

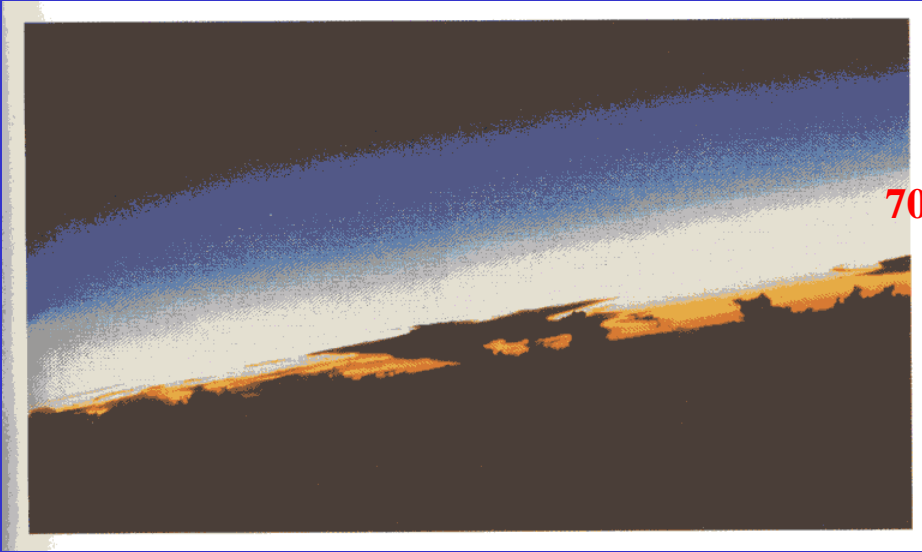
# Lecture 1: A Brief Survey of the Atmosphere

- Origins of the atmosphere
- Vertical structures of the atmosphere
- Weather maps



# 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.

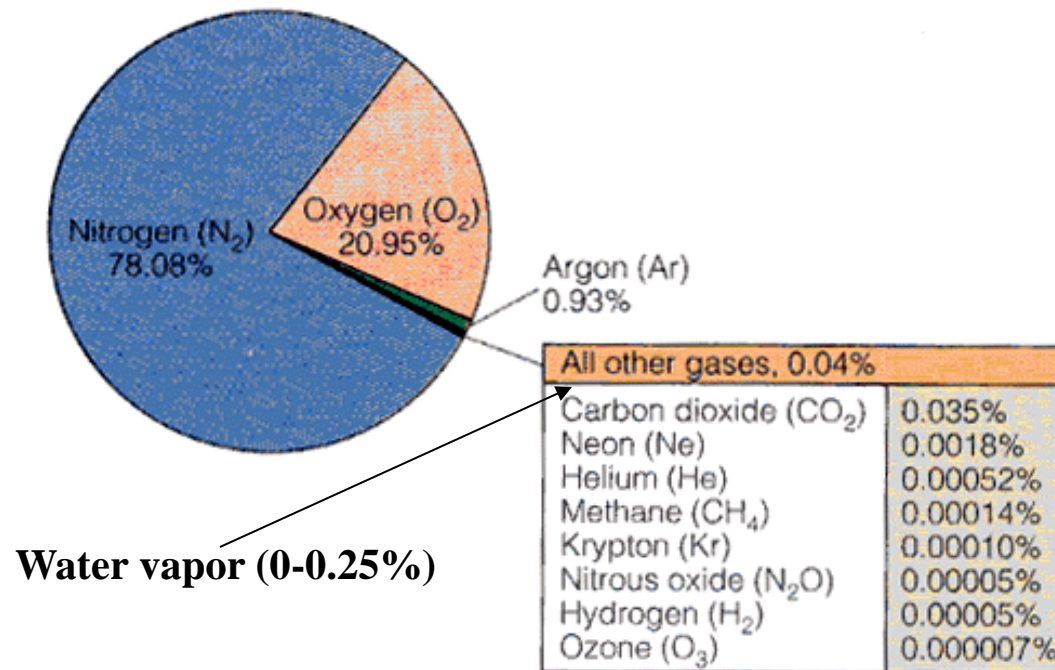
❑ Because of the shallowness of the atmosphere, its motions over large areas are primarily horizontal.

→ 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.)



# Composition of the Atmosphere (inside the DRY homosphere)



*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*)



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# 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<sub>4</sub>) and ammonia (NH<sub>3</sub>).
  - ➔ 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 water vapor (**H<sub>2</sub>O**), with some Nitrogen (**N<sub>2</sub>**) and Carbon dioxide (**CO<sub>2</sub>**), and trace amounts of other gases.



# What Happened to H<sub>2</sub>O?

**Table 1.2**  
An inventory of the hydrosphere<sup>a,b</sup>

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

<sup>a</sup> Total mass =  $1.36 \times 10^{21}$  kg =  $2.66 \times 10^6$  kg m<sup>-2</sup> over surface of earth.

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

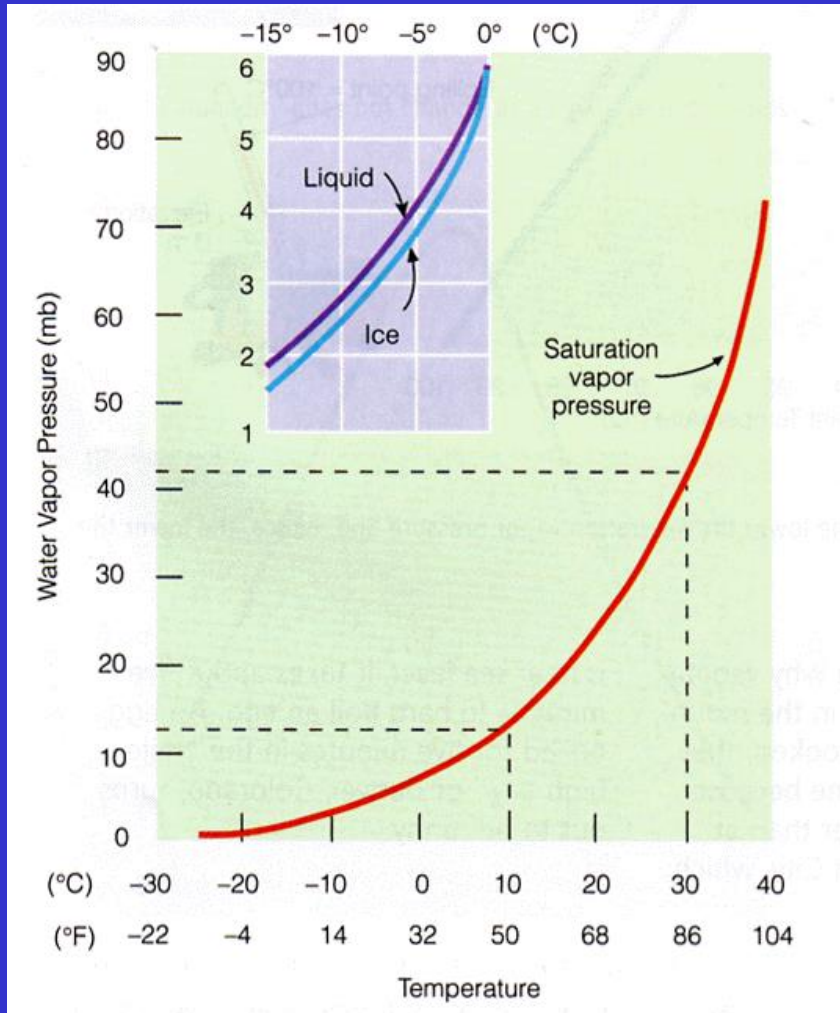
(from *Atmospheric Sciences: An Introductory Survey*)

□ 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**

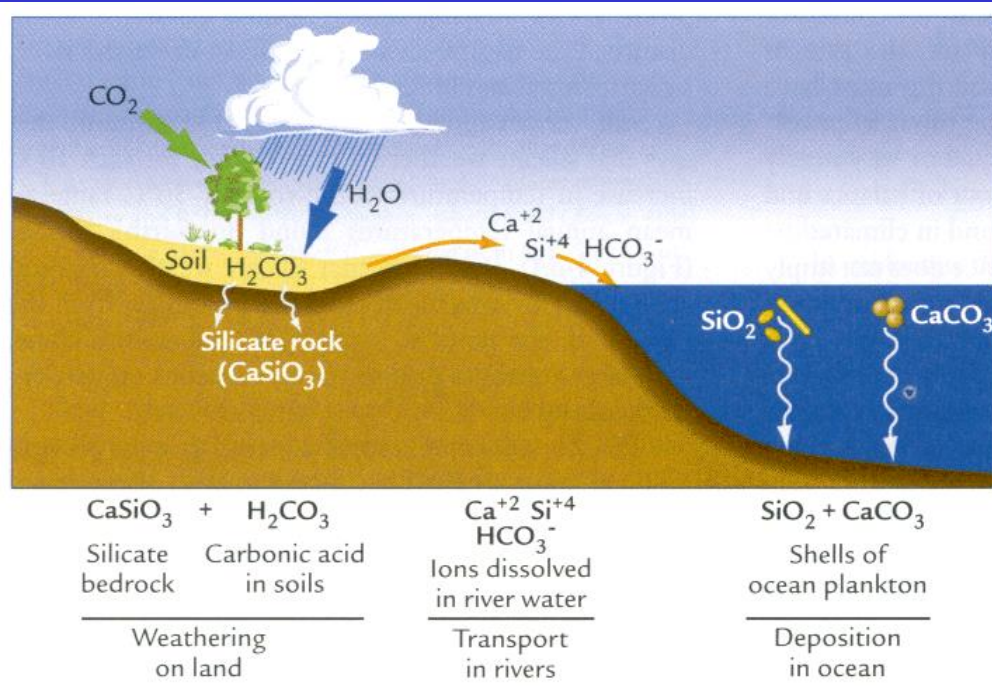
$$\rightarrow e_s \cong 6.11 \cdot \exp \left\{ \frac{L}{R_v} \left( \frac{1}{273} - \frac{1}{T} \right) \right\}$$

- Saturation pressure increases exponentially with air temperature.

L: latent heat of evaporation;  $\alpha$ : specific volume of vapor and liquid



# What happened to CO<sub>2</sub>?



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

- Chemical weathering is the primary process to remove CO<sub>2</sub> from the atmosphere.
- ➔ In this process, CO<sub>2</sub> dissolves in rainwater producing weak carbonic acid that reacts chemically with bedrock and produces carbonate compounds.
- This biogeochemical process reduced CO<sub>2</sub> in the atmosphere and locked carbon in rocks and mineral.



# Carbon Inventory

**Table 1.3**

Inventory of carbon near the earth's surface<sup>a</sup>

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Biosphere	marine	1
	nonmarine	1
Atmosphere (in CO <sub>2</sub> )		70
Ocean (in dissolved CO <sub>2</sub> )		4000
Fossil fuels		800
Shales		800,000
Carbonate rocks		2,000,000

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<sup>a</sup> 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<sub>2</sub>?

□ Nitrogen (N<sub>2</sub>):

(1) is inert chemically,

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

(3) is not very soluble in water.

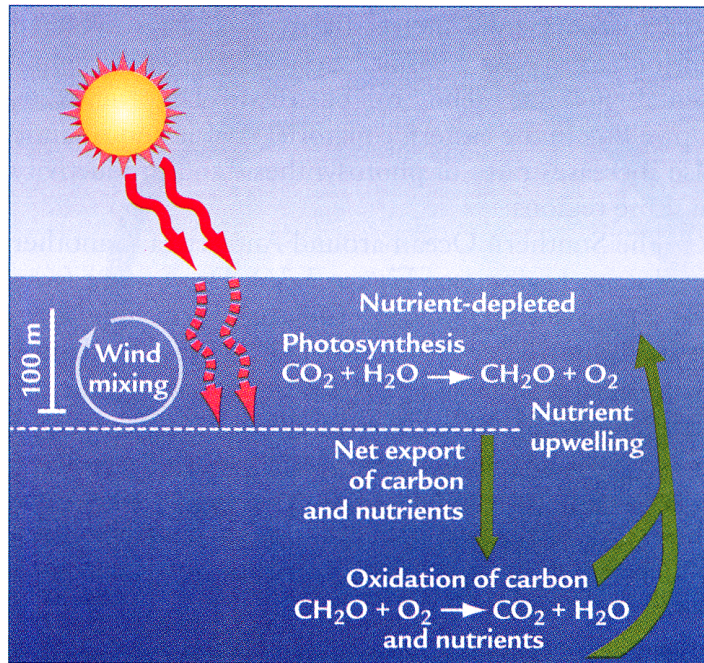
→ The amount of nitrogen being cycled out of the atmosphere was limited.

→ Nitrogen became the most abundant gas in the atmosphere.



# Where Did O<sub>2</sub> Come from?

- ❑ 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 CO<sub>2</sub>, oxygen became the second most abundant atmospheric gas after nitrogen.



**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*)



# 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 <sub>2</sub>	78.08	28.01
Oxygen	O <sub>2</sub>	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 <sub>2</sub>	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 <sub>2</sub> O	0.25	18.01
Carbon Dioxide	CO <sub>2</sub>	0.037	44.01
Ozone	O <sub>3</sub>	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.

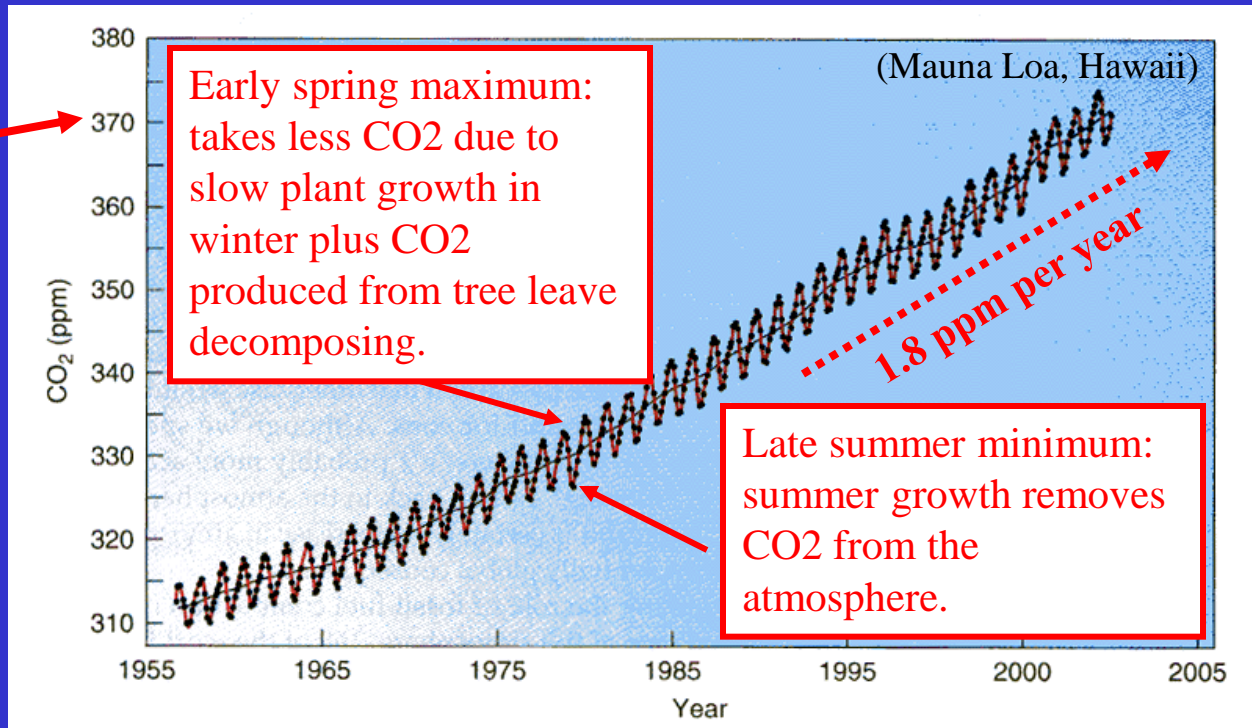


# Water Vapor (H<sub>2</sub>O)

- ❑ 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 (CO<sub>2</sub>)



(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.
- ❑ CO<sub>2</sub> is an important greenhouse gas.



# Level of Carbon Dioxide Now

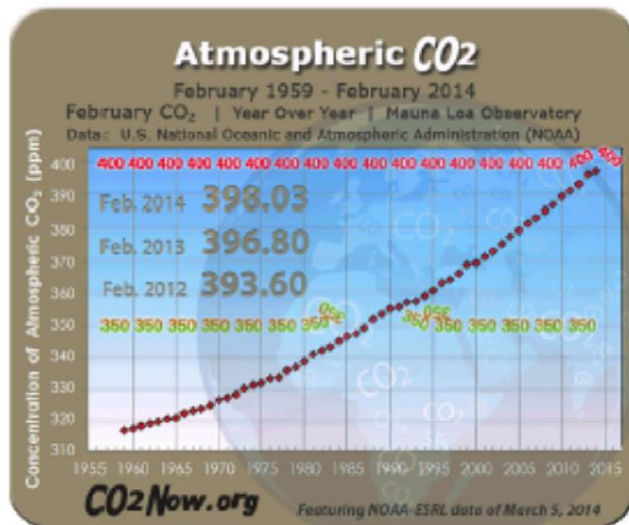
398.03 ppm

Atmospheric CO<sub>2</sub> for February 2014

Preliminary monthly average as of March 5, 2014

(Mauna Loa Observatory: NOAA-ESRL)

NOTE: On May 10, 2013, NOAA's *Scripps* first reported daily averages that temporarily reached 400 ppm.

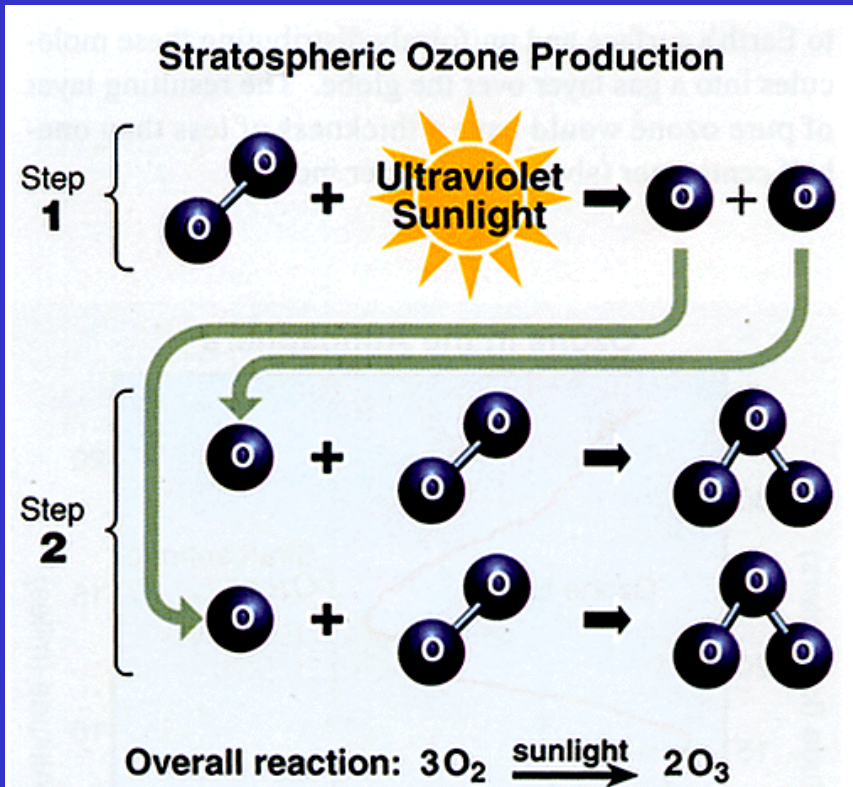


*On March 12, 2014, NOAA MLO recorded the first daily average above 400 ppm since Spring 2013.*



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# Formation of Ozone (O<sub>3</sub>)



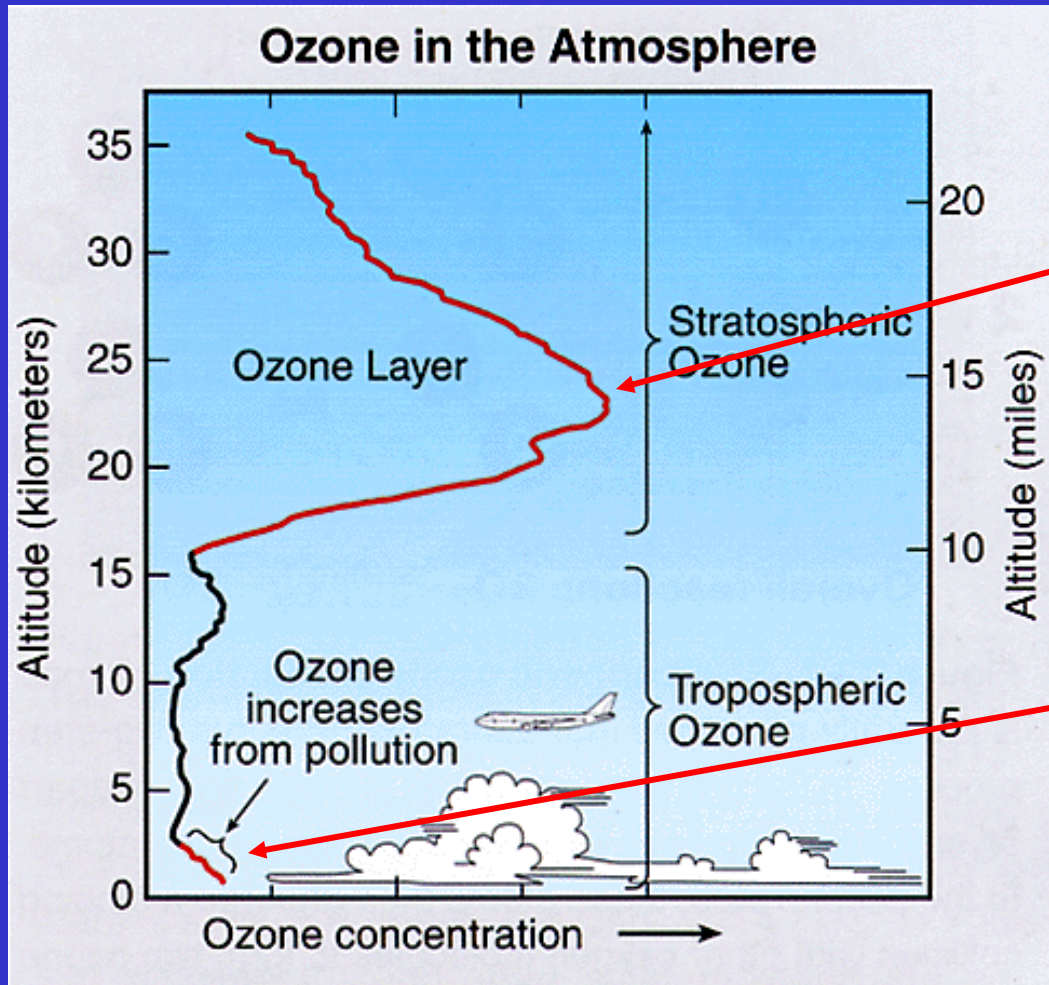
**Figure Q2-1. Stratospheric ozone production.** Ozone is naturally produced in the stratosphere in a two-step process. In the first step, ultraviolet sunlight breaks apart an oxygen molecule to form two separate oxygen atoms. In the second step, these atoms then undergo a binding collision with other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

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





# Ozone (O<sub>3</sub>)



“good” ozone  
~ 15ppm

“bad” ozone  
~ 0.15ppm

(from WMO Report 2003)

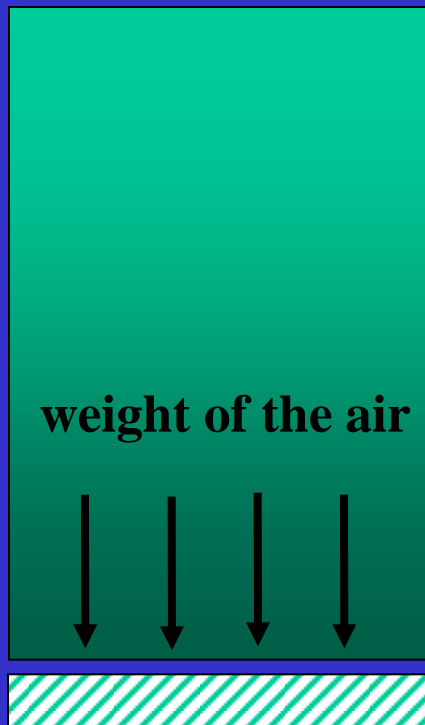


# Other Atmospheric Constituents

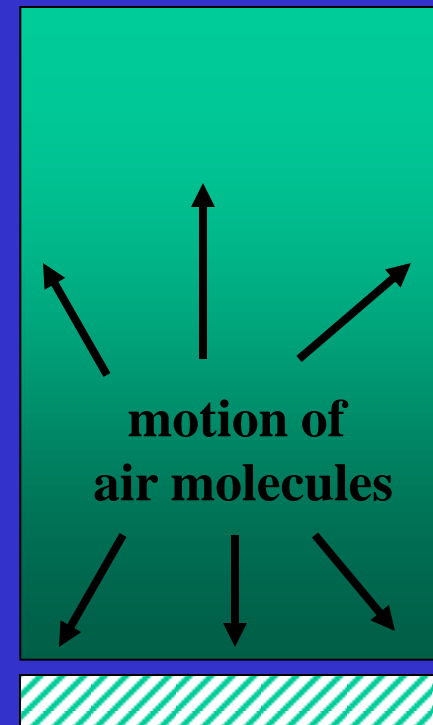
- ❑ **Aerosols**: small solid particles and liquid droplets in the air. They serve as condensation nuclei for cloud formation.
- ❑ **Air Pollutant**: a gas or aerosol produce by human activity whose concentration threatens living organisms or the environment.



# Air Pressure Can Be Explained As:



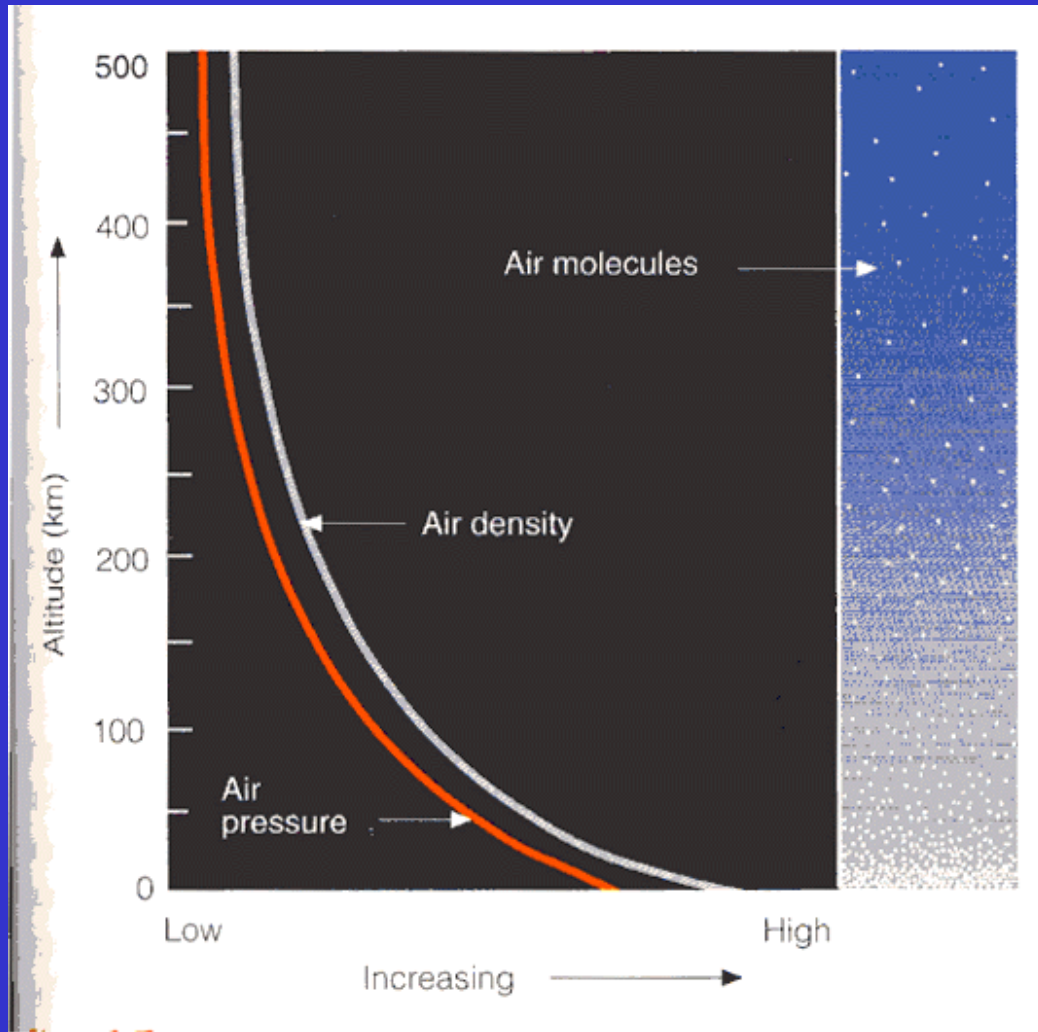
The weight of air above a surface  
(due to Earth's gravity)



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



# Air Pressure and Air Density

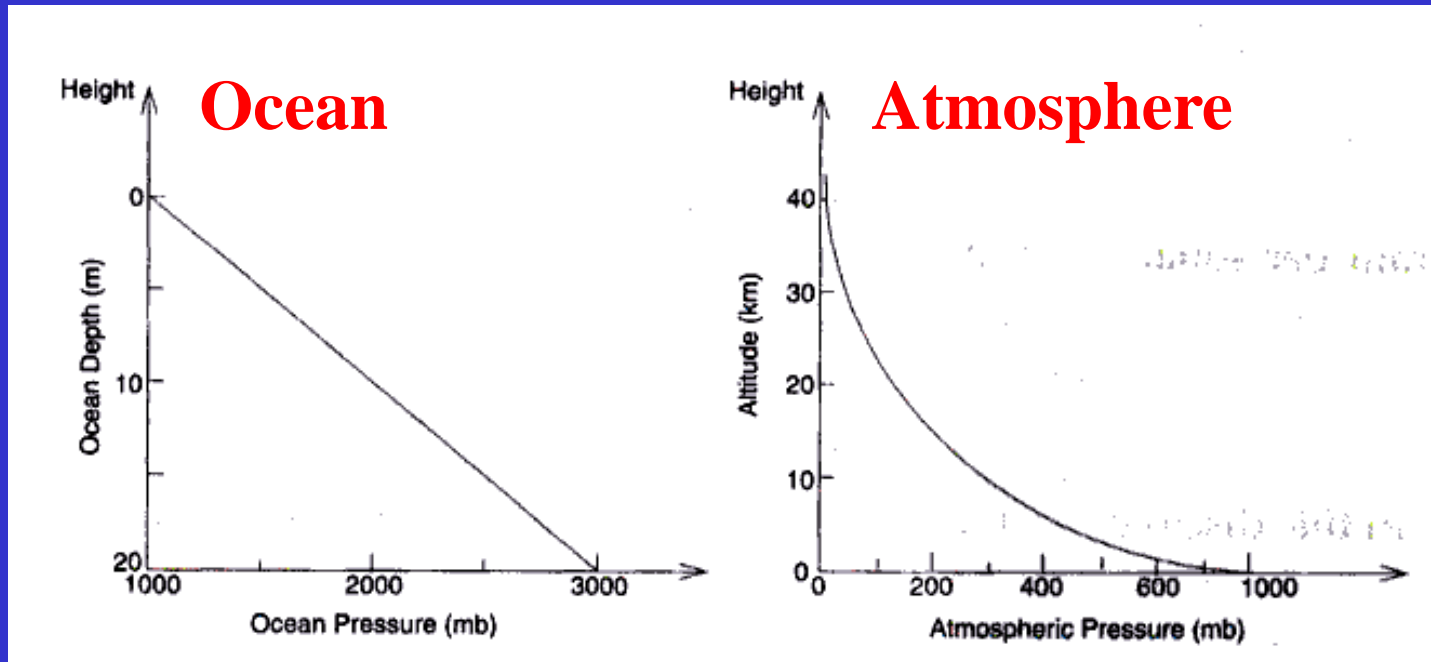


- $\text{Weight} = \text{mass} \times \text{gravity}$
- $\text{Density} = \text{mass} / \text{volume}$
- $\text{Pressure} = \text{force} / \text{area}$   
 $= \text{weight} / \text{area}$

(from *Meteorology Today*)



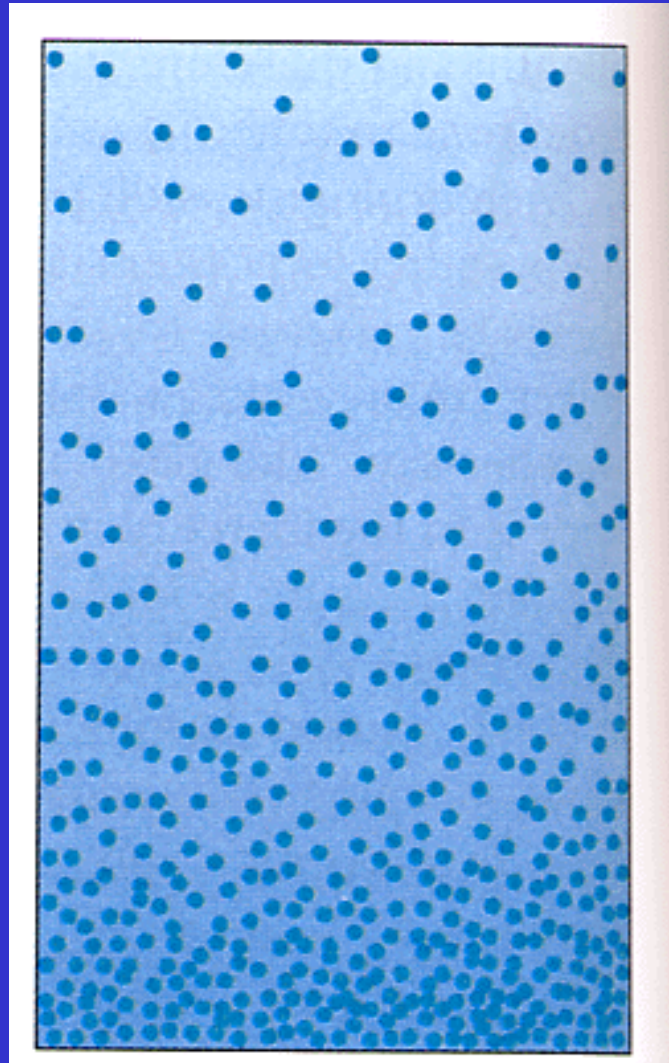
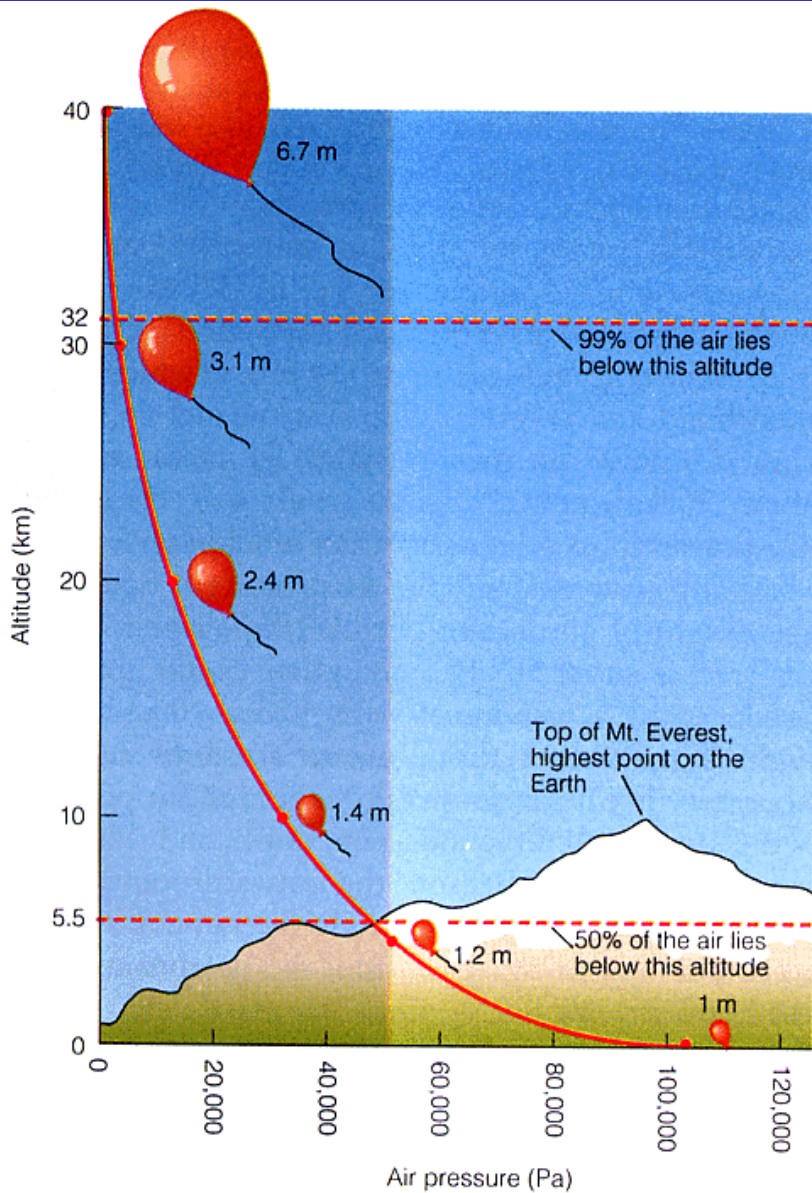
# How Soon Pressure Drops With Height?



(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.

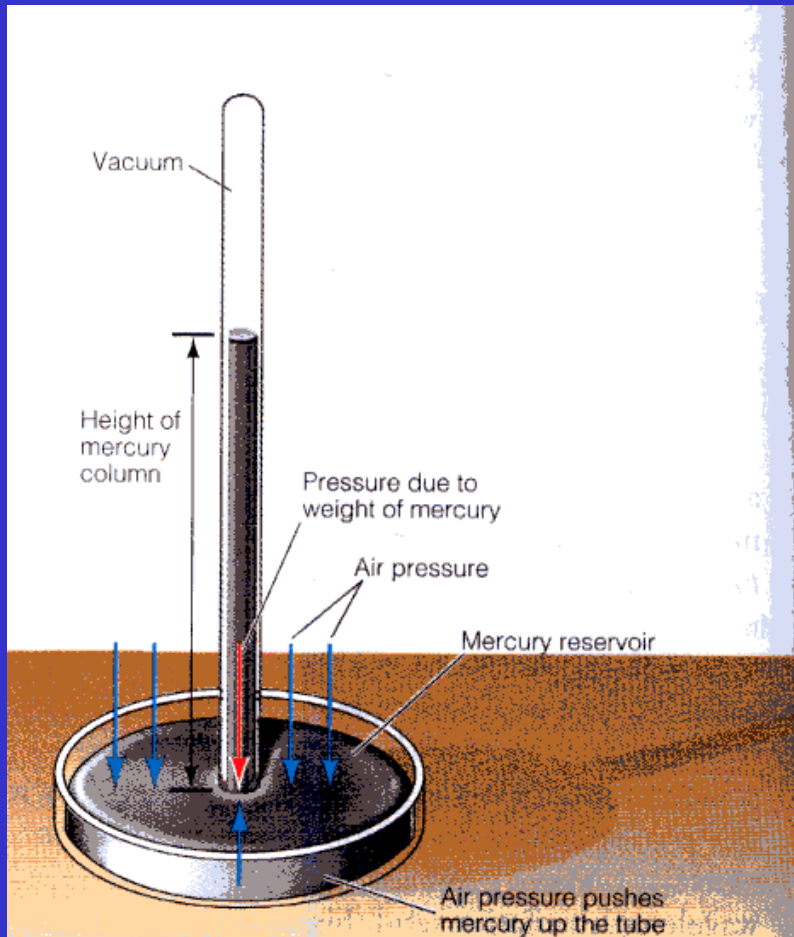




(from *The Atmosphere*)



# One Atmospheric Pressure



- 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.

(from *The Blue Planet*)



# 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*

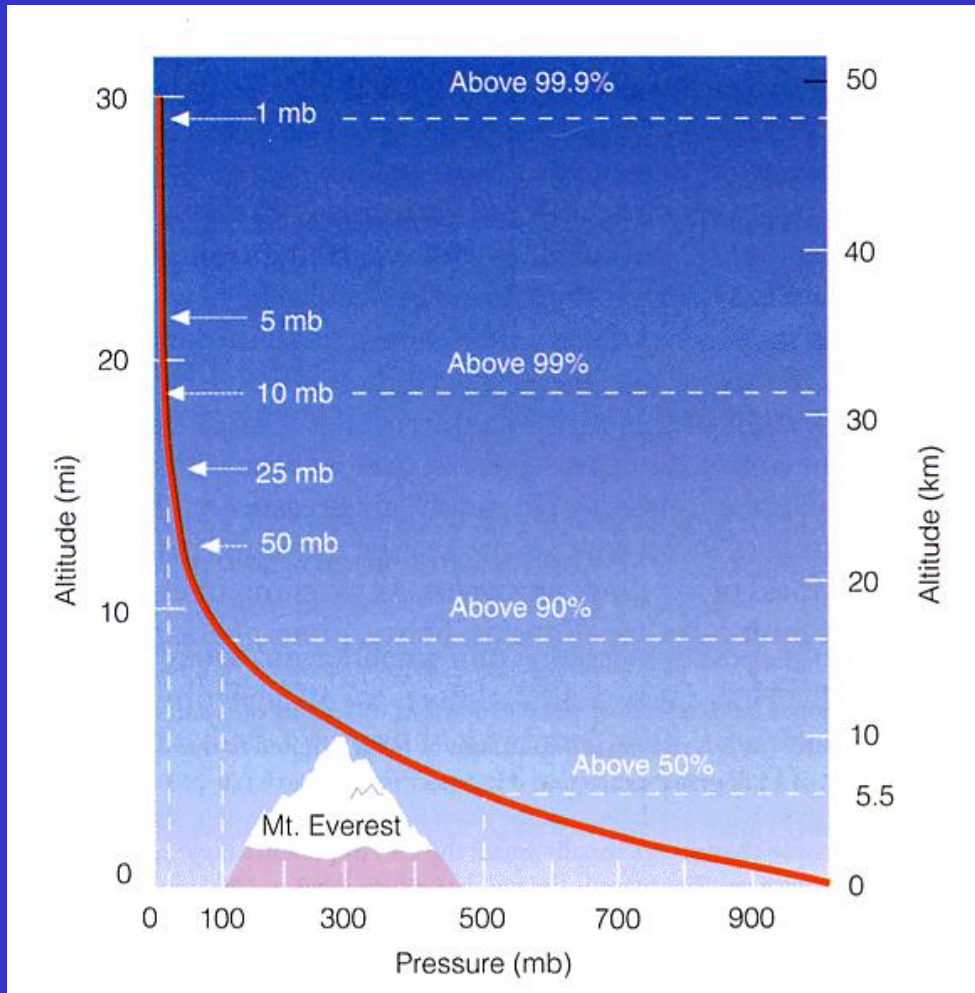
*= 1000 mb*

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





# Air Mass and Pressure



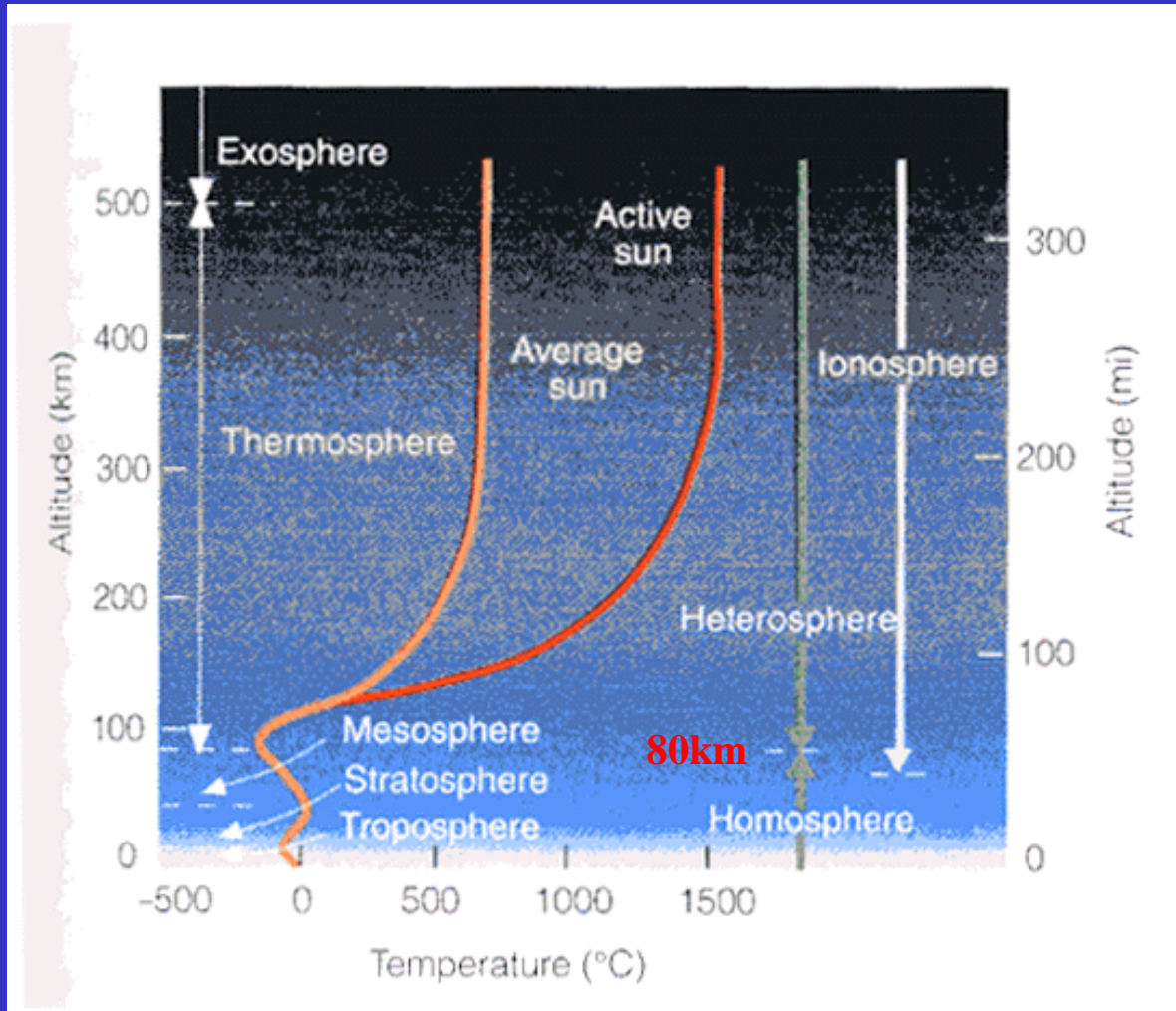
□ Atmospheric pressure tells you how much atmospheric mass is above a particular altitude.

□ Atmospheric pressure decreases by about 100 mb for every 1 km increase in elevation.

(from *Meteorology Today*)



# Vertical Structure of the Atmosphere



composition

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temperature

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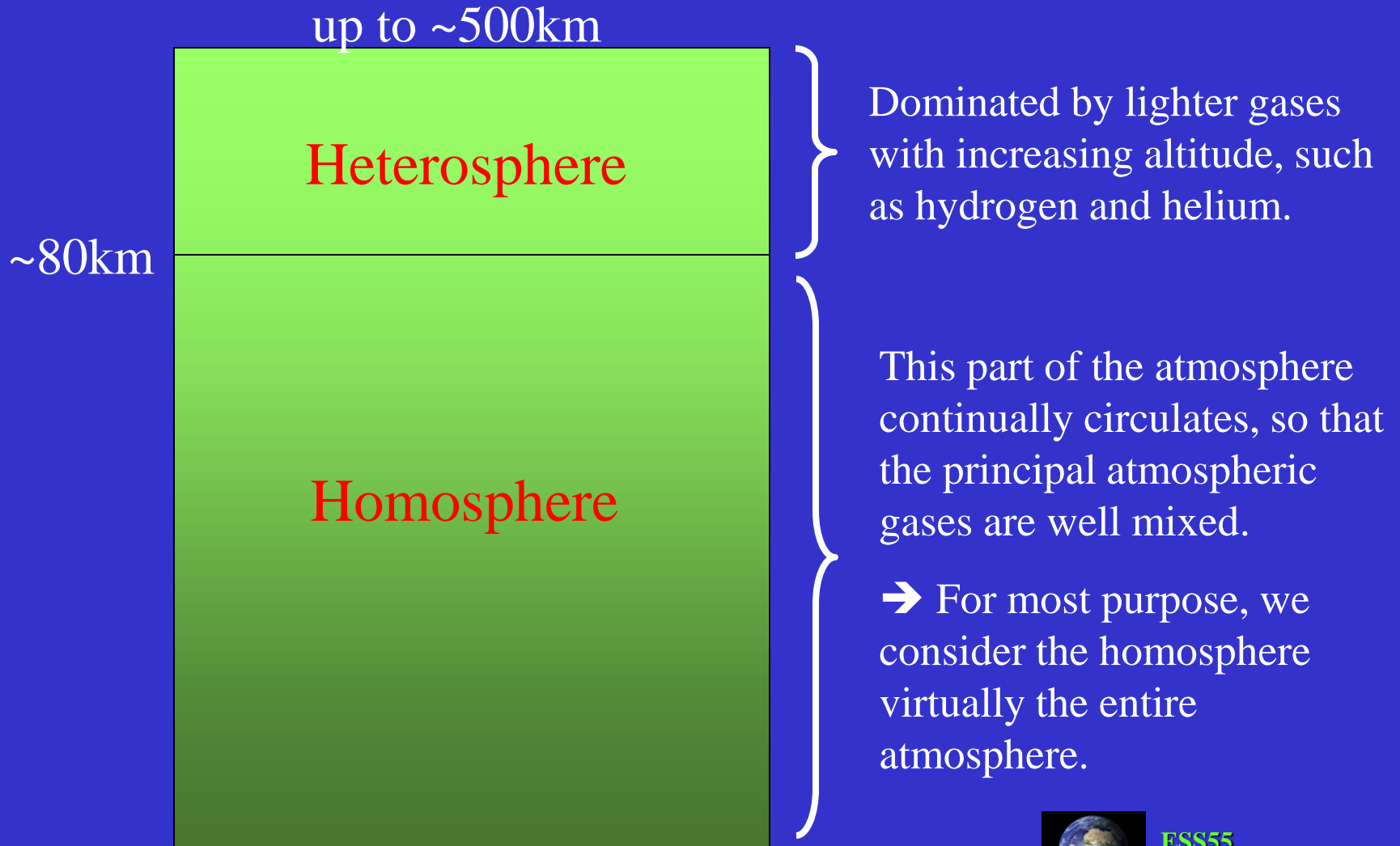
electricity

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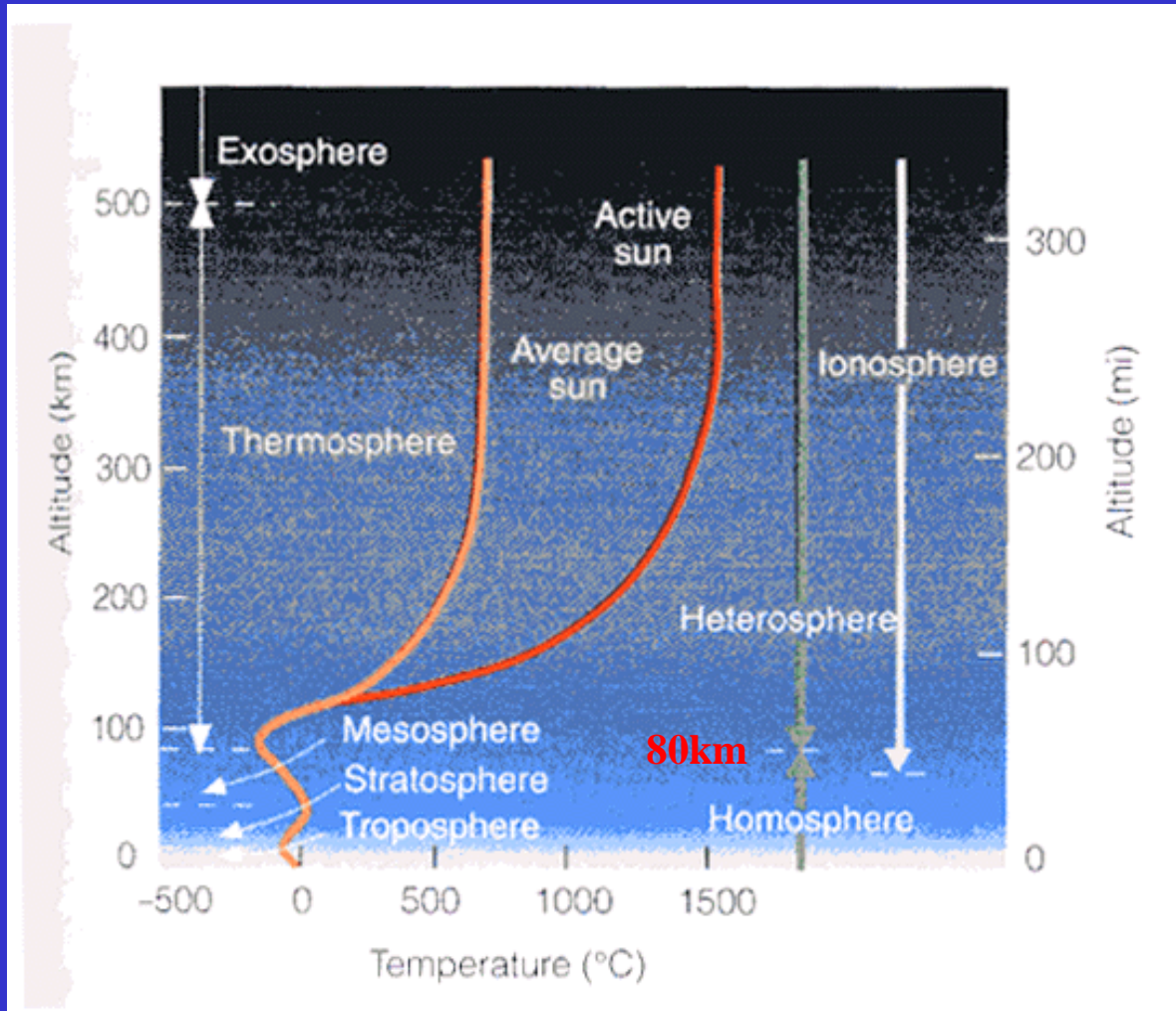
(from *Meteorology Today*)



# Vertical Structure of Composition



# Vertical Structure of the Atmosphere



composition

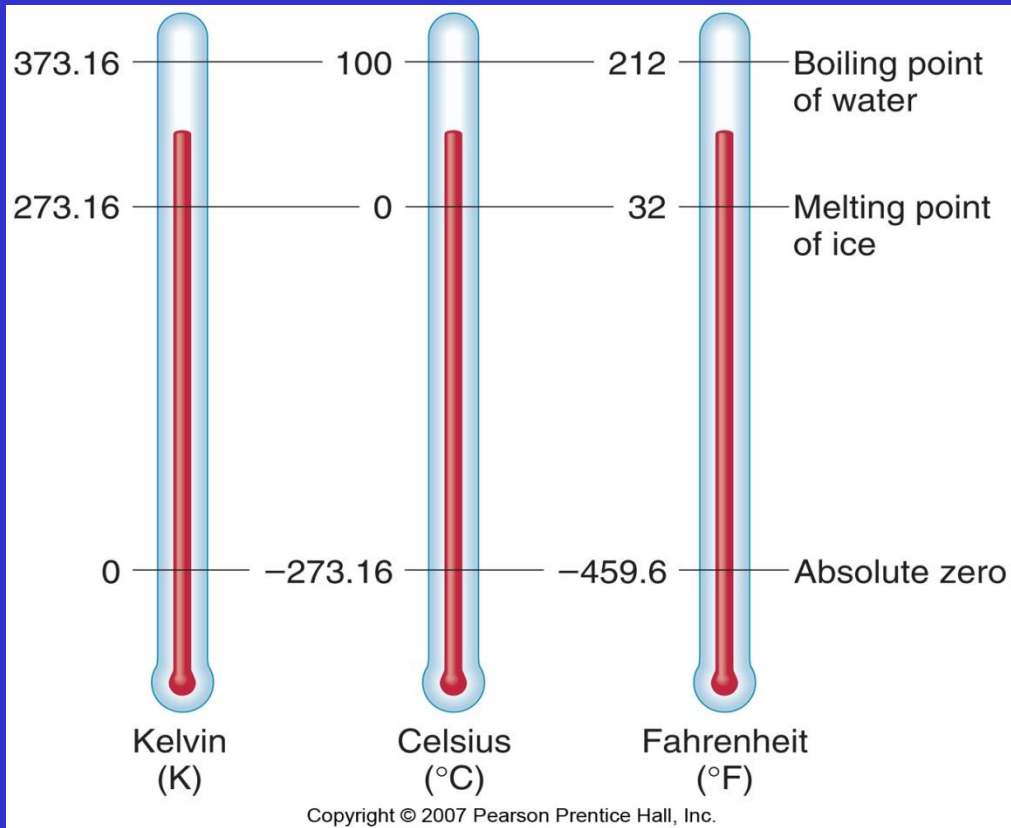
temperature

electricity

(from *Meteorology Today*)



# Units of Air Temperature



□ Fahrenheit (°F)

□ Celsius (°C)

→  $^{\circ}\text{C} = (^{\circ}\text{F} - 32) / 1.8$

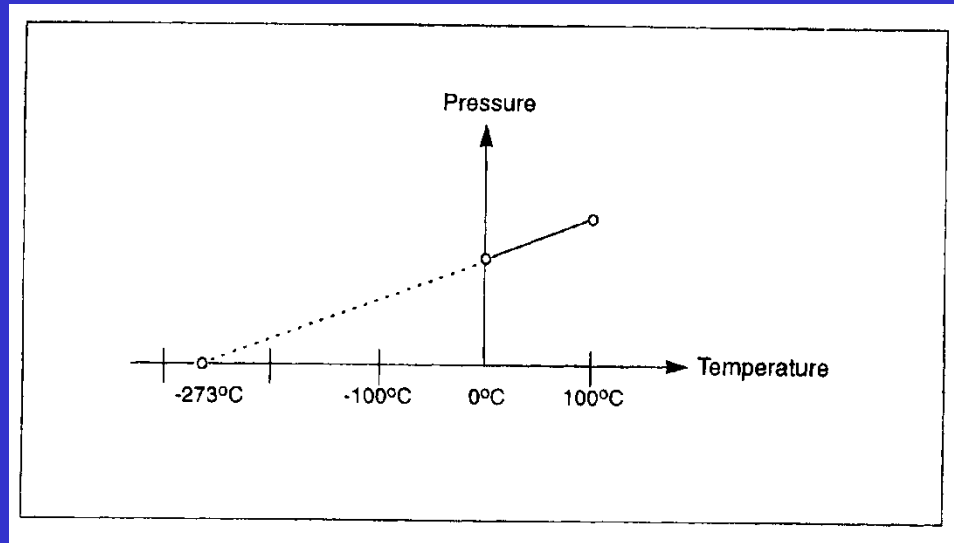
□ Kelvin (K): a SI unit

→  $\text{K} = ^{\circ}\text{C} + 273$

**$1 \text{ K} = 1 ^{\circ}\text{C} > 1 ^{\circ}\text{F}$**



# “Absolute Zero” Temperature



(from *Is The Temperature Rising?*)

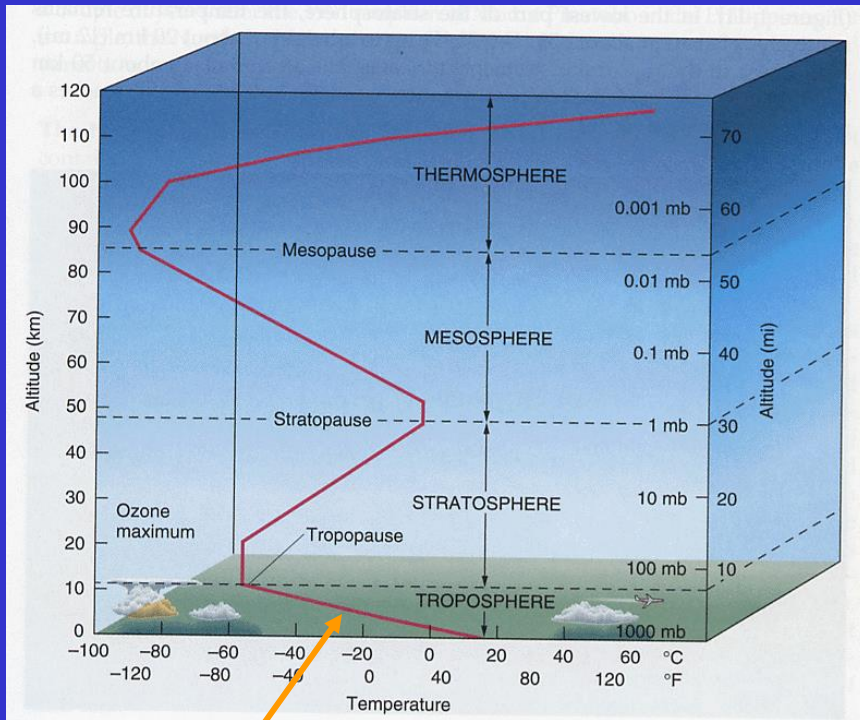
- ❑ The absolute zero temperature is the temperature that the molecules do not move at all.
- ❑ This temperature occurs at  $-273^{\circ}\text{C}$ .
- ❑ The Kelvin Scale (K) is a new temperature scale that has its “zero” temperature at this absolute temperature:

$$\text{K} = ^{\circ}\text{C} + 273$$



# 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**

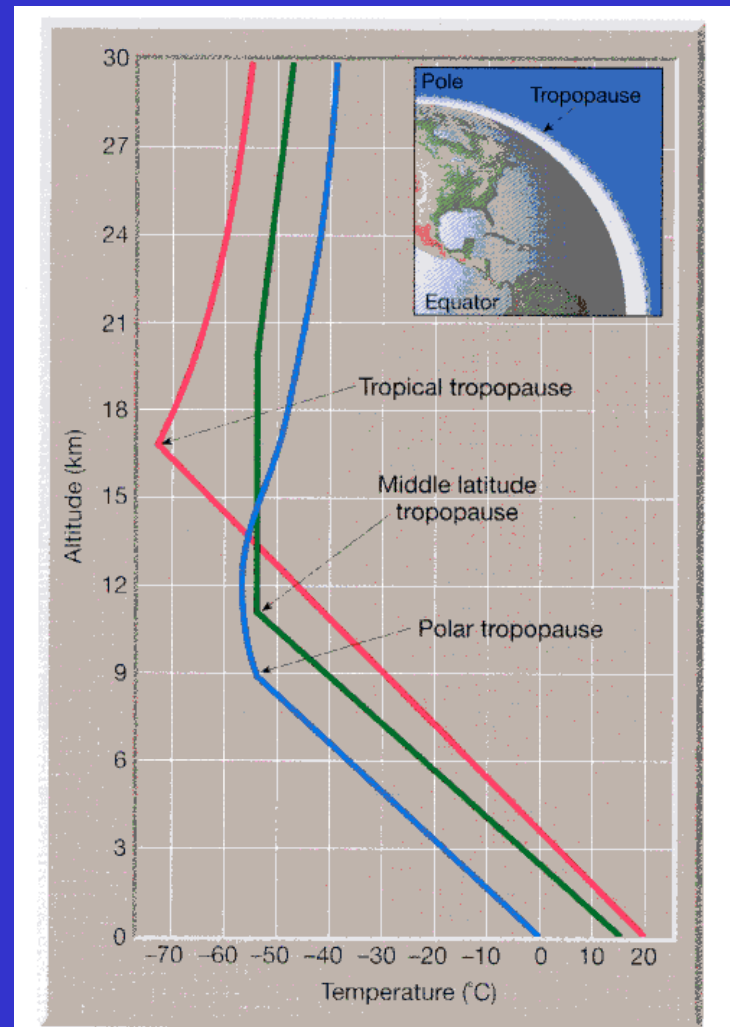
- heated by solar radiation at the base
- heat dispersed upward by vertical motion

**Thermosphere**

- very little mass



# Variations in Tropopause Height



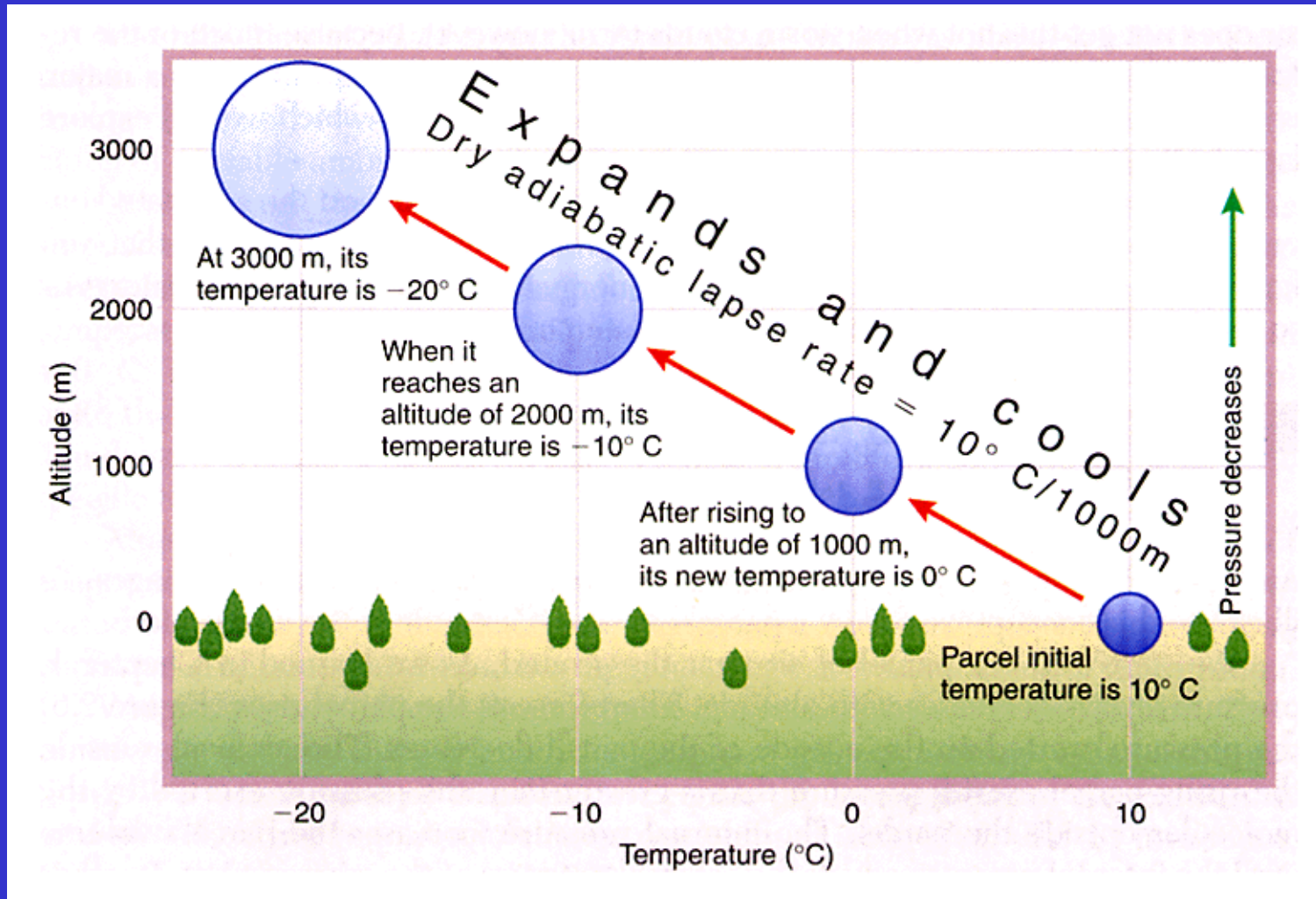
(from *The Atmosphere*)

**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.





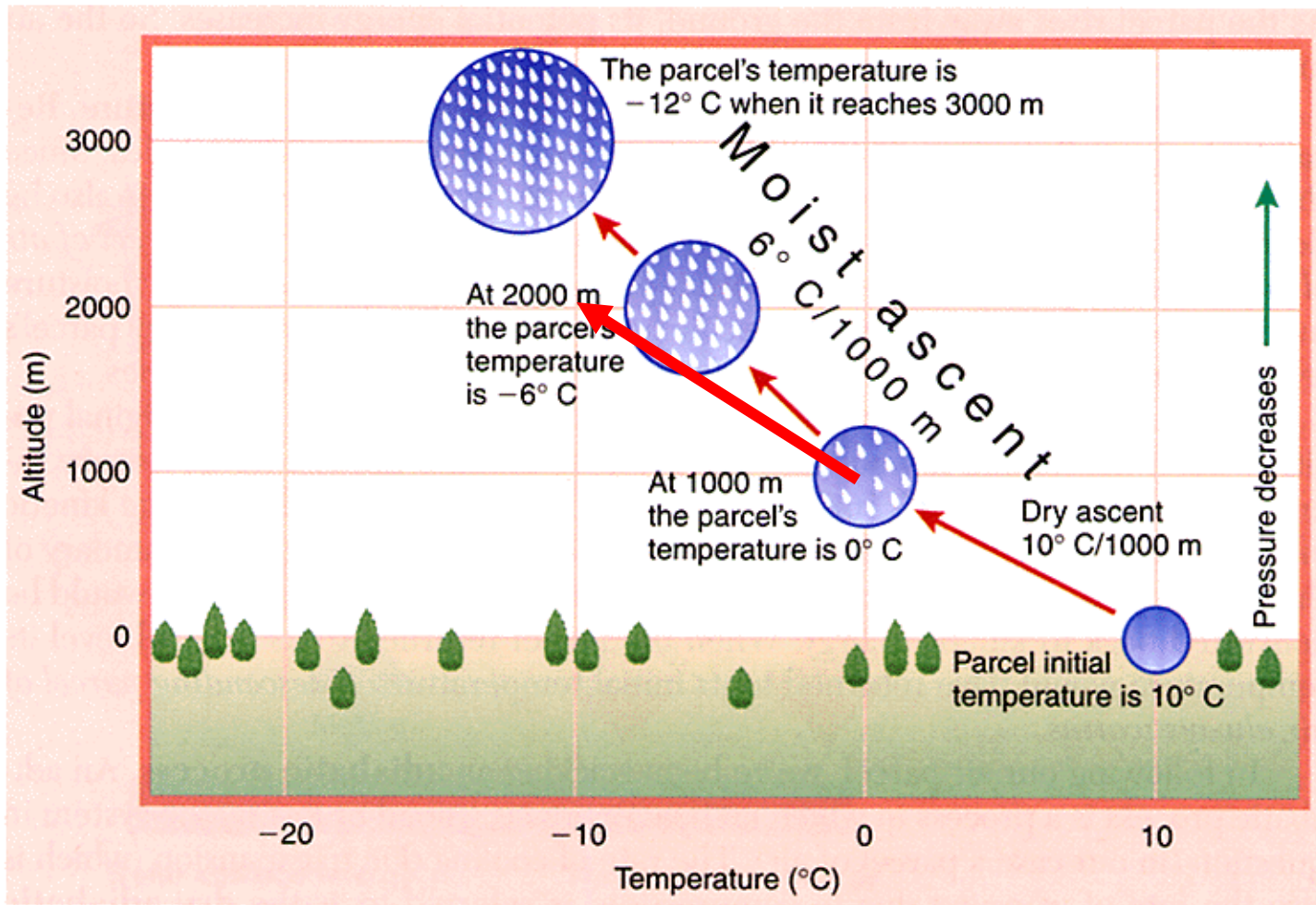
# Dry Adiabatic Lapse Rate



(from *Meteorology: Understanding the Atmosphere*)



# Moist Adiabatic Lapse Rate

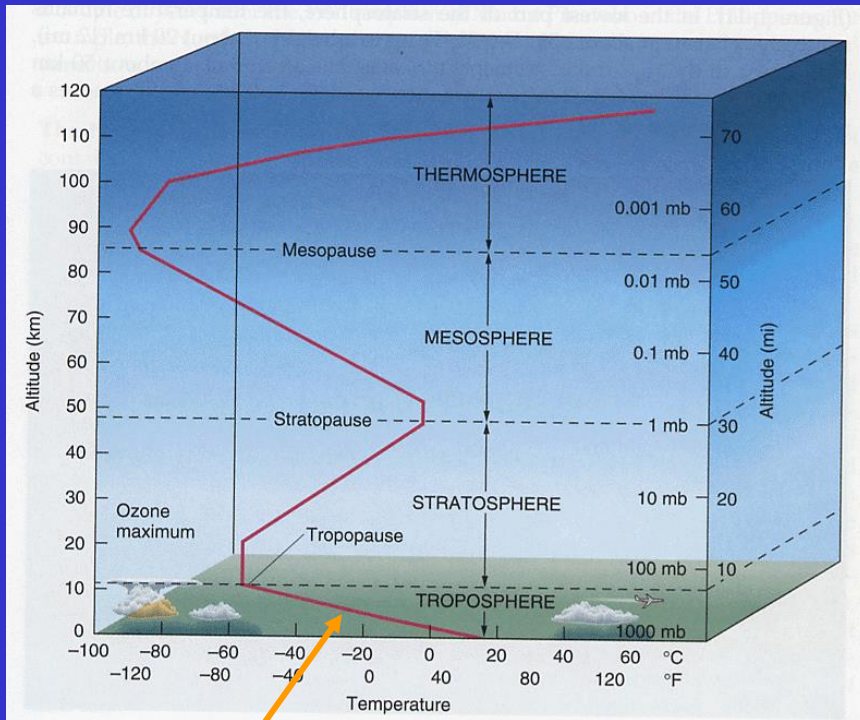


(from *Meteorology: Understanding the Atmosphere*)



# Stratosphere

## Standard Atmosphere



(from *Understanding Weather & Climate*)

lapse rate = 6.5 C/km

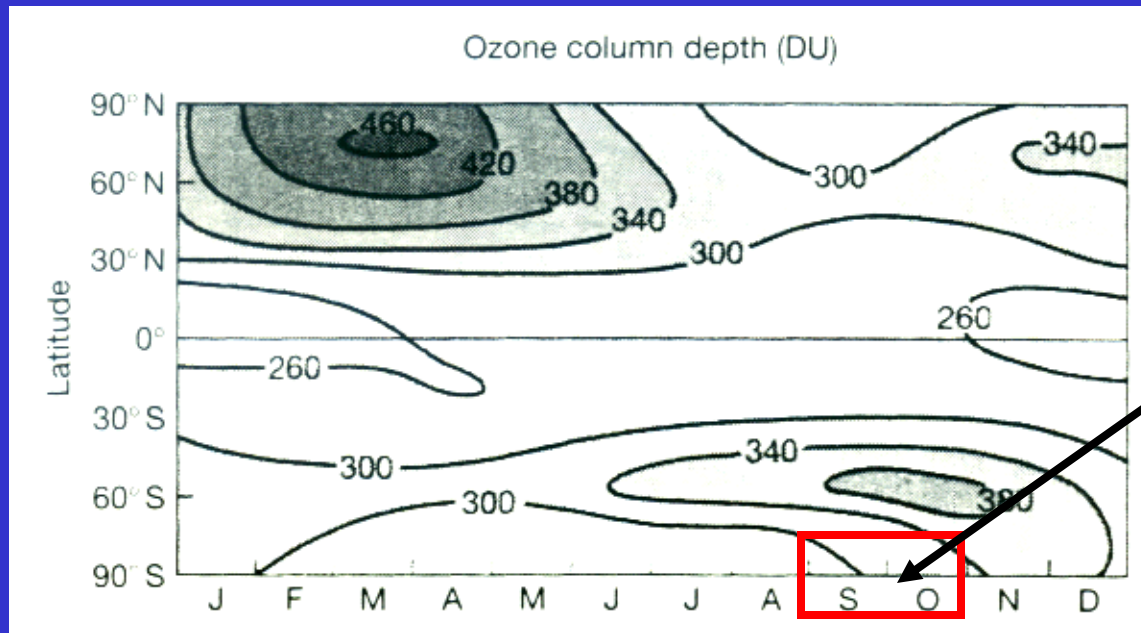
□ The reasons for the inversion in the stratosphere is due to the ozone absorption of ultraviolet solar energy.

□ Although maximum ozone concentration occurs at 25km, much solar energy is absorbed in the upper stratosphere and can not reach the level of ozone maximum.

□ Also, the lower air density at 50km allows solar energy to heat up temperature there at a much greater degree.



# Ozone Distribution



Antarctic  
Ozone  
Hole

(from *The Earth System*)

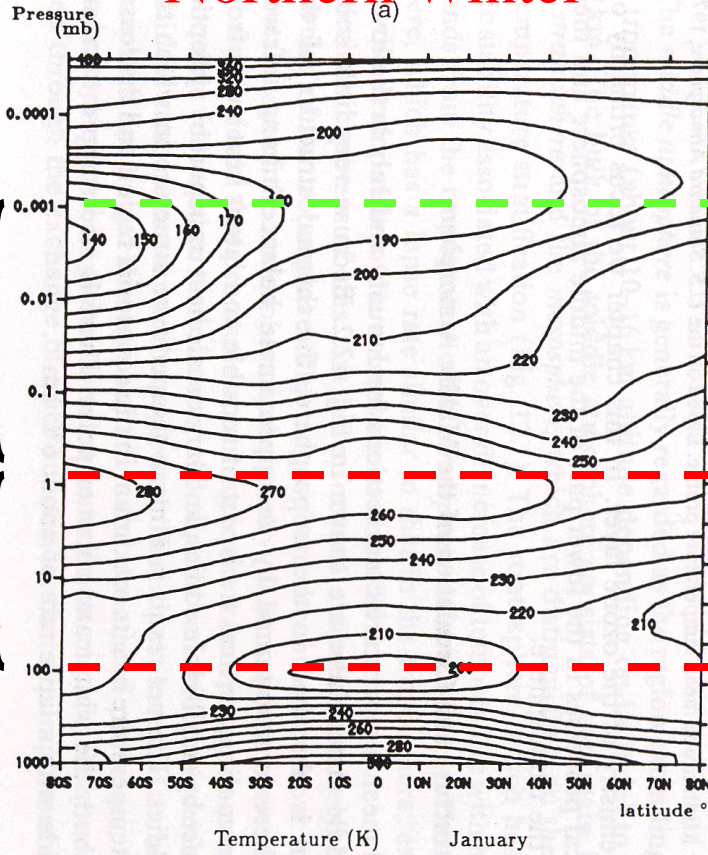
- ❑ The greatest production of ozone occurs in the tropics, where the solar UV flux is the highest.
- ❑ However, the general circulation in the stratosphere transport ozone-rich air from the tropical upper stratosphere to mid-to-high latitudes.
- ❑ Ozone column depths are highest during springtime at mid-to-high latitudes.
- ❑ Ozone column depths are the lowest over the equator.



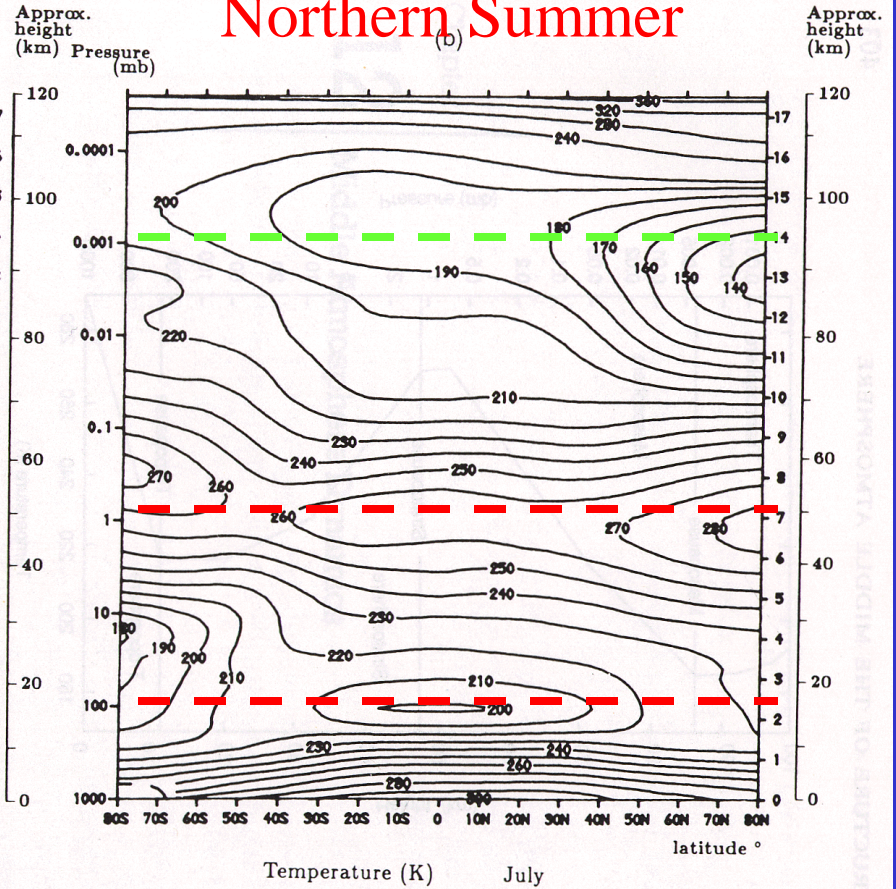
# Temperatures in Stratosphere

stratosphere mesosphere

Northern Winter (a)



Northern Summer (b)

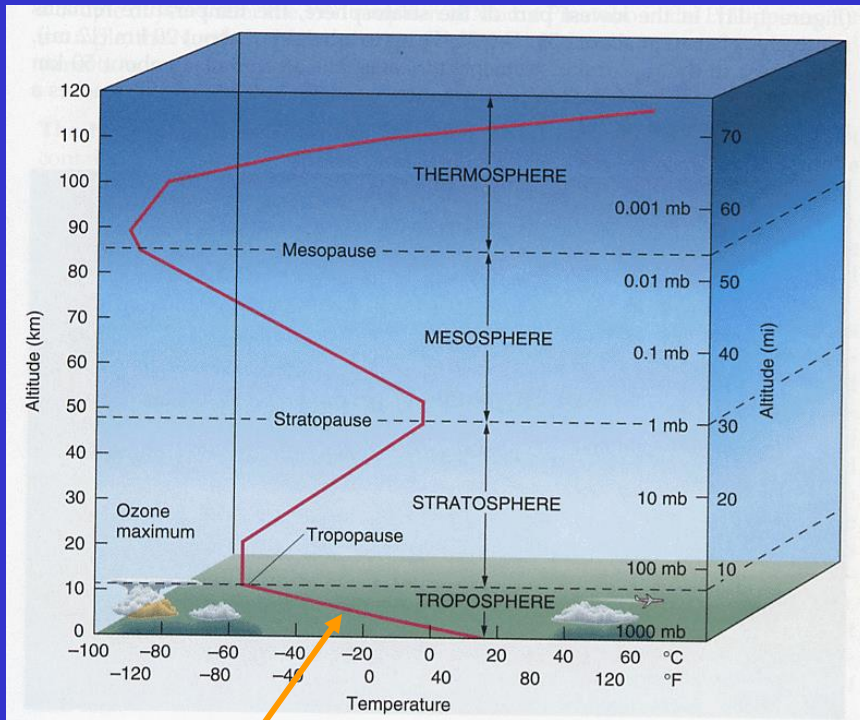


(from *Dynamic Meteorology*)



# Mesosphere

## Standard Atmosphere



(from *Understanding Weather & Climate*)

$\text{lapse rate} = 6.5 \text{ C/km}$

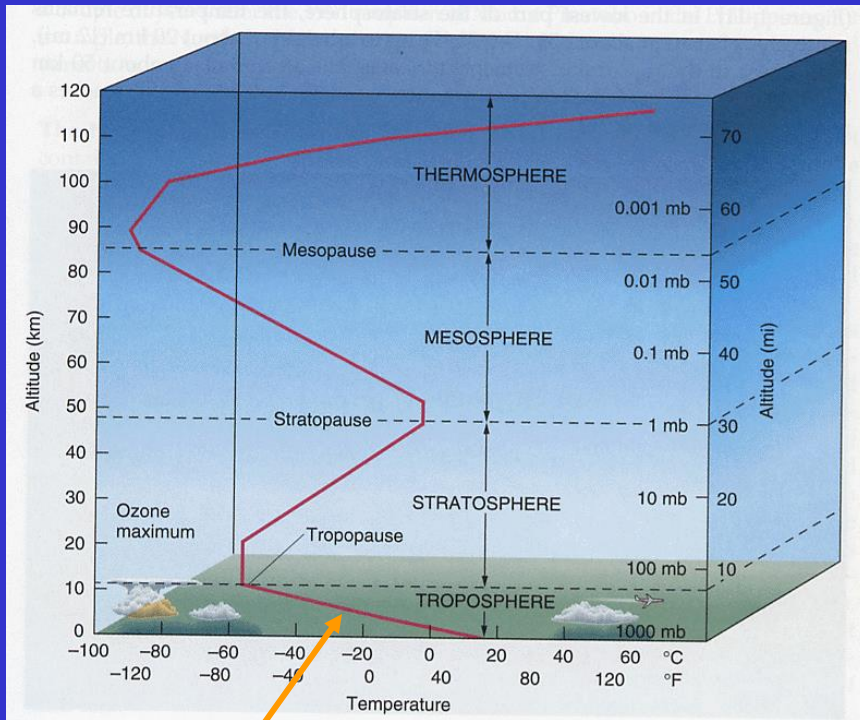
□ There is little ozone to absorb solar energy in the mesosphere, and therefore, the air temperature in the mesosphere decreases with height.

□ 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



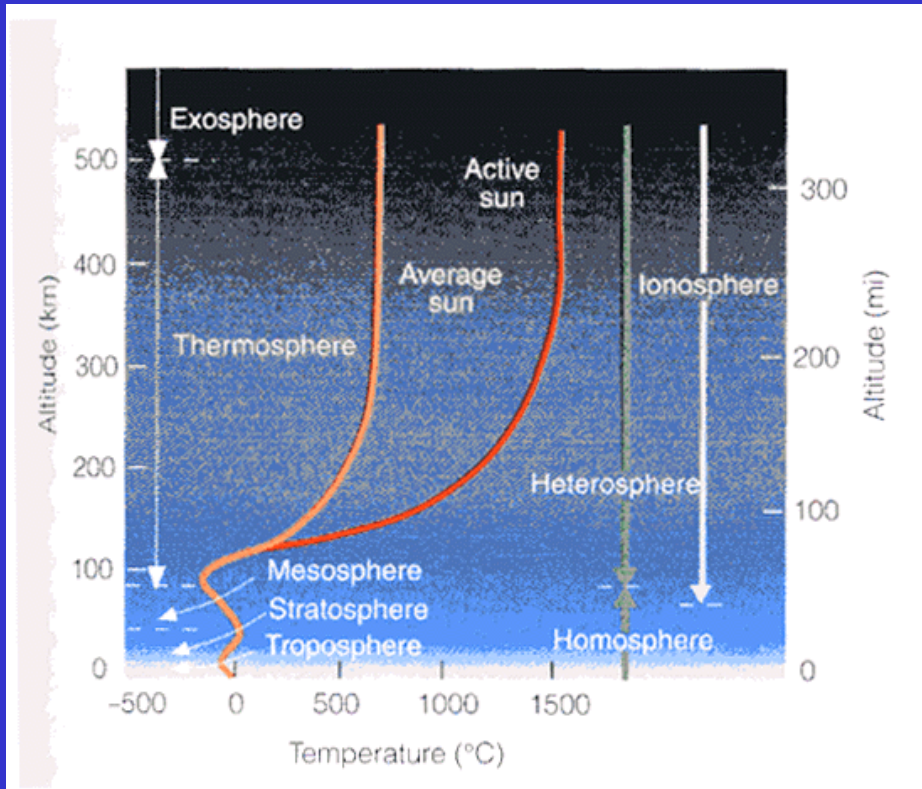
(from *Understanding Weather & Climate*)

**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



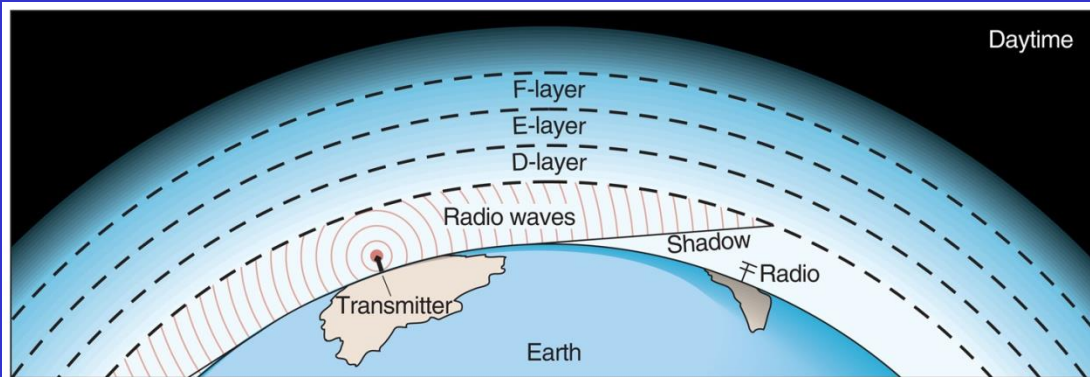
(from *Meteorology Today*)

- ❑ 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.

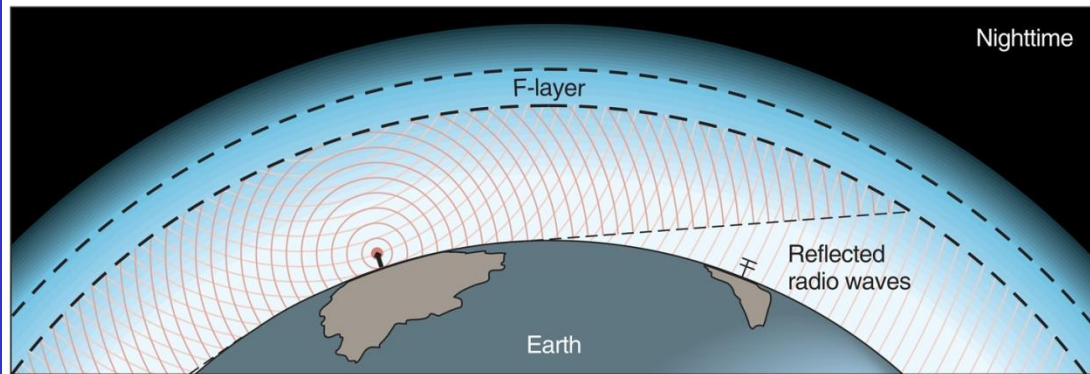




# Ionosphere and AM Radio



(a)



(b)

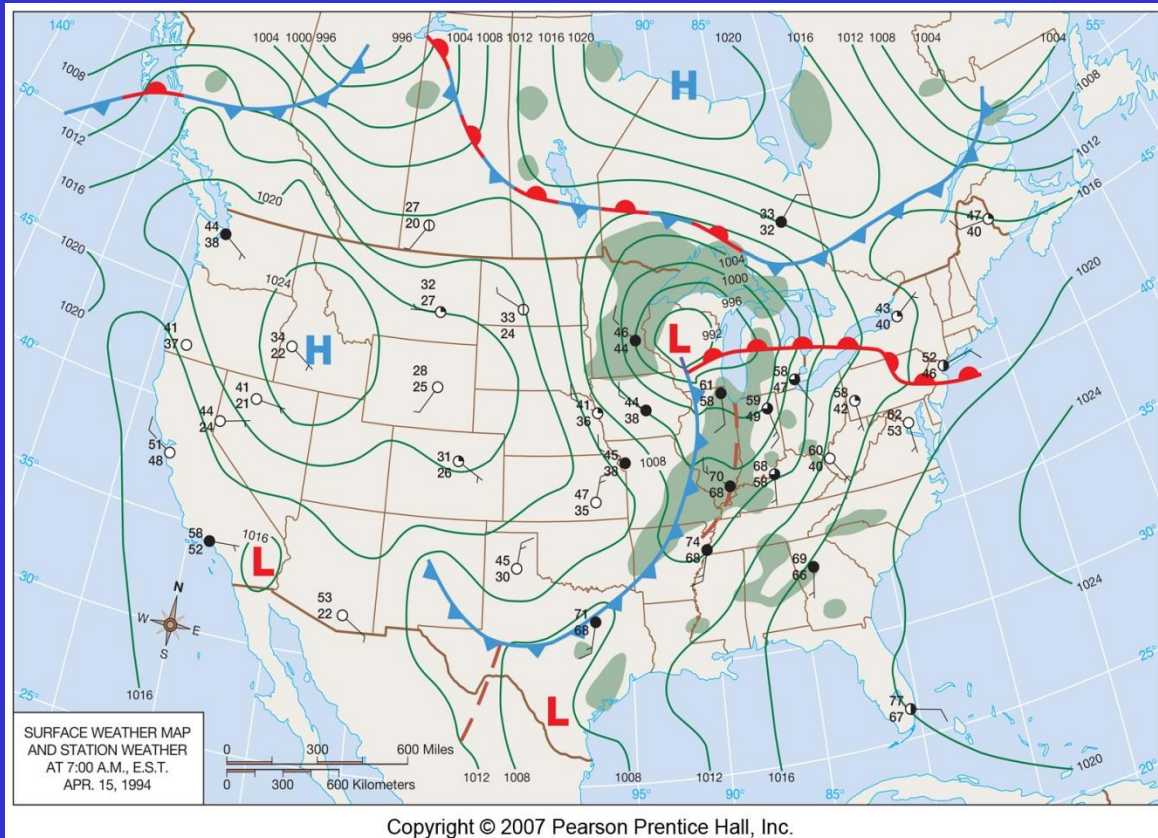
Copyright © 2007 Pearson Prentice Hall, Inc.

(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 reflection of radio waves between Earth surface and the F-layer allows them to overcome the effect of Earth's curvature.



# Weather Maps

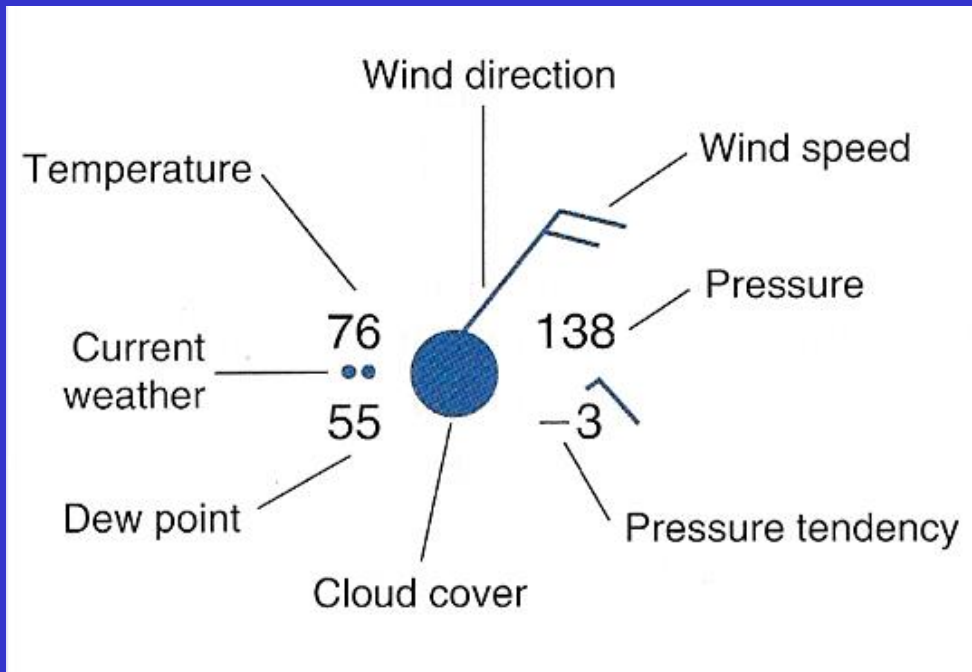


(from *Understanding Weather & Climate*)

- ❑ Many variables are needed to describe weather conditions.
- ❑ Local weathers are affected by weather patterns.
- ➔ 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

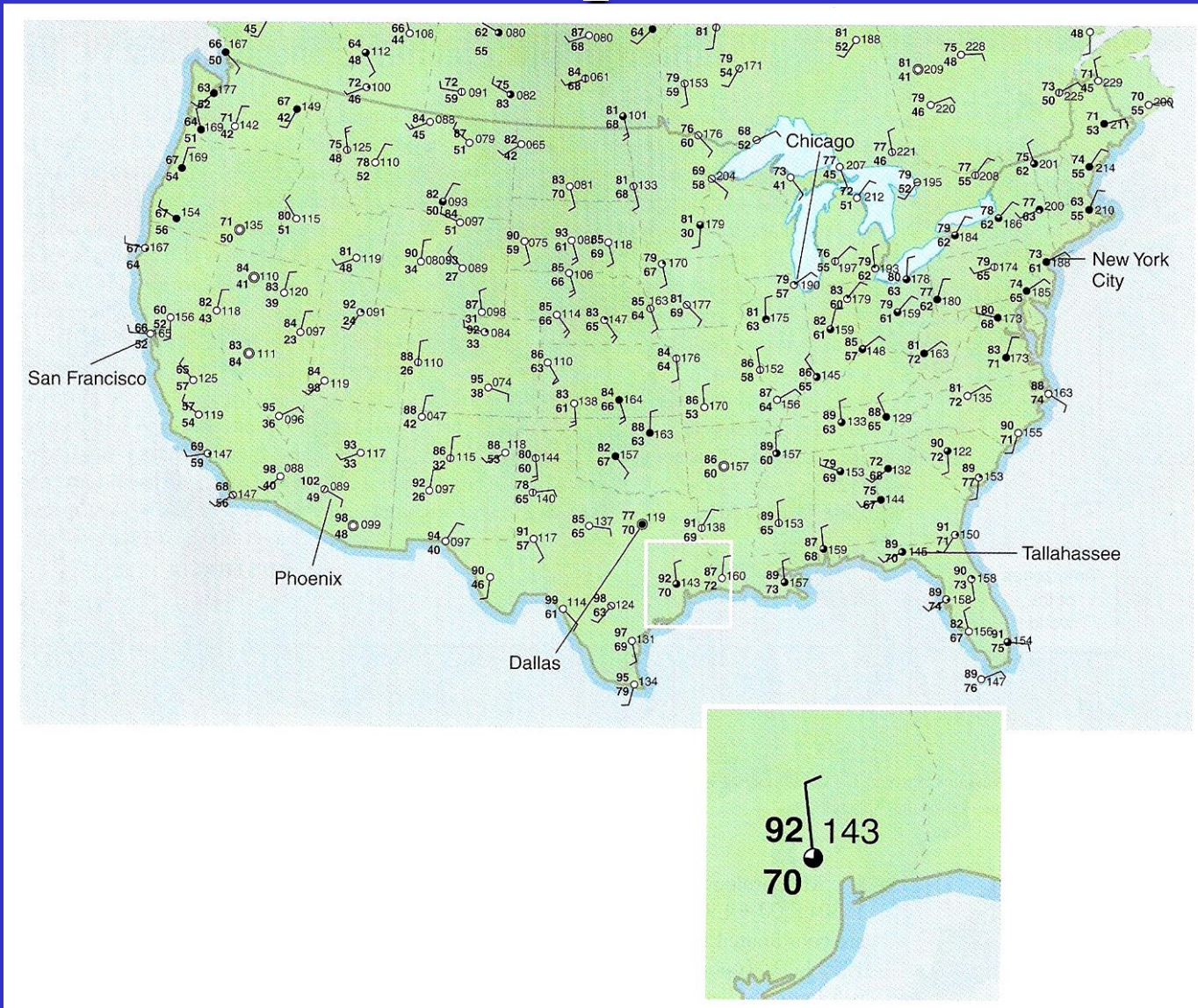


(from *Meteorology: Understanding the Atmosphere*)

- ❑ 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*.



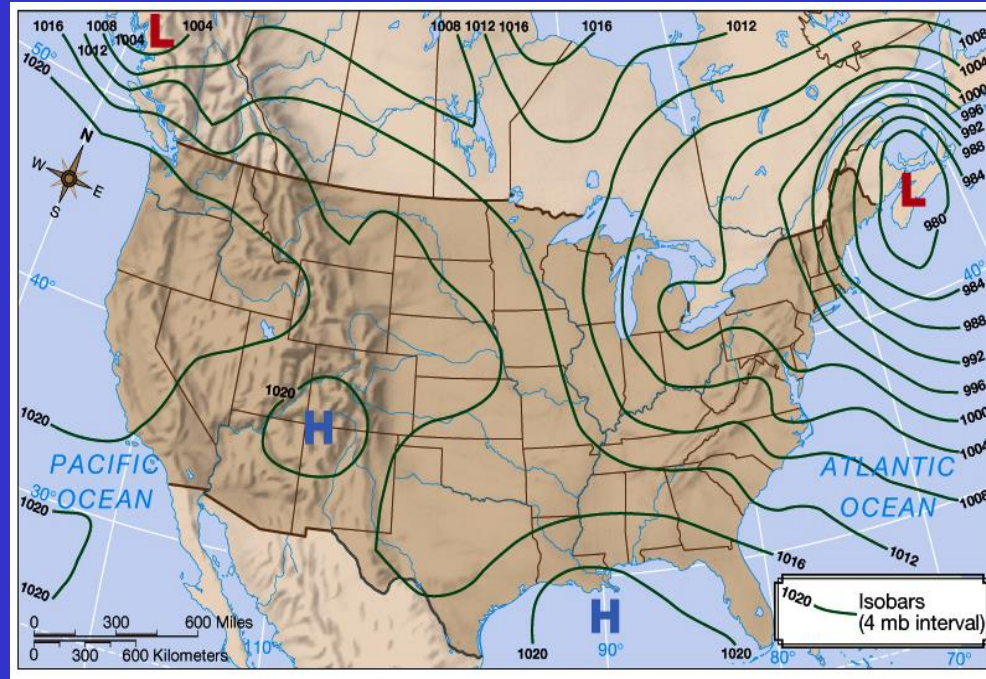
# Weather Map on 7/7/2005



(from *Meteorology: Understanding the Atmosphere*)



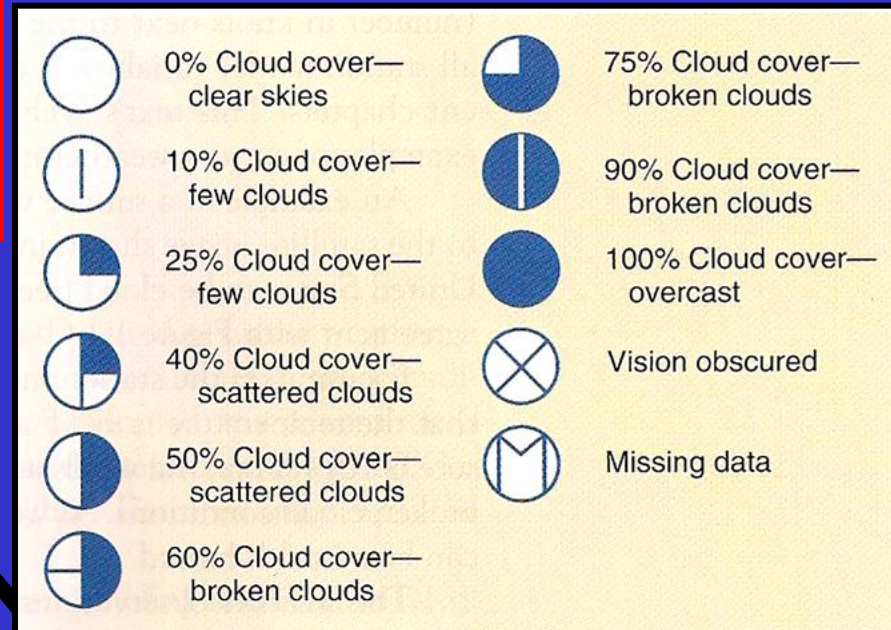
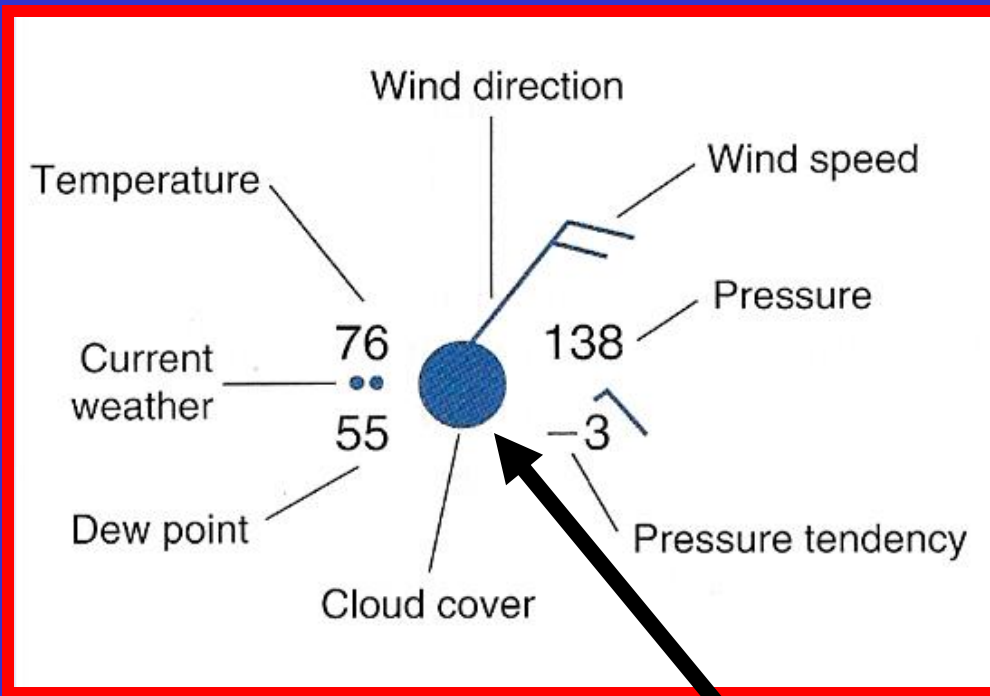
# Isobar



- ❑ 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



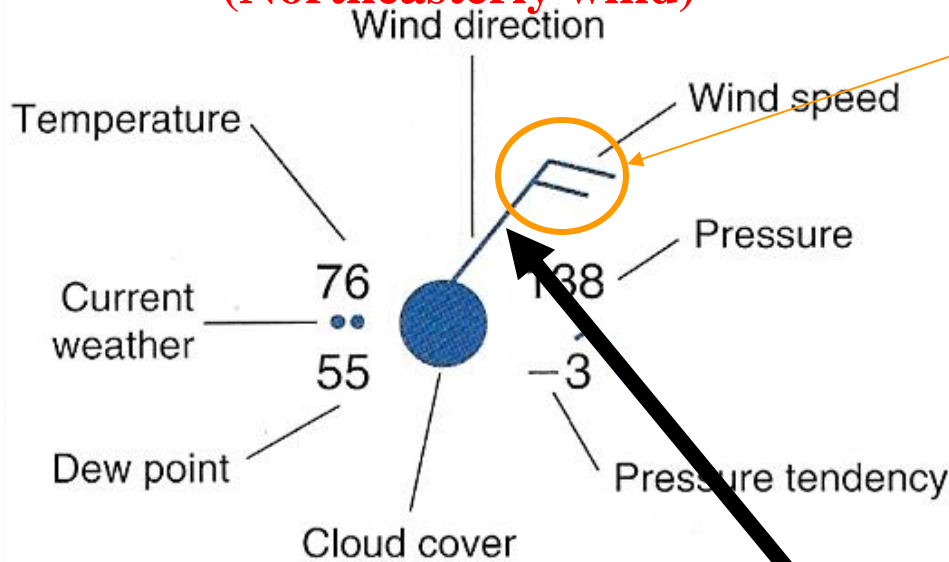
(from *Meteorology: Understanding the Atmosphere*)



# The Station Model: Wind

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

**(Northeasterly wind)**

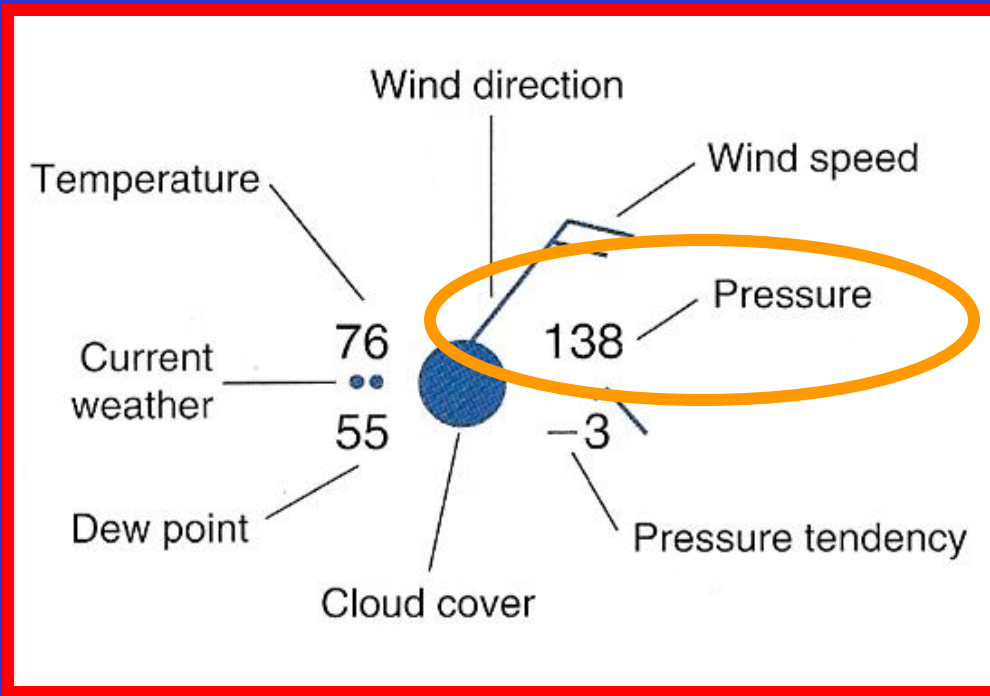


	WIND SPEED				
	miles per hour	kilometers per hour	miles per hour	kilometers per hour	
	Calm	Calm		50-54	80-87
	1-2	1-3		<b>50</b> 55-60	88-96
	<b>5</b> 3-8	4-13		61-66	97-106
	<b>10</b> 9-14	14-19		67-71	107-114
	<b>15</b> 15-20	20-32	.		
	21-25	33-40	.		
	26-31	41-50	.		
	32-37	51-60		113-118	182-190
	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



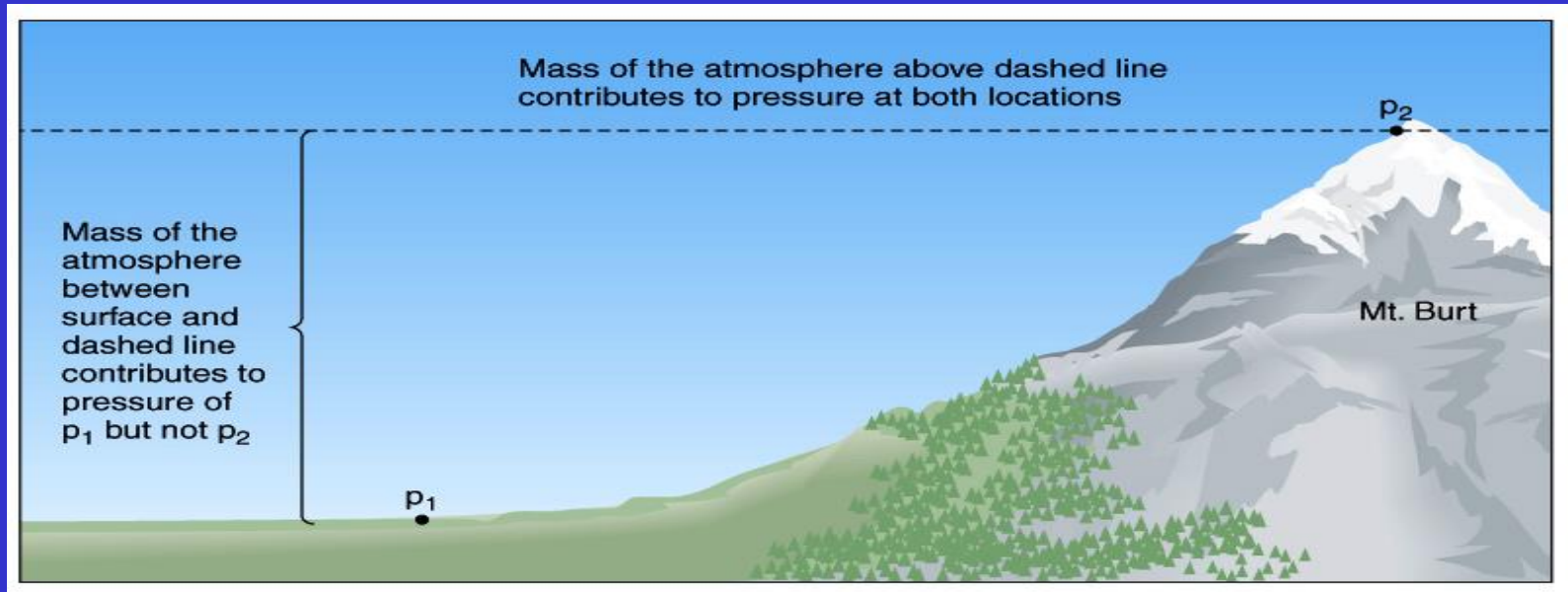
- ❑ The pressure value shown is the measured atmospheric pressure adjusted to sea level.
- ❑ The units used are “mb”.
- ❑ To save space, the “thousand” and the “hundred” values, and the decimal point are dropped.  
→ So “**138**” means 10**13.8** mb

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.





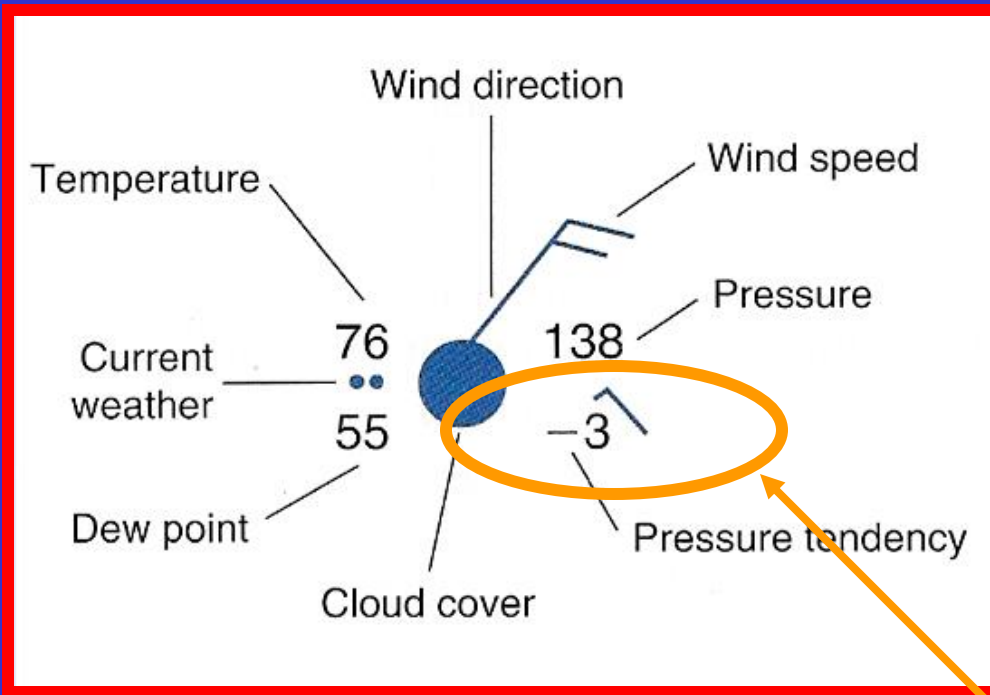
# Pressure Correction for Elevation



- 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

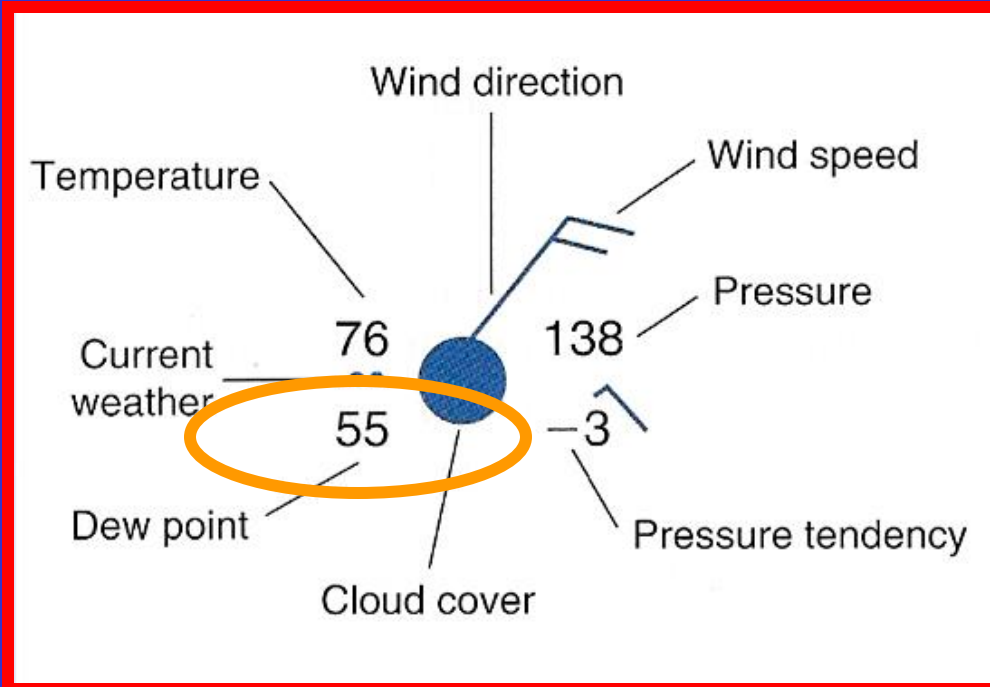


- The change in surface pressure in the past three hours is plotted numerically and graphically on the lower right of the station model.

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



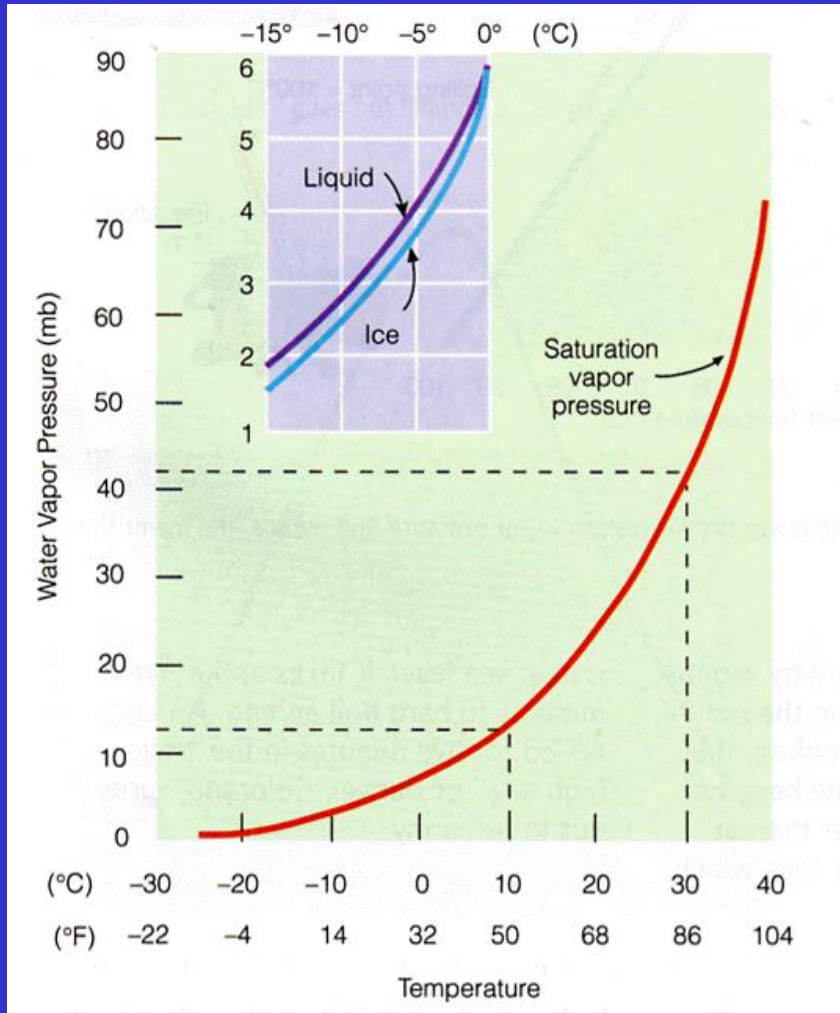
# The Station Model: Dew Point Temperature



- ❑ Dew point temperature (in units of °F) 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**

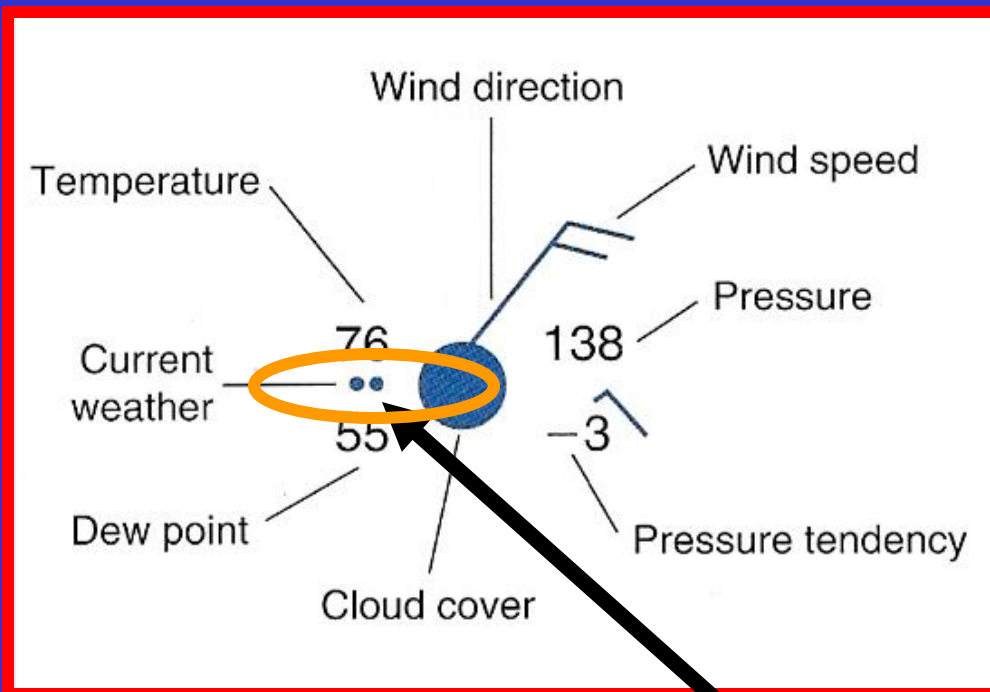
$$\rightarrow e_s \cong 6.11 \cdot \exp \left\{ \frac{L}{R_v} \left( \frac{1}{273} - \frac{1}{T} \right) \right\}$$

- Saturation pressure increases exponentially with air temperature.

L: latent heat of evaporation;  $\alpha$ : specific volume of vapor and liquid



# The Station Model: Current Weather

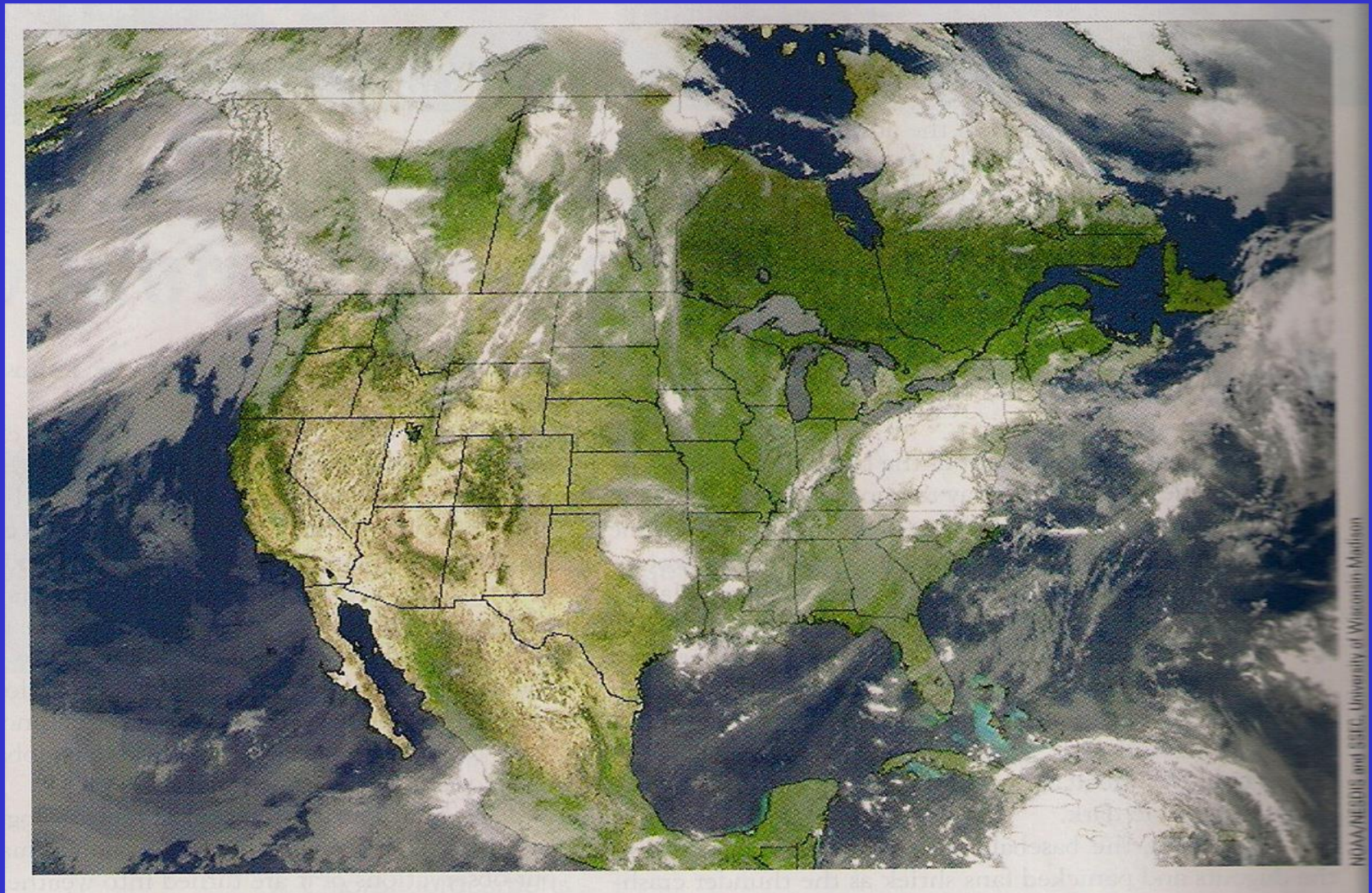


<p>RAIN</p> <p>••</p> <p>Light</p> <p>•••</p> <p>Moderate</p> <p>••••</p> <p>Heavy</p> <p>•</p> <p>▽</p> <p>Light shower</p> <p>•</p> <p>▽</p> <p>Moderate shower</p> <p>⚡</p> <p>Thunderstorm</p> <p>⚡</p> <p>Heavy T-storm</p>	<p>SNOW</p> <p>* *</p> <p>Light</p> <p>* * *</p> <p>Moderate</p> <p>* * *</p> <p>Heavy</p> <p>*</p> <p>▽</p> <p>Light shower</p> <p>*</p> <p>▽</p> <p>Moderate shower</p> <p>OTHER</p> <p>∞</p> <p>Haze</p> <p>==</p> <p>Fog</p>	<p>DRIZZLE</p> <p>” ”</p> <p>Light</p> <p>” ” ”</p> <p>Moderate</p> <p>” ” ”</p> <p>Heavy</p> <p>FREEZING RAIN</p> <p>~</p> <p>Light</p> <p>~</p> <p>Moderate</p> <p>↔</p> <p>Ice crystals</p> <p>△</p> <p>Ice pellets (sleet)</p>
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(from *Meteorology: Understanding the Atmosphere*)



# Satellite Picture on 7/7/2005



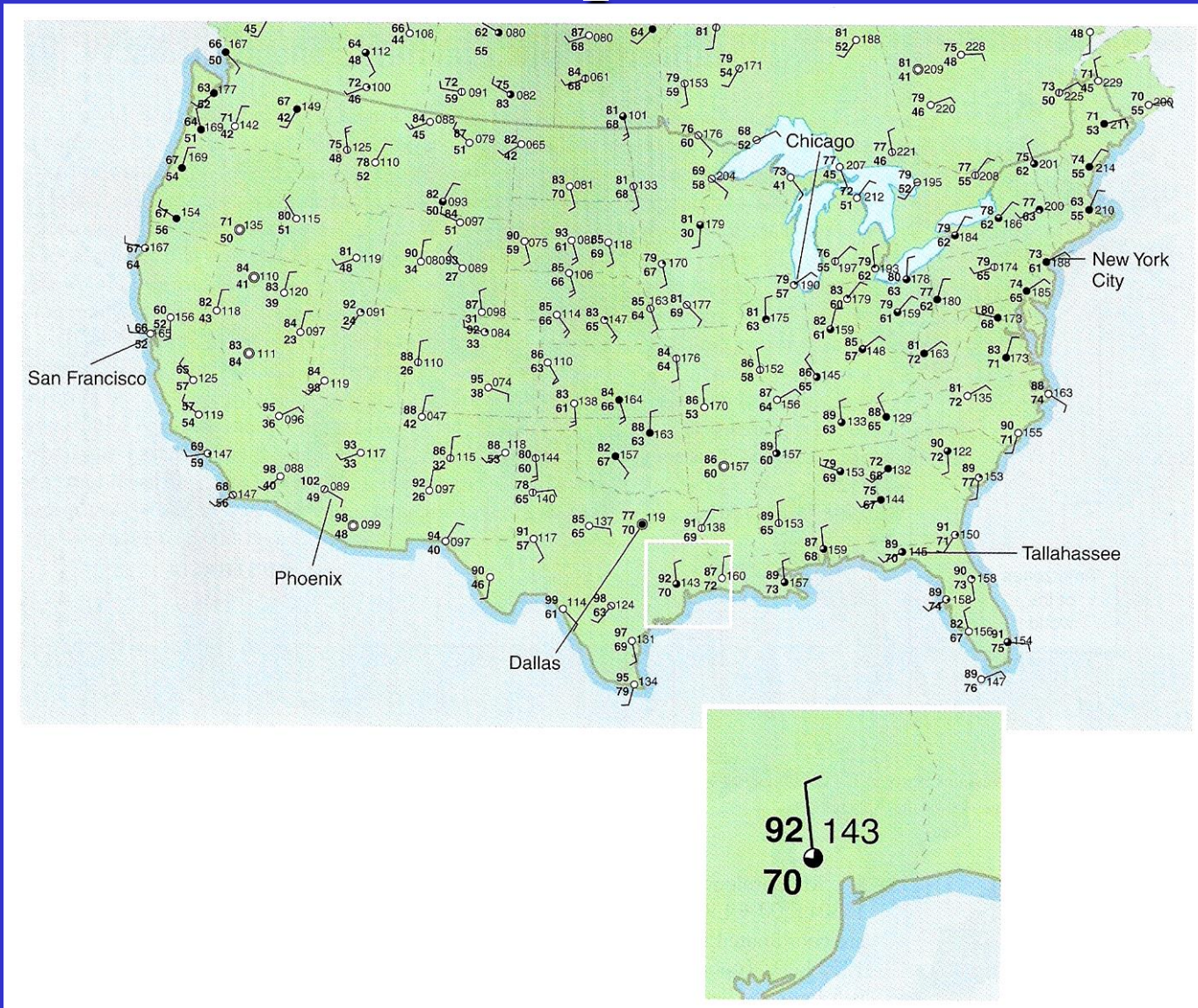
NOAA/NEADS and SSEC, University of Wisconsin-Madison

(from *Meteorology: Understanding the Atmosphere*)



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# Weather Map on 7/7/2005



(from *Meteorology: Understanding the Atmosphere*)



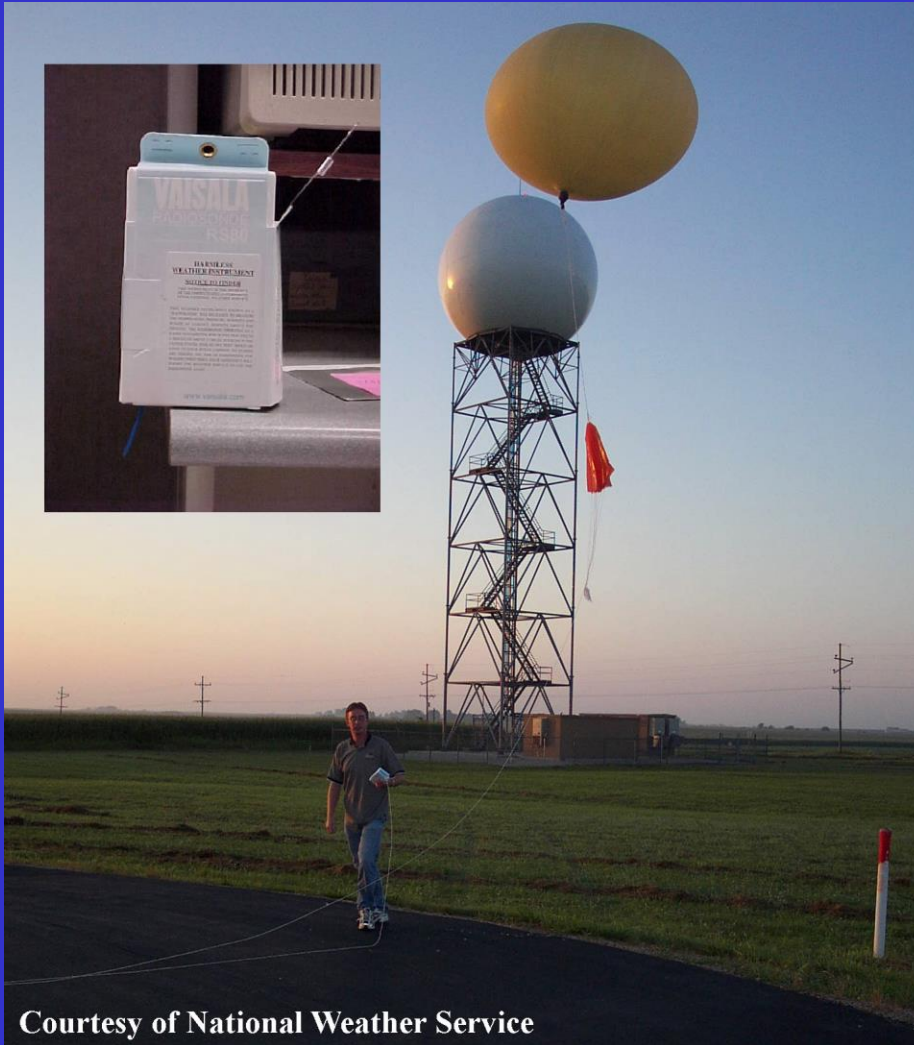
# Observation Time for Weather Map

- ❑ 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  $(360/24)=15^\circ$  of longitude west of Greenwich.
- ➔ Local time in Los Angeles ( $118^\circ$  W) and the rest of the Pacific Standard Time is 8 ( $= 118^\circ/15^\circ$ ) hours earlier than Greenwich.





# Rawinsondes



Courtesy of National Weather Service

- To understand weather systems, measurements are required through the depth of the troposphere and well into the stratosphere.
- Rawinsondes are designed for this purpose.
- A rawinsonde is a balloon-borne instruments system that measure pressure, temperature, dewpoint temperature, wind direction, and speed.



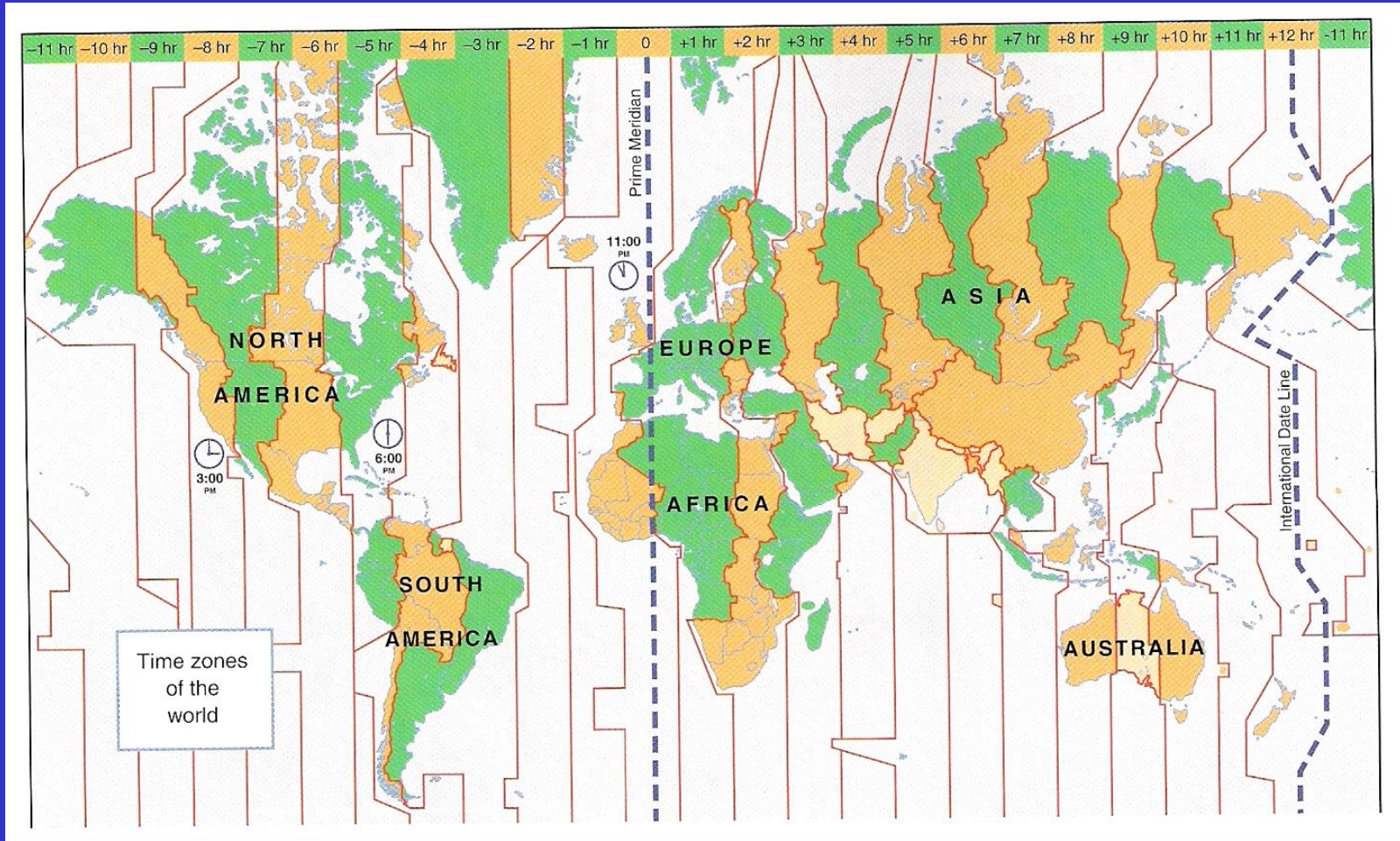
# Surface Measurements: ASOS/AWOS



- Automated Surface (Weather) Observing Systems (ASOS or AWOS) are now used to make standard measurements of atmospheric properties at most locations in North America.
- The measurements are reported hourly in North America and every three hours worldwide, at 0000, 0300, 0600, 0900, 1200, 1500, 1800, and 2100 UTC.



# Time Zone



(from *Meteorology: Understanding the Atmosphere*)

7/7/2005

7/8/2005

7/7/2005



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