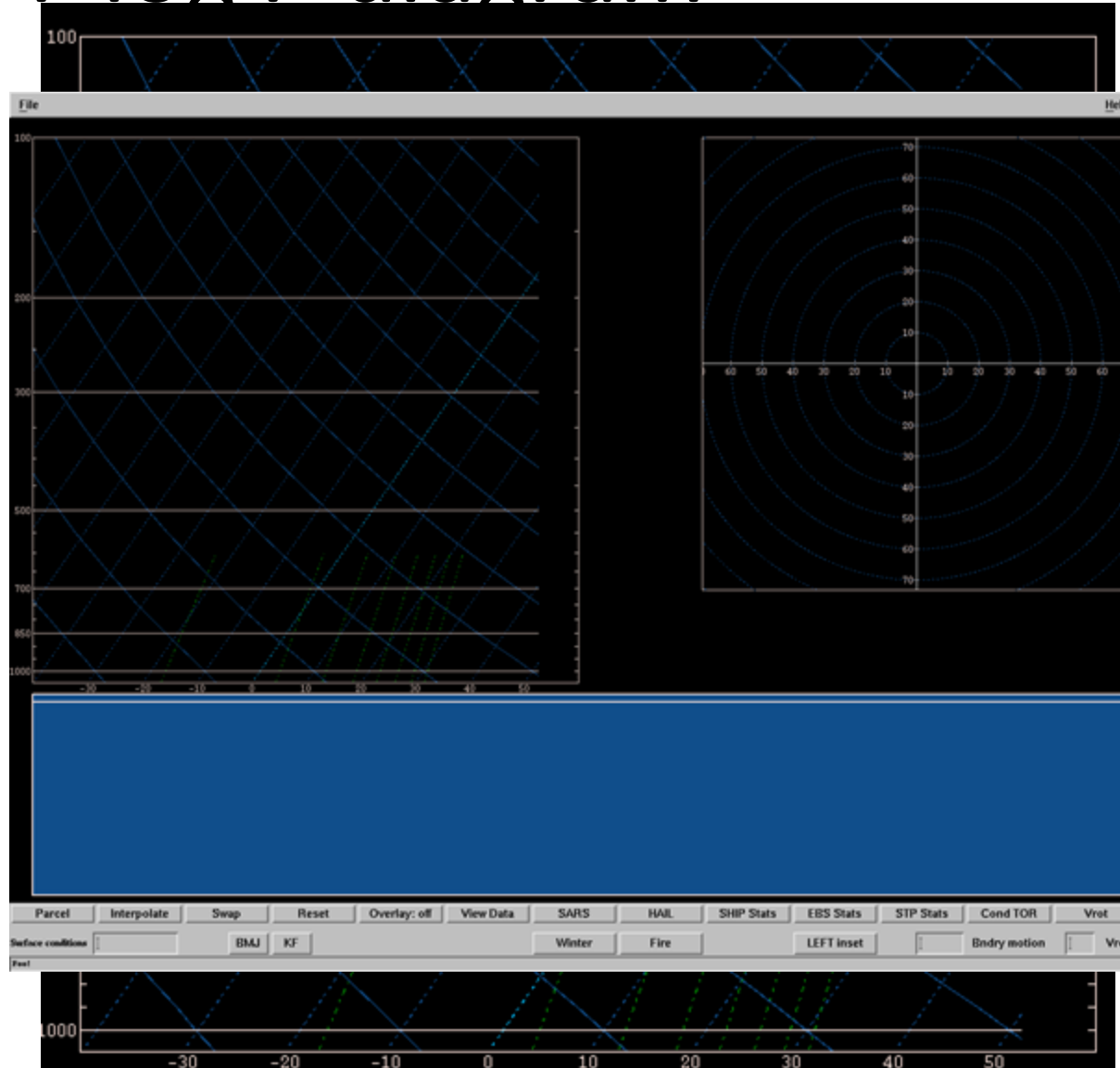


# Skew-T Diagram Basics

METR 4403/5403 – Spring 2021

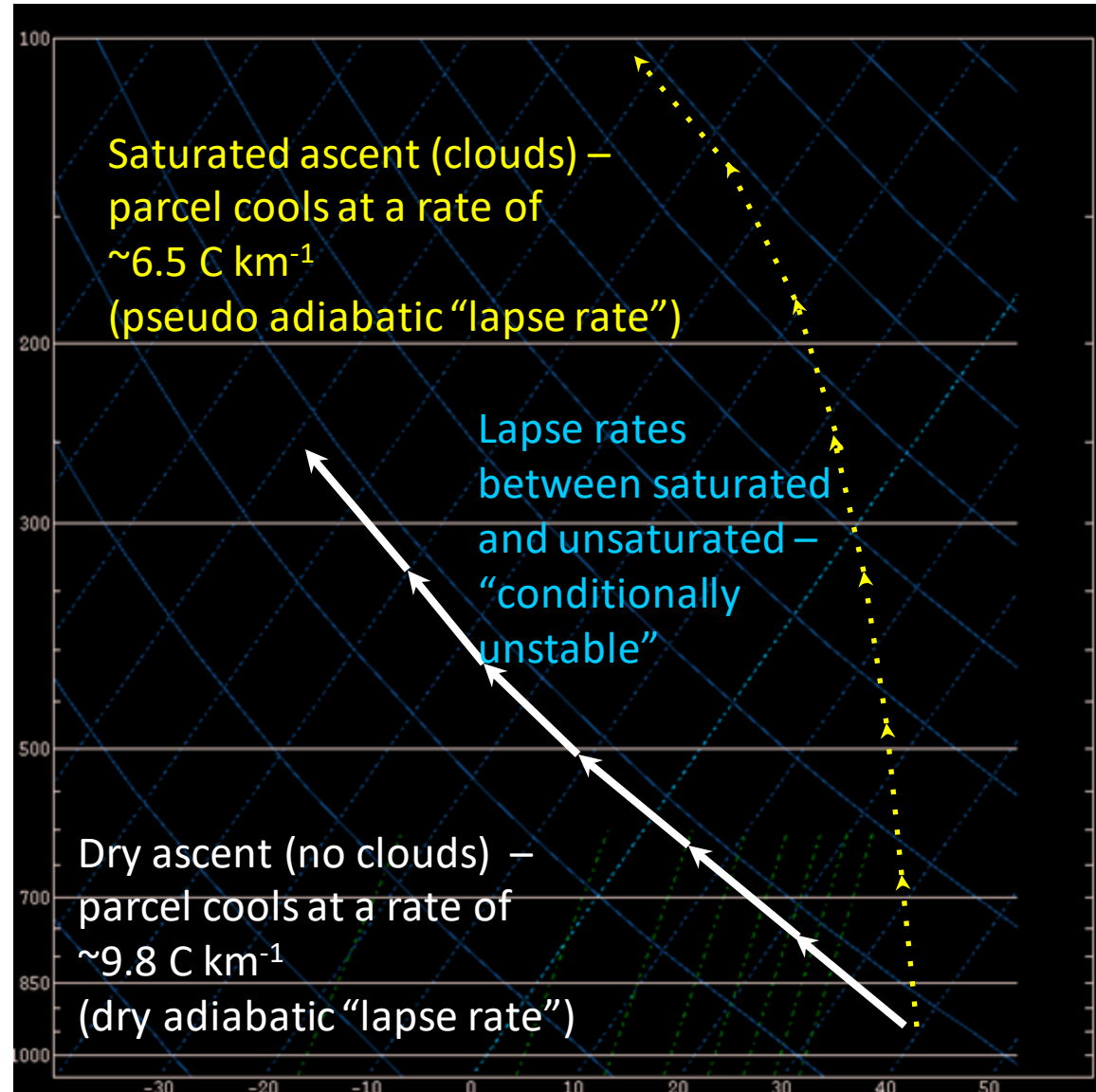
Material originally prepared by Rich Thompson

# Raw SkewT-log P diagram



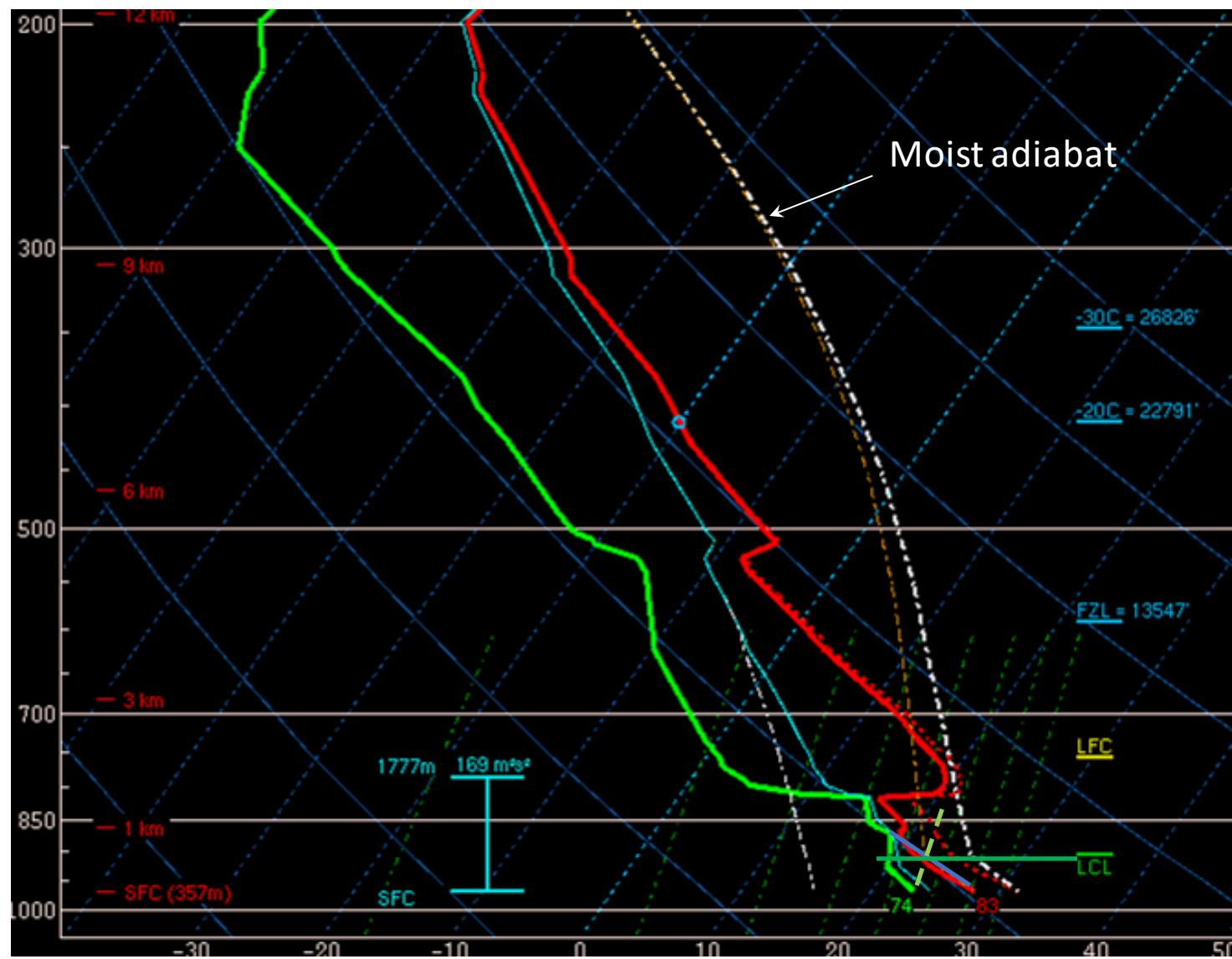
# Features of note in SkewT log P

- Temperature is **skewed** about  $90^\circ$  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



# Lifted Parcel (chunk of air)

- Begin at lifted parcel level (ground)
- Rise “dry adiabatically” until saturation
  - Where dry adiabat crosses mixing ratio
  - We call this the “lifting condensation level” or **LCL**
  - First guess at cloud base



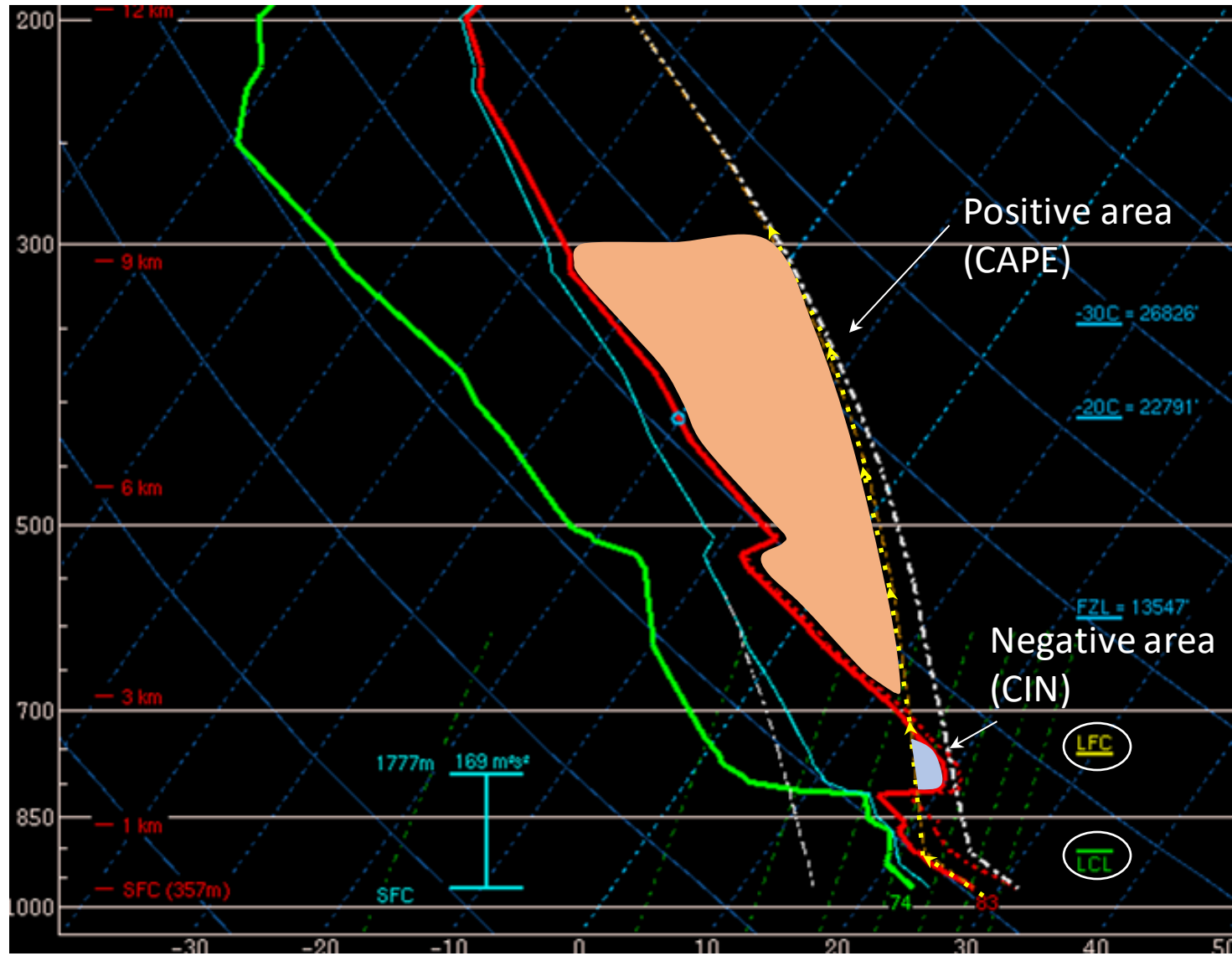
# Illustration of lifted parcel

- From LCL, rise “moist adiabatically” to “level of free convection” or **LFC**
  - “Free convection” begins where lifted parcel becomes warmer than environment
  - Energy resisting lift below LFC is known as “convective inhibition” or **CIN**
- From LFC, continue up to the “equilibrium level” or **EL**. Accumulated area (energy) from LFC to EL is known as **CAPE**
  - “Overshoot” above EL

# Common Sounding Terms

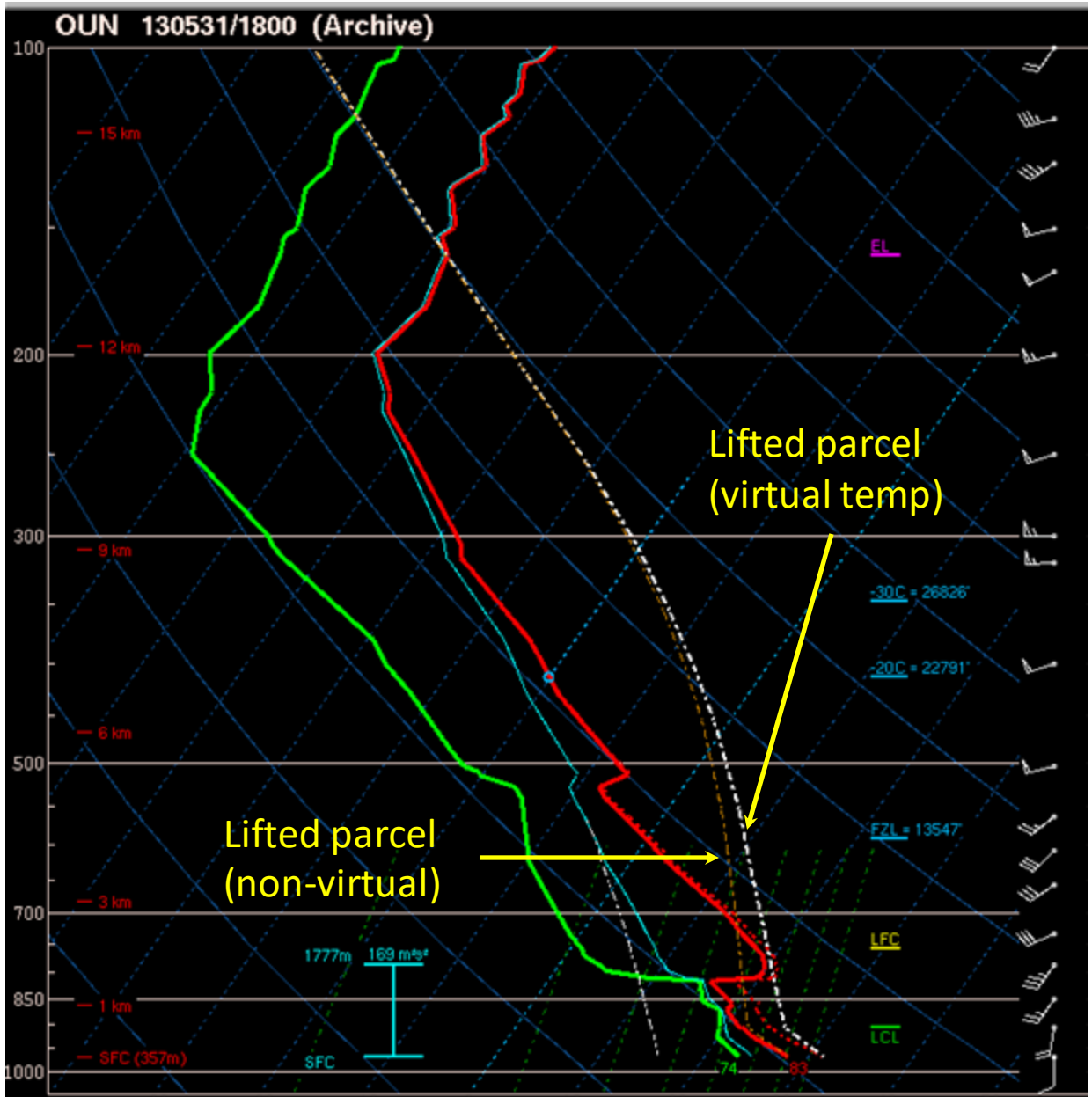
- Lapse rate – change in temperature with height
  - Dry adiabat  $\approx 9.8 \text{ C km}^{-1}$
  - Moist adiabat  $\approx 6.5 \text{ C km}^{-1}$
- Conditional instability – lapse rate between dry and moist adiabatic
- **LCL** – lifting condensation level
- **LFC** – level of free convection
- **EL** – equilibrium level
- **CAPE** – buoyancy (positive area)
- **CIN** – convective inhibition (negative area)

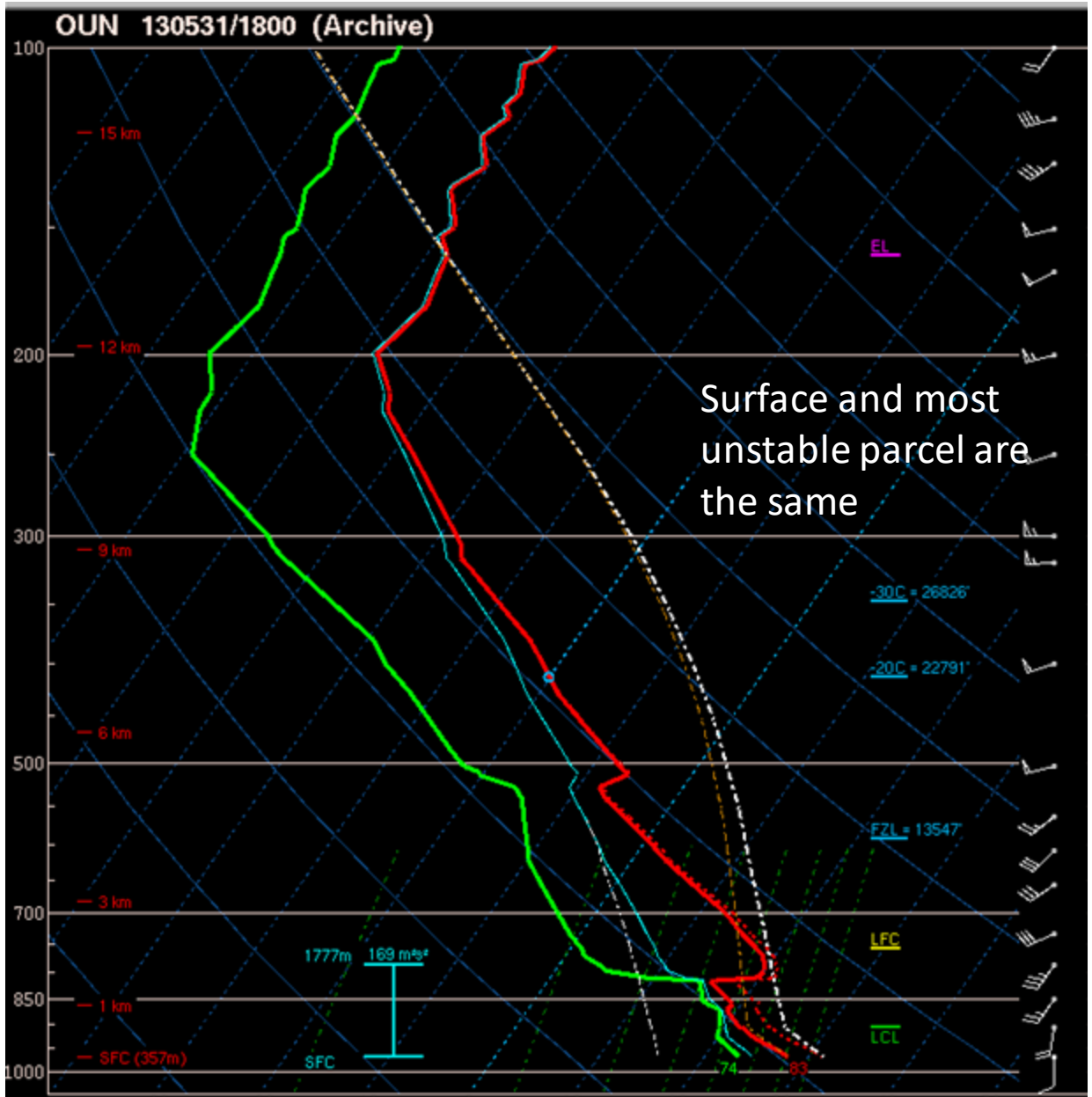


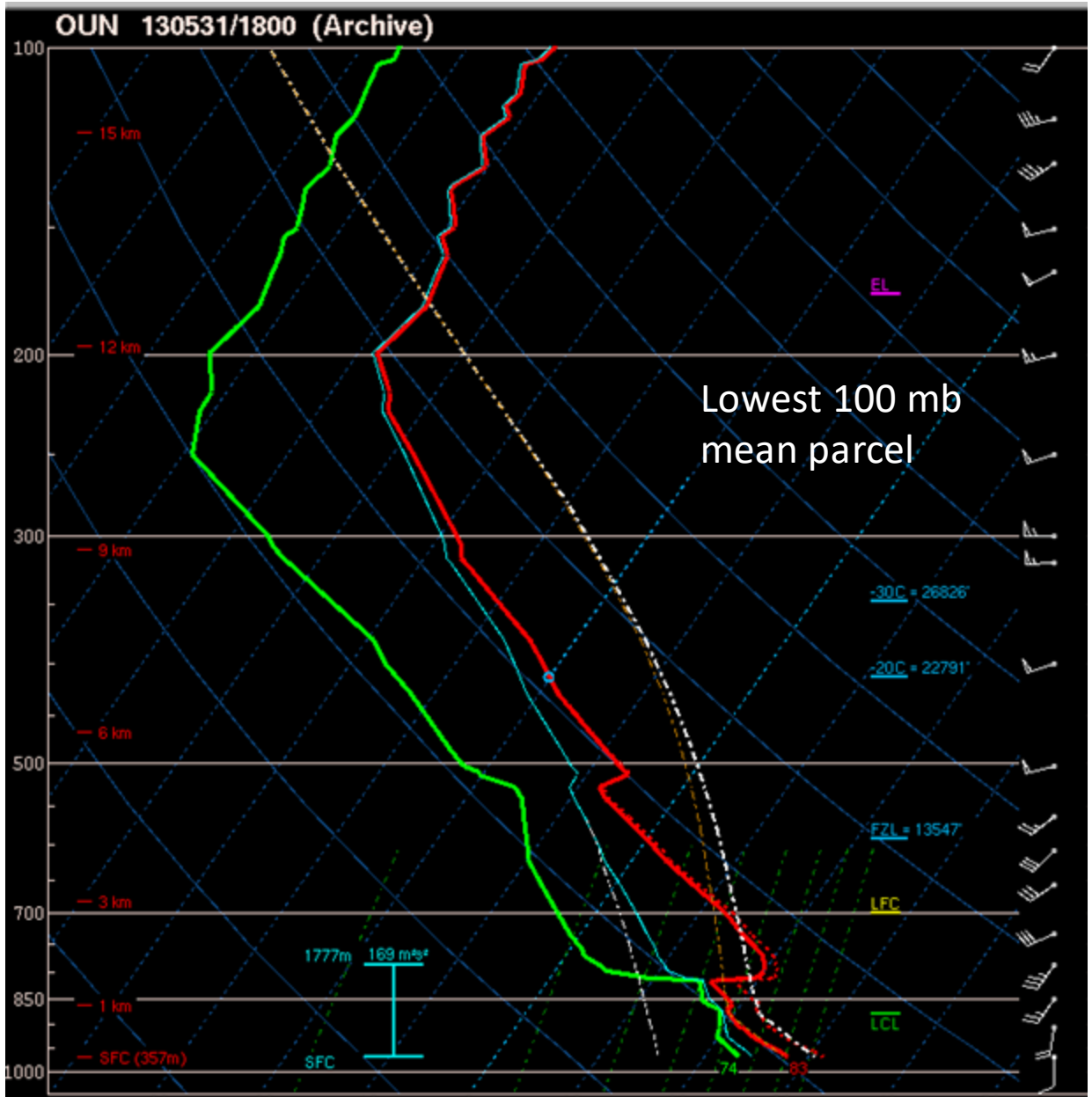


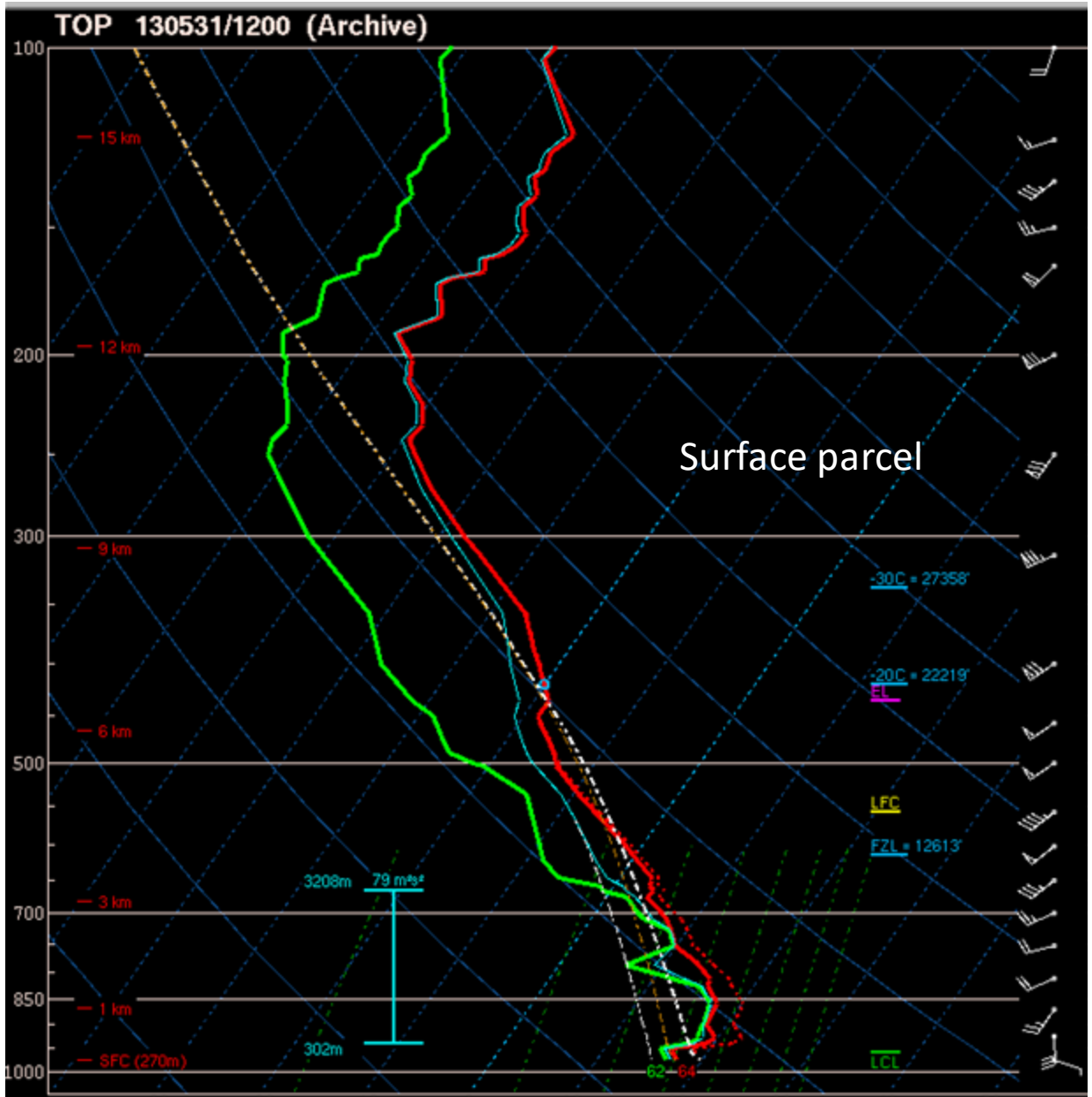
# What's the difference between the lifted parcels?

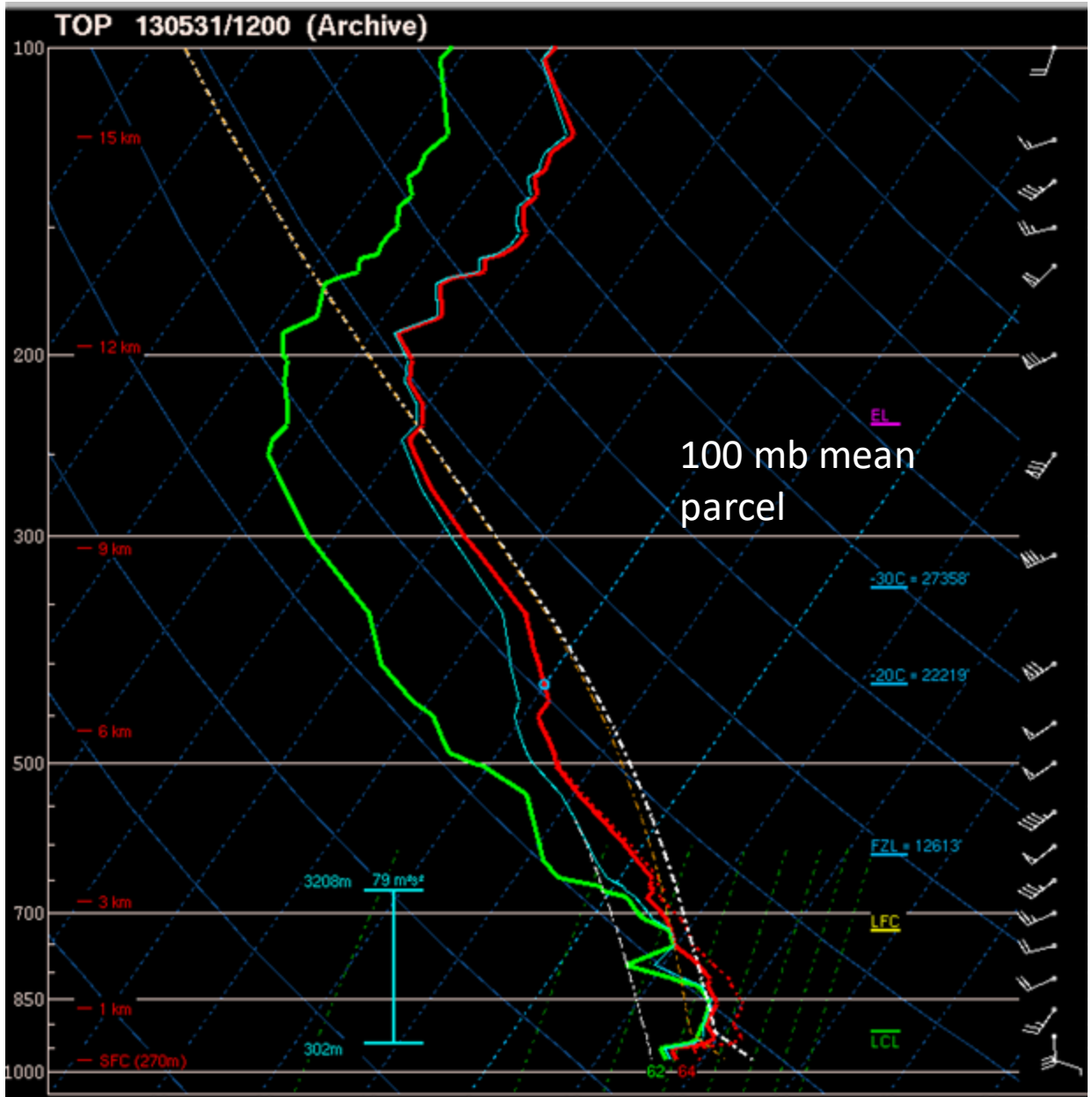
- Virtual temperature accounts for moisture
  - Warmer than measured temperature
  - Makes most difference with tropical moisture
- Virtual temperature correction increases CAPE and reduces CIN
- Which chunk of air to lift?
  - Some sort of averaging is usually more representative
  - Surface vs. “mixed layer” or “most unstable”

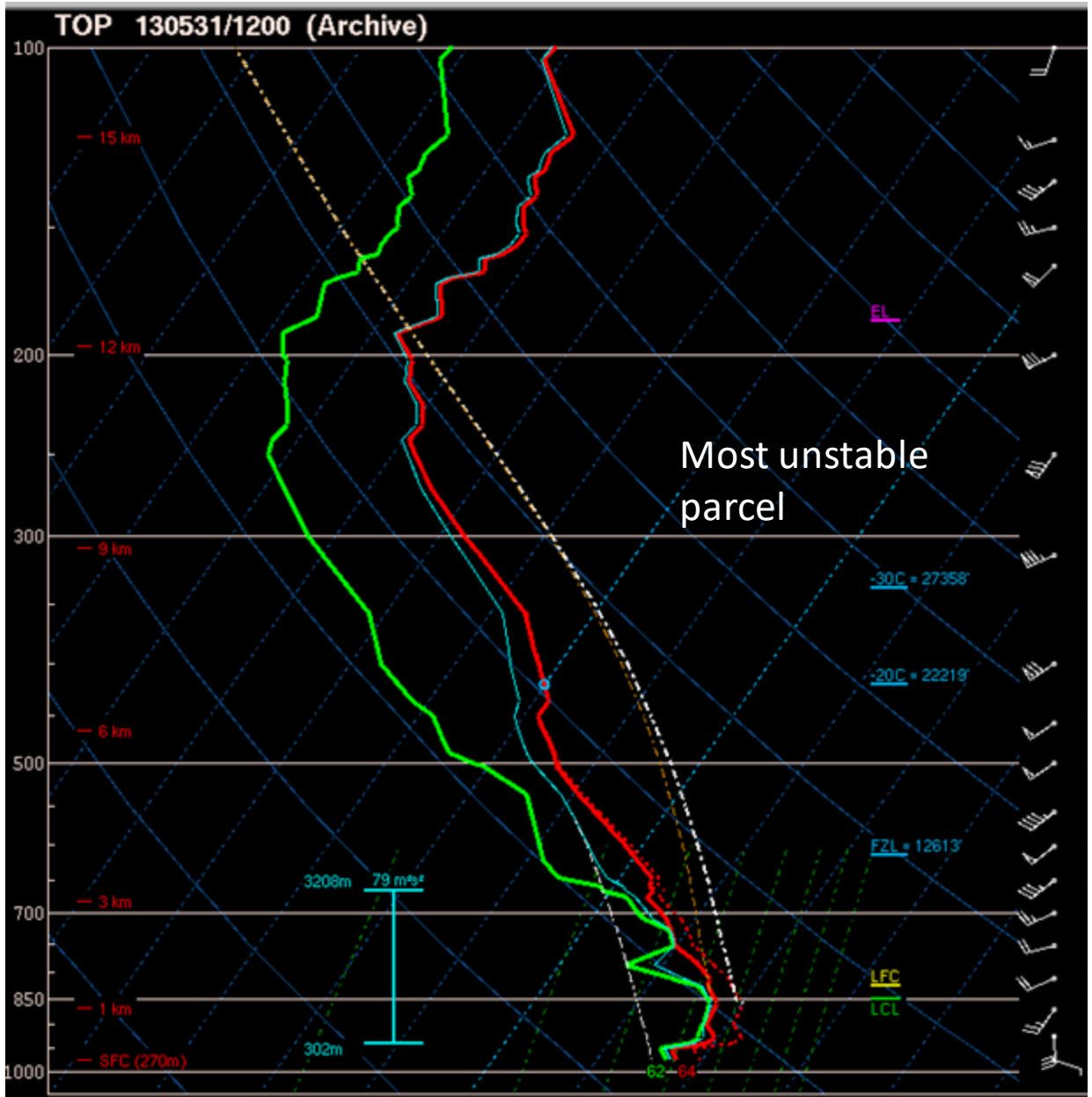














# What are we assuming?

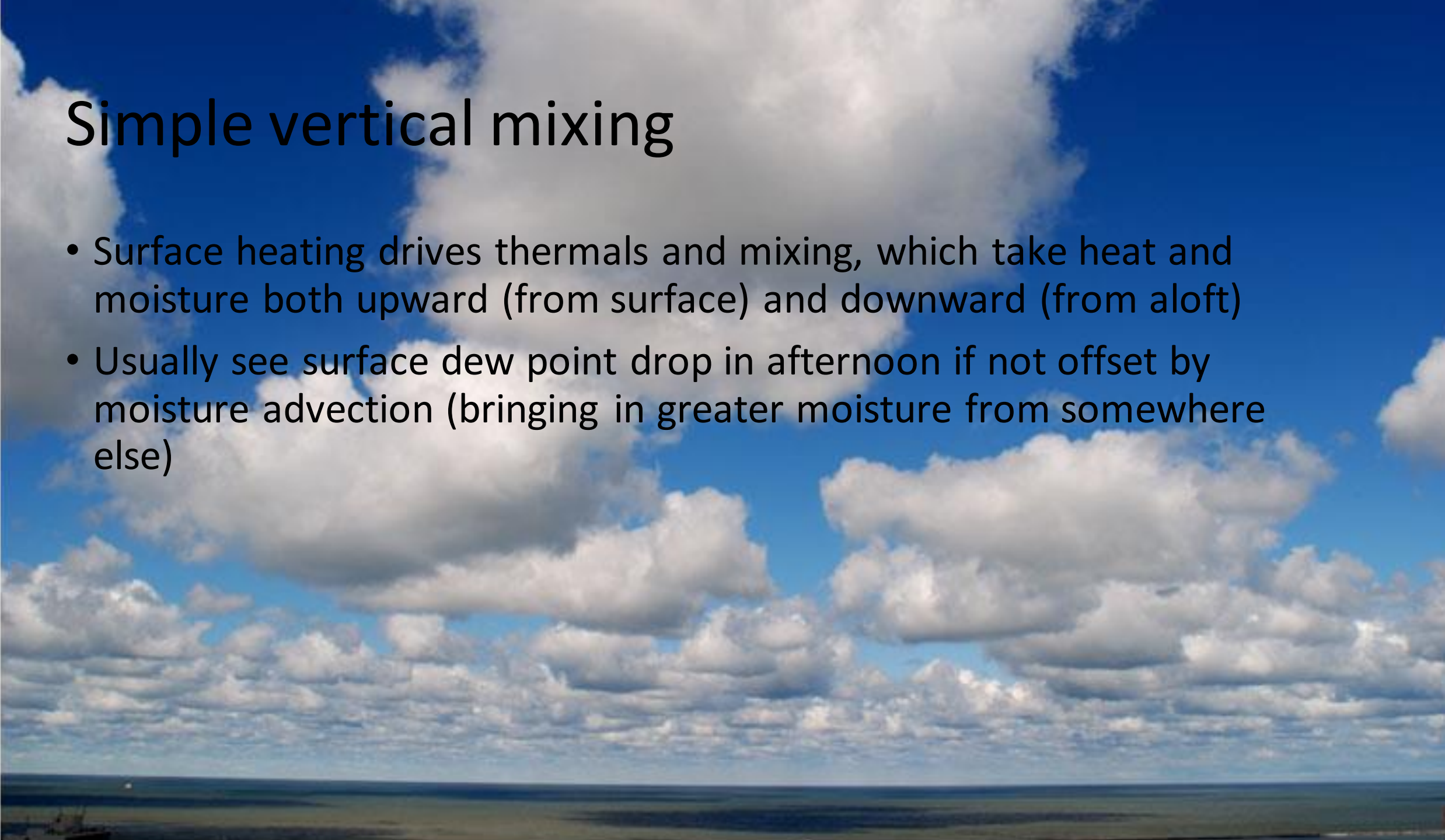
- No mixing with environment (not true)
  - “entrainment” usually reduces updraft strength from expectations based on CAPE alone
- All rain falls out instantly (not true)
  - Suspended rain particles reduces updraft strength
  - That’s why we say “pseudo” adiabatic for saturated parcel ascent
- “Parcel Theory” is a first guess at a complicated process!

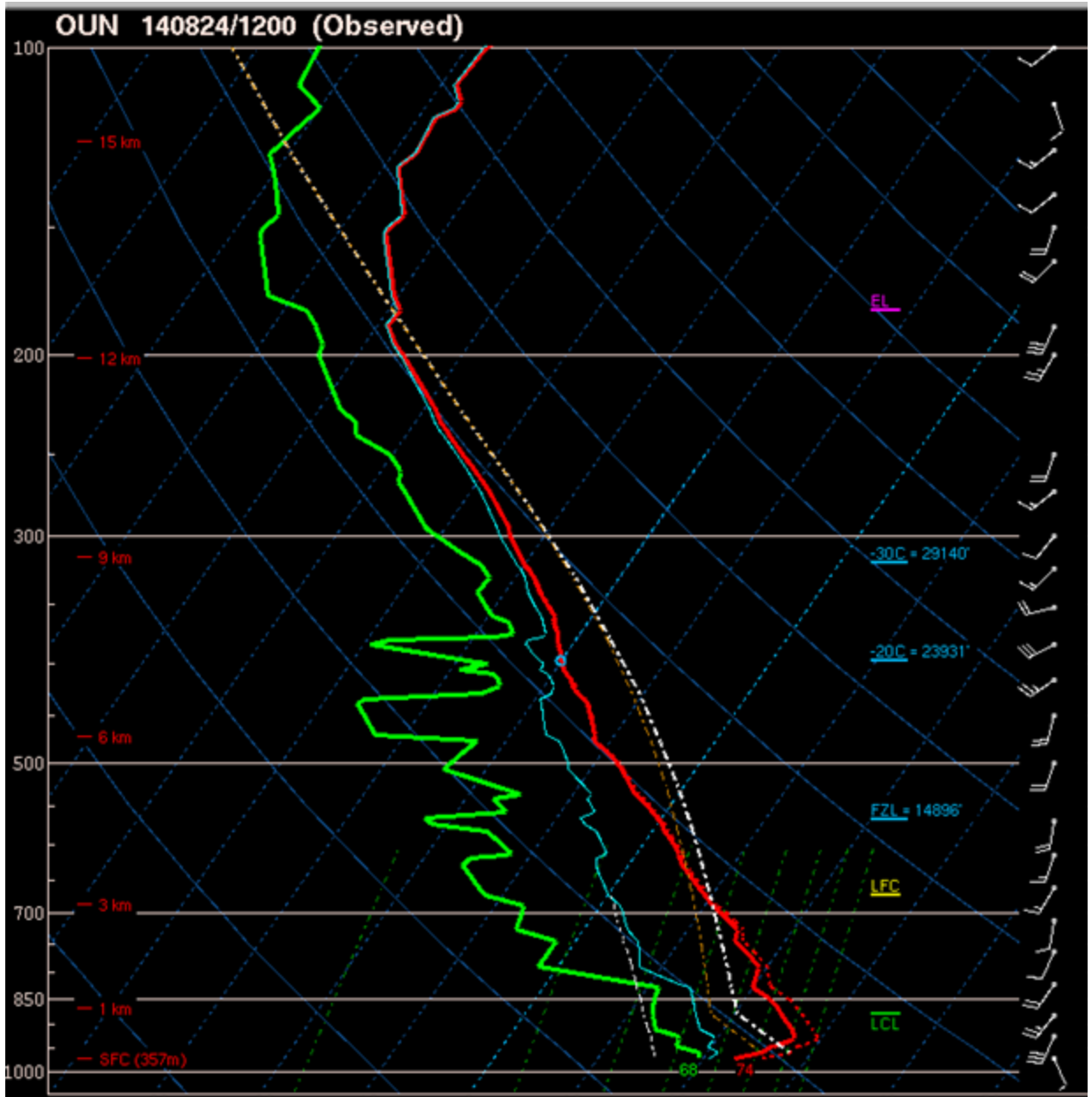
# Always keep in mind what we don't know:

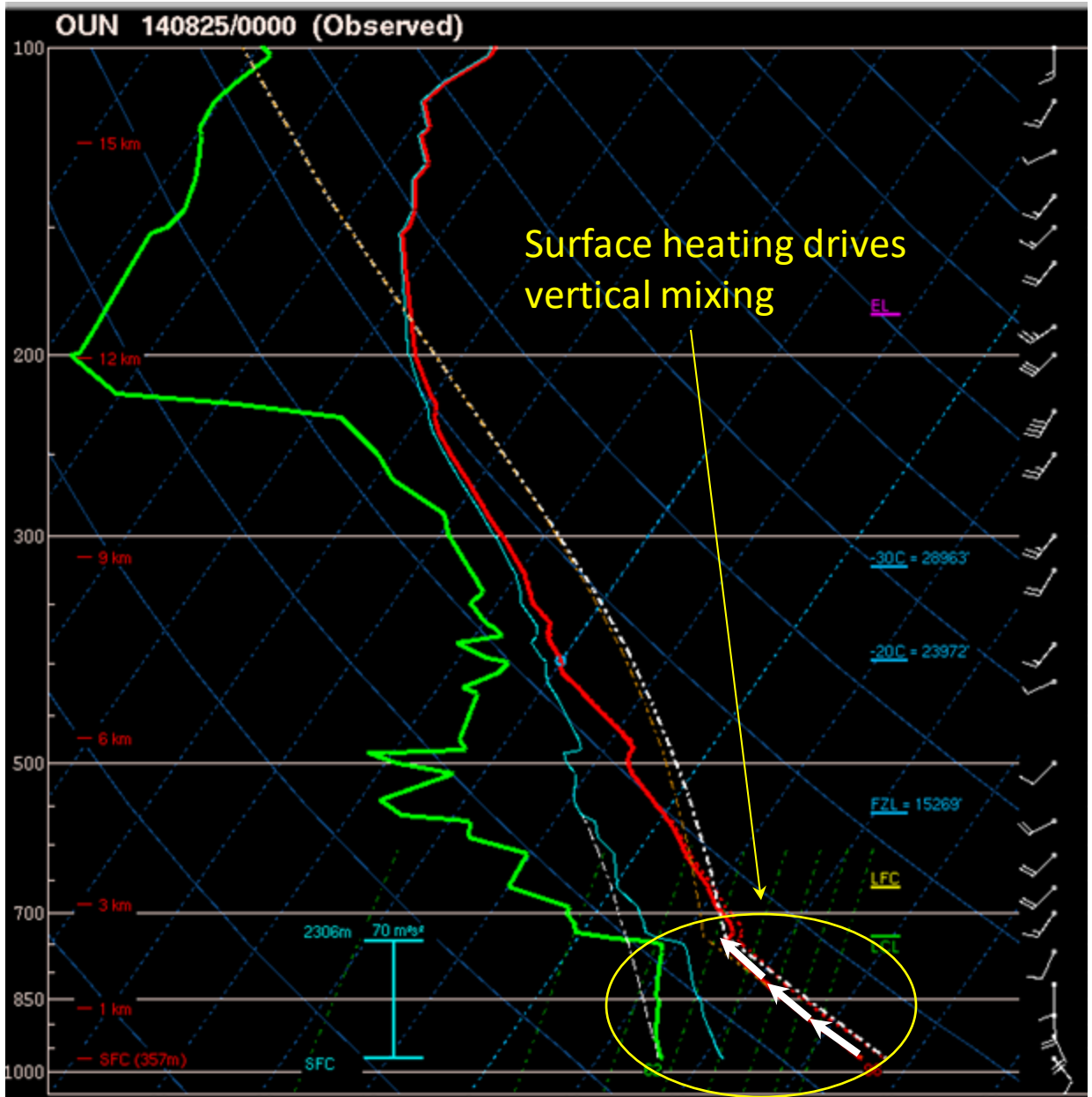
- Uncertainty in observations
  - “Good” measurements?
  - Do they represent what we're trying to forecast?
- Unknown details with lifted parcels
  - What is right layer to view?
  - What assumptions are valid, and which might be terribly wrong?
- Lots of room for error, but the concepts are useful!

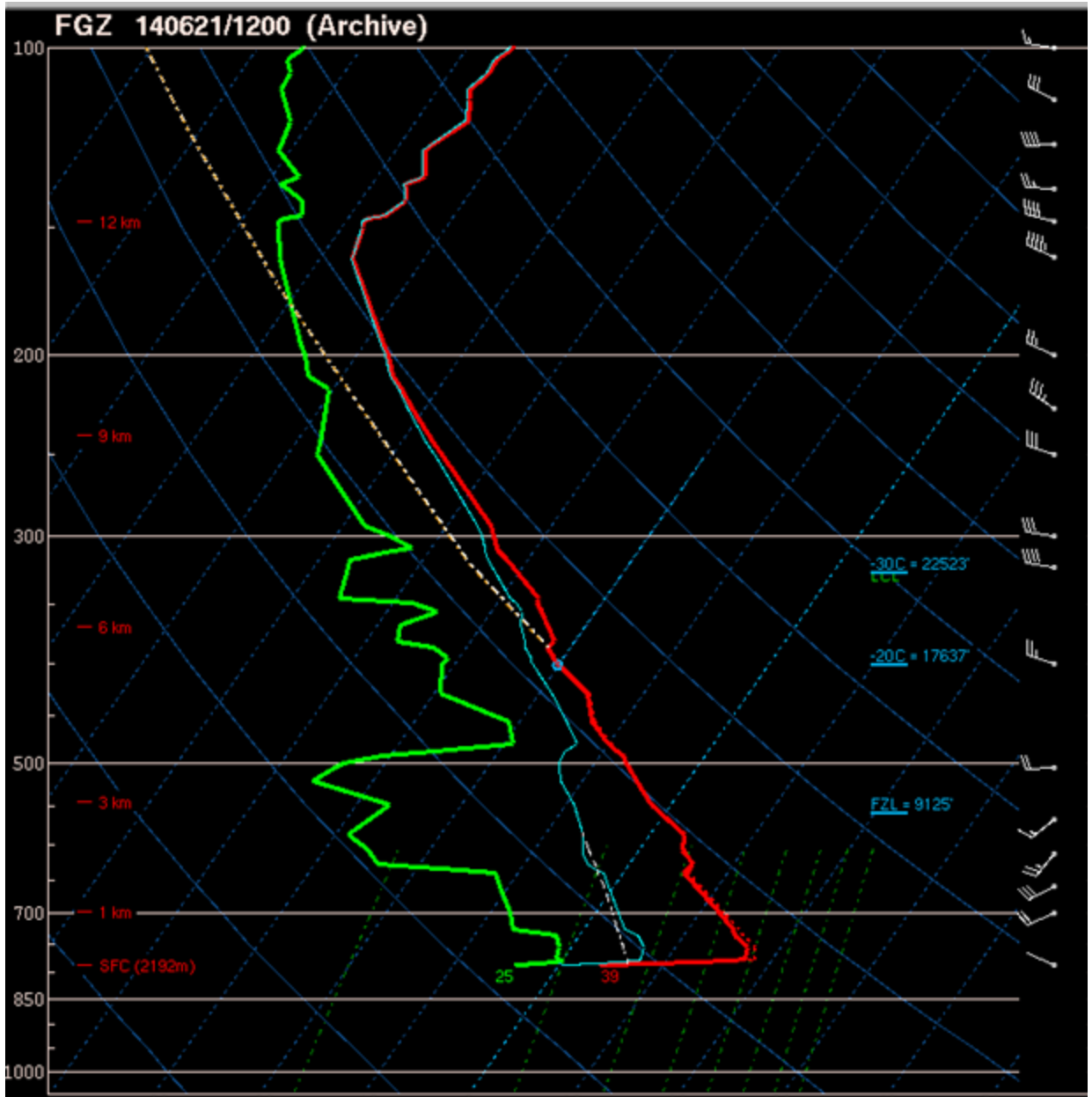
# Simple vertical mixing

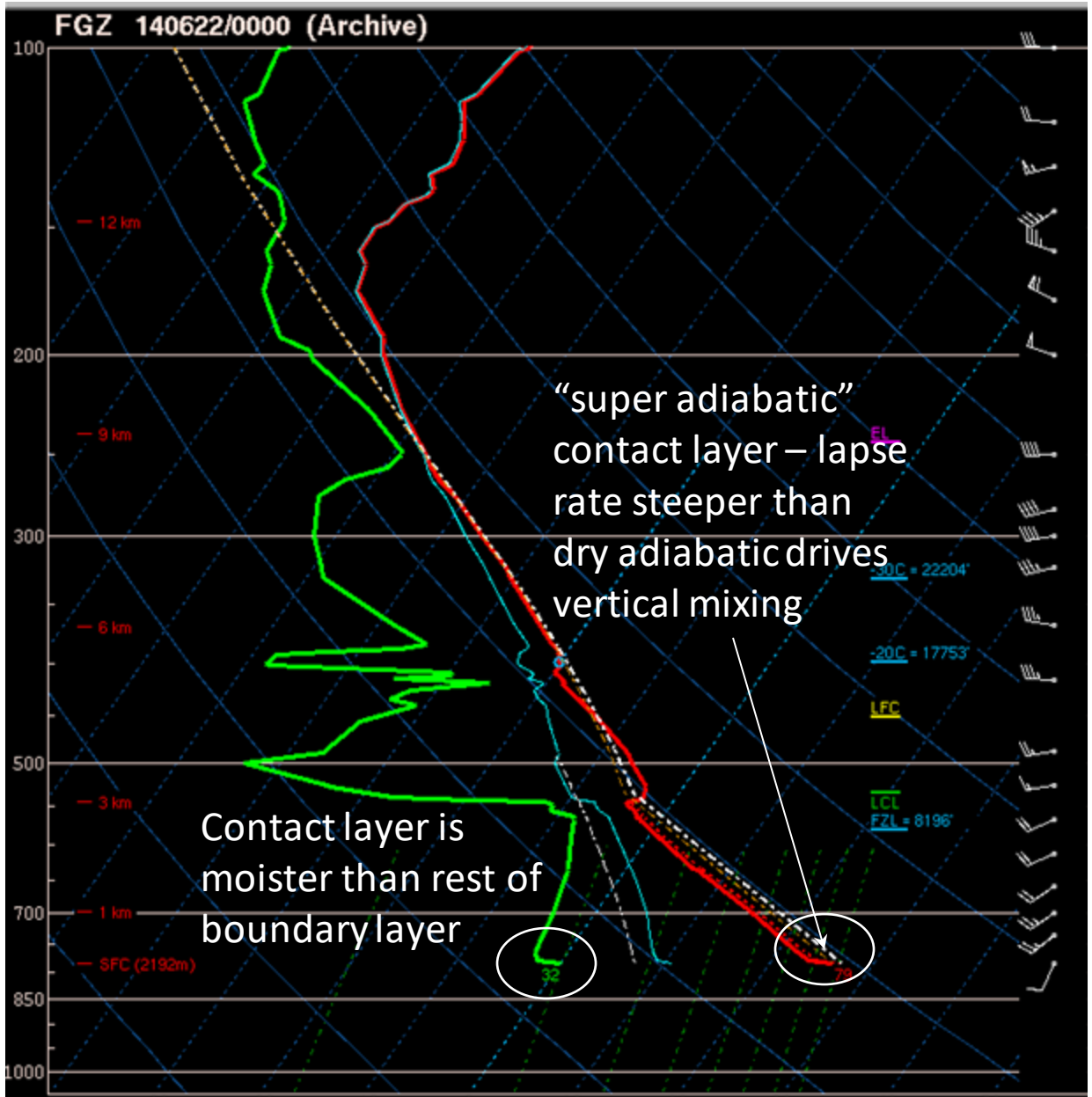
- Surface heating drives thermals and mixing, which take heat and moisture both upward (from surface) and downward (from aloft)
- Usually see surface dew point drop in afternoon if not offset by moisture advection (bringing in greater moisture from somewhere else)







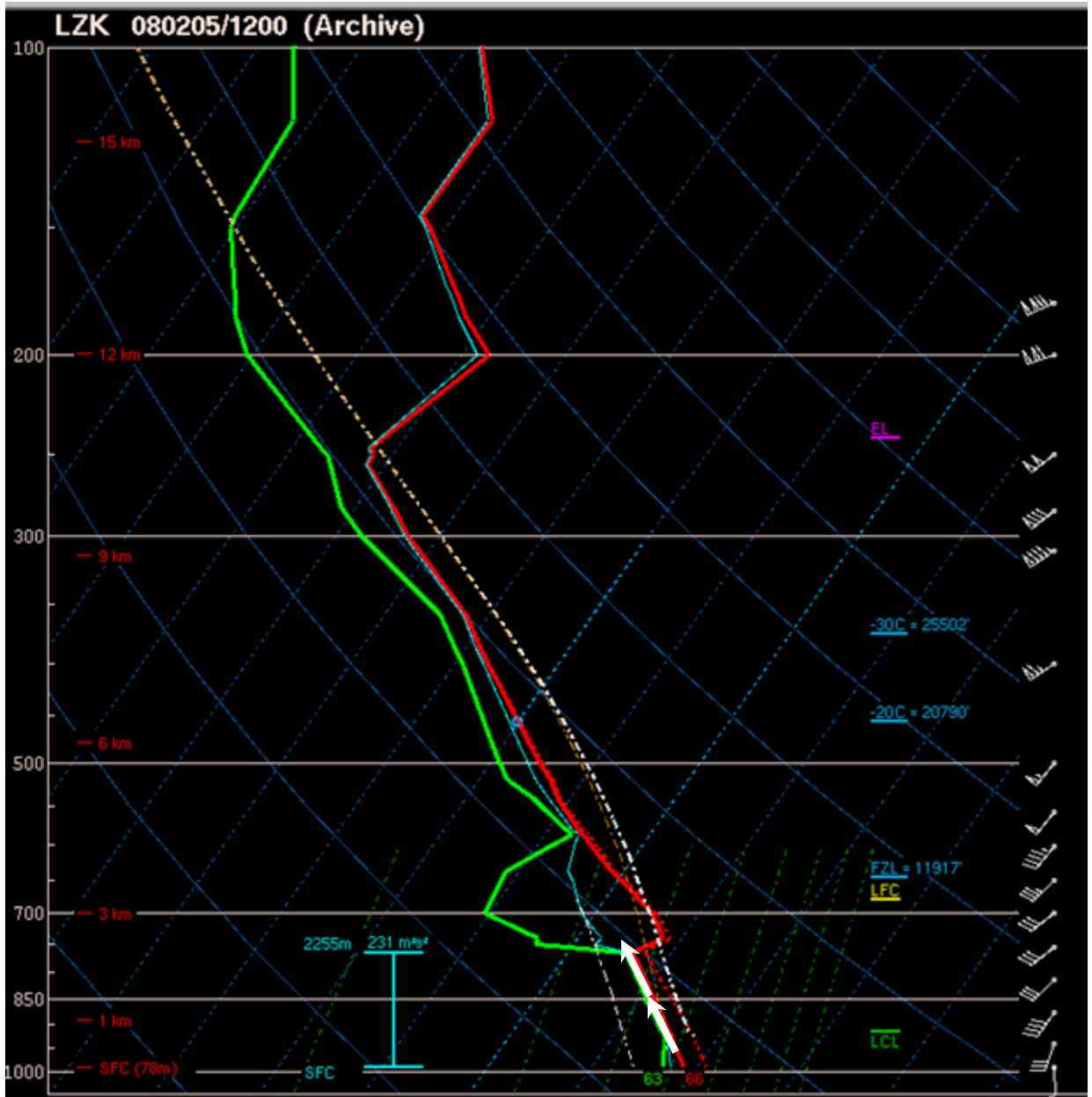


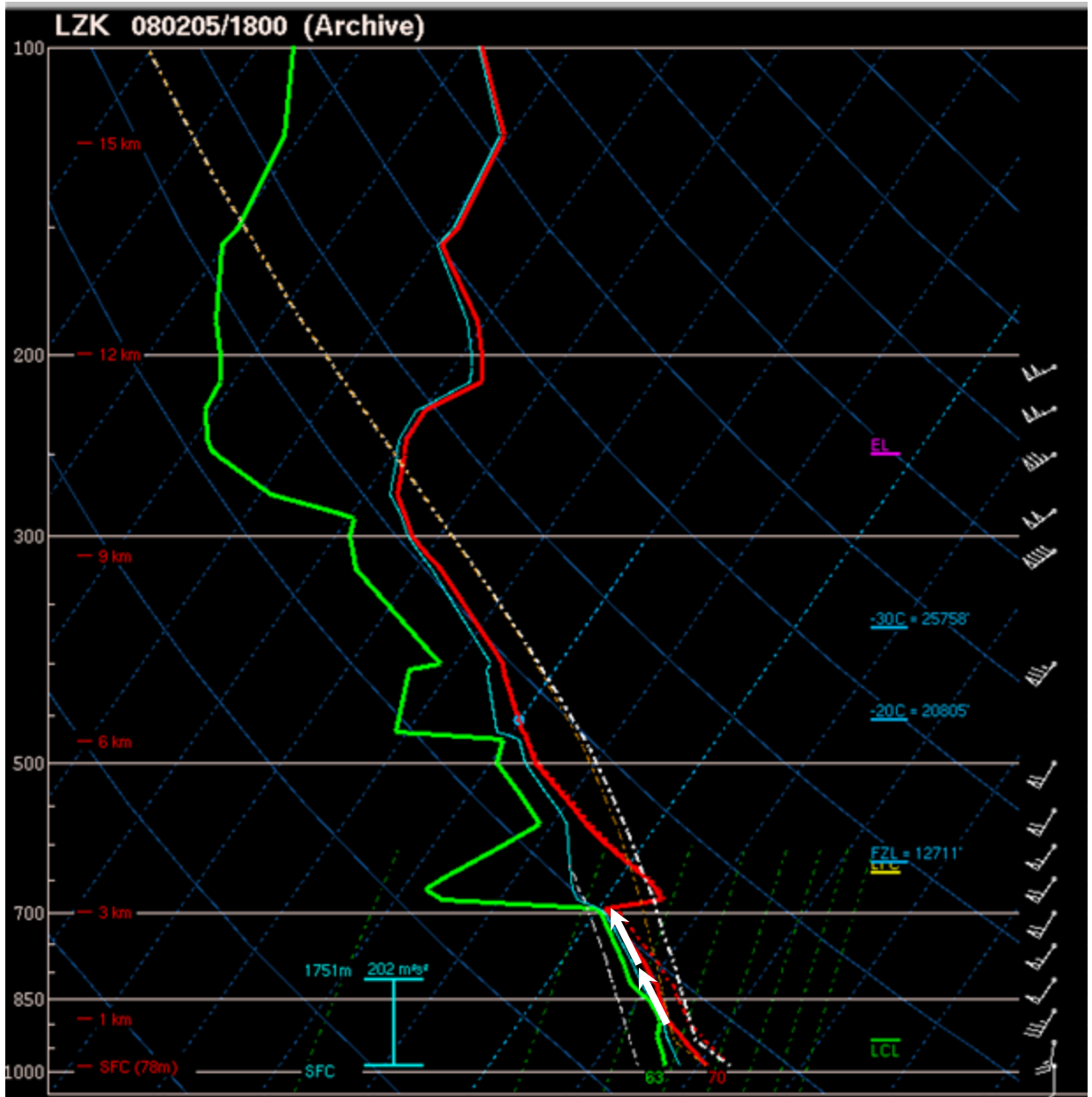


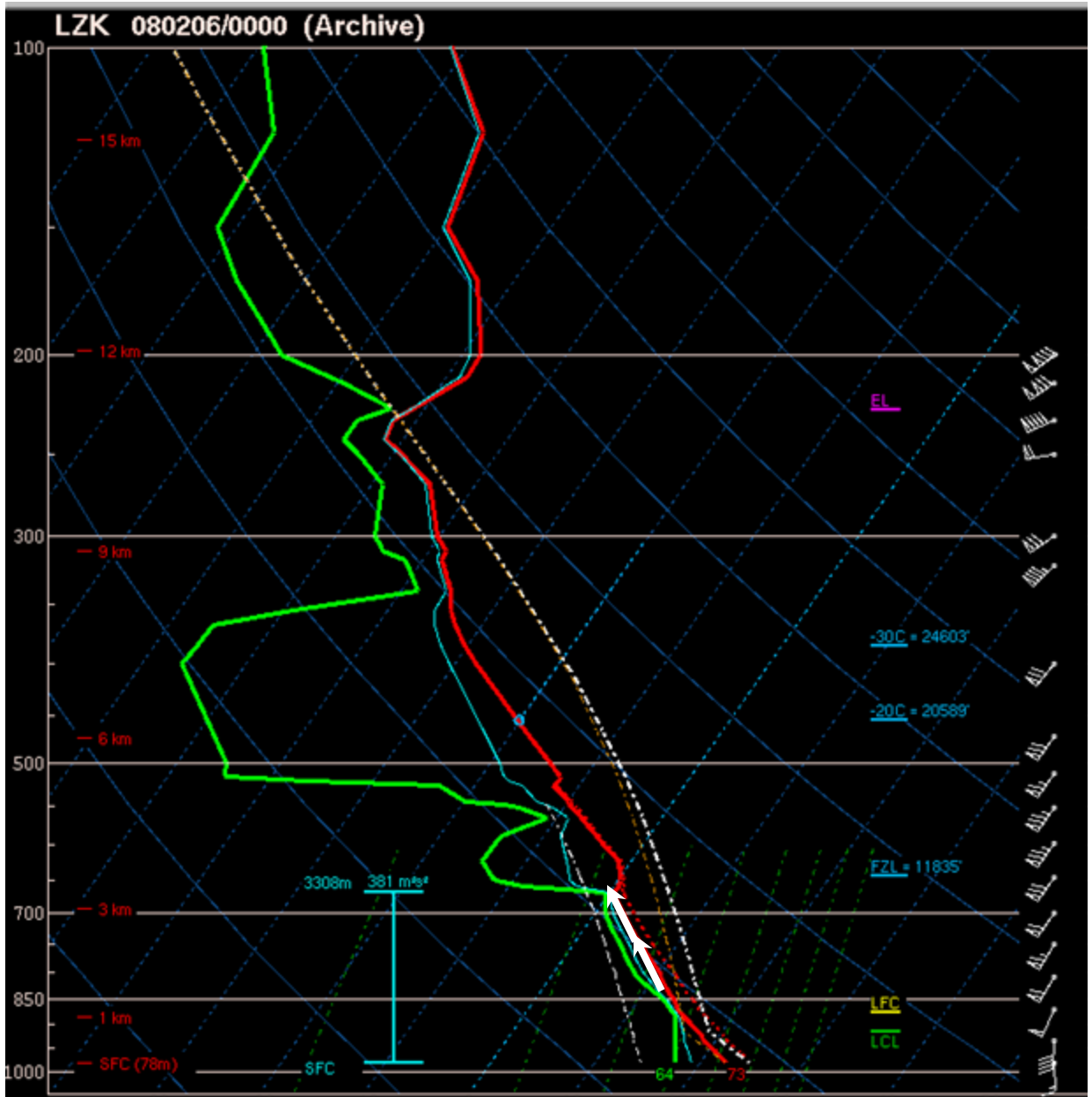
# Impact of ascent and moisture advection

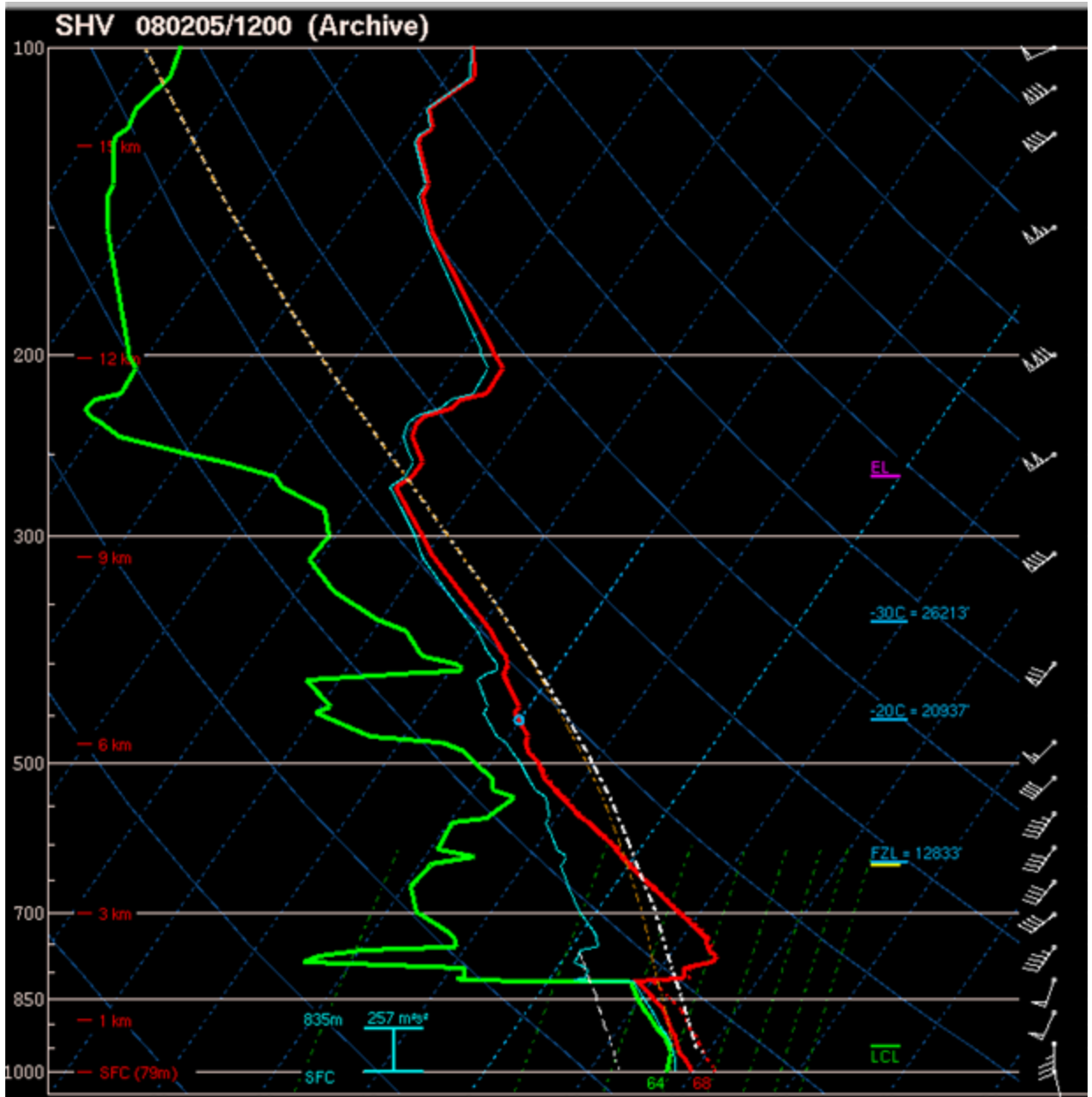
- See moist layer deepen faster than you would expect with just surface heating and mixing
- “Deep” moist layer and horizontal moisture advection both combat vertical mixing driven by surface heating
  - Can see moist layer deepen while dew points increase near surface

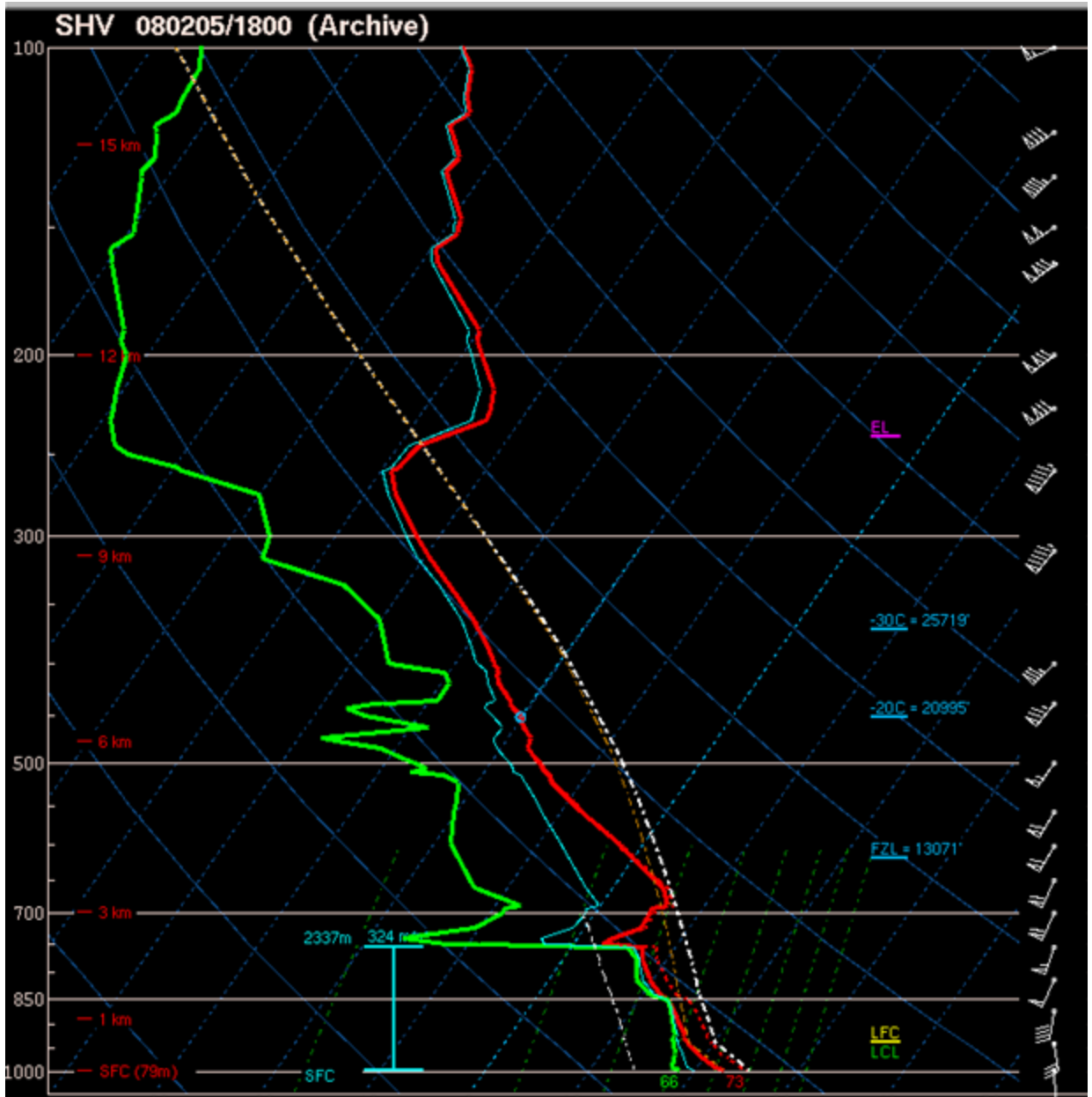


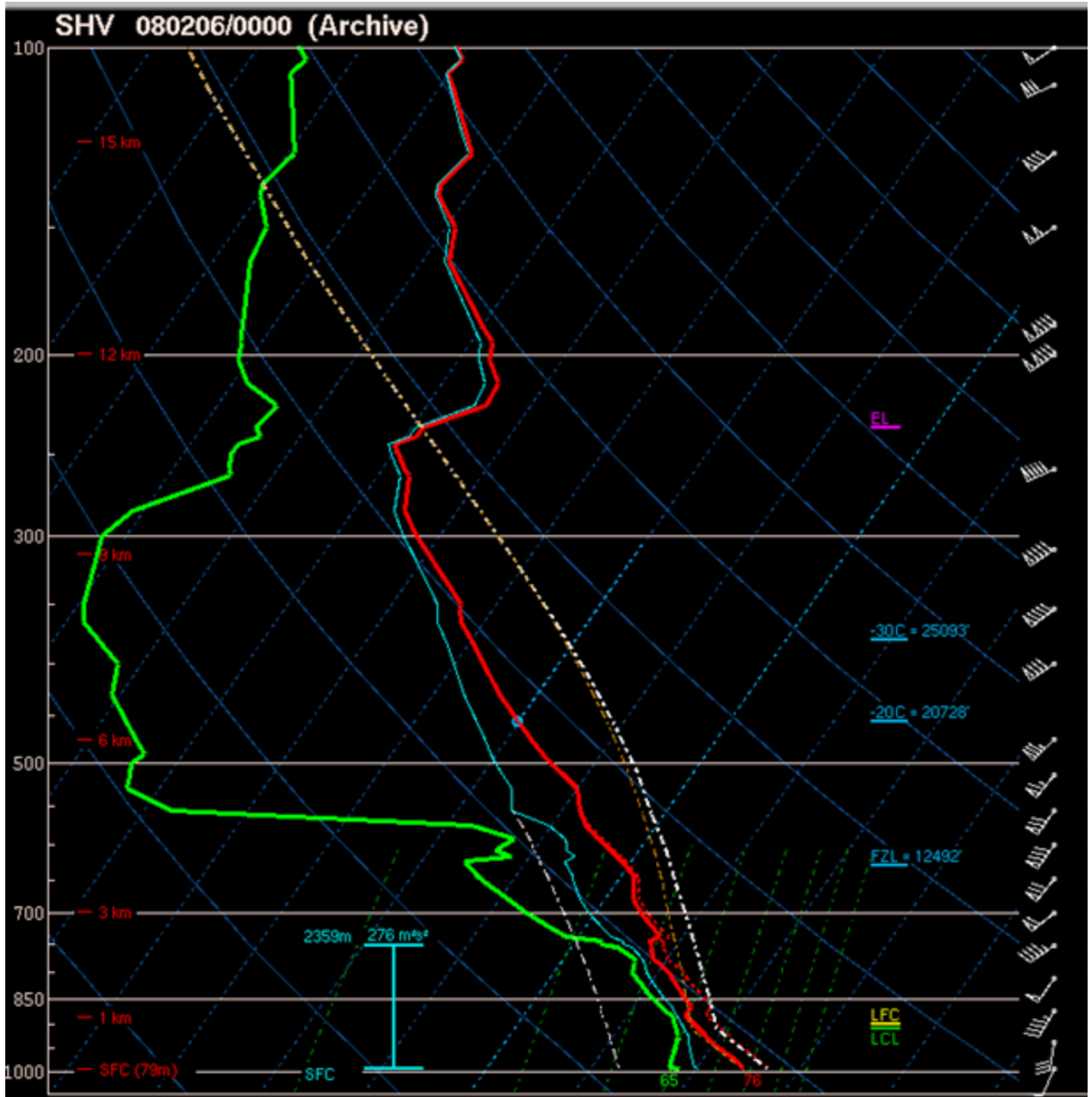












# Sounding diagrams are used for...

- Moisture and temperature profiles
- Estimates of CAPE, CIN, Lifted Index, etc.
  - Will storms form?
- Vertical wind shear (material on hodographs next week!)
  - 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!

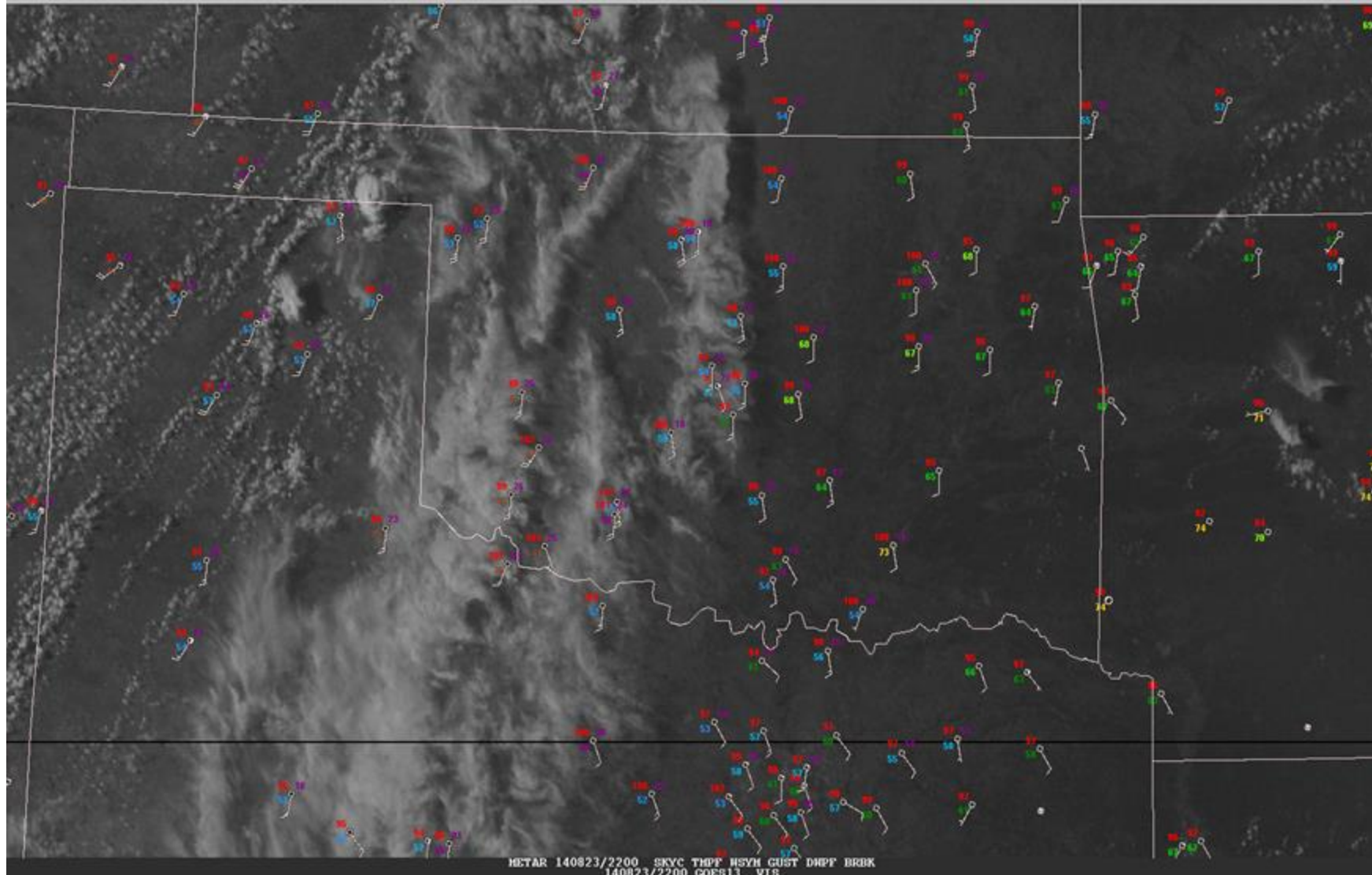
# Quality of Surface Observations?



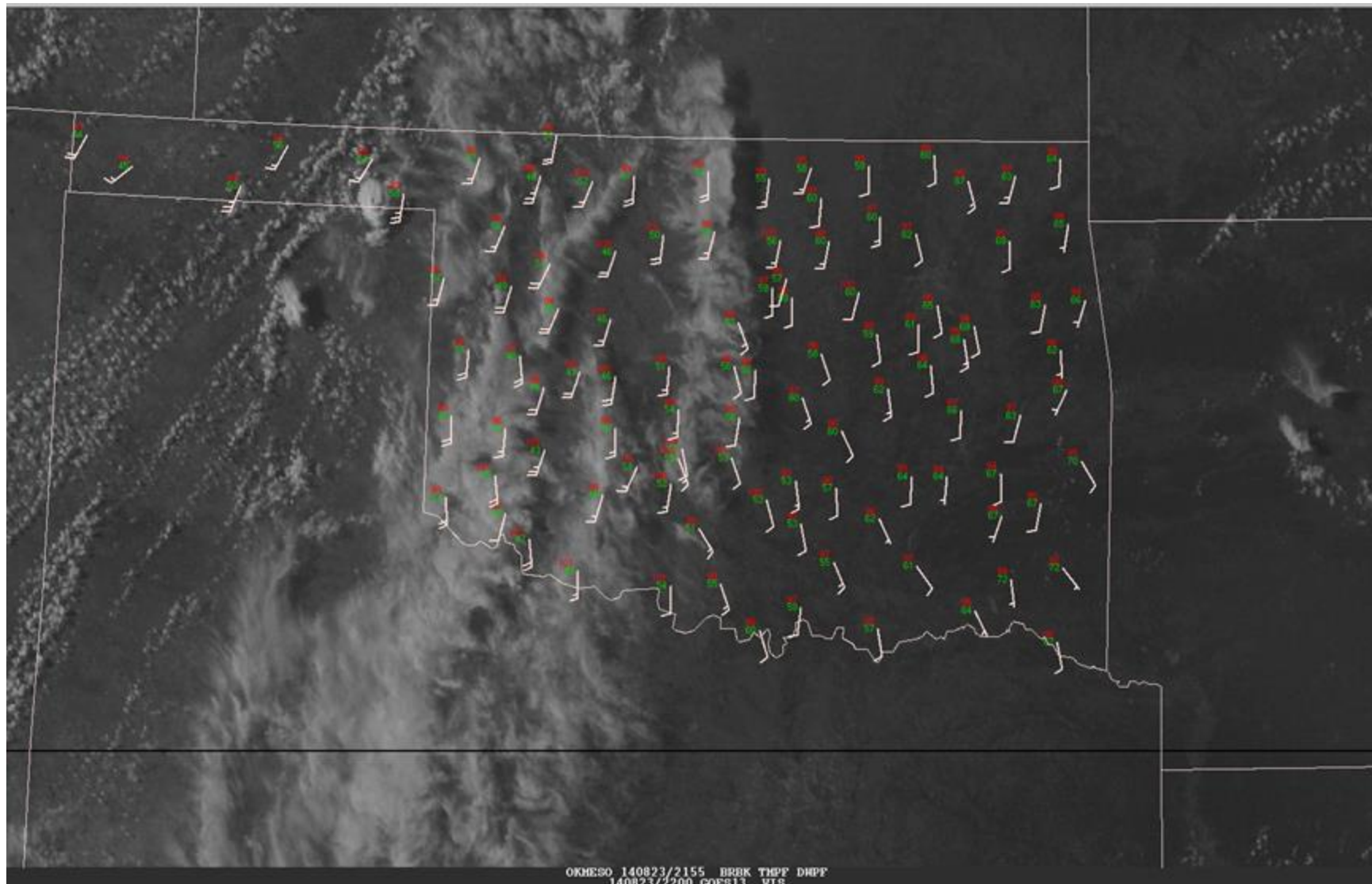
Courtesy of Oklahoma Mesonet



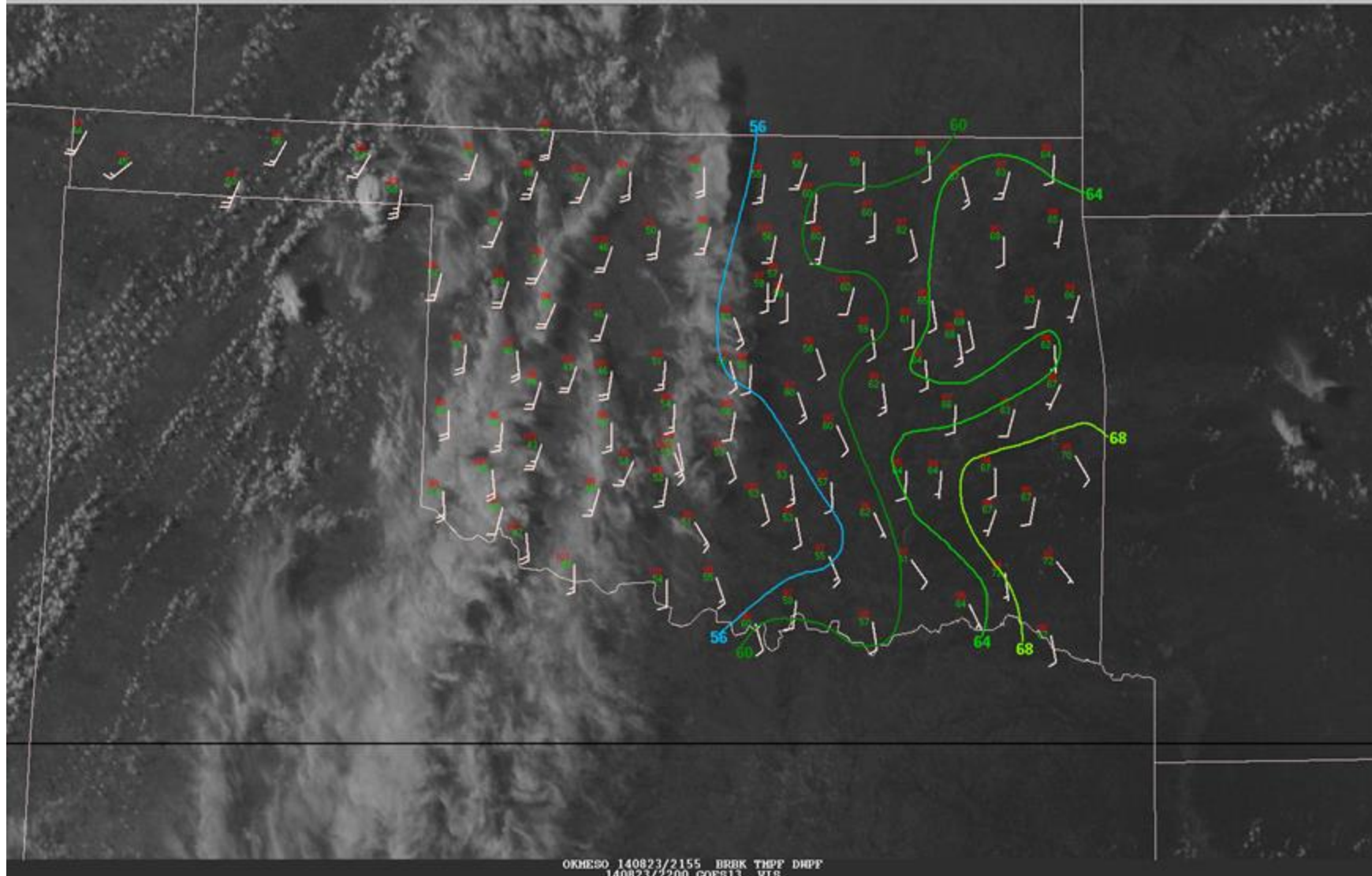
# Standard surface observations



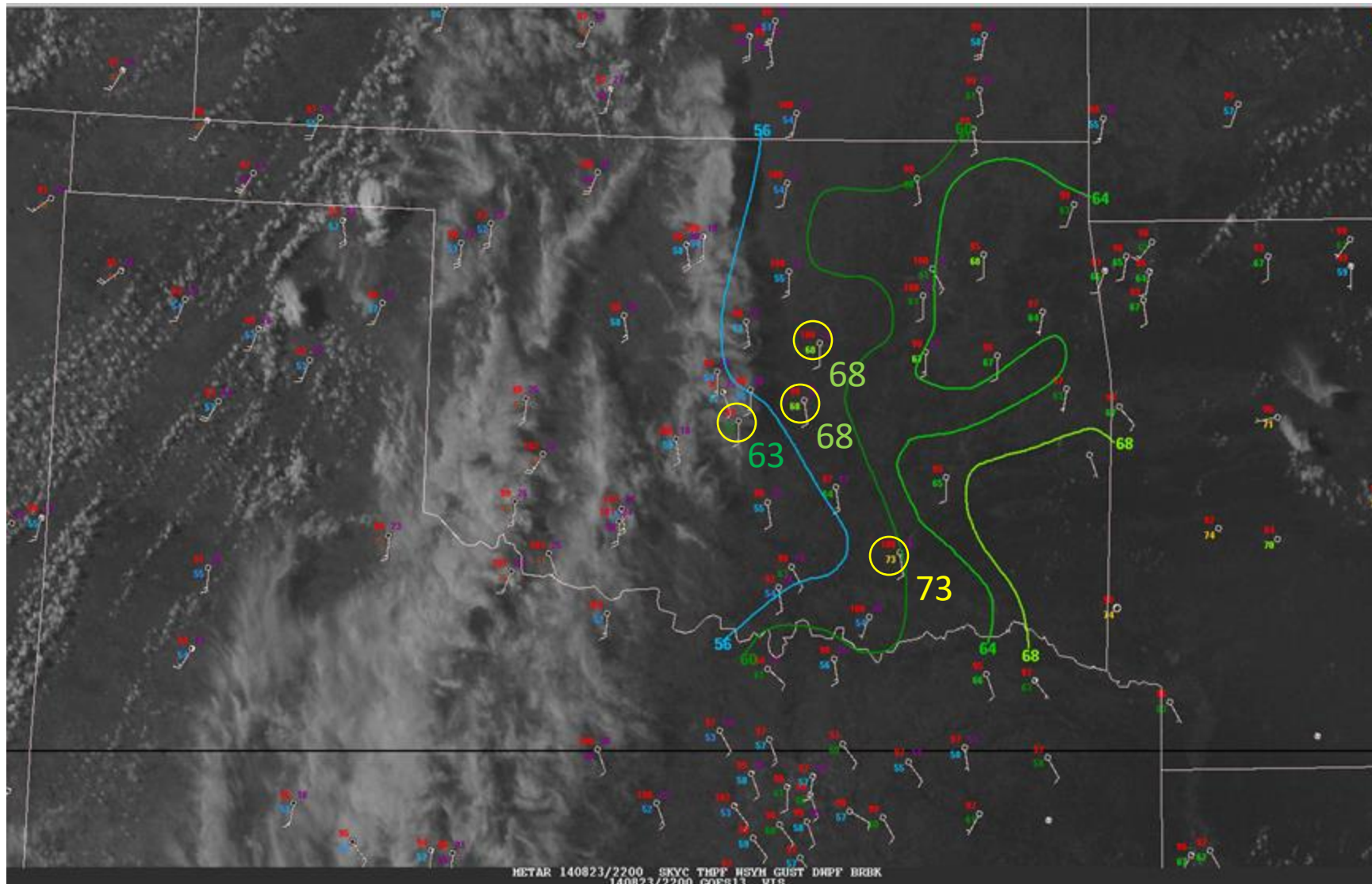
## OK mesonet observations at the same time



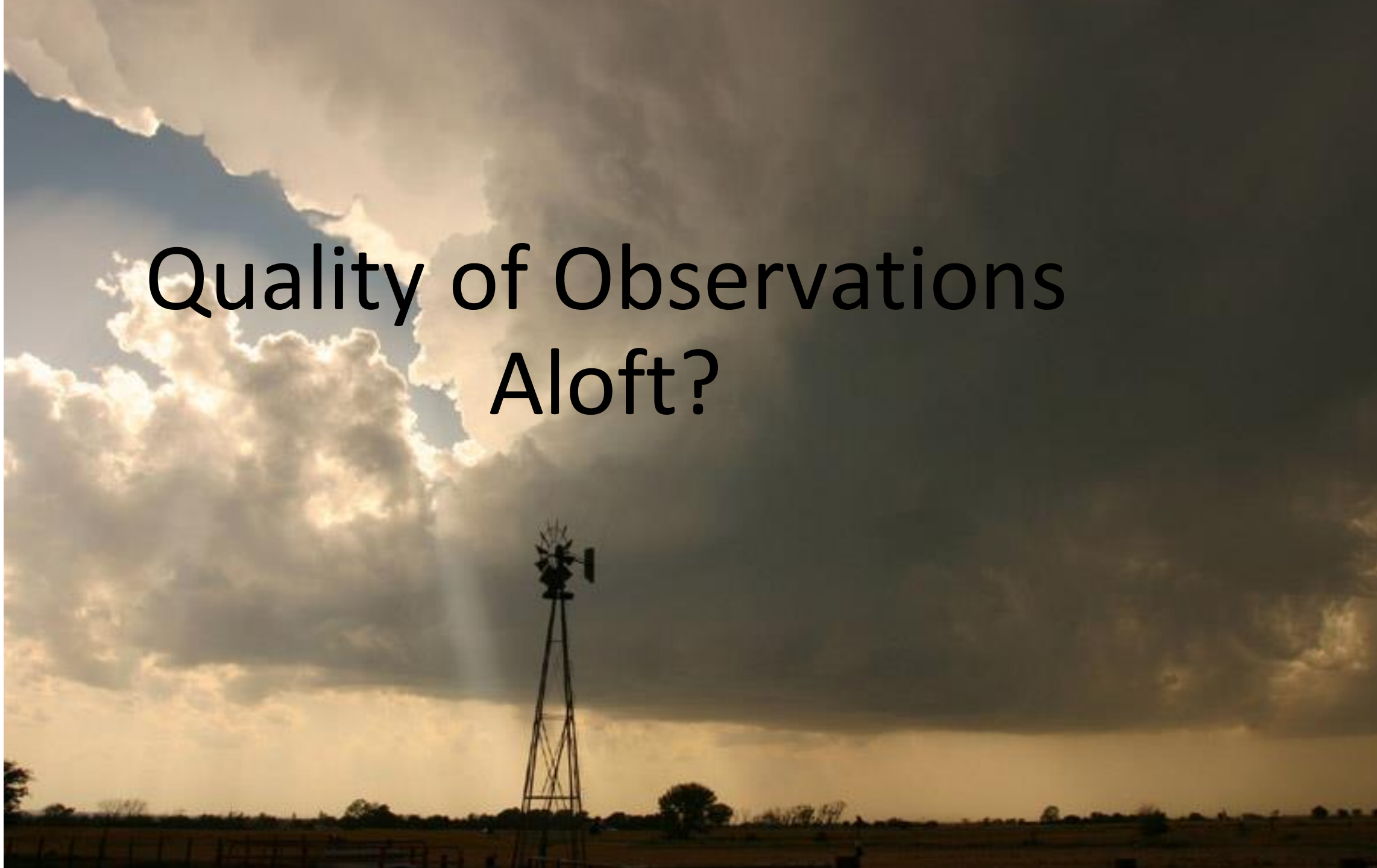
# Dew point analysis for OK mesonet observations



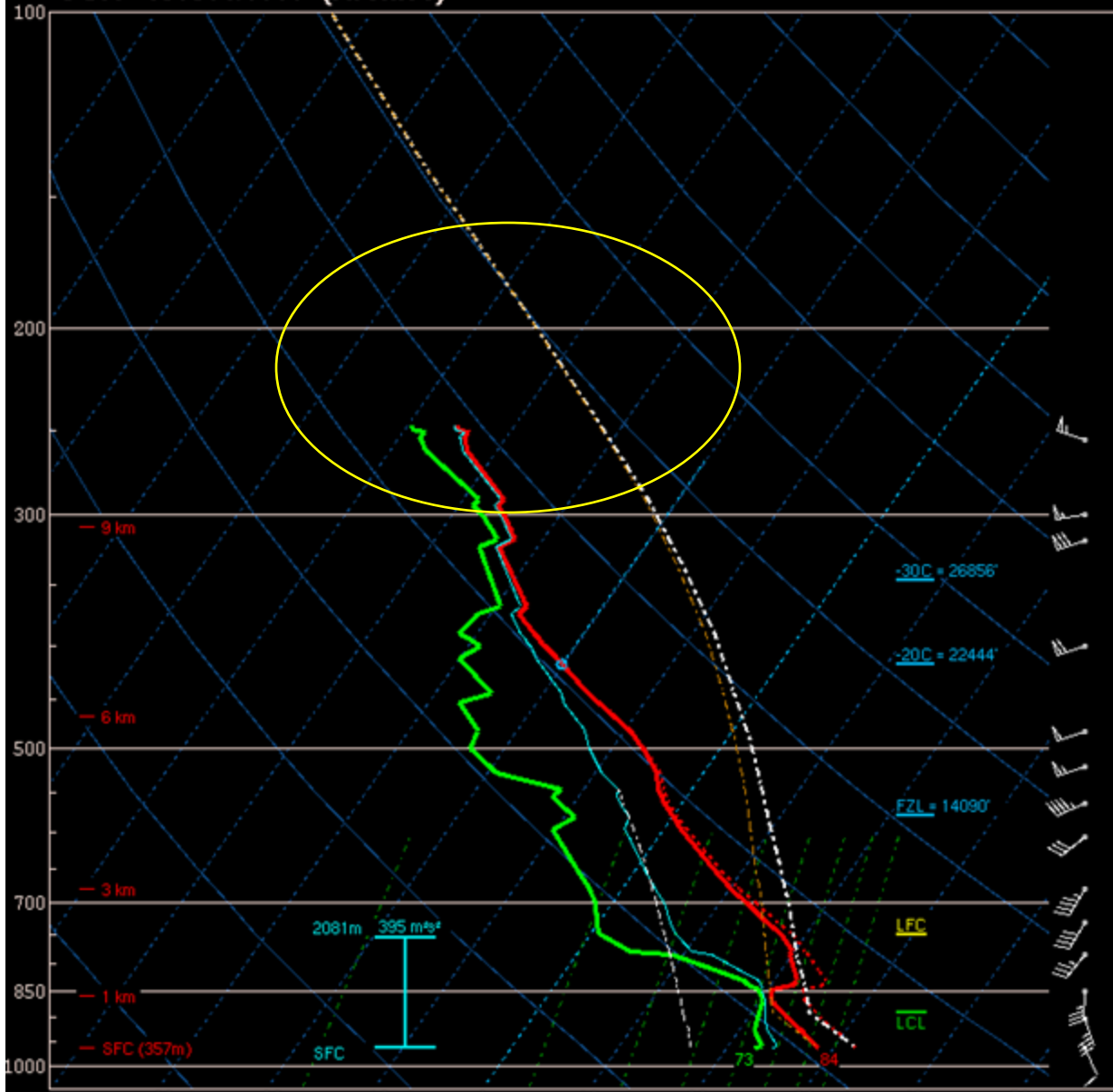
What do these sites have in common?

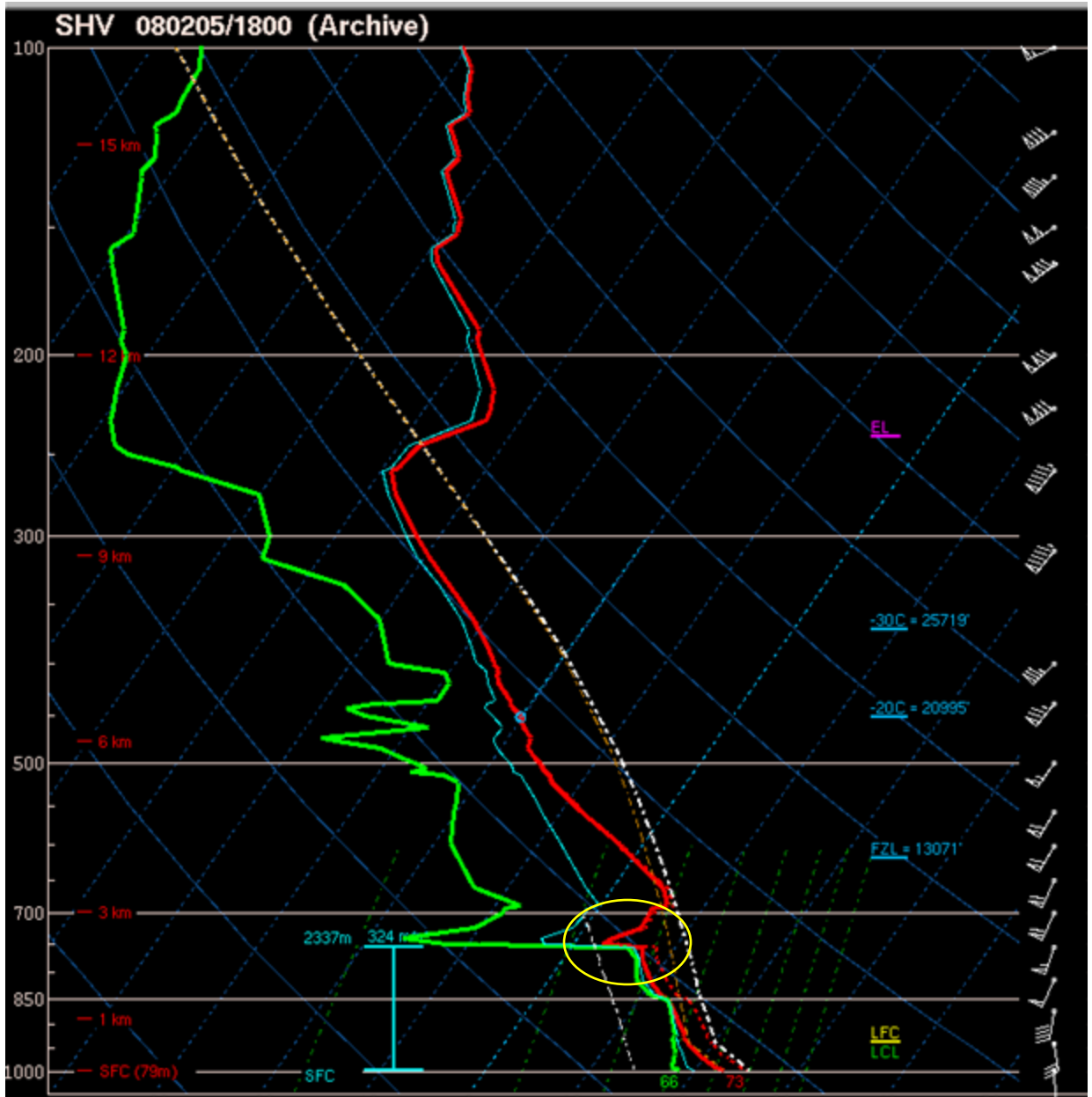


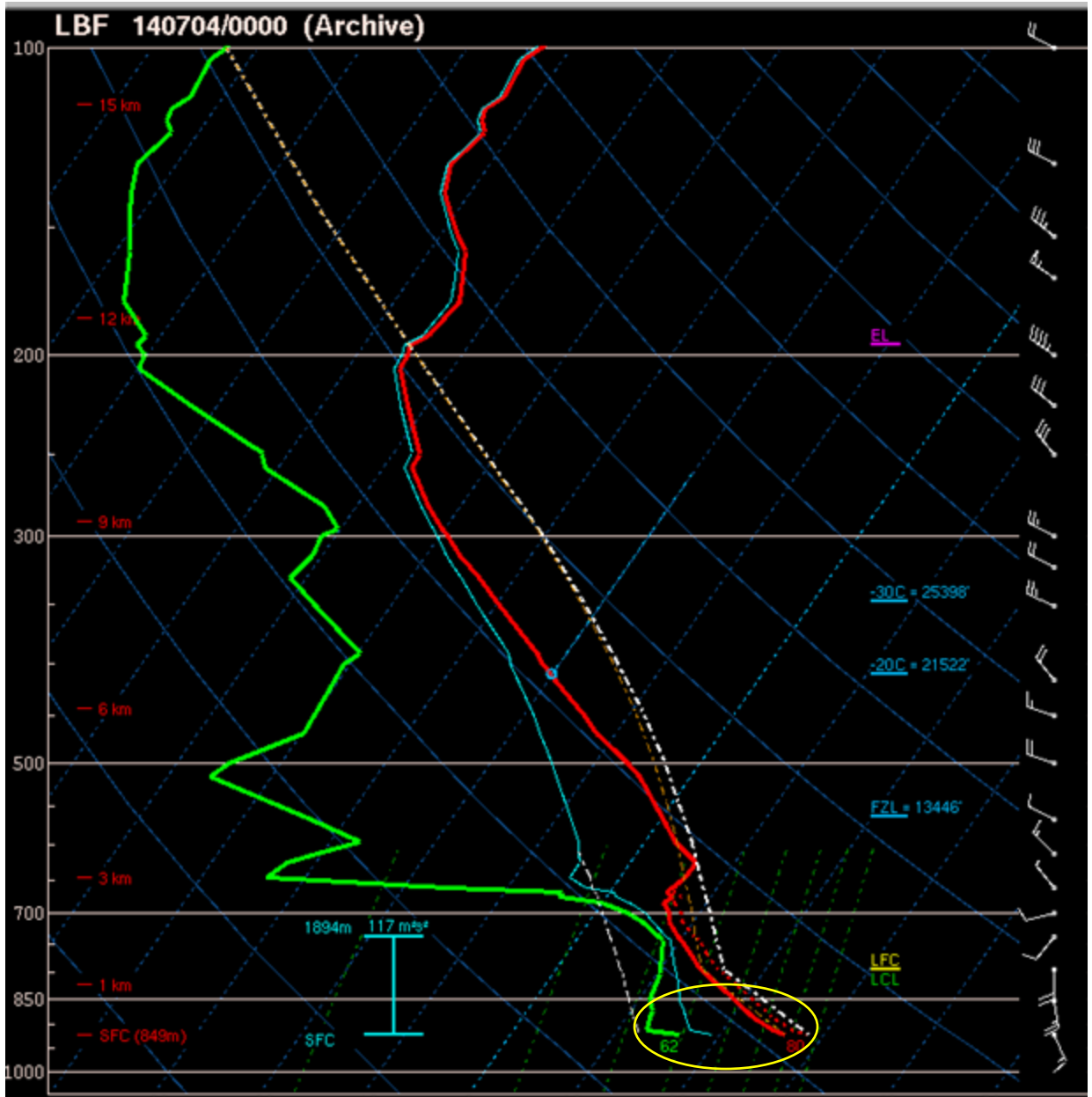
# Quality of Observations Aloft?



OUN 130601/0000 (Archive)









# 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!

# Parcel Theory

METR 4403/5403 – Spring 2021

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:

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

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:  $B = -g \frac{\rho'}{\bar{\rho}} = g \left( \frac{T_v'}{\bar{T}_v} - \frac{p'}{\bar{p}} \right)$

For small mach number:  $B = \left| \frac{p'}{\bar{p}} \right| \ll \left| \frac{T_v'}{\bar{T}_v} \right|$   $\therefore B = g \frac{T_v'}{\bar{T}_v} = g \frac{\theta_v'}{\bar{\theta}_v}$   $B = g \frac{\theta'}{\bar{\theta}}$  Neglecting water vapor

- 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.  $\therefore B > 0 \rightarrow \frac{dw}{dt} > 0$

## NOTES AND CORRESPONDENCE

# The Effect of Neglecting the Virtual Temperature Correction on CAPE Calculations

CHARLES A. DOSWELL III AND ERIK N. RASMUSSEN\*

*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.

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Inclusion of water vapor impacts CAPE/CIN calculation

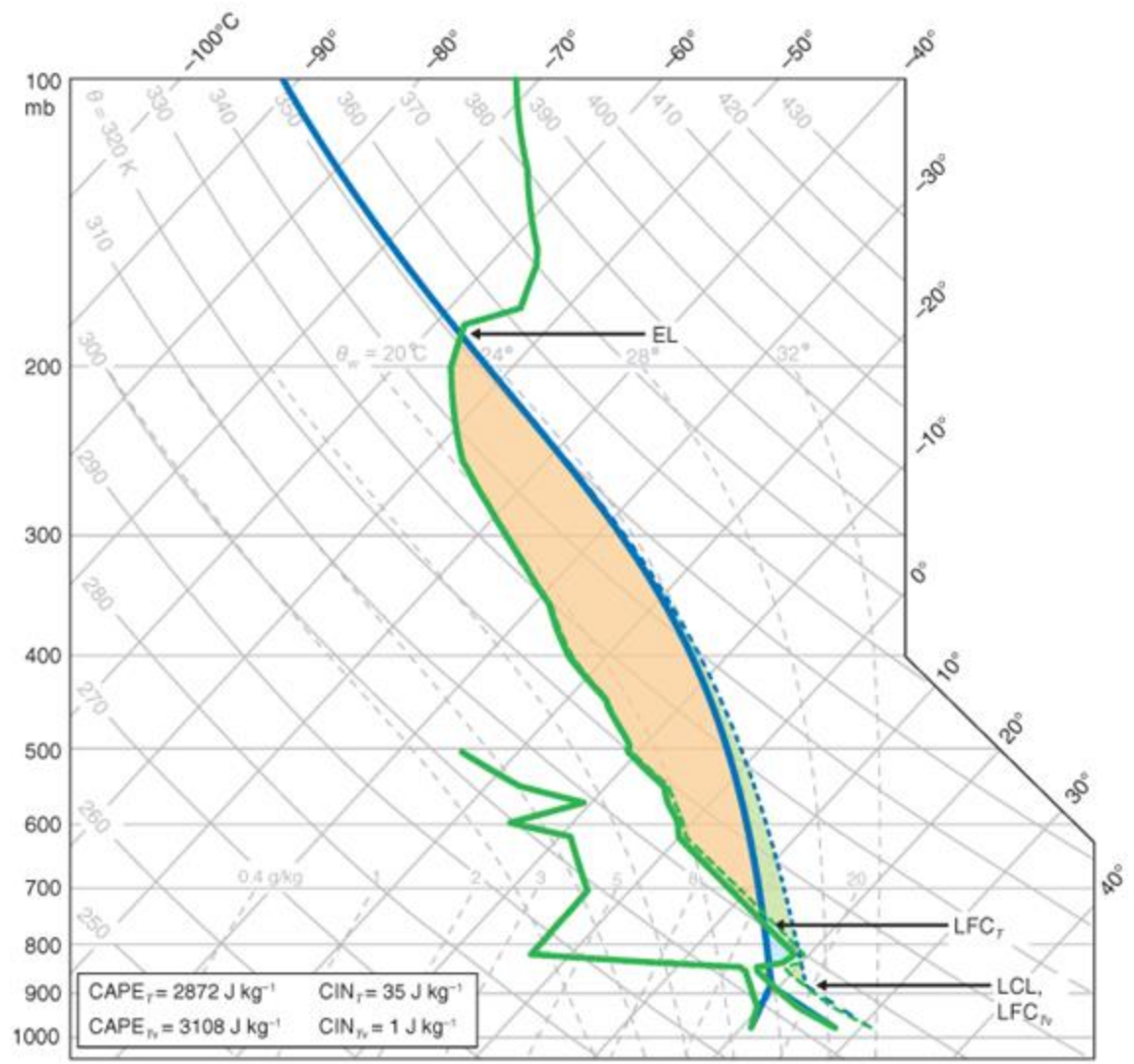


Figure 2.9

# 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

$$w_{max} = \sqrt{2 * CAPE} \quad 1000 \text{ J kg}^{-1} \text{ CAPE} \approx 45 \text{ m s}^{-1} \text{ updraft (??)}$$

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:

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



## 1. 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 ( $dw/dt=0$ )
- **Narrow updrafts more favorable for thunderstorm development**

## 2. Entrainment

- Mixing of environment air into rising thermal
- If env is cooler/drier, evaporation cools thermal, reduces B
- **Updraft dilution more detrimental for narrow or tilted updrafts (wider is better)**

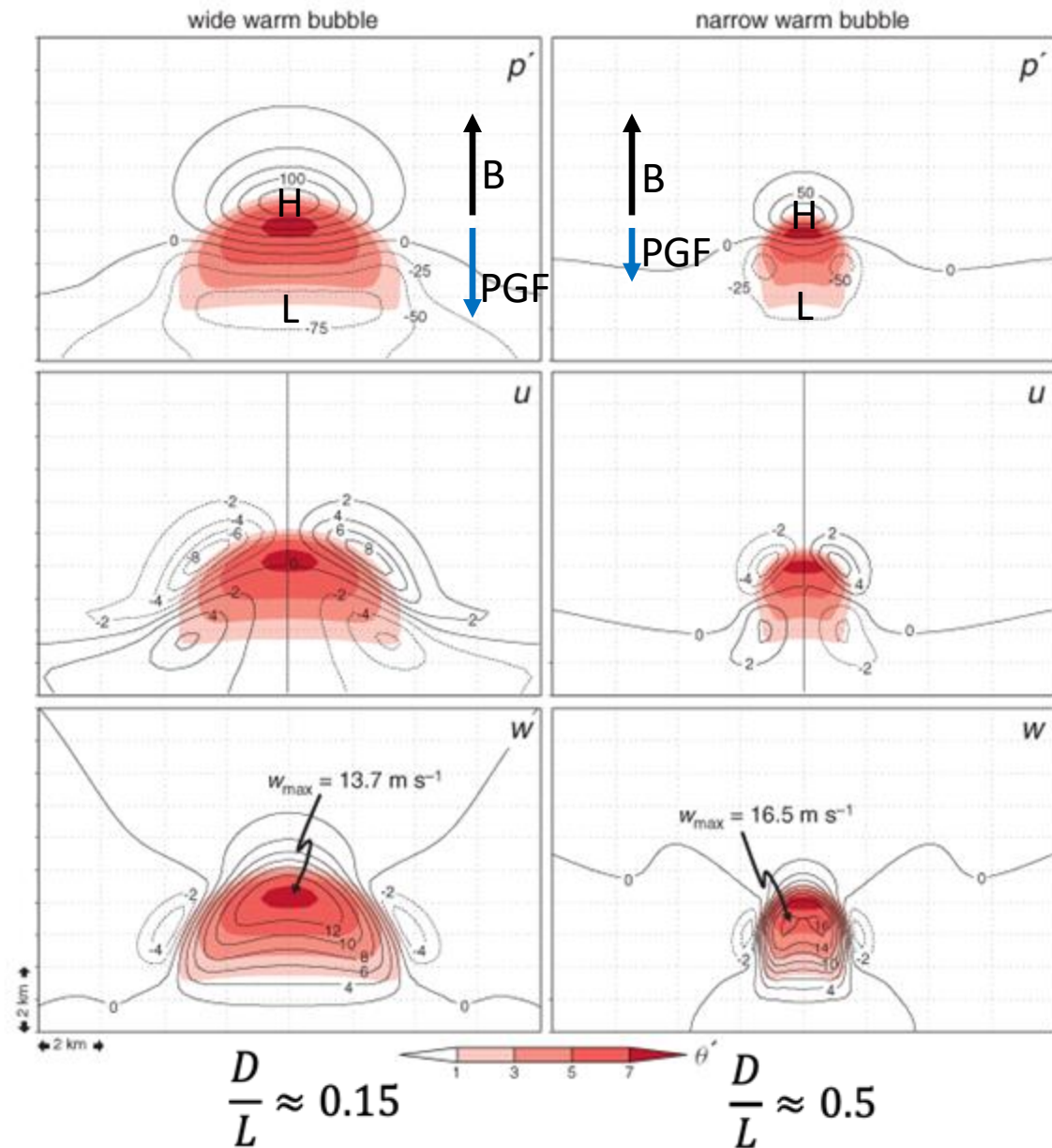


Figure 3.1

# 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
- Parcel theory does not account for layer lifting and development of moist absolutely unstable layers (MAULs)

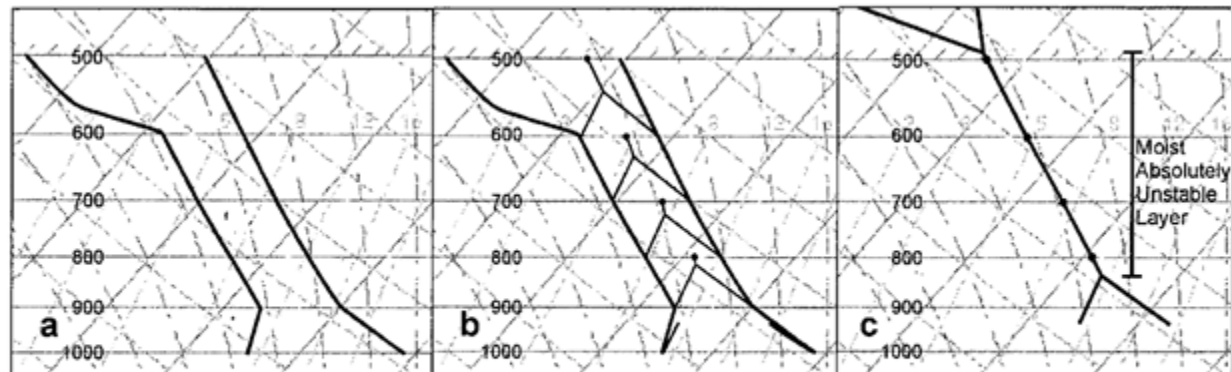


FIG. 1. Idealized sounding: (a) initial conditionally unstable sounding, (b) layer lifting is applied (thin black lines represent the path of selected parcels within the lifted layer), and (c) resulting structure after lifting, which features a deep moist absolutely unstable layer.

## Layer Lifting

- Layer lifting can lead to convectively unstable conditions
- Unsaturated layer lifted, bottom reaches saturation before top of layer
- Bottom of layer cools at  $\Gamma_m$
- Top of layer cools at  $\Gamma_d$
- **Layer destabilizes!**

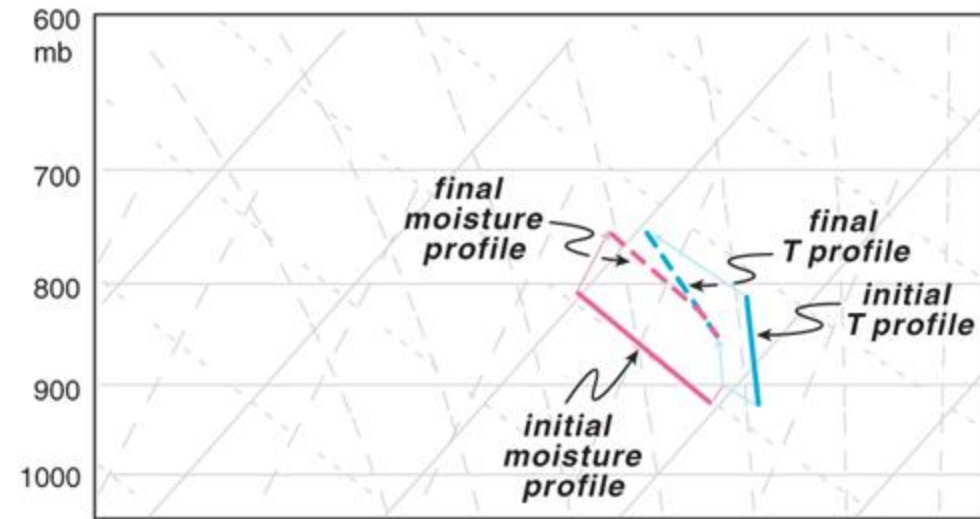
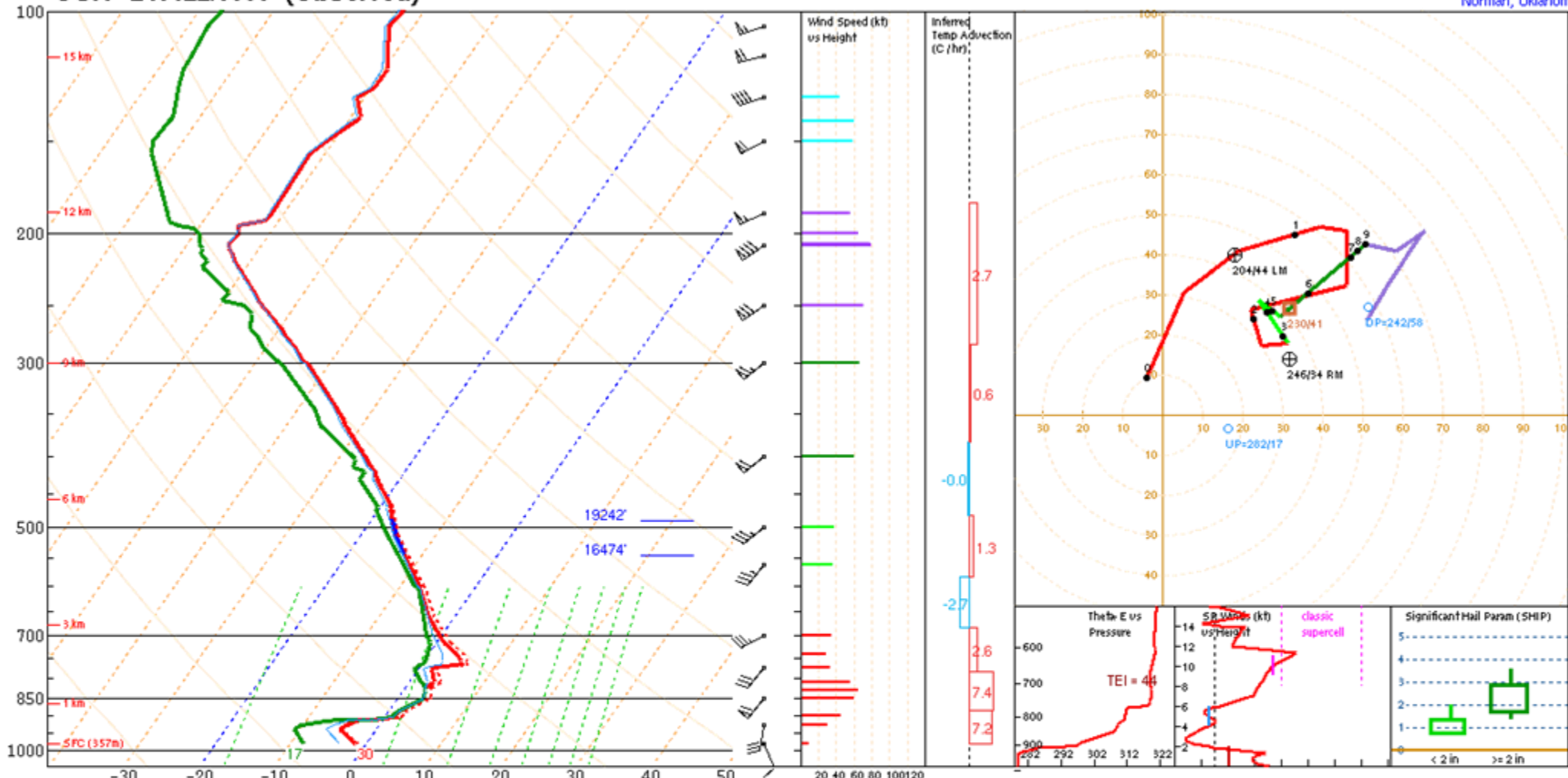


Figure 3.3

Illustration of the concept of potential instability. A potentially unstable layer initially spanning the pressure range of 910–810 mb has been lifted to 850–750 mb. Although destabilization of the layer has occurred, lifting would have cooled the layer (and therefore reduced CIN) regardless of whether or not lifting led to saturation at the bottom of the layer.



PARCEL	CAPE	CINH	LCL	LI	LFC	EL
SURFACE	0	0	863m	29	M	2830'
MIXED LAYER	0	0	872m	22	M	2859'
FCST SURFACE	0	0	1888m	16	M	6193'
MU (602 mb)	0	0	3934m	1	M	12904'

PW = 0.84 in	3CAPE = 115 J/kg	WBZ = 0'	WNDG = 0.0
K = 22	DCAPE = -374 J/kg	FZL = 0'	ESP = 0.0
MidRH = 85%	DownT = 53 F	ConvT = M	MMP = 0.58
LowRH = 86%	MeanW = 3.1 g/kg	MaxT = 55F	NCAPE = 0.00
SigSevere = 0 m3/s3			
Sfc-3km Agl Lapse Rate = 0.3 C/km			
3-6km Agl Lapse Rate = 5.9 C/km			
850-500mb Lapse Rate = 4.7 C/km			
700-500mb Lapse Rate = 6.2 C/km			

<b>Supercell = 0.0</b>	
<b>Left Supercell = 0.0</b>	
<b>STP (eff layer) = 0.0</b>	
<b>STP (fix layer) = 0.0</b>	
<b>Sig Hail = 0.0</b>	

SRH(m2/s2)	Shear(kt)	MnWind	SRW
SFC - 1 km	432	199/31	123/27
SFC - 3 km	496	219/36	148/17
SFC - 6 km	46	221/36	149/15
SFC - 8 km	62	223/38	159/15

BRN Shear = 76 m/s<sup>2</sup>  
4-6km SR Wind = 163/13 kt

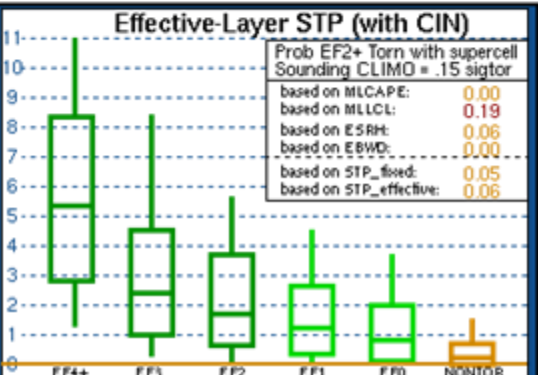
.....Storm Motion Vectors.....  
Bunkers Right = 246/34 kt  
Bunkers Left = 204/44 kt

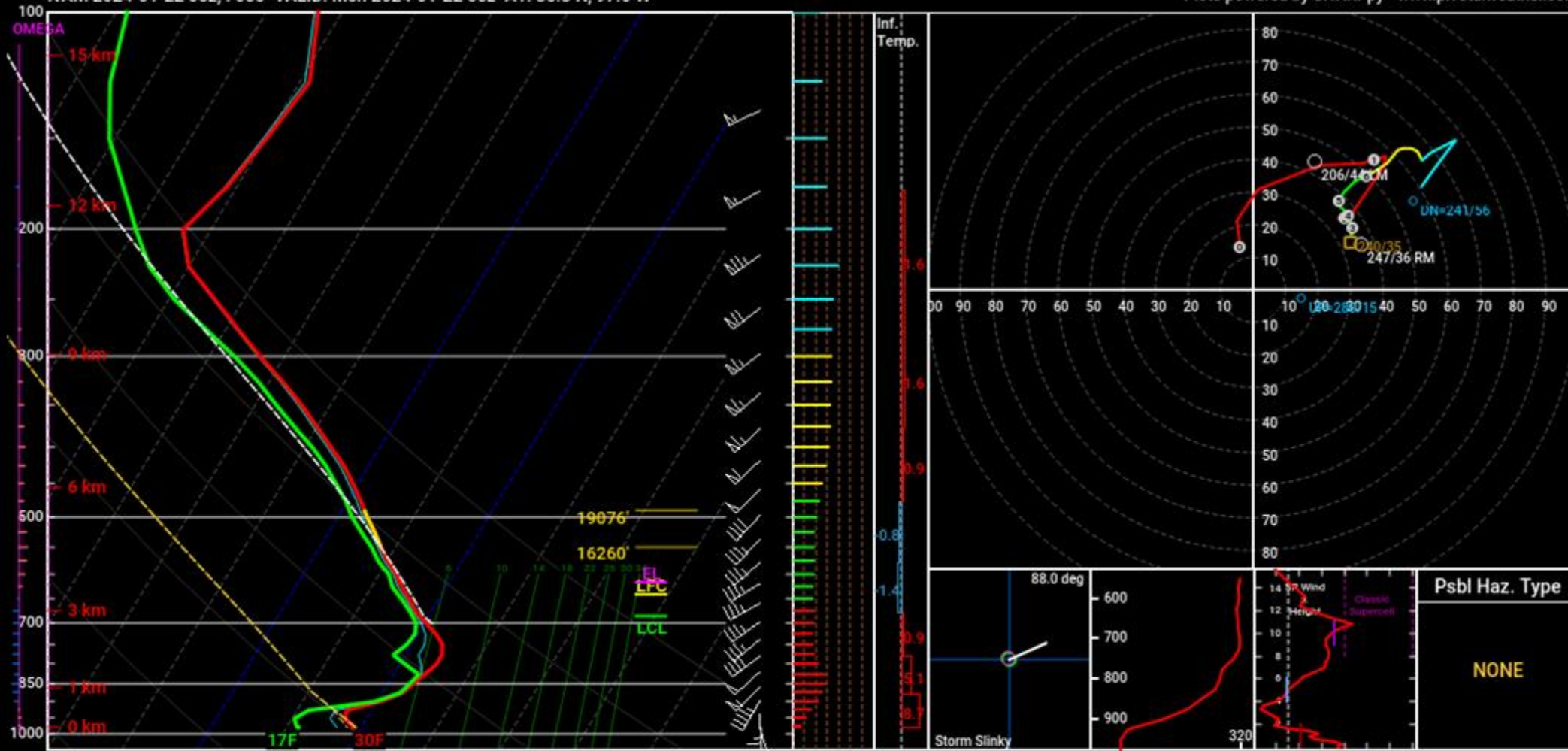
Corfidi Downshear = 242/58 kt  
Corfidi Upshear = 282/17 kt

\*\*\* BEST GUESS PRECIP TYPE \*\*\*  
**Freezing Rain.**  
Based on sfc temperature of 30.0 F.

**SARS - Sounding Analogs**

SUPERCCELL	SGFNTHAIL
No Quality Matches	No Quality Matches





PCL	CAPE	CINH	LCL	LI	LFC	EL
SFC	0	0	918	28	--	918
ML	0	0	951	25	--	951
FCST	0	0	2294	16	--	2294
MU	0	0	2849	1	3408	3720

PW = 0.8in	K = 21	WNDG = 0.0
MeanW = 2.9g/kg	TT = 39	TEI = 40
LowRH = 74%	ConvT = -F	3CAPE = 0
MidRH = 82%	maxT = 56F	
DCAPE = 14	ESP = 0.0	
DownT = 28F	MMP = 0.0	SigSvr = 0 m3/s3

Sfc-3km AGL LR = 0.2 C/km	Supercell = 0.0
3-6km AGL LR = 6.1 C/km	STP (cin) = 0.0
850-500mb LR = 4.8 C/km	STP (fix) = 0.0
700-500mb LR = 6.4 C/km	SHIP = 0.0

	EHI	SRH	Shear	MnWind	SRW
SFC-1km	0.0	444	49	199/31	124/28
SFC-3km	0.0	431	35	219/37	145/18
Eff Inflow	--	--	--	--/--	--/--
SFC-6km			45	223/37	148/15
SFC-8km			61	223/39	157/16
LCL-EL (Cloud Layer)			2	240/35	141/5
Eff Shear (EBWD)			--	--/--	--/--
BRN Shear =		101 m2/s2			
4-6km SR Wind =		151/13 kt			
...Storm Motion Vectors...					
Bunkers Right =		247/36 kt			
Bunkers Left =		206/44 kt			
Corfidi Downshear =		241/56 kt			
Corfidi Upshear =		280/15 kt			

### SARS - Sounding Analogs

SUPERCCELL	SGFNT HAIL
No Quality Matches	No Quality Matches

\*\*\* DENDRITIC GROWTH ZONE (-12 TO -17 C) \*\*\*

OPRH (Omega\*PW\*RH) -0.11

Layer Depth: 2816 ft (16260-19076 ft msl)

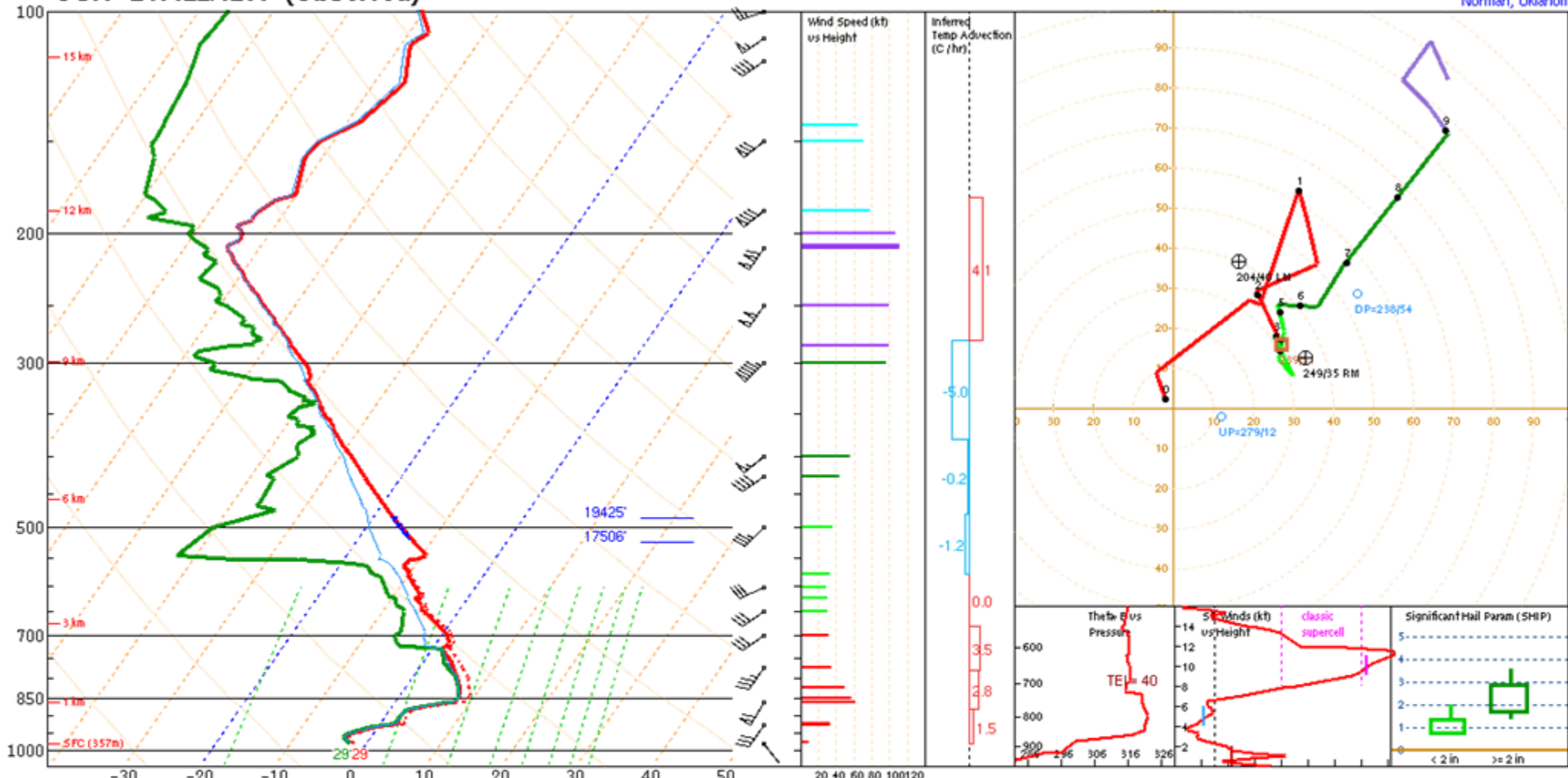
Mean RH: 87.0 %	Mean MixRat: 2.1 g/kg
Mean PW: 0.05 in	Mean Omega: -2.5 ub/s

Initial Phase: Snow from: 550 mb (16260 ft msl; -12.0 C)

TEMPERATURE PROFILE	WETBULB PROFILE
P/N: 231.0 / -55.0 J/kg	P/N: 138.0 / -93.0 J/kg
Melt Lyr: 725-925 mb	Melt Lyr: 725-900 mb
Frz Lyr: 925-976 mb	Frz Lyr: 900-976 mb

\*\*\* BEST GUESS PRECIP TYPE \*\*\*

### Freezing Rain.



PARCEL	CAPE	CINH	LCL	LI	LFC	EL
SURFACE	0	0	0m	28	39m	653'
MIXED LAYER	0	0	415m	21	M	1360'
FCST SURFACE	0	0	1609m	14	M	5278'
MU (795 mb)	89	-1	1704m	1	2874m	15052'

PW = 0.83 in	3CAPE = 199 J/kg	WBZ = 0'	WNDG = 0.0
K = 24	DCAPE = 46 J/kg	FZL = 0'	ESP = 0.0
MidRH = 81%	DownT = 54 F	ConvT = M	MMP = 0.87
LowRH = 99%	MeanW = 4.0 g/kg	MaxT = 57F	NCAPE = 0.05
SigSevere = 0 m3/s3			
Sfc-3km Agl Lapse Rate = -0.2 C/km			
3-6km Agl Lapse Rate = 6.4 C/km			
850-500mb Lapse Rate = 5.5 C/km			
700-500mb Lapse Rate = 6.1 C/km			

<b>Supercell = 0.0</b>	
<b>Left Supercell = 0.0</b>	
<b>STP (eff layer) = 0.0</b>	
<b>STP (fix layer) = 0.0</b>	
<b>Sig Hail = 0.0</b>	

	SRH(m2/s2)	Shear(kt)	MnWind	SRW
SFC - 1 km	348	62	210/33	134/23
SFC - 3 km	290	32	218/36	147/19
SFC - 6 km		41	223/35	143/16
SFC - 8 km		77	224/37	152/15
LCL - EL (Cloud Layer)		16	181/12	88/33

BRN Shear = 38 m/s <sup>2</sup>	
4-6km SR Wind = 152/11 kt	
.....Storm Motion Vectors.....	
Bunkers Right = 249/35 kt	
Bunkers Left = 204/40 kt	
Corfidi Downshear = 238/54 kt	
Corfidi Upshear = 279/12 kt	

\*\*\* BEST GUESS PRECIP TYPE \*\*\*

**Freezing Rain.**  
Based on sfc temperature of 28.6 F.

**SARS - Sounding Analogs**

SUPERCELL	SGFNT HAIL
No Quality Matches	No Quality Matches

