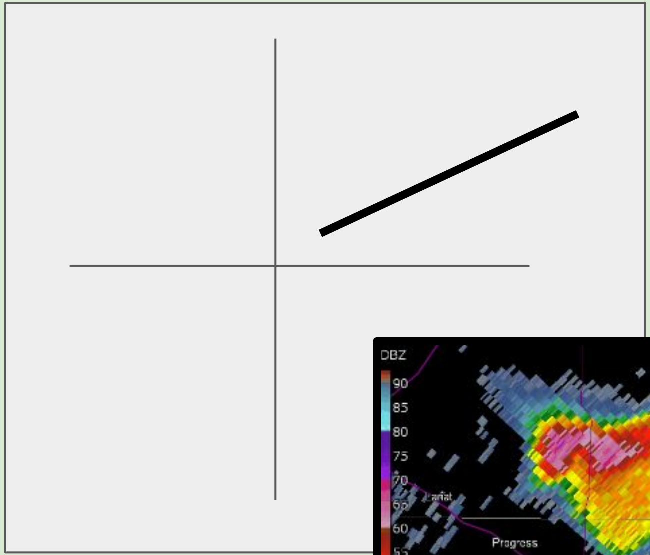


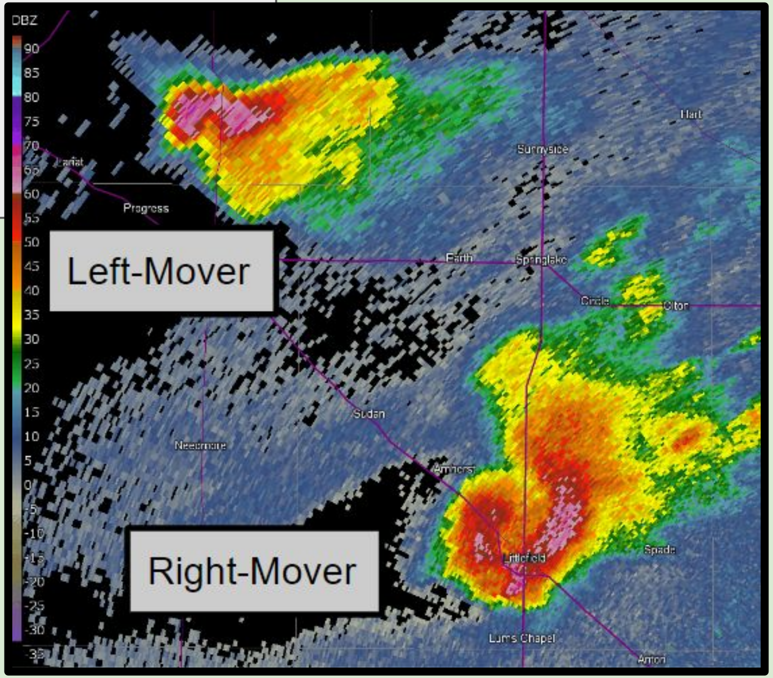


Bulk Shear Summary

1. Bulk shear is the difference in wind between two levels
2. Shear matters to storms between the Eff. Inflow Base and EL
3. Effective bulk shear is a good “go-to” bulk shear parameter
4. Stronger shear can support more hazardous storms

Lesson 3: Hodograph Shape



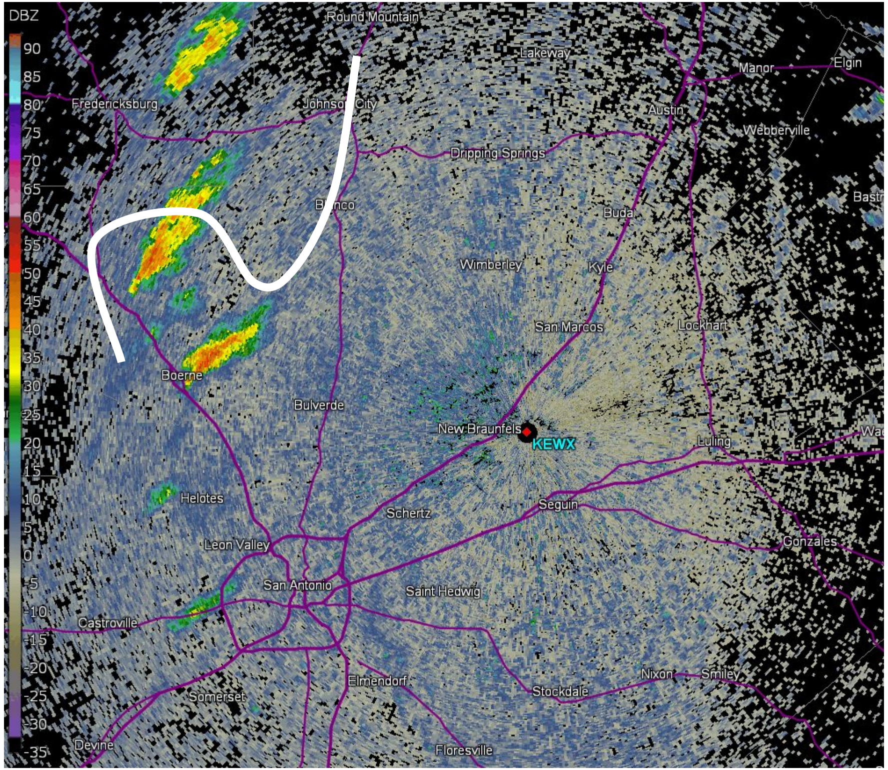


Harry Weinman – Meteorologist, Storm Prediction Center
(harry.weinman@noaa.gov)

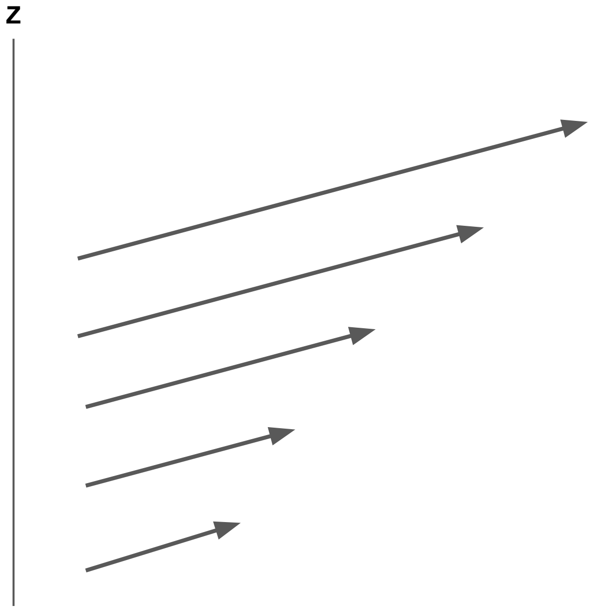
Cameron Nixon – Research Scientist, SPC / CIWRO
(cameron.nixon@noaa.gov)

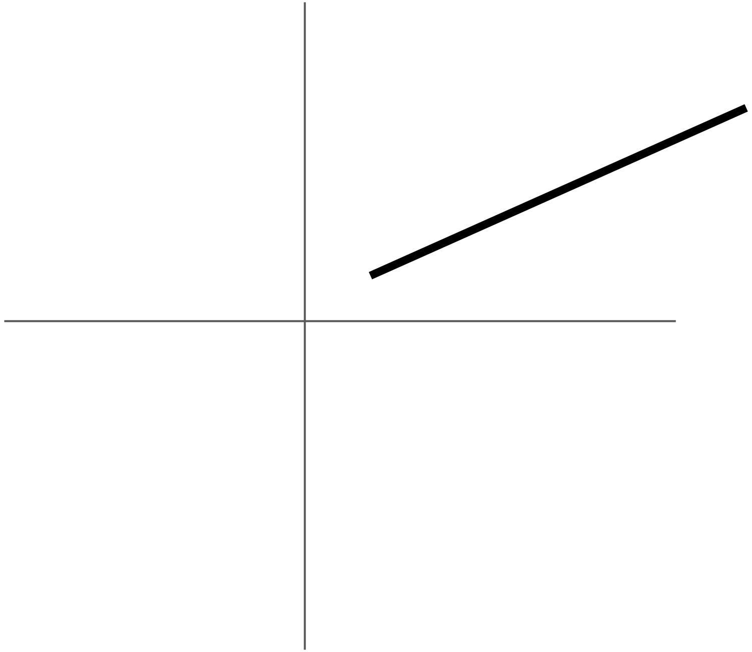
Hodograph Shapes

The shape of the hodograph can help us determine what types of storms are favored and how they will evolve



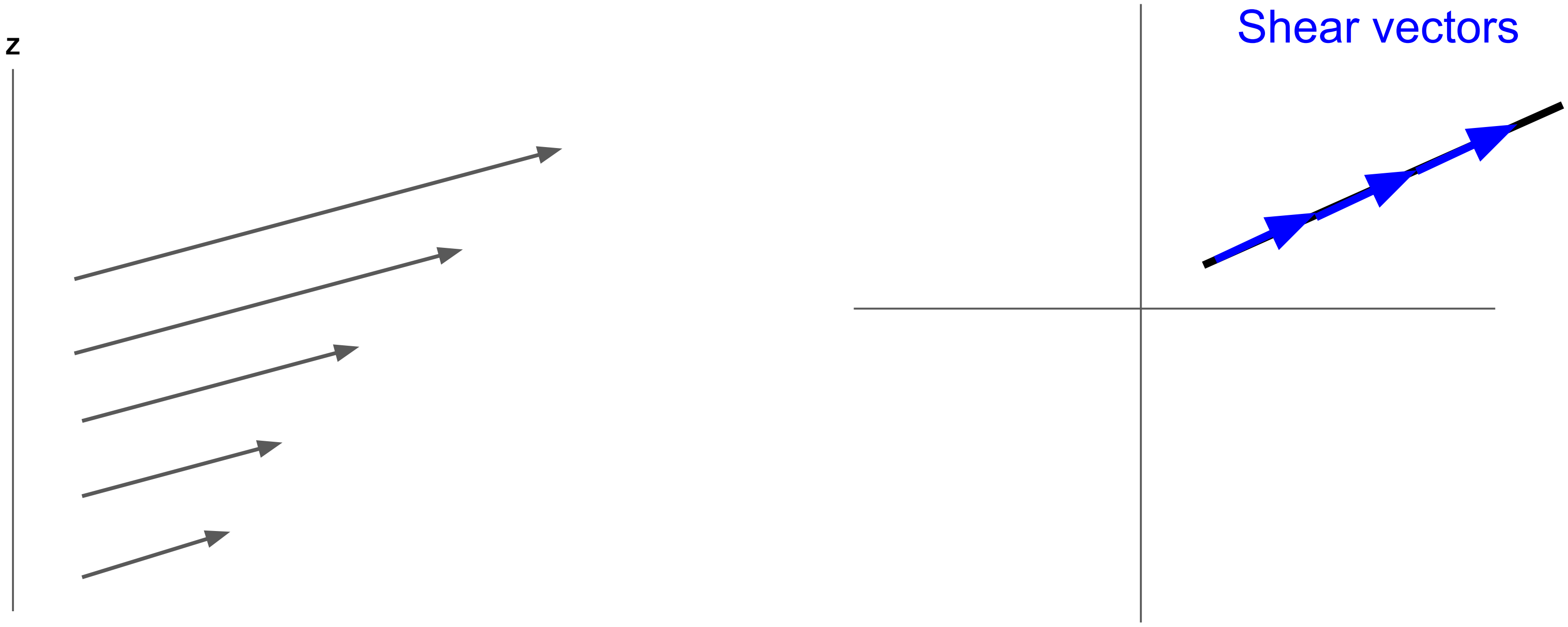
Straight Hodograph





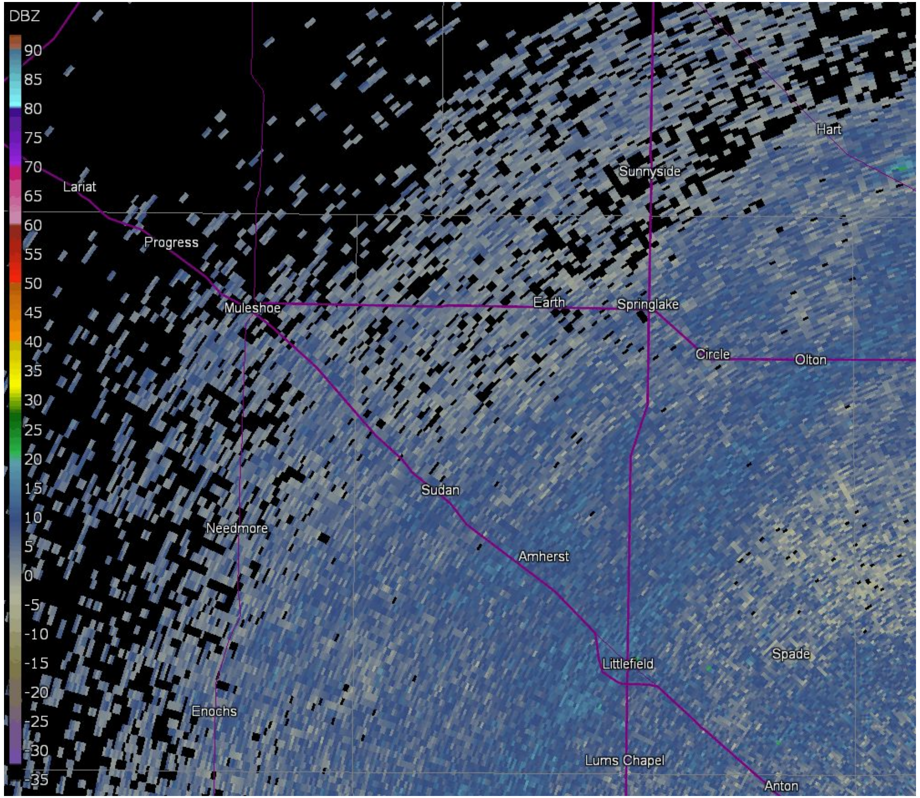
Unidirectional wind profile, straight hodograph

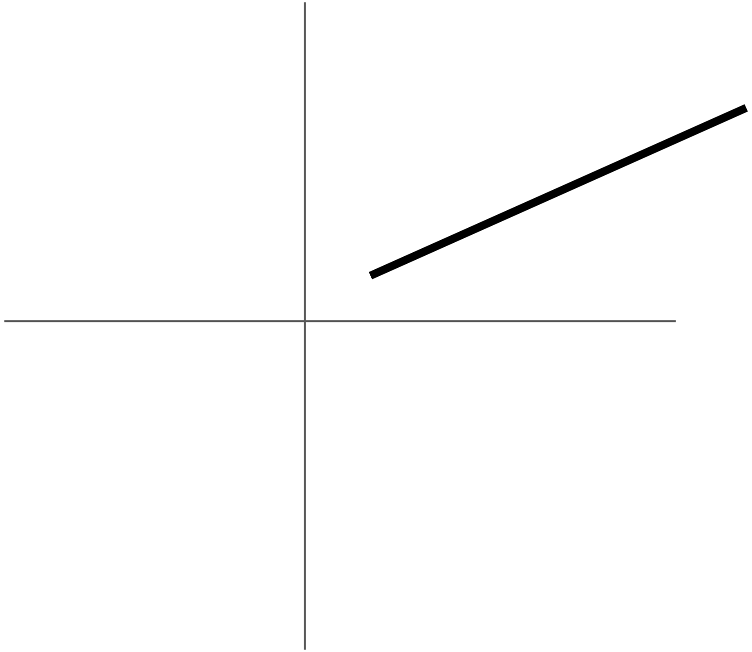
Straight Hodograph



Unidirectional wind profile, straight hodograph

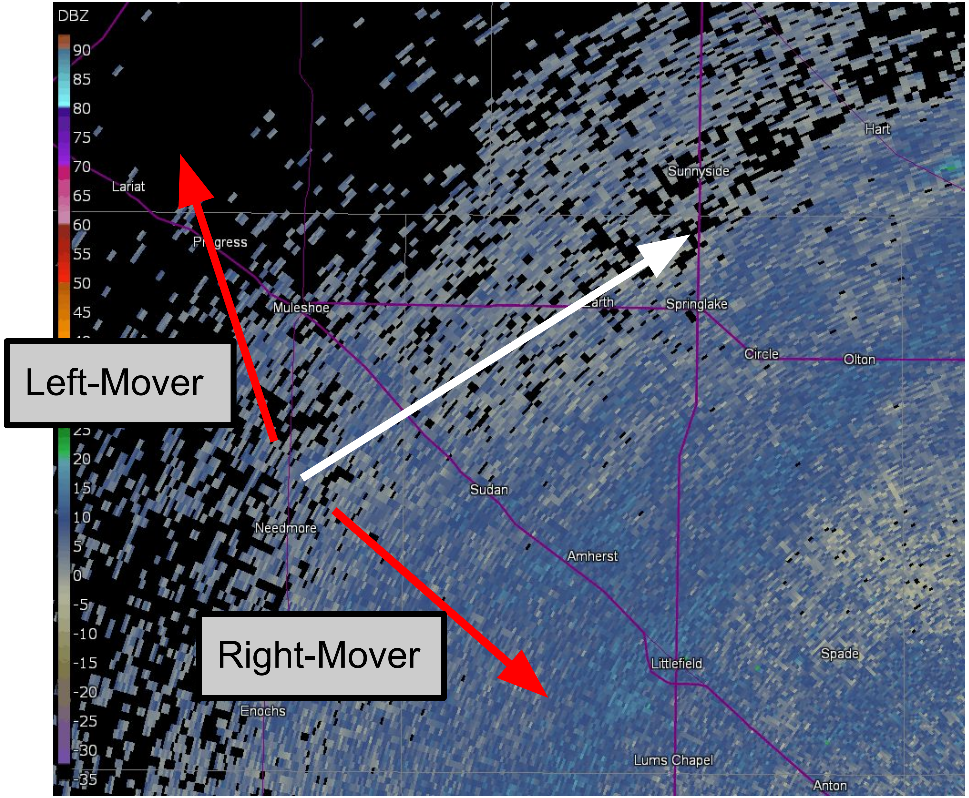
Straight Hodograph

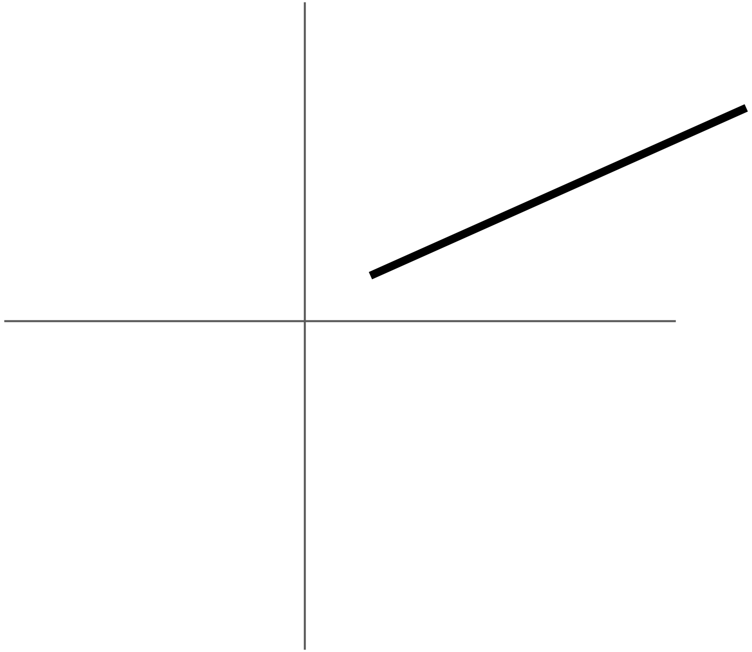




Supports mirror-image splitting storms

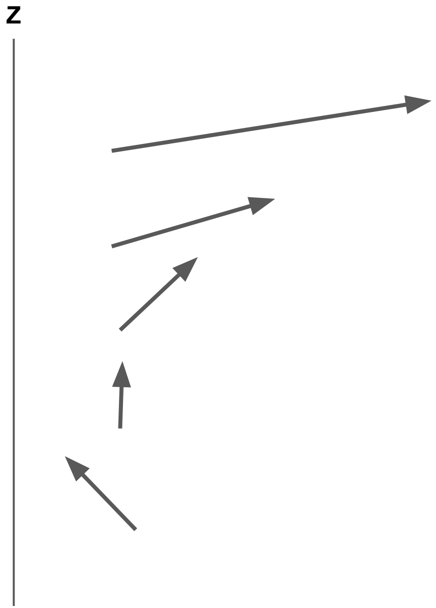
Straight Hodograph

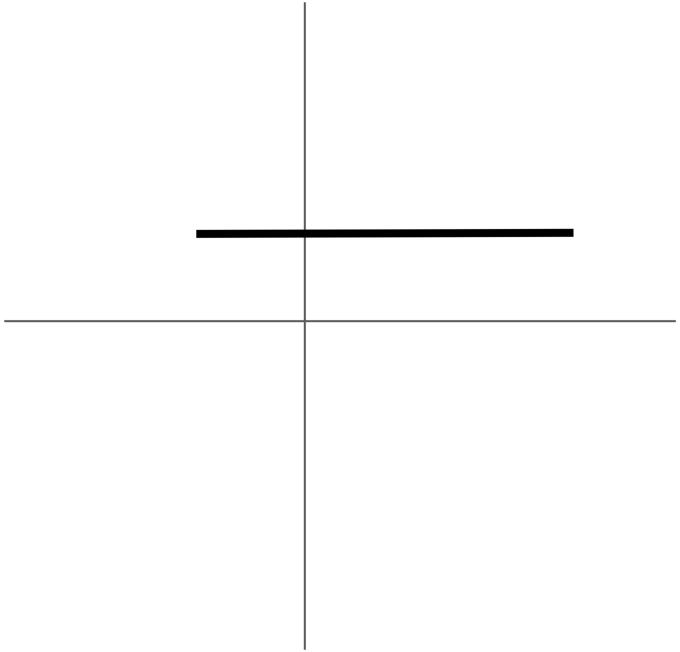




Storms split apart from the shear vector!

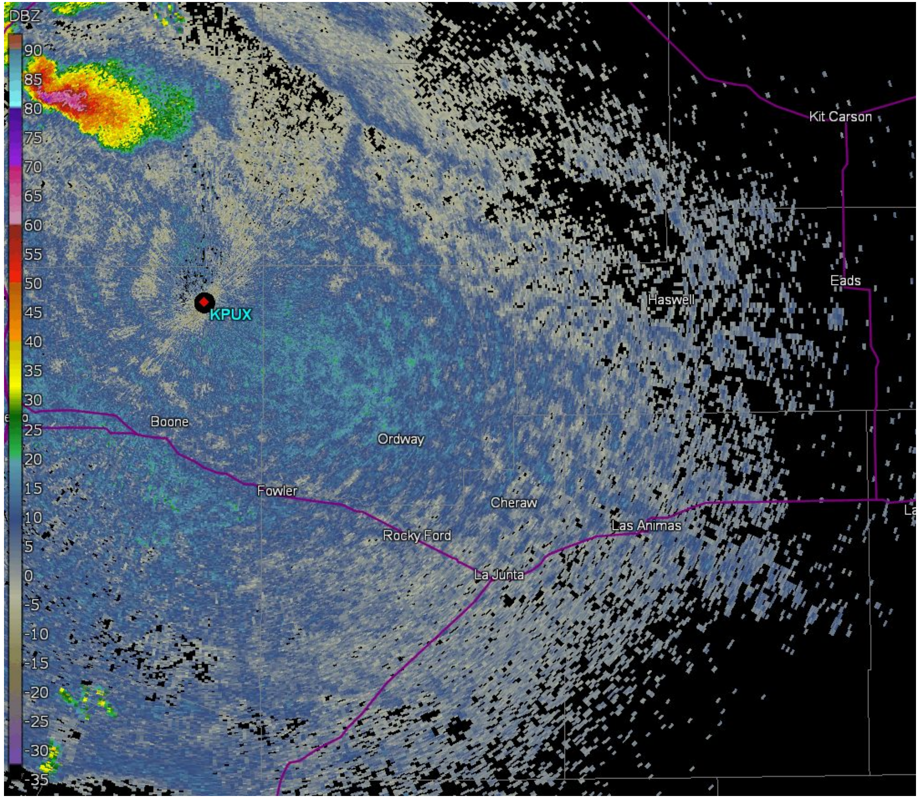
Straight Hodograph

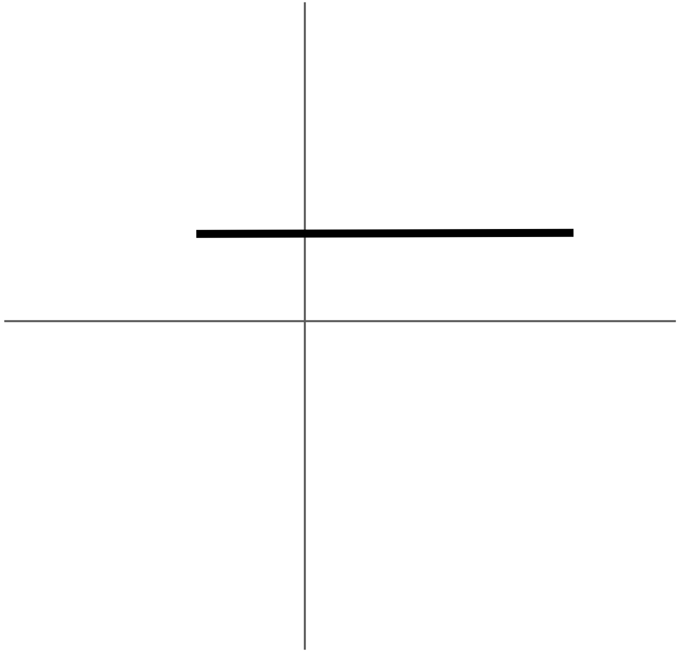




Veering wind profile, still a straight hodograph!

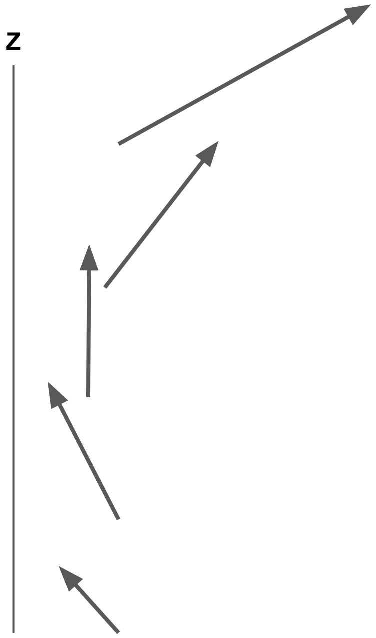
Straight Hodograph

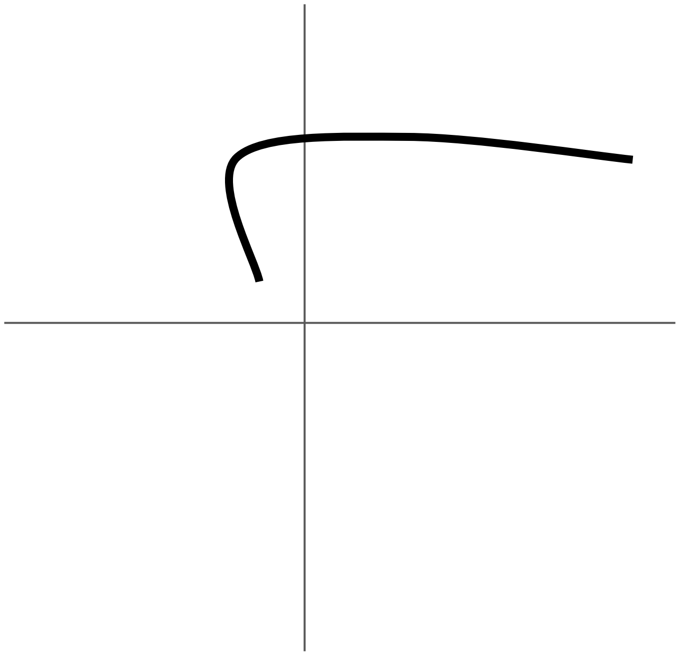




Supports both left-moving and right-moving storms (and many cell interactions!)

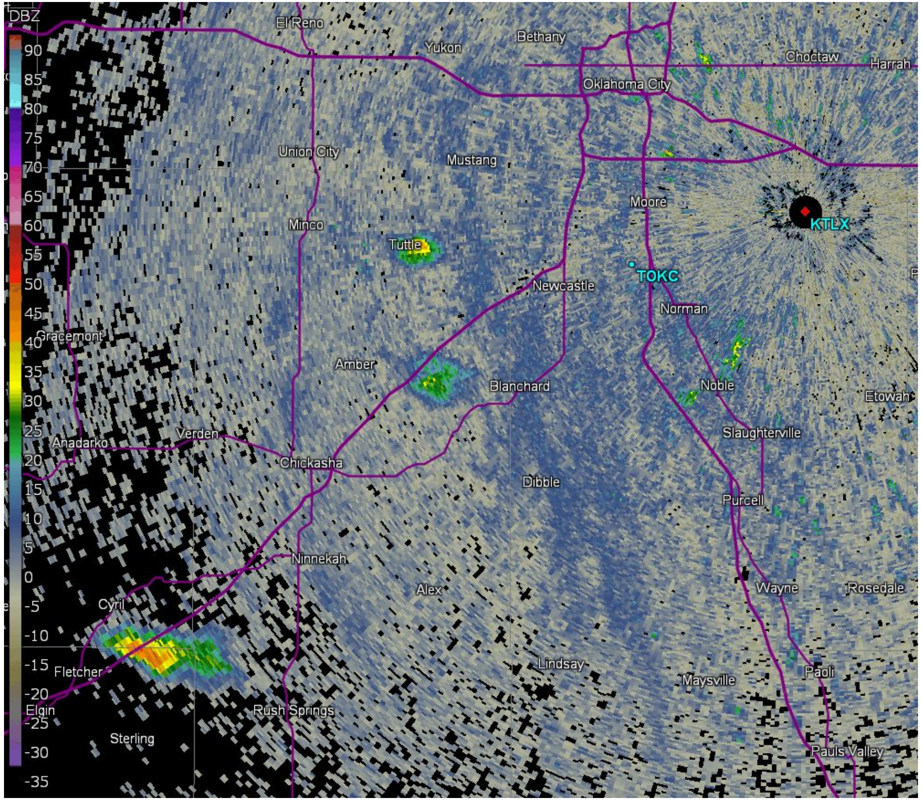
Quarter-Circle Hodograph

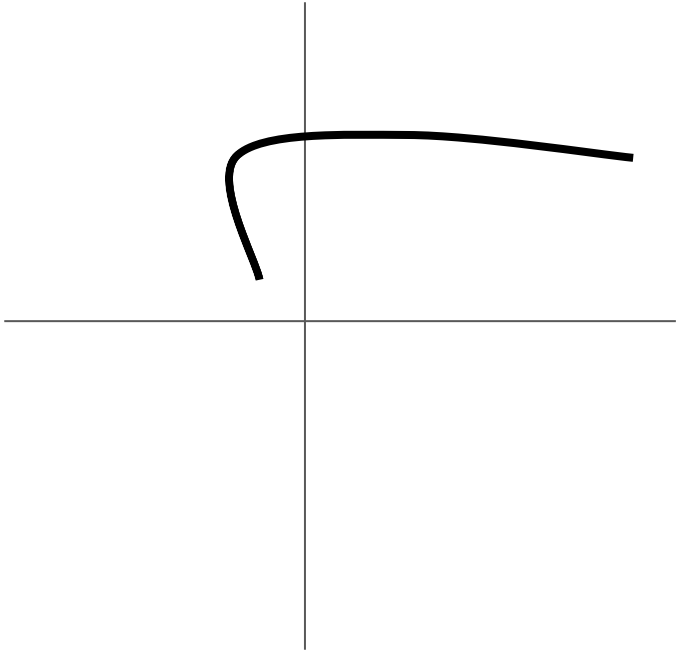




Weakly veering wind profile, clockwise-curved hodograph.
Found in warm-air advection regimes.

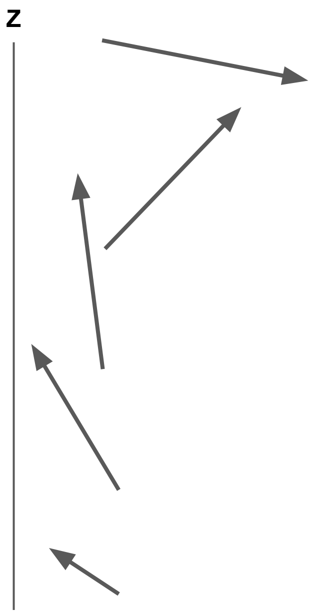
Quarter-Circle Hodograph

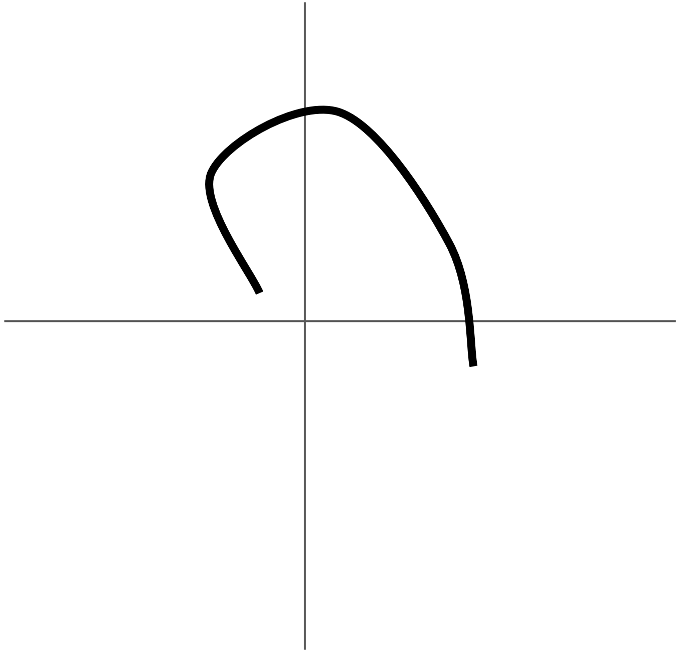




Supports splitting storms, with dominant right-movers

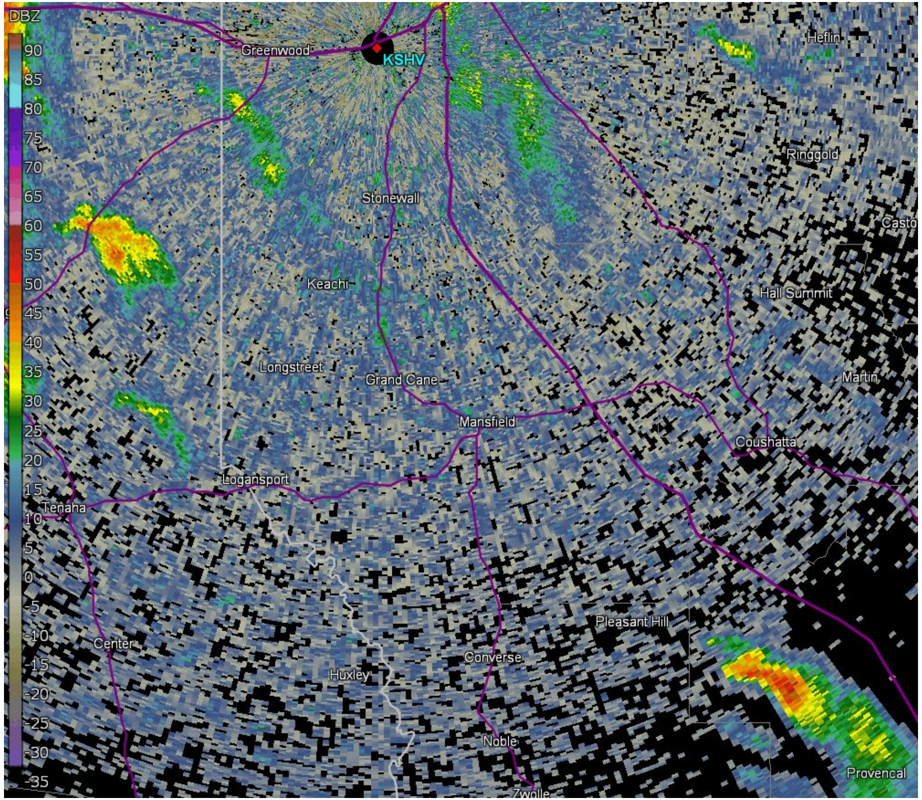
Half-Circle Hodograph

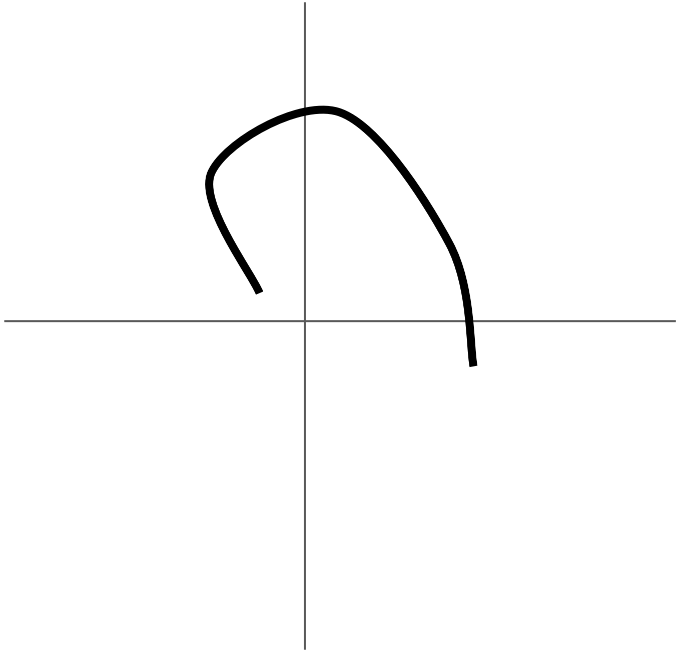




Strongly veering wind profile, clockwise-curved hodograph.
Found in strong warm-air advection regimes and warm-core systems.

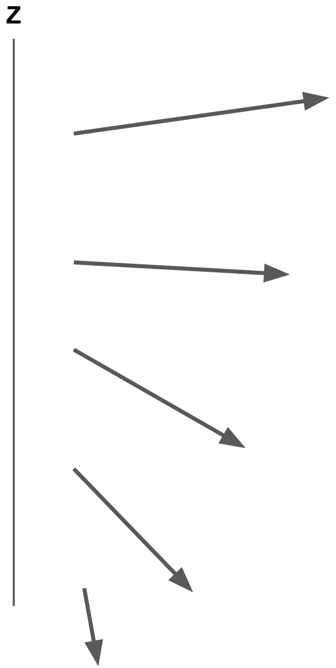
Half-Circle Hodograph

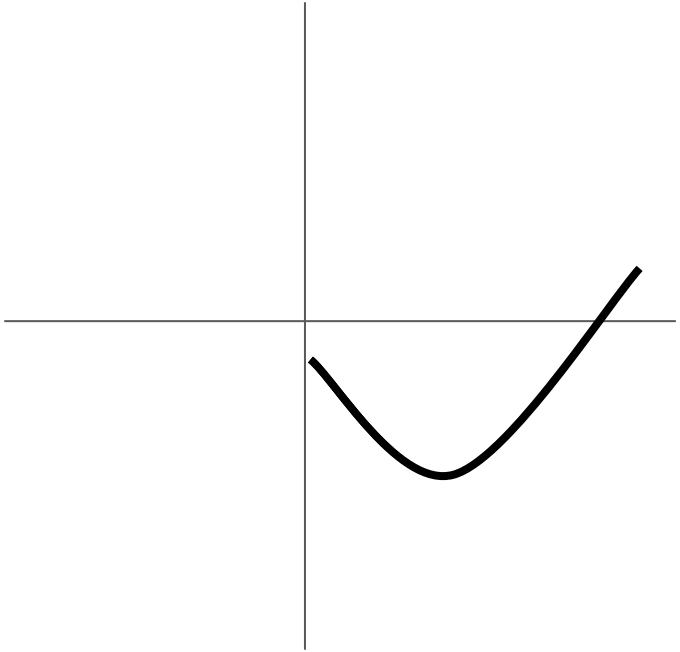




Typically supports right-moving storms only

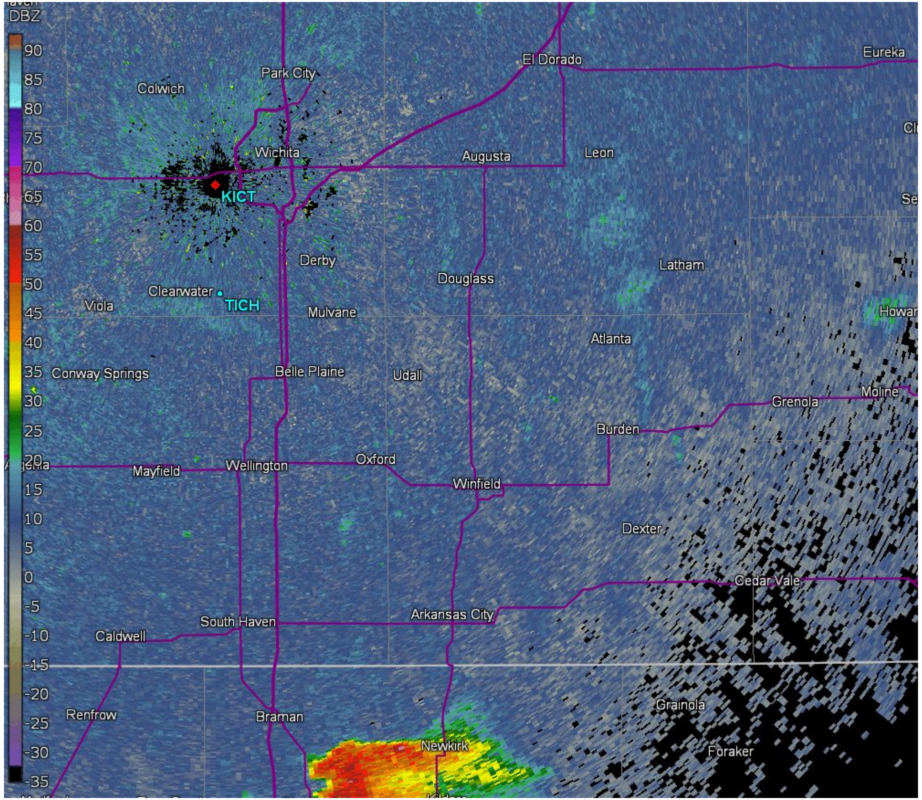
Counter-Clockwise Curved Hodograph

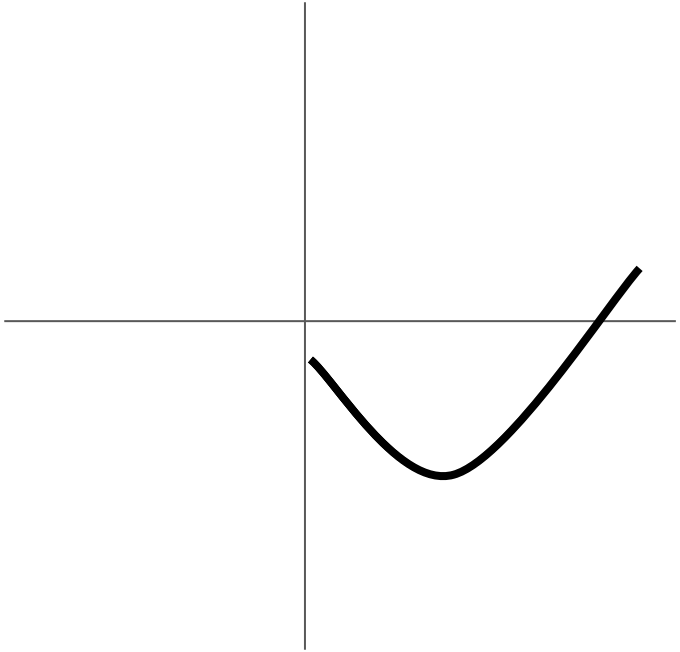




Backing wind profile, counter-clockwise curved hodograph.
Found in cold-air advection regimes.

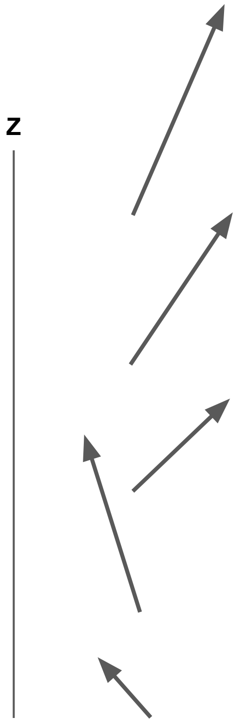
Counter-Clockwise Curved Hodograph

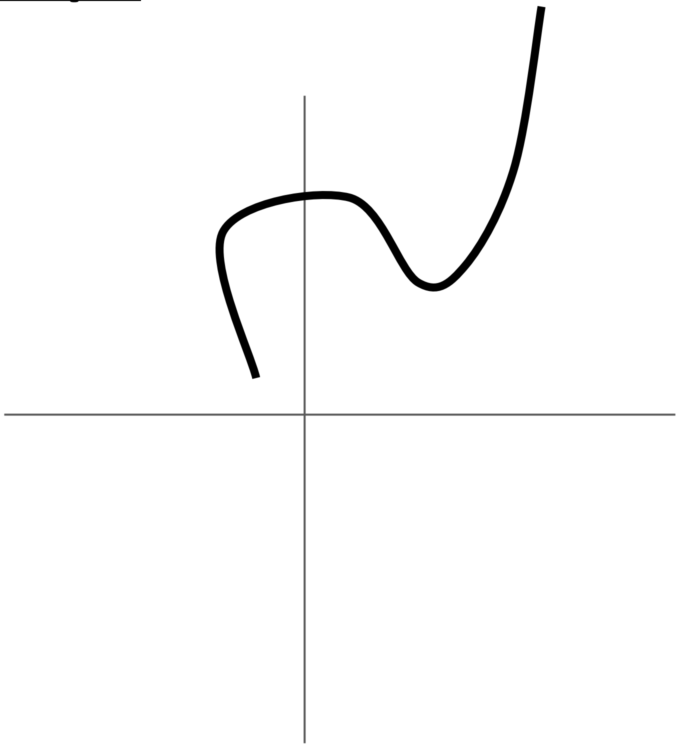




Supports splitting storms, with dominant left-movers

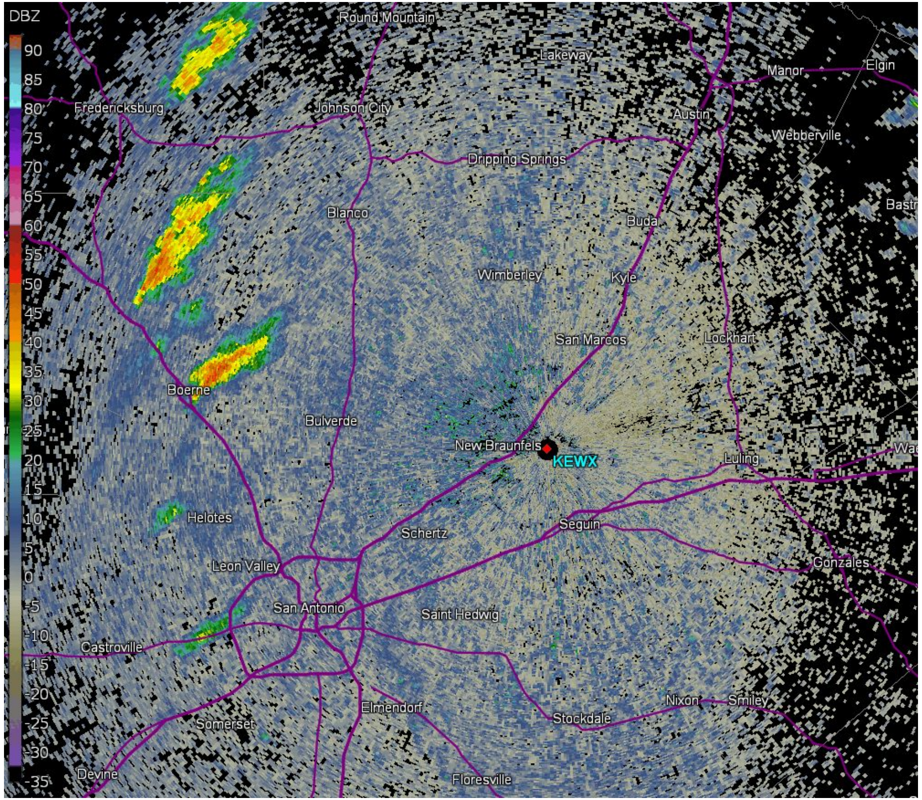
N-Shaped Hodograph

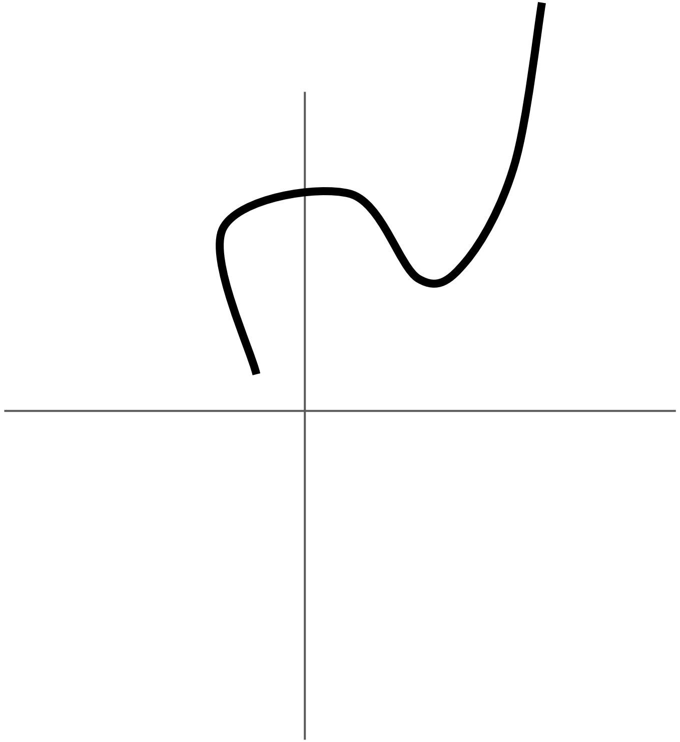




Veer-back wind profile.
Found in the wakes of midlevel troughs, CFAs, and in cold-core systems.

N-Shaped Hodograph





Supports splitting storms, with dominant right-movers

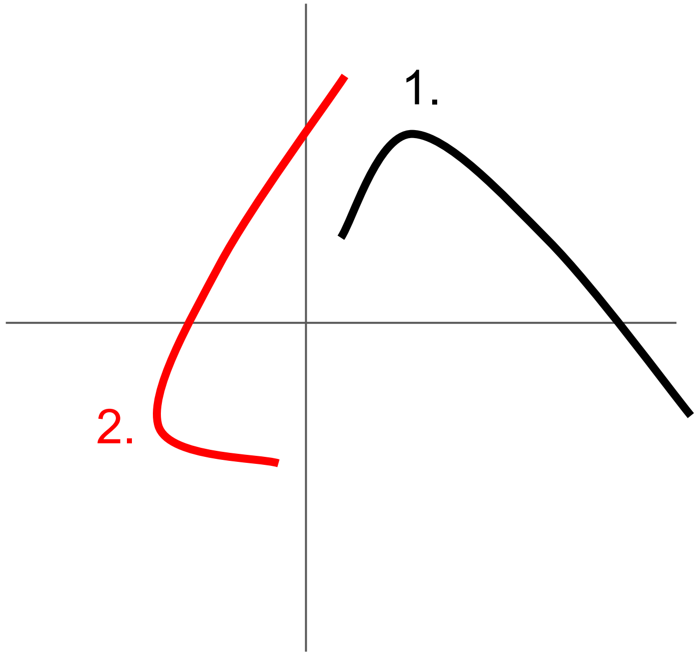
Hodograph Shape

Compared to hodograph #1, how might storms behave differently with hodograph #2 (all else being equal)?

a. Storms would split faster

b. Left-movers would be more dominant

c. Storms wouldn't behave much differently



Hodograph Shape

Compared to hodograph #1, how might storms behave differently with hodograph #2 (all else being equal)?

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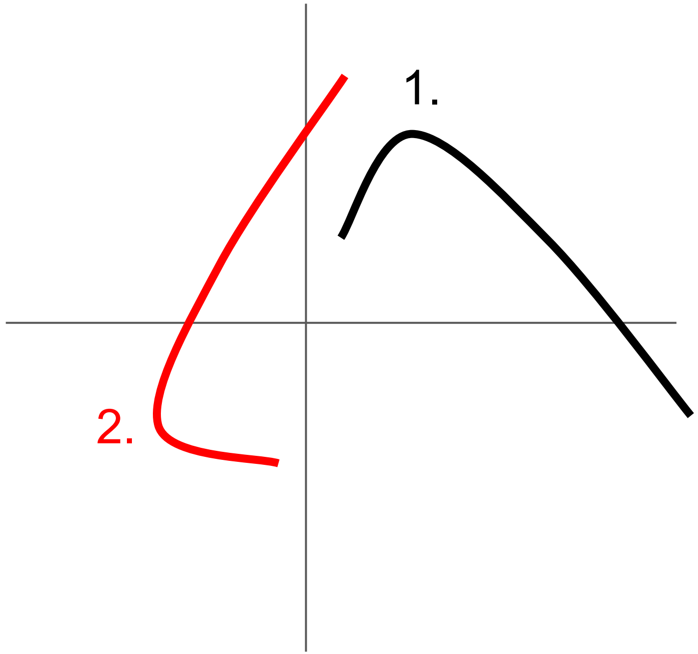
b. Left-movers would be more dominant

c. Storms wouldn't behave much differently

You got it!



Hodograph Shape

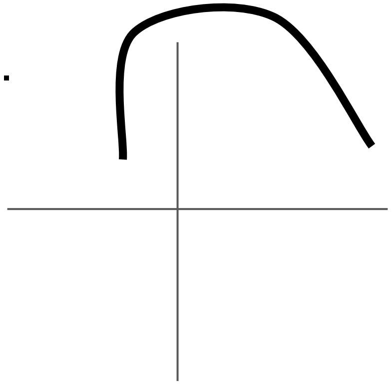
Which hodograph would favor a right-moving storm?

a. Hodograph 2

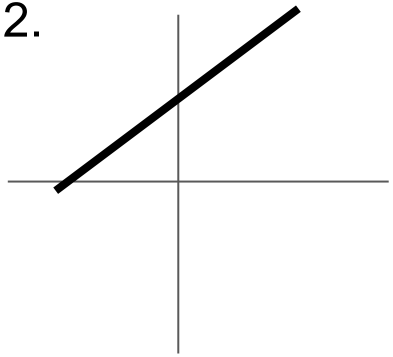
b. Hodograph 1

c. Neither of these hodographs favor RM

1.



2.



Hodograph Shape

Which hodograph would favor a right-moving storm?

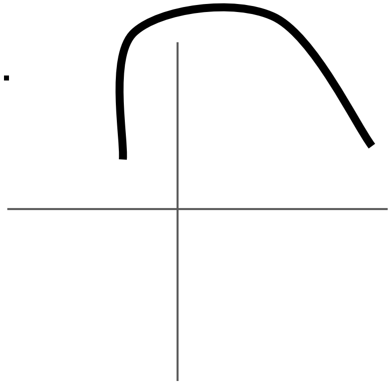
a. Hodograph 2

b. Hodograph 1

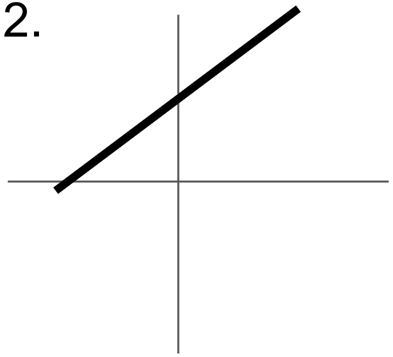
c. Neither of these hodographs favor RM

Great work!

1.

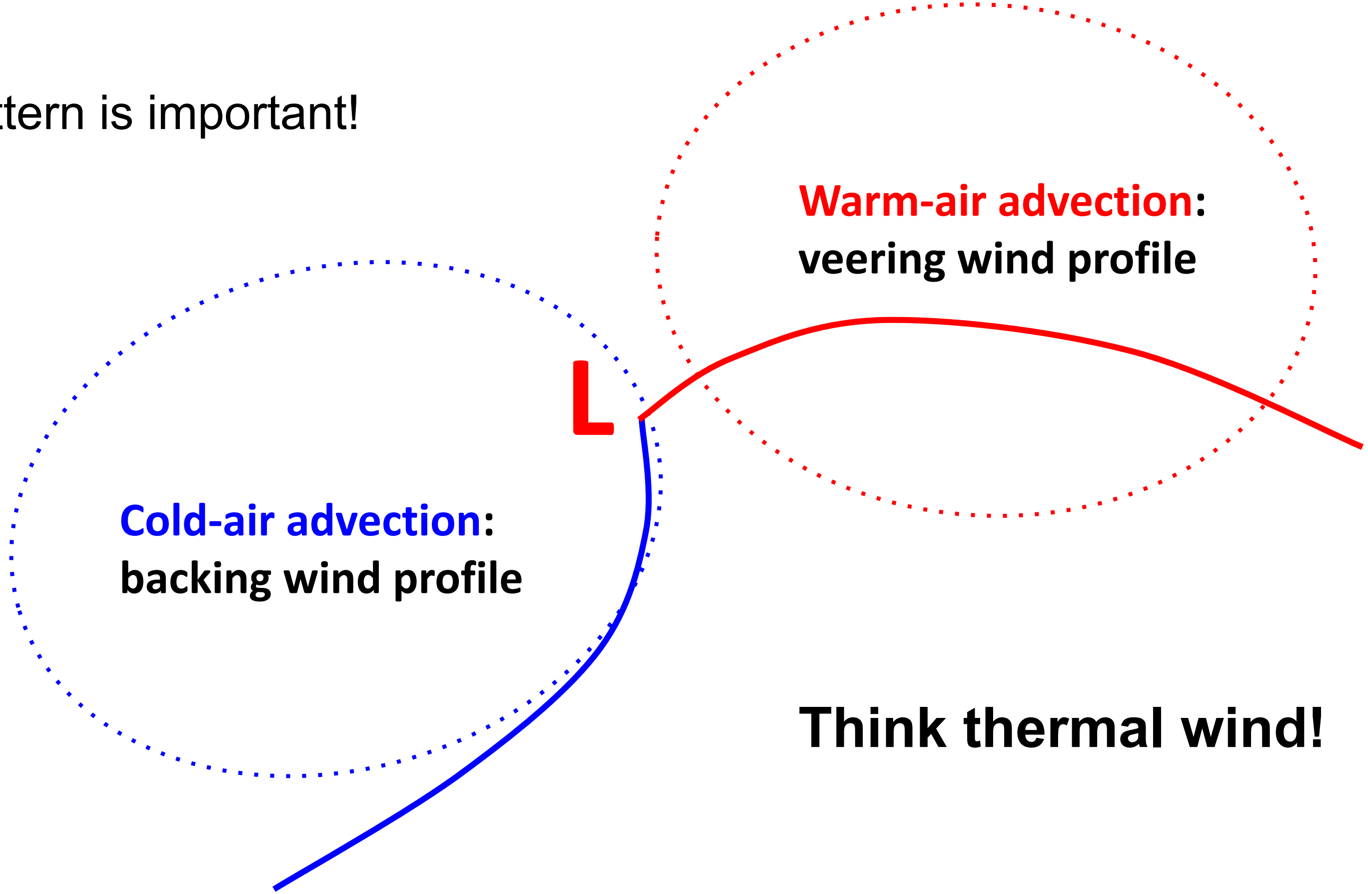


2.



Hodograph Variability

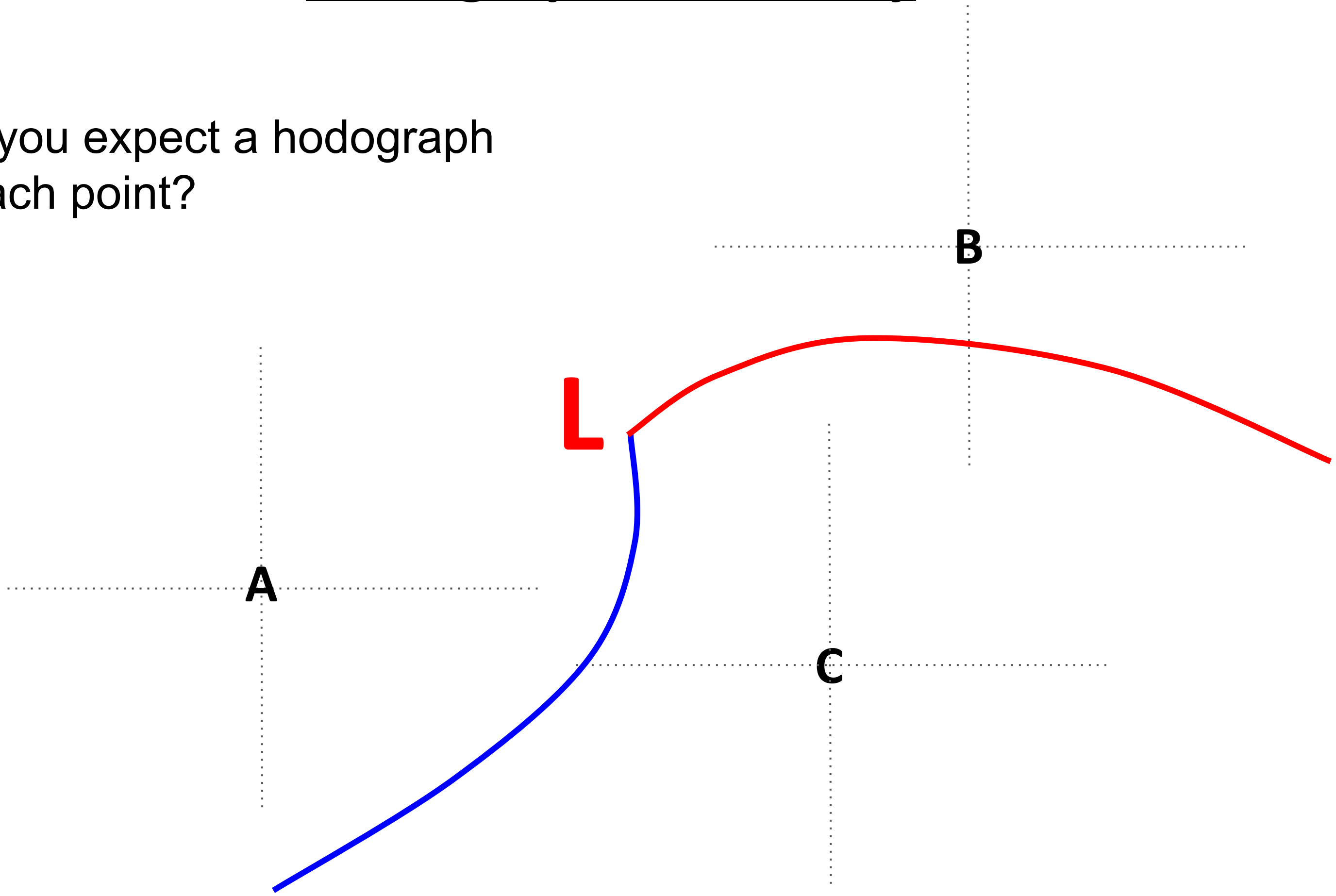
Synoptic pattern is important!



Think thermal wind!

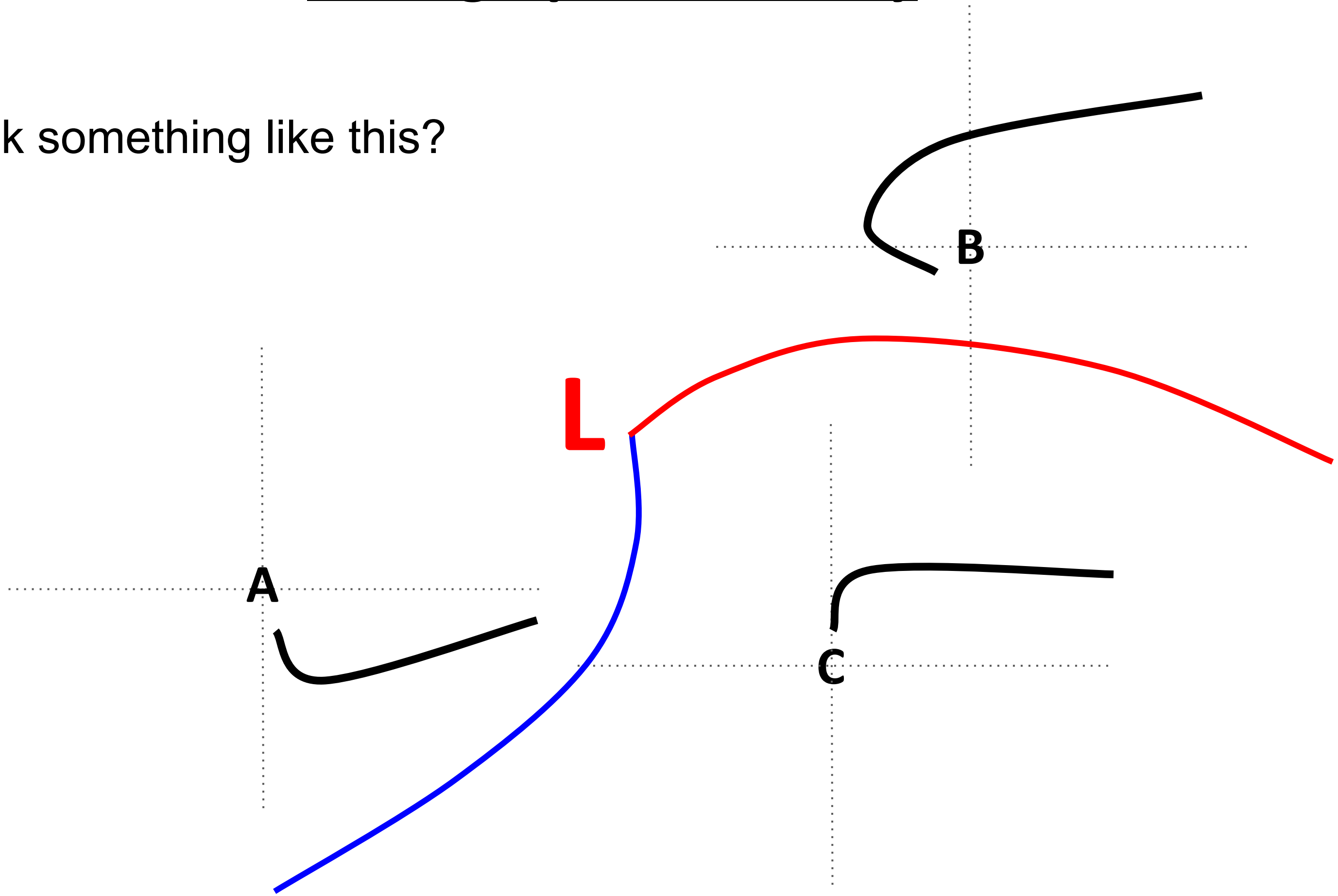
Hodograph Variability

How would you expect a hodograph to look at each point?



Hodograph Variability

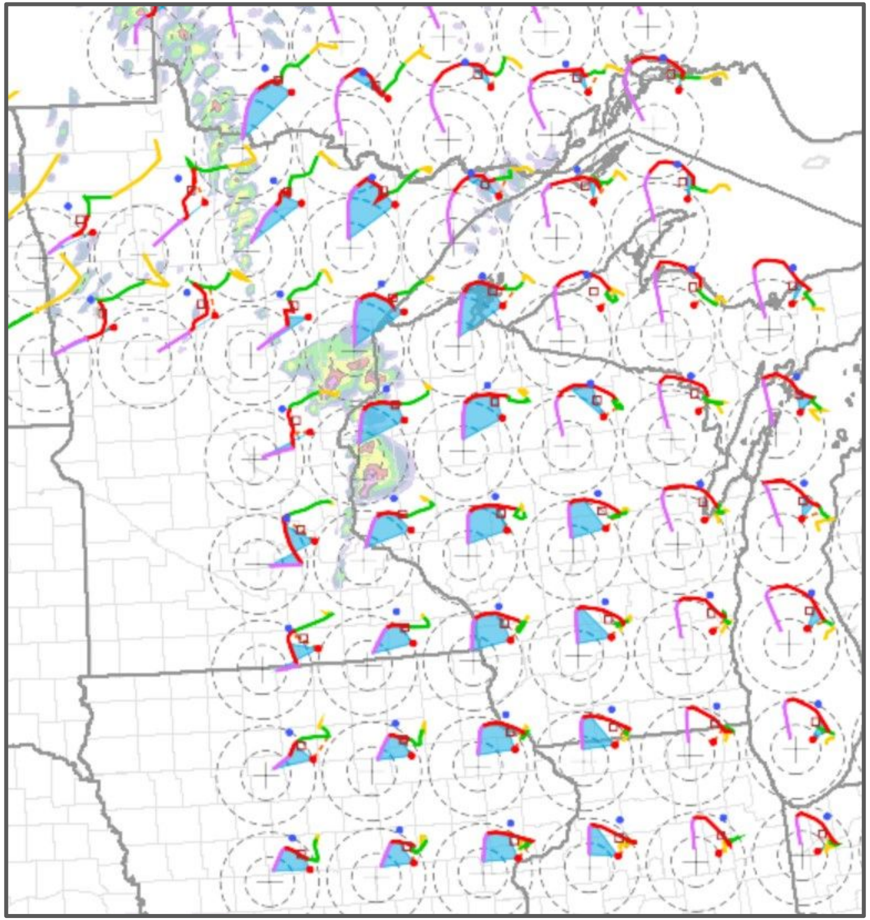
Did they look something like this?



Hodograph Variability

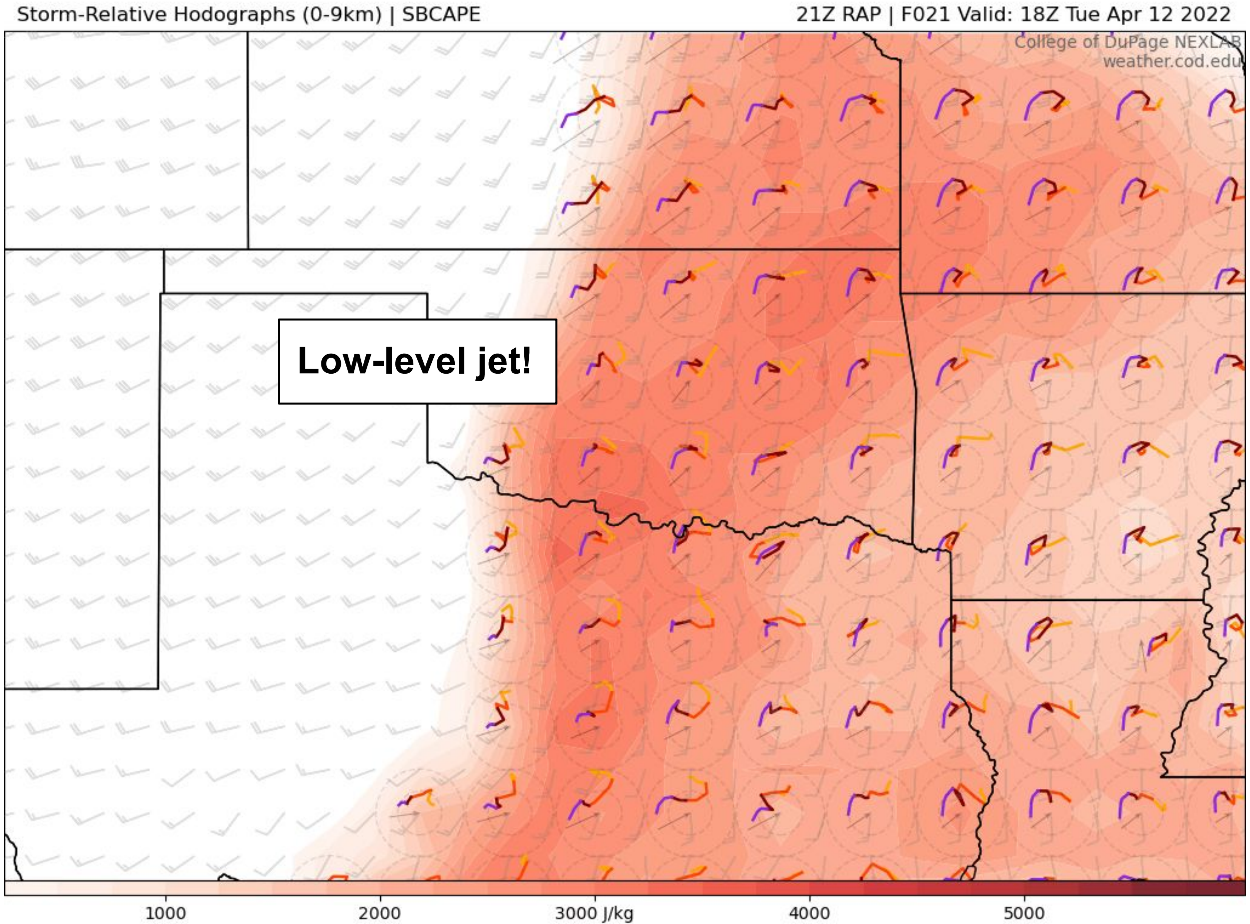
Hodograph shape can vary considerably over a given area

Use a hodograph map for this!



Hodograph Variability

Hodograph shape can change quickly over time!



Hodograph Shape Summary

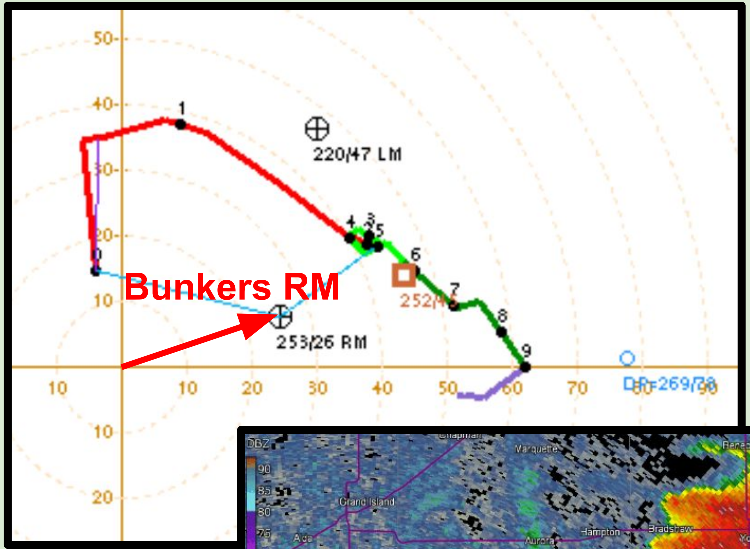
1. Hodograph shape is directly related to the vertical wind profile.

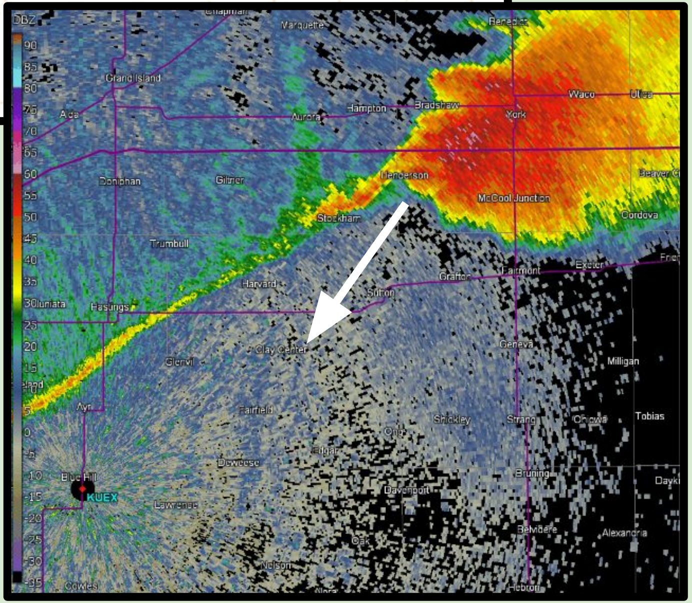
2. It is the shape of the hodograph that matters, not the orientation of the hodograph itself (all else being equal).

3. Straight hodographs favor splitting storms, clockwise curvature favors RM, counterclockwise curvature favors LM.

4. Synoptic and mesoscale pattern/features influence hodograph shape.

Lesson 4: Storm Motion



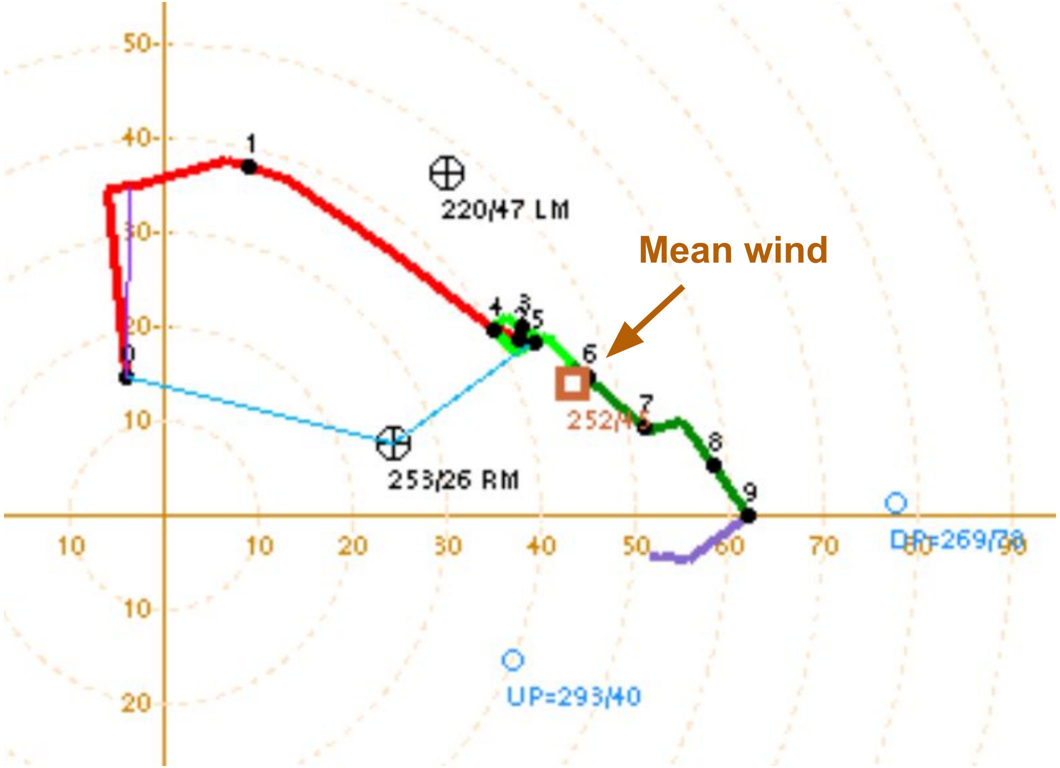


Cameron Nixon – Research Scientist, SPC / CIWRO
(cameron.nixon@noaa.gov)

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

Finding Storm Motion

Some *predictions* of storm motion can be calculated from the hodograph!



Finding Storm Motion

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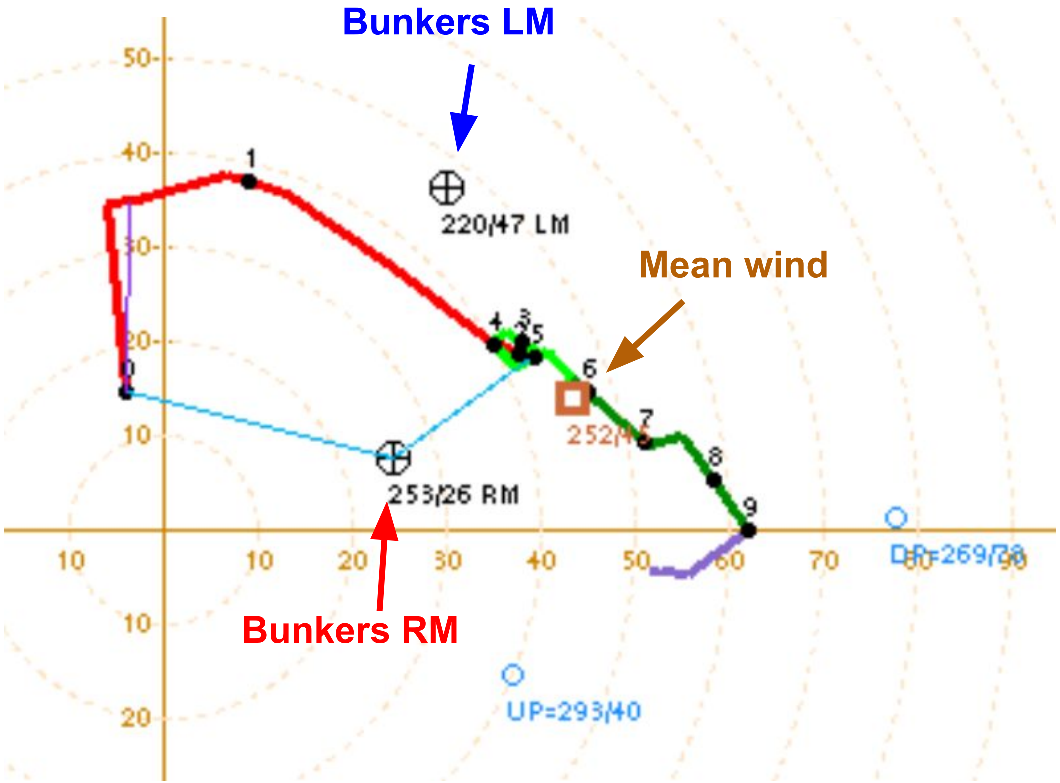
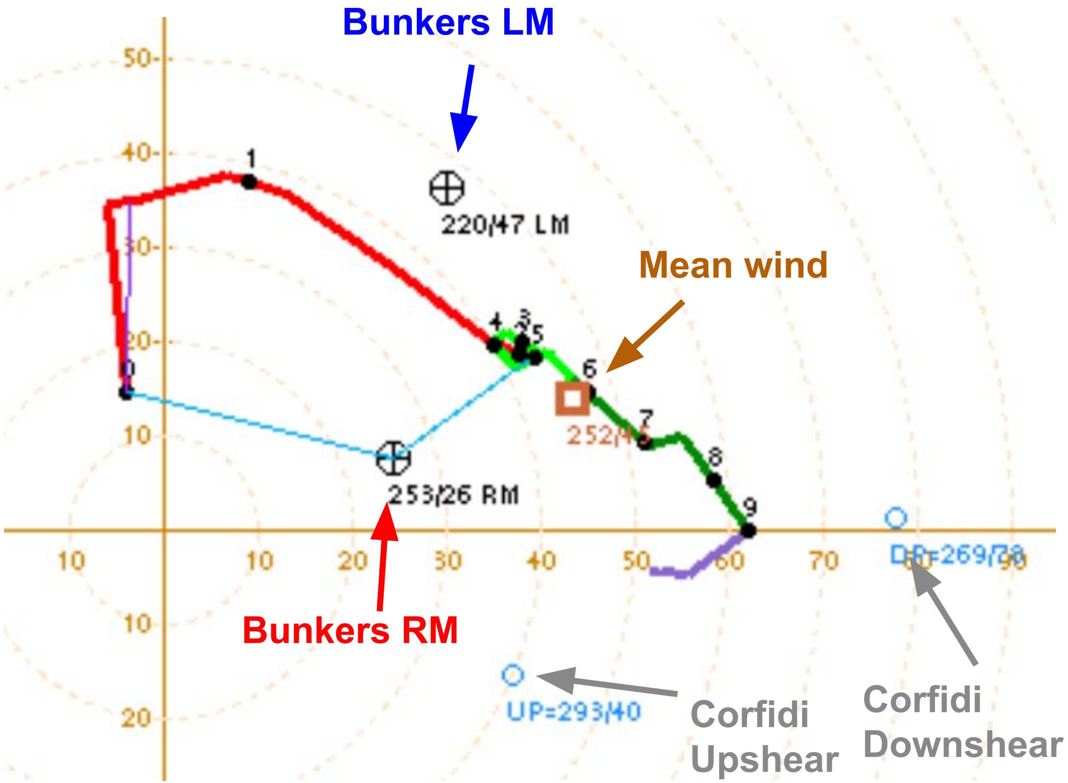


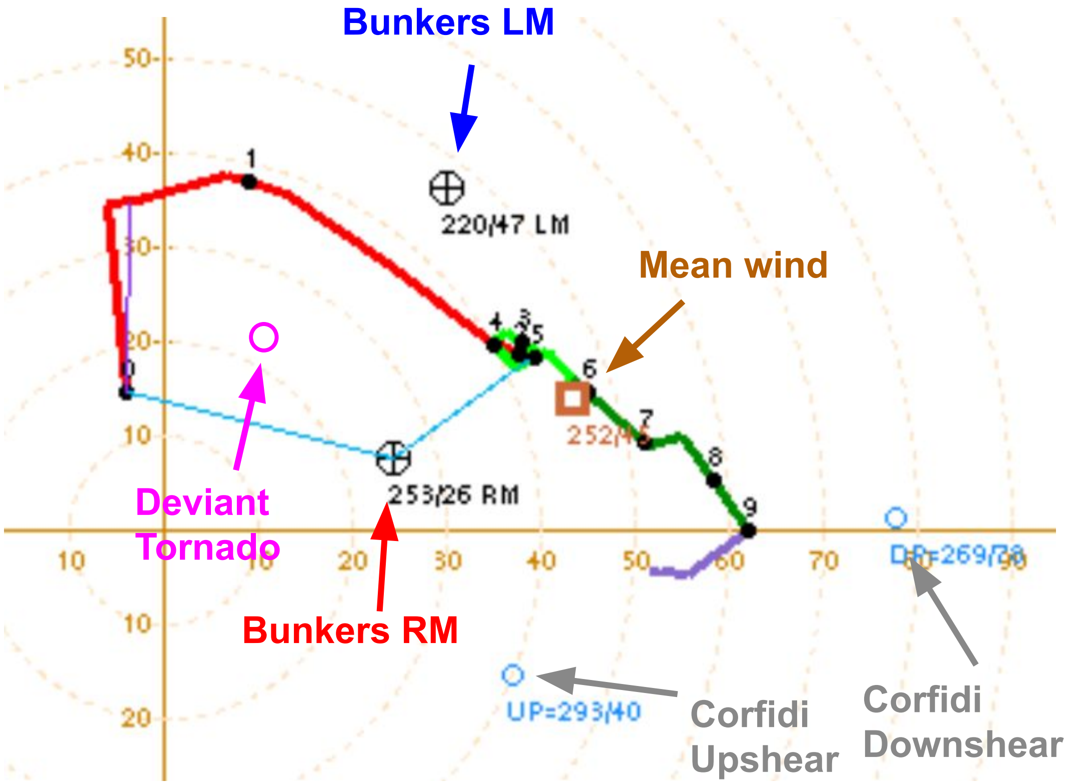
Finding Storm Motion

Some *predictions* of storm motion can be calculated from the hodograph!



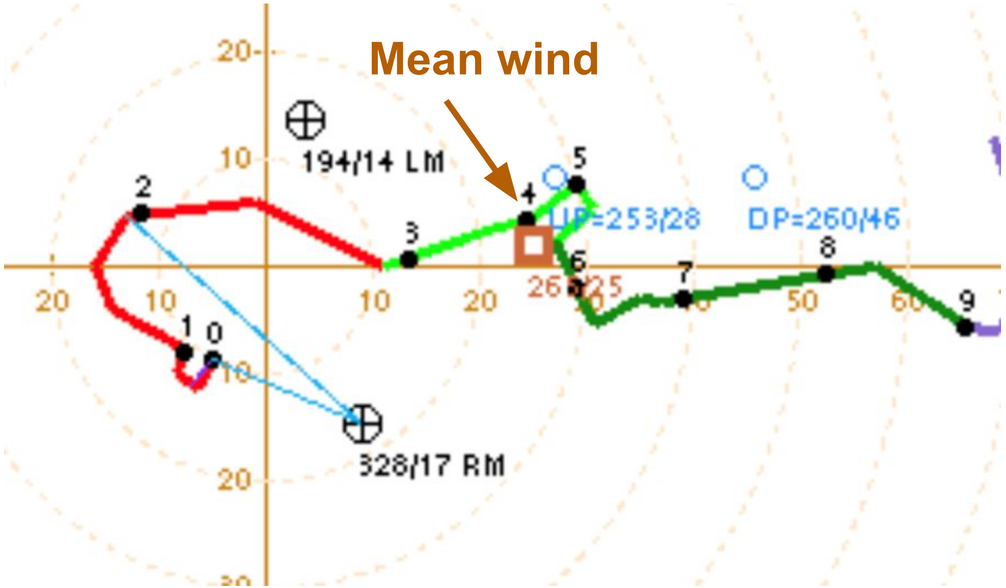
Finding Storm Motion

Some *predictions* of storm motion can be calculated from the hodograph!



Mean Wind

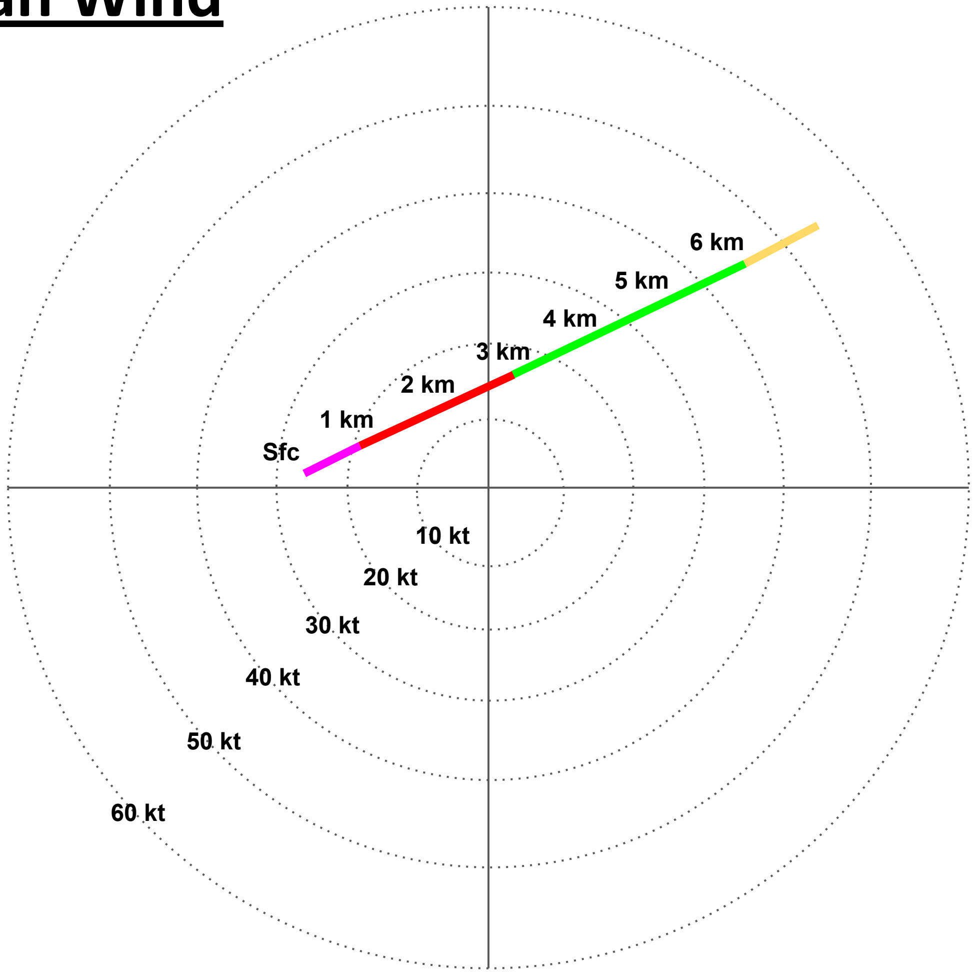
Initially, a good approximation for storm motion is the mean wind



Mean Wind

How to find the mean wind:

Take the average of points along the hodograph (in this case, we'll do 0-6 km)



Mean Wind

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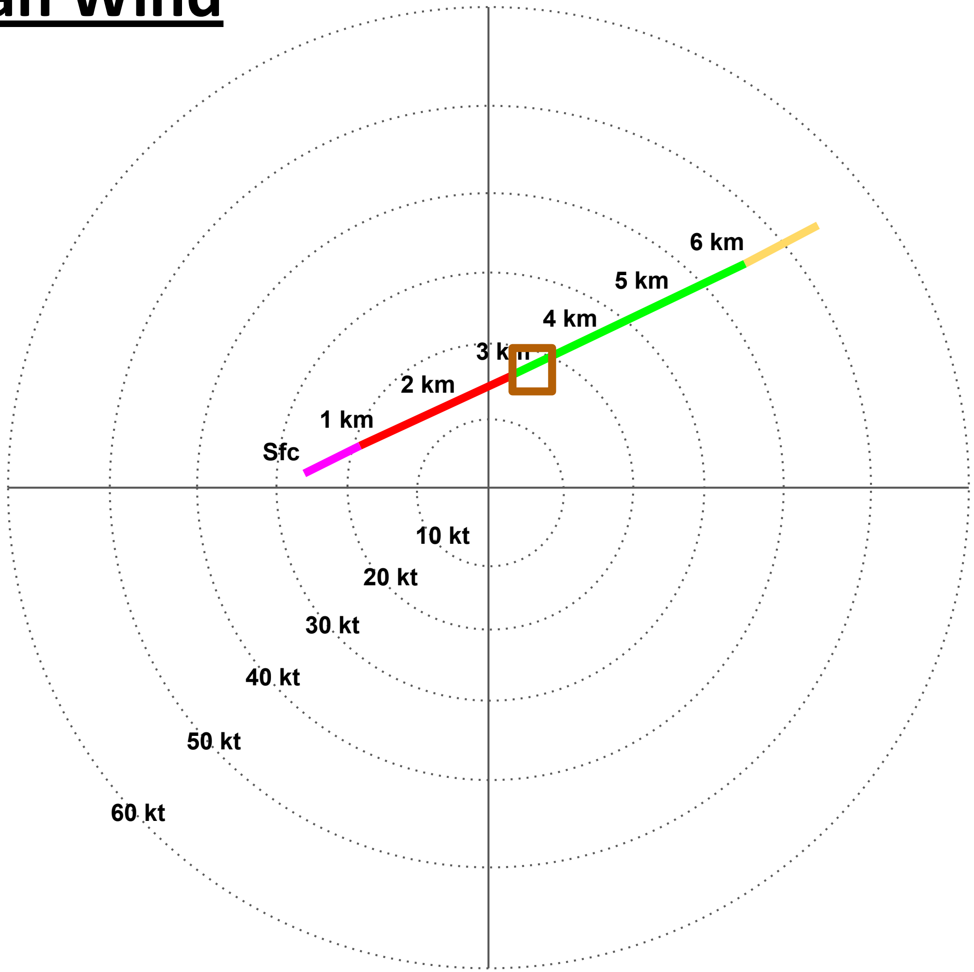
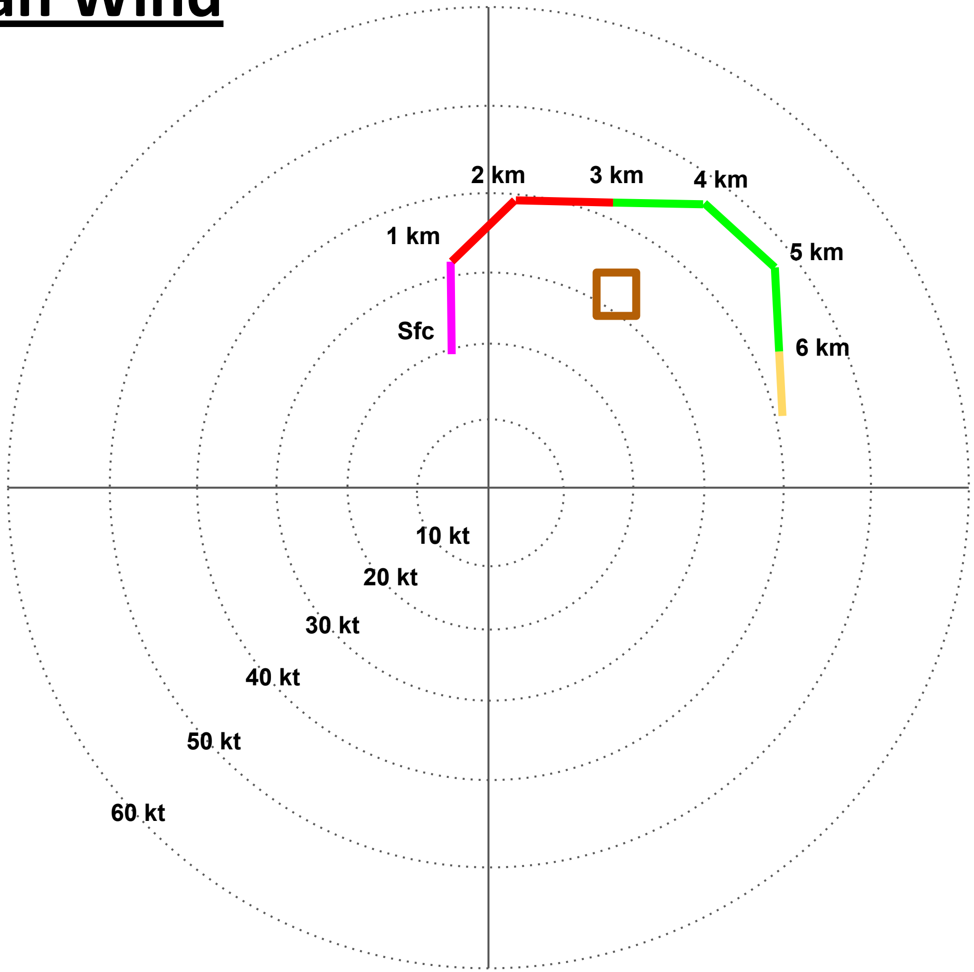


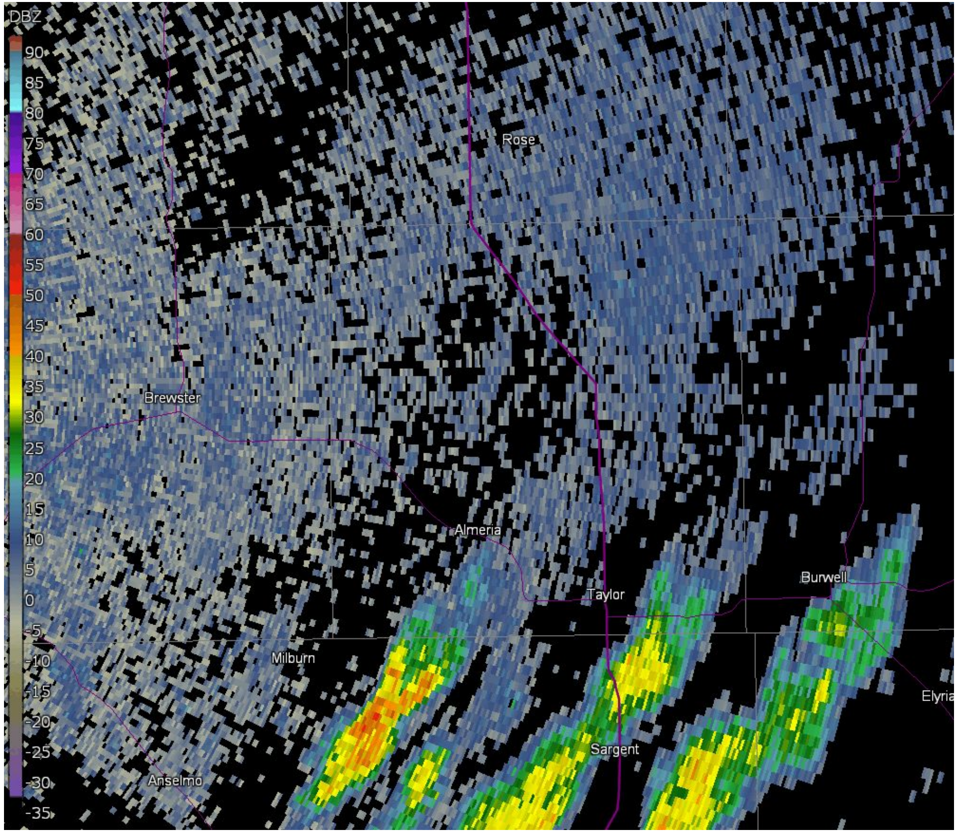
Mean Wind

For a curved hodograph, the
mean wind may lie "off the hodograph"



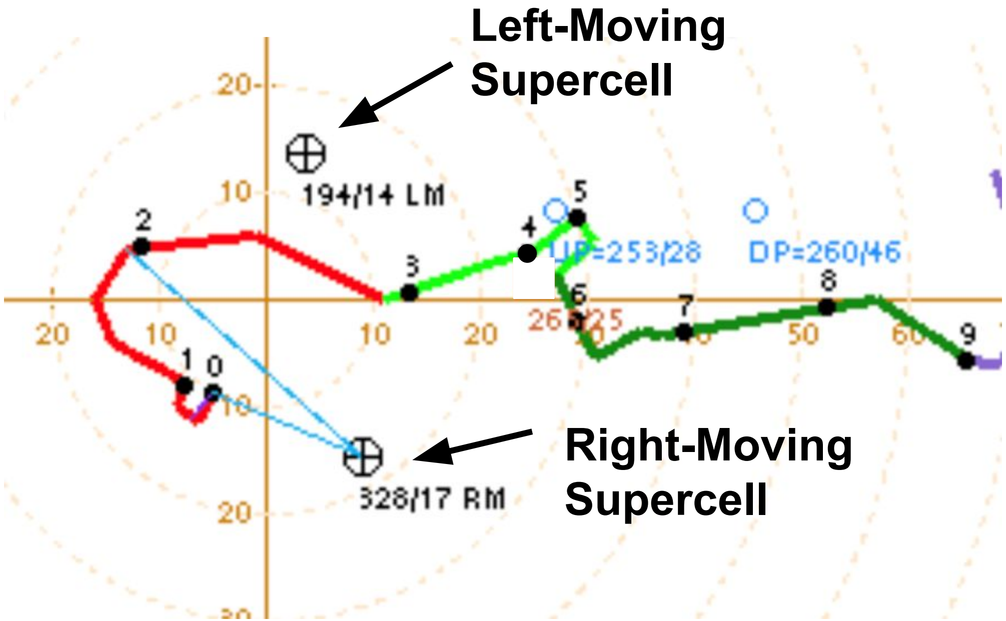
Deviant Motion

Supercells can propagate **deviantly** from the mean wind, due to their internal dynamics



Bunkers Motion

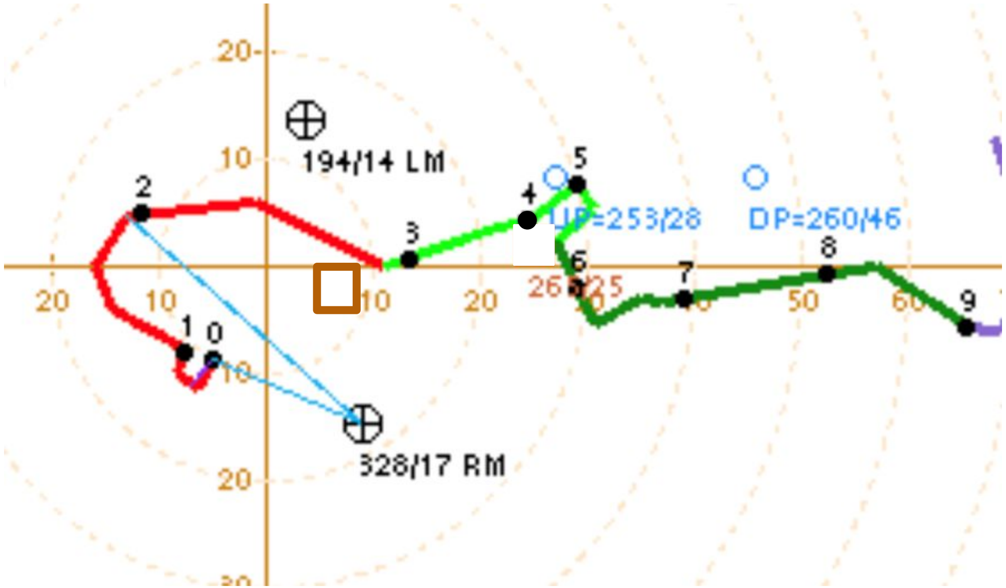
We can predict supercell motion using the Bunkers method:



Bunkers Motion

We can predict supercell motion using the Bunkers method:

1. Find the mean wind

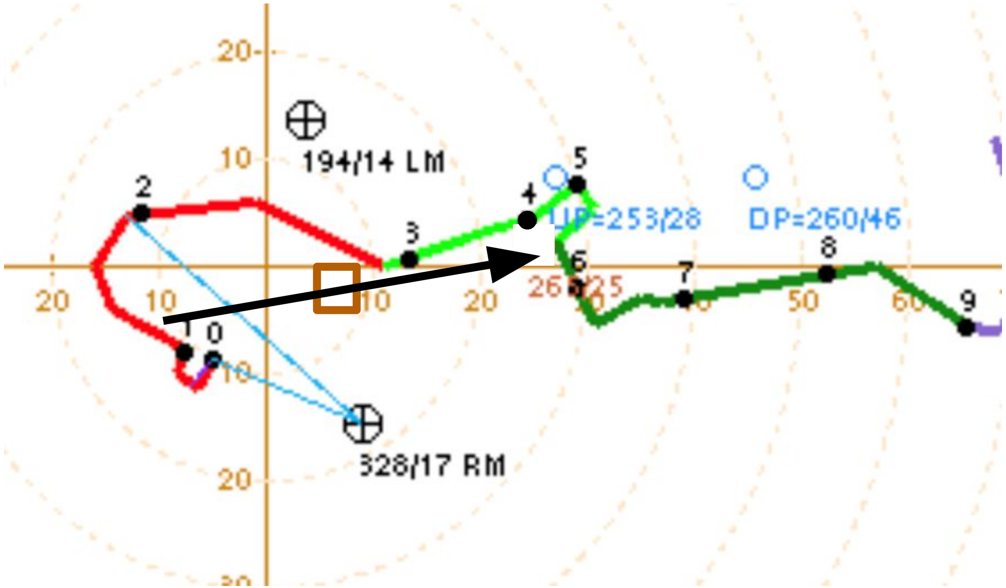


Bunkers Motion

We can predict supercell motion using the Bunkers method:

1. Find the mean wind

2. Draw the deep-layer shear vector*



*these are approximations

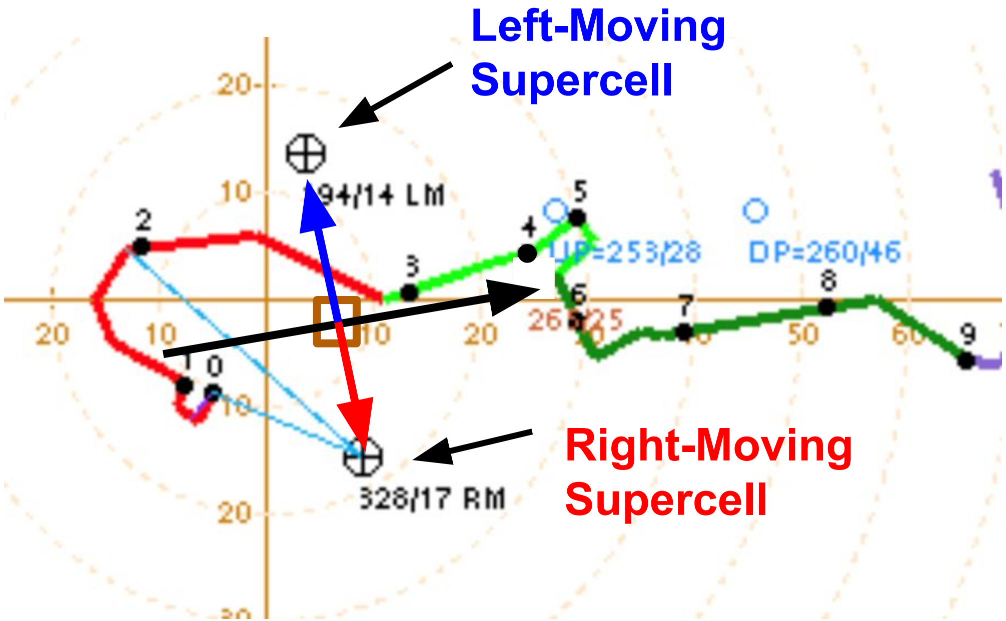
Bunkers Motion

We can predict supercell motion using the Bunkers method:

1. Find the mean wind

2. Draw the deep-layer shear vector*

3. Deviate left / right from this vector (by about 15 kts*)



*these are approximations

Bunkers Motion

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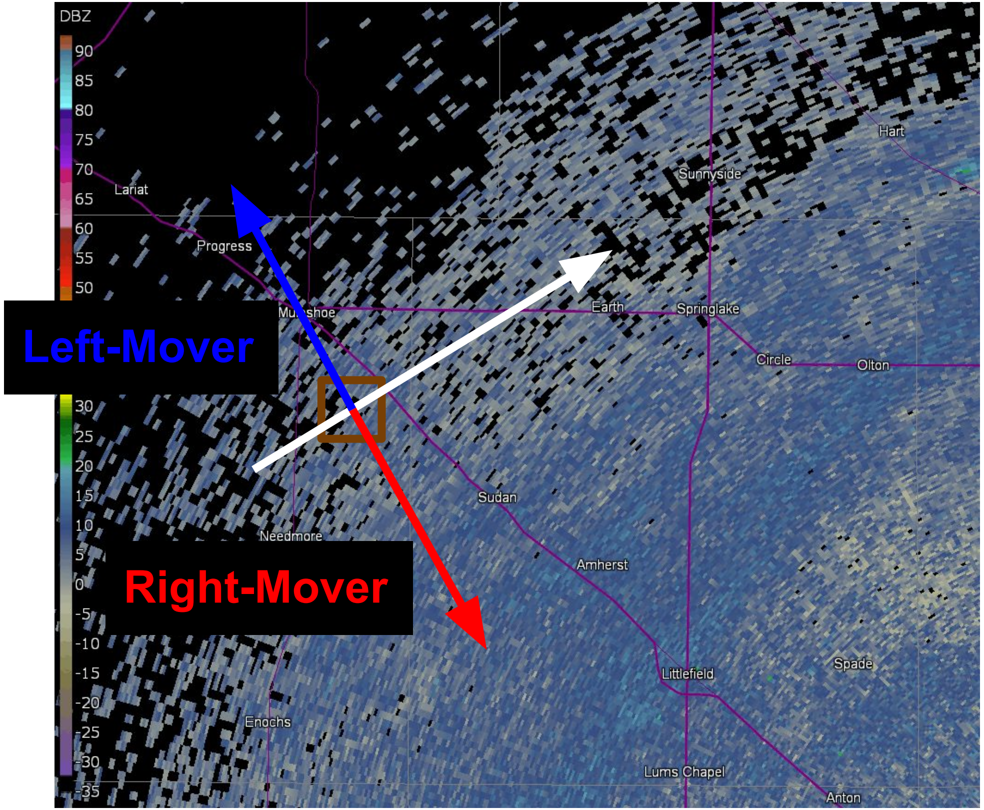
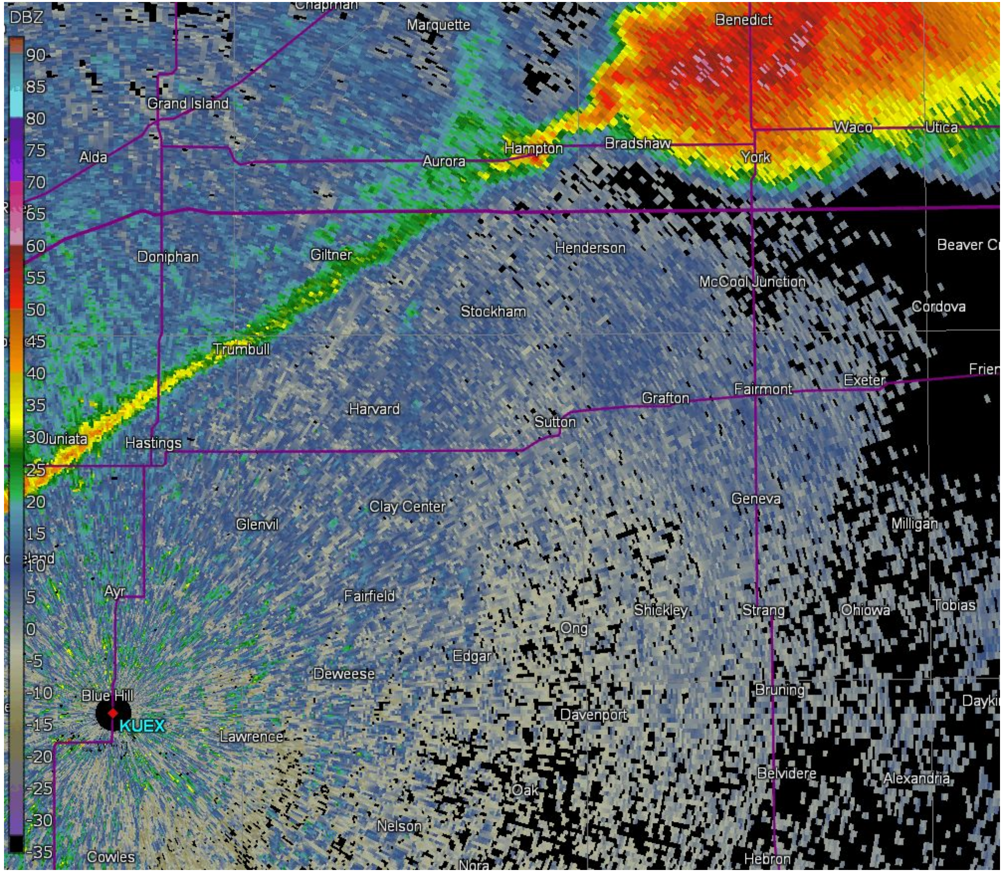


*these are approximations

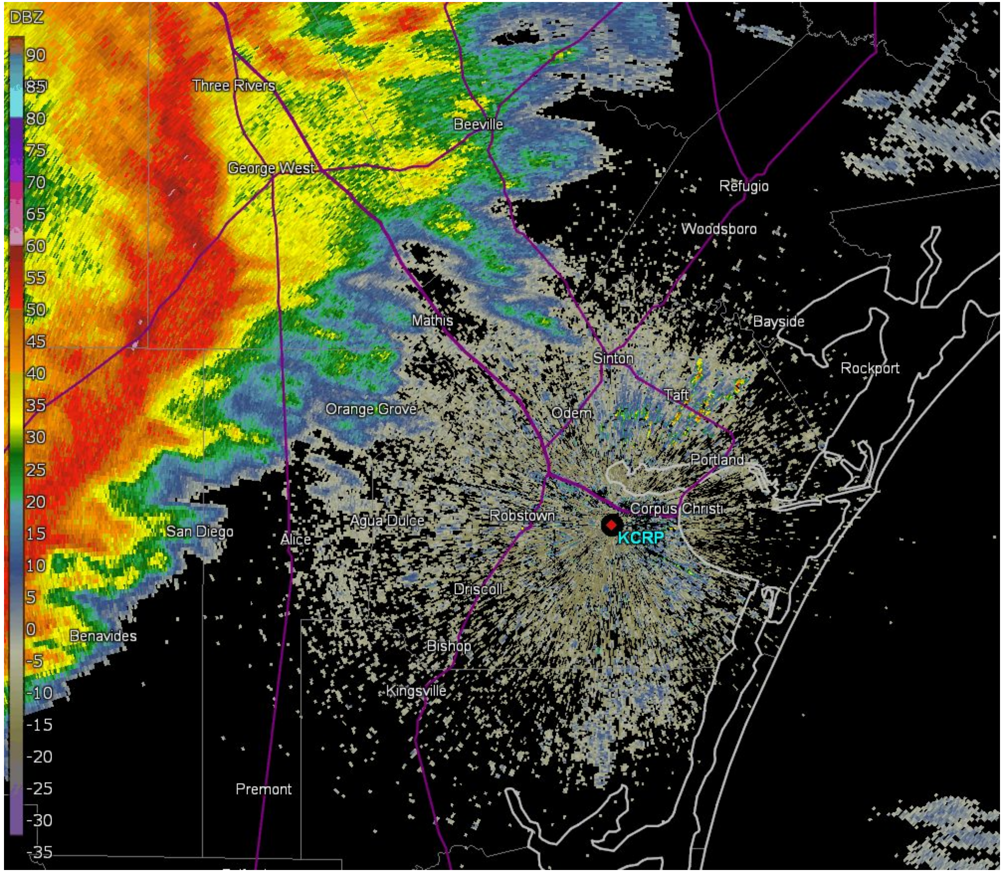
Deviant Motion

Deviant storm motion also associated with:
-boundaries



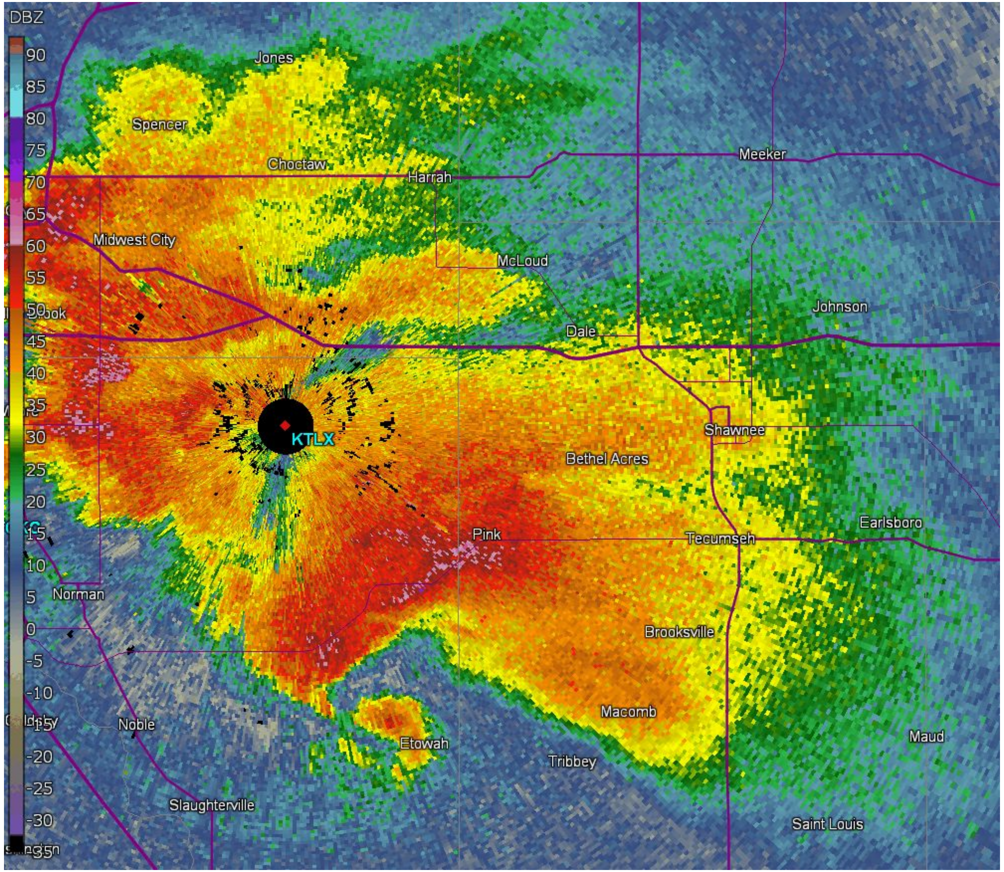
Deviant Motion

Deviant storm motion also associated with:
-boundaries
-cold pools



Deviant Motion

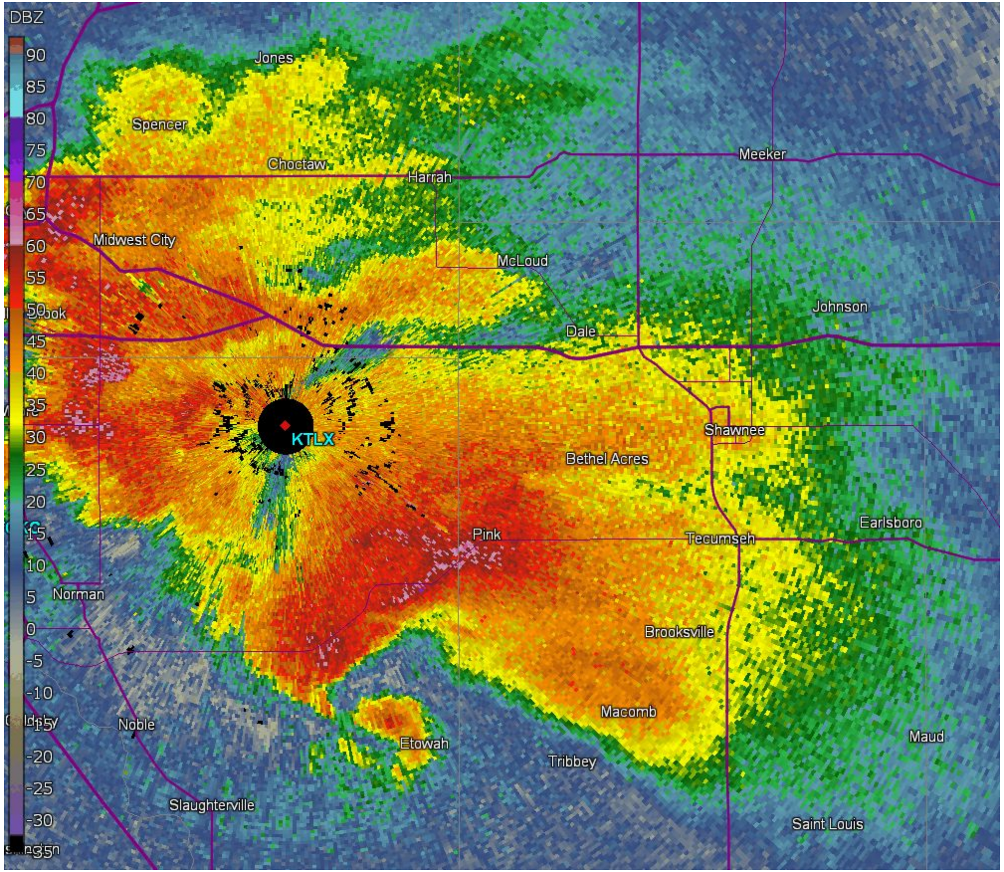
Deviant storm motion also associated with:
-boundaries
-cold pools
-cell interactions



Deviant Motion

Deviant storm motion also associated with:
-boundaries
-cold pools
-cell interactions

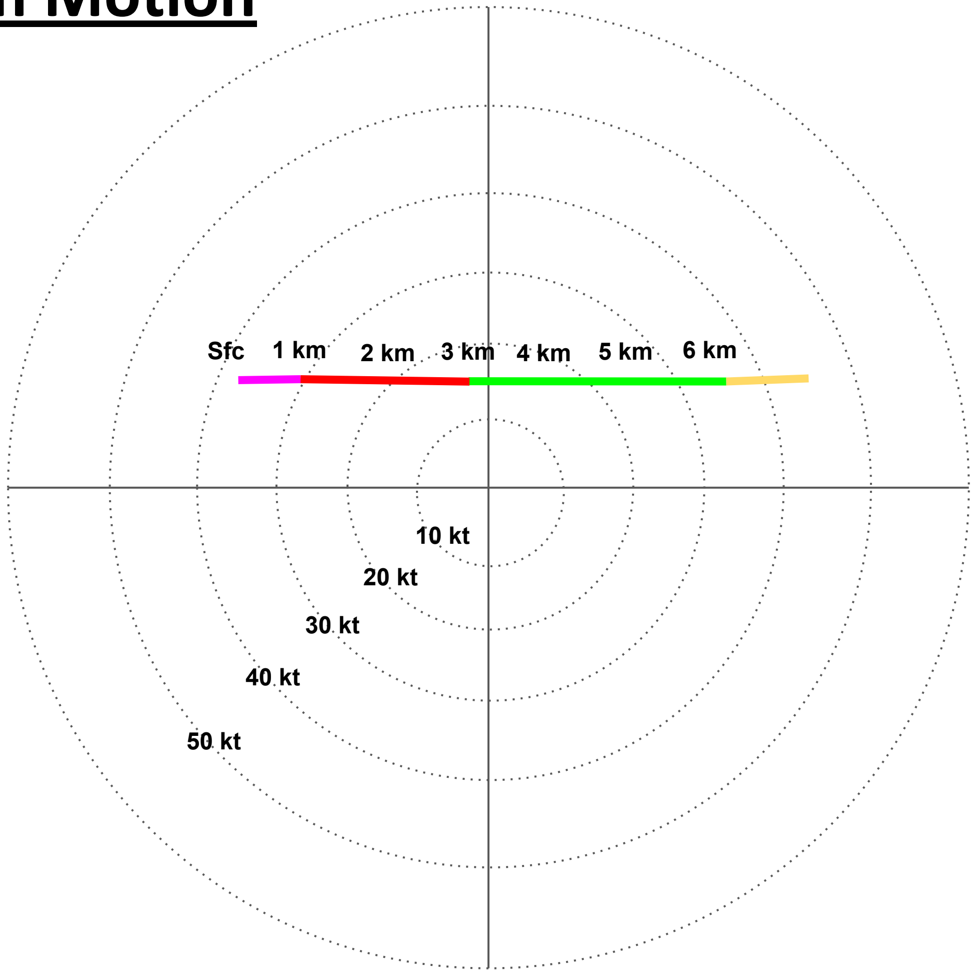
These can **not** be predicted by the hodograph!



Storm Motion

Now you try:

Estimate the mean wind for this hodograph:

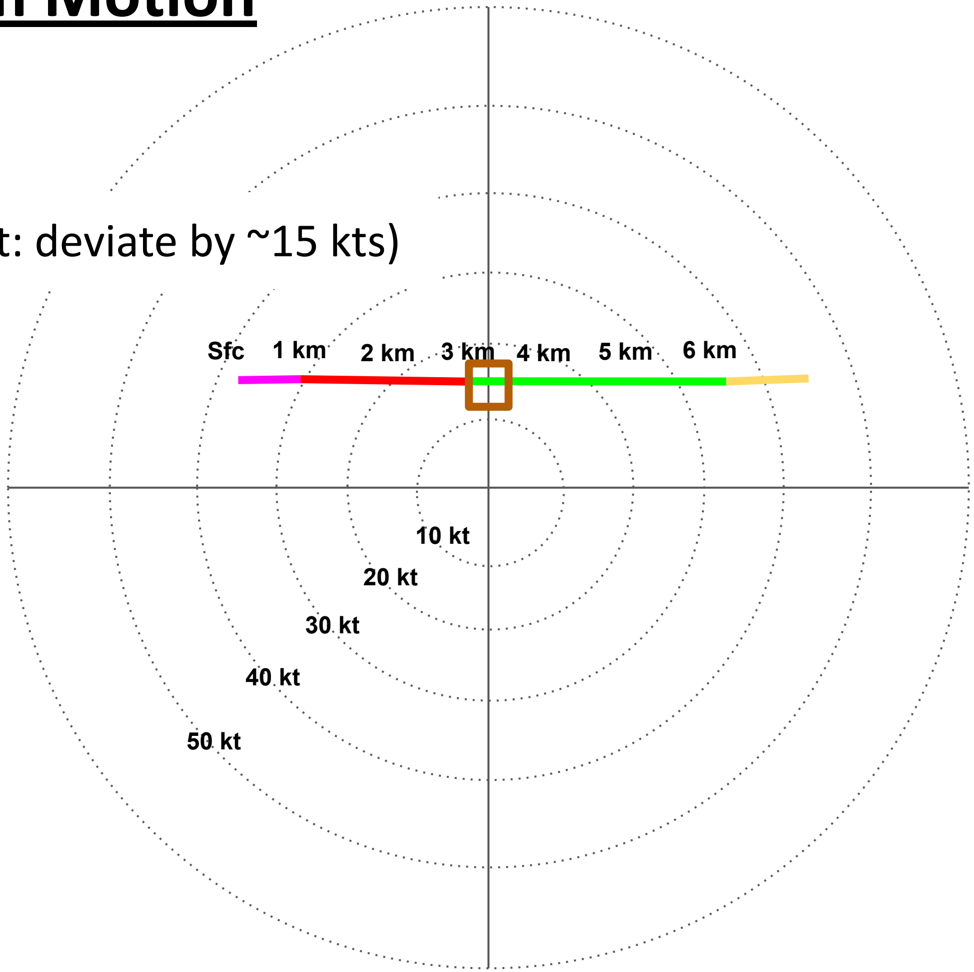


Storm Motion

Now you try:

Now, estimate the motion of a *right-moving* supercell:

(hint: deviate by ~15 kts)

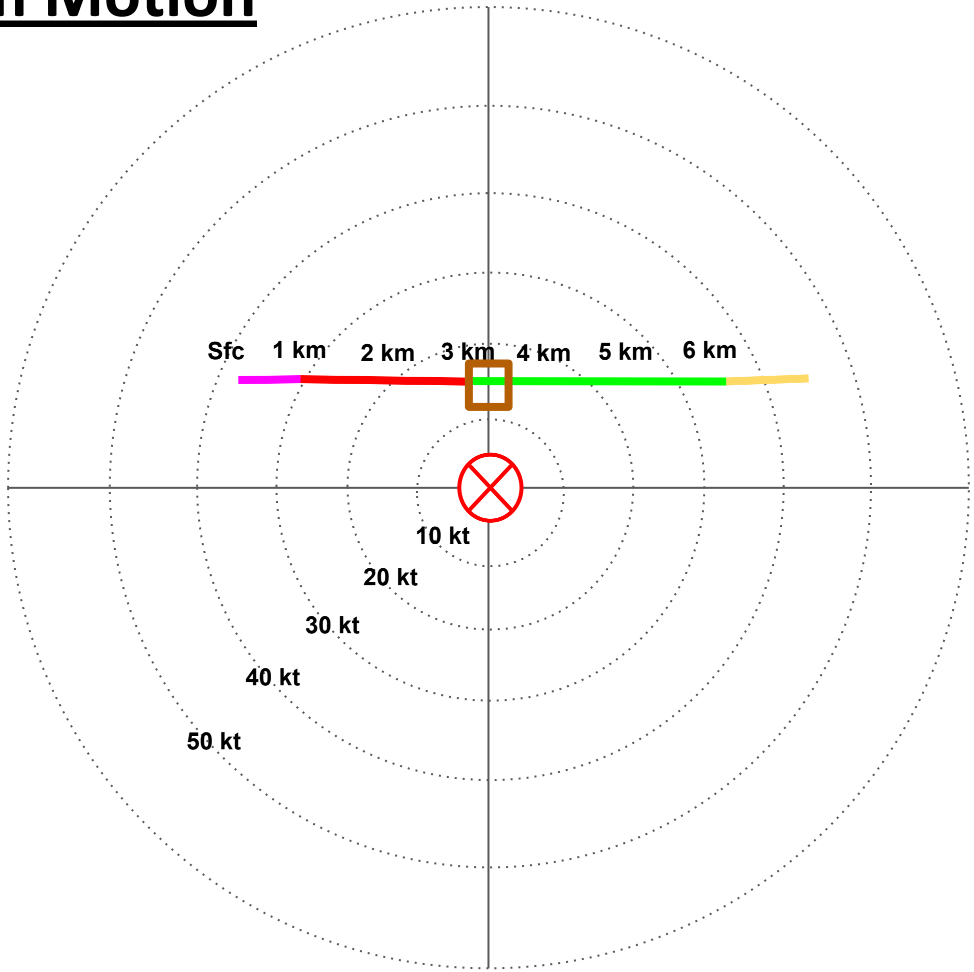


Storm Motion

Now you try:

Now, estimate the motion of a *right-moving* supercell:

You were "right" :)

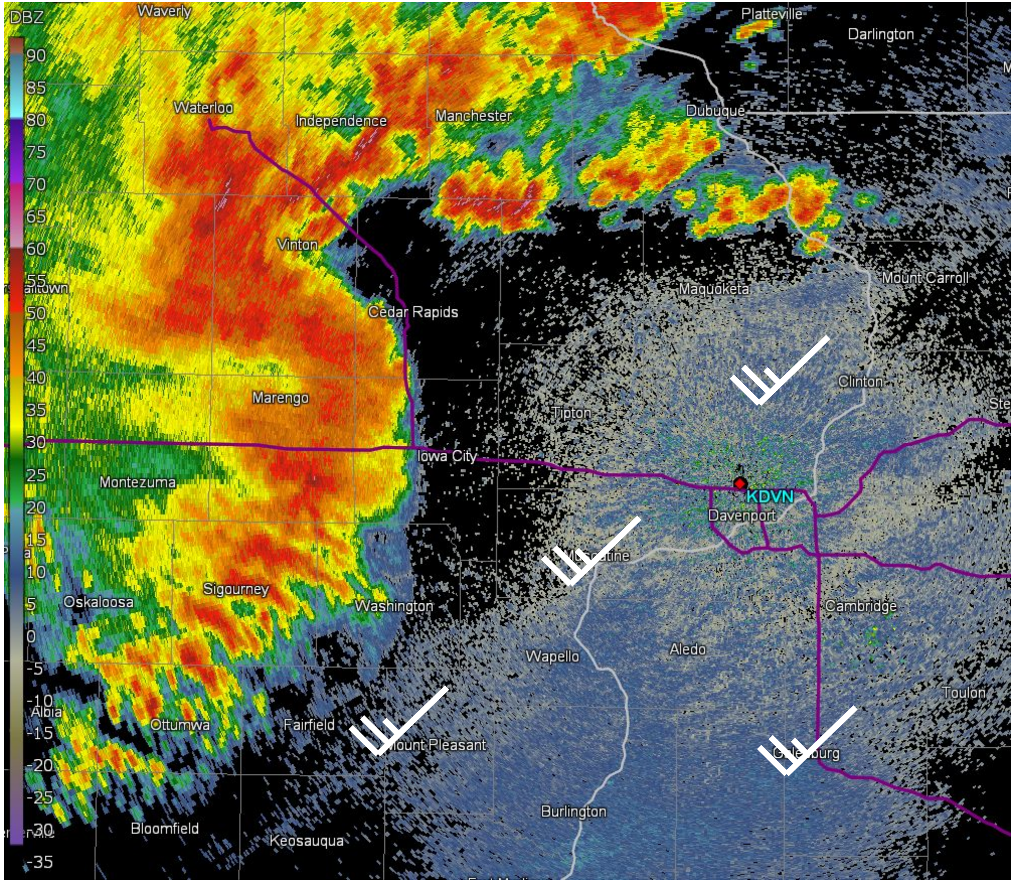


Storm Motion

What about this scenario?

You’re using Bunkers’ storm motion to estimate the potential path of an intensifying bow echo.
Is this a good idea?

a. Yes
b. No



Storm Motion

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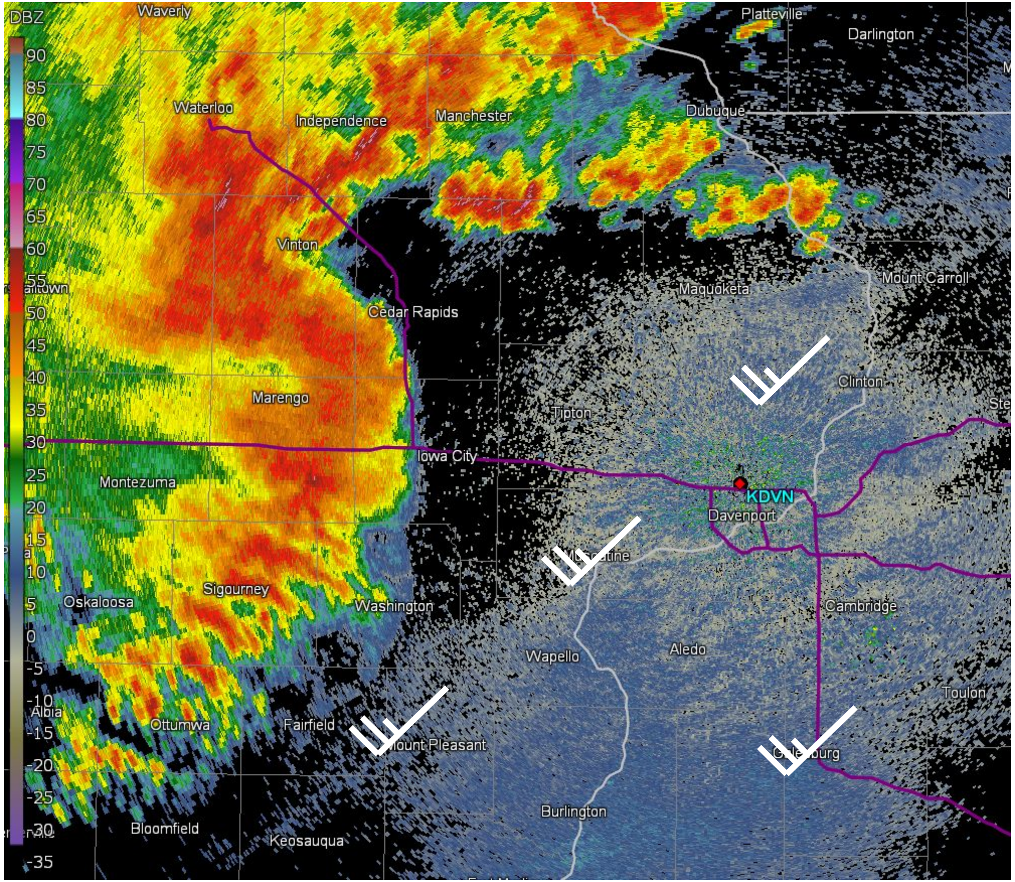


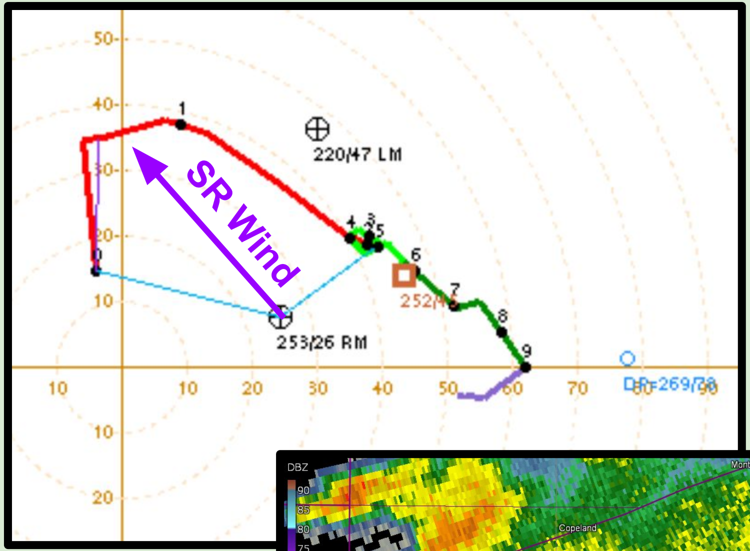
Storm Motion Summary

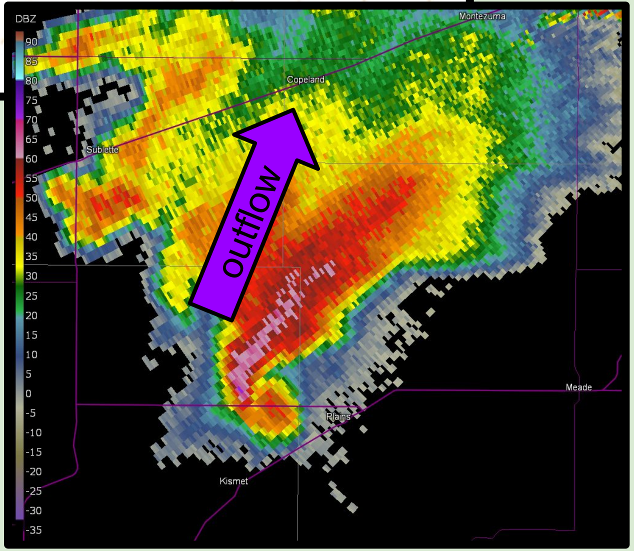
1. Initially, the mean wind is a good estimate of storm motion

2. Bunkers’ storm motion is an estimation of supercell motion

3. Boundaries, convective systems, and cell interactions may also affect storm motion

Lesson 5: Storm-Relative Winds





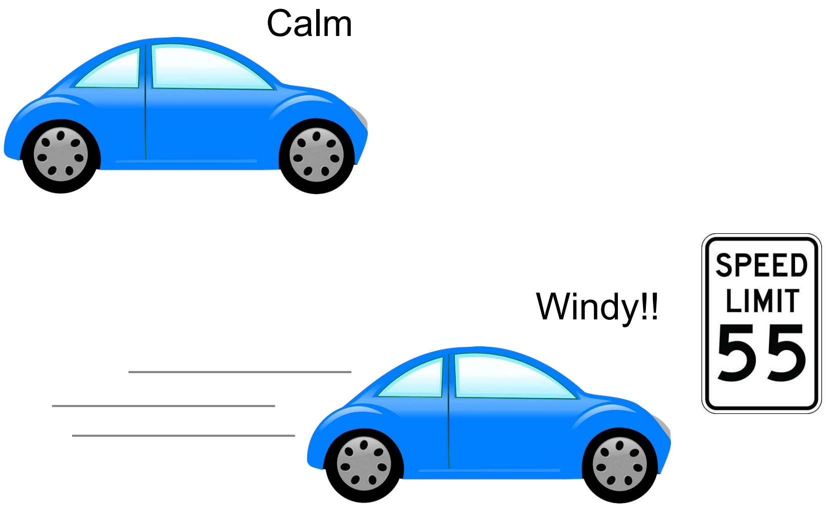
Cameron Nixon – Research Scientist, SPC / CIWRO
(cameron.nixon@noaa.gov)

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

Storm-Relative Winds

What are storm-relative winds?

These are the winds a storm actually *feels* when it's moving!



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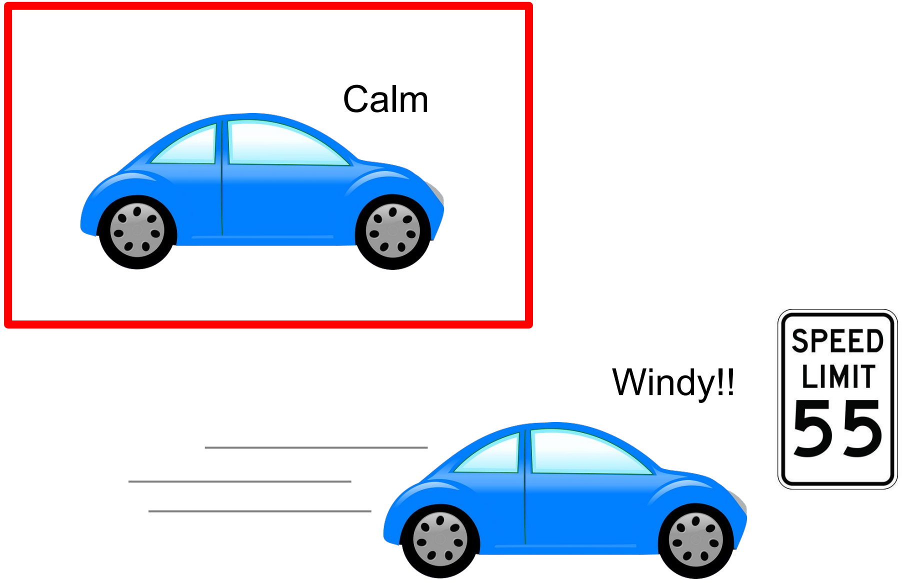

Storm-Relative Winds

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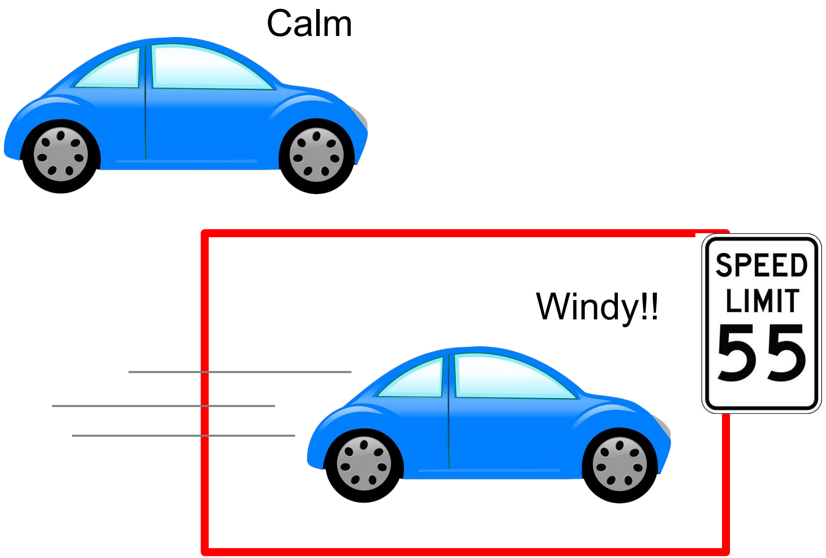
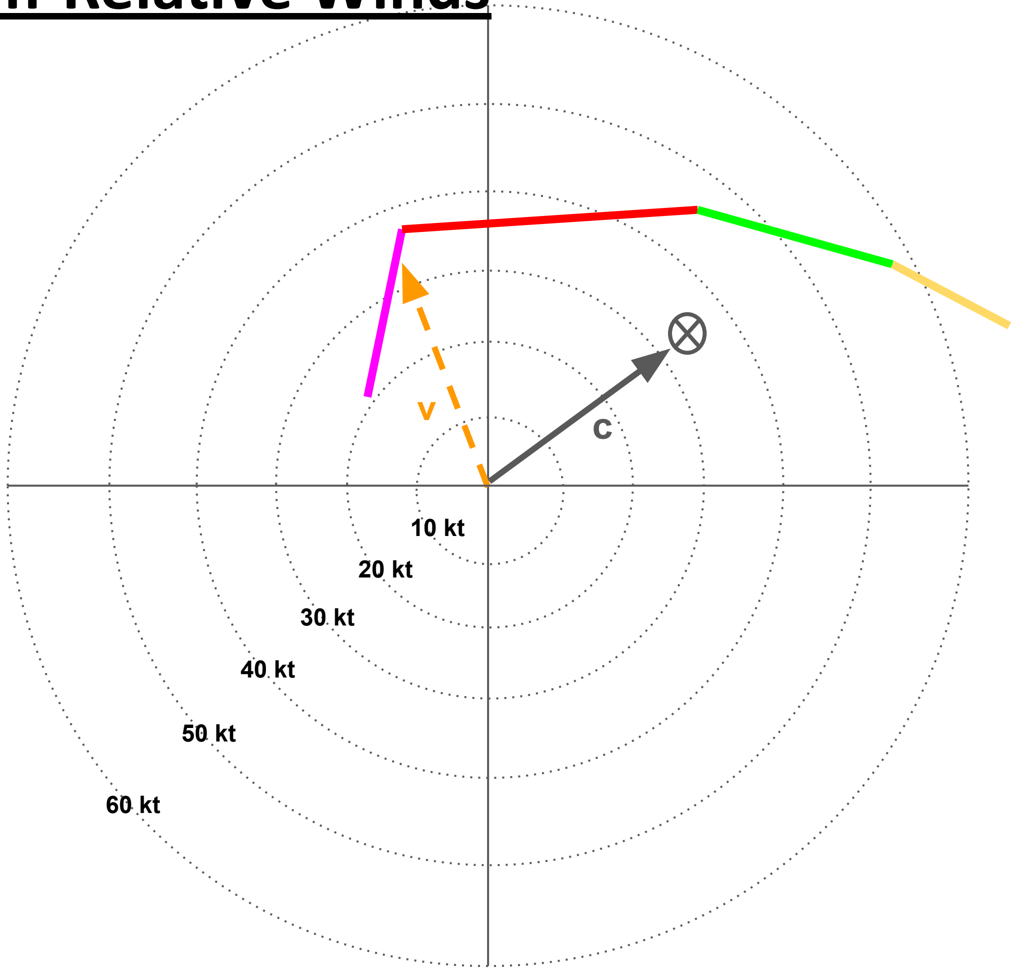


Finding Storm-Relative Winds

How do we find storm-relative winds?

V = Ground Relative Wind

C = Storm Motion



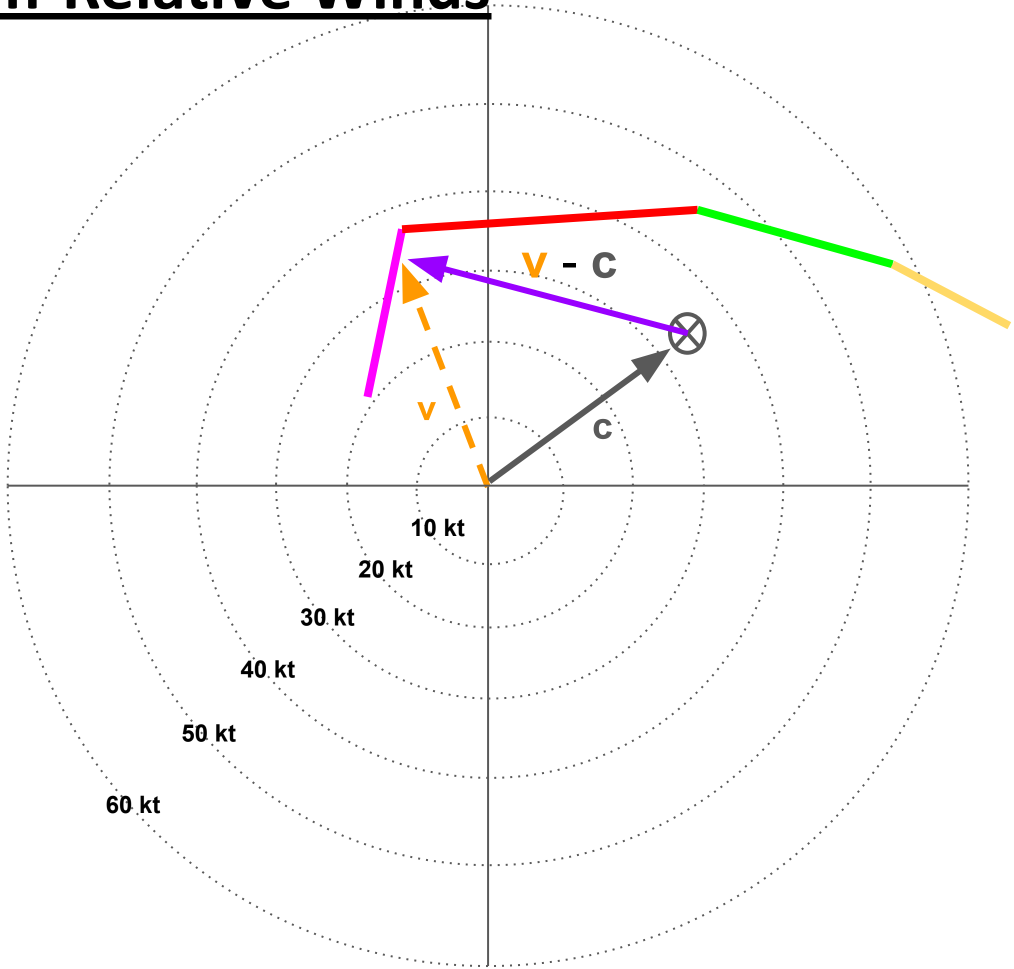
Finding Storm-Relative Winds

How do we find storm-relative winds?

V = Ground Relative Wind

C = Storm Motion

V - C = Storm Relative Wind!



Finding Storm-Relative Winds

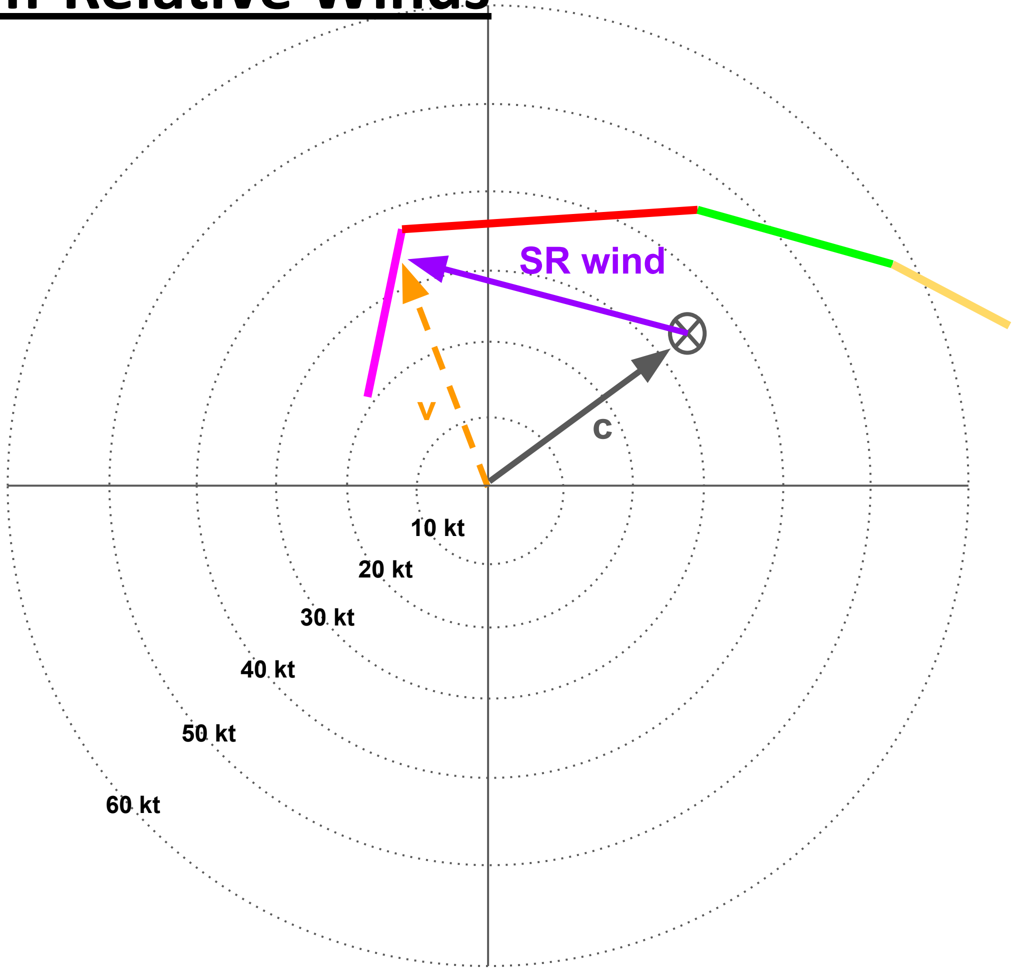
How do we find storm-relative winds?

V = Ground Relative Wind

C = Storm Motion

V - C = Storm Relative Wind!

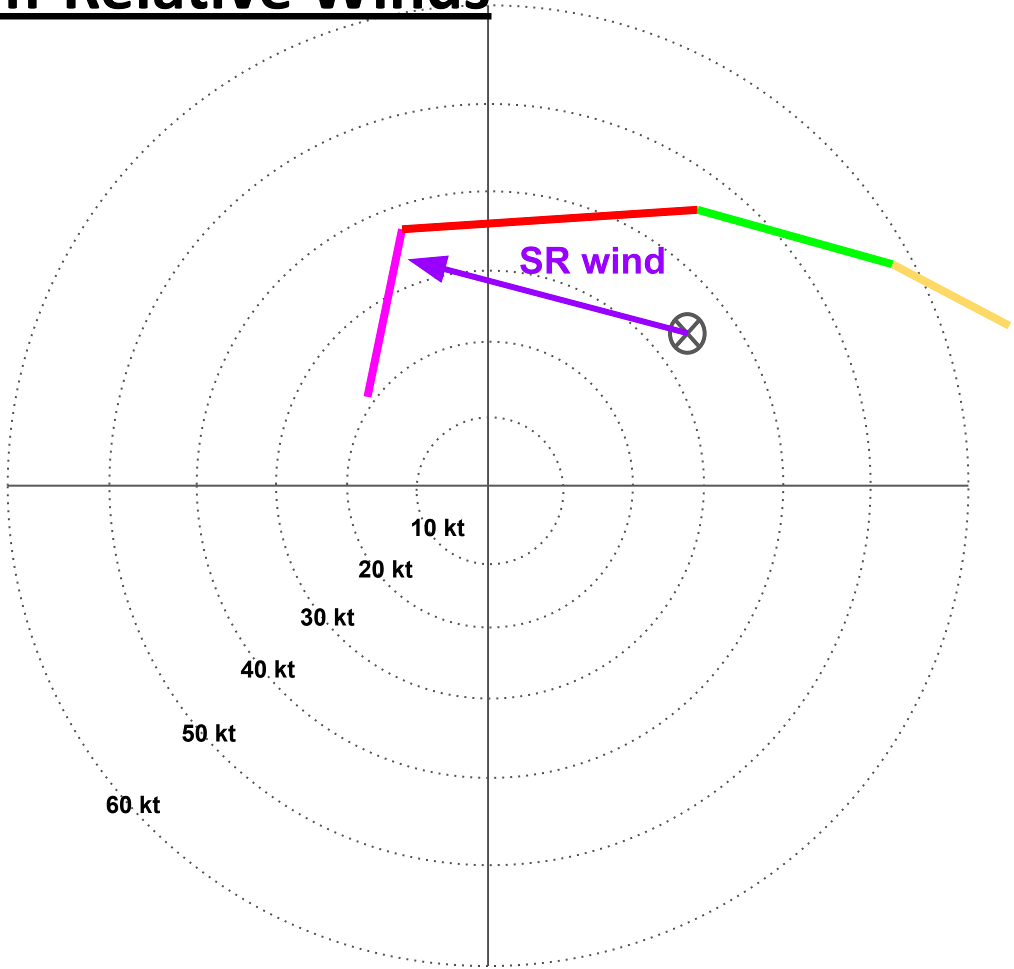
(we are subtracting out storm motion!)



Finding Storm-Relative Winds

How do we find storm-relative winds?

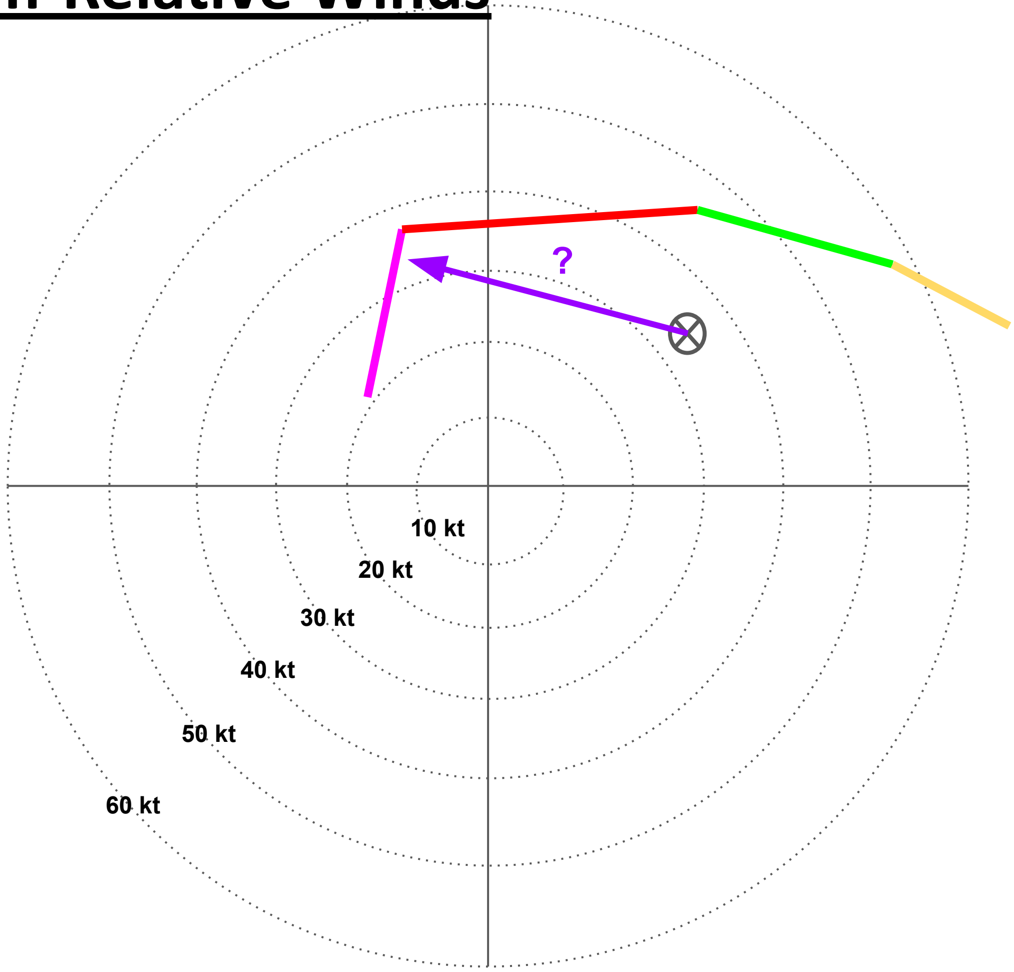
Simply draw a vector from **storm motion** to desired point on the hodograph



Finding Storm-Relative Winds

How strong is this storm-relative wind?

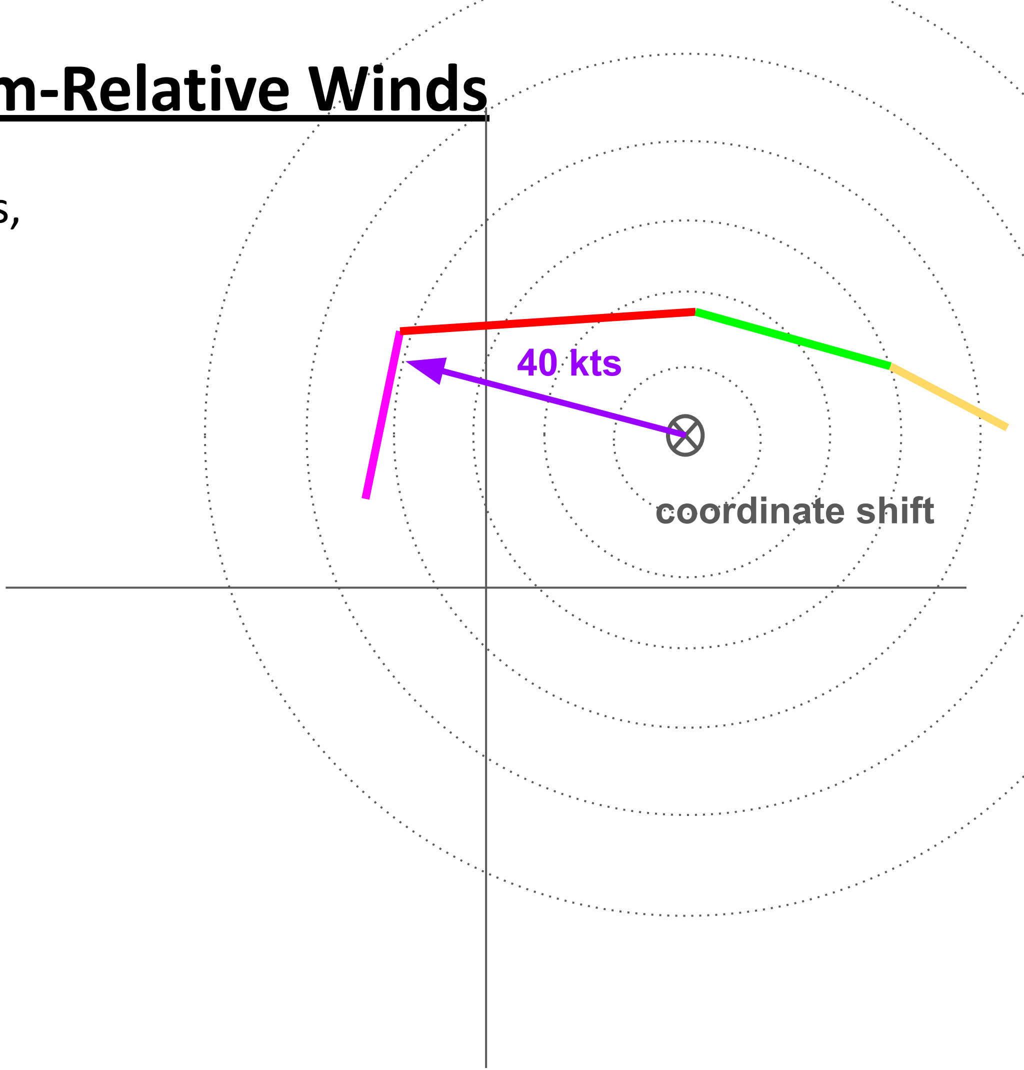
It's hard to tell



Finding Storm-Relative Winds

To help measure the storm-relative winds, we can use a **storm-relative** hodograph!

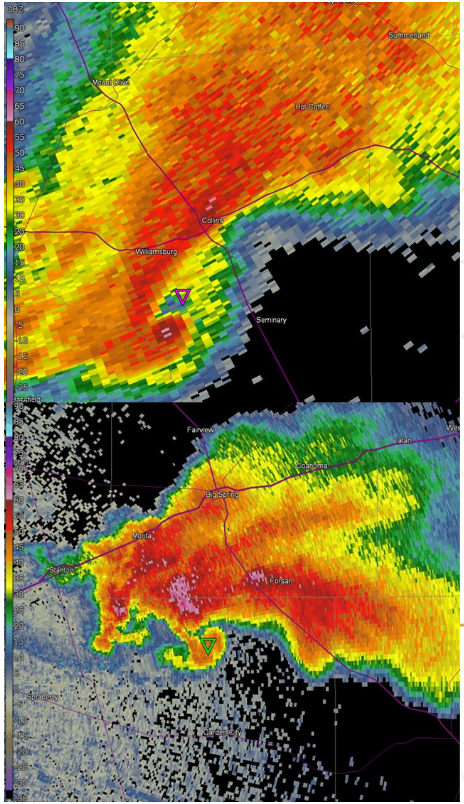
Shift the origin of the hodograph to the storm motion

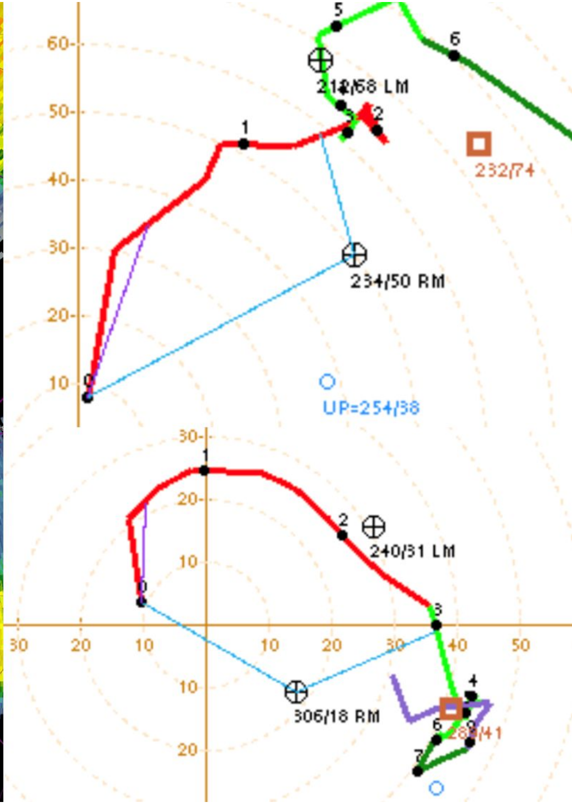


Storm-Relative Winds

Why is **storm-relative wind** important?

It directly governs storm structure!

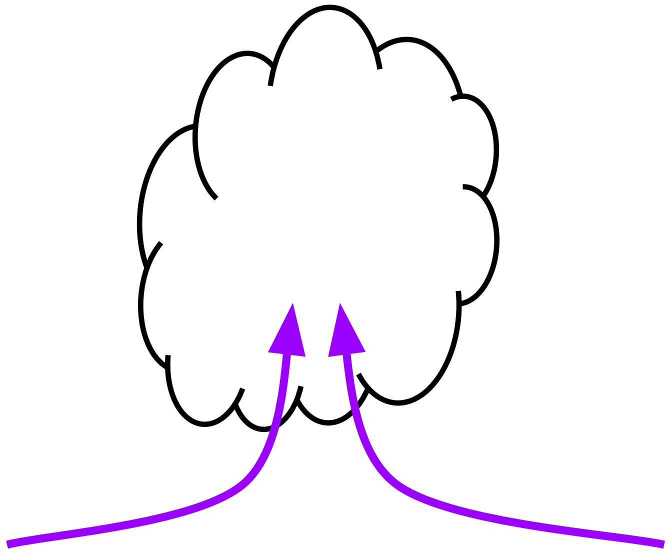


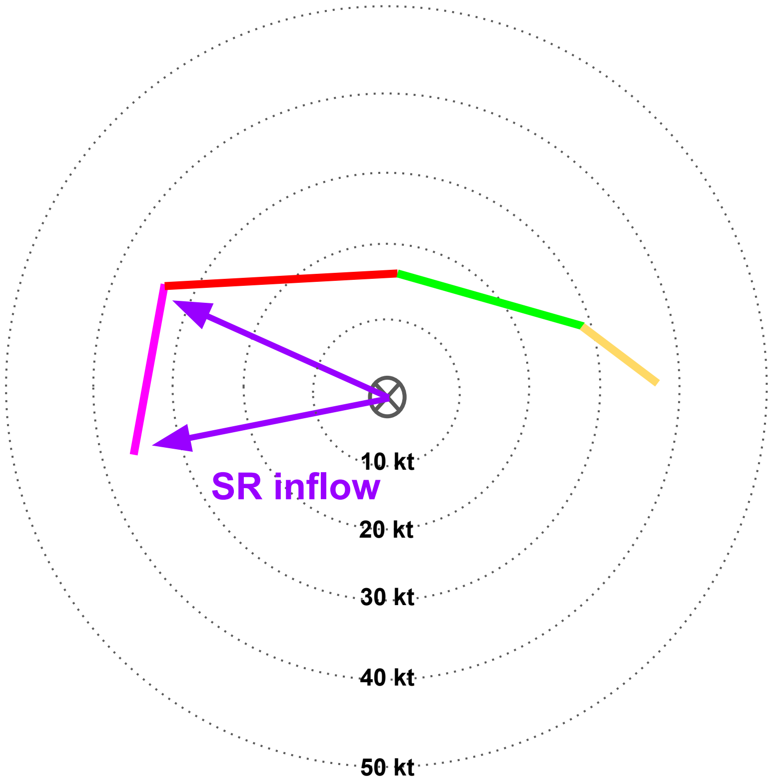


Storm-Relative Winds and Storm Structure

Storm-Relative Inflow

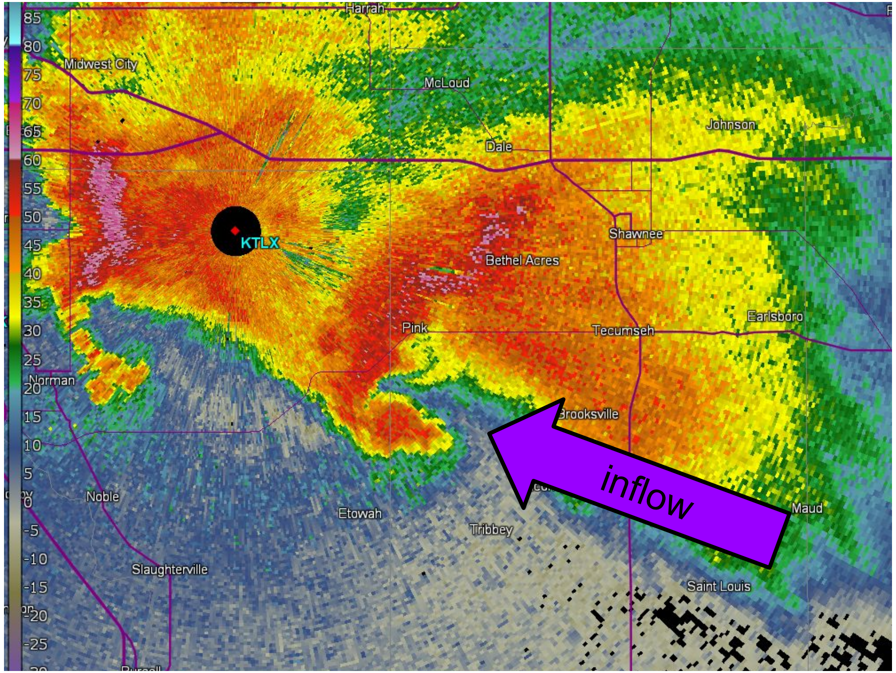
SR Inflow is the wind
in the lower levels of a storm,
where mass enters the storm

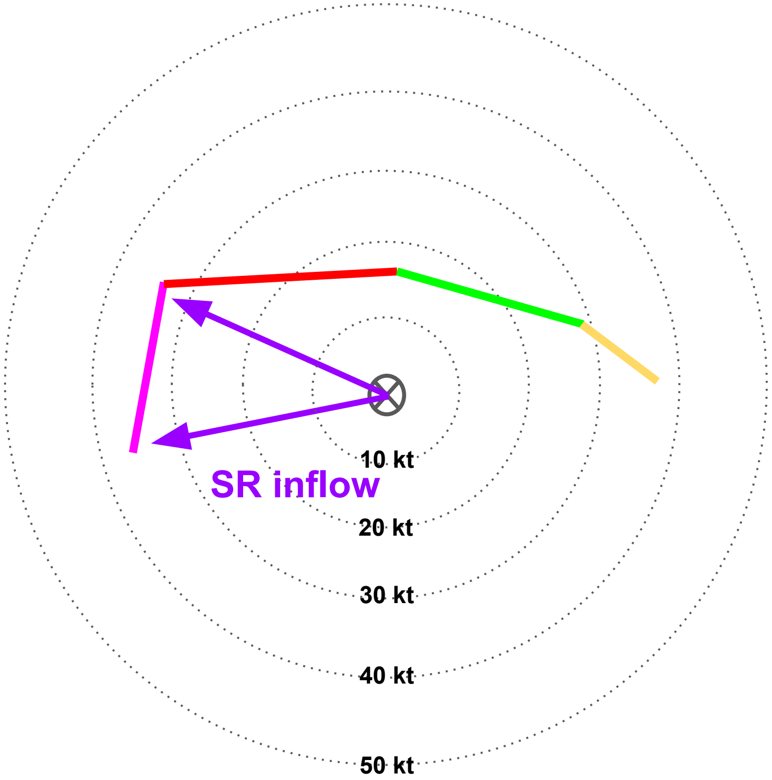




Storm-Relative Inflow

The direction of inflow can help determine whether or not a storm has access to “clean”, unstable air





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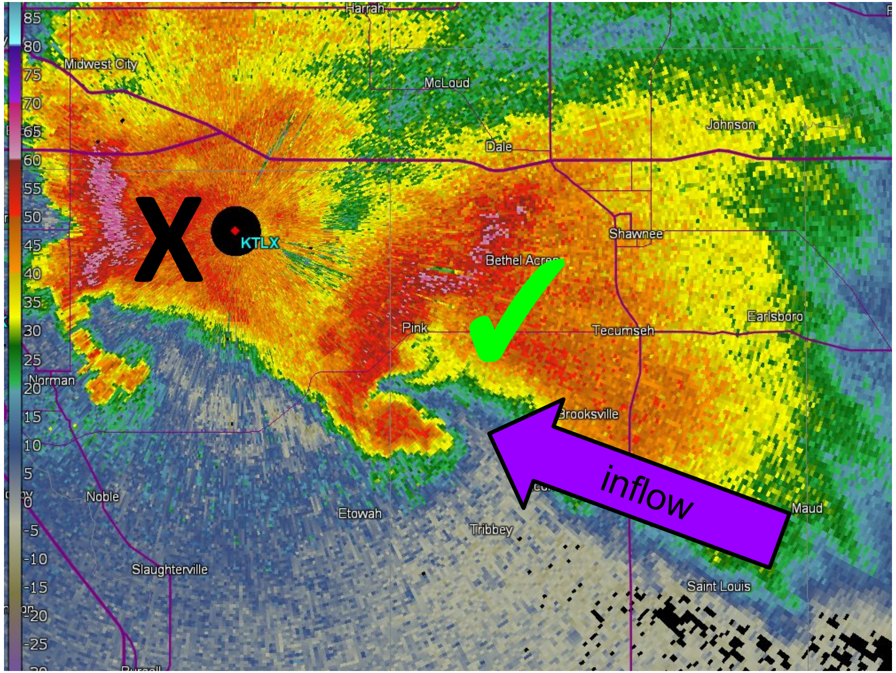
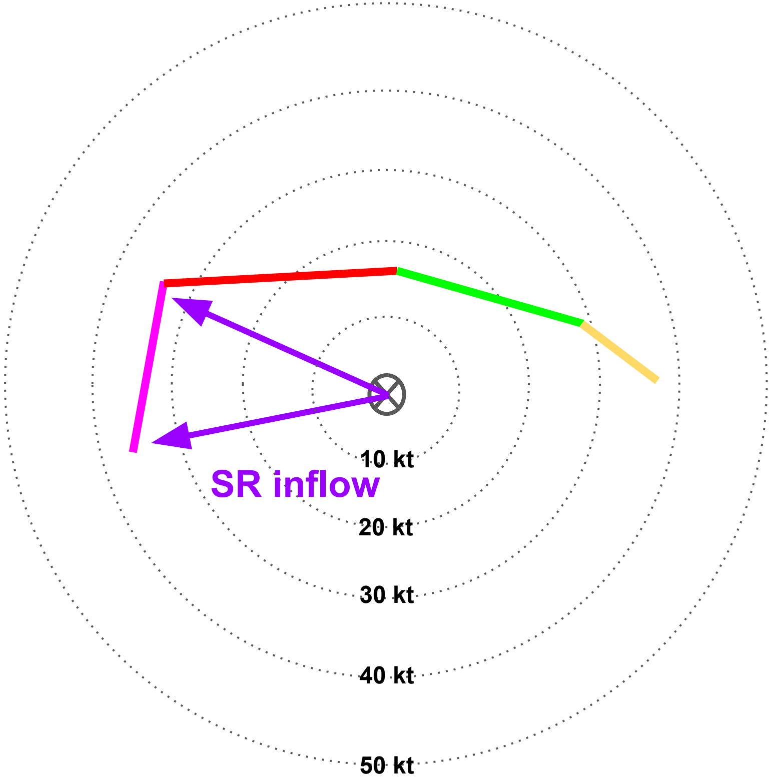
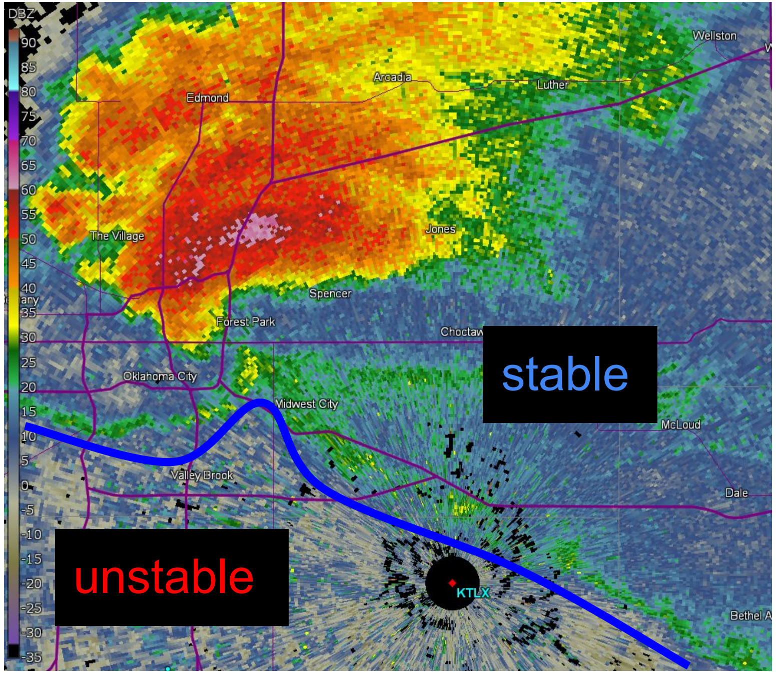


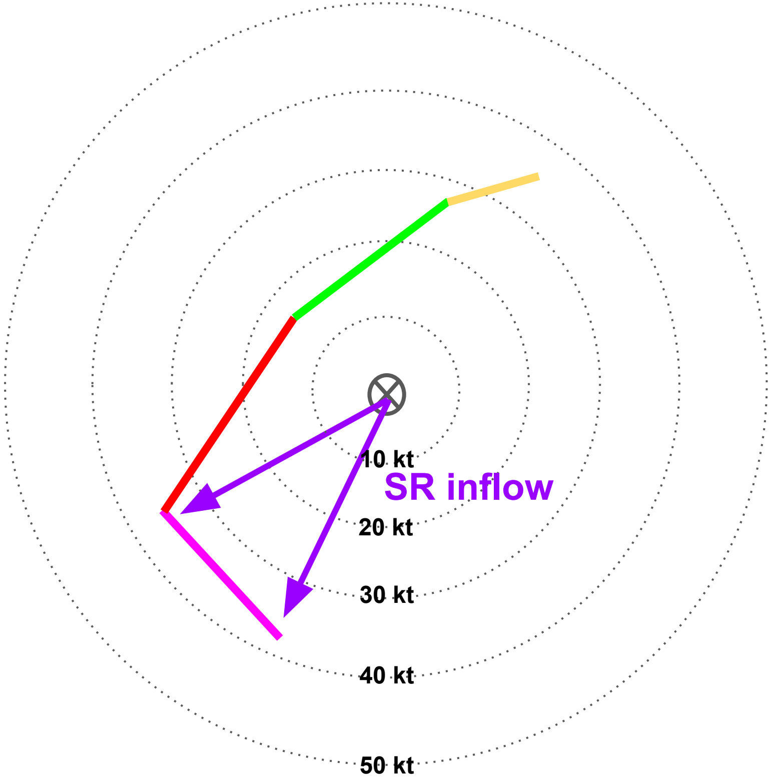


Storm-Relative Inflow

This storm is "anchored" to a boundary. Is its inflow air from the unstable or stable side?

a. Stable b. Unstable

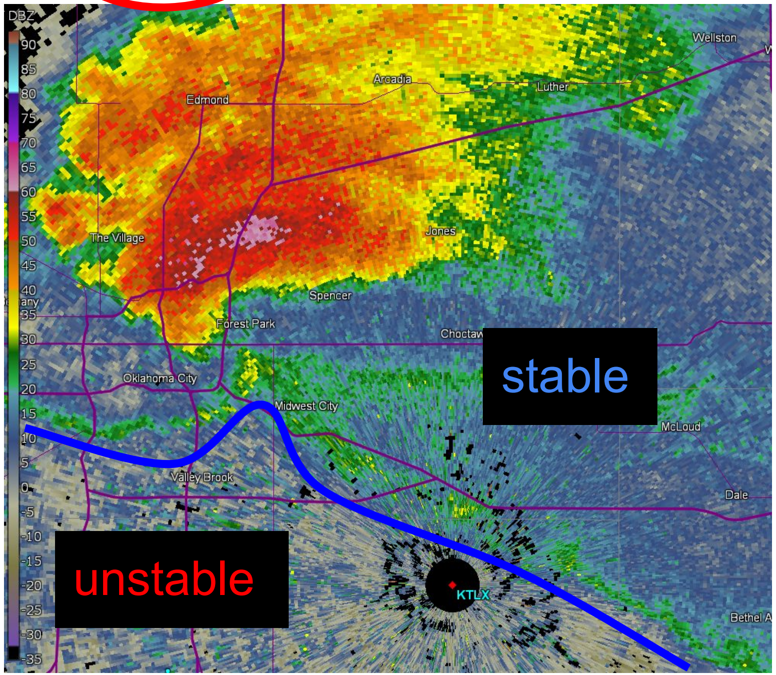


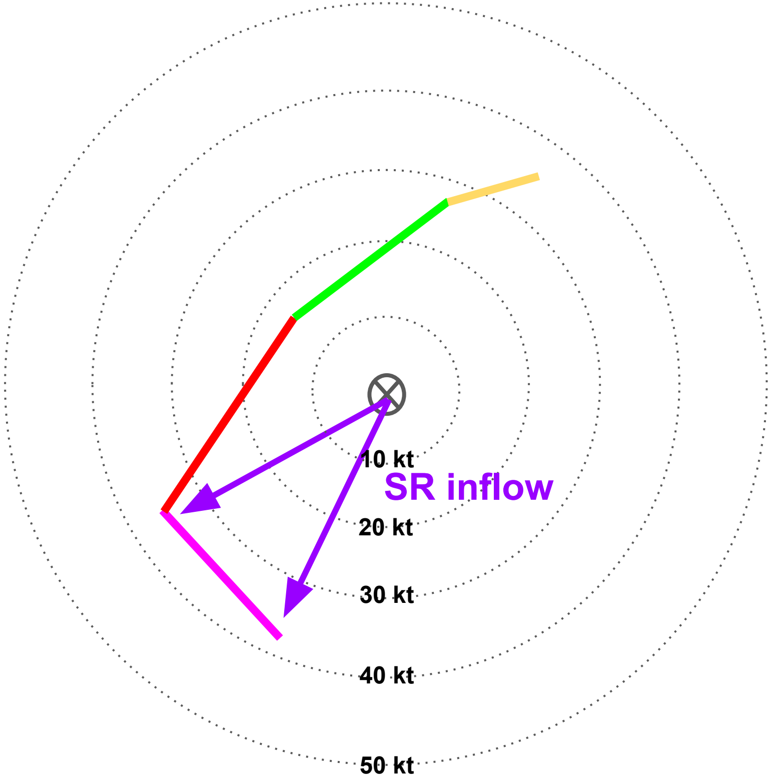


Storm-Relative Inflow

This storm is "anchored" to a boundary. Is its inflow air from the unstable or stable side?

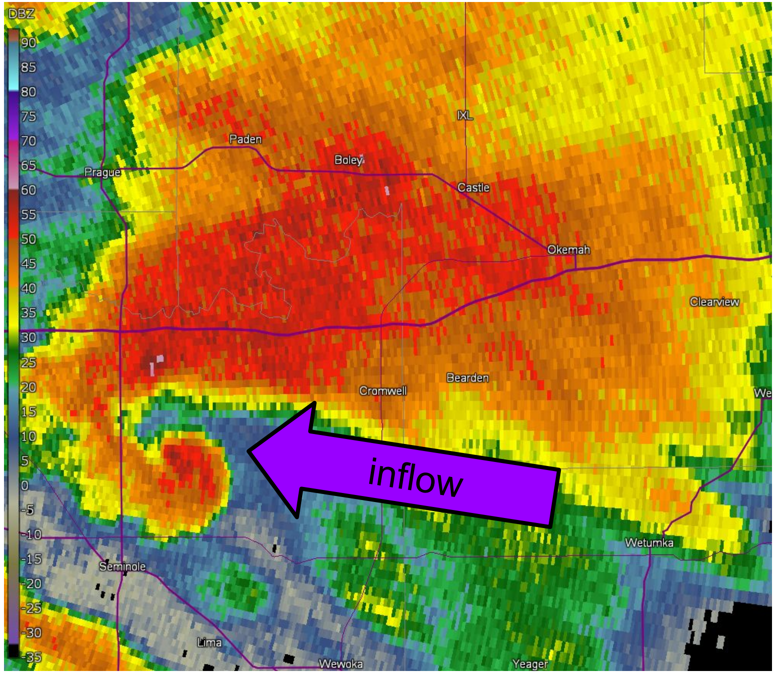
a. Stable   b. Unstable

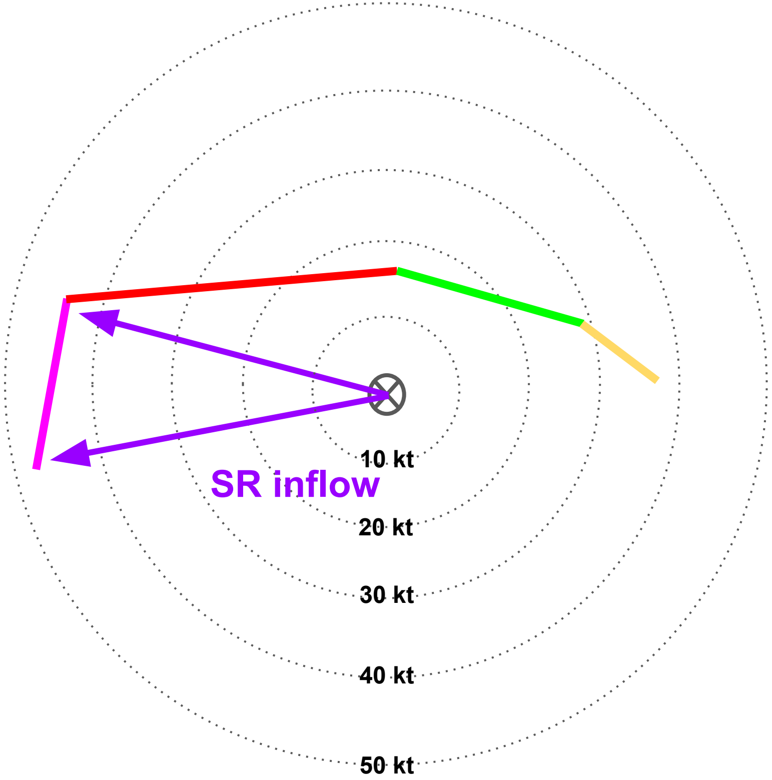




Storm-Relative Inflow

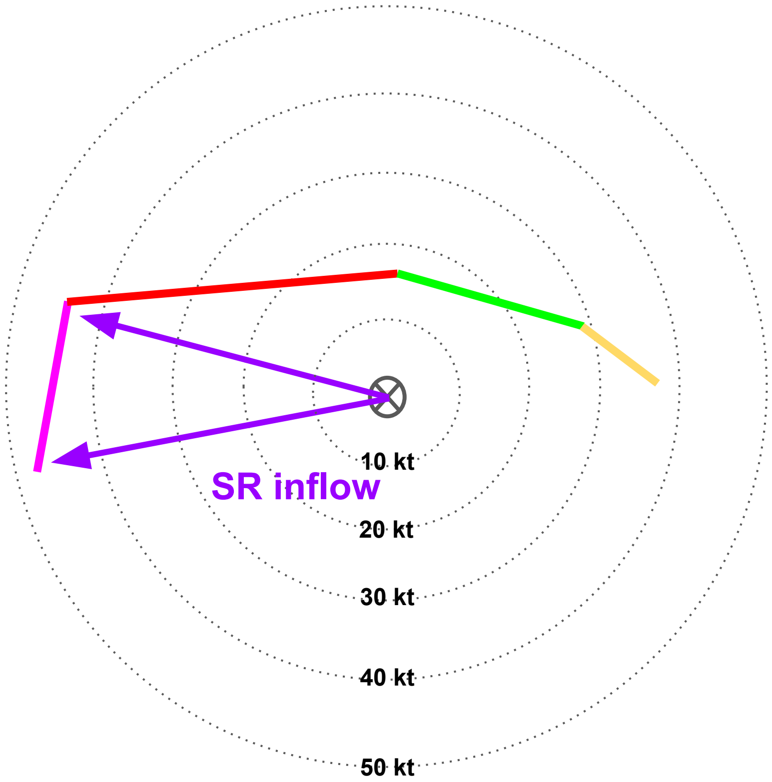
Stronger inflow can sustain larger storms with more precipitation





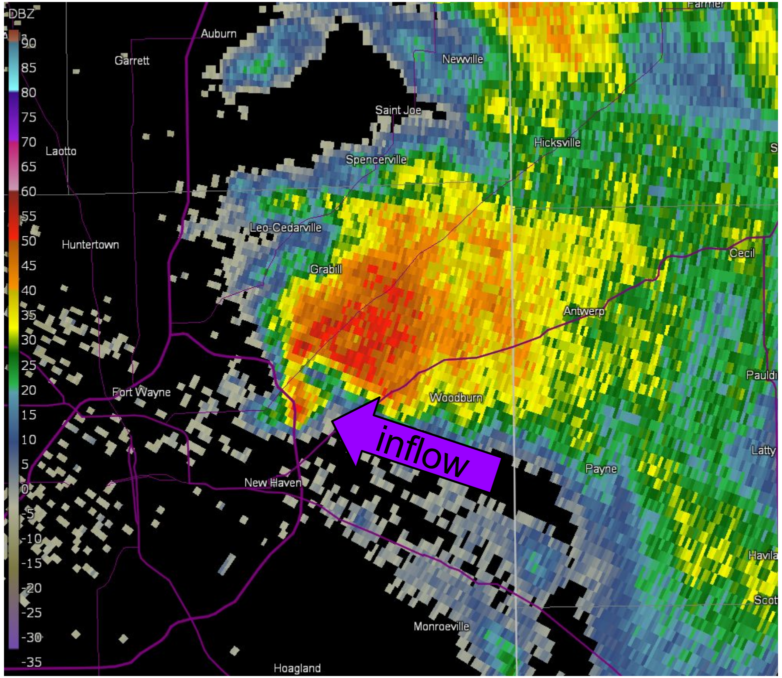
Storm-Relative Inflow

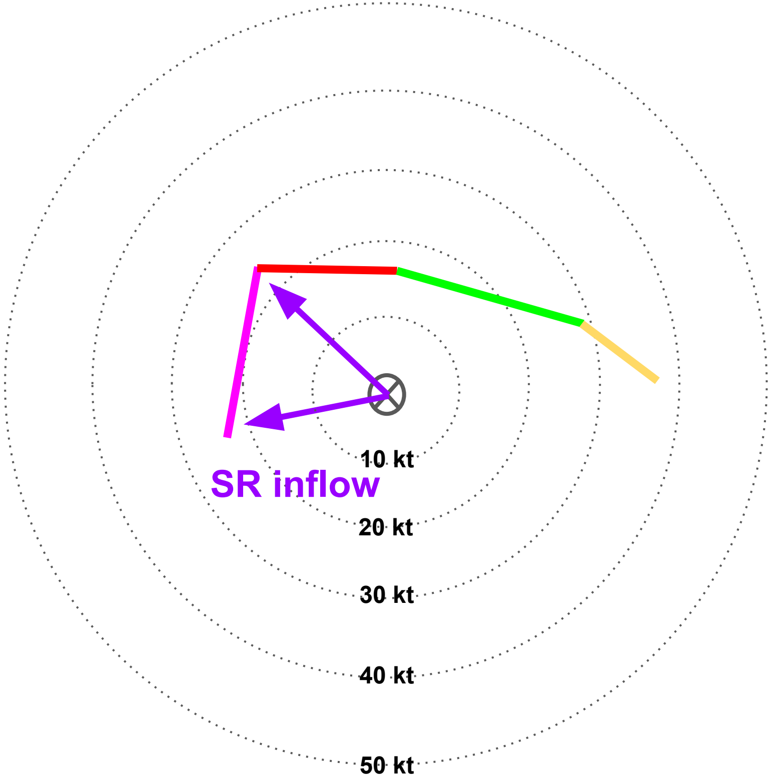
Inflow > 40 kts can support particularly large supercells



Storm-Relative Inflow

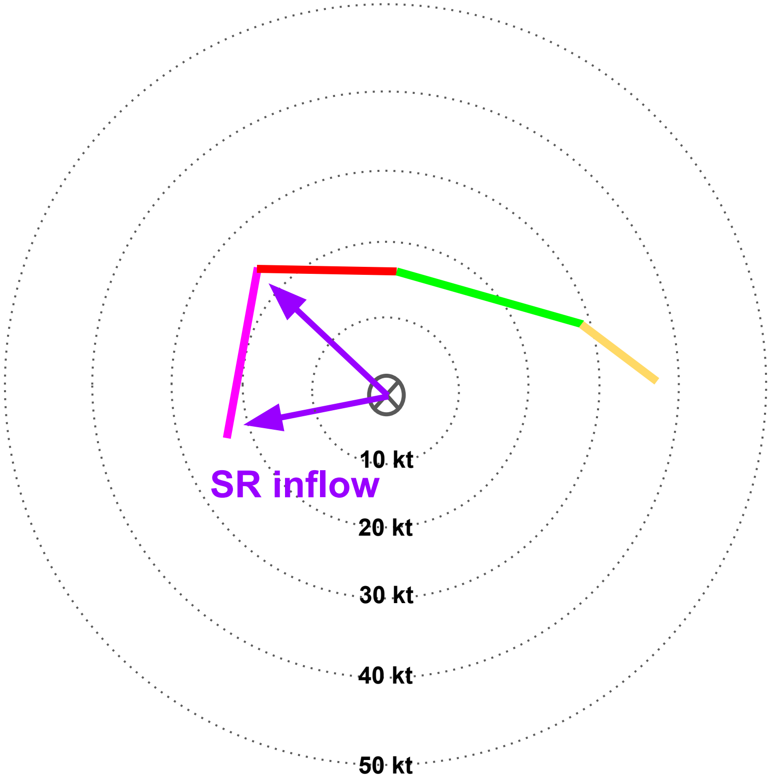
Weaker inflow often only supports smaller updrafts or "mini-supercells" with less precipitation





Storm-Relative Inflow

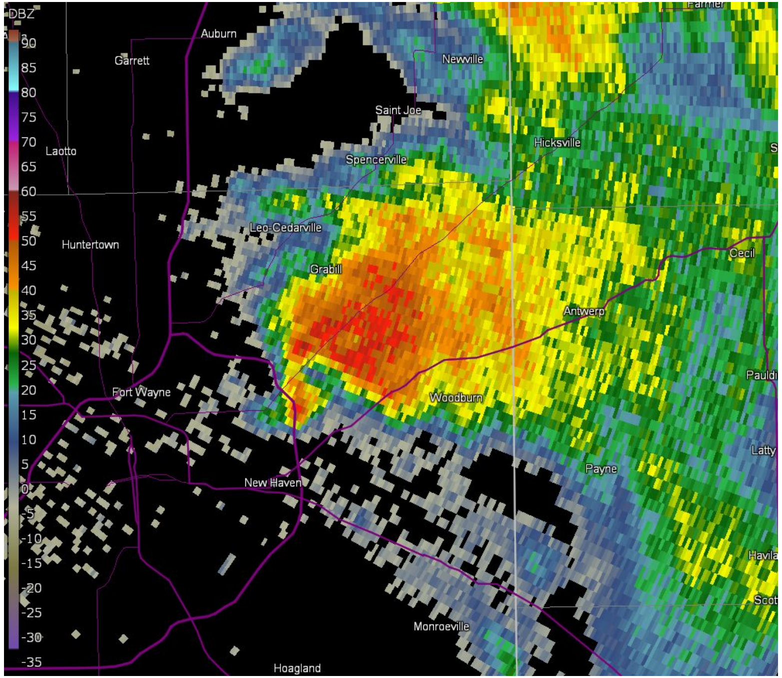
Inflow < 25 kts is often associated with mini-supercells

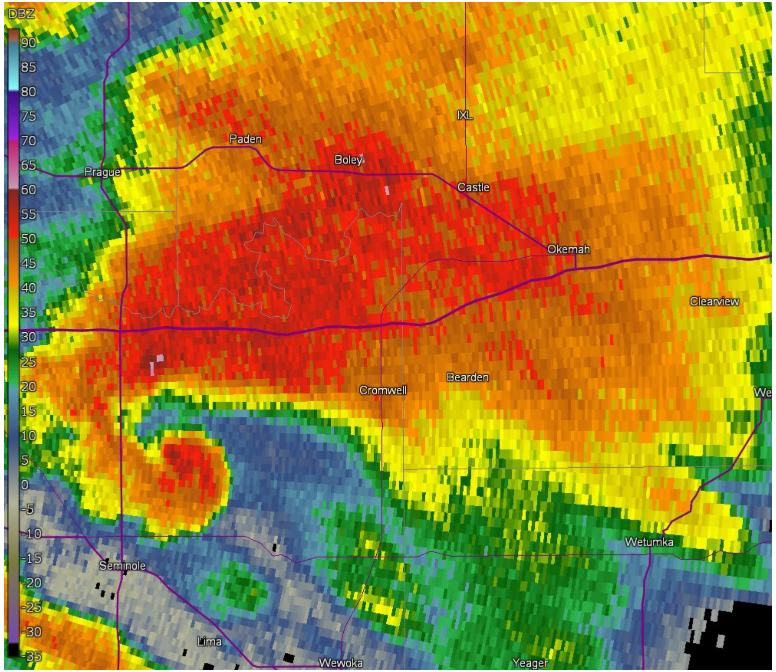


Storm-Relative Inflow

Generally, larger storms can produce more significant hazards

More severe

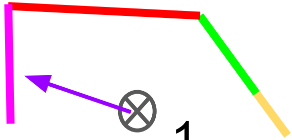


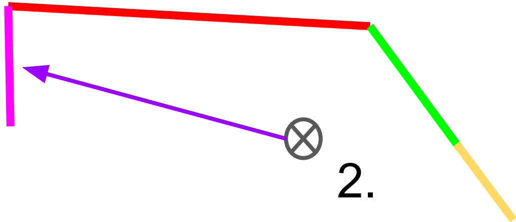


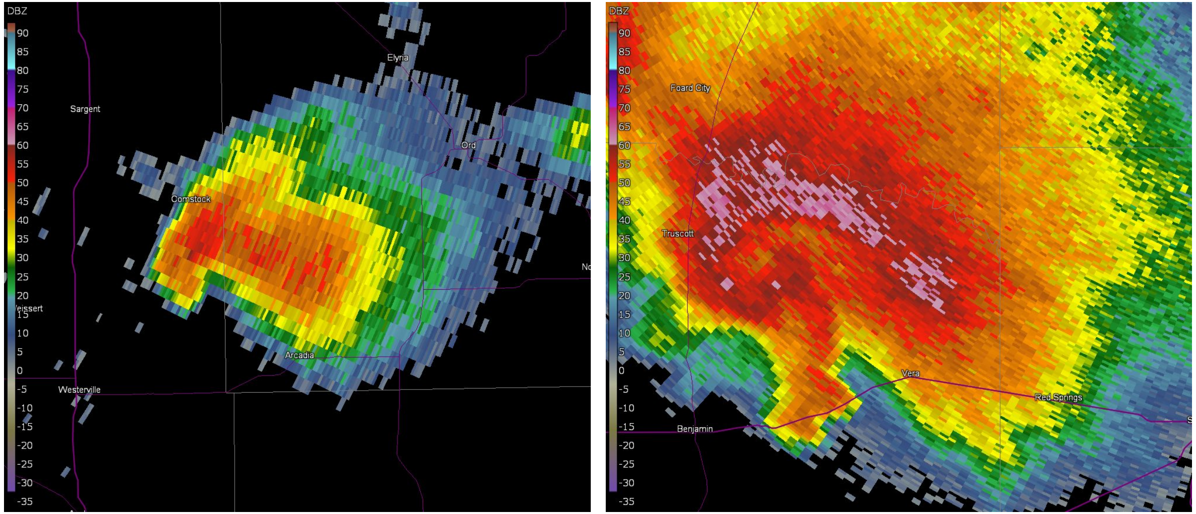
Storm-Relative Inflow

Think you've got it figured out?

Match the supercell with its most likely hodograph:



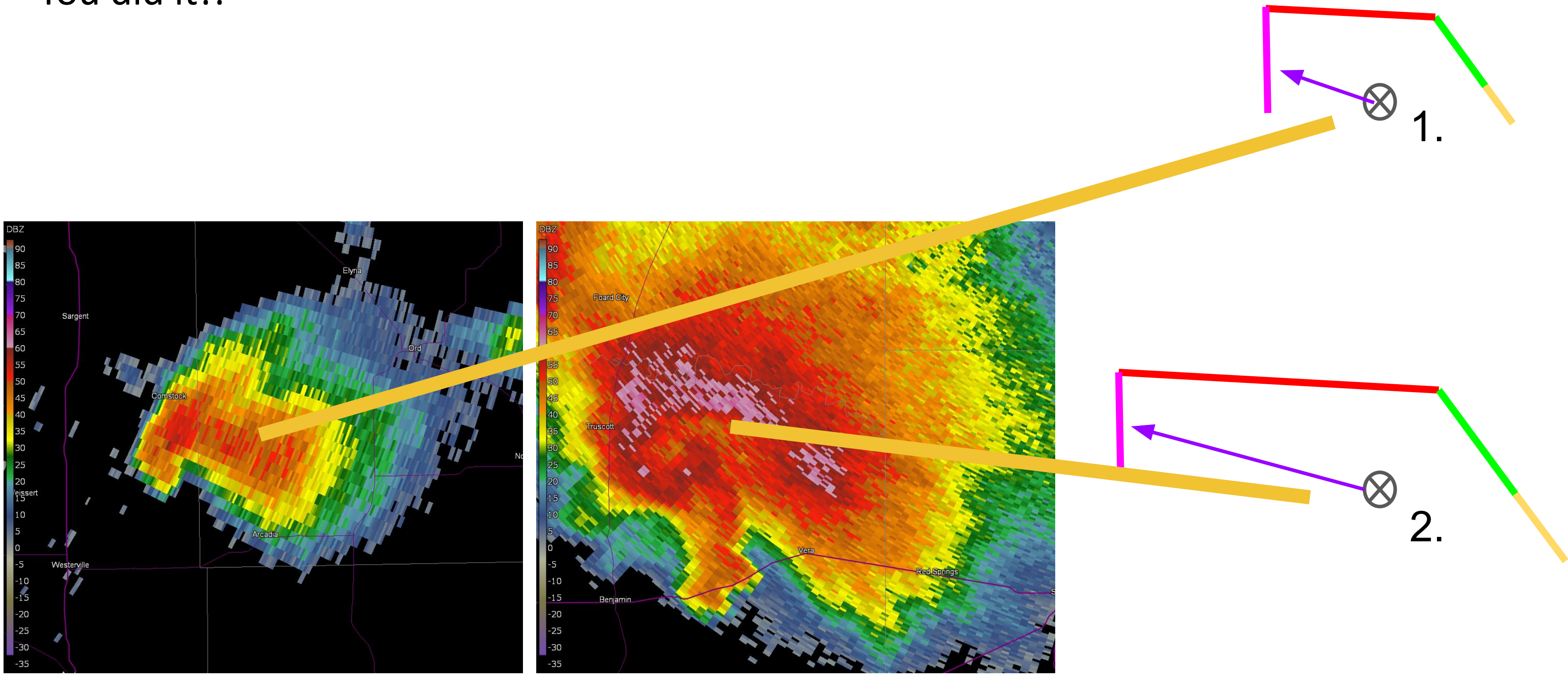




(shown to scale)

Storm-Relative Inflow

You did it!!



(shown to scale)

Storm-Relative Outflow

SR Outflow is the wind
in the upper levels of a storm,
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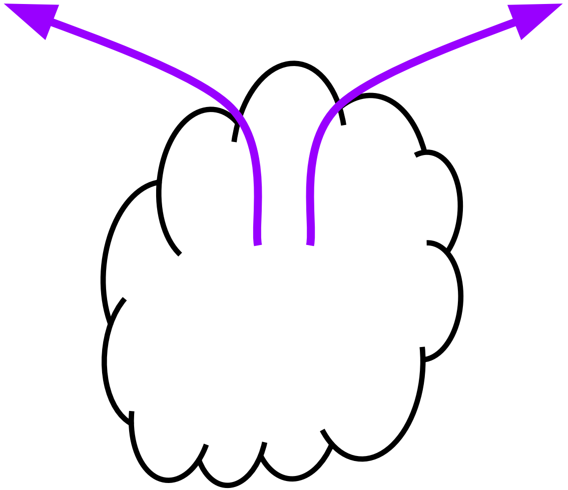
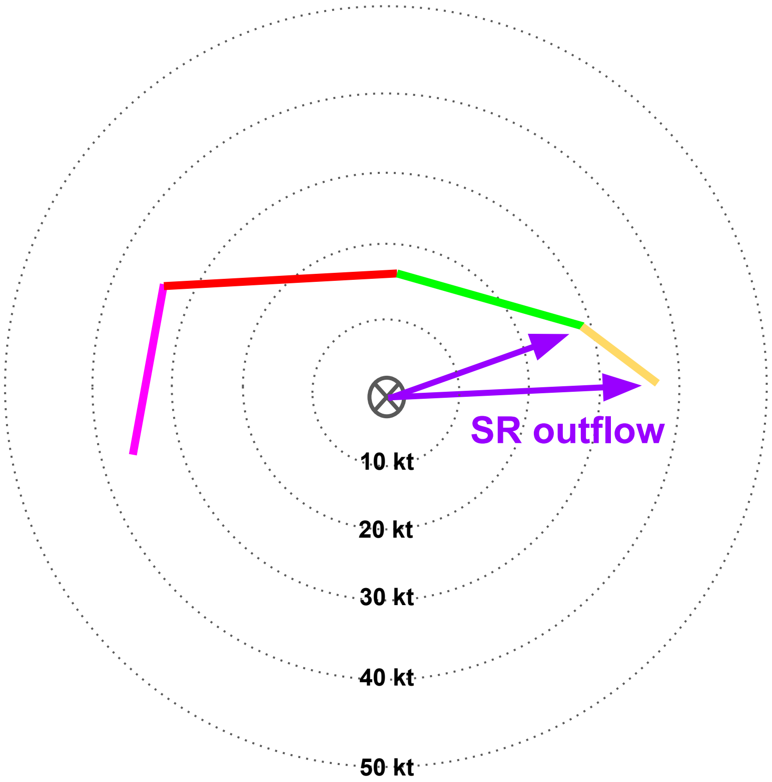
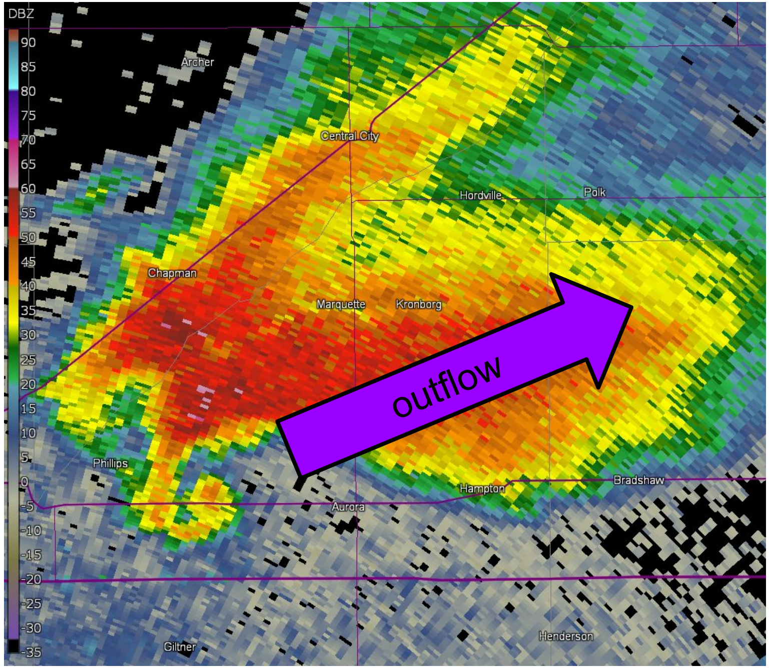
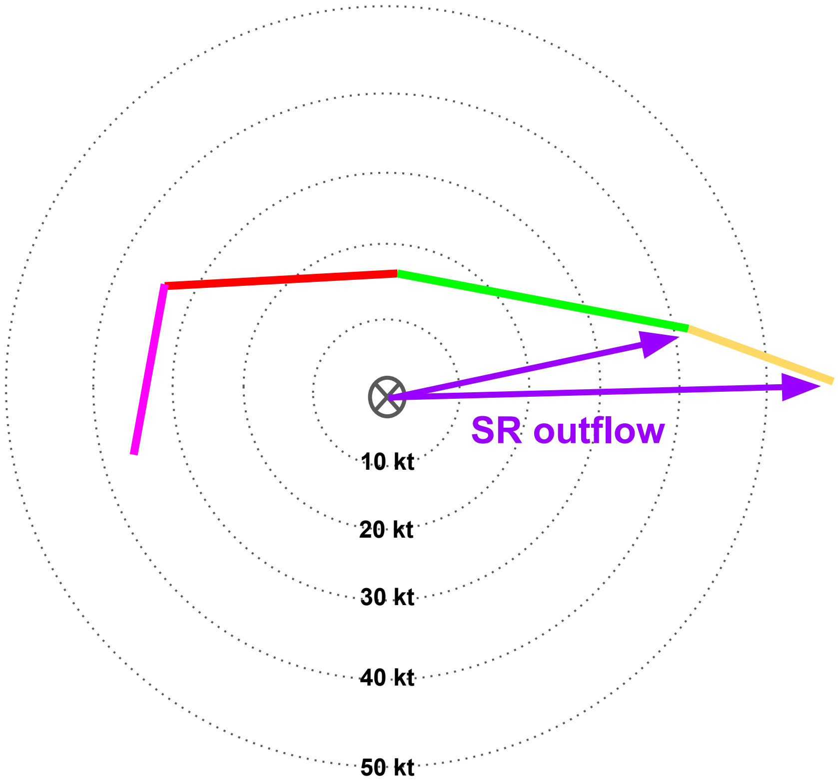




Storm-Relative Outflow

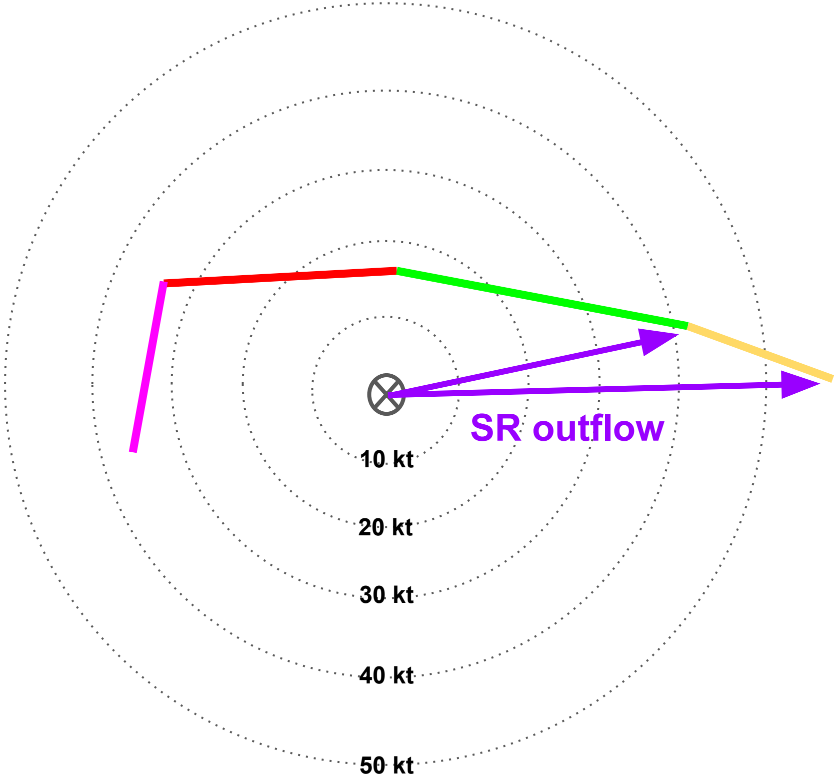
Stronger outflow can improve precipitation ventilation, supporting better updraft/downdraft separation





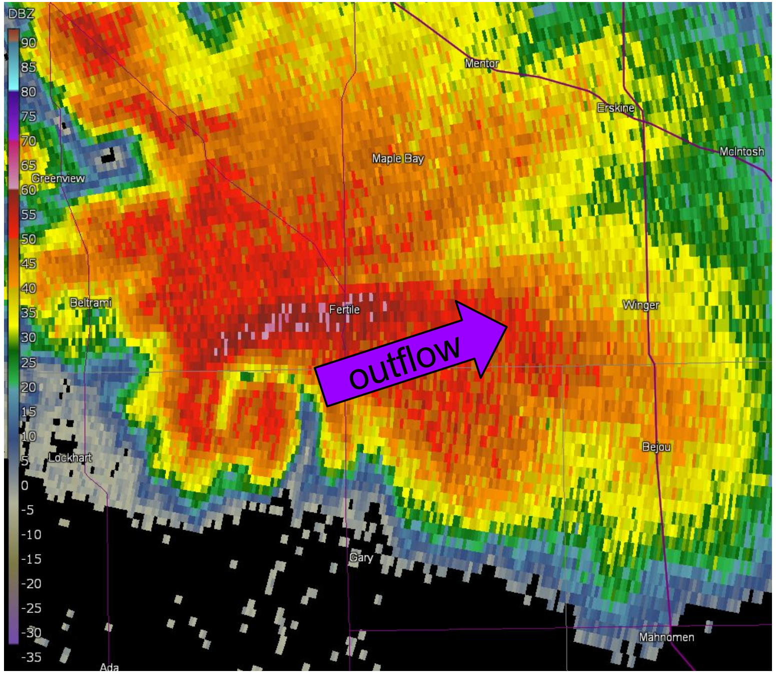
Storm-Relative Outflow

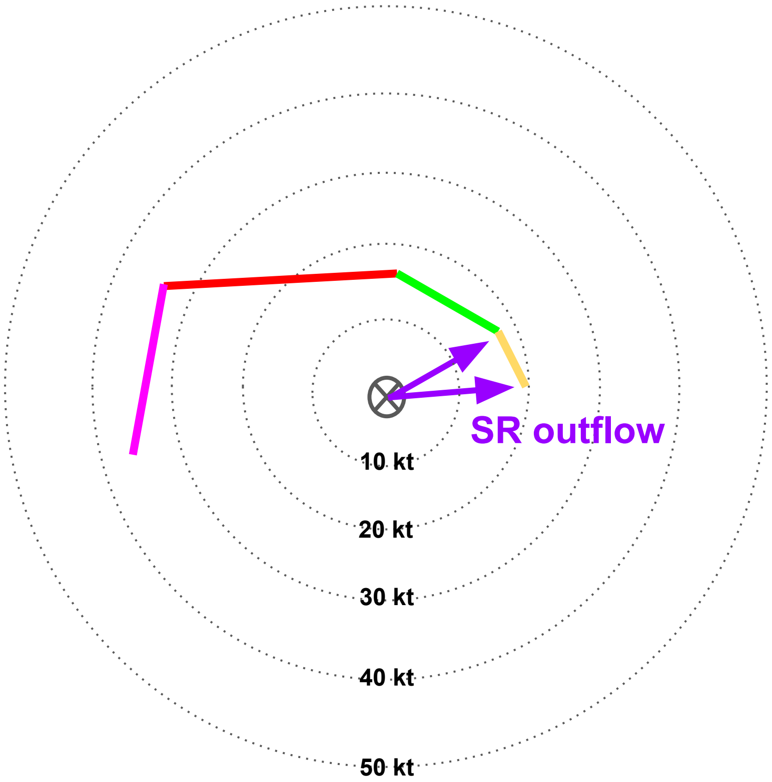
Outflow > 40 kts is particularly strong



Storm-Relative Outflow

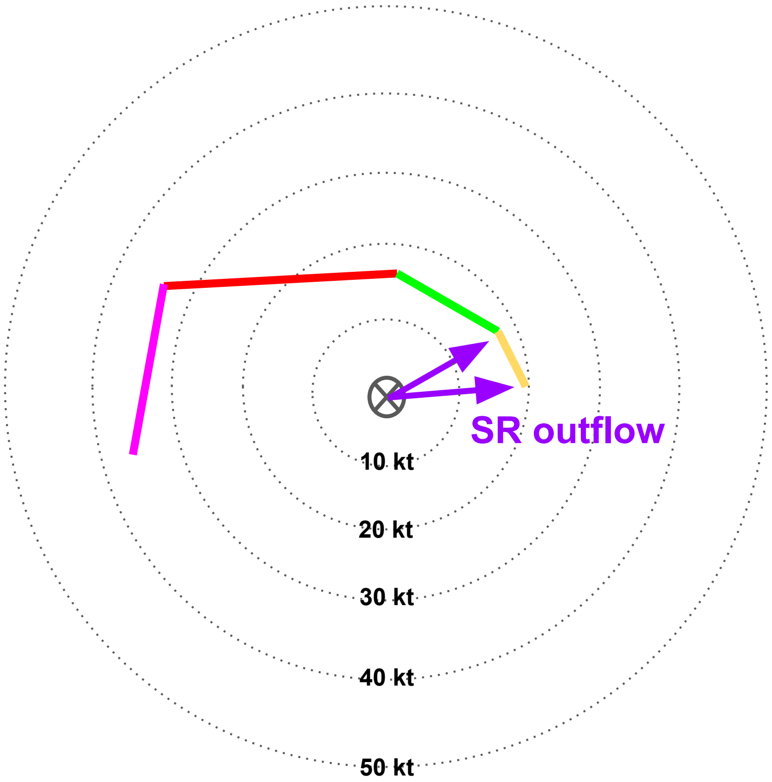
Weaker outflow can limit precipitation ventilation, inducing downdrafts close to the updraft





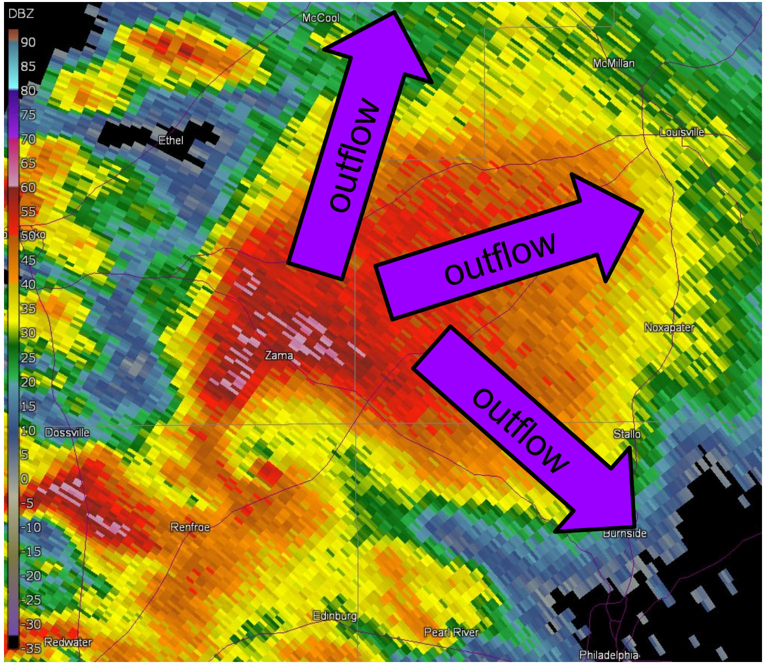
Storm-Relative Outflow

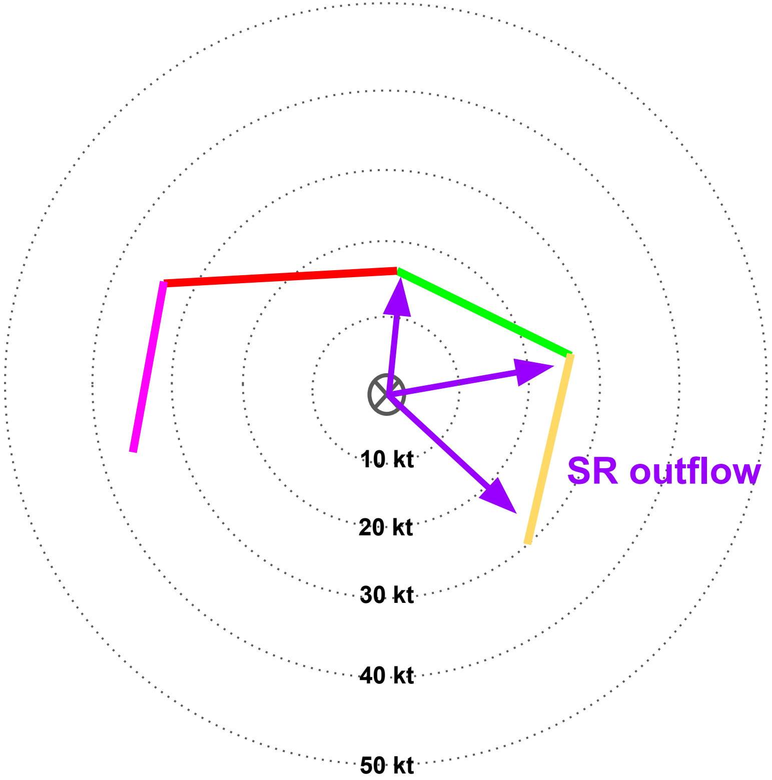
Outflow < 20 kts is particularly weak



Storm-Relative Outflow

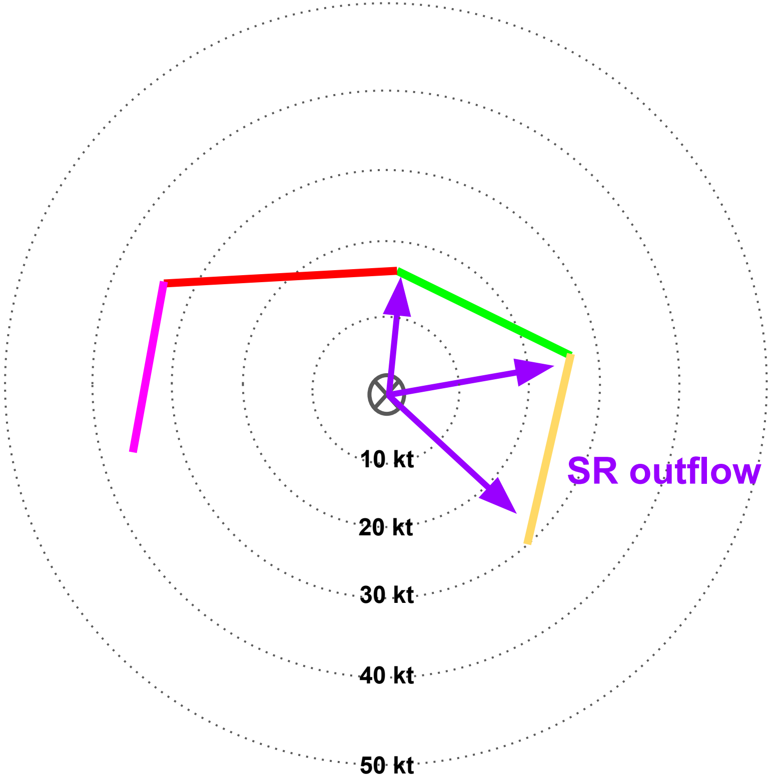
Multidirectional outflow can disperse precipitation fallout, inducing broader, more obstructive downdrafts





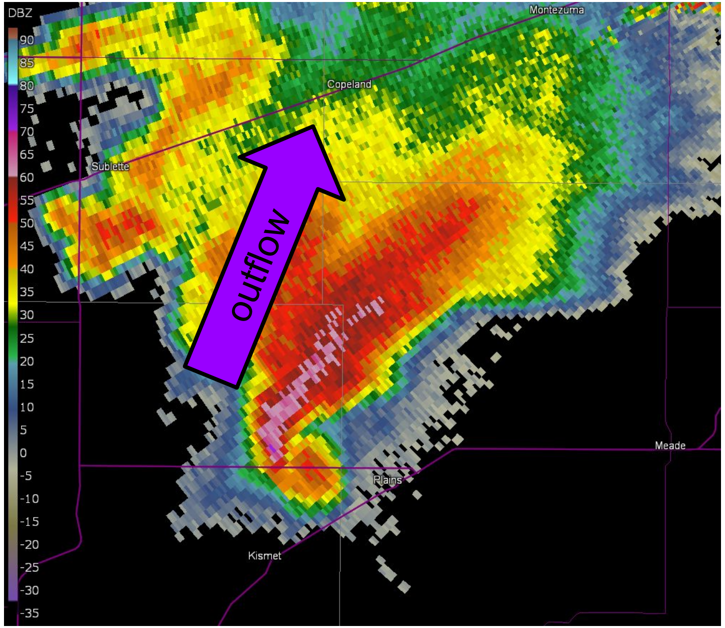
Storm-Relative Outflow

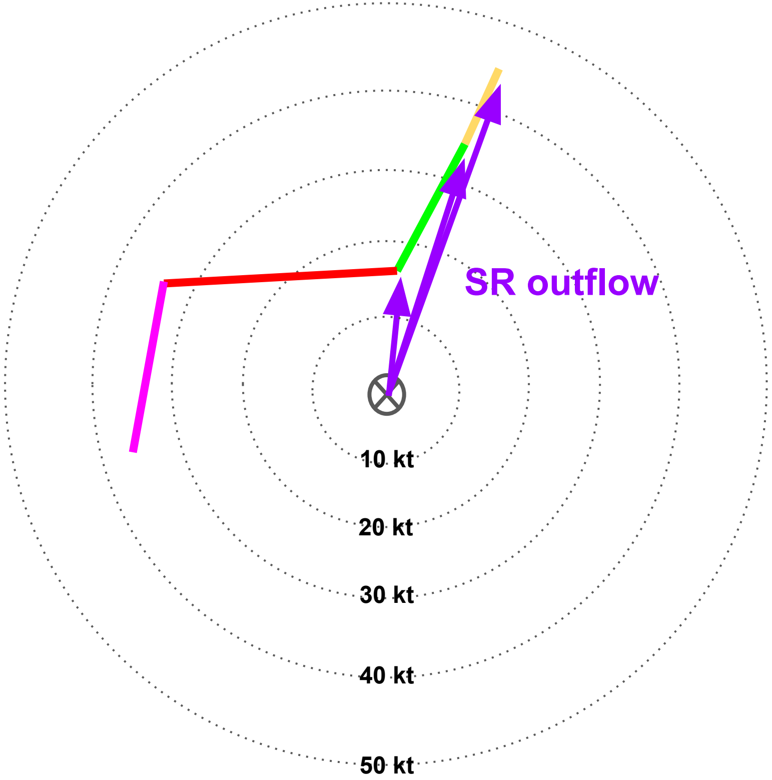
Excessive veering can make a storm appear more high-precipitation



Storm-Relative Outflow

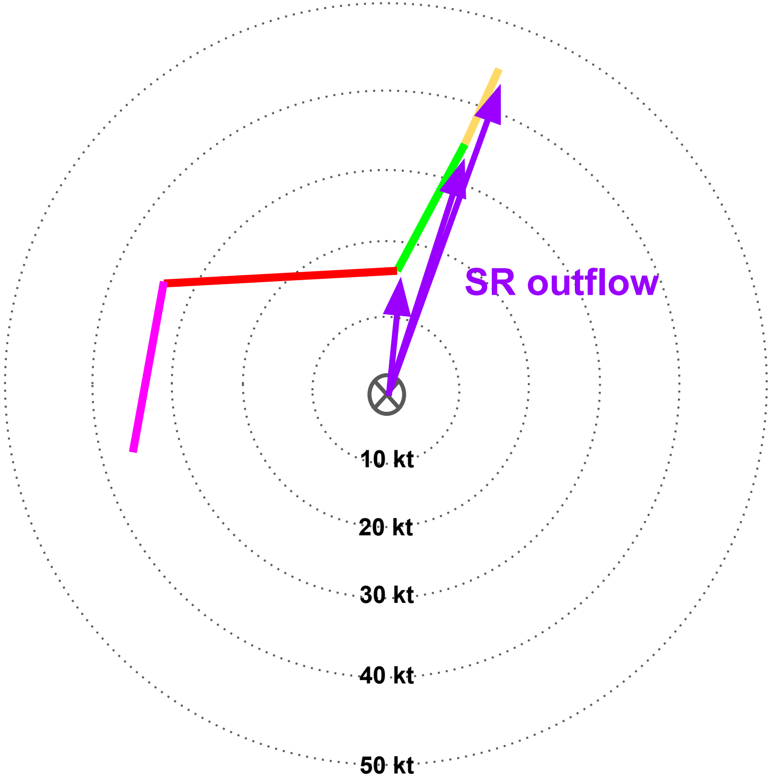
Unidirectional outflow can focus precipitation fallout, supporting less obstructive downdrafts





Storm-Relative Outflow

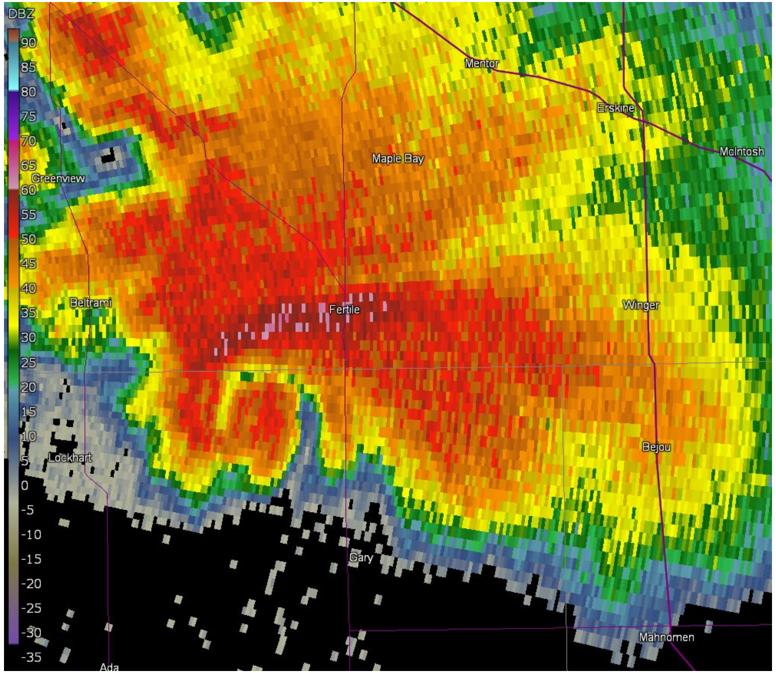
Backing shear aloft can make a storm appear more low-precipitation

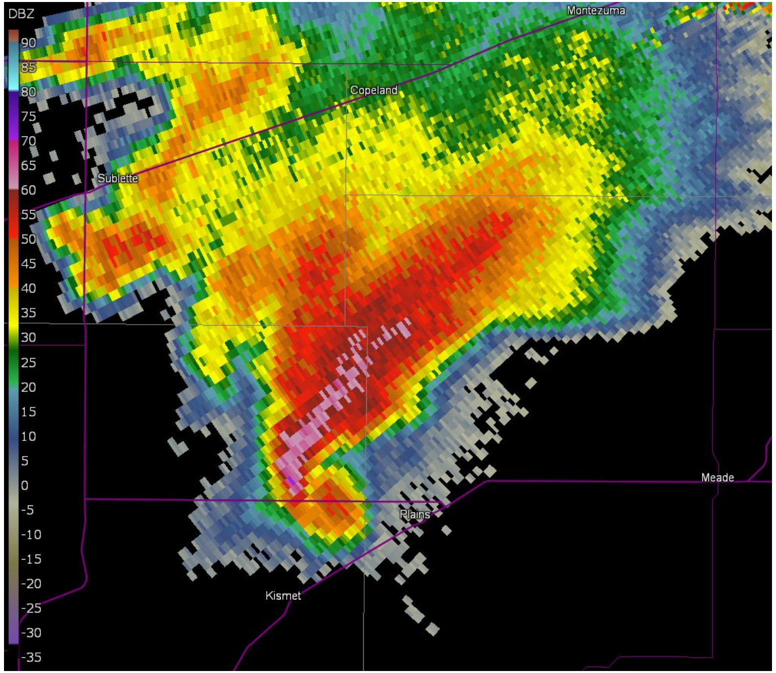


Storm-Relative Outflow

Generally, less obstructive downdrafts can support longer-lived tornadoes.

Longer-lived tornadoes

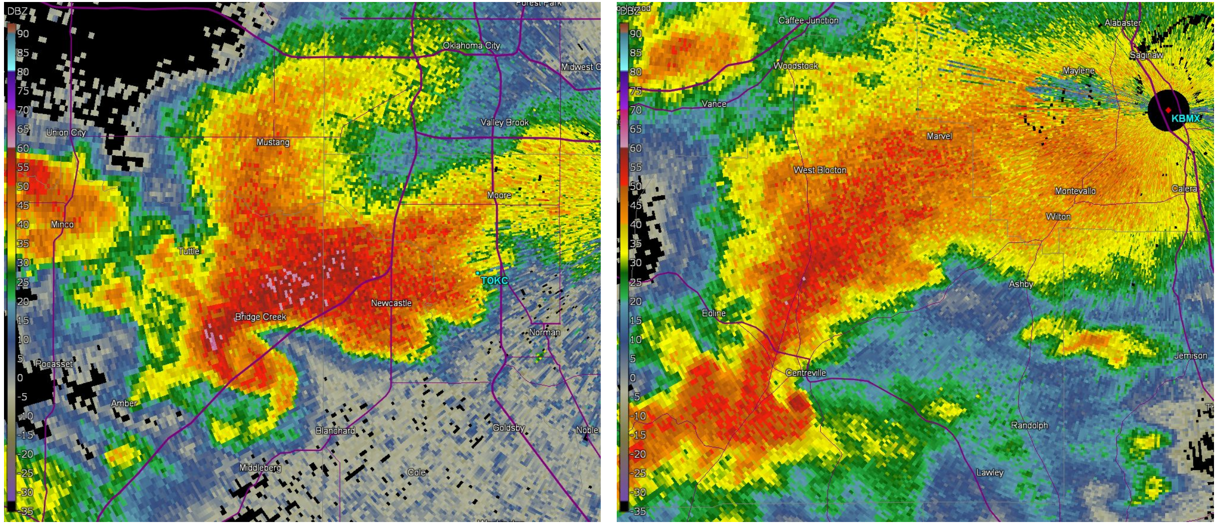




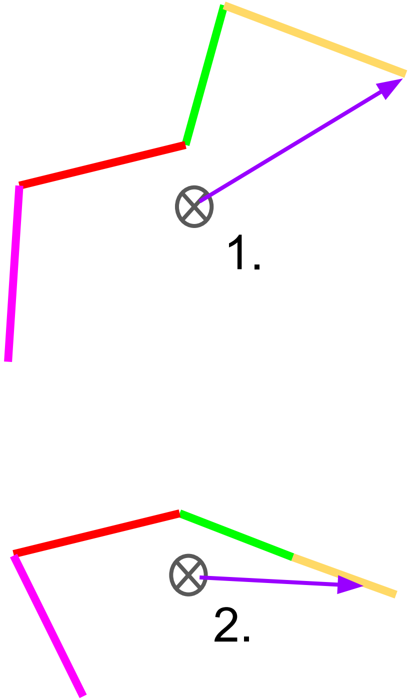
Storm-Relative Outflow

Here's an example for you!

Match the supercell with its most-likely hodograph:

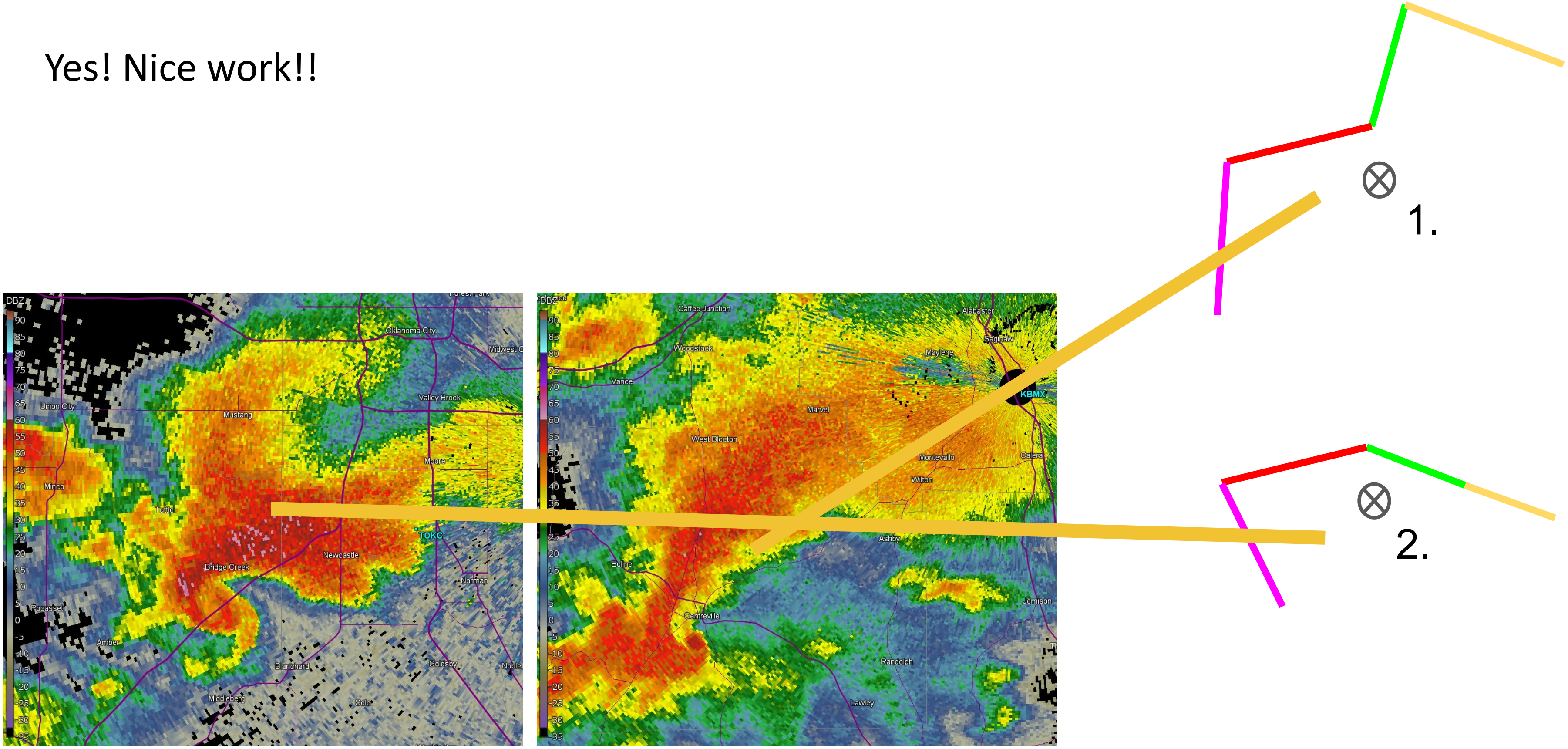


(shown to scale)



Storm-Relative Outflow

Yes! Nice work!!

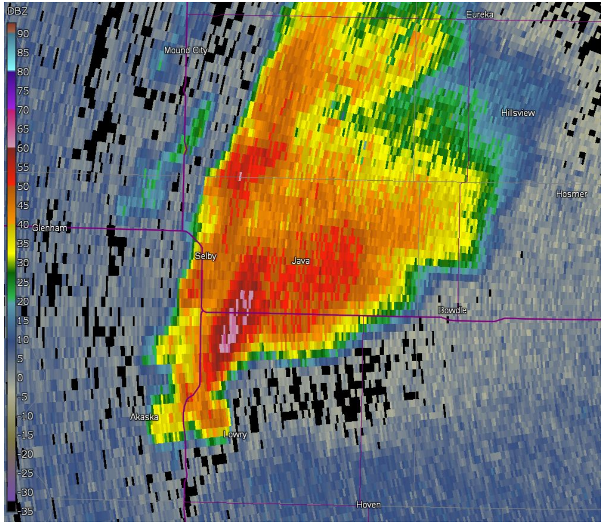


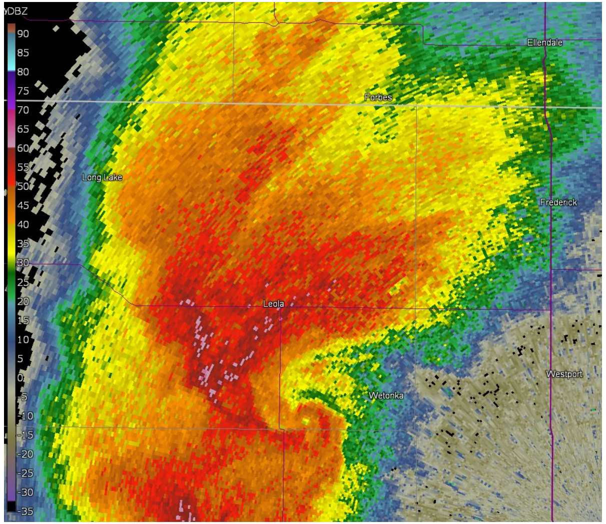
(shown to scale)

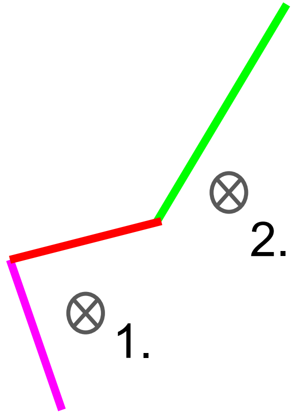
<u>Storm-Relative Inflow *and* Outflow</u>

This was the same storm, just two hours apart.

Match the radar presentation with its most likely storm motion:



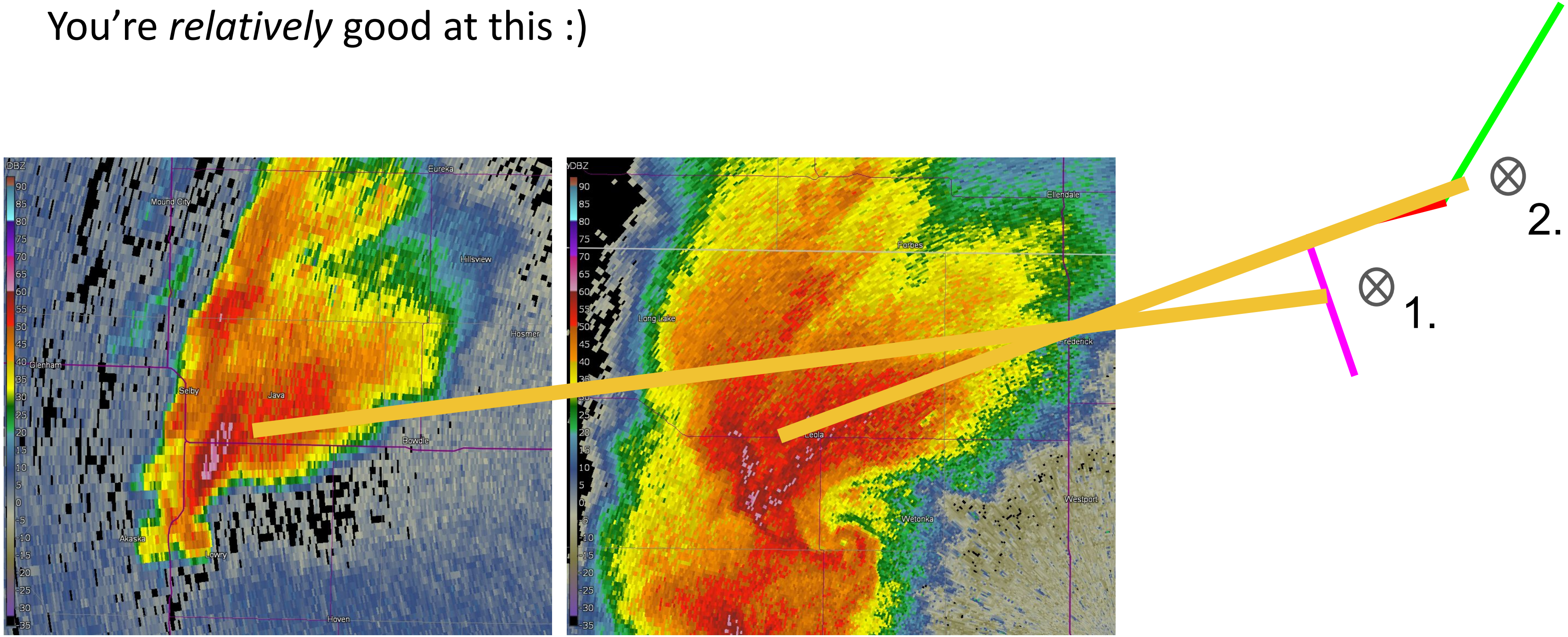




Storm-Relative Inflow *and* Outflow

That's right!!

You're *relatively* good at this :)



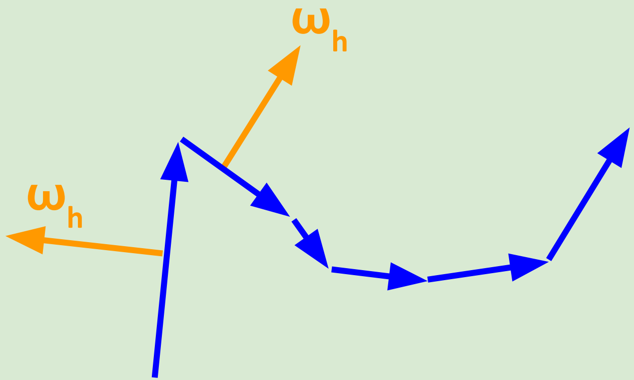
Storm-Relative Winds Summary

1. Storm-relative winds govern storm structure

2. Storm-relative inflow can affect a storm's size, and how much precipitation it can produce

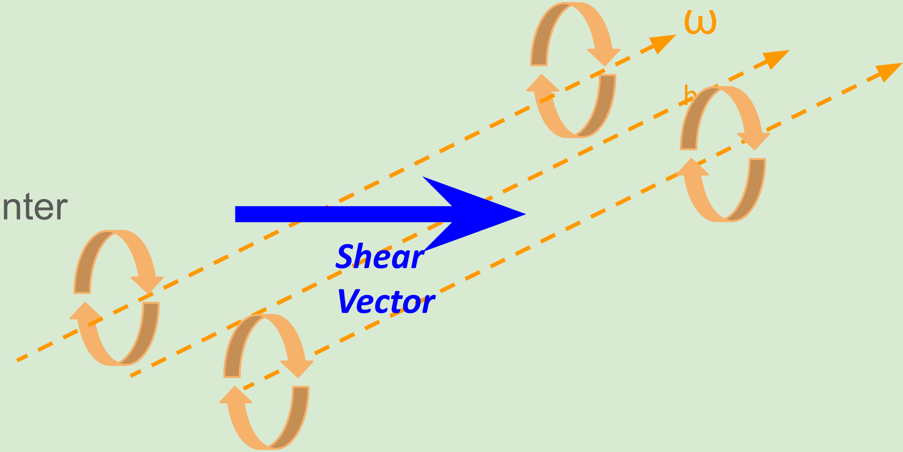
3. Storm-relative outflow can affect precipitation ventilation, downdraft placement, and tornado maintenance

Lesson 6: Horizontal Vorticity



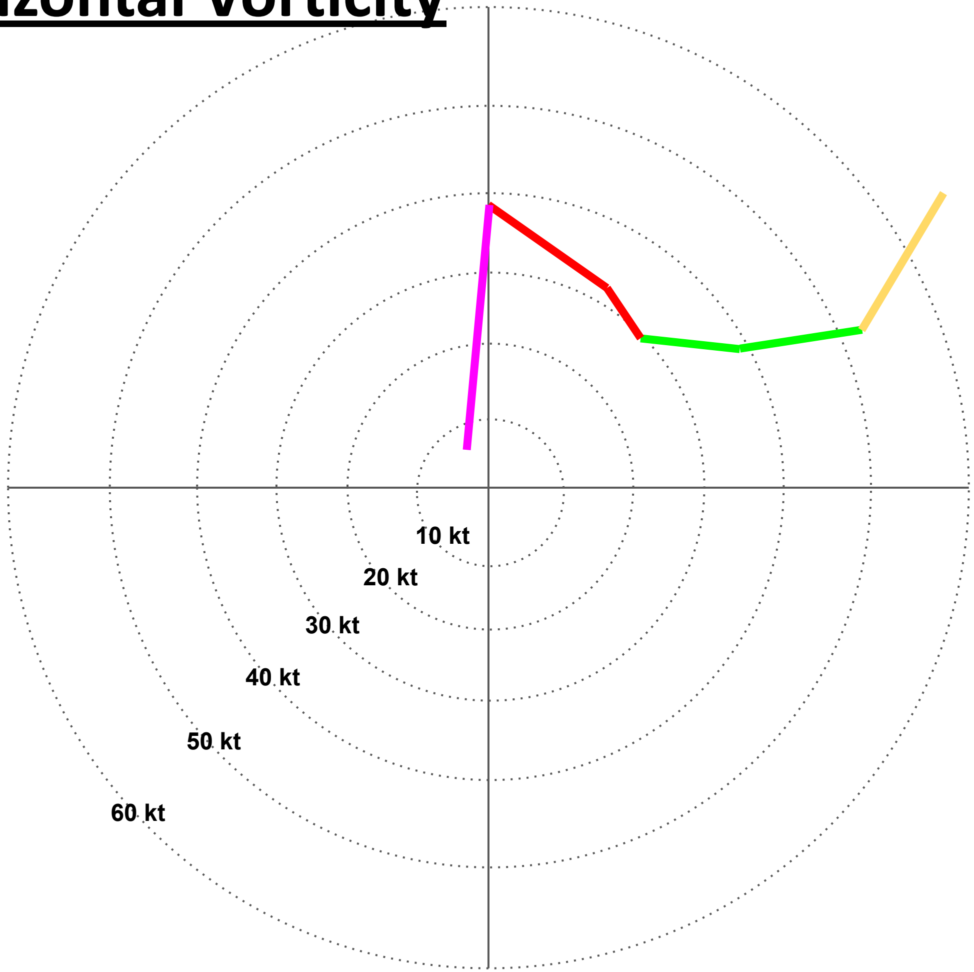
Harry Weinman – Meteorologist, Storm Prediction Center
(harry.weinman@noaa.gov)

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



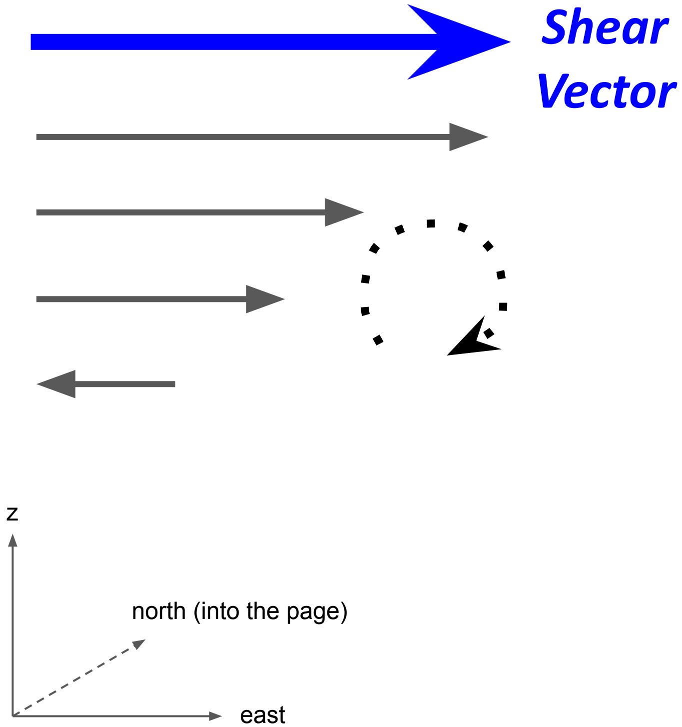
Finding Horizontal Vorticity

How do we find horizontal vorticity on the hodograph?



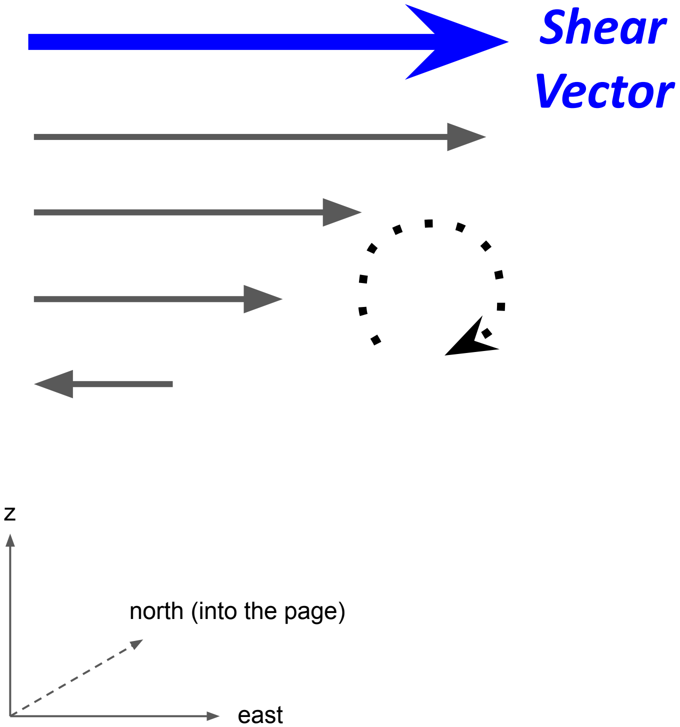
Shear and Horizontal Vorticity

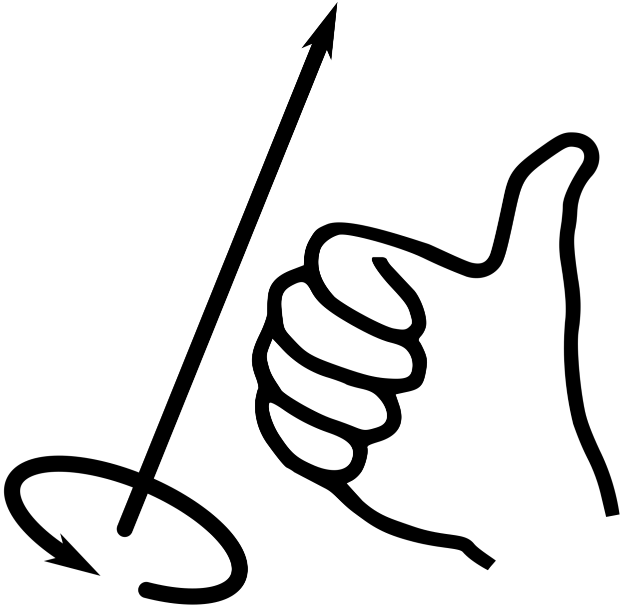
Vertical Wind Shear



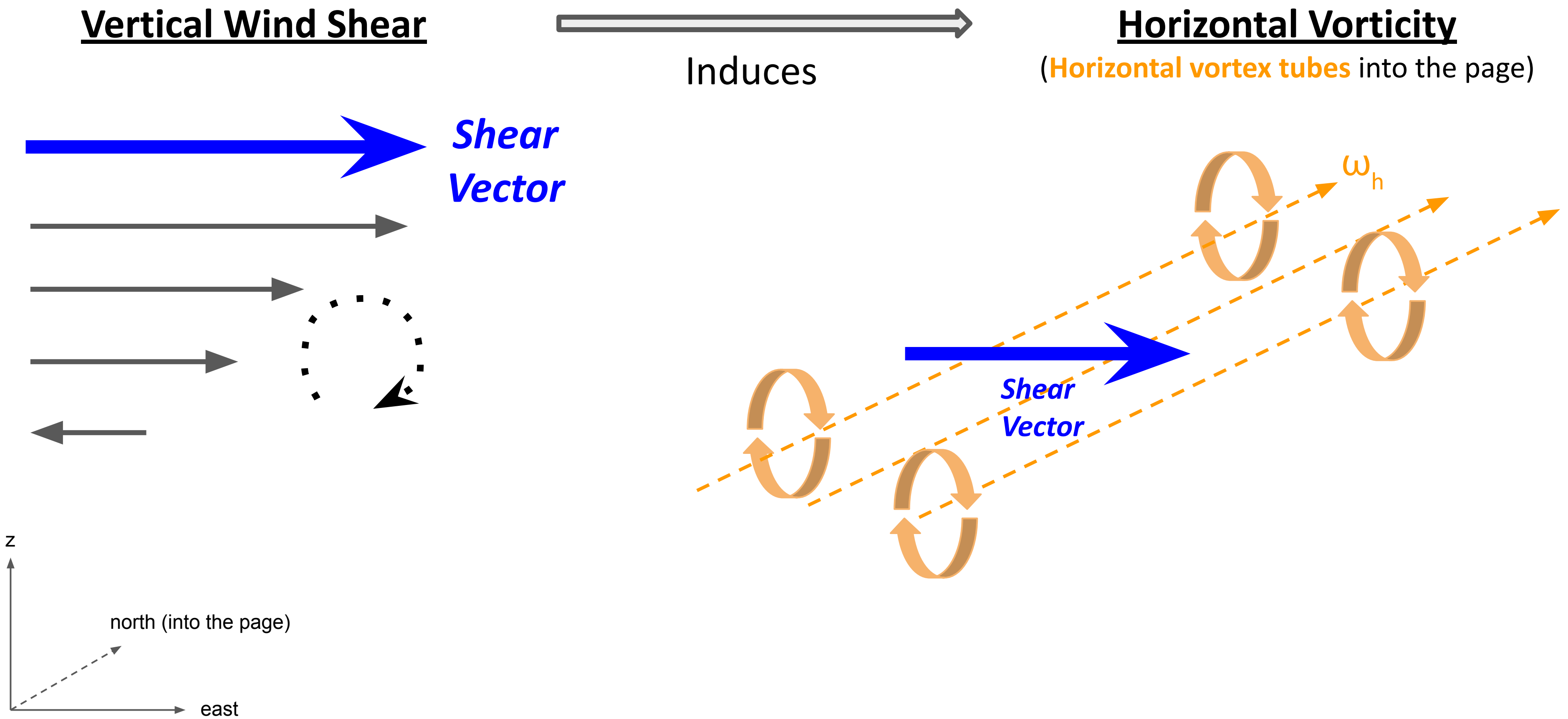
Shear and Horizontal Vorticity

Vertical Wind Shear



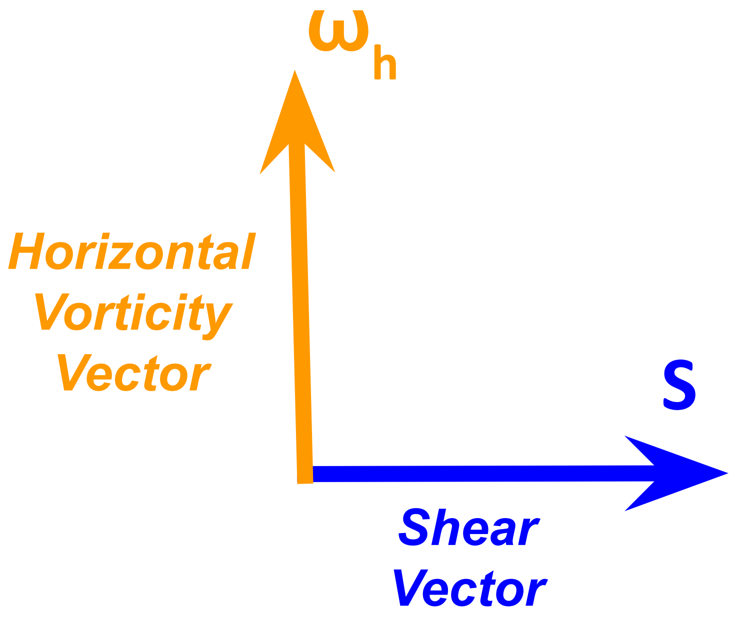


Shear and Horizontal Vorticity



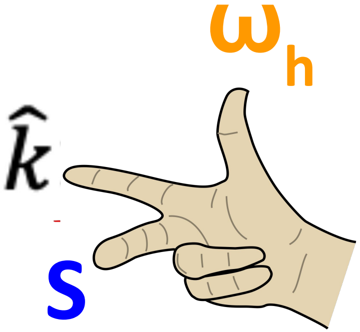
Shear and Horizontal Vorticity

Horizontal vorticity vectors are always perpendicular and to the left of the **shear vectors**



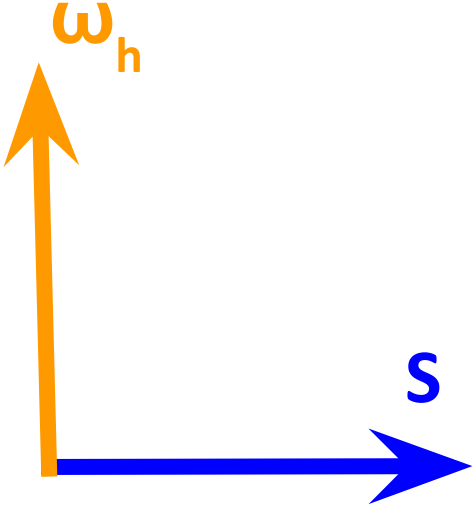
Shear and Horizontal Vorticity

Explained using the right-hand rule!



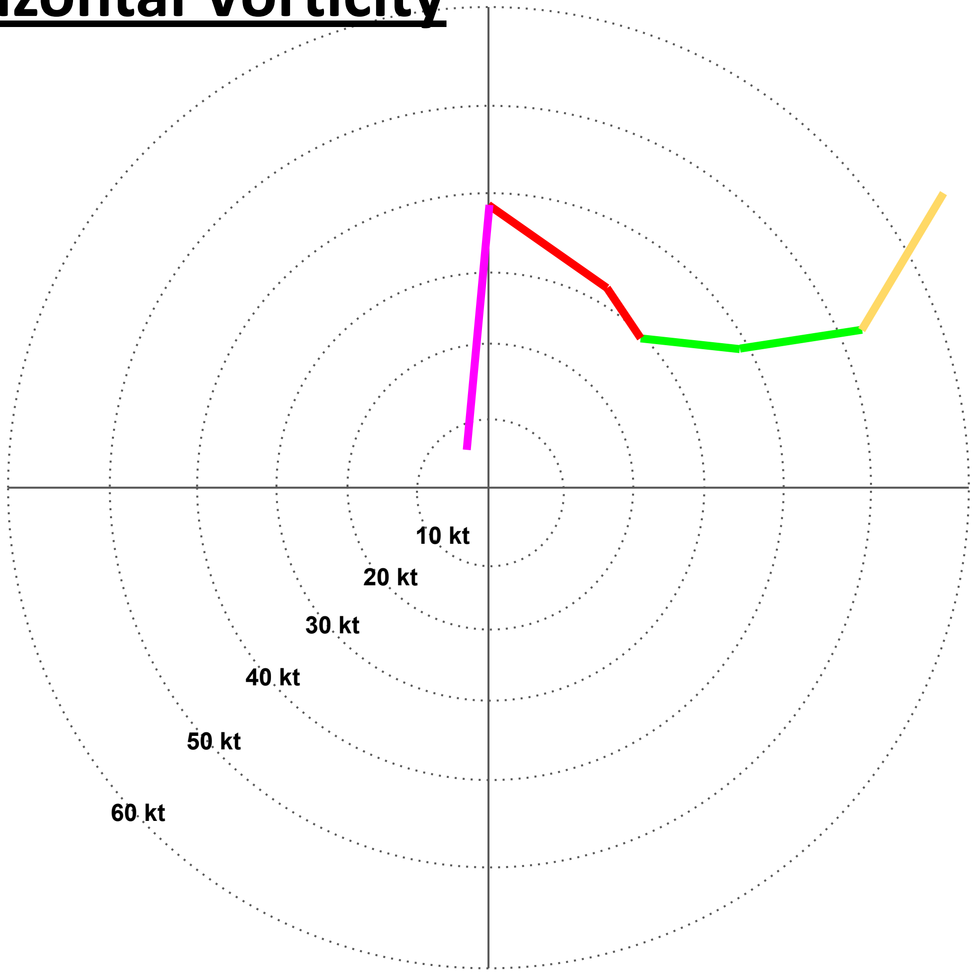
$$\omega = \hat{k} \times S$$

h



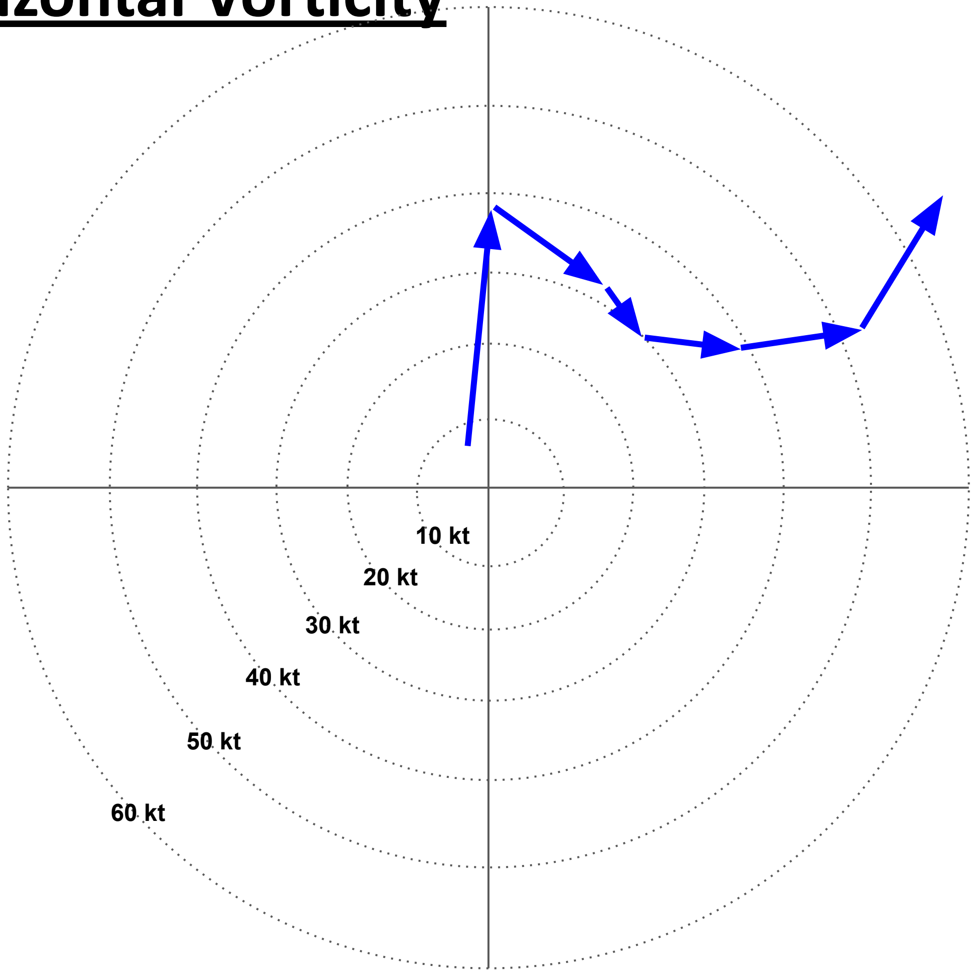
Finding Horizontal Vorticity

How do we find horizontal vorticity on the hodograph?



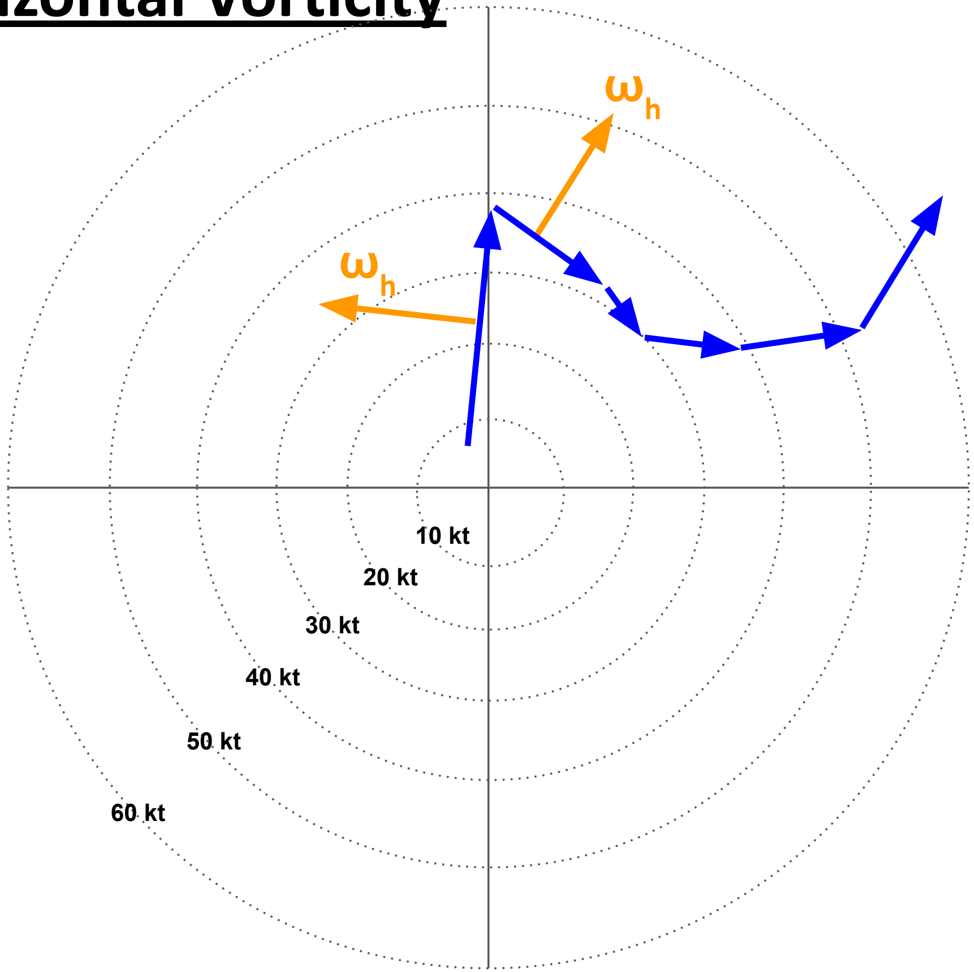
Finding Horizontal Vorticity

Remember, the hodograph is a plot of shear vectors



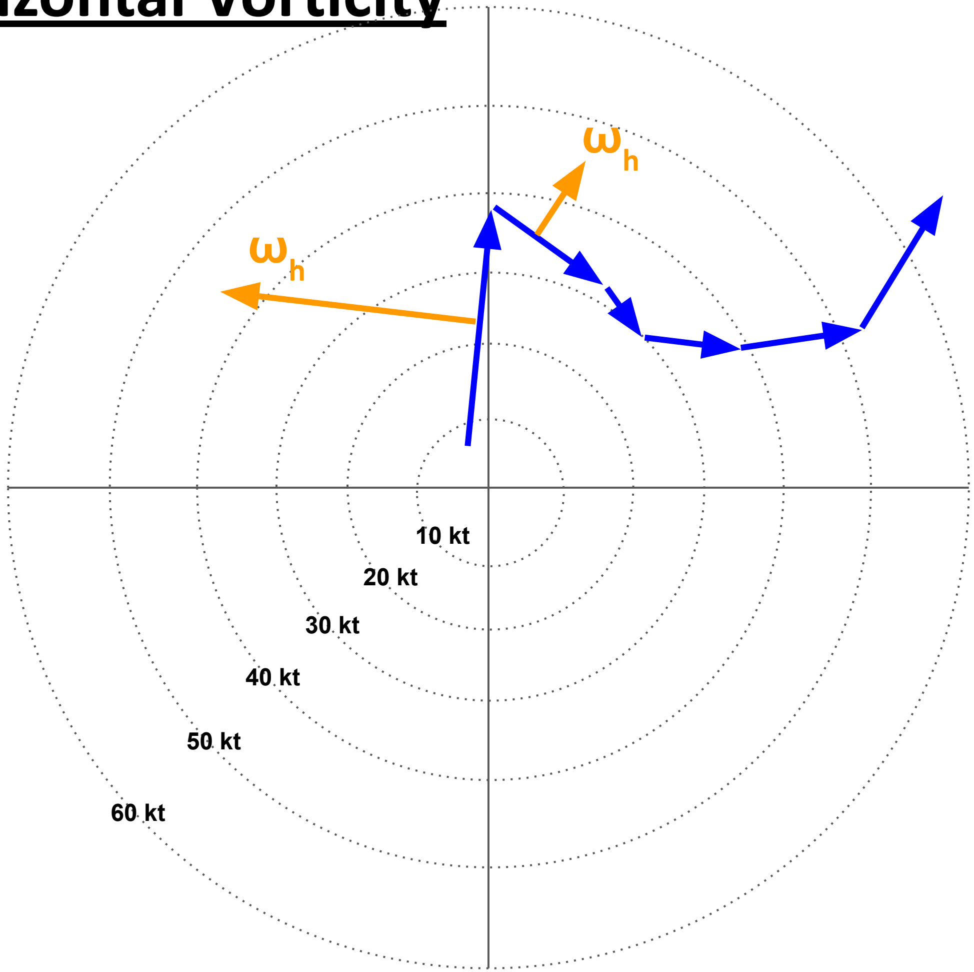
Finding Horizontal Vorticity

Therefore, **horizontal vorticity vectors** are perpendicular and to the left of the **hodograph**!



Finding Horizontal Vorticity

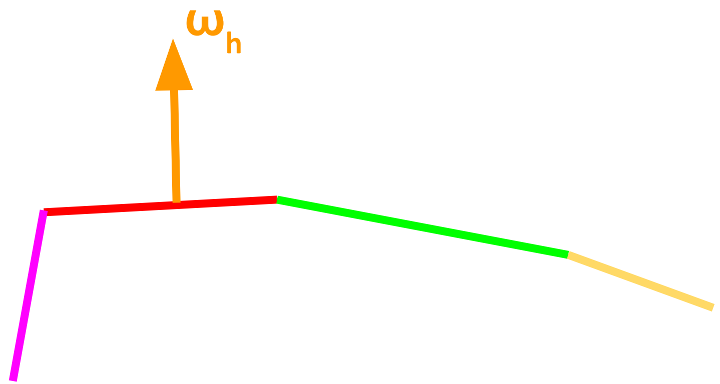
The stronger the **shear** in any given layer, the stronger the **horizontal vorticity**!



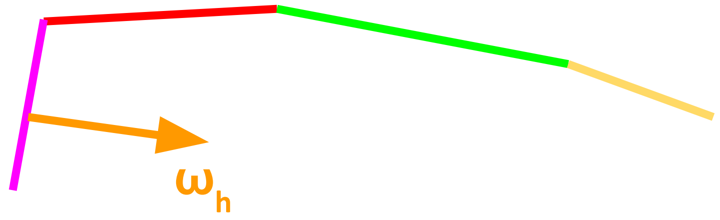
Finding Horizontal Vorticity

Which hodograph has the correctly drawn horizontal vorticity vector?

A.



B.

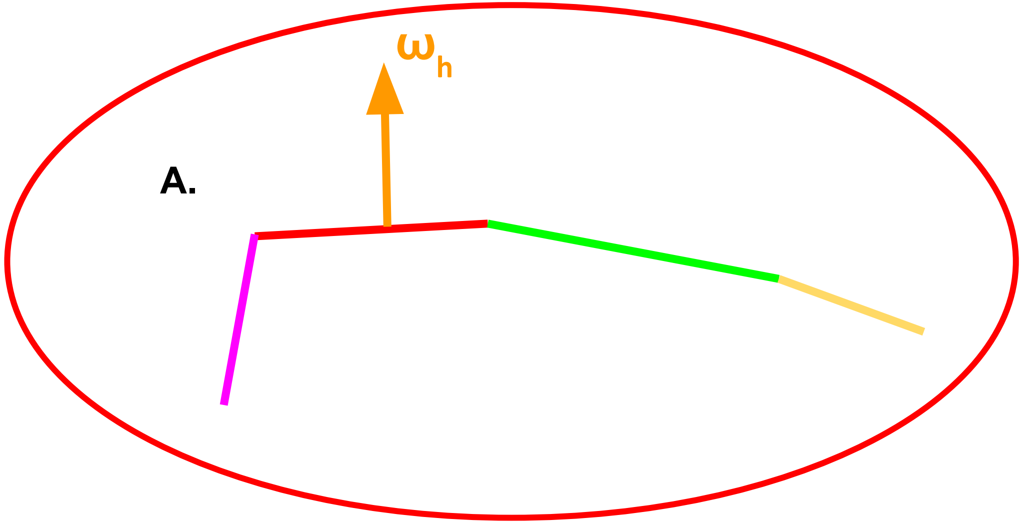


Finding Horizontal Vorticity

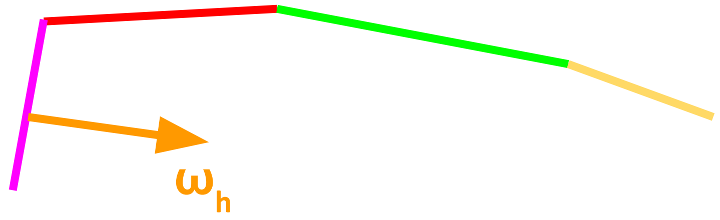
Which hodograph has the correctly drawn horizontal vorticity vector?

Great work!

A.

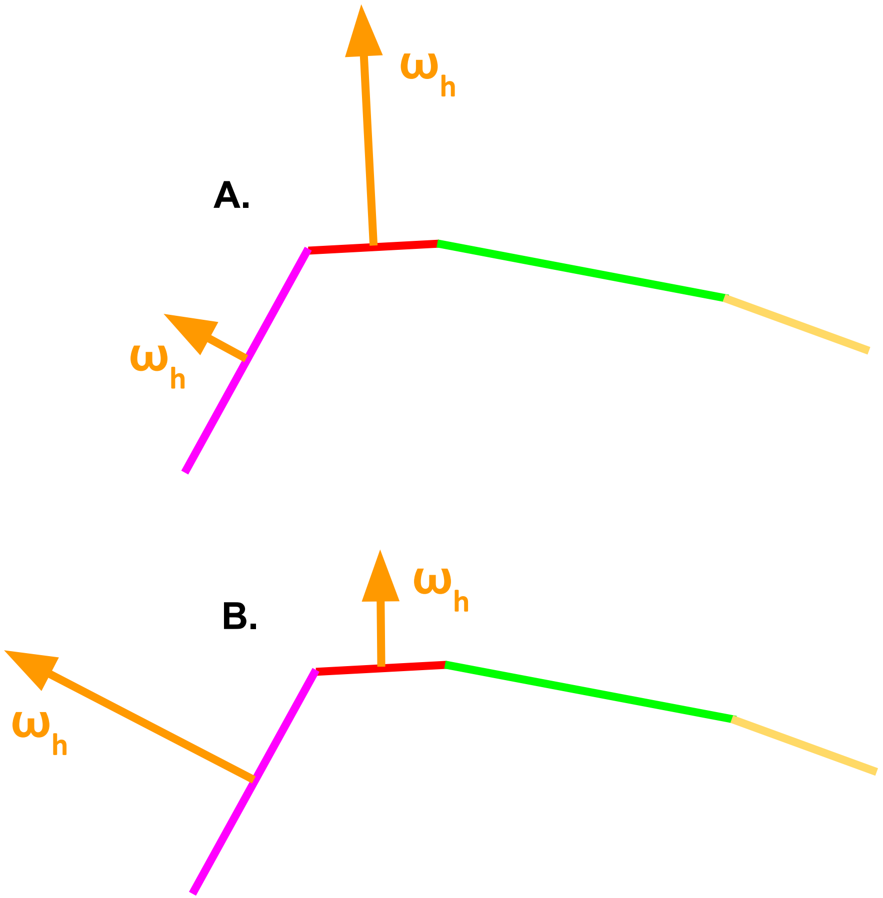


B.



Finding Horizontal Vorticity

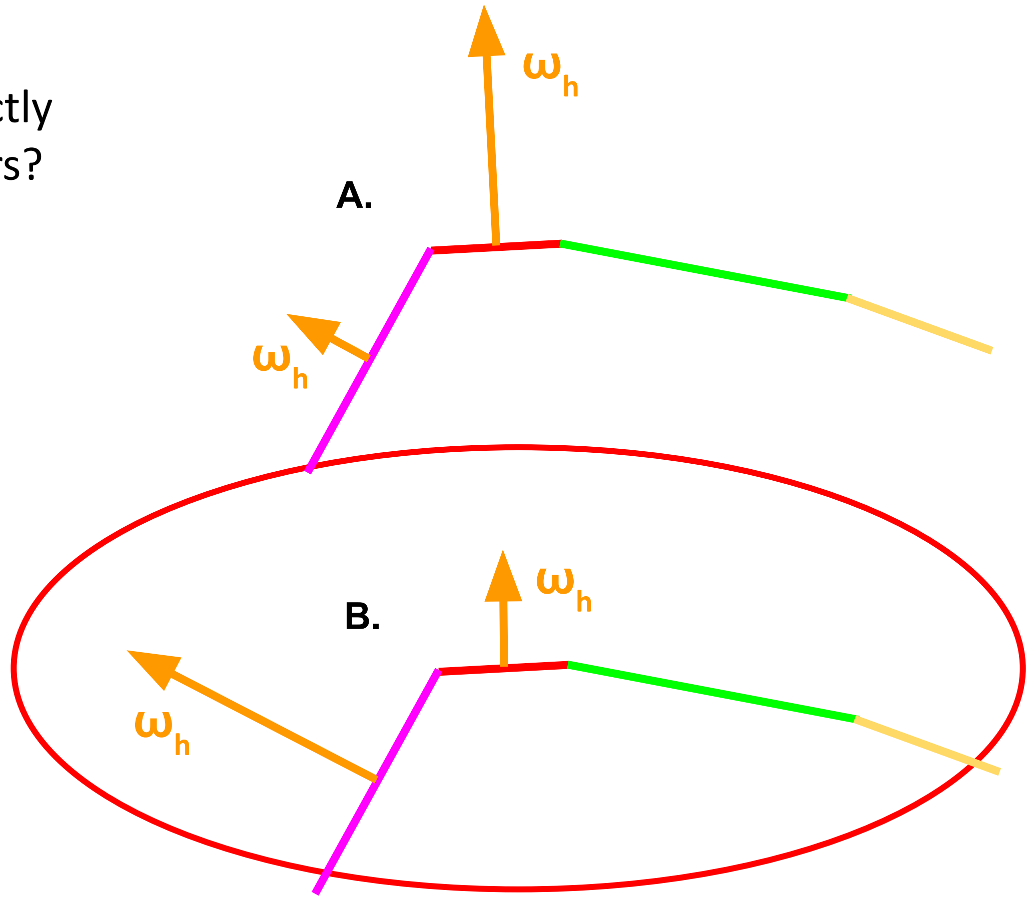
Which hodograph has the correctly drawn horizontal vorticity vectors?



Finding Horizontal Vorticity

Which hodograph has the correctly drawn horizontal vorticity vectors?

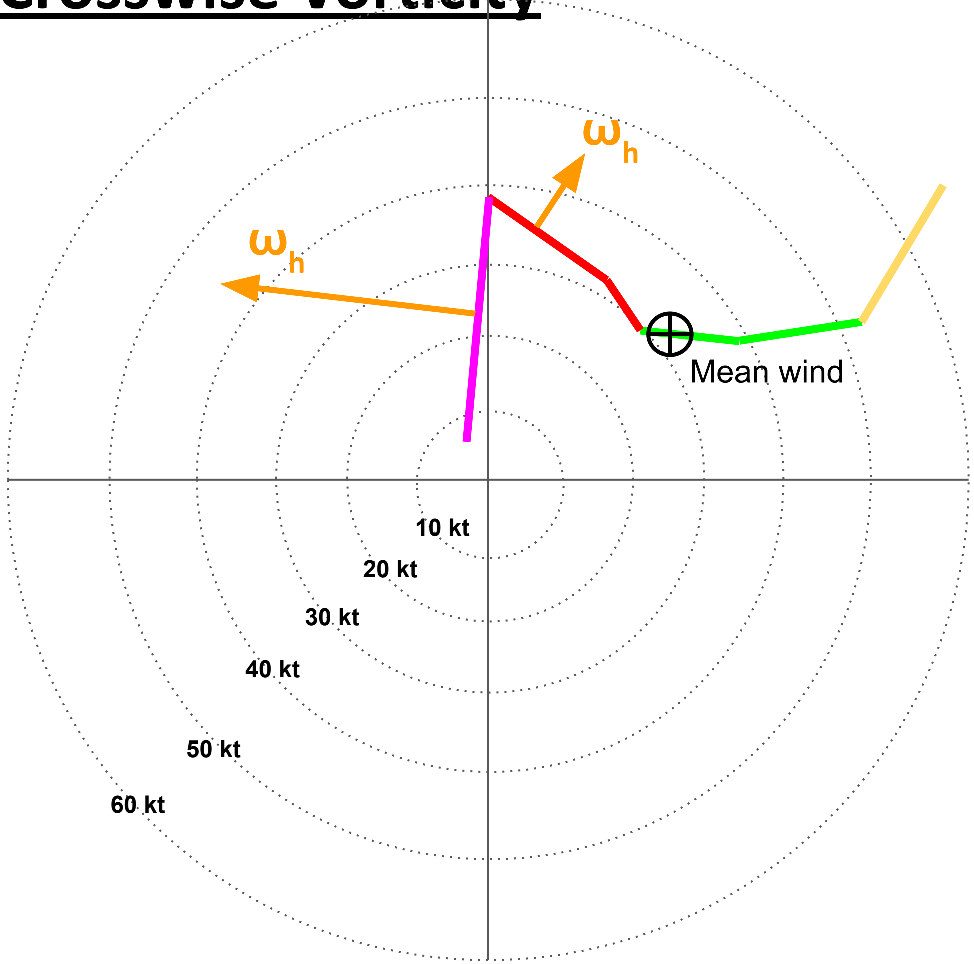
You got it!



<u>Streamwise vs Crosswise Vorticity</u>

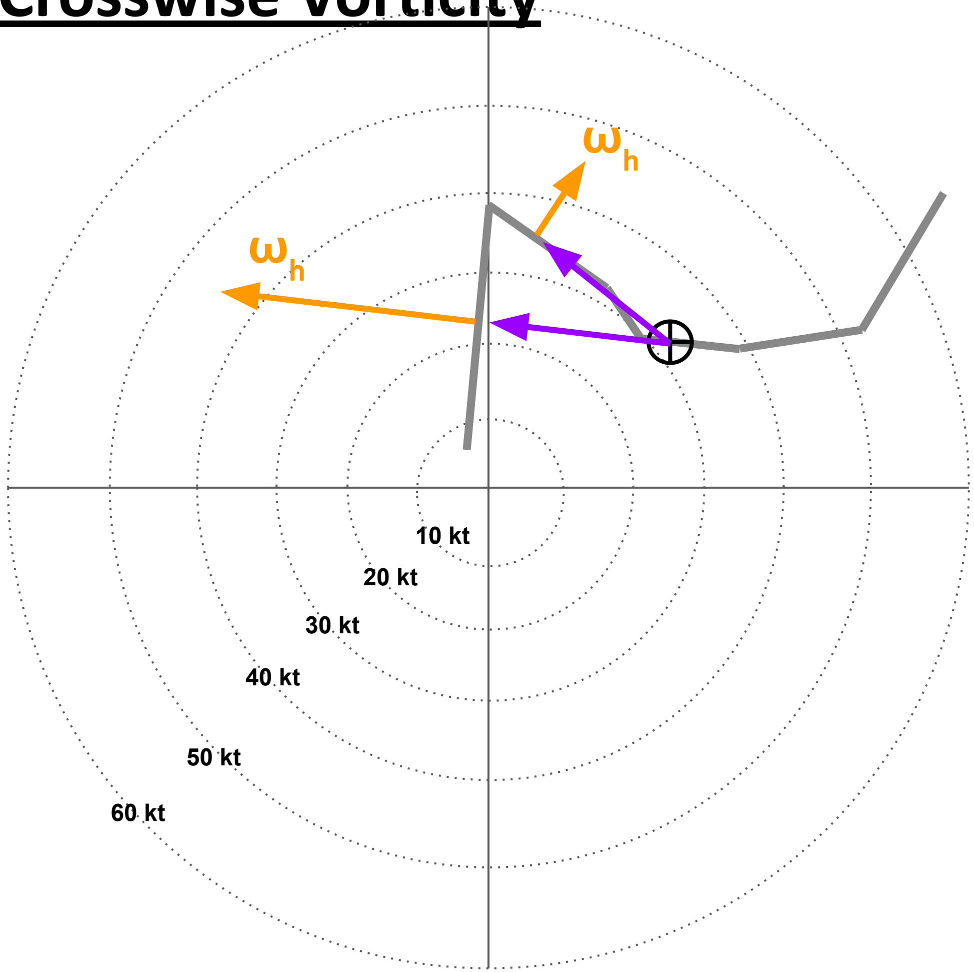
Streamwise vs Crosswise Vorticity

We want to know how a ***storm*** interacts with this **horizontal vorticity**



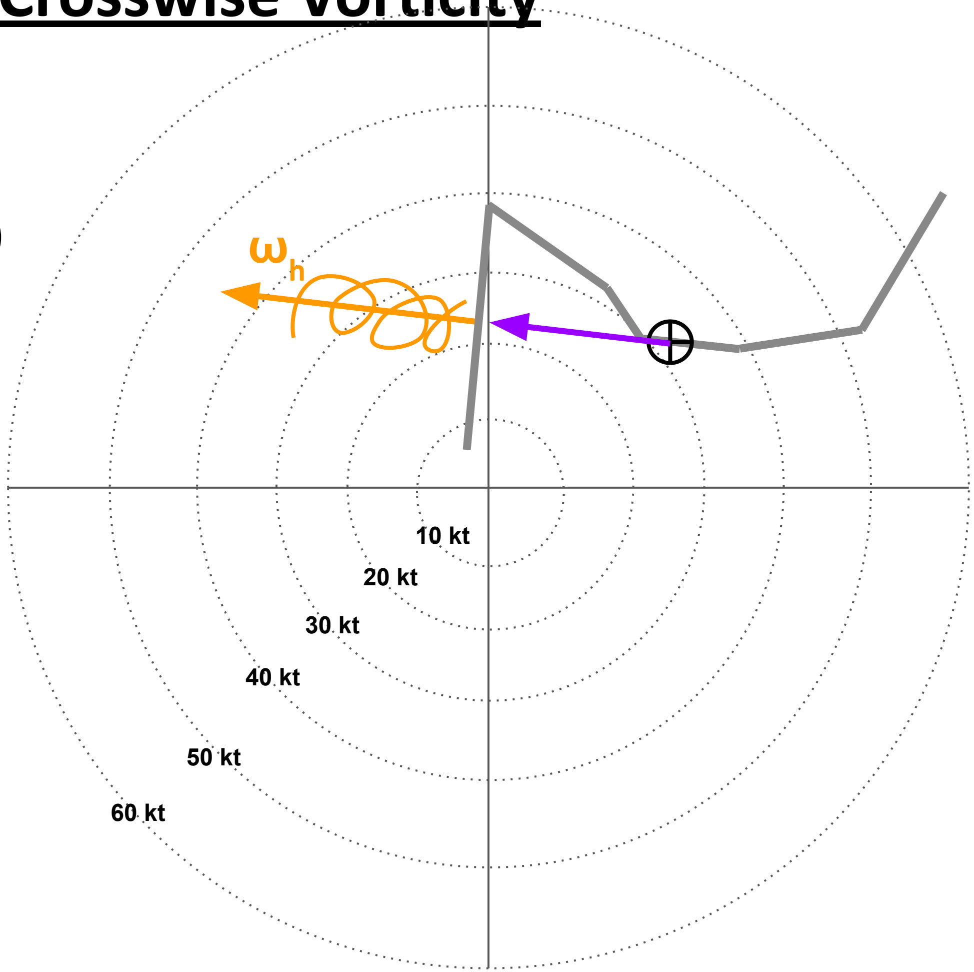
Streamwise vs Crosswise Vorticity

Let's compare the **horizontal vorticity** vectors with the **storm-relative wind** vectors



Streamwise vs Crosswise Vorticity

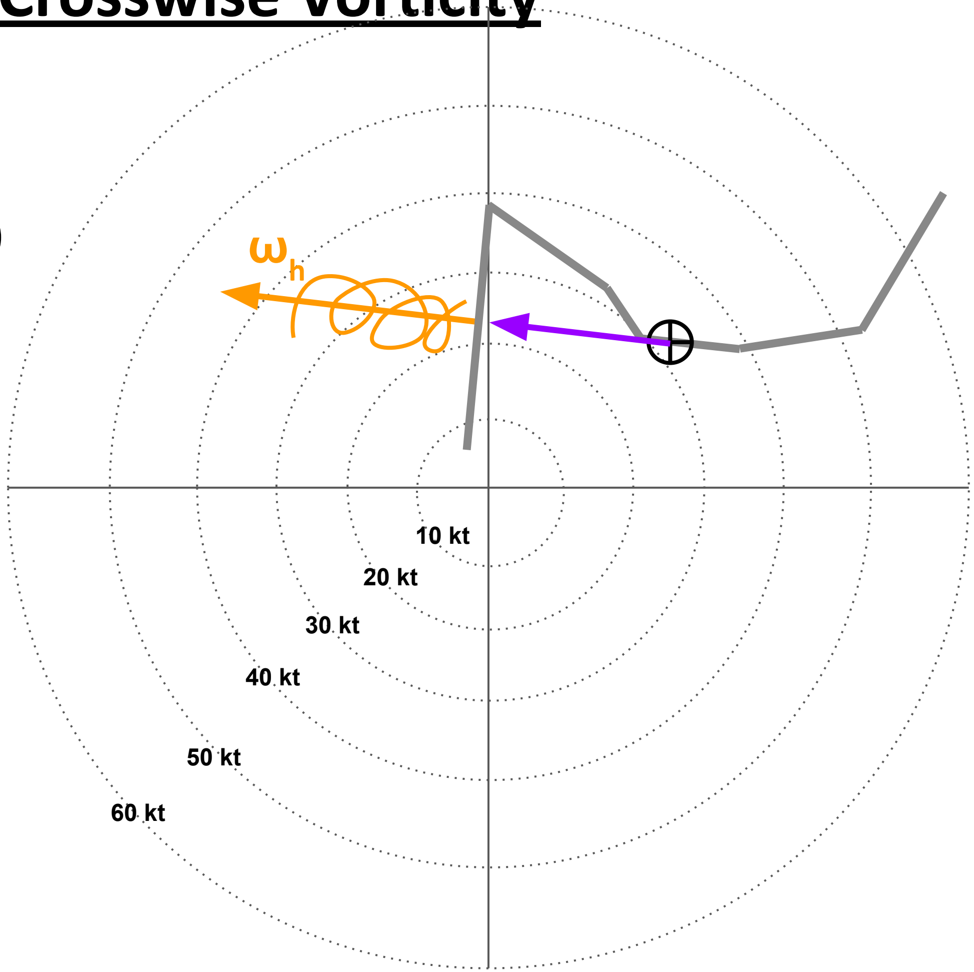
Here, storm-relative wind is **parallel** to horizontal vorticity (the two are aligned)



Streamwise vs Crosswise Vorticity

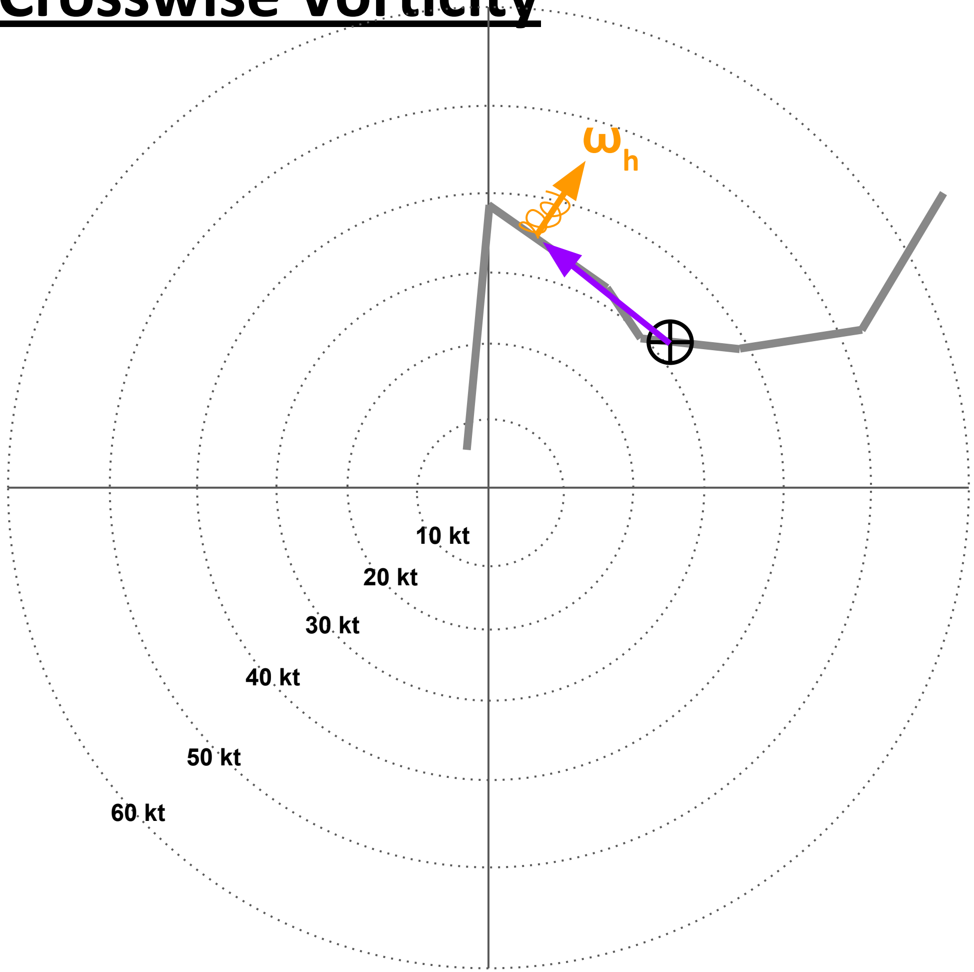
Here, storm-relative wind is **parallel** to horizontal vorticity (the two are aligned)

This is called streamwise vorticity!



Streamwise vs Crosswise Vorticity

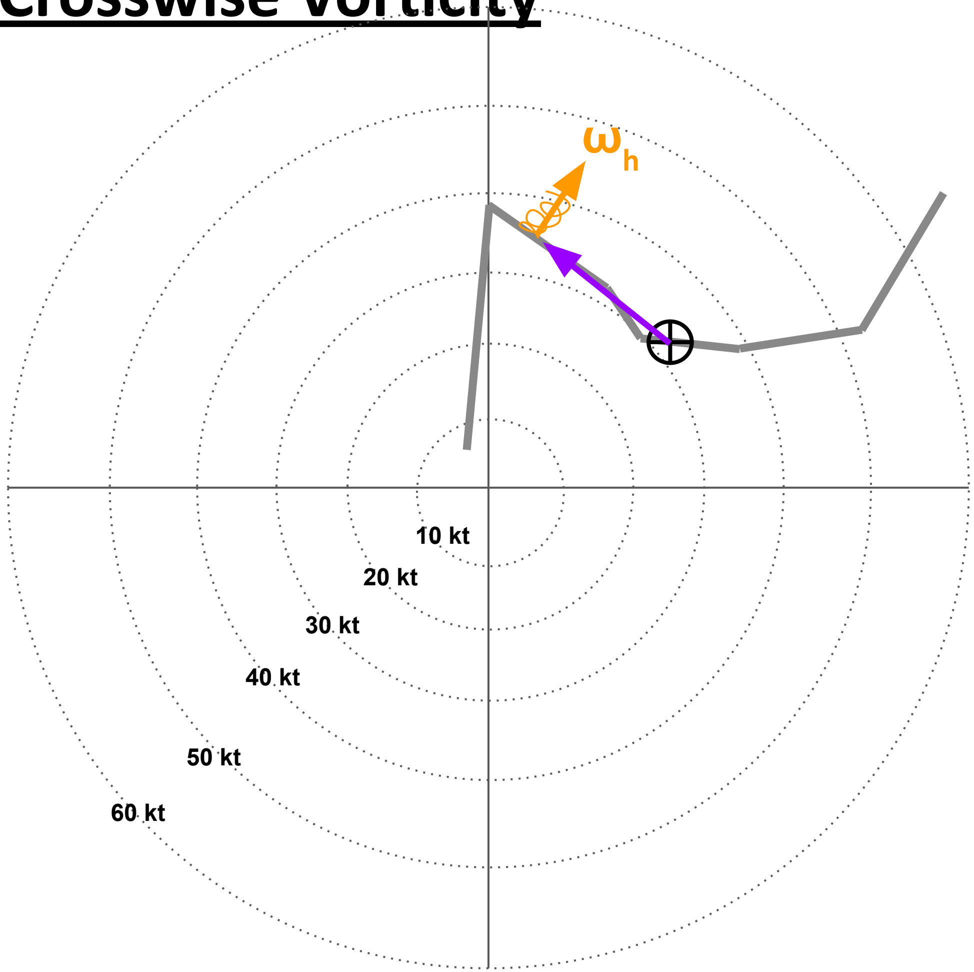
Here, **storm-relative wind** is **perpendicular** to **horizontal vorticity** (the two are NOT aligned)



Streamwise vs Crosswise Vorticity

Here, storm-relative wind is **perpendicular** to horizontal vorticity (the two are NOT aligned)

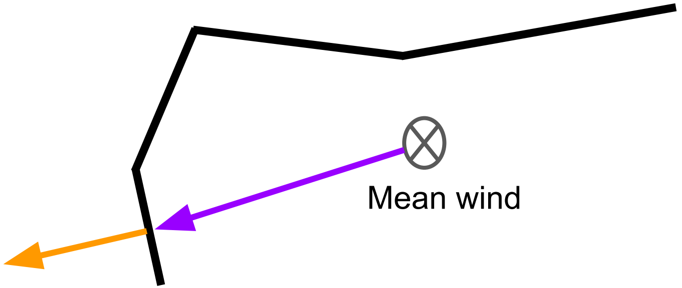
This is called crosswise vorticity.



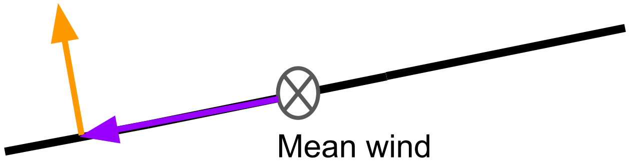
Streamwise vs Crosswise Vorticity

Hodograph shape (and storm motion) affects streamwise vorticity:

Streamwise vorticity!



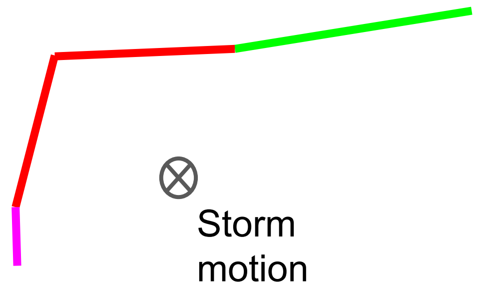
Crosswise vorticity



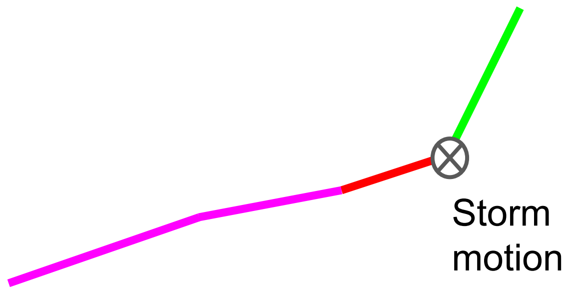
Streamwise vs Crosswise Vorticity

Which hodograph contains more crosswise vorticity?

A.



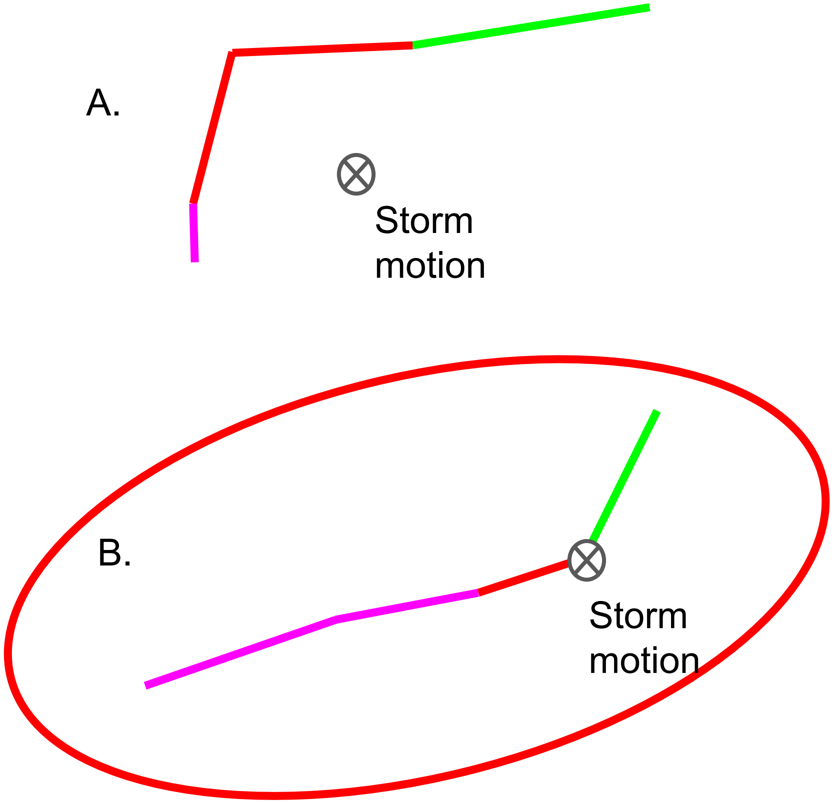
B.



Streamwise vs Crosswise Vorticity

Which hodograph contains more crosswise vorticity?

You got it!



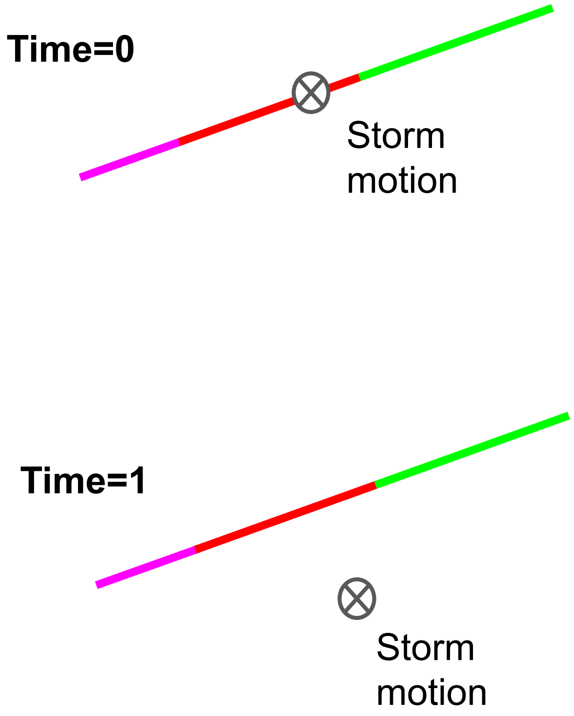
Streamwise vs Crosswise Vorticity

What happens from Time=0 to Time=1?

a. Storm loses streamwise vorticity

b. Storm acquires a greater streamwise vorticity component and can rotate

c. No change, hodograph remains straight



Streamwise vs Crosswise Vorticity

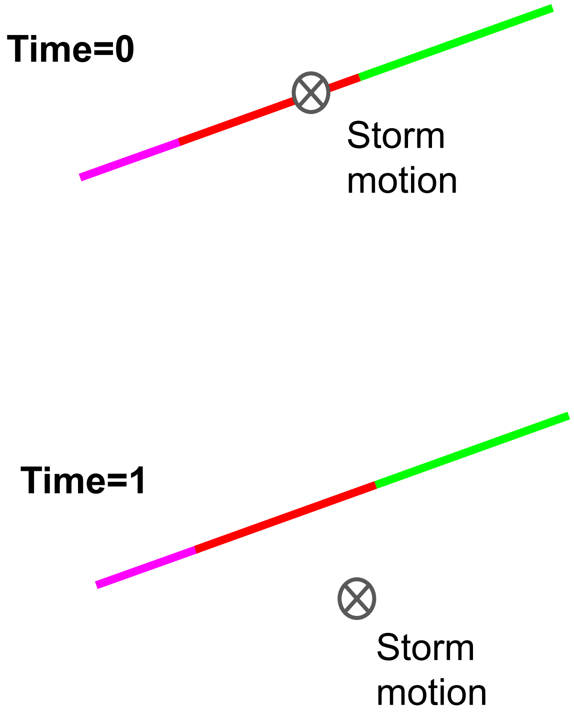
What happens from Time=0 to Time=1?

a. Storm loses streamwise vorticity

b. Storm acquires a greater streamwise vorticity component and can rotate

c. No change, hodograph remains straight

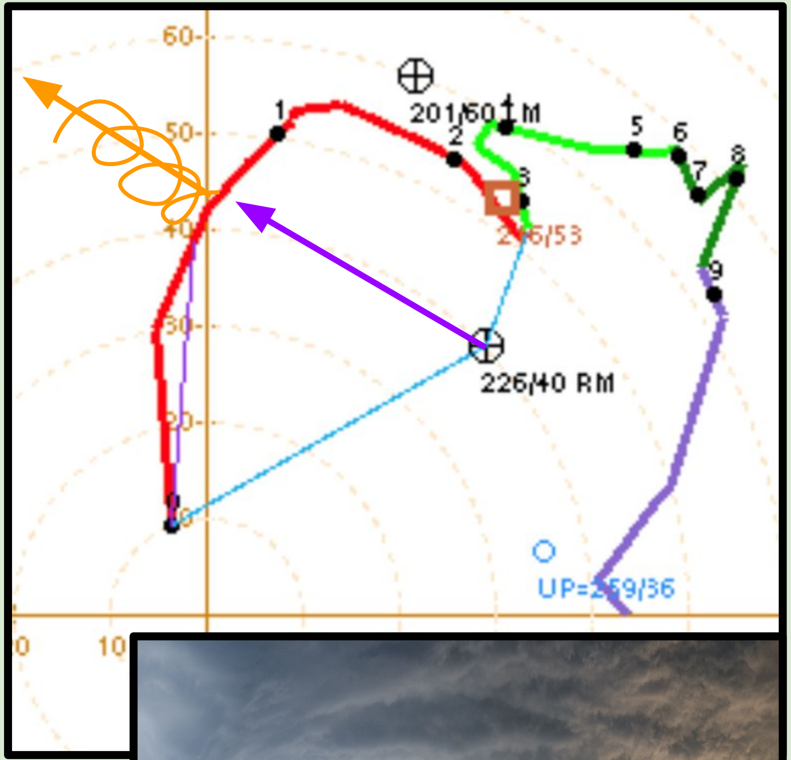
Yes!

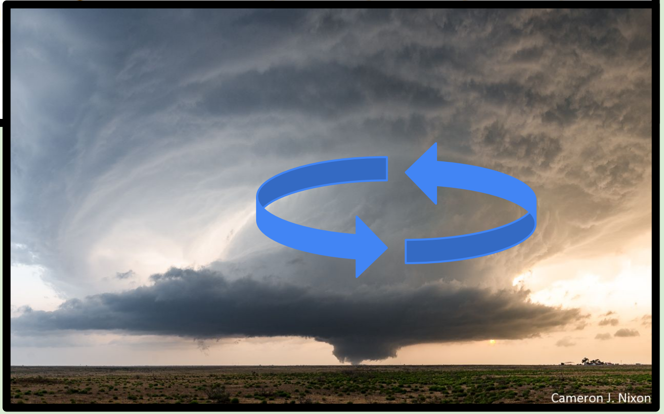


Horizontal Vorticity Summary

1. Horizontal vorticity is always perpendicular and to the left of the shear and therefore the hodograph.
2. The stronger the shear, the stronger the vorticity in that layer.
3. When SR winds are parallel to horizontal vorticity, the vorticity is streamwise. When SR winds are perpendicular to horizontal vorticity, the vorticity is crosswise.
4. Both hodograph shape and storm motion influence development of streamwise and crosswise vorticity.

Lesson 7: Streamwise Vorticity and SRH





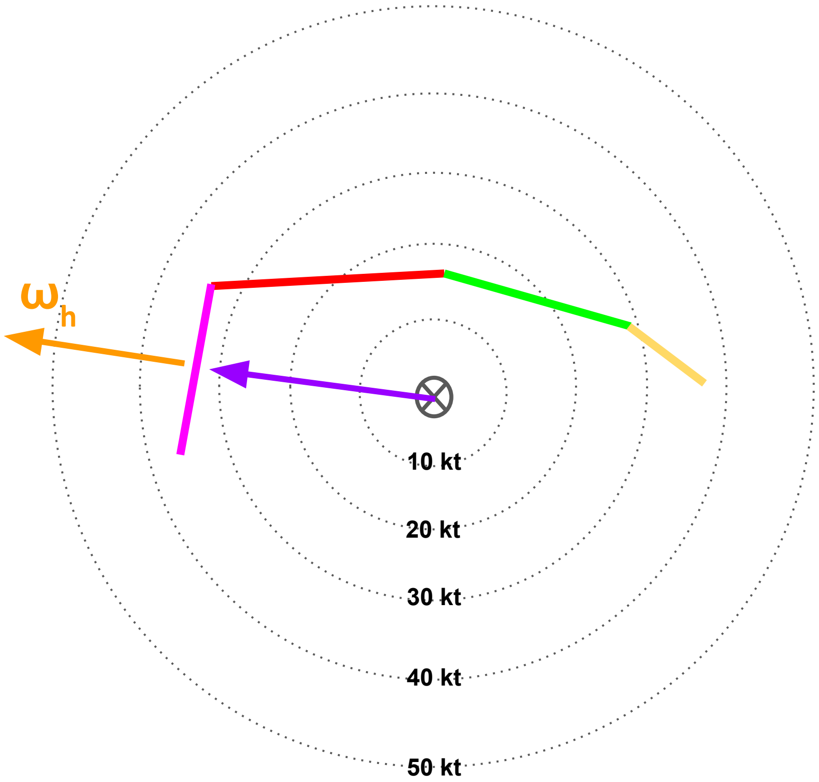
Cameron Nixon – Research Scientist, SPC / CIWRO
(cameron.nixon@noaa.gov)

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

Streamwise Vorticity

There are two ways to describe streamwise vorticity:

1. How streamwise is the vorticity?
2. How much streamwise vorticity is there?

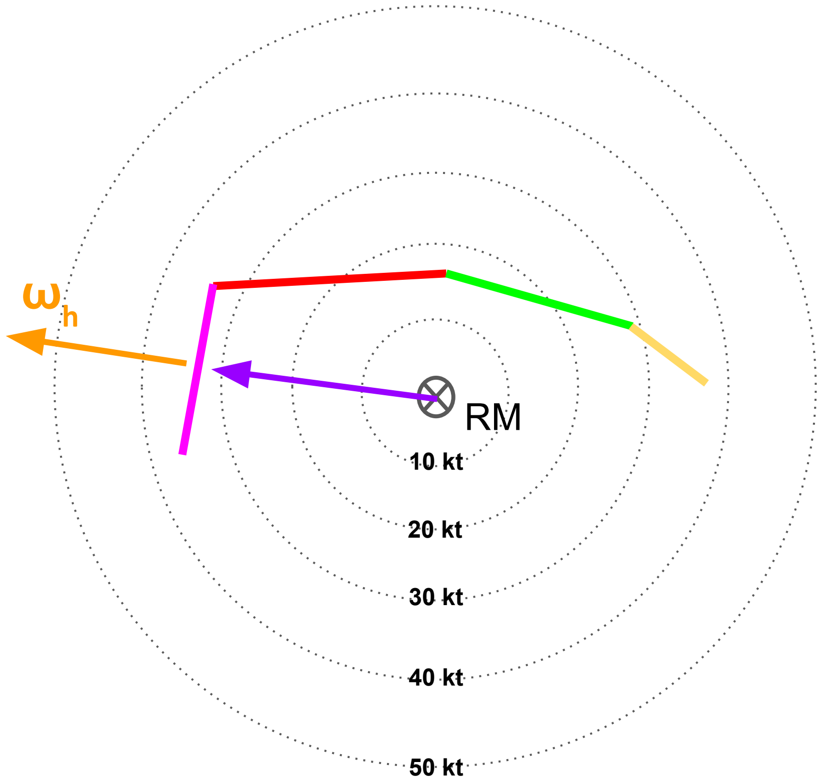


Streamwise Vorticity and Mesocyclogenesis

Streamwiseness

Streamwiseness is how parallel the **storm-relative wind** is to the **horizontal vorticity**

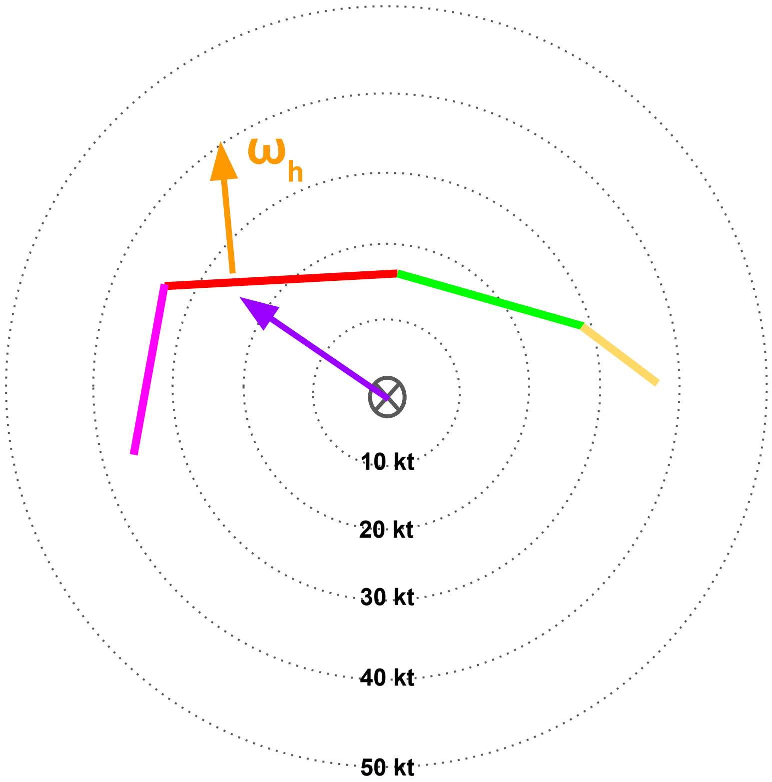
Here, vorticity is purely streamwise.



Streamwiseness

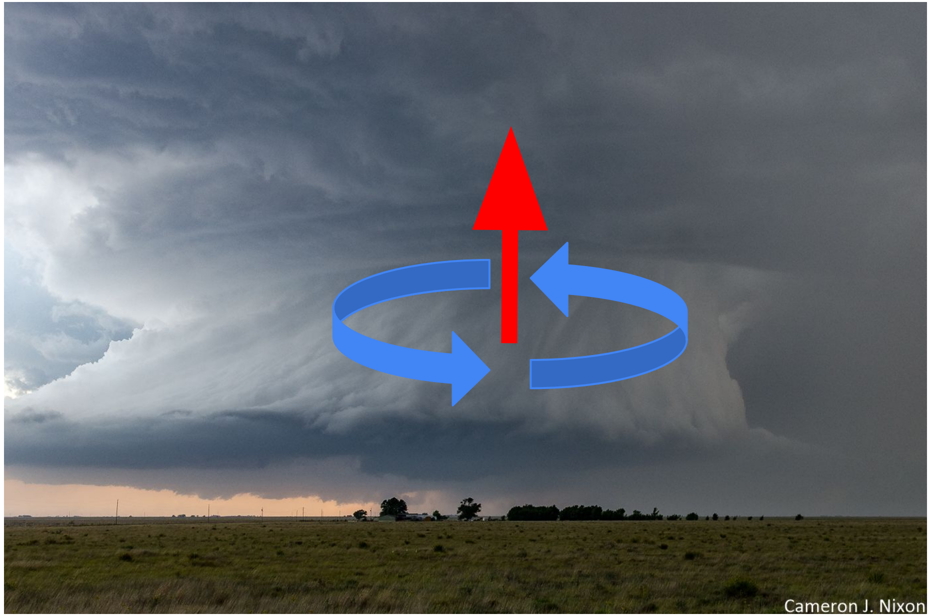
Streamwiseness is how parallel the storm-relative wind is to the horizontal vorticity

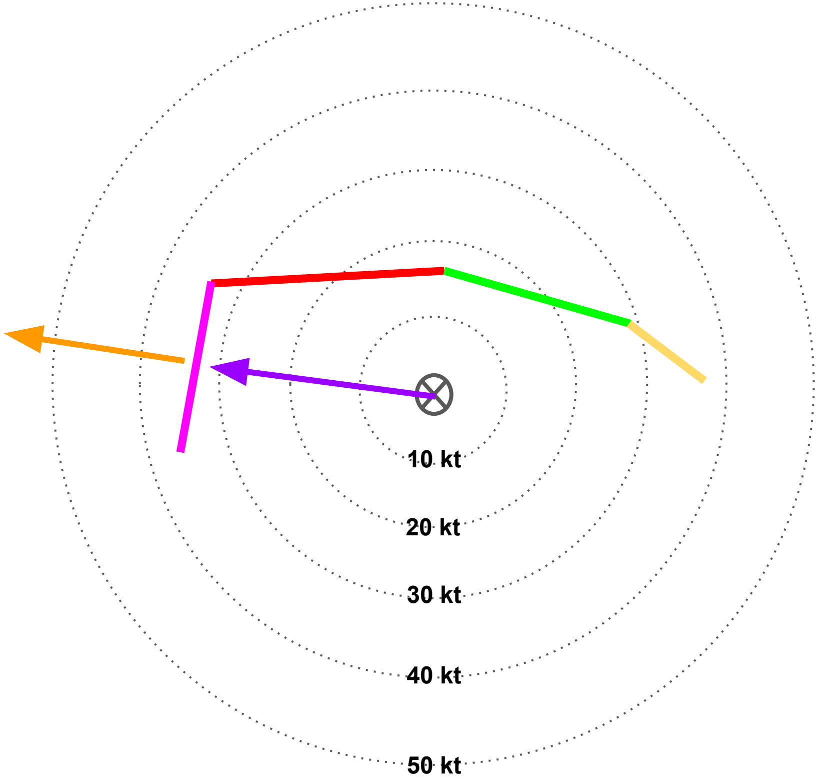
Here, vorticity is less streamwise.
(it's at an angle to the inflow)



Streamwiseness

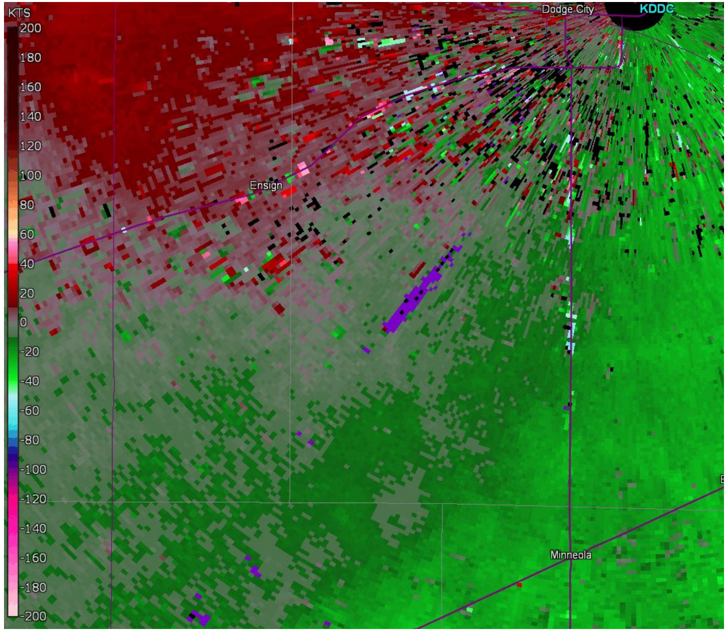
With more streamwiseness, vorticity tends to be aligned with the updraft, so mesocyclogenesis can be faster.

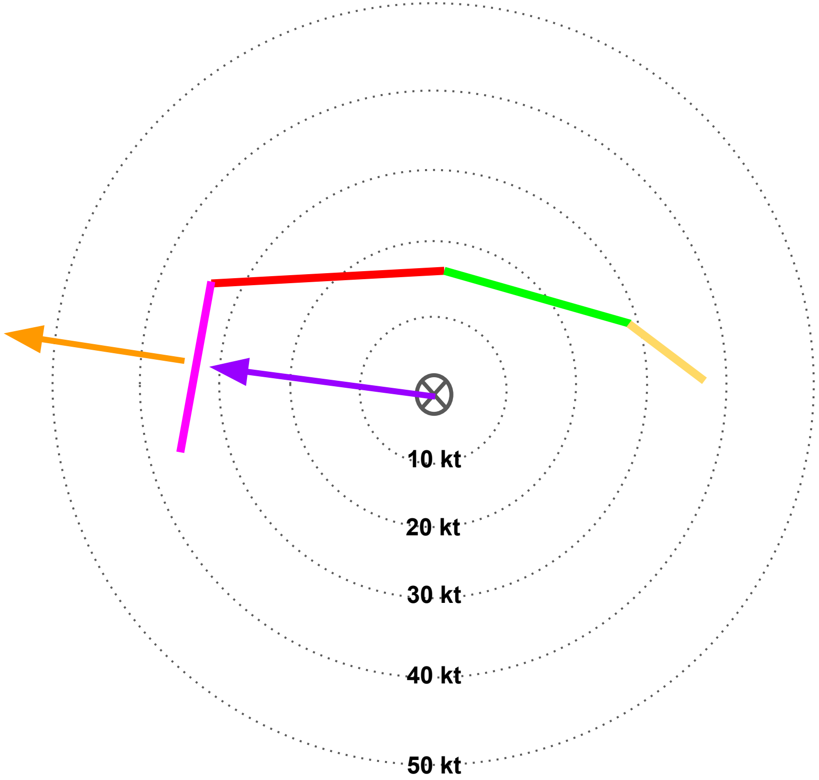




Streamwiseness

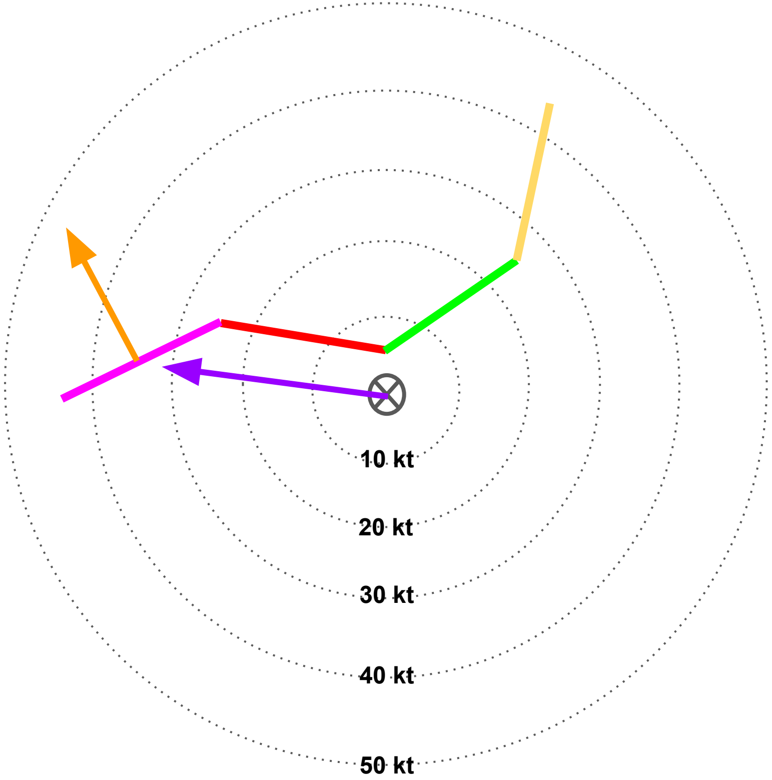
With more streamwiseness, vorticity tends to be aligned with the updraft, so mesocyclogenesis can be faster.





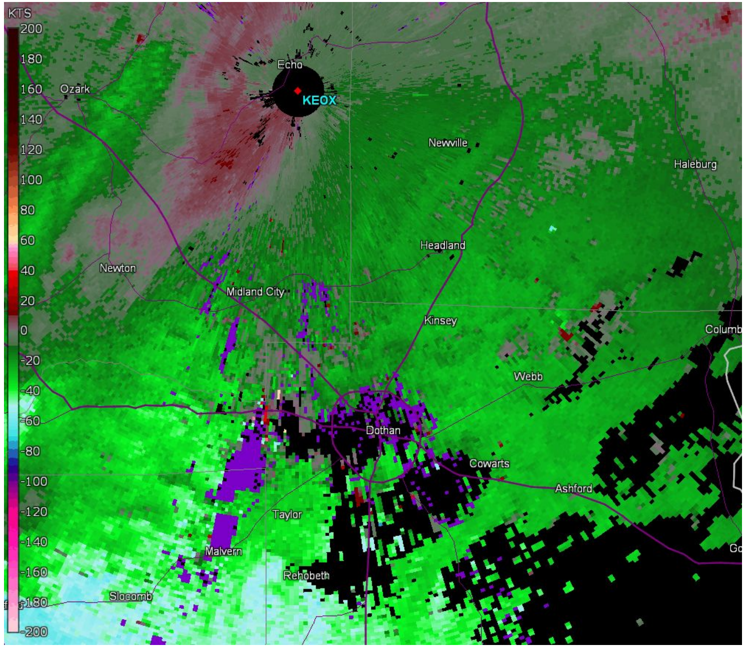
Streamwiseness

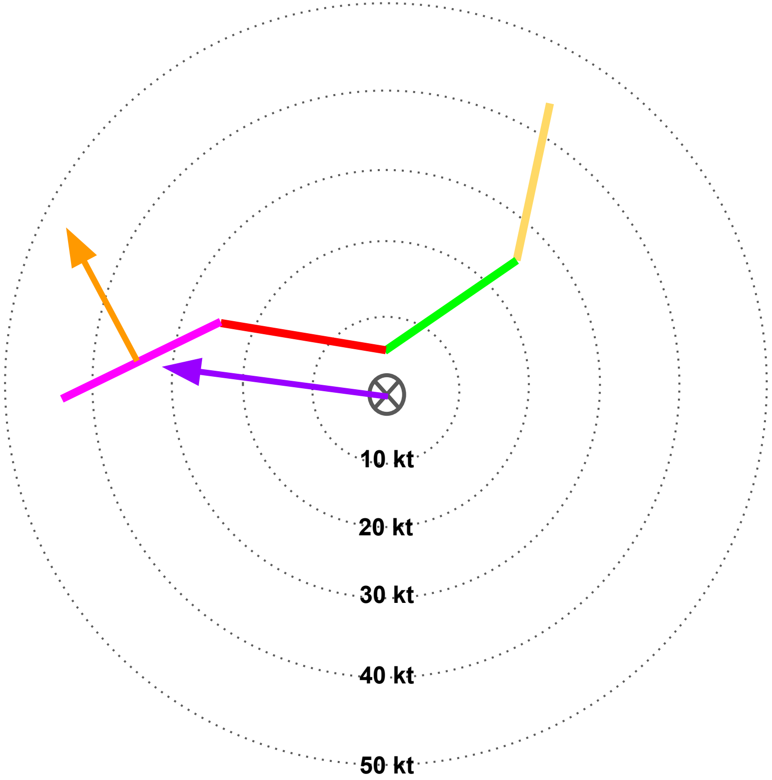
With less streamwiseness, vorticity tends to be dislocated from the updraft, so mesocyclogenesis may be slower.



Streamwiseness

With less streamwiseness, vorticity tends to be dislocated from the updraft, so mesocyclogenesis may be slower.

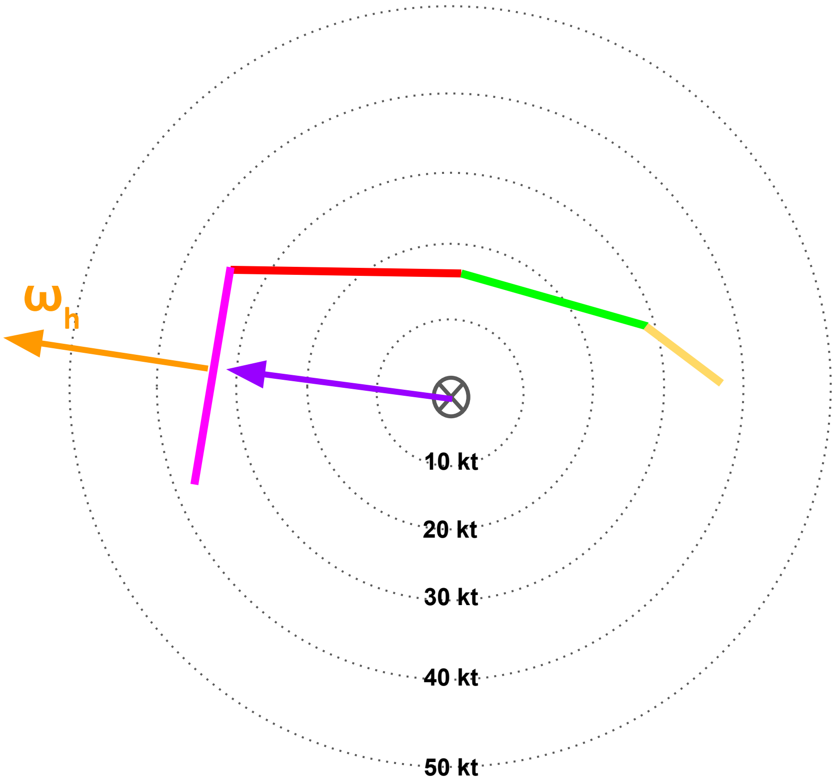




Streamwise Vorticity

But streamwiseness doesn't tell the whole story…

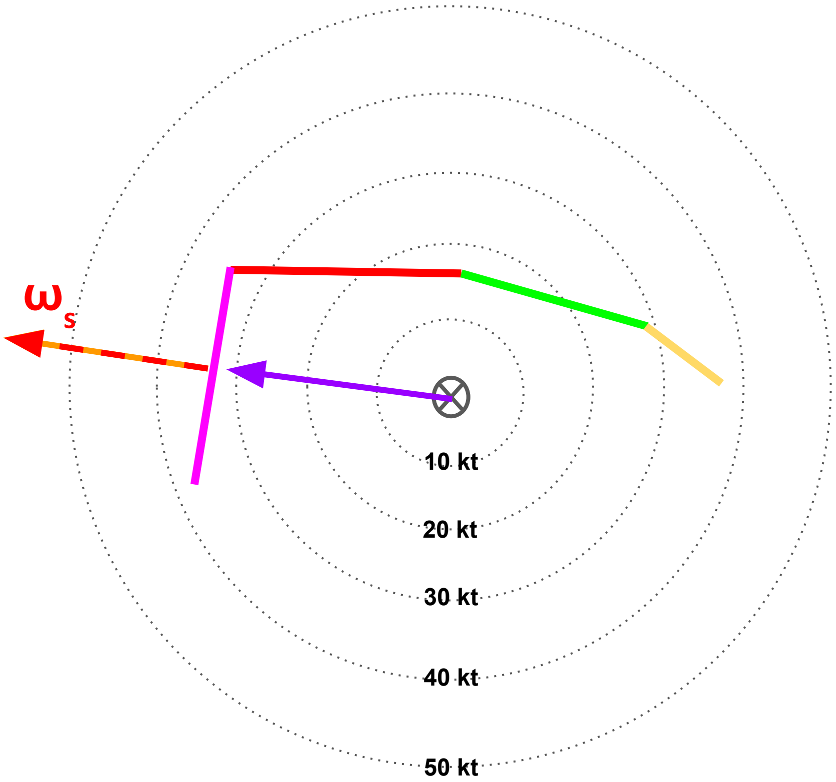
The **magnitude** of streamwise vorticity is important!



Streamwise Vorticity

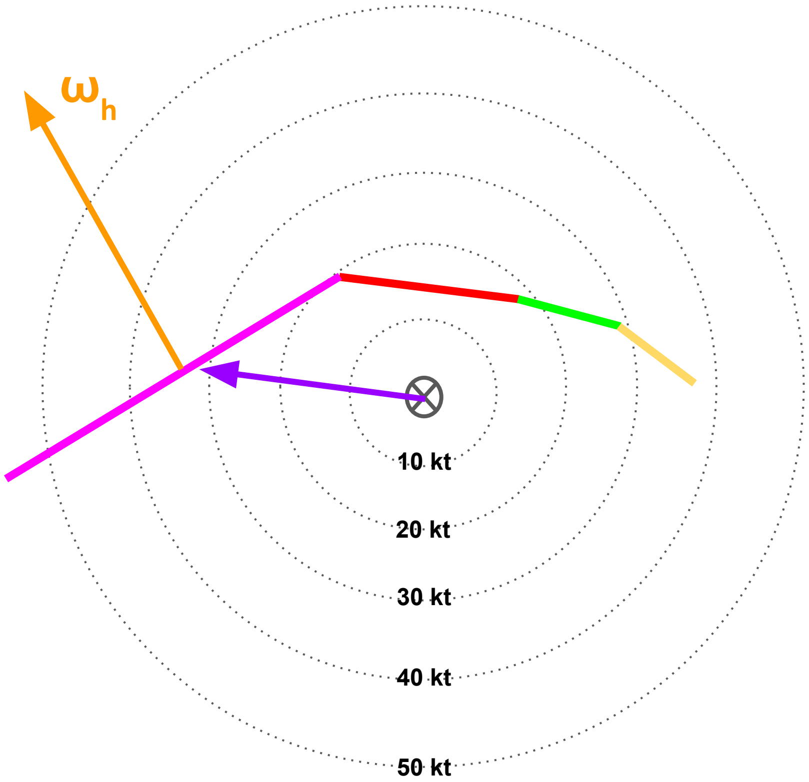
The **magnitude** of streamwise vorticity is important!

Here, there is .03 s^{-1} of streamwise vorticity



Streamwise Vorticity

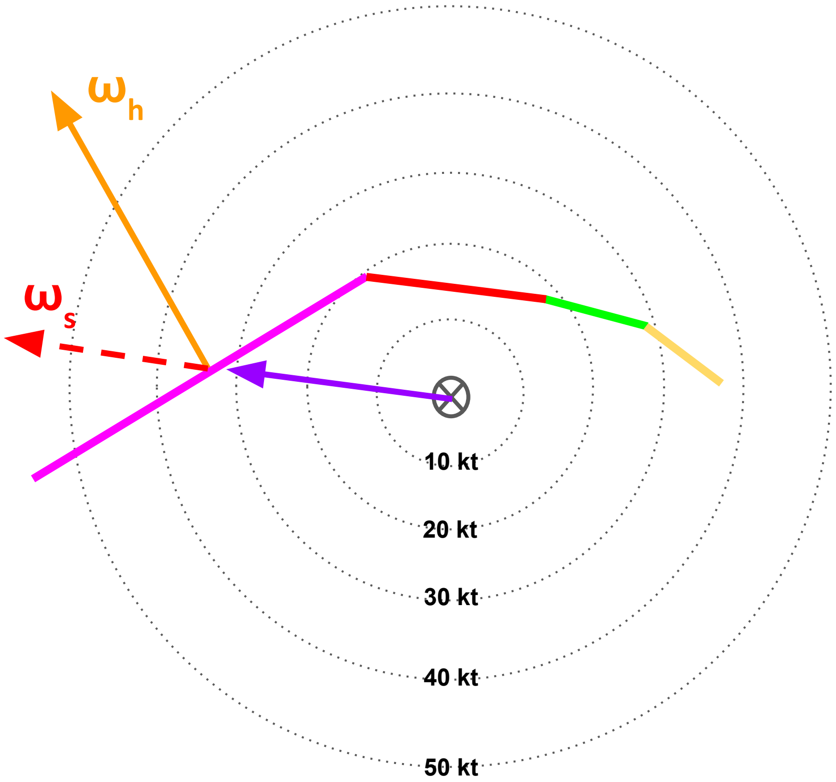
Even if **horizontal vorticity** is not purely streamwise, there may still be a **streamwise component.**



Streamwise Vorticity

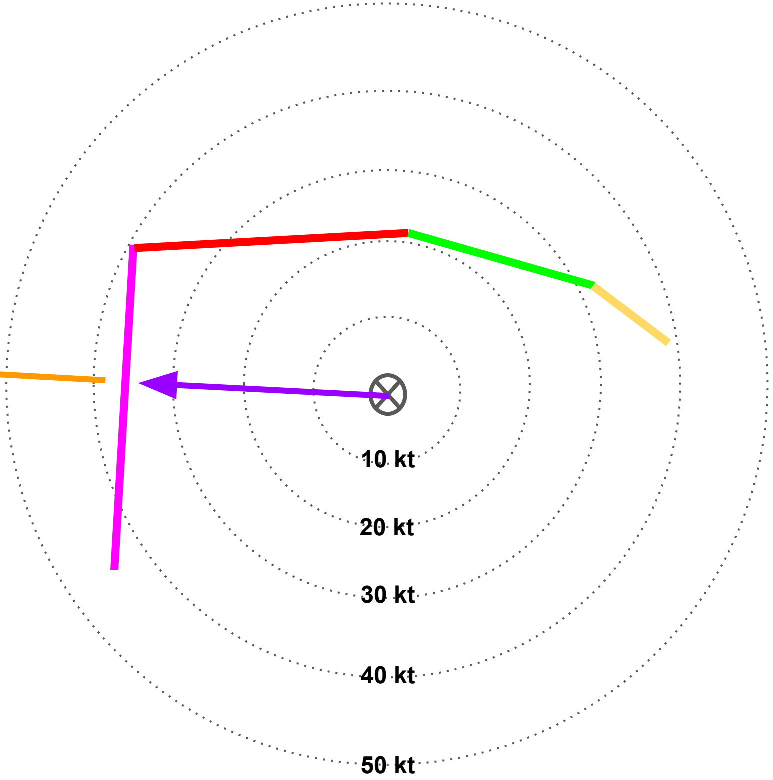
Even if **horizontal vorticity** is not purely streamwise, there may still be a **streamwise component.**

Here, there is .03 s^{-1} of **streamwise vorticity**



Streamwise Vorticity

With a greater magnitude of streamwise vorticity, mesocyclones can be **stronger** and more persistent.



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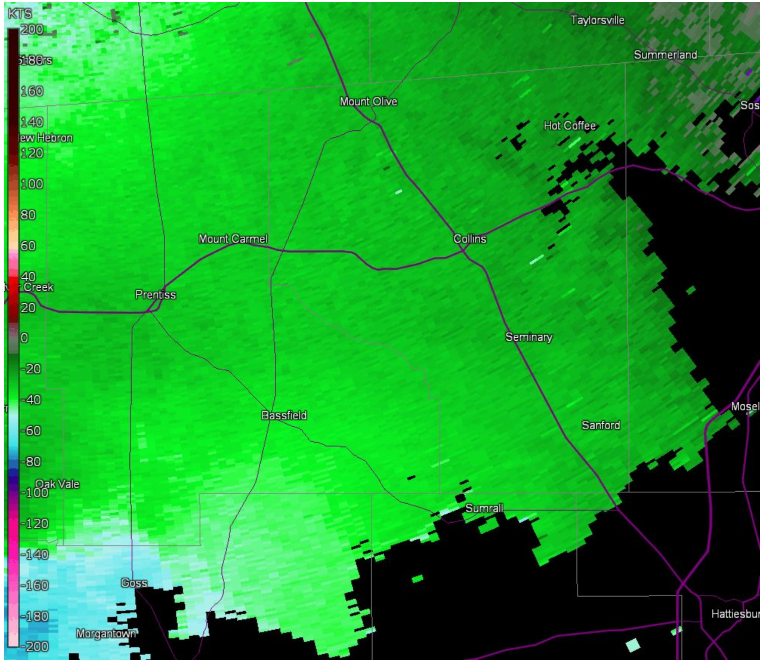
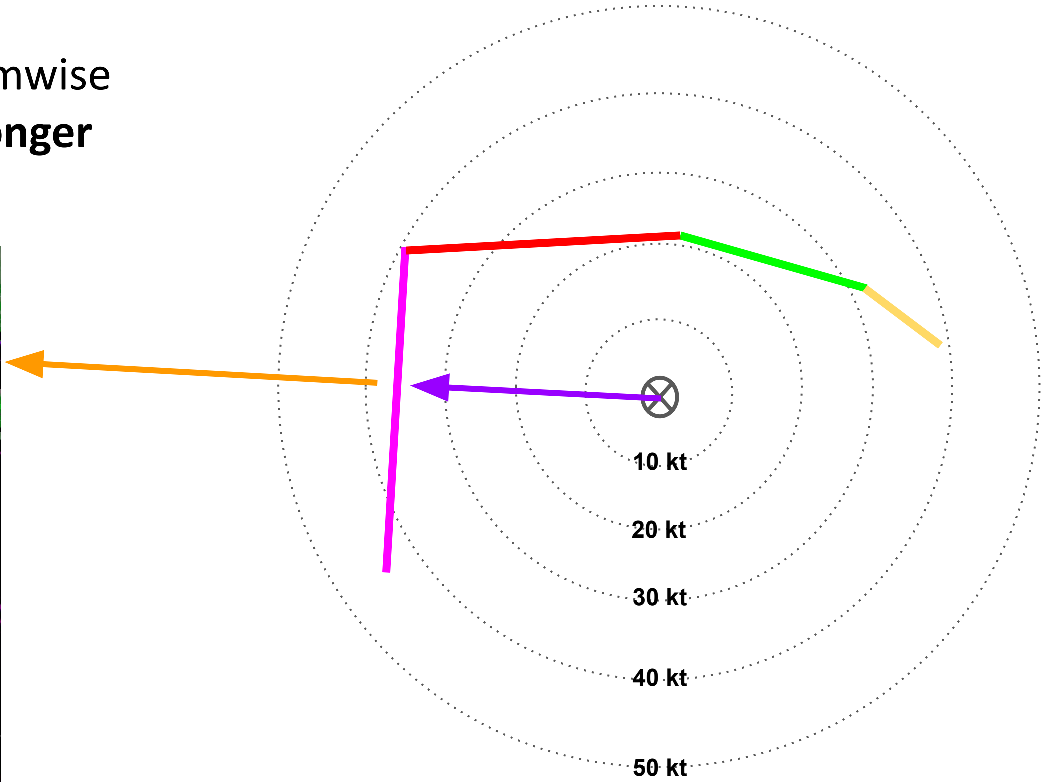
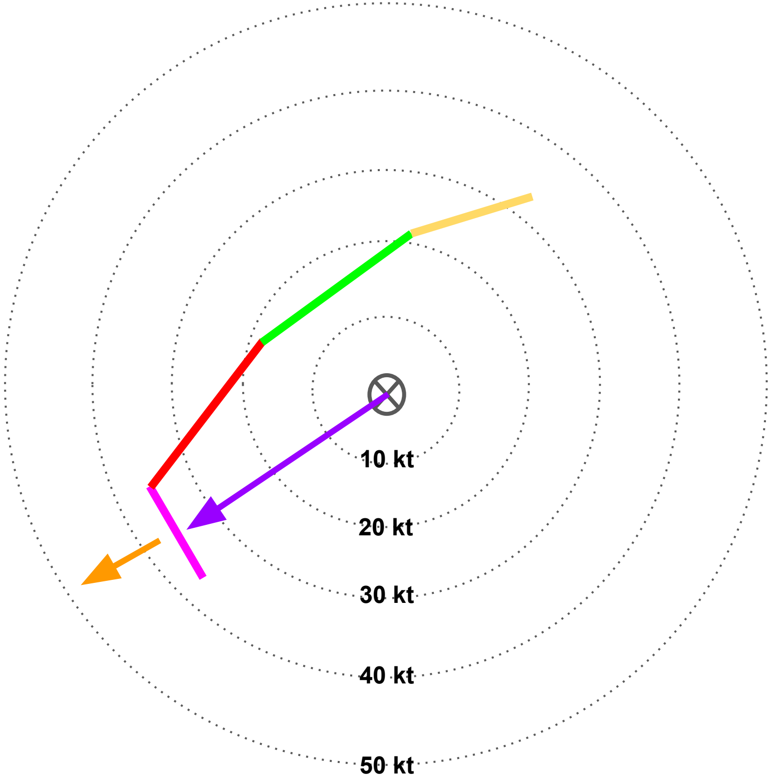




Streamwise Vorticity

With a lesser magnitude of streamwise vorticity, mesocyclones are generally weaker and more transient.



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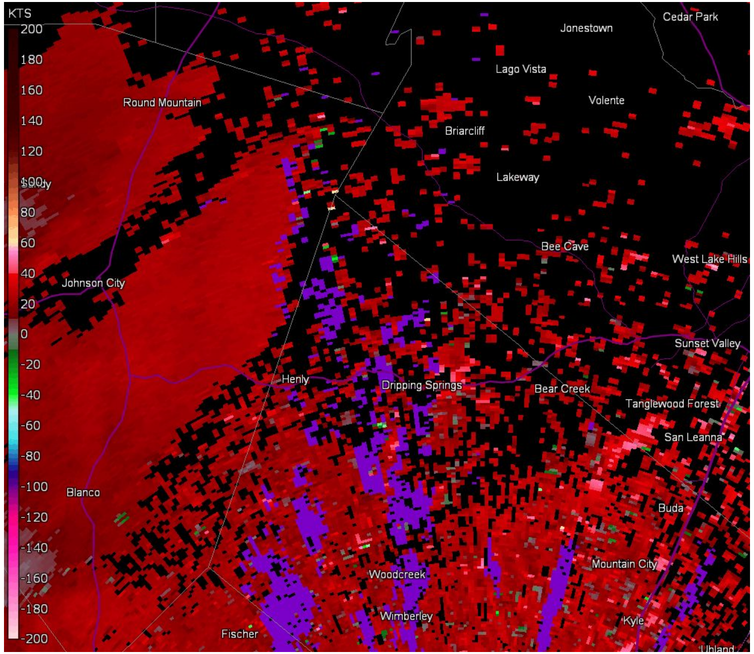
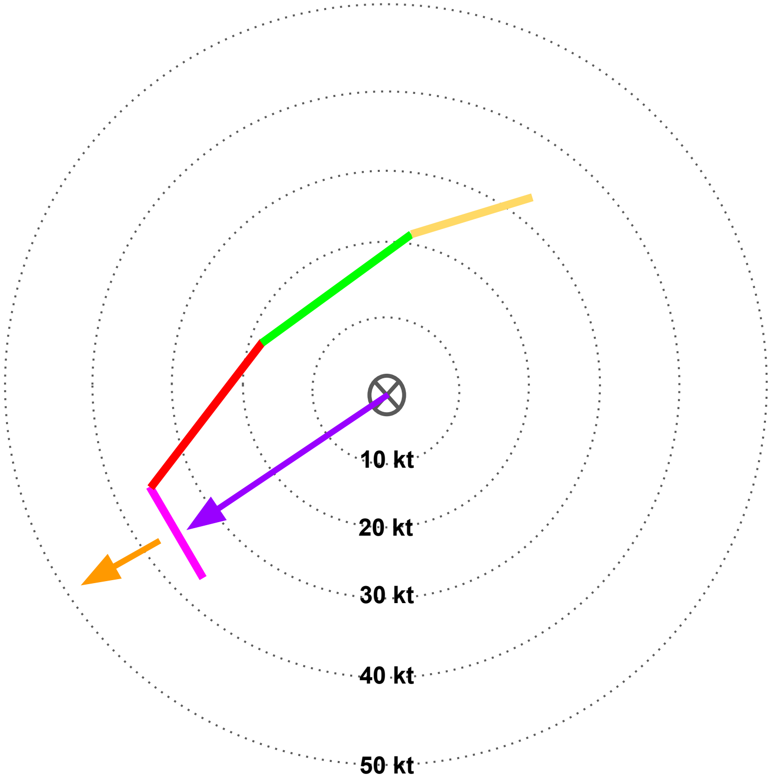
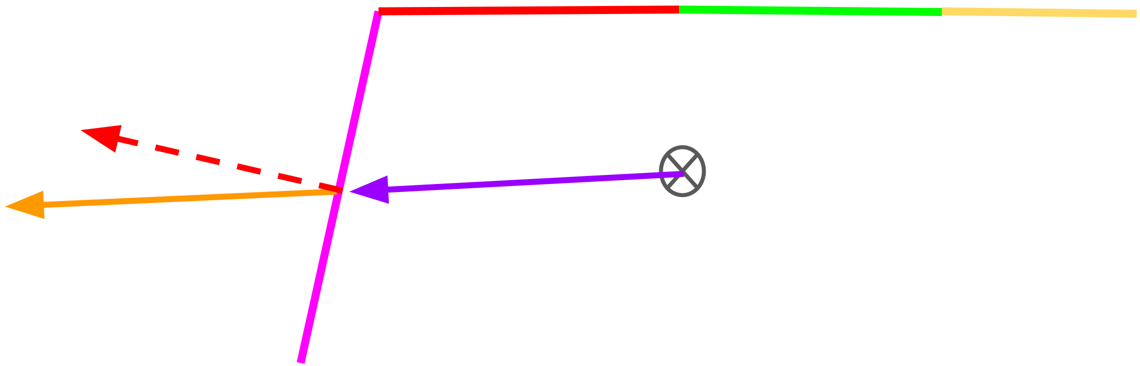




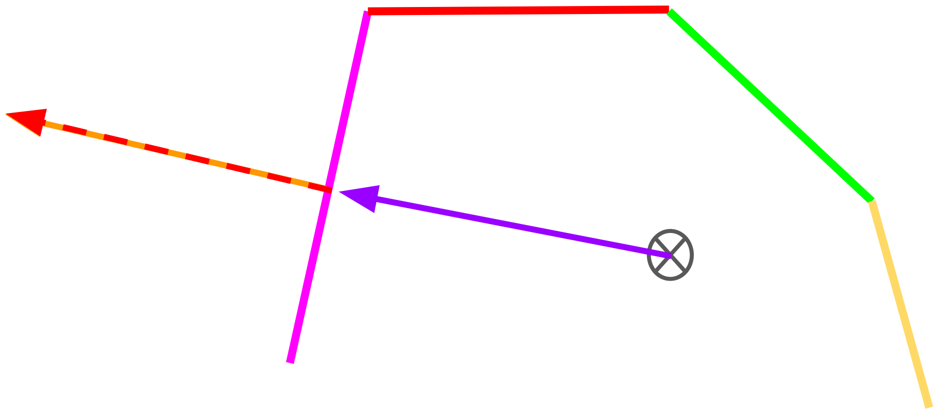
Streamwise Vorticity

Keep in mind: storm motion affects streamwise vorticity



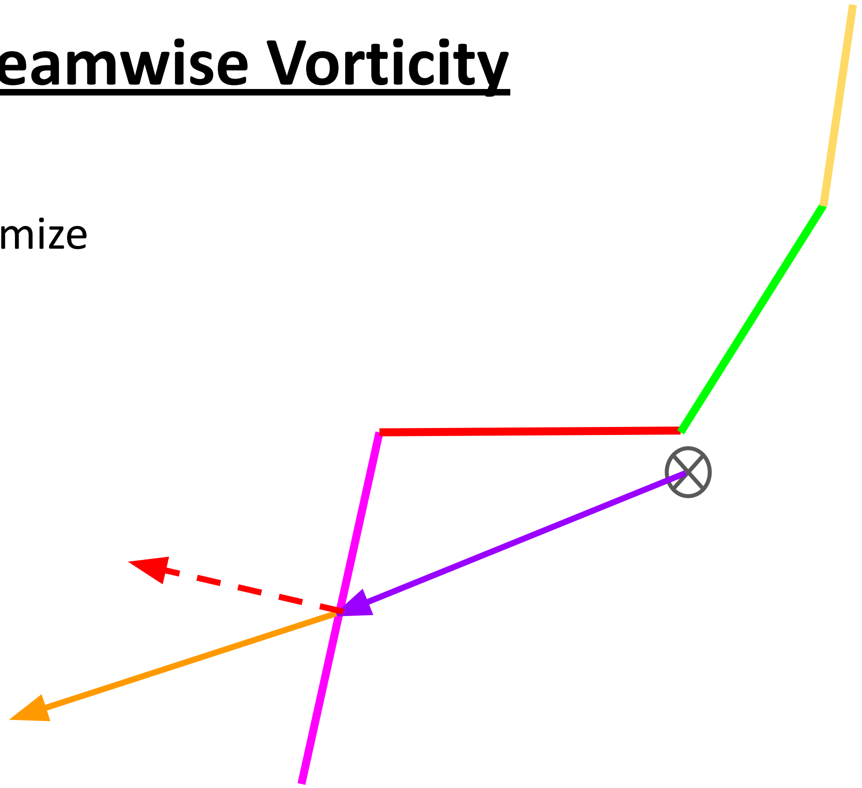
Streamwise Vorticity

Larger hodograph curvature can maximize streamwise vorticity



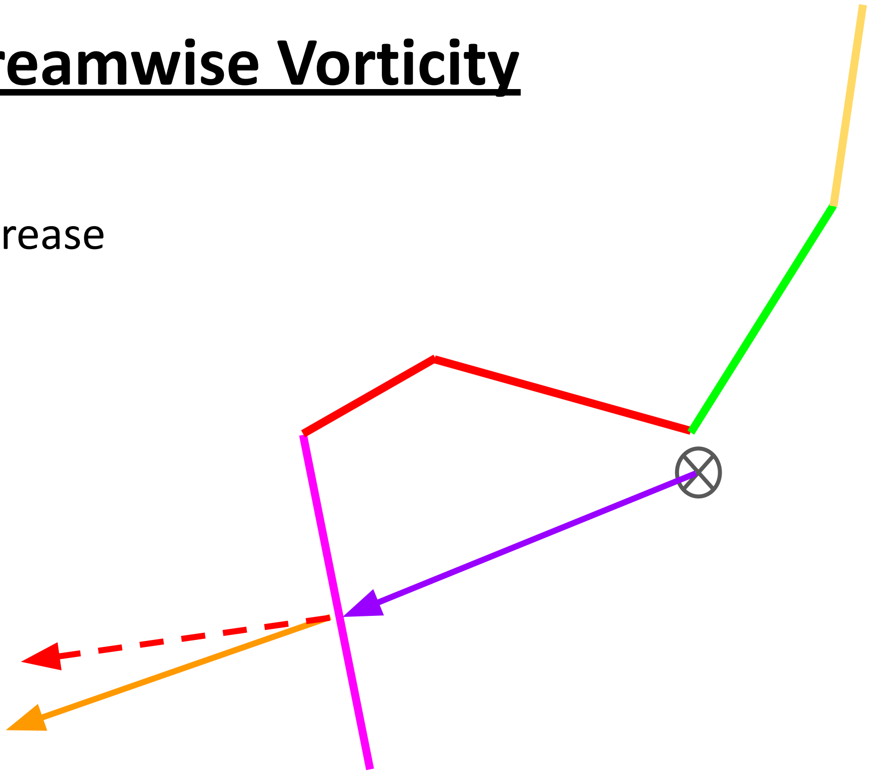
Streamwise Vorticity

More backing shear aloft can minimize streamwise vorticity



Streamwise Vorticity

Larger low-level curvature can increase streamwise vorticity

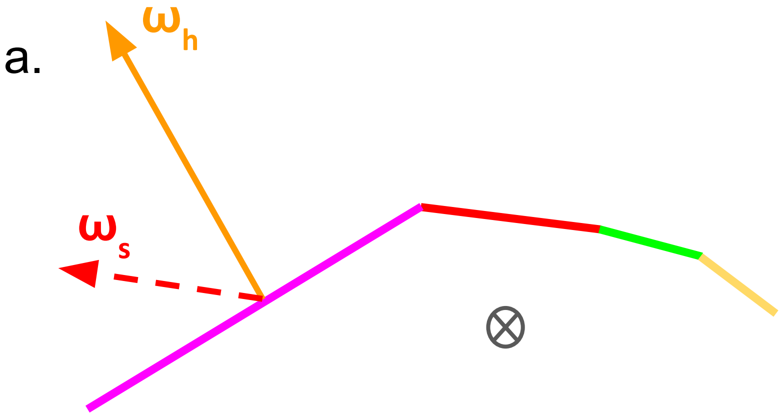


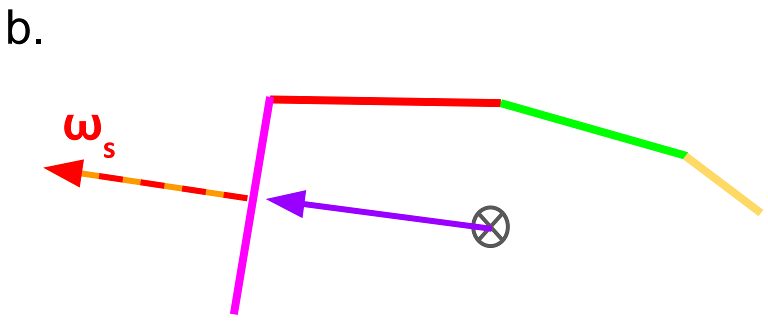
Streamwise Vorticity

Quiz time!

Which of these two hodographs has a greater magnitude of **streamwise vorticity**?

a. a
b. b
c. they both have the same





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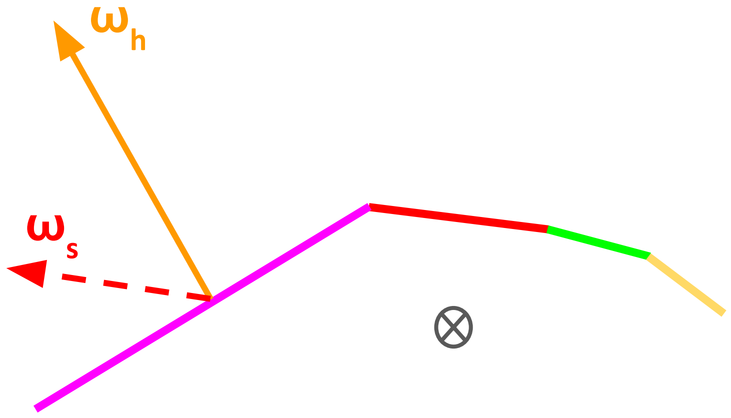
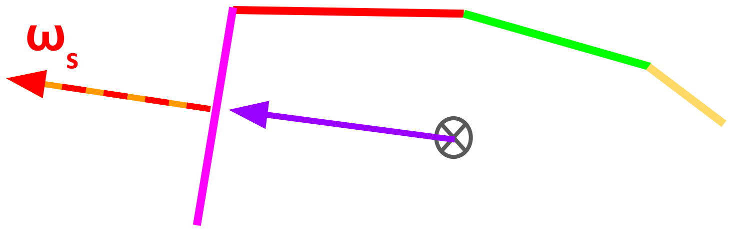
a.



b.

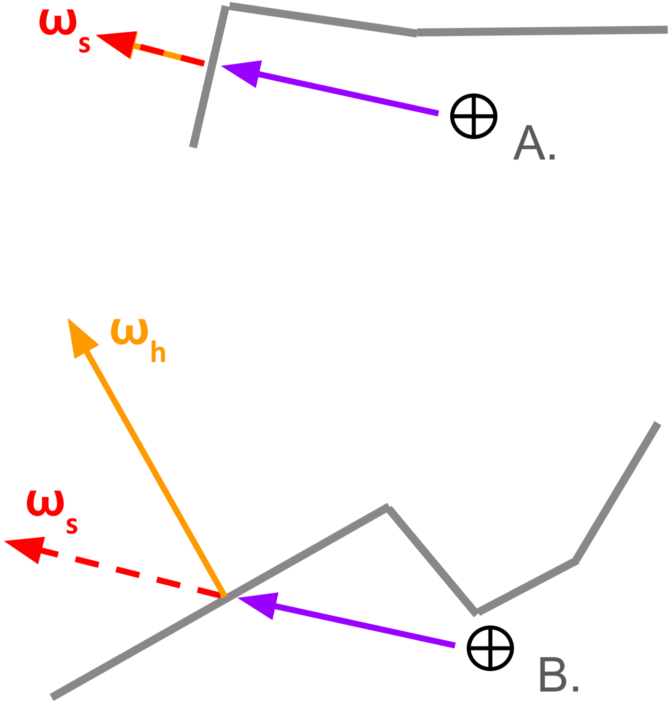


Streamwise Vorticity

Quiz time!

Compared to hodograph A, hodograph B shows:

a. A lesser magnitude of streamwise vorticity, but this vorticity is more streamwise
b. A greater magnitude of streamwise vorticity, but this vorticity is less streamwise



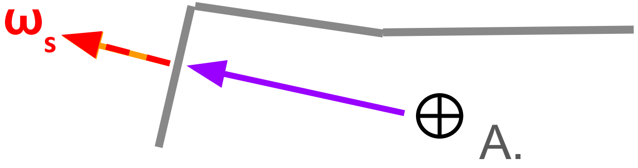
Streamwise Vorticity

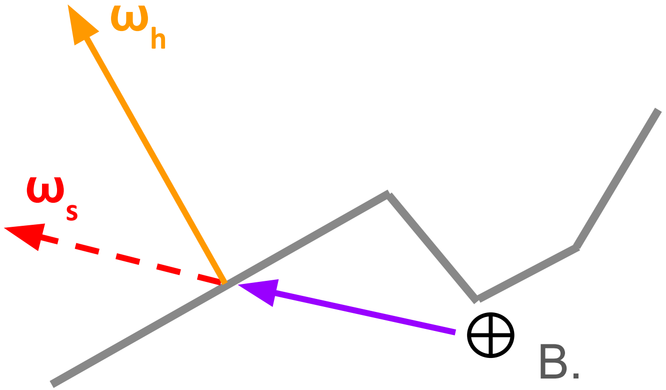
Quiz time!

Compared to hodograph A, hodograph B shows:

a. A lesser magnitude of streamwise vorticity, but this vorticity is more streamwise
b. A greater magnitude of streamwise vorticity, but this vorticity is less streamwise

You’re very (stream)wise :)





Storm Relative Helicity (SRH)

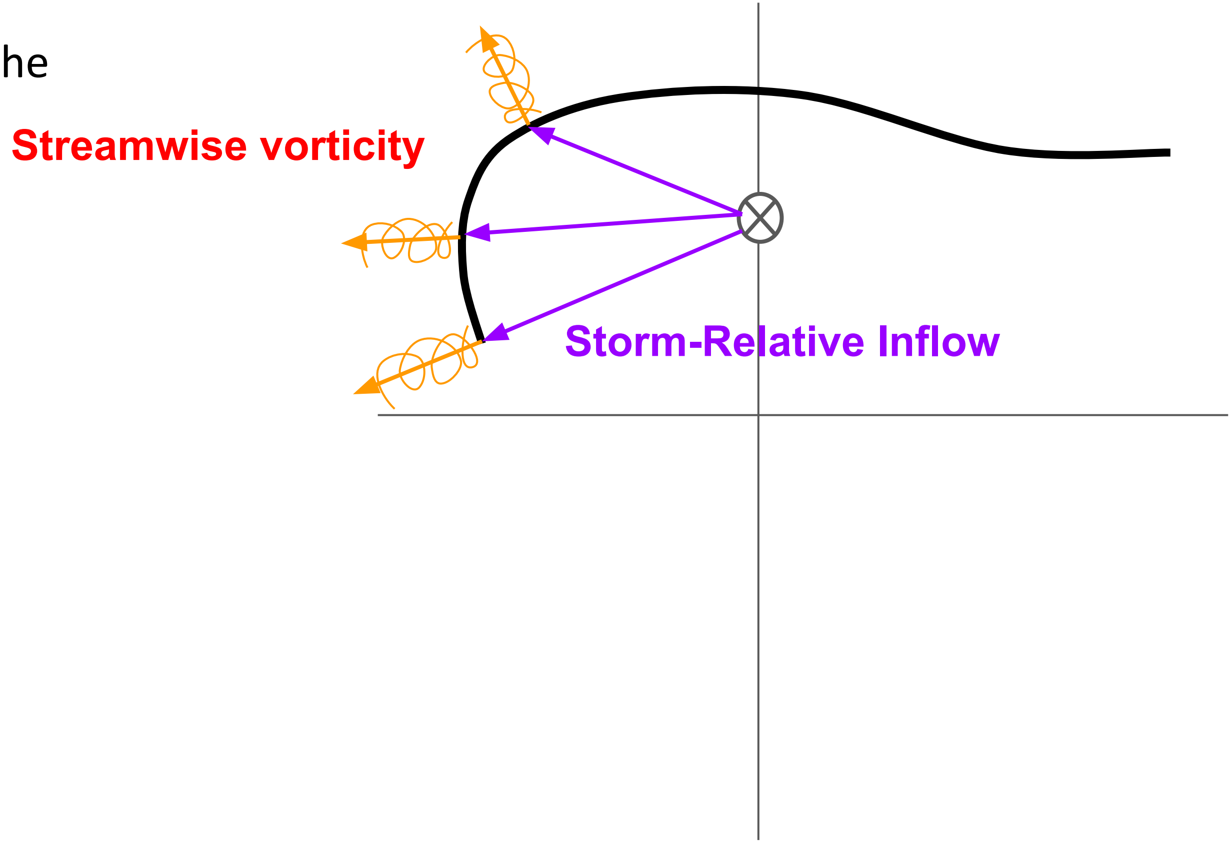
The magnitude of streamwise vorticity can be approximated using **SRH**.

$$\text{Storm Relative Helicity (SRH)} = \int_{Zb}^{Vt} (\textbf{inflow}) \bullet (\textbf{horizontal vorticity})\, dz$$

$$\Rightarrow \quad |\textbf{inflow}| \cdot |\textbf{streamwise vorticity}|$$

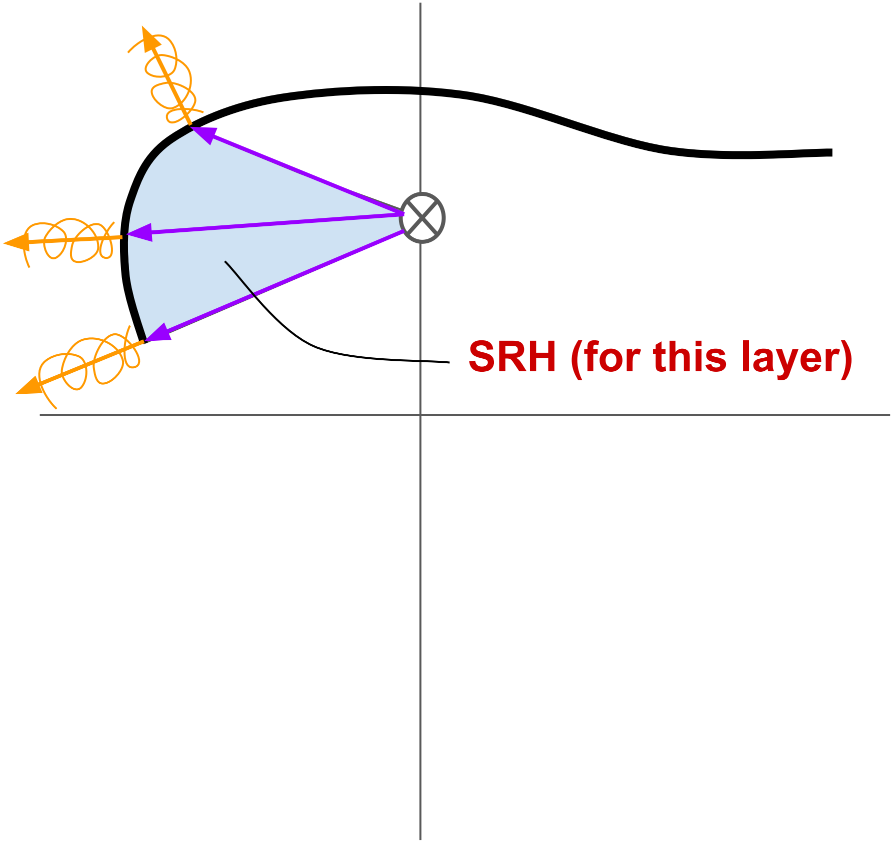
Storm Relative Helicity (SRH)

What does this look like on the hodograph?



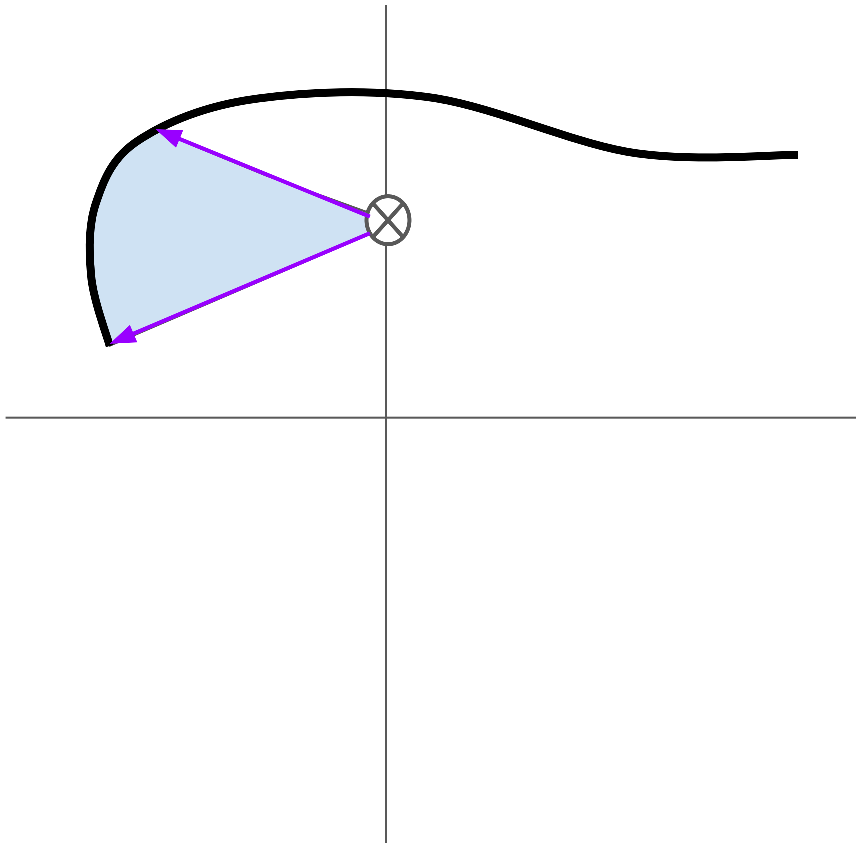
Storm Relative Helicity (SRH)

Just take the **area** under the hodograph swept out by the **storm-relative winds** over some depth!



Storm Relative Helicity (SRH)

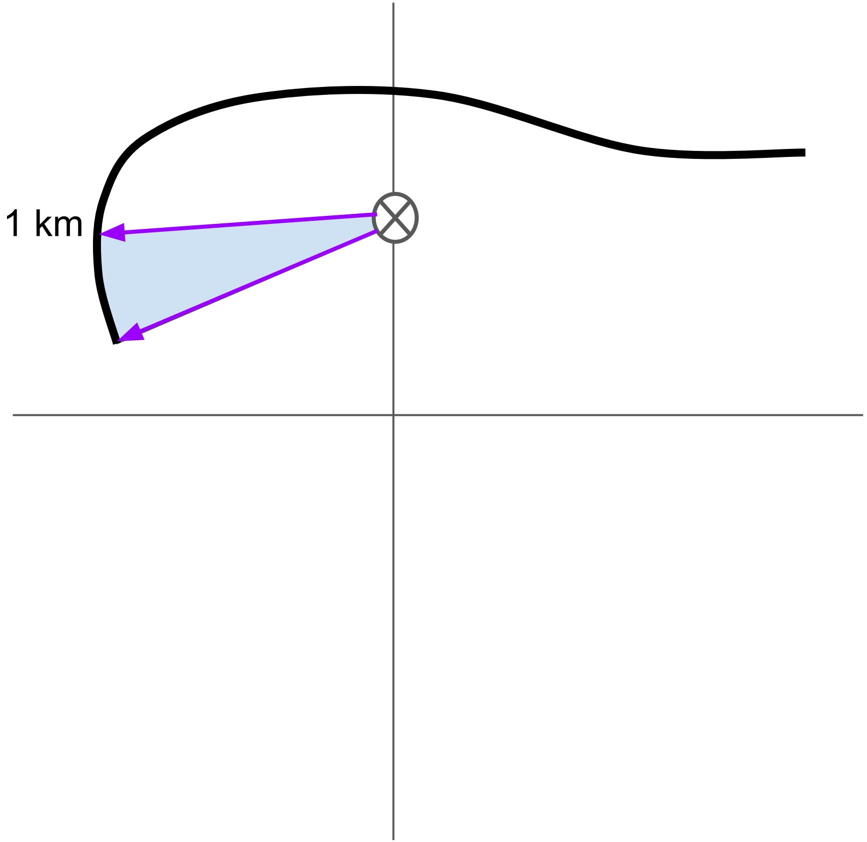
Where does SRH really matter?



Storm Relative Helicity (SRH)

Where does SRH really matter?

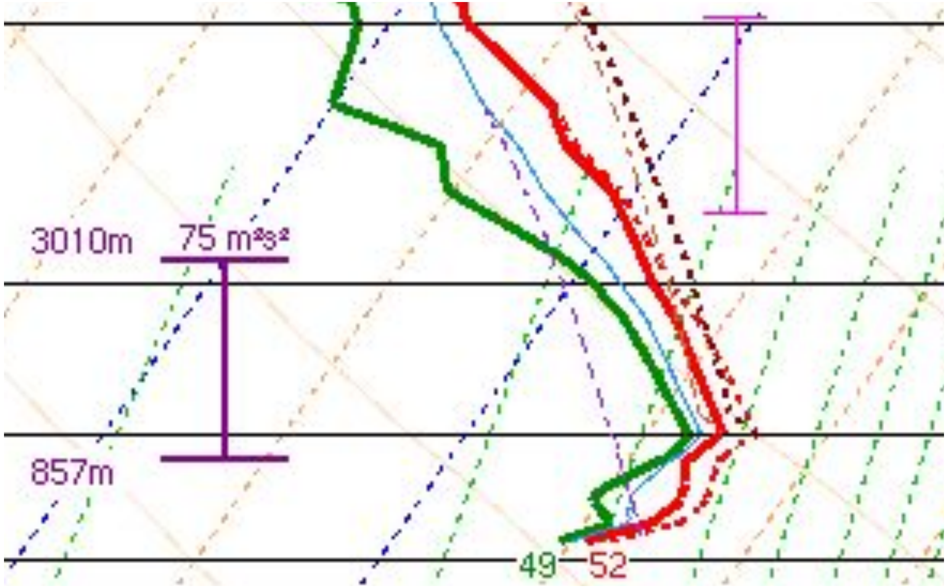
SRH in the lowest kilometer is most relevant for mesocyclogenesis

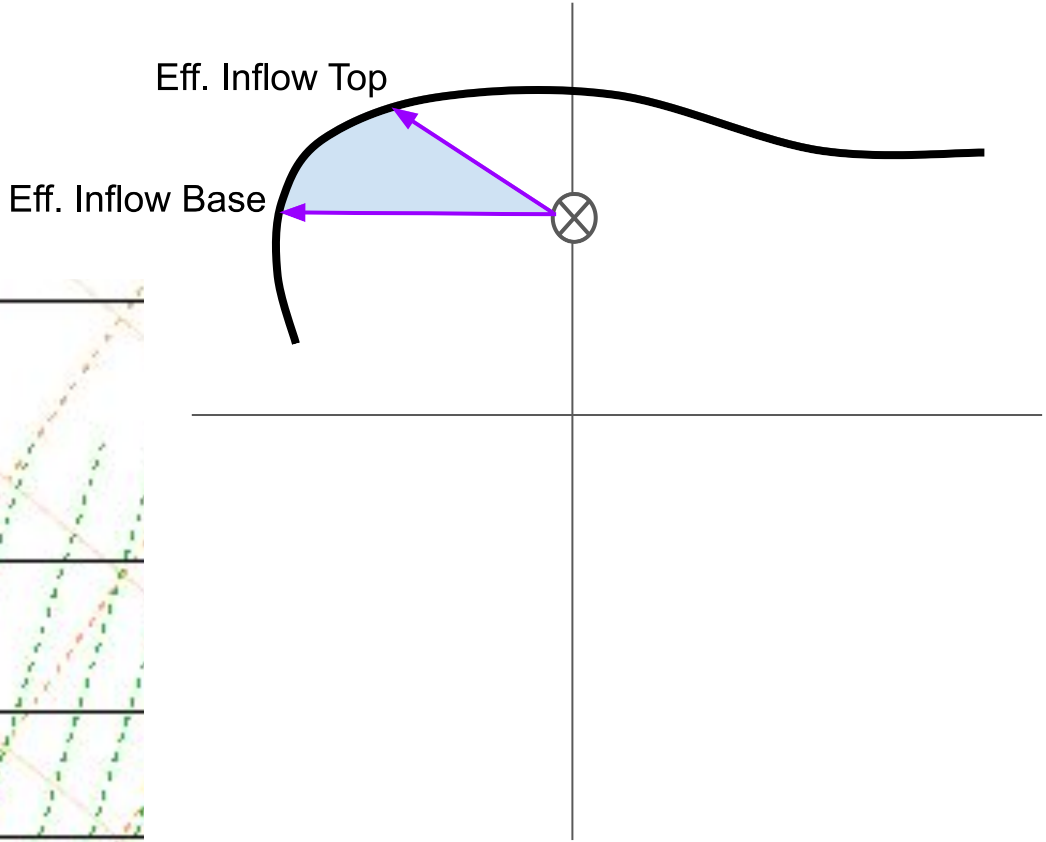


Storm Relative Helicity (SRH)

Where does SRH really matter?

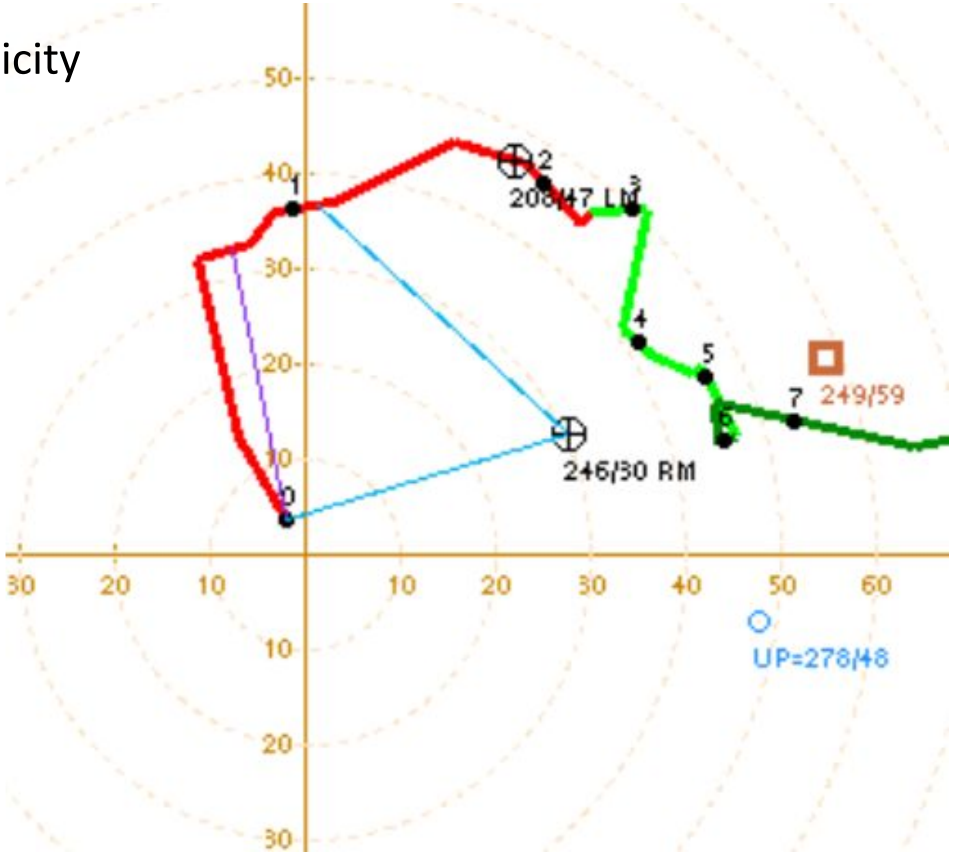
Effective SRH is necessary when dealing with “elevated” storms





Storm Relative Helicity (SRH)

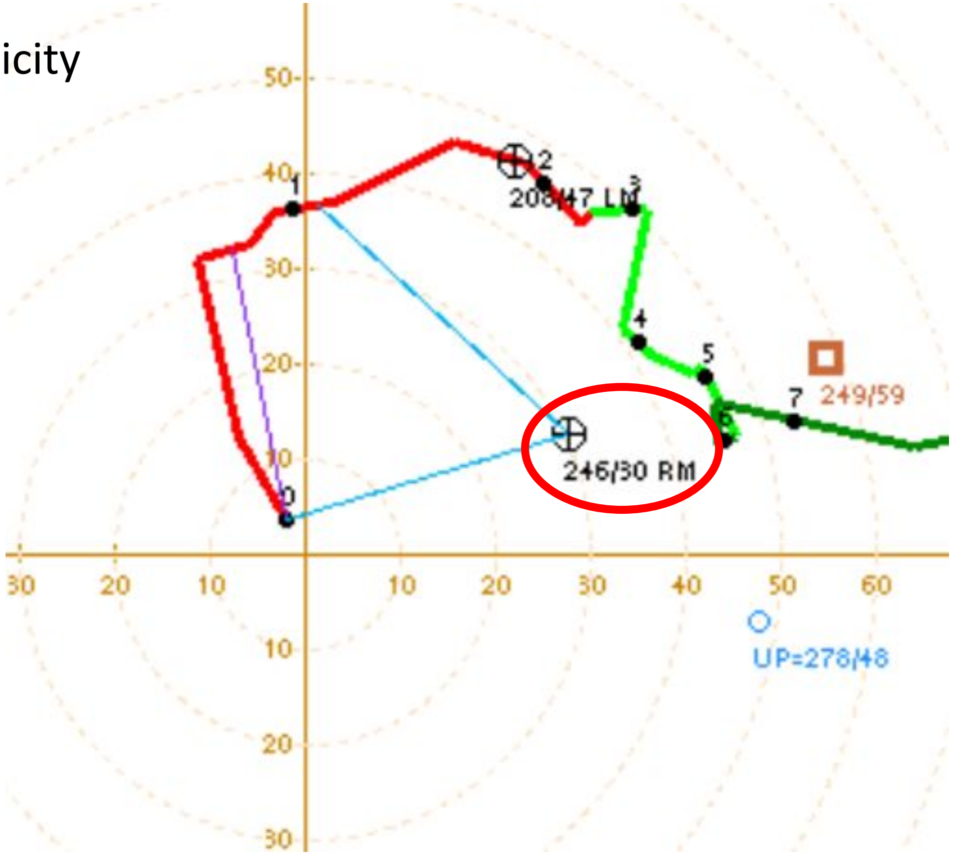
Remember, *all measures* of streamwise vorticity (including SRH) depend on storm motion.



Storm Relative Helicity (SRH)

Remember, *all measures* of streamwise vorticity (including SRH) depend on storm motion.

In fact, most calculations of SRH use Bunkers Right Storm Motion

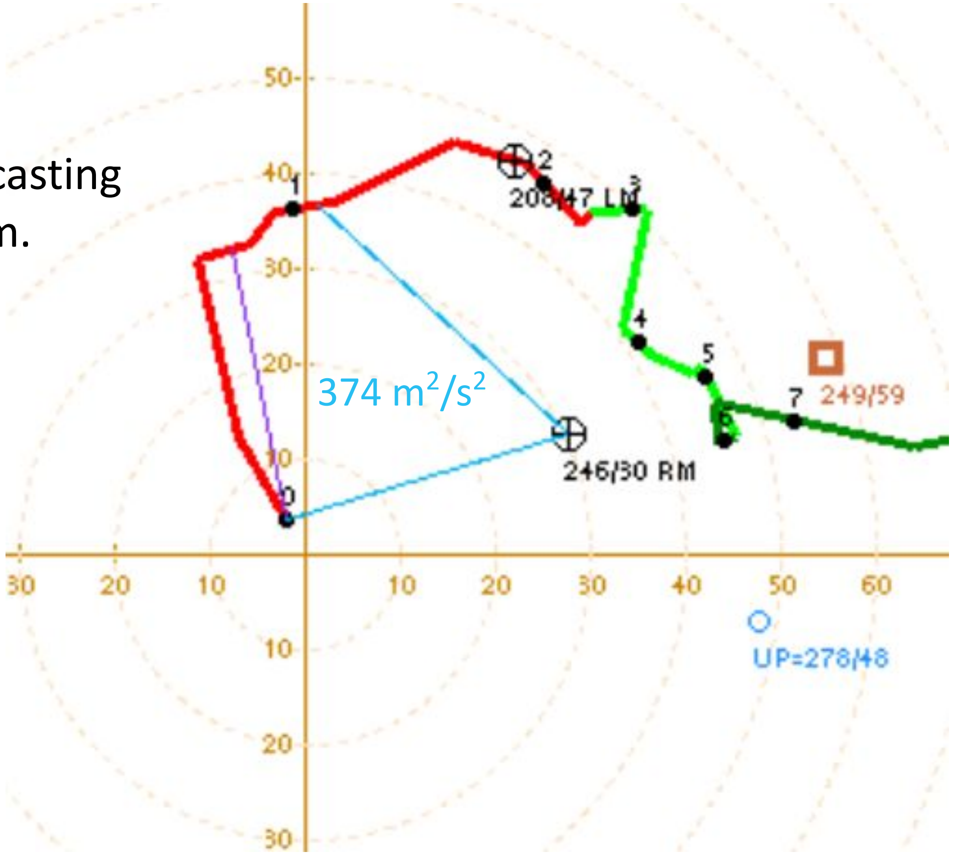


Storm Relative Helicity (SRH)

What about this scenario?

There is lots of 0-1 km SRH, and you're forecasting a slow, southward-moving convective system. Are embedded tornadoes possible?

a. Yes, 374 m^2/s^2 is a lot of SRH
b. Be careful, use the right storm motion



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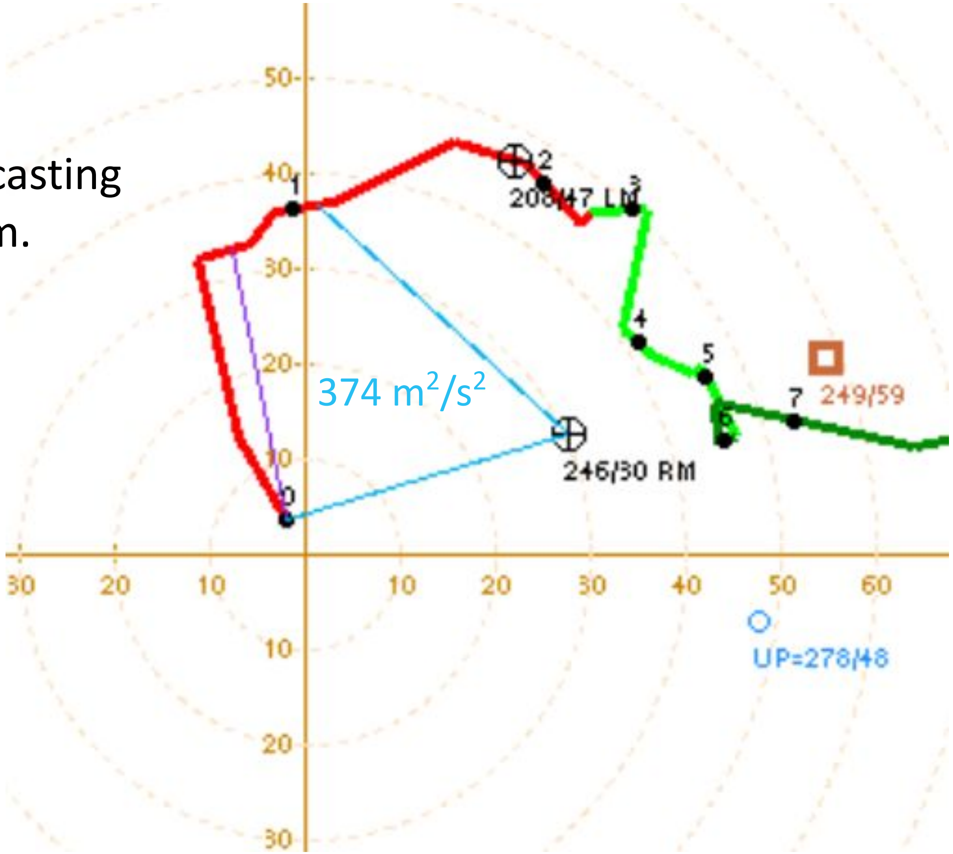
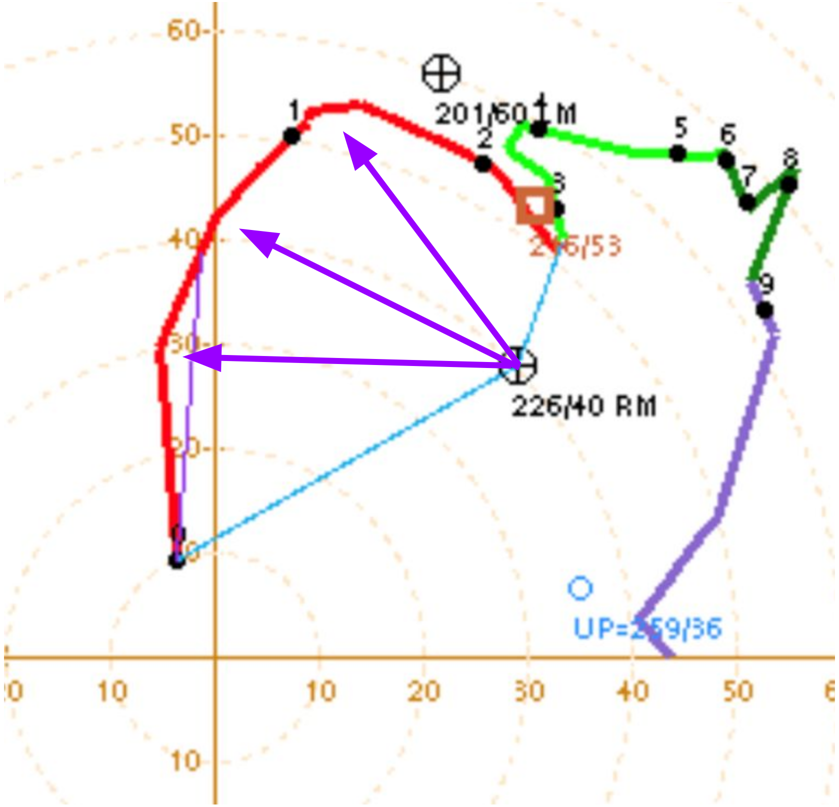
Good choice.



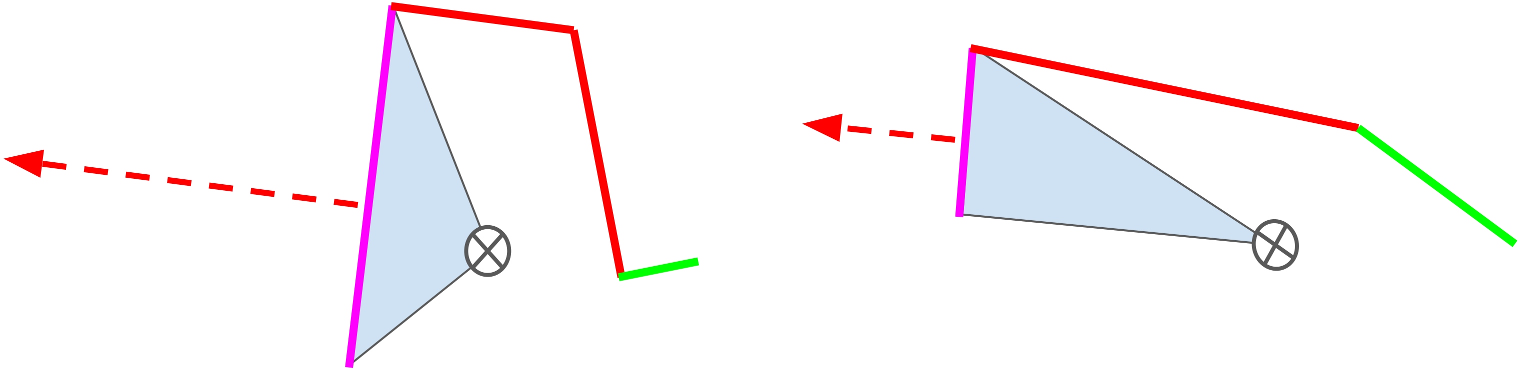
Storm Relative Helicity (SRH)

Also keep in mind, SRH is *not just* the streamwise vorticity, but also the strength of the *storm-relative winds*!



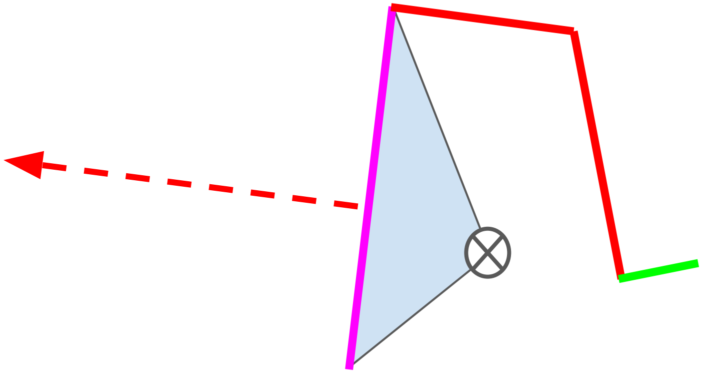
Storm Relative Helicity (SRH)

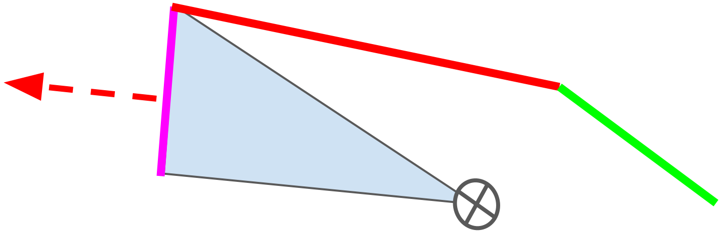
So, despite having equal SRH, two hodographs can have *different* magnitudes of streamwise vorticity.



Storm Relative Helicity (SRH)

Which hodograph would you expect to be
most conducive to strong low-level mesocyclones?





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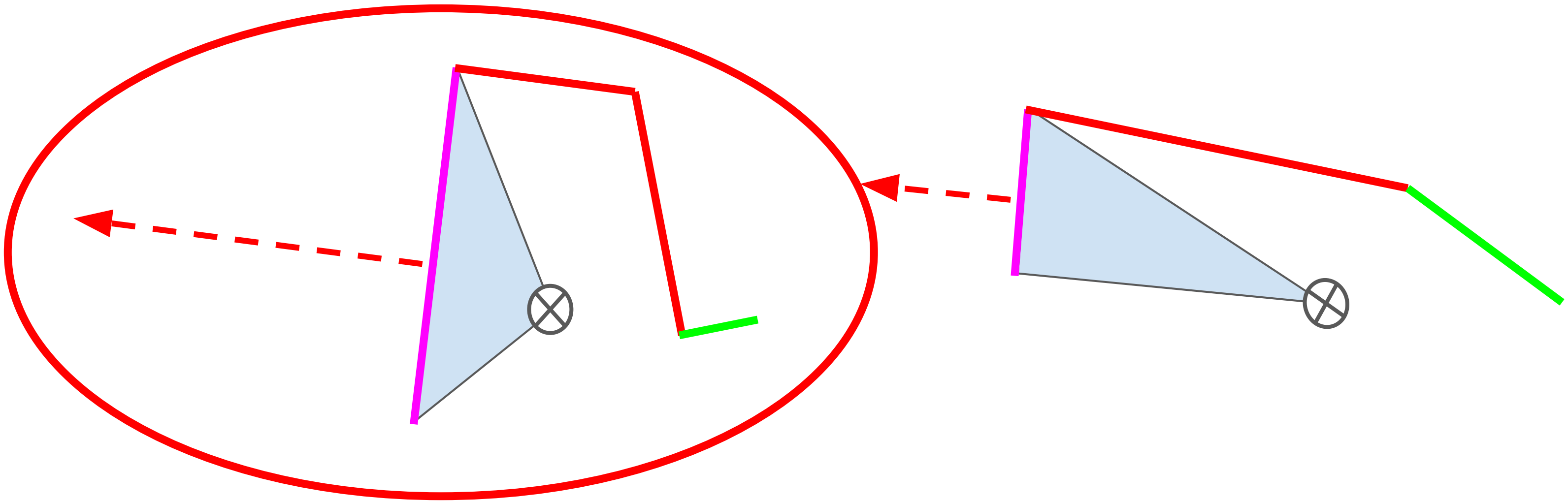
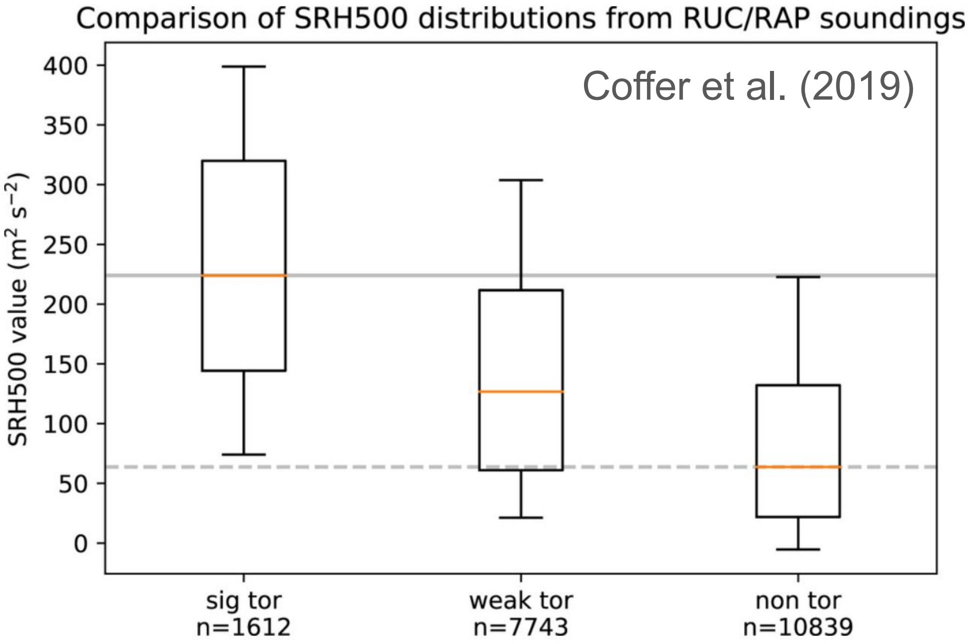


That's right! Streamwise vorticity and inflow strength both contribute to SRH

Storm Relative Helicity (SRH)

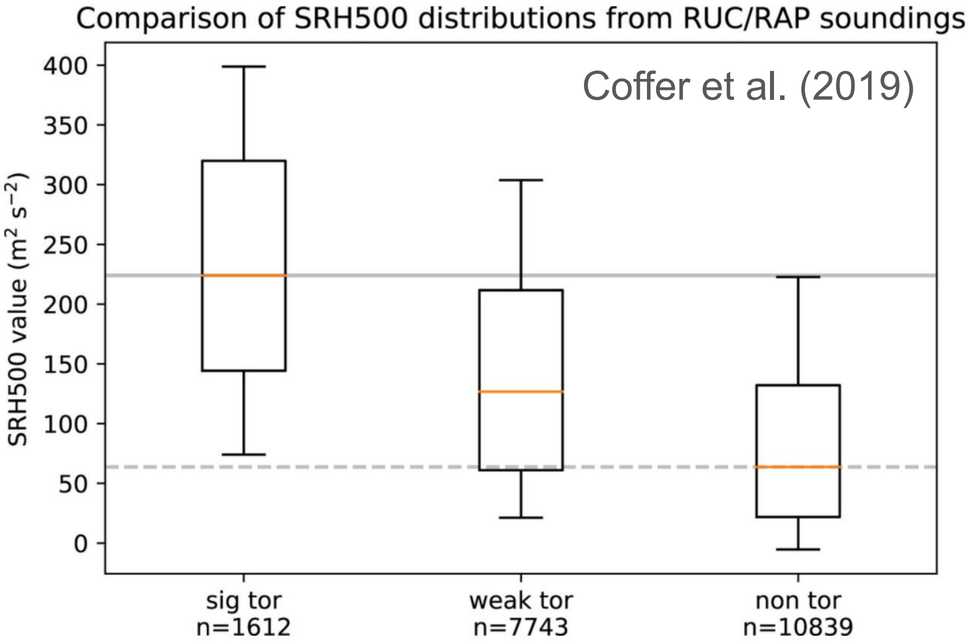
SRH is a useful and convenient parameter to assess the potential for mesocyclones and tornadoes



Storm Relative Helicity (SRH)

SRH is a useful and convenient parameter to assess the potential for mesocyclones and tornadoes

Just keep in mind that streamwise vorticity and inflow strength can affect storms in different ways!



Streamwise Vorticity Summary

1. The streamwiseness of vorticity can affect how quickly an updraft rotates

2. The magnitude of streamwise vorticity can affect how strong and persistent a mesocyclone can become

3. Storm-Relative Helicity (SRH) is an estimate of streamwise vorticity

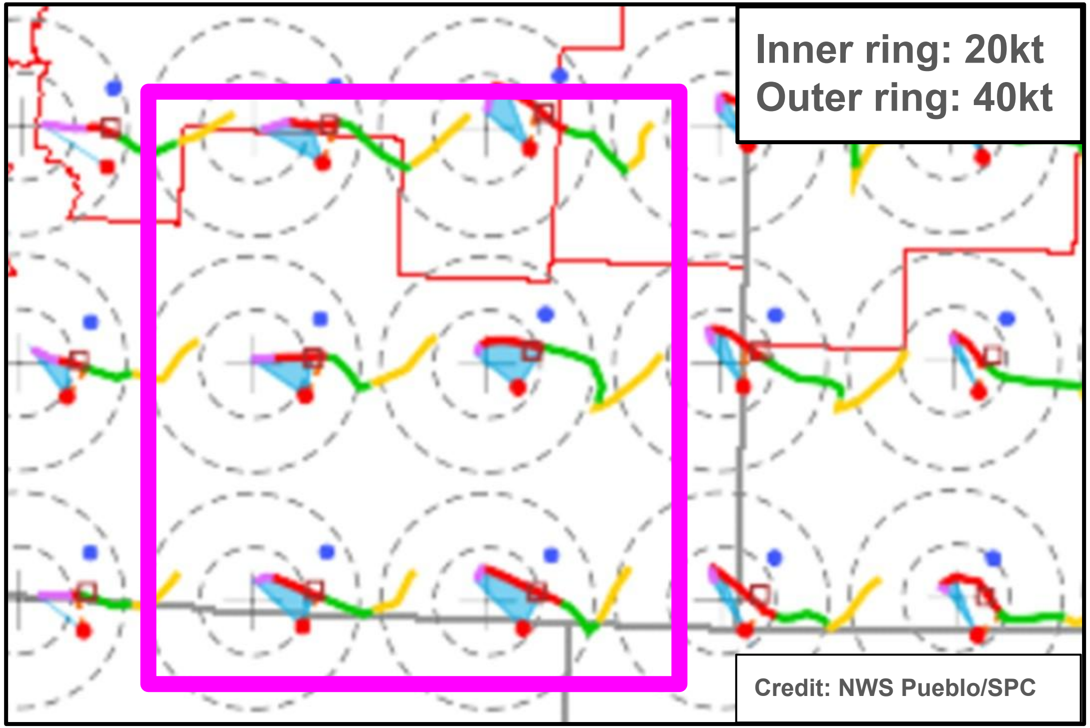
Case Study!

2100z: Ample buoyancy exists over your CWA, and storms are beginning to initiate. Looking at the hodograph map, what is *most likely* from initial activity?

a. Weak multicells (wind)

b. Splitting supercells (hail+wind)

c. Strong, right-moving supercells (tor+hail+wind)



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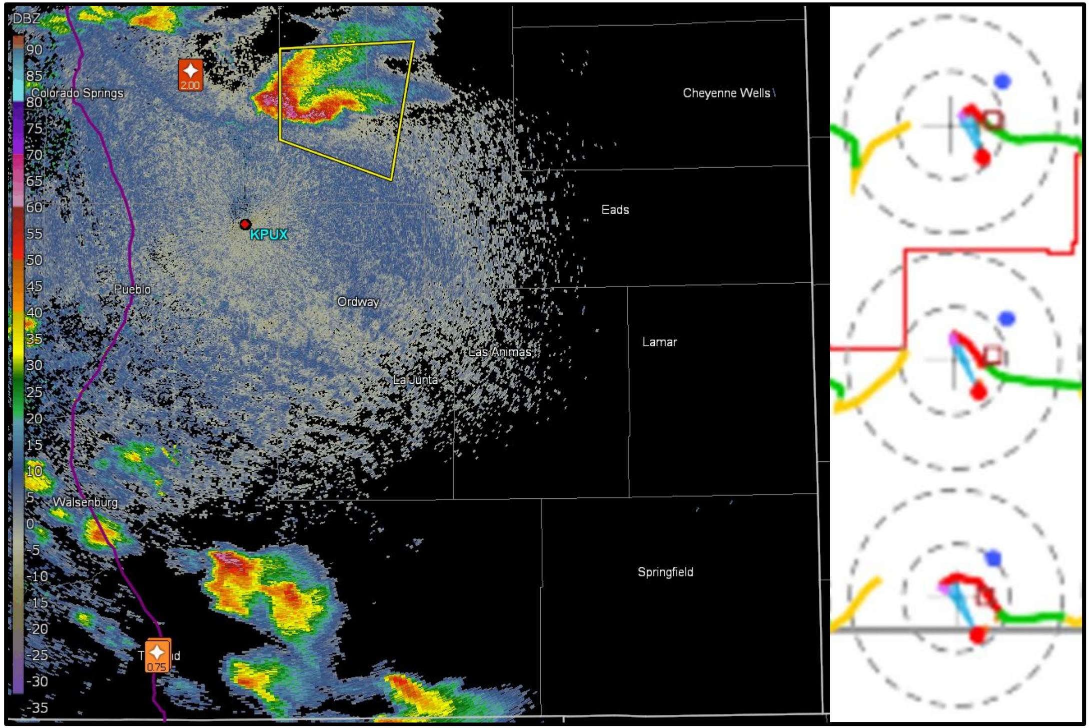


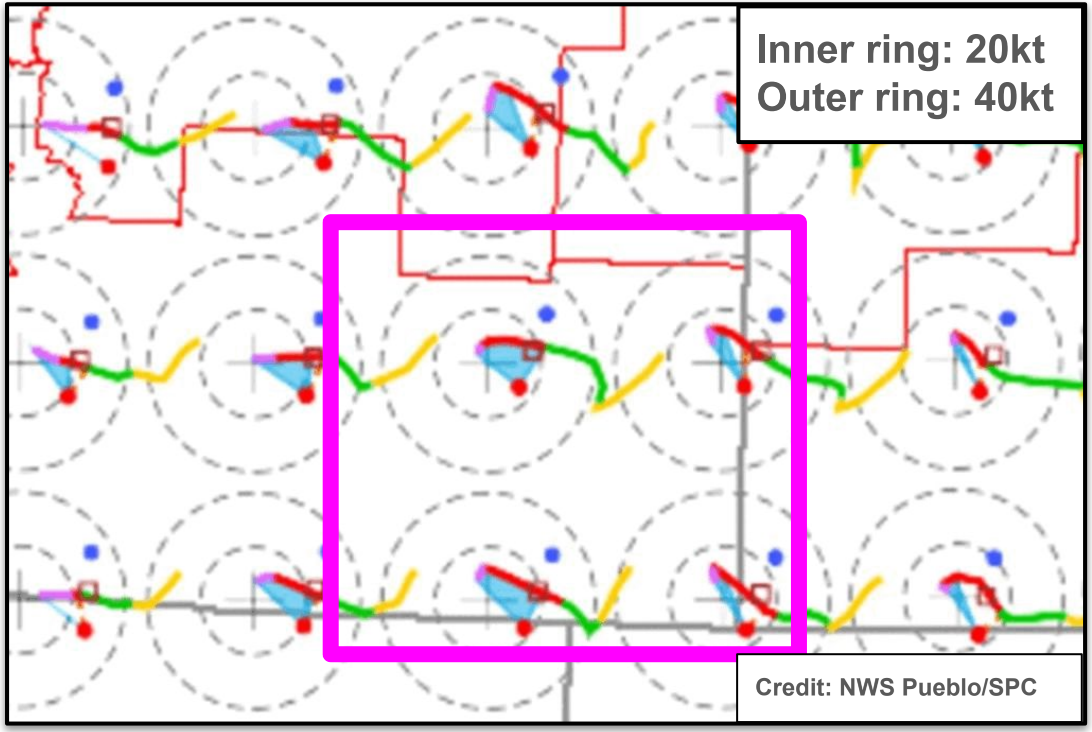
Case Study!

2300z: Now, you examine forecast hodographs.
What should you expect over the next couple hours?

a. Storms continue to split, and grow upscale (wind)

b. Left-movers become dominant (hail+wind)

c. Right-movers become dominant (tor+hail+wind)



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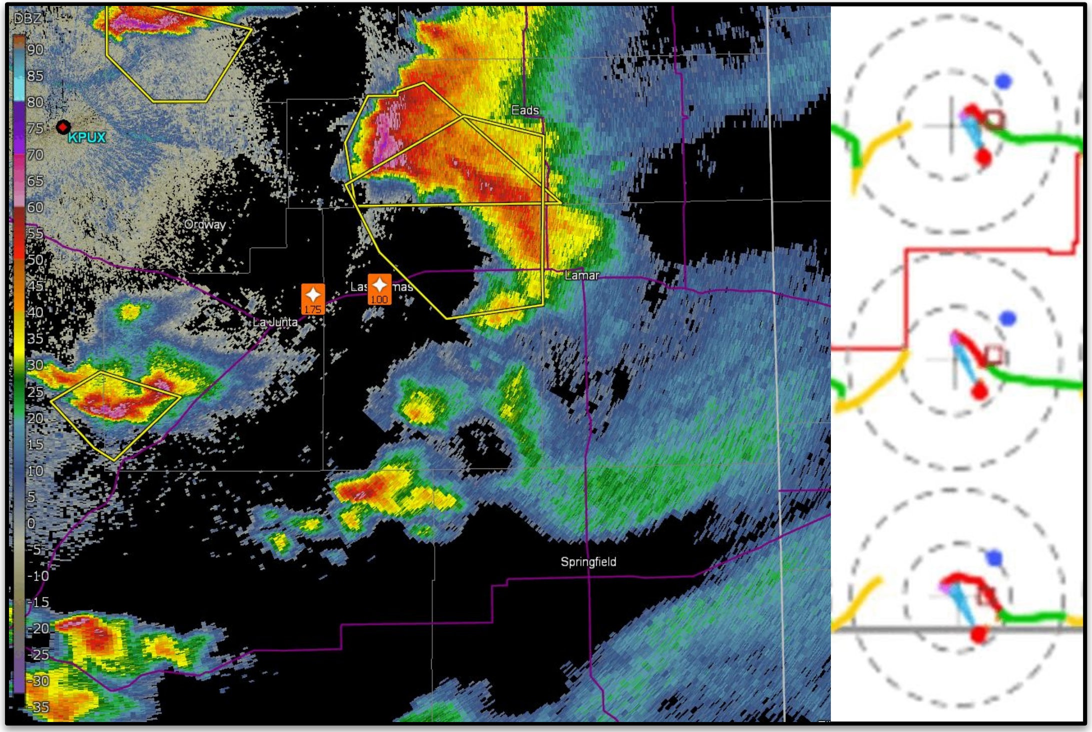


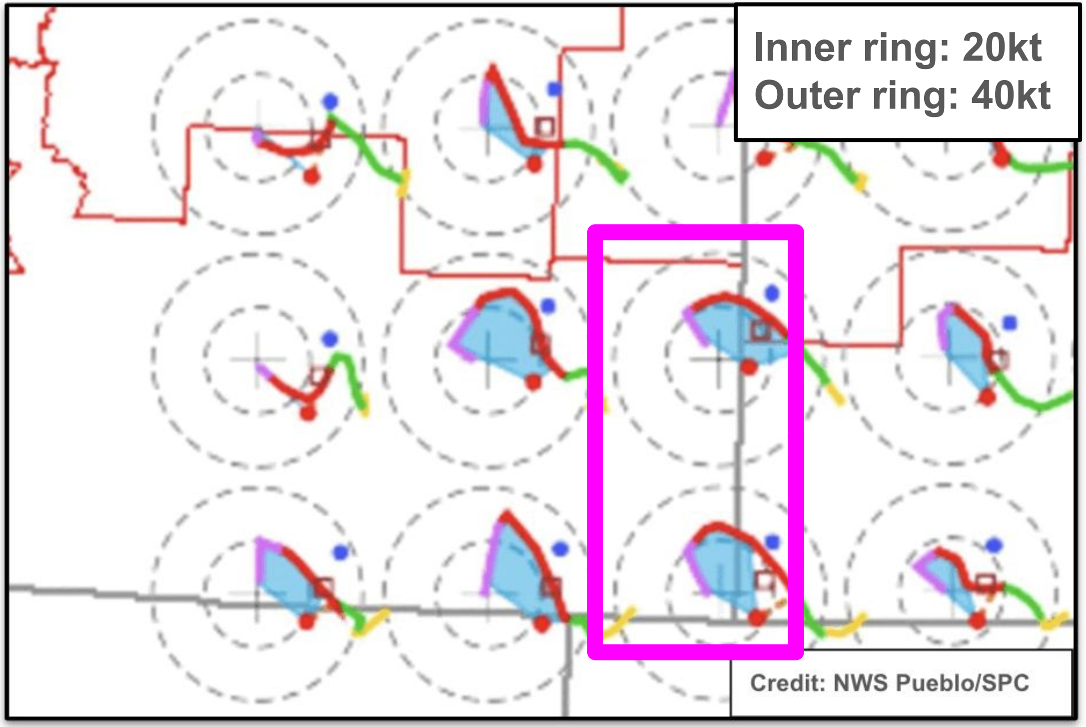
Case Study!

0000z: The cap is setting in, and CIN is greater than -200 J/kg in some locations! What do you think will happen next?

a. All storms should dissipate. That's a lot of CIN!

b. Some storms will dissipate, but supercells can persist

c. All storms should persist



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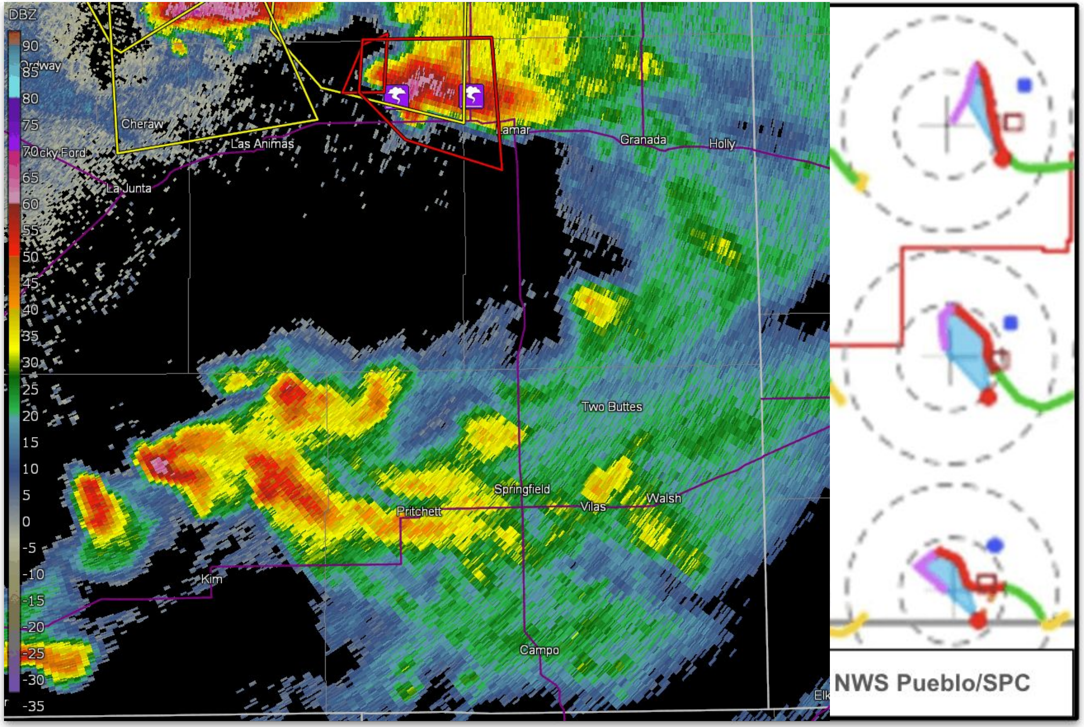
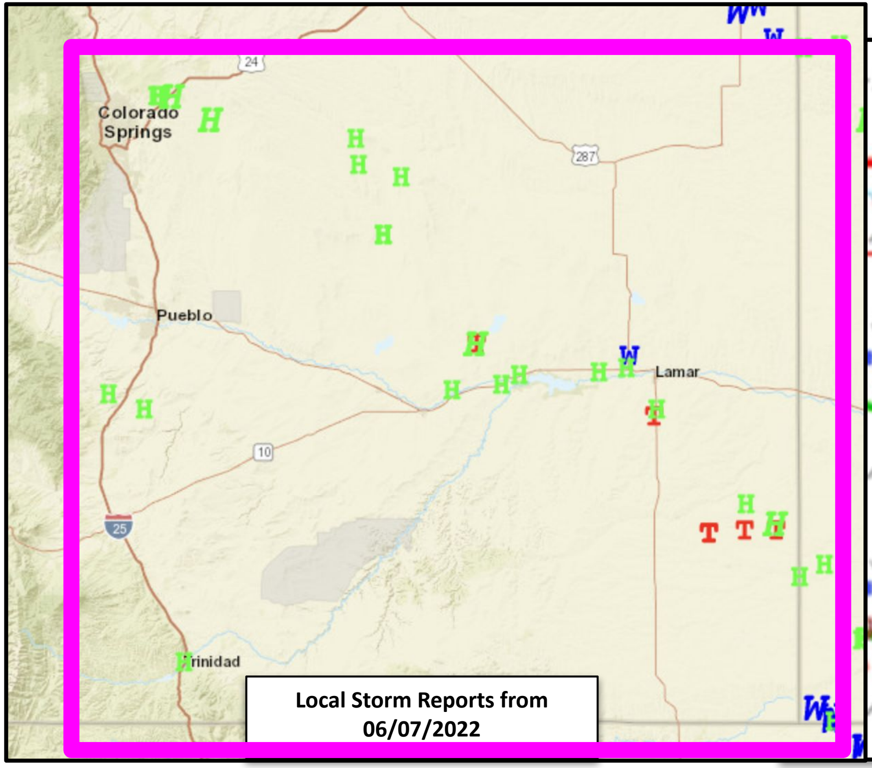
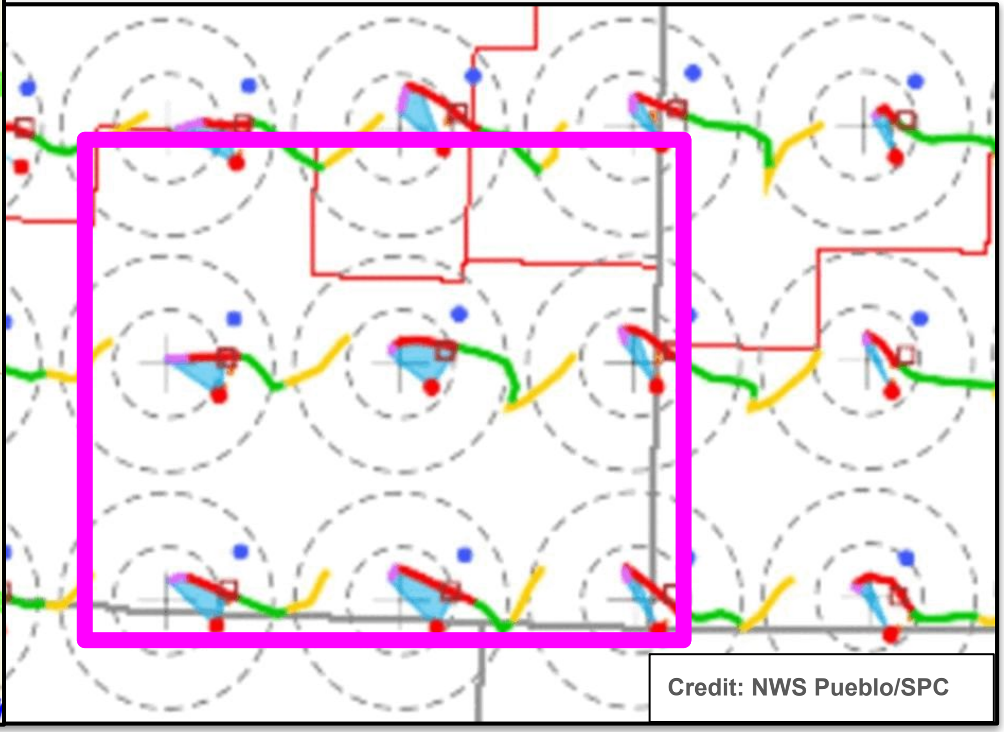
Good call!



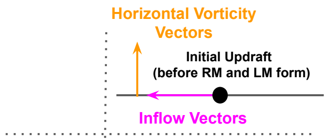
Case Study!

Summary





Straight Hodograph

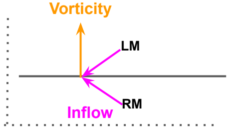


When an initial updraft forms…

1. Purely *crosswise vorticity* (no SRH) for initial updraft.

2. Initial updraft not rotating because none of the inflow is aligned with the vorticity (inflow vectors normal to vorticity vectors).

3. The initial updraft draws the horizontal vorticity upward, resulting in two new updrafts: one to the right of the shear vector, the other to the left -- see below.



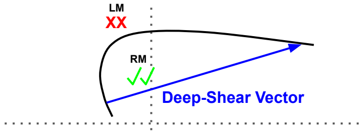
After initial updraft tilts vorticity into the vertical, creating two new updrafts…

1. New updrafts to the left and right of deep-shear vector gain rotation as they are now aligned with the vorticity **tilted into the vertical**. There is also an added contribution to updraft rotation from the now *non-zero SRH* (inflow vectors and vorticity vectors have a parallel/antiparallel component).

2. Both updrafts are neither enhanced nor suppressed with this hodograph shape, with mirror-image cell splitting.

3. The survival of both left and right members can introduce higher potential for cell interactions, fostering the potential for upscale growth.

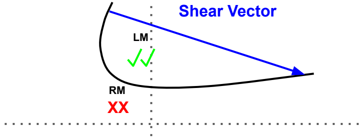
Single Concavity Hodograph



1. Within a layer containing hodograph concavity, dynamic lifting/suppression occurs on the concave/convex side of the initial updraft, relative to the deep shear vector (the vector can be transposed anywhere on the coordinate system).

2. The concave side of this hodograph favors dynamic lifting to the right of the initial updraft relative to the shear vector -- i.e., dominant right-mover (following Bunkers motion). The convex side of this hodograph yields left-of-shear dynamic suppression -- i.e., vanishing left-mover.

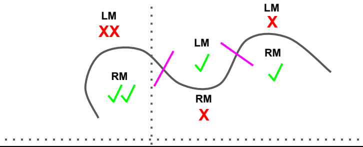
3. Also, area swept out between inflow vectors and the hodograph (i.e., SRH) increases with the hodograph bow, resulting in much more efficient mesocyclogenesis.



1. The concave side of this hodograph favors left-of-shear dynamic lifting -- i.e., dominant left-mover (following Bunkers motion). The convex side of this hodograph yields right-of-shear dynamic suppression -- i.e., vanishing right-mover.

2. Negative SRH given counter-clockwise hodograph bow favors efficient meso-anticyclone-enhancement for left-mover.

Multi-Inflection Hodograph



1. Both right and left members are enhanced **and** suppressed at alternating levels in the vertical -- separated by / inflection points.

2. Lift ✓ for **right member** in lower and upper levels of hodograph, suppression X for **right member** at middle levels.

3. Lift ✓ for **left member** in middle levels of hodograph, suppression X for **left member** at lower and upper levels.

4. SRH beneath the second inflection is reduced by the hodograph concavity alternation, and weak storm-relative flow between the first and second inflections results in updraft seeding and precipitation drag suppressing the updraft.

5. Both members of the split survive in a degraded manner, sometimes yielding convective clustering/upscale growth.

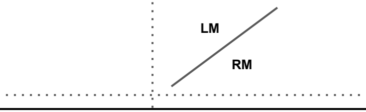
6. The larger the looping action, the more induced vertical motion.

✓✓ means more lift than ✓

XX means more suppression than X

Note: **RM and LM as marked on hodographs do *not* indicate a storm motion vector (use Bunkers supercell motion). However, RM and LM make reference to the updraft members on either side of the deep-shear vector (right and left, respectively) that potentially experience additional dynamic lifting/subsidence, specifically owing to the updraft-in-shear effect.**

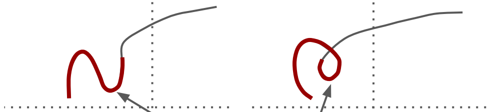
Additional Examples



1. Unidirectional shear profile, though still a veering hodograph.

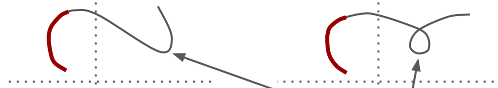
2. This hodograph favors splitting mirror-image cells, with no enhancement or suppression for either member.

3. This has less suppressive effects compared to a looping hodograph with multiple inflections.



1. For RM (as an example), suppressive effects from hodograph concavity alternations have greatest destructive effects on updrafts when they're **in the effective-inflow layer** (as above).

2. SRH is much reduced with this hodograph shape, in addition to the dynamic suppressive effects fostering upscale growth.



1. For RM (as an example), these concavity alternations will be much less detrimental on the updraft, as they are located well above **the effective-inflow layer**.

2. The source region (where updrafts get their start) is not disrupted by dynamic subsidence -- owing to the favorable single/dominant concavity seen in the lower and middle levels.