Final Exam Answers

1. [4] A planet in a distant galaxy has a solar constant of 3000W/m2, a radius of 12,000km and an albedo of a=0.6.

a. Estimate the surface temperature of the planet.

$$T = [\frac{S(1-a)}{4\sigma}]^{\frac{1}{4}} = [\frac{3000(0.4)}{4(5.735 \times 10^{-8})}]^{\frac{1}{4}} = 269K$$

b. List the assumptions you made.

Steady state heat and uniform temperature

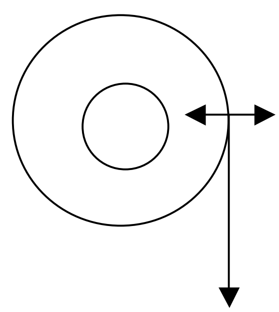
2. [4] Explain qualitatively, using the concept of escape velocity, why earth has an atmosphere dominated by N_2 with little H_2 or He.

Molecules in lighter gases (e.g. H_2 and He) move faster than heavier gases (e.g. N_2 and O_2) at the same temperature. Thus, they are more likely to exceed the escape velocity for their planet.

3. [4] Consider the circular isobars in a southern hemisphere cyclone shown below.

a. Indicate the high and low pressure regions of the cyclone
b. At one point in the cyclone, sketch and label vectors representing the wind, pressure gradient force and Coriolis force.

Center should be marked L
Periphery marked with H
Wind vector points south
CF point east
PGF points west



4. [4] Air in a large rectangular valley (5km by 20km) is capped by an elevated inversion at z=800m. Into this valley, 100kg of toxic gas is released and distributed. Find the toxic gas concentration. Give units.

$$Vol = (5000)(20,000)(800) = 8 \times 10^{10} m^3$$

$$Mass = Vol \times \rho = (8 \times 10^{10})(1.2) = 10^{11} kg$$

$$Concentration = \frac{100kg}{10^{11}kg} = 10^{-9} = 1ppmm$$

5. [4] Explain why clouds form in rising air.

   Rising air moves into lower pressure and cools adiabatically by expansion. As the temperature drops, so does Psat, so RH increases.

6. [4] Explain why most clouds do not precipitate.

   Cloud droplets are small (~10microns) and thus fall too slowly to reach the earth before evaporating. About a million droplets must be combined to form a raindrop or snowflake.

7. [4] A HAWT wind turbine with blade length of 10 meters experiences a steady 10 m/s wind. Assuming that the turbine efficiency is 40%, estimate the total energy generated in 24 hours. Express your answer in both **Joules** and **kWhr**.

   $$SweptArea = \pi R^2 = 314m^2$$

   $$Power = \varepsilon \left(\frac{1}{2}\right) \rho U^3 A = (.4)(.5)(1.2)(10^3)(314) = 75.4 \times 10^3 W$$

   Over 24 hours $Energy = Power(W) \times Time(s) = 6.5 \times 10^9 J$

   or $Energy = Power(W) \times Time(hr) = 1810kWhr$

8. [4] Consider a reservoir of water with dimensions 5km by 10km with 10 meters of standing water. The water drains from the reservoir into a large pipe (i.e. the penstock) and falls 100 meters into a turbine with efficiency of 30%. Estimate the total electrical energy that can be generated by draining the reservoir.

   $$Mass = Vol \times density = (5000)(10000)(10)(1000) = 5 \times 10^{11} kg$$

9. [4] Explain the advantages or disadvantages of electricity generation from natural gas compared to coal in regard to

a. a) local air pollution (e.g. SO_2, NO and HgO)

Natural gas has much less Sulfur and Mercury than coal and thus produces less SO_2 and HgO. If it is burned at high temperature, it might still produce NO.

b. b) CO_2 emissions

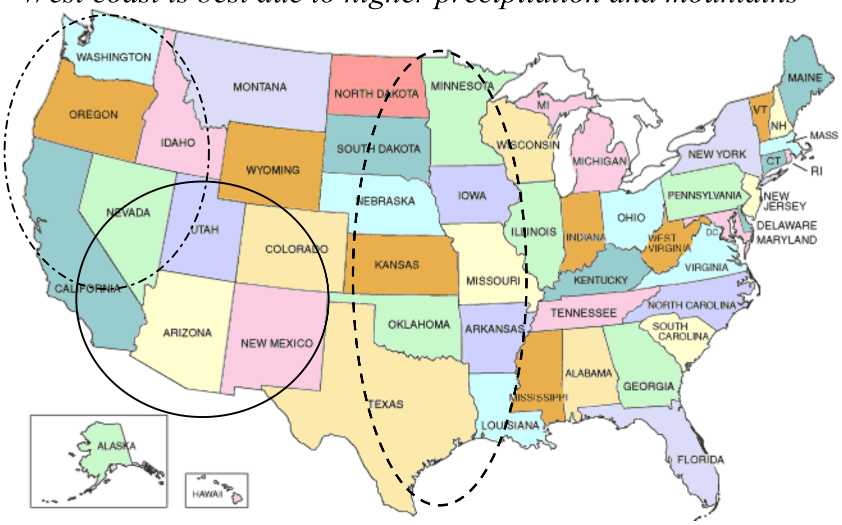
Natural gas emits about 25% less CO_2 for the same energy production.

10. [6] On the USA map provided, circle the areas best suited for three types of renewable energy and explain why below.

a. Wind energy
High Plains is best due to lack of forests and smooth terrain (Coastal California is also good due to sea breeze. Offshore along both coasts is good too.)

b. Solar
The southwest USA is best due to clear skies.

c. Hydroelectric
West coast is best due to higher precipitation and mountains



11. [4] Where and when does the ozone hole appear? Explain why?

The ozone hole appears over the south pole in October. At the end of the winter, low temperature create PSC that release ClO. With the return of light in the spring season, the ClO reacts photochemically to destroy ozone. The north pole stratosphere does not get as cold in its winter/spring due to meridional exchange.

12. [4] During a Pleistocene glacial period the $^{18}O/^{16}O$ ratio in ocean sediments became *greater* or *less* (circle one) than during an interglacial period. Explain

why?

Water evaporated from the ocean and stored on land as ice is isotopically light so the remaining ocean water is isotopically heavier during a glacial period.

13. [4] The North Atlantic Gyre moves 50SV of water northward with T=20C and an equal amount of water southward with T=10C. Compute the net rate of northward heat transport by these currents.

$NetHeatTransport = C_p \times \Delta T \times MassTransport =$
$(4218)(10)(1000)(50 \times 10^6) = 211 \times 10^{14}$
W

14. [4] At a point in the South Pacific Ocean at 20S latitude, an easterly wind blows over the ocean with speed 10m/s. Determine the average direction and speed of the Ekman Drift. Assume that the wind stress is felt down to a depth of 50 meters.

$WindStress = \tau = 0.003\rho U^2 = (0.003)(1.2)(10^2) = 0.36Pa$

$EkmanDrift = \tau/(2\rho D\Omega \sin(\phi)) = \frac{0.36}{(2)(1025)(50)(7.27\times10^{-5})(.34)} =$
0.142m/s
Drift is towards the south.

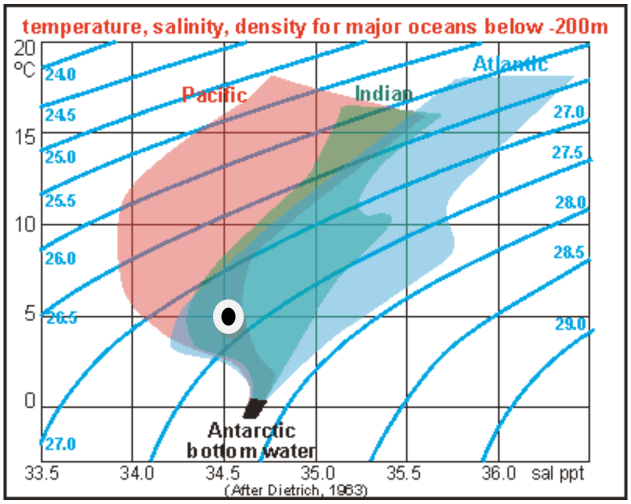
15. [4] Consider a location in the ocean where the sea water temperature is 5C and the salinity is 34.5ppt.

a. What is the density of this water?

Plotting the point and interpolating between density curves gives
$\rho = 1027.3kg/m3$

b. How much does the pressure increase for every ten meters of added depth?

Using the hydrostatic law $\Delta P = \rho g \Delta z = (1027.3)(9.81)(10) = 100{,}778.1Pa$



16. [4] If the partial pressure of water vapor is 20mb and the temperature is 20C determine the

a. The water vapor density

$$Gas\ constant\ for\ water\ vapor\ R_W = \frac{8314}{18} = 462$$

$$Using\ \ the\ perfect\ gas\ law\ \ \rho_W = \frac{P_W}{R_W T} = \frac{2000}{(462)(293.1)} = 0.0148 kg/m3$$

b. The relative humidity

$$RH = \frac{P_W}{P_{SAT}} = \frac{2000}{2340} = 0.855 \approx 86\%$$

17. [4] Consider a day with surface temperature of 10C and a constant tropospheric lapse rate of -6.5C/km. A parcel of air is lifted adiabatically from the surface to z=4km. Determine the temperature of the

a. lifted parcel

$$T = 10 - 4(9.8) = -29.2C$$

b. air surrounding the parcel

$$T = 10 - 4(6.5) = -16C$$

18. [5] Consider two Sites on earth with clear skies. Site A has a surface temperature of 30C, an albedo of 0.1 and a solar zenith angle of 20 degrees. Site B has a surface temperature of -10C and albedo of 0.6 and a solar zenith angle of 60 degrees.

a. Compute the absorbed solar radiation per unit area at each site.

Site A $S(1-a)\cos(\varphi) = (1380)(.9)\cos(20) = 1167W/m2$

Site B $S(1-a)\cos(\varphi) = (1380)(.4)\cos(60) = 276W/m2$

b. Compute the emitted long wave radiation per unit area at each site.

Site A $F = \sigma T^4 = (5.735 \times 10^{-8})(303.1)^4 = 484W/m2$

Site B $F = \sigma T^4 = (5.735 \times 10^{-8})(263.1)^4 = 275W/m2$

c. Is either Site in a state of near radiative balance?

Site B is nearly in radiative balance as the absorbed solar equals the emitted long wave radiation.

19. [3] Explain why the sky appears blue but a cloud appears white.

Air molecules are small and cause Rayleigh scattering with short wavelengths (i.e. blue) scattering more intensely than longer wavelengths (i.e. red) in the visible spectrum. Cloud droplets are larger and cause Mie scattering where all wavelengths are scattered equally. The sun's radiation (i.e. mix of blue, green and red) is white, so the cloud appears white.

20. [3] Consider a human population of 6 billion in the year 2000. Estimate the population in the year 2100 assuming that the population growth rate is 0.005 /yr.

$$P(t) = P(0)\exp(\alpha t) = (6 \times 10^9)\exp\big((0.005)(100)\big) = 9.9 \times 10^9$$

This is almost 10 billion people.

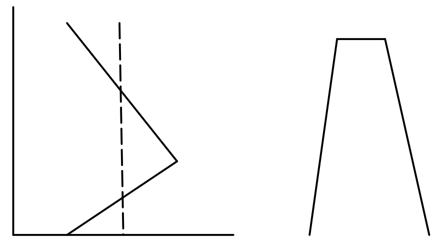
21. [4] Consider, due to increased greenhouse gases, that the downward longwave radiation at the earth's surface increases by 3W/m2. If this is the only change in the ocean heat budget, how much will the ocean warm in one year? Assume that only the top 100 meters of the ocean is affected.

The extra heat added per unit area is $\frac{Q}{A} = \left(\frac{3W}{m2}\right)\left(\frac{seconds}{year}\right) = 94.6 \times 10^6 J/m2$

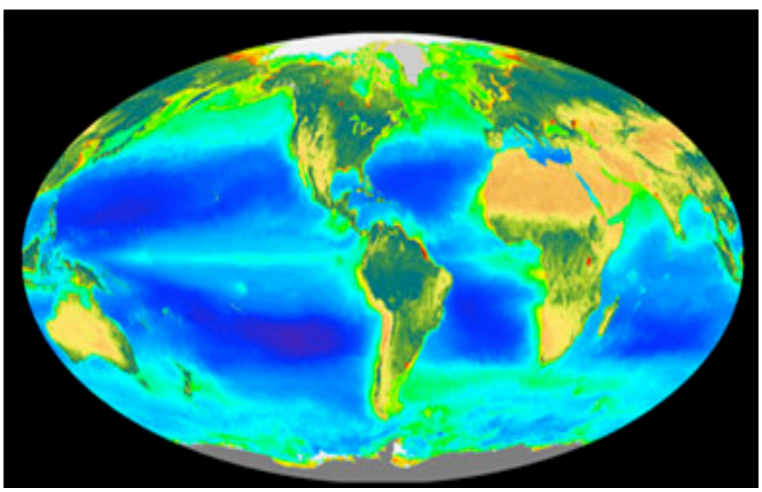
$$\Delta T = \frac{Q/A}{\rho C_p D} = \frac{94.6 \times 10^6}{(1025)(4218)(100)} = 0.22C$$

22. [3] In an early winter storm in the mountains of New England, the mountain tops received snow and the valley bottoms had freezing rain. Explain how this might happen, using appropriate sketches of the temperature profile and mountain height.

    The snow melted to form rain in a warm air layer below mountain top. Near the valley surface the rain fell into very cold air and became supercooled. It then froze upon impact with trees and ground.



23. [3] Referring to the ocean chlorophyll distribution shown below, describe briefly the physical and biological processes that cause the ocean productivity to vary spatially.



Productivity in the ocean requires getting nutrients up into the euphotic zone. This requires vertical mixing or upwelling, which are controlled by winds, coasts, currents and latitude. Examples high-latitude mixing, coastal and equatorial upwelling and river discharge are seen.

24. [6] **Explain** the reason for the rainy season at each location below. **Estimate** the net water added to the soil (i.e. P-E) in the wettest month.

a. **Valparaiso, Chile** (Lat =33S, Long = 72W) The wettest month is June (P = 5.9 inches; temperature of T = 56F). The driest month is February (P=0; T=66F).

The rain in June is winter rain from frontal cyclones.

$T(June) = 56F = 13.3C$

$P - E = 150 - 67 = 83mm$

b. **Mexico City, Mexico** (Lat=19N, Long=100W) The wettest month is August (P=4.6 inches, T=62F). The driest month is January (P=0.2 inches, T=54F)

The rain in August is summer rain from convective clouds as the ITCZ shifts northward.

$T = 62F = 16.7C \quad P = 4.6inches = 117mm \quad E = (5)(16.7) = 83mm$

$P - E = 117 - 83 = 34mm$

25. [8] Define the following terms

a. El Nino

A warming of the SST in the eastern tropical Pacific, connected with changes in tradewinds, pressure, precipitation and biological productivity.

b. Stratosphere

The layer of air from about 10 to 30km with a positive lapse rate.

c. NADW

North Atlantic Deep Water is an ocean water mass formed in the North Atlantic and filling the medium depth range.

d. Cirrus

Ice clouds in the upper troposphere (i.e. 8 to 12km)

e. Esker

A ridge of high ground left by a melting ice sheet. It is debris from flowing water under the glacier.

f. Cold front

A boundary between warm and cold air with the cold air advancing.

g. Little Ice Age
A recent period with slightly cooler climate from 1400 to 1800AD.

h. Pancake Ice
A stage in the formation of sea ice under cold winds. Disks of ice freeze at the edges and bottom while bouncing against each other.