MAE 119 Professor G.R. Tynan
Winter 2018
Homework 4

Assigned 6 Februrary 2018 Due 19 February 2018

1. Wave Power:

Using internet resources, determine the typical wave amplitude and wavelength for ocean waves off of the eastern and western coasts of the US. Also examine the Gulf of Mexico region. Use these values to estimate the power per unit length along the wavefront (i.e. parallel to the coastline) for these regions, and then estimate the maximum power that could be converted into electricity if 10% of the available coastline were dedicated to this purpose. What fraction of total US electrical power demand does this represent?

2. Wave power: Find the power production from a wave machine that reduces the wave height by a factor of 2. In other words, if the incident waves have a height a. The machine then only extracts a portion of the available wave energy, allowing a wave of height a/2 to exit the machine. If a=1 m, and the period is 10 seconds, estimate how much power could be produced from a machine 100m long in the direction parallel to the wave face.

3. Hot dry rock Geothermal Energy:

A geothermal heat mine located at a depth between 10 and 11 km deep, and the volume to be mined has horizontal dimensions of 1 km x 1 km. Use the MIT Report on Hot Rock Geothermal Energy (located on the class website) to estimate the energy required to (a) drill and (b) operate such a heat mine. Cite your sources. (c) if the mine has a power output of 100 MW, on what time-scale does the rock cool down? How might this relate to the lifetime of the mine?

4. Solar Thermal Power:

During the lecture in class about solar thermal power systems, we found the following time-dependent energy balance equation for the case where there was no heat input into the system (e.g. night time without any auxiliary power input from e.g. natural gas combustion).

$$\rho C_p V \frac{\partial T}{\partial t} = -\frac{1}{\eta_{th}} P_{out}$$

a. Define and explain the meaning of each term in this equation.
b. Assuming all terms except T are constant and the temperature is a function of time, find the exact solution T=T(t).
c. If the power output of such a system is 50 MW, the working fluid was molten salt (see e.g. http://en.wikipedia.org/wiki/Solar_thermal_energy for more information the properties of such a thermal storage system.) estimate the volume V such that the e-folding time of the system is at least 12 hours (i.e. enough to last through the night).

5. Solar Thermal Power

For the system described in the previous problem:

a) If there ***is*** power input into the system from the sun, which we denote as P_{in} what would be the new energy balance equation? In order words, how would you modify the equation above to account for the power input?
b) If this input power from the sun is constant in time, and the system had zero output power, what would the functional form of T(t) be?
c) If the solar intensity is 300 W/m^2 and the thermal conversion efficiency is 30%, what is the area of the collecting mirrors required for a 100 MW output power? You may assume that the plant would be operating in steady-state.

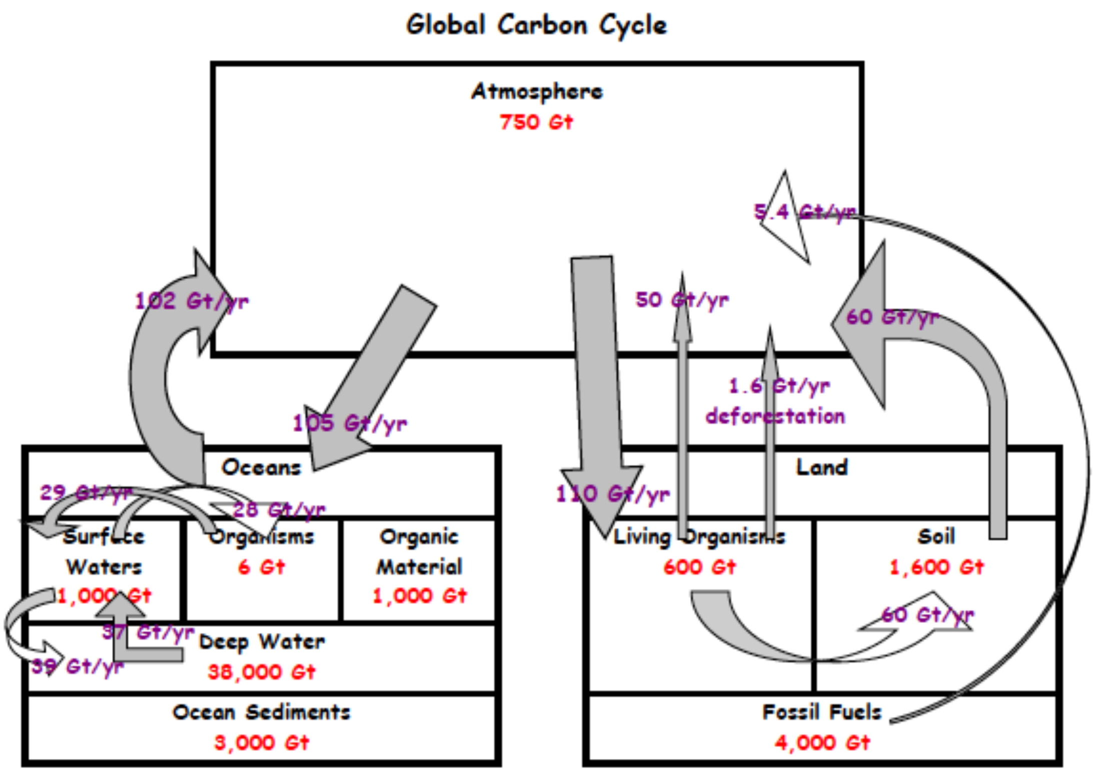
6. Tidal Power

The Rance Tidal Power Station is a utility-scale tidal power system located in France. Find the power output of this station. What is the typical height of the tides in this system? What is the tidal basin area (i.e. the surface area of the water impounded and utilized in this station? Using the simple models developed in lecture, compare the idealized power output to the published power output of this station. What fraction of France's electricity demand is met by this station? Using internet resources, what is the estimated global power capacity of feasible tidal basins that could be used to generate electrical power? What fraction of current global demand does this represent?

7. Carbon Balance:

A more complete control-volume model of the Earth's C-balance for the conditions of the atmosphere in ~2005 is given in the figure below. Suppose the C transfer rates between atmosphere, ocean, and land given the figure were the same during pre-industrial times, and that during pre-industrial times, de-forestation was negligible and the atmosphere held 600 Gt of C in the form of CO_2.

a) Referring to our discussion of the Earth's C-balance, estimate the net effective equilibration time for atmospheric C.
b) If this equilibration time find in part (a) doesn't change and CO2 emission rates were to stop growing and were to be held at today's value of ~10 Gt-C/year, what will be the steady-state atmospheric C content?
c) Using our simple IR radiation transport model developed in class, what would the new equilibrium IR transmission coefficient be?
d) Using the other values for the Earth's heat balance model given in lecture notes, estimate the change in temperature for the atmosphere and Earth's surface.



8.

Solar Thermal: A solar power tower design concept has a centrally located point-like target illuminated by an array of heliostat mirrors that can be oriented to reflect sunlight onto the target. The ratio of the mirror collecting area to the target area is a factor of 1000.

a. If the direct normal incidence (DNI) solar irradiation is 1000 W/m^2, what is the incident heat flux to the target?

b. If the working fluid of the power plant removes heat from the target at a rate of 500 kW/m^2, what will be the equilibrium temperature of the target? [Hint: write a power balance for a unit surface area of the target and then recall that the emitted heat flux from a radiating body goes like σT^4 where σ denotes the Stefan-Boltzmann constant which has a value of ~6x10-8 W/m^2-K^4]

c. If the working fluid has a temperature that is half of the target temperature, estimate the thermal conversion efficiency of an ideal heat engine deployed in this system.

d. Suppose a cloud layer moves over that has a thickness of 1km. The cloud is composed of aerosol particles with a cross-sectional area of 10^{-9} m^2. These particles have a density of 10^6 particles/m^3. What is the DNI now? If the plant were to keep operating, by how much will the power plant power output decline (you may neglect any change in the thermal conversion efficiency).