Fundamentals of Atmospheric Physics

Lecture 14

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Skew-T Log-P Diagram

Atmospheric Soundings Plotted on Thermodynamic Diagrams

Useful Parameters for Rising Air Parcels

Convective Condensation Level (CCL)

Convective Temperature (T_c)

Lifting Condensation Level (LCL)

Level of Free Convection (LFC)

Equilibrium Level (EL)

Thunderstorms

Definition: A thunderstorm is a local storm, invariably produced by a cumulonimbus cloud, that always is accompanied by lightning and thunder.

It usually contains strong gusts of wind, heavy rain, and sometimes hail.

We often use the word "convection" to describe such storms in a general manner, though the term convection specifically refers to the motion of a fluid resulting in the transport and mixing of properties of the fluid.

To be more precise, a convective cloud is one which owes its vertical development, and possibly its origin, to convection (upward air currents).

What meteorological conditions precede a thunderstorm?

1. A conditionally unstable atmosphere
2. Substantial boundary layer moisture
3. A trigger to release the instability

On a skew T-log p plot

CAPE: Convective Available Potential Energy = energy that can be released

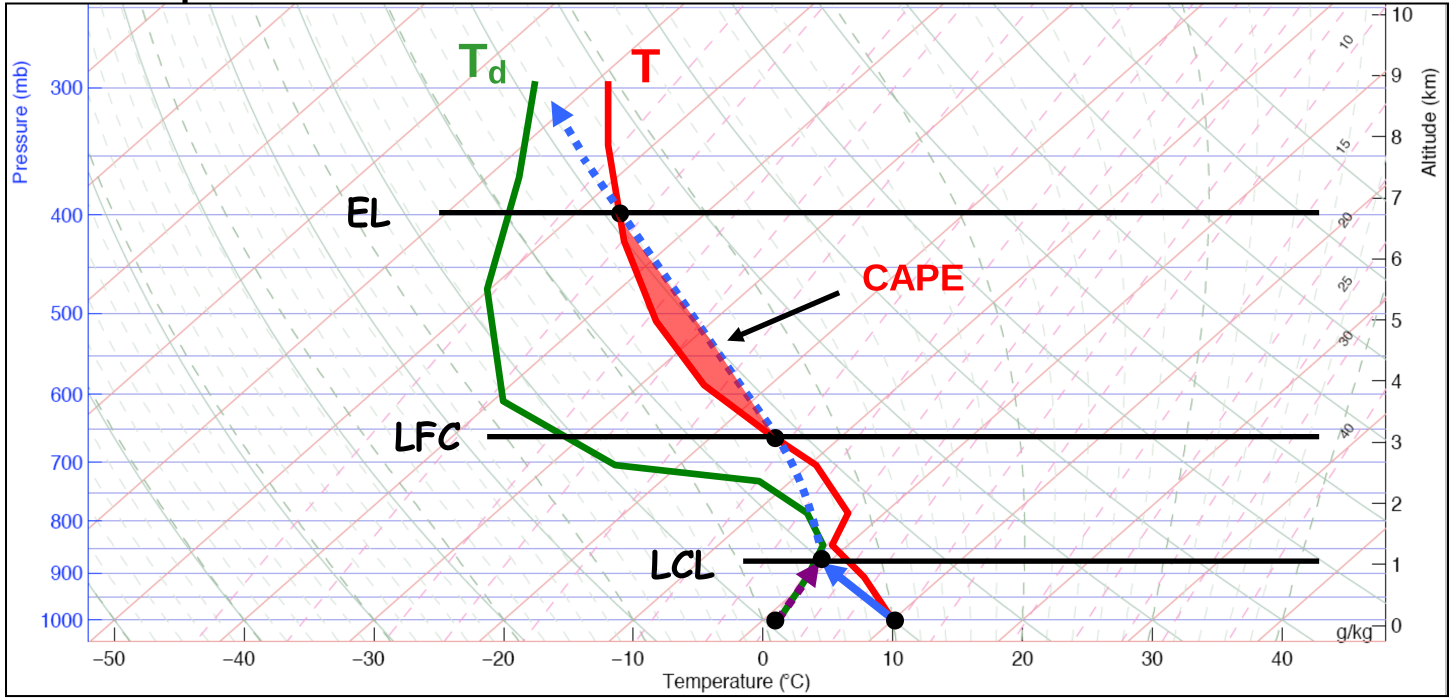
CIN: Convective INhibition = energy barrier that has to be overcome

LIFT	8.21
LFTV	8.07
SWET	77.00
KINX	4.50
CTOT	7.10
VTOT	29.10
TOTL	36.20
CAPE	0.00
CAPE	0.00
CINS	0.00
CINV	0.00
EQLV	-9999
EQTV	-9999
LFCT	-9999
LFCV	-9999
BRCH	0.00
BRCV	0.00
LCLT	262.0
LCLP	598.3
MLTH	303.5
MLMR	2.78
THCK	5680.
PWAT	8.10

Stability Indices

Convective Available Potential Energy (CAPE)

1. Find the LCL for a parcel lifted from the surface
2. Find the LFC and EL for the same parcel
3. Identify those layers above the LFC and EL in which the parcel temperature is greater than the environmental temperature
4. The CAPE is the total positive area

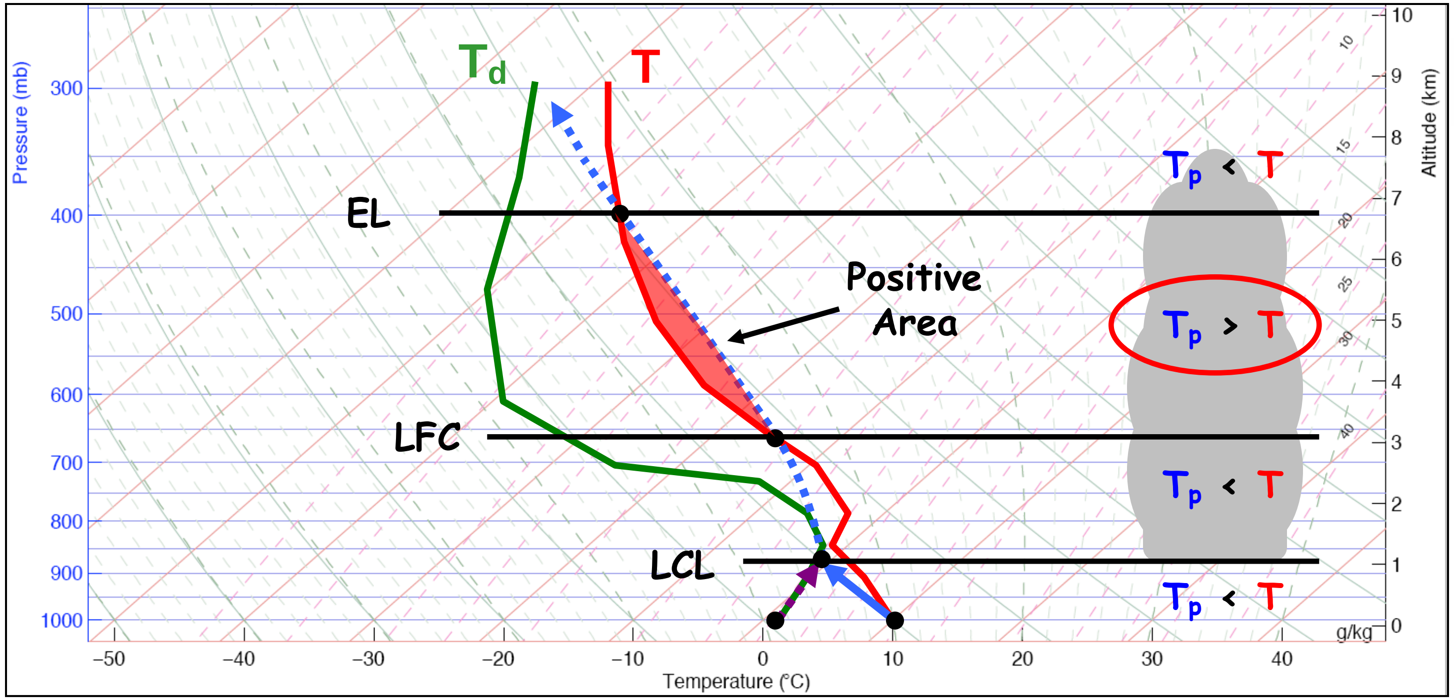


Convective Available Potential Energy (CAPE)

Positive Area: Area between the sounding and the moist adiabat that intersects the LFC, above the LFC. Proportional to the amount of energy the parcel gains from the environment.

Layers within which a parcel can rise freely through the atmosphere (i.e. the parcel will experience an upward buoyancy force).

Parcel temperature is greater than the environmental temperature ($T_p > T$).



Convective available potential energy

CAPE is the amount of bouyant energy available to air parcels for conversion to kinetic energy.

The CAPE of 511 J/kg is not particularly large. CAPE over 1500 J/kg usually yields thunderstorms.

CAPE over 3000 J/kg usually yield severe thunderstorms.

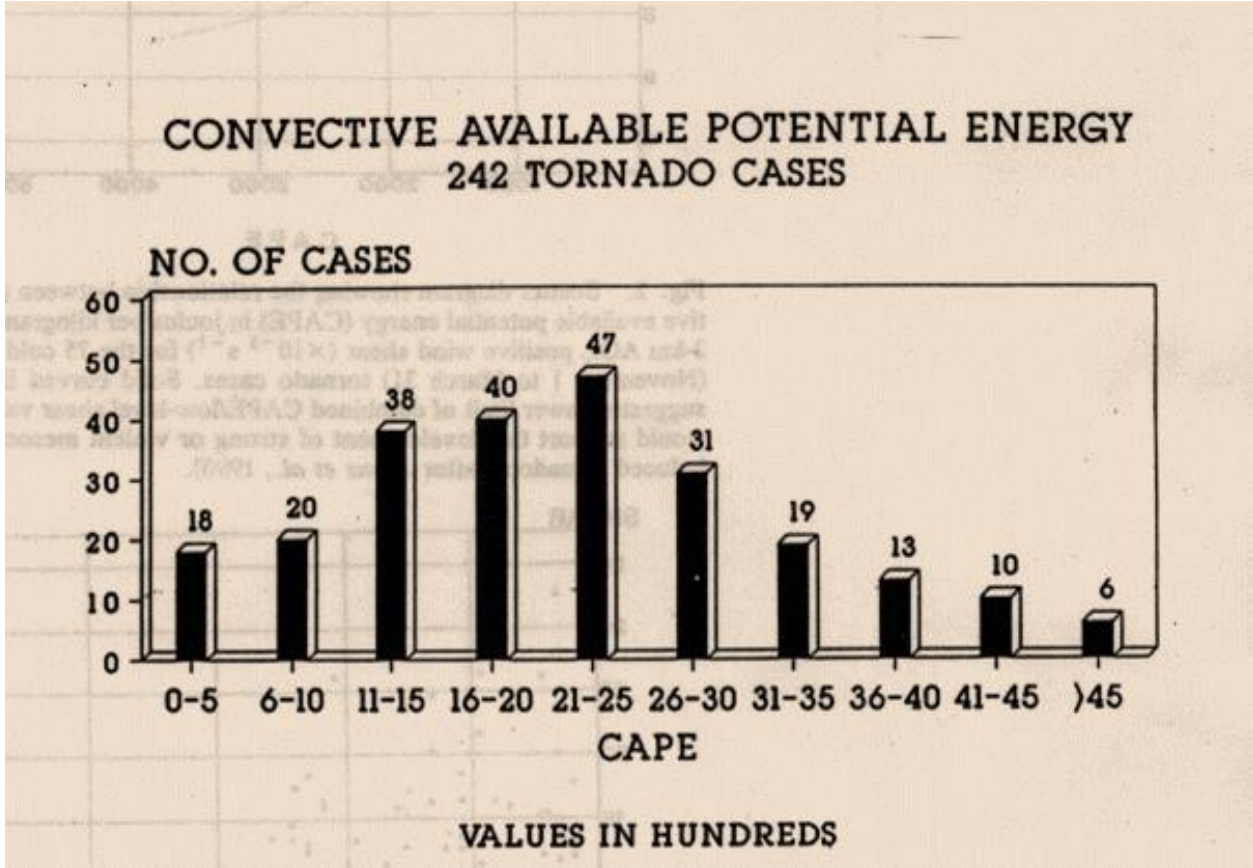
$$CAPE = -R_d \int_{p_{LFC}}^{p_{EL}} (T_p - T_e)\ d \ln p$$

CAPE

< 300	Very weak convection
300-1000	Weak convection
1000-2500	Moderate convection
2500-3000	Strong convection
3000+	Very strong convection

Sturtevant (1995)

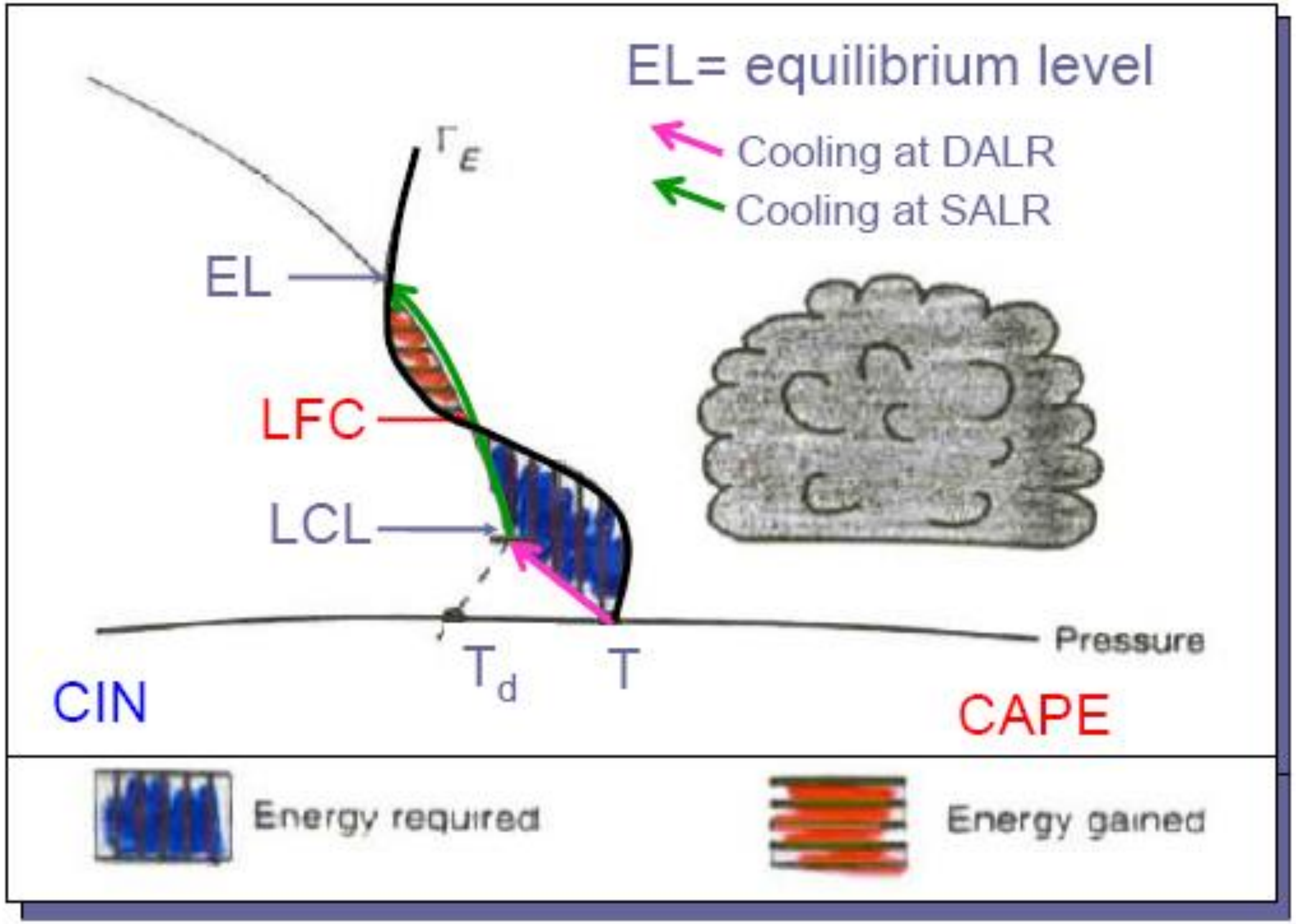
CAPE



Note in the figure the CAPE is given in hundreds.

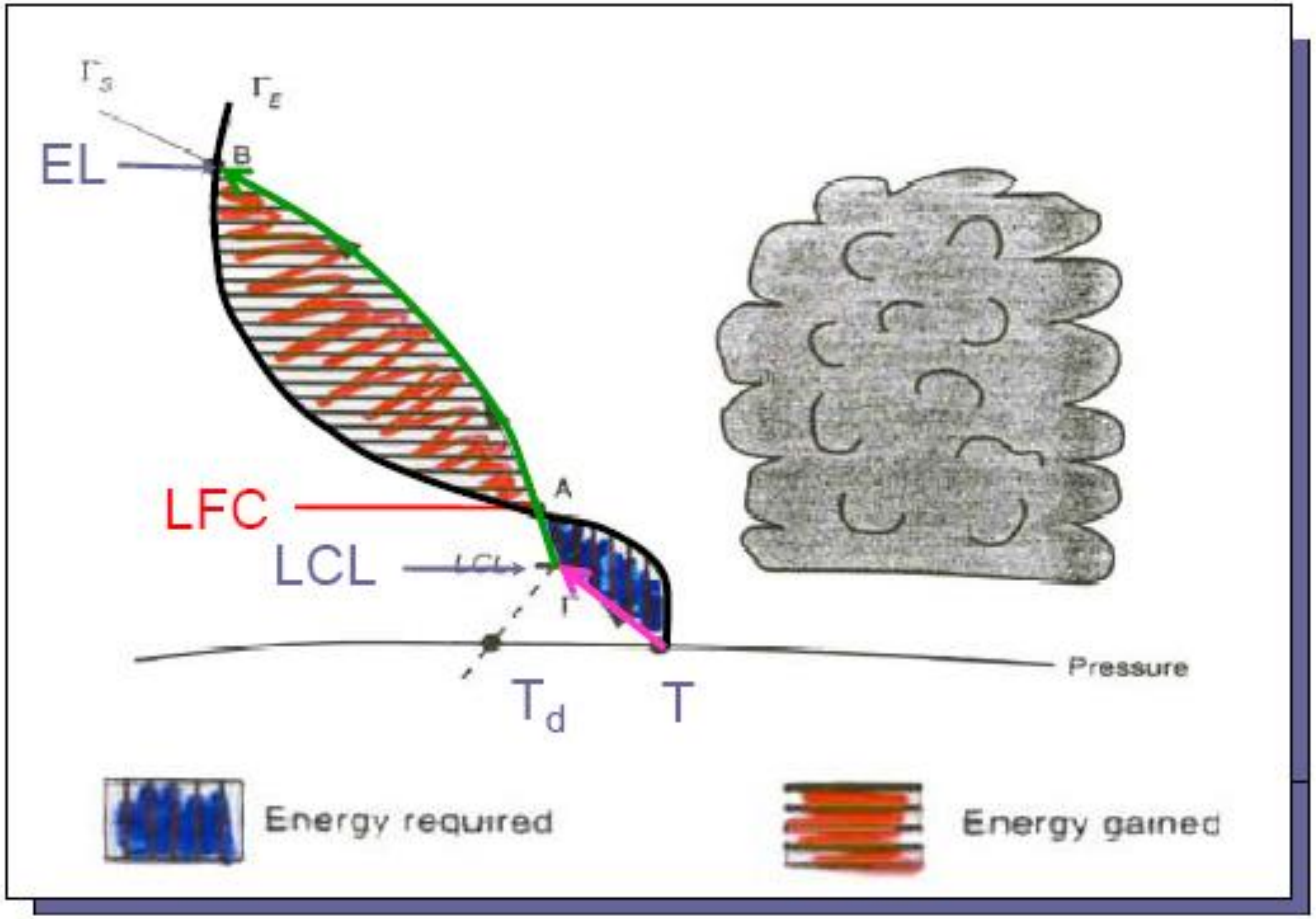
So the scale goes from 0-500 at the lower end to greater than 4500 Jkg^{-1} at the upper end.

Convective Cloud Growth: Cumulus

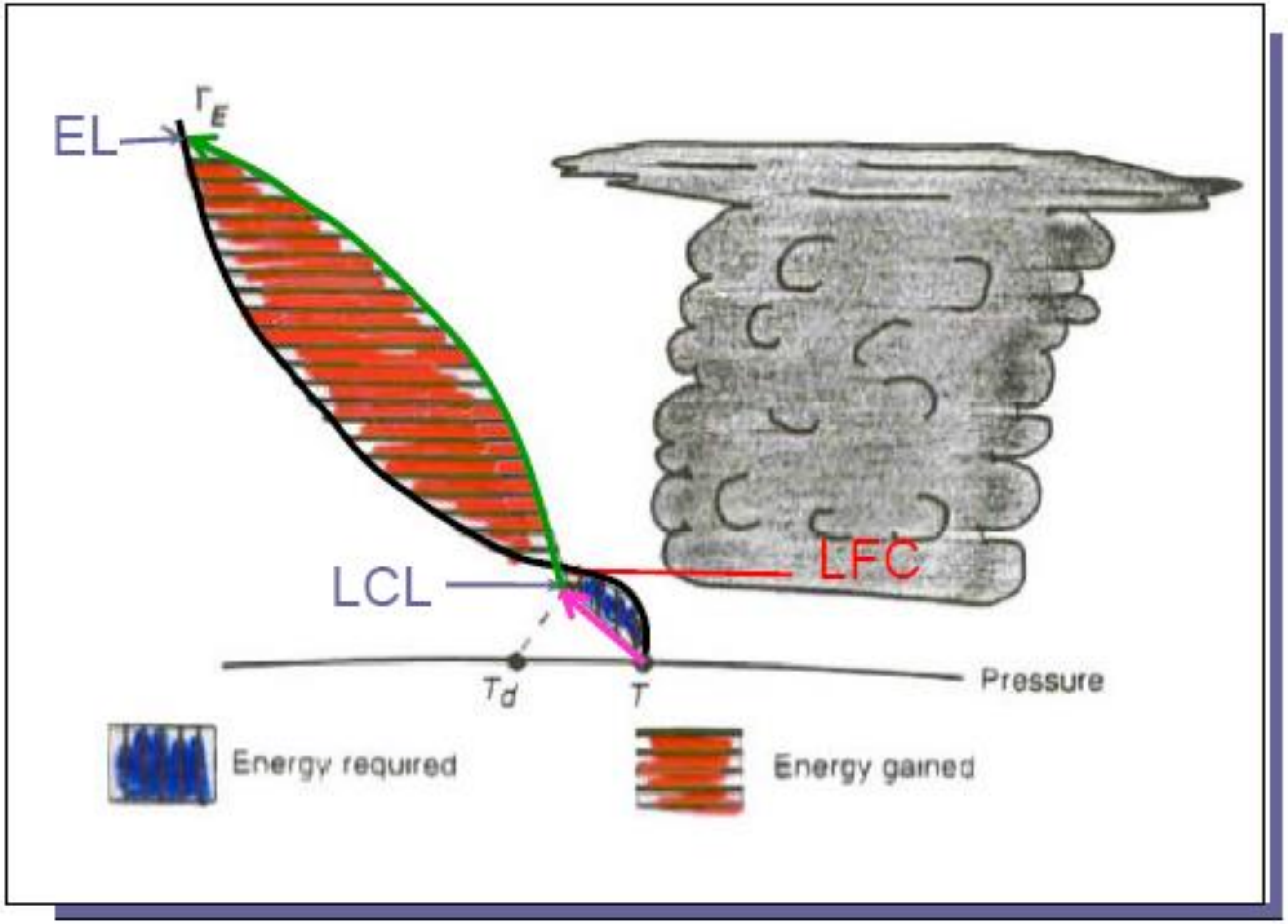


Remember: Area on a thermodynamic diagram is proportional to energy.

Convective Cloud Growth: Towering Cumulus



Convective Cloud Growth: Cumulonimbus



Negative Area:

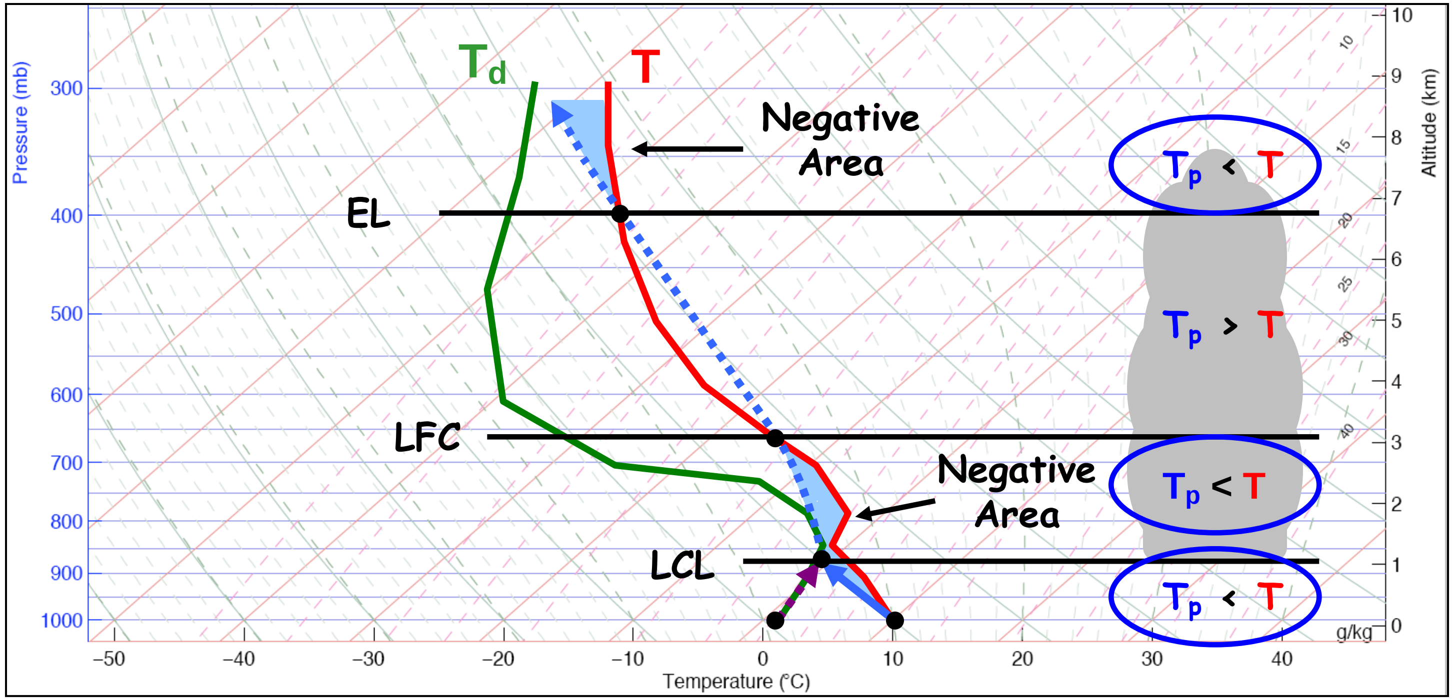
Convective inhibition (CIN)

Area between the sounding and the dry adiabat that intersects the LFC, below the LFC.

Proportional to the energy needed to move the parcel.

Layers within which a parcel requires forced ascent to remain in or rise through (i.e. the parcel will experience a downward buoyancy force)

Parcel temperature is less than the environmental temperature ($T_p < T$)



Convective inhibition (CIN)

Convective INhibition (CIN)

A numerical measure in meteorology that indicates the amount of energy that will prevent an air parcel rising from the surface to the level of free convection. (J kg^{-1}).

$$CIN = R_d \int_{p_{SFC}}^{p_{LFC}} (T_p - T_e)\ \mathrm{dlnp}$$

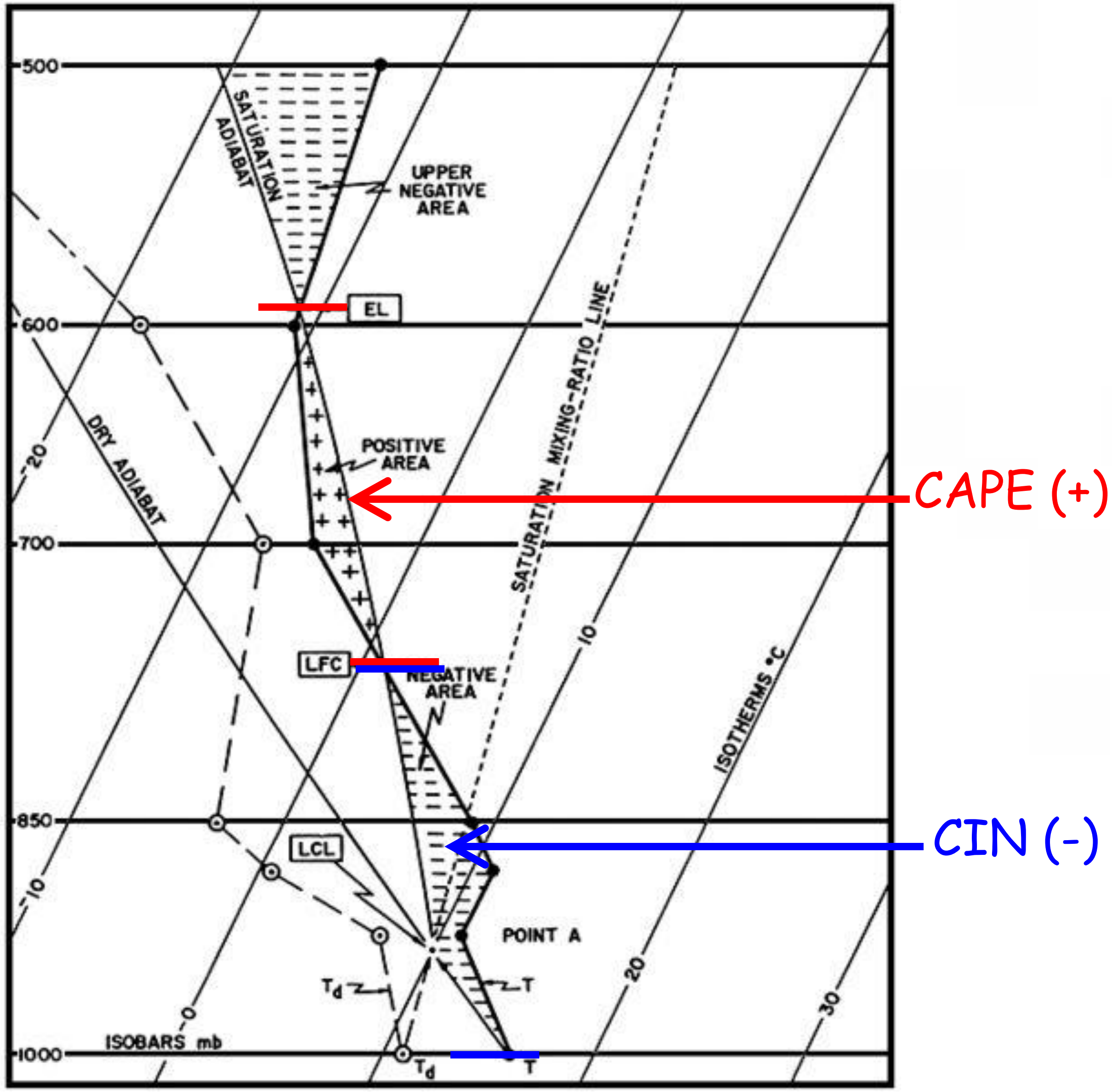
defines the work required to bring parcel to the LFC.

The convective inhibition of 11.9 J/kg is very small but is enough to prevent convection from occuring.

Convective inhibition (CIN)

$$CAPE = -R_d \int_{p_{LFC}}^{p_{EL}} (T_p - T_e)\ d\ln p$$

$$CIN = R_d \int_{p_{SFC}}^{p_{LFC}} (T_p - T_e)\ d\ln p$$



Stability Indices

Stability Indices

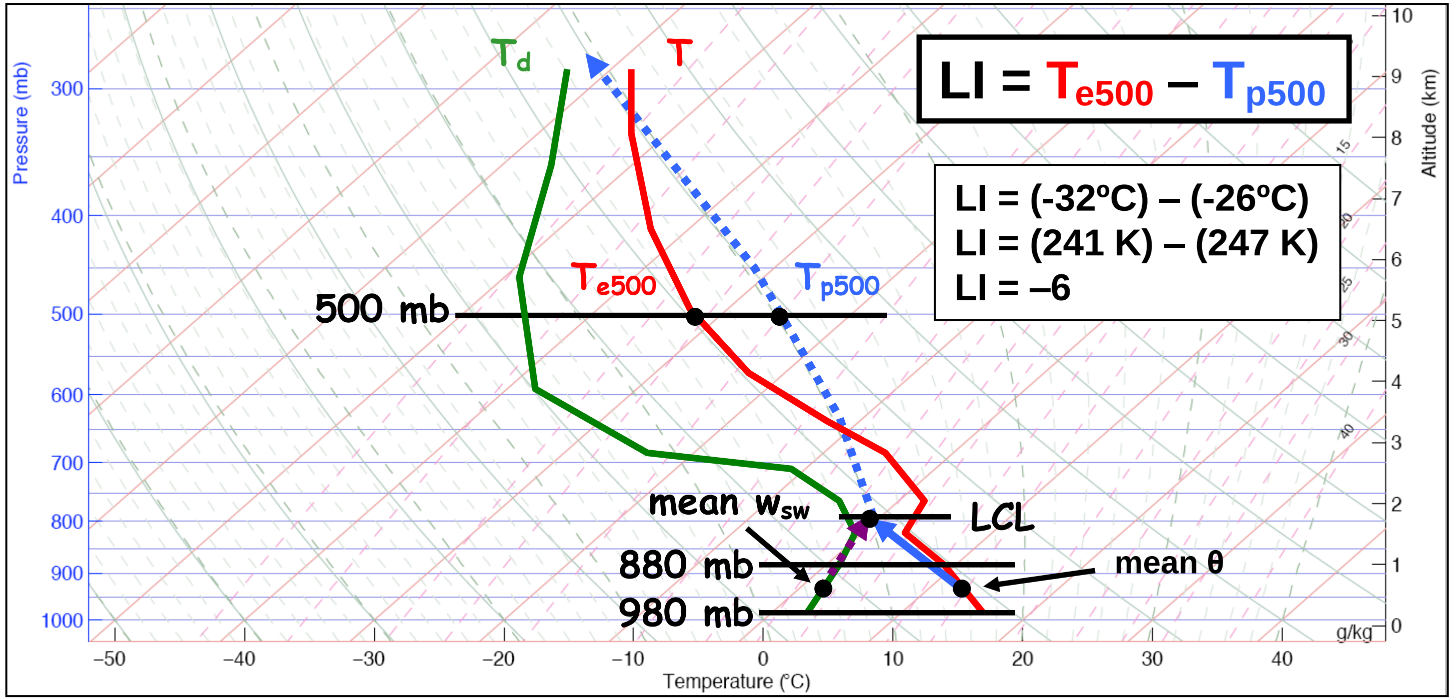
- Convective Inhibition (CIN)
- Convective Available Potential Energy (CAPE)

- Showalter Index (SI)
- Lifted Index (LI)
- K Index (K)
- Total Totals (TT)
- Severe Weather Threat Index (SWEAT)

Lifted Index (LI)

difference in temperature between atmosphere and lifted parcel:

$$LI = T_e(500mb) - T_p(500mb)$$



LI = T 500 mb – T_p at 500 mb

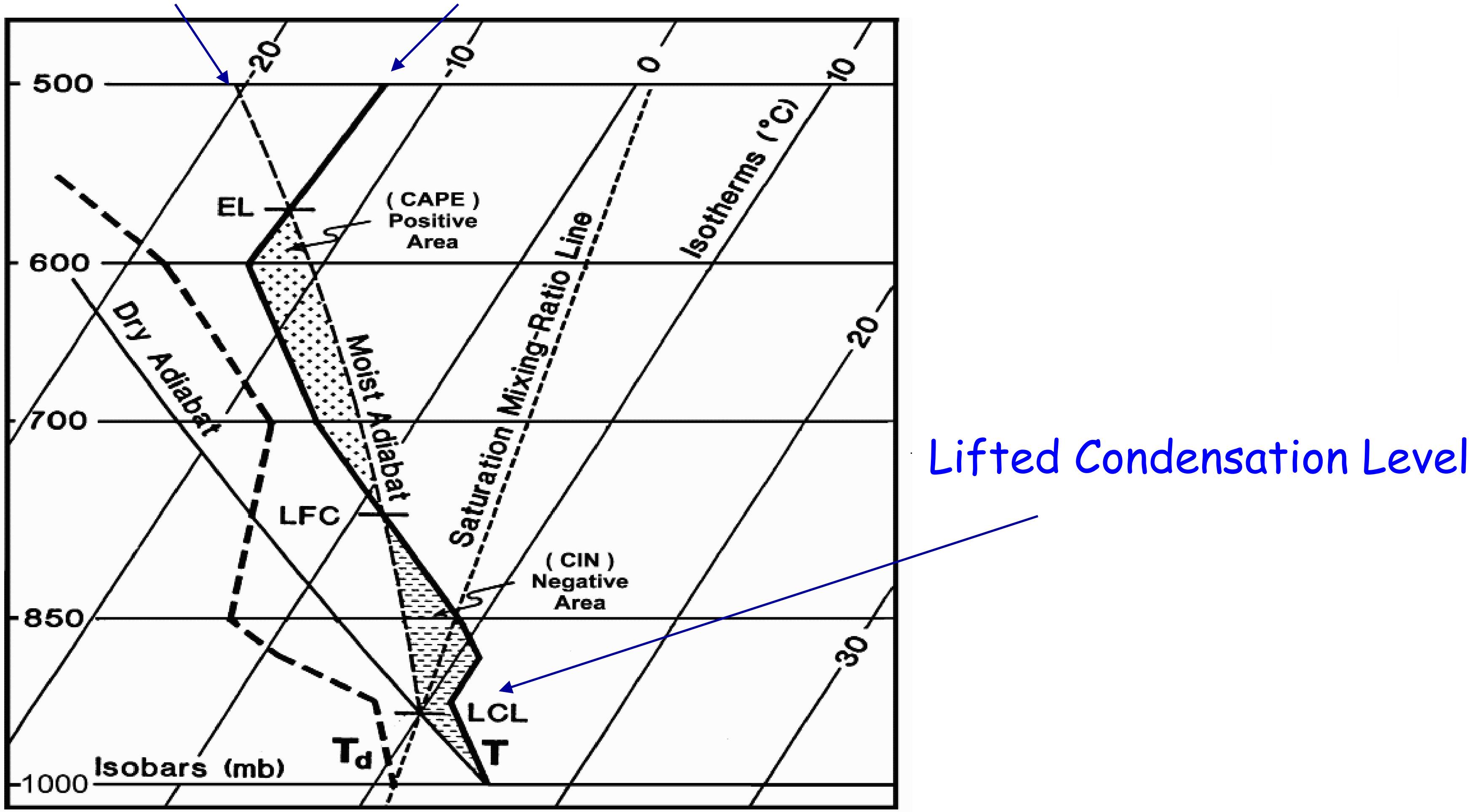


Figure 1 Showing the Positive (CAPE) and Negative (CIN) areas. (from NWS/OSF/OTB, 1991)

Lifted Index

> 0	Thunderstorms unlikely
0 - -2	Thunderstorms possible – triggered needed
-3 - -5	Thunderstorms probable
-5 - -7	Strong/severe thunderstorms. Tornadoes possible
-7 - -9	Move to Alaska
< -9	Yikes

Sturtevant (1995)

Showalter Index (SI)

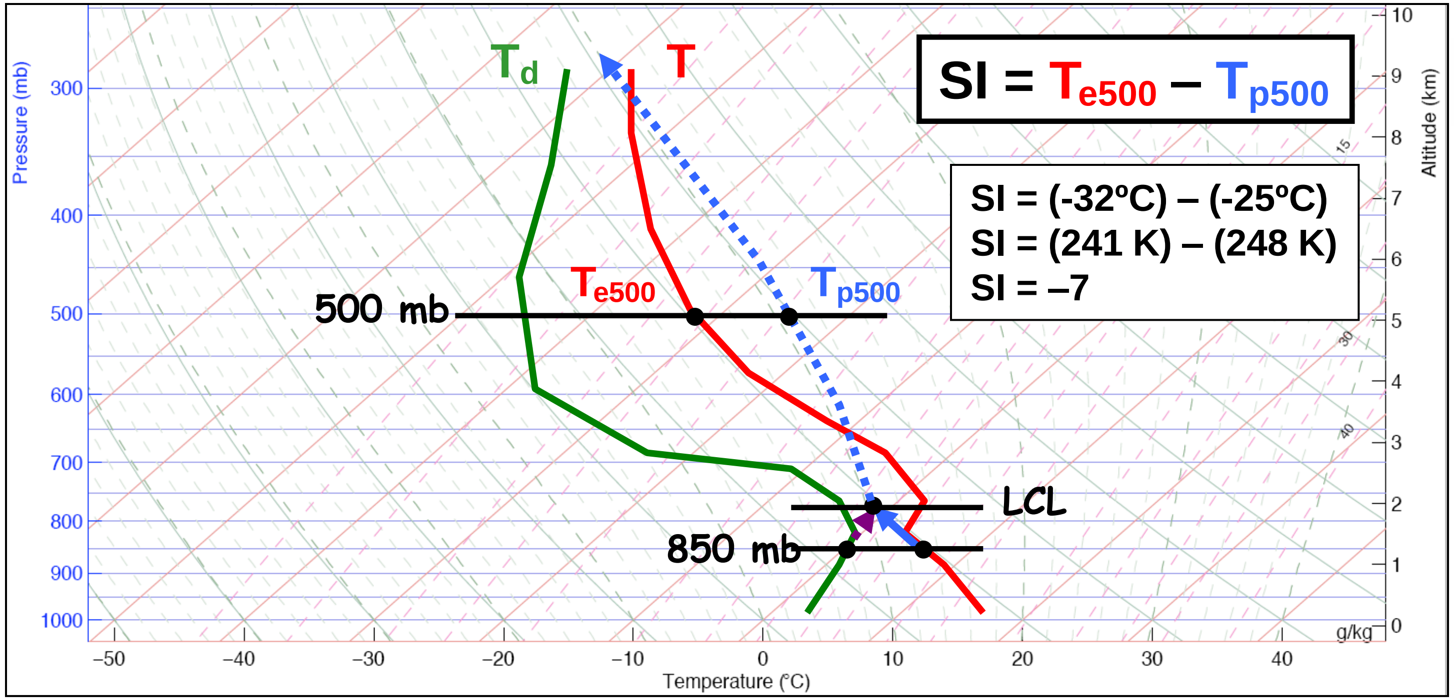
Lift 850 mb parcel by appropriate processes to 500 mb and subtract its temperature from the observed 500 mb temperature. The smaller (more negative) the number the more unstable the environment.

(a measure of thunderstorm potential and severity. Especially useful when a shallow, cool layer of air below 850 mb conceals greater convective potential above)

$$SI = T_e(500mb) - T_p(from\ 850mb \text{ to } 500mb)$$

Showalter Index (SI)

1. Find the LCL for a parcel lifted from 850 mb
2. Find the LFC for the same parcel
3. From the LCL move up a pseudo-adiabat to 500 mb
4. Subtract the parcel temperature (T_p) at 500 mb from the environmental temperature (T_e) at 500 mb



Showalter Index (SI)

> 4	Thunderstorms unlikely
1 – 4	Thunderstorms possible – triggered needed (need strong forced ascent)
1 - -2	Increasing chance of thunderstorms
-2 - -3	High potential of heavy thunderstorms
-3 - -5	Getting scary
-5 - -10	Extremely unstable
< -9	Head for the storm shelter

Sturtevant (1995)

K-Index

Attempts to include a measure of low level moisture (T_d(850mb)) and the depth of the moist layer by including the 700 mb dew points depression.

Large K means a lot of moisture available to drive cumulus clouds.

$$K = T_e(850mb) - T_e(500mb) + T_d(850mb) - [T_e(700mb) - T_d(700mb)]$$

K-Index

0 - 15	No thunderstorms
16 - 19	Thunderstorms unlikely
20 - 25	Isolated thunderstorms
26 - 29	Widely scattered thunderstorms
30 - 35	Numerous thunderstorms
36 - 39	Thunderstorms very likely
40+	100% chance of thunderstorms

Sturtevant (1995)

Modified K-Index

Replace the 850 mb T and T_d with low altitude averaged values.

$$Mod - K$$

$$= Te^* - T_e(500mb) + {T_d}^*$$

$$- [T_e(700mb) - T_d(700mb)],$$

$$where\ {T_e}^* = [T_e(sfc) + T_e(850mb)]/2$$

$${T_d}^* = [T_d(sfc) + T_d(850mb)]/2$$

Vertical, Cross, and Total Totals indices

Here, the larger the number is, the more unstable the atmosphere is. VT or CT >= 30 or TT > 60 indicates moderate thunderstorms with the possibility of scattered severe T-storms.

(A measurement of thunderstorm potential. Generally, the value is higher if low-level moisture extends up through the 850 mb level)

$$VT = T_e(850mb) - T_e(500mb)$$

$$CT = T_d(850mb) - T_e(500mb)$$

$$TT = VT + CT$$

$$= T_e(850mb) + T_d(850mb) - 2T_e(500mb)$$

TT

< 43	Thunderstorms unlikely
43 – 44	Isolated thunderstorms
45 – 46	Scattered thunderstorms
47 – 48	Scattered thunderstorms/isolated severe
49 – 50	Scattered T-storms/few severe/isolated tornadoes
51 – 52	Scattered-numerous T-storms/few-scattered severe/isolated tornadoes
53 – 55	Numerous thunderstorms/scattered tornadoes
56+	You don't wanna know…

Sturtevant (1995)

Severe Weather Threat (SWEAT)

This is a complicated index involving both buoyancy and wind shear and a series of "ifs".

$$\text{SWEAT} = 12T_{d\,850} + 20(TT - 49) + 2ff_{850} + ff_{500} + 125[\sin(dd_{500} - dd_{850}) + 0.2]$$

$ff = wind\ speed\ in\ knots$

$dd = the\ wind\ direction$

All members must have positive values, otherwise set it to 0.

Last member = 0, unless

$$NOTE: the\ whole\ shear\ term \neq 0\ \ if \begin{cases} 1.\ 130 < dd(850\text{mb}) < 250 \\ 2.\ 210 < dd(500\text{mb}) < 310 \\ 3.\ dd(500\text{mb}) - dd(850\text{mb}) > 0 \\ 4.\ ff(500\text{mb})\ \text{and}\ ff(850\text{mb})\ \text{both} > 15\ \text{knots} \end{cases}$$

No term in the equation may be negative; if so, that term is set to zero.

$$\text{SWEAT} = 12T_{d\,850} + 20(TT - 49) + 2ff_{850} + ff_{500} + 125[\sin(dd_{500} - dd_{850}) + 0.2]$$

If TT less than 49, then that term of the equation is set to zero

If any term is negative then that term is set to zero

Winds must be veering with height or that term is set to zero

The sounding below gives a SWEAT value of 148. Here is how that value was found:

$850T_d$ = 9 C
TT = 44
ff_{850} = 15 knots
ff_{500} = 10 knots
dd_{500} - dd_{850} = SSW (200 degrees) - SW (220 degrees) = sin(-20) = term set to zero since wind is not veering
Since TT is less than 49, that term is set to zero

SWEAT = 12(9) + 2(15) + 10 = 148

Severe Weather Threat (SWEAT)

< 272	Thunderstorms unlikely
273-299	Slight risk – general thunderstorms
300-400	Moderate risk – approaching severe limits
401-600	Strong risk – few severe T-storms/isolated tornadoes
601-800	High risk of severe –T storms/scattered tornadoes
801+	High wind damage, but not favorable for severe weather

Sturtevant (1995)