NATS 101
Section 13: Lecture 12

Stability and Cloud Development

A "Parcel" of Air

In the case of the atmosphere, our "object" is not a rock but a parcel of air.

<u>Characteristics of air parcel</u>

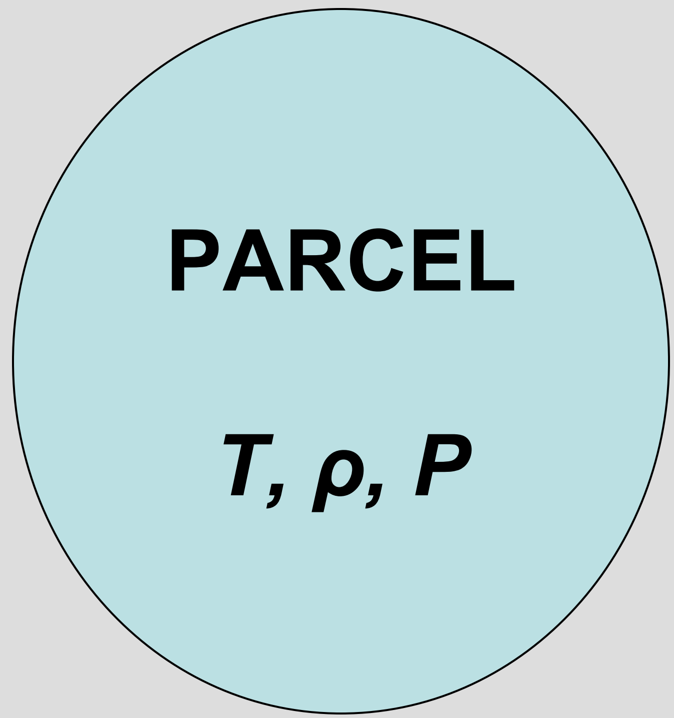
Volume which expands and contracts freely

Does not break apart

Does not interact with the surrounding environment and remains a single unit.

Parcel has temperature, density, and pressure

Pressure in the parcel is equal to the pressure outside.



The First Law of Thermodynamics as applied to air parcel

Energy exchange with the surrounding environment (*heating or cooling*) = **Change in parcel volume (*work done*)** + **Change in parcel temperature (*internal energy*)**

Change in parcel volume (*work done*) → **Expansion or Compression**

Change in parcel temperature (*internal energy*) → **Cooling or Warming**

Adiabatic process
No exchange of heat with surroundings

0 = **Change in parcel volume (*work done*)** + **Change in parcel temperature (*internal energy*)**

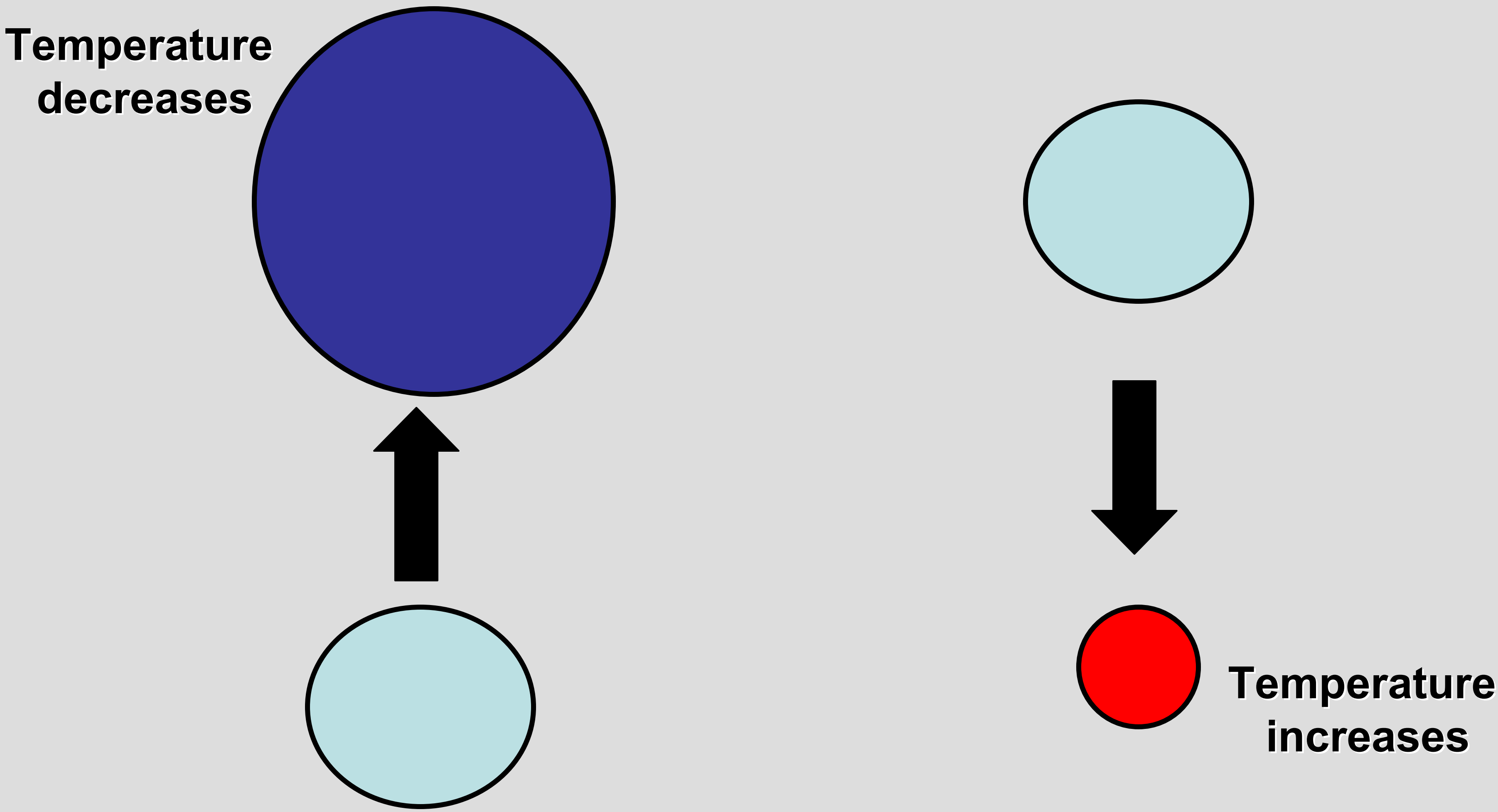
Expansion or Compression — **Cooling or Warming**

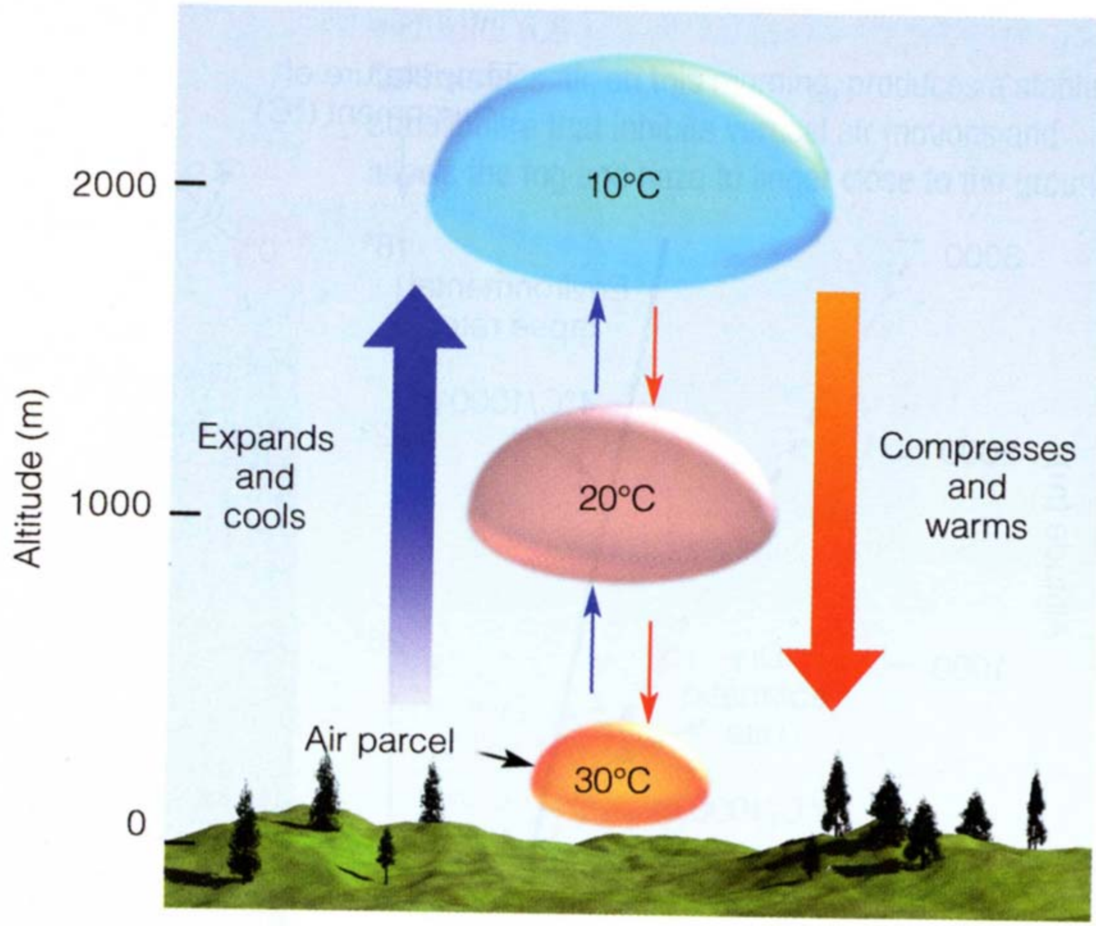
ADIABATIC EXPANSION

Parcel ________

ADIABATIC COMPRESSION

Parcel _________



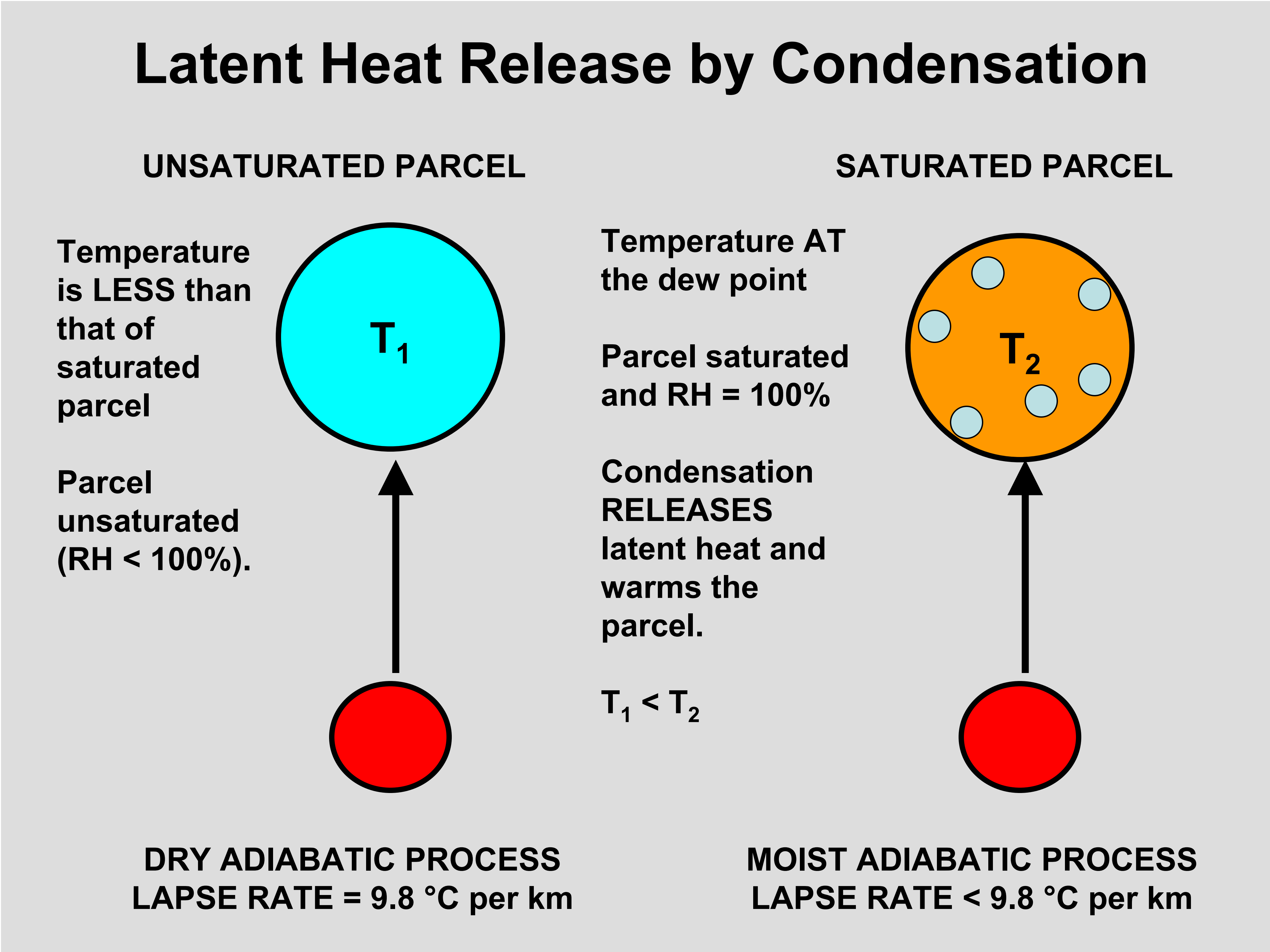


• FIGURE 6.2

The dry adiabatic rate. As long as the air parcel remains unsaturated, it expands and cools by 10°C per 1000 m; the sinking parcel compresses and warms by 10°C per 1000 m.

In the atmosphere, the rate of adiabatic warming or cooling remains constant.

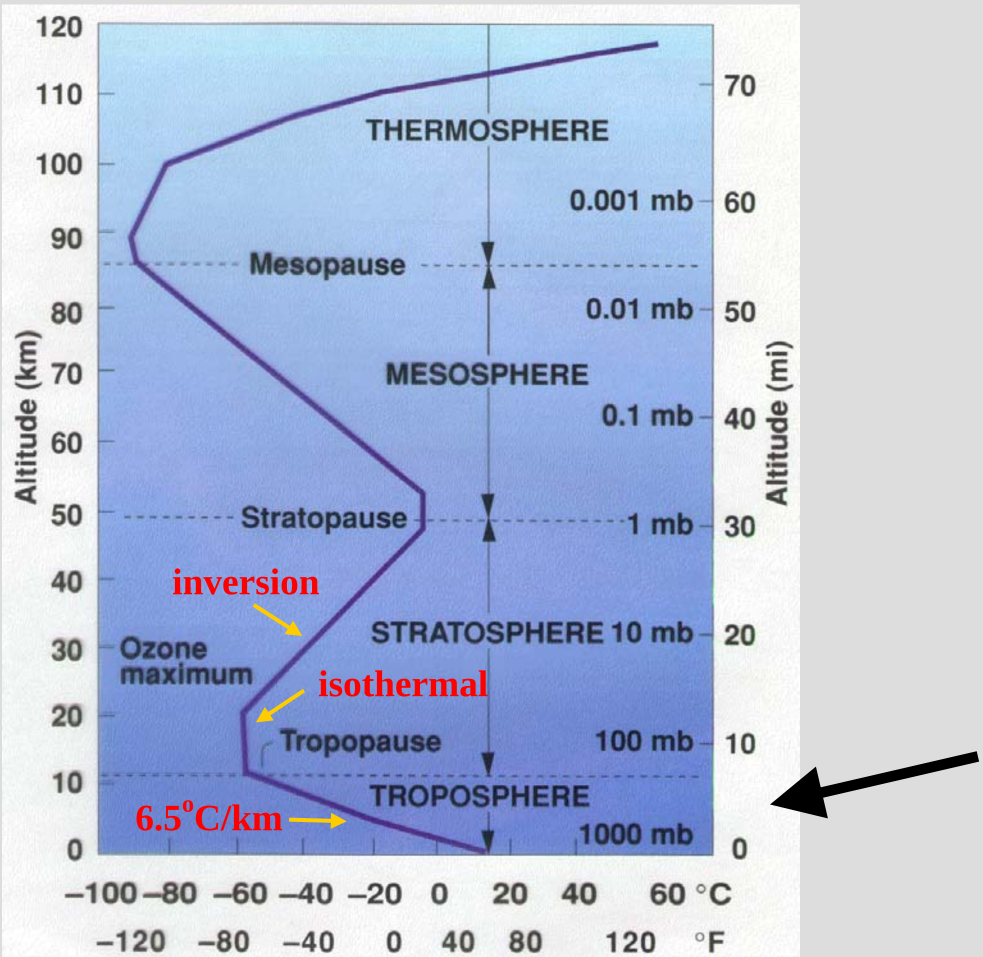
Dry Adiabatic Lapse rate = 9.8 °C per km


Latent Heat Release by Condensation
UNSATURATED PARCEL
SATURATED PARCEL
Temperature is LESS than that of saturated parcel
Parcel unsaturated (RH < 100%).
T_1
Temperature AT the dew point
Parcel saturated and RH = 100%
Condensation RELEASES latent heat and warms the parcel.
$T_1 < T_2$
T_2
DRY ADIABATIC PROCESS
LAPSE RATE = 9.8 °C per km
MOIST ADIABATIC PROCESS
LAPSE RATE < 9.8 °C per km

The moist adiabatic lapse rate is NOT constant, but varies with temperature and moisture content.

It approaches the dry adiabatic lapse rate when temperature gets very cold. Why?

Another Flashback: Why is the lapse rate the way it is in the troposphere?



Because there is ________________, the average lapse rate is 6.5 °C per kilometer in the troposphere—and not the dry adiabatic lapse rate.

Recap of possibilities for the parcel

1. Parcel rising and no condensation:

   Temperature decreases at the _______________ lapse rate of 9.8 °C per kilometer

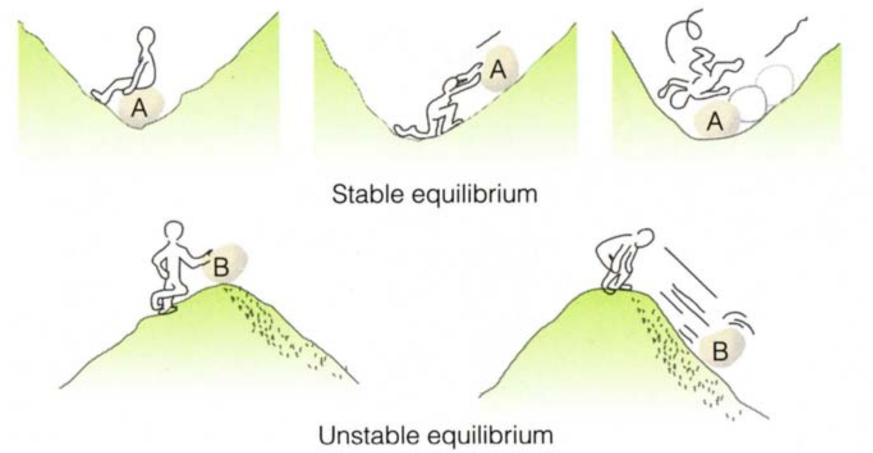
2. Parcel rising, saturated, and there is condensation:

   Temperature decreases at the ________________ lapse rate, about 6 °C per kilometer.

3. Parcel sinking :

   Temperature increases at the ______________ lapse rate, since the parcel is warming and no condensation is taking place.

Concept of Stability

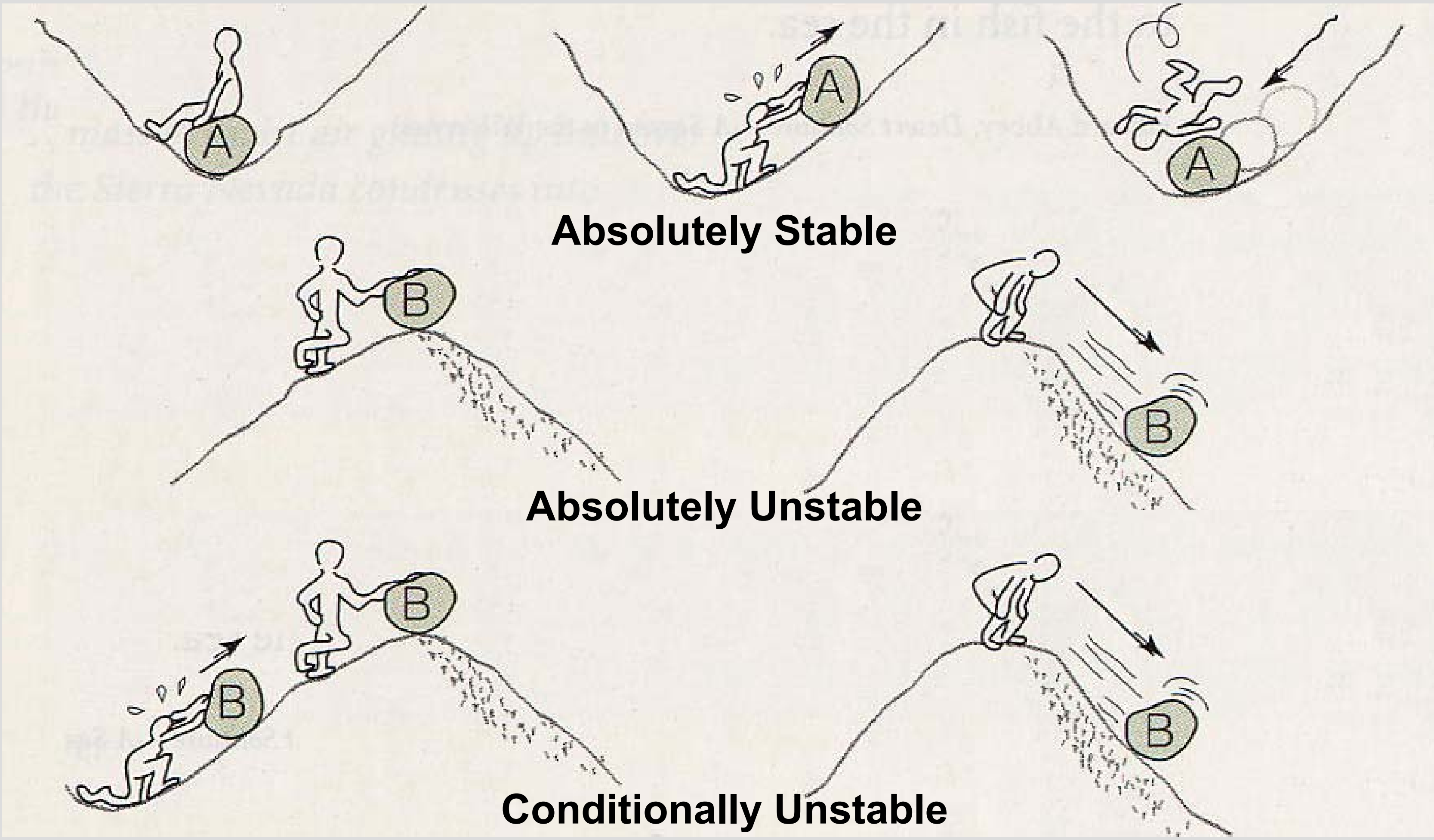


● FIGURE 6.1
When rock A is disturbed, it will return to its original position; rock B, however, will accelerate away from its original position.

Stability **refers to the tendency of an object to return to its original position when disturbed.**

The classic example in physics is the rock at the bottom of the top of the hill.

Concept of Stability—one more possibility for the rock.



Stability and Buoyancy

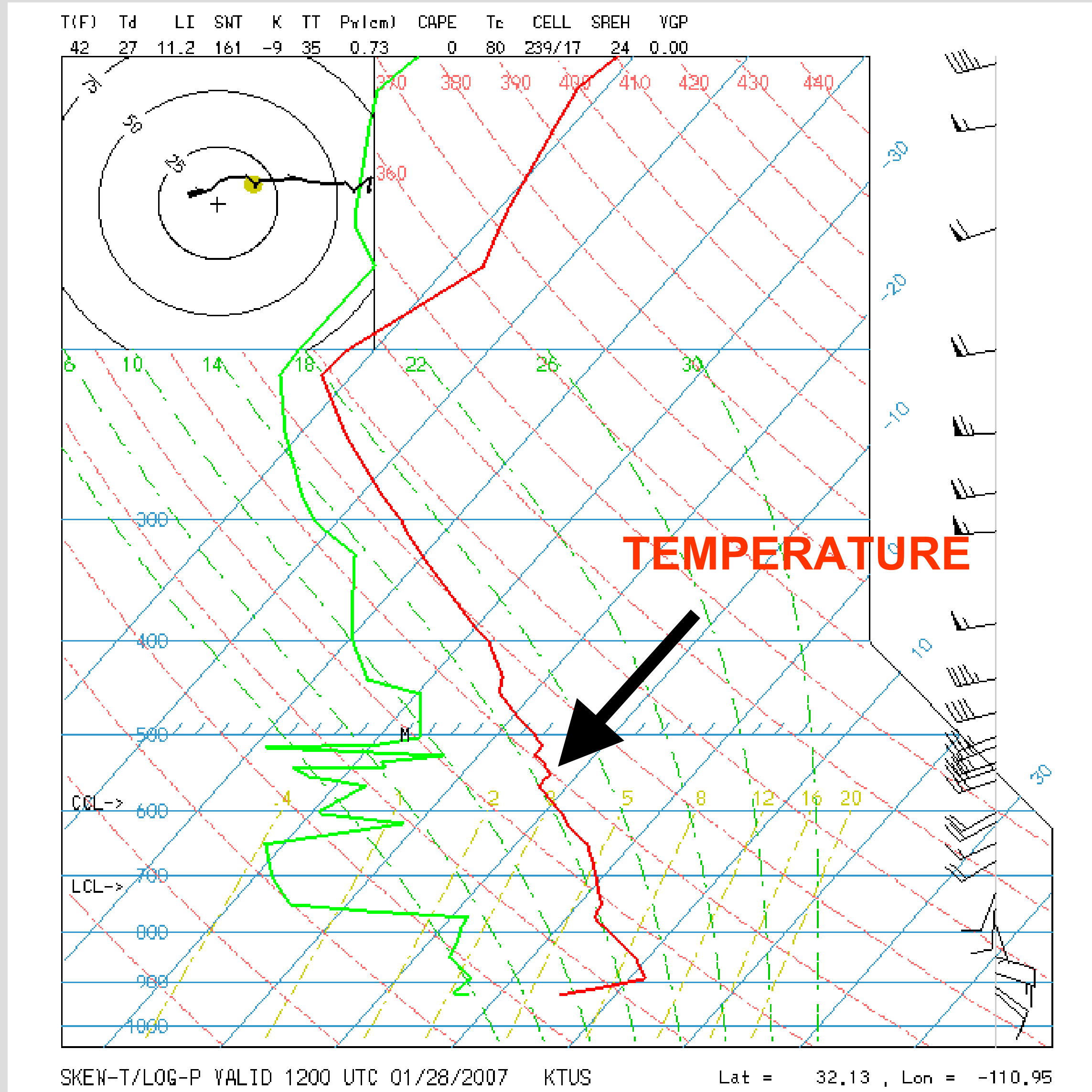
In the atmosphere, the stability is related to the ***buoyancy***, the upward force exerted on the air parcel by virtue of the temperature difference between the parcel and the surrounding air.

We determine which conditions exists in the atmosphere by the environmental lapse rate.

Environmental Lapse Rate (Γ)

Refers to the change in observed temperature with height, as recorded for example by a radiosonde.

$$\Gamma = \frac{\Delta T}{\Delta z}$$



Absolutely Stable

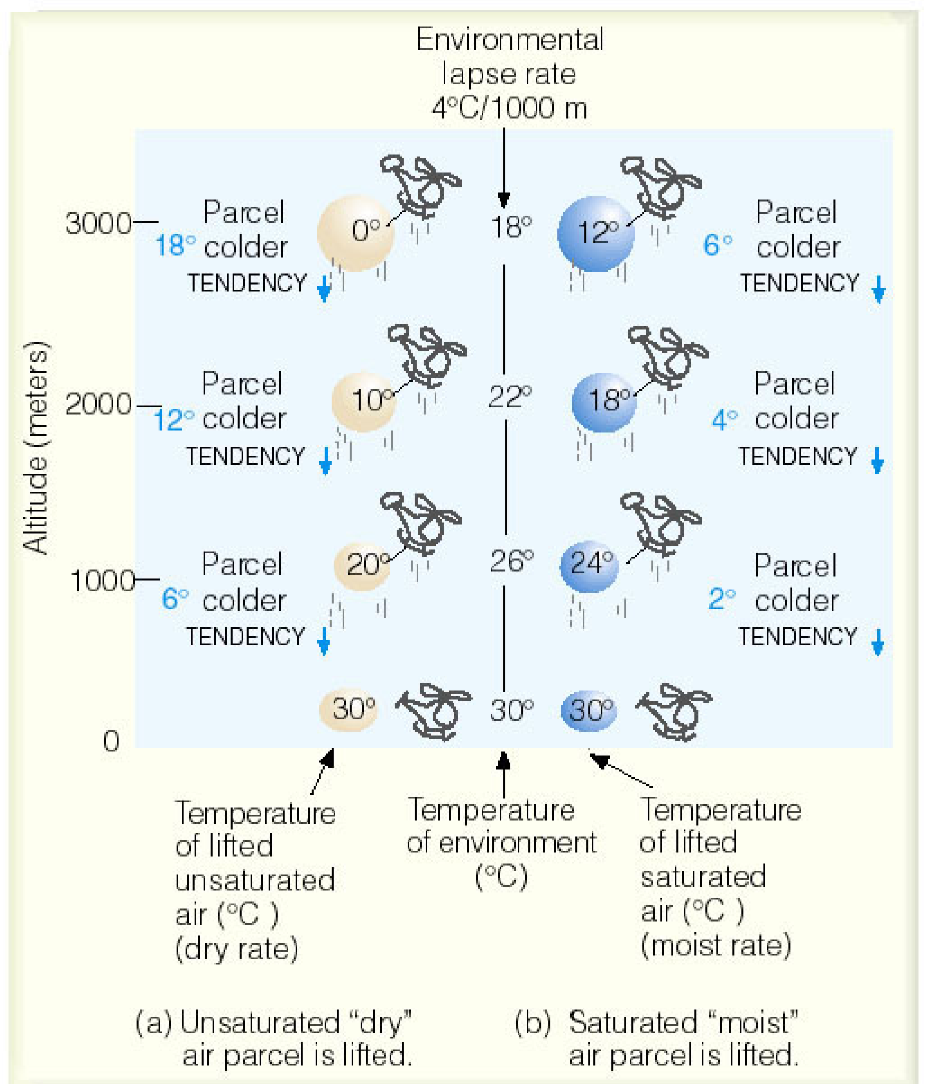
Environmental lapse rate less than moist adiabatic lapse rate

Air resists upward motion

Force must be applied to a parcel so it can rise

If clouds form, they will spread out horizontally.

UNSATURATED **SATURATED**



Clouds in a Stable Environment

RADIATION FOG

Forms in inversion caused by surface radiational cooling. The inversion acts like a "lid"

STRATUS

NIBMOSTRATUS

Form because air is being forced up and over something, for example a front or terrain barrier.

Absolutely Unstable

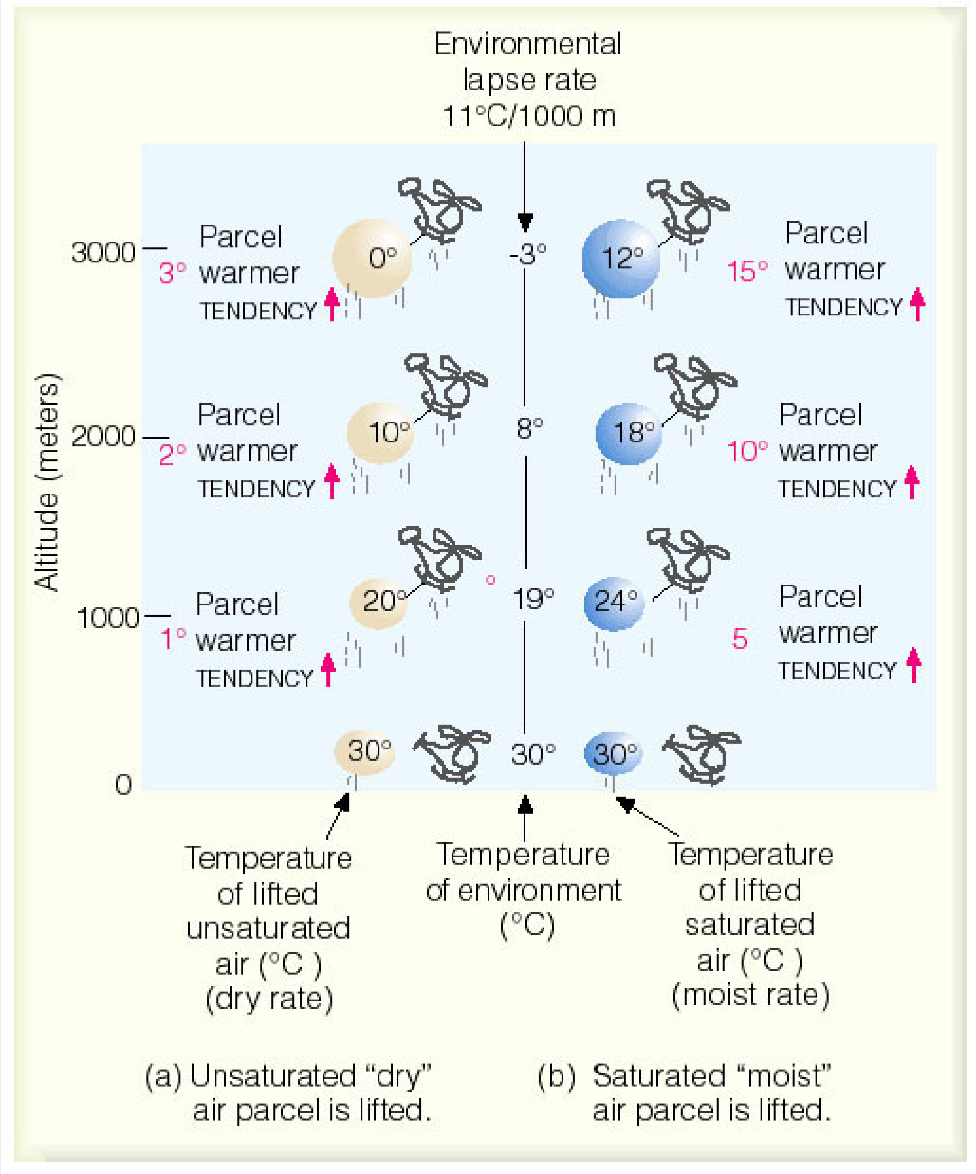
Environmental lapse rate greater than dry adiabatic lapse rate

Air does not resist upward motion.

This condition is rare in the atmosphere and usually occurs in air that is just above the ground on a hot, sunny day.

Also called superadiabatic.

UNSATURATED **SATURATED**

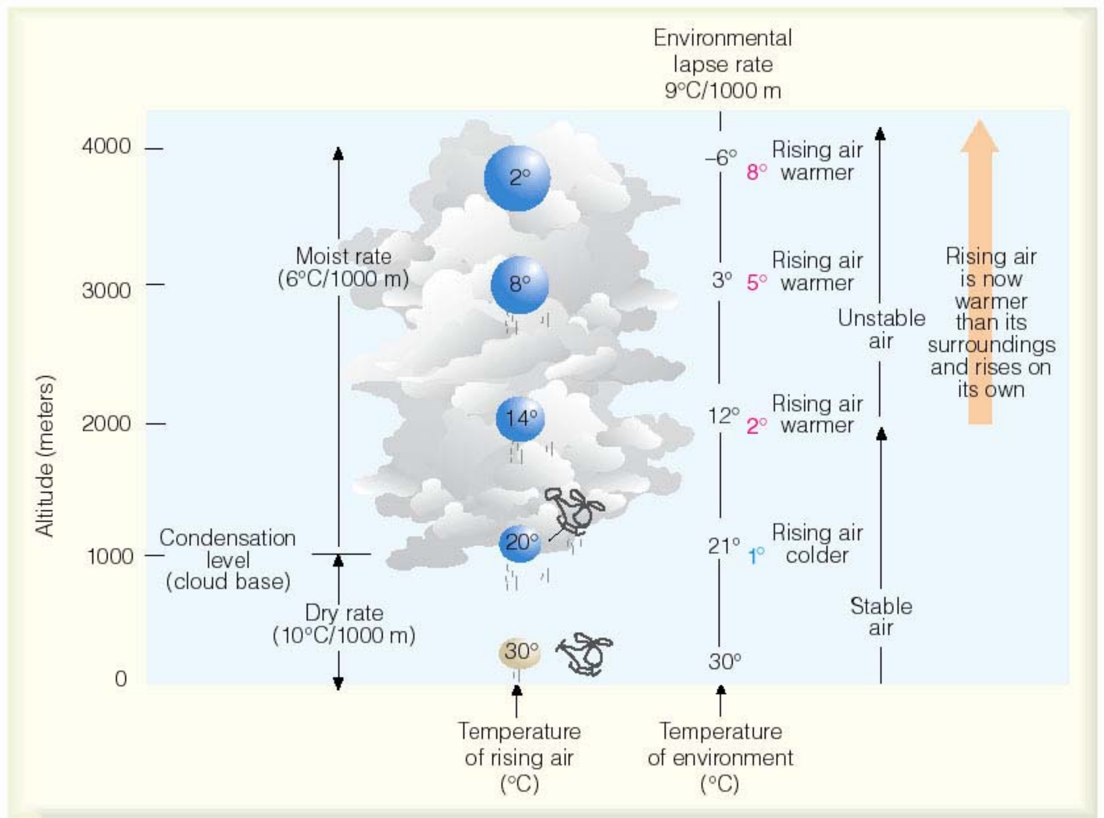


Conditionally Unstable

Environmental lapse rate between the moist and dry adiabatic lapse rate.

Air does not resist upward motion *if* ______________ *is occurring*.

Unlike the absolute unstable case, this condition can happen a lot in the atmosphere!



Clouds in a Conditionally Unstable Environment

Cumulus Humilis

Cumulus Congestus

Cumulonimbus

Basically any type of cumulus cloud indicates conditional instability somewhere in the atmosphere.

What process of heat transfer is happening here?

Causes of Instability in the Atmosphere

Occurs by any process which ____________ the environmental lapse rate.

<u>Cooling Aloft</u>

Winds bringing in colder air
Clouds (radiational cooling)

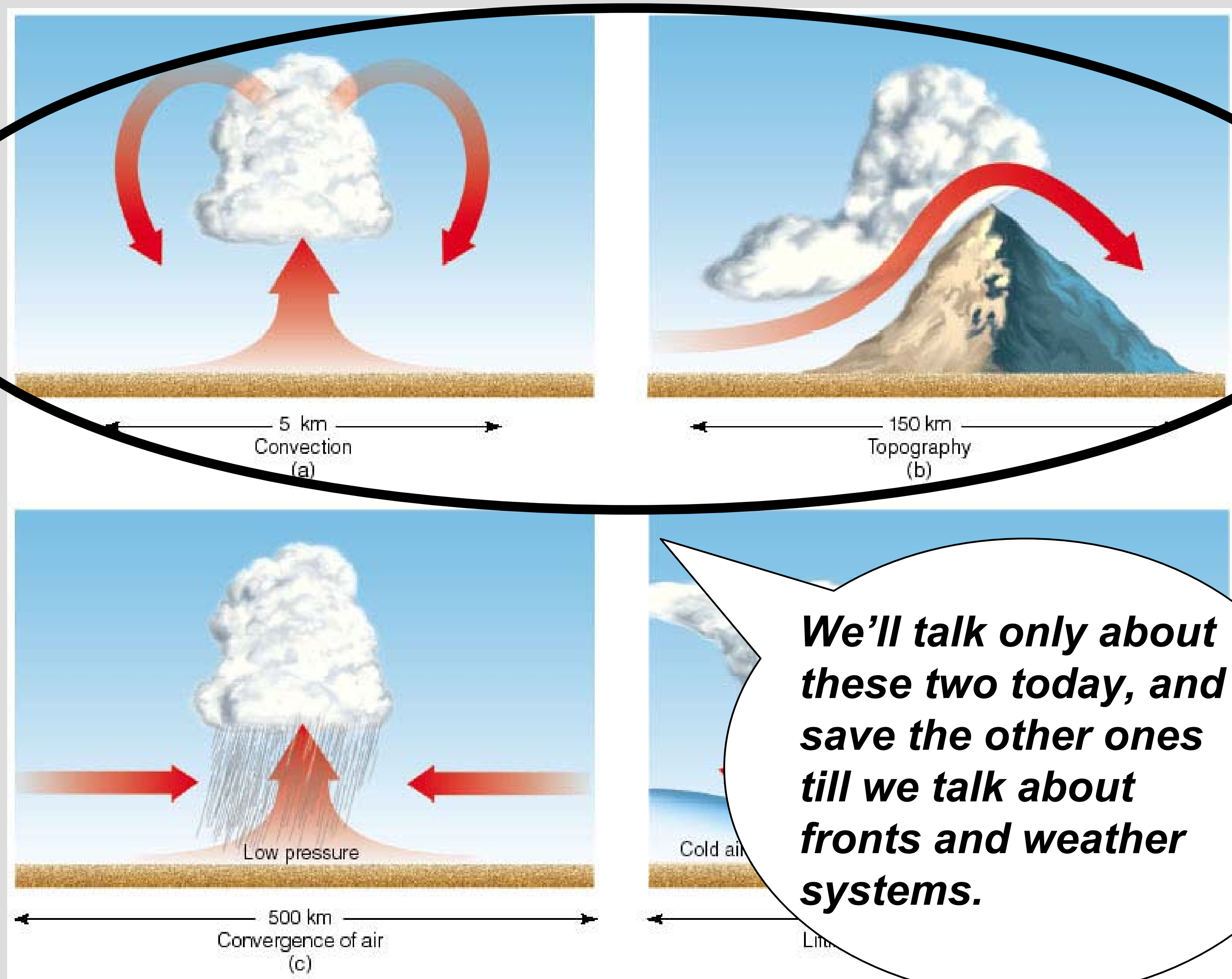
<u>Warming of the surface</u>

Daytime solar heating
Winds bringing in warmer air
Air moving over a warm surface.

Diurnal Cycle

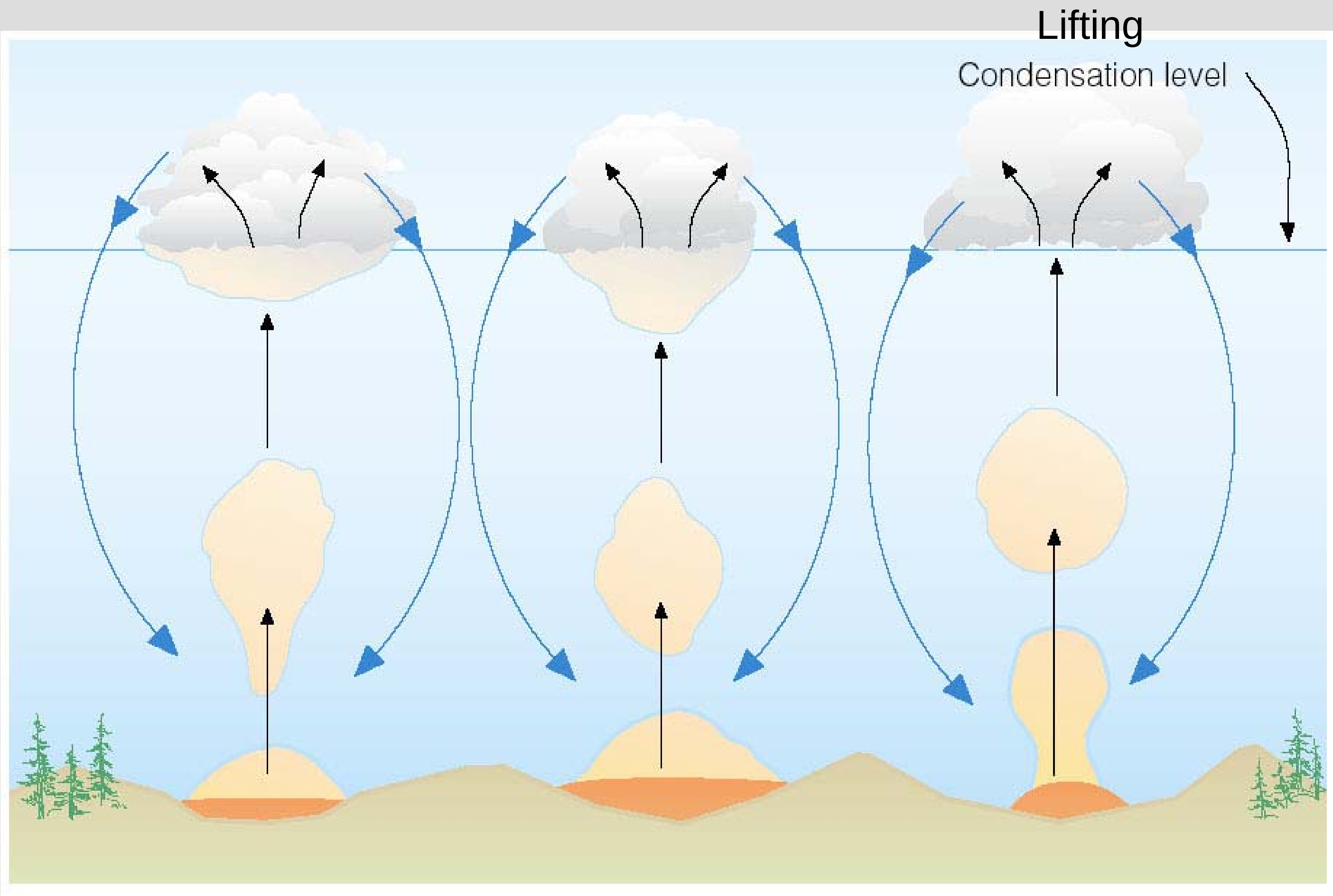
What time(s) of day would you expect to see clouds like these in Arizona during the monsoon? Why?

Causes of Cloud Development



We'll talk only about these two today, and save the other ones till we talk about fronts and weather systems.

Cloud development by convection



RH = _______

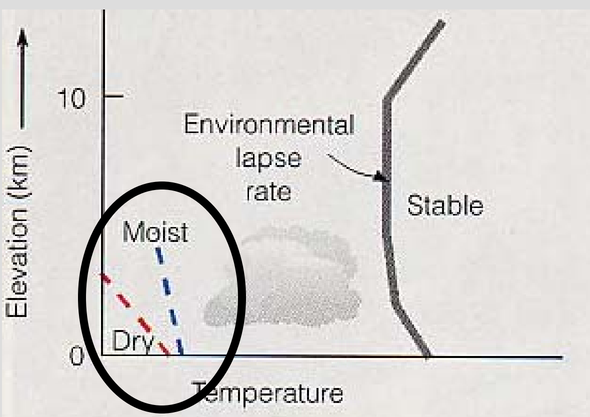
Convection starts with rising bubbles of warm air or thermals. When these reach the point in the atmosphere where RH =______ a cloud begins to form.

How deep convection is depends on how far up the instability goes in the atmosphere

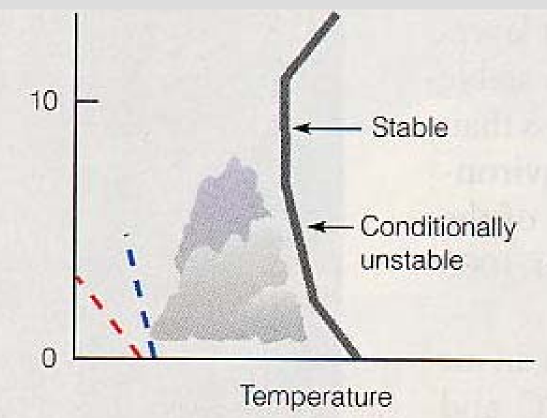
Cumulus humilis

Cumulus congestus

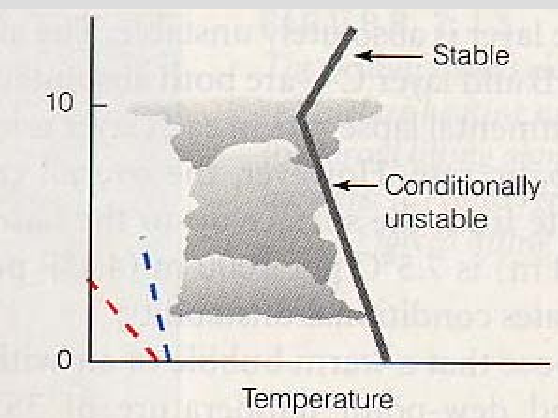
Cumulonimbus



Conditionally unstable in a shallow layer

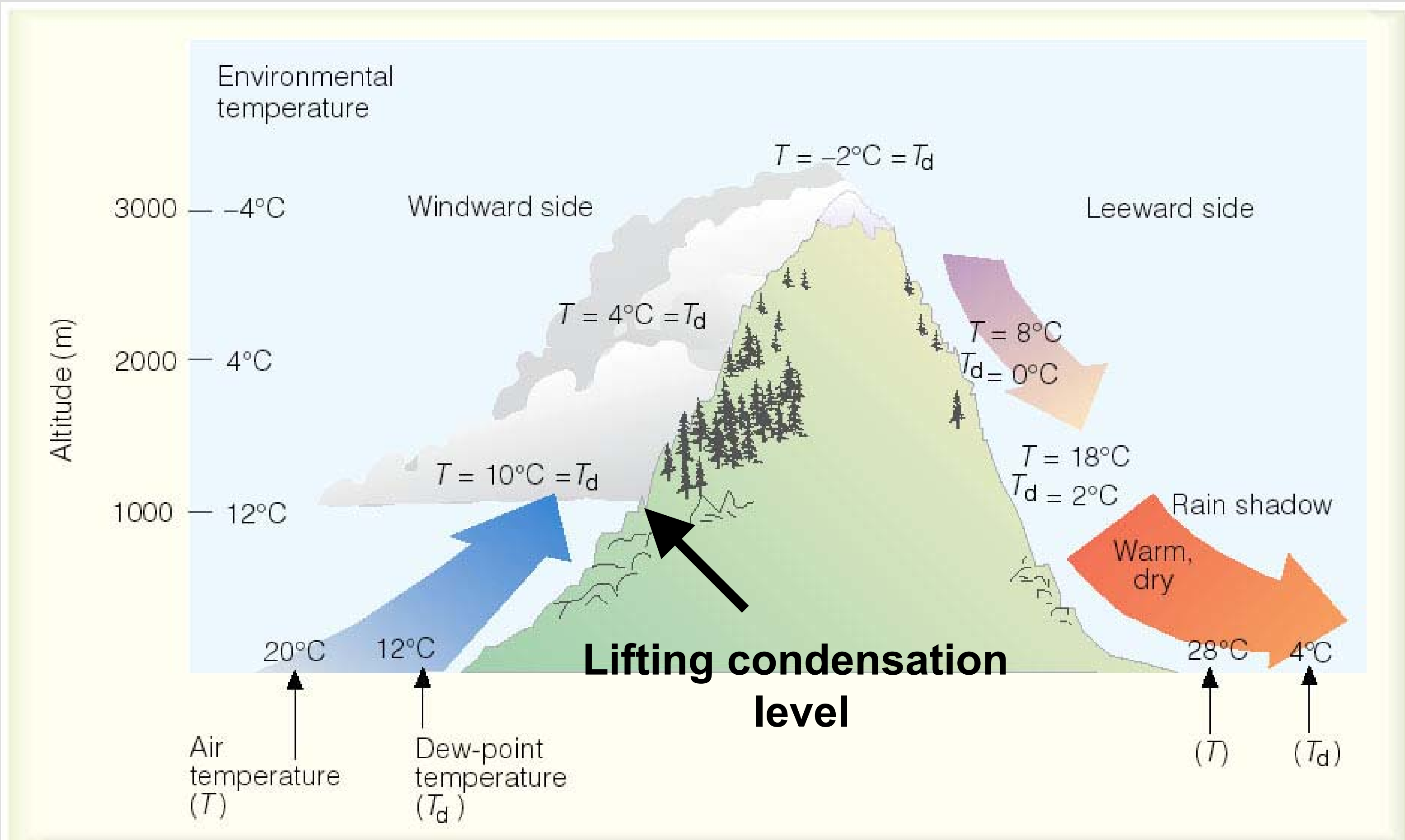


Conditionally unstable about midway through troposphere

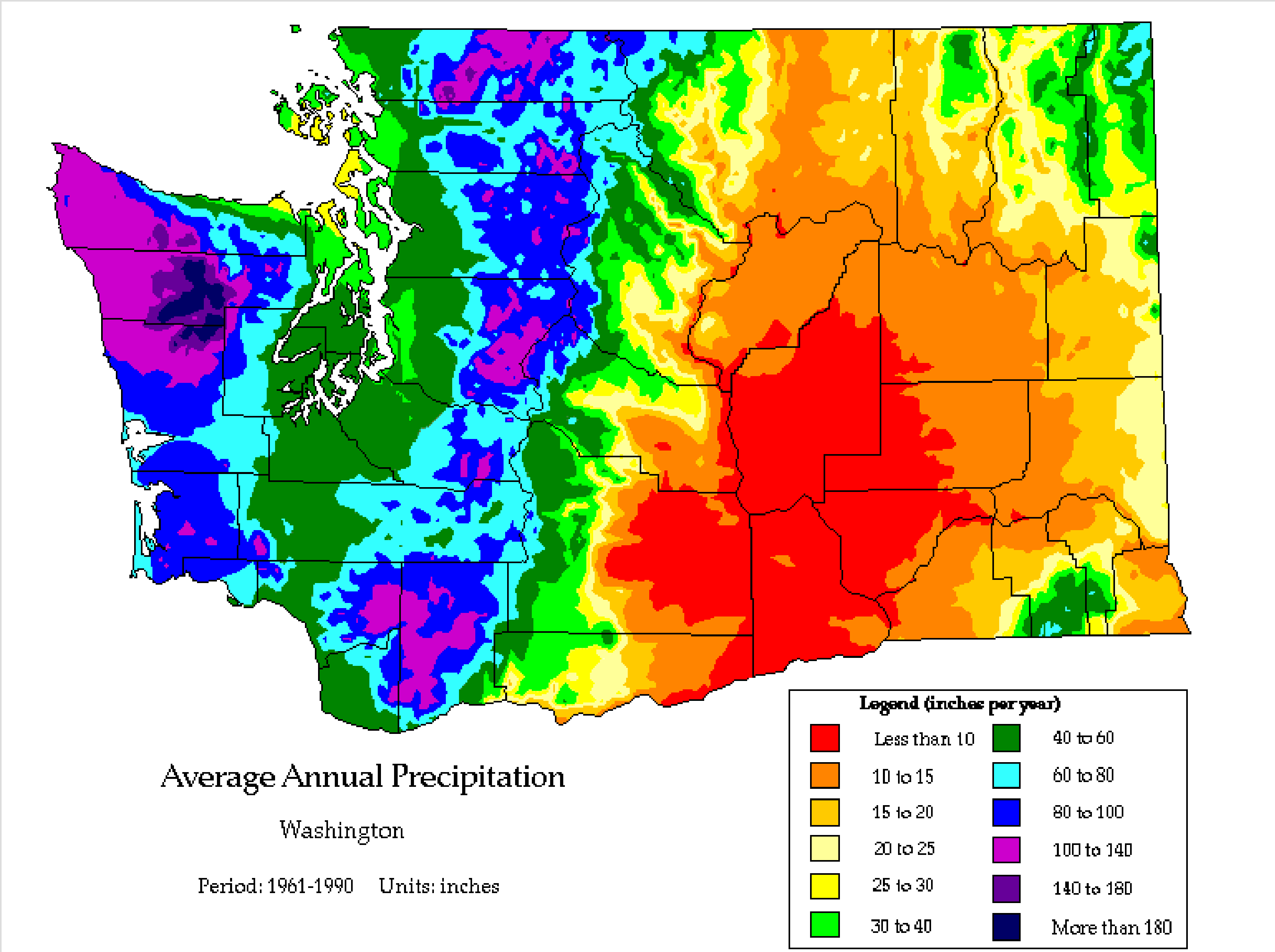


Conditionally unstable nearly to the tropopause

Cloud development by topography: Orographic uplift

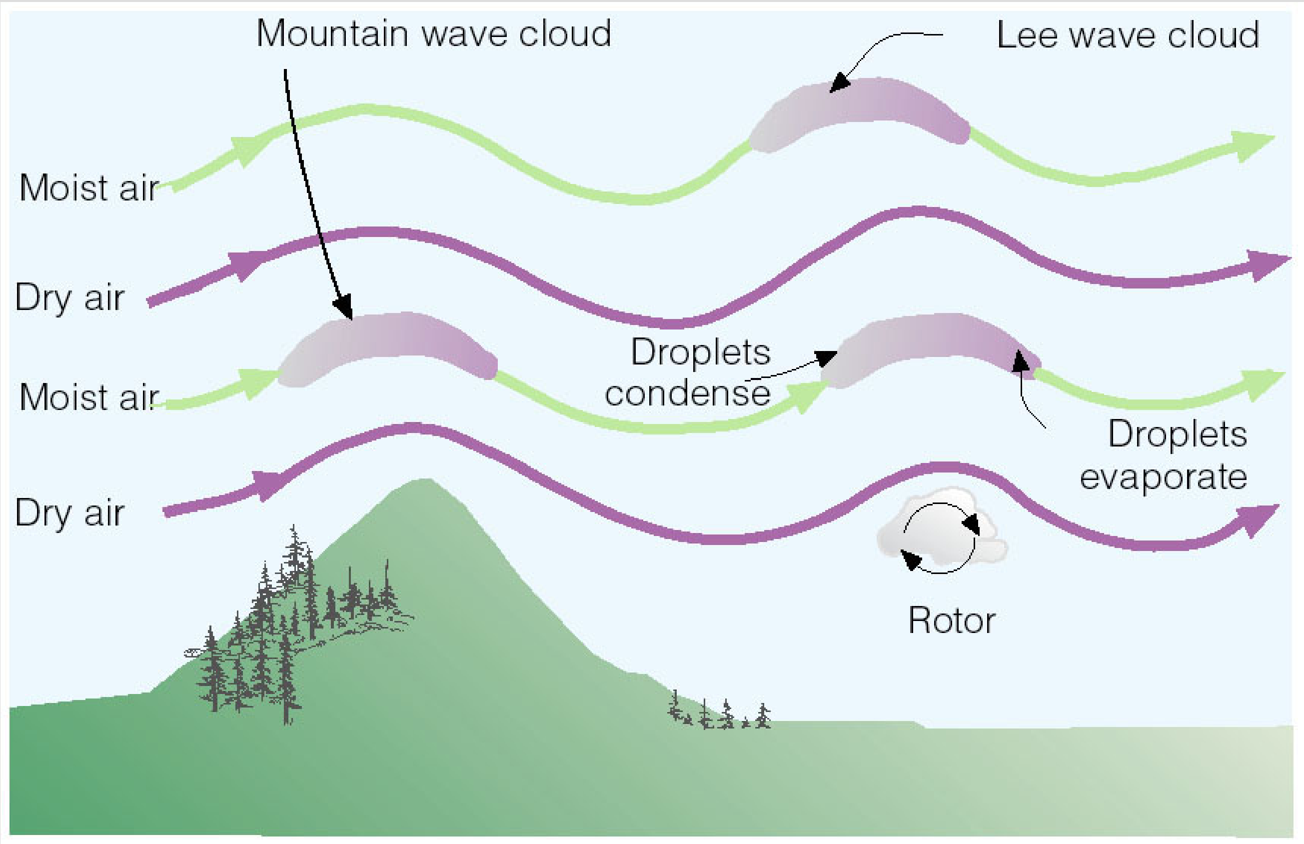


Typical on the windward side of mountain slopes



PRISM Precipitation Product

Cloud development by topography: Mountain wave clouds



Air forced to rise over a mountain and/or the presence topography causes a lee wave in the atmosphere. Responsible for lenticular clouds.

Lenticular cloud caused by lee waves in Boulder, Colorado (UCAR image).

Lee wave clouds are a common occurrence in on the Colorado Front Range during the winter months.

Summary of Lecture 12

An adiabatic process is a process that takes place without a transfer of heat between the system (parcel) and its surroundings. Adiabatic expansion leads to cooling and adiabatic compression leads to warming.

The dry adiabatic lapse rate is 9.8 °C per kilometer. atmosphere condensation is important, and this releases heat and warms the air, so the environmental lapse rate is typically less (e.g. 6.5 °C per kilometer)

Stability refers to the tendency of an object to return to its original position when disturbed. In the atmosphere this is related to the buoyancy.

- **Absolutely stable: Air resists upward motion. Results in flat, spread out clouds.**
- **Absolutely unstable: Air does not resist upward motion. Rare in the atmosphere**
- **Conditionally unstable: Air does not resist upward motion if condensation is occurring. Results in vertically developed clouds.**

Convective clouds are caused by warm air rising which condenses. How deep the convection goes depends on the depth of instability.

Topography can cause clouds to form by orographic lift or mountain waves

Reading Assignment and Review Questions

Reading: Chapter 7