1. Use the toy model called "Two-layer graybody atmosphere" from the class website to answer the following questions. The model lets you vary the absorptivity (also called emissivity) of the layers of air, and also the amount of convective mixing of heat from the surface into the atmosphere. You will probably need the "Diagram" tab for this problem.

    a. Increase the emissivity of the lower layer to 0.75 and the upper layer to 0.65. What are the temperatures of the surface, lower atmosphere, and upper atmosphere? How does the simulated surface temperature compare to the actual global mean surface temperature of the Earth?

    b. Is it reasonable that the emissivity (absorptivity) of the lower atmosphere is greater than the upper atmosphere? Why or why not?

    c. Add convective mixing of heat: 100 W m^{-2} from the surface to the lower atmosphere and 50 W m^{-2} from the lower to upper atmosphere. What is the effect on the temperature of each layer? Is this arrangement more or less realistic than the situation you simulated in part (a)?

    d. Turn down the brightness of the Sun by 10%. Can you bring the surface temperature back up to the Earth's average surface temperature by adjusting the emissivity of the atmospheric layers? What values for the emissivity did you use?

2. Use the toy model called "Infrared absorption by greenhouse gases" from the class website to answer the following questions. The model lets you vary the amount of carbon dioxide (CO_2), methane (CH_4), and water vapor (H_2O) in the atmosphere and the surface temperature. It computes the emission of thermal infrared radiation at the top of the atmosphere and calculates the net rate of warming or cooling of the planet.

    a. Increase the amount of CO_2 to 800 ppm. What is the resulting net radiation imbalance at the top of the atmosphere?

    b. Adjust the surface temperature to get rid of the net radiation imbalance at the top of the atmosphere with CO_2 = 800 ppm. By how much did you have to warm the surface?

    c. What were the concentrations of atmospheric CO_2 and CH_4 before the industrial revolution? (Google is your friend!).

    d. What is the contribution of the increase of each gas since preindustrial times to the current radiation imbalance at the top of the atmosphere?

   e. Adjust the surface temperature to eliminate the net energy imbalance with both CO_2 and CH_4 at their preindustrial values. How much warming can be attributed to the increase of these gases since 1800?

3. Imagine that you can take a "parcel" of air from CSU straight upward in a hot air balloon. The parcel would be free to expand as it rose, and would not get any heat from the hot air balloon. If the temperature at CSU is 20 °C, what temperature would the air parcel have if it's lifted 1500 meters above the ground?

4. Earth's "tropical belt" extends from 22° N to 22° S. Over what tropical regions is the emission of thermal infrared radiation strongest? Where is it weakest? Why?

5. If there were no climate feedback, just solar radiation coming in and thermal radiation going out, what would the Earth's **climate sensitivity** be, in (degrees Celsius) per (Watt per square meter)?

6. For each of the following "**climate feedback**" mechanisms, indicate whether the process is a *positive* or a *negative* feedback, and briefly explain how it works:

   a. Water vapor
   b. Lapse Rate
   c. High Clouds
   d. Low Clouds
   e. Ice-Albedo

7. What is ***climate forcing***? Name three kinds of ***climate forcing*** that have caused climate to change over the past 1000 years.

8. Briefly explain two different ways we can estimate the total **sensitivity** of Earth's climate, including all the feedbacks. About how sensitive do we think the real climate is, in °C per (W m^{-2})?

9. Describe three ways that geologists think the process of continental drift (also called "plate tectonics") causes major climate changes on Earth over many millions of years.

10. List two examples of abrupt climate change from the past, as recorded in the geologic record. What caused them?

11. Ice core temperature reconstructions have a "saw tooth" pattern: cooling into each Ice Age was much slower than warming at the end of each Ice Age. Why?

12. Explain three ways that changes in the Earth's orbit around the Sun work together to control the timing of the Ice Ages.

13. Briefly explain how scientists estimate the following changes in Earth's properties after the end of the last Ice Age:

    a. Albedo
    b. CO_2 Concentration
    c. Global mean temperature