PUAF 741 **GLOBAL ENVIRONMENTAL PROBLEMS** FALL 1995

FINAL EXAM SOLUTIONS

1. Coal consumption in China is about 900 Mte/yr, and is increasing at a rate of 5.6 percent per year. Chinese coal is 2.5 percent sulfur by weight.

   A. At this rate of growth, what would China's coal consumption be in 20 years? (4 points)

   $F = F_o(1 + i)^t = 900 \cdot (1.056)^{20} = 900 \cdot (3) = 2700$ Mte(coal)/yr

   B. Estimate China's emissions of sulfur dioxide, now and in 20 years, assuming no controls on emissions. Compare this to the 40 Mte of sulfur dioxide emitted today by the OECD states. (5 points)

   $$\left(\frac{900\,\text{Mte(coal)}}{\text{yr}}\right)\left(\frac{0.025\,\text{Mte(S)}}{\text{Mte(coal)}}\right)\left(\frac{(32 + 2 \cdot 16)\,\text{Mte}(SO_2)}{32\,\text{Mte(S)}}\right) = 45\,\frac{\text{Mte}(SO_2)}{\text{yr}}\ \text{today}$$

   20 years from now: $45 \cdot (3) = 130$ Mte(SO_2)/yr

   C. Roughly how much will the pH of rainfall in China change with this increase in sulfur emissions? (Assume that sulfuric acid is the principle source of acidity in today's rainfall.) If today the average pH in a certain region is 4.8, what would it be 20 years later? (6 points)

   If the amount of sulfur released is increased by a factor of three, the average concentration of H+ will also be increased by a factor of three, all else (conversion to sulfate, rainfall, etc.) being equal.

   $pH = -\log_{10}[H^+] = -\log_{10}(3 \cdot [H^+]_o) = -\log_{10}(3) - \log_{10}[H^+]_o = -0.48 + pH_o$

   In other words, the new pH will be about 0.5 units lower than the old pH.

   D. What considerations would be important in determining the effects of acid rain on plants, animals, and humans in China? (5 points)

   The most important consideration would be the buffering capacity of soils where the acid is deposited. Soils and lakes with low alkalinity are very sensitive to acidification; the response of lakes can be particularly rapid. Also important would be the sensitivity of animal and plant species in these areas; trout, for example, are very sensitive to acids. Regarding direct effects on human health, the leaching of toxic metals from soils and distribution pipes into water supplies would be an important consideration. Acid rain can also damage buildings and forests and, if very severe, crops.

2. The population of Belgium is about 10 million. The population growth rate is very close to zero. Using stock-flow-residence time considerations, estimate the number births and deaths in Belgium each year. (5 points)

   Since the growth rate is zero, we are in equilibrium: birth rate = death rate = stock ÷ residence time. (Ignore immigration.) The residence time of a human is the life expectancy, which is about 76 years in Belgium. (Anything in the 70 to 80 year range would be fine.) Thus:

   birth rate = death rate = (10 million) ÷ (76 years) = 130,000/yr

   The actual birth and death rates are 121,000 per year and 115,000 per year, respectively. The differences occur because of immigration, gradually increasing life expectancy, and a slightly non-zero and time-varying growth rate.

3. Fluorescent lighting is much more efficient than incandescent, using one-fourth the electricity to deliver the same amount of light. In the U.S., about 7 percent of electricity is used for incandescent lighting. If all incandescent lights were replaced by fluorescents, by what fraction would U.S. emissions of carbon dioxide be reduced? (20 points)

   Since fluorescents use one-fourth the electricity, we would save 75 percent of the 7 percent of U.S. electricity used for incandescent lighting, of which 60 percent is produced by coal and 10 percent by natural gas:

   (2800 GkWh/yr)·(0.07)·(0.60)·(0.75) = 88 GkWh/yr of coal-fired electricity saved

   (2800 GkWh/yr)·(0.07)·(0.10)·(0.75) = 15 GkWh/yr of gas-fired electricity saved

   Now compute the amount of carbon emitted per kWh by coal-fired plants:

$$\left(\frac{kg(coal)}{29\cdot 0.3\ MJ}\right)\left(\frac{0.7\ kg(C)}{kg(coal)}\right)\left(\frac{MJ}{MW\cdot s}\right)\left(\frac{3600\ s}{h}\right)\left(\frac{MW}{1000\ kW}\right)=0.29\ \frac{kg(C)}{kWh}\ for\ coal-fired$$

   Half of this, or 0.14 kg(C)/kWh, for gas-fired plants.

   The total reduction in carbon emissions is therefore:

$$\left(88\cdot 10^{9}\ kWh\right)\left(\frac{0.29\ kg(C)}{kWh}\right)+\left(15\cdot 10^{9}\ kWh\right)\left(\frac{0.14\ kg(C)}{kWh}\right)=28\cdot 10^{9}\ kg=28\ Mte(C)$$

   To compare this to U.S. emissions of 5000 Mte(CO_2), we note that there are 12 ÷ (12 + 2·16) = (12/44) = 0.273 te(C)/te(CO_2), so we would save (28/1360) = 0.02 = 2 percent of total U.S. emissions.

4. Some have suggested using liquid fuels derived from biomass as substitutes for oil. How much land would be required to offset 10 percent of U.S. oil consumption? How does this compare with the total amount of land now under cultivation in the U.S. (about one billion acres)? (15 pts)

   A kilogram of dry biomass, which is 40 percent carbon, has an energy content of 16 MJ, 90 percent of which can be captured in the form of a liquid fuel. The NPP of agricultural systems is about 0.3 kg(C)/m^2·yr. The energy content of petroleum is 43 MJ/kg or 6.1 GJ/bbl; U.S. oil consumption is 16,900,000 barrels per day.

$$\left(\frac{16.9\ \text{Mbbl}}{\text{day}}\right)\left(\frac{365\ \text{d}}{\text{yr}}\right)\left(\frac{6.1\ \text{GJ}}{\text{bbl}}\right) = 38{,}000\ \frac{\text{MGJ}}{\text{yr}} = 38\ \frac{\text{EJ}}{\text{yr}}$$

$$\left(\frac{3.8\cdot 10^{18}\ \text{J}}{\text{yr}}\right)\left(\frac{\text{kg(dom)}}{0.9\cdot 16\cdot 10^{6}\ \text{J}}\right)\left(\frac{0.4\ \text{kg(C)}}{\text{kg(dom)}}\right)\left(\frac{\text{m}^2\cdot\text{yr}}{0.3\ \text{kg(C)}}\right)\left(\frac{\text{ha}}{10^{4}\ \text{m}^2}\right)\left(\frac{2.47\ \text{acre}}{\text{ha}}\right) = 86\ \text{Macre}$$

   In other words, about 9 percent of U.S. land under cultivation would be required to displace 10 percent of U.S. oil consumption.

5. One of the complications of the climate-change problem is that so many substances released by humans influence global climate.

   A. List the emissions that influence climate and list the human activities that give rise to these emissions. (5 points)

      Carbon dioxide: fossil-fuel burning; biomass clearing; cement manufacture
      Methane: natural gas leakage; livestock; rice growing
      Nitrous oxide: overapplication of nitrogen fertilizers
      Halocarbons: industrial use of CFCs and certain solvents
      Ozone: created in urban environments from NO_x, hydrocarbons, and sunlight
      Aerosols: coal and biomass burning

   B. The effect of emissions on climate is often measured in terms of their "instantaneous radiative forcing." What is this? For which substances is the relationship between emissions and radiative forcing not well understood? Why is radiative forcing an inadequate basis for comparing different types of emissions? (5 pts)

      Instantaneous radiative forcing is the effect that a given amount of gas or aerosol would have on the radiation balance of the Earth, if it were added to the atmosphere all at once. For example, doubling CO_2 would result in a forcing of 4.4 W/m^2; which means that if CO_2 was doubled instantly, the Earth would radiate 4.4 fewer *watts of energy back to space than it receives from the Sun.*

      The relationship between emissions and radiative forcing is well understood for the so-called "direct" greenhouse gases: carbon dioxide, methane, nitrous oxide, and halocarbons. The relationship is more uncertain for ozone; it is much less certain for aerosols.

Instantaneous radiative forcing is an inadequate basis for comparing emissions because substances have very different residence times in the atmosphere. The residence time of CO_2 is roughly ten times longer than CH_4, so that even if the radiative forcing of CO_2 and CH_4 emissions were equal, the warming effects of CO_2 would remain with us much longer than those of CH_4.

C. Suppose the radiative forcing that results from the emission of a given amount of each substance is known. Describe the uncertainties in translating this into a description of how climate would change. (10 pts)

The uncertainties are due primarily to uncertainties in feedbacks in the global climate system. Without these uncertainties, translating a certain radiative forcing into a change in temperature would be straightforward. But as the Earth warms, the climate system adjusts in many ways to offset or amplify the temperature increase. For example, the concentration of water vapor may increase, trapping more infrared radiation; cloud cover, type, or altitude may change, altering the reflection of incoming solar and the trapping of outgoing infrared; ice and snow may melt, changing the albedo of the Earth; the rate of biological decay may increase, releasing additional methane or carbon dioxide into the atmosphere; or the rate of biological growth may increase, drawing carbon out of the air. The effects vary over the surface of the Earth in ways that cannot be predicted in detail.

There is far more to climate and climate change than increasing temperature, however. Plants are affected by changes in precipitation, soil moisture, sunlight/cloudiness, and the length of the growing season. Climate models do not predict these changes very well. Even more important than changes in average values may be changes in the variance: floods and droughts, storms, periods of unusually hot or cold weather, etc. Changes in ocean currents may be very important.

6. You read an editorial stating that there has been no observed increase in ultraviolet radiation or skin cancer in the United States, contrary to the dire predictions of environmentalists; concern over ozone depletion is therefore greatly exaggerated, and compliance with the Montreal Protocol can be relaxed. Write a short response. (10 points)

- *No, we haven't seen increases in UV or skin cancer, but no one predicted that we would see such increases—yet. Small changes in UV are very hard to measure. Small changes in the incidence of skin cancer would also be difficult to detect, and will occur many years after exposure.*

- *The link between CFC emissions, ozone depletion, increased UV, and skin cancer is virtually undisputed by the scientific community. The evidence is especially persuasive in the Antarctic, where unusual atmospheric conditions have combined with chlorine from CFCs to lower ozone levels by as much as 65 percent, increasing*

UV by as much as 150 percent. Increases in skin cancer have already been detected in Australia.

- *The Montreal Protocol and its amendments were enacted to halt the destruction of ozone before it reached dangerous levels in more populated areas such as the U.S. Baring unexpected events such as a major volcanic explosion, scientists expect ozone levels to reach a minimum around the turn of the century. But because of the long lifetimes of CFCs in the atmosphere, the ozone layer won't recover fully until the middle of the next century.*

- *Although the worst may be averted, even the small decreases in ozone that have been observed over the U.S. will have serious consequences. A 2 percent decrease in ozone will cause result in 15,000 additional cases of cancer and 800 additional deaths per year, in the U.S. alone. Worldwide, these numbers would be about five times greater.*

- *Delaying compliance with the Protocol and its amendments until we see signs of dramatic increases in UV or skin cancer would be foolish, since such damage would take decades to reverse, during which time we would condemn hundreds of thousands of people to premature death. Nor has industry requested a delay in compliance. Affordable substitutes are on the market right now that can perform the same functions as CFCs without threatening the ozone layer.*

- *The Montreal Protocol and its amendments represent a landmark achievement in the efforts of the world community to deal with global environmental problems before they becomes a catastrophe. Don't steal defeat from the jaws of victory.*

7. What do we mean by the term "biodiversity"? What are the main threats to biodiversity? Why is it important to preserve biodiversity? (10 points)

   Biodiversity refers to the full range of ecosystems, species, and genetic variants of species that exist on Earth.

   The main threats to biodiversity are habitat destruction through deforestation, agriculture, grazing, and other land-use changes; over-harvesting, hunting, or pest control; the introduction of non-native species; and the effects of pollution.

   Biodiversity has direct and indirect value to humanity. Direct values include genetic diversity for agriculture and drugs; plants and animals that have economic value as products or pets; and esthetic values. Indirect values include ecosystem services such as flood control, waste processing, and climate regulation. Biodiversity also has intrinsic value. In other words, a species may have value apart from humanity.