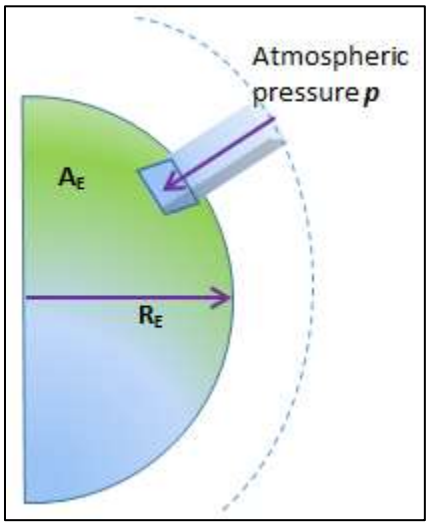
Due: 1 Oct 2025

Energy: Science, Technology, and Society

Problem Set 4

Indicate assistance obtained with each of the tasks defined below, e.g., by naming web source (Wikipedia, Google/Gemini, ChatGPT,…) and a (summary) prompt.

1. Atmospheric Carbon Content



The global average of CO_2 in the atmosphere has currently (2024) a value of $[CO_2]$=422.8 ppmv (parts per million in volume, according to NOAA). Calculate the total CO_2 and the carbon content in (metric) tons *t* of the atmosphere, if CO_2 were the only carbon carrier in the atmosphere. Air is a mixture of many gases whose weighted mean molecular weight is M_{air}=29*g/mol*. In the calculations assume that all components behave like ideal gases.

a) Use the standard atmospheric pressure to calculate the weight of the atmosphere.

b) Calculate the current mole fraction of CO_2 in the atmosphere.

c) Calculate the amounts of atmospheric carbon and CO_2 in Gt.

(The mean radius of Earth is R_E=6,371 km).

2. Northern Sea Shipping Route Alternative

Much of the present world trade is maintained by large and ultra large container ships (ULCS). On an average day of the year, about 80% of the fleet of about 700 ships is at sea. A ULCS like the one on the photograph can hold about 18,000 standard TEU (20'×8'× 8'6") containers. These ships are slow when loaded (16kn) but burn a large amount of heavy fuel oil (⌣100 t/day). The "regular" HSFO fuel oil ($399/mt) contained about 3% sulfur (by weight) and produced high emissions in SO_2 pollutants. Since 2020, a desulfurized VLSFO ($482/mt) with ≤0.5% has been mandated by the International Maritime Organization. For the following tasks, consider a typical

trip from Rotterdam (Holland) to Yokohama (Japan) by one ULCS, where the route (SCR) passes through the Suez Canal. Because of the disappearing sea ice around the North Pole, the Northern Sea Shipping route (NSR) becomes an economically interesting alternative to the SCR.

a) Obtain the routing distances for the SCR and the NSR and the corresponding days at sea of the fully loaded ULSC vessel introduced above.
b) Determine the corresponding amounts of HSFO fuel oil needed for both routes, and the associated costs.
c) Estimate the pollution in terms of CO_2 and SO_2 emissions in MtC and MtS.
d) What are the cost differentials if the low-sulfur fuel is used instead of HSFO?
e) What role can the fleet play in hypothetical geoengineering studies of sun dimming by sulfate aerosols?

3. Proposal tp Mitigate CO_2 Emission by Geo-Engineering (Parasol)

Estimated radiative forcings ($\backsim$3 W/m^2) at Earth's surface due to current anthropogenic greenhouse gas emissions suggest that this effect is equivalent to about 1 percent extra solar radiative influx. Therefore, a dimming of sunlight by a corresponding fraction with an artificial "parasol" could offset the effects of future GHG emissions. The parasol material would have to be placed into a low-Earth orbit, where it could remain for a period of 2 years. The current cost of launching 1 kg of payload into orbit is approximately $6.5k.

a) Estimate the annual total cost of a geo-engineering scheme, whereby a screen of totally reflective aerosol particles (1μ diameter, mass density ρ = 1g/cm^3) is constructed around Earth at an altitude of 200 km, corresponding to a low Earth orbit.
b) Estimate the "carbon tax" in \$/tCO_2 that would have to be raised by the emitters to pay for such a parasol, to compensate for the effect caused by the average emitter over two years.
c) Consider reforestation of land (in the tropics) as a CO_2 sequestration alternative. Using the information available in the published Keeling curve to make a rough estimate of how many new trees would have to mature every year to sequester the emitted CO_2 in that period, what land are would be needed for ongoing forestation?