** Required for students taking class for graduate credit (not required for GEOG313)*
Complete the assignment by filling out the forms on bblearn.

1. The figure below is a crude representation of the Earth's surface energy balance.
    a. Assume there is an imbalance in the diagram such that there is more downward shortwave radiation than upwelling longwave radiation. How will the system respond to this imbalance? (1 pt)
    b. Identify at least TWO critical components missing in the diagram that are important in controlling Earth's surface energy balance. (2 pts)
    c. * Rewrite the energy budget equation in mathematical terms given your modification. By adding each additional piece to the puzzle, what is the net influence on global surface temperature? (2 pts)

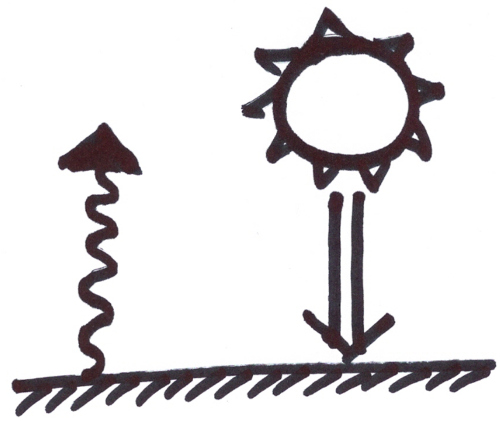


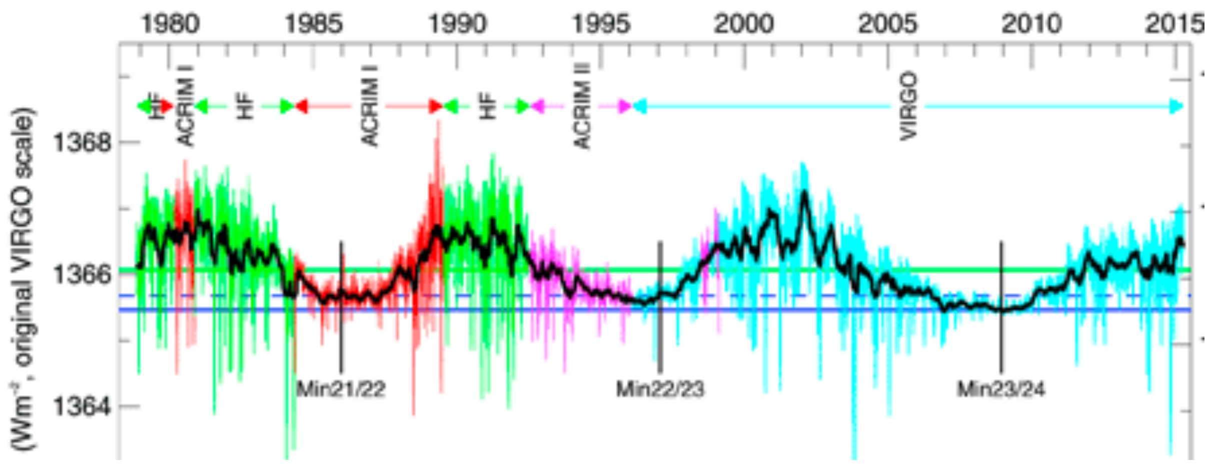
Figure 1: Simple Energy Balance showing incoming solar radiation and outgoing longwave radiation.

2. Using the MODTRAN model http://climatemodels.uchicago.edu/modtran/ that includes a line-by-line radiative transfer code you will perform the following experiments. For each experiment set the default values as follows
    - Set atmospheric CO2 to 415 parts per million
    - Set methane (CH4) to 1.9 parts per million
    - Set locality to "1976 US Standard Atmosphere" and " No Clouds or Rain"
    - Have your sensor altitude at 70-km looking down as you are interested in the downward longwave radiation only.
    - Pay attention to **Upward IR Heat Flux** under Model Output

    a. Would an additional 10 ppm of methane (CH4) in the atmosphere have a larger or smaller impact on the amount of infrared energy **trapped** by the earth's atmosphere than an addition of 10 ppm of carbon dioxide (CO2)? Provide support for your answer. (2 pts)
    b. * Using the module, estimate the carbon equivalency of methane. In other words, for how much of a change in CO2 (in ppm) are needed per every 1 ppm change in methane. (1 pts)
    c. From current conditions, examine the response of the amount of longwave radiation the sensor sees AND the energy absorption in the radiation spectrum (figures) when you increase CO2 by 200ppm, 400ppm and 600ppm. Report your numbers to 3 significant digits. Explain your results and discuss

whether the addition of CO_2 into the atmosphere results in a linear or non-linear influence on the greenhouse effect.

3. The solar minimum of 2009/2010 marked the least amount of solar energy received at the top of the atmosphere in at least 50 years. This contrasts to solar maxima (e.g., 2002) that occur about every 11 years.
    a. Using the information in the graph provided below calculate the radiative temperature of the Earth (radiative temperature is the equilibrium temperature at the top of the atmosphere and sensitive only to incoming radiation) assuming a constant global albedo of 0.3. Report your numbers to 2 significant digits.
        i. Global temperature during solar maximum (e.g., 2002)
        ii. Global temperature during solar minimum (e.g., 2009)
        iii. Net change in global temperature from this model between 2009 and 2002.



    b. * Reconstructions of solar irradiance over the past 500 years suggests that solar activity had a sustained minimum in the second half of the 17th century where solar irradiance was around 1364 W/m2. See: http://sparcsolaris.geomar.de/Input_data/Lean2001.pdf
    Estimate the change in radiative temperature of the planet between this minimum (called the Maunder Minimum) and the solar maximum in 2002.
    Part 1: Assume no net change in global albedo (albedo=0.3);

    Part 2: Assume that the Maunder Minimum coincided with a period of intense volcanic activity that have a +1% relative increase in albedo (albedo =0.303).