Cloud Development and Forms

LIFTING MECHANISMS

1. Orographic
2. Frontal
3. Convergence
4. Convection

Orographic Cloud

The Orographic Cloud
Orographic Cloud

- Rising air cools initially at the DAR
- If saturation occurs, further rising causes air to cool at the MAR
- If a significant amount of moisture is released via rain, the process is not fully reversed as the air descends and temperature is higher on the leeward side at the same elevation

Frontal Lifting

Convergence

- Results in rising air:
  - Lower level convergence
  - Upper level divergence
- Results in sinking air:
  - Lower level divergence
  - Upper level convergence

Convection

- A parcel of air becomes buoyant and rises when it is less dense than surrounding air at the same elevation
- Air density is a function of temperature, pressure, and humidity
- At the same level, temperature is the main determinant of density: warm air is less dense than cold air
Environmental Lapse Rate

- The ENVIRONMENTAL LAPSE RATE is highly variable. Its value in relation to the DAR and MAR determines the STABILITY of the air.
- STABLE AIR is not easily moved vertically.
- UNSTABLE AIR will move vertically on its own due to buoyancy effects.
- CONDITIONALLY UNSTABLE AIR will become unstable if condensation occurs.
- The stability is determined by the ENVIRONMENTAL LAPSE RATE.

Environmental Lapse Rate in Hawaii

The Trade Wind Inversion

Effect of Inversion on Rising Air

Trade Wind Inversion
Trade-Wind Inversion

- Mean altitude ~2200 m (7200 ft)
- Frequency ~80%
- Stable atmospheric layer
- Forms a barrier to rising air
- Because rising air is the predominant means by which clouds form, cloud development is capped at the TWI level
- As a result, relatively thin clouds produce less precipitation when TWI is present
- Climate changes resulting in either more frequent or lower altitude TWI will cause a reduction in rainfall

Effect of Inversion on Rainfall

**Source:** Adapted from Tran (1995)

**HaleNet:** Haleakalā Maui

TWI Trends

**Source:** Cao et al. (2007)

**TWI affected Hawai’i more of the time starting in early 1990s**
TWI Trends

TWI also appears to be moving lower in elevation
Source: Cao et al. (2007)

How high will air be lifted by buoyancy?

- Stability and the degree of surface heating determine the maximum lifting height.

- For Unsaturated Air:
  - Suppose the ELR = 5°C per 1000 m, the surface temperature is 25°C and an air parcel over a bare field is heated to 30°C and begins to rise. How high will it rise?
  - The environmental temperature $T_E = T_{E0} - ELR * x$
    where $x = \text{elevation in kilometers}$$
  - The temperature of the parcel $T_P = T_{P0} - DAR * x$
  - The parcel will rise until $T_E = T_P$. We can find that by solving for $x$:
    $x = \frac{T_{P0} - T_{E0}}{DAR - ELR} = \frac{30 - 25}{10 - 5} = 1000 \text{ m}$
  - Suppose the surface dewpoint temperature is 21°C in the above example. Will a cloud form? Will anything else be affected?

At what height will the air become saturated?

LIFTING CONDENSATION LEVEL

- LCL = the height to which air must be lifted to bring it to saturation; the height of the cloud base
- A simple method of estimating the LCL:
  - Air reaches the LCL when it has cooled to its dew point temperature (DPT).
  - However, DPT, a function of vapor pressure, and vapor pressure of a rising parcel of air is decreasing because the atmospheric pressure is decreasing. Therefore it is best to use some a conservative measure of humidity, such as mixing ratio or specific humidity when tracking a rising air parcel.
  - To a reasonable approximation, however, we can just assume that the dew point temperature decreases at about 2°C per 1000 m.
  - To get the LCL, we have to determine the height at which the air temperature is equal to the dew point temperature.
    - Air temperature: $T = T_0 - 10x$
    - Dew point temperature: $T_d = T_{d0} - 2x$
    - We can set $T = T_d$ and solve for $x$:
      
        $x \text{ (km)} = \frac{T_0 - T_{d0}}{10 - 2}$

LIFTING CONDENSATION LEVEL

Example:

- $T_0 = 18^\circ C$
- $T_{d0} = 10^\circ C$
- $LCL = ?$
- $T_{LCL} = ?$

Answer:

- $LCL = 1000 \text{ m}$
- $T_{LCL} = 8^\circ C$

Another example:

- $T = 25^\circ C$
  - a) $\text{RH} = 61.2\%$
  - b) $\text{RH} = 78.5\%$

In each case, what is the LCL?

Answers

- a) $T_{a0} = 17^\circ C$, $LCL = 1000 \text{ m}$
- b) $T_{a0} = 21^\circ C$, $LCL = 500 \text{ m}$
Cloud Types

Unlimited variety of size, shape, and composition
Classes based on appearance and/or height

High clouds
- Bases above 6000m (19,000 ft)
- Ice composition
- Cirrus
  - Fall streaks, mares tails
  - Cirrus, cirrocumulus, contrails

Middle clouds
- Bases between 2000 and 6000m (6-19,000 ft)
- Liquid/ice composition
- "Alto" prefix
  - Altostratus, altocumulus

Low clouds
- Bases below 2000m (6,000 ft)
- Liquid composition
- Stratus
  - Nimbostratus, stratocumulus
- Cirrus
  - Altostratus
  - Stratus
  - Stratocumulus
  - Cumulus
  - Cumulus congestus
  - Cumulonimbus