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

Problem Set #1 Due: Thurs, 12 Feb 2015 (start of class)

Late penalty: 10 points per day late, unless there is a legitimate medical or extra-curricular circumstance (i.e., band, athletics, GREs, etc) brought to our attention ***prior to the due date!***

Final deadline: Monday, 16 February, 5 pm: ***no credit*** will be given after final deadline.

Please "show your work", "carry units" while plugging numbers into equations, and express answers using a *reasonable* number of significant digits.

Ross, Austin, & Tim will be present during posted office hrs and are happy to arrange other times to meet.

Information needed to complete this assignment is contained in the lecture notes and reading assignments. However it is fine to use any resource (book, website, etc) to complete this assignment provided the answers you provide reflect *your understanding of the solution*. While we encourage students to share notes and discuss course material, we also expect that problem set solutions reflect individual efforts.

Please get started early!

1. Radiative Forcing of Climate by CH_4, N_2O, and CO_2 (40 points total)

Note: you should be able to complete this question after Lecture 2

a) (20 points) As we will explore in more detail later in class, and as is written in Equation (4.3) of *Chemistry in Context*, the combustion of methane (CH_4), aka natural gas, yields **802.3 kJ** of energy **per mole of atmospheric CO_2 produced**.

The combustion of coal (notional formula of $C_{135}H_{96}O_9NS$) is much less efficient than the combustion of methane. The energy yield from combustion of coal varies based on the type of coal, but roughly coal yields about half the energy, per mole of atmospheric CO_2 produced, than provided by combustion of methane. Here we will assume combustion of coal yields **401.15 kJ** of **energy per mole of atmospheric CO_2 produced**.

Clearly, since CH_4 yields more energy than coal on a per mole of atmospheric CO_2 released basis, society would be better off by converting coal power plants to natural gas burning plants, at least in terms of mitigating future climate change.

Not so fast! The natural gas industry is ***notorious*** for small, insidious leaks of CH_4.

Assume that a certain percentage of methane is lost to the atmosphere via leaks rather than being burned. Making use of the Global Warming Potential for CH_4 given in Lecture 2, estimate the **percentage of leaked methane** that would **mitigate the climate benefit** of **switching from coal to natural gas**.

433 students: make this estimate using the GWP of CH_4 for a 100 year time horizon

633 students: make this estimate using the GWP of CH_4 for all 3 time horizons

All students: the GWP potentials given in Lecture 2 are on a per mass basis: i.e. per gram of CH_4 relative to per gram of CO_2. Since this question is posed in terms of **moles of atmospheric CO_2** produced from each energy source, the easiest way to proceed is to convert the GWPs from Lecture 2 from a "per mass basis" to a "per molecule basis", using the molecular weights of CO_2 and CH_4.

b) (10 points) As we shall see later in class, a consequence of the emerging market for biofuels is that production of these compounds tends to be fertilizer intensive, which could result in a rise in atmospheric nitrous oxide (N_2O).

Assume a **biofuel industry** is established that is entirely **carbon neutral**: in other words, the carbon content of this new fuel is derived from atmospheric CO_2 via photosynthesis, so that atmospheric CO_2 does not change as society meets its energy needs via combustion of this new fuel. Also assume the energy yield from this process is the same as the aggregate energy yield from combustion of the fossil fuels that are displaced.

If it is later discovered that N_2O is inadvertently released to the atmosphere via the fertilizer used to make this new fossil fuel, estimate the percentage of N_2O released, relative to amount of CO_2 that was "saved" by the carbon neutrality of this process, for the entire enterprise to turn out to be ***harmful to the environment***, from a climate mitigation point of view. Please answer using the 20 year time horizon.

> **Hint:** once you have computed the GWP of N_2O on a per molecule basis the answer should be straightforward to derive.

c) (10 points) If we are concerned about long-term effects of climate change: i.e., what will happen hundreds of years in the future, which process is more troubling: the switch to methane combustion described in part a) or the switch to a carbon neutral, but nitrogen fertilized intensive (with attendant release of N_2O) described in part b)?

> Please first write your answer (i.e., either **"Methane is more troubling"** or **"Biofuels is more troubling"**) then give a brief sentence or two supporting this answer.

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2. Effective Temperature (40 points total)

Note: you should be able to complete this question after Lecture 3

a) (20 points) In class we found the effective temperature for Earth. Using the same method, compute the effective temperatures for Mars and Venus.

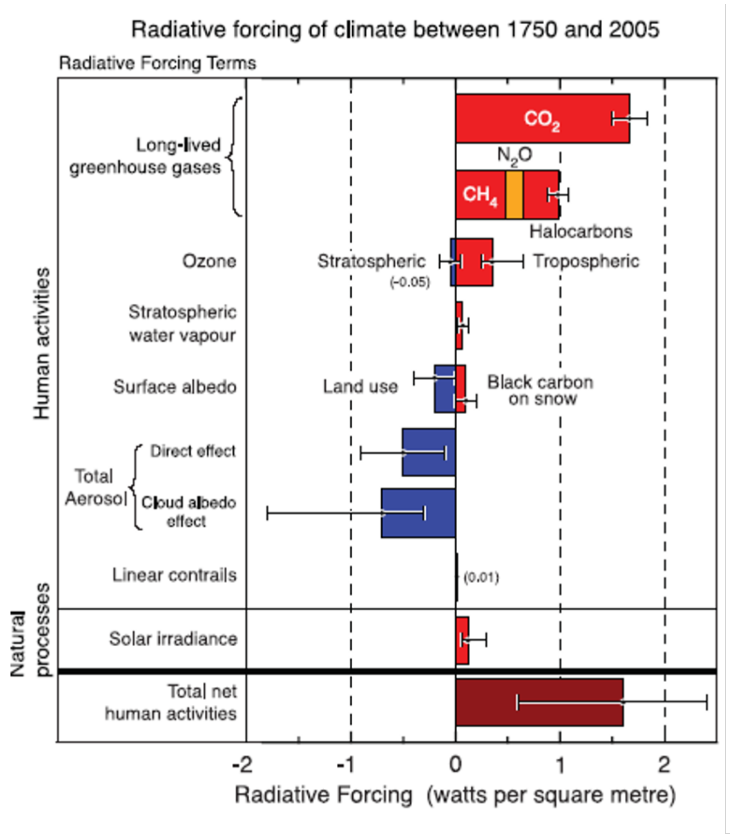
b) (10 points) Compare the effective temperature for Venus, Earth and Mars to the mean surface temperature of these three planets: i.e., write all 6 numbers and state which planet has an actual temperature closest to its effective temperature (for Mars, you should use the mean value of the two surface temperature numbers presented in class).

c) (10 points) Which planet is furthest from its effective temperature and what process is responsible for this difference?

3. Climate Change (40 points for 433; 60 points for 633)

Note: you should be able to complete this question after Lecture 4

The chart below shows the Radiative Forcing (RF) of climate, from 1750 to year 2005,



FAQ 2.1, Figure 2. *Summary of the principal components of the radiative forcing of climate change.*

from greenhouse gases (GHGs) and aerosols. Assume that there was little change in atmospheric composition due to humans between 1750 and 1900, so that this chart would apply equally well for the tine period 1900 to 2005.

a) (5 points) Based on material presented in Lecture 2, how much did the global mean temperature rise between 1900 and year 2005 (you can read this value off of the first slide titled **Are humans responsible?** that was shown in Lecture 2). This should be a single, numerical value, with appropriate units, denoted as $\Delta T_{1900 \text{ to } 2005}$.

b) (5 points) Estimate the three possible values for the change in RF of climate due to human activity from the chart above:

1) the best estimate of the total net human activities
2) the upper limit of the total net human activities
3) the lower limit of the total net human activities

Denote these three values as $RF^{HUMAN-1}$, $RF^{HUMAN-2}$, and $RF^{HUMAN-3}$ and give units.

c) (10 points) Estimate λ_{ACTUAL} of Earth's climate over the 1900 to 2005 time horizon: i.e., the sensitivity of surface temperature for RF, for each value of RF_{HUMAN} given above.

You are welcome to denote these three values of λ_{ACTUAL} as $\lambda_{ACTUAL-1}$, $\lambda_{ACTUAL-2}$, and $\lambda_{ACTUAL-3}$.

d) (10 points) If atmospheric CO_2 happens to double, the RF of climate will be about 3.7 W m^{-2}.

Estimate how much surface temperature will rise, in response to this forcing, for the three values of $\lambda_{ACTUAL-1}$, $\lambda_{ACTUAL-2}$, and $\lambda_{ACTUAL-3}$ found in part c).

633 students:

e) (10 points) In a few cogent sentences, explain why this calculation supports our contention that it is "much easier to understand the past than predict the future"

f) (10 points) Based on all of the above, explain what aspect of the climate system would enable a more accurate prediction of future global warming, if only we could obtain a precise measurement of this quantity.