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ESYS10 Winter '08 MIDTERM EXAM.
ANSWER ALL QUESTIONS. THE TOTAL POINTS FOR EACH QUESTION ARE INDICATED NEXT TO THE NUMBER OF THE QUESTION. PARTIAL CREDIT WILL BE GIVEN FOR INCOMPLETE ANSWERS, BUT ONLY IF THE RESPONSE IS RELEVANT AND LOGICAL. (IN OTHER WORDS, BE BRIEF!)

1. (4 pts.) Rank the following quantities in order of their absolute magnitude (1 is largest, 4 is smallest):

__1__ Emission of fossil fuel carbon per year
__3__ Uptake of carbon by the ocean per year
__4__ Uptake of carbon in weathering of rocks
__2__ Growth of carbon in the present atmosphere per year

2. (4 pts.) Rank the following quantities in order of their absolute magnitude (1 is largest, 4 is smallest):

__2__ Greenhouse effect of the earth's atmosphere
__4__ Albedo of the earth, expressed in w/m^2 (including the atmosphere)
__1__ Greenhouse effect of Venus' atmosphere
__3__ Solar radiation absorbed by the earth's surface

3. (5 pts.) Rank the following quantities in order of their absolute magnitude (1 is largest, 5 is smallest):

__3__ Thickness of typical marine crust
__2__ Thickness of typical continental crust
__4__ Thickness of the ocean's surface mixed layer
__5__ Width of new marine crust added each year
__1__ Thickness of the Earth's mantle

4. (4 pts.) Rank the following quantities in order of their absolute magnitude (1 is largest, 4 is smallest):

__1__ Quantity of carbon currently dissolved in the ocean
__4__ Amount of carbon in the present atmosphere
__2__ Amount of carbon in the known reserves of fossil fuels (coal, petroleum, etc.)
__3__ Quantity of carbon currently stored in the terrestrial biosphere (including soils)

5. (4 pts) The vertical mixing time of the oceans is significantly longer than that of the atmosphere Think about why this is the case by indicating whether the following statements are true or false (circle the appropriate choice)

For both the atmosphere and the ocean, density decreases with height. (True or False)
The atmosphere (in the troposphere) is typically heated from top down. (True or False)
The ocean is being heated from bottom up. (True or False)
For any given mass, air and water both become less dense when warmed (True or False)

6. (4 pts) Indicate whether the following statements are true or false (circle one):

CO2 is currently the most significant contributor to the greenhouse effect (True / False)
The earth's surface temperature has increased by 5°C over the last 100 years (True / False)
Solar variability is a viable explanation for the surface temperature increase of the early 20th century (True/ F
The earth's average surface temperature has never been warmer than it is today (True / False)

7. (7 pts) There are several ways by which geologists can reconstruct the movement of lithospheric plates through earth history (and therefore chart the former position of continents and ocean basins). Describe one of these ways.

One possibility: Follow the trail of oceanic "hotspots" such as the Hawaiian islands, that record the passage of the plate over a plume of hot mantle material.

Another possibility: Use the symmetrical pattern of magnetism (on either side of the spreading center such as a midocean ridge). The magnetic "stripes" lock in the prevailing magnetic field at the time of new crust formation; and the polarity of the earth's magnetic field has flipped repeatedly over the last 100 million years. The crust can be dated, and, as a result, the pattern of "stripes" allows reconstruction of past plate movement.

Some credit was also given for answers that dealt with fitting the outlines of continents together.

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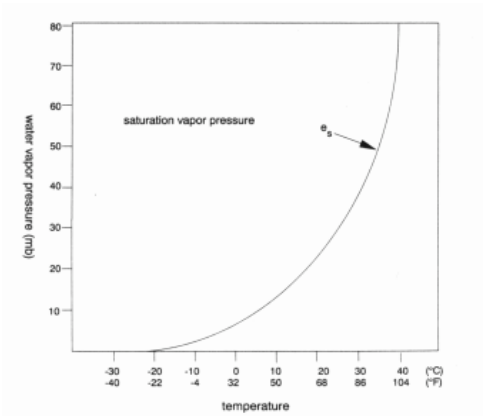
8. (8 pts) Sketch the shape of the relationship between water holding capacity of the atmosphere and the temperature of air. Identify one way in which the predictions of future drought depend on this shape.



Warming of the earth's surface will cause an increase in evaporation rate, particularly in regions that are already warmer than about 15 deg. C. (the mid to low latitude regions on earth). This temperature is a sort of "hinge point" in the water holding capacity of the atmosphere. This behavior of water is what leads to the predictions of increased drought frequency in a globally warmer world for the low-mid latitudes.

9. (7 pts) In what way could a volcanic eruption cool the surface of the earth? Would the Hawaiian volcanoes influence climate on timecales of years to decades? Why or why not?

Explosive volcanoes inject particles and other aerosols (e.g. sulfates) into the atmosphere. These aerosols create a dimming effect for the earth's surface, because they reflect away solar radiation—in other words, they increase the albedo of the earth. The key for having a significant cooling effect is whether these aerosols hang around for a long enough time in our atmosphere before being rained out. Thus, the volcanoes that have a short term cooling effect are those that inject particles way up into the stratosphere, where they can't easily be rained out. Mt. Pinatubo (Philippenes) was the most recent example. Hawaiian volcanoes are not explosive enough to do this and therefore don't really contribute to any short term climatic effect.

10. (6 pts) If humans were to immediately stop deforestation globally without changing fossil fuel carbon emissions, would the carbon dioxide content of the atmosphere drop over the next few years? Why or why not?

No. The fossil fuel emissions are currently much greater than any effect involving the terrestrial biosphere. Deforestation currently adds about 2 gigatons of carbon to the atmosphere every year, while humans are emitting nearly 8 gigatons every year. The ocean takes up about 2 GT per year. As a result, a halt in deforestation would slow the rise of CO2 in the atmosphere, but it would not decrease the overall amount of CO2 in the atmosphere.

11. (7 pts) There are several ways in which oceanographers know that the ocean is currently taking up a little more than 2 gigatons of fossil fuel-derived carbon per year. Describe one of these ways.

One way: repeated measurements of ocean carbon (e.g. pH) throughout the entire ocean. The difference from year to year gives you a rate of penetration of fossil fuel carbon.

Another way: use of man made tracers such as bomb-derived radiocarbon. Atmospheric bomb tests in the late 1950's created a huge spike in radiocarbon that then mixed into the ocean as part of the carbon cycle. The total penetration of bomb radiocarbon into the ocean since 1960 gives you a rate of ocean uptake

Third way: comparison of atmospheric oxygen and atmospheric carbon dioxide changes. Photosynthesis (plant growth) and respiration (e.g. fossil fuel burning or deforestation) influence oxygen and carbon dioxide in nearly mirror image ways. However, oxygen DOES NOT participate in the same ocean uptake mechanism as CO2. Therefore, the difference between the trends in atmospheric oxygen and carbon dioxide tells us how much CO2 has been taken up by the ocean.

12. (7 pts) How and why is the ocean becoming more "acidified"?

Carbon dioxide is taken up by the ocean in an acid-base reaction.

$CO2 + CO_3^{-2} >>> HCO_3^-$

The ocean is naturally basic (it's average pH is around 8). However, as more fossil fuels are burned, the carbon released goes into the atmosphere and then is "neutralized" by the ocean. Thus, as the level of CO2 in the atmosphere increases, the pH of the ocean will decrease correspondingly.

13. (6 pts) When viewed over its entire history, the earth's surface temperature has never experienced the extremes of Venus or Mars. The implication is that there must be some negative feedback loop in the earth's system to keep temperatures from ever going into "run away" greenhouse or icehouse conditions. Identify the one most likely negative feedback that operates in the earth's climate system over millions of years.

The cycling of carbon through the "rock cycle" is the one most likely negative feedback loop. Under warm (greenhouse) conditions, carbon dioxide is taken up in rock weathering. Eventually, this enhanced rock weathering would remove enough CO2 from the atmosphere to reduce the greenhouse effect. On the other hand, the earth could never remain entirely frozen over for extended periods, because carbon dioxide from volcanoes would eventually build up in the atmosphere, enhancing the greenhouse effect. The presence of life and liquid water on earth facilitate this cycle, but the general cycling of materials would occur even in the absence of these factors. For as yet unknown reasons, Venus' carbon all went into the atmosphere (no cycling), while Mars' carbon was lost to space.

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14. (9 pts) El Niño warm events are known to have resulted in some of the warmest global annual average temperatures recorded over the 20th century. To answer the question of why this is the case: (i) List the 3 factors that can result in global temperature change, and (ii) briefly state how the El Niño cycle might affect each of these factors, if at all.

1. Solar radiation—not influenced by El Niño

2. Greenhouse gas content of the atmosphere—the altered pattern of ocean temperature certainly influences the water vapor content of the atmosphere (increased area of warm water leads to increased water vapor)

3. Albedo—El Niño could influence cloud patterns (reduce low cloud amout) and could also influence the extent of snow and ice fields (e.g. reduced sea ice means lower albedo)

15. (9 pts) The El Niño warm events of the 20th century are also known to have temporarily reduced the level of carbon dioxide in the atmosphere by a few parts per million. Using your knowledge of the natural carbon cycle, identify one possible reason for why we might expect such an association between El Niño events and atmospheric CO2. (Note: there is more than one plausible answer here, so feel free to use your imagination).

The subtle changes in the carbon content of the atmosphere over El Niño cycles could either be the result of

1.) the different patterns of upper ocean mixing: CO2 is normally puffed out of the ocean in the eastern equatorial Pacific, as carbon rich waters are upwelled and warmed up. If the upwelling of carbon rich subsurface water decreased during an El Nino event, then more carbon would remain in the ocean temporarily.

2.) the changing patterns of vegetation. We know that El Niño creates regions of enhanced rainfall (e.g. North and South America). This extra rainfall in otherwise arid regions probably stimulates plant growth that temporarily draws CO2 out of the atmosphere.

16. (9 pts) One potential concern with unrestrained burning of fossil fuels is that the physical mixing of the ocean (the "conveyor belt" circulation) will slow down when temperatures increase globally. This effect on the ocean would then in turn affect the carbon cycle, because the physical mixing of the ocean is responsible for much of the CO2 uptake from the atmosphere (faster vertical mixing leads to more CO2 uptake). Construct a systems diagram that illustrates this potential feedback. The components of the diagram should be: fossil fuel burning, atmospheric carbon dioxide, atmospheric temperature, and the ocean's conveyor belt circulation. Indicate positive interactions as lines with arrow heads and negative interactions as lines with circle heads (just as in the textbook.) Is this a positive feedback or negative feedback loop?

Positive feedback