AOSC 433/633 & CHEM 433 Atmospheric Chemistry and Climate

Problem Set #2 (160 points for 433 / 195 points for 633) Due: Thurs, 26 Feb 2015 (start of class)

Late penalty: 30 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: Mon, 2 March, 6 pm: ***no credit*** will be given after final deadline. We have a very tight final deadline, relative to the due date, because we will grade these questions on Wed and conduct a review on Wed evening, prior to the exam on Thurs. **Please get started soon.**

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

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. ***These questions are new for 2015 so archived notes from prior years are not likely to be helpful.***

1. Atmospheric Mass & Terra Framing Mars (40 points for 433 / 50 points for 633)

This problem can be completed using material presented as of Lecture 3, except for the 633 question which will draw on other lectures and one of the readings.

a) (10 points) The acceleration of gravity at the Martian surface is 371 cm/s². Given this information and other details about the Martian Atmosphere and Mars presented in Lecture 1, calculate the mass of the Martian atmosphere in units of gm.

b) (10 points) Calculate the mean molecular weight of the Martian atmosphere, in units of gm/mole.

c) (10 points) The present Martian atmosphere has very low levels of molecular oxygen, O_2. As part of a terra-farming enterprise to prepare the Martian atmosphere for *eventual* human habitation, NASA and other space agencies have decided to place on Mars a photosynthetic, oxygen (O_2) generation system: i.e., seeds will be spread over Mars leading to plants that can grow in this habitat.

The system will cover the entire Martian surface and will be capable of producing 1.875×10^{15} moles of O_2 per year via photosynthesis, which is close to the annual output of O_2 by photosynthesis on Earth. Assuming the O_2 produced simply accumulates in the Martian atmosphere, how many years will it take for this system to bring the O_2 mixing ratio of the Martian atmosphere to the same *mixing ratio* in Earth's present atmosphere?

d) (**633 students only**) (10 points) Another aspect that will need to be considered, for the terra-farming of Mars, is a means to raise the Martian surface T to Earth-like values. What type of trace gas could likely be transported from Earth and added to the Martian atmosphere to significantly raise that Martian surface T? What physical characteristics of this gas would likely be crucial for selection?

e) (10 points) All students … so after a period of time the surface T of Mars has been raised to Earth-like values via injection of a trace gas (part d, 633 students only) and the mixing ratio of O_2 is now at present day, Earth-like values (part c). Would a human be able to safely breathe in this terra-farmed Martian atmosphere? Provide a sentence supporting either a yes or no answer.

2. The U.S. / China Climate Accord (70 points)

This problem can be completed using material presented up to and including Lecture 5.

On 12 Nov 2014 the Presidents of the U.S. and China announced that the U.S. intends, by year 2025, to reduce their total carbon emissions to a benchmark of 27% below the emission level that occurred in year 2005, whereas China intends to achieve peak CO_2 emissions around 2030, while also making "best effort" to peak early. This question involves examining the impact, on global climate in year 2030, of this accord.

Computer files:

http://www.atmos.umd.edu/~rjs/class/spr2015/problem_sets/ps02_data_table.dat

&

http://www.atmos.umd.edu/~rjs/class/spr2015/problem_sets/ps02_data_table.xlsx

contain time series of the global mean $CO_{2\ MR}$, total global C emissions, global population, as well as total C emissions and population for the U.S. and China. The same information content appears in both files; two file formats are provided to facilitate completion using either Excel (*.xls file) or some other computational tool. Also for your convenience the same information is given here:

Column #1: Year

Column #2: Global Mean $CO_{2\ MR}$ (ppm)

Column #3: Global C emissions, Gt C

Column #4: Global Population

Column #5: U.S. C emissions, Gt C

Column #6: U.S. Population

Column #7: China C emissions, Gt C

Column #8: China Population

2000	370.00	6.765	6076558000	1.558	282158000	0.929	1262645000
2001	371.81	6.927	6154791000	1.527	284915000	0.951	1271850000
2002	374.19	6.996	6231704000	1.541	287501000	1.007	1280400000
2003	376.44	7.416	6308364000	1.549	289986000	1.234	1288400000
2004	378.05	7.807	6374056000	1.579	292806000	1.442	1296075000
2005	380.48	8.093	6462987000	1.589	295583000	1.579	1303720000
2006	382.22	8.370	6540214000	1.564	298442000	1.749	1311020000
2007	384.31	8.566	6616689000	1.589	301280000	1.852	1317885000
2008	386.07	8.783	6694832000	1.544	304228000	1.919	1324786000
2009	387.76	8.740	6764086000	1.449	307212000	2.098	1331400000
2010	390.17	9.167	6843856368	1.482	309766766	2.260	1337845000
2011	391.86	9.460	6924982023	1.450	312023035	2.480	1344270000
2012	394.27	9.667	7003449587	1.397	314314156	2.626	1350835000

Obama / Xi table to complete:

	U.S. Emissions (Gt C/yr)	China Emissions (Gt C/yr)	Rest of the World Emissions (Gt C/yr)	Global C Emissions (Gt C/yr)
2013			5.644	
2014			5.644	
2015			5.644	
2016			5.644	
2017			5.644	
2018			5.644	
2019			5.644	
2020			5.644	
2021			5.644	
2022			5.644	
2023			5.644	
2024			5.644	
2025			5.644	
2026			5.644	
2027			5.644	
2028			5.644	
2029			5.644	
2030			5.644	

Total Cumulative Global C Emissions, years 2013 to 2030 (this is the sum of the numbers in the last column) ____________

a) (10 points) Complete the entries in the table above for future **U.S.** C emissions, assuming the U.S. imposes the same percentage reduction, per year, in this countries total C emissions starting in year 2012 (when the emissions were 1.397 Gt C / yr) to achieve the 2025 benchmark of the accord. For years 2026 to 2030, assume the U.S. emissions remain the same as in year 2025.

b) (10 points) Complete the entries in the table above for future **China** C emissions, assuming the that for years 2013 to 2027, the yearly C emissions from China continue to grow at the same average annual percentage increase that had occurred between years 2000 and 2012.

For years 2028, 2029, and 2030, assume the emissions from China continue to grow, but at a rate ***half*** of the annual percentage increase that China experienced from years 2000 to 2027: i.e. eventually the *rate* of increase will slow.

c) (10 points) Assuming for computational ease that the population of the U.S. and the population of China both stay fixed in the future at their respective 2012 levels, will the per capita C emissions from China ever exceed the per capita C emissions from the U.S. ?

If so, in what year will this occur?

If not, state the per capita C emissions from the U.S. and from China, in year 2030.

d) (10 points) Complete the last column of the Obama/Xi table by summing the emissions from the U.S., China, and the rest of the world for each year. Assume the emissions from the rest of the world stay constant, at the 2012 level of 5.644 Gt C / yr.

Also sum the numbers in the final column of the table to arrive at the Total Cumulative Global C Emissions, years 2013 to 2030, and enter this numerical estimate in the indicated spot at the bottom of the table.

e) (10 points) Using a reasonable value for the relation between the rise in global mean CO_2 $_{MR}$ and total global C emissions, provide an estimate of how much CO_2 $_{MR}$ will rise in year 2030, relative to year 2012, if the Obama / Xi accord is actually followed.

For the relation between global mean CO_2 $_{MR}$ and the total global C emissions you have used, please state both the numerical value *and* the origin of this quantity.

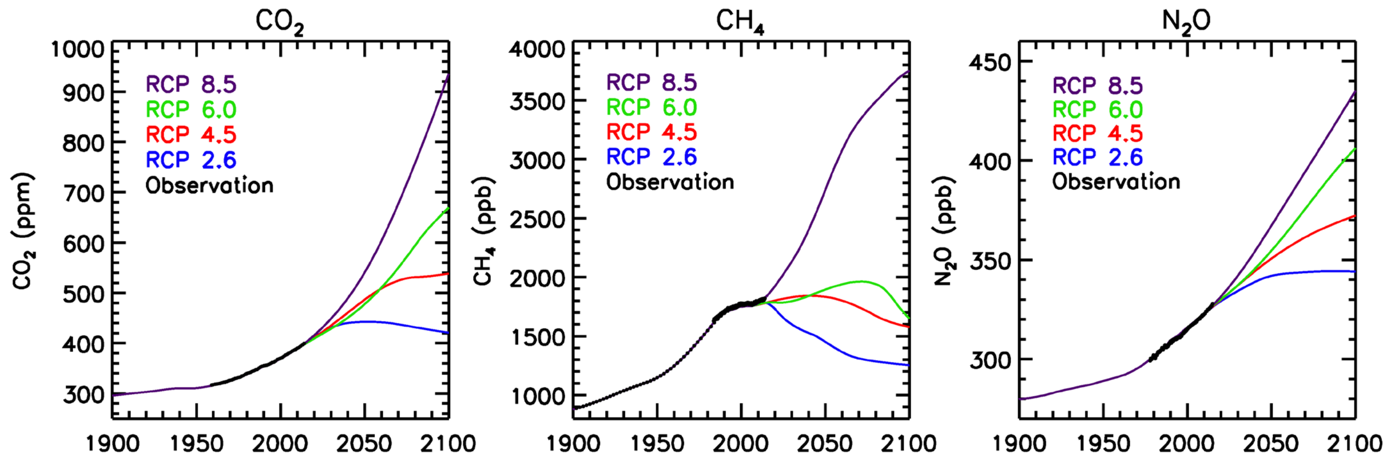
f) (10 points) Using some reasonable value for Earth's climate sensitivity parameter (λ from class and prior problem set), provide an estimate of how much Earth's global mean surface temperature (GMST) is likely to rise ***in year 2030***, relative to year 2012, if global mean CO_2 $_{MR}$ truly reaches the level you have estimated for part d). You are welcome to consider also additional RF of climate due to CH_4 and N_2O: if so, make a simple assumption and state what you have assumed.

g) (10 points) In your opinion which country "got the better" of the Obama / Xi accord? Briefly explain why you think this is the case: i.e., justify your answer as to who fared better, in a sentence or two.

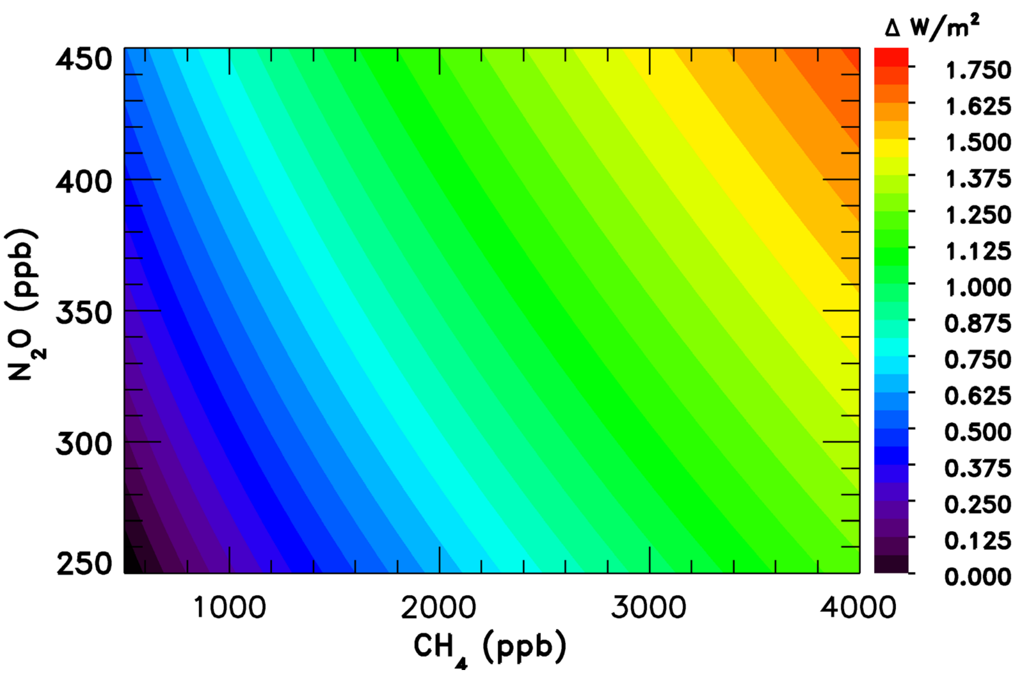
3. Radiative Forcing from CO_2, CH_4, and N_2O (50 points for 433 / 75 points for 633)

This problem can be completed using material presented up to and including Lecture 7.

This figure shows time series of CO_2, CH_4 and N_2O from 1900 to 2100 from the 4 Representative Concentration Pathway (RCP) scenarios devised for the 2013 Intergovernmental Panel on Climate Change (IPCC) report, as well as modern observational data for each of GHG:



This figure shows the RF of climate due to CH_4 and N_2O as a function of the mixing ratio of each GHG, for a range of values appropriate to the 1900 to 2100 projections:



a) (25 points) Find the change in radiative forcing (ΔRF) of the climate, between years 1900 and 2100, due to the rise in CO_2, CH_4, and N_2O between 1900 and 2100, as projected by RCP 8.5.

> ***Students enrolled in 433*** **may use a numerical evaluation of the formula that accounts for the overlap between CH_4 and N_2O absorption bands that was presented in class on Tues, Feb 17 *or* may use the graphical representation of this formula given above.**
>
> ***Students enrolled in 633*** **must use a *numerical evaluation* of the formula. For numerical evaluation, consider using a computational tool such as MATLAB, FORTRAN, or IDL.**
>
> **However you solve the problem, please state the initial and final conditions for CH_4 and N_2O and the method used to calculate ΔRF.**

b) (5 points) Compare your numerical estimate of the total change in radiative forcing (ΔRF) of climate between years 1900 and 2100, due to CO_2, CH_4, and N_2O, to the "8.5" in the designation RCP 8.5: i.e., does your estimate above "make sense"? If so, briefly state why? If not, briefly state what might be the reason for this disagreement?

c) **633 students only** (25 points) Repeat a) and b) above, for the other 3 RCP scenarios, providing in your reply for *each RCP* the ΔRF due to CO_2, the ΔRF due to CH_4 and N_2O, and the sum of these two numbers.

d) (10 points) Using some reasonable value for Earth's climate sensitivity parameter (λ from class and prior problem sets), provide an estimate of how much Earth's global mean surface temperature (GMST) is likely to rise in year 2100, relative to year 1900, if the rise of GHGs truly follows RCP 8.5. Please also state the origin of the value of λ you have used.

e) (5 points) State a reasonable scenario whereby the rise in Earth's GMST could be considerably *larger* than your estimate in part d), even if the three major anthropogenic GHGs follow RCP 8.5.

f) (5 points) State a reasonable scenario whereby the rise in Earth's GMST could be considerably *smaller* than your estimate in part d), even if the three major anthropogenic GHGs follow RCP 8.5.