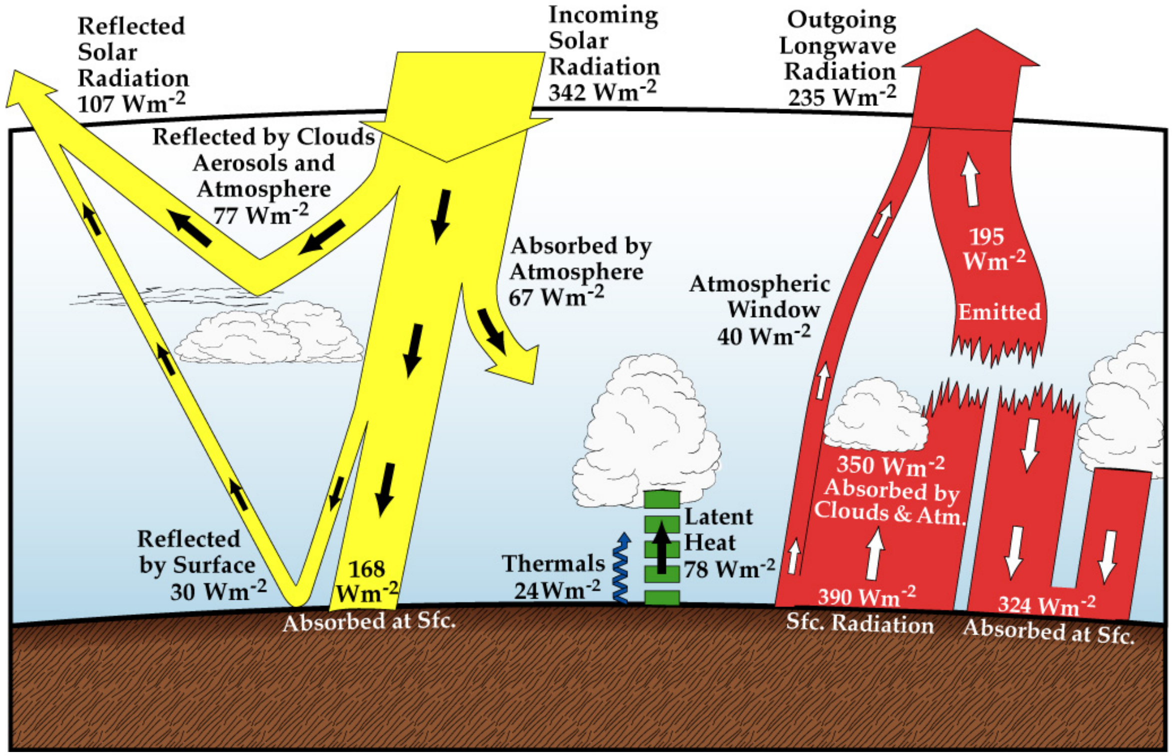
Name:
ID #:
Section #: (important!)

AOS1 Homework Assignment #1
Due Friday, April 21, 2017, at 5pm in your TA's mailbox

The purpose of this homework assignment is to help you understand Earth's energy balance and the greenhouse effect. Show your work in the space provided and put your final answers in the boxes, with ***brief*** discussion below if requested. Please underline your brief discussion. [28 points total]



This figure gives the global average energy balance of Earth.

a) [2 points] Calculate the average albedo of the Earth including clouds where

$$\text{albedo} = \frac{\text{reflected solar radiation}}{\text{total incoming solar radiation}}$$

albedo =

b) [2 points] Calculate the average albedo of the Earth's surface. [hint: total solar radiation reaching the surface = 198 W/m^2]. If clouds did not reflect sunlight would the Earth absorb a larger fraction of incoming solar radiation?

albedo =

c) [3 points] The global-mean surface temperature of the earth is about 288 degrees Kelvin. Use the Stefan-Boltzman law to calculate the radiative flux corresponding to an object with this temperature. [hint: use σT^4 with $\sigma = 5.67 \times 10^{-8}\ Wm^{-2}K^{-4}$]

Flux =

Is this similar to observed surface emissions of infrared (IR) radiation shown on the figure?

d) [4 points] Now calculate Earth's surface temperature if it had no atmosphere but the same albedo as you calculated in part (a). To do this use a surface energy balance:

upward IR = net solar radiation absorbed, i.e.,

$\sigma T^4 = 342\ Wm^{-2} \times (1 - \text{albedo})$.

Divide by σ and take the 4^{th} root (or hit square root twice). This gives temperature in degrees Kelvin. Subtract 273.15 to get degrees Celsius.

T =

Why does this differ so much from the observed average temperature of around 15C?

e) [5 points] Now let's do a more realistic case, where we include the downward IR associated with the greenhouse effect by using the observed current climate value of 324 Wm^{-2} from the figure. For consistency, we'll also use the observed value of solar radiation absorbed at the surface, 168 Wm^{-2}. The surface energy balance is thus

σT^4 = (solar radiation absorbed in the Earth system + downward IR)

= $(168 + 324\ Wm^{-2})$

Compute the temperature and convert to Celsius.

T =

Comment: you should now have a T somewhat warmer than observed and a sense that the greenhouse effect in current climate is very large. Discuss briefly (it might help to do part f first).

f) [3 points] To get close to the observed temperature of Earth, include all the surface heat flux contributions, i.e., calculate the surface temperature in Celsius from the following surface energy balance taken from the figure

σT^4 = net solar + downward IR – sensible heat – latent heat

$= 168\ Wm^{-2} + 324\ Wm^{-2} - 24\ Wm^{-2} - 78\ Wm^{-2}$

T =

Comment: Notice that while solar and IR are the biggest effects, the other forms of heat transfer have to be taken into account if you want a precise answer.

g) [4 points] Suppose the Earth's surface had a lower albedo of 0.1. (This is between ocean values and land values without snow or ice.) Keeping reflection by clouds and aerosols the same, the solar absorbed at the surface would be (1 – 0.1) x 198 Wm^{-2} = 178. Use

$\sigma T^4 = 178\ Wm^{-2} + 324\ Wm^{-2} - 24\ Wm^{-2} - 78\ Wm^{-2}$

to calculate T.

Compare to part (f) to discuss briefly how big the effect of reflection of sunlight by snow and ice is on Earth's current climate. Bear in mind that a 2 C change in global average temperature is associated with substantial climate differences.

T =

h) [5 points] Suppose you are on an arctic land region during the part of winter with no sunlight. Suppose the downward IR is 220 Wm^{-2}, a typical arctic value in December. This is less than the global average in the previous question but atmospheric transport of heat keeps the atmospheric temperature high enough to have substantial downward IR. Let's assume sensible and latent heat are small.

Calculate the surface temperature and convert to Celsius. [note: we chose land so we don't have to consider ocean heat storage]. Find T from the surface heat balance

$\sigma T^4 = 0 + 220\ Wm^{-2}$

T =

Now do the same if there is were no downward IR from the atmosphere, i.e.,

$\sigma T^4 = 0$. Is the downward IR (sustained by atmospheric transport) important to polar temperatures?

T =