ESYS10 Final examination

Monday, March 14, 2005

11:30 - 2:30 PM

Stats on finishing exam: 1st finished at 1 hour 15 minutes, 7 by 2 hours, 15 by 2.5 hours, 22 by 2.75 hours

I. Very short answer (3 points each) (30 points total)

1. Ozone is created in the stratosphere by which type of radiation? (circle all that apply)
visible light
long wavelength UV
short wavelength UV
middle wavelength UV
("long, middle or short" mean within the UV range)

2. The layer in the ocean between the surface layer and the deep layer is called the __thermocline_____.

3. The organic carbon cycle **does not** include which of the following elements (circle all that apply):
fungi siliceous rocks fossil fuel shells respiration

4. A molecule that speeds up a reaction between two other molecules or atoms is called a _____catalyst_____.

5. When ocean surface waters are warmer everywhere, the following can happen (circle all that apply):
the waters absorbs more CO_2 from the atmosphere
sea level rises
sea ice regions contract
an El Nino occurs

6. The ultimate and original source of CO_2 for the atmosphere is __volcanoes__.

7. When sea ice melts, the surface layer of the ocean becomes (circle all that apply):
fresher colder saltier higher

8. Name at least one type of proxy record that is used to reconstruct temperature records for the past 1000 years. tree rings (growth rates), sediment core isotopes, ice core isotopes, pollen isotopes

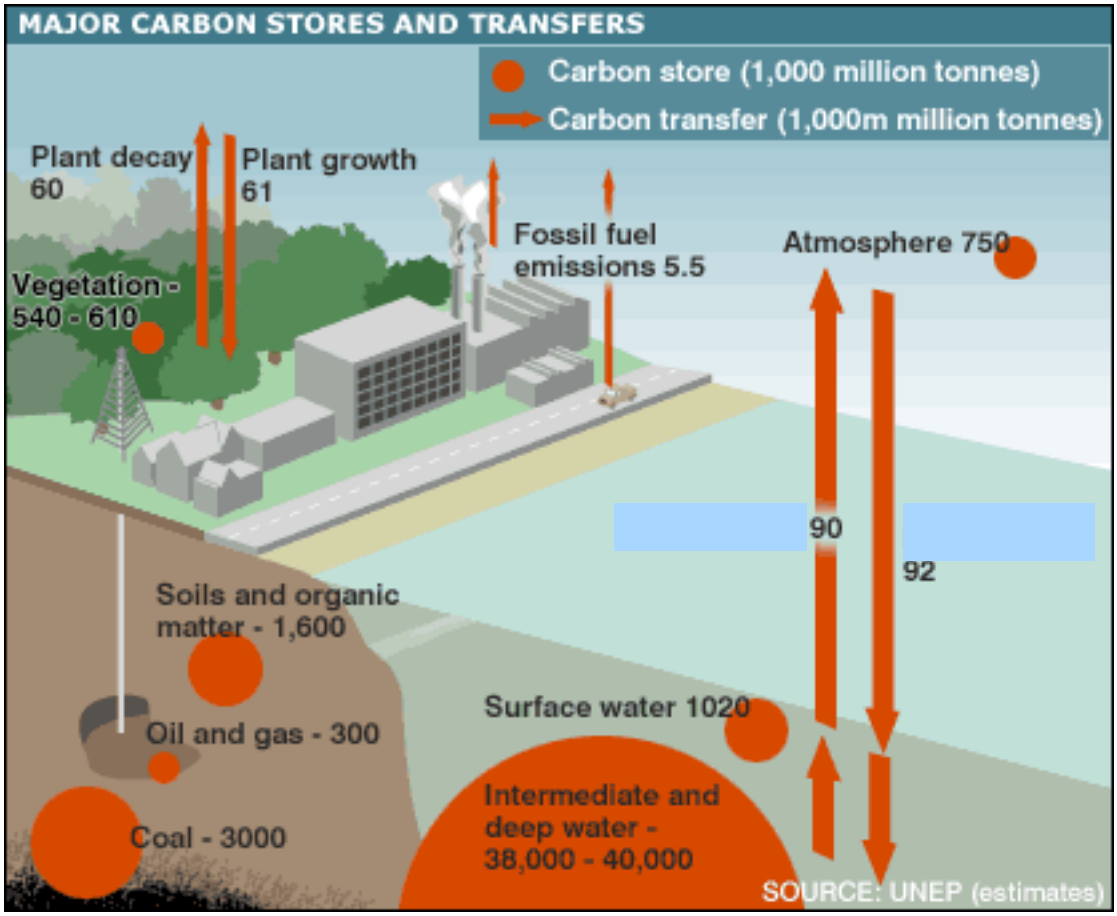
9. Which of the following gases contribute to greenhouse warming? (circle all that apply)

oxygen
methane
chlorofluorocarbons (freons)
CO2
Water vapor

10. The international agreement that is in effect to limit ozone depletion is called the _Montreal protocol_____

II. Short answer (90 points total)

1. (15 points) The figure shows some of the elements of the carbon system. ("1 million tonnes" is equal to 1 Gton).



(a) Define "carbon reservoir". List at least three carbon reservoirs that appear on the figure. A carbon reservoir is a part of the system that holds carbon in a particular form. Everything called a "carbon store" in the figure is a carbon reservoir – surface water,

intermediate and deep water, coal, oil and gas, soils and organic matter, vegetation, atmosphere.

(b) Using information in the figure, compute the residence time of CO_2 in the atmosphere associated with photosynthesis. If you don't have a calculator, please write down the expression, including actual numbers, that you need to evaluate to compute the residence time, and estimate the answer.

Atmosphere reservoir holds 750 Gtons(C)

Photosynthesis rate is 60 Gtons(C)/yr

The residence time is

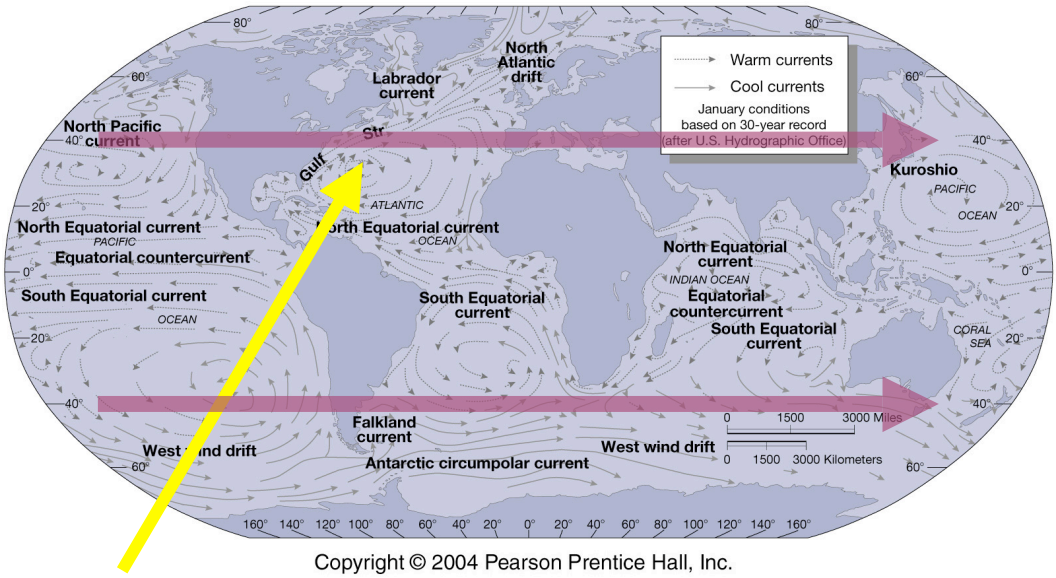
(Reservoir size)/ (Photosynthesis rate) = 750/60 = 75/6 = 12.5 years

c) Describe a process that could move CO_2 from the ocean to the atmosphere.

CO2 is produced in the ocean by respiration (tiny amounts).

It is also outgassed when temperature increases, so upwelling deep/intermediate waters would reach the surface, warm, and lose their excess CO2 to the atmosphere.

2. (20 points) The attached figure shows the major surface circulation features of the world ocean.



(a) Find the Gulf Stream and the circulation that goes with it. **Mark** where the sea level should be highest, assuming that the flow in the Gulf Stream circulation is geostrophic (Coriolis and pressure gradient or difference force). **Explain** how you chose this region.
The Gulf Stream circulation is clockwise and in the northern hemisphere. The highest sea level in this circulation has to be in the center of it (not on the outside), so that the pressure gradient (difference) force points from the center of the circulation (gyre) to the outside. Coriolis force then moves the water particles to the right, which would give the clockwise circulation around the high pressure.

(b) For this surface circulation map, is the flow mainly associated with the winds or with heating and cooling? Explain briefly.
This is surface flow and is mainly driven by the winds, which act directly on the surface. Circulation driven by heating and cooling is much weaker, and is overpowered in the surface layer by this wind-driven circulation.

c) On the figure, mark the general location of the westerly winds.
Are the westerly winds associated with the Hadley circulation or the Walker circulation in the atmosphere? Explain briefly, to reflect your knowledge of the difference between the two atmospheric circulations.
The westerly winds are associated with the Hadley circulation, which has rising air in the equatorial region and sinking air at mid-latitudes. The winds aloft (top of troposphere) turn to the right, that is, to the east, creating westerly winds at height. As the air sinks in mid-latitudes, the westerly wind energy is carried downwards to the surface. (I didn't provide the full set of choices – the westerlies at the surface are also associated with the Ferrel cell, which is the higher latitude atmospheric overturn.) The Walker cell is strictly tropical, and does not affect the mid-latitude westerlies.

(d) In each ocean (that is, N. Atlantic, S. Atlantic, N. Pacific, S. Pacific, Indian), in each circulation pattern, the currents are strongest in one special region and weaker elsewhere. (Ignore the tropics and equatorial region for this question.) Where is this special region in each ocean? Western boundary.

3. (15 points)

(a) The reaction $CO_2 + H_2O$ <---> H_2CO_3 takes place in __water (raindrops, seawater, etc).__ _. The H_2CO_3 then causes the process of weathering.

(b) The reaction

$$Ca^{2+} + 2HCO_3^- \text{ ---> } CaCO_3 + H_2CO_3$$

takes place in _the ocean__ and is mediated (carried out) by _marine organisms that create shells and skeletons___.

c) What happens to the products of this reaction? (describe)

When the organisms die, the shells and skeletons sink downwards out of the ocean's surface layer. If the water is shallow enough (< 2000 meters, approximately), then the shells accumulate on the sea floor, in the marine sediments. After a long time, they may be uplifted and become rocks. If the water is deep, then the shells dissolve, and release the carbonate back into the water. (Patrick – if they also answer this for part (a), they can have extra credit – 5 points.)

4. (20 points)

(a) Agencies that monitor air pollution measure the ozone concentration on a regular basis. They become concerned when ozone levels are too high. Explain the dichotomy between this and the international agreements that deal with the ozone hole.

Ozone in air pollution occurs only in the surface layer (planetary boundary layer), where we live. It is highly reactive and can cause major lung problems. It is created by reactions in catalytic converters???? The less of it, the better for health.

Ozone in the stratosphere is created by the interaction of highly energetic photons with oxygen. The process of ozone creation shields the troposphere from the harmful effects

of the energetic photons. When there is less ozone, then there is less absorption of photons (xxx).

(b) During periods of high solar activity (sunspots), there is more ozone in the atmosphere. Why? Because there are more high energy photons zinging around, creating ozone.

c) Does the following pair of reactions create or destroy ozone? Explain.

$$Cl + O_3 \rightarrow Cl\,O + O_2$$
$$Cl\,O + O \rightarrow Cl + O_2$$

This pair of reactions clearly destroys ozone, which is O3. The reaction is between single atoms of chlorine and ozone, and ends up with the single chlorine still available to destroy another ozone. This is called a catalytic reaction, since the Cl is not consumed, but facilitates the change of ozone to O2.

(d) For the ozone hole problem, where in the atmosphere does the reaction in c) occur? What has been the main general source of the Cl in this reaction during the latter part of the 20^{th} century?

This reaction is most destructive in the ozone layer in the stratosphere, particularly over Antarctica, because of the isolation of the polar stratosphere in the Antarctic winter, lack of sunshine to destroy ozone then, and concentration of Cl on polar stratospheric clouds. There is also a weaker ozone hole over the Arctic, and there has been general weakening of the ozone concentration at all latitudes. The sources of Cl are anthropogenic, and were clearly a result of the production of chlorofluorocarbons for commercial use.

5. (20 points)

The present atmosphere contains approximately 700 Gton(C) in the form of CO_2. Earth's total recoverable fossil fuel reserves contain at least 4200 Gton(C).

(a) At present, about half the CO_2 produced by the burning of fossil fuels stays in the atmosphere. The other half dissolves in the oceans or is taken up by the terrestrial

biosphere. If this ratio remained constant and we burned up all of our fossil fuels *instantaneously*, by how much would atmospheric CO_2 concentrations rise? (Express your answer as a fraction or percentage.)

The CO_2 level would increase by 4200 Gton(C) / 2 = 2100 Gton(C). The new atmospheric concentration would be:

$$700\ Gton(C) + 2100\ Gton(C) = 2800\ Gton(C).$$

2800 Gton(C) / 700 Gton(C) = 4, so atmospheric CO_2 levels would be 4 times the present-day levels after such a change.

(b) Climate models predict that each doubling of the atmospheric CO_2 concentration will cause the mean global temperature to increase by 1.5ºC-4.5ºC. By how much would the mean temperature increase for the scenario described in part (a)?

Increasing the CO_2 concentrations to 4 times their present-day levels would represent two doublings. According to these models, this would lead to two increases of 1.5ºC – 4.5ºC, a total increase of 3.0ºC – 9.0ºC. To convert this to Fahrenheit, multiply by (9ºF / 5ºC). When this is done, we find that the temperature increase would be 5.4ºF-16.2ºF.

(c) If we continue burning fossil fuels at a rate of 6 Gton(C)/yr, how long would it take to deplete the Earth's recoverable fossil fuels?

4200 Gton(c) / 6 Gton(C)/yr = 700 years.

III. Informed science reporting (40 points).

As the Arctic Warms
By ANDREW C. REVKIN (NYT) 456 words
Published: November 9, 2004

OPENING WATER -- The Arctic Climate Impact Assessment, a study commissioned four years ago by the United States and the seven other countries with Arctic territory, projects that rising global concentrations of heat-trapping emissions will drive up temperatures particularly quickly at high latitudes. Some benefits are predicted. For instance, expanding areas of open water in summer could be a boon to whales and cod stocks. The ice retreat could also create summertime shipping shortcuts between the Atlantic and Pacific and allow oil and gas exploration in

previously ice-cloaked waters. But a host of troubles lie ahead as well. The loss of sea ice, for example, could hurt both polar bears and Inuit seal hunters. Details are available on the Web at www.amap.no/acia.
ANDREW C. REVKIN

A BIG THAW -- The warming of many parts of the Arctic is already reducing the amount of perpetually frozen ground, or permafrost, and that trend will almost certainly continue, creating problems for oil companies, road networks and structures built on a thawing landscape. The frozen season has also been shrinking. The number of days in which oil companies can explore for oil on Alaska's North Slope has been cut in half in 30 years. The ecological impact of the trend is harder to predict. For example, while water may drain from existing tundra lakes through thawed ground, other ponds and lakes may form in thawed spots where the surface sinks, creating more aquatic habitat.

FOREST VS. TUNDRA -- In a trend already measured in Arctic portions of Alaska, shrubs and small trees will likely thrive and grow farther north in a warming world, according to the new report. Caught between rising seas on one side and expanding shrub-filled zones to the south, tundra ecosystems around the Arctic (as in eastern Russia, left) will likely shrink to their smallest extent in at least 21,000 years, the scientists concluded. This could reduce breeding areas for many tundra-dwelling bird species and grazing lands for caribou and other mammals.

RISING SEAS -- One of the most important consequences of Arctic warming will be increased flows of meltwater and icebergs from glaciers and ice sheets, and thus an accelerated rise in sea levels. The zone of melting on the flanks of Greenland's two-mile-high ice sheet (above) has already grown about 16 percent since 1979, with 2002 setting a record.

(a) Give at least one reason for why anthropogenic warming is stronger in the Arctic than at mid-latitudes.

1. Sea ice/snow-albedo feedback. Sea ice/snow reflect a lot of the incoming radiation, so the radiation is not available to heat up the land/ocean. When the snow/ice are reduced, more radiation enters the ocean/land, warming them up.

2. CO2 is more evenly distributed over the planet than is the incoming solar radiation (which is much stronger in the tropics than at high latitude). With increased greenhouse gas, the higher latitudes can retain more heat proportionally. Compared with the natural state, the warming is greater at high latitudes.

(b) How might shrinking ice cover itself affect the climate? Does it produce a feedback and if so, is the feedback positive or negative? Explain your answer.

As for (a), the sea ice/albedo feedback would kick in, and the climate would warm more equickly. This is a feedback, and it is positive. (Less sea ice, lower albedo, more warming, hence even less sea ice).

c) Revken lists one reason for why sea level could rise in response to global warming. Explain why he only discusses glaciers and ice sheets and not Arctic sea ice cover.

Because sea ice itself does not change sea level. When the ice is melted, the sea level remains the same as when there was ice. Sea level can only be changed by adding actual water, which has to come from land-bound ice/snow.

(d) In addition to melting ice, what other global warming effect can contribute to sea level rise?

The other effect is thermal expansion – sea water expands as it warms.

(e) As climate changes, organisms and populations are affected. In Revken's essay, he mentions effects on tundras and tundra species. Speculate about the difference in response of these species if the climate changes relatively slowly compared with large changes that might occur quickly, say, over less than 10 years.

If climate change is rapid and large, then species can be eliminated. If it occurs slowly, then there is time for species to shift to adjacent regions that retain favorable conditions.

IV. Essay (40 points). Read and see questions that follow the article.

(1 million tonnes = 1 GTon)

UK 'climbs down' over climate

By Richard Black
BBC Environment Correspondent
Friday, 11 March, 2005, 15:32 GMT

Environmental groups have welcomed the move
The UK government has announced tougher limits on greenhouse gas emissions following pressure from the European Commission.

The announcement will enable UK firms to join fully with the fledgling European Emissions Trading Scheme (ETS), a key component in EU plans to combat global warming.

It may also allow the government to avoid a damaging political row at an electorally sensitive time.

Under the ETS, every EU member state has to set a limit - a National Allocations Plan (NAP) - on the amount of carbon dioxide which its industrial plants can produce during the next three years.

Each government must then divide up this limit between the companies involved, each company receiving an "allowance", which it can trade with other companies at a rate set by the market.

The aim is to reduce carbon dioxide emissions in a business-friendly fashion.

Energy demand
Britain published what it called a "draft" figure in April; the government calculated that during the period 2005-7, UK companies involved in the scheme should produce no more than 736 million tonnes of CO2.

"We are delighted the Government has re-introduced proposals for sensible cuts in UK CO2 levels", said Bryony Worthington, Friends of the Earth.

With some small caveats, the European Commission approved the plan.

Then, in October, the government revised its limit upwards, to 756 million tonnes; the reason, said Environment Secretary Margaret Beckett, was that forecasts of Britain's energy demand had changed - the country would need more energy in the next three years, and so would need to produce more CO2.

Environmental groups accused the government of caving in to demands from big business, and the Commission was clearly not convinced that the UK, alone among EU countries, had a case for raising its emissions cap.

The result has been a stand-off, which the Commission has clearly won; the government has gone back to its original figure of 736 million tonnes, though it aims to take legal action against the Commission.

Expensive electricity

Environmental groups have welcomed the move.

"Tony Blair has promised to put climate change at the top of the international agenda; and undermining EU plans to cut carbon dioxide is the wrong way to go about achieving this."

The electricity industry will be most affected by the change to the NAP - it will have to cut all of the extra 20 million tonnes of CO2.

"We are naturally disappointed, but not surprised," the chief executive of the Association of Electricity Producers, David Porter, told BBC News.

"Electricity will be more expensive as a result."

The government has made much of its stated commitment to combating climate change, and has won plaudits from environmental groups for its stance.

It may have been unwilling, at a time when a general election is anticipated, to see the UK cast as the country obstructing European attempts to tackle global warming.

Write an essay commenting on this article. Include in your essay at least the following.

(1) a discussion of how greenhouse gas increases cause warming;

(2) the evidence that climate is now changing in response to greenhouse gas changes;

(3) a quantitative description of how much the planet is predicted to warm in response to current forcing, if the forcing continues unabated.

(4) The status of the Kyoto protocol as a setting for why European nations are now embarking on emissions trading.

(5) The effect that enforcement of the Kyoto protocol is expected to have on climate.

(6) Possible outcomes for businesses that are forced to comply with the emissions limits.