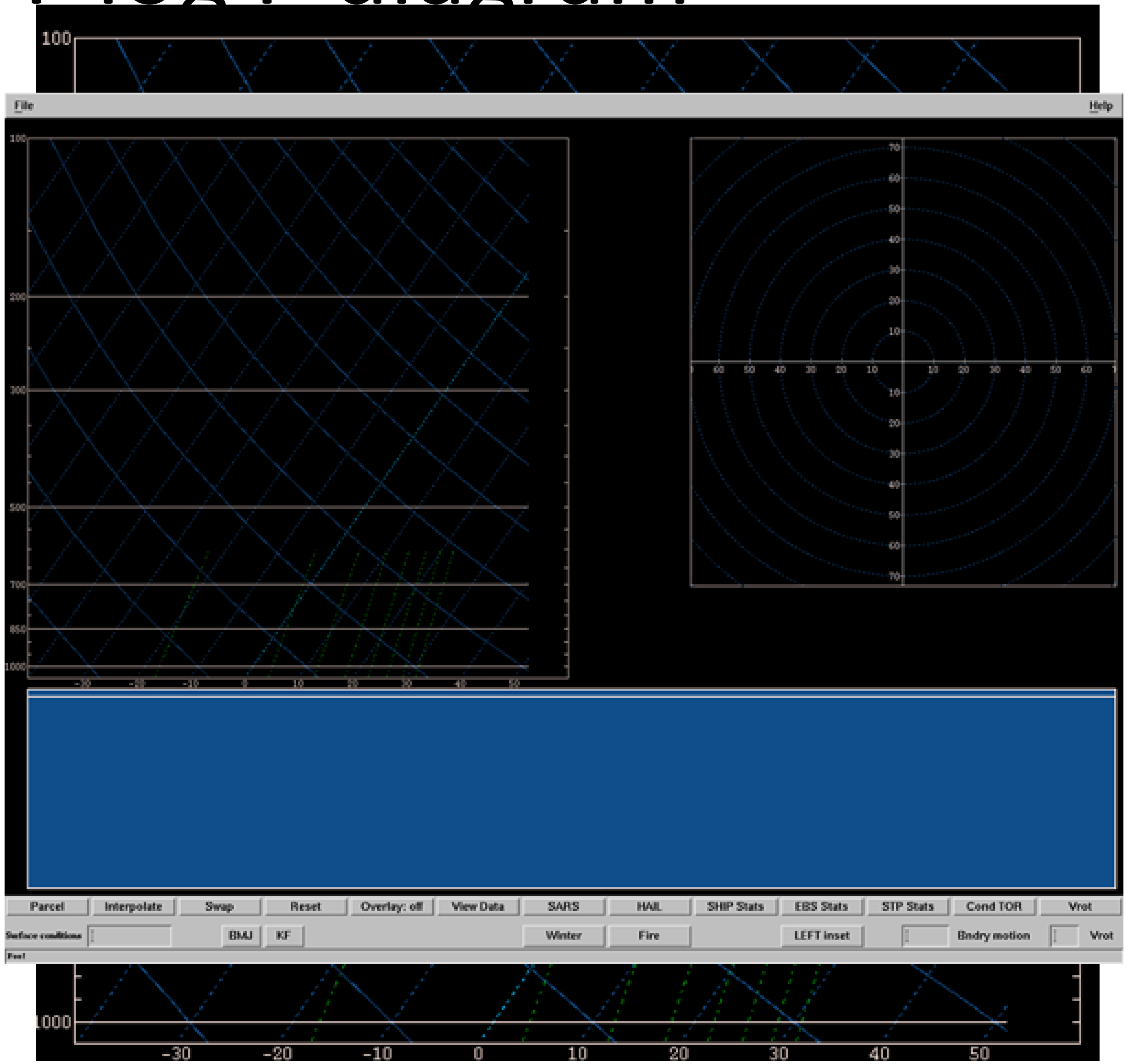
# Skew-T Diagram Basics

METR 4403/5403

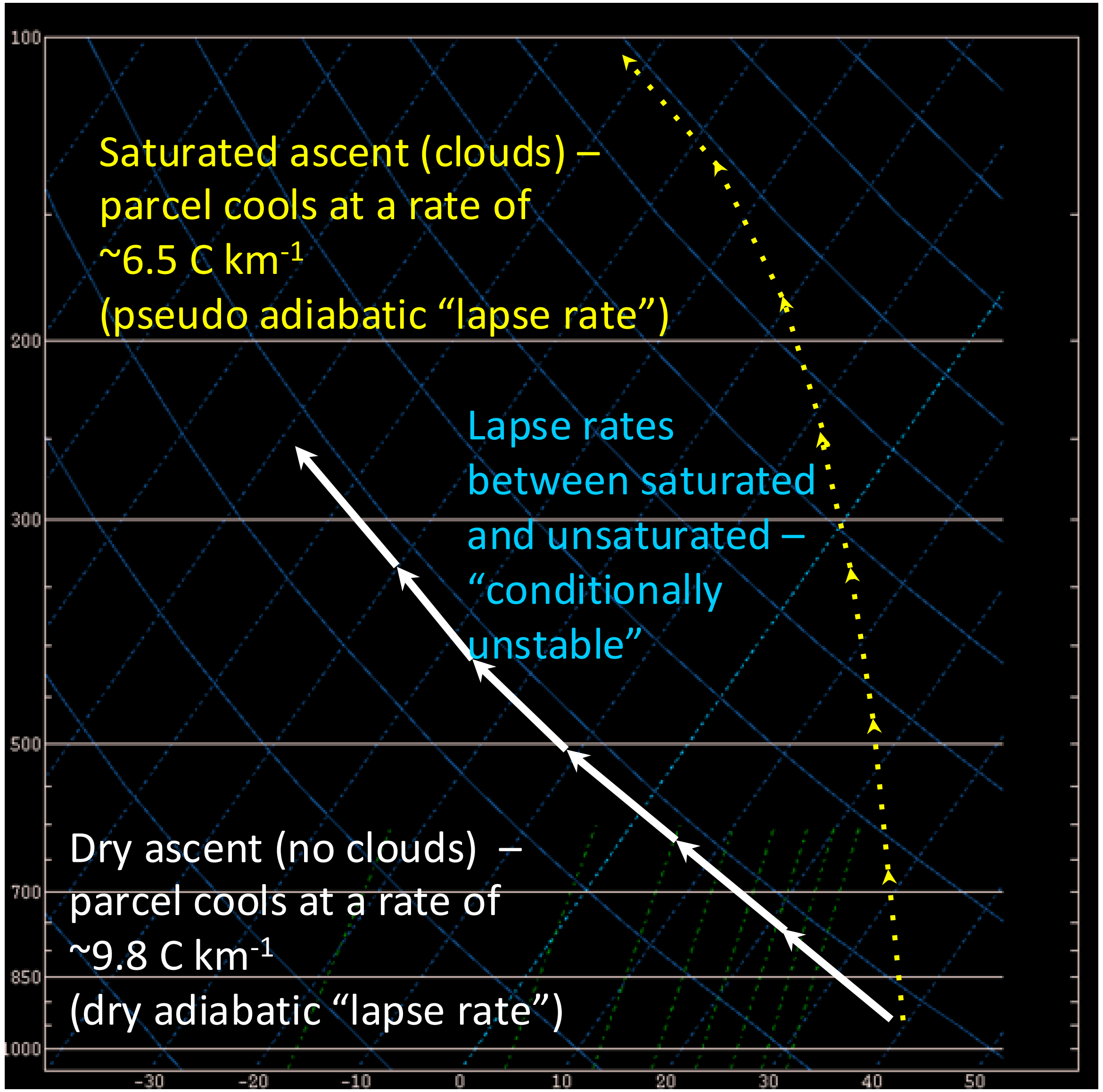
Material originally prepared by Rich Thompson

# Raw SkewT-log P diagram



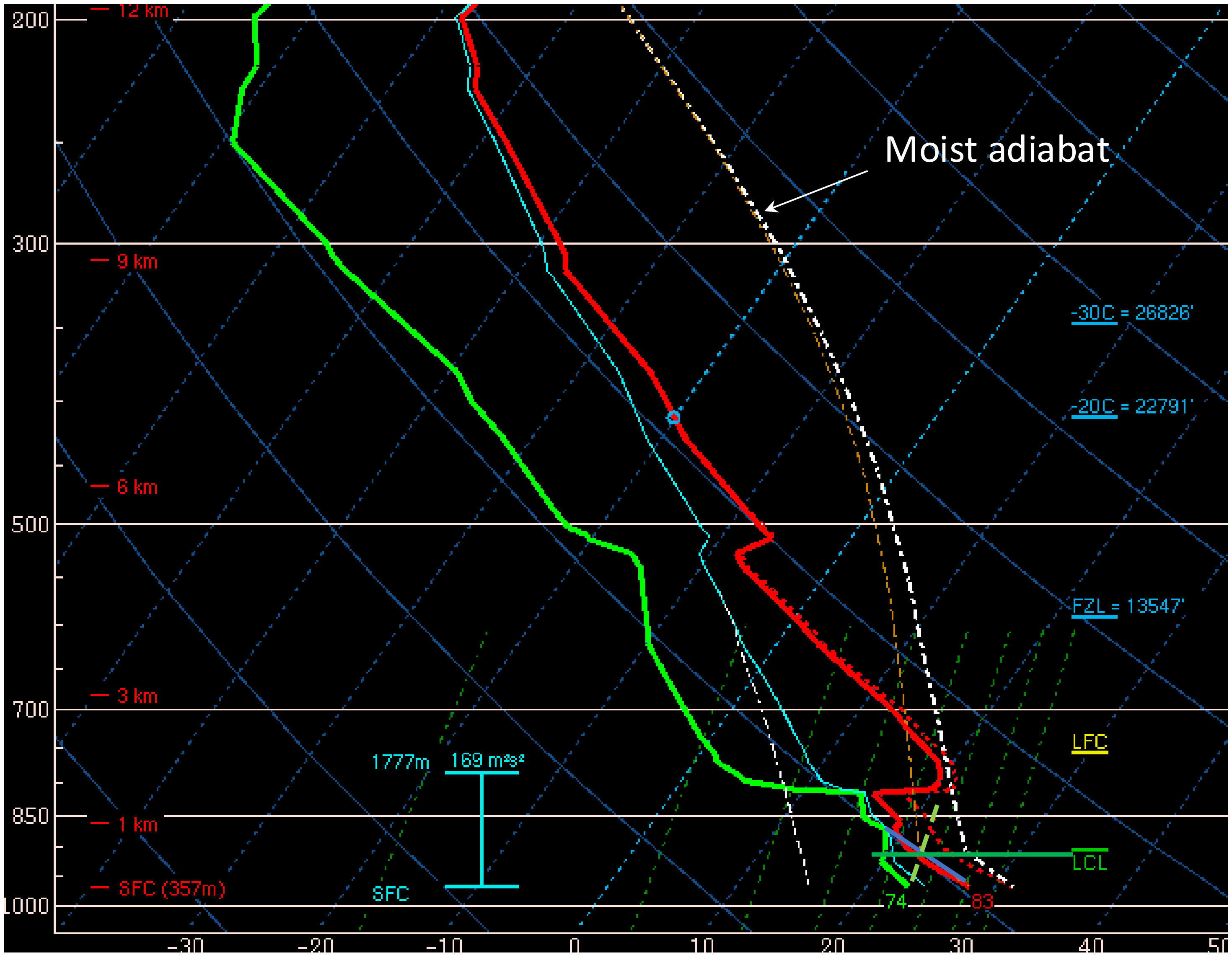
# Features of note in SkewT log P

- 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


Saturated ascent (clouds) –
parcel cools at a rate of
~6.5 C km-1
(pseudo adiabatic "lapse rate")
Lapse rates
between saturated
and unsaturated –
"conditionally
unstable"
Dry ascent (no clouds) –
parcel cools at a rate of
~9.8 C km-1
(dry adiabatic "lapse rate")
100
200
300
500
700
850
1000
-30
-20
-10
0
10
20
30
40
50

# 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

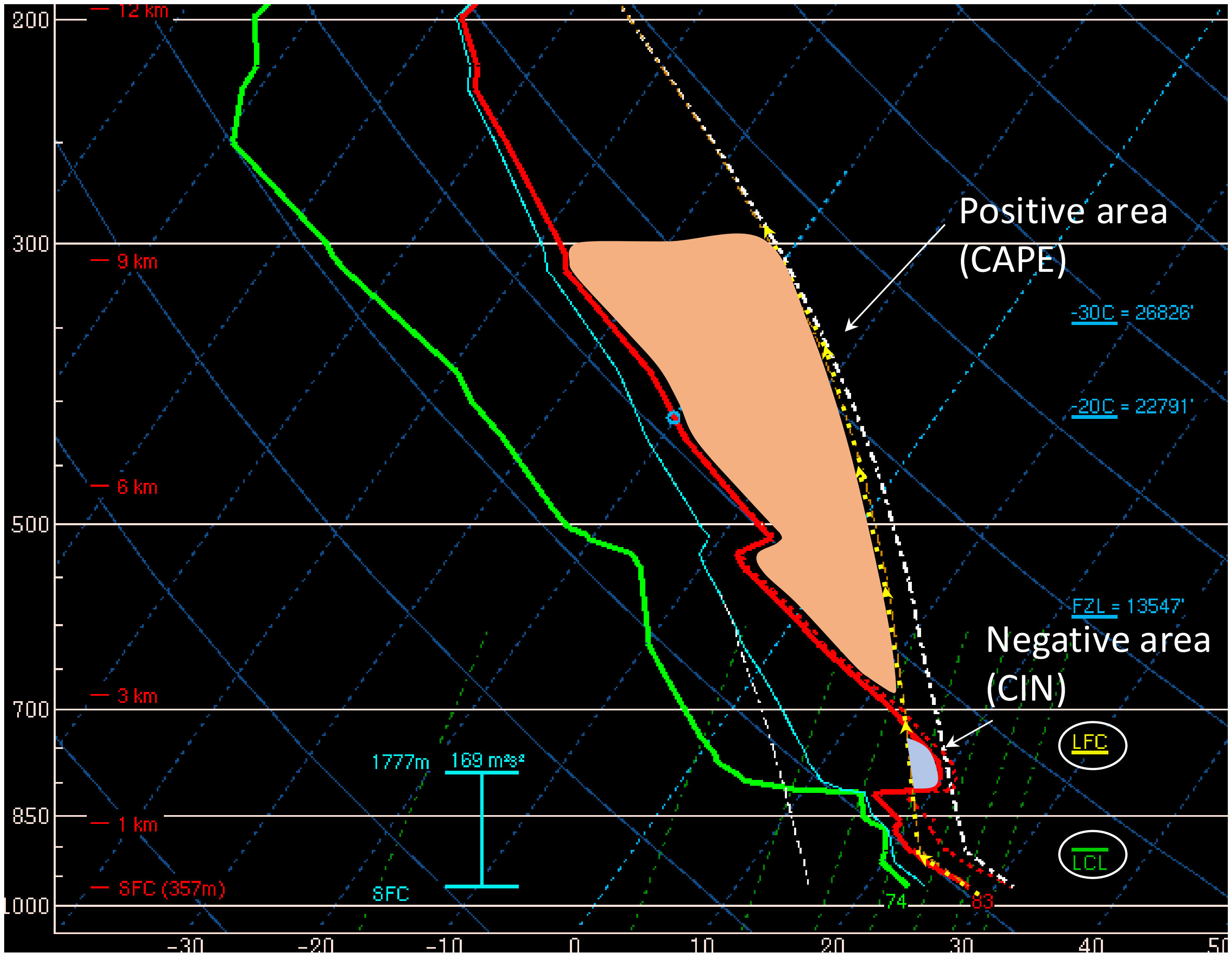

Moist adiabat
12 km
9 km
6 km
3 km
1 km
SFC (357m)
200
300
500
700
850
1000
-30C = 26826'
-20C = 22791'
FZL = 13547'
LFC
LCL
1777m
169 m²s²
SFC
74
83
-30
-20
-10
0
10
20
30
40
50

# 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

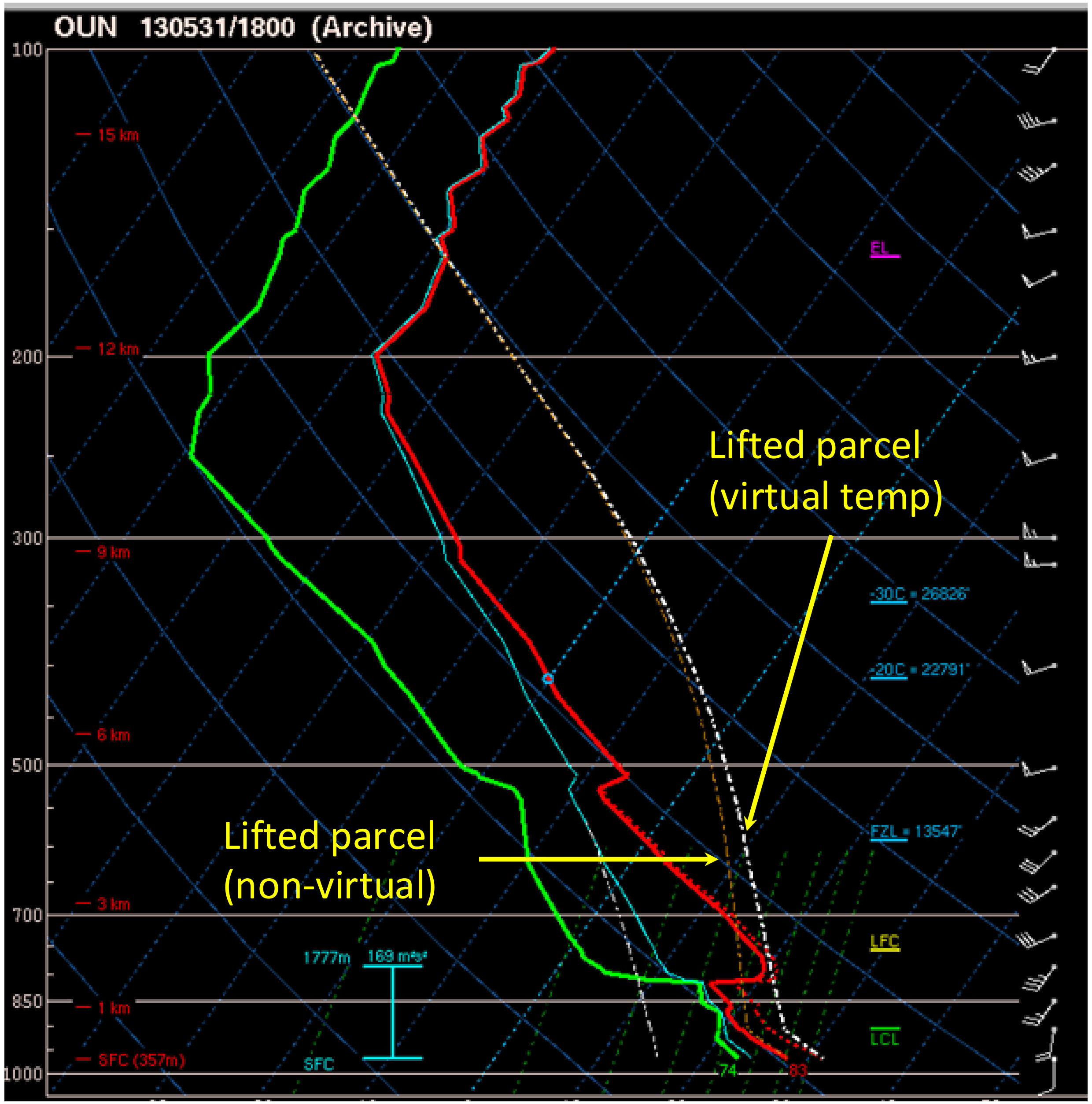
- Lapse rate – change in temperature with height
  - Dry adiabat ≈ 9.8 C $km^{-1}$
  - Moist adiabat ≈ 6.5 C $km^{-1}$
- Conditional instability – lapse rate between dry and moist adiabatic
- LCL – lifting condensation level
- LFC – level of free convection
- EL – equilibrium level
- CAPE – buoyancy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

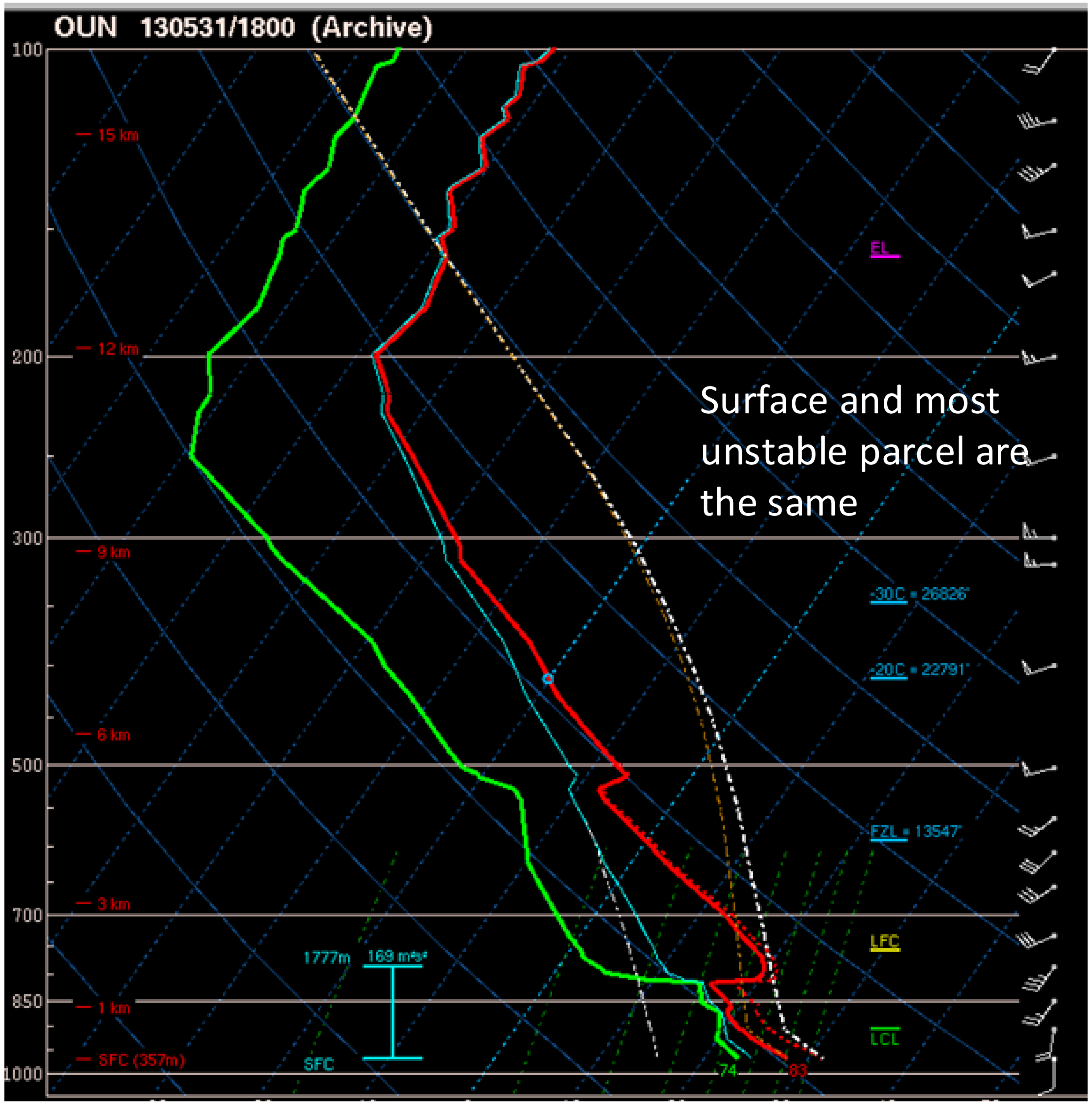


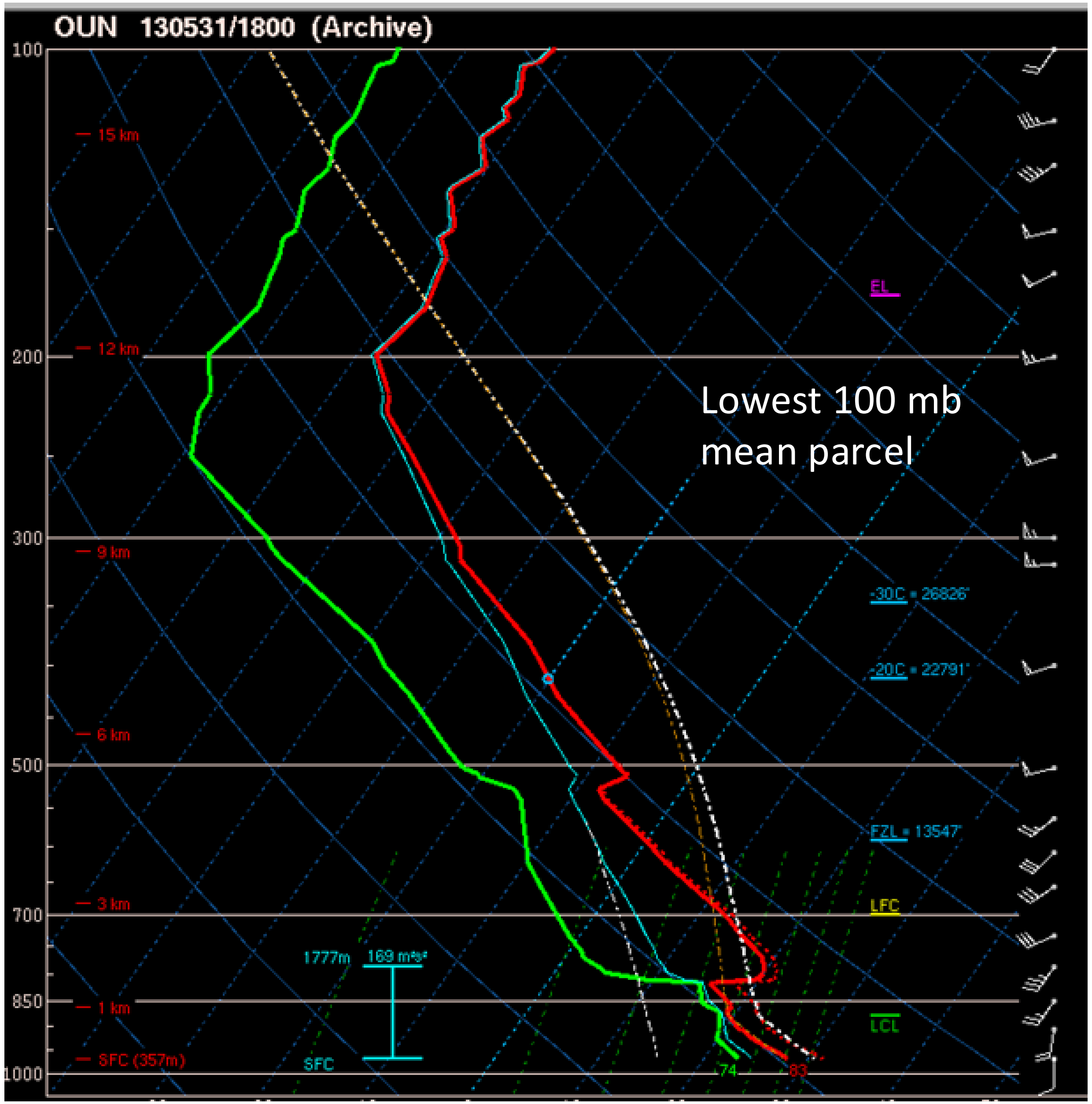
Positive area (CAPE)
Negative area (CIN)
-30C = 26826'
-20C = 22791'
FZL = 13547'
LFC
LCL
12 km
9 km
6 km
3 km
1 km
SFC (357m)
1777m
169 m²s²
SFC
200
300
500
700
850
1000
-30
-20
-10
0
10
20
30
40
50
74
83

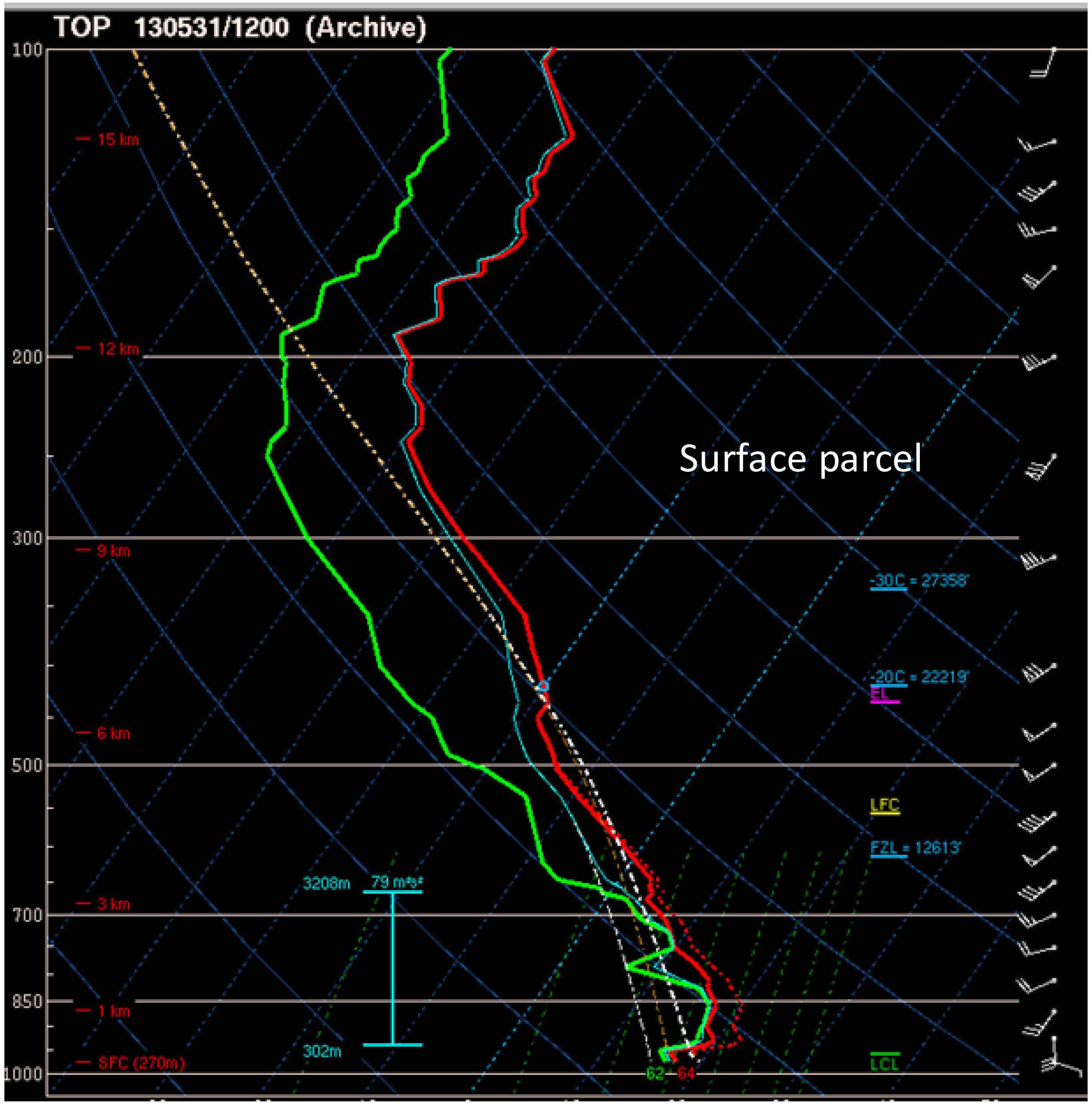
# What’s the difference between the lifted parcels?

- 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”

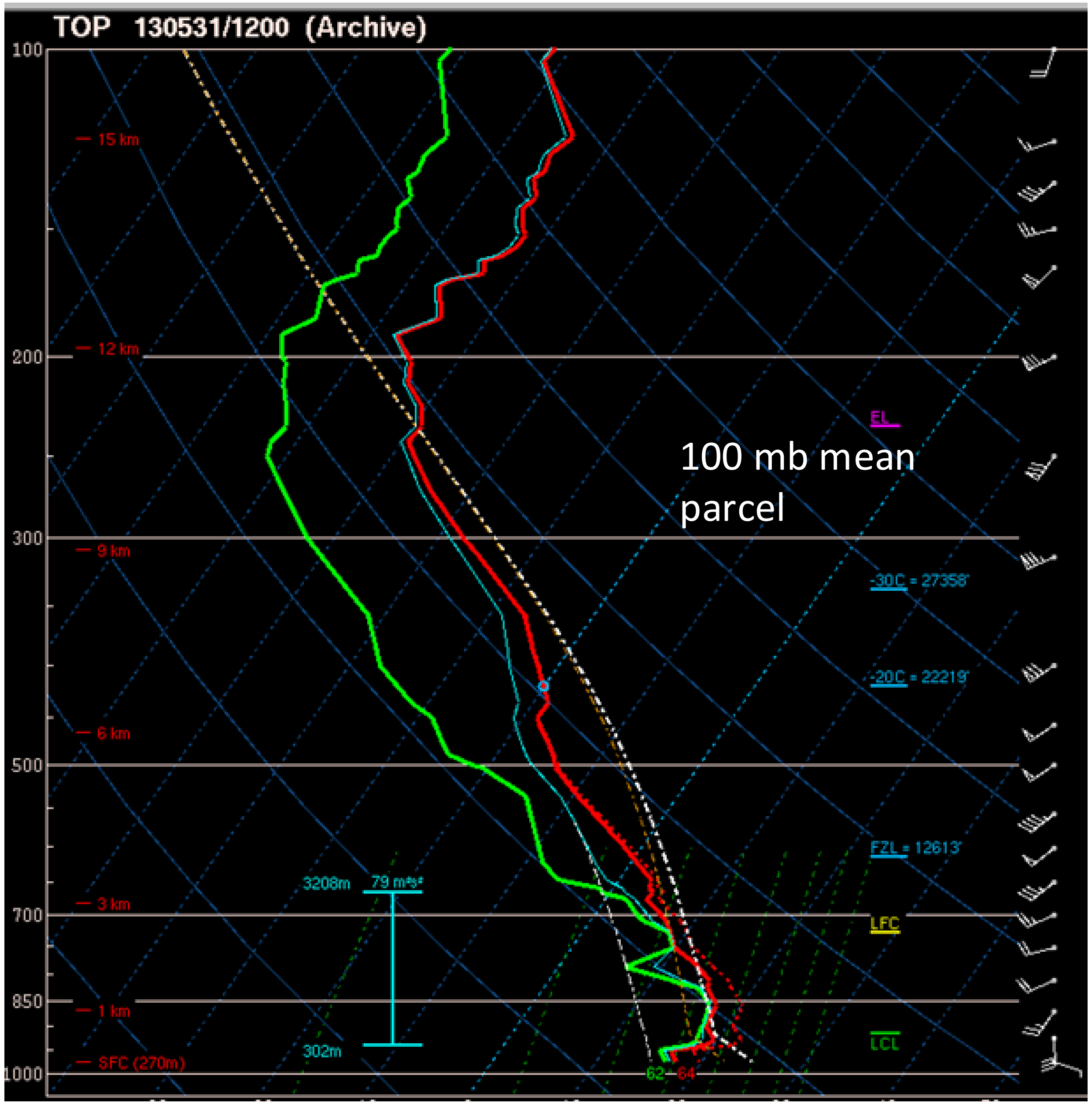

OUN 130531/1800 (Archive)
100
200
300
500
700
850
1000
15 km
12 km
9 km
6 km
3 km
1 km
SFC (357m)
EL
-30C = 26826'
-20C = 22791'
FZL = 13547'
LFC
LCL
1777m
SFC
74
83
Lifted parcel
(virtual temp)
Lifted parcel
(non-virtual)


OUN 130531/1800 (Archive)
100
15 km
12 km
200
300
9 km
6 km
500
3 km
700
850
1 km
1000
SFC (357m)
1777m
169 m²s²
SFC
EL
-30C = 26826'
-20C = 22791'
FZL = 13547'
LFC
LCL
74
83
Surface and most unstable parcel are the same

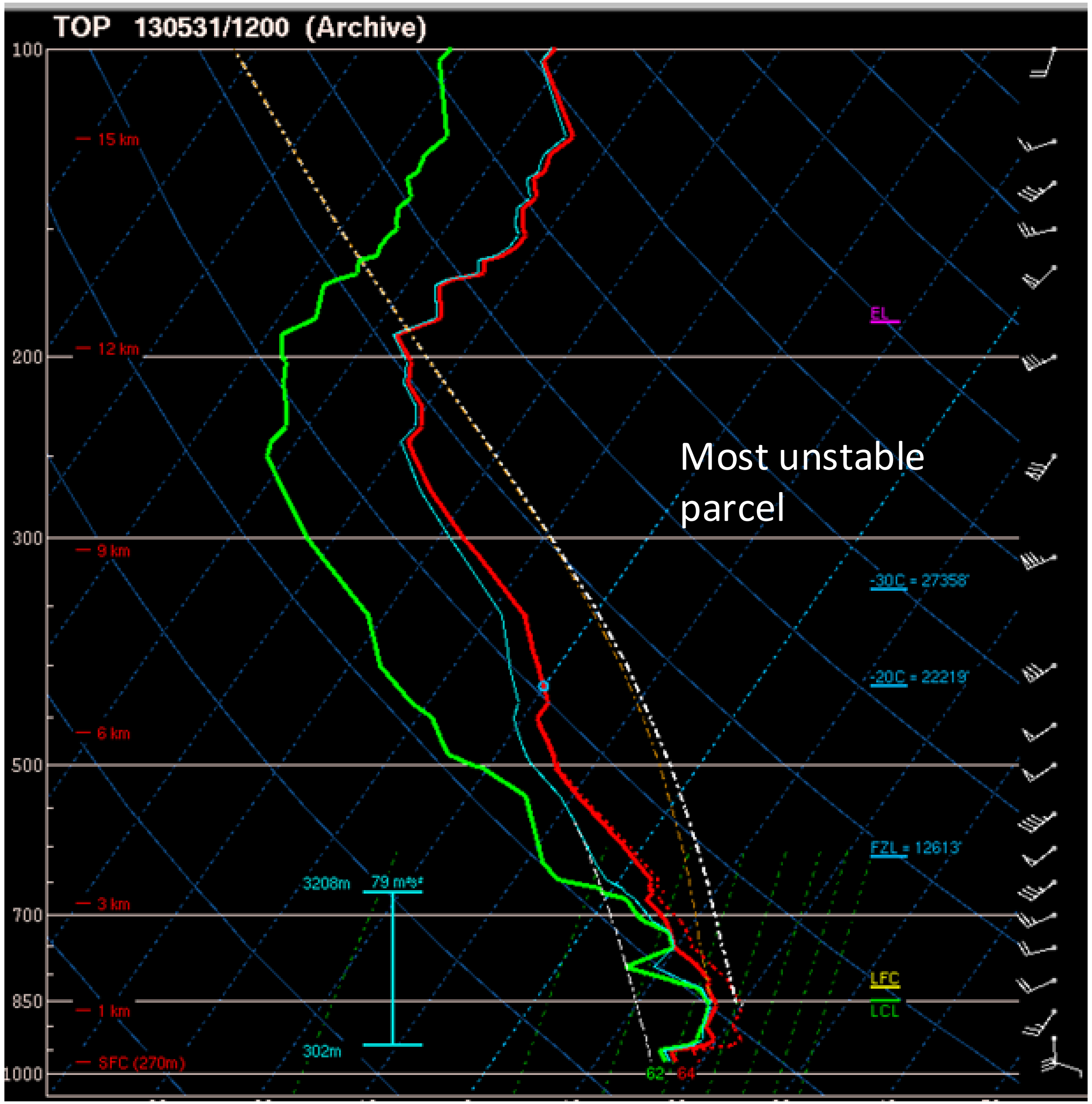

OUN 130531/1800 (Archive)
Lowest 100 mb mean parcel
100
200
300
500
700
850
1000
15 km
12 km
9 km
6 km
3 km
1 km
SFC (357m)
EL
-30C = 26826'
-20C = 22791'
FZL = 13547'
LFC
LCL
1777m
169 m²/s²
SFC
74
83



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




100 mb mean parcel


TOP 130531/1200 (Archive)
Most unstable parcel
15 km
12 km
9 km
6 km
3 km
1 km
SFC (270m)
100
200
300
500
700
850
1000
EL
-30C = 27358'
-20C = 22219'
FZL = 12613'
LFC
LCL
3208m
79 m²/s²
302m
62
64

# What are we assuming?

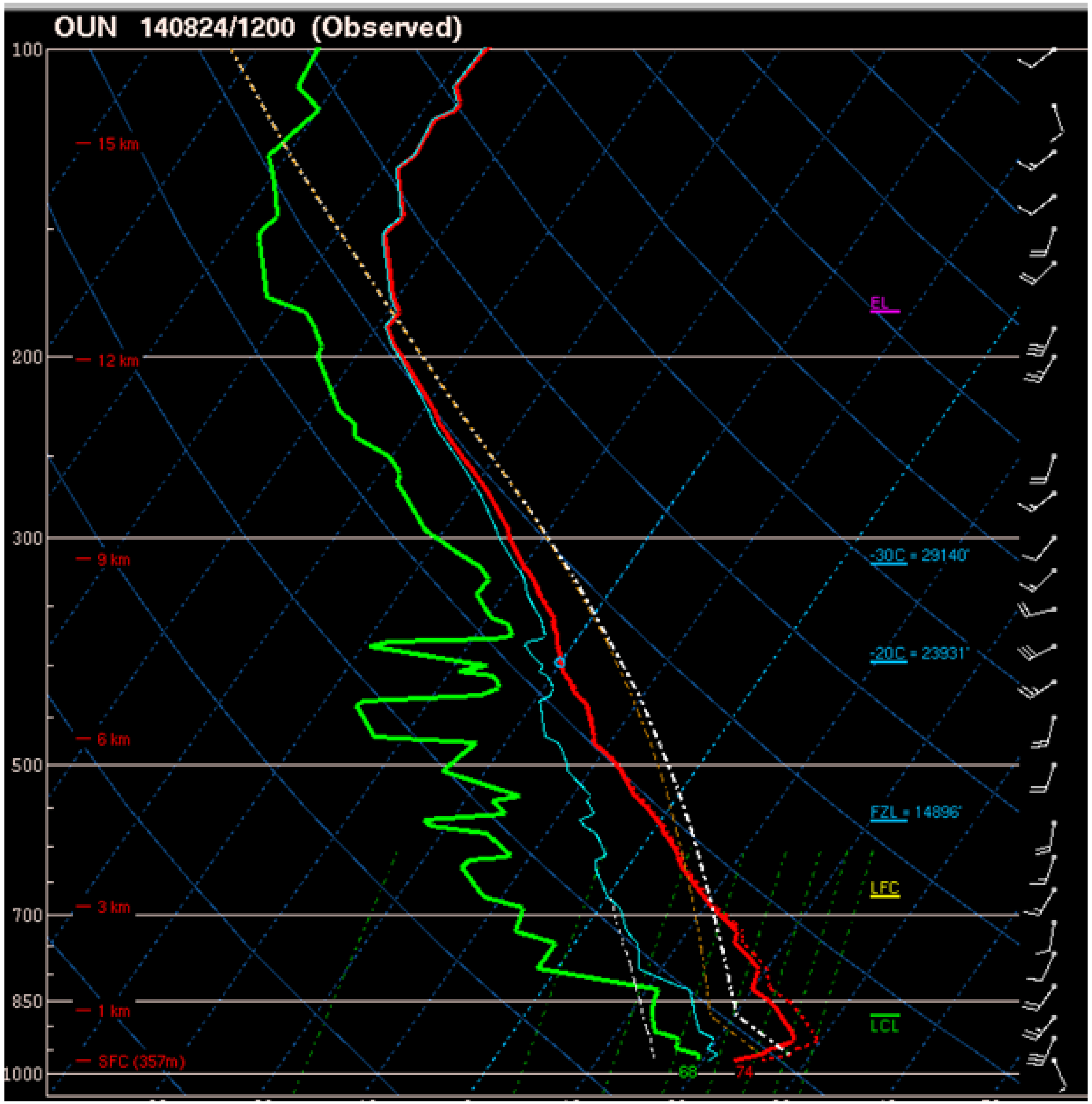
- No mixing with environment (not true)
  - “entrainment” usually reduces updraft strength from expectations based on CAPE alone
- All rain falls out instantly (not true)
  - Suspended rain particles reduces updraft strength
  - That’s why we say “pseudo” adiabatic for saturated parcel ascent
- “Parcel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

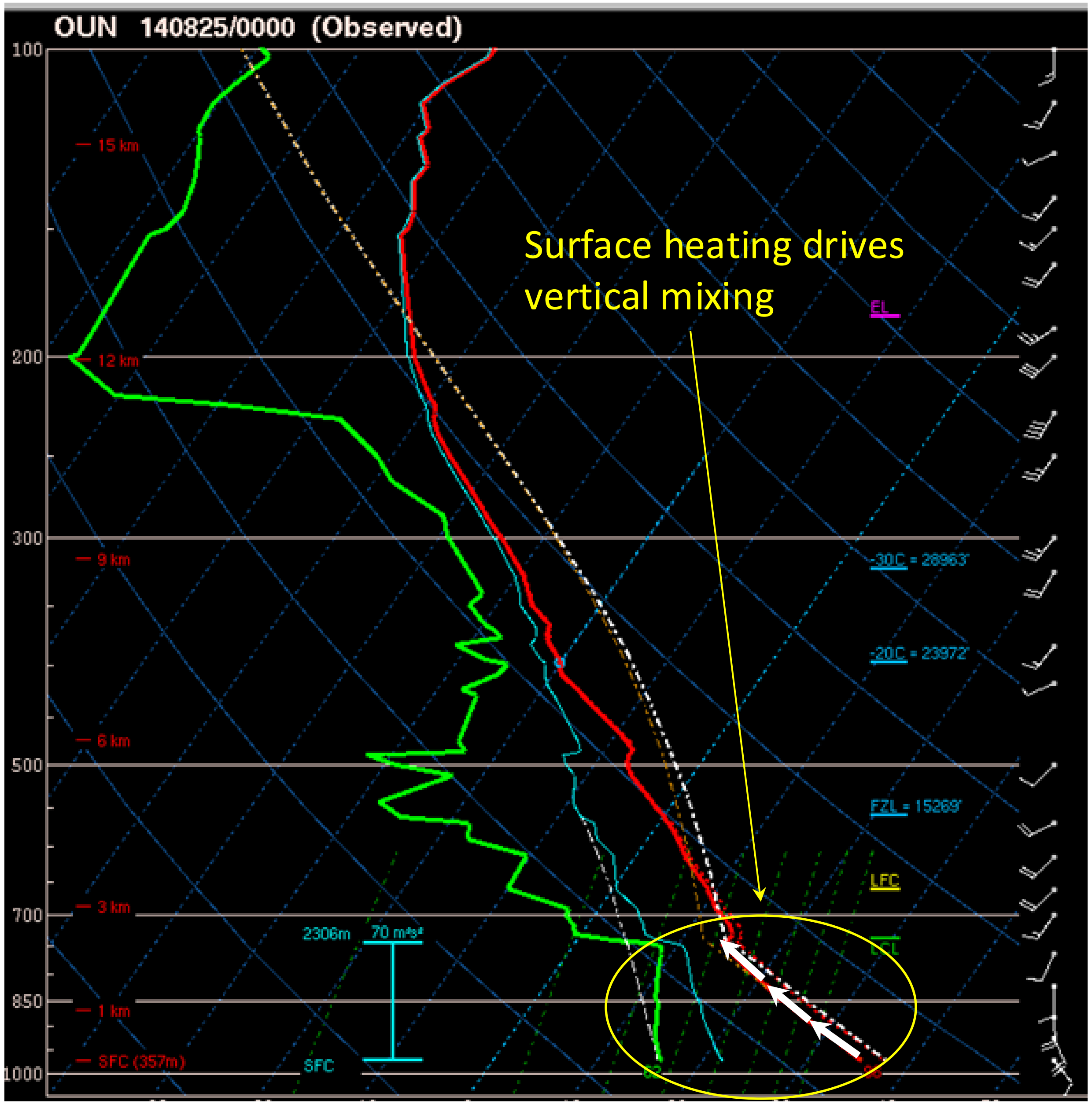
# Always keep in mind what we don’t know:

- 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!

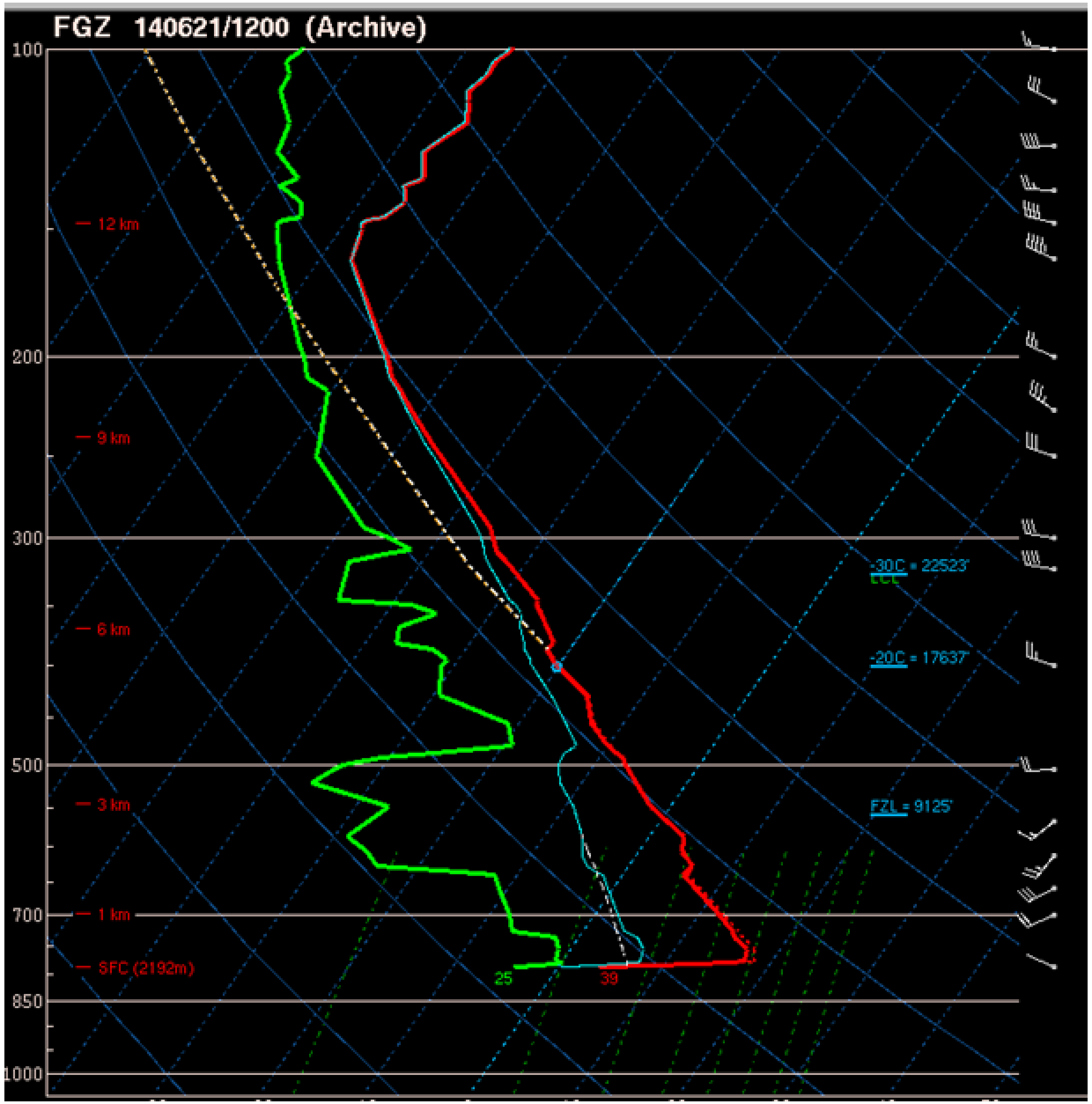
# Simple vertical mixing

- 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)

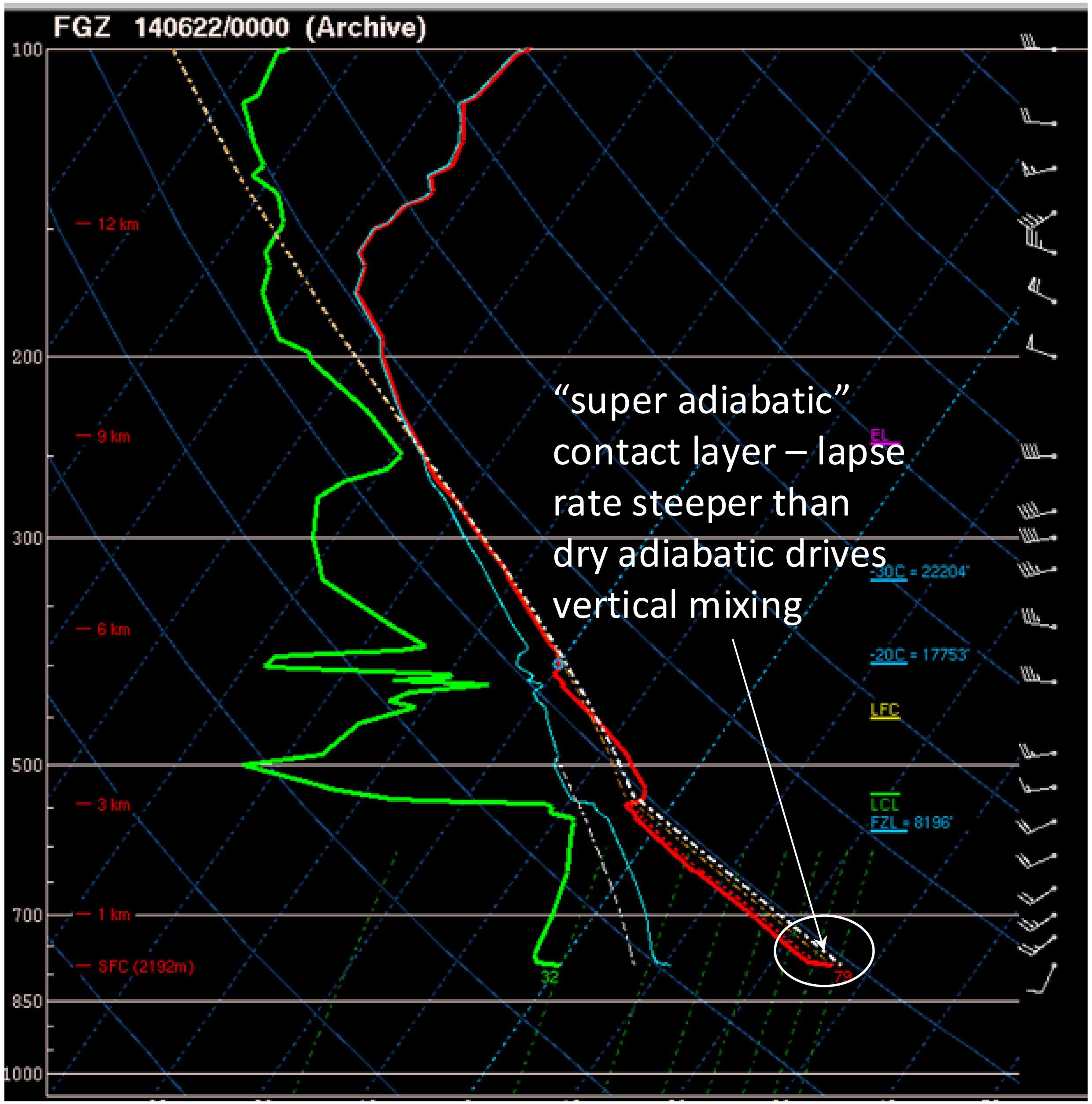

OUN 140824/1200 (Observed)
100
200
300
500
700
850
1000
15 km
12 km
9 km
6 km
3 km
1 km
SFC (357m)
EL
-30C = 29140'
-20C = 23931'
FZL = 14896'
LFC
LCL
68
74



OUN 140825/0000 (Observed)
Surface heating drives
vertical mixing
15 km
12 km
9 km
6 km
3 km
1 km
SFC (357m)
100
200
300
500
700
850
1000
EL
-30C = 28963'
-20C = 23972'
FZL = 15269'
LFC
2306m
70 m²/s²
SFC

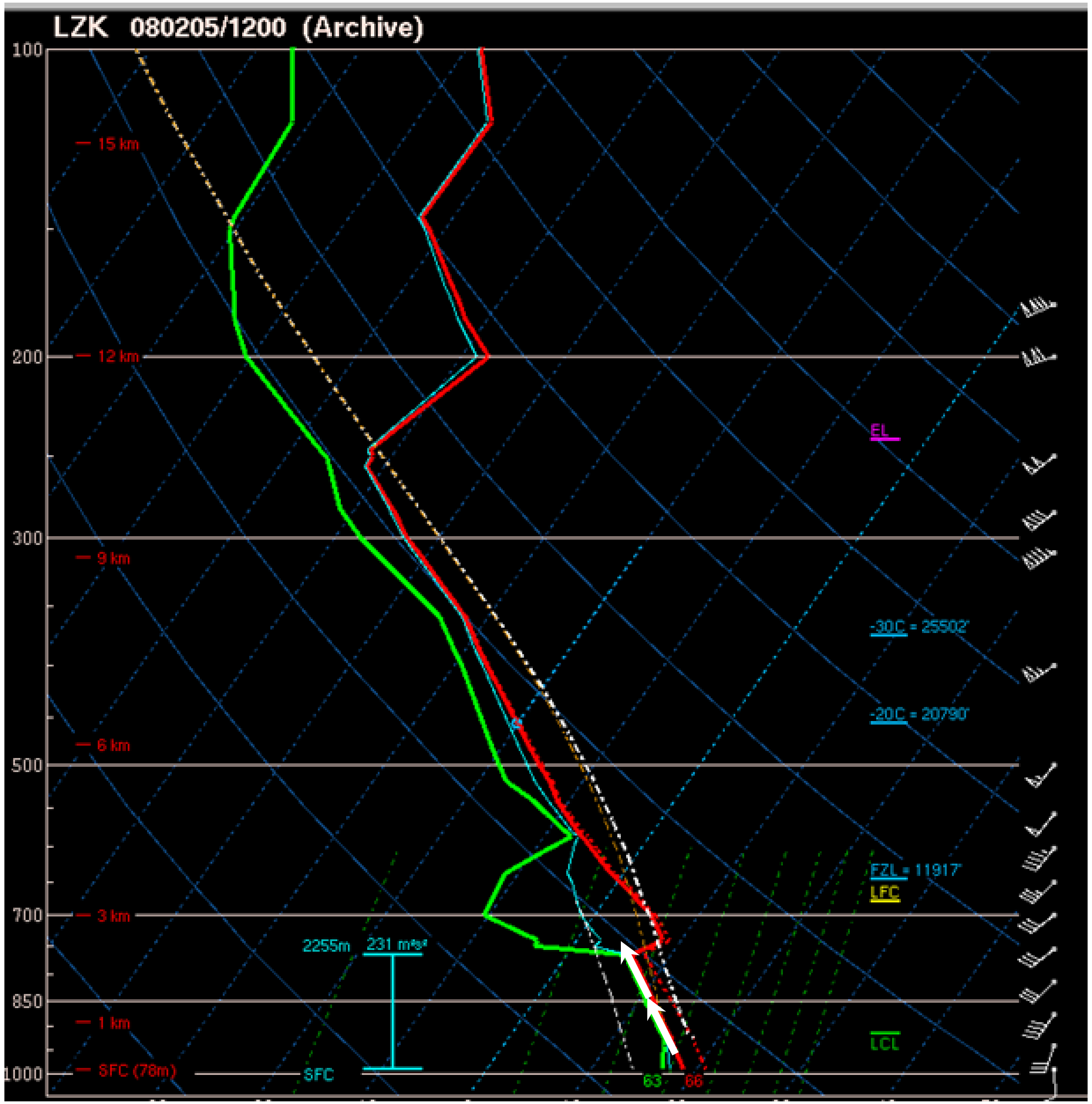


FGZ 140621/1200 (Archive)
100
200
300
500
700
850
1000
12 km
9 km
6 km
3 km
1 km
SFC (2192m)
25
39
-30C = 22523'
LCL
-20C = 17637'
FZL = 9125'

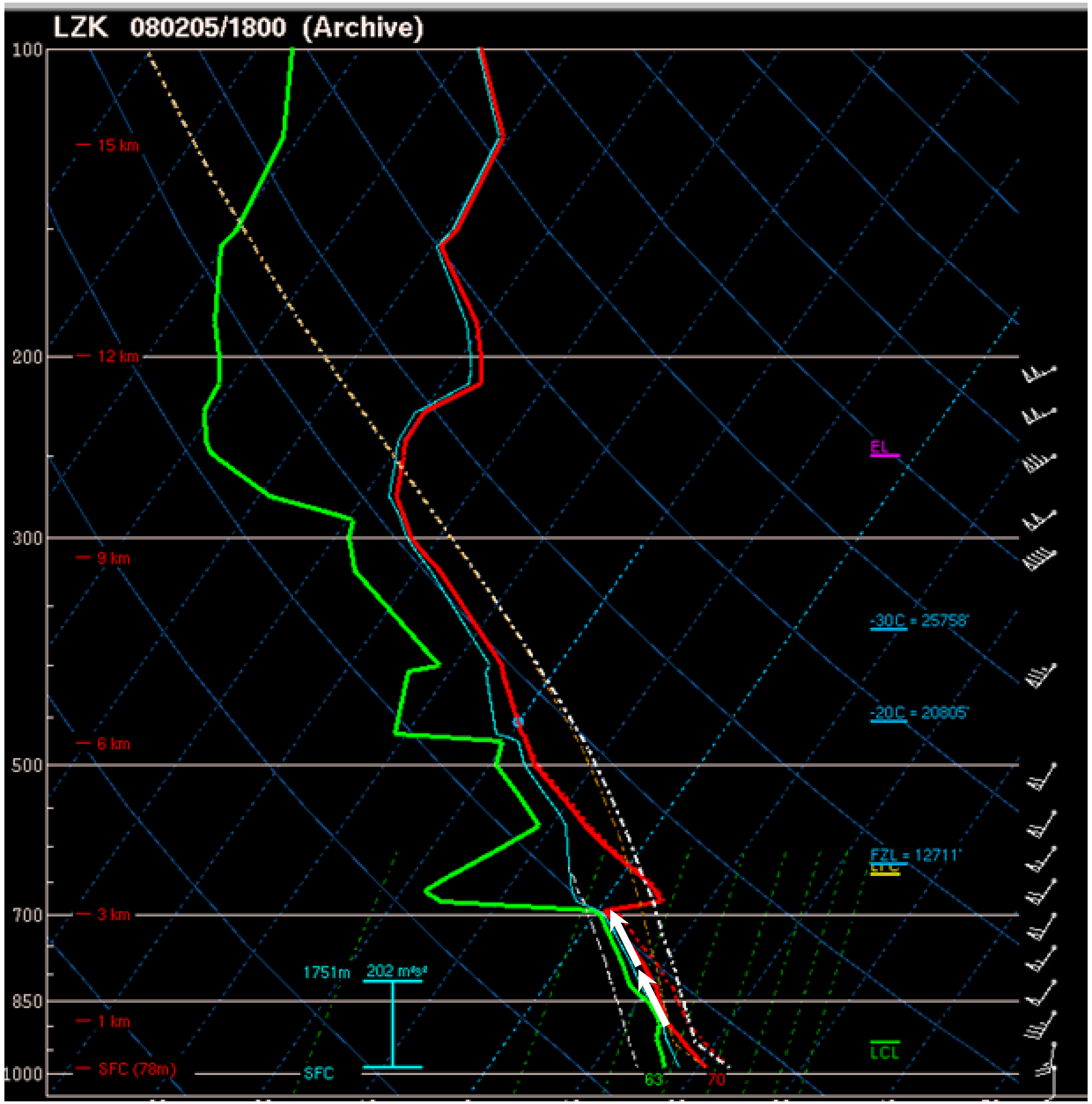

FGZ 140622/0000 (Archive)
100
200
300
500
700
850
1000
12 km
9 km
6 km
3 km
1 km
SFC (2192m)
32
79
EL
-30C = 22204'
-20C = 17753'
LFC
LCL
FZL = 8196'
"super adiabatic" contact layer – lapse rate steeper than dry adiabatic drives vertical mixing

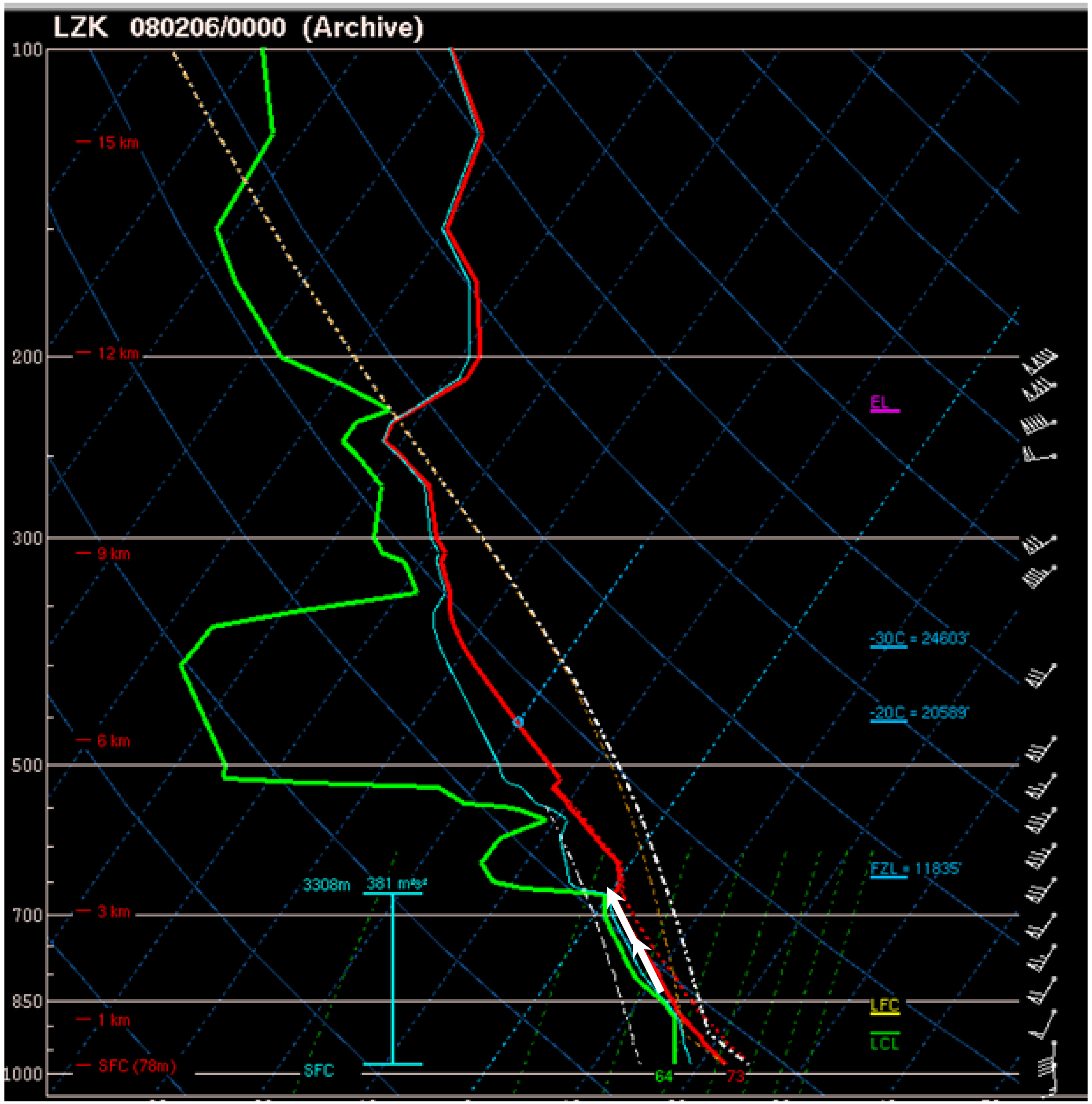
# Impact of ascent and moisture advection

- 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

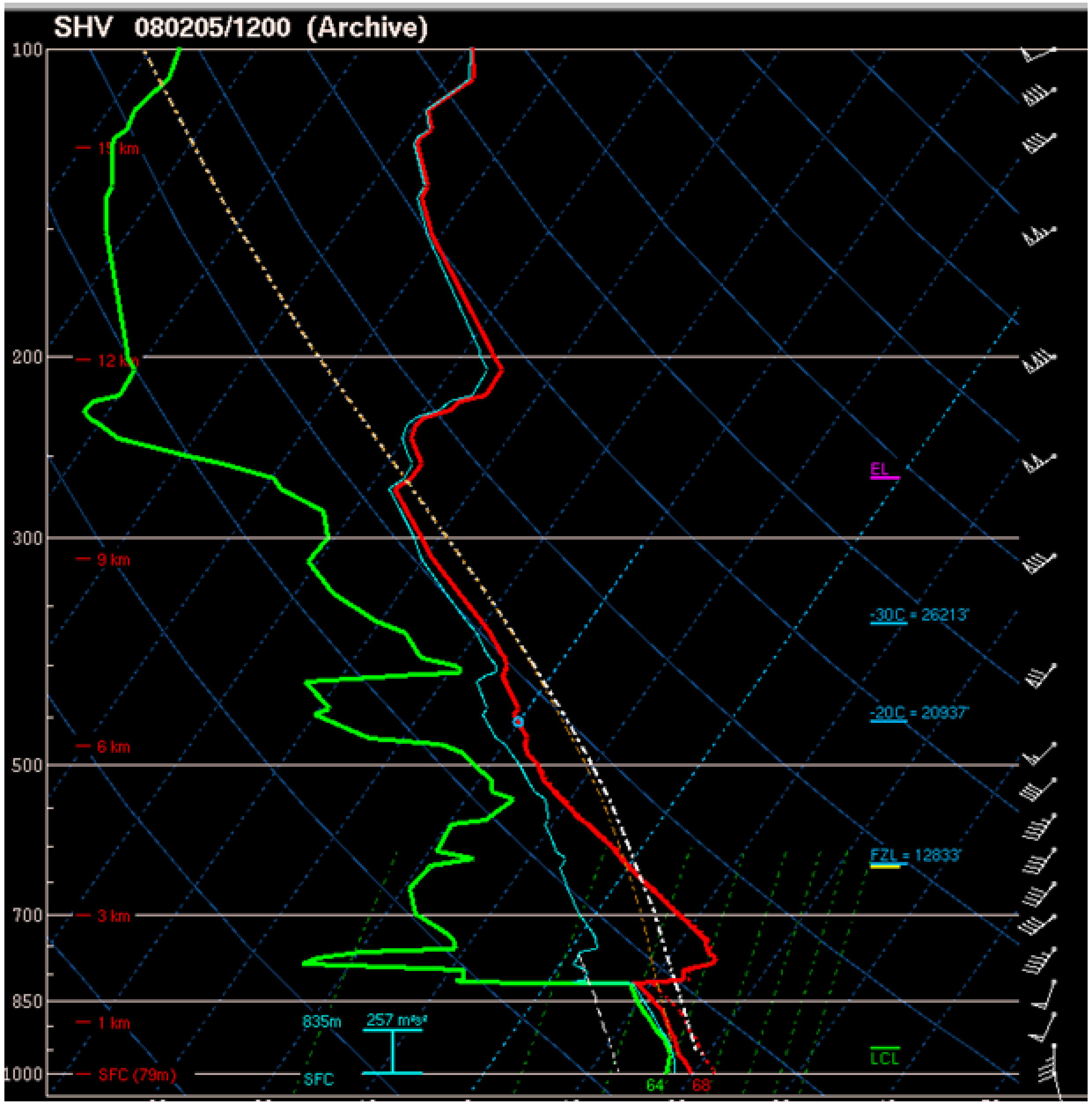


LZK 080205/1200 (Archive)
100
200
300
500
700
850
1000
15 km
12 km
9 km
6 km
3 km
1 km
SFC (78m)
SFC
2255m
231 m²s²
EL
-30C = 25502'
-20C = 20790'
FZL = 11917'
LFC
LCL
63
66

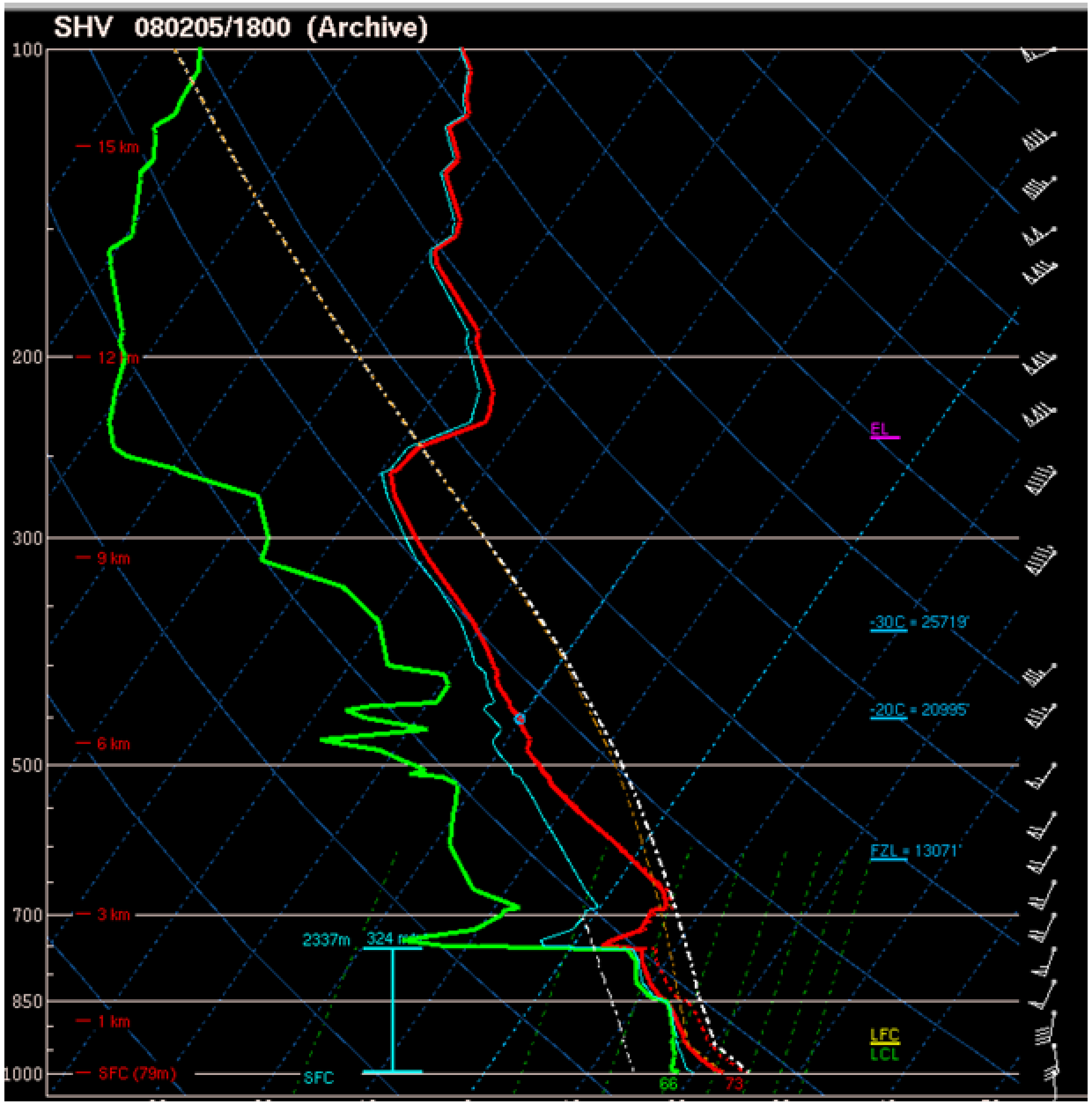

LZK 080205/1800 (Archive)
100
200
300
500
700
850
1000
15 km
12 km
9 km
6 km
3 km
1 km
SFC (78m)
SFC
1751m
202 m²s²
EL
-30C = 25758'
-20C = 20805'
FZL = 12711'
LCL
63
70



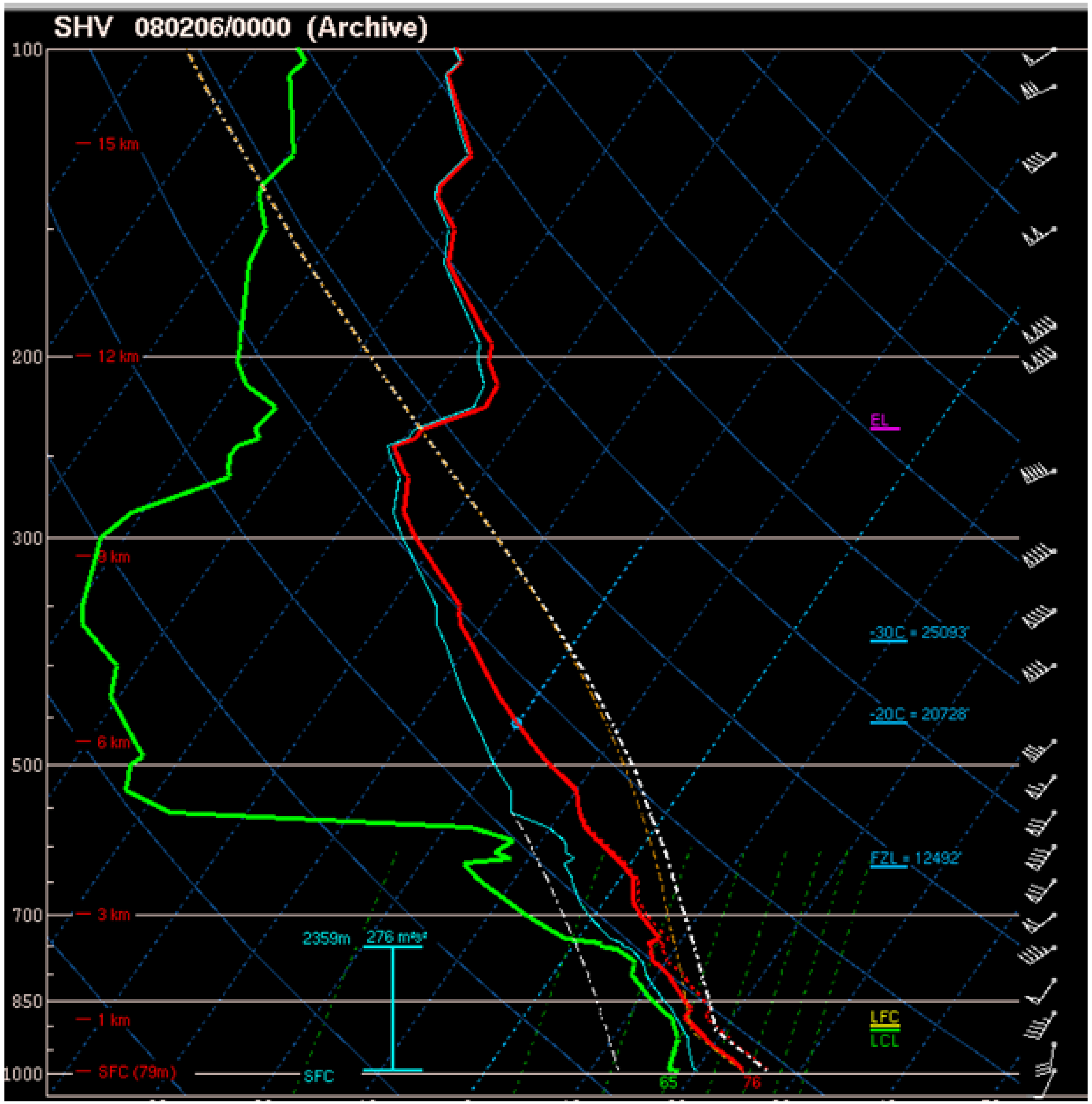
LZK 080206/0000 (Archive)
100
15 km
200
12 km
EL
300
9 km
-30C = 24603'
-20C = 20589'
6 km
500
FZL = 11835'
3308m
381 m²s²
700
3 km
850
LFC
1 km
LCL
1000
SFC (78m)
SFC
64
73



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



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


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

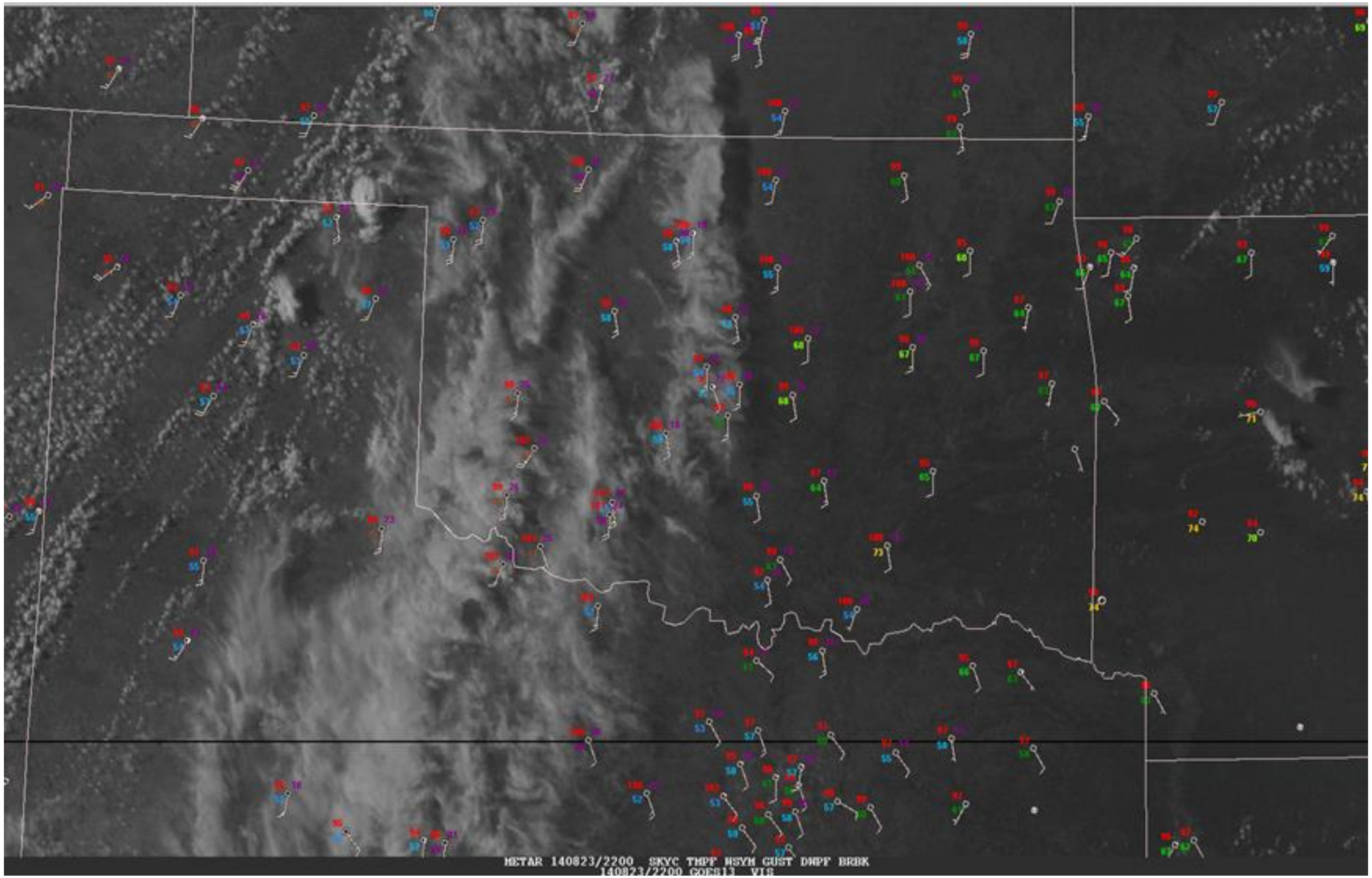
# Sounding diagrams are used for…

- 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!

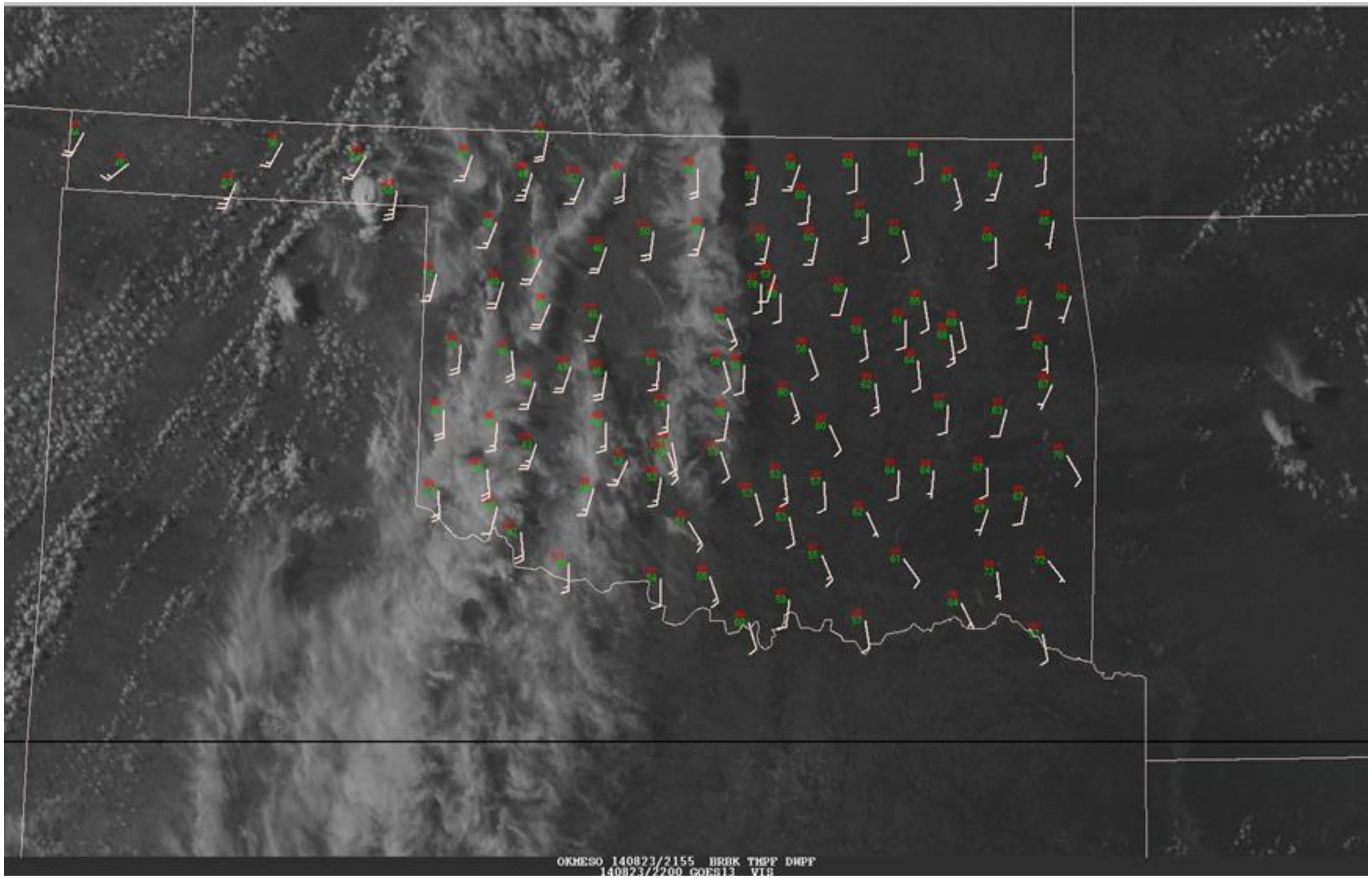
# Quality of Surface Observations?

Courtesy of Oklahoma Mesonet

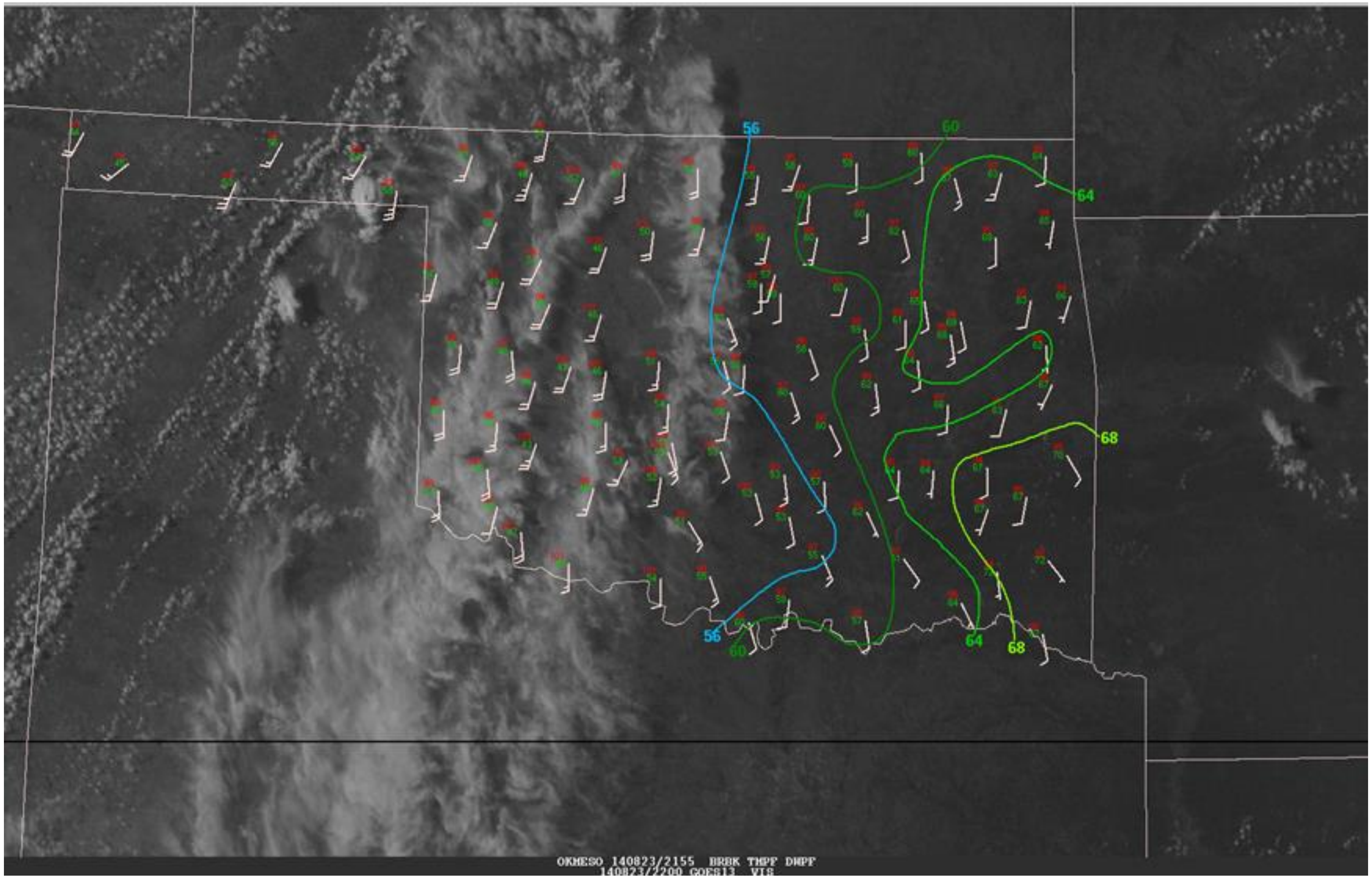
# Standard surface observations



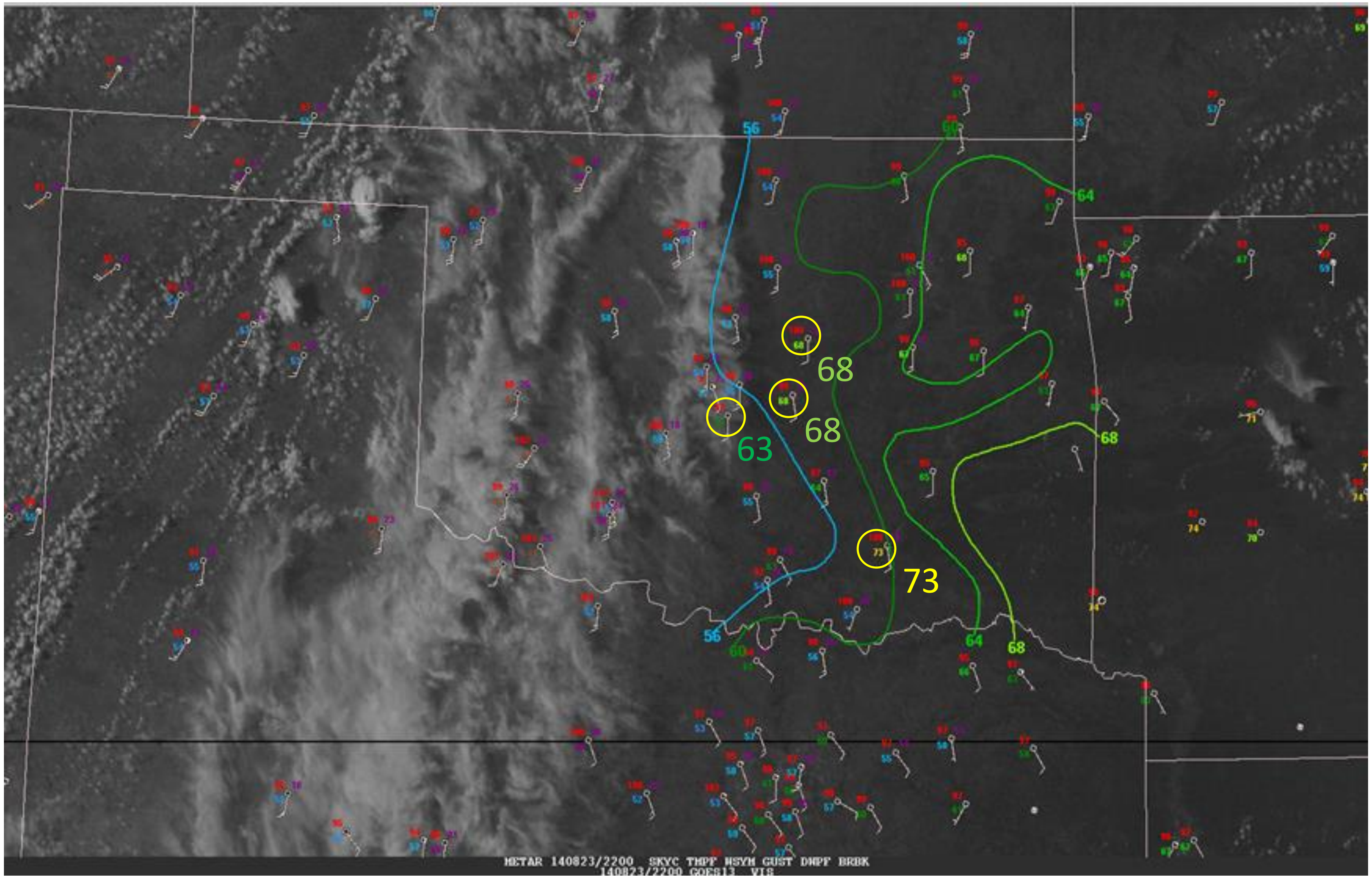
# OK mesonet observations at the same time



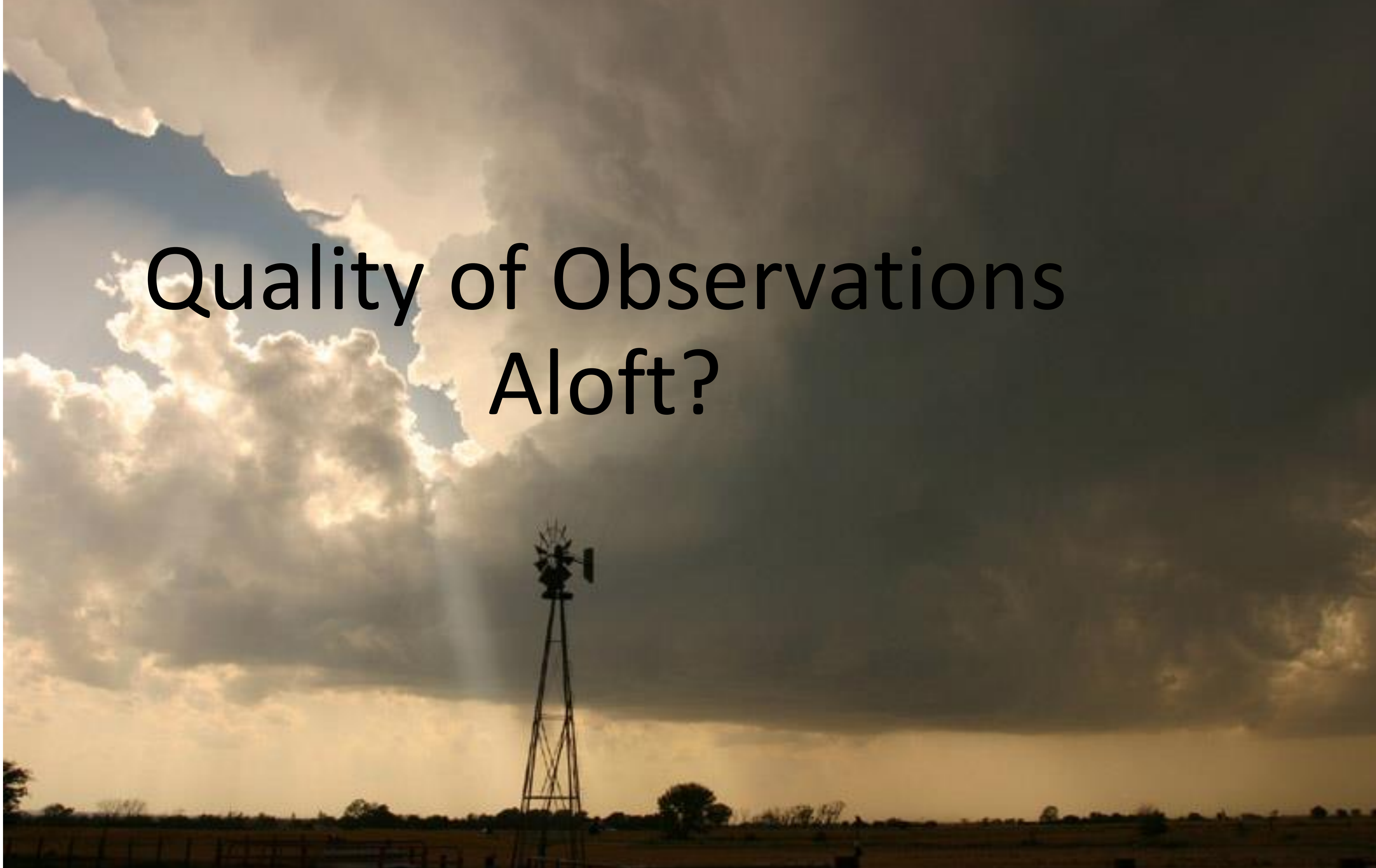
# Dew point analysis for OK mesonet observations

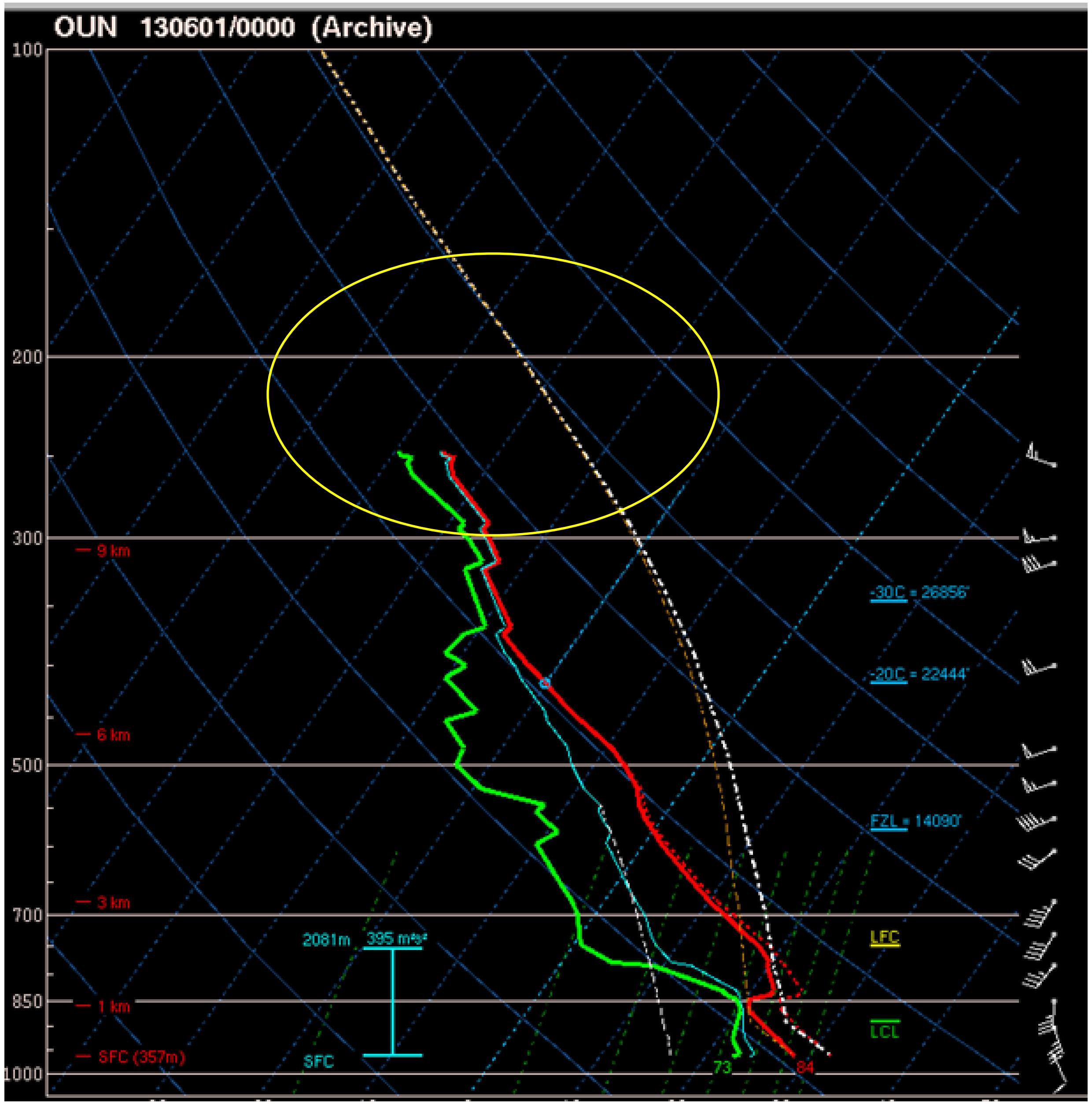


# What do these sites have in common?

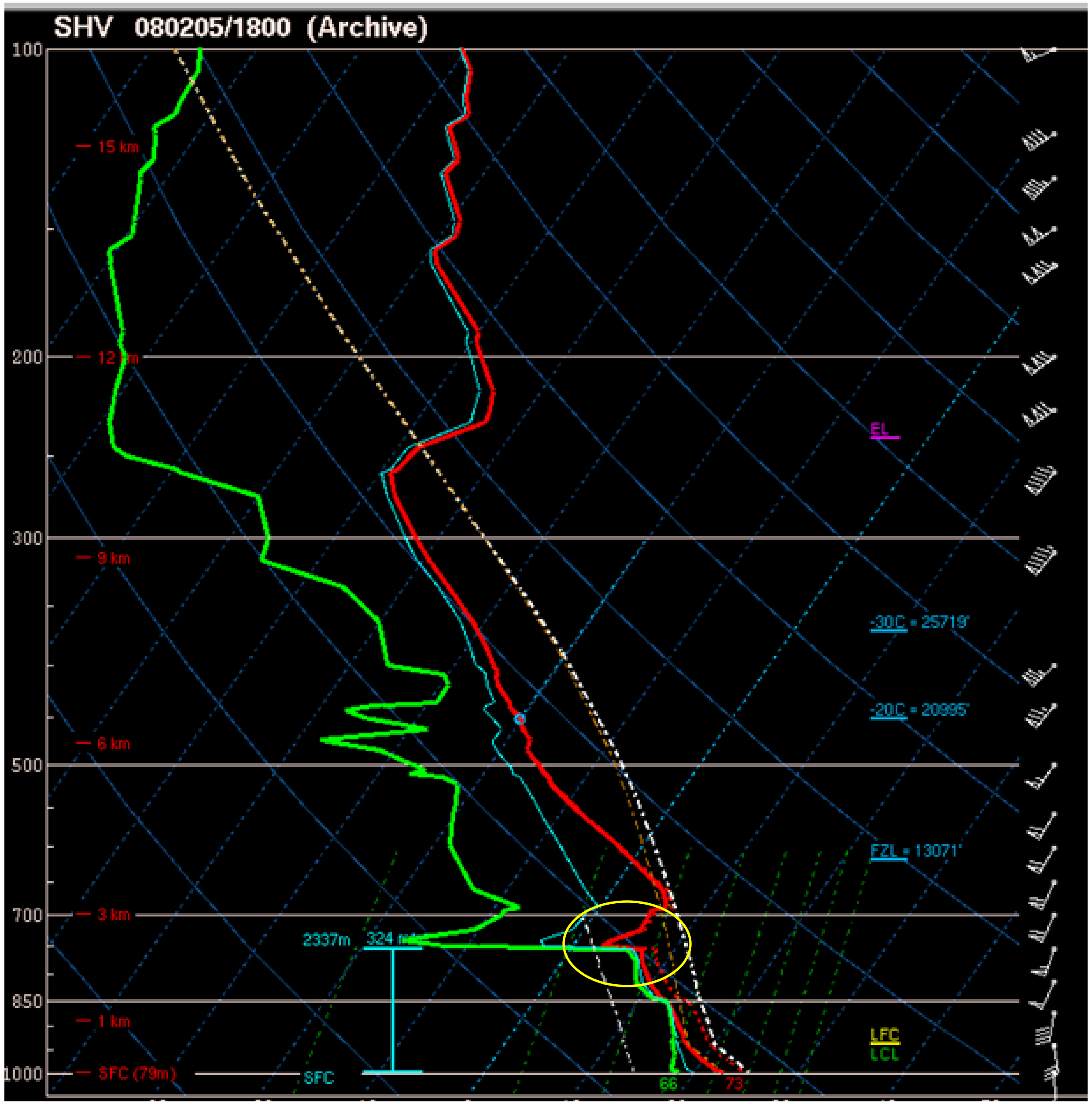


# Quality of Observations Aloft?

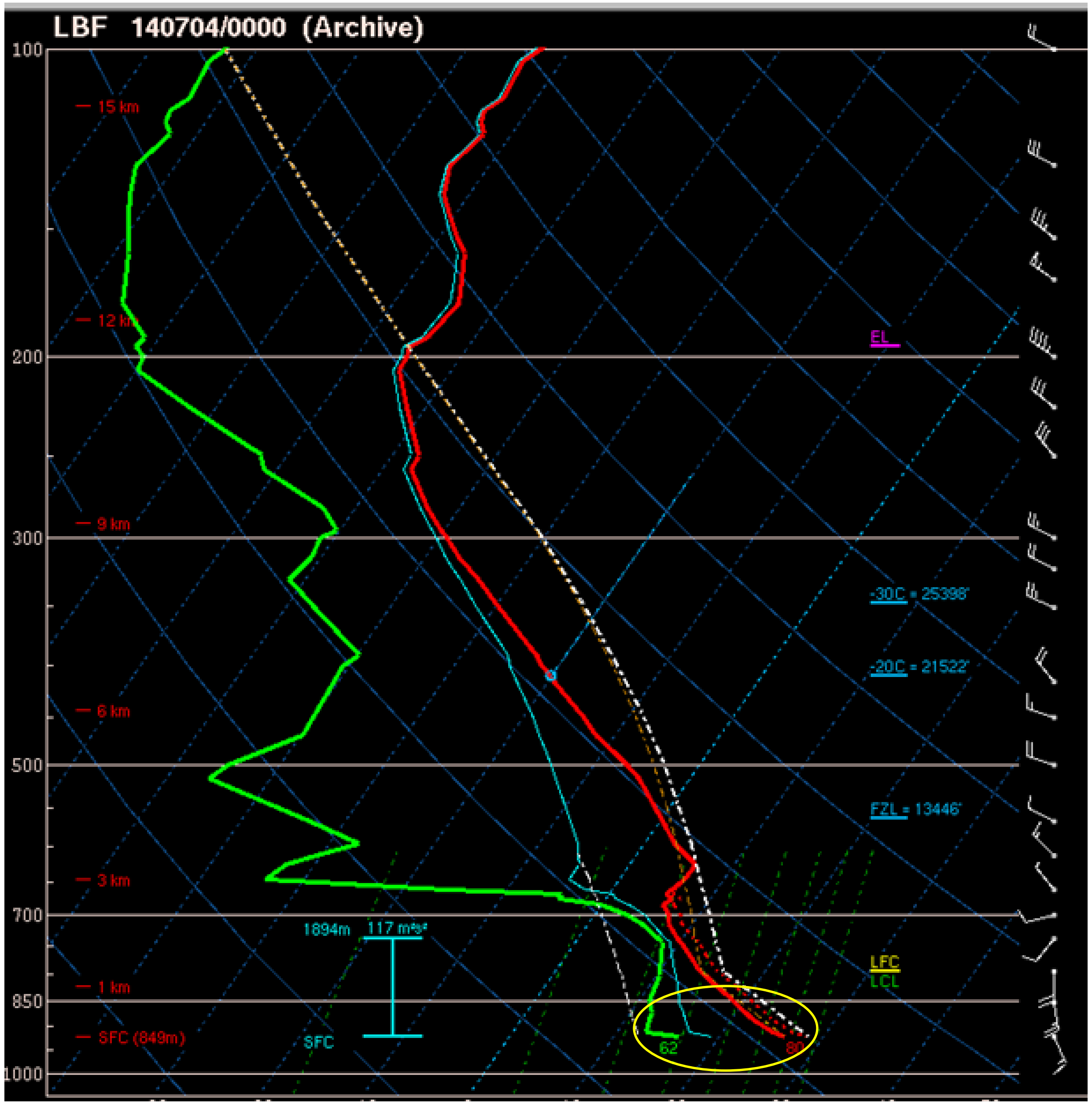




OUN 130601/0000 (Archive)
100
200
300
500
700
850
1000
9 km
6 km
3 km
1 km
SFC (357m)
-30C = 26856'
-20C = 22444'
FZL = 14090'
LFC
LCL
2081m 395 m²/s²
SFC
73
84



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)
2337m
SFC
EL
-30C = 25719'
-20C = 20995'
FZL = 13071'
LFC
LCL
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!

# 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:

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

## 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)
- **In theory, narrow thermals more favorable for convective initiation**

## 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)**

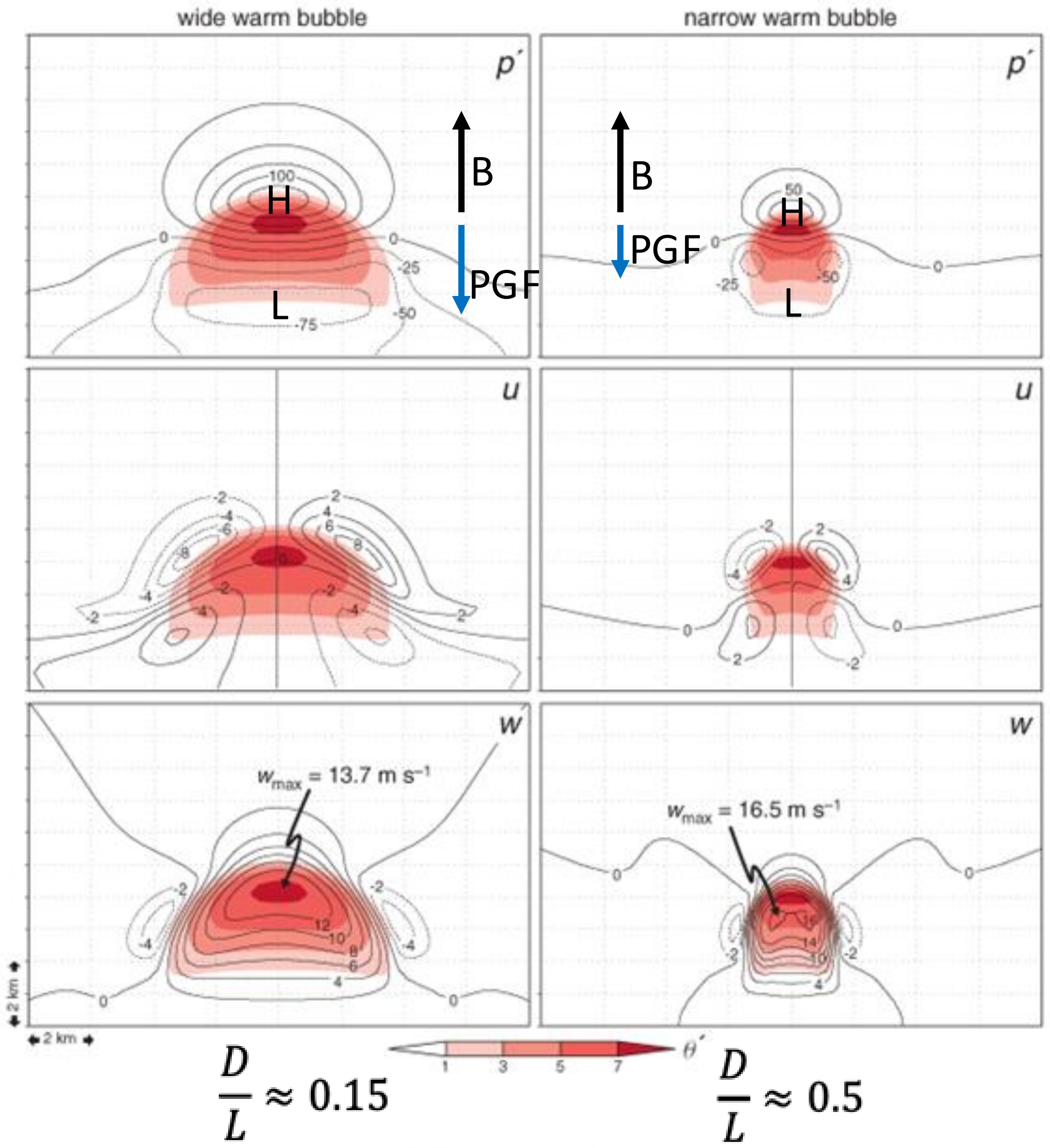



Figure 3.1

Fig. 3.1 MR 2010

# 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