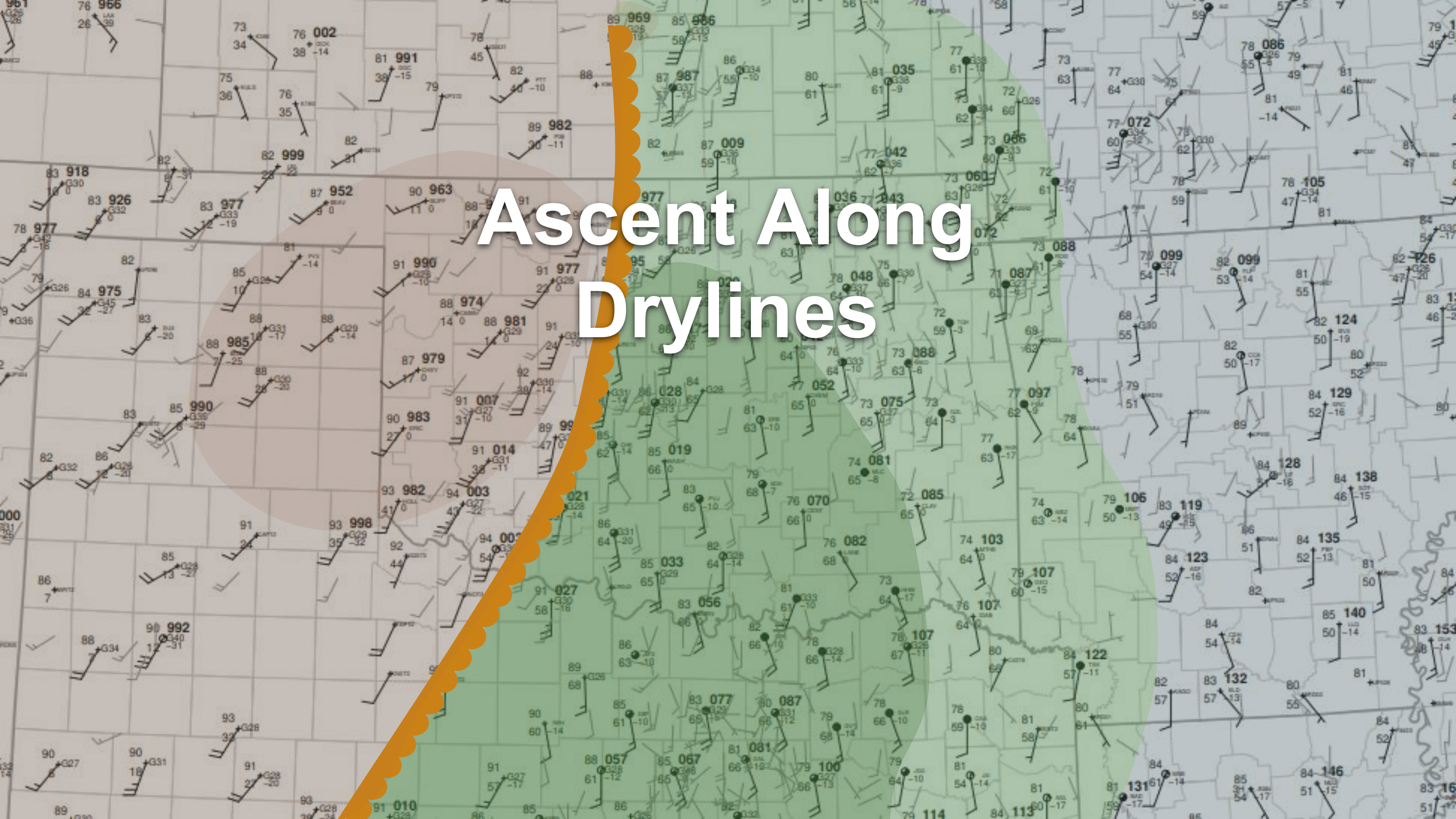
# QG Omega

## (and drylines!)

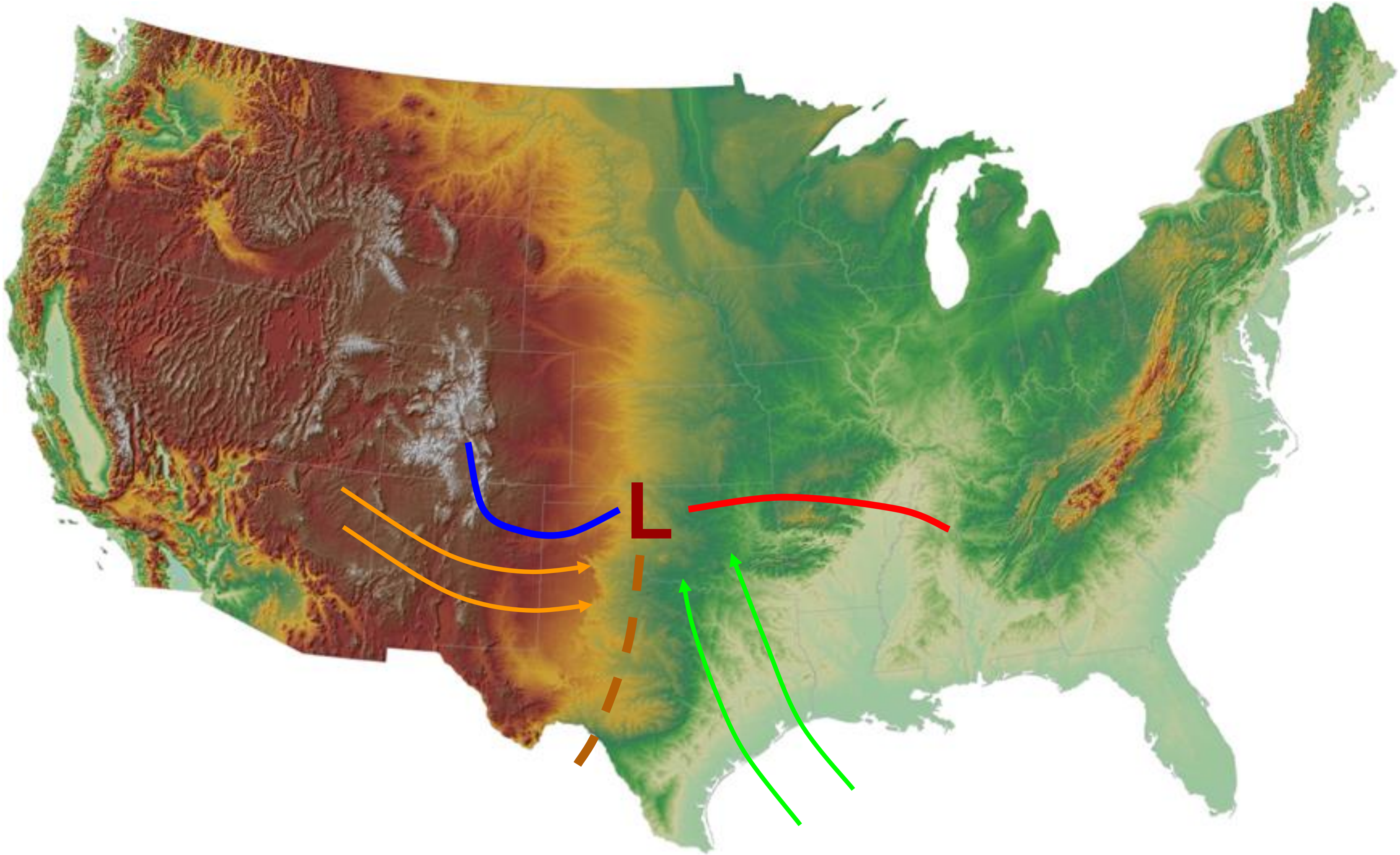
Arranged by Andrew Moore
Contributions from Thomas Galarneau

# Ascent Along Drylines



# What is a dryline?

## This is simply a density discontinuity between warm/moist air and hot/dry air.



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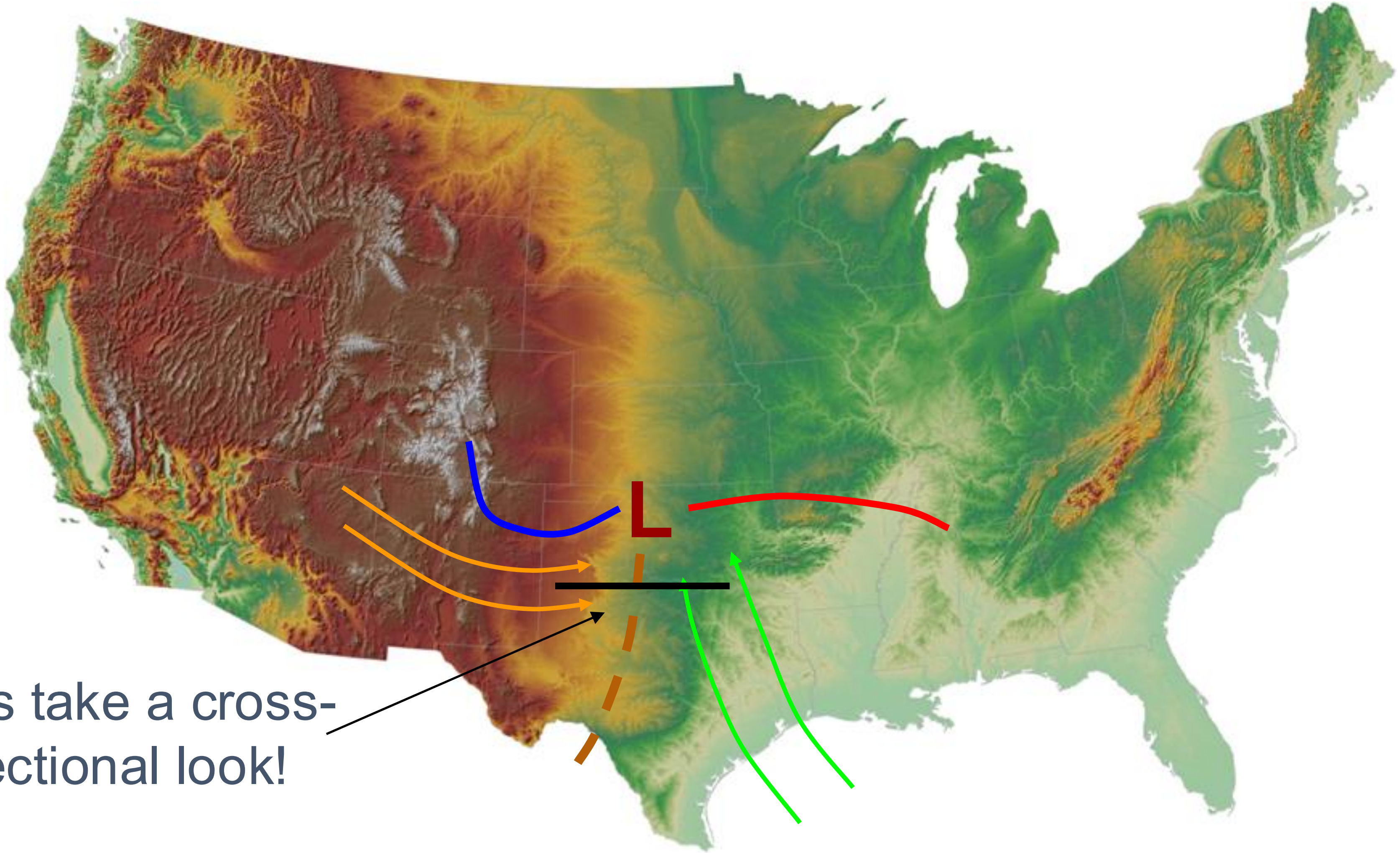

Let’s take a cross-sectional look!

# What is a dryline?

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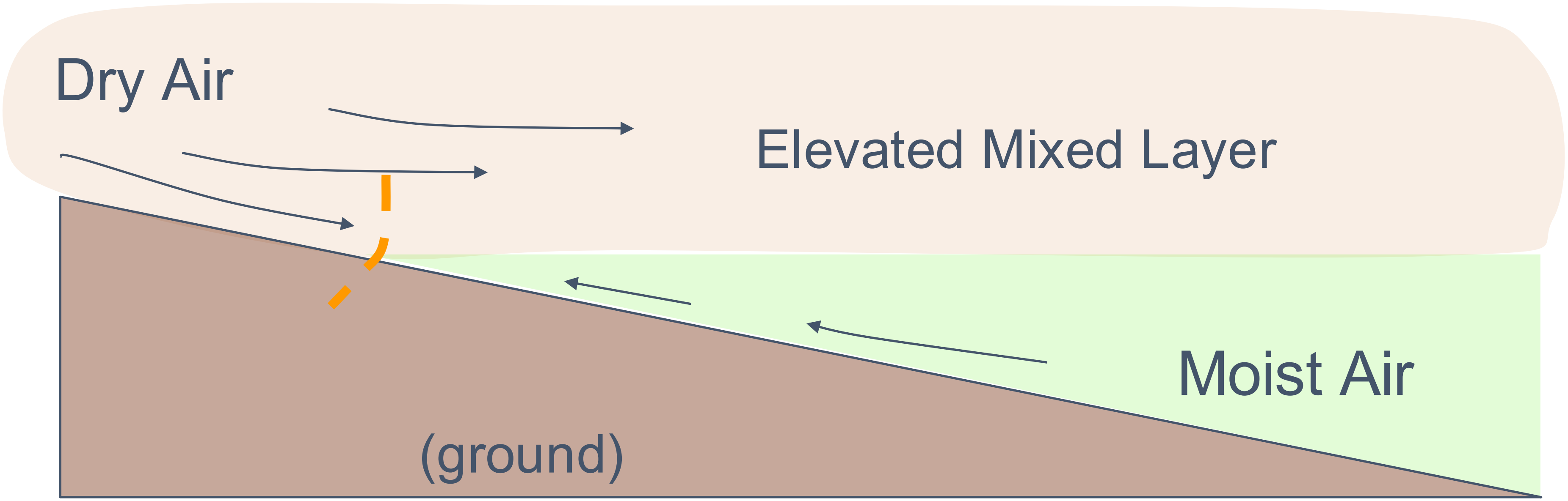

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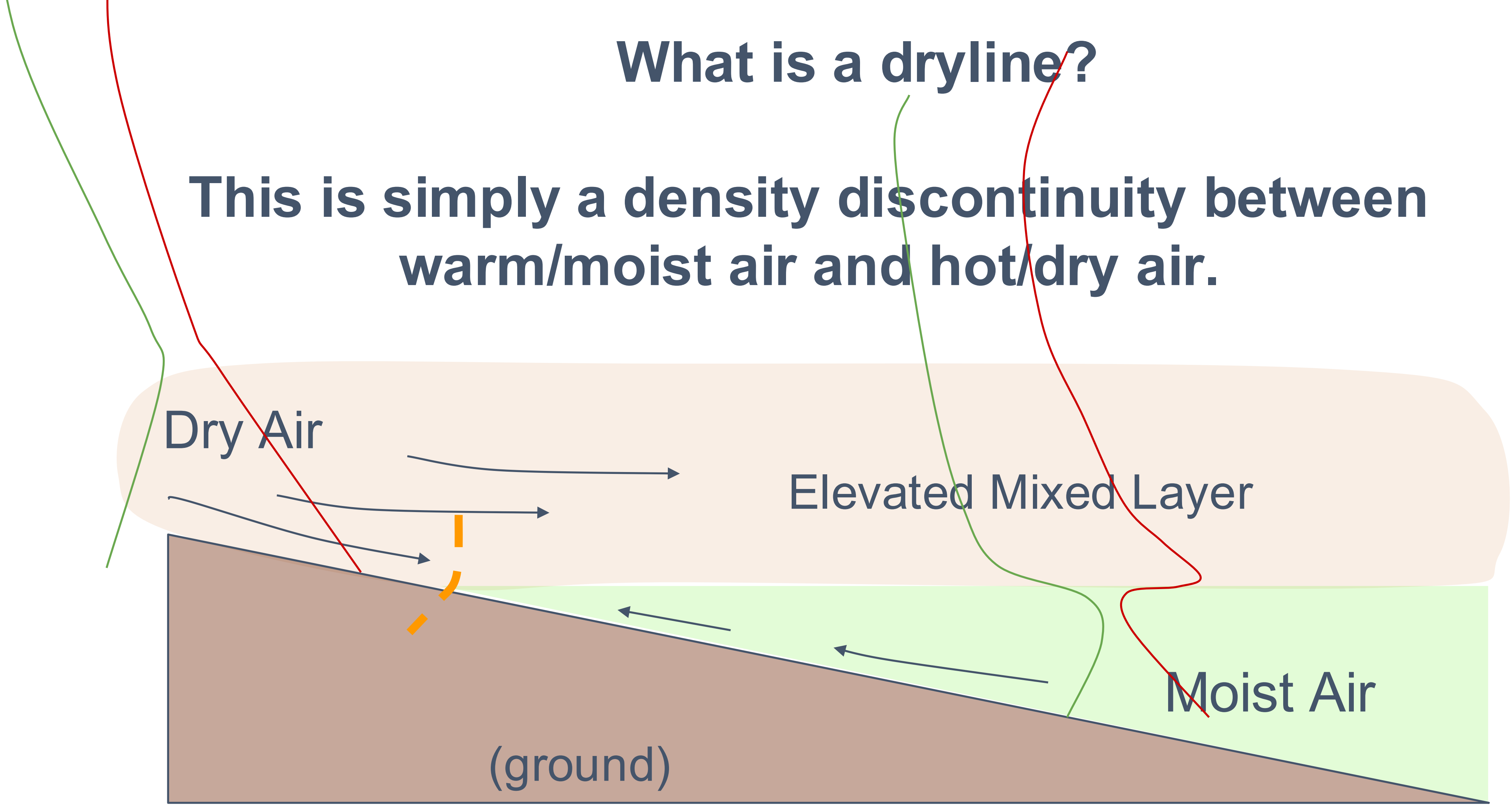
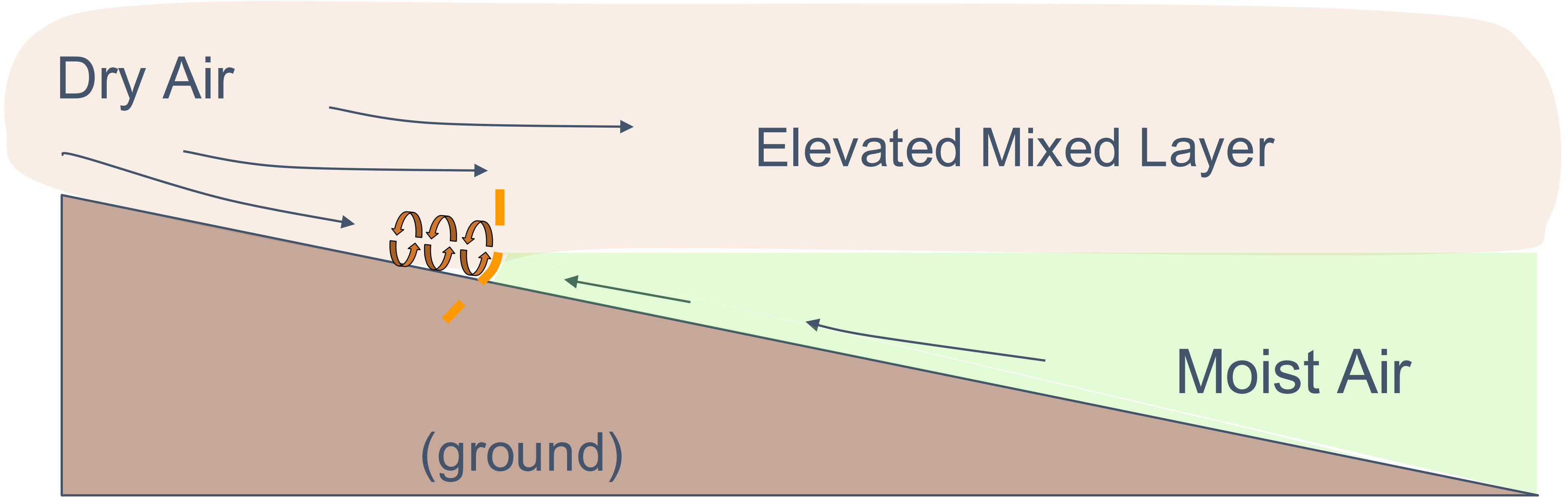


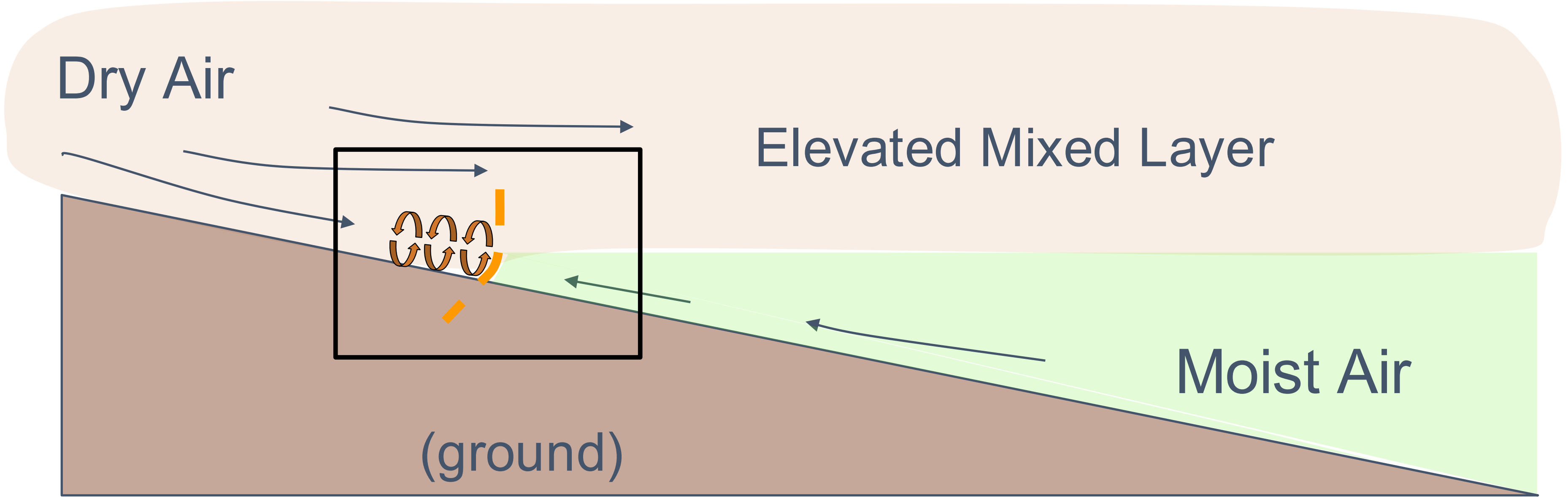
# How does a dryline move?

**By mixing!**
**Strong boundary-layer flow within the hot/dry air mechanically mixes out the moisture.**



# How does a dryline move?

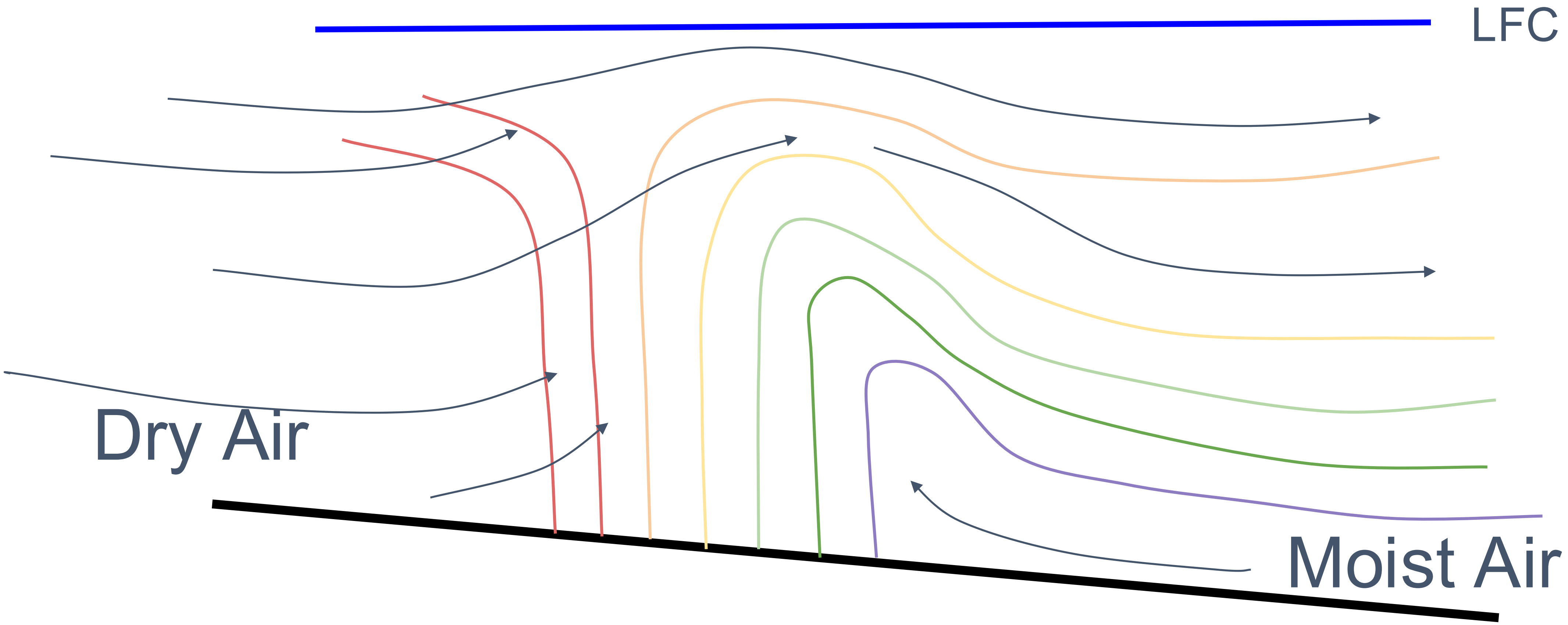
**Eventually, low-level convergence and/or moisture depth is strong enough to resist further eastward mixing**




Let's zoom in again!

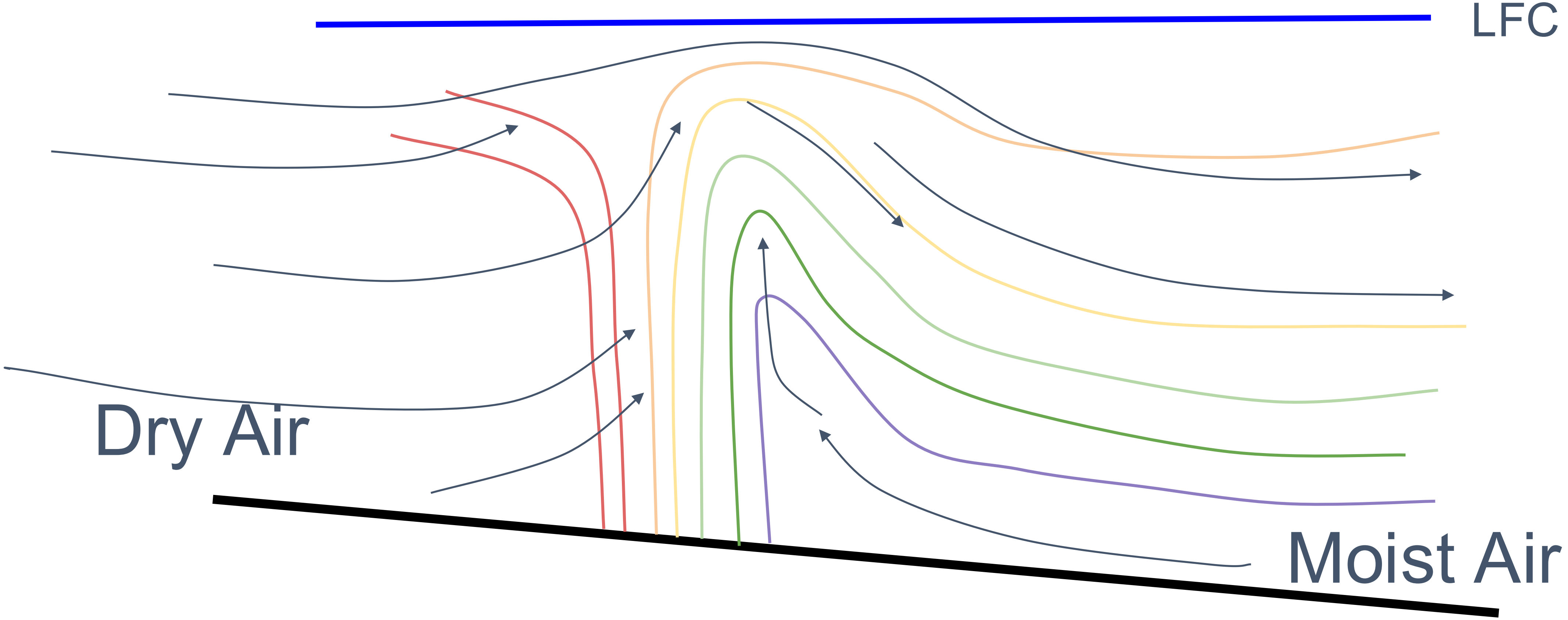
# How do we get T-storm development?

**Low-level convergence acts to tighten moisture gradient.**
**Dry air overruns the low-level moisture.**
**Parcels can not yet reach their LFC**



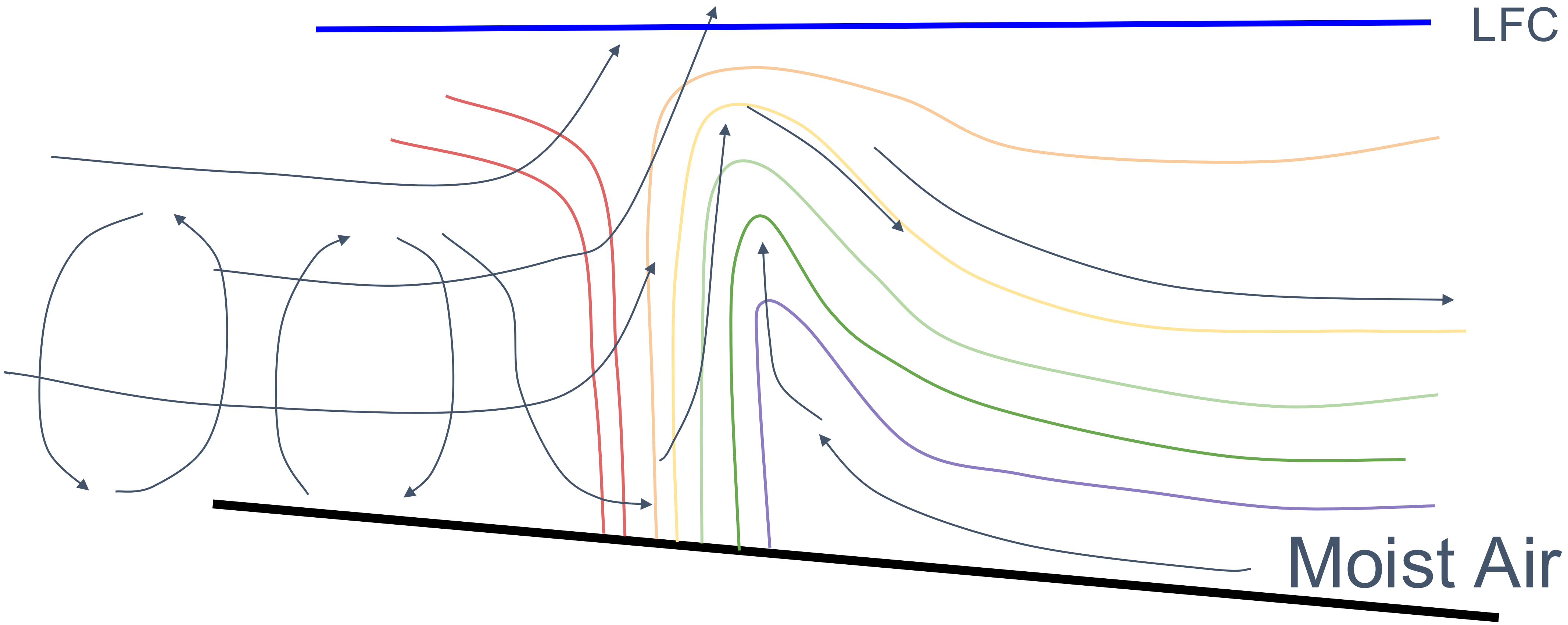
# How do we get T-storm development?

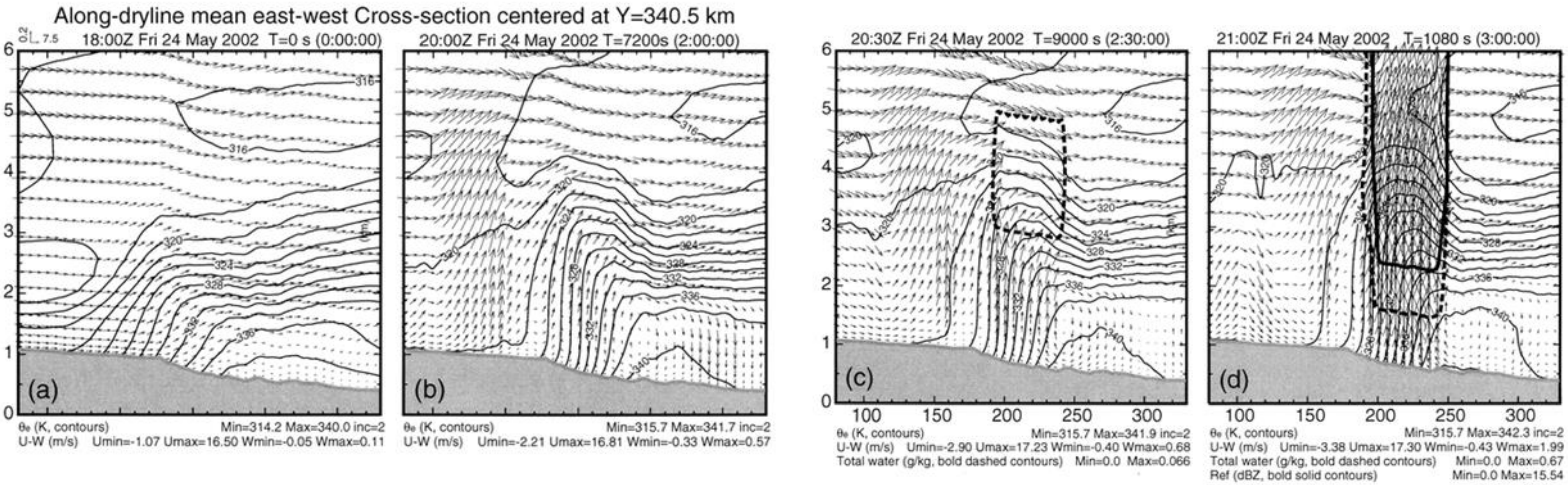
**With time, there is an upward moisture flux.**
**Ascent increases, parcels begin to approach LFC,**
**but need additional ascent…**



# How do we get T-storm development?

**Boundary-layer eddies (such as HCRs) locally enhance ascent along dryline, helps parcels reach the LFC.**






Dryline & ascent strengthening in ARPS simulations
(Fig 10 from Xue and Martin 2006a)

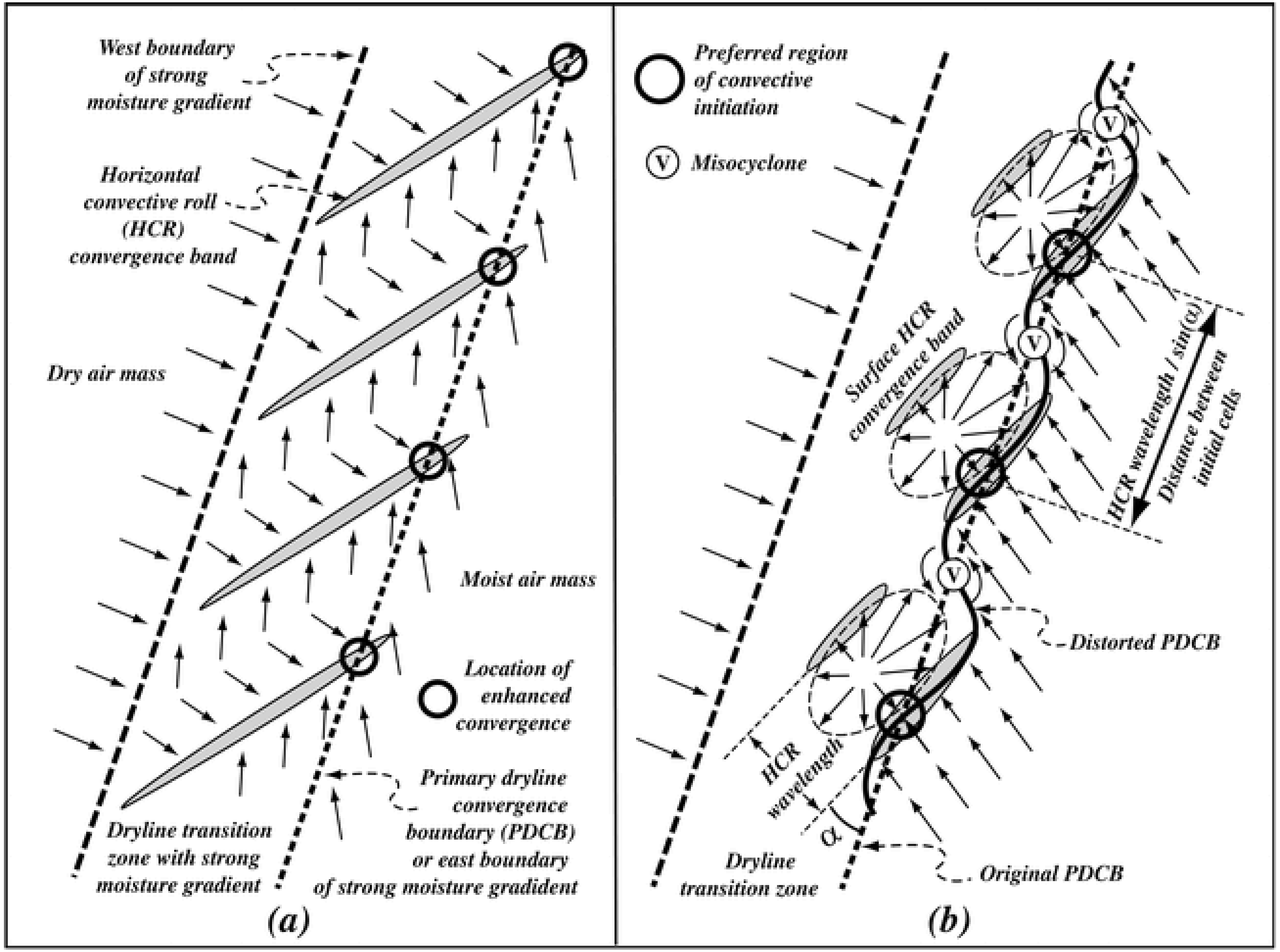



Fig 11 from Xue and Martin 2006b

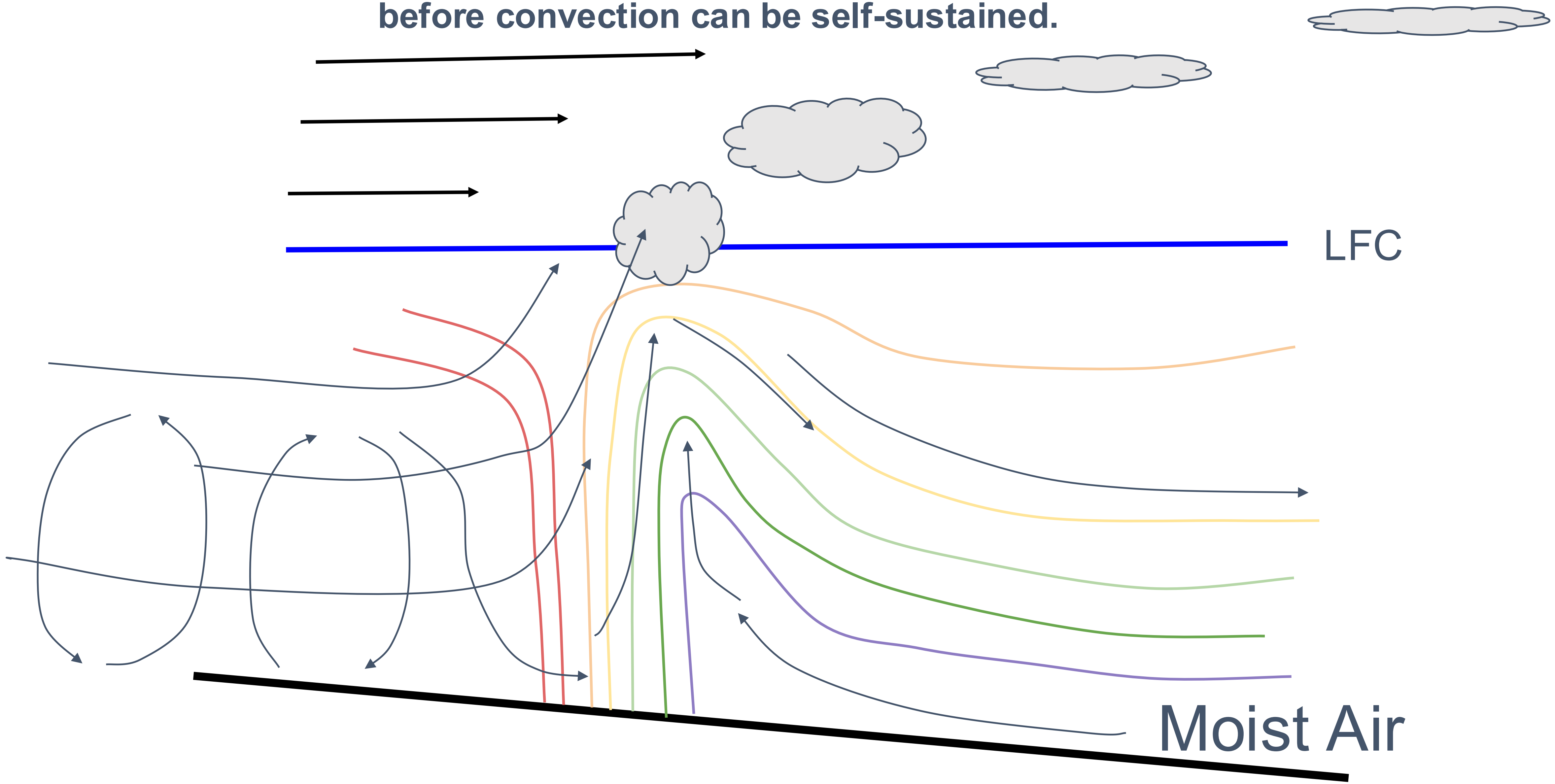
Boundary-layer eddies/discontinuities intersect the dryline and cause it to distort.

Areas of localized low-level convergence emerge.

CI becomes more probable in these localized area.

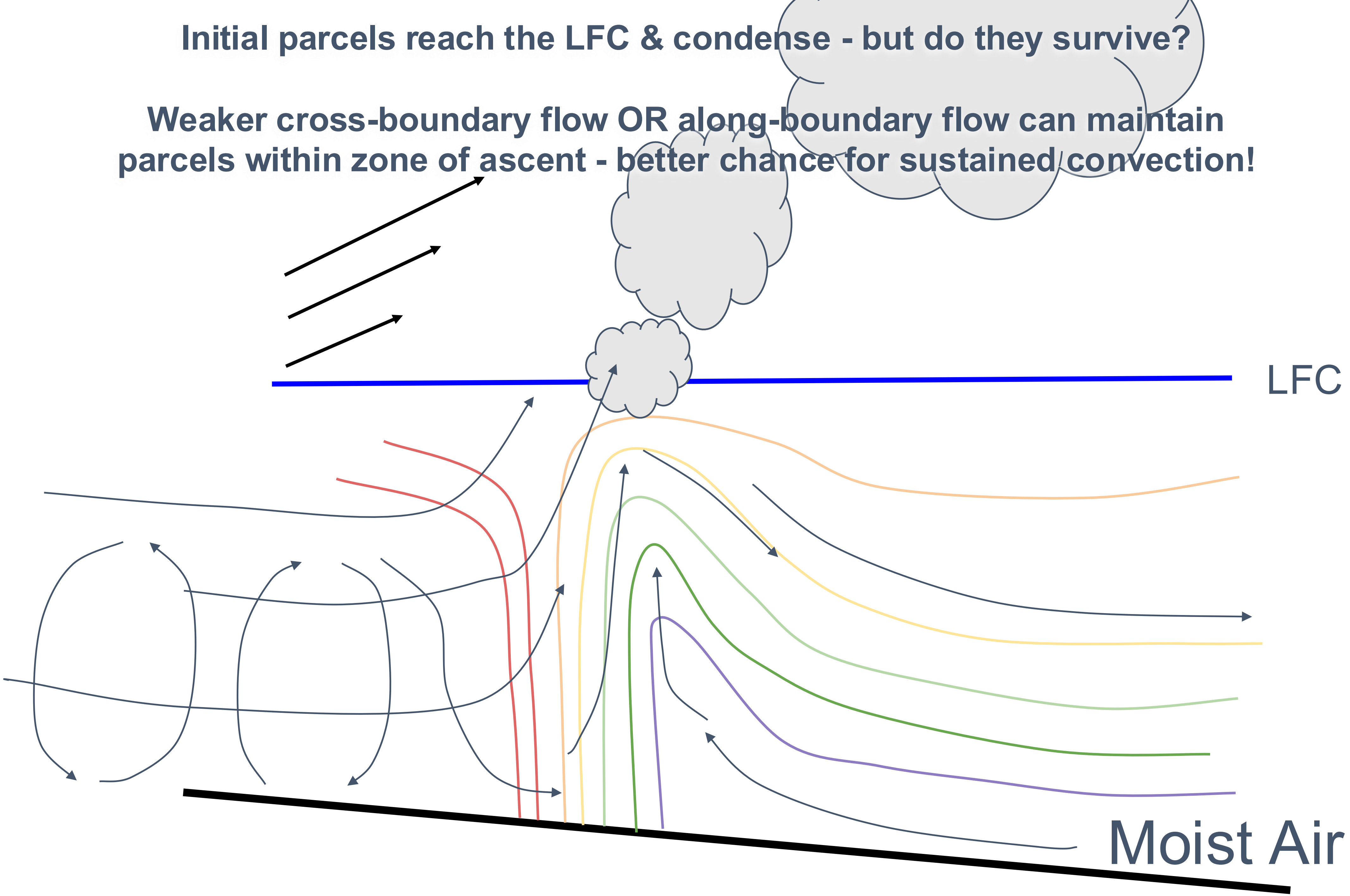
Initial parcels reach the LFC & condense - but do they survive?

Strong cross-boundary flow may displace parcels away from ascent before convection can be self-sustained.

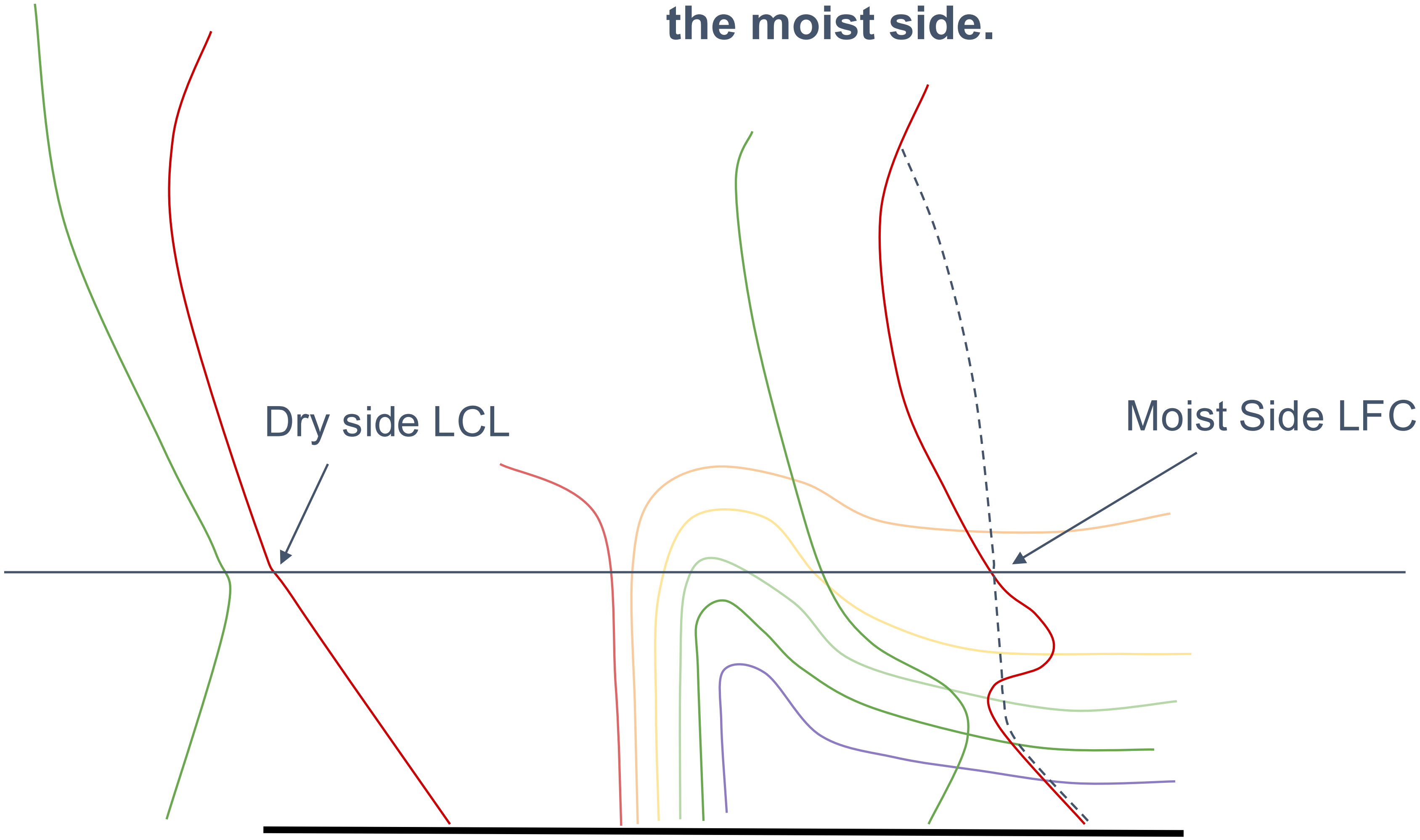


**Initial parcels reach the LFC & condense - but do they survive?**

**Weaker cross-boundary flow OR along-boundary flow can maintain parcels within zone of ascent - better chance for sustained convection!**



**The question becomes whether the circulation can lift parcels to their LFC. The depth of the ascent can be estimated by comparing the height of the LCL on the dry side to the LFC on the moist side.**




Favorable for convective initiation

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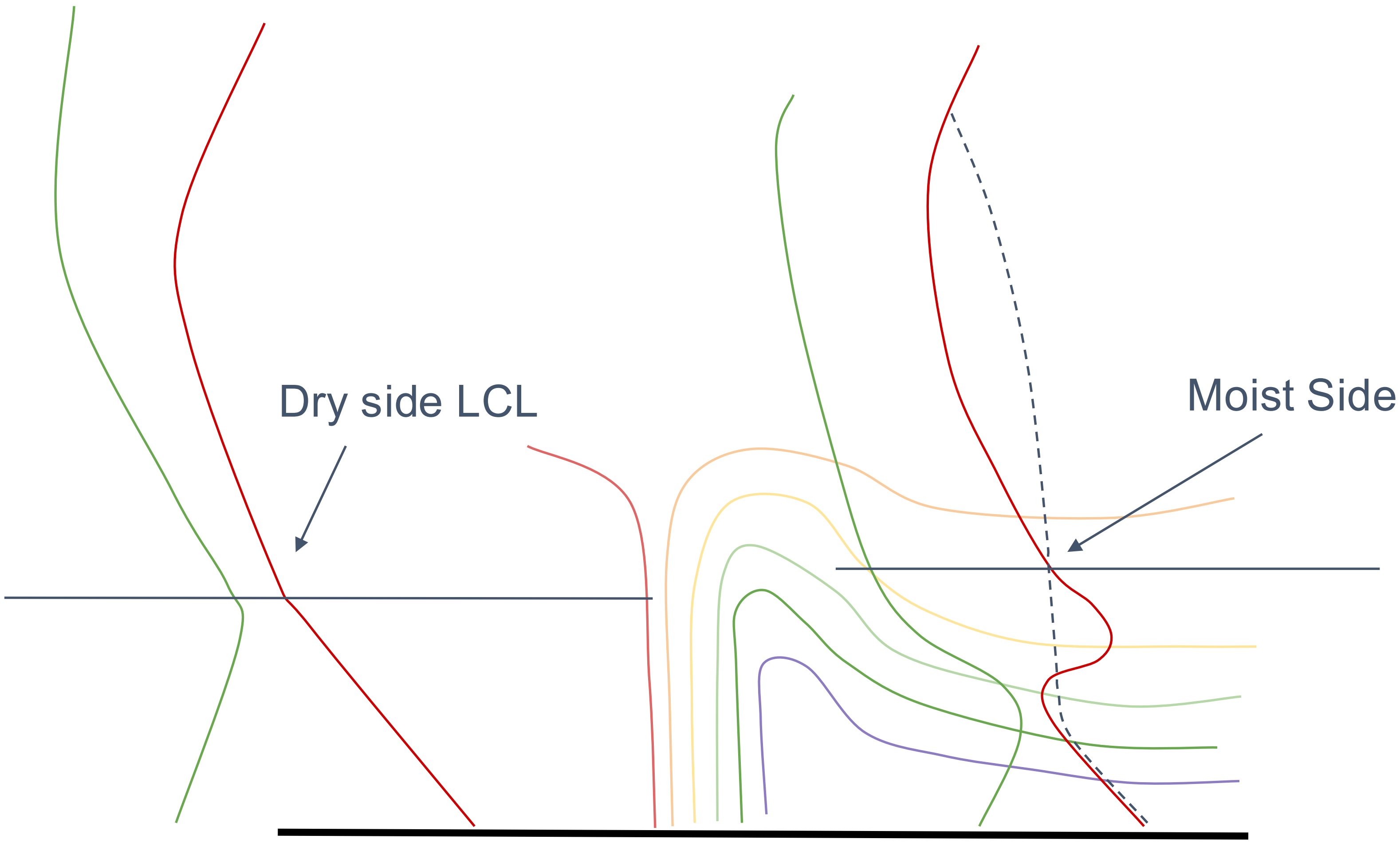
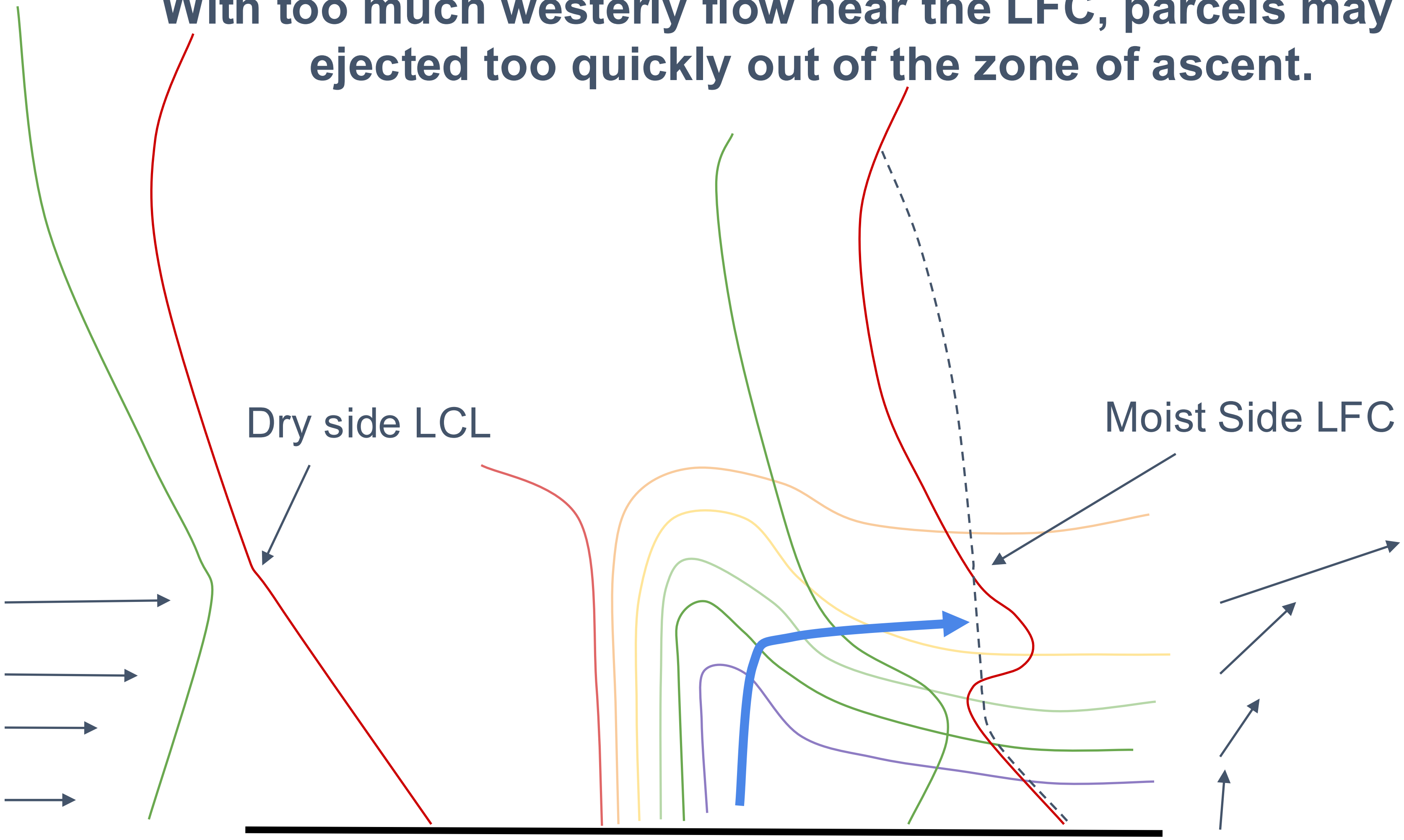



Unfavorable for convective initiation

**The other consideration is how long will air parcels reside within the zone of ascent. If they are ejected from the zone prematurely, they may not reach their LFCs.**

**With too much westerly flow near the LFC, parcels may be ejected too quickly out of the zone of ascent.**

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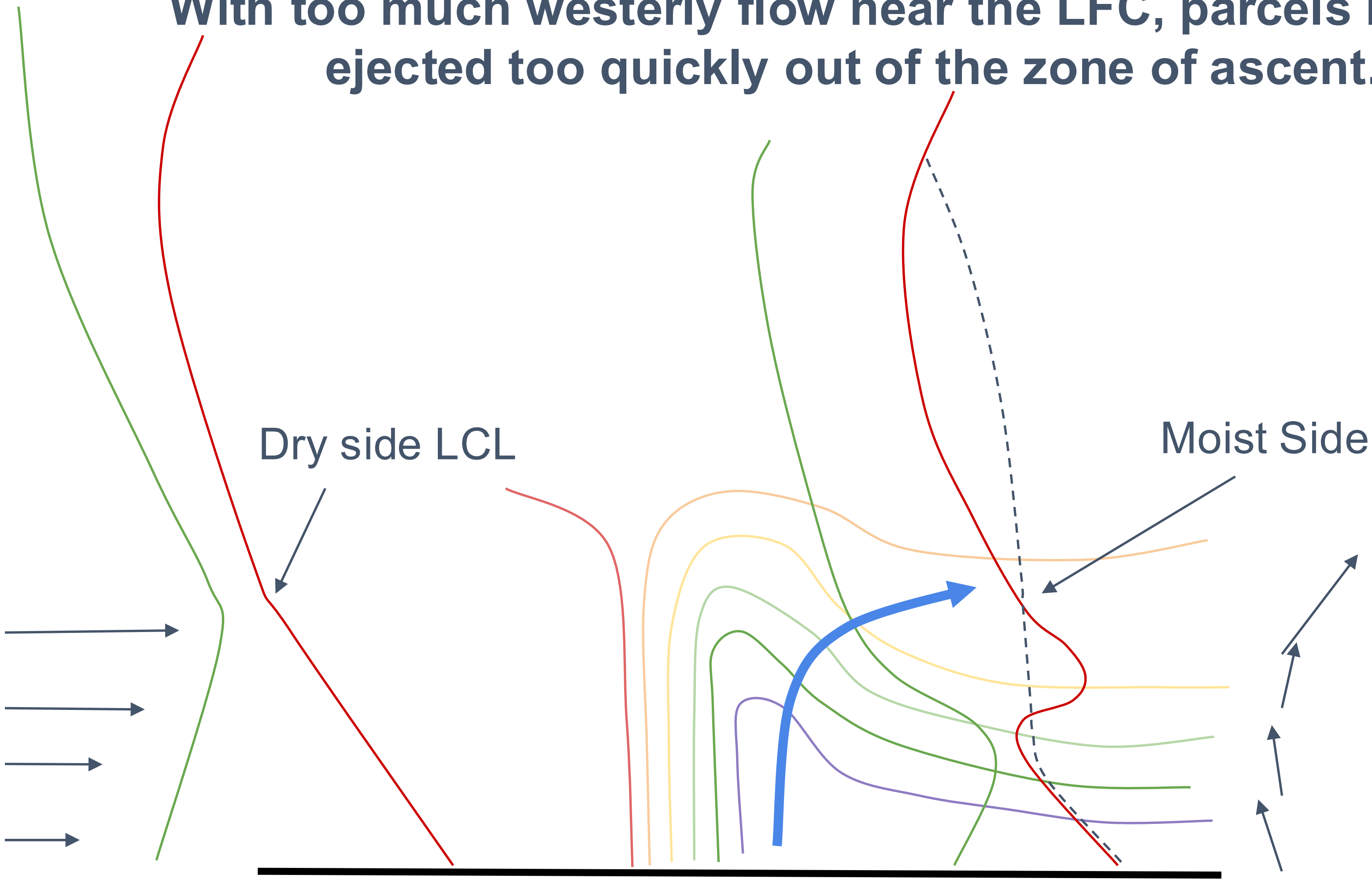
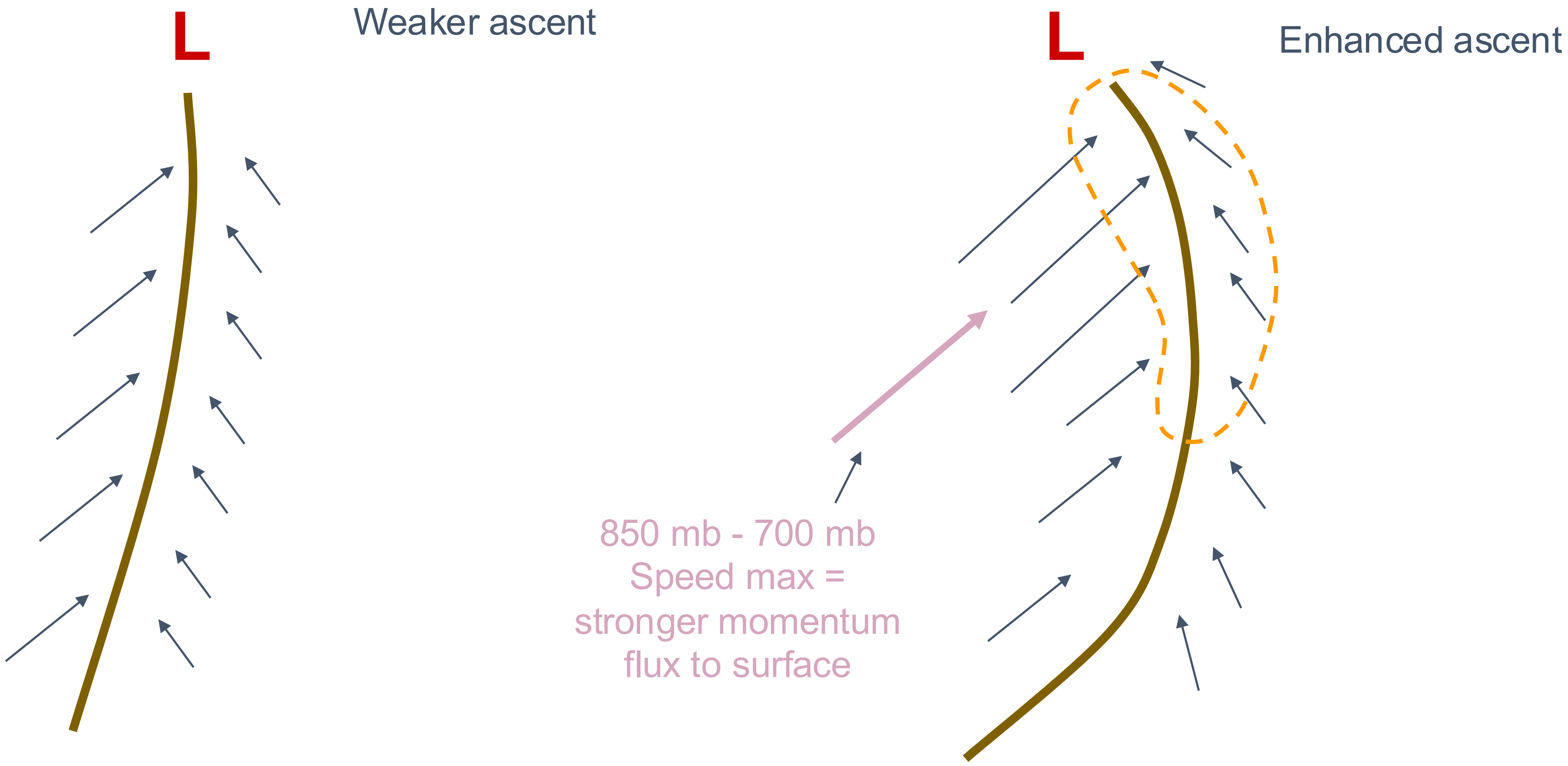
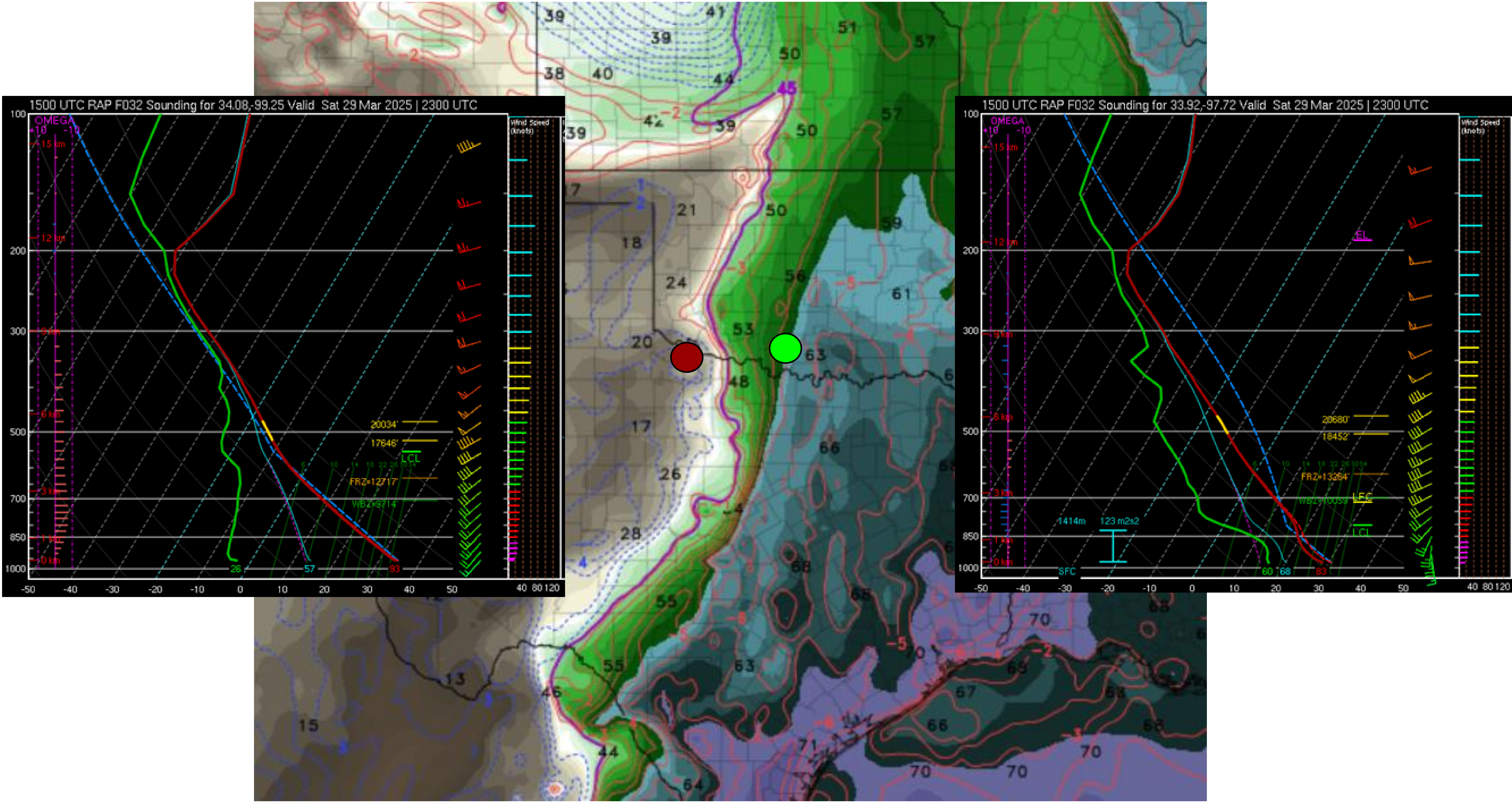
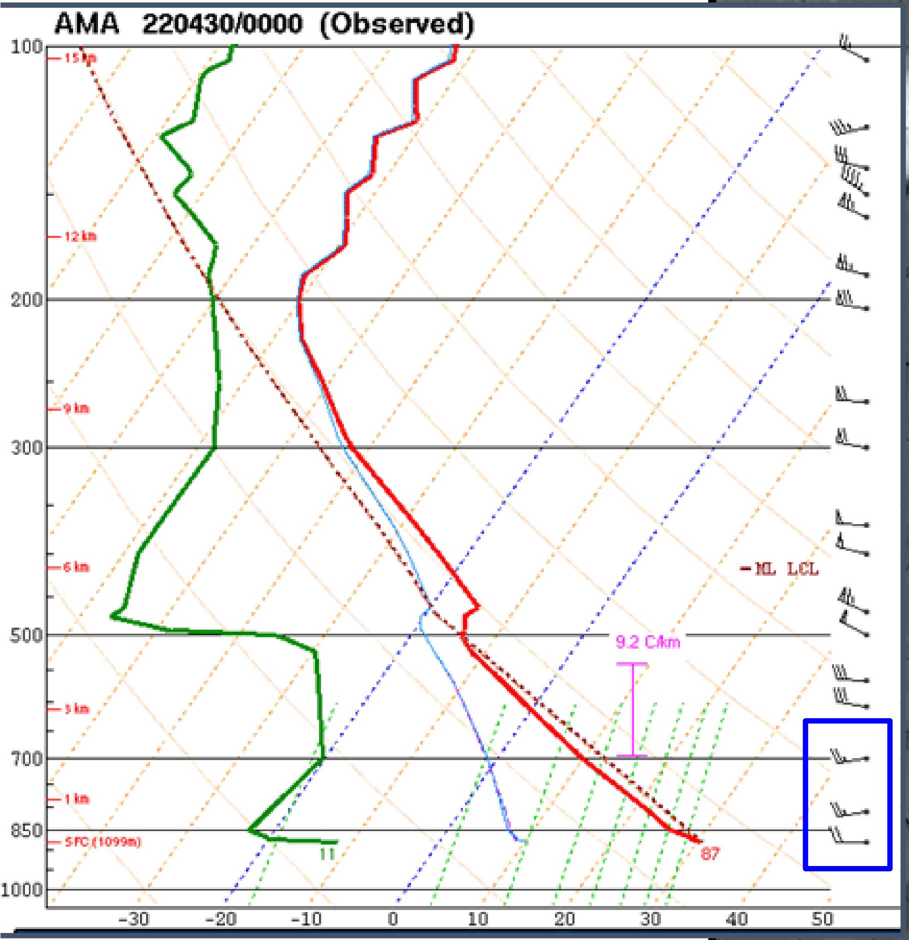


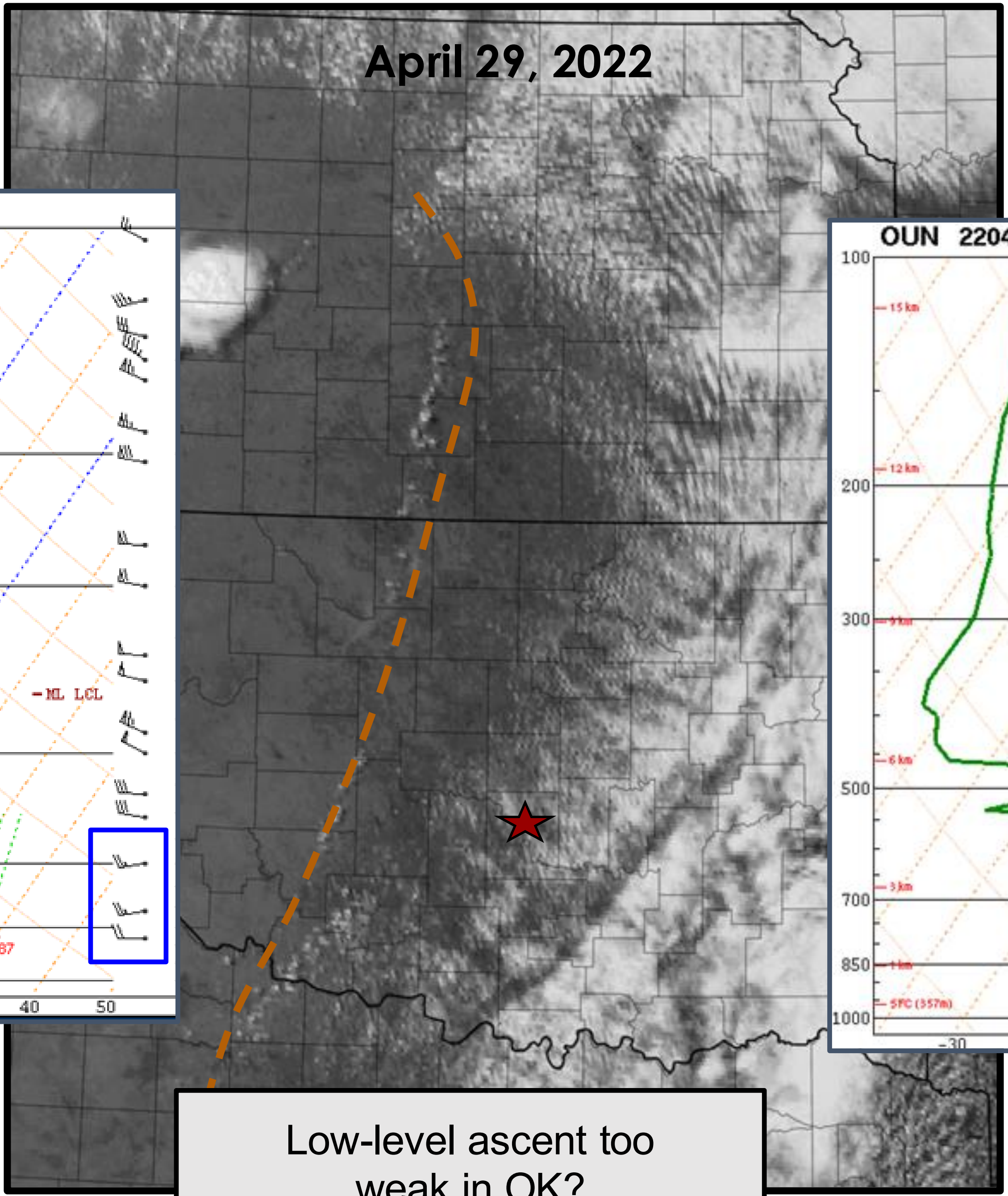

Unfavorable for convective initiation

# Lift along the dryline can be enhanced simply by mass convergence associated with the eastward progression of the boundary.

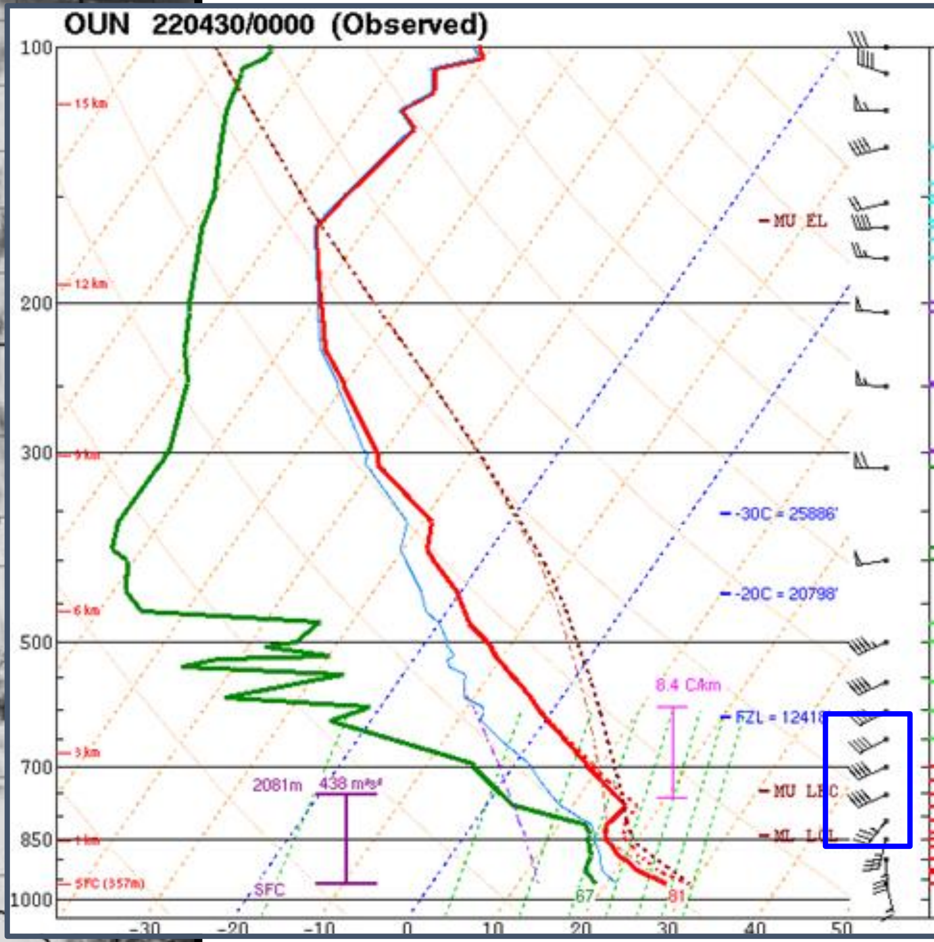



1500 UTC RAP F032 Sounding for 34.08,-99.25 Valid Sat 29 Mar 2025 | 2300 UTC
OMEGA
20034'
17646'
LCL
FRZ=12717'
WBZ=9714'
26
57
93
Wind Speed (knots)
1500 UTC RAP F032 Sounding for 33.92,-97.72 Valid Sat 29 Mar 2025 | 2300 UTC
OMEGA
EL
20680'
18452'
FRZ=13264'
WBZ=10059'
LFC
LCL
1414m
123 m2s2
SFC
60
68
83
Wind Speed (knots)



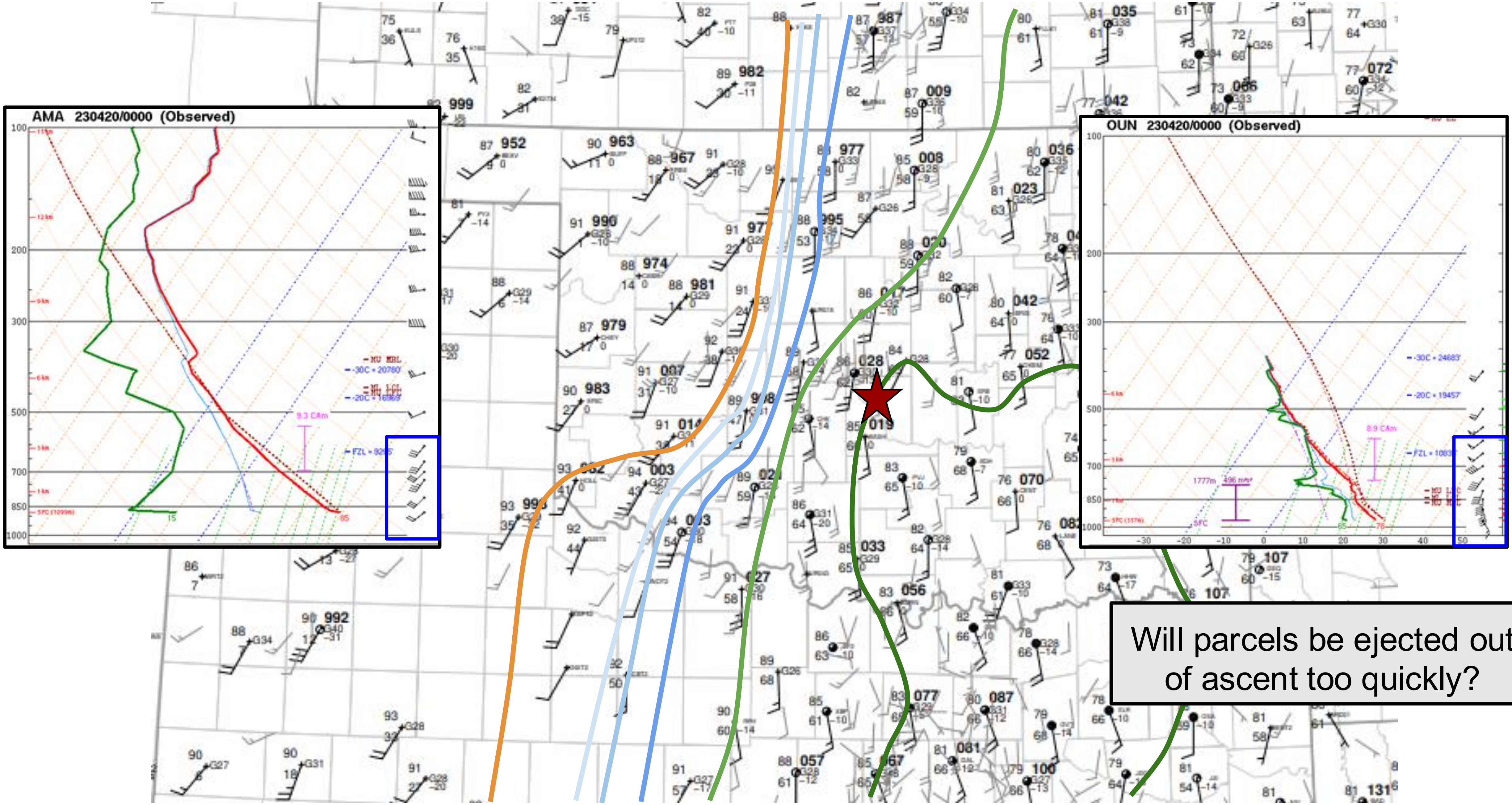




Low-level ascent too weak in OK?




Parcels ejected out of ascent too quickly?

# April 19, 2023

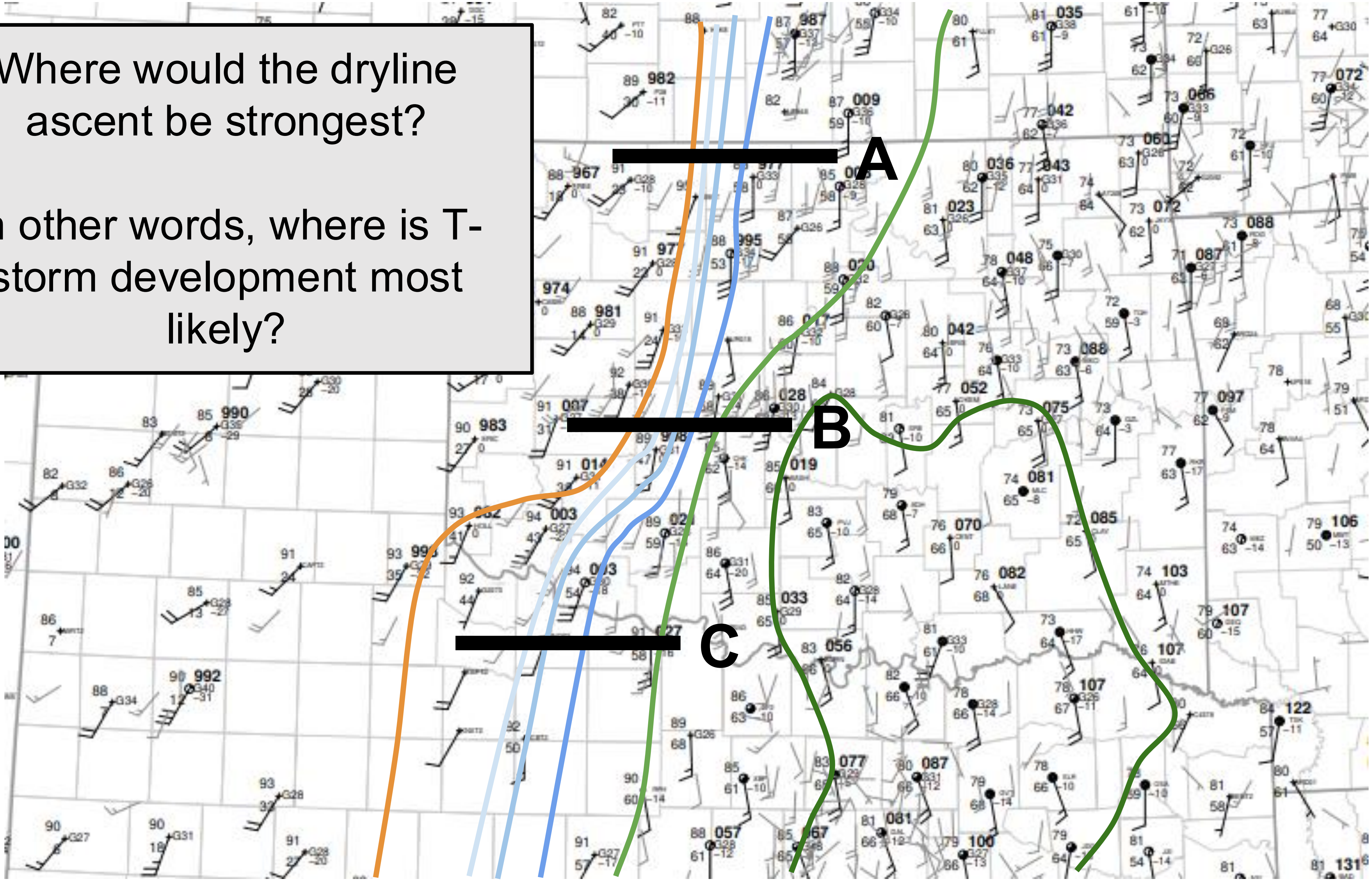



Will parcels be ejected out of ascent too quickly?

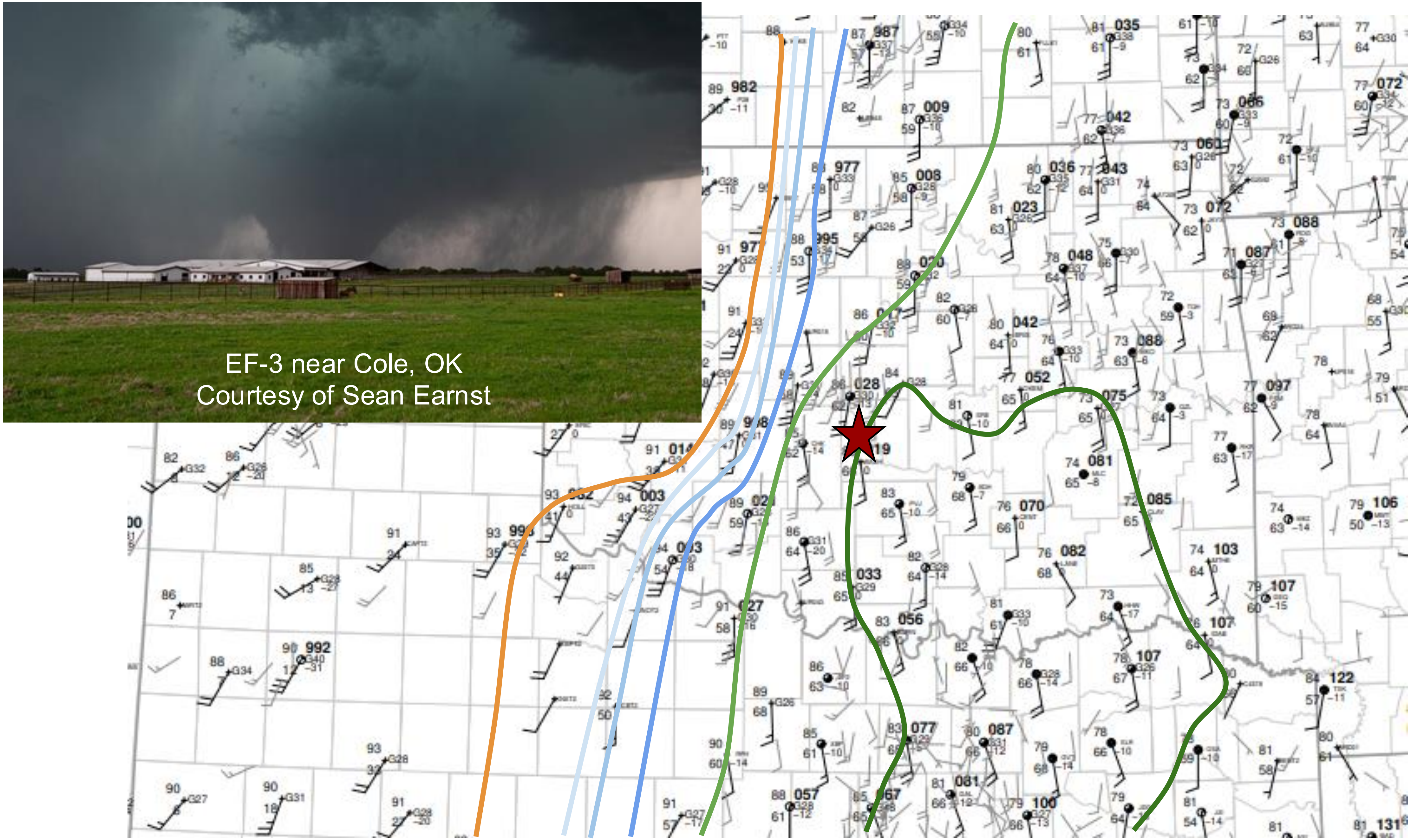
## April 19, 2023

Where would the dryline ascent be strongest?

In other words, where is T-storm development most likely?



# April 19, 2023



# Back to QG Omega…

# Physical Intuition: Vorticity and Divergence

Another example: https://i.imgur.com/7h5GvdK.mp4

Notice what happens when the weights (i.e. mass) are brought inward.

Spin (i.e. vorticity) increases!

$$\frac{d(\zeta_g + f)}{dt} = f_0 \frac{\partial \omega}{\partial p}$$

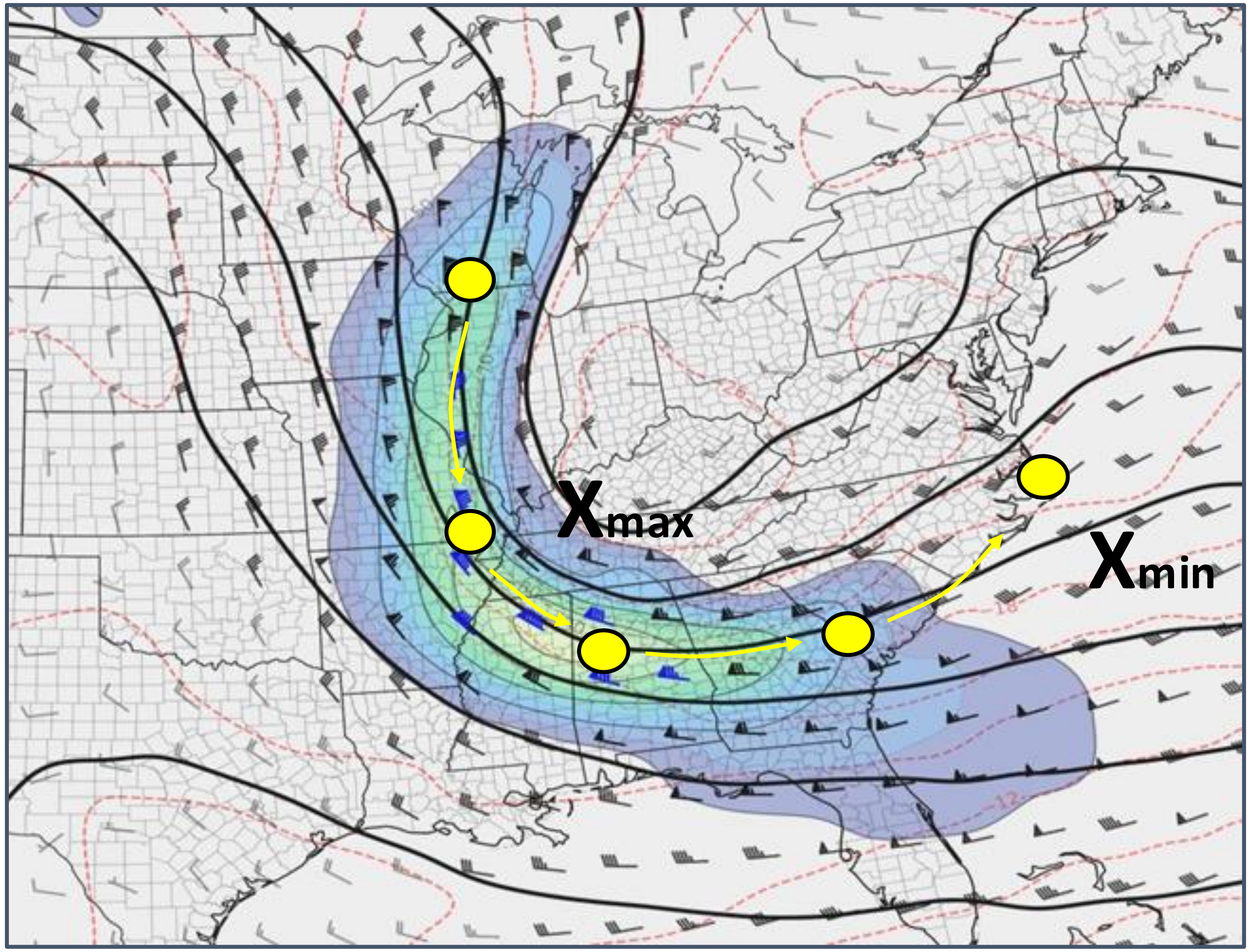
Change in a parcel's vorticity (spin)

Vertical acceleration

but by mass conservation this is also convergence/divergence!

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial \omega}{\partial p} = 0$$

# Physical Intuition: Vorticity and Divergence




Let's imagine we have this 500 mb chart.

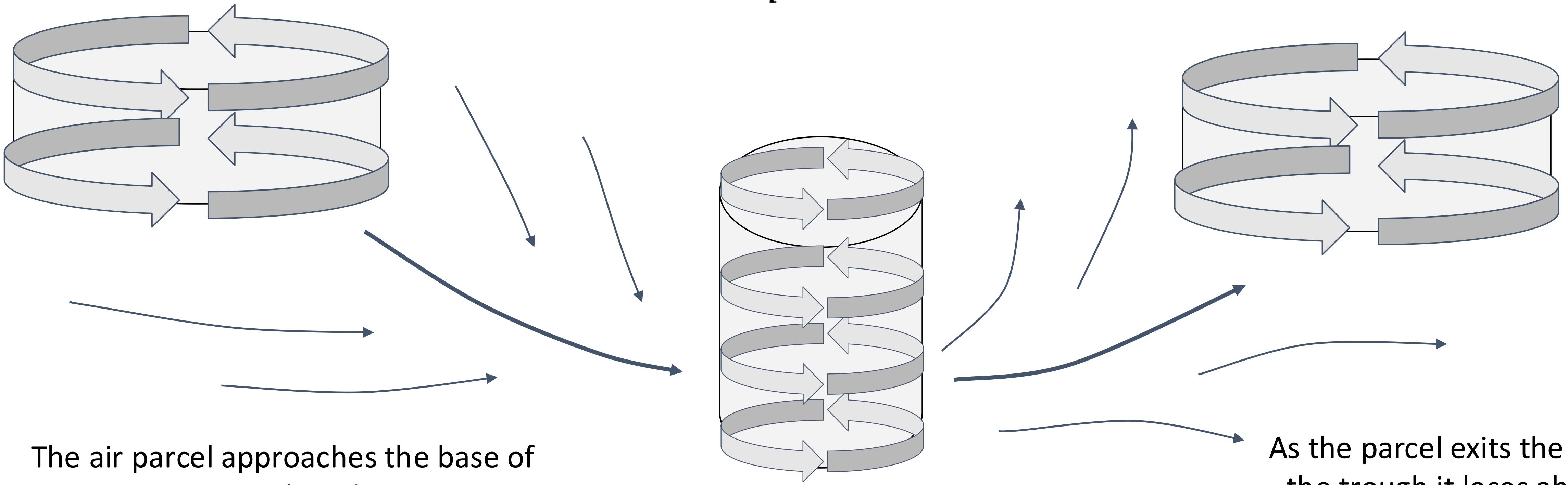
Let's assume that a parcel will propagate through the mean flow faster than the speed of the upper-wave/jet-streak.

This means that the parcel's vorticity will change as it moves through the trough.

$$\frac{d(\zeta_g + f)}{dt} = f_0 \frac{\partial \omega}{\partial p}$$

# Physical Intuition: Vorticity and Divergence

$$\frac{d(\zeta_g + f)}{dt} = f_0 \frac{\partial \omega}{\partial p} \qquad \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial \omega}{\partial p} = 0$$



The air parcel approaches the base of an upper trough and acquires absolute vorticity

As the parcel exits the base of the trough it loses absolute vorticity.

# Physical Intuition: Vorticity and Divergence

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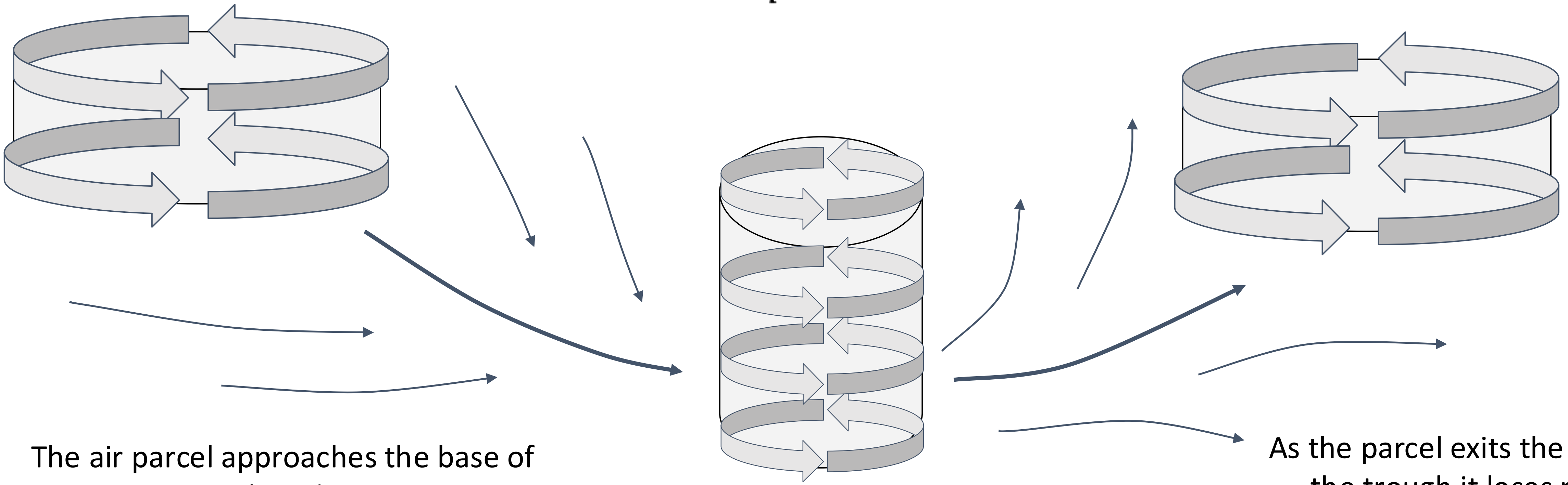
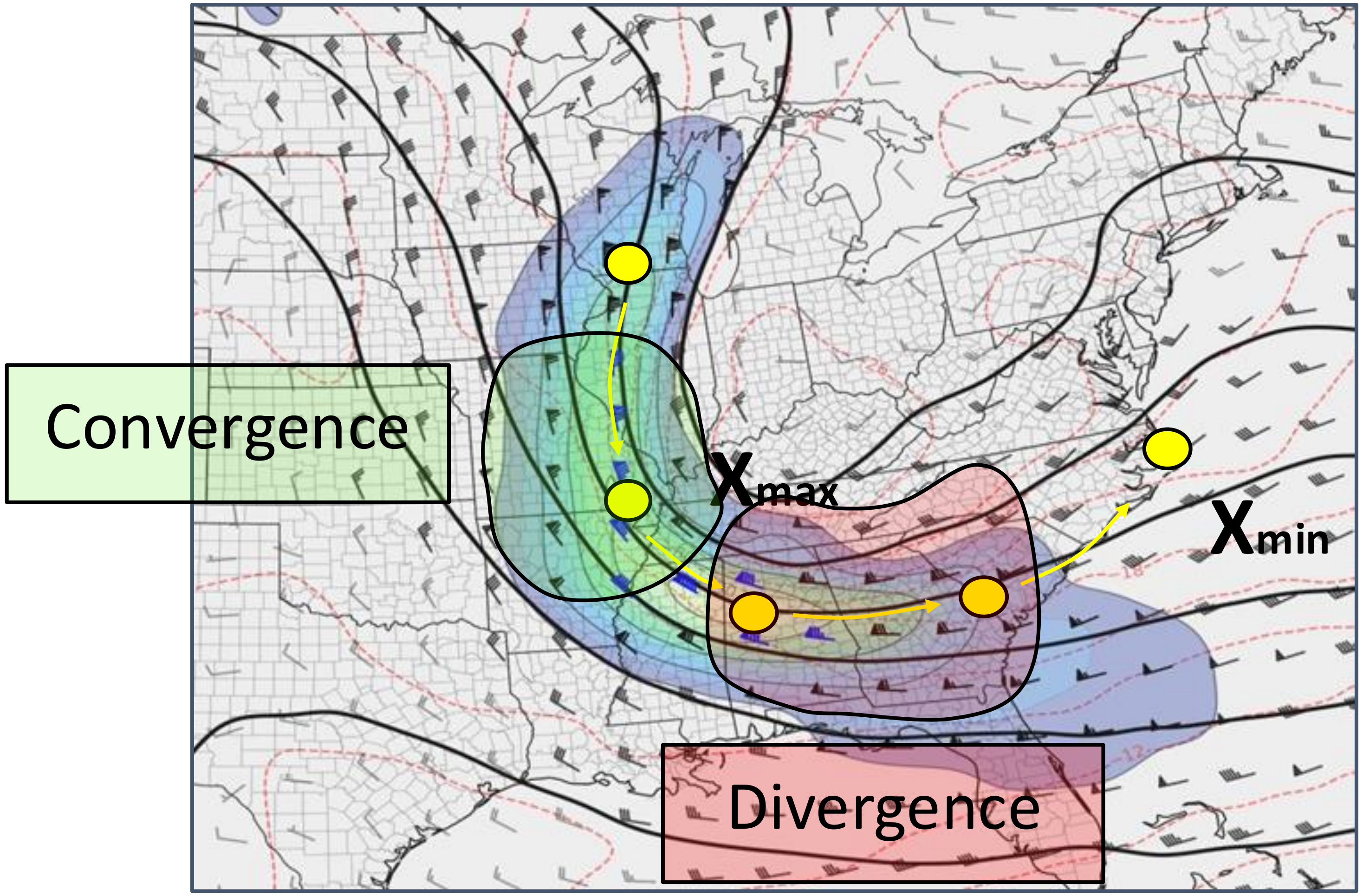


The air parcel approaches the base of an upper trough and acquires mass (convergence)

As the parcel exits the base of the trough it loses mass (divergence)

# Physical Intuition: Vorticity and Divergence

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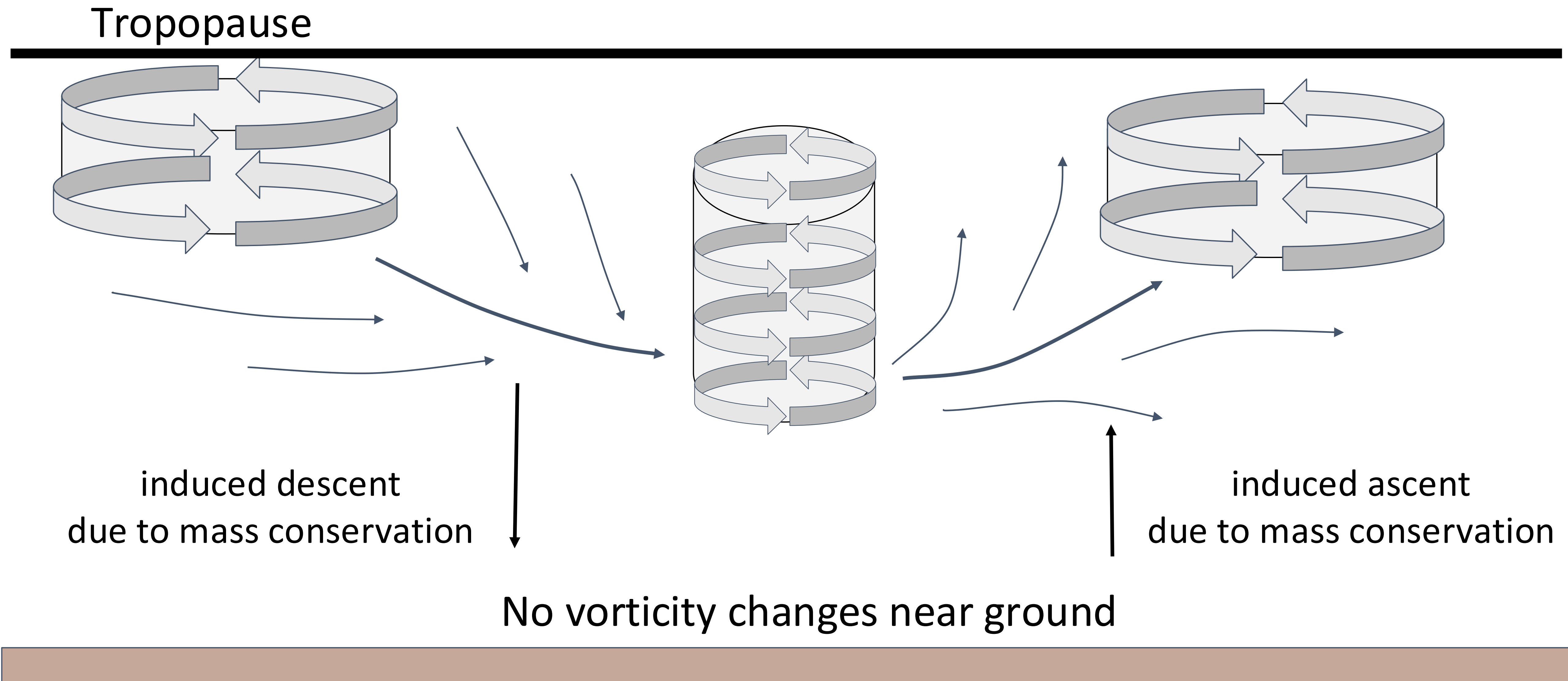
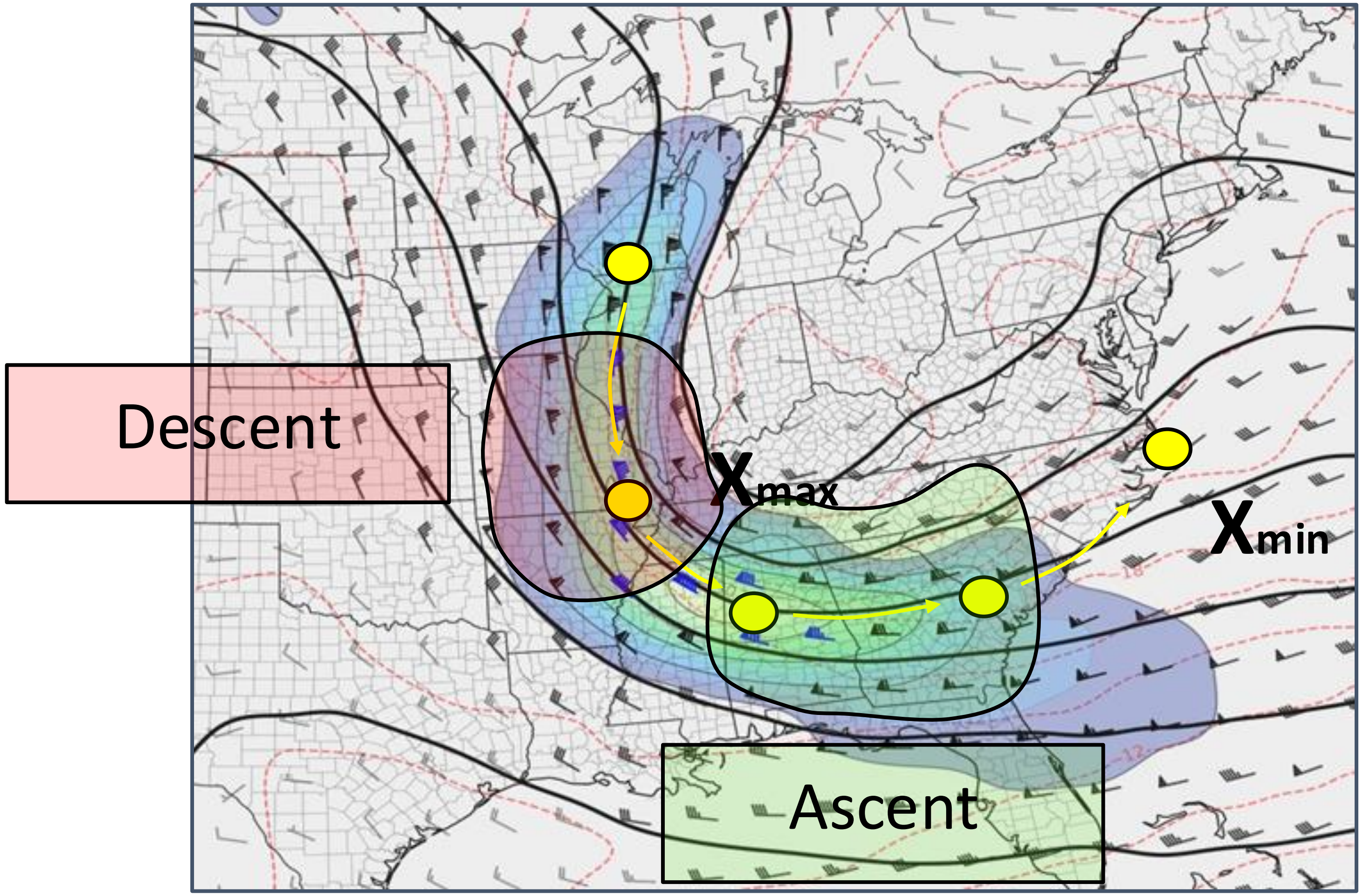
$$\frac{d(\zeta_g + f)}{dt} = f_0 \frac{\partial \omega}{\partial p}$$

**So then how do we get ascent?**

# Physical Intuition: Vorticity and Divergence



# Physical Intuition: Vorticity and Divergence




Differential changes in vorticity with height induce upward/downward motions.

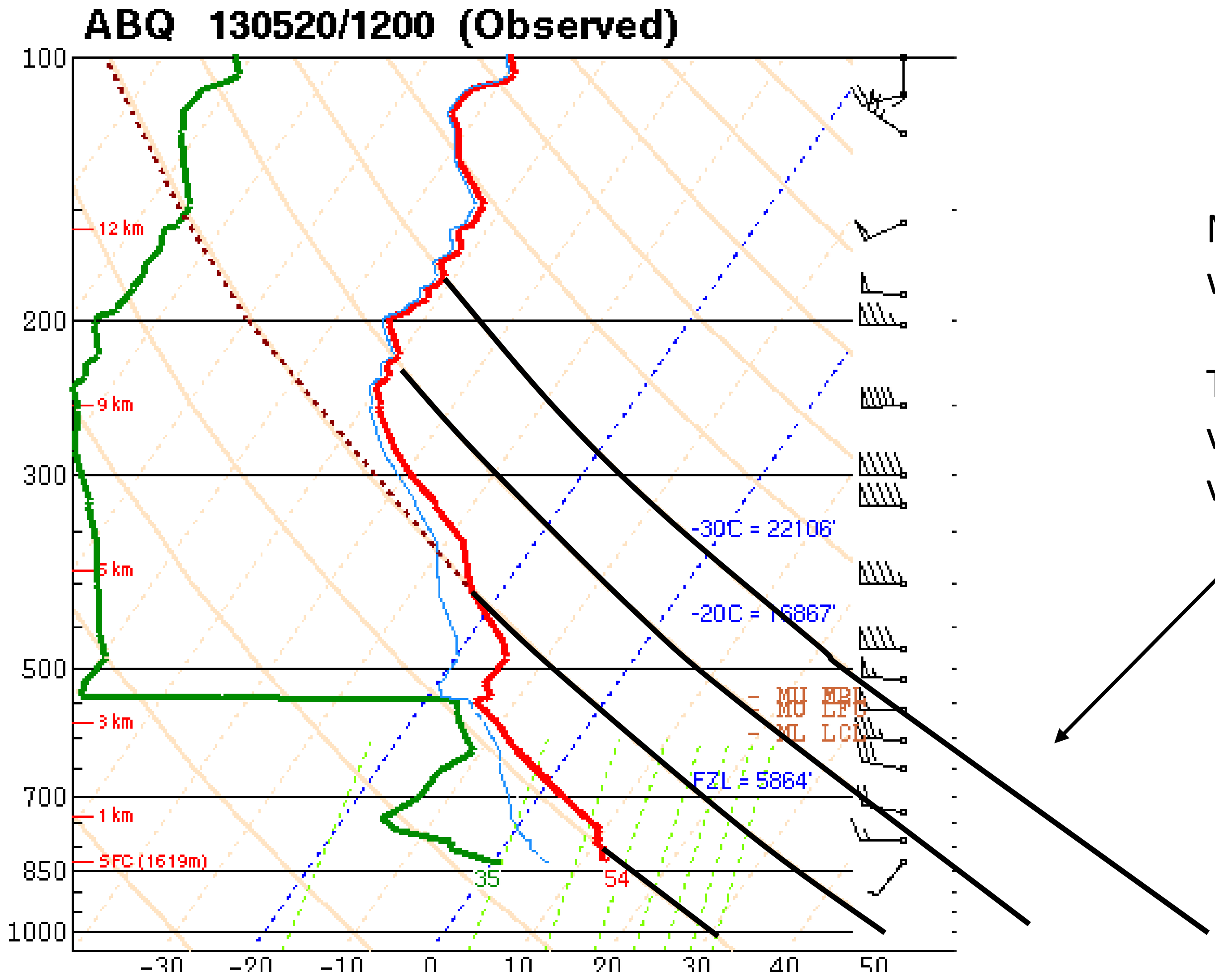
The direction of vertical motion is determined by which level has the strongest change in vorticity (and the sign).

In general, it's safe to assume that vorticity changes (i.e. advection) near ground is weaker than vorticity changes aloft.

Not always the case in some scenarios.

$$\frac{d(\zeta_g + f)}{dt} = f_0 \frac{\partial \omega}{\partial p}$$

# Physical Intuition: Temperature Advection & Ascent

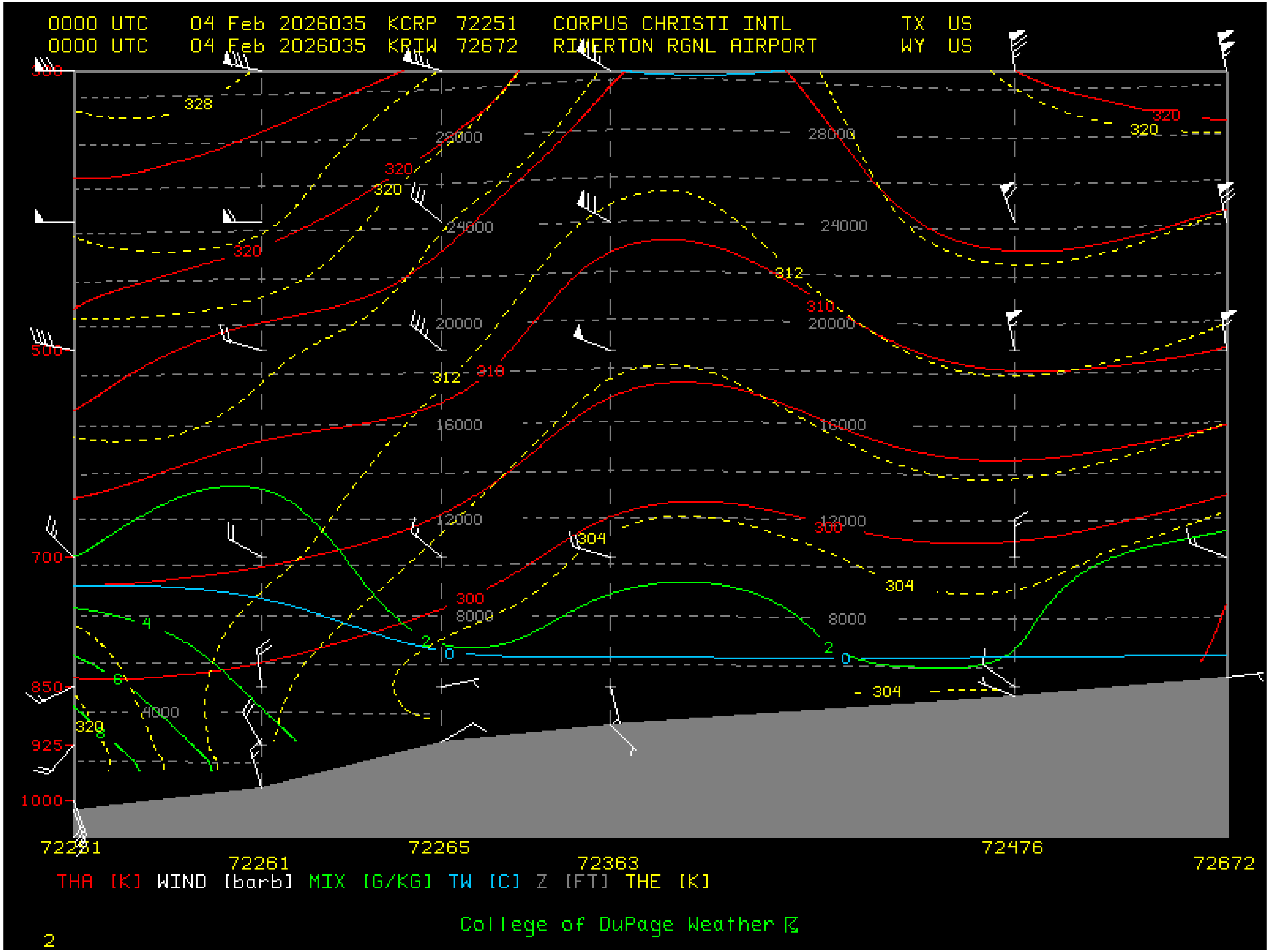



Let's start with isentropes!

Notice that the potential temperatures increase with height!

This means we can use potential temperature values and/or isentropes as an approximate vertical coordinate.

Focus on the red lines



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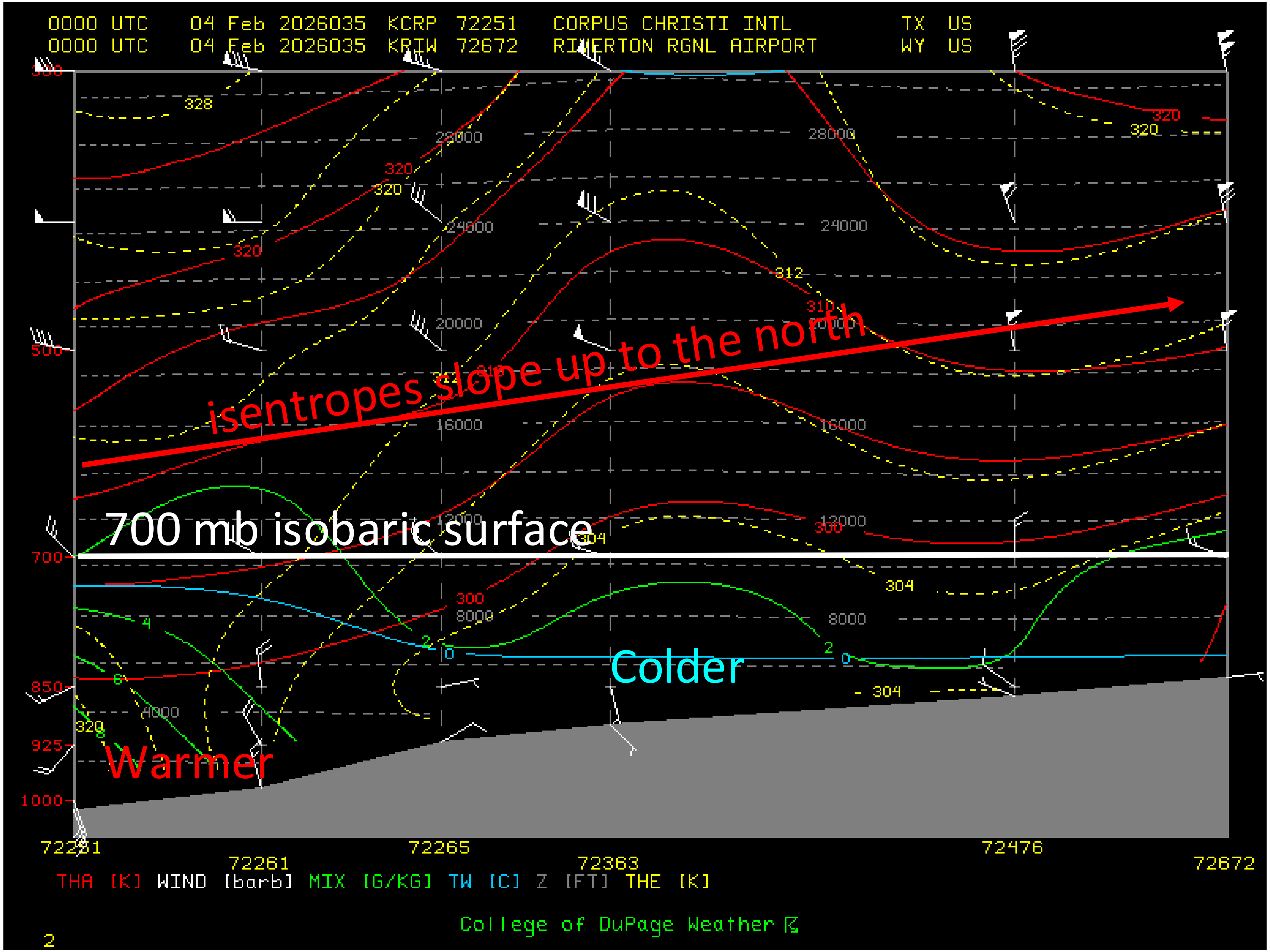

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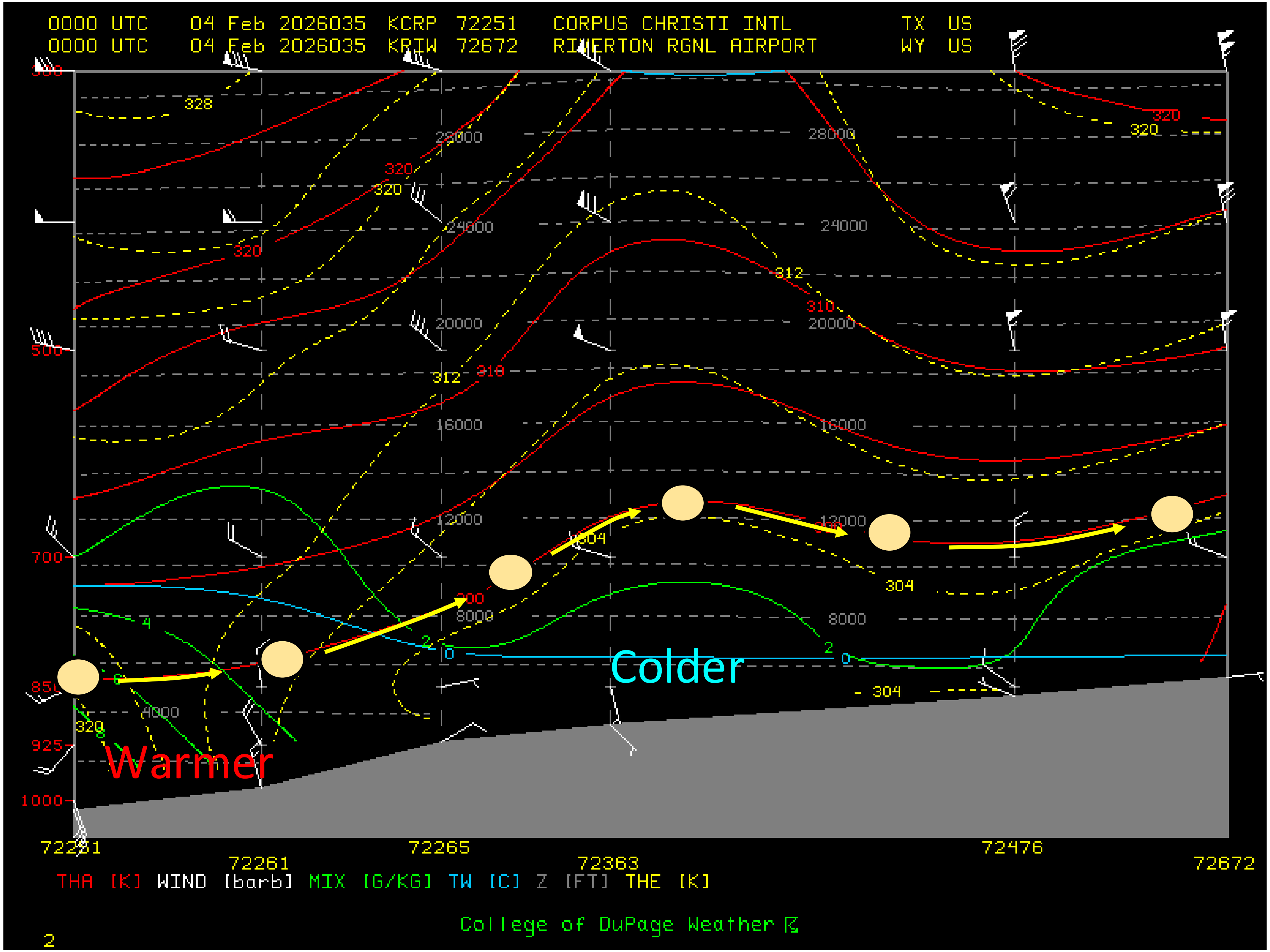
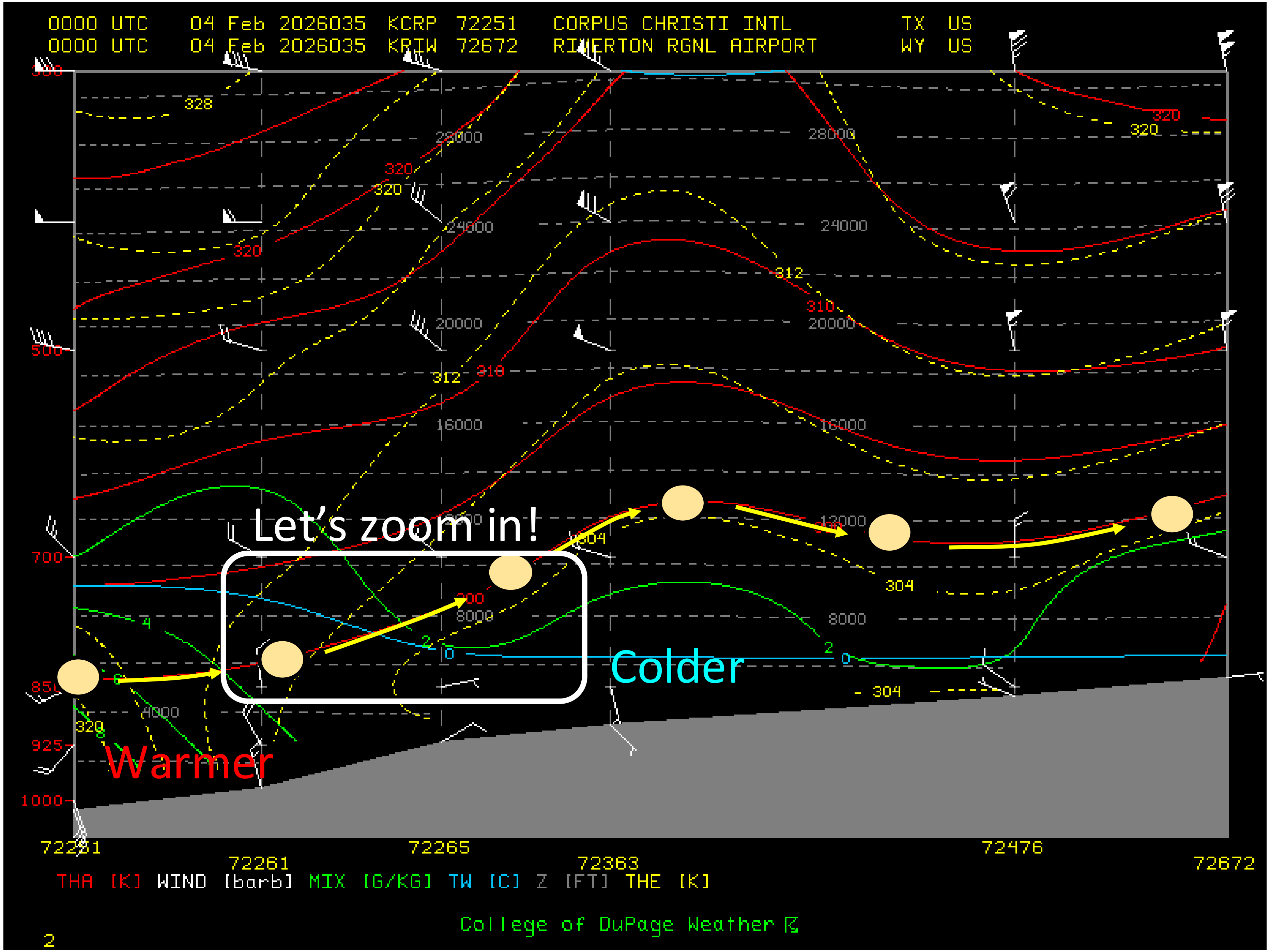


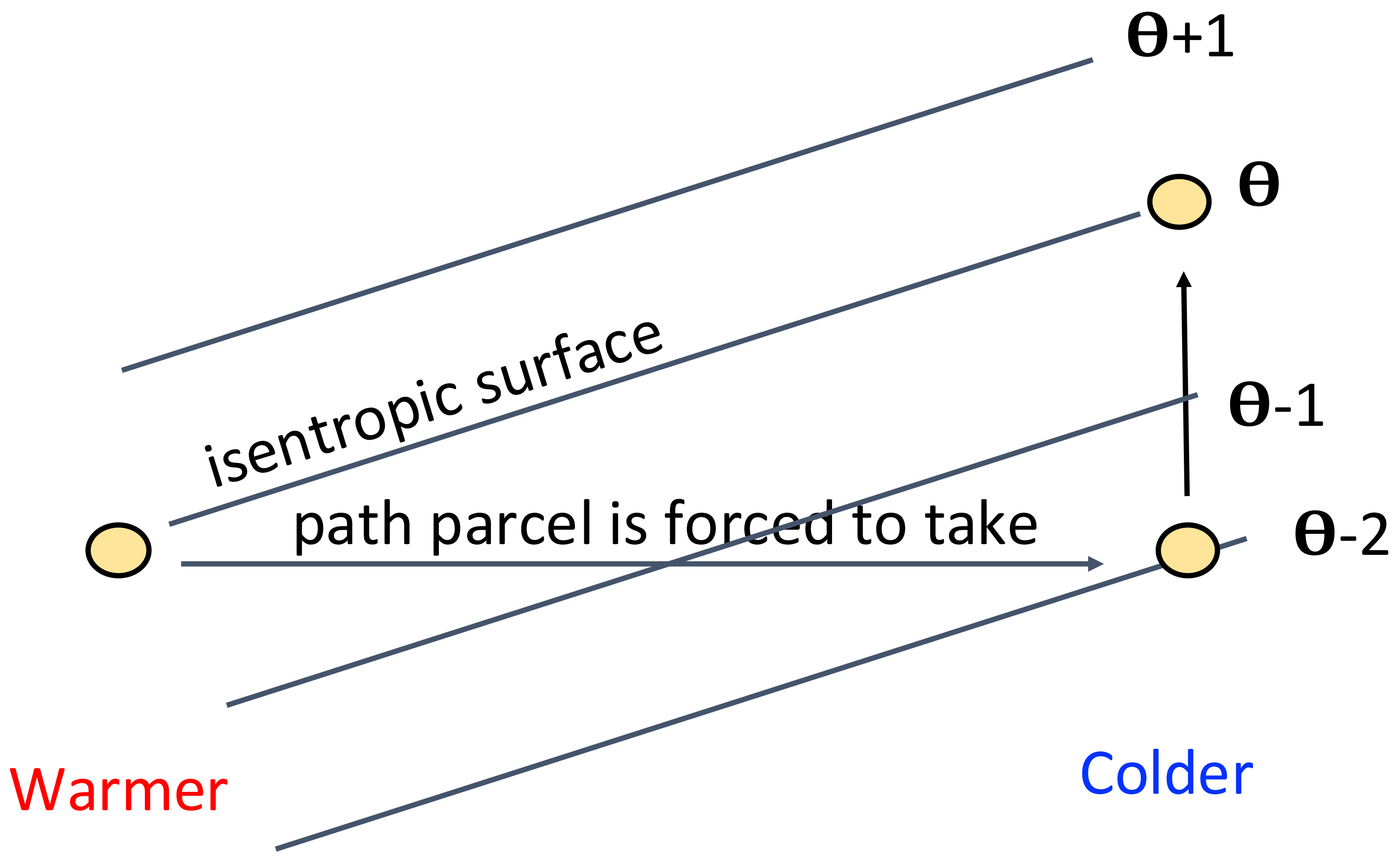

# Path a parcel would take on its trek north

# Focus on the red lines

Note what's happening:

- parcel starts at 850 mb
  - Is being pushed northward into colder air.
- Increases its height to above 700 mb.



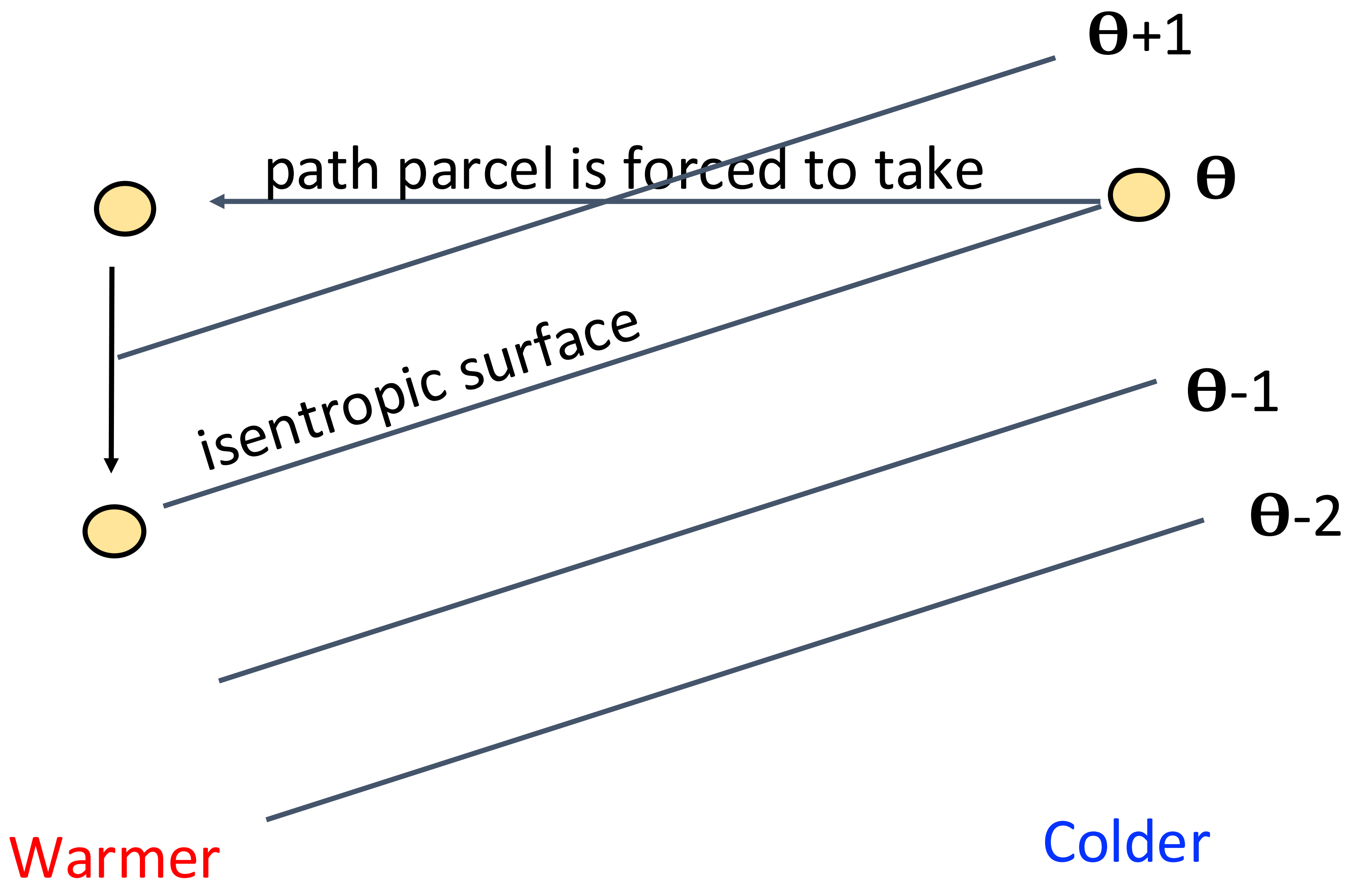



Our parcel is displaced horizontally.

Because of the sloped isentropic surfaces, it is now warmer than its environment.

Adiabatic ascent must occur to restore the parcel to its isentrope.

This response is adiabatic ascent due to warm advection!




The opposite is true for cold air advection.

Parcel is displaced to a warmer isentropic surface.

Adiabatic descent must occur to restore the parcel to its original isentropic surface.

# QG Omega Equation (Traditional form)

See Bluestein Vol1 p329.

$$\left(\nabla_p^2 + \frac{f_0^2}{\sigma}\frac{\partial^2}{\partial p^2}\right)\omega = -\frac{f_0}{\sigma}\frac{\partial}{\partial p}\left[-\boldsymbol{V_g}\cdot\boldsymbol{\nabla_p}(\zeta_g + f)\right] - \frac{R_d}{\sigma p}\nabla_p^2(-\boldsymbol{V_g}\cdot\boldsymbol{\nabla_p}T)$$

- $2^{nd}$ derivative in space of $\omega$
- Proportional to negative of $\omega$
- RHS ("forcing") positive, $\omega$<0 (ascent)
- RHS ("forcing") negative, $\omega$>0 (descent)

- Differential advection of geostrophic absolute vorticity by the geostrophic wind
- Cyclonic vorticity advection increasing with height, $\omega$<0 (ascent)
- Anticyclonic vorticity advection increasing with height, $\omega$>0 (descent)

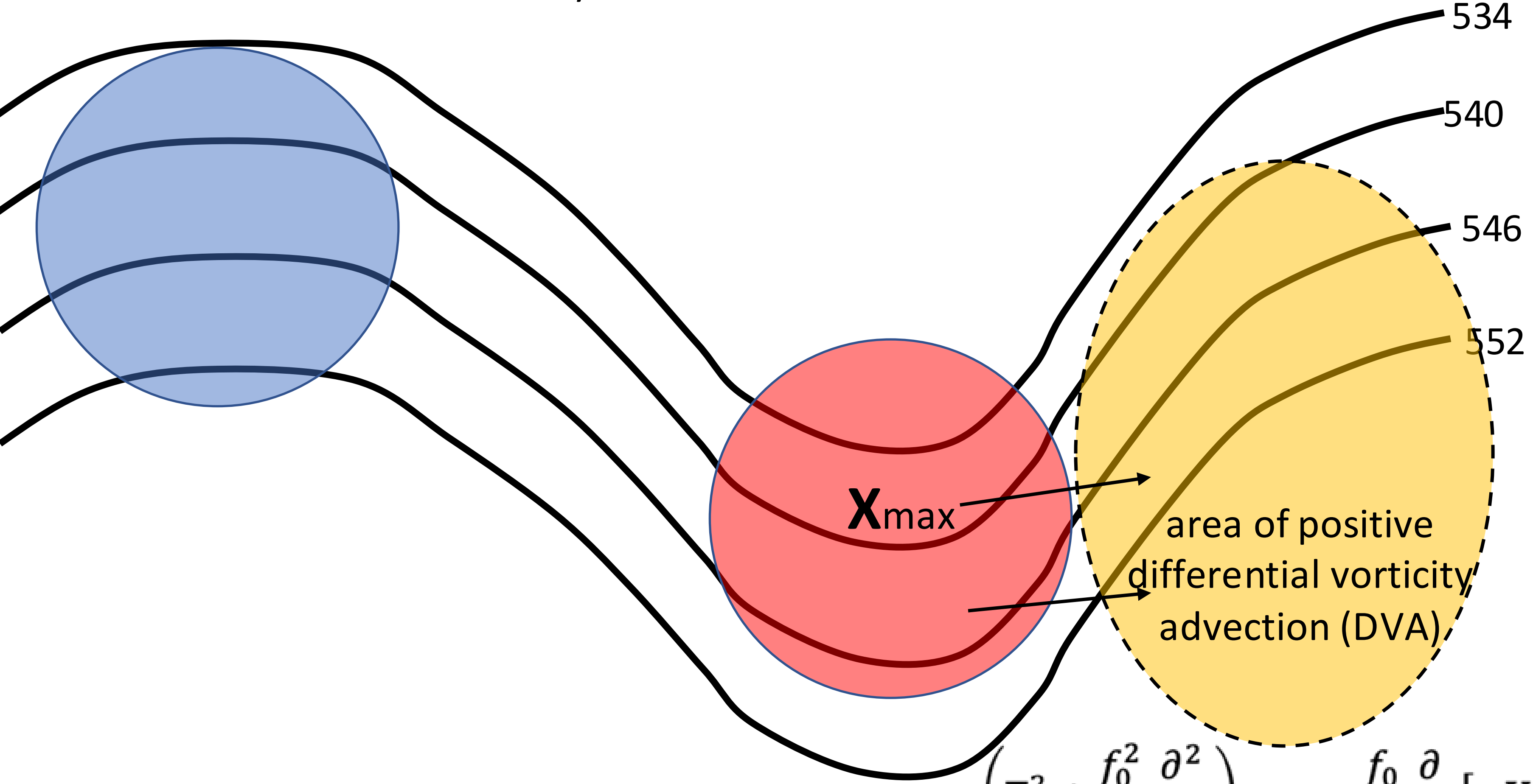
- Laplacian of temperature advection by geostrophic wind
- Warm advection, $\omega$<0 (ascent)
- Cold advection, $\omega$>0 (descent)

$$\omega = \sin(\pi p/p_0)\sin(kx)\sin(ly)$$

$$\left(\nabla_p^2 + \frac{f_0^2}{\sigma}\frac{\partial^2}{\partial p^2}\right)\omega \simeq -\left[(k^2 + l^2) + \frac{f_0^2}{\sigma}\frac{\pi^2}{p_0^2}\right]\omega$$

# QG Omega Equation: differential vorticity advection term

Differential advection of geostrophic absolute vorticity by the geostrophic wind
Assume vorticity advection near surface = 0.




$-1 * -1 * (+DVA) = -1 * \omega$

$+DVA = -1 * \omega$

+DVA = ascent!

$$\left(\nabla_p^2 + \frac{f_0^2}{\sigma}\frac{\partial^2}{\partial p^2}\right)\omega = -\frac{f_0}{\sigma}\frac{\partial}{\partial p}\left[-\boldsymbol{V_g}\cdot\boldsymbol{\nabla_p}(\zeta_g + f)\right] - \frac{R_d}{\sigma p}\nabla_p^2(-\boldsymbol{V_g}\cdot\boldsymbol{\nabla_p}T)$$

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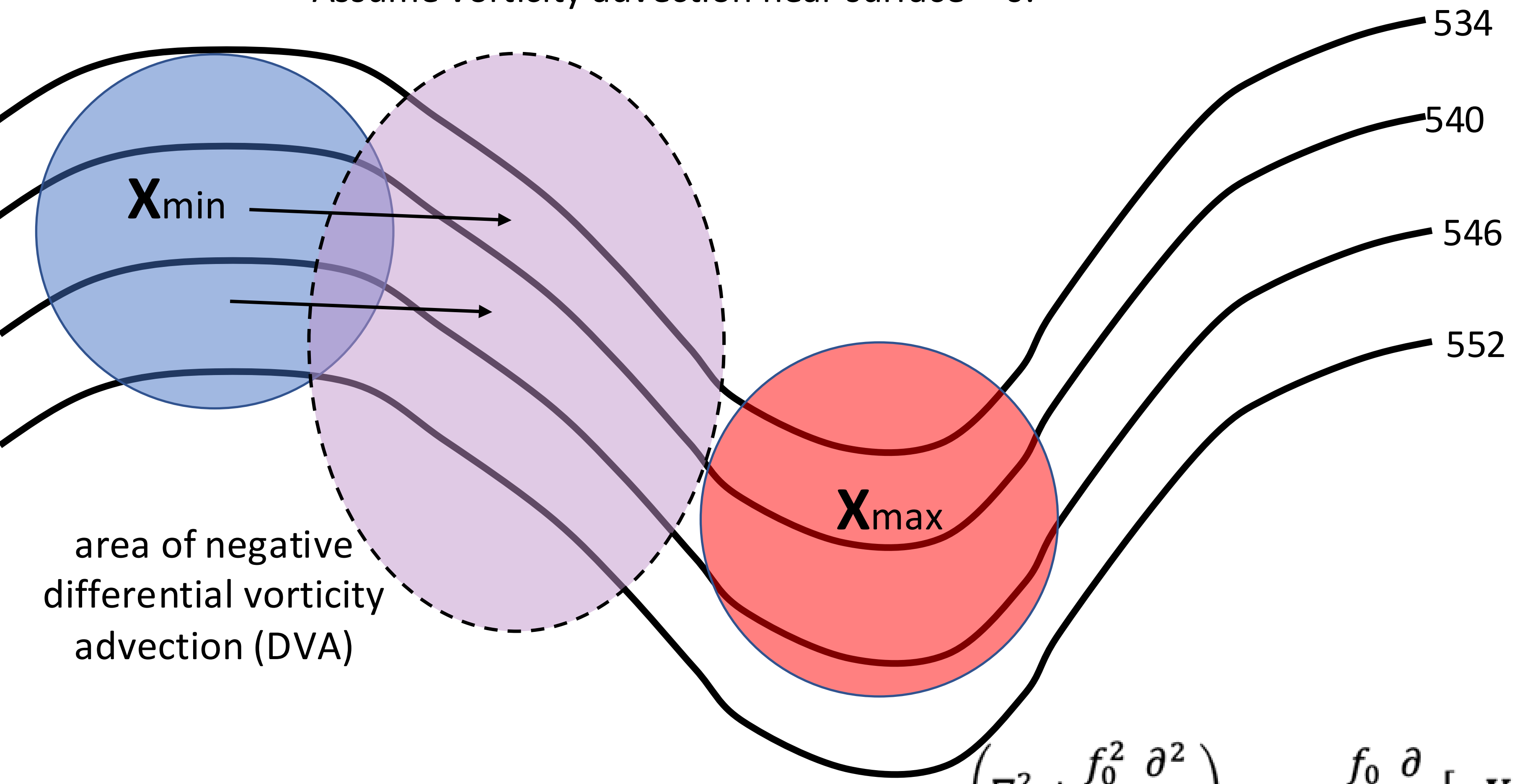


-1 * -1* (-DVA) = -1* ω

-DVA = -1* ω

DVA = ω

DVA = descent!

$$\left(\nabla_p^2 + \frac{f_0^2}{\sigma}\frac{\partial^2}{\partial p^2}\right)\omega = -\frac{f_0}{\sigma}\frac{\partial}{\partial p}\left[-\boldsymbol{V_g}\cdot\boldsymbol{\nabla_p}(\zeta_g + f)\right] - \frac{R_d}{\sigma p}\nabla_p^2(-\boldsymbol{V_g}\cdot\boldsymbol{\nabla_p}T)$$

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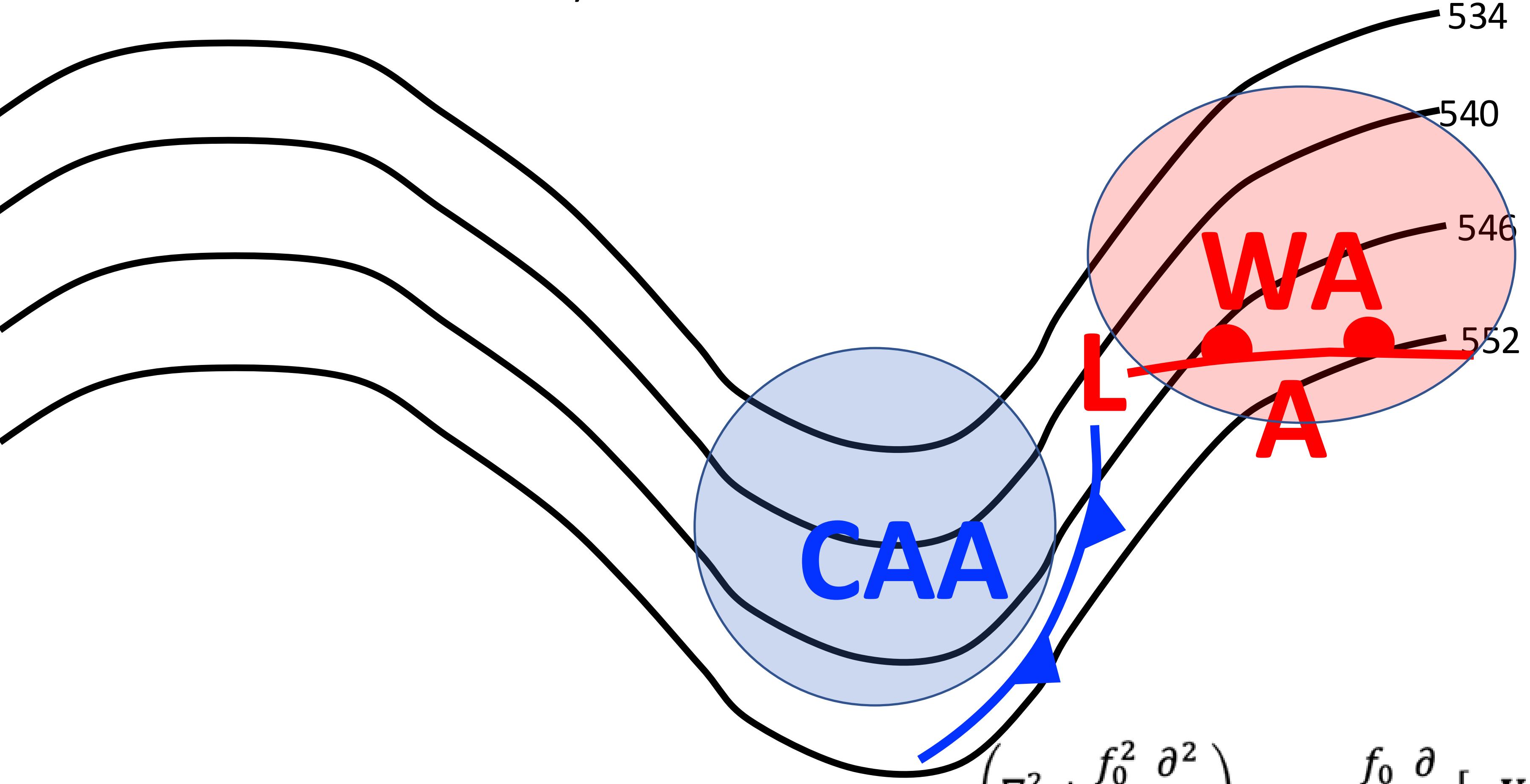


TA = Temperature Advection

-1 * -1* (+TA) = -1* ω

+TA = -1* ω

+TA = ascent!

$$\left(\nabla_p^2 + \frac{f_0^2}{\sigma}\frac{\partial^2}{\partial p^2}\right)\omega = -\frac{f_0}{\sigma}\frac{\partial}{\partial p}\left[-\boldsymbol{V_g}\cdot\boldsymbol{\nabla_p}(\zeta_g + f)\right] - \frac{R_d}{\sigma p}\nabla_p^2(-\boldsymbol{V_g}\cdot\boldsymbol{\nabla_p}T)$$

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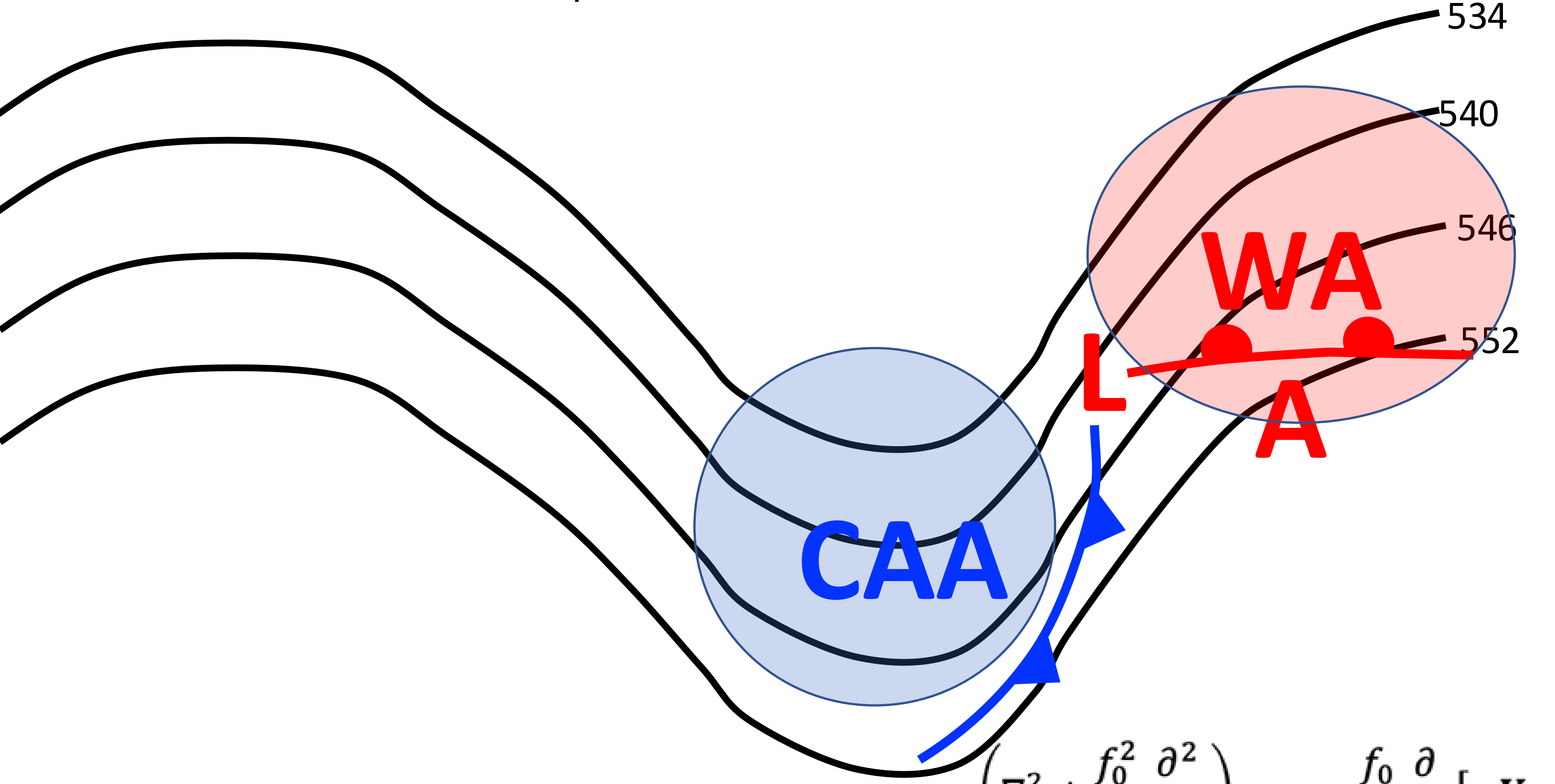


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-TA = -1* ω

-TA = descent!

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# One Final Consideration: Static Stability

$$\left(\nabla_p^2 + \frac{f_0^2}{\sigma}\frac{\partial^2}{\partial p^2}\right)\omega = -\frac{f_0}{\sigma}\frac{\partial}{\partial p}\left[-\boldsymbol{V}_g \cdot \boldsymbol{\nabla}_p(\zeta_g + f)\right] - \frac{R_d}{\sigma p}\nabla_p^2\left(-\boldsymbol{V}_g \cdot \boldsymbol{\nabla}_p T\right)$$

Consider this:
Which is easier to sip up through a straw?

Note that static stability is found in each term of the QG Omega equation.
But what does this mean?

More dense air = higher static stability

Less dense air = lower static stability

Omega is inversely related to static stability.

Higher density => lower omega!

**So in other words, cold air may subdue ascent compared to warm air!**

# One Final Consideration: Static Stability

$$\left(\nabla_p^2 + \frac{f_0^2}{\sigma}\frac{\partial^2}{\partial p^2}\right)\omega = -\frac{f_0}{\sigma}\frac{\partial}{\partial p}\left[-\boldsymbol{V}_g \cdot \boldsymbol{\nabla}_p(\zeta_g + f)\right] - \frac{R_d}{\sigma p}\nabla_p^2(-\boldsymbol{V}_g \cdot \boldsymbol{\nabla}_p T)$$

Consider this:
Which is easier to sip up through a straw?

Note that static stability is found in each term of the QG Omega equation. But what does this mean?

More dense air = higher static stability

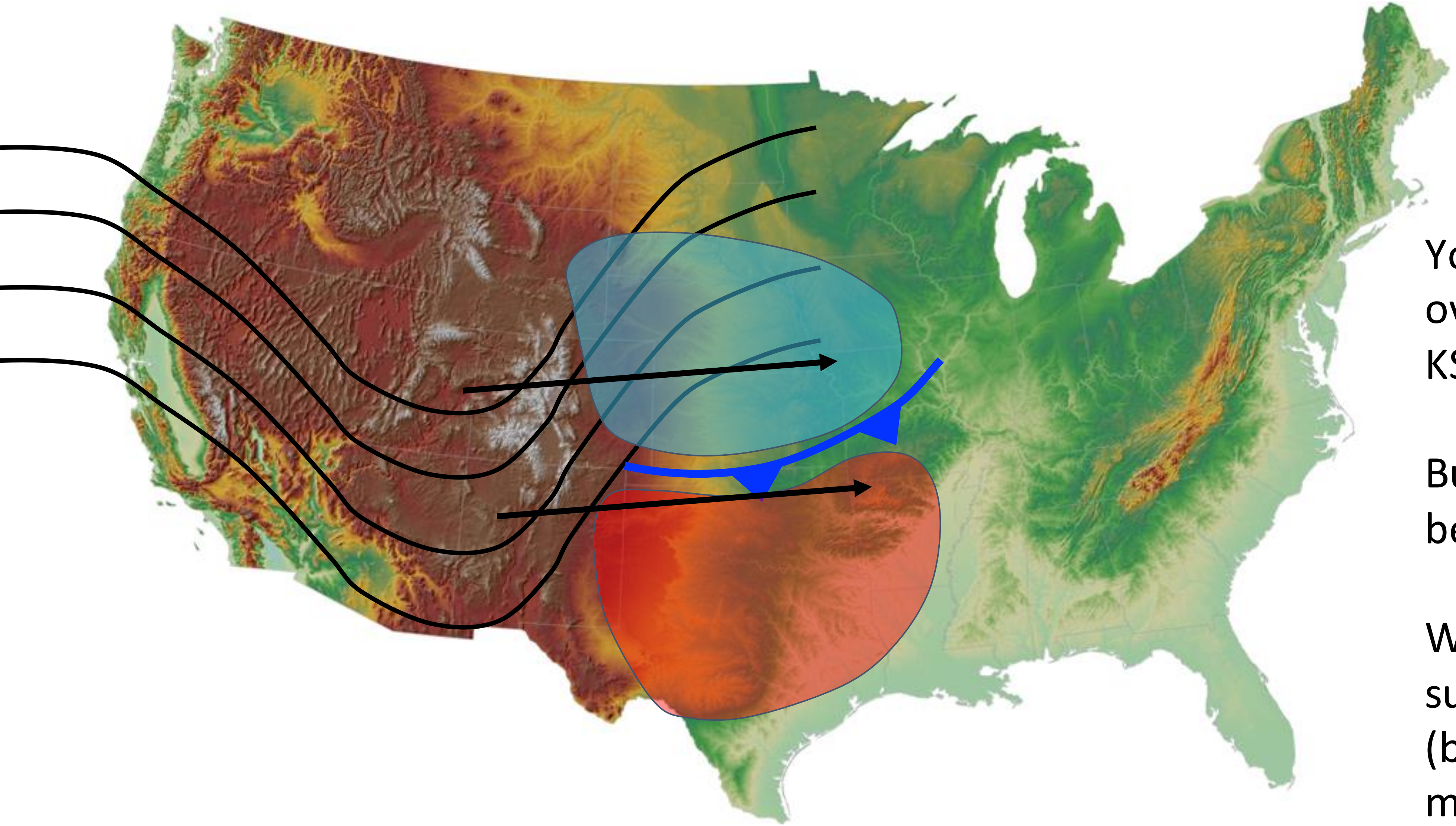
Less dense air = lower static stability

Omega is inversely related to static stability.

Higher density => lower omega!

**So in other words, cold air may subdue ascent compared to warm air!**

# One Final Consideration: Static Stability

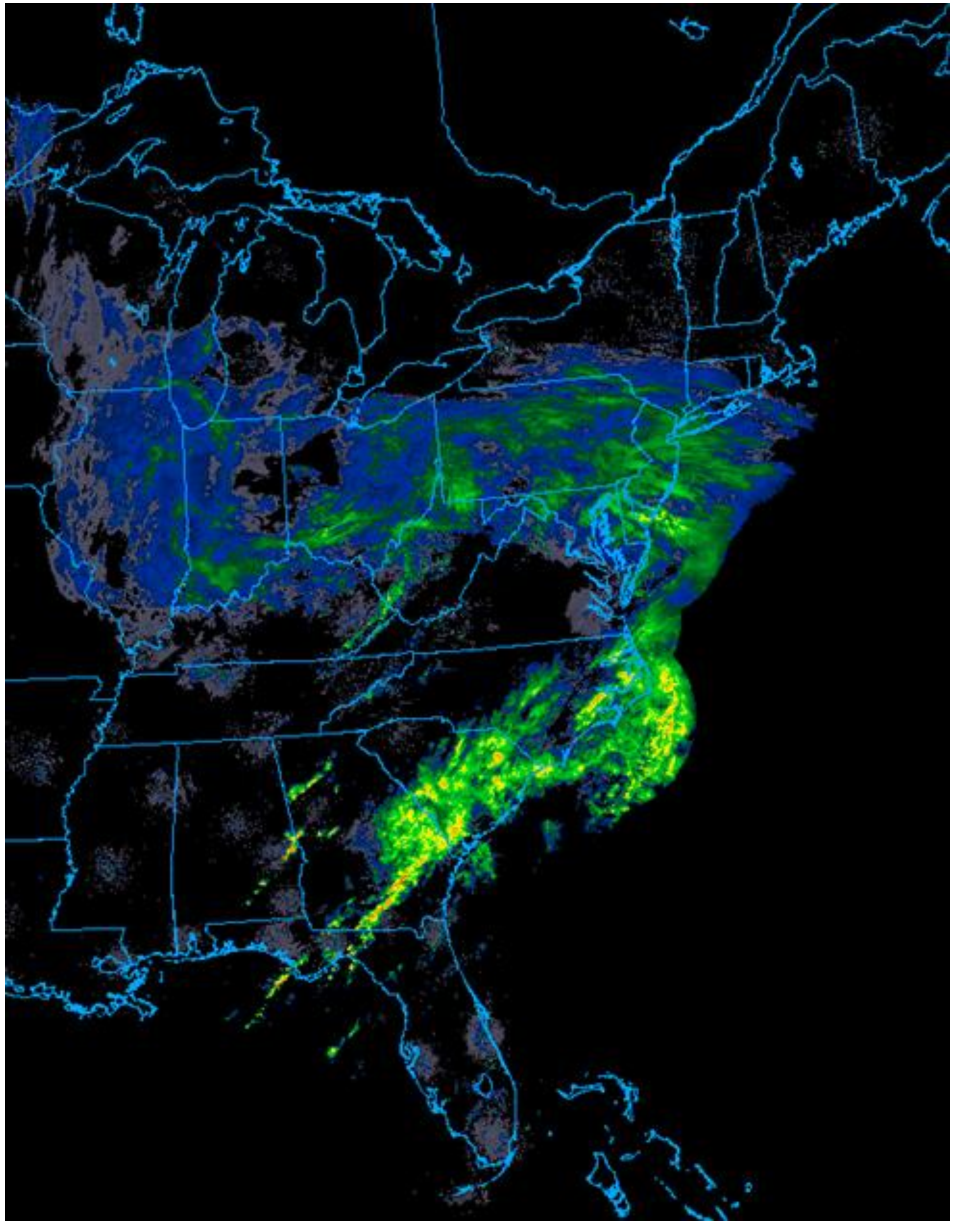


You expect ascent to overspread OK and KS.

But where will ascent be subdued?

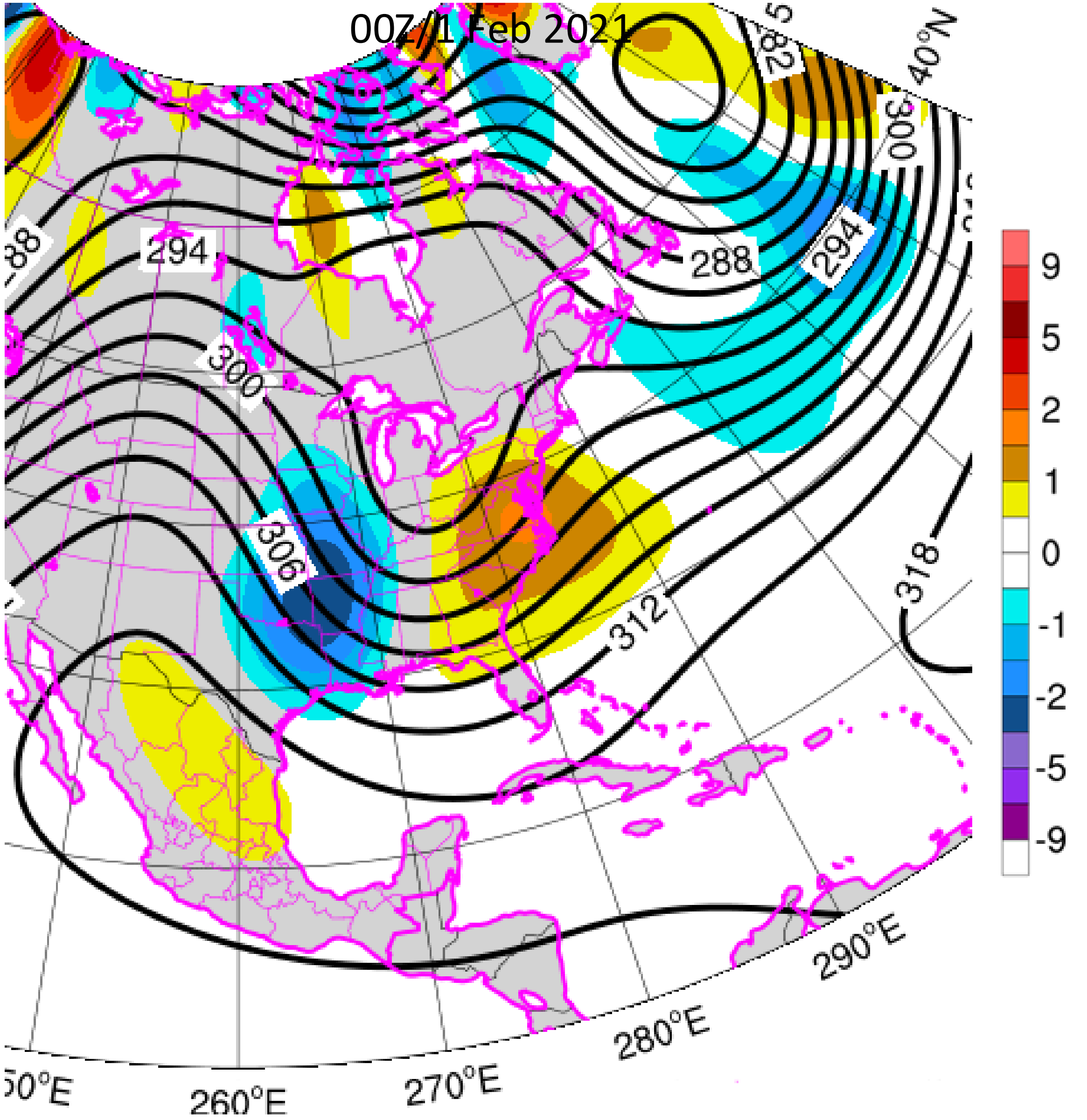
Where might a surface low develop (based on ascent and mass continuity)?

Reflectivity Mosaic
2355Z/31 Jan 2021

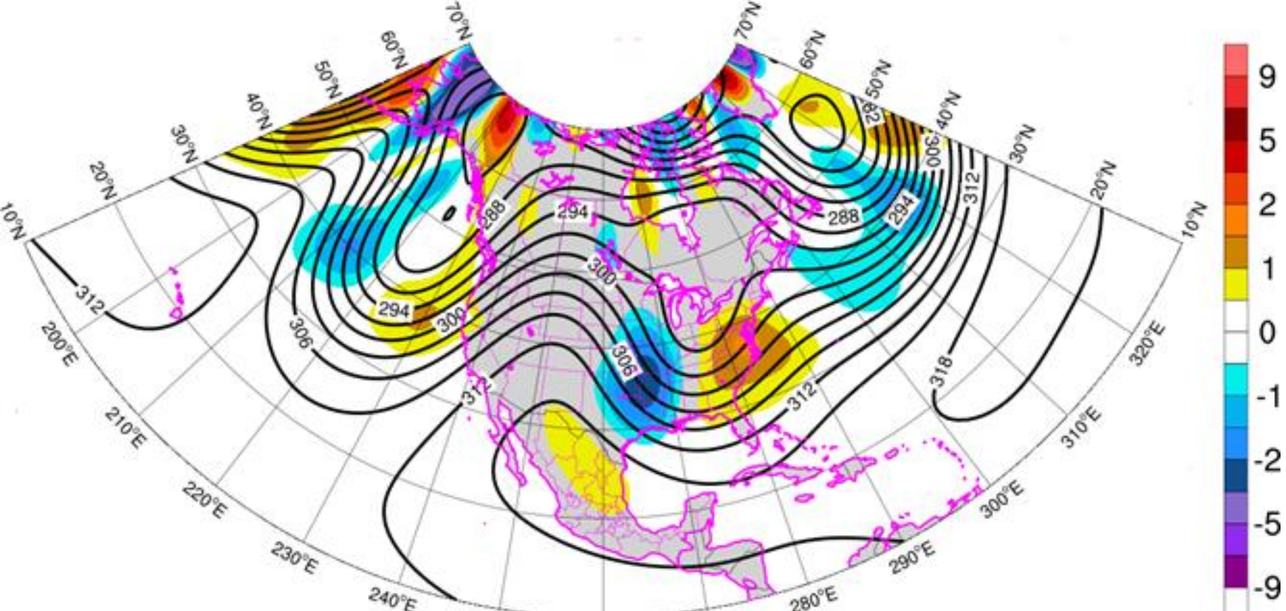


https://www2.mmm.ucar.edu/imagearchive/

700 hPa Z and QG Omega Forcing (Term B+Term C)
00Z/1 Feb 2021

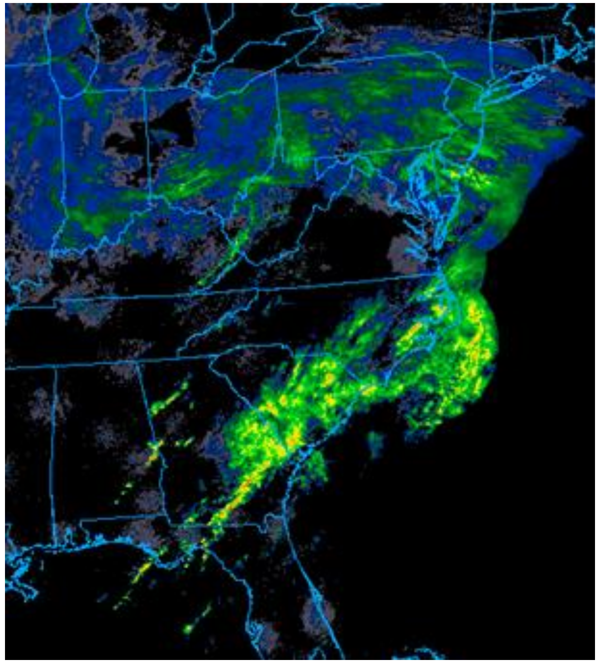



https://inside.nssl.noaa.gov/tgalarneau/real-time-qg-diagnostics/

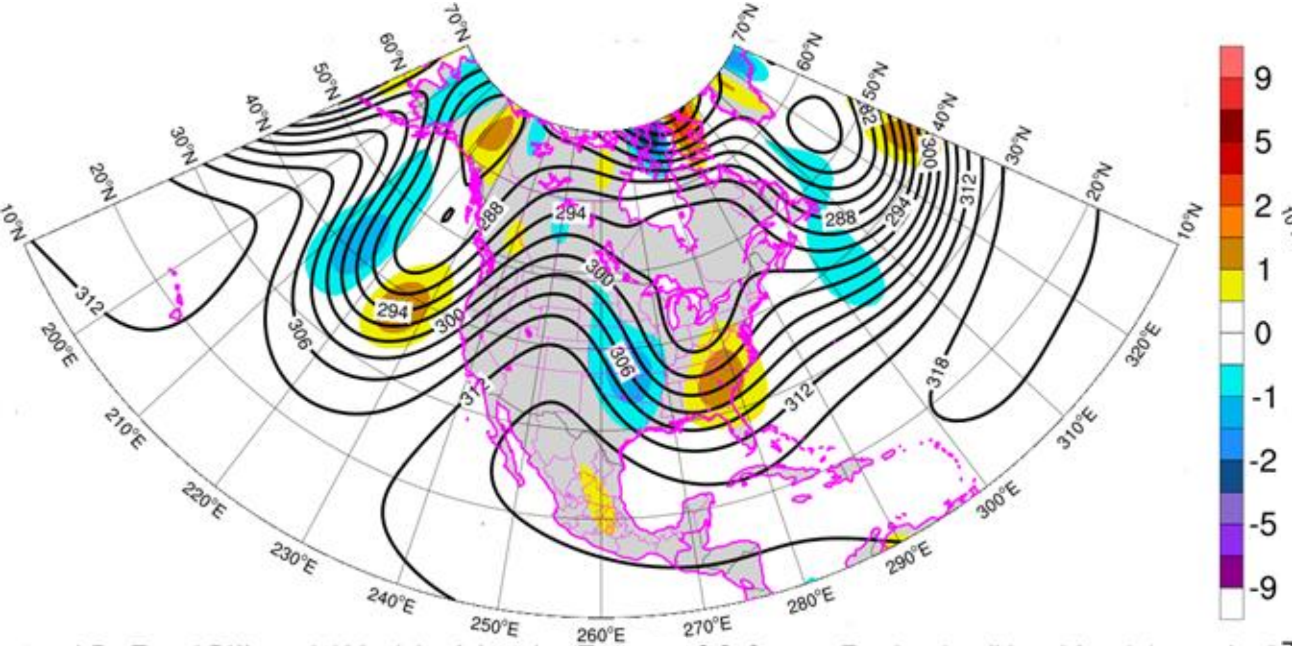


Total forcing=Term B+Term C

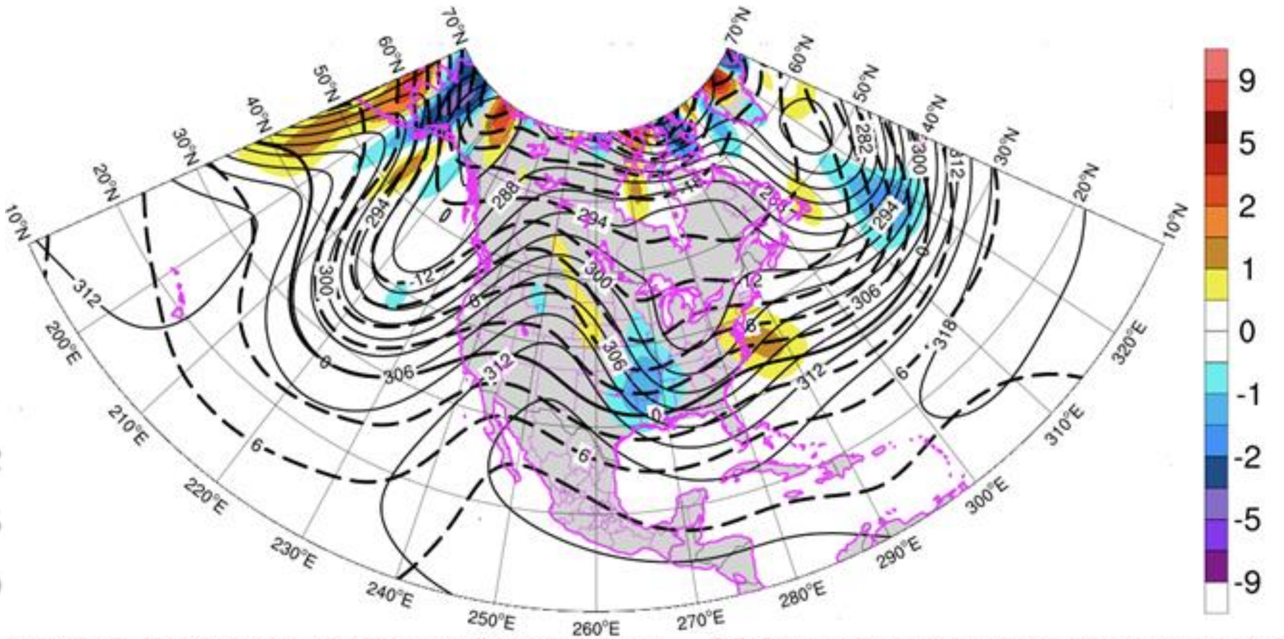
700 hPa Z and Total RHS QG Omega Forcing (traditional form) (smoothed)
0-h CMC Global forecast at 2021020100



- Precip in PA/NJ in region of QG ascent assoc. with **warm advection**
- Convection in NC to FL in region of QG ascent assoc. with **differential cyclonic vorticity advection**



700 hPa Z and Differential Vorticity Advection Term B QG Omega Forcing (traditional form) (smoothed)
0-h CMC Global forecast at 2021020100



700 hPa Z, Temperature, and Thermal Advection Term C QG Omega Forcing (traditional form) (smoothed)
0-h CMC Global forecast at 2021020100