

Lapse Rate Tendency



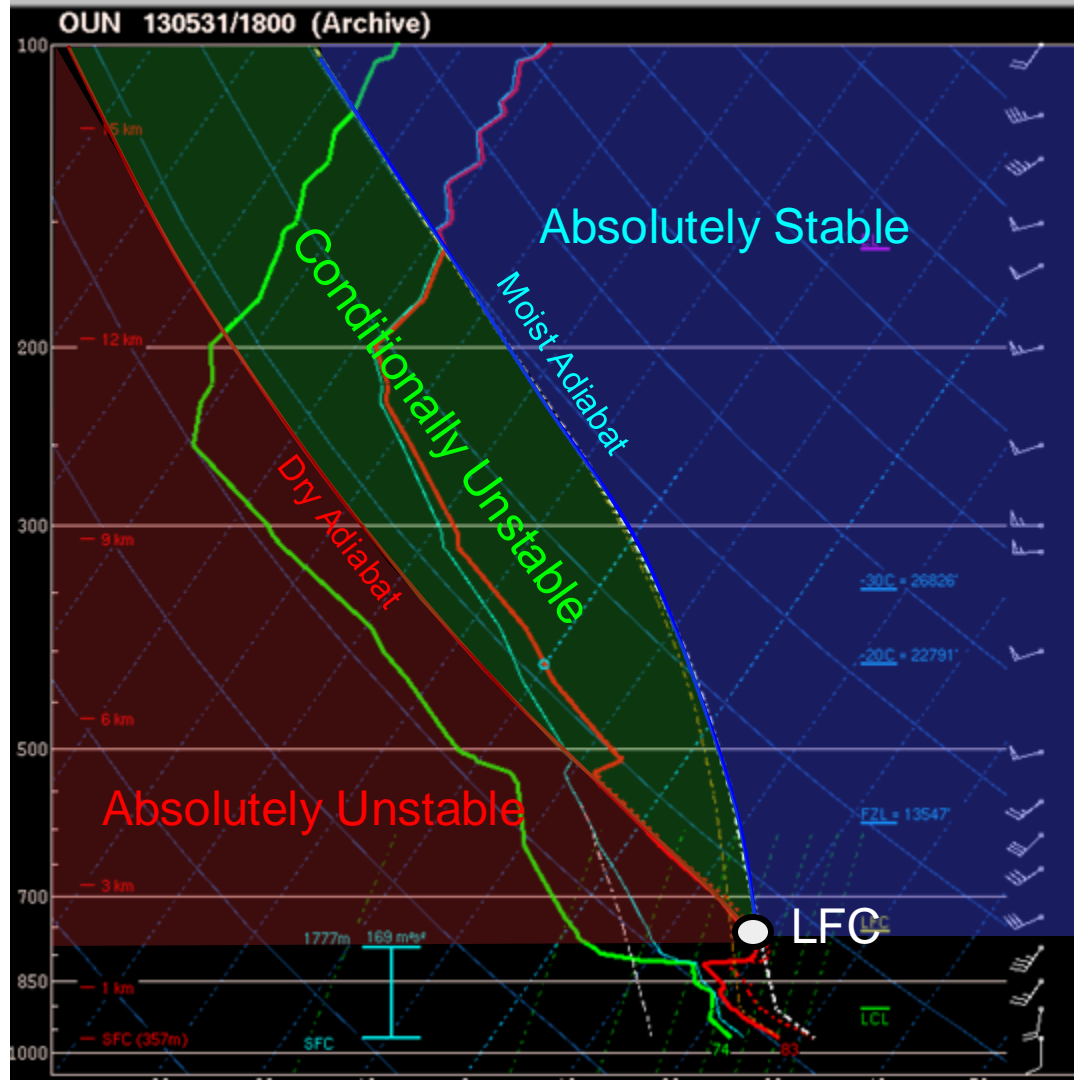
Material by Rich Thompson, Ariel Cohen,
Andrew Moore, Tom Galarneau

Why do we care about lapse rates?

- Helps generate buoyancy (influences T-storm intensity)
- Influences convective initiation (Houston and Niyogi 2007)
- Influence precipitation intensity (Takemi 2009)

Lapse rates in most T-storm environments will be conditionally unstable...

In other words, between the dry adiabatic lapse rate (9.8 C/km) and the moist adiabatic lapse rate.

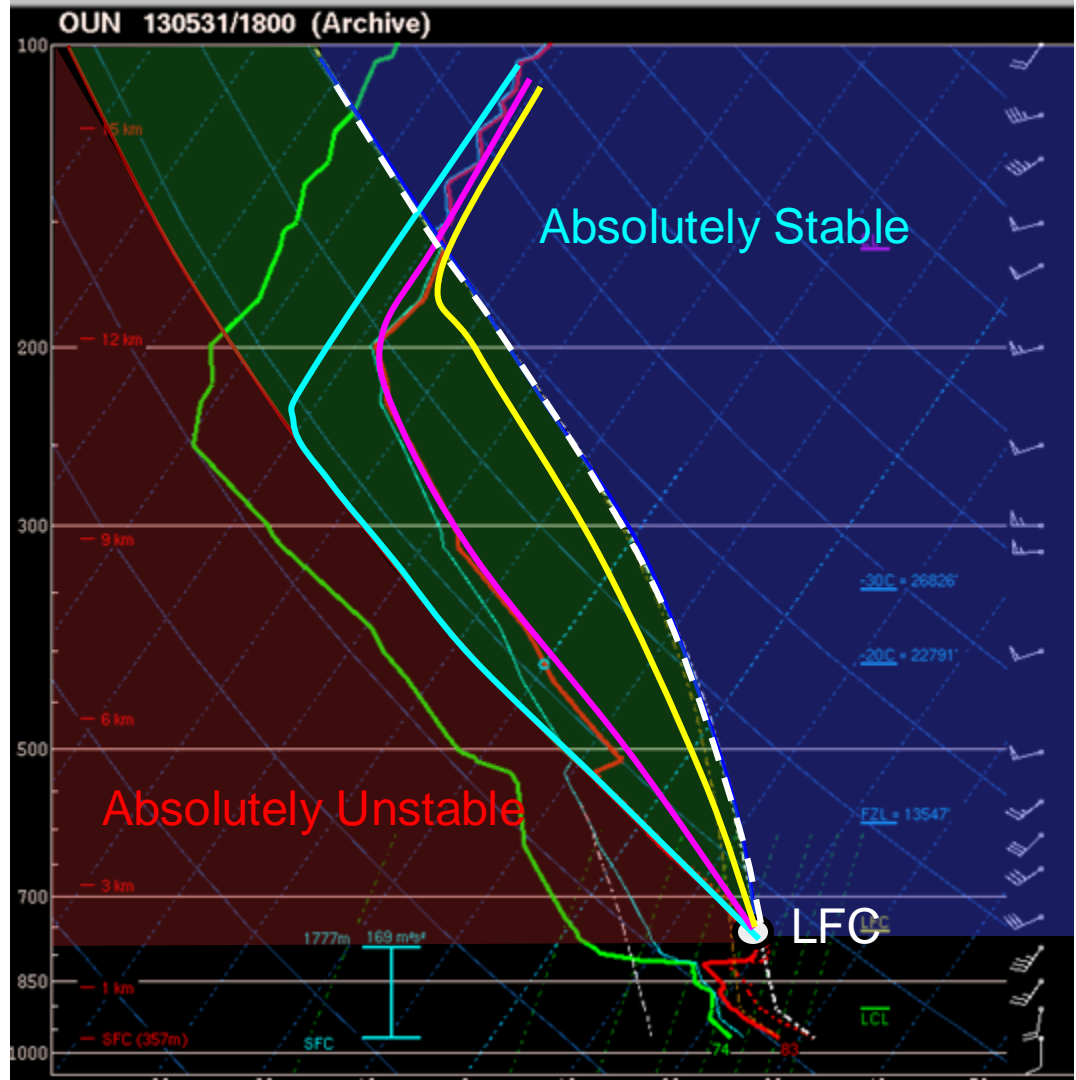


Lapse rates in most T-storm environments will be conditionally unstable...

In other words, between the dry adiabatic lapse rate (9.8 C/km) and the moist adiabatic lapse rate.

Compare the CAPE profiles for these three environmental lapse rates. What are the implications for updraft acceleration?

(Recall: $W_{max} = \sqrt{2 \cdot CAPE}$)



How do lapse rates change?

$$\text{Local change in lapse rate} = \left\{ \begin{array}{l} \text{Horizontal lapse rate advection} \\ \text{Influence of lift/stretching} \\ \text{Differential Thermal Advection} \\ \text{Diabatic Heating} \end{array} \right.$$

Lapse Rate Tendency

- What physical processes alter the environment lapse rate?

Start with 1st Law of Thermodynamics

The diagram shows the equation $q = c_p \frac{dT}{dt} - \alpha \frac{dp}{dt}$ with blue arrows pointing to each term and its units:

- q : heating rate
- c_p : specific heat
- $\frac{dT}{dt}$: temperature (labeled 'e' for environmental) over time
- α : specific volume ($\frac{1}{\rho}$)
- $\frac{dp}{dt}$: pressure over time

This is an important point!
Our ability to anticipate changes in lapse rate
derives directly from the first law of
thermodynamics!

Lapse Rate Tendency

- What physical processes alter the environment lapse rate?

Start with 1st Law of Thermodynamics

Diagram illustrating the first law of thermodynamics equation:

$$q = C_p \frac{dT}{dt} - \alpha \frac{dp}{dt}$$

Labels and arrows pointing to the equation:

- heating rate (points to q)
- specific heat (points to C_p)
- temperature (points to T)
- specific volume ($\frac{1}{\rho}$) (points to α)
- pressure (points to p)
- time (points to dt)

Expand full derivatives and assume hydrostatic conditions (OK for synoptic and mesoscale)

$$q = C_p \left(\frac{\partial T}{\partial t} + v_h \cdot \nabla_h T + w \frac{\partial T}{\partial z} \right) - \frac{1}{\rho} \left(\frac{\partial p}{\partial t} + v_h \cdot \nabla_h p + w \frac{\partial p}{\partial z} \right)$$

Local change in temperature with time

Horizontal temperature advection

Vertical temperature advection

Local change in pressure

Horizontal pressure advection

Vertical pressure advection

Lapse Rate Tendency

- What physical processes alter the environment lapse rate?

Start with 1st Law of Thermodynamics

$$q = C_p \frac{dT}{dt} - \alpha \frac{dp}{dt}$$

Diagram illustrating the 1st Law of Thermodynamics equation with labels:

- q : heating rate
- C_p : specific heat
- $\frac{dT}{dt}$: temperature change over time
- α : specific volume ($\frac{1}{\rho}$)
- $\frac{dp}{dt}$: pressure change over time

Expand full derivatives and assume hydrostatic conditions (OK for synoptic and mesoscale)

$$q = C_p \left(\frac{\partial T}{\partial t} + \mathbf{v}_h \cdot \nabla_h T + w \frac{\partial T}{\partial z} \right) - \frac{1}{\rho} \left(\cancel{\frac{\partial}{\partial t}} + \mathbf{v}_h \cdot \cancel{\nabla_h} p + w \frac{\partial p}{\partial z} \right) = C_p \left(\frac{\partial T}{\partial t} + \mathbf{v}_h \cdot \nabla_h T + w \frac{\partial T}{\partial z} \right) + gw$$

Relatively small

$$= -\rho g$$

Assume that the
hydrostatic approx
applies

Lapse Rate Tendency

- What physical processes alter the environment lapse rate?

Start with 1st Law of Thermodynamics

$$q = C_p \frac{dT}{dt} - \alpha \frac{dp}{dt}$$

Diagram labels for the equation above:

- heating rate $\rightarrow q$
- specific heat $\rightarrow C_p$
- temperature $\rightarrow T$
- specific volume $\left(\frac{1}{\rho}\right) \rightarrow \alpha$
- pressure $\rightarrow p$
- time $\rightarrow t$

Expand full derivatives and assume hydrostatic conditions (OK for synoptic and mesoscale)

$$q = C_p \left(\frac{\partial T}{\partial t} + \mathbf{v}_h \cdot \nabla_h T + w \frac{\partial T}{\partial z} \right) - \frac{1}{\rho} \left(\cancel{\frac{\partial}{\partial t}} + \mathbf{v}_h \cdot \nabla_h \cancel{p} + w \frac{\partial p}{\partial z} \right) = C_p \left(\frac{\partial T}{\partial t} + \mathbf{v}_h \cdot \nabla_h T + w \frac{\partial T}{\partial z} \right) + gw$$

Diagram annotations for the expanded equation:

- Red slashes over $\frac{\partial}{\partial t}$ and $\nabla_h p$ indicate they are neglected.
- Red text: "Relatively small, assume hydrostatic" points to the neglected terms.
- Red box around $\frac{\partial p}{\partial z}$ with red text below: $= -\rho g$.

Differentiate with respect to $-z$

$$-\frac{\partial q}{\partial z} = C_p \left[\frac{\partial}{\partial t} \left(-\frac{\partial T}{\partial z} \right) + \mathbf{v}_h \cdot \nabla_h \left(-\frac{\partial T}{\partial z} \right) + w \frac{\partial}{\partial z} \left(-\frac{\partial T}{\partial z} \right) - \frac{\partial \mathbf{v}_h}{\partial z} \cdot \nabla_h T - \frac{\partial w}{\partial z} \frac{\partial T}{\partial z} \right] - g \frac{\partial w}{\partial z}$$

Lapse Rate Tendency

- What physical processes alter the environment lapse rate?

Start with 1st Law of Thermodynamics

$$q = c_p \frac{dT}{dt} - \alpha \frac{dp}{dt}$$

Diagram labels for the equation above:

- heating rate $\rightarrow q$
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- time $\rightarrow t$

Expand full derivatives and assume hydrostatic conditions (OK for synoptic and mesoscale)

$$q = c_p \left(\frac{\partial T}{\partial t} + \mathbf{v}_h \cdot \nabla_h T + w \frac{\partial T}{\partial z} \right) - \frac{1}{\rho} \left(\cancel{\frac{\partial \rho}{\partial t}} + \mathbf{v}_h \cdot \nabla_h \cancel{\rho} + w \frac{\partial \rho}{\partial z} \right) = c_p \left(\frac{\partial T}{\partial t} + \mathbf{v}_h \cdot \nabla_h T + w \frac{\partial T}{\partial z} \right) + gw$$

Diagram annotations for the equation above:

- Relatively small, assume hydrostatic \rightarrow (points to the $\frac{\partial \rho}{\partial t}$ and $\nabla_h \rho$ terms)
- $\frac{\partial \rho}{\partial z} = -\rho g$ (points to the $\frac{\partial \rho}{\partial z}$ term)

Differentiate with respect to $-z$

$$-\frac{\partial q}{\partial z} = c_p \left[\frac{\partial}{\partial t} \left(-\frac{\partial T}{\partial z} \right) + \mathbf{v}_h \cdot \nabla_h \left(-\frac{\partial T}{\partial z} \right) + w \frac{\partial}{\partial z} \left(-\frac{\partial T}{\partial z} \right) - \frac{\partial \mathbf{v}_h}{\partial z} \cdot \nabla_h T - \frac{\partial w}{\partial z} \frac{\partial T}{\partial z} \right] - g \frac{\partial w}{\partial z}$$

We neglected $\frac{\partial^2 T}{\partial z^2}$ terms

Substitute in definition for environment lapse rate $\gamma = -\partial T / \partial z$ and dry adiabatic lapse rate $\Gamma_d = g / c_p$

$$\frac{\partial \gamma}{\partial t} = -\mathbf{v}_h \cdot \nabla_h \gamma - w \frac{\partial \gamma}{\partial z} + \frac{\partial \mathbf{v}_h}{\partial z} \cdot \nabla_h T + \frac{\partial w}{\partial z} (\Gamma_d - \gamma) - \frac{1}{c_p} \frac{\partial q}{\partial z}$$

Lapse Rate Tendency

- What physical processes alter the environment lapse rate?

Start with 1st Law of Thermodynamics

$$q = C_p \frac{dT}{dt} - \alpha \frac{dp}{dt}$$

Diagram labels for the first law equation:

- heating rate $\rightarrow q$
- specific heat $\rightarrow C_p$
- temperature $\rightarrow T$
- specific volume $\rightarrow \alpha$
- pressure $\rightarrow p$
- time $\rightarrow t$

Expand full derivatives and assume hydrostatic conditions (OK for synoptic and mesoscale)

$$q = C_p \left(\frac{\partial T}{\partial t} + v_h \cdot \nabla_h T + w \frac{\partial T}{\partial z} \right) - \frac{1}{\rho} \left(\cancel{\frac{\partial \rho}{\partial t}} + v_h \cdot \cancel{\nabla_h \rho} + w \frac{\partial \rho}{\partial z} \right) = C_p \left(\frac{\partial T}{\partial t} + v_h \cdot \nabla_h T + w \frac{\partial T}{\partial z} \right) + gw$$

Relatively small, assume hydrostatic $\rightarrow \frac{\partial \rho}{\partial z} = -\rho g$

Differentiate with respect to $-z$

$$-\frac{\partial q}{\partial z} = C_p \left[\frac{\partial}{\partial t} \left(-\frac{\partial T}{\partial z} \right) + v_h \cdot \nabla_h \left(-\frac{\partial T}{\partial z} \right) + w \frac{\partial}{\partial z} \left(-\frac{\partial T}{\partial z} \right) - \frac{\partial v_h}{\partial z} \cdot \nabla_h T - \frac{\partial w}{\partial z} \frac{\partial T}{\partial z} \right] - g \frac{\partial w}{\partial z}$$

Substitute in definition for environment lapse rate $\gamma = -\partial T / \partial z$ and dry adiabatic lapse rate $\Gamma_d = g / c_p$

$$\frac{\partial \gamma}{\partial t} = -v_h \cdot \nabla_h \gamma - w \frac{\partial \gamma}{\partial z} + \frac{\partial v_h}{\partial z} \cdot \nabla_h T + \frac{\partial w}{\partial z} (\Gamma_d - \gamma) - \frac{1}{C_p} \frac{\partial q}{\partial z}$$

Lapse rate tendency equation

Lapse Rate Tendency Equation

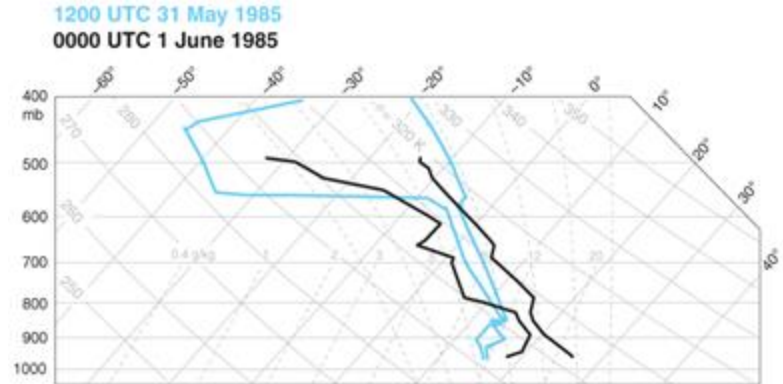
$$\frac{\partial \gamma}{\partial t} = \underbrace{-\mathbf{v}_h \cdot \nabla_h \gamma}_B - \underbrace{w \frac{\partial \gamma}{\partial z}}_C + \underbrace{\frac{\partial \mathbf{v}_h}{\partial z} \cdot \nabla_h T}_D + \underbrace{\frac{\partial w}{\partial z} (\Gamma_d - \gamma)}_E - \underbrace{\frac{1}{c_p} \frac{\partial q}{\partial z}}_F$$

**We'll work through each term to understand
the physical mechanisms**

Lapse Rate Tendency Equation

$$\boxed{\frac{\partial \gamma}{\partial t}} = \underbrace{-\mathbf{v}_h \cdot \nabla_h \gamma}_{\mathbf{B}} - \underbrace{w \frac{\partial \gamma}{\partial z}}_{\mathbf{C}} + \underbrace{\frac{\partial \mathbf{v}_h}{\partial z} \cdot \nabla_h T}_{\mathbf{D}} + \underbrace{\frac{\partial w}{\partial z} (\Gamma_d - \gamma)}_{\mathbf{E}} - \underbrace{\frac{1}{C_p} \frac{\partial q}{\partial z}}_{\mathbf{F}}$$

Term A: local time rate of change of environment lapse rate



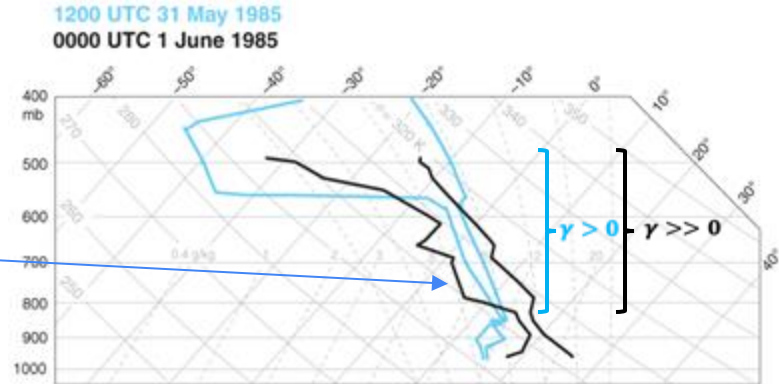
(Markowski and Richardson 2010, Fig. 7.3)

Lapse Rate Tendency Equation

$$\boxed{\frac{\partial \gamma}{\partial t}} = \underbrace{-\mathbf{v}_h \cdot \nabla_h \gamma}_{\mathbf{B}} - \underbrace{w \frac{\partial \gamma}{\partial z}}_{\mathbf{C}} + \underbrace{\frac{\partial \mathbf{v}_h}{\partial z} \cdot \nabla_h T}_{\mathbf{D}} + \underbrace{\frac{\partial w}{\partial z} (\Gamma_d - \gamma)}_{\mathbf{E}} - \underbrace{\frac{1}{C_p} \frac{\partial q}{\partial z}}_{\mathbf{F}}$$

Term A: local time rate of change of environment lapse rate

$\frac{\partial \gamma}{\partial t} > 0$ lapse rate increasing at PIT
due to warming below 600 mb



(Markowski and Richardson 2010, Fig. 7.3)

Lapse Rate Tendency Equation

$$\frac{\partial \gamma}{\partial t} = \underbrace{-\mathbf{v}_h \cdot \nabla_h \gamma}_{\text{B}} - \underbrace{w \frac{\partial \gamma}{\partial z}}_{\text{C}} + \underbrace{\frac{\partial \mathbf{v}_h}{\partial z} \cdot \nabla_h T}_{\text{D}} + \underbrace{\frac{\partial w}{\partial z} (\Gamma_d - \gamma)}_{\text{E}} - \underbrace{\frac{1}{C_p} \frac{\partial q}{\partial z}}_{\text{F}}$$

A
B
C
D
E
F

Term B: horizontal lapse rate advection - this one is very important! Let's take a closer look!

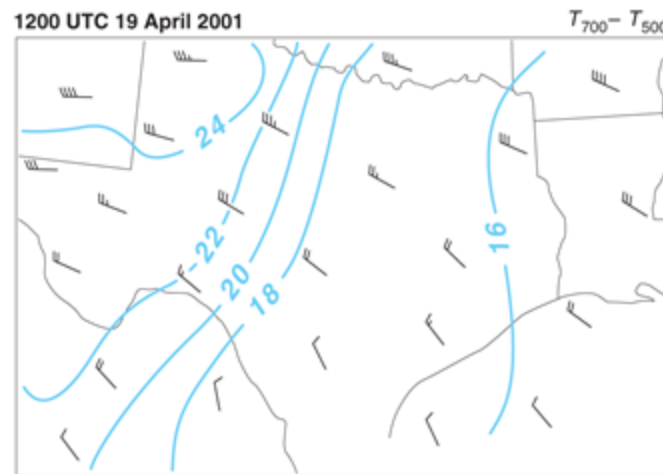


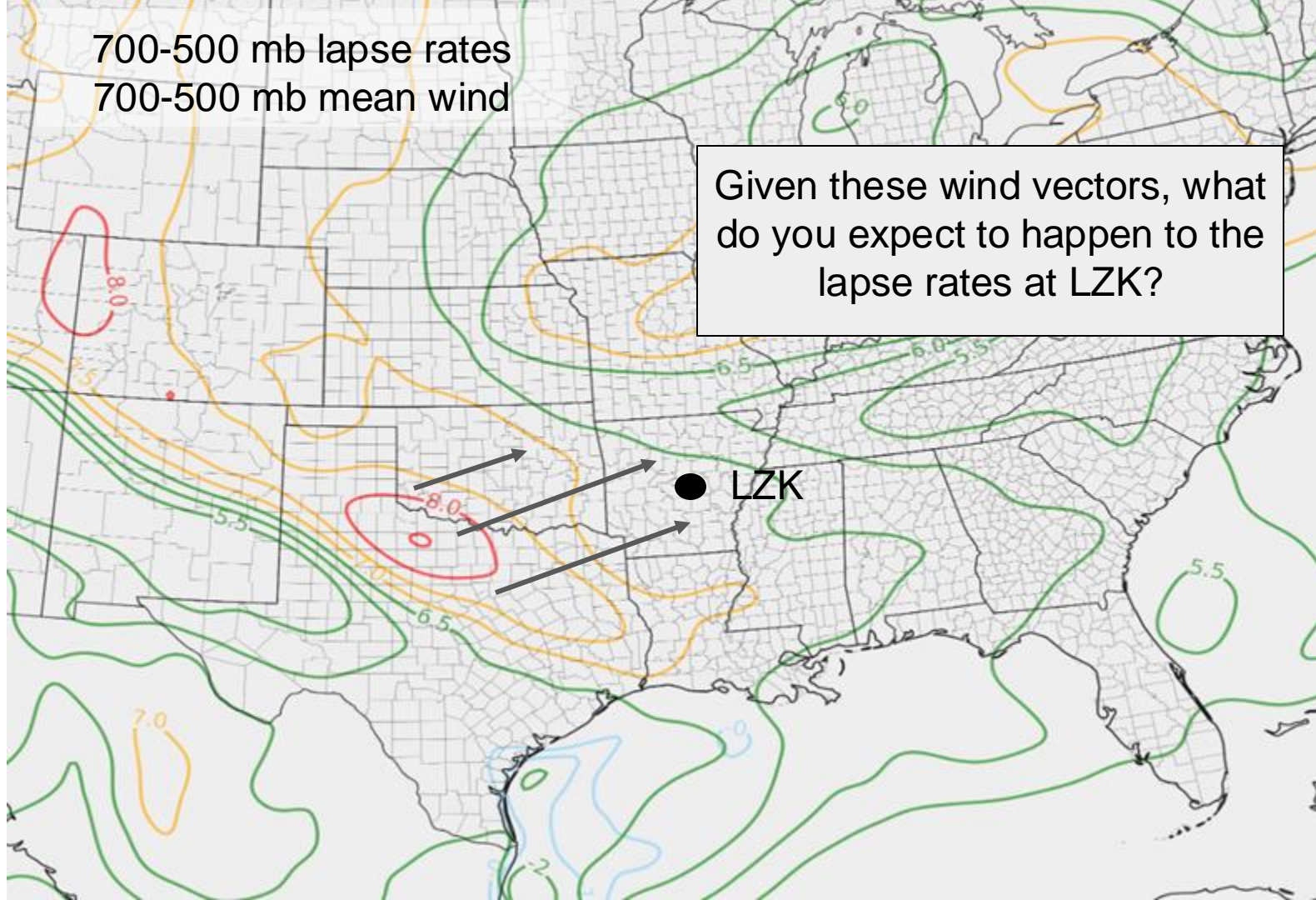
Figure 7.4

Analysis of the environmental temperature difference between 500 and 700 mb (K), which is a bulk measure of the midlevel lapse rate (a temperature difference of 27 K between 500 and 700 mb corresponds to an approximately dry adiabatic environmental temperature profile), revealing the presence of horizontal lapse rate advection. Wind barbs depict the mean wind in the 500–700 mb layer. Large lapse rates from the high terrain of northern Mexico and eastern New Mexico are being advected toward the southern Great Plains of the United States. This common warm season phenomenon leads to the formation of the elevated mixed layer that caps soundings in the Great Plains region.

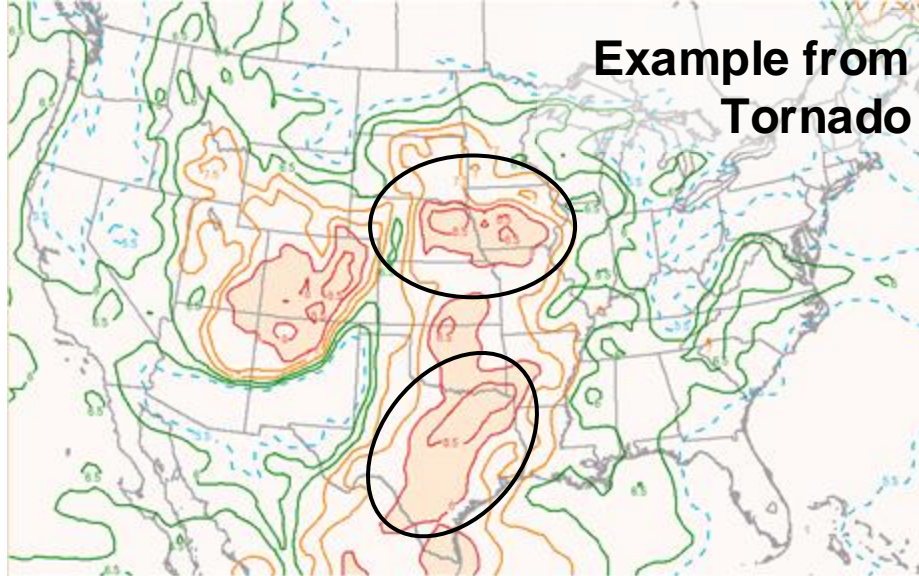
(Markowski and Richardson 2010, Fig. 7.4)

700-500 mb lapse rates
700-500 mb mean wind

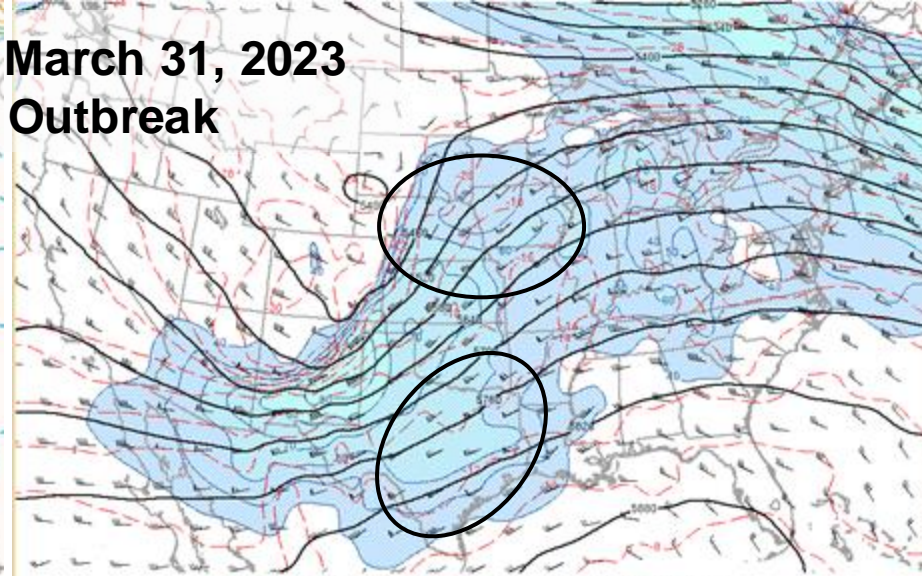
Given these wind vectors, what do you expect to happen to the lapse rates at LZK?



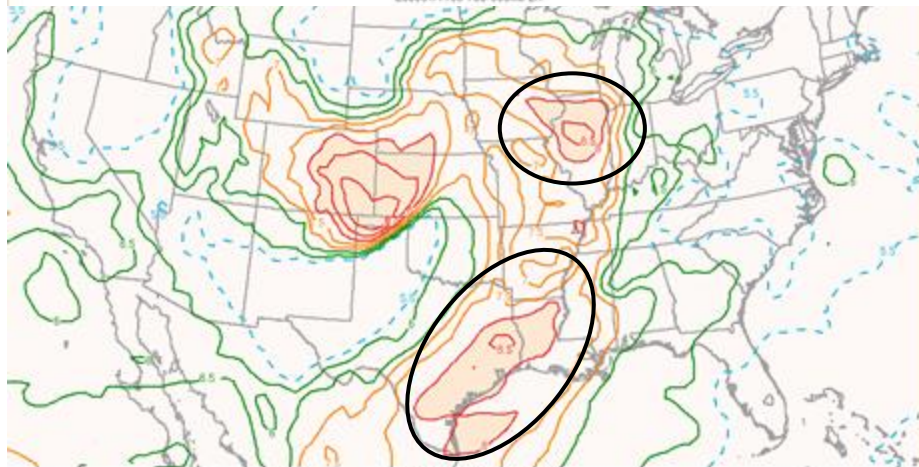
Example from March 31, 2023 Tornado Outbreak



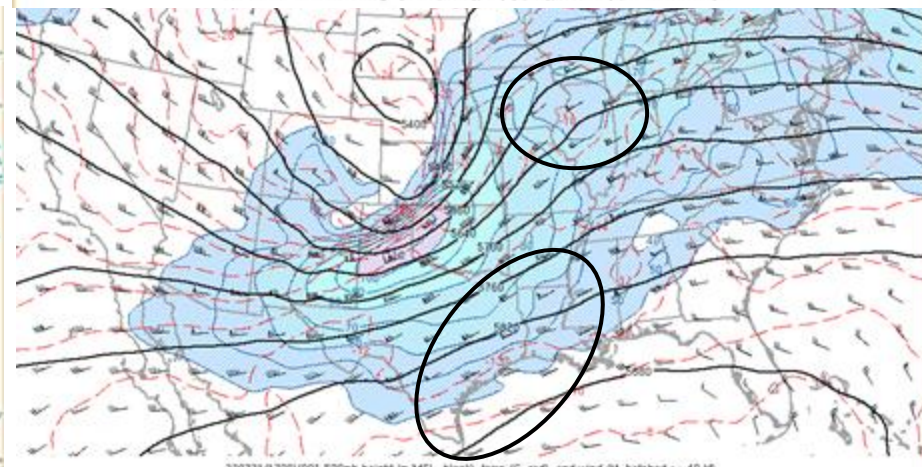
230331/1100 700-500mb LR



230331/1200V001 500mb height (in MSL, black), temp (C, red), and wind (kt, hatched >= 40 kt)



230331/1700 700-500mb LR



230331/1700V001 500mb height (in MSL, black), temp (C, red), and wind (kt, hatched >= 40 kt)

Example from Tornado

Just like moisture, lapse rates
can be tracked days ahead of a
severe weather outbreak!

April 2010

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Revisiting the 3–4 April 1974 Super Outbreak of Tornadoes

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(Manuscript received 27 April 2009, in final form 22 October 2009)

ABSTRACT

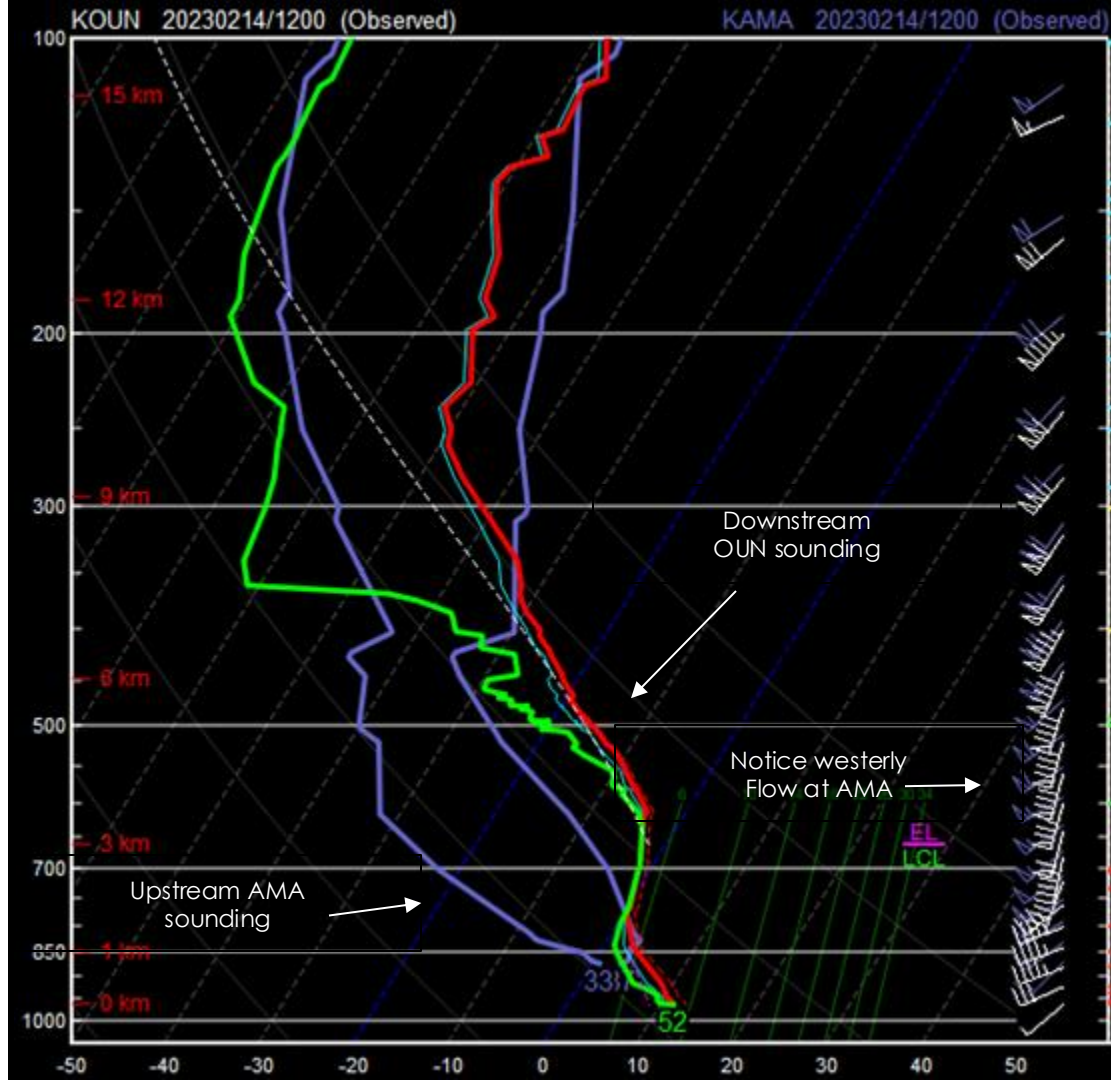
The Super Outbreak of tornadoes over the central and eastern United States on 3–4 April 1974 remains the most outstanding severe convective weather episode on record in the continental United States. The outbreak far surpassed previous and succeeding events in severity, longevity, and extent. In this paper, surface, upper air, radar, and satellite data are used to provide an updated synoptic and subsynoptic overview of the event. Emphasis is placed on identifying the major factors that contributed to the development of the three main convective bands associated with the outbreak, and on identifying the conditions that may have contributed to the outstanding number of intense and long-lasting tornadoes. Selected output from a 29 km, 50 layer version of the Eta forecast model, a version similar to that available operationally in the mid 1990s, also is presented to help depict the evolution of thermodynamic stability during the event.

1. Introduction

The Super Outbreak of tornadoes of 3–4 April 1974 remains the most outstanding severe convective weather episode on record in the continental United States (Fig. 1). By nearly every metric imaginable, the outbreak far surpassed previous and succeeding events in severity, longevity, and extent. A sampling of statistics only partially conveys its enormity: 148 tornadoes, of which 95 were F2 or stronger and 30 were F4 or F5; 48 killer tornadoes resulting in 335 deaths and more than 6000 injured;

pathlengths up to 145 km (90 mi), with a total pathlength >4000 km (2500 mi); F2s or greater present for each three-hour period between 1200 UTC 3 April and 1500 UTC 4 April; 15 tornadoes in progress simultaneously at the height of the event; and 10 states declared federal disaster areas. Further appreciation for the phenomenal nature of the Super Outbreak may be gleaned from Fig. 2, which depicts the maximum, week-long running total of F2 or greater tornadoes from 1915 through 2008. Entire years noted for their prominent tornado counts (e.g., 1947, 1953, and 2003) pale in comparison to the 18-h period that began around midday on Wednesday, 3 April 1974. Twenty-five F3 or greater long-track (>40 km [25 mi]) tornadoes occurred during the same period, more than triple the annual average of such events since 1880 (Broyles and Crobie 2004).

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E-mail: stephen.corfidi@noaa.gov



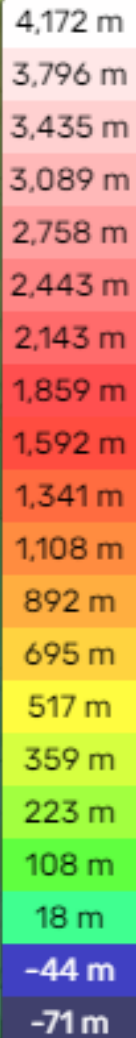
Here's another example.

Notice the steeper lapse rates upstream at AMA.

Given westerly winds, what do you think will happen to the lapse rates at OUN?

Consider the terrain!

Elevation generally increases as you go west towards the mountains. What would happen if we advected a surface parcel from ABQ to OUN?



Consider the terrain!



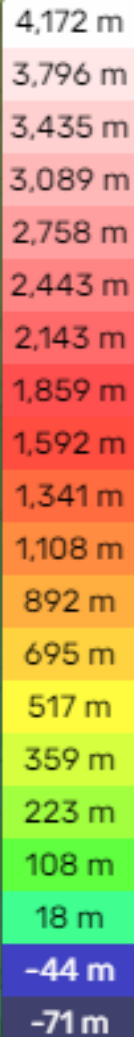
Elevation generally increases as you go west towards the mountains. What would happen if we advected a surface parcel from ABQ to OUN?



Parcel is now at a higher altitude AGL!

ABQ
5309 ft MSL

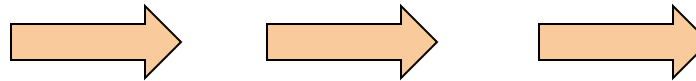
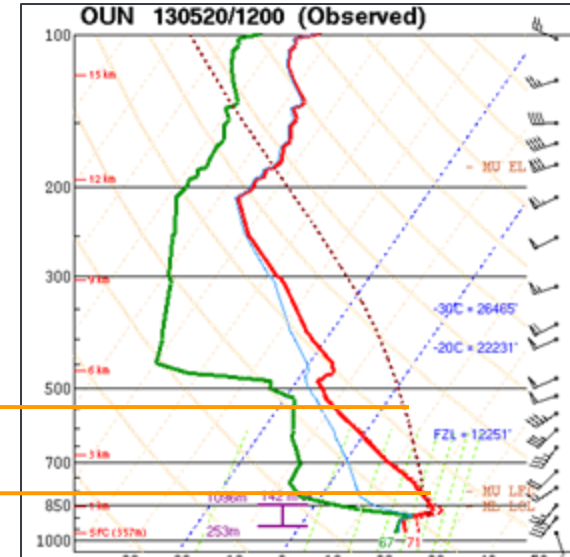
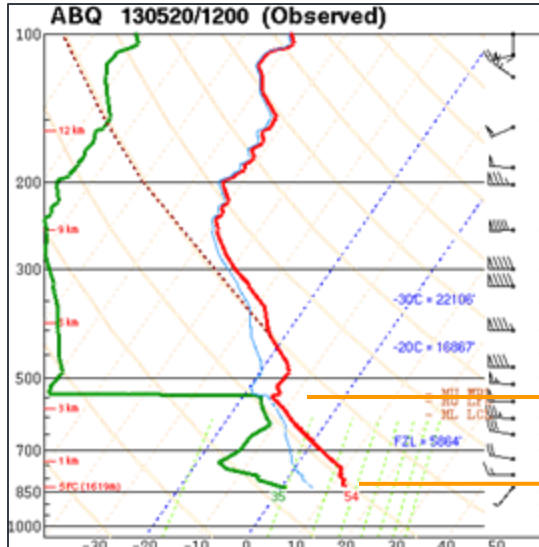
OUN
1238 ft MSL

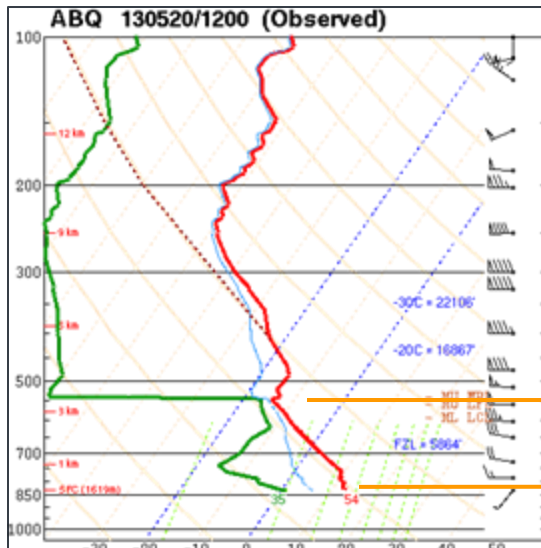


The last slide was a slight exaggeration of what occurs (parcels can descend in altitude), but illustrates an important point.

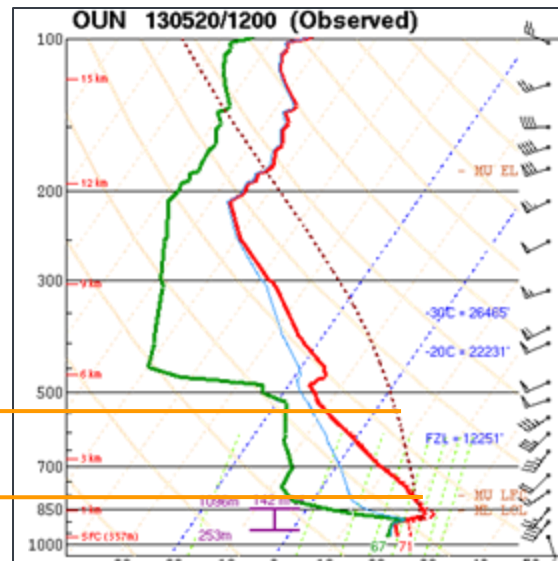
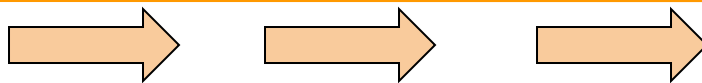
The deep, well-mixed boundary layer over the southern Rockies can be advected east over the plains...

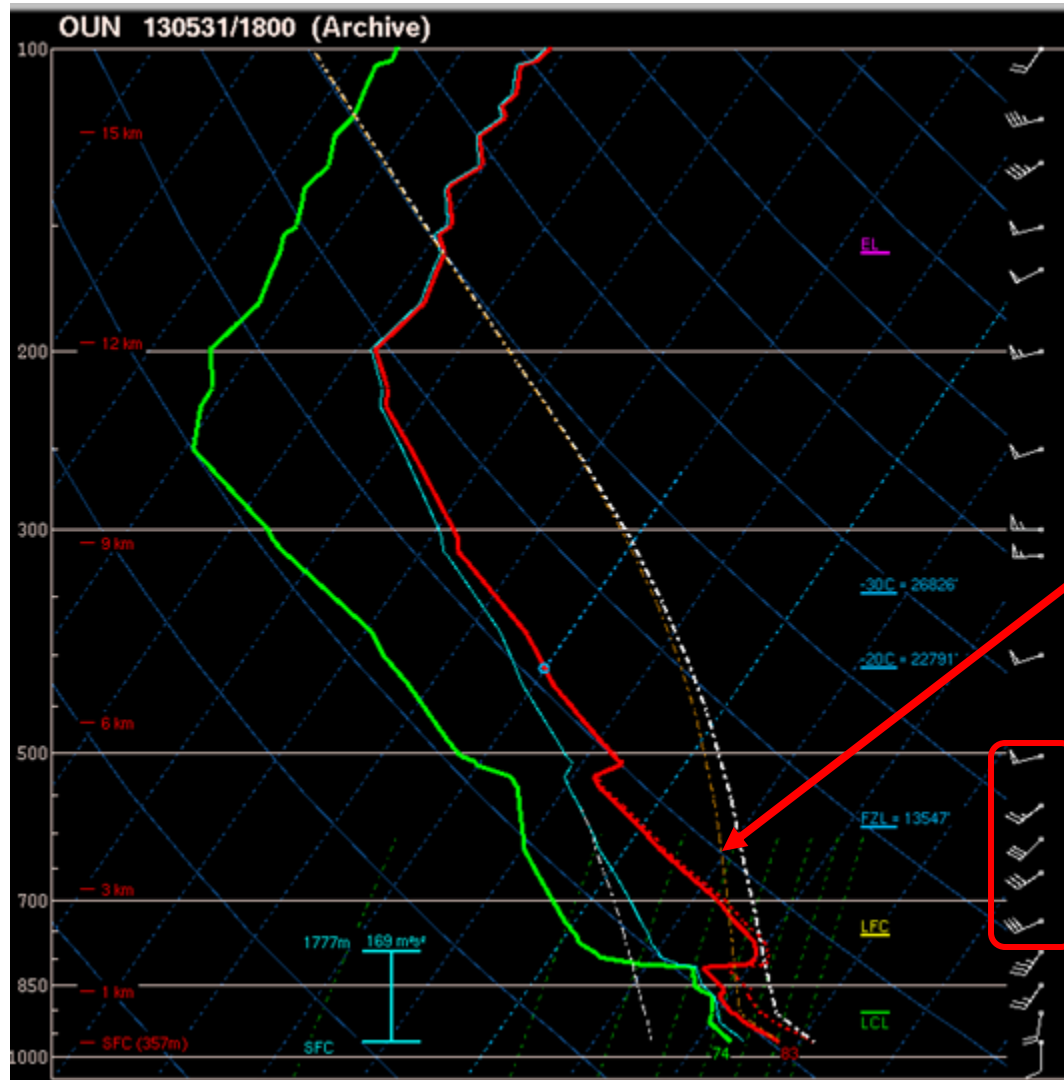
And becomes an **Elevated Mixed Layer**!





This is an important process for generating steep lapse rates over the Plains, which in turn support large CAPE values.

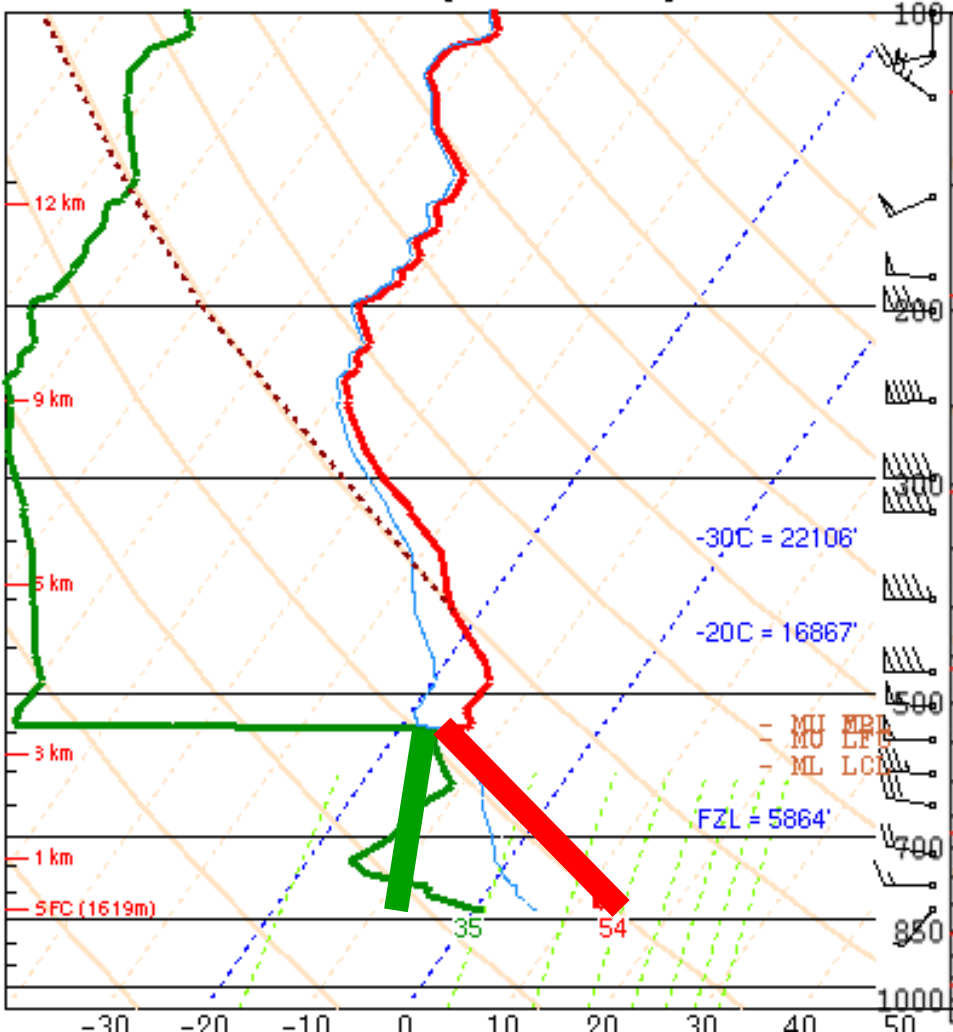




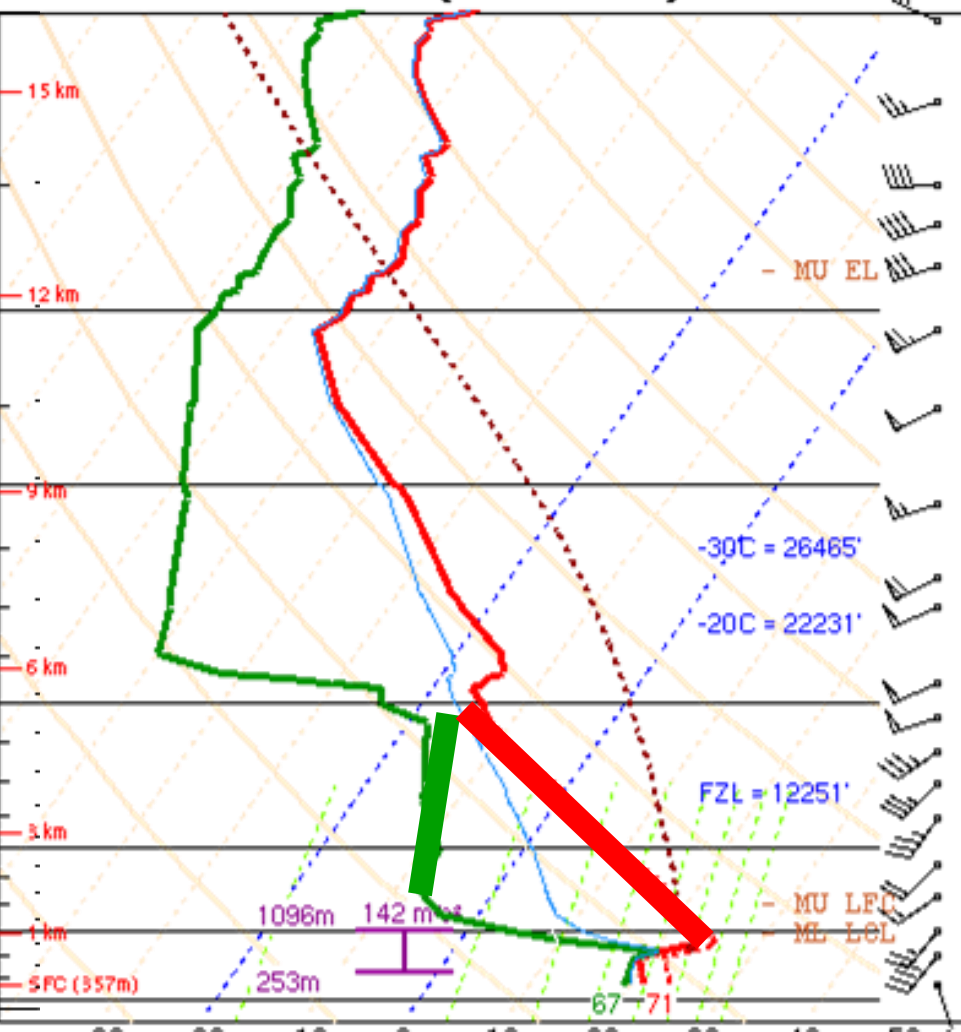
Nearly neutral layer
above boundary layer in
Norman noon sounding.

Notice the southwesterly flow in
this layer - it likely originated from
New Mexico plateau!

ABQ 130520/1200 (Observed)



OUN 130520/1200 (Observed)



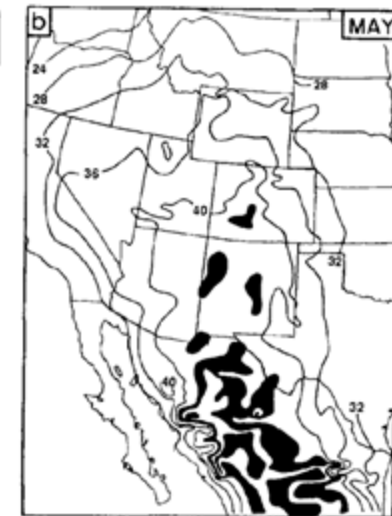
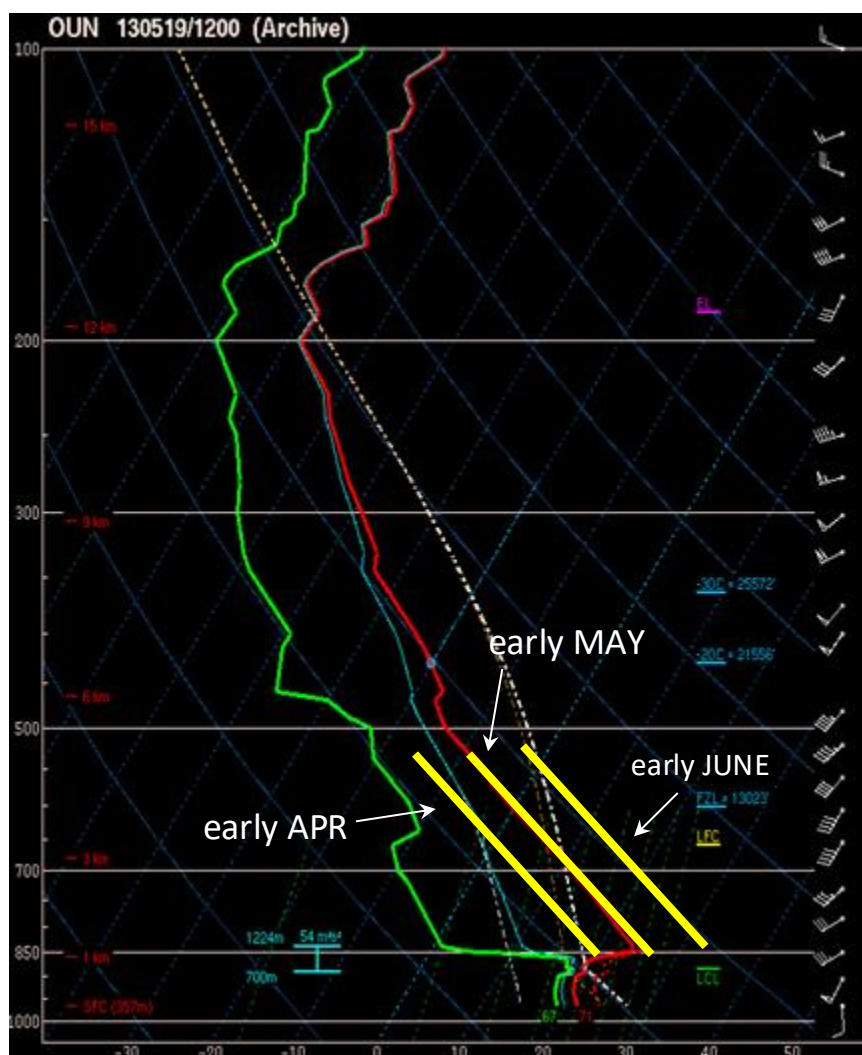
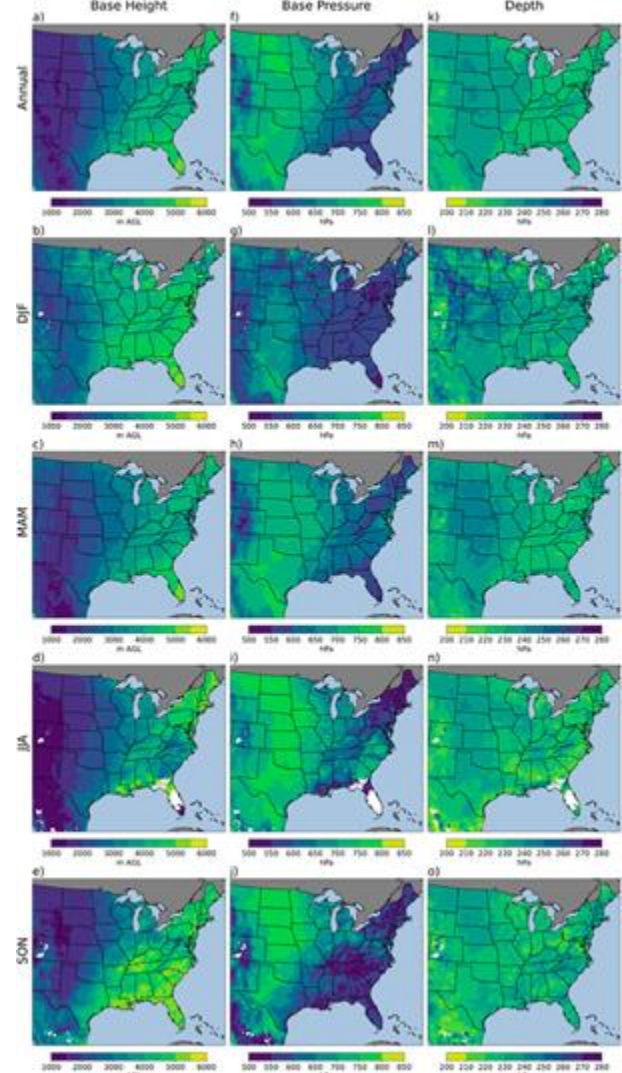
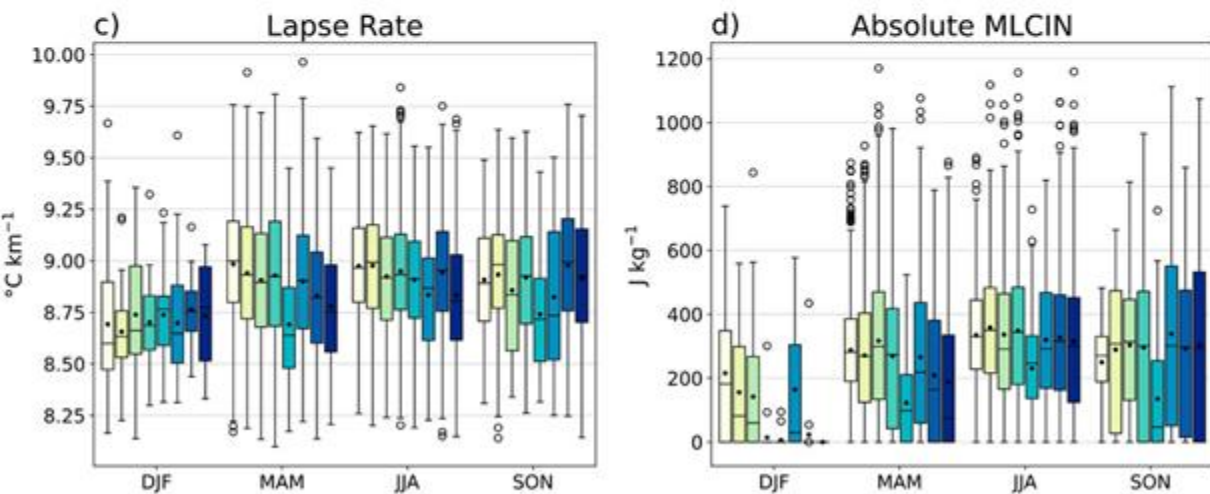
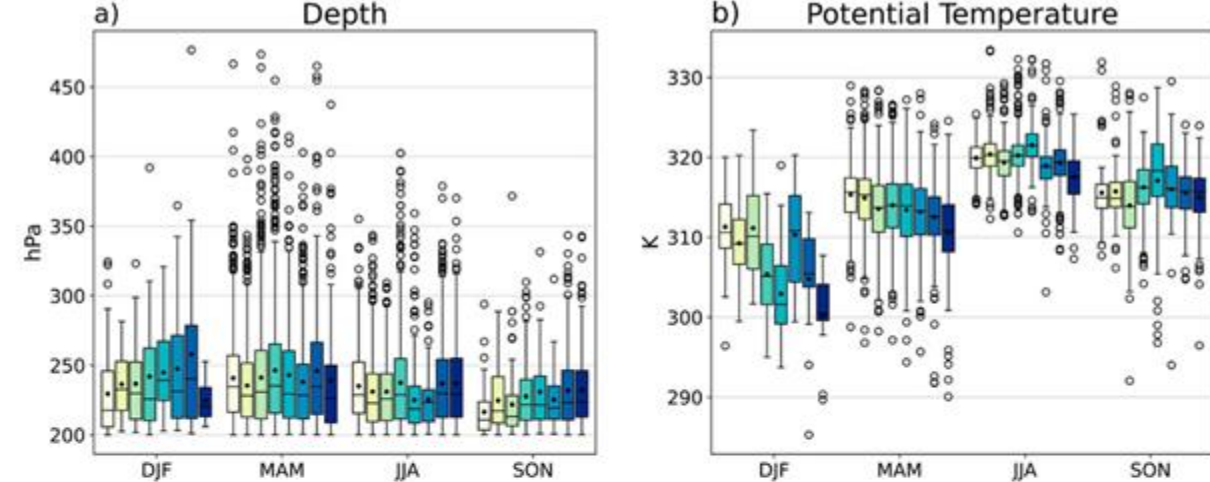
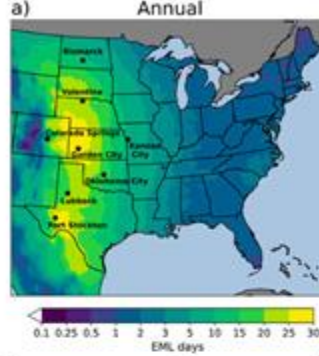
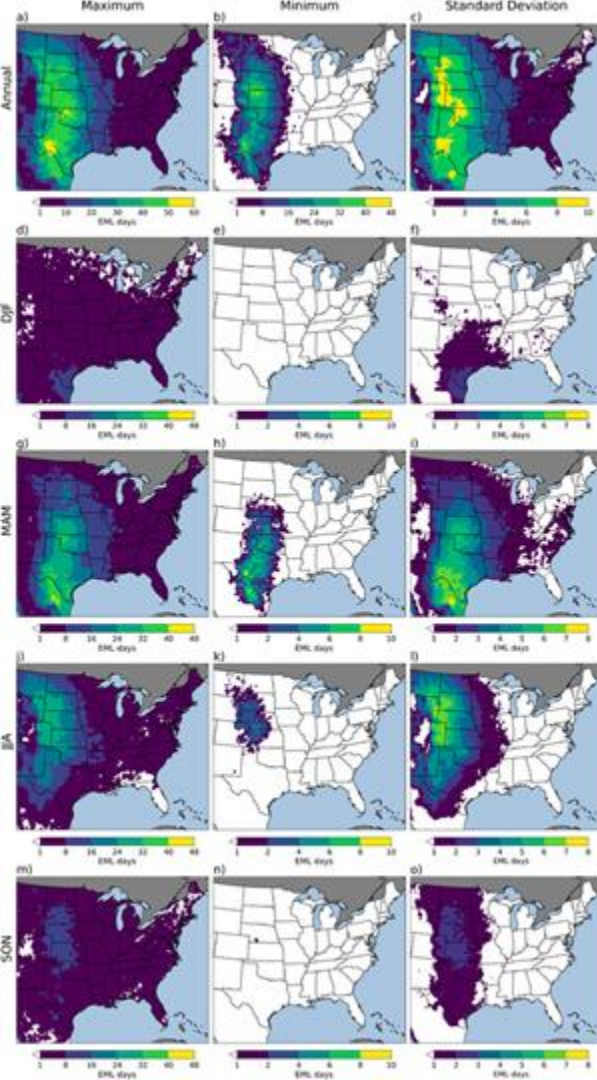


FIG. 6. Climatological mean maximum surface potential temperature analysis (in °C) over northern Mexico and the western U.S. for a) April, b) May, and c) June. Values greater than or equal to 44°C are alternately highlighted in 4°C intervals as shown in the lower left corner of chart (a).

Climatology of
surface theta
(and EML)

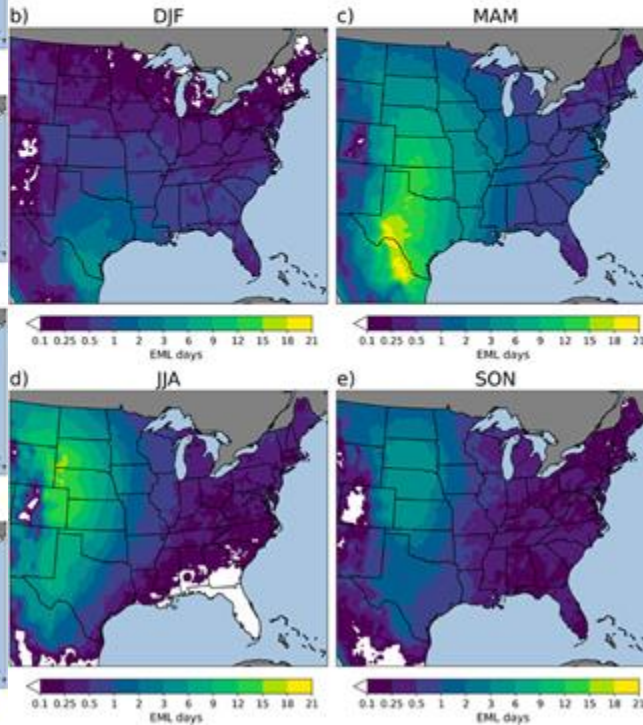
Lanicci and Warner (1991)





Source: Climatology of the Elevated Mixed Layer over the Contiguous United States and Northern Mexico Using ERA5: 1979–2021

Andrews et., al 2024 JOC



Lapse Rate Tendency Equation

$$\frac{\partial \gamma}{\partial t} = \underbrace{-\mathbf{v}_h \cdot \nabla_h \gamma}_{\text{B}} - \underbrace{w \frac{\partial \gamma}{\partial z}}_{\text{C}} + \underbrace{\frac{\partial \mathbf{v}_h}{\partial z} \cdot \nabla_h T}_{\text{D}} + \underbrace{\frac{\partial w}{\partial z} (\Gamma_d - \gamma)}_{\text{E}} - \underbrace{\frac{1}{C_p} \frac{\partial q}{\partial z}}_{\text{F}}$$

A
B
C
D
E
F

Term C: vertical lapse rate advection

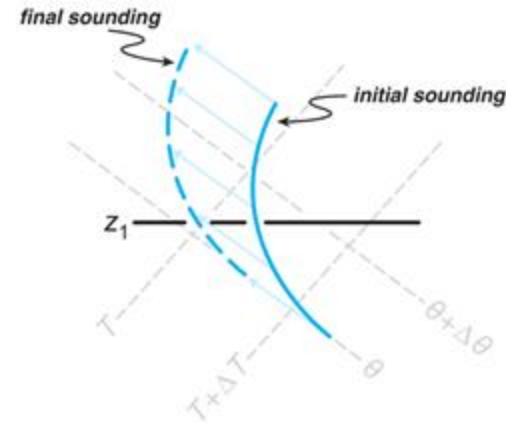


Figure 7.5

Schematic thermodynamic diagram illustrating the effect of vertical lapse rate advection. The light blue arrows indicate dry adiabatic parcel displacements. At level z_1 , $\partial \gamma / \partial z < 0$, so when upward motion is imposed ($w > 0$ but $\partial w / \partial z = 0$, so that all of the parcels are displaced upward by the same distance) larger lapse rates are advected from below z_1 upward to z_1 , increasing the lapse rate there. Note that this process occurs adiabatically, so that cooling has occurred at z_1 in addition to increasing the lapse rate there. This cooling associated with upward motion is typically more important for cap removal and thunderstorm initiation than just the increasing lapse rate. For example, dry adiabatic large-scale ascent *always* leads to cooling (and cap weakening) when lapse rates are less than dry adiabatic, but lapse rate changes resulting from large-scale ascent may or may not be significant, depending on the initial γ , $\partial \gamma / \partial z$, and $\partial w / \partial z$.

Lapse Rate Tendency Equation

$$\frac{\partial \gamma}{\partial t} = \underbrace{-\mathbf{v}_h \cdot \nabla_h \gamma}_B \underbrace{- w \frac{\partial \gamma}{\partial z}}_C + \underbrace{\frac{\partial \mathbf{v}_h}{\partial z} \cdot \nabla_h T}_D + \underbrace{\frac{\partial w}{\partial z} (\Gamma_d - \gamma)}_E - \underbrace{\frac{1}{C_p} \frac{\partial q}{\partial z}}_F$$

A B C D E F

Term C: vertical lapse rate advection

Positive lapse rate advection will contribute to increasing lapse rates

In this case, lapse rates at level z_1 increase as steeper lapse rates from below are advected upward

Can be order of magnitude larger than term B on mesoscale
What mesoscale features might this be important for?

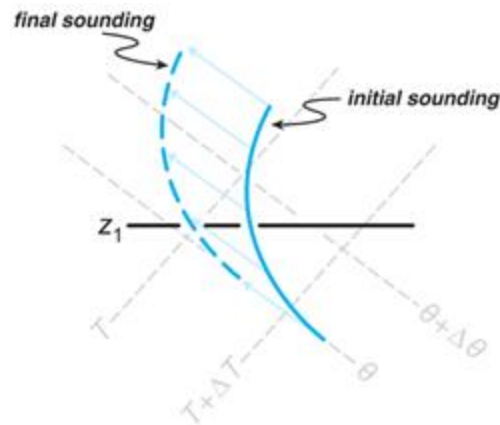
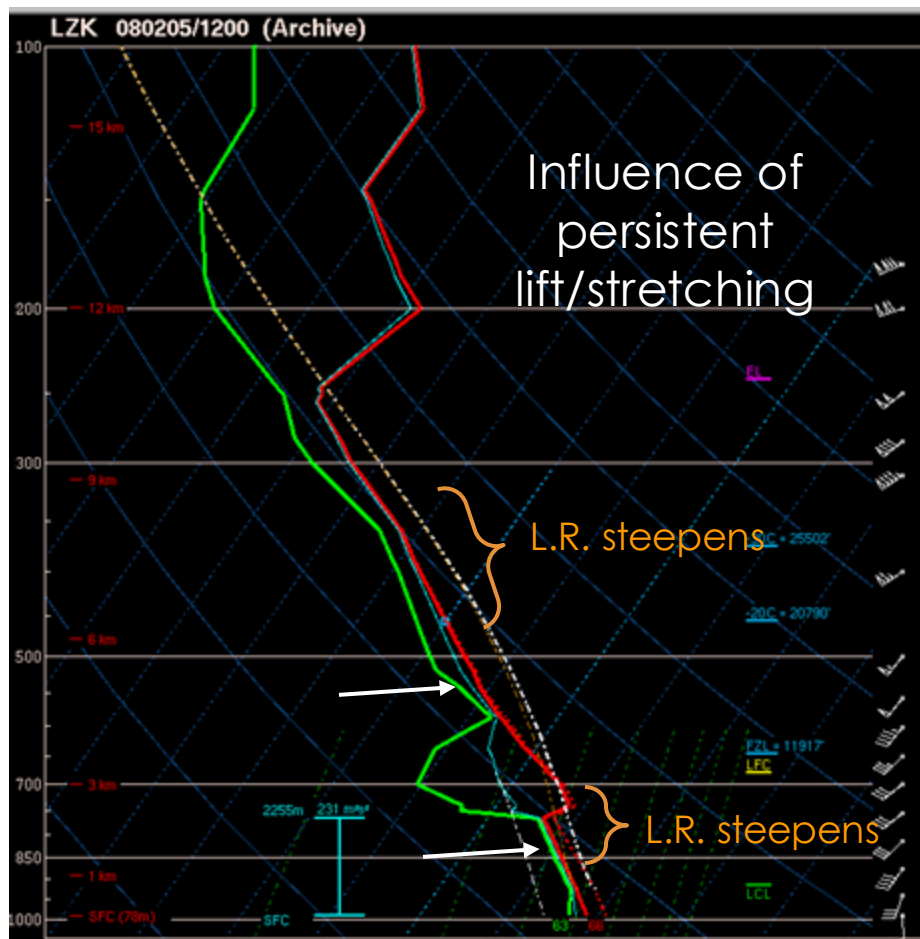
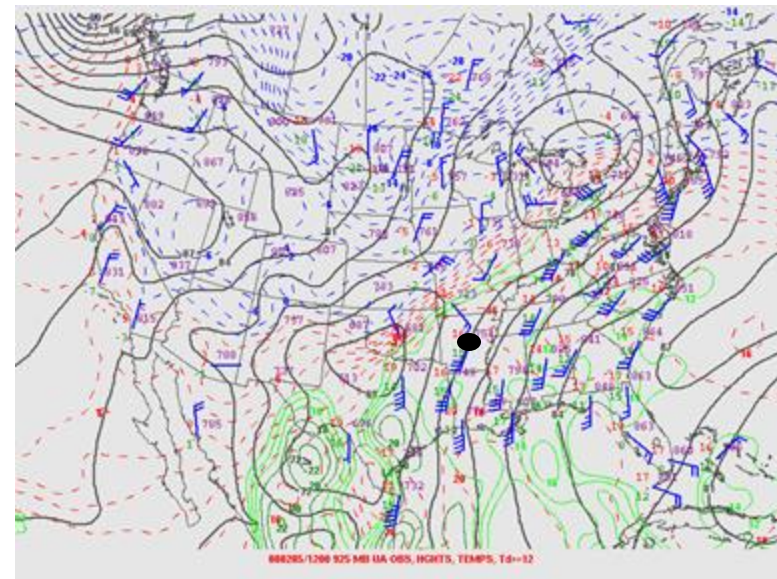


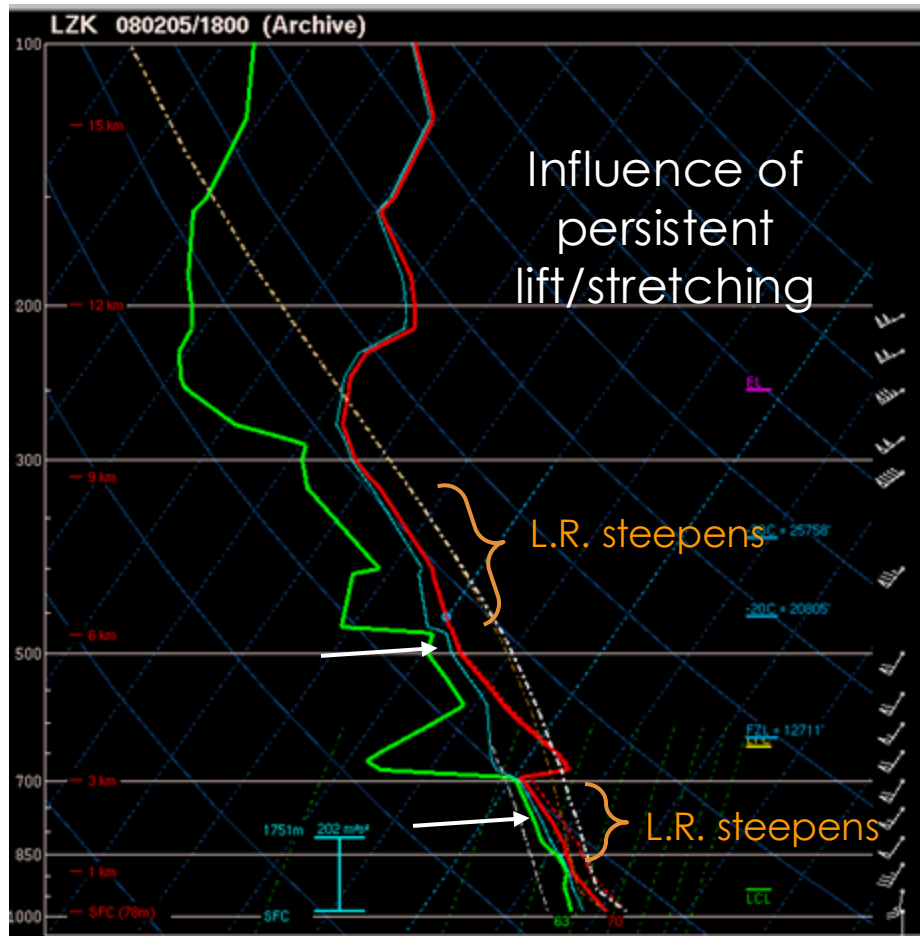
Figure 7.5

Schematic thermodynamic diagram illustrating the effect of vertical lapse rate advection. The light blue arrows indicate dry adiabatic parcel displacements. At level z_1 , $\partial \gamma / \partial z < 0$, so when upward motion is imposed ($w > 0$ but $\partial w / \partial z = 0$, so that all of the parcels are displaced upward by the same distance) larger lapse rates are advected from below z_1 upward to z_1 , increasing the lapse rate there. Note that this process occurs adiabatically, so that cooling has occurred at z_1 in addition to increasing the lapse rate there. This cooling associated with upward motion is typically more important for cap removal and thunderstorm initiation than just the increasing lapse rate. For example, dry adiabatic large-scale ascent *always* leads to cooling (and cap weakening) when lapse rates are less than dry adiabatic, but lapse rate changes resulting from large-scale ascent may or may not be significant, depending on the initial γ , $\partial \gamma / \partial z$, and $\partial w / \partial z$.

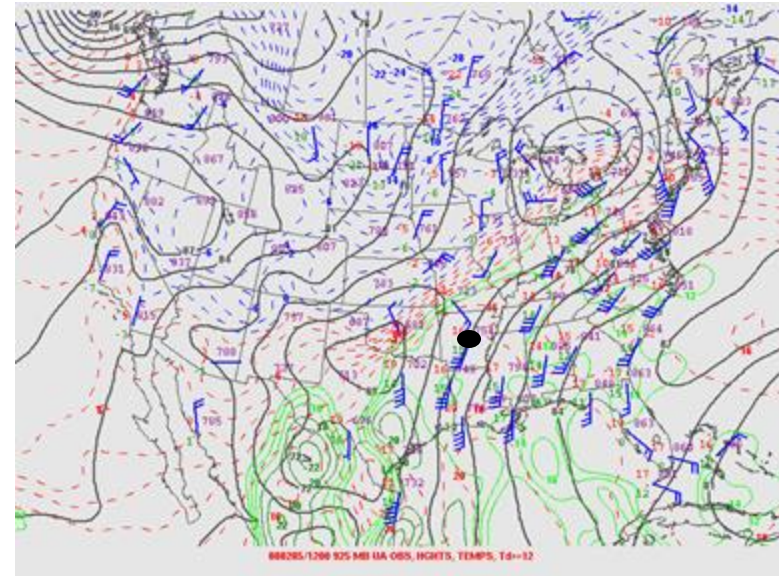


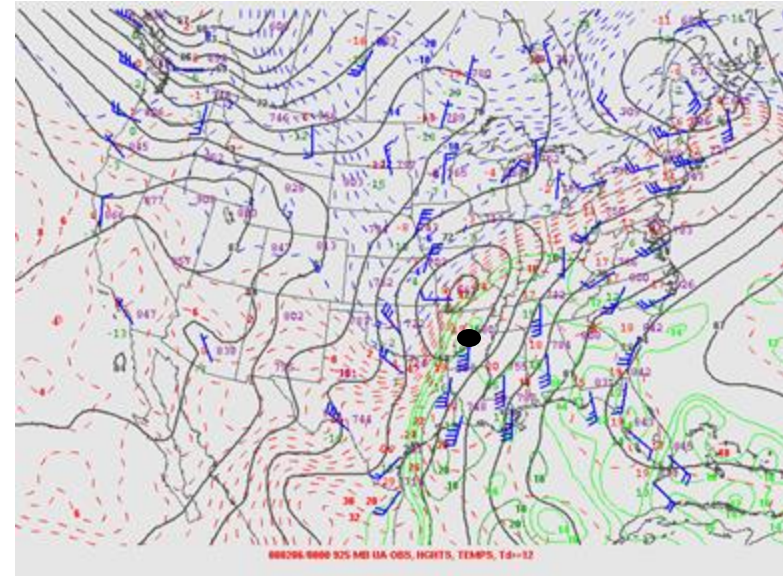
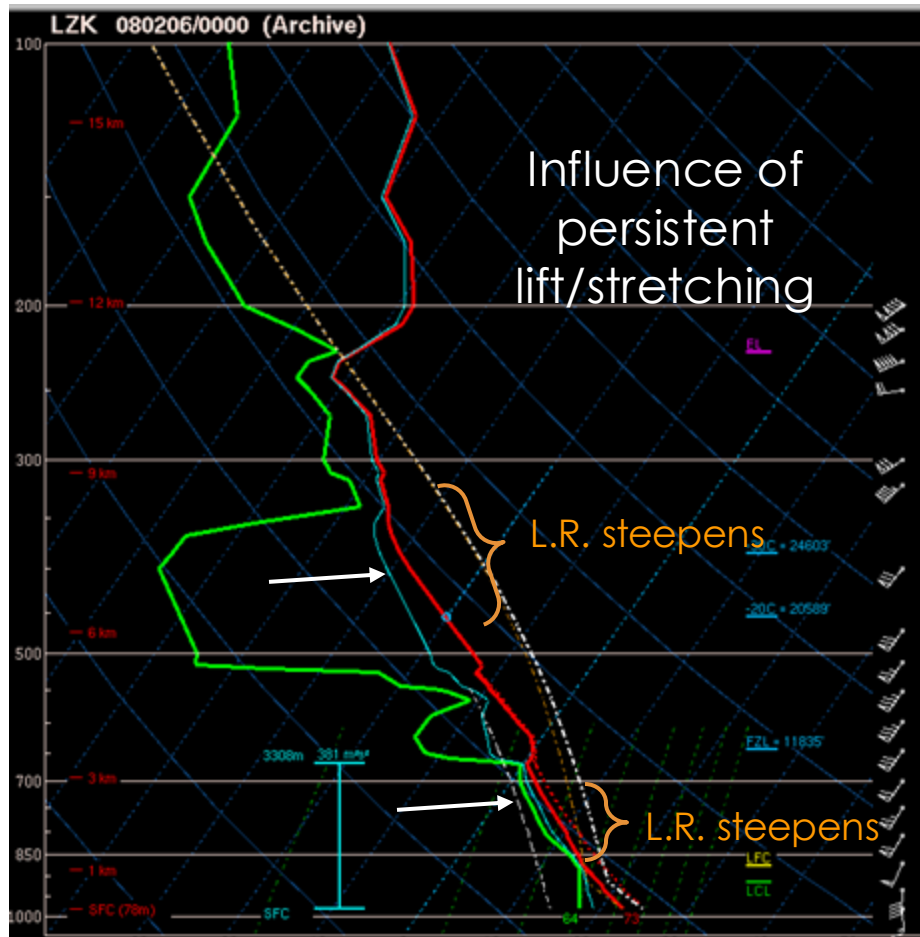
Influence of Lift/Stretching





Influence of Lift/Stretching





Lapse Rate Tendency Equation

$$\frac{\partial \gamma}{\partial t} = \underbrace{-\mathbf{v}_h \cdot \nabla_h \gamma}_{\text{B}} - \underbrace{w \frac{\partial \gamma}{\partial z}}_{\text{C}} + \underbrace{\frac{\partial \mathbf{v}_h}{\partial z} \cdot \nabla_h T}_{\text{D}} + \underbrace{\frac{\partial w}{\partial z} (\Gamma_d - \gamma)}_{\text{E}} - \underbrace{\frac{1}{C_p} \frac{\partial q}{\partial z}}_{\text{F}}$$

Term D: when combined with term B, this term represents differential temperature advection

$$\frac{\partial \mathbf{v}_h}{\partial z} \cdot \nabla_h T - \mathbf{v}_h \cdot \nabla_h \gamma = -\frac{\partial}{\partial z} (-\mathbf{v}_h \cdot \nabla_h T)$$

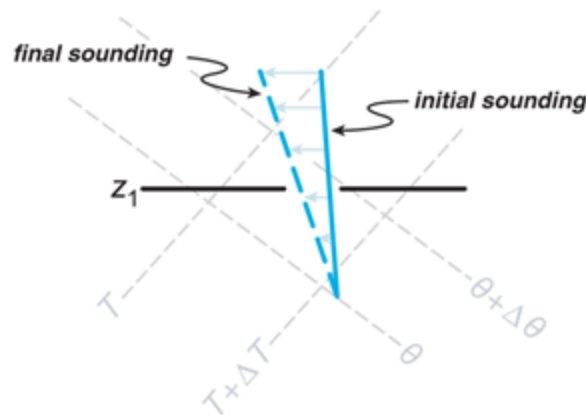


Figure 7.6

Schematic thermodynamic diagram illustrating the effect of differential horizontal temperature advection (by the ageostrophic wind) on the lapse rate (temperature changes are indicated by the light blue arrows). Cold advection increases with height at level z_1 , which leads to an increase in the lapse rate at that level. This effect is really the same effect as illustrated in Figure 7.4.

Lapse Rate Tendency Equation

$$\frac{\partial \gamma}{\partial t} = \underbrace{-\mathbf{v}_h \cdot \nabla_h \gamma}_{\text{B}} - \underbrace{w \frac{\partial \gamma}{\partial z}}_{\text{C}} + \underbrace{\frac{\partial \mathbf{v}_h}{\partial z} \cdot \nabla_h T}_{\text{D}} + \underbrace{\frac{\partial w}{\partial z} (\Gamma_d - \gamma)}_{\text{E}} - \underbrace{\frac{1}{C_p} \frac{\partial q}{\partial z}}_{\text{F}}$$

Term D: when combined with term B, this term represents differential temperature advection

$$\frac{\partial \mathbf{v}_h}{\partial z} \cdot \nabla_h T - \mathbf{v}_h \cdot \nabla_h \gamma = -\frac{\partial}{\partial z} (-\mathbf{v}_h \cdot \nabla_h T)$$

Lapse rates will increase in situations where cold advection is increasing with height or warm advection is decreasing with height

In this case, lapse rates at level z_1 increase in response to cold air advection increasing with height

Can be order of magnitude larger than term B on mesoscale

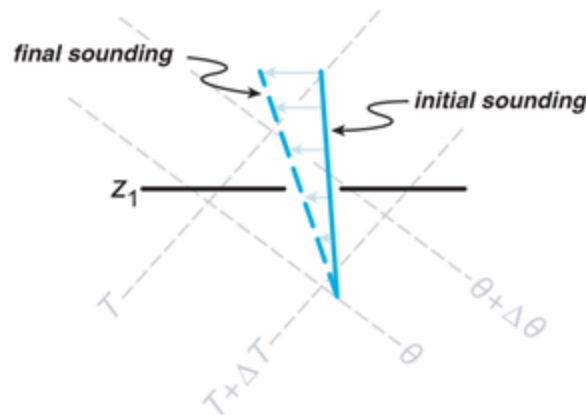
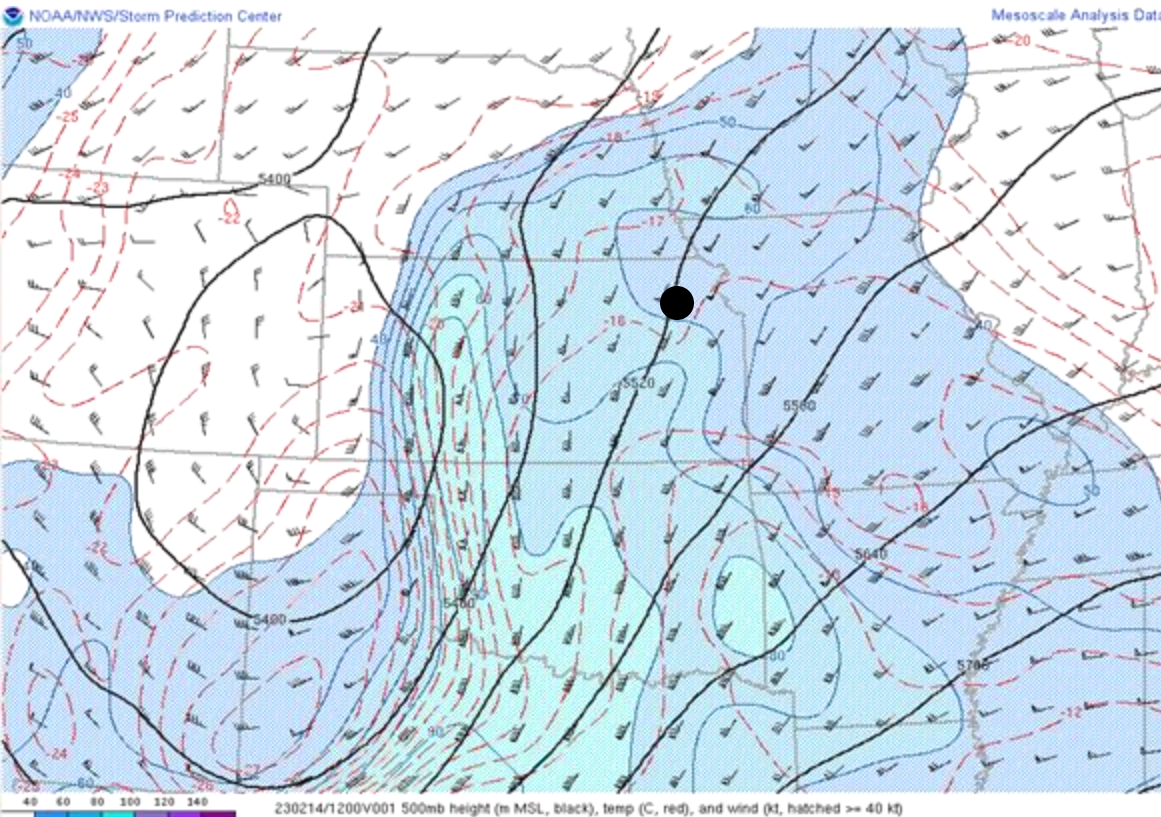


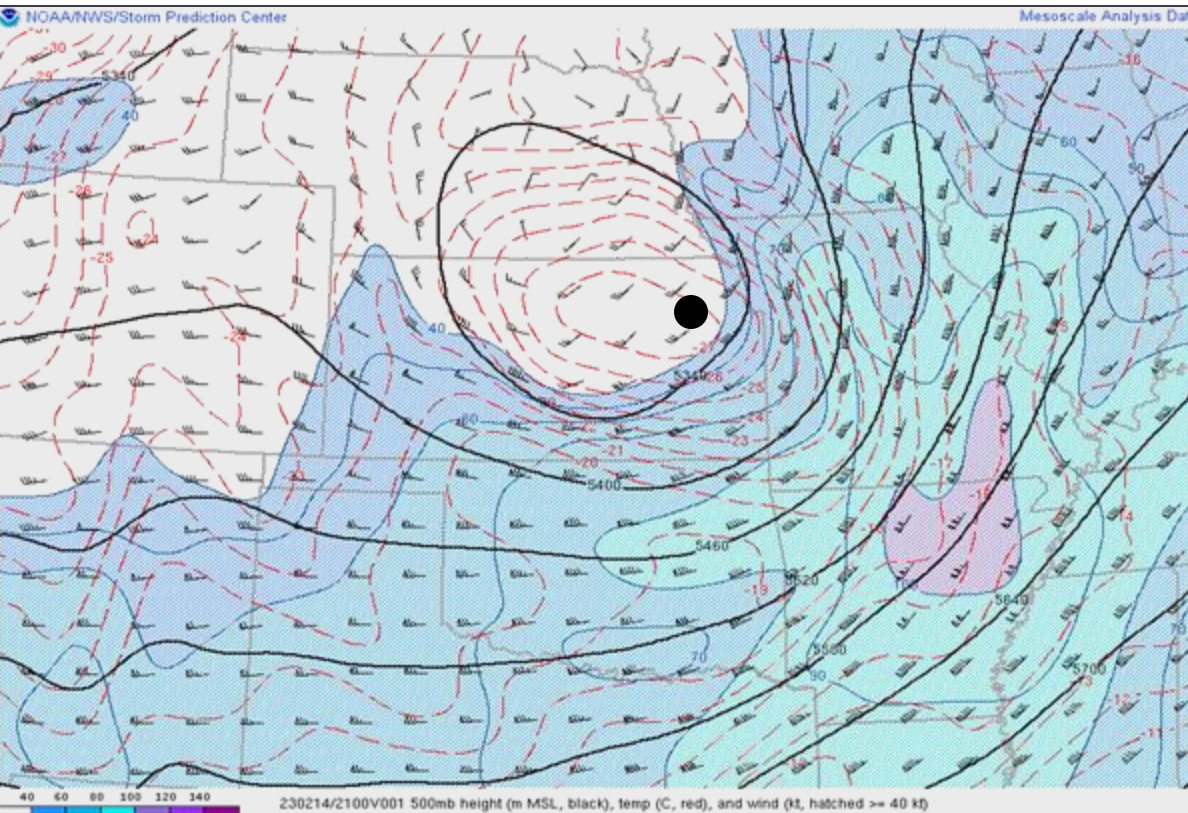
Figure 7.6

Schematic thermodynamic diagram illustrating the effect of differential horizontal temperature advection (by the ageostrophic wind) on the lapse rate (temperature changes are indicated by the light blue arrows). Cold advection increases with height at level z_1 , which leads to an increase in the lapse rate at that level. This effect is really the same effect as illustrated in Figure 7.4.

Differential Thermal Advection



Differential Thermal Advection



Lapse Rate Tendency Equation

$$\frac{\partial \gamma}{\partial t} = \underbrace{-\mathbf{v}_h \cdot \nabla_h \gamma}_{\text{B}} - \underbrace{w \frac{\partial \gamma}{\partial z}}_{\text{C}} + \underbrace{\frac{\partial \mathbf{v}_h}{\partial z} \cdot \nabla_h T}_{\text{D}} + \underbrace{\frac{\partial w}{\partial z} (\Gamma_d - \gamma)}_{\text{E}} - \underbrace{\frac{1}{C_p} \frac{\partial q}{\partial z}}_{\text{F}}$$

Term E: stretching effect on lapse rate

Horizontal convergence increases lapse rate
 Horizontal divergence decreases lapse rate
 Term = 0 when environment lapse rate is dry
 adiabatic ($\gamma = \Gamma_d$)

In this case, lapse rates at level z_1 increase in
 response to convergence ($\frac{\partial w}{\partial z} > 0$)

Can be order of magnitude larger than term
 B on mesoscale

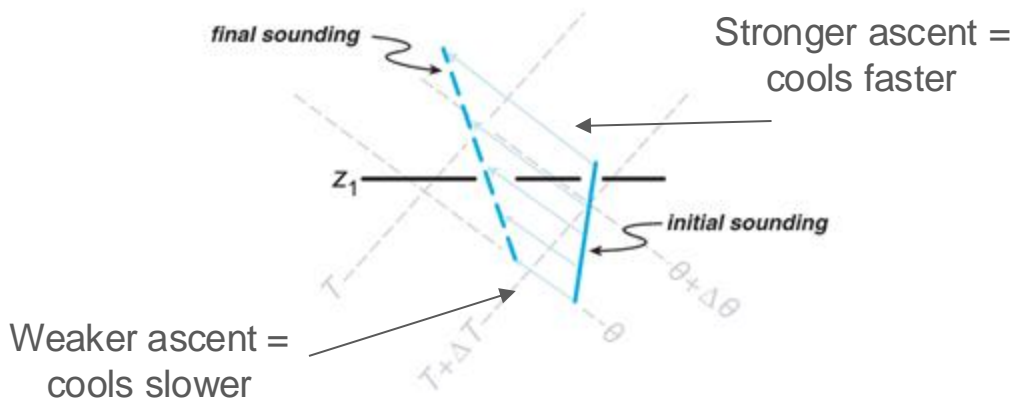
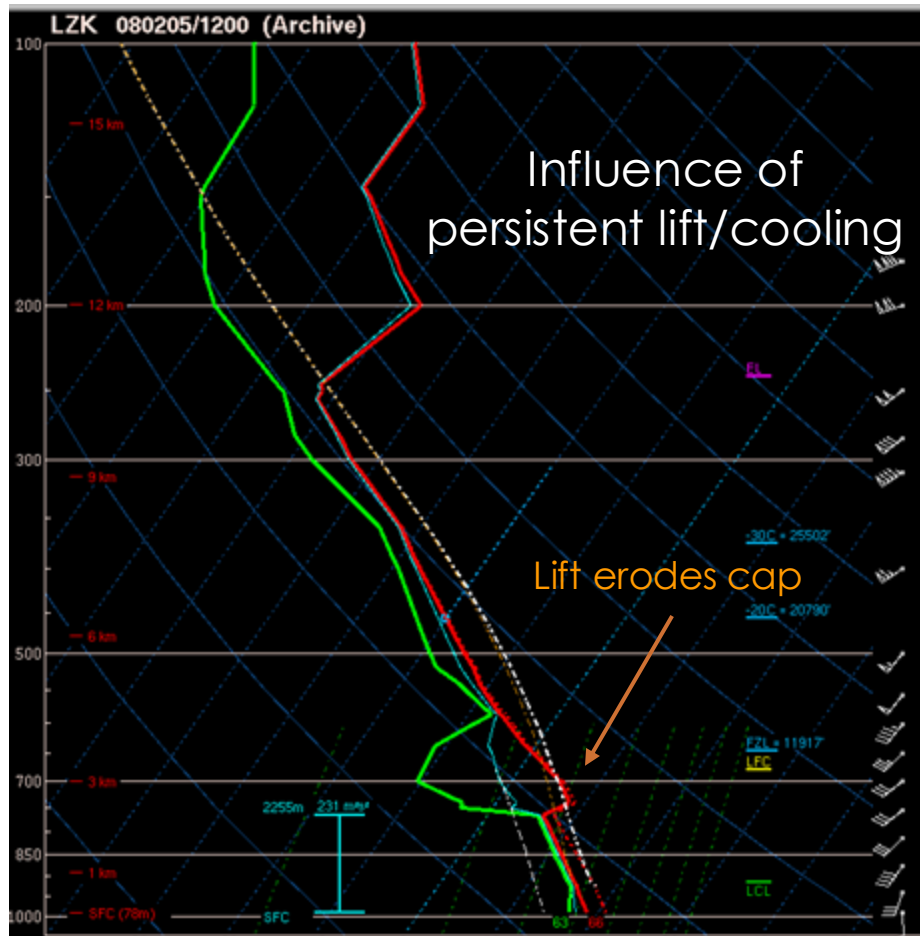
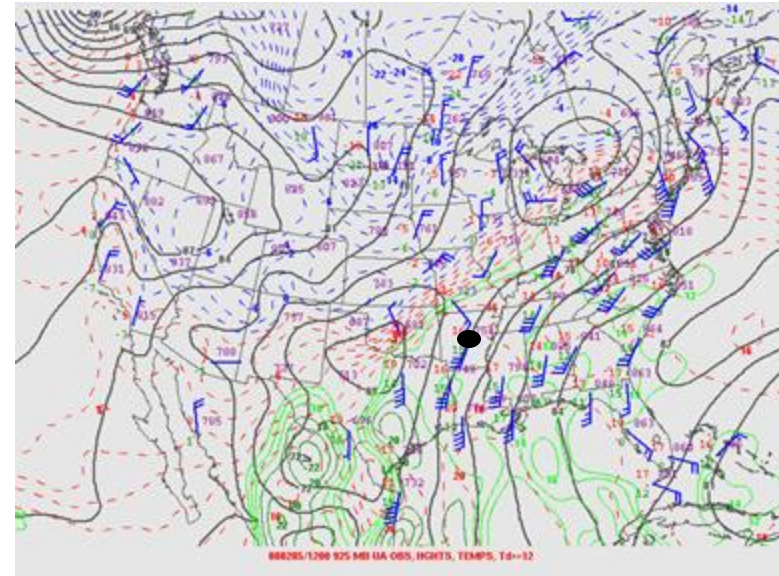


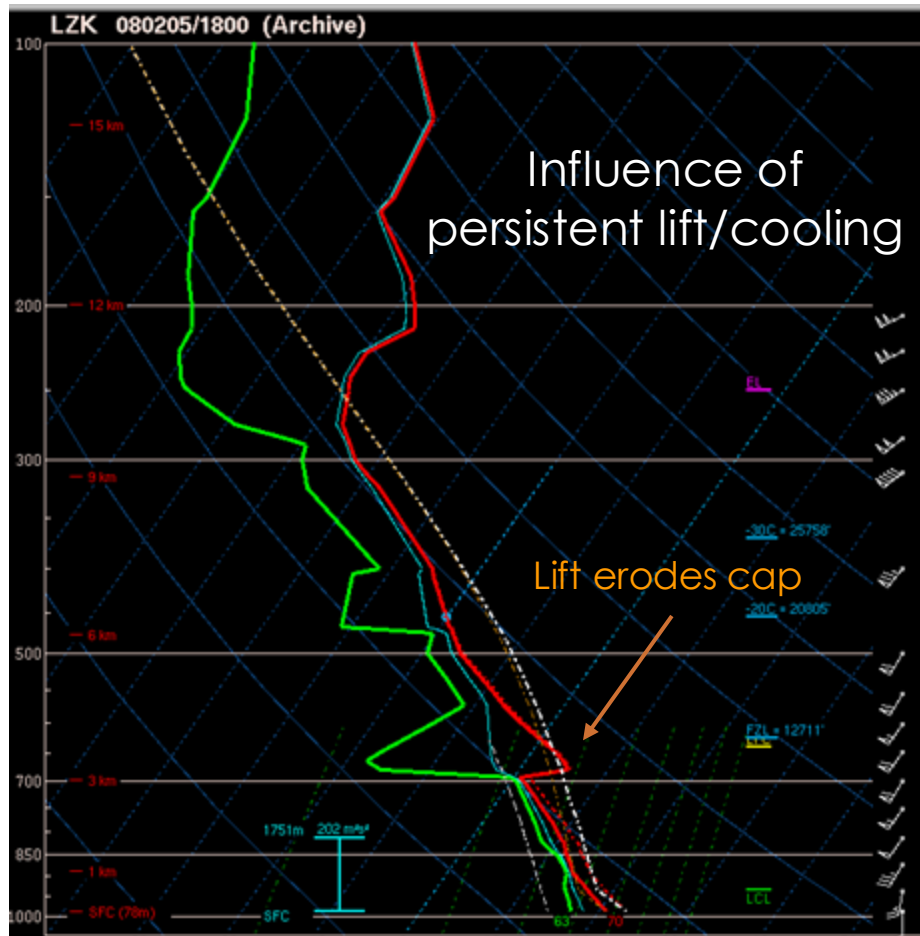
Figure 7.7

Schematic thermodynamic diagram illustrating the stretching effect on lapse rate. In this example, $\Gamma_d > \gamma$ and $\partial w / \partial z > 0$, therefore the lapse rate at level z_1 increases in time. The light blue arrows indicate dry adiabatic upward parcel displacements (because $\partial w / \partial z > 0$, the displacements increase with height).

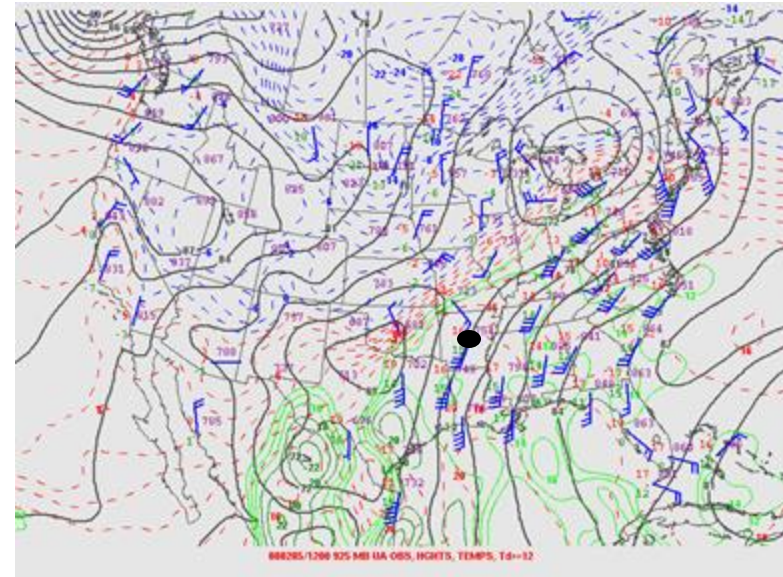


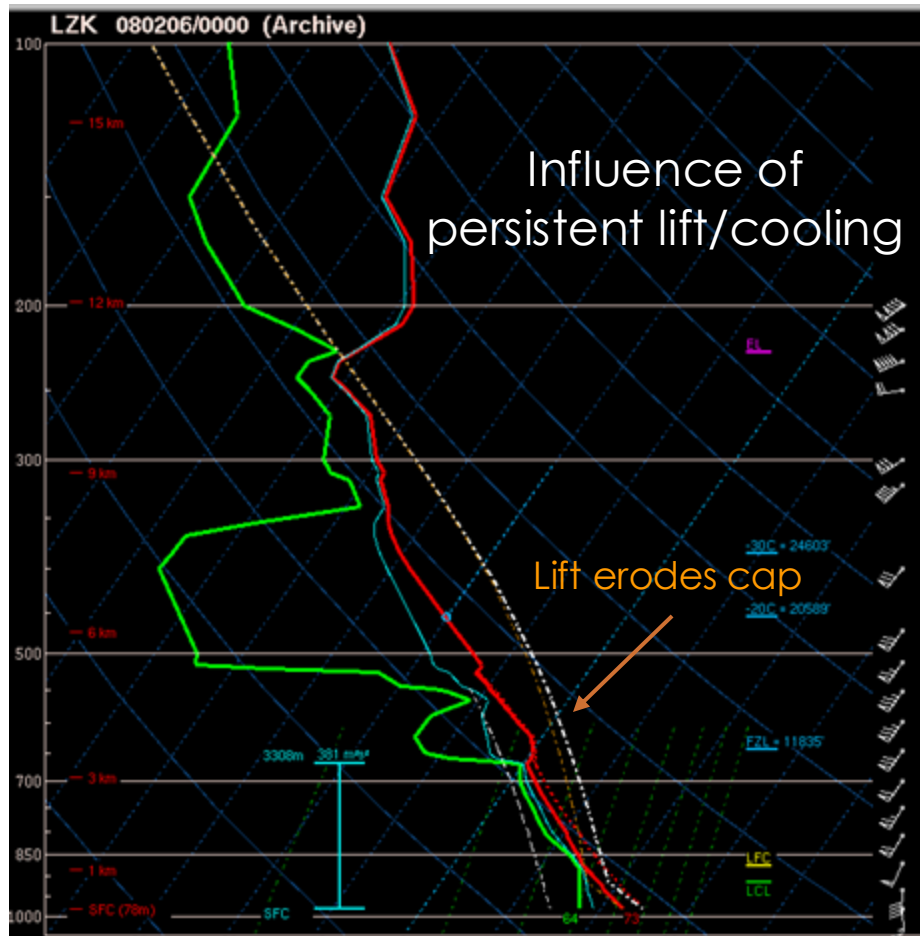
Influence of Lift/Stretching



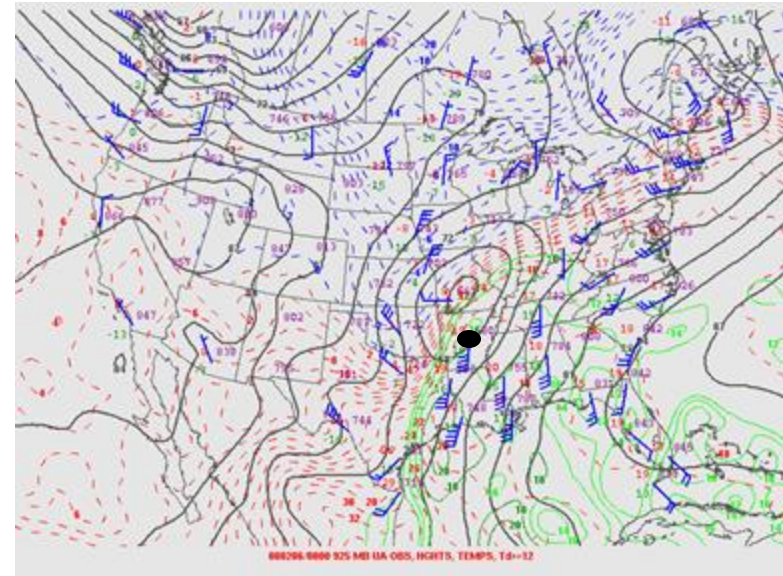


Influence of Lift/Stretching





Influence of Lift/Stretching



Lapse Rate Tendency Equation

$$\frac{\partial \gamma}{\partial t} = \underbrace{-\mathbf{v}_h \cdot \nabla_h \gamma}_{\text{A}} - \underbrace{w \frac{\partial \gamma}{\partial z}}_{\text{B}} + \underbrace{\frac{\partial \mathbf{v}_h}{\partial z} \cdot \nabla_h T}_{\text{C}} + \underbrace{\frac{\partial w}{\partial z} (\Gamma_d - \gamma)}_{\text{E}} \underbrace{- \frac{1}{C_p} \frac{\partial q}{\partial z}}_{\text{F}}$$

Term F: diabatic heating effect on lapse rate

In this case, in response to a diabatic heating maximum at level z_1 , lapse rates increase above and decrease below level z_1 .

Where does most diabatic heating occur?

Can be order of magnitude larger than term B on mesoscale

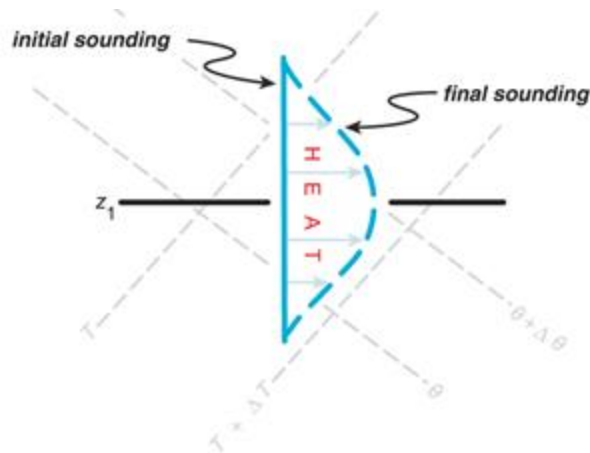
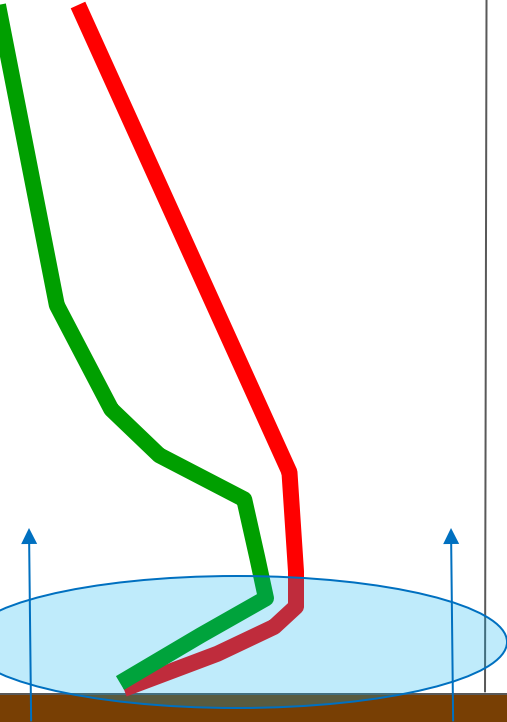


Figure 7.8

Schematic thermodynamic diagram illustrating the effects of differential diabatic heating on lapse rate (temperature changes are indicated by the light blue arrows). The maximum latent heating occurs at level z_1 , where $\partial q / \partial z = 0$ and the lapse rate is unchanged. The lapse rate increases above the level of maximum heating ($z > z_1$) and decreases below the level of maximum heating ($z < z_1$).

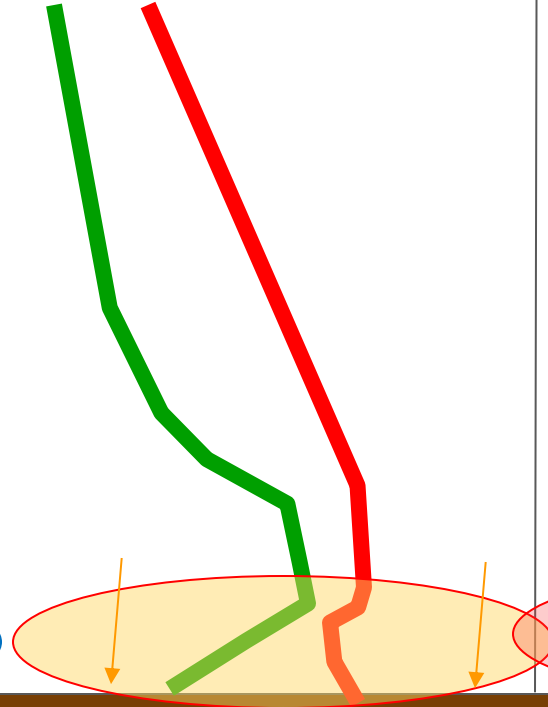
T=morning

Maximum in
diabatic cooling



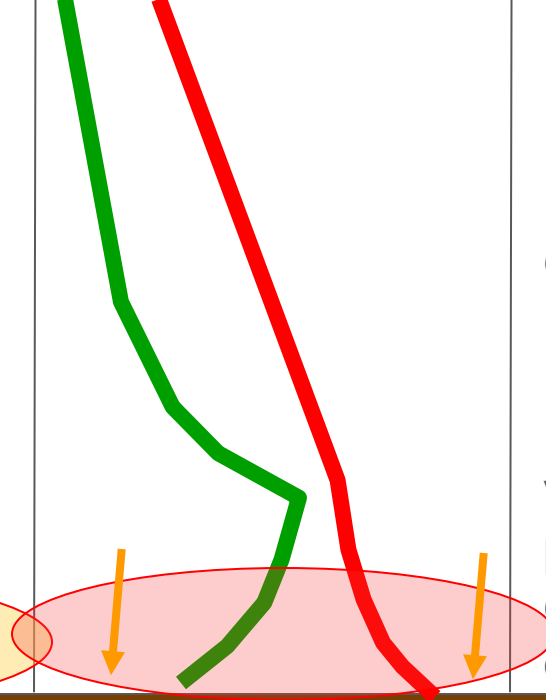
T=mid day

Radiation has reversed
sun warming the
ground



T= afternoon

Maximum solar
heating



Solar/terrestrial
radiation of near
surface air is a
primary driver of
low-level lapse
rates.

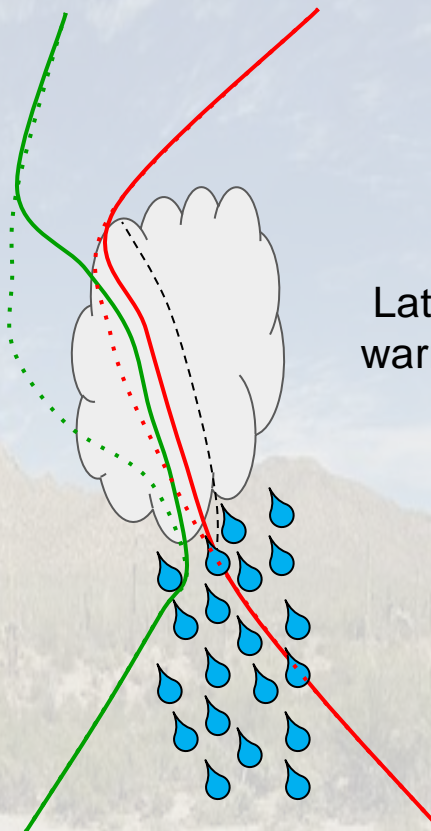
Increases lapse
rates near the
ground when
heated.

Heating is a
very important
part of
convective
development.

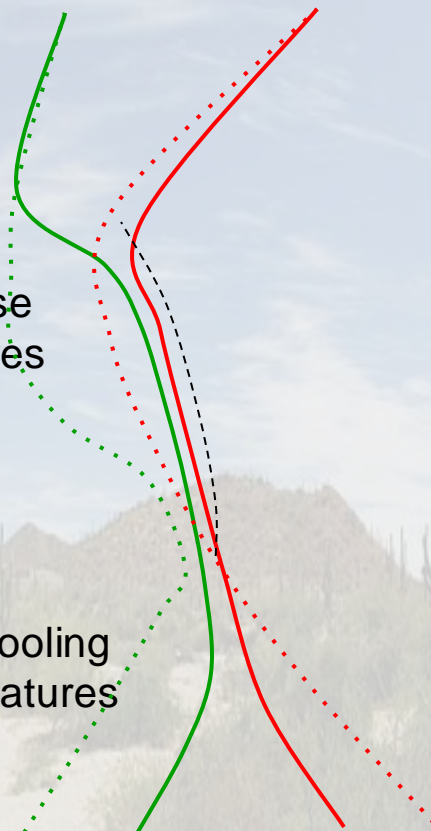
Initial Profile



Convection Occurs



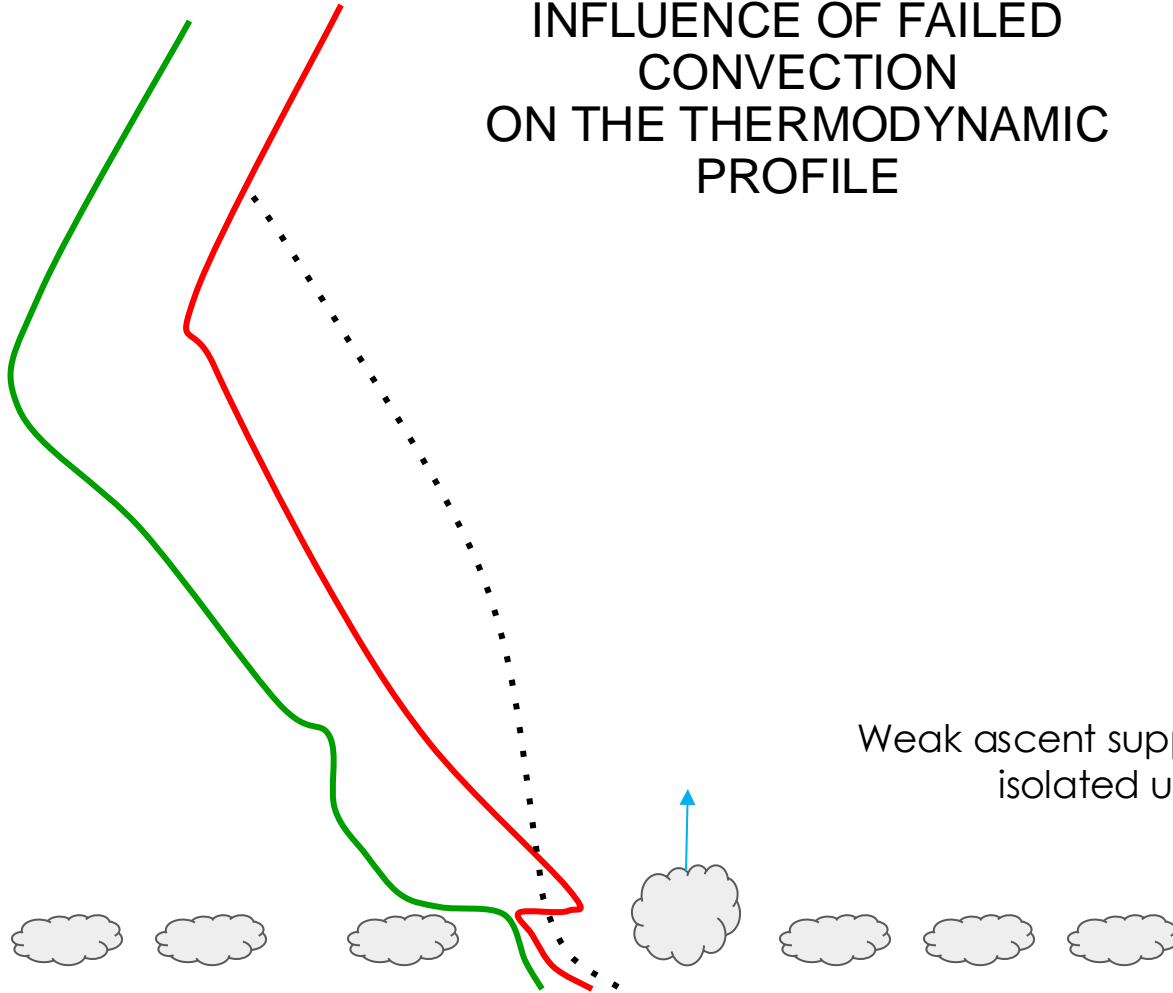
Final Profile



Latent heat release
warms temperatures

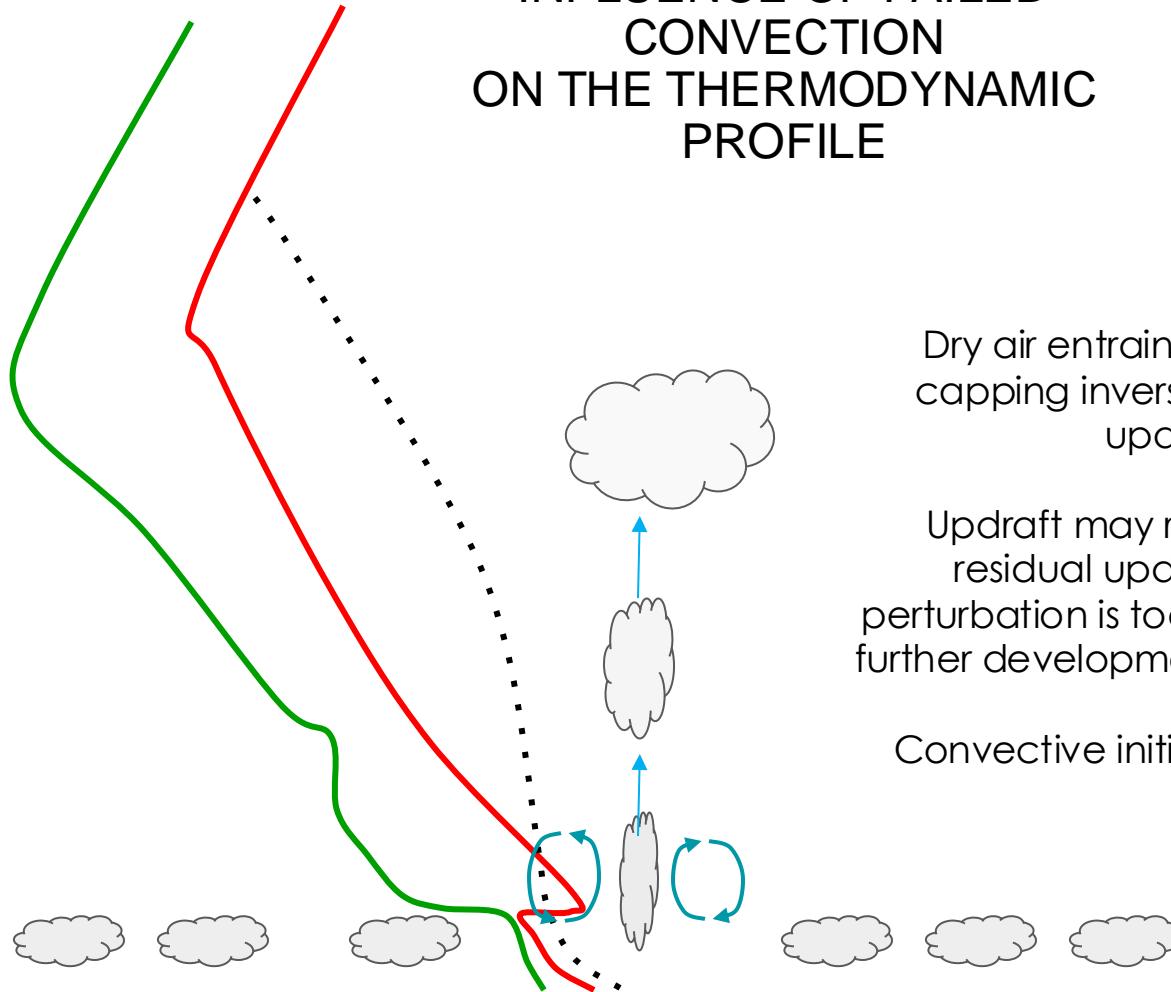
Evaporative cooling
lowers temperatures

INFLUENCE OF FAILED CONVECTION ON THE THERMODYNAMIC PROFILE



Weak ascent supports an initial,
isolated updraft

INFLUENCE OF FAILED CONVECTION ON THE THERMODYNAMIC PROFILE

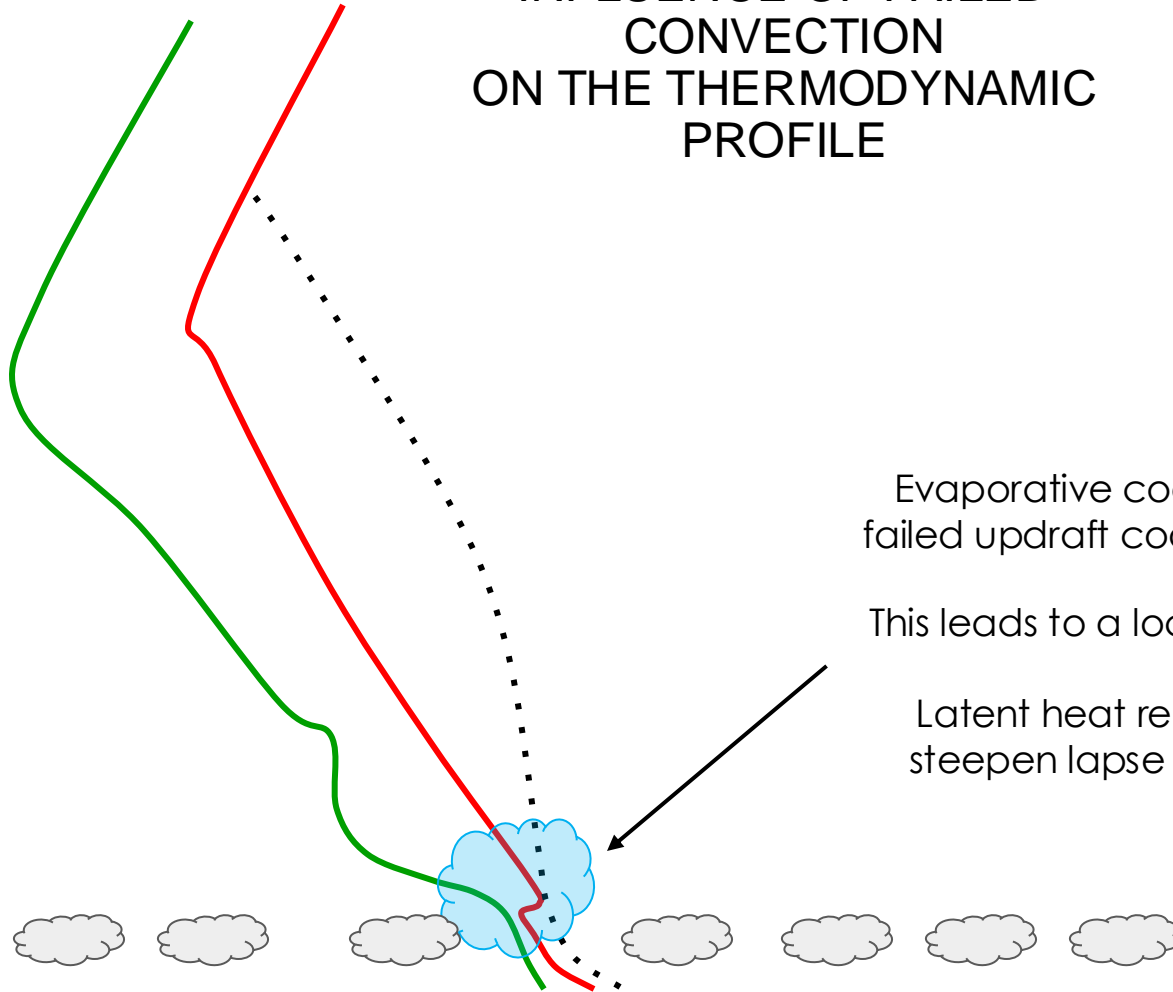


Dry air entrainment near the capping inversion erodes the updraft.

Updraft may reach LFC, but residual updraft/pressure perturbation is too weak to support further development (turkey tower).

Convective initiation has failed.

INFLUENCE OF FAILED CONVECTION ON THE THERMODYNAMIC PROFILE

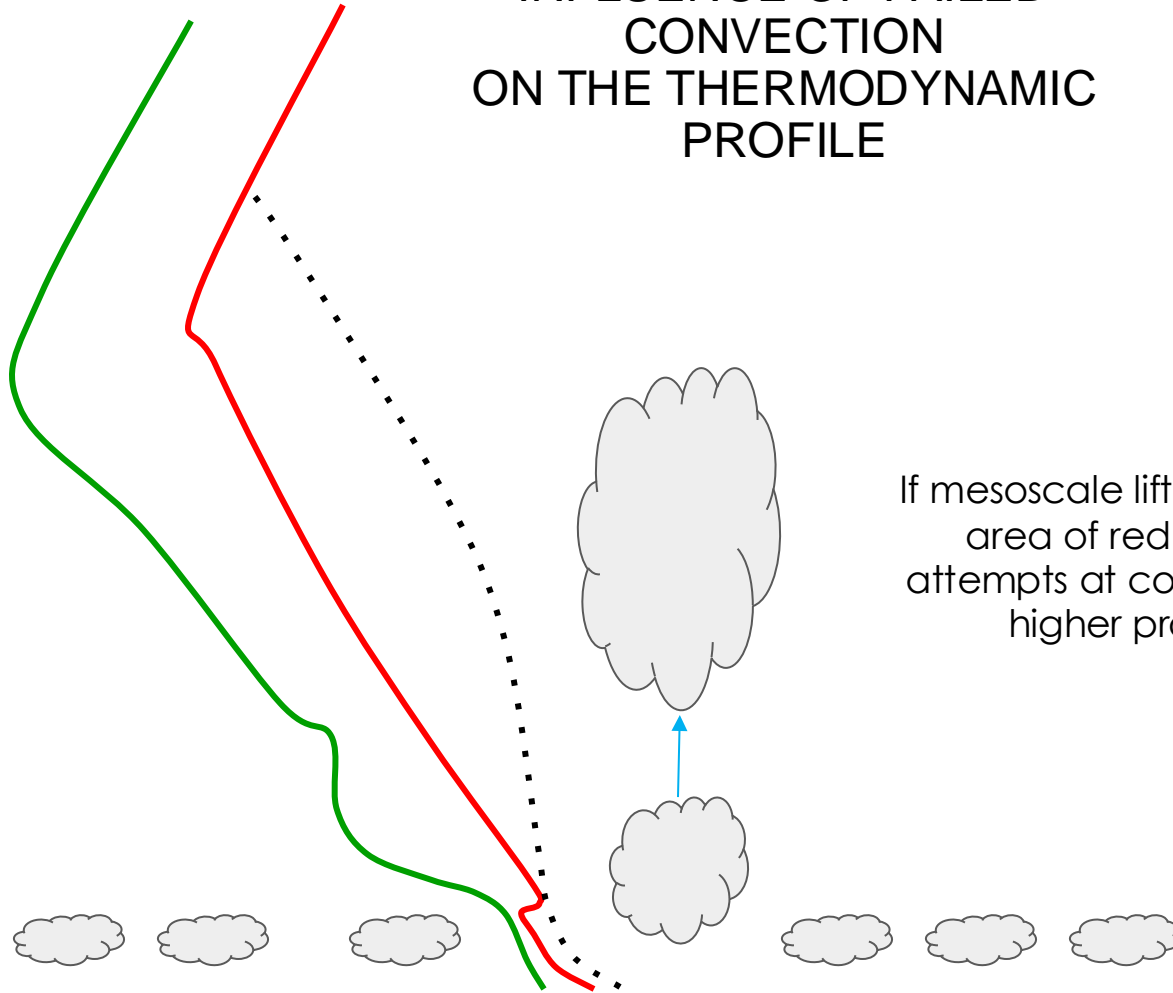


Evaporative cooling in the path of the failed updraft cools/moistens the column.

This leads to a localized reduction in CIN.

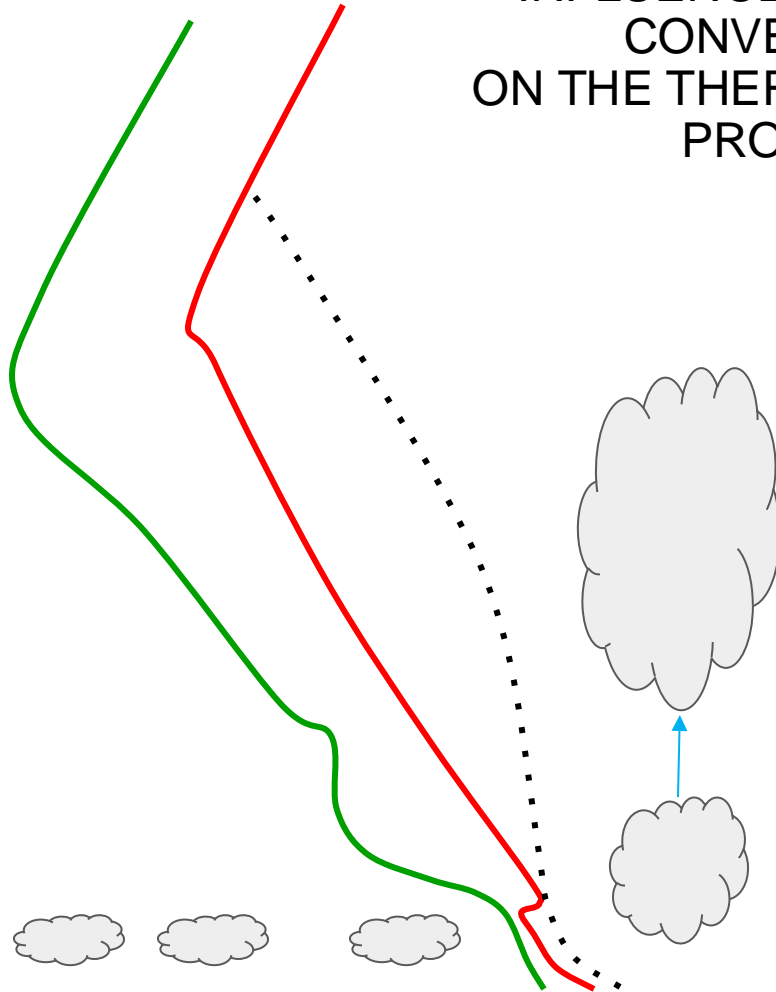
Latent heat release can also locally steepen lapse rates above failed CI.

INFLUENCE OF FAILED CONVECTION ON THE THERMODYNAMIC PROFILE



If mesoscale lift continues in this localized area of reduced CIN, subsequent attempts at convective initiation have a higher probability of success!

INFLUENCE OF FAILED CONVECTION ON THE THERMODYNAMIC PROFILE



Additional Considerations:

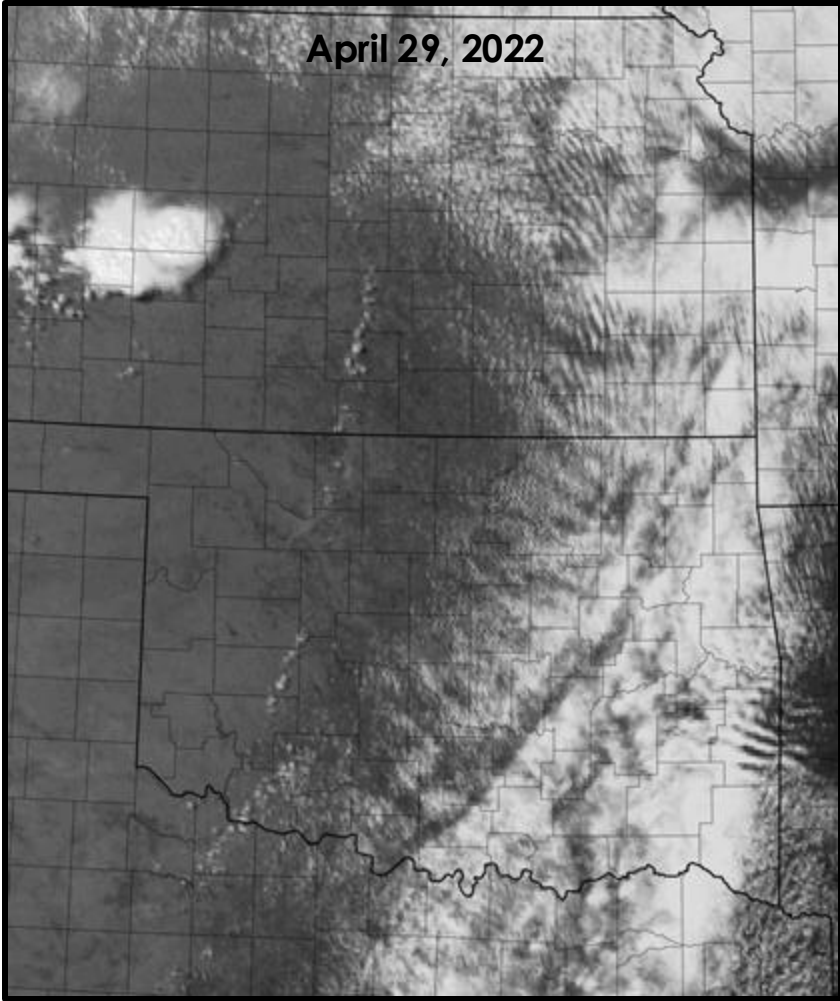
It may take multiple attempts at CI to sufficiently reduce CIN.

Consider time of day (is this occurring at 20 UTC (additional diurnal heating expected) or at 00 UTC (peak diurnal heating)?

Strong forcing for ascent can reduce CIN via lift/cooling and/or overcoming cap by lifting parcels to LFC (i.e. is the depth of the lift greater than the LFC?)

Watching satellite trends is vital!

April 29, 2022



In this loop, watch for:

- Initial attempts at CI along dryline
- Successful CI following the failed attempts
- Maturation of tornadic supercells

CAPE/CIN Changes Independent of γ Tendency

- CIN can be reduced and/or CAPE increased by:

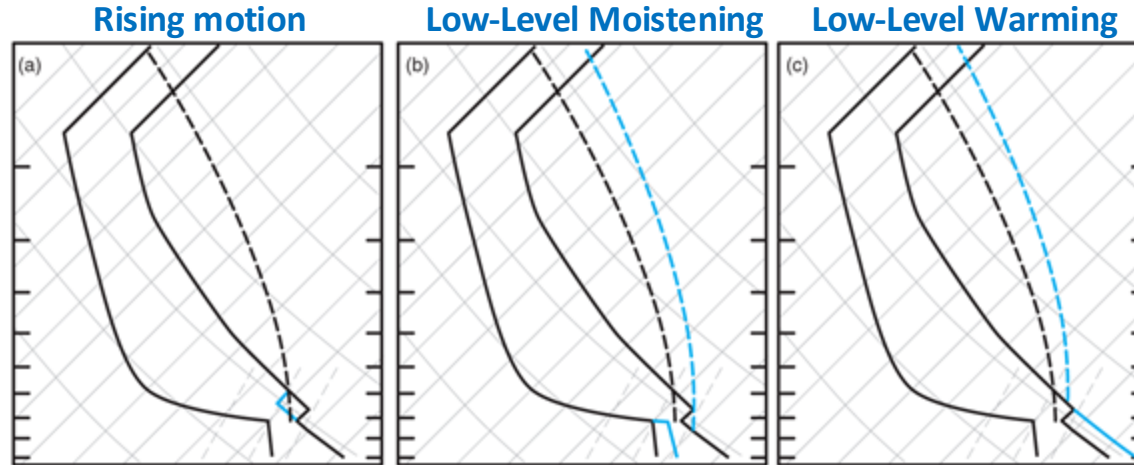


Figure 7.9

CIN can be reduced by (a) large-scale rising motion, (b) low-level moistening (e.g., moisture advection), and (c) low-level warming (e.g., insolation), despite the fact that the CIN modifications may not be accompanied by lapse rate changes, at least not over a significant depth. In (a)–(c), the isotherms and isentropes are solid gray lines, the constant mixing ratio lines are gray dashed lines, the sounding and trajectory taken by an air parcel lifted from the surface are solid and dashed black curves, respectively, and the modified sounding and parcel trajectory are blue solid and dashed curves, respectively. In (a), for clarity, only the temperature profile has been modified (the moisture profile has not been modified in accordance with the vertical motion that has been imposed in the layer of the capping inversion). Note that (b) and (c) are also accompanied by increases in CAPE. Conversely, CIN is augmented by large-scale descent, boundary layer cooling (although this would typically not occur without a concurrent stabilization of the lapse rate), and boundary layer drying (not shown).

In reality a combination of processes change γ

$$\frac{\partial \gamma}{\partial t} = -\mathbf{v}_h \cdot \nabla_h \gamma - w \frac{\partial \gamma}{\partial z} + \frac{\partial \mathbf{v}_h}{\partial z} \cdot \nabla_h T + \frac{\partial w}{\partial z} (\Gamma_d - \gamma) - \frac{1}{C_p} \frac{\partial q}{\partial z}$$

- Horizontal lapse rate advection
- Differential thermal advection
- Ascent stretching/vertical advection
- Low-level diabatic heating
- Net Effect: Steep lapse rates!

