NAME_____Answers_____

1. (19 points) Briefly define or describe:

cryosphere

all ice on Earth

TOMS

Total Ozone Mapping Spectrometer

Halley Bay

Location of British Antarctic station where ozone hole was discovered

IPCC Intergovernmental Panel on Climate Change

CFCs chlorofluorocarbons

dropstone rock carried by iceberg, dropped into ocean when iceberg melted, deforming sedimentary layers

Holocene the most recent 10,000 years of Earth history

What are the three most common gases in Earth's atmosphere?

O_2 N_2 Ar

What are the two most common stable (i.e. non-radioactive) isotopes of oxygen?

^{18}O ^{16}O

2. a. (3 points) Climate models of the ice ages suggest that retreat of northern hemisphere ice sheets would be favored when incident solar radiation in summer at 60°N is maximum. Within their range of variation, what conditions of the earth's orbital configuration would favor this:

tilt: (large or small?)

eccentricity: (large or small?)

perihelion: in what month?   July

b. (2 points) Seawater is denser at (high / low) salinity and (high / low) temperature. (circle the correct words)

3. (16 points) Two-point short answers.

(a) If you walked outside right now and looked up at the sky, what are two visual clues you could use to assess the intensity of UV-B sunlight reaching the surface?

clouds

sun angle

(b) Which resource is expected to be used up first, coal or oil? Which is preferable as an energy source from the point of view of its CO_2 emissions? Why?

oil.   oil. CO_2 emitted per Joule of energy obtained is greater for coal.

(c) CO_2 absorbs strongly in two wavelength regions: near 4 µm and near 15 µm. Which absorption is more important for Earth's climate? Why?

15 µm. This is near the peak of the terrestrial emission spectrum.

(d) The surface temperature of the Northern Hemisphere reaches its maximum about 30 days after the June solstice. Why does the surface temperature of the Southern Hemisphere not reach its maximum until 45 days after the December solstice?

S.H. is mostly ocean; has large thermal inertia.

(e) The world average sea level is now rising by about 3.5 mm per year. Give two causes that contribute to the rise of sea level.

melting of glaciers
thermal expansion of sea water

(f) Why is sea level *dropping* in Hudson Bay?

Bedrock of Canada is rebounding after removal of North American ice sheet

(g) The Cretaceous period (the time of the dinosaurs), centered on 100 million years ago, was a time of very warm climate on Earth. Approximately how much different (in percent) was the Sun's luminosity at that time than now, and was it larger or smaller?

~ 1% smaller luminosity

(h) The *Northwest Power Act of 1980* required purchase of energy conservation instead of new electric power plants to the extent that energy conservation is cost-competitive. As a result, the Pacific Northwest region initiated widespread energy conservation grant programs administered by the electric utilities. What economic catastrophe motivated the passage of the Northwest Power Act?

Four nuclear power plants were partly or completely built but never used because of lack of demand for electricity. Washington State defaulted on its bonds.

4. Give approximate numerical values (4 points)

(a) Average planetary albedo of Earth

0.3

(b) Tilt (obliquity) of Earth's axis:

present value   23.5°

range of values in the last million years   22-25°

period of oscillation   40,000 yr.

5. (18 points) Multiple choice. Circle the closest number or the correct word.

Solar zenith angle at noon on June 21:

at the equator	0°	(23.5°)	45°	66.5°	90°
at Seattle (47°N)	0°	(23.5°)	45°	66.5°	90°

How much (in parts per million) has atmospheric CO_2 varied during

(a) the year 2010 (at Mauna Loa)	1	(8)	90	800
(b) the last 100 years	1	8	(90)	800
(c) a 100,000-year glacial-interglacial cycle	1	8	(90)	800

What is the normal ozone column amount
(in millimeters at 1-atmosphere pressure)   0.3   (3)   30   300

global average precipitation (mm)   1   10   100   (1000)

typical thickness (meters) of
sea ice   (2)   20   200   2000

iceberg   2   20   (200)   2000

ice shelf   2   20   (200)   2000

ice sheet   2   20   200   (2000)

Sea-level equivalent of Greenland Ice Sheet (m)   0.6   (6)   60   600   6000

Sea-level equivalent of Antarctic Ice Sheet (m)   0.6   6   (60)   600   6000

For water, the latent heat of melting is 80 cal/g;
the latent heat of vaporization is 600 cal/g; what
is the latent heat of sublimation?   80   520   (680)

Earth is closest to the Sun in   (January)   April   July   October

In the seasonal cycle of Arctic sea ice,
the minimum extent occurs in   March   June   (September)   December

In an El Nino event, surface water is anomalously
warm along the equator in which ocean:

(Eastern Pacific)   Western Pacific   Eastern Atlantic   Indian Ocean

During the next hundred years, the most significant impact of climate change in the
Pacific Northwest is expected to be:

sea-level rise   increased snowfall   (decreased snowfall)   malaria mosquitoes

6. (5 points) *Matching.* **In front of each equation write the appropriate letter (a, b, c, d, or e)**

b $F = \sigma T^4$

c $(S/4)(1-A) = \sigma T_e^4$

d $F = (9/5)C + 32$

a $\lambda_{max} = 2898/T$

e $PV = nRT$

a. Wien's law

b. Stefan-Boltzmann law

c. Planetary energy balance

d. Conversion of temperature scales

e. Ideal gas law

7. (9 points) *Matching.* **In front of each reaction write the appropriate letter (a, b, c, etc.)**

a $CO_2 + H_2O \rightarrow CH_2O + O_2$

c $CO_2 + H_2O \rightarrow H_2CO_3$

e $CaSiO_3 + 2H_2CO_3 \rightarrow Ca^{++} + 2HCO_3^-$
$+ SiO_2 + H_2O$

b $CH_2O + O_2 \rightarrow CO_2 + H_2O$

g $O + O_2 \rightarrow O_3$

i $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$

d $4H \rightarrow He$

h $Cl_2 \rightarrow 2Cl$

f $CaCO_3 + SiO_2 \rightarrow CaSiO_3 + CO_2$

a. Photosynthesis

b. Respiration

c. Formation of carbonic acid

d. Energy production in the Sun

e. Weathering of silicate rocks

f. Carbonate metamorphism in Earth's mantle

g. Ozone production

h. Chlorine dissociation

i. Methane combustion

8. (9 points) The figure on the next page shows reservoirs and flows in the carbon system. Amounts in the reservoirs are in gigatons of carbon and the flows are in gigatons of carbon per year, where one gigaton is 10^9 metric tons. Thick lines indicate flows due to human activity. Use the figure to answer the following questions.

(a) (2 points) What is the residence time for carbon in the land biosphere (vegetation, plus soils and detritus)? Show how you get your estimate.

$$60 + 1.5 + 0.5 = 62$$

$$\frac{2200 \ GT}{62 \ GT/yr} = 35 \ yr.$$

(b) (2 points) What human activities are responsible for the conversion of 2 gigatons carbon per year from the land biosphere, corresponding to the bold lines labelled "changing land use"?
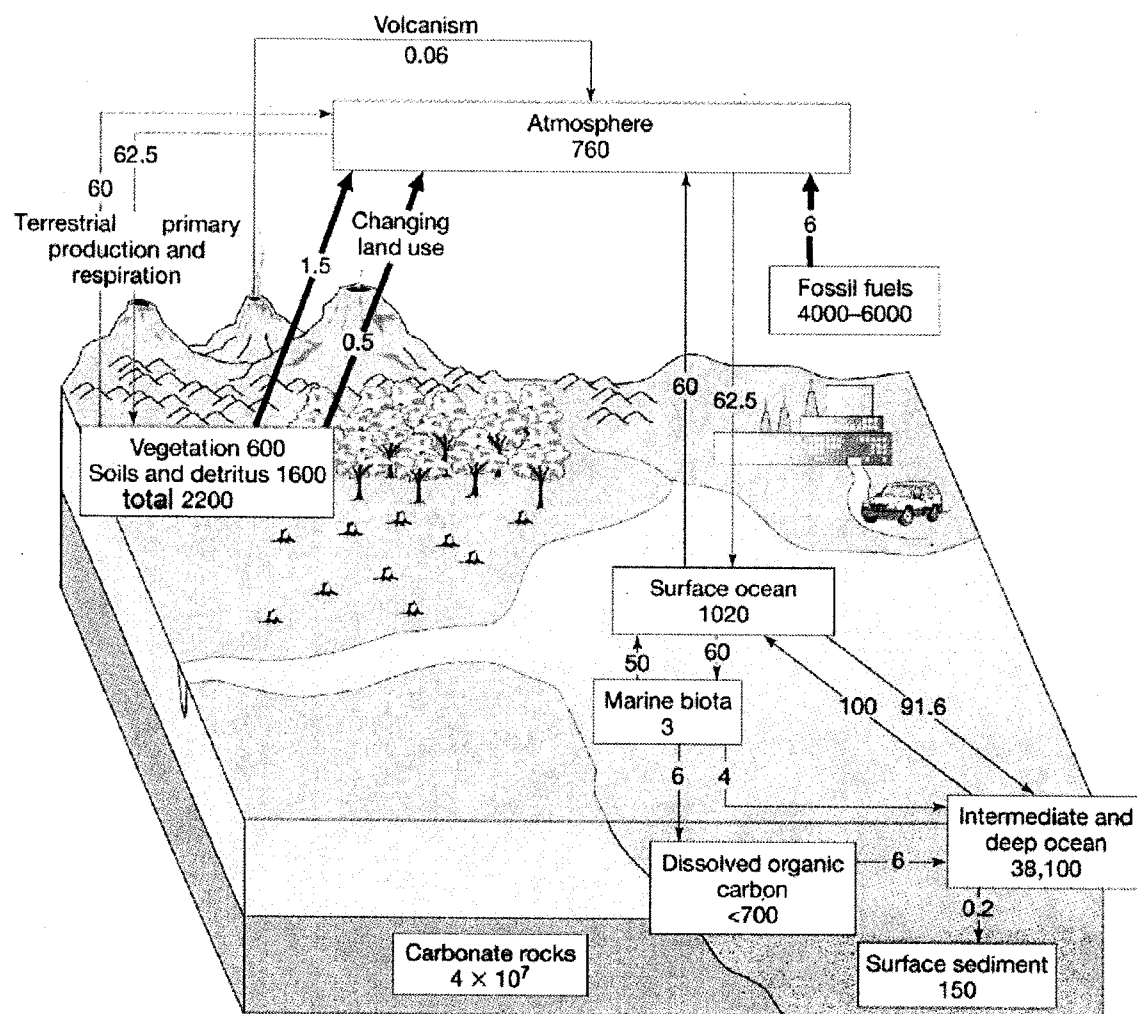
deforestation
biomass burning

(c) (3 points) According to the figure, what is the current rate of increase of carbon dioxide in the atmosphere (in gigatons per year)? Show your work.

$$6 + 1.5 + 0.5 + 60 + 0.06 + 60 - 62.5 - 62.5$$

$$= 3.06 \ GT \ C/yr$$

(d) (2 points) What would be the rate of increase of carbon in the atmosphere (in gigatons per year) if the sources due to human activity remained the same, but if none of this excess carbon were stored in the ocean or in the land biosphere?

$$6 + 1.5 + 0.5 + 0.06 = 8.06 \ GT \ C/yr.$$

Volcanism
0.06

Atmosphere
760

62.5

60

Terrestrial   primary
production and
respiration

Changing
land use

1.5

0.5

Fossil fuels
4000–6000

6

Vegetation 600
Soils and detritus 1600
total 2200

60   62.5

Surface ocean
1020

50   60

Marine biota
3

100   91.6

6   4

Intermediate and
deep ocean
38,100

Dissolved organic
carbon
<700

6

0.2

Carbonate rocks
4×10^7

Surface sediment
150

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9. (6 points) The two maps below are from Trenberth's 1983 article "What are the seasons?" The annual cycle of insolation at the top of the atmosphere is compared to the annual cycle of surface temperature, averaged over many years. The maps give the relation of these two cycles. For example, if the mean temperature of the warmest month is 20°C and the mean temperature of the coldest month is 0°C, then the amplitude of the annual cycle is 10 K. If the maximum of insolation occurs on 21 June and the maximum of temperature occurs on average on 21 July then the phase lag is 30 days.

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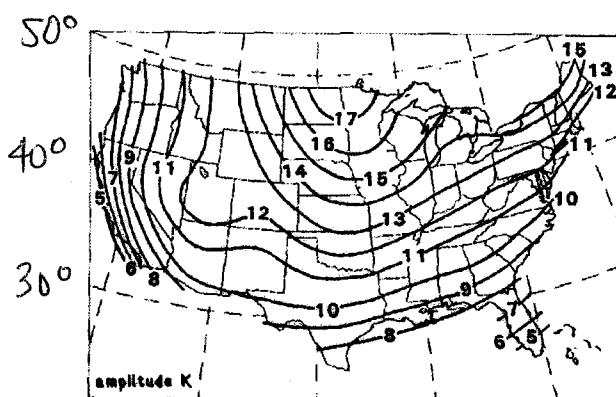

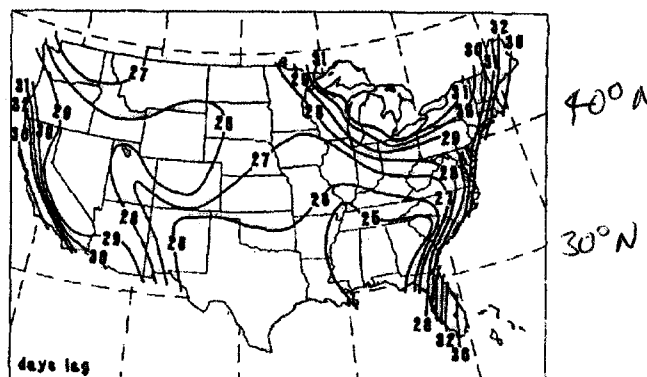FIG. 8. The amplitude in K of the 365-day period annual cycle in surface temperature over the United States.

FIG. 9. The phase of the 365-day period annual cycle in surface temperature expressed as days lag behind the sun. The contour interval is one day except along the coast.

(a) The amplitude along the Atlantic coast increases steadily from 5 K in south Florida to 13 K in Maine. What is the reason for this increase?

Annual cycle of solar radiation has larger amplitude at higher latitude.

(b) Following the 40°N latitude line from west to east, the phase lag goes from 36 days (California) to 27 days (Nebraska) to 32 days (New Jersey). Why is lag(California) > lag(Nebraska)? Why is lag(California) > lag(New Jersey)?

CA > NE : Calif is on coast; Ne. is inland with smaller thermal inertia.
Calif & NJ are both coastal but winds come from west so Calif has more marine influence; NJ has more continental influence.

(c) Why is the phase lag larger in Michigan (31 days) than in Kentucky (26 days)?

thermal inertia of Great Lakes.

10. (5 points) *Matching.* **In front of each wavelength value write the appropriate letter.**

_e_ 1 nm   a. infrared

_c_ 300 nm   b. visible

_b_ 500 nm   c. ultraviolet

_a_ 10 μm   d. microwave

_d_ 10 cm   e. X-ray

11. Plot each symbol at the correct location on the map (10 points).

A	Aleutian Islands	M	Mediterranean Sea
C	Chile	N	Antarctica
D	Iceland	O	Ob' River
E	Greenland	Q	Kalahari Desert
G	Gulf Stream	R	Sahara Desert
H	Hawaii	S	Svalbard
I	India	T	Tibet
J	Japan	U	New Guinea
K	Congo River	Y	Lake Eyre
L	Sahel	Z	Amazon River