ESCI 107/109 – The Atmosphere
Lesson 2 – Solar and Terrestrial Radiation

Reading: *Meteorology Today*, Chapters 2 and 3

EARTH-SUN GEOMETRY

- **The Earth has an elliptical orbit around the sun**
- **The average Earth-Sun distance is 93,000,000 mi (150,000,000 km)**
- ***Aphelion* – the farthest Earth-Sun distance occurs in early July, and is about 94,000,000 mi.**
- ***Perihelion* – the closest Earth-Sun distance occurs early January, and is about 91,000,000 mi.**
- **The difference between aphelion and perihelion is small compared to the overall distance between the earth and sun, and is not the cause of the seasons.**
- **Declination and sun angle**
  - **The angle the Sun's rays make with the surface of the Earth is called the *sun angle***
  - **The Sun angle varies from place to place and from season to season.**
  - **The Sun angle also changes throughout the day.**
    - **Sun angle is zero at sunrise and sunset.**
    - **Sun angle is maximum at local noon.**
    - **Sun angle is negative at night (since Sun is below the horizon).**
  - **To find the sun angle at noon we need to know the Sun's *declination* angle, and our *latitude*. We then use the formula**

    Sun angle = 90° + declination – latitude

    - **If the formula gives you a sun angle greater than 90°, then subtract it from 180° (e.g., if the formula gives 130° then the sun angle is 50°).**
    - **Declinations and latitudes south of the equator are negative.**
- **The seasons**
  - **The seasons occur because the Earth's axis is tilted 23 ½ ° with respect to the plane of its orbit. This means that the declination is not constant, but changes over the course of one year, from +23.5° to –23.5° and back.**

- **The change in maximum Sun angle over the course of the year is what results in the temperature difference between seasons. This is because:**
  - **Sun angle determines how much energy per unit area strikes surface of the Earth.**
    - **Lower Sun angle means less energy per area in beam.**
    - **Lower Sun angle means rays travel through more atmosphere and lose more energy before striking the surface.**
  - **Change in maximum Sun angle changes length of day and night**
- **Equinoxes occur when the declination is zero (the sun directly over the Equator).**
- **Solstices occur when the sun is at its maximum declination (either North or South) of 23.5°**
- **Astronomical seasons and climatological seasons are different:**
  - ***Astronomical seasons* are defined from the solstices and equinoxes**
    - ***Winter* – Winter Solstice to Spring Equinox (Dec 21 – Mar 21)**
    - ***Spring* – Spring Equinox to Summer Solstice (Mar 21- Jun 21)**
    - ***Summer* – Summer Solstice to Fall Equinox (Jun 21 – Sep 21)**
    - ***Autumn* – Fall Equinox to Winter Solstice (Sep 21 – Dec 21)**
  - ***Climatological seasons* are defined from experience**
    - ***Winter* – December, January, February**
    - ***Spring* – March, April, May**
    - ***Summer* – June, July, August**
    - ***Autumn* – September, October, November**

ENERGY, HEAT, AND TEMPERATURE

- ***Energy* is defined as *the ability to do work*.**
- **Types of energy**
  - ***Kinetic energy* – energy of motion**
  - ***Potential energy* – stored energy**
- ***Thermal Energy* is defined as *the total kinetic energy of all the atoms and molecules that make up a substance.***

- ***Temperature* is *a measure of the average of kinetic energy of all the atoms or molecules of the substance.***
- **Adding heat to a substance raises its temperature. Subtracting heat will lower its temperature.**
- **Methods of energy transfer**
  - **Conduction**
  - **Convection**
    - **Meteorologists refer to horizontal convection as *advection*.**
  - **Radiation**

RADIATION

- **Radiation is comprised of electromagnetic waves of differing wavelengths.**
- **Shorter wavelengths (higher frequencies) are more energetic.**
- **Visible light comprises only a small part of the spectrum.**
- **Ultra-violet (UV) radiation has shorter wavelengths than visible.**
- **Infrared (IR) radiation has longer wavelengths than visible.**
- **The spectrum is also divided into short-wave and long wave radiation, with dividing line at about 4 μm.**
- **Laws of radiation**
  - **All objects emit radiation (even an ice cube).**
  - **No object can be colder than negative 273°C (absolute zero).**
  - **Hotter objects radiate more energy per unit area than do cold objects (the *Stefan-Boltzman law*)**

    $$E \propto T^4$$

  - **The hotter the object the shorter the wavelength of maximum radiation (*Wien's displacement law*).**

    $$\lambda_{\max} \propto T^{-1}$$

  - **Objects that are good absorbers of radiation are also good emitters.**
    - **A perfect absorber/emitter is called a *blackbody*.**
- **The Earth and Sun are nearly blackbodies, and are often assumed to be so.**

SOLAR RADIATION

- **The Sun emits at about 6000 K, while the earth emits at about 288 K.**
- **From Wien's displacement law**
  - **The Sun emits its peak radiation at a wavelength of 0.460μm, which is in the visible part of the spectrum (green light).**
  - **The Earth emits its peak radiation at a wavelength of 10μm, which is in the IR part of the spectrum.**
- **From the Stefan-Boltzman law**
  - **The Sun emits 7.35×10^{7} W m^{-2} of energy per unit area.**
  - **The Earth emits 390 W m^{-2} of energy per unit area.**
- **Incoming solar radiation can be absorbed, reflected, or scattered by the atmosphere or Earth's surface.**
  - **Absorption**
    - **20% absorbed directly in the atmosphere, primarily by ozone in the stratosphere, oxygen and nitrogen in the thermosphere, and water vapor and clouds in the troposphere.**
    - **50% absorbed by land and sea**
  - **Reflection**
    - **30% reflected back to space by both clouds and the surface.**
    - ***Albedo* is defined as the fraction of radiation reflected by a surface.**
      - **The Albedo of the Earth is 0.3.**
  - **Scattering**
    - **Produces a bunch of weaker rays that move off in different directions.**
    - **Scattering from small molecules is dependent of wavelength, with short wavelengths scattered more than longer wavelengths.**
      - **This is the reason the sky is blue, and why sunsets are red!**
    - **Scattering off of larger particles is not wavelength dependent. This is reason why clouds are white, and also why hazy days appear whitish.**

TERRESTRIAL RADIATION

- **Earth emits IR radiation.**

- **To balance the incoming solar radiation the earth must radiate at a temperature of about 255 K. But the surface of the earth averages about 288 K!!! Why?**
- **The atmosphere absorbs and reradiates much of the emitted IR radiation (the "greenhouse effect."**
- **The "greenhouse" gases**
  - **H_2O – Ever notice that humid nights are warmer than dry nights, or that deserts can be very cold at night?**
  - **CO_2**
  - **N_2O**
  - **CH_4**
  - **O_3**
- **Clouds have a dual role in the radiation balance of the earth.**
  - **The reflect incoming solar radiation, keeping daytime temperatures lower.**
  - **They absorb outgoing terrestrial radiation, keeping nighttime temperatures higher.**
- **Latitudinal heat balance**
  - **Tropics have net surplus of heat.**
  - **Polar Regions have net deficit of heat.**
  - **Heat must be transported from tropics to poles.**
- ***LATITUDINAL HEAT BALANCE IS WHAT DRIVES THE CIRCULATION OF THE ATMOSPHERE AND OCEANS*.**