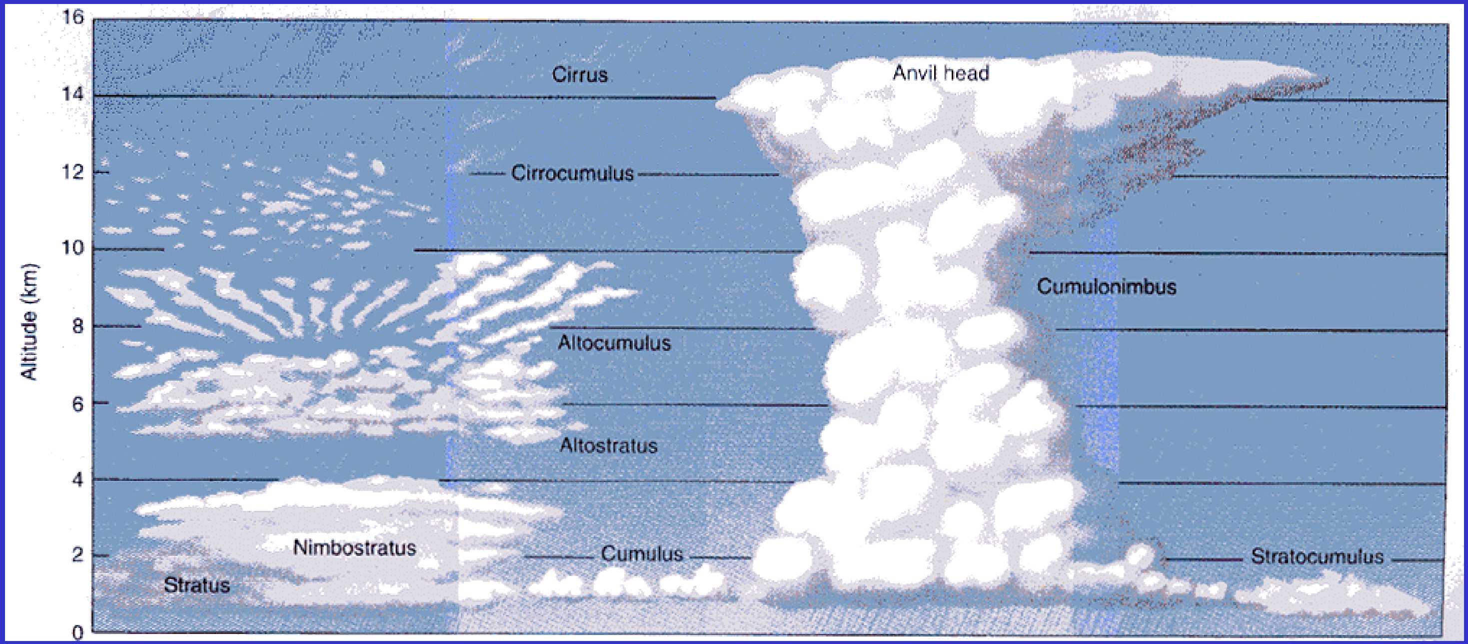
Chapter 6: Cloud Development and Forms



(from "*The Blue Planet*")

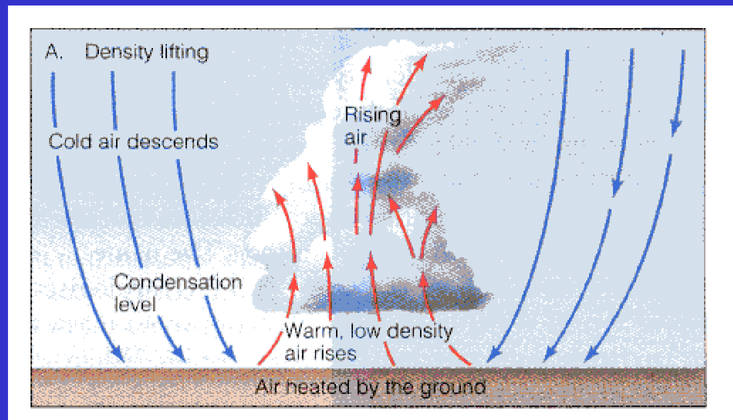
- ❑ Why Clouds Form
- ❑ Static Stability
- ❑ Cloud Types

Why Clouds Form?

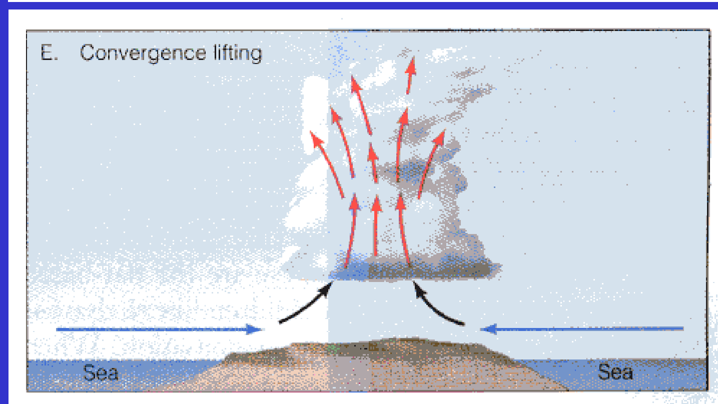
Clouds form when air rises and becomes saturated in response to adiabatic cooling.

Four Ways to Lift Air Upward

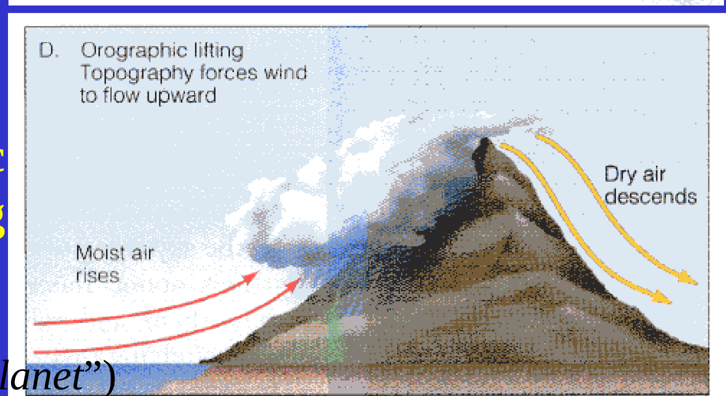
(1) Localized Convection



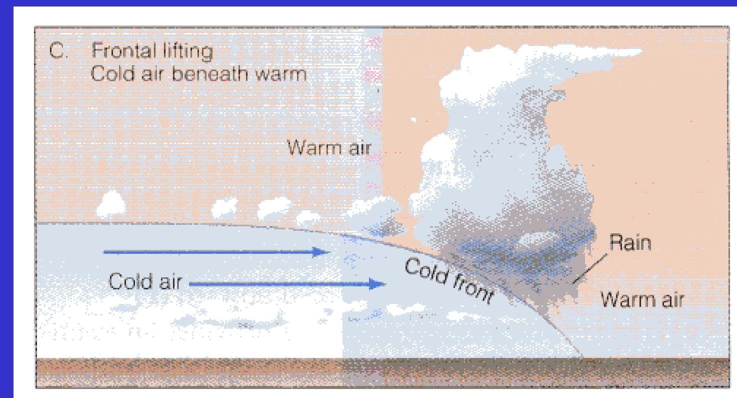
(2) Convergence Lifting



(3) Orographic Lifting



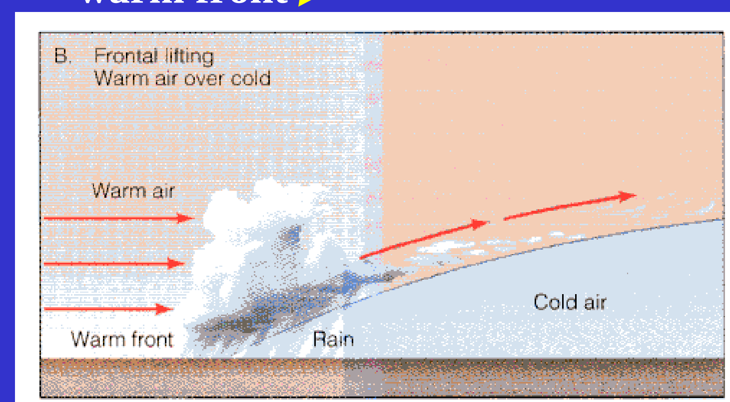
(from "*The Blue Planet*")



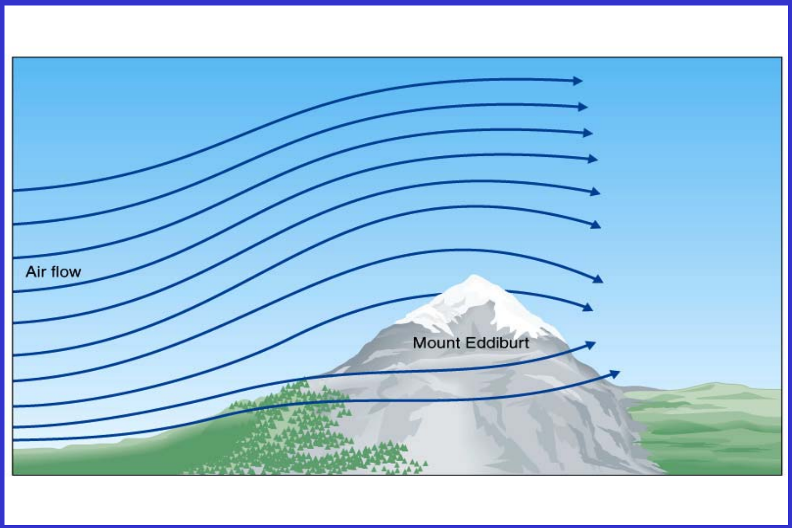
cold front

(4) Frontal Lifting

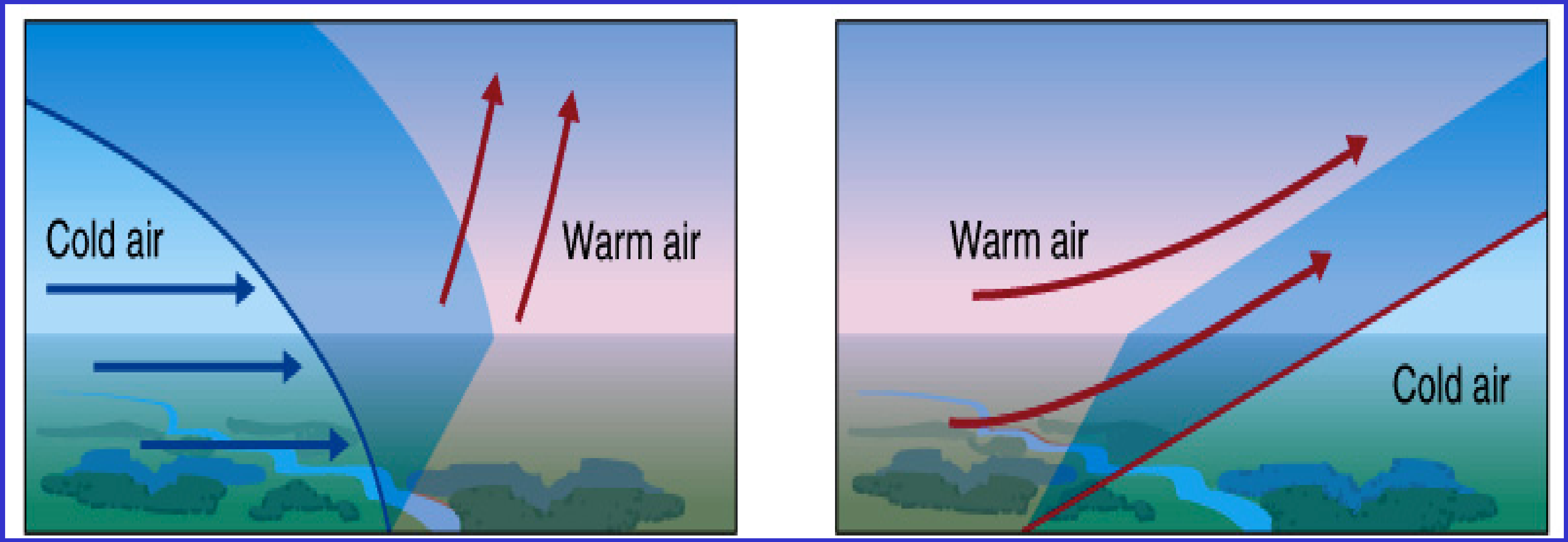
warm front



Orographic Lifting



Frontal Lifting



- When boundaries between air of unlike temperatures (fronts) migrate, warmer air is pushed aloft.
- This results in adiabatic cooling and cloud formation.
- ***Cold fronts*** occur when warm air is displaced by cooler air.
- ***Warm fronts*** occur when warm air rises over and displaces cold air.

Diabatic Process

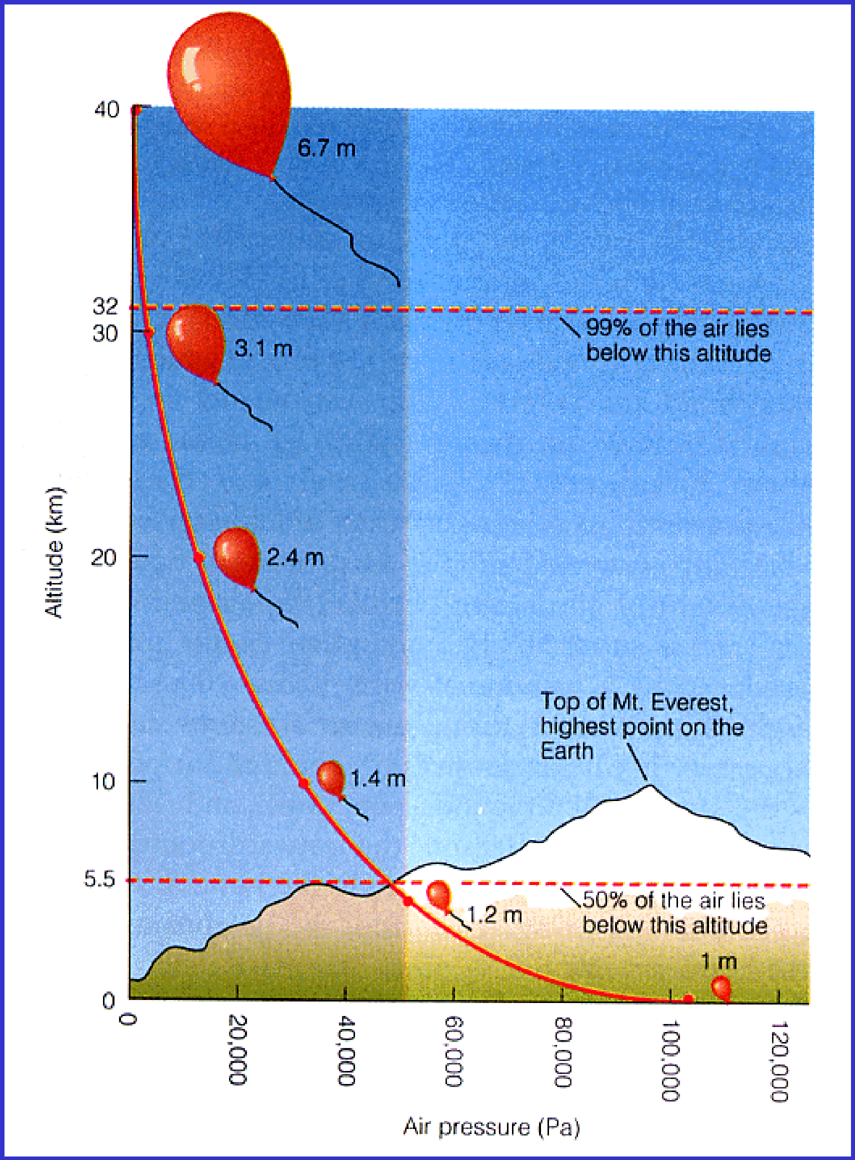
- Involve the direct addition or removal of heat energy.
- Example: Air passing over a cool surface loses energy through conduction.

Adiabatic Process

- If a material changes its state (pressure, volume, or temperature) without any heat being added to it or withdrawn from it, the change is said to be adiabatic.

- The adiabatic process often occurs when air rises or descends and is an important process in the atmosphere.

Air Parcel Expands As It Rises…



(from *The Blue Planet*)

- Air pressure decreases with elevation.
- If a helium balloon 1 m in diameter is released at sea level, it expands as it floats upward because of the pressure decrease. The balloon would be 6.7 m in diameter as a height of 40 km.

What Happens to the Temperature?

- Air molecules in the parcel (or the balloon) have to use their kinetic energy to expand the parcel/balloon.

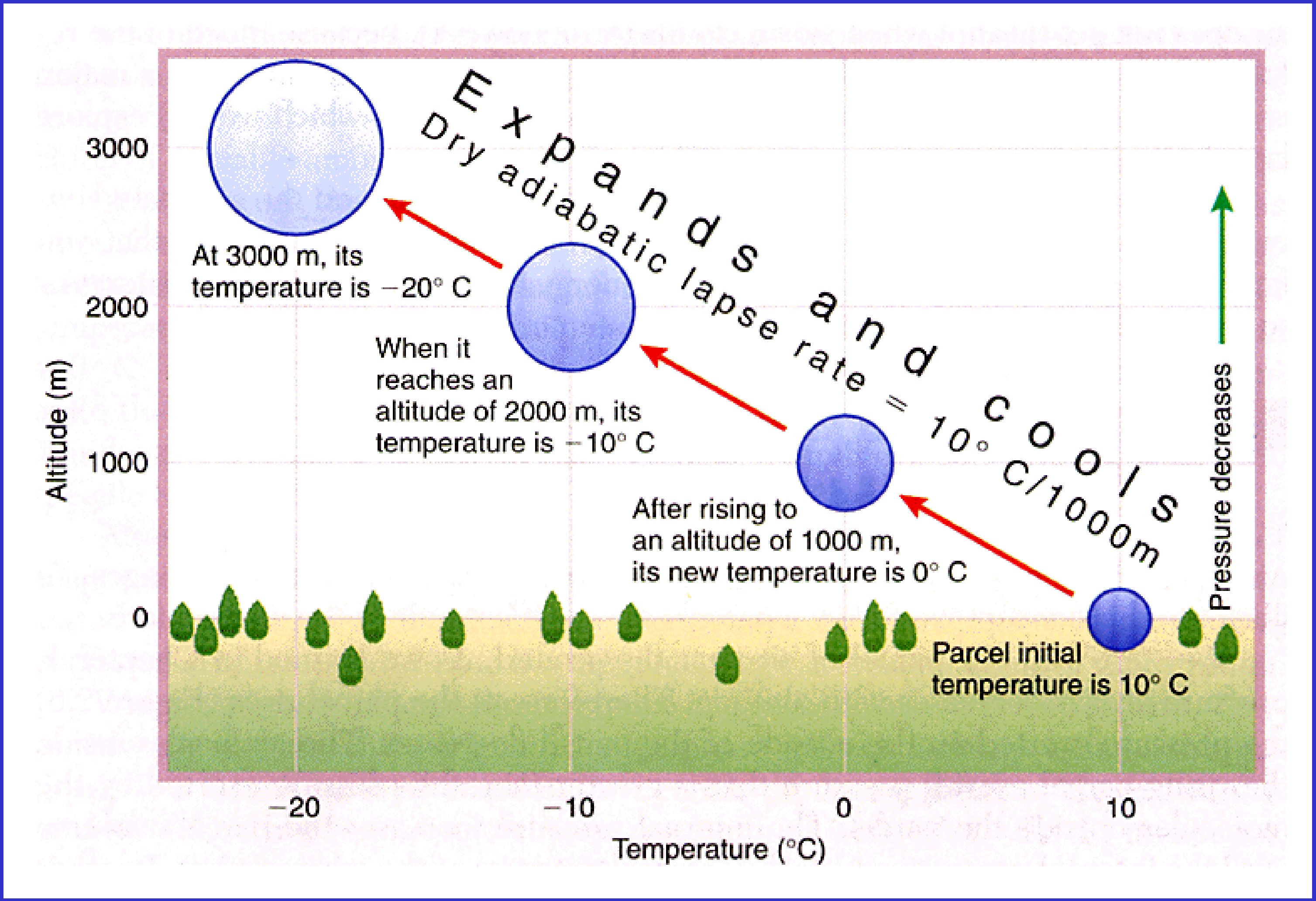
- Therefore, the molecules lost energy and slow down their motions

➔ The temperature of the air parcel (or balloon) decreases with elevation. The lost energy is used to increase the potential energy of air molecular.

- Similarly when the air parcel descends, the potential energy of air molecular is converted back to kinetic energy.

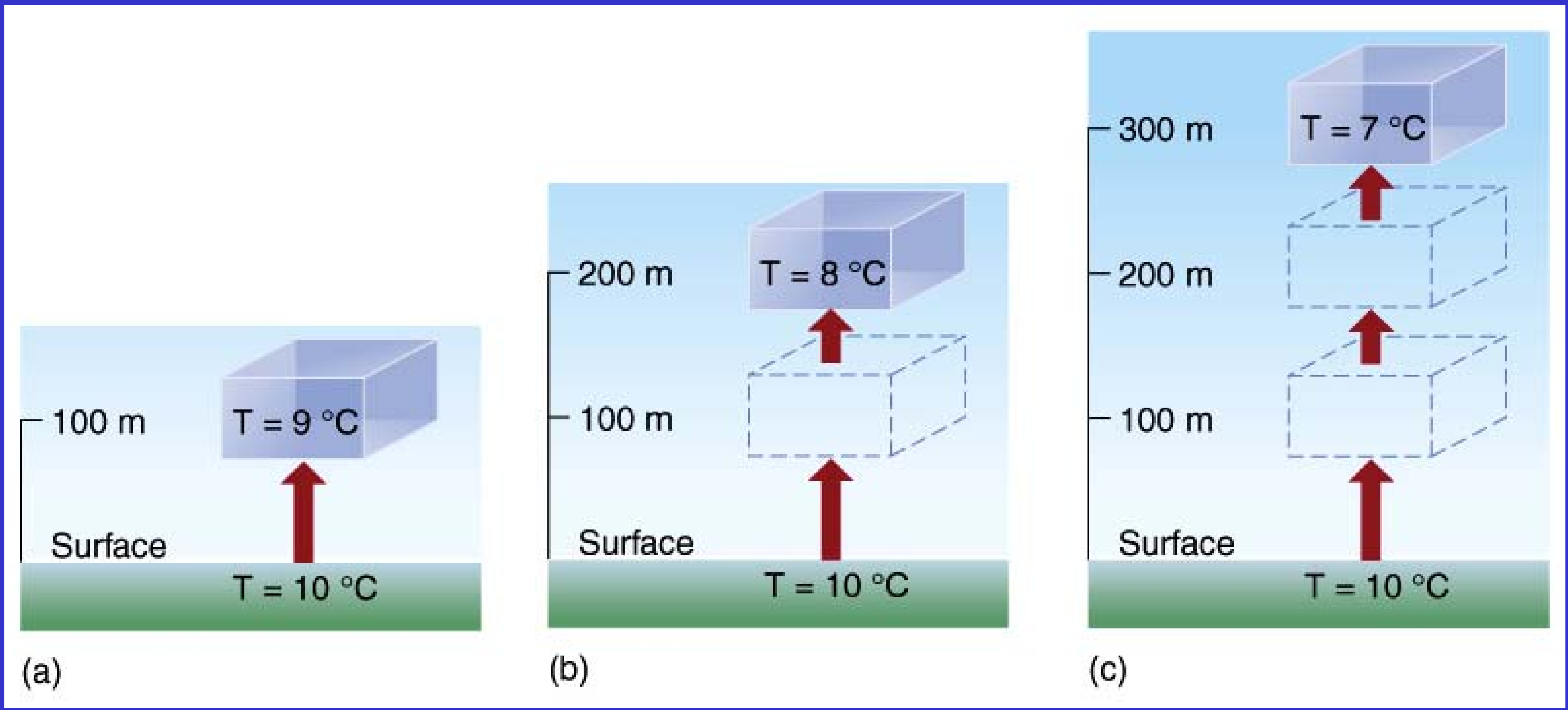
  ➔ Air temperature rises.

Dry Adiabatic Lapse Rate

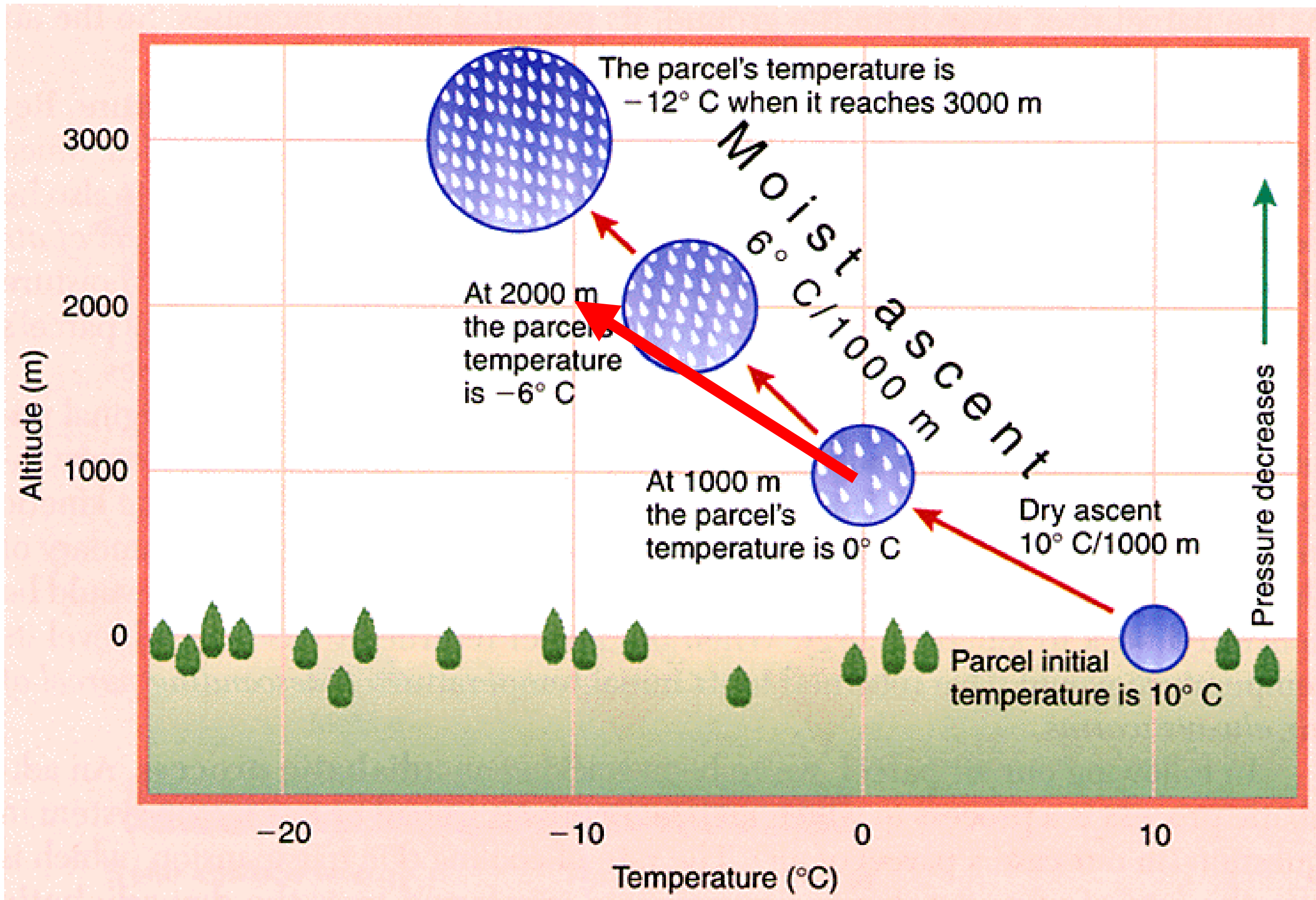


(from *Meteorology: Understanding the Atmosphere*)

Dry Adiabatic Lapse Rate



Moist Adiabatic Lapse Rate

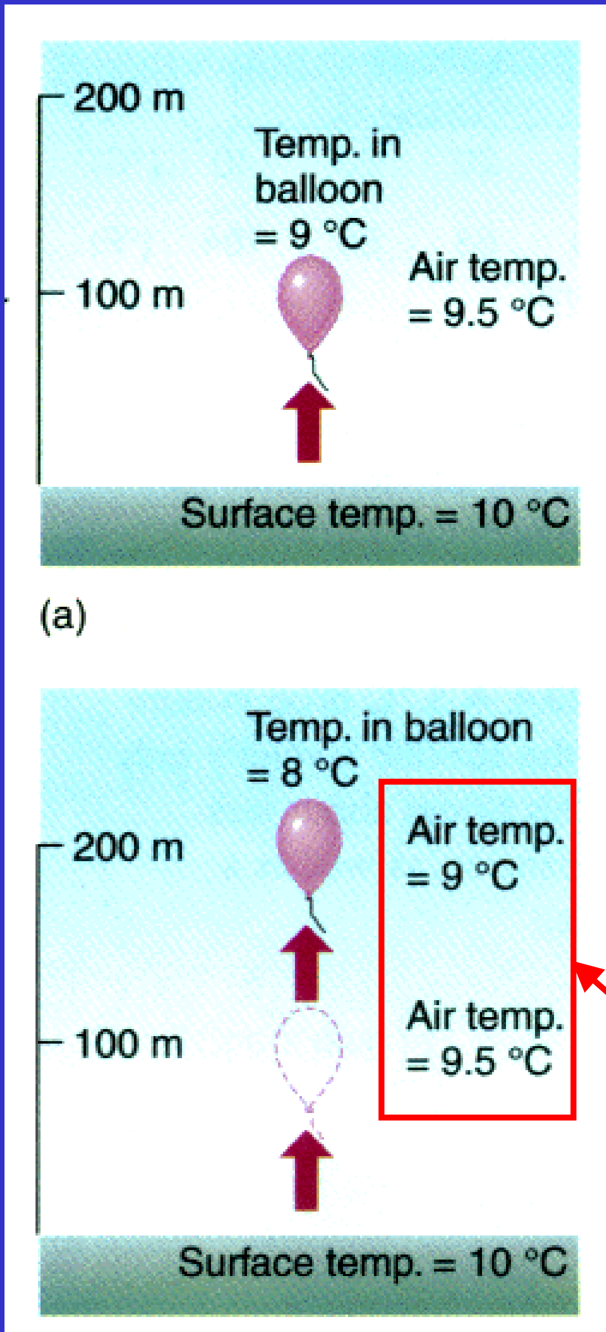


(from *Meteorology: Understanding the Atmosphere*)

Environmental Lapse Rate

- The environmental lapse rate is referred to as the rate at which the air temperature surrounding us would be changed if we were to climb upward into the atmosphere.
- This rate varies from time to time and from place to place.

Environmental Lapse Rate

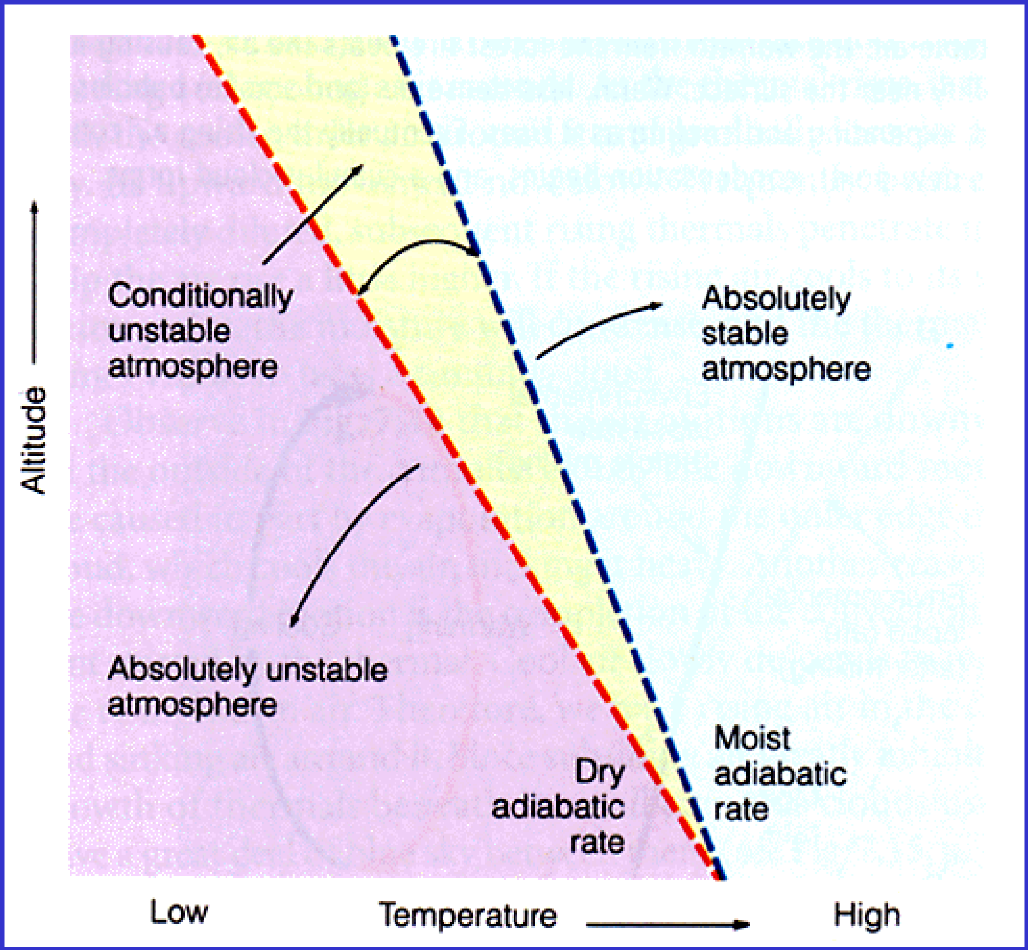


- The environmental (or ambient) lapse rate is referred to the vertical change in temperature through still air.
- The environmental lapse rate is not fixed. It changes from day to day and from place to place.

environmental lapse rate =0.5°C/100m

(from *Understanding Weather & Climate*)

Static Stability of the Atmosphere



(from *Meteorology Today)*

Γe = environmental lapse rate

Γd = dry adiabatic lapse rate

Γm = moist adiabatic lapse rate

- Absolutely Stable

  $\Gamma e < \Gamma m$

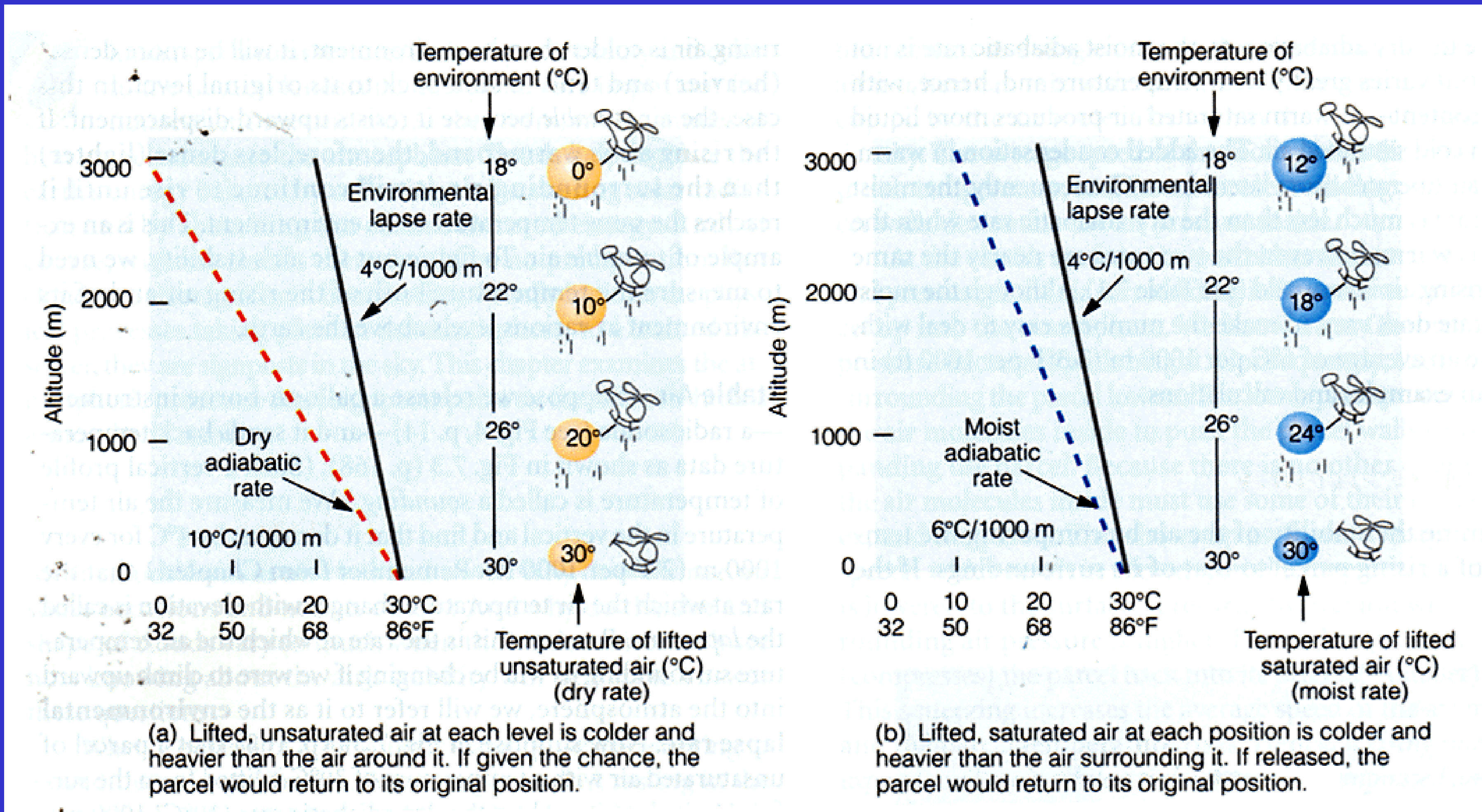
- Absolutely Unstable

  $\Gamma e > \Gamma d$

- Conditionally Unstable

  $\Gamma m < \Gamma e < \Gamma d$

Absolutely Stable Atmosphere

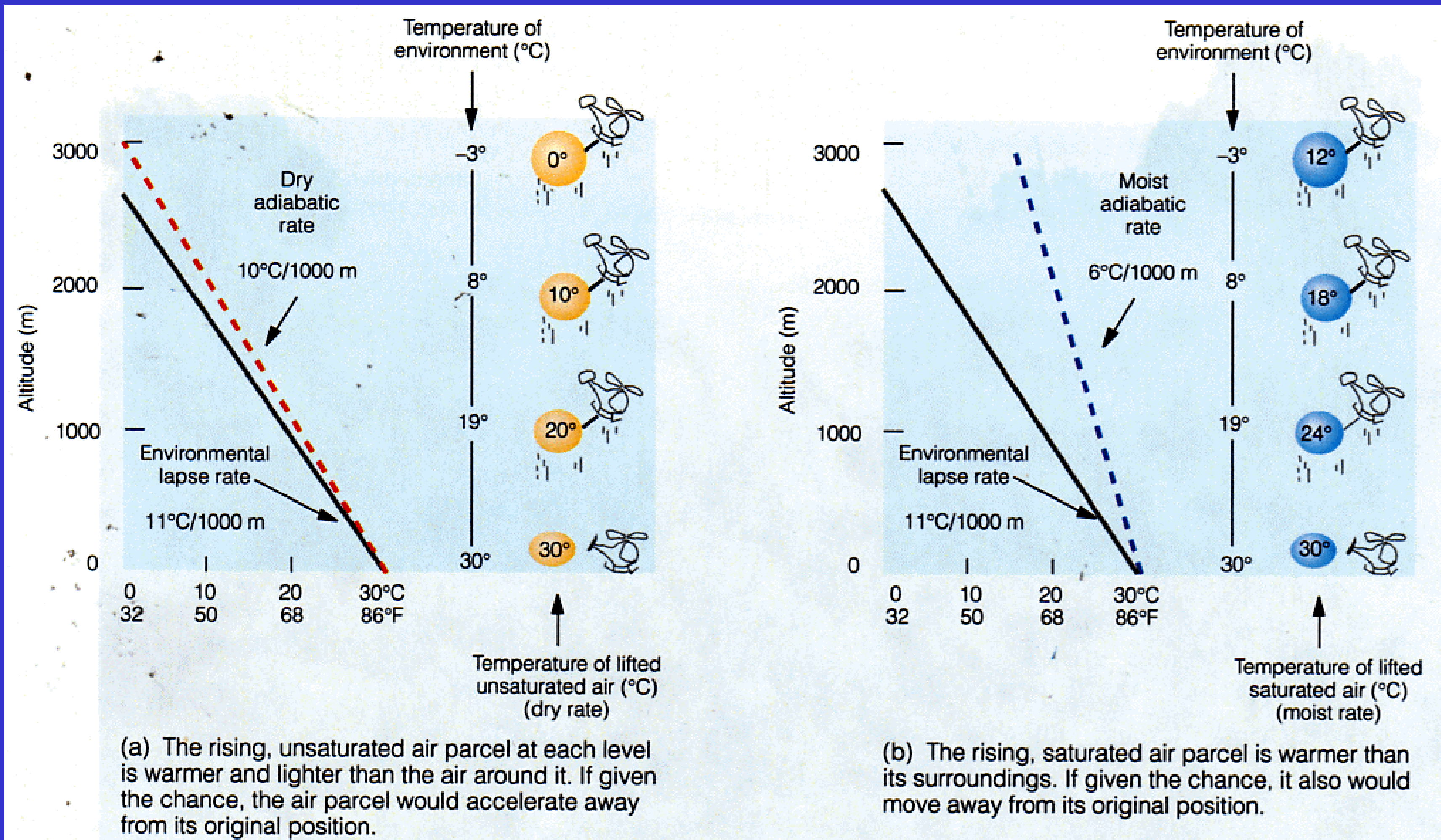


(a) Lifted, unsaturated air at each level is colder and heavier than the air around it. If given the chance, the parcel would return to its original position.

(b) Lifted, saturated air at each position is colder and heavier than the air surrounding it. If released, the parcel would return to its original position.

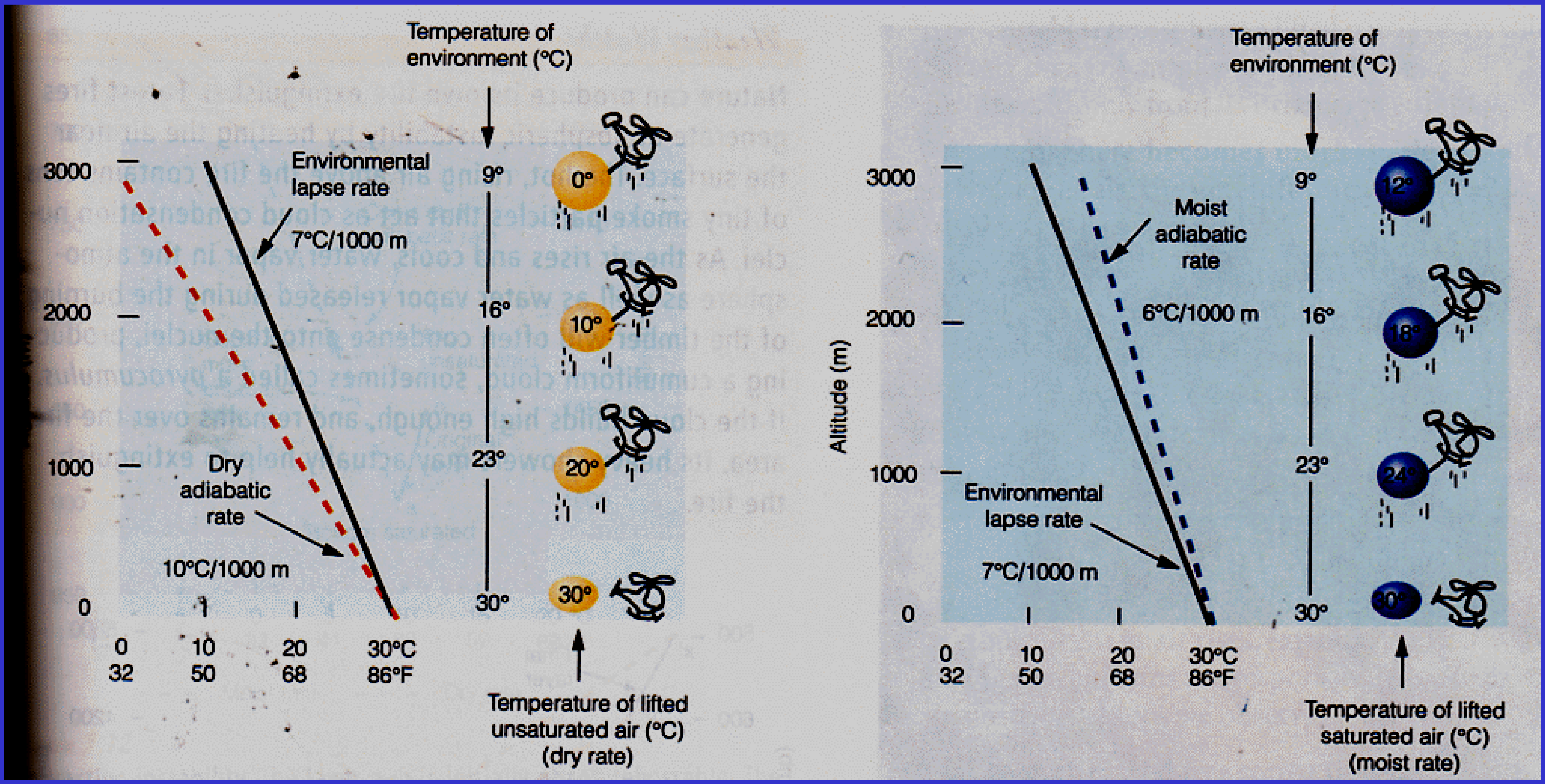
(from *Meteorology Today)*

Absolutely Unstable Atmosphere



(from *Meteorology Today)*

Conditionally Unstable Atmosphere



(from *Meteorology Today*)

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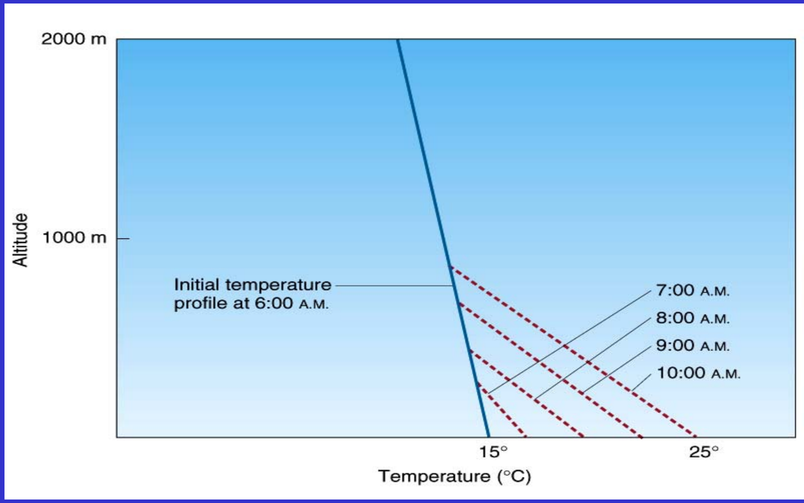
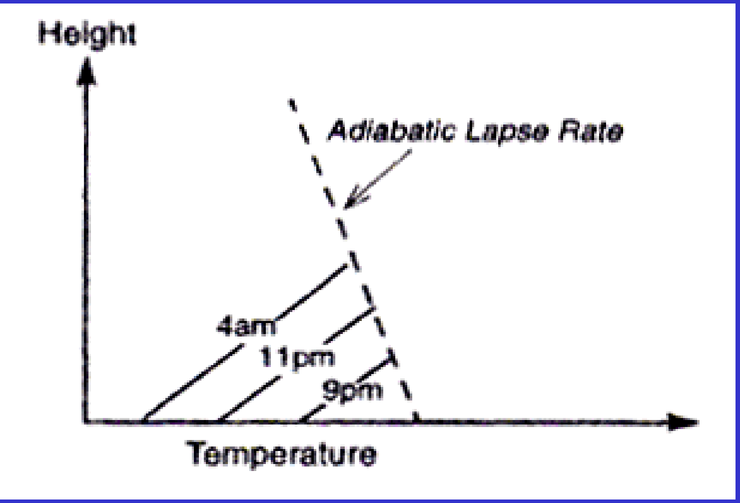
Heating/Cooling of Lower Atmosphere

Daytime



Nighttime



- During the day, surface insolation gains result in greater heating near the surface than aloft.
- At night, the situation reverses as terrestrial radiation loss causes near surface chilling → a ***temperature inversion.***

Cloud Type Based On Properties

❑ Four basic cloud categories:

✓ Cirrus --- thin, wispy cloud of ice.

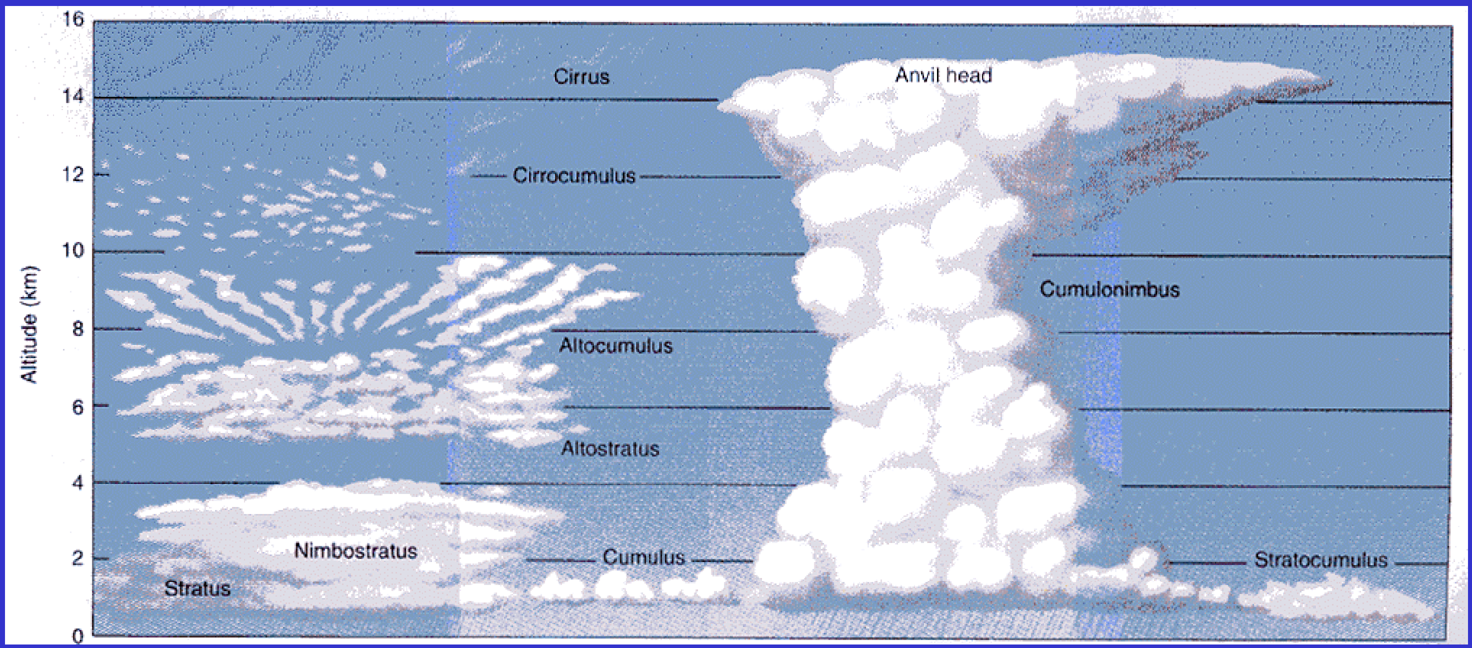
✓ Stratus --- layered cloud

✓ Cumulus --- clouds having vertical development.

✓ Nimbus --- rain-producing cloud

❑ These basic cloud types can be combined to generate ***ten different cloud types***, such as cirrostratus clouds that have the characteristics of cirrus clouds and stratus clouds.

Cloud Types Based On Height



If based on cloud base height, the ten principal cloud types can then grouped into four cloud types:

- ✓ High clouds -- cirrus, cirrostratus, cirroscumulus.
- ✓ Middle clouds – altostratus and altocumulus
- ✓ Low clouds – stratus, stratocumulus, and nimbostartus
- ✓ Clouds with extensive vertical development – cumulus and cumulonimbus.

(from "*The Blue Planet*")

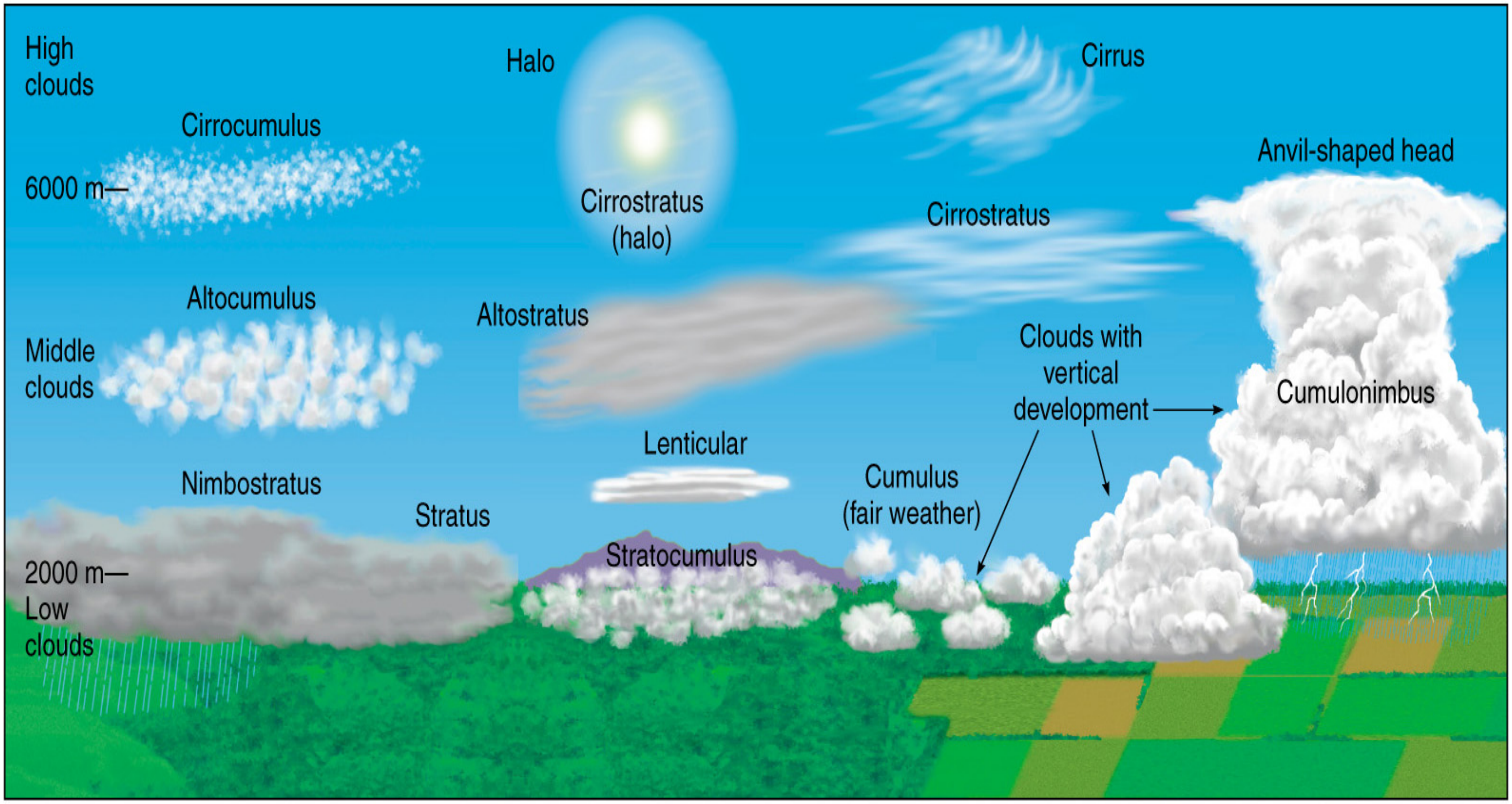
Cloud Classifications

Table 12.1 Classification of Clouds in the Troposphere by Altitude

Height	Name	Shape and Appearance
High-level clouds		
Cloud base 6 to 15 km above sea level	Cirrus	Feathery streaks
	Cirrocumulus	Small ripples and delicate puffs
	Cirrostratus	Translucent to transparent sheet, like a veil across the sky
Middle-level clouds		
Cloud base 2 to 6 km above sea level	Altocumulus	White to dark gray puffs and elongate ripples
	Altostratus	Uniform white to gray sheet covering the sky
Low-level clouds		
Cloud base below 2 km above sea level	Stratus	Uniform dull gray cover over the sky
	Nimbostratus	Uniform gray cover, rain generally falling
	Stratocumulus	Patches of soft gray; in places patches coalescing to a layer
Clouds with great vertical development		
Cloud base below 3 km above sea level	Cumulus	Puffy cauliflower shape with flat base
	Cumulonimbus	Large, puffy; white, gray and black; great vertical extent, often with anvil-shaped head

(from "*The Blue Planet*")

Cloud Types



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High Clouds

1. Cirrus Clouds

3. Cirrocumulus Clouds

(from Australian Weather Service)

2. Cirrostratus Clouds

- High clouds have low cloud temperature and low water content and consist most of ice crystal.

Middle Clouds

4. Altostratus Clouds

5. Altocumulus Clouds

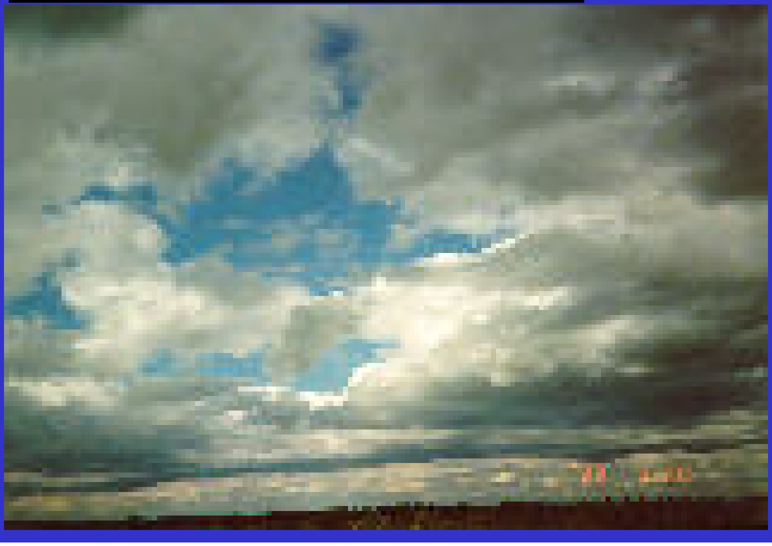
(from Australian Weather Service)

- Middle clouds are usually composite of liquid droplets.
- They block more sunlight to the surface than the high clouds.

Low Clouds

6. Stratus Clouds

7. Stratocumulus Clouds



8. Nimbostratus Clouds

(from Australian Weather Service)

- Low, thick, layered clouds with large horizontal extends, which can exceed that of several states.

Clouds With Vertical Development

9. Cumulus Clouds

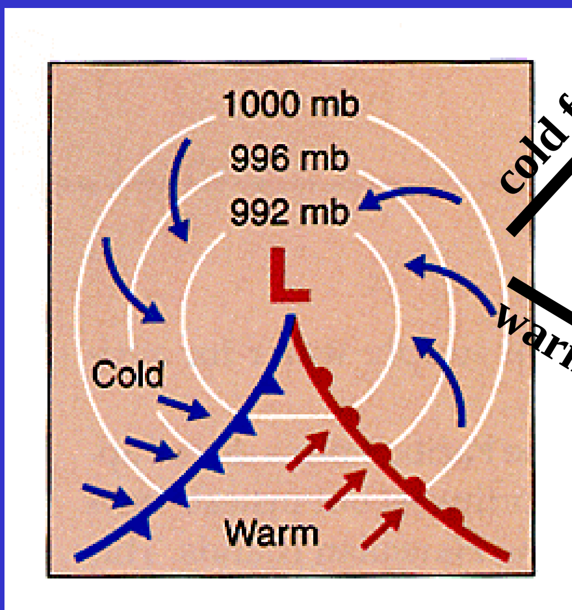
10. Cumulonimbus Clouds

(from Australian Weather Service)

- They are clouds with substantial vertical development and occur when the air is absolute or conditionally unstable.

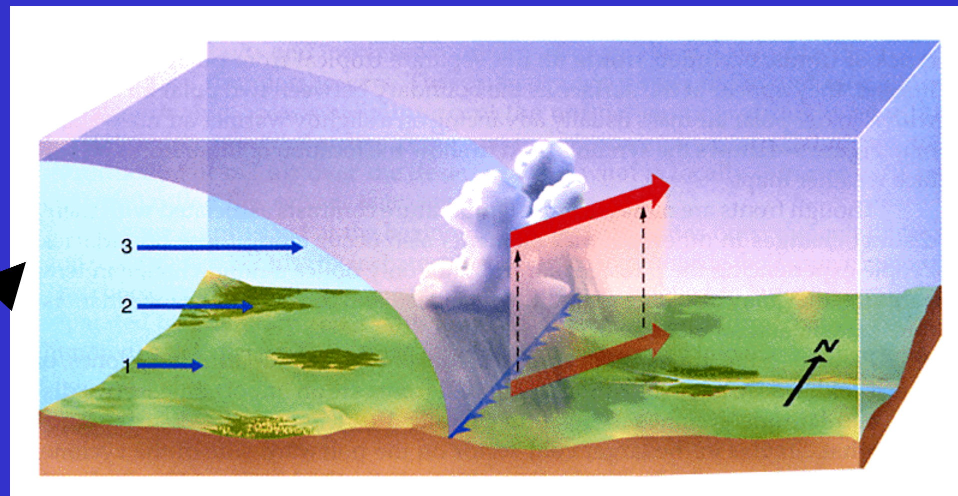
Clouds and Fronts

Mid-Latitude Cyclone

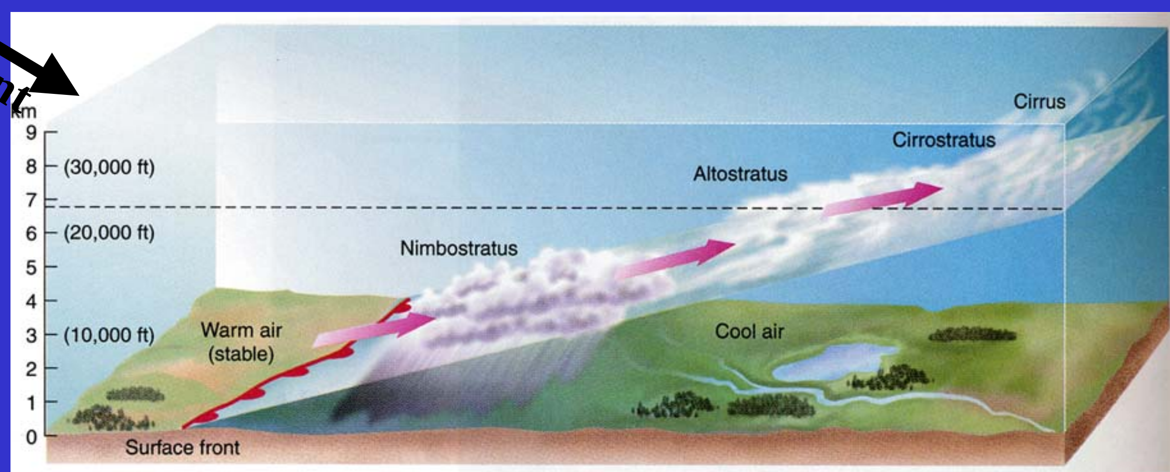


(From *Weather & Climate*)

cold front



warm front



Polar Stratospheric Clouds (PSCs)

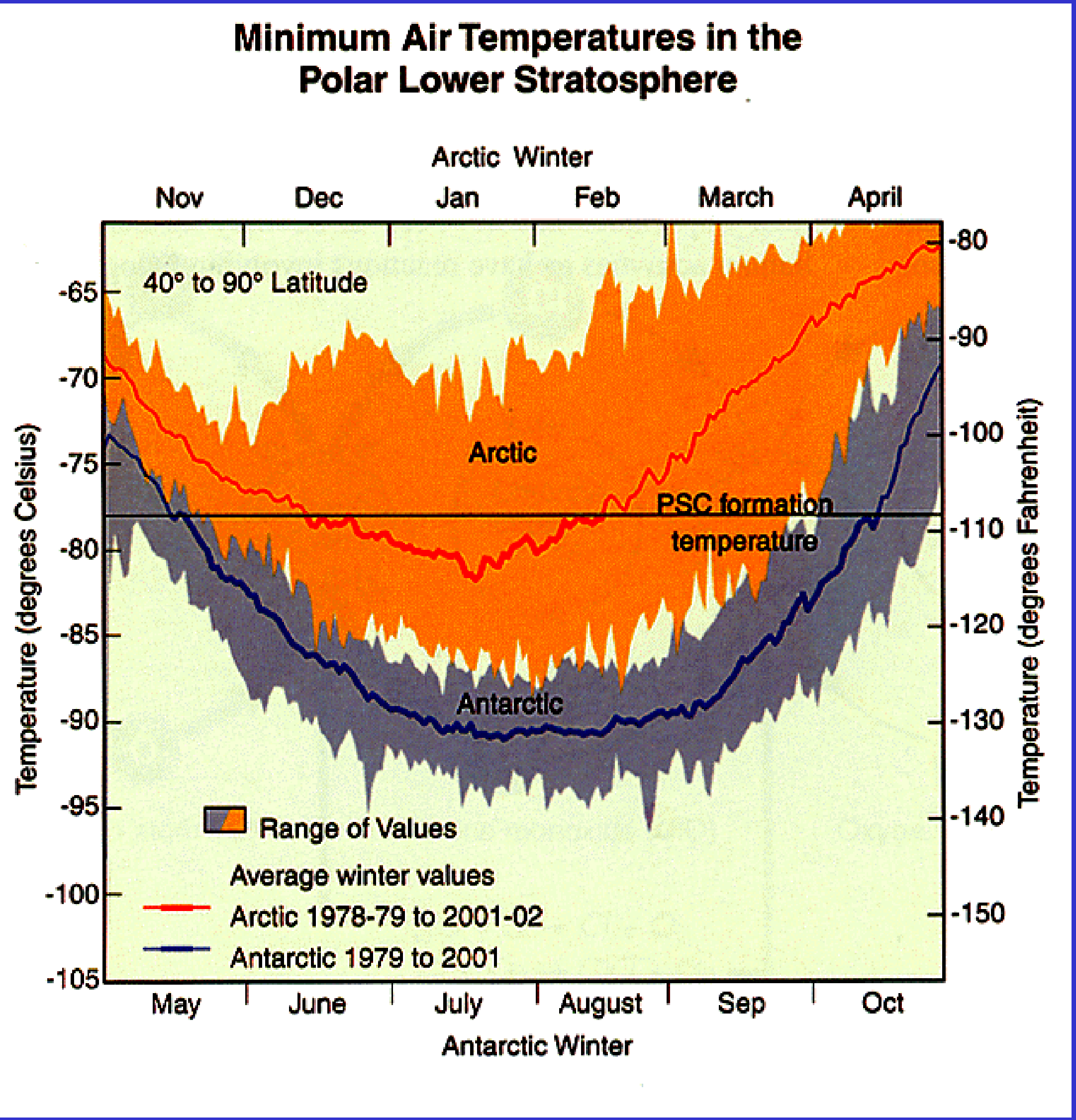
(Sweden, January 2000; from NASA website)

- In winter the polar stratosphere is so cold (-80°C or below) that certain trace atmospheric constituents can condense.
- These clouds are called “polar stratospheric clouds” (PSCs).
- The particles that form typically consist of a mixture of water and nitric acid (HNO3).
- The PSCs alter the chemistry of the lower stratosphere in two ways:

  (1) by coupling between the odd nitrogen and chlorine cycles

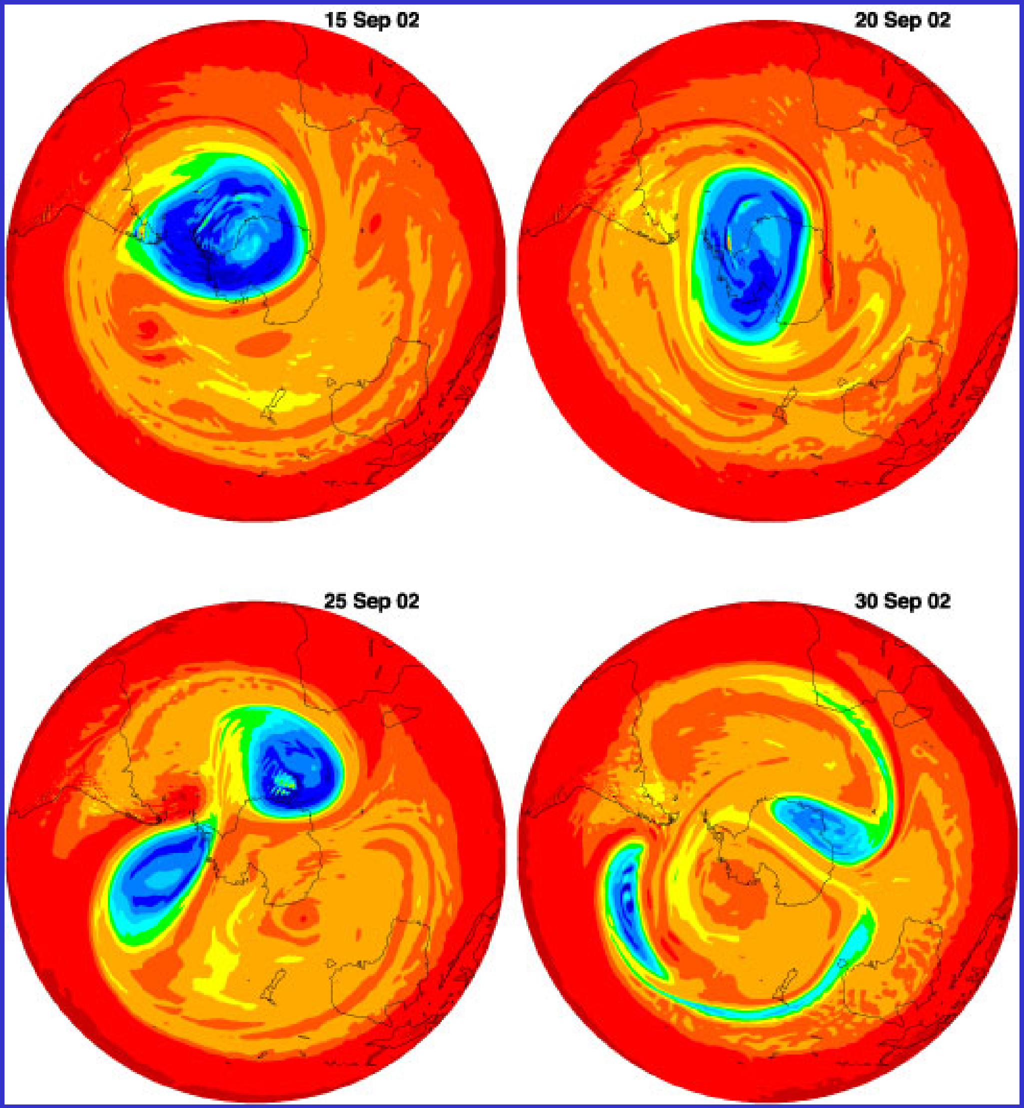
  (2) by providing surfaces on which heterogeneous reactions can occur.

Why No Ozone Hole in Artic?



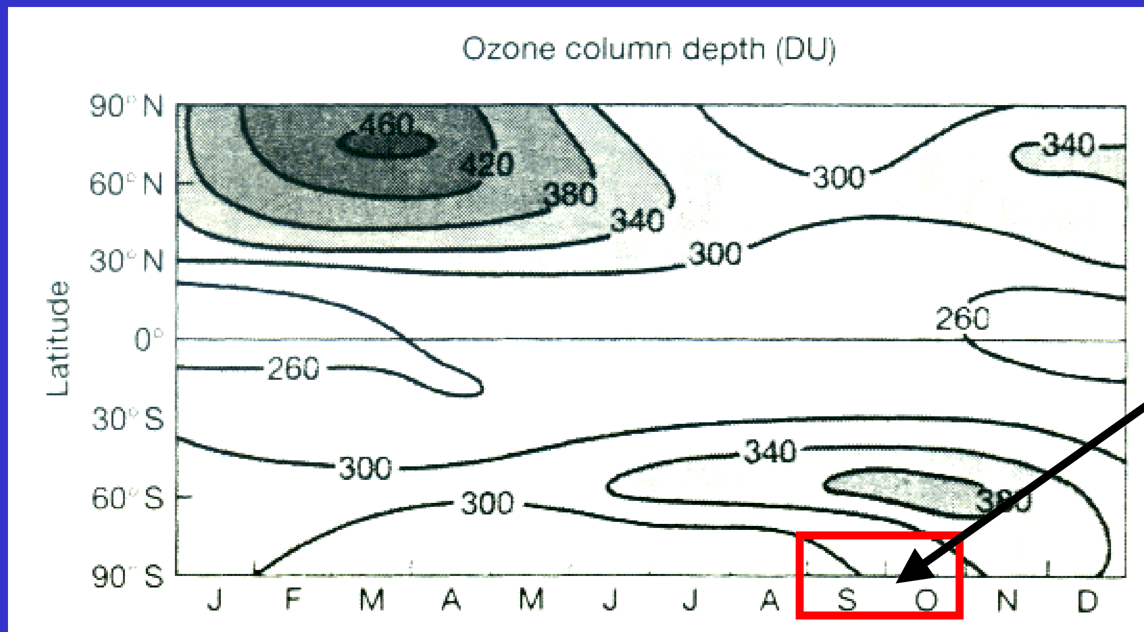
(from WMO Report 2003)

The Polar Vortex



- The wintertime circulation over the South Pole is characterized by a gigantic whirlpool of cold and dense air, called the polar vortex.
- The cold and dense cold air in the middle of the vortex is subsiding.
- The sinking air

Ozone Distribution



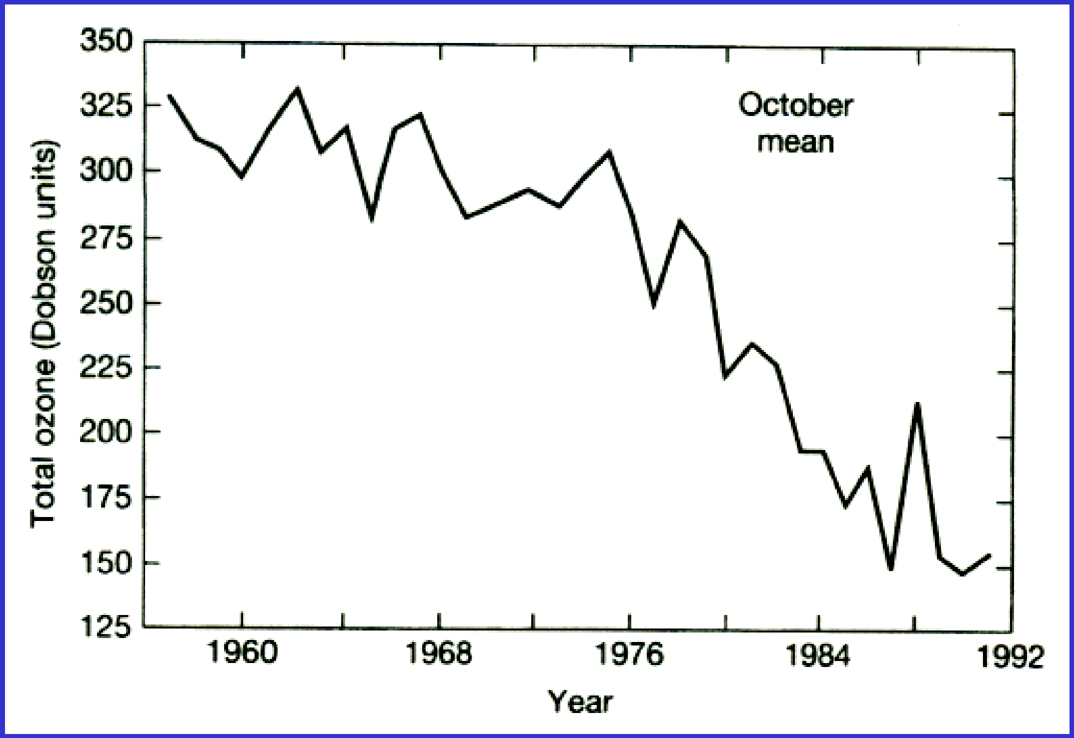
Antarctic Ozone Hole

(from *The Earth System*)

- The greatest production of ozone occurs in the tropics, where the solar UV flux is the highest.
- However, the general circulation in the stratosphere transport ozone-rich air from the tropical upper stratosphere to mid-to-high latitudes.

Antarctic Ozone Hole

Mean Total Ozone Over Antarctic in October



(from *The Earth System*)

- The decrease in ozone near the South Pole is most striking near the spring time (October).
- During the rest of the year, ozone levels have remained close to normal in the region.

The 1997 Ozone Hole