Practice Questions for Test #1

EES 2110 Introduction to Climate Change

Wednesday, February 8, 2023

Physical Constants

Stefan-Boltzmann constant	$\sigma = 5.67 \times 10^{-8}\,\mathrm{W\,m^{-2}\,K^{-4}}$
Average Distance from Earth to sun	1.50×10^{8} km
Average Distance from Mars to sun	2.28×10^{8} km
Average Distance from Venus to sun	1.08×10^{8} km
Radius of Earth	6.37×10^{6} km
Solar constant (solar flux at Earth)	$S_0 = 1370\,\mathrm{W/m^2}$
Average albedo of the Earth	$\alpha = 0.3$
Average albedo of Venus	$\alpha = 0.8$
Average albedo of Mars	$\alpha = 0.2$
Greenhouse effect on Venus	510 K
Greenhouse effect on Mars	6 K
Skin temperature of the Earth	$T_{\text{skin}} = 255\,\mathrm{K}$
Average surface temperature of the Earth	$T_s = 288\,\mathrm{K}$

Calculations

Calculating fourth roots	The fourth root ($\sqrt[4]{\ }$) is the same as the square root of the square root. On your calculator, it may be easier to push the square-root ($\sqrt{\ }$) key twice than to take the fourth root directly.
Calculating fourth powers	The fourth power is the same as the square of the square. On your calculator, if you have an x^2 key, it may be easier to push x^2 twice than to take the fourth power directly.

EQUATIONS

Stefan-Boltzmann equation	$I = \varepsilon \sigma T^4$
Wien's law	$\lambda_{\text{max}} = \dfrac{2898\,\mu\text{m/K}}{T}$
Inverse-square law	$S_1 = S_0 \left(\dfrac{r_0}{r_1}\right)^2$
Skin temperature	$T_{\text{skin}} = \sqrt[4]{\dfrac{1-\alpha}{4\sigma} S_0}$, where α is the albedo, σ is the Stefan-Boltzmann constant, and S_0 is the solar constant.
Temperature conversion:	
Kelvin to Celsius	$T(^\circ\text{C}) = T(\text{K}) - 273$
Fahrenheit to Celsius	$T(^\circ\text{C}) = \dfrac{T(^\circ\text{F}) - 32}{1.8}$
Celsius to Fahrenheit	$T(^\circ\text{F}) = 1.8\,T(^\circ\text{C}) + 32$

Multiple Choice Questions:

Choose the one alternative that best completes the statement or answers the question. Mark your choice on the optical scan sheet.

1. Molecule for molecule, methane is a much more powerful greenhouse gas than carbon dioxide. Why is this?
   - (a) Because methane has a much longer lifetime in the atmosphere than carbon dioxide.
   - (b) Because plants remove carbon dioxide from the atmosphere by photosynthesis, but they do not remove methane.
   - (c) Because carbon dioxide is strongly band-saturated but methane is not.
   - (d) (a) and (b)
   - (e) All of the above.
2. Which of the following is a flaw in layer models of the greenhouse effect?
   - (a) Layer models assume that the atmosphere is completely opaque to longwave radiation, but the atmosphere is partially transparent to some longwave radiation.
   - (b) Layer models assume that the emissivity of the atmosphere (ε) is the same for all wavelengths of longwave radiation, but the emissivity is actually very different for different wavelengths.
   - (c) Layer models assume that radiation is the only thing that carries heat away from the surface.
   - (d) (a) and (c).
   - (e) all of the above.
3. Adding more carbon dioxide to the atmosphere ________ the albedo and ________ the greenhouse effect, so they ________ the surface temperature.
   - (a) increase, strengthen, have little effect on.
   - (b) decrease, weaken, cool.
   - (c) increase, have little effect on, cool.
   - (d) have little effect on, weaken, cool
   - (e) have little effect on, strengthen, warm
4. Water vapor is a greenhouse gas just like CO_2. Why do we worry a lot about CO_2 emissions, but not water vapor emissions?
   - (a) Because there is already almost as much water vapor as the atmosphere can hold.
   - (b) Because water vapor has a very short residence time in the atmosphere.
   - (c) Because band saturation means that adding more water vapor will have very little effect on the greenhouse effect.
   - (d) (a) and (b)
   - (e) All of the above.
5. If the solar constant were 1500 W/m^2 and the Earth's albedo were 0.25, what would the skin temperature (bare-rock temperature) be?
   - (a) 202 K
   - (b) 265 K
   - (c) 375 K
   - (d) 4.07×10^4 K
   - (e) 7.04×10^4 K

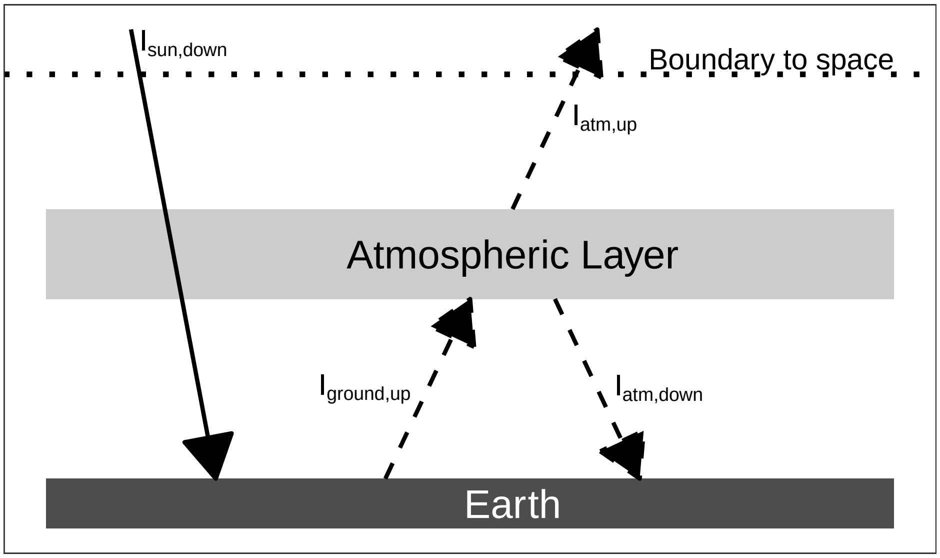
Short Answer Questions:

Answer questions in the space provided. You should be able to answer the questions in a couple of sentences. I have tried to write the questions carefully so you can answer each question, or each part of a multi-part question, in one or two brief sentences.

You **do not** need to fill the page. Lengthy answers are *not* necessary!

1. Consider a layer model of the atmosphere, as shown below.

   NOTE: You do not have to do complicated calculations with the Stefan-Boltzmann equation for this problem. You should be able to answer the different parts simply, using only the quantities I shown in the diagram. You do not need to calculate numbers for the intensities.



   (a) How does $I_{\text{atm, up}}$ compare to $I_{\text{sun, down}}$? Why?

   (b) How does $I_{\text{atm, down}}$ compare to $I_{\text{atm, up}}$? Why?

   (c) The heat going into the ground has to balance the heat coming out ($I_{\text{ground, up}}$). Write a mathematical formula for the heat going into the ground in terms of the intensities I that appear in the diagram. You *do not need to solve the equation*, just write it down.

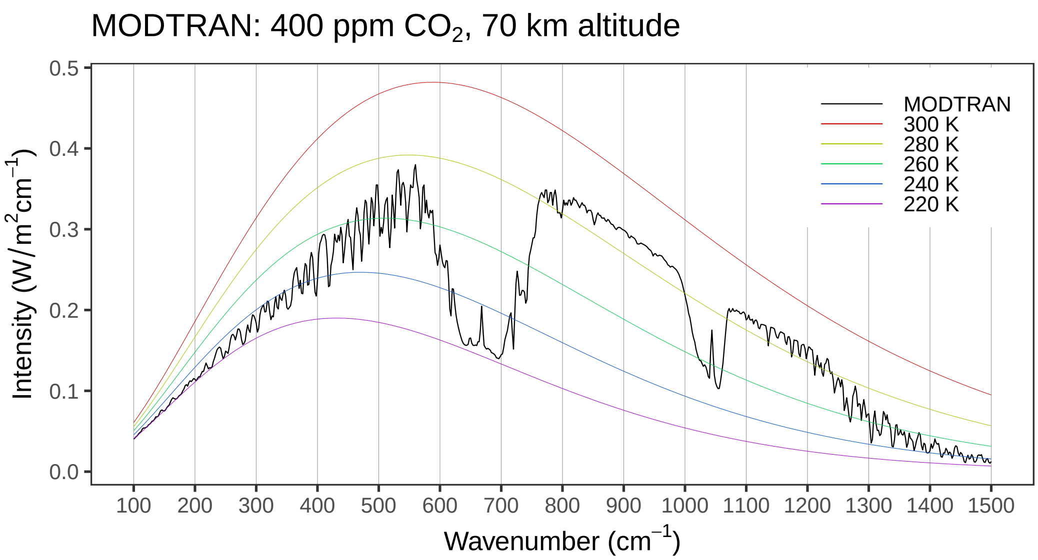
   (d) If you took the atmosphere away (i.e., turned this into a bare rock model with no layers), how much would the heat going into the ground change (give a numeric ratio, such as "it would increase by 30%" or "it would be 40% smaller.").

2. (a) Define an economic **externality.**

(b) Are greenhouse gas emissions externalities? Why or why not?

(c) What does this imply for climate policy?

3. The figure below shows the spectrum of longwave radiation seen by a satellite at night when the sky is clear, together with the intensity of longwave radiation that would be emitted from ideal blackbodies at different temperatures.



(a) Consider radiation with wavenumbers of 300, 700, 900, 1200, and 1400 cycles per centimeter. For which of these wavenumbers is the skin height close to the ground and for which is it fairly high in the atmosphere?

(b) Do greenhouse gases absorb more longwave light for the wavenumbers corresponding to high or low skin heights?

(c) Roughly, what is the skin temperature for 700 and 900 wavenumbers?

Answer Key

Multiple Choice Questions:

Choose the one alternative that best completes the statement or answers the question. Mark your choice on the optical scan sheet.

1. Molecule for molecule, methane is a much more powerful greenhouse gas than carbon dioxide. Why is this?

   (a) Because methane has a much longer lifetime in the atmosphere than carbon dioxide.

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4. Water vapor is a greenhouse gas just like CO_2. Why do we worry a lot about CO_2 emissions, but not water vapor emissions?

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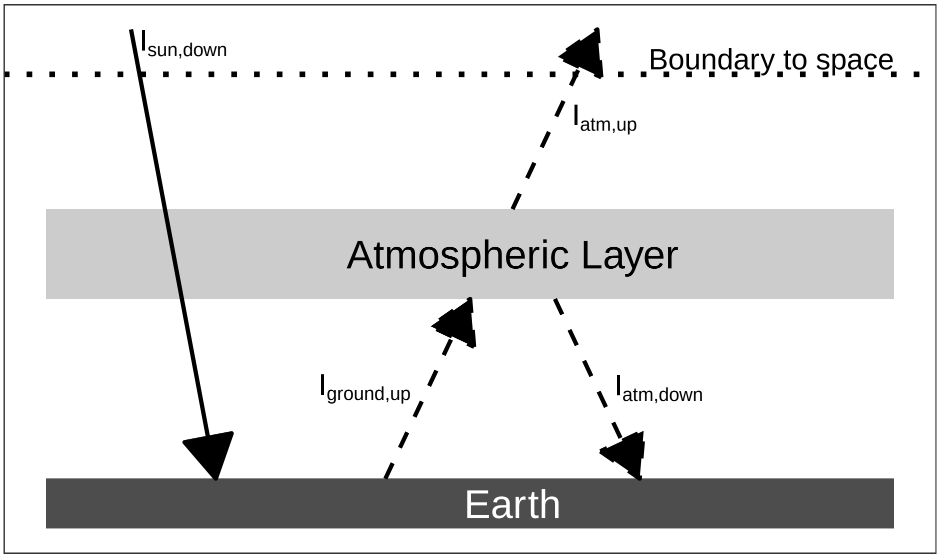

   (a) How does $I_{\text{atm, up}}$ compare to $I_{\text{sun, down}}$? Why?

   ANSWER: $I_{atm,\ up} = I_{sun,\ down}$. *This is a simple balance of heat at the boundary to space.* ***(6 points).***

   (b) How does $I_{\text{atm, down}}$ compare to $I_{\text{atm, up}}$? Why?

   ANSWER: $I_{atm,\ down} = I_{atm,\ up}$. *The intensity is given by the Stefan-Boltzmann law* $I = \varepsilon\sigma T^4$ *and in a layer model the temperature of a layer is the uniform so the bottom of the layer has the same temperature as the top.* ***(6 points).***

   (c) The heat going into the ground has to balance the heat coming out ($I_{\text{ground, up}}$). Write a mathematical formula for the heat going into the ground in terms of the intensities I that appear in the diagram. You *do not need to solve the equation*, just write it down.

   ANSWER: $I_{into\ ground} = I_{sun,\ down} + I_{atm,\ down}$. *You could simplify this to* $I_{into\ ground} = 2I_{sun,\ down}$ *because* $I_{atm,\ down} = I_{sun,\ down}$*, but that's not necessary.* ***(5 points).***

   (d) If you took the atmosphere away (i.e., turned this into a bare rock model with no layers), how much would the heat going into the ground change (give a numeric ratio, such as "it would increase by 30%" or "it would be 40% smaller.").

   ANSWER: *In the bare rock model,* $I_{into\ ground} = I_{sun,\ down}$*, so the heat in reduces from* $I_{sun,\ down} + I_{atm,\ down}$ *to* $I_{sun,\ down}$*, which means it becomes 50% smaller because* $I_{atm,\ down} = I_{sun,\ down}$. ***(3 points).***

2. (a) Define an economic **externality**.

   ANSWER: *When two people (or a group of people) conduct a transaction, an externality is a good or bad thing that benefits or hurts people who did not participate in the transaction.* ***(7 points).***

   (b) Are greenhouse gas emissions externalities? Why or why not?

ANSWER: *Greenhouse gases are externalities because when I fill my car with gasoline or charge my phone with electricity that was generated by burning fossil fuels, I benefit from using the energy and the gas station or the electric company benefits from me buying their product, but the greenhouse gas emissions affect everyone on earth.* ***(7 points).***

(c) What does this imply for climate policy?

ANSWER: *Because I get all the benefits from using energy, but I don't suffer all the harm from the greenhouse gas emissions, I won't have a strong incentive to cut my emissions. This means that markets won't work effectively and only government intervention can provide adequate incentives to cut emissions.*
Students don't need to spell out interventions, but some examples could be command-and-control regulations, or they could be market-based interventions such as imposing a tax on emissions or selling tradable permits (cap-and-trade). ***(6 points).***

3. The figure below shows the spectrum of longwave radiation seen by a satellite at night when the sky is clear, together with the intensity of longwave radiation that would be emitted from ideal blackbodies at different temperatures.

(a) Consider radiation with wavenumbers of 300, 700, 900, 1200, and 1400 cycles per centimeter. For which of these wavenumbers is the skin height close to the ground and for which is it fairly high in the atmosphere?

ANSWER: *300, 700, and 1400 are high up, which you can tell because they are cold. 900 and 1200 are fairly low because they are warm.* ***(6 points).***

(b) Do greenhouse gases absorb more longwave light for the wavenumbers corresponding to high or low skin heights?

ANSWER: *Greenhouse gases absorb more light at the high skin height.* ***(6 points).***

(c) Roughly, what is the skin temperature for 700 and 900 wavenumbers?

ANSWER: *For 700,* $T \approx 220\,\mathrm{K}$. *For 900,* $T \approx 280\,\mathrm{K}$ *(a little warmer, but 280 K is close enough).* ***(6 points).***