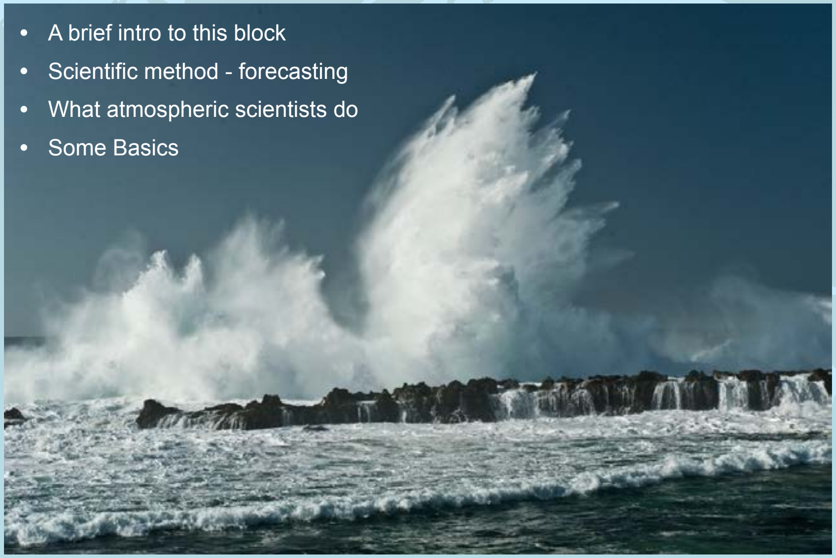
# MFE 659 Lecture 1a Intro



- A brief intro to this block
- Scientific method - forecasting
- What atmospheric scientists do
- Some Basics

# Science

- What is it that defines science?
- How is science distinguished from other academic endeavors (e.g, history or English)?
- Why is creationism or intelligent design not considered science by scientists?

# Science is about Observing

"No amount of experimentation can ever prove me right; a single experiment can prove me wrong." Einstein

"We live in a scientific age, yet we assume that knowledge of science is the prerogative of only a small number of human beings, isolated and priestlike in their laboratories. This is not true. Science is part of the reality of living; it is the what, the how and the why of everything in our experience."

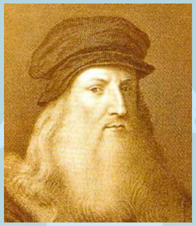
Rachel Carson (Silent Spring)

---

"Evolution is a theory. It is also a fact. Facts and theories are not rungs in the hierarchy of increasing certainty. Facts are the world's data. Theories are the structures of ideas that explain and interpret facts. Facts do not go away while scientists debate theories to explain them. Einstein's theory of gravitation replaced Newton's, but apples did not suspend themselves in midair pending the outcome."

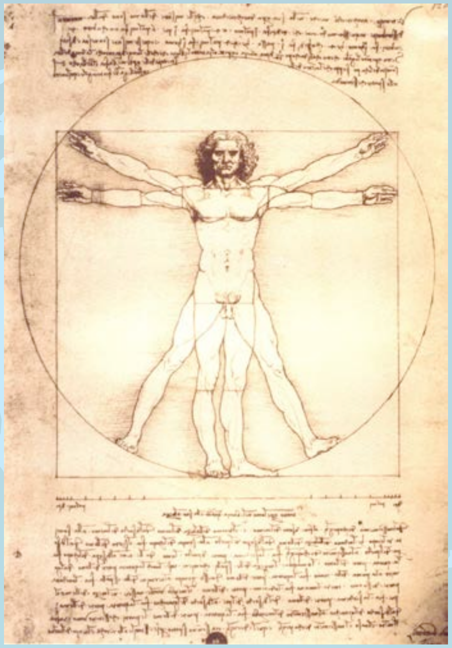
Stephen Jay Gould

---



# da Vinci

1452-1519



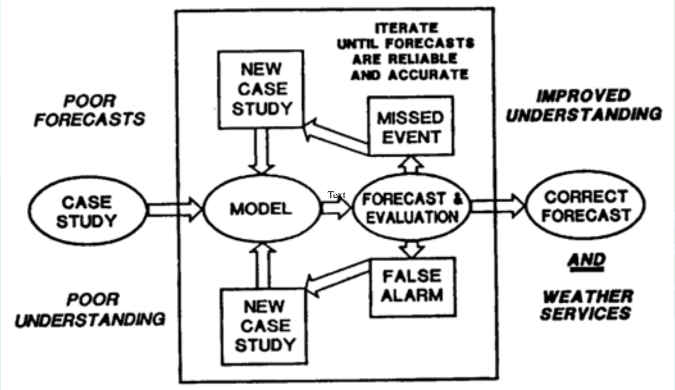
- Study available literature
- Systematic observations
- Experimentation
- Careful repeated measurements
- Formulation of theoretical models
- Frequent attempts at mathematical generalizations

---

# Scientific Method

- Our understanding of the world grows as our theories become more complete and precise.
- The scientific method involves the dynamic interplay between theory and experiment.
- A key to science is the scientific method, in which the results of a good experiment can be reproduced. The same experiment using the same hardware will produce the same results time after time.
- If a hypothesis can not be experimentally tested then it falls outside the current realm of scientific understanding or knowledge, and is considered "speculation."

# FORECASTING



Weather Forecasting as an iterative process is a prime example of the scientific method.

# Atmospheric Scientist

use scientific principles to observe, understand, explain, or forecast the atmosphere's behavior.

# Fields in Atmospheric Science

Fields in meteorology include

- Agricultural and forest meteorology
- Atmospheric chemistry
- Aviation/navigation weather
- Biometeorology
- Climate
- Dynamic meteorology
- Global climate change
- Instrument development
- Mesoscale meteorology
- Micrometeorology
- Paleoclimatology
- Tropical meteorology
- Extra-terrestrial atmospheres

# Jobs in Atm. Sci.

- Weather Forecaster
- Forensic meteorologist
- Air-quality meteorologist
- Research in all the sub-fields
- Teaching, Etc…

# Employers

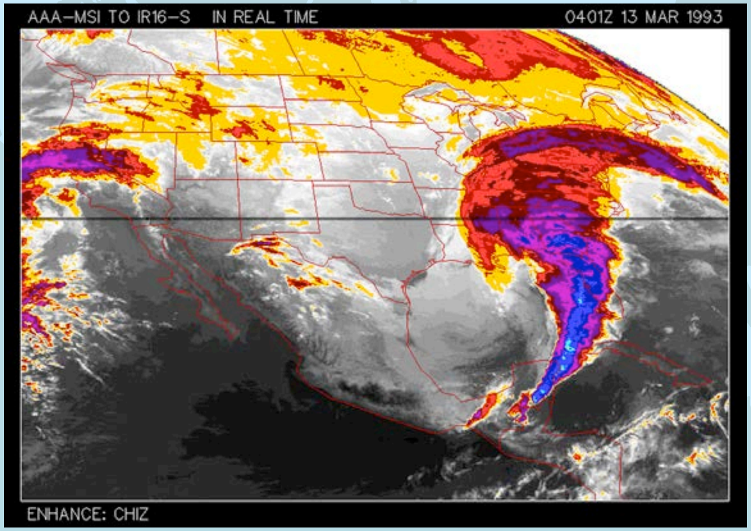
- Federal Government
  - NOAA (NWS), EPA, NASA, DoE, FAA, etc.
- Military
  - Air Force, Navy, Army, etc.
- Civilian
  - Airlines, Investment firms, Instrument makers, Law Firms, Utilities, Agriculture, Forecasting …Accuweather, TV Stations, etc…

# Atmospheric Science at the University of Hawaii?

- There are 14 faculty and about 40 students in the UH Met department
- We each have research specialties
  - Weather prediction
  - Dynamical meteorology
  - Atmospheric physics
  - Climate change
  - Etc.

---

# My Specialty is Bad Weather



---

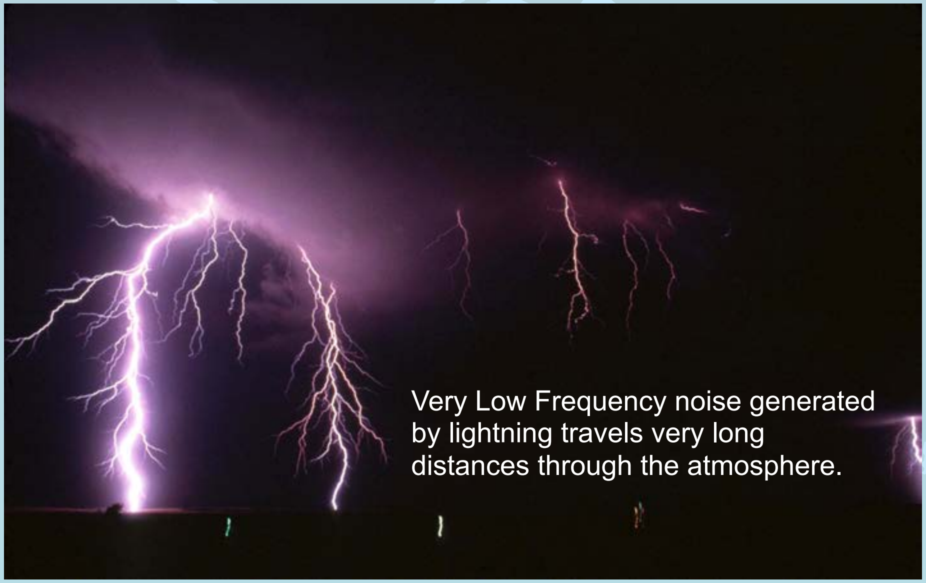
# My Specialty is Bad Weather

Hazardous Weather Causes Loss of Life and $Billions in Damage to Property and Lost Crops.

*Goal: To find new ways to observe and model our atmosphere to better understand and predict the storms that cause the weather hazards.*

---

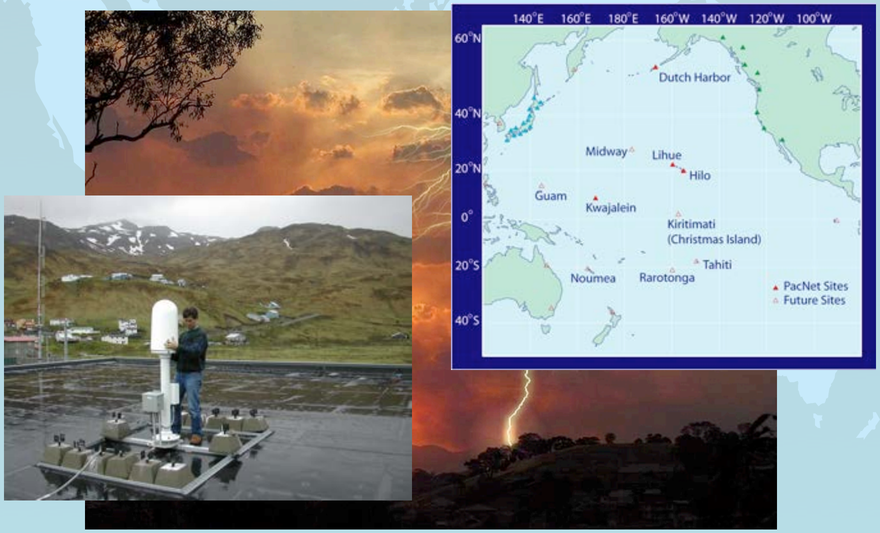
# Detecting Lightning with a Radio



Very Low Frequency noise generated by lightning travels very long distances through the atmosphere.

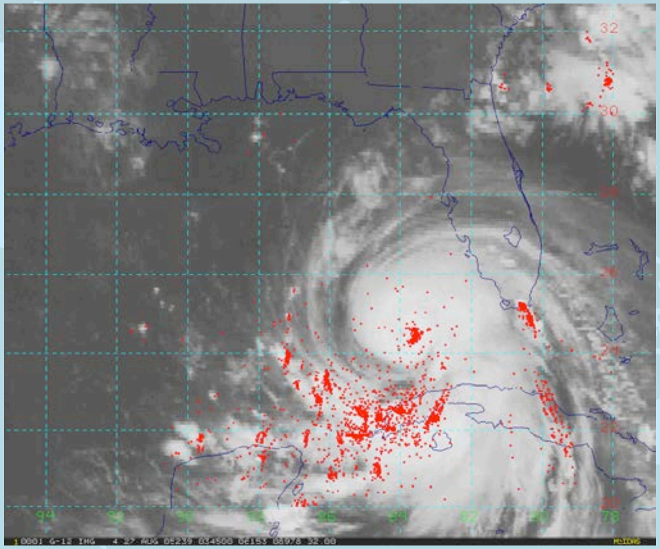
# Detecting Lightning with a Radio

This noise can be detected by a network of special receivers located on remote Pacific islands.



---

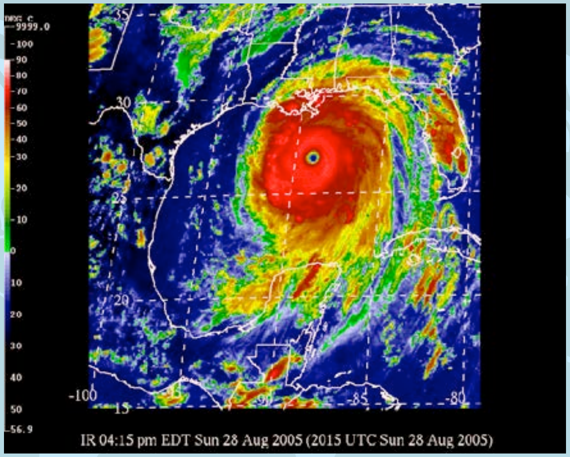
# Studying Hurricanes



Water the Engine that Fuels Storms

---

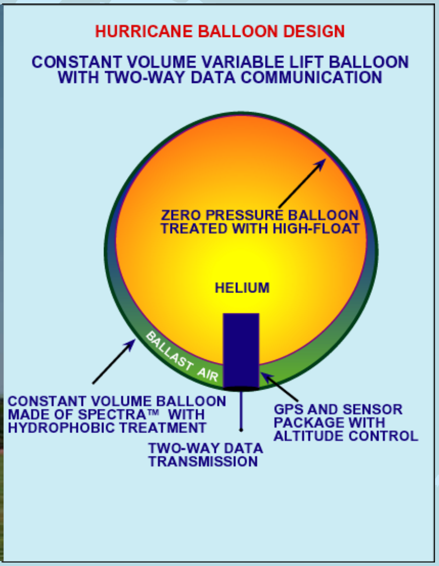
# Studying Hurricanes



- We know hurricanes gain their energy (water vapor) from the ocean, but we are not exactly sure how they do this.
- Airplane pilots will not fly through hurricanes near the ocean surface. So how do we make the critical measurements that we need?

---

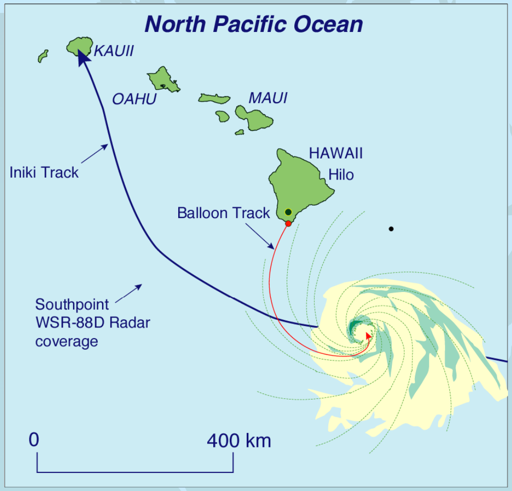
# Developing a Hurricane Balloon



**HURRICANE BALLOON DESIGN**

**CONSTANT VOLUME VARIABLE LIFT BALLOON WITH TWO-WAY DATA COMMUNICATION**

# Developing a Hurricane Balloon



Release in Hawaii

---

# Background: Some Basics

## Outline

- Some Basic Variables
- Force Balance and Wind in the Atmosphere
- Laws of Radiation
- Earth's Radiation Balance
- Greenhouse Effect

---

# Some Basics

Some quick definitions used in this block

Velocity – distance per unit time, m/s

Acceleration – change in velocity per change in time, m/s$^2$

Force – mass times acceleration, Newton, kg*m/s$^2$, 1N = 102 gm

Energy (Work) – force over a distance: Joule, J = Nm = kg*m$^2$/s$^2$

Power – energy per time, Watt = J/s = Nm/s = force x speed

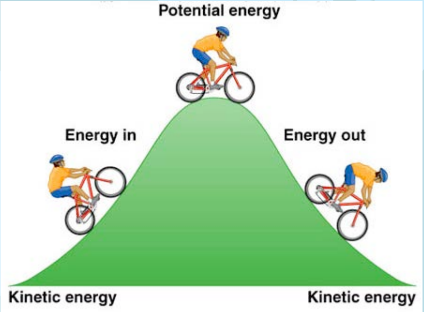
---

# The Definition of Energy

Energy – the ability to do work

Two familiar types

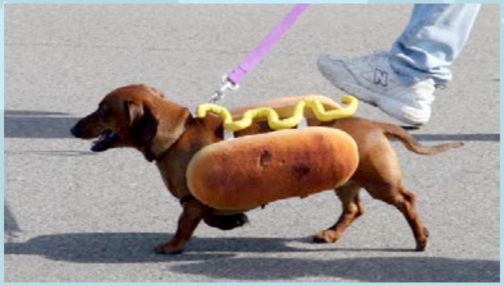
1. Kinetic energy – the energy of motion: $K = 1/2mV^2$
2. Potential energy – stored energy: $P = mgh$



KE = 1/2 x mass x velocity$^2$

# Temperature

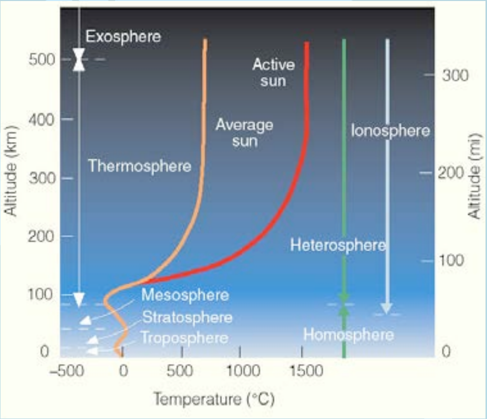
- The degree of hotness or coldness of an object.
- The higher the temperature the greater the energy of motion of the molecules.
- Temperature is proportional to the average kinetic energy of the air molecules.



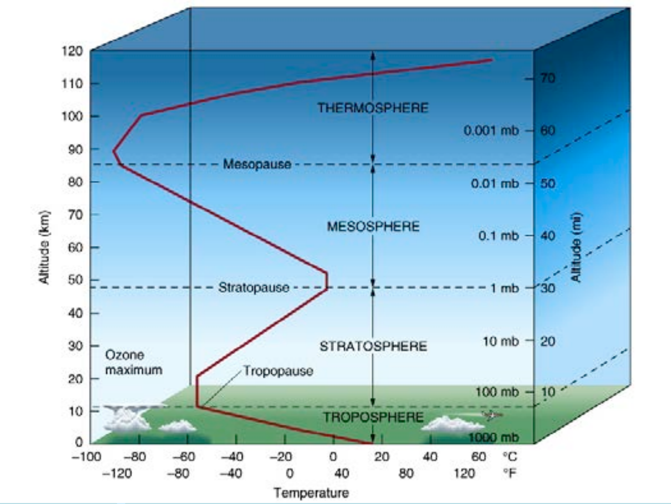
# Characterizing with Temperature

Standard Atmosphere

- Troposphere (lowest)
- Stratosphere
- Mesosphere
- Thermosphere (highest)



# Vertical Structure of Atmosphere

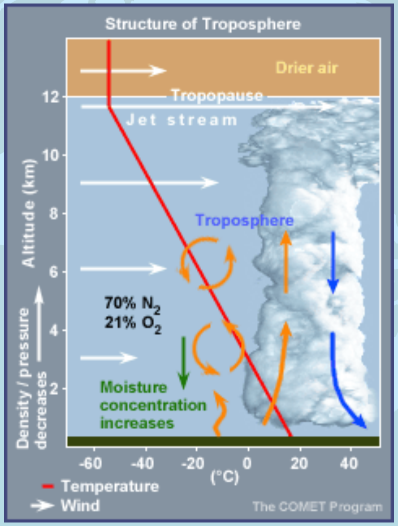


Characterizing Structure with Temperature

# Troposphere

The warm air of the stratosphere acts as a lid on updrafts in the troposphere.

The stratosphere is warm because of absorption of UV sunlight by ozone.



# Stratosphere puts a lid on the weather

---

# Pressure

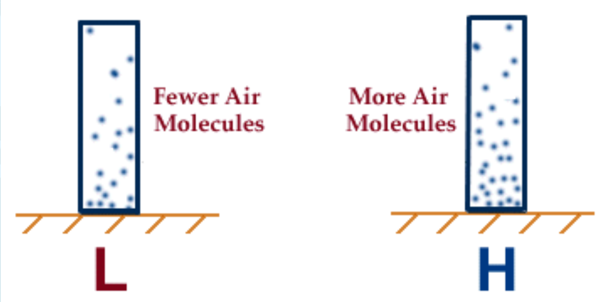
The force exerted against a surface by continuous collisions of gas molecules.

Pressure depends on:

1) The speed of the molecules
2) Mass of molecules
3) Frequency of their impacts

---

# Pressure



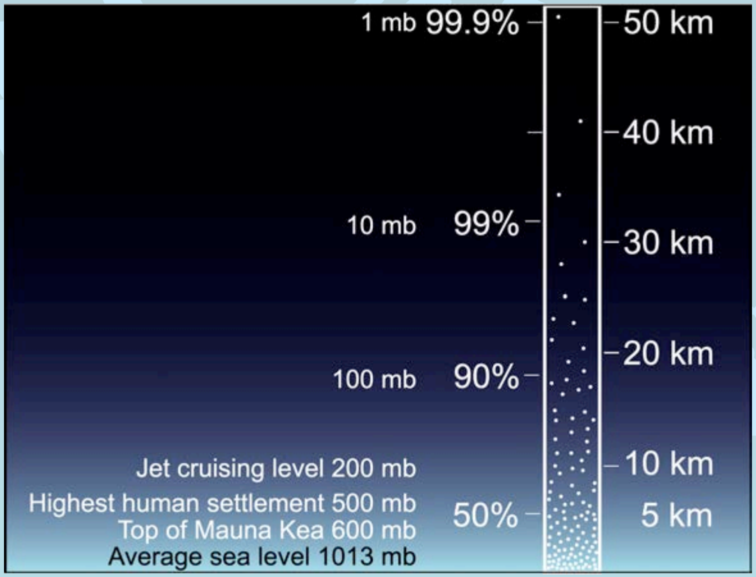
The force exerted on a surface is equal to the weight of the air in a column from that surface to the top of the atmosphere.

---

# Pressure

A column of air 1 m$^2$ (11 sq ft) weighs about 100 kilo-newtons (equivalent to a mass of 10.2 metric tons at the surface).

# Pressure Decrease with Altitude



# Relationship between Pressure Temperature and Density

Ideal Gas Law – Pressure is proportional to the density of the air times the temperature of the air.

P = Constant x T x D or $P = \rho RT$

Charles Law – At constant volume (e.g., a closed can) pressure is proportional to temperature.

P = Constant x T

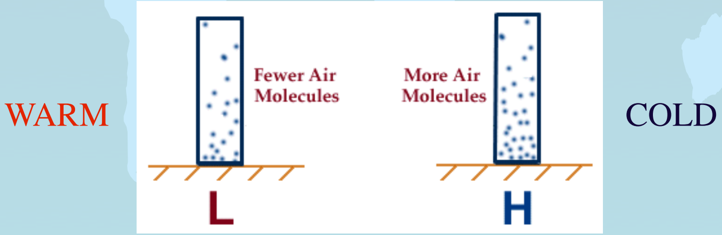
For demo link:

http://intro.chem.okstate.edu/1314F00/Laboratory/GLP.htm

# Relationship between Pressure & Temperature in the Atmosphere

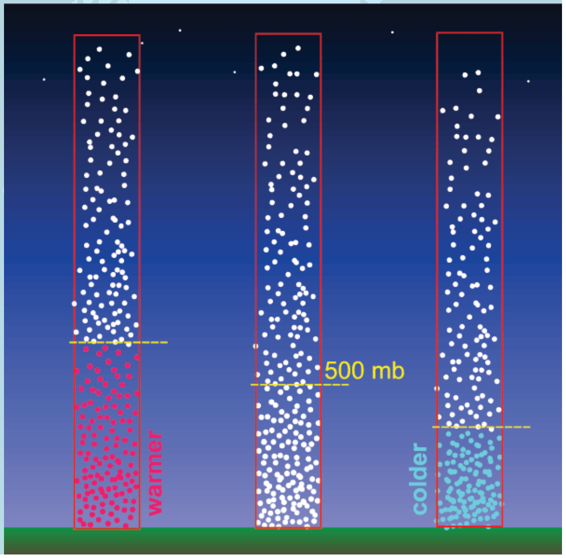
Warm air molecules move faster than cold air molecules, therefore, they take up more space in the atmosphere (because the atmosphere is not a closed container).

Since surface pressure is the weight of all the overlying air molecules, areas of warm air relative to their surroundings will have lower surface pressure.



# Relationship between Pressure & Temperature in the Atmosphere

Warm air in the tropics and cold air over the poles results in a change in pressure as you move horizontally. This "pressure gradient" is responsible for the formation of the jet stream, a river of fast moving air in the upper troposphere.



# Heat

- Heat is a transfer of energy from a warmer object to a colder object.
- Heat makes things warmer.
- Heat is measured in units called calories.
- A calorie is the heat (energy) required to raise one cubic centimeter of water by 1˚C.

# Heat in the Atmosphere

There are four ways in which heat is transferred.

1. Radiation – heat transfer by electromagnetic waves, which are emitted by all objects.
2. Conduction – heat transfer by direct contact.
3. Convection – heat carried by currents.
4. Latent heat – hidden heat associated with changes of state (aka phase).

# Moist Convection

Almost a daily occurrence in Hawaii over the mountains -- caused by surface heating, rising buoyant plumes, and the release of latent heat in clouds

# Important Heat Concepts

Heat capacity – amount of heat that must be added to a gram of substance to achieve a 1˚C change in its temperature. (e.g., water has a higher heat capacity than air)

Sensible heat – heat that can be measured (sensed) by a thermometer.

Latent heat – heat required/released when a substance changes from one state to another. (Latent means hidden in latin, e.g., heat when added/removed from a substance does not change its temperature when a change in state occurs.)

# Wind

Motion in the atmosphere is the result of the action of forces.

The equation that describes the forces that cause the acceleration of the wind is the momentum equation.

Many consider the momentum equation to be the most important equation in meteorology.

---

# Forces and Wind

Wind in the Atmosphere is measured by

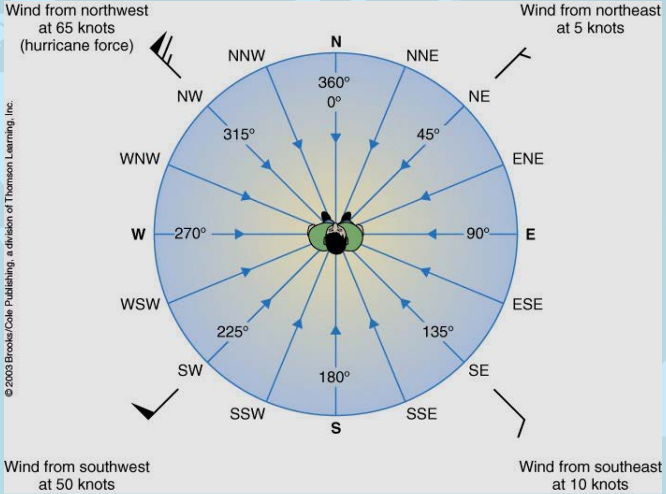
Anemometer (10 m tower)

Doppler Radar (rain)

Radiosonde (balloon)

---

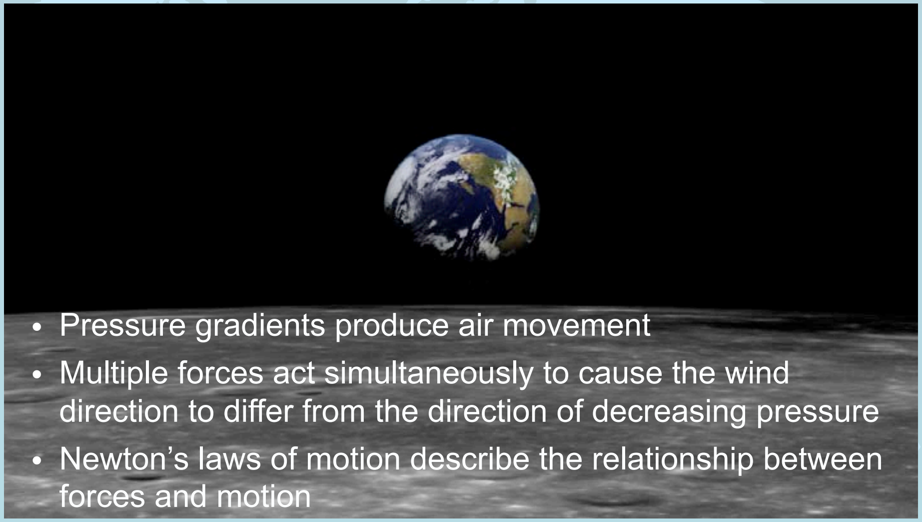
# Forces and Wind



Wind data are plotted using the convention above.

---

# Forces and Winds



- Pressure gradients produce air movement
- Multiple forces act simultaneously to cause the wind direction to differ from the direction of decreasing pressure
- Newton's laws of motion describe the relationship between forces and motion

# Forces and Wind

A force is a pushing or pulling that will result in motion if it is unopposed.

## Newton's Laws of Motion

1. In the absence of forces an object at rest will remain at rest and an object in motion will remain so with the same velocity.
2. Force equals mass times acceleration (F = m·a)
3. To every action there's an equal and opposite reaction.

# What are the macro-scale forces that operate in the Earth's atmosphere?

There are only five:

| | |
|---|---|
| 1. Pressure Gradient | PG |
| 2. Gravity | g |
| 3. Coriolis | $C_o$ |
| 4. Friction | $F_r$ |
| 5. Centrifugal | $C_e$ |

# Five Forces

Pressure gradient – a change in pressure over a distance.

Gravity ~ acceleration due to the Earth's gravitational field; directed downward.

Coriolis – a fictitious force due to the rotation of the Earth underneath the air as it moves. $C_o$ is proportional to the velocity and varies from a maximum at the poles and zero on the equator.

Friction – acts to dissipate motion into heat, converting motion into heat through turbulence. Friction is greatest at the ground and it influence decreases upward until it vanishes at ~ 1 km height.

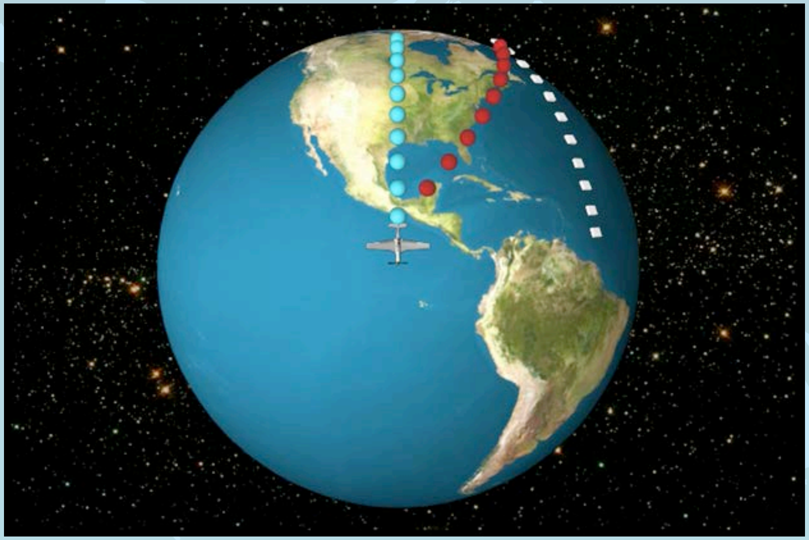
Centrifugal – a fictitious force due to the fact that an object will continue to move in a straight line unless acted on by an unbalanced force.

# Coriolis Force

$$F_c = 2\Omega v \sin\phi$$

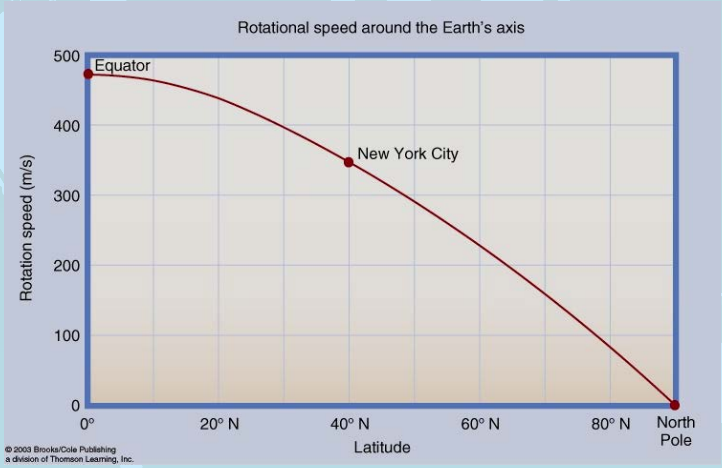
- $C_O$ = Coriolis Force
- $\Omega$ = Earth rotation
- V = Wind Speed
- $\phi$ = Latitude

# Coriolis Force



Apparent force due to rotation of the earth

# Coriolis Force



Rotation speed due to rotation of the earth

# Momentum Equation

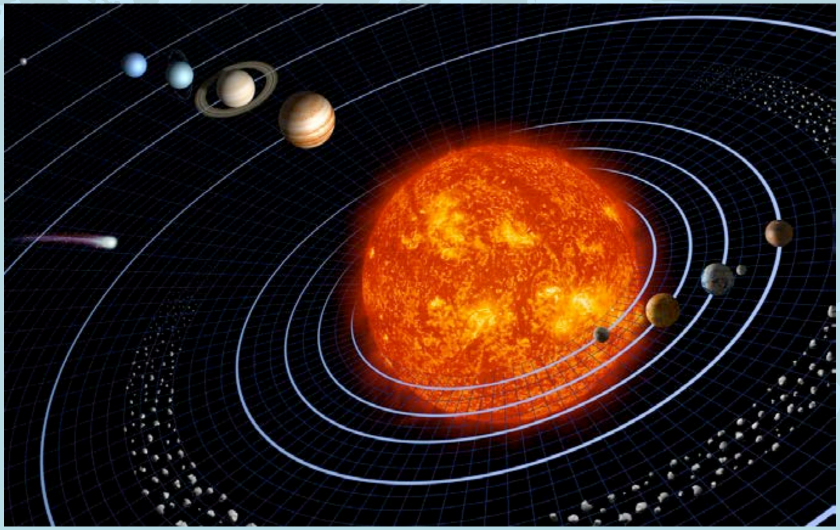
$$\frac{D\mathbf{V}}{Dt} = -2\Omega \times \mathbf{V} - \frac{1}{\rho}\nabla p + g + F_r$$

1 2 3 4

| | |
|---|---|
| 1. Coriolis | $C_o$ |
| 2. Pressure Gradient | PG |
| 3. Gravity | g |
| 4. Friction | $F_r$ |

*Where is Centrifugal force?

# Radiation & Earth's Radiation Balance



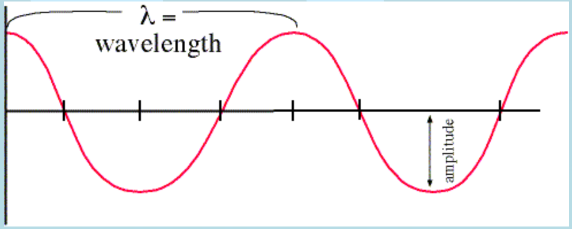
# Radiation

## Outline

- Laws of Radiation
- Earth’s Radiation Balance
- Greenhouse Effect

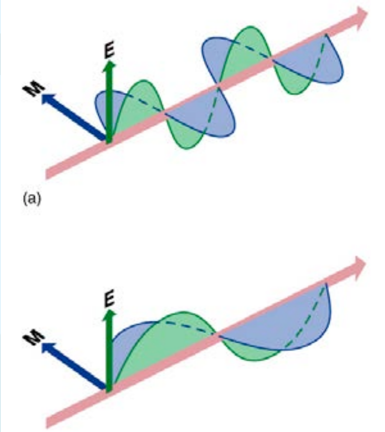
# Radiation

- Radiation - energy leaving a body in the form of electromagnetic waves.
- Light is a form of electromagnetic radiation.
- The speed of light is 299,792,458 m/s or ~ $3 \times 10^8$ m/s through a vacuum (slightly slower through air).

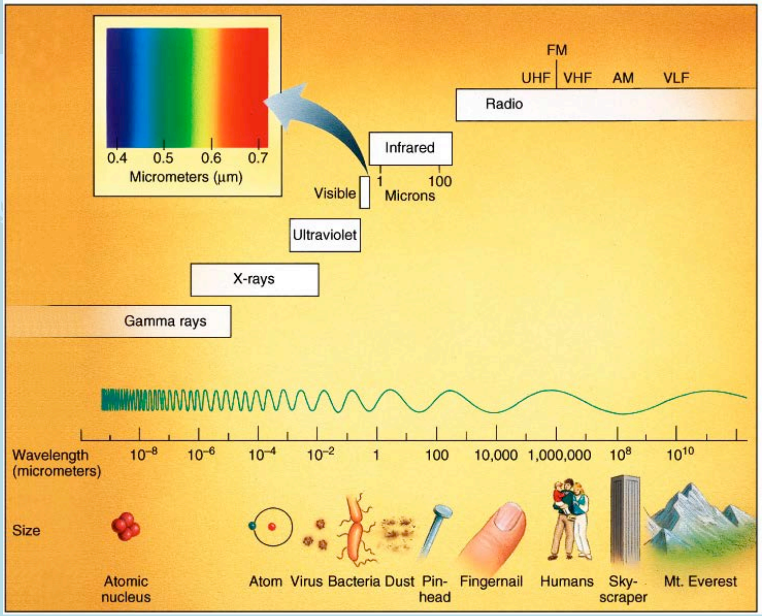


# Radiation Quality and Quantity

- The amplitude corresponds to the energy carried
- The wavelength corresponds to the type



# Radiation – Types



# Planck's Law

The amount of radiation emitted by a blackbody is described by Planck's Law

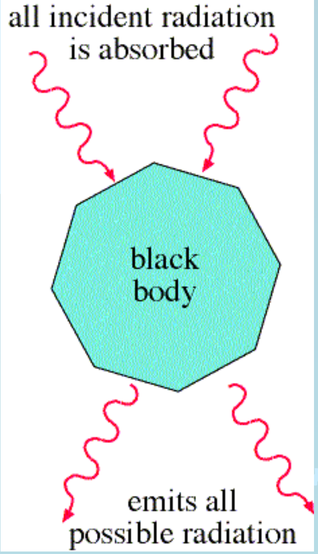
$$E_\lambda = \frac{2hc^2}{\lambda^5\left[\exp\left(hc/k\lambda T\right)-1\right]}$$

- k is the Boltzmann constant, and is $1.38\text{x}10^{-23}$ J/K
- h is Planck's constant and is $6.626\text{x}10^{-34}$ Js
- c is the speed of light in a vacuum and is $2.9979\text{x}10^{8}$ m $s^{-1}$.
- Blackbody radiation is isotropic, homogeneous, unpolarized and incoherent.
- Planck's Law means that the sun isn't special, all objects radiate

---

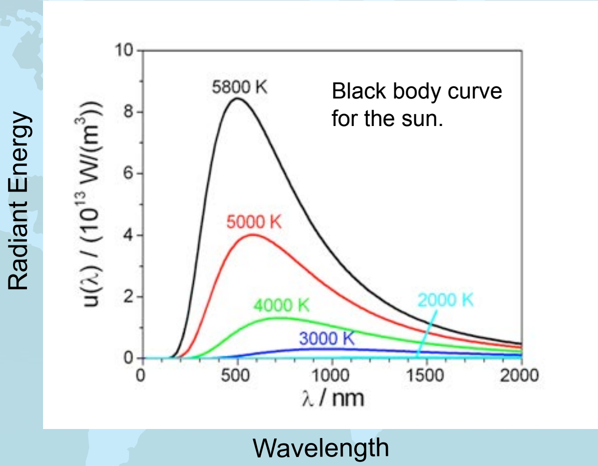
# Radiation Concepts

Blackbody - is a theoretical object that absorbs all incident radiation and emits the maximum possible radiation for its temperature – according to Planck's Law.



---

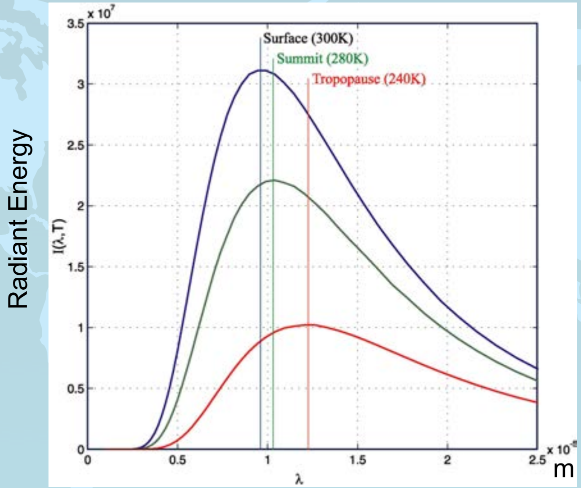
# Planck's Law



Planck's Law describes the radiant energy at all wavelengths emitted from a black body.

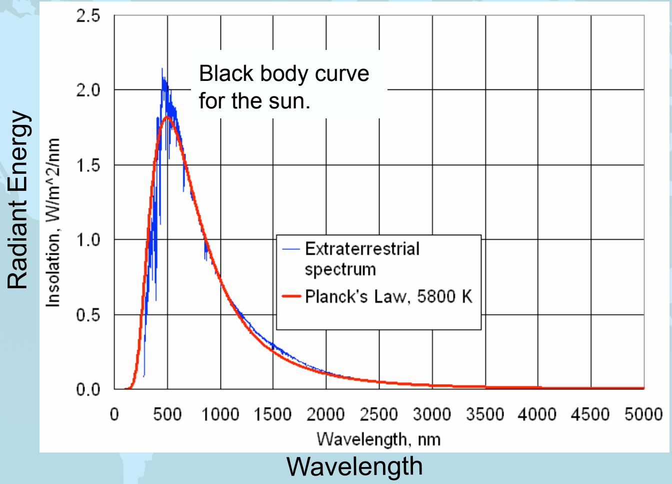
---

# Planck's Law and Black Body Radiation



Planck's Law describes the radiant energy at all wavelengths emitted from a black body.

# Planck’s Law



Planck’s Law describes the radiant energy at all wavelengths emitted from a black body.

# STEFAN - BOLTZMAN LAW

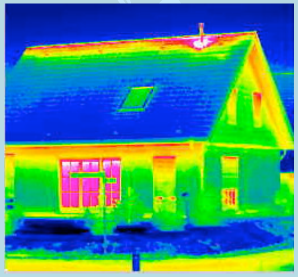
Stefan-Boltzman law is obtained by integrating Planck’s Law across all wavelengths. As the temperature of a black body increases, the *irradiance* (E) emitted by that object per unit time and unit area increases by a power of 4.

$E = \sigma T^4$

where $\sigma$ is a constant = $5.67\times10^{-8}$ W $m^{-2}$ $K^{-4}$

If T doubles, E increases by 16 times!

E is in Watts/$m^2$



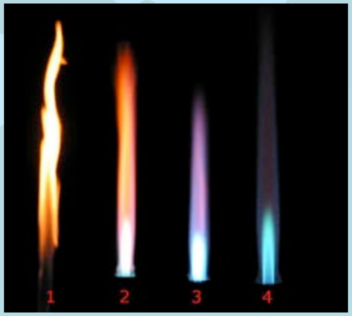
# Wein’s Law*

The wavelength ($\lambda_{max}$) of peak radiation emitted by an object is inversely related to temperature (T).

$\lambda_{max} \sim b/T = 2897/T$, b = Wien’s displacement constant

$\lambda_{max}$ is in µm and T is in Kelvin

*Wein’s Law is obtained by taking the derivative of Planck’s Law



# Kirchhoff's law of thermal radiation

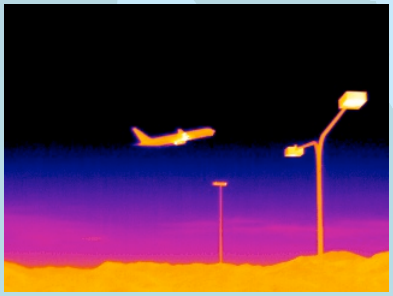
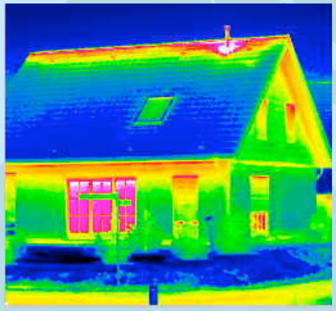
For an arbitrary body emitting and absorbing thermal radiation in thermodynamic equilibrium, the absorptivity is equal to the emissivity for each wavelength.

$a_\lambda = \varepsilon_\lambda$

A good absorber is a good emitter, and a poor absorber is a poor emitter. Naturally, a good reflector must be a poor absorber. This is why, for example, lightweight emergency thermal blankets are based on reflective metallic coatings: they lose little heat by radiation.

# Summary of Laws of Radiation

1. All objects emit radiation (except at 0°K).
2. Hotter objects emit more energy per unit area than colder objects.
3. The hotter the object the shorter the wavelength of maximum radiation.
4. Objects that are good absorbers of radiation are good emitters of radiation.

---

# Radiation Concepts

Solar constant - Amount of solar radiation passing through a unit area at the top of the earth's atmosphere perpendicular to the direction of the radiation at the mean Earth-sun distance.

Solar Constant = S = $E_s$*( $R_s$ /$R_{sE}$)$^2$

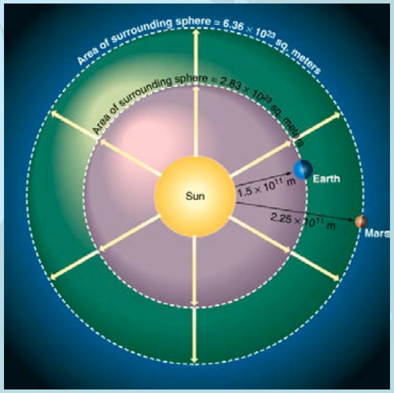
At the sun's surface:

$E_s$ = σ $T^4$ = 5.67*$10^{-8}$ W/($m^2$*$K^4$)*(5800K)$^4$ = 6.416X$10^7$ W/$m^2$

The radius of the sun $R_s$ = 6.955x$10^8$ m

Distance of sun to Earth $R_{sE}$ = 1.5x$10^{11}$ m

S = $E_s$( $R_s$ /$R_{sE}$)$^2$ = 1379 W/$m^2$



---

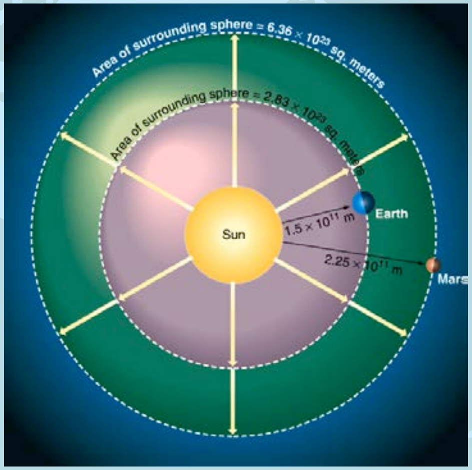
# Radiation Concepts

What happens to sunlight once it reaches the Earth?

Transmission

Scattering (reflection)

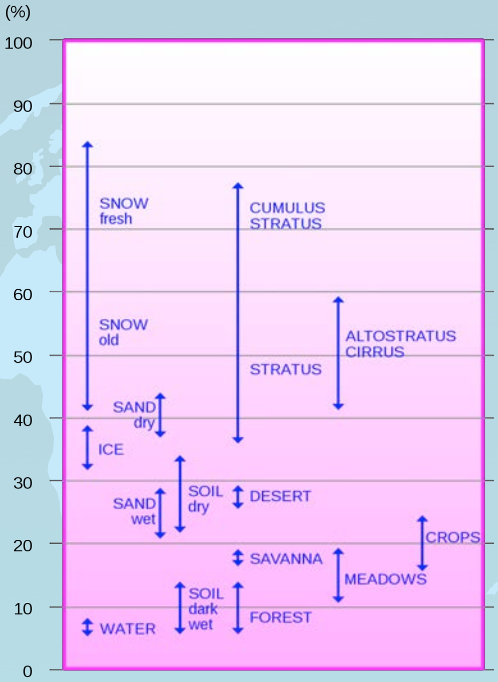
Absorption



---

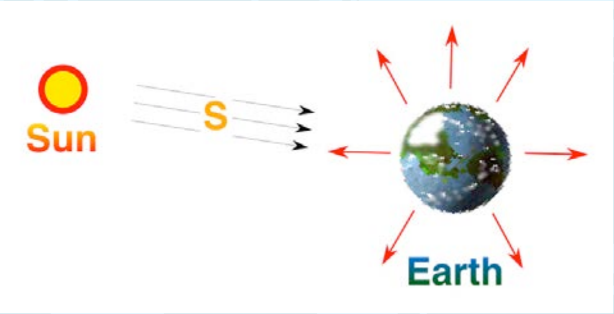
# Reflection and Scattering of Incoming Sunlight

- Albedo: the ratio of reflected radiation to incident radiation
- Surface albedo varies geographically and in time.



# Earth Radiation Balance

Without an atmosphere: radiative equilibrium temperature = **-18ºC**



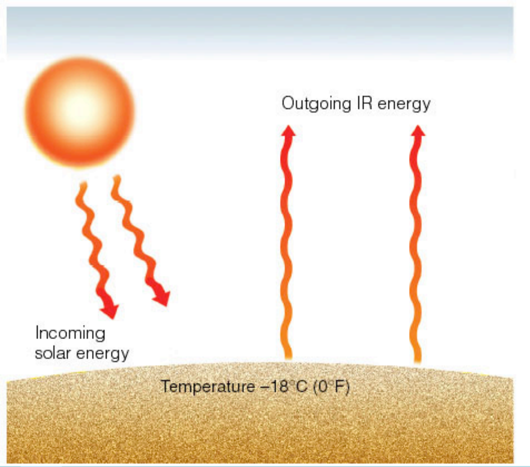
Incoming Energy (visible) = Outgoing Energy (IR)

$$S(1\text{-}a)\ \pi r^2 \ = \ \sigma\ T_E^4\ (4\ \pi r^2)$$

$$T_E = [S\ (1\text{-}a)/4\sigma]^{1/4} \ = 255K = -18^{\circ}C$$

*Where S = solar constant, a = albedo, and σ = constant.*

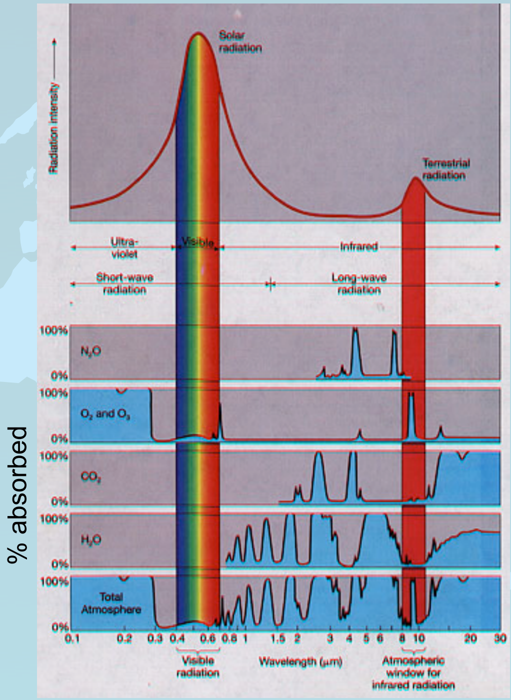
# Without an Atmosphere



Radiative Equilibrium Temperature = **-18˚C**
and we would have an frozen planet

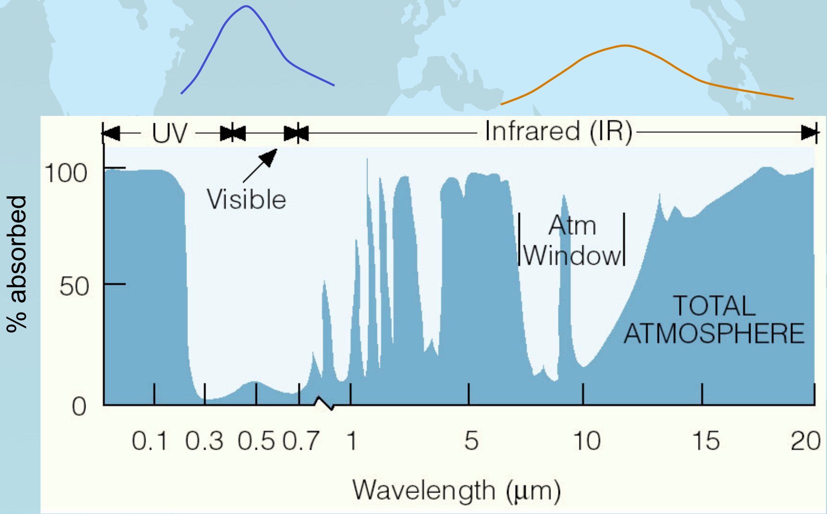
# Atmospheric Windows

Transmission vs Absorption

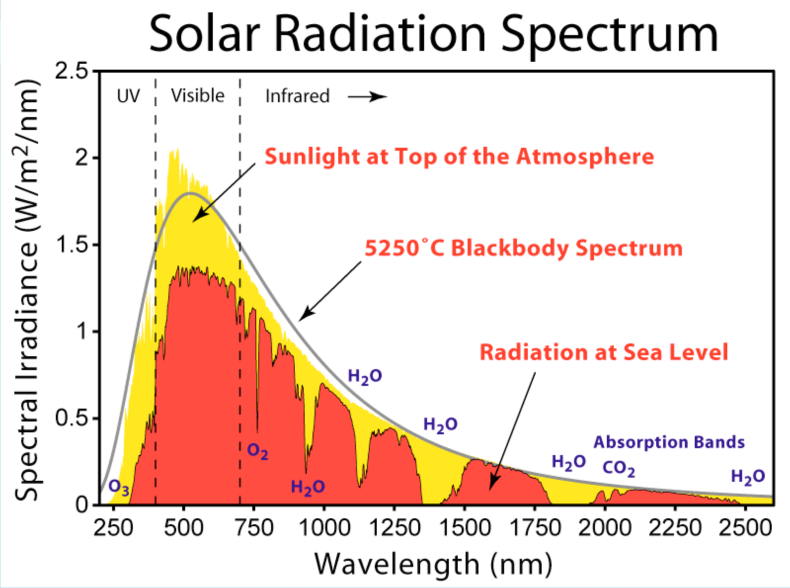


# Atmosphere Absorbs Radiation

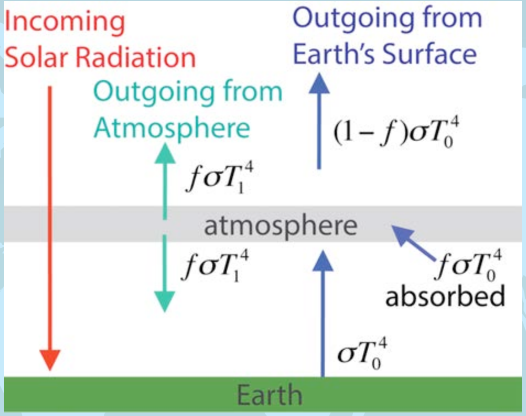
The Atmosphere is nearly transparent for shortwave but absorbs strongly longwave radiation.



# Atmospheric Absorption of Solar Radiation

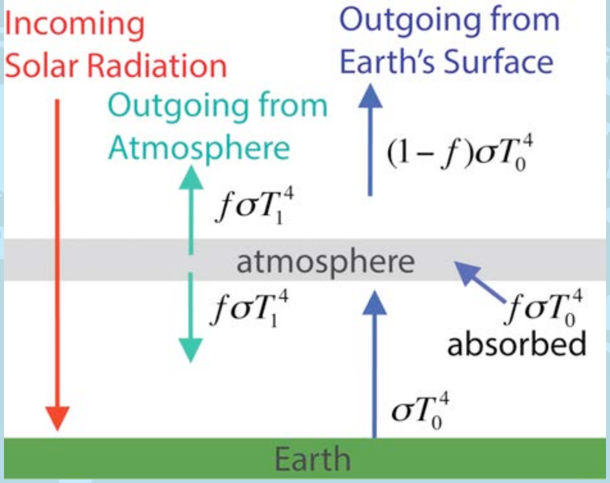


# A Simple Greenhouse Model



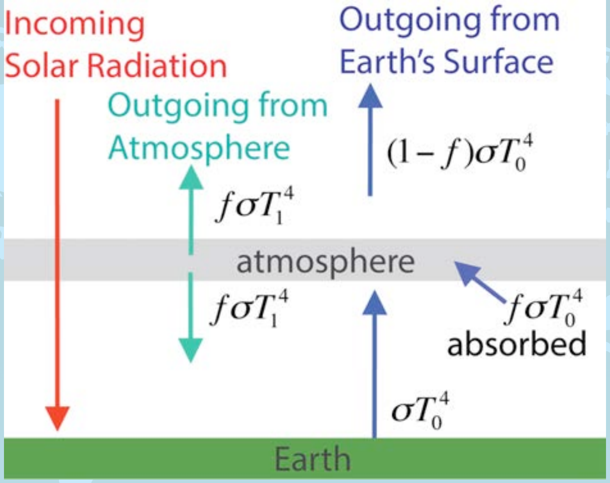
- Incoming solar radiation = (0.7*1379)/4 W m$^{-2}$ = 241 W m$^{-2}$
- IR flux from surface = $\sigma T_o^4$
- Assume atmospheric layer has an absorption efficiency = *f*
- Kirchhoff's law: absorptivity = emissivity
- IR flux from atmospheric layer = $f \sigma T_1^4$ (up and down)

# A Simple Greenhouse Model



Balance at top of atmosphere $f \sigma T_1^4 + (1-f) \sigma T_o^4 = 241$
Balance for atmospheric layer $f \sigma T_1^4 + f \sigma T_1^4 = f \sigma T_o^4$
Balance at the surface $\sigma T_o^4 = 241 + f \sigma T_1^4$

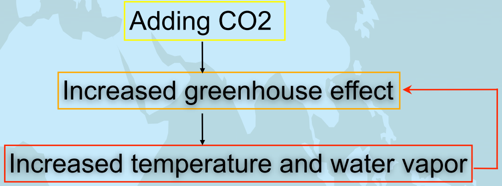
# A Simple Greenhouse Model



We have two equations and two unknowns, can solve.
$T_o = 288$ K ; f = 0.77; $T_1 = 241$ K
Greenhouse gases affect f; as f increases, $T_o$ and $T_1$ increase

# Increasing the Greenhouse Effect

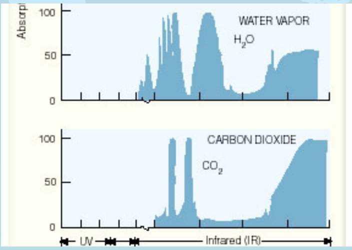
**Water vapor feedback**



Adding CO2

Increased greenhouse effect

Increased temperature and water vapor



---

# Questions?

---

# Questions?