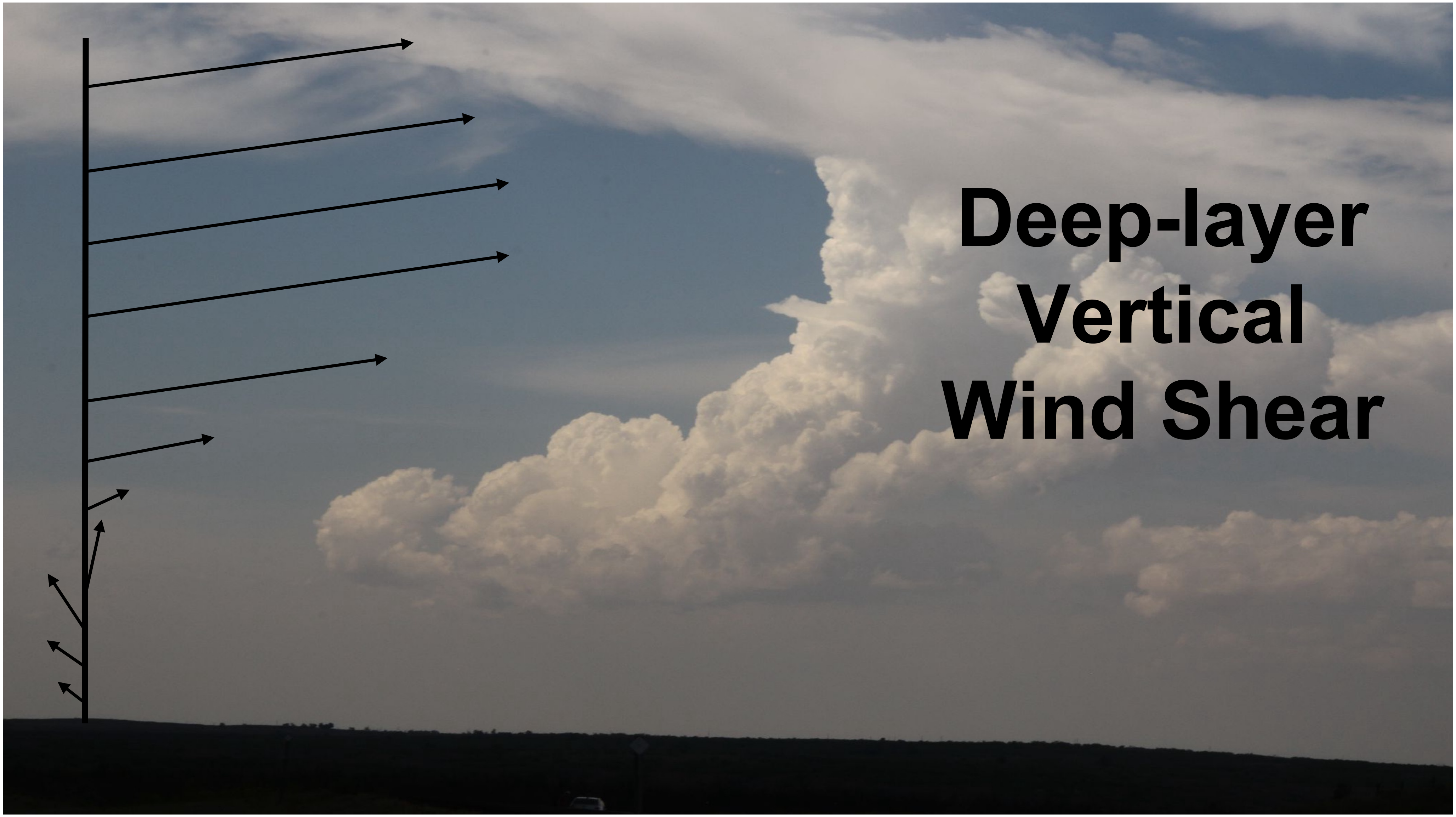

Deep-layer
Vertical
Wind Shear

# Deep-layer Vertical Wind Shear

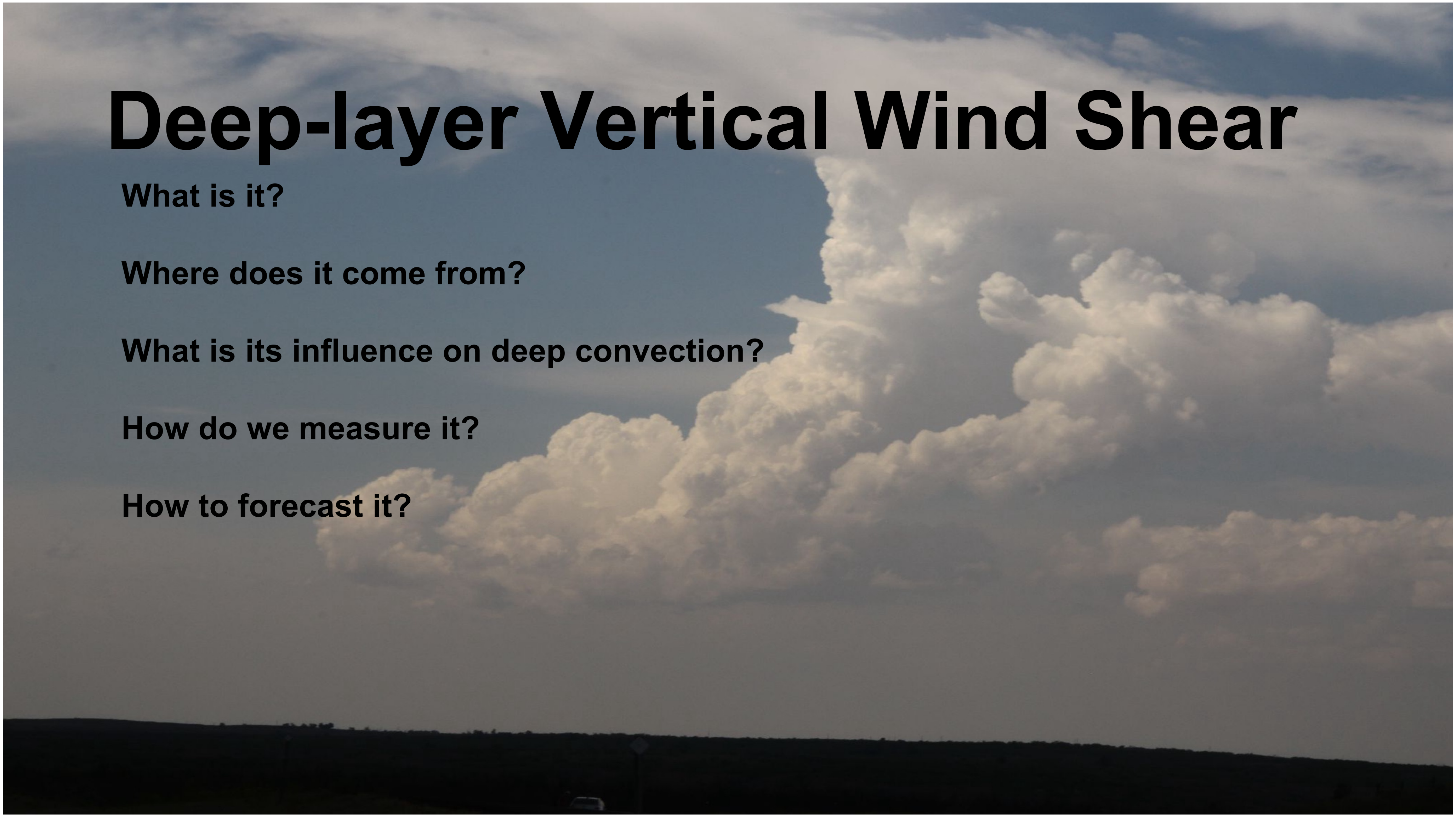
**What is it?**

**Where does it come from?**

**What is its influence on deep convection?**

**How do we measure it?**

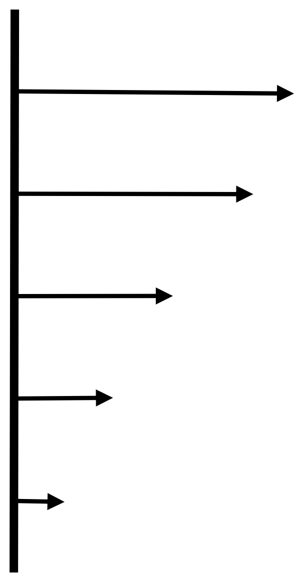
**How to forecast it?**



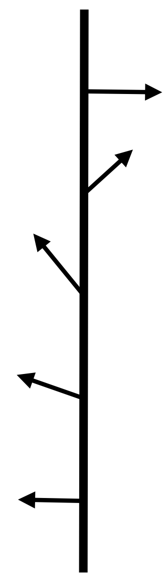
# Vertical Wind Shear **What is it?**

Defined as:
"The condition produced by a change in wind velocity (speed and/or direction) with height."
- AMS Glossary

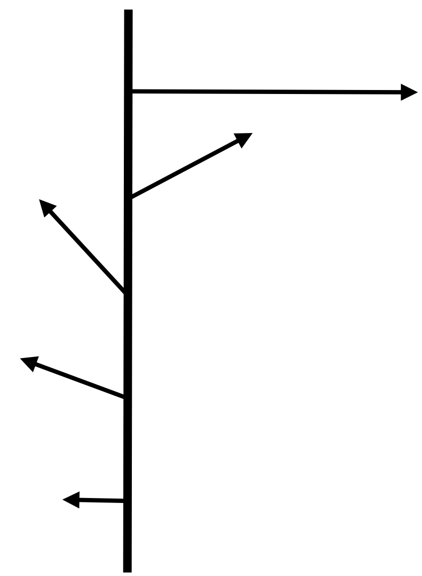
Speed Shear



Directional Shear



Combination of both
(most common)



# Vertical Wind Shear **Where does it come from?**

Primary contribution:
"Large-scale horizontal temperature gradients via the thermal-wind relation"
(M.R. 2010)

$$(1)\ u_g = -\frac{g}{f}\frac{\partial Z}{\partial y}$$ geostrophic wind

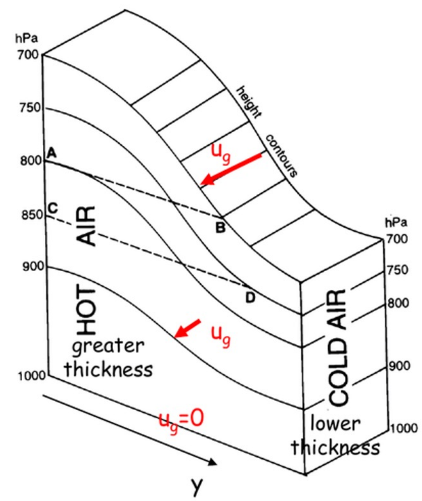
$$(2)\ \frac{\partial Z}{\partial p} = -\frac{RT}{gp}$$ hypsometric eqn

plug (2) into (1)

$$\frac{\partial u_g}{\partial p} = \frac{g}{f}\frac{\partial\left(RT/gp\right)}{\partial y} = \frac{R}{fp}\frac{\partial T}{\partial y}$$

finite difference expression:

$$\Delta u_g = \frac{R}{f}\frac{\Delta p}{p}\frac{\Delta \overline{T}}{\Delta y}$$ this is the thermal wind: an increase in wind with height due to a temperature gradient



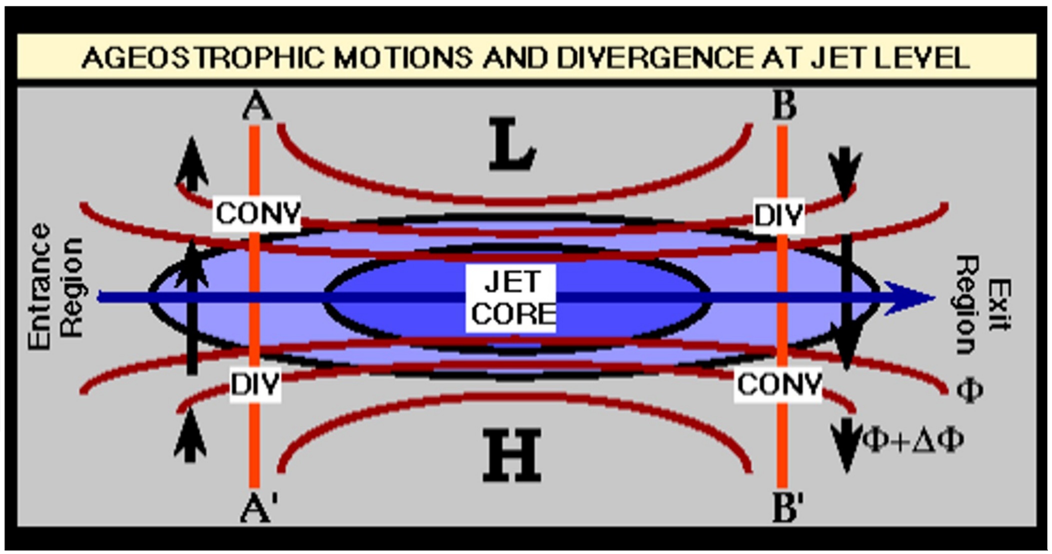

The thermal wind blows ccw around cold pools in the same way as the geostrophic wind blows ccw around lows. The thermal wind is proportional to the T gradient, while the geostrophic wind is proportional to the pressure (or height) gradient.

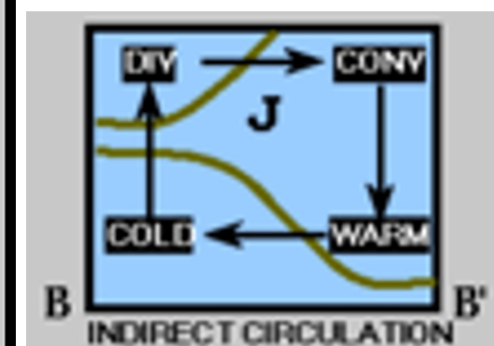
For additional reading: M.R. 2010 and Doswell 1991

# Vertical Wind Shear **Where does it come from?**

Secondary contributions:
Large accelerations of the horizontal wind due to large ageostropic winds
(think near jet streaks, areas of frontogenesis, and/or rapidly intensifying cyclones).


Erodes horizontal temperature gradient (weaker thermal wind)



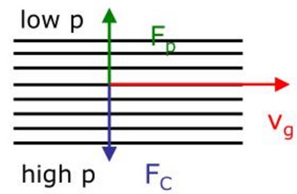

Enhances horizontal temperature gradient (stronger thermal wind!)

For additional reading: M.R. 2010 and Doswell 1991

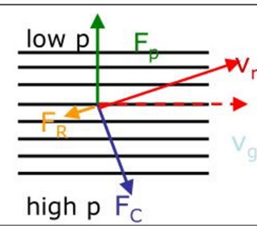
# Vertical Wind Shear **Where does it come from?**

Tertiary contributions: Boundary-layer friction, which may be present in the absence of large-scale baroclinicity (think Ekman Spiral).

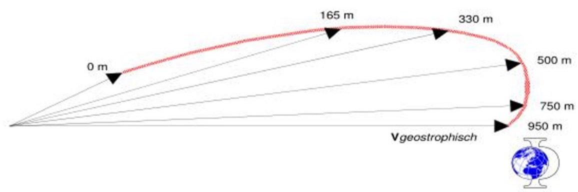
- In the free atmosphere (free of friction), the wind is geostrophic (i.e., parallel to isobars due to the balance between pressure gradient and Coriolis force)




- Close to the surface, friction will cause a deviation of the wind direction from geostrophic solution (flow from high to low pressure)

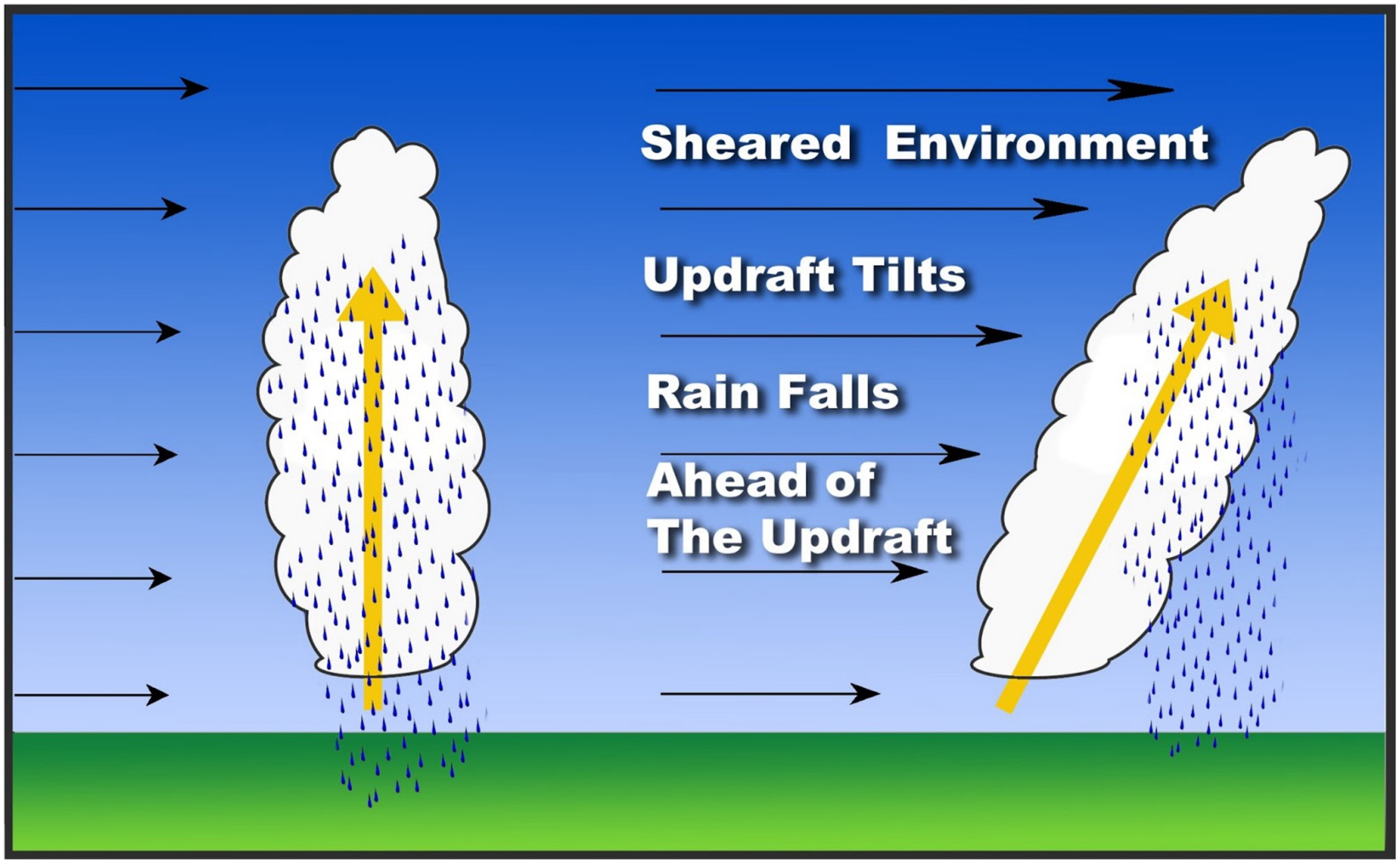



- Consequences:
  - wind speed increases with altitude
  - wind direction canges with altitude in form of a spiral, the so-called **Ekman Spiral**




For additional reading: M.R. 2010 and Doswell 1991

# Vertical Wind Shear Influence on convection?



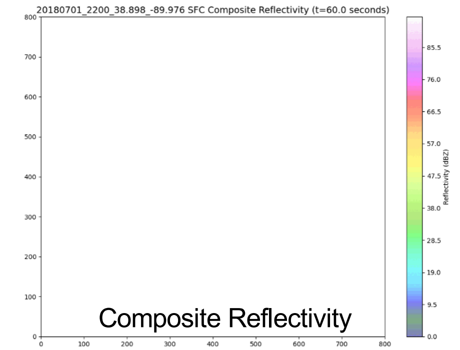

The role of deep-layer vertical wind shear is to displace negatively buoyant air and hydrometeors away from the updraft region.

This favors storm longevity and (perhaps more importantly) is the origin of mesocyclone rotation.

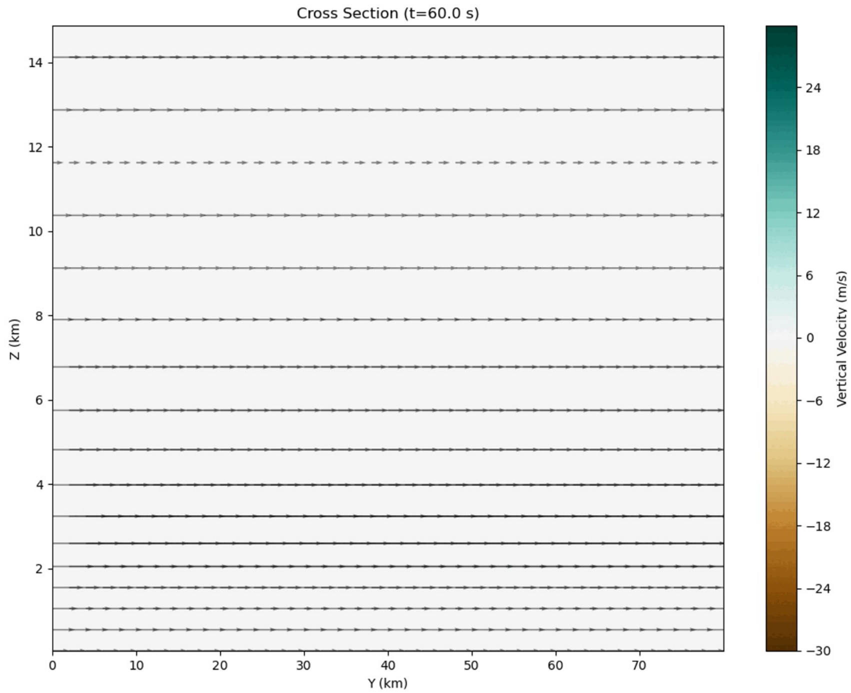
(Much more on that idea later in the class!)

# Vertical Wind Shear

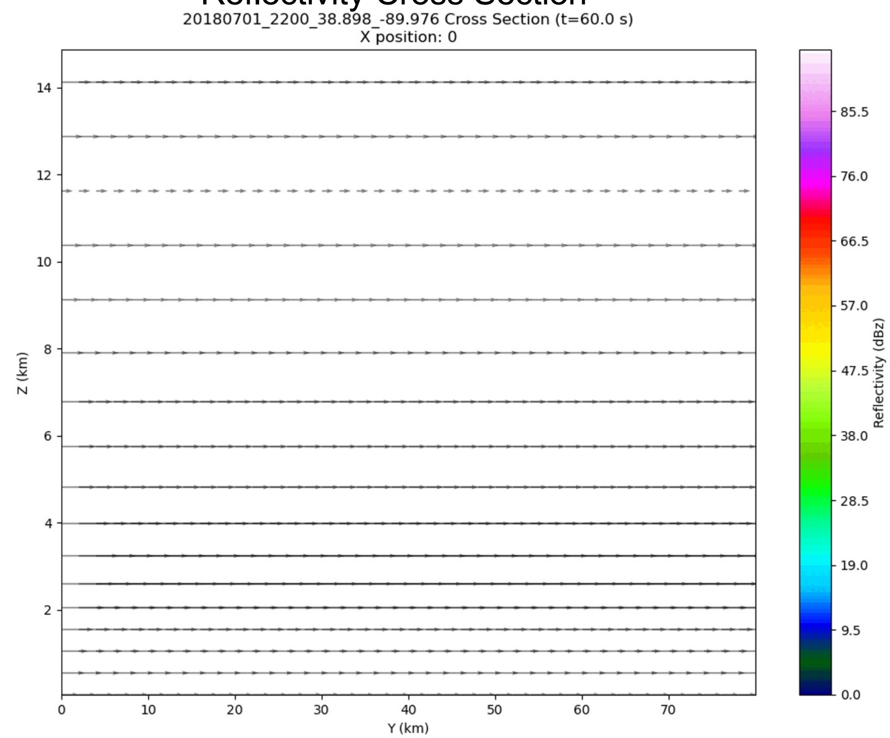
Simulation of a T-storm in a low-shear environment.
(Note the single updraft pulse followed by a quick collapse.)




Vertical Velocity Cross Section

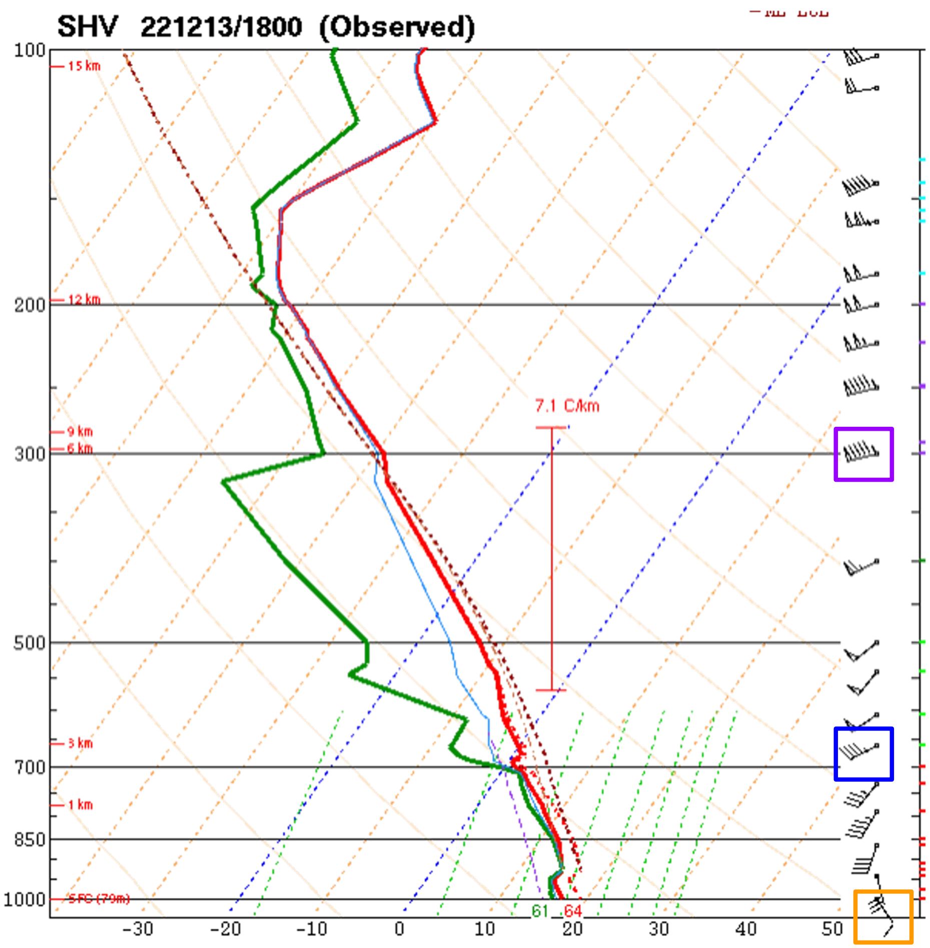



Reflectivity Cross Section



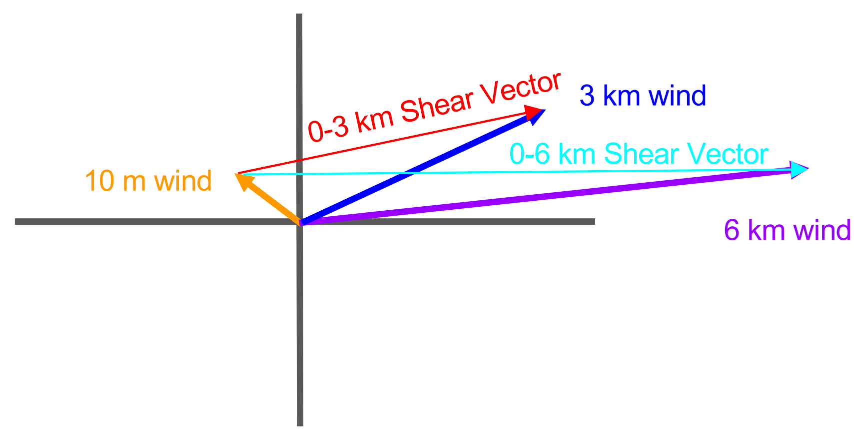
# Vertical Wind Shear

## How do we measure it?




Bulk Wind Difference:

The magnitude of the vector difference between the winds at two different levels.



# Vertical Wind Shear **How do we measure it?**

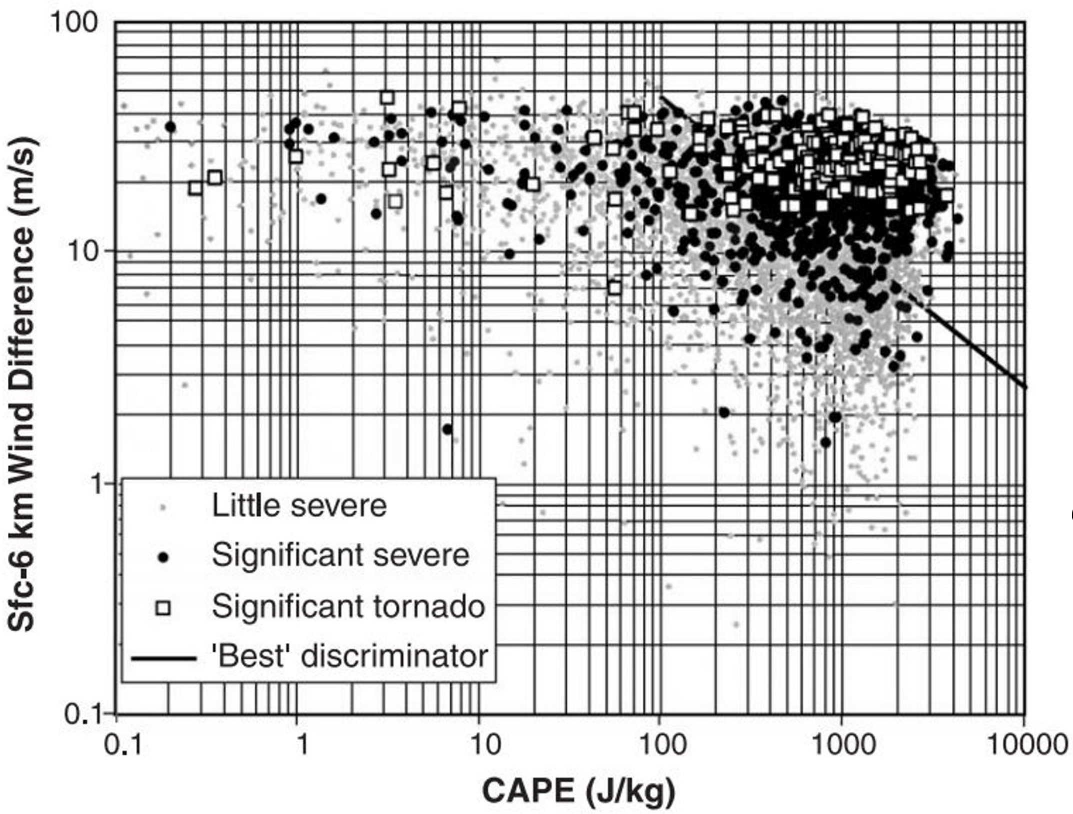



Fig. 1 from Brooks et al. 2003

Surface to 6 km BWD is a very common metric to gauge the magnitude of deep-layer wind shear.

Many studies have shown that around <u>10 m/s (~20 knots)</u> is a reasonable discriminator between severe and non-severe environments. (although not perfect!)

Other common BWD metrics used in convective forecasting include:

0-1 km BWD
0-3 km BWD
0-8 km BWD

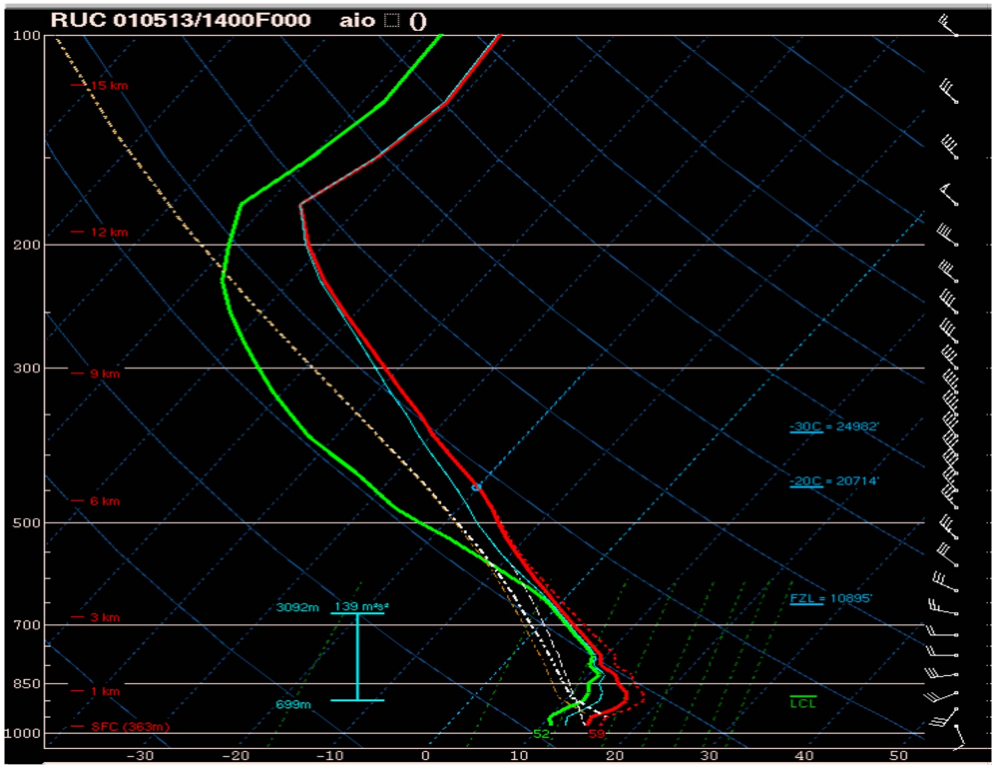
# Vertical Wind Shear How do we measure it?

0-6 km Bulk Wind Difference Pros:

- Quick estimate of whether or not the environment will support downdraft displacement from the updraft region (i.e. will the environment support storm venting).
- Very easy to calculate and interpret.

0-6 km Bulk Wind Difference Cons:

- Does not contain information about the “shape” of the wind profile (i.e. there is no information about the hodograph).
- **May not accurately represent the layer of the atmosphere contributing to deep convection.**



# Vertical Wind Shear

## How do we measure it?

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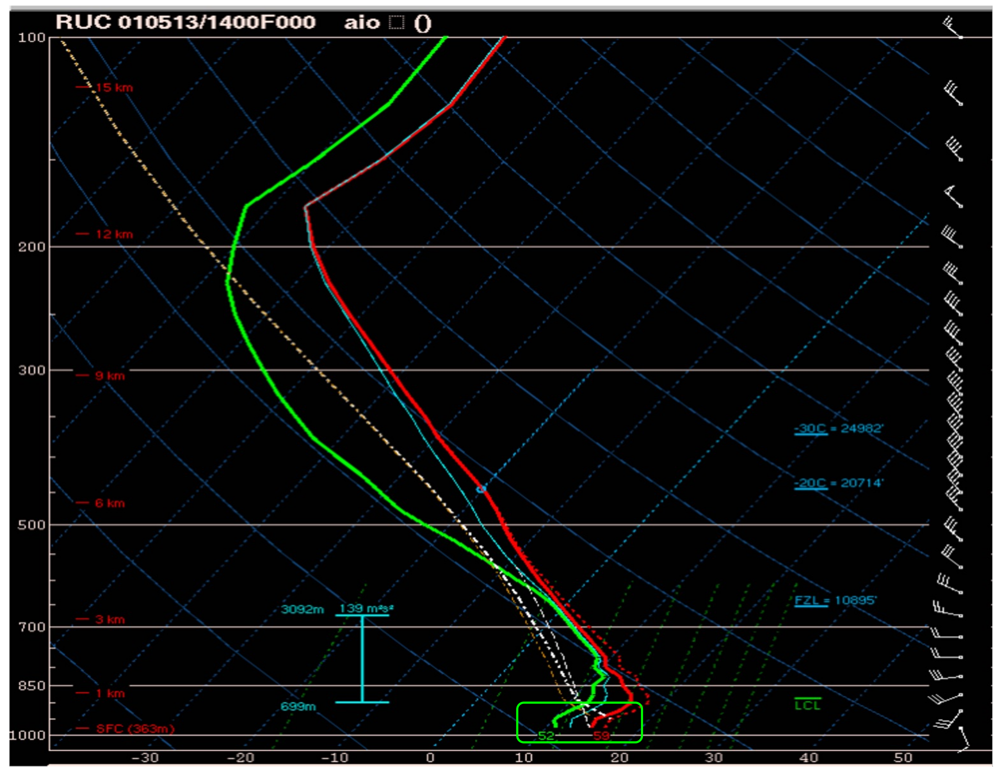
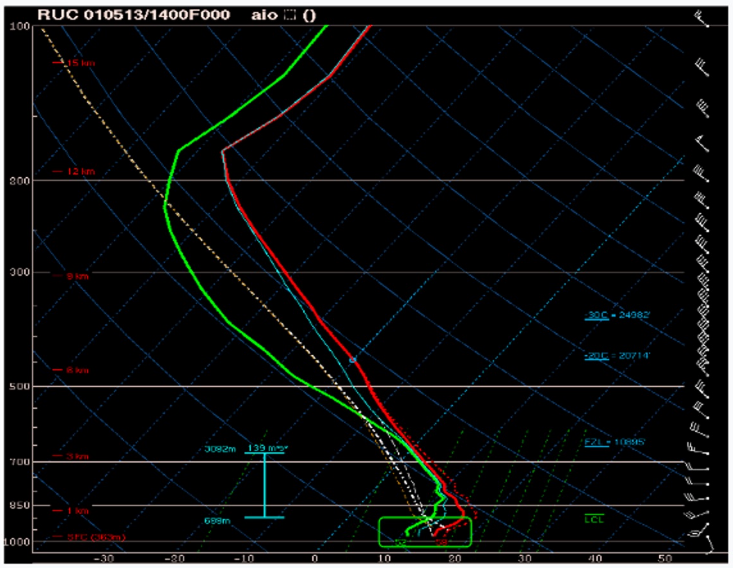



Is the surface parcel contributing to the updraft?

When poll is active, respond at **pollev.com/severeclass641**

# Is the surface parcel is contributing to the updraft?




Yes

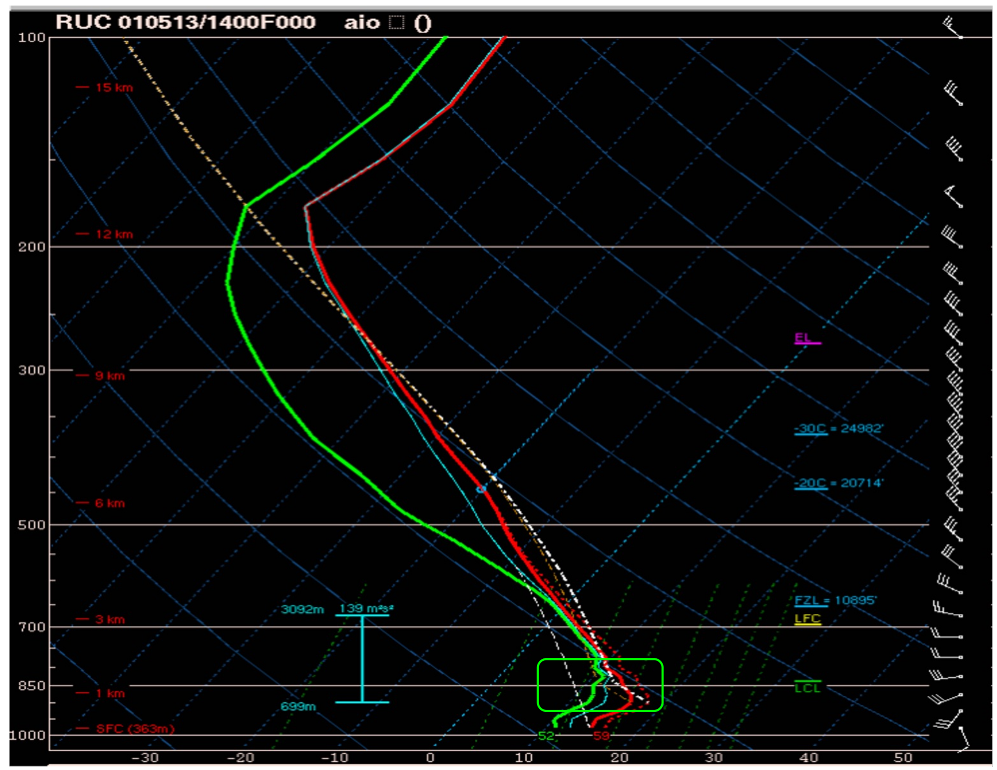
No

Powered by Poll Everywhere

# Vertical Wind Shear How do we measure it?

**0-6 km BWD may not accurately represent the layer of the atmosphere contributing to deep convection.**

How about this parcel (green)?
Probably!

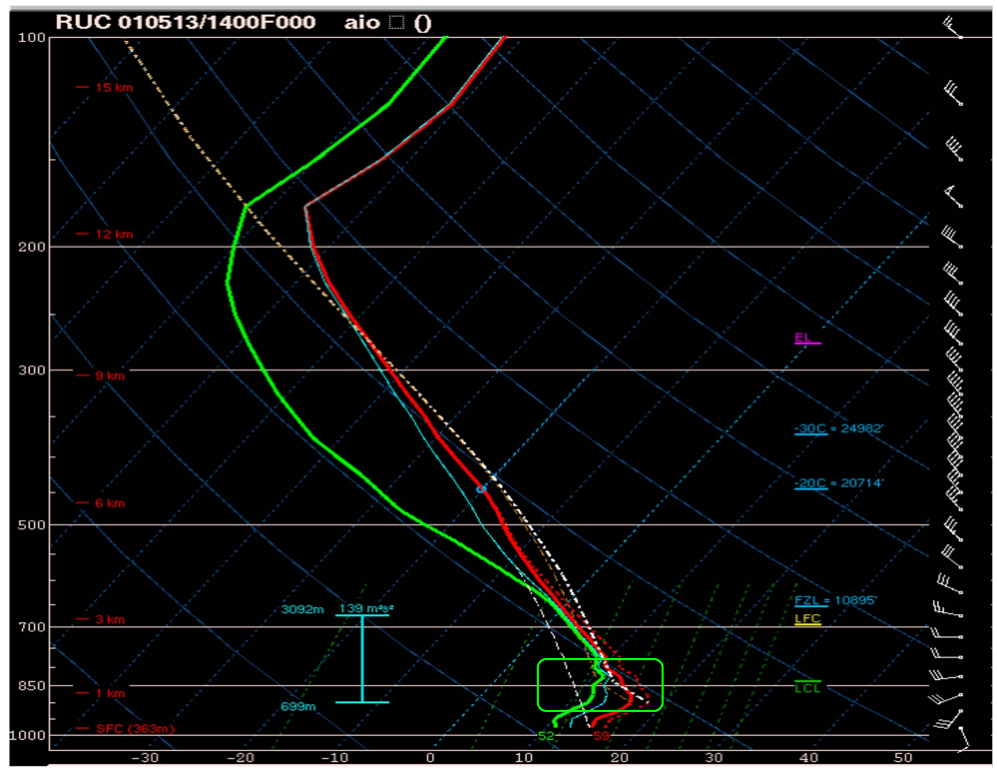


# Vertical Wind Shear **How do we measure it?**

**0-6 km BWD may not accurately represent the layer of the atmosphere contributing to deep convection.**

How about this parcel (green)?
Probably!

Parcels below this layer are NOT contributing to the updraft, therefore we don't want to consider the parcel's trajectory/wind velocity in shear calculations.



# Vertical Wind Shear

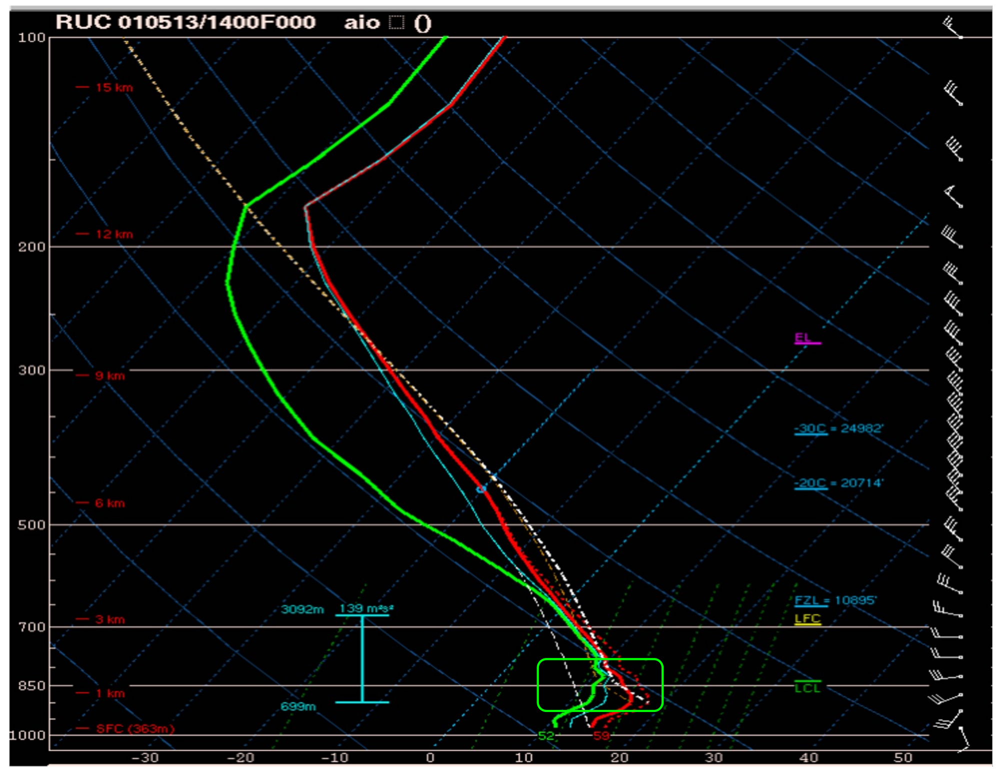
## How do we measure it?

**0-6 km BWD may not accurately represent the layer of the atmosphere contributing to deep convection.**

Let's identify *all* of the parcels that are contributing to the storm's updraft.

We'll use the criteria:

>= 100 J/kg CAPE
>= -250 J/kg CIN



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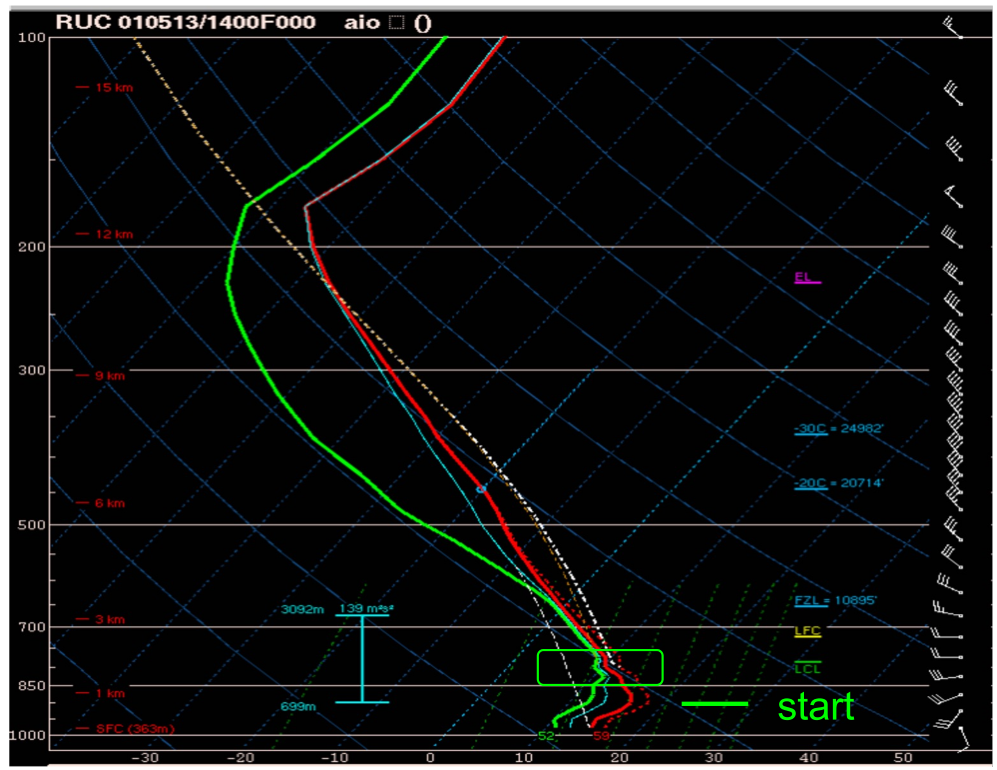

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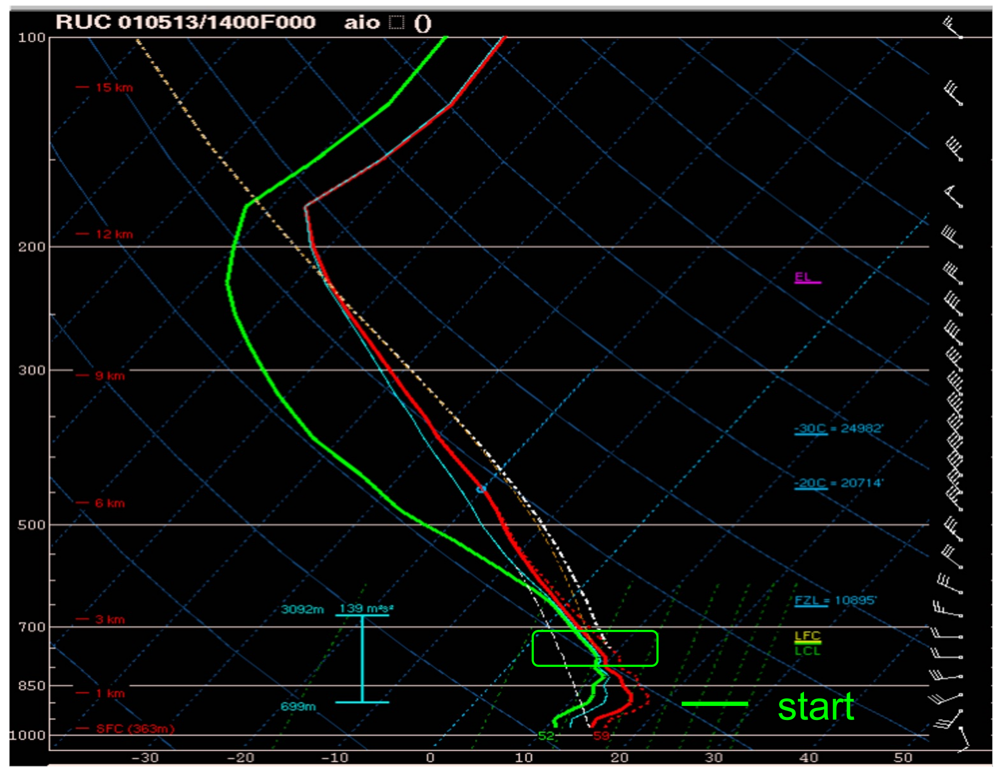

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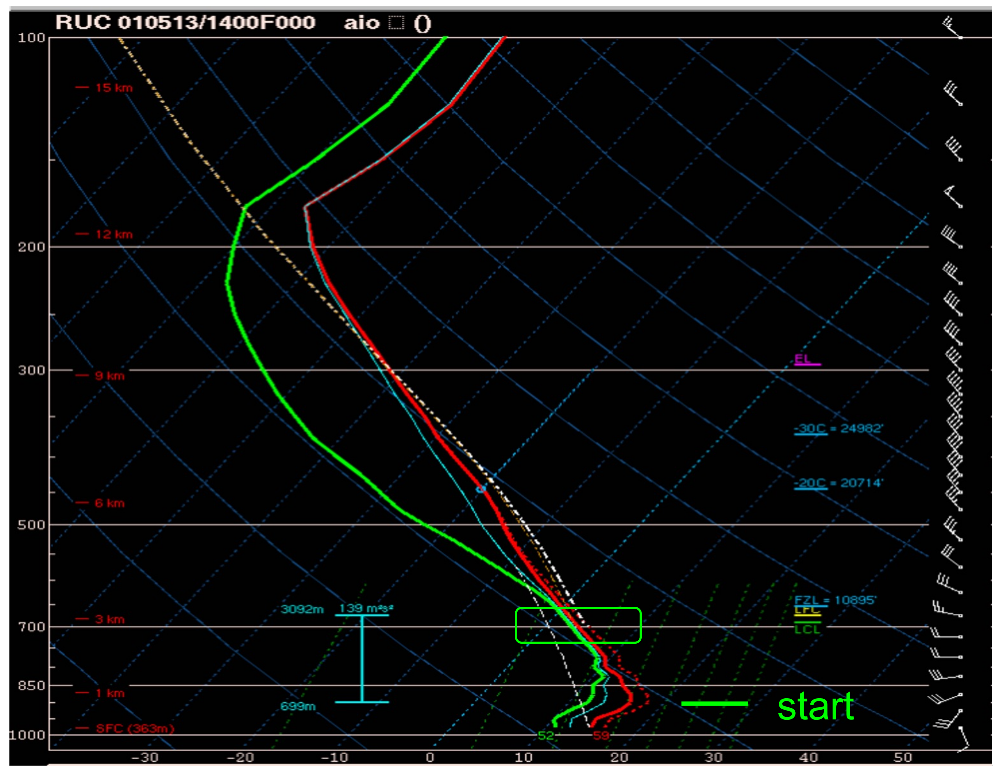

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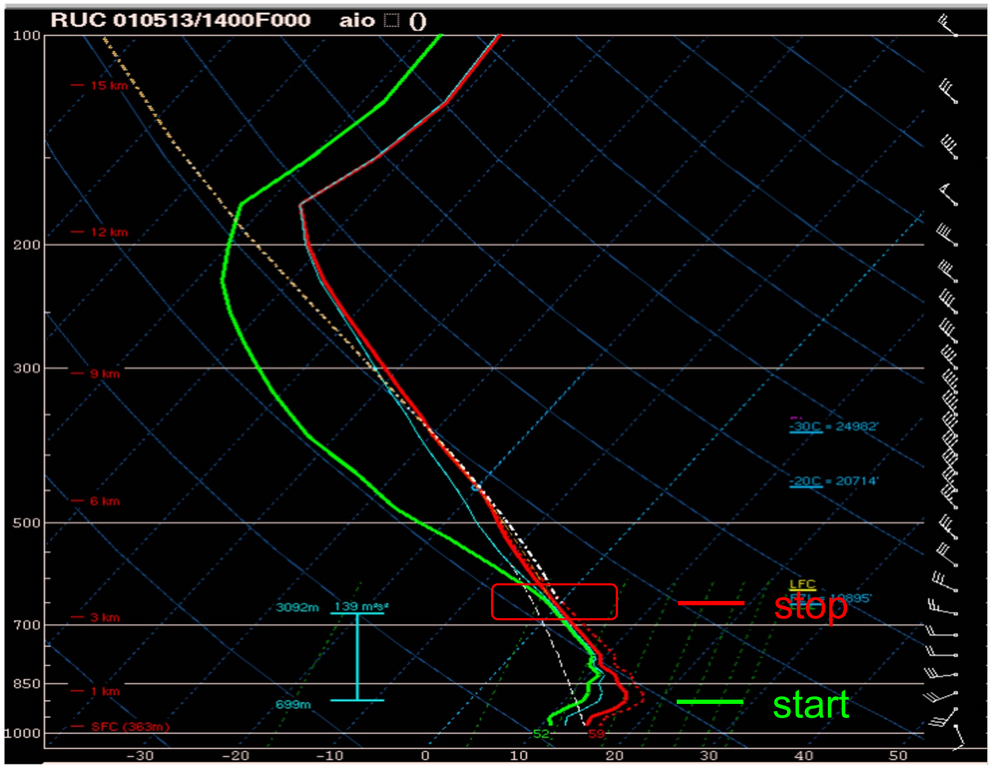

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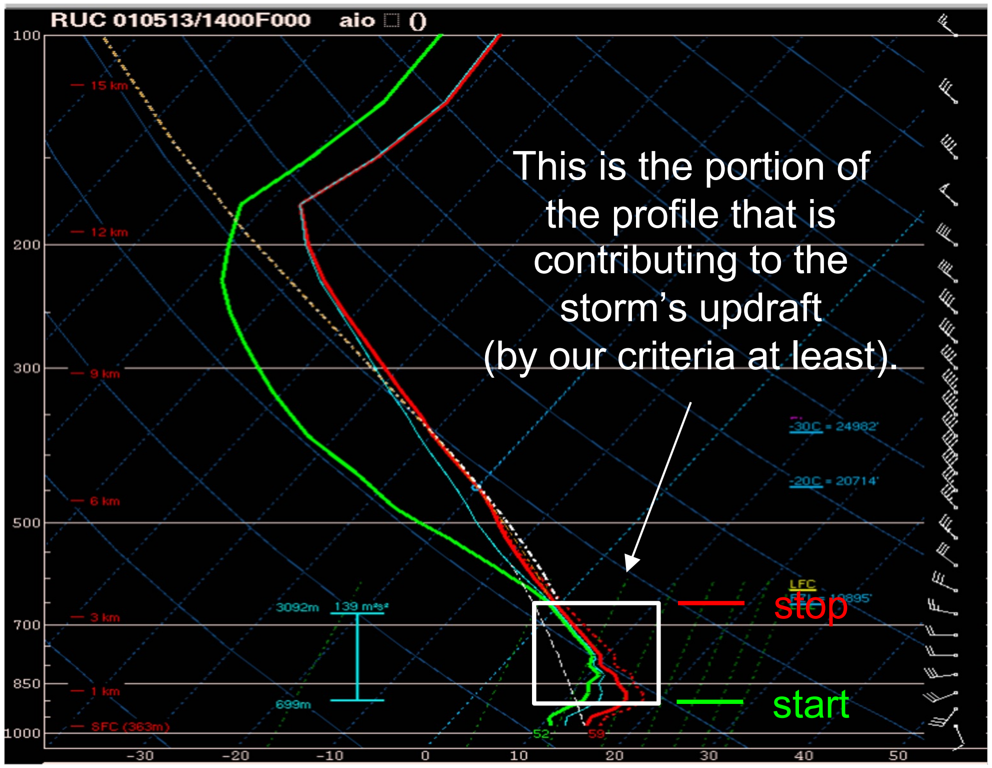

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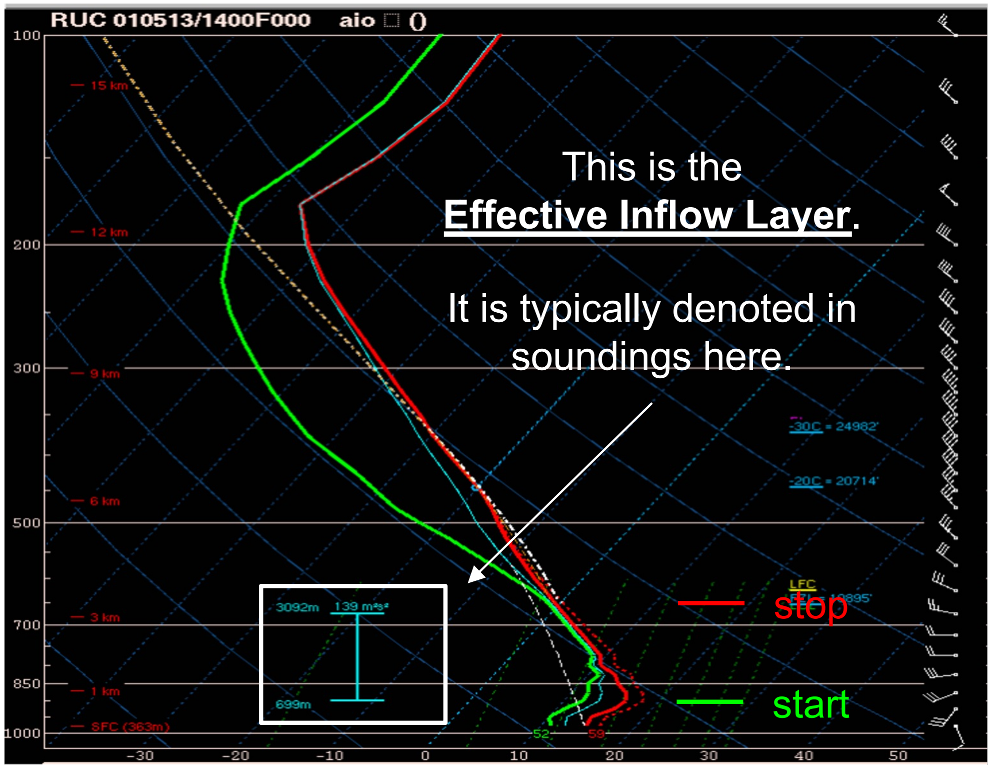
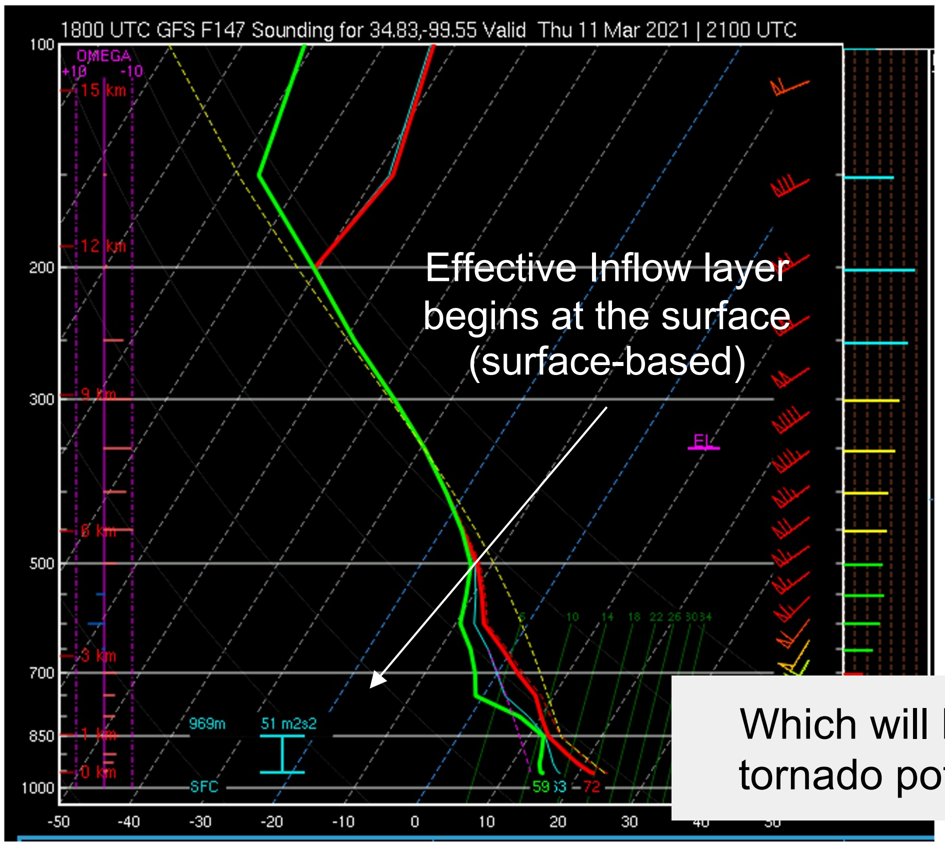
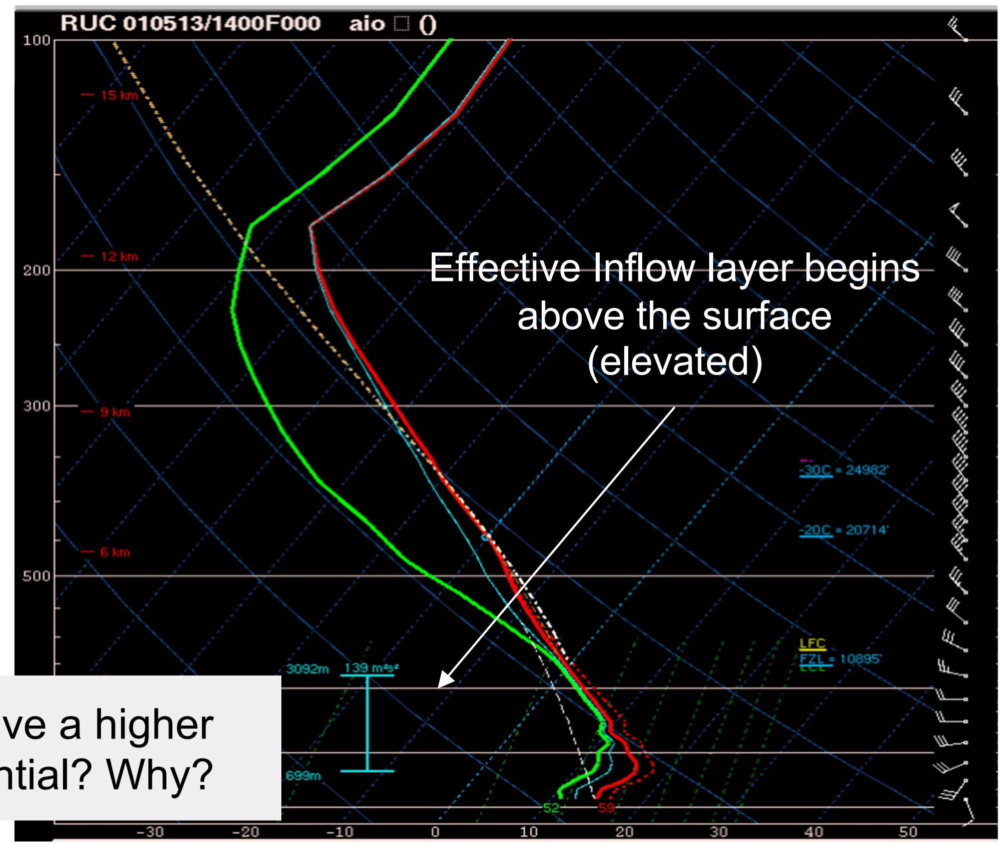


# Vertical Wind Shear How do we measure it?



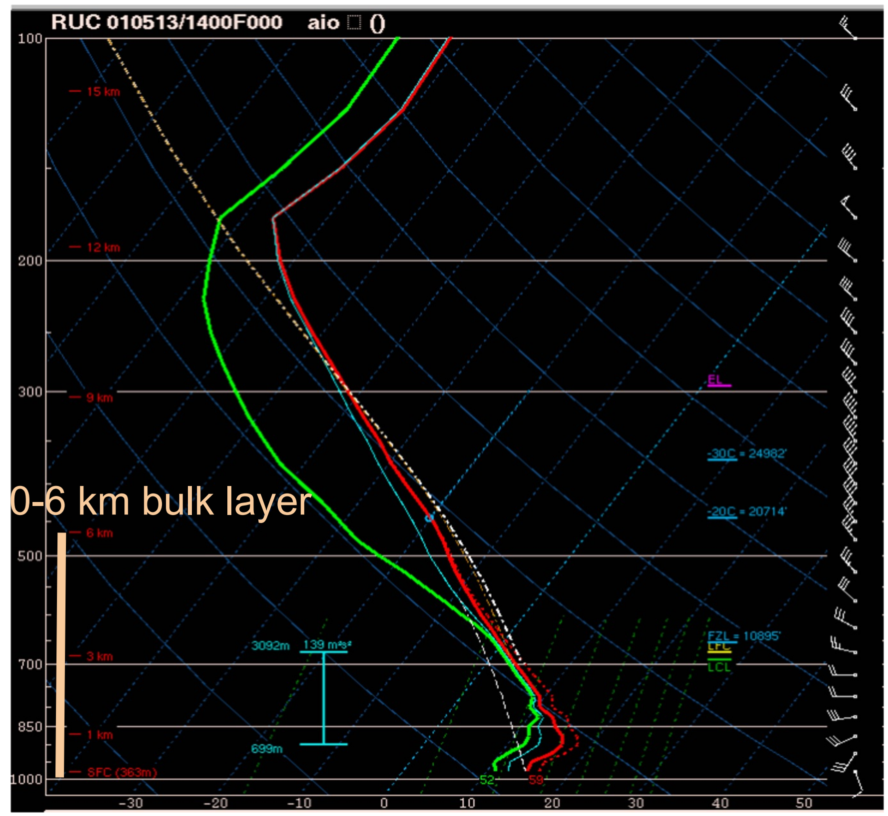

Which will have a higher tornado potential? Why?

# Vertical Wind Shear

**How do we measure it?**

"Deep-layer" shear should represent the storm's depth

Simulations show sufficient
ıear
from 0 to 5/6 km AGL sustains supercells...



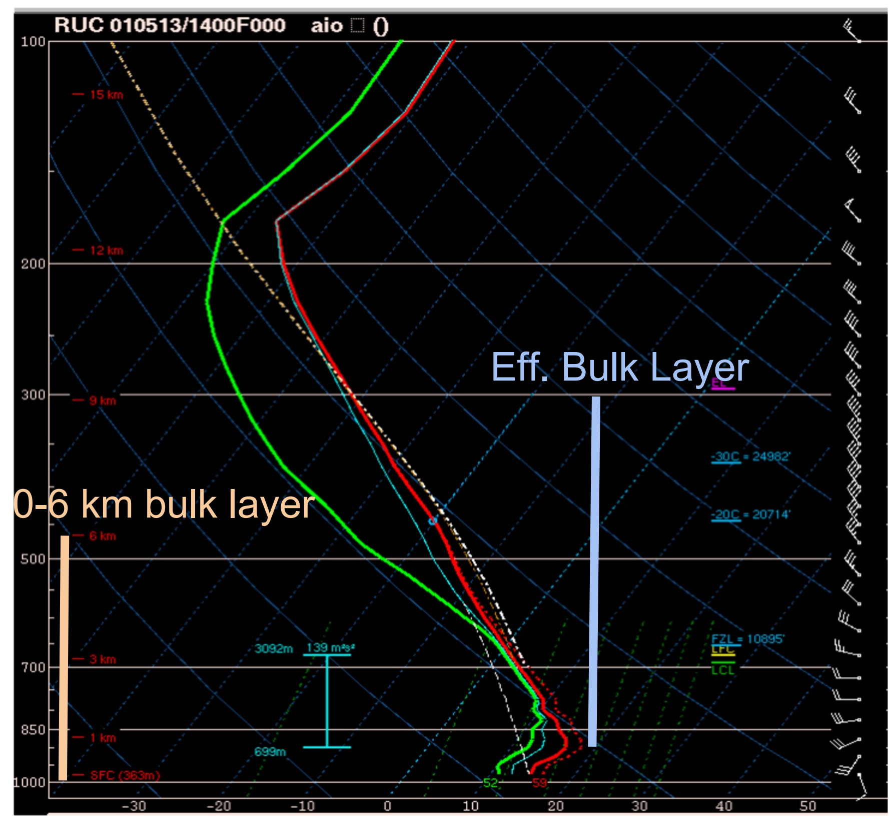
# Vertical Wind Shear

## How do we measure it?

"Deep-layer" shear should represent the storm's depth

Simulations show sufficient
ıear
from 0 to 5/6 km AGL sustains supercells...

But we can use the Eff. inflow layer to consider the depth from the CAPE bearing layer to the EL



# Vertical Wind Shear How do we measure it?

"Deep-layer" shear should represent the storm's depth

Simulations show sufficient
ıear
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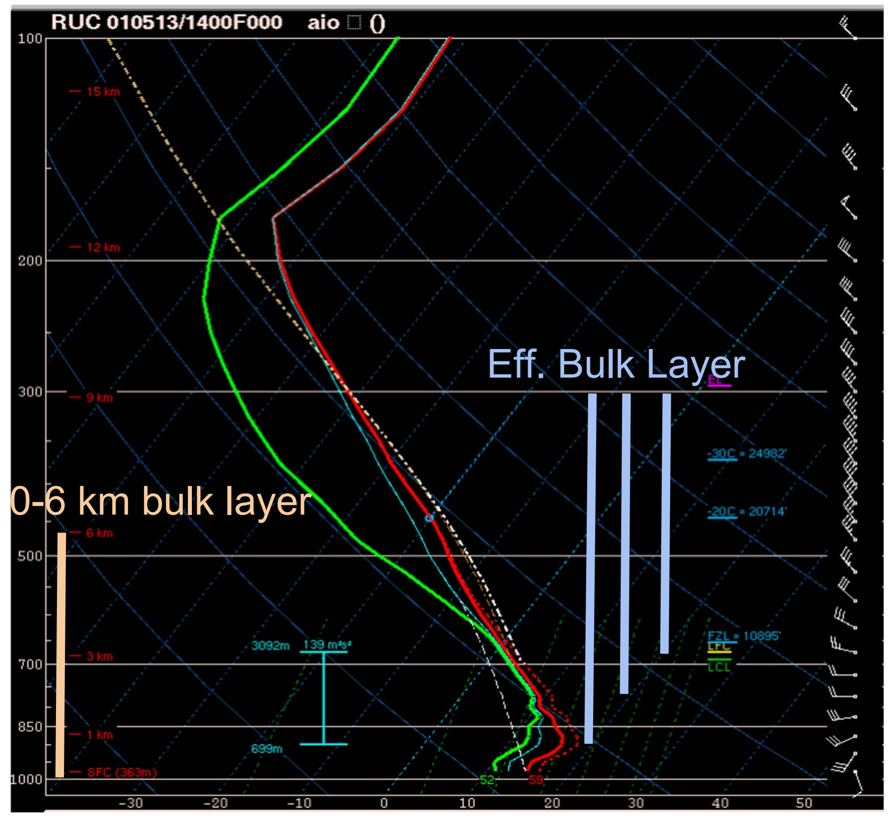
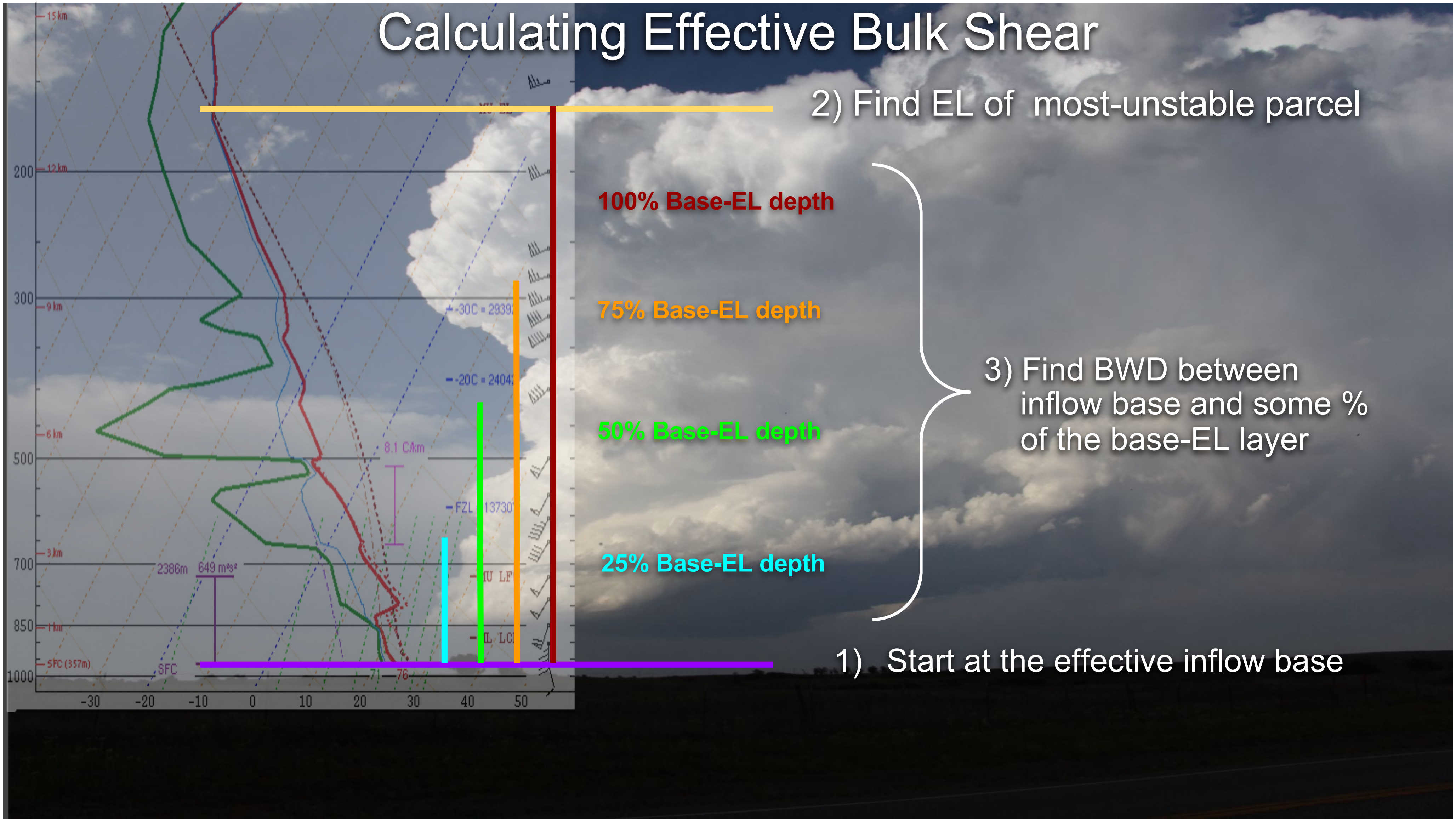
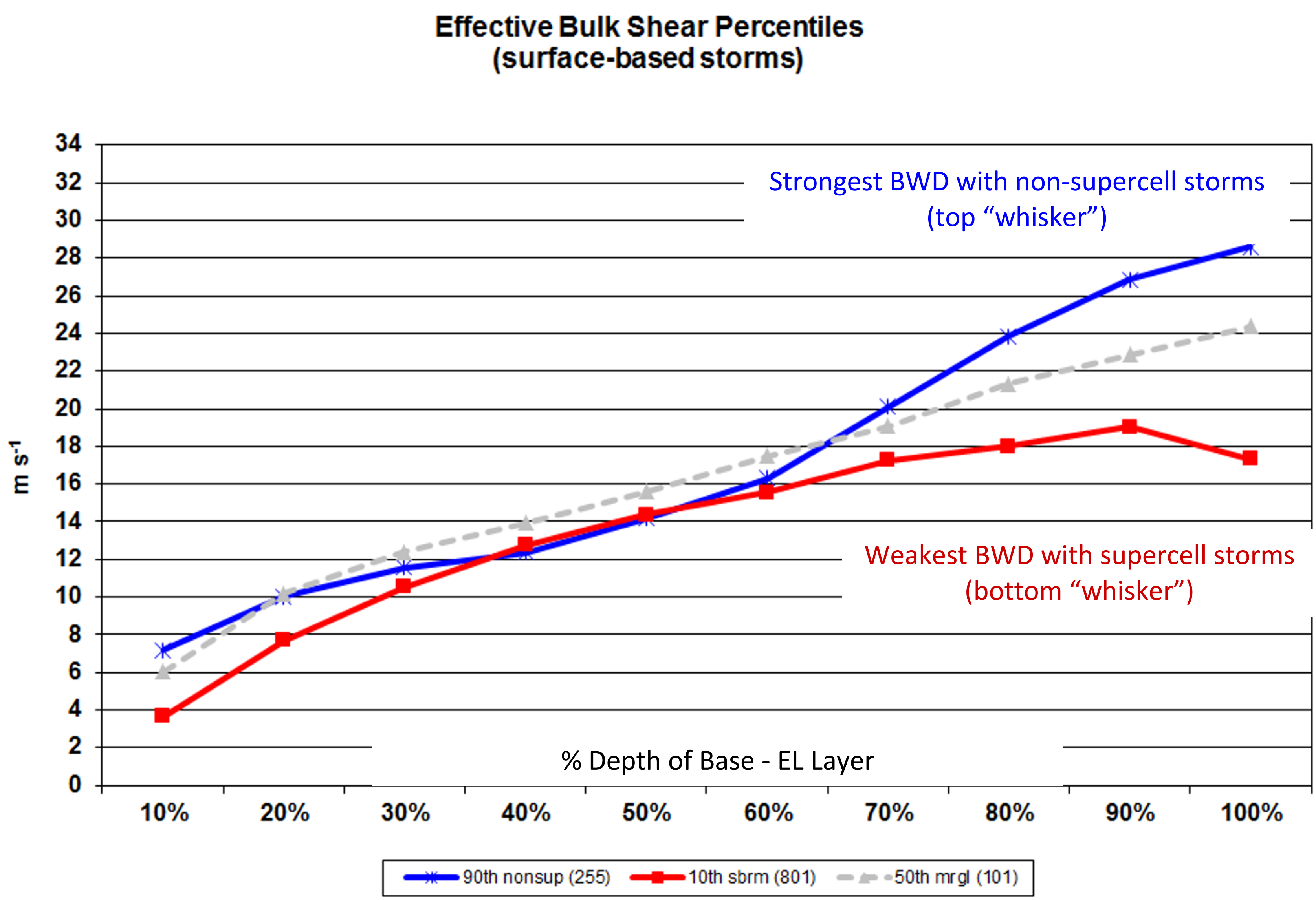
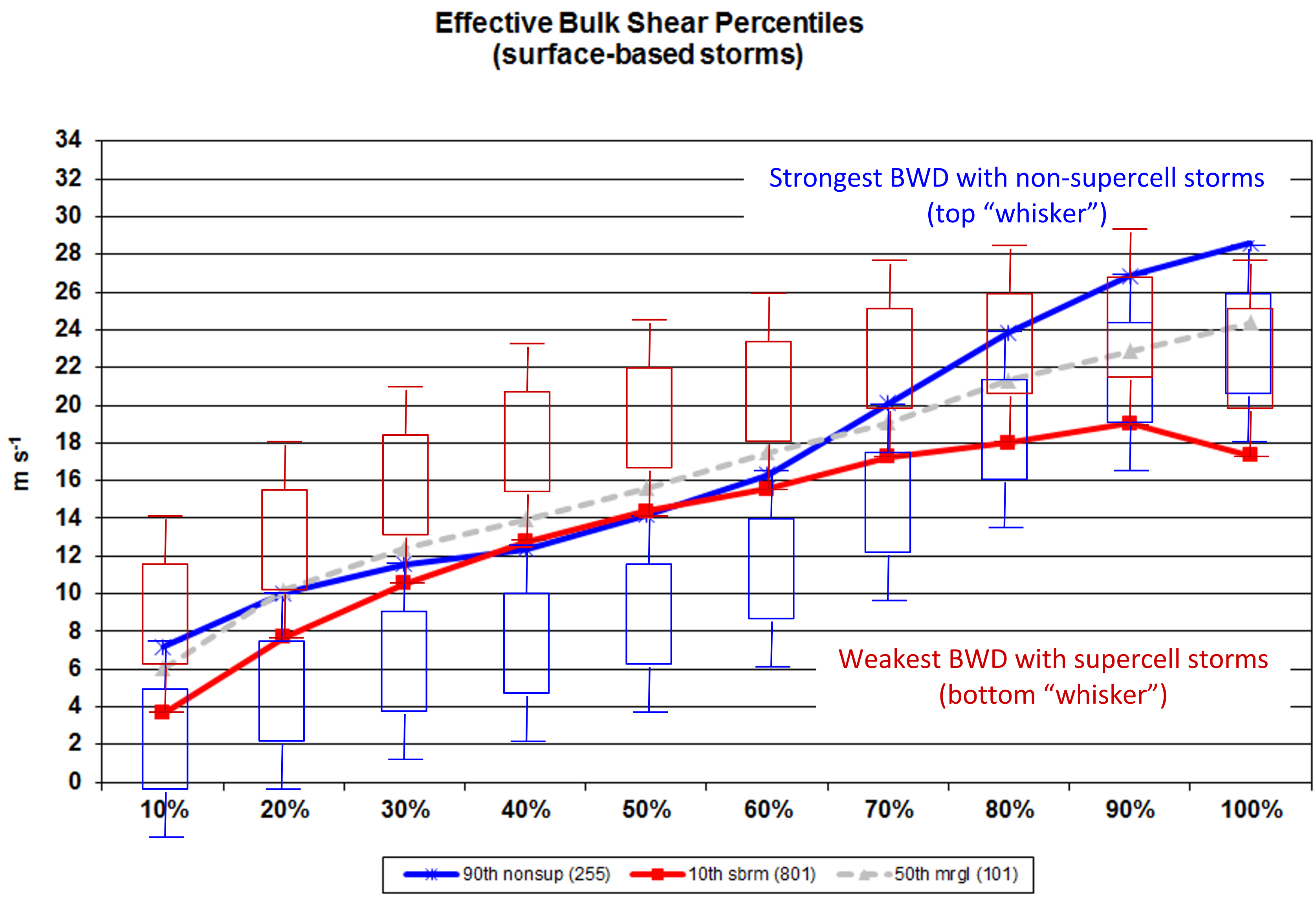
But how do we define the bottom of this layer? Top of the eff. layer? Bottom of the eff. layer?





Calculating Effective Bulk Shear
2) Find EL of most-unstable parcel
100% Base-EL depth
75% Base-EL depth
50% Base-EL depth
25% Base-EL depth
3) Find BWD between inflow base and some % of the base-EL layer
1) Start at the effective inflow base


Effective Bulk Shear Percentiles
(surface-based storms)
Strongest BWD with non-supercell storms
(top "whisker")
Weakest BWD with supercell storms
(bottom "whisker")
m s-1
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
% Depth of Base - EL Layer
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
90th nonsup (255)
10th sbrm (801)
50th mrgl (101)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m s-1
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22
20
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16
14
12
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8
6
4
2
0
10%
20%
30%
40%
50%
60%
70%
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90%
100%
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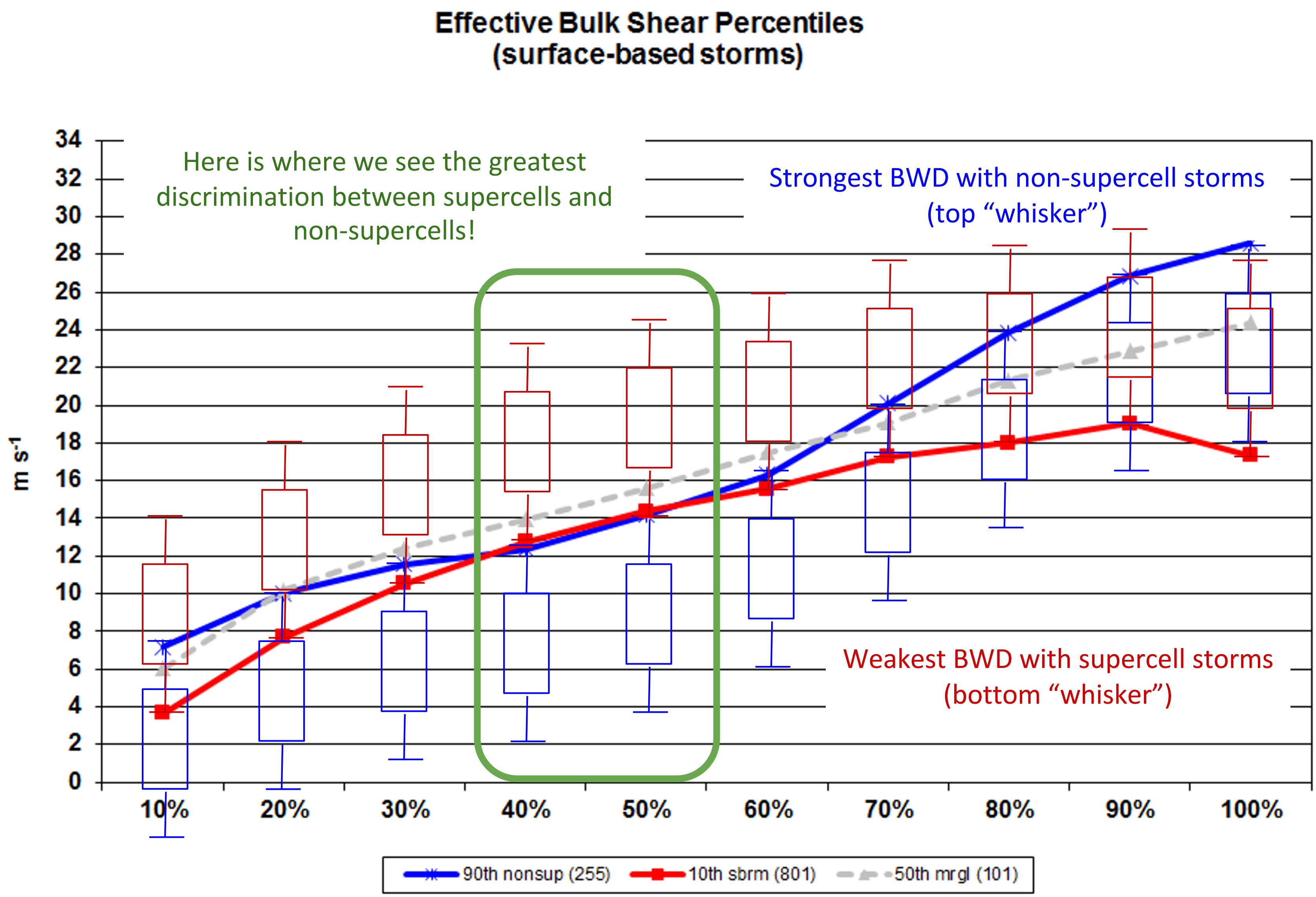
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m s-1
34
32
30
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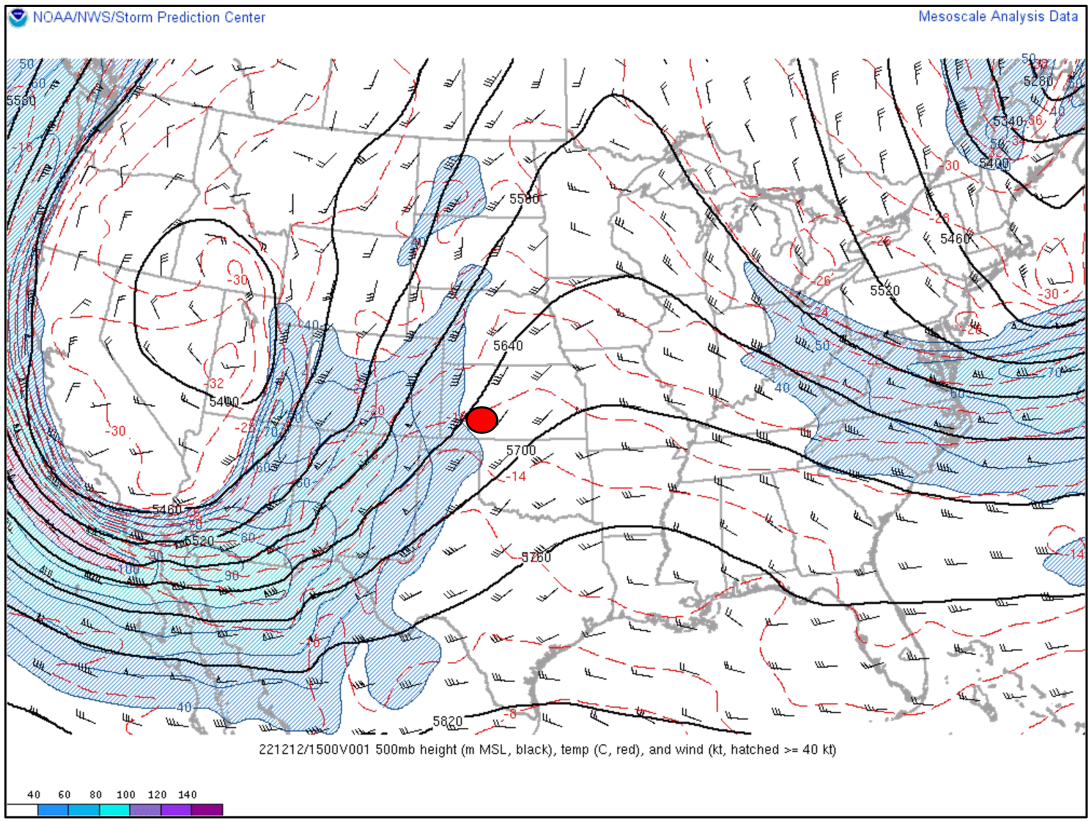
16
14
12
10
8
6
4
2
0
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Here is where we see the greatest discrimination between supercells and non-supercells!
Strongest BWD with non-supercell storms (top "whisker")
Weakest BWD with supercell storms (bottom "whisker")
90th nonsup (255)
10th sbrm (801)
50th mrgl (101)

# Effective Bulk Wind Difference

- ➢ BWD between the bottom of the Eff. Inflow layer and 50% of the [Eff. inflow layer - EL] layer depth.
- ➢ Similar to 0-6 km Bulk Wind Difference in “typical” (surface-based) scenarios
- ➢ More flexible than 0-6 km BWD
  - Captures shallow and deep buoyancy environments
  - Captures elevated thunderstorm environments

# Vertical Wind Shear **How to forecast it?**

Use Q.G. methods to anticipate how the wind profile will change.




Using the Q.G. Height tendency equation, how will the 500 mb field change over the next 8-12 hours?

What will this do to the winds at 500 mb over Dodge City, KS (red dot)?

Assuming steady state conditions near the ground, what will this do to the 0-6 km BWD?

When poll is active, respond at **pollev.com/severeclass641**

# What will happen to the 0-6 km BWD over the next 8-12 hours?

Increase

Decrease

Stay the same

Impossible to tell!

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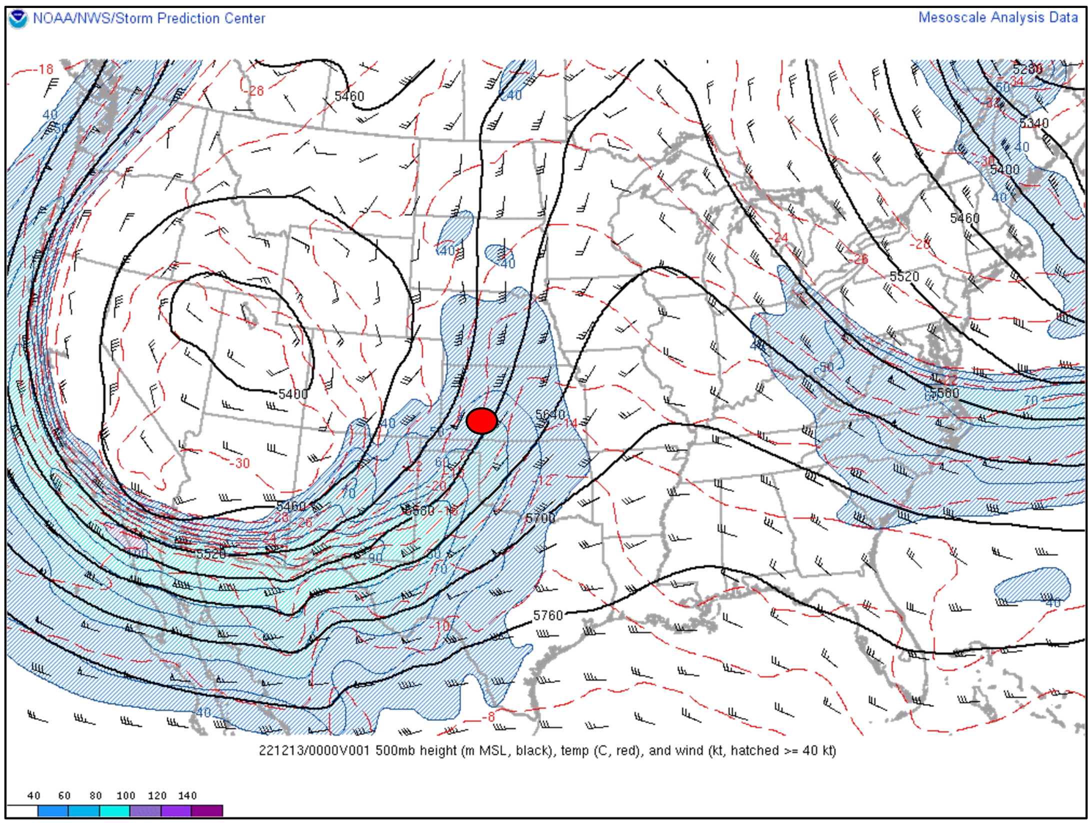


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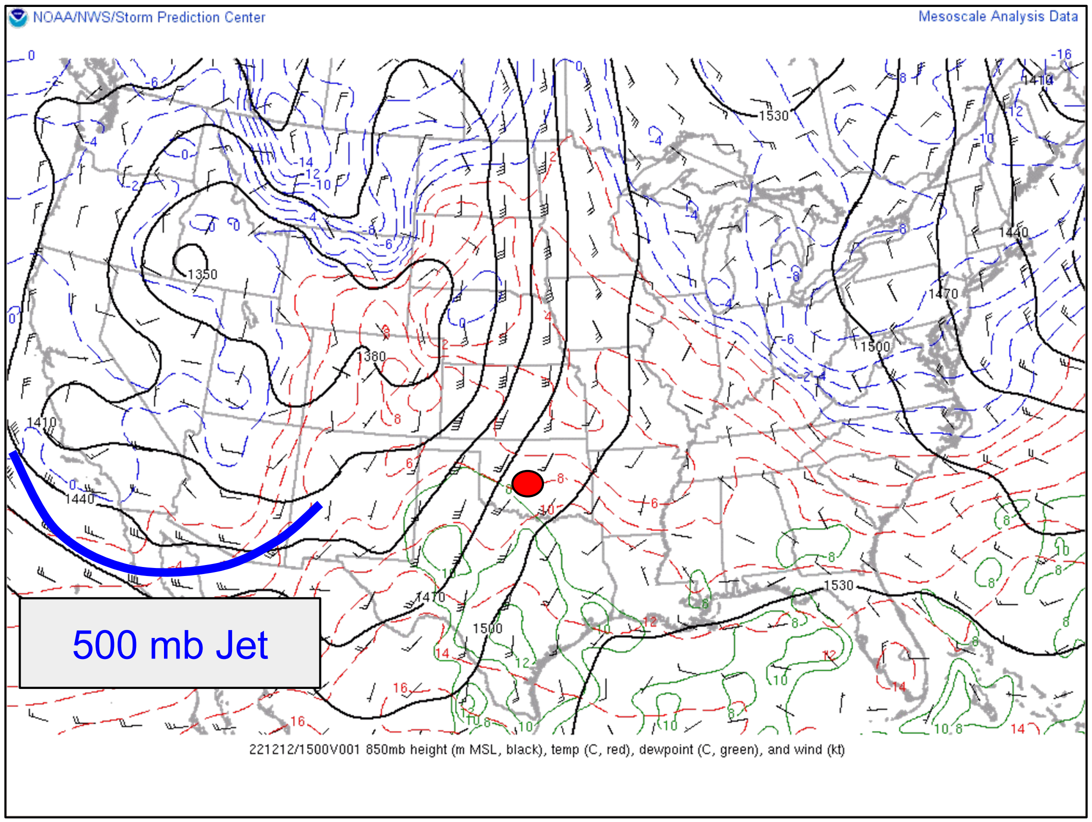



Using the Q.G. Omega equation, will the 850 mb low over the CO/NE/WY region deepen or weaken?

What will this do to the winds at 850 mb over Norman, OK (red dot)?

Assuming steady state conditions near the ground, what will this do to the surface to 850 mb BWD?

*also consider thermal wind response of tightening 850 mb thermal gradient.

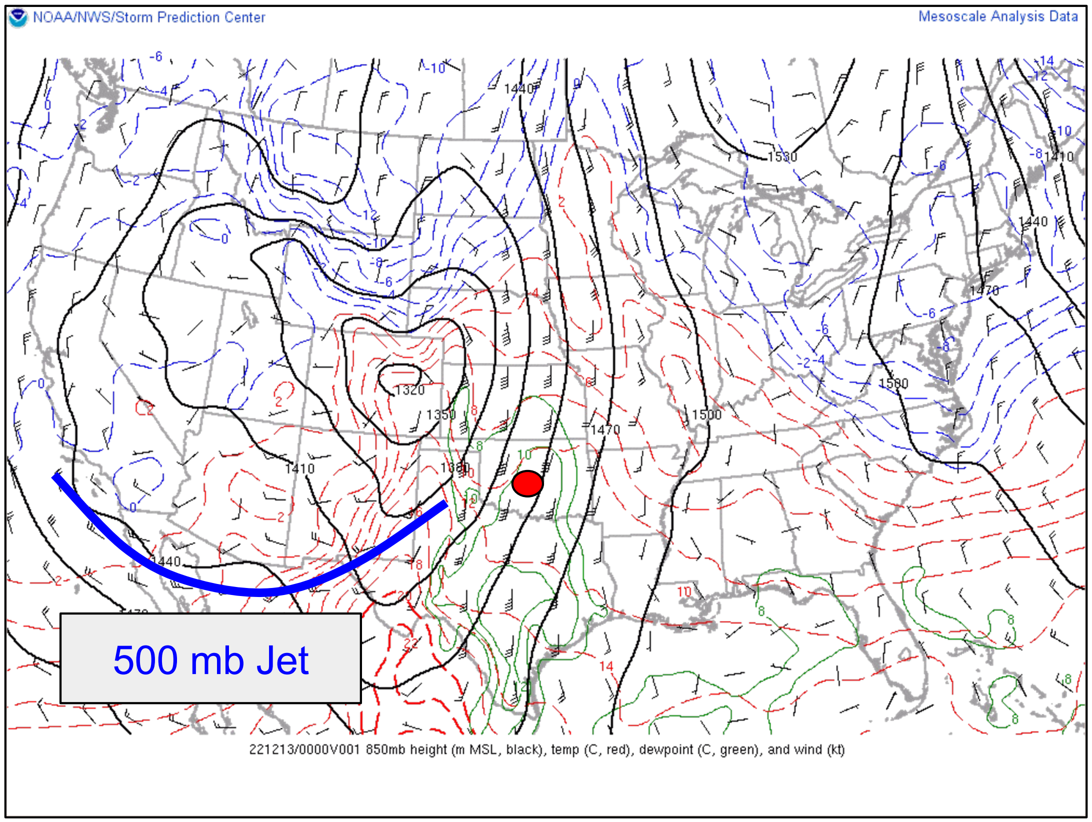
When poll is active, respond at **pollev.com/severeclass641**

# What will happen to the sfc-850 mb BWD at Norman, OK over the next 8-12 hours?

- Increase
- Decrease
- Stay the same
- Impossible to tell!

# Vertical Wind Shear **How to forecast it?**

Use Q.G. methods to anticipate how the wind profile will change.

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What will this do to the winds at 850 mb over Norman, OK (red dot)?

Assuming steady state conditions near the ground, what will this do to the surface to 850 mb BWD?

*also consider thermal wind response of tightening 850 mb thermal gradient.

# Nocturnal Low-Level Jet (LLJ)

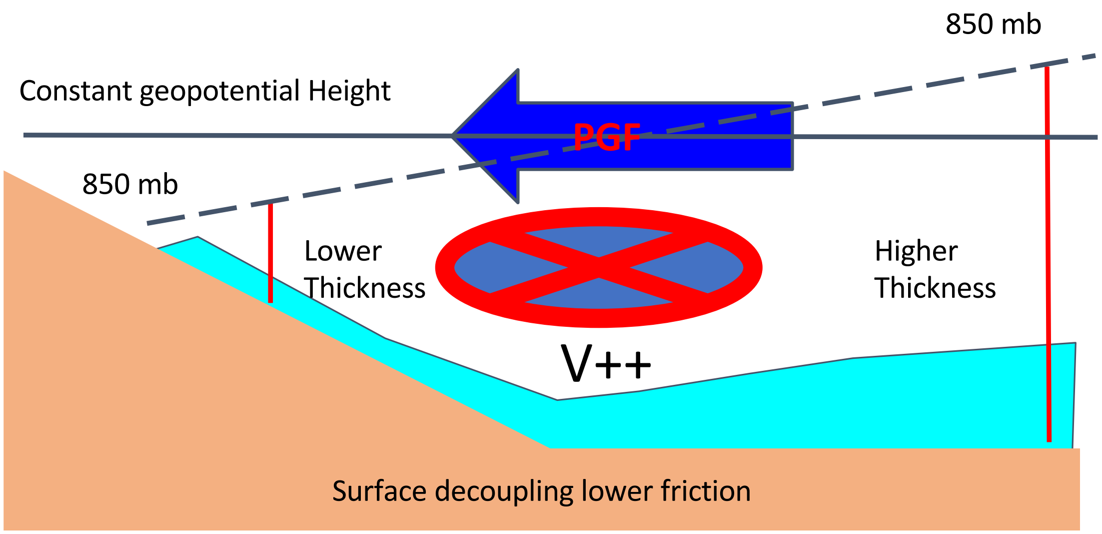
- **Plains often see early nocturnal low-level jet (LLJ) ramp up with lee cyclogenesis**

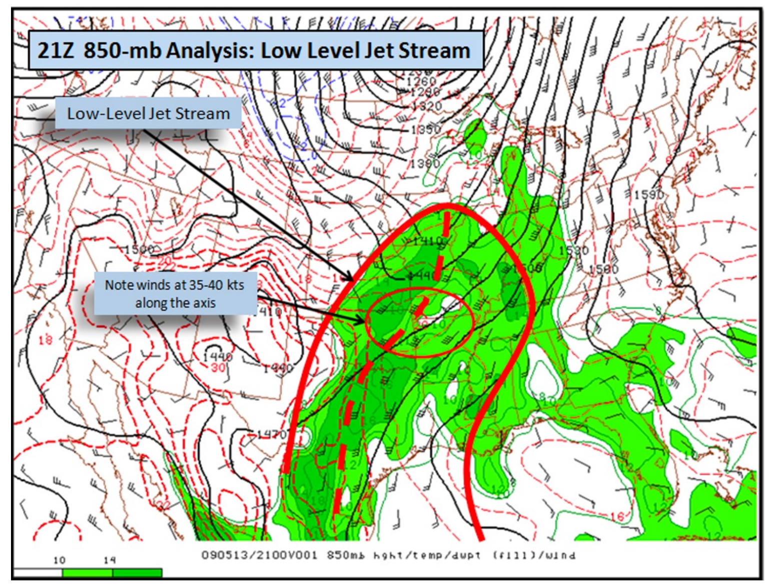
- **Related to two primary factors:**
  - **Boundary-layer decoupling and loss of surface friction ("inertial oscillation")**
  - **Diurnal temperature variations over sloped terrain (thermal wind)**

- **Part of the process that can favor late evening/early overnight tornadoes (with favorable moisture/CAPE)**

# Nocturnal Low-Level Jet (LLJ) Formation

- LLJs form in response to difference in terrain heights, heat fluxes and thickness across pressure surfaces that induces a horizontal Pressure Gradient Force.
- Coriolis forcing turns the momentum northward resulting in an enhanced southerly flow.
- Surface decoupling favors lower friction and acceleration of the jet above the surface
- Lee Cyclones can also enhance it by increasing the PGF.



# Cyclone induced  Low-Level Jet (LLJ) Formation

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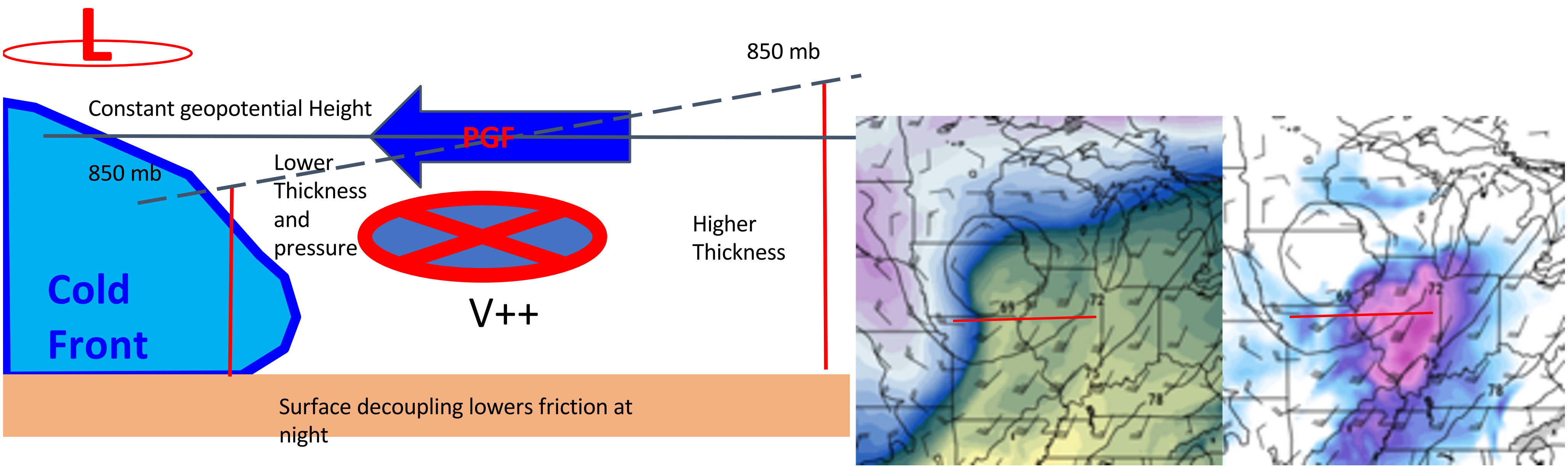

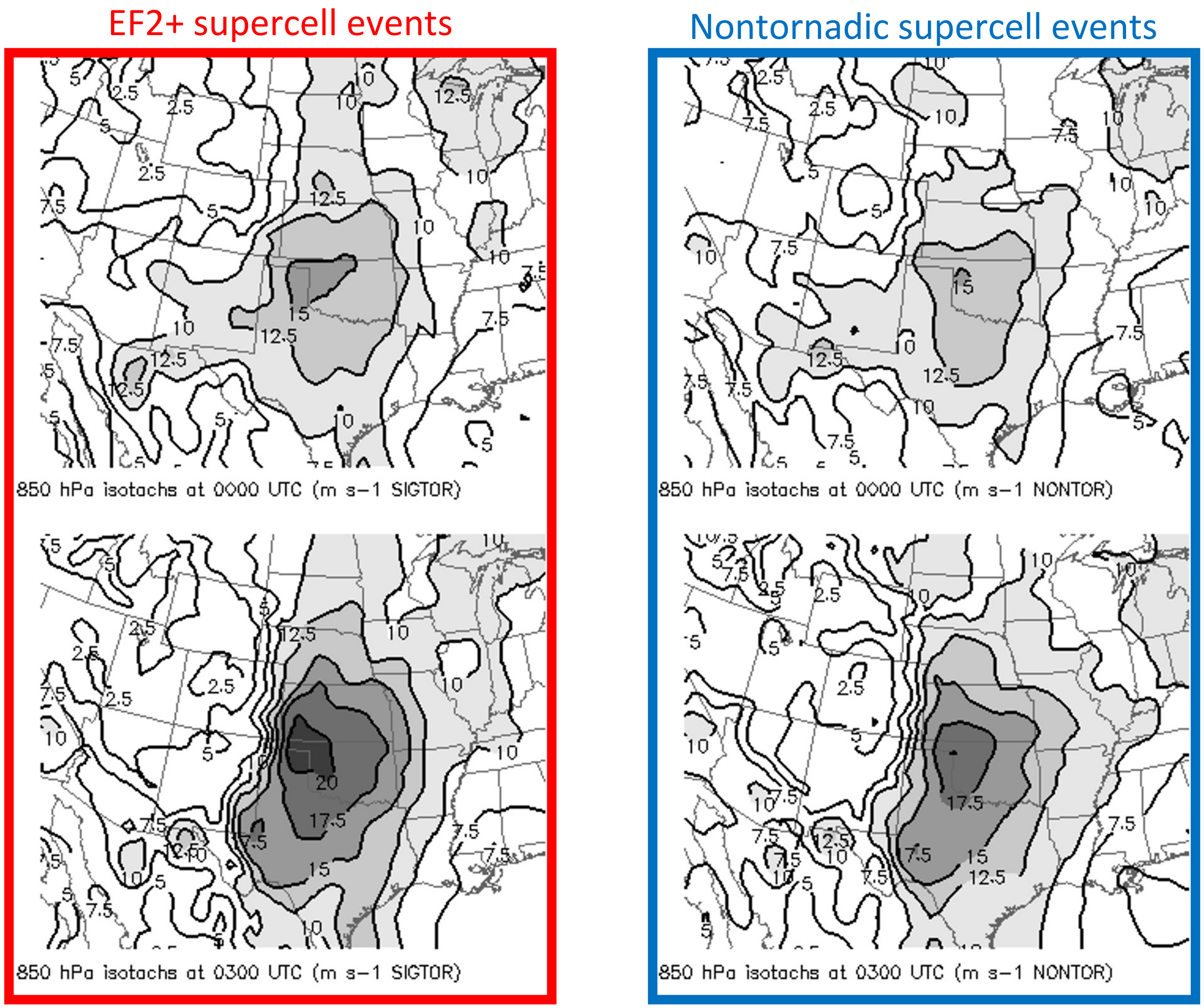
EF2+ supercell events
Nontornadic supercell events
850 hPa isotachs at 0000 UTC (m s-1 SIGTOR)
850 hPa isotachs at 0300 UTC (m s-1 SIGTOR)
850 hPa isotachs at 0000 UTC (m s-1 NONTOR)
850 hPa isotachs at 0300 UTC (m s-1 NONTOR)