CHAPTER 4 – Lectures 05 - 09

The Global Energy System

I. Electromagnetic Radiation: This form of energy is emitted by all objects. Light and radiant heat are two familiar examples. Light is radiation that is visible to our eyes. Heat radiation, though not visible, is felt when you hold out your hand near a warm object. Electromagnetic radiation is one of several fundamental forms of energy. The electromagnetic radiation spectrum is made up of a wide range of wavelengths traveling away from the surface of an object. Wavelength describes the distance separating one wave crest from the next crest. A micrometer (µm) is the unit used to measure wavelength. Radiant energy can exist at any wavelength.

a) *Visible light:* This portion of the spectrum starts at a wavelength of 0 .4µm with the colour violet. Colours then grade through blue, green, yellow, orange, and red reaching the end of the visible spectrum at about 0.7µm.

b) *Near-infrared radiation:* wavelengths from 0.7 to 1.2µm. Comes mostly from the sun, but it is not visible to us.

c) *Short-wave infrared radiation:* lies in the range of 1.2 to 3.0µm. Comes mostly from the sun.

d) *Middle-infrared radiation:* from 3.0 to 6µm. It comes from the sun and is emitted by fires burning at the Earth's surface, such as forest fires or gas well flames.

e) *Thermal infrared radiation:* between 6 and 300 nanometers (10^{-9} meters). Includes the heat given off by bodies at temperatures normally found at the Earth's surface.

A. Radiation and Temperature - There are two important laws that concern the emission of electromagnetic radiation. One, Wein's Law states that there is an inverse relationship between the range of wavelengths of the radiation that an object emits and the temperature of the object emitting it (e.g. the hot sun emits very short wavelength energy). Two, the Stephan-Boltzmann Law states that hot objects radiate more energy than cooler objects.

B. Solar Radiation - The sun emits energy in the form of electromagnetic radiation. The energy travels outward in straight lines, or rays, from the Sun at a speed of about 300,000 km per second. As solar radiation travels through space, none of it is lost, however, the rays spread apart as they move away from the Sun.

C. Characteristics of Solar Energy - The sun's output peaks in the visible part of the spectrum. Thus, human vision is adapted to the most abundant solar energy wavelengths. As solar radiation passes through the atmosphere it is absorbed and scattered. Solar energy received at the surface ranges from 0.3 to 3 µm and is known as short wave radiation.

D. Longwave Radiation from the Earth - The Earth radiates less energy than the Sun, and the energy emitted has longer wavelengths. The thermal infrared radiation emitted by the Earth is referred to as longwave radiation. Absorption of Earth radiation by the atmosphere is an important part of the greenhouse effect. Water and carbon dioxide are the primary absorbers.

E. The Global Radiation Balance - The Earth constantly receives solar short wave radiation and emits longwave radiation; this is the Earth's global radiation balance. Shortwave radiation from the Sun is transmitted through space, where Earth intercepts it. The absorbed radiation is then ultimately emitted as longwave radiation to outer space. These flows balance – the incoming energy absorbed and outgoing radiation emitted are equal. Since the temperature of a surface is determined by the amount of energy it absorbs and emits, the Earth's overall temperature tends to remain constant.

II. Insolation Over the Globe: Insolation, an acronym for incoming solar radiation, is the flow of solar energy intercepted by an exposed surface assuming a uniformly spherical Earth with no atmosphere. It is a flow rate expressed in units of watts per square meter (W/m^2). Insolation depends on the angle of the sun above the horizon. Daily insolation at a location depends upon the angle at which the Sun's rays strike the Earth and the length of time of exposure to the rays. In the northern hemisphere daily insolation is greatest during the June solstice and then falls to zero at the September equinox, remains at zero between September and March equinoxes, and then increases as the Sun rises above the horizon to reach its position at the June solstice again.

A. Insolation and the Path of the Sun in the Sky - Insolation is greatest when the sun is highest above the horizon. Both the height of the sun above the horizon and day length varies with latitude and the time of year. In the northern hemisphere, the lowest insolation values are in December and the highest values are in June. For equatorial locations, there are two maximums of insolation – one at each equinox, and two minimums – one at each solstice.

B. Daily Insolation through the Year -

1. Latitudes between the tropics of cancer and Capricorn and arctic and antarctic circles show a wavelike pattern of greater daily insolation at the summer solstice and lower daily insolation at the winter solstice.
2. Pole ward of the arctic and Antarctic circles, the Sun is below the horizon for at least part of the year and daily insolation drops to zero.
3. Daily insolation is greatest at the pole at the summer solstice.
4. There are two maximums and two minimums in daily insolation at the equator, occurring at the equinoxes and solstices, respectively.
5. Between the equator and the tropics of Capricorn and Cancer, there are also two maximum and minimum daily insolation values, however, the timing of the maximum periods get closer and merge into a single maximum at the tropic.

C. Annual Insolation by Latitude - Annual insolation is greater at lower latitudes. The high latitudes still receive a considerable flow of solar energy – the annual insolation value at the pole is about 40 percent of the value at the equator.

III. World Latitude Zones: The seasonal pattern of insolation can be used to divide the Earth into broad latitude zones. The zone limits are a generalization used to better understand regional variation.

- Equatorial zone- encompasses the equator and covers the latitude belt roughly 10° north to 10° south.
- Tropical zones- range from latitudes 10° to 25° north and south.
- Subtropical zones- latitude belts 25° to 25° north and south.
- Midlatitude zones- lie between 35° and 55° north and south latitude.
- Subarctic and subantarctic zones- Fall between 55° and 60° north and south latitude.
- Arctic and Antarctic zones- astride the arctic and Antarctic circles from latitudes 60° to 75° north and south.
- Polar zones- circular areas both north and south between about 75° latitude and the poles.

IV. Composition of the Atmosphere: The atmosphere consists of air – a mixture of various gasses surrounding the Earth with 97 percent within 30 km of the Earth's surface. From the Earth's surface upward to an altitude of about 80 km, the chemical composition of air is highly uniform in terms of gas proportions. Pure, dry air consists of nitrogen, 78 percent by volume, and oxygen, 21 percent by volume. Other gases account for the remaining 1 percent.

A. Ozone in the Upper Atmosphere - Ozone is a form of oxygen in which three oxygen atoms are bonded together (O_3). It exists in the upper atmosphere (stratosphere) about fifteen to fifty-five km. above the Earth's surface. Ozone absorbs ultraviolet radiation from the Sun as it passes through the atmosphere. Ozone can also be destroyed. If the concentration of ozone is reduced, ultraviolet absorption is reduced. Certain forms of air pollution are currently reducing ozone concentrations substantially in some portions of the atmosphere at certain times of the year.

V. Sensible Heat and Latent Transfer

A. Sensible Heat - The quantity of heat held by an object that can be sensed by touching or feeling. Sensible heat energy can move by conduction or convection. This type of heat flow is referred to as sensible heat transfer.

B. Latent Heat - hidden heat that cannot be measured by a thermometer. It is heat that is stored in the form of molecular motion when a substance changes state from a solid to a liquid, from a liquid to a gas, or from a solid directly to a gas. In the Earth-atmosphere system, latent heat transfer occurs when water evaporates from a moist land surface or open water surface. This process transfers heat from the surface to the atmosphere.

VI. The Global Energy System The flow of energy from the Sun to the Earth and then back out into space is a complex system involving not only radiant energy flow, but also energy storage and transport.

A. Solar Energy Losses in the Atmosphere – As the shortwave radiation penetrates the atmosphere, its energy is absorbed and diverted in various ways. It is scattered by gas molecules and dust to become diffuse radiation. Scattering turns radiation back to space through a process called diffuse reflection. Absorption accounts for about 15 percent of the incoming solar radiation. Cloud reflection can account for 30 to 60 percent of incoming radiation and can absorb as much as 5 to 20 percent.

B. Albedo – refers to the proportion of shortwave energy scattered upward by a surface. It is an important property of a surface because it measures how much incident solar energy will be absorbed. Light colored surfaces, like snow and ice, have a high albedo, and dark surfaces, such as black pavement, have a low albedo. The albedo of the Earth is between 0.29 and 0.34.

C. Counterradiation and the Greenhouse Effect – Shortwave radiation passes through the atmosphere and is absorbed at the surface, warming the surface. The surface emits longwave radiation. Some of this flow passes directly to space, but the atmosphere absorbs most. The atmosphere radiates longwave energy back to the surface as counterradiation and also to space. The return of outbound longwave radiation by counterradiation constitutes the greenhouse effect.

D. Global Energy Budgets of the Atmosphere and Surface – The global energy budget of the Earth's atmosphere and surface must balance over the long term.

E. Incoming Shortwave Radiation - Thirty-one percent of incoming shortwav radiation is reflected by molecules, dust, clouds, and the surface. Twenty percent is absorbed by molecules, dust, and clouds leaving forty-nine percent which reaches the Earth to be absorbed by land and water surfaces.

F. Surface Energy Flows - The Earth loses energy through longwave radiation, latent heat transfers and sensible heat transfers.

G. Energy Flows to and from the Atmosphere – Like the Earth's surface, the atmosphere gains energy by absorption of shortwave radiation, latent heat transfer, sensible heat transfer, and longwave radiation. It also loses energy through longwave radiation, and counterradiation.

VII. Net Radiation, Latitude, and the Energy Balance: Net radiation is the difference between all incoming radiation and all outgoing radiation. The net energy for any given area differs. For latitudes between forty degrees north and south the net energy is positive. For the latitudes between forty degrees and the poles the net energy is negative. Poleward heat transfer is driven by the imbalance in net radiation between low and high latitudes, and is the power source for ocean currents and broad-scale atmospheric circulation patterns.