AOSC 433/633 & CHEM 433/633 Atmospheric Chemistry and Climate

Problem Set #5

Due: Thursday, 2 May 2013

140 points total.

Late penalty: ***10 points per day late***, unless there is a legitimate circumstance brought to our attention ***prior to the due date!***

1. (50 points). Effective Temperature and Sea Ice

a) (10 points) Calculate the effective temperature of the Earth for the following case: present solar conditions (i.e., value of S given in Lecture 3) and an albedo = 0.3

b) (5 points) Compare and contrast the average surface temperature of Earth to the effective temperature found in a) and briefly describe why these two terms differ.

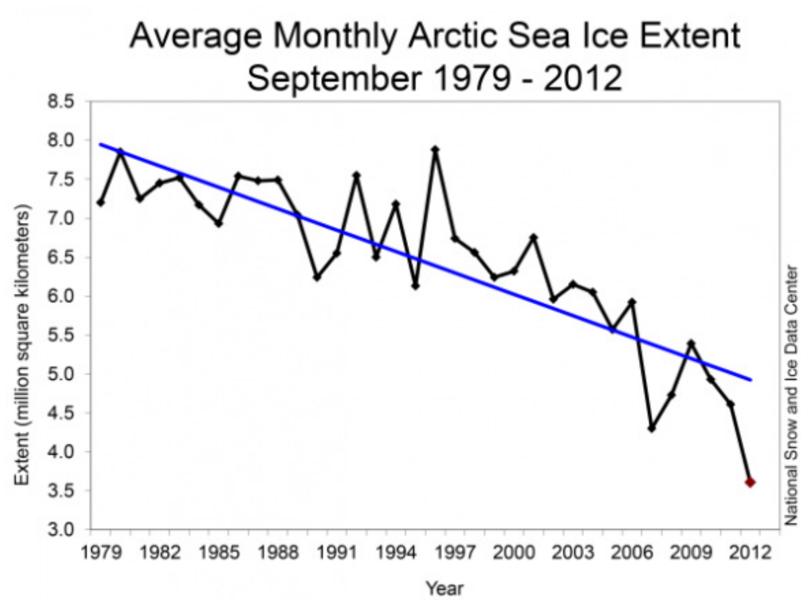
c) On 12 April 2013, NOAA issued a rather alarming press release:

http://www.noaanews.noaa.gov/stories2013/20130412_arcticseaice.html

that stated:

> **For scientists studying summer sea ice in the Arctic, it's not a question of "if" there will be nearly ice-free summers, but "when." And two scientists say that "when" is sooner than many thought — before 2050 and possibly within the next decade or two.**

Here we will examine the RF of climate due to a change in Earth's albedo due to melting sea ice, for the month of Sept. The graph below shows a time series of Arctic Sea Ice extent during September:



Source:http://scienceblogs.com/illconsidered/2012/10/september-monthly-arctic-sea-ice-extent-smashes-previous-record/

i) (5 points) The global average CO_2 mixing ratio was 337.1 ppm in 1979 (data for CO_2 is at http://data.giss.nasa.gov/modelforce/ghgases/Fig1A.ext.txt). Assume global average CO2 will reach 560 ppm in 2050. What will be the RF of climate due to this rise in CO_2, from 1979 to 2050?

ii) (20 points) Assume the surface area of Arctic Sea Ice in 1979 given above, that Arctic sea ice will unfortunately disappear in 2050, and that the albedo of Arctic Sea Ice and open ocean are given by the second and third panels of the figures at:

http://www.teachersdomain.org/assets/wgbh/ipy07/ipy07_int_albedo/ipy07_int_albedo.html

Assuming that the only change in Earth's albedo between 1979 and 2050 will be due to the disappearance of Arctic Sea Ice, estimate the RF of climate due to the change in Earth's albedo caused by the disappearance of Arctic Sea Ice.

Hint: Lecture 8 may be of use for completing this part.

d) (10 points) Compare and contrast the RF of climate due to the factors considered in parts i) and parts ii) above and comment on whether scientists who model Earth's climate should be concerned about the change in albedo caused by the disappearance of Arctic Sea Ice either amplifying, or dampening, the expected future warming that will be induced by rising CO_2. Be sure to indicate whether the disappearance of Arctic Sea Ice either amplifies or dampens the effect of rising CO_2.

2. Carbon capture and storage (50 points). The burning of fossil fuel, globally, released about 9.5 Gigatons (9.5×10^9 tons of carbon into the atmosphere in year 2011. As we had worked out early in the semester, this equals 9.5×10^{15} grams of carbon.

According to Table ES-2 of http://www.epa.gov/climatechange/Downloads/ghgemissions/US-GHG-Inventory-2013-ES.pdf, the United States was responsible for release of 1.5×10^{15} grams of carbon into the atmosphere in 2011 (note this table gives mass of CO_2 released, but we have converted to mass of carbon).

Here we will quantify the land resource needed to sequester atmospheric CO_2 into sodium carbonate Na_2CO_3, a stable (though caustic) way to store carbon. The physical properties of sodium carbonate are described at:

http://en.wikipedia.org/wiki/Sodium_carbonate

Our goal is to calculate the land resource needed to sequester, on an *annual* basis, the carbon released to the atmosphere by the burning of fossil fuels. Since each nation will be responsible for sequestration of their own emissions, we will start with the total U.S. emissions for 2011.

a) (10 points) What mass of sodium carbonate would be produced for year 2011, if all of the carbon release by the U.S. could be converted to sodium carbonate?

b) i) (5 points) Using the density for sodium carbonate given at the wiki page cited above, what volume would be occupied by the mass of sodium carbonate found in part a)?

ii) (8 points) Because sodium carbonate is caustic, carbon sequestered in this manner must be stored in a shelter of some type. Assume that the shelter will be 4 stories high, about the height of the Computer and Space Sciences building. How much *surface area* (footprint of the buildings revealed on Google Earth) would be needed to store the resulting "heap" of sodium carbonate?

iii) (10 points) Assume that each state will be responsible for housing the carbon used by its residents: i.e., Maryland must house its share of the total US storage. Calculate the surface area "footprint" of the structure needed to house Maryland's Carbon emissions for year 2011? Please make a reasonable assumption about Maryland's share of total U.S. Carbon emissions and describe your assumption.

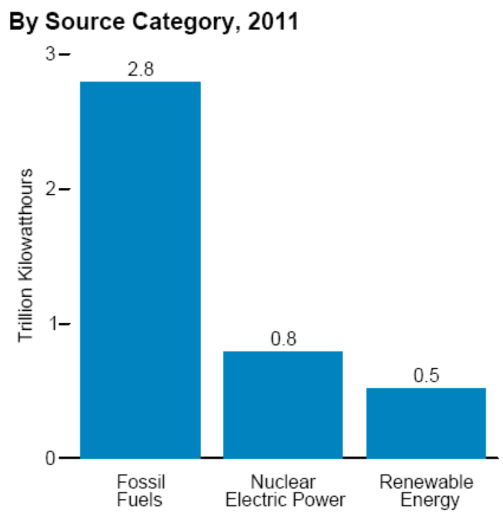
iv) (2 points) Is a structure of this size tenable to build?

c) (15 points) Assume for the next 50 years that society decides to continue to rely on the combustion of fossil fuel to supply its energy needs. What is the surface area "footprint" needed, within Maryland, to sequester all of the carbon produced over the next 50 years, in the form of sodium carbonate? Make a reasonable assumption about how fossil fuel emissions will change over the next 50 yrs and describe your assumption.

How does this surface area "footprint" compare to the size of Maryland?

Is the use of this much land for carbon sequestration tenable?

3. US Energy Needs & Solar PVs (40 points). The US consumes 4.1×10^{12} kilowatt-hrs in electricity per year, primarily from combustion of fossil fuels and nuclear energy, as shown below (from page 222 of http://www.eia.gov/totalenergy/data/annual/pdf/aer.pdf).



Also:

1 kilowatt-hr = 3.6×10^6 J
1 kilowatt = 10^3 Watt
1 W = 1 J/s

Here, we will explore the potential energy yield and cost of using traditional solar photovoltaic (PV) panels to meet this entire energy need.

There are 80 million single-family homes (1-unit, detached) homes in the United States, according to: http://www.census.gov/compendia/statab/2011/tables/11s0984.pdf

Assume that the U.S. government decides to place a 5 kilowatt solar PV panel array on the roof of very single family home in the nation: ***5 kilowatt refers to the output of this system at noon (peak sun), for clear sky conditions.***

a) (20 points) What fraction of the US current electricity consumption would be provided if a 5 kilowatt solar PV system was placed on the roof of every US single family home?

> Note: in arriving at this estimate, please take into consideration the fact these systems only produce full energy under clear sky conditions, for overhead sun (local noon during summer for latitude of Md). Provide a "reasonable estimate" of the annual electricity output from solar PV panel arrays, taking into consideration factors such as day vs night, clear sky vs cloudy sky, and that the sun sweeps through the sky each day (we are looking for rough, "back of the envelope" estimates!).

b) (10 points) Assume each system costs \$5.20 per watt of output, the blended price for Q2 of 2011 detailed at http://www.greentechmedia.com/articles/read/average-system-price-of-5.20-w and that the gross domestic product (GDP) of the United Stated was \$15.0 trillion in year 2011. What fraction of the US GDP would be required to install a 5 kilowatt solar PV system on the rooftop of every single family home?

c) (10 points) If you were advising the U.S. government, would you recommend the government invest in the installation of a 5 kilowatt solar PV panel array on the roof top of every single family home?