Atmospheric Stability/Skew-T Diagrams

Fall 2015
Air Parcel

- Consider a parcel of infinitesimal dimensions that is:
  - Thermally isolated from the environment so that its temperature changes adiabatically as it sinks or rises.
  - Always at the same pressure as the environmental air at the same level, assumed to be in hydrostatic equilibrium.
  - Moving slowly enough that its kinetic energy is a negligible fraction of its total energy.
Stability

- Stability describes how air parcels react to an initial vertical push by some external force.

- Forced to return to its original position: stable.

- Continues to accelerate away from its original position without outside help: unstable.

- Continues to move away from its original position without accelerating: neutral.
Stability cont.

- Consider a small disturbance from equilibrium....
  - Note: Primed values refer to the PARCEL.

- $P = P'$

- Adiabatic, displacements on small time scales.
Lapse Rates

. Dry adiabatic lapse rate
   - Rate at which “dry” parcel changes temperature if raised or lowered in the atmosphere.
   - $10 \, ^\circ C/km$

. Moist adiabatic lapse rate
   - Rate at which “moist” parcel changes temperature if raised or lowered in the atmosphere.
   - $6 \, ^\circ C/km$

. Environmental lapse rate, $\Gamma$
   - Temperature structure of the environment.
Γ < Parcel Lapse rate

- Buoyant acceleration < 0.
- Buoyant force is opposite the displacement (negatively buoyant).
- Positive restoring force.
- Hydrostatically stable or positive stability.
\[ \Gamma = \text{Parcel Lapse Rate} \]

- Buoyant acceleration = 0.
- No restoring force.
- Displacements are met without opposition.
- Hydrostatically neutral or neutral stability.
Γ > Parcel Lapse Rate

- Buoyant acceleration > 0

- Buoyant force in direction of displacement.

- Negative restoring force.

- Hydrostatically unstable or negative stability.
Stability - Visually

(a) Stable ($\Gamma < \Gamma'$)
- $T' < T$
- $f_b < 0$
- $T' > T$
- $f_b > 0$

(b) Neutral ($\Gamma = \Gamma'$)
- $f_b = 0$

(c) Unstable ($\Gamma > \Gamma'$)
- $T' > T$
- $f_b > 0$
- $T' < T$
- $f_b < 0$

Meteorology 311
Stability – Visual cont.

Figure 7.3 Vertical stability in terms of temperature and the environmental lapse rate $\Gamma$. 

$\Gamma' = \begin{cases} 
\Gamma_d & \text{Unsaturated} \\
\Gamma_s & \text{Saturated} 
\end{cases}$
Stability - Theta

Figure 7.4: Vertical stability, under unsaturated conditions, in terms of potential temperature.
Moisture

\[ \Gamma < \Gamma_m < \Gamma_d \]
- Absolutely stable.

\[ \Gamma > \Gamma_d > \Gamma_m \]
- Absolutely unstable.

\[ \Gamma_m < \Gamma < \Gamma_d \]
- Conditionally unstable.
- Stable for unsaturated conditions.
- Unstable for saturated conditions.
Conditional Stability

Figure 7.5 Vertical stability of moist air in terms of temperature and the environmental lapse rate $\Gamma$. 
Vertical Motion

- Stability determines a layer's ability to support vertical motion and transfer of heat, momentum, and constituents.

- How do you get vertical motion?
  - Frontal boundaries (airmass differences)
  - Topography
  - Convergence (continuity equation)
  - Differential heating
Changes in Lapse Rate

- Environmental Lapse Rate can change over time.
- Non-adiabatic heating and cooling
- Solid advection
- Differential advection
- Vertical motion
Thermodynamic Diagrams

- Let us plot the vertical structure of the atmosphere.
- Tephigram
- Stuve Diagram
  - Pseudo-adiabatic chart
- Skew-T, log P diagram
  - Most used operationally by forecasters.
Skew-T Diagram

- Y-Axis is logarithmic in pressure.
- Isotherms are “skewed” 45° from lower left to upper right.
- Dry adiabats: slope from upper left to lower right. Label in degrees Celcius.
- Saturation or “moist” adiabats – curved
  –(green on official charts)
- Mixing ratio lines: dashed and slope a little from lower left to upper right (g/kg).
Movement

- If air is dry (not-saturated), $\Theta$ is conserved.
  - Adiabatic, move along a dry adiabat or line of constant $\Theta$.
  - Mixing ratio does not change.

- If air is saturated, moisture condenses or evaporates, heat released impacts the temperature.
  - $\Theta_e$ and $\Theta_w$ keep the same value.
  - Mixing ratio changes.
Temperatures

- **Potential temperature**
  - Conserved in an adiabatic process
  - Dry adiabat

- **Wet-bulb temperature**
  - Conserved in a moist adiabatic process
  - Moist adiabat

- **Equivalent potential temperature**
  - Raise parcel until all moisture has condensed out and bring parcel back to 1000mb.
  - Used to compare parcels with different moisture contents and temperatures.
Important Variables

● Mixing ratio (w)
  - Use w line through $T_d$.

● Saturated mixing ratio ($w_s$).
  - Use w line through T.

● $\text{RH} = 100\% \ (w/w_s)$

● Vapor pressure (e)
  - Go from $T_d$ up isotherm to 622mb and read off mixing ratio in mb.

● Saturation vapor pressure
  - Use T, not $T_d$. 
More Variables

- Wet-bulb temperature ($T_w$).
- Wet-bulb potential temperature ($\theta_w$).
- Equivalent temperature ($T_e$).
- Equivalent potential temperature ($\theta_e$).
Important Levels

- **LCL** – lifting condensation level
  - Where lifted air becomes saturated.

- **LFC** – level of free convection
  - Where lifted air becomes positively buoyant.

- **EL** – Equilibrium level
  - Where lifted air becomes negatively buoyant up high.

- **CCL** – Convective condensation level.
  - Height to which a parcel of air would rise adiabatically to saturation from surface heating.
CAPE

• CAPE = Convective Available Potential Energy

• Positive area between parcel path and environmental profile.

• Gives energy available to be converted to kinetic energy and upward motion.
Stability Indicies

● LI – Lifted Index

● SI – Showalter Index

● K Index

● TT – Total totals

● SWEAT – Severe WEAT Threat index

● Precipitable water
Example #2
Example #3
Example #4