Lecture 4: Radiation Transfer

- ❑ Spectrum of radiation
- ❑ Stefan-Boltzmann law
- ❑ Selective absorption and emission
- ❑ Reflection and scattering
- ❑ Remote sensing

Importance of Radiation Transfer

- ❑ Virtually all the exchange of energy between the Earth and the rest of the universe takes place by radiation transfer.
- ❑ Radiation transfer is also a major way of energy transfer between the atmosphere and the underlying surface and between different layers of the atmosphere.

Spectrum of Radiation

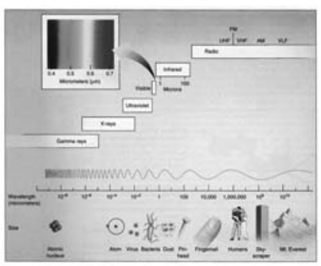


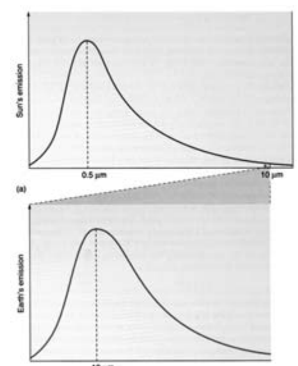
Table 2–1 Wavelength Categorizations

Type of Energy	Wavelength (micrometers)
Gamma	<0.0001
X ray	0.0001 to 0.01
Ultraviolet	0.01 to 0.4
Visible	0.4 to 0.7
Near Infrared (NIR)	0.7 to 4.0
Thermal Infrared	4 to 100
Microwave	100 to 1,000,000 (1 meter)
Radio	>1,000,000 (1 meter)

(from *Understanding Weather & Climate*)

- ❑ Radiation energy comes in an infinite number of wavelengths.
- ❑ We can divide these wavelengths into a few bands.

Solar and Terrestrial Radiation



(from *Understanding Weather & Climate*)

- ❑ All objectives radiate energy, not merely at one single wavelength but over a wide range of different wavelengths.
- ❑ The sun radiates more energy than the Earth.
- ❑ The greatest intensity of solar energy is radiated at a wavelength much shorter than that of the greatest energy emitted by the Earth.

Stefan-Boltzmann Law

$$E = \sigma T^4$$

E = radiation emitted in W/m^2

σ= 5.67 x 10^{-8} W/m^2 * K *sec

T = temperate (K)

- ❑ The single factor that determine how much energy is emitted by a blackbody is its temperature.
- ❑ The intensity of energy radiated by a blackbody increases according to the fourth power of its absolute temperature.
- ❑ This relationship is called the Stefan-Boltzmann Law.

Apply Stefan-Boltzmann Law To Sun and Earth

❑ **Sun**

E_s = (5.67 x 10^{-8} W/m^2 K^4) * $(6000K)^4$

= 73,483,200 W/m^2

❑ **Earth**

E_e = (5.67 x 10^{-8} W/m^2 K^4) * $(300K)^4$

= 459 W/m^2

❑ Sun emits about 160,000 times more radiation per unit area than the Earth because Sun's temperature is about 20 times higher than Earth's temperature.

➔ 20^4 = 160,000

Wien's Law

$$\lambda_{max} = w/T$$

λ_{max} = wavelength (micrometers)

W = 2897 μm K

T = temperate (K)

- ❑ Wien's law relates an objective's maximum emitted wavelength of radiation to the objective's temperature.
- ❑ It states that the wavelength of the maximum emitted radiation by an object is inversely proportional to the objective's absolute temperature.

Apply Wien's Law To Sun and Earth

❑ **Sun**

λ_{max} = 2898 μm K / 6000K

= 0.483 μm

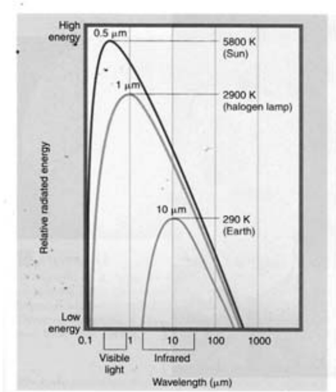
❑ **Earth**

λ_{max} = 2898 μm K / 300K

= 9.66 μm

❑ Sun radiates its maximum energy within the visible portion of the radiation spectrum, while Earth radiates its maximum energy in the infrared portion of the spectrum.

Wavelength and Temperature



- The hotter the objective, the shorter the wavelength of the peak radiation.

(from *Meteorology: Understanding the Atmosphere*)

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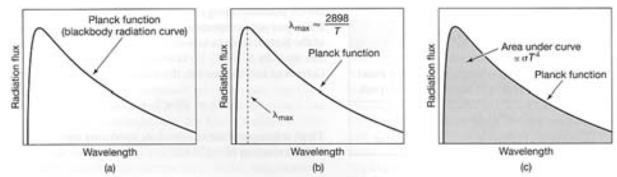
Planck Function

- The Planck function relates the intensity of radiation from a blackbody to its wavelength.



(from *The Earth System*)

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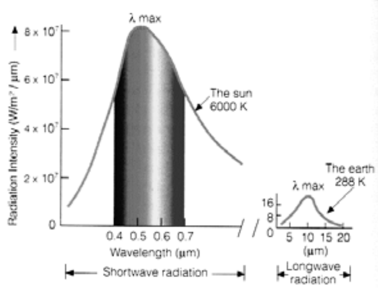
Shortwave and Longwave Radiations



- Solar radiation is often referred to as "shortwave radiation".
- Terrestrial radiation is referred to as "longwave radiation".

(from *Meteorology: Understanding the Atmosphere*)

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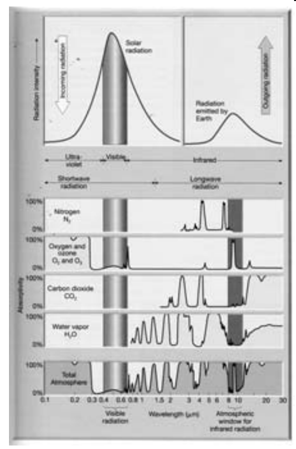
Selective Absorption and Emission



- The atmosphere is not a perfect blackbody, it absorbs some wavelength of radiation and is transparent to others (such as solar radiation). ➔ Greenhouse effect.
- Objective that selectively absorbs radiation usually selectively emit radiation at the same wavelength.
- For example, water vapor and CO2 are strong absorbers of infrared radiation and poor absorbers of visible solar radiation.

(from *The Atmosphere*)

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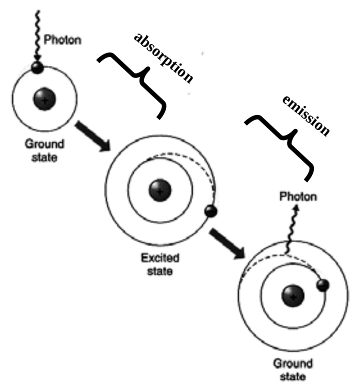
Why Selective Absorption/Emission?



- Radiation energy is absorbed or emitted to change the energy levels of atoms or molecular.
- The energy levels of atoms and molecular are discrete but not continuous.
- Therefore, atoms and molecular can absorb or emit certain amounts of energy that correspond to the differences between the differences of their energy levels.

➔ Absorb or emit at selective frequencies.

(from *Understanding Weather & Climate*)

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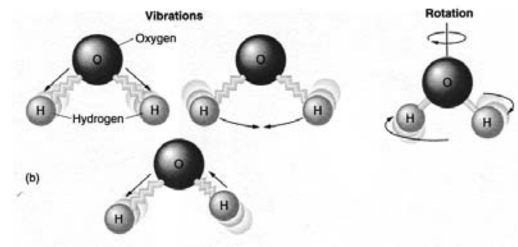
Different Forms of Energy Levels



(from *Understanding Weather & Climate*)

- The energy of a molecule can be stored in (1) translational (the gross movement of molecules or atoms through space), (2) vibrational, (3) rotational, and (4) electronic (energy related to the orbit) forms.

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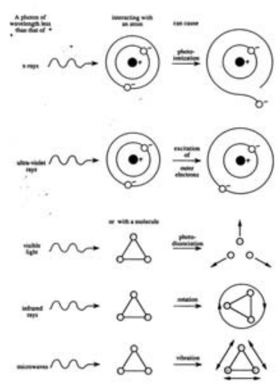
Energy Required to Change the Levels



- The most energetic photons (with shortest wavelength) are at the top of the figure, toward the bottom, energy level decreases, and wavelengths increase.

(from *Is The Temperature Rising?*)

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Radiation Intensity and Wavelength

- The shorter the wavelength of the radiation, the larger the amount of energy carried by that radiation.

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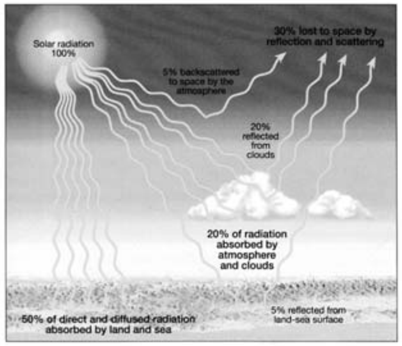
Absorption, Reflection, Scattering



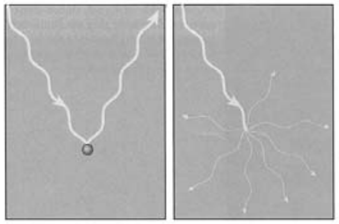
(from *The Atmosphere*)

- What happens to incoming solar radiations?

(1) Absorption
(2) Reflection
(3) Scattering
(4) Transmission (through the atmosphere)

Reflection and Scattering

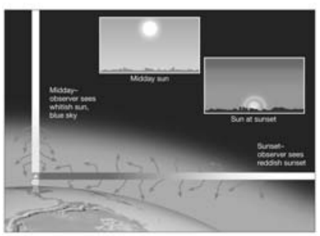
Reflection Scattering



(from *The Atmosphere*)

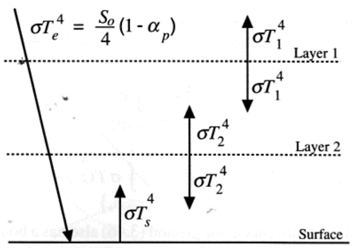
- Reflection: light bounces back from an objective at the same angle at which it encounters a surface and with the same intensity.
- Scattering: light is split into a larger number of rays, traveling in different directions.
- Although scattering disperses light both forward and backward (backscattering), more energy is dispersed in the forward direction.

Scattering and Colors



- Short wavelengths (blue and violet) of visible light are scattered more effectively than are longer wavelengths (red, orange). Therefore, when the Sun is overhead, an observed can look in any direction and see predominantly blue light that was selectively scattered by the gases in the atmosphere.
- At sunset, the path of light must take through the atmosphere is much longer. Most of the blue light is scattered before it reaches an observer. Thus the Sun appears reddish in color.

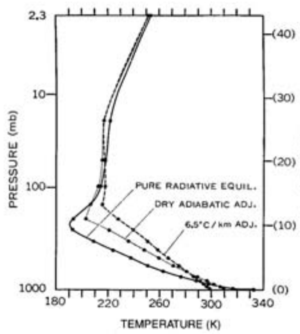
Model of Radiative Equilibrium



(from *Global Physical Climatology*)

- We assume the atmosphere is opaque for longwave radiation and transparent to shortwave radiation.
- We divide the atmosphere into many layers.
- We assume energy is balance at each atmospheric layers.
- We can determine the temperature of each atmospheric layers.

Radiative Equilibrium Temperature



(from *Global Physical Climatology*)

- ❑ The radiative equilibrium temperature calculated from the energy balance model is hydrostatically unstable. (meaning the lapse rate is larger than the dry adiabatic lapse rate).
- ❑ As a result, convections occur.
- ➔ The atmosphere becomes stable with a radiative-convective equilibrium temperature.

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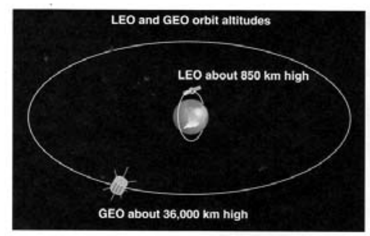
Remote Sensing



(from *Meteorology: Understanding the Atmosphere*)

- ❑ By measuring the amounts of solar and infrared radiation, satellites can give us information of the atmosphere, such as temperature, cloudiness, water vapor,..
- ❑ There are two types of weather satellites:

(1) GEO (Geostationary Earth Orbit) satellites
(2) LEO (Low Earth Orbit) satellites

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GEO and LEO

- ❑ GEO satellites orbit the earth as fast as the Earth spins.
- ❑ They hover over a single point above the Earth at an altitude of about 36,000 km.
- ❑ To maintain their positions, GEO satellites must stay over the equator.
- ❑ They have continuous high-quality views of the tropics and mid-latitudes.
- ❑ They have a poor view of the polar regions.

- ❑ LEO satellites go around and around from pole to pole.
- ❑ They have a better view of the polar regions.
- ❑ But they fly over any particular certain regions of the Earth twice a day.
- ❑ They can not provide a global view of the Earth.

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Radiometers On Satellites

- ❑ Satellite instruments measure radiation that the Earth and the atmosphere reflect, scatter, transmit, and emit.
- ❑ These instruments are called radiometers.
- ❑ There are two types of radiometers:

(1) Visible: measure the amount of visible light from the Sun that is reflected back to space by the earth's surface or by clouds.
(2) Infrared: measures the amount of infrared radiation emitted by Earth's surface or clouds.

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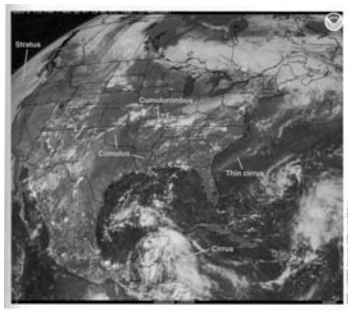
Visible Image



(from *Meteorology: Understanding the Atmosphere*)

- A visible satellite image represents sunlight scattered or reflected by objectives on Earth.
- Dark areas represent geographic regions where small amounts of visible light from the Sun are reflect back to space, such as oceans.
- White areas represent snow or clouds.

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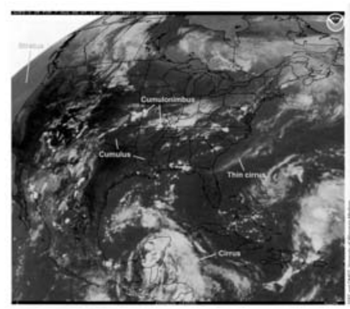
Infrared Image



(from *Meteorology: Understanding the Atmosphere*)

- The infrared radiometers on satellites measure radiations with wavelengths between 10-12 micrometers (the "atmospheric window").
- The infrared radiometers measure HEAT. ➔ They provides information on the temperature of land, water, and clouds.
- Cold objectives are white and hot surfaces are black.

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