Chapter 6: Stability and Cloud Development

Comments on chapter
Definition of stability
Buoyancy force
Vertical stability in atmosphere
Lapse rate and stability
Stability and clouds
Changing cloud forms
Determining the height of the cloud base

Comments on chapter 6

- In this chapter, hard concepts are mixed in with straightforward concepts.
- Be guided by these notes and my review questions as to what to learn. I don't expect you to know too many things from this chapter. Just strengthen the concepts presented in these notes.
- If you want to be a meteorology major, you'll ultimately need to understand everything in this chapter, so it won't hurt to get started now.
- Only about 6-8 exam questions for exam 3 will come from this chapter.

Classical Definition of Stability (p. 140)

- Something at rest is in equilibrium. Give something at rest a small push. Then see whether there is a force on the object. The equilibrium is:
- **Stable** if a force pushes it back toward its initial position
- **Unstable** if a force pushes it further away from its initial position
- **Neutrally (un)stable** if there is no push either toward or away from its initial position (ball on flat surface, not pictured)

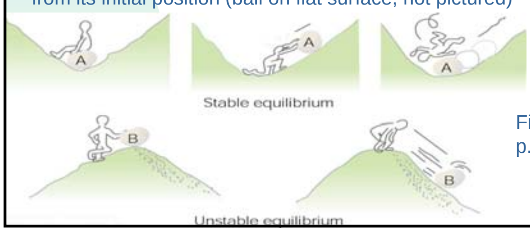


Fig 6.1, p. 140

Stability: Psychology Example

Apply the preceding stability definitions to psychology. If you experience a small disturbance in life, you would be:

- **stable** if you adjust back to the way you were before the incident
- **unstable** if the small disturbance becomes a big deal in your life
- **neutrally stable** if you don't go back to the way you were nor do you become more extreme ("go with the flow")

Buoyancy Force (not in book)

- A "fluid" is anything that can flow. Liquids (like water) and gases (like air) are both fluids.
- An object in a fluid has at least 3 vertical forces pushing on it:
  (1) the force of gravity pulling it down,
  (2) the pressure in the fluid pushing down on its top side, and
  (3) the pressure in the fluid pushing up on its bottom side.
- The combination of these three forces is called the **buoyancy force**.
- If the object is moving up or down, there is also a drag force, which will slow its motion, but whether an object goes up or down depends on whether the buoyancy force is up or down.

Buoyancy Force (continued)

- If an object is less dense than the fluid around it, the buoyancy force will be upward and it will rise. If it is denser than its surroundings, the buoyancy force will be downward and it will sink.
- Example: In water, cork rises, and lead sinks.
- Typically, an air parcel is less dense than its environment if it is warmer than its environment and denser if it is cooler. Hence, the saying: Warm air rises, cold air sinks.

Vertical Stability in the Atmosphere

Suppose an air parcel (blob of air) is given a small push up or down. The atmosphere is:

- **stable** if the buoyancy force pushes the air parcel back toward its original level before push. (Usual situation.)
- **unstable** if the buoyancy force pushes the air parcel even further away. (Happens on hot day near surface and in clouds with warm air rising, cool air sinking.)
- **neutrally (un)stable** if the buoyancy force does not push the air either higher or lower. (Happens following instability when air is well mixed & homogeneous.)

Lapse Rate (p. 141)

- For an air parcel that starts in equilibrium with its surroundings, stability depends on how the temperature of its surroundings decrease with height.
- Lapse rate = rate at which temperature decreases with height. Expressed as a certain number of degrees per kilometer or per 1000 feet. A positive lapse rate means that temperature *decreases* with height.
- The atmospheric lapse rate, also called the environmental lapse rate, is often around 6-7°C per kilometer. This means that the temperature of a "parcel" (blob) of air one kilometer higher than another parcel is 6 to 7°C colder. This is equivalent to a temperature decrease of about 3-4°F per 1000 feet.

Large Lapse Rate: Unstable

- The larger the lapse rate, the colder the environment is as you go up, so the more likely it will be that a rising parcel will be warmer than its environment and will rise buoyantly. That is, when the environmental lapse rate is large, the atmosphere is unstable.
- Example: On a typical summer day in Florida, the surface is much warmer than the air aloft, so a warm bubble of air near the surface will rise easily. In other words, the lapse rate is large, and the atmosphere is vertically unstable. You can see the evidence of this in the tall cumulus congestus and cumulonimbus clouds that are common in Florida summer afternoons.

Small or Negative Lapse Rate: Stable

- If the lapse rate is small, the environment does not get much cooler is as you go up, so the surrounding environment will be warmer than a rising parcel. The air parcel will sink. The atmosphere is stable.
- The extreme case of stability is where the atmospheric temperature is constant or increasing with height (negative lapse rate). This is called a temperature inversion.

Examples of Temperature Inversions

- Example 1: The temperature in the stratosphere is constant or increasing with height. That is, there is an inversion in the stratosphere, so it is always very stable. The first part of the word "stratosphere" comes from the Latin root meaning "stratified," i.e., having horizontal layers. These layers are a sign of vertical stability, i.e., it is hard for an air parcel to rise.
- Example 2: Overnight, the surface of the Earth cools more than the overlying air does. An inversion develops near the surface growing to a depth of roughly 1 km during the night.

Conditional (In)stability (pp. 145-146)

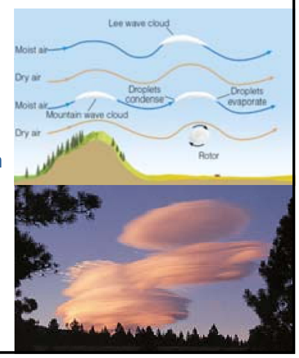
- Recall that rising air cools by doing expansion work.
- If rising air cools to saturation and rises further, condensation will result, releasing latent heat. This air will still cool as it rises but not as much. In some cases, this extra warmth is enough to make conditions unstable.
- There is **conditional (in)stability** if:
  - the air is stable if unsaturated air is rising
  - the air is unstable if saturated air is rising
- Conditional (in)stability is common in Earth's atmosphere. That is, the atmosphere is often not far from vertical instability.

Stability and Clouds

- Unstable conditions result in clouds with vertical development, such as cumulus congestus and cumulonimbus.
- Stable conditions result in no clouds or stratus clouds and its variants, i.e., clouds with "stratus" as part of the name. Recall "stratus" means (horizontal) layer, so stratified air is not moving up or down much.

Example of clouds in stable atmosphere (col 2 of p. 154 & p. 155)

- Air blowing over a mountain is shoved upward. If it cools to saturation, a cloud will form: stratus lenticularis, also called lenticular (lens-like) cloud
- When air is stable, parcels blowing over mountain sink on the downwind side, going below their original level
- They bob up & down like a cork on water as they travel downstream. Other similar clouds can form downwind.



Changing Cloud Forms (pp. 156-57)

- Clouds will change if the stability changes
- To increase stability, *decrease* the lapse rate by:
  - Warming air aloft (sun heats cloud top) and/or
  - Cooling air near surface (infrared radiation from surface)
- Temperature inversion (i.e., zero or negative lapse rate) is very stable. The warm air is up above, and the colder air is near the surface, so the air stays put.

Changing Cloud Forms (pp. 156-57)

- To decrease stability, *increase* the lapse rate by:
  - Cooling air aloft (cloud top cools by infrared emission) &/or
  - Warming the surface (sun heats surface)
- Stability can change without radiation if temperature advection is different in upper and lower troposphere.
  - Low-level warm advection & upper-level cold advection increase instability.
  - Low-level cold advection & upper-level warm advection increase stability.

Changing stability: Example 1

- From morning to afternoon, the Earth's surface warms, while the temperature 1000m & above does not change much.
  - Lapse rate increases because temperature contrast between surface and aloft increase
  - Stability decreases
  - Cumulus clouds often develop
  - Cumulus congestus and cumulonimbus develop when atmosphere is more unstable

Changing stability: Example 2

- When sun goes down, the Earth's surface cools, while the temperature 1000m & above does not change much.
  - Lapse rate decreases, and stability increases.
  - Cumulus clouds and thunderstorms often dissipate
- Explain how a low-level warm wind and/or an upper-level cold wind would *decrease* vertical stability.

Determining convective cloud base heights (p. 153)

- Cumulus clouds are often referred to as convective clouds because convection is rising motion
- Cumulus cloud base will occur at height at which lifted air parcel reaches saturation
- Cumulus cloud base may be:
  - 1000 m above ground in southeast US where relative humidity is high. Because dew point near temperature, air does not have to rise much to cool to dew point.
  - 3000 m above ground in desert SW where relative humidity is low. Dew point much lower than temperature, so air must rise a lot to cool to dew point.