SIO 115 Winter Quarter 2019 Homework 1 (due Friday 18th January 2019)

The Cryosphere and its importance for climate

Guidelines:

- *Please write your answers on a separate sheet with your name clearly written at the top.*
- *You will be graded on your presentation and writing style as well as the content of your answer.*
- *The marks for each answer are in parentheses (Question 3 has many parts! Refer to the Week 1 lecture slides).*

Questions

1. (a) What is the "cryosphere" and where does it exist? [2]

(b) What is the largest component of the cryosphere in the following context:

(i) by <u>volume</u> in Northern Hemisphere (NH) summer [1]

(ii) by <u>volume</u> in NH winter [1]

(iii) by <u>area</u> in NH summer [1]

(iv) by <u>area</u> in NH winter [1] ?

Explain why (i) and (ii) are the same and (iii) and (iv) are different. [2]

(c) Which hemisphere has the largest seasonal variation in cryosphere extent? Give some numbers to quantify your answer. [2]

2. (a) What makes the cryosphere so important to climate? [2]

(b) Why is the cryosphere is so sensitive to climate change? [2]

(c) What is the ice-albedo feedback? [2]

(d) Apart from the atmosphere, what is another component of the Earth system with which the cryosphere interacts, and how? [2]

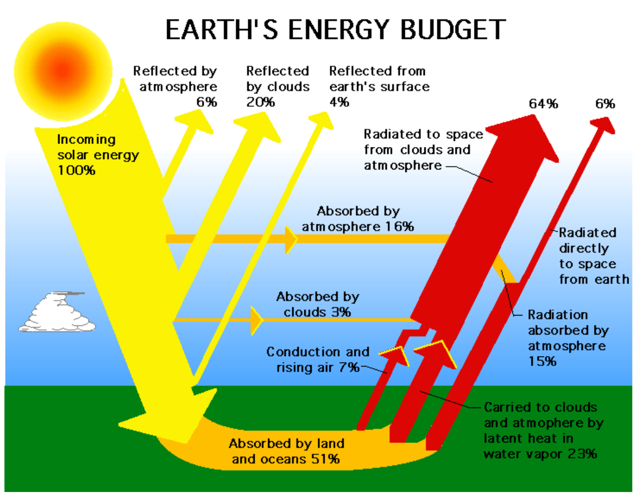
3. The balance of energy in from the sun and energy radiated back out to space determines the global average temperature.

(a) *Energy in from sun.* The amount of energy arriving at a point in space (solar flux), S, varies with distance from the sun, D, through the Inverse Square Law:

$$S = S_{sun}\left(\frac{r_{sun}}{D}\right)^2$$

where: S_{sun} is the solar flux at the sun's surface (6.42×10^7 W m^{-2}) and

r_{sun} in the radius of the sun (6.96×10^5 km).



If Earth is 1.50×10^8 km away from the sun, what is the solar flux arriving at the top of the Earth's atmosphere in W m^{-2}? [2]

(b) What is the total amount of energy hitting the Earth's atmosphere in W? Assume the Earth's radius is 6378 km (*hint*: the area of the Earth facing the sun is equal to πr^2, where r is the Earth's radius) [2]

(c) Not all of this energy makes it to the Earth's surface -- some gets reflected back to space. The amount of energy reflected divided by the total amount is the Albedo, α. If the average albedo of the Earth's atmosphere and surface is $\alpha = 0.3$, based on your answer for part (b), how much energy, in W, is absorbed by Earth's atmosphere? [2]

(d) Using your calculations from parts (b) and (c), derive an equation for the total energy into the Earth's atmosphere. The equation should have "Energy in from the sun" on the left side of the equal sign and the variables for π, earth's radius, the solar flux and albedo on the right hand side. [2]

(e) *Energy Emitted Back to Space.* The flux of energy out will vary with the temperature (in Kelvin) of the earth's atmosphere, T_a, as:

$$\text{Energy Emitted To Space} = \sigma T_a^{\ 4}$$

where σ is the *Stefan-Boltzmann constant* = 5.67x10-8 $Wm^{-2}K^{-4}$. This flux will be emitted over the entire sphere of the Earth. Using your calculation for energy absorbed from the sun from part (c), calculate the temperature at the top of the Earth's atmosphere using this equation. (Hint: the area of a sphere is $4\pi r^2$). [2]

(f) Write an equation equating the energy absorbed by the atmosphere (energy in, from part (d)) to the energy emitted to space (energy out, part (e)) and simplify. [2]

(g) *Temperature at the Earth's Surface.* The mean temperature at the earth surface is 288 K (15°C). Your answer from part (e) should be quite a bit less than this. This is because energy emitted by the earth is absorbed by the atmosphere and radiated back to Earth (and outward to space), heating the surface. If we assume that the atmosphere absorbs all the energy emitted by the Earth, the balance between energy emitted by the atmosphere and the earth's surface is:

$$\sigma T_s^{\ 4} = 2\sigma T_a^{\ 4}$$

where T_s is the temperature at the Earth's surface (the factor of 2 is included because energy goes both upwards and downwards in the atmosphere). Using your answer for T_a from part (e), calculate the temperature at the Earth's surface. [2]

(h) Your answer from part (g) should be greater the true global average temperature. This is because, in reality, not all the energy emitted from the Earth is absorbed by the atmosphere. In order to get T_s = 288 K, you need to multiply the right hand side of your equation in part (g) by a fraction. This is the atmospheric *absorption*. Calculate what the absorption must be to get a global average temperature of 288 K. [2]

(i) In order to have a "*Snowball Earth*" (the entire planet frozen), the global average surface temperature would have to be close to 0°C (273.15 K). Calculate (a) the atmospheric absorption and (b) the albedo needed to have a mean global temperature of 273 K. [4]