Practice Questions for Test #2

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	$T_{\mathrm{skin}} = 255\,\mathrm{K}$
Average surface temperature of the Earth	$T_s = 288\,\mathrm{K}$
Atmospheric pressure at sea level	$P_0 = 1013\,\mathrm{mbar}$
Dry adiabatic lapse rate	10 °C/km
Average environmental lapse rate in troposphere	6 °C/km
Scale height of the atmosphere	$H_0 = 5.6\,\mathrm{km}$

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.
Radiative-convective temperature	$T_{\text{ground}} = T_{\text{skin}} + L h_{\text{skin}}$, where L is the environmental lapse rate and h_{skin} is the skin height
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	$T(^\circ\text{F}) = 1.8\,T(^\circ\text{C}) + 32$
Temperature lapse	$T(h) = T_{\text{ground}} - Lh$, where h is the height above sea level and L is the lapse rate.
Barometric law	$P(h) = P_0 \times 0.5^{h/H_0} = P_0 \times e^{-h/H_e}$, where $P(h)$ is the pressure at height h, P_0 is the pressure at sea level, and H_0 is the scale height of the atmosphere.
Urey reaction:	$CaSiO_3 + CO_2 \rightleftharpoons CaCO_3 + SiO_2$
Carbon solubility:	$CO_2 + H_2O \rightleftharpoons H_2CO_3$ (carbonic acid) $H_2CO_3 \rightleftharpoons H^+ + HCO_3^-$ (bicarbonate ion) $HCO_3^- \rightleftharpoons H^+ + CO_3^{-2}$ (carbonate ion)
Buffering reactions:	these three reactions, taken together, add up to $CO_2 + CO_3^{-2} + H_2O \rightleftharpoons 2HCO_3^-$

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. If people were not emitting any CO_2 into the atmosphere, describe the relationship between silicate weathering and volcanic ougassing of CO_2. (Don't assume that volcanic outgassing is constant.)
   (a) Silicate weathering would be constant.
   (b) Silicate weathering would vary, but it would depend on the temperature and would not be affected by outgassing.
   (c) If volcanic outgassing changed, silicate weathering would act as a positive feedback and amplify the change.
   (d) If volcanic outgassing changed, silicate weathering would change over time to become equal to the outgassing.
   (e) If silicate weathering changed, volcanic outgassing would change to become equal to silicate weathering.

2. Reduced forms of carbon ________
   (a) include carbonate minerals
   (b) can be burned to produce energy
   (c) have less ^{13}C than other forms.
   (d) can only be produced by photosynthesis.
   (e) (c) and (d)

3. Which feedback is the greatest source of uncertainty in the climate system?
   (a) Stefan-Boltzmann
   (b) Ice-albedo
   (c) Clouds
   (d) Water-vapor greenhouse effect
   (e) Lapse-rate

4. Today, the oceans absorb about one quarter of all CO_2 released by burning fossil fuels. Which of the following most directly controls the amount of CO_2 the oceans absorb from the atmosphere each year?
   (a) The concentration of H^+ in the mixed layer near the surface of the ocean.
   (b) The concentration of HCO_3^- in the mixed layer near the surface of the ocean.
   (c) The concentration of CO_3^{2-} in the mixed layer near the surface of the ocean.
   (d) The concentration of HCO_3^- in the deep ocean.
   (e) The concentration of CO_3^{2-} in the deep ocean.

5. Low clouds in 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

6. In a radiative-convective treatment of the climate, what effect would raising the skin height have on the surface temperature?

    (a) It would make the surface warmer.
    (b) It would make the surface cooler.
    (c) It would make the surface warmer at night and cooler during the day.
    (d) It would make the surface cooler at night and warmer during the day.
    (e) It would not change the surface temperature.

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. What does the temperature of the stratosphere tell us about whether global warming is due to rising amounts of greenhouse gases or to the sun getting brighter?

2. The thermocline in the ocean plays a very important role in controlling how the ocean responds to rising temperatures and rising levels of carbon dioxide.

   (a) What is the thermocline?

   (b) How does the thermocline affect the ocean's ability to absorb CO_2?

   (c) In the ocean, water at the bottom is coldest and the warmest water is at the surface. How does this compare to air temperatures in the troposphere (the lower 10 km or so of the atmosphere)?

   (d) What is the principal cause of the distinctive ways that the temperature varies with depth or altitude in the oceans and troposphere?

   (e) What important role does the "conveyor belt" current play in the ocean's response to rising CO_2 concentrations in the atmosphere?

3. A scientist is studying ice cores from Antarctica and Greeenland and carbonate sediments from the deep oceans from some time a few hundred thousand years ago. She observes that at some time:

- The fraction of ^{18}O in the ice starts to rise and continues rising for around 1000 years.
- Then it levels off and remains fairly steady for several thousand years.
- The fraction of ^{18}O in the ocean sediments is fairly steady for the first 100 years or so after the fraction in the ice starts to rise.
- Then the fraction of ^{18}O in the ocean sediments gradually begins to fall, and continues falling for about 2000 years.

(a) What does the ^{18}O in the ice tell you about what happened?

(b) What does the ^{18}O in the deep-sea sediments tell you about what happened?

(c) Why does the ^{18}O change later and more slowly in the deep-sea sediments than the ice?

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. If people were not emitting any CO_2 into the atmosphere, describe the relationship between silicate weathering and volcanic ougassing of CO_2. (Don't assume that volcanic outgassing is constant.)
   - (a) Silicate weathering would be constant.
   - (b) Silicate weathering would vary, but it would depend on the temperature and would not be affected by outgassing.
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   - [(d)] If volcanic outgassing changed, silicate weathering would change over time to become equal to the outgassing.
   - (e) If silicate weathering changed, volcanic outgassing would change to become equal to silicate weathering.
2. Reduced forms of carbon ________
   - (a) include carbonate minerals
   - [(b)] can be burned to produce energy
   - (c) have less ^{13}C than other forms.
   - (d) can only be produced by photosynthesis.
   - (e) (c) and (d)
3. Which feedback is the greatest source of uncertainty in the climate system?
   - (a) Stefan-Boltzmann
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4. Today, the oceans absorb about one quarter of all CO_2 released by burning fossil fuels. Which of the following most directly controls the amount of CO_2 the oceans absorb from the atmosphere each year?
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   (d) It would make the surface cooler at night and warmer during the day.

   (e) It would not change the surface temperature.

Short Answer Questions:

1. What does the temperature of the stratosphere tell us about whether global warming is due to rising amounts of greenhouse gases or to the sun getting brighter?

   ANSWER: *Over the past 50 years, the stratosphere has cooled while the troposphere has warmed up. Scientists predicted that raising the amount of greenhouse gases would cause the troposphere and earth's surface to warm and the stratosphere to cool, whereas they predicted that a brighter sun would cause the stratosphere and the troposphere to warm simultaneously.* ***(20 points).***

2. The thermocline in the ocean plays a very important role in controlling how the ocean responds to rising temperatures and rising levels of carbon dioxide.

   (a) What is the thermocline?

   ANSWER: *It is a layer in the ocean where the temperature changes very quickly with depth. Above it, the water is warm and below it the water is cold. It acts as a barrier that prevents the warm water above from mixing with the cold water below.* ***(4 points).***

   (b) How does the thermocline affect the ocean's ability to absorb CO_2?

   ANSWER: *The thermocline stops the warm water above it from mixing with the cold water below it. This prevents carbonate from the deep oceans from replenishing depleted carbonate in the mixed layer near the surface. This slows down the rate at which the ocean can absorbe* CO_2.
   A different correct answer would be to say that it prevents CO_2 *dissolved in the mixed layer near the surface from mixing with the deep ocean water, and thus slows down the absorption of* CO_2 *by the ocean.* ***(4 points).***

   (c) In the ocean, water at the bottom is coldest and the warmest water is at the surface. How does this compare to air temperatures in the troposphere (the lower 10 km or so of the atmosphere)?

   ANSWER: *In the troposphere, the air at the bottom of the atmosphere is warmer than the air higher up. This part is all that's necessary for a correct answer.*
   Students do not need to provide the detail below, but this is important because of the relationship between temperature and convection: Warm air rises, so the atmosphere tends to have convection, which mixes the air, whereas in the ocean, the warm water is already at the top so there is no convective mixing. ***(4 points).***

   (d) What is the principal cause of the distinctive ways that the temperature varies with depth or altitude in the oceans and troposphere?

   ANSWER: *The reason the atmosphere is warmest at the bottom (near the ground) and the ocean is warmest at the top (near the surface) is because the atmosphere is transparent to sunlight, so the sunlight is mostly absorbed by the ground, at the bottom of the atmosphere, whereas the water in the ocean absorbs sunlight, so sunlight doesn't penetrate very far below the surface (the ocean is many miles deep, but sunlight doesn't penetrate below a few hundred feet, so the deep oceans are pitch black), and the solar energy goes into heating the top part of the ocean.* ***(4 points).***

   (e) What important role does the "conveyor belt" current play in the ocean's response to rising CO_2 concentrations in the atmosphere?

   ANSWER: *Because the thermocline prevents the oceans from mixing very much, the conveyor belt current is almost the only thing that mixes water from the surface layer with water from the deep oceans. In terms of* CO_2 *the conveyor belt brings fresh carbonate from the deep oceans to the surface. This replenishes depleted carbonate and allows the surface oceans to continue absorbing* CO_2 *from the atmosphere.* ***(4 points).***

3. A scientist is studying ice cores from Antarctica and Greeenland and carbonate sediments from the deep oceans from some time a few hundred thousand years ago. She observes that at some time:

   - The fraction of ^{18}O in the ice starts to rise and continues rising for around 1000 years.
   - Then it levels off and remains fairly steady for several thousand years.
   - The fraction of ^{18}O in the ocean sediments is fairly steady for the first 100 years or so after the fraction in the ice starts to rise.
   - Then the fraction of ^{18}O in the ocean sediments gradually begins to fall, and continues falling for about 2000 years.

   (a) What does the ^{18}O in the ice tell you about what happened?

   ANSWER: *The air temperature warmed up for about 1000 years and then stayed warm.* ***(9 points for getting the temperature rise: 5 points for identifying temperature and 4 points for the direction of the change. Students don't need to talk about the timing.).***

   (b) What does the ^{18}O in the deep-sea sediments tell you about what happened?

   ANSWER: *The sea level didn't change much for 100 years or so and then rose for about 2000 years.* ***(9 points for getting the sea-level rise: 5 points for identifying sea level and 4 points for getting the direction of the change. They don't need to talk about timing here.).***

   (c) Why does the ^{18}O change later and more slowly in the deep-sea sediments than the ice?

   ANSWER: *The sea level rose because glaciers were melting. Glaciers melt slowly: first the temperature rises, then the glaciers gradually melt.* ***(2 points).***

   Students don't need to say this to get points, but there's some interesting detail: When the temperatures start to rise, most of the glaciers are at subfreezing temperatures. The glaciers don't start to melt until the temperature rises above freezing, so during the time when the temperature is rising, but is still below freezing, the glaciers won't melt.