Lab 4 for GEOL 1147 (Introduction to Meteorology Lab)

I. Introduction

Global warming, caused by greenhouse gases and particulates that absorb sunlight, is a topic frequently discussed in the mass media. Predictions of warming of several degrees Celsius are often reported. In this lab we will explore the causes of the greenhouse effect using a simple model of the Earth/atmosphere system.

Scientists, including meteorologists, often construct simple mathematical models of complex systems in order to study their behavior. A model is just a simplified mathematical description of a real system, such as the atmosphere of the Earth. To produce a model, simplifying assumptions are made concerning the physical processes that occur within the system to be modeled. For today's lab we will use a model of the radiative transfers that occur between the Earth, the atmosphere, and space. Using this model we can "experiment" with different configurations of the system, such as increased greenhouse gas concentrations. Whenever a model is used it is important to realize that because the model is a simplification of the real system, the results of the model experiments may not be completely accurate.

Lab Goals:

(1) Understand what causes the 'greenhouse effect'.
(2) Realize that physical phenomena can often be described by mathematical models that simulate their behavior under both existing and changing environmental conditions.
(3) Explore the nature of solar energy entering Earth's atmosphere, and how it affects both surface and atmospheric temperatures.

II. Review of the Greenhouse Effect

Solar energy is the dominant source of energy for the Earth/atmosphere system, excluding a small contribution from radioactive decay in the Earth's crust. Approximately 30% of the solar energy that enters the top of the atmosphere is reflected back to space by the atmosphere and the surface of the Earth. This reflected radiant energy therefore plays no part in the energy budget of the Earth/atmosphere system. The fraction of the incoming solar energy reflected by the Earth/atmosphere system is referred to as the planetary albedo. Most of the non-reflected solar radiation passes through the atmosphere and is absorbed at the surface of the Earth.

Since the average temperature of the Earth remains relatively constant from year to year, we know that the amount of energy received at the surface must be balanced by an equal amount of energy that is lost. This loss of energy is in the form of longwave radiation as well as sensible and latent heat fluxes. Longwave radiation is strongly absorbed in the atmosphere by greenhouse gases, such as water vapor and CO_2. In addition, because the temperature of the atmosphere is not changing very much from year to year, the energy gained by the atmosphere from longwave radiation from the Earth and by sensible and latent heat fluxes from the surface must be balanced by equal energy losses. These losses occur as longwave radiation that is directed both out to space and back to the surface of the Earth. The emission of longwave radiation from the atmosphere back to the surface of the Earth results in the greenhouse effect. The greenhouse effect keeps the surface of the Earth substantially warmer than it would be if the atmosphere contained no gases that absorbed longwave radiation. In this lab we will calculate the temperature of a planet identical to Earth, except that its atmosphere contains no greenhouse gases.

If the amounts of atmospheric greenhouse gases were to increase, it would be expected that the amount of longwave radiation trapped by the atmosphere would increase, and that the temperature of the Earth/atmosphere system would warm. Again, we will conduct a number of experiments in the lab to test this theory, using our simple model of the Earth/atmosphere system.

III. The Model

As stated above, a model is a simplified description of a real system, written in the language of mathematics. We are interested in modeling the transfer of radiation to, from, and within the Earth/atmosphere system. To do this we will make the following assumptions:

(a) No atmospheric motion occurs. Since sensible and latent heat fluxes require atmospheric motion, these fluxes will be equal to zero in our model.

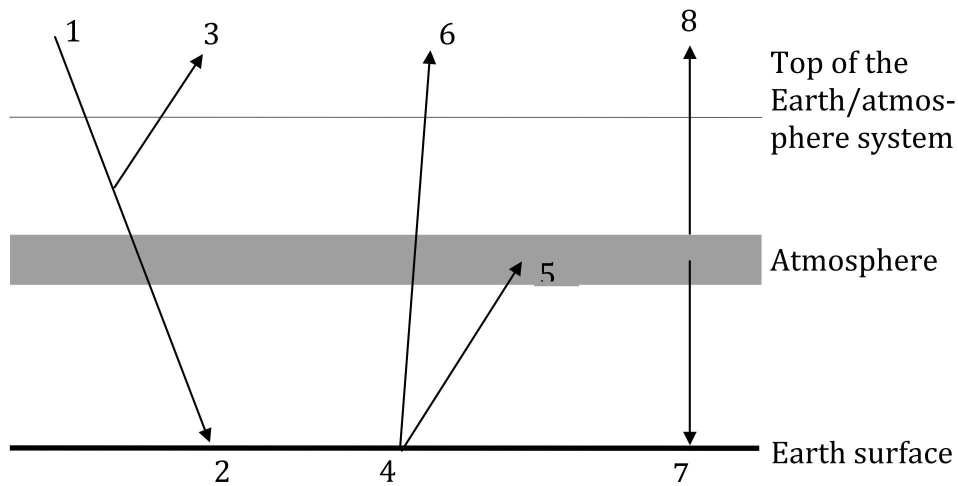
(b) The atmosphere is entirely transparent to shortwave radiation so that it does not *absorb* any solar radiation. It can, however, contribute to shortwave *reflection*.

(c) The amount of longwave radiation absorbed by the atmosphere increases as the concentration of greenhouse gases increases.

(d) The atmosphere is treated as a single layer, with one average temperature and constant radiative properties (i.e. no absorption of shortwave radiation and a fixed value of absorption for longwave radiation). More complex models could be constructed that treat the atmosphere as multiple layers.

The model then is just a set of mathematical equations that describe the physical processes of the simplified system. All models require input, or values that describe some initial condition of the system. The required inputs for the model used in this lab are the incoming solar radiation, the planetary albedo, and a value for the extent of longwave absorption by the atmosphere. We will vary these input values to determine their impact on the final state of the system.

Below is a diagram that represents the radiative fluxes in our model for the assumptions listed above.



The numbers in the diagram refer to the following radiative fluxes:

1. Incoming solar radiation
2. Solar radiation absorbed at the surface
3. Reflected solar radiation
4. Emitted longwave radiation from the surface
5. Longwave radiation absorbed by the atmosphere
6. Longwave radiation emitted from the surface to space
7. Longwave radiation emitted from the atmosphere to the surface
8. Longwave radiation emitted from the atmosphere to space

A list of equations that are used to calculate these radiative fluxes is given in the last page of this lab. You do not need to be able to understand these equations to complete this lab successfully. They are included for students interested in understanding the model used.

IV. Exercises

Before starting the lab, answer the following questions after you have read the relevant sections of the textbook and the above introductory material.

1. What is the dominant source of the Earth/atmosphere system's energy?

2. What would happen to the temperature at the surface of the Earth if no greenhouse gases were present in the atmosphere?

3. What assumptions are made for the model of radiative transfer used in this lab?

The equations that describe our model have been programmed into an interactive spreadsheet lab4.xls.
For this assignment the incoming solar radiation will be 342 Wm^{-2}, and will not be varied for our experiments. Use the following input pairs of values for the Albedo and the Longwave Absorptivity for the five indicated experiments. (Just enter these values in the appropriate boxes (rows #2 and #3) on the spreadsheet).

Experiment	**Planetary Albedo**	**Longwave Absorptivity**
1. Atmosphere with No Greenhouse Gas	0.30	0.00
2. Current values	0.30	0.77
3. Doubled CO_2	0.30	0.82
4. Doubled CO_2 with cloud feedback	0.40	0.82
5. Doubled CO_2 with ice cap feedback	0.20	0.82

4. Input the values from the table above, and use the model output in the Results column of the spreadsheet to complete the following tables:

Solar Radiation Fluxes ($W\ m^{-2}$)

Experiment	**incoming solar radiation**	**solar radiation absorbed at the surface**	**reflected solar radiation**
1	342		
2	342		
3	342		
4	342		
5	342		

Longwave (LW) Radiation Fluxes ($W\ m^{-2}$)

Exp-eriment	LW radiation emitted from the surface	LW radiation from surface absorbed by the atmosphere	LW radiation emitted from the surface to space	LW radiation emitted from the atmosphere to surface	LW radiation emitted from the atmosphere to space
1					
2					
3					
4					
5					

Temperature

Experiment	Surface Temperature		Atmospheric Temperature	
	K	°F	K	°F
1				
2				
3				
4				
5				

5a. How does the surface temperature change when the current concentrations of gases that absorb longwave radiation are added to the atmosphere? (Compare experiments 1 and 2).

5b. What name is given by meteorologists to this effect where the atmosphere can modify surface temperatures?

5c. Name *five* important trace atmospheric gases that can promote this effect.

6a. What happens to the atmospheric temperature as the amount of absorption of longwave radiation in the atmosphere is increased in the experiments?

6b. What happens to the surface temperature as the amount of absorption of longwave radiation in the atmosphere is increased in the experiments?

7a. Experiment 4 simulates the effect of increased cloud cover. How is this achieved?

7b. Why does the planetary albedo increase when the cloud cover increases?

7c. How does the change in planetary albedo affect the surface temperature?

7d. Is the change in cloud cover, caused by global warming, a positive or negative feedback to the initial warming? In other words, does an increase in cloud cover caused by global warming, lead to enhanced or reduced warming, and the formation of even more or fewer clouds?

7e. Why might cloud cover increase if global warming were to occur?

8a. Experiment 5 simulates the effect of a reduction in the area covered by the polar ice caps on a globally warmed planet. How does the planetary albedo change?

8b. Why does the planetary albedo change in this way?

8c. How does this change in planetary albedo affect the surface temperature?

8d. Is the change in the polar ice caps, caused by global warming, a positive or negative feedback to the initial warming? Why?

8e. What reason is there to expect that the area covered by ice caps would decrease if global warming were to occur?

Appendix. Equations used in the model

Below is a list of the equations used in the model of radiative transfer for this lab.

$$SW_{in} = S/4$$

$$SW_{refl} = SW_{in} \cdot A$$

$$SW_{abs\_sfc} = (1 - A) \cdot SW_{in}$$

$$LW_{up\_sfc} = \frac{SW_{abs\_sfc}}{1 - \frac{a}{2}}$$

$$LW_{abs\_atmos} = a \cdot LW_{up\_sfc}$$

$$LW_{sfc\_to\_space} = (1 - a) \cdot LW_{up\_sfc}$$

$$LW_{atmos\_to\_sfc} = \frac{LW_{abs\_atmos}}{2}$$

$$LW_{atmos\_to\_space} = \frac{LW_{abs\_atmos}}{2}$$

$$T_{sfc} = \left(\frac{LW_{up\_sfc}}{\sigma} \right)^{0.25}$$

$$T_{atmos} = \left(\frac{LW_{abs\_atmos}}{\sigma} \right)^{0.25}$$

Definition of Variables

SW_{in} : incoming solar radiation (averaged over surface of Earth)

S : solar constant (1367 W m^{-2})

SW_{refl} : reflected solar radiation

A : planetary albedo

SW_{abs_sfc} : solar radiation absorbed at the surface

LW_{up_sfc} : longwave radiation emitted from the surface

a : longwave absorptivity

LW_{abs_atmos} : longwave radiation absorbed by the atmosphere

$LW_{sfc\_to\_space}$: longwave radiation emitted from the surface to space

$LW_{atmos\_to\_sfc}$: longwave radiation emitted from the atmosphere to the surface

$LW_{atmos\_to\_space}$: longwave radiation emitted from the atmosphere to space

T_{sfc} : temperature of the surface

σ : Stefan-Boltzman constant

T_{atmos} : temperature of the atmosphere