# General Meteorology

## Lecture 9

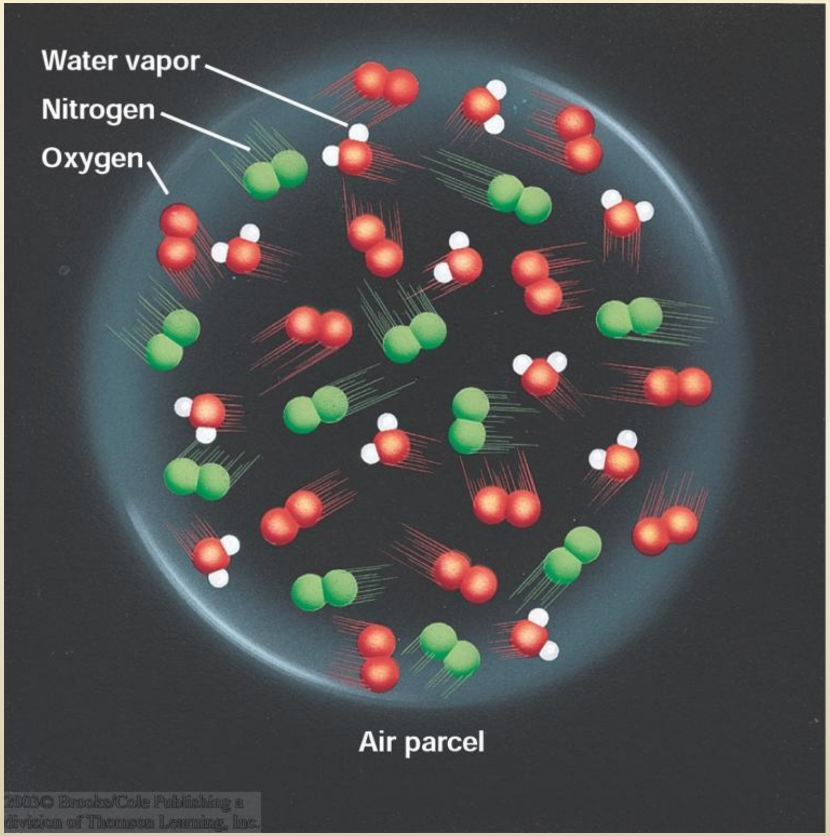
*Sahraei*

Physics Department,
Razi University

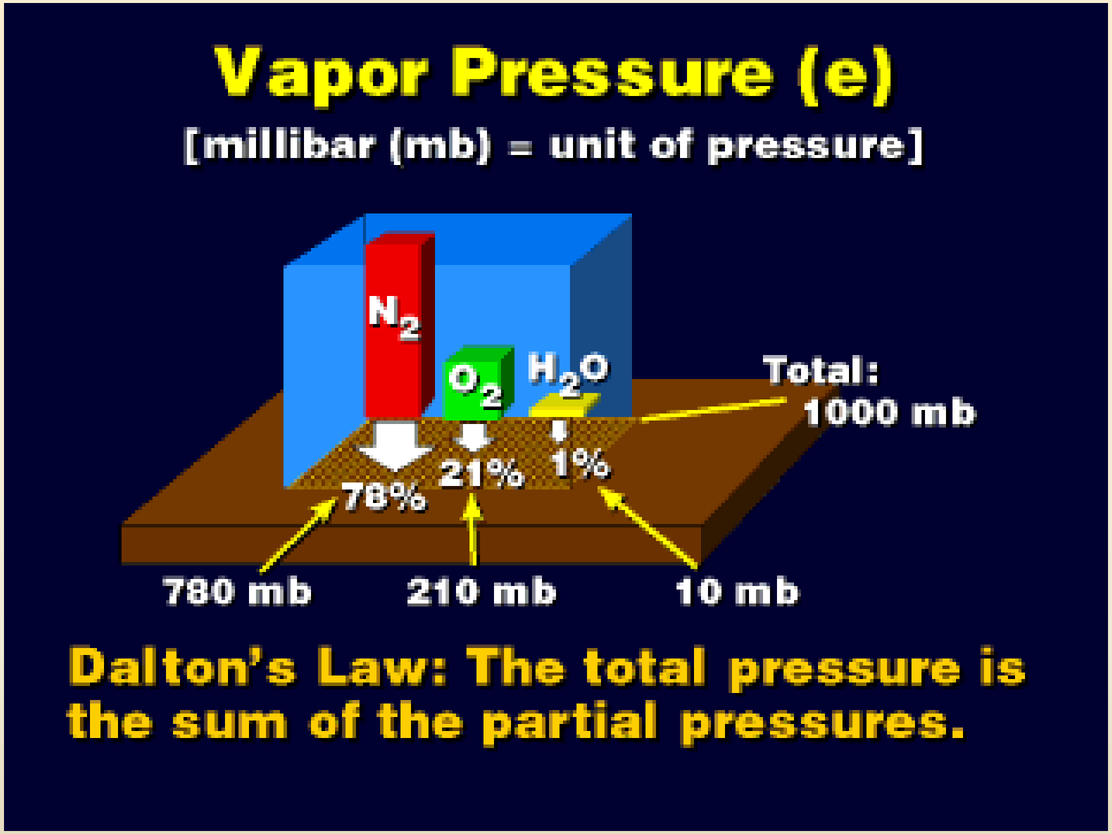
http://www.razi.ac.ir/sahraei

# Describing Atmospheric Moisture

**Atmospheric water vapor has been defined several different ways.**



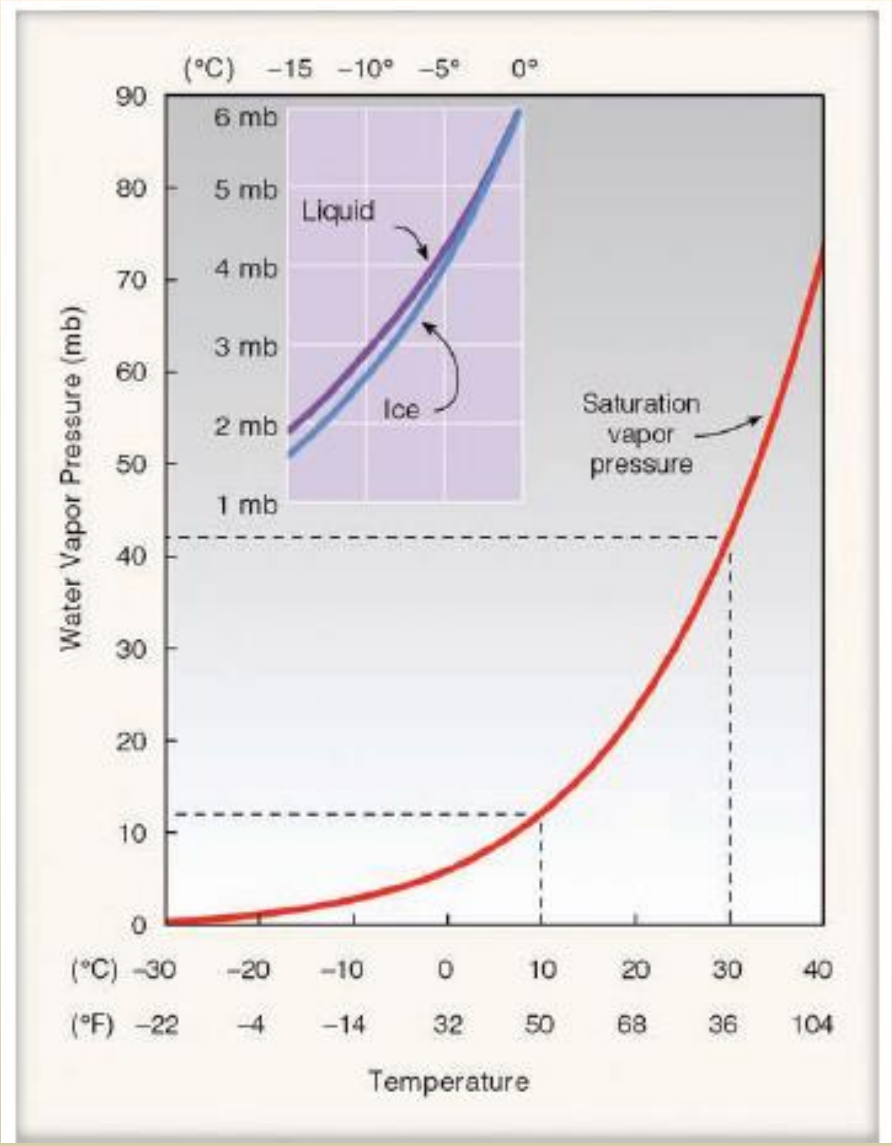
Vapour Presure (e): part of the atmospheric pressure due to water vapor.




Total Pressure $p = p_{O_2} + p_{N_2} + p_{H_2O}$

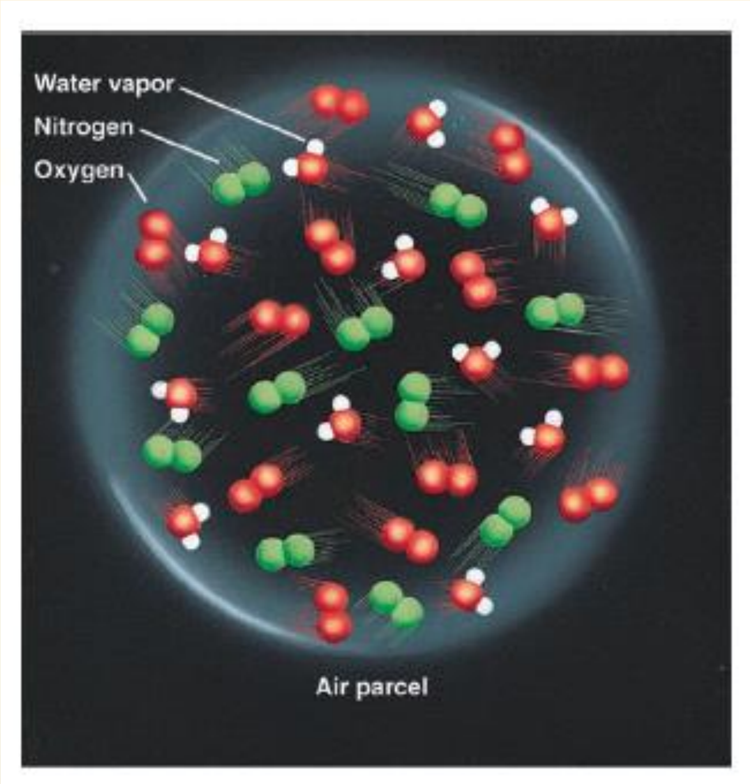
$$e = p_{H_2O}$$

# SATURATION VAPOUR PRESSURE



# Humidity

**a number of ways** of specifying the amount of water vapor in the air. Since there are several ways to express atmospheric water vapor content, there are several meanings for the concept of humidity.
The first type of humidity we'll take a look at is *absolute humidity.*




$$\text{Absolute humidity} = \frac{\text{mass of water vapor}}{\text{volume of air}}.$$

Absolute humidity represents the *water vapor density (mass/*volume) in the parcel and, normally,

grams of water vapor in a cubic meter of air ($g/m^3$)

# SPECIFIC HUMIDITY

however, can be expressed in ways that are not influenced by changes in air volume. When the mass of the water vapor in the air parcel in Fig. is compared with the mass of all the air in the parcel (including vapor), the result is called the **specific humidity; thus**

$$\text{Specific humidity} = \frac{\text{mass of water vapor}}{\text{total mass of air}}.$$

$$q = \frac{m_v}{m_v + m_d}$$

$$q = \frac{\rho_v}{\rho_v + \rho_d}$$

$$e = \rho_v R_v T$$

$$P - e = \rho_d R_d T$$

$$q = \frac{\rho_v}{\rho_v + \rho_d} = \varepsilon \frac{e}{p - (1 - \varepsilon) e} \approx \varepsilon \frac{e}{p}$$

$$\frac{R_d}{R_v} = \frac{R^* / M_d}{R^* / M_v} = \frac{M_v}{M_d} = \varepsilon \cong 0.622$$

# MIXING RATIO

Another convenient way to express humidity is to compare the mass of the water vapor in the parcel to the mass of the remaining dry air. Humidity expressed in this manner is called the **mixing ratio; thus**

$$\text{Mixing ratio} = \frac{\text{mass of water vapor}}{\text{mass of dry air}}$$

$$r = \frac{m_v}{m_d}$$

$$r = \frac{m_v / v}{m_d / v} = \frac{\rho_v}{\rho_d}$$

$$e = \rho_v R_v T$$

$$P - e = \rho_d R_d T$$

$$r = \frac{\frac{e}{R_v T}}{\frac{P - e}{R_d T}} = \frac{R_d}{R_v}\frac{e}{P - e}$$

$$\frac{R_d}{R_v} = \frac{R^* / M_d}{R^* / M_v} = \frac{M_v}{M_d} = \varepsilon \cong 0.622$$

$$r = \varepsilon \frac{e}{p - e} \approx \varepsilon \frac{e}{p}$$

Both specific humidity and mixing ratio are expressed as grams of water vapor per kilogram of air (g/kg). Typical range = 0-25 g/kg

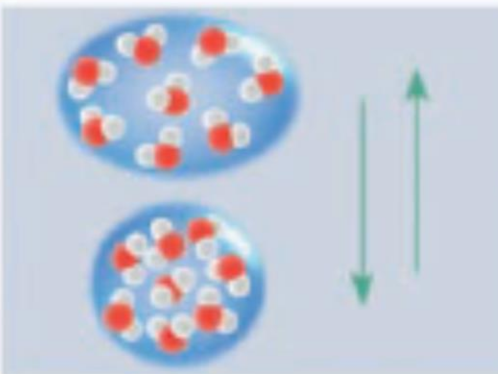
$$q = \frac{r}{1 + r}$$

$$r = \frac{q}{1 - q}$$

Since both q << 1 and r << 1 in our atmosphere, we often assume

$$q \approx r$$

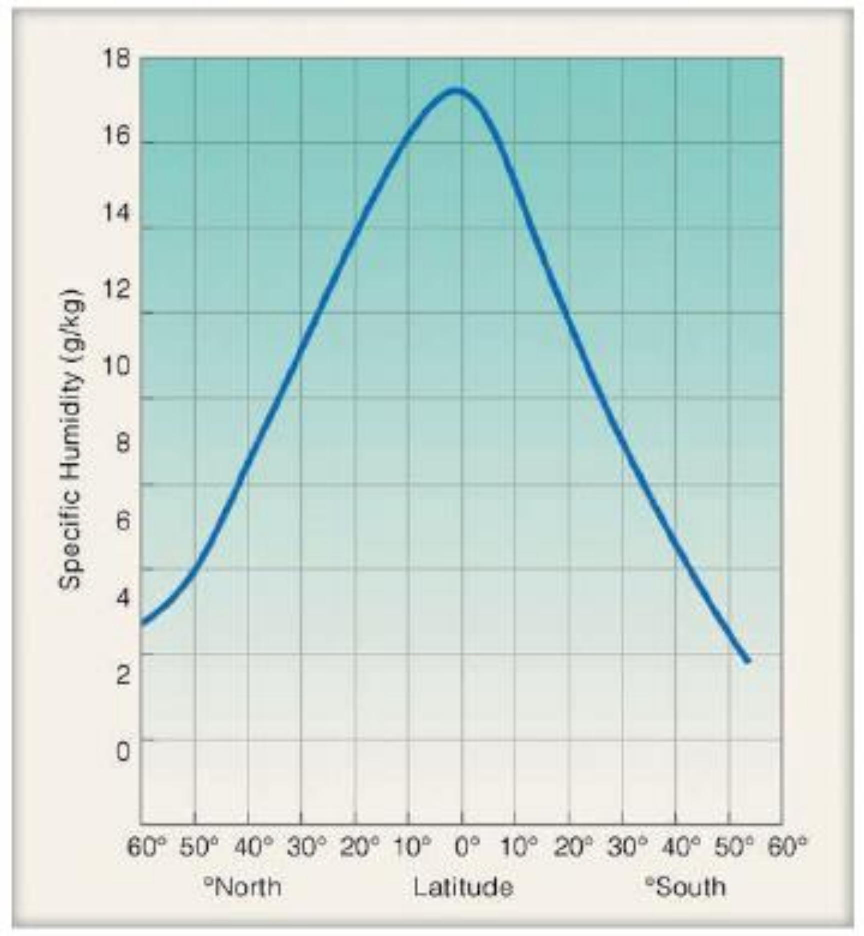
The specific humidity and mixing ratio of an air parcel remain constant *as long as water vapor is not added to or removed from the parcel. This happens because the total number* of molecules (and, hence, the mass of the parcel) remains constant, even as the parcel expands or contracts. Since changes in parcel size do not affect specific humidity and mixing ratio, these two concepts are used extensively in the study of the atmosphere.



| Mass of Parcel | Mass of $H_2O$ Vapor | Specific Humidity |
|---|---|---|
| 1 kg | 1 g | 1 g/kg |
| 1 kg | 1 g | 1 g/kg |

• FIGURE 4.8 The specific humidity does not change as air rises and descends.

Figure shows how specific humidity varies with latitude. The average specific humidity is highest in the warm, muggy tropics. As we move away from the tropics, it decreases, reaching its lowest average value in the polar latitudes.



# SATURATION MIXING RATIO

Actual vapor pressure indicates the air's total water vapor content, whereas **saturation vapor pressure describes how** much water vapor is necessary to make the air saturated at any given temperature. Put another way, *saturation vapor pressure is the pressure that the water vapor molecules would exert if the air were saturated with vapor at a given temperature.*

$$r_s = \varepsilon \frac{e_s}{p - e_s}$$

$$r_s \cong 0.622 \frac{e_s}{p - e_s}$$

# RELATIVE HUMIDITY

The *actual vapor pressure of air expresses the amount of* water vapor in terms of the amount of *pressure that the* water vapor molecules exert.

***The saturation vapor pressure is the pressure that the water*** vapor molecules would exert if the air were saturated with vapor at a given temperature.

The **relative humidity (RH)** ***is the ratio of the amount of water vapor actually*** *in the air to the maximum amount of water vapor required for saturation at that particular temperature (and pressure). It* is the *ratio of the air's water vapor content to its capacity;* thus

$$RH = \frac{\text{water vapor content}}{\text{water vapor capacity}}$$

We can think of the actual vapor pressure as a measure of the air's actual water vapor content, and the saturation vapor pressure as a measure of air's total capacity for water vapor.

Hence, the relative humidity can be expressed as

$$\text{RH} = \frac{\text{actual vapor pressure}}{\text{saturation vapor pressure}} \times 100 \text{ percent.}$$

Air with a 50 percent relative humidity actually contains one-half the amount required for saturation. Air with a 100 percent relative humidity is said to be saturated because it is filled to capacity with water vapor. Air with a relative humidity greater than 100 percent is said to be **supersaturated**.

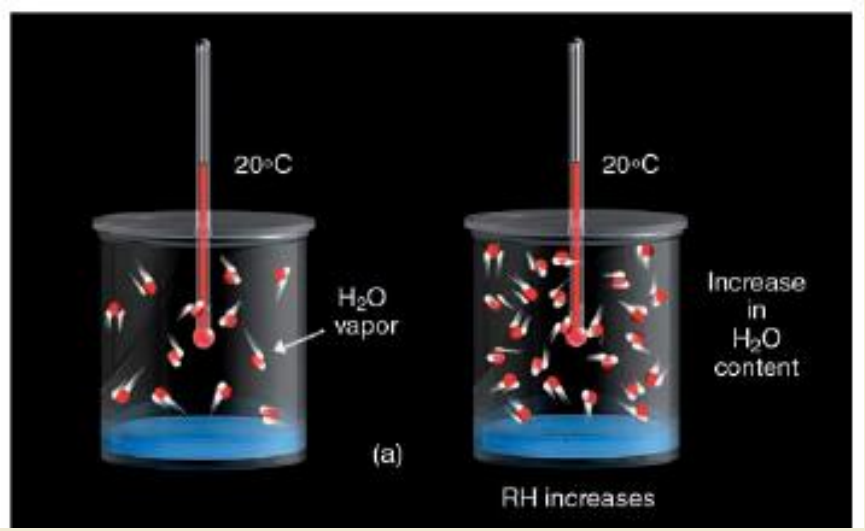
$$\text{RH} = \frac{\text{actual mixing ratio}}{\text{saturation mixing ratio}} \times 100 \text{ percent,}$$

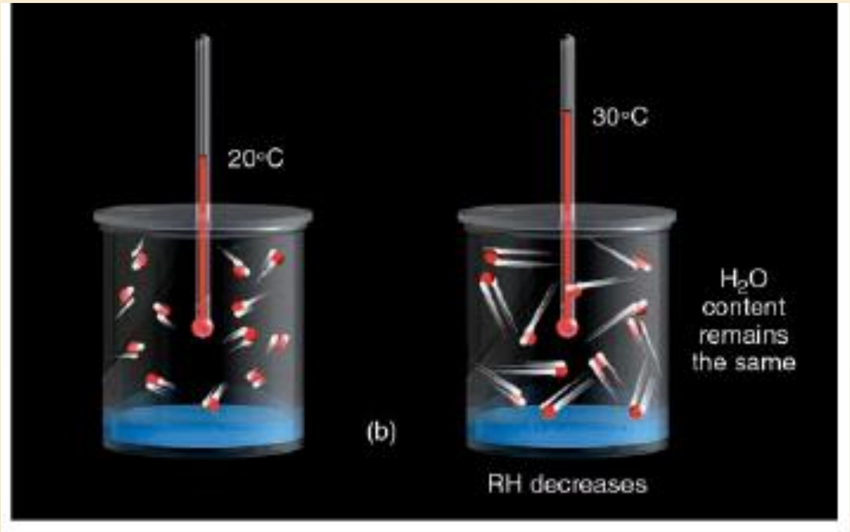
$$RH = \frac{r}{r_s} \times 100\ \% \approx \frac{e}{e_s} \times 100\ \%$$

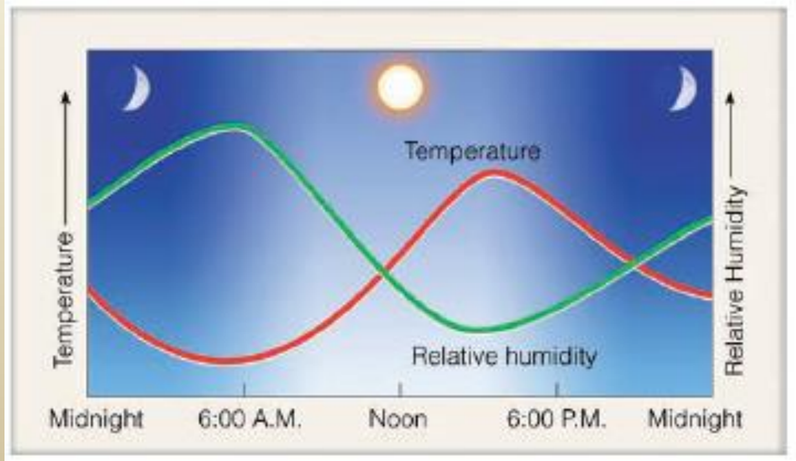
A change in relative humidity can be brought about in two primary ways:

1. by changing the air's water vapor content

2. by changing the air temperature



## RELATIVE HUMIDITY

Suppose it is early morning and the outside air is saturated. The air temperature is 10°C (50°F) and the relative humidity is 100 percent. We know that relative humidity can be expressed as

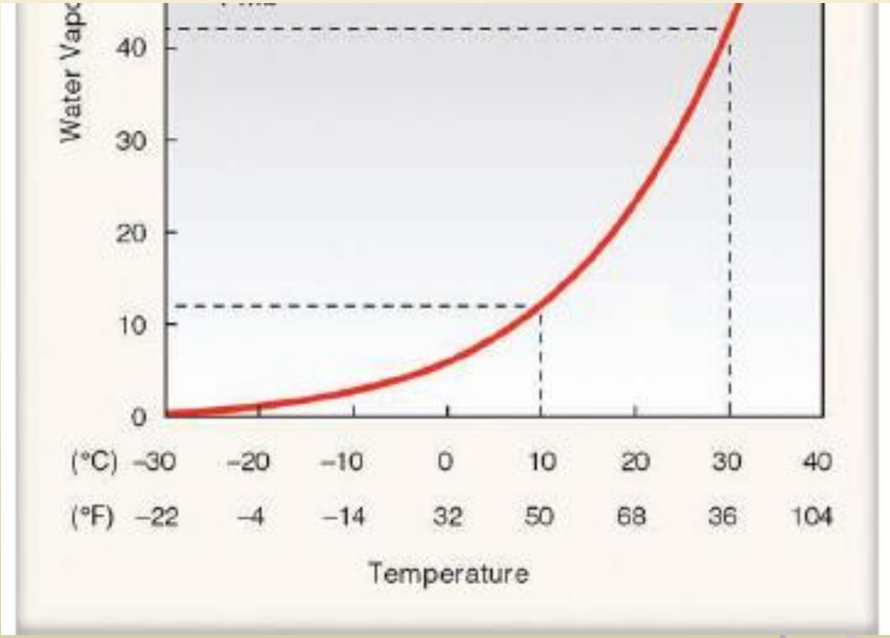
$$RH = \frac{\text{actual vapor pressure}}{\text{saturation vapor pressure}} \times 100 \text{ percent.}$$

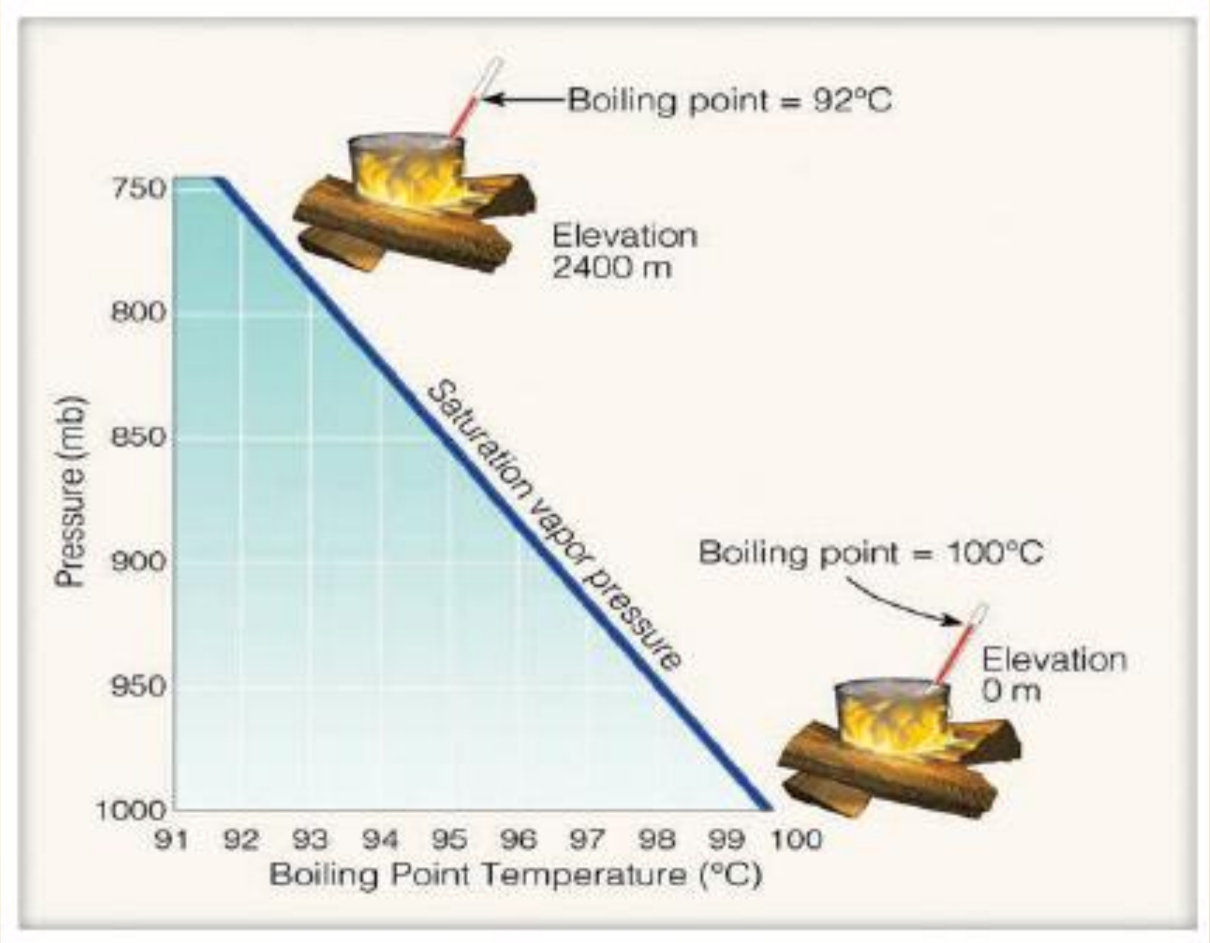
Looking back at Fig we can see that air with a temperature of 10°C has a saturation vapor pressure of 12 mb. Since the air is saturated and the relative humidity is 100 percent, the actual vapor pressure *must be the same as the* saturation vapor pressure (12 mb), since

$$RH = \frac{12 \text{ mb}}{12 \text{ mb}} \times 100\% = 100 \text{ percent.}$$

Suppose during the day the air warms to 30°C (86°F), with no change in water vapor content (or air pressure). Because there is no change in water vapor content, the actual vapor pressure must be the same (12 mb) as it was in the early morning when the air was saturated. The saturation vapor pressure, however, has increased because the air temperature has increased. From Fig note that air with a temperature of 30°C has a saturation vapor pressure of 42 mb. The relative humidity of this unsaturated, warmer air is now much lower, as

$$RH = \frac{12 \text{ mb}}{42 \text{ mb}} \times 100\% = 29 \text{ percent.}$$




Boiling point = 92°C
Elevation
2400 m
750
800
850
900
950
1000
Pressure (mb)
Saturation vapor pressure
Boiling point = 100°C
Elevation
0 m
91 92 93 94 95 96 97 98 99 100
Boiling Point Temperature (°C)

# Moist Air Parameters during Processes

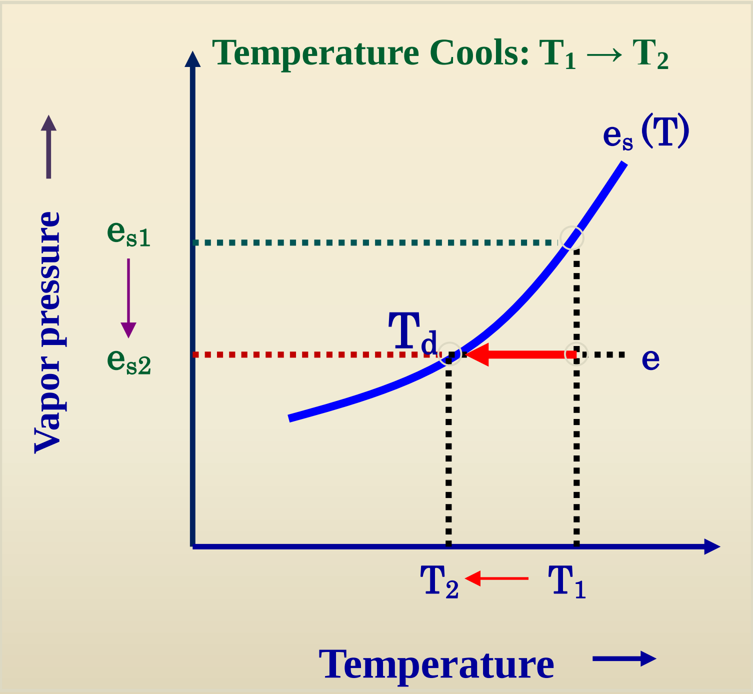
## Isobaric Cooling: Dew Point Temperature ($T_d$)

**Definition:** Temperature at which saturation (with respect to liquid water) is reached when an unsaturated moist air parcel is cooled at constant pressure

- Parcel is a closed system
  - Mass of water vapor and dry air are constant

- Isobaric transformation
  - Total pressure (p) constant
  - Vapor pressure (e) constant
  - Mixing ratio (r) constant

- Saturation vapor pressure ($e_s$) and saturation mixing ratio ($r_s$) change since they are both functions of the temperature



# Moist Air Parameters during Processes

**Isobaric Cooling: Dew Point Temperature ($T_d$)**

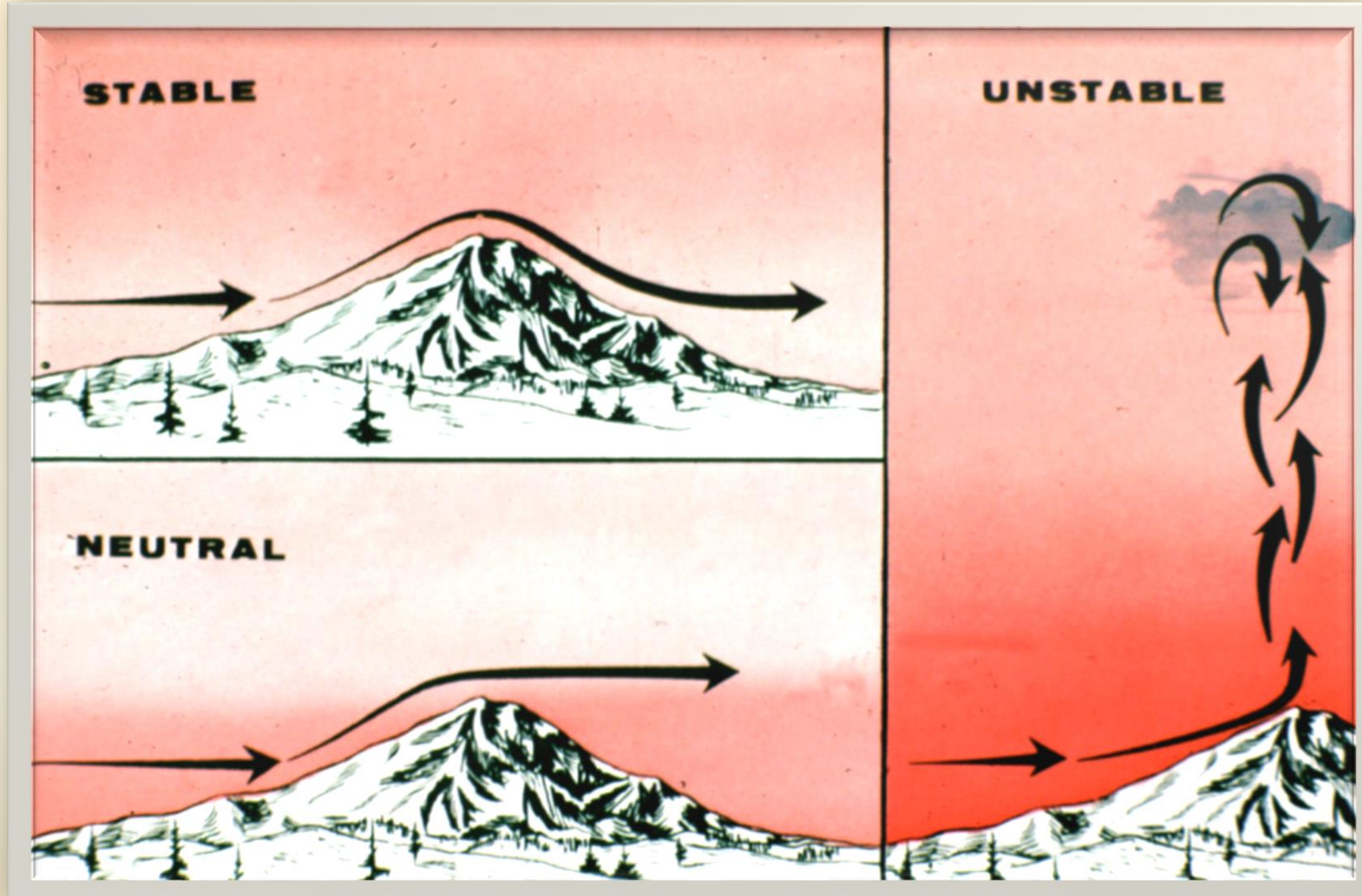
- Such a process regularly occurs
  - Radiational cooling near surface
  - Often occurs at night (no solar heating)
  - Can occur at ground level (dew) or through a layer (fog)

# Moist Air Parameters during Processes

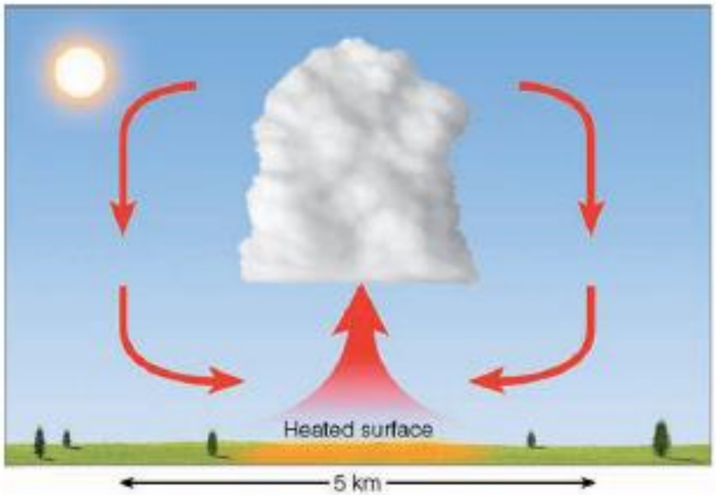
**Adiabatic Isobaric Process: Wet-Bulb Temperature ($T_w$)**

**Definition:** Temperature at which saturation (with respect to liquid water) is reached when an unsaturated moist air parcel is cooled by the evaporation of liquid water

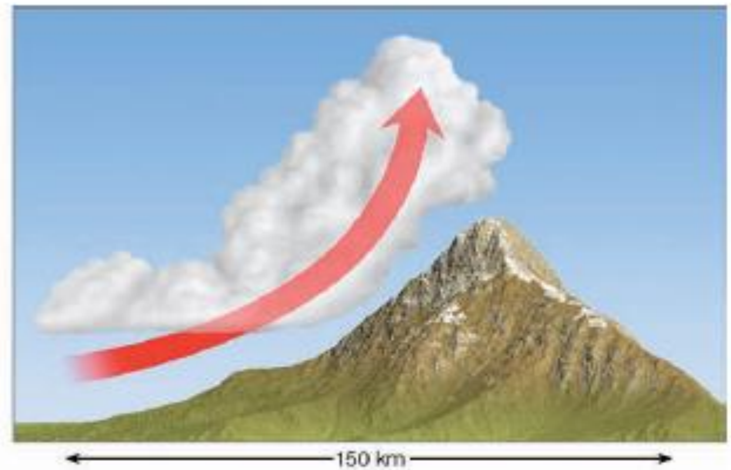
- Such a process regularly occurs
  - Evaporational cooling occurs near the surface during light rain
  - The temperature often feels colder when its raining → It is!


STABLE
UNSTABLE
NEUTRAL

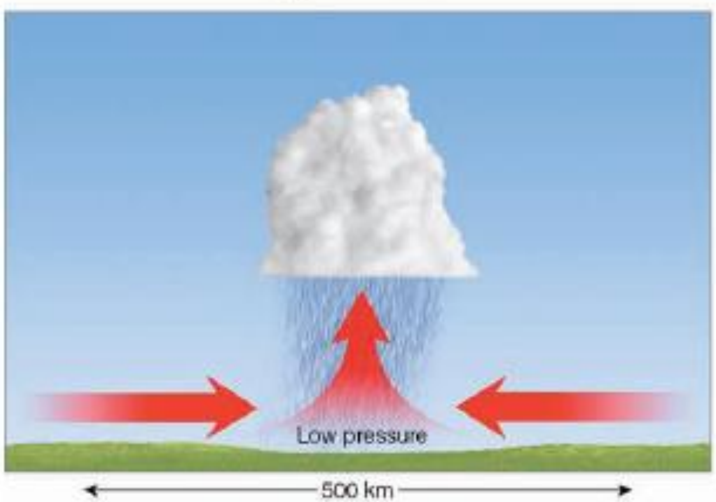
# Cloud Formation



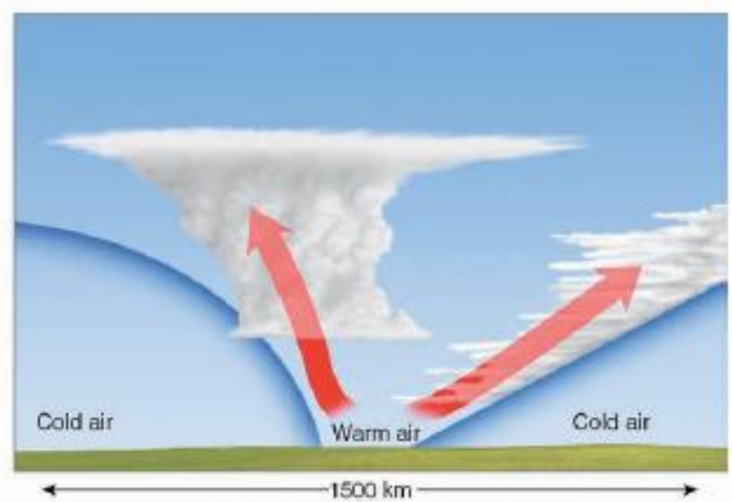
(a) Convection



(b) Lifting along topography



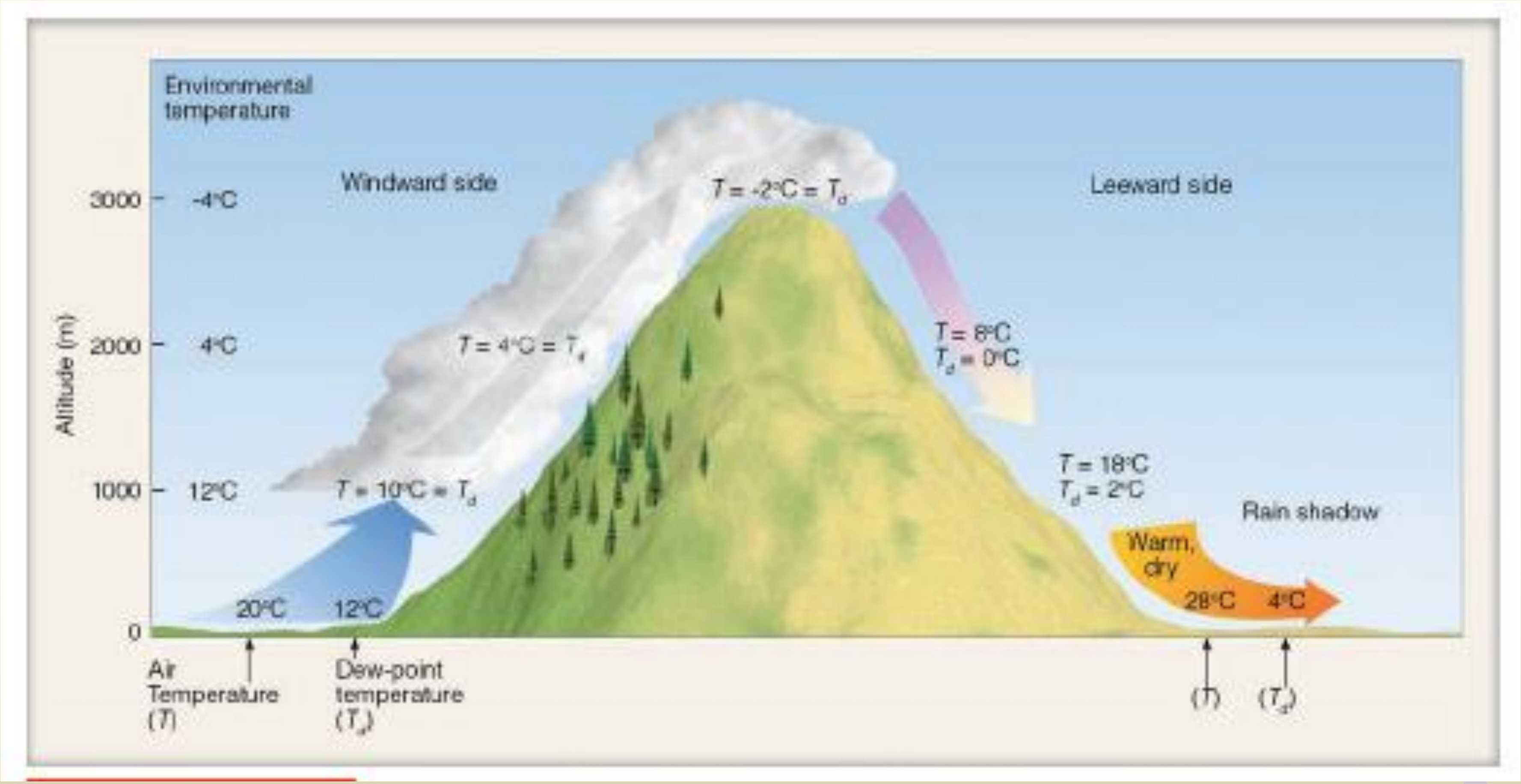
(c) Convergence of air



(d) Lifting along weather fronts

# Orographic Lifting

The process where air is forced to rise up the side of a mountain is sometimes called **orographic lifting**.




The Effect of Topography on Precipitation Patterns