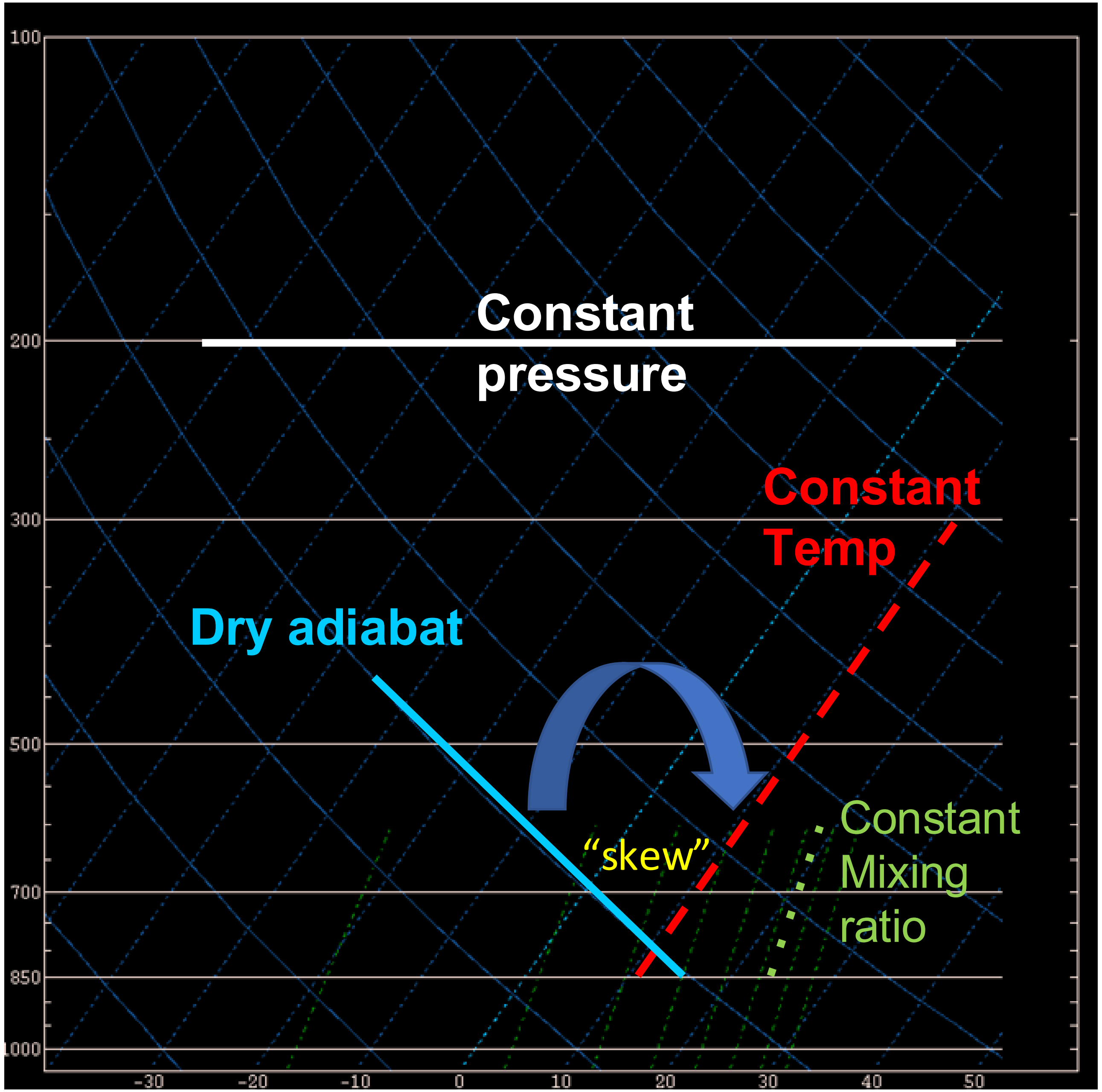
Skew-T Diagram Basics

METR 4403/5403

Material originally prepared by Rich Thompson
Updated by Andrew Lyons, Andrew Moore

Raw SkewT-log P diagram

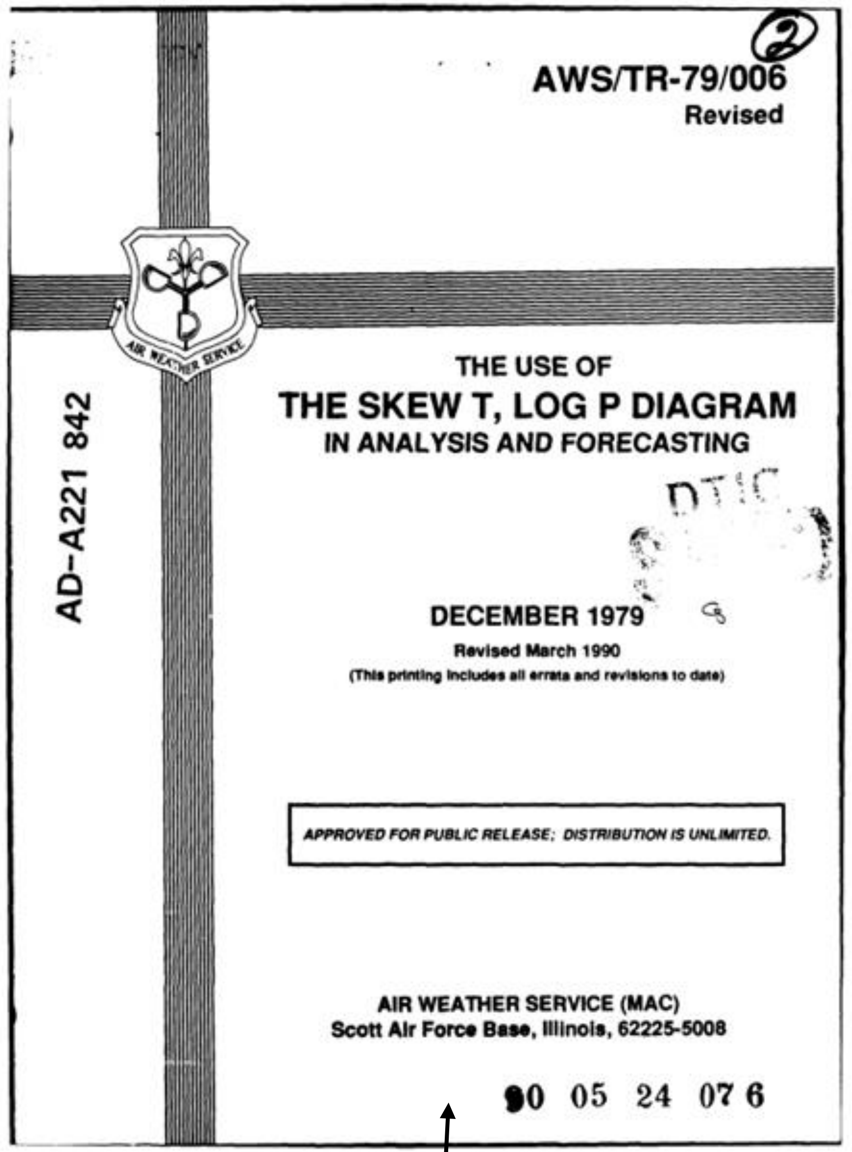


Features of note in SkewT log P

- Temperature is skewed about 90^o from the dry adiabats
- Pressure decreases as a logarithm of height (faster at bottom than top)
- Mixing ratio crosses over temperature lines
  - It's a function of pressure, which is why the same dew point temperature at higher elevation contributes more to buoyancy
- One thing missing is a plot of saturated parcel ascent

Common Sounding Terms

- LCL – lifting condensation level
- LFC – level of free convection
- EL – equilibrium level
- CAPE – buoyancy (positive area)
- CIN – convective inhibition (negative area)
- Autoconvective Lapse Rate (34.2 C/km)
- Convective Temperature
- Virtual Temperature
- Potential Temperature
- Equivalent Potential Temperature
- Lifted Index

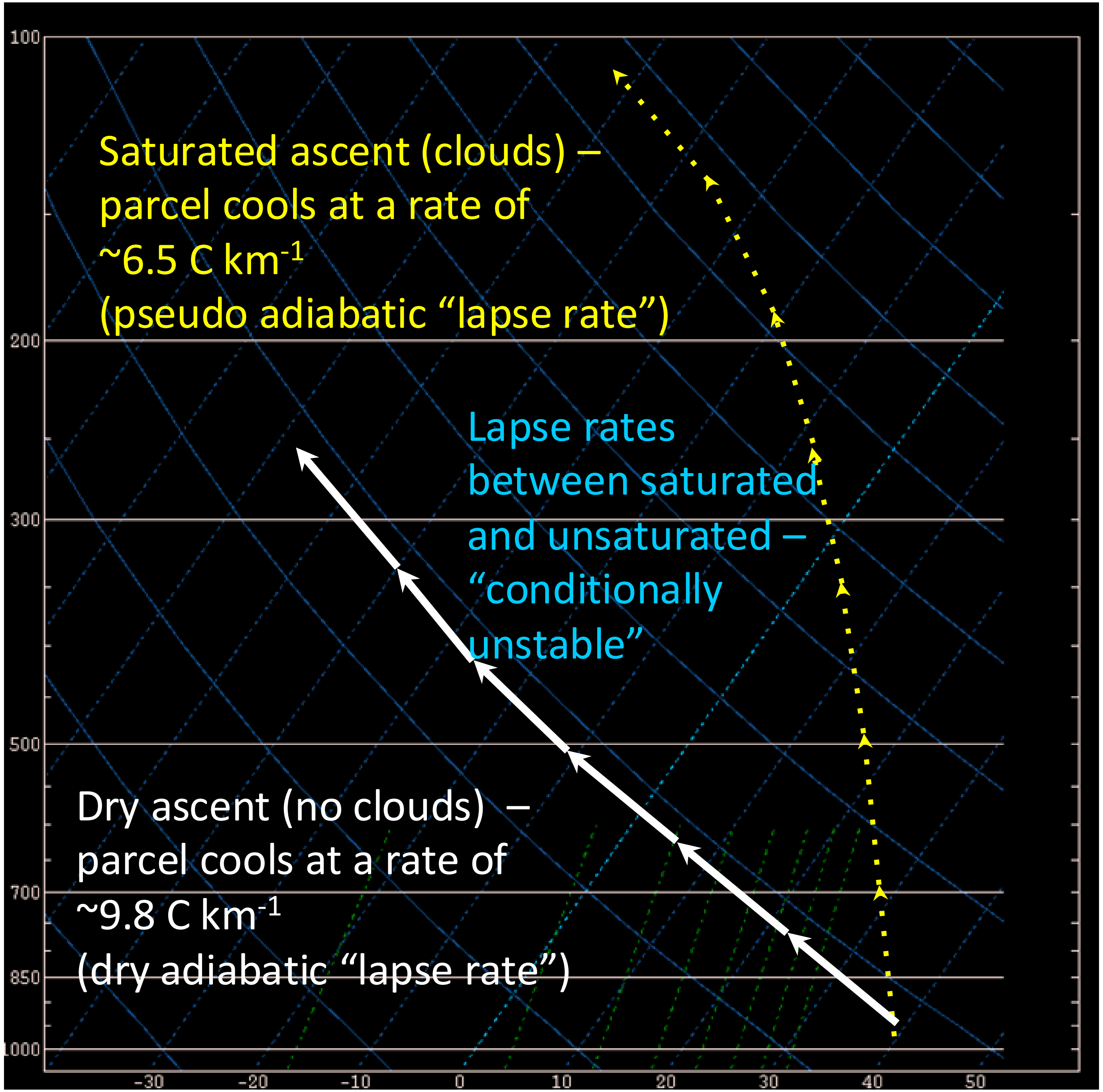


A tremendous resource!

Adiabatic Motion

In parcel theory it is assumed that parcel motions are adiabatic processes - that is parcel exchange no energy/mass with their environment (not true!).

This also means there paths are predictable along lines of constant entropy (isentropes).

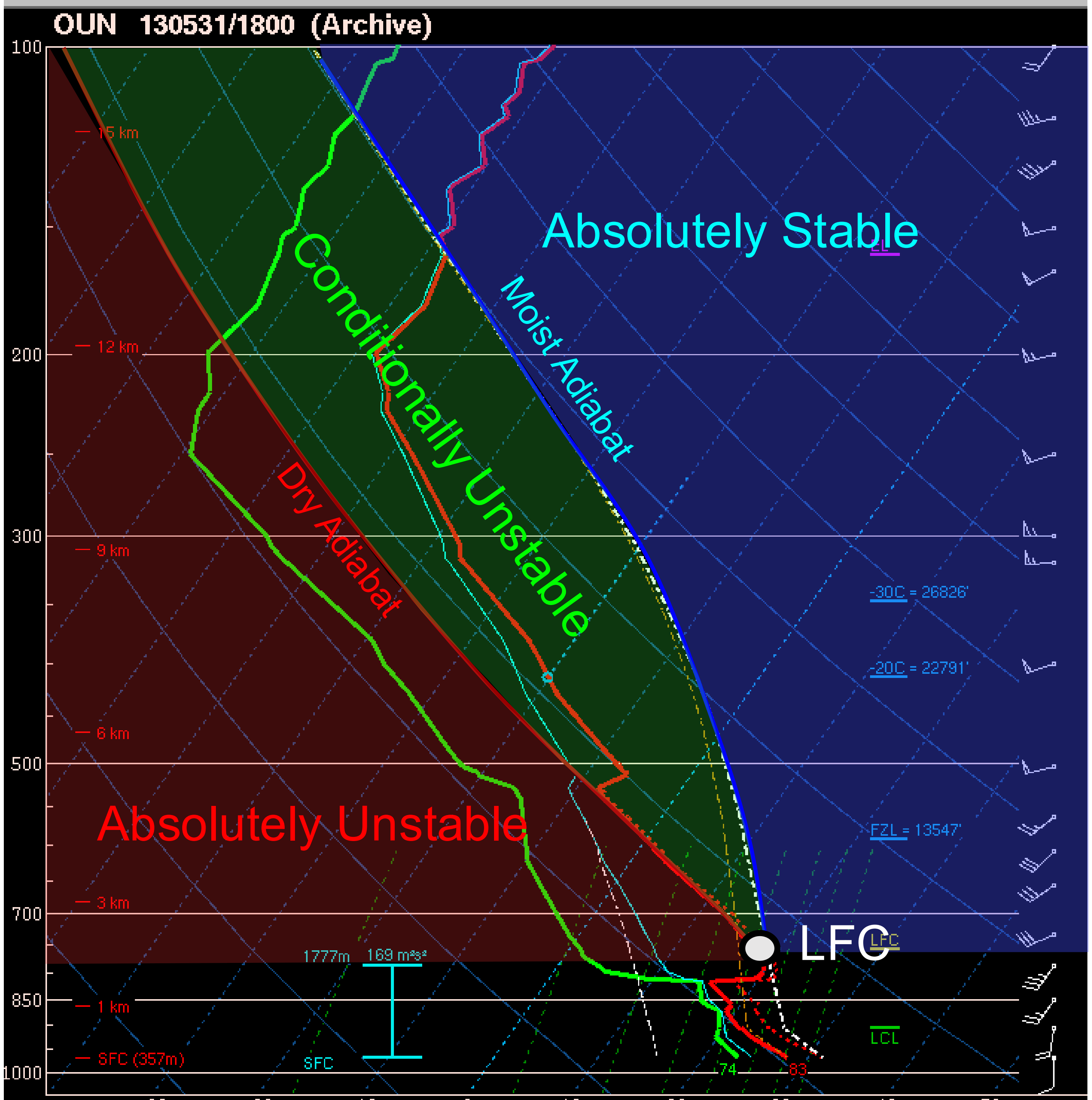


<u>**Lapse Rate**</u>

A lapse rate is simply the change in temperature over some depth (dT/dz)

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 (~6.5 C/km).



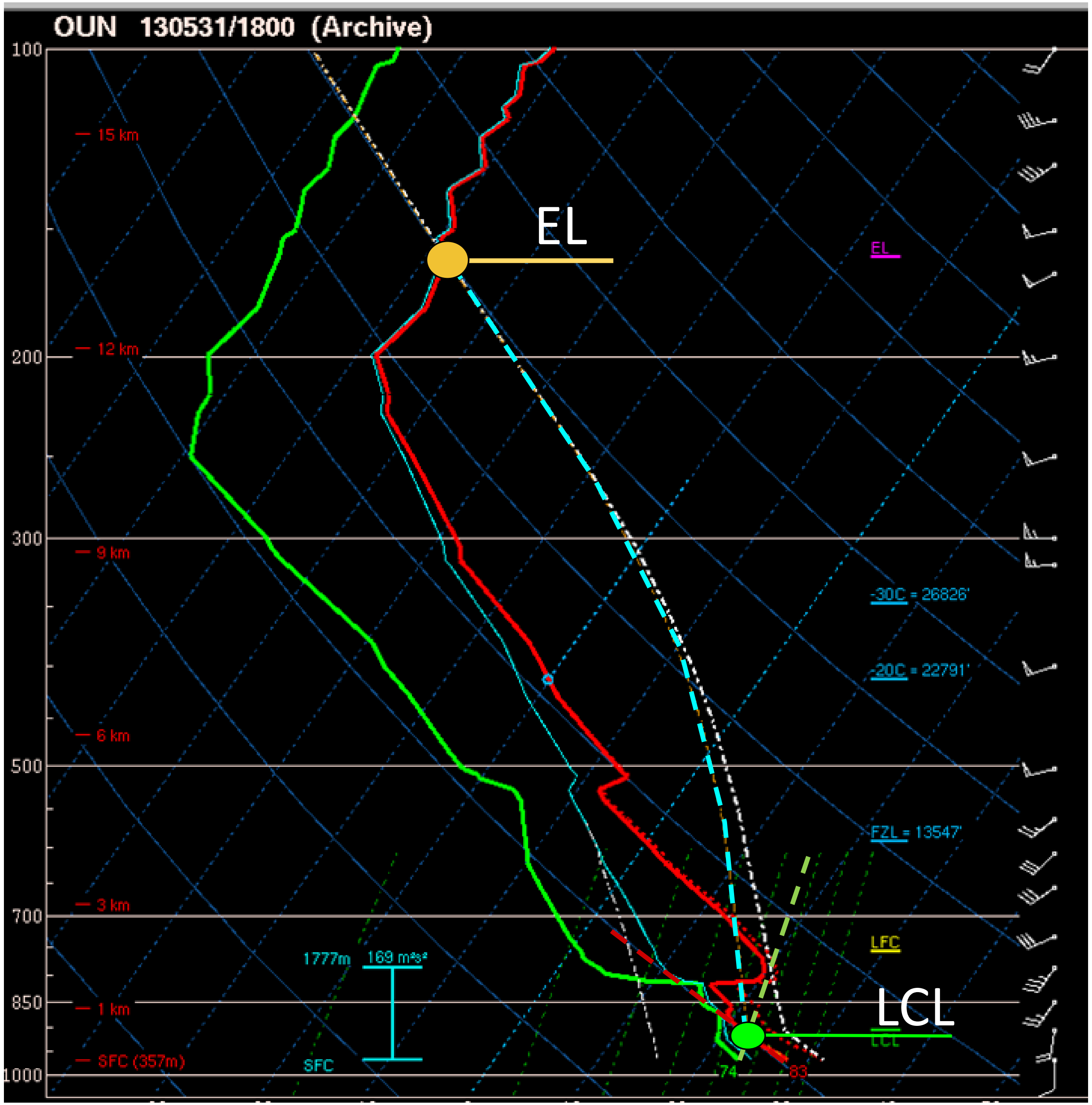
Lifting a Parcel

1) Choose a parcel (sfc, mixed layer, most-unstable, etc…)

1) Find temperature and dewpoint.

1) Assume dry adiabatic ascent until you reach **Lifted Condensation Level (LCL)**.

1) Assume moist adiabatic ascent until you reach the **Equilibrium Level (EL)**.



Buoyancy Basics

If parcel temperature > ambient temperature:

Buoyancy > 0

Parcel accelerates upwards

If parcel temperature < ambient temperature:

Buoyancy < 0

Parcel accelerates downward

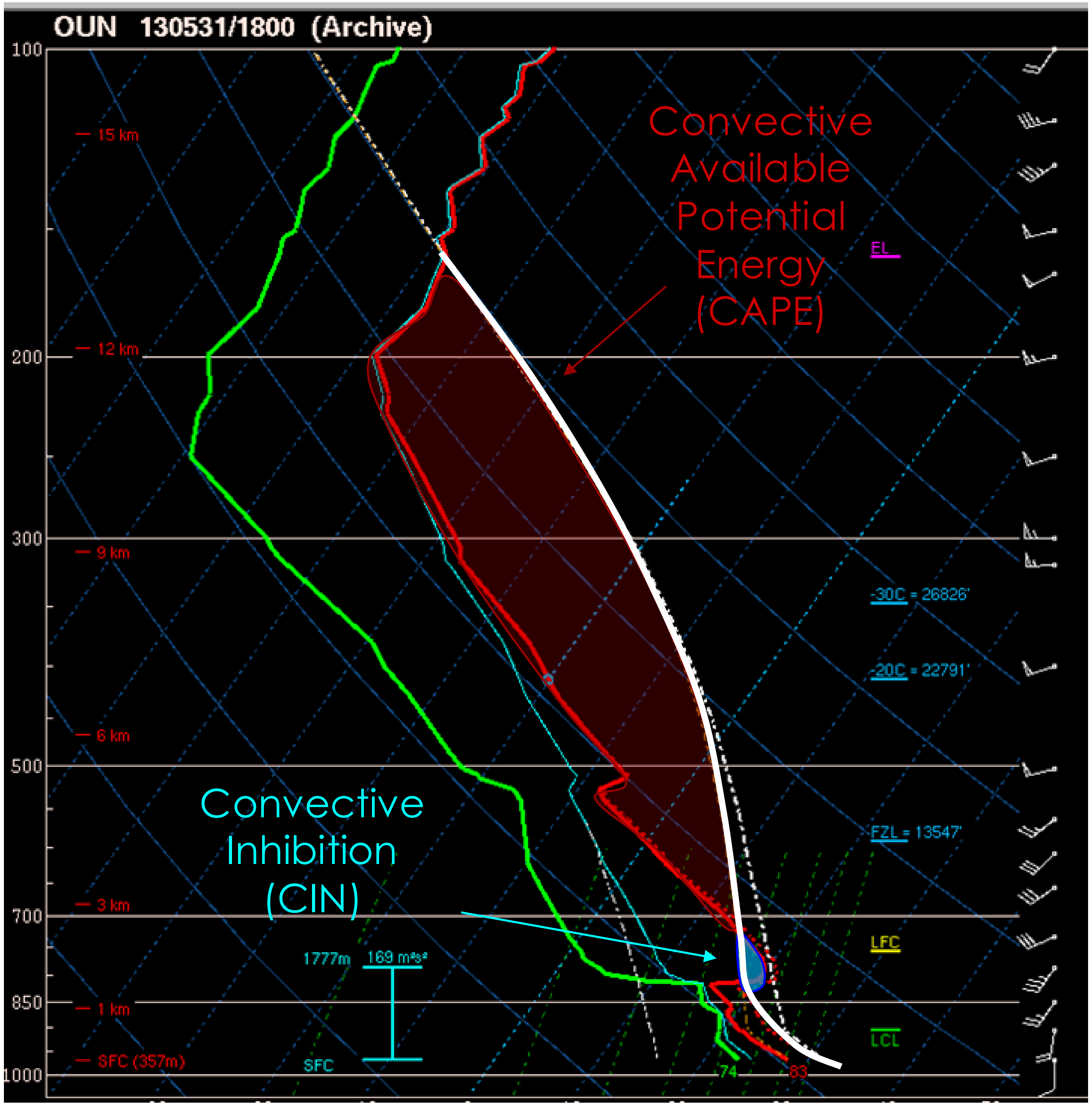
If parcel temperature = ambient temperature:

Buoyancy = 0

Parcel experiences no buoyant forces (either continues in direction of motion or remains motionless)

From ideal gas law:

$$B = -g\frac{\rho'}{\bar{\rho}} = g\left(\frac{T_v{}'}{\overline{T_v}} - \frac{p'}{\bar{p}}\right)$$



Lifted Index

A more simplistic way to quantify buoyancy of a parcel.

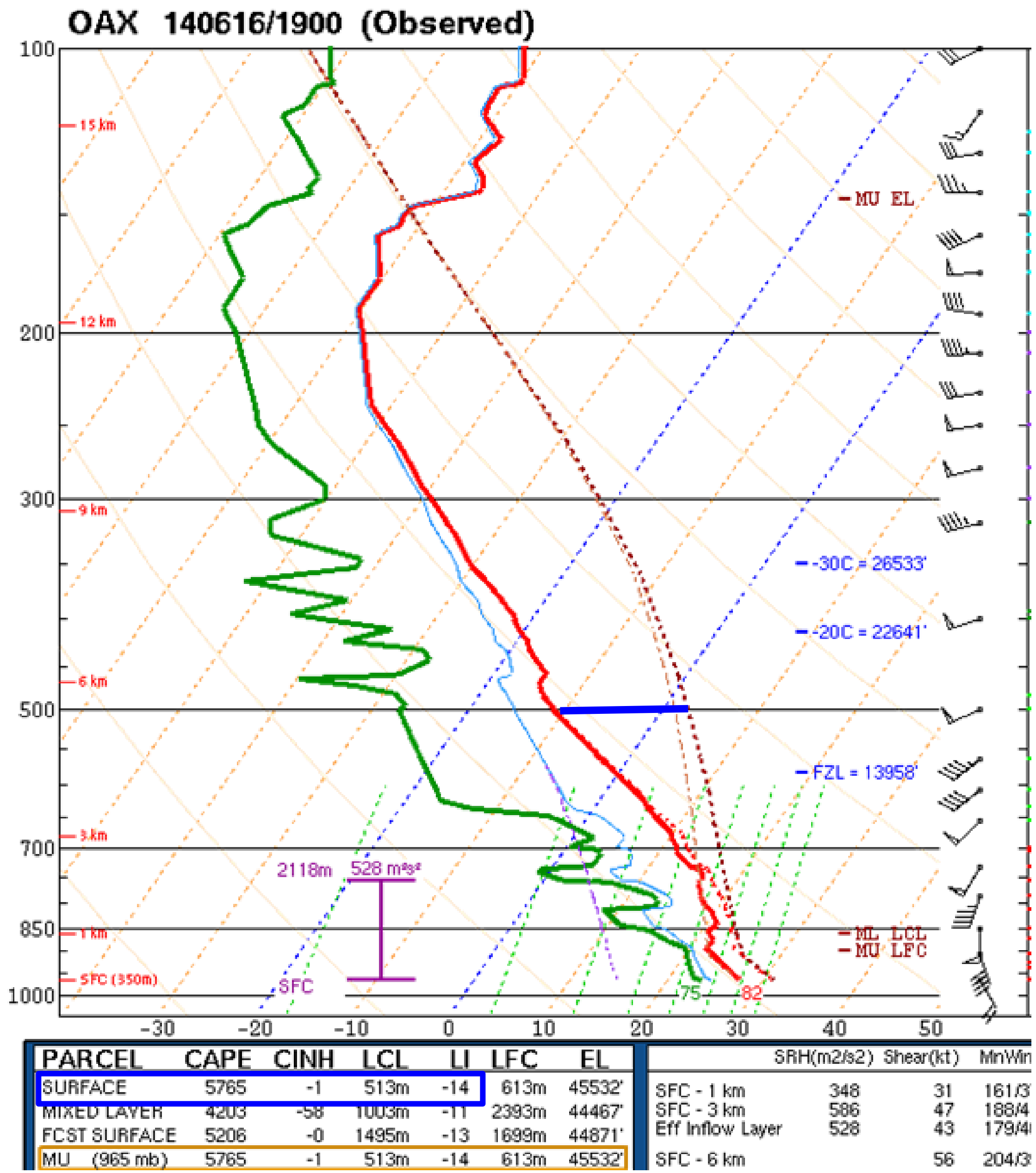
1) Lift a parcel from the surface (or whatever level you want)

2) Find the temperature of the parcel at 500 mb

3) Find the environmental temperature at 500 mb

4) LI = Env Temp 500 mb - Parcel Temp 500 mb

LI > 0 = Stable!
-1 to -4 = Weakly unstable
-5 to -9 = Very unstable
-10 and lower = Extremely unstable!



Lifted Index

A more simplistic way to quantify buoyancy of a parcel.

Pros:

- Very simple to calculate and interpret!
- Implicitly accounts for lapse rates!

Cons:

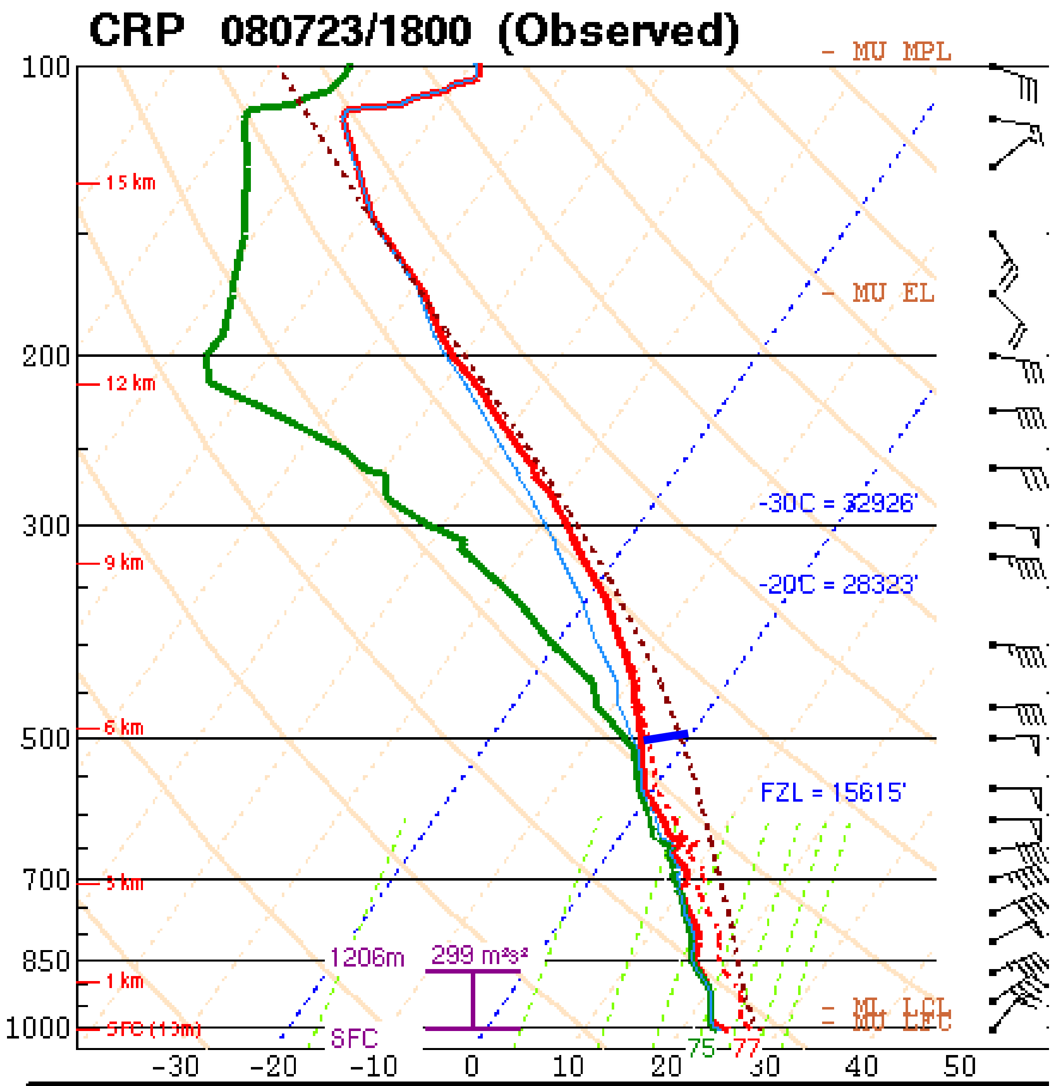
- Very simplistic.
- May miss critical buoyancy (e.g. elevated buoyancy)

LI > 0 = Stable!

-1 to -4 = Weakly unstable

-5 to -9 = Very unstable

-10 and lower = Extremely unstable!



PARCEL	CAPE	CINH	LCL	LI	LFC	EL
SURFACE	853	0	155m	-3	155m	43942'
MIXED LAYER	390	-1	470m	-2	901m	29948'
FCST SURFACE	1523	0	1025m	-4	1025m	49941'
MU (1006 mb)	853	0	155m	-3	155m	43942'

SFC - 1 km
SFC - 3 km
Eff Inflow La
SFC - 6 km

Downdraft CAPE (DCAPE)

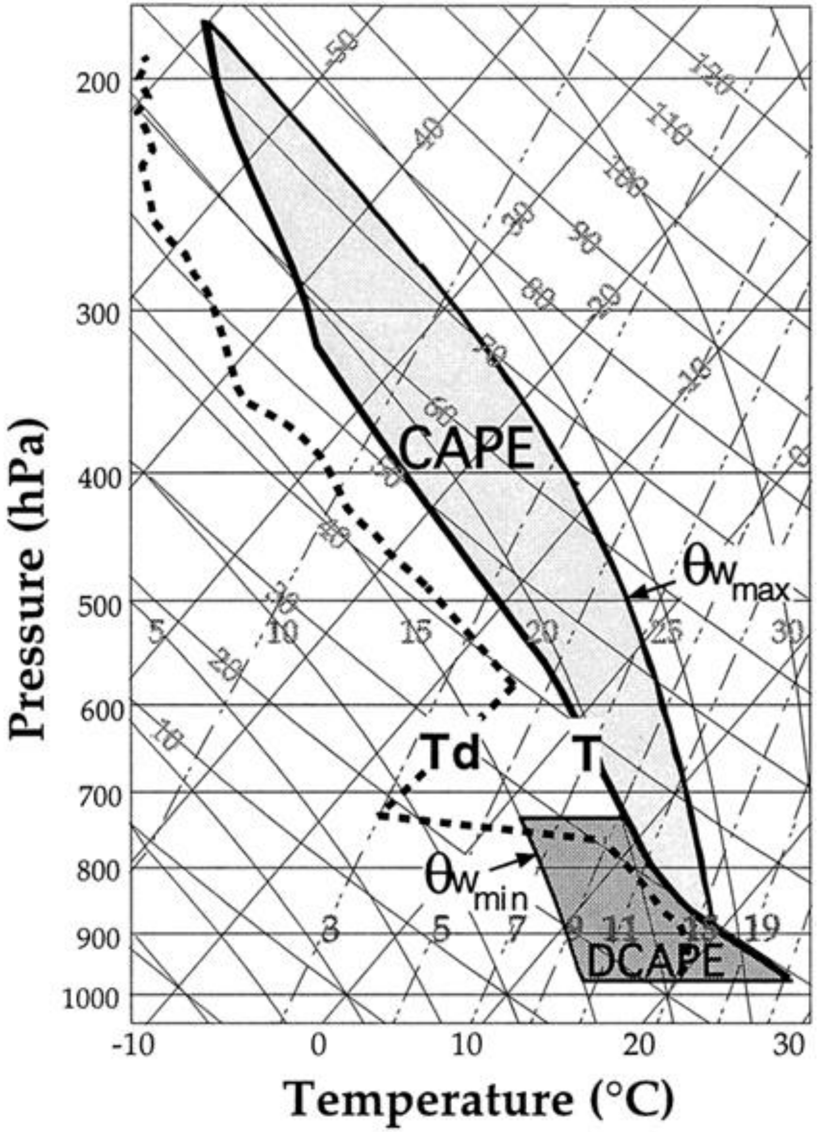


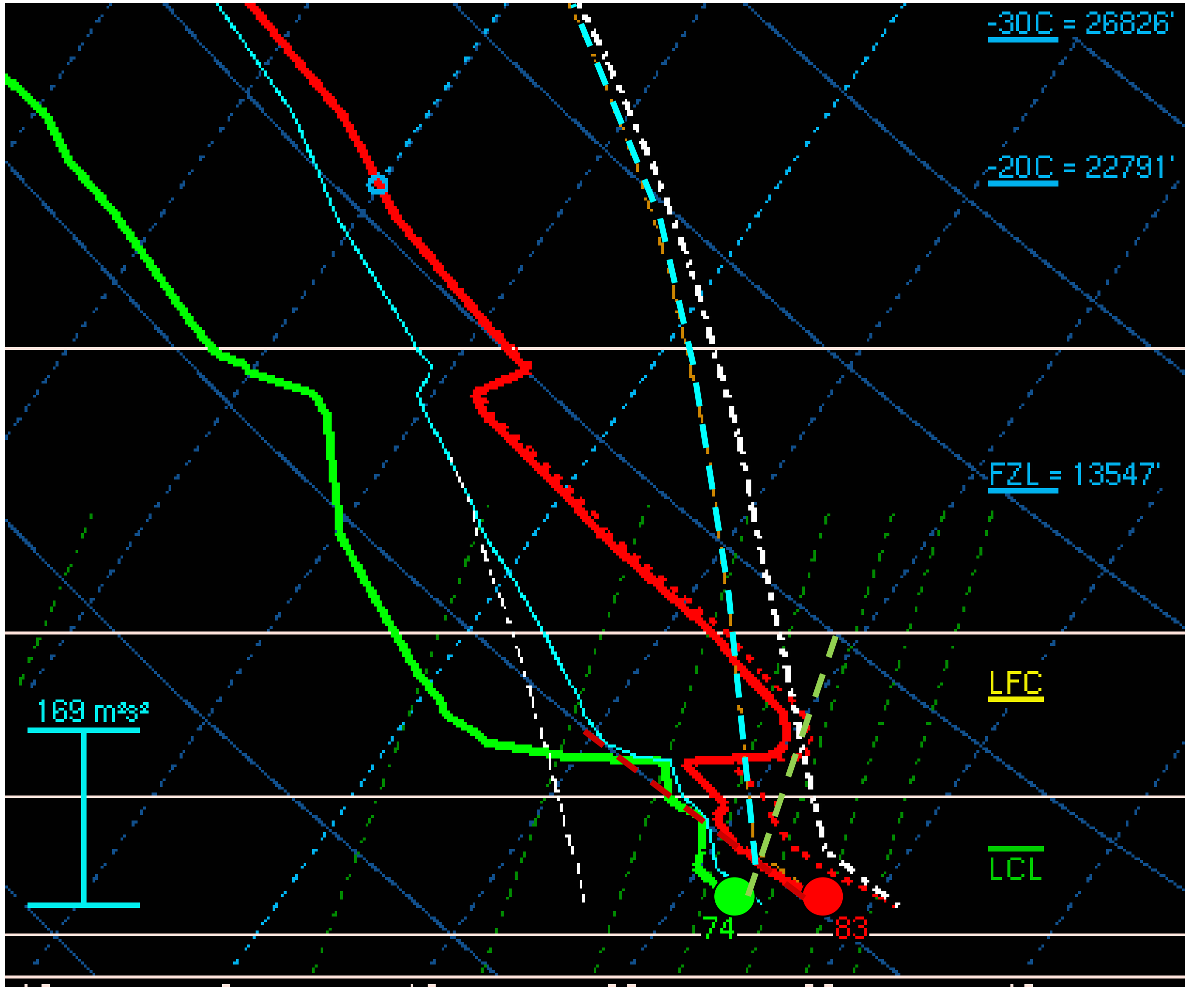
Fig. 1 Gilmore and Wicker 1998

- Estimates the negative buoyancy a downdraft parcel could have.
- This gives you an estimation of potential downdraft strength.
- Assumes you know where the downdraft is originating from! (Other parcel theory assumptions apply.)
- Because of this, it often doesn't show up as a strong discriminator for severe wind.

Parcel Selection - Which is Best?

Surface-Based (SB) Parcel

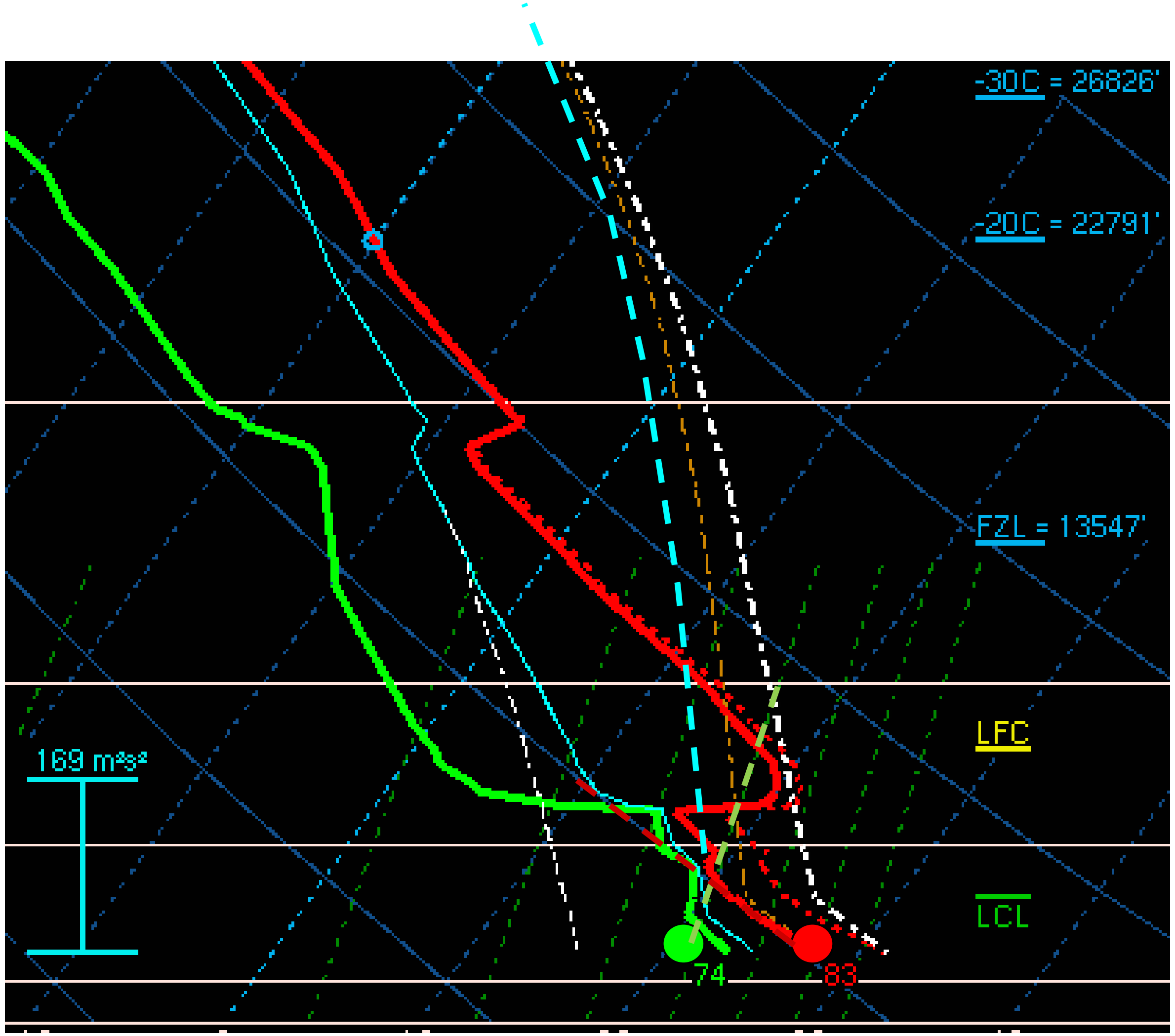
- Lift a parcel from the surface pressure using the surface temperature and dewpoint.
- Easy to calculate!
- Often unrepresentative: too unstable with too little inhibition. Does not account for elevated convection (more later).



Parcel Selection - Which is Best?

Mixed-Layer (ML) Parcel

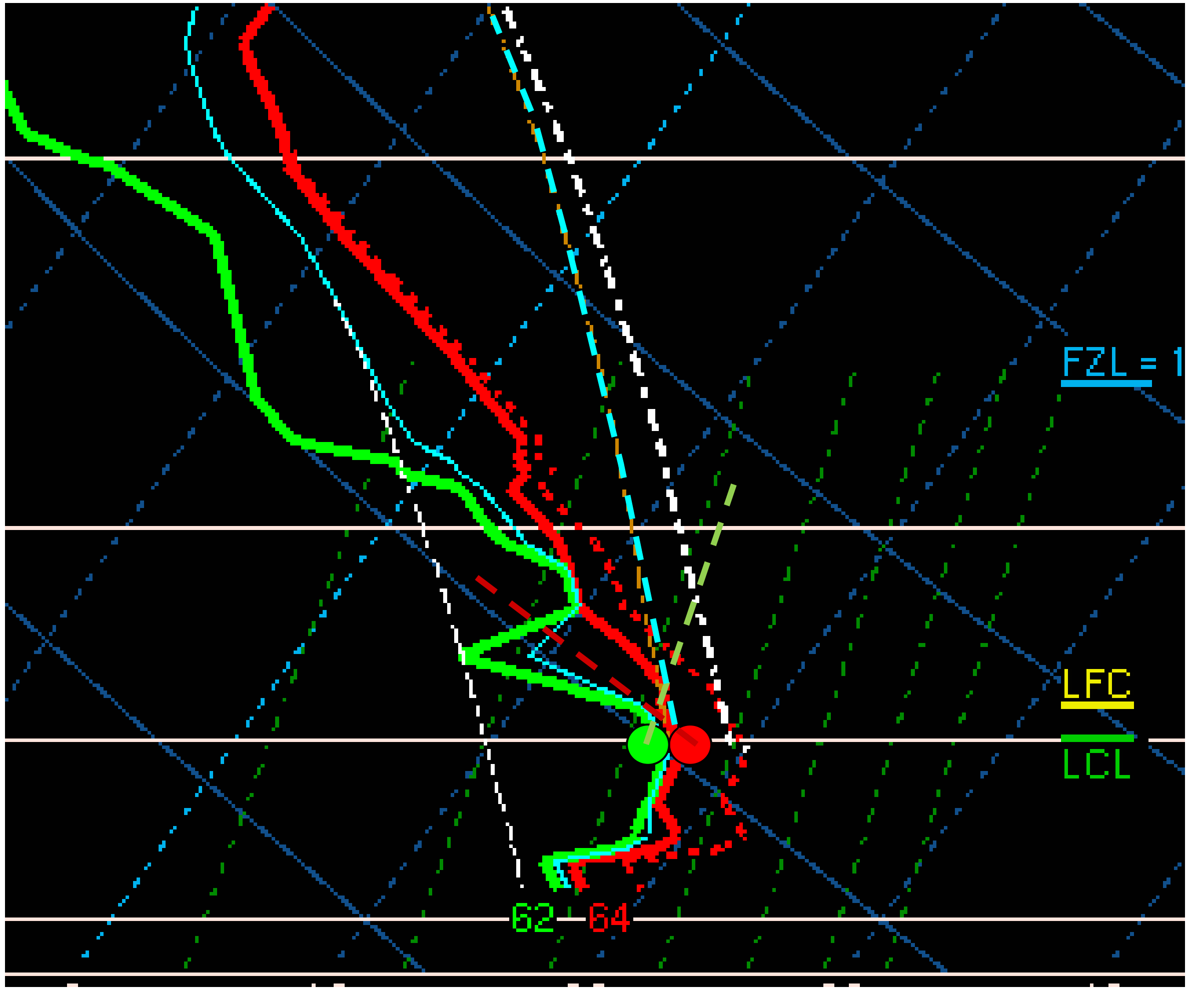
- Find the average temperature, & dewpoint from the lowest 100 mb. Lift this parcel from the surface.
- Found to be a good representation of parcel buoyancy on most typical severe weather days.
- Often features less CAPE and more CIN compared to other parcels.



Parcel Selection - Which is Best?

Most-Unstable (MU) Parcel

- Find the highest Theta-e value in the lowest 400 mb (typically). Use this level's temperature, dewpoint, and pressure level to lift a parcel.*
- Essential for identifying elevated T-storm environments.
- Often overestimates CAPE and underestimates CIN in non-elevated T-storm environments.
- The SB Parcel is often the MU Parcel when if there is a convective boundary layer in place.



*This is not the only method!

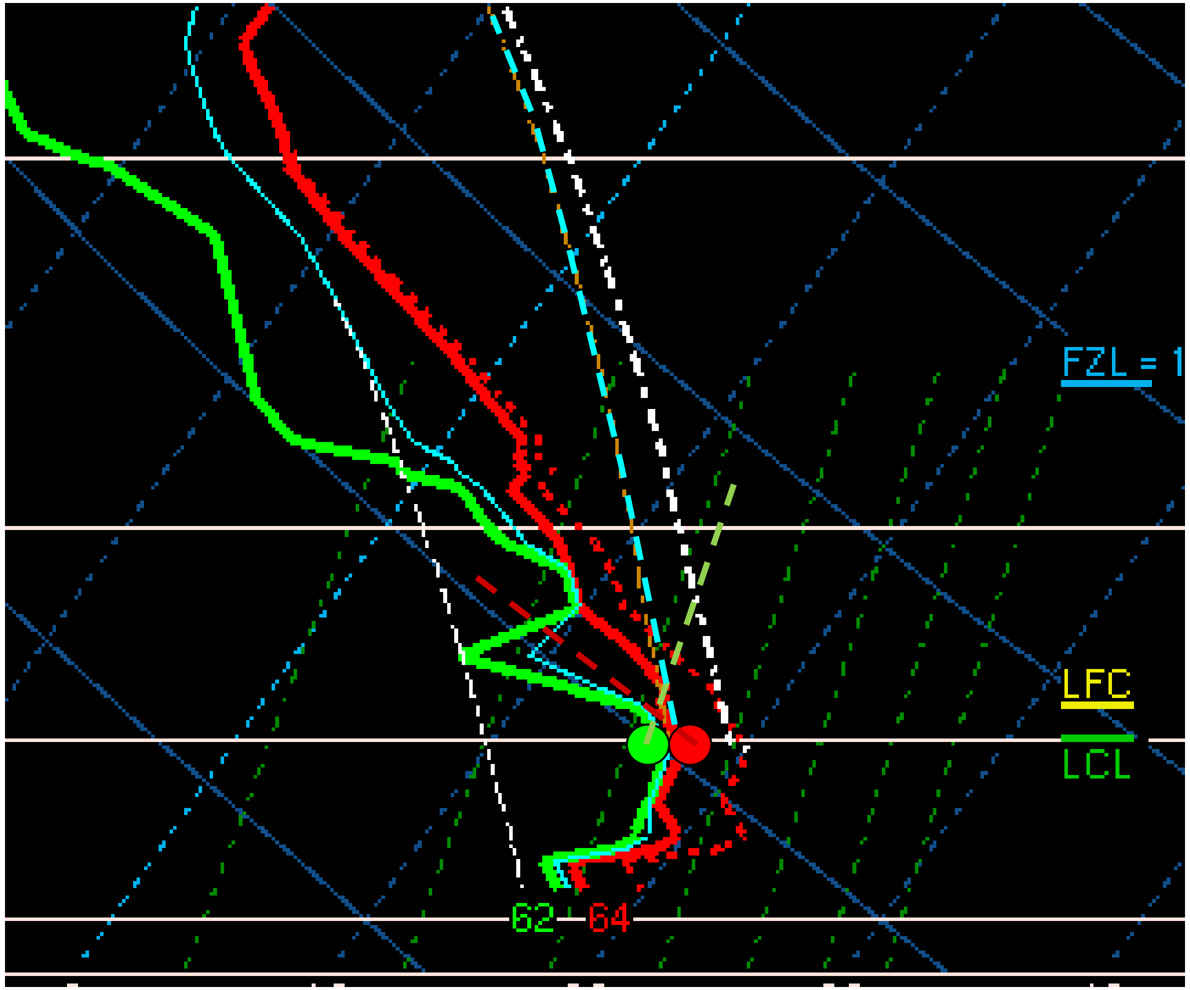
Parcel Selection - Which is Best?

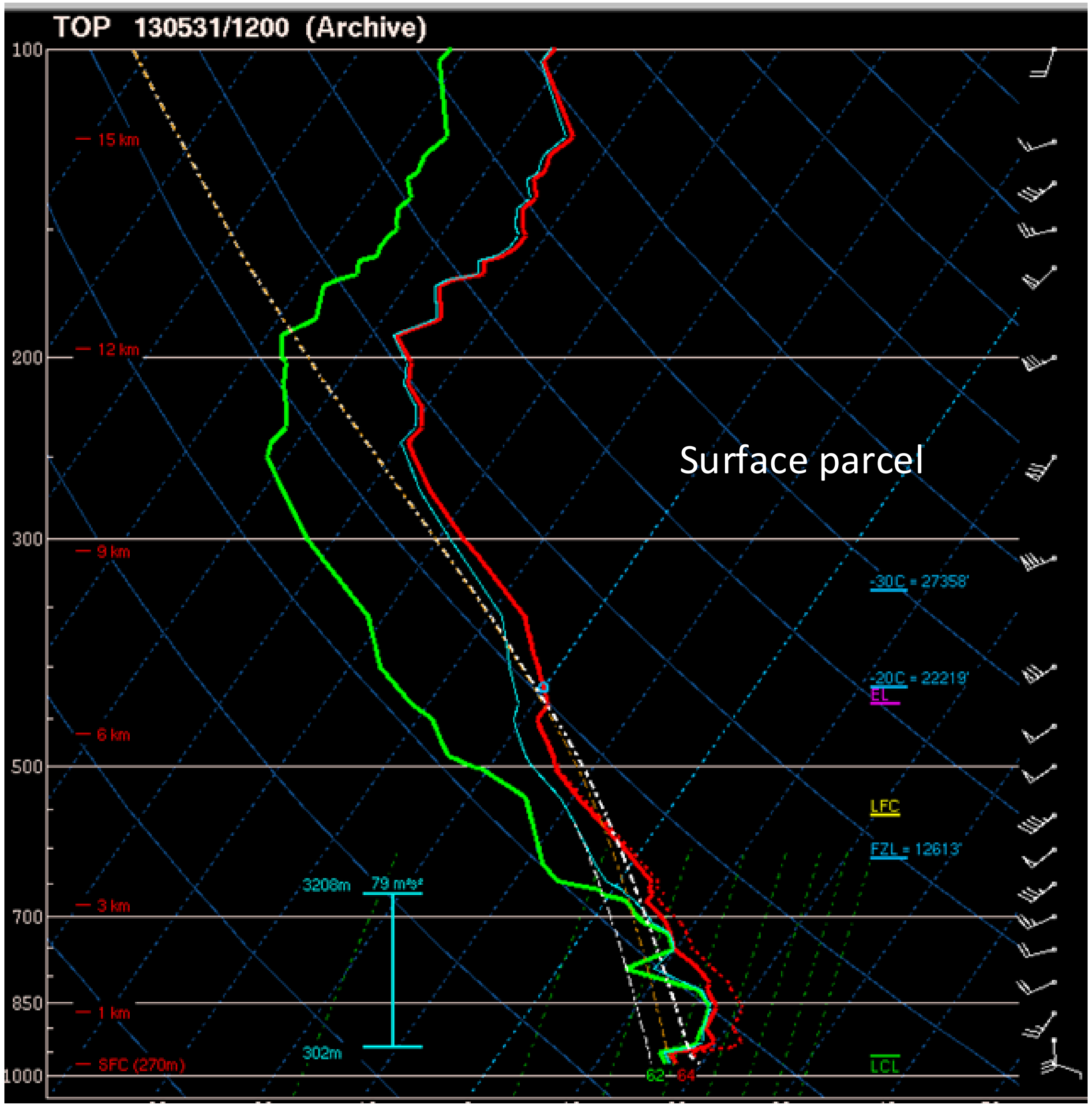
Least Inhibited (LI) Parcel

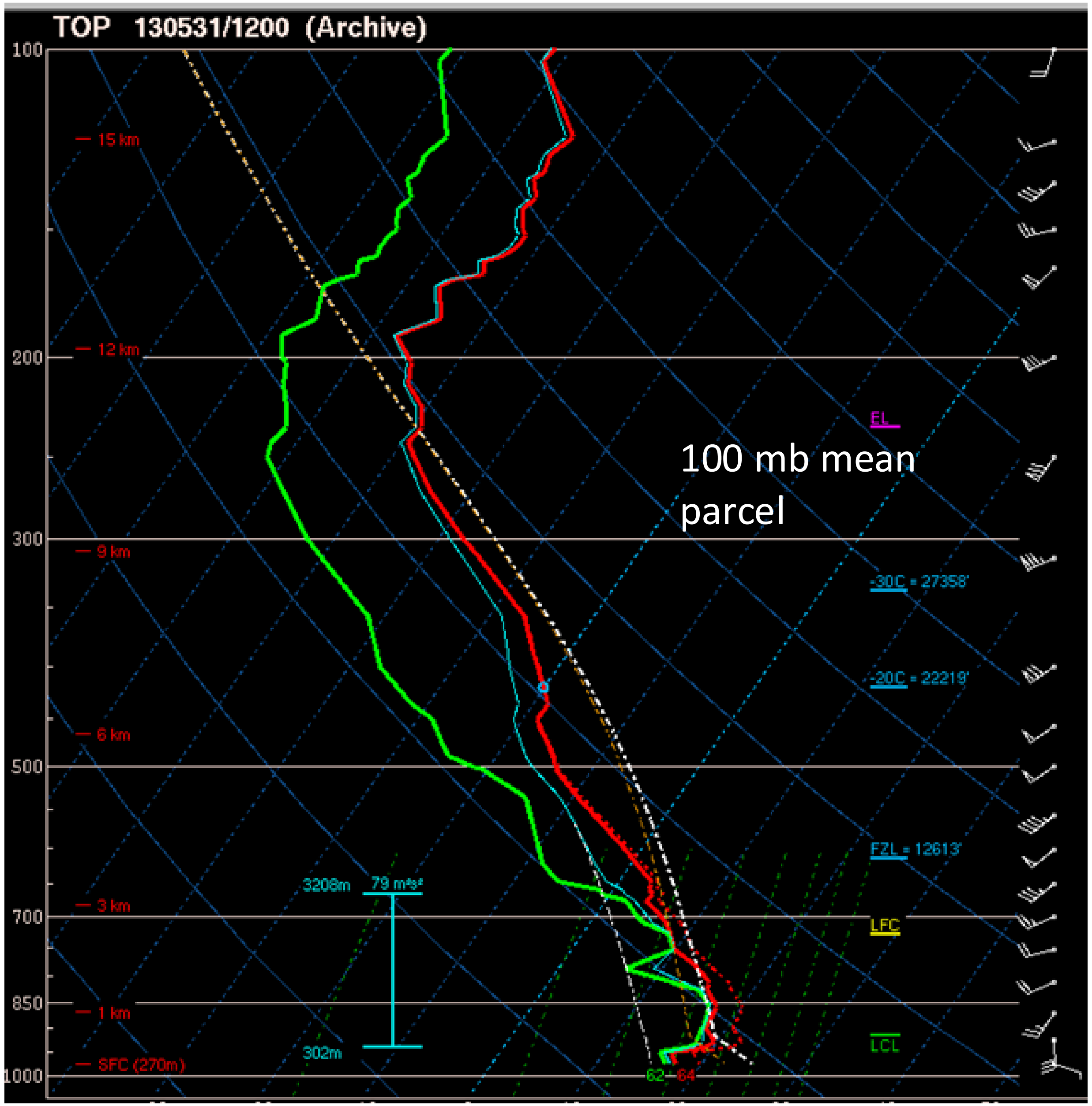
- Lift a series of parcels, find the parcel with the lowest amount of inhibition.

- This is often, but not always, the MU Parcel.

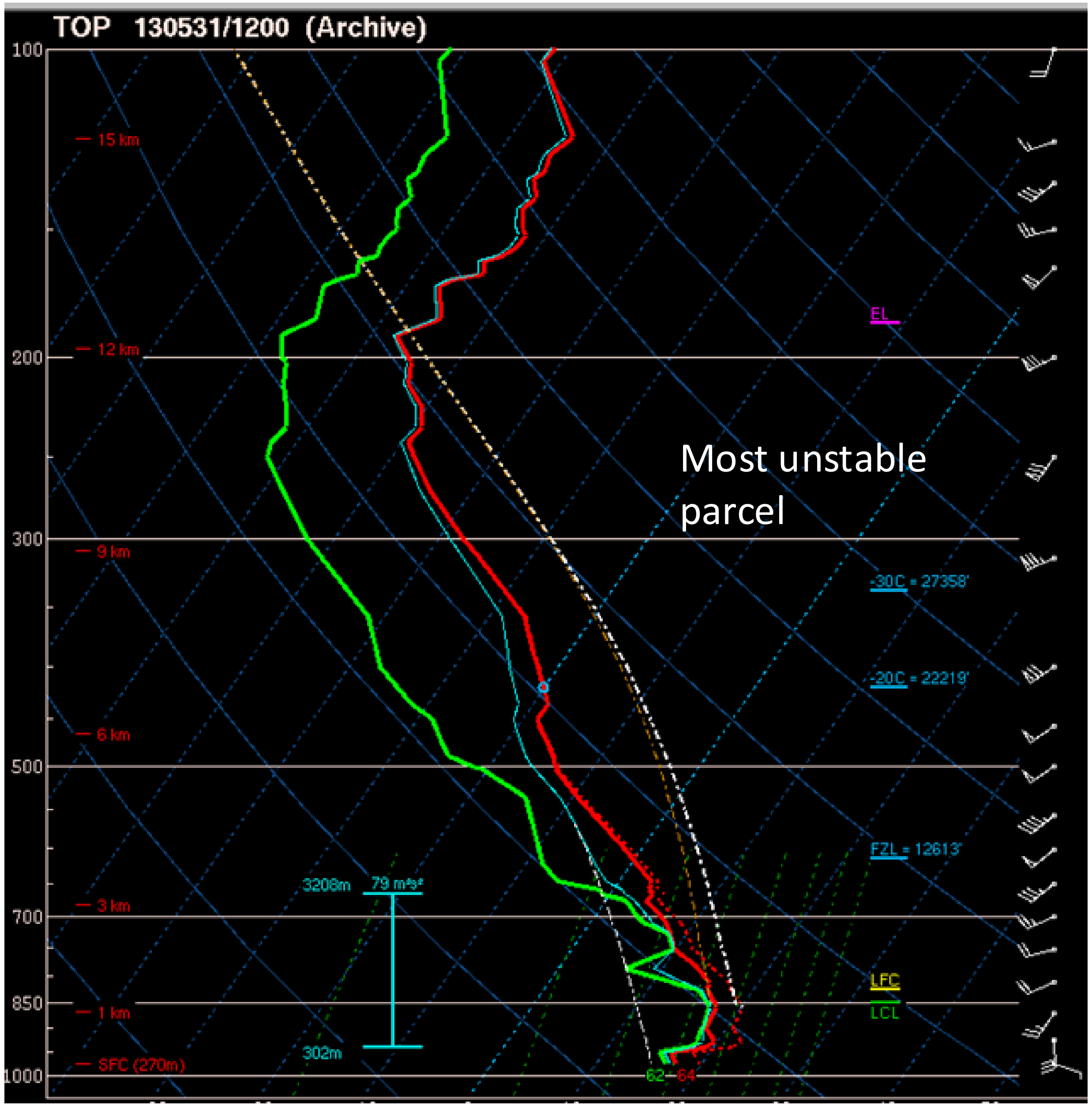
- Not particularly useful for severe convection, but can be helpful for identifying or explaining areas of weak thunderstorms.




TOP 130531/1200 (Archive)
100
200
300
500
700
850
1000
15 km
12 km
9 km
6 km
3 km
1 km
SFC (270m)
3208m
79 m²s²
302m
-30C = 27358'
-20C = 22219'
EL
LFC
FZL = 12613'
LCL
62
64
Surface parcel



100 mb mean parcel



Most unstable parcel

What do we assume in parcel theory?

- <u>No mixing with environment</u> (not true)
  - "entrainment" usually reduces updraft strength from expectations based on CAPE alone

- <u>Hydrometeor falls out instantly</u> (not true)
  - Suspended rain particles reduces updraft strength. That's why we say "pseudo" adiabatic for saturated parcel ascent

- <u>Neglects downward pressure perturbation pressure</u>
  - Acts to hinder the upward motion of parcels.

- <u>Parcel vertical motion is due to buoyancy alone</u>
  - We don't explicitly incorporate environmental ascent (e.g. mesoscale, synoptic ascent, etc…)

Vertical PGF

- Wider thermal has larger PGF compared to narrow thermal (more air needs to be moved out of the way)
- As thermal becomes wider the scenario approaches hydrostatic where PGF offsets buoyancy (dw/dt=0)
- **In theory, narrow thermals more favorable for convective initiation**

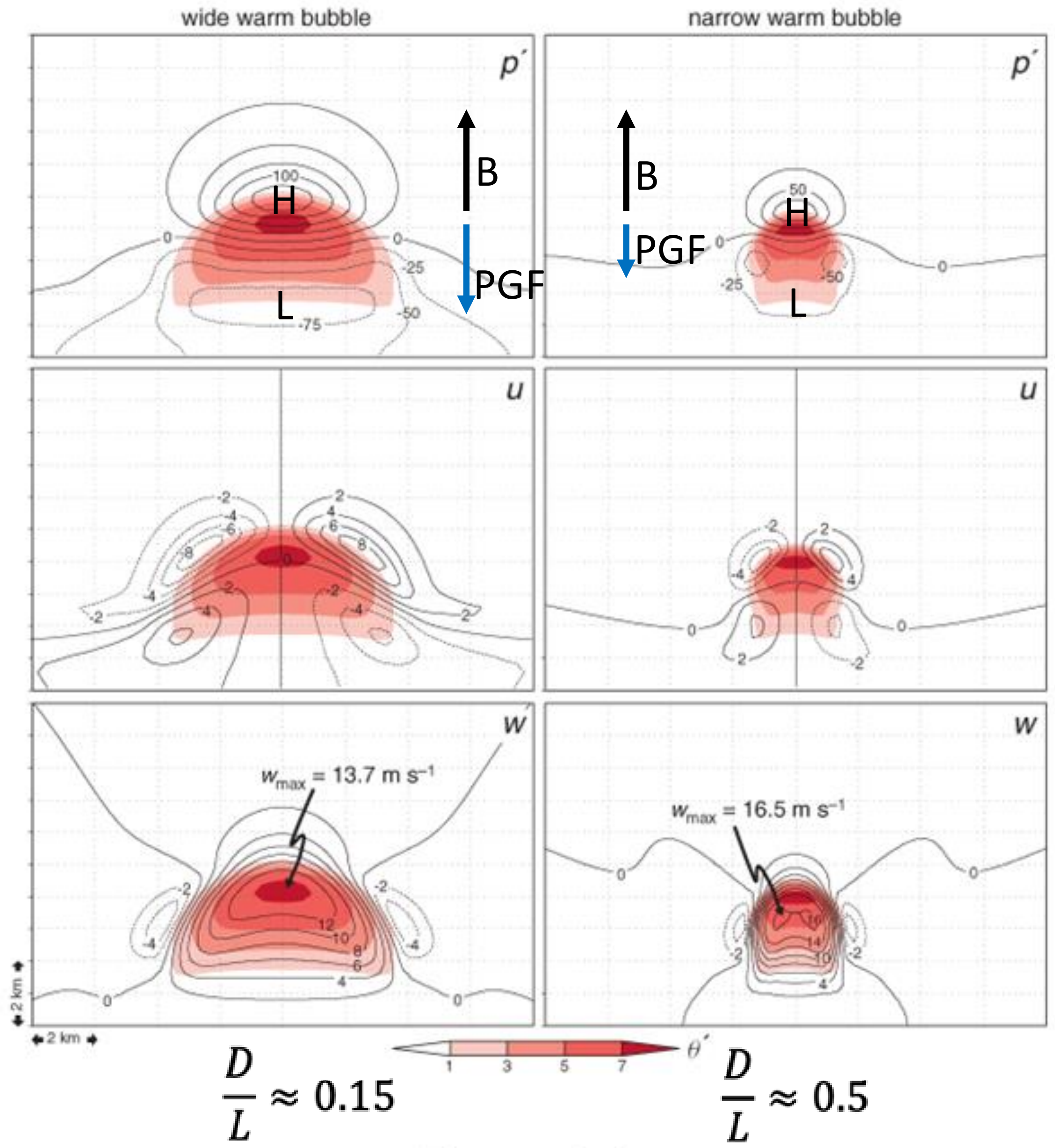
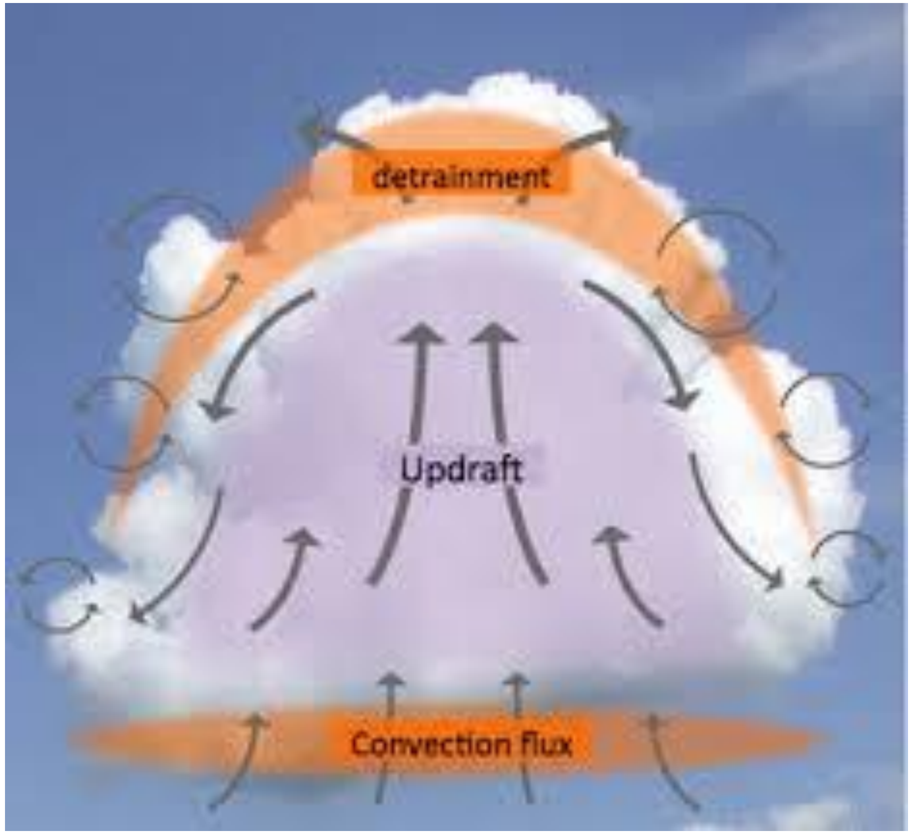


Figure 3.1

Fig. 3.1 MR 2010

Dry Air Entrainment & E-CAPE

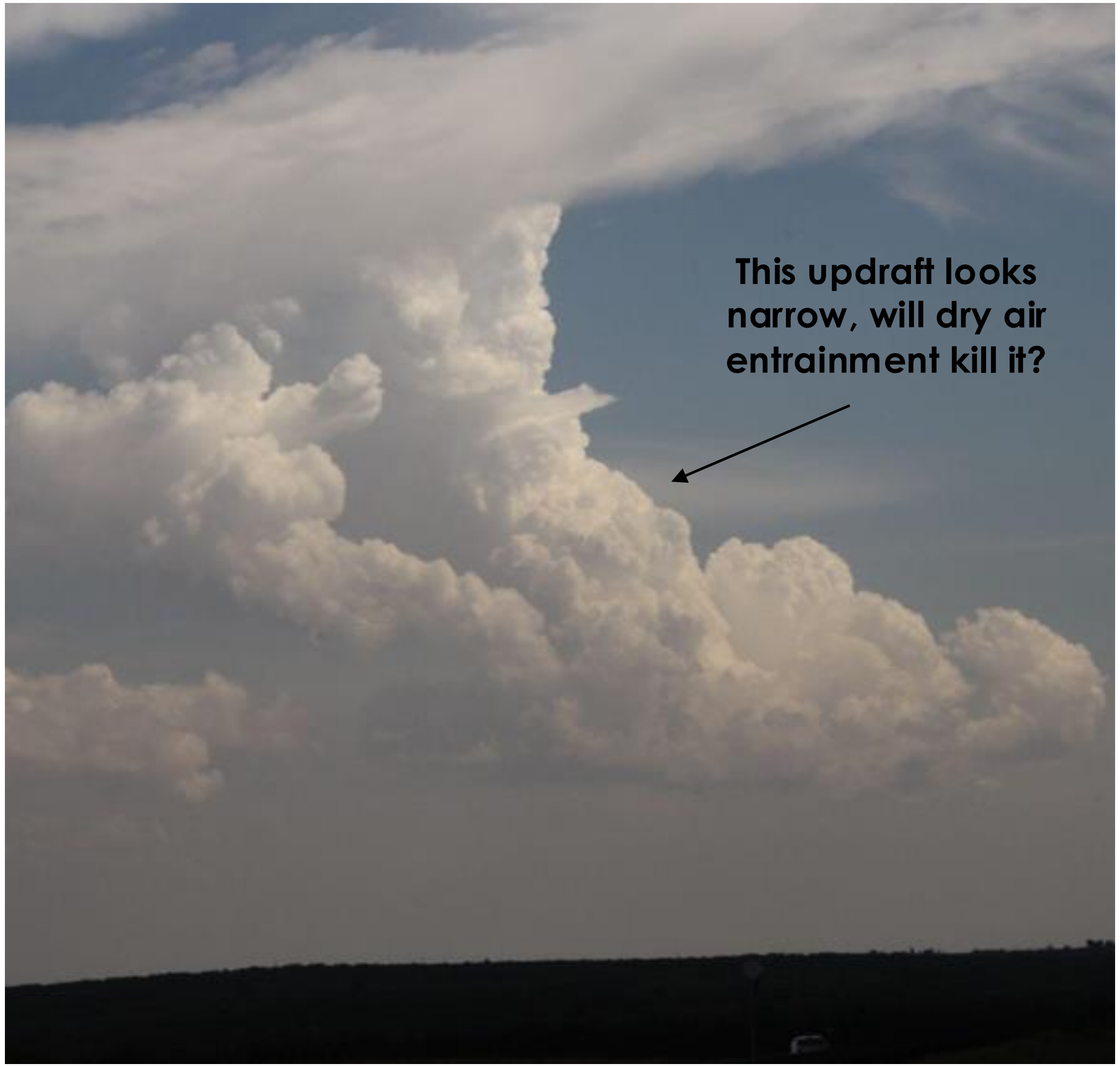


Mixing by two mechanisms:

1) The condensed updraft is very moist (RH near 100%), the environment is relatively dry. Moisture flux from updraft to the environment to restore thermodynamic equilibrium.

1) Differential vertical motion across the updraft (dw/dx and dw/dy) causes mechanical mixing on the cloud exterior.

Dry Air Entrainment & E-CAPE



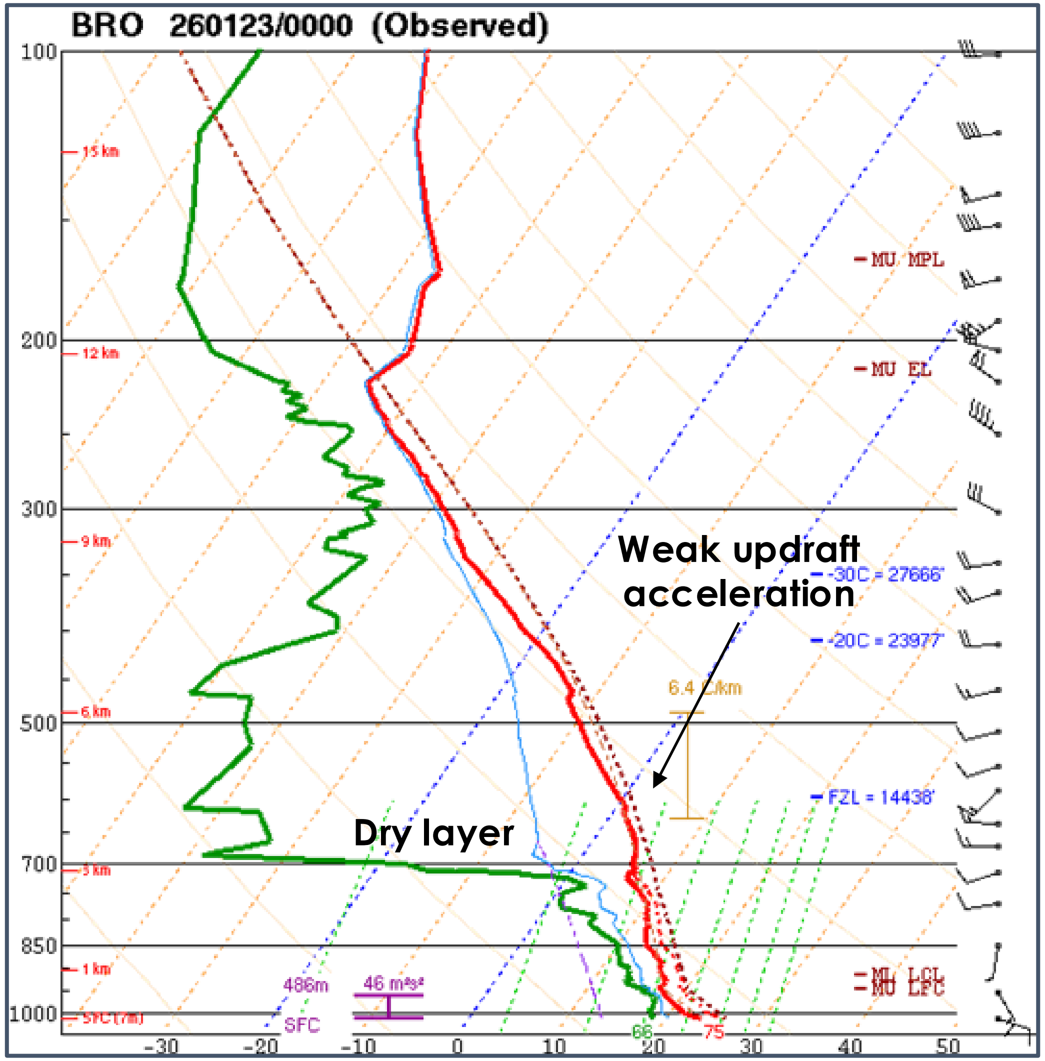
Dry Air Entrainment & E-CAPE

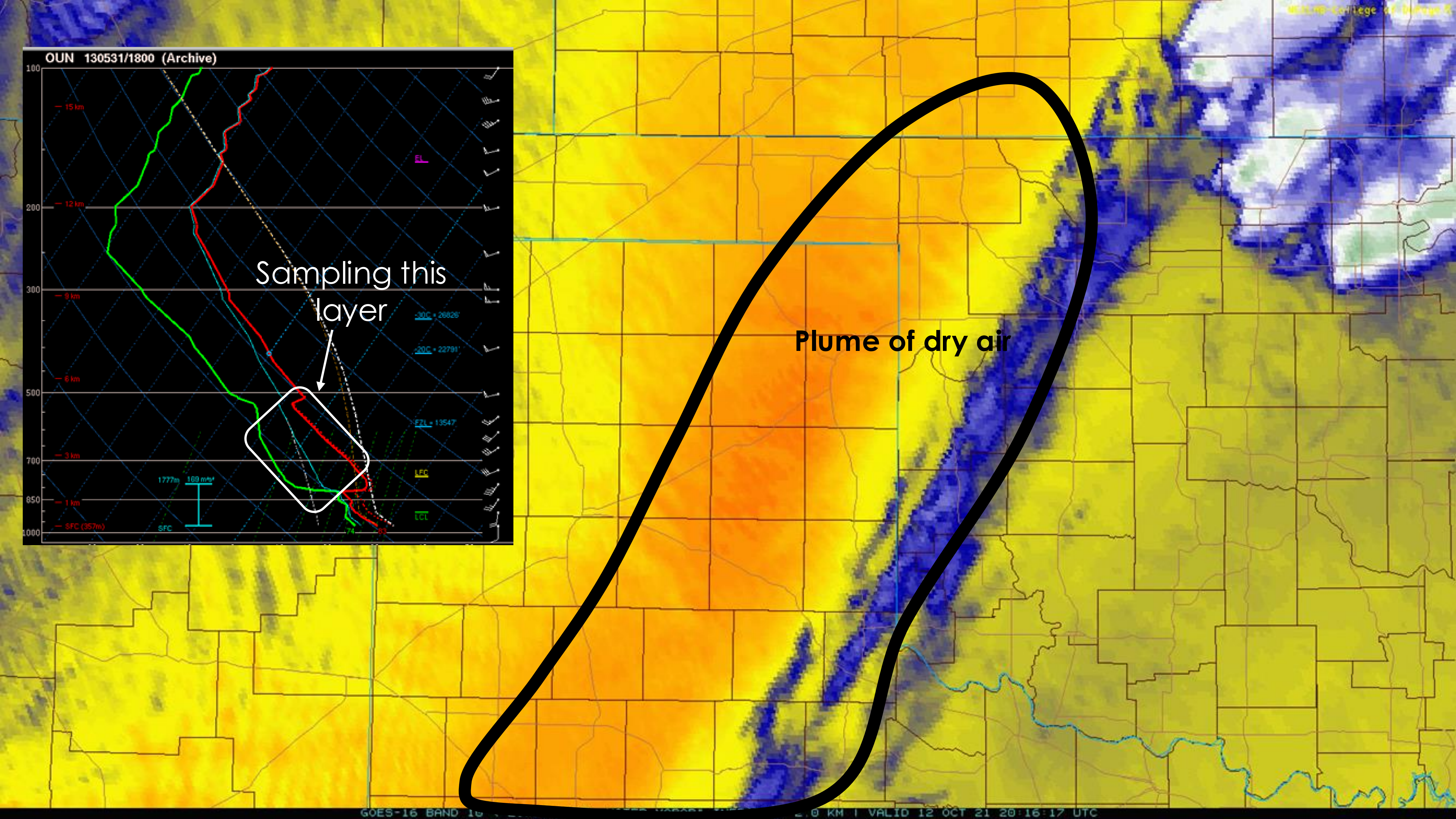
Dry air entrainment occurs all of the time!

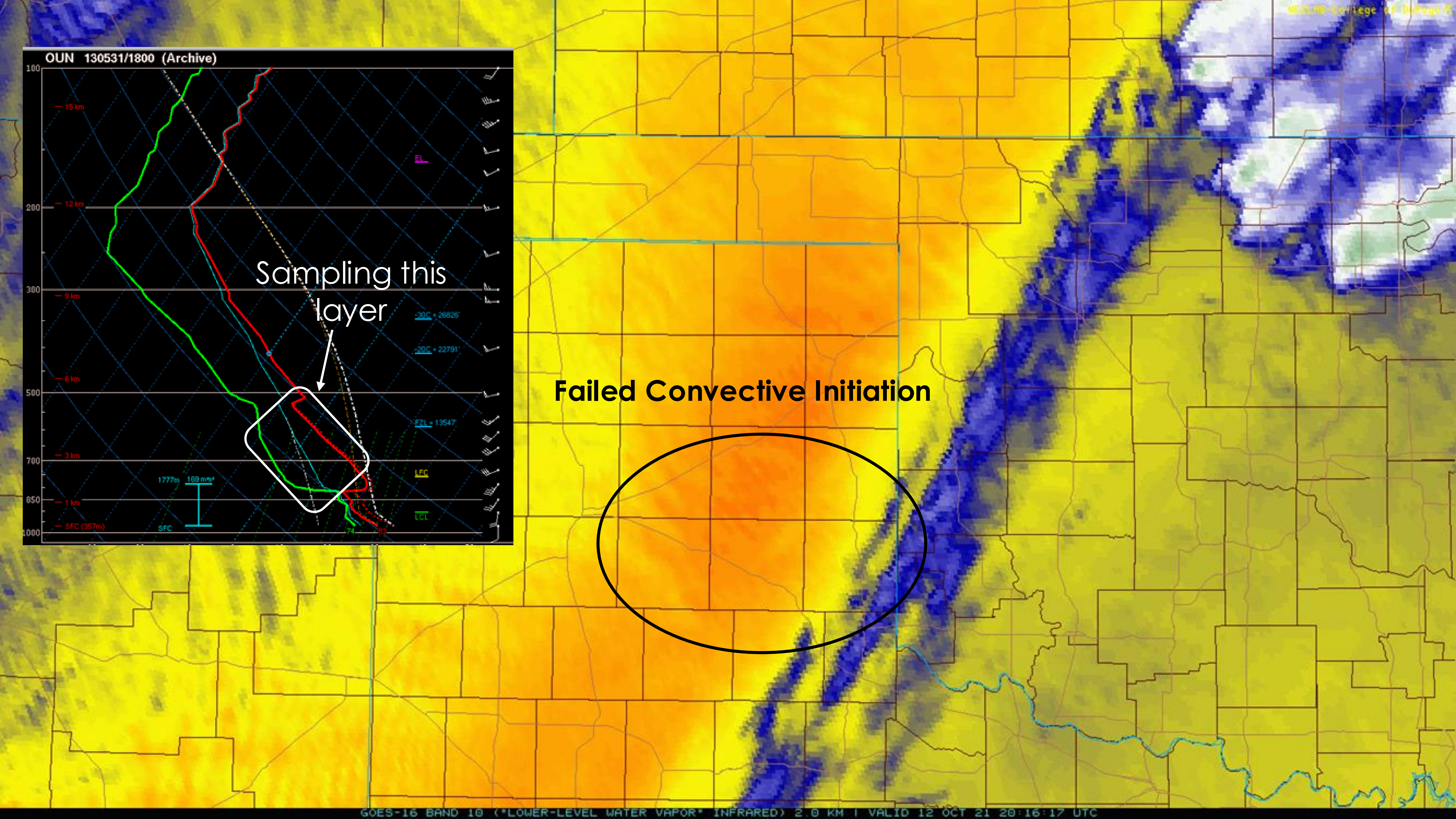
How do we know when it could be a problem?

Thermodynamically: look for dry layers coincident with very narrow buoyancy profile (i.e. weak CAPE).

Mechanical lift: In weak-lift regimes, T-storms are dependent on their own thermodynamic buoyancy with no help from environmental ascent.




OUN 130531/1800 (Archive)
Sampling this layer
Plume of dry air
EL
LFC
LCL
SFC
SFC (357m)
100
200
300
500
700
850
1000
15 km
12 km
9 km
6 km
3 km
1 km


OUN 130531/1800 (Archive)
Sampling this layer
Failed Convective Initiation
GOES-16 BAND 10 ("LOWER-LEVEL WATER VAPOR" INFRARED) 2.0 KM | VALID 12 OCT 21 20:16:17 UTC

Dry Air Entrainment & E-CAPE

So how can we account for this?

By using ECAPE!

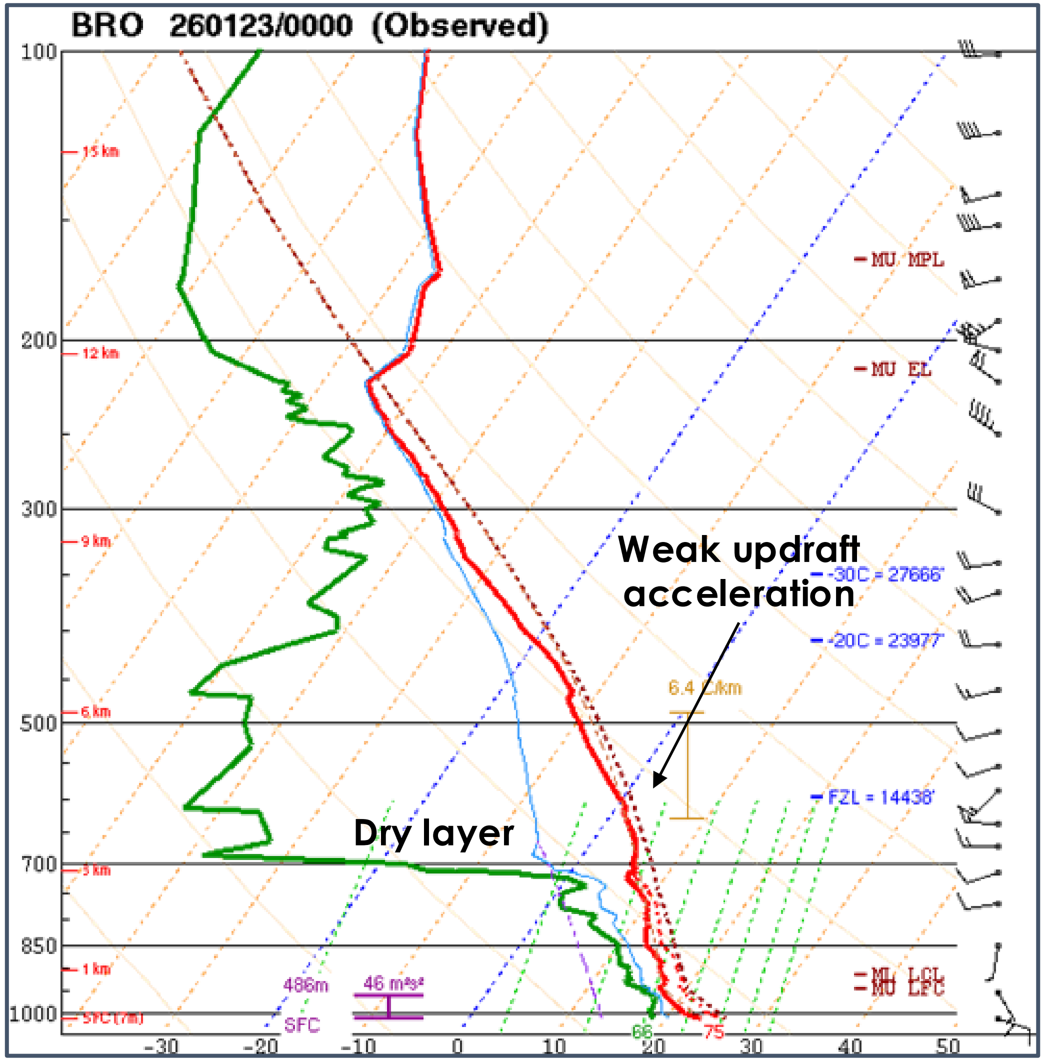
$$\mathrm{ECAPE} = \frac{-1-\frac{2\psi}{V_{SR}^2}\mathrm{NCAPE}+\sqrt{\left(1+\frac{2\psi}{V_{SR}^2}\mathrm{NCAPE}\right)^2+\frac{8\psi}{V_{SR}^2}\mathrm{CAPE}}}{4\frac{\psi}{V_{SR}^2}}.$$

Pros:

- Accounts for dry air entrainment!
- Reduces CAPE in dry environments
- Increase CAPE in moist environments.

Cons:

- Computationally expensive (changing)
- Not as intuitive to determine from sounding.



Dry Air Entrainment & E-CAPE

Ultimately, why and when does this matter?

$$w_{max} = \sqrt{2 * CAPE}$$

$$\mathrm{CAPE} = \int_{z_f}^{z_n} g \left(\frac{T_{\mathrm{v,parcel}} - T_{\mathrm{v,env}}}{T_{\mathrm{v,env}}} \right) dz$$

$$\mathrm{ECAPE} = \frac{-1 - \frac{2\psi}{v_{\mathrm{SR}}^2}\mathrm{NCAPE} + \sqrt{\left(1 + \frac{2\psi}{v_{\mathrm{SR}}^2}\mathrm{NCAPE}\right)^2 + \frac{8\psi}{v_{\mathrm{SR}}^2}\mathrm{CAPE}}}{4\frac{\psi}{v_{\mathrm{SR}}^2}}.$$

Which CAPE you use an influence how you interpret updraft intensity.

But be weary, they're all still just estimates!

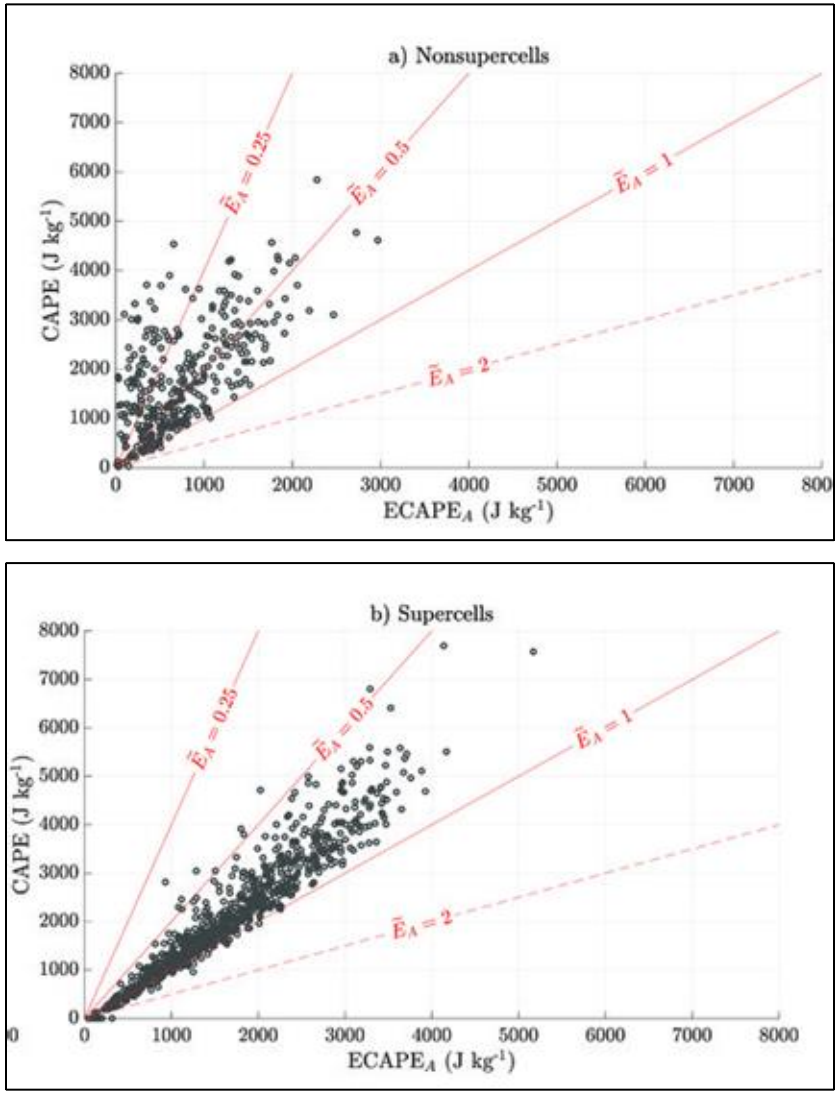
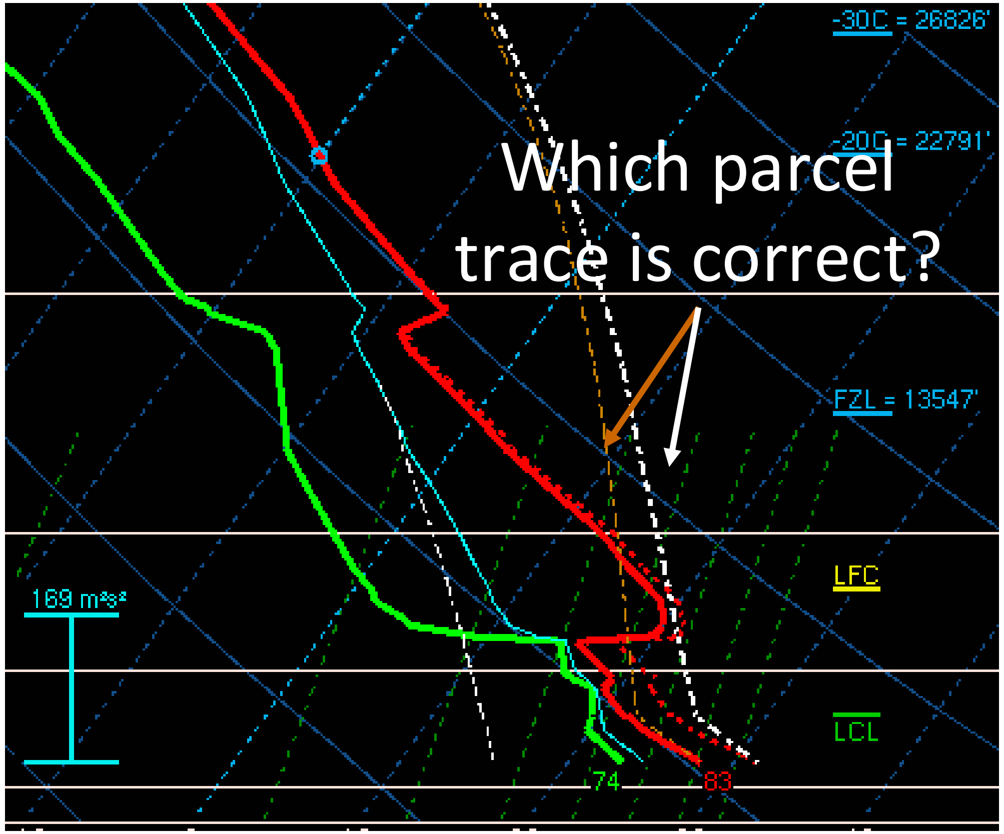


Fig 10 from Peters et al 2023



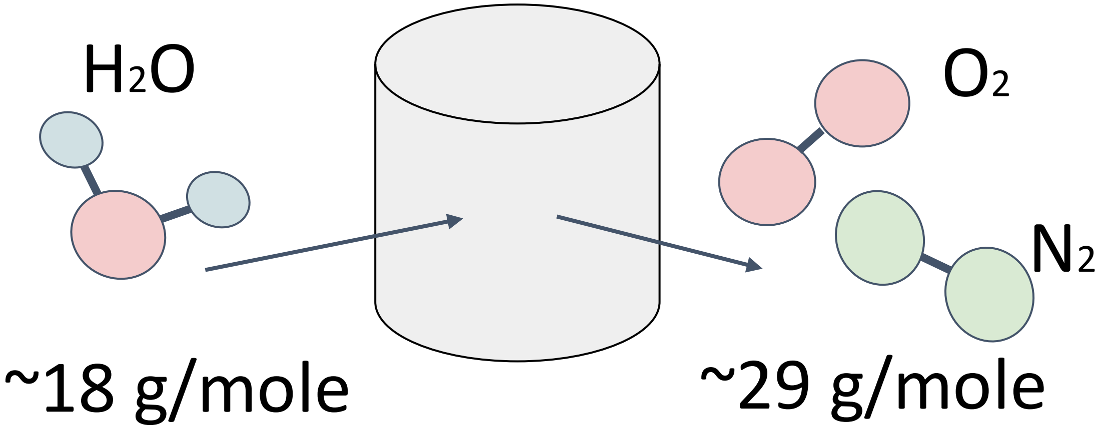
Virtual Temperature Correction

Accounts for the reduction in density a parcel experiences as the proportion of water vapor in the parcel increases.

$$T_v = \frac{T + 273.15}{1 - 0.379 \times \left(\frac{6.11 \times 10^{\left(\frac{7.5 \times T_d}{237.3 + T_d}\right)}}{P_{sta}} \right)}$$

$$\text{CAPE} = \int_{z_f}^{z_n} g \left(\frac{T_{v,\text{parcel}} - T_{v,\text{env}}}{T_{v,\text{env}}} \right) dz$$

Conservation of mass in a parcel



In effect, this makes our parcel trace more representative of reality by:

- Increasing CAPE
- Reducing CIN

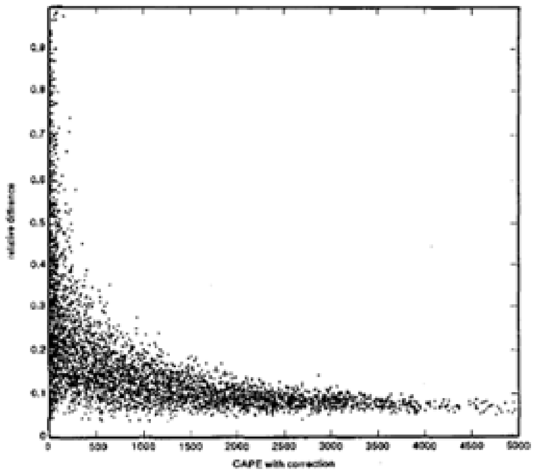


FIG. 4. Plot of the relative difference in the CAPE with and without the virtual correction for the 1992 positive CAPE soundings (as in Fig. 2) versus CAPE (with correction).

Matters most in moist, low-CAPE environments

NOTES AND CORRESPONDENCE

The Effect of Neglecting the Virtual Temperature Correction on CAPE Calculations

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NOAA/Environmental Research Laboratories, National Severe Storms Laboratory, Norman, Oklahoma

3 March 1994 and 22 June 1994

ABSTRACT

A simple theoretical analysis of the impact of neglecting the virtual correction on calculation of CAPE is made. This theory suggests that while ignoring the virtual correction does not introduce much error for large CAPE values, the relative error can become substantial for small CAPE. A test of the theory is done by finding the error made by ignoring the virtual correction to CAPE for all the soundings in 1992 having positive CAPE (when the correction is made). Results of this empirical test confirm that the relative error made in ignoring the correction increases with decreasing CAPE. A number of other "corrections" to CAPE might be considered. In a discussion of the issues associated with the results of the analysis, it is recommended that CAPE calculations should include the virtual correction but that other complications should be avoided for most purposes, especially when making comparisons of CAPE values. A standardized CAPE calculation also is recommended.

1. Introduction

This note addresses the calculation of convective available potential energy (CAPE). CAPE is a quantity most closely associated with the environment in which deep convection might occur, and has become widely accepted as a *forecasting* parameter with the advent of computer programs that calculate CAPE from operational soundings or model forecasts. Recently, it has come to our attention that the algorithms for computing CAPE are not all the same. In particular, some schemes do not include the virtual temperature correction in the calculations.

It is well known that the *virtual* temperature T_v is the proper temperature to use in the equation of state $p = \rho R T_v$ in order that the gas constant R be truly constant. Otherwise, the addition of moisture changes the "constant," with the change depending on the amount of moisture. Use of the virtual correction to temperature T such that

$$T_v = T(1 + \epsilon q), \tag{1}$$

where $\epsilon = 0.608$ when the mixing ratio q is expressed in g g^{-1}, allows the use of the gas constant for *dry* air, $R = 2.87 \times 10^2$ m^2 s^{-2} K^{-1}, in the equation of state. The virtual correction is always positive because adding water vapor to a parcel makes it less dense, which can be considered equivalent to warming the parcel.

Since CAPE concerns the *difference* in density between a rising parcel and its environment, and since an accurate calculation of density requires the virtual temperature, it should be obvious that the virtual correction is necessary when estimating CAPE. To assess the impact of ignoring the virtual correction, an analysis of the contribution from this error follows in section 2. In section 3, the application of CAPE estimates is discussed and some recommendations are made.

2. Theoretical analysis of the error

We begin with logarithmic differencing of the equation of state,

$$\frac{\delta\rho}{\rho} = \frac{\delta p}{p} - \frac{\delta T_v}{T_v}, \tag{2}$$

where the difference operator $\delta(\ )$ is between the parcel and its environment:

$$\delta(\ ) = (\ )_{parcel} - (\ )_{env}.$$

The standard assumption in parcel theory is to ignore the contribution to differences in density due to differences in *pressure* between the parcel and the environment. If this standard assumption is made and (1) is logarithmically differenced, substitution into (2) gives

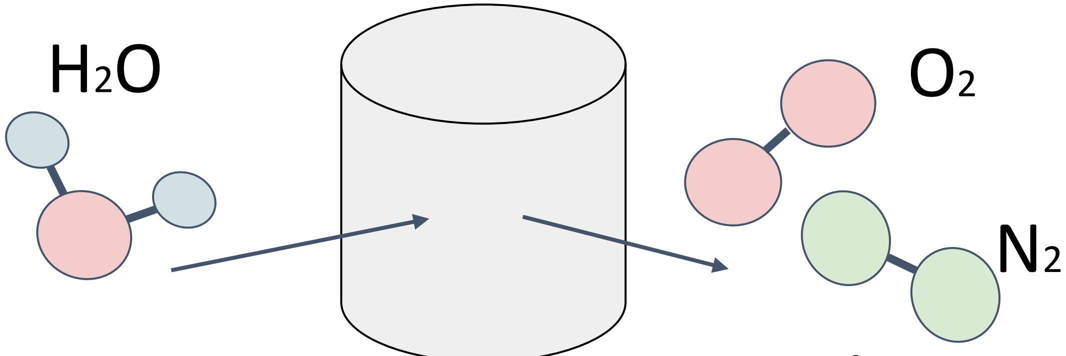
$$\frac{\delta\rho}{\rho} \approx -\frac{\delta T_v}{T_v},$$

$$= -\left[\frac{\delta T}{T} + \frac{\epsilon \delta q}{(1 + \epsilon q)}\right]. \tag{3}$$

* Additional affiliation: Cooperative Institute for Mesoscale Meteorological Studies, Norman, Oklahoma.

Corresponding author address: Dr. Charles A. Doswell III, National Severe Storms Laboratory, 1313 Halley Circle, Norman, OK 73069.

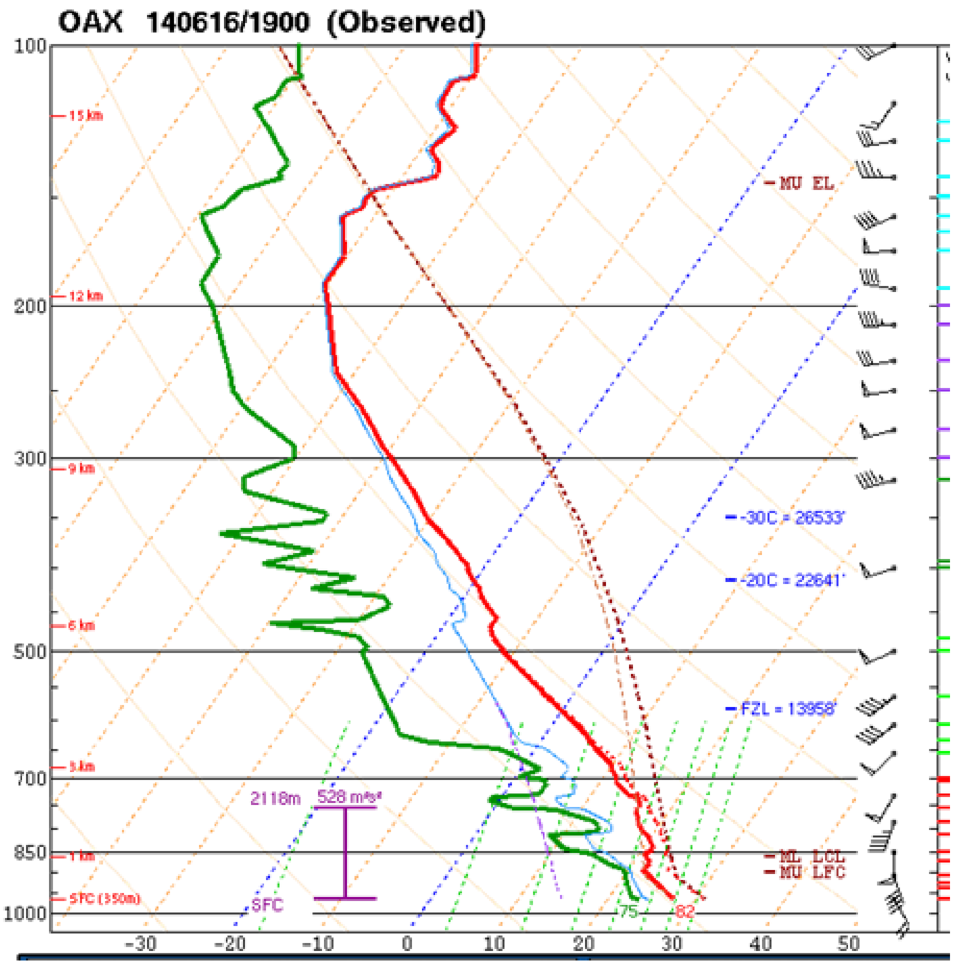
Conservation of mass in a parcel

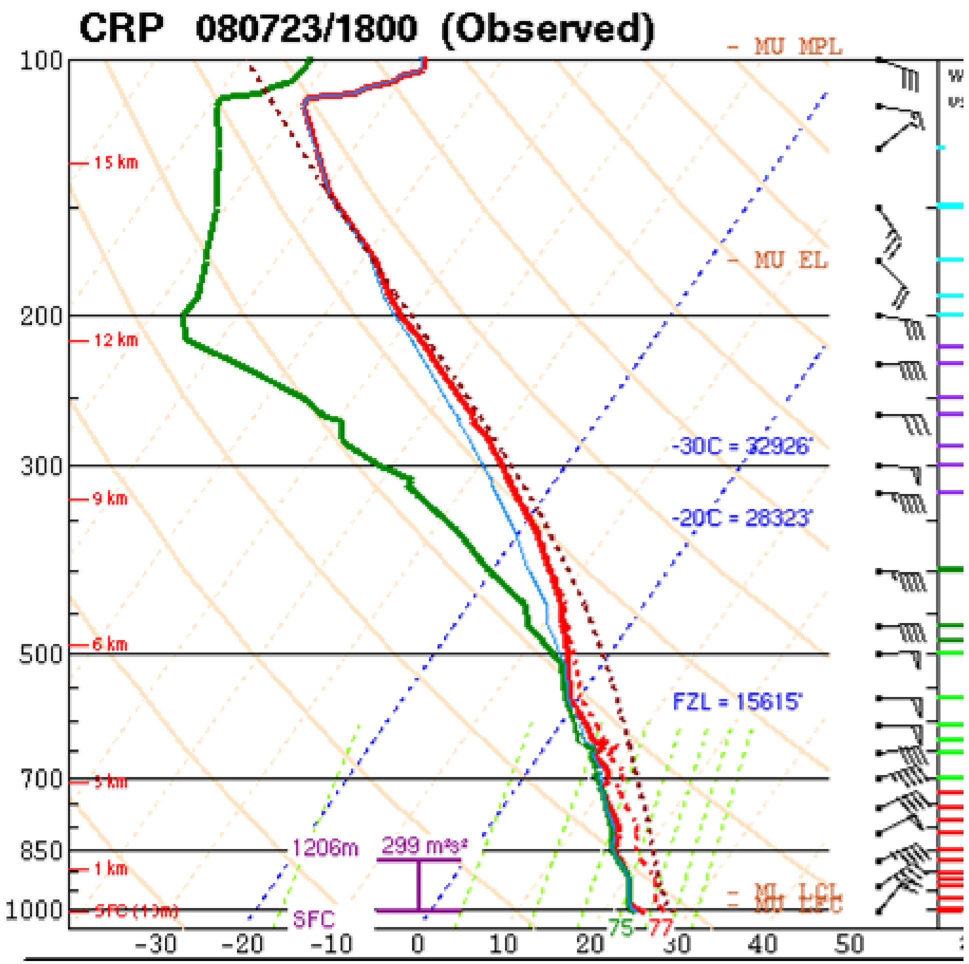


~18 g/mole

~29 g/mole

In which sounding will the virtual temperature correction matter more?



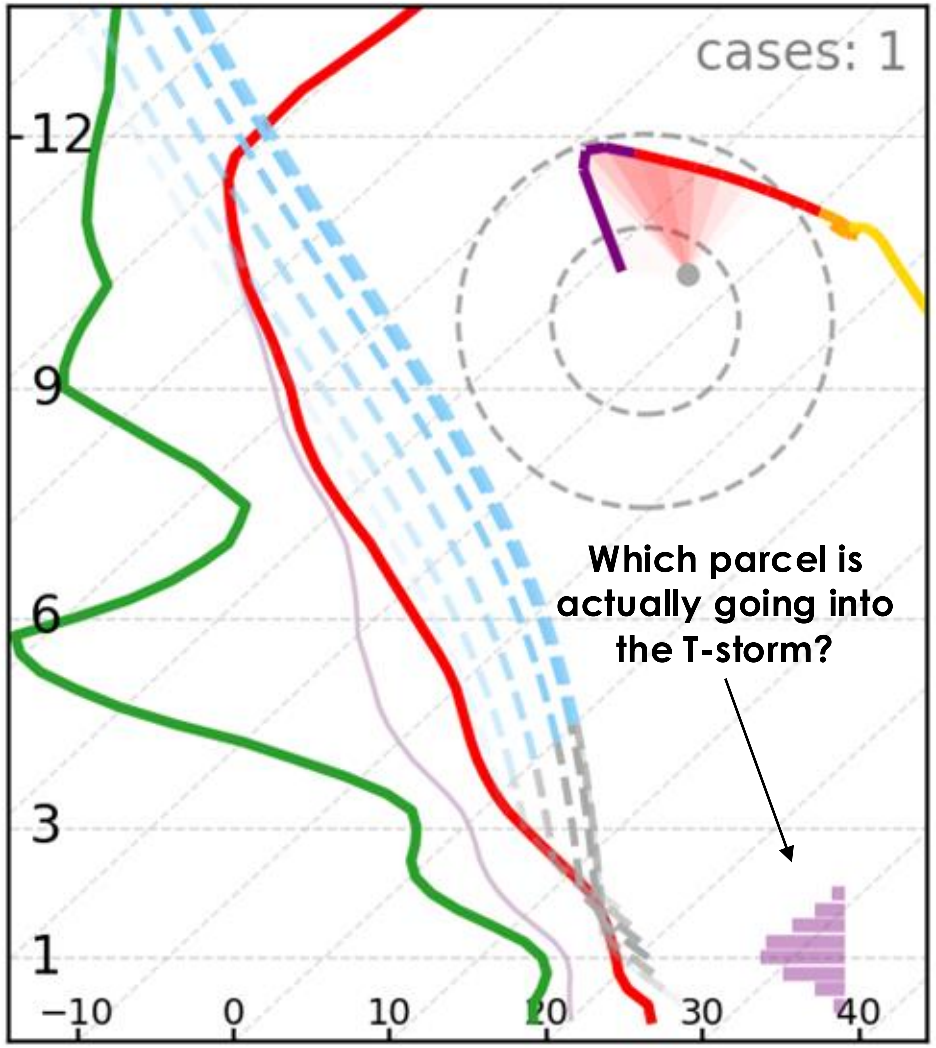


At the end of the day…

- Parcel selection matters!
  - Influences your interpretation of the environment.

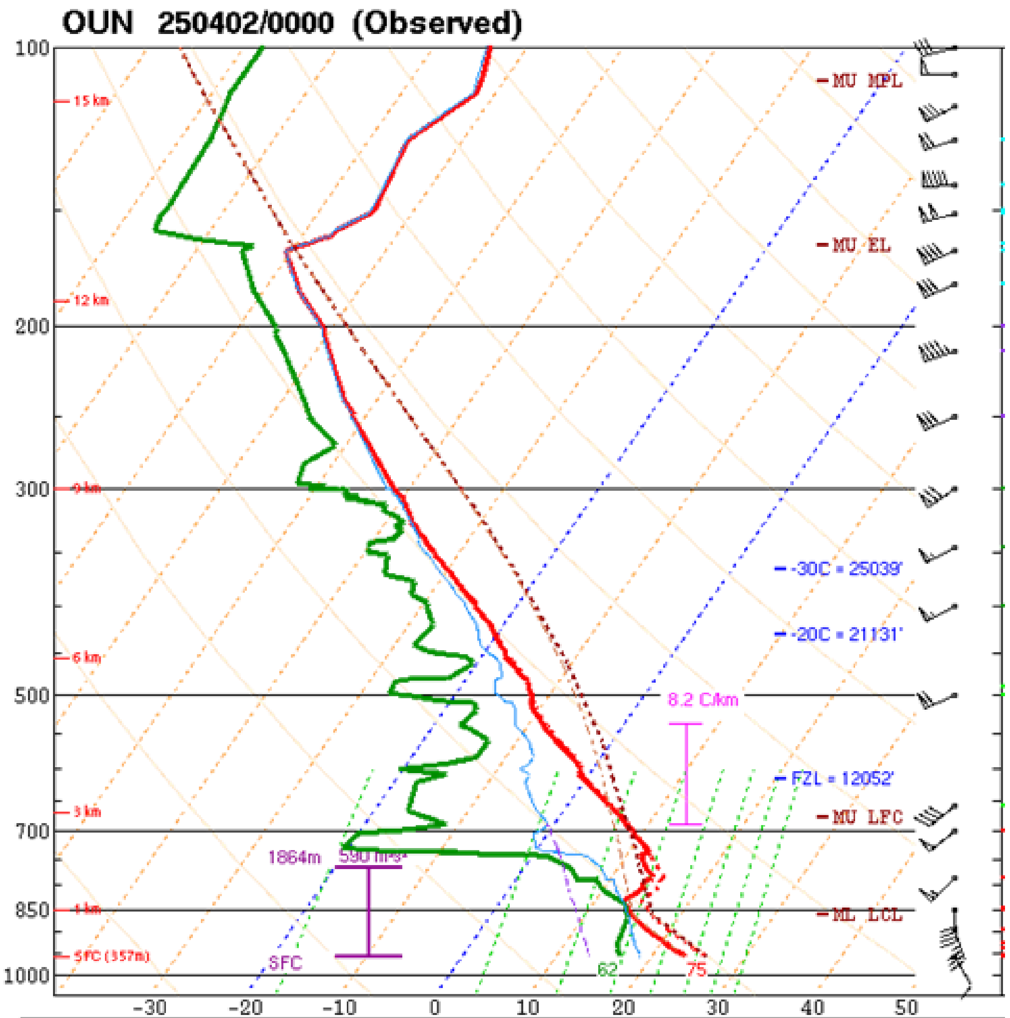
- Know when to use the right parcel and when to make adjustments.

- Realize that we're working with an imperfect model of the atmosphere. Treat thermodynamic parameters as estimates!



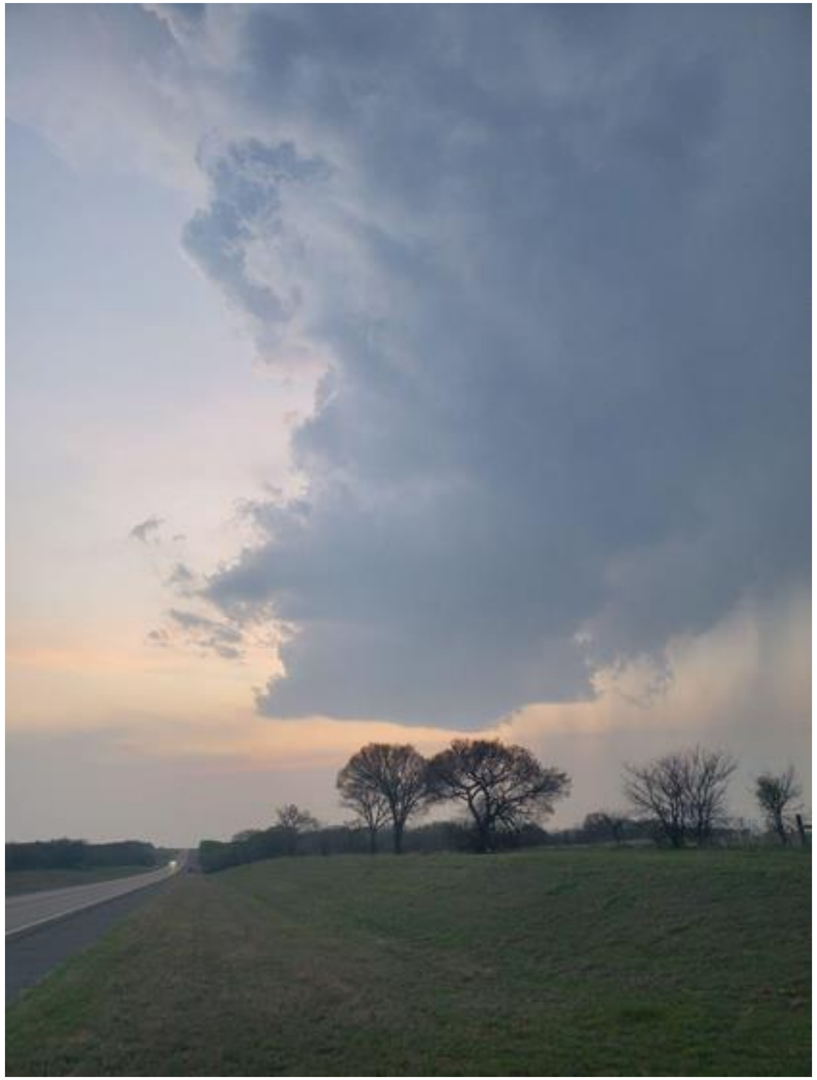
Courtesy of Dr. Cameron Nixon

What is feeding the storm?



PARCEL	CAPE	CINH	LCL	LI	LFC	EL
SURFACE	1981	-66	874m	-5	2902m	42058'
MIXED LAYER	1826	-80	894m	-5	3024m	42420'
FCST SURFACE	2437	-33	1187m	-6	2603m	42178'
MU (956 mb)	1981	-66	874m	-5	2902m	42058'

	SRH(m2/s2)	Shear(kt)	MnWin
SFC - 1 km	342	33	167/3
SFC - 3 km	587	44	202/3
Eff Inflow Layer	590	51	187/3
SFC - 6 km		63	217/3



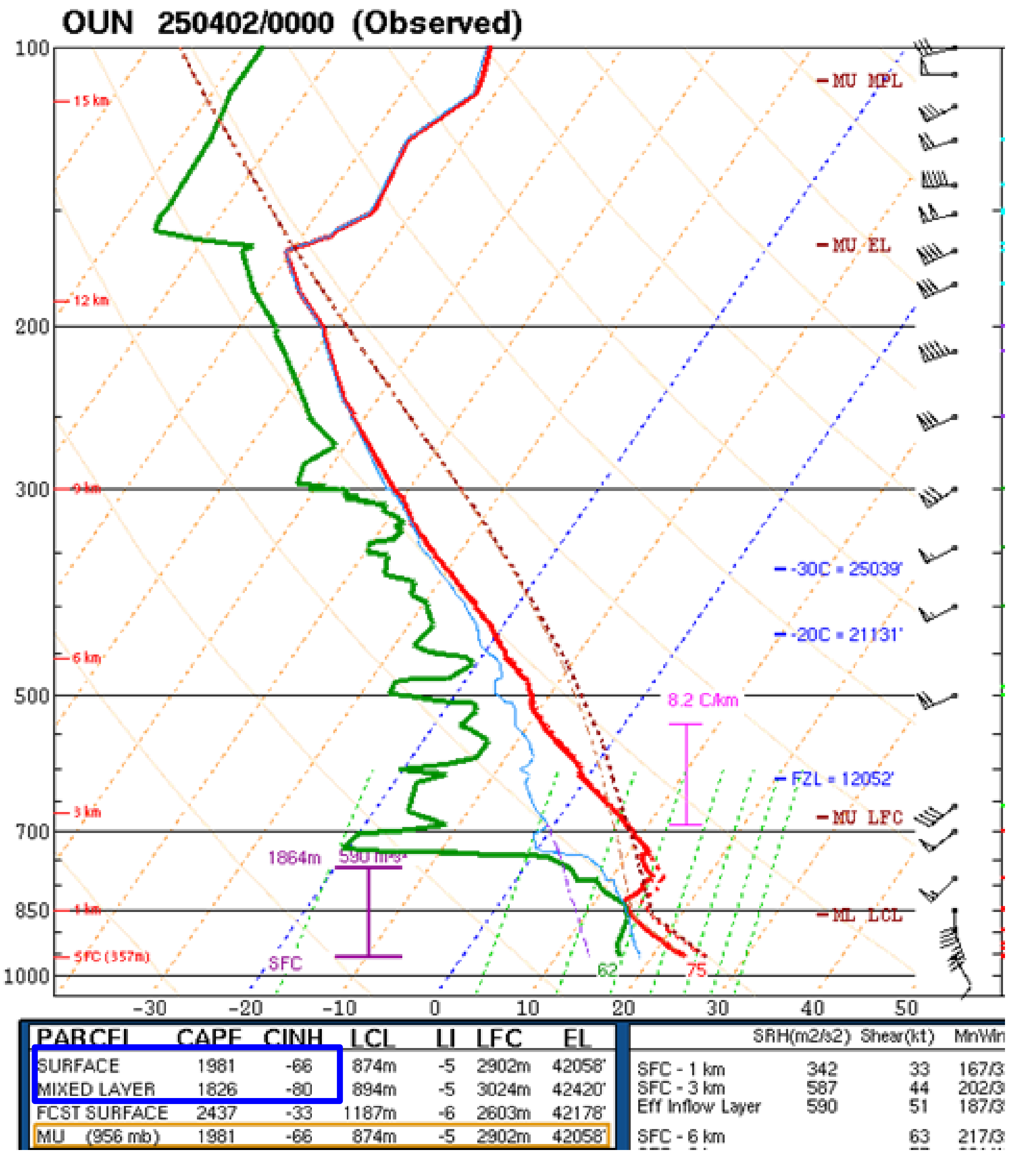
Is this storm surface-based?

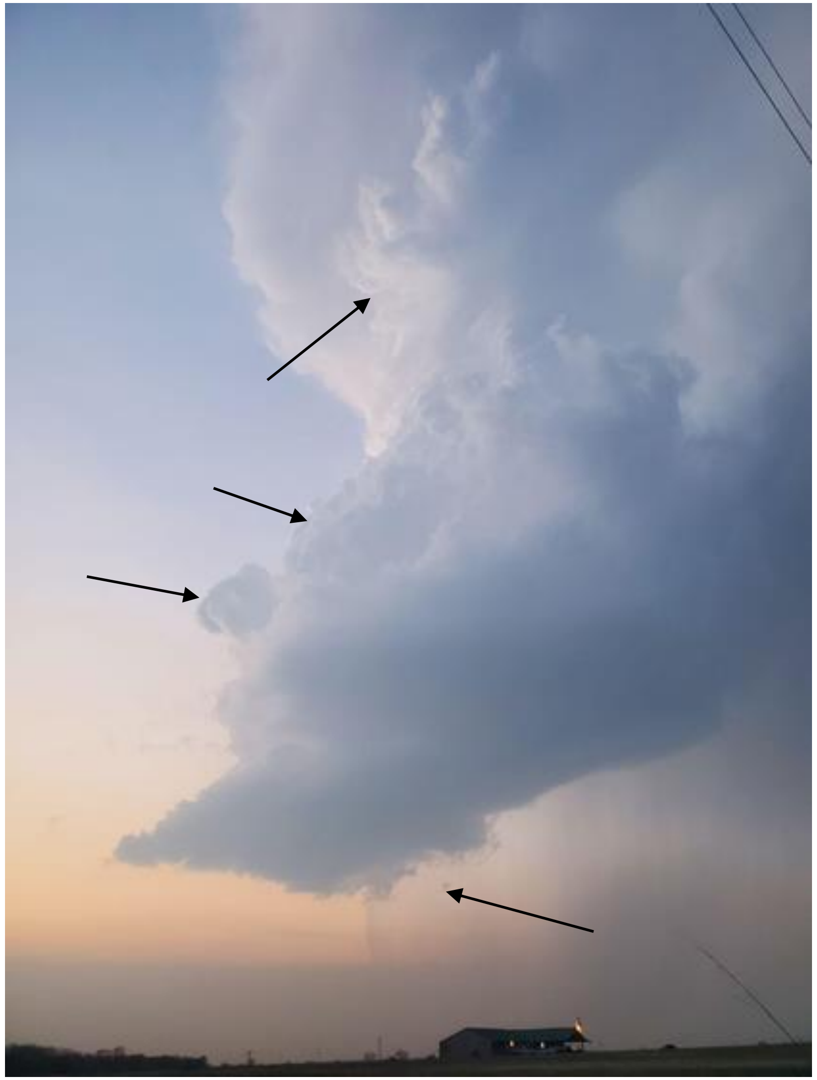
Storm motion suggested it was not.

(more on that later)

No discernable rising scud.

What is feeding the storm?





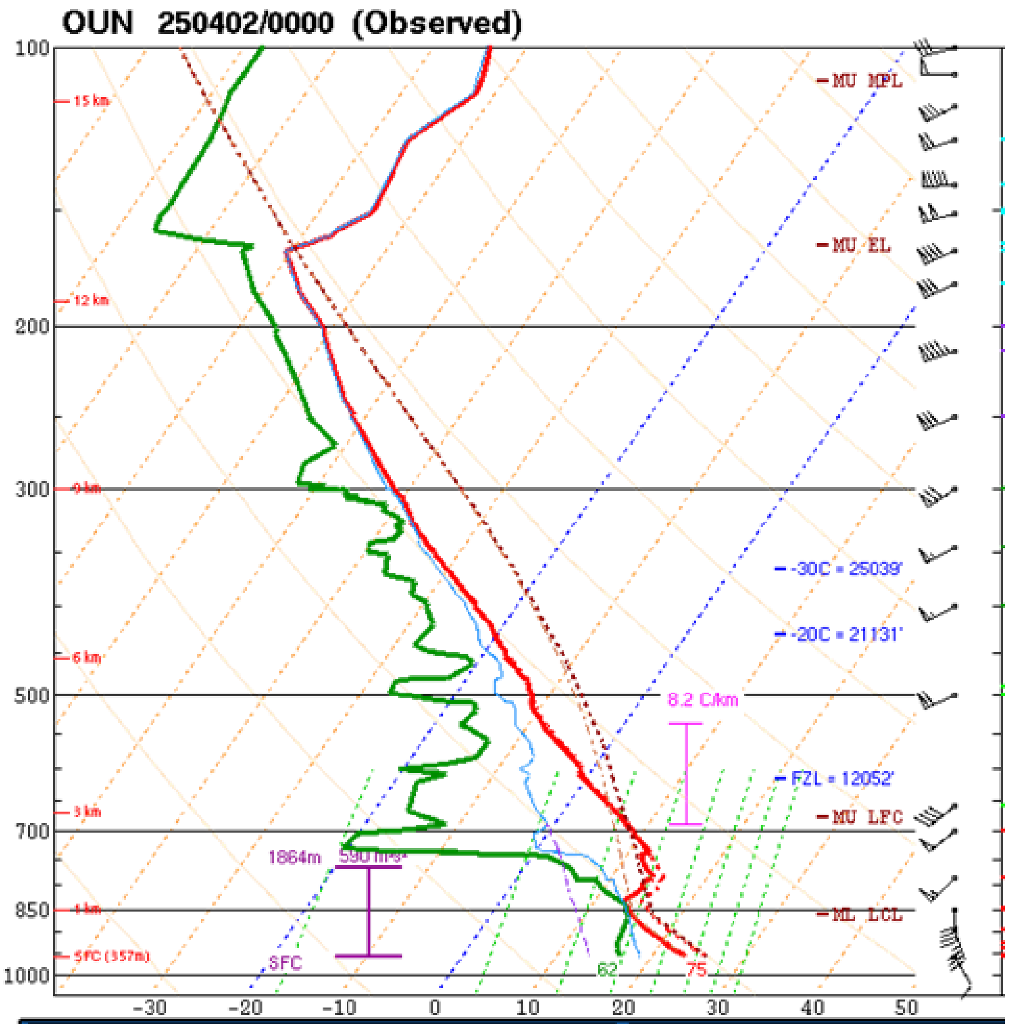
Is this storm surface-based?

Increasing rising scud into a lowering cloud base.

Notable updraft pulses.

Suggested the storm was ingesting near-surface parcels!

What is feeding the storm?



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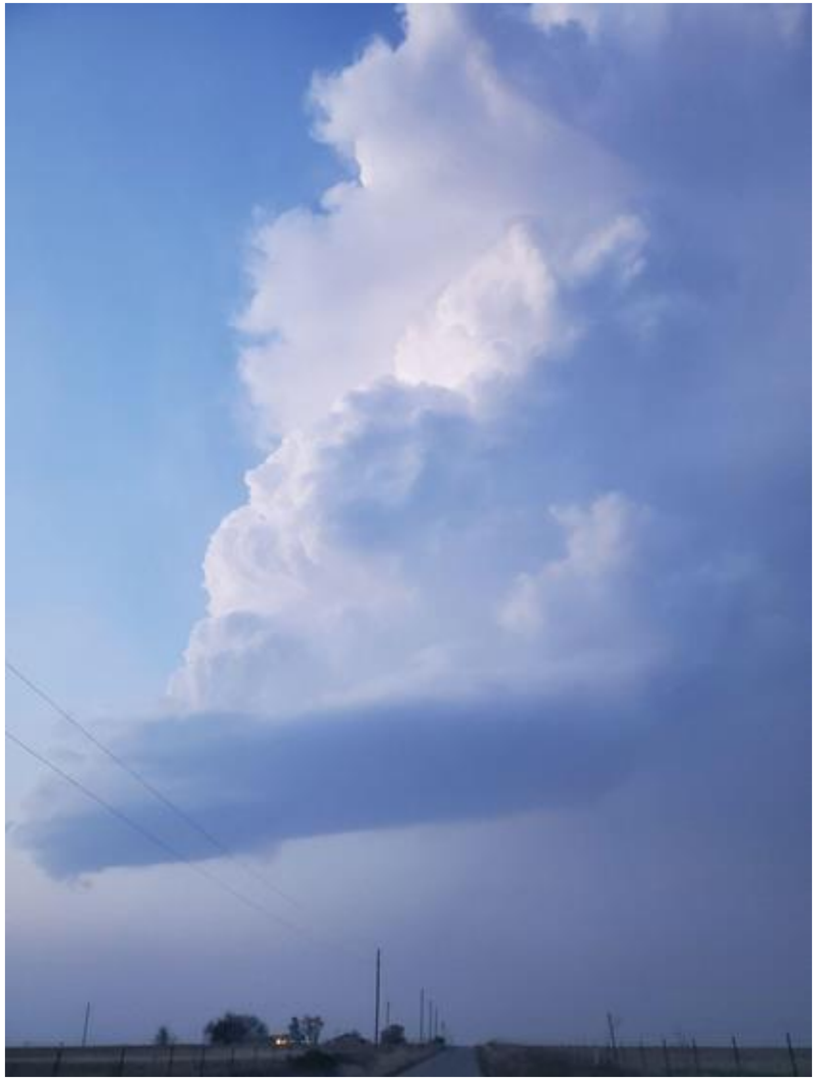
Eff Inflow Layer	590	51	187/3
SFC - 6 km		63	217/3



Is this storm surface-based?

Rising scud diminishes.

Weak updraft pulses.

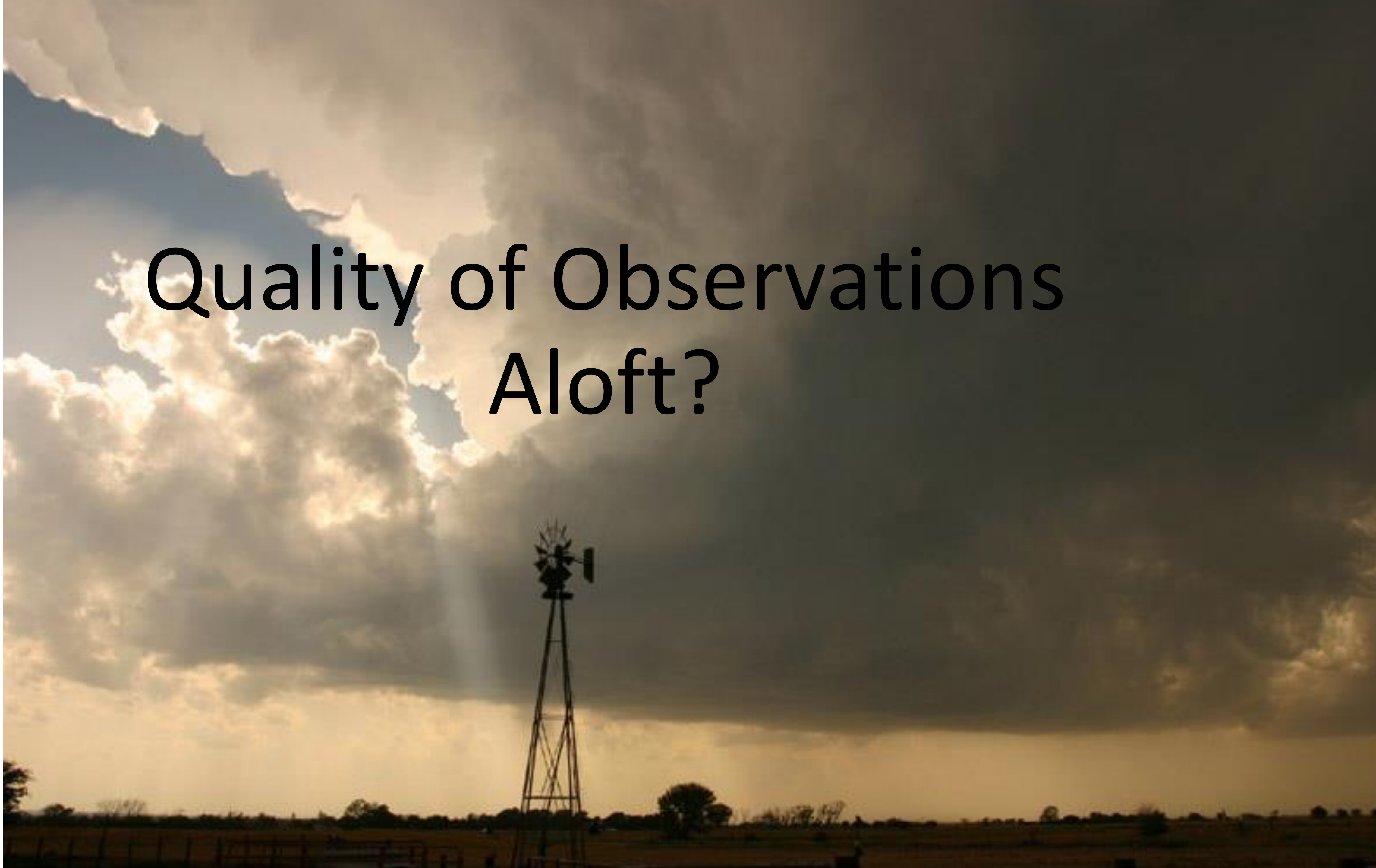
Cloud based climbs up and elongates.

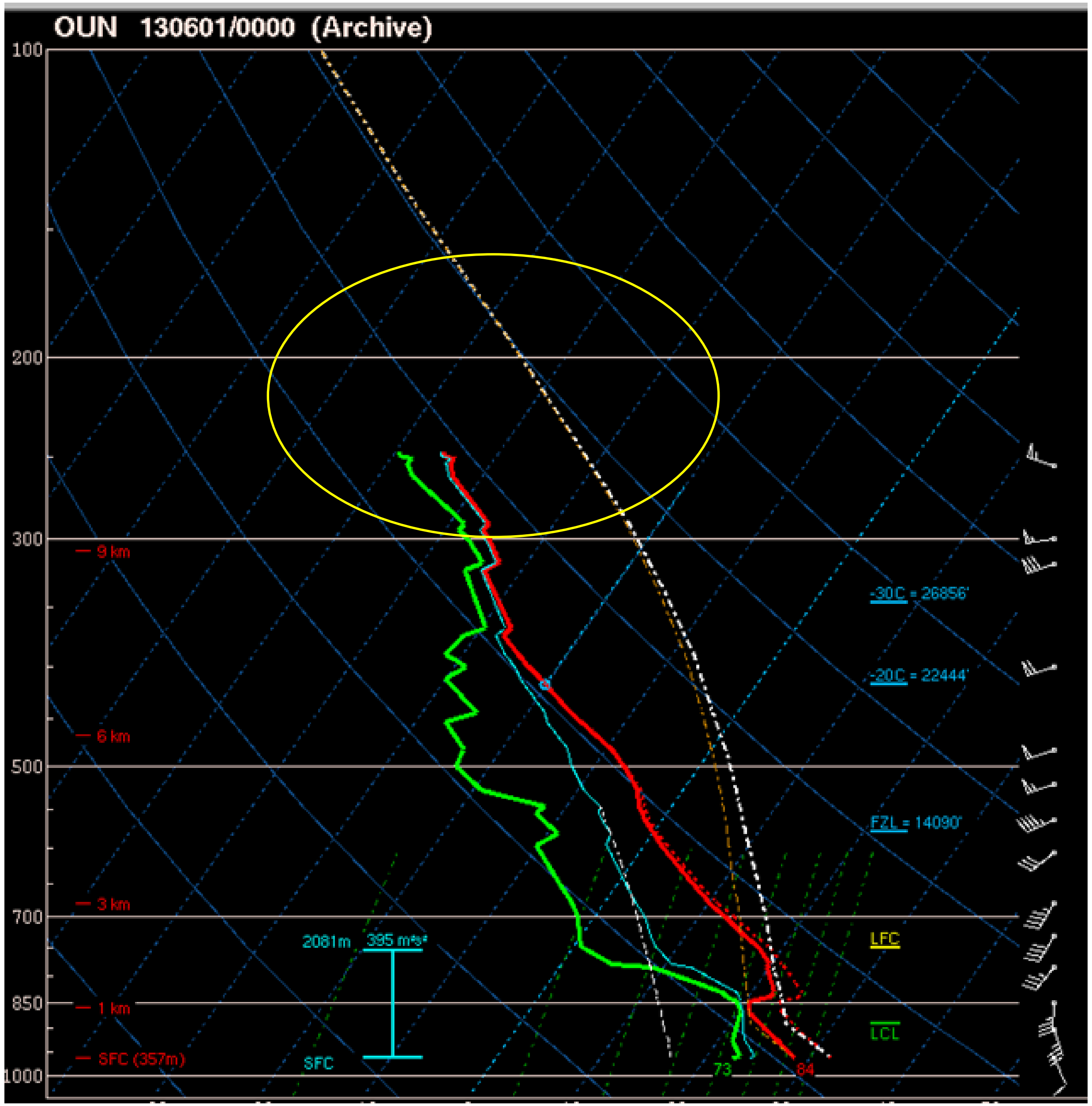
Storm begins accelerating away from us.

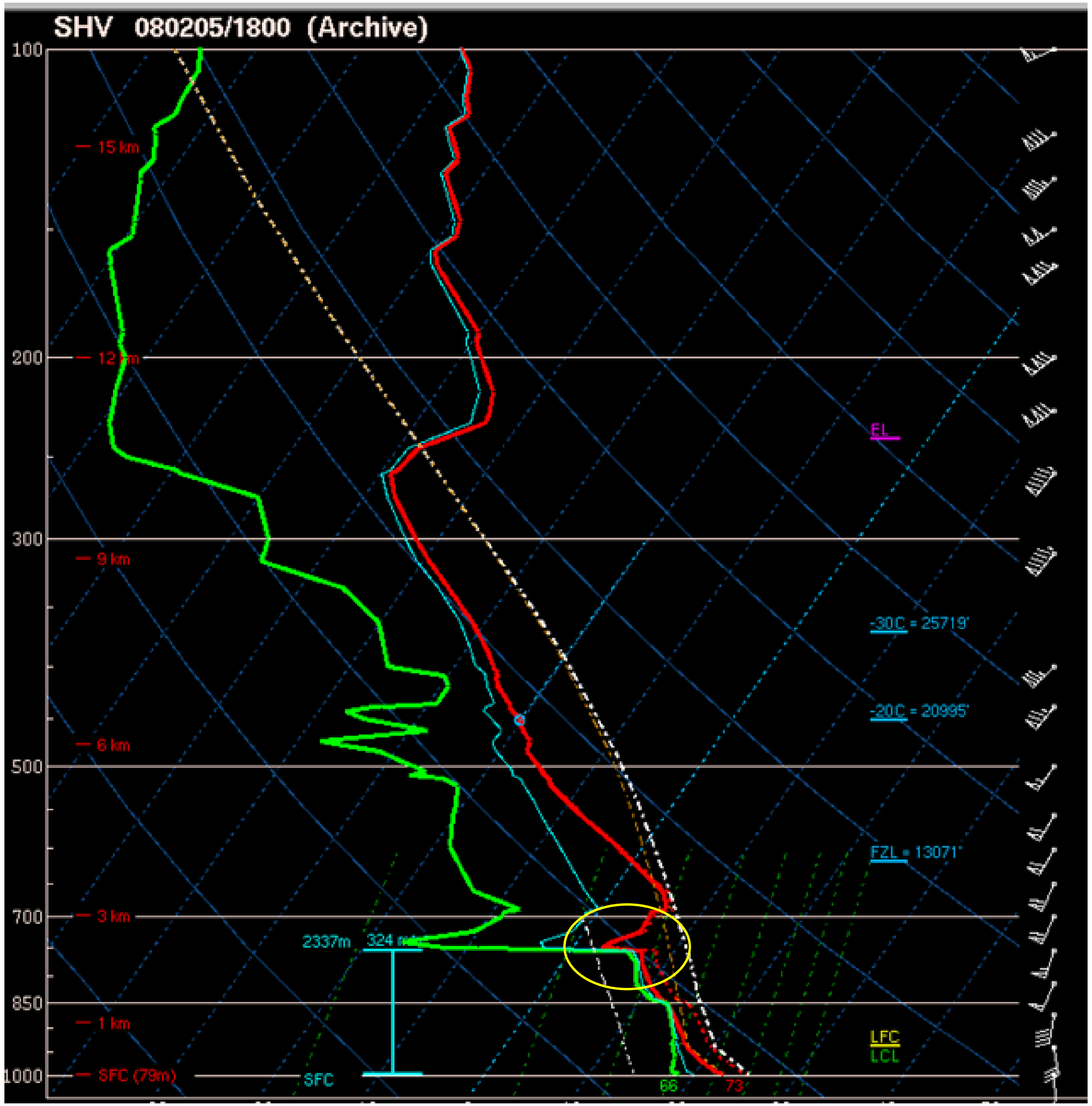
Storm dies within 20 minutes.

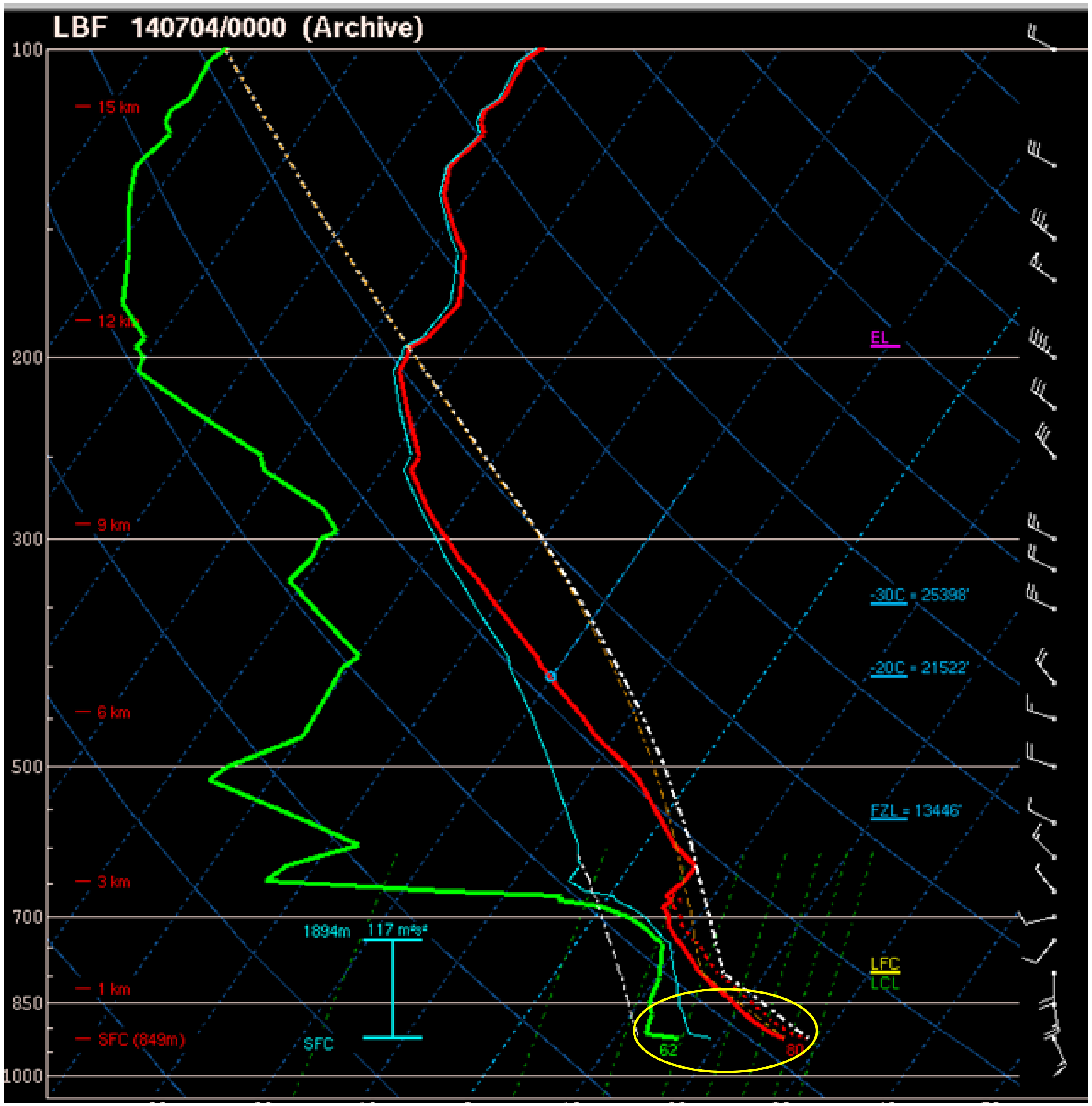
Was the storm elevated the whole time? Storm behavior suggested it was!

Quality of Observations Aloft?



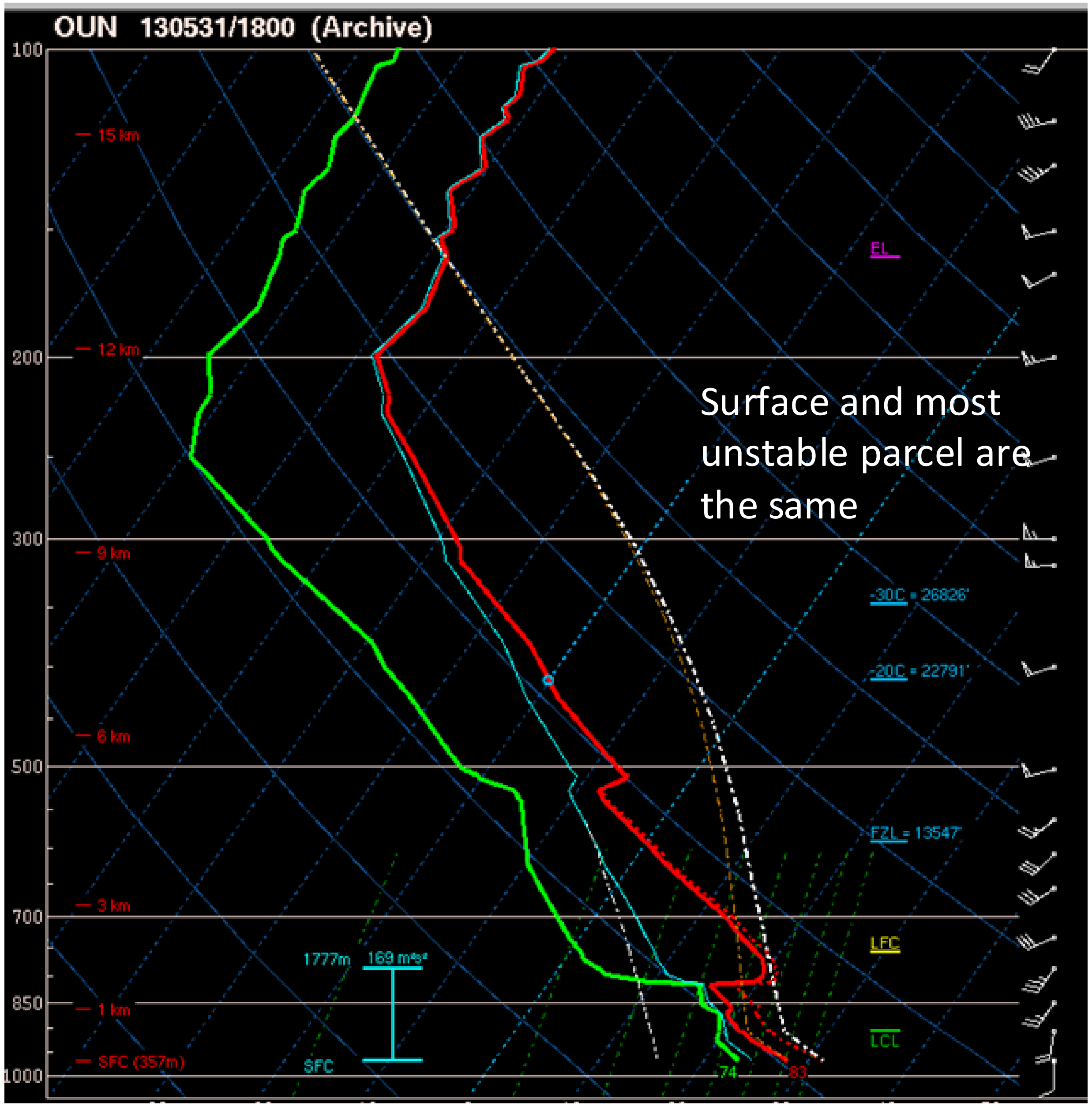

OUN 130601/0000 (Archive)
100
200
300
500
700
850
1000
9 km
6 km
3 km
1 km
SFC (357m)
2081m
395 m²s²
SFC
-30C = 26856'
-20C = 22444'
FZL = 14090'
LFC
LCL
73
84


SHV 080205/1800 (Archive)
100
200
300
500
700
850
1000
15 km
12 km
9 km
6 km
3 km
1 km
SFC (79m)
EL
-30C = 25719'
-20C = 20995'
FZL = 13071'
LFC
LCL
2337m
324 m
SFC
66
73

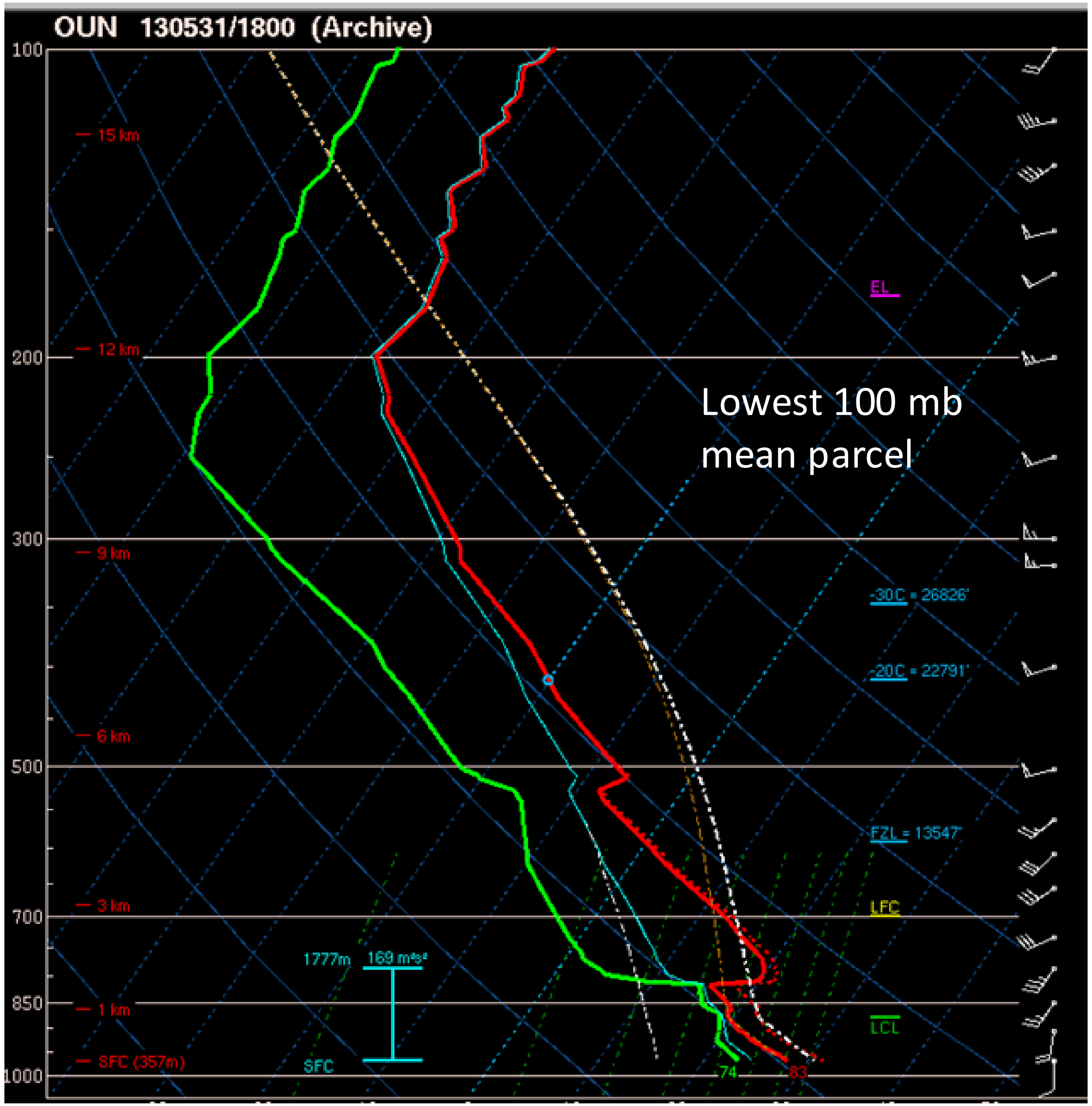

LBF 140704/0000 (Archive)
100
200
300
500
700
850
1000
15 km
12 km
9 km
6 km
3 km
1 km
SFC (849m)
EL
-30C = 25398'
-20C = 21522'
FZL = 13446'
LFC
LCL
1894m
117 m²/s²
SFC
62
80

Understand the Data and Processes!

- Understanding the processes gives you a sound way to interpret weather data, and recognize errors
- If you don’t know what you’re using, how do you know if you’re using it correctly?
  - Must consider data quality
- Focus on observations!



Surface and most unstable parcel are the same



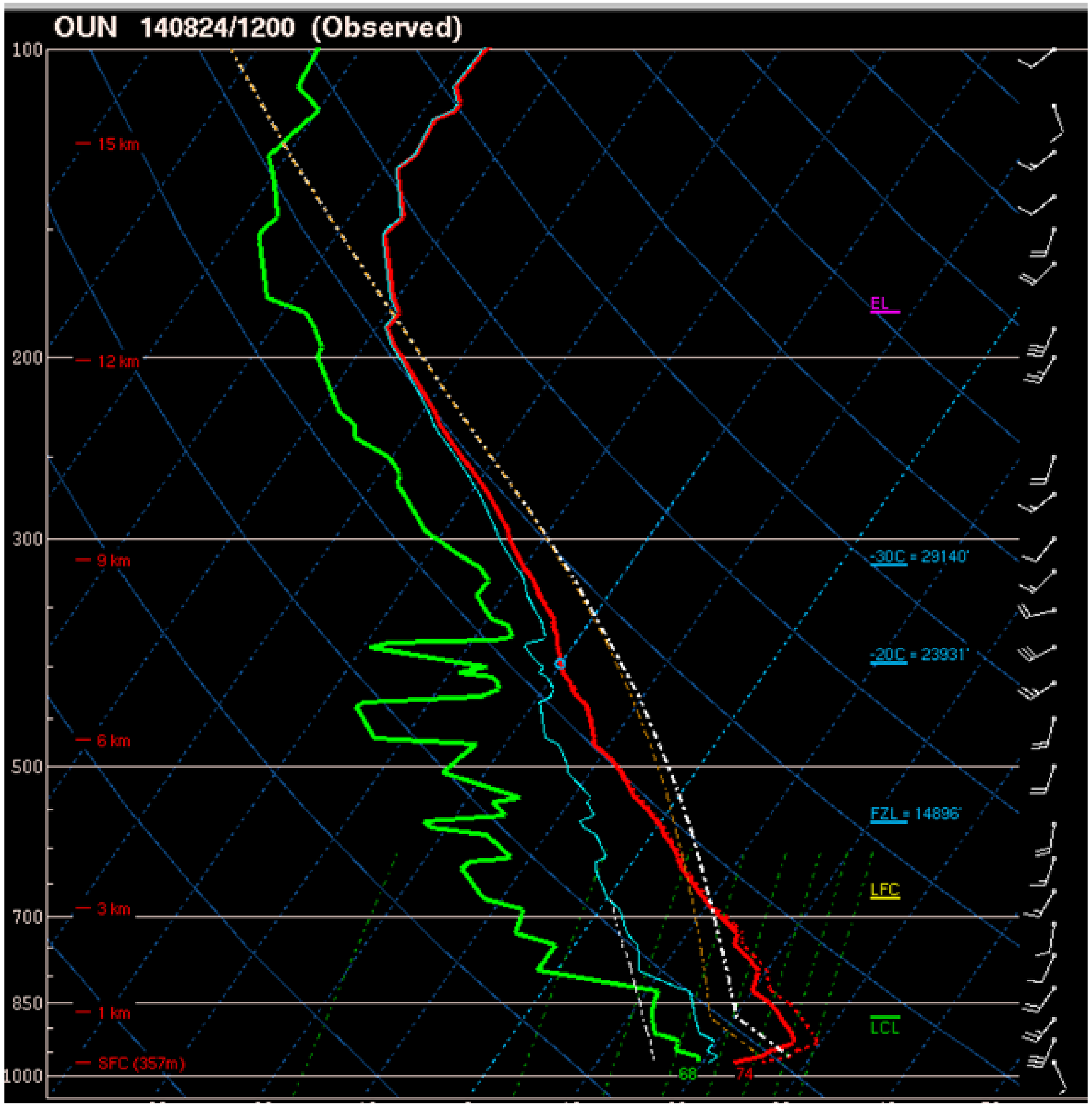
OUN 130531/1800 (Archive)
100
200
300
500
700
850
1000
15 km
12 km
9 km
6 km
3 km
1 km
SFC (357m)
EL
-30C = 26826'
-20C = 22791'
FZL = 13547'
LFC
LCL
1777m
SFC
74
83
Lowest 100 mb
mean parcel

Always keep in mind what we don't know:

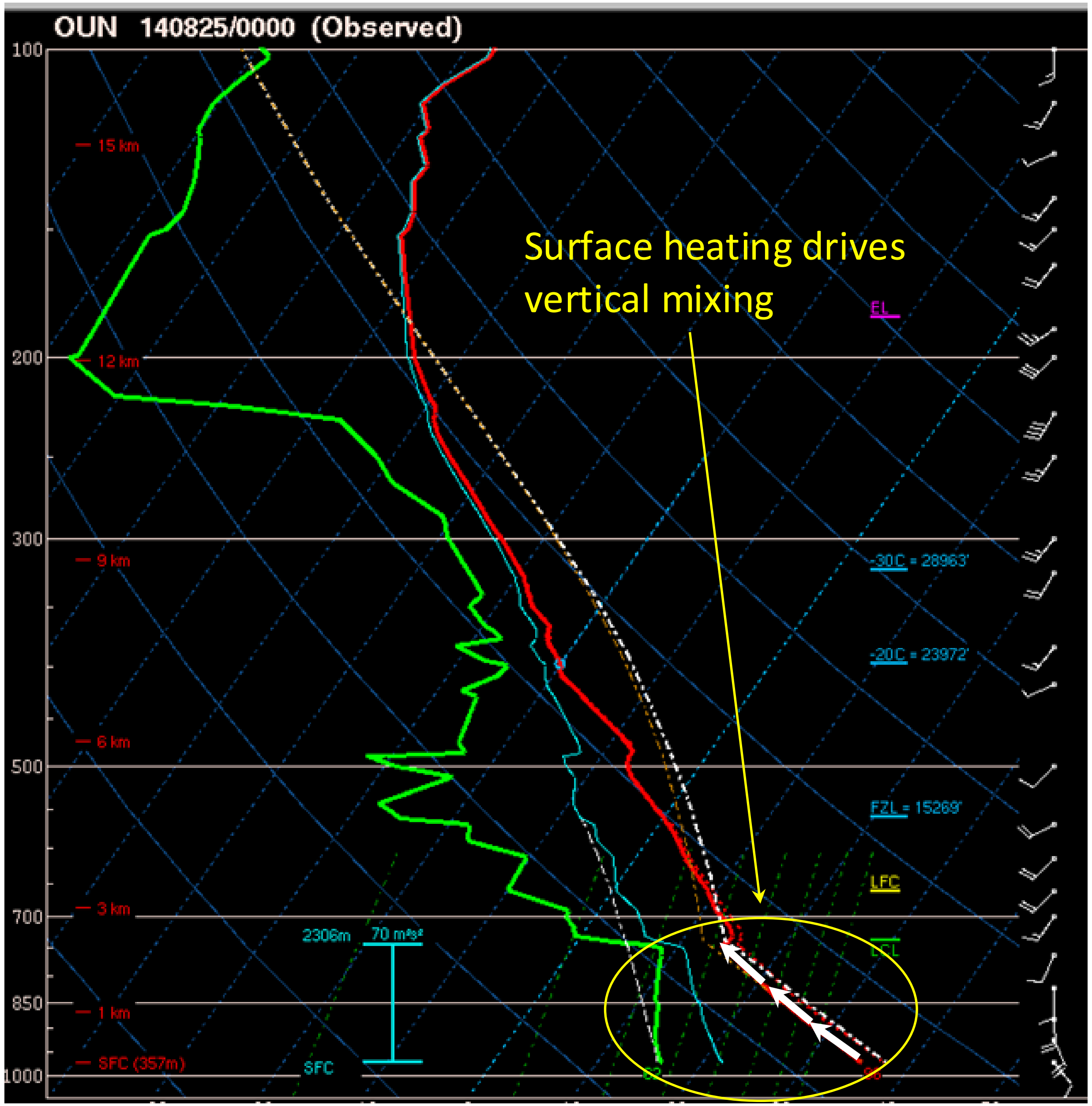
- Uncertainty in observations
  - "Good" measurements?
  - Do they represent what we're trying to forecast?
- Unknown details with lifted parcels
  - What is right layer to view?
  - What assumptions are valid, and which might be terribly wrong?
- Lots of room for error, but the concepts are useful!

Simple vertical mixing

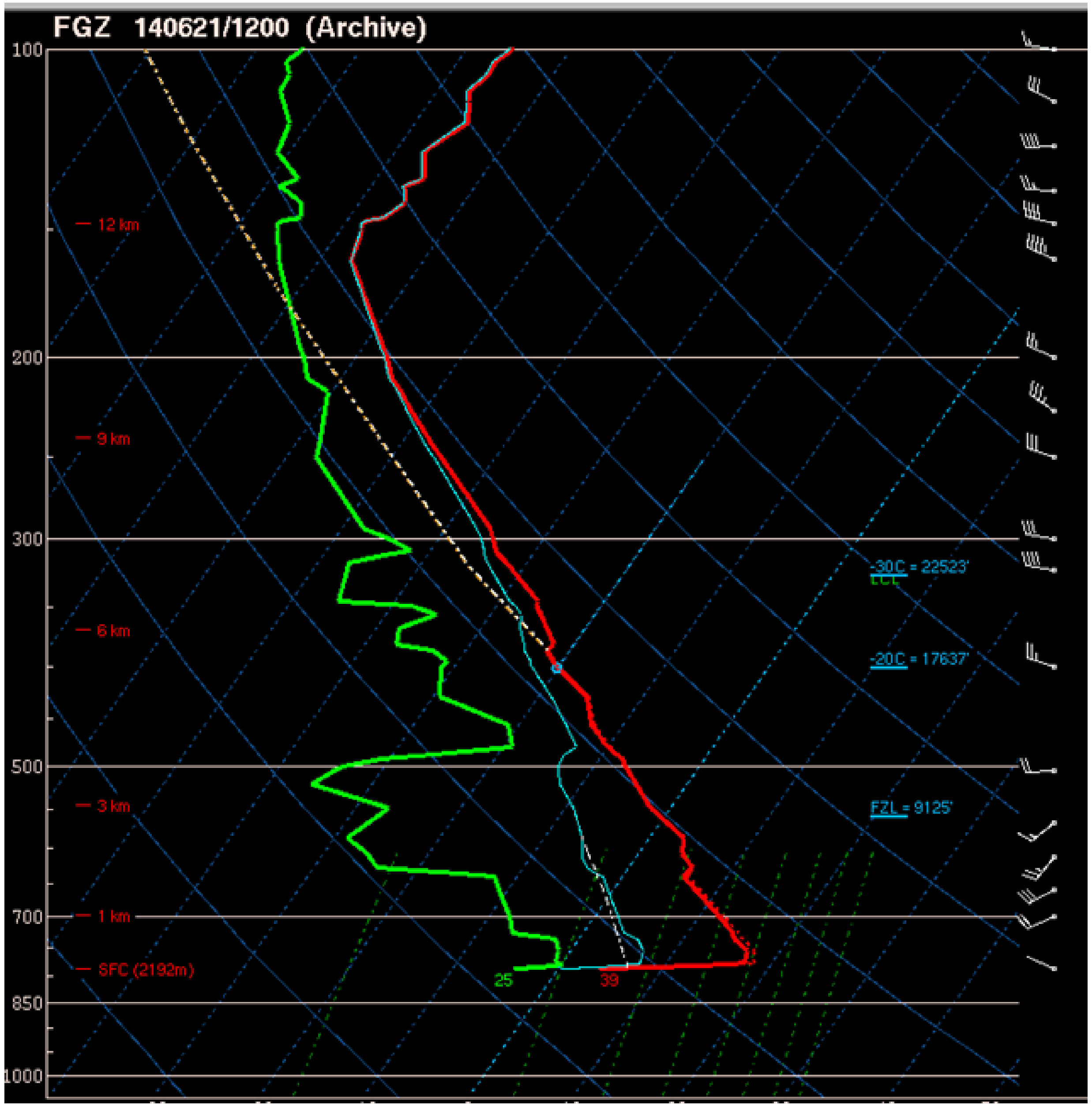
- Surface heating drives thermals and mixing, which take heat and moisture both upward (from surface) and downward (from aloft)
- Usually see surface dew point drop in afternoon if not offset by moisture advection (bringing in greater moisture from somewhere else)



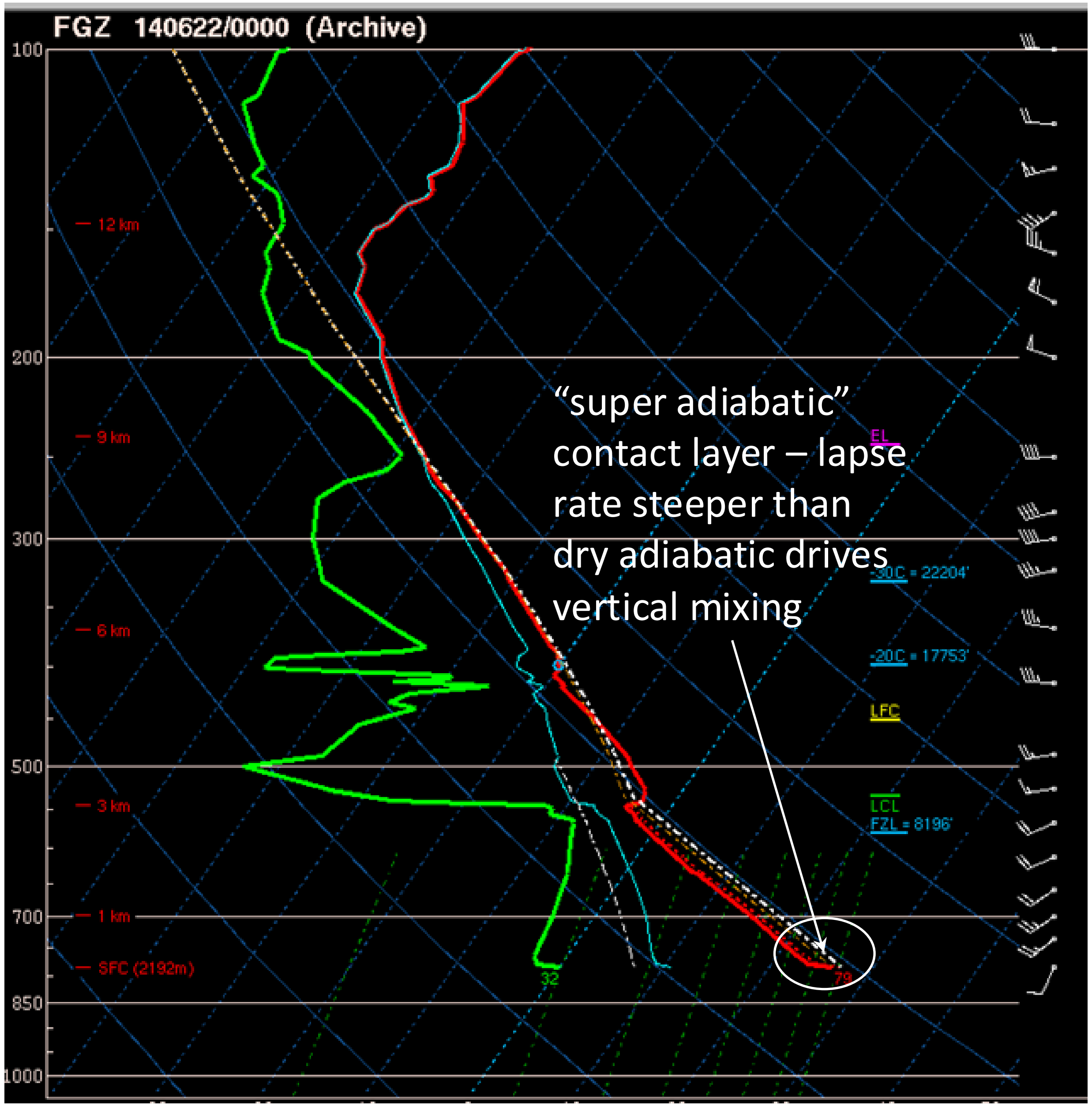
OUN 140824/1200 (Observed)
100
200
300
500
700
850
1000
15 km
12 km
9 km
6 km
3 km
1 km
SFC (357m)
EL
-30C = 29140'
-20C = 23931'
FZL = 14896'
LFC
LCL
68
74



OUN 140825/0000 (Observed)
Surface heating drives vertical mixing
100
200
300
500
700
850
1000
15 km
12 km
9 km
6 km
3 km
1 km
SFC (357m)
EL
-30C = 28963'
-20C = 23972'
FZL = 15269'
LFC
LCL
2306m
70 m²s²
SFC

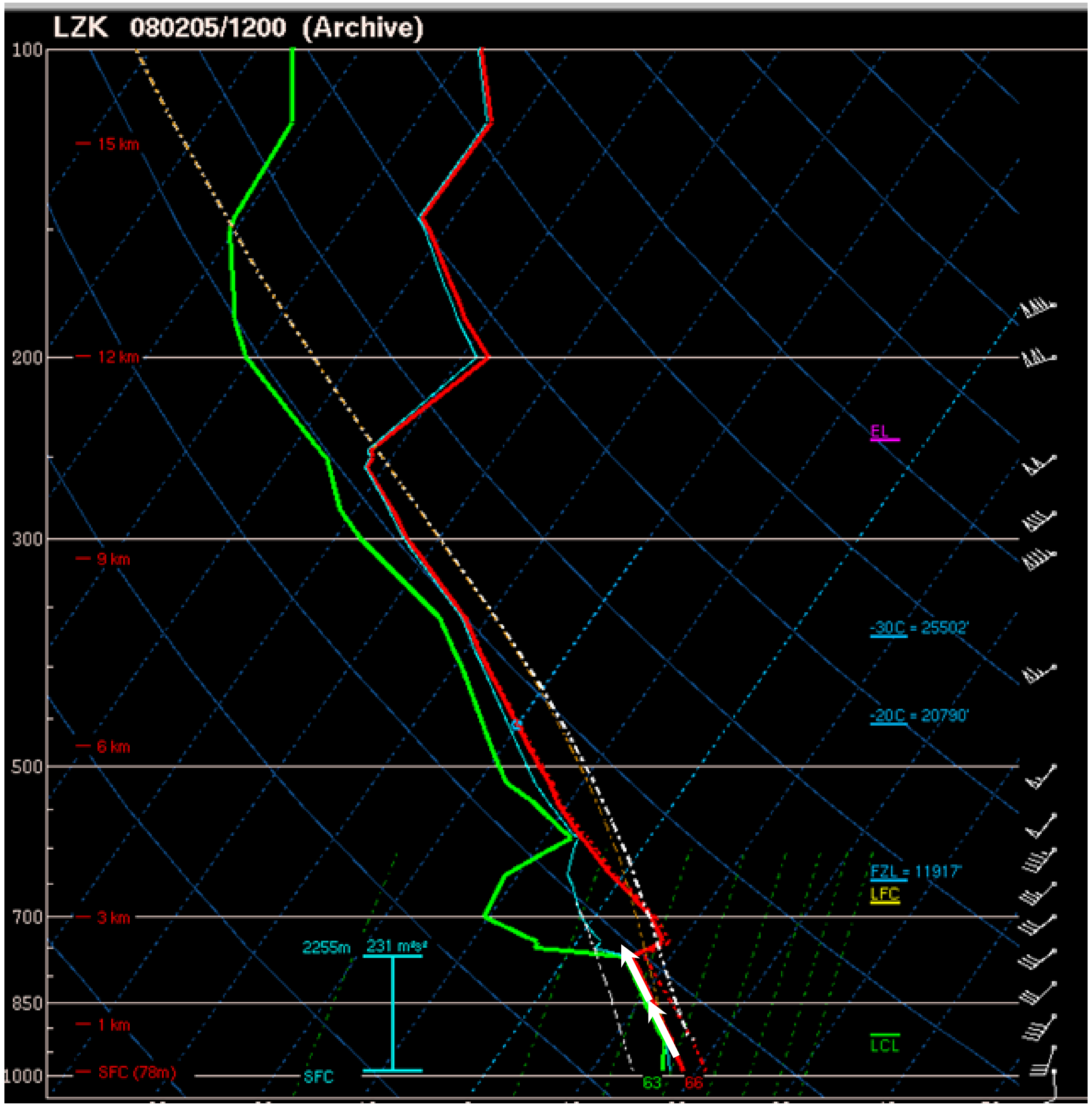


FGZ 140621/1200 (Archive)
100
200
300
500
700
850
1000
12 km
9 km
6 km
3 km
1 km
SFC (2192m)
25
39
-30C = 22523'
LCL
-20C = 17637'
FZL = 9125'

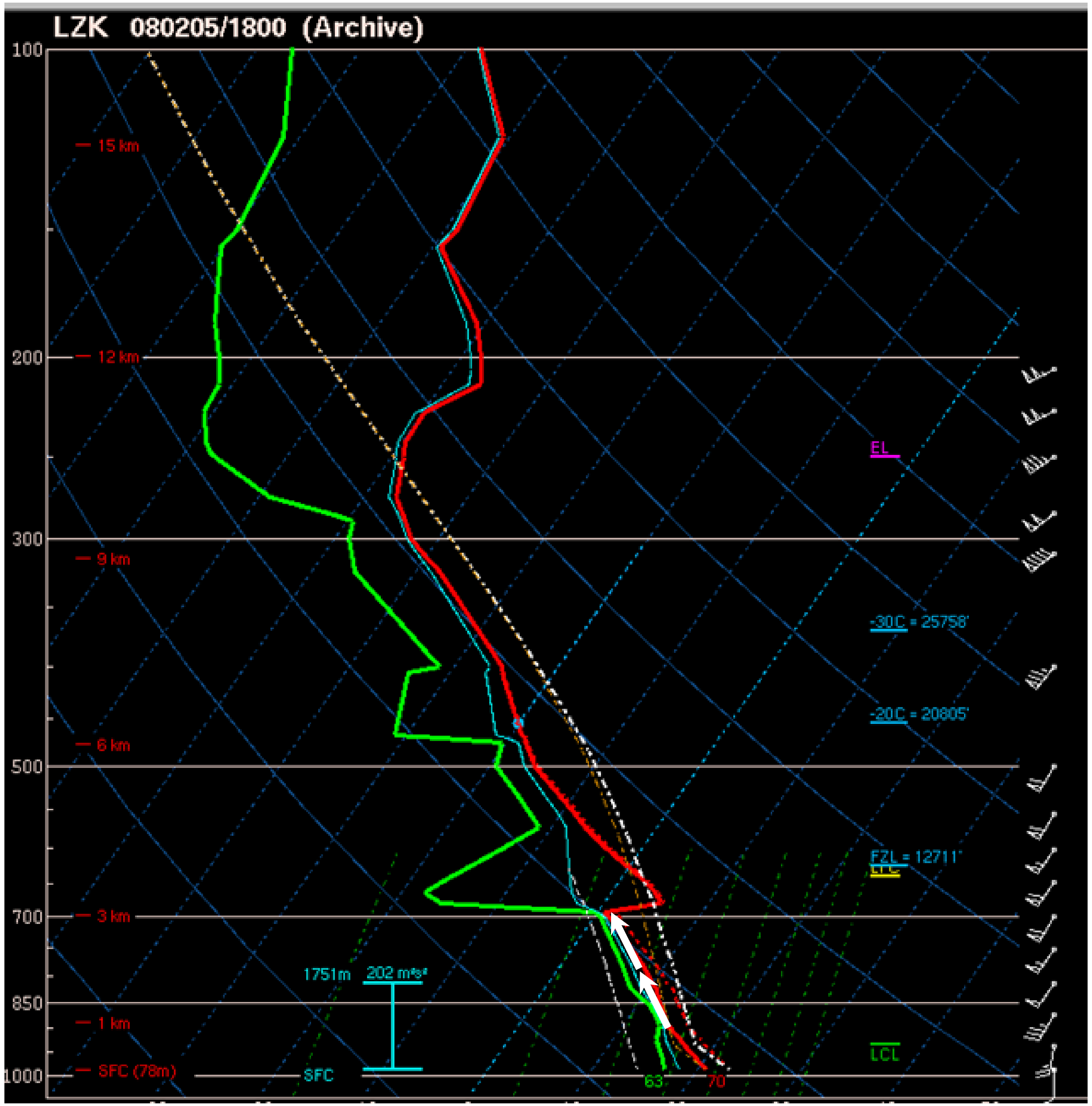

FGZ 140622/0000 (Archive)
100
200
300
500
700
850
1000
12 km
9 km
6 km
3 km
1 km
SFC (2192m)
EL
-30C = 22204'
-20C = 17753'
LFC
LCL
FZL = 8196'
32
79
"super adiabatic" contact layer – lapse rate steeper than dry adiabatic drives vertical mixing

Impact of ascent and moisture advection

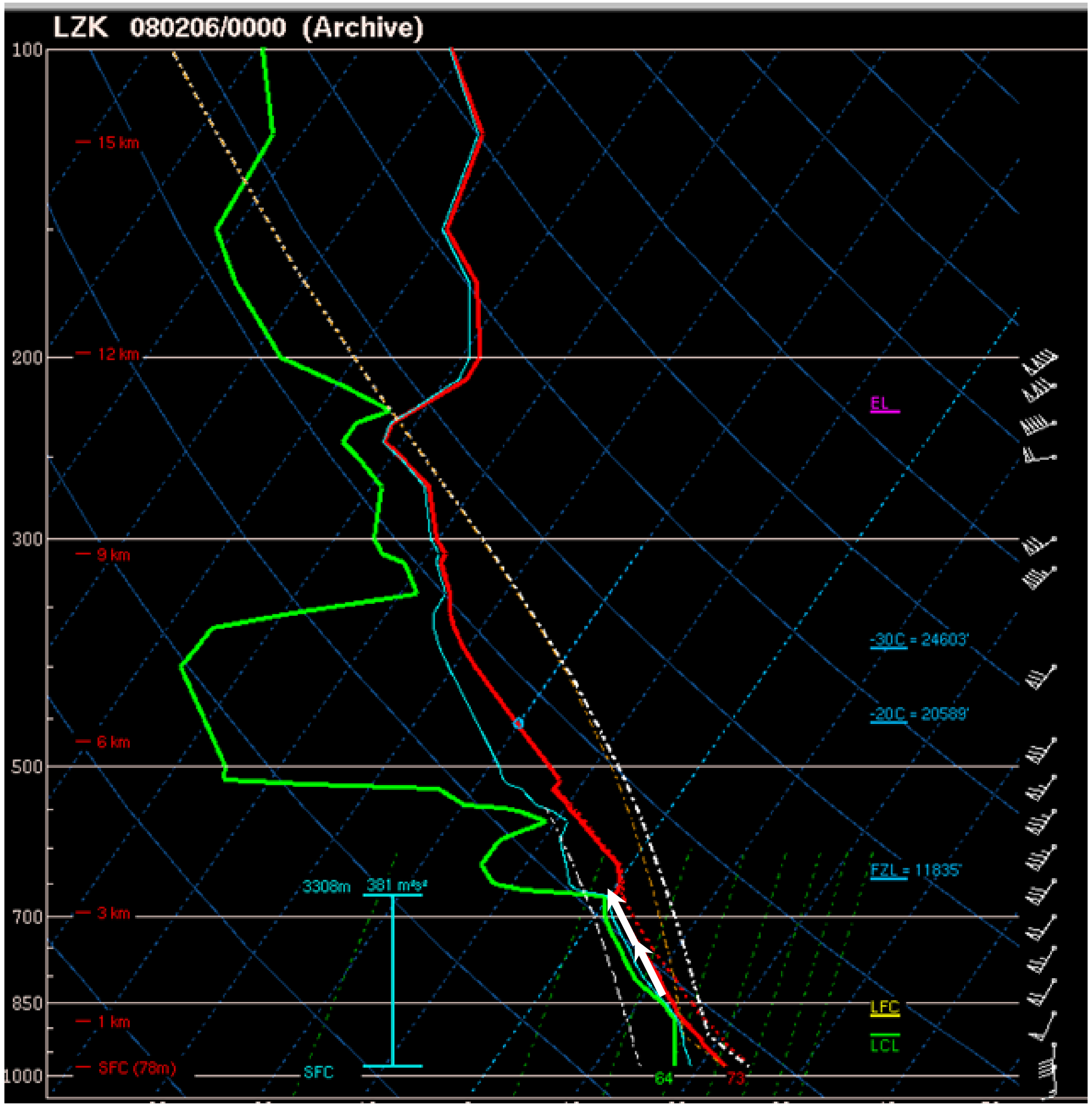
- See moist layer deepen faster than you would expect with just surface heating and mixing
- “Deep” moist layer and horizontal moisture advection both combat vertical mixing driven by surface heating
  - Can see moist layer deepen while dew points increase near surface



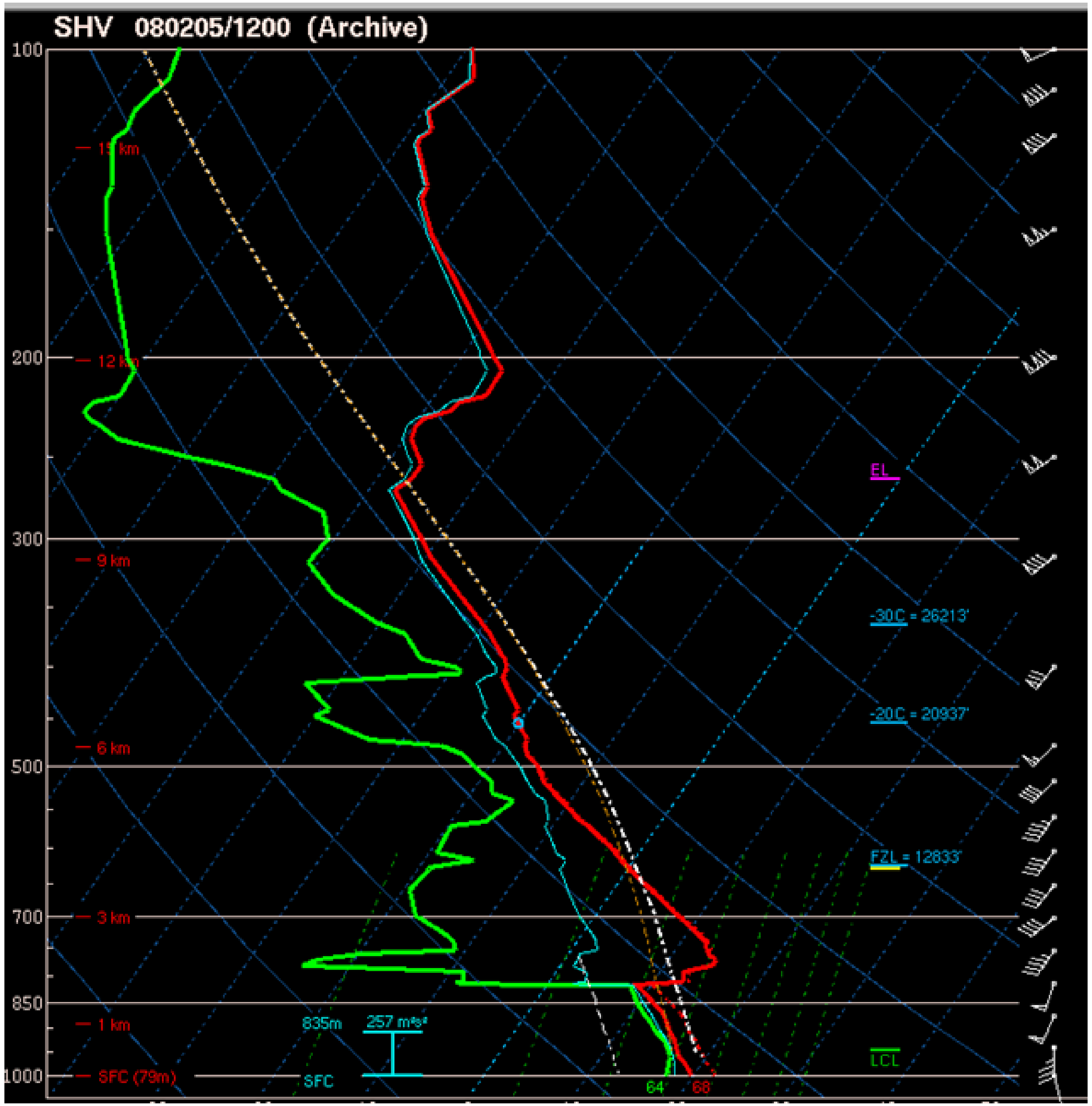
LZK 080205/1200 (Archive)
100
200
300
500
700
850
1000
15 km
12 km
9 km
6 km
3 km
1 km
SFC (78m)
SFC
2255m
231 m²s²
EL
-30C = 25502'
-20C = 20790'
FZL = 11917'
LFC
LCL
63
66

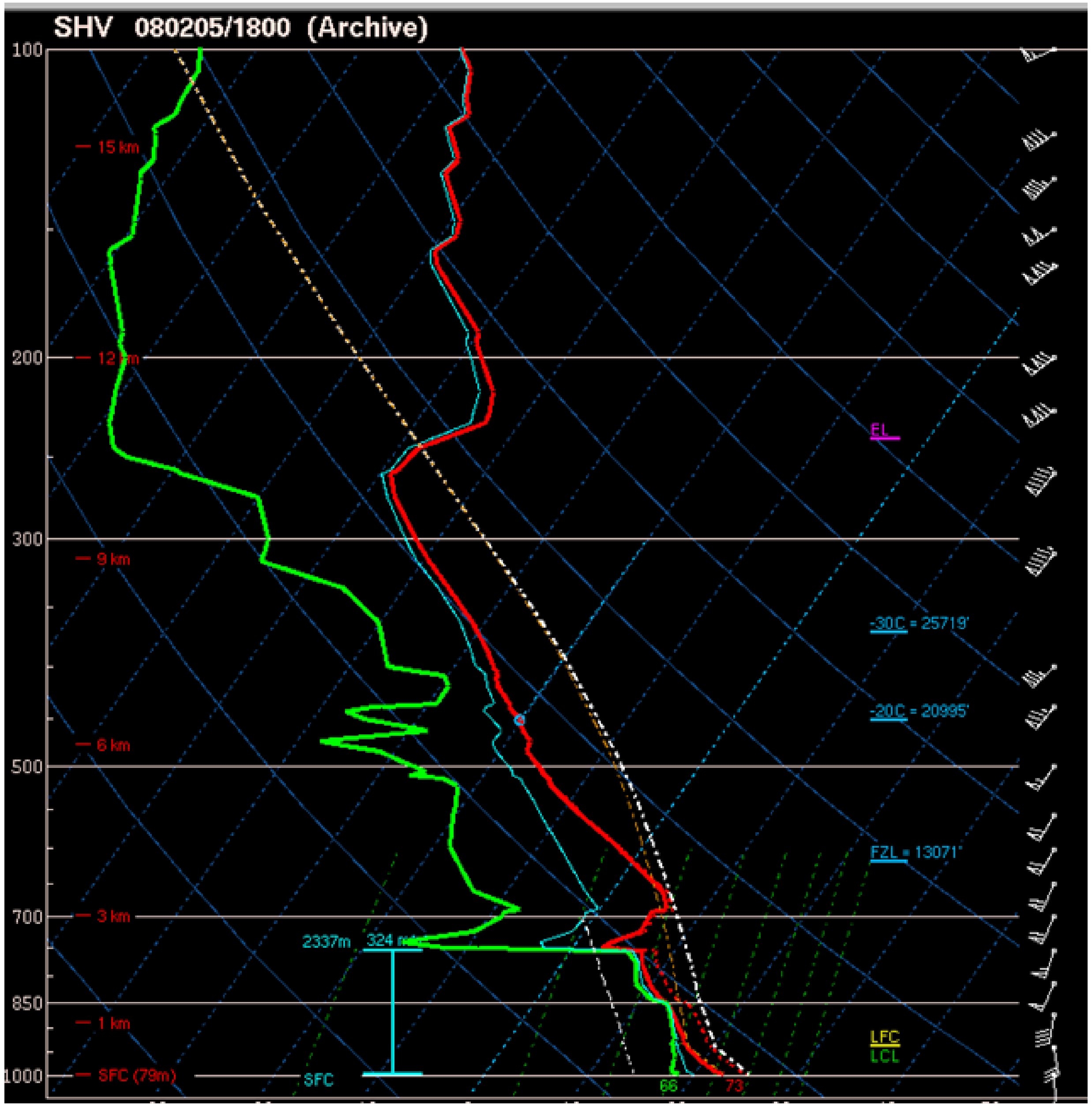


LZK 080205/1800 (Archive)
100
200
300
500
700
850
1000
15 km
12 km
9 km
6 km
3 km
1 km
SFC (78m)
SFC
1751m
202 m²/s²
EL
-30C = 25758'
-20C = 20805'
FZL = 12711'
LFC
LCL
63
70

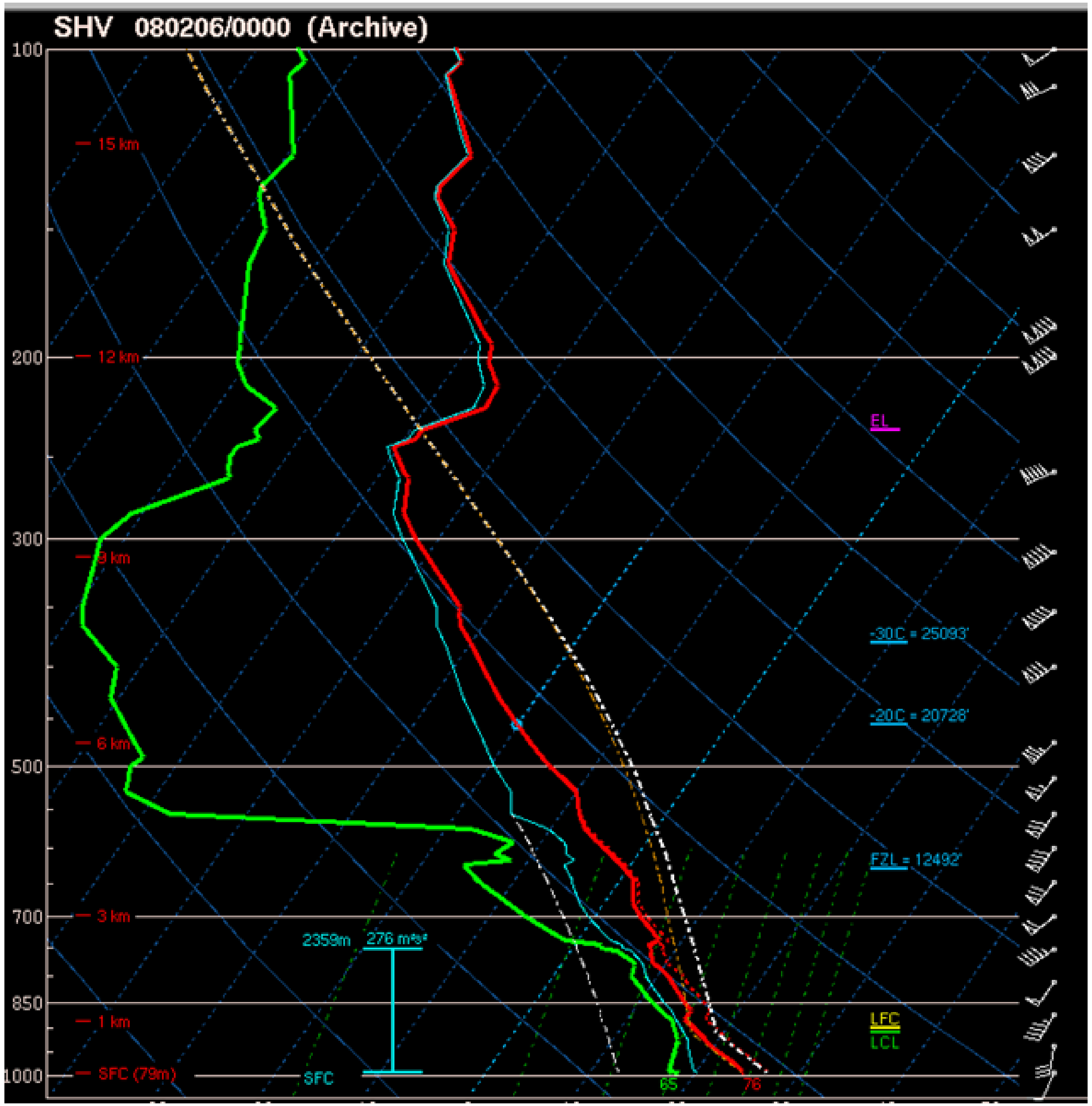


LZK 080206/0000 (Archive)
100
200
300
500
700
850
1000
15 km
12 km
9 km
6 km
3 km
1 km
SFC (78m)
3308m
381
SFC
64
73
EL
-30C = 24603'
-20C = 20589'
FZL = 11835'
LFC
LCL


SHV 080205/1200 (Archive)
100
200
300
500
700
850
1000
15 km
12 km
9 km
6 km
3 km
1 km
SFC (79m)
EL
-30C = 26213'
-20C = 20937'
FZL = 12833'
LCL
835m
257 m²/s²
SFC
64
68



SHV 080205/1800 (Archive)
100
200
300
500
700
850
1000
15 km
12 km
9 km
6 km
3 km
1 km
SFC (79m)
SFC
2337m
324 m
EL
-30C = 25719'
-20C = 20995'
FZL = 13071'
LFC
LCL
66
73



SHV 080206/0000 (Archive)
100
200
300
500
700
850
1000
15 km
12 km
9 km
6 km
3 km
1 km
SFC (79m)
SFC
2359m
276 m²/s²
EL
-30C = 25093'
-20C = 20728'
FZL = 12492'
LFC
LCL
65
76

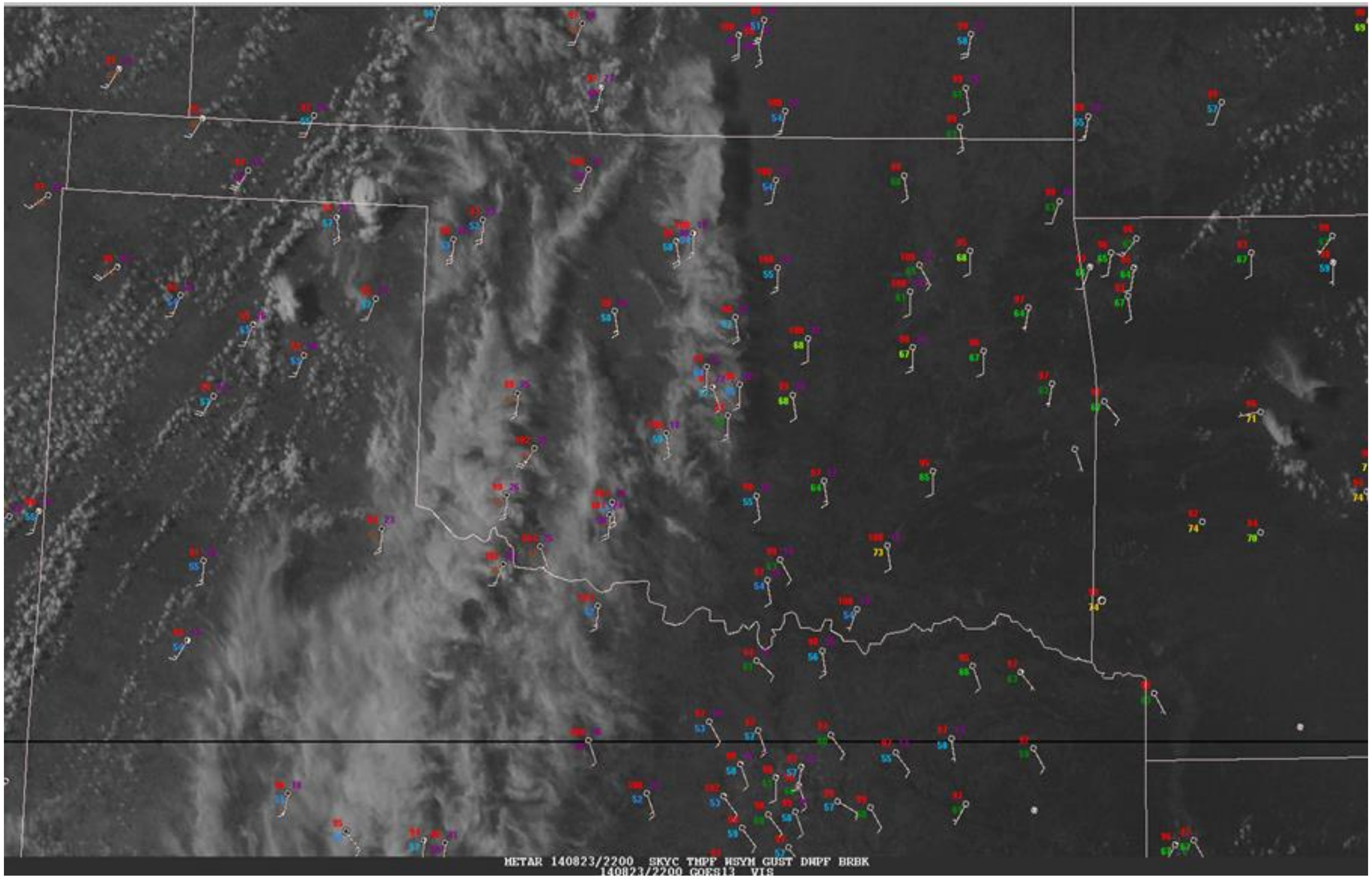
Sounding diagrams are used for…

- Moisture and temperature profiles
- Estimates of CAPE, CIN, Lifted Index, etc.
  - Will storms form?
- Vertical wind shear (material on hodographs to come!)
  - What kind of storms will form?
- Many of your favorite thunderstorm parameters are based in these diagrams, and subject to the same errors and concerns!

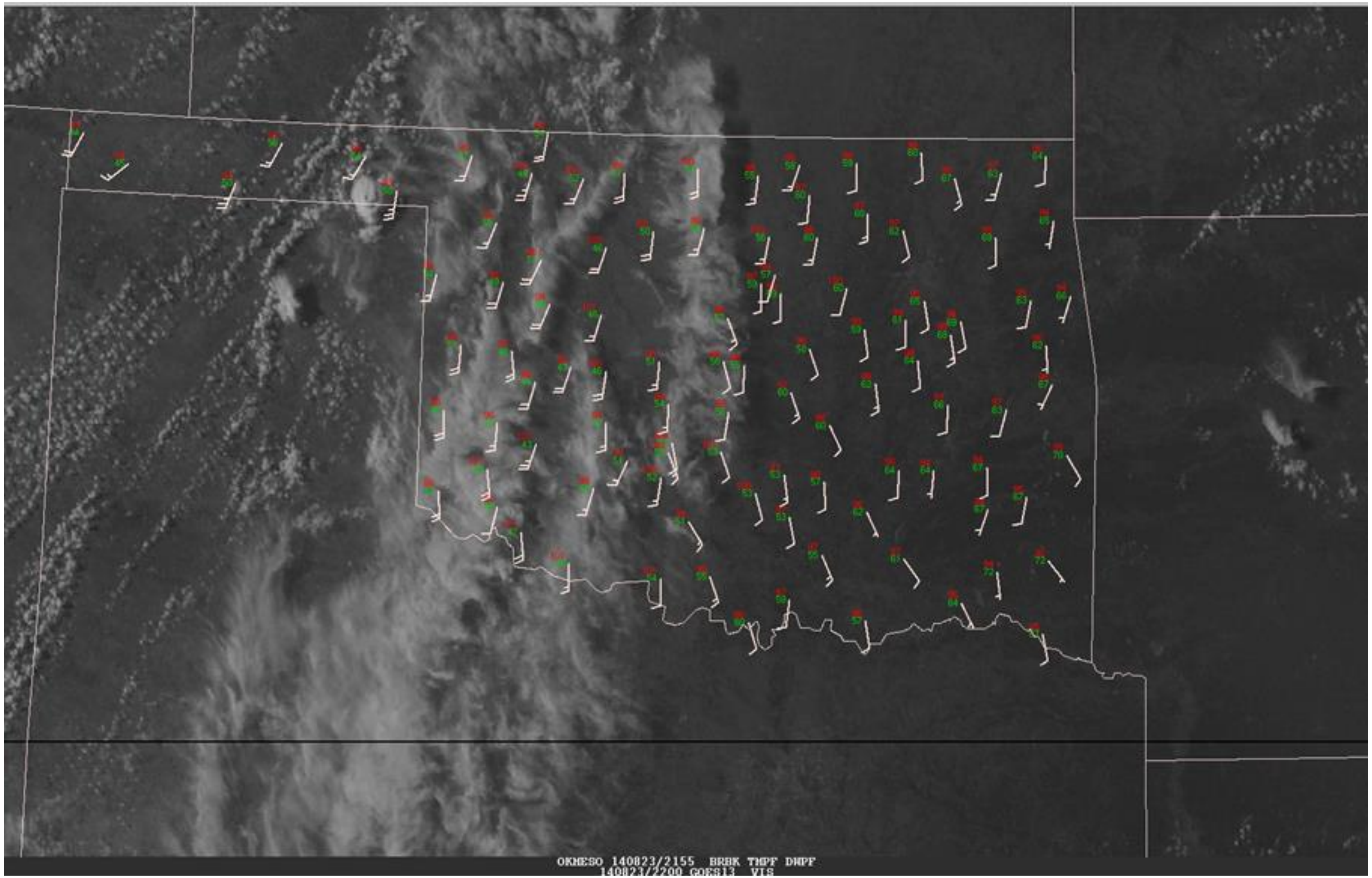
Quality of Surface Observations?

Courtesy of Oklahoma Mesonet

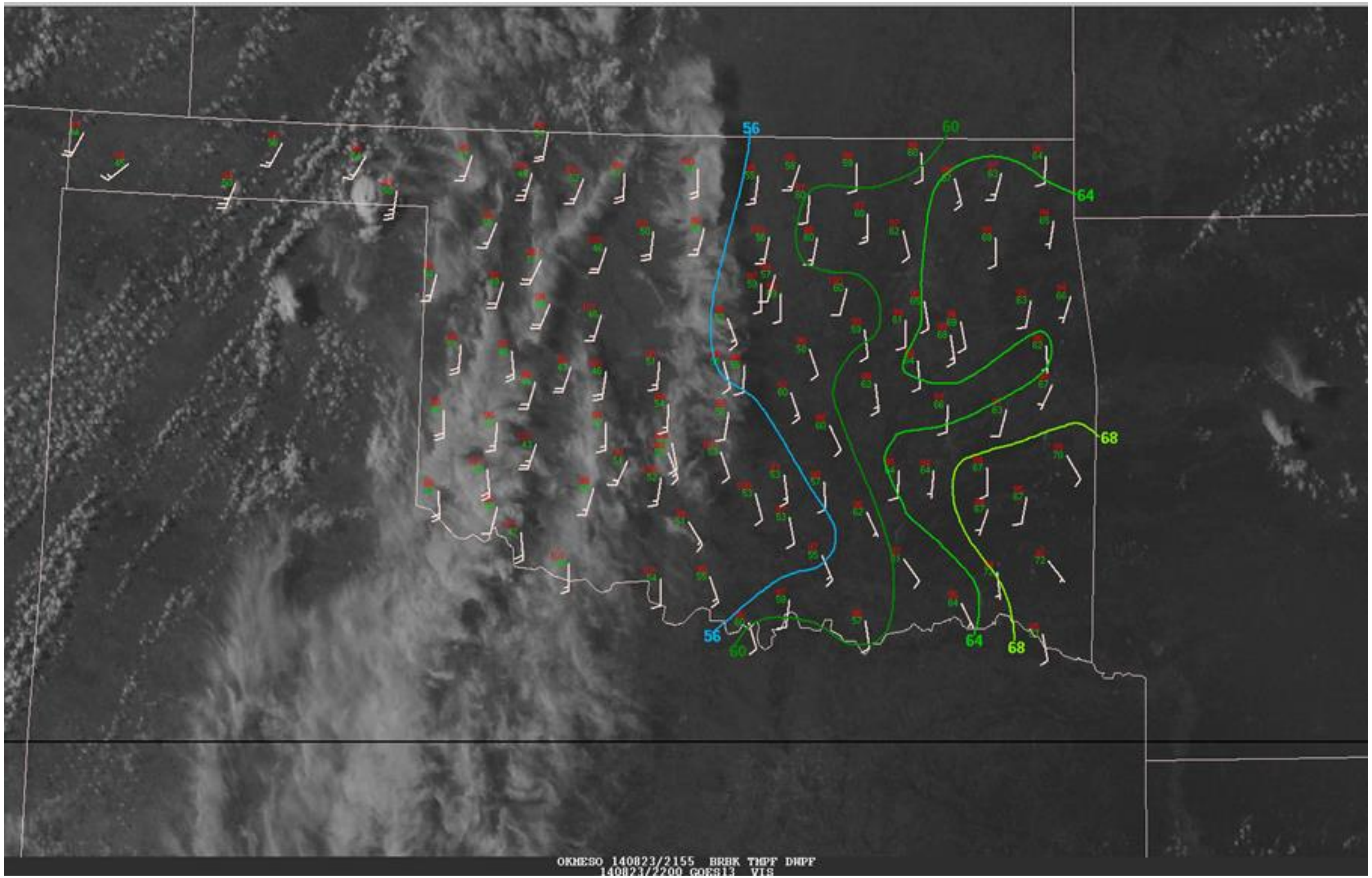
Standard surface observations



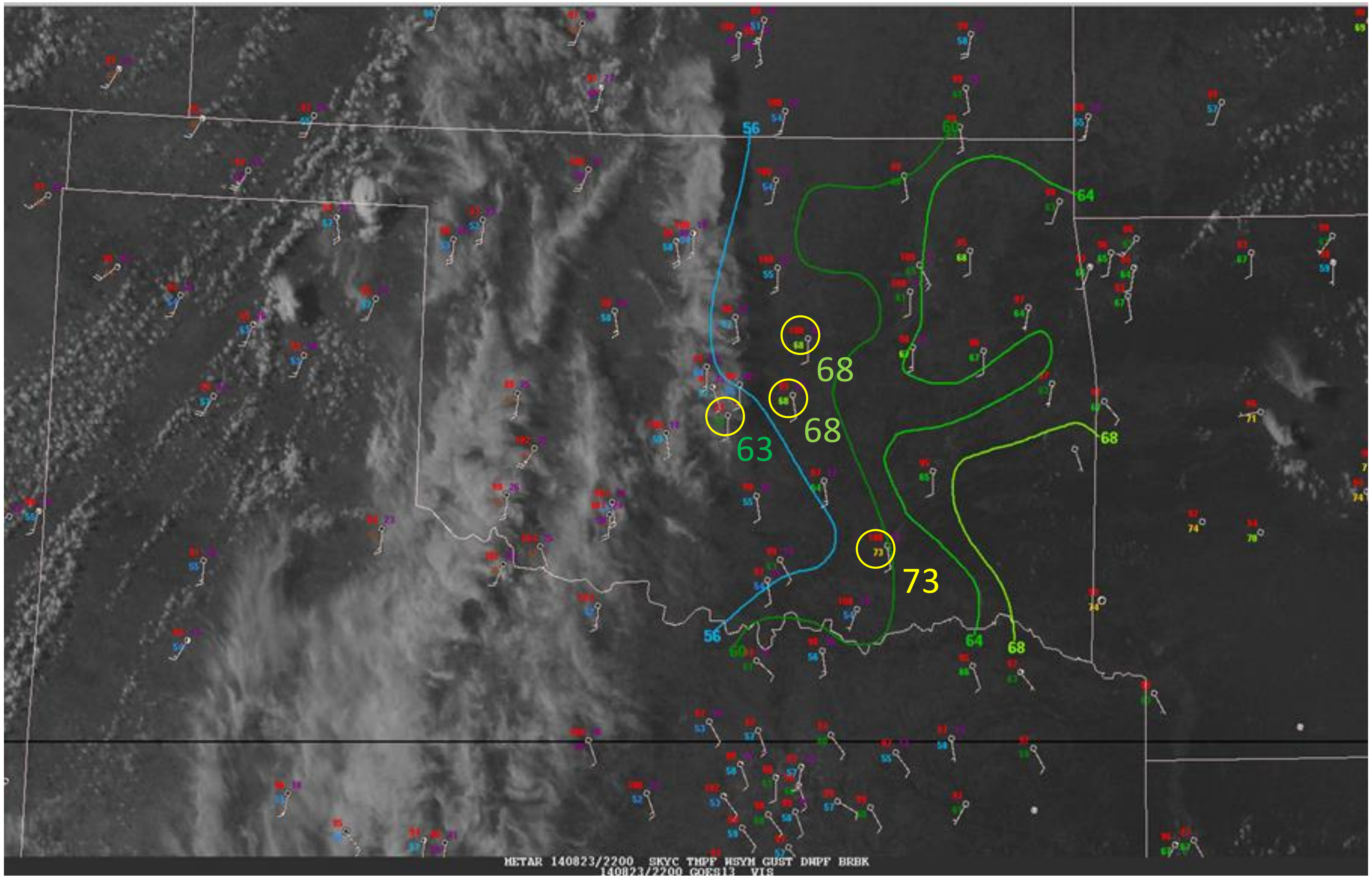
OK mesonet observations at the same time



Dew point analysis for OK mesonet observations



What do these sites have in common?



Parcel Theory

Material prepared by Tom Galarneau

Buoyancy

- **Buoyancy is the upward force arising from the displacement of a fluid by another fluid or object (Archimedes' Principle)**
  - **The upward force is equal to the weight of the displaced fluid**
  - **Buoyancy is the key force for convection! (Supercells are more complicated…)**

- **Vertical momentum equation for convective scales goes as:**

$$\frac{dw}{dt} = -\frac{1}{\rho}\frac{\partial p'}{\partial z} - g\frac{\rho'}{\rho} = -\frac{1}{\rho}\frac{\partial p'}{\partial z} + B \qquad B = -g\frac{\rho'}{\rho} = buoyancy$$

If $\rho' > 0$, parcel is more dense than environment. $\therefore B < 0 \rightarrow \frac{dw}{dt} < 0$

If $\rho' < 0$, parcel is less dense than environment. $\therefore B > 0 \rightarrow \frac{dw}{dt} > 0$

- **B controls the parcel acceleration. So, rising parcels can continue to rise for some time after becoming negatively buoyant (like overshooting top!)**

Buoyancy

- **Write buoyancy in terms of temperature since we measure that**

Using ideal gas law: $B = -g\frac{\rho'}{\bar{\rho}} = g\left(\frac{T_v{}'}{\overline{T_v}} - \frac{p'}{\bar{p}}\right)$

For small mach number: $B = \left|\frac{p'}{\bar{p}}\right| \ll \left|\frac{T_v{}'}{\overline{T_v}}\right|$

$\therefore B = g\frac{T_v{}'}{\overline{T_v}} = g\frac{\theta_v{}'}{\overline{\theta_v}}$

- **Reference state temperature is environment (temperature line on sounding)**

$\therefore B = g\left(\frac{T_{vp} - T_{venv}}{T_{venv}}\right)$

T_{vp} is virtual temperature of air parcel
T_{venv} is virtual temperature of ambient environment

If $T_{vp} < T_{venv}$, parcel is colder than environment. $\therefore B < 0 \rightarrow \frac{dw}{dt} < 0$

If $T_{vp} > T_{venv}$, parcel is warmer than environment. $\therefore B > 0 \rightarrow \frac{dw}{dt} > 0$

Parcel theory

- **We need to be able to determine whether a lifted parcel has buoyancy**

- **Convective available potential energy (CAPE) tells us the kinetic energy a parcel may gain due to buoyant acceleration**

$$CAPE = \int_{LFC}^{EL} B\,dz$$

Vertical integration of buoyancy from LFC to EL.

Caveats: CAPE>0 does not guarantee convection.
Not all parcels have an LFC.

- **Convective inhibition (CIN) tells is the work done by a parcel against stable stratification to reach its LFC**

$$CIN = -\int_{0}^{LFC} B\,dz$$

Vertical integration of buoyancy from ground to EL.

Need to overcome CIN to trigger convection.

Theoretical Maximum Updraft Speed

- **Parcel theory can be used to estimate w_{max} from buoyancy alone**

- **Manipulate vertical momentum equation ($\frac{dw}{dt} = B$) for parcel theory**

$$w_{max} = \sqrt{2 * CAPE}$$

1000 J kg^{-1} CAPE → 45 m s^{-1} updraft (??)

STORM UVV (m/s)	
40 or less	Regular updraft
41 to 60	Strong updraft
61 to 80	Very strong updraft
81 or greater	Extreme updraft

- **Theoretical updraft speeds based on CAPE seem large – what factors counteract buoyant accelerations for air parcels?**

One can relate CIN to a vertical velocity, w_{lift}, or the estimated amount of lifting required to overcome the negative area by the following expression:

$$W_{lift} = \sqrt{2 * CIN}$$

Summary

- **Parcel theory overestimates updraft speed**
  - **Vertical PGF limits updraft speed; significant for wide updrafts**
  - **Entrainment limits updraft speed; significant for narrow/tilted updrafts**
  - **Hydrometeor loading also limits updraft speed**

Bryan and Weisman 2000