# AOSC / CHEM 433 & AOSC 633

## Problem Set #1 Due: Tuesday, 19 February 2019 (at start of class)

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

**1. Effective Temperature (433: 35 points; 633: 45 points).**

Calculate the effective temperature of the Earth for the following cases. ***Please show your work.***

a) (5 points) Current solar conditions (i.e., use the value of S given in class) and an albedo = 0.3 that we'll assume applies at the start of the sea-ice data record.

b) (10 points) As the Earth warms, snow and ice will melt. Indeed, scientists have reported a rather precipitous drop in so-called perennial sea ice in the Arctic ocean, as shown below:

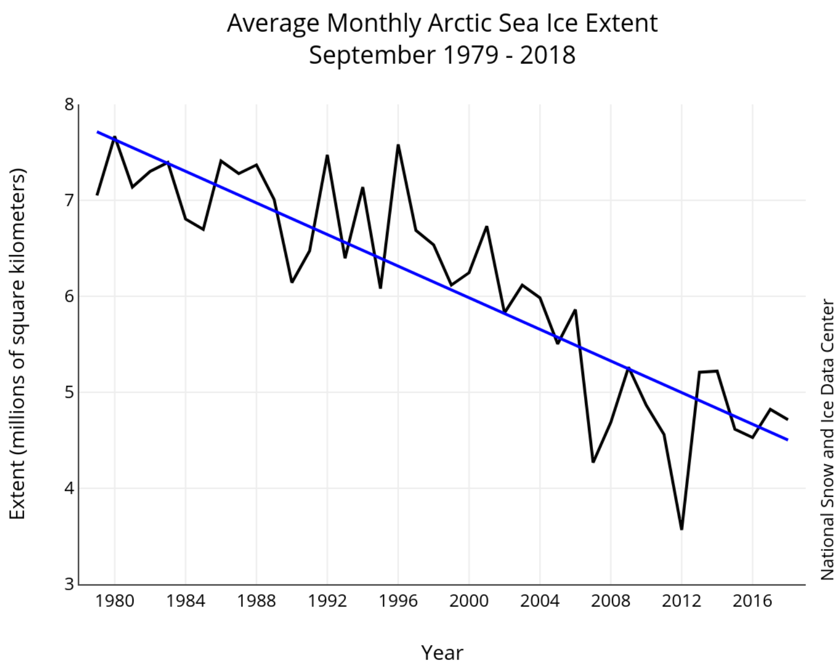



Figure from http://nsidc.org/arcticseaicenews/2018/10/september-extent-ties-for-sixth-lowest

The reflectivity (albedo) of the open ocean is 0.06, whereas the reflectivity of sea ice is about 0.6:

https://nsidc.org/cryosphere/seaice/processes/albedo.html

Using the radius of Earth given in Lectures 1 and 3, find:

i) the surface area of Earth in units of $km^2$

ii) how much Earth's albedo would have changed, from the beginning of the Arctic Sea Ice Extent record (i.e., earliest part of blue line) to the end of this record (latest part of the blue line), based on loss of sea ice. In your reply, **state whether this change is either a rise or a fall in albedo.** Also, for this calculation, assume Earth's albedo was 0.30 at the start of the sea-ice data record shown above.

c) (10 points) Compute a new effective temperature for Earth, using the albedo found in part ii of Q1b.

d) (10 points) Compare the two effective temperatures found in a) and c), and state whether:

i) the difference is physically consistent with the direction implied by the change in Earth's albedo that would result from a massive loss of sea-ice

ii) you think your calculations support the notion **that the "positive feedback": that is, a response (melting ice) to a driver (global warming) that re-inforces the initial action (warming) called the "ice-albedo" effect is a potentially important process.**

Note: there is also genuine concern about the impact of melting Arctic sea ice on the habitat for polar bears and the ecology of the Arctic. For ii) of this question, we would like your focus to be on the numerical calculations you have conducted.

**e) 633 Students Only: (10 additional points)**

i) repeat the calculation above assuming complete loss of Arctic sea ice: i.e., how much would Earth's effective temperature change (and would $T_E$ rise or fall?) if all Arctic sea ice were to melt?

ii) conduct a brief web search for how Earth's albedo has actually changed over time and assess whether or not the focus of part ii) of this question (i.e., change albedo due to declining sea ice) has actually been realized?

If so, provide a direct URL link to the evidence.

If not, summarize in a sentence or two what other factors might be driving Earth's overall albedo.

**2. Global Warming Potential (30 points).**

The generalized form of the global warming potential (GWP) equation for a gas, Z, can be written as follows (you may want to review your notes and/or the appropriate reading for the definition of terms):

$$\mathrm{GWP} = \frac{\int_0^{\mathit{Time\ Horizon}} \mathrm{a_Z} \times [Z(t)]\, dt}{\int_0^{\mathit{Time\ Horizon}} \mathrm{a_{CO2}} \times [\mathrm{CO_2}(t)]\, dt}$$

The time dependent response, Z(*t*), to an injection into the atmosphere of a "unit pulse" of a gas is often written as a simple exponential decay:

$$\mathrm{Z}\,(t) = \mathrm{Z_o}\; e^{\frac{-t}{\tau}}$$

where $\tau$ is the atmospheric lifetime and $Z_o$ is the initial abundance of the gas in question, **which we'll assume is 1 kg**

We can integrate this expression over time to get the following relation:

$$\int_0^{\mathrm{T}} \mathrm{Z}\,(t)\; dt = \mathrm{Z_o} \int_0^{\mathrm{T}} e^{\frac{-t}{\tau}}\, dt = \mathrm{Z_o}\tau\;(1 - e^{\frac{-\mathrm{T}}{\tau}}) \qquad \text{Units: kg year}$$

a) (15 points) Find the GWP for gas Z over time horizons of 20, 50, and 100 years, using the information in the following table and assuming that:

- Gas Z is 80 times more *radiatively efficient* than $CO_2$ (on a per mass basis)
- the atmospheric lifetime of Z is 10 years.
- the following numerical values apply, **for release of 1 kg of $CO_2$**

| *Time Horizon* (yrs) | $\int_0^{\mathit{Time\ Horizon}} [\mathrm{CO_2}(t)]\, dt$ (kg • year) |
|---|---|
| 20 | 14.4 |
| 50 | 28.9 |
| 100 | 48.5 |

Place your answers in the table below, and please **show your work.**

| *Time Horizon* (yrs) | GWP of Gas Z |
|---|---|
| 20 | |
| 50 | |
| 100 | |

b) (10 points) Explain why the numerical values of Gas Z vary, in the manner you have found in part a).

c) (5 points) Suppose you are asked to testify on behalf of a progressive organization such as the Sierra Club, on the environmental effects of gas Z, particularly in relation to global warming. Specifically, a proposal has been put forth to use gas Z in an emergent industry, and the application will likely lead to some leakage of gas Z to the atmosphere.

If the policy goal is to restrict the rise of global T relative to pre-industrial to no more than 1.5°C *at any time in the future*, which ***time horizon*** for the GWP for gas Z would you use in your testimony? State the time horizon followed by a sentence or two to support this decision.

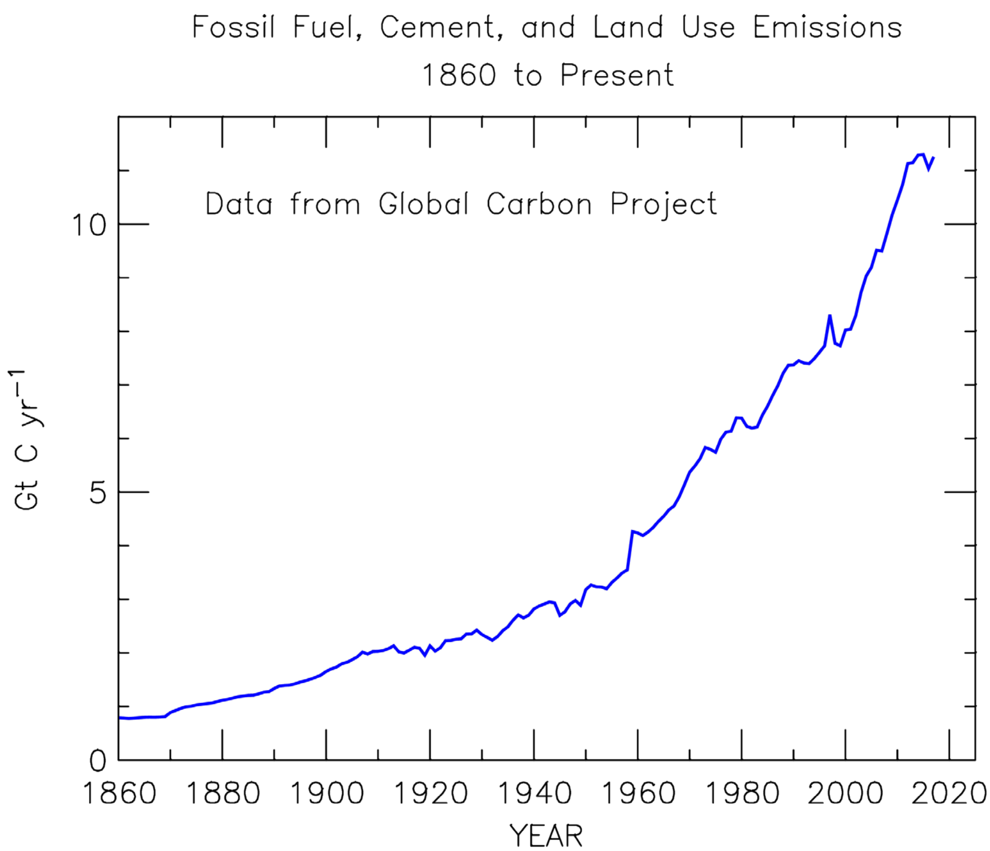
**3. Global Carbon Cycle (433: 35 points; 633: 45 points).** Carbon dioxide ($CO_2$) is the single largest waste product of modern society. The mixing ratio of atmospheric $CO_2$ has risen from a pre-industrial value of 260 ppm to 406.5 ppm at the end of 2017.

a) (15 points) Calculate the **increase in the mass of atmospheric $CO_2$**, from pre-industrial to end of 2017, in units of Gt C.

Note: Gt is an abbreviation for giga tons, or $10^9$ tons. Here we are using *metric tons*:
**1 metric ton = $10^3$ kg ; therefore, 1 Giga ton = $10^{15}$ g, where g is grams.**

To find the rise in the mass of atmospheric $CO_2$ in units of Gt C, you must make use of the mixing ratio of $CO_2$ via proper numerical representation of a "ppm", realize the mass of Earth's entire atmosphere is $5.27 \times 10^{21}$ g, and also relate the molecular weight of the C in $CO_2$ (i.e., 12 g/mole) to the mean molecular weight of air in Earth's atmosphere (28.8 g/mole).

b) (15 points) This figure summarizes annual, global emissions of $CO_2$, in units of Gt C, from 1860 to 2017:




Using this chart, estimate the ***total mass of carbon*** emitted into the atmosphere by fossil fuel, cement, and land use emissions, over the time interval 1860 to 2017. Here, we are seeking an estimate of the total cumulative carbon emissions, again in units of Gt C.

c) (5 points) The ratio of the increase in the mass of atmospheric $CO_2$, pre-industrial to end of 2017 (i.e., answer to part a) divided by the total mass of carbon emitted into the atmosphere over this same period of time (i.e., answer to part b) due to human activities is termed the "airborne fraction" Estimate the airborne fraction using the numbers given above, and compare to your answer to Q2 of AT05.

**d) 633 Students Only: (10 additional points)**

Find the mass of Earth's atmosphere in units of grams by assuming:

Surface Pressure = 1013.15 mbar

by noting that:

Pressure = Force per unit area

Force = Mass × Acceleration

and further assuming that Earth is a perfect sphere the radius given in Lectures 1 and 3.

Also:

1 millibar = 1000 dynes $cm^{-2}$ = 1000 g $cm^{-1}$ $sec^{-2}$

Acceleration of gravity, *g*, at Earth's surface = 981 cm $sec^{-2}$

For this question, the "answer" is actually given in part a) above. Here, we're asking you to derive this (or a similar) value for the mass of the atmosphere based on the definition of pressure as well as the values of the various parameters given above.