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15.023J / 12.848J / ESD.128J Global Climate Change: Economics, Science, and Policy
Spring 2008

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PROBLEM SET # 1

Note) PSET #1 is due Feb 27 (Wed). The TA who is mainly responsible for this PSET #1 is Eunjee Lee.

P1. [CARBON CYCLE and GHGs]

Briefly discuss:

1.1. Global Carbon cycle

We observe lower atmospheric CO_2 concentration in the atmosphere than what would have been observed if all emission remains in the atmosphere.

   a) Role of Ocean in carbon uptake

   b) Role of Land in carbon uptake

1.2. GreenHouse Gases (GHGs) and Radiation balance

   a) What are six GHGs to be regulated according to Kyoto Protocol, and sinks and sources of those gases

   b) Why they matter in global warming (i.e., their contributions in increasing the global temperature)

P2. [EFFECTS of AEROSOLS on CLIMATE]

In Climate lectures (I, II), we studied the roles of aerosols on climate. We were also assigned to read Penner's article, The Cloud Conundrum (2004), which describes the roles of aerosols on climate.

Based on the lecture material and the article, briefly discuss:

2.1. What the AEROSOL is

2.2. Direct effects

2.3. Indirect effects (i.e., two indirect effects)

2.4. Why the aerosol effects are important on climate change issue, and where the uncertainties come from

P3. [EARTH's ENERGY BUDGET] BUILD YOUR CLIMATE MODEL!

Now let us calculate the global temperature by writing our own, simplified energy balance model.

3.1. Case 1: Earth with no atmosphere

First, let us calculate the average temperature that the earth's surface would attain if there were no atmosphere. Remember in this case, we assume that there is no production/destruction in Energy so that we only consider INFLOW of the energy from the Sun and OUTFLOW of the energy emitted the Earth to be balanced (i.e., the Earth is in radiative equilibrium). The earth absorbs all sunlight received from the sun with the exception of the fraction that is reflected back to space.

- Solar radiation

We assume that the amount of sunlight arriving at the earth is a constant value per square meter: the solar constant, F. Assume that $F = 1378$ W/m^2. A fraction of the sunlight to the real earth reflects back to space: the Earth's albedo, a, which is typically 30% or 0.3.

- Thermal radiation (from the Earth)

The Stefan-Boltzman law of physics states that a unit surface of an object radiates energy to space proportional to the fourth power of temperature (expressed in degrees Kelvin): Emission = σT^4, where σ is the Stefan-Boltzman constant = 5.67×10^{-8} W m^{-2} K^{-4}.

Calculate the equilibrium temperature (T_E) that the earth would maintain if it had no atmosphere (unit is in Kalvin [K]). Keep in mind the geometric consideration that, while the entire surface area of the spherical earth radiates energy to space, only an area equivalent to the circular disc intercepting the sunlight (i.e. the area of the shadow of the earth) receives direct sunlight (see figure below):
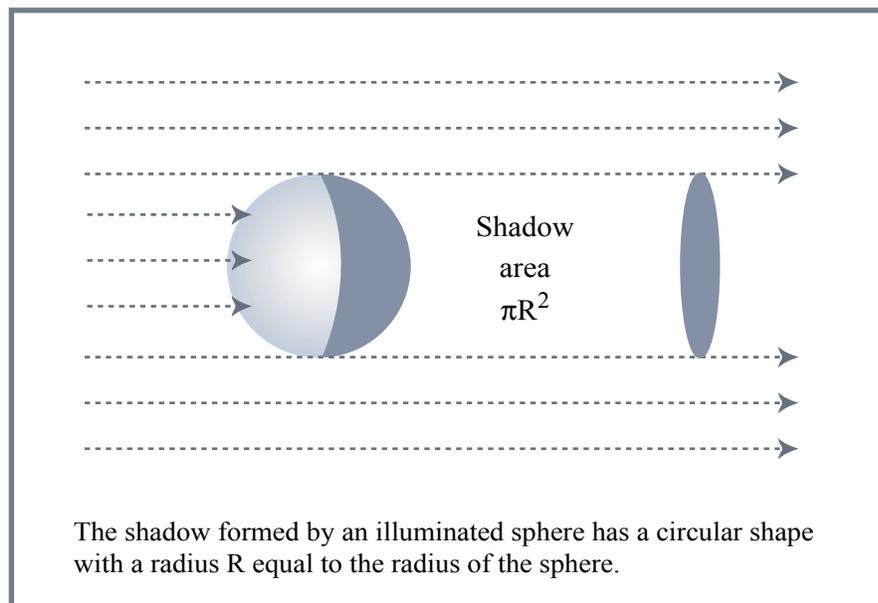

Shadow area πR^2

The shadow formed by an illuminated sphere has a circular shape with a radius R equal to the radius of the sphere.

Figure by MIT OpenCourseWare, adapted from M. B. McElroy, The Atmospheric Environment, 2002.

3.2.Case 2: Earth with a layer of atmosphere

Now let us model the effect of an atmosphere containing greenhouse gases. We model this situation by considering the atmosphere to be a single layer that does not absorb any incoming solar radiation, but absorbs all infrared radiation coming up from the earth's surface. If we want the atmosphere to maintain a stable temperature, then we have to assume that it re-emits the same amount of energy as it absorbs, but half upwards, and half downwards:

SUN

F(a)

F

σT_a^4

T_a ATMOSPHERE

σT_a^4

σT_s^4
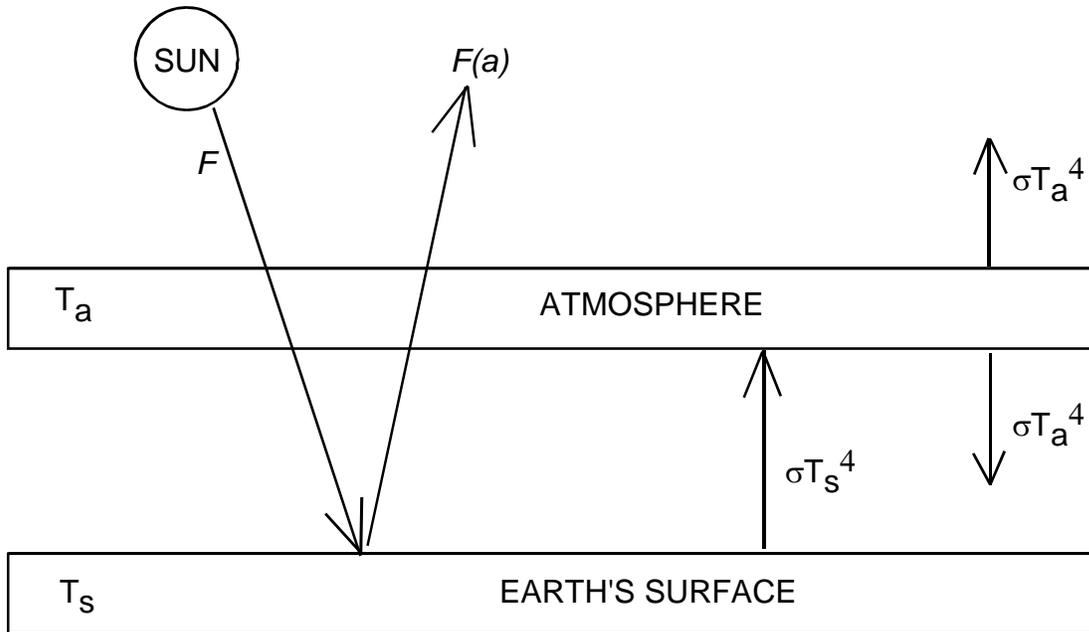
T_s EARTH'S SURFACE

Calculate the temperature for the earth's surface (T_s) and for the atmospheric layer (T_a). Hint: write one equation for each location, equating energy absorbed with energy radiated. Also note that the amount of incoming solar radiation absorbed by the earth's surface is *F(1-a)*. How does the surface temperature calculated here compare to the actual earth's surface temperature?

3.3. Compare your answers to the observed value and evaluate your model

The average temperature of the earth's surface is 288 °K. Briefly discuss:

a) What are missing from your model?

b) What you can do to improve this model (i.e., more factors to be considered; you could also revisit your answers in P1 and P2 above if needed)