

**+Reading Assignment:**

- A&B: Ch. 1 (p. 1-18),  
Ch. 4 (p. 93-100)
- www: Atmosphere: Pressure & Gas laws

<http://www.nws.noaa.gov/>

## Introduction

- The sun's energy drives the *Earth-Atmosphere (E-A) system*
- Energy from the sun: *solar radiation*
- Amount of solar radiation to reach the surface of the Earth: 2 principal controls
  - i. the atmosphere (~ kind of filter)
  - ii. Earth-sun geometry (~ distance and exposure to solar radiation)

## 1. The Atmosphere

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- air = a *fluid*, and is constantly changing in its
  - motion (wind)
  - pressure distribution
  - temperature
  - composition / cloud cover

To understand this, need to consider a number of *characteristics of the atmosphere*:

## A. **Composition:**

- Permanent (dry) gases
- Variable Gases
- Greenhouse gases
- Ozone
- Suspended Particles

## B. **Temperature structure**

## C. **Pressure:**

- Definition, units
- Structure: Why are there more air molecules close to the surface
- Gas Laws, “Equation of State”
- Adiabatic Processes

## A. Composition

Air - MIXTURE - of many **discrete gases** (each with their own physical properties) and varying quantities of **solids** and **liquid particles** are suspended (aerosol, droplets)

- Composition is not Constant

◆ main **permanent gases** of clean, DRY air

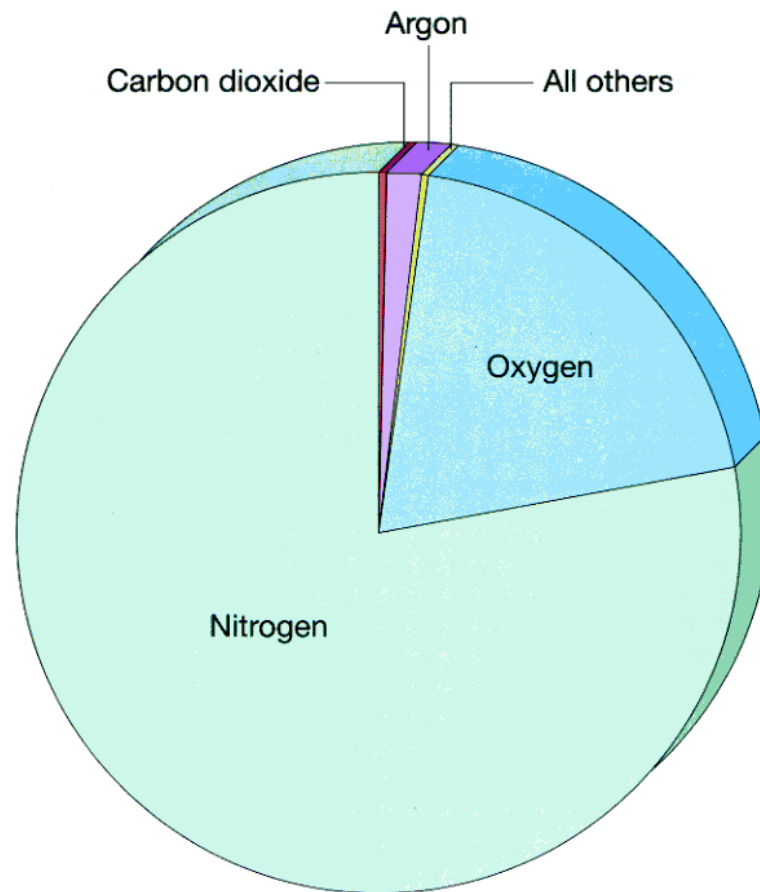
**Table I-1 Permanent Gases of the Atmosphere**

| 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             |

**Nitrogen** (N<sub>2</sub>, 78%) & **Oxygen** (O<sub>2</sub>, 21%)

- most plentiful
- have little or no importance in affecting weather

**Argon** (Ar, 1%): a noble gas with no effect



### Permanent Gases (from Lutgens & Tarbuck, 1998)

- ◆ **variable gases** - very important for weather and climate (despite their small amount)

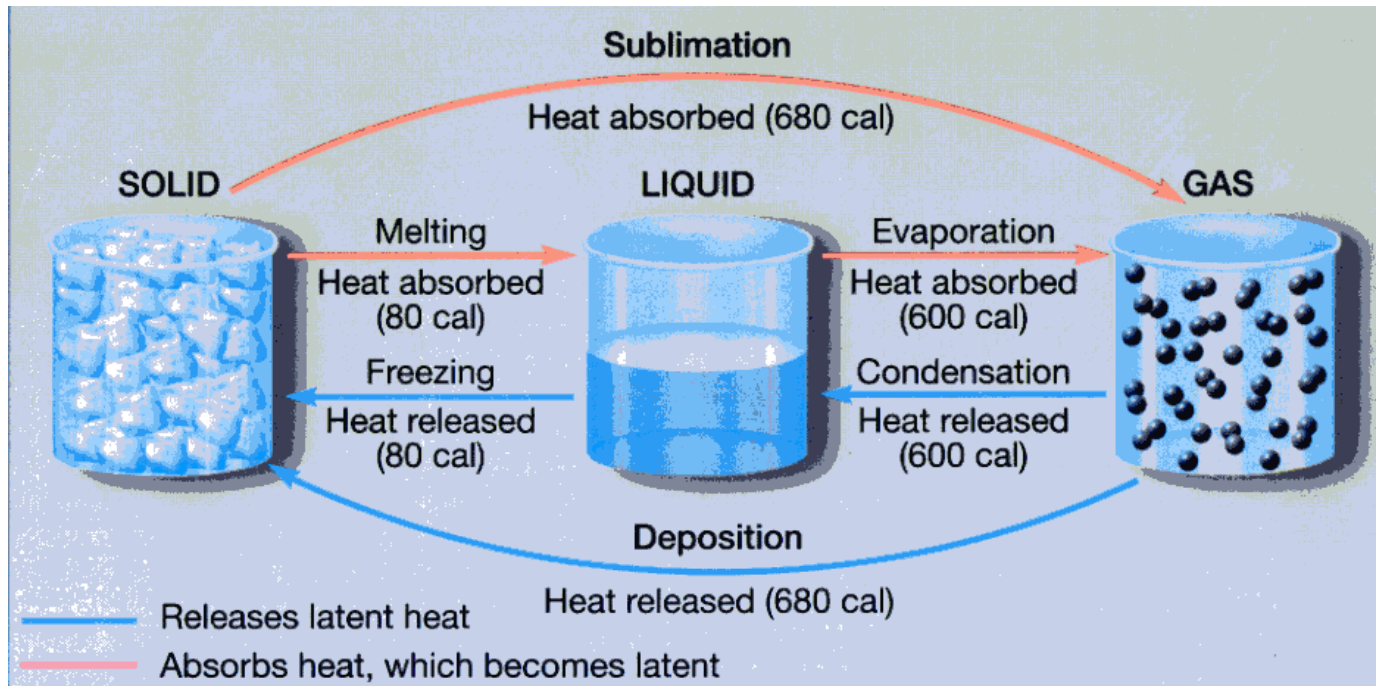
**Table 1-2 Variable Gases of the Atmosphere**

| Constituent    | Formula          | Percent by Volume | Molecular Weight |
|----------------|------------------|-------------------|------------------|
| Water Vapor    | H <sub>2</sub> O | 0.25              | 18.01            |
| Carbon Dioxide | CO <sub>2</sub>  | 0.036             | 44.01            |
| Ozone          | O <sub>3</sub>   | 0.01              | 48.00            |

## 1. Water Vapor

- greenhouse gas (~ 33 K)
- “weather maker”
- stores latent heat

**Three phases: solid  $\Rightarrow$  liquid  $\Rightarrow$  gas**



(from Lutgens and Tarbuck, 1998)

*Phase change* - takes energy  $\Rightarrow$   
 - releases energy  $\Leftarrow$

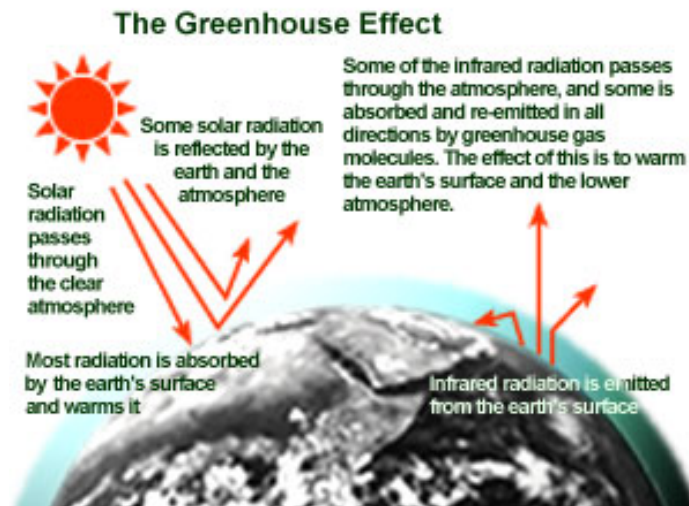
Latent heat of **vaporization**

Latent heat of **fusion**

Latent heat of **deposition**

## 2. Carbon dioxide

## Inset: Greenhouse Effect (A&B: p. 82-83)

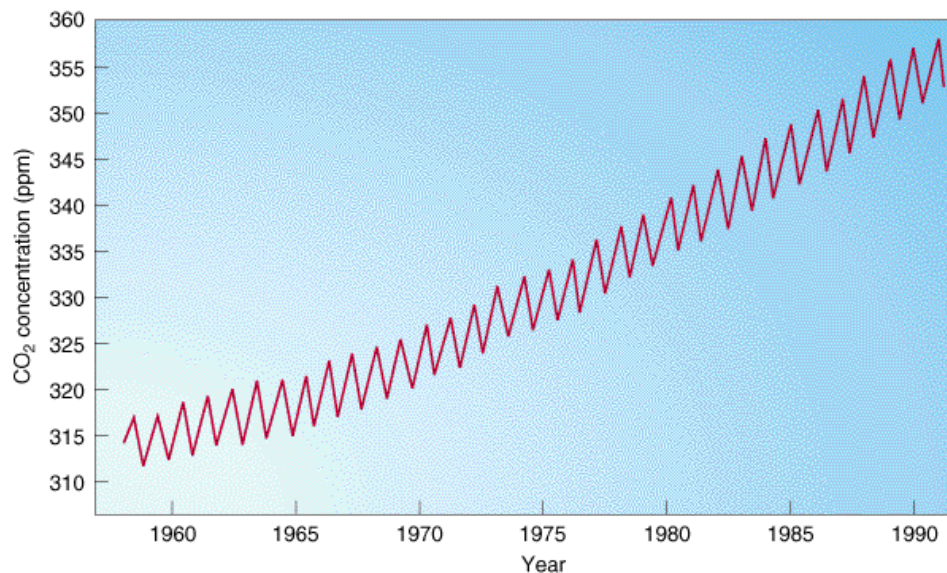


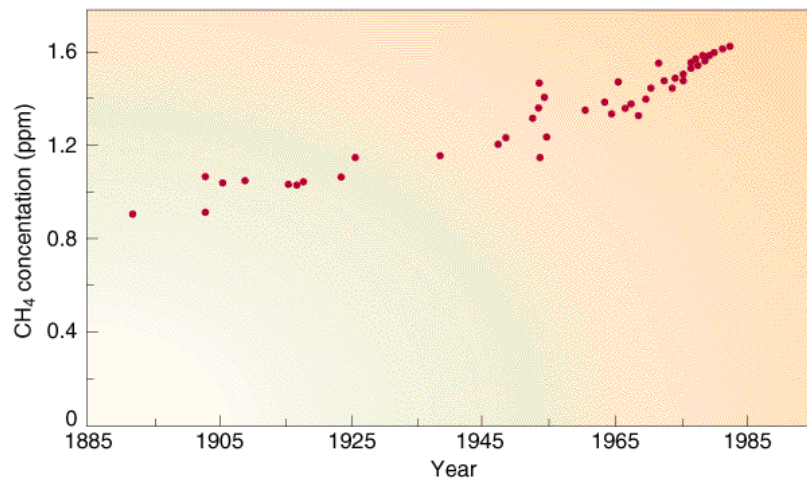
Most greenhouse gases occur naturally in the atmosphere, but some are significantly increased by human activities.

### Anthropogenic Greenhouse Gas Sources:

#### *a. Carbon dioxide:*

*Photosynthesis and Decomposition/Combustion form the Global Carbon Cycle (A&B - focus: 1-1)*



**b. Methane:**

(see also A&B Figure 1-6)

**c. Nitrous oxide:** (laughing gas)

Greenhouse gases -- not naturally occurring

- include byproducts of foam production, refrigeration, and air conditioning called *chlorofluorocarbons (CFCs)*, as well as *hydrofluorocarbons (HFCs)* and *perfluorocarbons (PFCs)*

generated by industrial processes.

Most of these also contribute to *Ozone Hole* in the stratosphere (A&B - focus: 1-2).

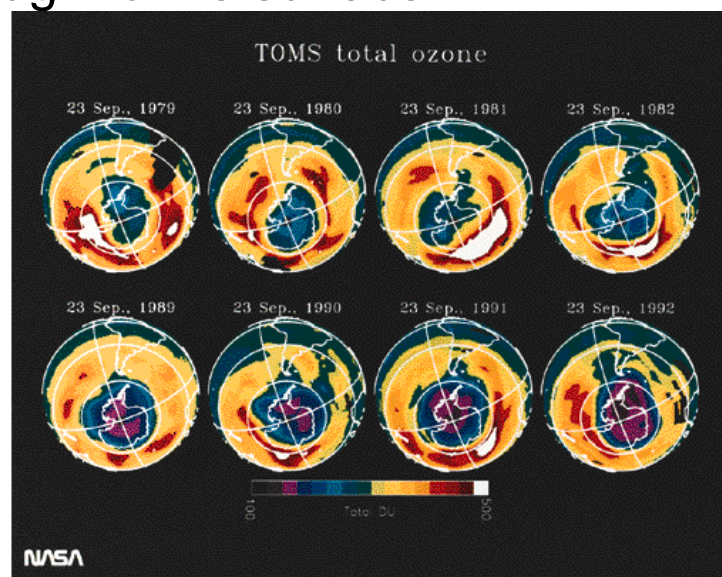
- HFCs and PFCs are the most heat-absorbent.
- Methane would trap over 21 times more, and Nitrous Oxide 270 times more heat than CO<sub>2</sub>, if they had the same concentration.

(back to variable gases...)

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

- At the **surface** – a noxious pollutant
- In the **stratosphere** - essential for life !!

(CFCs etc., see **A&B - focus: 1-2**) deplete ozone to form the antarctic/arctic **Ozone Hole**, which lets harmful UV radiation through to the surface.



**Also present in the atmosphere:**

### 4. Aerosol = tiny suspended particles/droplets

- most are invisible
- smaller they are the longer they are likely to stay in the atmosphere
- in average air ~ 1000 particles in 1 cm<sup>3</sup> (the size of the tip of your little finger)

**Natural:** sea salt, pollen, soil, volcanic dust

**Human:** smog, soot, industrial dust

**Very important meteorologically:**

- a) many are water absorbent
- b) dust may absorb and reflect radiation
  - noticeable decrease in  $K\downarrow$

$K\downarrow$  - incoming solar or shortwave radiation

All of these variable constituents:

- variations from natural & from human causes
- change by latitude, geography, season, time of day, weather patterns, volcanic activity, solar activity etc.

## Vertical Variations of Composition

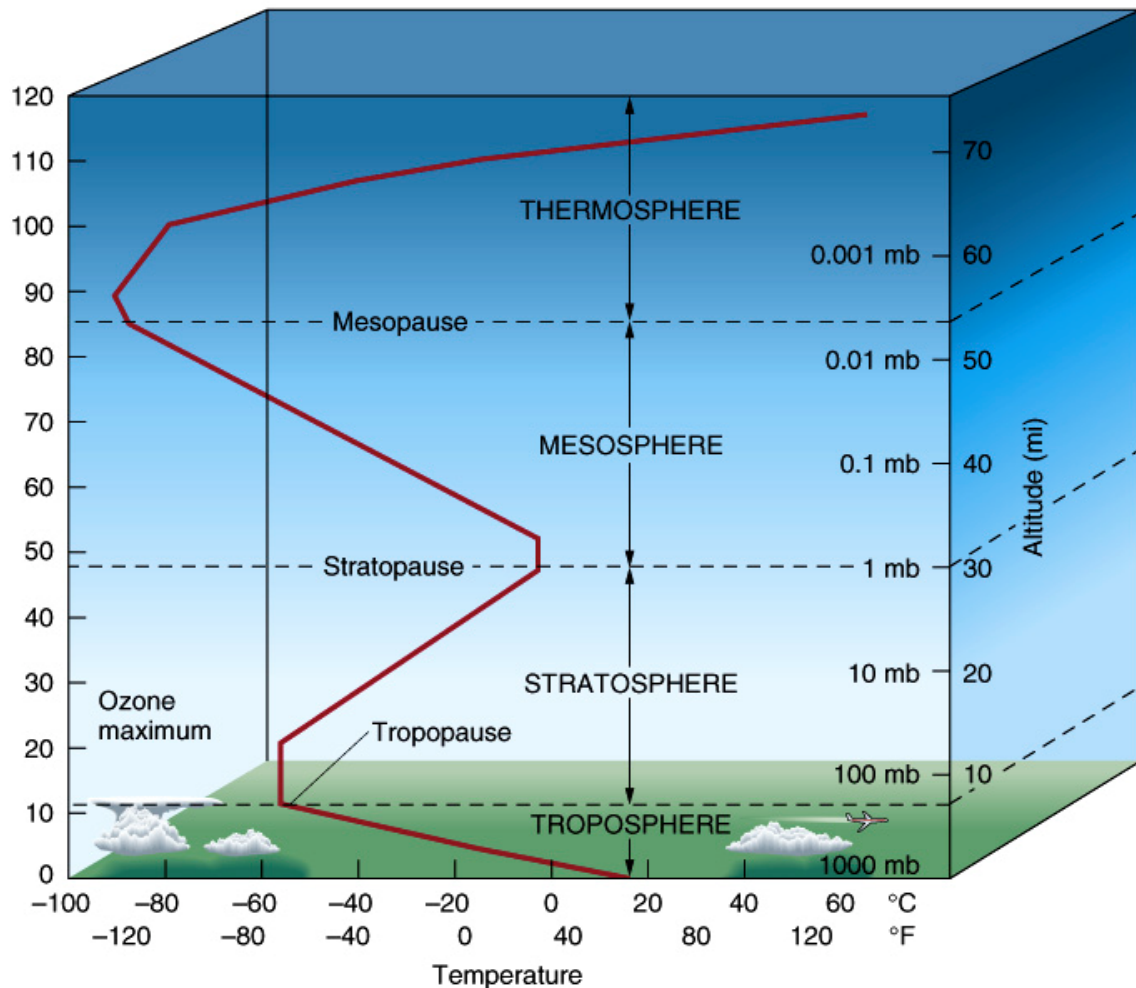
Two layers

1. **Homosphere:** 0-80 km
2. **Heterosphere:** > 80 km

## B. Temperature Structure

### Vertical Structure of the Atmosphere

- Convenient way to distinguish **layers**: by the **temperature profile**



## 1. **Troposphere:** (greek: “overturning”)

- 0 ~ 10 km
- **Temperature decrease** with height:  
~ 6.5 °C/km (due to adiabatic cooling)
- Strong vertical **mixing** (cumulonimbus clouds)
- Contains **80%** of the atmospheric **mass**
- Contains **almost all** atmospheric **H<sub>2</sub>O**
- Called the “**weather layer**”

→ **Tropopause:** very cold (**1st cold trap**), boundary between troposphere and stratosphere; start of temperature inversion

## 2. **Stratosphere**: (greek: “lying flat”)

- 10 ~ 50 km
- **Temperature increase** with height: temperature inversion, due to
- **Absorption of UV-radiation by Ozone**: the “Ozone Layer”
- **Temperature inversion**: stable layering, **reduced vertical mixing**

→ **Stratopause**: boundary between stratosphere and mesosphere; upper end of temperature inversion

## 3. **Mesosphere**: (greek: “middle layer”)

- 50 ~ 90 km
- **Temperature decrease** with height (almost adiabatically)
- Upper part: **coldest part** of the atmosphere

→ **Mesopause**: extremely cold (**2<sup>nd</sup> cold trap**), boundary between mesosphere and thermosphere; start of temperature inversion

## 4. **Thermosphere**: (greek: “hot layer”)

- above ~ 90 km
- **strong temperature increase** with height (temperature inversion), due to
- **absorbption of UV-radiation** by **O<sub>2</sub> and N<sub>2</sub>**

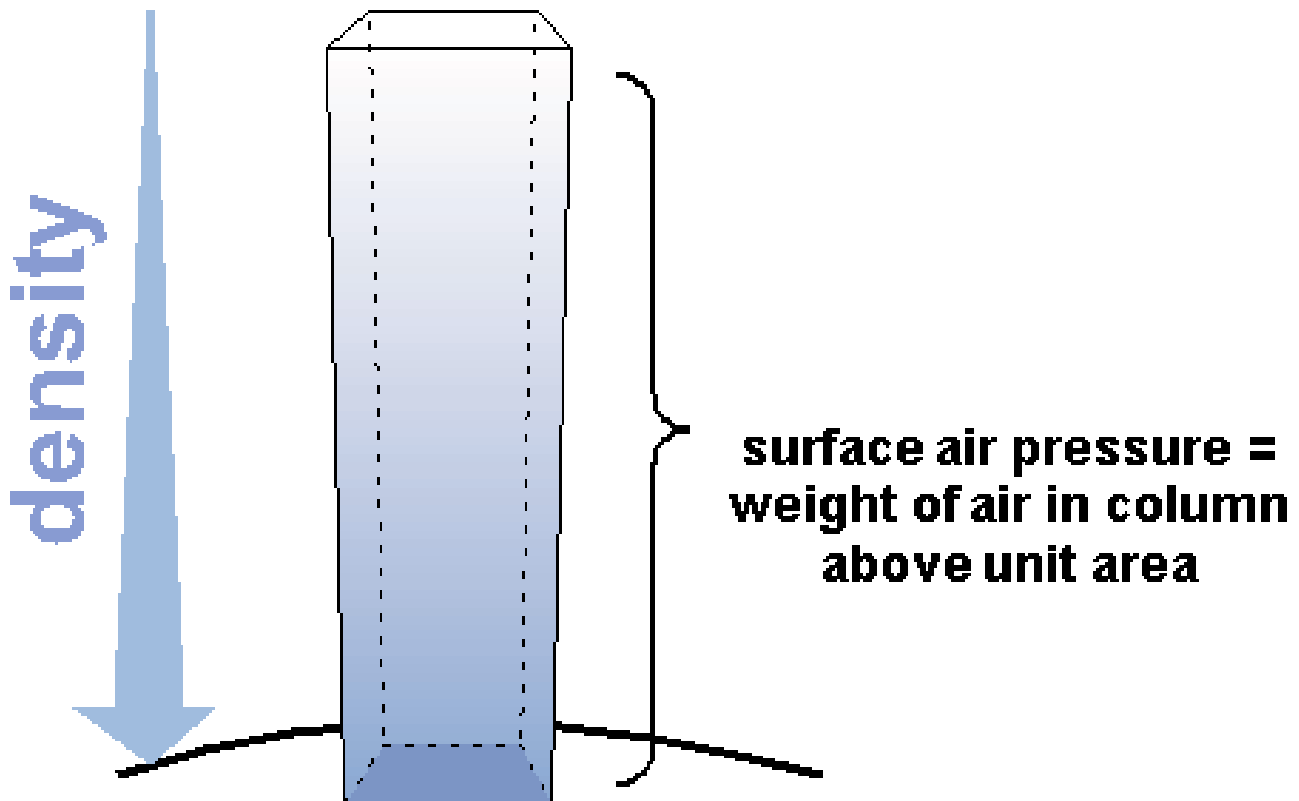
- 
- extremely “thin” atmosphere (temperature high, but almost no mass: energy content is low)
  - no defined upper end

## C. Pressure

### Pressure Profile of the Atmosphere

Read: A&B p. 105-112, Web page, LM 3

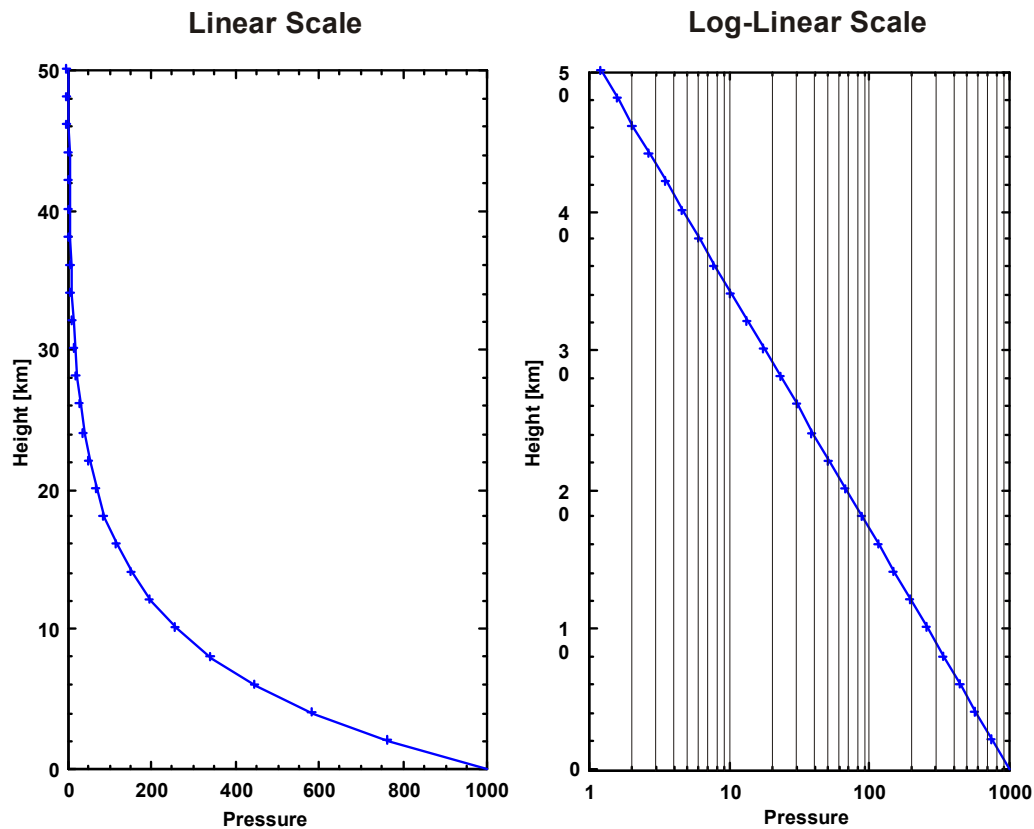
- Pressure := Force/Area
- Units: - SI-unit: [Pa], [kPa]  
- meteorology: "millibar" mb = 100 Pa
- Atmospheric Pressure := weight of air above/area



## Measurements show (on average):

| height (km) | Pressure (mb)   | Fraction of $P_0$ |
|-------------|-----------------|-------------------|
| 0           | 1000 (= $P_0$ ) | 1                 |
| 6           | 500             | 1/2               |
| 12          | 250             | 1/4               |
| 18          | 125             | 1/8               |
| 24          | 63              | 1/16              |
| ...         | ...             | ...               |

- Decrease of pressure is **not linear**: **negative exponential**:



→ plots as a **straight line on semi-logarithmic graph**  
[log(height) vs. pressure]

- Pressure: important **variable** describing the **thermodynamic state** of the atmosphere (with Temperature and density)

→ see **Gas Laws – Equation of State:**  
(www, LM 3, A&B: p 109-110):

$$P = \rho T R_d$$

P: pressure [Pa = kg m<sup>-1</sup> s<sup>-2</sup>]

$\rho$ : density (“rho”) [kg m<sup>-3</sup>]

T: abs. temperature [K]

$R_d$ : spec. gas constant for dry air  
= 287 [J kg<sup>-1</sup> K<sup>-1</sup> = m<sup>2</sup> s<sup>-2</sup> K<sup>-1</sup>]

### Useful conversions

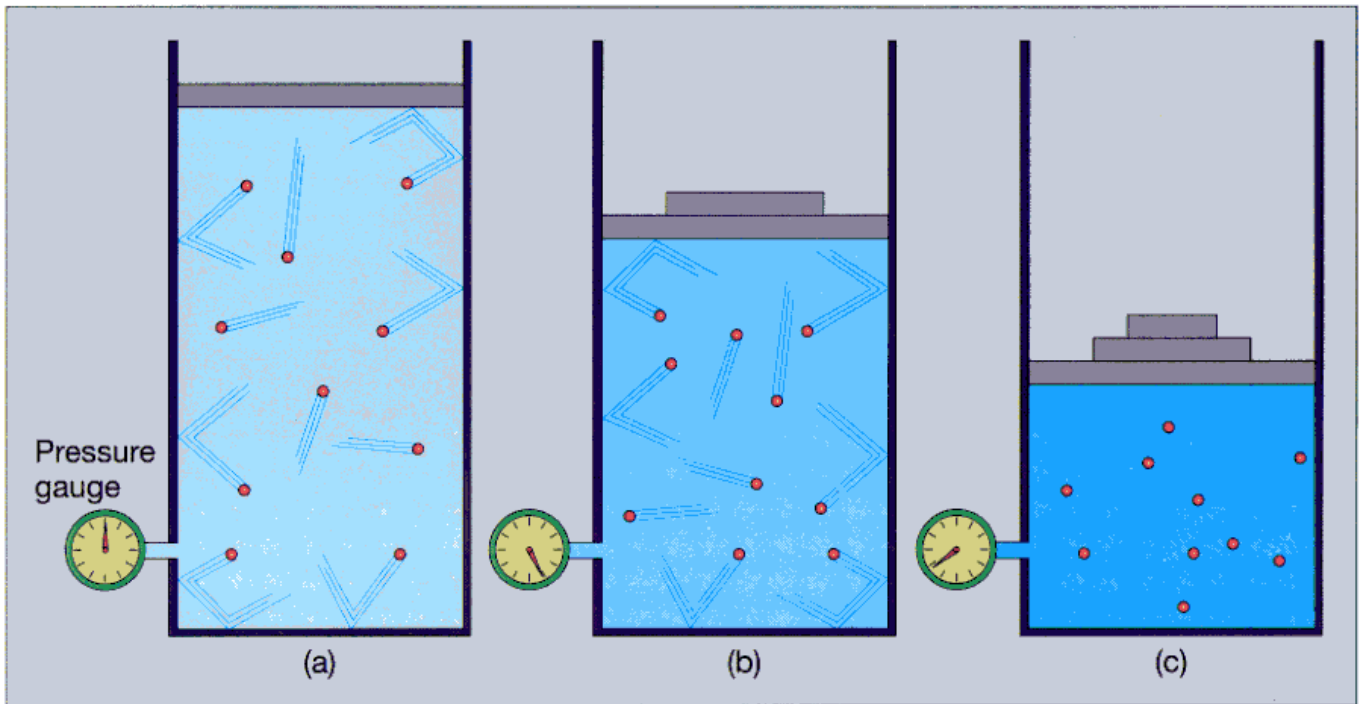
$$J = \text{kg m}^2 \text{ s}^{-2}$$

$$10^{-2} \text{ mb } [0.01] = \text{Pa or, mb} = 10^2 \text{ Pa } [100]$$

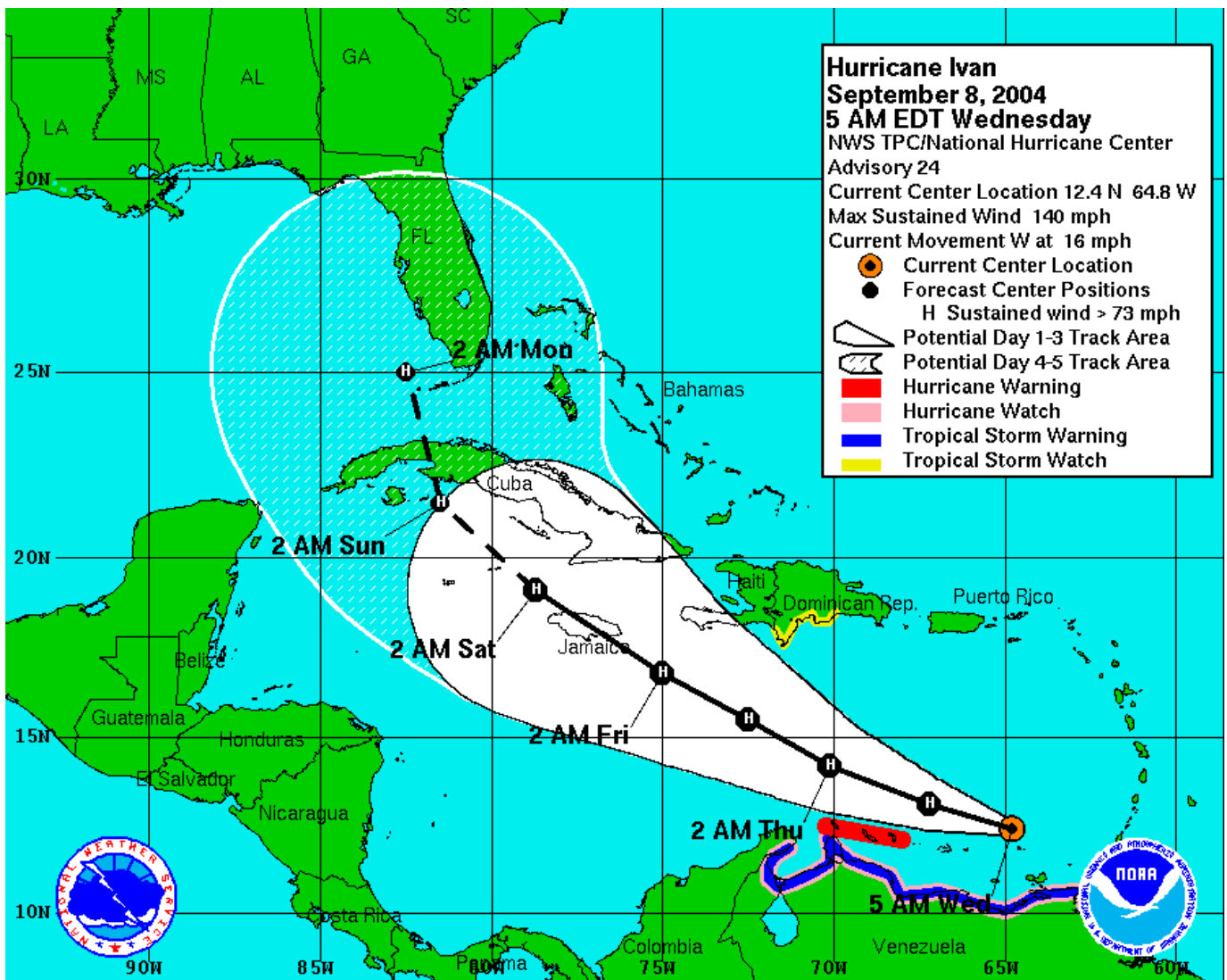
$$\text{kPa} = 10^3 \text{ Pa } [1000] = 10 \text{ mb}$$

$$\text{Pa} = \text{kg m}^{-1} \text{ s}^{-2}$$

$$^\circ\text{C} = \text{K} - 273.16$$



(from Lutgens & Tarbuck, 1998) – *density relationship*



Currently Hurricane Ivan has gone from a Category 3 (945-965) to a Category 4 (920-945 mb). Assuming that density remained constant (which it wouldn't) at  $1.225 \text{ kg m}^{-3}$  and using the lower limits of the pressure range, what would be the temperatures in K and in  $^{\circ}\text{C}$ ?

*Remember: (convert pressure to Pa in the EQ.)*

$$P = \rho T R_d \quad \text{so: } T = \frac{P}{\rho R_d}$$