CLIM-319 / GGS-319
Atmospheric Pressure



Homework

- ✓ HW # 1

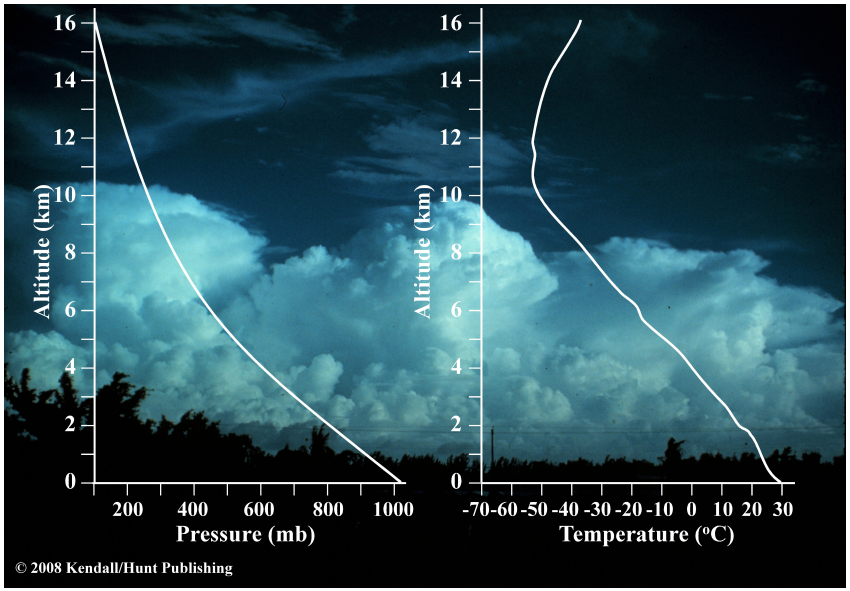
  On page 22 of the text book, Problem 2.1

  Due Sep 17, Tuesday

Properties of the Atmosphere

- There are 3 atmospheric state variables;
  - Temperature
  - Pressure
  - Density

- Other variables include
  - moisture content
  - wind speed
  - wind direction
  - precipitation rate
  - cloud cover
  - visibility
  - etc.



Ideal Gas Law

- The ideal gas law relates the three state atmospheric variables (pressure, temperature, & density)

$$p = \rho R T$$

- Where p is "pressure, ρ is "density", T is "temperature", and R is the "gas constant", which varies among the different gases
- The good news is that $R = R_d = 287$ J kg^{-1} K^{-1} for the dry air mixture

IGL & Virtual Temperature

- The bad news is that water vapor varies

$$T_v = T\left(1 + 0.61 q_v\right)$$

Water vapor mixing ratio

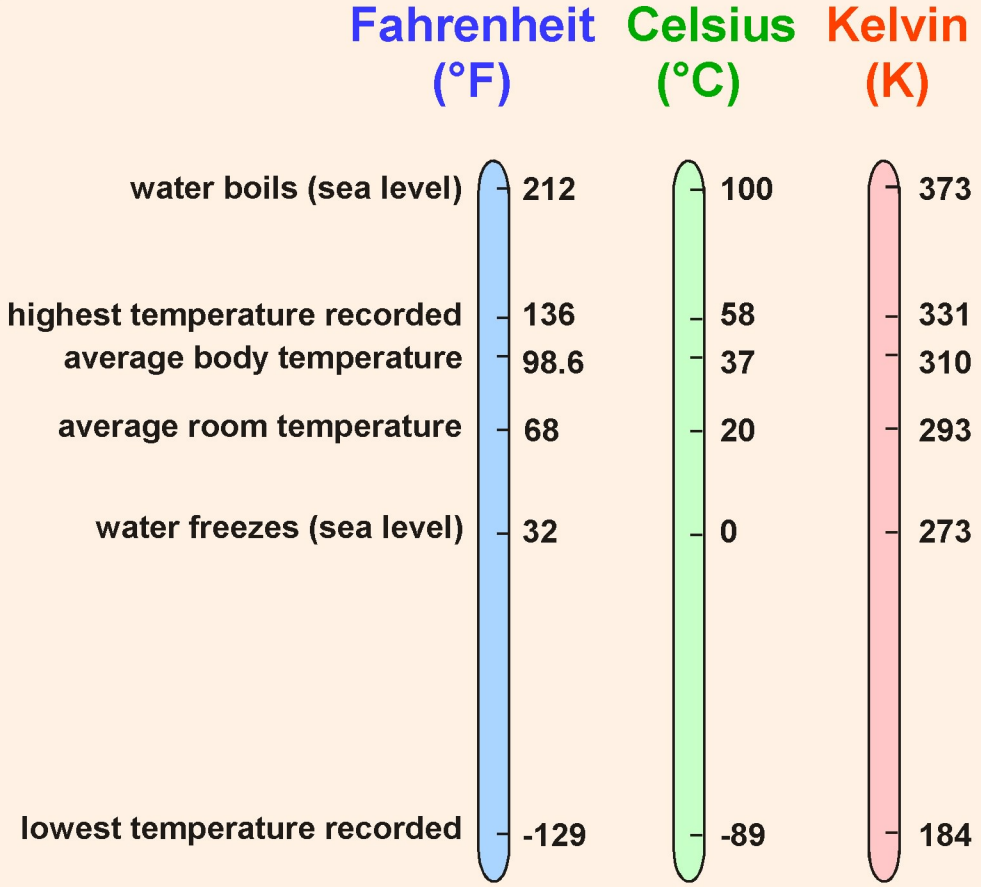
$$p = \rho R_d T_v$$

- A moist air parcel is less dense than a dry one at the same *T* & *p*

Temperature

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°C	°F
35	95
30	86
25	77
20	68
15	59
10	50
5	41
0	32
-5	23
-10	14
-15	5
-20	-4
-25	-13
-30	-22
-35	-31
-40	-40

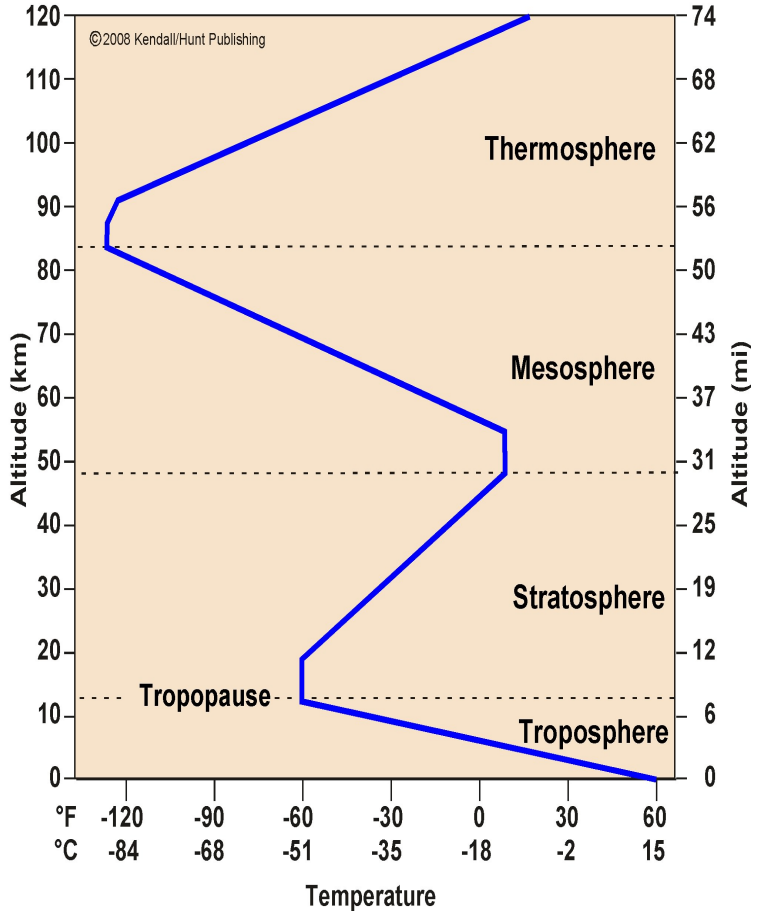


Temperature Conversions

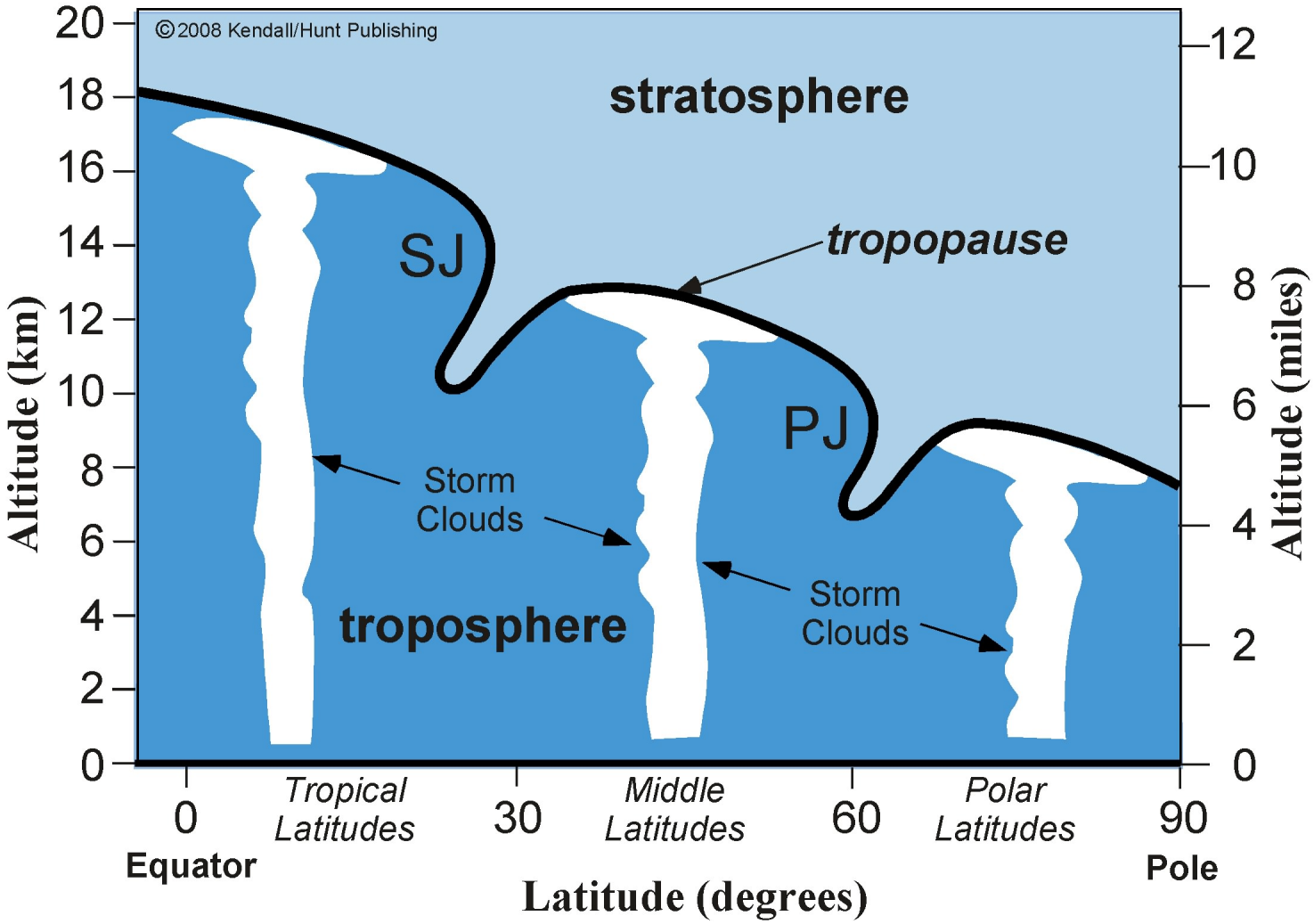
$°C = (°F - 32)/1.8$

$K = °C + 273.15$

Vertical Temperature Structure

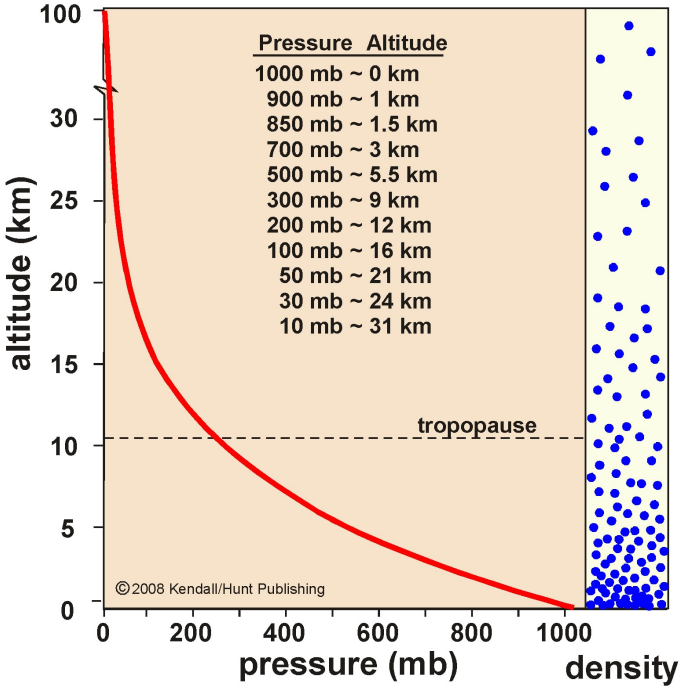


- ✓ Troposphere extends 9-16 km
  - ✓ Lapse rate 6.5 ^{0}C/km
  - ✓ Well mixed
  - ✓ All weather formation
  - ✓ Pollutants and moisture confine in this layer
- ✓ Stratosphere extends to 50 km
  - ✓ Ozone formation
  - ✓ Absorption of SW radiation
  - ✓ Little mixing
  - ✓ No clouds and precipitation
  - ✓ Pollutants alter the radiation budget
- ✓ Mesosphere extends to 85 km
  - ✓ Temperature decreases
  - ✓ Coldest temperature occurrence
- ✓ Thermosphere
  - ✓ Conversion of solar energy into sensible heat


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stratosphere
SJ
tropopause
PJ
Storm Clouds
Storm Clouds
troposphere
Altitude (km)
Altitude (miles)
20
18
16
14
12
10
8
6
4
2
0
12
10
8
6
4
2
0
0
Equator
Tropical Latitudes
30
Middle Latitudes
60
Polar Latitudes
90
Pole
Latitude (degrees)

Pressure

- The atmospheric pressure is the weight exerted by the overhead atmosphere on a unit area of surface
- Pressure unit
  - Pascal, 1 Pa = 1 kg m^{-1} s^{-2}
  - 1 atm = 1.013 x 10^5 Pa
  - 1 bar = 1 x 10^5 Pa
  - 1 mb = 100 Pa



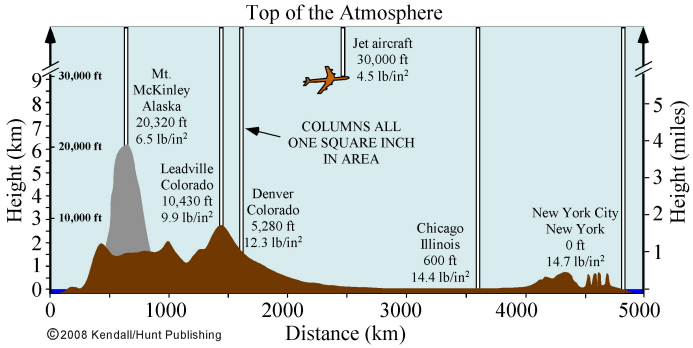
  - Mean sea level standard pressure

    P = 1.013 x 10^5 Pa = 1013 mb = 1 atm
  - The global mean pressure at the surface of the Earth

    Ps = 984 mb
  - The total mass of the atmosphere

    m_a = 5.2x10^{18} kg
  - The total number of moles of air

    N_a = 1.8x10^{20} moles



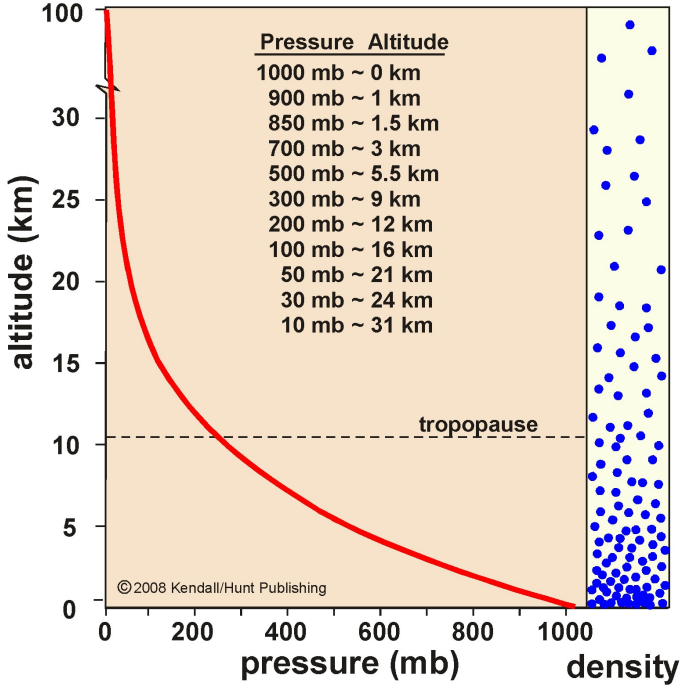
Pressure

Table 1.1: Range of sea level pressures observed on earth

	Inches of Mercury (in. Hg)	**Pounds per Square inch (lbs/in^2)**	**Millibars (mb)**
Highest recorded sea level pressure	32.01	15.7	1084
Strong high-pressure system	30.86	15.2	1045
Average sea level pressure	29.92	14.7	1013
Deep low-pressure system	28.94	14.2	980
Lowest recorded sea level pressure	25.70	12.6	870

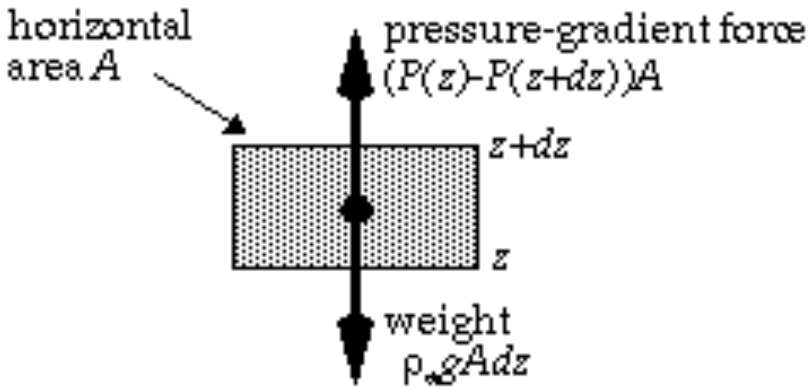
Pressure

- ✓ The atmospheric pressure decreases exponentially with altitude
- ✓ At 80 km altitude the atmospheric pressure is down to 0.01 mb, meaning that 99.999% of the atmosphere is below that altitude
- ✓ The atmosphere is relatively thin vertical extent



Barometric Law

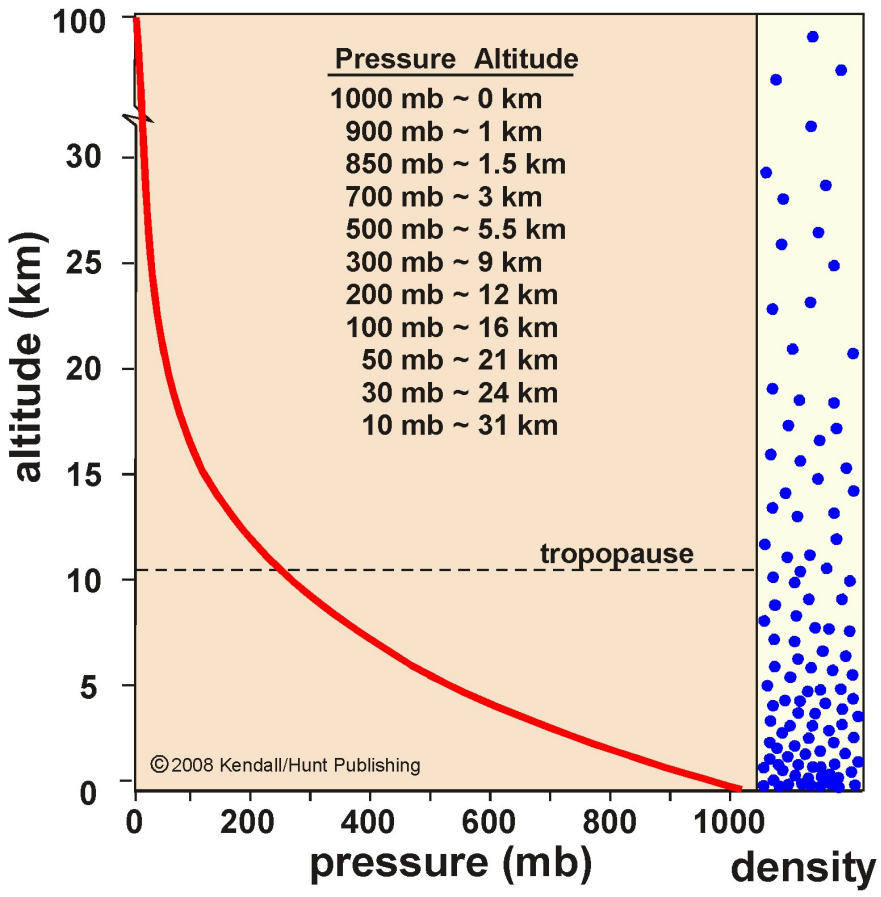
- ✓ Pressure gradient force directed upward is balanced by its weight



Barometric Law
The Hydrostatic Equilibrium

- Hydrostatic balance represents the balance between the vertical pressure gradient (PG) and gravity forces (G)
- Pressure is force per unit area
- Where the minus sign is needed because pressure (p) decreases with increasing height (z)

$$\frac{dp}{dz} = -\rho g$$



Pressure
The Hydrostatic Equation

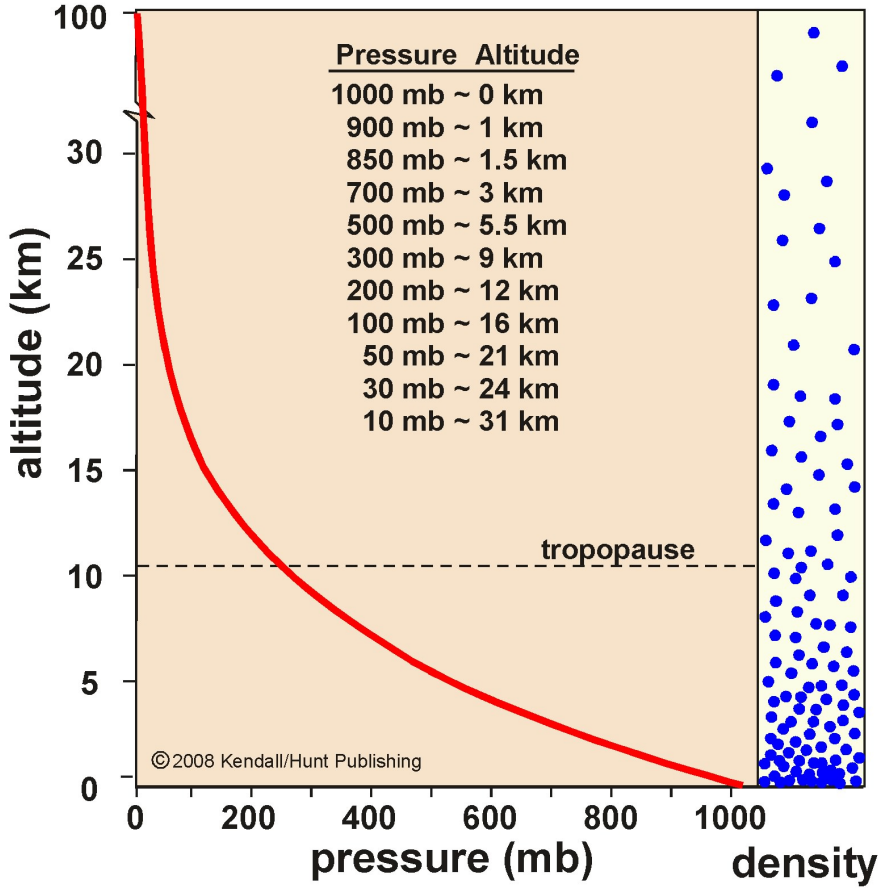
$$\rho = 1.25\ kg/m^3$$

g = 9.806 m/s²

$$\frac{dp}{dz} = \frac{p_2 - p_1}{z_2 - z_1} = -\rho g$$

$$P(z) = P(0)e^{-z/H}$$

$$H = \frac{RT}{M_a g}$$



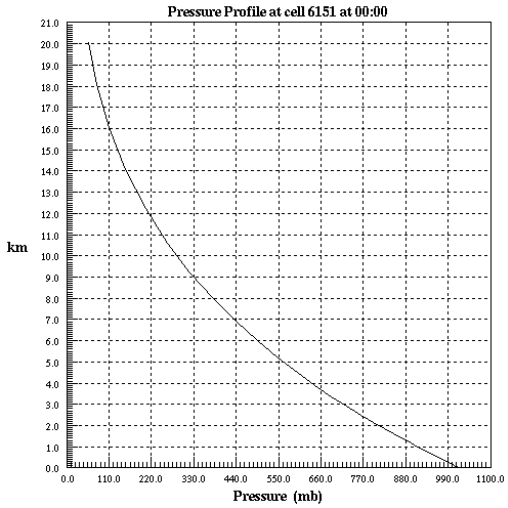
The Hydrostatic Equation

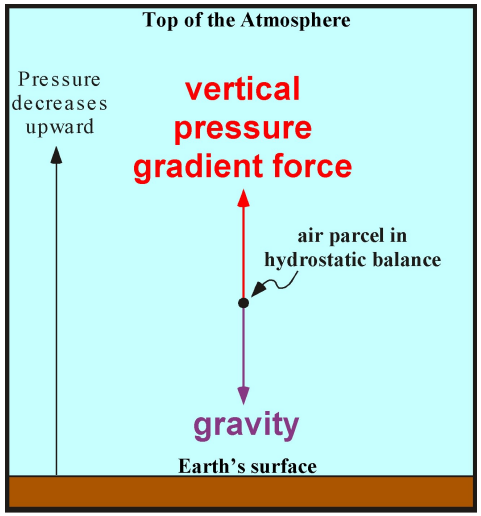
- ✓ PG and G forces can be thought of as the basic forces, since without them there would be no motion
- ✓ They are the "driving" forces and are independent of the velocity, i.e., they exist regardless of the state of the motion of the air

$$\frac{dp}{dz} = -\rho g$$

Factors Affecting Wind
Vertical Pressure-Gradients

- ✓ We have learned that airflow is from H to L pressures.
- ✓ We also know that air pressure is highest near Earth's surface and exponentially decreases with height.
- ✓ Then, one wonders why air does not rapidly accelerate upward and escape into space.
- ✓ Because, G (which acts in the opposite direction of PG) balances PG.
- ✓ The balance between these two forces is called hydrostatic equilibrium or balance.





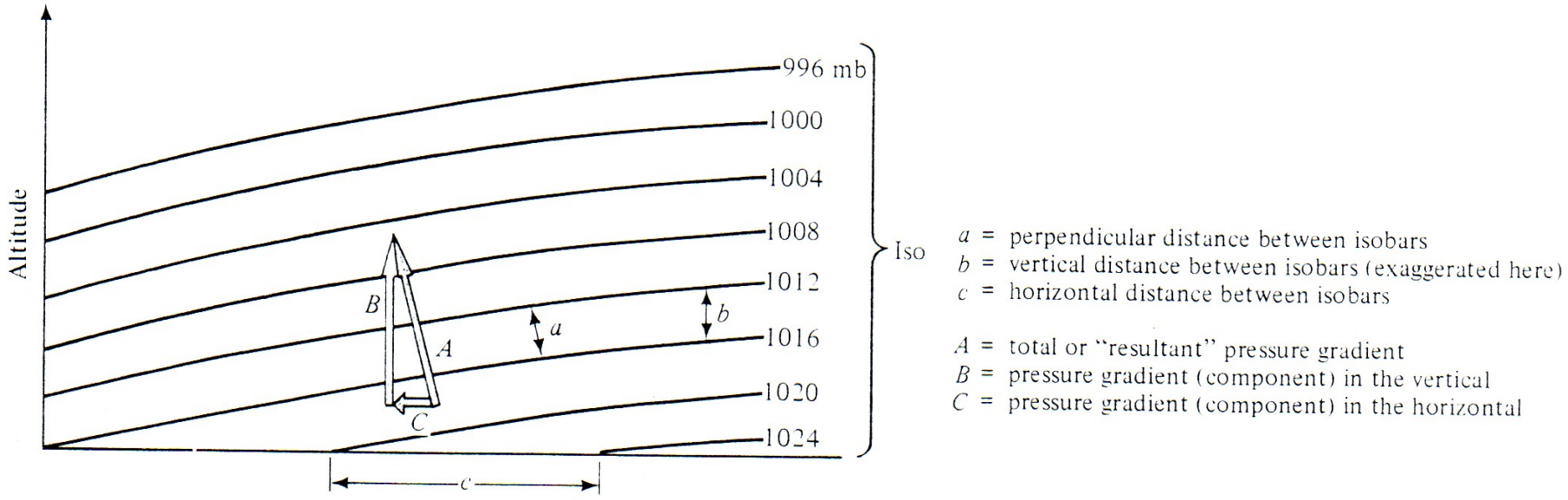
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The Hydrostatic Equation

- ✓ Unlike PG which can act in any direction, the gravitational pull of the Earth is always directed downward, toward the center of the earth
- ✓ The strength is proportional to the mass of the air parcel
- ✓ Gravity varies slightly with latitude and altitude and even with the irregular mass distribution
- ✓ For most atmospheric purposes, the following mean sea level value may be used $G = 9.806\ m/s^2$

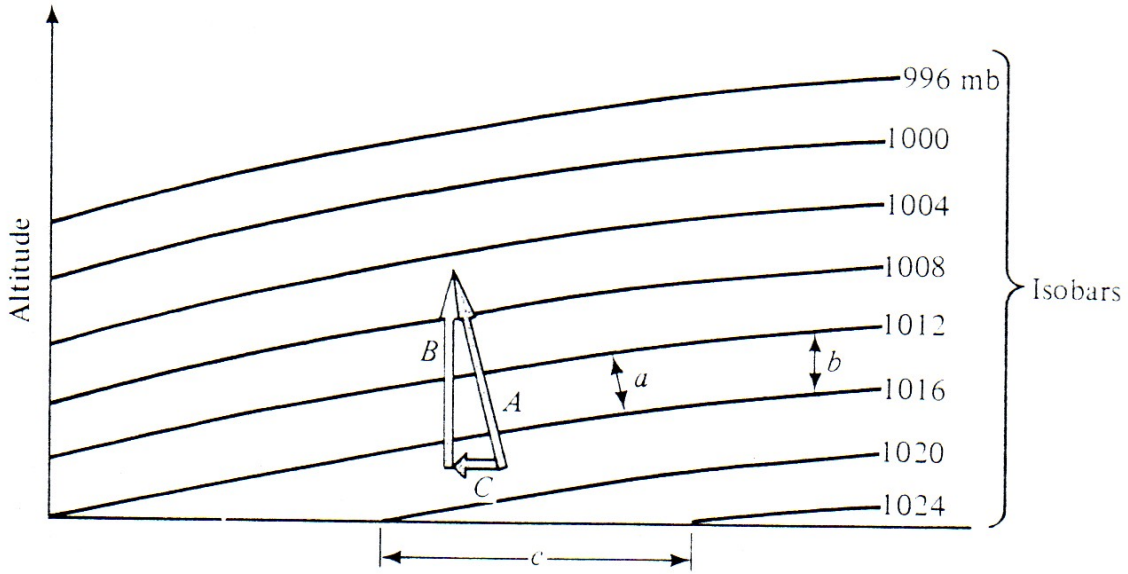
The Hydrostatic Equation

- ✓ Typical values for the distances b = 33m and **c** = 300km
- ✓ Thus, the slope would be only 33/300,000 or about 1km height change in almost 10,000km



The Hydrostatic Equation

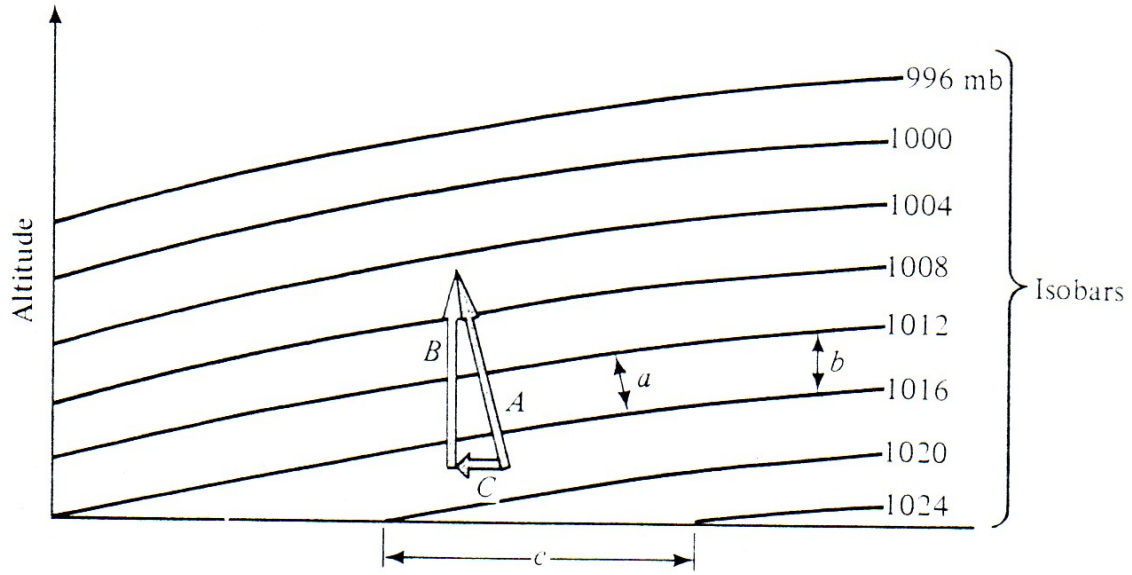
- The horizontal pressure gradient in this example would be 4mb/300km ($0.13X10^{-4}$ mb/m),
- While the vertical pressure gradient would be 4mb/33m (0.12 mb/m)
- The pressure gradient force in the vertical is thus almost 10,000 times that in the horizontal



The Hydrostatic Equation

- ✓ The horizontal and vertical components of the acceleration produced by the pressure gradient can be obtained by dividing by density
- ✓ Using the standard sea level density value,

  $d = 1.230 \times 10^{-3}$ g/cm^3
- ✓ The horizontal component of the acceleration due to the pressure gradient would be 0.11 cm/s^2
- ✓ While the vertical component would be 976 cm/s^2



The Hydrostatic Equation

- So, these two relatively large forces that due to gravity (980 cm/s^2) and that due to the vertical pressure gradient (976 cm/s^2) forms *the hydrostatic balance*
- It is the net difference between these oppositely directed vertical forces that determines whether a parcel will accelerate upward or downward and at what rate it will do it so
- Since gravity is essentially constant, the vertical acceleration will depend on the magnitude of the upward component of the pressure gradient force

The Hydrostatic Equation

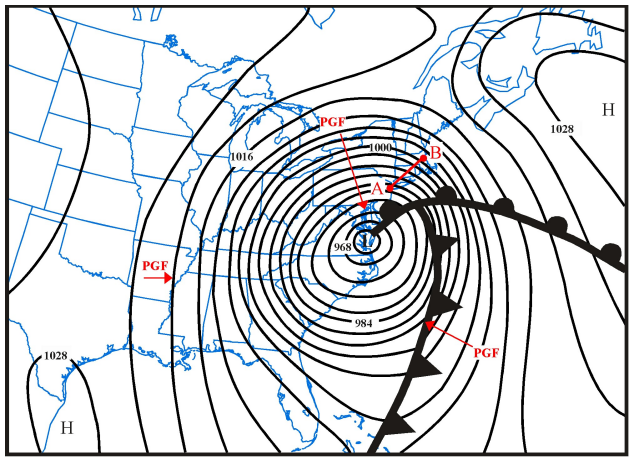
- The vertical pressure gradient is greater in cold air than in warm air, and to a lesser extent is greater in dry air than in moist air
- For example, this occurs within a dense Arctic air mass, where cold air is subsiding and spreading out at the surface
- What are the typical magnitudes of the vertical accelerations?

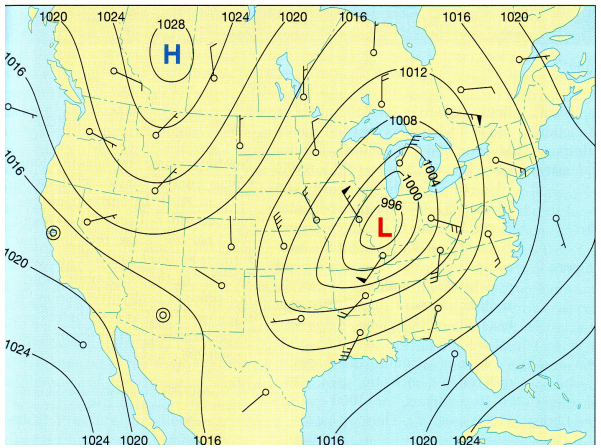
The Hydrostatic Equation

- ✓ Most large-scale downward (upward) motions are slow, averaging a few cm/s (less than 1 mile per day)
- ✓ However, some smaller-scale vertical motions are much more rapid (e.g., 10 m/s in a sea breeze front or 30 m/s within a severe thunderstorm)
- ✓ Fortunately these phenomena are sporadic and localized

Factors Affecting Wind
Pressure-Gradient Force (PG)

- ✓ Variations in air pressure over Earth's surface are determined from barometric readings taken at hundreds of weather stations.
- ✓ These pressure data are shown on surface weather maps by means of isobars (iso= equal, bar=pressure).
- ✓ The spacing of the isobars indicates the amount of pressure change occurring over a given distance (i.e., PG)



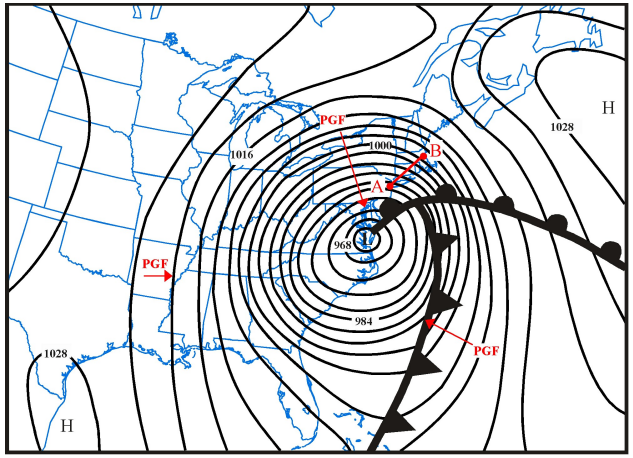


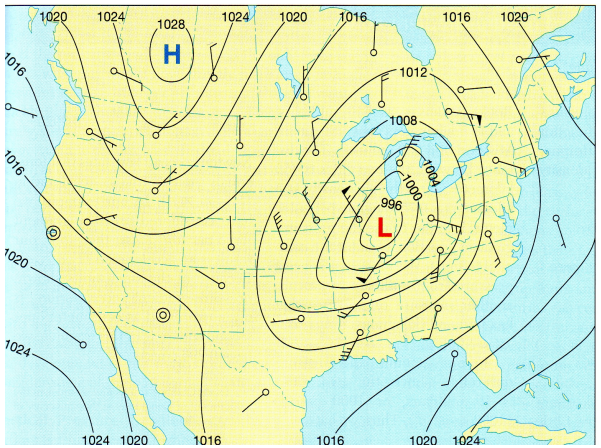
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◎	Calm
	1–2
	3–8
	9–14
	15–20
	21–25
	26–31
	32–37
	38–43
	44–49
	50–54
	55–60
	61–66
	67–71
	72–77
	78–83
	84–89
	119–123

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Factors Affecting Wind
Pressure-Gradient Force (PG)

- ✓ Analogous to the slope of a hill,
- ✓ Closely spaced isobars indicate a steep PG (steep hill) and strong winds.
- ✓ Widely spaced isobars indicate a weak PG (gentle hill) and light winds.
- ✓ Acceleration is thus downslope (i.e., from high to low pressure).





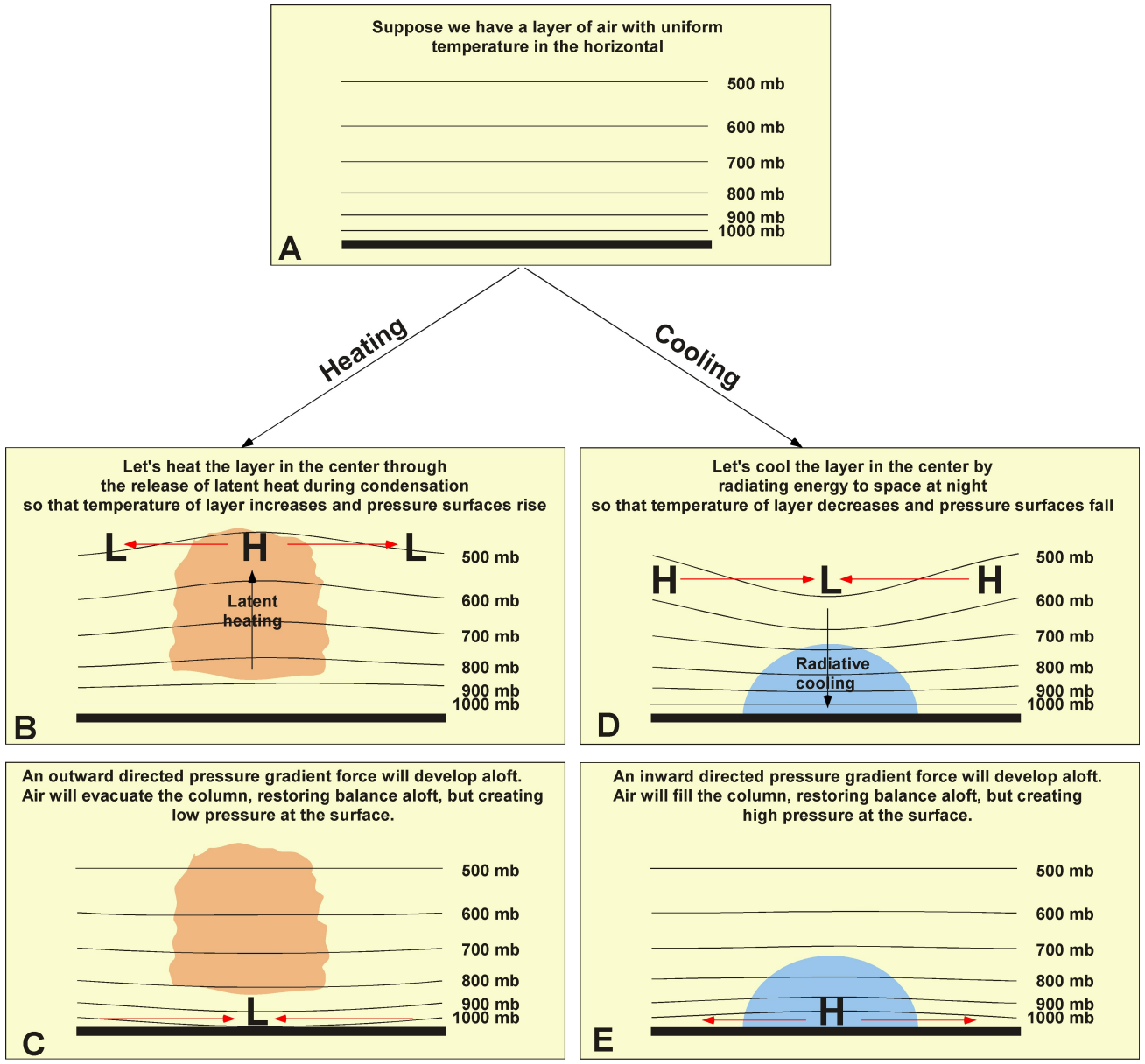
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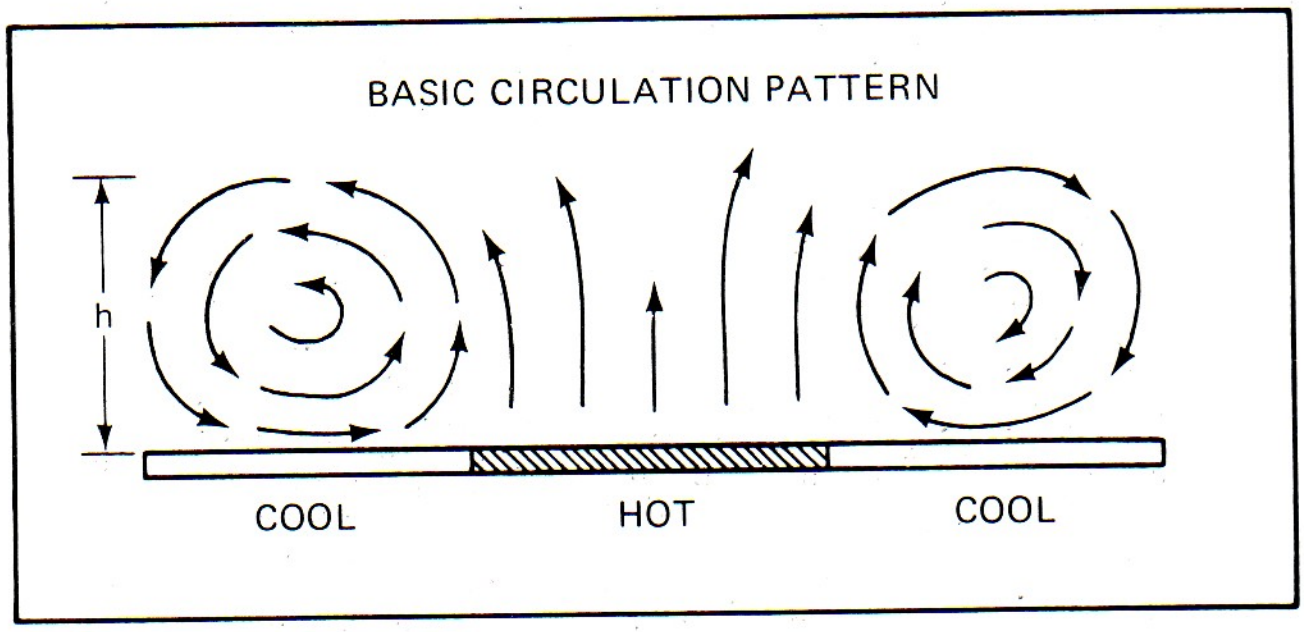
Factors Affecting Wind
Vertical Pressure-Gradients

- ✓ In summary, the horizontal PG is the driving force of wind.
- ✓ It has both magnitude and direction.
- ✓ Its magnitude is determined from the spacing of isobars, and the direction of force is always from areas of higher pressure to areas of lower pressure and at right angles to the isobars.
- ✓ By contrast, the vertical PG is usually in, or near, balance with gravity (G).
- ✓ Thus, upward and downward flow in the atmosphere is comparatively slow (with exception of localized updrafts and downdrafts).

Effects of Heating & Cooling

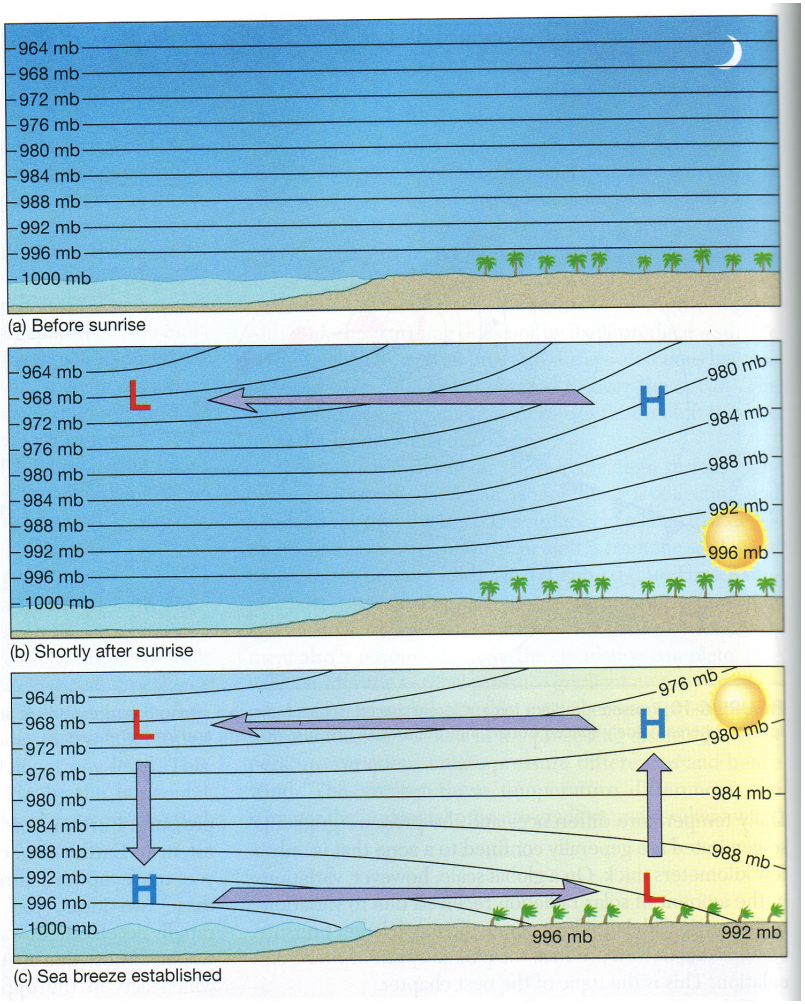


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BASIC CIRCULATION PATTERN
h
COOL
HOT
COOL

The Sea Breeze Circulation

- ✓ Before sunrise, equal pressure at equal height (i.e., PG = 0 and hence Wind = 0).
- ✓ After sunrise, the unequal rates at which land & water heat will initiate pressure differences and hence airflow.
- ✓ Later, during day, a simple thermal circulation develops, called sea breeze.
- ✓ Note that vertical movement also is required to make the circulation complete.



The Sea Breeze Circulation

