PUAF 741

Global Environmental Problems

FINAL EXAM

Wednesday, 17 May 2005, 4–7 pm, room 1101 VMH

Enter your UMCP student number here: ☐☐☐-☐☐-☐☐☐☐

Do not enter your name anywhere on this exam (5-point penalty!)

This exam contains 100 points. You have three hours to complete the exam (I hope it won't take that long!).

This is a closed-book exam, except for one sheet of notes. Useful information is attached. Calculators are allowed; computers are not.

Enter all answers and do all your work on this exam. If you need more space, use the back side of the sheet.

Quantitative questions should include an appropriate number of significant digits and the proper units. **Circle final answers**. Partial credit for incorrect answers can be given only if you show your work. If you need a number you can't find or derive, define a symbol for it or take a guess as to its value and continue. If you don't have time to complete a problem but think you know how to do it, describe the steps. If you know your answer is wrong, say so. If you're uncertain about the nature of the question, ask me.

Qualitative questions should be answered precisely and succinctly; it is neither necessary nor desirable to exceed the space provided. Do not exceed the space provided. Complete, polished sentences are not necessary, but **your handwriting must be legible.**

Exam scores and course grades will be posted on the course web site no later than Monday morning.

Good luck!

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1. CFC-12 (CF_2Cl_2) has a residence time in the atmosphere of 100 years. In 1986, global emissions of CFC-12 totaled 440,000 metric tons per year, and the atmospheric concentration of CFC-12 was 400 pptv and increasing at a rate of 4 percent per year. The 1987 Montreal Protocol called for a 50% reduction in global CFC emissions below the 1986 level by 2000.

   A. Estimate the steady-state concentration of CFC-12 if no additional reductions had been negotiated, and compare this to the 1986 concentration. (5 points)

   B. Roughly how long would it take to achieve this steady-state concentration? (2 points)

C. What evidence was available in 1987 to indicate that a 50% reduction would not be adequate? Why didn't the 1987 agreement mandate deeper reductions? (5 points)

D. Explain the following statement: "CFC-12 is nontoxic, nonflammable, inert, and nonreactive. These characteristics, which make it ideal for a wide variety of industrial applications, also make it a threat to the stratosphere." (3 points)

2. The predominant biomass crop in the United States is corn, which is grown using fertilizer. Because the production of fertilizer releases CO_2 into the atmosphere, such biomass crops are not truly carbon free. Ammonia (NH_3) for fertilizer is produced from atmospheric nitrogen (N_2) using the Haber process: $N_2 + 3H_2 \rightarrow 2NH_3$. The needed hydrogen gas usually is produced by reacting methane with steam: $CH_4 + 2H_2O \rightarrow CO_2 + 4H_2$. The overall reaction for the production of ammonia is therefore:

   $3CH_4 + 6H_2O + 4N_2 \rightarrow 3CO_2 + 8NH_3$

   A. If every N atom in the energy crop came from the Haber process, how many grams of carbon are emitted into the atmosphere from fertilizer production, per megajoule of biomass energy? Assume dry biomass is about 5 percent nitrogen by weight. (4 points)

   B. How does your answer to part A compare with the carbon released from burning natural gas? (4 points)

C. How many megajoules of natural gas (mostly methane) are required to produce one megajoule of biomass energy? (4 points)

D. To what extent can biomass replace fossil fuels? What are the advantages and disadvantages of using biomass as a fuel? (5 pts)

3. World air travel is growing steadily. In 2005, civilian passenger aircraft flew 20 billion nautical miles (nmi), compared to only 5 billion nmi in 1980. (1 nmi = 1850 meters)

   A. What was the average rate of growth of air travel from 1980 to 2005? (3 points)

   B. If aircraft mileage continues to grow at this rate, how many miles will aircraft fly in 2050? (3 points)

   C. In 2005, the average plane carried 200 passengers and consumed 8.7 kilograms of fuel per nautical mile flown; the average U.S. car carried one passenger and traveled 20 miles per gallon of gasoline consumed. Compare the fuel efficiency of air and car travel, per passenger-mile traveled. (The density of jet fuel and gasoline are about 0.8 kg/L.) (5 points)

D. Jet aircraft emit about 13 grams of NO_2 per kilogram of fuel consumed. Assuming that there are no changes in fuel consumption or NO_2 emissions per mile, how many million metric tons of NO_2 would be emitted by passenger aircraft in 2050? (4 points)

E. Unlike other sources of acid precursors, aircraft emissions of NO_2 are spread fairly uniformly around the northern hemisphere. What would be the pH of rainfall in the northern hemisphere in 2050, far from other sources of acid precursors? Assume that 90% of the NO_2 emissions calculated in part D occur in the northern hemisphere, that 100% of the NO_2 is converted to nitric acid (HNO_3) and deposited in rainfall averaging 1 meter per year, and that there are no other sources of acid in the rain. (5 points)

F. How does your answer compare to the pH of pristine rainfall? (2 points)

4. In 1993, Harvard biologist E.O. Wilson estimated that Earth is currently losing something on the order of 30,000 species per year. Describe how such estimates are produced, and illustrate this with a rough calculation of your own. (6 points)

5. Short answers (2 points each)

   A. The impact of acid deposition of aquatic ecosystems depends primarily on what factor (besides the pH of rainfall)?

   B. The population of Russia, currently about 140 million, is declining at a rate of about 1 percent per year. If this continues, how long will it take the population to decline to 70 million?

   C. If per-capita GDP is growing at a rate of 5 percent per year in Russia, and carbon intensity (tons of carbon per dollar of GDP) is declining at a rate of 1 percent per year, what is the growth rate of Russian carbon emissions?

   D. Heat can be converted to electricity using a variety of mechanical means. Why is the temperature of the heat source important?

   E. Give two examples of phenomena that can be described using a logistic equation.

   F. If consumption of a resource is growing exponentially at a fixed growth rate r, the amount consumed in the next doubling time is equal to…

   G. Describe what is meant by “radiative forcing.”

   H. What change in mean global temperature is expected from a doubling of CO_2?

   I. The atmospheric CO_2 concentration has increased from 275 to 375 ppmv. How do we know that most of the added carbon is from the burning of fossil fuels?

   J. A carbon tax will have the greatest impact of the price of what type of fossil fuel? the smallest impact?

6. Short answers (4 points each)

   A. Identify and describe four factors thought to be responsible for declining fertility rates.

   B. Name three greenhouse gases and identify their principle natural and anthropogenic sources.

   C. The effects of various greenhouse gases can be aggregated using “global warming potentials” or “equivalent carbon dioxide concentrations.” Under what circumstances is it appropriate to use each of these?

D. Describe two climate-change feedback loops, one that involves a greenhouse gas and one that does not. In each case, describe the linkages in the loop and state whether the entire feedback is positive or negative.

E. Describe variations in the pattern of global temperature change that would be expected if these changes were a result of increased greenhouse gas concentrations (land v. ocean, poles v. equator, etc.).

POSSIBLY USEFUL INFORMATION

1 meter (m) = 3.281 feet (ft)

1 mile (mi) = 1609 m = 5280 ft

1 hectare (ha) = 10^4 m^2 = 2.47 acres

1 m^3 = 1000 liter (L) = 1 t(H_2O)

1 gallon (gal) = 3.785 L

1 barrel (bbl) = 42 gal

1 acre-foot = 1234 m^3

1 pound(lb) = 454 grams = 16 ounces (oz)

1 metric ton (t) = 1000 kg

1 mole = $6.02 \cdot 10^{23}$ molecules

1 mole(gas) = 22.4 L @ STP

1 hour (h) = 3600 seconds (s)

1 year (y) = $3.155 \cdot 10^7$ s

1 joule (J) = kg·m^2/s^2

1 BTU = 1055 J

1 kilowatt-hour (kWh) = 3.6 MJ

1 watt (W) = 1 J/s

Kelvin (K) = degrees Celsius + 273

$S = F \cdot \tau$ $\quad$ $c = S/V$

$S(t) = S_0 e^{rt} = S_0(1 + i)^t$

$i = [S(t)/S_0]^{1/t} - 1 = e^r - 1$

$r = \ln[S(t)/S_0]/t = \ln(1+i)$

$T_{2X} = \ln(2)/r = 0.69/r$

$S(t) = F_0(e^{rt} - 1)/r$

$T = \ln[rS(t)/F_0 + 1)/r$

$\ln(a \cdot b) = \ln(a) + \ln(b)$

$e^a e^b = e^{(a+b)}$

$pH = -\log_{10}[H^+]$ $\quad$ $[H^+]$ = moles(H^+) per liter

$S = cA^z = S_0(A/A_0)^z$

area of Earth = $5.10 \cdot 10^{14}$ m^2

mass of oceans = $1.35 \cdot 10^{21}$ kg

$(1 - \alpha)\, \pi R^2\, \Omega = 4\pi R^2\, \sigma T^4$

$\sigma = 5.67 \cdot 10^{-8}$ W/m^2K^4

Ω = 1370 W/m^2

$\Delta T = (\Delta F/3.7)\, \Delta T_{2X}$

$\Delta F_{CO2} = 5.35 \ln(C/C_0)$ W/m^2

mass of atmosphere = $5.14 \cdot 10^{18}$ kg

moles of dry air = $1.8 \cdot 10^{20}$

gravitational acceleration = g = 9.8 m/s^2

energy = mgh = ½mv^2 = mCT

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h = 10^2; $\quad$ k = 10^3; $\quad$ M = 10^6; $\quad$ G = 10^9; $\quad$ T = 10^{12}; $\quad$ P = 10^{15}; $\quad$ E = 10^{18}

c = 10^{-2}; m = 10^{-3}; $\quad$ μ = 10^{-6}; $\quad$ n = 10^{-9}; $\quad$ p = 10^{-12}; $\quad$ f = 10^{-15}; $\quad$ a = 10^{-18}

Atomic weights: H = 1; $\quad$ C = 12; $\quad$ N = 14; $\quad$ O = 16; $\quad$ F = 19; S = 32; Cl = 35.5 Ca = 40 g/mole