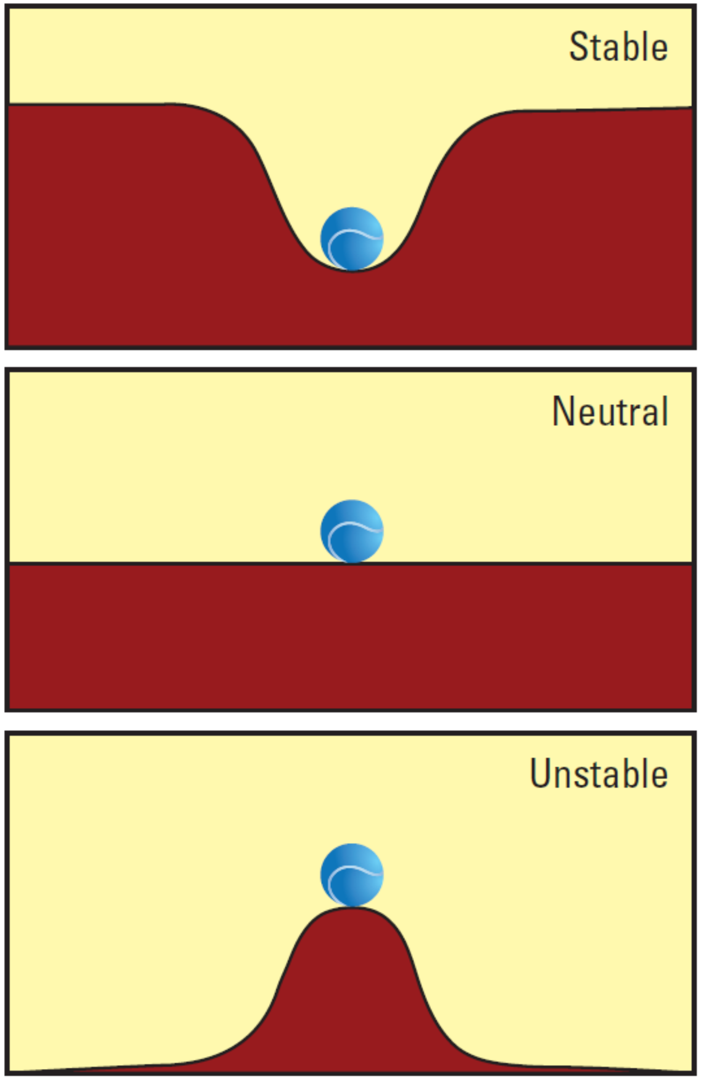
MET 4300/5355

Lecture 6
Atmospheric Stability (CH6)

Stability Concept



Thunderstorms→

Convection→air rising→

Stability

With a tiny bump--

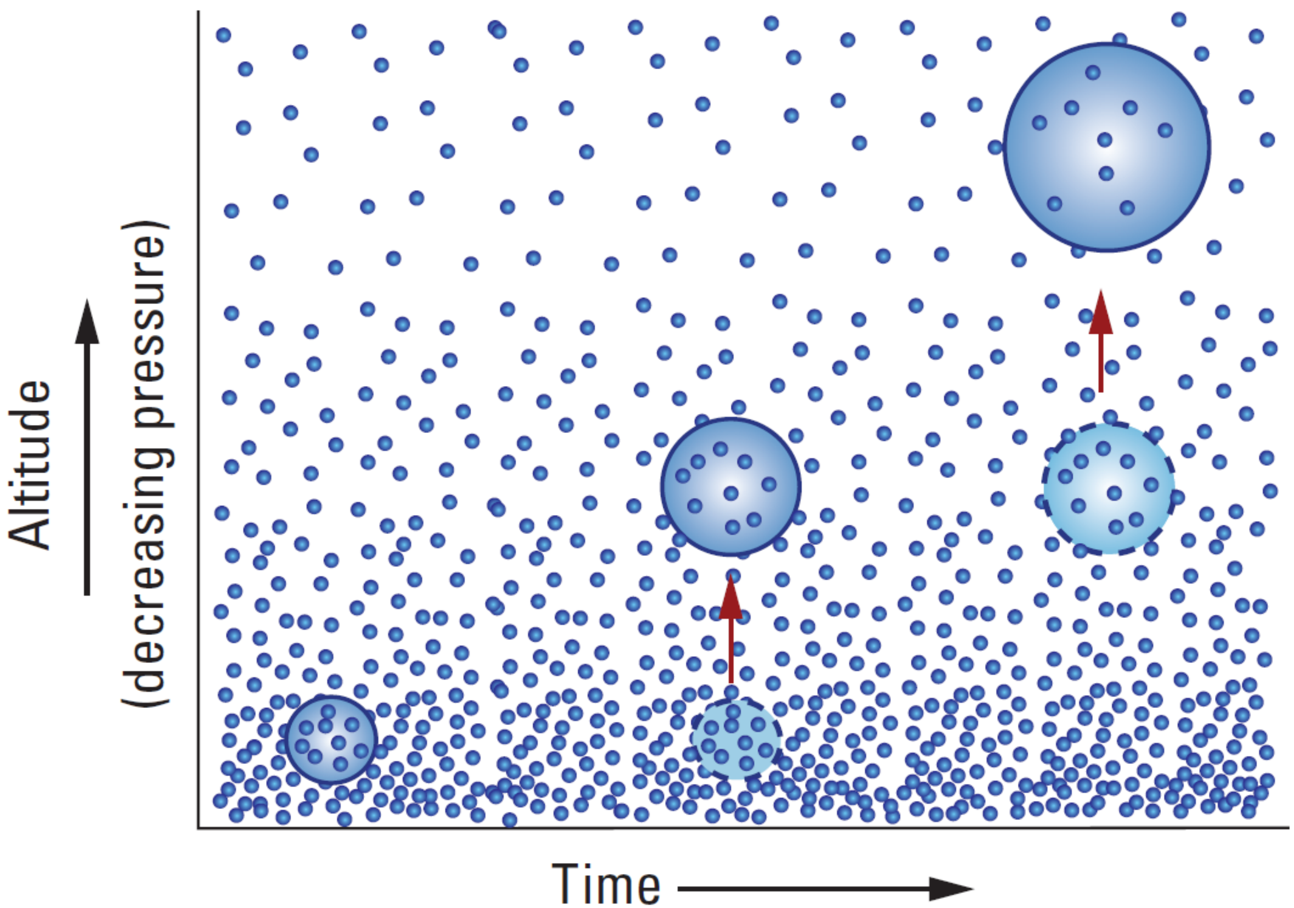
- **Stable:** Ball returns to original position
- **Neutral:** Ball stays wherever it is placed
- **Unstable:** Displacement grows with time.

Atmospheric Stability

- Air parcel: a distinct blob of air that we will imagine we can identify as it moves through the atmosphere

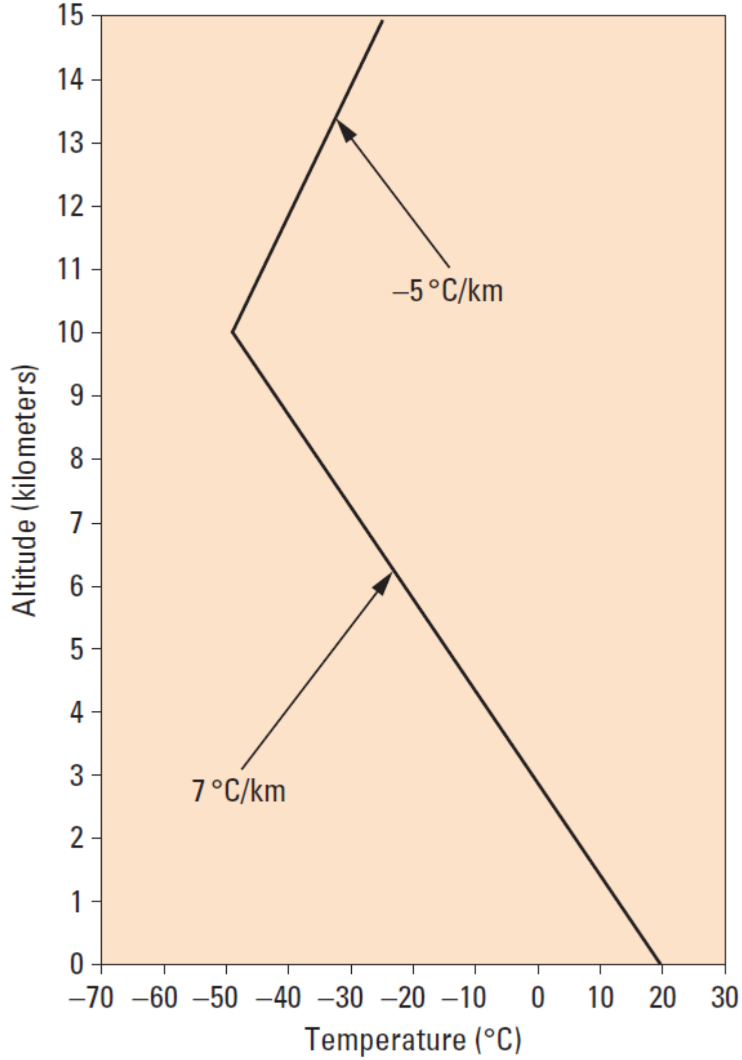
  - **Stable:** If the parcel is displaced vertically, it will return to its original position
  - **Neutral:** If the parcel is displaced vertically, it will remain in its new position
  - **Unstable:** If the parcel is displaced vertically, it will accelerate away (upward or downward) from its original position

Adiabatic Process: is one in which a parcel of air does not mix or exchange heat energy with its environment.



- **What happens during rising?**
- **Rising:** expansion because of lower pressure→ cool
- **What happens during sinking?**
- **Sinking:** compression because of higher pressure → warm

Lapse Rate



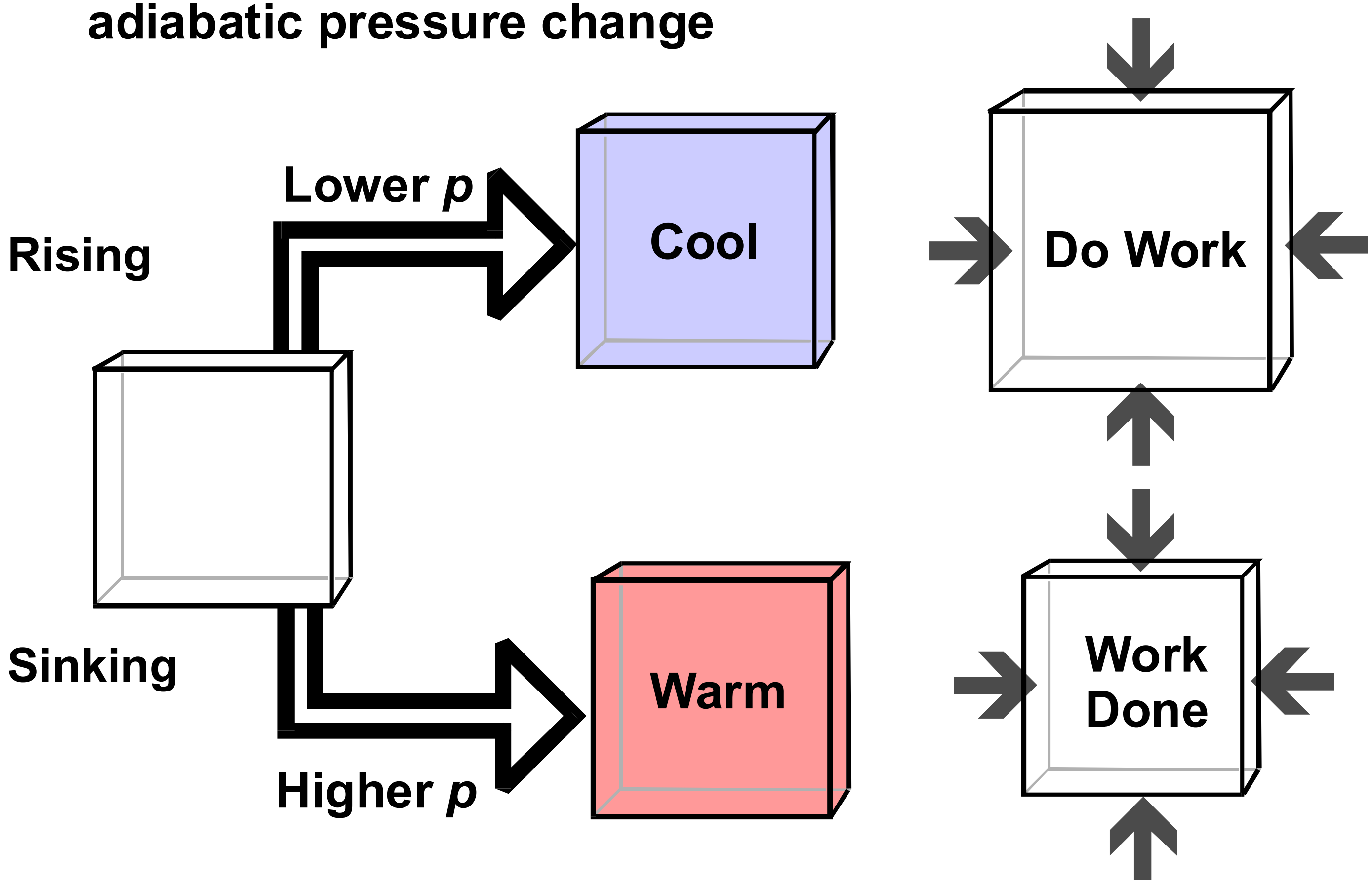
- The rate at which temperature decreases with height in the atmosphere
- **Environmental lapse rate** = 4-9 (6.5 for standard atmosphere) $^{o}C\ km^{-1}$
- **Dry Adiabatic lapse rate** (for unsaturated air): $10^{o}C\ km^{-1}$
  - Cooling (warming) balances work done as air expands (compresses)
- **Moist Adiabatic lapse rate** (for saturated air): ~6 (at lower-level, 8 at mid-level, and 10 at upper level) $^{o}C\ km^{-1}$
  - Cooling and latent heat released by condensation balance pressure work

Parcel Thermodynamics

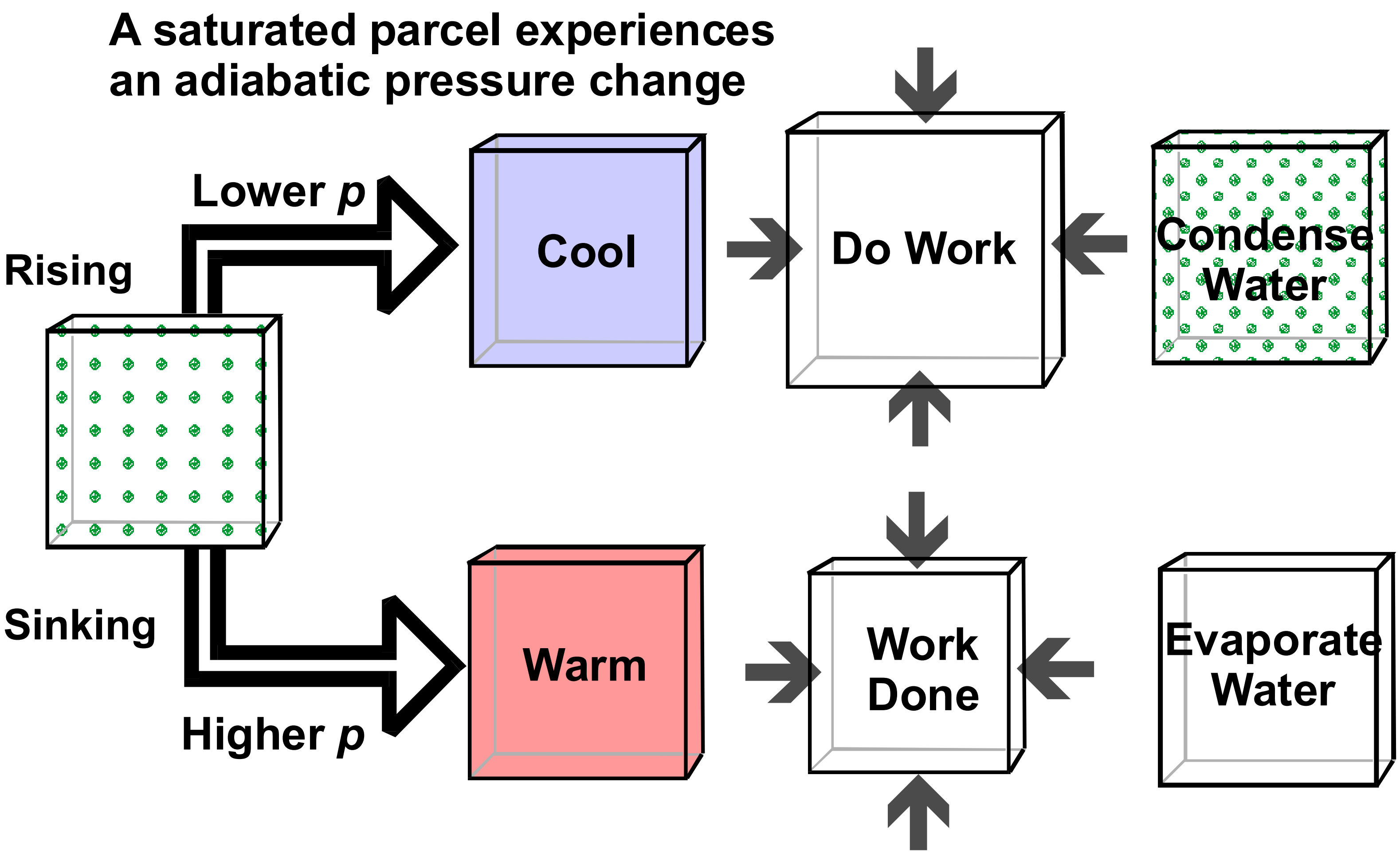
- A ***Parcel*** is a mass of air that moves from one point to another, perhaps changing its properties in reaction to its surroundings
- ***Adiabatic Process***: No heat added or removed, but temperature and/or water mixing ratio can change as the parcel
  - Expands into lower pressure using internal energy to do work
  - Is compressed by higher pressure converting work done by its surroundings into internal energy

Dry Adiabatic Process

An unsaturated parcel experiences an adiabatic pressure change



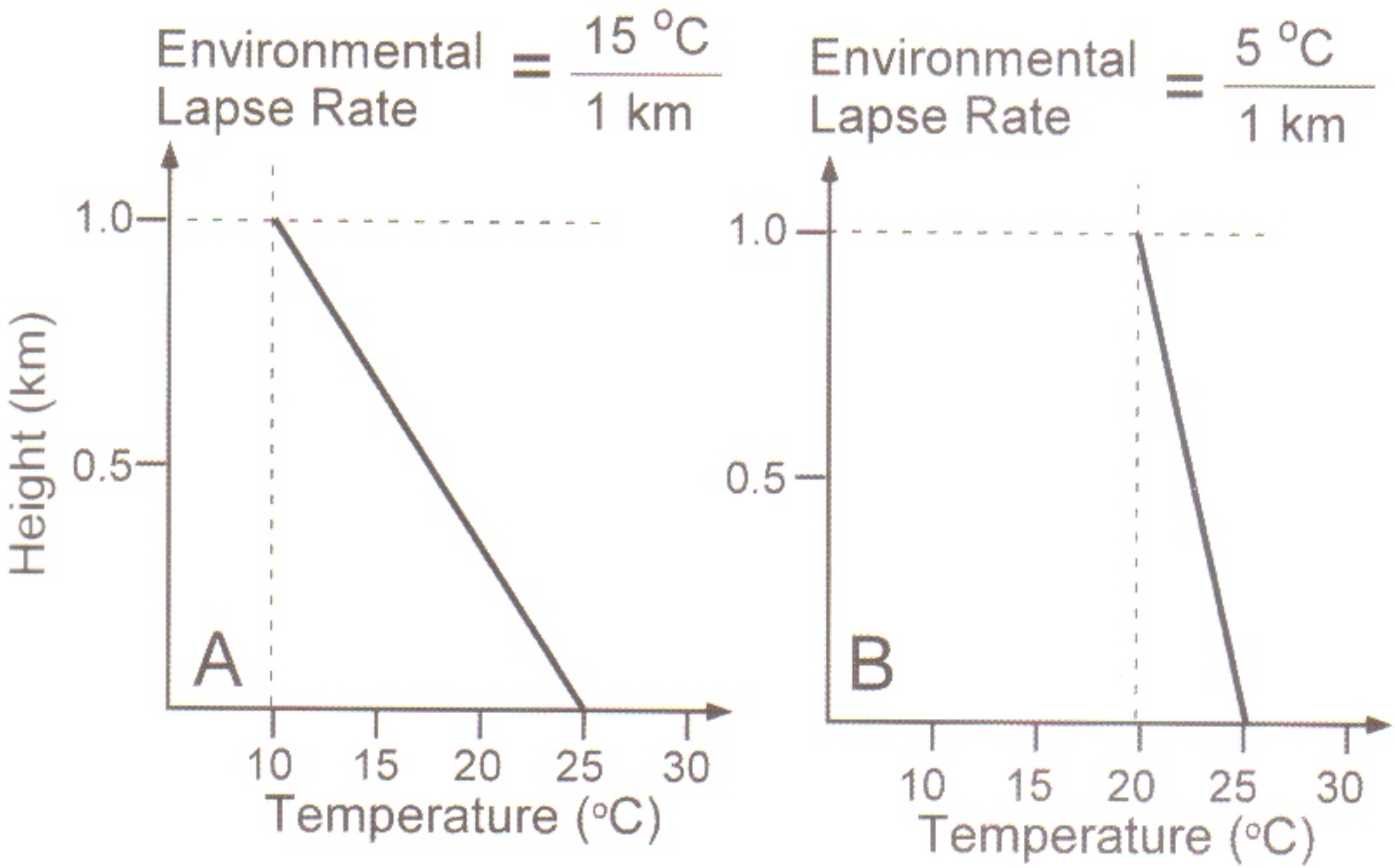
Moist Adiabatic Process



Determining Atmosphere Stability

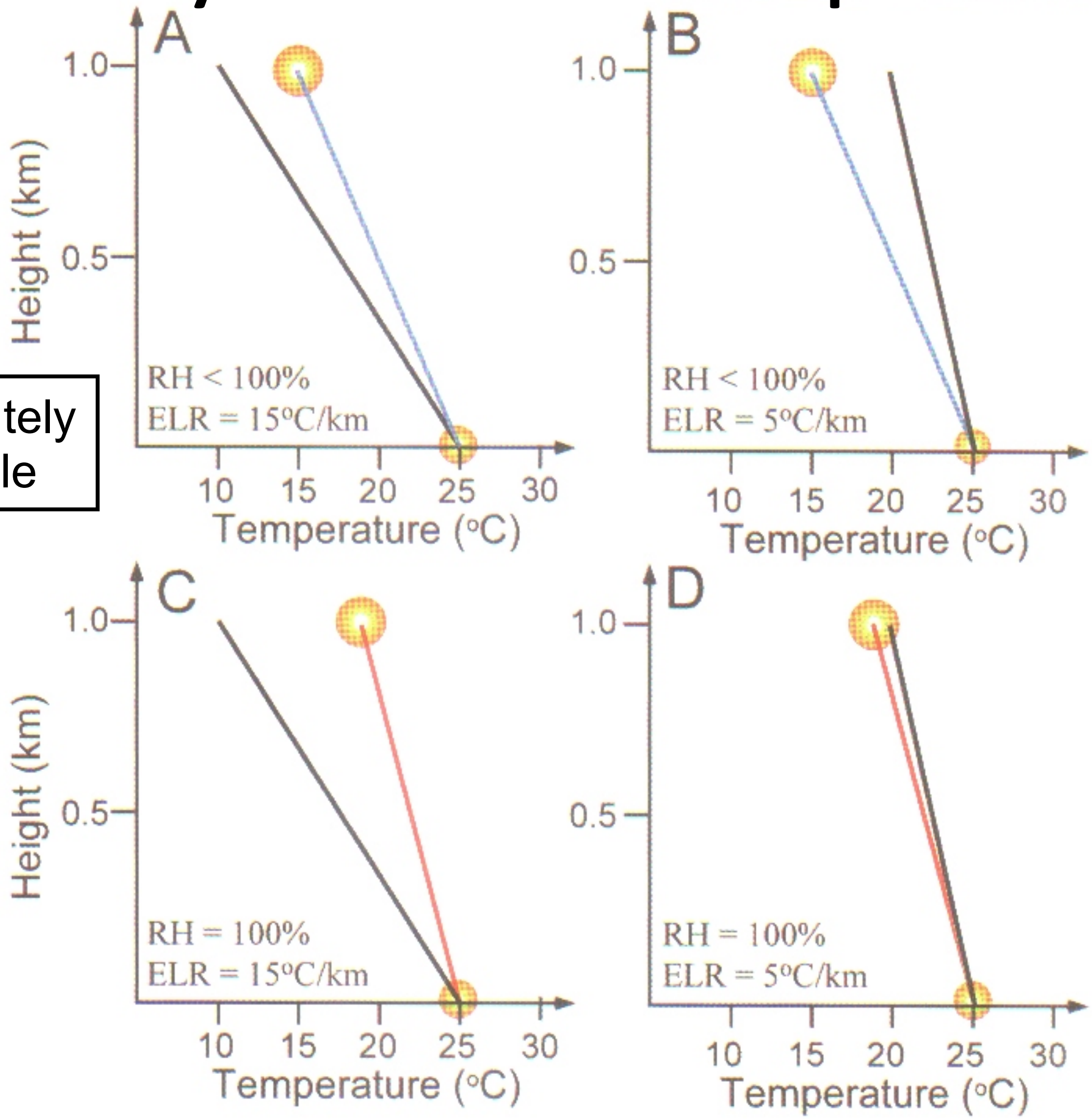
- **Stable (negatively buoyant)**: a parcel of air is more dense than its environment when it's colder than the environment
- **Unstable (buoyant)**: a parcel of air is less dense than its environment when it's warmer than the environment
- **Neutral**: a parcel of air has the same density as its environment air when it has the same temperature as its environment

Two Different Environmental Lapse Rates (ELR)



Stability for These Lapse Rates

Absolutely unstable



Absolutely Stable

Conditionally Unstable

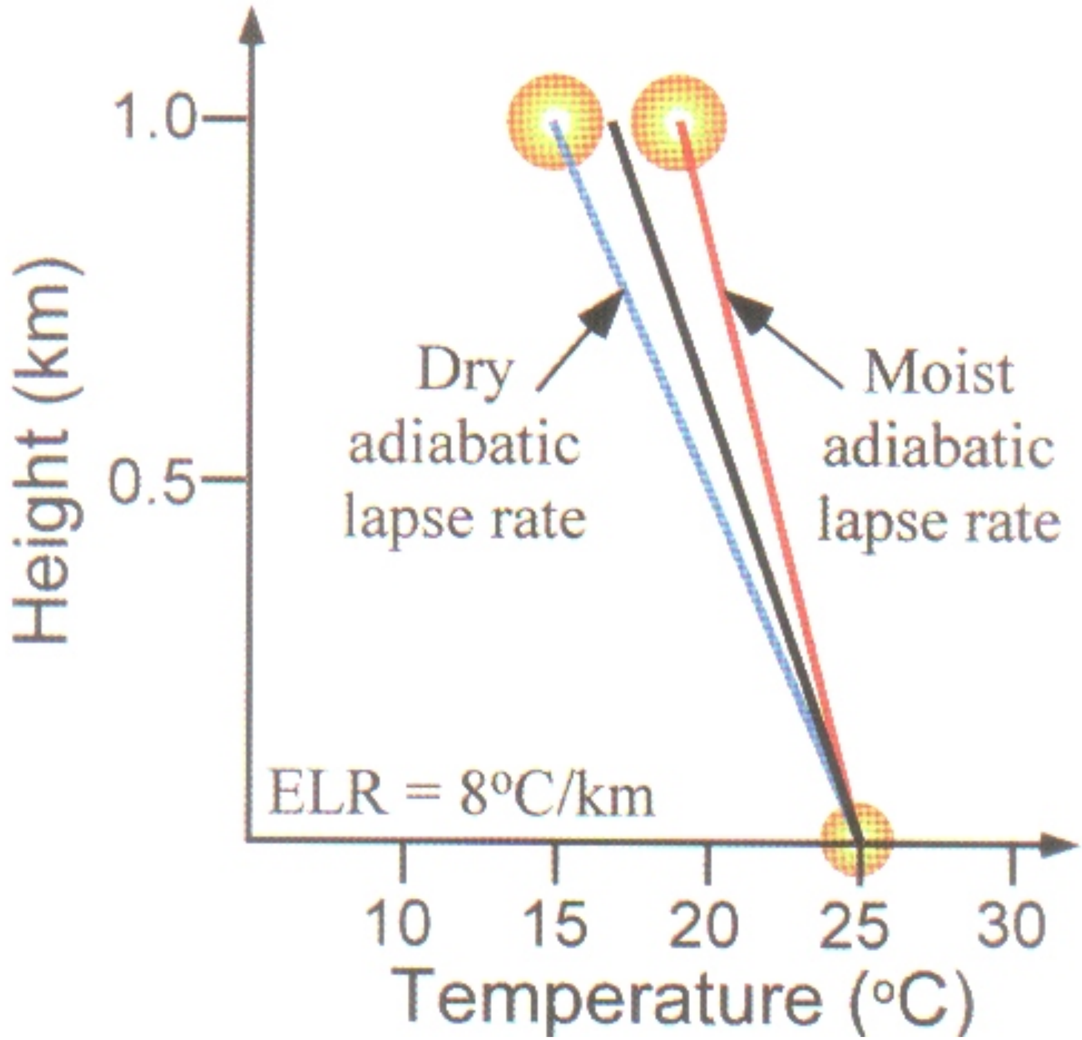


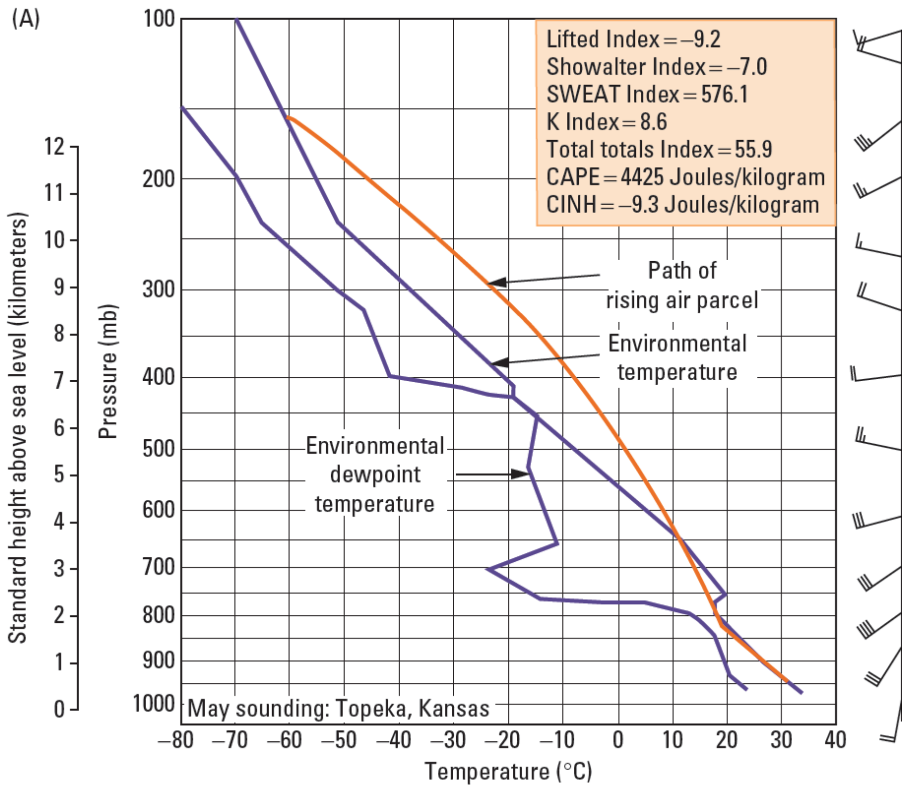
TABLE 6.1 Summary of Categories of Atmospheric Layer Stability

Environmental lapse rate (ELR)	Stability
ELR > 10°C/km	Unstable
6°C/km < ELR < 10°C/km	Conditionally unstable (Unstable if saturated, stable if unsaturated)
ELR < 6°C/km	Stable
ELR = 10°C/km	Neutral if unsaturated, unstable if saturated
ELR = 6°C/km	Neutral if saturated, stable if unsaturated

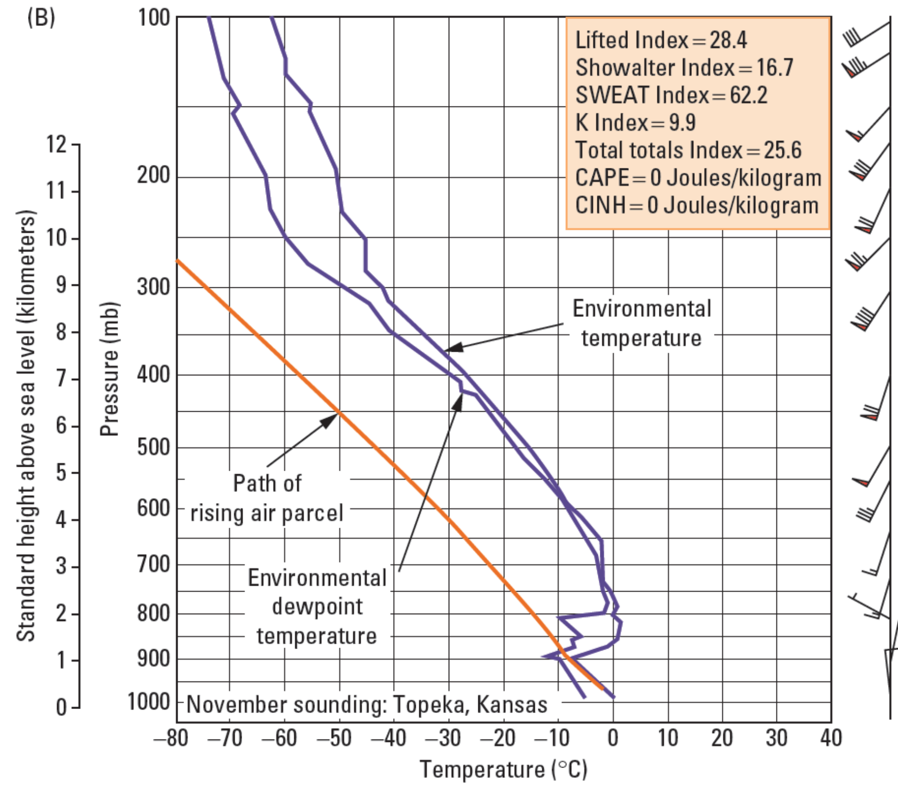
- ELR is not fixed but changes with altitude.
- The moist adiabatic lapse rate actually may vary from 4 to 10 ^{o}C km^{-1}

Path of Rising Air Parcel in Different Soundings: stability assessment when ELR is not constant

Conditionally Unstable



Very Stable



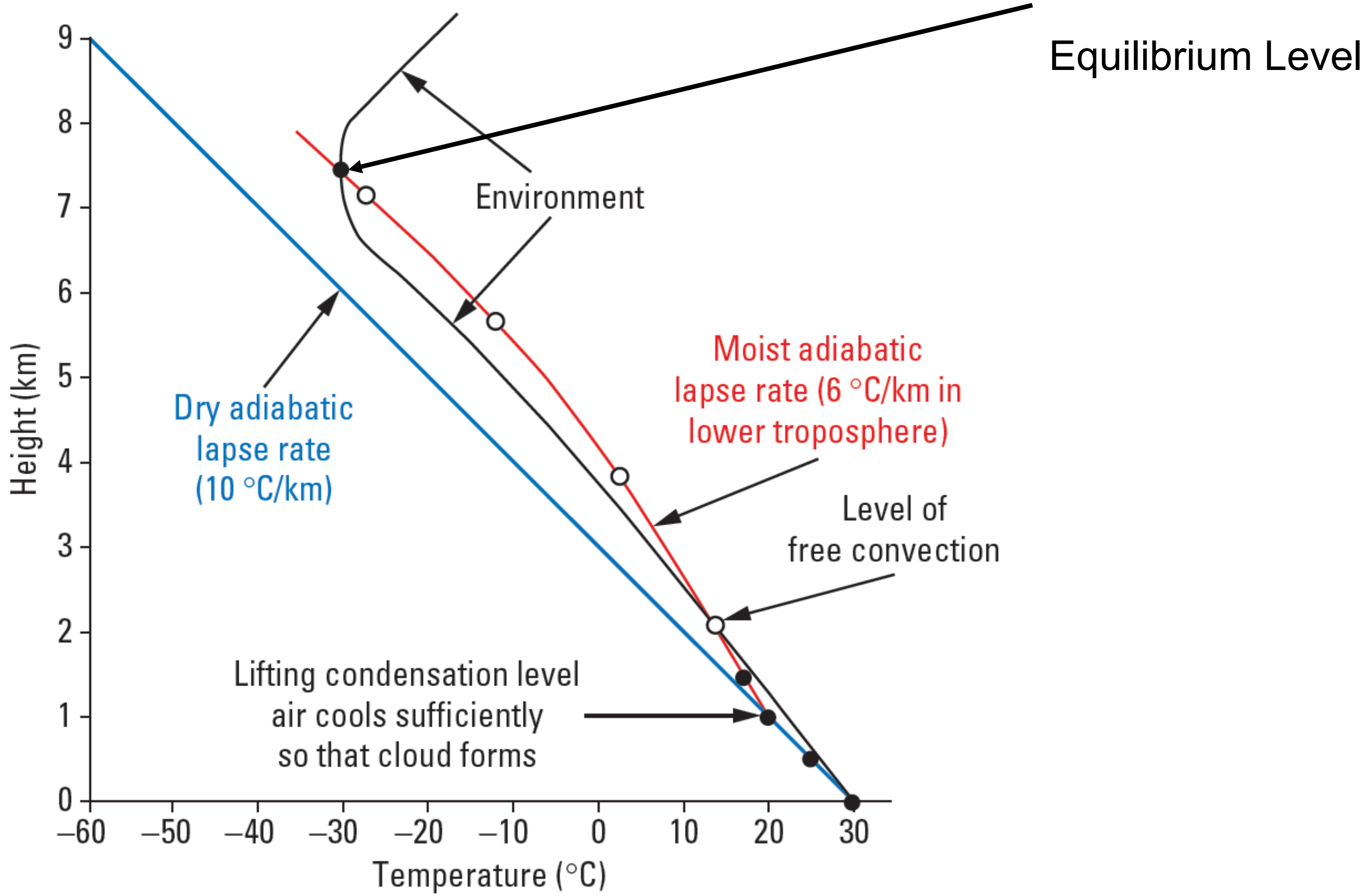
Sounding & Thunderstorms

- Stability can be changed by changing ELR: a layer’s ELR can be changed by cooling or warming the top or bottom of the layer.
- Thunderstorms are common in the afternoon due to diurnal heating of the surface
- Thunderstorms consist of unstable air parcels rising through the environment that is cooler than the rising air parcels. The atmosphere is usually conditionally unstable in the thunderstorm environment.

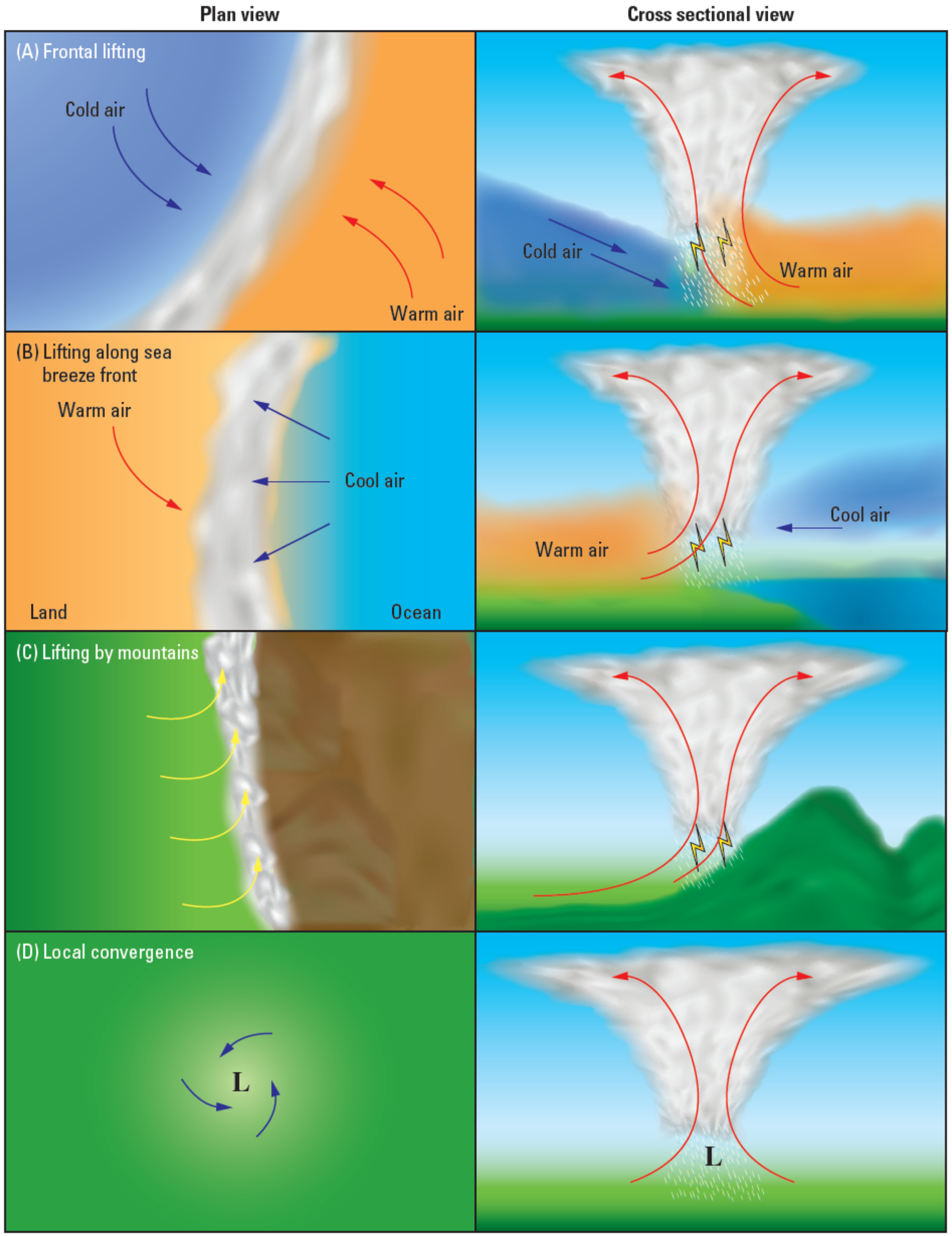
A few Definitions

- **Convection**: buoyantly rising air
- **Condensation level**: the level where saturation first occurs. It is the cloud base.
- **Lifting Condensation Level (LCL):** If the air is lifted to cloud base, the level is called LCL. Or LCL is the level at which a parcel of air becomes saturated by lifting dry-adiabatically.
- **Convective condensation level (CCL):** The height to which a parcel of air, if heated sufficiently from below, will rise adiabatically until it is just saturated. This is the height of the base of cumuliform clouds which are, or would be, produced by thermal convection from surface heating.
- **Level of free convection** (LFC): The level at which an air parcel first becomes buoyant **(warmer than the surrounding air).**

An Adiabatically Rising Parcel Forming A Thunderstorm



How is determined LCL: the turning point on the parcel's path where the path changes from dry adiabatic lapse rate to moist adiabatic lapse rate.



Mechanisms that Cause Air to Rise

- Mechanical Lifting (LCL)
  - Fronts (cold dense air lifts warm less dense air)
  - Sea Breeze
  - Flow over mountains
  - Frictional convergence
  - Jet stream dynamics
- Surface heating (CCL)
  - Wind blowing over a warm surface (advection)
  - Solar heating

Stability Indices

- Calculating the lapse rates for different layers & areas manually from a sounding is not practical.
- Indices are "tools" to describe the stability of the atmosphere from sounding data.
- Each index provides slightly different information about the potential for severe weather (SWX)– not where

Lifted Index (LI)

- LI is a measure of the instability.
- LI = T (environment at 500 mb) – T (parcel lifted to 500 mb)
- The lower the value of the LI, the warmer the parcel is relative to the environment. So negative LI indicates instability.

Showalter Index (SI)

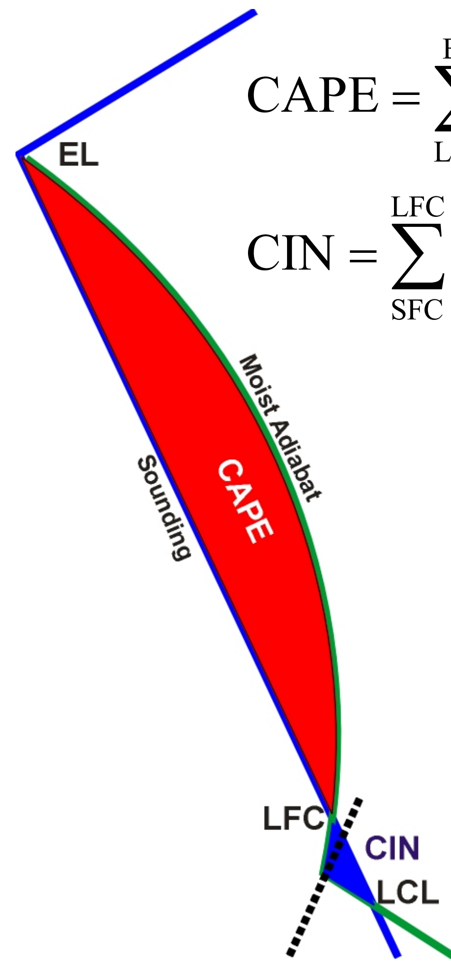
- SI= T (environment at 850 mb) – T (parcel lifted to 850 mb)
- The lower the value of the SI, the warmer the parcel is relative to the environment. So negative SI indicates instability.

Convective Available Potential Energy (CAPE)

- CAPE and CIN are more modern measures of stability and instability
- CAPE is the area between the sounding and the moist adiabat when the parcel is warmer than the surrounding environment. CAPE is proportional to the amount of energy that can be released between the LFC and EL in buoyant updrafts
- CIN (Convective INhibition) is the negative buoyancy area, or energy required to get to the LFC
- Units are m^2/s^2
- Maximum possible vertical velocity is $(2 \times \text{CAPE})^{1/2}$
- CAPE can be as large as 4500 m^2/s^2, but typically is 1500 to 2500 on unstable days
- CAPE = 2500 m^2/s^2 works out to a maximum vertical velocity of 70 m/s

$$\text{CAPE} = \sum_{\text{LFC}}^{\text{EL}} g \frac{T_{parcel} - T_{sound}}{T_{sound}} \Delta z$$

$$\text{CIN} = \sum_{\text{SFC}}^{\text{LFC}} g \frac{T_{parcel} - T_{sound}}{T_{sound}} \Delta z$$



Vertical Totals Index (VT)

- Difference between temperatures at 850 mb and 500 mb, VT = T(850)-T(500)
- A measure of lapse rate
- Values
  - 25 Storms likely
  - 30 Scattered thunderstorms (TR), a few severe
  - > 34 Numerous TR, some severe, possible tornadoes

Cross Totals Index (CT)

- Difference between dewpoint at 850 mb and temperature at 500 mb, CT = TD(850)-T(500)
- A measure of moisture content
- Values
  - < 17 TR unlikely
  - 17-19 Isolated TR
  - 20-23 Scattered TR
  - 24-25 Scattered TR, some SWX
  - 26-29 Scattered to numerous TR, few SWX
  - > 30 Numerous TR, scattered SWX and tornadoes

Total Totals Index (TT)

- Sum of VT + CT, TT = T(850) + TD(850)-2T(500)
- A measure of both moisture and instability
- Values
  - < 43 TR unlikely
  - 44-45 Isolated TR
  - 46-47 Scattered TR
  - 48-49 Scattered TR, some SWX
  - 50-55 Scattered to numerous heavy TR, few SWX
  - > 60 Numerous heavy TR, scattered SWX and tornadoes

K Index

- $(T_{850}-TD_{500}) - TD_{850}+(T_{700}-TD_{700})$
- K > 20 → Chance of Air-Mass thunderstorms
- K > 40 → Air Mass thunderstorms certain
- K > 30 → Potential for Mesoscale Convective Complexes
- Advantage, does not require a plotted sounding

TABLE 6.2 Stability categories and likelihood of severe convective storms for various ranges of the Lifted Index (LI), Showalter Index (SI), Convective Available Potential Energy (CAPE), Total Totals (TT) index, and SWEAT (SW) index.

Stability	LI	SI	CAPE	TT	SW
Very stable (no significant activity)	> +3				
Stable (Showers possible; T'showers unlikely)	0 to +3	> +2	< 0		
Marginally unstable (T'showers possible)	–2 to 0	0 to 2	0 to 1000	45 to 50	
Moderately unstable (Thunderstorms possible)	–4 to –2	–3 to 0	1000 to 2500	50 to 55	250 to 300
Very unstable (Severe T'storms possible)	–6 to –4	–6 to –3	2500 to 3500	55 to 60	300 to 400
Extremely unstable (Severe T'storms probable; tornadoes possible)	< –6	< –6	> 3500	> 60	> 400

SWEAT---Severe WEather Threat---a weighted sum of T850mb, TT, and differences in wind between the 850 & 1000 mb.

Summary

- Kinds Stability: Stable, Unstable, Neutral
- ***Lapse Rate:*** The decrease of temperature with height---Comes in environmental and ***Parcel*** flavors
- ***Adiabatic Process:*** No heat added or removed
  - Dry: Work balances temperature change
  - Moist: Work balances temperature and vapor mixing ratio change
- Stability depends upon environmental lapse rate
  - Absolute stability: ELR < both moist and dry adiabats
  - Absolute instability: ELR > both moist and dry adiabats
  - Conditional instability: ELR between moist and dry adiabats
- Parcel dynamics: Rises dry adiabatically to LCL, then moist adiabatically (but not buoyantly) to LFC, then buoyantly to EL, which corresponds to cloud top because the parcel is not buoyant above
- Parcel requires mechanical lifting or heating to get to LFC
- Stability indices – a measure of the potential of severe wather