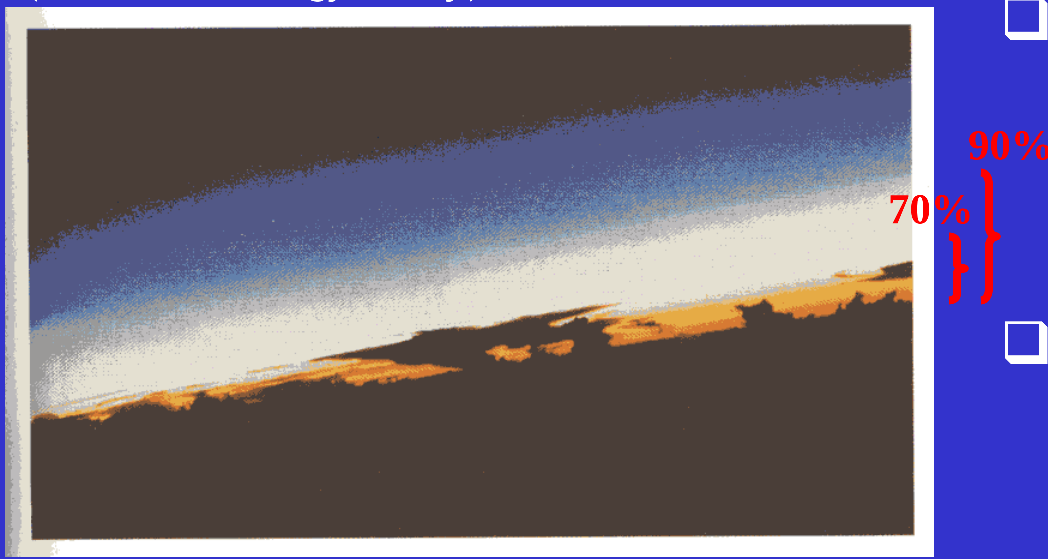
Lecture 1: A Brief Survey of the Atmosphere

- Origins of the atmosphere
- Vertical structure of composition
- Vertical structure of air pressure
- Vertical structure of temperature
- The ionosphere

Thickness of the Atmosphere

(from *Meteorology Today*)



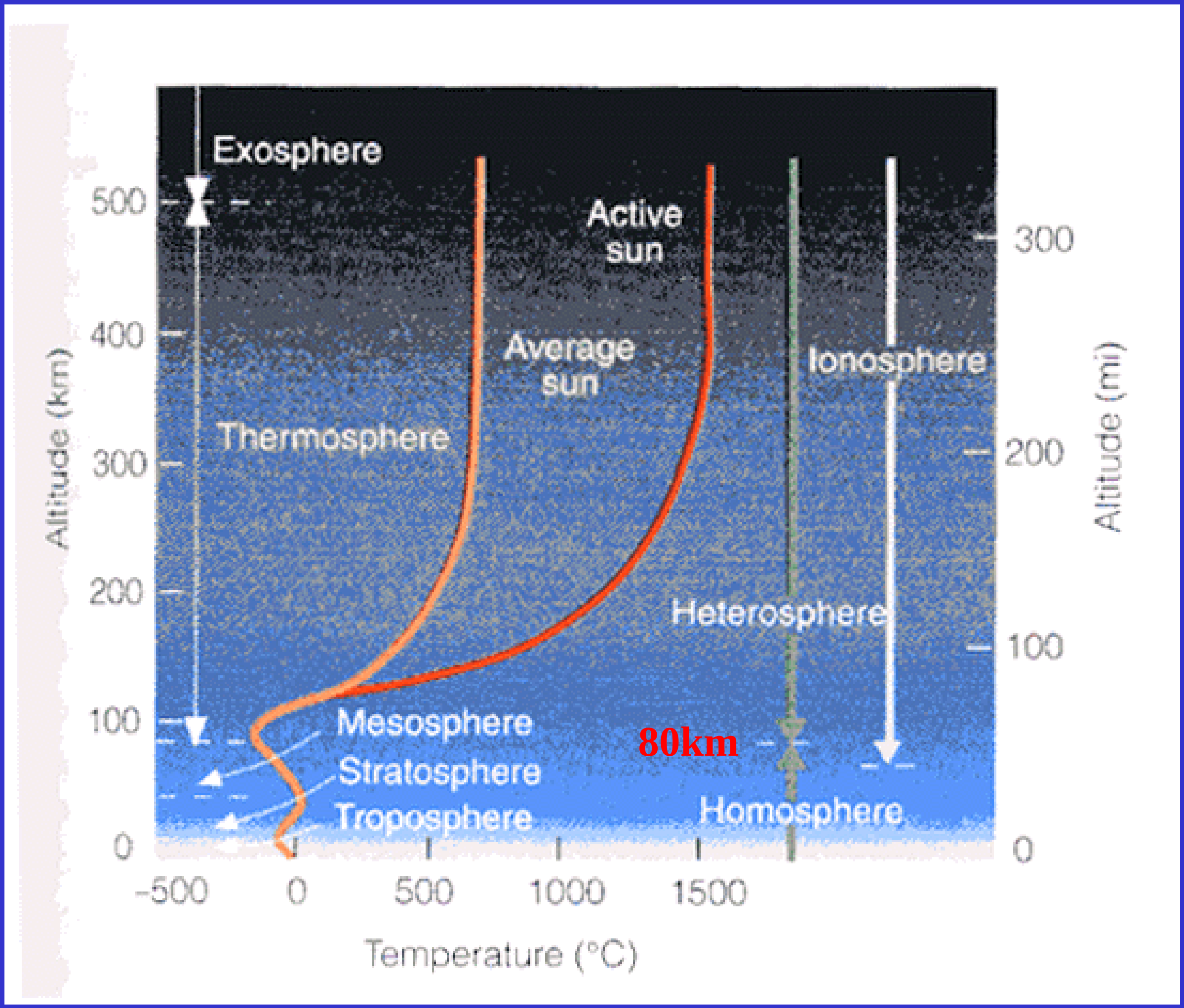
- The thickness of the atmosphere is only about 2% of Earth's thickness (Earth's radius = ~6400km).
- Most of the atmospheric mass is confined in the lowest 100 km above the sea level.

- Because of the shallowness of the atmosphere, its motions over large areas are primarily horizontal.

➔Typically, horizontal wind speeds are a thousands time greater than vertical wind speeds.

(But the small vertical displacements of air have an important impact on the state of the atmosphere.)

Vertical Structure of the Atmosphere



(from *Meteorology Today*)

composition

temperature

electricity

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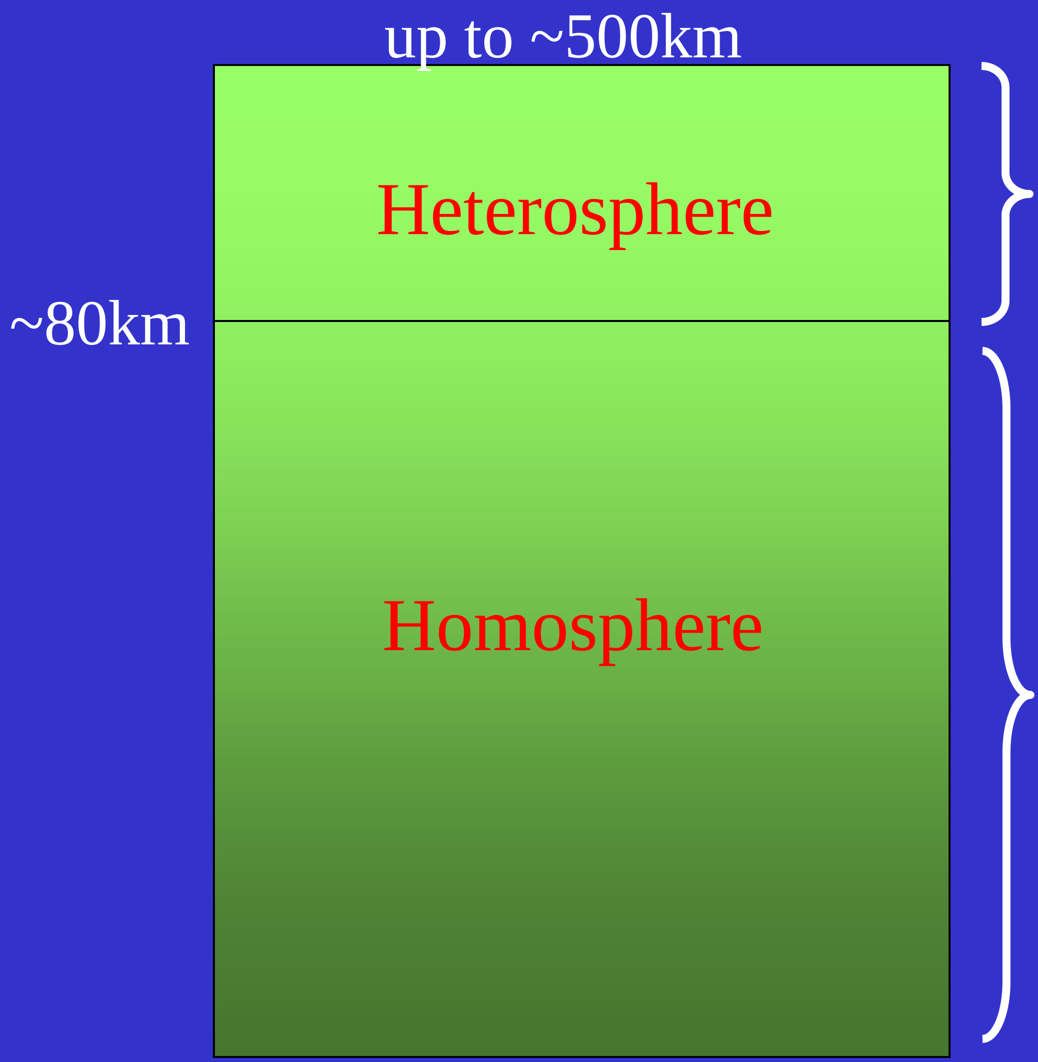
Vertical Structure of Composition

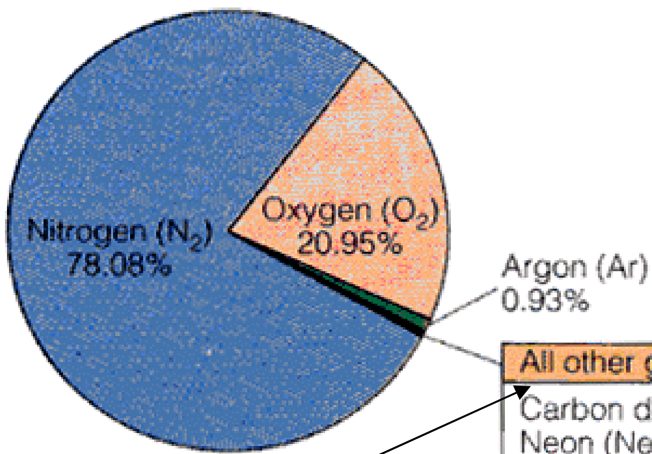


Dominated by lighter gases with increasing altitude, such as hydrogen and helium.

This part of the atmosphere continually circulates, so that the principal atmospheric gases are well mixed.

➔ For most purpose, we consider the homosphere virtually the entire atmosphere.

Composition of the Atmosphere
(inside the DRY homosphere)



All other gases, 0.04%	
Carbon dioxide (CO_2)	0.035%
Neon (Ne)	0.0018%
Helium (He)	0.00052%
Methane (CH_4)	0.00014%
Krypton (Kr)	0.00010%
Nitrous oxide (N_2O)	0.00005%
Hydrogen (H_2)	0.00005%
Ozone (O_3)	0.000007%

Water vapor (0-0.25%)

Figure 12.2 Composition of dry, aerosol-free air in volume percent. Three gases—nitrogen, oxygen, and argon—make up 99.96 percent of the air.

(from *The Blue Planet*)

Origins of the Atmosphere

- When the Earth was formed 4.6 billion years ago, Earth's atmosphere was probably mostly hydrogen (H) and helium (He) plus hydrogen compounds, such as methane (CH_4) and ammonia (NH_3).

→ Those gases eventually escaped to the space.

- The release of gases from rock through volcanic eruption (so-called **outgassing**) was the principal source of atmospheric gases.

→ The primeval atmosphere produced by the outgassing was mostly carbon dioxide (**CO_2**) with some Nitrogen (**N_2**) and water vapor (**H_2O**), and trace amounts of other gases.

What Happened to H_2O?

Table 1.2

An inventory of the hydrosphere[a,b]

Component	Percentage of mass of hydrosphere
Oceans	97.
Ice	2.4
Fresh water (underground)	0.6
Fresh water in lakes, rivers, etc.	0.02
Atmosphere	0.001

[a] Total mass = 1.36×10^{21} kg = 2.66×10^{6} kg m^{-2} over surface of earth.

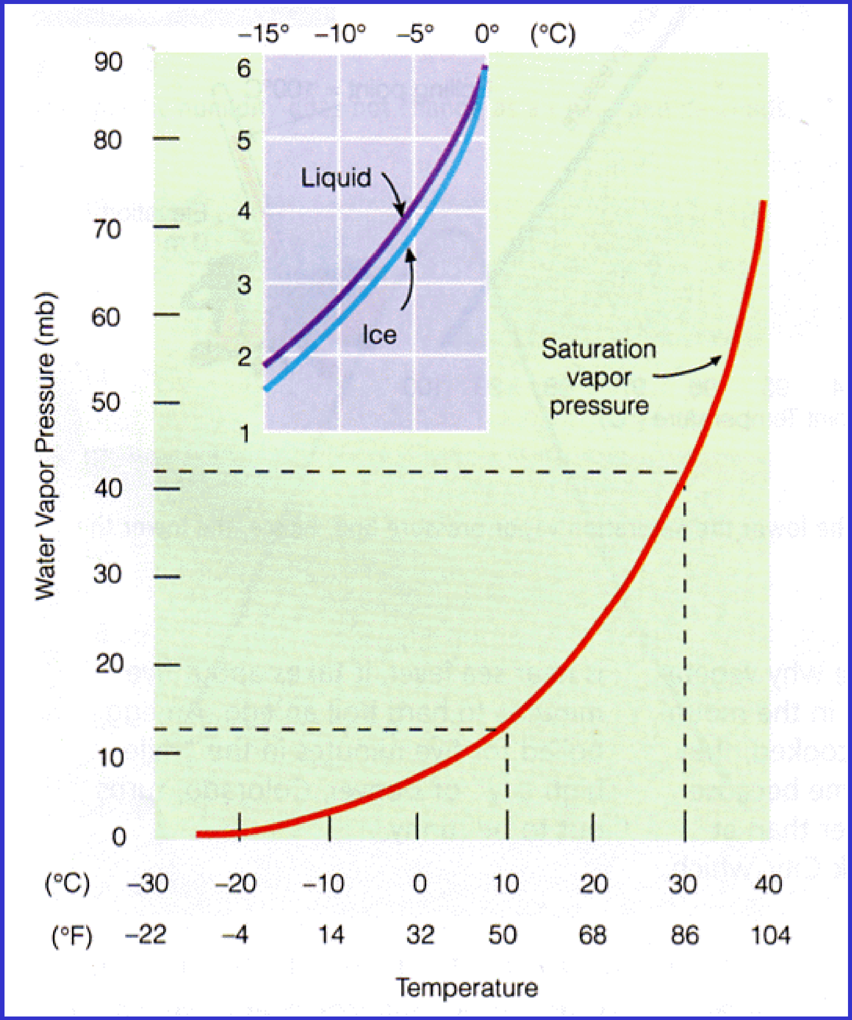
[b] Based on data given in H. H. Lamb, "Climate: Present, Past and Future," Methuen Co. Ltd., London, 1972, p. 482.

(from *Atmospheric Sciences: An Introductory Survey*)

- ❑ The atmosphere can only hold small fraction of the mass of water vapor that has been injected into it during volcanic eruption, most of the water vapor was condensed into clouds and rains and gave rise to rivers, lakes, and oceans.

➔ The concentration of water vapor in the atmosphere was substantially reduced.

Saturation Vapor Pressure



- Saturation vapor pressure describes how much water vapor is needed to make the air saturated at any given temperature.
- Saturation vapor pressure depends primarily on the air temperature in the following way:

$$\frac{de_s}{dT} = \frac{L}{T(\alpha_v - \alpha_l)}$$

The Clausius-Clapeyron Equation

➔ $$e_s \cong 6.11 \cdot \exp\left\{\frac{L}{R_v}\left(\frac{1}{273} - \frac{1}{T}\right)\right\}$$

- Saturation pressure increases exponentially with air temperature.

L: latent heat of evaporation; α: specific volume of vapor and liquid

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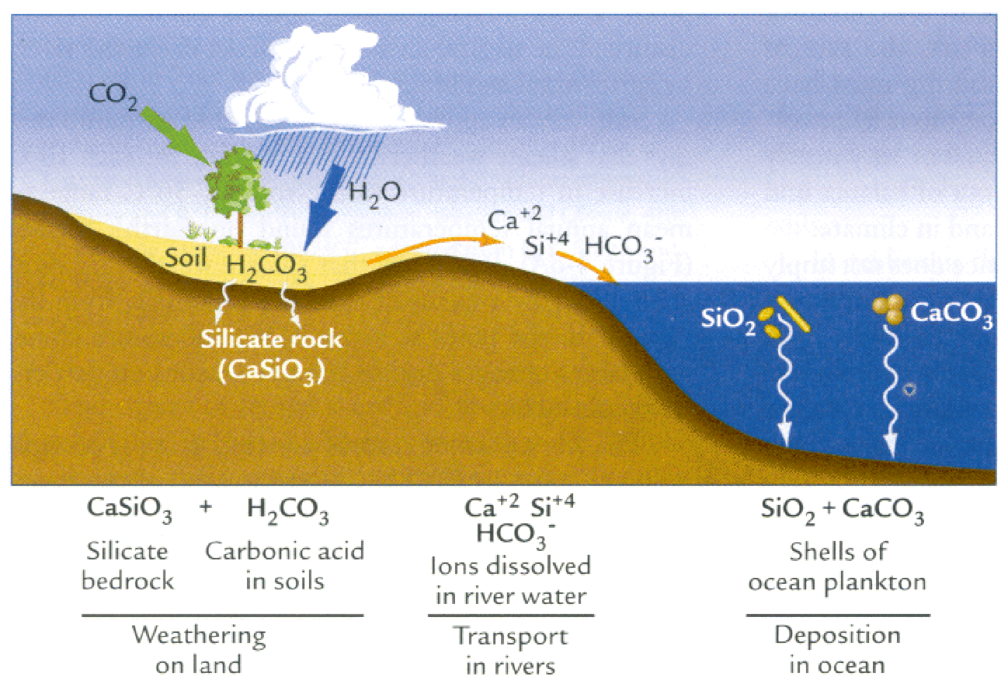
What happened to CO_2?



(from *Earth's Climate: Past and Future*)

- ❑ Chemical weather is the primary process to remove CO2 from the atmosphere.
- ➔ In this process, CO2 dissolves in rainwater producing weak carbonic acid that reacts chemically with bedrock and produces carbonate compounds.

- ❑ This biogeochemical process reduced CO2 in the atmosphere and locked carbon in rocks and mineral.

Carbon Inventory

Table 1.3

Inventory of carbon near the earth's surface[a]

Biosphere	marine	1
	nonmarine	1
Atmosphere (in CO_2)		70
Ocean (in dissolved CO_2)		4000
Fossil fuels		800
Shales		800,000
Carbonate rocks		2,000,000

[a] Given in relative units. After P. K. Weyl, "Oceanography," John Wiley & Sons, New York, 1970.

(from *Atmospheric Sciences: An Introductory Survey*)

What Happened to N_2?

- Nitrogen (N2):

  (1) is inert chemically,

  (2) has molecular speeds too slow to escape to space,

  (3) is not very soluble in water.

➔ The amount of nitrogen being cycled out of the atmosphere was limited.

➔ Nitrogen became the most abundant gas in the atmosphere.

Where Did O_2 Come from?

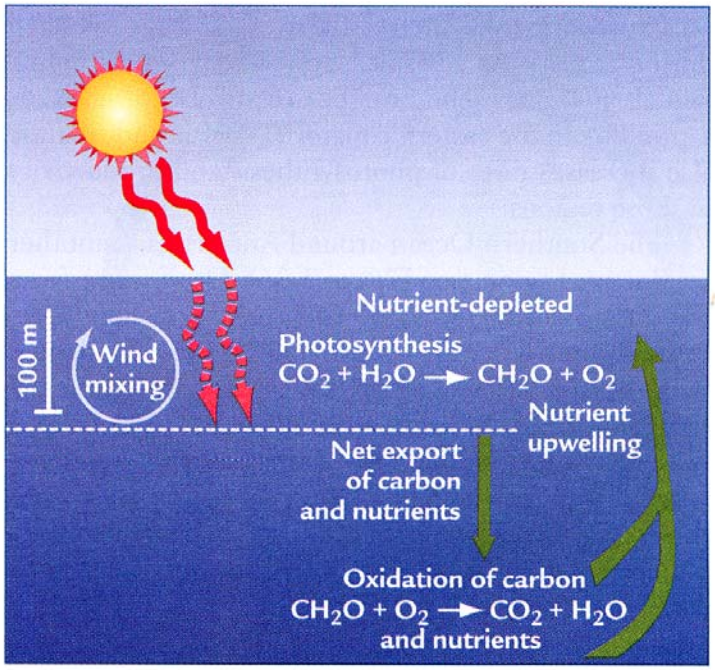


FIGURE 2-35 **Photosynthesis in the ocean** Sunlight penetrating the surface ocean causes photosynthesis by microscopic plants. As they die, their nutrient-bearing organic tissue descends to the seafloor. Oxidation of this tissue at depth returns nutrients and inorganic carbon to the surface ocean in regions of upwelling.

(from *Earth's Climate: Past and Future*)

- ❑ Photosynthesis was the primary process to increase the amount of oxygen in the atmosphere.

➔ Primitive forms of life in oceans began to produce oxygen through photosynthesis probably 2.5 billion years ago.

➔ With the concurrent decline of CO2, oxygen became the second most abundant atmospheric as after nitrogen.

Where Did Argon Come from?

- Radioactive decay in the planet’s bedrock added argon (**Ar**) to the evolving atmosphere.

➔ Argon became the third abundant gas in the atmosphere.

Permanent and Variable Gases

Table 1–2 • Permanent Gases of the Atmosphere

Constituent	Formula	Percent by Volume	Molecular Weight
Nitrogen	N_2	78.08	28.01
Oxygen	O_2	20.95	32.00
Argon	Ar	0.93	39.95
Neon	Ne	0.002	20.18
Helium	He	0.0005	4.00
Krypton	Kr	0.0001	83.8
Xenon	Xe	0.00009	131.3
Hydrogen	H_2	0.00005	2.02

Those gases that form a constant portion of the atmospheric mass.

Table 1–3 • Variable Gases of the Atmosphere

Constituent	Formula	Percent by Volume	Molecular Weight
Water Vapor	H_2O	0.25	18.01
Carbon Dioxide	CO_2	0.037	44.01
Ozone	O_3	0.01	48.00

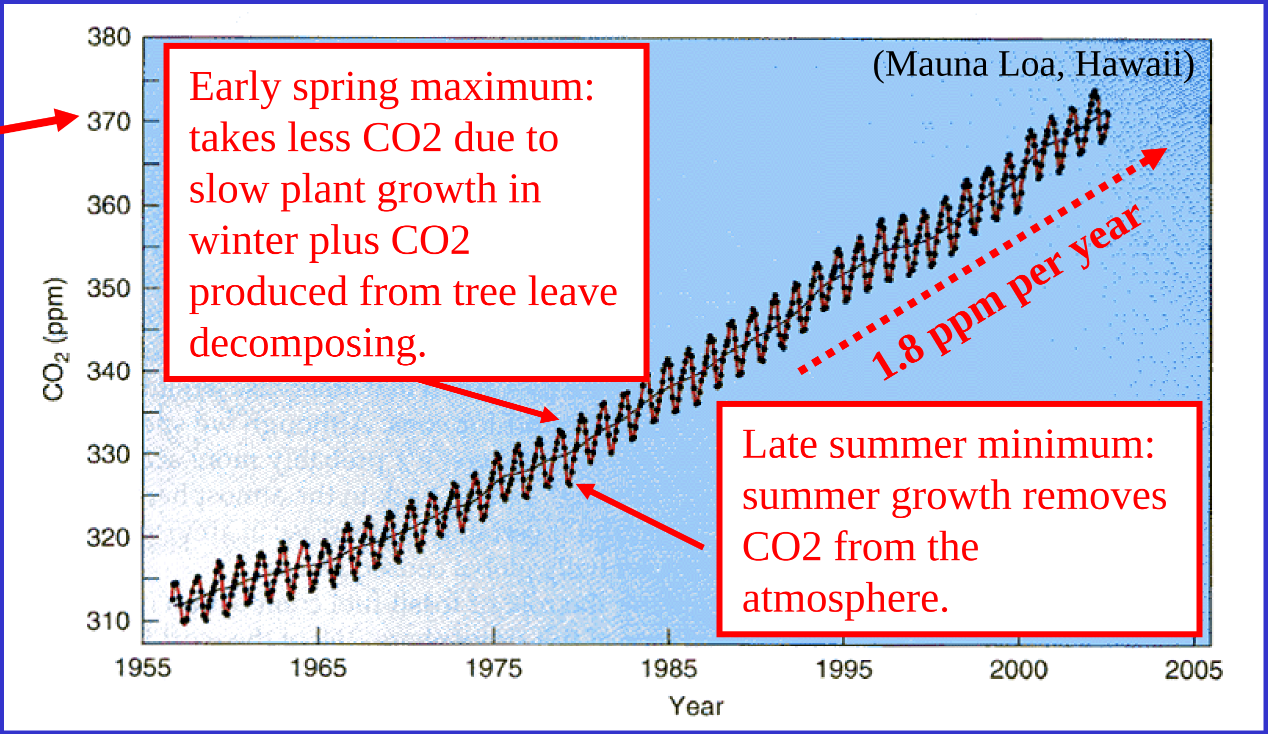
Those gases whose concentrations changes from time to time and from place to place, and are important to weather and climate.

Water Vapor (H_2O)

- Water vapor is supplied to the atmosphere by evaporation from the surface and is removed from the atmosphere by condensation (clouds and rains).
- The concentration of water vapor is maximum near the surface and the tropics (~ 0.25% of the atmosphere) and decreases rapidly toward higher altitudes and latitudes (~ 0% of the atmosphere).
- Water vapor is important to climate because it is a greenhouse gas that can absorb thermal energy emitted by Earth, and can release “latent heat” to fuel weather phenomena.

Carbon Dioxide (CO2)

current level



(from *Understanding Weather & Climate*)

- Carbon dioxide is supplied into the atmosphere by plant and animal respiration, the decay of organic material, volcanic eruptions, and natural and anthropogenic combustion.
- Carbon dioxide is removed from the atmosphere by photosynthesis.
- CO2 is an important greenhouse gas.

Formation of Ozone (O_3)

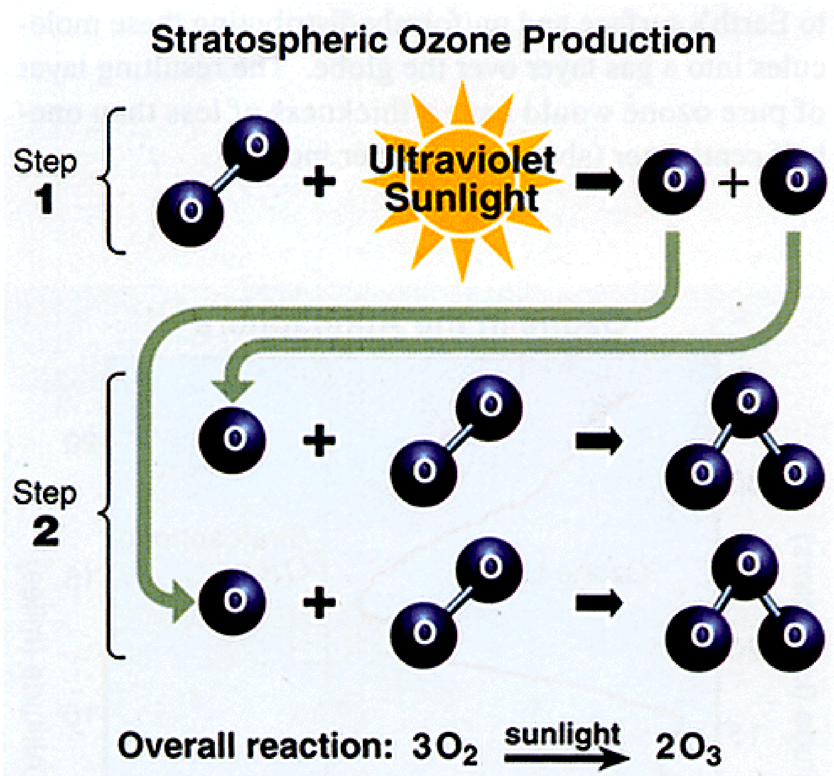
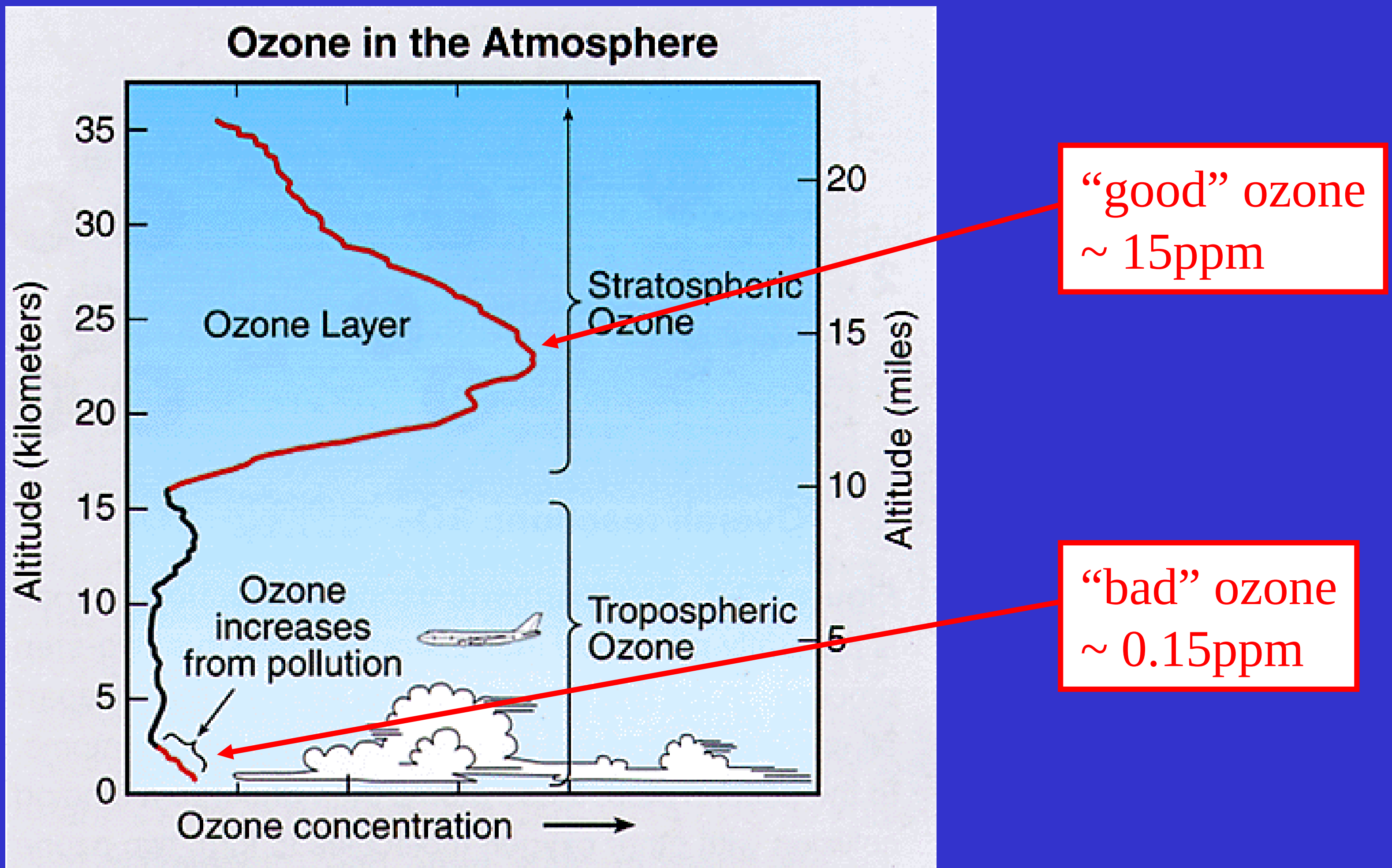


Figure Q2-1. Stratospheric ozone production. Ozone is naturally produced in the stratosphere in a two-step process. In the first step, ultraviolet sunlight breaks apart an oxygen molecule to form two separate oxygen atoms. In the second step, these atoms then undergo a binding collision with other oxygen molecules to form two ozone molecules. In the overall process, three oxygen molecules react to form two ozone molecules.

(from *WMO Report 2003*)

- With oxygen emerging as a major component of the atmosphere, the concentration of ozone increased in the atmosphere through a photodissociation process.

Ozone (O_3)



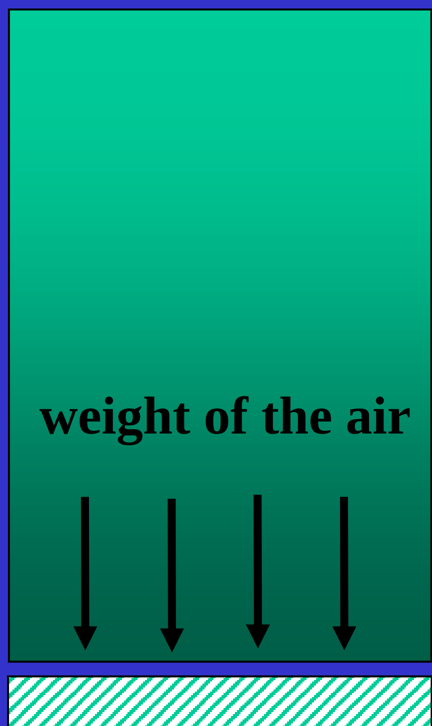
(from WMO Report 2003)

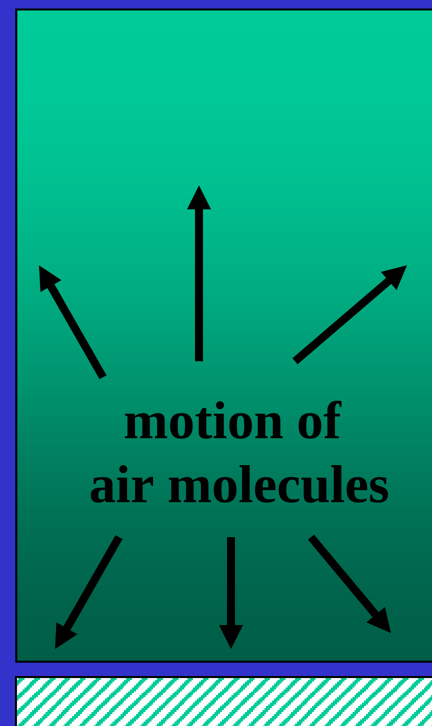
Other Atmospheric Constituents

- **Aerosols**: small solid particles and liquid droplets in the air. They serve as condensation nuclei for cloud formation.

- **Air Pollutant**: a gas or aerosol produce by human activity whose concentration threatens living organisms or the environment.

Air Pressure Can Be Explained As:

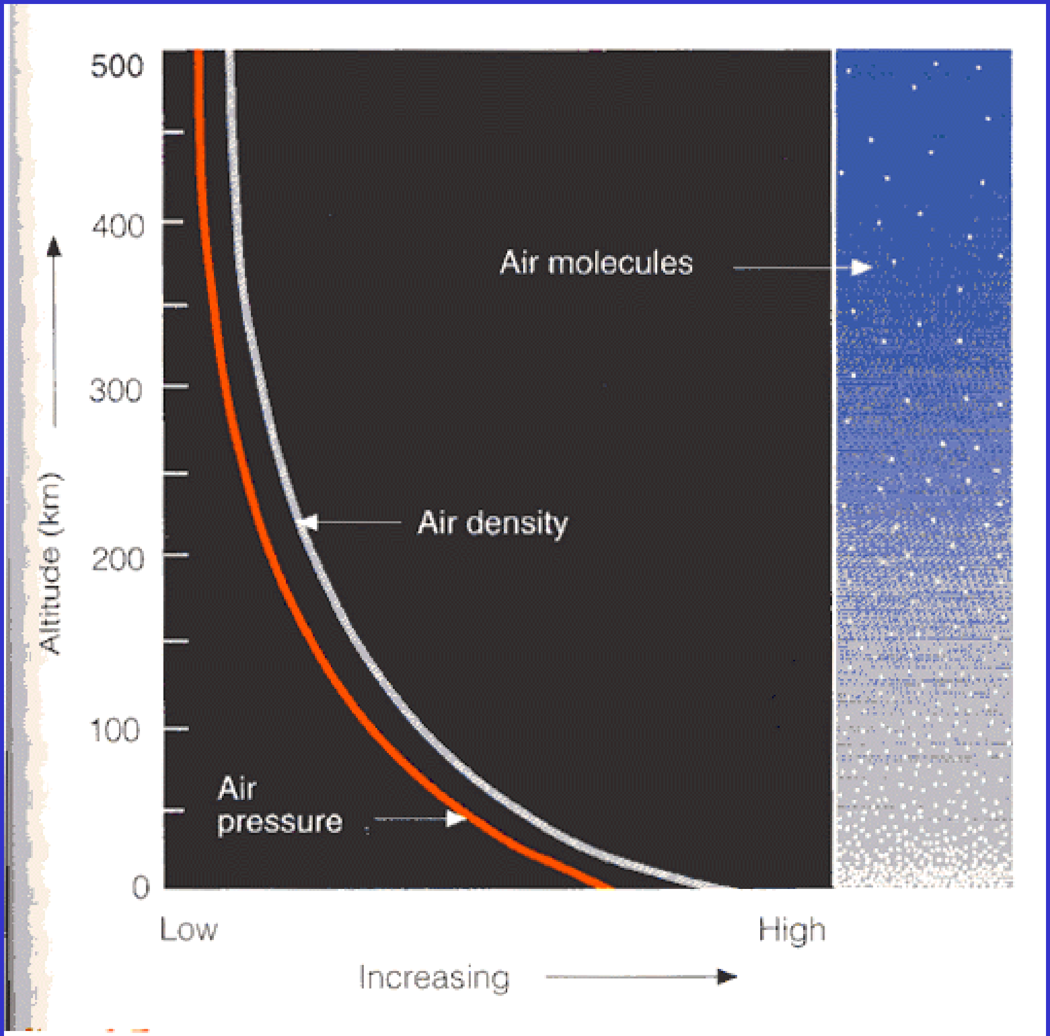




The weight of air above a surface (due to Earth's gravity)

The bombardment of air molecules on a surface (due to motion)

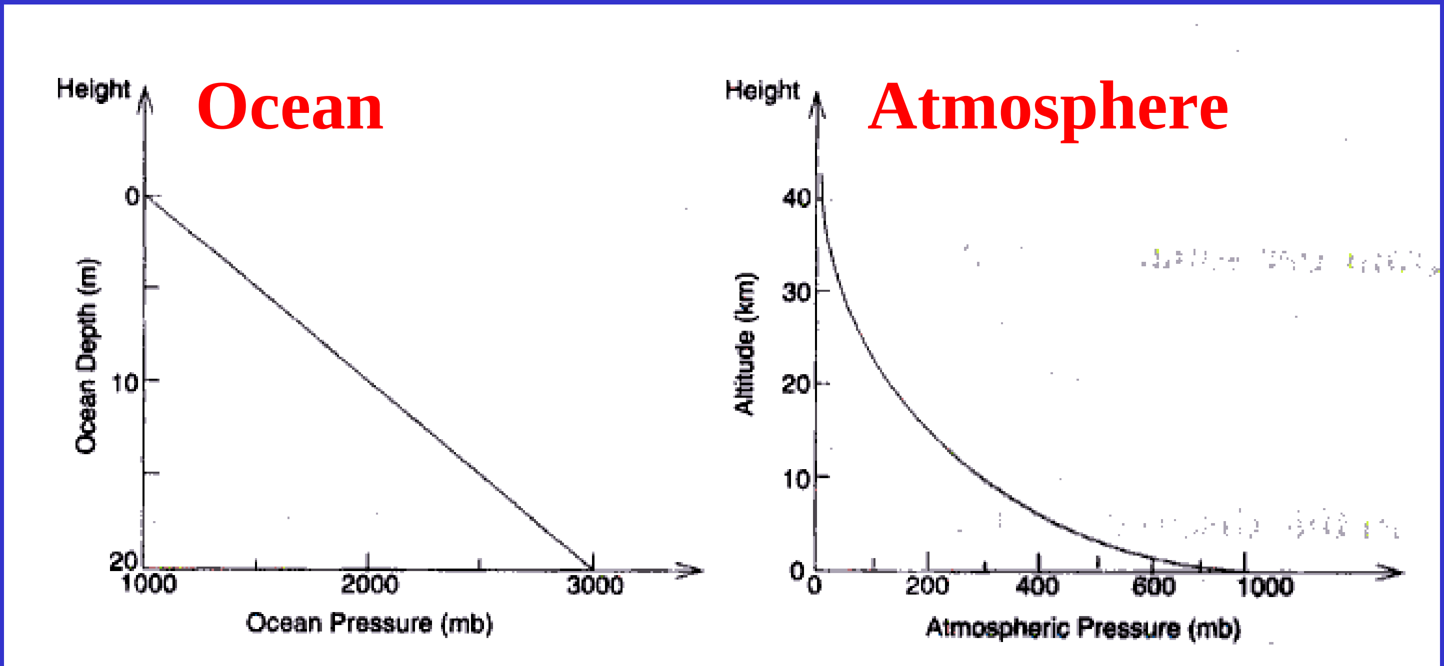
Air Pressure and Air Density



(from *Meteorology Today*)

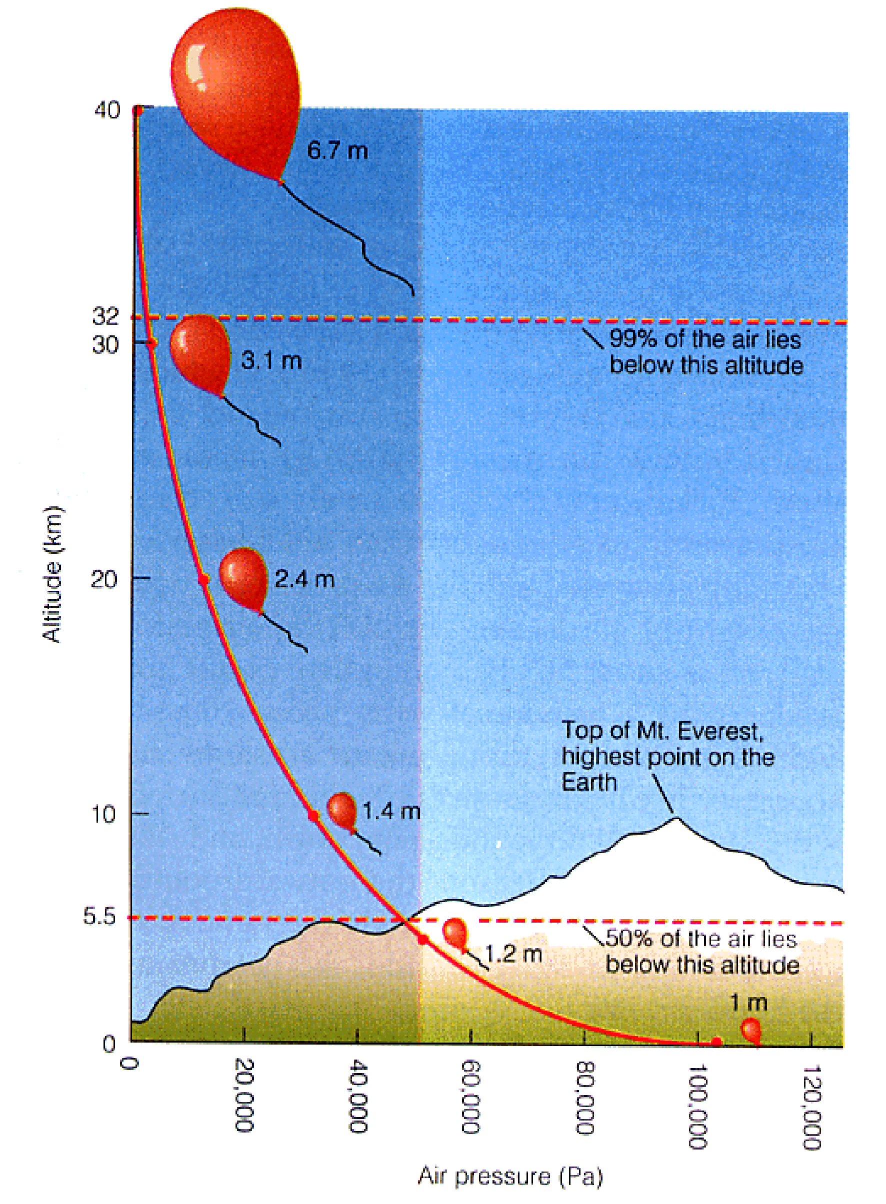
- Weight = mass x gravity
- Density = mass / volume
- Pressure = force / area
  = weight / area

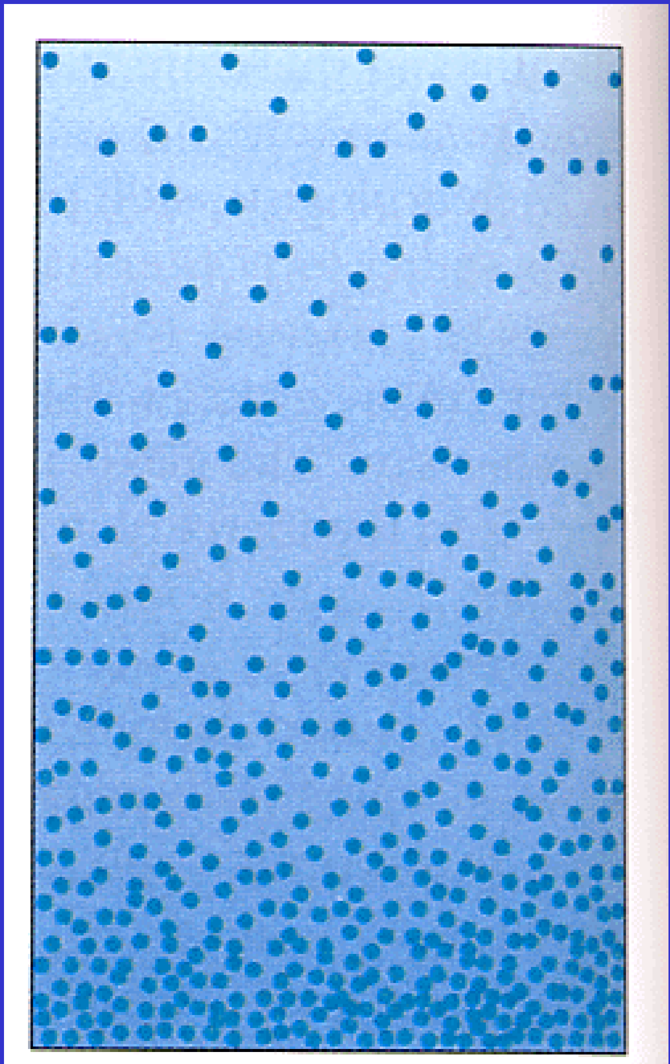
How Soon Pressure Drops With Height?



(from ***Is The Temperature Rising?***)

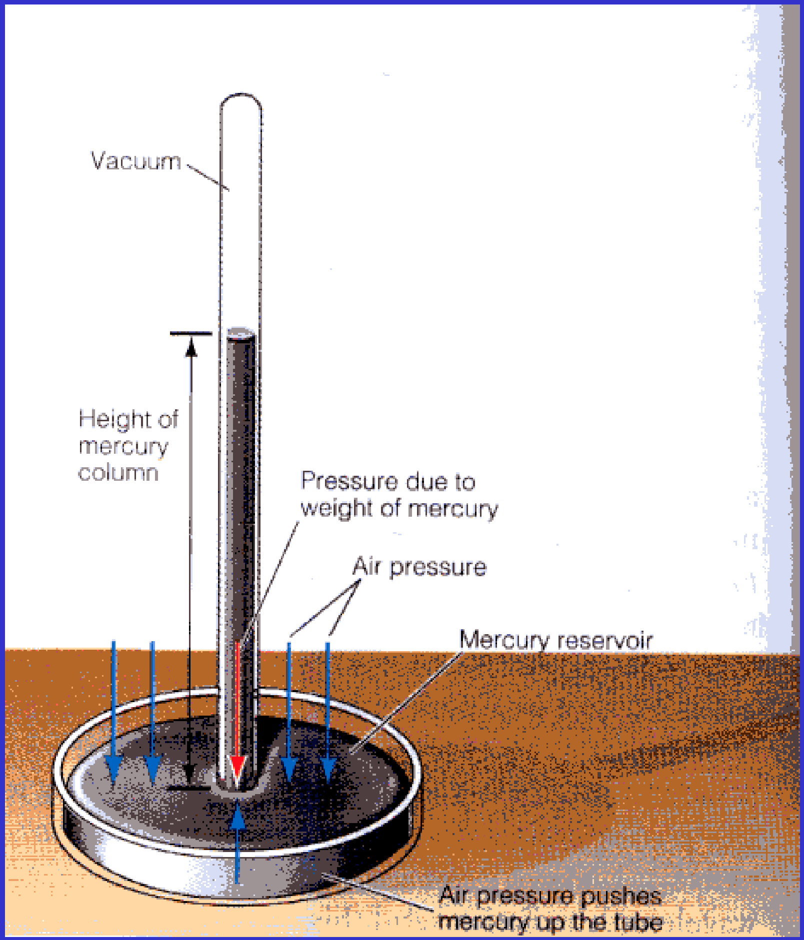
- ❑ In the ocean, which has an essentially constant density, pressure increases linearly with depth.
- ❑ In the atmosphere, both pressure and density decrease exponentially with elevation.





(from *The Atmosphere*)

One Atmospheric Pressure



(from *The Blue Planet*)

- The average air pressure at sea level is equivalent to the pressure produced by a column of water about 10 meters (or about 76 cm of mercury column).
- This standard atmosphere pressure is often expressed as 1013 mb (millibars), which means a pressure of about 1 kilogram per square centimeter.

Units of Atmospheric Pressure

- **Pascal (Pa):** a SI (Systeme Internationale) unit for air pressure.

  1 Pa = a force of 1 newton acting on a surface of one square meter

  1 hectopascal (hPa) = 1 millibar (mb) [hecto = one hundred =100]

- **Bar:** a more popular unit for air pressure.

  1 bar = a force of 100,000 newtons acting on a surface of one square meter

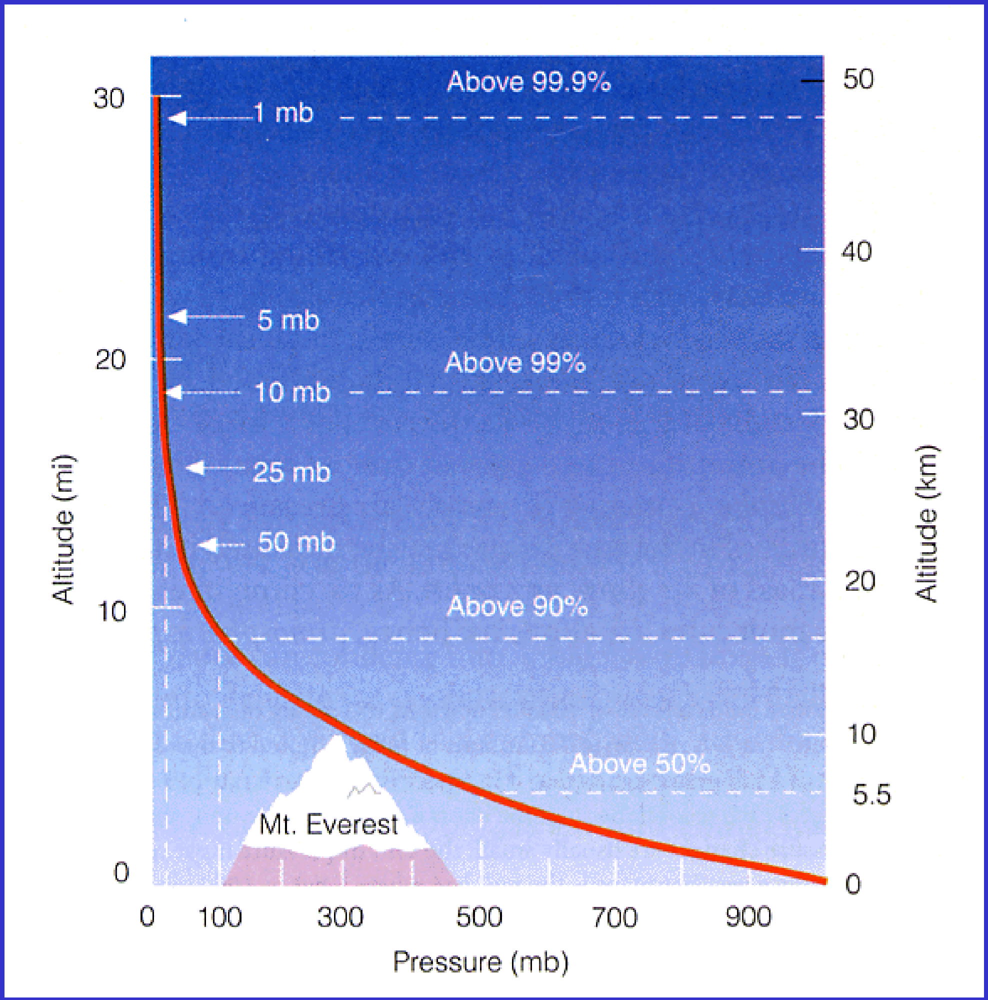
  = 100,000 Pa

  = 1000 hPa

  = 1000 mb

- **One atmospheric pressure** = standard value of atmospheric pressure at lea level = 1013.25 mb = 1013.25 hPa.

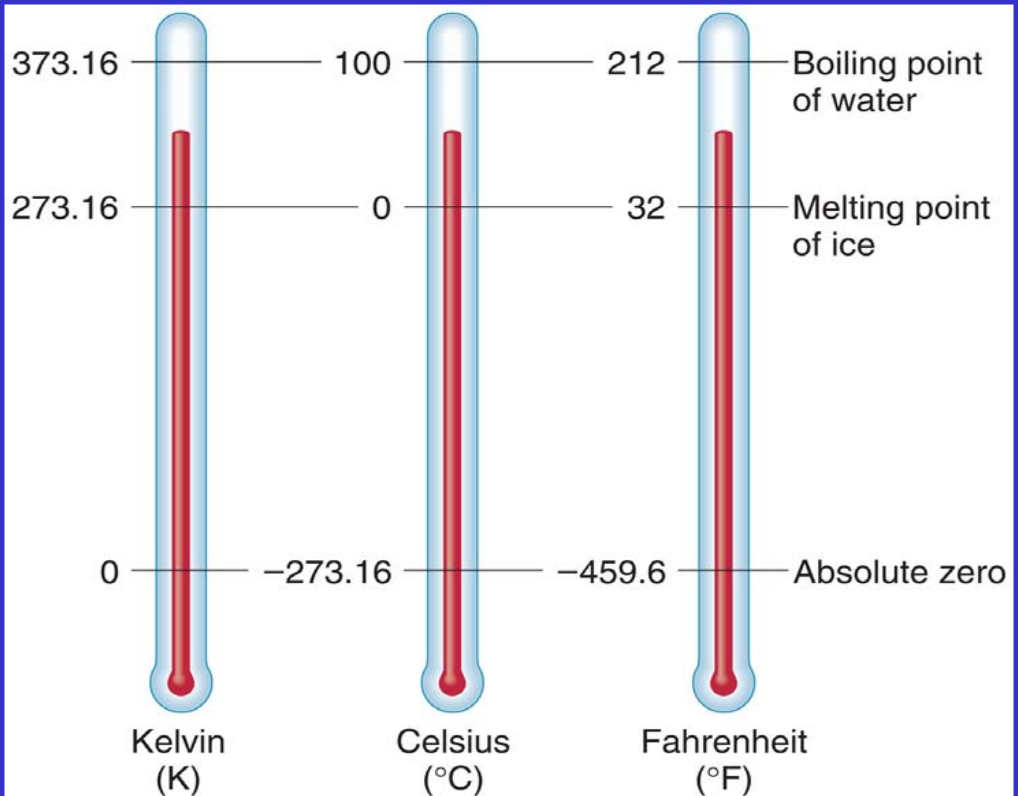
Air Mass and Pressure



(from *Meteorology Today*)

- ❑ Atmospheric pressure tells you how much atmospheric mass is above a particular altitude.
- ❑ Atmospheric pressure decreases by about 10mb for every 100 meters increase in elevation.

Units of Air Temperature



- Fahrenheit (ºF)

- Celsius (ºC)

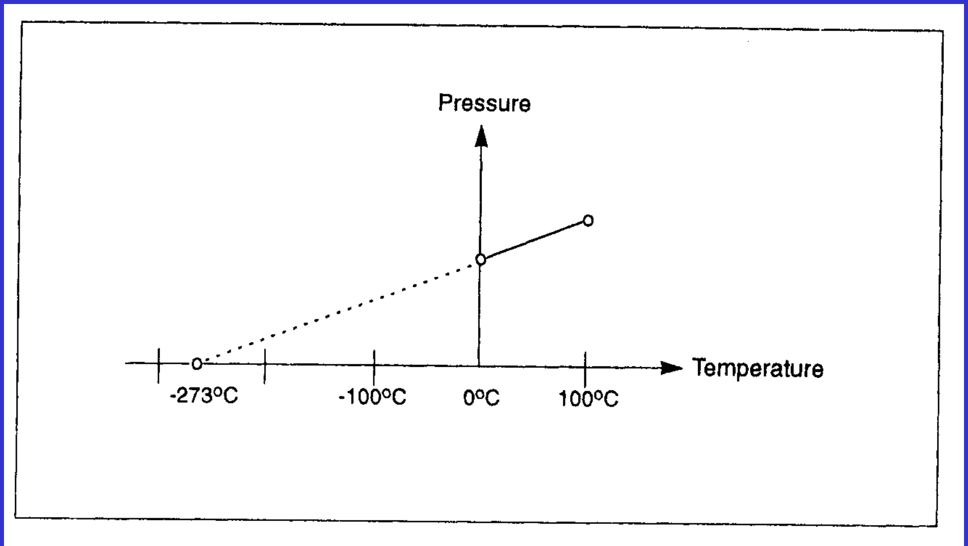
→ ºC = (ºF-32)/1.8

- Kelvin (K): a SI unit

→ K= ºC+273

1 K = 1 ºC > 1 ºF

“*Absolute Zero*” Temperature



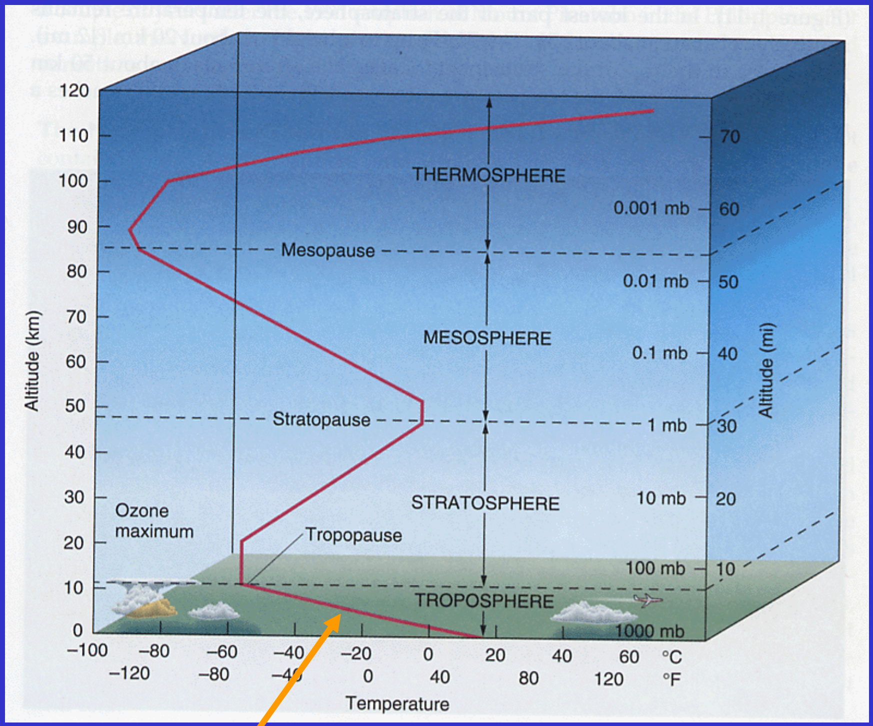
(from ***Is The Temperature Rising?***)

- The absolute zero temperature is the temperature that the molecules do not move at all.
- This temperature occurs at –273°C.
- The Kelvin Scale (K) is a new temperature scale that has its “zero” temperature at this absolute temperature:

K = °C + 273

Vertical Thermal Structure

Standard Atmosphere



(from *Understanding Weather & Climate*)

lapse rate = 6.5 C/km

Troposphere ("overturning" sphere)
- contains 80% of the mass
- surface heated by solar radiation
- strong vertical motion
- where most weather events occur

Stratosphere ("layer" sphere)
- weak vertical motions
- dominated by radiative processes
- heated by ozone absorption of solar ultraviolet (UV) radiation
- warmest (coldest) temperatures at summer (winter) pole

middle atmosphere

Mesosphere
- heated by solar radiation at the base
- heat dispersed upward by vertical motion

Thermosphere
- very little mass

Variations in Tropopause Height

(from *The Atmosphere*)

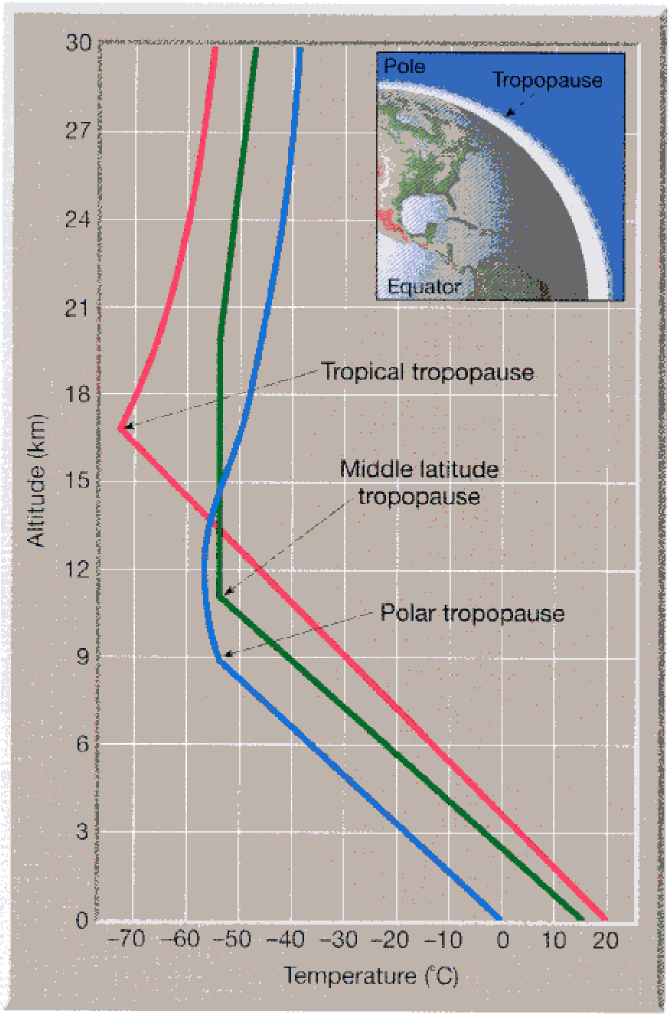
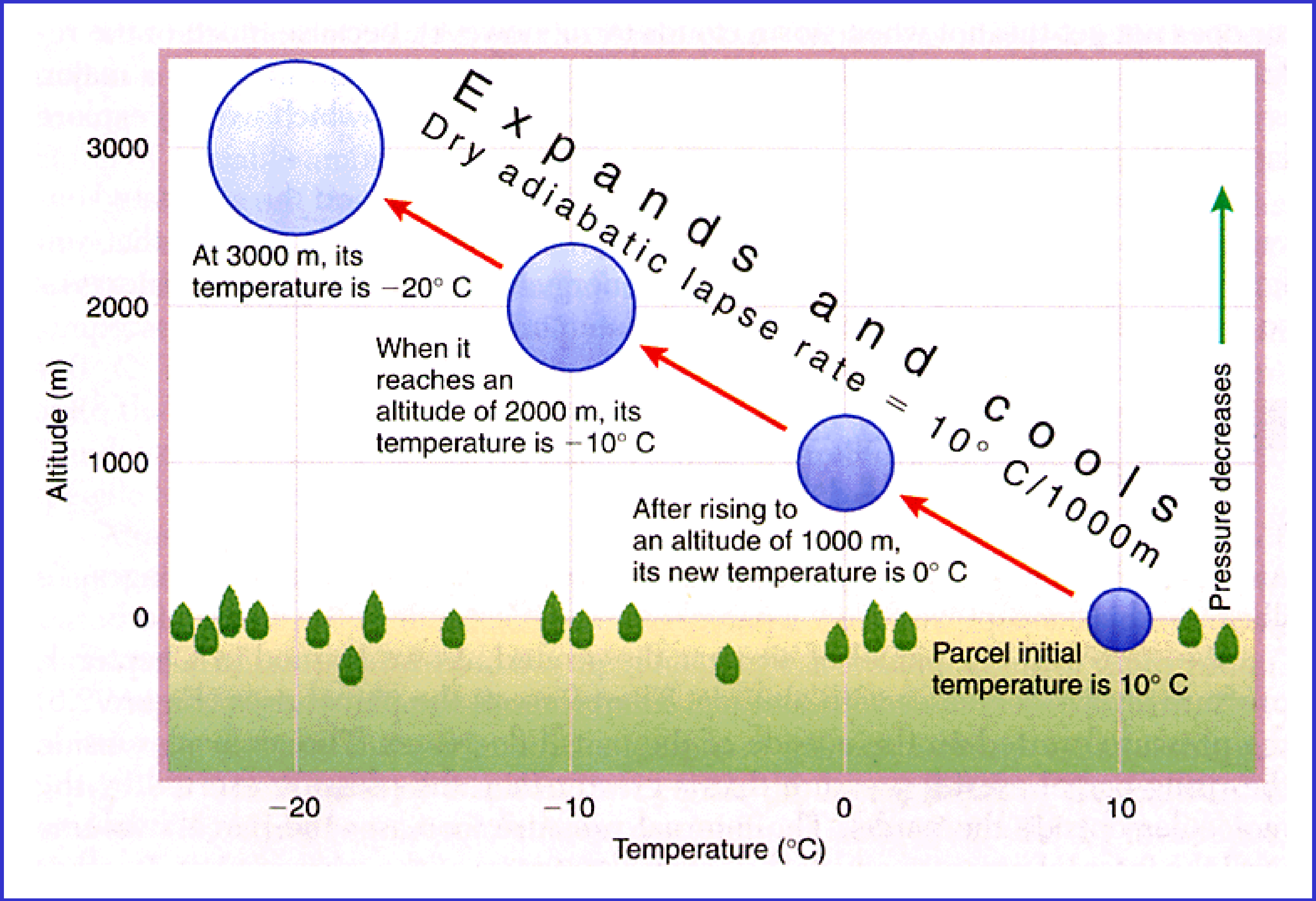


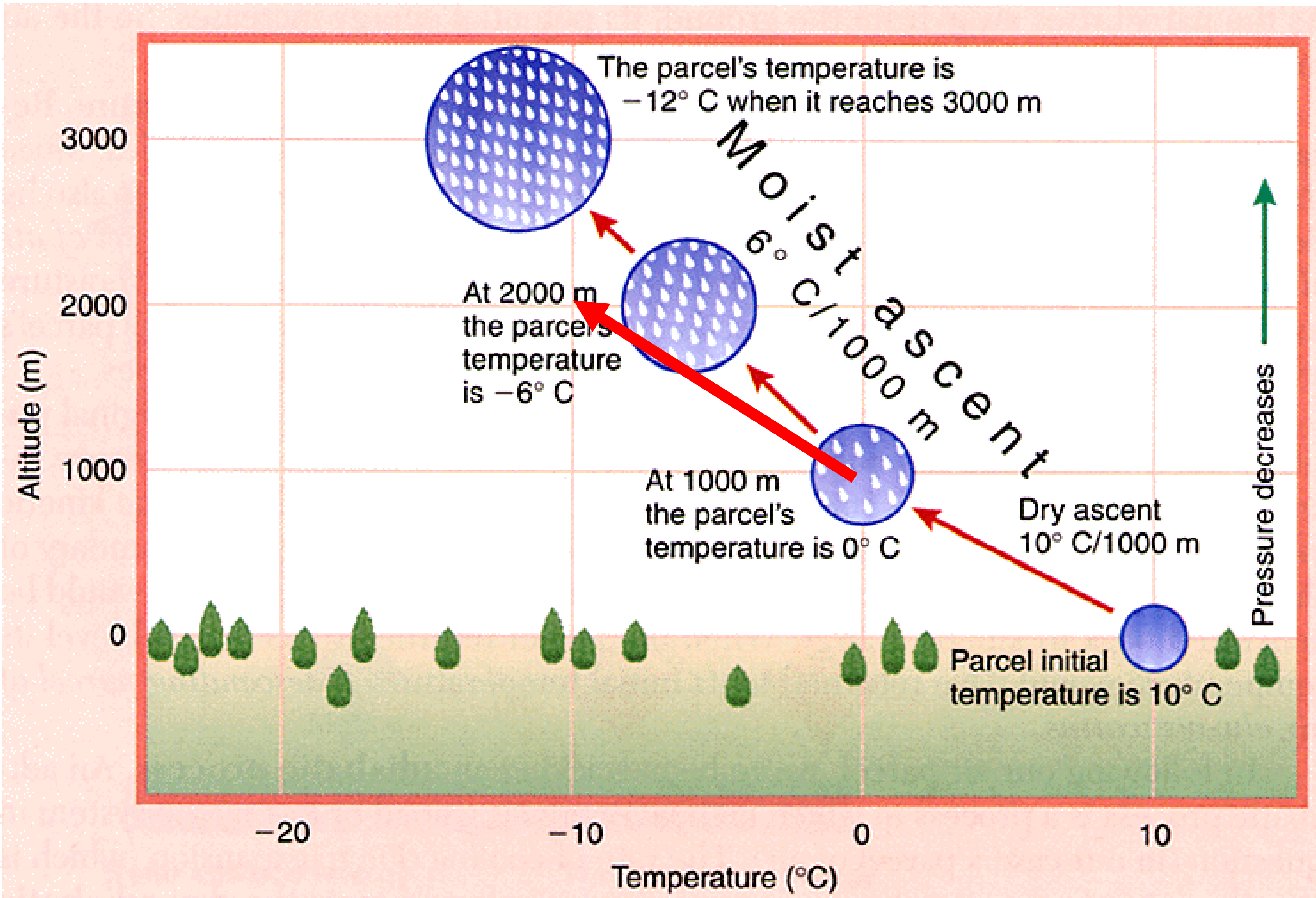
FIGURE 1-23 Differences in the height of the tropopause. The variation in the height of the tropopause, as shown on the small inset diagram, is greatly exaggerated.

Dry Adiabatic Lapse Rate



(from *Meteorology: Understanding the Atmosphere*)

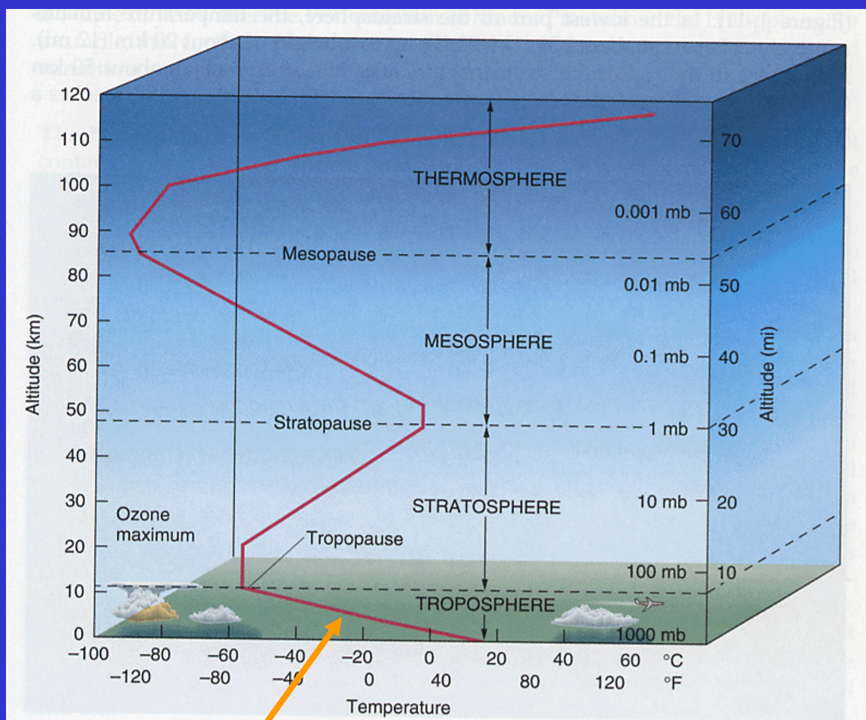
Moist Adiabatic Lapse Rate



(from *Meteorology: Understanding the Atmosphere*)

Stratosphere

Standard Atmosphere

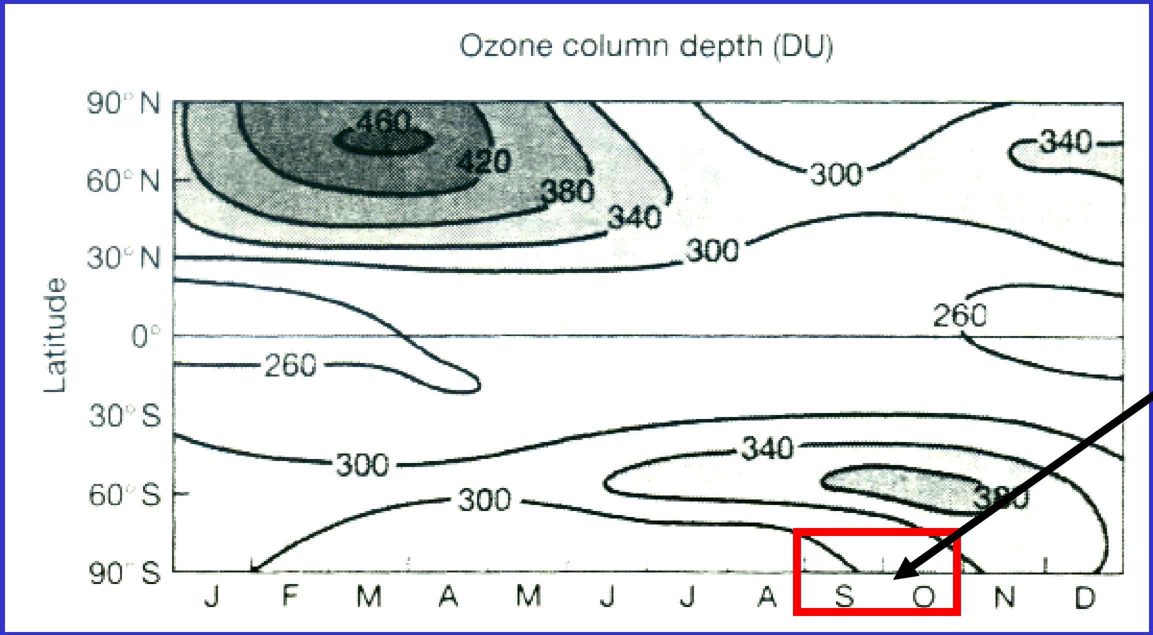


(from *Understanding Weather & Climate*)

lapse rate = 6.5 C/km

- ❑ The reasons for the inversion in the stratosphere is due to the ozone absorption of ultraviolet solar energy.
- ❑ Although maximum ozone concentration occurs at 25km, the lower air density at 50km allows solar energy to heat up temperature there at a much greater degree.
- ❑ Also, much solar energy is absorbed in the upper stratosphere and can not reach the level of ozone maximum.

Ozone Distribution

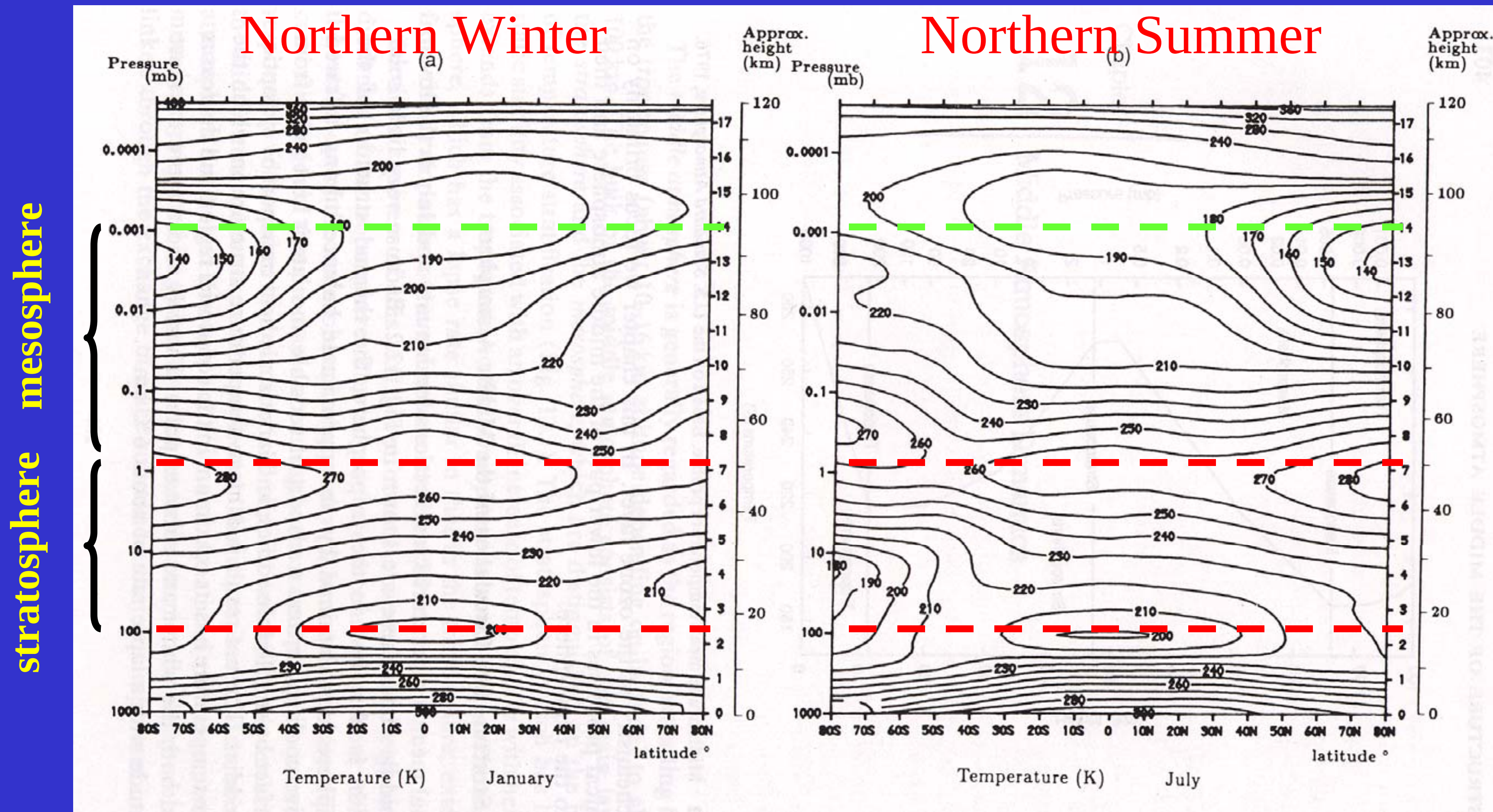


Antarctic Ozone Hole

(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.
- Ozone column depths are highest during springtime at mid-to-high latitudes.
- Ozone column depths are the lowest over the equator.

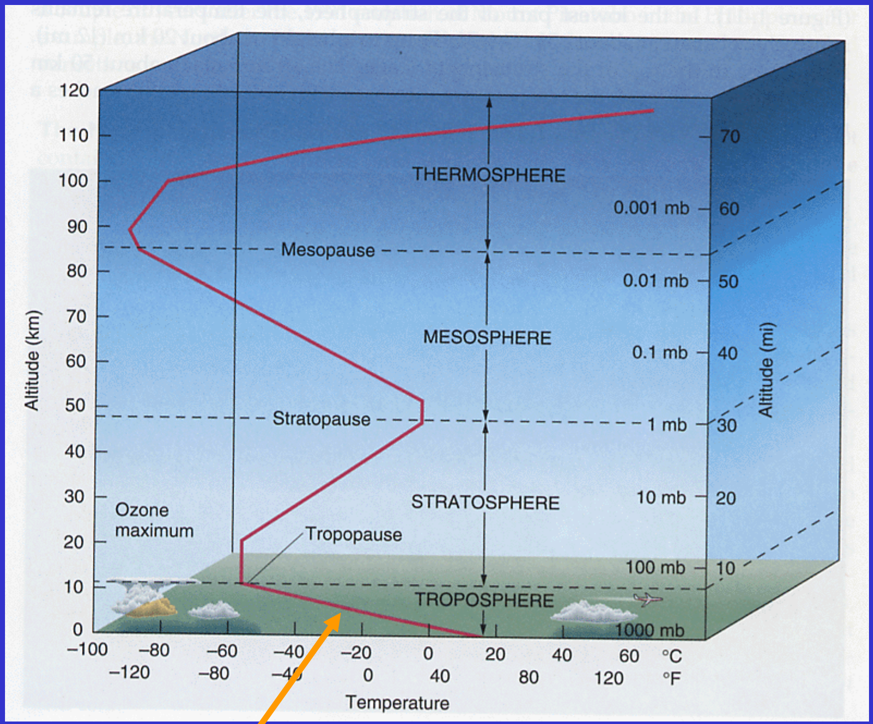
Temperatures in Stratosphere



(from *Dynamic Meteorology*)

Mesosphere

Standard Atmosphere



(from *Understanding Weather & Climate*)

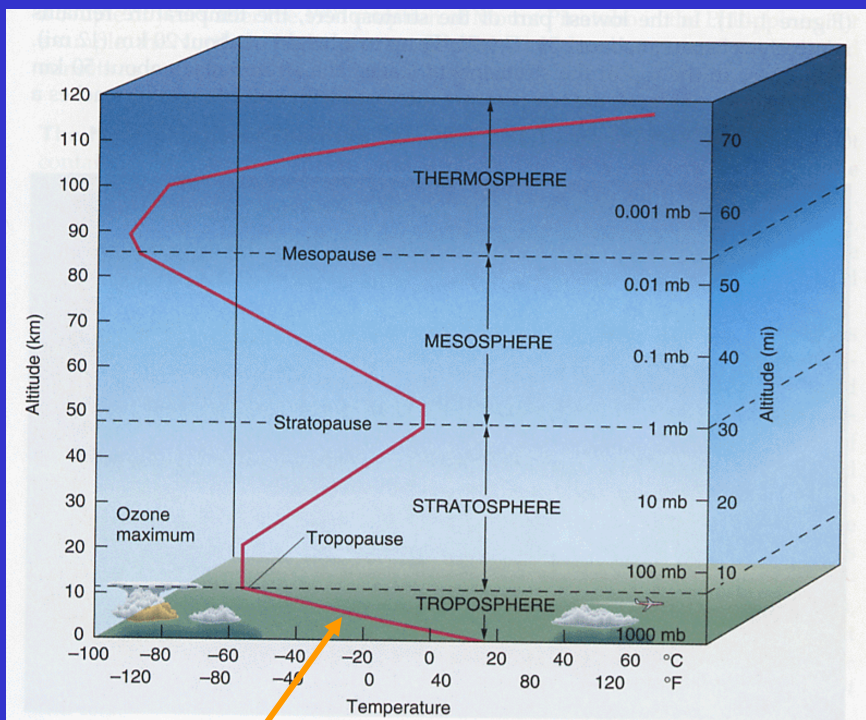
lapse rate = 6.5 C/km

❑ There is little ozone to absorb solar energy in the mesosphere, and therefore, the air temperature in the mesosphere decreases with height.

❑ Also, air molecules are able to lose more energy than they absorb. This cooling effect is particularly large near the top of the mesosphere.

Thermosphere

Standard Atmosphere

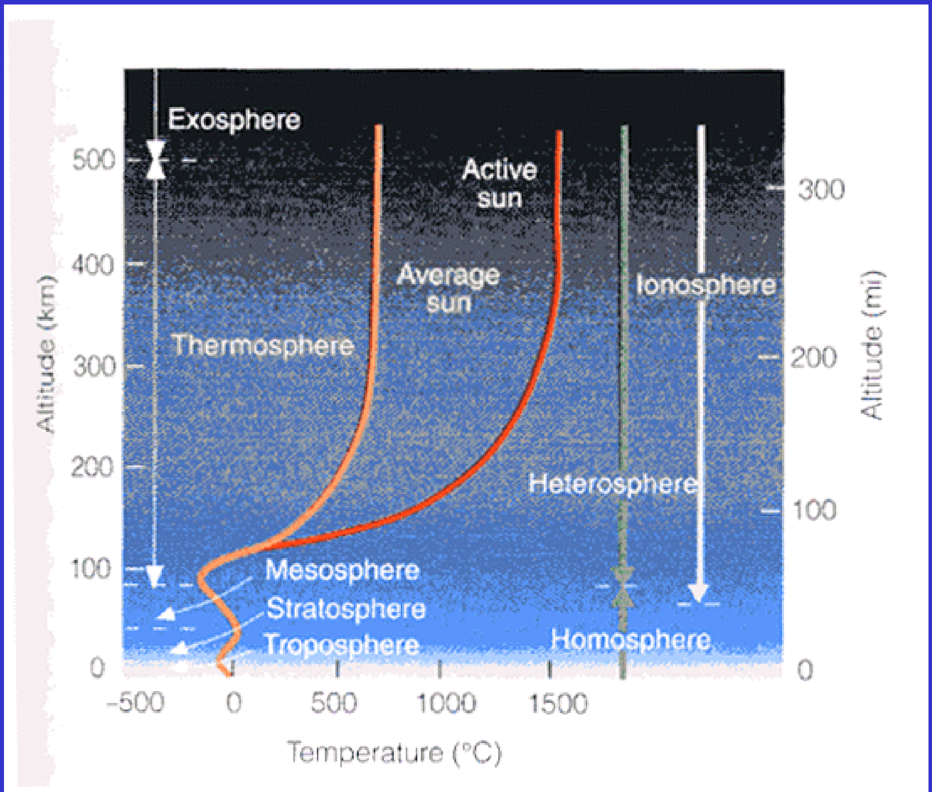


(from ***Understanding Weather & Climate***)

lapse rate = 6.5 C/km

- ❑ In thermosphere, oxygen molecules absorb solar rays and warms the air.
- ❑ Because this layer has a low air density, the absorption of small amount of solar energy can cause large temperature increase.
- ❑ The air temperature in the thermosphere is affected greatly by solar activity.

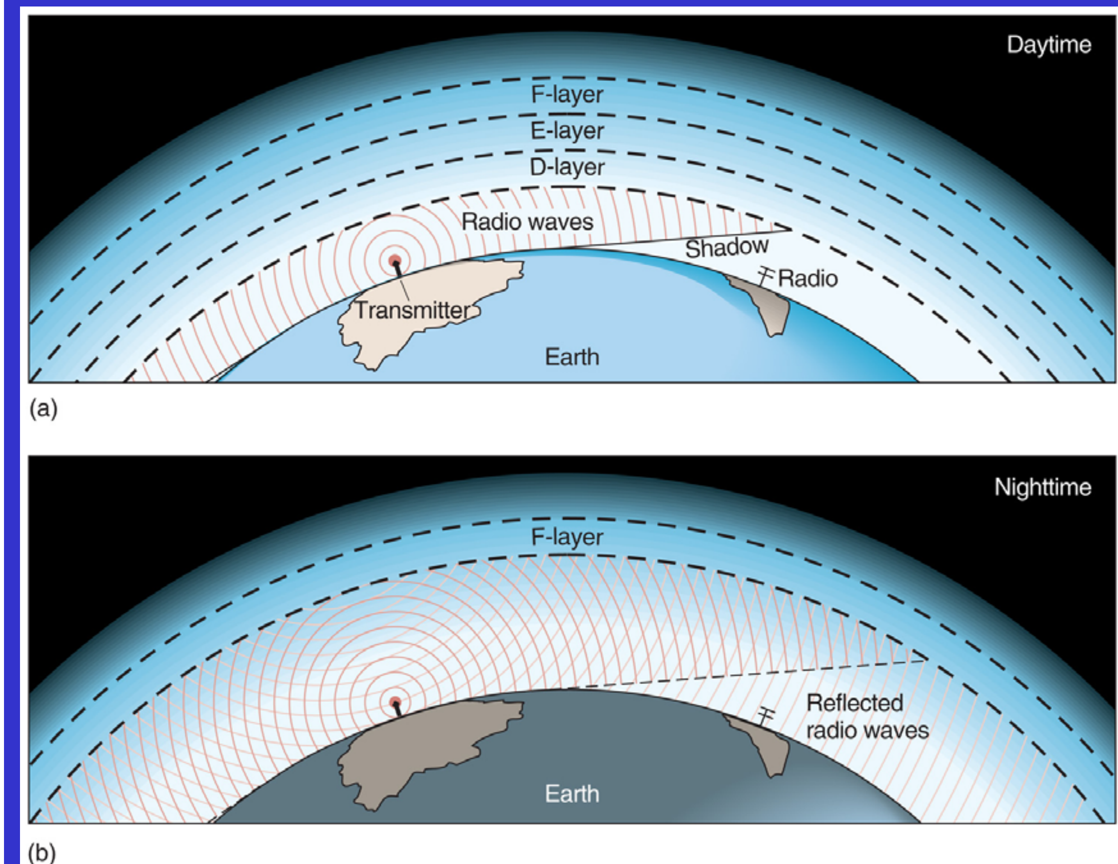
Ionosphere



(from *Meteorology Today*)

- The ionosphere is an electrified region within the upper atmosphere where large concentration of ions and free electrons exist.
- The ionosphere starts from about 60km above Earth's surface and extends upward to the top of the atmosphere. Most of the ionosphere is in the thermosphere.
- The ionosphere plays an important role in radio communication.

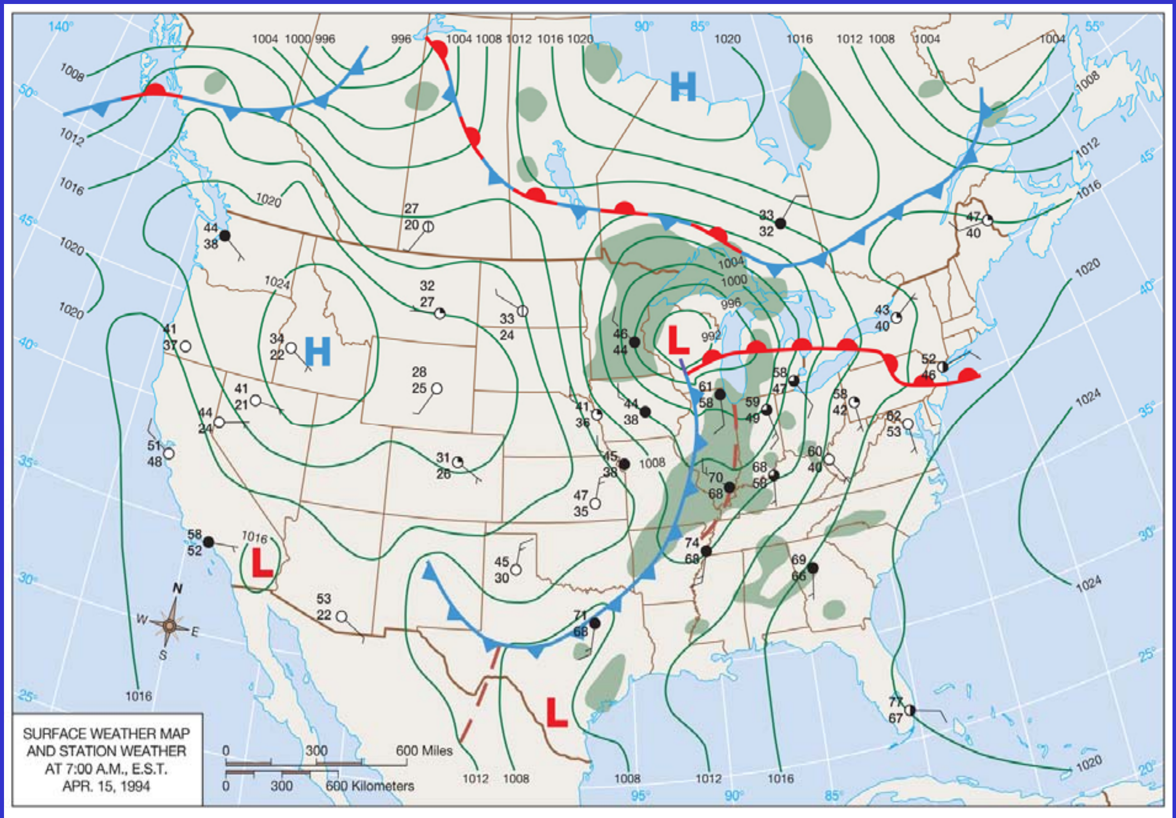
Ionosphere and AM Radio



(from *Understanding Weather & Climate*)

- The D- and E-layers absorb AM radio, while the F-layer reflect radio waves.
- When night comes, the D-layer disappears and the E-layer weakens. Radio waves are able to reach the F-layer and get reflected further.
- The repeated refection of radio waves between Earth surface and the F-layer allows them to overcome the effect of Earth's curvature.

Weather Maps



(from *Understanding Weather & Climate*)

- Many variables are needed to described weather conditions.

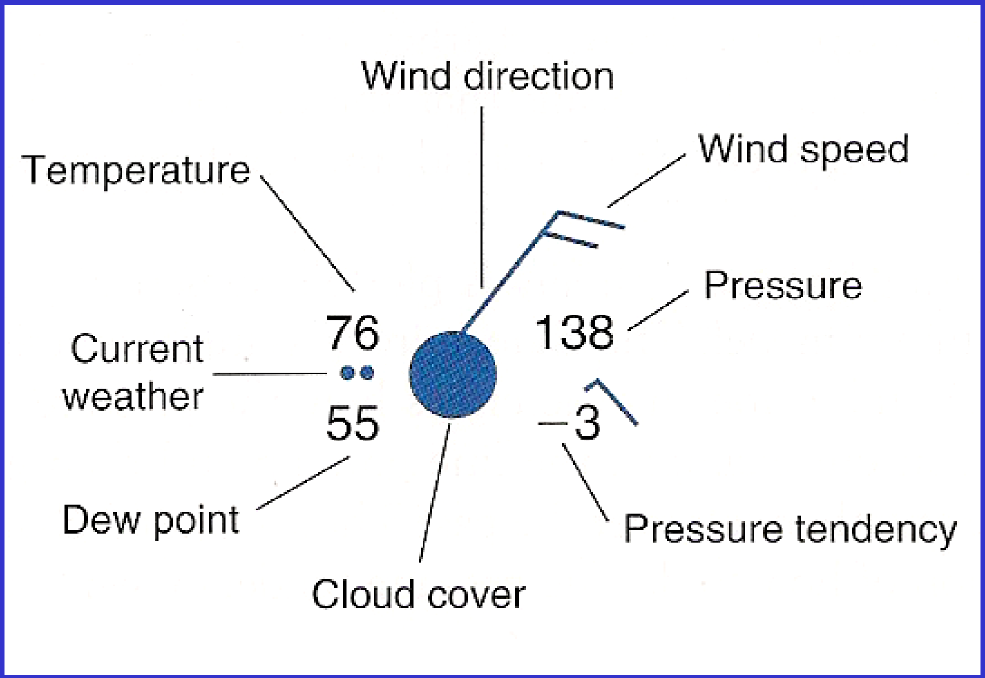
- Local weathers are affected by weather pattern.

➔ We need to see all the numbers describing weathers at many locations.

➔ We need weather maps.

- "A picture is worth a thousand words".

The Station Model

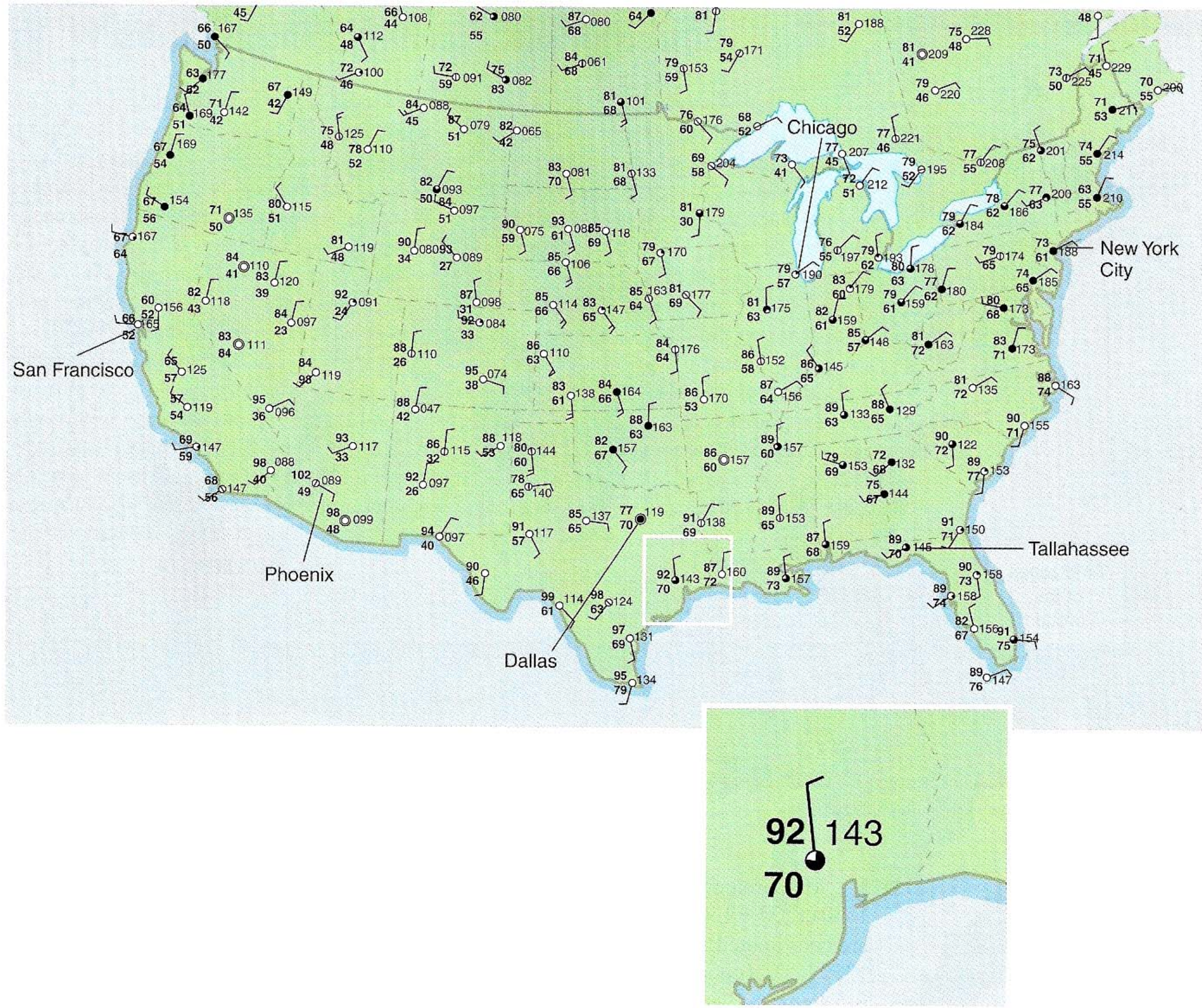


(from *Meteorology: Understanding the Atmosphere*)

- Meteorologists need a way to condense all the numbers describing the current weather at a location into a compact diagram that takes up as little space as possible on a weather map.

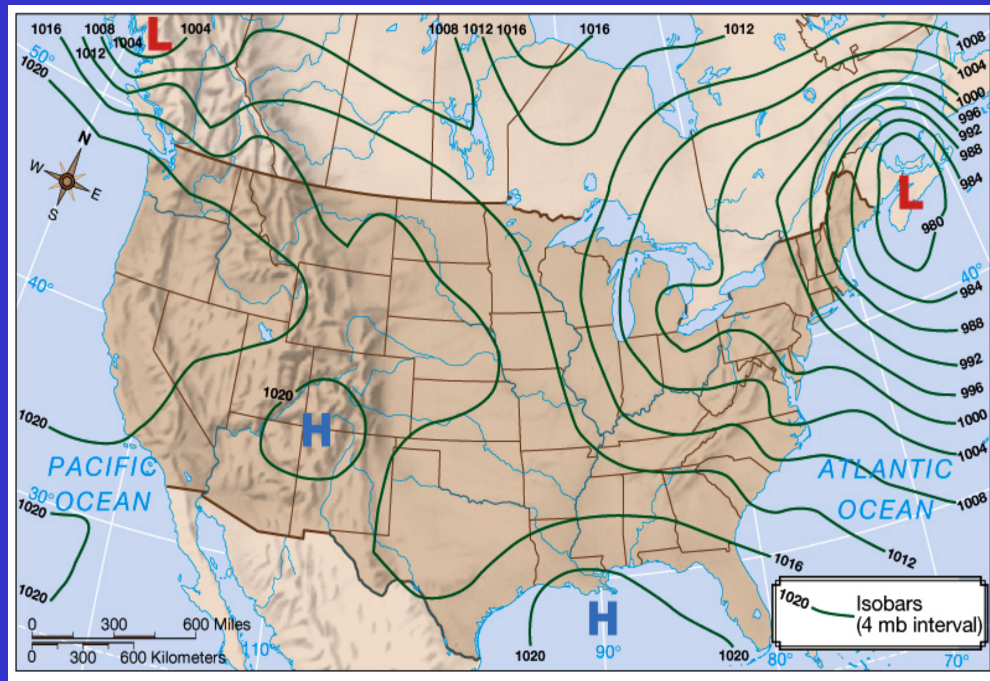
- This compressed geographical weather report is called a ***station model***.

Weather Map on 7/7/2005



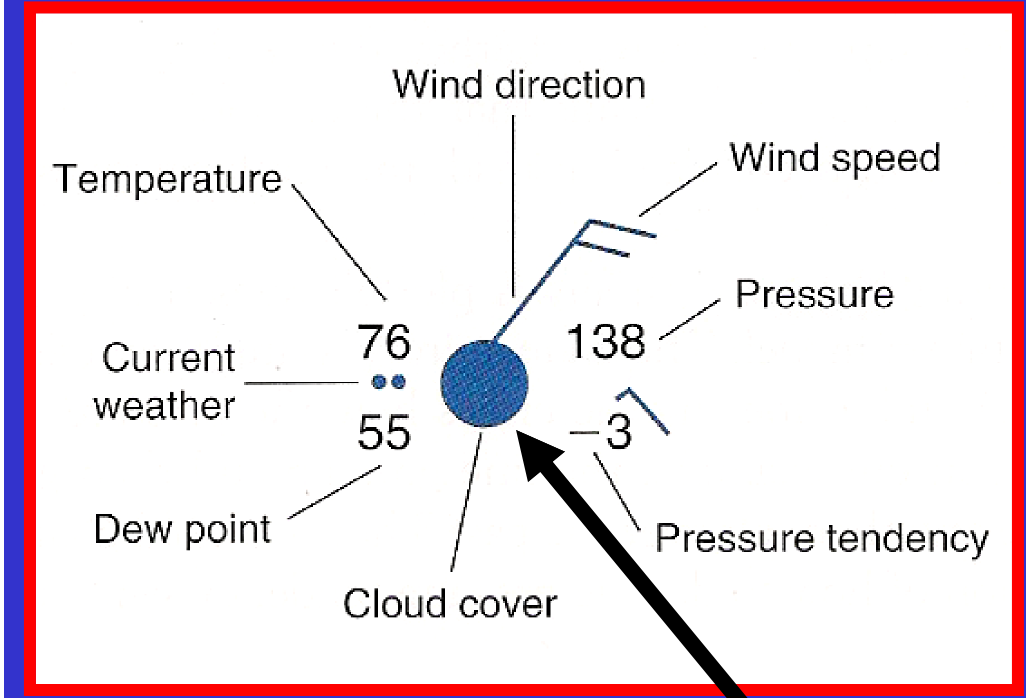
(from *Meteorology: Understanding the Atmosphere*)

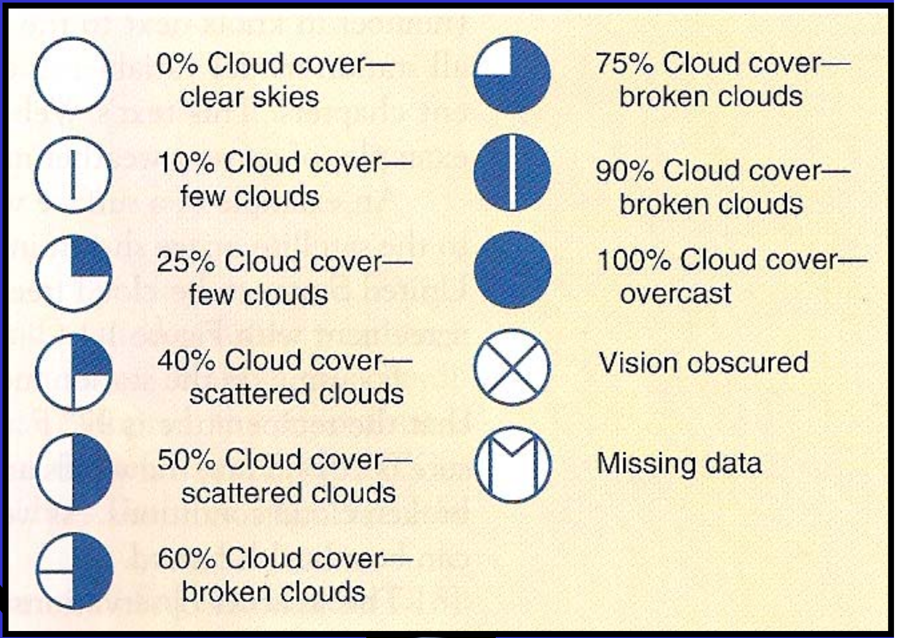
Isobar



- It is useful to examine horizontal pressure differences across space.
- Pressure maps depict ***isobars***, lines of equal pressure.
- Through analysis of ***isobaric charts***, pressure gradients are apparent.
- Steep (weak) pressure gradients are indicated by closely (widely) spaced isobars.

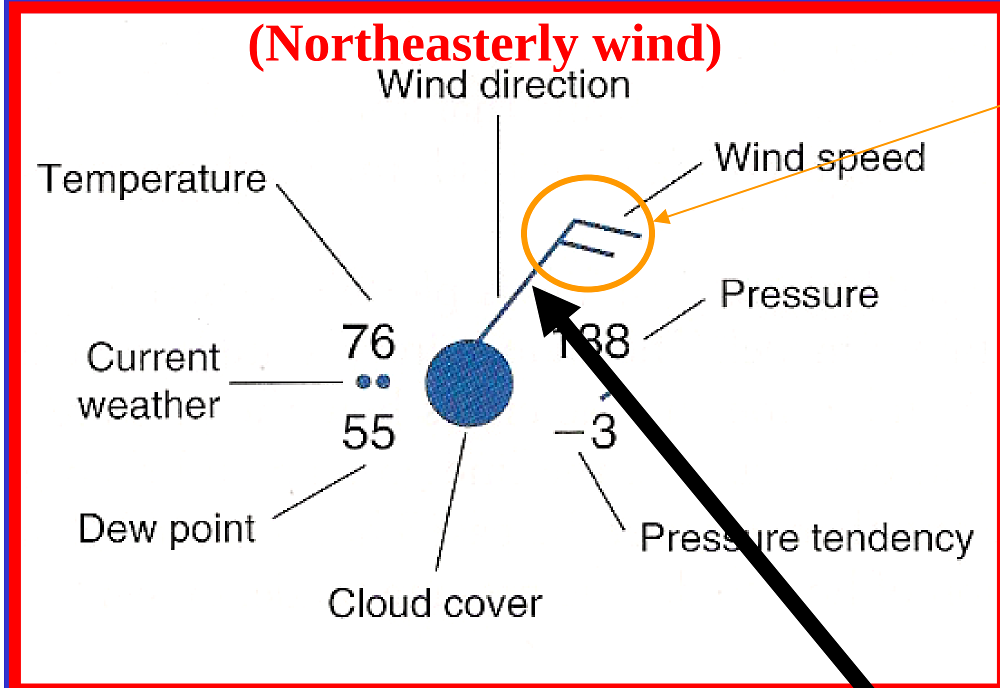
The Station Model: Cloudiness



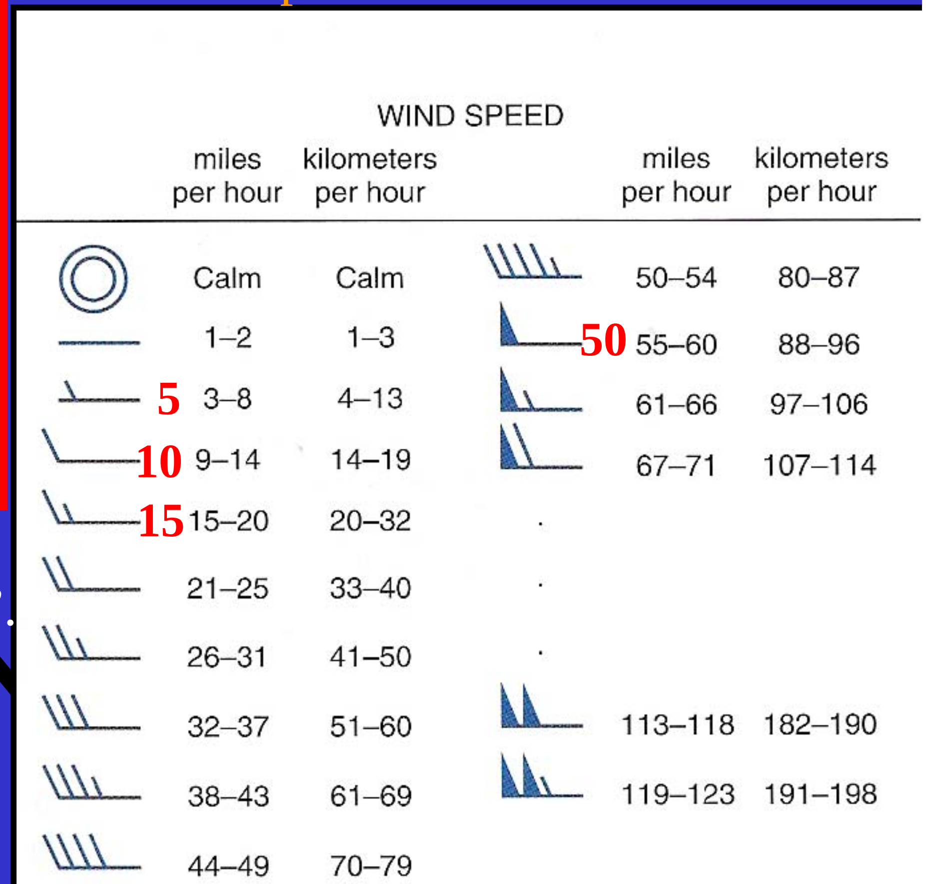


(from *Meteorology: Understanding the Atmosphere*)

The Station Model: Wind



Wind speed is indicated to the right (left) side of the coming wind vector in the Northern (Southern) Hemisphere

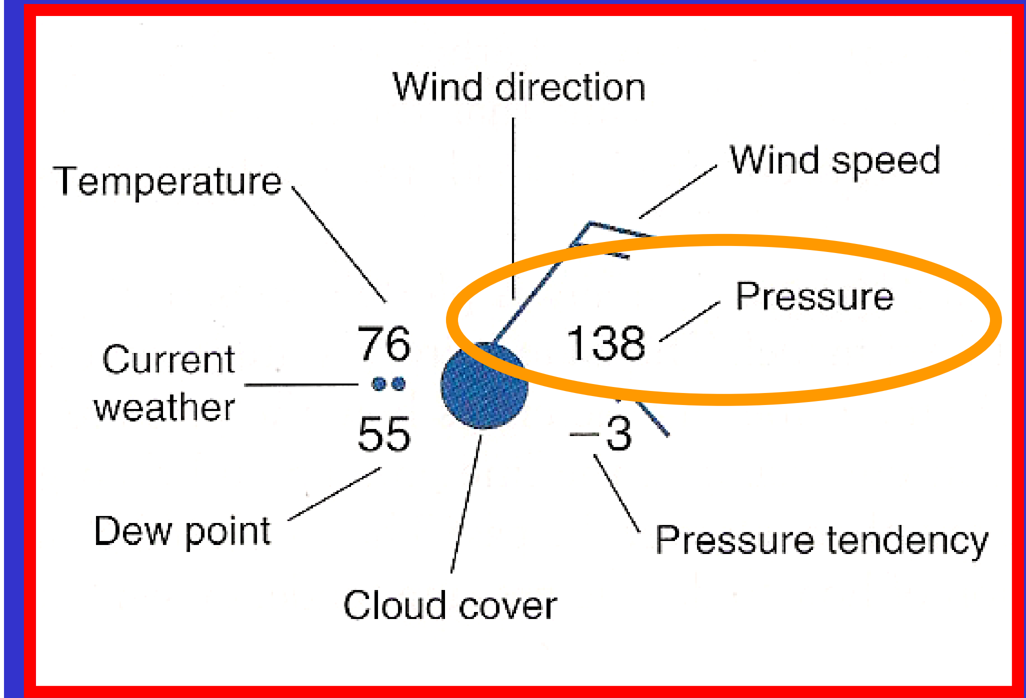


WIND SPEED

miles per hour	kilometers per hour	miles per hour	kilometers per hour
Calm	Calm	50–54	80–87
1–2	1–3	50 55–60	88–96
5 3–8	4–13	61–66	97–106
10 9–14	14–19	67–71	107–114
15 15–20	20–32		
21–25	33–40		
26–31	41–50		
32–37	51–60	113–118	182–190
38–43	61–69	119–123	191–198
44–49	70–79		

- Wind speeds are indicated in units of "knot".
- 1 international knot
  = 1 nautical mile per hour (exactly),
  = 1.852 kilometres per hour (exactly),
  = 0.514 meters per second,
  = 1.15077945 miles per hour (approximately)

The Station Model: Pressure

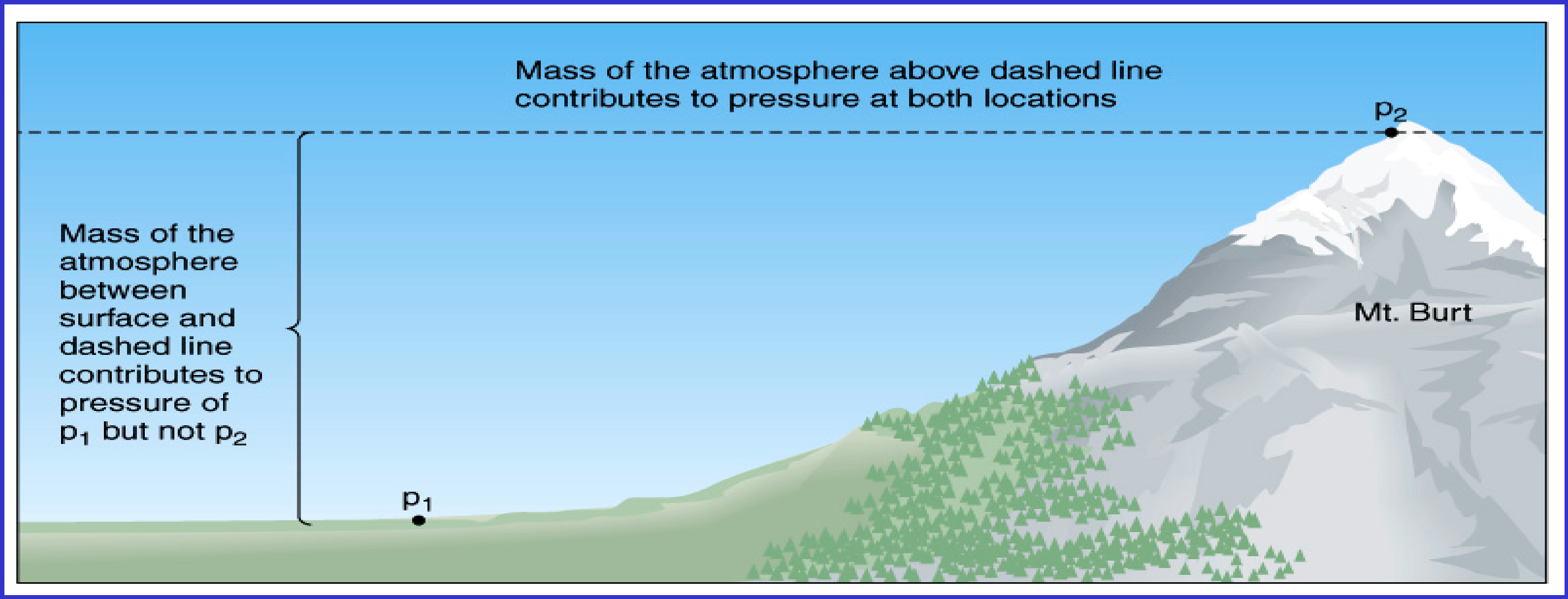


- The pressure value shown is the measured atmospheric pressure adjusted to sea level.
- The units used are "mb".
- To save space, the "thousand" and the "hundred" values, and the decimal point are dropped.

➔ So "**138**" means 10**13.8** mb

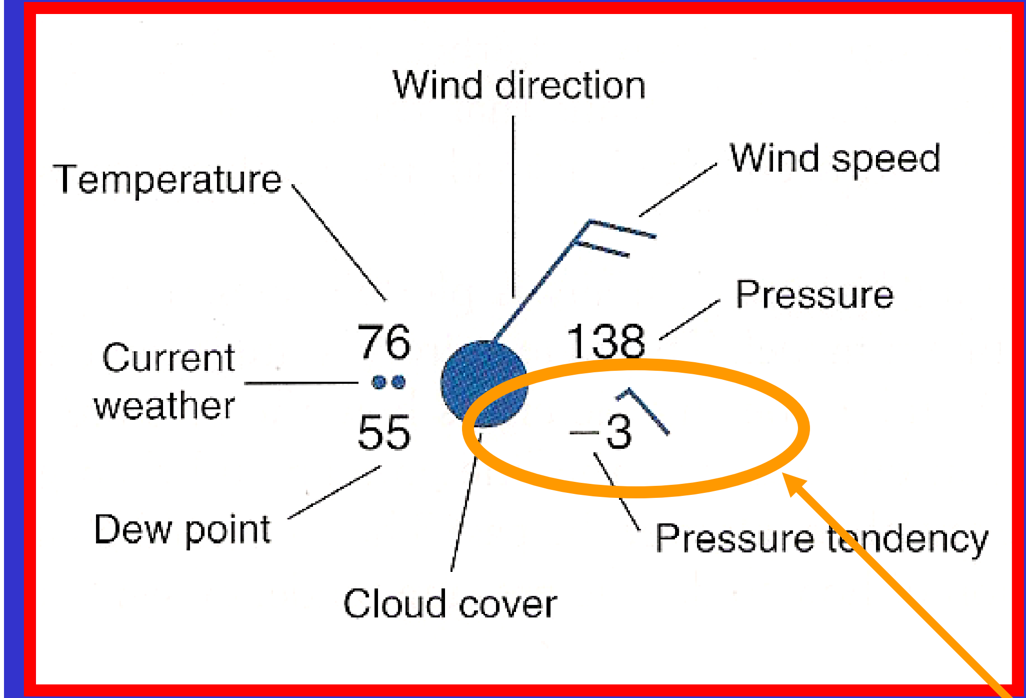
To decode the value of pressure on the station model, add a 9 if the first number is 7, 8, or 9; otherwise add a 10.

Pressure Correction for Elevation



- Pressure decreases with height.
- Recording actual pressures may be misleading as a result.
- All recording stations are reduced to sea level pressure equivalents to facilitate horizontal comparisons.
- Near the surface, the pressure decreases about 100mb by moving 1km higher in elevation.

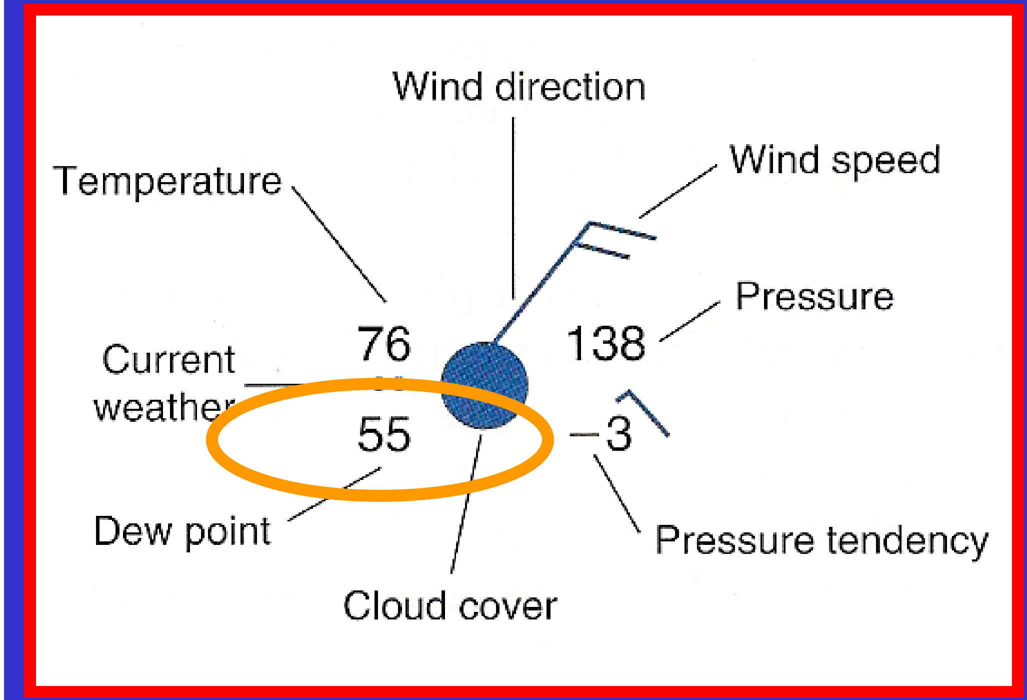
The Station Model: Pressure Tendency



- The change in surface pressure in the past three hours is plotted numerically and graphically on the lower right of the station model.

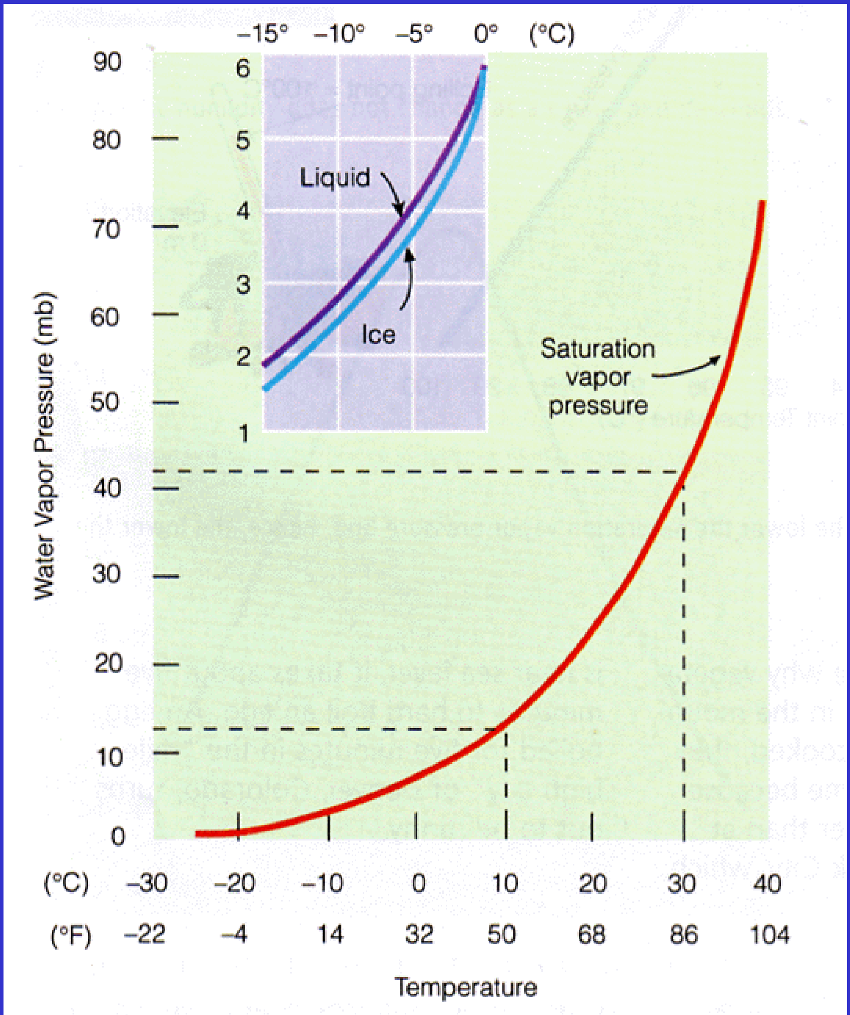
The pressure rose and then fell over the past three hours, a total change of ***0.3*** mb.

The Station Model: Dew Point Temperature



- Dew point temperature (in united of ºF) indicates the moisture content.
- A higher value indicates a larger amount of moisture.

Saturation Vapor Pressure



- Saturation vapor pressure describes how much water vapor is needed to make the air saturated at any given temperature.
- Saturation vapor pressure depends primarily on the air temperature in the following way:

$$\frac{de_s}{dT} = \frac{L}{T(\alpha_v - \alpha_l)}$$

The Clausius-Clapeyron Equation

→ $$e_s \cong 6.11 \cdot \exp\left\{\frac{L}{R_v}\left(\frac{1}{273} - \frac{1}{T}\right)\right\}$$

- Saturation pressure increases exponentially with air temperature.

L: latent heat of evaporation; α: specific volume of vapor and liquid

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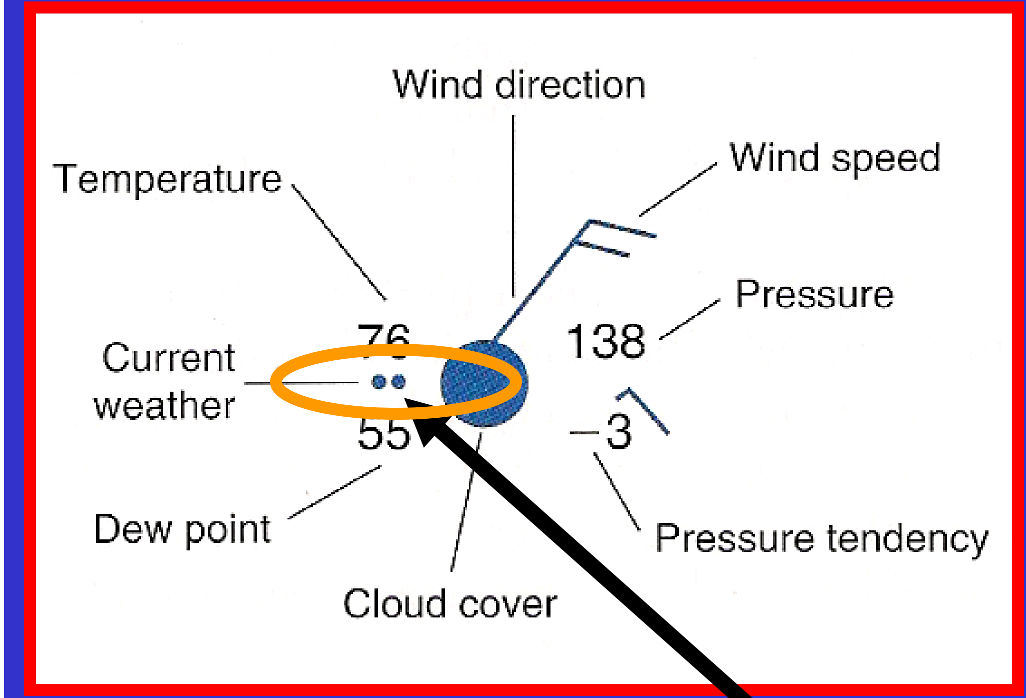
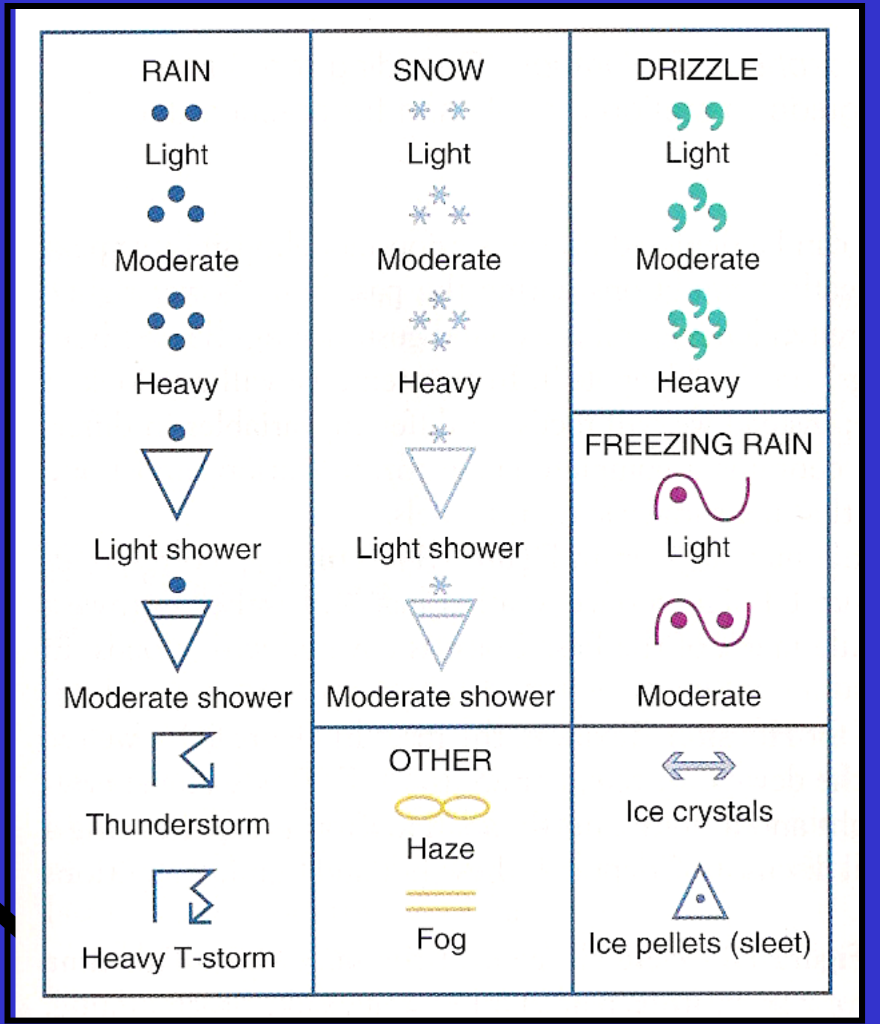
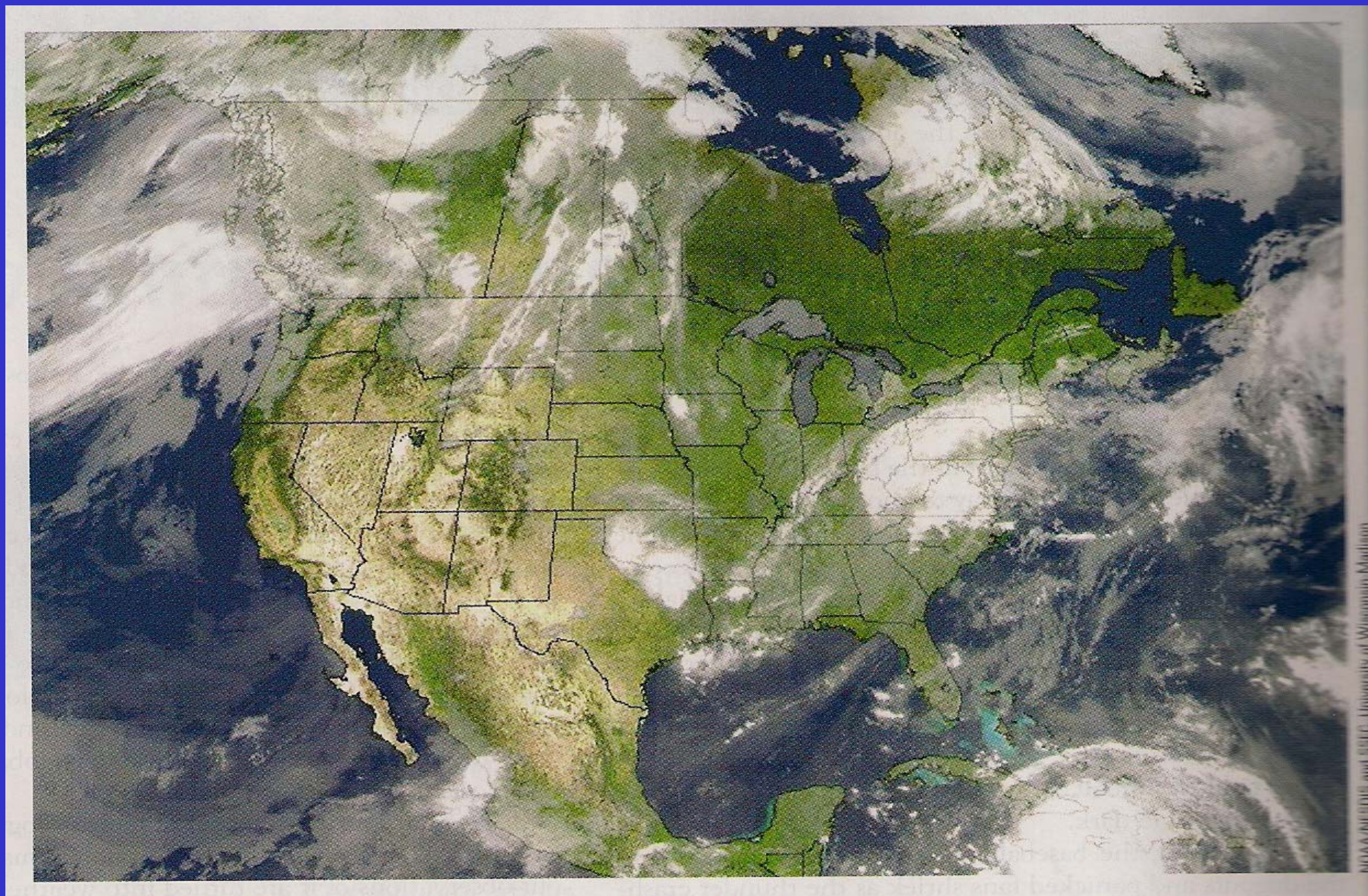
The Station Model: Current Weather





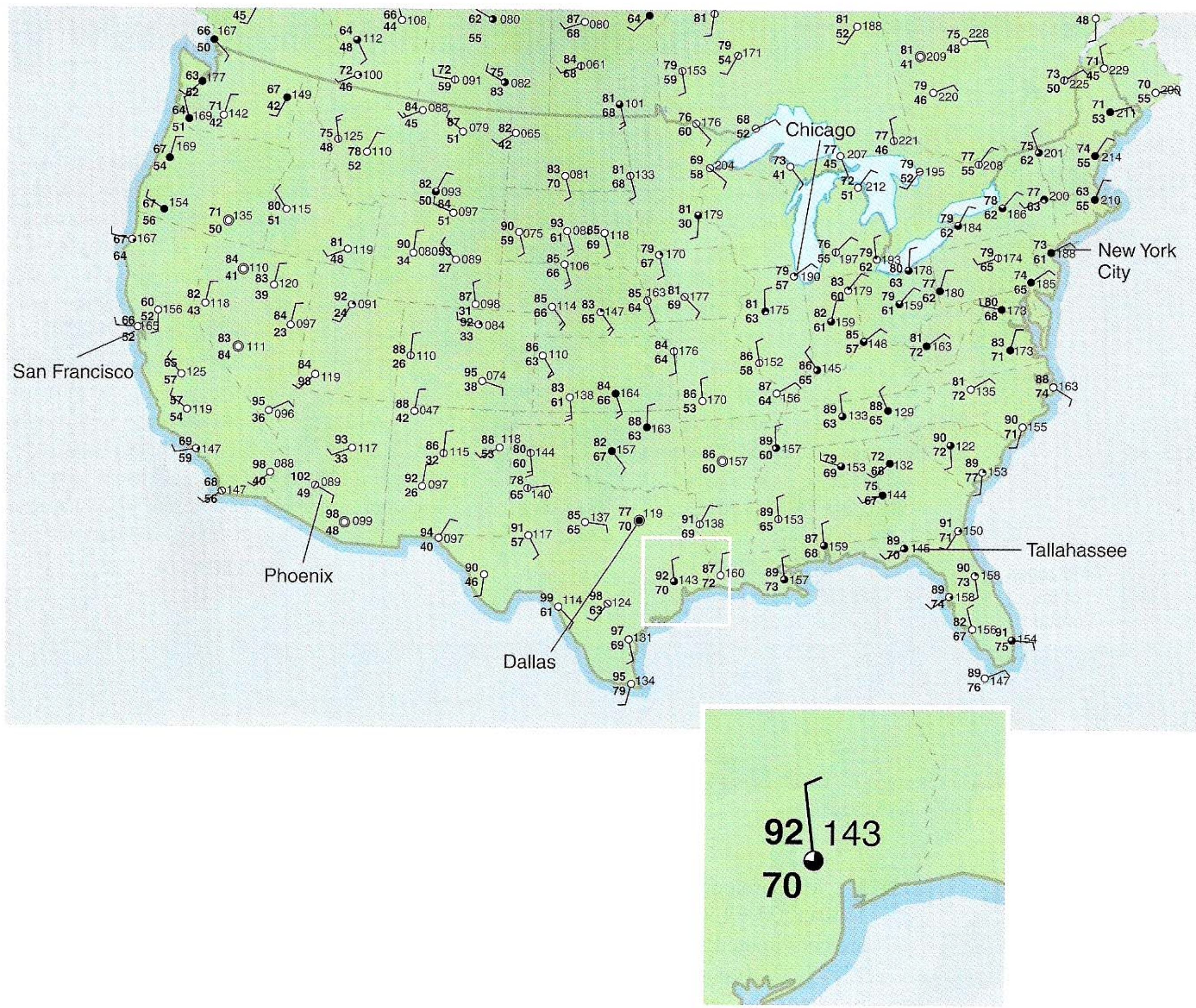
(from *Meteorology: Understanding the Atmosphere*)

Satellite Picture on 7/7/2005



(from *Meteorology: Understanding the Atmosphere*)

Weather Map on 7/7/2005



(from *Meteorology: Understanding the Atmosphere*)

Observation Time for Weather Map

❑ Weather organizations throughout the world use the **UTC** (Coordinated Universal Time) as the reference clock for weather observations.

❑ UTC is also denoted by the abbreviation **GMT** (Greenwich Meridian Time) or, often as the last two zeroes omitted, **Z** (Zulu).

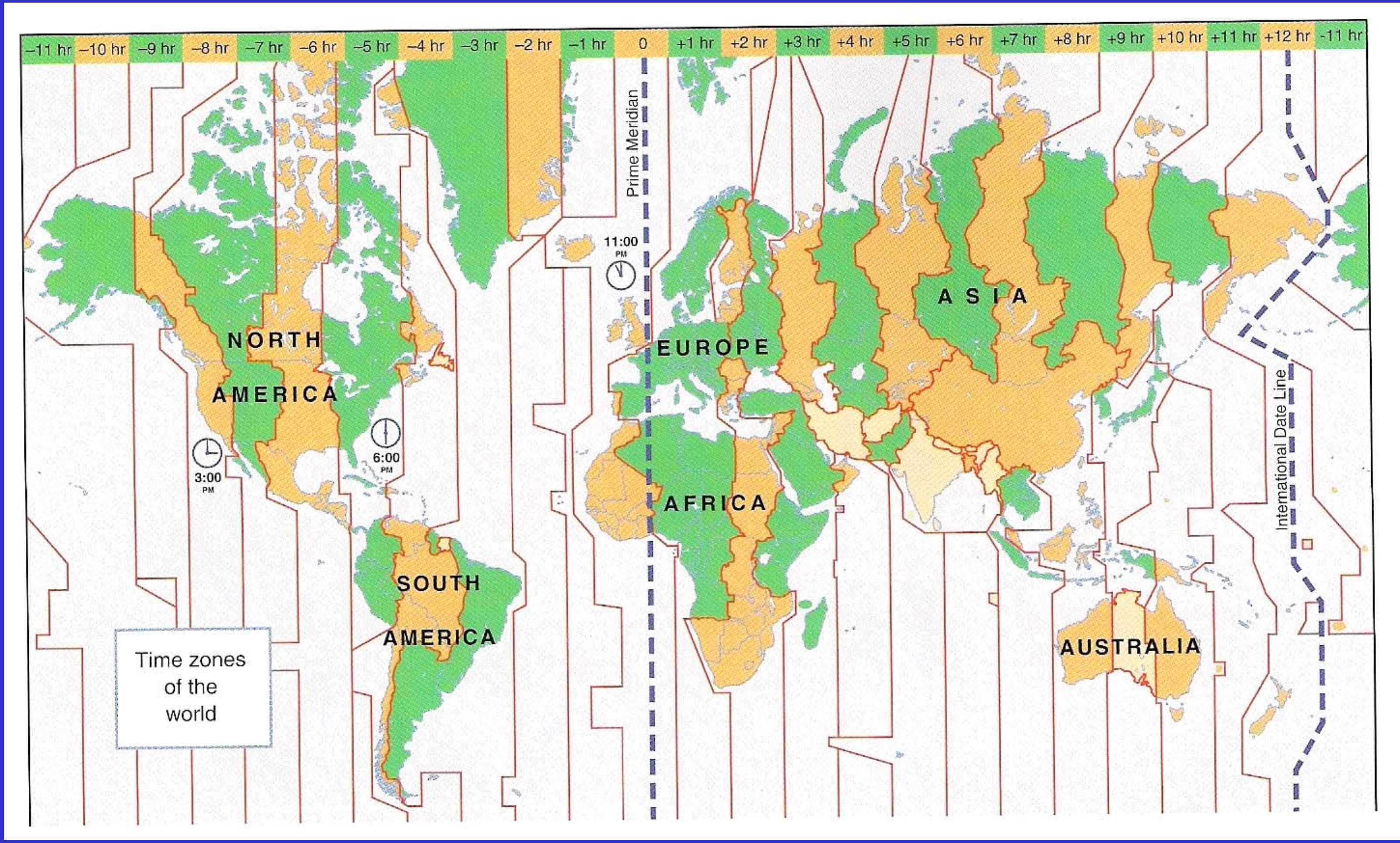
❑ Observations of the upper atmosphere are coordinately internationally to be made at 0000 UTC (midnight at Greenwich; 0Z; 0GMT) and 1200 UTC (noon at Greenwich; 12Z; 12GMT).

❑ Synoptic observations have traditionally been done every 6 hours or every 3 hours, depending on the station.

❑ Local time should be 1 hour earlier for every (360/24)=15° of longitude west of Greenwich.

➔Local time in Los Angeles (118 ° W) and the rest of the Pacific Standard Time is 8 (= 118°/15°) hours earlier than Greenwich.

Time Zone



(from *Meteorology: Understanding the Atmosphere*)

7/7/2005 7/8/2005 7/7/2005